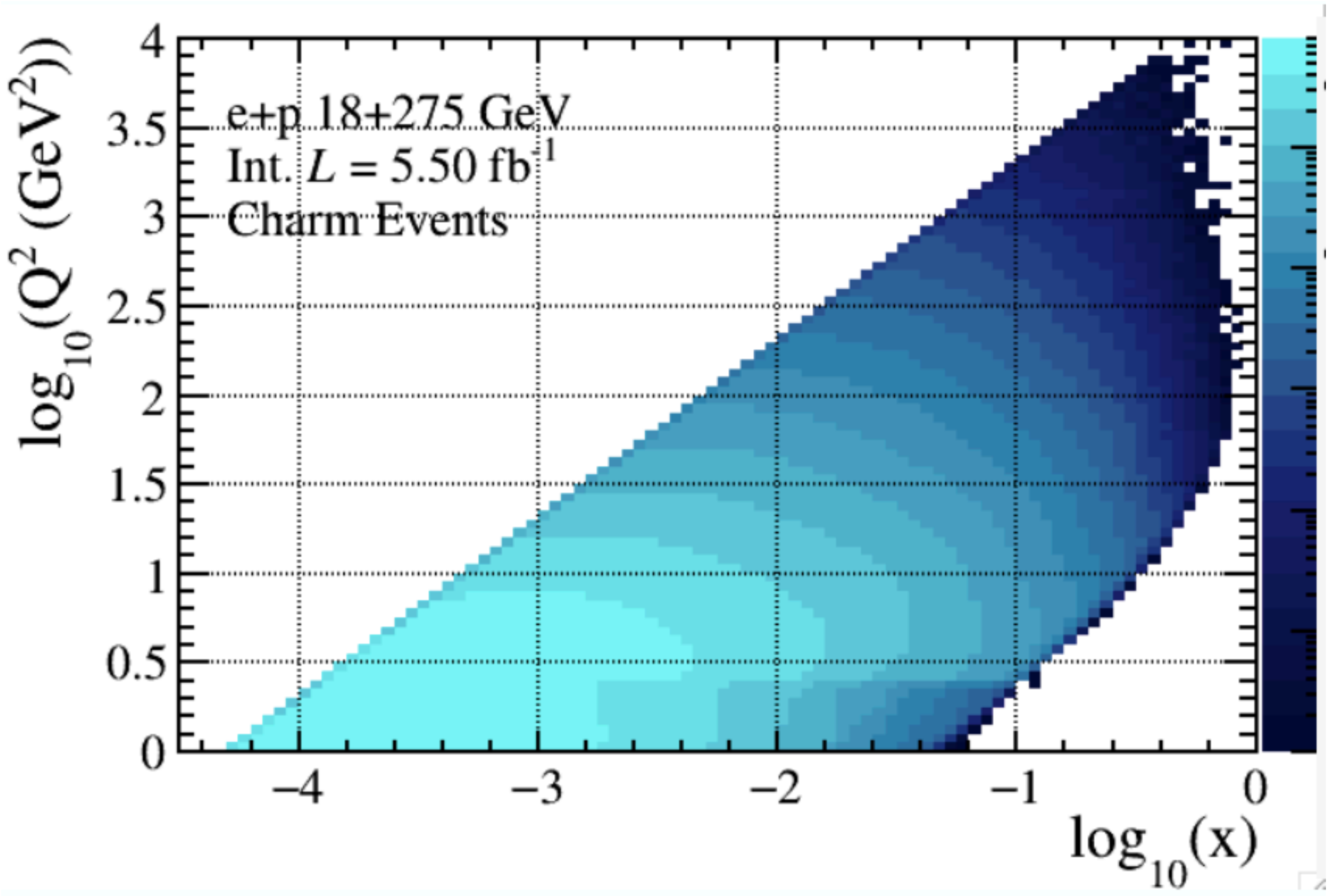
The Silicon Vertex Tracker for the ePIC detector at the Electron-Ion Collider

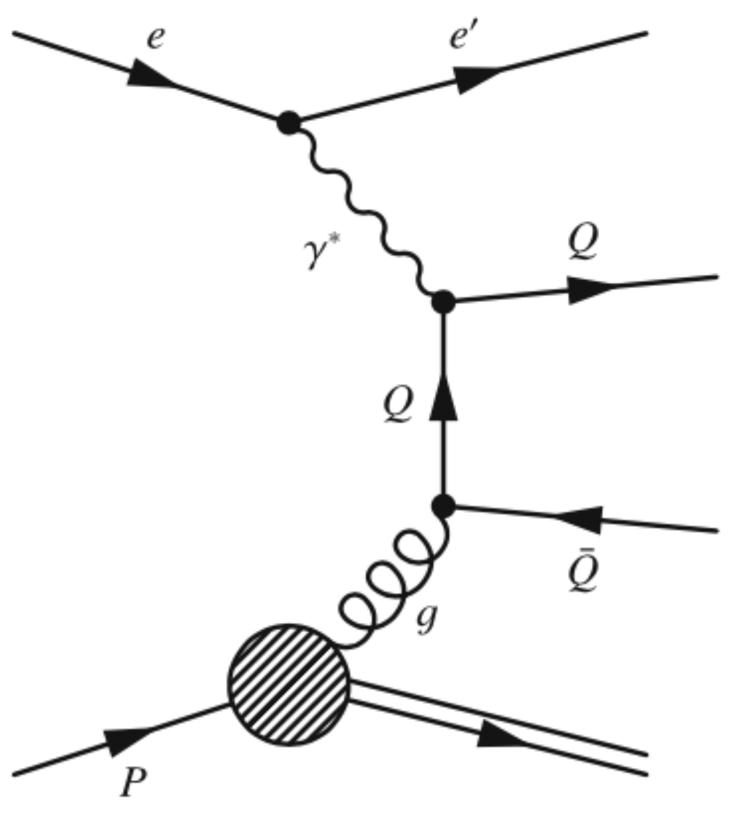
Gian Michele Innocenti for the ePIC collaboration
Massachusetts Institute of Technology

Heavy-flavor physics at the Electron-Ion Collider

B.S. Page et al. Phys. Rev. D 101, 072003
H. T. Li and I. Vitev, Phys. Rev. Lett. 126, 252001
EIC , BNL-98815-2012, arXiv:1212.1701

→ **Heavy-flavor observables are crucial to address the key physics questions of the EIC physics program**





Inclusive heavy-flavor measurements in ep/eA collisions:

→ gluon (n)PDFs down to moderate/low x_{BJ}

→ **evolution equations beyond DGLAP?**

$D\bar{D}$ **correlations:**

→ access to gluon TMDs

→ **nuclear structure beyond the collinear limit**

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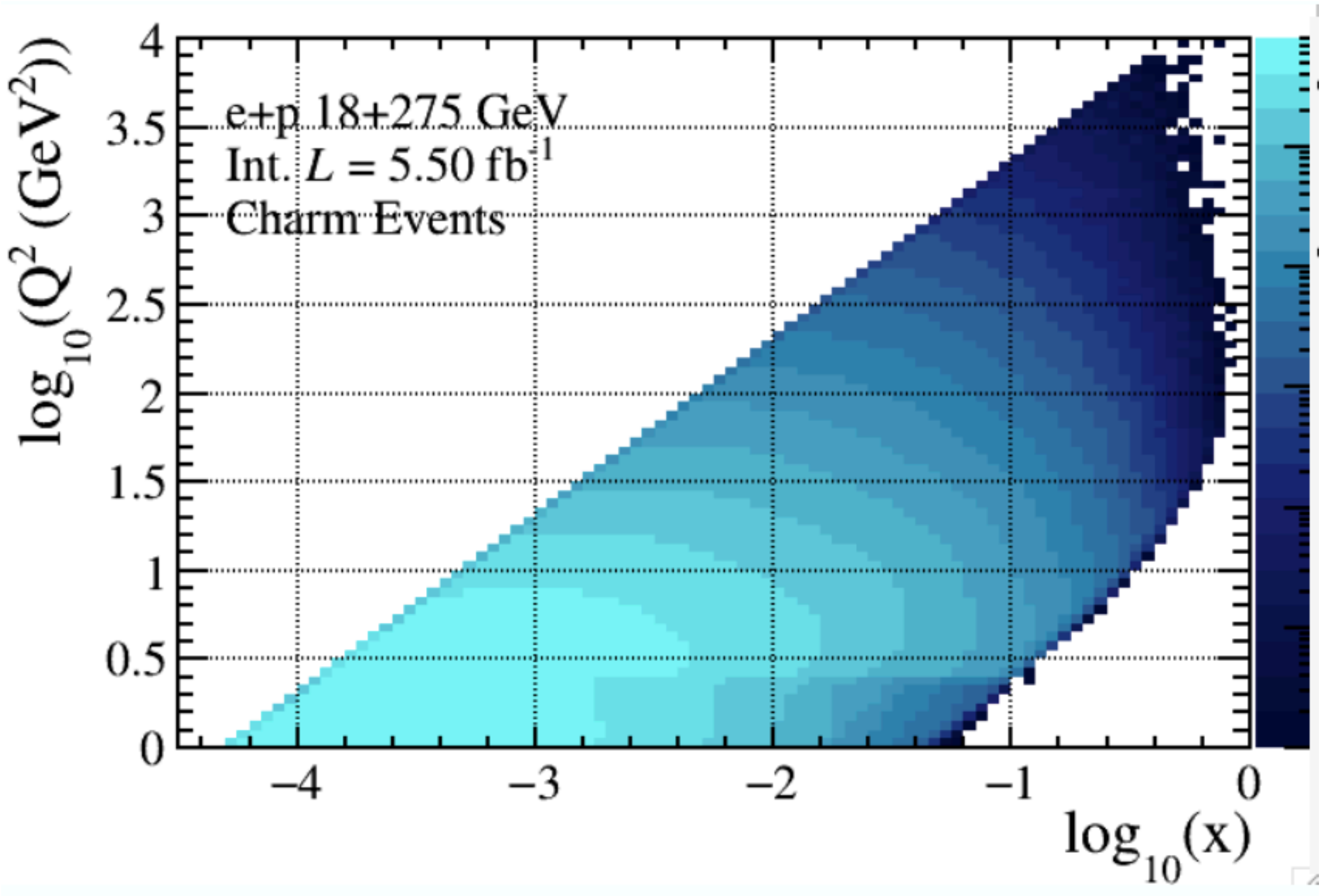

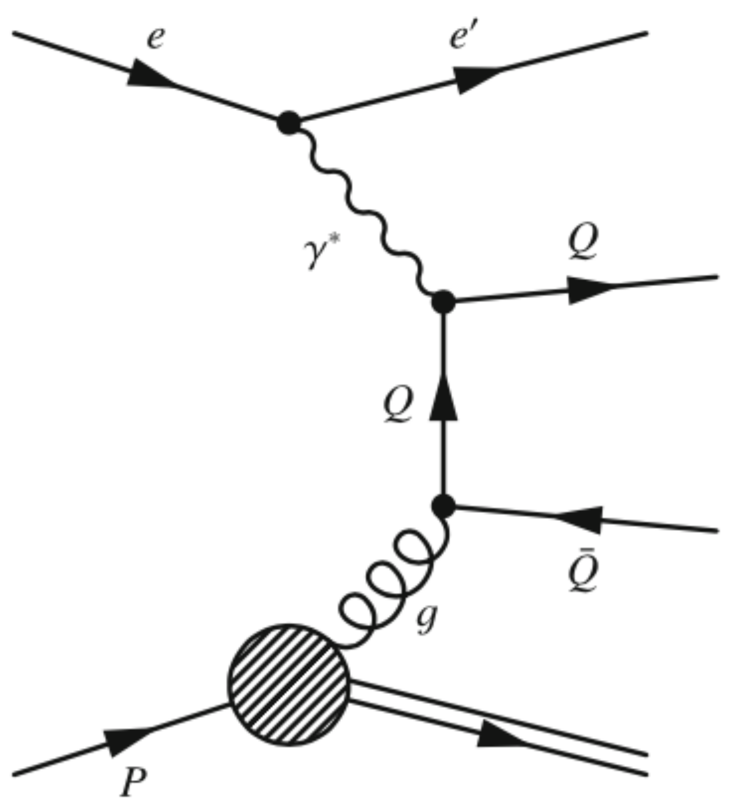

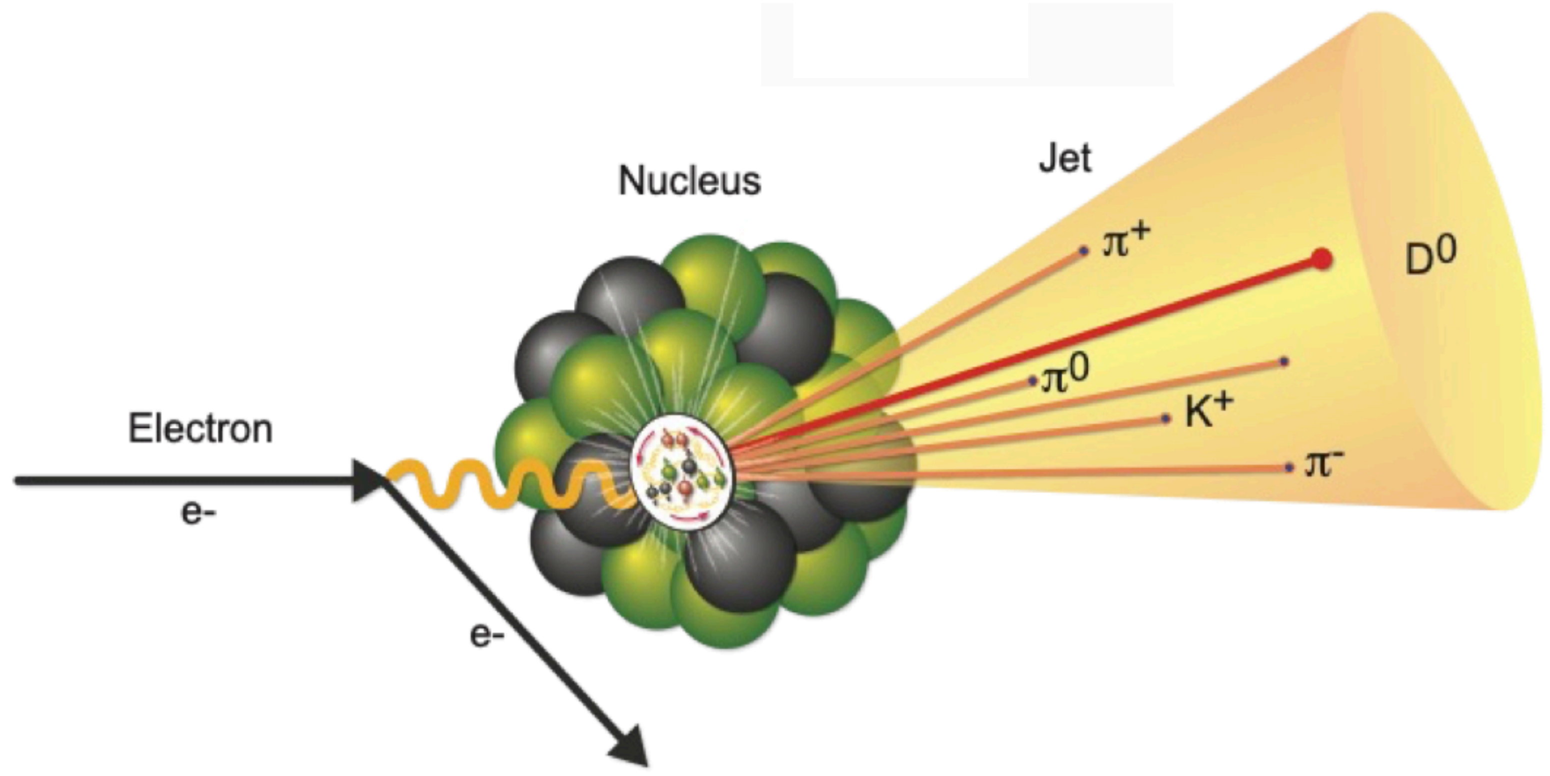

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Heavy-quark jet production and substructure in ep/eA:

→ **parton-propagation inside the "cold" nuclear matter**

→ parton-shower evolution in a vacuum-like environment

Heavy-flavor hadrochemistry and collectivity:

→ hadronization modification in cold-nuclear matter

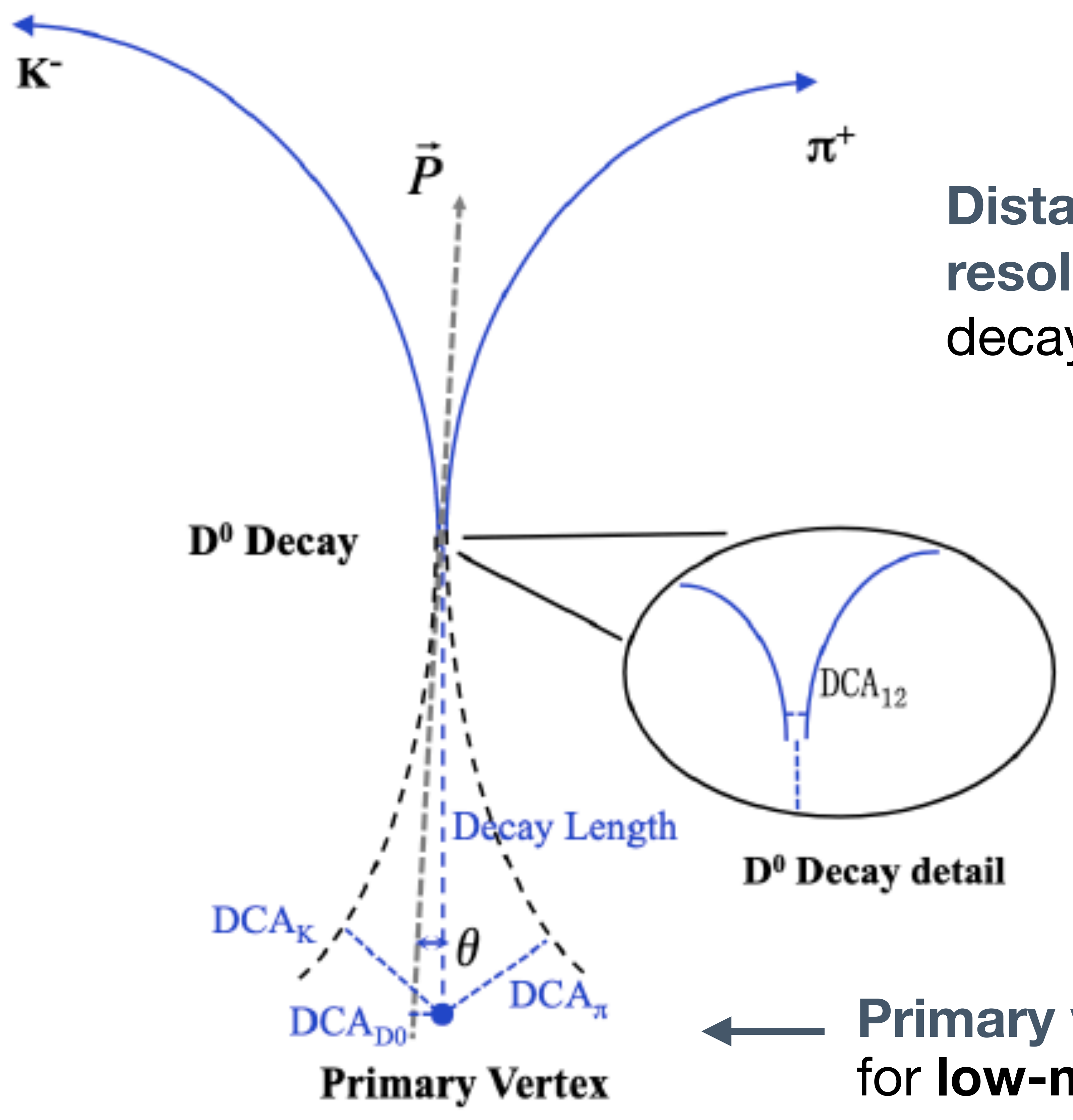
→ **what is the time scale of hadronization?**

SVT detector requirements

EIC Yellow Report, BNL-220990-2021-FORE

Main reconstruction channels for heavy-quark topologies:
- hadronic decays of charmed mesons and baryons
- jet flavor tagging

→ outstanding DCA/p_T resolutions down to low p_T in a wide pseudorapidity region ($|\eta|<3.0$-3.5)

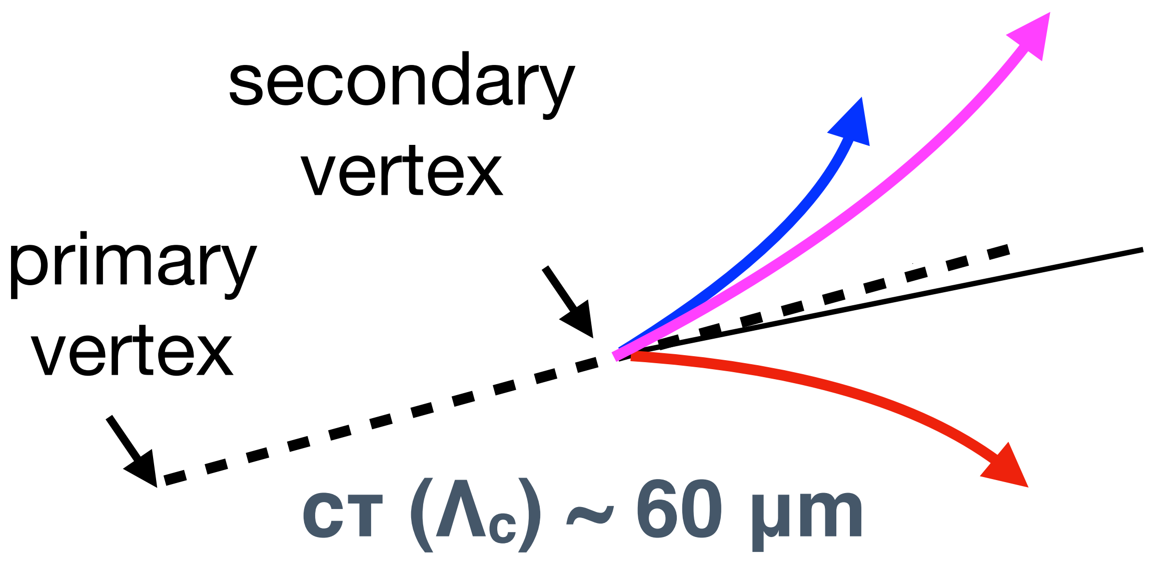


Distance-of-closest approach (DCA) resolution to separate heavy-flavor decay tracks from primary tracks

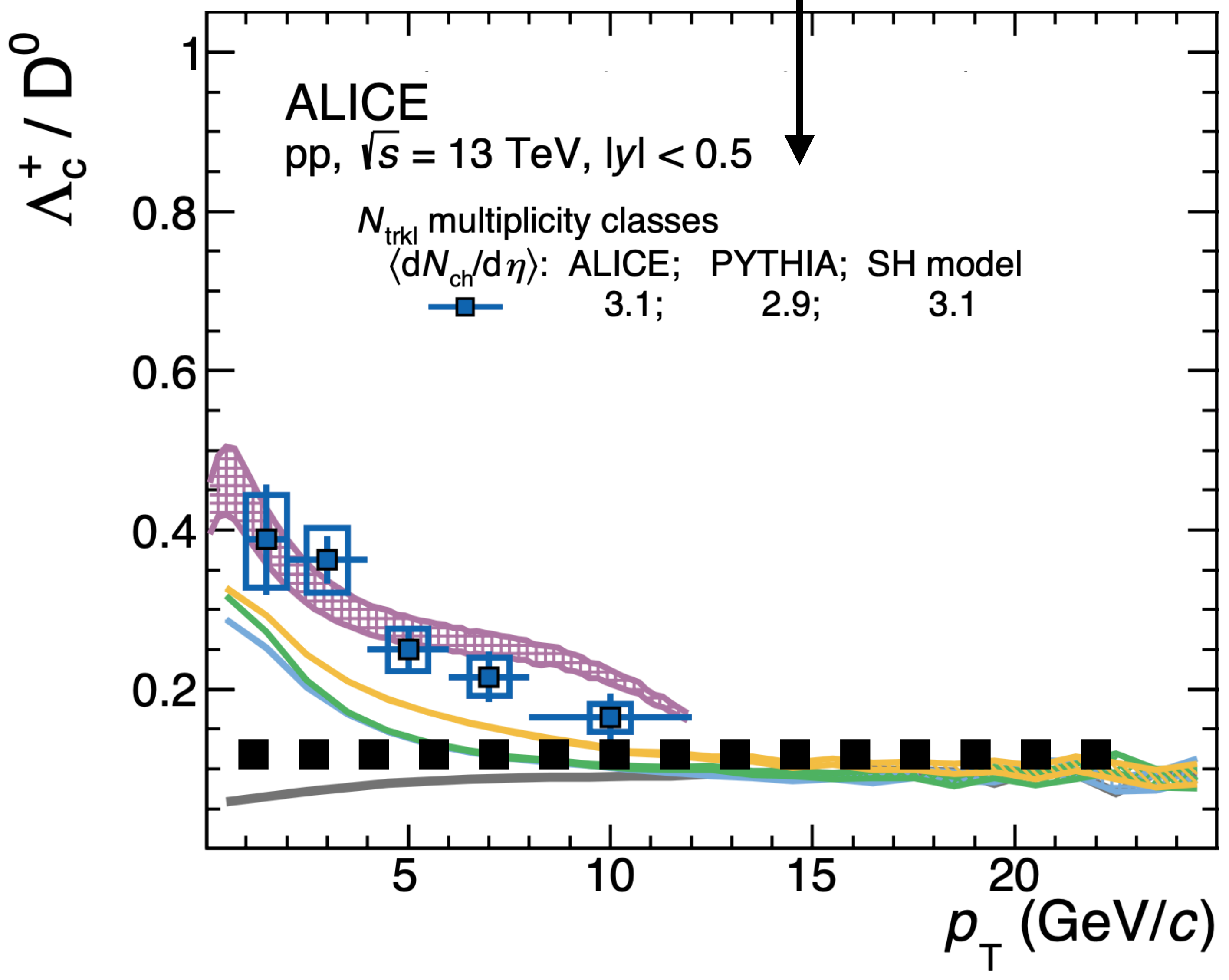
Primary vertex resolution σ_{PV}^{XYZ} also for **low-multiplicity events**

SVT detector requirements

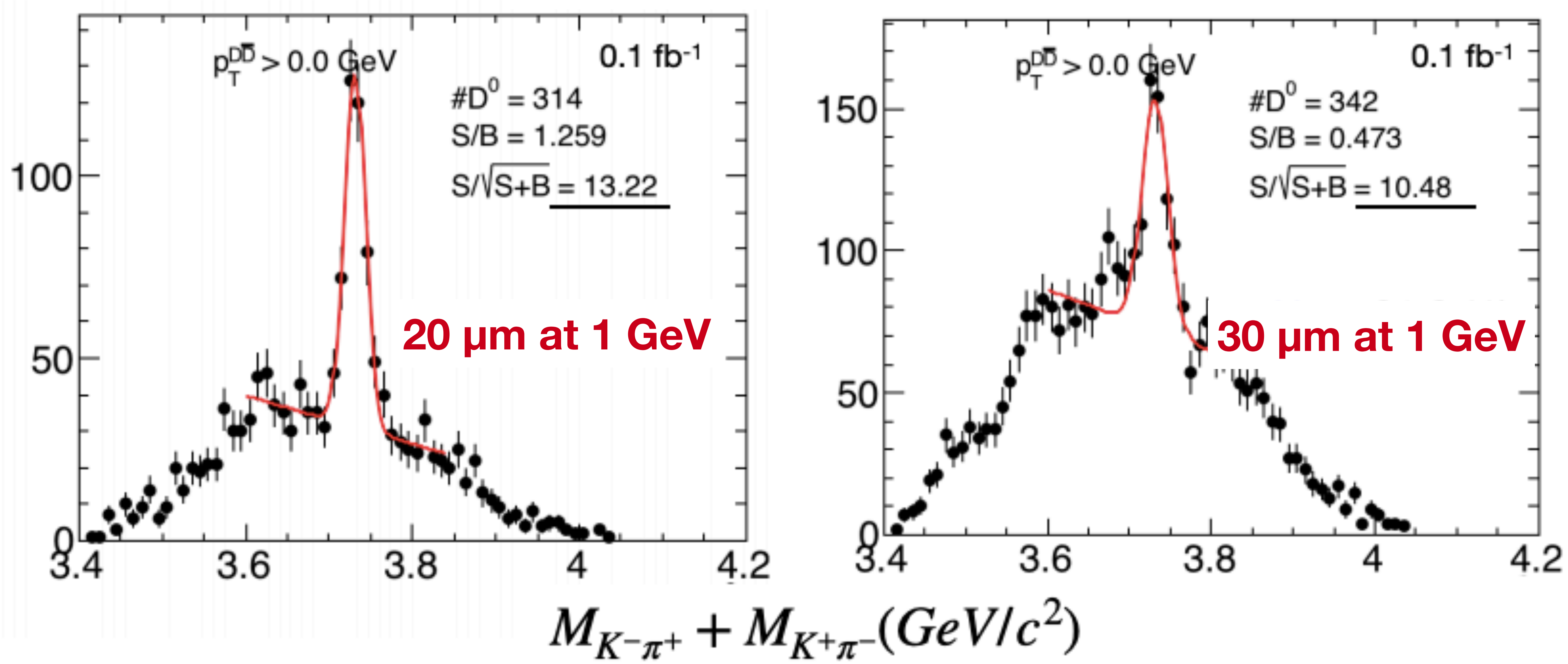
EIC Yellow Report, BNL-220990-2021-FORE



Charm baryons are crucial to have hadronization under control!



Performance study for $D^0\bar{D}^0$ correlations



→ Impact of DCA resolution is magnified in multiple HF hadron measurements

SVT detector requirements

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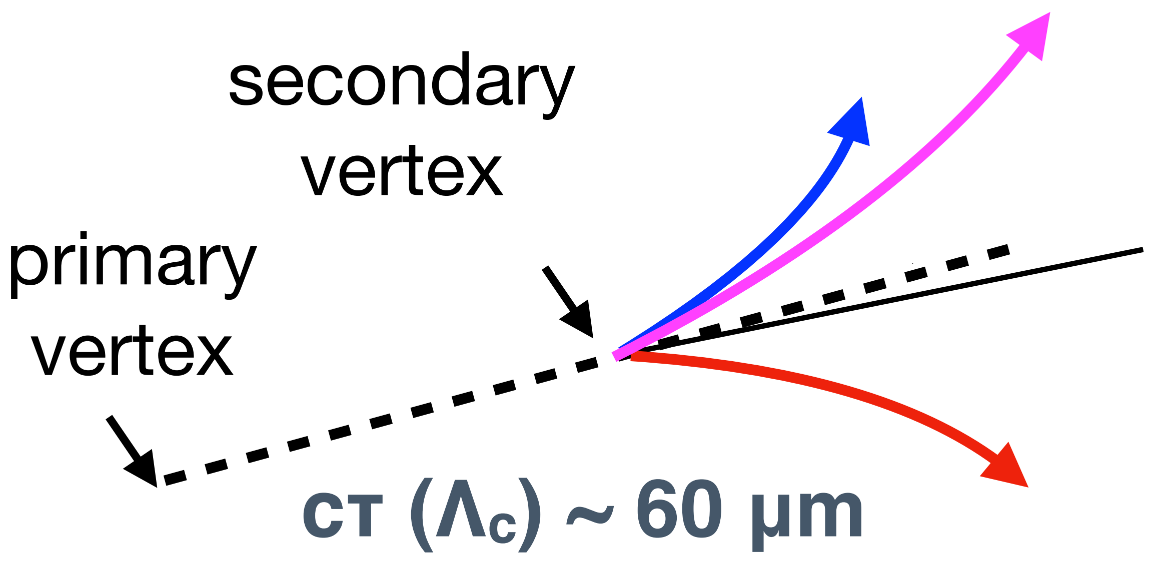

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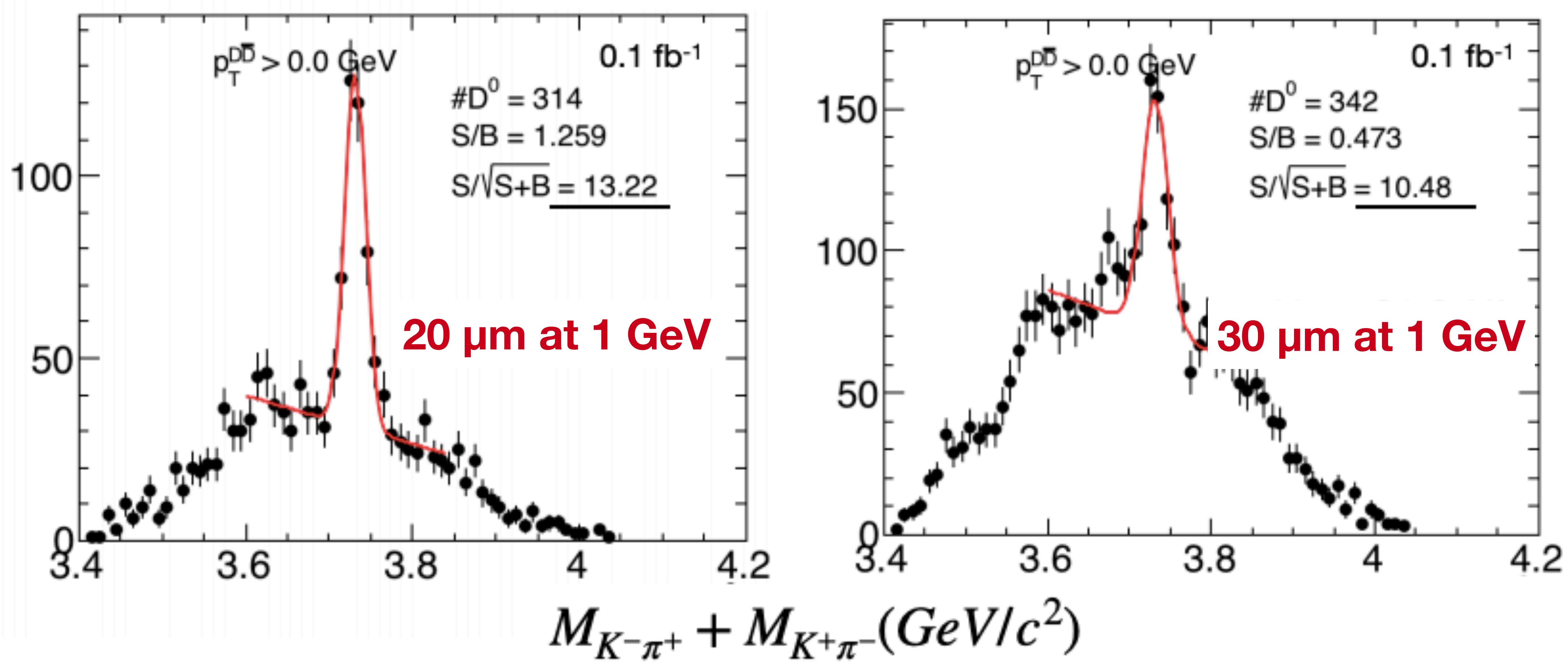


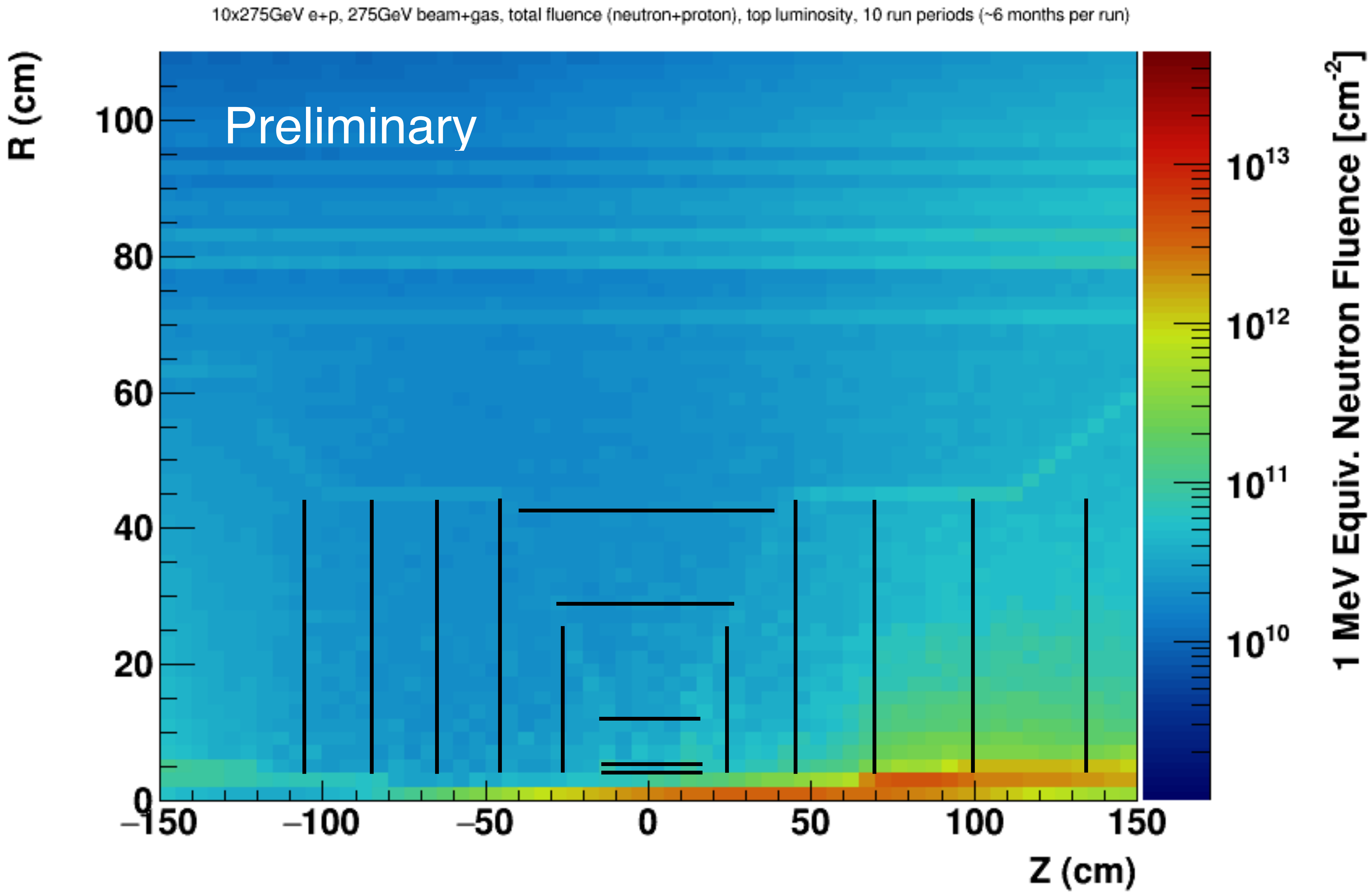
→ Impact of DCA resolution is magnified in multiple HF hadron measurements

Performance over the entire kinematic region (p_T, η) is essential for our physics program (e.g., low/high x reach):
→ unprecedented constraints on the detector design

	Momentum Resolution	Spatial Resolution
Backward (-3.5 to -2.5)	~0.10%×p⊕2.0%	~ 30/pT μm ⊕ 40 μm
Backward (-2.5 to -1.0)	~ 0.05%×p⊕1.0%	~ 30/pT μm ⊕ 20 μm
Barrel (-1.0 to 1.0)	~0.05%×p⊕0.5%	~ 20/pT μm ⊕ 5 μm
Forward (1.0 to 2.5)	~0.05%×p⊕1.0%	~ 30/pT μm ⊕ 20 μm
Forward (2.5 to 3.5)	~0.10%×p⊕2.0%	~ 30/pT μm ⊕ 40 μm

Expected radiation dose (preliminary)

EIC Yellow Report, BNL-220990-2021-FORE



Beam energies:
- 10 GeV electron beam
- 275 GeV proton beam

Luminosity and int. rate:
- 10^{-34} $cm^{-2}s^{-1}$ luminosity
- DIS interactions (~ 500kHz)
- Beam-gas background 10 kAhr
- No synchrotron radiation included (yet)

Running time:
- 10 half-year running periods
- 100% up time

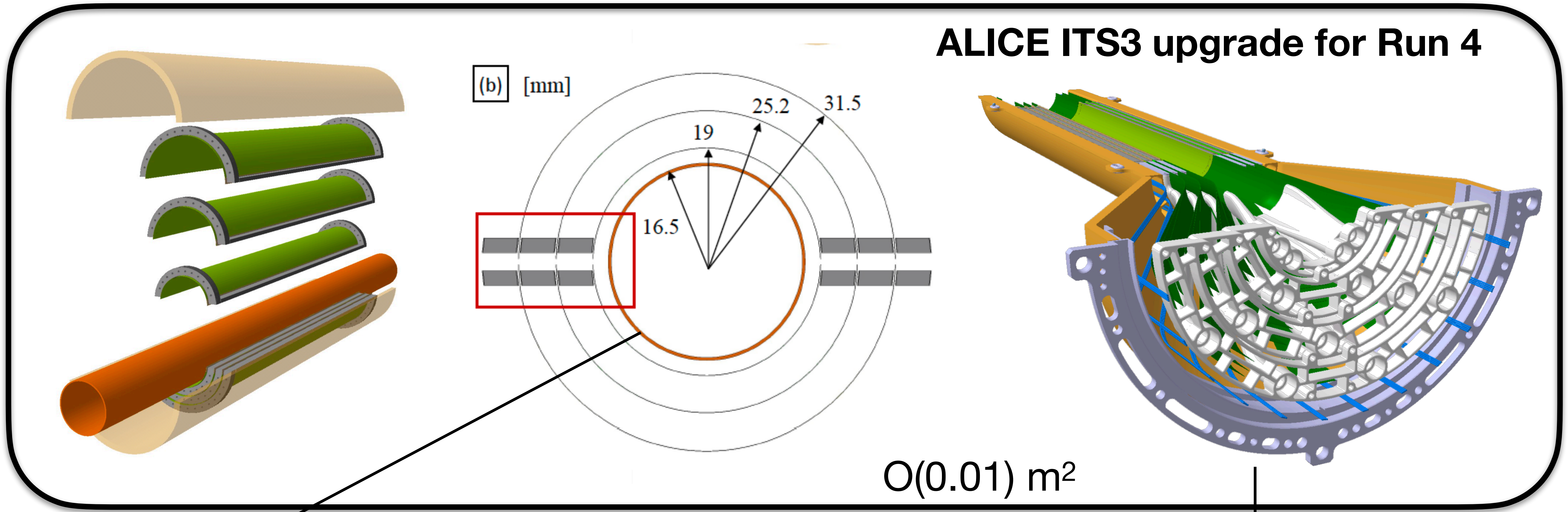
Fluence up to a few 10^{12} n_{eq}/cm^2 for the inner region of the hadron endcap
→ much lower than in high-luminosity pp/PbPb collisions at RHIC or LHC

Sensor requirements and challenges

- **High-spatial-resolution and efficiency:**
  - high pixel granularity
  - very low material budget
- **No strong requirement for radiation**
- **Large-area coverage**

→ **Baseline technological choice for the sensor:**
MOSAIX sensor in 65 CMOS technology being developed for the ALICE ITS3 upgrade

ALICE ITS3. CERN-LHCC-2024-003 / ALICE-TDR-021

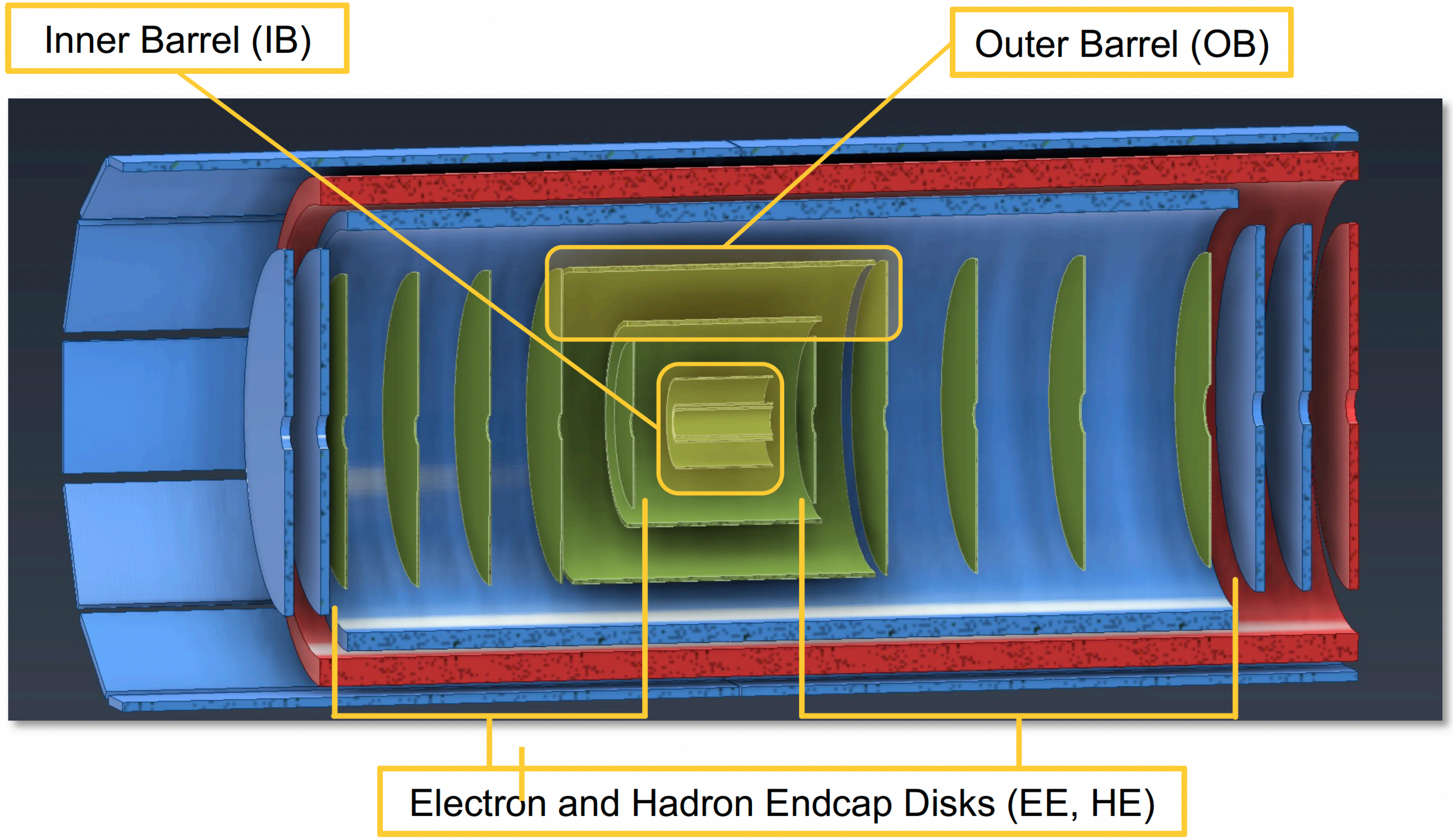


SVT sensor area is much larger (~$8m^2$)!
→ Adapt the ITS3 MOSAIX to develop EIC-Large Area Sensors (LAS)

SVT is a wide-η detector
→ strong constraints on material budget also at large η (challenge for services, cooling, powering…)

SVT environment has less particle occupancy
→ data multiplexing

Silicon Vertex Tracker for ePIC: detector concept



Outer Barrel (OB)
- Two layers, L3, L4
- Radii of 27 and 42 cm
- X/X0 ~ 0.25% and ~ 0.55%
- **Staved structure with LAS EIC MAPS sensors**

~ 8 m² of silicon sensors!

Inner Barrel (IB)
- Three layers, L0, L1, L2
- Radii of 36, 41, 120 mm
- Length of 27 cm
- X/X0 ~ 0.05% per layer
- **"Bent" MOSAIX MAPS sensors**

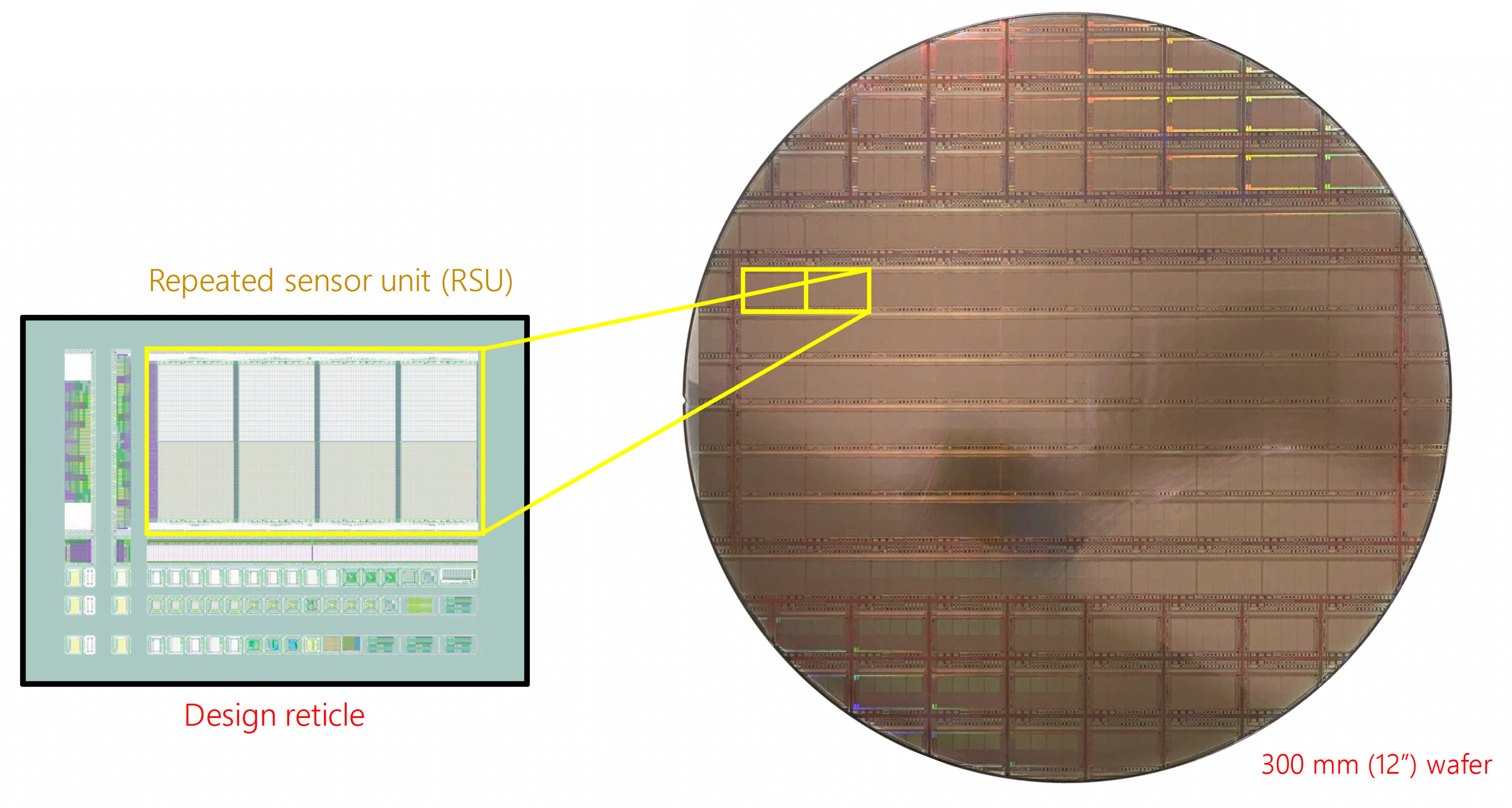
Electron/Hadron Endcaps:
- Two arrays with five disk structures with a corrugated core
- X/X0 ~ 0.25% per disk
- **LAS EIC MAPS sensors**

"Stitched" and "thinned" MAPS in 65 nm technology

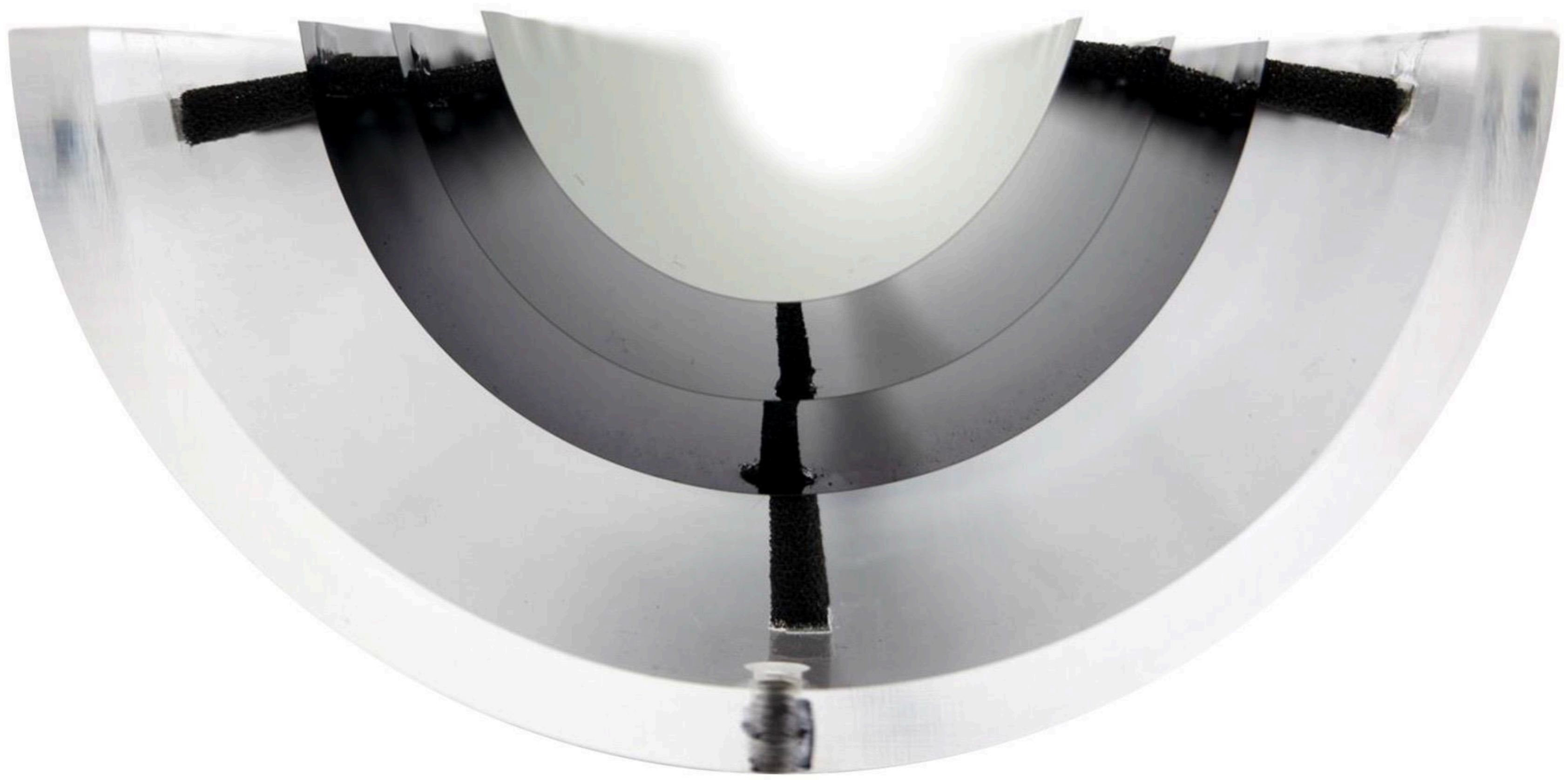
ALICE ITS3, CERN-LHCC-2024-003 / ALICE-TDR-021

Sensor stitching is one of the key features of the MOSAIX design:
- Repeated Sensor Units (RSUs) are printed during the lithographic process

→ **large-area MAPS sensors**



Wafers are then thinned below ~30-40 μm
→ below elastic threshold for silicon

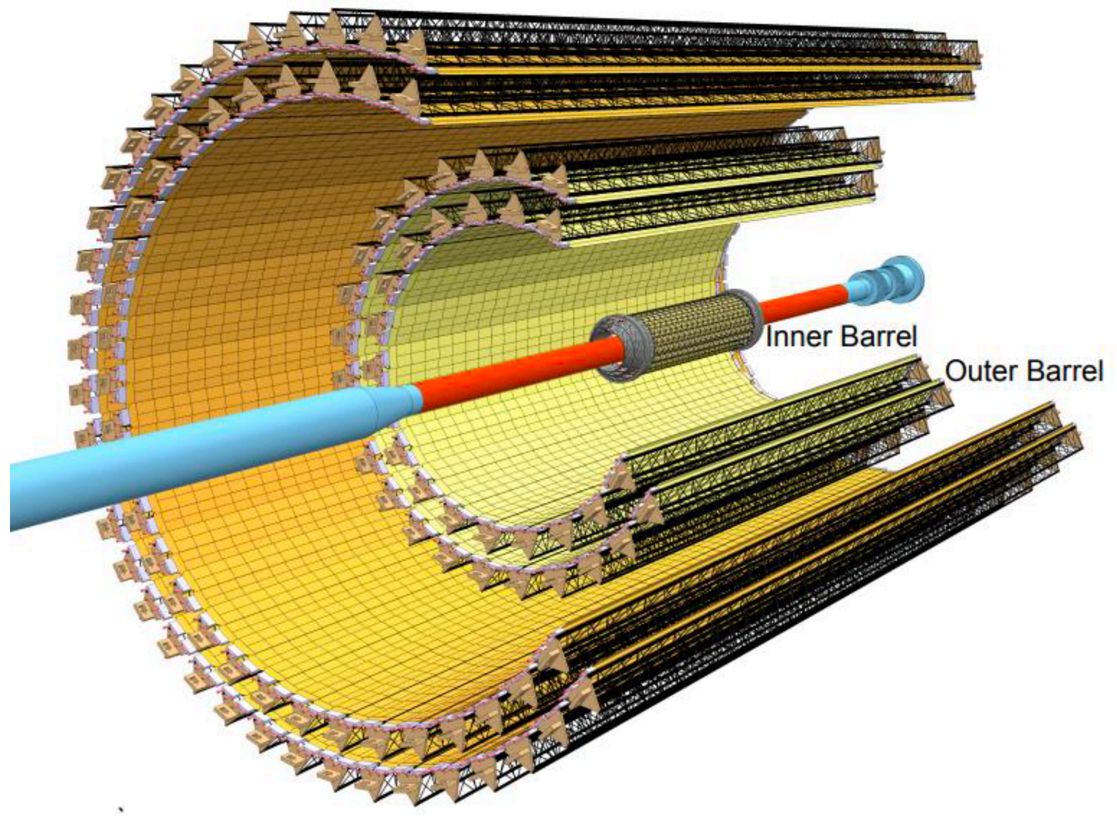


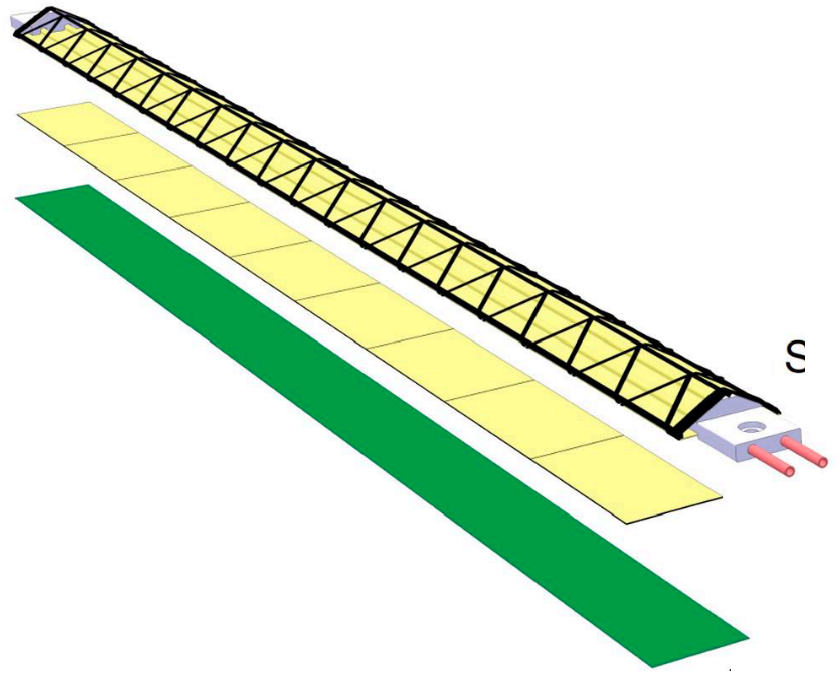
Wafers can be bent and held together by carbon foam profiting from the intrinsic stiffness of silicon

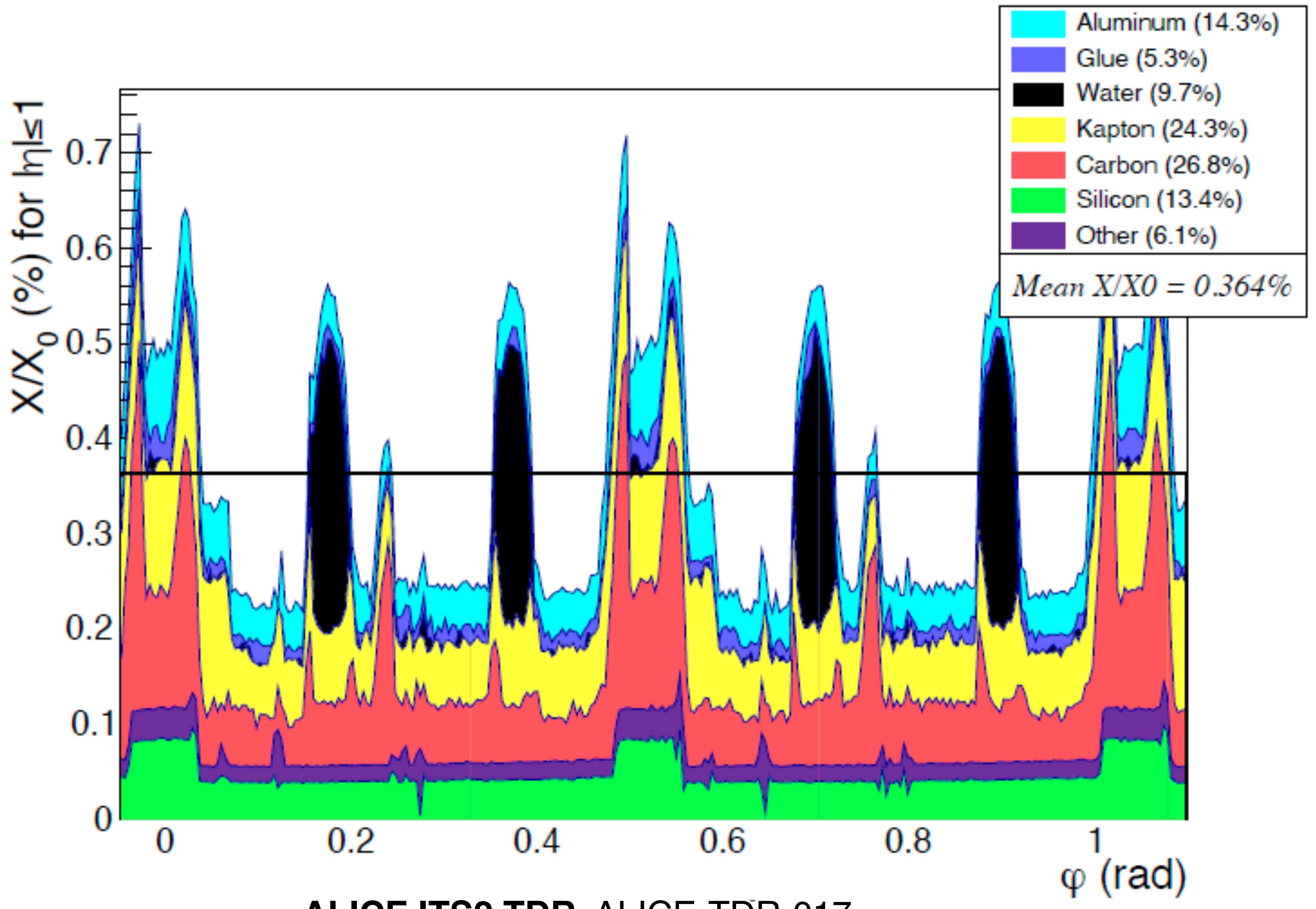
Material-budget reduction with next-generation MAPS

ALICE ITS3, CERN-LHCC-2024-003 / ALICE-TDR-021

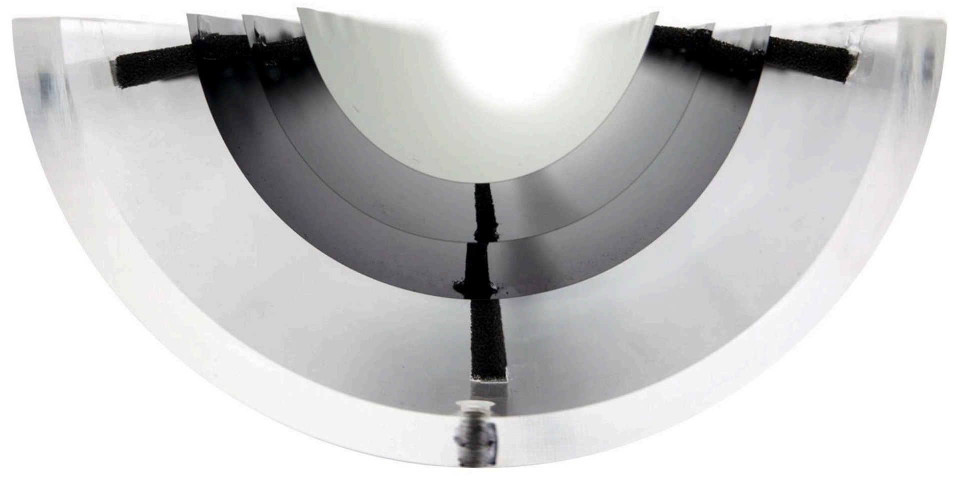
Existing MAPS sensors in 180 nm technology used for ITS2, MVTX detectors







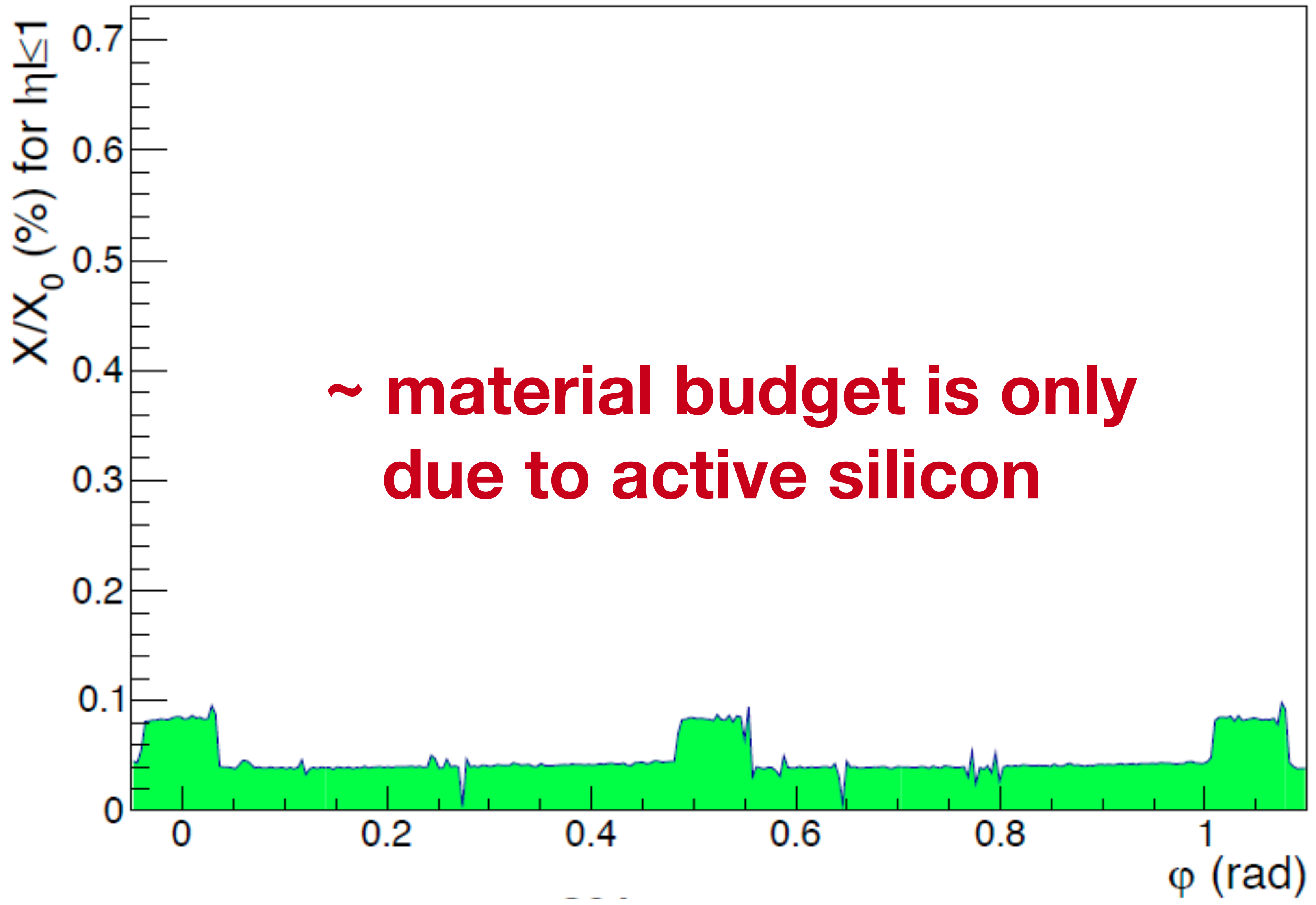
ALICE ITS2 TDR, ALICE-TDR-017



Stitched and thinned sensors in 65nm CMOS:

- low power consumption < 40 mW/cm²
- intrinsic stiffness of the curved silicon wafer

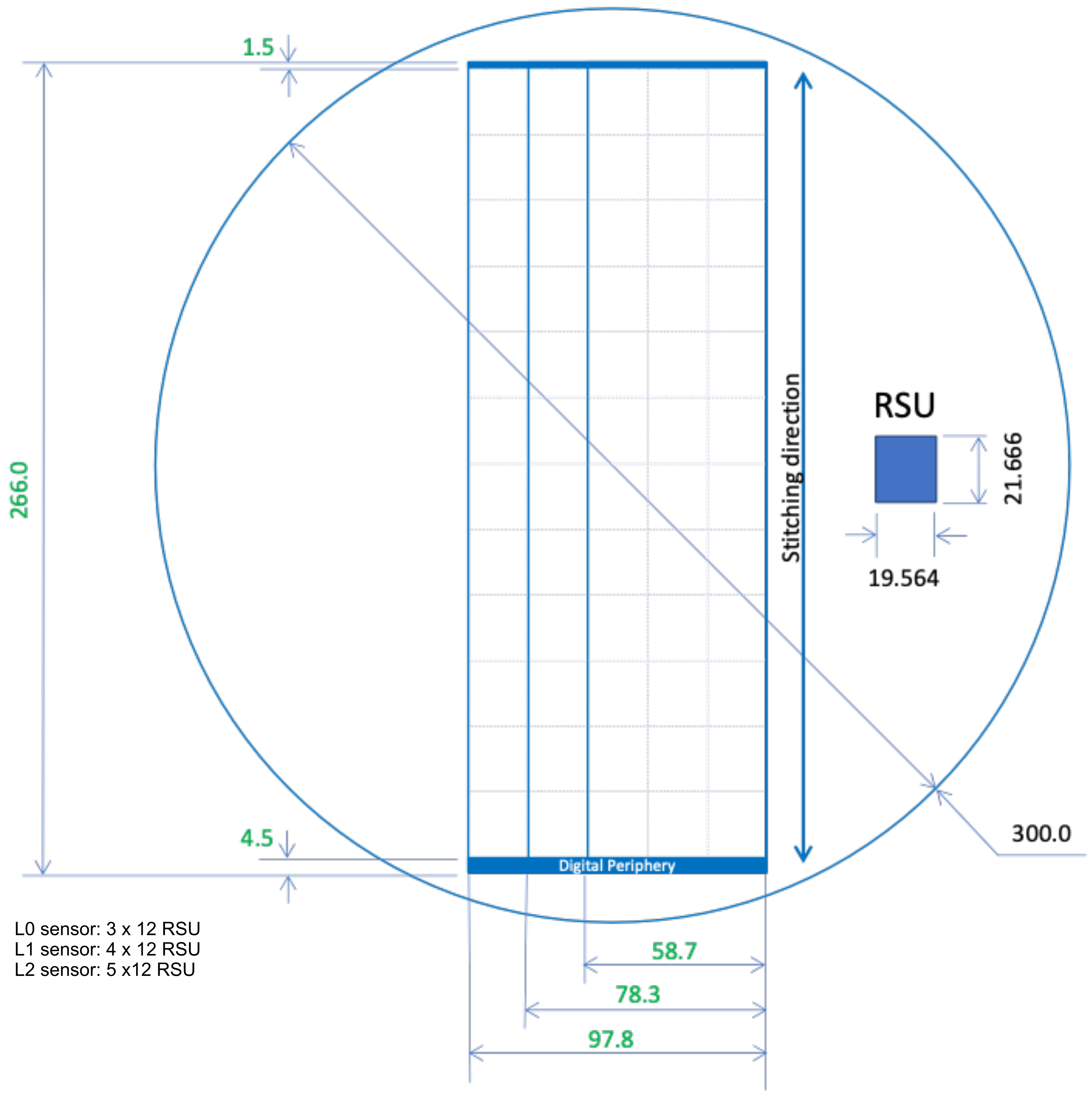
→ **Air-based cooling, no need for liquid-based cooling**
→ **No FPC for data readout and powering**
→ **Minimal mechanical support**



ALICE ITS3, CERN-LHCC-2024-003 / ALICE-TDR-021

A focus on the MOSAIX sensor design and specifications

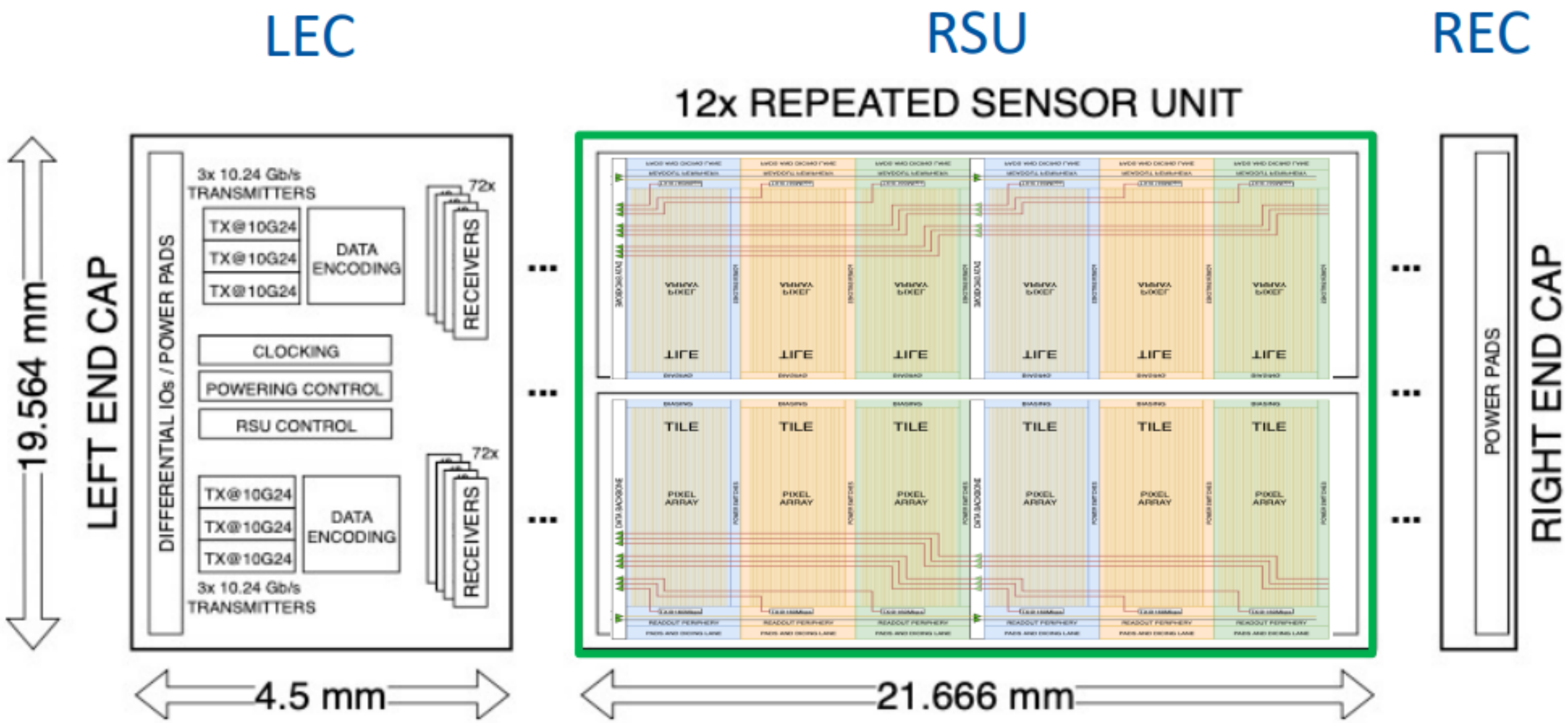
- **Pixel size**: ~ 20 x 22 μm^2
- **Frame duration**: 2 to 5 μs
- **Powering and readout only from endcaps**
- High-speed links (up to 10.24 Gbps)



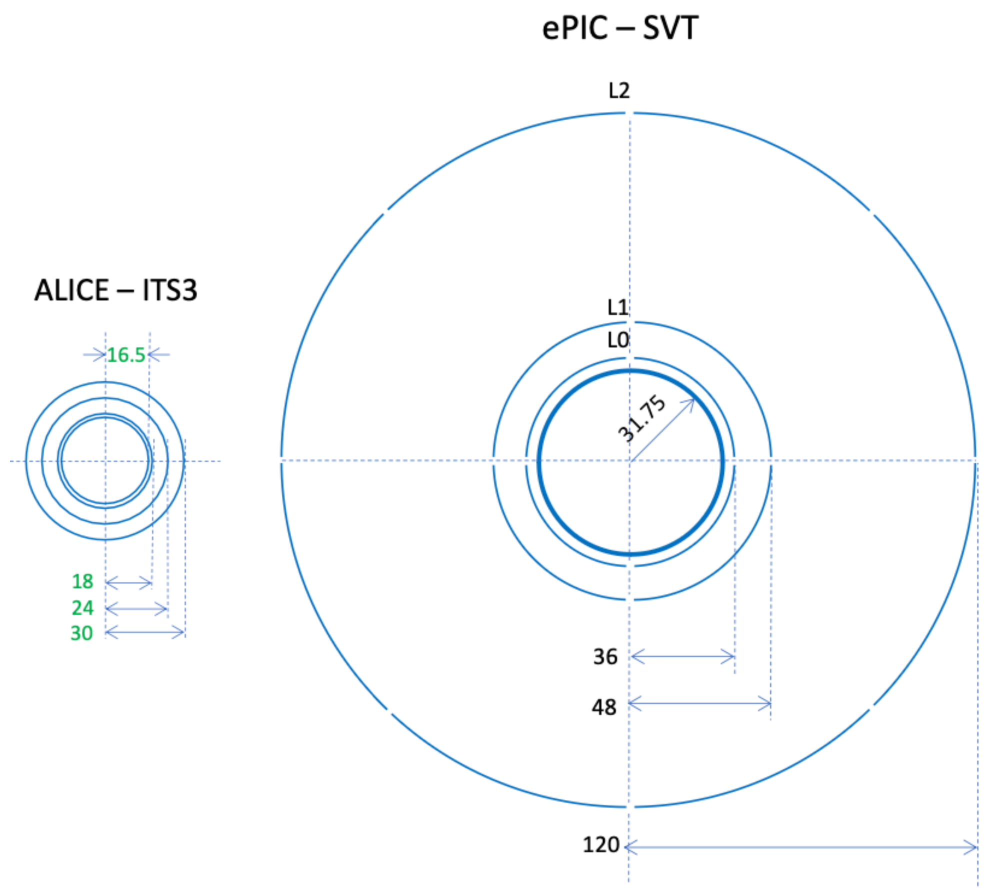
L0 sensor: 3 x 12 RSU
L1 sensor: 4 x 12 RSU
L2 sensor: 5 x12 RSU

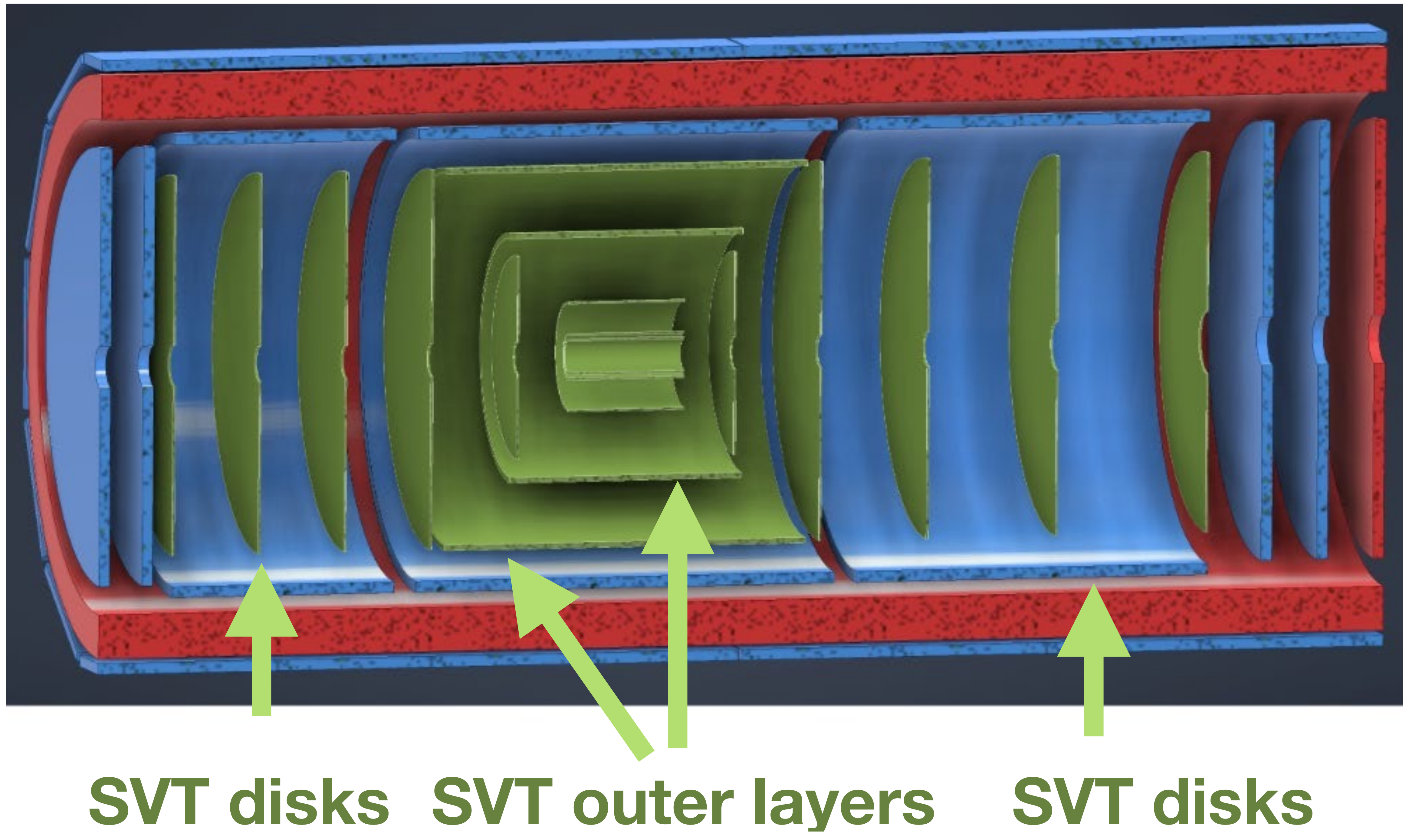
ER2 sensor widths

19.564 x 3 = 58.692
19.564 x 4 = 78.256
19.564 x 5 = 97.820



SVT: highlights on R&D activities





R&D for the Inner layers:

- **reduce services at forward/backward**
- **mechanical stability for the R=12 cm layer** (R^{max}_{ITS3} is < 4 cm!)
- **cooling** in the presence of forward disks obstructing air airflow

Outer layers and disks:

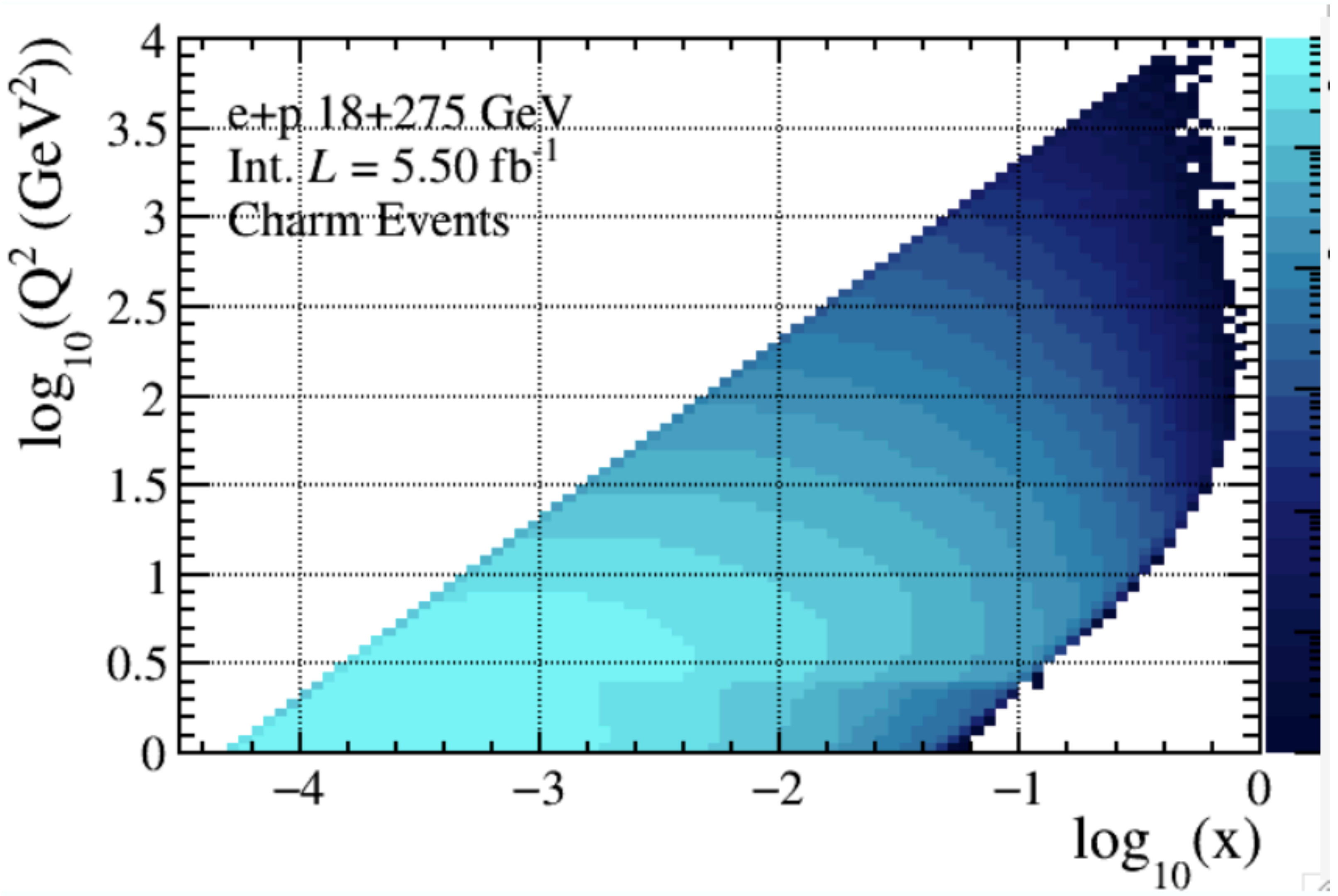
- **material budget** in the presence of additional support structures and services
- **cooling**

SVT at the ePIC: timescale of the sensor development

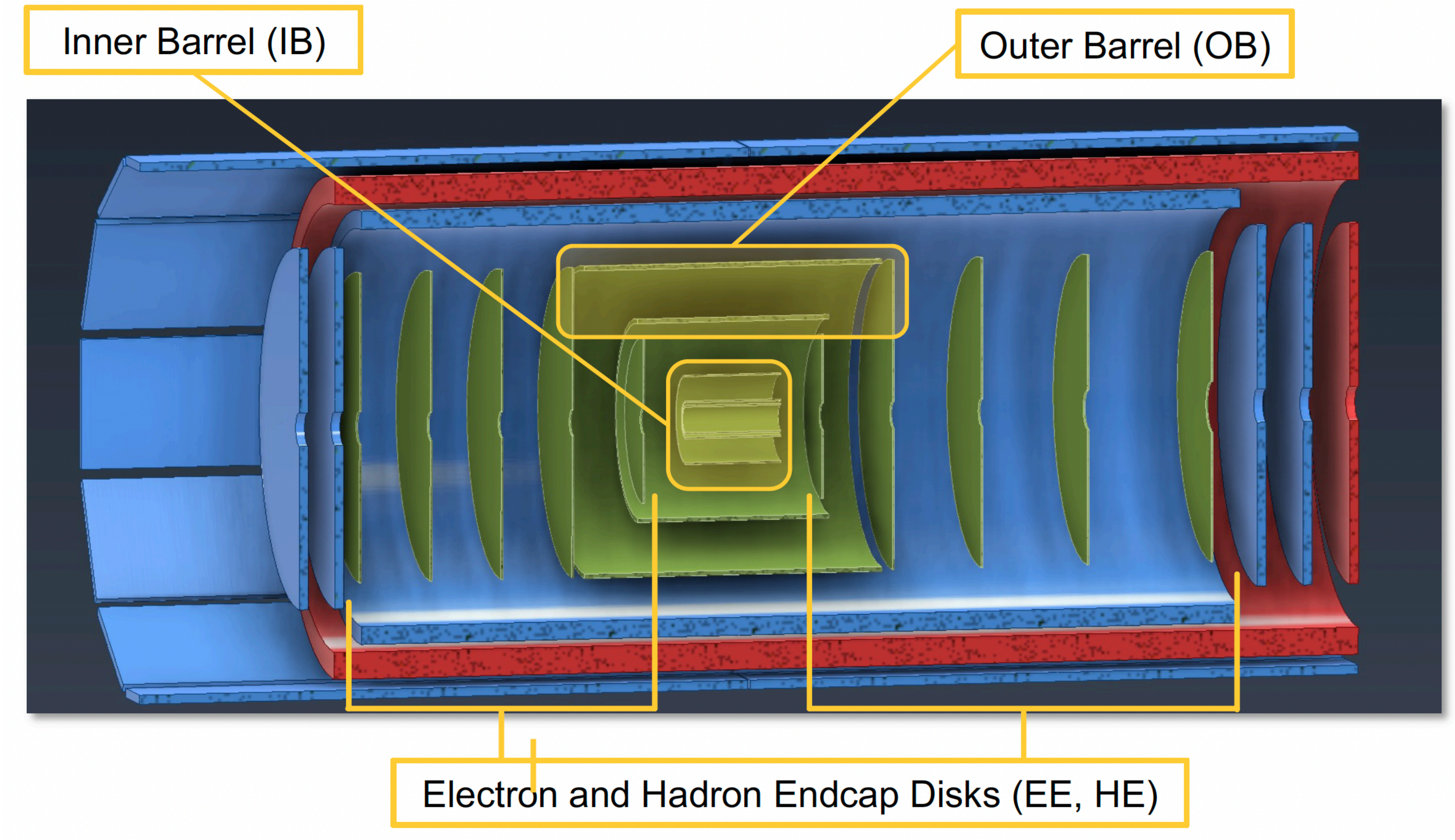
Institutions in SVT

Large (and growing) collaboration with strong involvement from the US, UK, Italy, and Czech Republic
→ Extensive Si-detector experience in the ALICE, ATLAS, CMS, sPHENIX, and STAR experiments
→ **we welcome new institutes interested in joining the challenge!**

Conclusion and outlook



Heavy-flavor capabilities in the widest p_T and η region essential for ePIC:
→ need for a wide-coverage, low-material budget vertexer detector
→ **outstanding DCA resolution as the key parameter for the detector design**



The Silicon Vertex Tracker will exploit stitched MAPS sensors (MOSAIX) with bent and staved geometry to meet these requirements

Extensive R&D program ongoing:
- MOSAIX sensor design (in collaboration with the ITS3 ALICE collaboration)
- Large-Area MAPS sensors
- cooling strategy, service reduction, mechanical design, …

→ **toward the first large-acceptance tracker detector ever built with stitched MAPS**

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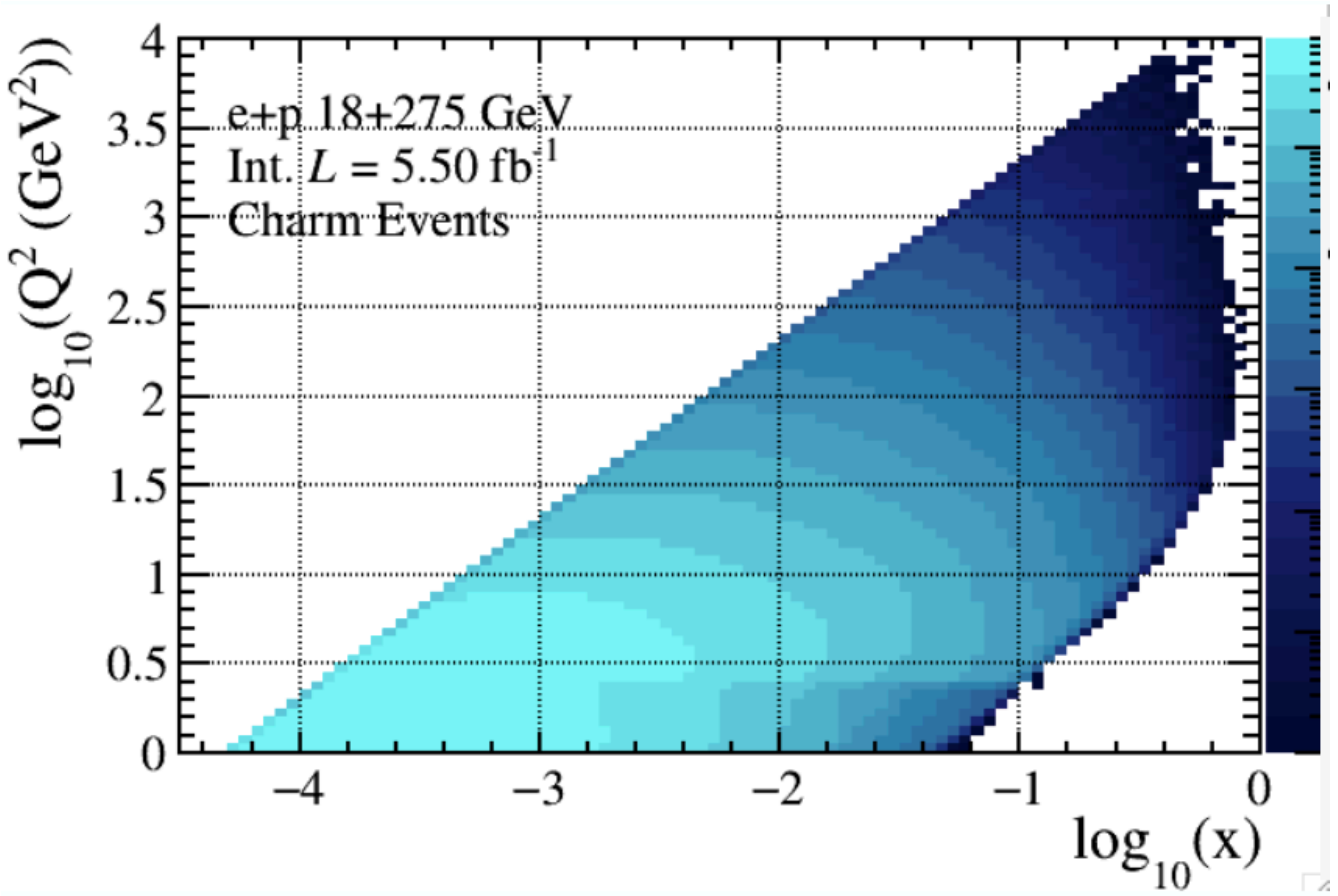

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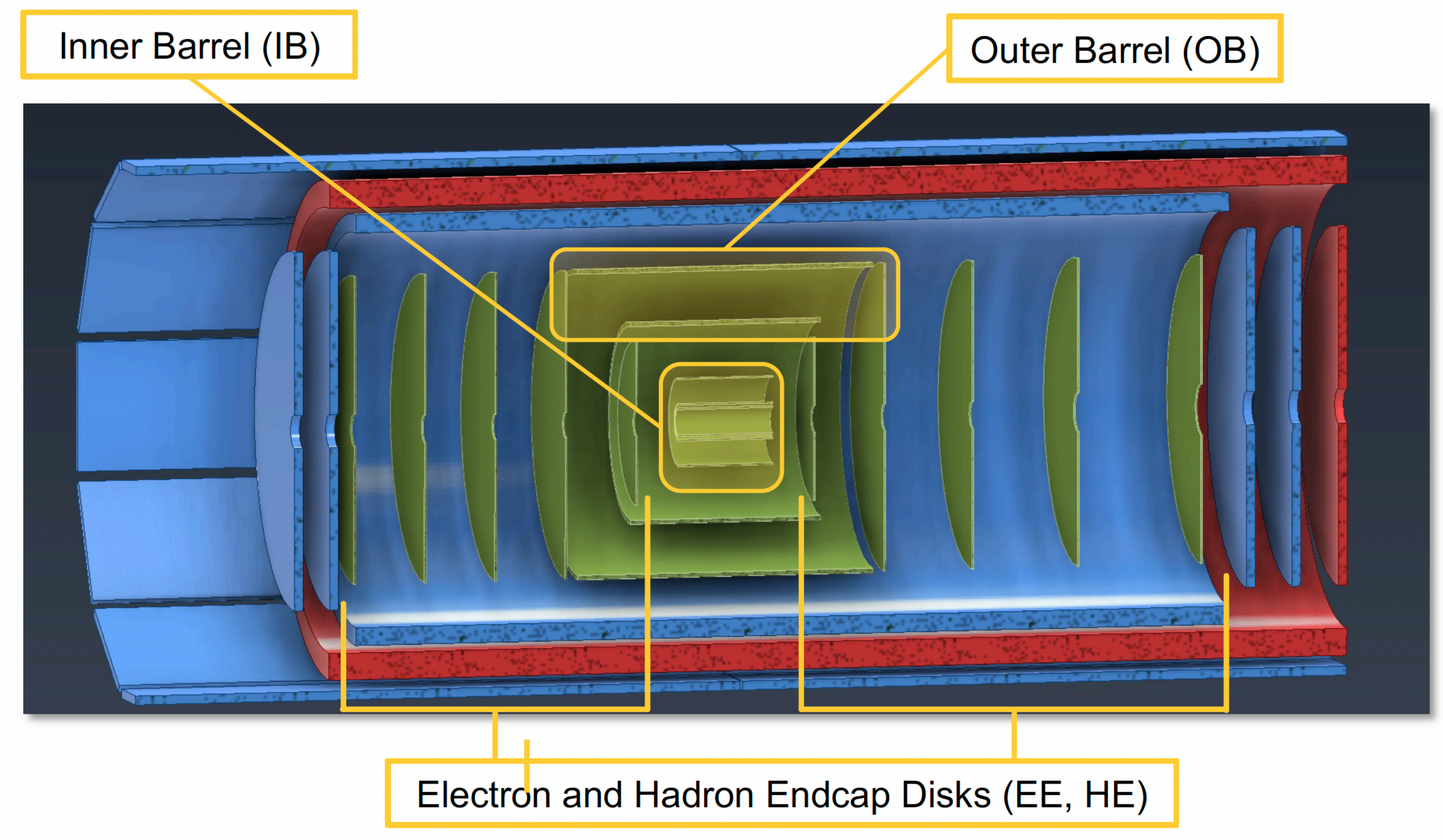

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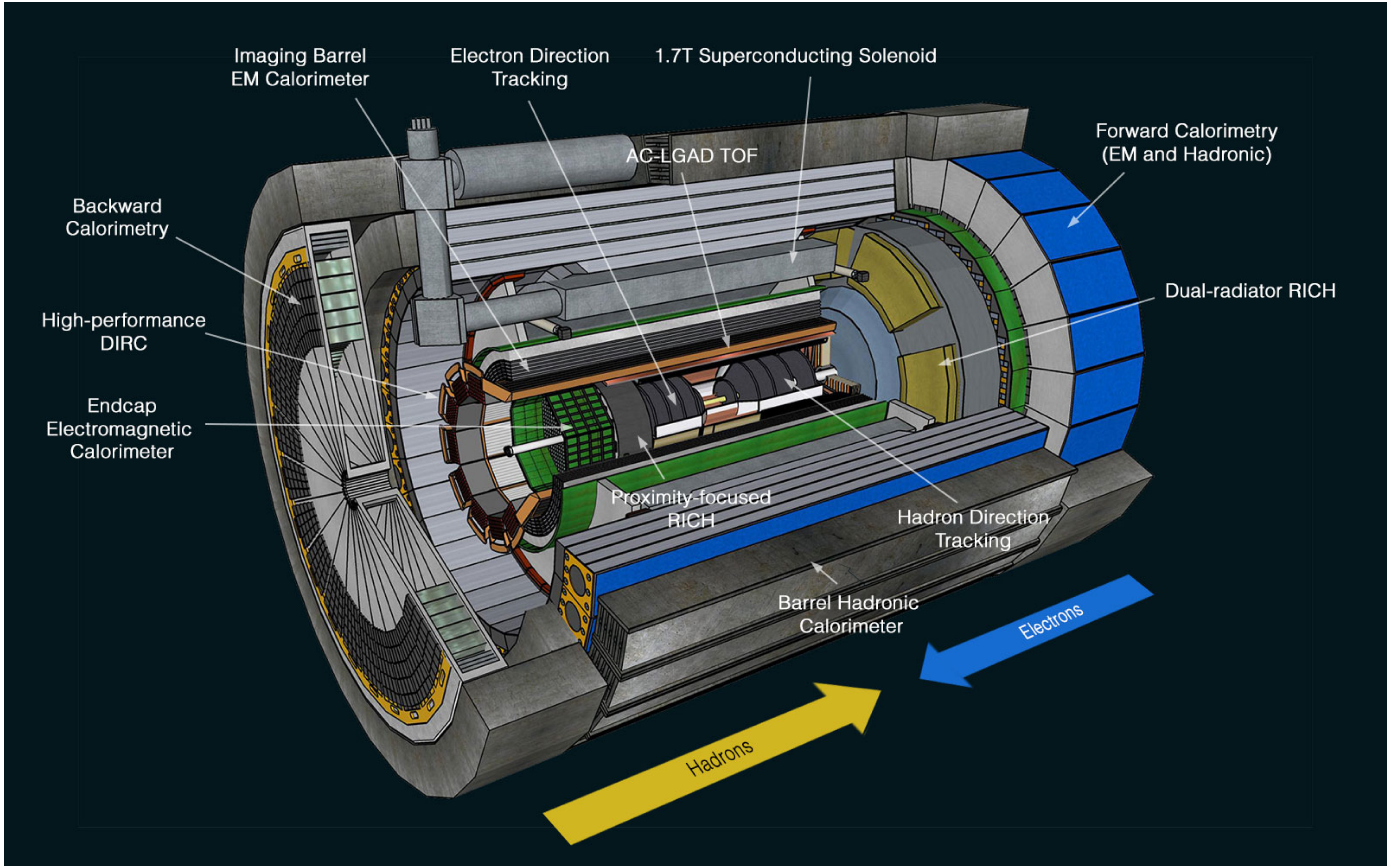
Thank you for your attention!

BACKUP

The ePIC experiment at the Electron-Ion Collider (EIC)



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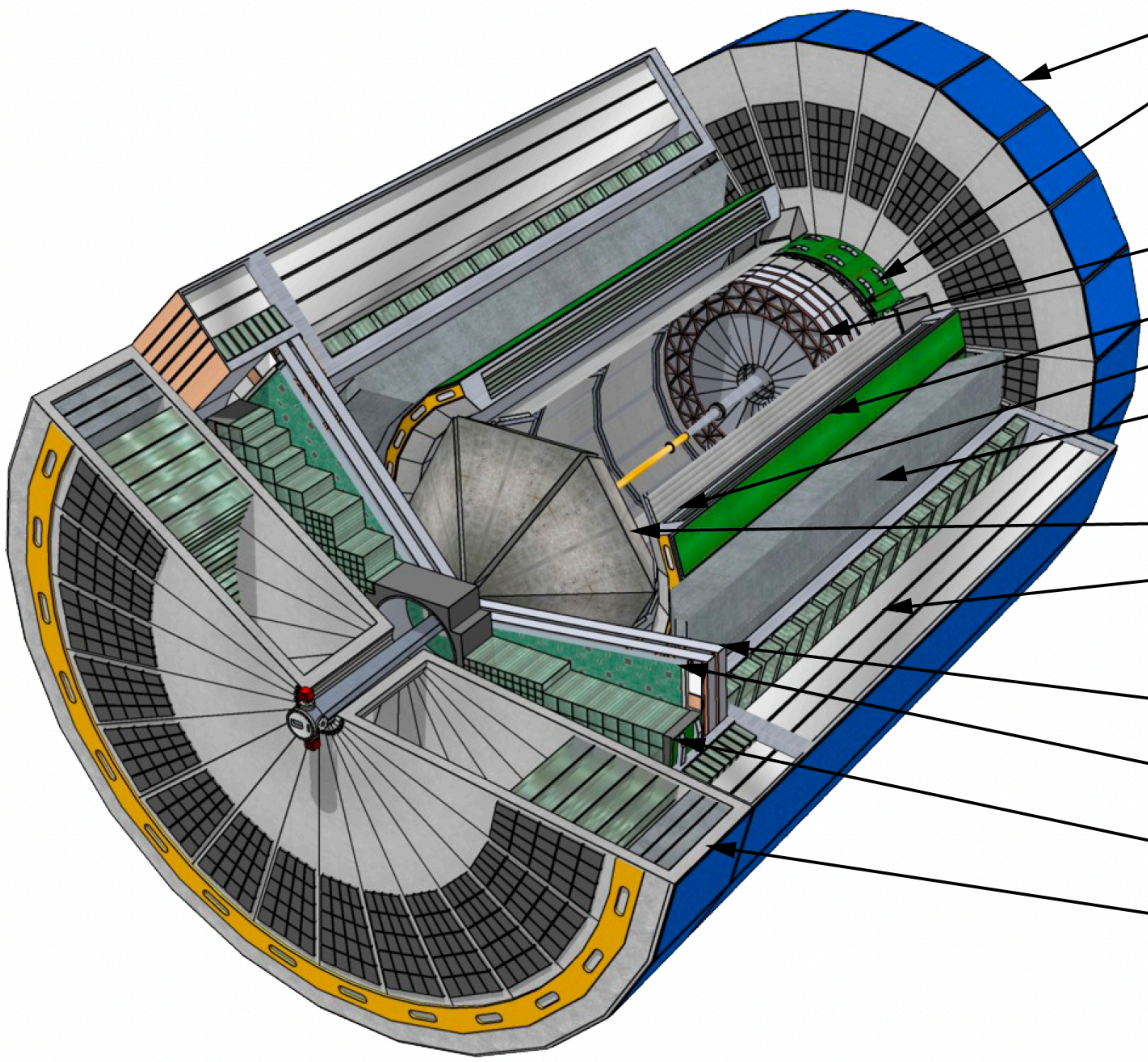
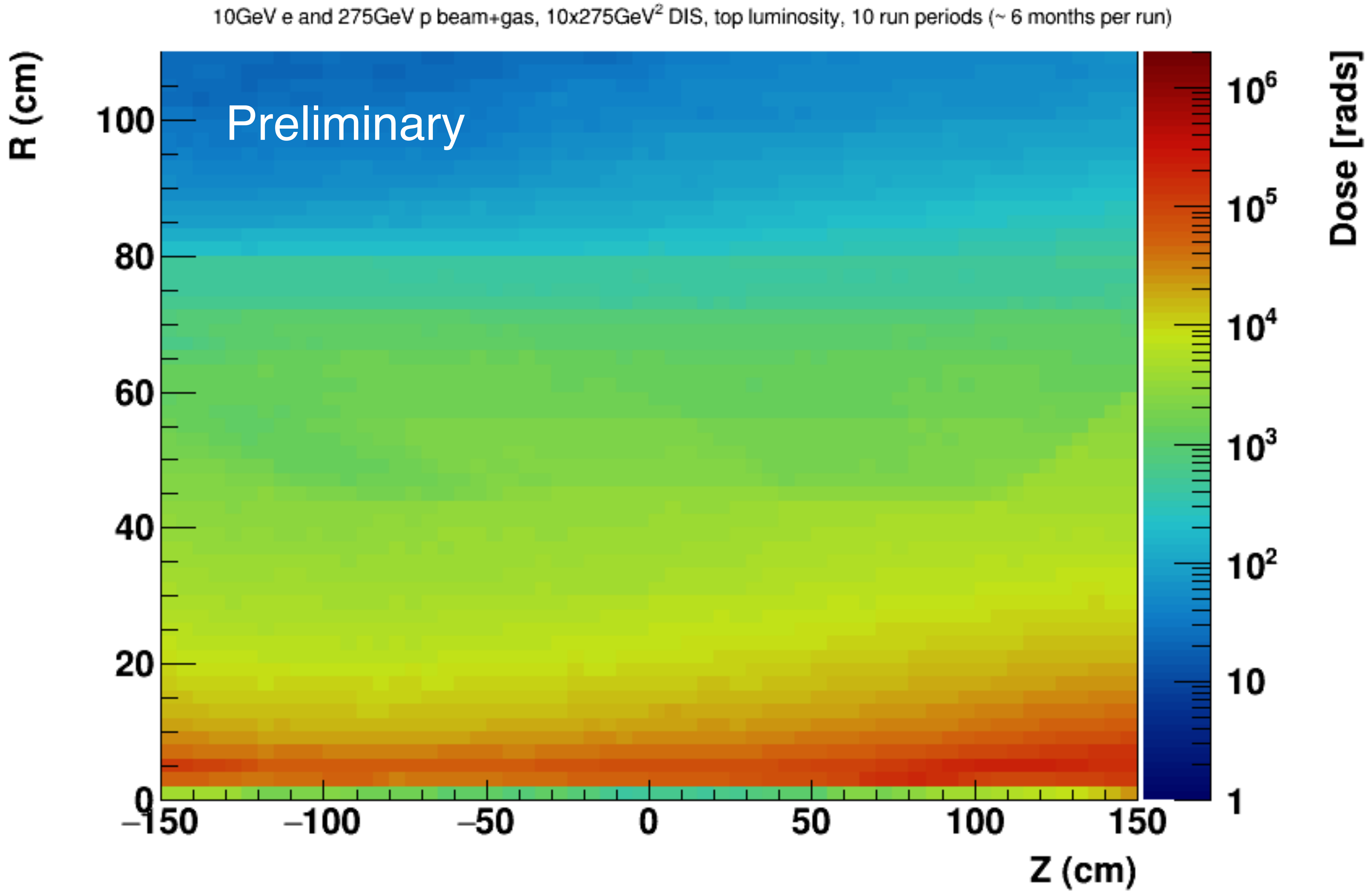


Summary of physics working group requirements

η	Nomenclature			Tracking				Electrons and Photons			π/K/p PID		HCAL		Muons
				Min p_T	Resolution	Allowed X/X_0	Si-Vertex	Min E	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Min E	Resolution σ_E/E	
-6.9 — -5.8	↓ p/A	Auxiliary Detectors	low-Q^2 tagger		$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2										
…															
-4.5 — -4.0			Instrumentation to separate charged particles from γ						2%/√E+(1-3)%						
-4.0 — -3.5				100 MeV π 135 MeV K				50 MeV						~50%/√E+6%	
-3.5 — -3.0		Central Detector	Backwards Detectors		σ_p/p ~ 0.1%×p+2.0%	~5% or less				π suppression up to 1:10^4	≤ 7 GeV/c	≥ 3σ	~500 MeV	~45%/√E+6%	Useful for bkg, improve resolution
-3.0 — -2.5							σ_{xy}~30μm/p_T+40μm								
-2.5 — -2.0															
-2.0 — -1.5					σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30μm/p_T+20μm		7%/√E+(1-3)%						
-1.5 — -1.0															
-1.0 — -0.5			Barrel		σ_p/p ~ 0.05%×p+0.5%		σ_{xyz} ~ 20 μm, $d_0(z)$ ~ $d_0(r\varphi)$ ~ 20/p_T GeV μm + 5 μm		(10-12)%/√E+(1-3)%		≤ 10 GeV/c			~85%/√E+7%	
-0.5 — 0.0															
0.0 — 0.5															
0.5 — 1.0											≤ 15 GeV/c				
1.0 — 1.5			Forward Detectors		σ_p/p ~ 0.05%×p+1.0%		σ_{xy}~30μm/p_T+20μm			3σ e/π	≤ 30 GeV/c			~35%/√E	
1.5 — 2.0											≤ 50 GeV/c				
2.0 — 2.5															
2.5 — 3.0					σ_p/p ~ 0.1%×p+2.0%		σ_{xy}~30μm/p_T+40μm				≤ 30 GeV/c				
3.0 — 3.5							σ_{xy}~30μm/p_T+60μm				≤ 45 GeV/c				
3.5 — 4.0	↑e	Auxiliary Detectors	Instrumentation to separate charged particles from γ												
4.0 — 4.5															
…															
> 6.2			Proton Spectrometer		$\sigma_{intrinsic}(\lvert t\rvert)/\lvert t\rvert$ < 1%; Acceptance: 0.2< p_T <1.2 GeV/c										

Projection for radiation dose

EIC Yellow Report, BNL-220990-2021-FORE



Beam energies:
- 10 GeV electron beam
- 275 GeV proton beam

Luminosity and int. rate:
- 10^{-34} $cm^{-2}s^{-1}$ luminosity
- DIS interactions (~ 500kHz)
- Beam-gas background 10 kAhr
- No synchrotron radiation (yet)

Running time:
- 10 half-year running periods
- 100% up time

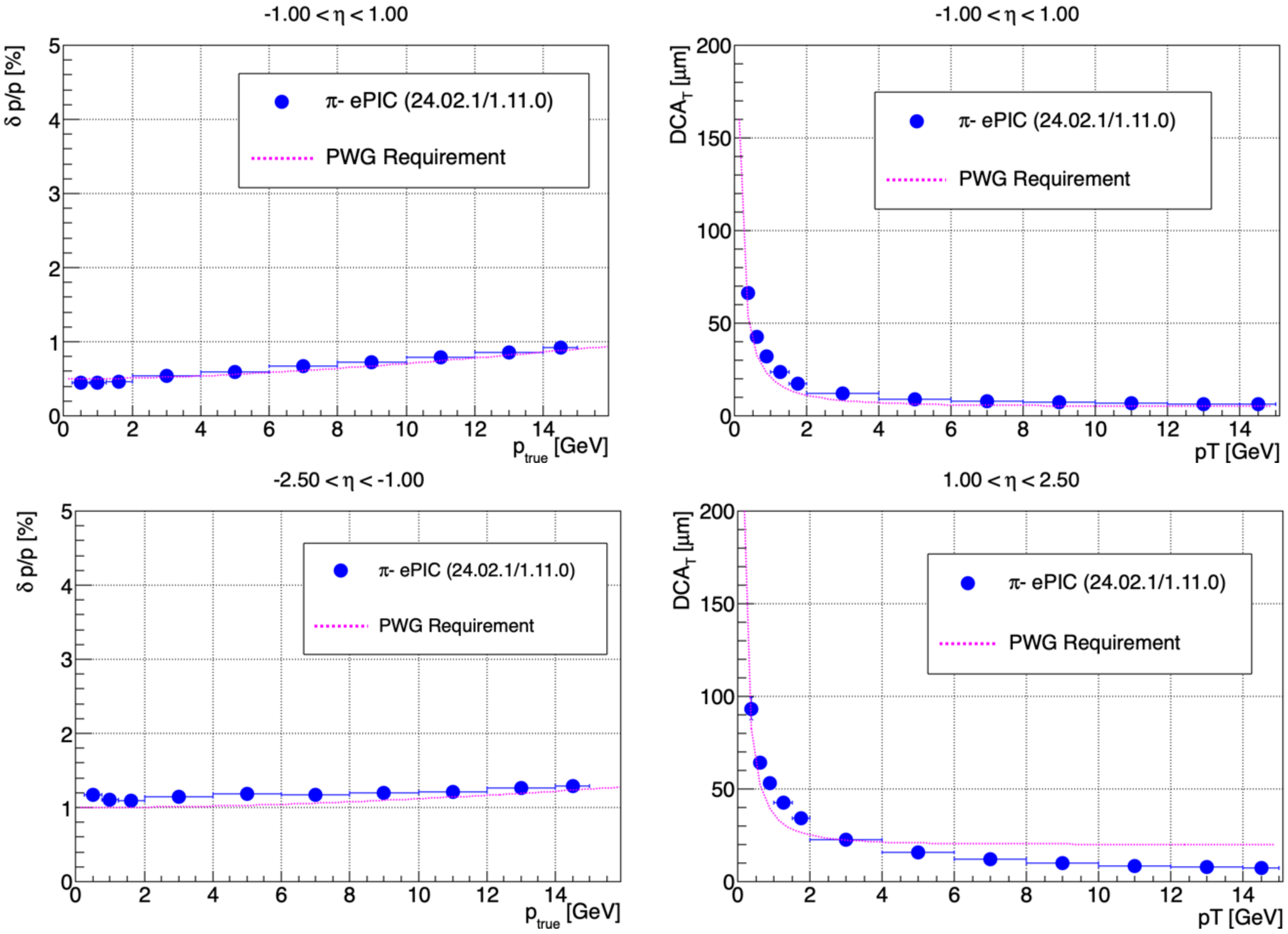
Low, O(10^{-7}) hit occupancy per pixel in a O(μs) readout frame

The region close to the beampipe is projected to experience a few hundred kRad

Tracking performance (DCA and p_T resolution)

EIC Yellow Report, BNL-220990-2021-FORE

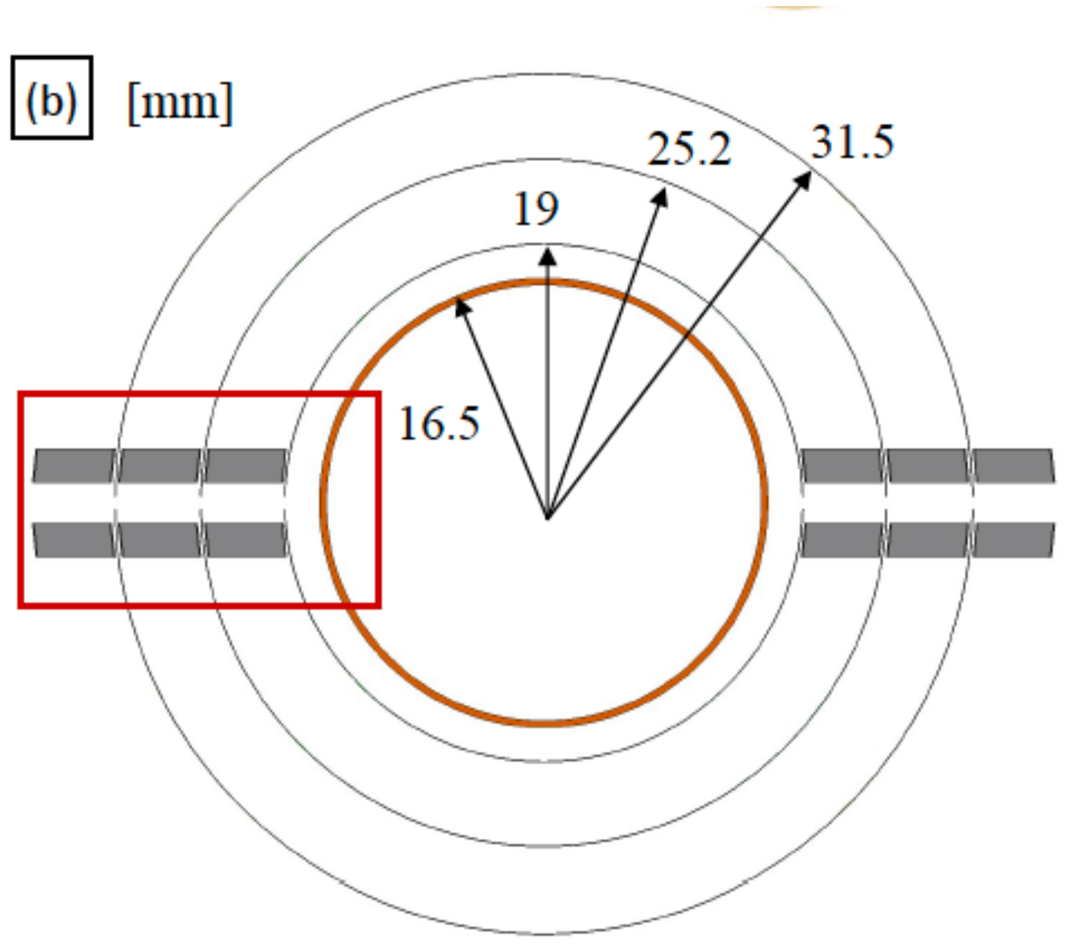
Momentum resolution

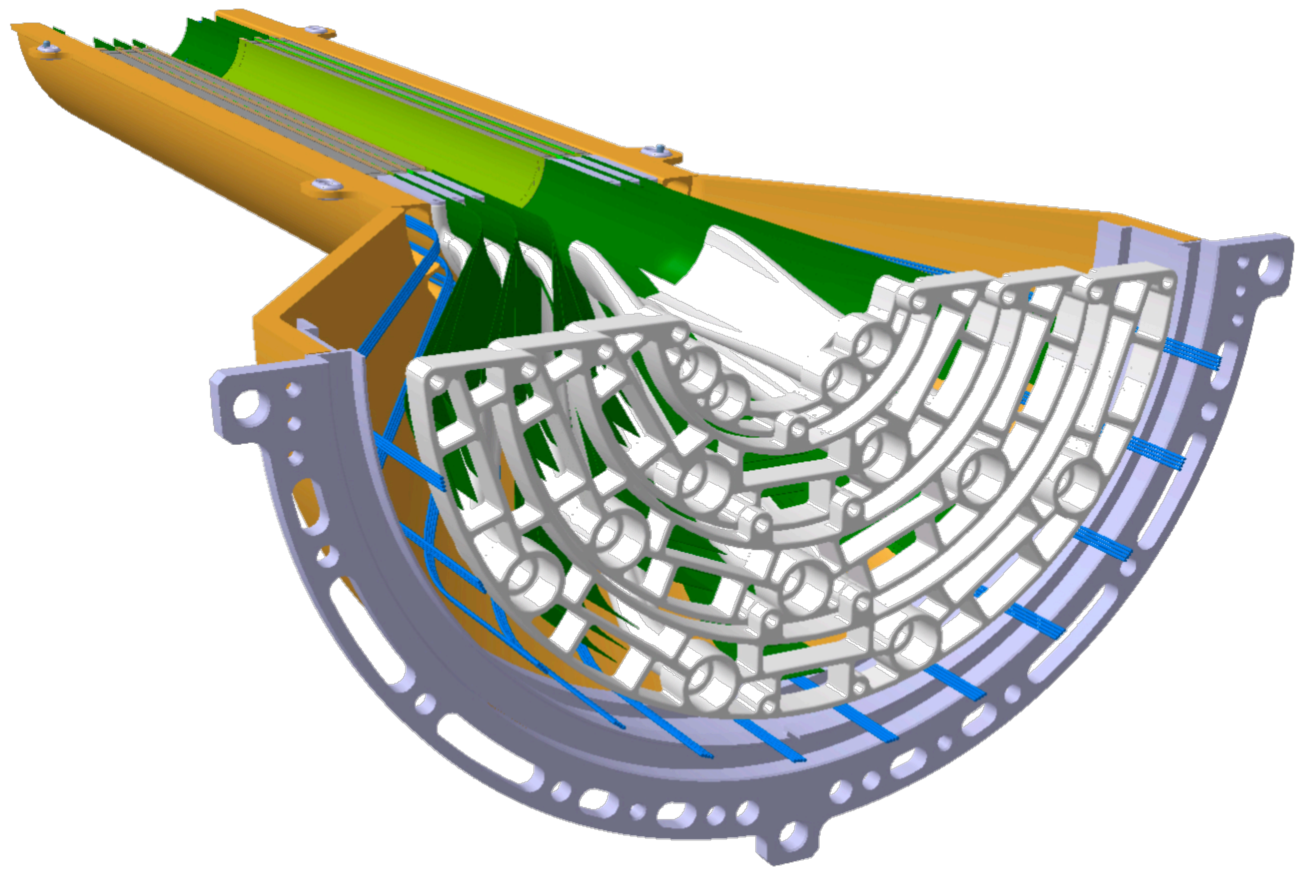


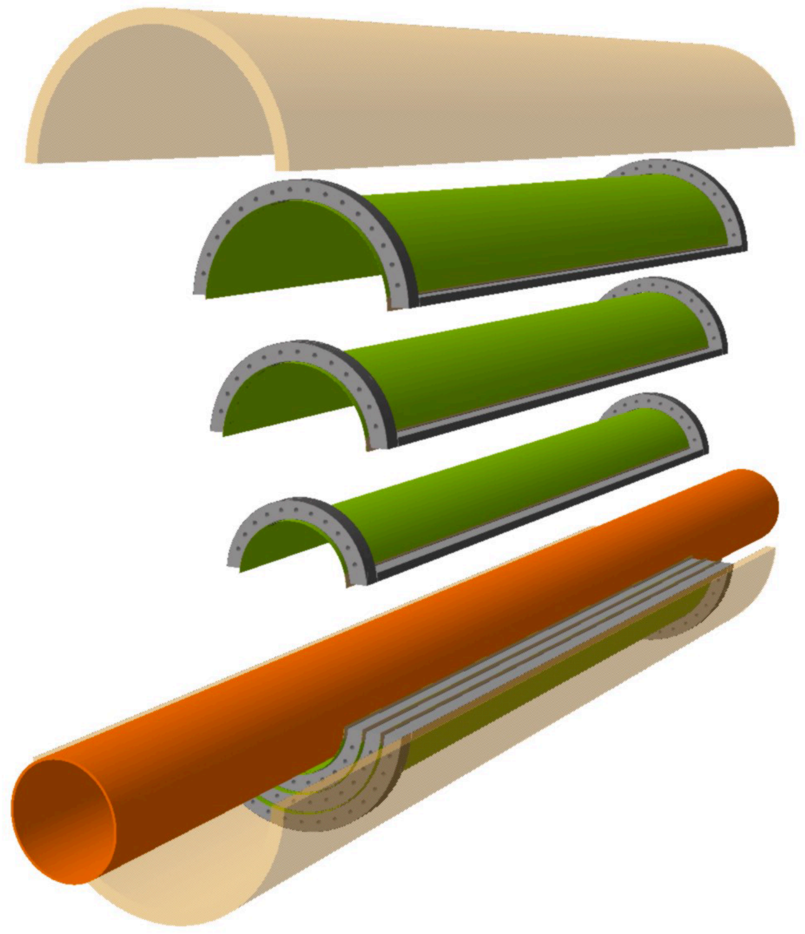
Distance of Closest Approach

The ITS3 upgrade for ALICE in Run 4

ITS3 upgrade:
- high-occupancy low-interaction rate (PbPb at the LHC)
- only three layers (radii from 1.90 to 3.15 cm)
- small pseudorapidity coverage (no strong constraints on material budget due to services)







Beampipe inner/outer radius (mm)	16.0/16.5		
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	19.0	25.2	31.5
Length (sensitive area) (mm)	260	260	260
Pseudo-rapidity coverage[a]	±2.5	±2.3	±2.0
Active area (cm^2)	305	407	507
Pixel sensors dimensions (mm^2)	266 × 58.7	266 × 78.3	266 × 97.8
Number of pixel sensors / layer		2	
Material budget ($\%X_0$ / layer)		0.07	
Silicon thickness (μm / layer)		≤50	
Pixel size (μm^2)		$O(20 \times 22.5)$	
Power density (mW/cm^2)		40	
NIEL (1 MeV n_{eq} cm^{-2})		10^{13}	
TID (kGray)		10	

Overview of the R&D phases for MOSAIX and LAS sensors

Stitched bent sensors for ITS3 and first three layers of the SVT

MLR1: qualification of CMOS 65nm technology, prototype for circuit blocks

ER1: stitching technology demonstrator (MOSS and MOST sensor), yield studies

ER2: fully functional sensor that satisfy ITS3 requirements

ER3: final production and design (bug fixes from ER2)

Stitched flat sensors for the outer layers of the SVT detector:

Large Area Sensor (11): stitched “flat” larger area sensor