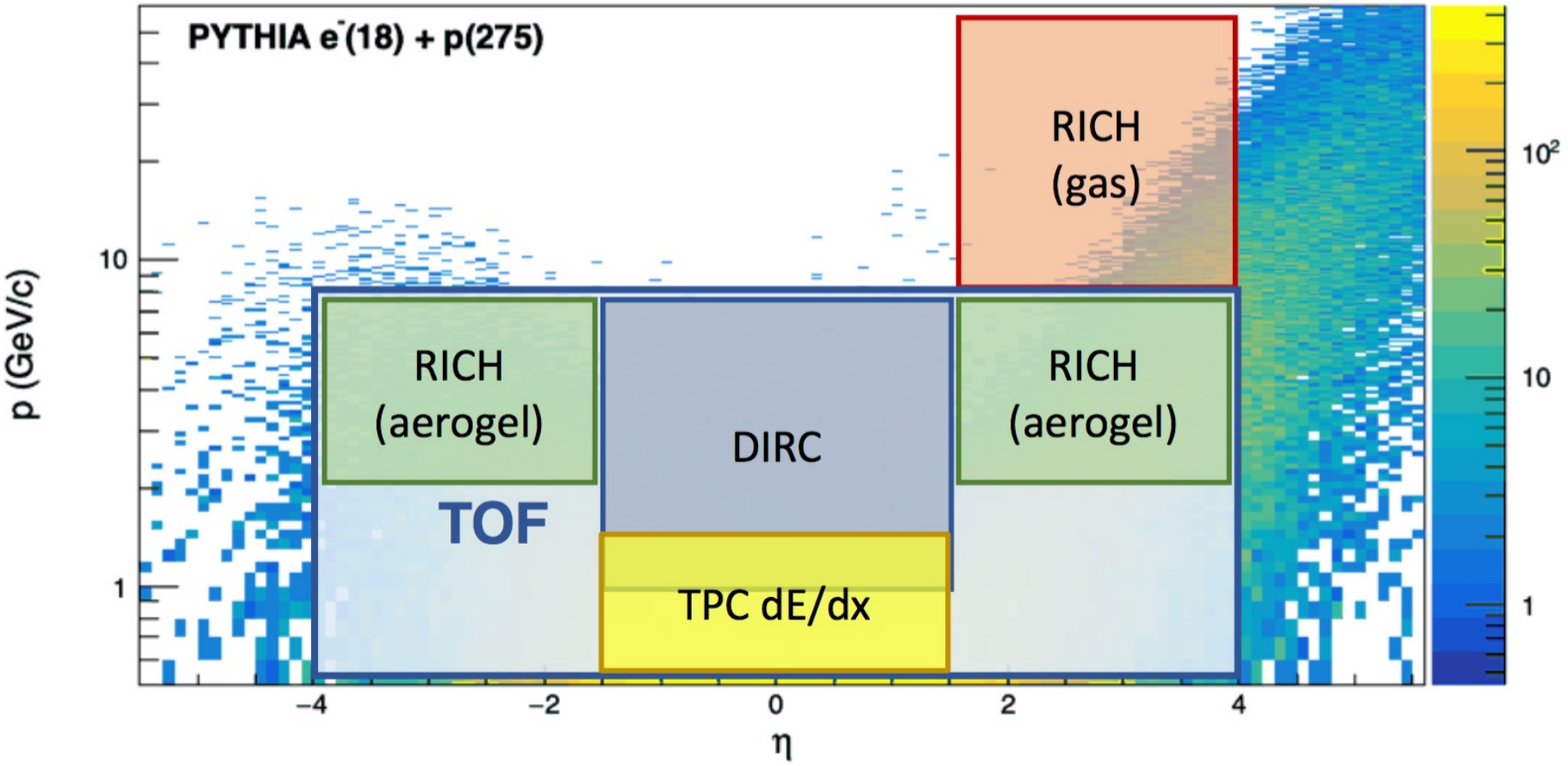
AC-LGAD TOF for ATHENA

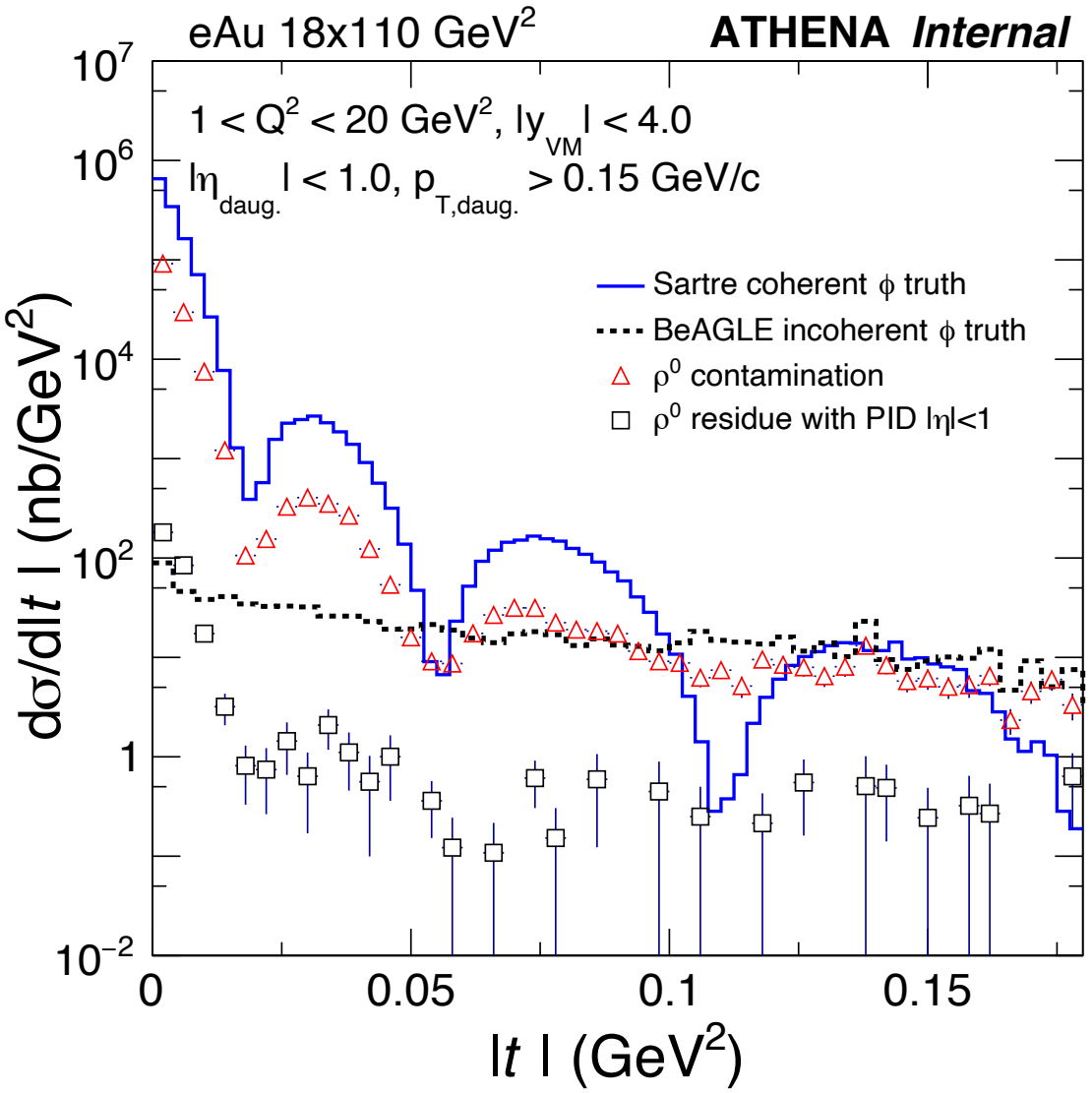
Zhenyu Ye

University of Illinois at Chicago

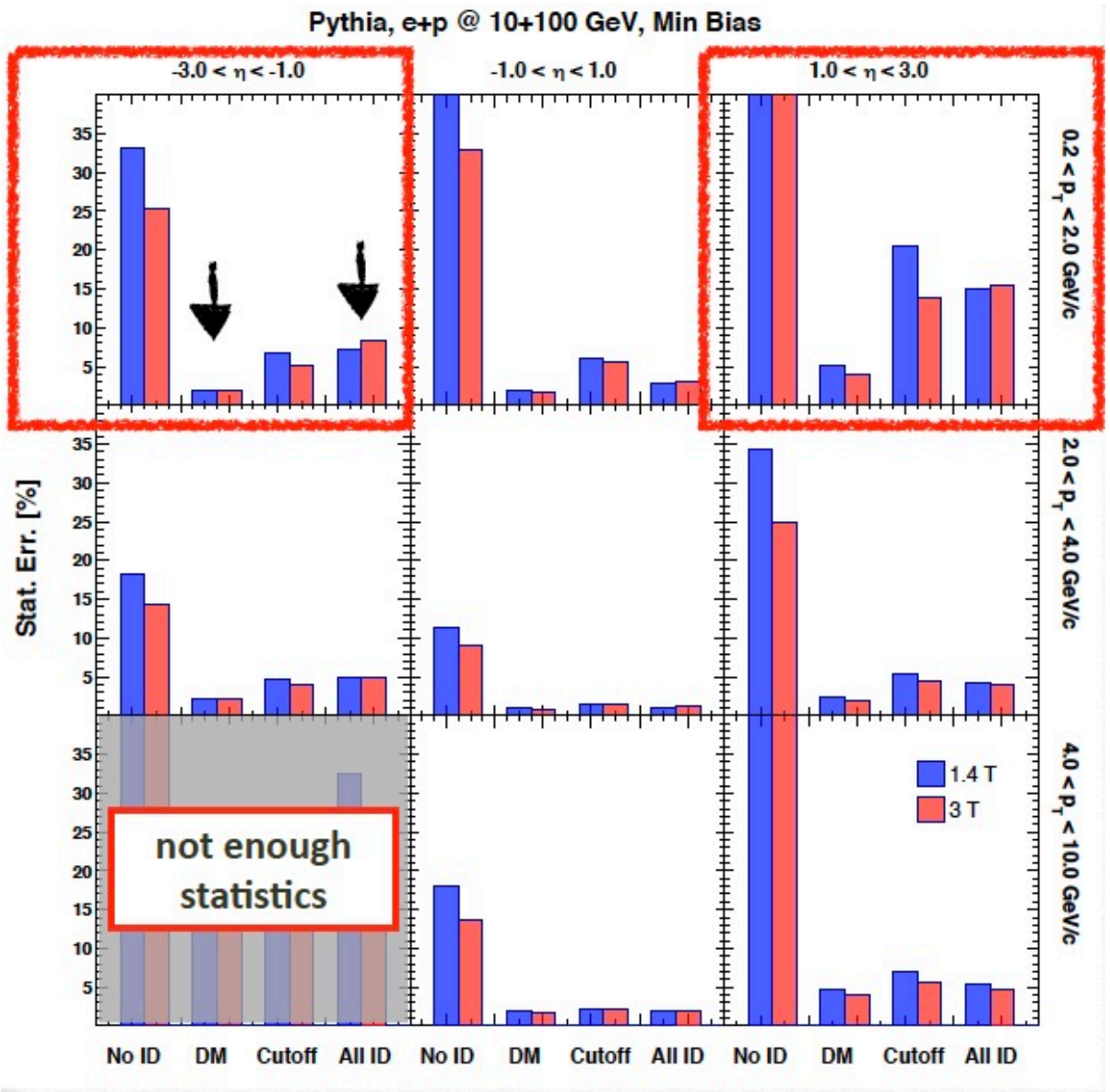


Low pT PID for Physics Measurements at EIC

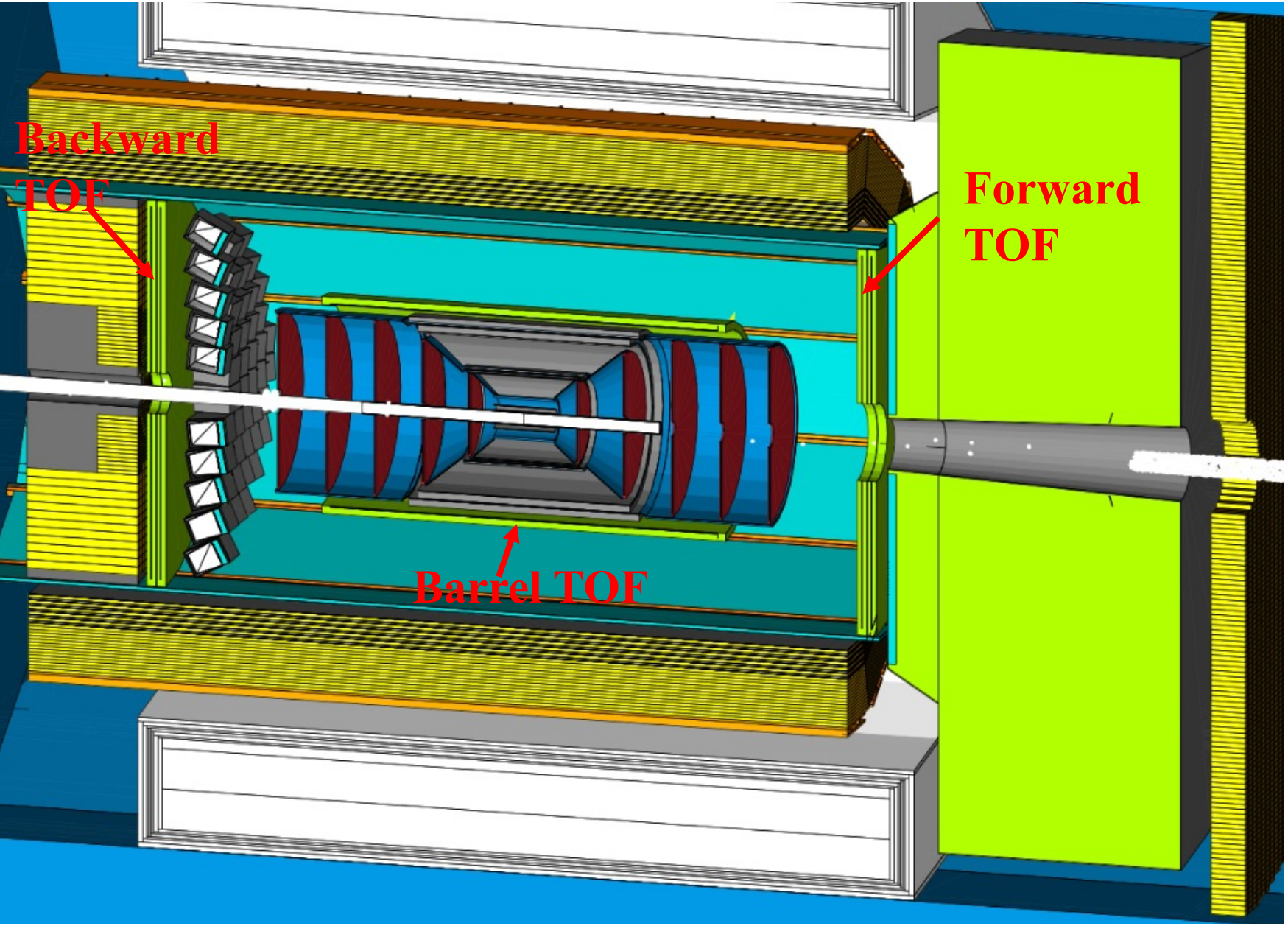
Exclusive ϕ (Z. Tu)



Λ_c (W. Fan)



AC-LGAD TOF Detectors in ATHENA DD4HEP

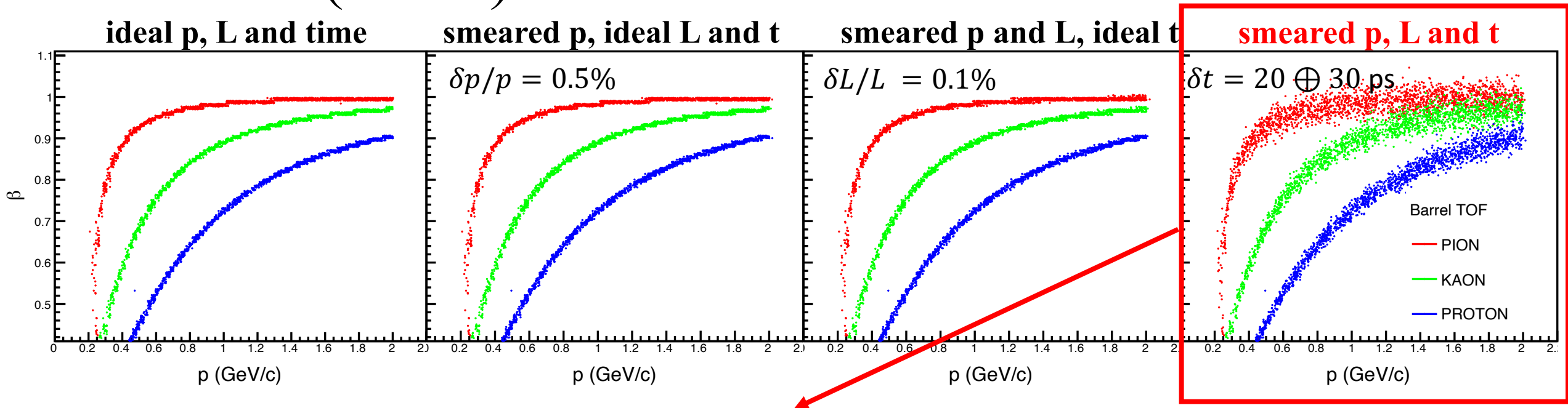


