FCC Detector Radiation Studies

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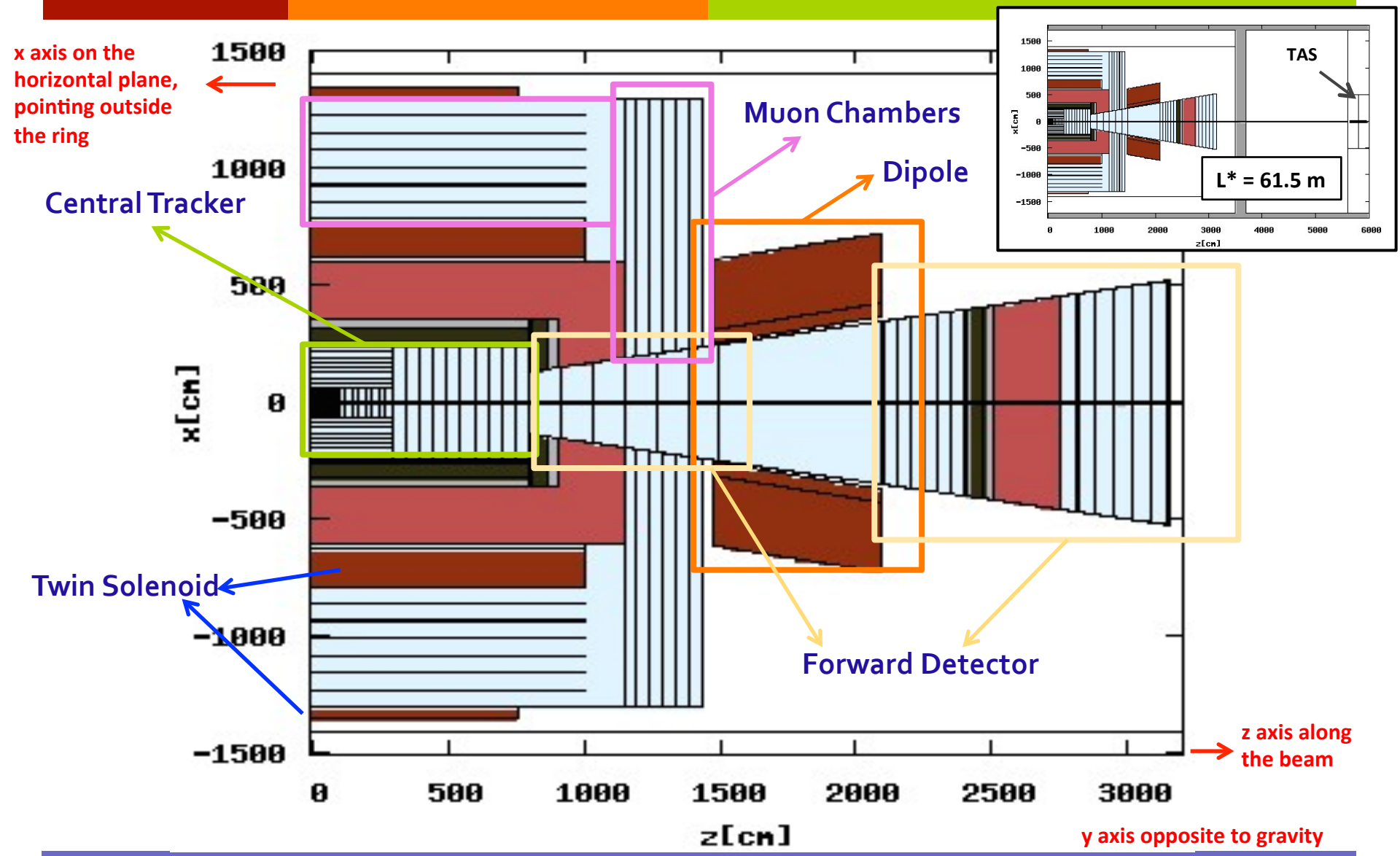
Outline

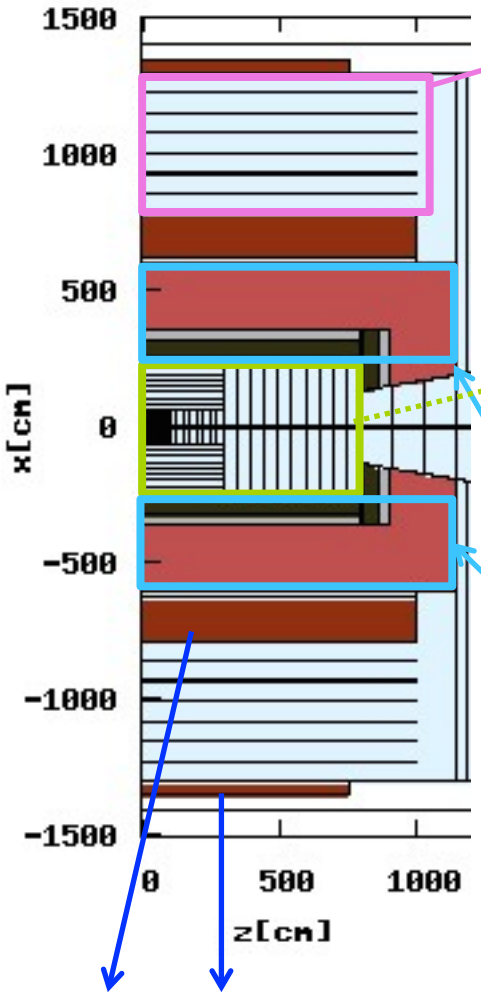
- Detector modeling by FLUKA:
  - geometry
  - magnetic field
- Particle Fluence Rate
  - all charged particles
  - charged hadrons
  - neutrons
  - photons
  - muons
  - high energy (>20 MeV) hadrons
- Long Term Damage
  - 1 MeV Neutron equivalent fluence
  - dose
- Shielding
  - design
  - effect on the fluence rate values in the muon chambers
  - effect of iron in the forward muon detector
- Conclusions and Outlooks

Detector Model

Detector Geometry: layout

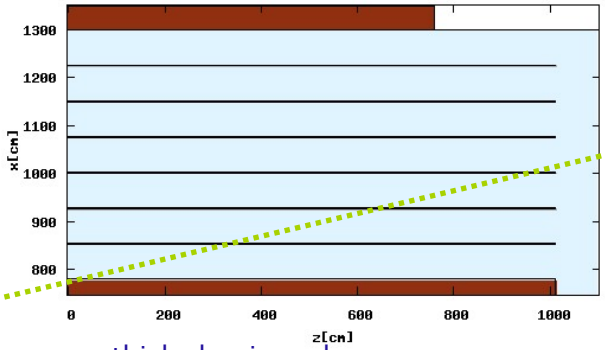


Detector Geometry: Central Region



Twin Solenoid

Muon Detector



1.5 cm thick aluminum layers:

- 6 cylinders in the barrel
- 6 disks in the end-cap

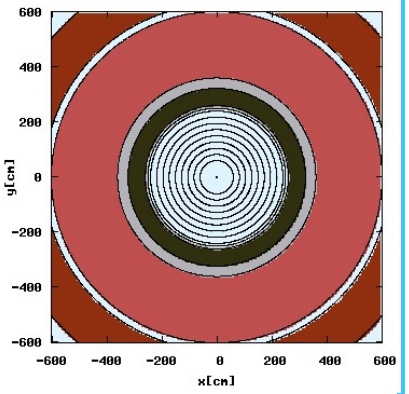
EM calorimeter

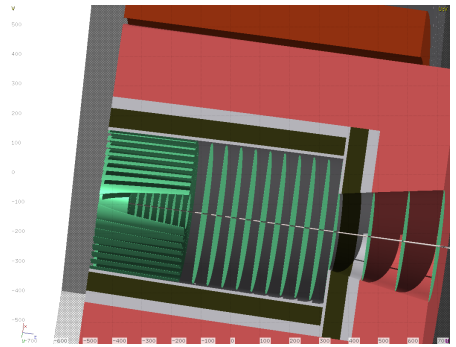
- 10 cm aluminum
- 62 cm (LArg 64.8%, Pb 21%, Cu 7.2%, Polystyrene 6.3%)
- 38 cm aluminum

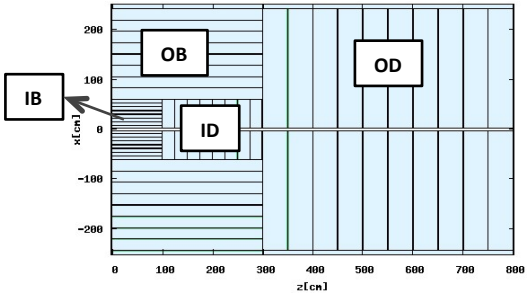
HAD calorimeter

Homogenous material of 240 cm

- Polystyrene 20%,
- Fe 80%,







Tracker layers (0.43 cm each):

- Inner Barrel (IB): 8+1 cylinders
- Inner Disk (ID): 8 disks
- Outer Barrel (OB): 8 cylinders
- Outer Disk (OD): 10 cylinders

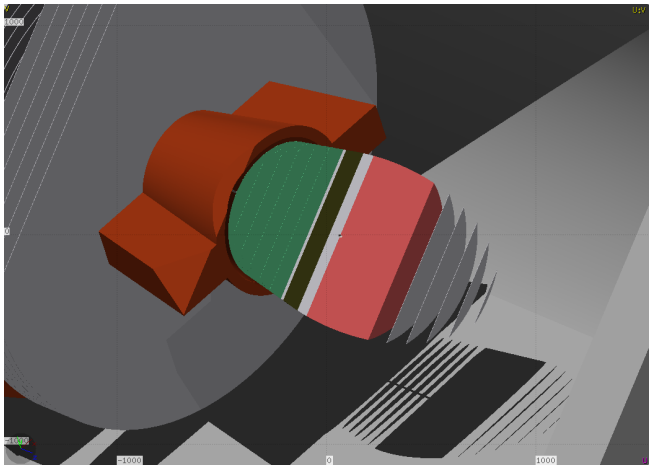
Composition:

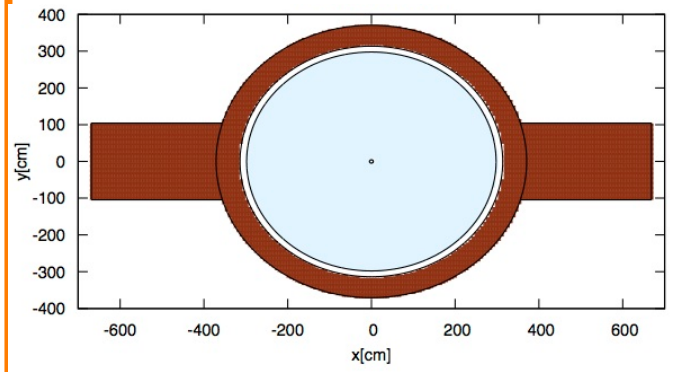
- Si 20%,
- C 42%,
- Cu 2%,
- Al 6%,
- Plastic 30%

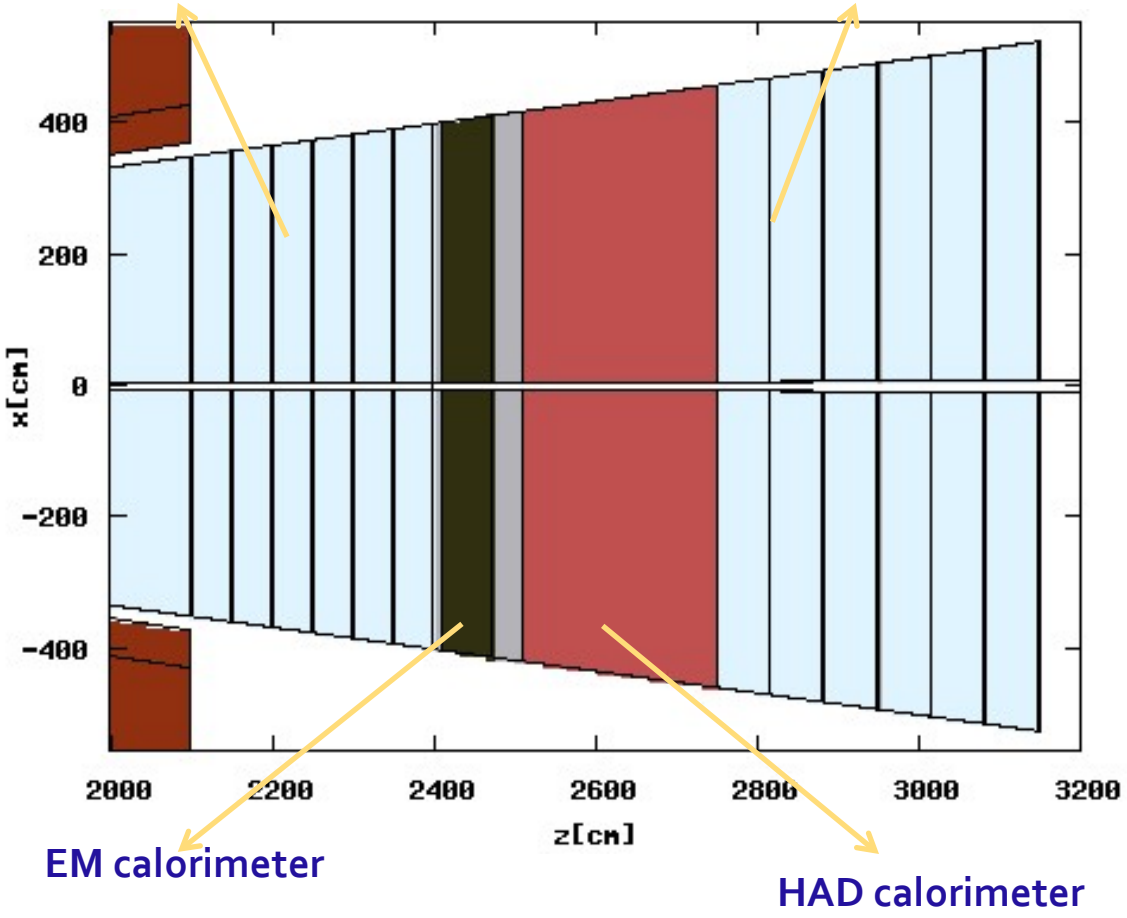
Detector Geometry: Dipole & Forward Region

TAS

Dipole

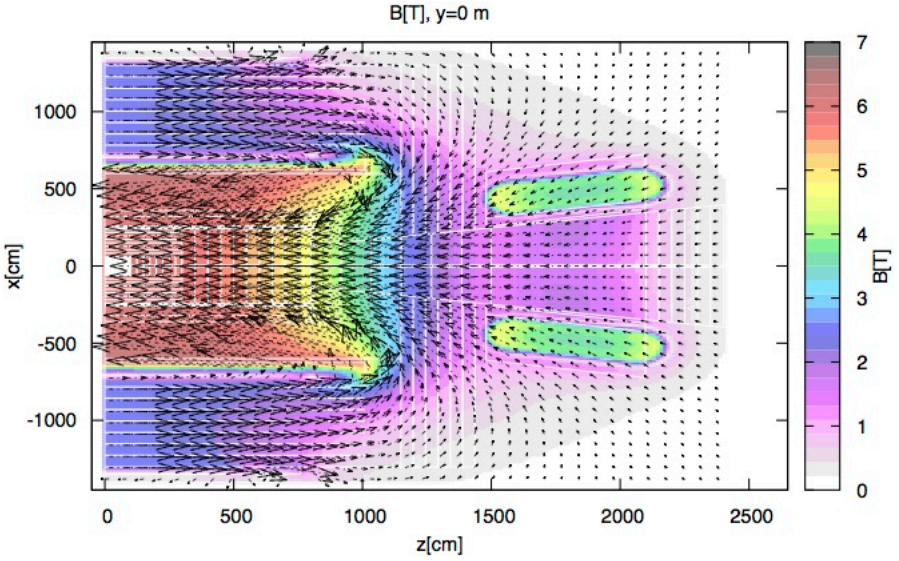


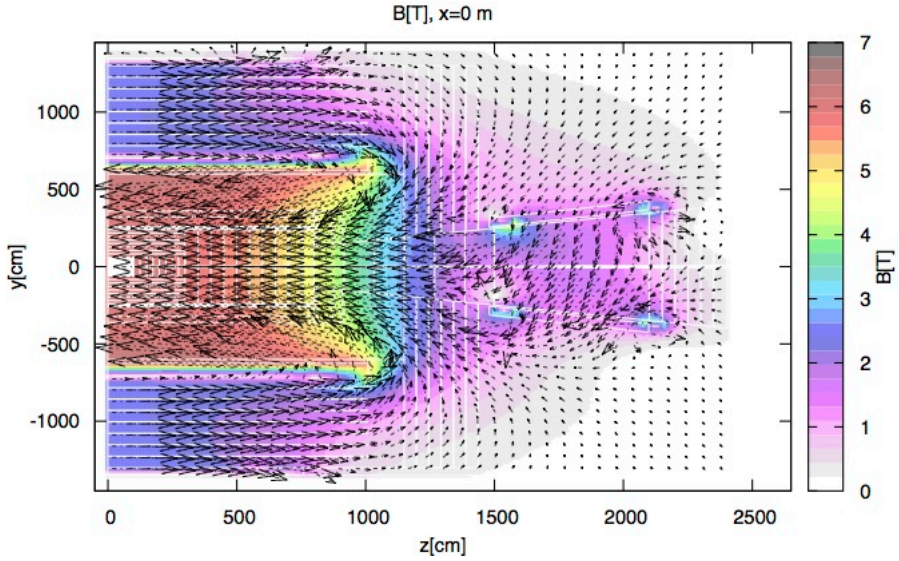




Werner Riegler talk FCC MDI 29/05/2015:
https://indico.cern.ch/event/396183/contribution/4/attachments/794018/1088412/fcc_mdi_may_29_2015_riegler.pdf

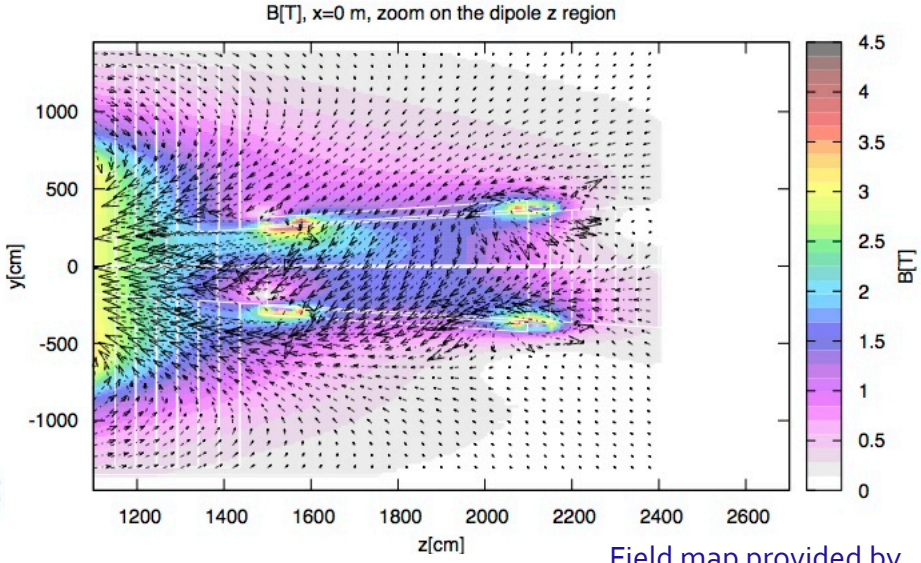
Detector: Magnetic Field





The magnetic field has been modeled as well as the geometry:

- solenoid field directed along z in the central region
- dipole field directed along y in the forward region



Field map provided by Herman Ten Kate and Matthias Mentink

Details about the Simulation

- Only half of the detector has been simulated at this stage, but the contribution coming from the other half of the detector is taken into account
  - re-interaction products that leave the geometry on the left are reflected back to simulate contribution coming from the other part of the detector
- Normalization:
  - fluence rates [Hz cm^{-2}] for an instantaneous luminosity of 30 10^{34} $cm^{-2}s^{-1}$
  - 1MeV neutron equivalent fluence [cm^{-2}] for an integrated luminosity of 30 ab^{-1}
  - dose [MGy] for an integrated luminosity of 30 ab^{-1}
  - non-elastic cross section of 108 mbarn
- The contribution coming from the TAS has not been included in this simulation consistently with an L* value of 61.5 m
  - for shorter L* configurations TAS effect has to be considered and suitably mitigated

Monte Carlo Generator

- FLUKA simulations using DPMJET-III generator →
  - c-hadrons included, but b-hadrons are not included
  - W/Z bosons production not included

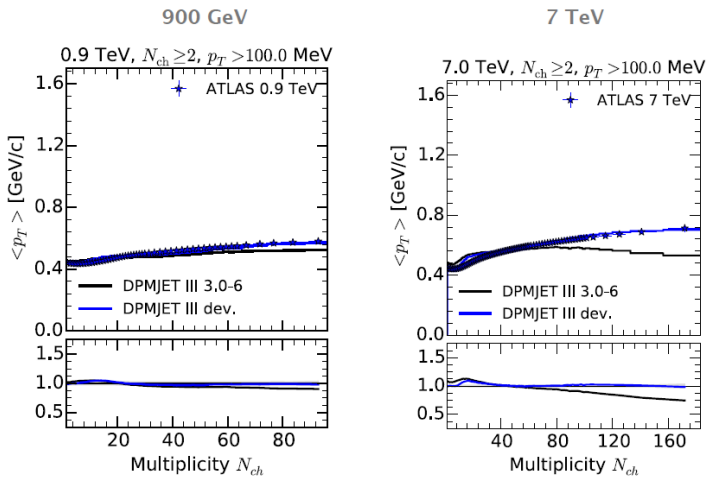
S. Roesler, R. Engel and J. Ranft, The Monte Carlo event generator DPMJET-III, Proc. Monte Carlo 2000

Conference, Lisbon, October 23-26 2000, A. Kling, F. Barao, M. Nakagawa, L. Tavora, P. Vaz eds., Springer-Verlag Berlin, (2001) pp. 1033-1038.

