Background radiation studies using *Geant4* in *LHCb*: first results

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- *Introduction*
- *Simulation conditions*
- *Results*
- *Future activities*

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* (during the whole lifetime of the device)
- *Local and acute,* such as SEU (upset of a memory cell and revert individual triggers or switches) or SEL (permanent damage of the device). Ex: high energy hadrons interaction with the device.

☞ Previous background radiation studies for LHCb have been performed using FLUKA. Additional calcs with MARS, GCALOR

[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

Simulation conditions

☞ Geant4 is being used in the GAUSS framework to do similar studies

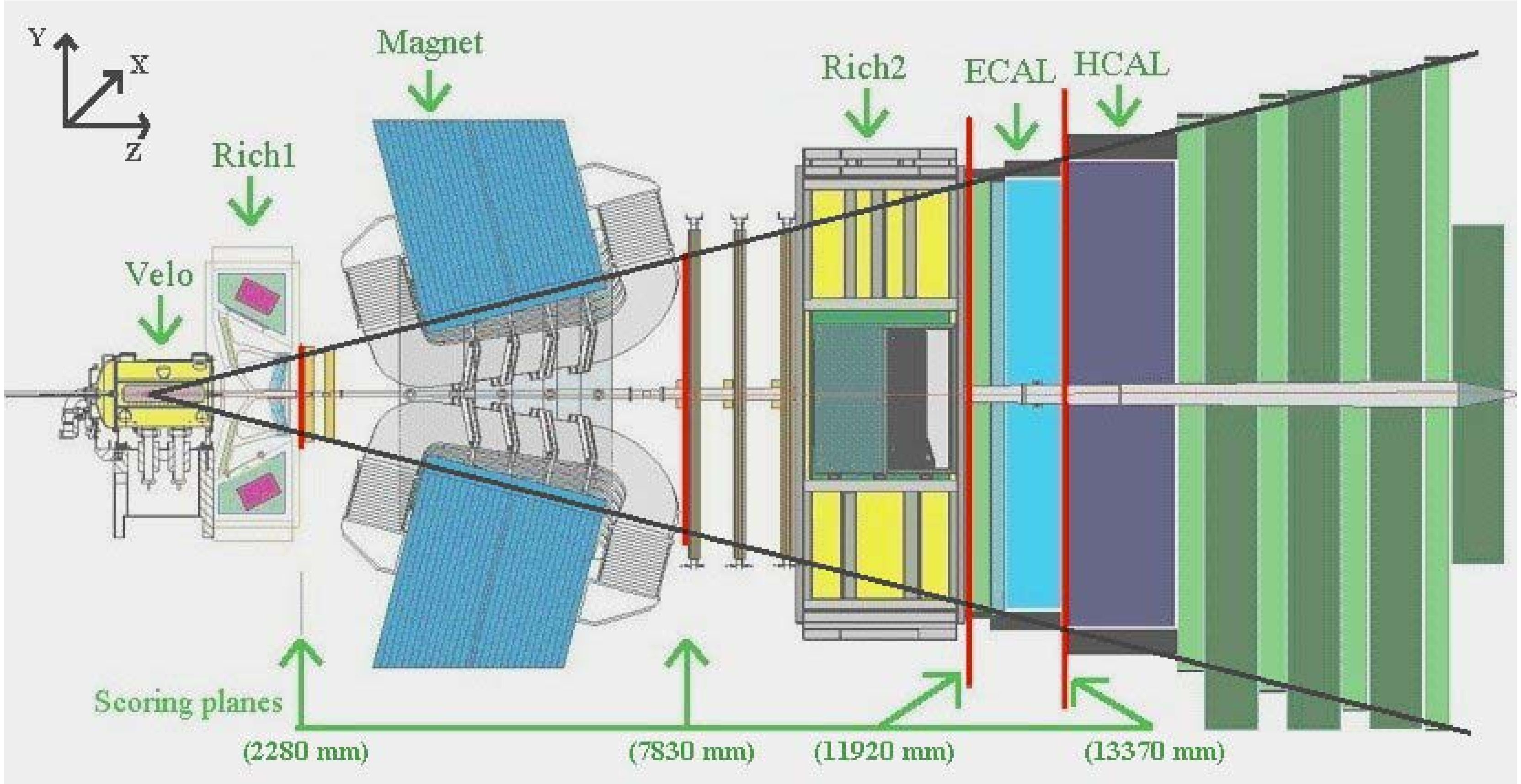
☞ Scoring planes have been added to the LHCb geometry to this purpose. These are voxelized planes, with a resolution 40 – 150 mm. The planes are defined according to the XML geometry description of the LHCb setup.

☞ No tracking cuts for particles transport.

☞ Production cuts: electron/positrons = 5 mm, gammas = 10 mm

☞ Primary events are generated with Pythia 6.2

Geometrical setup



☞ Each voxelized plane is associated to several hit collections, having the same resolution as the user-defined voxelization. The association is done automatically, based on the XML geometry definition of the scoring plane.

Simulation conditions

☞ Using GAUSS properties, the user decides the tallies to be switched on. In other words, which particle should be tracked for fluence and dose calcs.

☞ Scored particles: neutrons, charged hadrons (pions, kaons, protons), electrons/positrons, gammas

☞The output is shown in terms of particle energy spectra or 2D mappings. The user can switch them on (either both or separately)

- 2D histo: proton, elec./pos, gamma, charged hadr. dose, high energy (> 20 MeV) hadr. dose, total ion. dose (post processing)
- 2D histo: proton, neutrons, electrons/posistrons, gamma, charged hadrons fluence
- 1D histo: neutrons, electrons/positrons, protons, pions spectra, total charged hadrons spectra (post-processing)

☞ First results using LHEP, QGSP, QGSP_HP, LHEP_HP, LHEP_BERT_HP physics lists, with 5000 primary events.

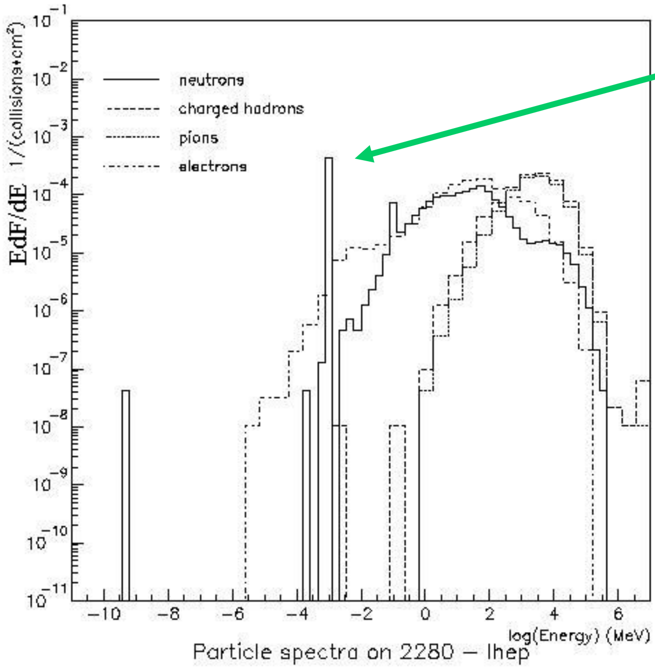
☞ The events are generated in LHCb (min-bias), using the same run numbers for all the physics lists. Therefore, differences in the outcome are not connected to the primary events.

Results

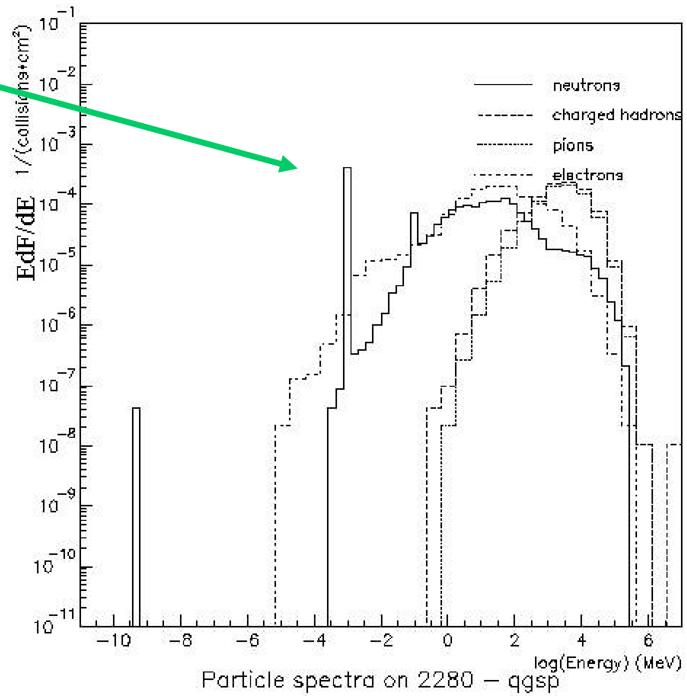
☞ Attempt to use LHEP and QGSP for these studies

☞ As expected, these physics lists have not been designed to cover such studies range. Neutrons energy spectra show missing tracking at low energies.

spectra are binning-independent

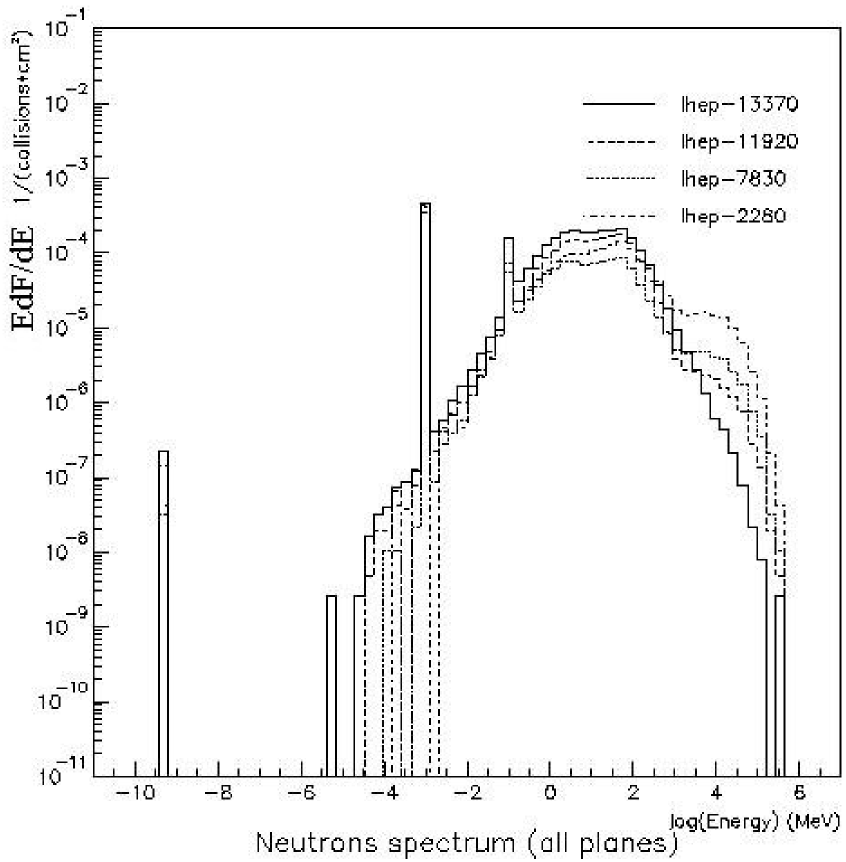


LHEP

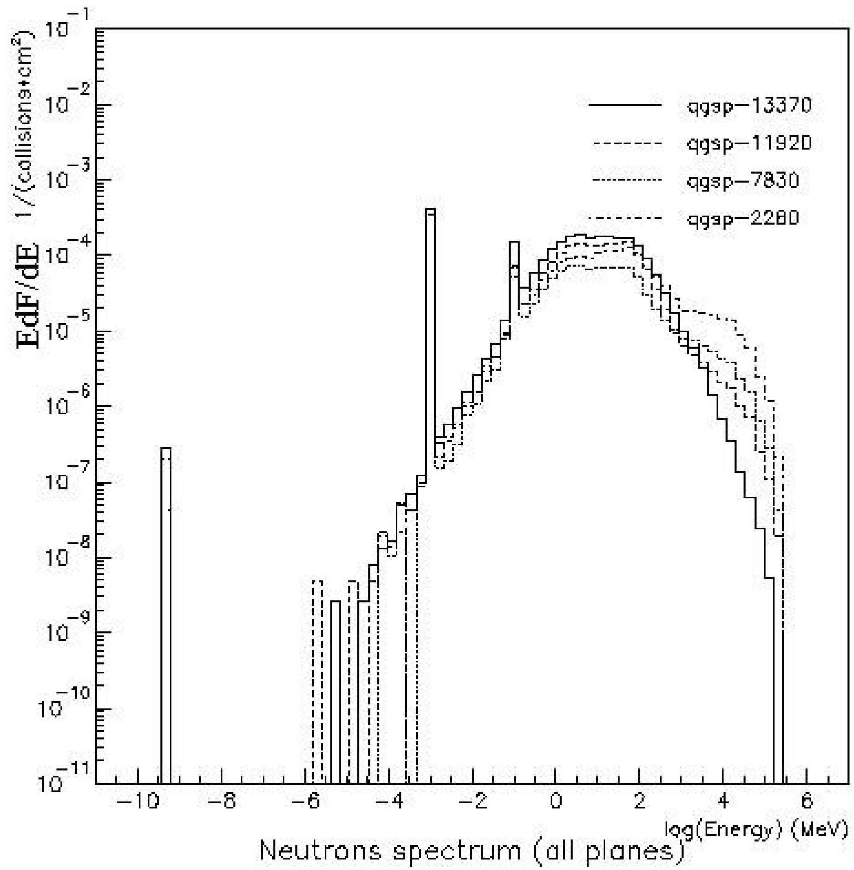


QGSP

☞ Reasonable neutrons energy spectra in high energy region.



