AC-LGAD TOF for ATHENA

Zhangbu Xu @ BNL

Frank Geurts, Wei Li @ Rice Univ.

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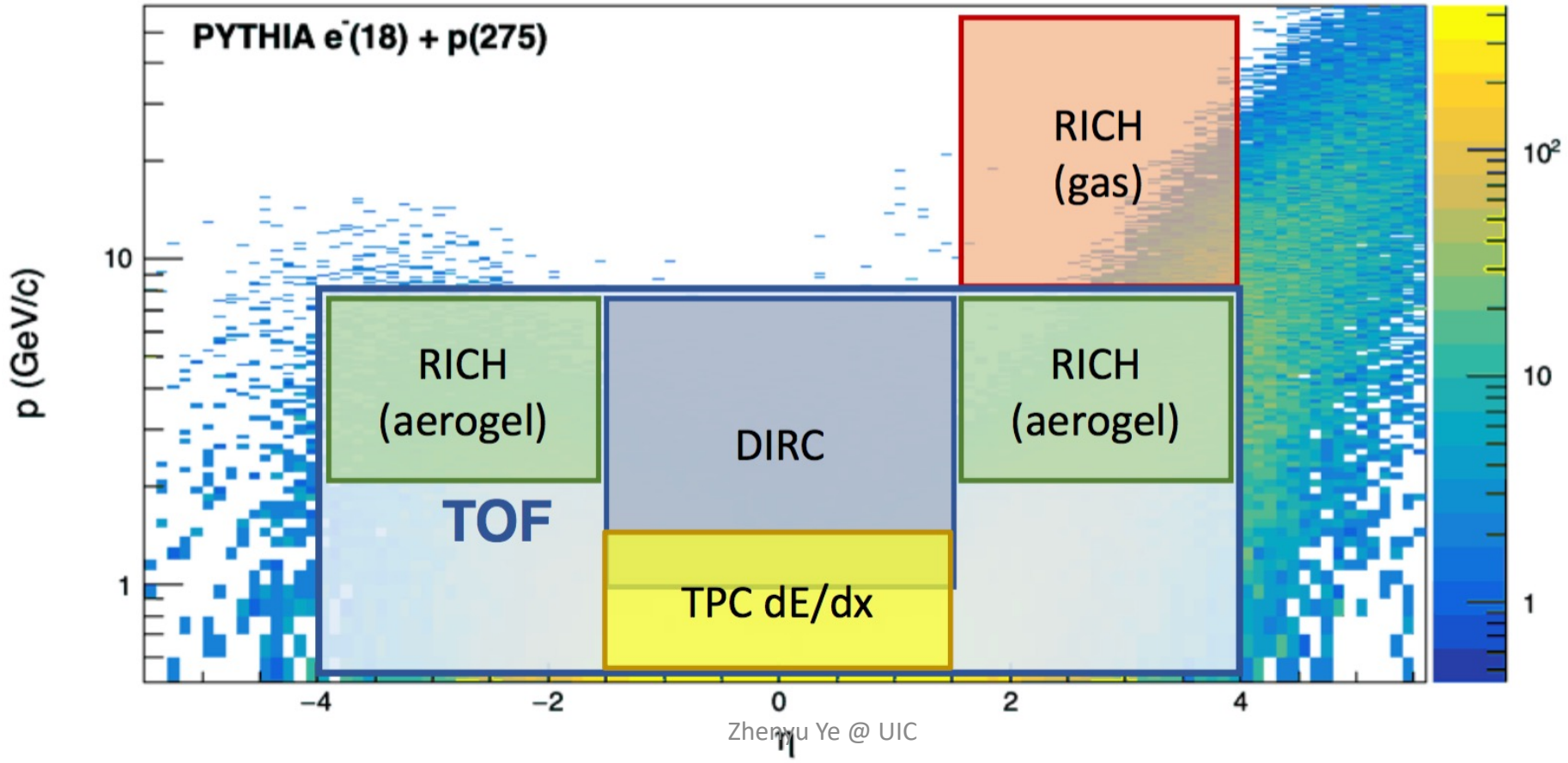
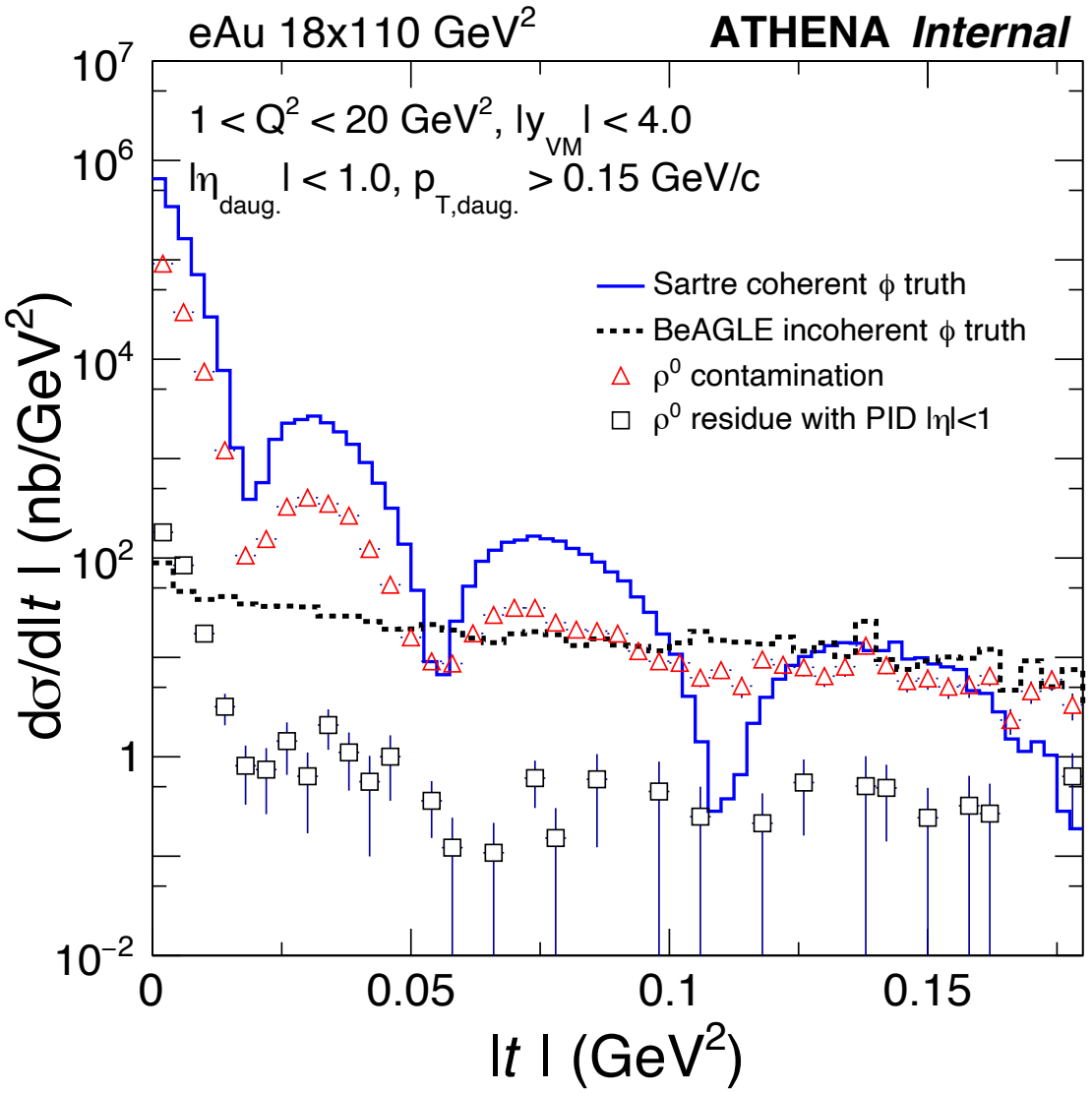
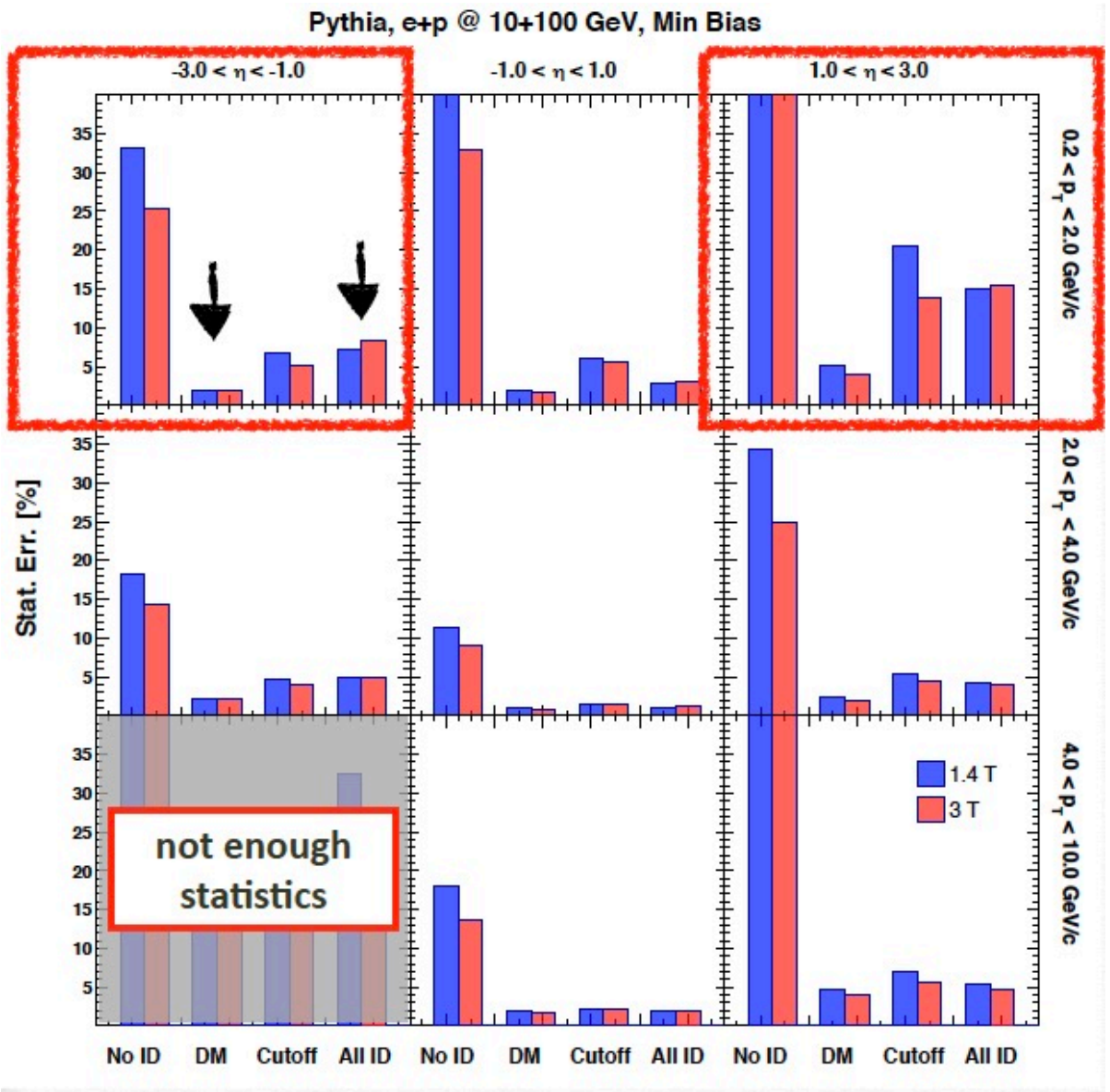


Low pT PID for Physics Measurements at EIC

Exclusive ϕ (Z. Tu)



Λ_c (W. Fan)

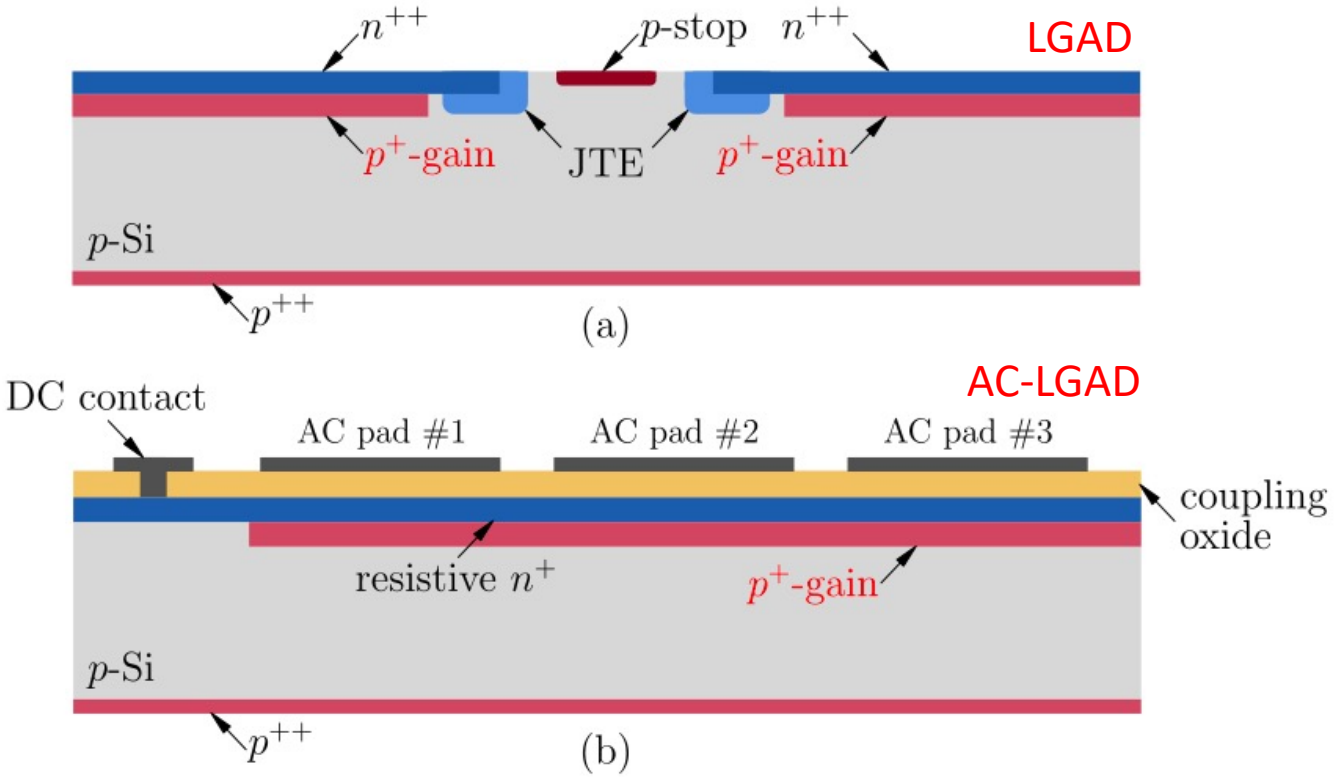


AC-LGAD for EIC

- Large area LGAD detectors are being built by ATLAS (6.4 m^2) and CMS (14 m^2) for data taking starting in 2026.

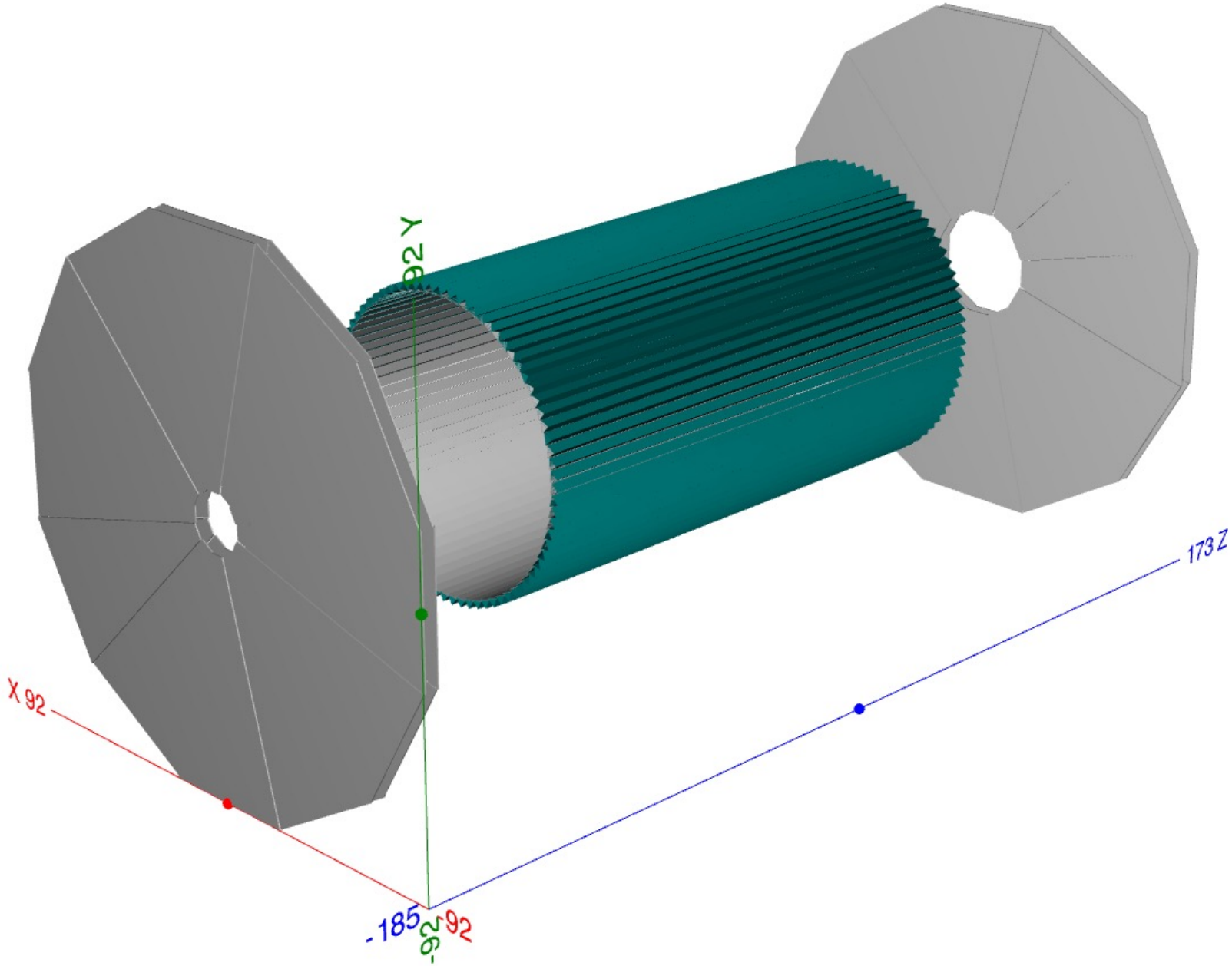
- AC LGAD detectors proposed for EIC
  - Roman Pots and B0
  - TOF for PID (and tracking)

- Have common designs in sensor, ASIC etc. when possible, combine R&D efforts



	Time resolution / hit	Position resolution / hit	Material budget / layer
Barrel ToF (Tracker)	<30 ps	(3-30 μm for Tracker)	$< 0.01\ X_0$
Endcap ToF (Tracker)	<25 ps	(30-50 μm for Tracker)	e-direction $< 0.05 X_0$ h-direction $< 0.15 X_0$
Roman Pots	<50 ps	$< 500/\sqrt{12}\ \mu m$	N/A
B0	<50 ps	$O(50)\ \mu m$	$< 0.01\ X_0$

AC-LGAD TOF Detectors for EIC



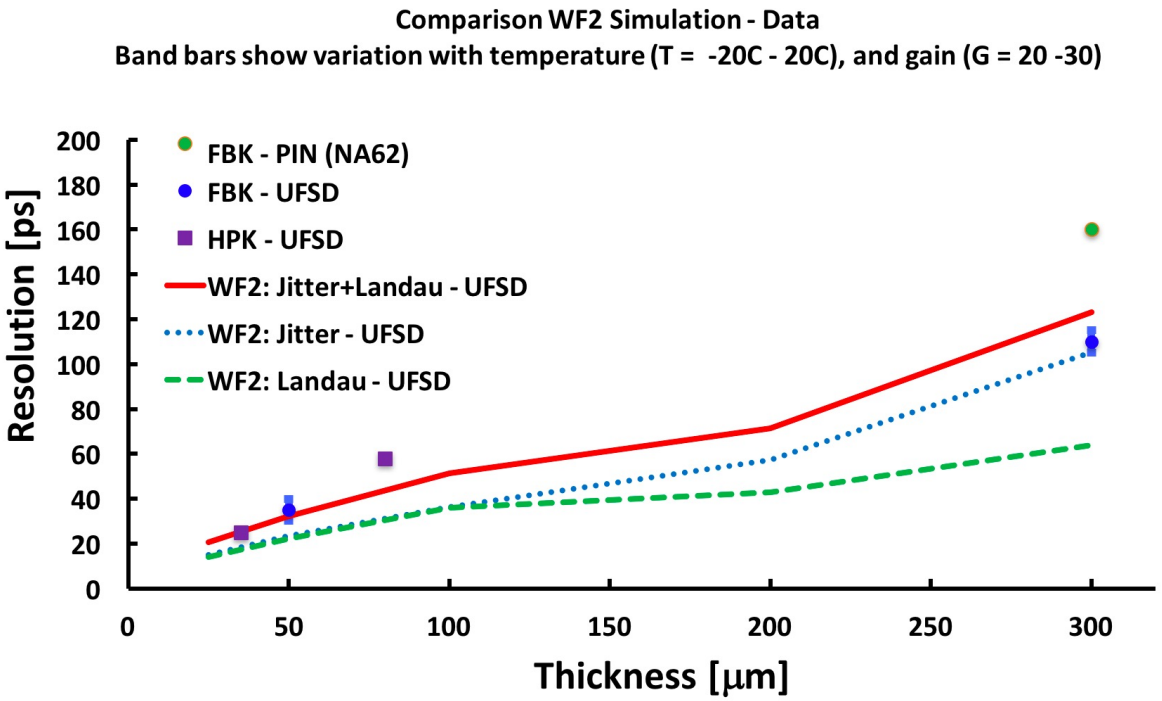
Barrel TOF
Single layer with 30 ps resolution and 1%X_0 material budget per layer

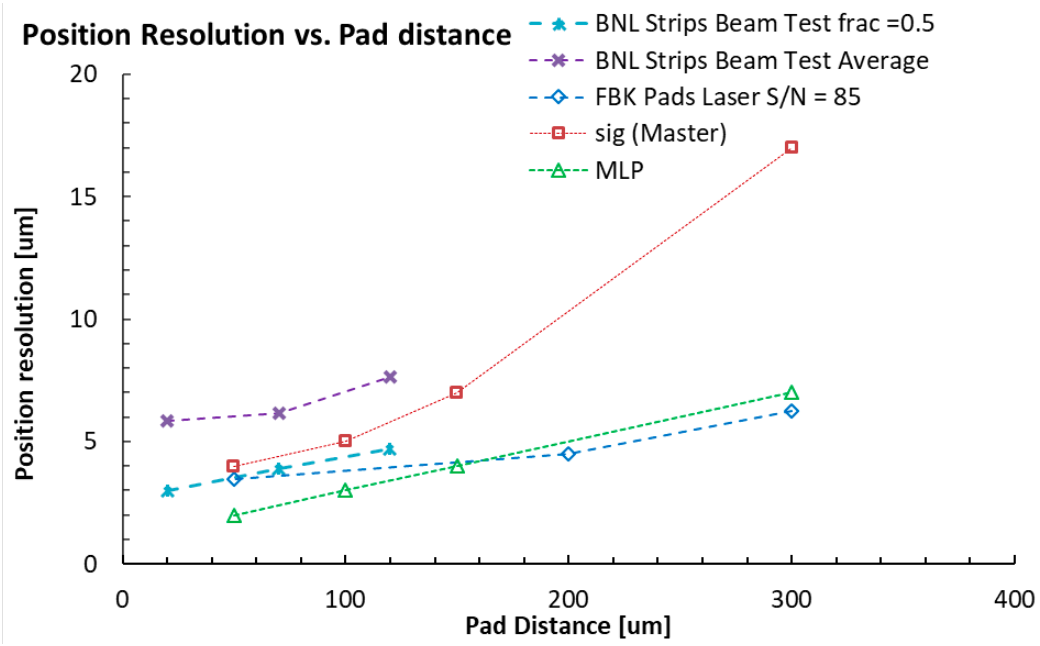
Forward TOF
Double layer with 25 ps resolution and 5%X_0 material budget per layer

Backward TOF
Double layer with 25 ps resolution and 5%X_0 material budget per layer

START Time
20 ps resolution

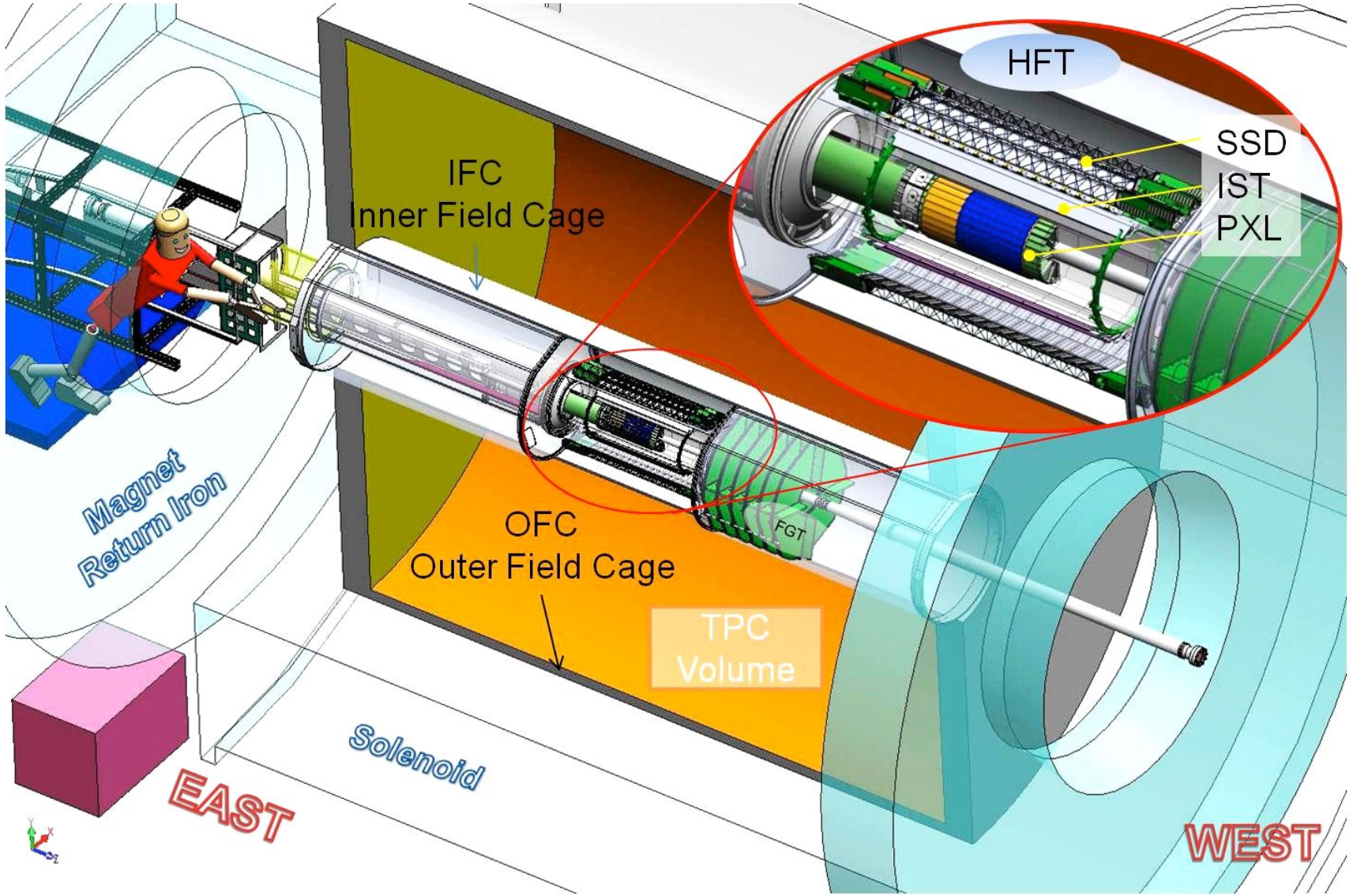
AC-LGAD Sensor R&D - eRD112





- **R&D Goals for AC-LGAD sensor**
  - 15-20 ps timing resolution, O(3-50μm) position resolution where needed
  - Minimal readout channel density (long strip, rectangular pixel) for reduced power and thus material and cost
- **Plan**
  - Produce and test sensors with thinner active volume to achieve the desired timing resolution
  - Optimize implantation parameters and AC-pad segmentation through simulation and real device studies
  - Engage commercial vendors to improve fabrication process and yield

AC-LGAD Barrel TOF Detector for EIC – STAR IST



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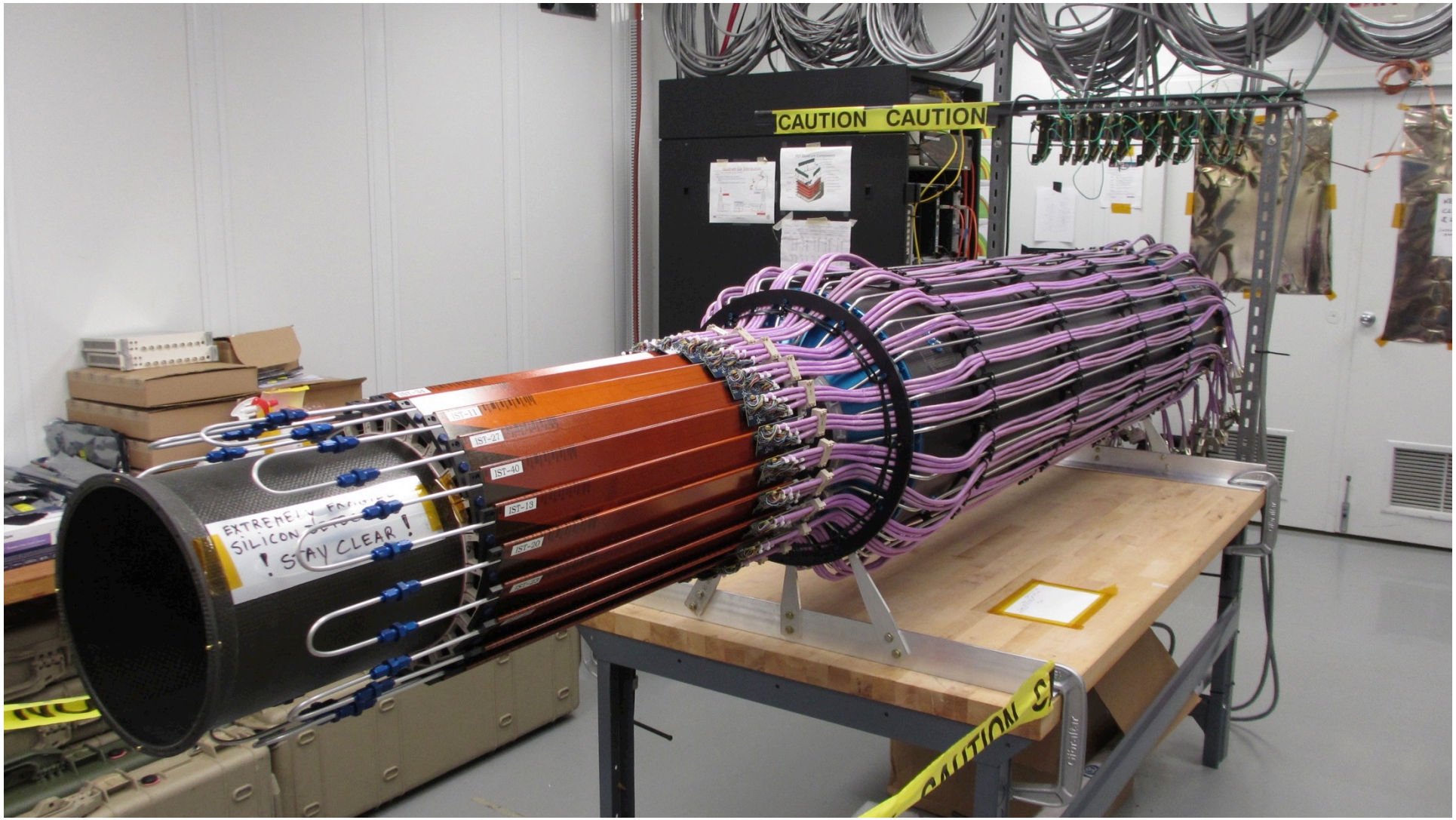

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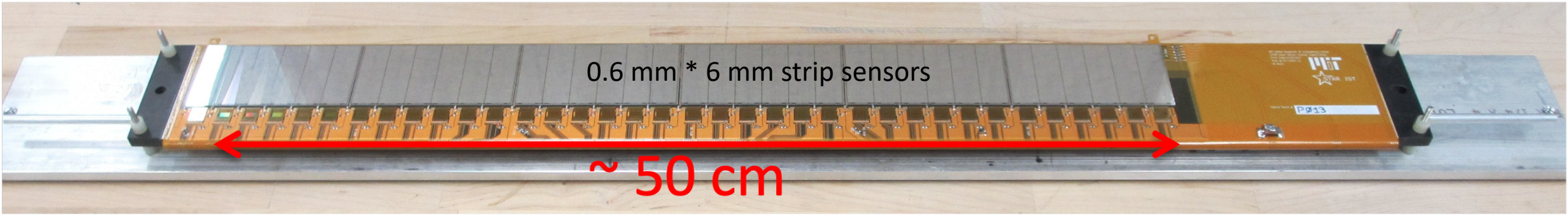
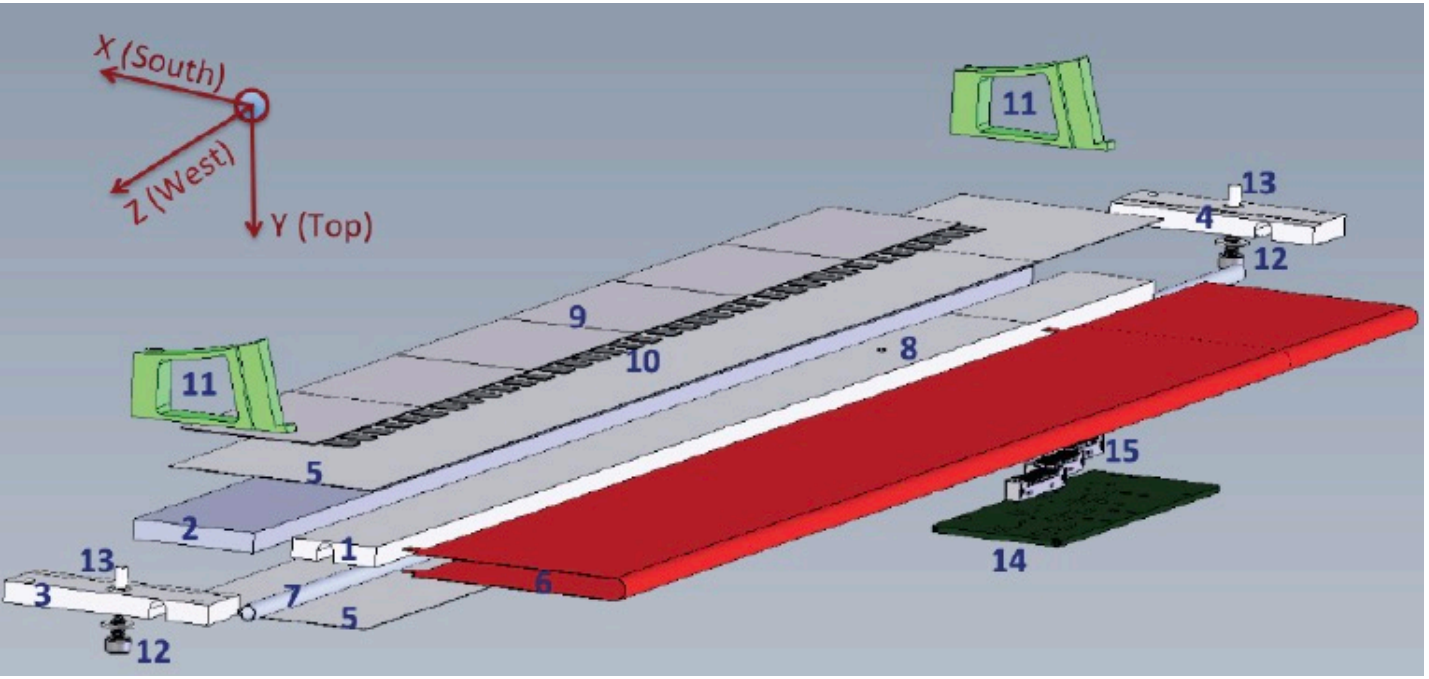
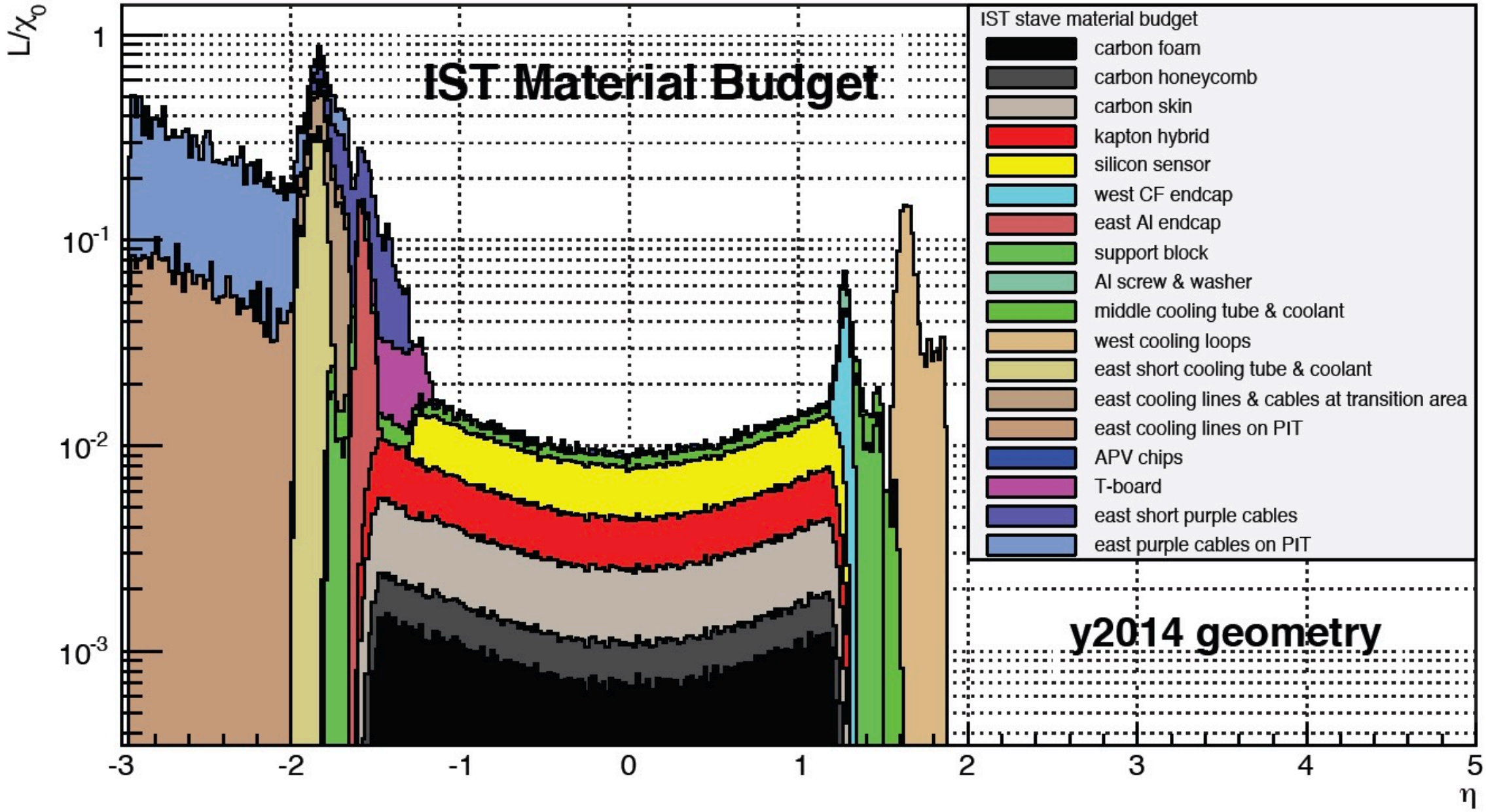




1) carbon foam 2) carbon honeycomb 3) west carbon end-cap 4) east Al end-cap 5) carbon fiber skins 6) Kapton hybrid 7) Al cooling tube with cooling liquid inside 8) thermal sensor 9) silicon sensors 10) APV chips 11) support blocks 12) screws with washers 13) spacers 14) transition board 15) readout connectors.

Material budget <1% X_0

AC-LGAD Endcap TOF Detectors for EIC – STAR IST



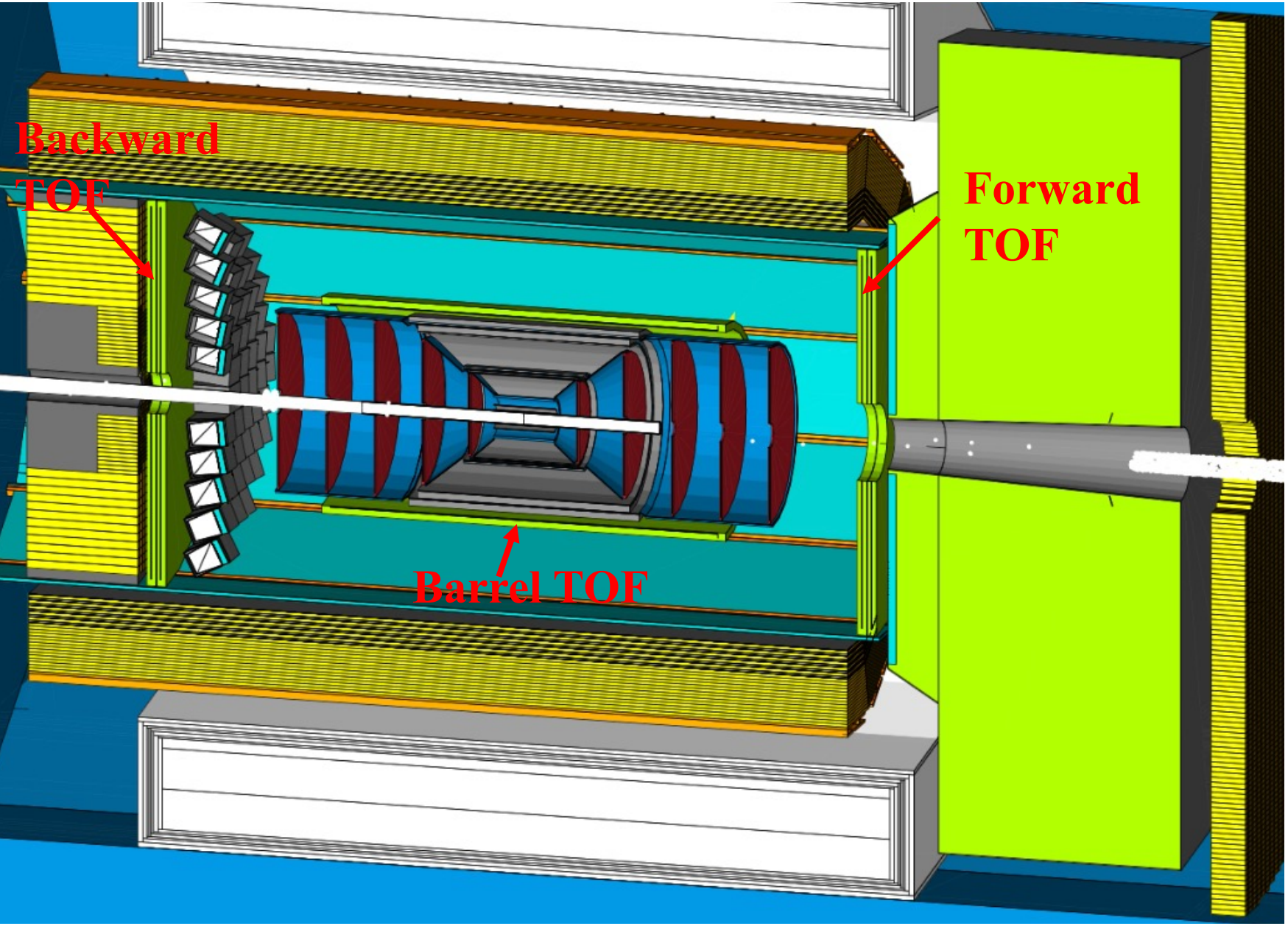
Outline

- Particle ID performance from BTOF - DD4HEP

- Impact on tracking by BTOF - Fun4All

- BTOF layout, module design and integration into ATHENA

AC-LGAD TOF Detectors in ATHENA DD4HEP



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Eta=[-1.44, 1.44]

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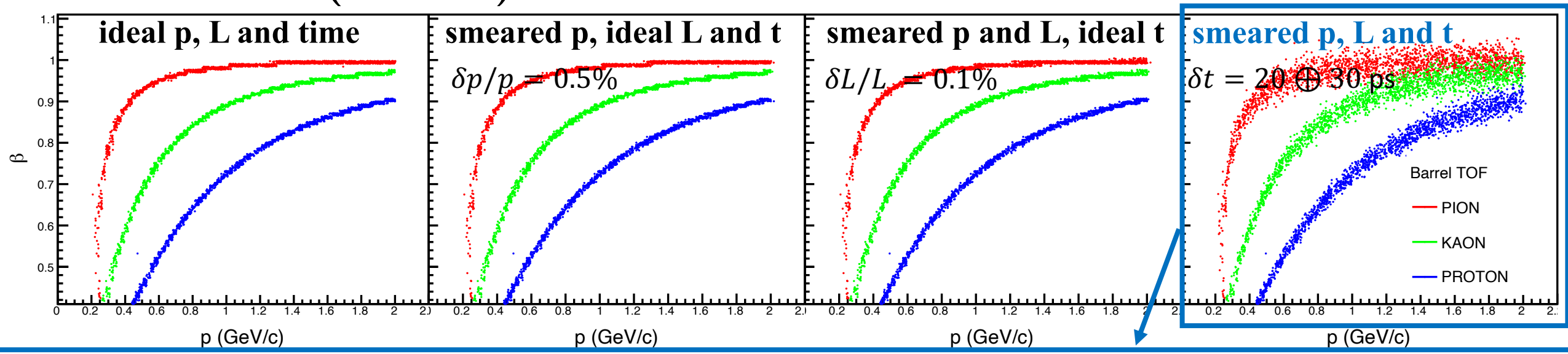
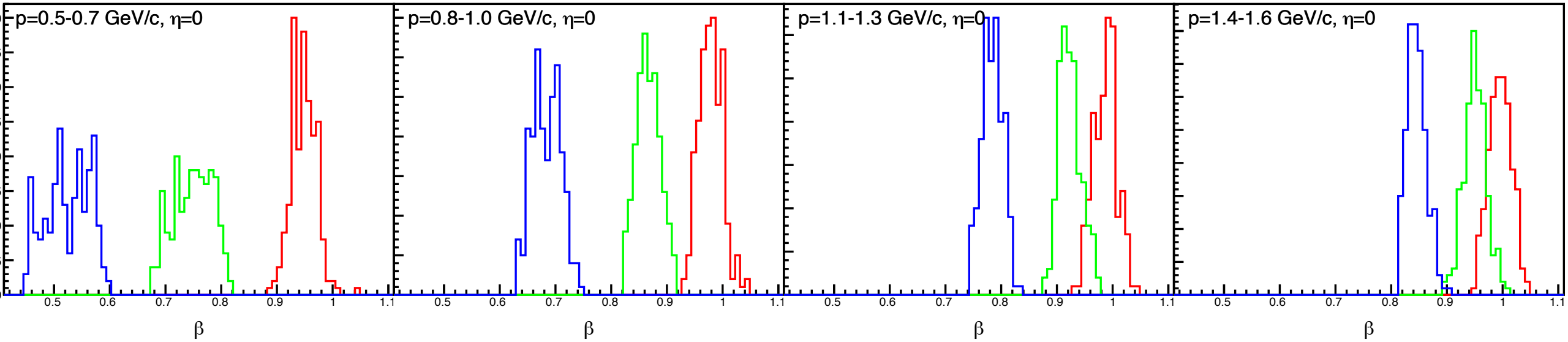
Barrel TOF (eta=0) in ATHENA DD4HEP





Excellent π/K/p separation at 0.2-1 GeV/c

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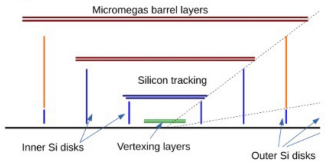
ATHENA Baseline 2.0 Tracker – Nick Lukow (10/5/2021)

Barrel layout

Si pixel pitch 10 um for vtx and barrel layers

Tracking WG Input for Next Iteration: Barrel

- **Barrel**: pretty settled by now - converging on hybrid setup
  - 3 D-MAPS Vertex layer
  - 2 D-MAPS tracking layer
  - 4 (2x2) MMG layer
  - No MPGD layer after DIRC since ECAL's first layer is Si (AstroPix) layer with $\sigma \approx 500/\sqrt{12}\ \mu\text{m} = 144\ \mu\text{m}$
  - Design leaves plenty of room for possible future upgrades
    - ToF (AC-LGAD/LAPPD)
    - miniTPC (GridPix)
    - high-p_T solution (RICH)
  - Covers $-1.1 < \eta < 1.1$
  - Minimal mass except at edges due to service (FEE, cables, …)



Thomas Ullrich, https://indico.bnl.gov/event/13175/contributions/54419/

Si Vertex	Radius (mm)	Length (cm)	% X/X0
Layer 1	33	28	0.05
Layer 2	44.1	28	0.05
Layer 3	55.1	28	0.05

- Three vtx layers for redundancy and low pT-threshold
- Radii from 1st engineering CAD model release based on possible stitched sensor size in phi
- Length = 28 cm: max length of a single sensor on wafer, allows for services on one side only; helps low material in negative direction

Si Barrel	Radius (cm)	Length (cm)	% X/X0
Layer 1	13.38	35.74	0.55
Layer 2	18	48.08	0.55

- 0.55% X/X0 might be conservative; Rey showed significant performance improvement for lower material in these layers; material optimisations to be looked into considering RD104 services reduction, inputs from engineers, etc. not necessarily for the proposal

Barrel MPGD Tracker (MM)	Radius (cm)	Length (cm)	Area (m^2)	Resolution (um)	% X/X0
Layer 1	47.72	127.47	3.82	150	0.4
Layer 2	49.57	127.47	3.97		
Layer 3	75.61	201.98	9.59		
Layer 4	77.47	201.98	9.83		

- Cheaper than silicon, no detrimental effect on performance
- Further optimisation of number of layers requires pattern recognition in presence of background, not for the proposal

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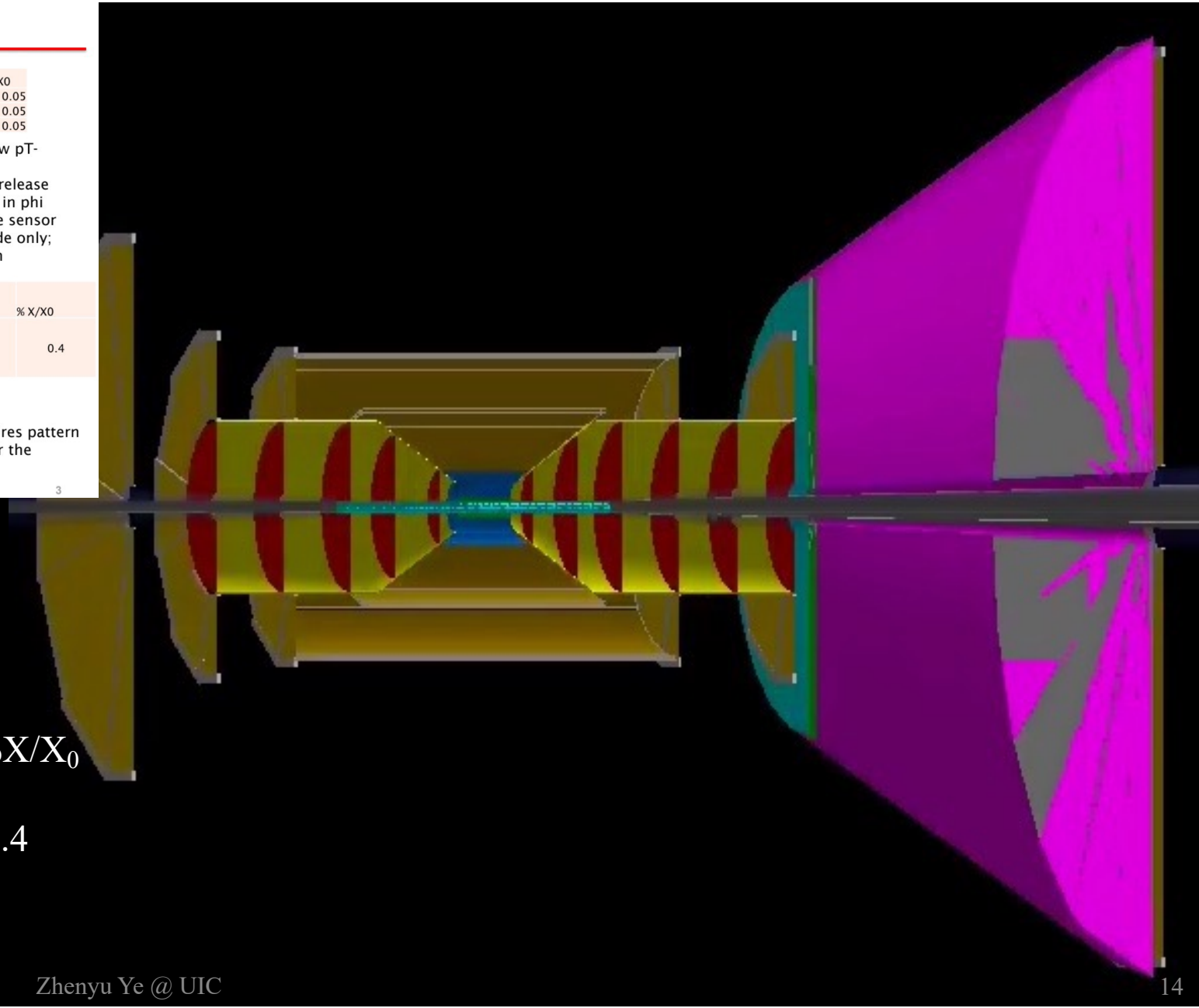

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Baseline 2.0 Tracker + BTOF in ATHENA Fun4All

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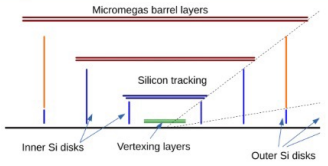

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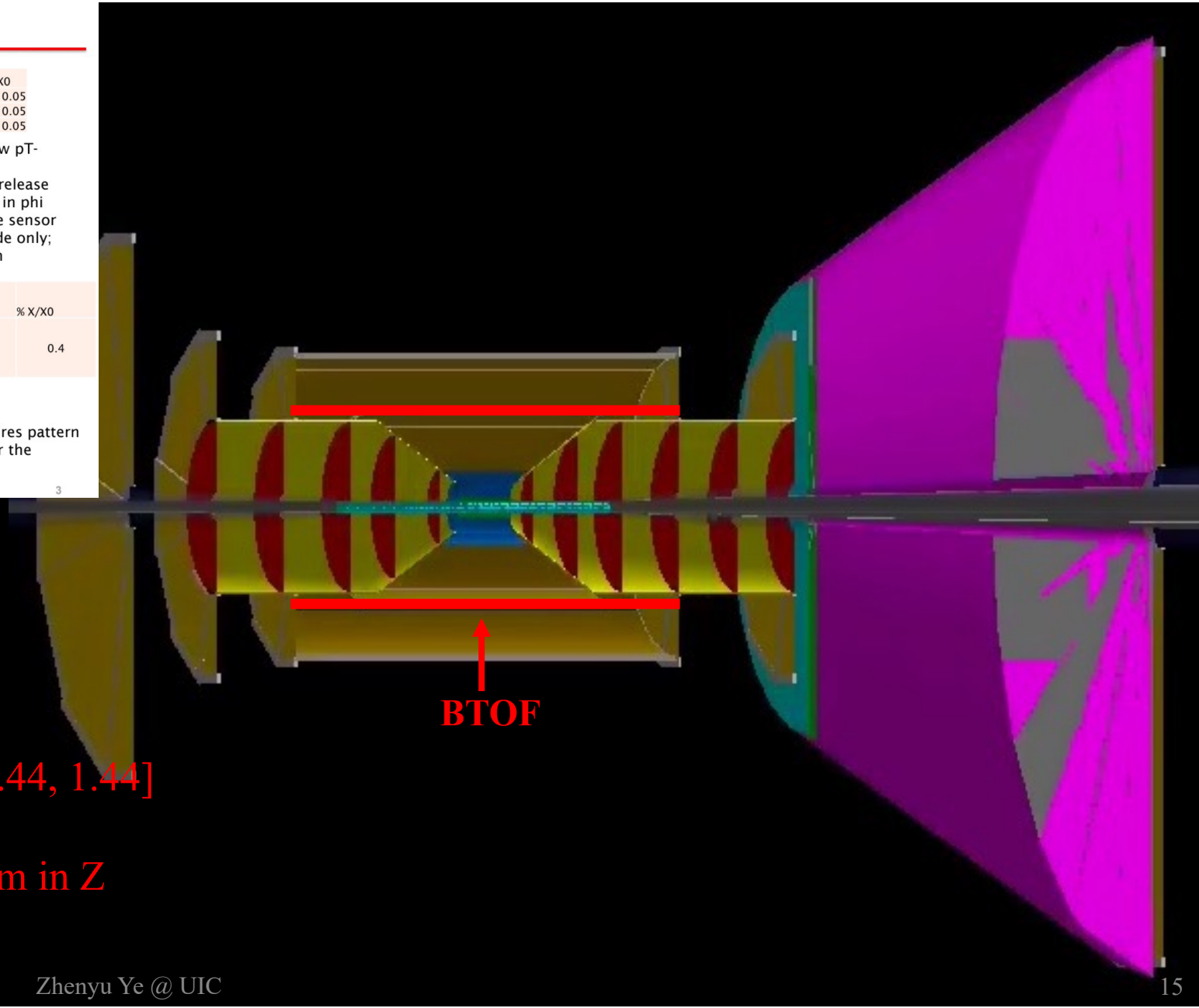


Additional Barrel Single Layer AC-LGAD

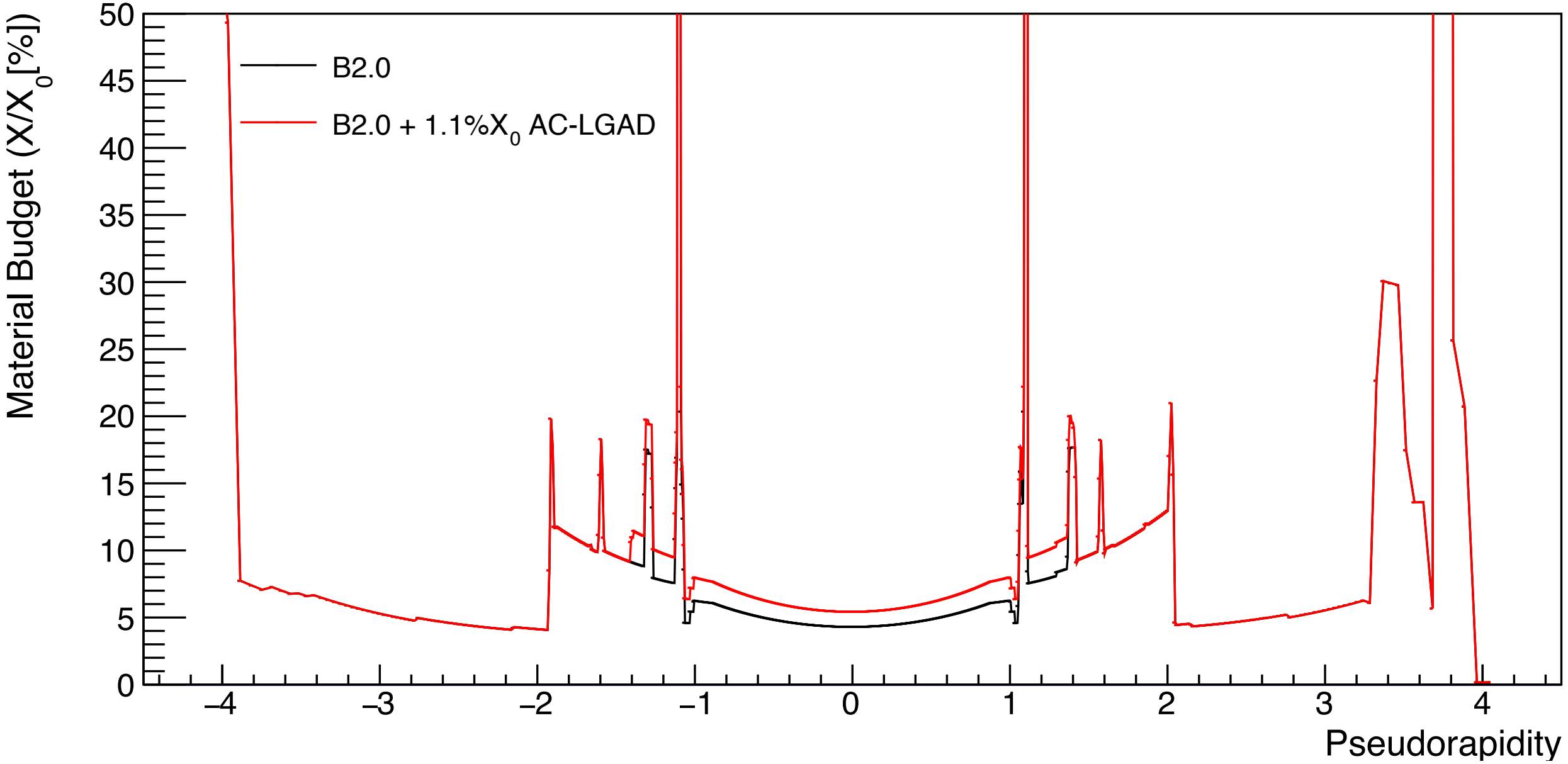
Z=[-1m, 1m], R=0.5m, Area=6.28 m^2, Eta=[-1.44, 1.44]

Strip pitch: 500 um in Rφ, 2.5 cm in Z

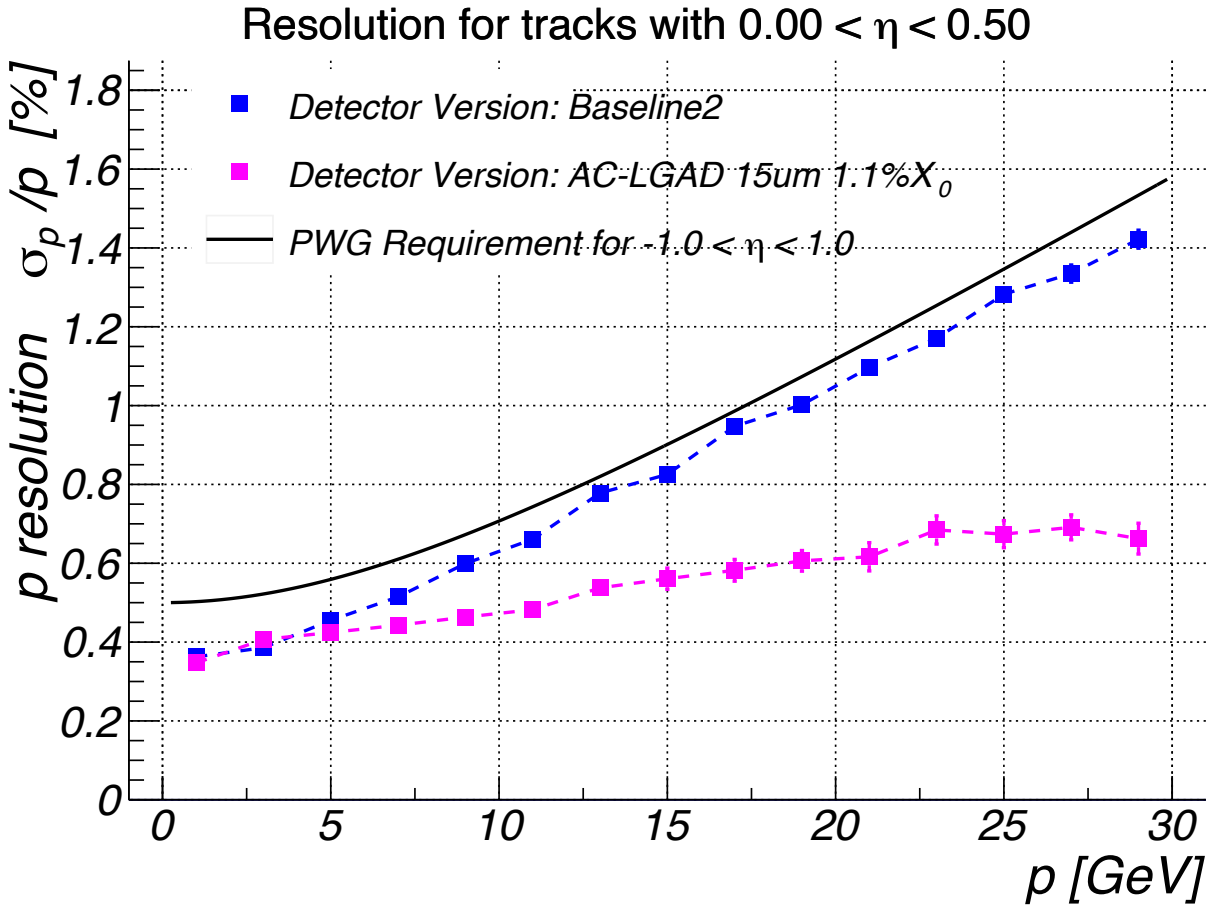
Spatial resolution: 15 um in Rφ, 2.5/sqrt(12) cm in Z

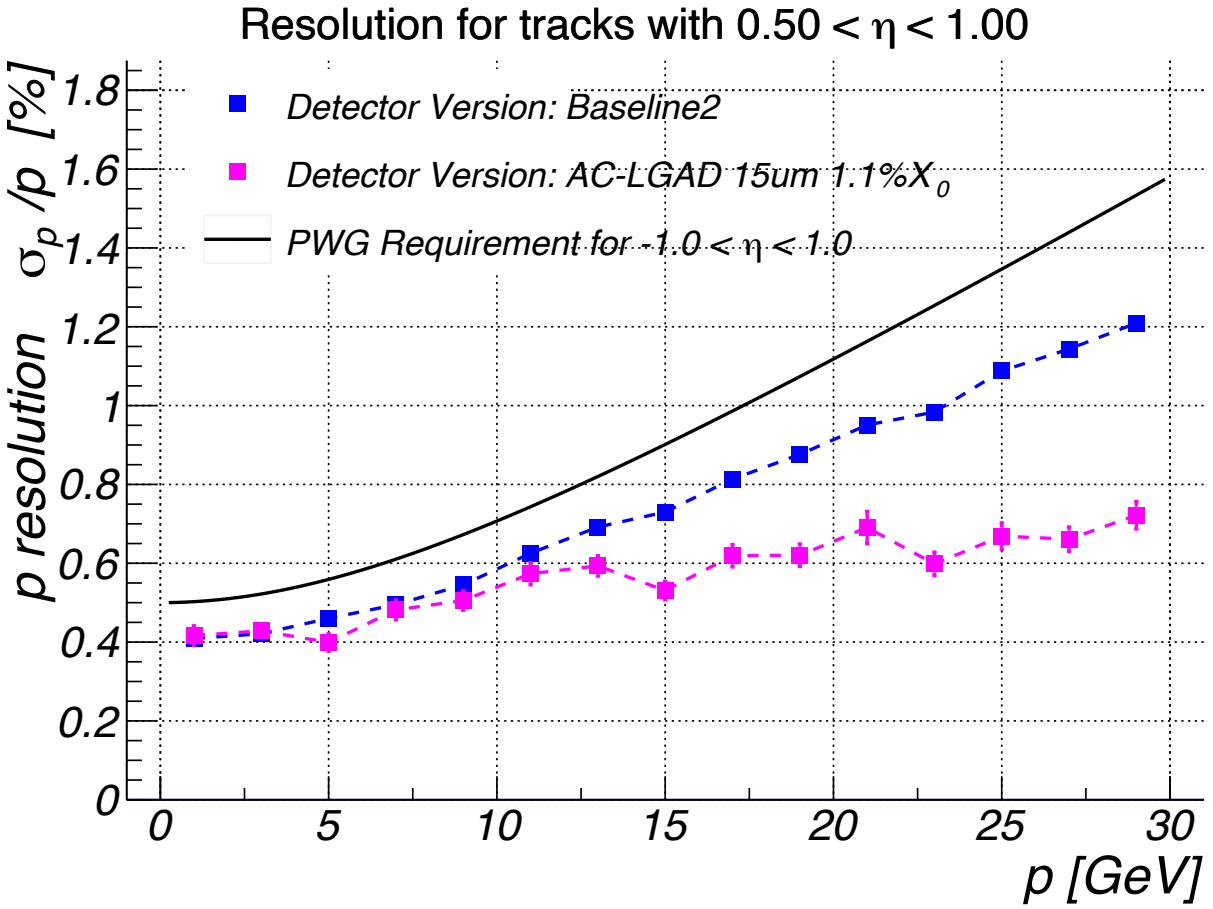
Material budget: 1.1%X_0

ATHENA Tracker Baseline 2.0 - Material Scan



Baseline 2.0 Tracker + BTOF in ATHENA Fun4All





Very small impact on the momentum resolution at low momentum and significantly improvement on the momentum resolution at high momentum

Outline

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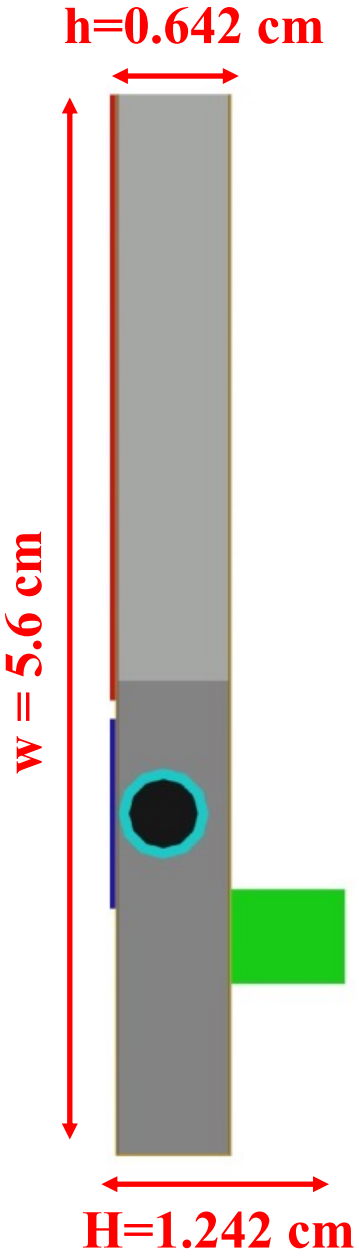
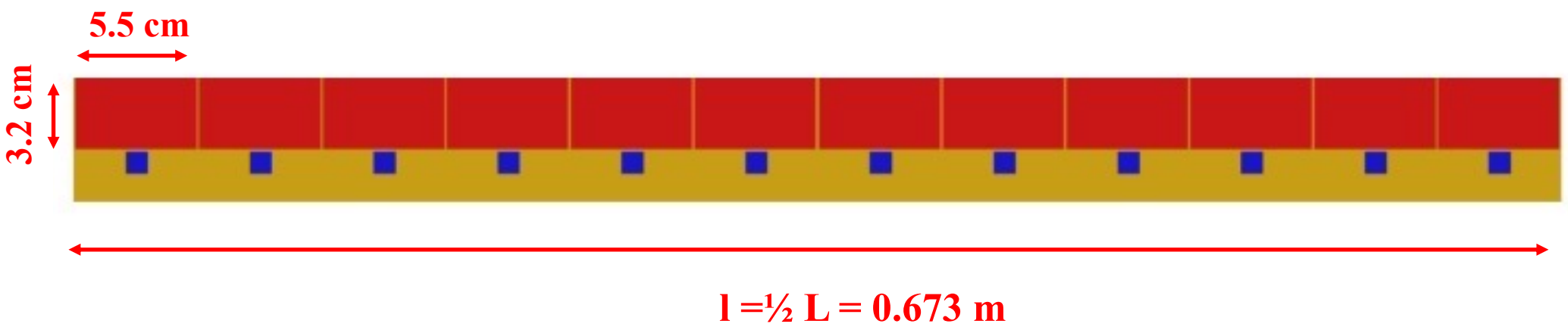
- Impact on tracking by BTOF - Fun4All
- BTOF layout, module design and integration into ATHENA

ATHENA Barrel TOF Module

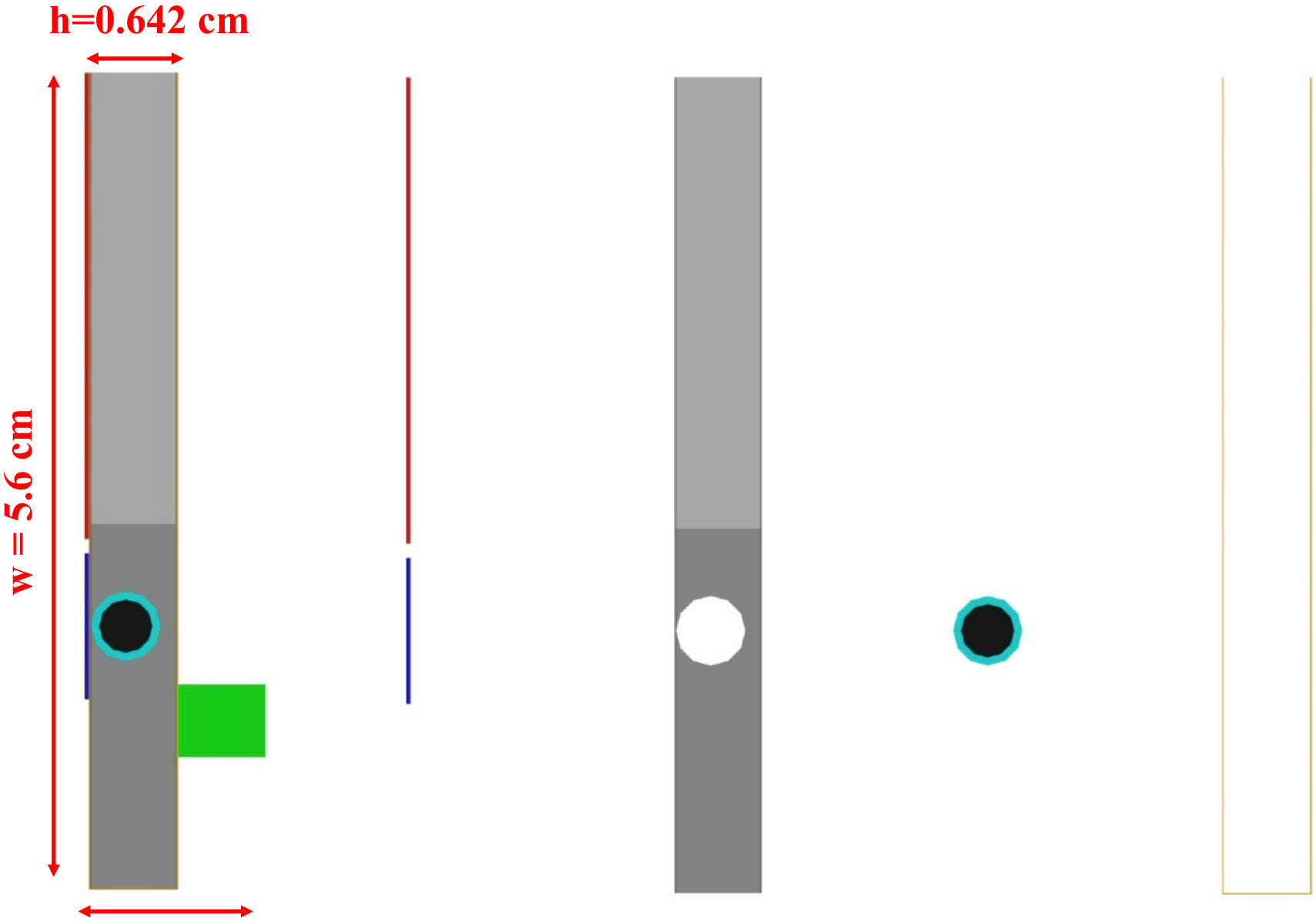
98 % coverage in Z





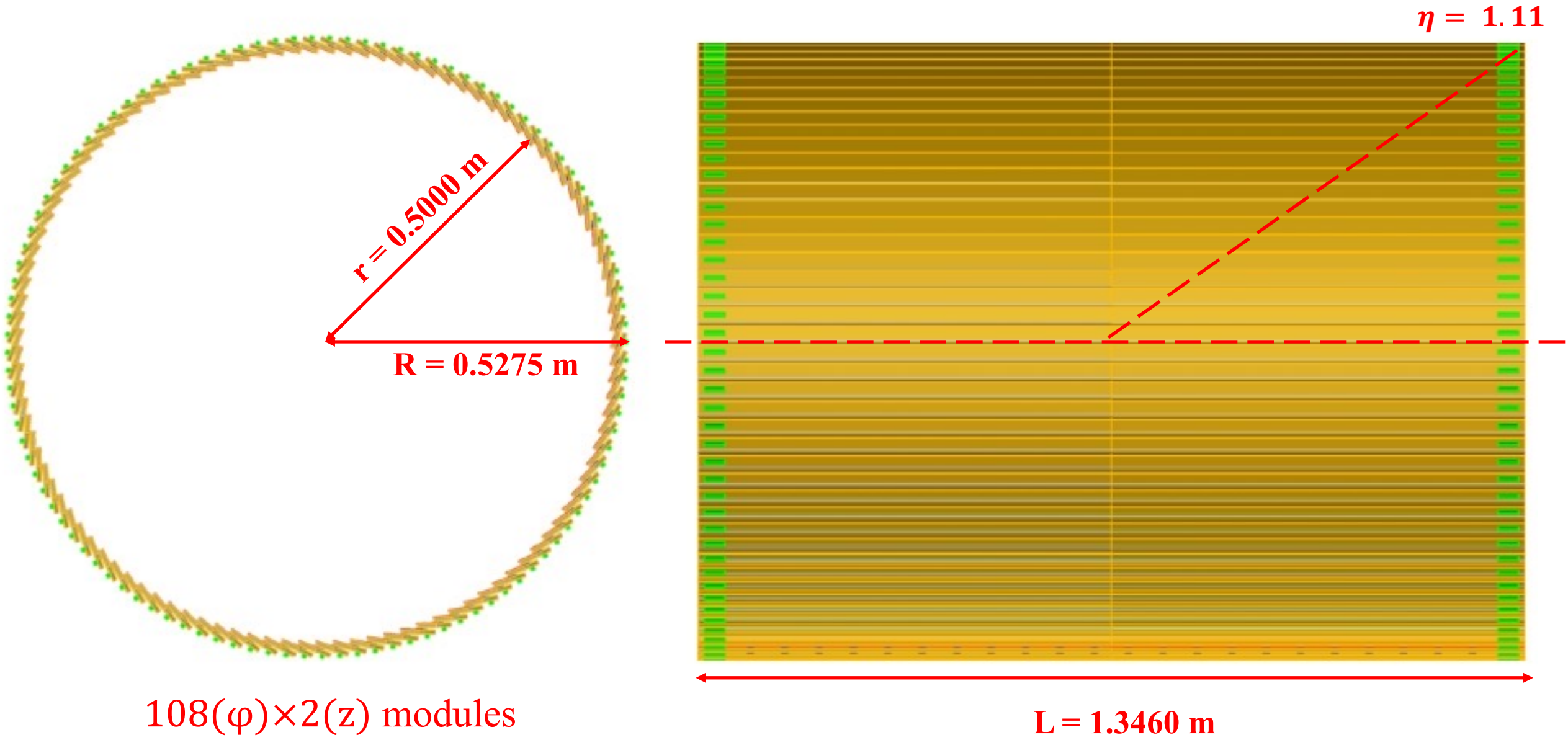
- **12 AC-LGAD sensors**, each with 64(φ)×2(z) strips, are read out by **12 frontend ASICs**, each with 128 readout channels
- **Low mass flexible Kapton PCB** distributes power and I/O signals from a low mass connector at the edge
- **Liquid coolant** in **Al cooling tube** takes away heat from the ASICs

ATHENA Barrel TOF Module



- AC-LGAD sensor
- Frontend ASICs
- Carbon foam+
  Carbon honeycomb+
  CF skins
- Al cooling tube
- Liquid coolant
- Kapton PCB
- Connector

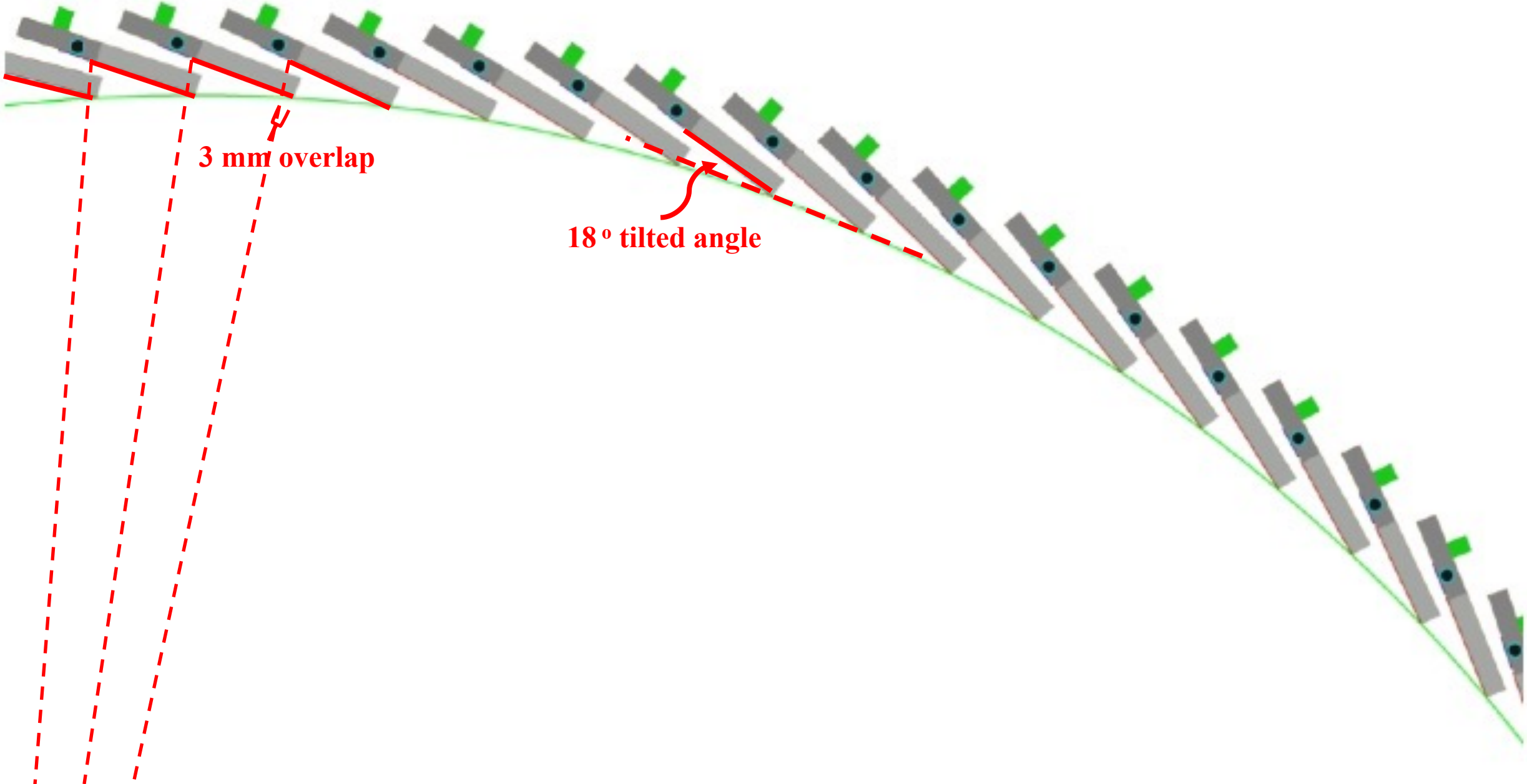
ATHENA Barrel TOF Detector Layout



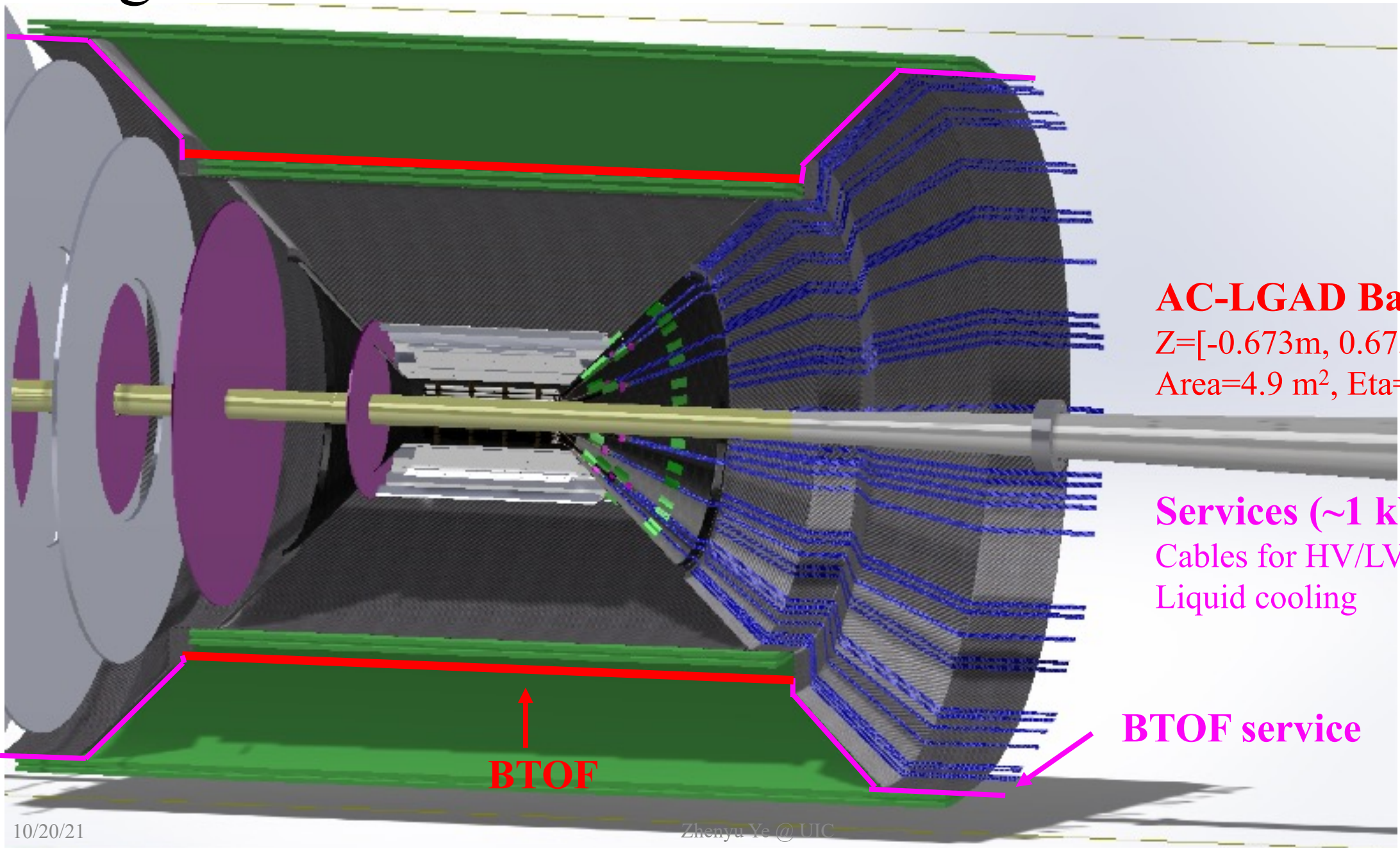
108(φ)×2(z) modules

ATHENA Barrel TOF Detector Layout

Full azimuthal coverage



Integration of BTOF into ATHENA



Summary

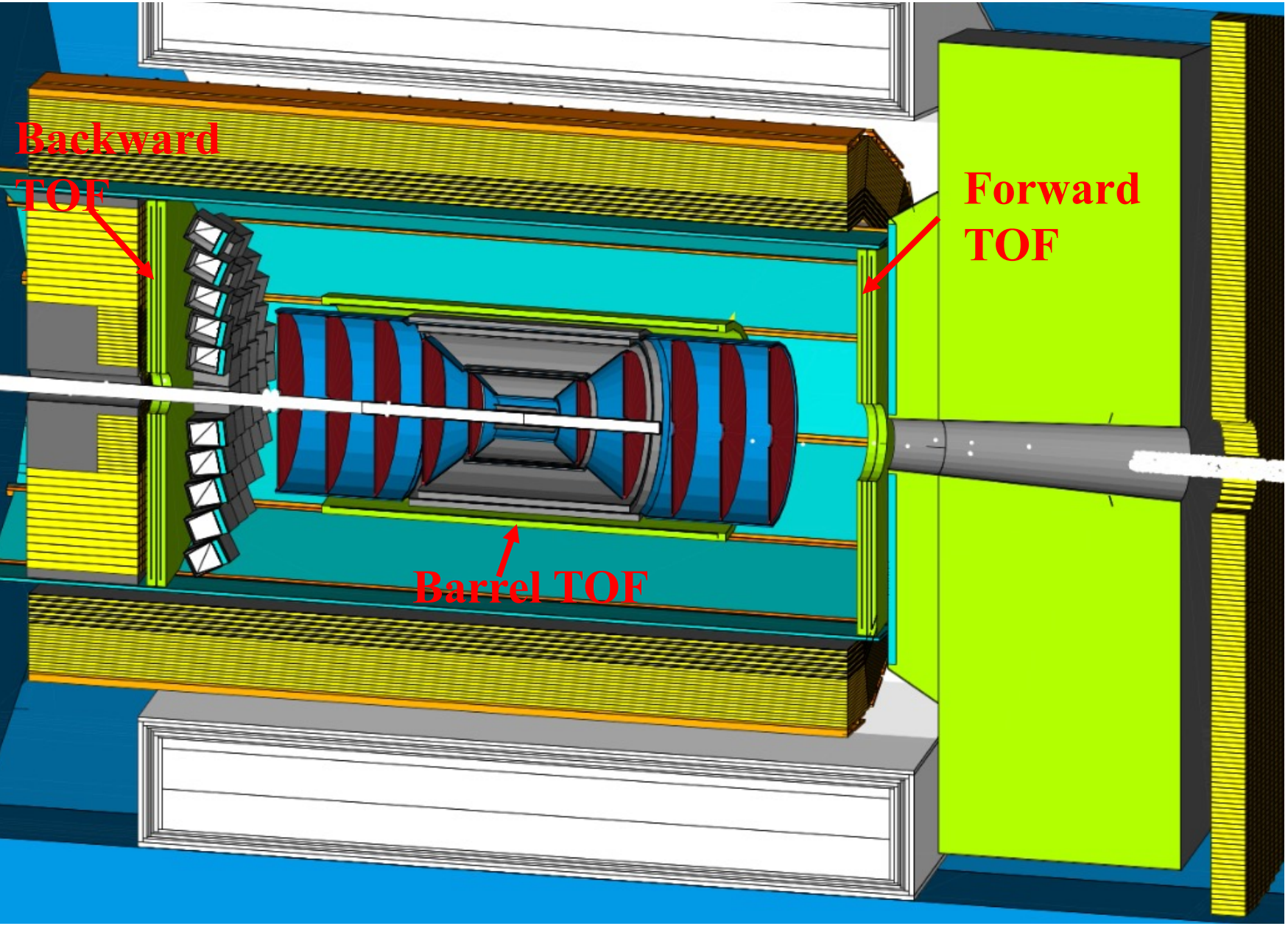
Adding an AC-LGAD TOF layer in the Barrel region at R~50cm can

- Provide low-p PID below DIRC threshold at small R (necessary to remove ρ contamination for exclusive ϕ)
- Very small impact on the momentum resolution at low p and significantly improvement on the momentum resolution at high p (based on Baseline 2.0 tracker design)
- A detector and module design has been worked out that facilitates easy integration into current ATHENA design
- We strongly urge the collaboration to consider including Barrel TOF in the baseline design

Adding TOF in the forward/backward enables PID with nearly 4π and wide p coverage

- We propose to include the Endcap TOFs as an upgrade option in the proposal

AC-LGAD TOF Detectors in ATHENA DD4HEP



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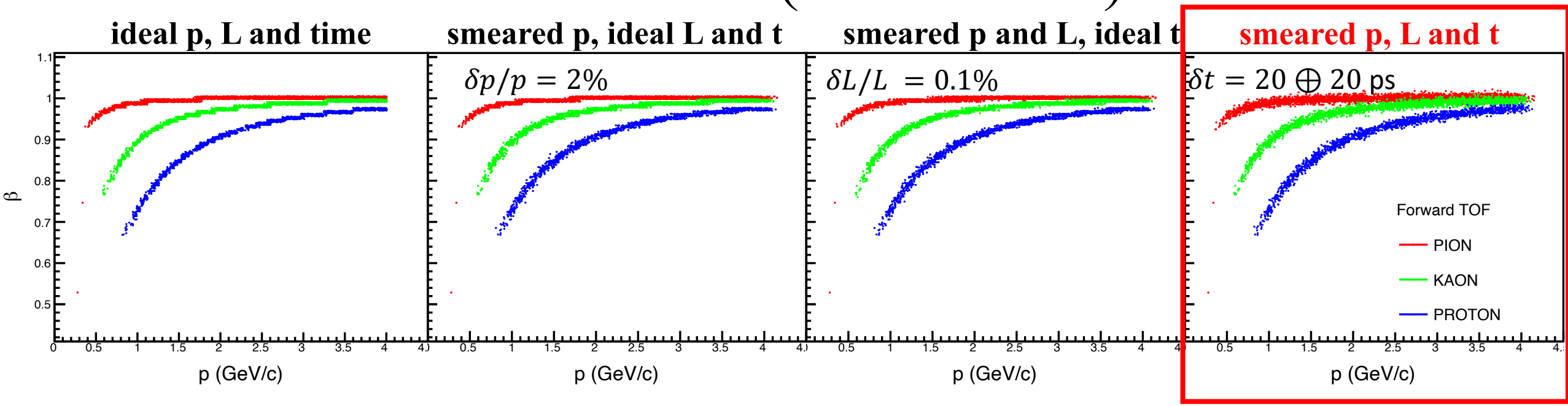
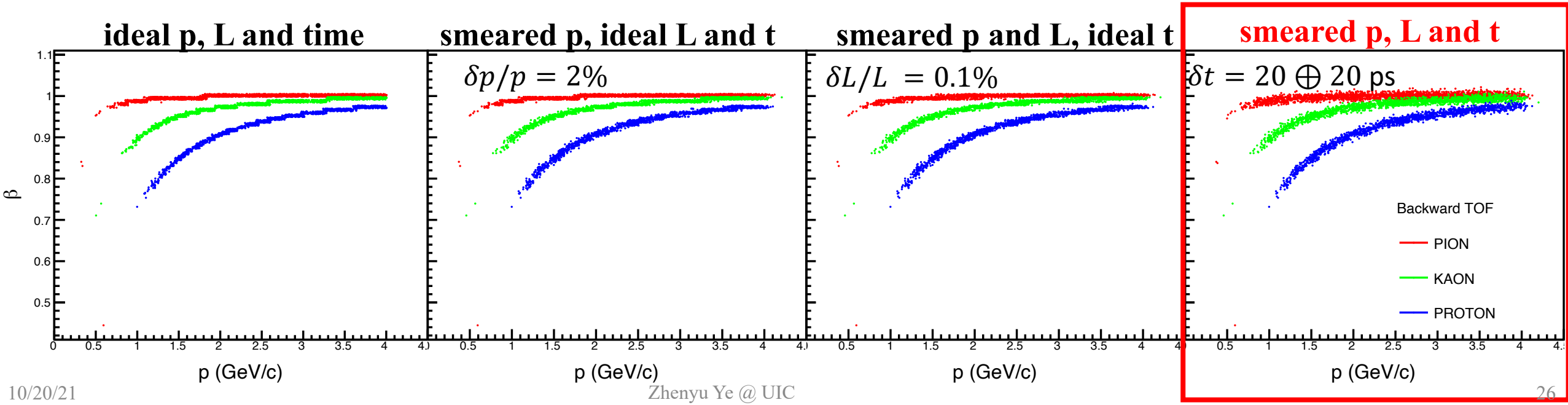
Forward and Backward TOF (eta=+/-2.25)





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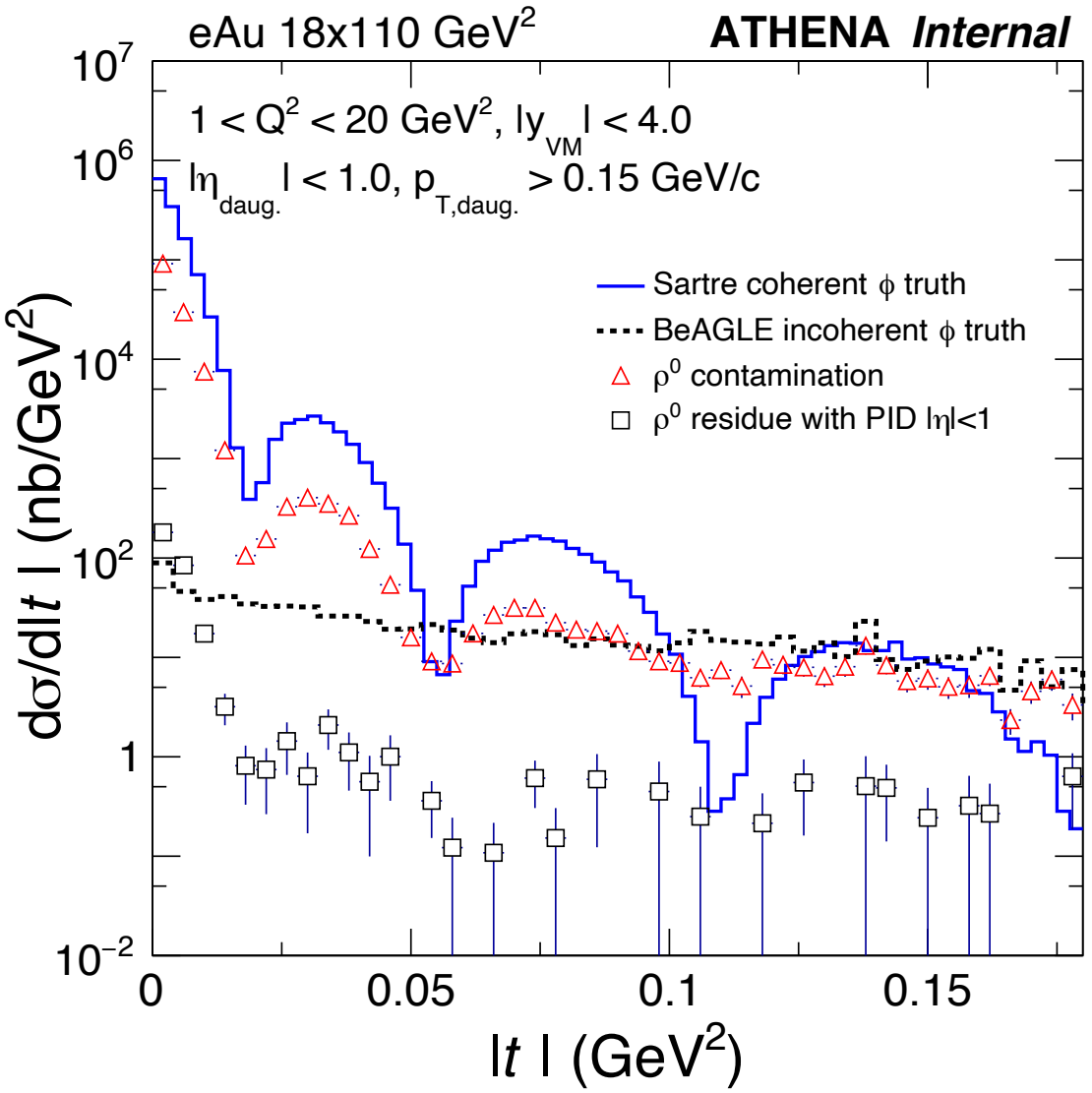

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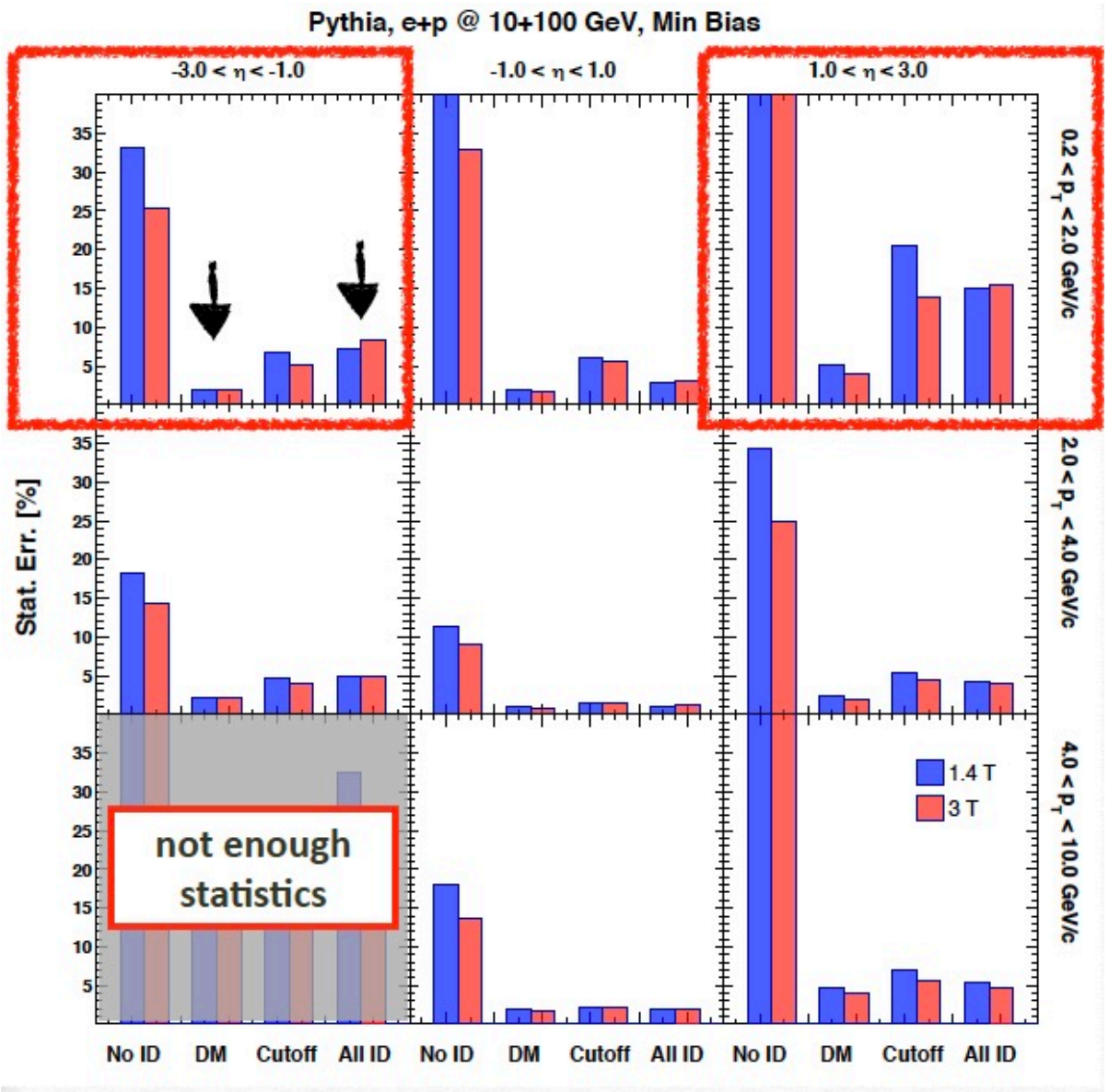

Backup

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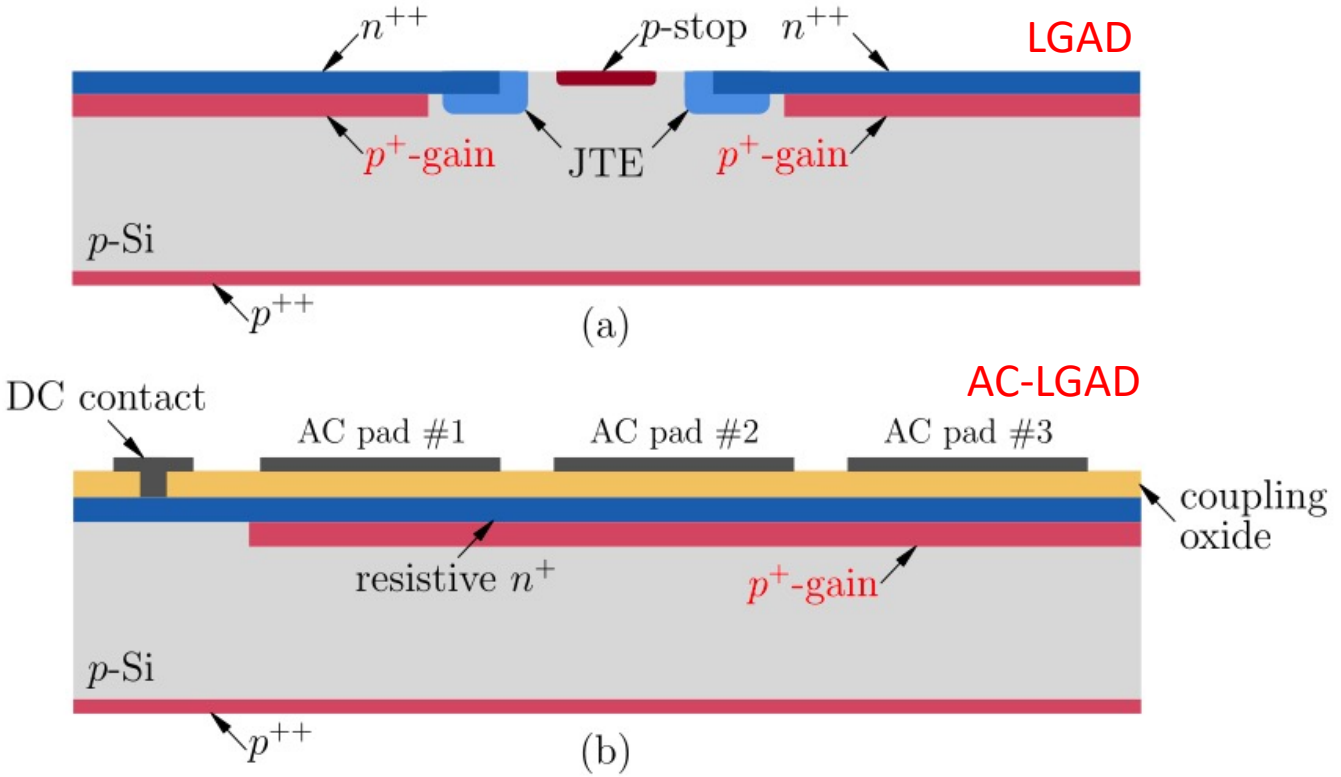

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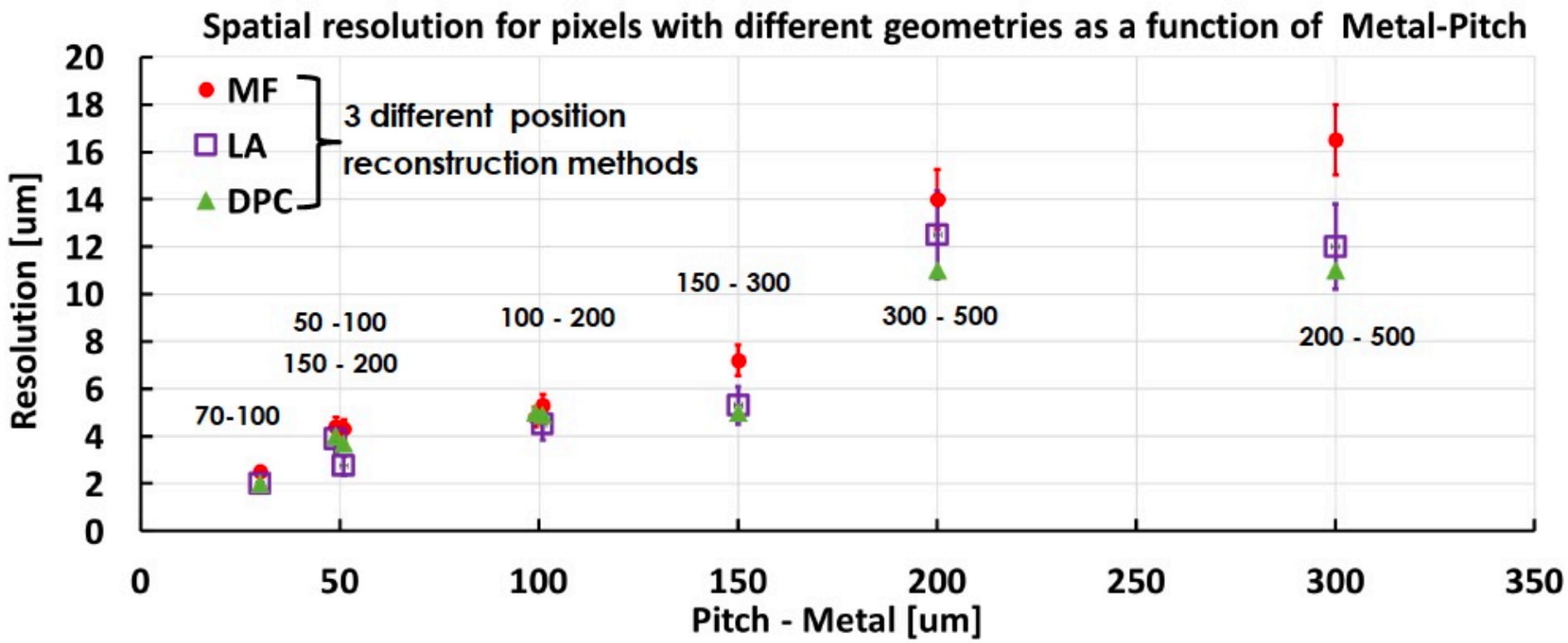
Laser study: position resolution as a function of pixel geometry

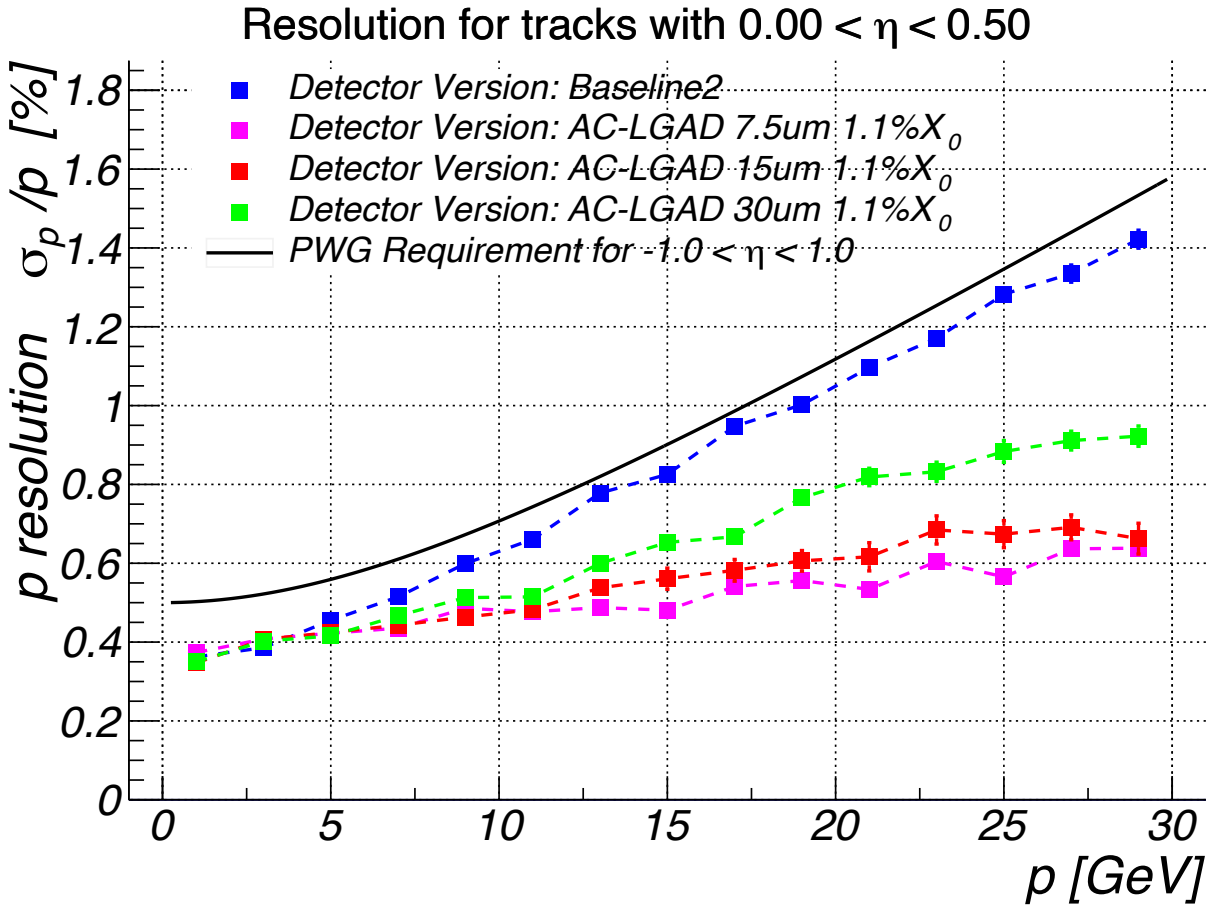


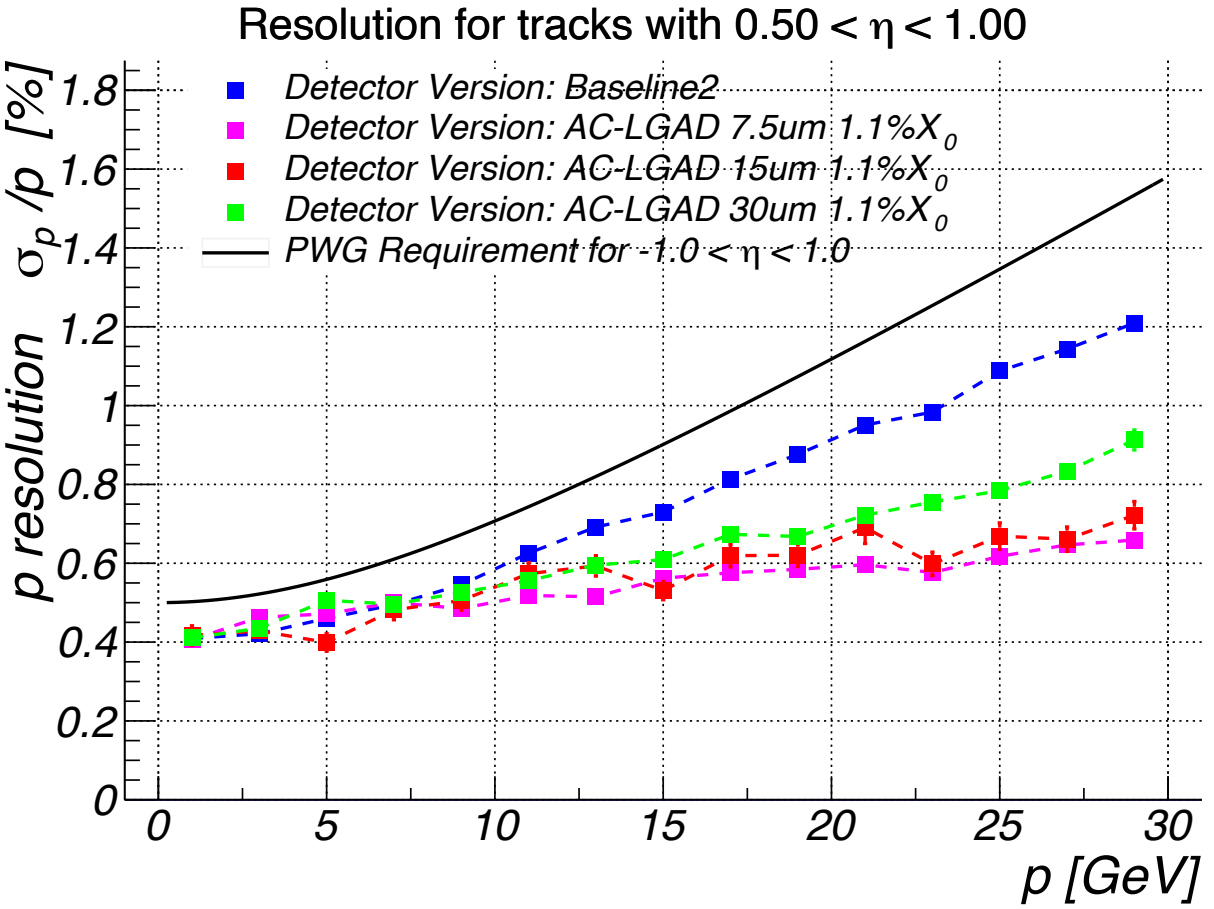
RSDs reach a spatial resolution that is about 5% of the inter-pad distance

➔ ~ 5 μm resolution with 150 μm pitch

RSDs have the "usual" UFSD temporal resolution of 30-40 ps

ATHENA Baseline 2.0 Tracker + Barrel AC-LGAD





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