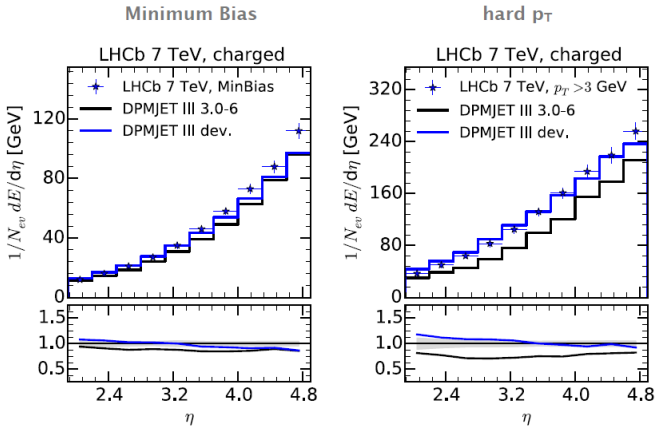
- Monte Carlo generator has been further developed →
  - all Regge parameters re-fitted to match cross-sections from low energy up to LHC as good as possible
  - improved hard scattering model

PhD thesis of A. Fedynitch
supervisors R. Engel (KIT) and A. Ferrari

ATLAS average p_T



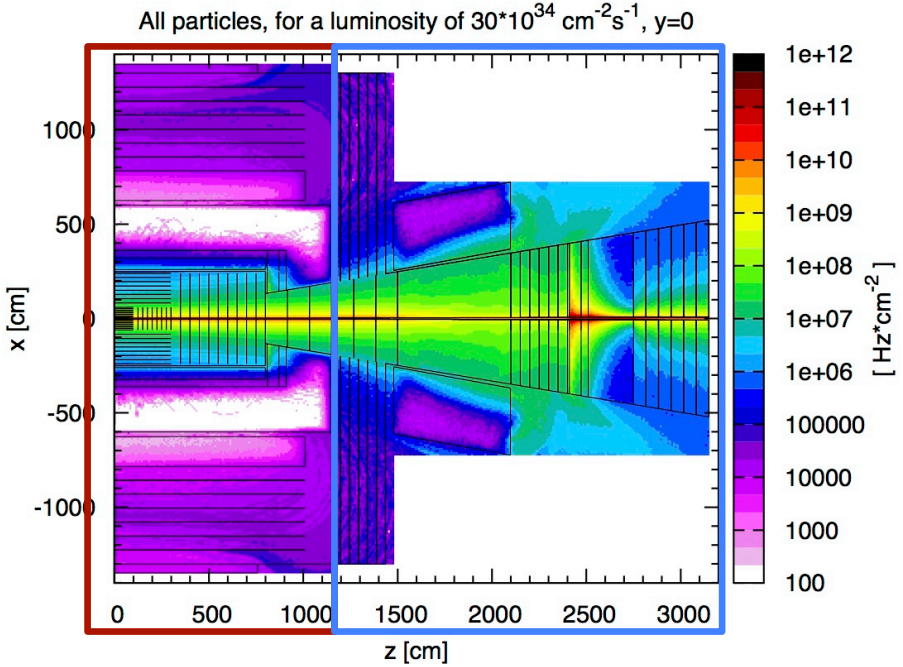
LHCb forward energy flow

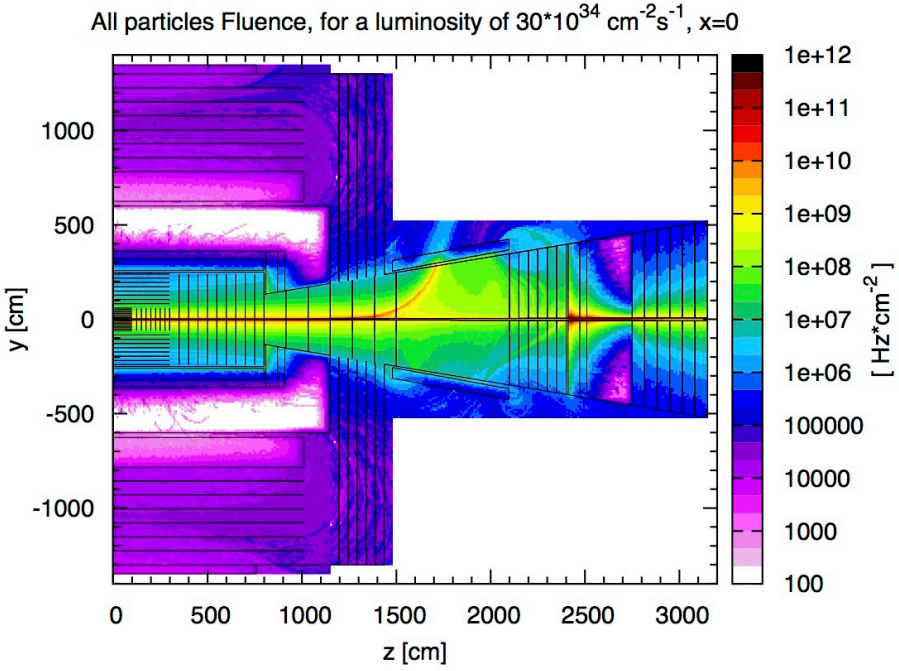


- Work ongoing:
  - implementation of new parton distributions functions

Particle Fluence Rate

All Charged Particles Fluence Rate



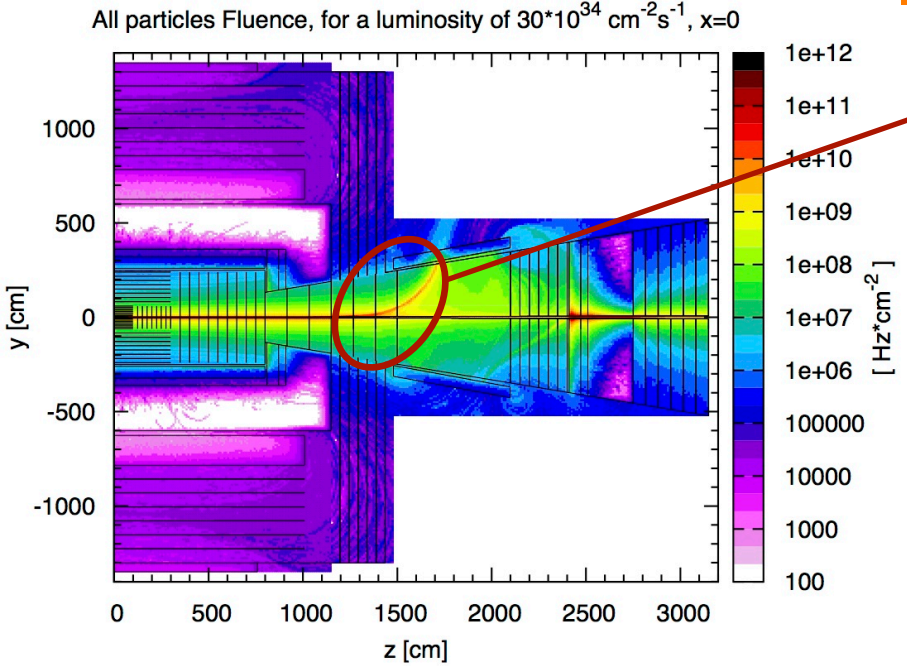


Central region (cylindrical symmetry):
the fluence rate value is averaged in Φ:
x= 0: average on a bin of 20 degrees bin around ±π/2
y= 0: average on a bin of 40 degrees around 0 and π

Forward region (x-y-z scoring):
average on a bin of 1 cm up to 0.6 m and on a 10 cm for larger values

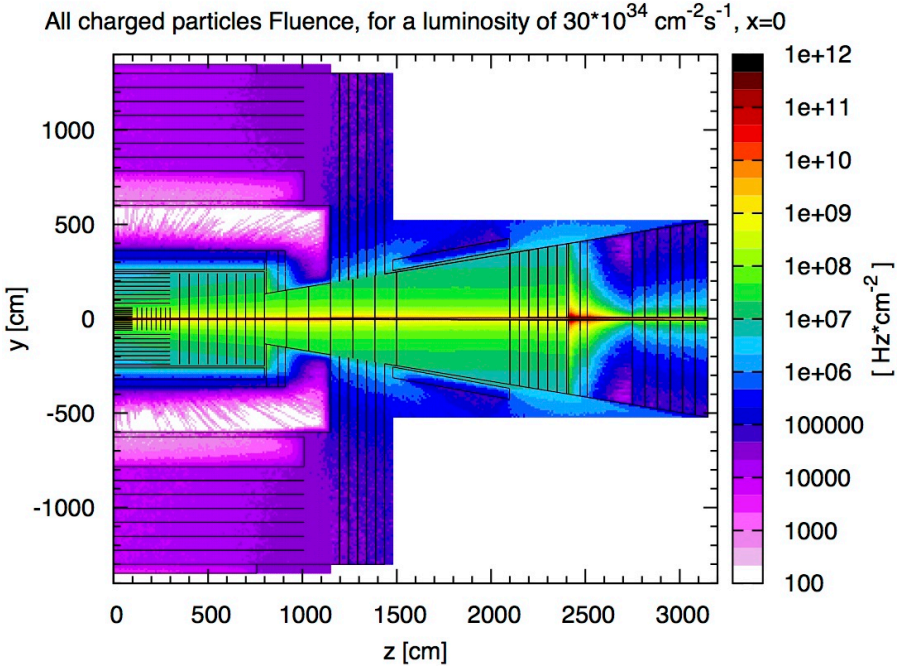
	Fluence Rate [Hzcm^{-2}]
First layer of the IB (R =2.5 cm)	~ 2 10^{10}
max in forward detector	10^{11}
max in barrel muon chambers	2 10^{5}
max in end-cap muon chambers	~10^{6}

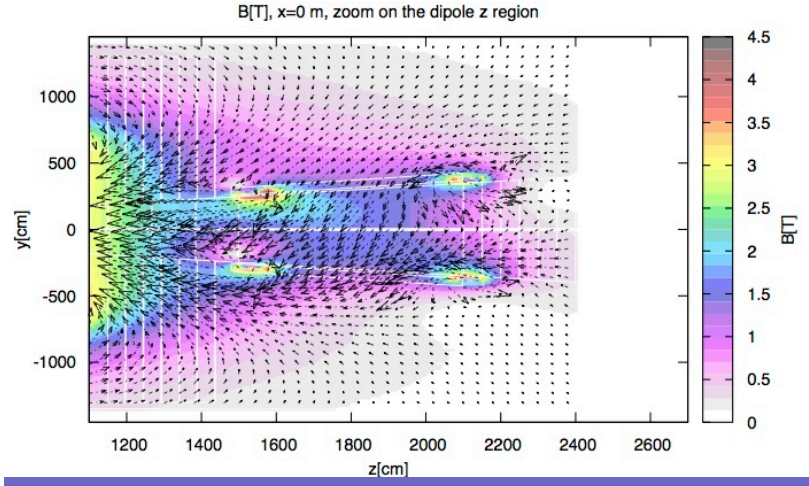
Effect of the dipole Field



Effect of the magnetic field: fluence due to particles moving along field lines

Without magnetic field:

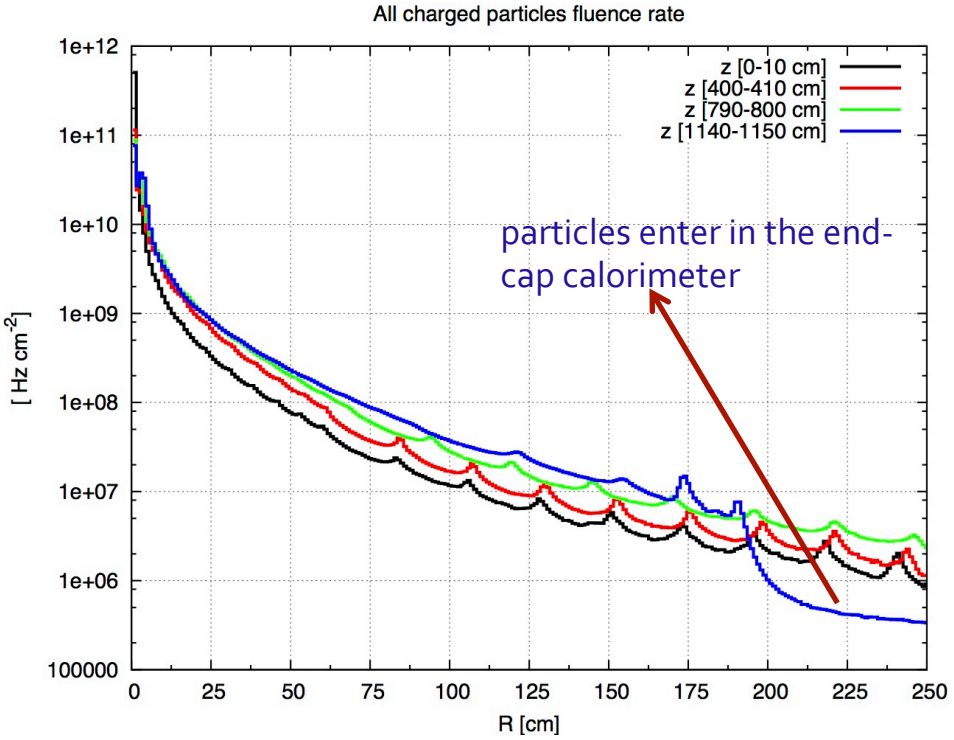


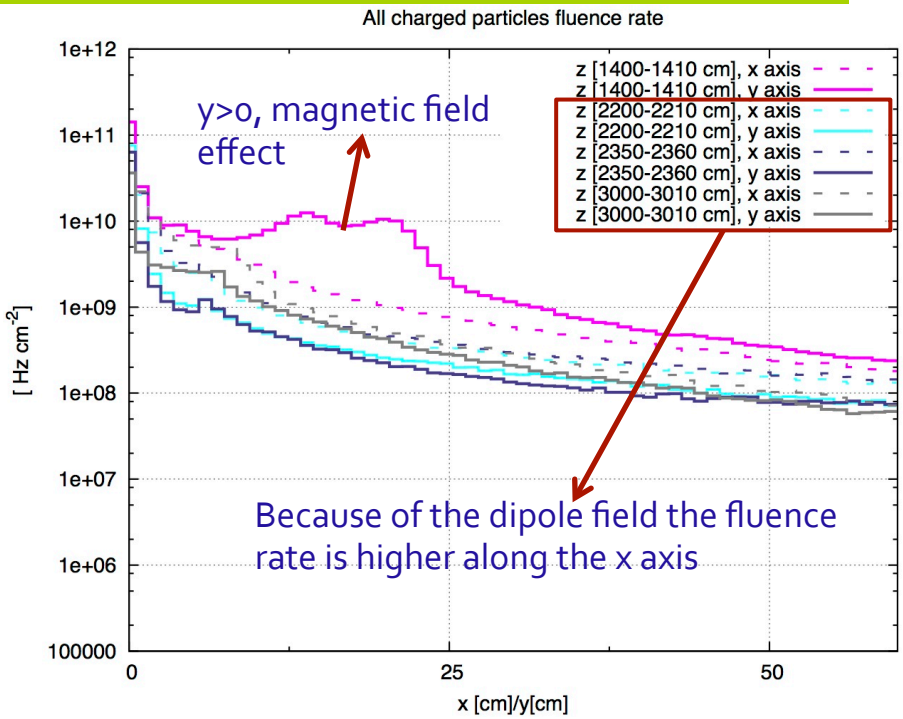


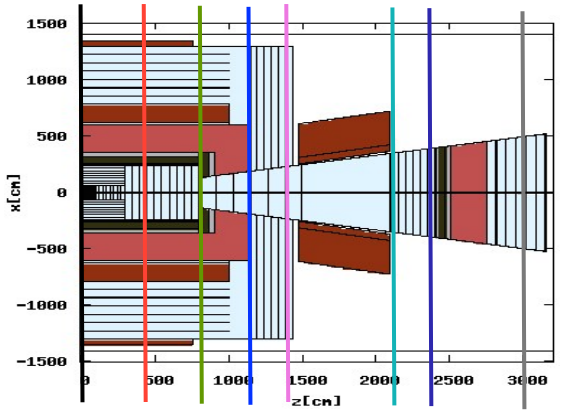
All Charged Particles Fluence Rate vs R I

In the tracker

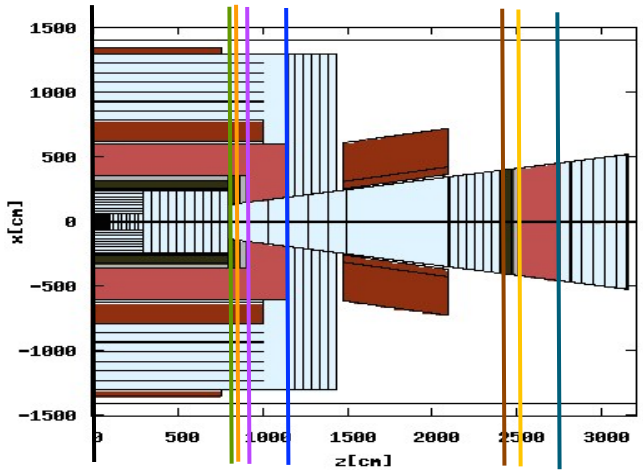
R dependence at different z positions: there is not a dramatic dependence of the fluence rate as a function of z

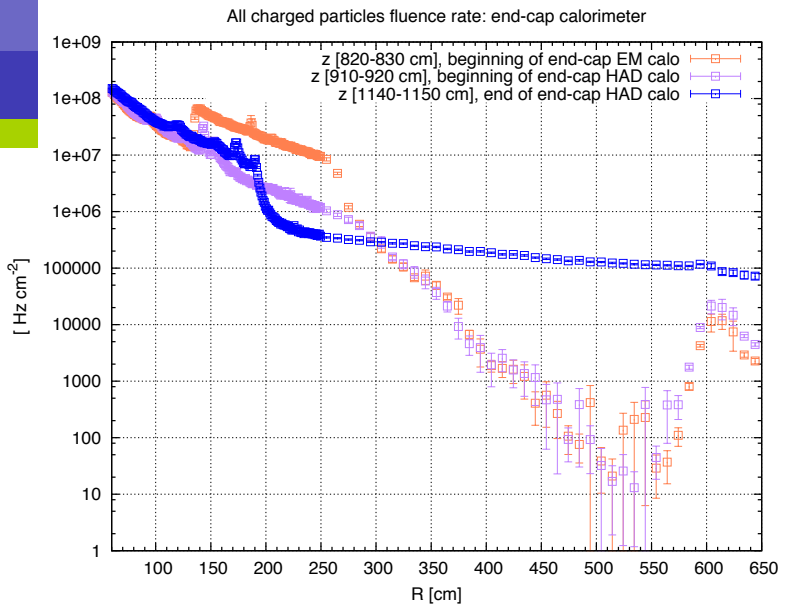


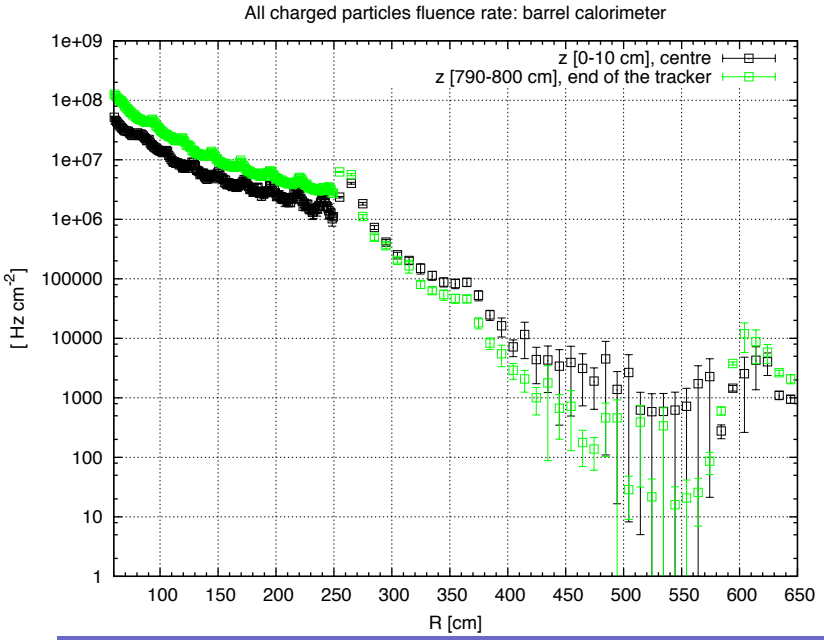


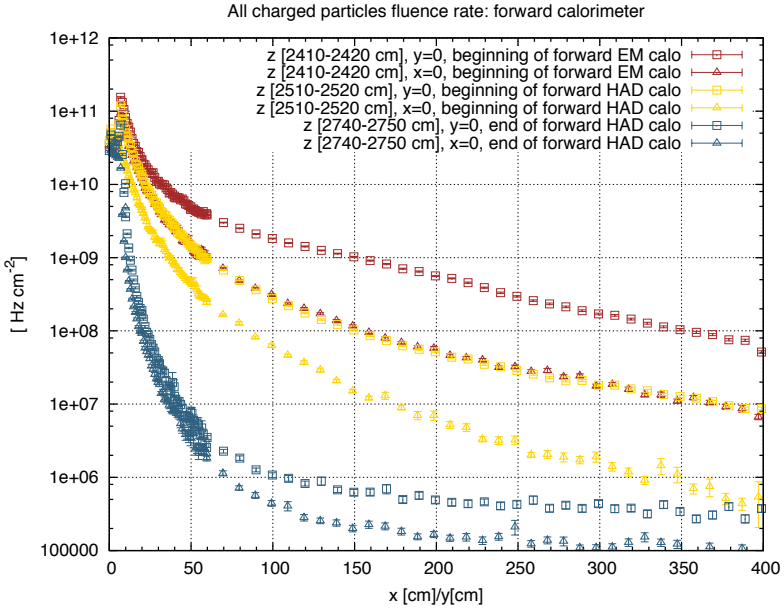


Values in the Calorimeters

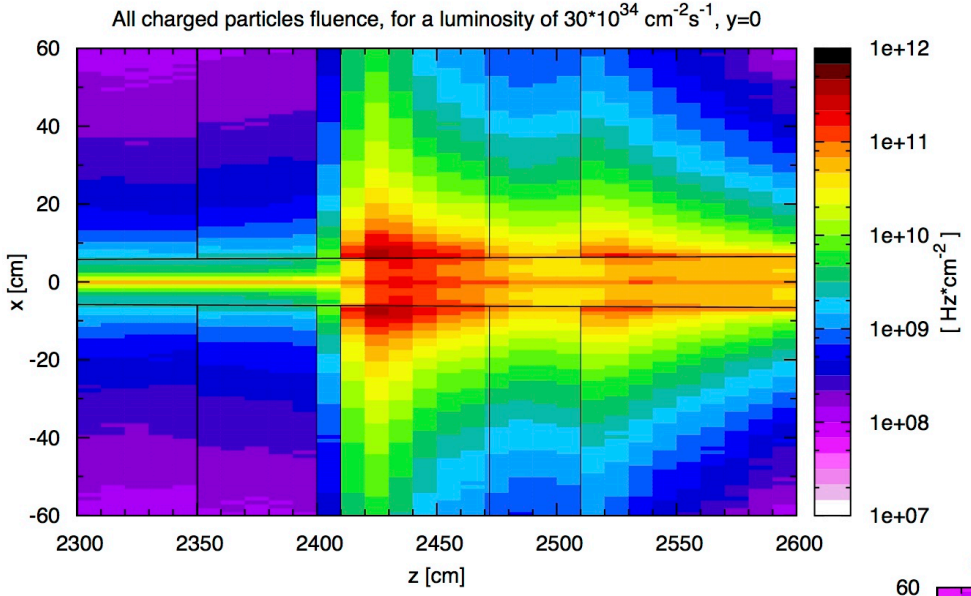


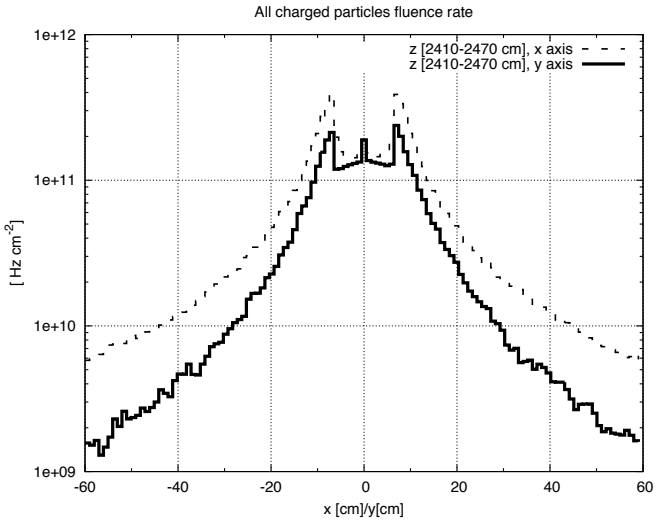


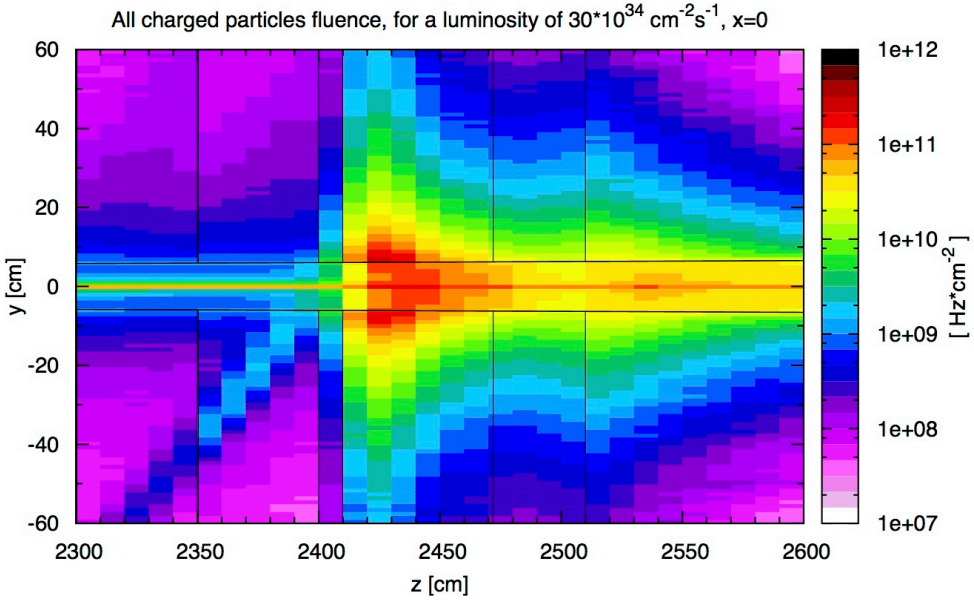




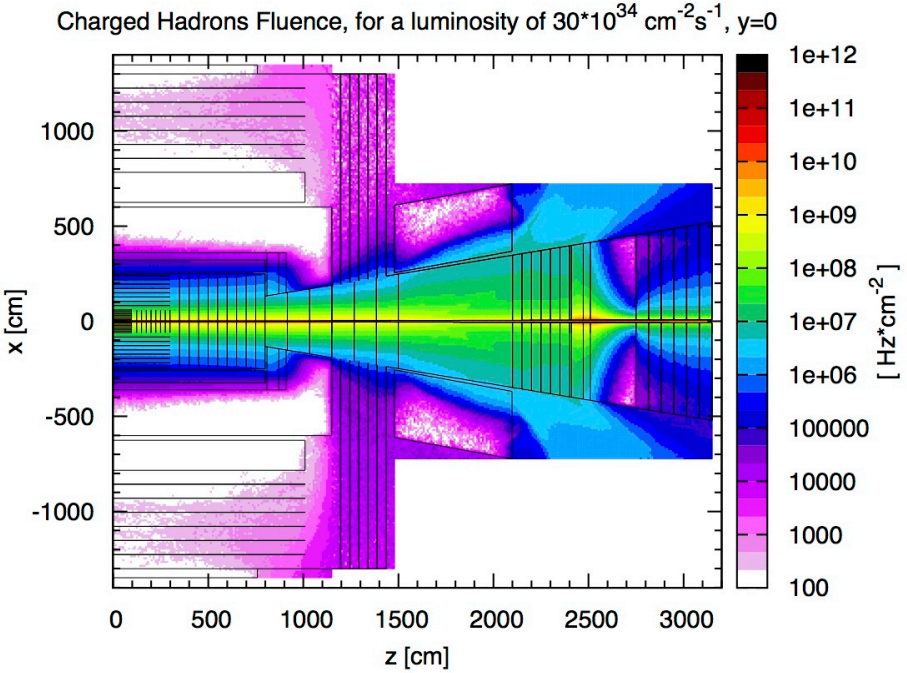
All Charged Particles Fluence Rate: Forward Calo



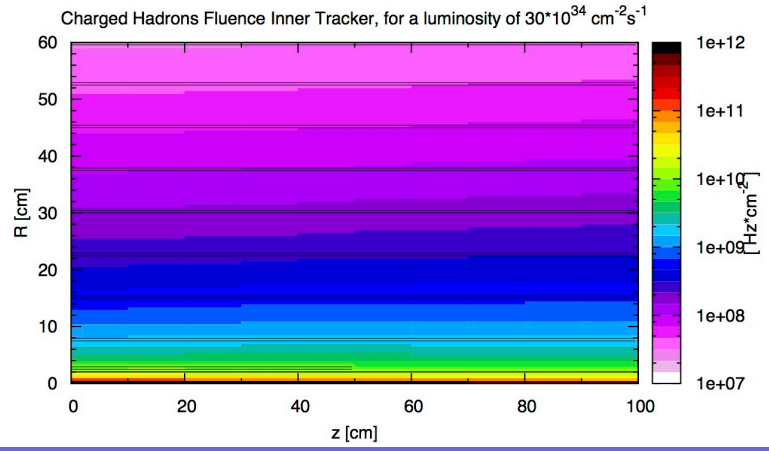


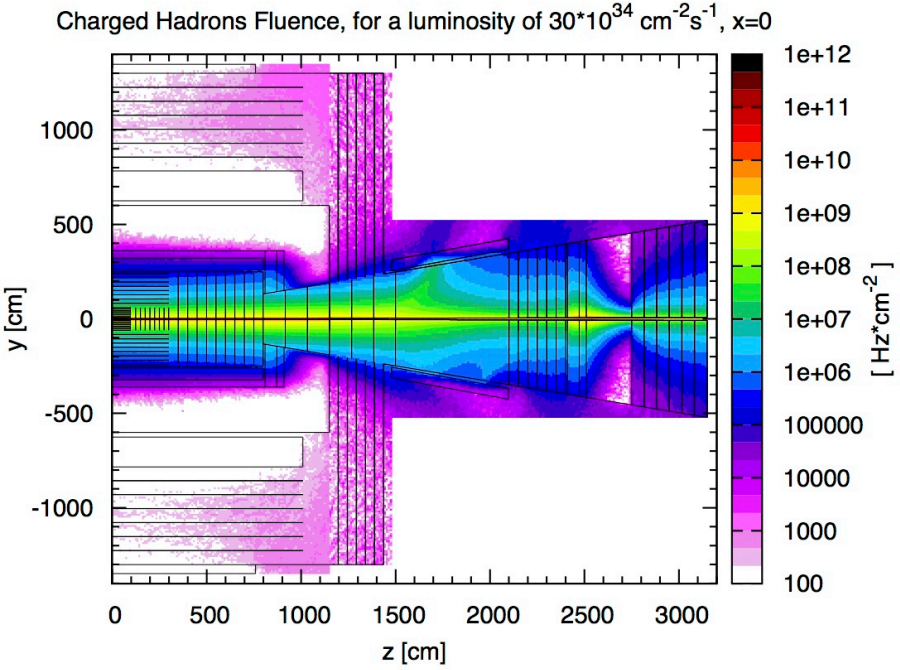


Charged Hadrons Fluence Rate



	Fluence Rate [Hzcm^{-2}]
First layer of the IB (R =2.5 cm)	10^{10}
max in forward detector	10^{10}
max in barrel muon chambers	$2\ 10^{3}$
max in end-cap muon chambers	10^{5}



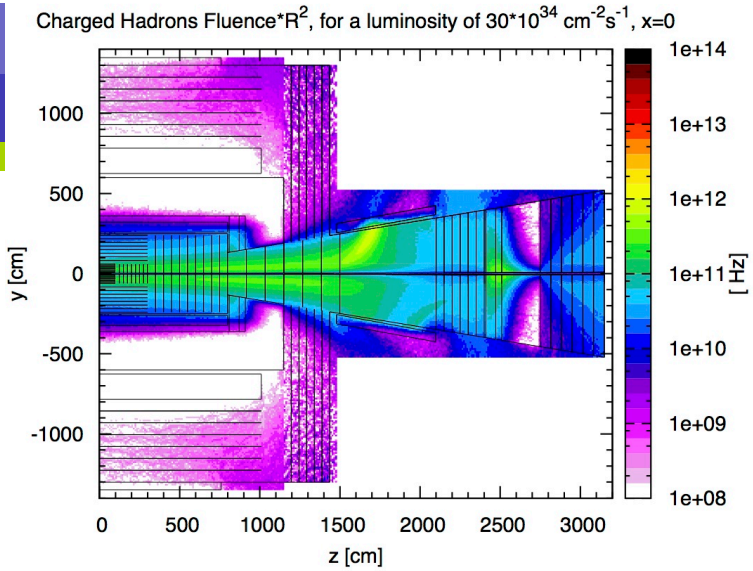


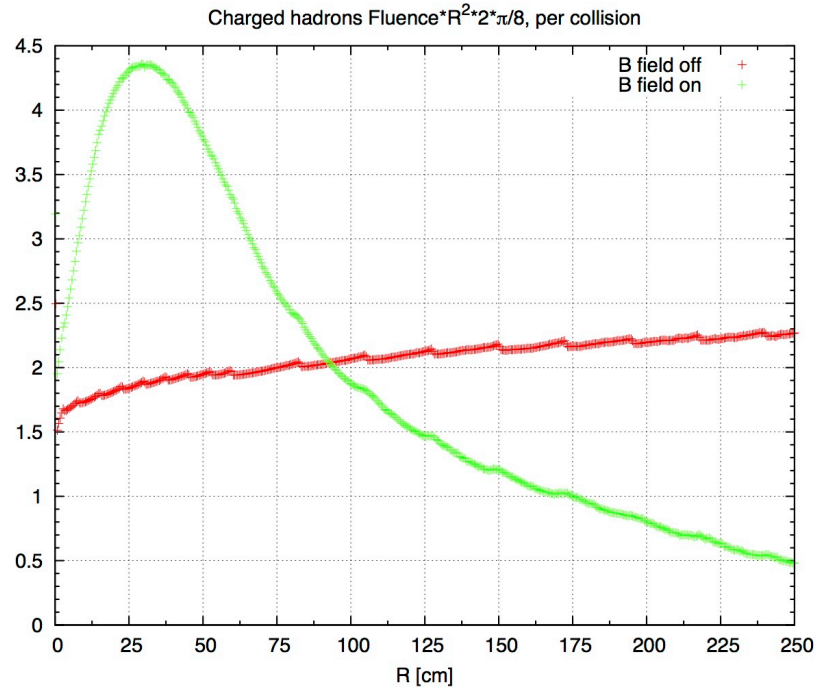
Charged Hadrons Fluence: R^2 scaling

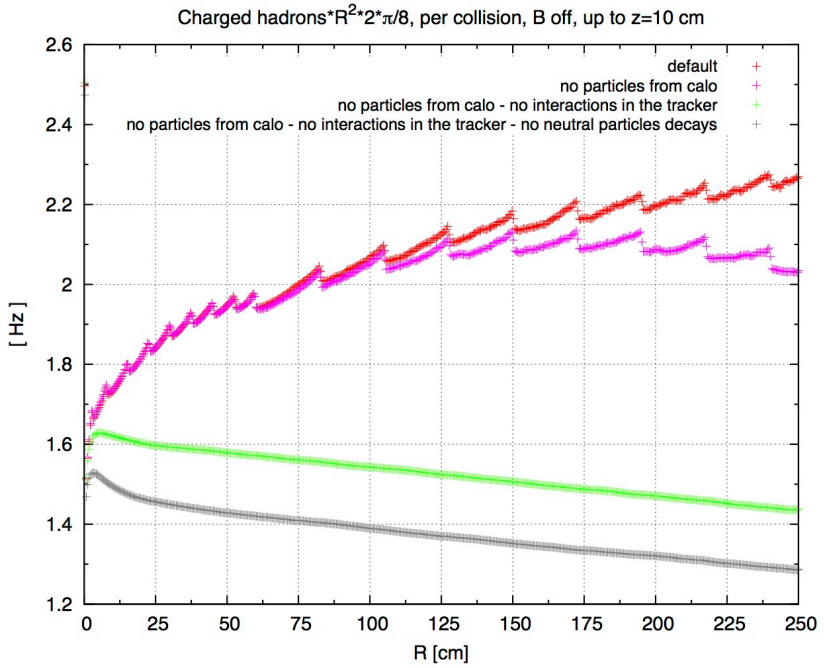
The fluence of primary particles is given by $No/(2\pi R^2)$, where No ~8

The product fluence*R^2 increases as a function of R up to about 30 cm, then it decreases because of the solenoid magnetic field.

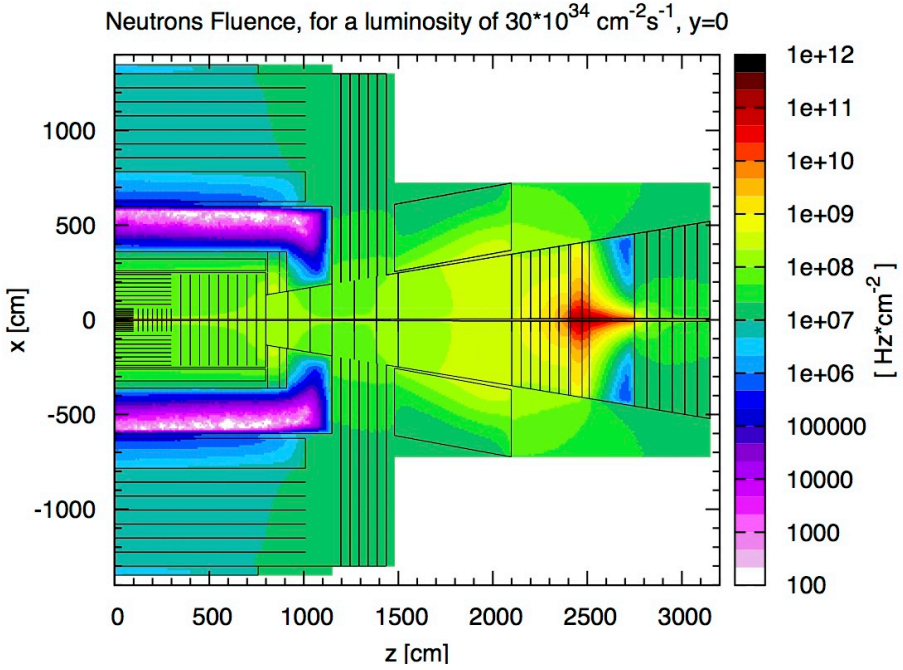
If the solenoid magnetic field is switched off, the fluence*R^2 mildly increases along the tracker, due mainly to the interaction in the tracker



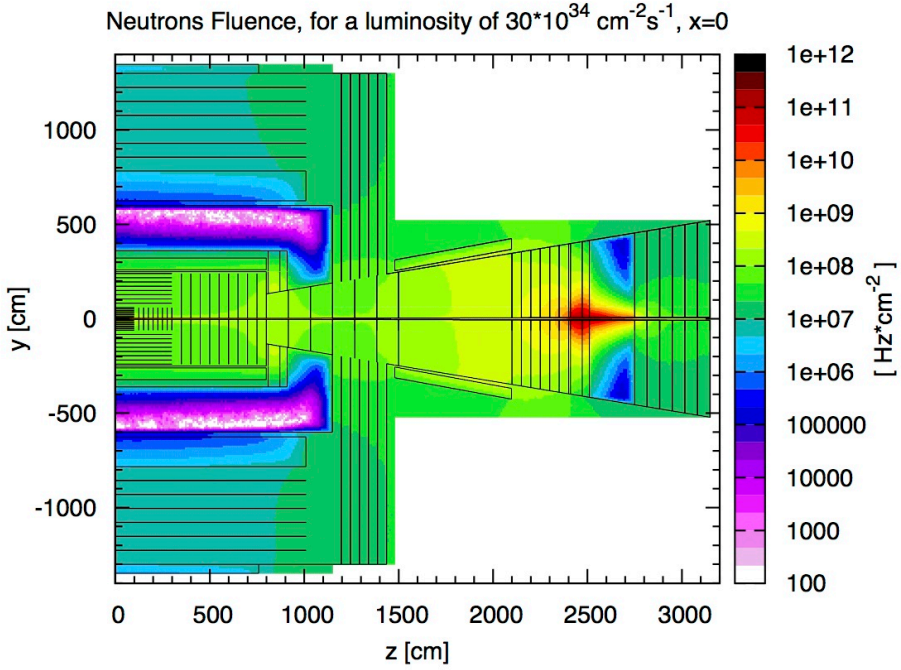




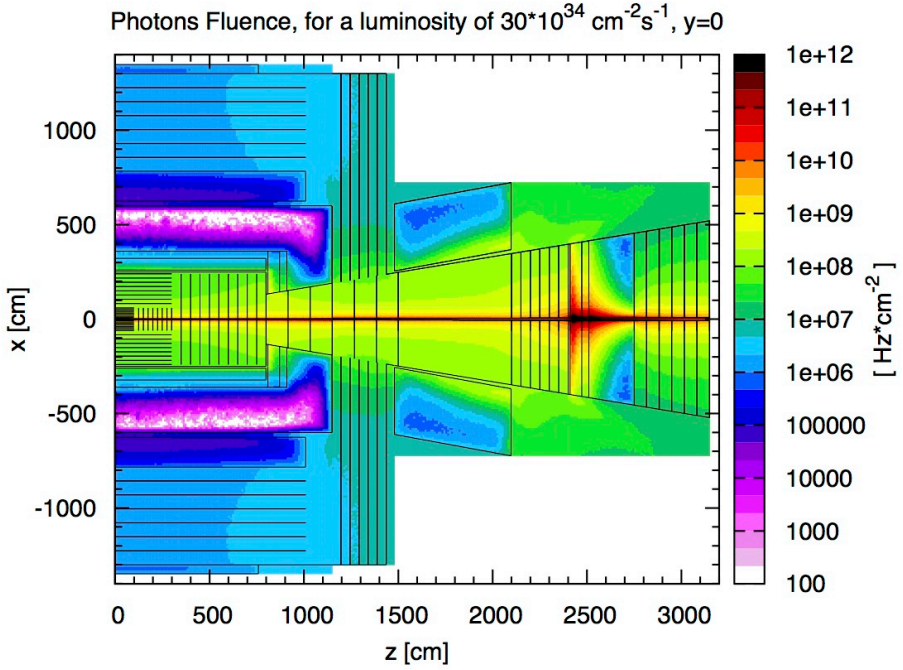
Neutron Fluence Rate



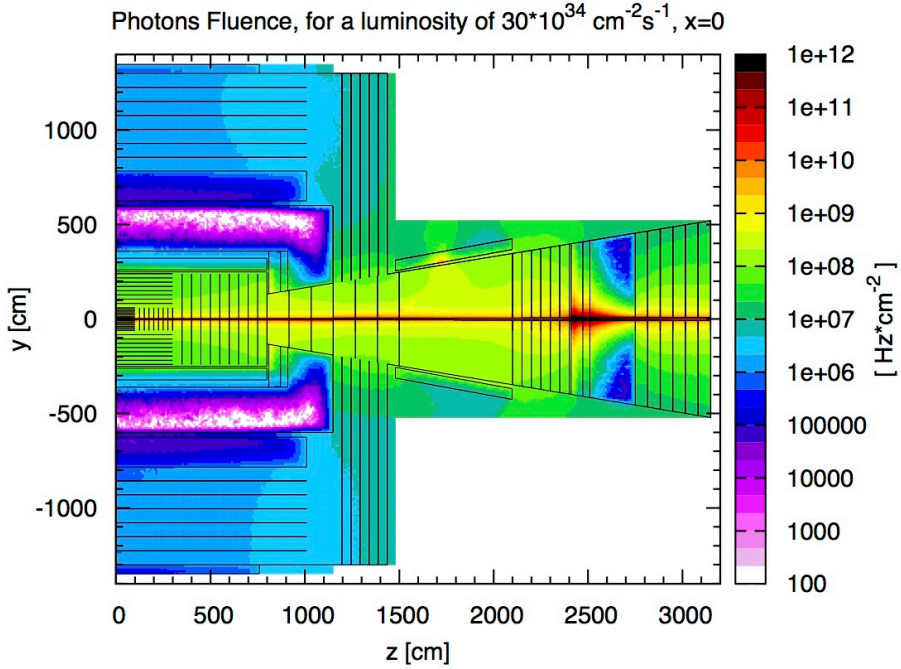
	Fluence Rate [Hzcm^{-2}]
First layer of the IB (R =2.5 cm)	10^9
max in forward detector	10^{11}
max in barrel muon chambers	$>10^7$
max in end-cap muon chambers	10^8



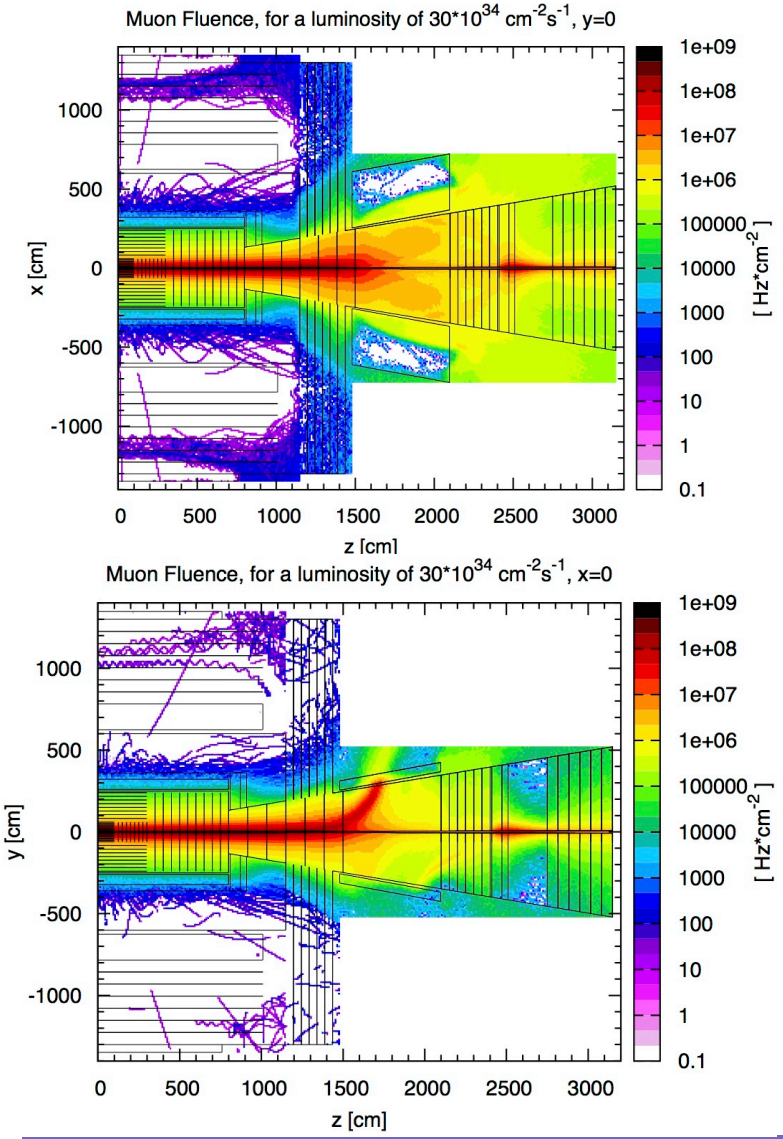
Photon Fluence Rate



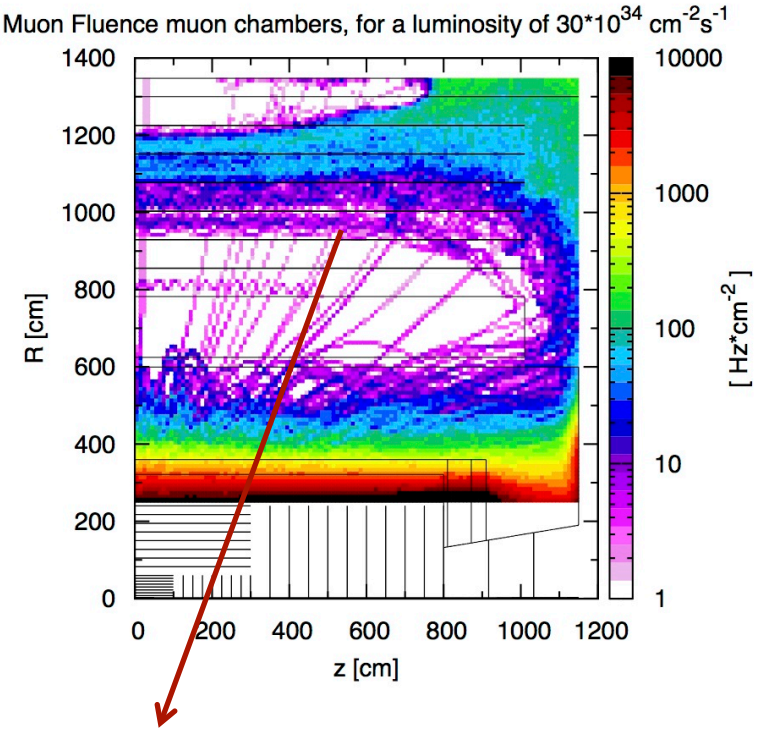
	Fluence Rate [Hzcm^{-2}]
First layer of the IB (R =2.5 cm)	2 10^{10}
max in forward detector	2 10^{12}
max in barrel muon chambers	5 10^{6}
max in end-cap muon chambers	5 10^{7}



Muon Fluence Rate



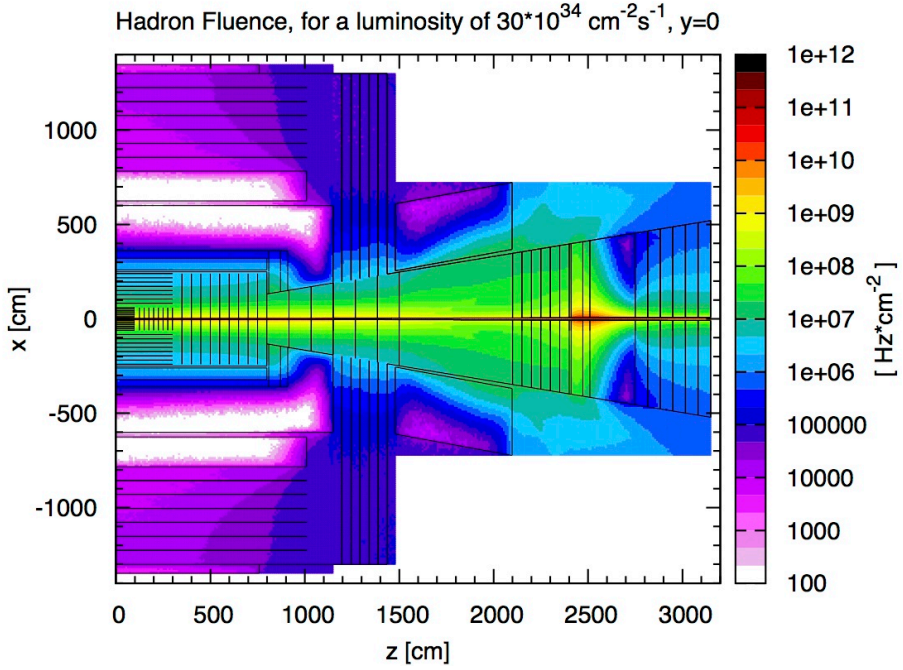
Muon fluence averaged on the whole Φ angle

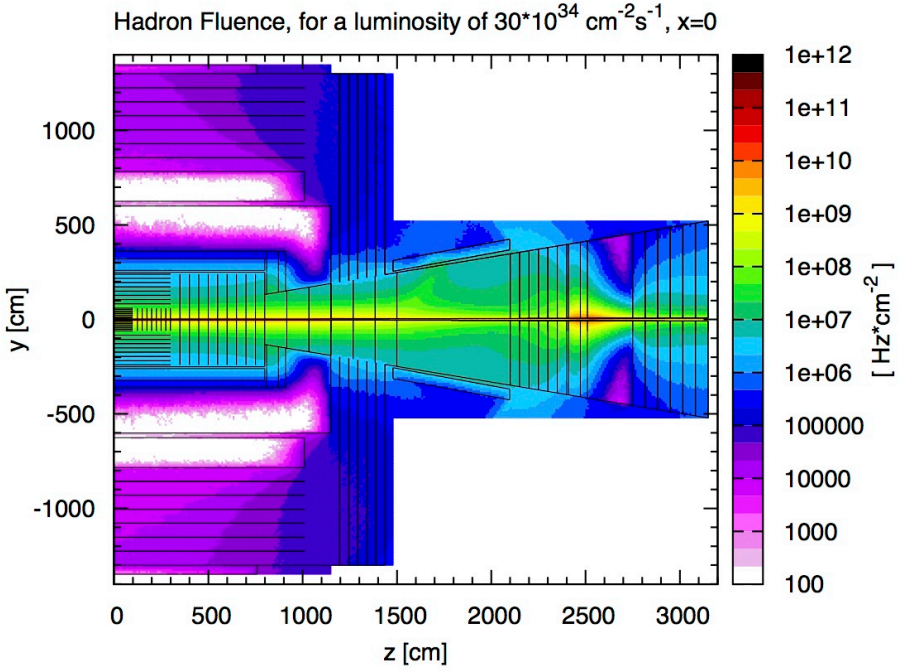


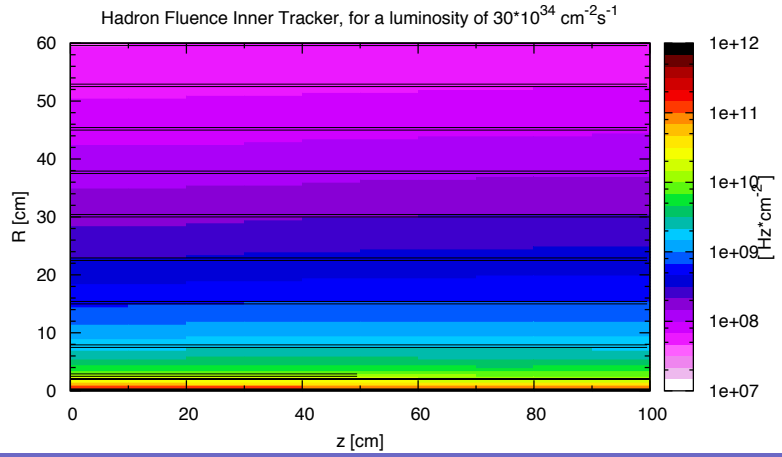
Lack of statistics: need of dedicated simulations using biasing techniques to study the muon fluence

- decay biasing n the tracker
- importance biasing in the calorimeter

High Energy Hadron (> 20 MeV) Fluence Rate



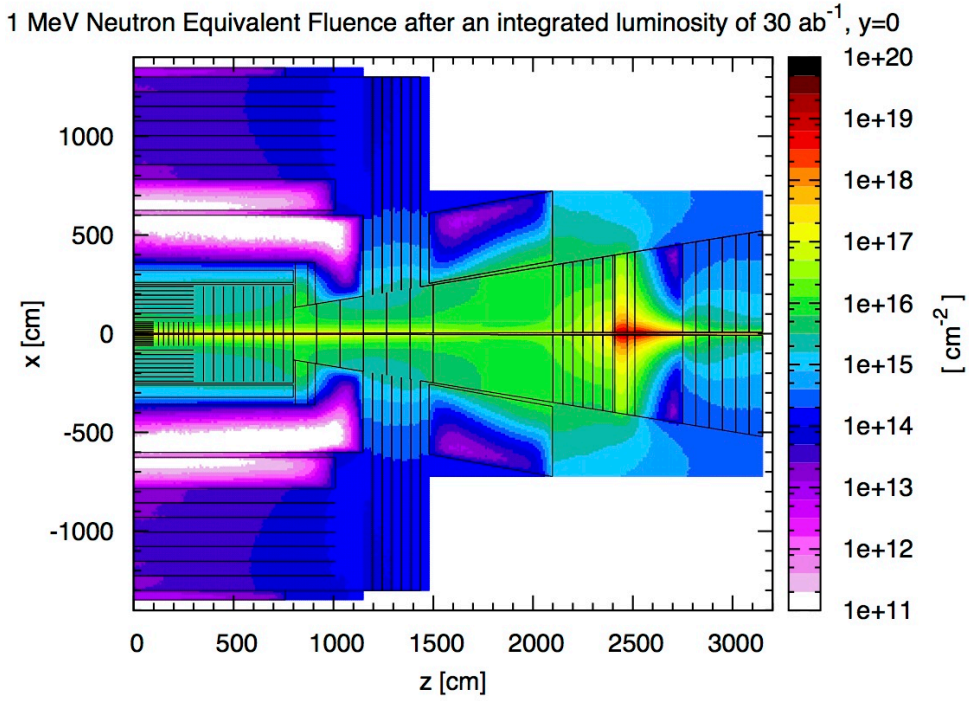


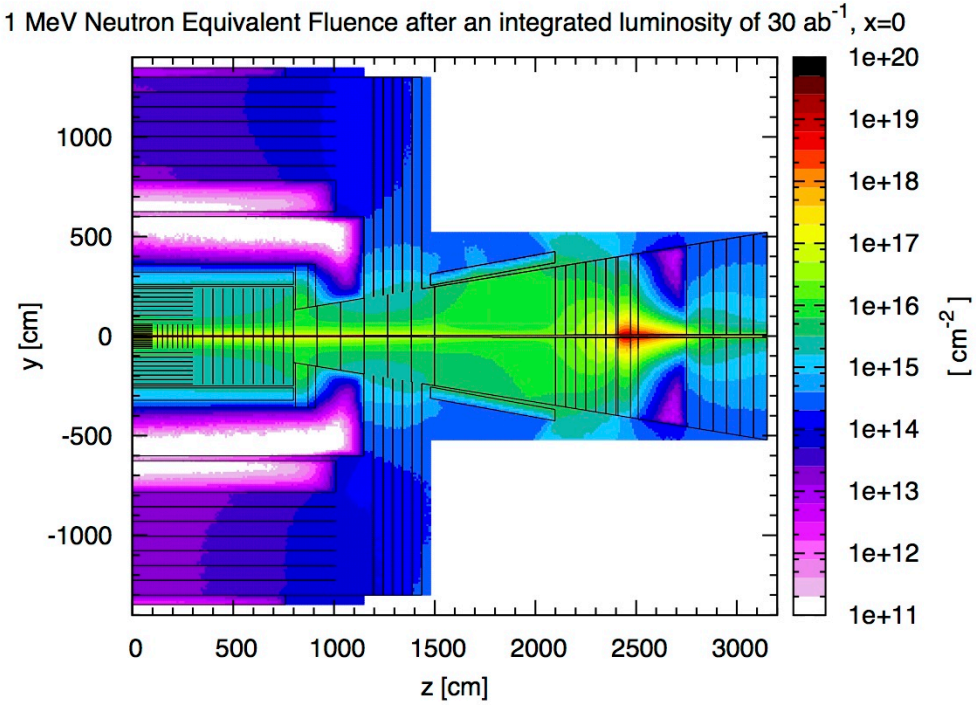


	Fluence Rate [Hzcm^{-2}]
First layer of the IB (R =2.5 cm)	10^{10}
max in forward detector	$3\ 10^{10}$
max in barrel muon chambers	$8\ 10^{4}$
max in end-cap muon chambers	$5\ 10^{6}$

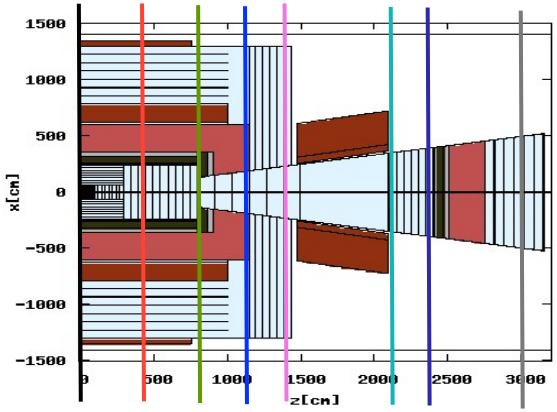
Long Term Damage

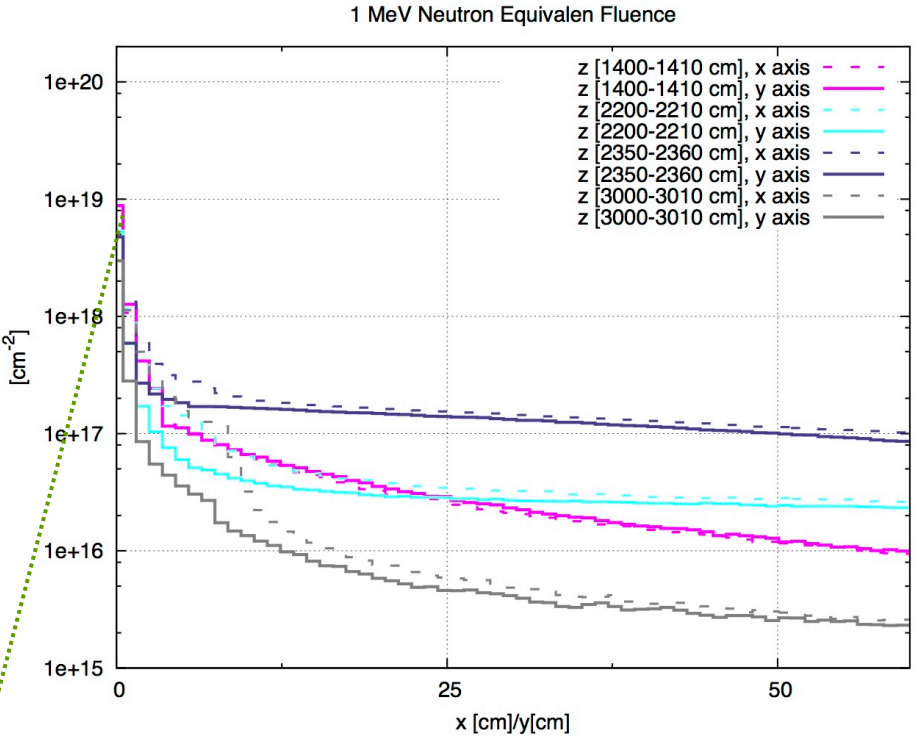
1 MeV Neutron Equivalent Fluence

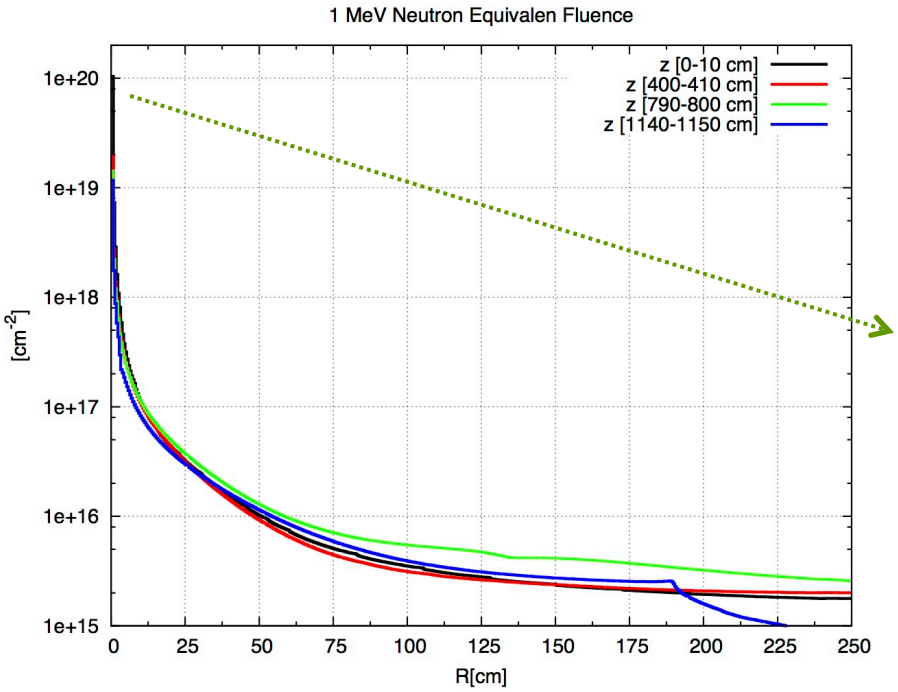




1 MeV Neutron Equivalent Fluence

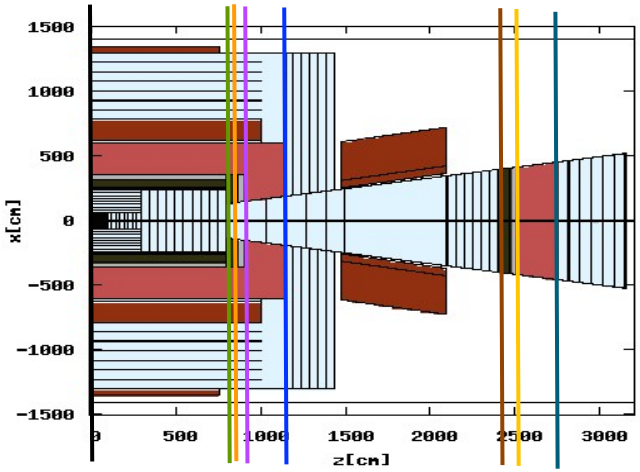


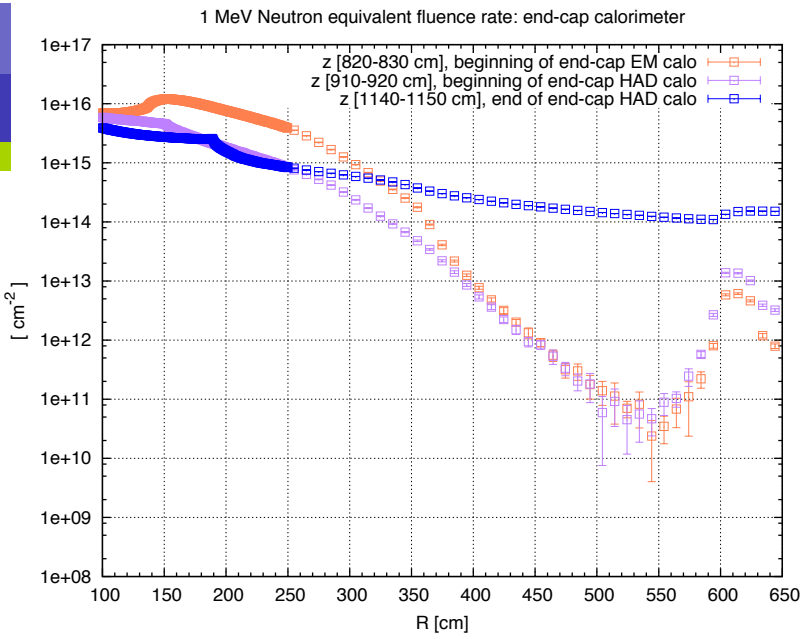


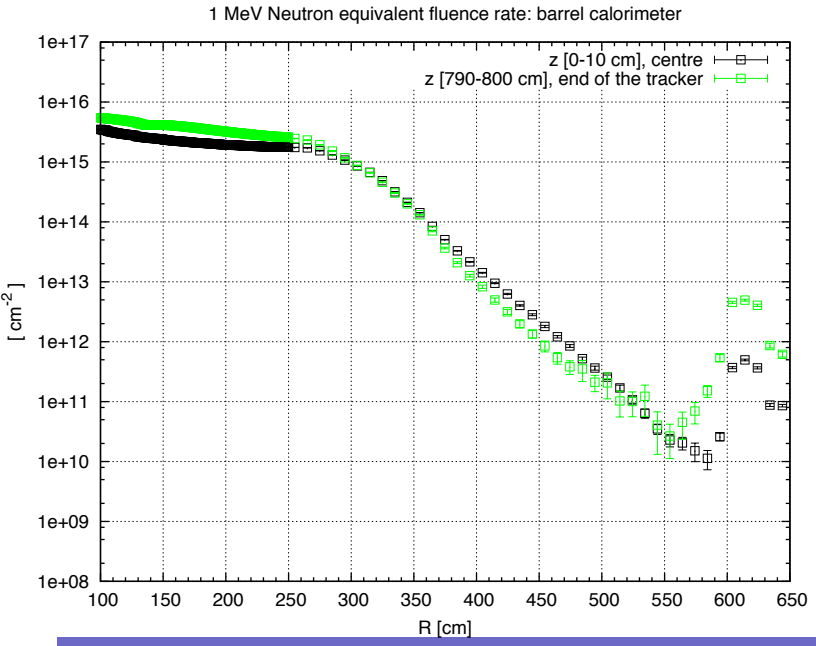


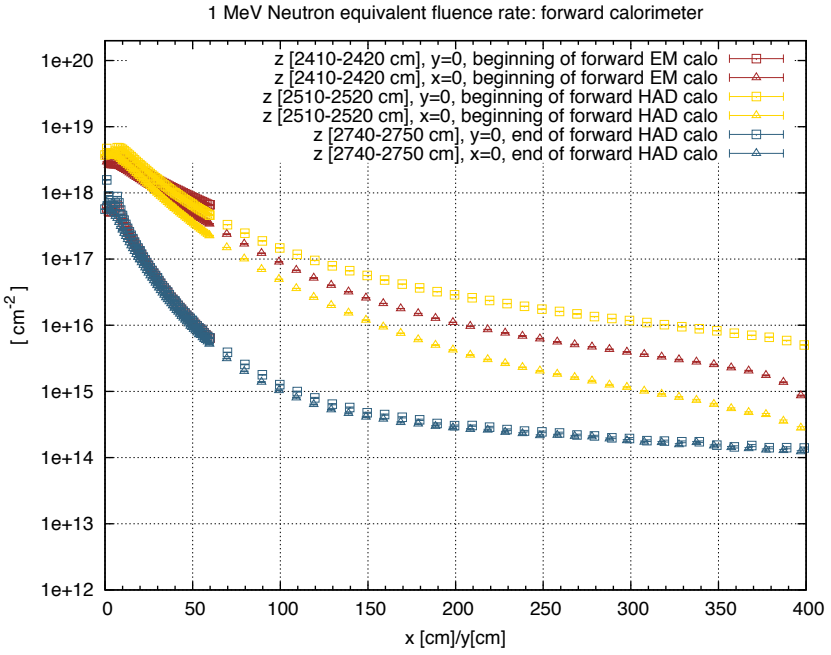
Different radial resolution!

