Detector Radiation Studies

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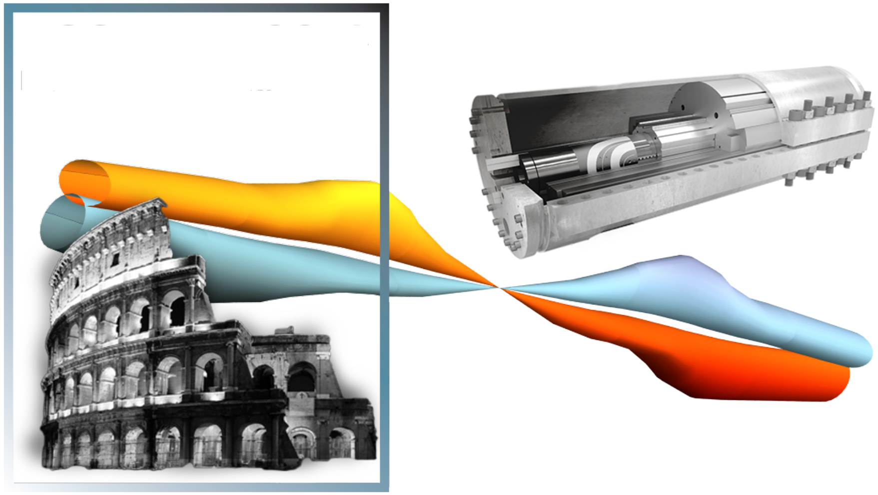

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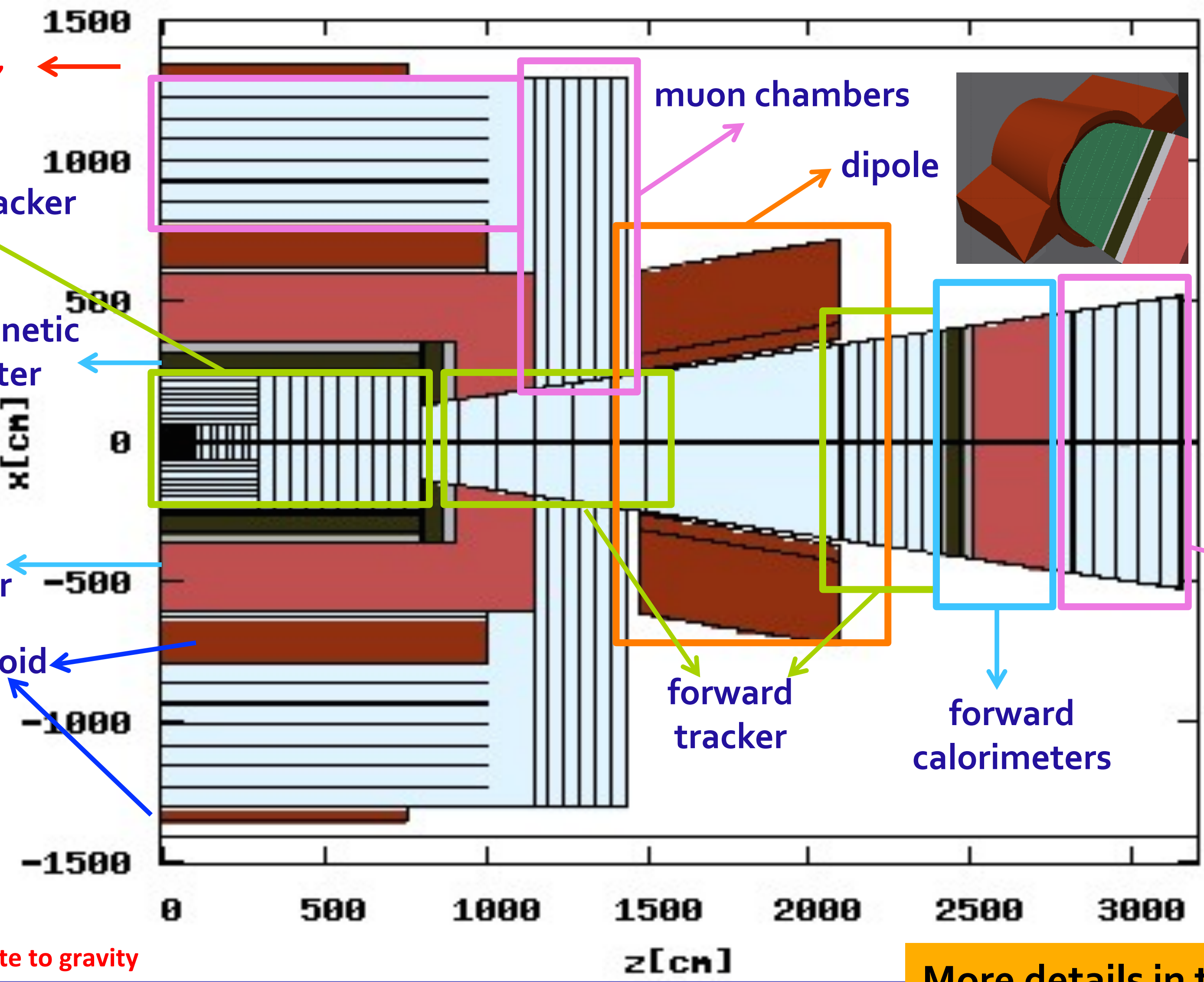
Outline

- Detector modeling by FLUKA:
  - geometry
  - magnetic field
- Radiation load on the detector:
  - all charged particle fluence rate
  - long term damage
    - 1 MeV neutron equivalent fluence
    - dose
- Shielding:
  - shielding in front of the forward calorimeter → effect on the tracking stations
  - shielding around the forward calorimeter → effect on the muon chambers
- Conclusions & Outlooks

Detector: Geometry



x axis on the horizontal plane, pointing outside the ring

central tracker

electromagnetic calorimeter

hadronic calorimeter

twin solenoid

muon chambers

dipole

forward tracker

forward calorimeters

forward muon chambers

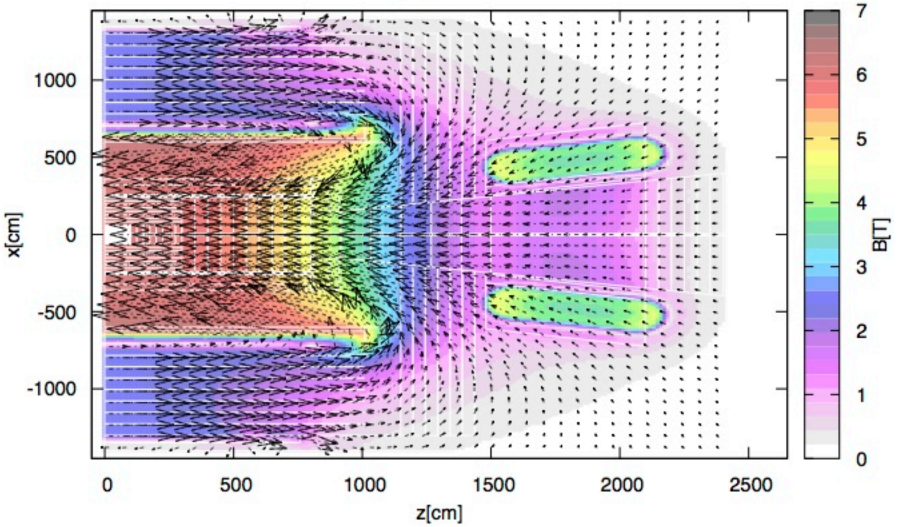
z axis along the beam

y axis opposite to gravity

More details in the back-up

Detector: Magnetic Field

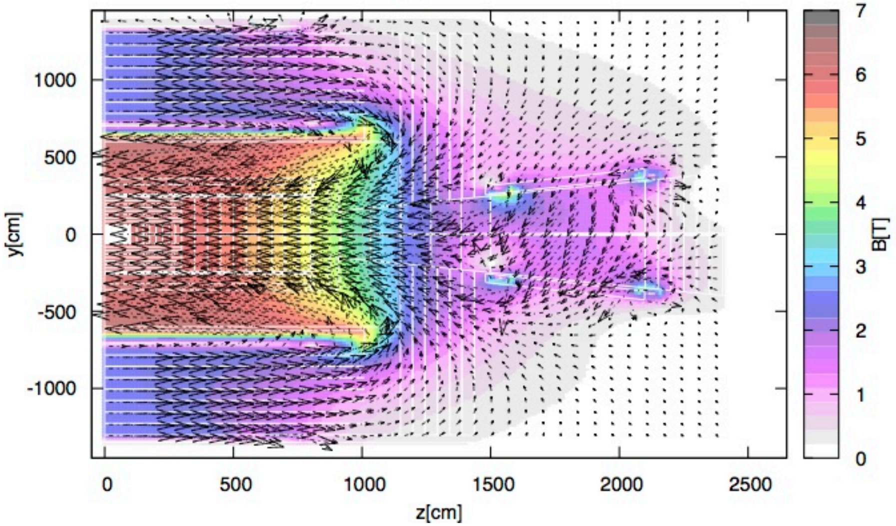
B[T], y=0 m



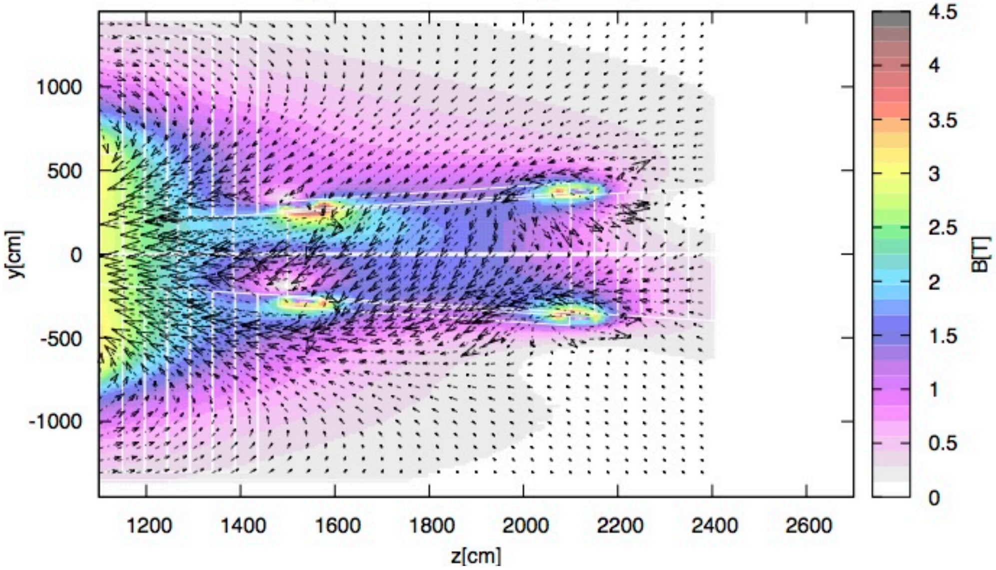
The magnetic field has been implemented:

