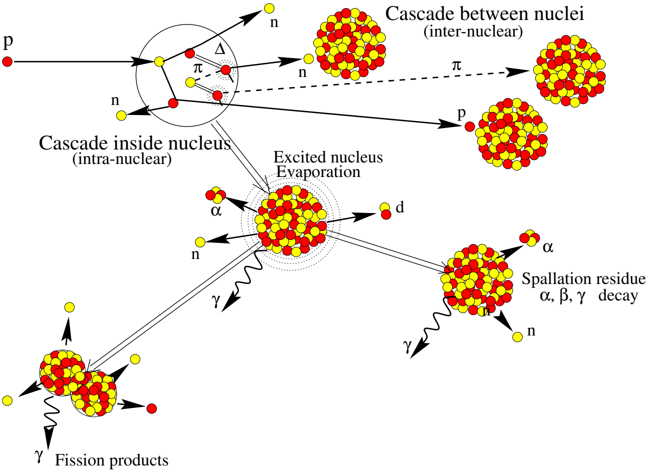
Thin target tests for Statistical and Binary Cascade hadronic models in Geant4

Vicente Lara

22nd June 2005

Spallation process



Models

Dynamical models

- Intranuclear Cascade: Binary Cascade

Statistical models

- Preequilibrium
  - Exciton model
- Equilibrium
  - Evaporation: two models (Dostrovsky and GEM)
  - Fission
  - Fermi Break–up
  - Multifragmentation

Note

By default Fermi Break–up model is switched off

Test suite

The goal was to test the Statistical Models but it is also a partial test for the Binary Cascade.

These tests were done in 2003 (and a few of them redone in 2004).

I can not give the G4 version because most of the times the header of the repository was used.

This is a bare model test. No geometries nor tracking at all.

Each simulation corresponds to 200000 events.

Experimental Data

All experimental data sets come from EXFOR database

EXFOR database is a valuable tool, however one should be cautious about the data quality:

- Data compiled from published papers
- Often do not contain the full systematic error
- Compiler mistakes (for example units)
- The data format is difficult to parse
- Data revision/modification changes the entry number
- From version to version there are missing data sets

Some examples

From entry O0101

```
COMMENT      * BY COMPILER *
             1. DATA POINT DENSITY ON THE FIGURES IS VERY HIGH.
             THEREFORE SOME DATA POINTS COULD BE MISSED OR ADDED.
             2. ERROR BARS ON THE EXPERIMENTAL DATA POINTS, WHICH
             ARE SHOWN ON THE FIGURES, INCLUDE UNCERTAINTIES DUE TO
             COUNTING STATISTICS, THE TIME-INDEPENDENT AND
             -DEPENDENT BACKGROUNDS, AND THE SHADOW-BAR CORRECTION.
             THE UNCERTAINTIES IN OTHER FACTORS (ATTENUATION,
             EFFICIENCY, LIVE TIME, AND CHARGE NORMALIZATION) ARE
             NOT INCLUDED.
             SORRY, BUT TO READ THESE UNCERTAINTIES FROM DATA
             FIGURES IS IMPOSSIBLE.
```

Some examples

... and another comment

```
COMMENT    *BY COMPILER* NEUTRON ENERGY UNCERTAINTIES HAVE BEEN
           SHOWN BY AUTHORS FOR HIGHEST ENERGIES ONLY. THIS
           UNCERTAINTY IS NOT SMALL (UP TO 20%).
           DATA UNCERTAINTIES HAVE BEEN SHOWN BY AUTHORS FOR SOME
           DATA POINTS ONLY.  THIS UNCERTAINTY CAN CHANGE ABSOLUTE
           CROSS SECTION UP TO 3-10 TIMES AT HIGHEST ENERGIES.
```

Some examples

From entry O0222

```
COMMENT     - By Compiler - The Size of Published Figures is Very
            Small.  Experimental Points Could not be Distinguished.
            Therefore Compiler Read Data from Smooth Curves.
```

From entry O0990

```
COMMENT     *BY COMPILER* NEUTRON ENERGY UNCERTAINTIES HAVE BEEN
            SHOWN BY AUTHORS FOR HIGHEST ENERGIES ONLY. THIS
            UNCERTAINTY IS NOT SMALL (UP TO 20%).
            DATA UNCERTAINTIES HAVE BEEN SHOWN BY AUTHORS FOR SOME
            DATA POINTS ONLY.  THIS UNCERTAINTY CAN CHANGE ABSOLUTE
            CROSS SECTION IN 10-20 TIMES AT HIGHEST ENERGIES.
```

Experimental data

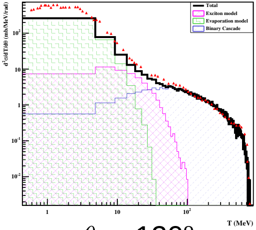
- $^{0}\mathrm{U}(\mathrm{p}, X\mathrm{n})$ at 800 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta = 30^{\circ}$, 60°, 120°, 150°
  - EXFOR: O0101.[042–043]
- $^{238}\mathrm{U}(\mathrm{p}, X\mathrm{n})$ at 800 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta = 30^{\circ}$, 60°, 120°, 150°
  - EXFOR: O0170.012
- $^{0}\mathrm{U}(\mathrm{p}, X\mathrm{n})$ at 597 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta = 30^{\circ}$, 60°, 120°, 150°
  - EXFOR: O0099.[034–037]
- $^{238}\mathrm{U}(\mathrm{p}, X\mathrm{n})$ at 597 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta = 30^{\circ}$, 60°, 120°, 150°
  - EXFOR: O0169.010

Experimental data

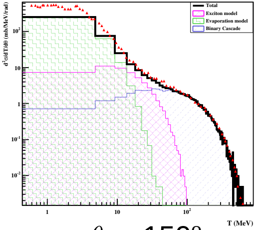
- $^{238}\mathrm{U}(\mathrm{p}, X\mathrm{n})$ at 256 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\mathrm{d}\theta$
  - Angles: $\theta = 7.5^{o}, 30^{o}, 60^{o}, 150^{o}$
  - EXFOR: O0168.008
- $^{238}\mathrm{U}(\mathrm{p}, X\mathrm{n})$ at 113 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\mathrm{d}\theta$
  - Angles: $\theta = 7.5^{o}, 30^{o}, 60^{o}, 150^{o}$
  - EXFOR: O0171.009

$^{0}\mathrm{U}(\mathrm{p}, X\mathrm{n})$

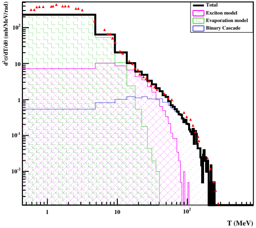
$\theta = 30^{\mathrm{o}}$



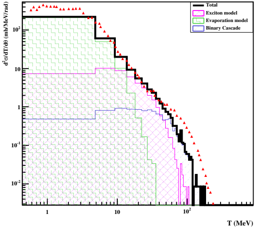
$\theta = 60^{\mathrm{o}}$



$\theta = 120^{\mathrm{o}}$

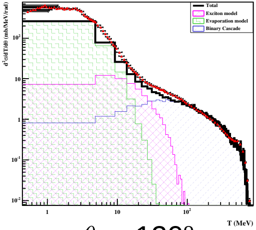


$\theta = 150^{\mathrm{o}}$

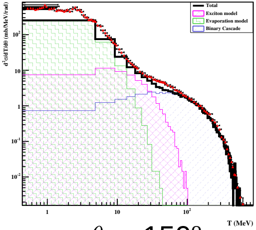


$^{238}\mathrm{U}(\mathrm{p}, X\mathrm{n})$

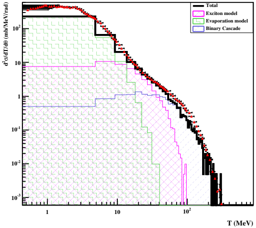
$\theta = 30^{\mathrm{o}}$



$\theta = 60^{\mathrm{o}}$



$\theta = 120^{\mathrm{o}}$



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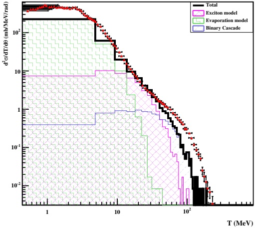
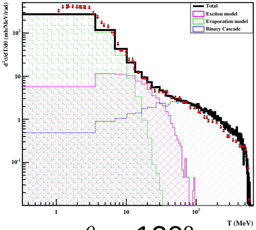


$^{0}\mathrm{U}(\mathrm{p}, X\mathrm{n})$

$\theta = 30^{o}$



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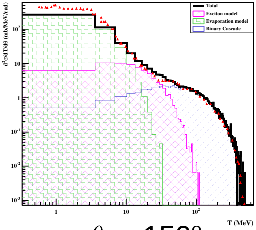
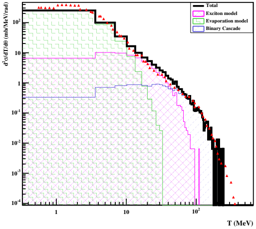
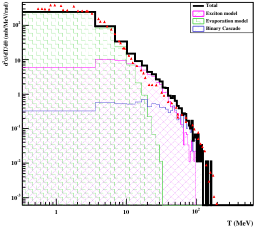


$\theta = 120^{o}$

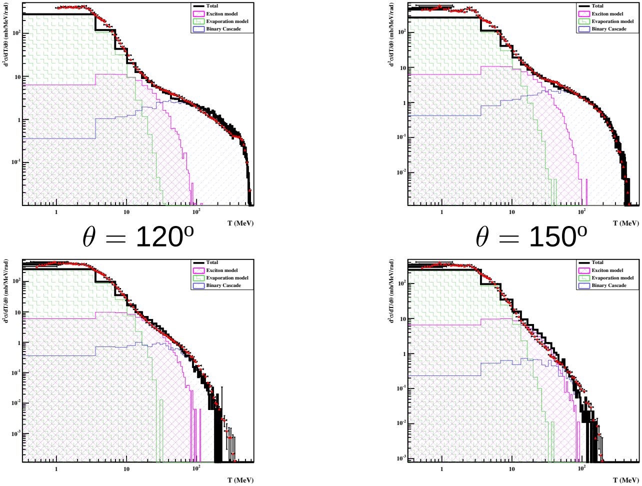


$\theta = 150^{o}$

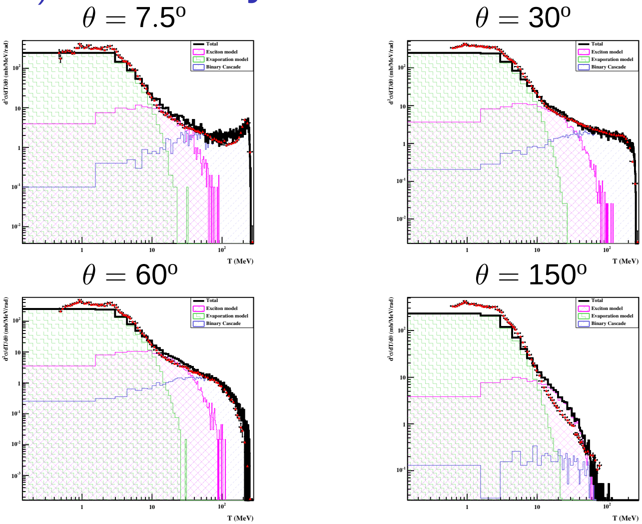


$^{238}\mathrm{U}(\mathrm{p}, X\mathrm{n})$

$\theta = 30^{\mathrm{o}}$ $\theta = 60^{\mathrm{o}}$ $\theta = 120^{\mathrm{o}}$ $\theta = 150^{\mathrm{o}}$

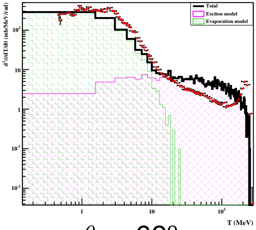


$^{238}\mathrm{U}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

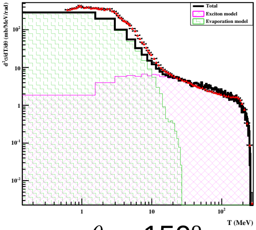


$^{238}\mathrm{U}(\mathrm{p}, X\,\mathrm{n})$ only Exciton model

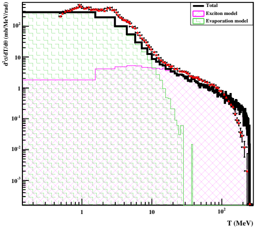
$\theta = 7.5^{o}$



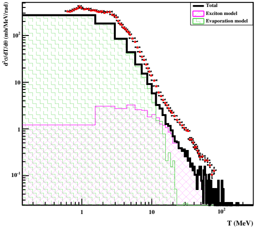
$\theta = 30^{o}$



$\theta = 60^{o}$

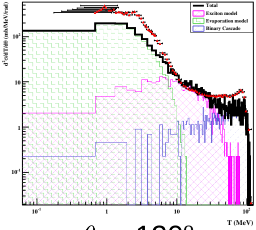


$\theta = 150^{o}$

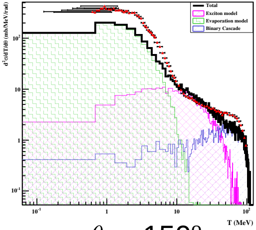


$^{238}\mathrm{U}(\mathrm{p}, X\,\mathrm{n})$ with Binary Cascade

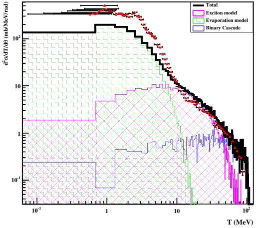
$\theta = 30^{\mathrm{o}}$



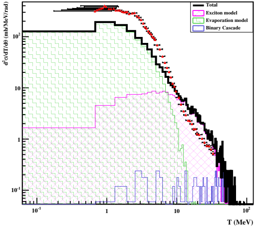
$\theta = 60^{\mathrm{o}}$



$\theta = 120^{\mathrm{o}}$

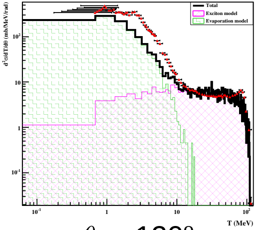


$\theta = 150^{\mathrm{o}}$

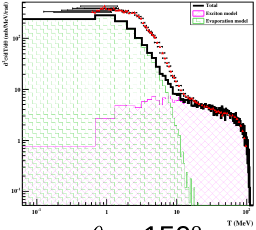


$^{238}\mathrm{U}(\mathrm{p}, X\mathrm{n})$ only Exciton model

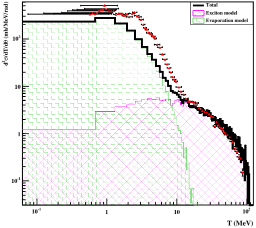
$\theta = 30^{o}$



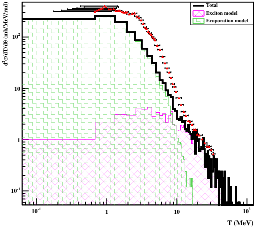
$\theta = 60^{o}$



$\theta = 120^{o}$



$\theta = 150^{o}$

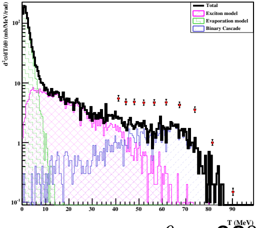


Experimental data

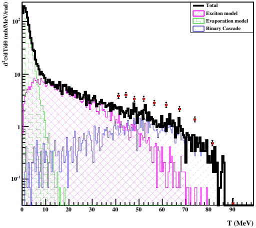
- $^{209}\mathrm{Bi}(\mathrm{p}, X\mathrm{n})$ at 90 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta =$ 20°, 30°, 45°, 60°, 90°
  - EXFOR: O0141.[026–030]
- $^{209}\mathrm{Bi}(\mathrm{p}, X\mathrm{n})$ at 90 MeV
  - $\mathrm{d}\sigma/\mathrm{d}T$
  - EXFOR: O0141.075

$^{209}\mathrm{Bi}(p, Xn)$ with Binary Cascade

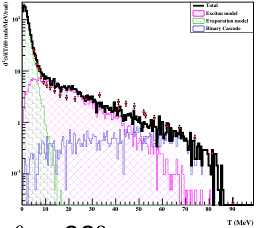
$\theta = 20^o$



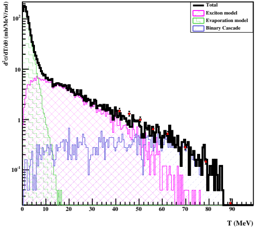
$\theta = 30^o$



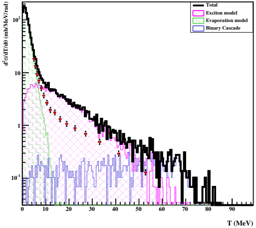
$\theta = 45^o$



$\theta = 60^o$

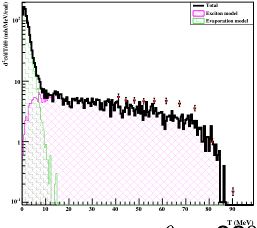


$\theta = 90^o$

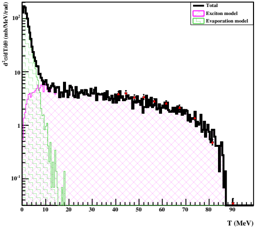


$^{209}\mathrm{Bi}(p, Xn)$ only Exciton model

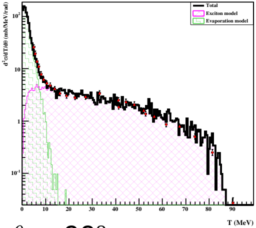
$\theta = 20^{o}$



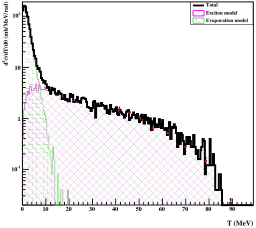
$\theta = 30^{o}$



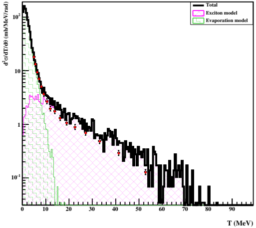
$\theta = 45^{o}$



$\theta = 60^{o}$

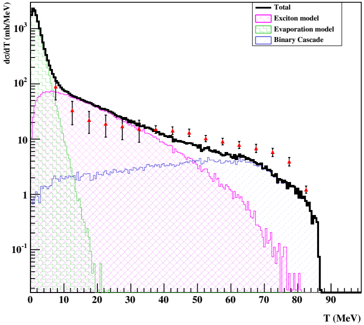


$\theta = 90^{o}$

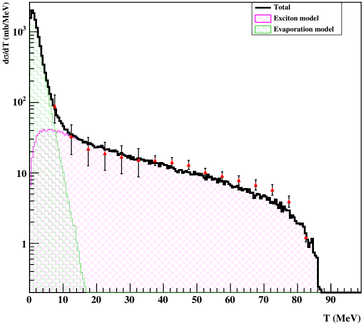


$^{209}\mathrm{Bi}(\mathrm{p}, X\mathrm{n})$

Binary Cascade + Exciton model



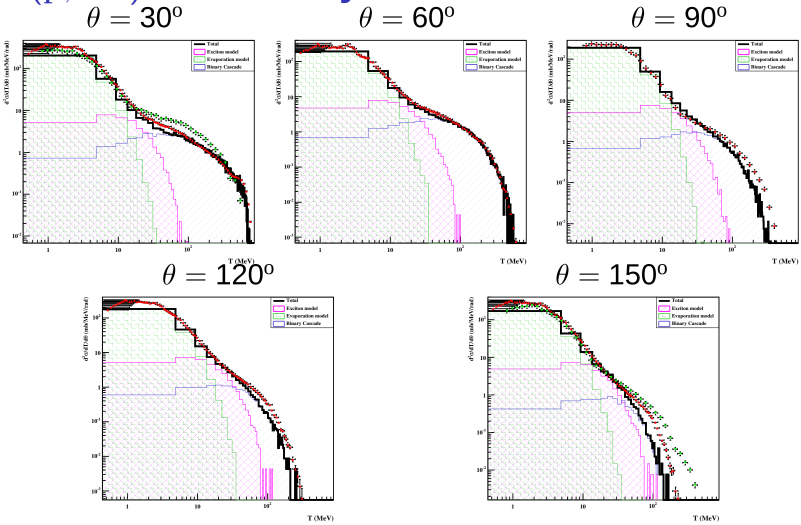
Exciton model



Experimental data

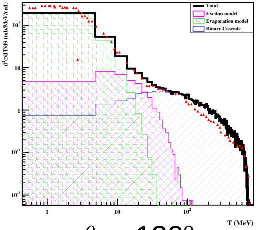
- $^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ at 800 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta =$ 30°, 60°, 120°, 150°
  - EXFOR: O0170.011
- $^{0}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ at 800 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta =$ 30°, 60°, 120°, 150°
  - EXFOR: O0101.[038–041]
- $^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ at 800 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta =$ 30°, 90°, 150°
  - EXFOR: 98219.[023–025]
- $^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ at 597 MeV
  - $\mathrm{d}^2\sigma/\mathrm{d}T\,\mathrm{d}\theta$
  - Angles: $\theta =$ 30°, 60°, 120°, 150°
  - EXFOR: C0169.009

