Radiation Environment

M. I. Besana, F. Cerutti, A. Ferrari, V. Vlachoudis - EN-STI-FDA
W. Riegler - EP-AIO

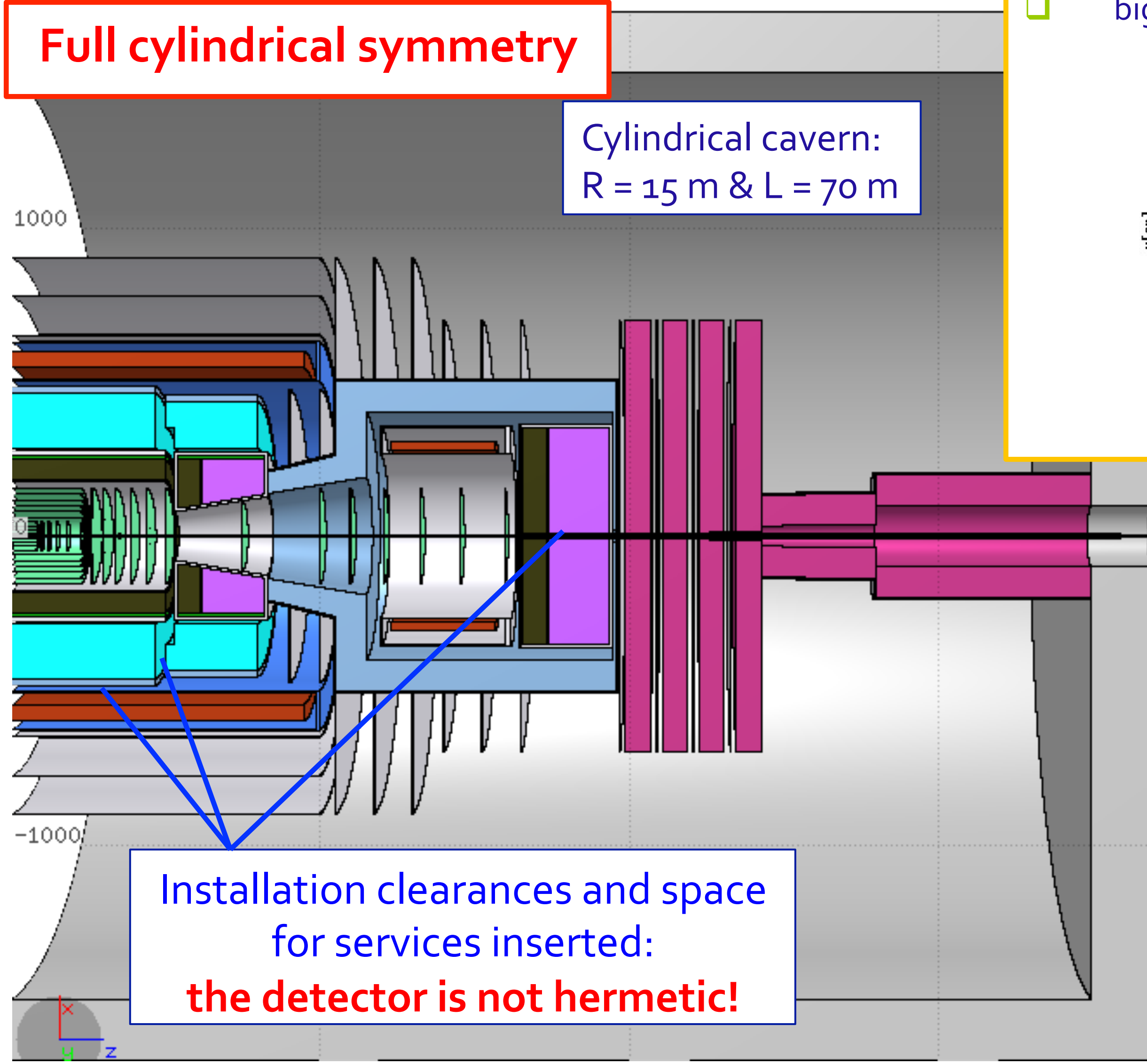
Outline

- Detector geometry:
  - conceptual design for a forward shielding
- Radiation levels:
  - effect of the shielding: neutron fluence rate
  - charged particle fluence rate
  - 1 MeV neutron equivalent fluence
  - dose
- Alternative geometry:
  - forward calorimeter split into “forward” and “very forward” part
  - forward muon sub-detector: reduced angular acceptance, but space for a thicker inner iron shielding
  - performance quantified in terms of:
    - 1 MeV neutron equivalent fluence in the forward tracking stations
    - charged particle fluence rates in the forward muon chambers
- Conclusions & Outlooks

Detector Geometry I

Full cylindrical symmetry

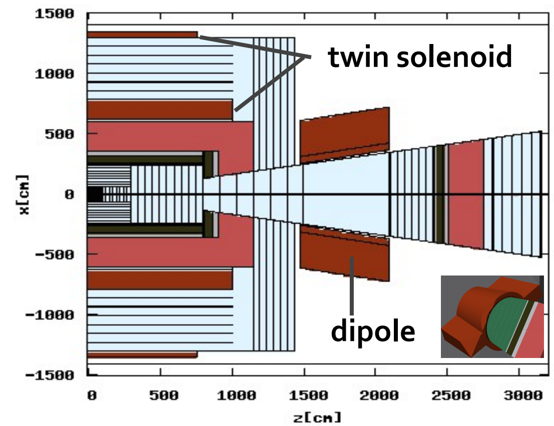
Cylindrical cavern:
R = 15 m & L = 70 m



Installation clearances and space for services inserted:
the detector is not hermetic!

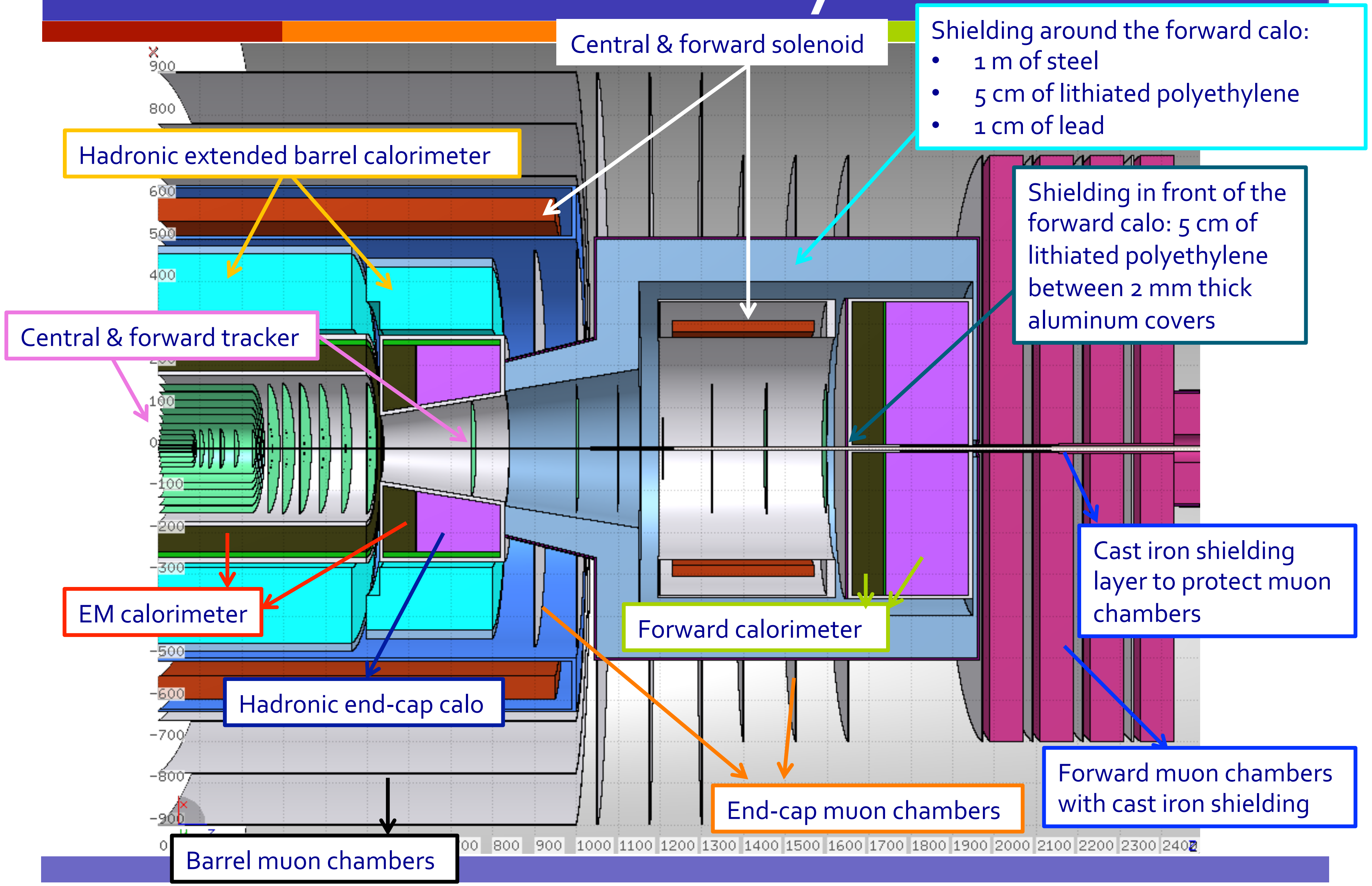
Old concept:

- solenoid+dipole field: no cylindrical symmetry
- bigger and hermetic detector

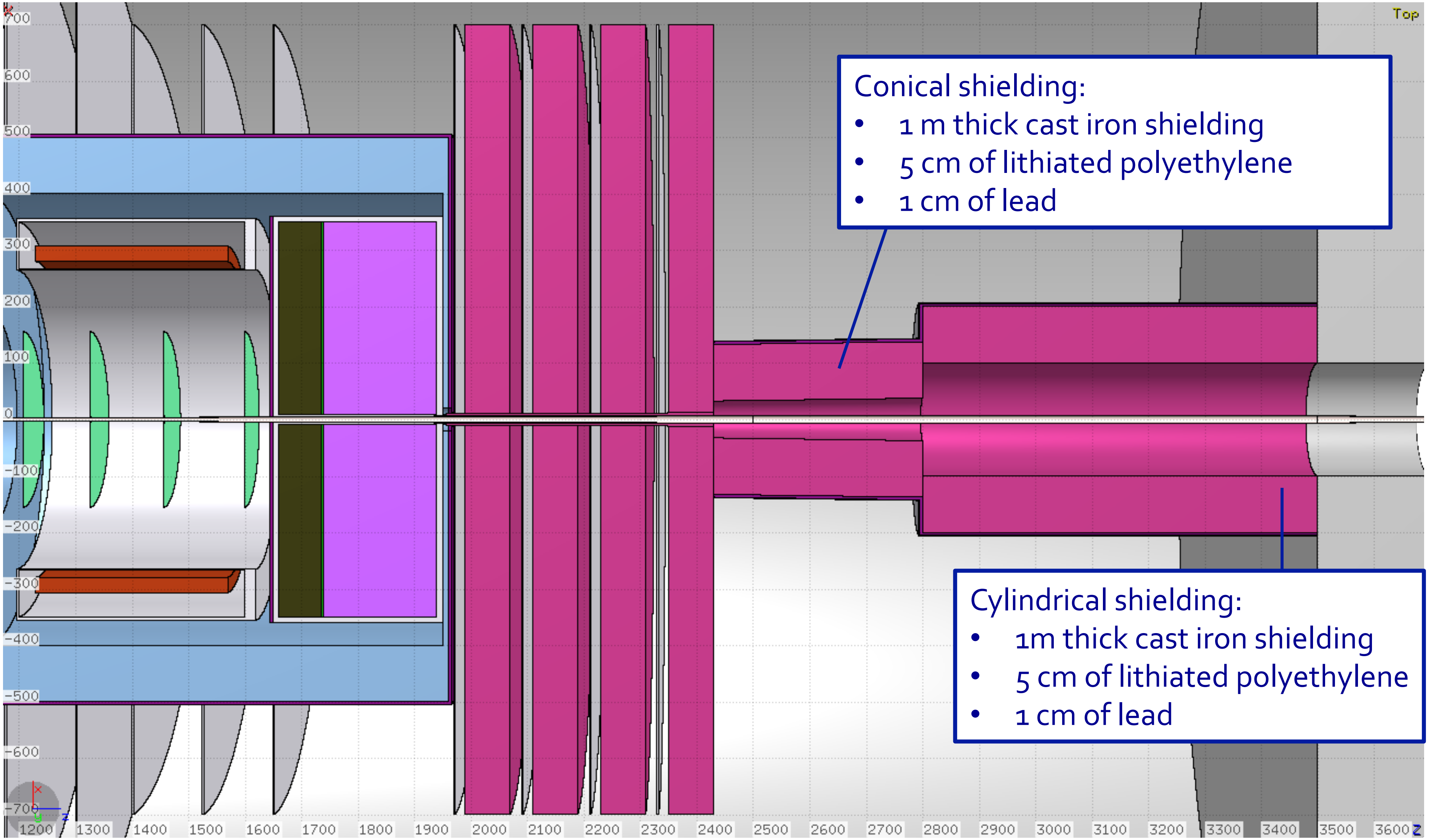


L* = 45 m, the TAS absorber is put from 40 m to 43 m behind a 2 m thick concrete wall

Detector Geometry II



Shielding in the Forward Region



Conical shielding:

- 1 m thick cast iron shielding
- 5 cm of lithiated polyethylene
- 1 cm of lead

Cylindrical shielding:

- 1m thick cast iron shielding
- 5 cm of lithiated polyethylene
- 1 cm of lead

Details about the Simulation

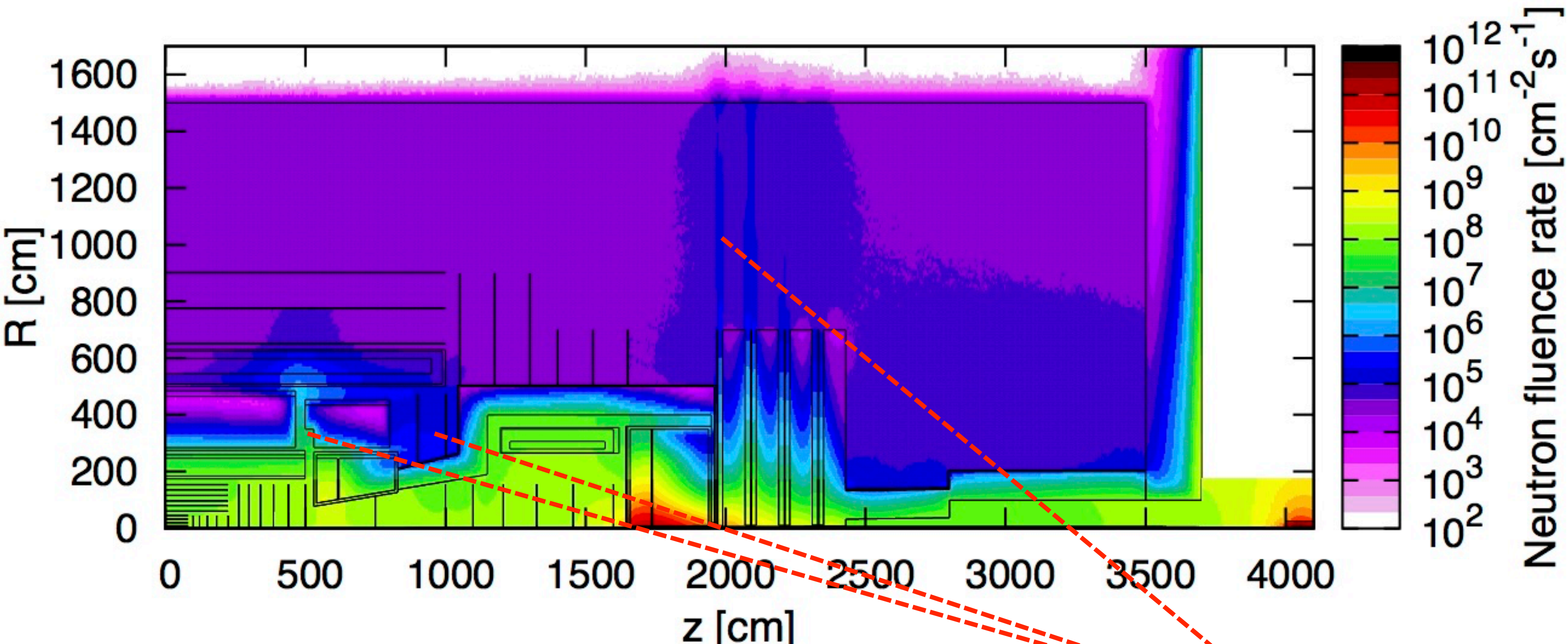
- FLUKA simulations using DPMJET-III generator
  - c-hadrons included (b-hadrons and W/Z bosons are not included)

- Normalization:
  - non-elastic proton-proton cross section at 100 TeV of 108 mbarn
  - fluence rates [$cm^{-2}s^{-1}$] for an instantaneous luminosity of $30\ 10^{34}\ cm^{-2}s^{-1}$
  - 1 MeV neutron equivalent fluence [cm^{-2}] and dose [MGy] for an integrated luminosity of 30 ab^{-1}

- Resolution:
  - inner part (R < 175 cm, z < 37 m): R x z: 5 mm x 5 cm
  - external part (R > 175 cm, z < 37 m): R x z: 10 cm x 5 cm
  - forward part (R < 350 cm, 37 m < z < 47 m): R x z: 5 mm x 10 cm

- The contribution coming from the TAS has been included in this simulation
  - NEW! Not included in the previous results