- ❑ solenoid field directed along z in the central region
- ❑ dipole field directed along y in the forward region
- → the magnetic field in the dipole region has not only a y component, but also a z component
- → the magnetic field is higher for y>o

B[T], x=0 m



B[T], x=0 m, zoom on the dipole z region



Field map provided by Herman Ten Kate and Matthias Mentink

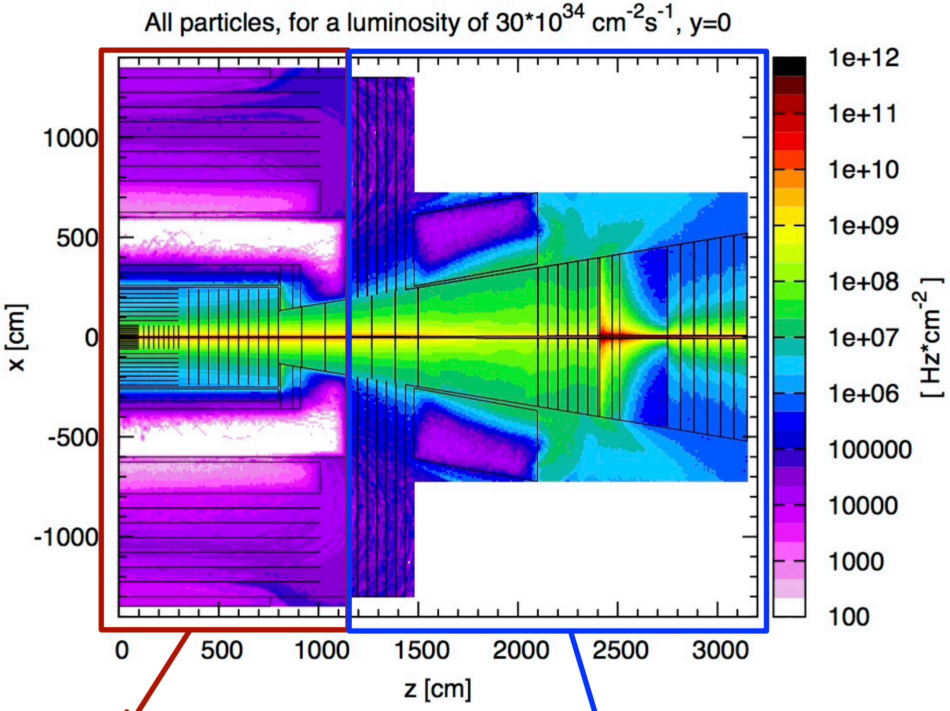
Details about the Simulation

- FLUKA simulations using DPMJET-III generator
  - c-hadrons included (b-hadrons and W/Z bosons are not included)

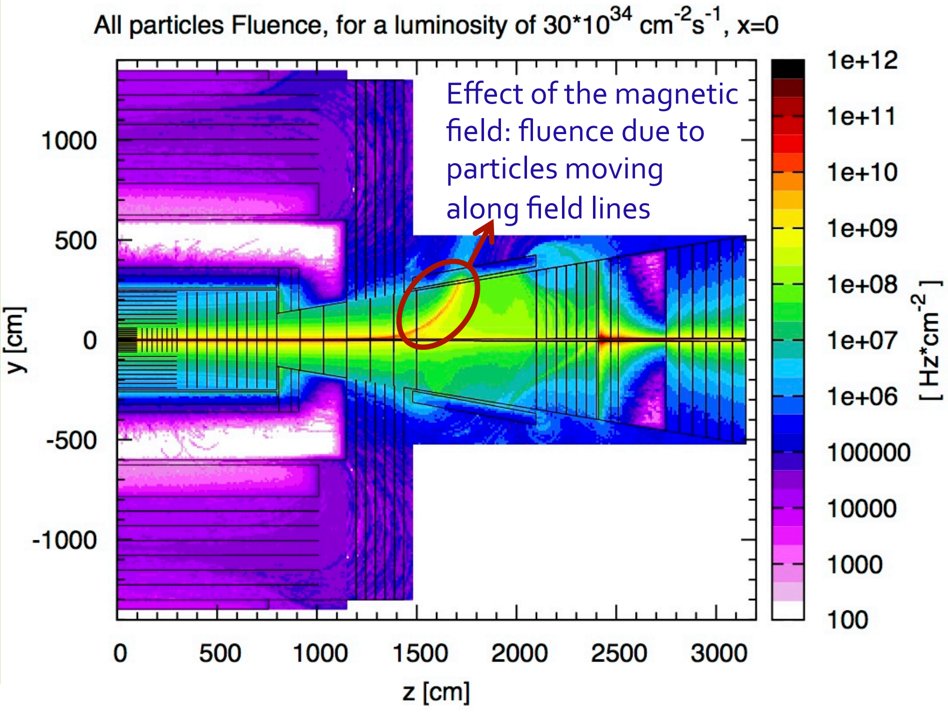
- Normalization:
  - non-elastic cross section of 108 mbarn
  - fluence rates [Hz cm^{-2}] for an instantaneous luminosity of 30 10^{34} $cm^{-2}s^{-1}$
  - 1 MeV neutron equivalent fluence [cm^{-2}] for an integrated luminosity of 30 ab^{-1}
  - dose [MGy] for an integrated luminosity of 30 ab^{-1}

- The contribution coming from the triplet protection absorber (TAS) has not been included in this simulation, since it is not in the cavern, but in the tunnel
  - it is expected to be adequately shielded by the cavern wall
  - this will be evaluated with future calculations

All Charged Particles Fluence Rate



All particles, for a luminosity of $30*10^{34}$ $cm^{-2}s^{-1}$, y=0



All particles Fluence, for a luminosity of $30*10^{34}$ $cm^{-2}s^{-1}$, x=0

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

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

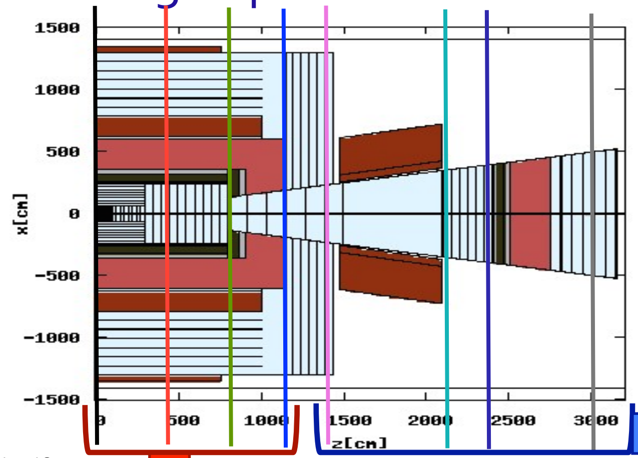
Forward region (x-y-z scoring):
average on a bin of 1 cm up to 0.6 m and on a 10 cm for larger values

	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}

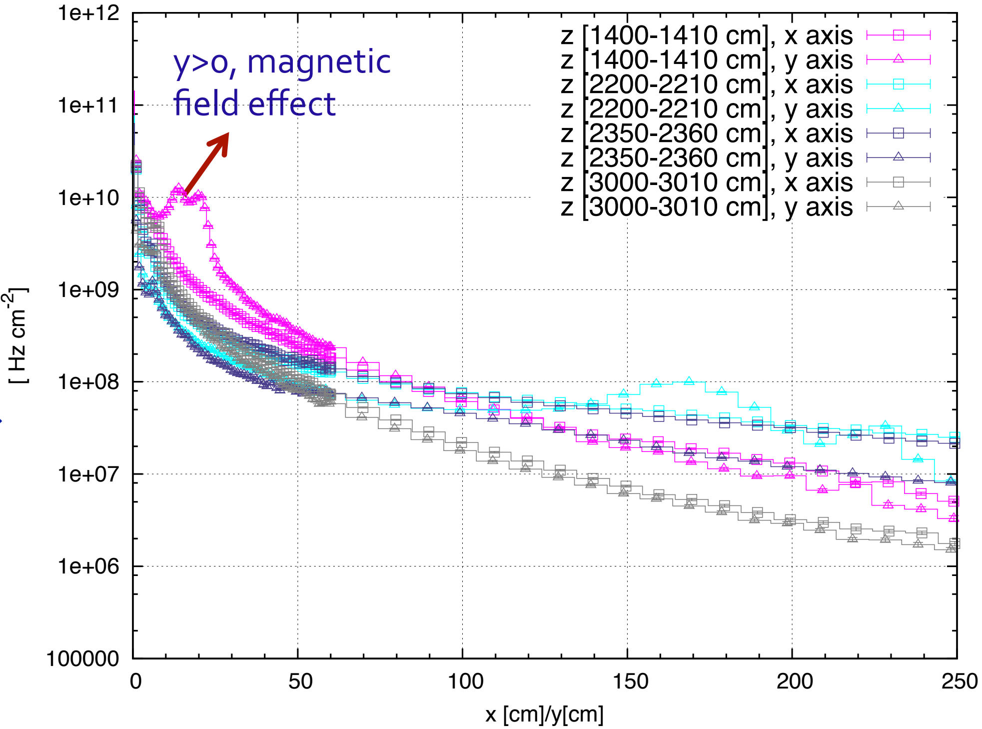
Too high values: shielding is needed!

