First Results from Simple Benchmark Studies

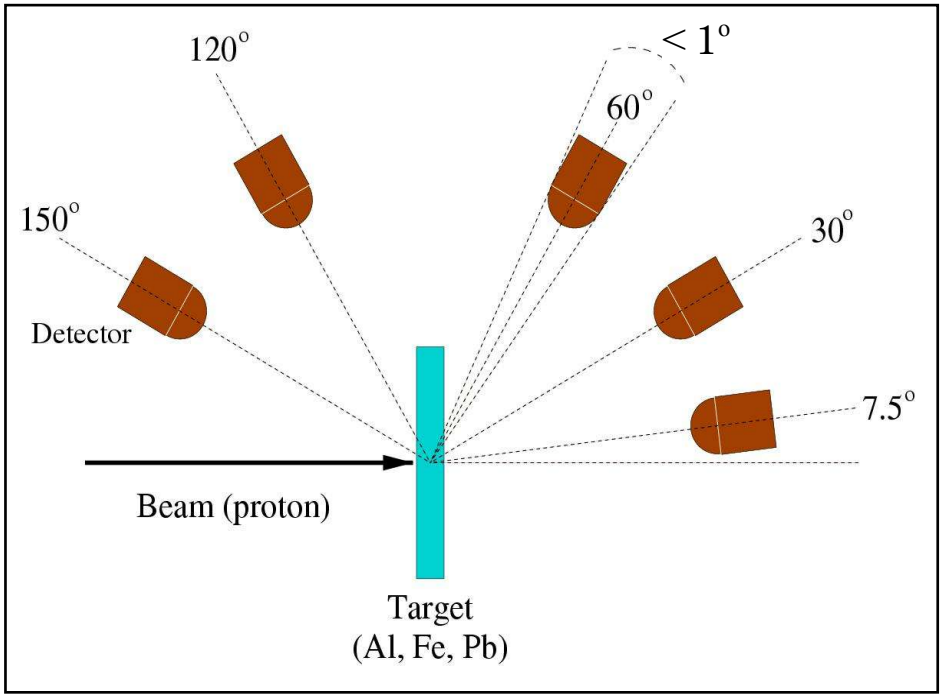
- Introduction
- Simulation setup and experimental data
- Double differential (p,xn) cross sections
- Azimuthal checks
- Conclusions

Introduction

- Predicitive power of detector simulation rests on correct simulation of individual interactions between particles and detector material
- Check that the simulation of such interactions is sufficiently accurate:
  - **Compare Geant4, Fluka and experimental data for simple benchmark geometries and materials for single incident particles of various energies**
- Should repeat all studies with each new release of simulation package
  - Would like a (semi-)automatic **test suite** to repeat these studies when desired
- Continuation of / complementary to
  - Validation work done within Geant4 and Fluka collaborations
  - Earlier studies, e.g. by I. Gonzalez et al (ALICE)
- Thin target hadronic benchmarks chosen as a starting point
  - Several other studies planned or in progress

Experimental Data

- Differential (p,xn) cross sections measured at LAMPF:
  - Incident proton energies: 113, 256, 597, 800 MeV
  - Thin targets (Al, Fe, Pb, ...)
    - ≤ 1 interaction per incident proton
    - Measure Al(p,xn) etc
  - Neutron detectors at 5 angles
  - Relative errors on double diff. cross sections typ. ~ 5%
  - References:
    - Nucl Sci Eng 102 (1989) 310
    - Nucl Sci Eng 110 (1992) 289
    - Nucl Sci Eng 112 (1992) 78
    - Nucl Sci Eng 115 (1993) 1



Simulation Setup

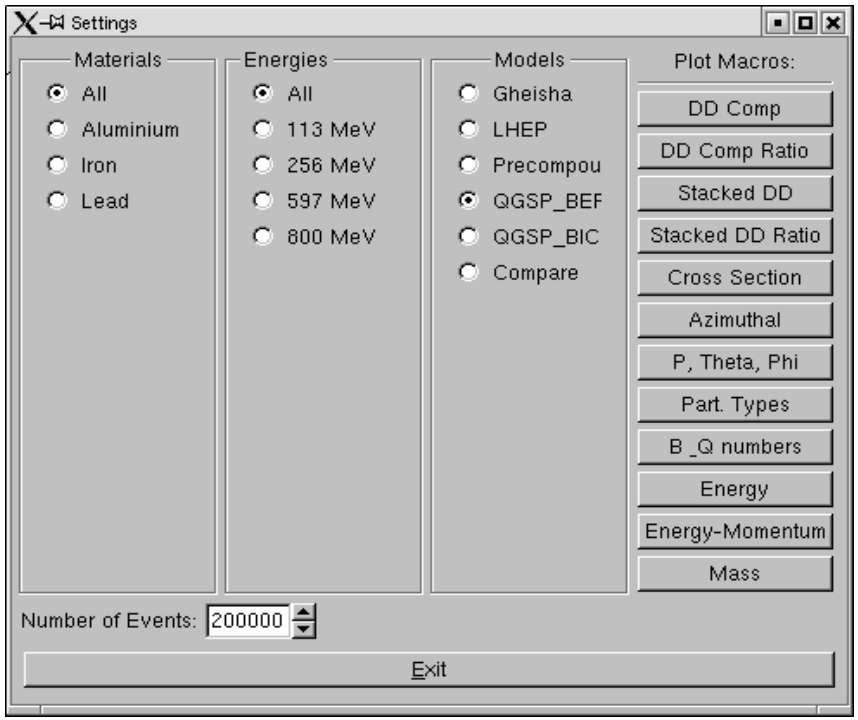
- Pseudo thin target setup to optimize CPU time
- **Geant4:**
  - Large block of material
  - Switch all processes off except transportation & inelastic hadronic interactions
  - After first hadronic interaction, collect information and restart with next event
  - Write ROOT file with information on generated tracks, residual nuclei etc
  - Analyze after simulation production to generate plots
- **Fluka:**
  - Use “developer's bypass” to simulate only inelastic hadronic interactions (Fluka datacard EVXTEST)
  - Results in good agreement with simulation of 3mm “thin” target
  - Use Fluka histograms to obtain double differential cross sections
  - *Future: produce ROOT file with identical structure as for Geant4*

