A LGAD-based TOF for EIC

– Leveraging experience with HL-LHC upgrades

Frank Geurts, Wei Li (Rice University)
Constantin Loizides (Oak Ridge National Lab)

in collaboration with
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The 1st EIC Yellow Report Workshop, Temple University

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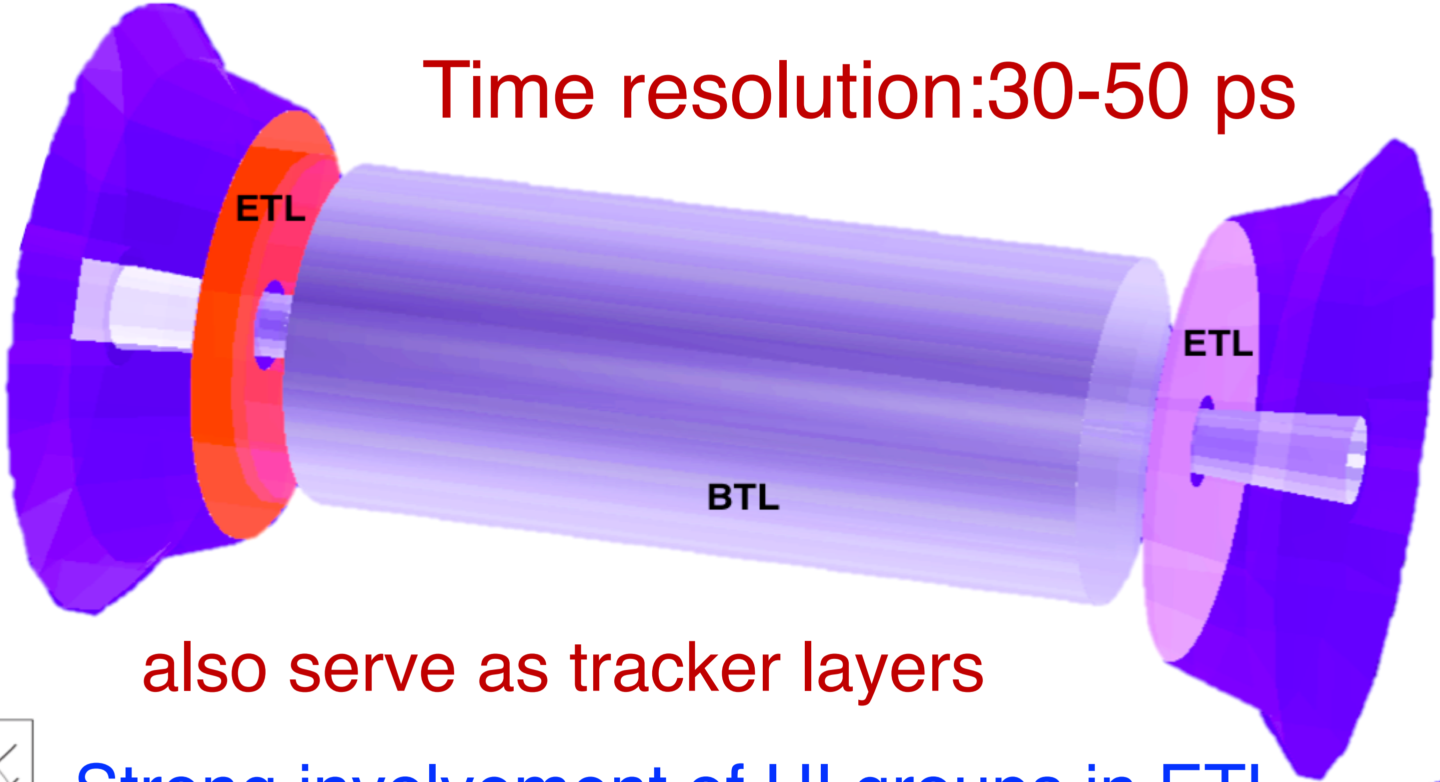
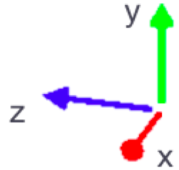
A Hermetic TOF for CMS at the HL-LHC

Barrel Timing Layer (BTL): |η|<1.5
- LYSO bars + SiPM readout
- Thickness ~ 40 mm
- Surface: ~38 m^2; Channels: 332k
- Radiation: 2×10^{14} n_{eq}/cm^2

Endcap Timing Layer (ETL): 1.6<|η|<3.0
- Si with internal gain (LGAD)
- Thickness ~ 45 mm for two layers
- Surface: ~14 m^2; Channels: 8.5 M
- Radiation: 2×10^{15} n_{eq}/cm^2