Tracker

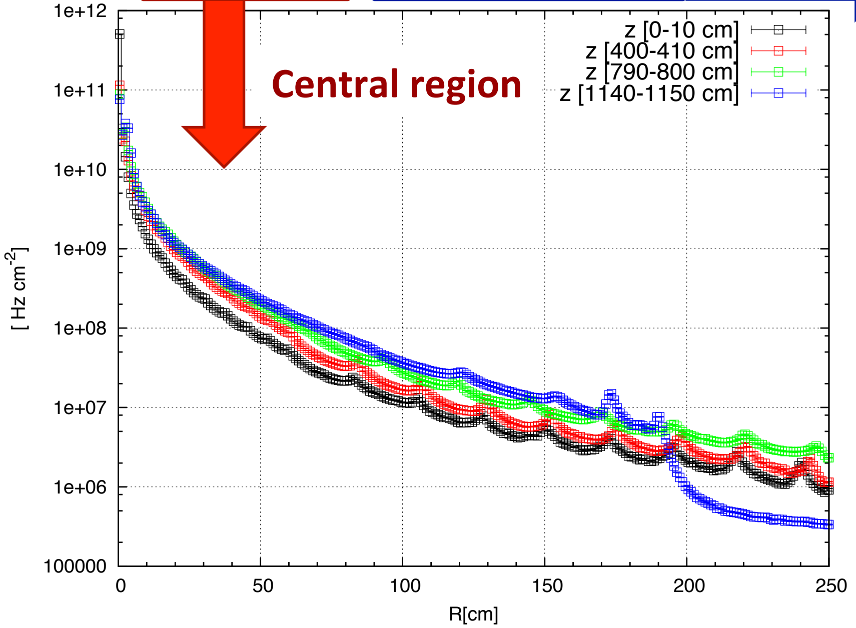
All charged particle fluence rate vs R, at different z positions i**n the tracker:**



Forward region



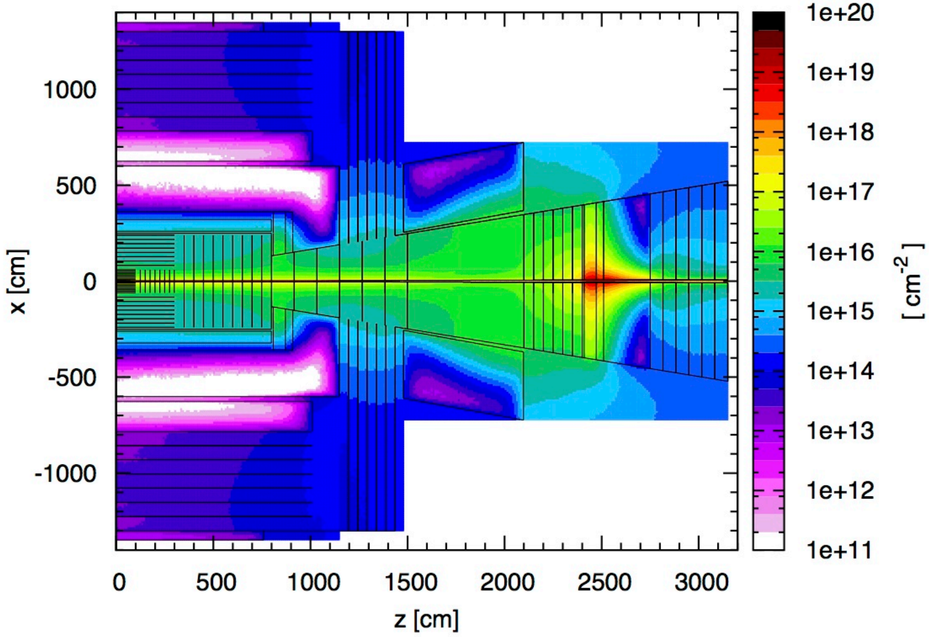
Central region

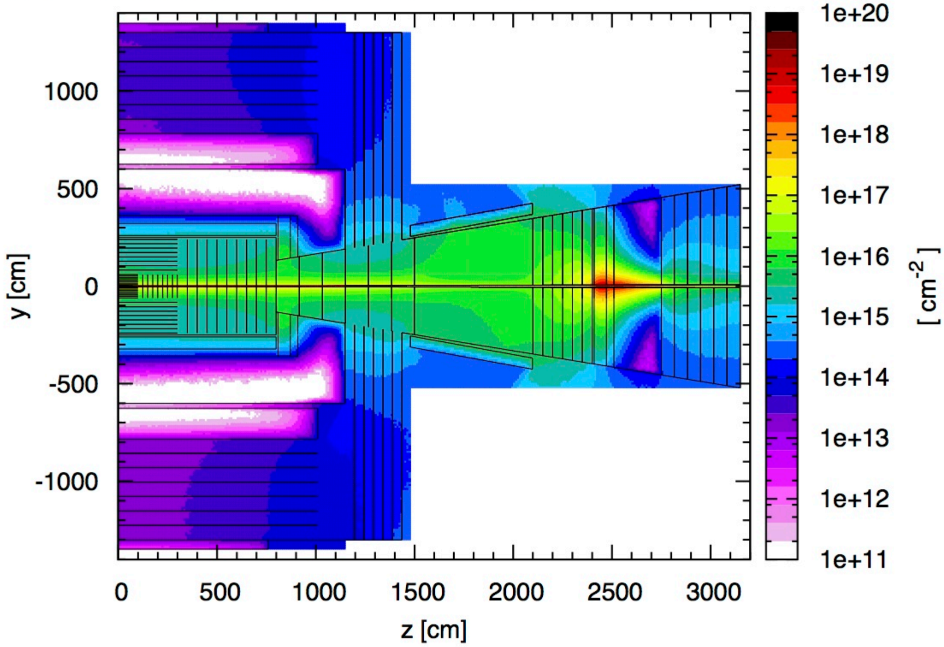


The fluence rates has a clear dependence on the radius, but a weak dependence on z

1 MeV Neutron Equivalent Fluence

Long term damage:


1 MeV Neutron Equivalent Fluence after an integrated luminosity of 30 ab^{-1}, y=0


1 MeV Neutron Equivalent Fluence after an integrated luminosity of 30 ab^{-1}, x=0

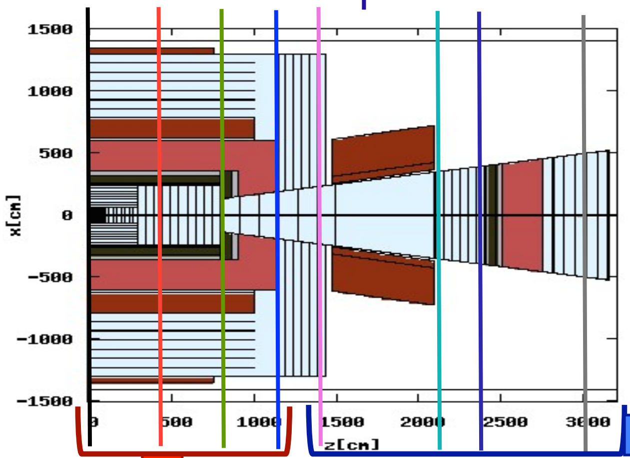
	Fluence [cm^{-2}]
first layer of the IB (R =2.5 cm)	~ 8 10^{17}
max in forward detector	7 10^{18}
max barrel muon chambers	~10^{14}
max end-cap muon chambers	3 10^{15}

The forward detector is a source of neutrons, which repopulate the muon chambers: a proper shielding is needed!

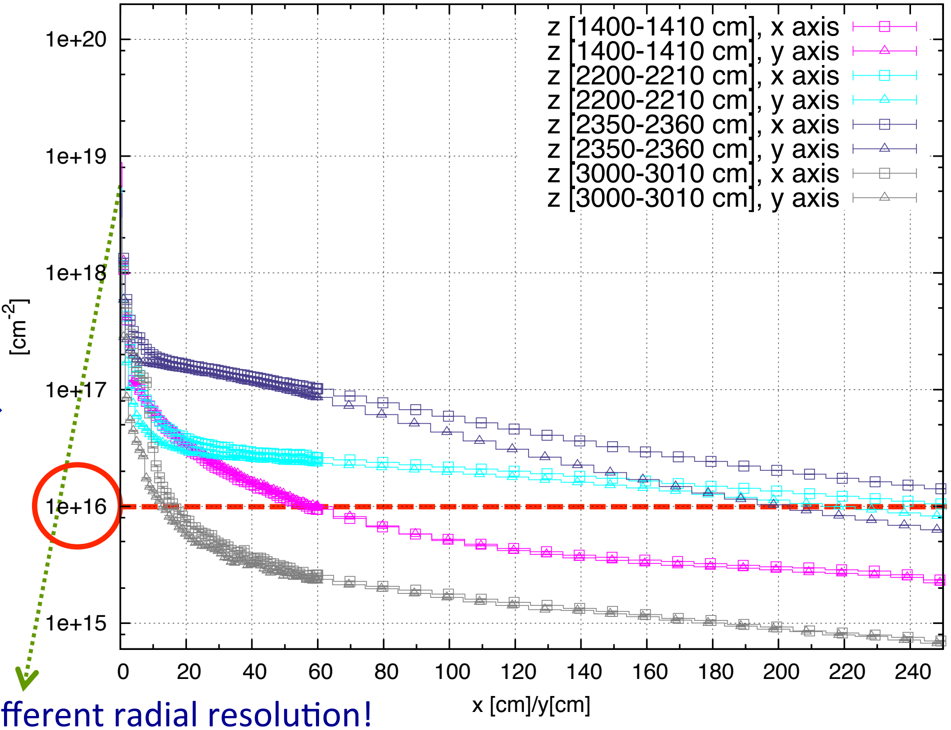
Too high values!

Tracker

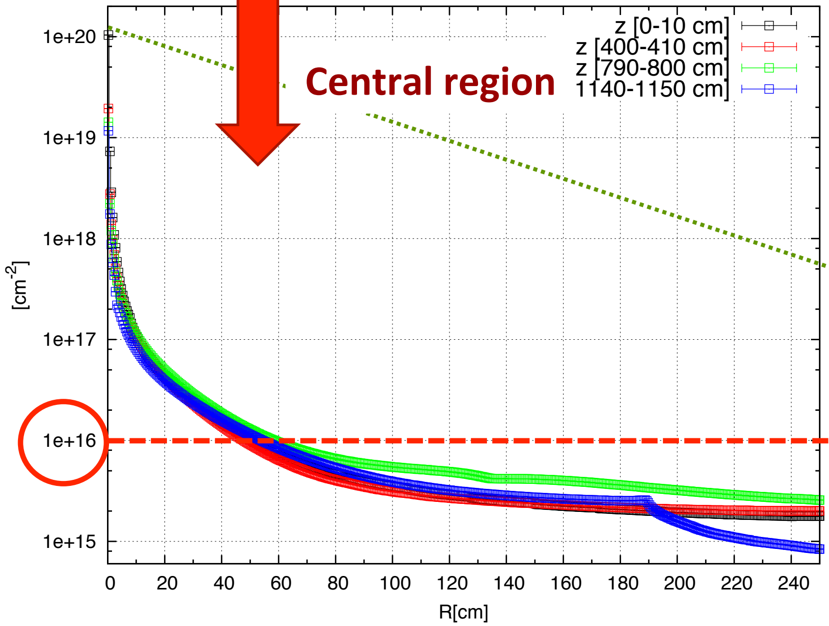
1 MeV neutron equivalent fluence vs R at different z positions i**n the tracker:**



Forward region



Central region

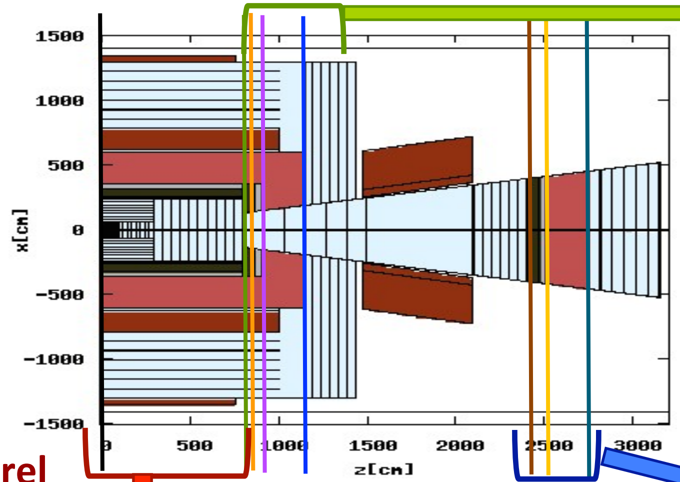


Different radial resolution!

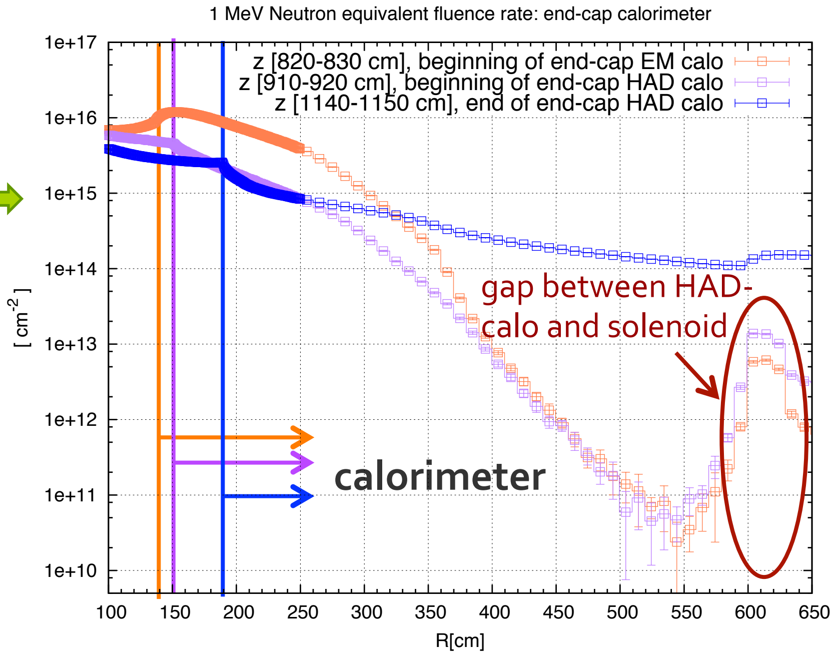
For radii < 50 cm the fluence exceed the value expected at HL-LHC (10^{16} cm^{-2}) by up to 2 orders of magnitude → **Technology challenge!**

Fluence is even higher close to forward calorimeter: at z= 23.5 m the fluence vs x > 10^{16} cm^{-2} for x<2.5 m

Calorimeters

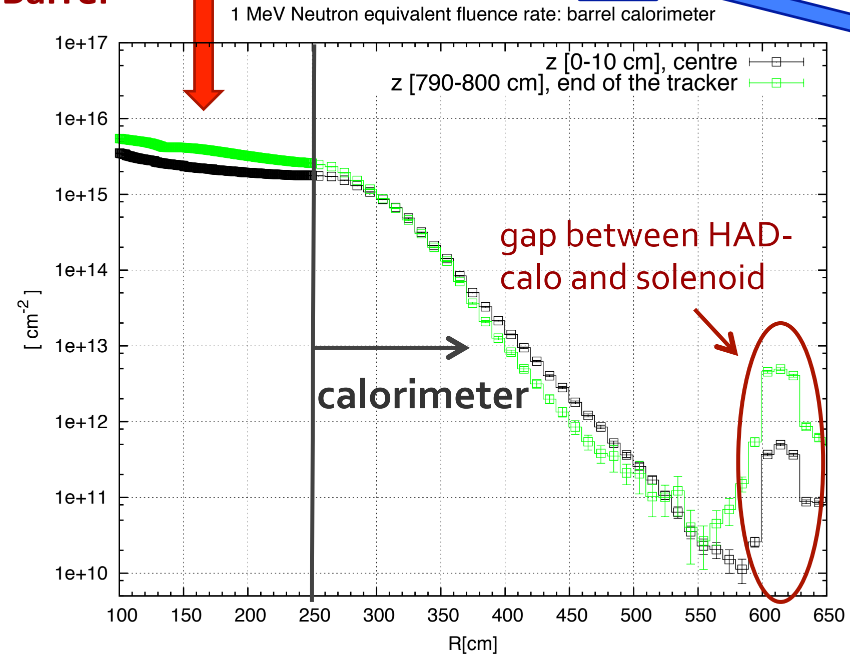


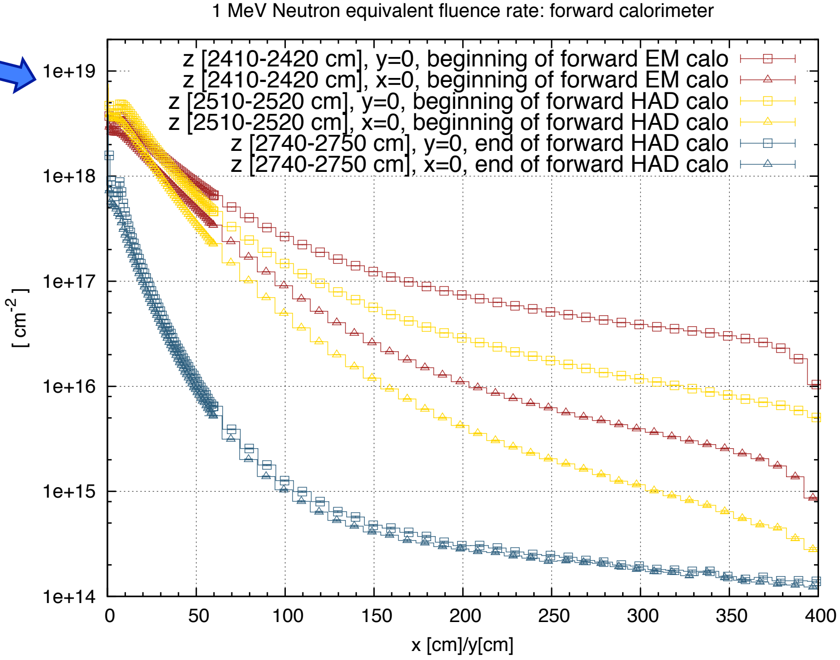
End-cap


1 MeV Neutron equivalent fluence rate: end-cap calorimeter

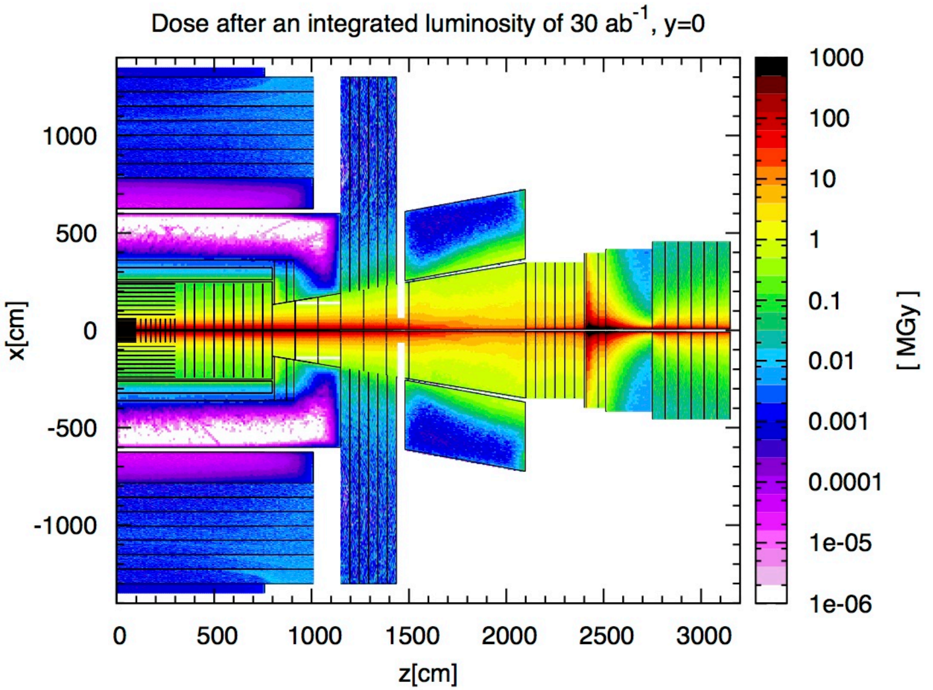
Forward

Barrel

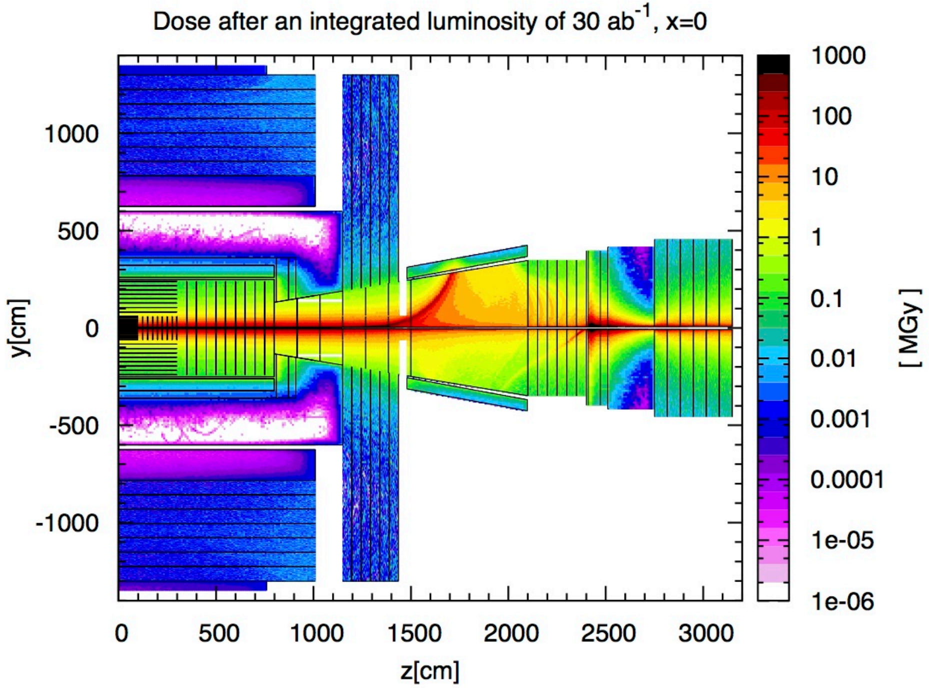

1 MeV Neutron equivalent fluence rate: barrel calorimeter


1 MeV Neutron equivalent fluence rate: forward calorimeter

Dose



Dose after an integrated luminosity of 30 ab^{-1}, y=0

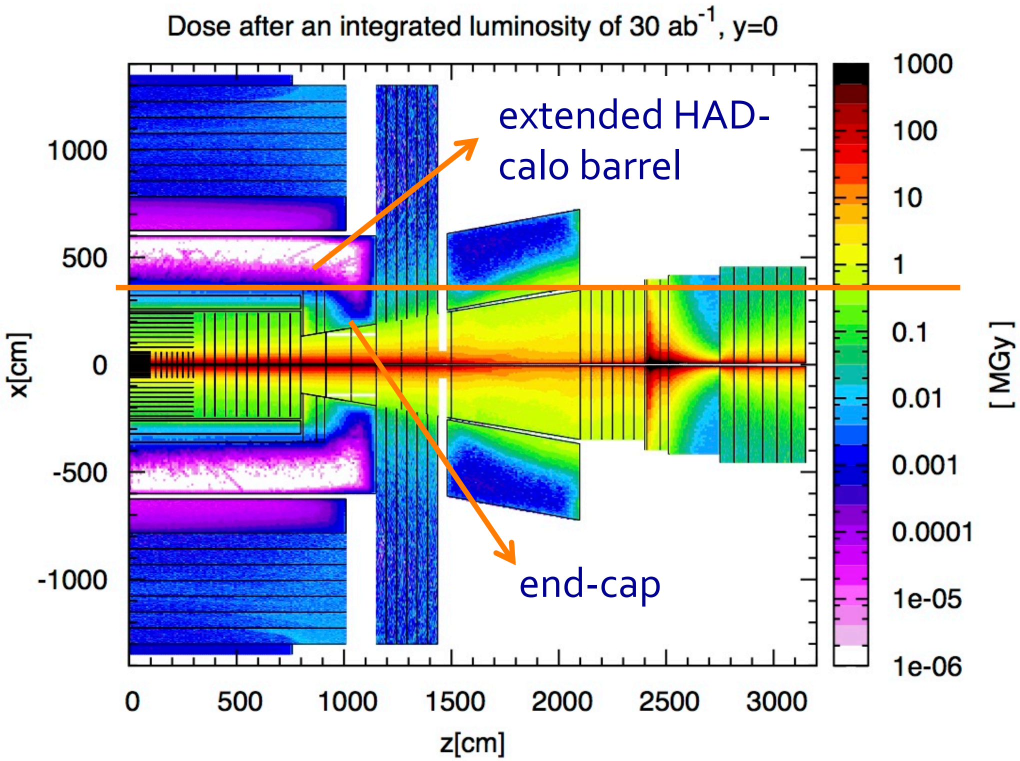


Dose after an integrated luminosity of 30 ab^{-1}, x=0

	Dose [MGy]
first layer of the IB (R =2.5 cm)	600
max in forward detector	10^4
max end-cap had-calorimeter	0.4

Too high value for scintillator technology

Dose



End-cap calorimeter technology:

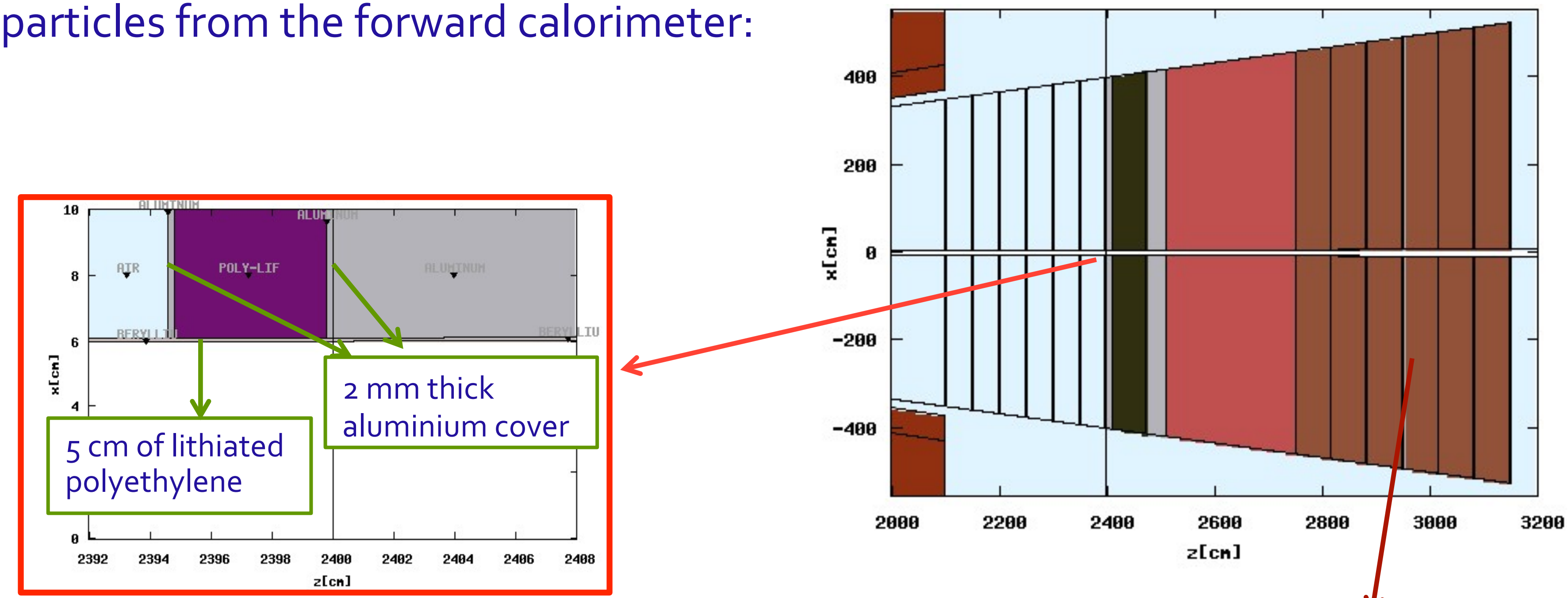
- ☐ extended hadronic calorimeter barrel for R>3.6 m up to z = 10.5 m using scintillator detector
- ☐ for R < 3.6 m liquid argon hadronic calorimeter

	Dose [MGy]
first layer of the IB (R =2.5 cm)	600
max in forward detector	10^4
max end-cap had-calorimeter	0.4
end-cap had-calorimeter R > 3.6 m	0.002(*)

(*) end cap face 0.01 MGy

Shielding Design I

Shielding in front of the forward calorimeter to protect tracking stations from particles from the forward calorimeter:

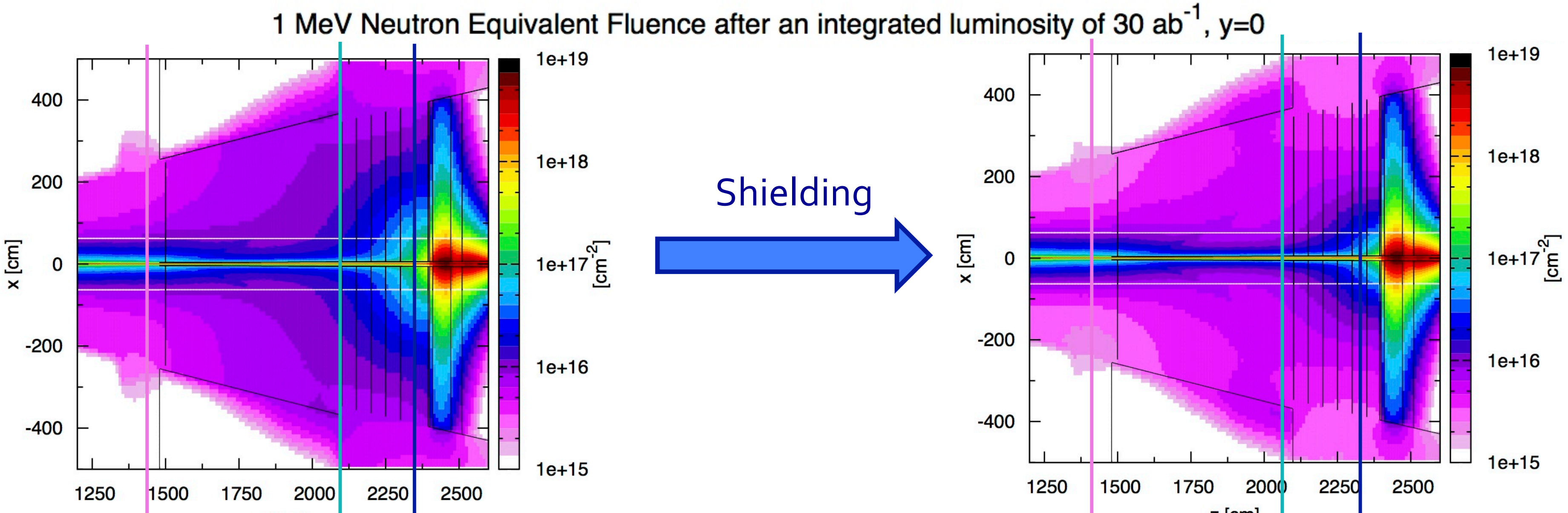


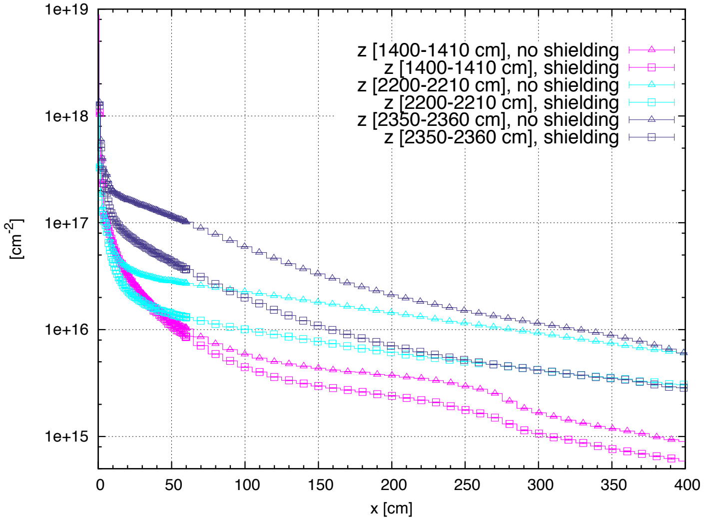
2 mm thick aluminium cover

5 cm of lithiated polyethylene

Iron between muon chambers to filter the particles as it is done in LHCb

Effect of the Shielding in the Tracker


1 MeV Neutron Equivalent Fluence after an integrated luminosity of 30 ab^{-1}, y=0

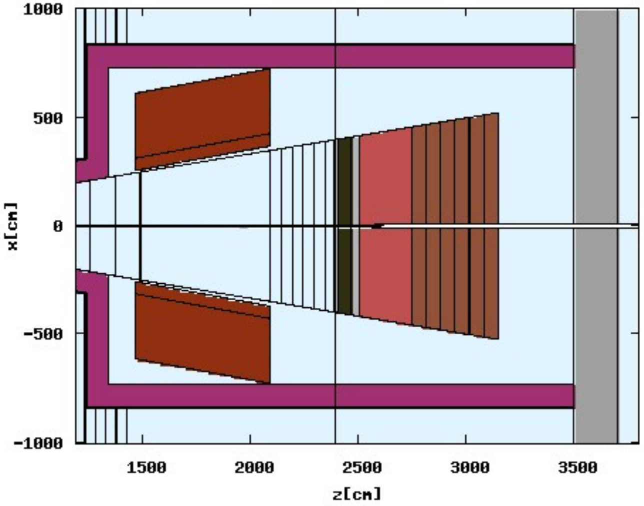


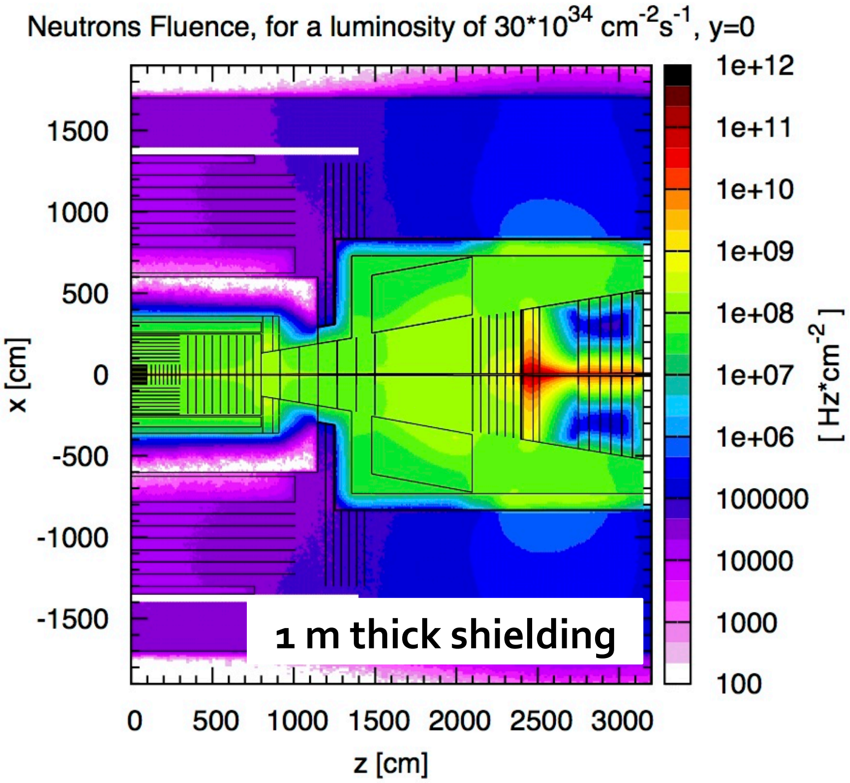
In the tracking station close to the forward calorimeter the gain is about a factor of 3.

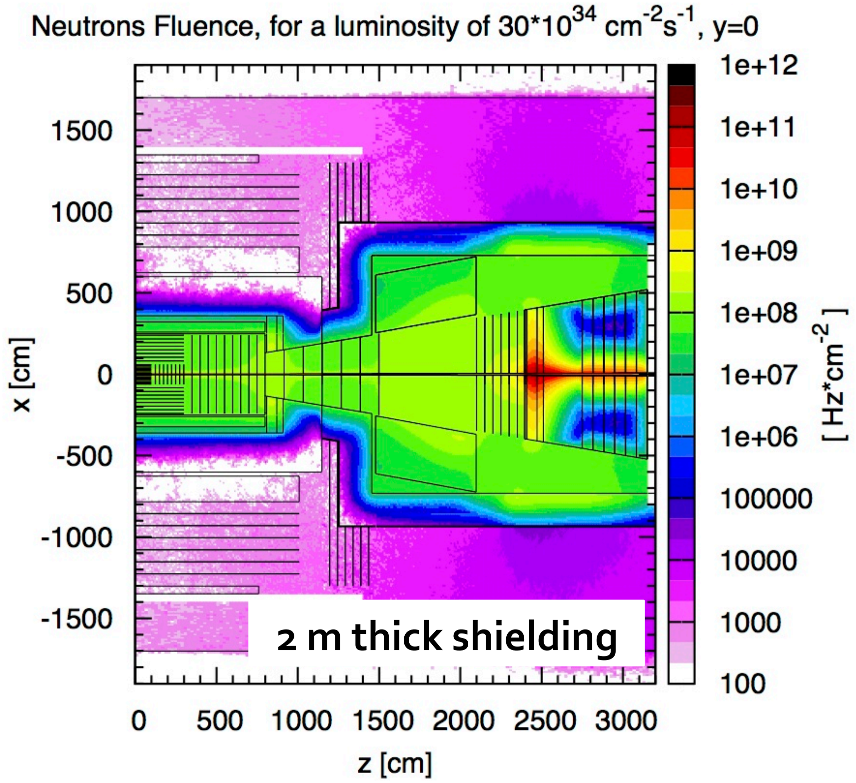
Shielding Design II

Shielding around the forward calorimeter, composed by:

- iron to attenuate high-energy particles:
  - different thicknesses considered: 1 m and 2 m
- 5 cm of lithiated polyethylene to slow down and capture neutrons
- 1 cm of lead to absorb photons



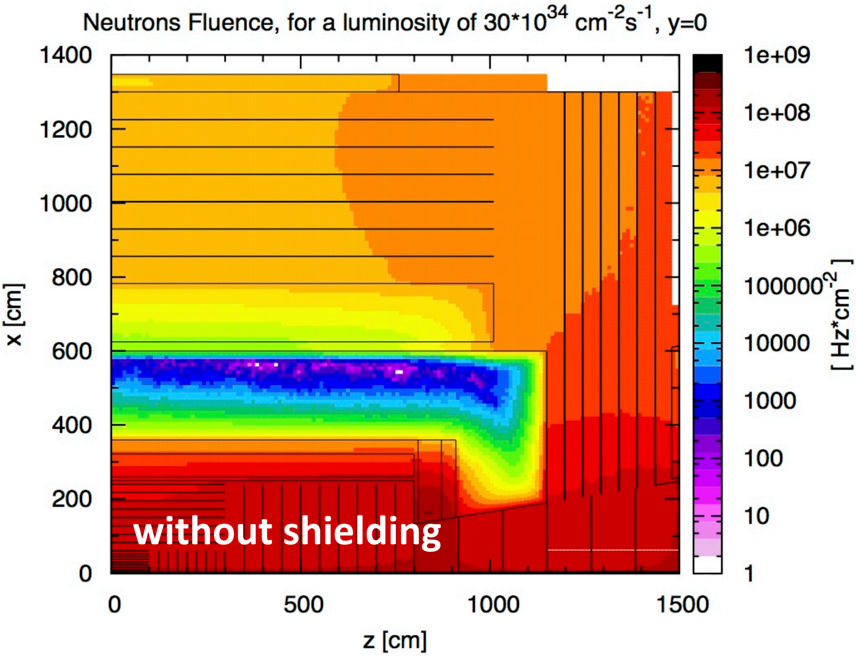


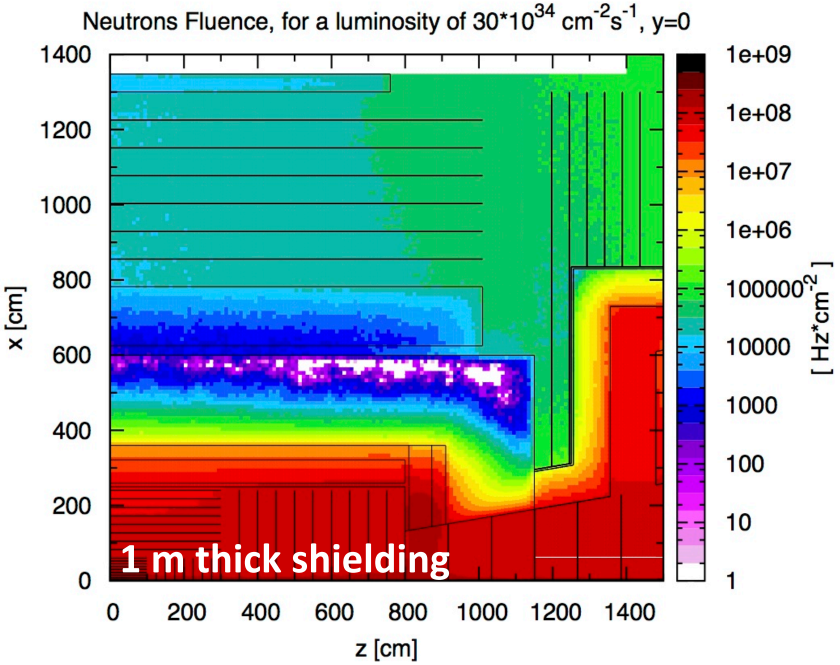


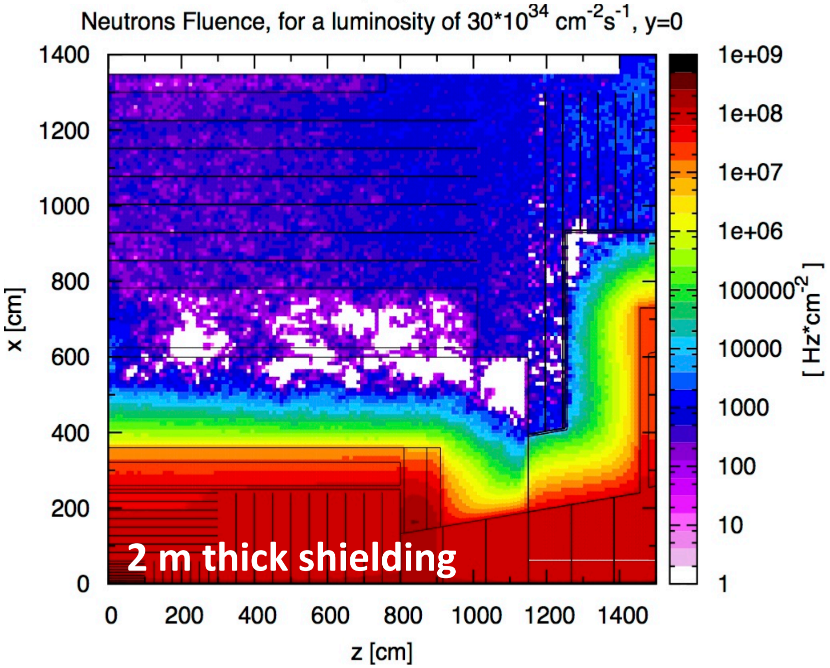
Neutron Fluence Rate

	Barrel Fluence rates [Hz cm^{-2}]	End Cap fluence rates [Hz cm^{-2}]
no shielding	10^7	> 10^8
1 m shielding	4 10^4	2 10^5
2 m shielding	~2 10^3	10^4

Neutron interaction probability in the muon chambers of ~0.1% → acceptable values ~ 10 Hz cm^{-2}



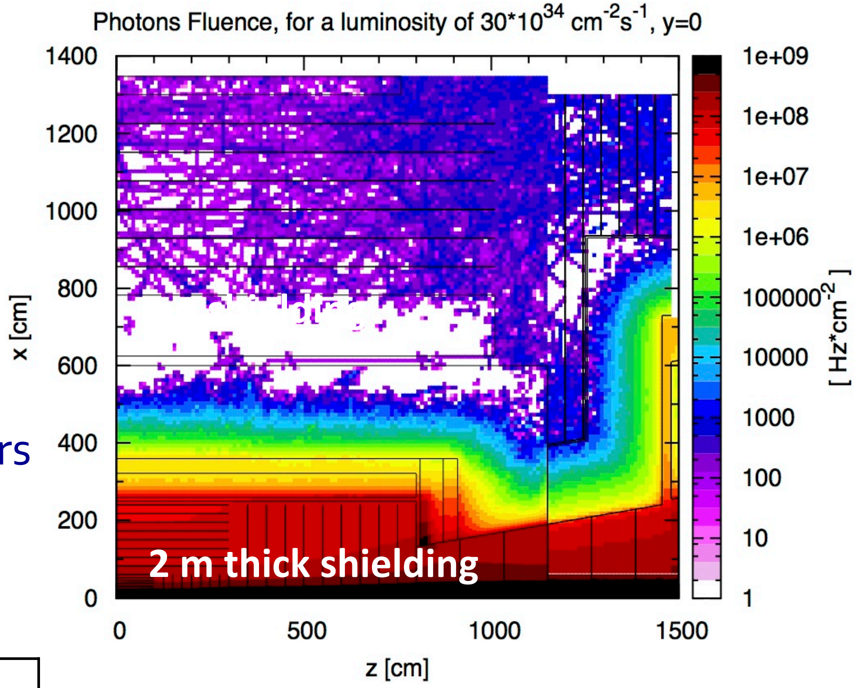




Photon & Charged Particle Fluence Rates

Photons:

	Barrel Fluence rates [Hz cm^{-2}]	End Cap fluence rates [Hz cm^{-2}]
no shielding	$5\ 10^6$	10^8
1 m shielding	$2\ 10^4$	$5\ 10^4$
2 m shielding	$< 10^3$	$2\ 10^3$



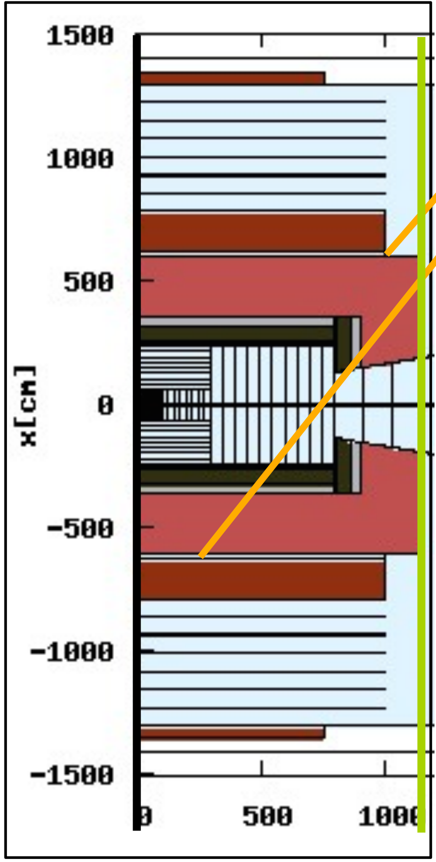
Photon interaction probability in the muon chambers ~1% → acceptable values up to 20 Hz cm^{-2}

All charged particles:

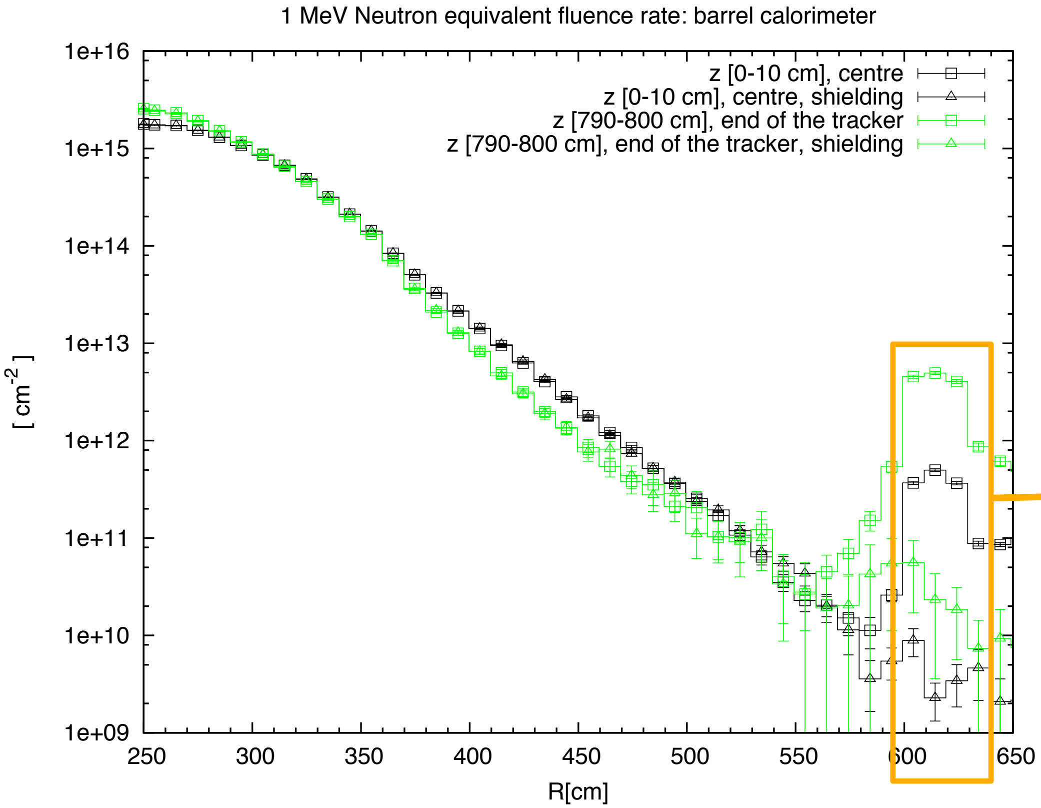
	Barrel Fluence rates [Hz cm^{-2}]	End Cap fluence rates [Hz cm^{-2}]
no shielding	$2\ 10^5$	10^6
1 m shielding	500	$<10^3$
2 m shielding(*)	~50	<100

(*) Work in progress: Monte Carlo statistics for all charged particles is low in the muon chambers region.

Effect of the Shielding on Read-Out Electronics



- Read-out electronics is expected to be put behind the hadronic calorimeter, in the free space between the calorimeter and the solenoid.
- The shielding around the forward calorimeter has an effect in reducing the fluence values in the gap region.



In the gap: the fluence is reduced by about 2 orders of magnitude

Conclusions and Outlooks

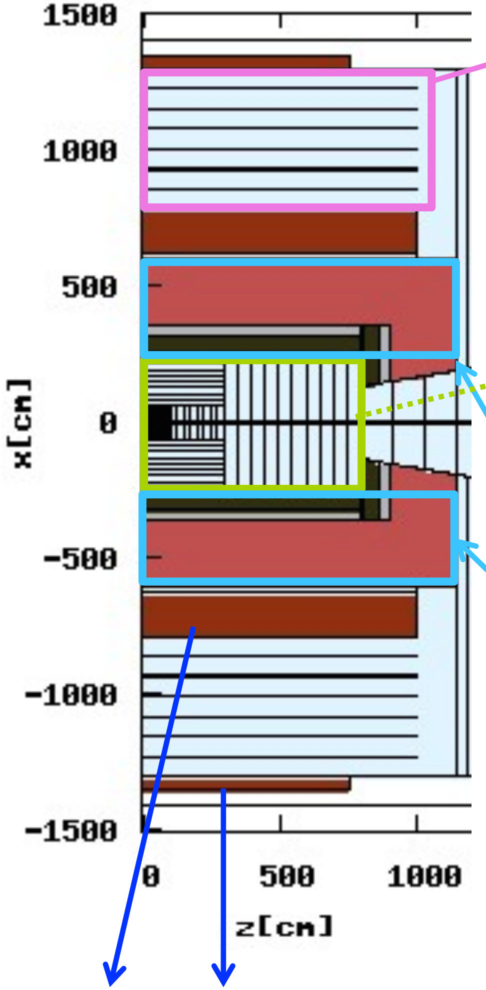
- **Conclusions:**
  - a first concept of the detector has been implemented in the FLUKA geometry
  - radiation load has been assessed in terms of
    - fluence rates → tracker occupancy studies
      - all charged particles, photons and neutrons fluence rates, but also charged hadrons and high energy hadrons fluence rates
    - 1 MeV neutron equivalent fluence
    - dose
  - two shieldings have been conceived to protect forward tracking stations, muon chambers and electronics
    - their conceptual design is effective: the fluence rate values obtained are manageable

- **Outlooks:**
  - the detector design needs to be further optimized to find the best compromise between cost and performance
  - alternative designs are under study:
    - ex. replace the forward dipoles with solenoids → impact on the triplet design

Thanks for your attention

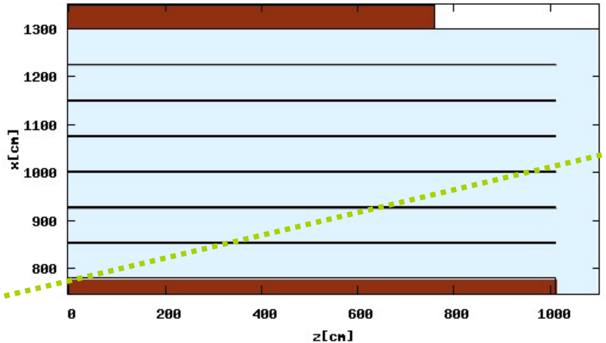
Back-up

Detector Geometry: Material



Twin Solenoid

Muon Detector

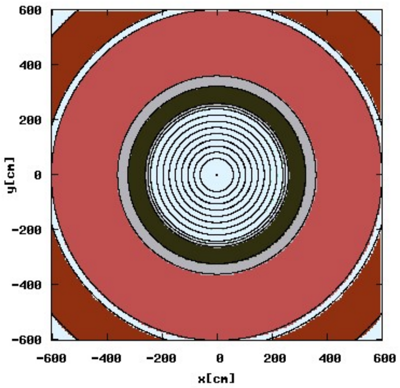


1.5 cm thick aluminum layers:

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

EM calorimeter

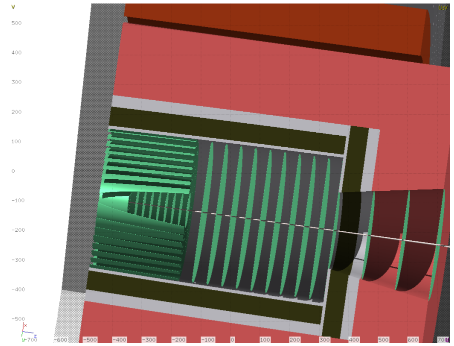
- 10 cm aluminum
- 62 cm (LArg 64.8%, Pb 21%, Cu 7.2%, Polystyrene 6.3%)
- 38 cm aluminum

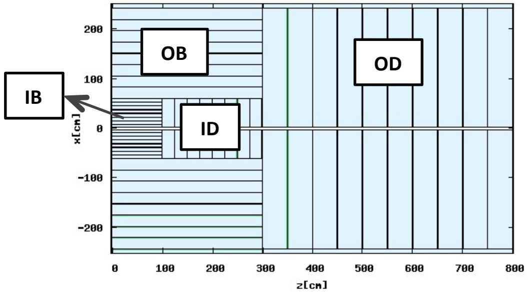


HAD calorimeter

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%

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.

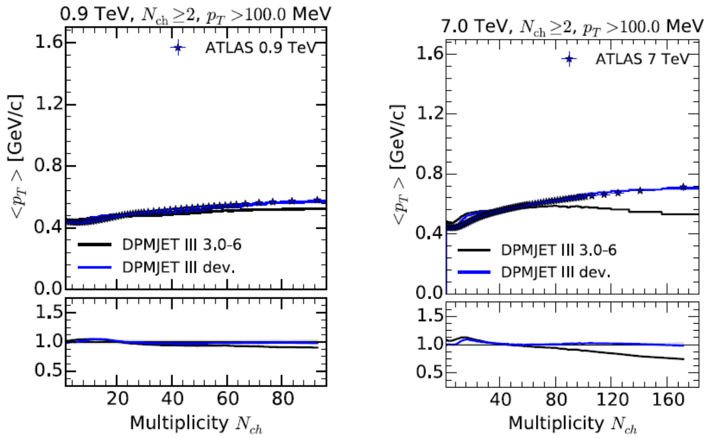
- Monte Carlo generator has been further developed →
  - all Regge parameters re-fitted to match cross-sections from low energy up to LHC as good as possible
  - improved hard scattering model
  - new particle distribution functions implemented

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

ATLAS average p_T

900 GeV

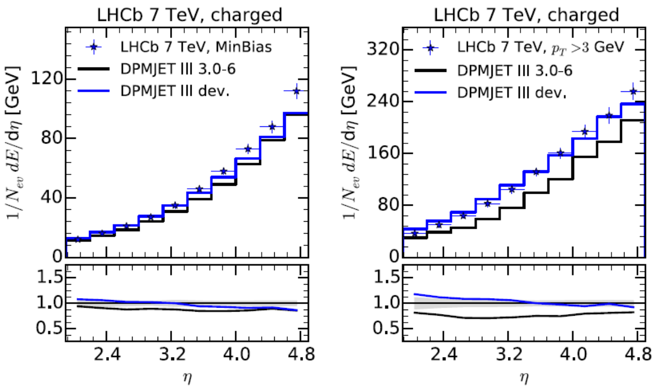
7 TeV



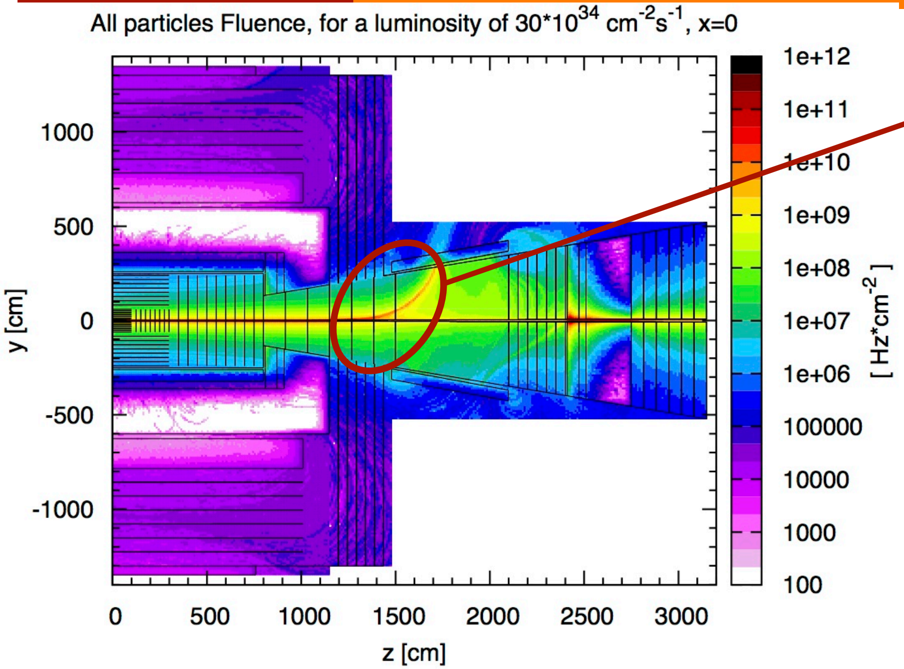
LHCb forward energy flow

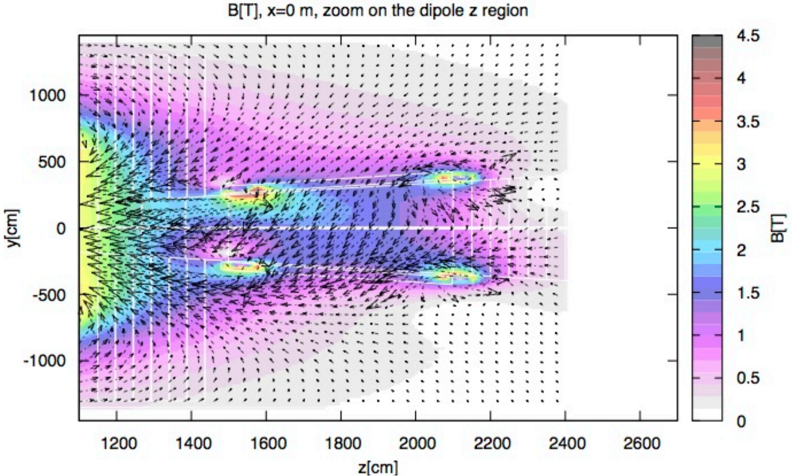
Minimum Bias

hard p_T



Effect of the dipole Field





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

Without magnetic field: