Update on background radiation studies in LHCb with GAUSS/Geant4

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Summary

- Introduction
- Methods
- Results
- Discussion
- Conclusions

Introduction

☞ Knowledge of particle fluences[1], their energy spectra and absorbed doses[2] is necessary to estimate the damage probability of detectors and electronics

☞ Possible background radiation effects are:

- *Gradual,* such as *total ionizing dose* or *displacement damage*
- *Local and acute,* such as SEU (upset of a memory cell and revert individual triggers or switches) or SEL (permanent damage of the device)

☞ Previous calcs have been performed using MARS, GCALOR and FLUKA

[1] *Fluence (1/cm2)* $\approx \frac{\sum_i dl_i}{V}$, where V is the voxel volume

[2] *Dose (Gy)* $\approx \frac{\sum_i dE_i}{M}$, where M is the voxel mass

☞ The displacement damage can be evaluated through the calculation of the 1MeV-neutrons equivalent fluence for silicon.

☞ The displacement damage cross section for silicon for 1 MeV-neutrons is set as normalizing value: *95 MeV·mb*. Damage efficiency of any particle is described by the hardness factor, defined as:

$$\frac{EDK}{EDK(1MeV)}$$

☞ EDK is the energy spectrum averaged displacement KERMA

$$EDK = \frac{\int D(E) \cdot \phi(E) dE}{\int \phi(E) dE} \qquad D(E) = \sum_k \sigma_k(E) \int dE_R f_k(E, E_R) P(E_R)$$

☞ The hardness factor is used as multiplication factor for the fluence distribution

$$\Phi_{eq}^{1MeV} = k \cdot \Phi_p$$

☞ In LHCb radiation calculations have been performed making use of FLUKA.

☞ A different *pp collision generator* and *geometry*

☞ Interest from Geant4 and LHCb collaboration to verify how to use Geant4 for the background radiation studies

☞ The GAUSS framework (Geant4 as simulation engine) has been used to study the background radiation in LHCb

Methods

☞ An *ad hoc* module, named *SensPlane*, has been integrated in GAUSS in order to score doses and fluences in planes positioned in proper locations

☞ The main items are:

- the module uses the Gauss standard for interfacing the geometry with G4
- *tallying* of doses and fluences in a specific plane and for a specific particle is controlled at run time
- the module provides automatically the 2D distributions and the energy spectra, provided that the geometry description of the scoring plane is a voxel parametrization.

Conditions and constraints...

☞ Used Geant4 v62r0p2, Gauss v18r4

☞ The doses and fluences are calculated taking the full information from G4Step (->G4Track)

☞ Four scoring planes positioned in LHCb setup, taking into account the angular coverage (300 mrad)

☞ Scoring planes cannot be positioned overlapping pre-existing geometry. Double navigation is not implemented yet in Geant4 in a magnetic field environment

☞ The space around the "beampipe" is approximated via a box-shaped hole, with size calculated through 10 mrad inclination

☞ The arbitrary choice of the 2D map binning can lead to a mismatch between the hole and the adjacent scoring voxels.

Tallies...

☞ SensPlane provides automatically the following results:

- particle "tallyable" are: p, n, $\pi^{\pm}$, $K^{\pm}$,γ, $e^{\pm}$, …
- energy spectra of fluence (1/cm^2) registered on the scoring plane by the tallied particles
- 2D distribution of the high energy hadrons (>20 MeV) fluence (1/cm^2) registered on the scoring plane
- 2D distribution of the fluence and dose of the tallied particle, registered in each voxel of the parametrized structure

☞ In post-processing this data can be combined in order to obtain other fruitful information:

- 2D distribution of the total ionising dose
- 2D distribution of the total charged hadrons fluence
- *1MeV neutron equivalent fluence*: a weighted sum of all the fluences due to protons, neutrons, electrons and pions, rescaled to the 1 MeV neutrons damage

☞ 1 MeV-neutrons equivalent fluence for silicon is calculated as sum of the weighted fluence contributions of each particle type.

G4 physics lists...

☞ G4 provides many models for hadronic interaction (specialized for particles in different energy ranges)

☞ Predefined combination of models are provided as *Physics Lists*. The combination of the models depends on the type of studies/applications.

☞ CPU performance is different for various physics lists.

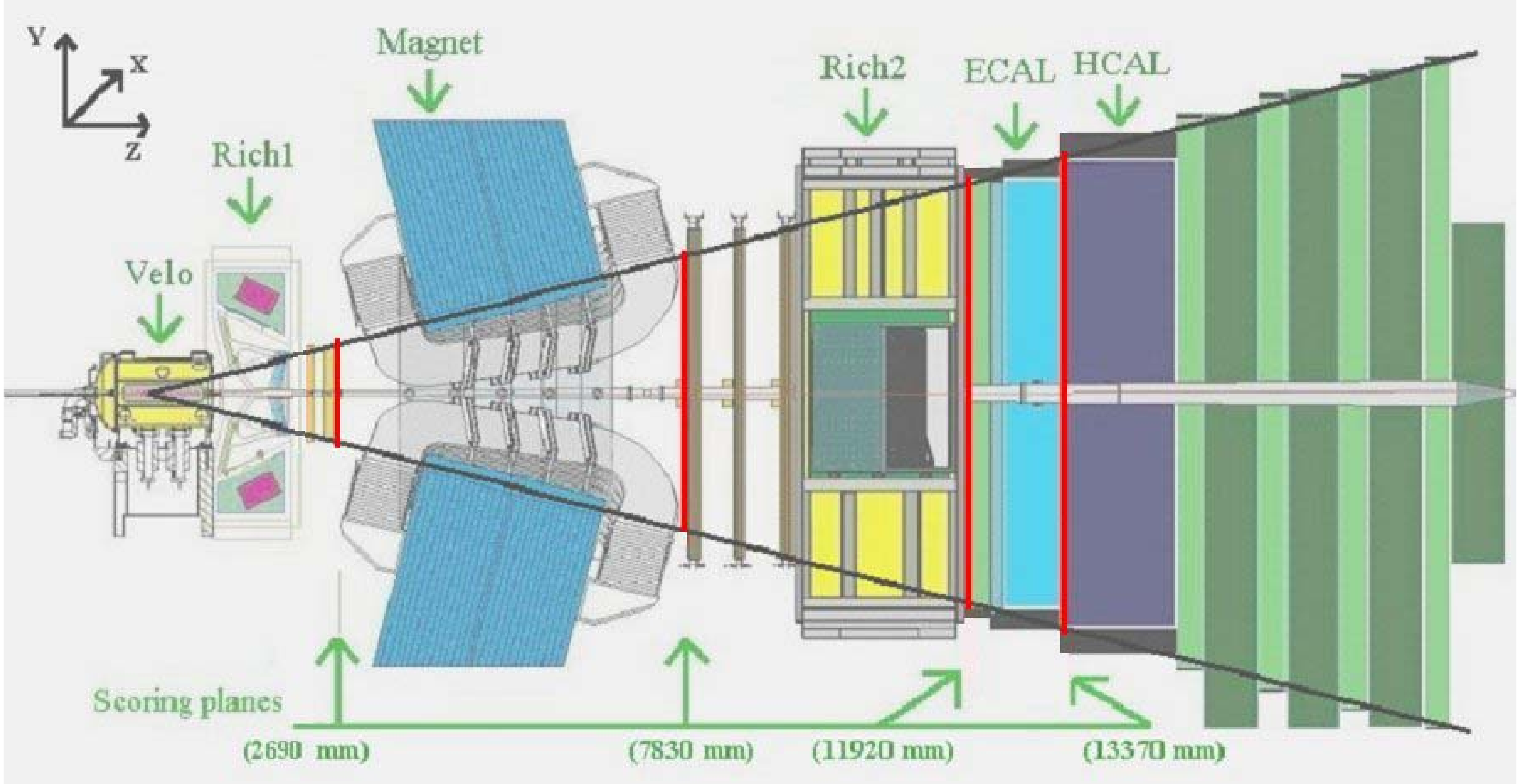
☞ The following results have been obtained with 6 hadronic physics lists: *lhep*, *lhep_hp*, *qgsp*, *qgsp_hp*, *lhep_bert_hp*, *qgsp_bert_hp*