Time resolution:30-50 ps

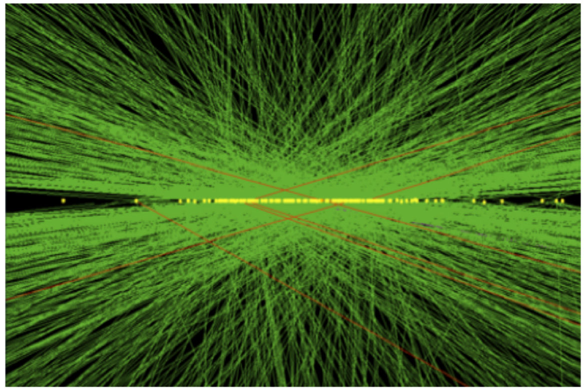




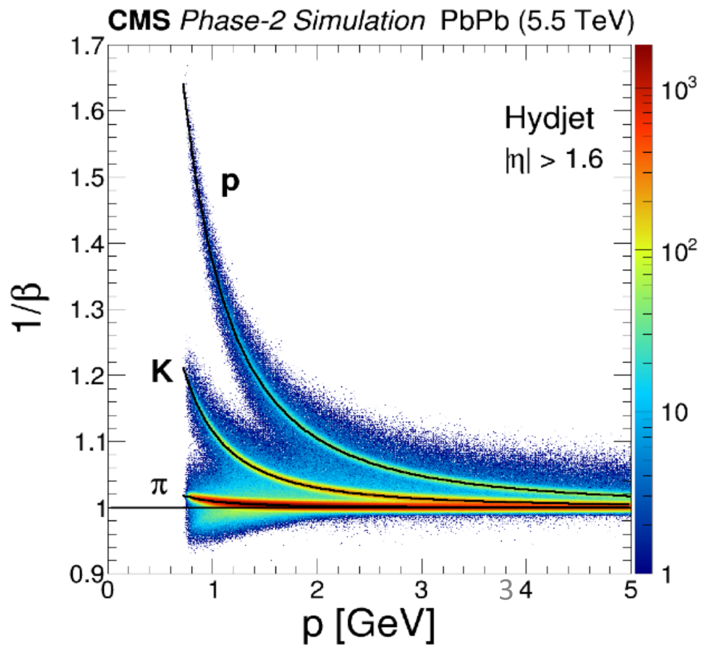
also serve as tracker layers

Strong involvement of HI groups in ETL

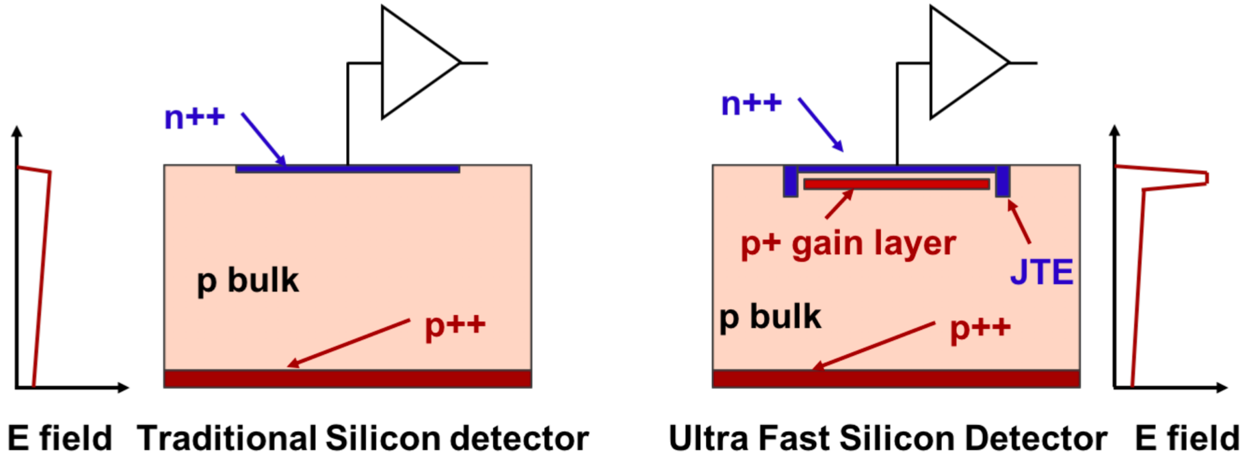
Pileup mitigation in pp

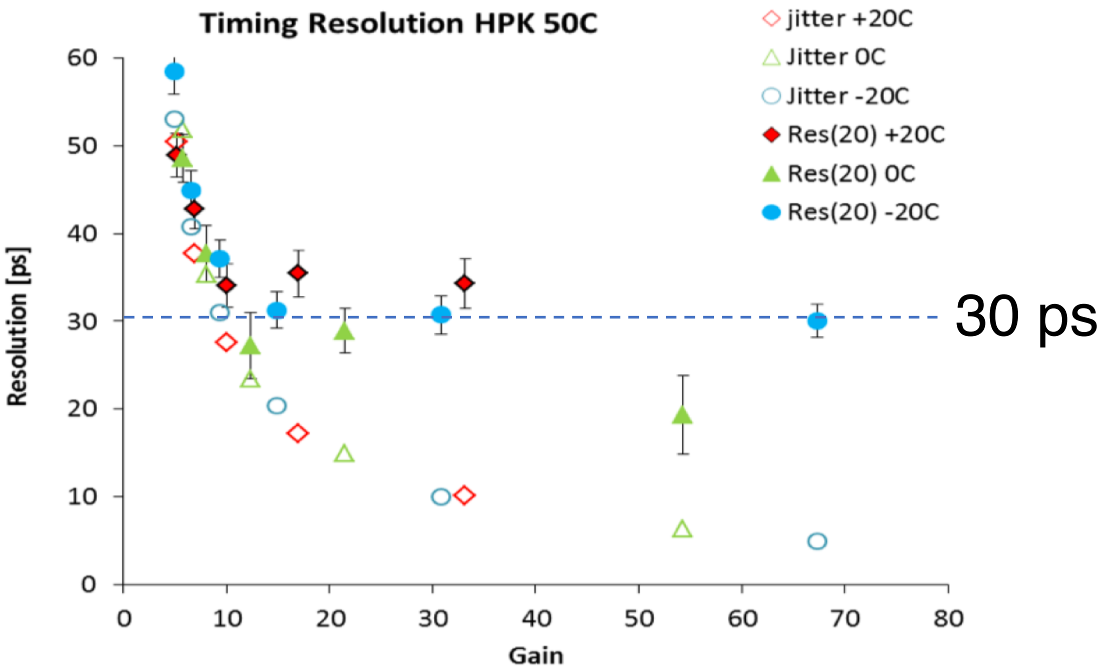


Particle ID in HI



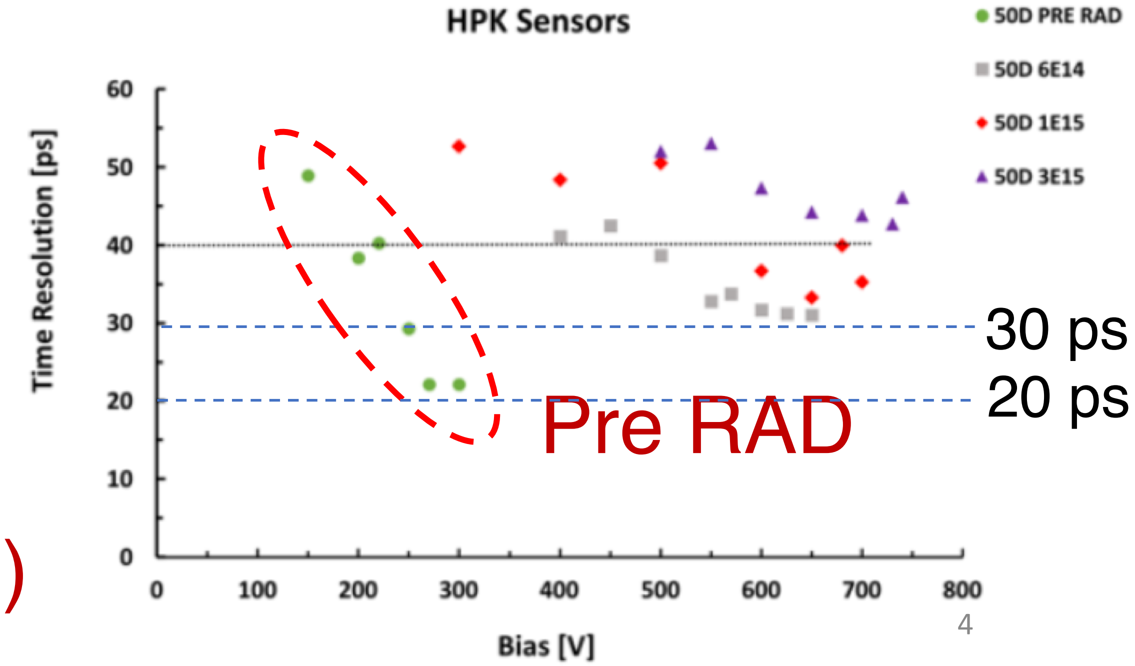
Endcap Timing Layer (ETL)





