Radiation Environment

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Outline

- Updated detector geometry:
  - with a 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
  - effectiveness 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
Old concept: bigger detector, without gaps, no cylindrical symmetry

Cylindrical cavern: \( R = 15 \text{ m} \) & \( L = 70 \text{ m} \)

Installation clearances and space for services inserted

Full cylindrical symmetry

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

Magnetic field

- 6 T solenoid
- 10 Tm dipole
Central & forward tracker
Central & forward tracker

EM calorimeter
Detector Geometry II

- Hadronic extended barrel calorimeter
- Central & forward tracker
- EM calorimeter
- Hadronic end-cap calo
Detector Geometry II

- Hadronic extended barrel calorimeter
- Central & forward tracker
- EM calorimeter
- Hadronic end-cap calo
- Central & forward solenoid
Detector Geometry II

Hadronic extended barrel calorimeter
Central & forward tracker
EM calorimeter
Hadronic end-cap calo
Barrel muon chambers
Central & forward solenoid
End-cap muon chambers
Shielding around the forward calo:
- 1 m of steel
- 5 cm of lithiated polyethylene
- 1 cm of lead

Shielding in front of the forward calo: 5 cm of lithiated polyethylene between 2 mm thick aluminum covers
Shielding around the forward calorimeter:
- 1 m of steel
- 5 cm of lithiated polyethylene
- 1 cm of lead

Shielding in front of the forward calorimeter: 5 cm of lithiated polyethylene between 2 mm thick aluminum covers

Forward muon chambers with cast iron shielding

Cast iron shielding layer to protect muon chambers

Central & forward solenoid

Hadronic extended barrel calorimeter

Central & forward tracker

EM calorimeter

Hadronic end-cap calorimeter

Forward calorimeter

End-cap muon chambers

Barrel muon chambers

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Hadronic extended barrel calorimeter

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EM calorimeter

Hadronic end-cap calorimeter

Forward calorimeter

End-cap muon chambers

Barrel muon chambers
Shielding in the Forward Region

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

Cylindrical shielding:
- 1 m 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

- Shielding concepts are effective in reducing the rates, but localized leakage points, which affect the rates in the muon chambers:
  - barrel: $7 \times 10^4 \text{ cm}^{-2}\text{s}^{-1}$, due to the leakage from the crack in the calorimeter
  - end-cap: six chambers at $z > 10 \text{ m}$: $10^5 \text{ cm}^{-2}\text{s}^{-1}$ & two chambers at $z < 10 \text{ m}$: $3 \times 10^5 \text{ cm}^{-2}\text{s}^{-1}$
  - expected rates: up to $300 \text{ cm}^{-2}\text{s}^{-1}$, compared to $\sim 10 \text{ cm}^{-2}\text{s}^{-1}$ of the previous layout
Charged Particle Fluence Rate ($3 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$)
Charged Particle Fluence Rate ($30 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$)

Barrel calorimeter:
- EM-cal: up to $6 \times 10^6 \text{ cm}^{-2}\text{s}^{-1}$
- HAD-cal: up to $1.5 \times 10^5 \text{ cm}^{-2}\text{s}^{-1}$
- higher values wrt previous layout, because of the smaller tracker volume and lower solenoid magnetic field

Central tracker:
- first IB layer (2.5 cm): $\sim 1.2 \times 10^{10} \text{ cm}^{-2}\text{s}^{-1}$
- external part: $3 \times 10^6 \text{ cm}^{-2}\text{s}^{-1}$
Charged Particle Fluence Rate ($30 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$)

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- external part: $3 \times 10^6 \text{ cm}^{-2}\text{s}^{-1}$

Forward calorimeter:
- EM-cal: $10^{11} \text{ cm}^{-2}\text{s}^{-1}$
- HAD-cal: $4 \times 10^{10} \text{ cm}^{-2}\text{s}^{-1}$

End-cap calorimeter:
- EM-cal: $10^8 \text{ cm}^{-2}\text{s}^{-1}$
- HAD-cal: $10^7 \text{ cm}^{-2}\text{s}^{-1}$
Charged Particle Fluence Rate (30 $10^{34}$ cm$^{-2}$s$^{-1}$)

**Barrel calorimeter:**
- EM-cal: up to $6 \times 10^6$ cm$^{-2}$s$^{-1}$
- HAD-cal: up to $1.5 \times 10^5$ cm$^{-2}$s$^{-1}$
- higher values wrt previous layout, because of the smaller tracker volume and lower solenoid magnetic field

**Barrel and end-cap muon chambers:**
- barrel: $\sim 300$ cm$^{-2}$s$^{-1}$
- end-cap chambers for $z > 10$ m: $\sim 500$ cm$^{-2}$s$^{-1}$, but for the two chambers at $z < 10$ m: $10^4$ cm$^{-2}$s$^{-1}$
- max previous detector layout: $< 100$ cm$^{-2}$s$^{-1}$, but with no gaps

**Forward calorimeter:**
- EM-cal: $10^{11}$ cm$^{-2}$s$^{-1}$
- HAD-cal: $4 \times 10^{10}$ cm$^{-2}$s$^{-1}$

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

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

**Central tracker:**
- first IB layer (2.5 cm): $\sim 1.2 \times 10^{10}$ cm$^{-2}$s$^{-1}$
- external part: $3 \times 10^6$ cm$^{-2}$s$^{-1}$
Tracking Stations

Charged particle fluence rate $[\text{cm}^{-2}\text{s}^{-1}]$

- $R[\text{cm}]$
- $z[2.45-2.5\text{ m}]$
- $z[4.75-4.8\text{ m}]$
- $z[7.5-7.55\text{ m}]$

