TTL detector performance studies
- follow-up -

EPIC TOF Meeting
August 8, 2022

Nicolas Schmidt

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Electron Proton and Ion Collider
EXPERIMENT

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Reminder: ECCE-style TTL Layers in Geant4

Support:

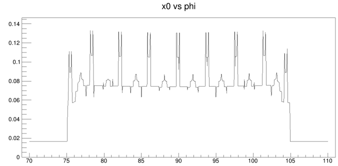
Layer	material	thickness
Top plate	aluminum	1mm
air gap	air	5mm
bottom plate	aluminum	1mm
cooling	aluminum	5mm diam. tube 1mm wall

Services:

Layer	material	thickness
Thermal pad	graphite	0.25mm
High Speed Board	polystyrene	1mm
Power board	polystyrene	3.1 mm

Sensor:

Layer	material	thickness
Thermal pad	graphite	0.25mm
AlN	AlN	0.79mm
Laird Film	graphite	0.08mm
ROC	plastic	0.25mm
Solder (Tin)	tin	0.03mm
Sensor	silicium	0.3mm
Epoxy	epoxy	0.08mm
AlN	AlN	0.51mm

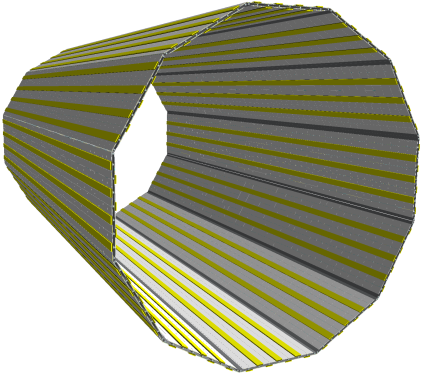


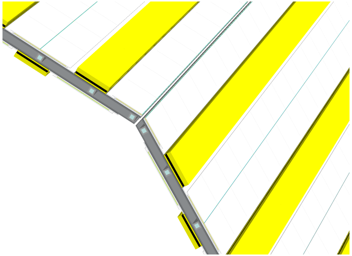
- Material budget $\sim 8\% X/X_0$ dominated by Al plates
  $\rightarrow$ cooling pipes with substantial material

More infos in CMS ETL TDR [[Link]]

Reminder: ECCE-style TTL Laye

- Barrel made of 12 modules in azimuth and multiple modules along z-axis
- Forward layers mounted on both sides of large disk
- AC-LGAD pixel sensors with 500μm pitch $\rightarrow$ 30μm position resolution

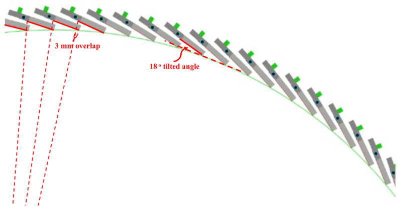




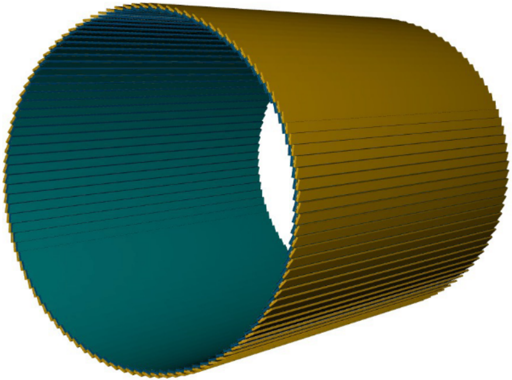
Reminder: ATHENA-style barrel TOF (DD4hep)

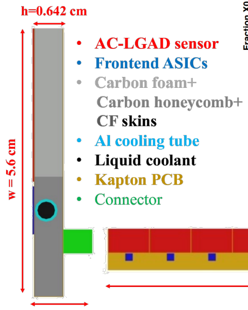
ATHENA Barrel TOF Detector Layout

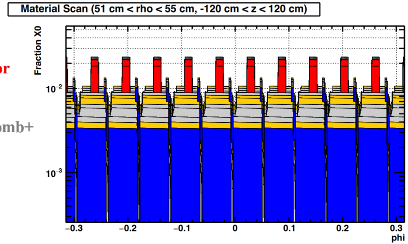
Full azimuthal coverage

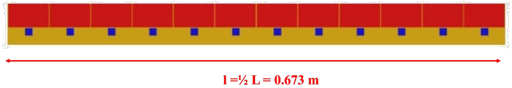


- Material budget $\sim 1\% X/X_0$
- ATHENA design placed at $R \sim 52.5$cm
- Strip AC-LGAD with 0.5×10mm pitch
- Full coverage in φ, 98% coverage in z

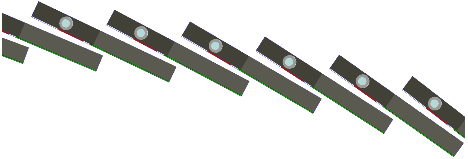




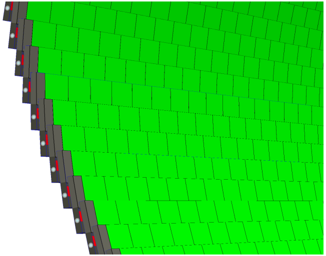


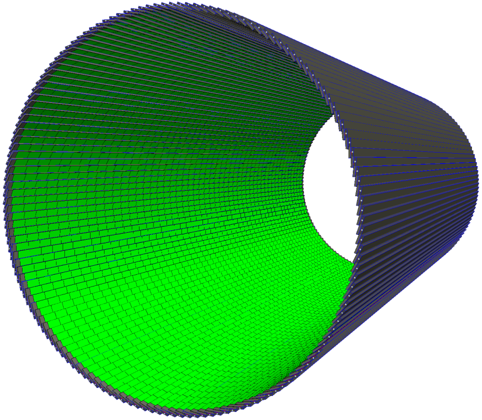


NEW: ATHENA-style barrel TOF (Fun4All)



- **Material budget** $\sim 1.2\% X/X_0$
  - $\rightarrow$ C-foam (honeycomb) density 0.09(0.03) g/cm^3
  - $\rightarrow$ cooling with significant material
- Detector placed at $R \sim 64$cm
- Detector length ~ 2.8m $\rightarrow \approx 11$m^2 of sensors





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Momentum resolution - Different Detectors

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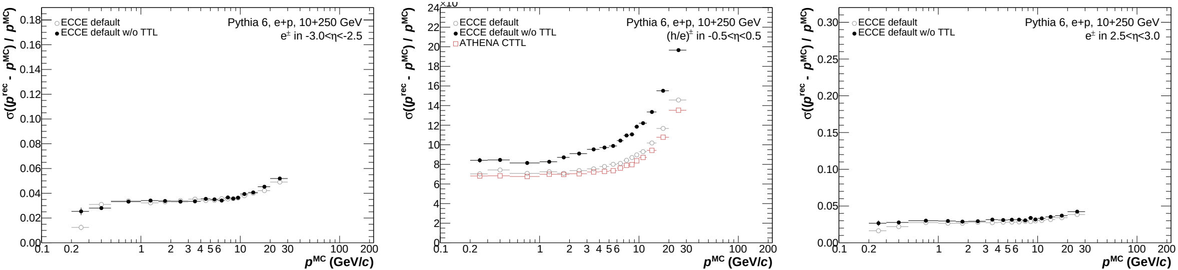
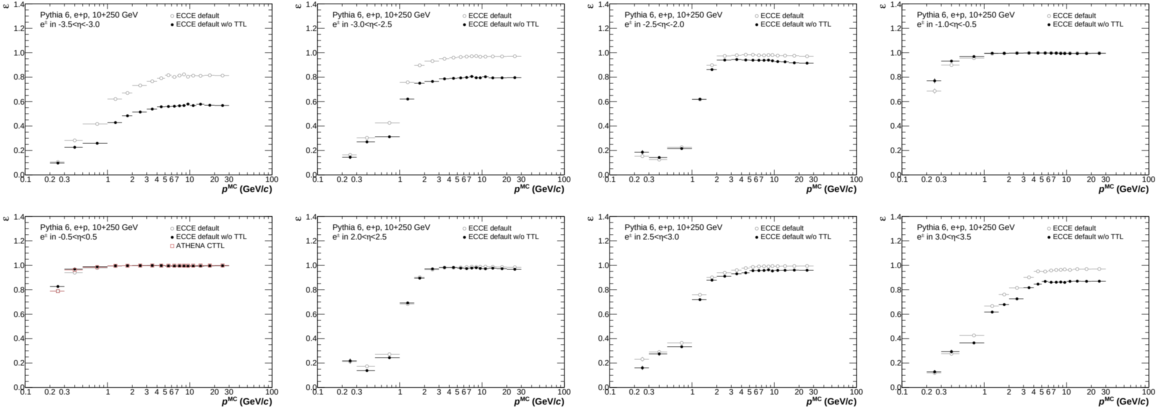
now with lower $|\eta|$ bins!



- Comparison between CTTL and ATHENA TOF detector design
  $\rightarrow$ slight improvement of tracking performance
  $\rightarrow$ possibly due to all sensors being in front of support material
- Comparison to TTL layers being excluded from Kalman filter
  $\rightarrow$ important tracking constraints in barrel and forward
  $\rightarrow$ surprisingly low impact in backward direction

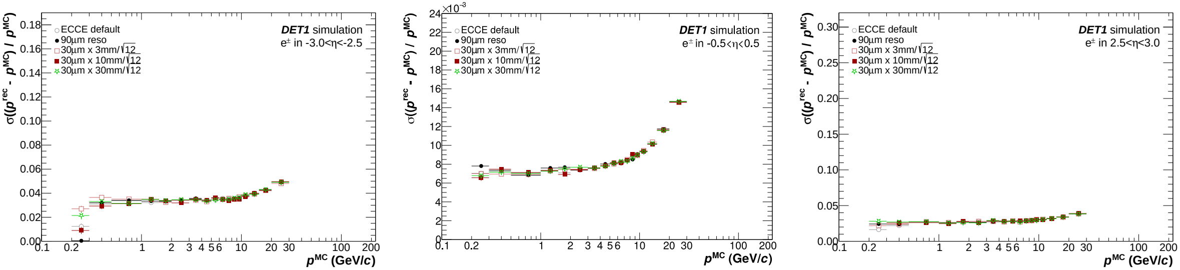
Tracking efficiency - Different Detectors



- Clear improvement of tracking efficiency with TTL, especially at high $|\eta|$
- Overall low efficiency for $p < 1$GeV in fwd/bwd

Momentum resolution - Different Sensors

now with lower $|\eta|$ bins!



- Studies performed via Kalman filter adjustments
  $\rightarrow$ Forward/backward sensor resolution changed in φ and R
  $\rightarrow$ Barrel sensor resolution changed in φ and z
- Momentum resolution appears unaffected by AC-LGAD pitch
  $\rightarrow$ strip sensors (also with larger pitch in φ) can be used

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Momentum resolution - Different Material

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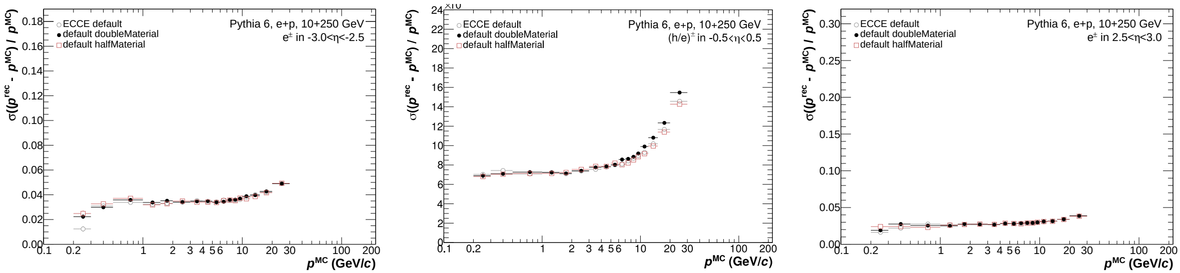
now with lower $|\eta|$ bins!



- Material of TTL layer with small/negligible impact on tracking resolution
  $\rightarrow$ however, ECal performance might depend on low material budget

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Calorimeter resolution - TTL Material

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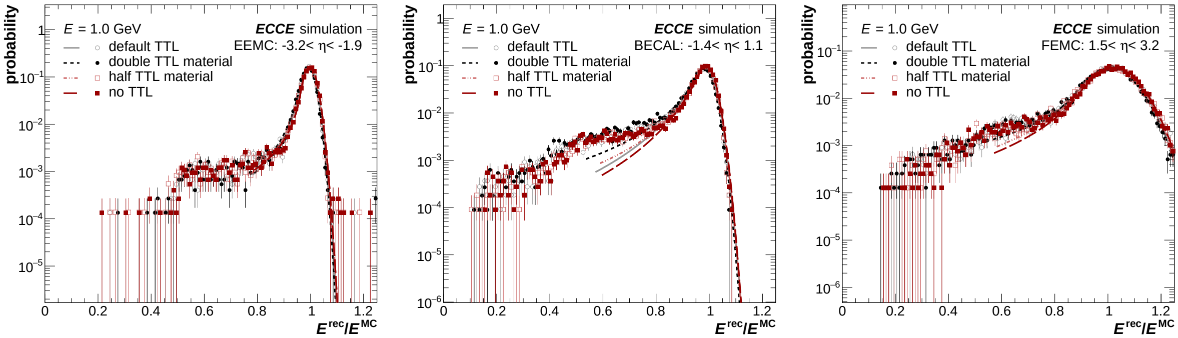


- Negligible impact of TTL material to calorimeter resolution in all directions
  $\rightarrow$ allows for more freedom with supports and cooling as tracking performance is similarly unaffected by material

Conclusions

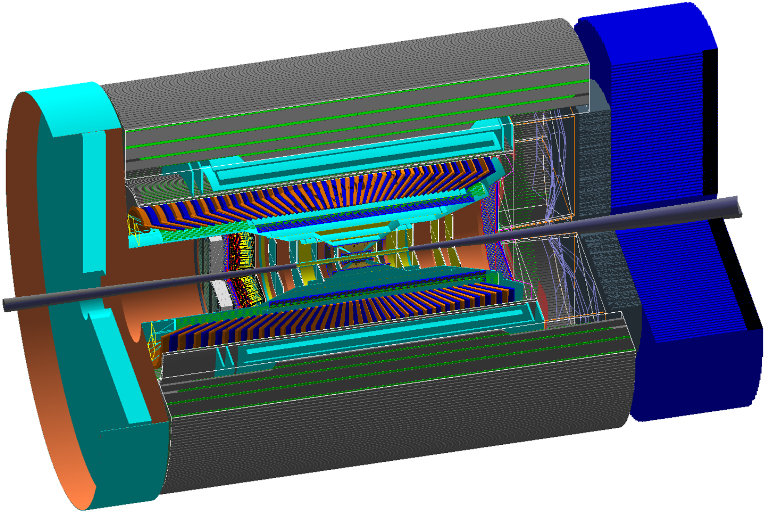
- ATHENA-style barrel design implemented in Fun4All
  $\rightarrow$ material, cooling and support to be further evaluated
- TTL layers have significant impact on momentum resolution in barrel and forward
  $\rightarrow$ not that sensitive to sensor pitch in φ direction
- Small effect from TTL layer material variations on tracking performance
  $\rightarrow$ but calorimeters would benefit from less material
- TTL layers provide crucial information for Cherenkov detectors
  $\rightarrow$ position and angle constraints at entrance of detector
  $\rightarrow$ significantly worse position resolution without TTL hits

Backup

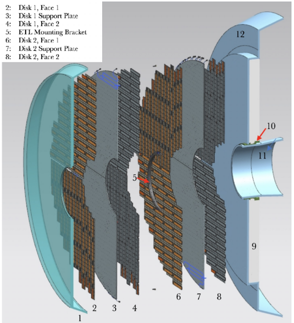
Performance studies in today's meeting

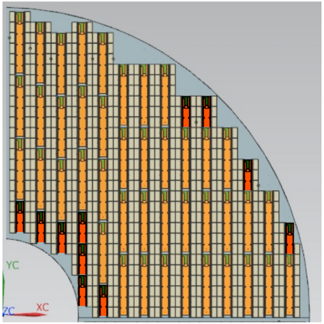
- **spatial resolution of sensors**
  1) Ideal 30*30 μm
  2) Barrel: 30μm along r*phi, while 3 mm/$\sqrt{12}$, 1cm/$\sqrt{12}$, or 3 cm/$\sqrt{12}$ in Z
  3) Endcap: 30μm along phi, while 3 mm/$\sqrt{12}$, 1cm/$\sqrt{12}$, or 3 cm/$\sqrt{12}$ in R
- **timing resolution of sensors (see presentation by Friederike next week)**
  1) 25 ps (Default ECCE design)
  2) variations: 30 ps, 35 ps, 40 ps, 50 ps
- **material budget**
  1.a) Default ($\sim$7.5%X_0 based on ECCE)
  1.b) $\sim$3.75%X_0 (half thickness of ECCE design)
  1.c) $\sim$15%X_0 (twice thickness of ECCE design)
  ~~2.a) $\sim$1%X_0 based on ATHENA design~~
  2.b) $\sim$2%X_0 (twice of ATHENA design)

ATHENA-style barrel TOF in Det1 (Fun4All)

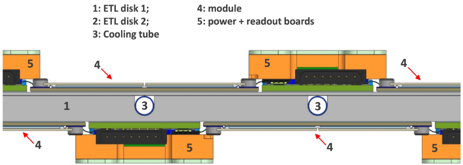


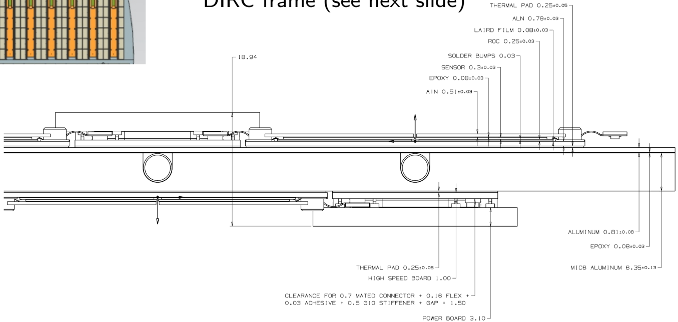
TTL disk design



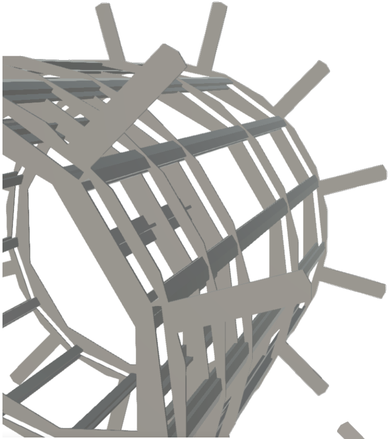


- Design based on the CMS forward upgrade [link]
- Basic elements: ladders of 3 or 6 LGAD sensors with service hybrid (for readout and power)
- Sensors mounted on aluminum plate (currently 6mm thick) and contains cooling
- Sensors on back side of plate shifted to cover service hybrid dead area (see bottom figure)
- Barrel layer to be mounted on inner or outer part of DIRC frame (see next slide)

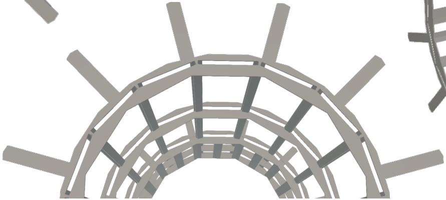


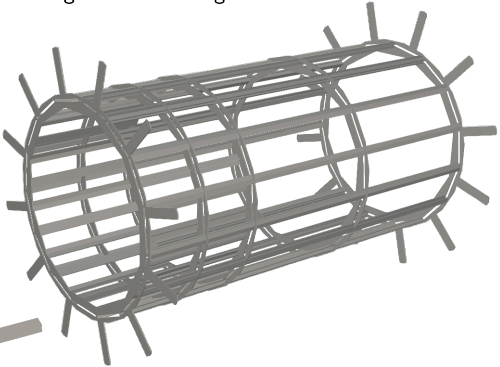


DIRC frame in barrel

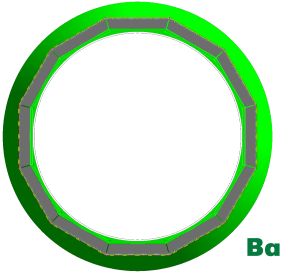


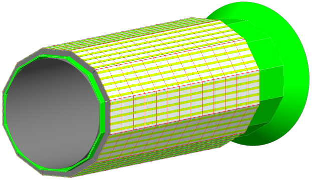
- Currently only stepping files of this frame exist (sent around by Tanja) $\rightarrow$ porting to Fun4All needed
- Frame allows to mount modules on various radial positions
- Considered material is steel at the moment $\rightarrow$ significant material budget in certain regions



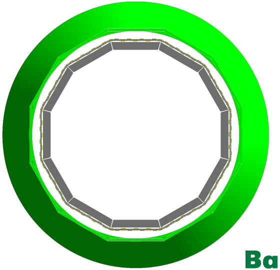


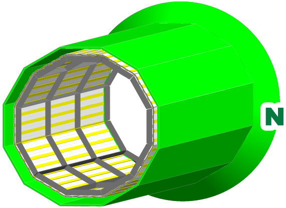
New Layers in Geant4 - 3





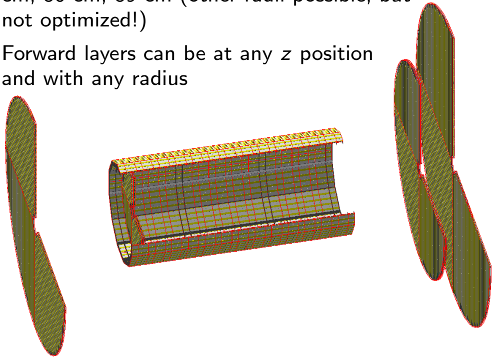
Barrel layer outside DIRC





Barrel layer inside DIRC

- Implemented barrel radial positions: 50 cm, 80 cm, 89 cm (other radii possible, but not optimized!)
- Forward layers can be at any z position and with any radius



New TTL layers in default ECCE configuration