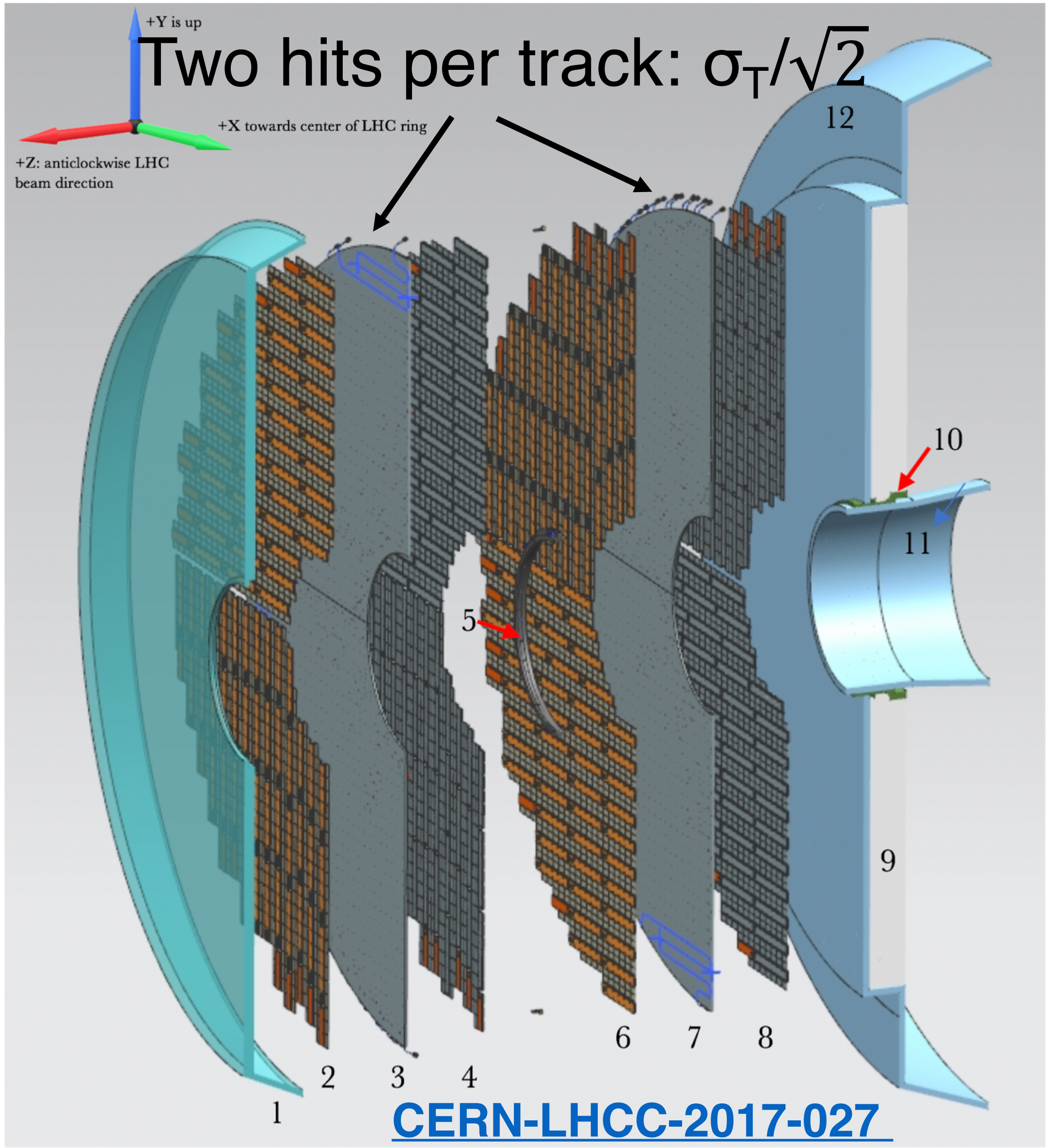
LGAD sensor for CMS ETL:

- Pixel size: 1.3 x 1.3 mm^2
- Thickness: 50 µm
- Time resolution: 30-50 ps



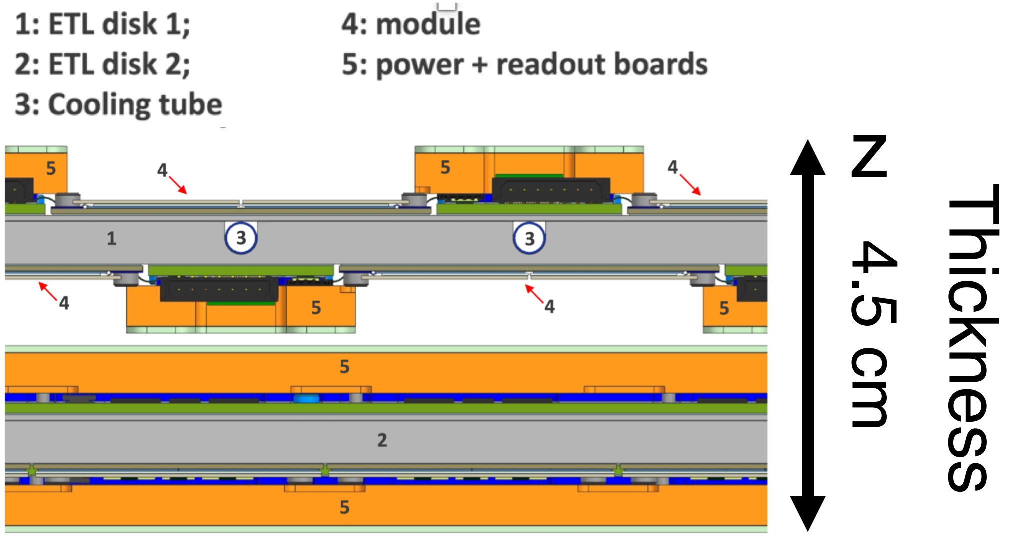
$\sigma_T \leq 30$ ps for Pre RAD (i.e., EIC-like)

Endcap Timing Layer (ETL)



CERN-LHCC-2017-027

Challenging ASICs, clock distribution, mechanics, and integration



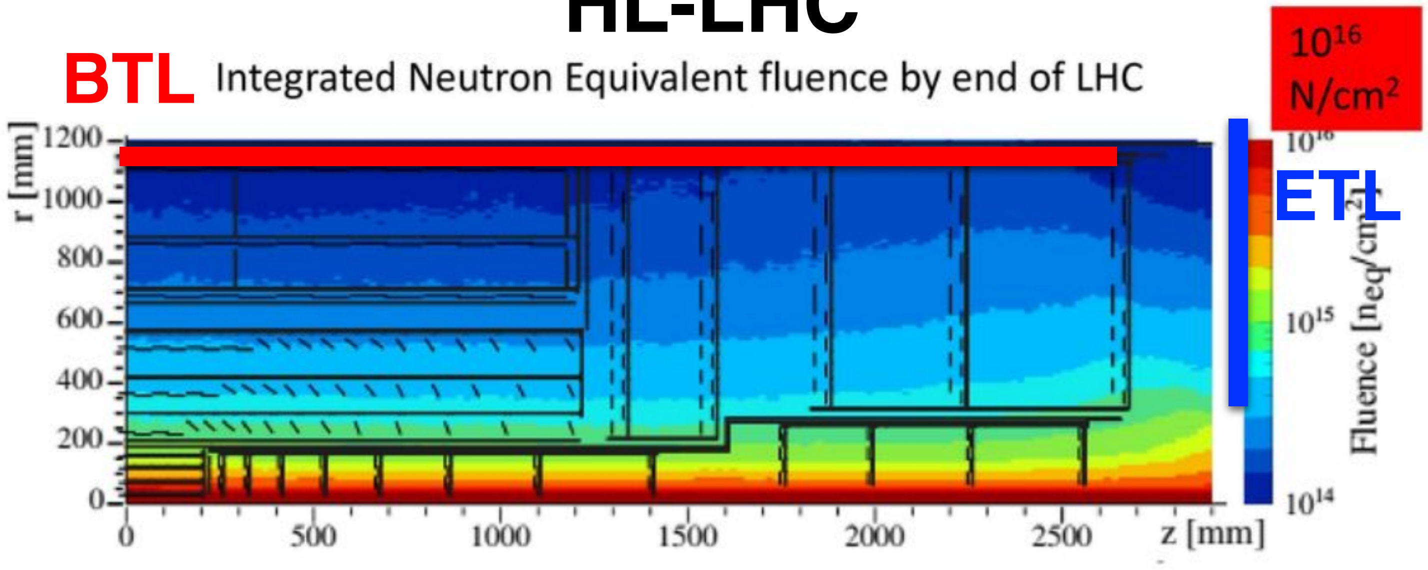
Radiation-hard (~ 2×10^{15} n_{eq}/cm^2), magnetic field tolerant (4 T), high DAQ rate (~ MHz)