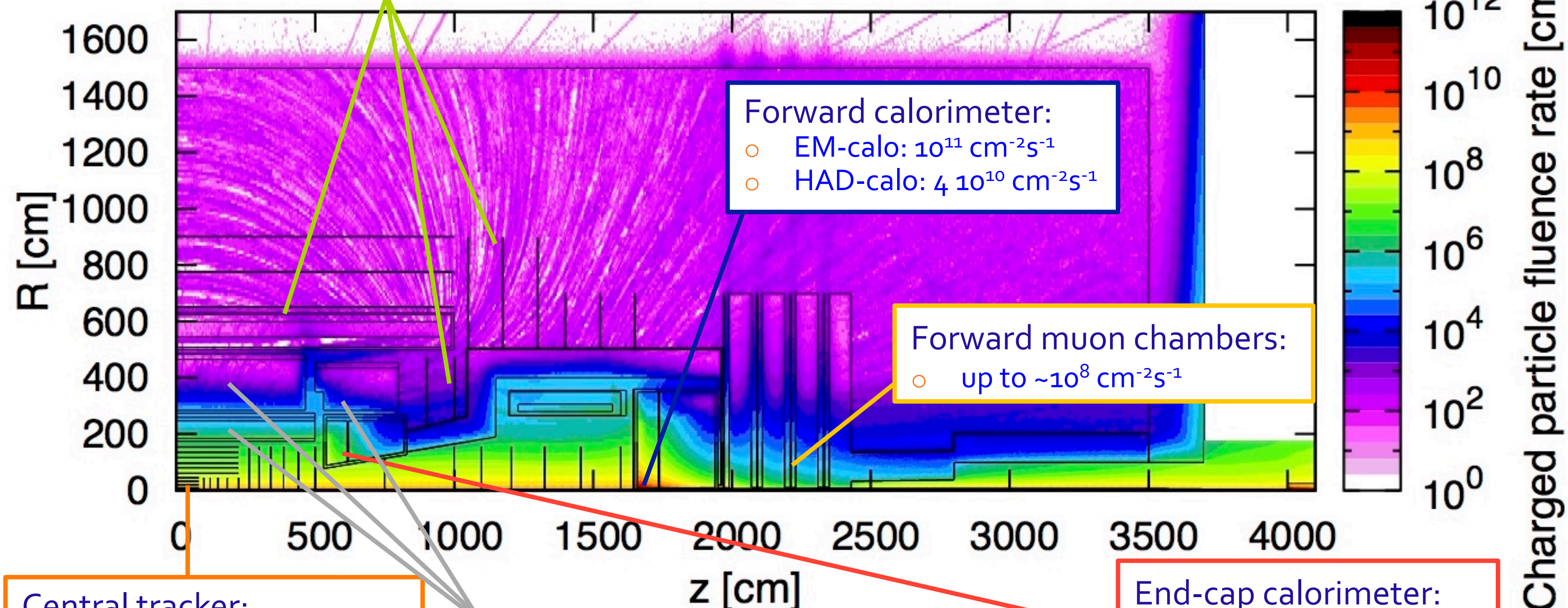
Shielding: Rates in the Muon Chambers



- Hot spots: forward calorimeter and TAS
- The shielding concepts are effective in reducing the rates, <u>but</u> localized **leakage points**
- These affect the rates in the muon chambers:
  - barrel: 7 10^4 cm^{-2}s^{-1}, due to the leakage from the crack in the calorimeter
  - end-cap: six chambers at z > 10 m: 10^5 cm^{-2}s^{-1} & two chambers at z < 10 m: 3 10^5 cm^{-2}s^{-1}
  - <u>expected rates:</u> up to 300 cm^{-2}s^{-1}, compared to ~10 cm^{-2}s^{-1} of the previous layout

Charged Particle Fluence Rate

Barrel and end-cap muon chambers:
- barrel: ~300 $cm^{-2}s^{-1}$
- end-cap chambers for z > 10 m: ~500 $cm^{-2}s^{-1}$, but for the two chambers at z < 10 m: 10^4 $cm^{-2}s^{-1}$
- max previous detecror layout: < 100 $cm^{-2}s^{-1}$, but with an hermetic detector



Forward calorimeter:
- EM-calo: 10^{11} $cm^{-2}s^{-1}$
- HAD-calo: 4 10^{10} $cm^{-2}s^{-1}$

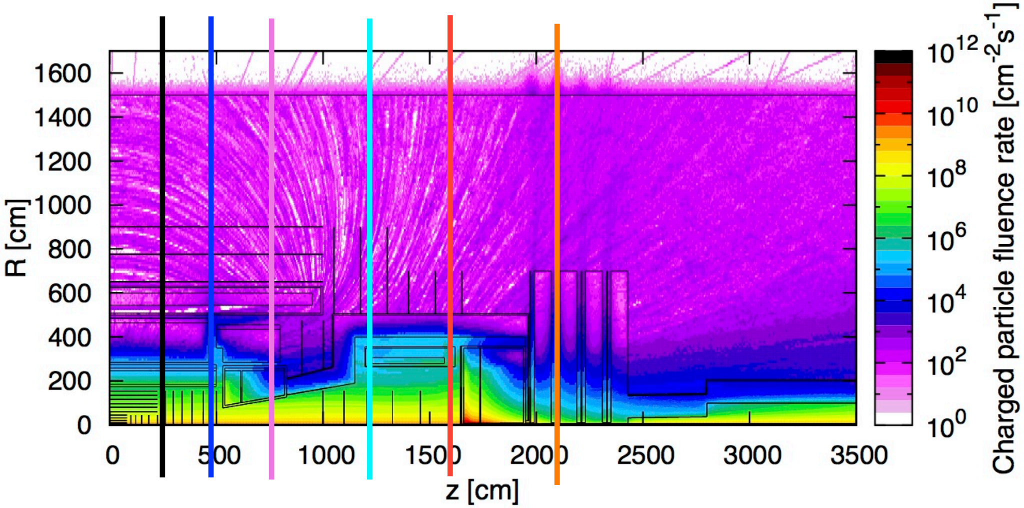
Forward muon chambers:
- up to ~10^8 $cm^{-2}s^{-1}$

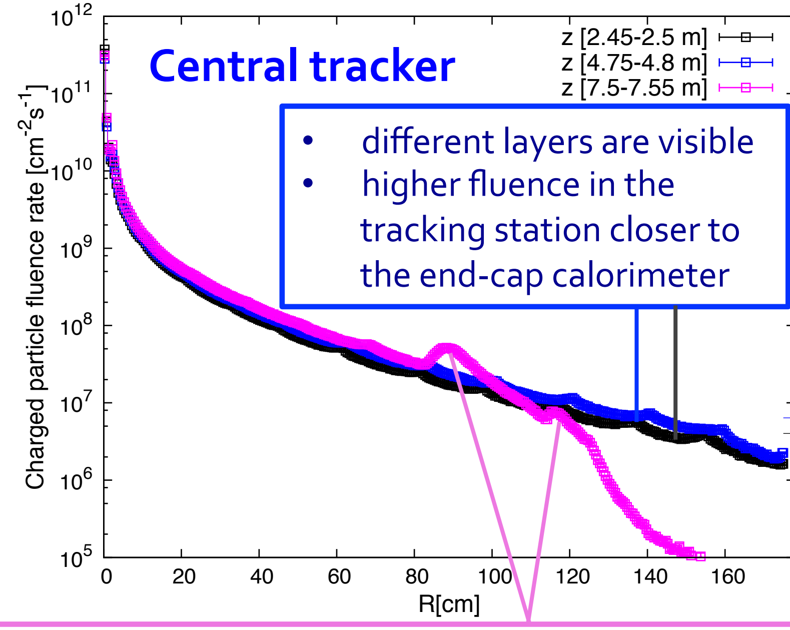
Central tracker:
- first IB layer (2.5 cm): ~1.2 10^{10} $cm^{-2}s^{-1}$
- external part: 3 10^6 $cm^{-2}s^{-1}$

Barrel calorimeter:
- EM-calo: up to 6 10^6 $cm^{-2}s^{-1}$
- HAD-calo: up to 1.5 10^5 $cm^{-2}s^{-1}$

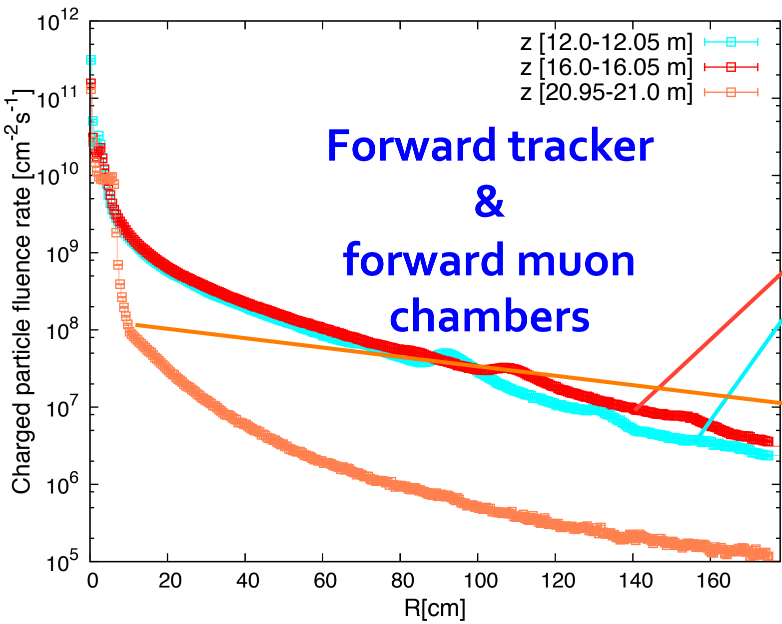
End-cap calorimeter:
- EM-calo: 10^8 $cm^{-2}s^{-1}$
- HAD-calo: 10^7 $cm^{-2}s^{-1}$

Tracking Stations





- first bump due to particles coming from the hot spot in the end-cap EM calorimeter
- second bump at the entrance of the end-cap hadronic calorimeter



- fluence rates in the forward tracking stations: slightly higher in the station closer to the forward calorimeters

- in the forward muon chambers it is clearly visible the impact of the shielding around the beam pipe