- $z[12.0-12.05\text{ m}]$
- $z[16.0-16.05\text{ m}]$
- $z[20.95-21.0\text{ m}]$

- Tracking stations

- Different layers are visible
- Higher fluence in the tracking station closer to the end-cap calorimeter

- 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 HAD calorimeter

- The fluence rate is slightly higher in the forward tracking station closer to the forward calorimeters

Central tracker

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

Forward tracker & forward muon chambers

M.I. Besana, FCC week 2017
31/05/17
1 MeV Neutron Equivalent Fluence for 30 ab$^{-1}$
1 MeV Neutron Equivalent Fluence for 30 ab$^{-1}$

Barrel calorimeter:
- EM-cal: $4 \times 10^{15}$ cm$^{-2}$ & HAD-cal: $4 \times 10^{14}$ cm$^{-2}$
- higher values wrt previous layout

Central tracker:
- first IB layer (2.5 cm): $\sim 5-6 \times 10^{17}$ cm$^{-2}$
- external part: $\sim 5 \times 10^{15}$ cm$^{-2}$
1 MeV Neutron Equivalent Fluence for 30 ab\(^{-1}\)

Barrel calorimeter:
- EM-cal: 4 \(10^{15}\) cm\(^{-2}\) & HAD-cal: 4 \(10^{16}\) cm\(^{-2}\)
- higher values wrt previous layout

End-cap calorimeter:
- EM-cal: 2.5 \(10^{16}\) cm\(^{-2}\)
- HAD-cal: 1.5 \(10^{16}\) cm\(^{-2}\)

Forward calorimeters:
- maximum at \(\sim 5 \times 10^{18}\) cm\(^{-2}\) for both the EM and the HAD-cal o
- 10\(^{16}\) cm\(^{-2}\) at R=2 m
- previous simulations: 7 \(10^{18}\) cm\(^{-2}\)
  EM-cal and 4 \(10^{18}\) cm\(^{-2}\) HAD calo

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

Calorimeter gap: from \(10^{16}\) cm\(^{-2}\) to \(10^{14}\) cm\(^{-2}\)
Barrel calorimeter:
- EM-calo: $4 \times 10^{15} \text{ cm}^{-2}$ & HAD-calo: $4 \times 10^{14} \text{ cm}^{-2}$
- higher values wrt previous layout

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

Forward calorimeters:
- maximum at $\sim 5 \times 10^{18} \text{ cm}^{-2}$ for both the EM and the HAD-calo
- $10^{16} \text{ cm}^{-2}$ at $R=2 \text{ m}$
- previous simulations: $7 \times 10^{18} \text{ cm}^{-2}$ EM-calo and $4 \times 10^{18} \text{ cm}^{-2}$ HAD calo

Muon Chambers:
- barrel: $10^{12} \text{ cm}^{-2}$
- end-cap: $10^{13} \text{ cm}^{-2}$
- forward: up to $10^{17} \text{ cm}^{-2}$, $10^{15}$ at $R=2 \text{ m}$

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

Calorimeter gap: from $10^{16} \text{ cm}^{-2}$ to $10^{14} \text{ cm}^{-2}$
1D distributions: Tracking Chambers

- Difference between the two forward tracking stations at 12 m and 16 m is about a factor of 4.

- 20% higher fluence in the tracking station closer to the end-cap calorimeter.

- For radii < 50-60 cm 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 calorimeter (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 for 30 ab\(^{-1}\)

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

**Forward calorimeters:**
- EM-calo: 5000 MGy
- HAD-calo: ~1000 MGy
- at R=2 m the dose is ~1 MGy

**Central tracker:**
- first IB layer (2.5 cm): ~400 MGy
- external part: 0.1 MGy
“Very forward” calo for $4.5 < |\eta| < 6.0$ region, displaced from $z=16.5$ m to $z=18$ m). Same calorimeter thickness and same shielding in front.

Cast iron shielding from $4.5 < |\eta| < 6.5$
1 MeV neutron equivalent fluence in the forward tracker

- Minor reduction with the new layout

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**Forward Tracker**

![Diagram of 1 MeV neutron equivalent fluence in the forward tracker with minor reduction with the new layout.](image)

**Maximum gain:**
- Forward calorimeter (forward calo) 2D distribution: 20%
- Very forward calorimeter (very forward calo) 2D distribution: 15%
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 rate in the last two, thanks to thicker inner shielding

Fluence rate values **50% higher**, because of the increased leakage from the forward calorimeters!

Fluence rate values reduced by up to **25%**

Fluence rate values reduced by ~**50%**
Conclusions & Outlooks

Conclusions:

- Radiation studies for the **second version** of FCC detector have been presented
  - the TAS contribution is taken into account
  - results have been shown in terms of:
    - neutron & charged particle fluence rates
    - long term damage: 1 MeV neutron equivalent fluence & dose
    - other quantities available not reported in this talk
  - the expected values pose challenges on detector technology, which will be highlighted in the following talks

- Shielding strategy proposed to protect muon chambers against leakage and back-scattering from forward calo and TAS:
  - the shielding is effective, but the localized leakage points affect fluence values in the muon chambers \(\rightarrow\) higher values wrt the previous layout

Outlooks:

- 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

- The “very forward” calorimeter option will be dropped for future studies
- To protect forward muon tracking stations:
  - the increase of the shielding around the beam pipe will be maintained
  - a thicker forward calorimeter will be considered
Thanks for your attention