LHEP

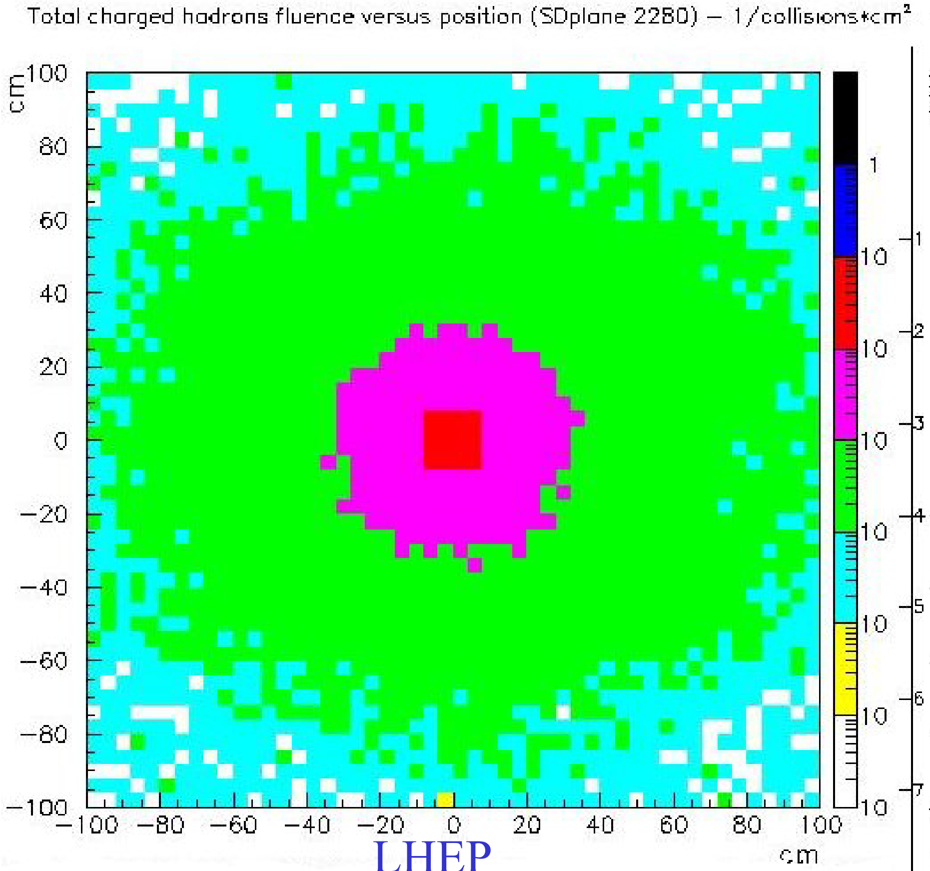


QGSP

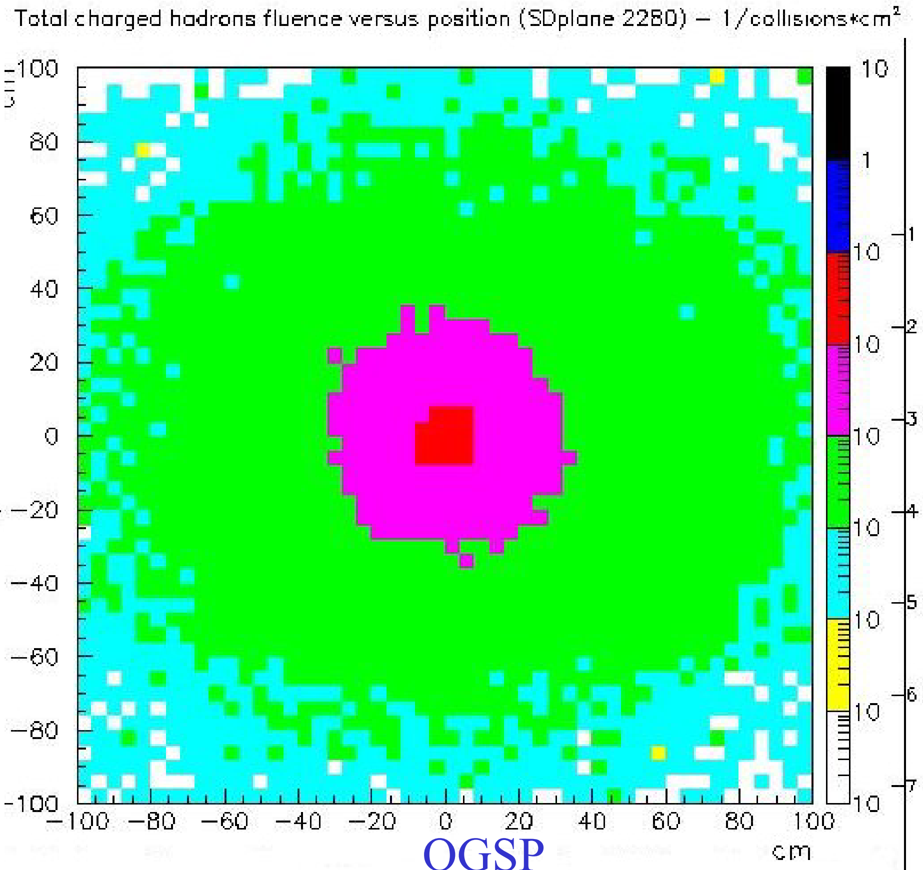
☞ Proper tracking of the charged particles. Both physics lists show similar results, taking into account the statistics accuracy.

Plane at 2280 mm

2D histograms per collision



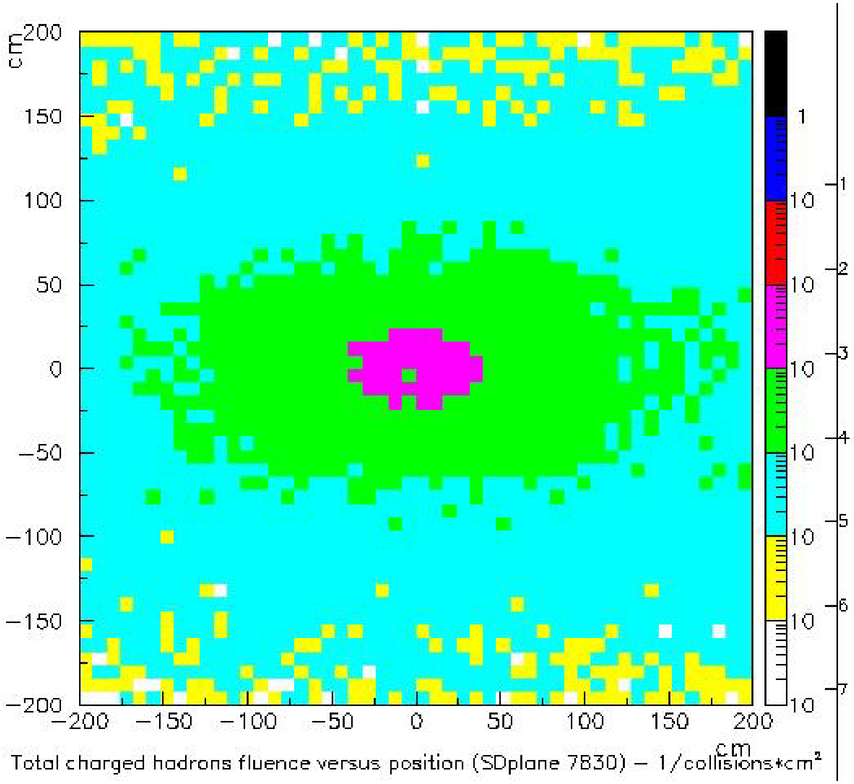
LHEP



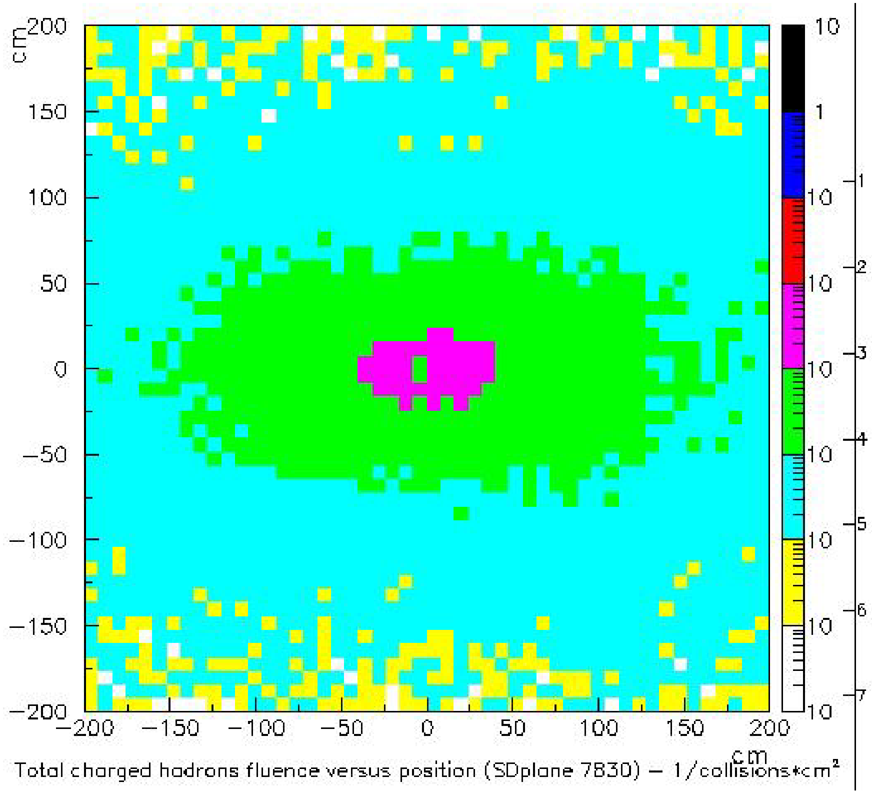
QGSP

Plane at 7830 mm

☞ Effect of the magnetic field

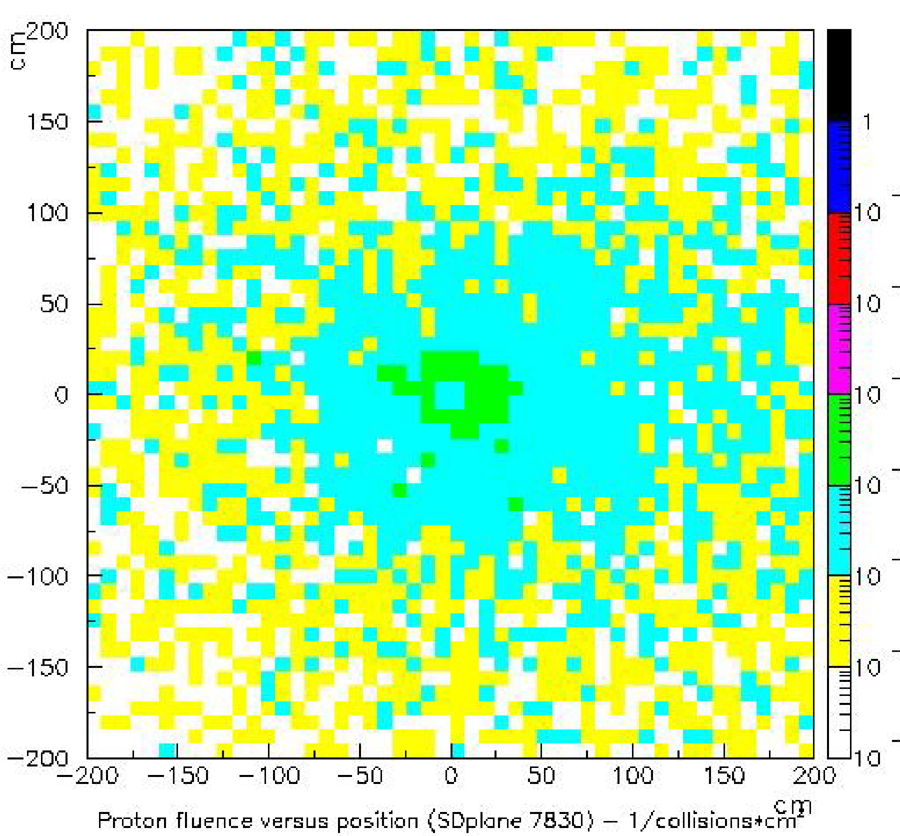


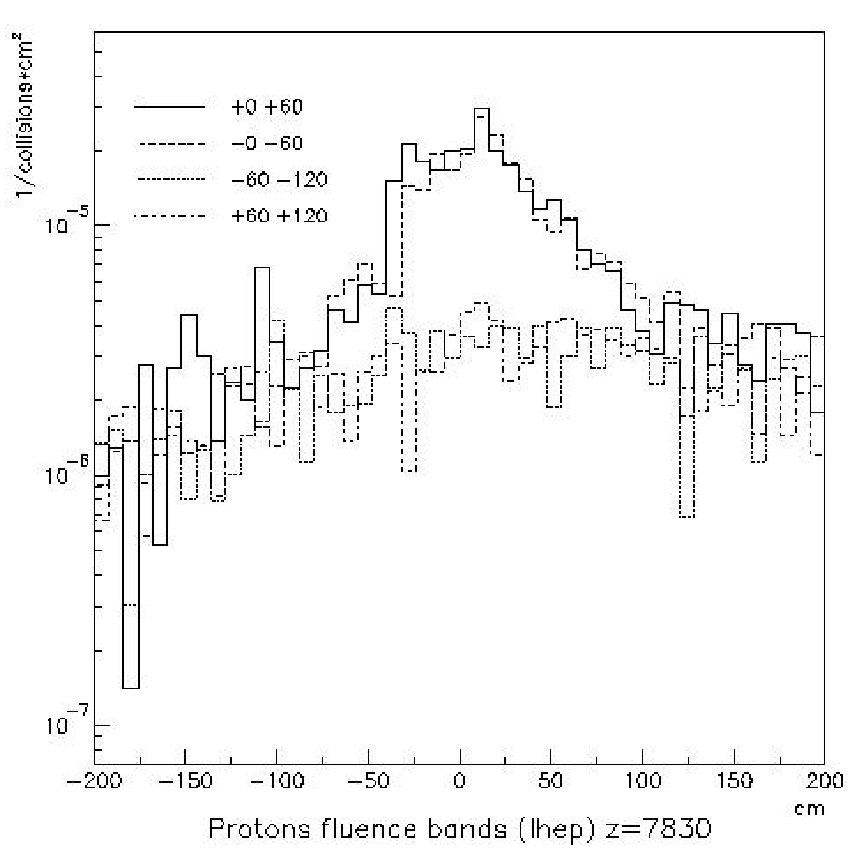
LHEP



QGSP

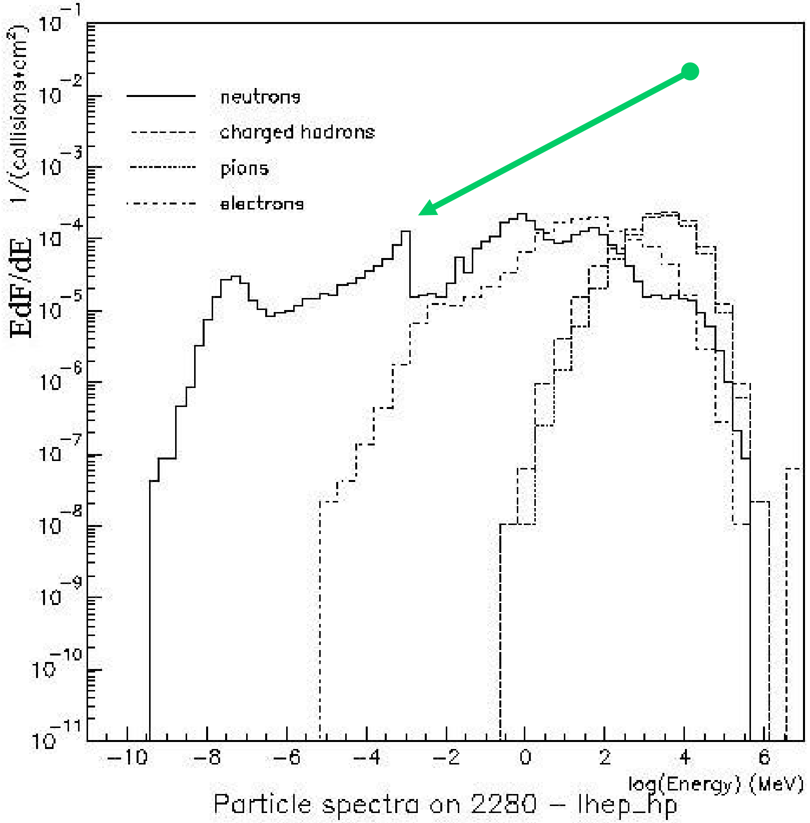
☞ For example, protons are deviated according to the polarity of the magnet. Using LHEP:



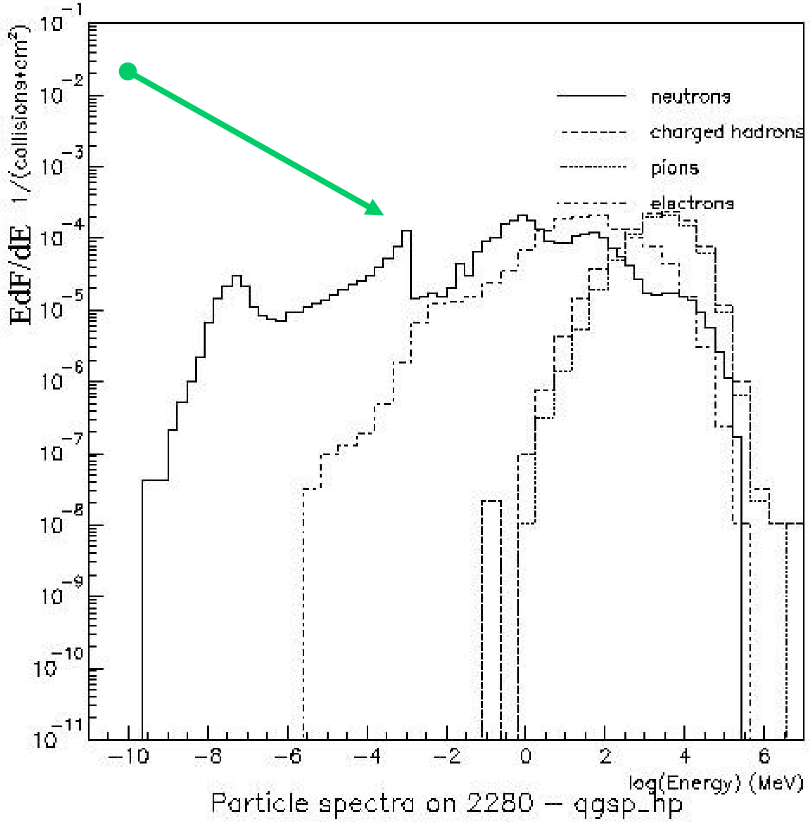


☞ Because low energy neutrons are not treated by LHEP/QGSP, it has been decided to use the same physics lists, but with the HP (high precision) extension

☞ This time, the neutrons spectra come out as expected



LHEP_HP



QGSP_HP

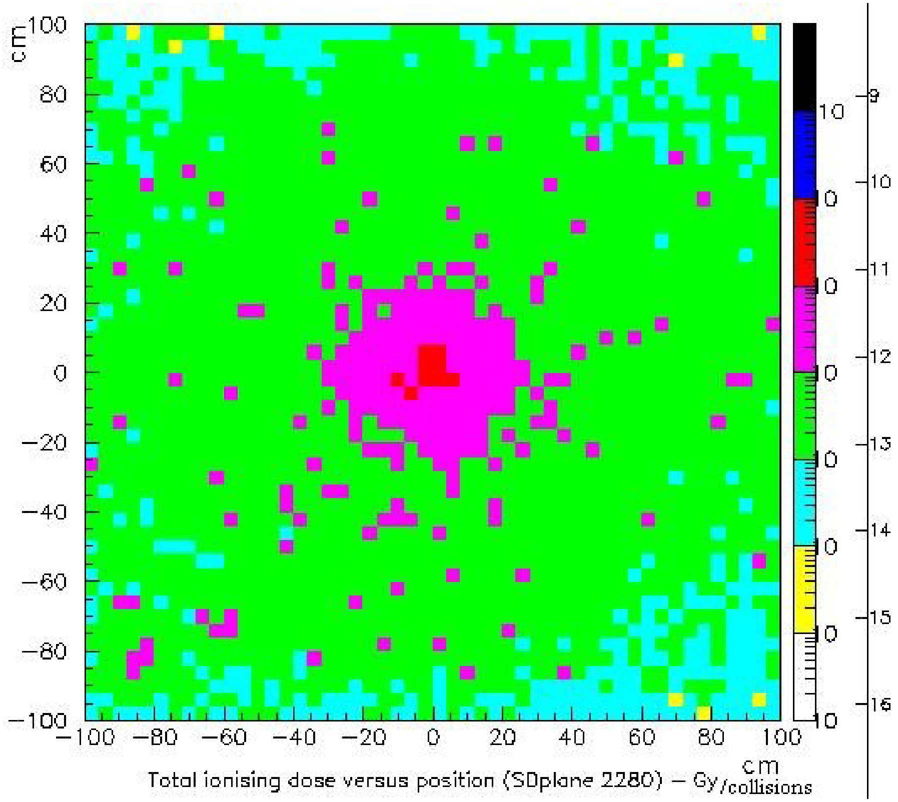
☞ An accurate evaluation of the 1 keV neutrons peak shows that most of these particles are generated in the calorimeters area (mainly by π^+ and π^- interaction).
☞ Then they travel back for ~ 10 m without interactions. This is justified by the low radiation length in LHCb between RICH1 and RICH2.

☞ The accumulation of 1 keV neutrons is due to the modelling of the evaporation code.

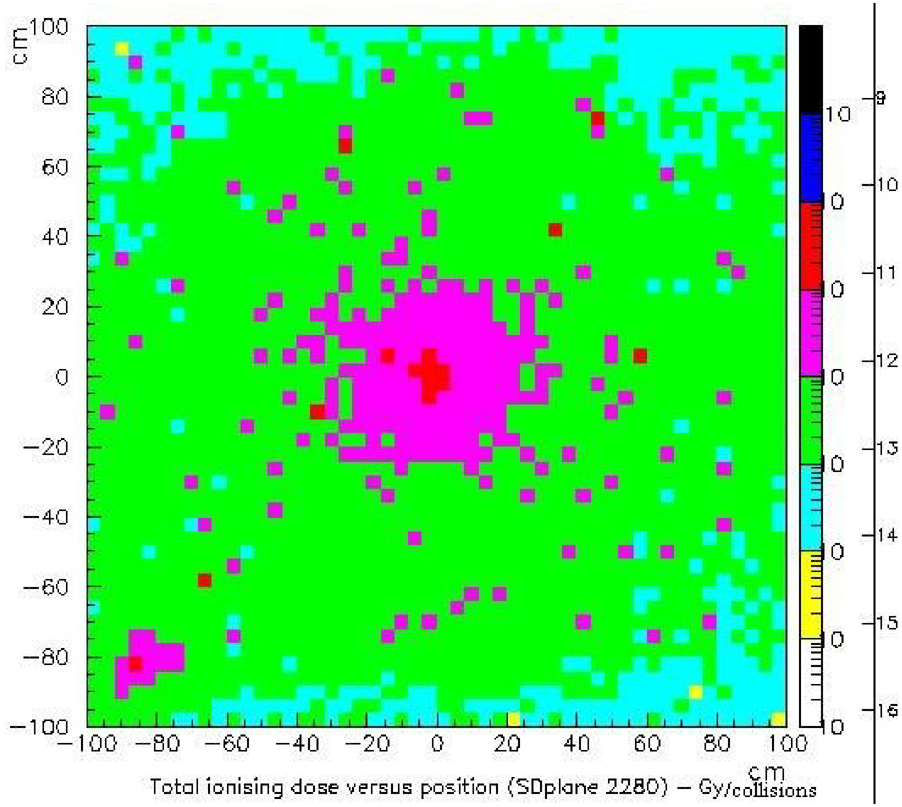
☞ Apart from this drawback, the HP physics lists show a reasonable response to the background radiation studies.
☞ The charged particles are properly treated.
☞ Next slides show the comparison between LHEP_HP and QGSP_HP in the 4 scoring planes for the total ionising dose, the total charged hadrons fluence and high energy hadrons fluence.

Plane at 2280 mm

Total ionising dose



LHEP_HP

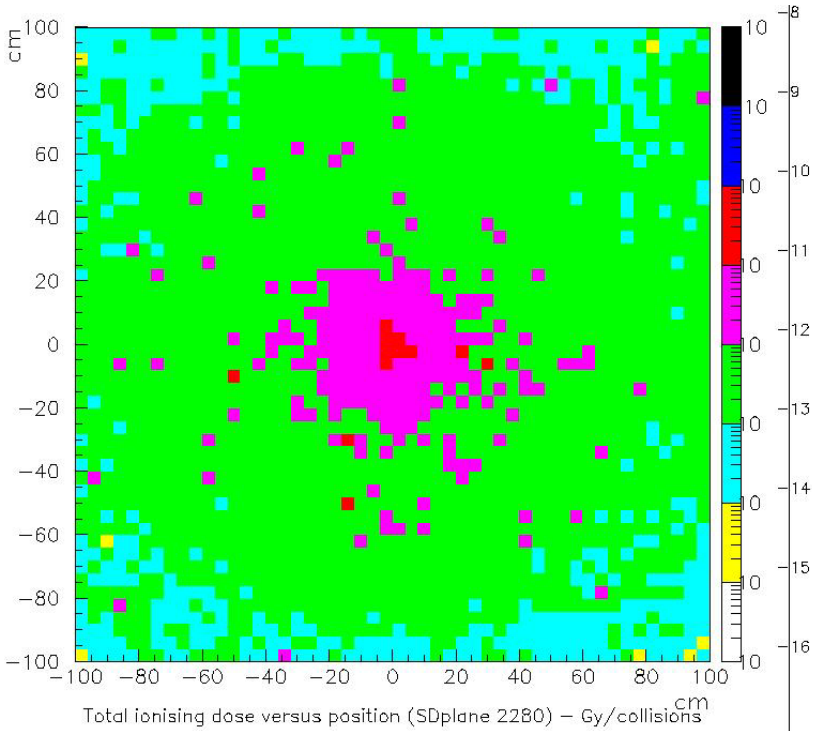


QGSP_HP

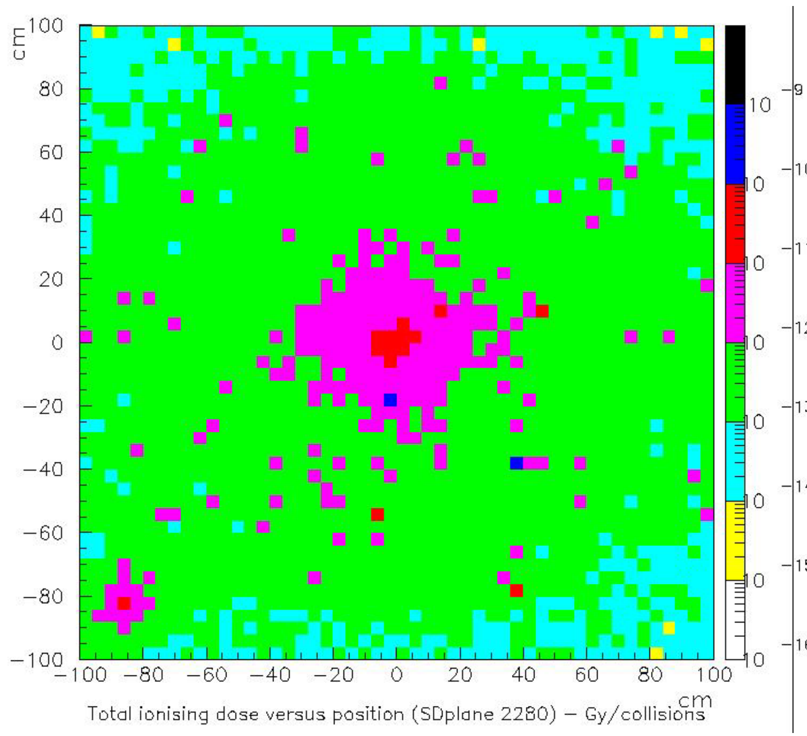
Plane at 2280 mm

Total ionising dose

☞ similar behaviour for LHEP and QGSP, as expected



LHEP

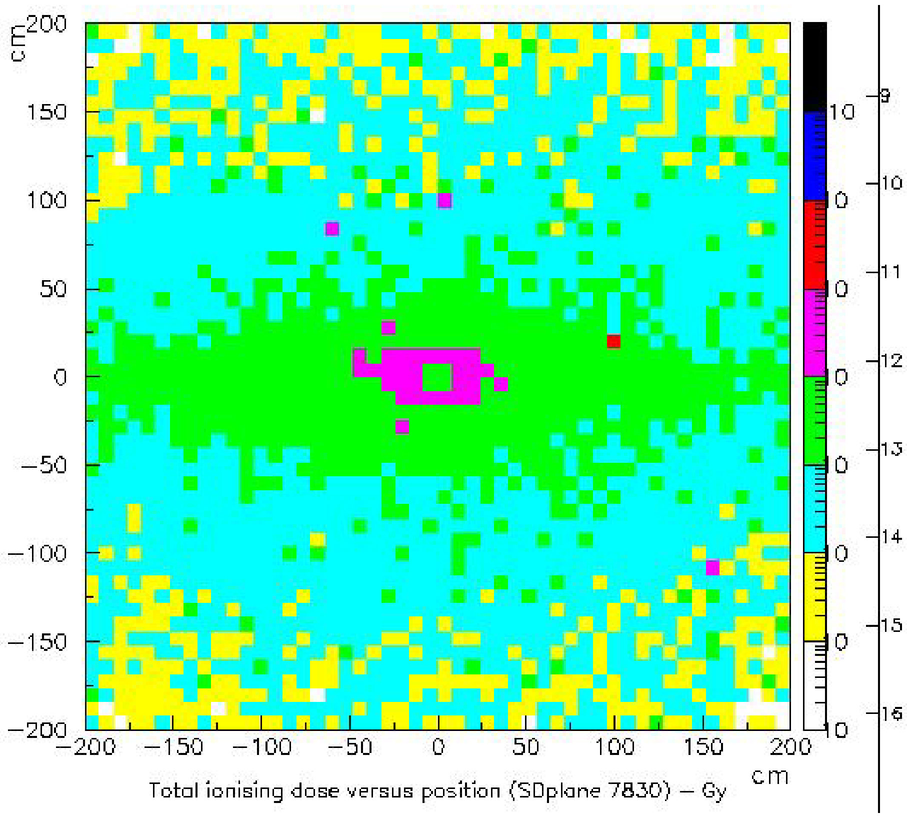


QGSP

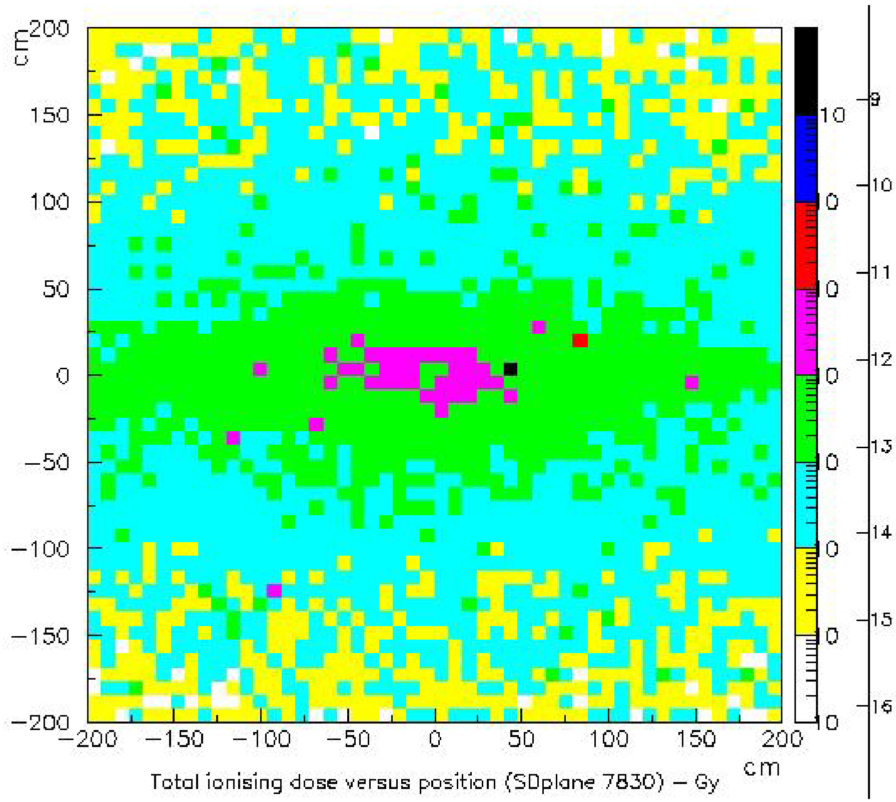
Plane at 7830 mm

Total ionising dose

☞ similar behaviour for 11920 and 13370 planes. QGSP_HP shows more hot spots. QGSP and LHEP shows similar response.



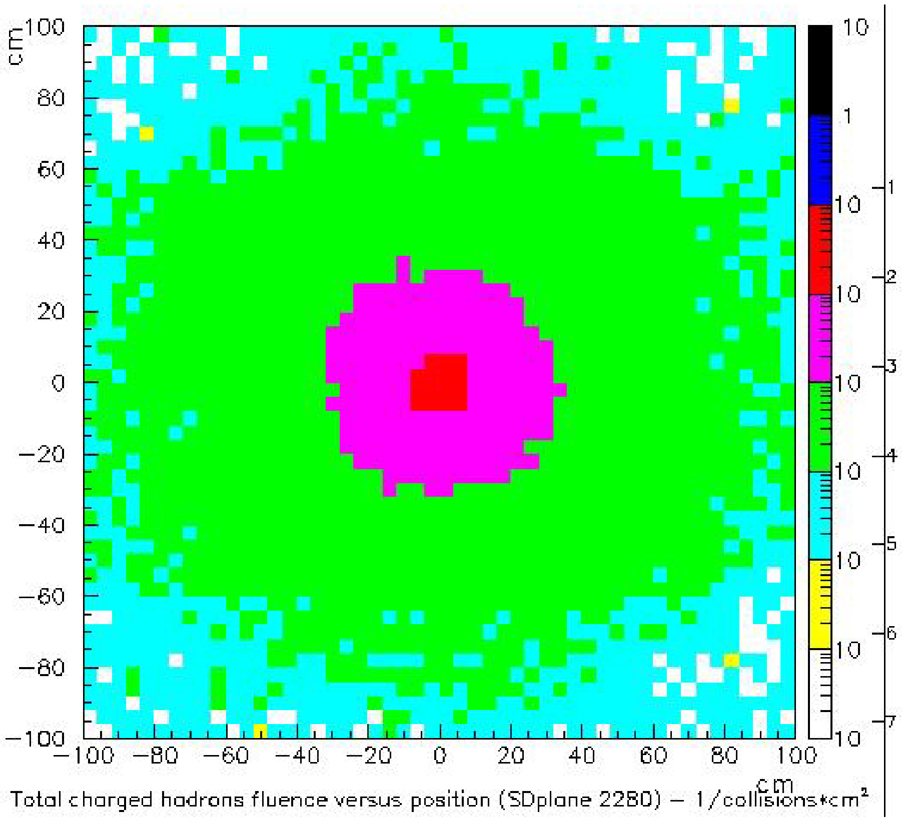
LHEP_HP



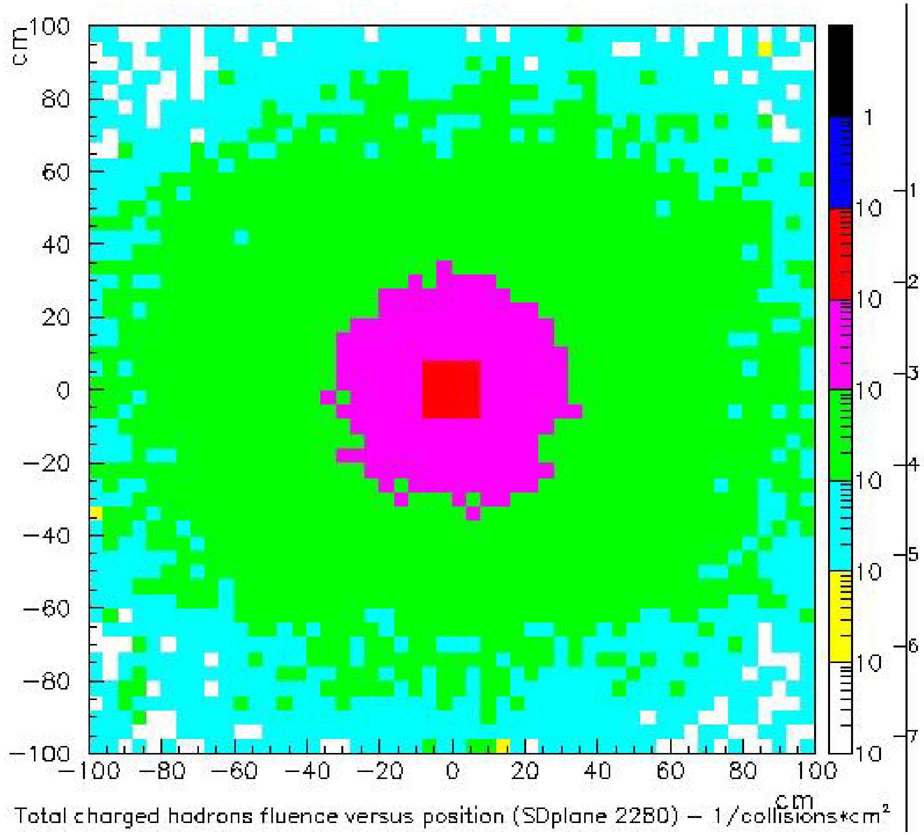
QGSP_HP

Plane at 2280 mm

Total charged hadrons fluence



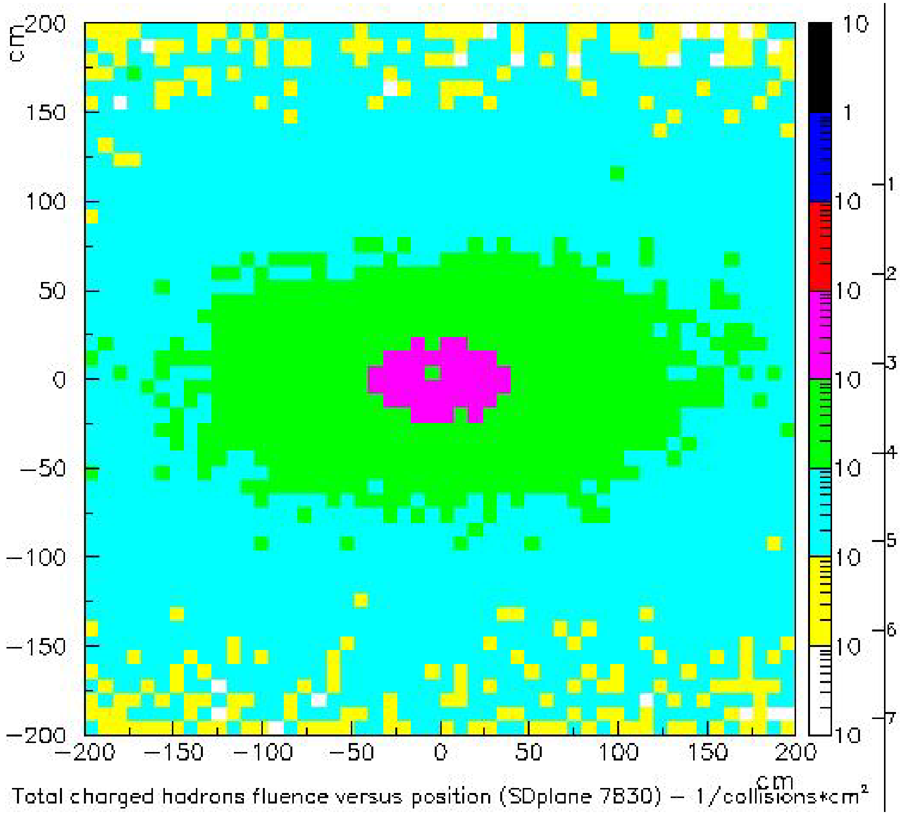
LHEP_HP



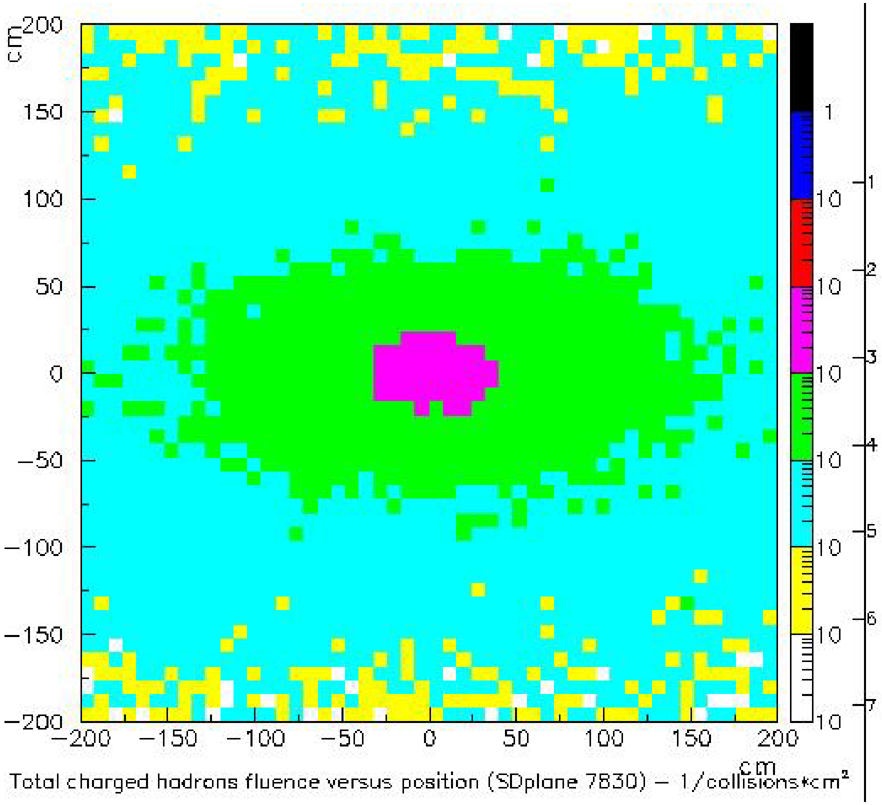
QGSP_HP

Plane at 7830 mm

Total charged hadrons fluence



LHEP_HP

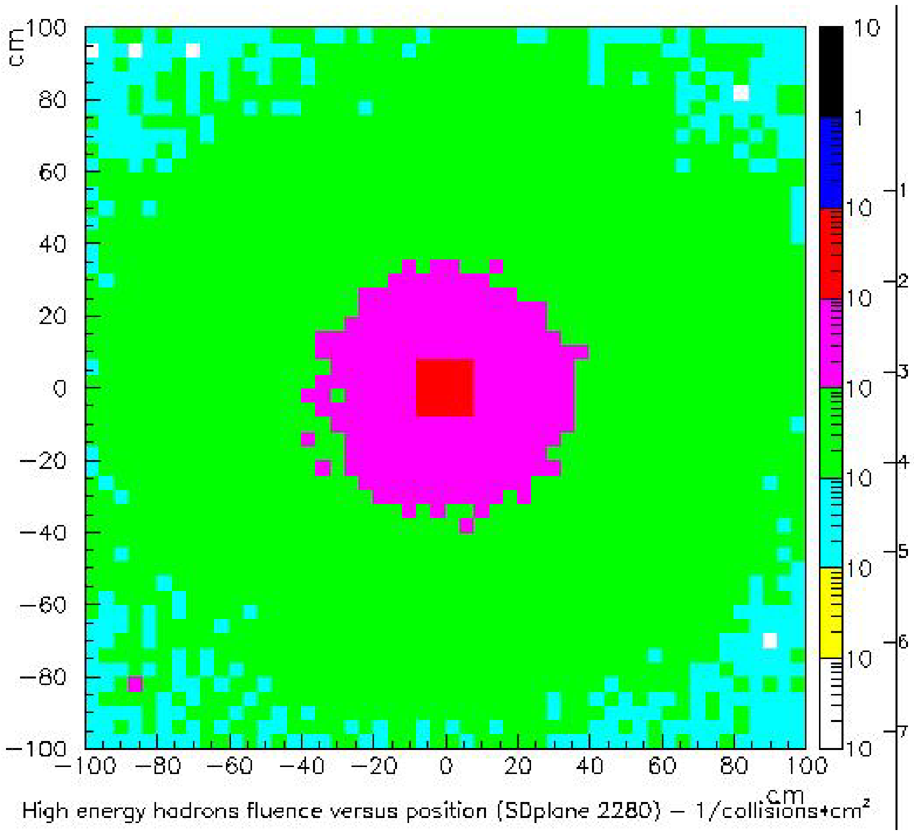


QGSP_HP

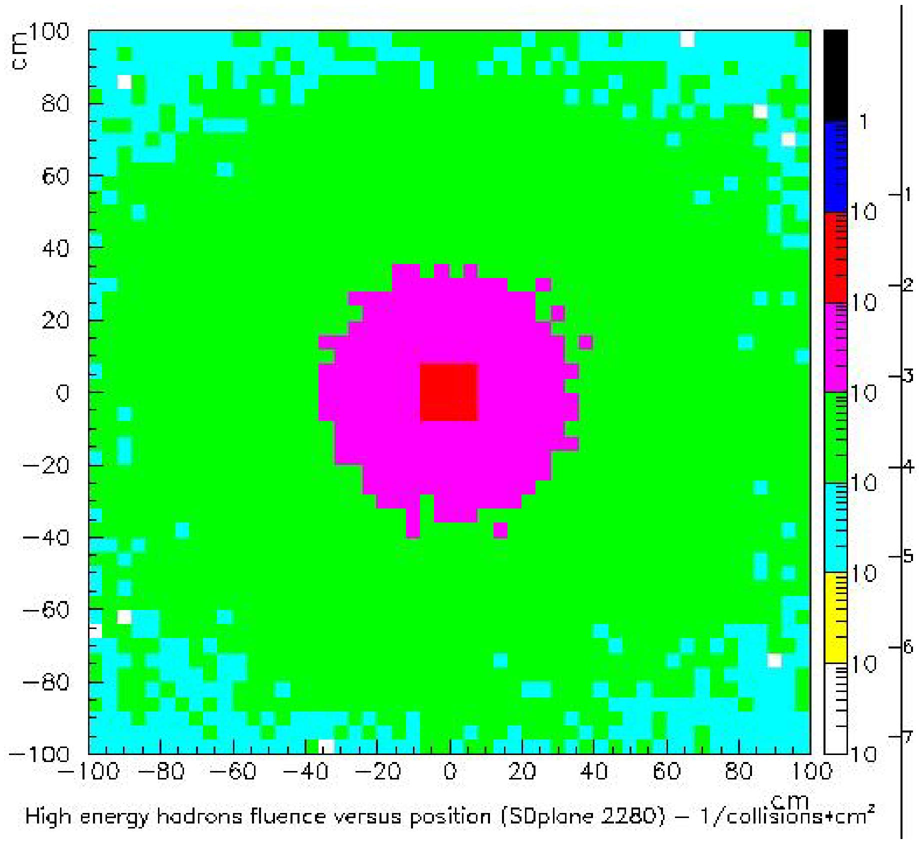
Plane at 2280 mm

High energy hadrons fluence

(for comparison with the device sensitivity to SEU or SEL)



LHEP_HP

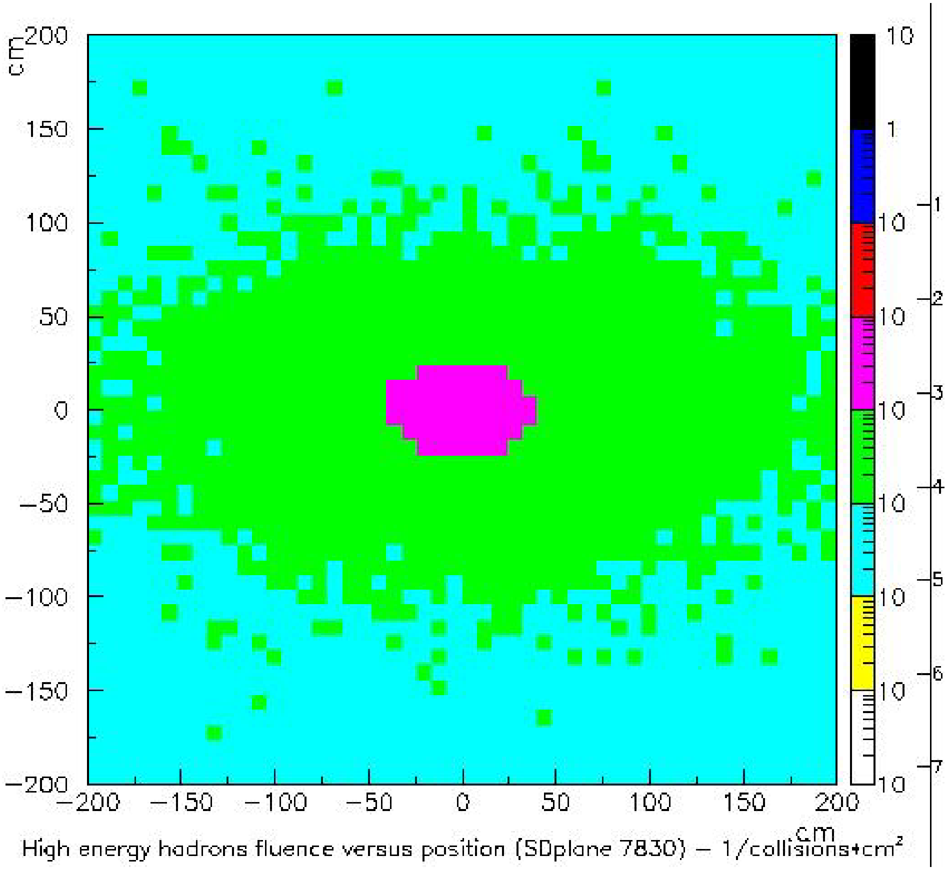


QGSP_HP

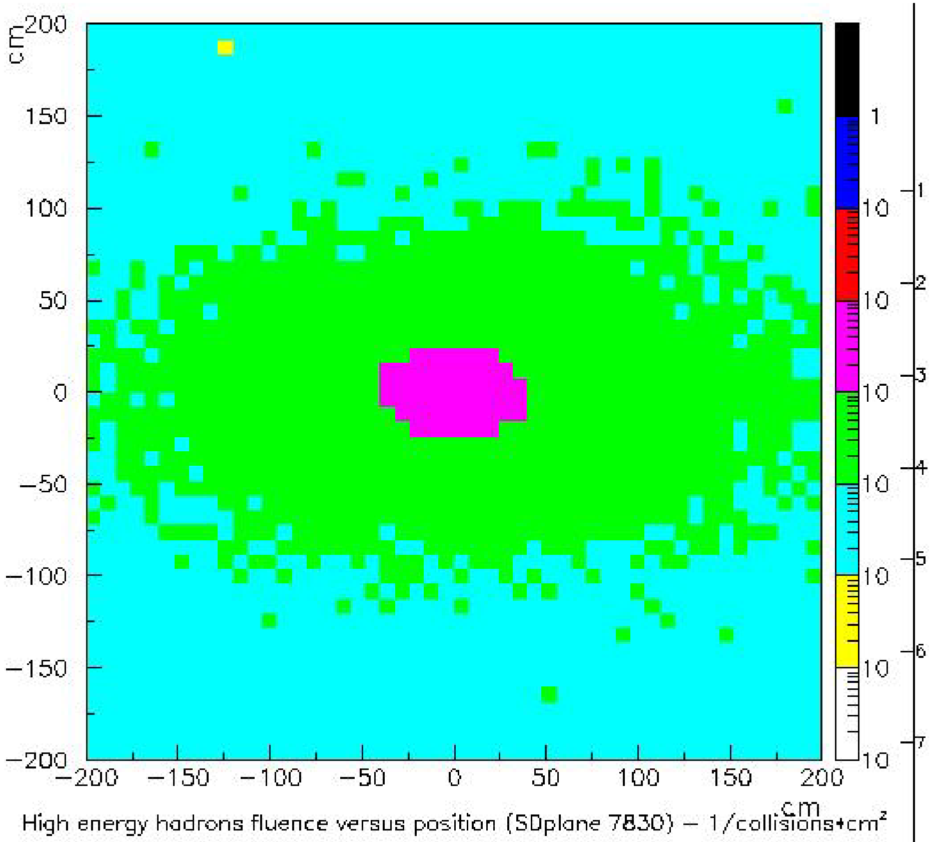
Plane at 7830 mm

High energy hadrons fluence

☞ similar behaviour for 11920 and 13370 planes



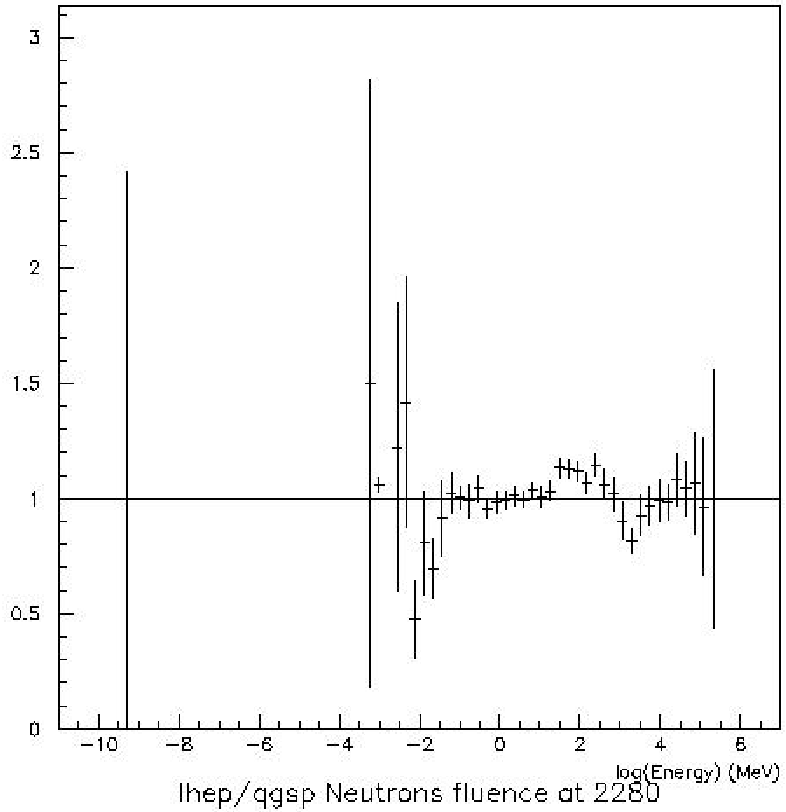
LHEP_HP



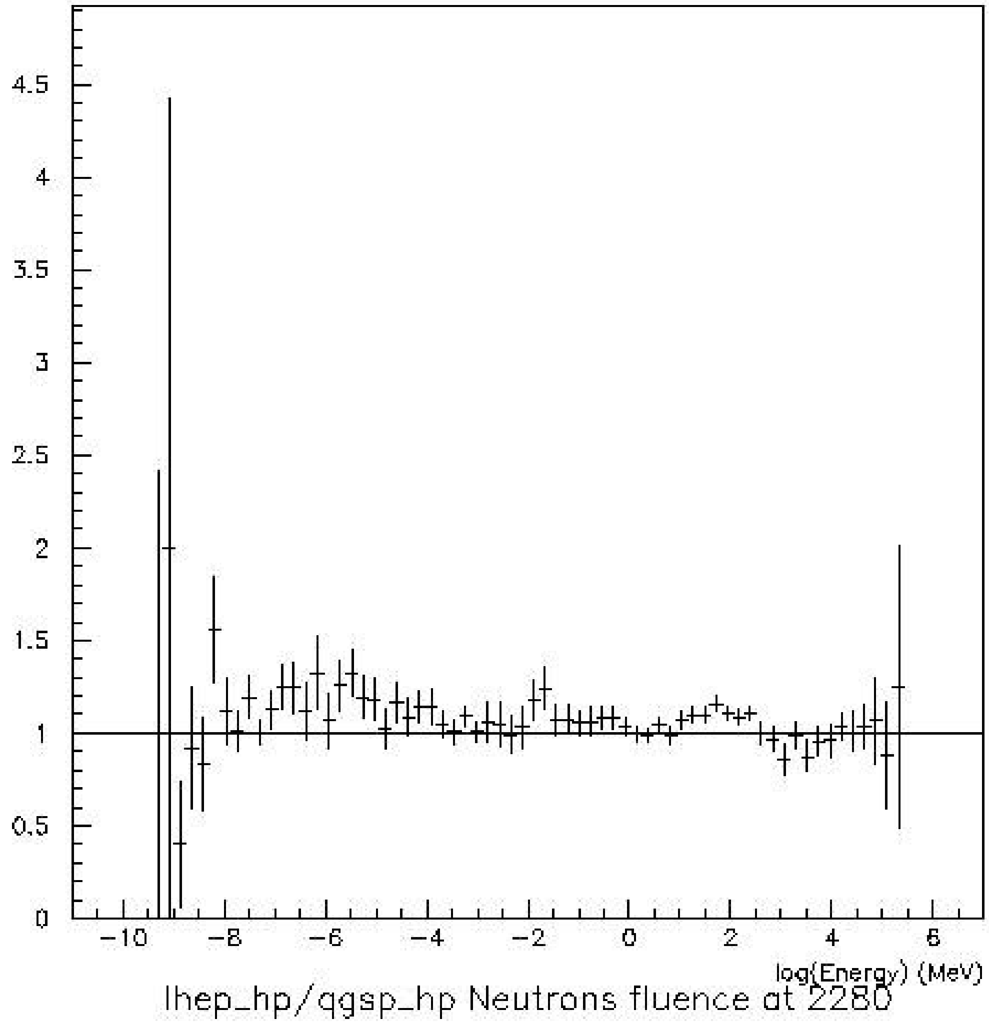
QGSP_HP

☞ Quantitative evaluation of the results obtained with different physics lists through the histograms ratio (LHEP/QGSP and LHEP_HP/QGSP_HP)

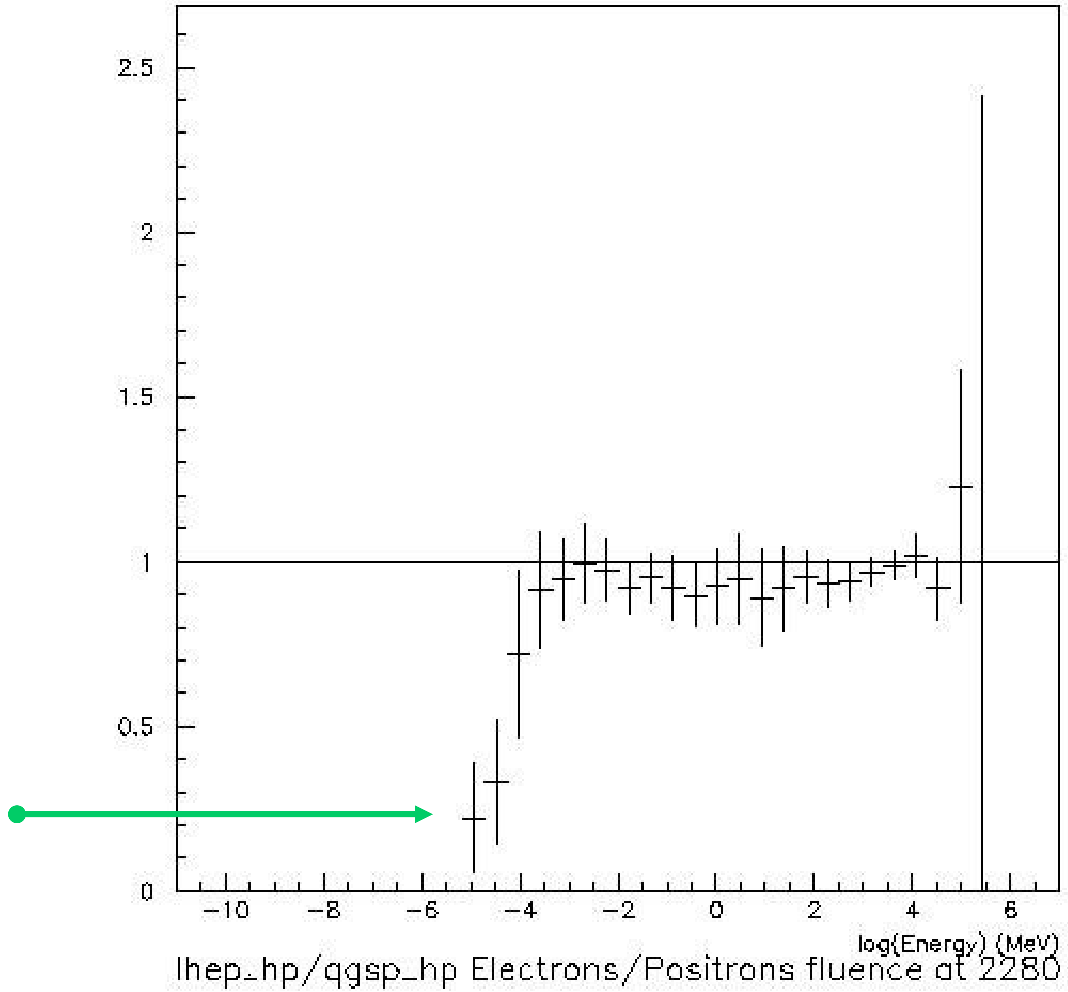
Neutrons energy spectrum at 2280 mm (LHEP/QGSP)