☞ Physics lists used:

- ➢ LHEP: parametrized models (similar to GEISHA/G3)
- ➢ QGSP: quark gluon string (>5 GeV) + parametrization (between 5GeV and 100 MeV) + pre-compound (<100MeV)
- ➢ HP: extension for the treatment of low energy neutrons (<20 MeV)
- ➢ BERT: Bertini cascade (for π, p, n, but not yet for K)

LHCb layout

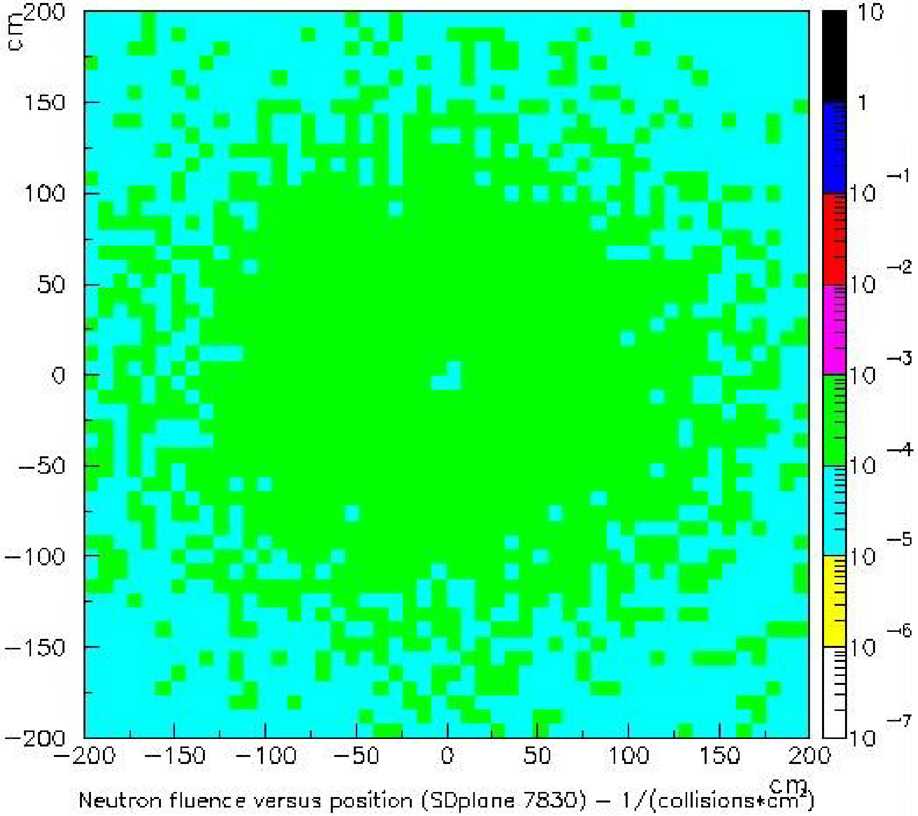
☞ and *4 scoring planes…*



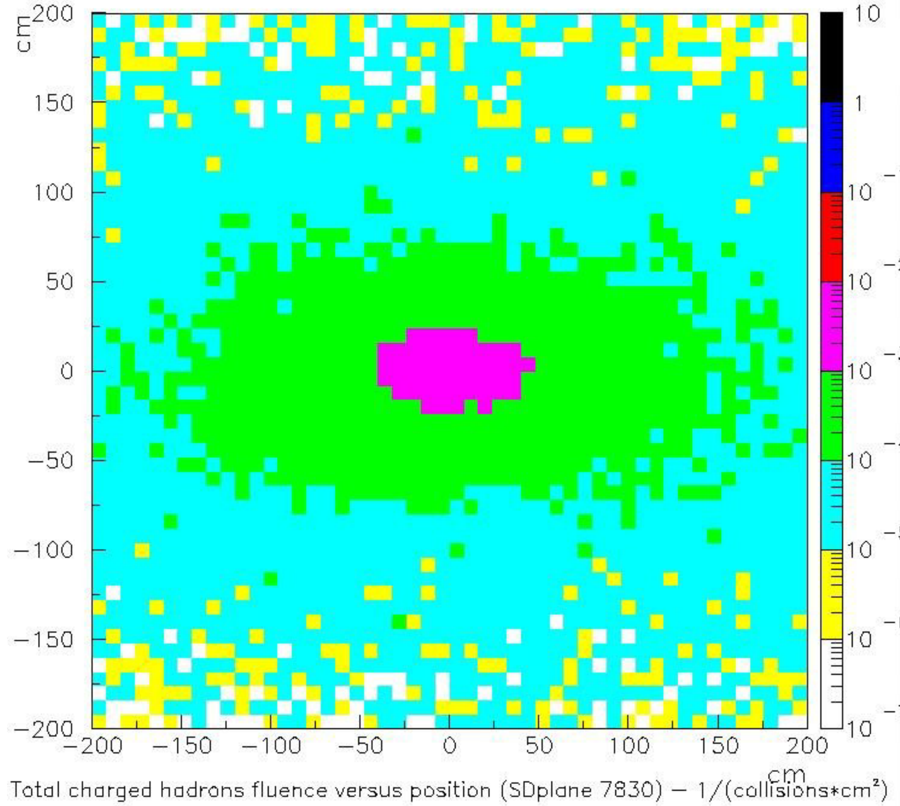
• *LHEP* used for mass production in LHCb
• Evaluation of the physics list for radiation studies in relevant energy range