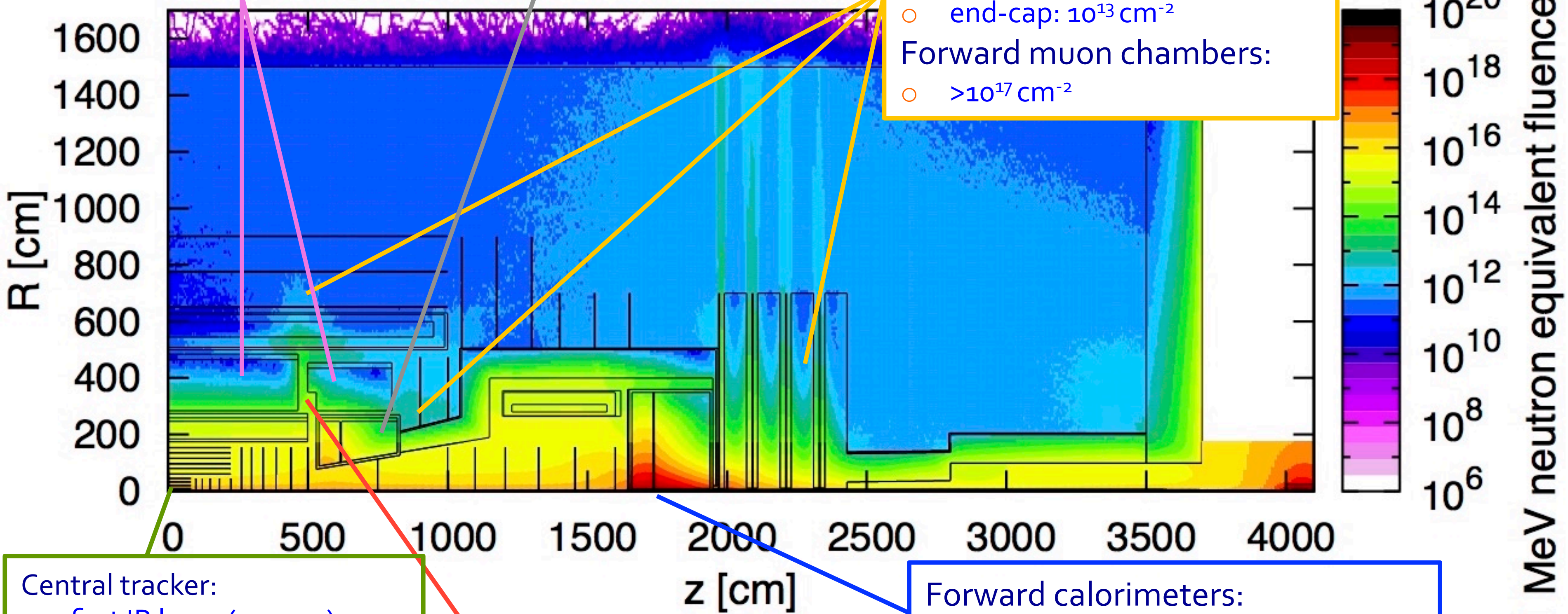
1 MeV Neutron Equivalent Fluence

Barrel calorimeter:
- EM-calo: $4\ 10^{15}\ cm^{-2}$
- HAD-calo: $4\ 10^{14}\ cm^{-2}$

End-cap calorimeter:
- EM-calo: $2.5\ 10^{16}\ cm^{-2}$
- HAD-calo: $1.5 10^{16}\ cm^{-2}$

Barrel and end-cap muon chambers:
- barrel: $10^{12}\ cm^{-2}$
- end-cap: $10^{13}\ cm^{-2}$

Forward muon chambers:
- $>10^{17}\ cm^{-2}$

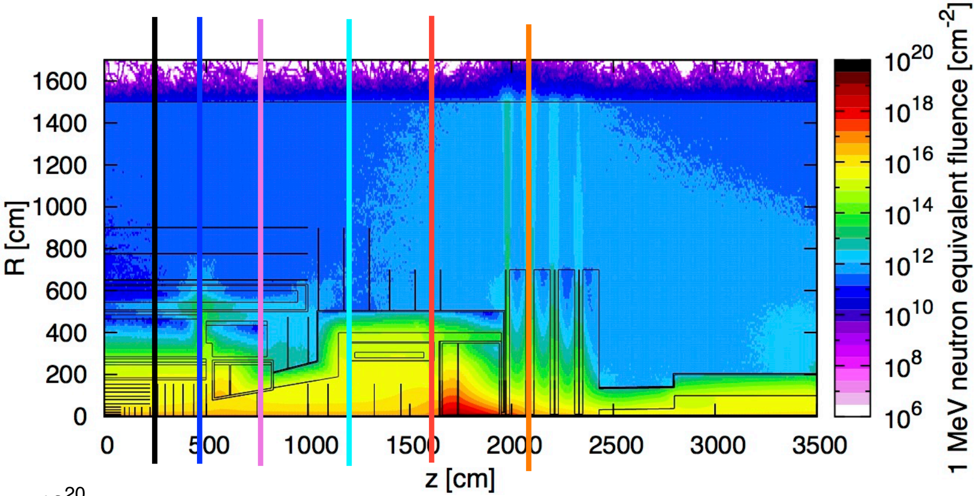


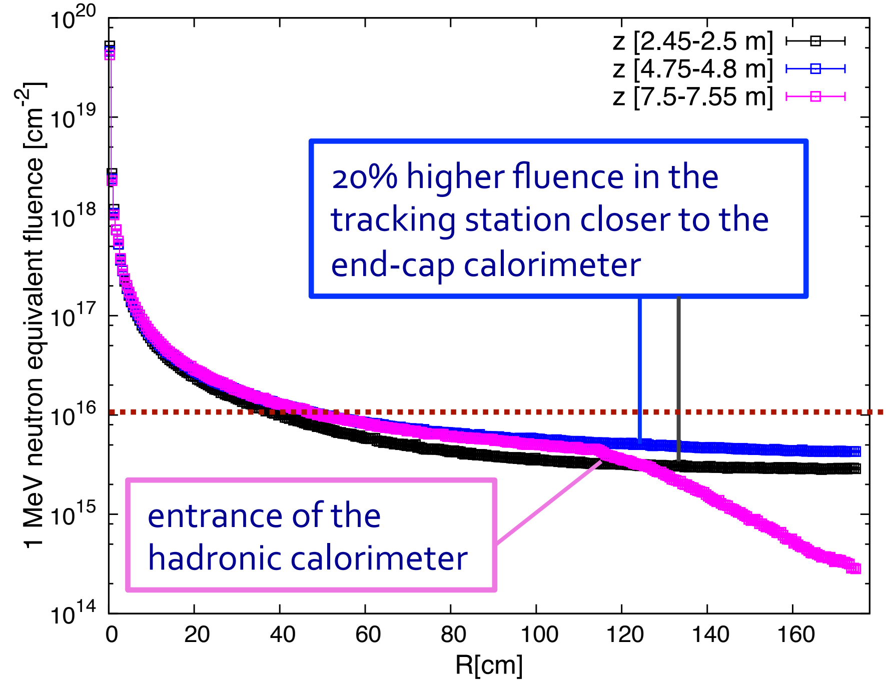
Central tracker:
- first IB layer (2.5 cm): ~$5\text{-}6\ 10^{17}\ cm^{-2}$
- external part: ~$5\ 10^{15}\ cm^{-2}$

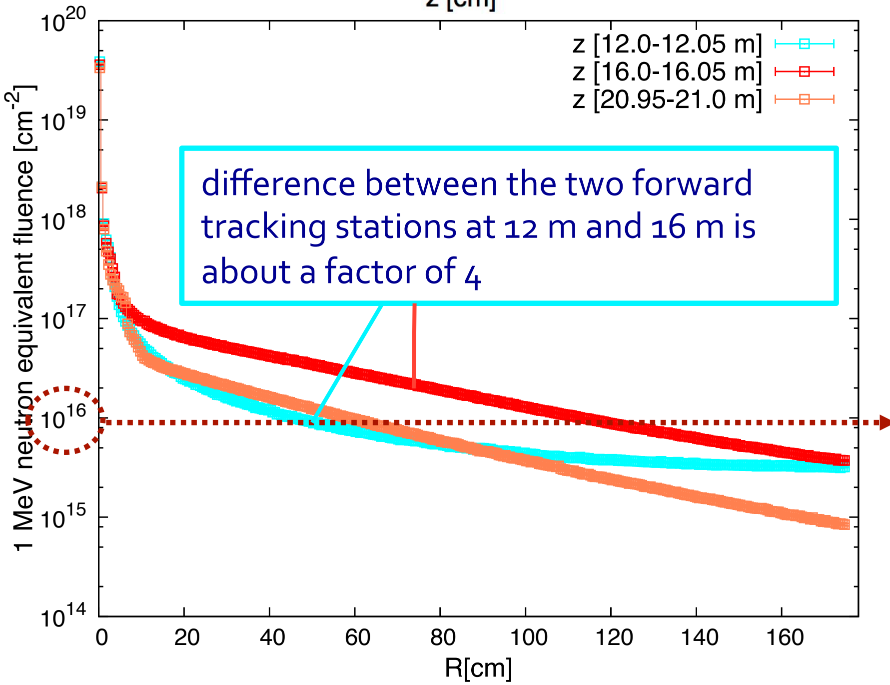
Calorimeter gap: from $10^{16}\ cm^{-2}$ to $10^{14}\ cm^{-2}$

Forward calorimeters:
- ~$5\ 10^{18}\ cm^{-2}$ for both the EM and the HAD-calo
- previous simulations: $7\ 10^{18}\ cm^{-2}$ EM-calo and $4\ 10^{18}\ cm^{-2}$ HAD calo