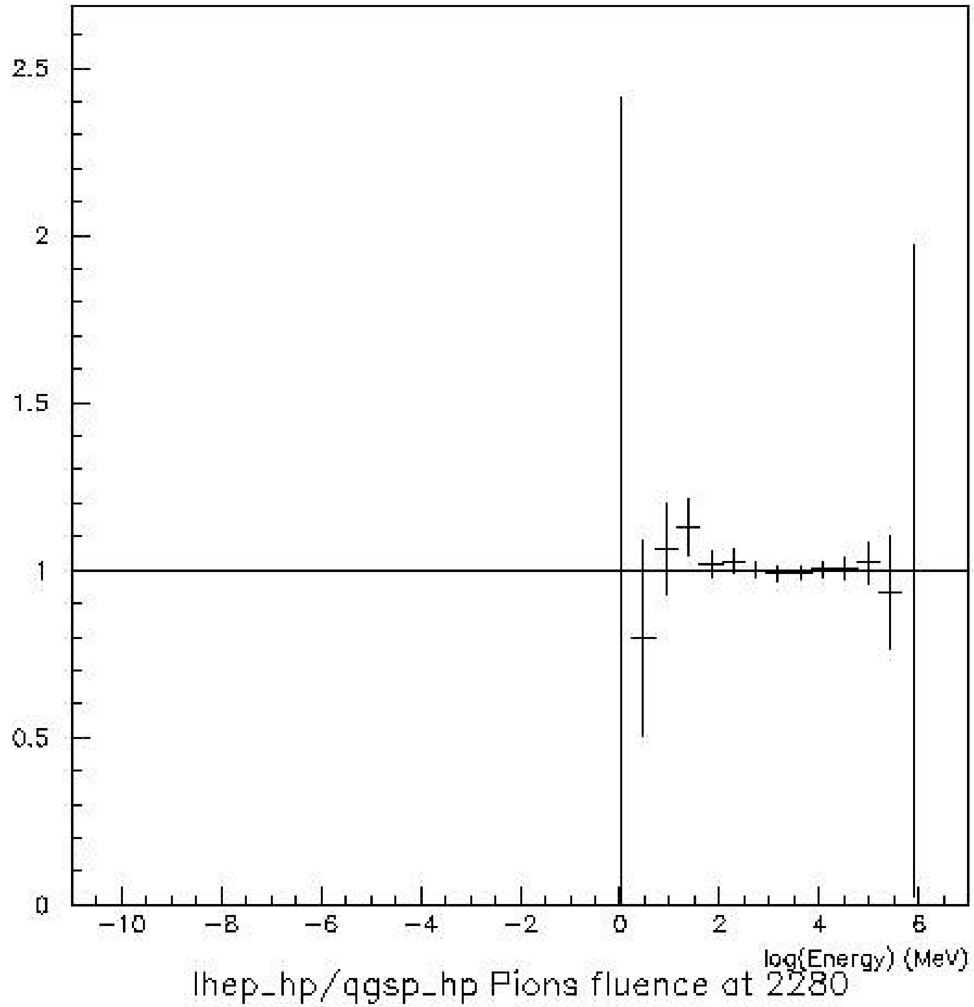
Neutrons energy spectrum at 2280 mm (LHEP_HP/QGSP_HP)



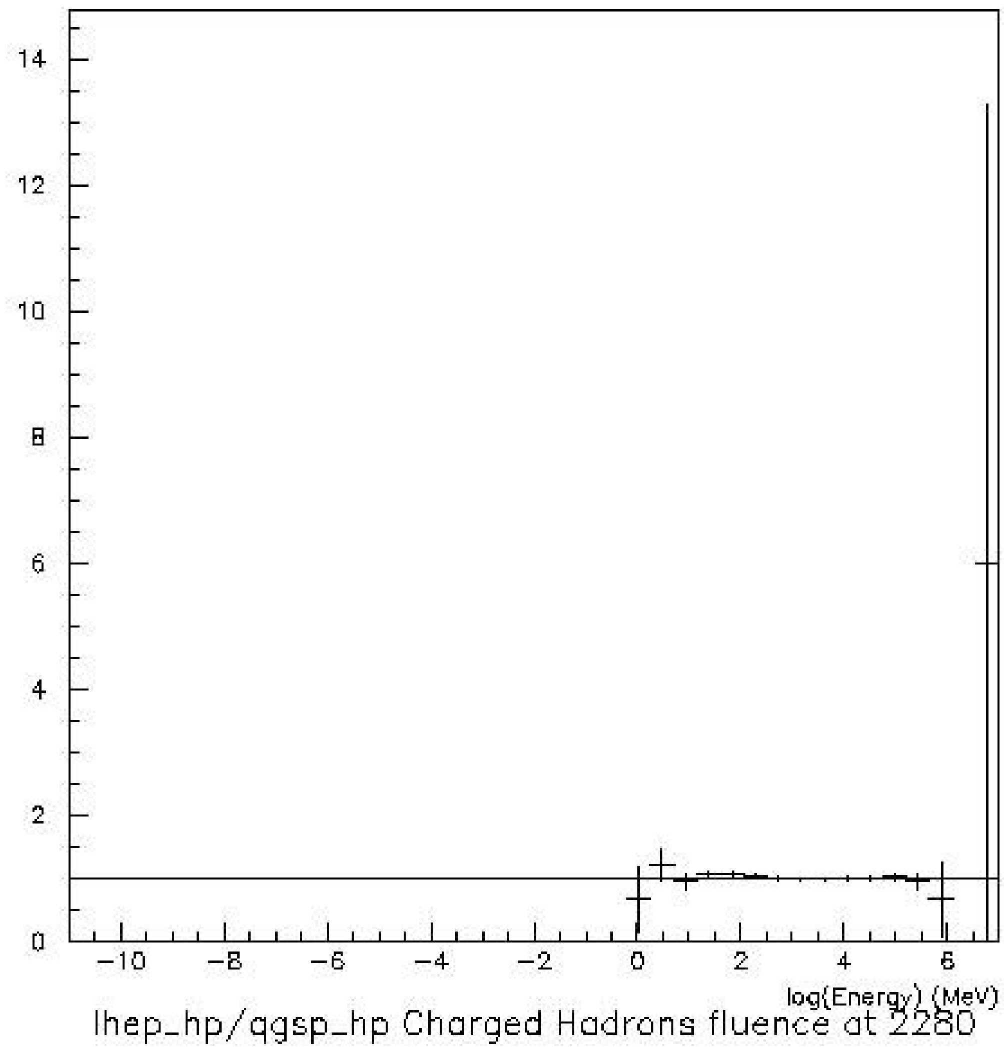
Electrons energy spectrum at 2280 mm (LHEP_HP/QGSP_HP)



Pions energy spectrum at 2280 mm (LHEP_HP/QGSP_HP)



Charged hadrons energy spectrum at 2280 mm (LHEP_HP/QGSP_HP)



☞ 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

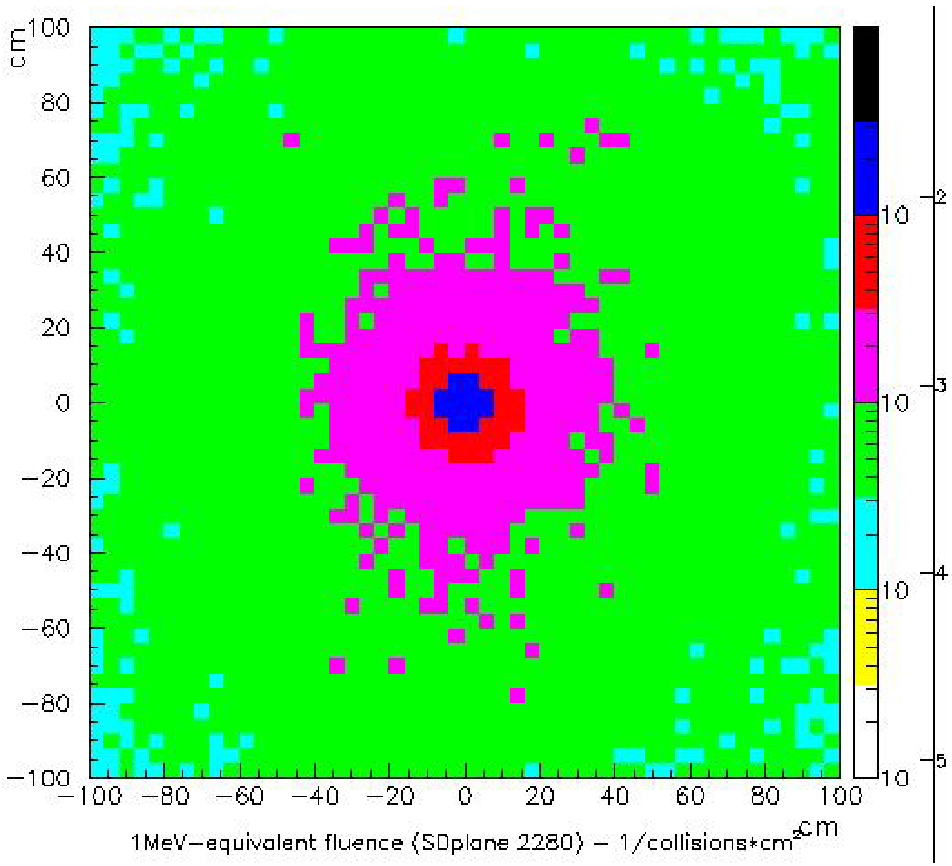
$$\Phi_{eq}^{1MeV} = k \cdot \Phi_p$$

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

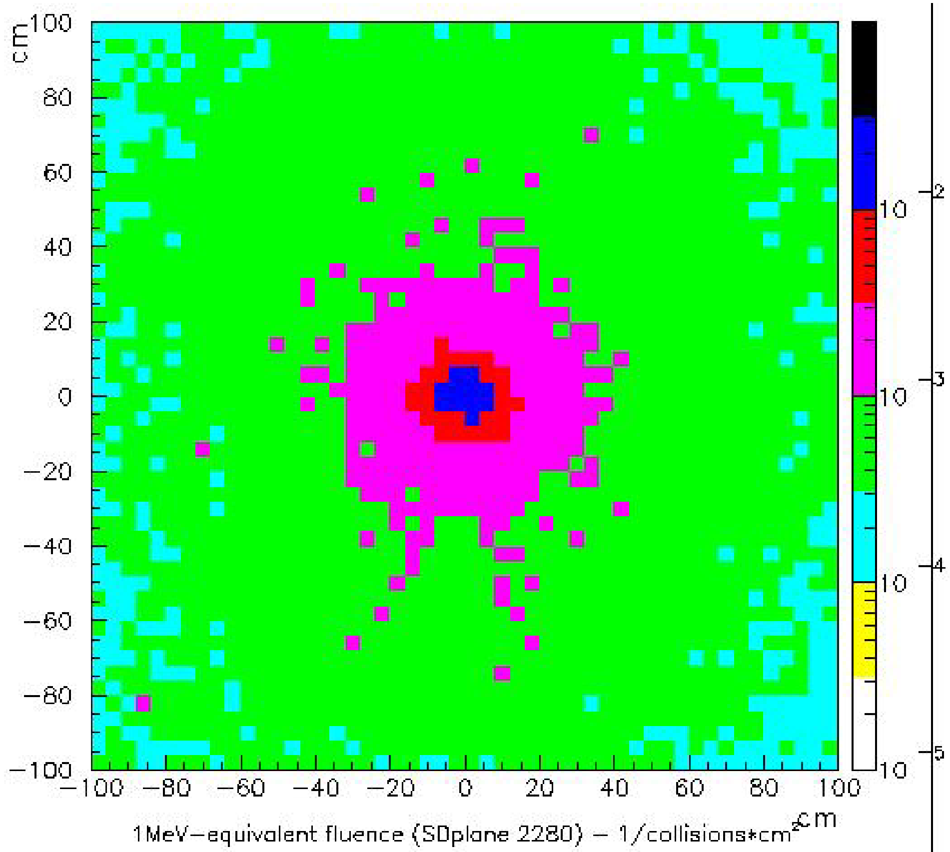
☞ 1 MeV-neutrons eq. fluence calculations is performed assuming that the scoring planes are made by silicon

Plane at 2280 mm

1 MeV-neutrons equivalent fluence for silicon



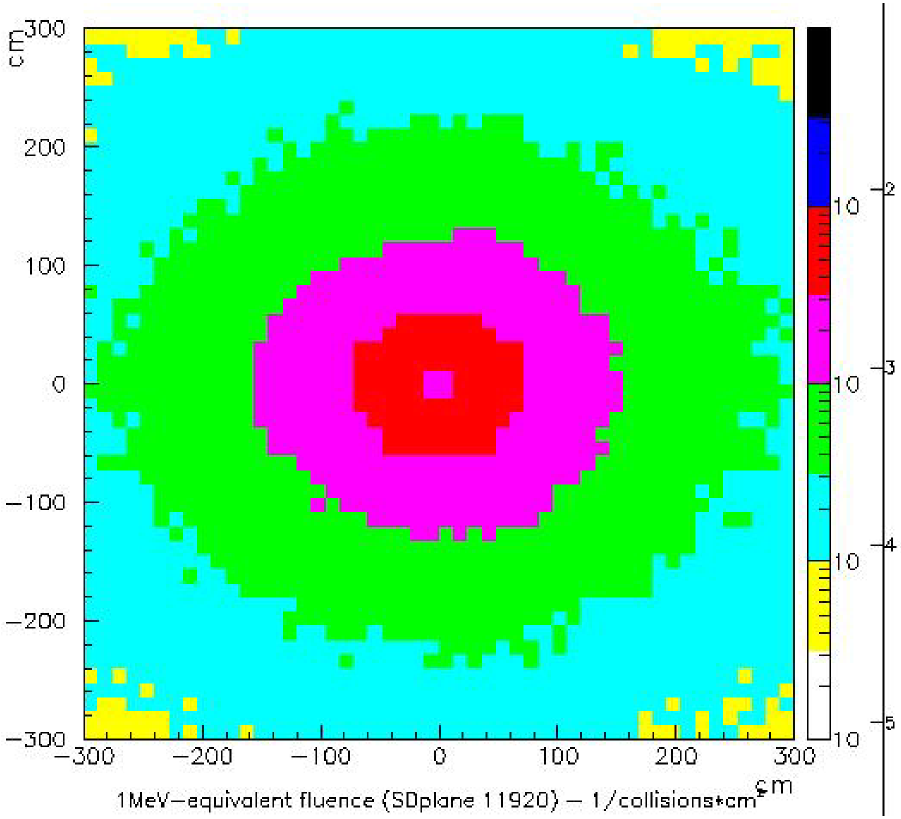
LHEP_HP



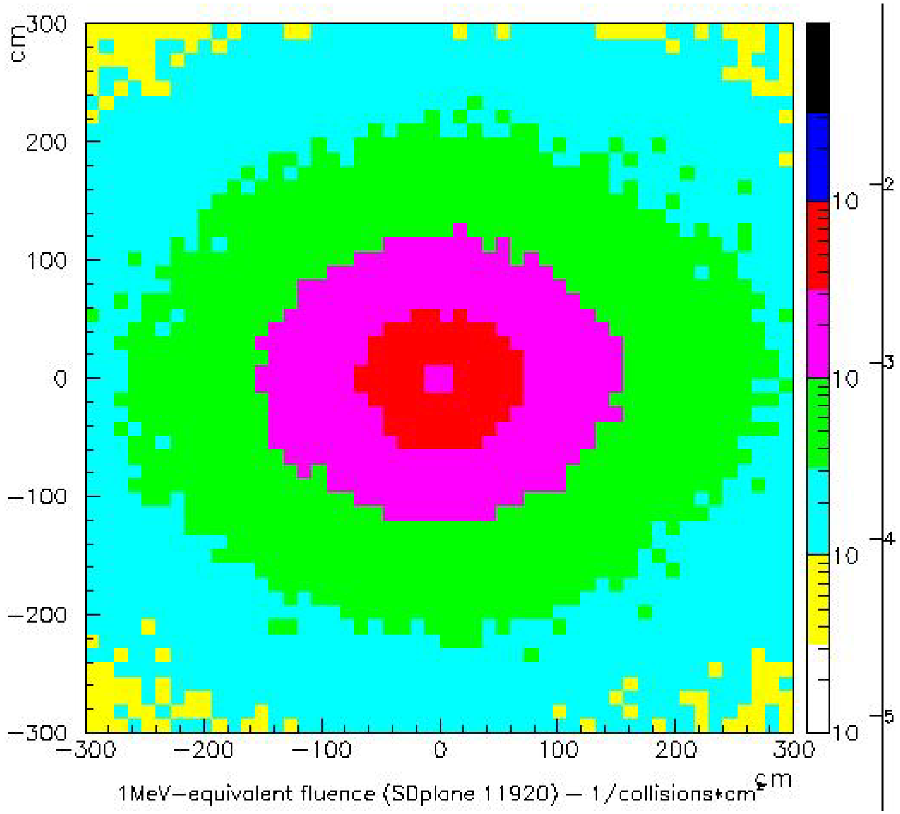
QGSP_HP

Plane at 11920 mm

1 MeV-neutrons equivalent fluence for silicon



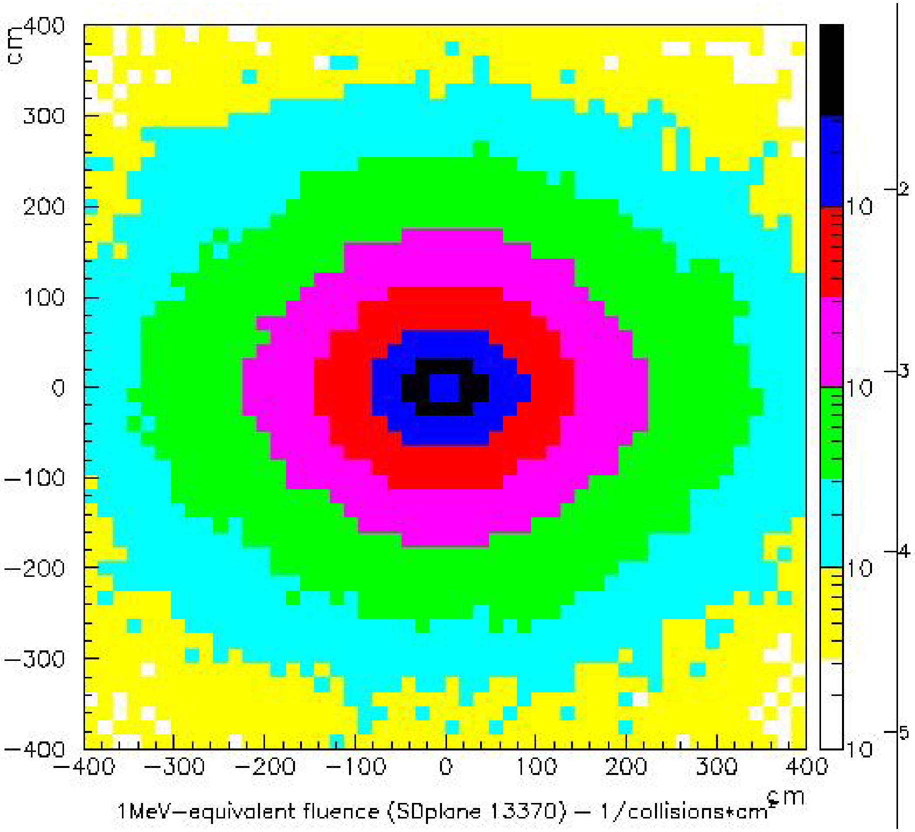
LHEP_HP



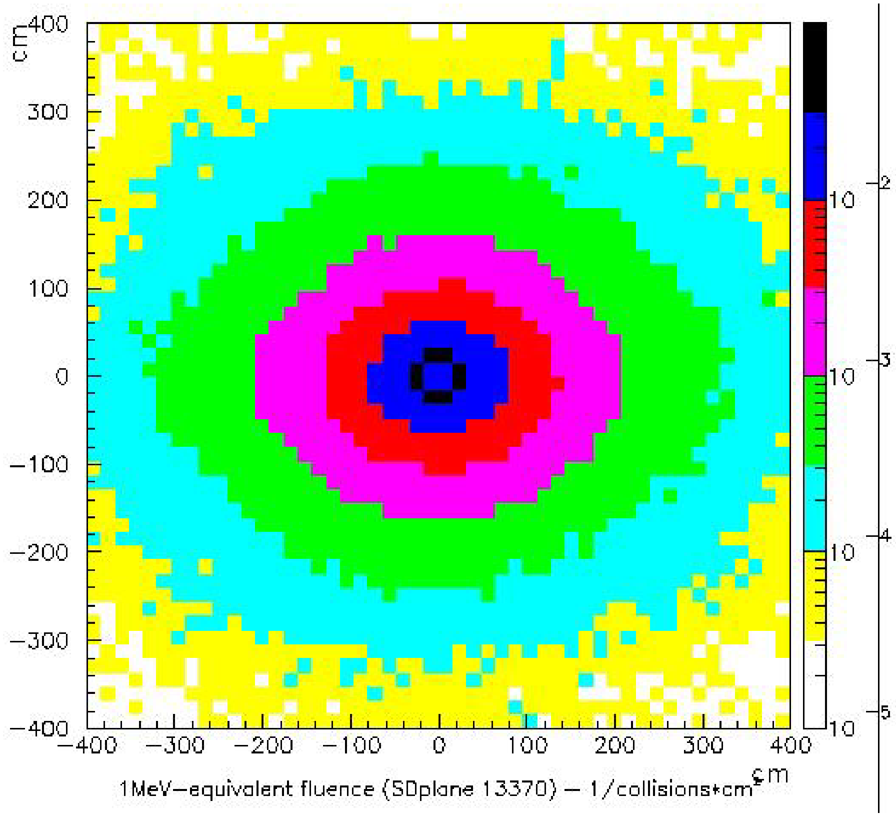
QGSP_HP

Plane at 13370 mm

1 MeV-neutrons equivalent fluence for silicon



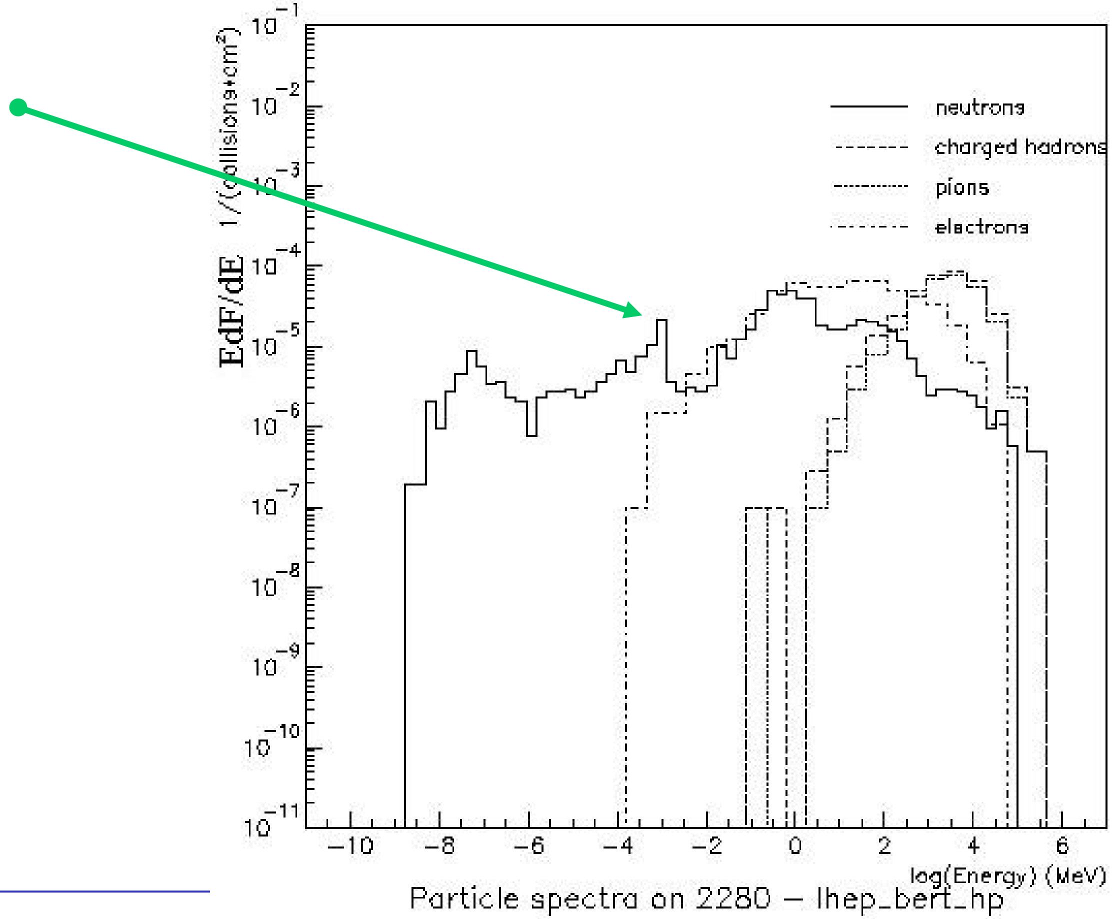
LHEP_HP



QGSP_HP

☞ LHEP_BERT_HP physics list has been used in order to evaluate the 1 keV peak in the neutron energy spectrum

☞ The 1 keV neutrons accumulation in the 2280 mm plane is still present, although less evident



Conclusions

☞ Reasonable agreement between LHEP and QGSP. By design, these physics lists are not suitable to such studies.

☞ The use of the HP extension provides a proper treatment of the low energy neutrons.

☞ Quantitative evaluation of the results obtained with LHEP_HP and QGSP_HP show a reasonable agreement, within the statistical accuracy. Only some doubts for low energy electrons.

☞ Obtained the *high energy hadrons (>20 MeV) fluence* for the evaluation of the acute effects.

☞ Obtained the *1MeV-neutrons equivalent fluence for Si* for the estimation of the displacement damage of devices.

Future activities

☞ Presence of 1 keV neutrons accumulation due to the evaporation code.

☞ *Application of QGSP_BERT_HP for a better treatment of the primary particles generating the 1 keV neutrons peak at 2280 mm from the LHCb vertex*

☞ *These results will be compared to the previous FLUKA results using the same scoring areas*

☞ Effect of the LHCb shielding and cavern to the present results.