Prototyping stage: 2020-2022

Total project cost: ~ $10M

Radiation environment: HL-LHC vs. EIC

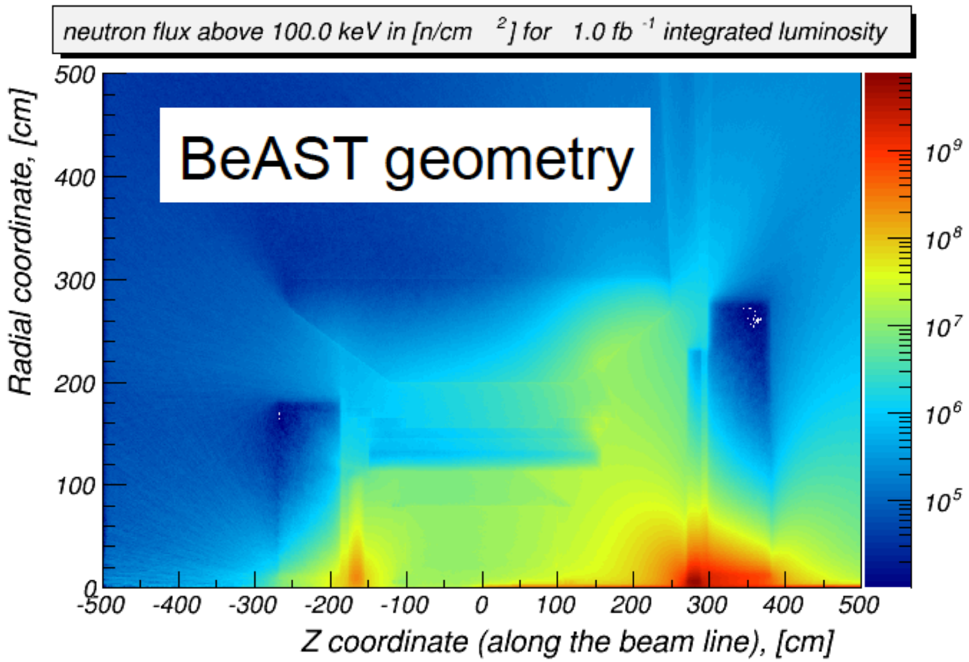
HL-LHC



~ 2×10^{14} n_{eq}/cm^2 for BTL

~ 2×10^{15} n_{eq}/cm^2 for inner radius of ETL

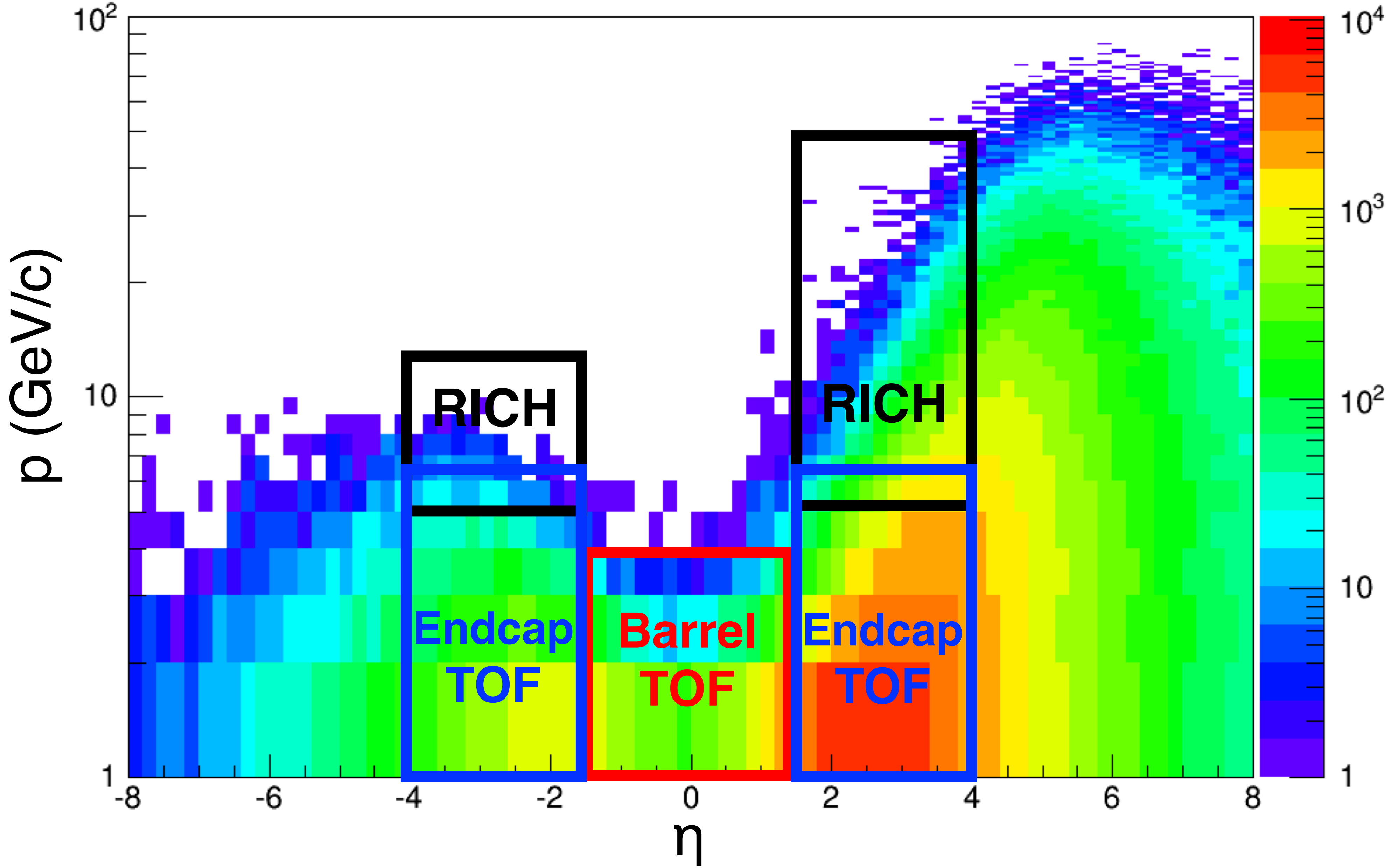
EIC



Up to 10^{11} n_{eq}/cm^2 over 10 y

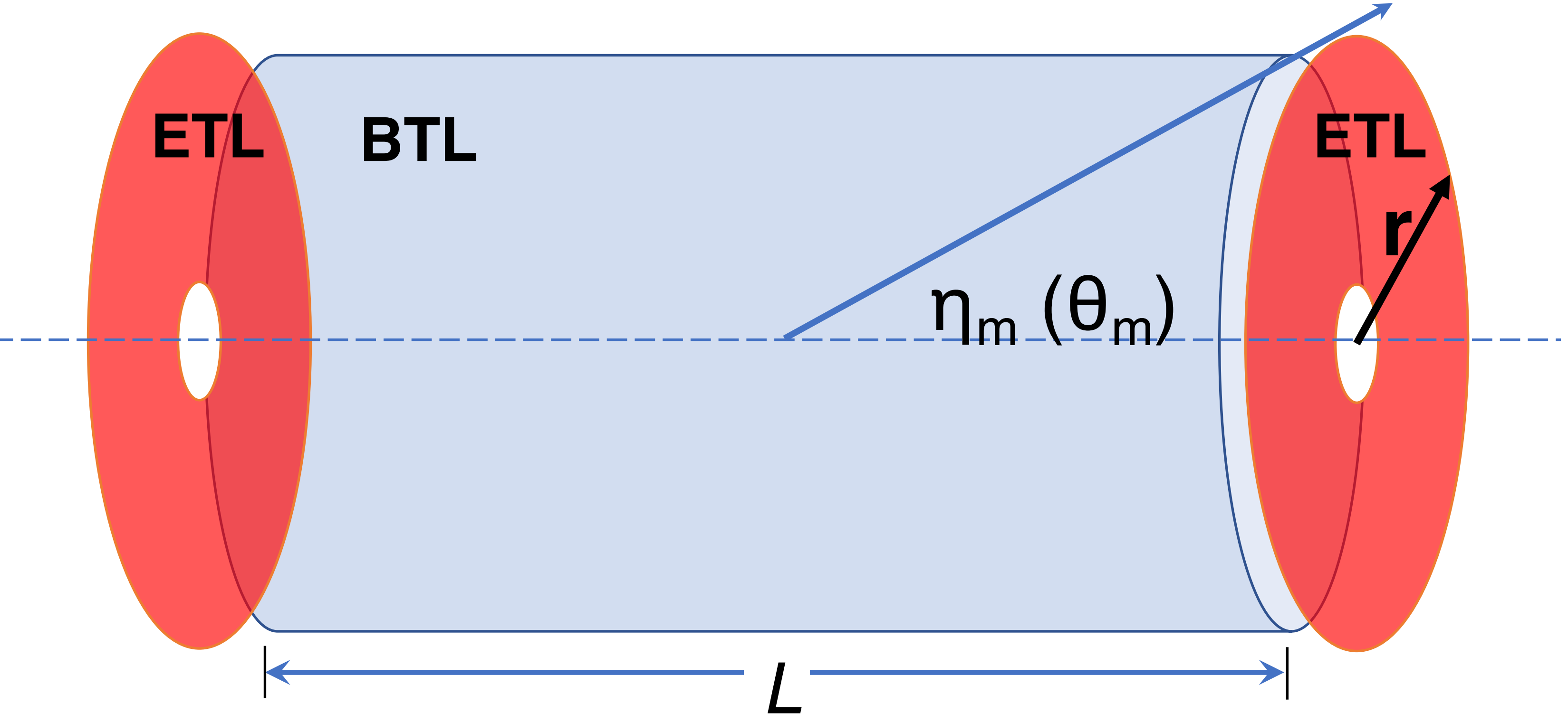
- No radiation-hard issue for EIC – good for the entire lifetime
- Optimizing for best time resolution is highest priority!

Phase space coverage for PID at EIC



A hermetic TOF system at EIC

- some genetic considerations



BTL to ETL area ratio:

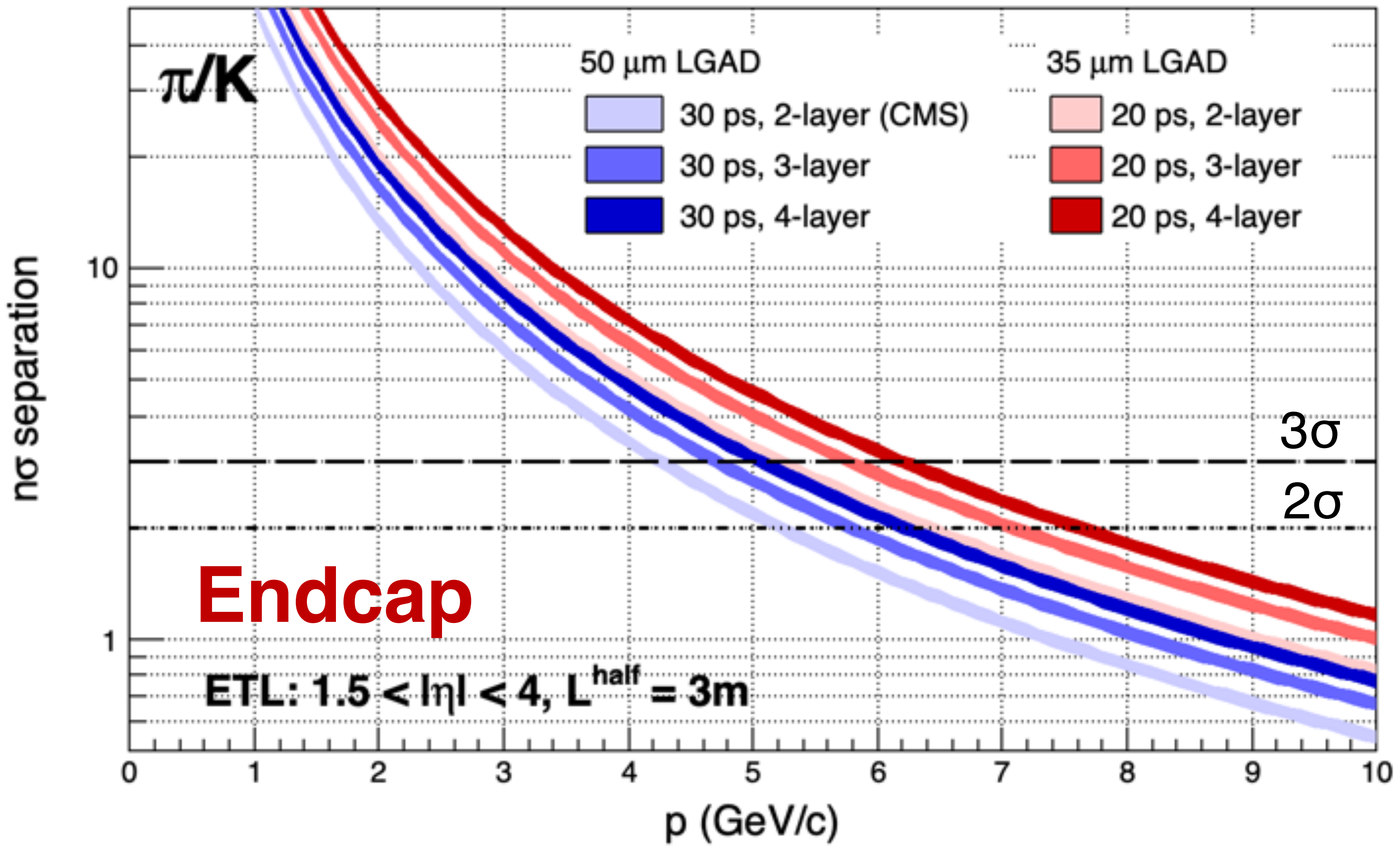
$$\frac{A_B}{A_E} = \frac{L}{r} = 2\sinh(\eta_m)$$

$$\begin{cases} 4.3, & \eta_m = 1.5 \\ 3.4, & \eta_m = 1.3 \\ 2.4, & \eta_m = 1.0 \end{cases}$$

With the same technology, BTL more costly than ETL

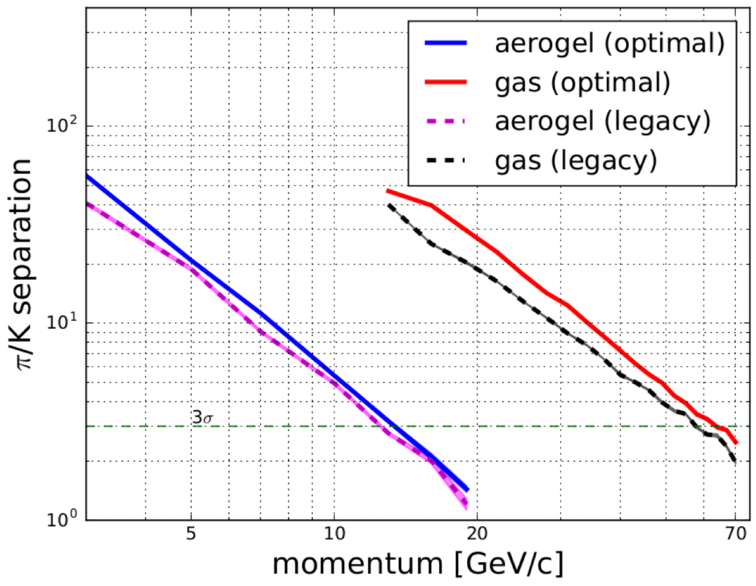
Consider a design case: η_m = 1.5; r = 1.4 m, L = 6 m (CMS-like)

Performance of a LGAD-TOF for EIC: Endcap



arXiv:1911.05797

dRICH

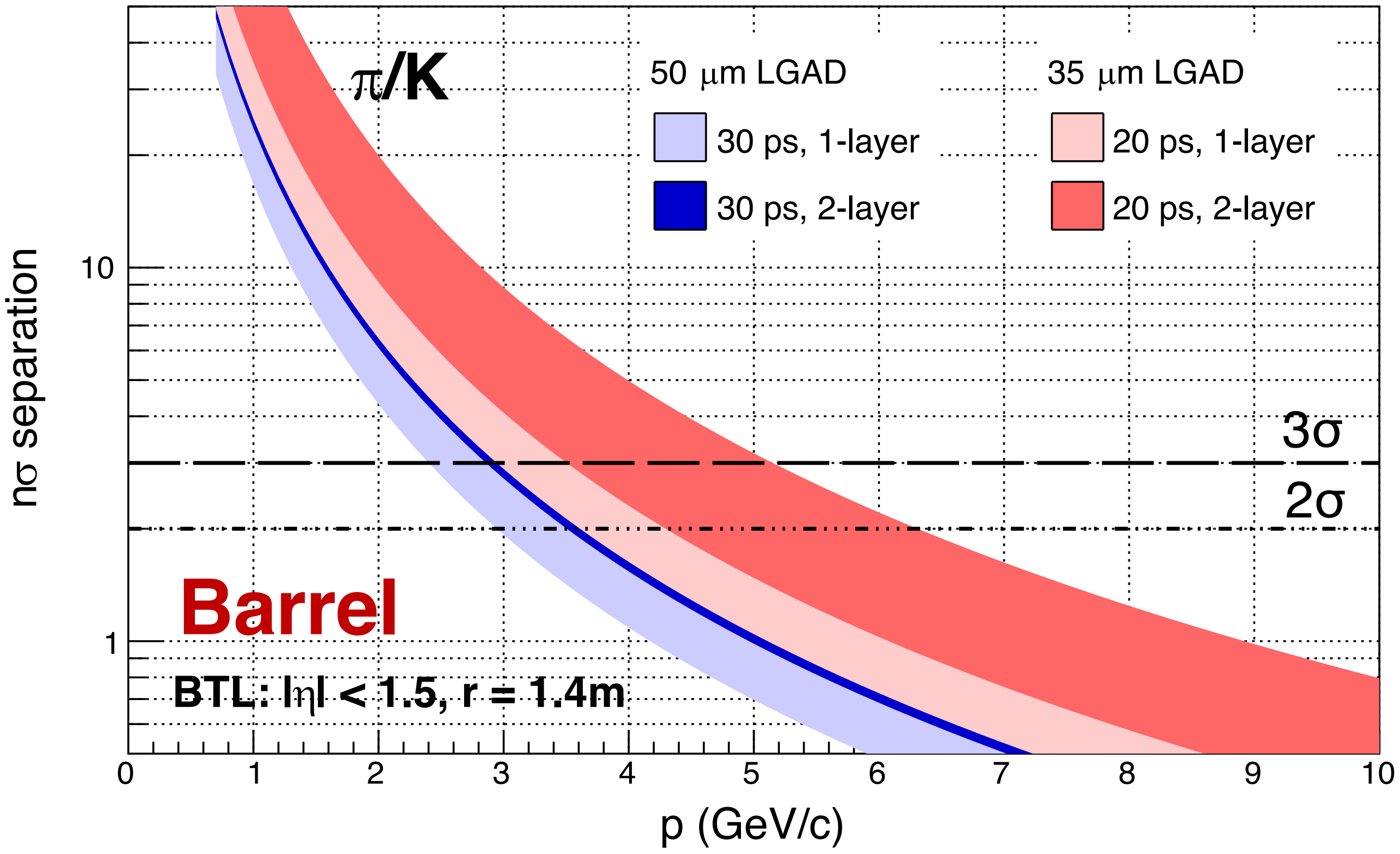


Cover p: 3-50 GeV/c

Coverage p up to 6-7 GeV/c for endcap ($1.5<|\eta|<4$)

- Thinner LGAD can further improve σ_T (not possible for CMS)
- Multi-layers (3-4) to improve σ_T and serve as tracker layers

Performance of a LGAD-TOF for EIC: Barrel



Coverage p up to ~ 4 GeV/c for barrel ($|\eta|<1.5$)

- Can more or less meet the requirement but likely more costly

Performance of a LGAD-TOF for EIC

EIC Detector Requirements

η	Nomenclature			Tracking			Electrons		π/K/p PID		HCAL	Muons
				Resolution	Allowed X/X_0	Si-Vertex	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Resolution σ_E/E	
-6.9 — -5.8	↓ p/A	Auxiliary Detectors	low-Q² tagger	$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV²								
…												
-4.5 — -4.0			Instrumentation to separate charged particles from photons				2%/√E					
-4.0 — -3.5												
-3.5 — -3.0		Central Detector	Backwards Detectors	$\sigma_p/p \sim 0.1\% \times p + 2.0\%$	~5% or less	TBD		π suppression up to 1:10⁴	≤ 7 GeV/c	≥ 3σ	~50%/√E	TBD
-3.0 — -2.5												
-2.5 — -2.0				$\sigma_p/p \sim 0.05\% \times p + 1.0\%$								
-2.0 — -1.5							7%/√E					
-1.5 — -1.0												
-1.0 — -0.5			Barrel	$\sigma_p/p \sim 0.05\% \times p + 0.5\%$		$\sigma_{xyz} \sim 20$ μm, $d_0(z) \sim d_0(r\phi) \sim 20/p_T$ GeV μm + 5 μm	(10-12)%/√E		≤ 5 GeV/c		TBD	
-0.5 — 0.0												
0.0 — 0.5												
0.5 — 1.0												
1.0 — 1.5			Forward Detectors	$\sigma_p/p \sim 0.05\% \times p + 1.0\%$		TBD			≤ 8 GeV/c		~50%/√E	
1.5 — 2.0												
2.0 — 2.5									≤ 20 GeV/c			
2.5 — 3.0				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$								
3.0 — 3.5									≤ 45 GeV/c			
3.5 — 4.0	↑e	Auxiliary Detectors	Instrumentation to separate charged particles from photons									
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								

Table 2: Physics requirements for a an EIC detector

LGAD

LGAD

Possible but may be costly

PID+tracker layers

[Electron-Ion Collider Detector Requirements and R&D Handbook]

R&D paths and plan: ~1-2 years

Baseline: leverage HL-LHC R&D as much as possible
(e.g., same ASIC design save huge efforts and cost)

INFN Torino

Test thinner 35 μm LGAD
→ 20 ps time resolution

AC-coupled LGAD R&D
→ increase fill factor, granularity, cost reduction

Collaboration with FNAL/Torino CMS groups and possibly eRD24 (?)

- Implement simulations for optimizing geometry, layout etc.
- Cost optimization (e.g., no need of rad-hard components?)

Summary

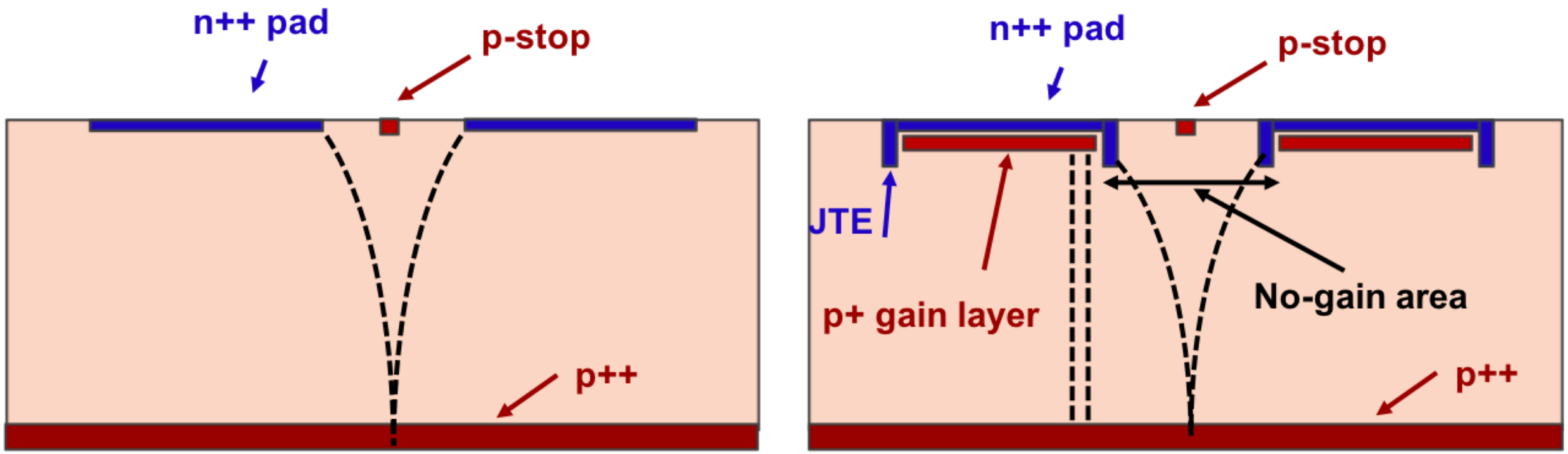
The case of a LGAD-based TOF for EIC

- Excellent time resolution ($\leq$ 20-30 ps)
- High granularity (esp. AC-coupled): tracker layers + heavy flavor reco.
- Highly compact: ~ 2 cm/layer, flexible for system integration
- Very rad-hard: good for the entire EIC lifetime
- Sustain high readout rate
- Stable calibration: crucial for prompt reconstruction

Cost is well understood and lots of room for optimization as the technology becomes mature and by leveraging HL-LHC R&D

Workforce being established (CMS/ALICE HI groups, FNAL, Torino etc.) and hope to grow stronger collaboration

Backups



a) Traditional Silicon detector **b) UFSD**

$$\sigma_t^2 = \sigma_{\text{Jitter}}^2 + (\sigma_{\text{Total ionization}} + \sigma_{\text{Local ionization}})^2 + \sigma_{\text{Distortion}}^2 + \sigma_{\text{TDC}}^2.$$

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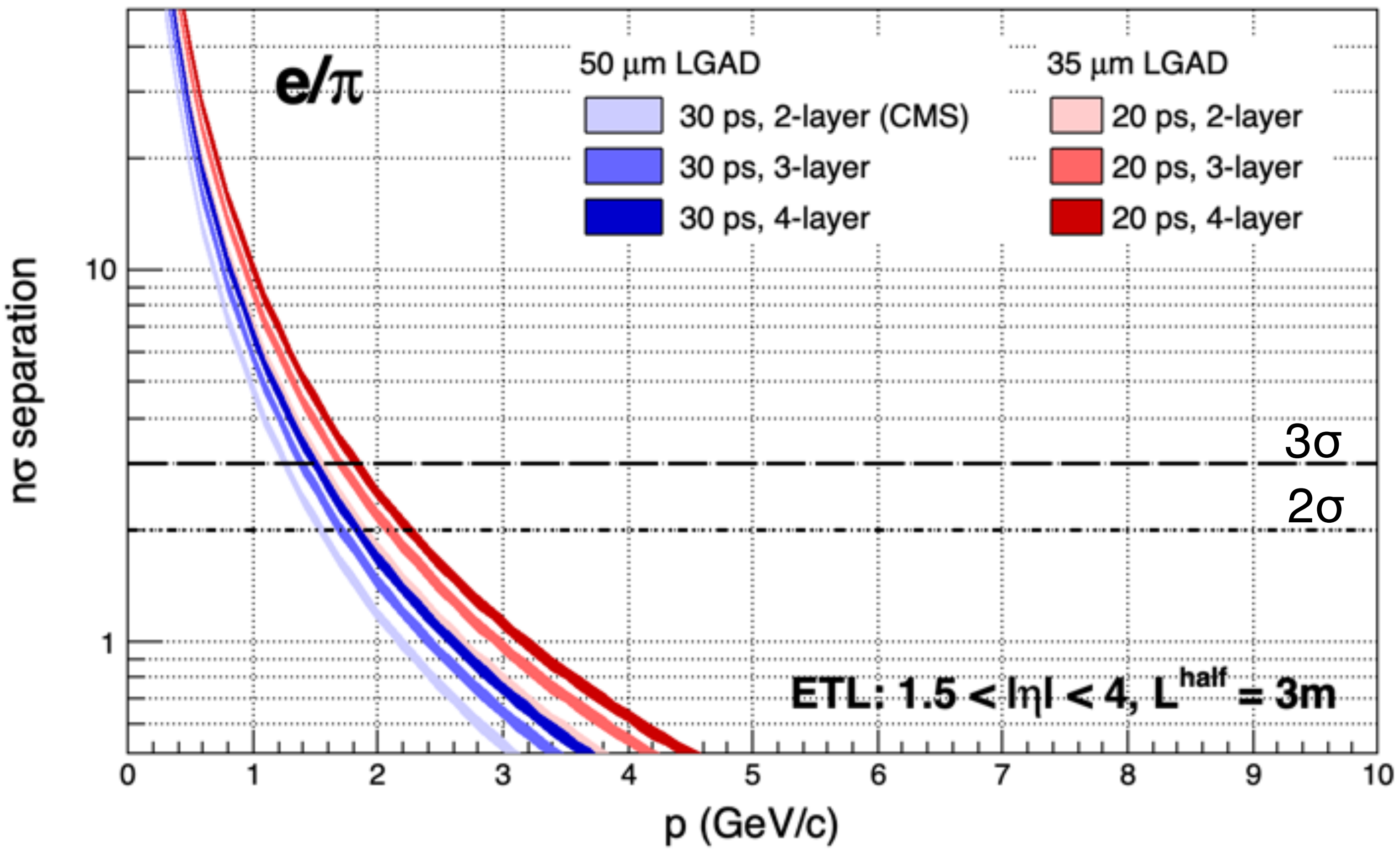
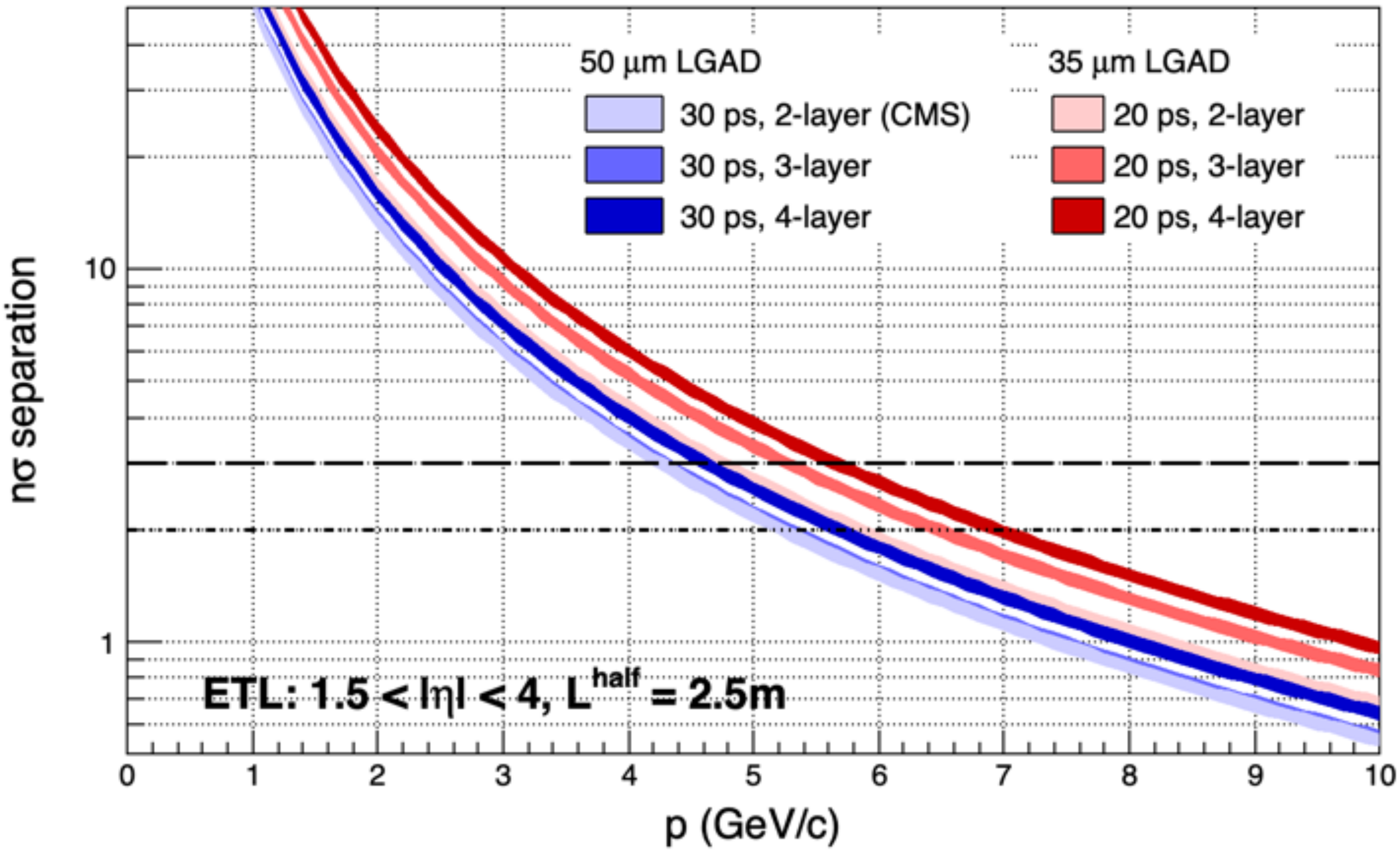


Electron ID up to p ~ 1.8-2 GeV/c


50 μm LGAD
30 ps, 2-layer (CMS)
30 ps, 3-layer
30 ps, 4-layer
35 μm LGAD
20 ps, 2-layer
20 ps, 3-layer
20 ps, 4-layer
ETL: 1.5 < lηl < 4, L^half = 2.5m
nσ separation
p (GeV/c)
10
1
0
1
2
3
4
5
6
7
8
9
10

Study of heavy flavor hadronization with ep/eA collisions