Results

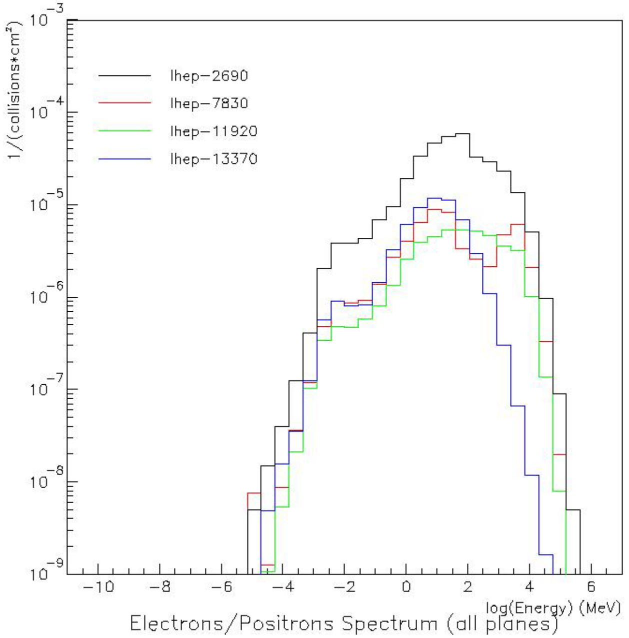
LHEP @ 7830



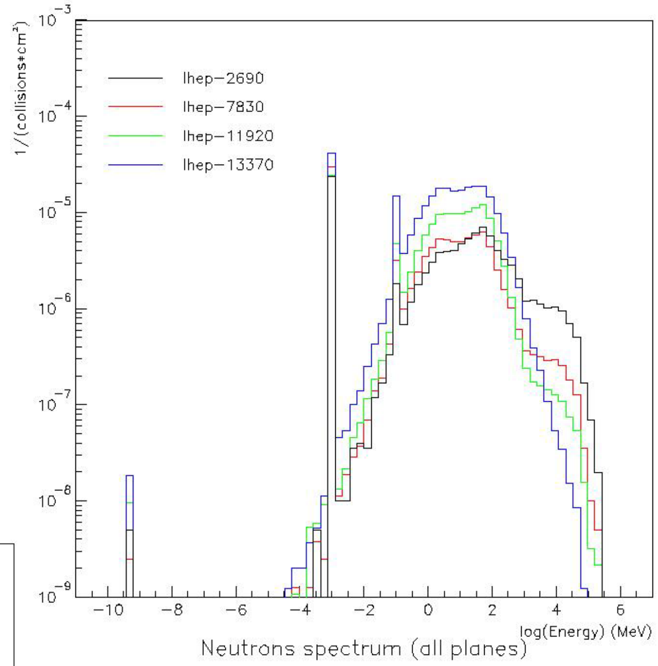
Neutron fluence



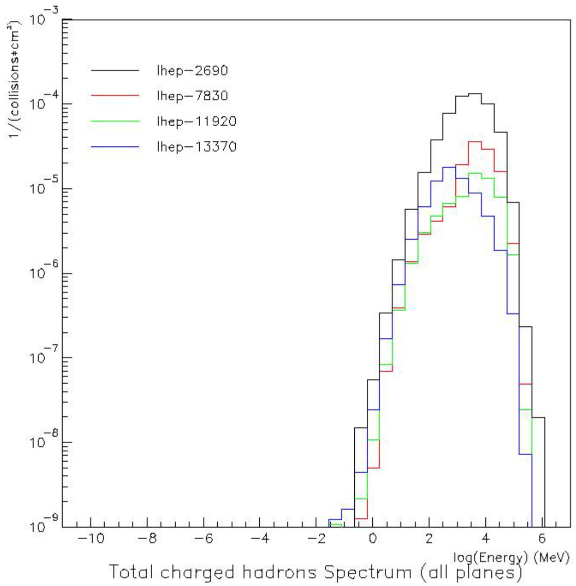
Total charged hadrons fluence



Electrons/Positrons spectrum



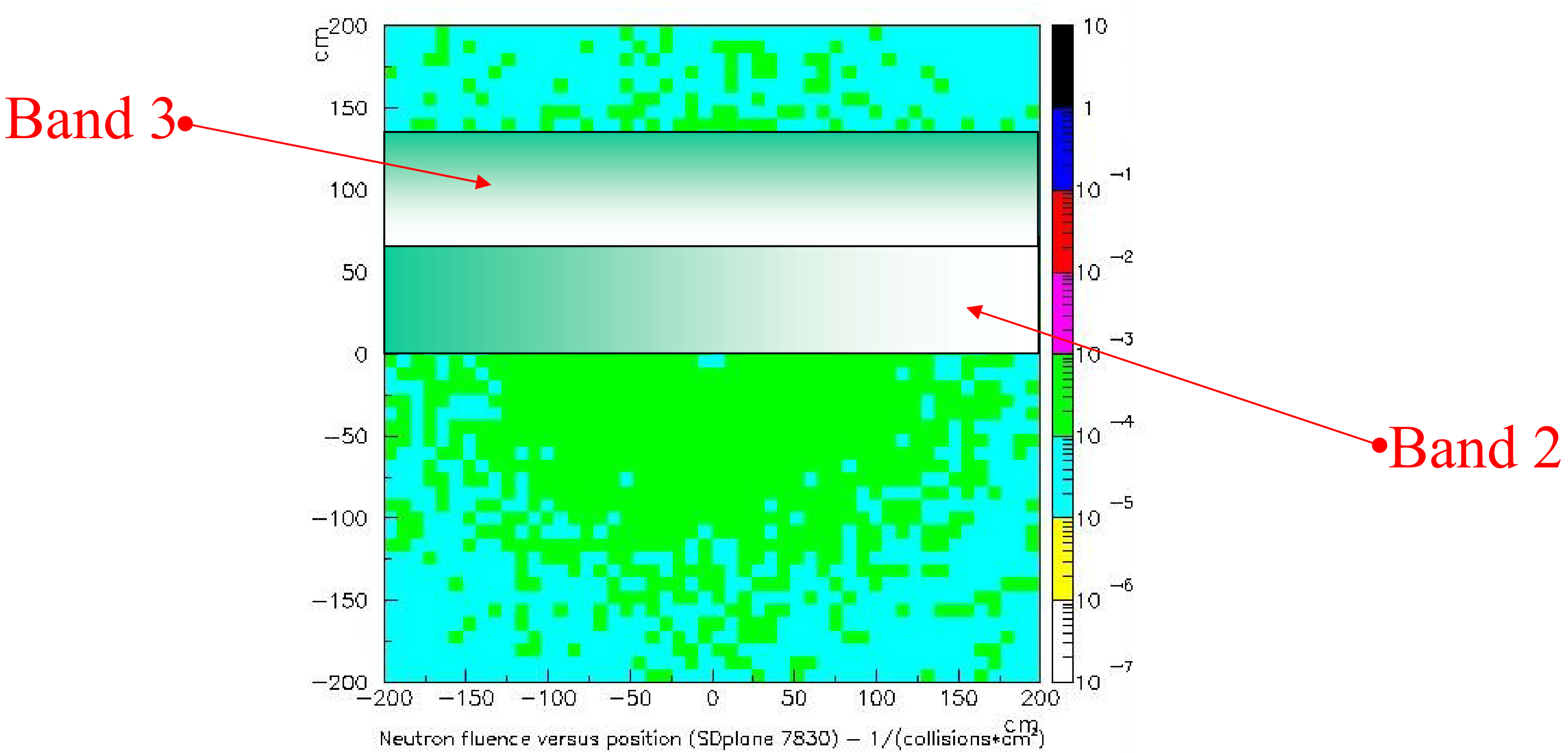
Neutrons spectrum