1D distributions: Tracking Chambers

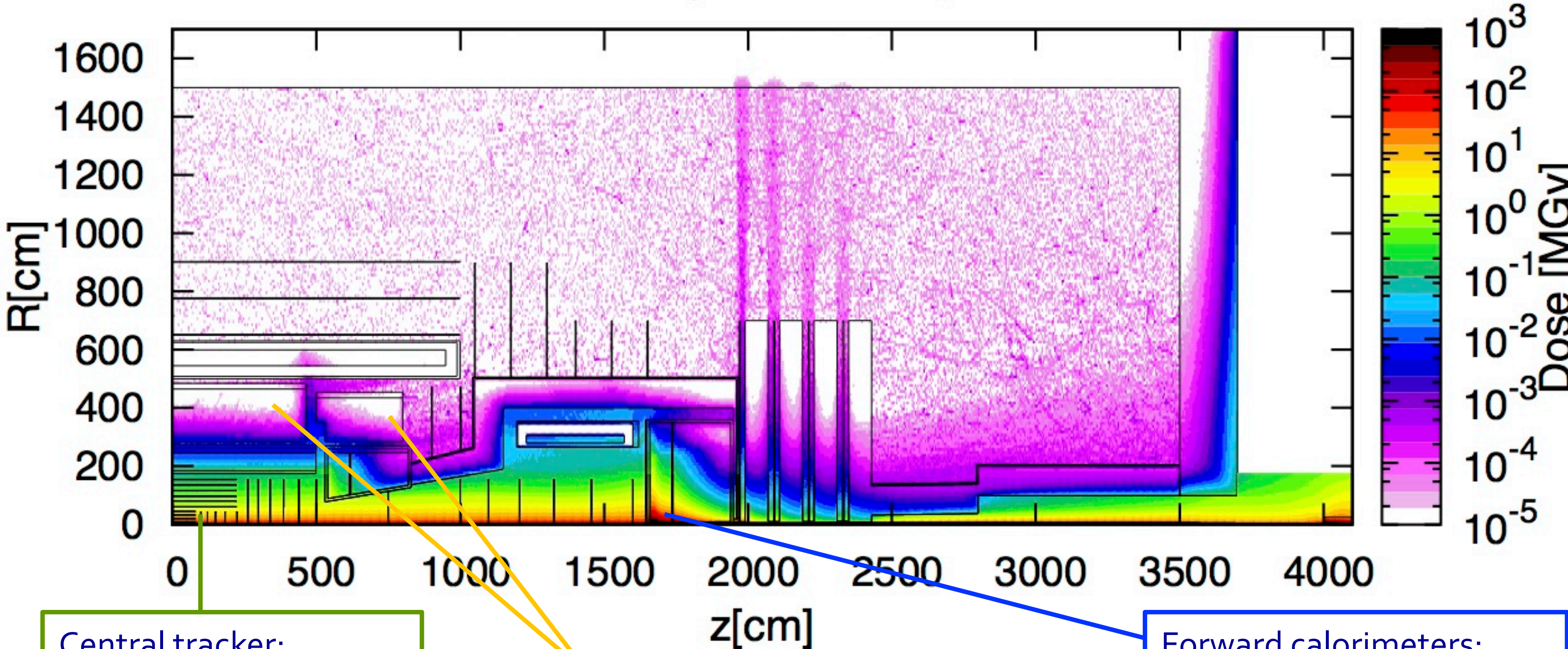






- For radii< 50-60 cm the fluence exceeds the value expected at HL-LHC (10^{16}cm^{-2}) by ~2 orders of magnitude
- In the tracking station closer to the forward calo (16 m) the fluence is higher up to R=1.2 m
  - previous layout the values were higher up to a radius of 2.5 m, because of the dipole field

Dose

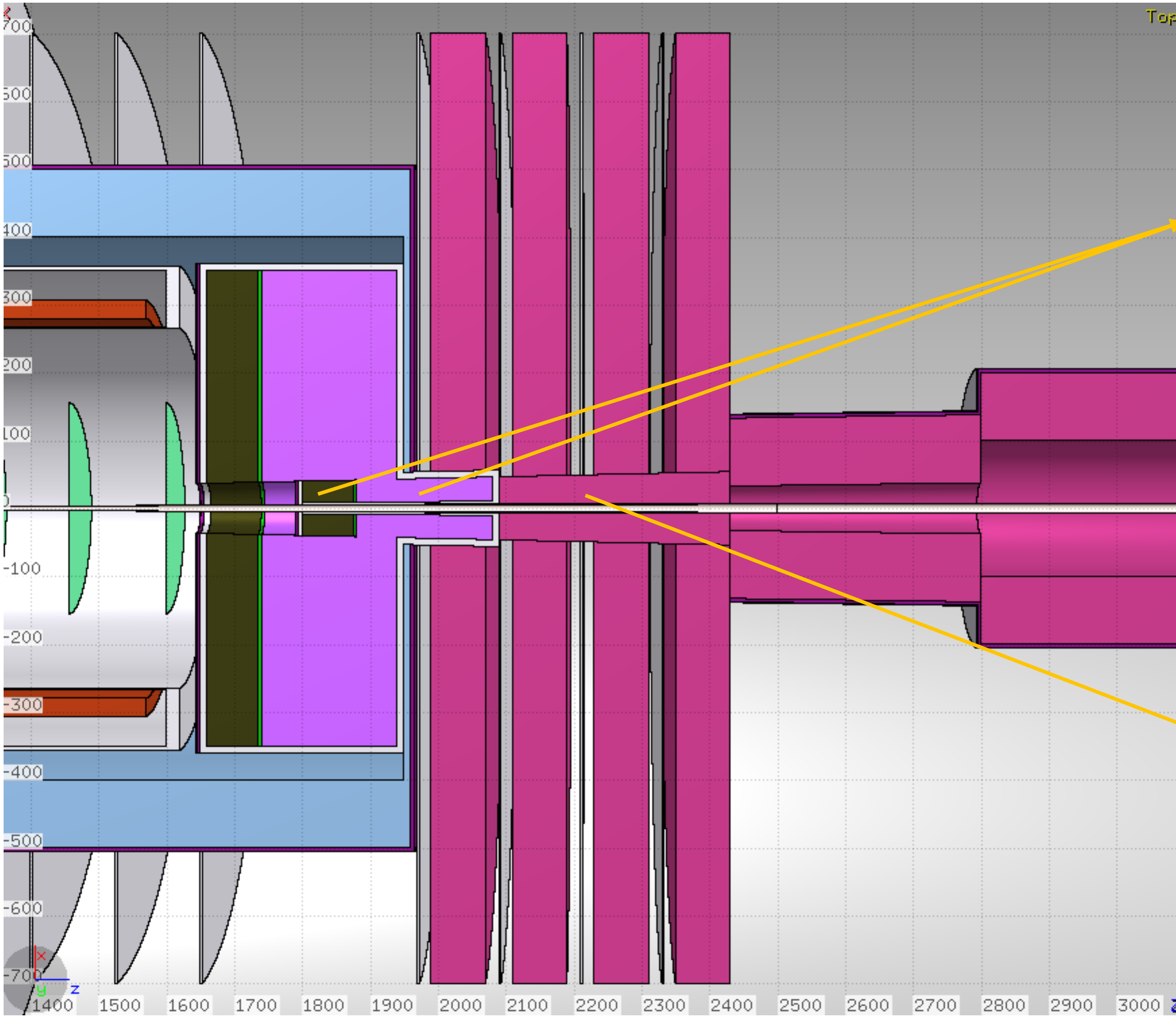


Central tracker:
- first IB layer (2.5 cm): ~400 MGy
- external part: 0.1 MGy

Hadronic calorimeter (scintillator):
- barrel: 6 kGy
- extended barrel: 8 kGy
- previous layout: 3 kGy, with 40% longer tracker and 10% deeper EM calorimeter

Forward calorimeters:
- EM-calo: 5000 MGy
- HAD-calo: ~1000 MGy

Alternative Geometry

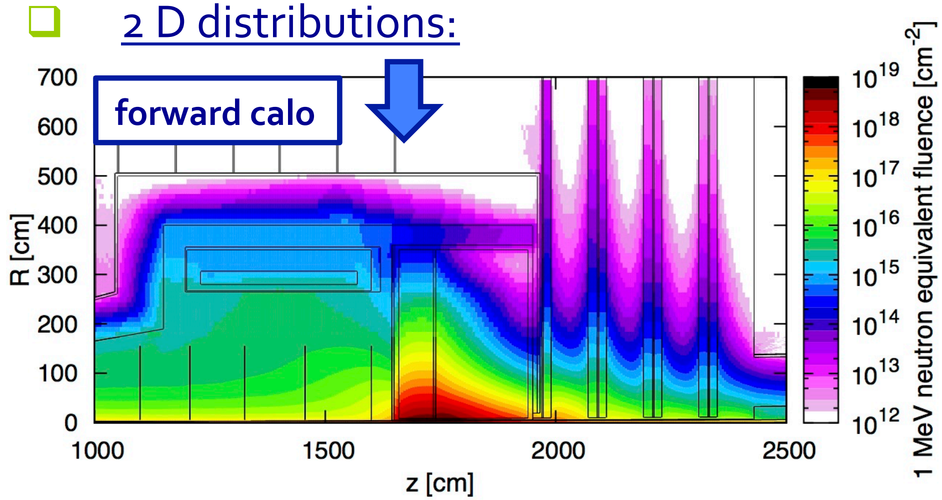


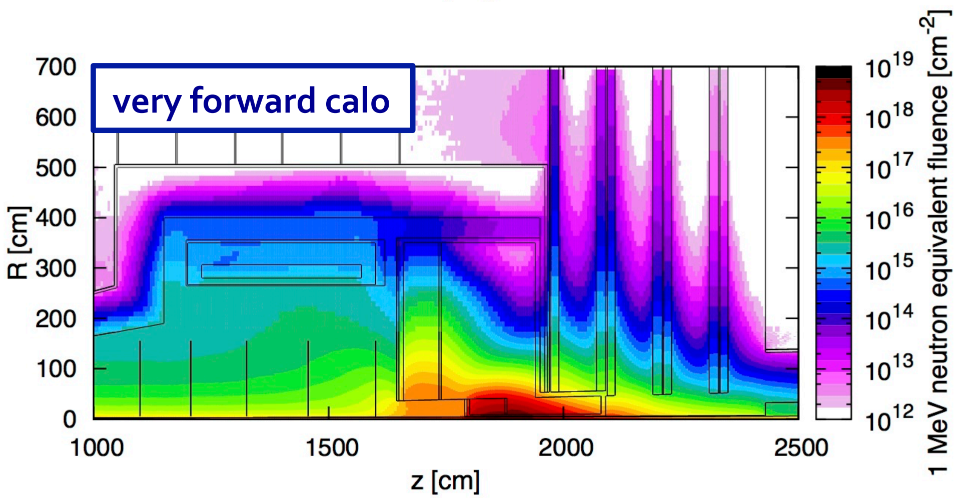
"Very forward" calo for 4.5<|η|<6.0 region, displaced from z=16.5 m to z=18 m).
Same calorimeter thickness and same shielding in front.

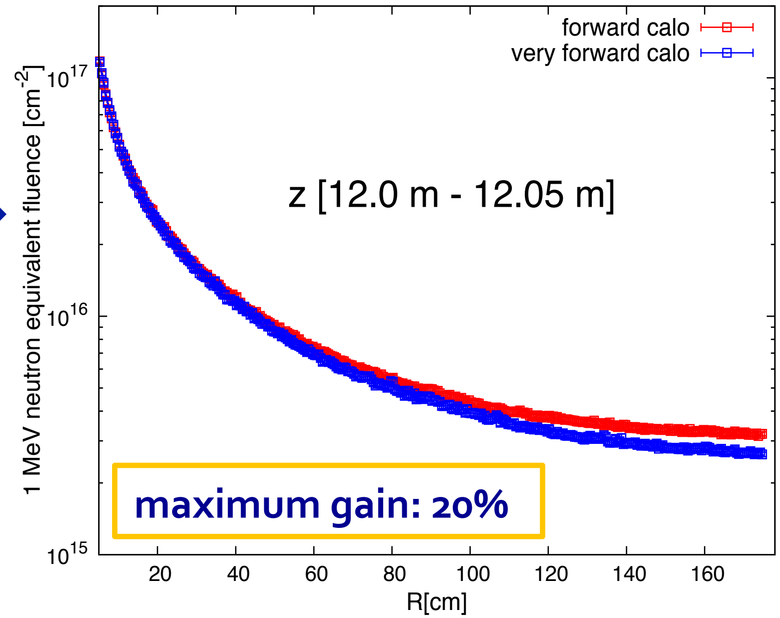
Cast iron shielding from 4.5<|η|<6.5

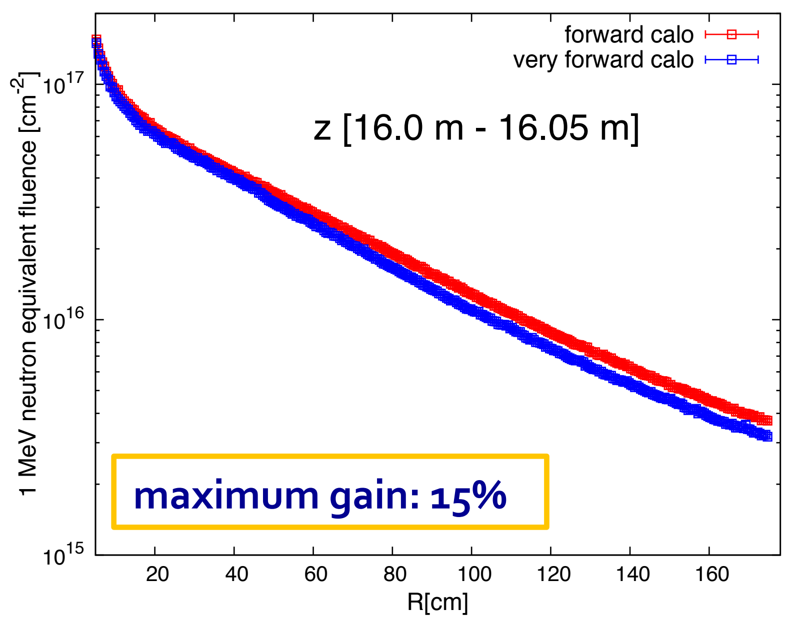
Forward Tracker

- 1 MeV neutron equivalent fluence in the forward tracking stations
  - minor reduction with the new layout
- 2 D distributions:



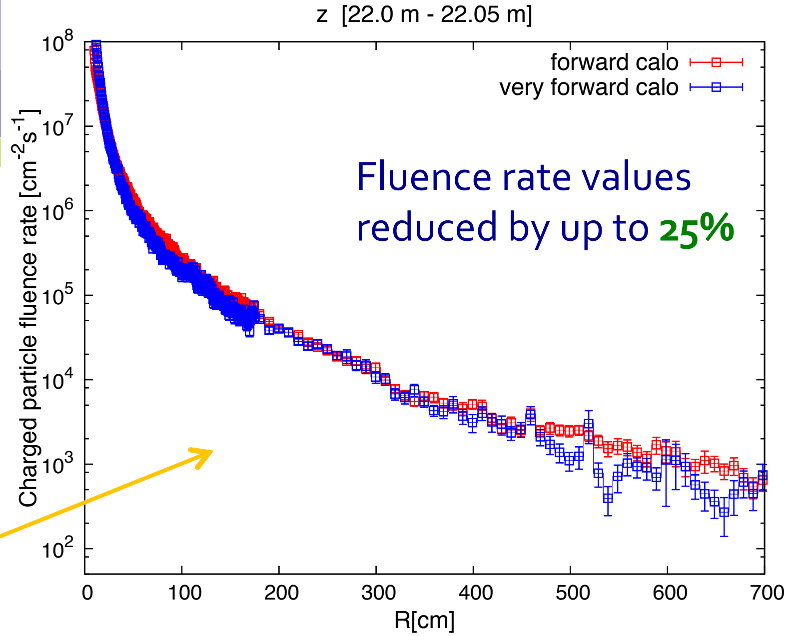


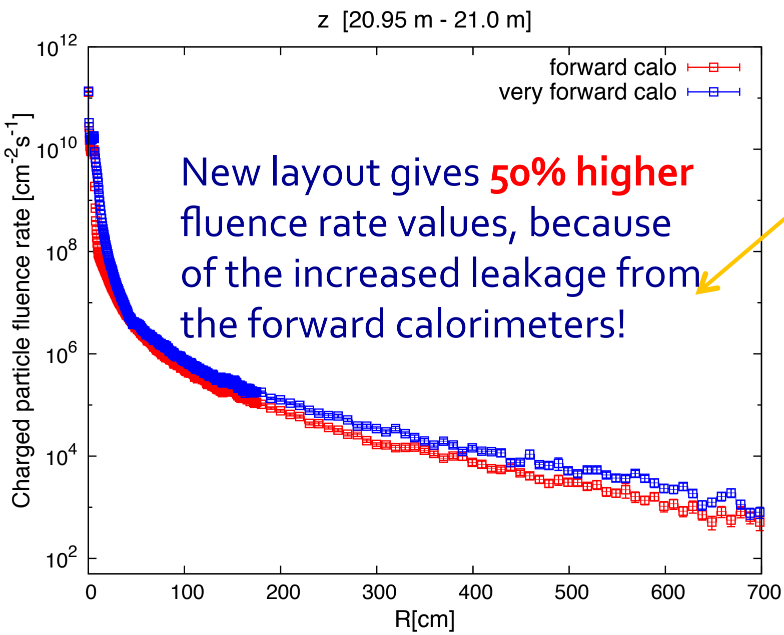


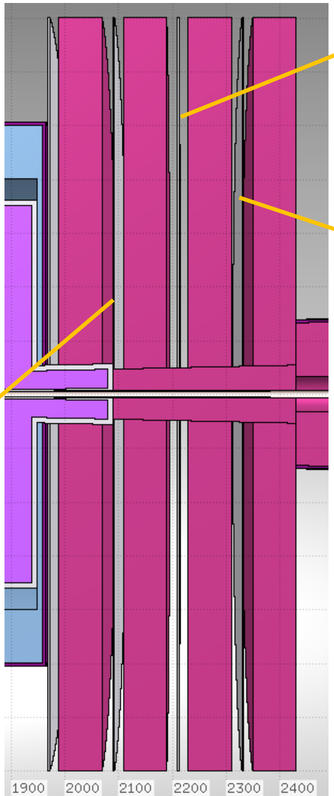


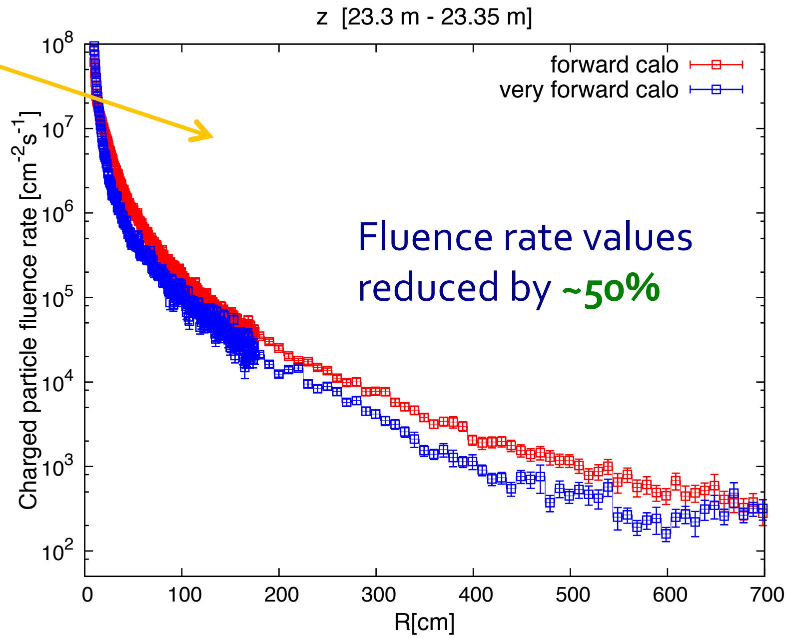
Forward Muon Chambers

- Charged particle fluence rates in the forward muon chambers: comparison between old and new layout
  - higher fluence rate in the first two tracking stations, because of the leakage from the “very forward” calorimeter
  - lower frate in the last two, thanks to thicker inner shielding









Conclusions

Conclusions:

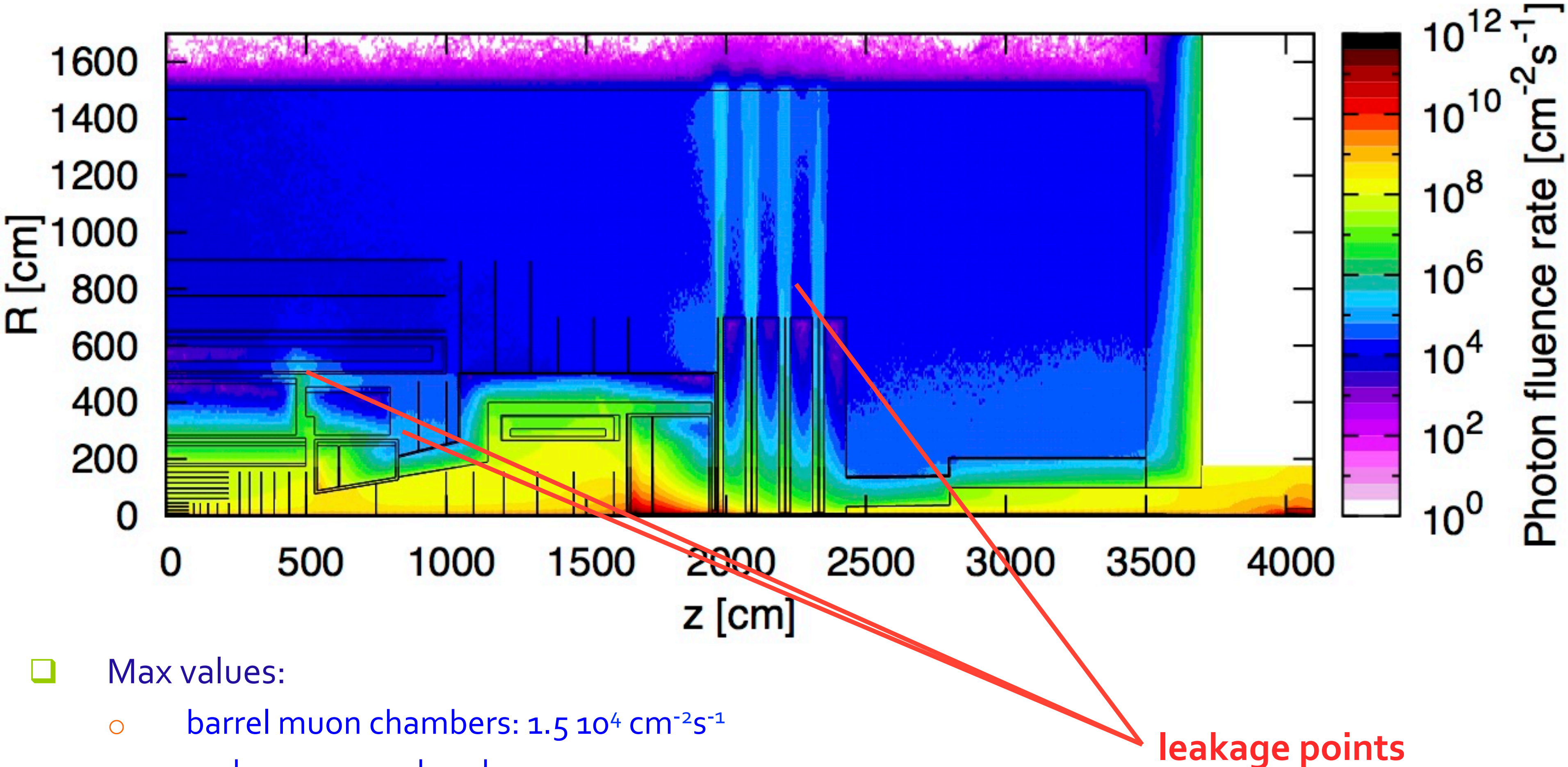
- First radiation studies for the second version of FCC detector have been shown
  - the contribution coming from the TAS is taken into account
  - results have been shown in terms of:
    - fluence rates: neutron & charged particle fluence rates
    - long term damage: 1 MeV neutron equivalent fluence & dose
    - other quantities available, like charged hadron, photon and high energy hadron fluence rates
- A shielding strategy has been proposed to protect muon chambers against the leakage from the forward calorimeters and the back-scattering from the TAS:
  - the shielding is effective, but there are localized leakage points that affect fluence values in the muon chambers → higher values wrt the previous hermetic layout
- An alternative geometry version has been explored with “very forward” calorimeters and a reduced muon acceptance
  - the calorimeter split is not effective in reducing the fluence in the tracking stations & it has a bad effect on the forward muon chambers
  - the shielding inside the muon chambers has instead a positive impact

Outlooks:

- The “very forward” calorimeter option will be dropped for future studies
- To protect forward muon tracking stations the shielding increase will be maintained and a deeper forward calorimeter will be considered