Values in the Calorimeters

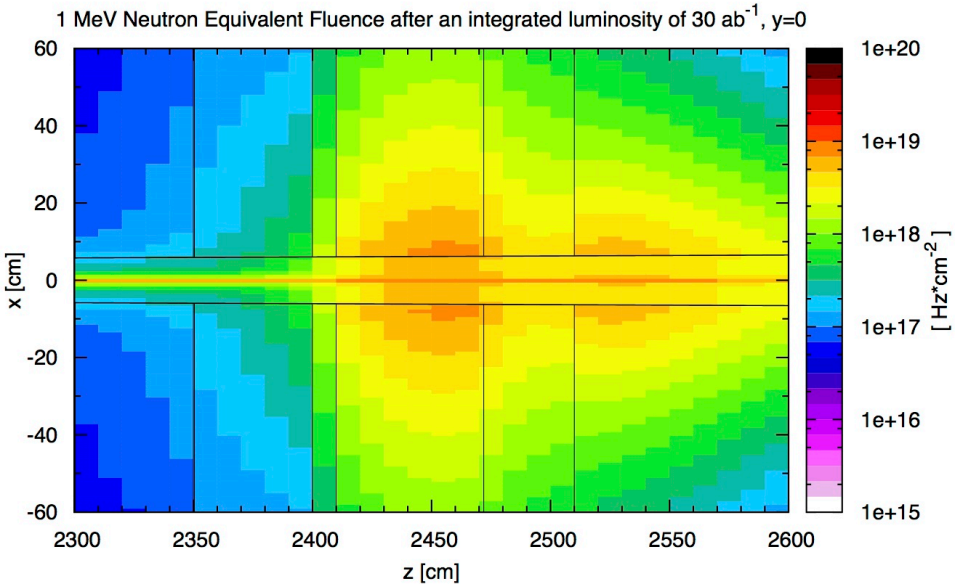


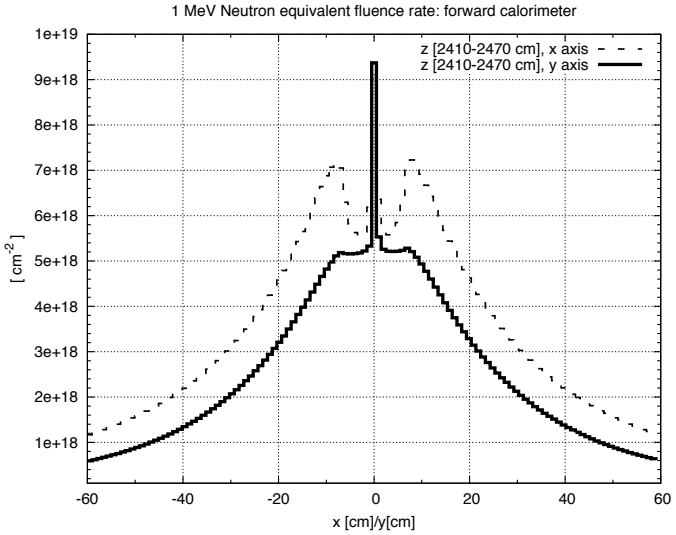


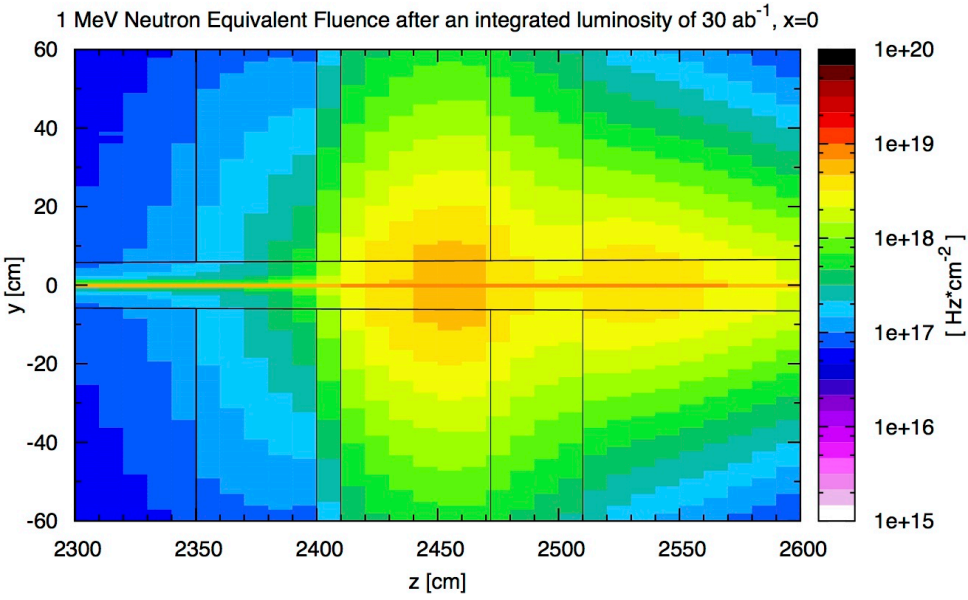




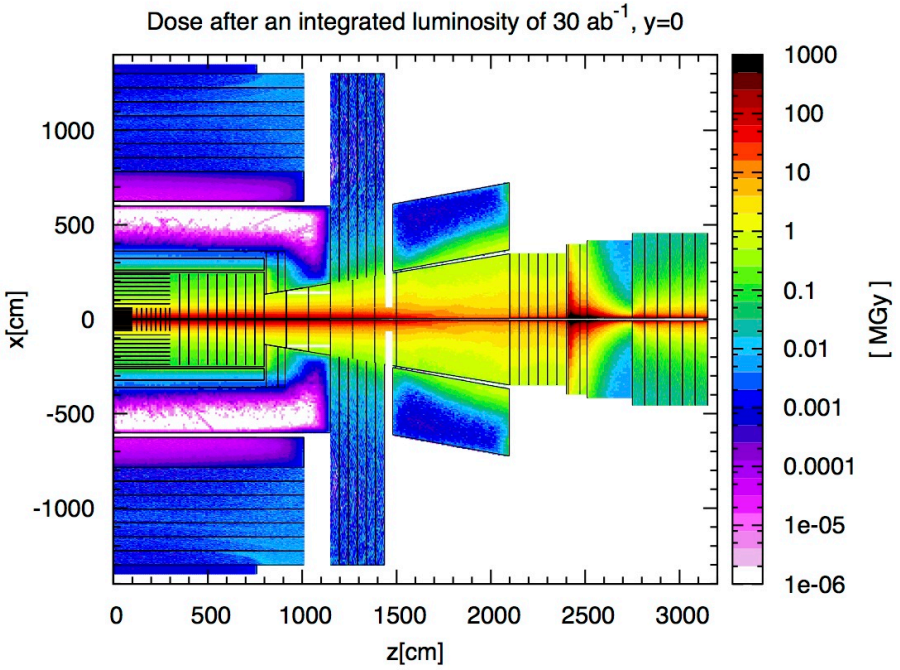
Zoom on the Forward Calorimeter

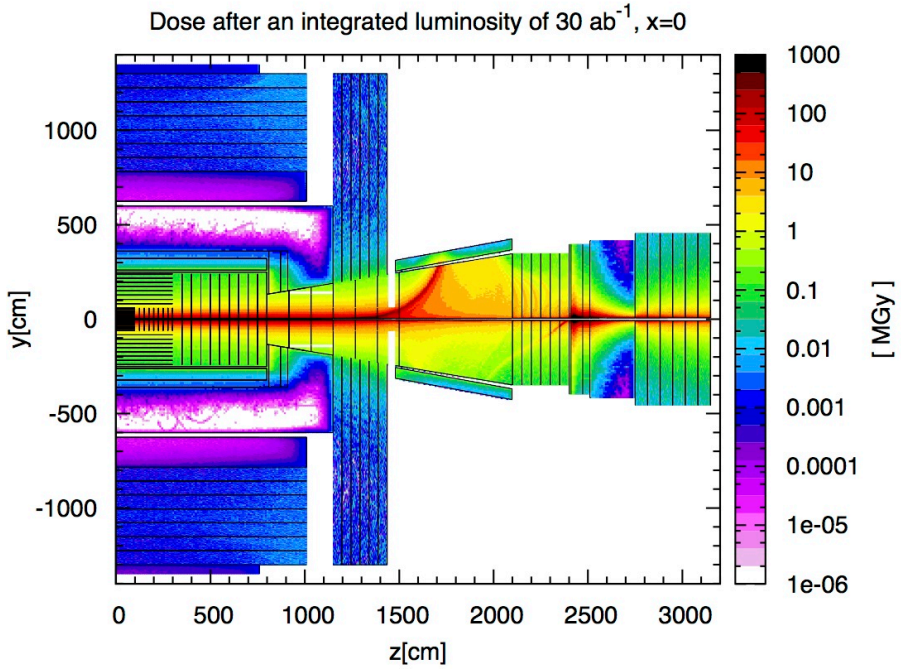


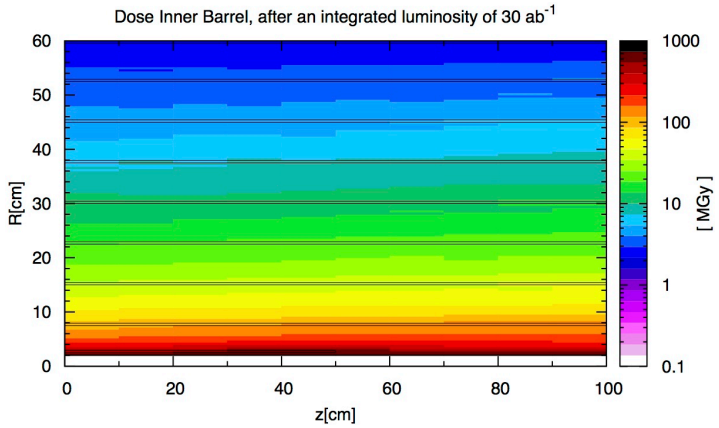




Dose



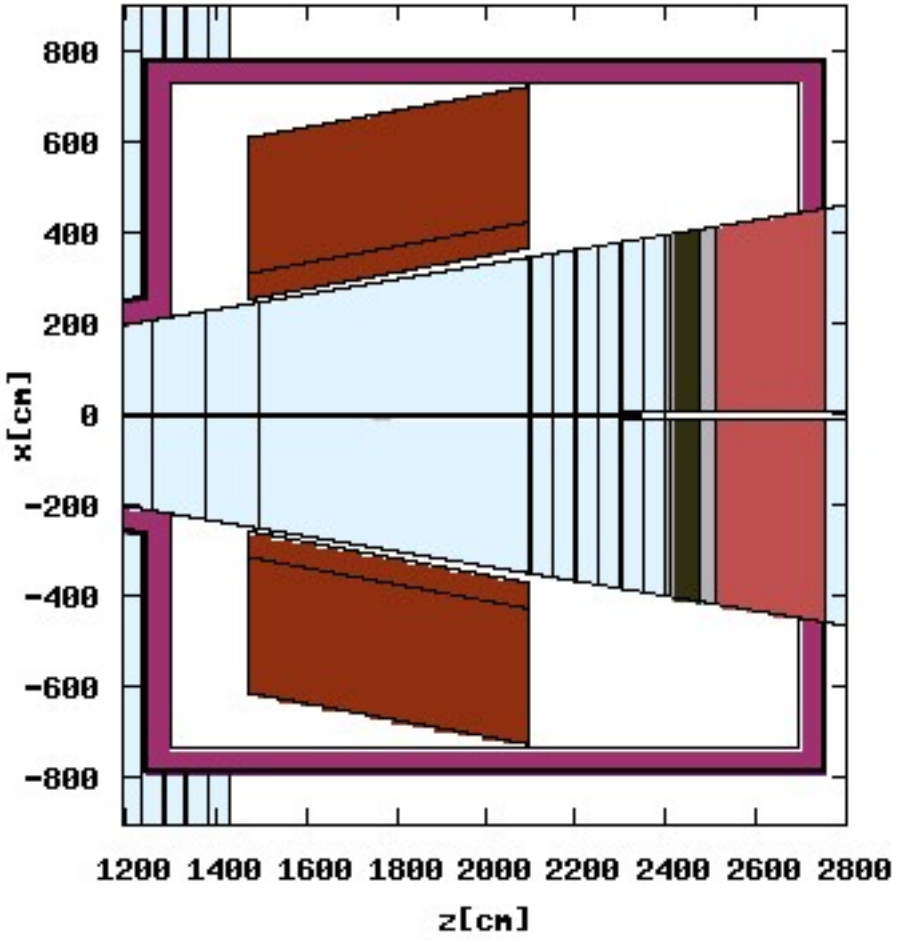




	Dose [MGy]
First layer of the IB (R =2.5 cm)	600
max in forward detector	10^4
max in barrel muon chambers	10^{-2}
max in end-cap muon chambers	10^{-1}

Shielding Design and Effect

Shielding Design

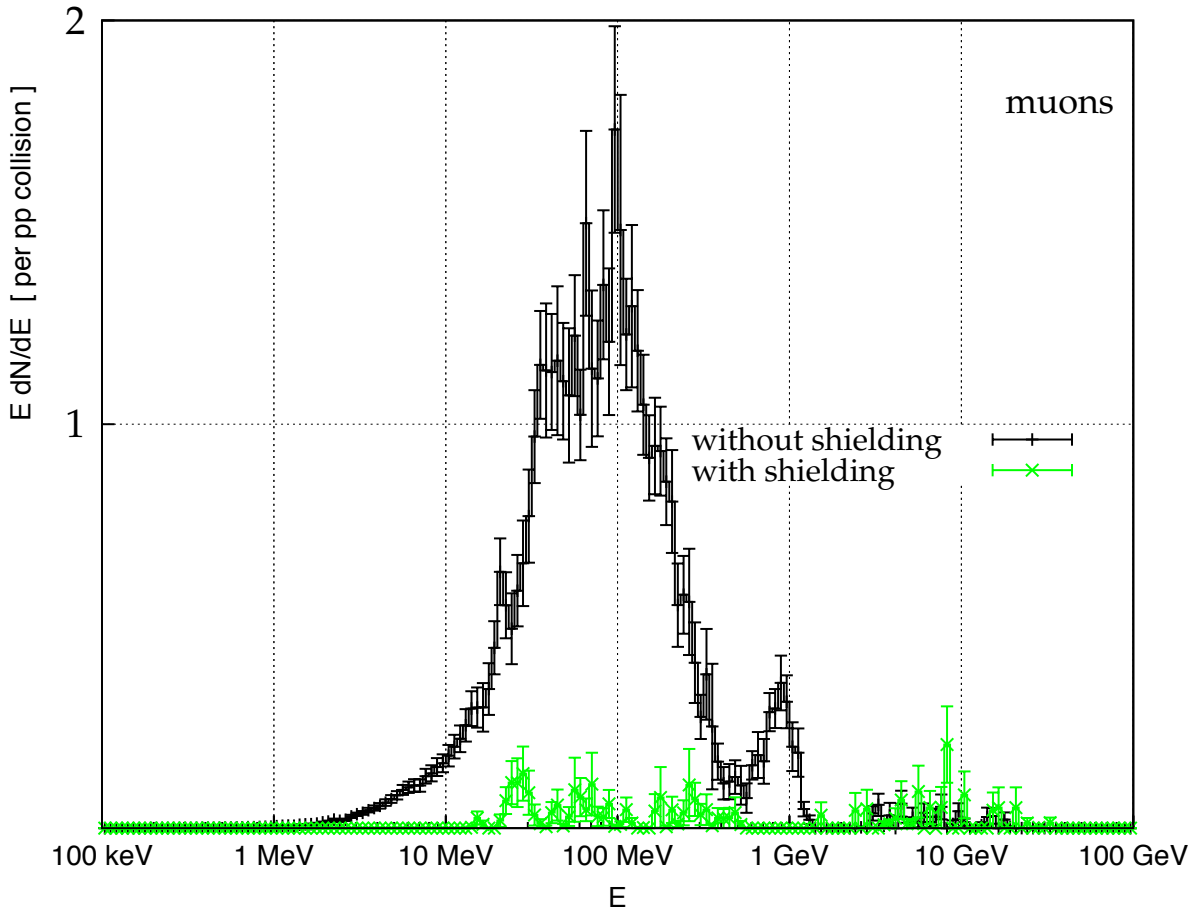


Shielding around the forward calorimeter, composed by:

- 50 cm/ 100 cm of iron to remove high-energy particles
- 5 cm of lithiated polyethylene to slow down and capture neutrons
- 1 cm of lead to absorb photons

Muon Spectrum

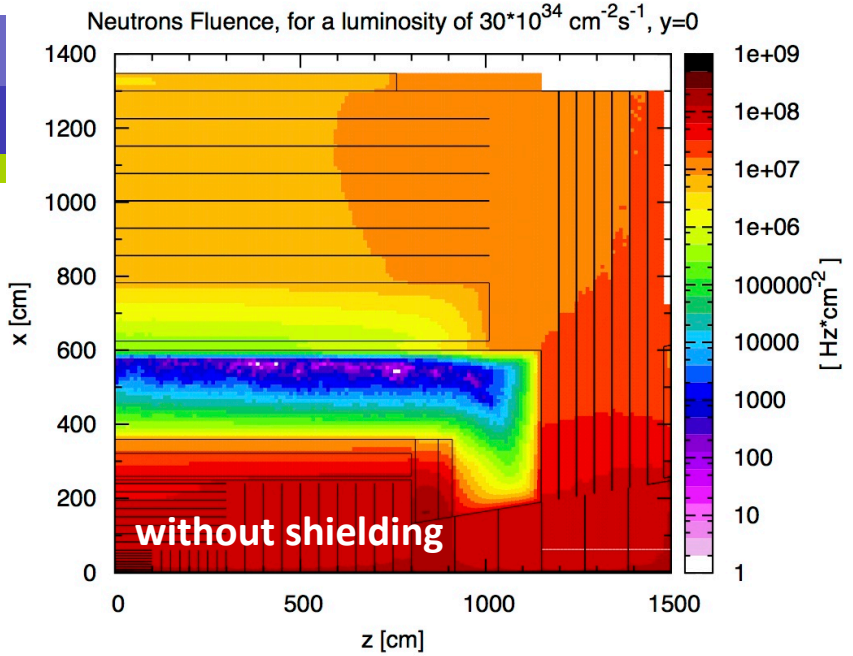
Muon spectrum in the barrel muon chambers:

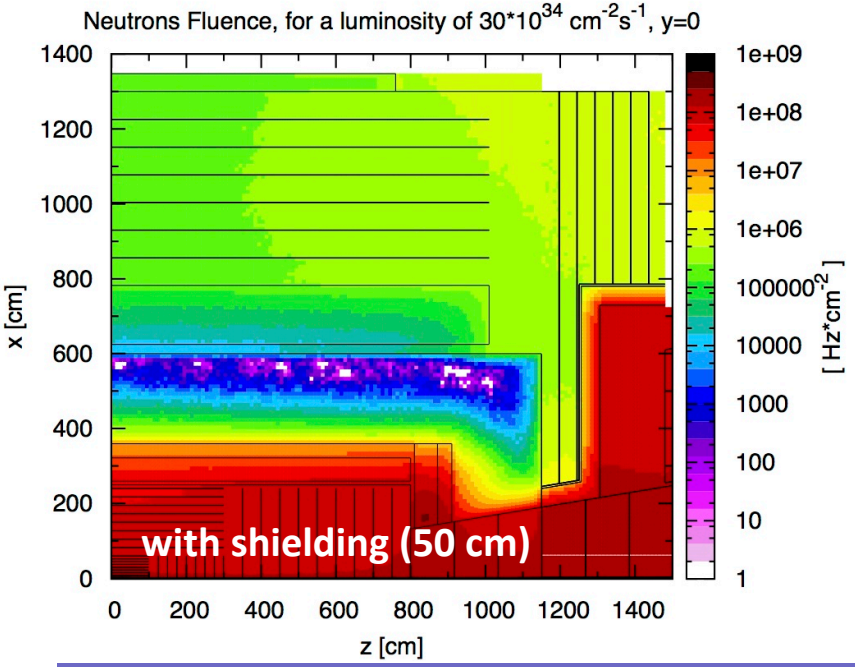


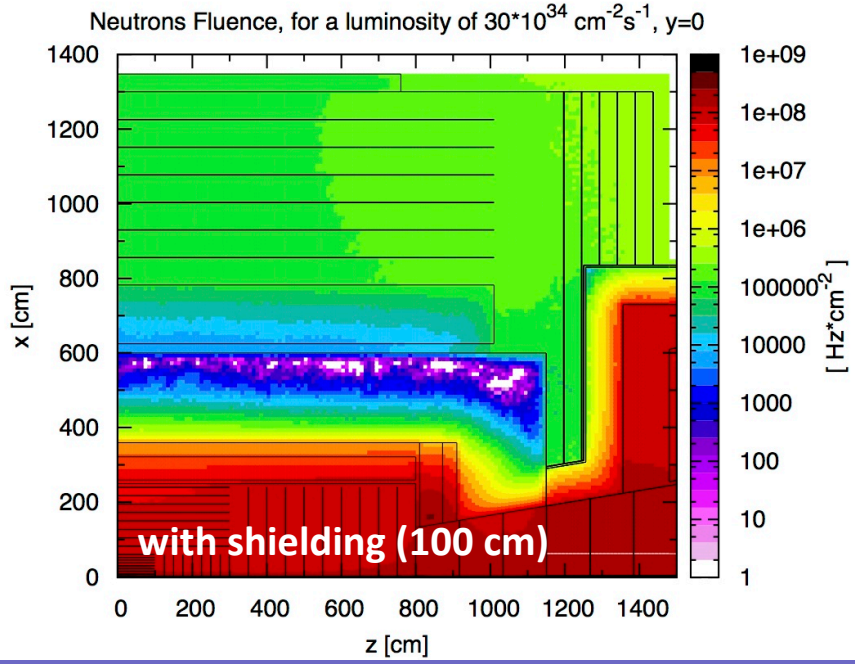
Shielding composed by 50 cm of iron, 5 cm of lithiated polyethylene and 1 cm of lead to absorb photons