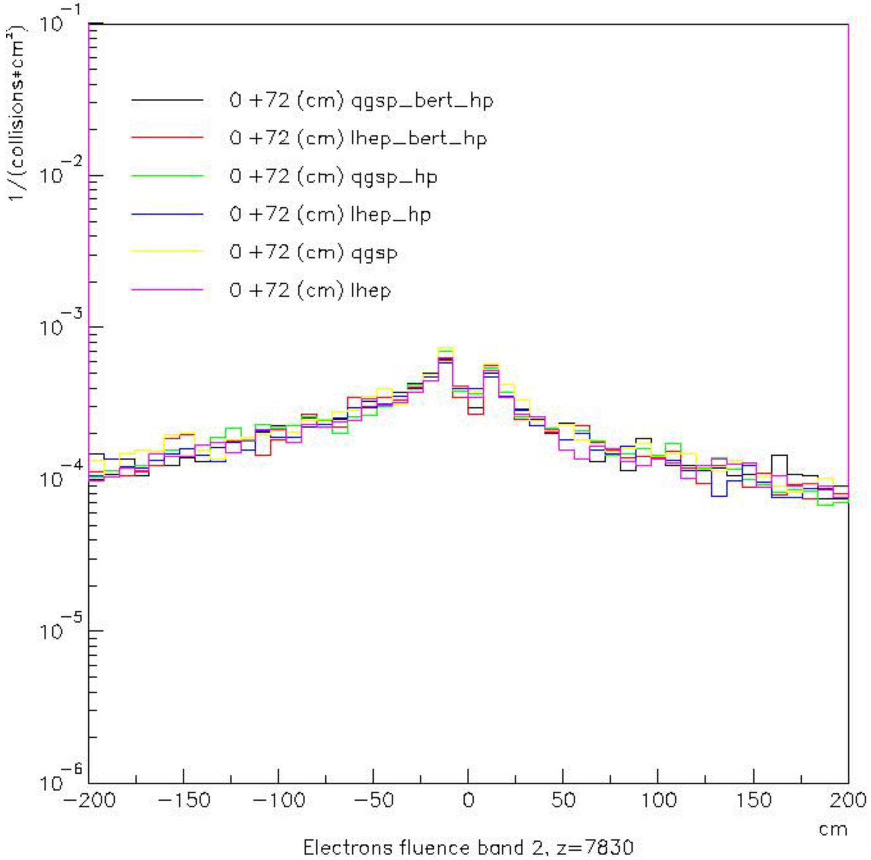


Total charged hadrons spectrum

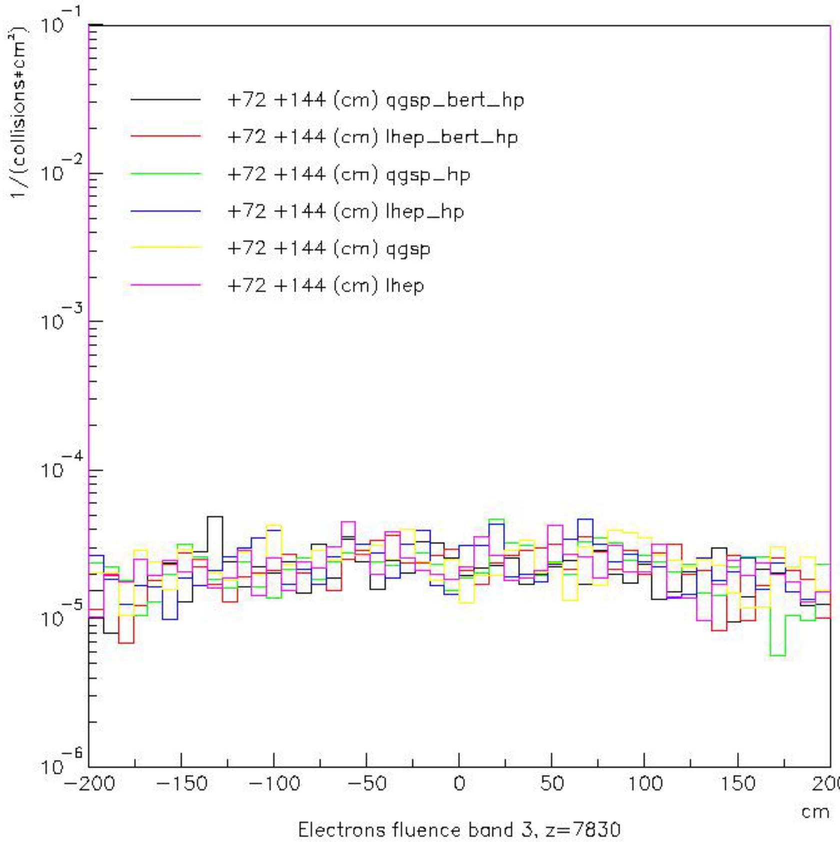
2 bands for physics lists comparison

...finding the most appropriate physics list

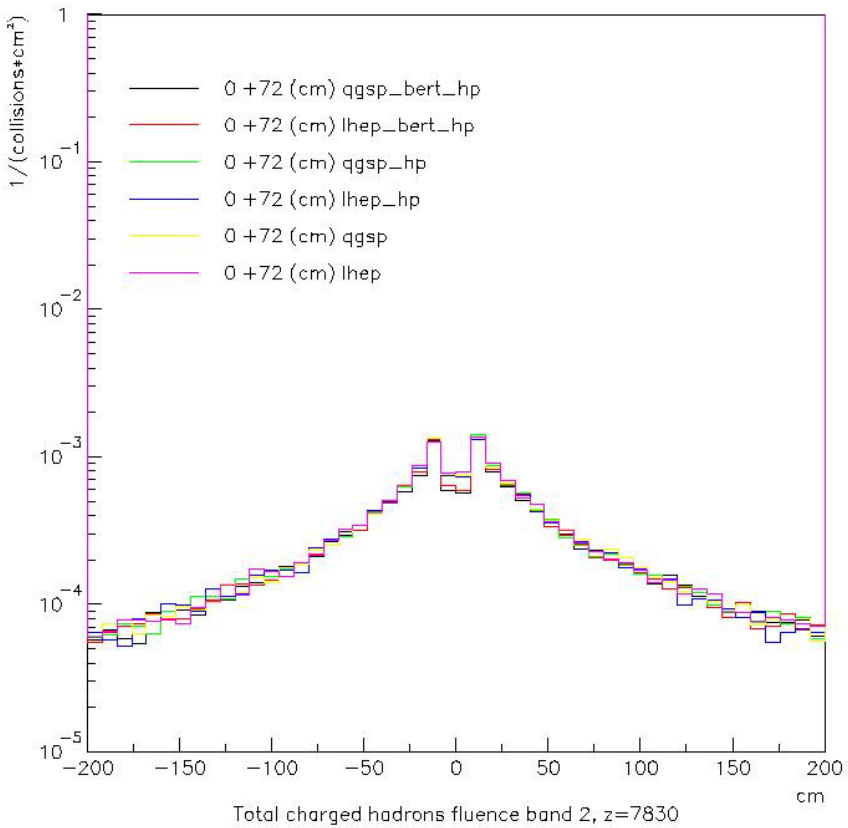




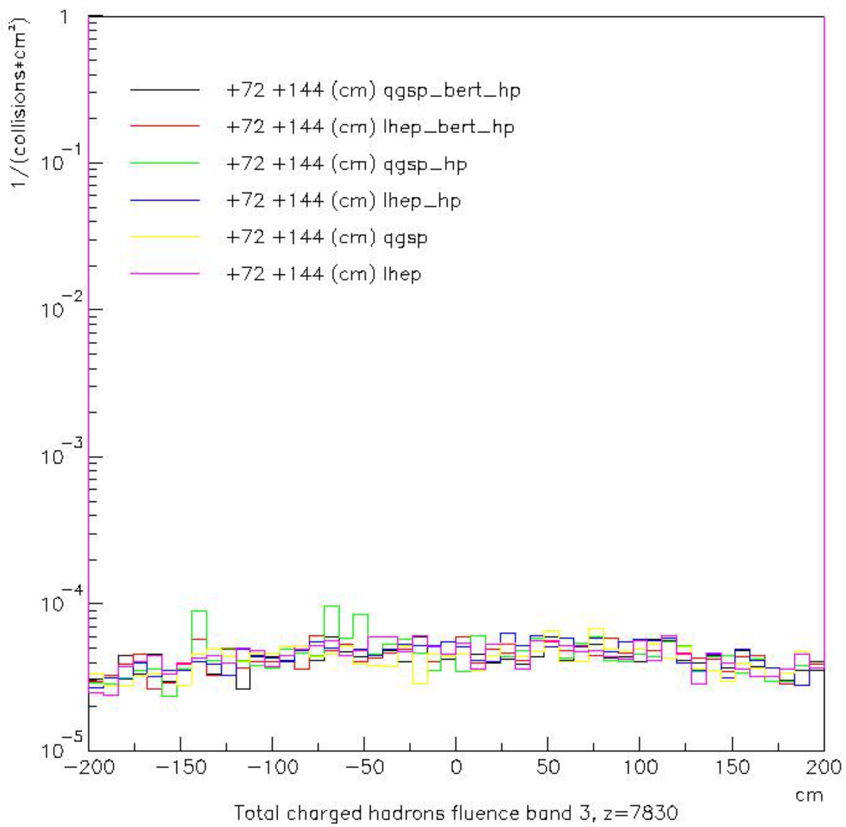
Electrons/Positrons fluence
Band 2 @ 7830



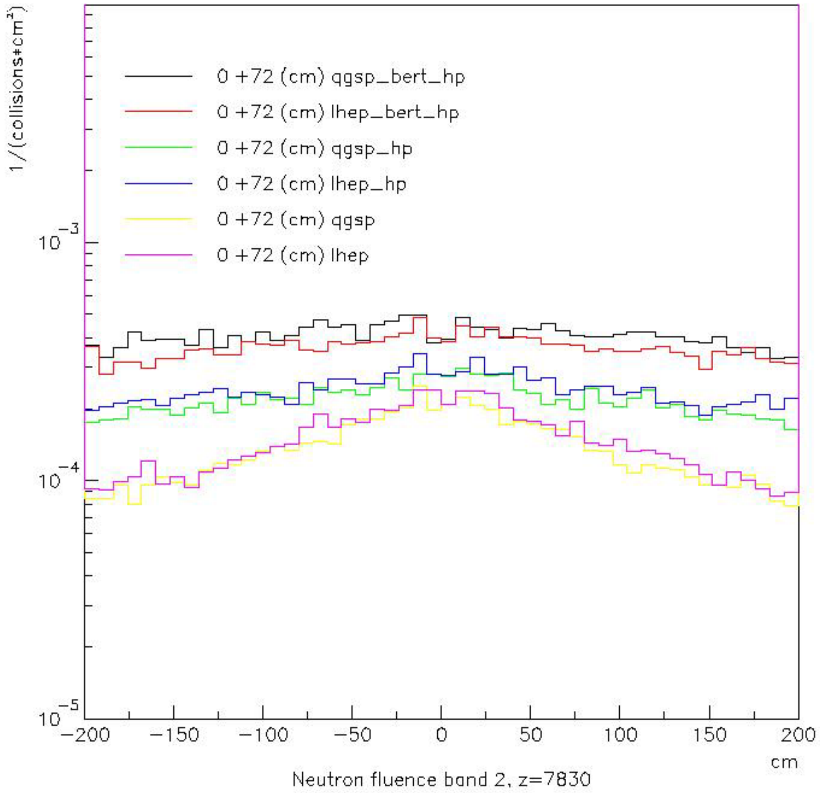
Electrons/Positrons fluence
Band 3 @ 7830



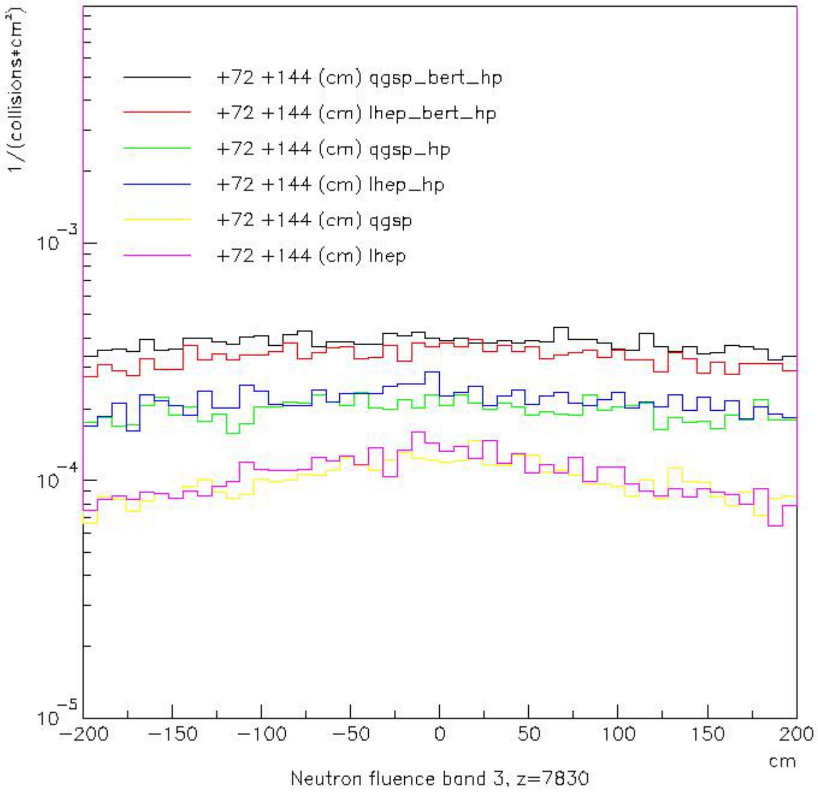
Total charged hadrons fluence
Band 2 @ 7830



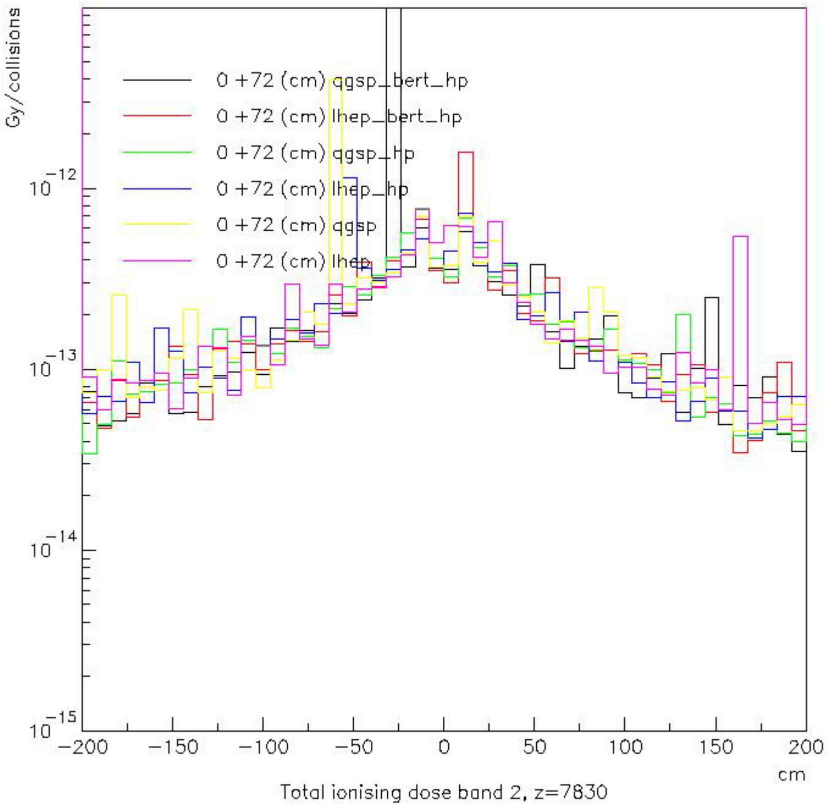
Total charged hadrons fluence
Band 3 @ 7830



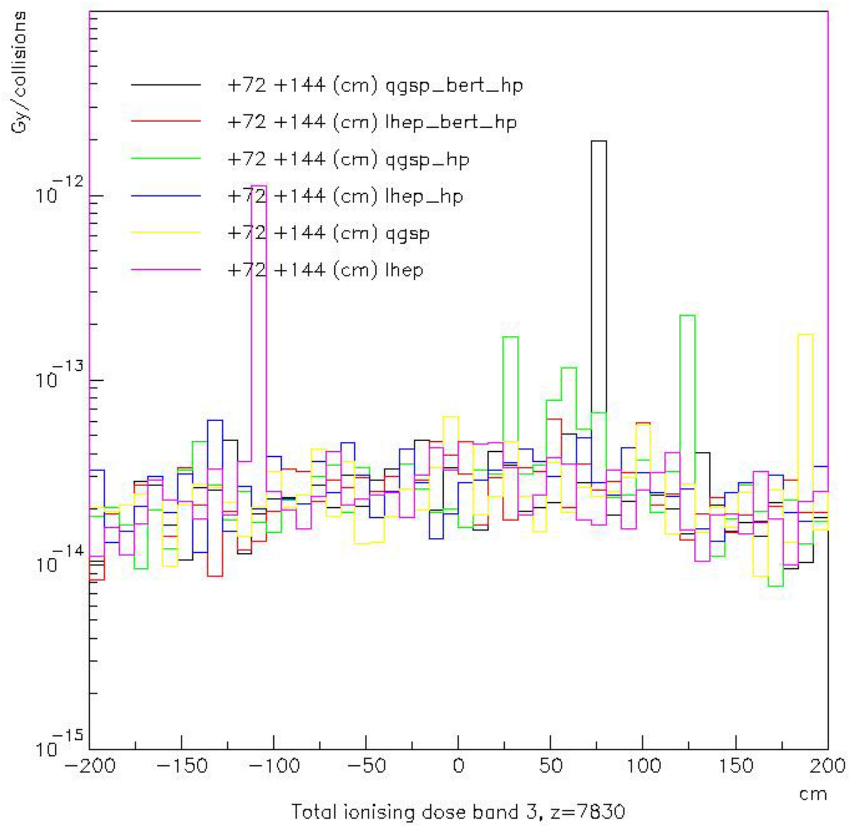
Neutrons fluence
Band 2 @ 7830



Neutrons fluence
Band 3 @ 7830



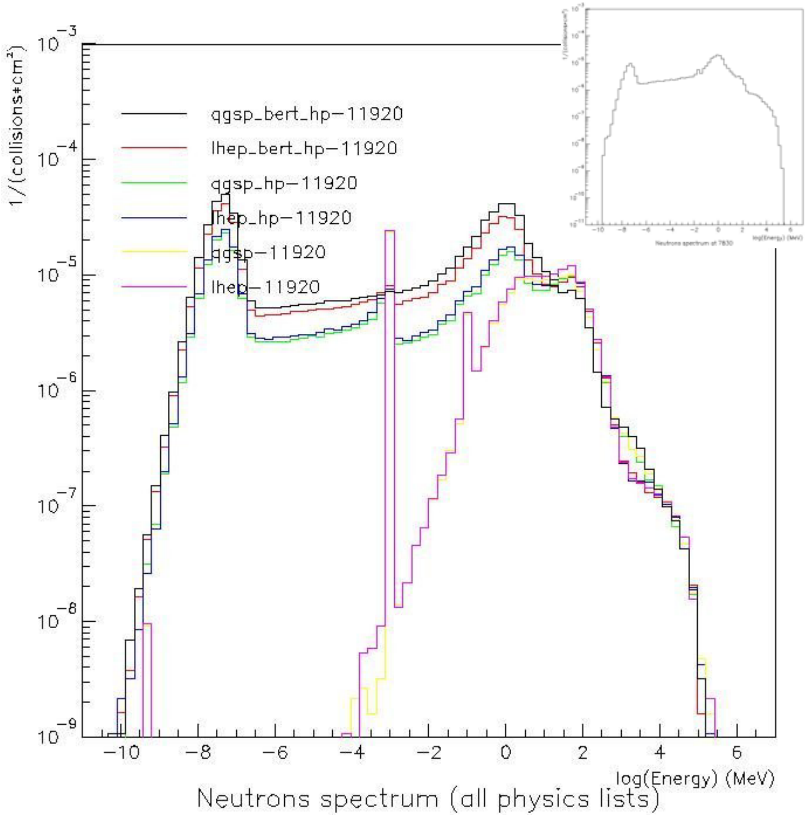
Total ionising dose
Band 2 @ 7830



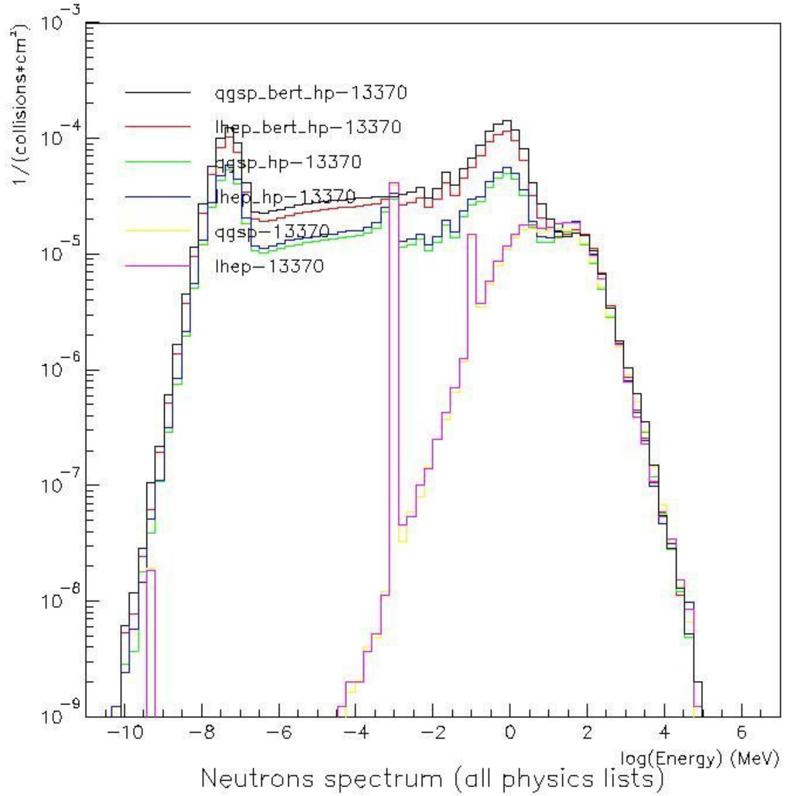
Total ionising dose
Band 3 @ 7830

Spectra calculated with all 4 physics lists

QGSP_BERT_HP



Neutrons spectrum @ 11920



Neutrons spectrum @ 13370

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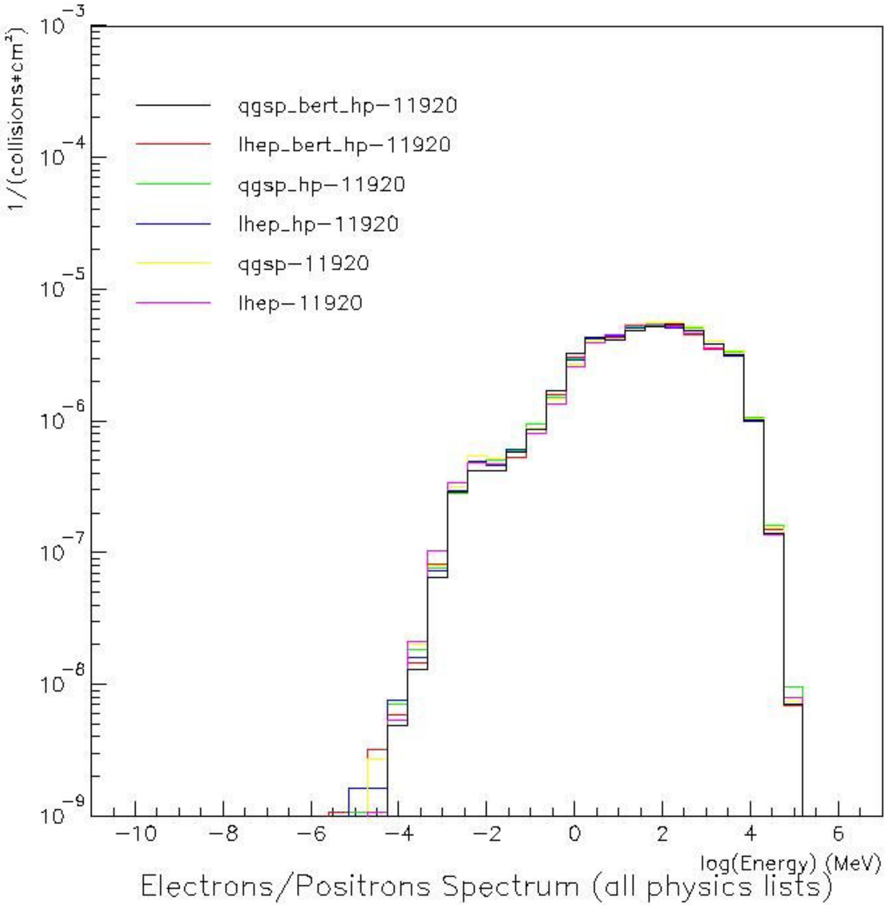
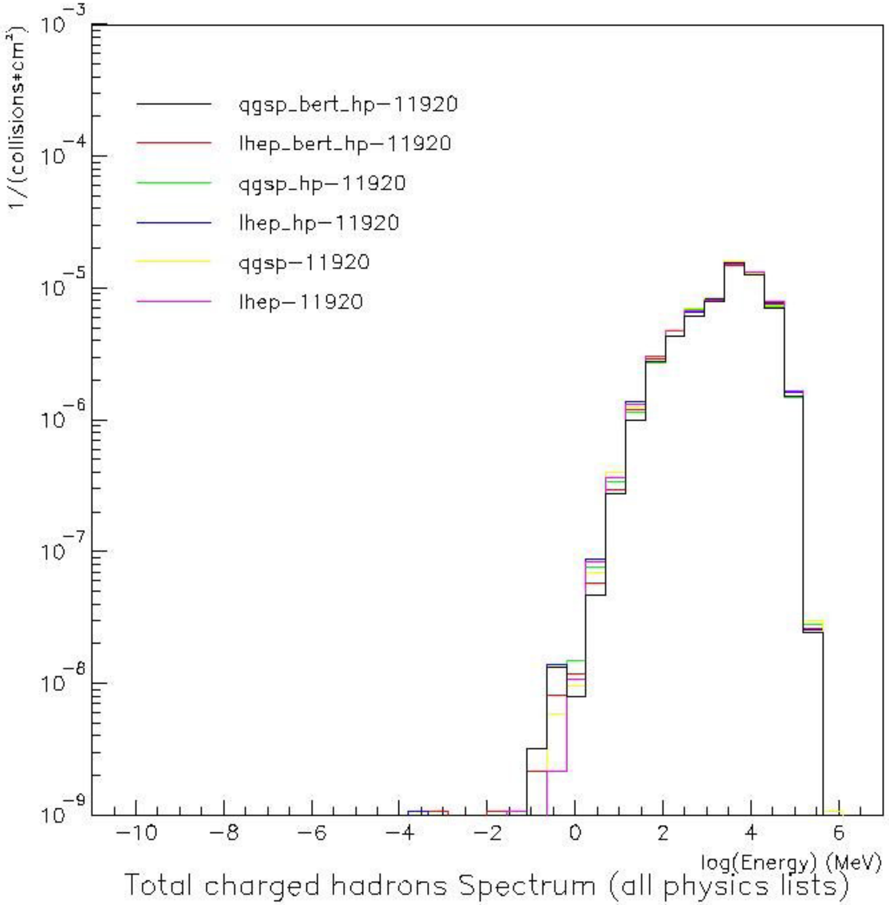
CERN, 4th May 2005