Physics Models for Hadronic Interactions

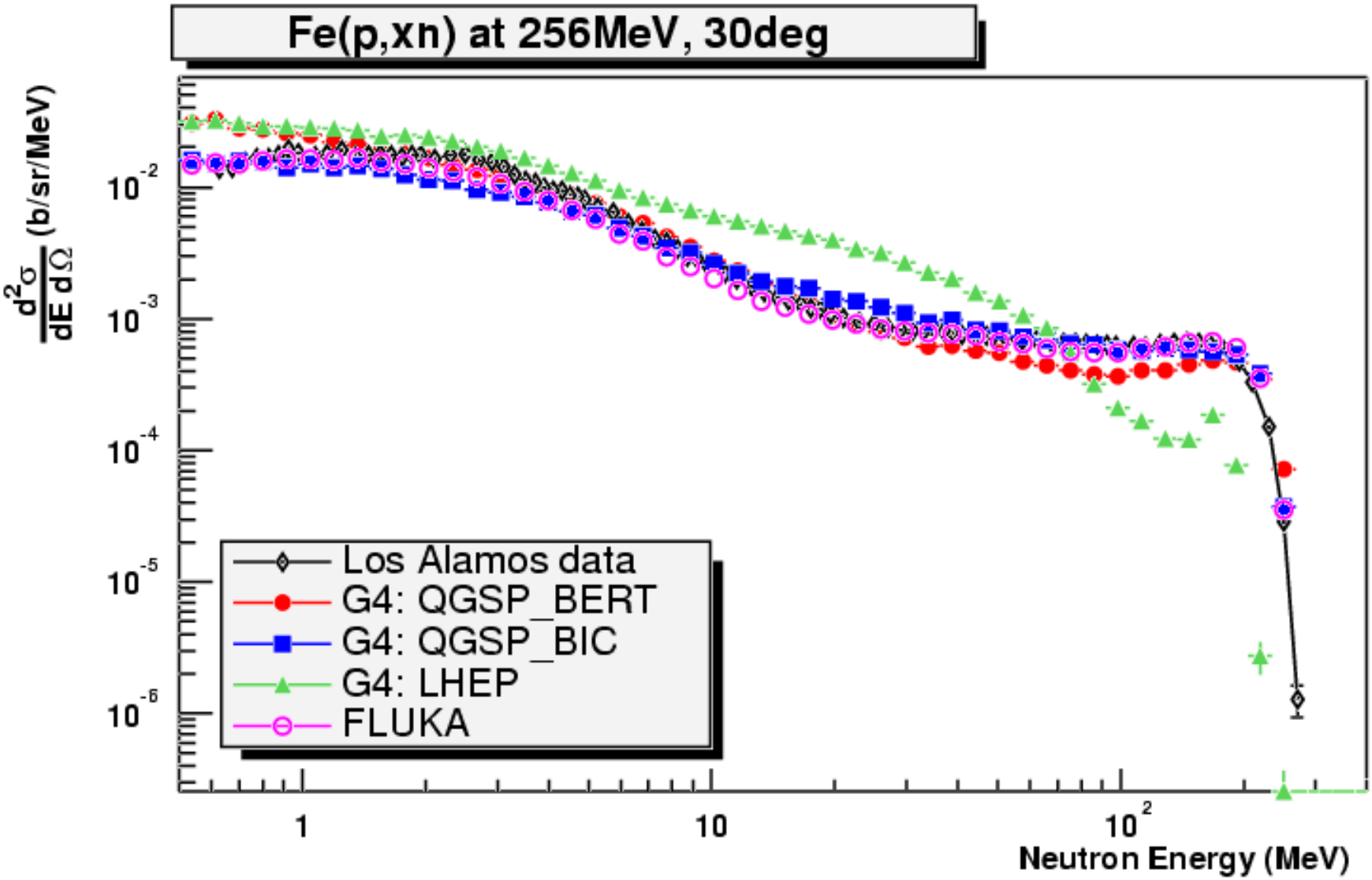
- LHEP (Geant4)
  - LEP and HEP parametrized models for inelastic scattering
  - Based on Gheisha package of Geant3
- QGSP_BERT (Geant4)
  - Quark gluon string model, pre-equilibrium decay model, evaporation phase
  - Bertini cascade below 3 GeV
- QGSP_BIC (Geant4)
  - Quark gluon string model, pre-equilibrium decay model, evaporation phase
  - Binary cascade below 3 GeV
  - Better description of forward scattered particles, significantly slower
- FLUKA
  - Physics model as implemented in Fluka package

Software and Tools

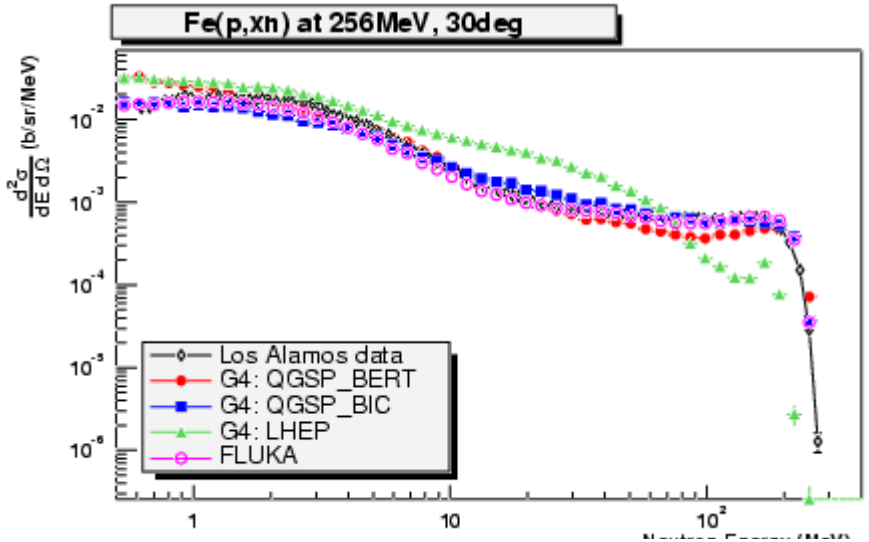
- Thin target benchmark code:
  - Source code and scripts for Geant4
  - Scripts for running Fluka
  - ROOT macros for producing plots
  - CVS tag jb-2003-07-28
- Fluka:
  - Version 2002.4 on CERN RedHat 7.3
- Geant4:
  - Version 5.2 with gcc 3.2 on CERN RedHat 7.3
  - Physics list versions: PACK 2.1, QGSP_BERT 0.5, QGSP_BIC 0.5
- For installation instructions, usage information, and results see:
  http://lcgapp.cern.ch/project/simu/validation/benchmarks/thintarget/index.html

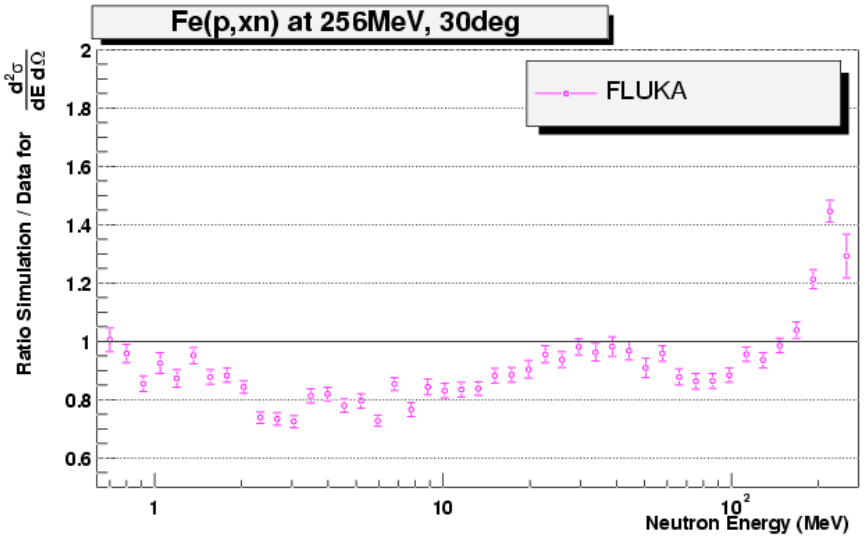


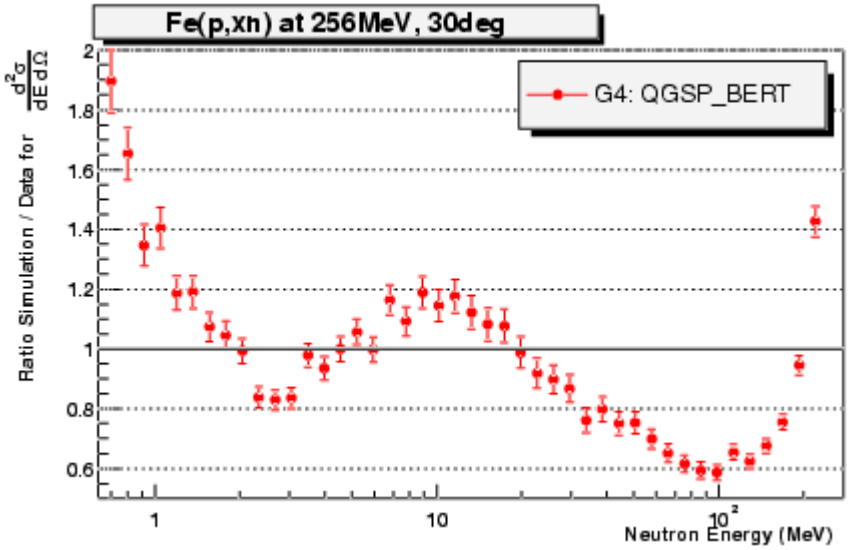
Sample Cross Section: Fe(p,xn), 256MeV, 30°

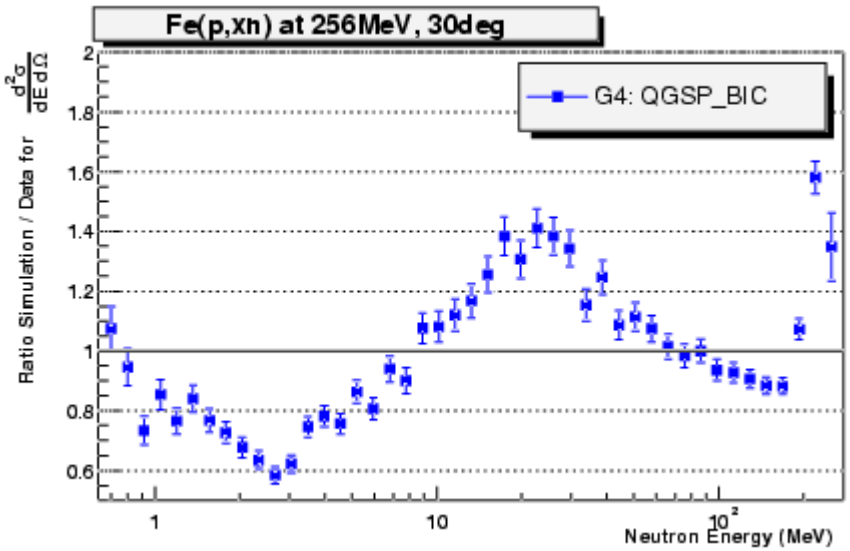


... and the Ratios to Los Alamos Data

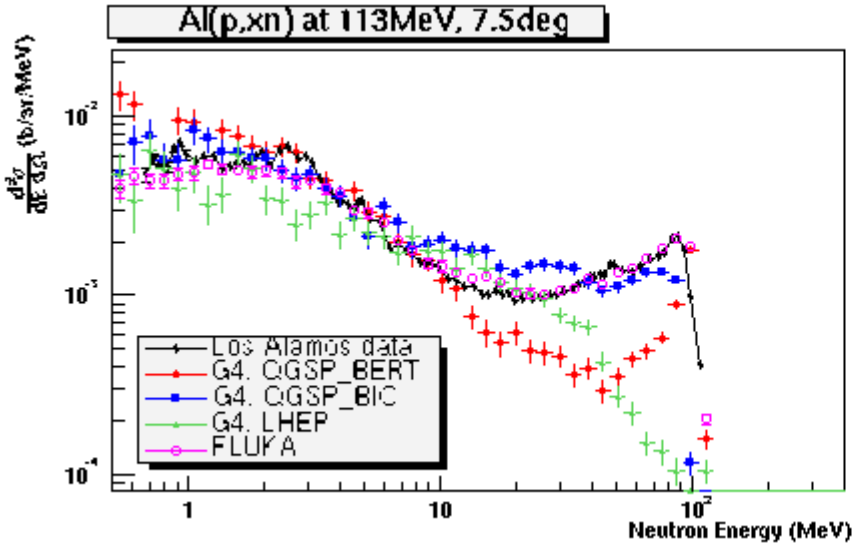


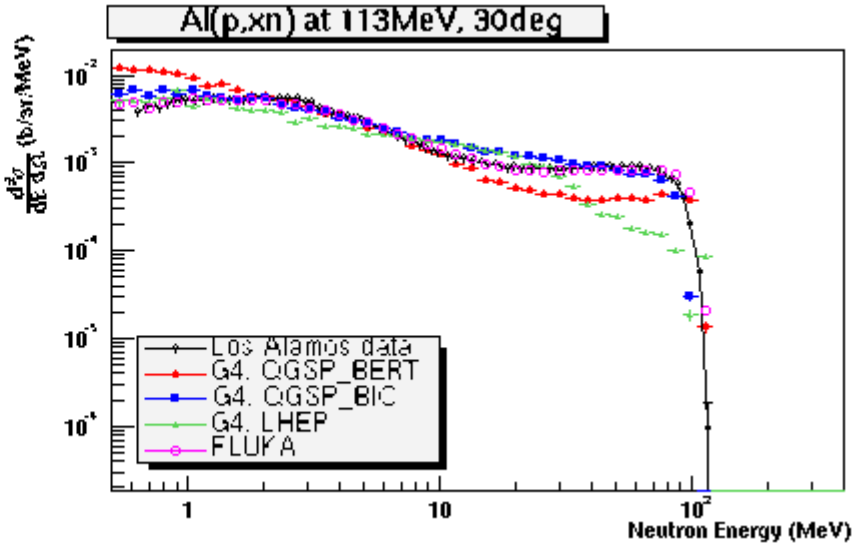


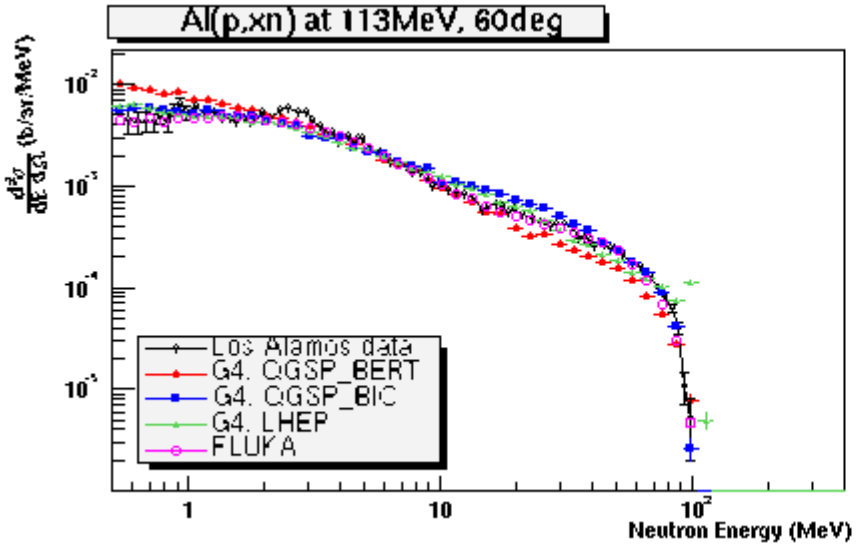


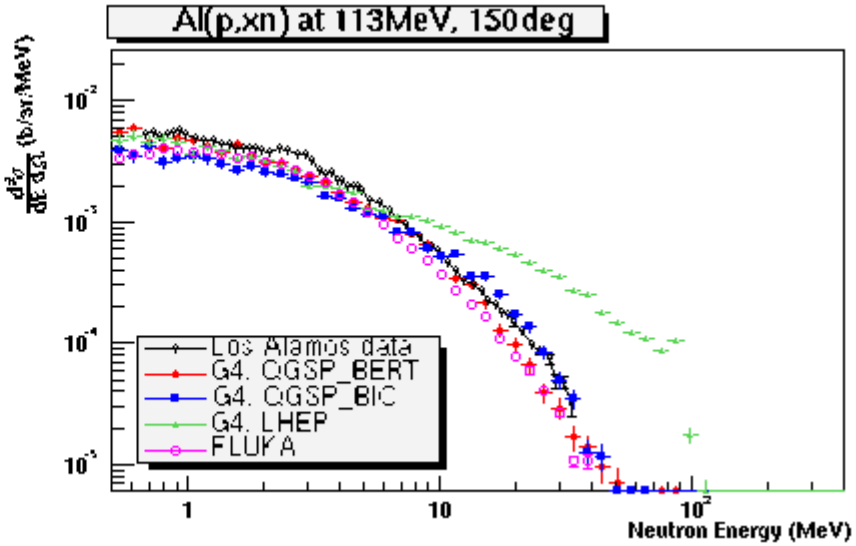


Al(p,xn) Cross Section

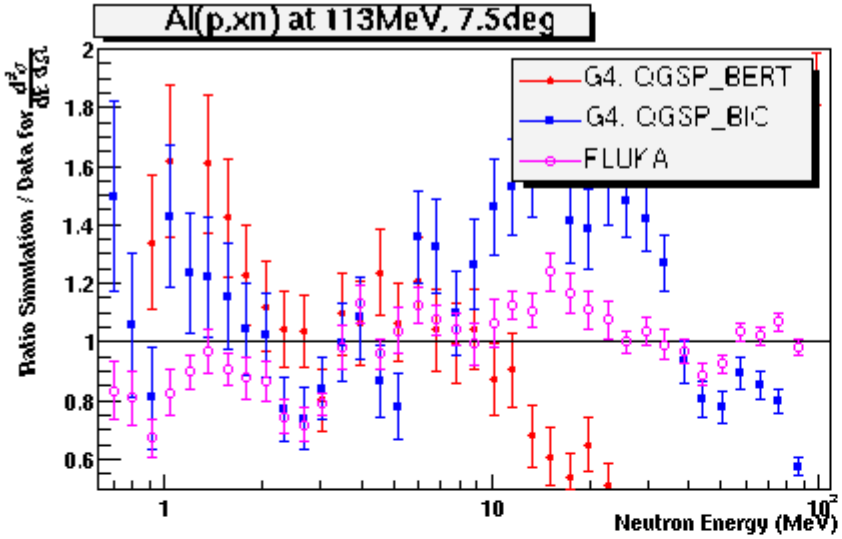


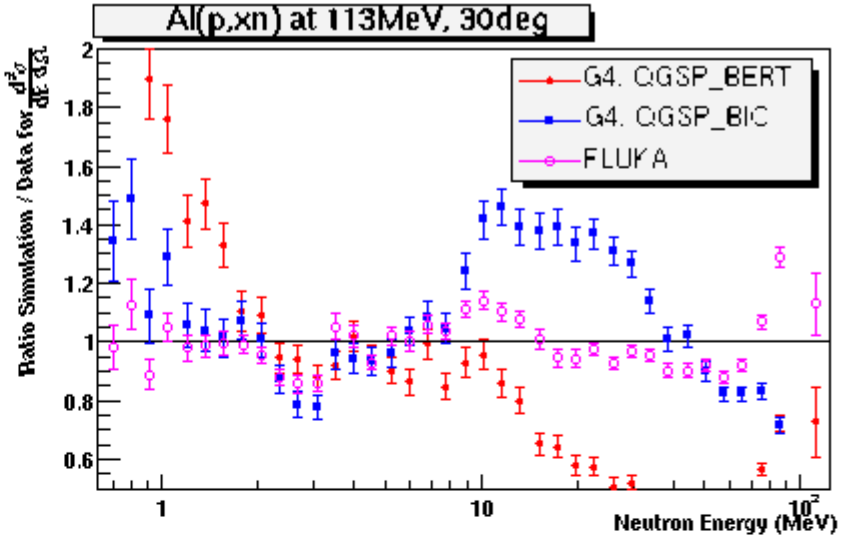


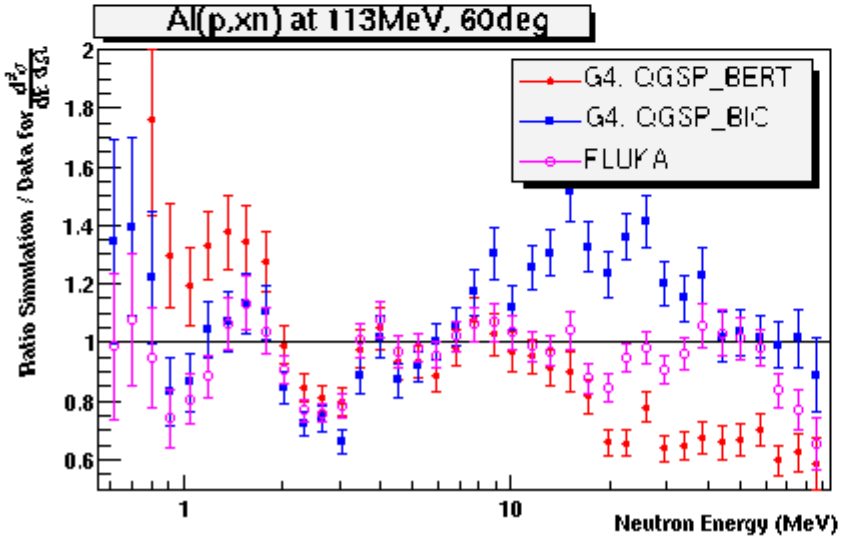


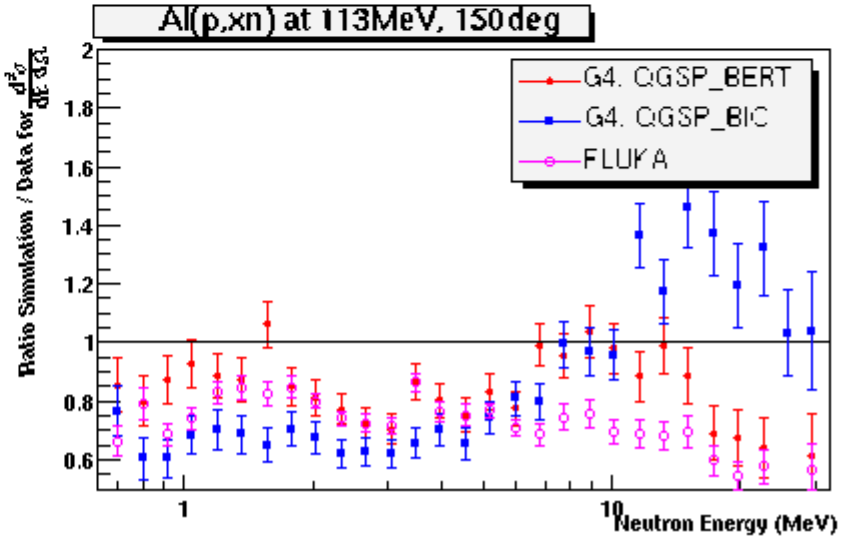


Al(p,xn) Cross Section Ratio

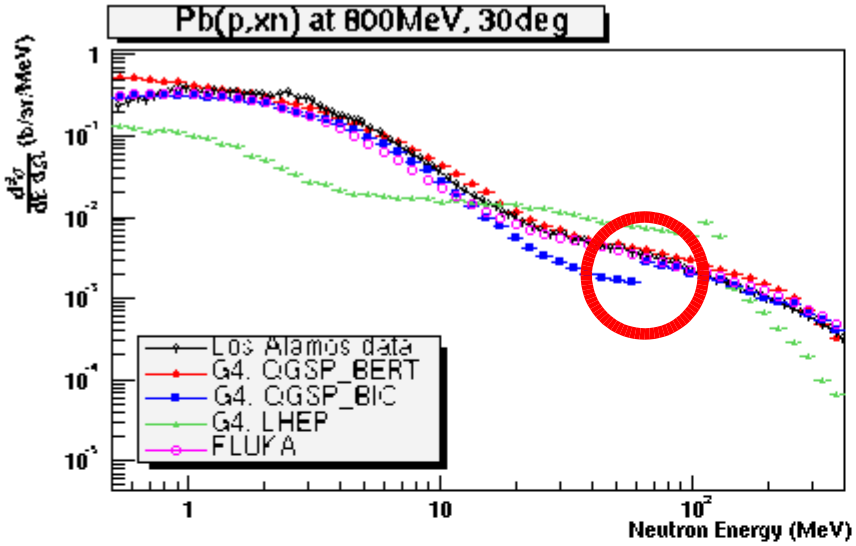


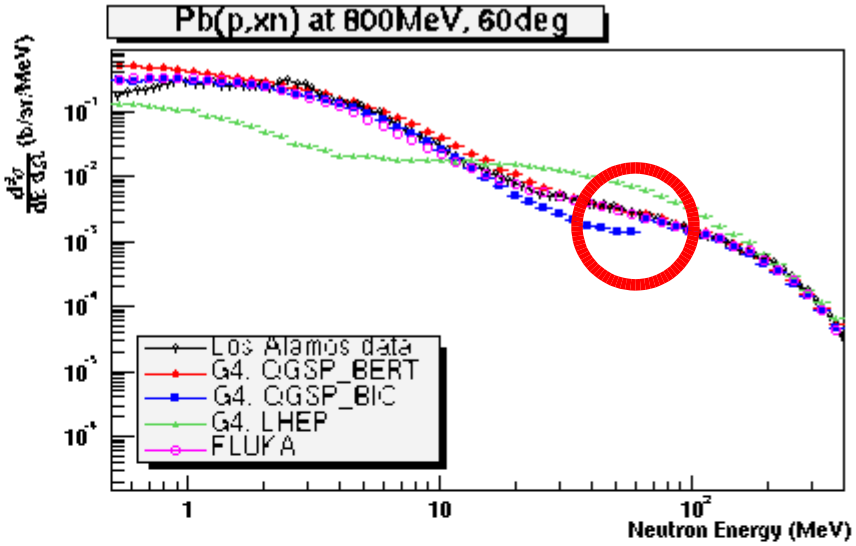


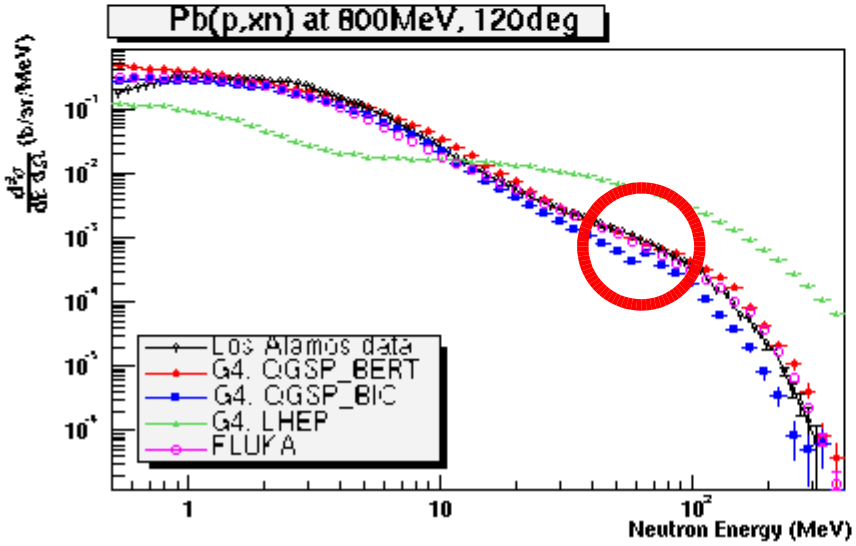


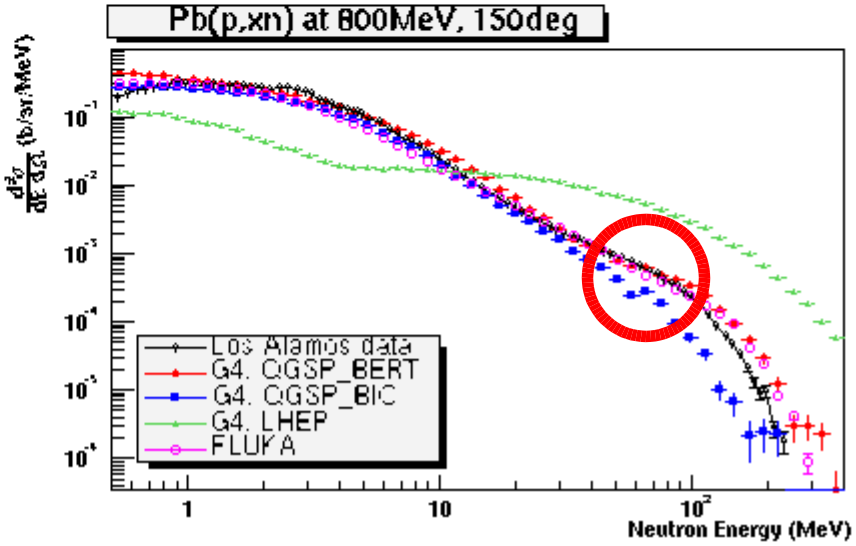


Pb(p,xn) Cross Section

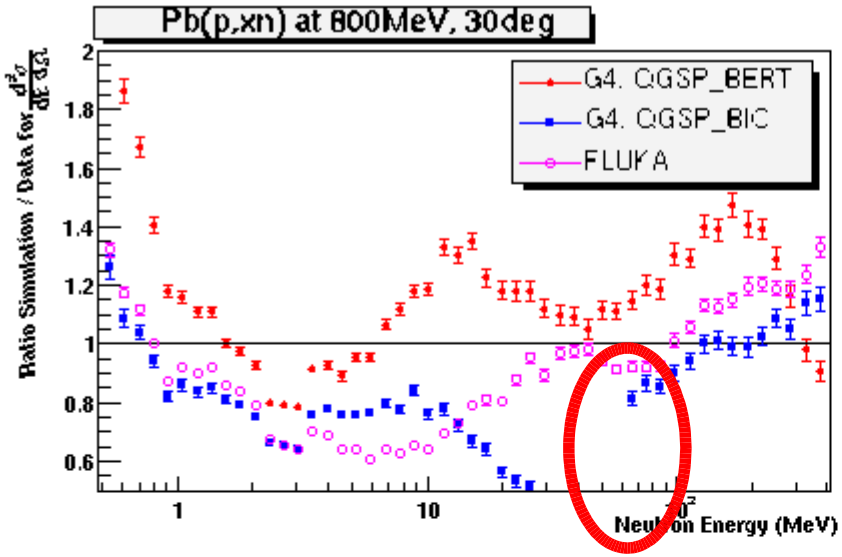


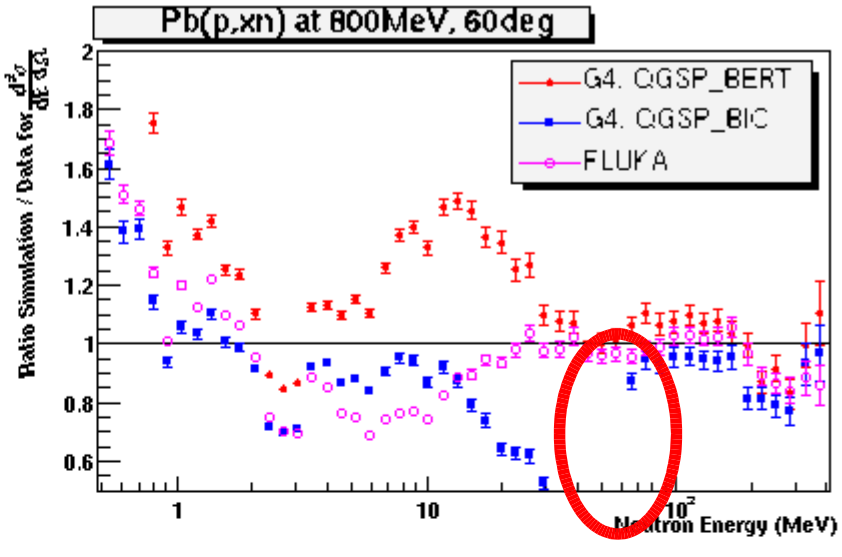


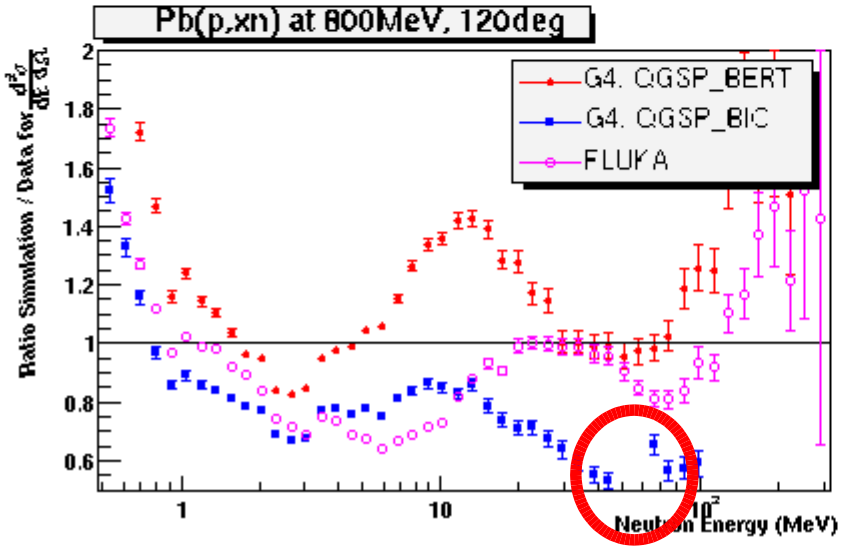


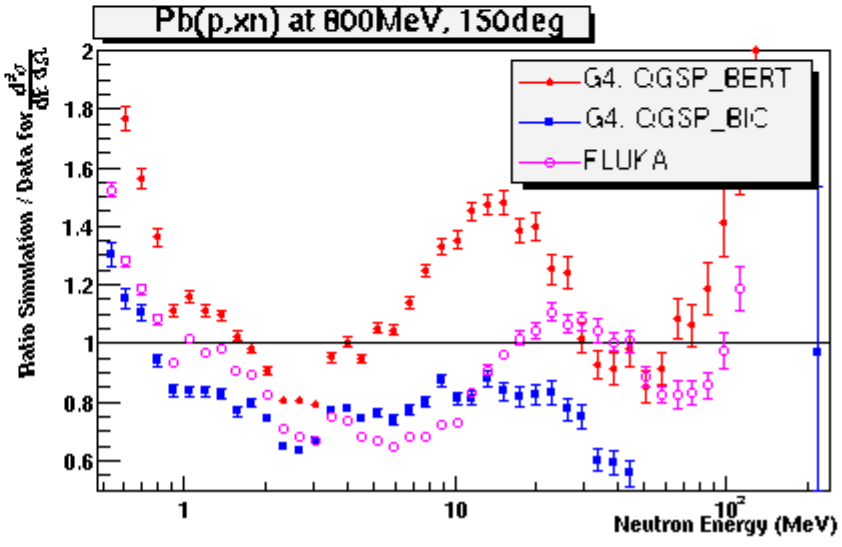


Pb(p,xn) Cross Section Ratio







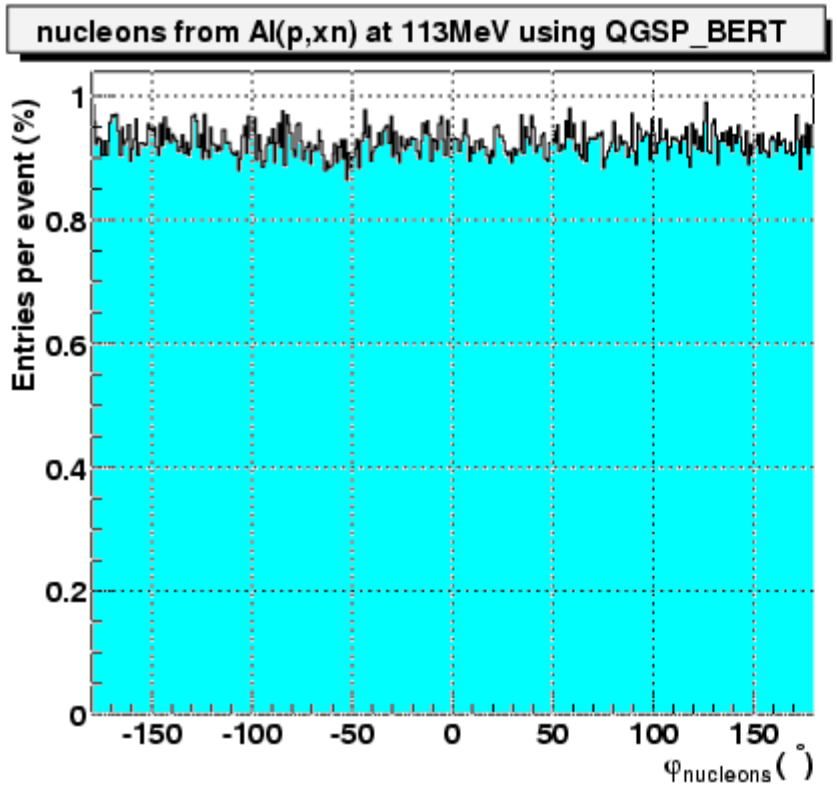


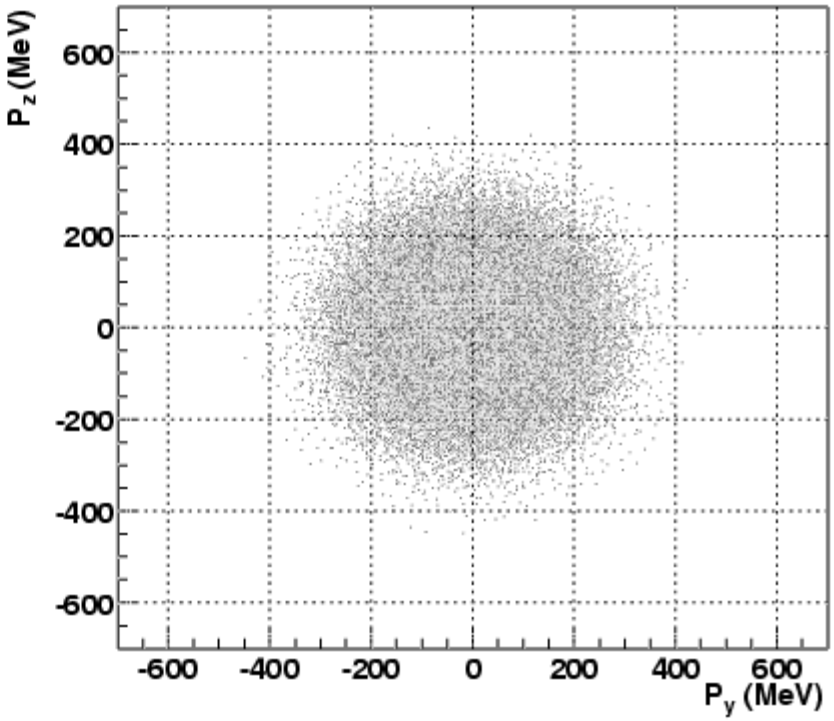
Observations

- LHEP physics list not suitable for (p,xn) double differential cross sections
- Fluka, QGSP_BERT and QGSP_BIC can all reproduce $d^2\sigma/dE/d\Omega$ with a typical level of agreement with Los Alamos data on the order of 20% - 50%
  - Not just a normalization problem – there is a lot of variation in the ratio between simulation and data as a function of neutron energy
  - For certain cases, agreement is much worse for QGSP_BERT & QGSP_BIC
  - In one case (113MeV p on Al), the Fluka cross section at 150^o is too low for all n energies, but is ok at the other angles – significance?
- Discontinuity in double differential cross sections for QGSP_BIC at n energy of ~65 MeV for 597 MeV and 800 MeV p on Pb
- QGSP_BIC does not produce recoiling nucleus (Geant4 bug report 510)

Azimuthal distribution: QGSP_BERT

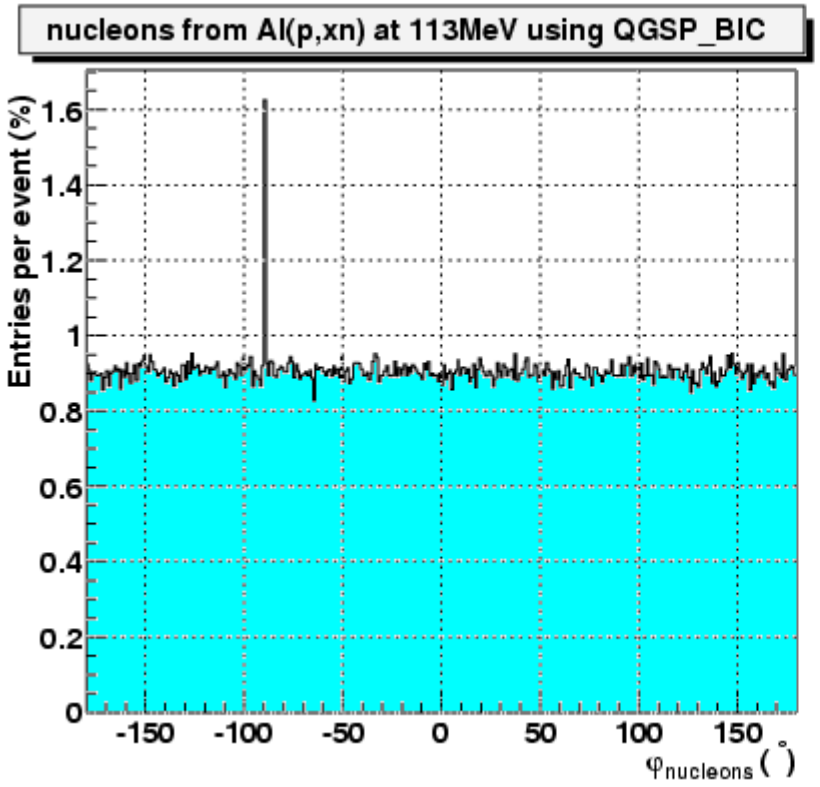
- Look e.g. at azimuthal distribution of generated nucleons (n,p):

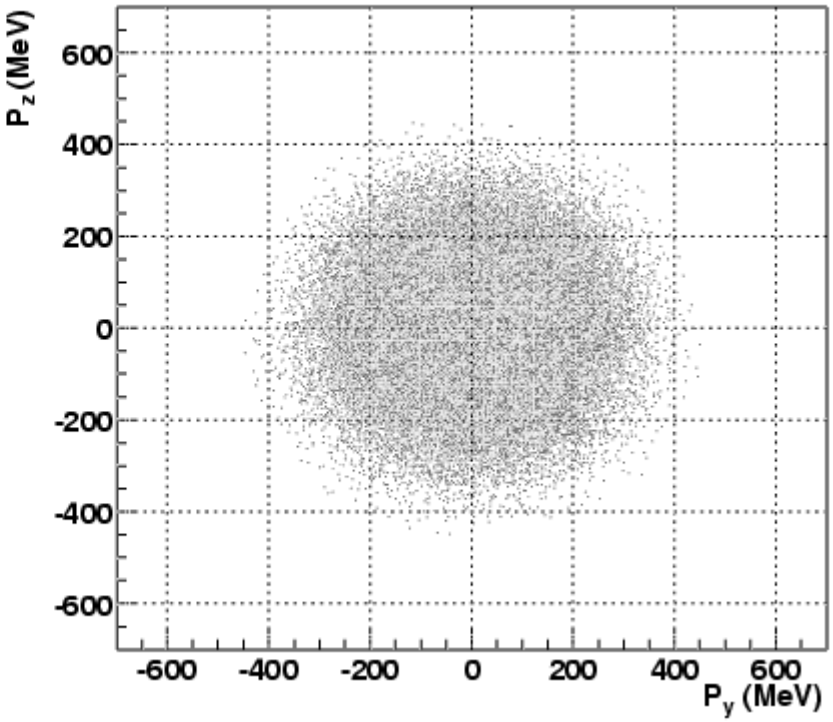




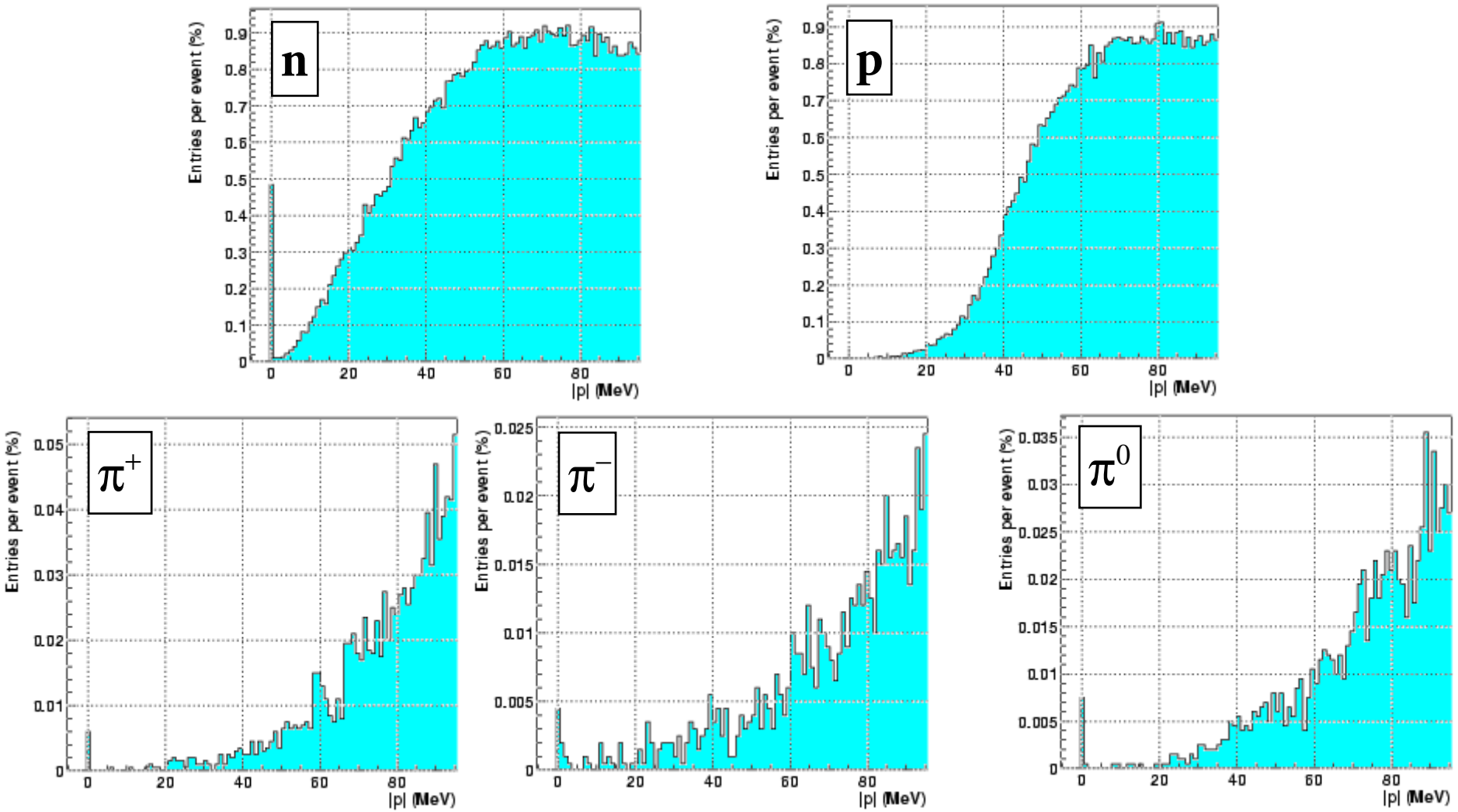
Azimuthal distribution: QGSP_BIC

- Same plot for QGSP_BIC
  - Spike due to neutrons produced at rest in lab frame





Stopped Particles: QGSP_BIC, 800MeV p on Al



- ~0.5% of events have a stopped n (for 113MeV p on Al)
- ~0.02% of events have a stopped pion (for 800MeV p on Al)

Plans for Simple Benchmark Studies

- Many similar studies can now be done quickly:
  - Look at other physics lists of interest
  - Double differential cross sections for other incident or outgoing particles
    - Experimental data?
- Working on consistency checks (E, P, Q, B conservation in Geant4)
- Produce ROOT files from Fluka (using e.g. TFluka)
  - Can use identical analysis macros for Geant4 and Fluka
  - Test case for Simulation Framework project
- Other simple benchmark studies:
  - Pion absorption
  - Rapidity distributions on H/Ar/Xe at 200GeV (I. Gonzales)
  - Slow nucleons in pA interactions (X. Li)

Conclusions

- Fluka, QGSP_BERT and QGSP_BIC can all reproduce the overall shape of double differential (p,xn) cross sections
  - **Typical agreement with Los Alamos data on the order of 20% to 50%**
  - Agreement worse for certain cases / neutron energies
  - Not just a matter of normalization
- Found and reported several bugs in Geant4
  - Mostly in most recently developed physics model (QGSP_BIC)
  - Some technical problems already fixed in Geant4 5.2
- Work on benchmark test suite is in progress
- Many thanks to Andrea, Alfredo, Hans-Peter and Isidro!