Neutron Fluence

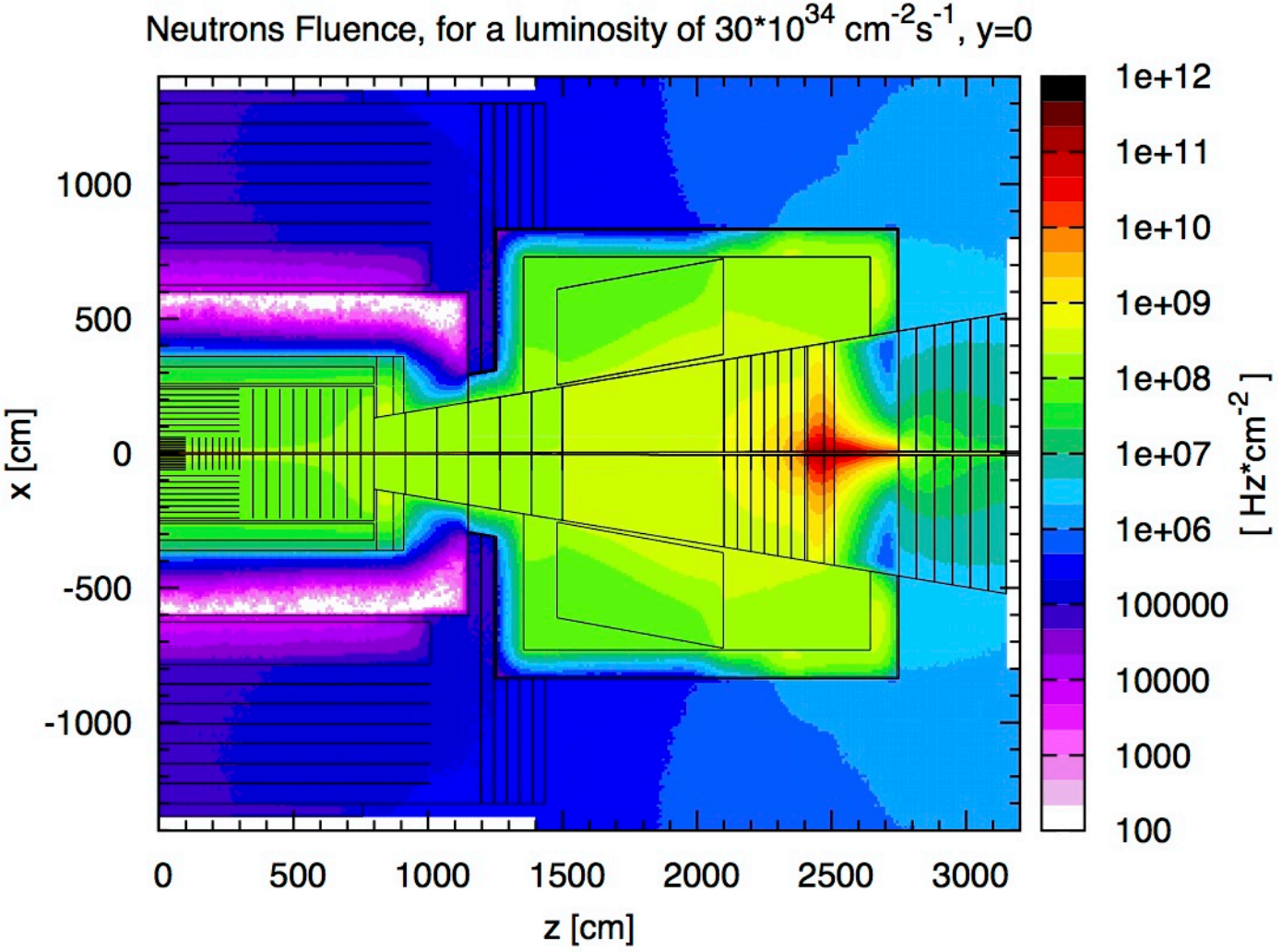
- Barrel muon chambers:
  - the fluence rate without shielding is above 10^7 Hz cm^{-2}
  - thanks to the a 50 cm thick shielding, the fluence goes below 5 10^5 Hz cm^{-2}
  - for a 100 cm thick iron shielding the rate is reduced to 2 10^5 Hz cm^{-2}
- End-cap muon chambers
  - the fluence rate without shielding is above 10^8 Hz cm^{-2}
  - thanks to the a 50 cm thick shielding, the fluence is reduced to 10^6 Hz cm^{-2}
  - for a 100 cm thick iron shielding the rate is reduced to 4 10^5 Hz cm^{-2}





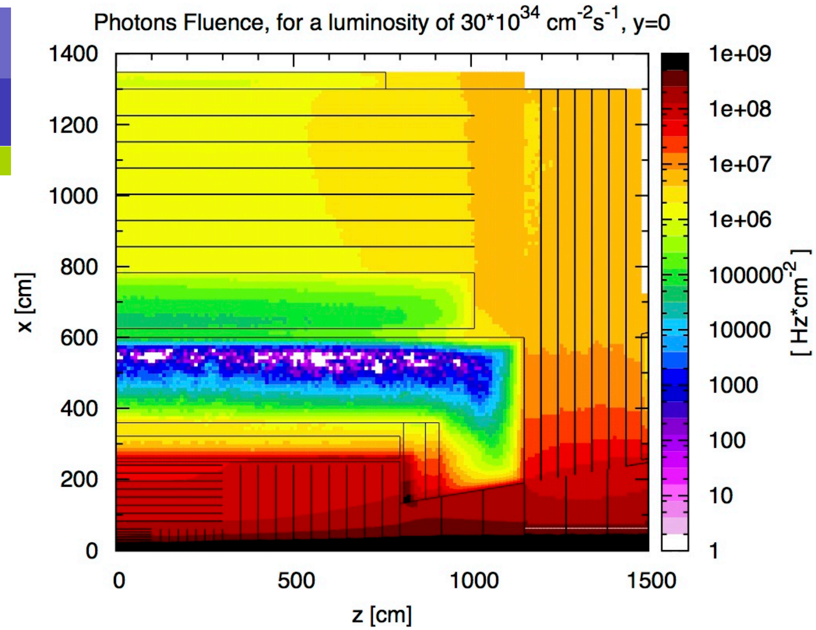


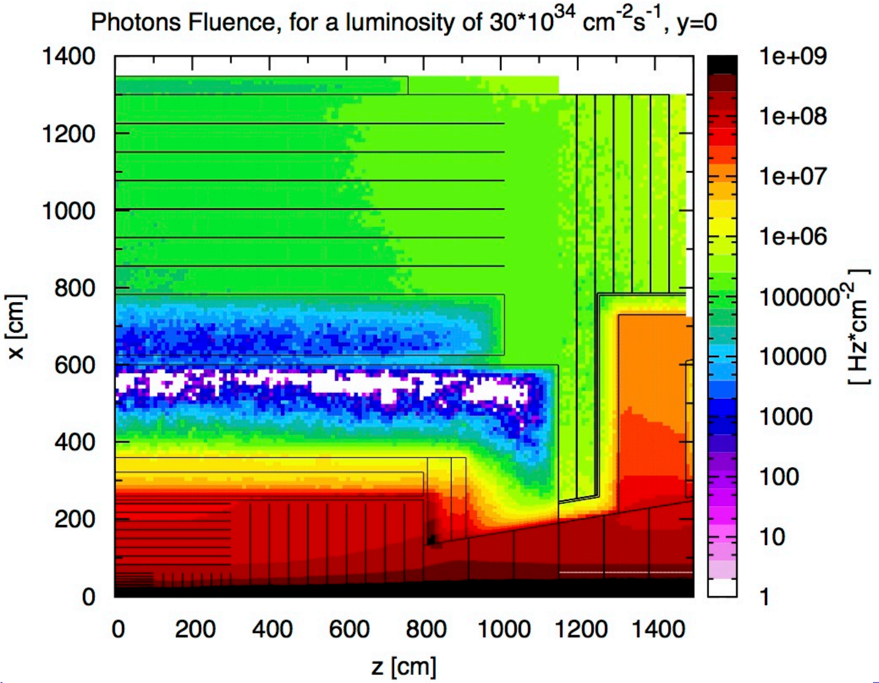
Neutron Fluence

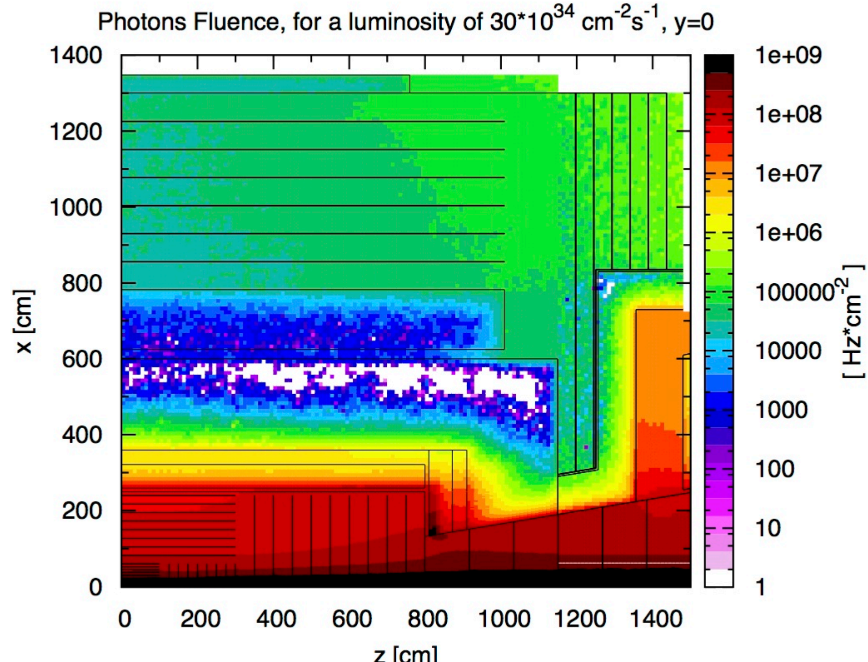


Photon Fluence

- Barrel muon chambers:
  - the fluence rate without shielding is above 5 10^6 Hz cm^{-2}
  - thanks to the a 50 cm thick shielding, the fluence goes below 2 10^5 Hz cm^{-2}.
  - for a 100 cm thick iron shielding the rate is 10^5 Hz cm^{-2}
- End-cap muon chambers
  - the fluence rate without shielding reaches 10^8 Hz cm^{-2}
  - thanks to the a 50 cm thick shielding, the fluence is reduced to 10^6 Hz cm^{-2}
  - for a 100 cm thick iron shielding the rate is reduced to 10^5 Hz cm^{-2}

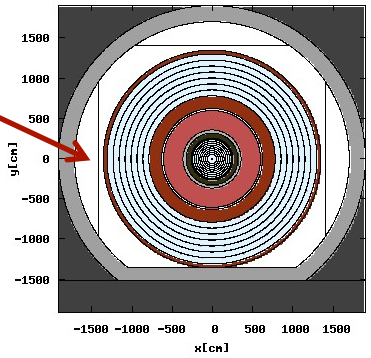


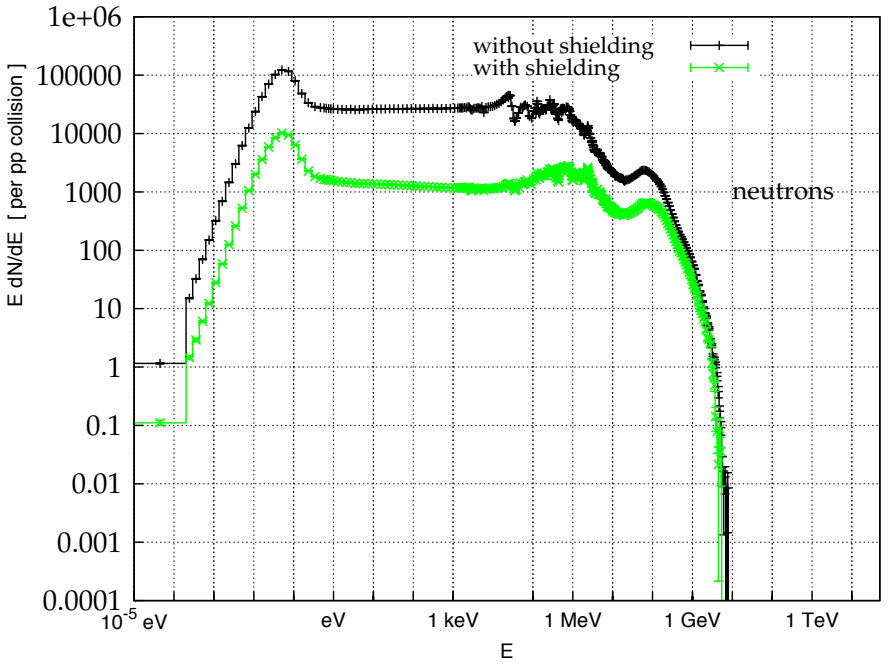


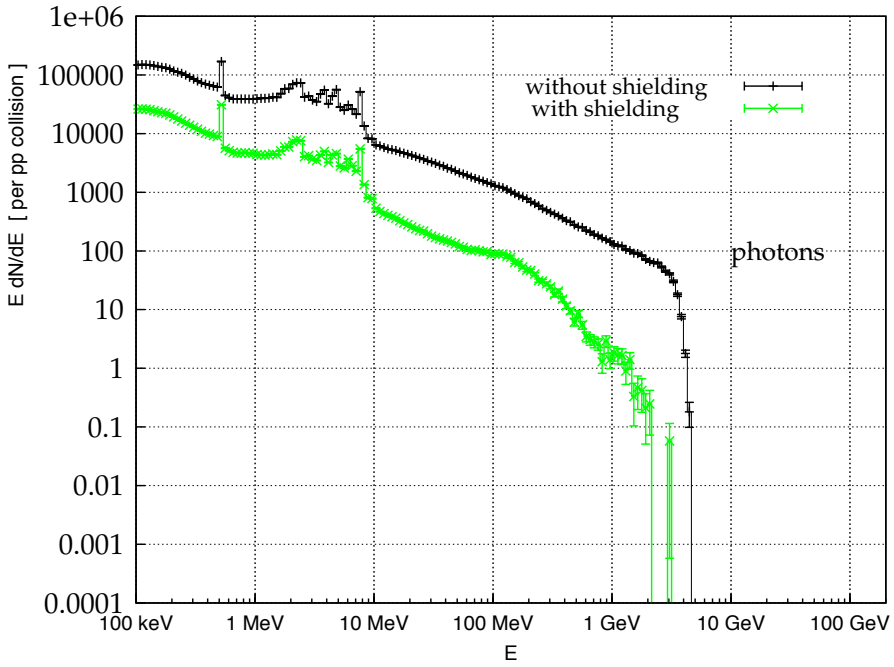


Spectra

Photons and neutrons spectra in the region outside the detector:



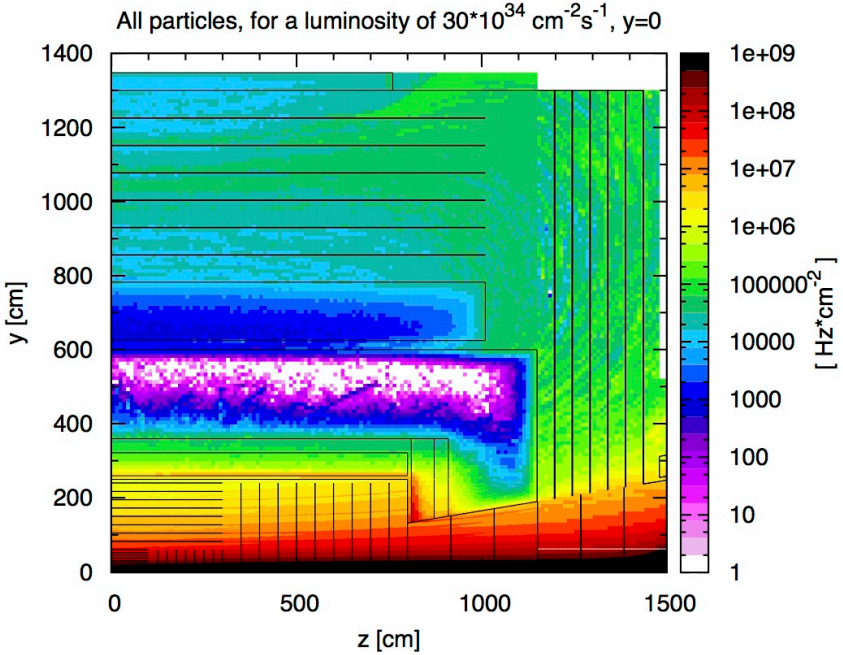


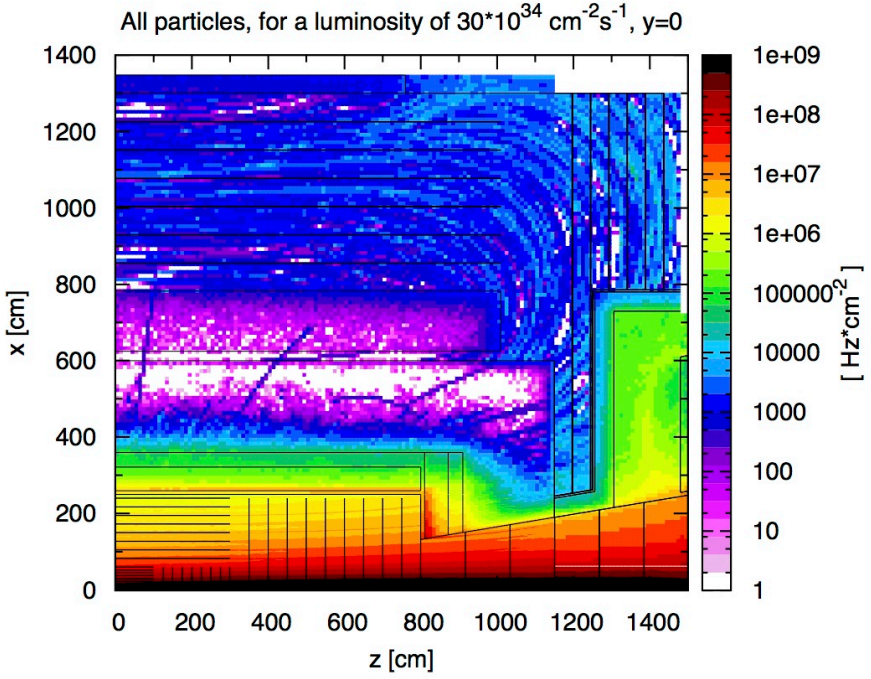


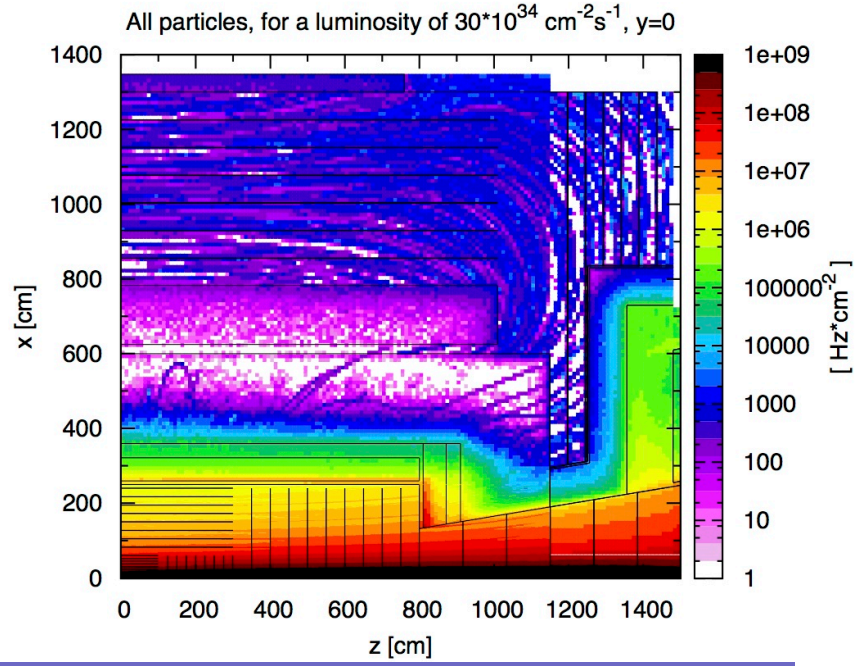
Shielding composed by 50 cm of iron, 5 cm of lithiated polyethylene and 1 cm of lead to absorb photons

All Charged Particles Fluence

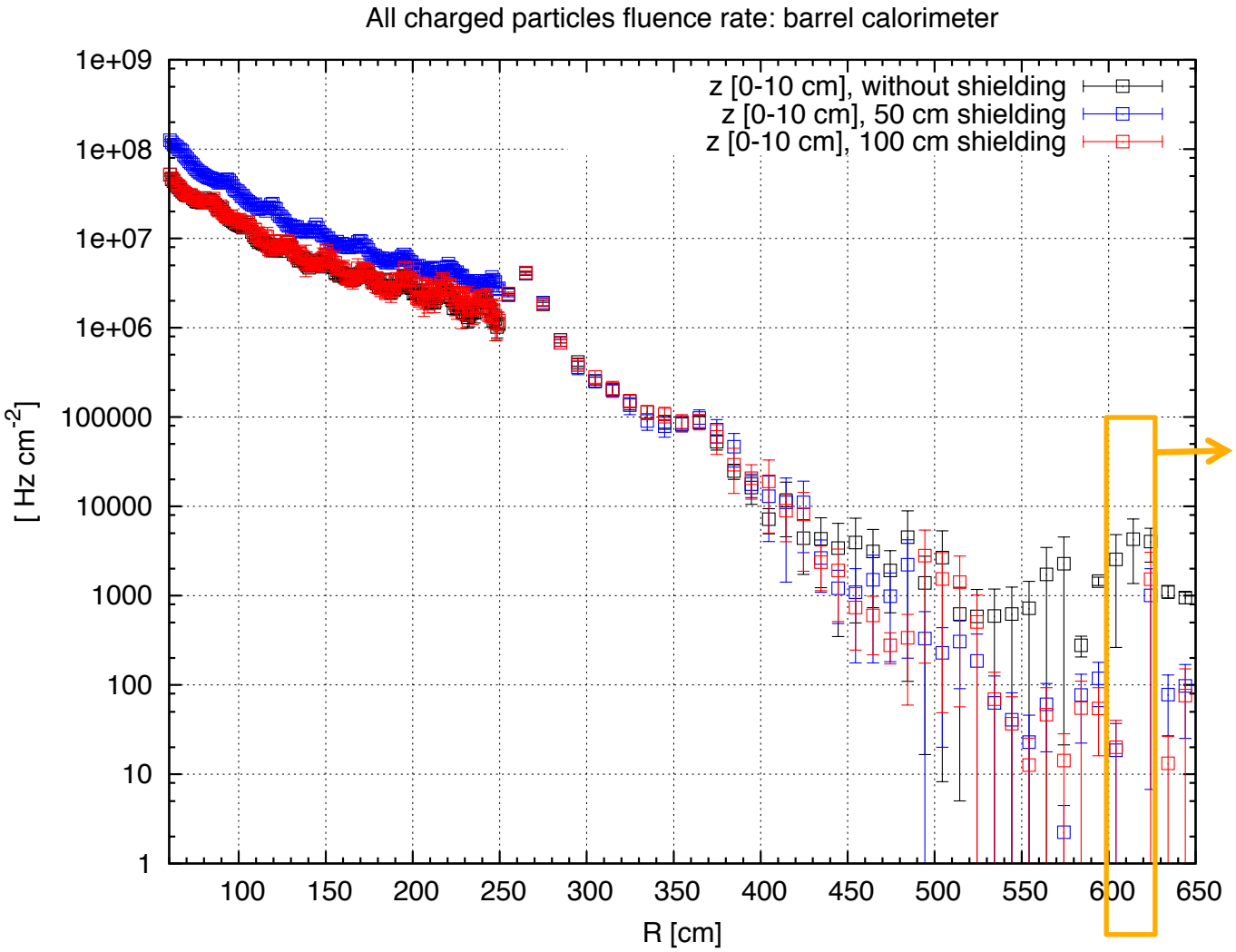
- Barrel muon chambers:
  - the fluence rate without shielding is about 2 10^5 Hz cm^{-2}
  - thanks to the a 50 cm thick shielding, the fluence is reduced to 4 10^3 Hz cm^{-2}
  - for a 100 cm thick iron shielding the rate is below 10^3 Hz cm^{-2}
- End-cap muon chambers
  - the fluence rate without shielding reaches 10^6 Hz cm^{-2}
  - thanks to the a 50 cm thick shielding, the fluence is at 10^4 Hz cm^{-2}
  - for a 100 cm thick iron shielding the rate is reduced to 10^3 Hz cm^{-2}







Effect of the Shielding on Read-Out Electronics

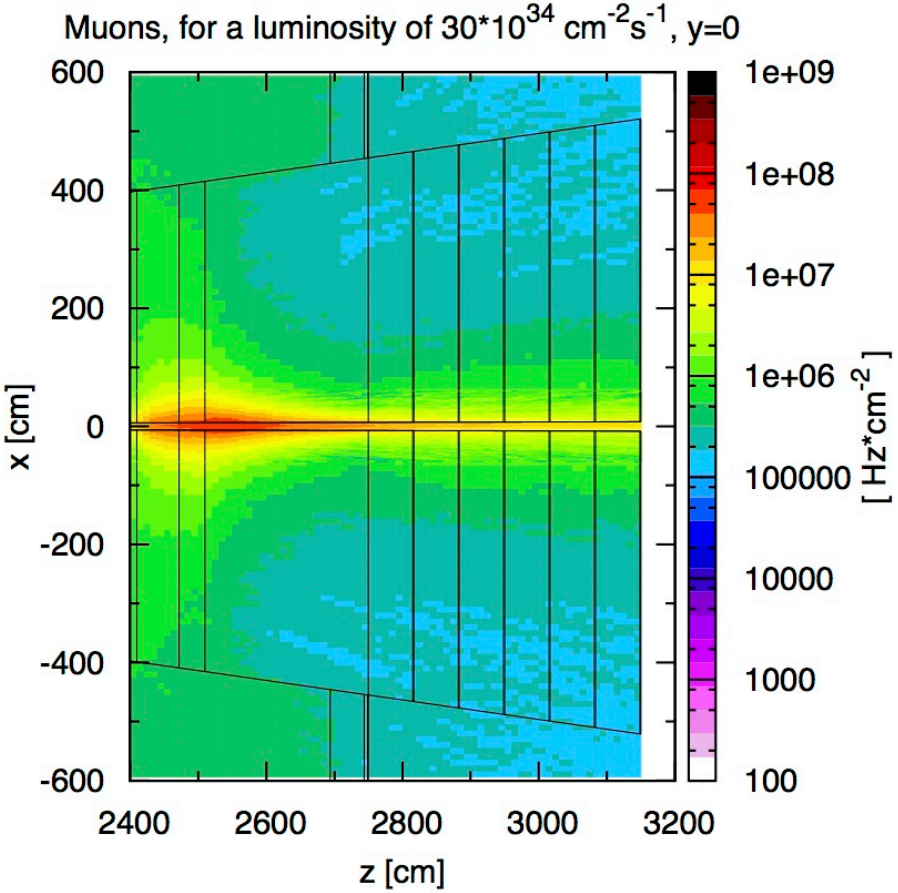


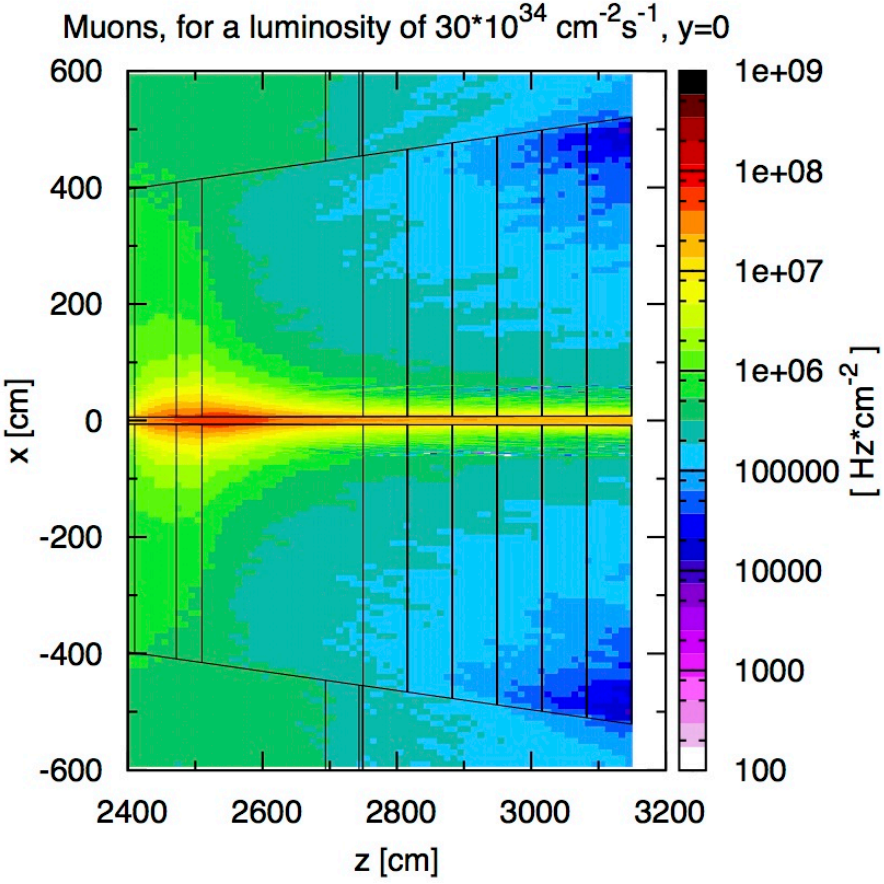
"Free" space between the calorimeter and the solenoid:

the fluence rate is reduced by at least 2 orders of magnitude

Iron in the Forward Muon Chambers

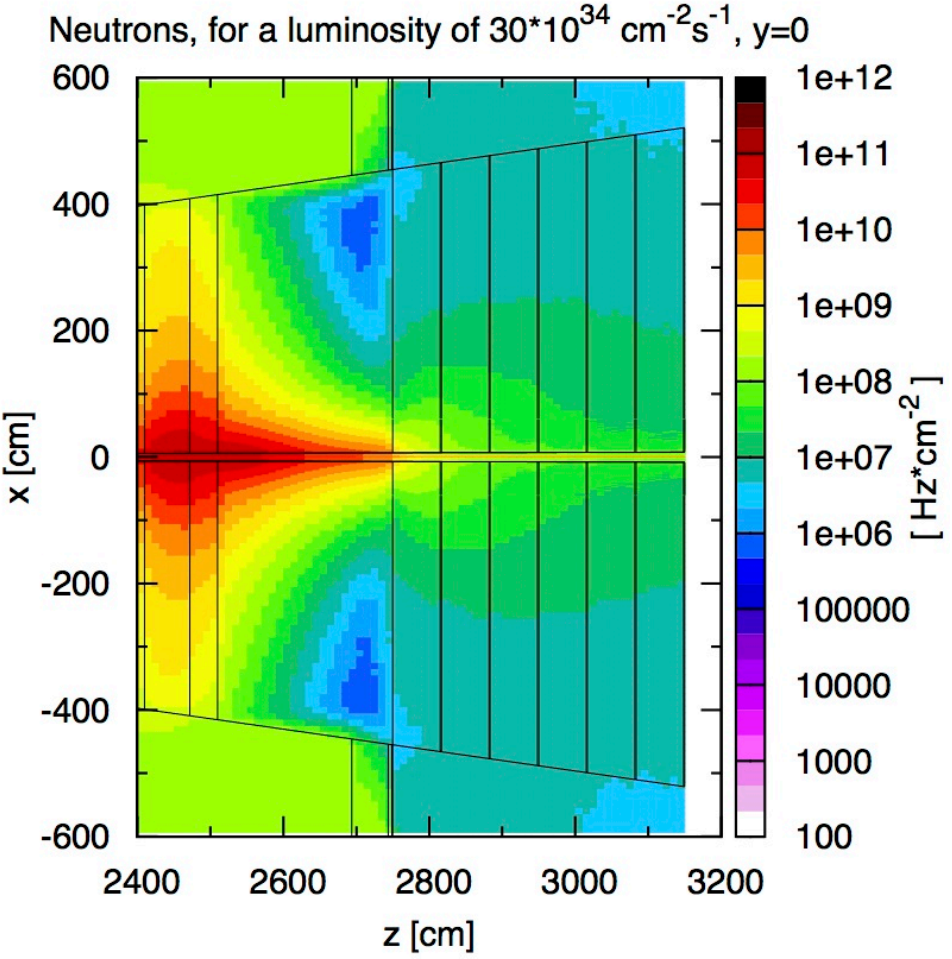
Muons fluence rate:

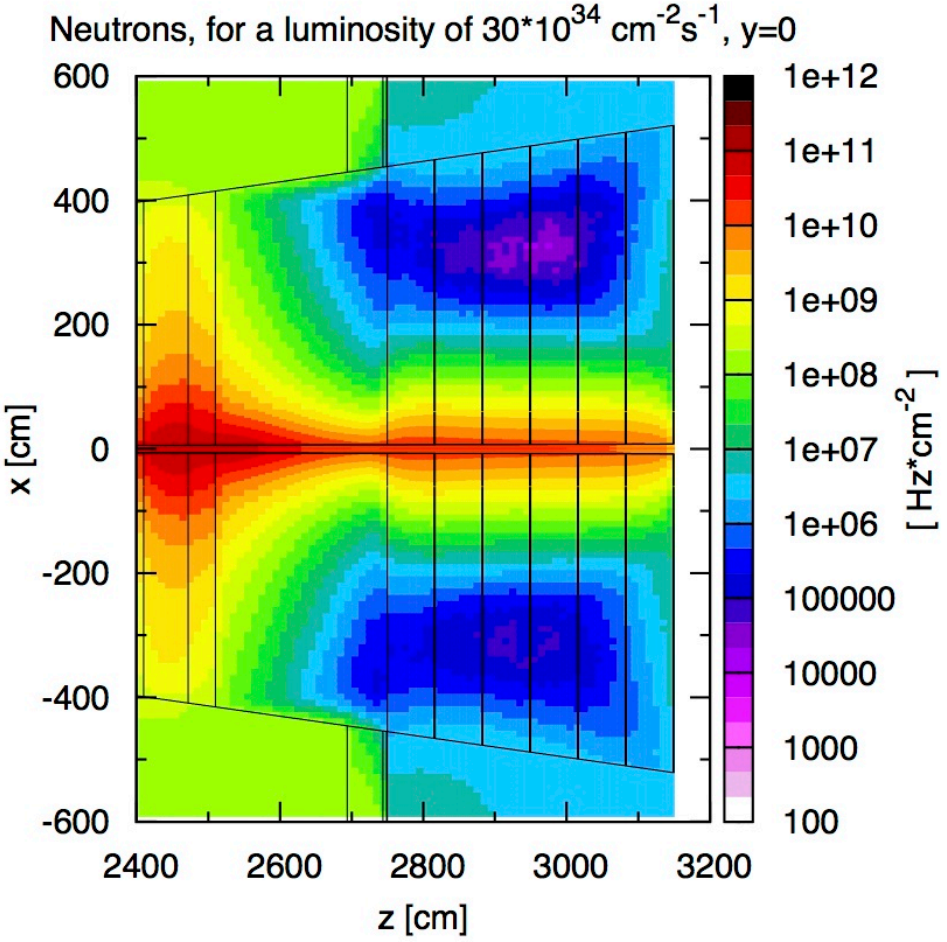




Iron in the Forward Muon Chambers

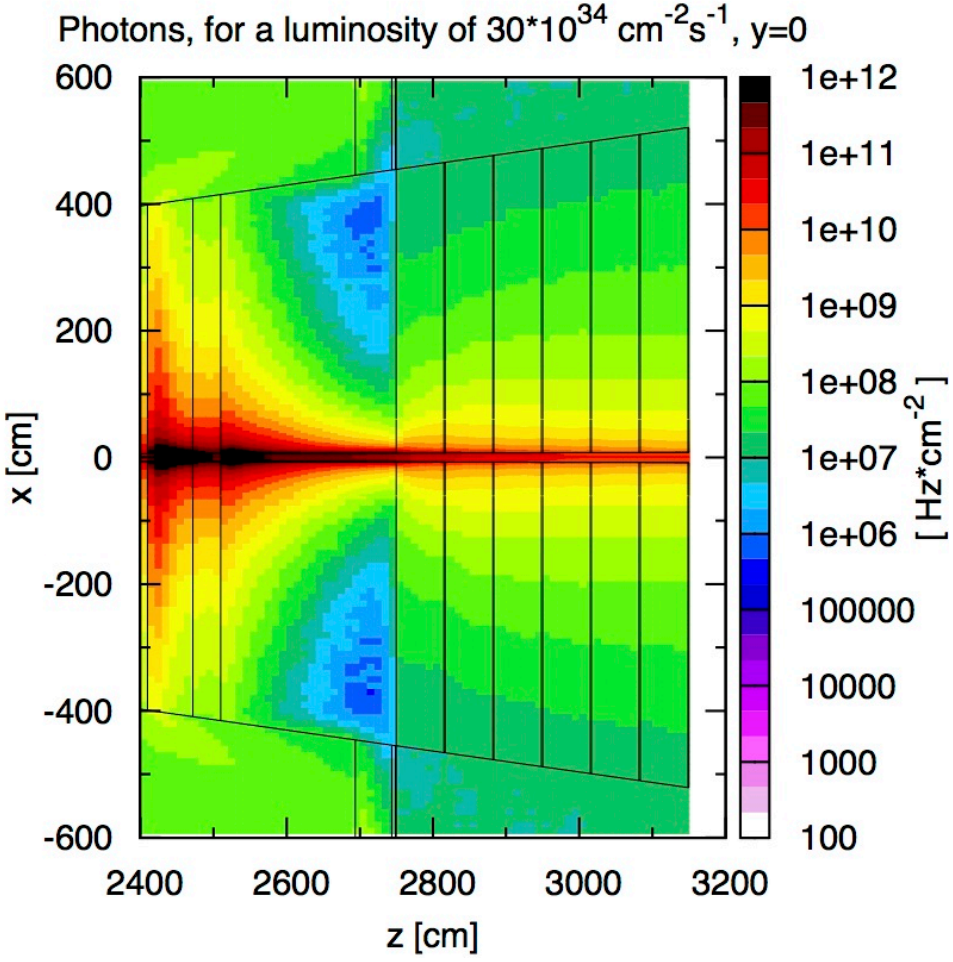
Neutrons fluence rate:

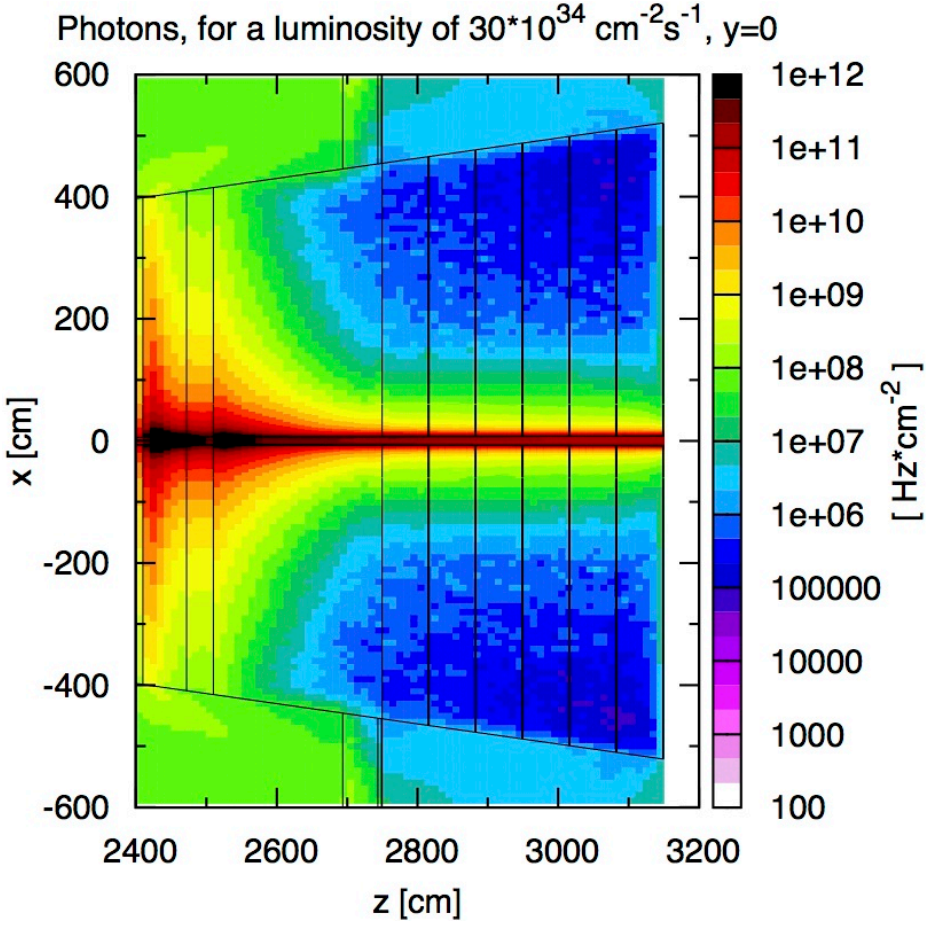




Iron in the Forward Muon Chambers

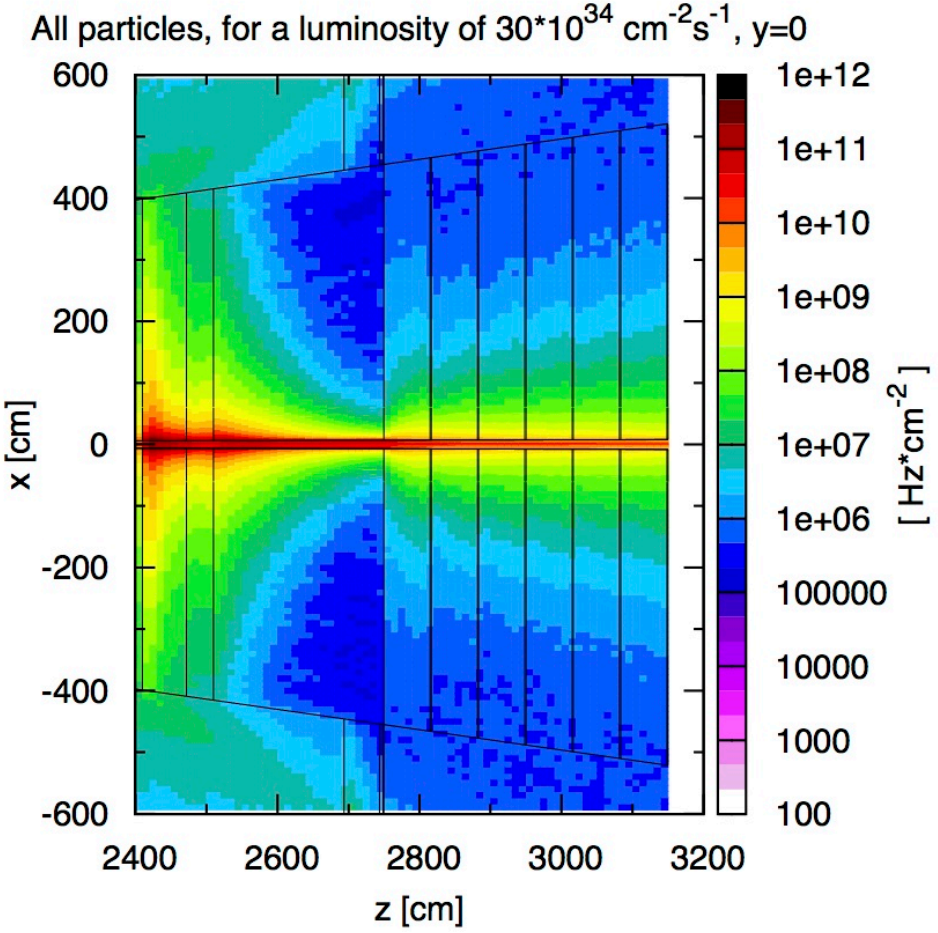
Photons fluence rate:

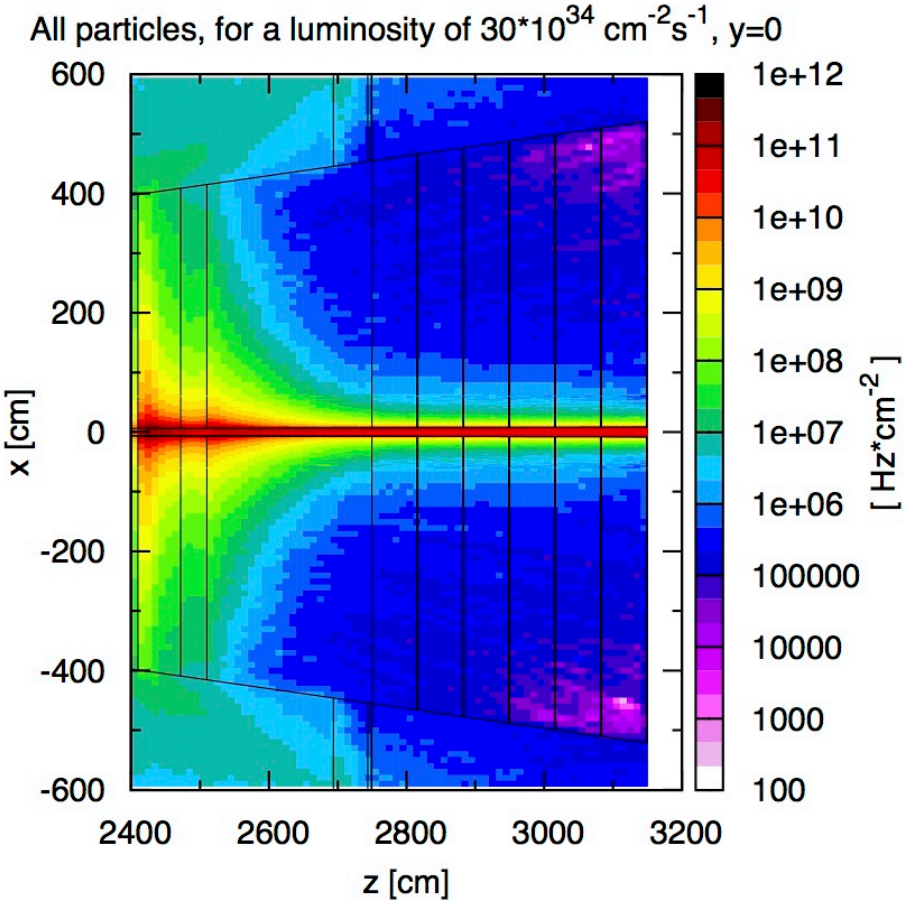




Iron in the Forward Muon Chambers

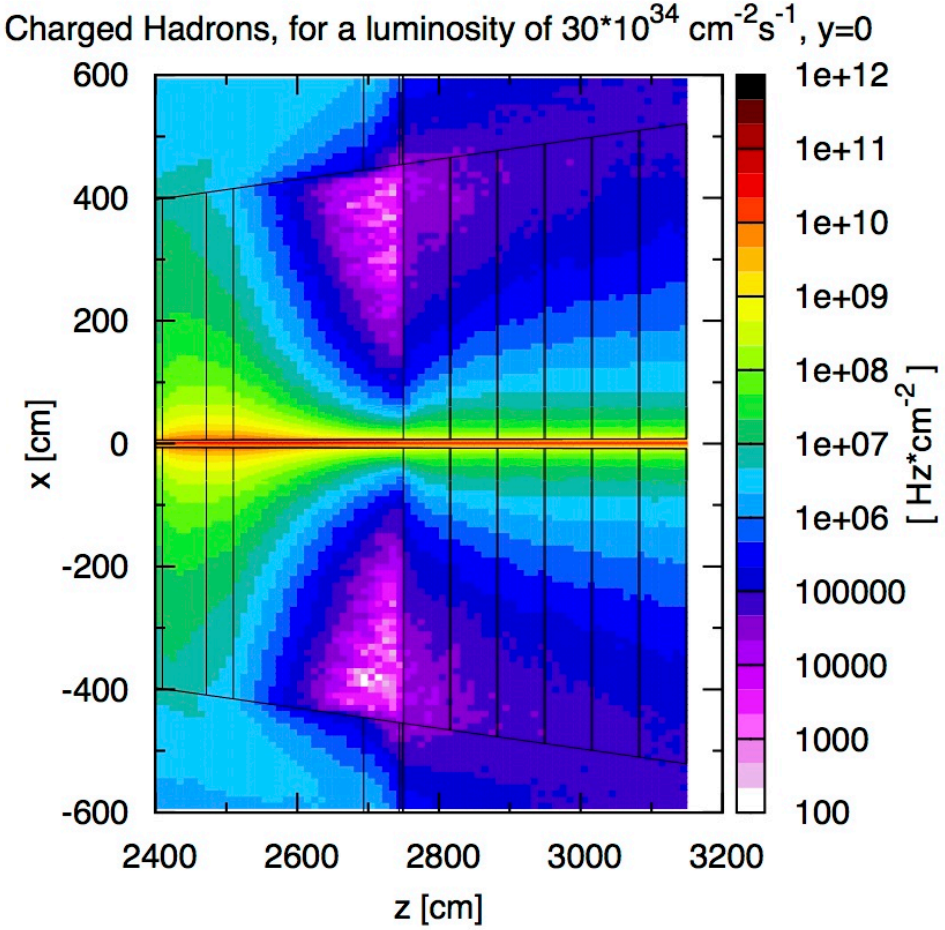
All charged particles fluence rate:

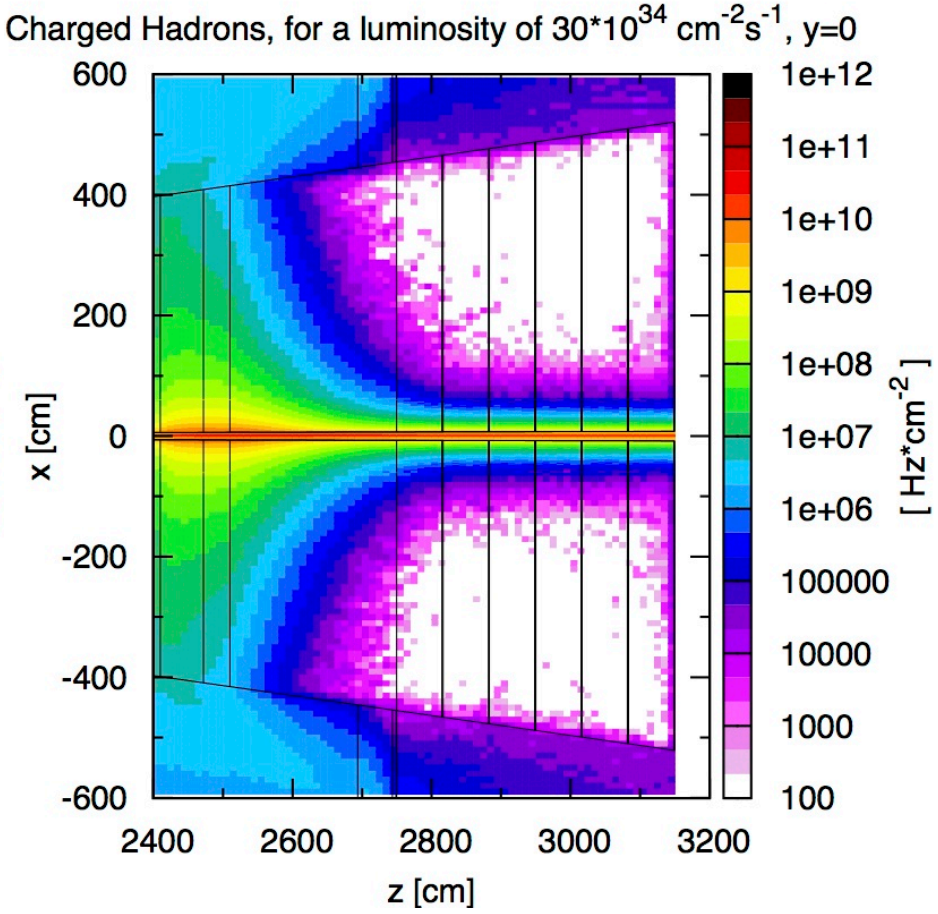




Iron in the Forward Muon Chambers

Charged hadrons fluence rate:





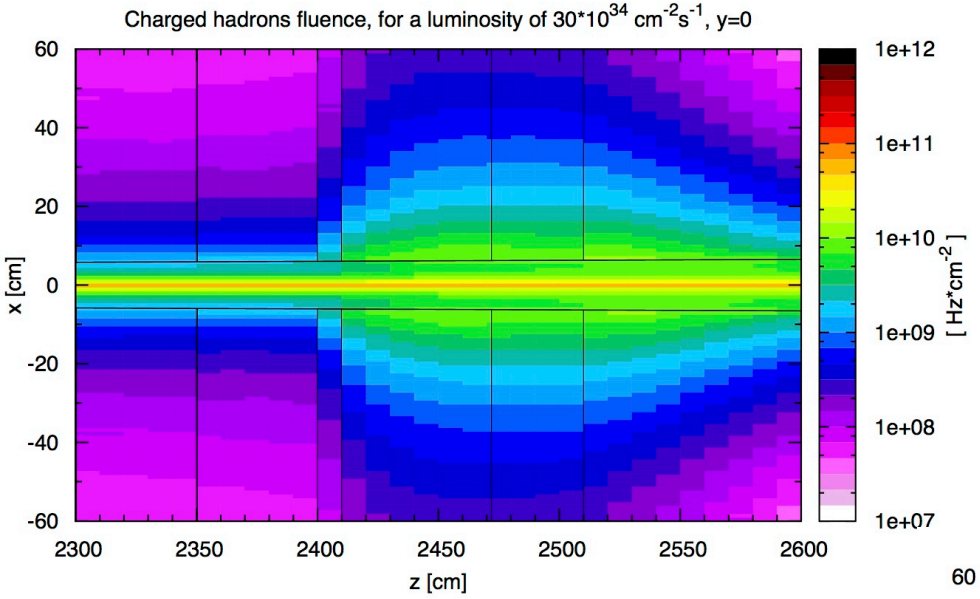
Conclusions and Outlooks

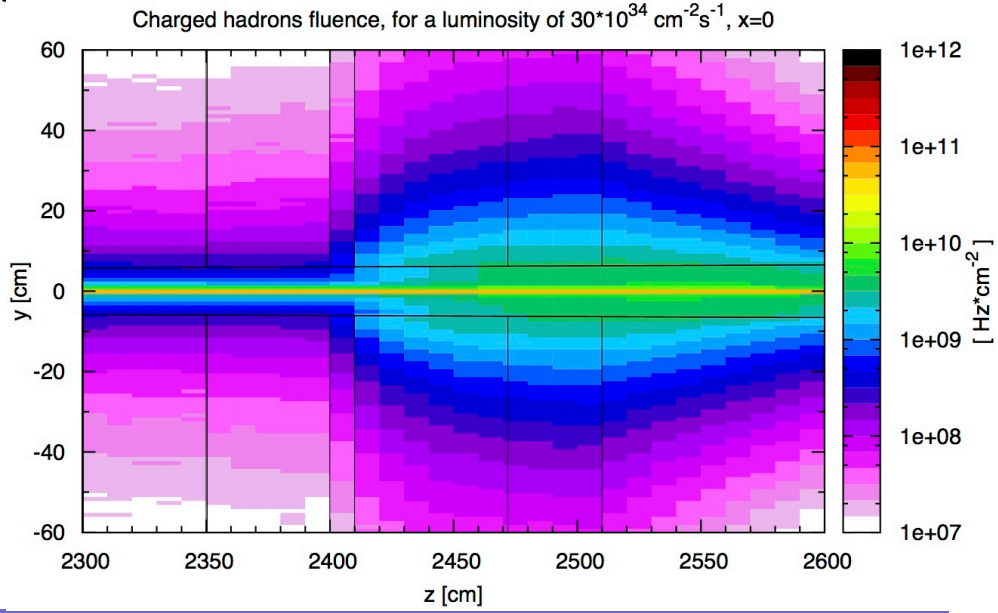
Conclusions and Outlooks

- The geometry for simulations is in place
  - we have also the magnetic field map for the whole detector and, if needed, we can also run a simulation on both sides detector geometry
- First results obtained have been shown today:
  - no major differences between the central and the forward region for trackers and muon detector, so similar detector technologies can be used
- Shielding is needed to protect the muon chambers
  - the designed shielding is effective: the fluence rate values obtained are manageable
  - optimization can be done to improve the performance
- To assess muon fluence rates in the muon chambers dedicated simulations are needed

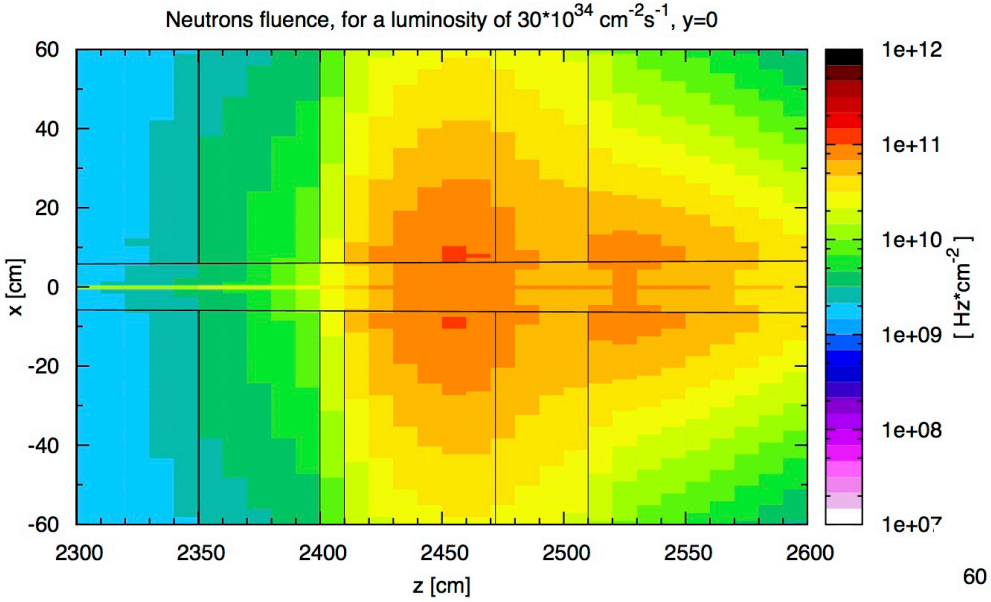
Back-up

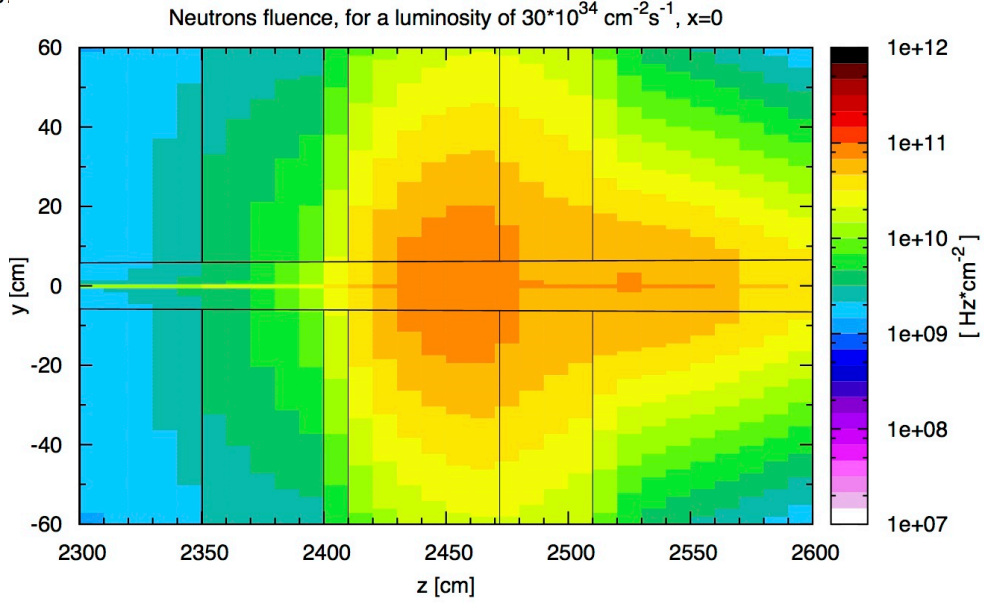
Charged Hadrons Fluence Rate: Forward Calo



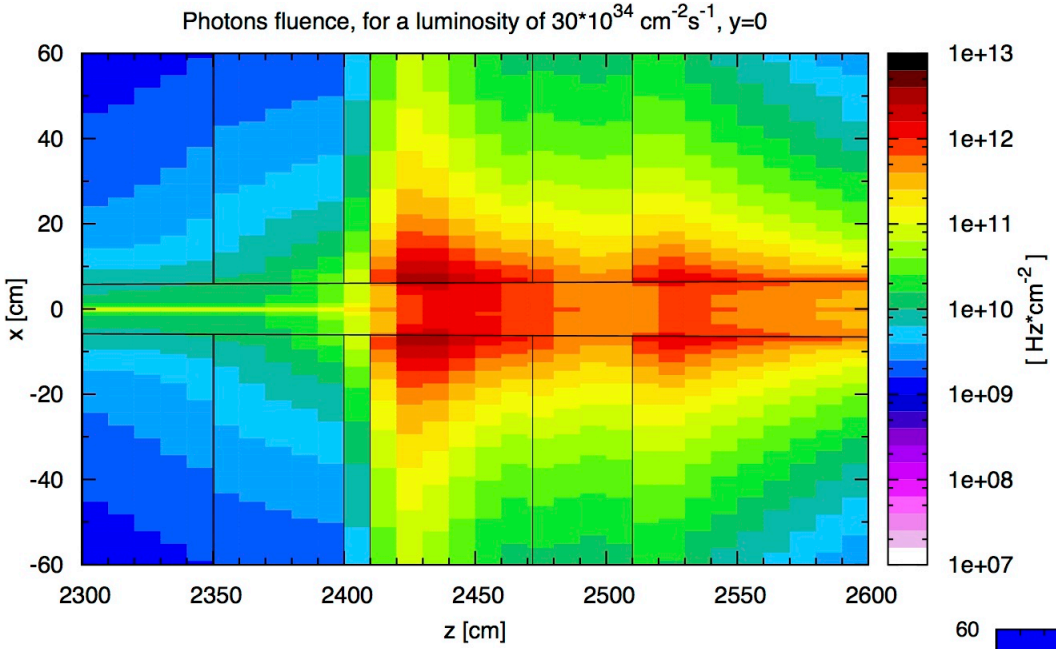


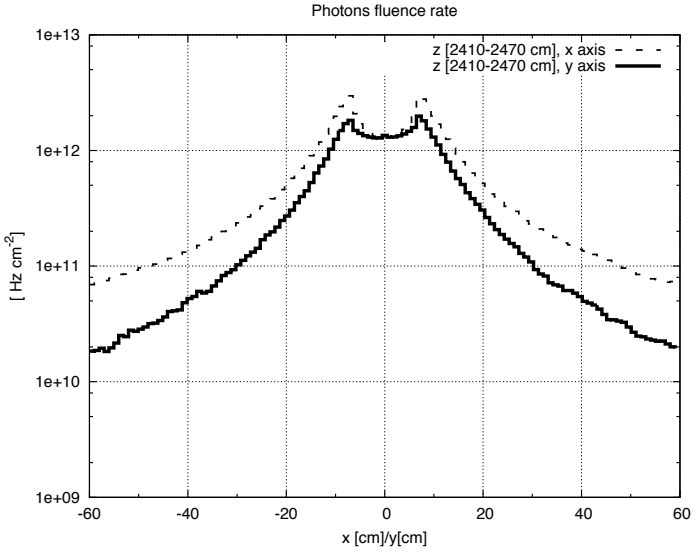
Neutron Fluence Rate: Forward Calo

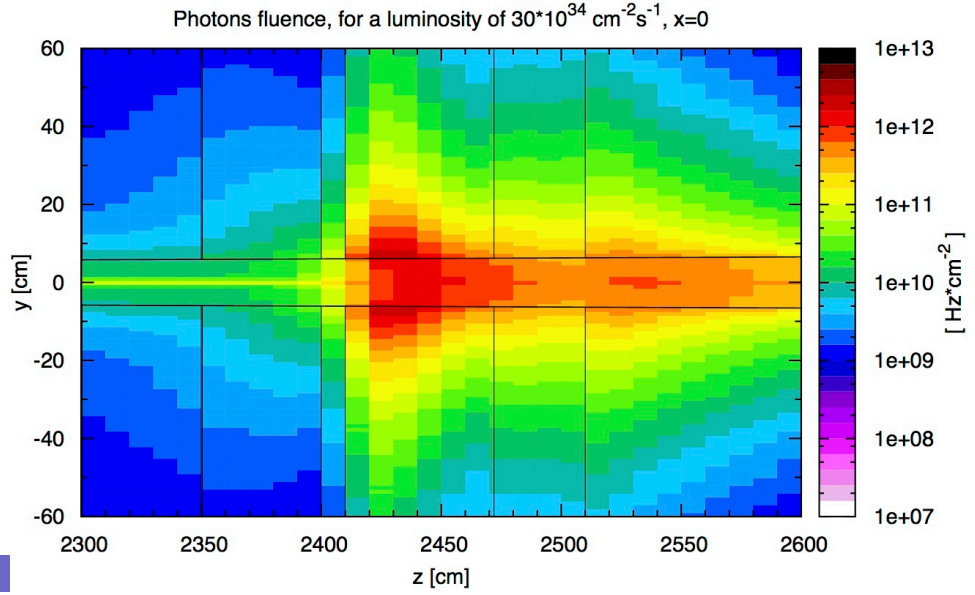




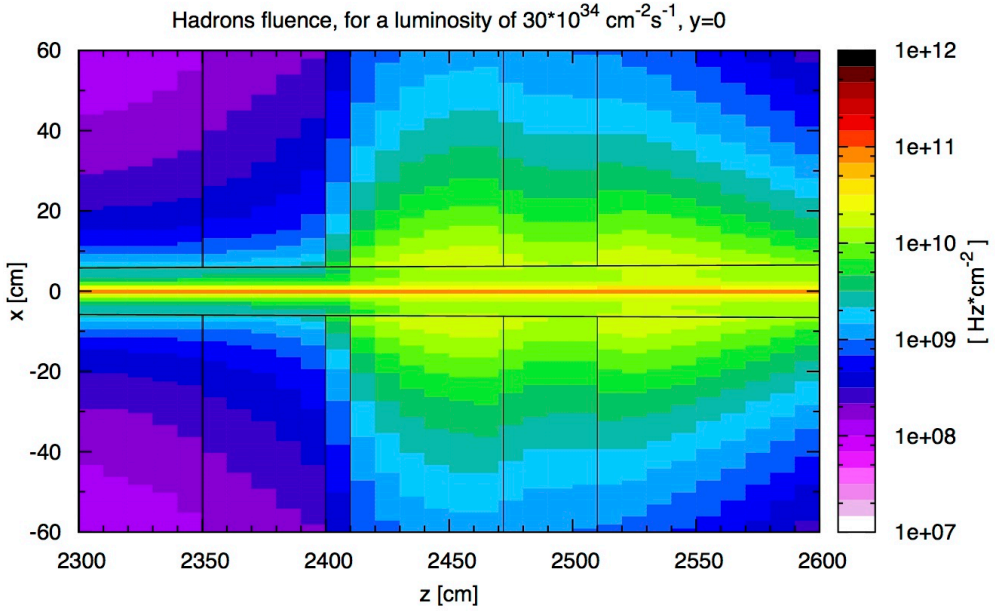
Photon Fluence Rate: Forward Calo

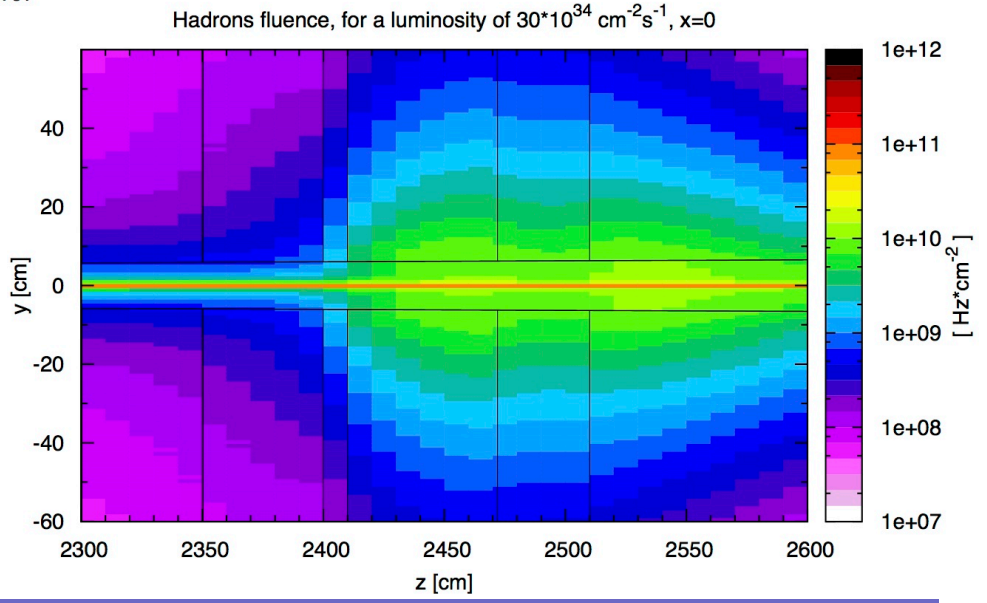






High Energy Hadron (> 20 MeV) Fluence Rate: Forward Calo





Dose: Forward Calorimeter