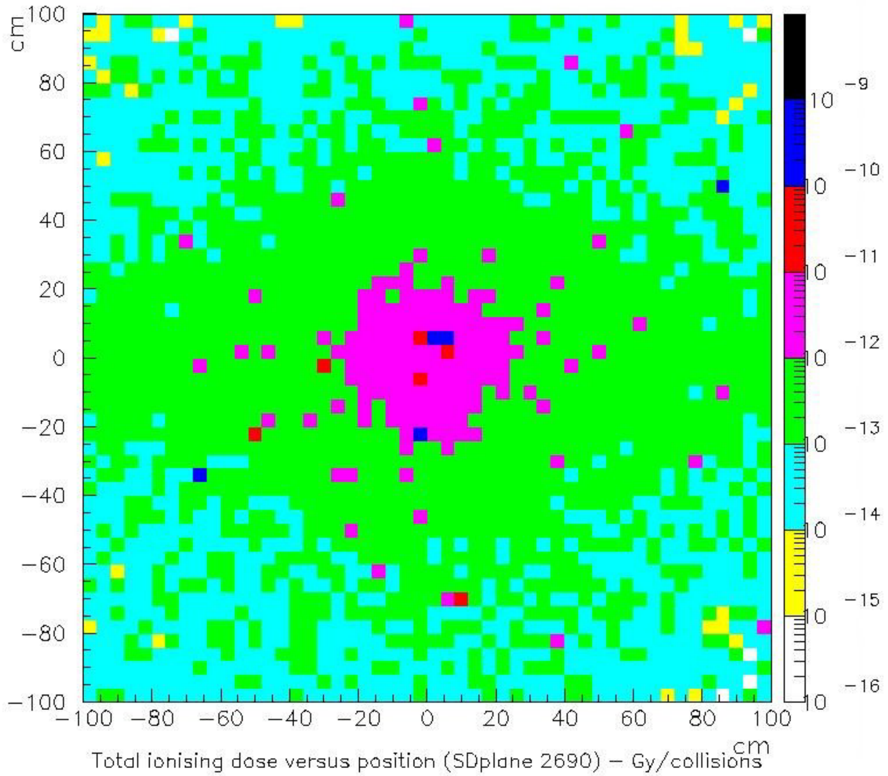
Electrons/positrons spectrum @ 11920

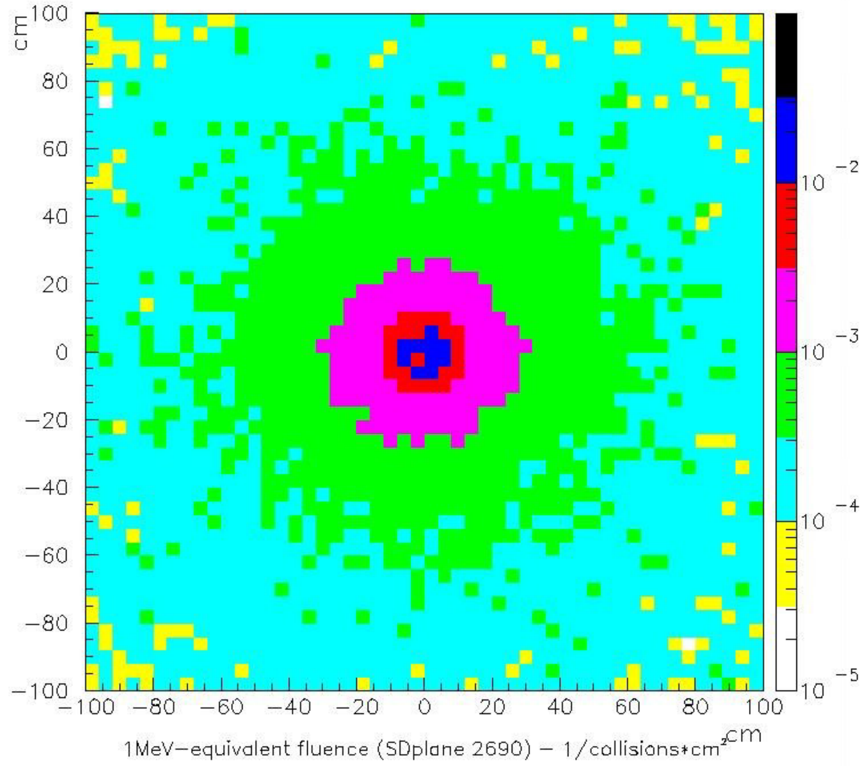


Total charged hadrons spectrum @ 11920

QGSP_BERT_HP results

Scoring plane @ 2960

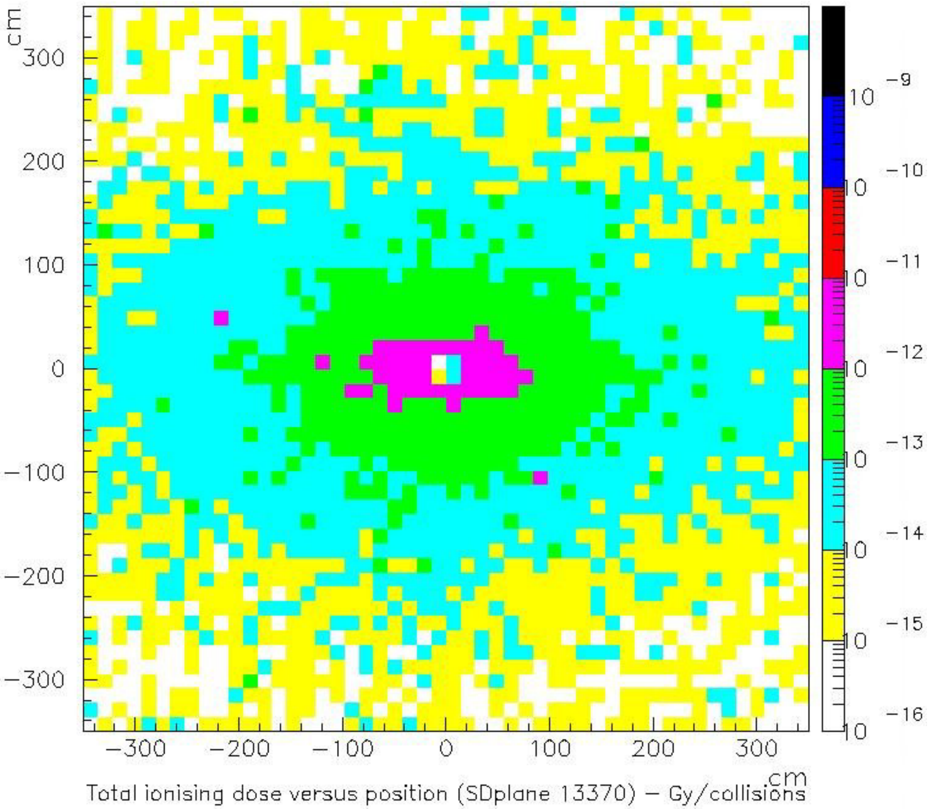




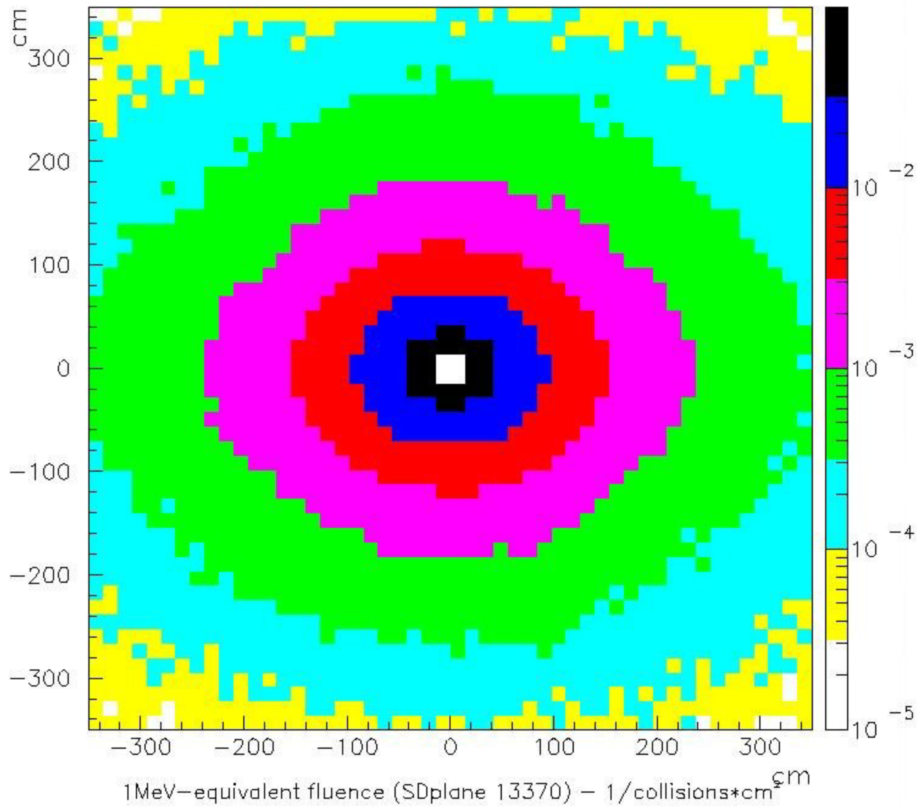
Total ionising dose

1 MeV neutron equivalent fluence

Scoring plane @ 13370



Total ionising dose



1 MeV neutron equivalent fluence

Discussion

☞ Results show expected 2D distributions for:

- ➢ neutrons (uniform)
- ➢ protons (slightly peaked on the right due to the polarity of the magnet, during the simulation)
- ➢ electrons/positrons balance
- ➢ low statistics at far-from-center bands
- ➢ neutrons production increase using the *HP extension*. Additional increase using the *Bertini cascade* to be investigated further.
- ➢ Peak-centered 2D distribution for the total ionising dose (up to $\sim 10^{-11}$ Gy/collisions). Influence of the magnet on the distribution.

Discussion (cont'd)

☞ Energy spectra show:

- physics lists provide a good agreement for the electrons/positrons and total charged hadron
- low energy neutrons are treated through the HP extension. But it still contains a 1keV peak, due to the evaporation code of the pararametrized model
- The addition of the *Bertini cascade,* to the *quark-gluon* model with *HP extension* is an adequate solution for the proper treatment of the neutrons throughout all the energy range (*QGSP_BERT_HP*)

☞ The use of the *LHEP* integrated with the *Bertini cascade* provides a physics list, which still shows the 1keV peak, because it still contains the evaporation code of the parametrized model

Discussion (cont'd)

☞ The 1MeV neutrons equivalent fluence gives an indication on the *displacement damage*. The QGSP_BERT_HP results show a centered-peak distribution (up to 10^{-1} $collisions^{-1} \cdot cm^{-2}$) in all the scoring planes

☞ Bigger values are present @ 2690 mm (mostly due to the primaries) and @ 13370 mm (due to the calorimeter effect)

☞ The total ionising dose is a reference for the *gradual radiation damage*. QGSP_BERT_HP results show centered-peak distributions (up to 10^{-11} Gy/collisions).

Conclusions

☞ We have shown that **Geant4** *can be used* for background radiation studies in LHCb, within the **GAUSS** framework.

☞ A module has been implemented in Gauss to *"tally"* a set of particles, to be monitored for the evaluation of the possible electronics damage

☞ Neutron fluence results show sensible differences between the use of 6 different physics lists. The reason is due to the models contained in them.

☞ All the 6 physics lists show a reasonable agreement for the other tallied particles fluence and the total ionising dose.

☞ The combination of the *QGSP*, the *Bertini cascade* and the *HP extension* gives a good answer to the problem requirements (QGSP_BERT_HP physics list).

THANK YOU