$^{208}\mathrm{Pb}(\mathrm{p}, X\,\mathrm{n})$ with Binary Cascade

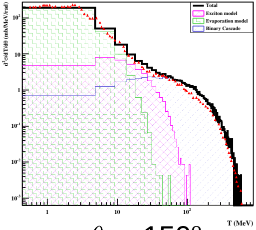


$^{0}\mathrm{Pb}(p, X)n$ with Binary Cascade

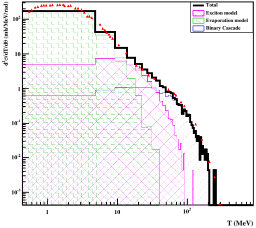
$\theta = 30^{o}$



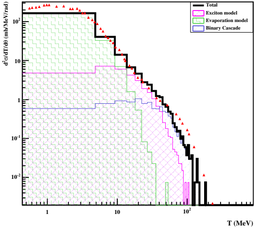
$\theta = 60^{o}$



$\theta = 120^{o}$

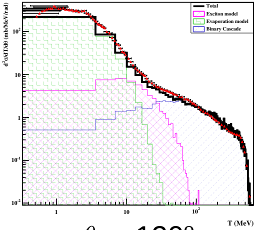


$\theta = 150^{o}$

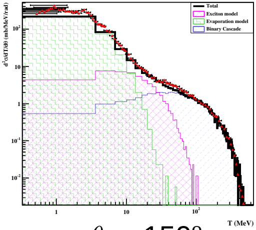


$^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

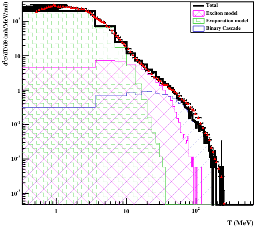
$\theta = 30^o$



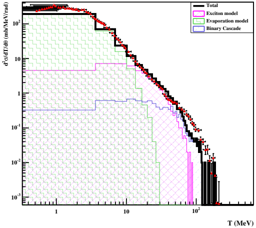
$\theta = 60^o$



$\theta = 120^o$

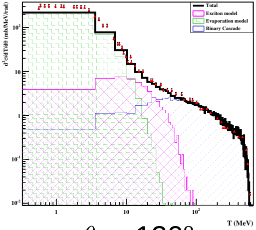


$\theta = 150^o$

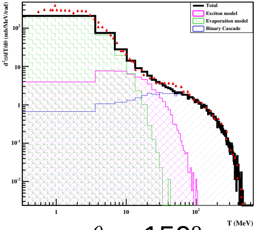


$^{0}\mathrm{Pb}(p, Xn)$ with Binary Cascade

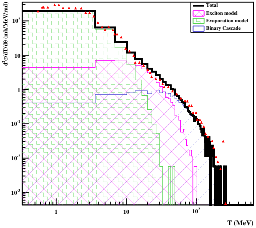
$\theta = 30^{o}$



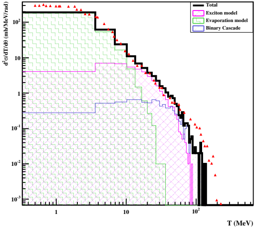
$\theta = 60^{o}$



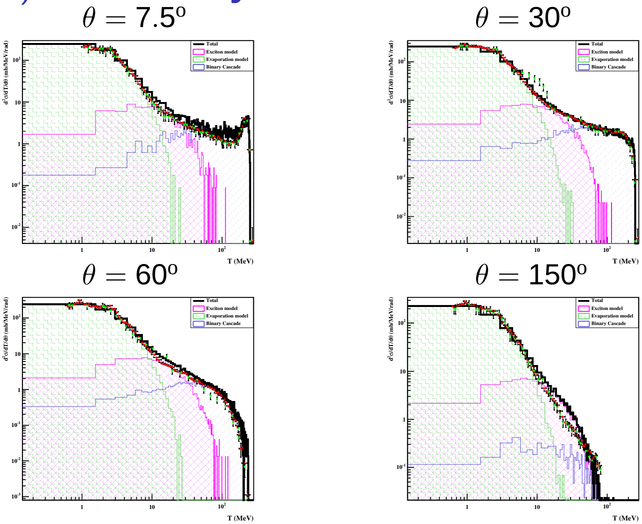
$\theta = 120^{o}$



$\theta = 150^{o}$

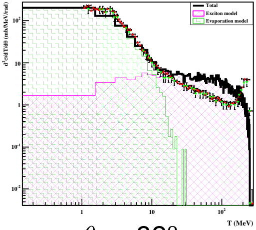


$^{0}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

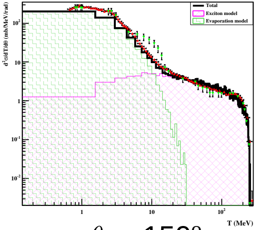


$^{0}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ only Exciton model

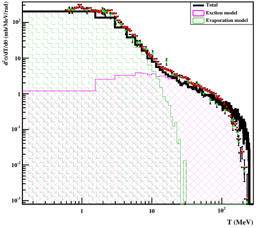
$\theta = 7.5^{o}$



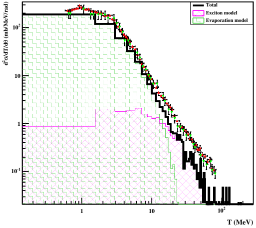
$\theta = 30^{o}$



$\theta = 60^{o}$

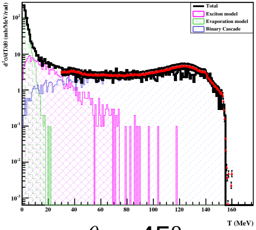


$\theta = 150^{o}$

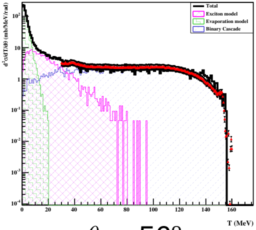


$^{208}\mathrm{Pb}(p, X n)$ with Binary Cascade

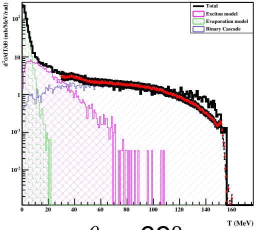
$\theta = 11^{o}$



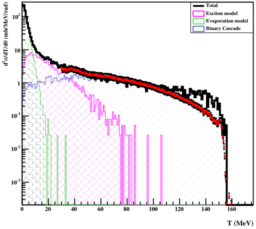
$\theta = 24^{o}$



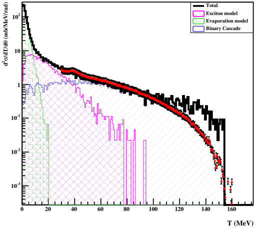
$\theta = 35^{o}$



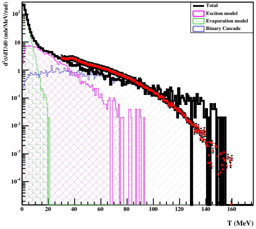
$\theta = 45^{o}$



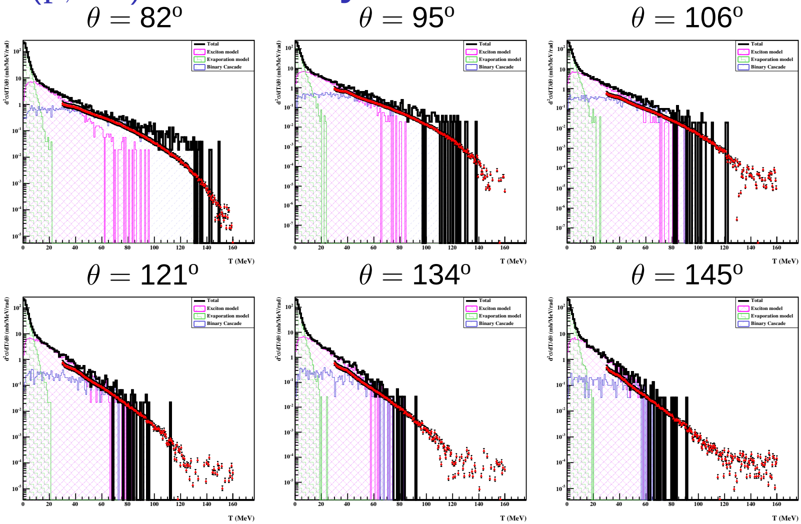
$\theta = 56^{o}$



$\theta = 69^{o}$

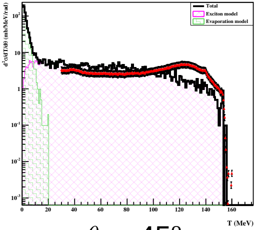


$^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

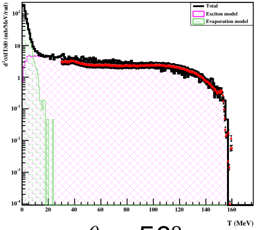


$^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ only Exciton model

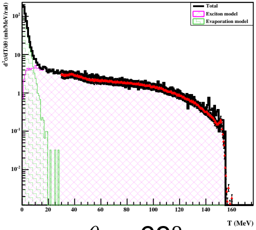
$\theta = 11^{o}$



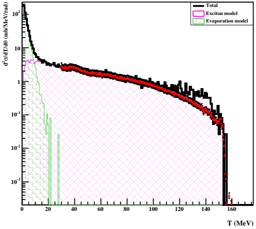
$\theta = 24^{o}$



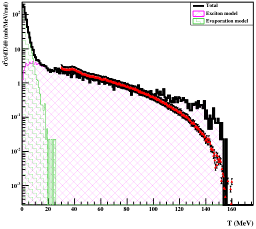
$\theta = 35^{o}$



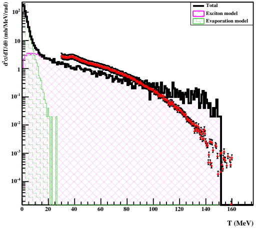
$\theta = 45^{o}$



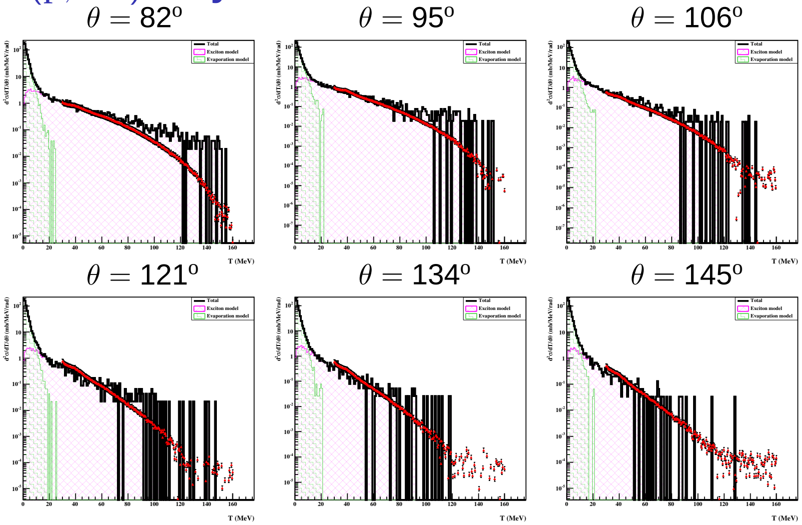
$\theta = 56^{o}$



$\theta = 69^{o}$

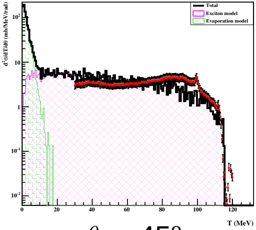


$^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ only Exciton model

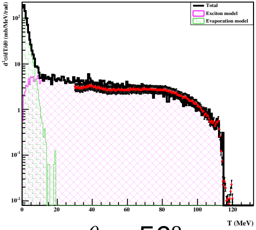


$^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ only Exciton model

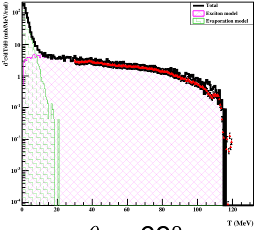
$\theta = 11^{o}$



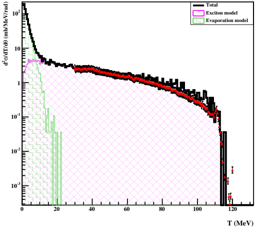
$\theta = 24^{o}$



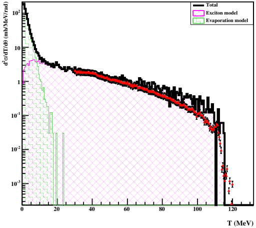
$\theta = 35^{o}$



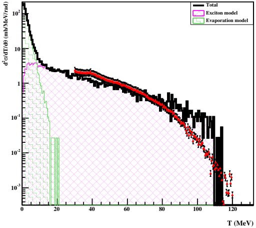
$\theta = 45^{o}$



$\theta = 56^{o}$

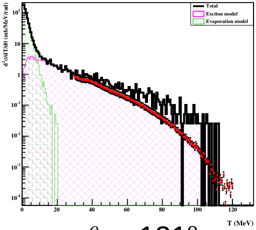


$\theta = 69^{o}$

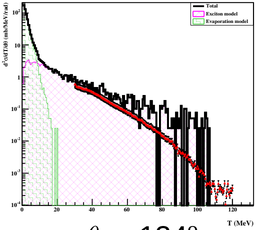


$^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ only Exciton model

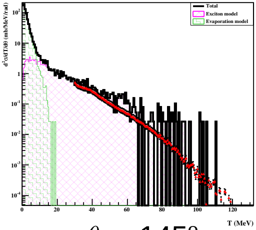
$\theta = 82^o$



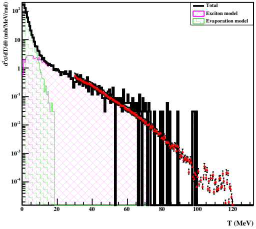
$\theta = 95^o$



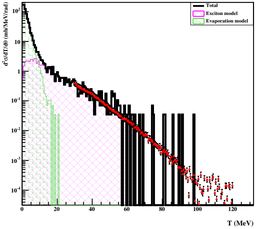
$\theta = 106^o$



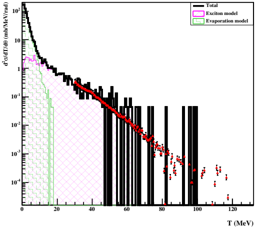
$\theta = 121^o$



$\theta = 134^o$

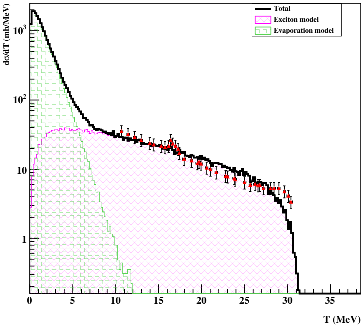


$\theta = 145^o$

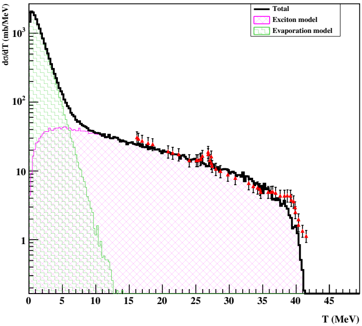


$^{208}\mathrm{Pb}(\mathrm{p}, X\mathrm{n})$ only Exciton model

35 MeV

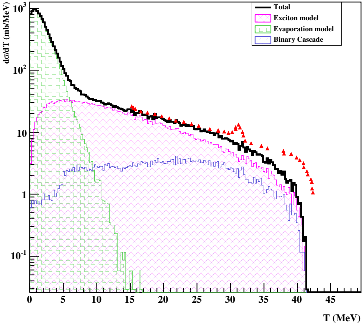


45 MeV

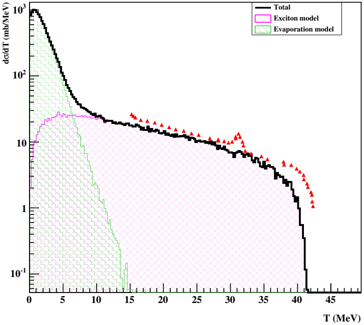


$^{120}Sn(p, Xn)$

Binary Cascade + Exction model

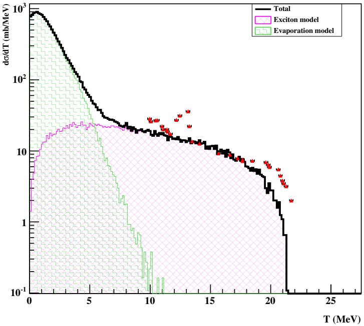


Exciton model

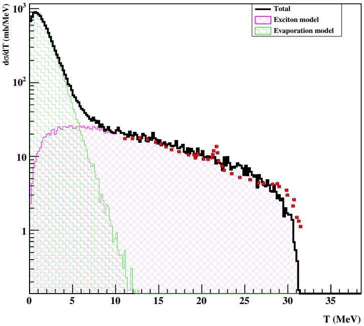


$^{120}\mathrm{Sn}(\mathrm{p}, X\mathrm{n})$

25 MeV

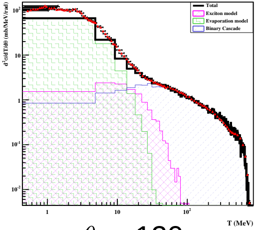


35 MeV

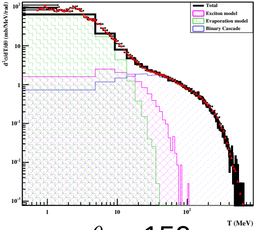


^{0}Cd(p, X n)

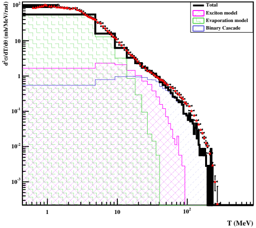
$\theta = 30$



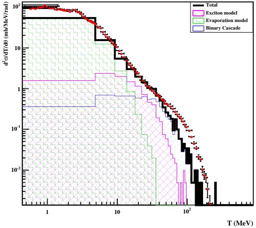
$\theta = 60$



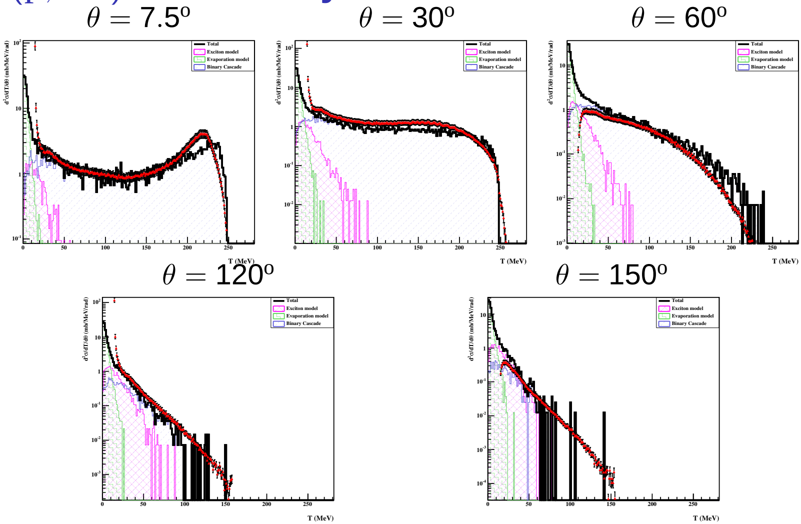
$\theta = 120$



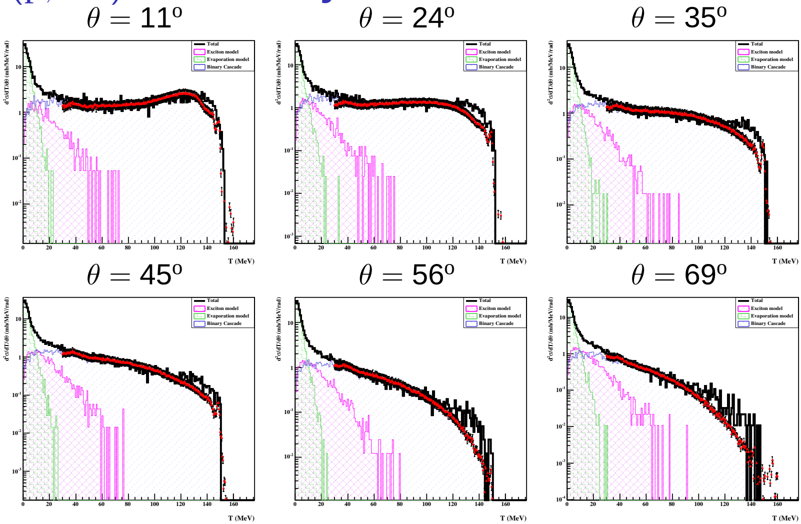
$\theta = 150$



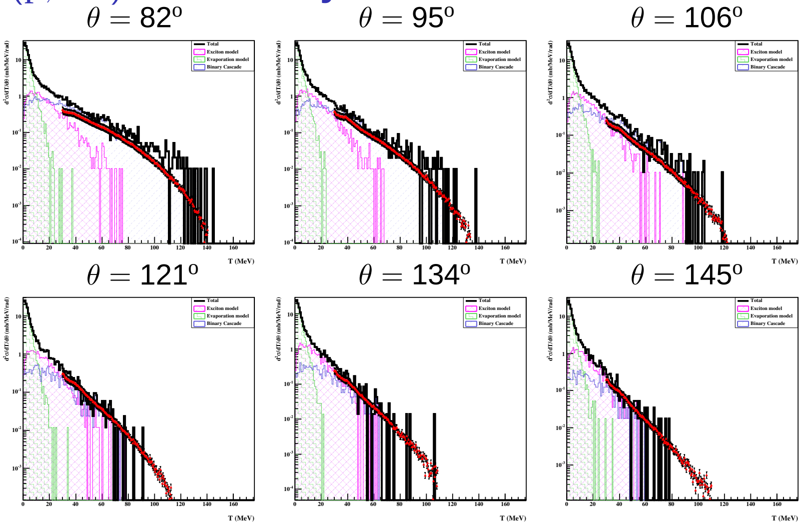
$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade



$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

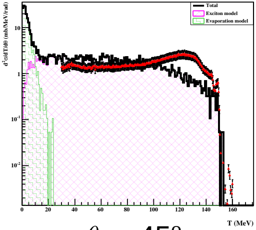


$^{90}\mathrm{Zr}(p, Xn)$ with Binary Cascade

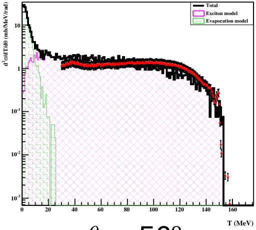


$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ only Exciton model

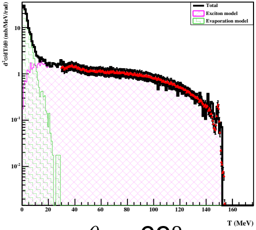
$\theta = 11^o$



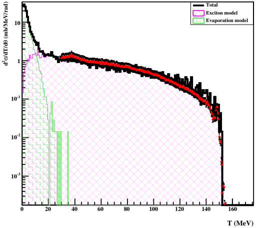
$\theta = 24^o$



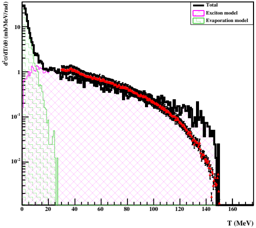
$\theta = 35^o$



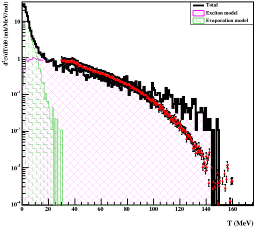
$\theta = 45^o$



$\theta = 56^o$



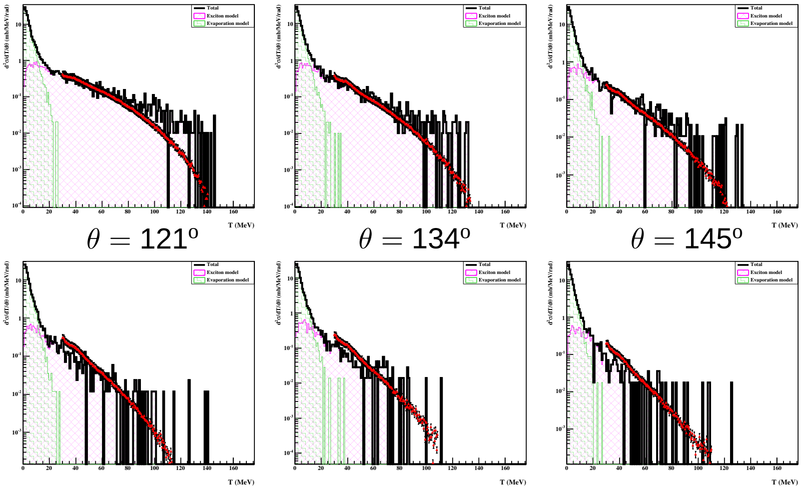
$\theta = 69^o$



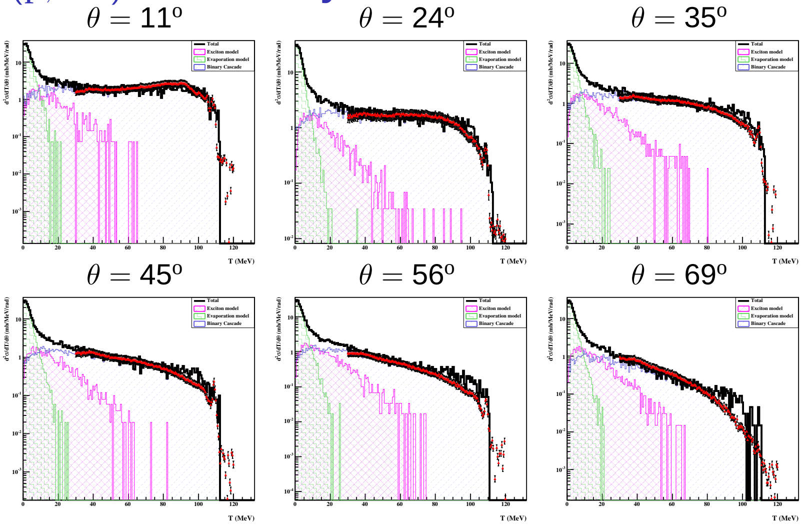
$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ only Exciton model

$\theta = 82^o$ $\theta = 95^o$ $\theta = 106^o$

$\theta = 121^o$ $\theta = 134^o$ $\theta = 145^o$

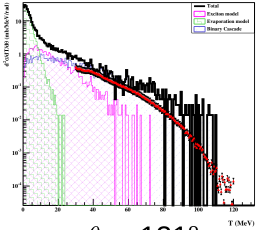


$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

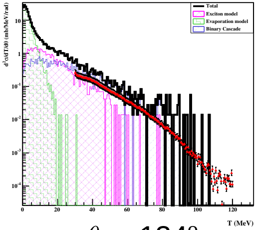


$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

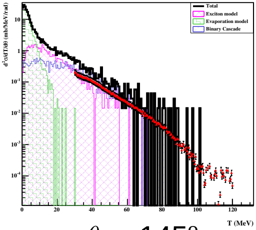
$\theta = 82^o$



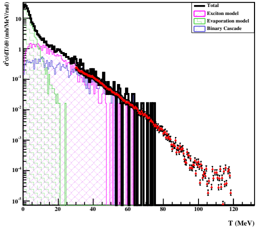
$\theta = 95^o$



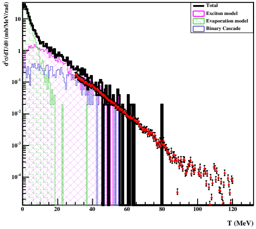
$\theta = 106^o$



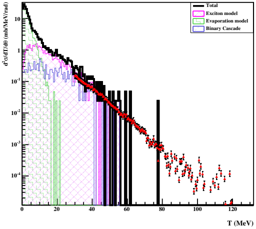
$\theta = 121^o$



$\theta = 134^o$

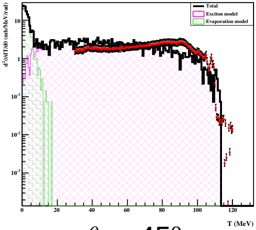


$\theta = 145^o$

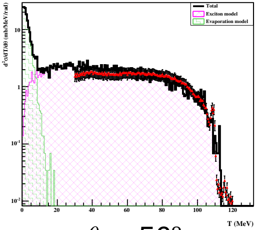


$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ only Exciton model

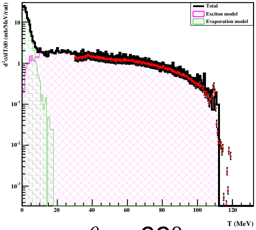
$\theta = 11^o$



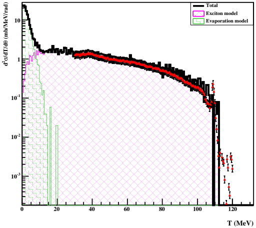
$\theta = 24^o$



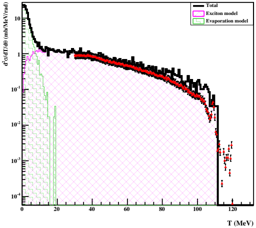
$\theta = 35^o$



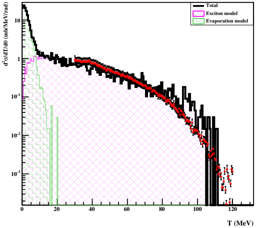
$\theta = 45^o$



$\theta = 56^o$

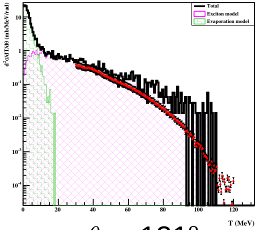


$\theta = 69^o$

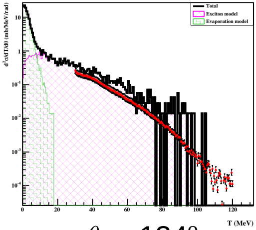


$^{90}\mathrm{Zr}(\mathrm{p},X\mathrm{n})$ only Exciton model

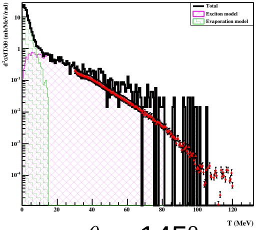
$\theta = 82^o$



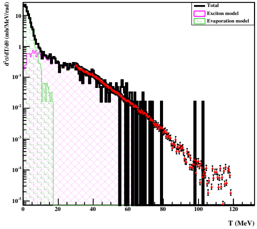
$\theta = 95^o$



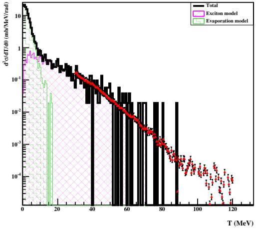
$\theta = 106^o$



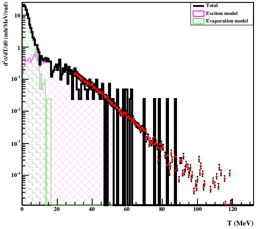
$\theta = 121^o$



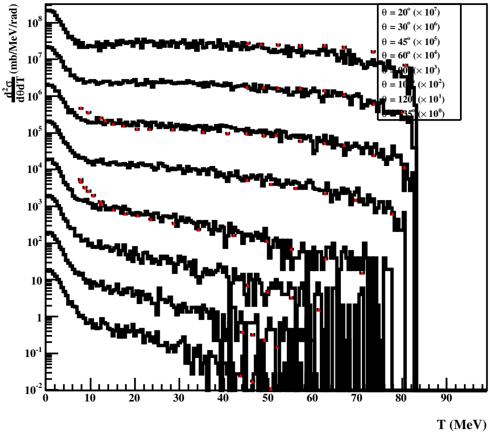
$\theta = 134^o$



$\theta = 145^o$



$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ only Exciton model



$\theta = 20^o(\times 10^7)$

$\theta = 30^o(\times 10^6)$

$\theta = 45^o(\times 10^5)$

$\theta = 60^o(\times 10^4)$

$\theta = 90^o(\times 10^3)$

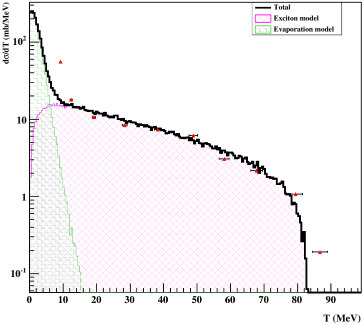
$\theta = 105^o(\times 10^2)$

$\theta = 120^o(\times 10^1)$

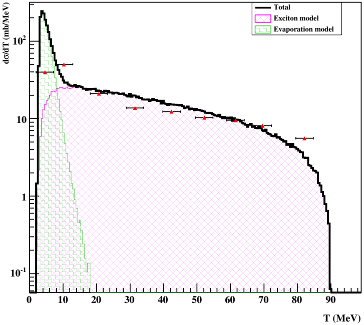
$\theta = 150^o(\times 10^0)$

$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ and $^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{p})$ only Exciton model

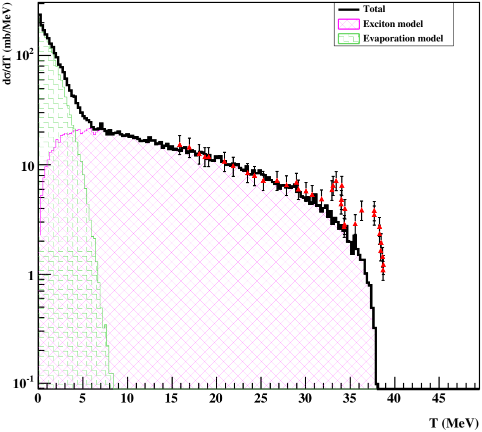
neutrons



protons

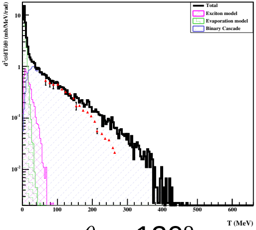


$^{90}\mathrm{Zr}(\mathrm{p}, X\mathrm{n})$ only Exciton model

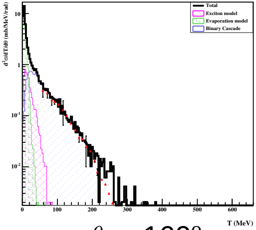


$^{0}\mathrm{Ni}(\mathrm{p}, X\,\mathrm{p})$ with Binary Cascade

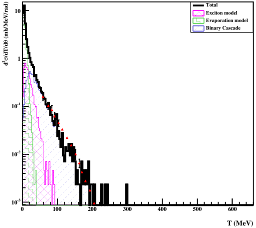
$\theta = 65^{\mathrm{o}}$



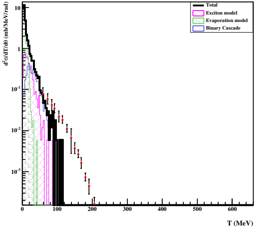
$\theta = 90^{\mathrm{o}}$



$\theta = 120^{\mathrm{o}}$

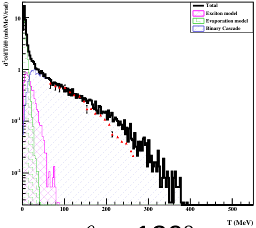


$\theta = 160^{\mathrm{o}}$

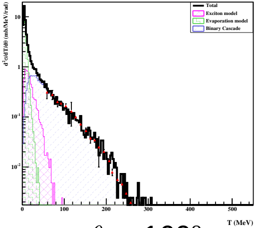


$^{0}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ with Binary Cascade

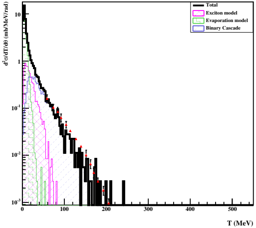
$\theta = 65^{o}$



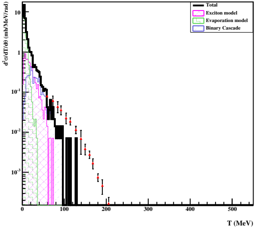
$\theta = 90^{o}$



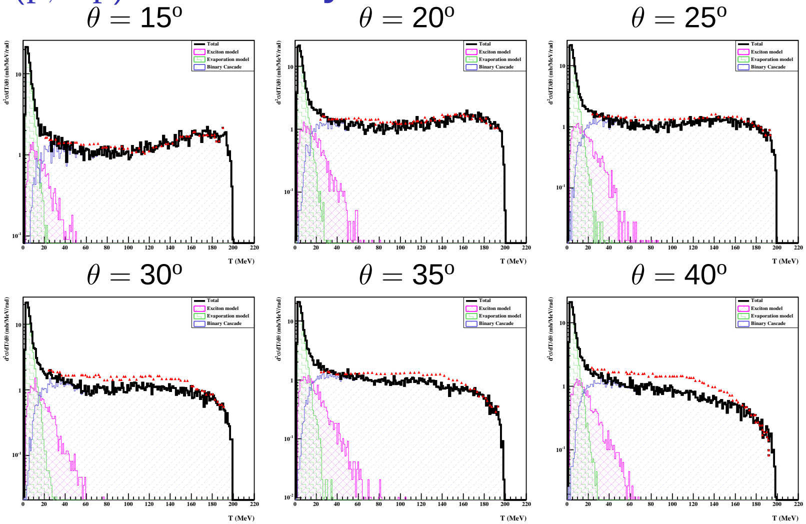
$\theta = 120^{o}$



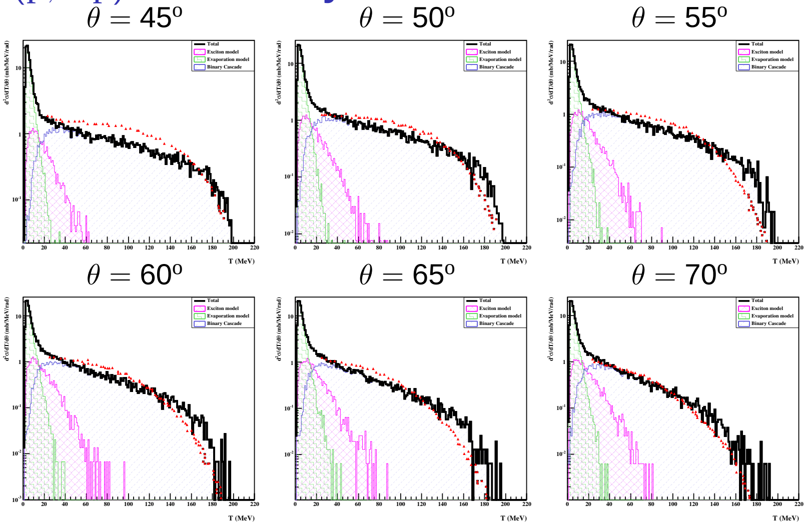
$\theta = 160^{o}$



$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ with Binary Cascade

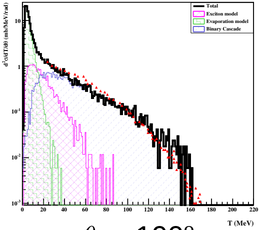


$^{58}\mathrm{Ni}(p, Xp)$ with Binary Cascade

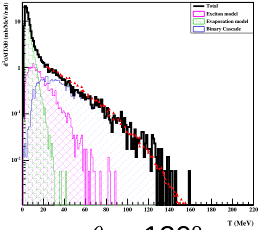


$^{58}\mathrm{Ni}(\mathrm{p}, X\,\mathrm{p})$ with Binary Cascade

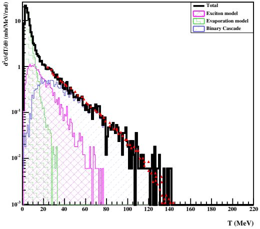
$\theta = 80^{o}$



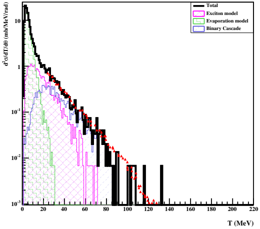
$\theta = 90^{o}$



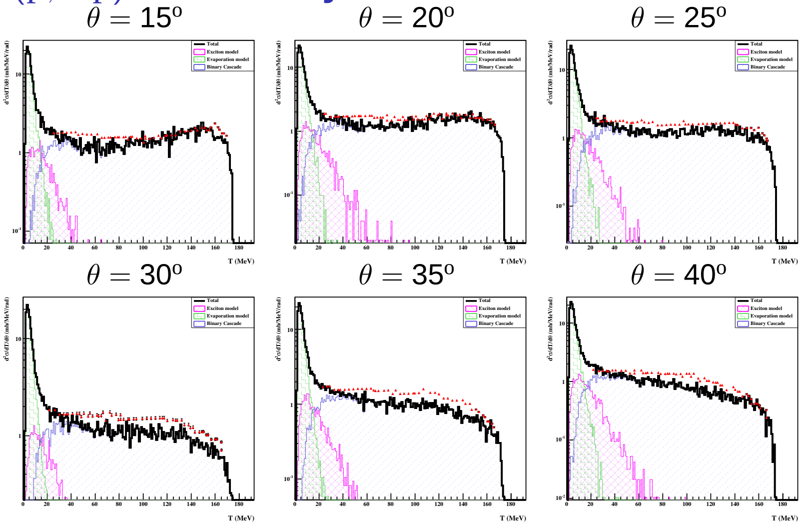
$\theta = 100^{o}$



$\theta = 120^{o}$

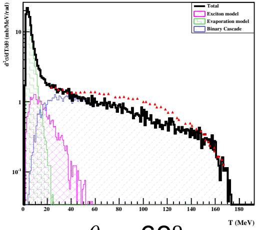


$^{58}\mathrm{Ni}(p, Xp)$ with Binary Cascade

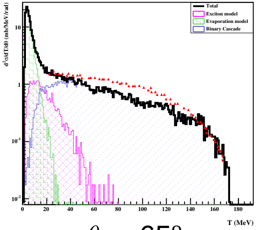


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ with Binary Cascade

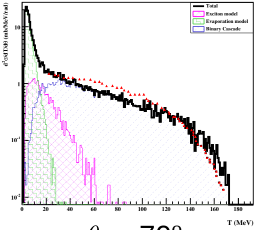
$\theta = 45^{o}$



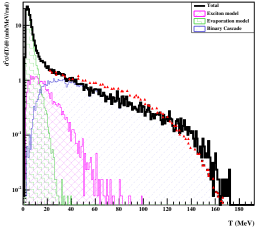
$\theta = 50^{o}$



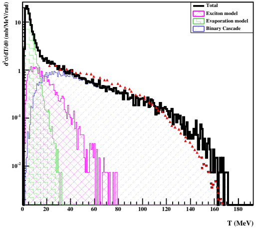
$\theta = 55^{o}$



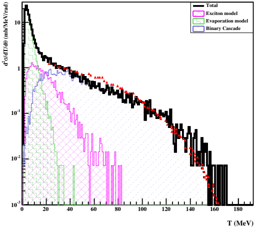
$\theta = 60^{o}$



$\theta = 65^{o}$

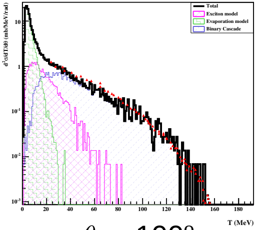


$\theta = 70^{o}$

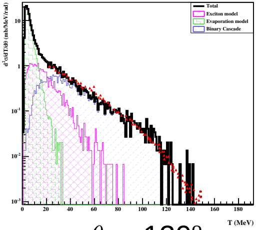


$^{58}\mathrm{Ni}(\mathrm{p}, X\,\mathrm{p})$ with Binary Cascade

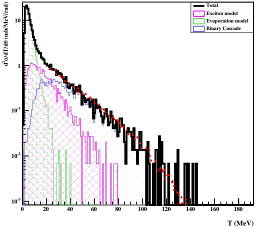
$\theta = 80^{o}$



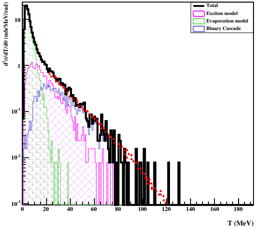
$\theta = 90^{o}$



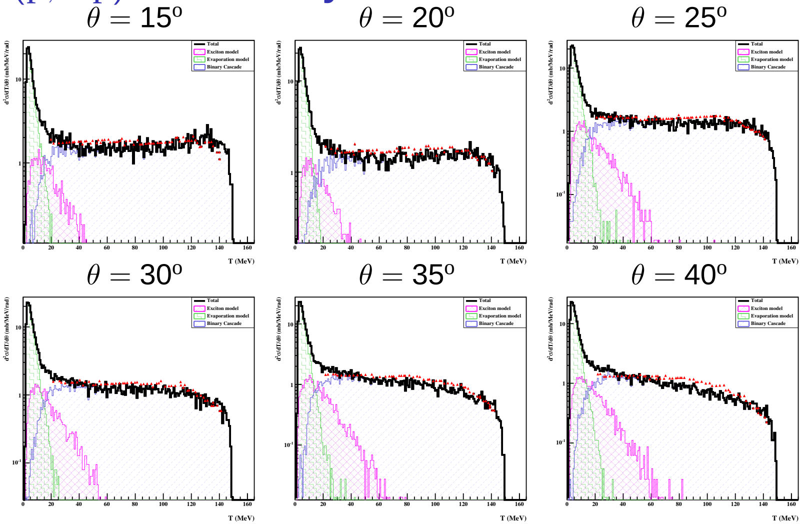
$\theta = 100^{o}$



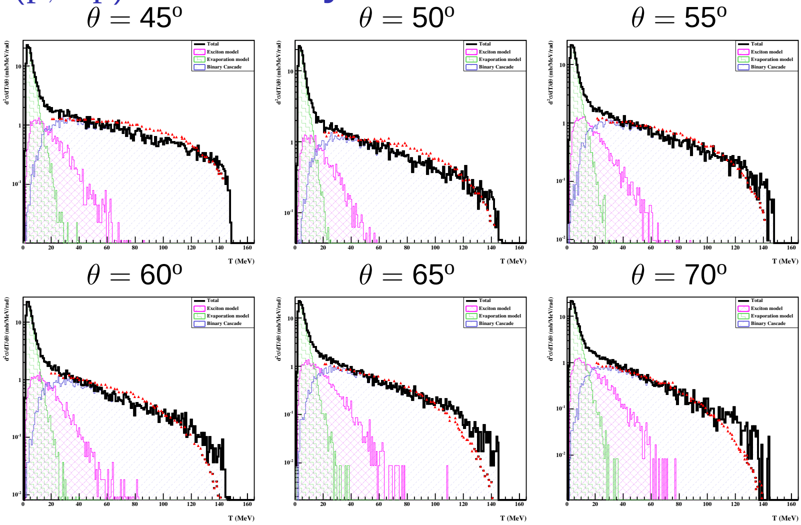
$\theta = 120^{o}$



$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ with Binary Cascade

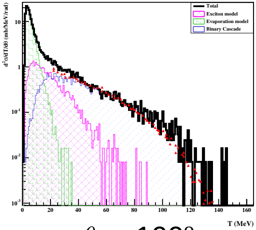


$^{58}\mathrm{Ni}(p, X p)$ with Binary Cascade

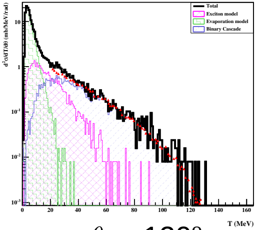


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ with Binary Cascade

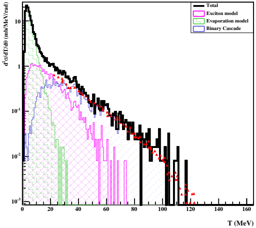
$\theta = 80^{o}$



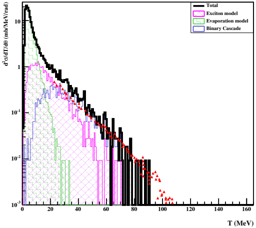
$\theta = 90^{o}$



$\theta = 100^{o}$

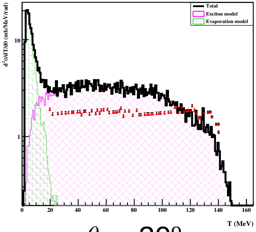


$\theta = 120^{o}$

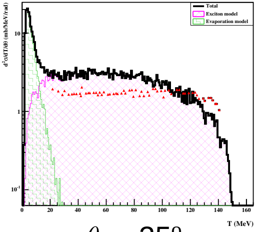


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ only Exciton model

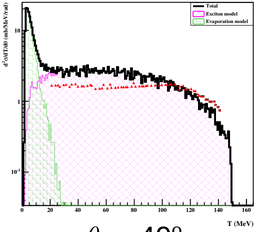
$\theta = 15^{o}$



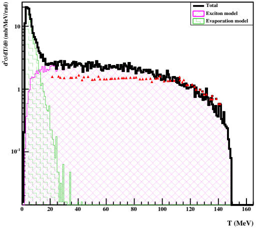
$\theta = 20^{o}$



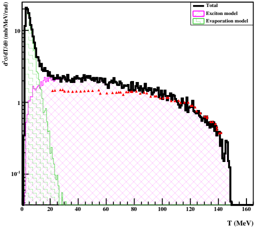
$\theta = 25^{o}$



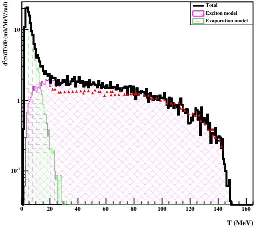
$\theta = 30^{o}$



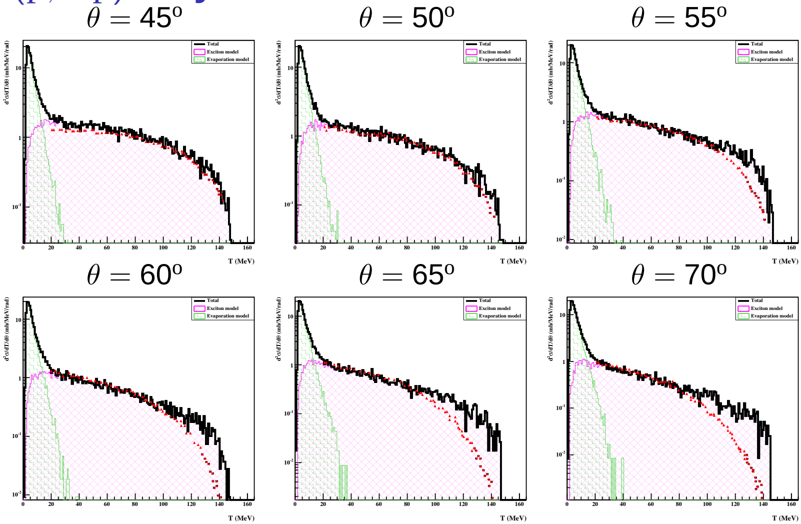
$\theta = 35^{o}$



$\theta = 40^{o}$

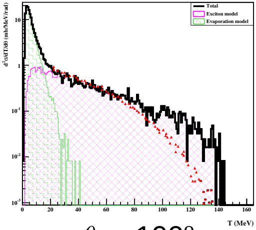


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ only Exciton model

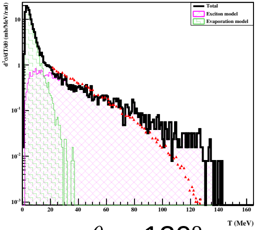


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ only Exciton model

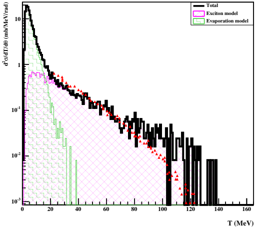
$\theta = 80^{o}$



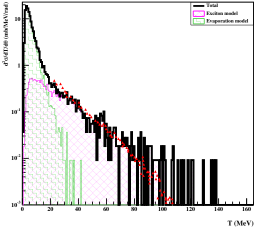
$\theta = 90^{o}$



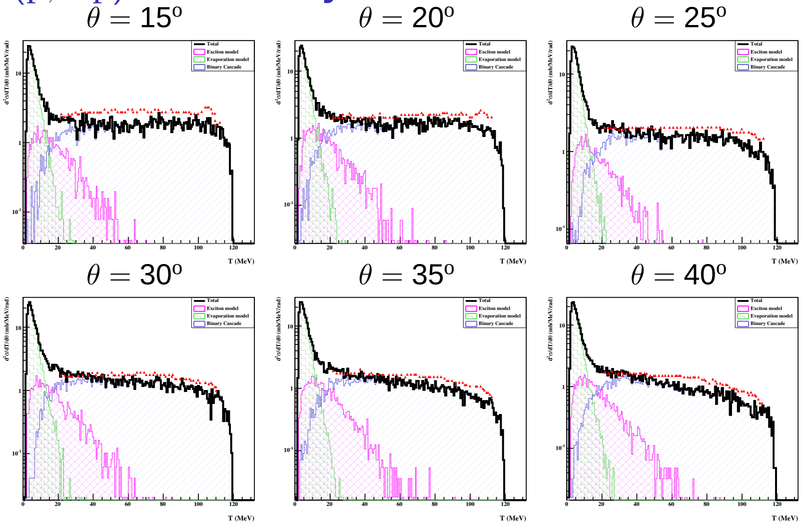
$\theta = 100^{o}$



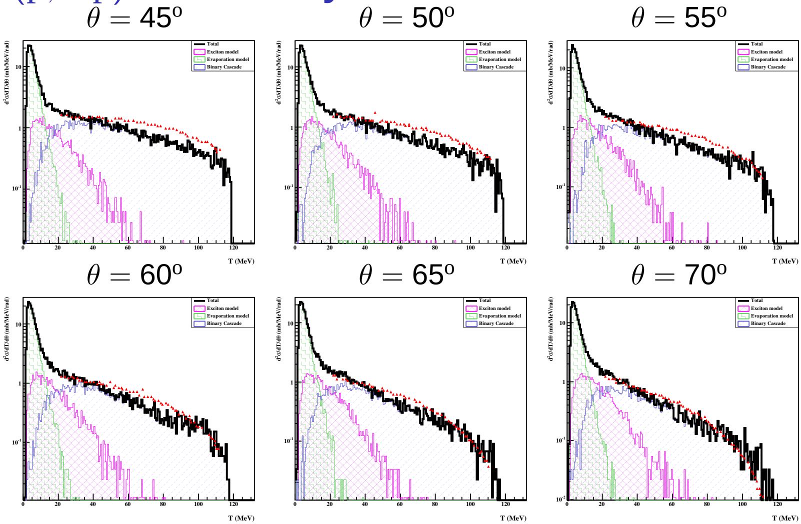
$\theta = 120^{o}$



$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ with Binary Cascade

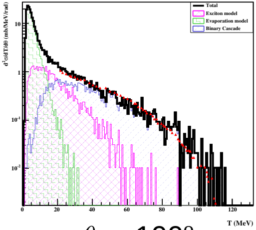


$^{58}\mathrm{Ni}(p, X p)$ with Binary Cascade

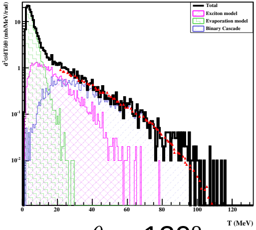


$^{58}\mathrm{Ni}(\mathrm{p}, X\,\mathrm{p})$ with Binary Cascade

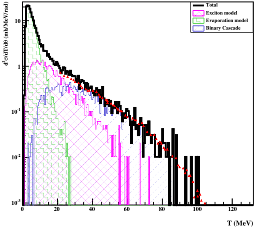
$\theta = 80^{\mathrm{o}}$



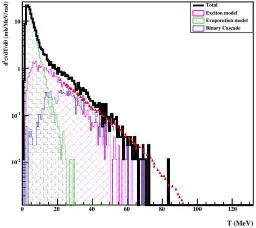
$\theta = 90^{\mathrm{o}}$



$\theta = 100^{\mathrm{o}}$

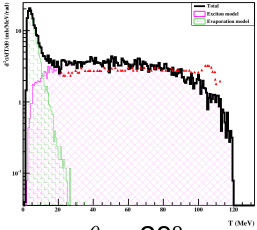


$\theta = 120^{\mathrm{o}}$

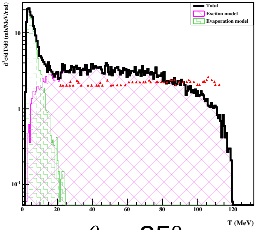


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ only Exciton model

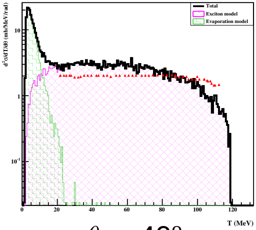
$\theta = 15^o$



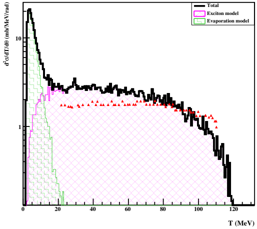
$\theta = 20^o$



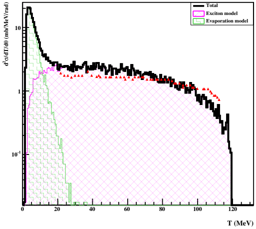
$\theta = 25^o$



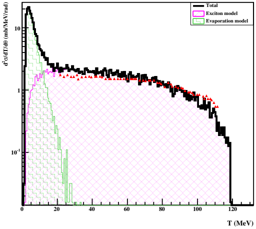
$\theta = 30^o$



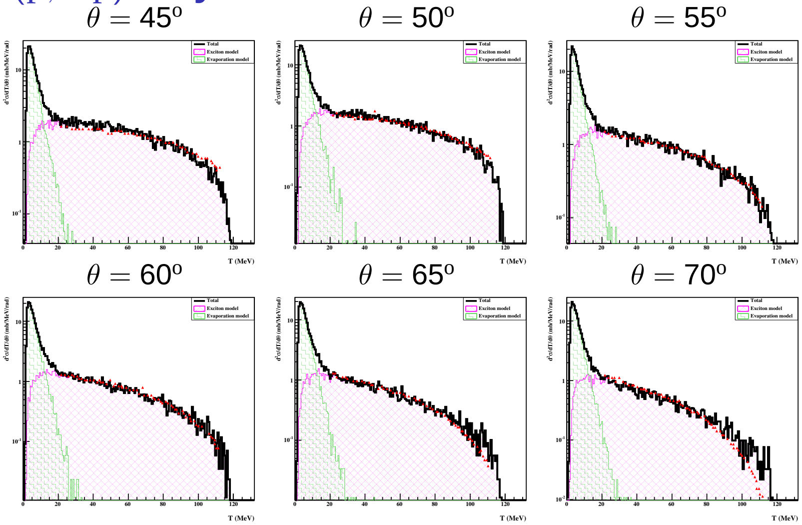
$\theta = 35^o$



$\theta = 40^o$

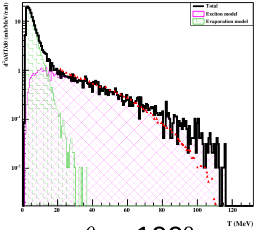


$^{58}\mathrm{Ni}(p, Xp)$ only Exciton model

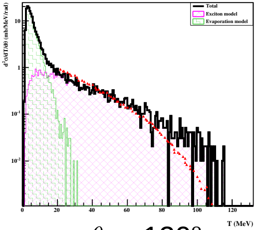


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$ only Exciton model

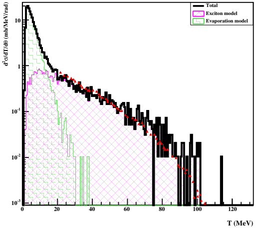
$\theta = 80^{o}$



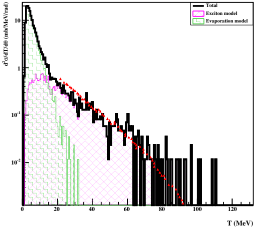
$\theta = 90^{o}$



$\theta = 100^{o}$

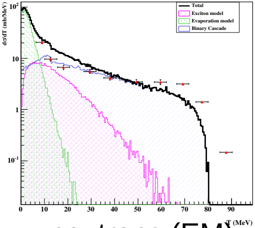


$\theta = 120^{o}$

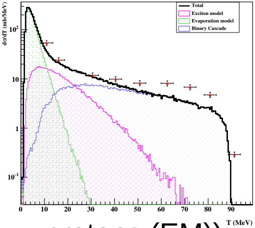


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{n})$ **and** $^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$

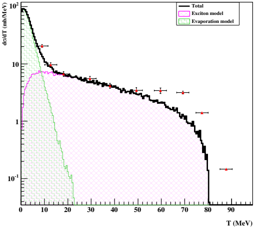
neutrons (BC+EM)



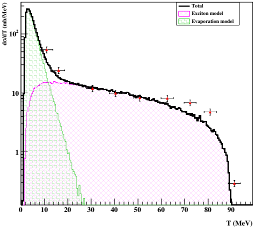
protons (BC+EM)



neutrons (EM)

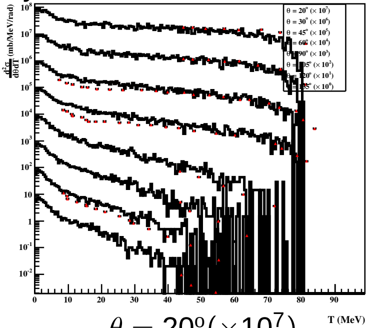


protons (EM))

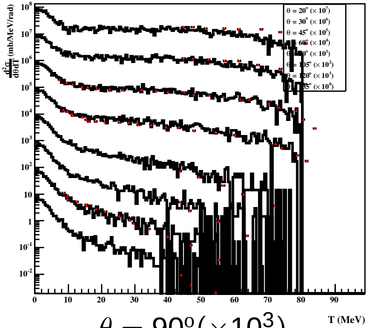


$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{n})$

Binary Cascade + Exciton model



Exciton model



$\theta = 20^o(\times 10^7)$

$\theta = 30^o(\times 10^6)$

$\theta = 45^o(\times 10^5)$

$\theta = 45^o(\times 10^4)$

$\theta = 90^o(\times 10^3)$

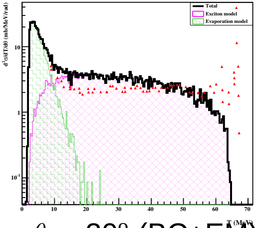
$\theta = 105^o(\times 10^2)$

$\theta = 120^o(\times 10^1)$

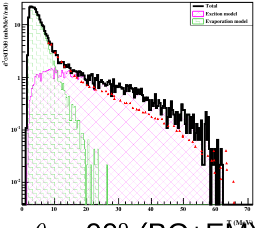
$\theta = 135^o(\times 10^0)$

$^{58}\mathrm{Ni}(\mathrm{p}, X\mathrm{p})$

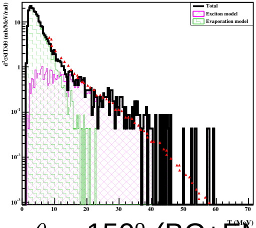
$\theta = 30^{\mathrm{o}}$ (EM)



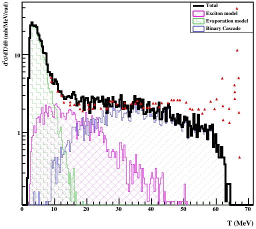
$\theta = 90^{\mathrm{o}}$ (EM)



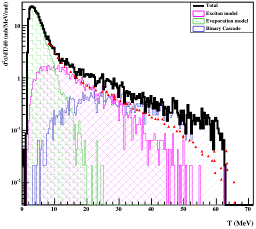
$\theta = 150^{\mathrm{o}}$ (EM)



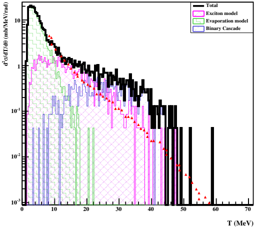
$\theta = 30^{\mathrm{o}}$ (BC+EM)



$\theta = 90^{\mathrm{o}}$ (BC+EM)

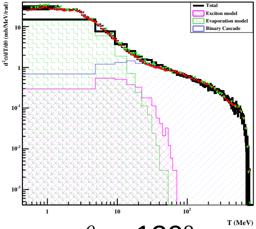


$\theta = 150^{\mathrm{o}}$ (BC+EM)

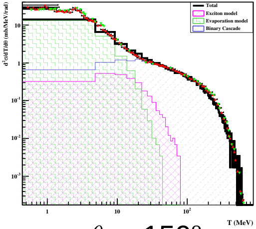


$^{0}\mathrm{Fe}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

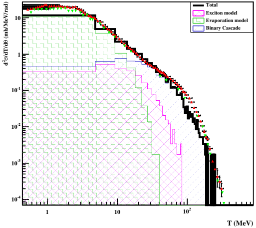
$\theta = 30^{o}$



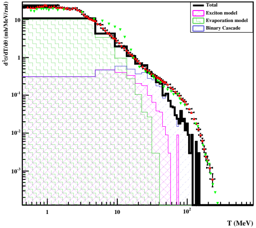
$\theta = 60^{o}$



$\theta = 120^{o}$

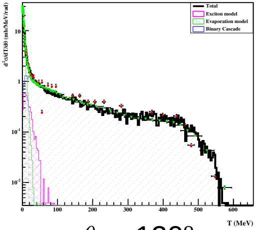


$\theta = 150^{o}$

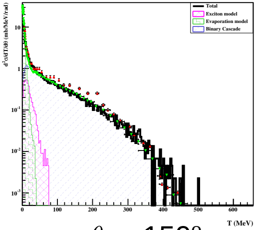


$^{0}\mathrm{Fe}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

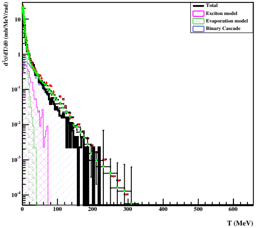
$\theta = 30^{o}$



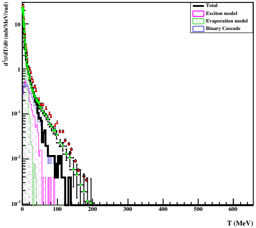
$\theta = 60^{o}$



$\theta = 120^{o}$

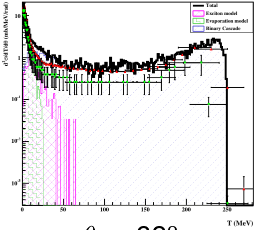


$\theta = 150^{o}$

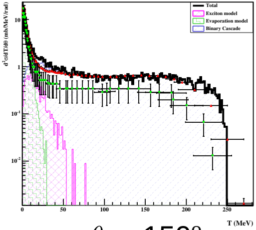


$^{0}\mathrm{Fe}(p, Xn)$ with Binary Cascade

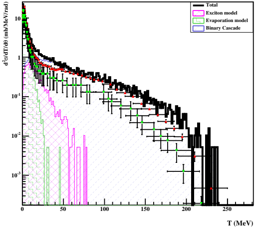
$\theta = 7.5^{o}$



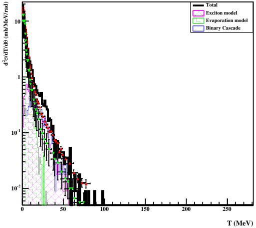
$\theta = 30^{o}$



$\theta = 60^{o}$

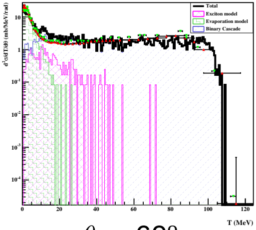


$\theta = 150^{o}$

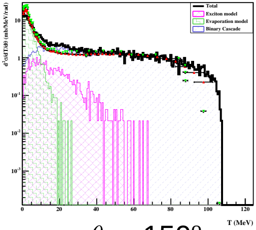


$^{0}\mathrm{Fe}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

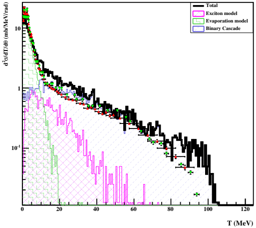
$\theta = 7.5^{o}$



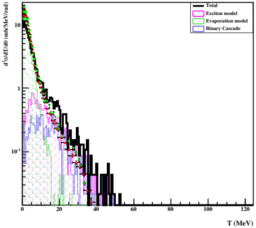
$\theta = 30^{o}$



$\theta = 60^{o}$

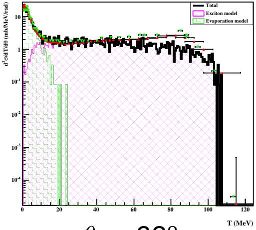


$\theta = 150^{o}$

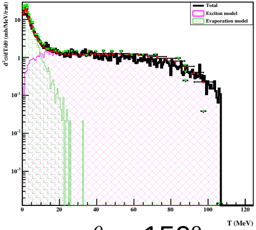


$^{0}\mathrm{Fe}(p, X n)$ only Exciton model

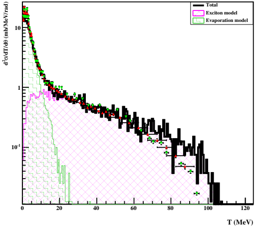
$\theta = 7.5^{o}$



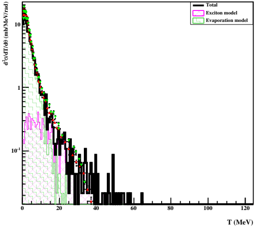
$\theta = 30^{o}$



$\theta = 60^{o}$

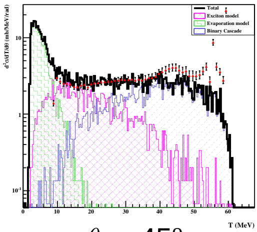


$\theta = 150^{o}$

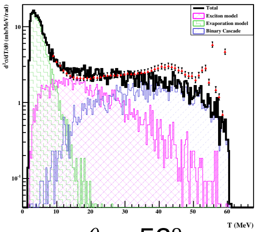


$^{56}\mathrm{Fe}(\mathrm{p},X\mathrm{p})$ with Binary Cascade

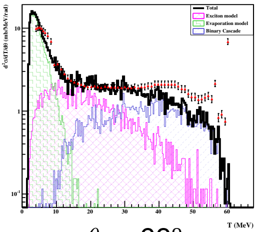
$\theta = 20^o$



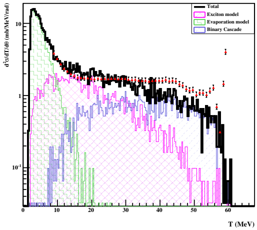
$\theta = 30^o$



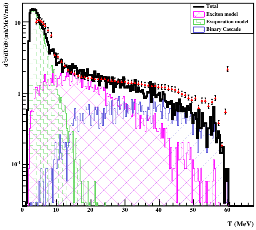
$\theta = 37^o$



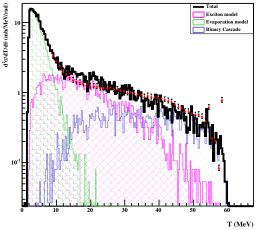
$\theta = 45^o$



$\theta = 52^o$

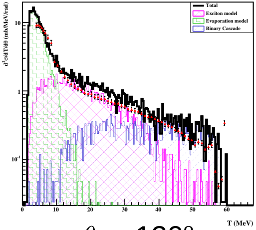


$\theta = 60^o$

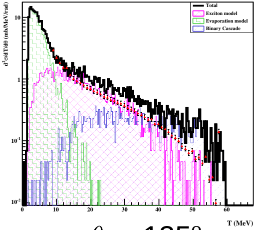


$^{56}\mathrm{Fe}(\mathrm{p}, X\mathrm{p})$ with Binary Cascade

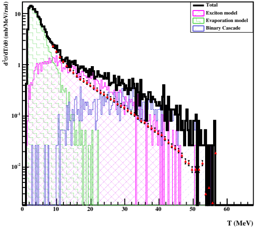
$\theta = 75^{o}$



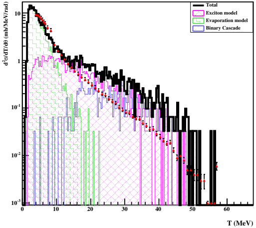
$\theta = 90^{o}$



$\theta = 120^{o}$

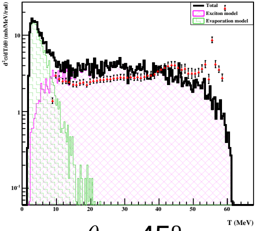


$\theta = 135^{o}$

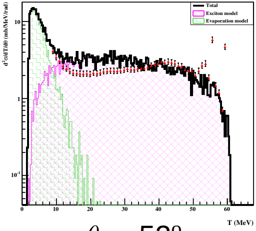


$^{56}\mathrm{Fe}(\mathrm{p}, X\mathrm{p})$ only Exciton model

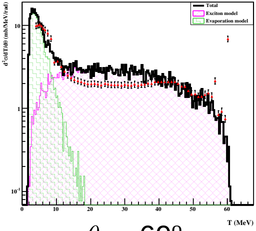
$\theta = 20^{\mathrm{o}}$



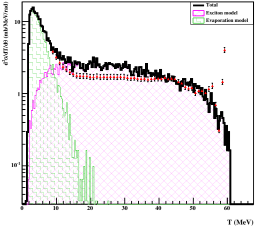
$\theta = 30^{\mathrm{o}}$



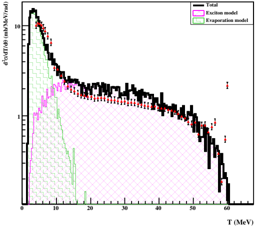
$\theta = 37^{\mathrm{o}}$



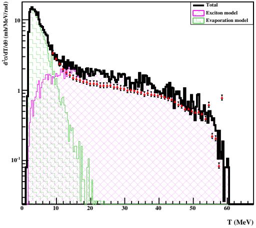
$\theta = 45^{\mathrm{o}}$



$\theta = 52^{\mathrm{o}}$

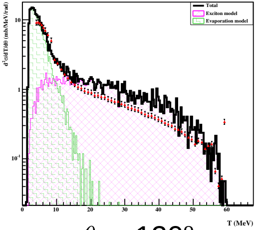


$\theta = 60^{\mathrm{o}}$

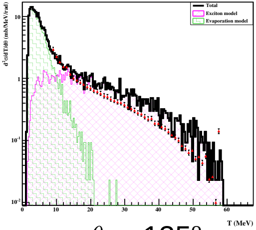


$^{56}\mathrm{Fe}(\mathrm{p}, X\,\mathrm{p})$ only Exciton model

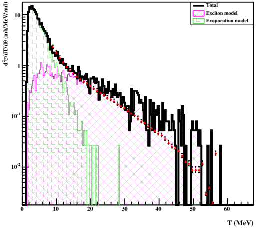
$\theta = 75^{o}$



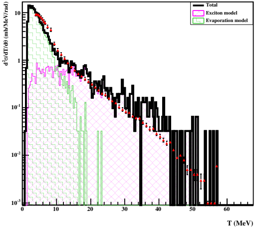
$\theta = 90^{o}$



$\theta = 120^{o}$

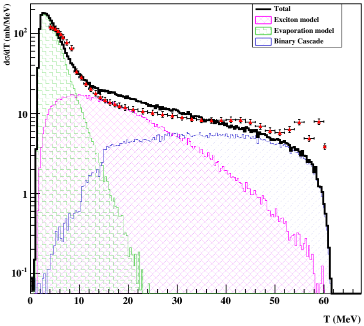


$\theta = 135^{o}$

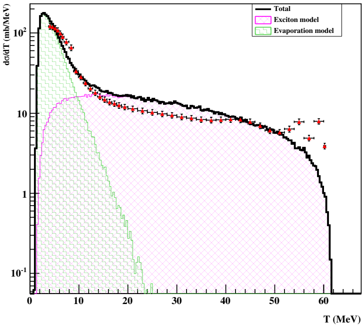


$^{56}Fe(p, X p)$

Binary Cascade + Exciton model

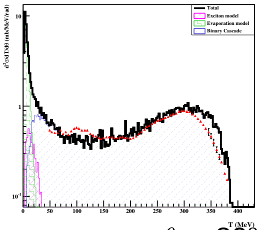


Exciton model

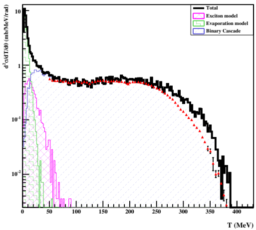


$^{40}\mathrm{Ca}(\mathrm{p}, X\mathrm{p})$ with Binary Cascade

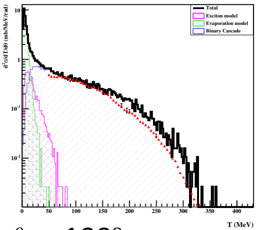
$\theta = 25^o$



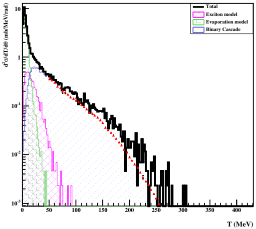
$\theta = 40^o$



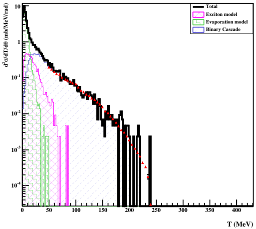
$\theta = 60^o$



$\theta = 80^o$

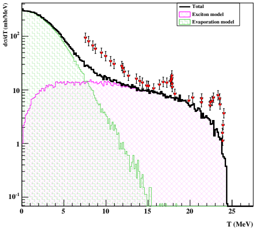


$\theta = 100^o$

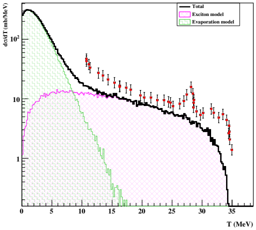


$^{48}\mathrm{Ca}(\mathrm{p}, X\mathrm{n})$ only Exciton model

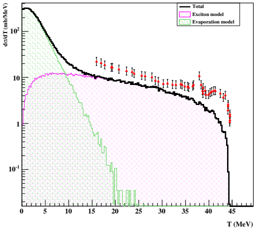
25 MeV



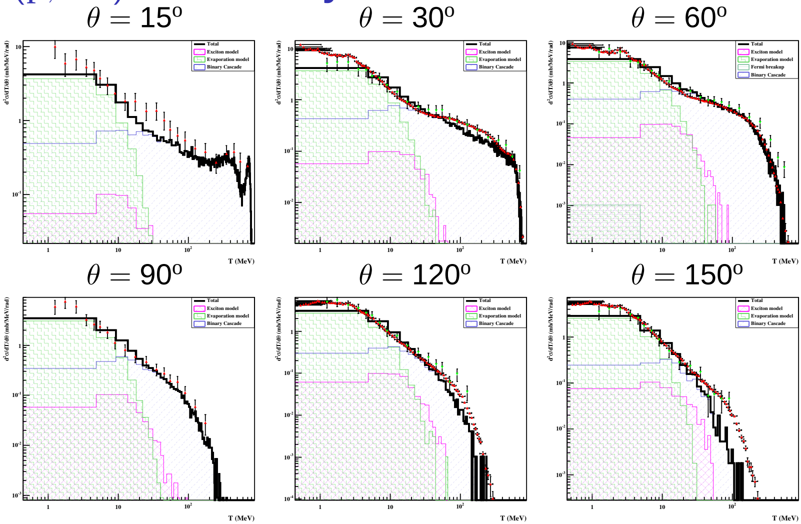
35 MeV



45 MeV

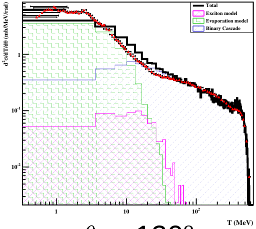


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

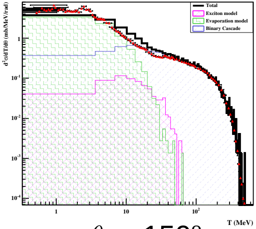


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

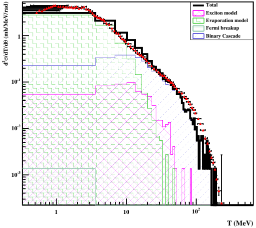
$\theta = 30^{\mathrm{o}}$



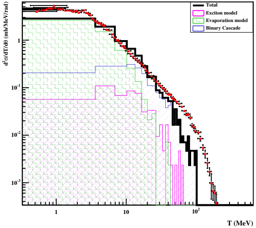
$\theta = 60^{\mathrm{o}}$



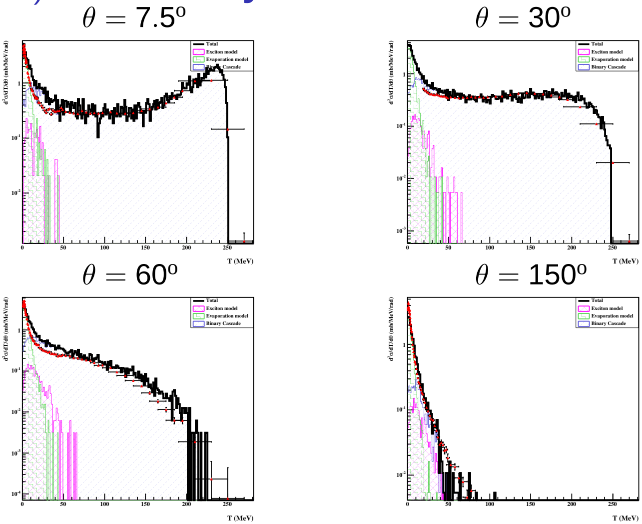
$\theta = 120^{\mathrm{o}}$



$\theta = 150^{\mathrm{o}}$

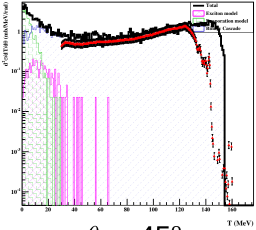


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

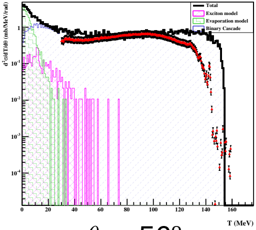


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

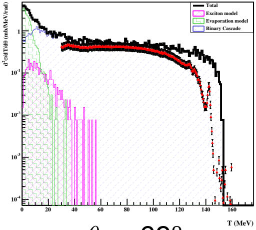
$\theta = 11^{o}$



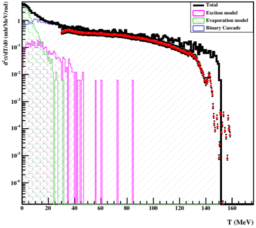
$\theta = 24^{o}$



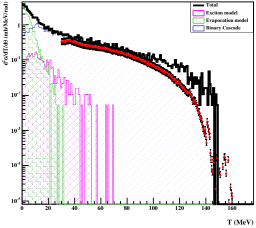
$\theta = 35^{o}$



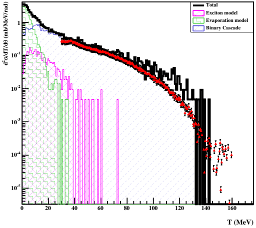
$\theta = 45^{o}$



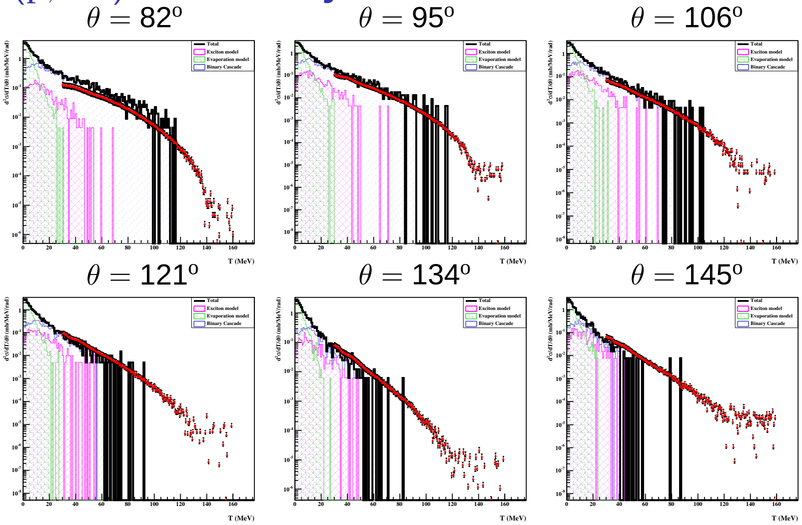
$\theta = 56^{o}$



$\theta = 69^{o}$

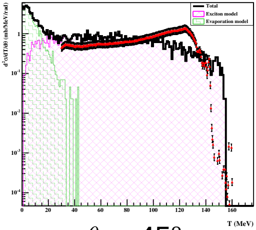


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

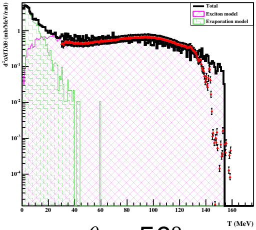


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ only Exciton model

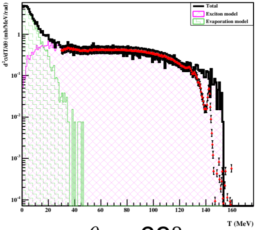
$\theta = 11^{o}$



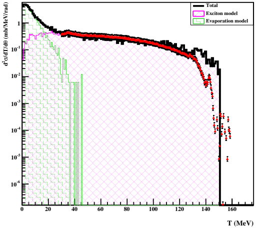
$\theta = 24^{o}$



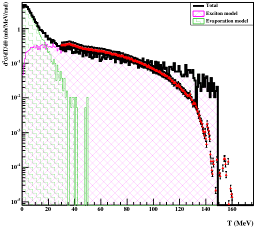
$\theta = 35^{o}$



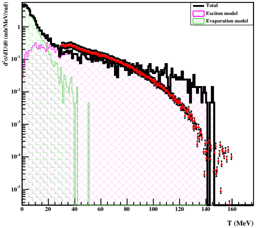
$\theta = 45^{o}$



$\theta = 56^{o}$

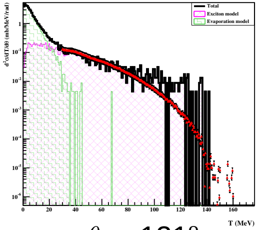


$\theta = 69^{o}$

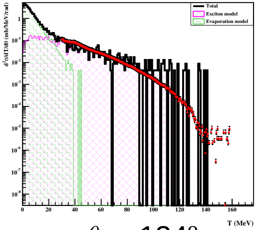


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ only Exciton model

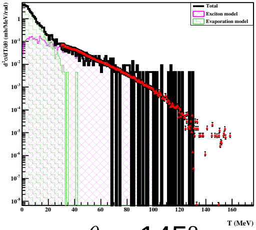
$\theta = 82^o$



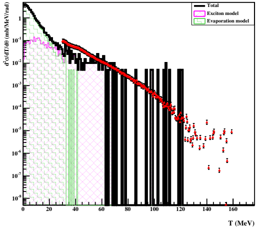
$\theta = 95^o$



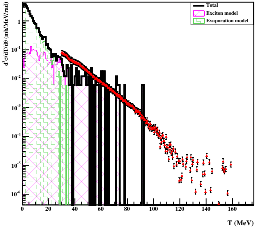
$\theta = 106^o$



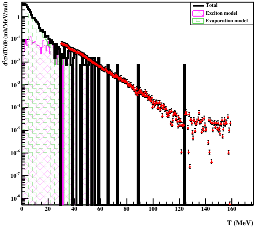
$\theta = 121^o$



$\theta = 134^o$

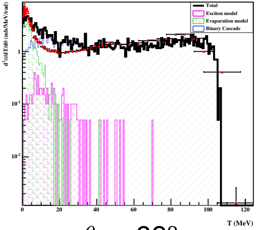


$\theta = 145^o$

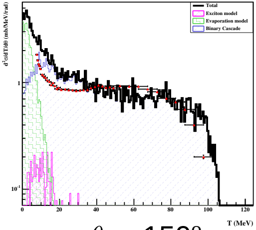


$^{27}\mathrm{Al}(p, X n)$ with Binary Cascade

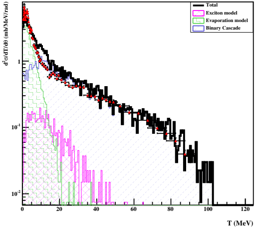
$\theta = 7.5^o$



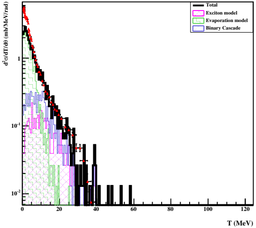
$\theta = 30^o$



$\theta = 60^o$

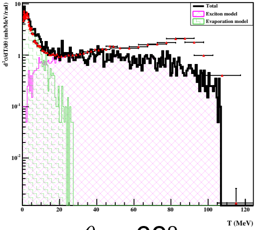


$\theta = 150^o$

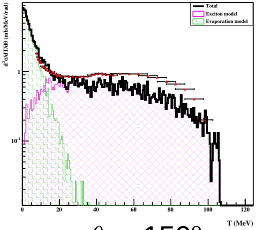


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

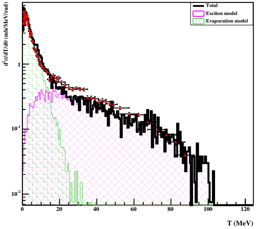
$\theta = 7.5^{o}$



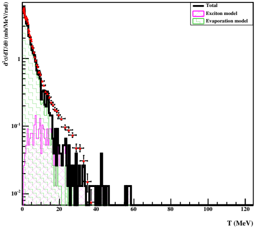
$\theta = 30^{o}$



$\theta = 60^{o}$

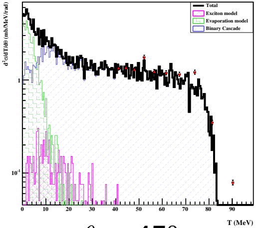


$\theta = 150^{o}$

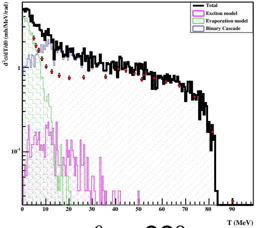


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

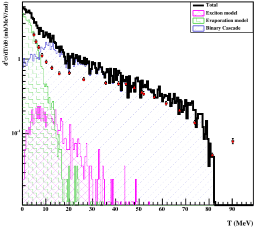
$\theta = 20^{o}$



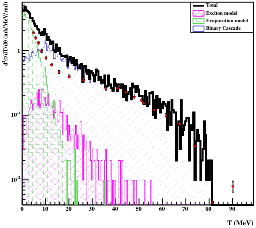
$\theta = 30^{o}$



$\theta = 45^{o}$

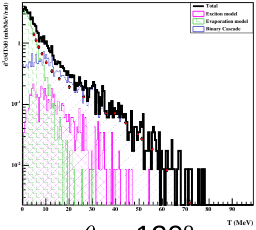


$\theta = 60^{o}$

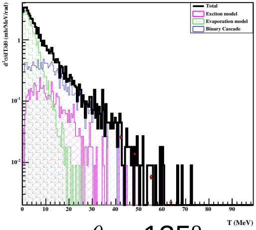


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ with Binary Cascade

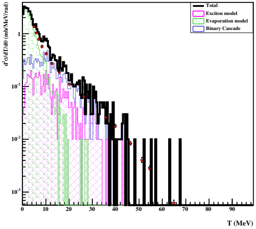
$\theta = 90^{o}$



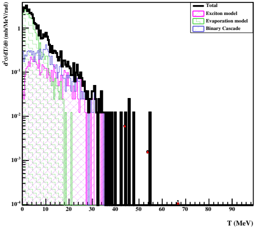
$\theta = 105^{o}$



$\theta = 120^{o}$

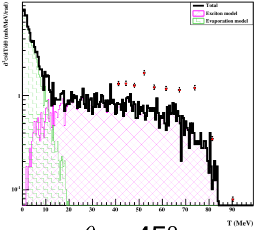


$\theta = 135^{o}$

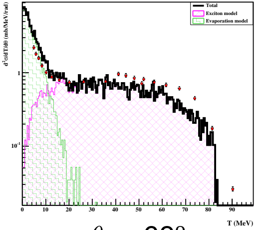


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{n})$ only Exciton model

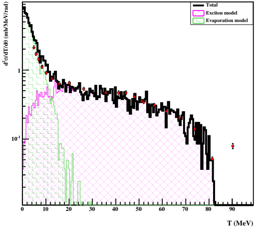
$\theta = 20^{\mathrm{o}}$



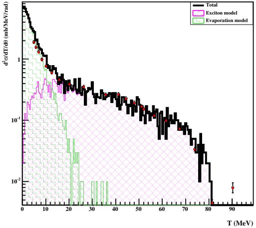
$\theta = 30^{\mathrm{o}}$



$\theta = 45^{\mathrm{o}}$

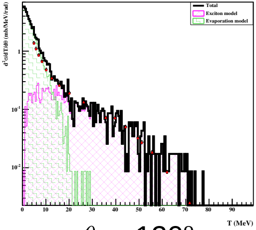


$\theta = 60^{\mathrm{o}}$

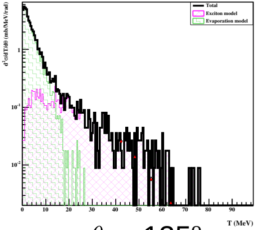


$^{27}\mathrm{Al}(\mathrm{p},X\mathrm{n})$ only Exciton model

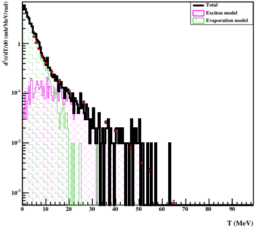
$\theta = 90^{o}$



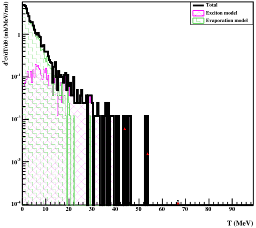
$\theta = 105^{o}$



$\theta = 120^{o}$

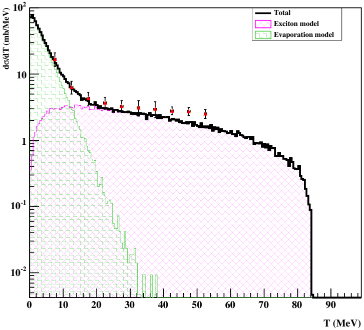


$\theta = 135^{o}$

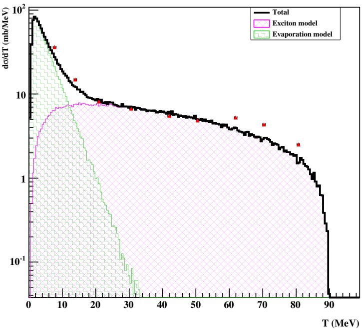


$^{27}\mathrm{Al}(\mathrm{p},X\mathrm{n})$ and $^{27}\mathrm{Al}(\mathrm{p},X\mathrm{p})$ only Exciton model

neutrons

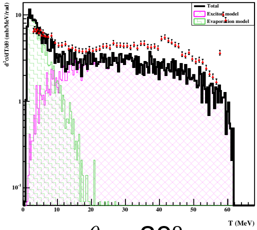


protons

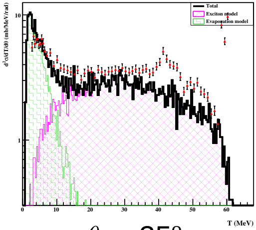


$^{27}\mathrm{Al}(\mathrm{p},X\mathrm{p})$ only Exciton model

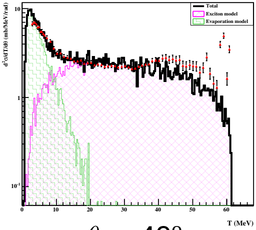
$\theta = 12^{o}$



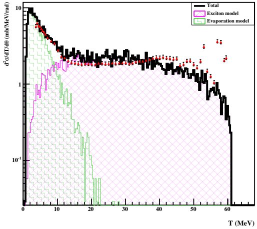
$\theta = 15^{o}$



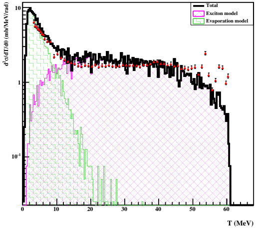
$\theta = 25^{o}$



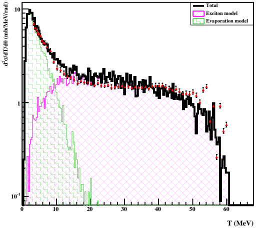
$\theta = 30^{o}$



$\theta = 35^{o}$

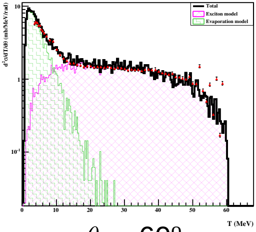


$\theta = 40^{o}$

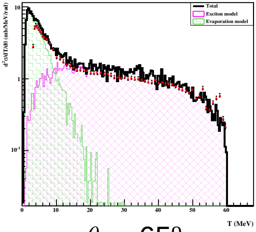


$^{27}\mathrm{Al}(p, Xp)$ only Exciton model

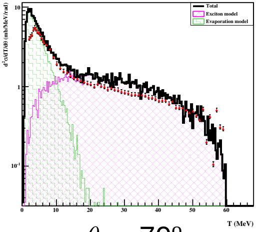
$\theta = 45^o$



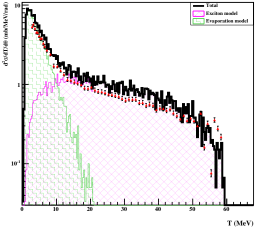
$\theta = 50^o$



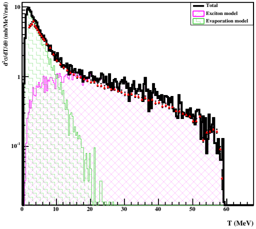
$\theta = 55^o$



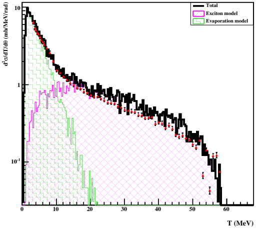
$\theta = 60^o$



$\theta = 65^o$

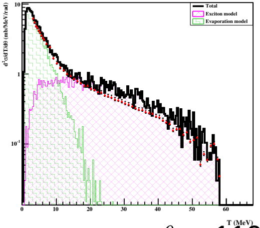


$\theta = 70^o$

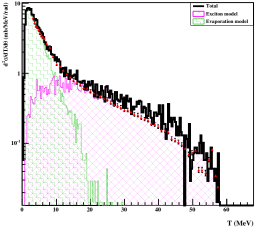


$^{27}\mathrm{Al}(\mathrm{p}, X\mathrm{p})$ only Exciton model

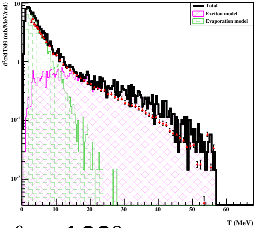
$\theta = 75^{\circ}$



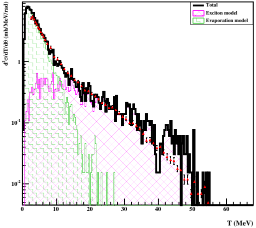
$\theta = 82^{\circ}$



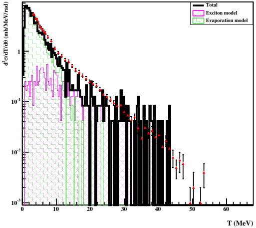
$\theta = 90^{\circ}$



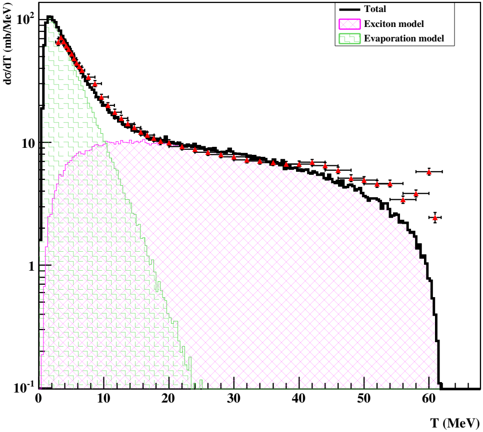
$\theta = 110^{\circ}$



$\theta = 160^{\circ}$

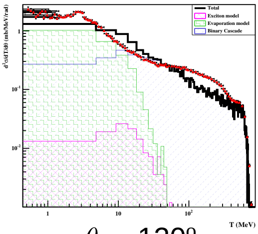


$^{27}\mathrm{Al}(\mathrm{p}, X\,\mathrm{p})$ only Exciton model

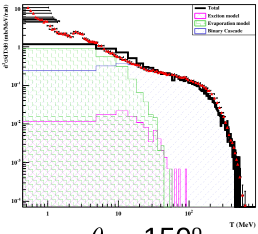


$^{16}\mathrm{O}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

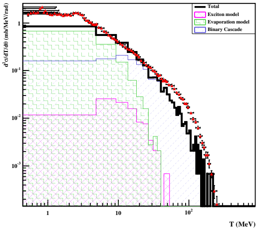
$\theta = 30^{o}$



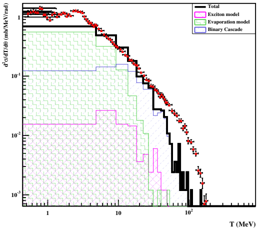
$\theta = 60^{o}$



$\theta = 120^{o}$

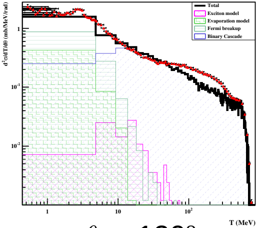


$\theta = 150^{o}$

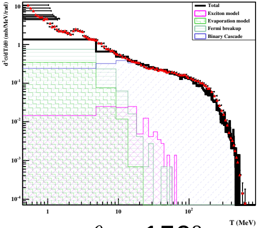


$^{16}\mathrm{O}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

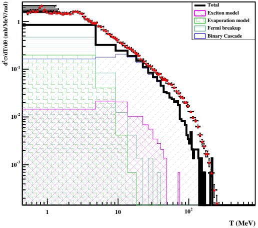
$\theta = 30^{\mathrm{o}}$



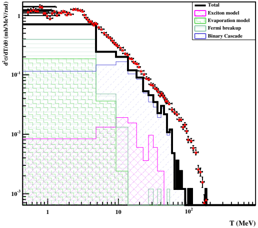
$\theta = 60^{\mathrm{o}}$



$\theta = 120^{\mathrm{o}}$

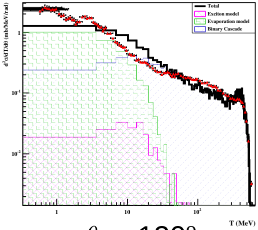


$\theta = 150^{\mathrm{o}}$

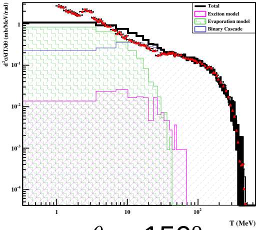


$^{16}\mathrm{O}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

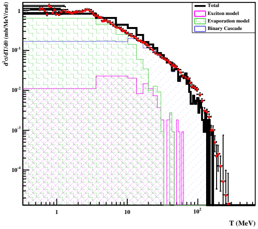
$\theta = 30^{\mathrm{o}}$



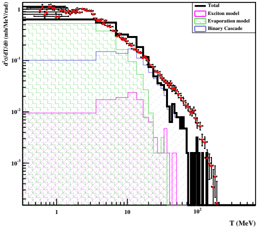
$\theta = 60^{\mathrm{o}}$



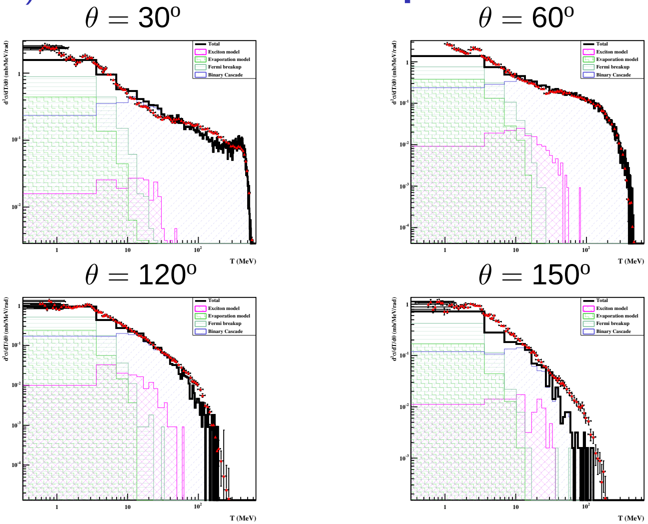
$\theta = 120^{\mathrm{o}}$



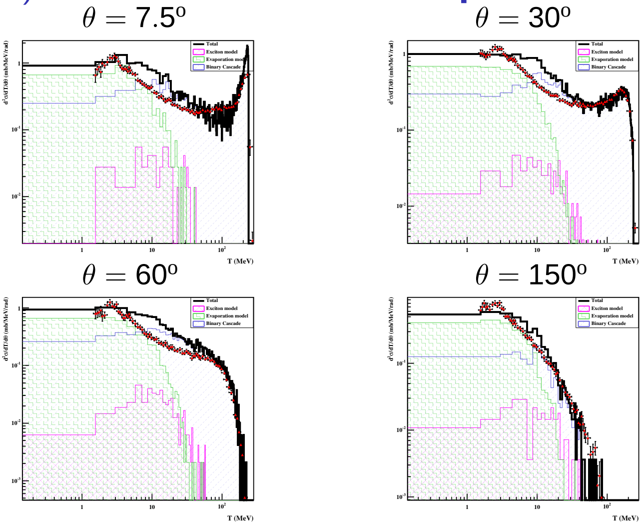
$\theta = 150^{\mathrm{o}}$



$^{16}O(p, Xn)$ with Fermi Break–up

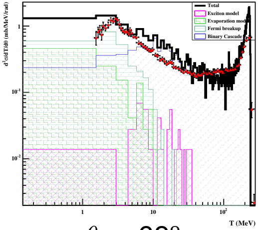


$^{16}\mathrm{O}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

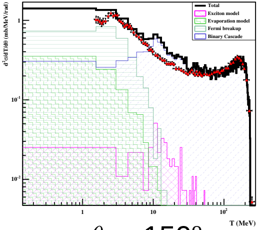


$^{16}\mathrm{O}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

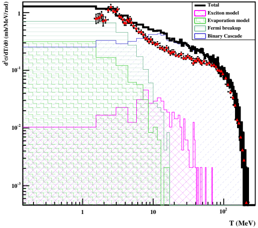
$\theta = 7.5^{\mathrm{o}}$



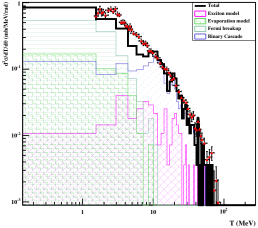
$\theta = 30^{\mathrm{o}}$



$\theta = 60^{\mathrm{o}}$

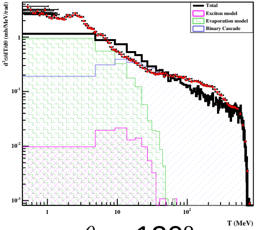


$\theta = 150^{\mathrm{o}}$

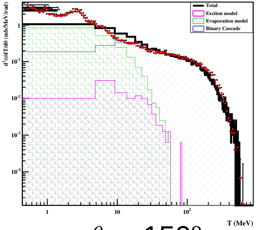


$^{0}\mathrm{N}(\mathrm{p}, X\,\mathrm{n})$ without Fermi Break–up

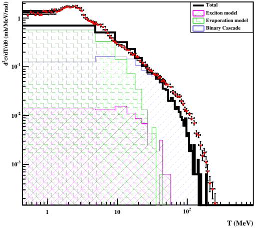
$\theta = 30^{o}$



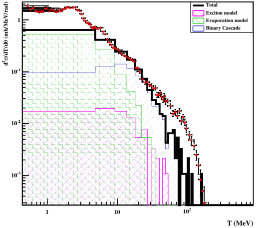
$\theta = 60^{o}$



$\theta = 120^{o}$

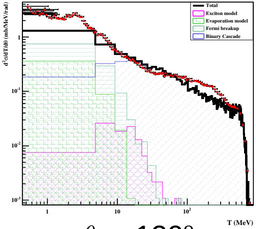


$\theta = 150^{o}$

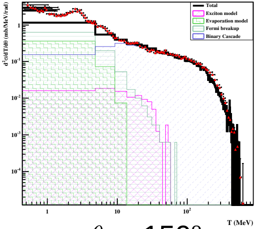


$^{0}\mathrm{N}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

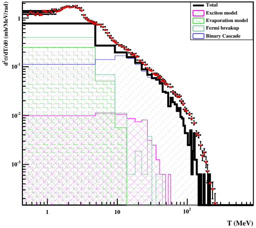
$\theta = 30^{o}$



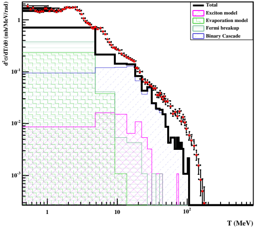
$\theta = 60^{o}$



$\theta = 120^{o}$

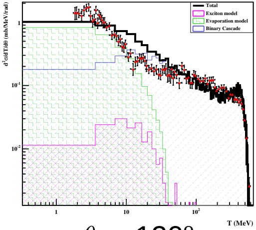


$\theta = 150^{o}$

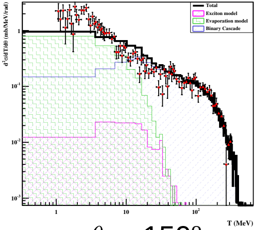


$^{0}\mathrm{N}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

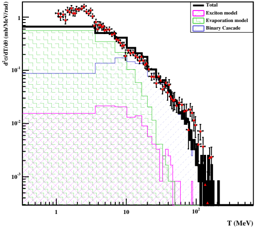
$\theta = 30^{o}$



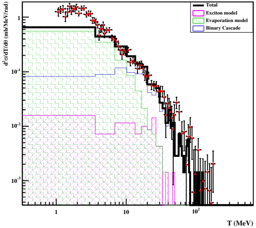
$\theta = 60^{o}$



$\theta = 120^{o}$

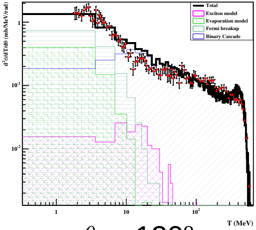


$\theta = 150^{o}$

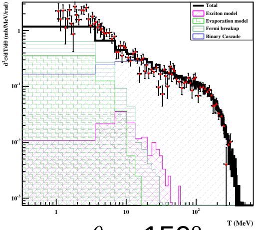


$^{0}\mathrm{N}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

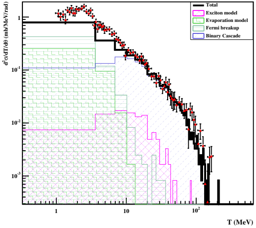
$\theta = 30^{o}$



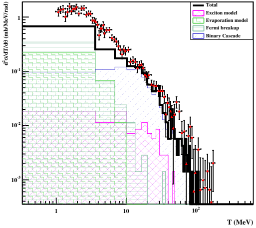
$\theta = 60^{o}$



$\theta = 120^{o}$

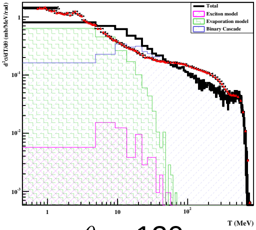


$\theta = 150^{o}$

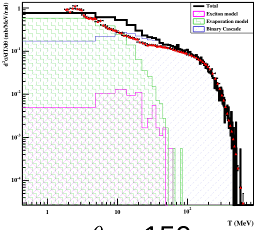


$^{0}\mathrm{C}(\mathrm{p}, X\mathrm{n})$ without Fermi Break-up

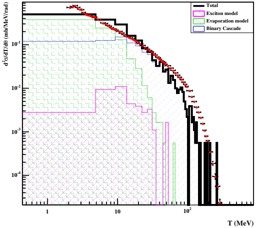
$\theta = 30$



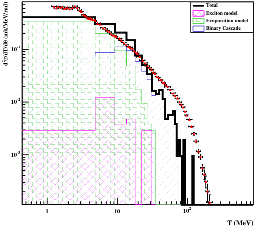
$\theta = 60$



$\theta = 120$

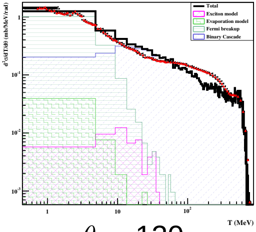


$\theta = 150$

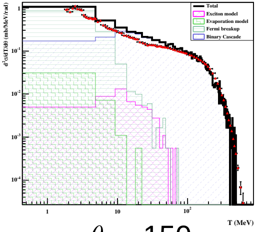


$^{0}\mathrm{C}(\mathrm{p}, X\mathrm{n})$ with Fermi Break-up

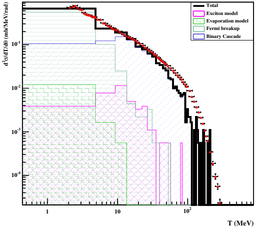
$\theta = 30$



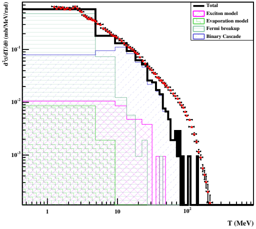
$\theta = 60$



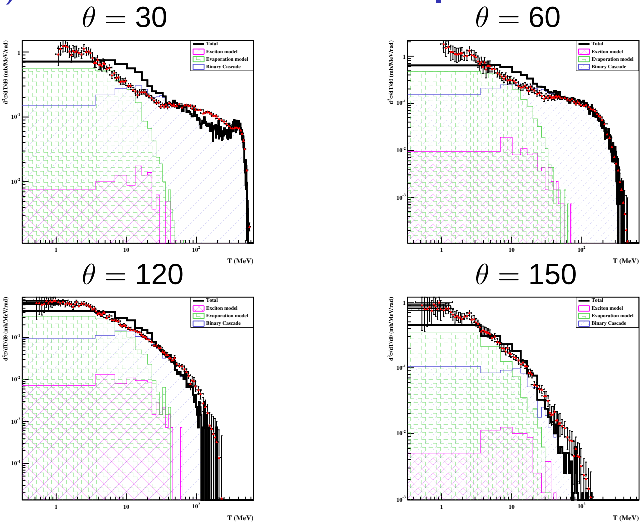
$\theta = 120$



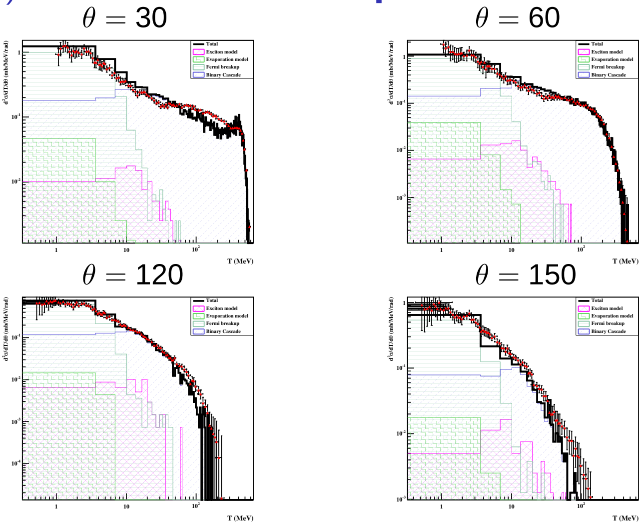
$\theta = 150$



$^{0}\mathrm{C}(\mathrm{p}, X\mathrm{n})$ without Fermi Break-up

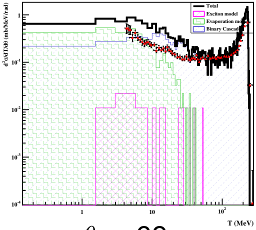


$^{0}\mathrm{C}(p, X n)$ with Fermi Break-up

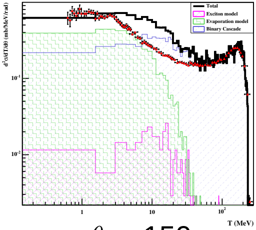


$^{0}\mathrm{C}(\mathrm{p},X\mathrm{n})$ without Fermi Break-up

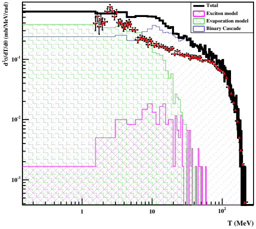
$\theta = 7.5$



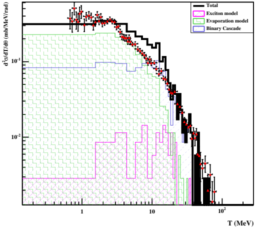
$\theta = 30$



$\theta = 60$

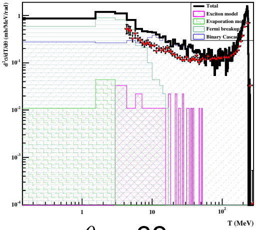


$\theta = 150$

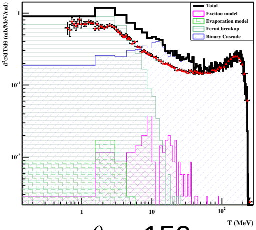


$^{0}\mathrm{C}(\mathrm{p}, X\mathrm{n})$ with Fermi Break-up

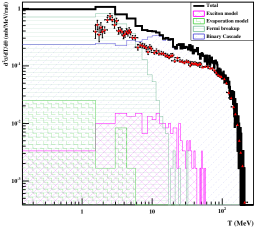
$\theta = 7.5$



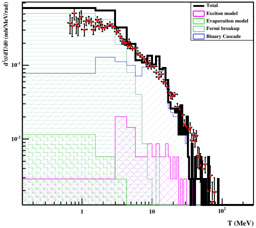
$\theta = 30$



$\theta = 60$

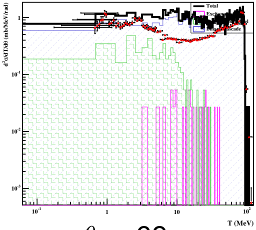


$\theta = 150$

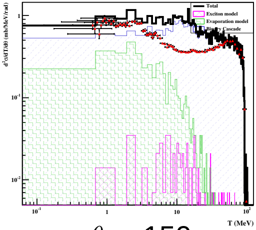


$^{0}\mathrm{C}(\mathrm{p}, X\mathrm{n})$ without Fermi Break-up

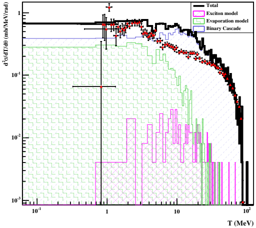
$\theta = 7.5$



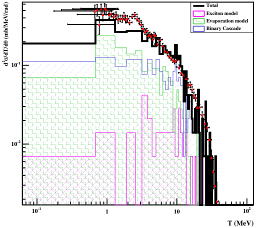
$\theta = 30$



$\theta = 60$

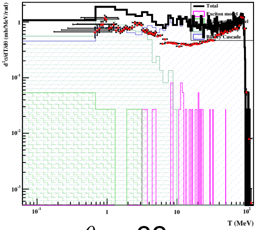


$\theta = 150$

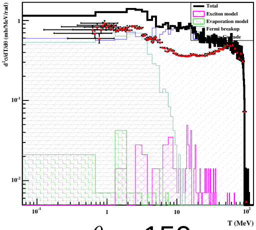


$^{0}\mathrm{C}(\mathrm{p}, X\mathrm{n})$ with Fermi Break-up

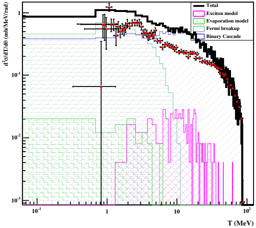
$\theta = 7.5$



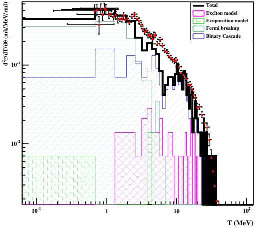
$\theta = 30$



$\theta = 60$

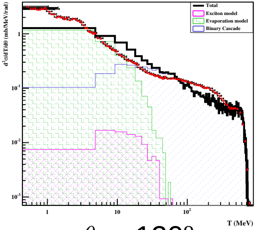


$\theta = 150$

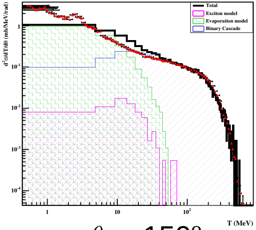


$^{0}\mathrm{B}(p, X n)$ without Fermi Break–up

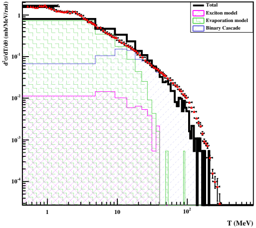
$\theta = 30^{o}$



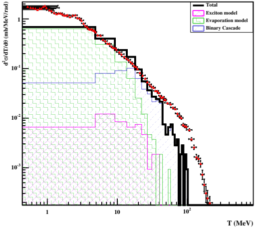
$\theta = 60^{o}$



$\theta = 120^{o}$

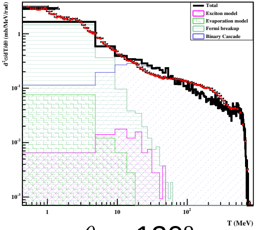


$\theta = 150^{o}$

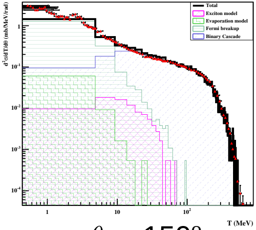


$^{0}\mathrm{B}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

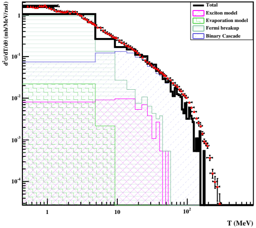
$\theta = 30^{o}$



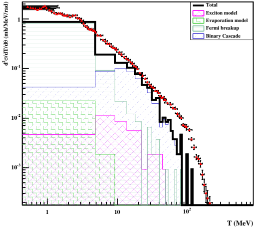
$\theta = 60^{o}$



$\theta = 120^{o}$

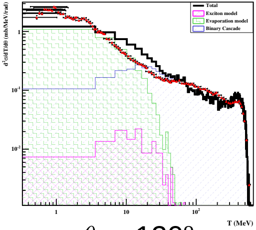


$\theta = 150^{o}$

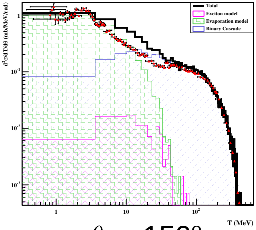


$^{0}\mathrm{B}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

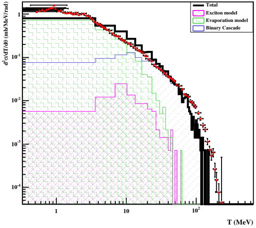
$\theta = 30^{o}$



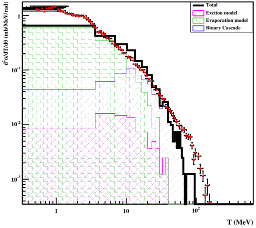
$\theta = 60^{o}$



$\theta = 120^{o}$

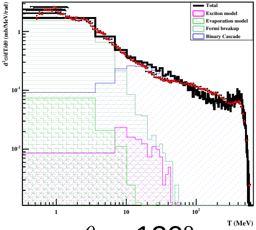


$\theta = 150^{o}$

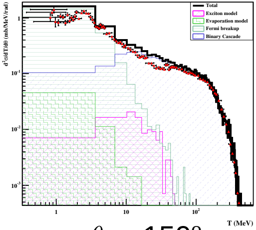


$^{0}\mathrm{O}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

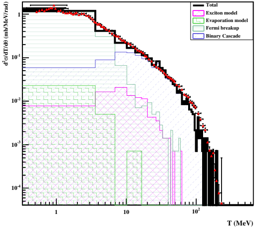
$\theta = 30^{o}$



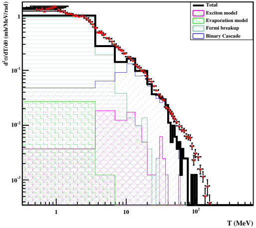
$\theta = 60^{o}$



$\theta = 120^{o}$

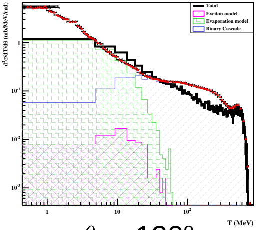


$\theta = 150^{o}$



$^{9}\mathrm{Be}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

$\theta = 30^{o}$



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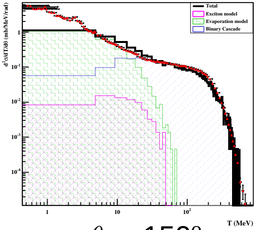
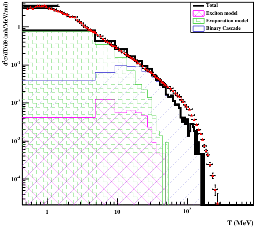
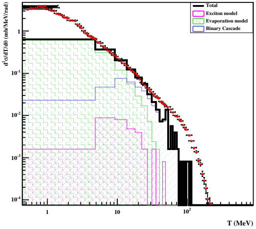


$\theta = 120^{o}$

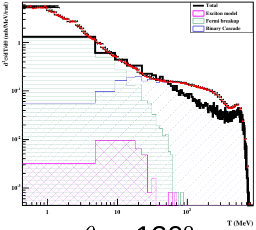


$\theta = 150^{o}$

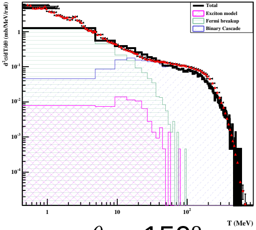


$^{9}\mathrm{Be}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

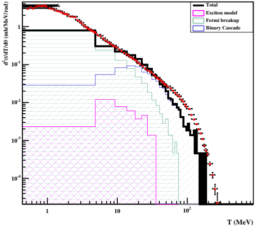
$\theta = 30^{\mathrm{o}}$



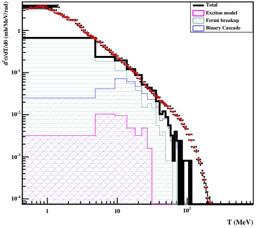
$\theta = 60^{\mathrm{o}}$



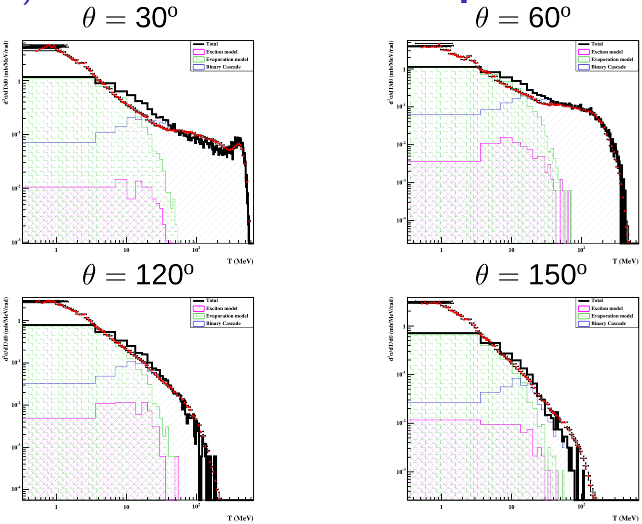
$\theta = 120^{\mathrm{o}}$



$\theta = 150^{\mathrm{o}}$

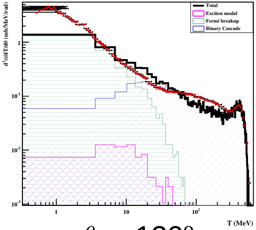


$^{9}\mathrm{Be}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

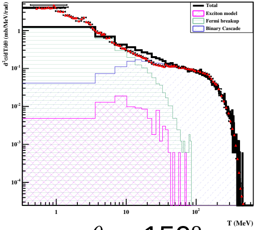


$^{9}\mathrm{Be}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

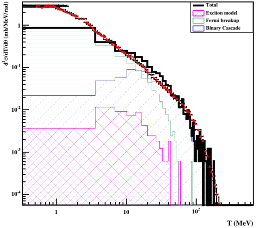
$\theta = 30^{o}$



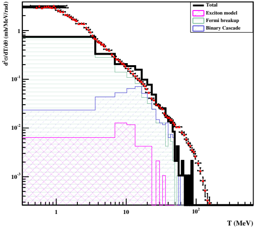
$\theta = 60^{o}$



$\theta = 120^{o}$



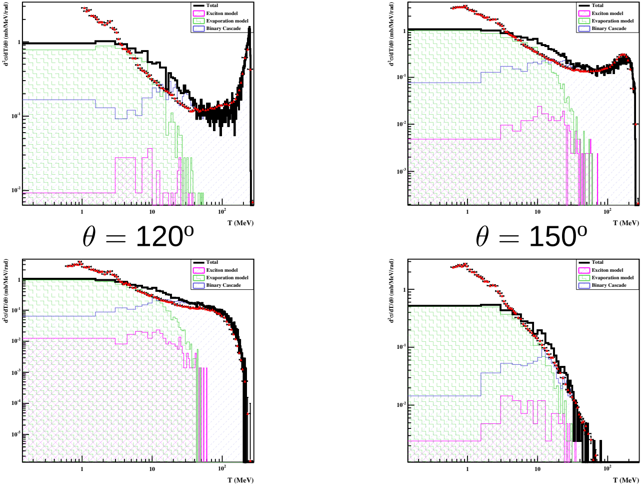
$\theta = 150^{o}$



$^{9}\mathrm{Be}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

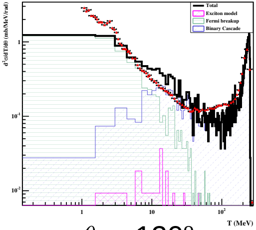
$\theta = 30^{o}$ $\theta = 60^{o}$

$\theta = 120^{o}$ $\theta = 150^{o}$

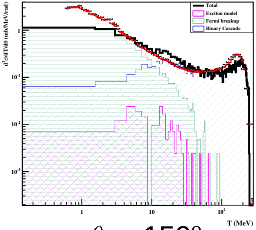


$^{9}\mathrm{Be}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

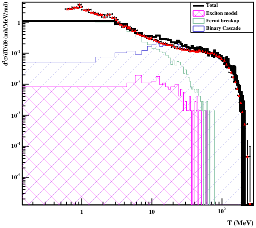
$\theta = 30^{o}$



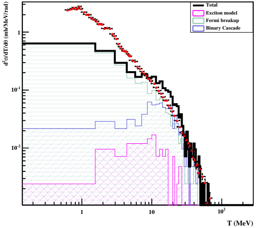
$\theta = 60^{o}$



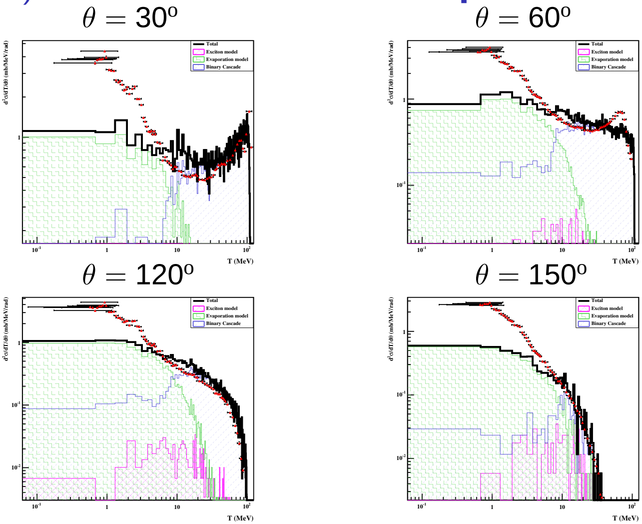
$\theta = 120^{o}$



$\theta = 150^{o}$

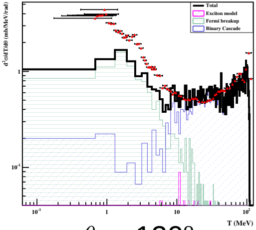


$^{9}\mathrm{Be}(\mathrm{p}, X\mathrm{n})$ without Fermi Break–up

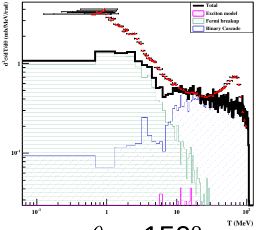


$^{9}\mathrm{Be}(\mathrm{p}, X\mathrm{n})$ with Fermi Break–up

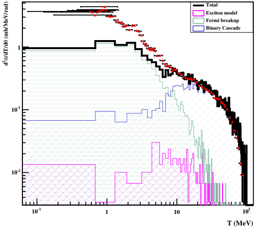
$\theta = 30^{o}$



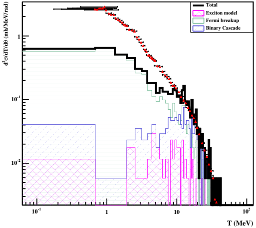
$\theta = 60^{o}$



$\theta = 120^{o}$



$\theta = 150^{o}$



Conclusions

- It is difficult to extract conclusions due to experimental data quality and mixed contribution from several models.
- The overall agreement is not so bad (depending on applications)
- There is still room for improvements. For example:
  - Switch from Binary Cascade to Preequilibrium (also between the other models)
  - Coulomb barriers
  - Take into account angular momentum

Open questions

Is this test enough? What about:

- Reactions to specific channels?
- Production of alphas, tritons, deuterons...?
- Residual nuclei distributions?

Is the fission model working properly?

Excitation functions are a convinient tool to test models of nuclear reactions (they are more sensitive to nuclear reaction mechanisms than double differential cross sections).