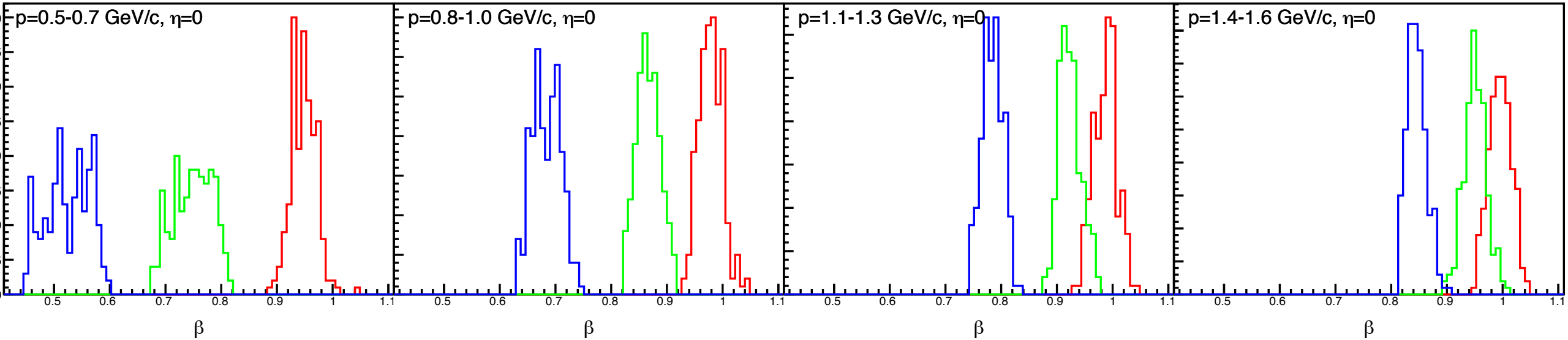
Barrel TOF (Area=6.28m^2)
Z=[-1m, 1m], R=0.5m,
Eta=[-1.44, 1.44]

Forward TOF (Area=5.44m^2)
Z=1.73m, R_{in}=0.19m, R_{out}=0.95m
Eta=[1.36, 2.91]

Backward TOF (Area=5.44m^2)
Z=-1.85m, R_{in}=0.19cm, R_{out}=0.95m,
Eta=[-2.97,-1.42]

Barrel TOF (eta=0) in ATHENA DD4HEP





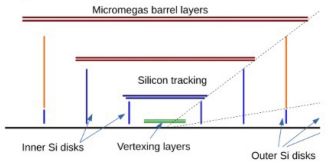
ATHENA Baseline 2.0 Tracker – Nick Lukow (10/5/2021)

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

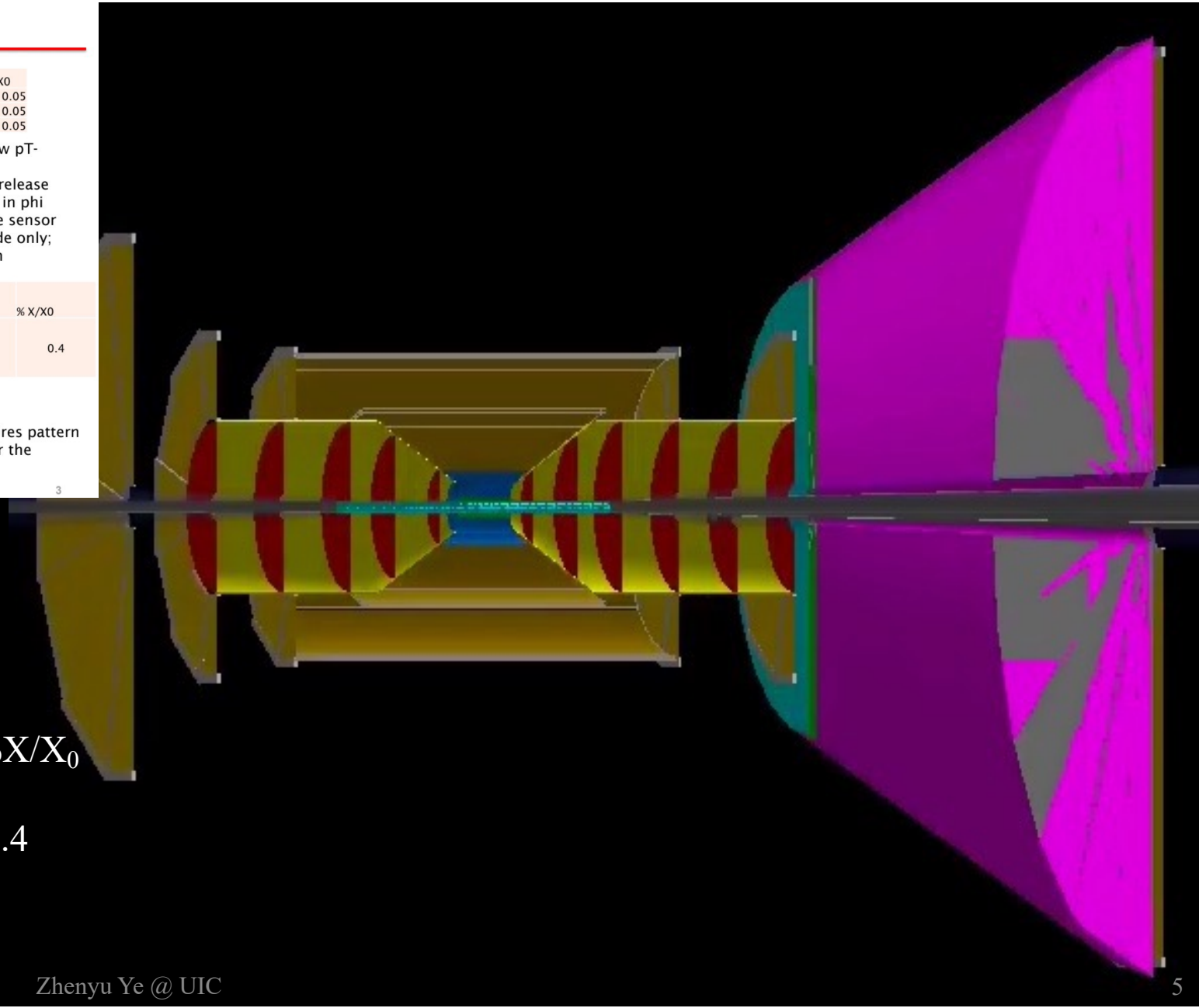
Si Barrel	Radius (cm)	Length (cm)	% X/X0
Layer 1	13.38	35.74	0.55
Layer 2	18	48.08	0.55

- 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

3



Barrel MPGD

R(cm)	Length(cm)	Area(m^2)	Resolution(um)	%X/X_0
47.72	127.47	3.82		
49.57	127.47	3.97	150	0.4
75.61	201.98	9.59		
77.47	201.98	9.83		

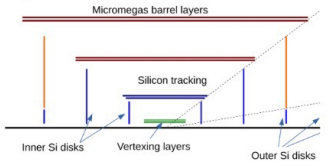
ATHENA Baseline 2.0 Tracker – Nick Lukow (10/5/2021)

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

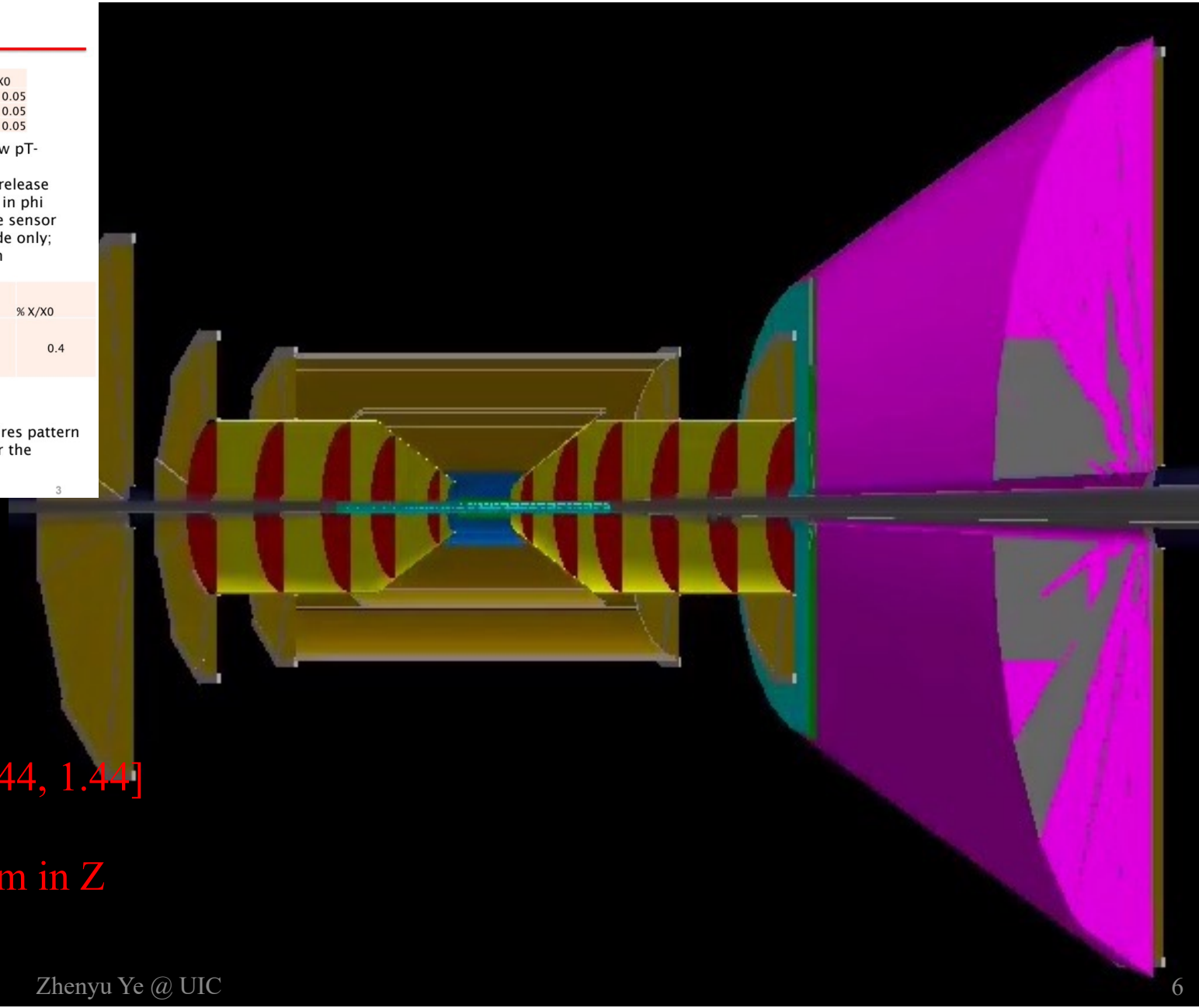
Si Barrel	Radius (cm)	Length (cm)	% X/X0
Layer 1	13.38	35.74	0.55
Layer 2	18	48.08	0.55

- 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

3



Additional Barrel Single Layer AC-LGAD

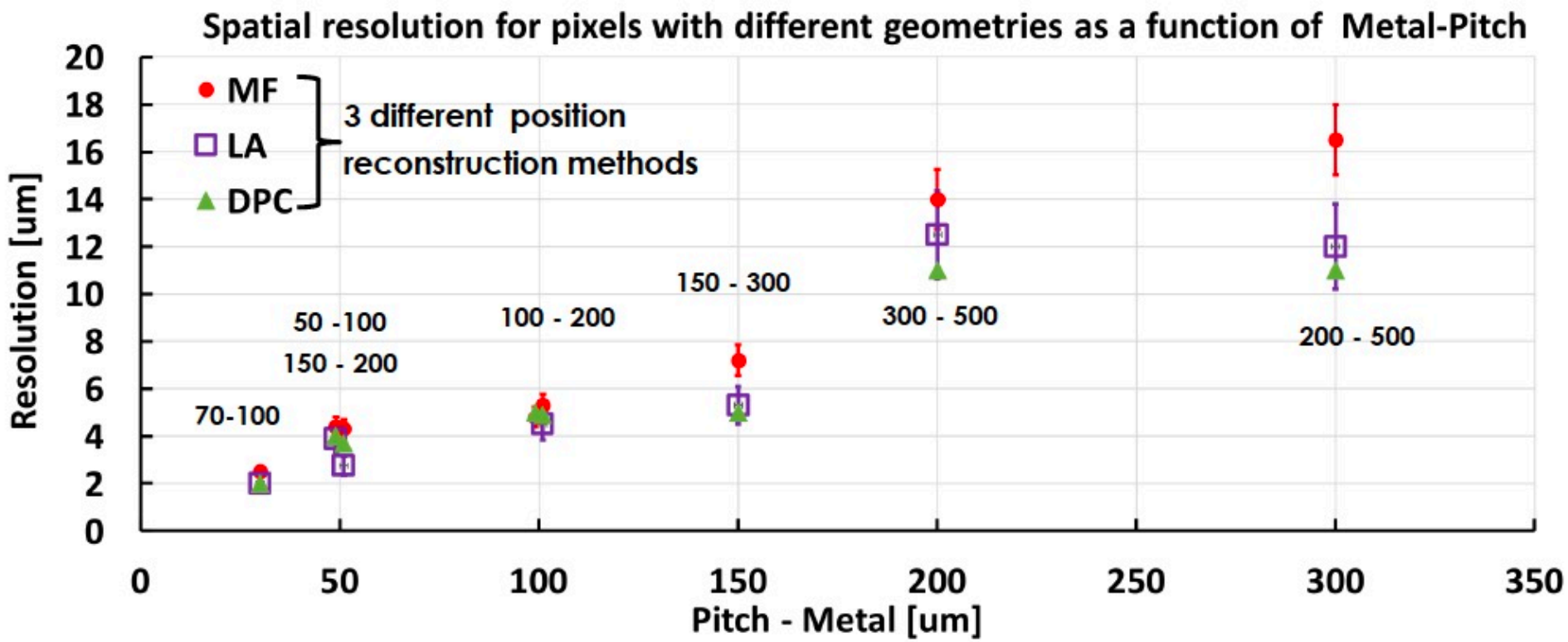
Z=[-1m, 1m], R=0.5m, Area=6.28m^2, Eta=[-1.44, 1.44]

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

Laser study: position resolution as a function of pixel geometry

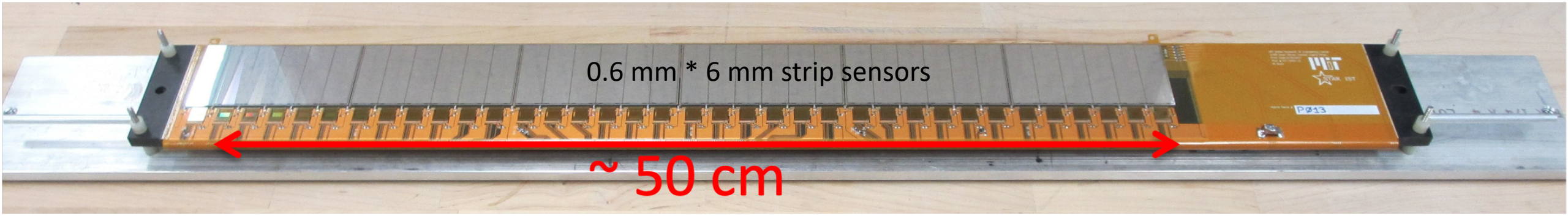


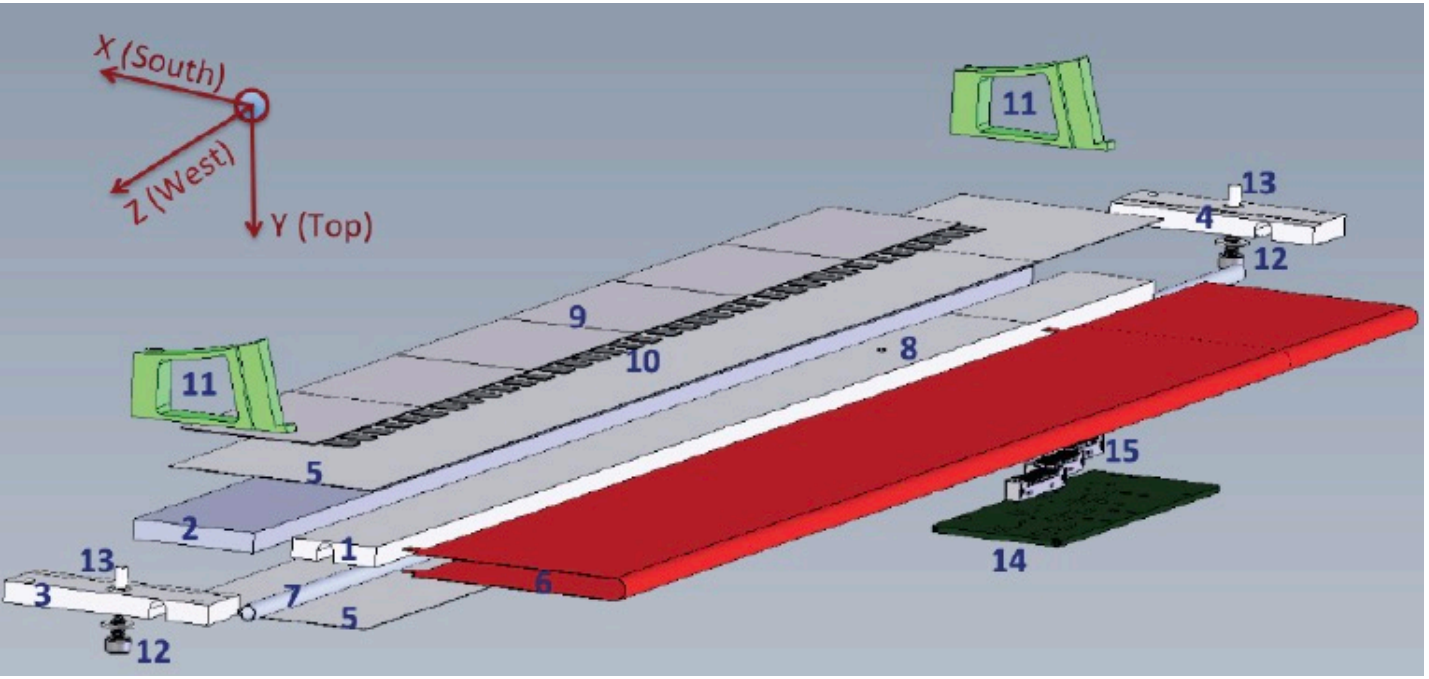
RSDs reach a spatial resolution that is about 5% of the inter-pad distance

➔ ~ 5 μm resolution with 150 μm pitch

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

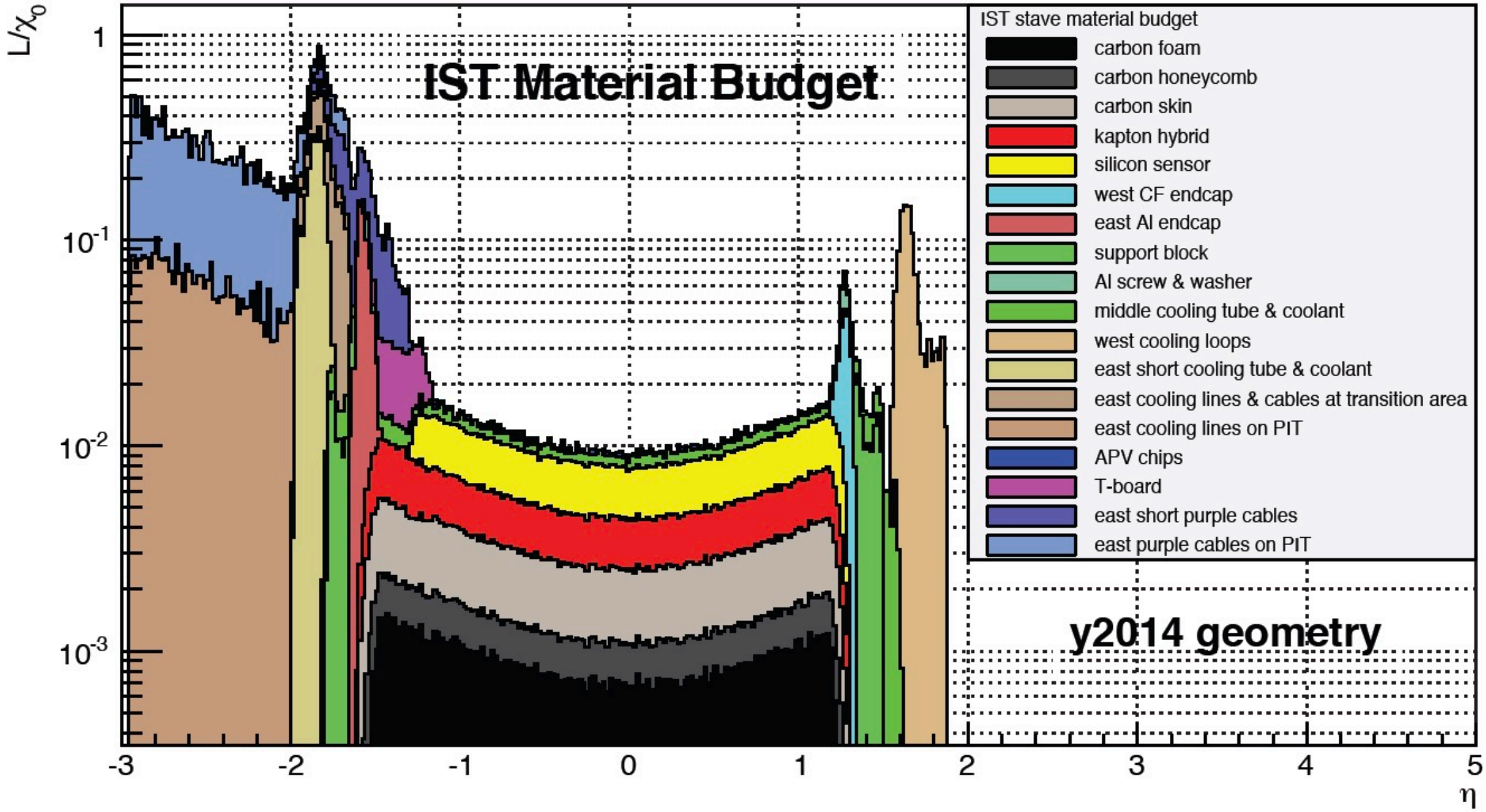
AC-LGAD Barrel TOF Detector for EIC – STAR IST



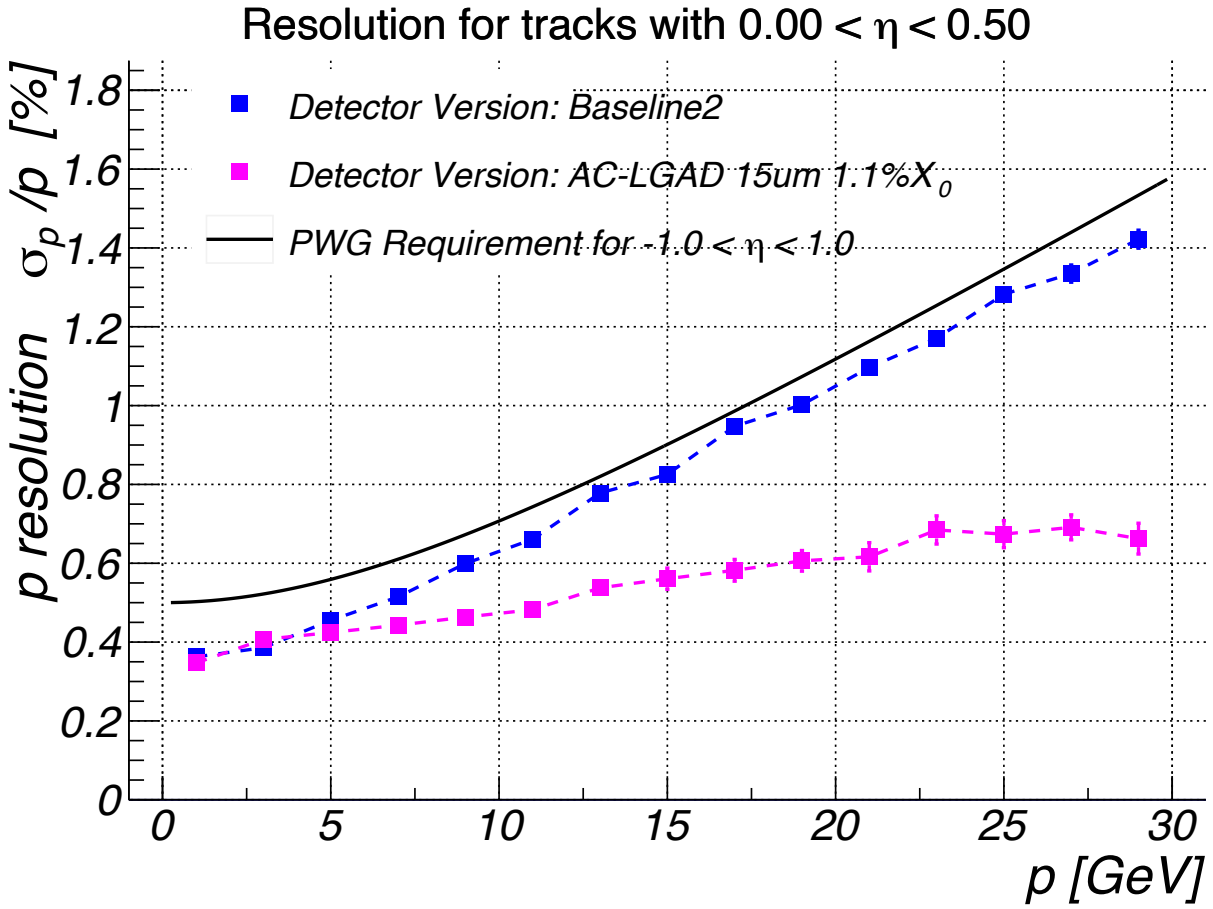


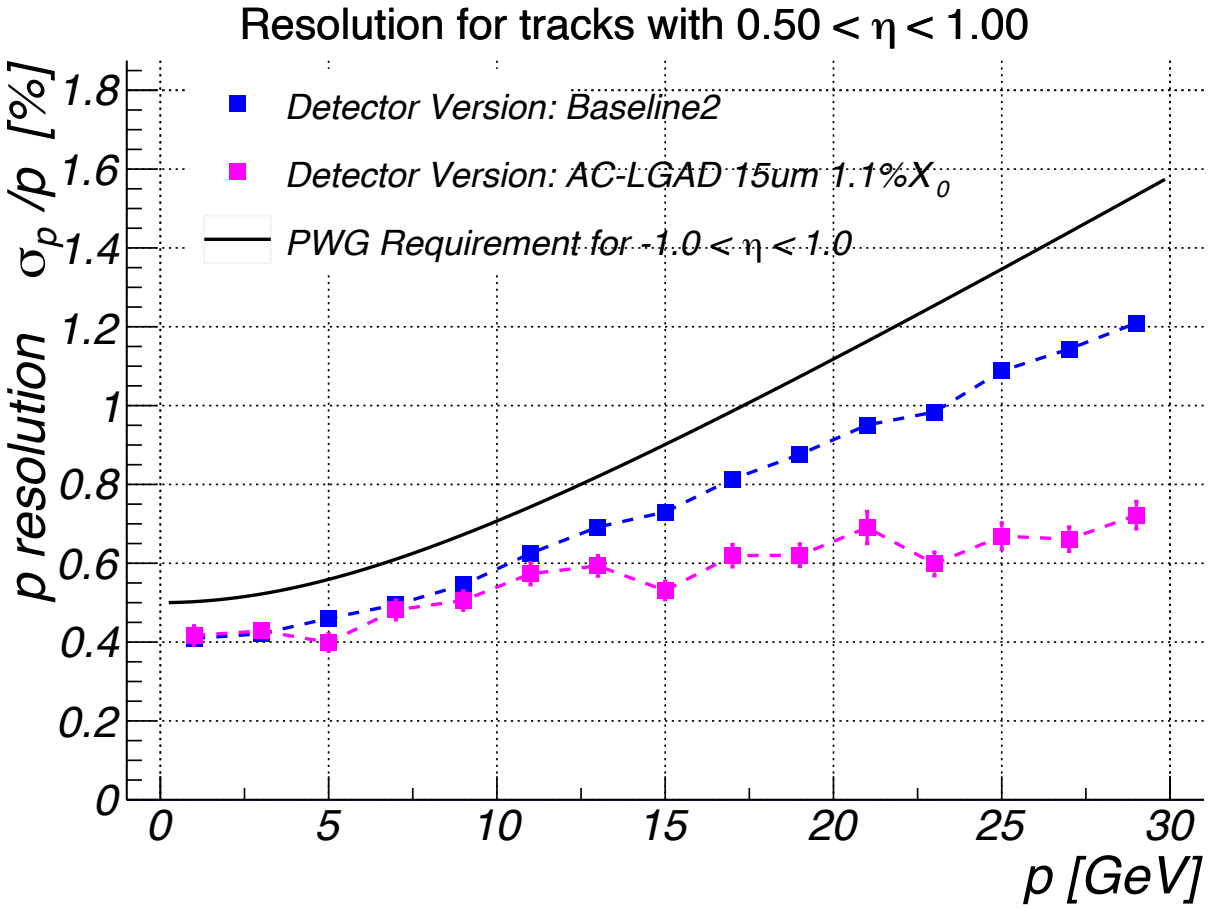
1) carbon foam 2) carbon honeycomb 3) west carbon end-cap 4) east Al end-cap 5) carbon fiber skins 6) Kapton hybrid 7) Al cooling tube with cooling liquid inside 8) thermal sensor 9) silicon sensors 10) APV chips 11) support blocks 12) screws with washers 13) spacers 14) transition board 15) readout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

AC-LGAD Endcap TOF Detectors for EIC – STAR IST



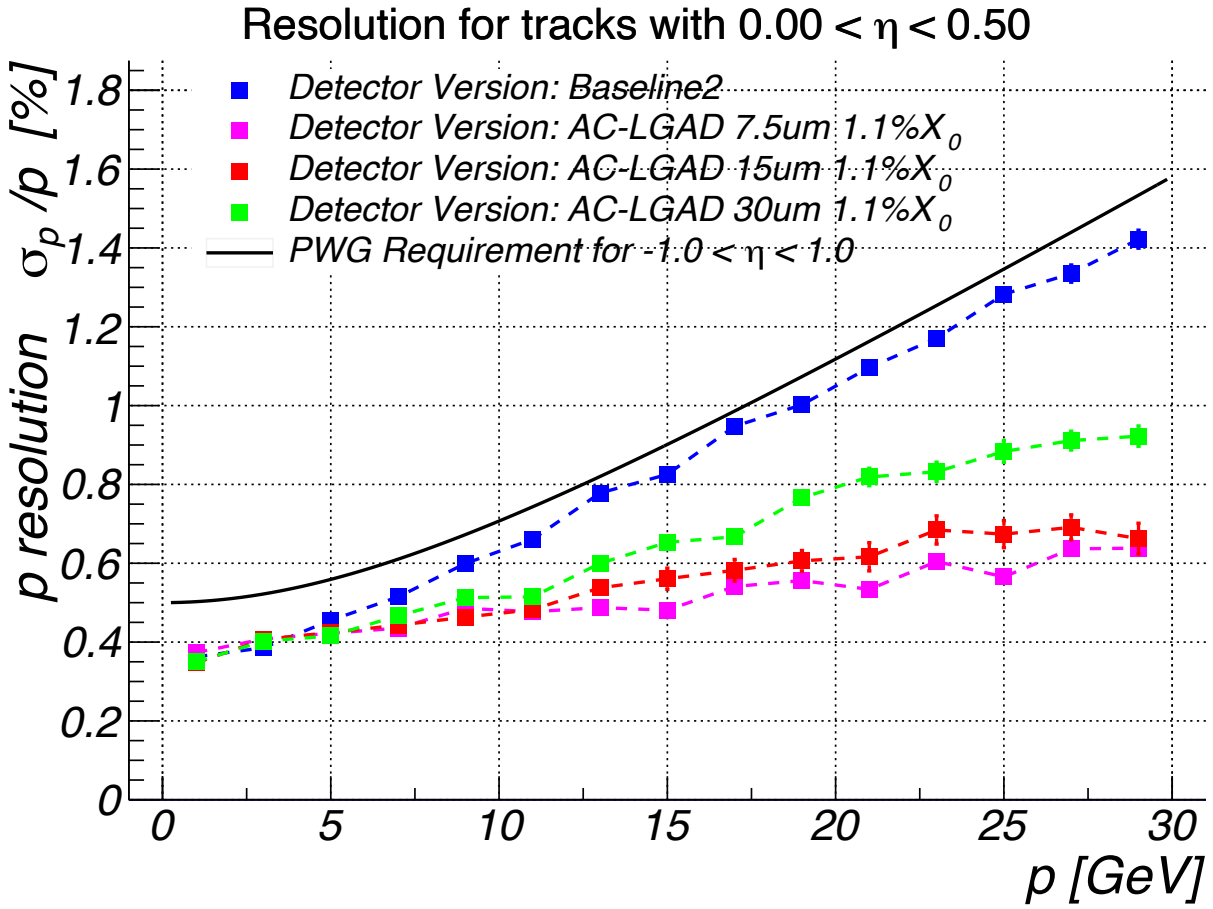
ATHENA Baseline 2.0 Tracker + Barrel AC-LGAD

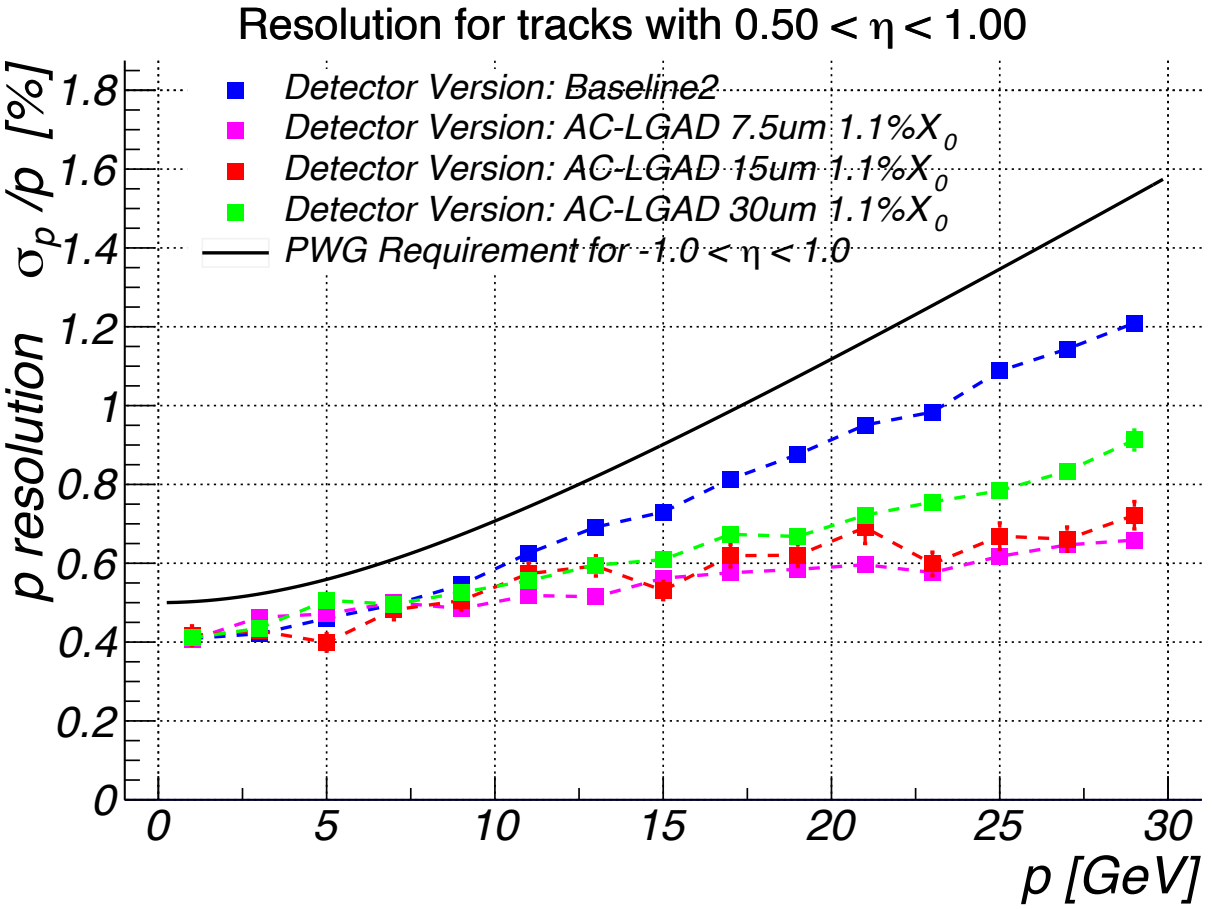




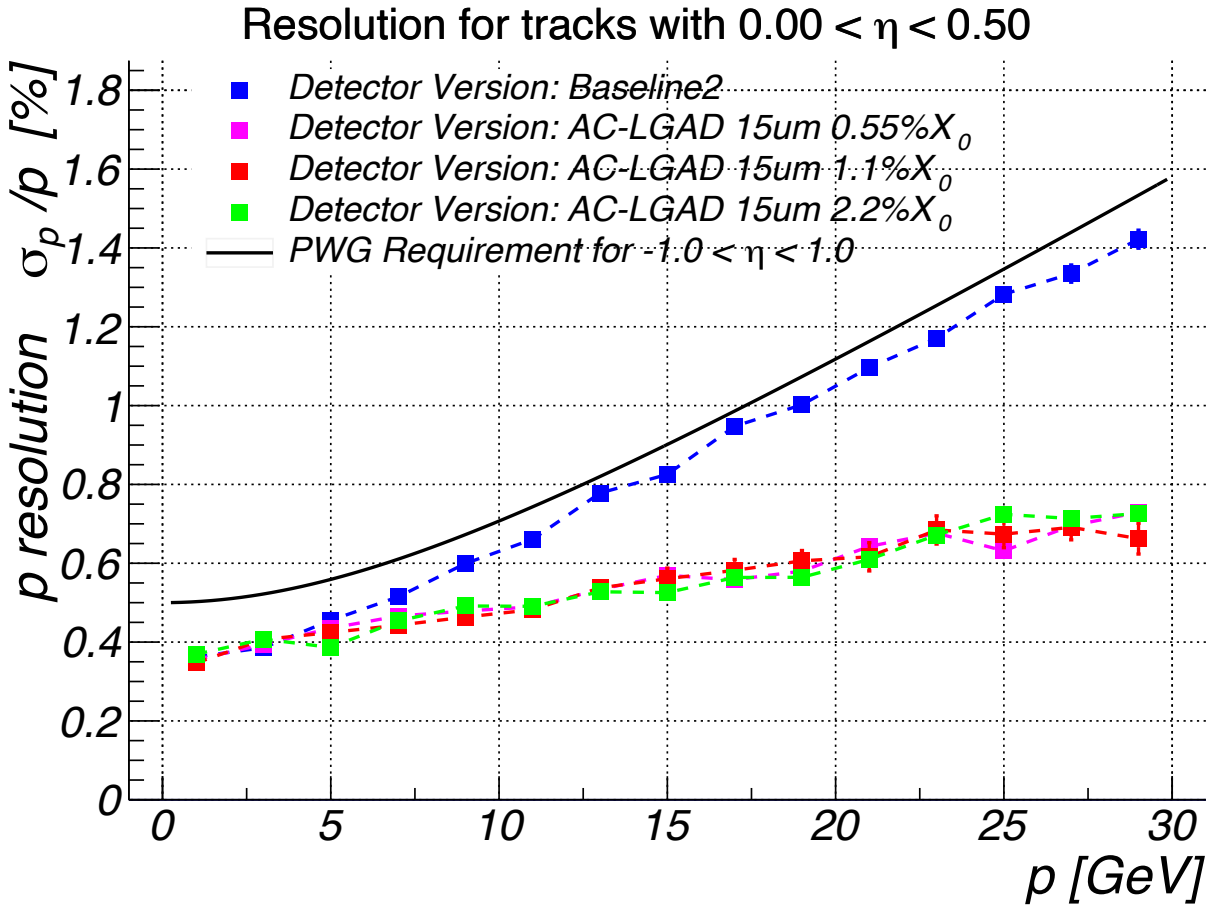
Adding the proposed Barrel AC-LGAD layer (e.g. 500 microns pitch perpendicular to the beam direction and ~1%X_0) can improve high momentum resolution

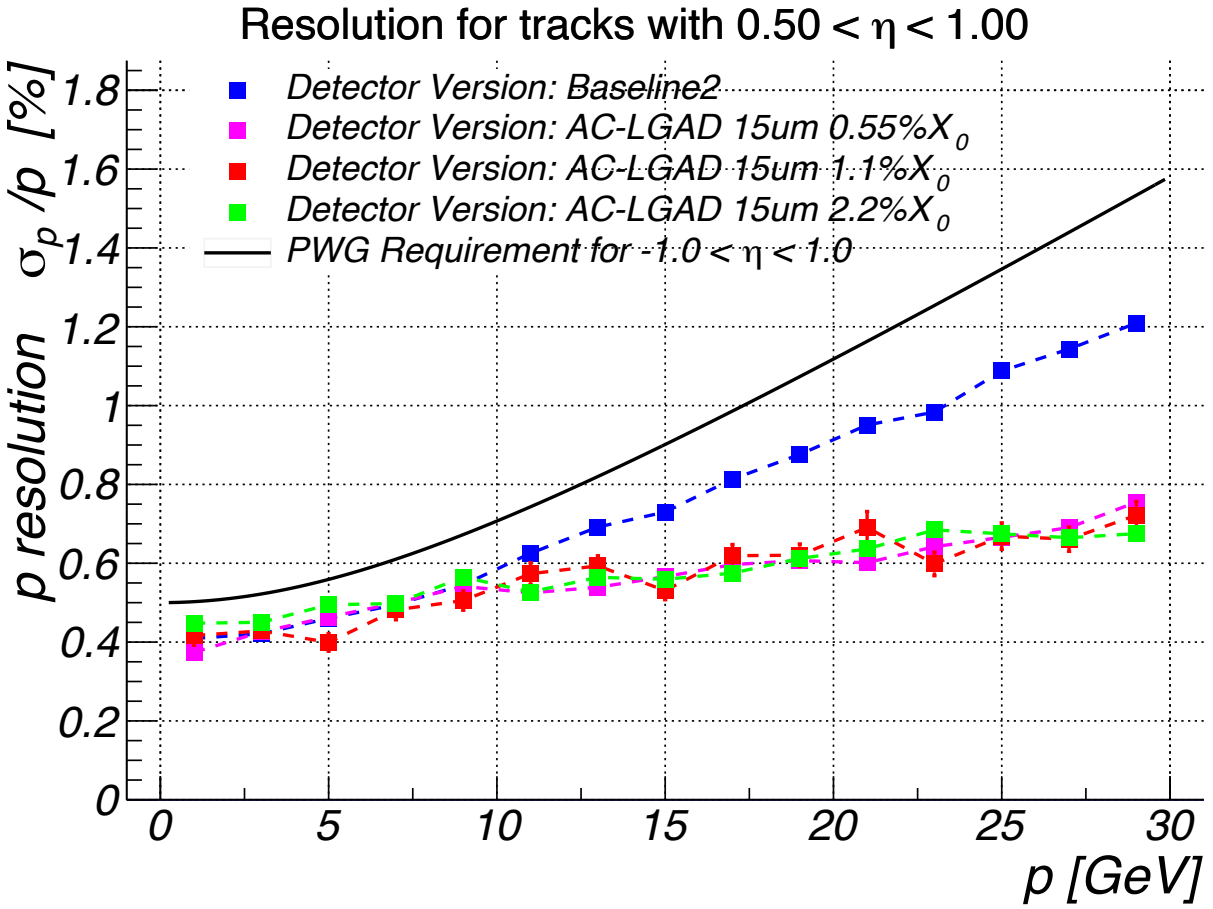
ATHENA Baseline 2.0 Tracker + Barrel AC-LGAD





ATHENA Baseline 2.0 Tracker + Barrel AC-LGAD



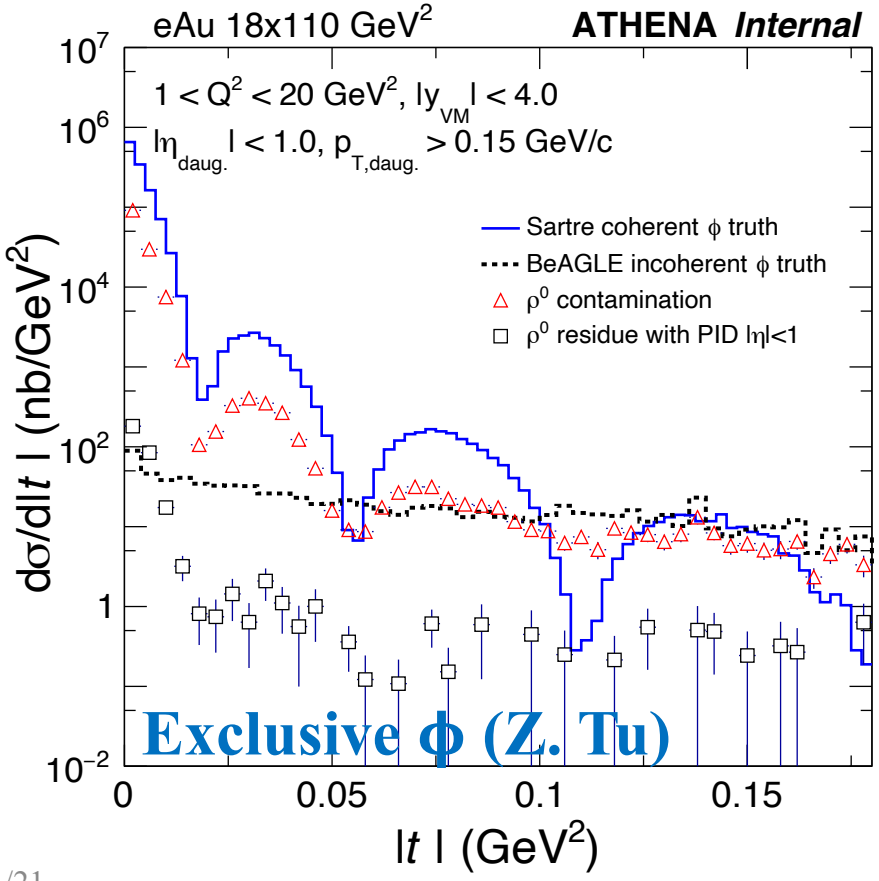


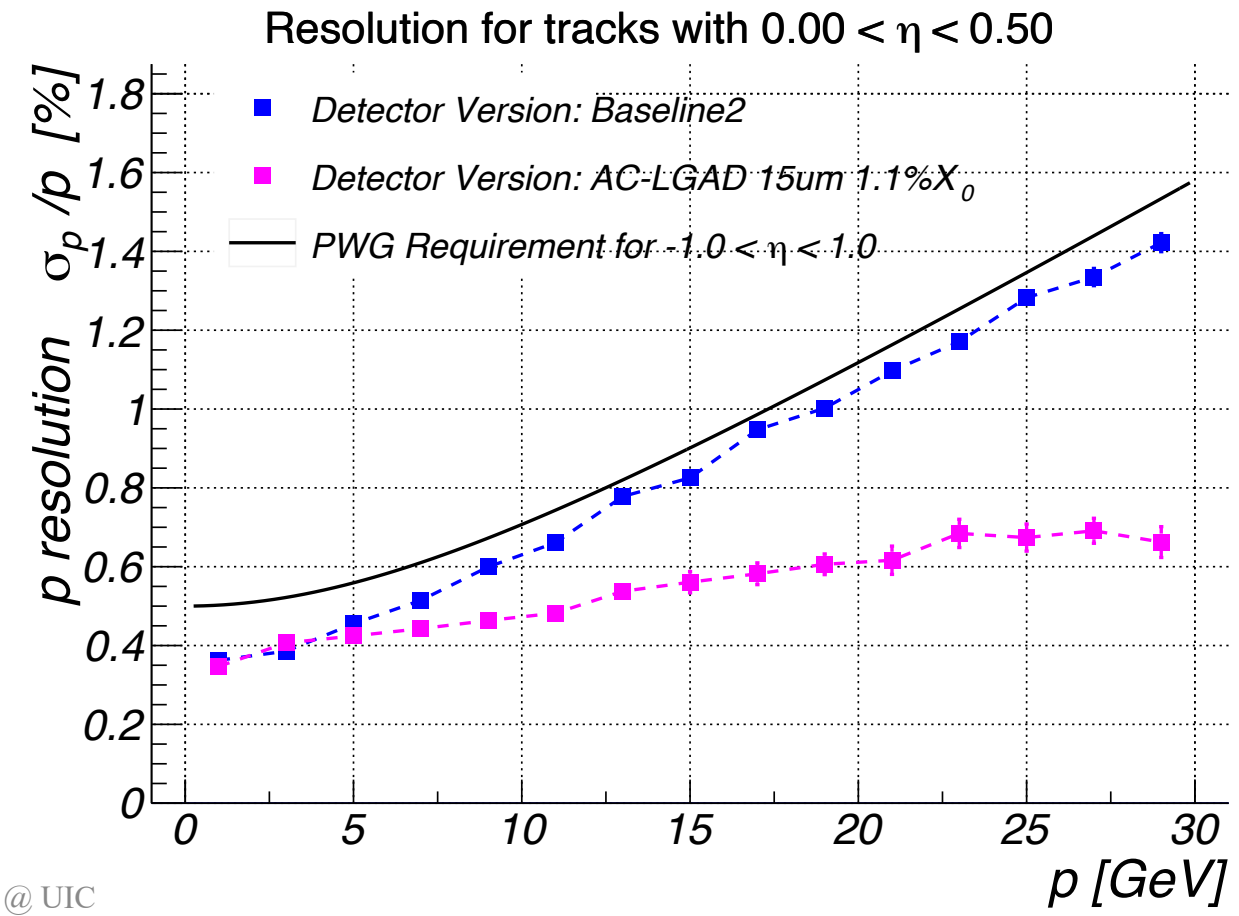
Conclusion

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

- **Provide low-p PID below DIRC threshold at small R** (necessary in removing ρ contamination for exclusive ϕ)
- **Significantly improve the momentum resolution at high momentum** (based on Baseline2.0 tracker design)

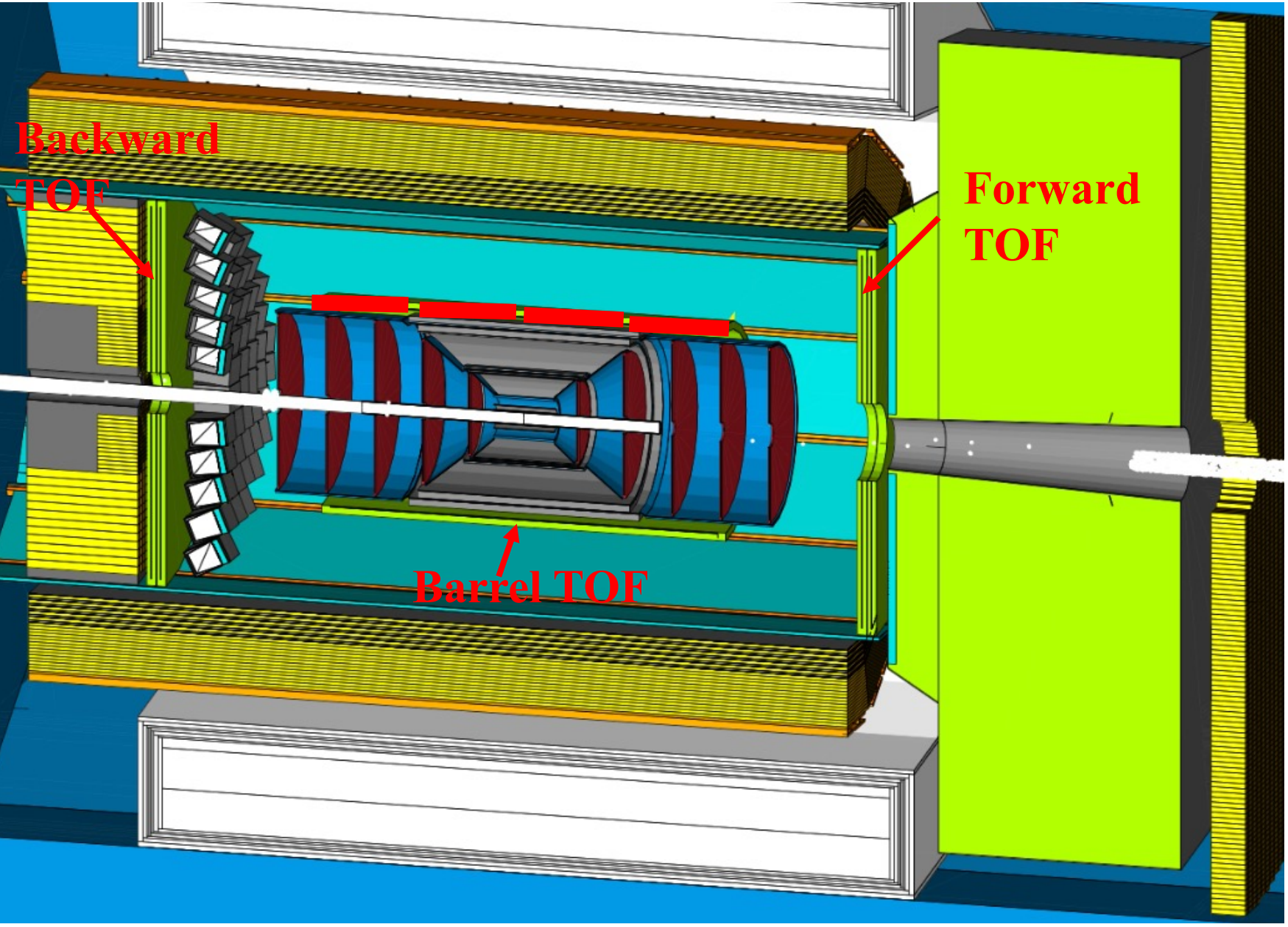
Therefore, we strongly urge the collaboration to consider adding it in the proposed baseline design





Backup

AC-LGAD TOF Detectors in ATHENA DD4HEP

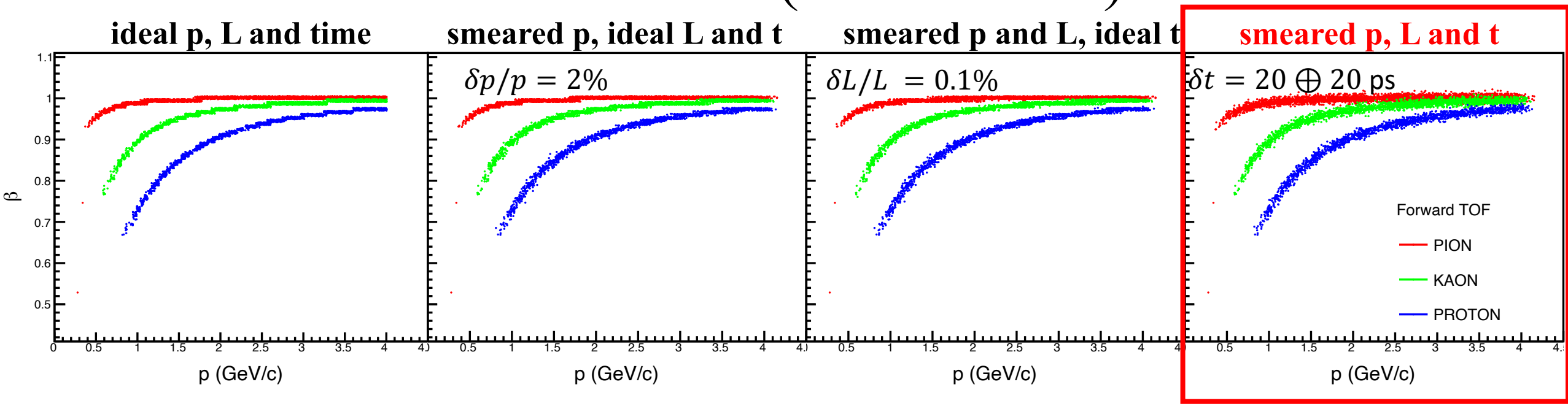


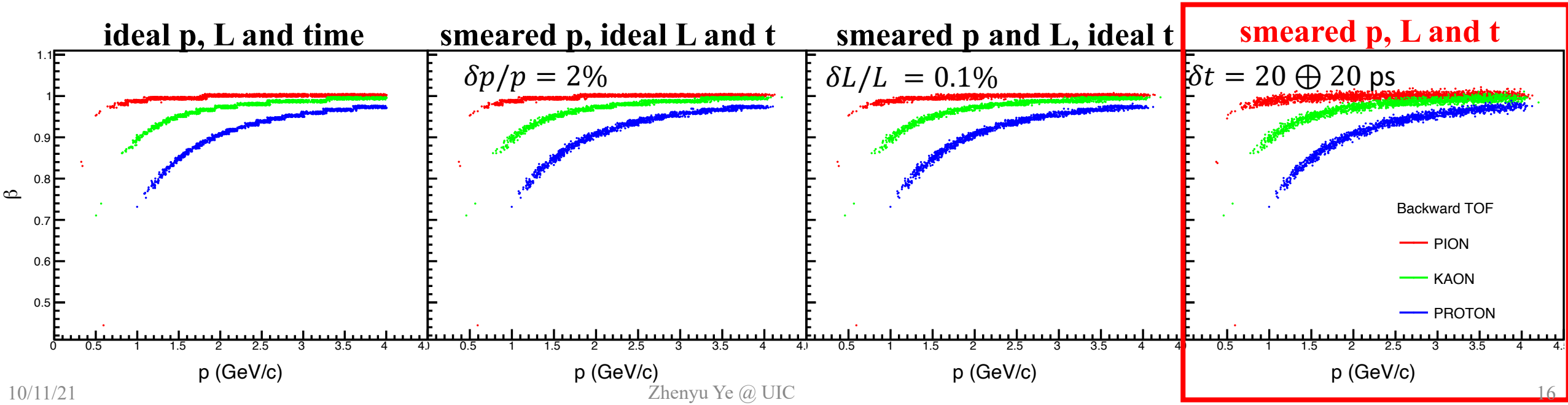
Barrel TOF (Area=6.28m^2)
Z=[-1m, 1m], R=0.5m,
Eta=[-1.44, 1.44]

Forward TOF (Area=5.44m^2)
Z=1.73m, R_{in}=0.19m, R_{out}=0.95m
Eta=[1.36, 2.91]

Backward TOF (Area=5.44m^2)
Z=-1.85m, R_{in}=0.19cm, R_{out}=0.95m,
Eta=[-2.97,-1.42]

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



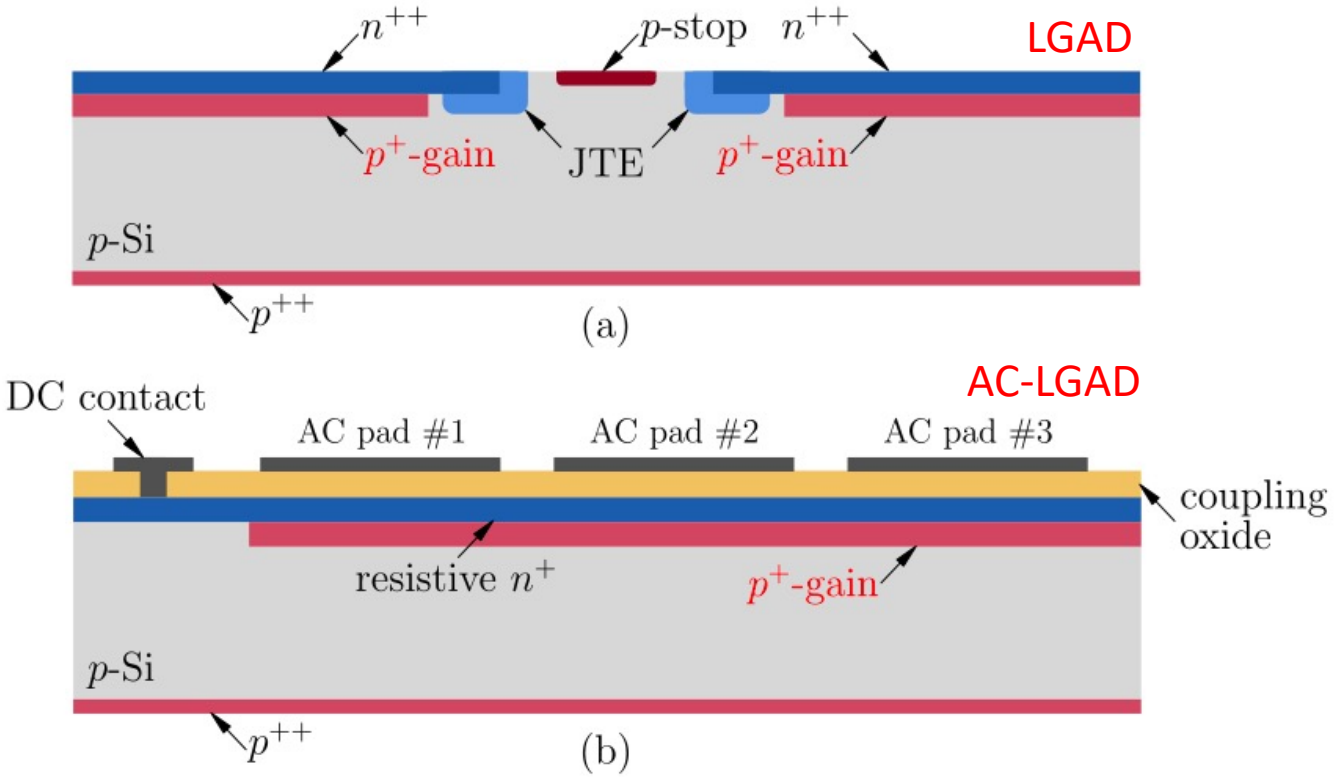


AC-LGAD for EIC

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

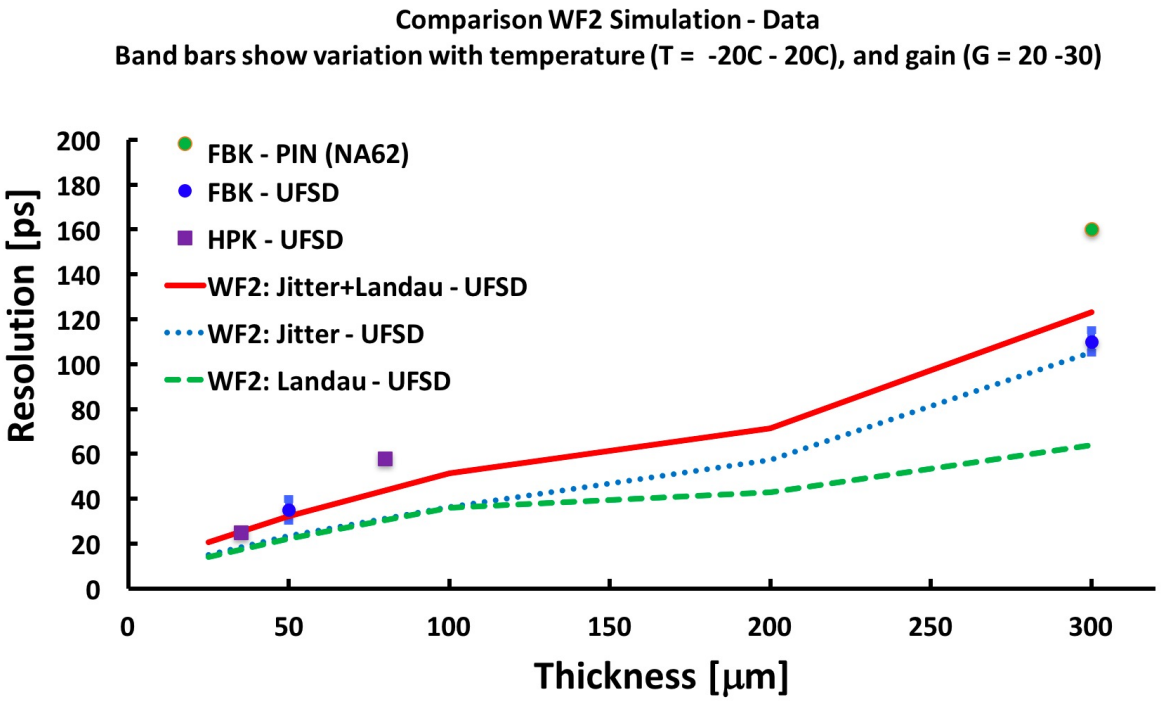
- AC LGAD detectors proposed for EIC
  - Roman Pots and B0
  - TOF for PID (and tracking)

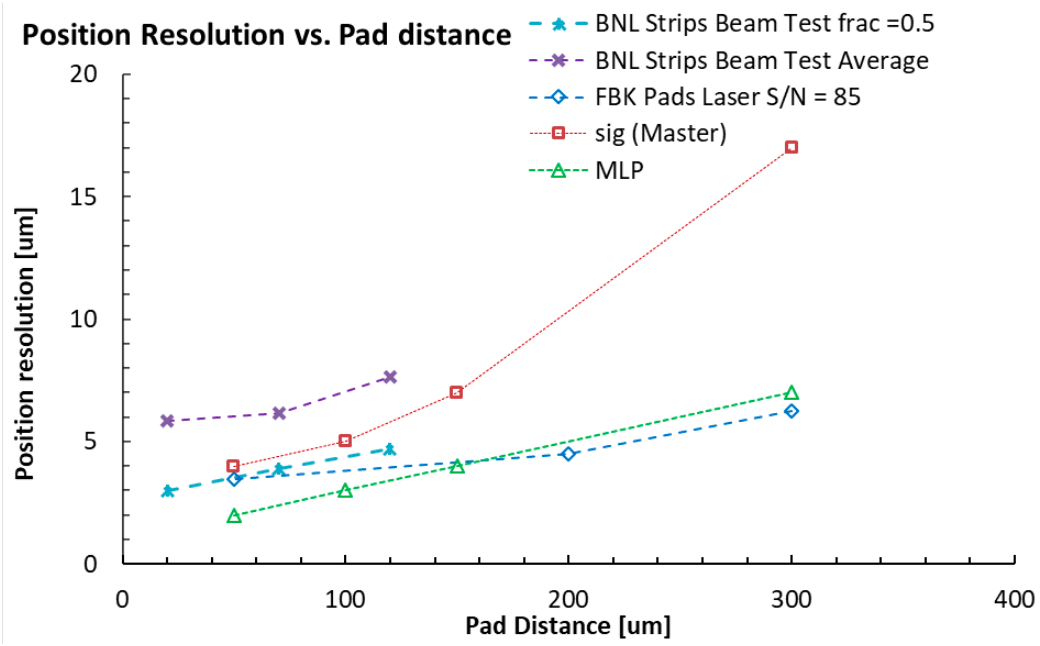
- Have common designs in sensor, ASIC etc. when possible, combine R&D efforts



	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	$O(50)\ \mu m$	$< 0.01\ X_0$

Sensor R&D





- **R&D Goals**
  - 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

ATHENA Tracker Baseline 2.0 - Material Scan