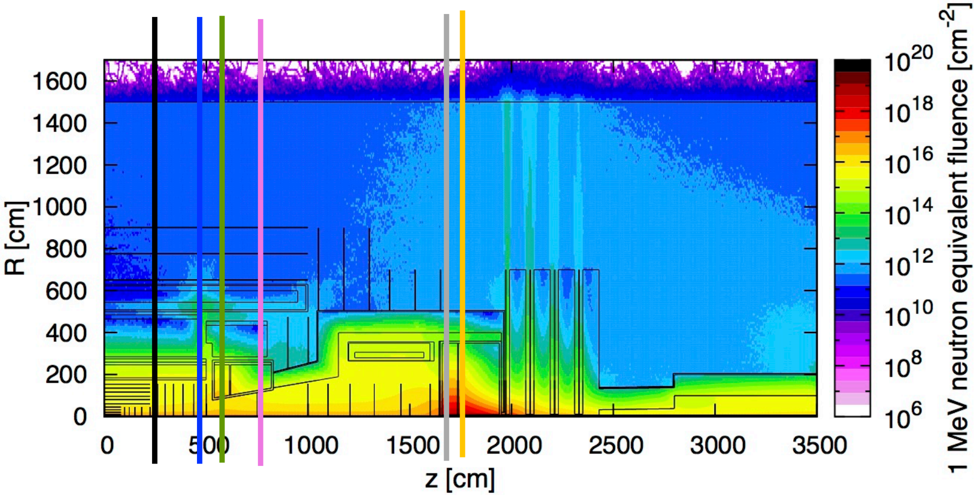
Back-up

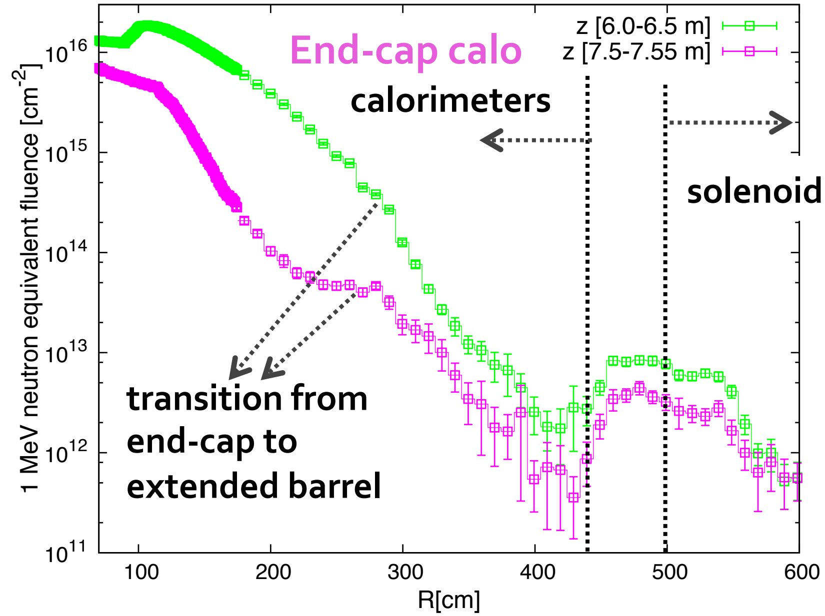
Photon Fluence Rate

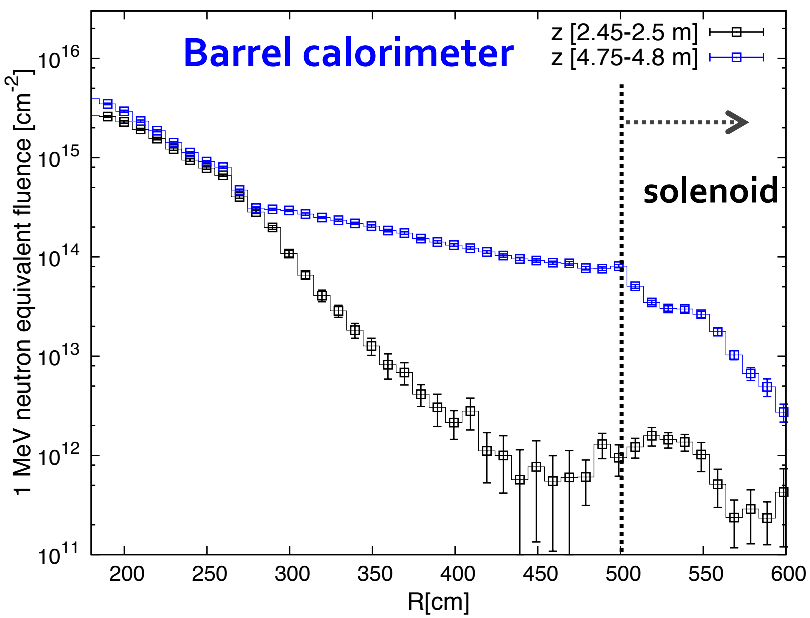


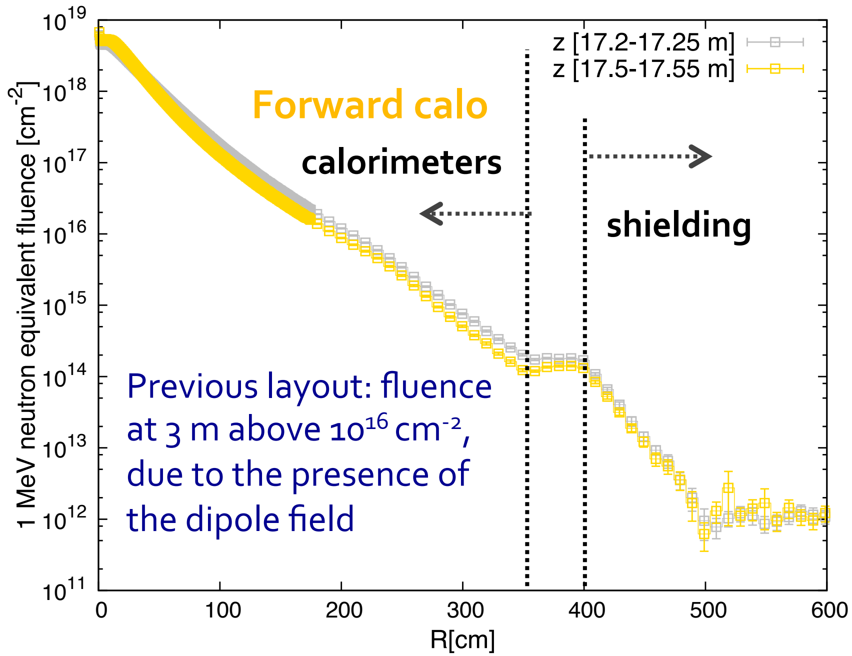
- Max values:
  - barrel muon chambers: 1.5 10^4 $cm^{-2}s^{-1}$
  - end-cap muon chambers:
    - six chambers at z > 10 m: 2 10^4 $cm^{-2}s^{-1}$
    - two chambers at z < 10 m: ~10^5 $cm^{-2}s^{-1}$
  - expected rate in muon chambers up to 10^3 $cm^{-2}s^{-1}$, compared to 20 $cm^{-2}s^{-1}$ of previous layout

Calorimeters



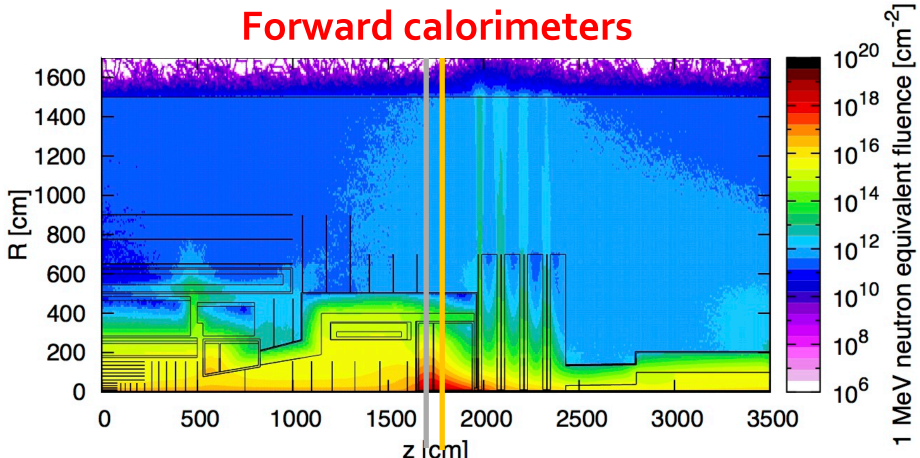


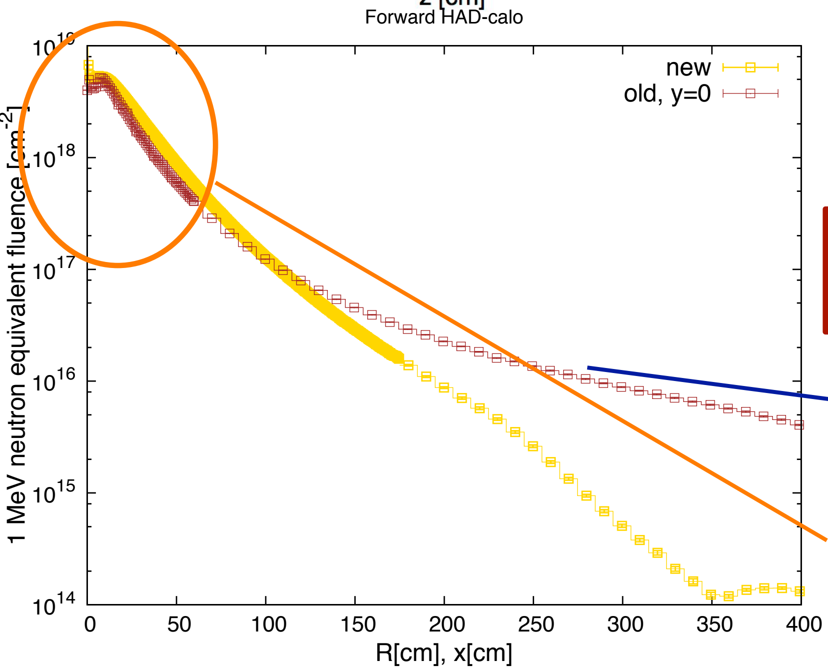


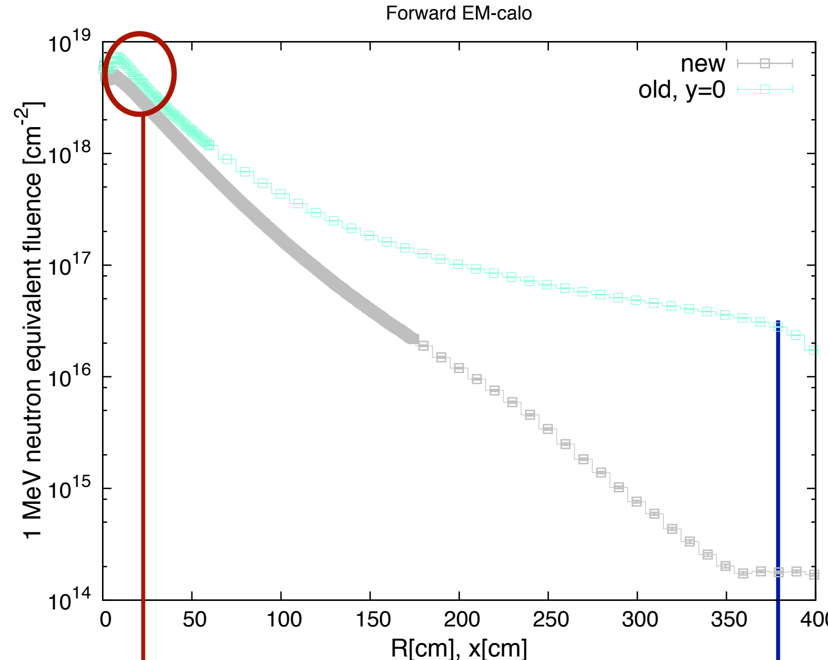


1 MeV Neutron Equivalent Fluence

Forward calorimeters







Lower, because of the different maximum |η| value,, decreased from 6.7 to 6.

The shower is significantly narrower for the new layout

The values in the forward hadron calorimeters are higher than in the previous layout and they are more similar to the values observed in the EM calorimeter

Dose in the Hadronic Calorimeter

Values for 30 ab^{-1}: