Considerations of TOF/tracking with LGADs at EIC

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RICE

1st LGADs consortium meeting
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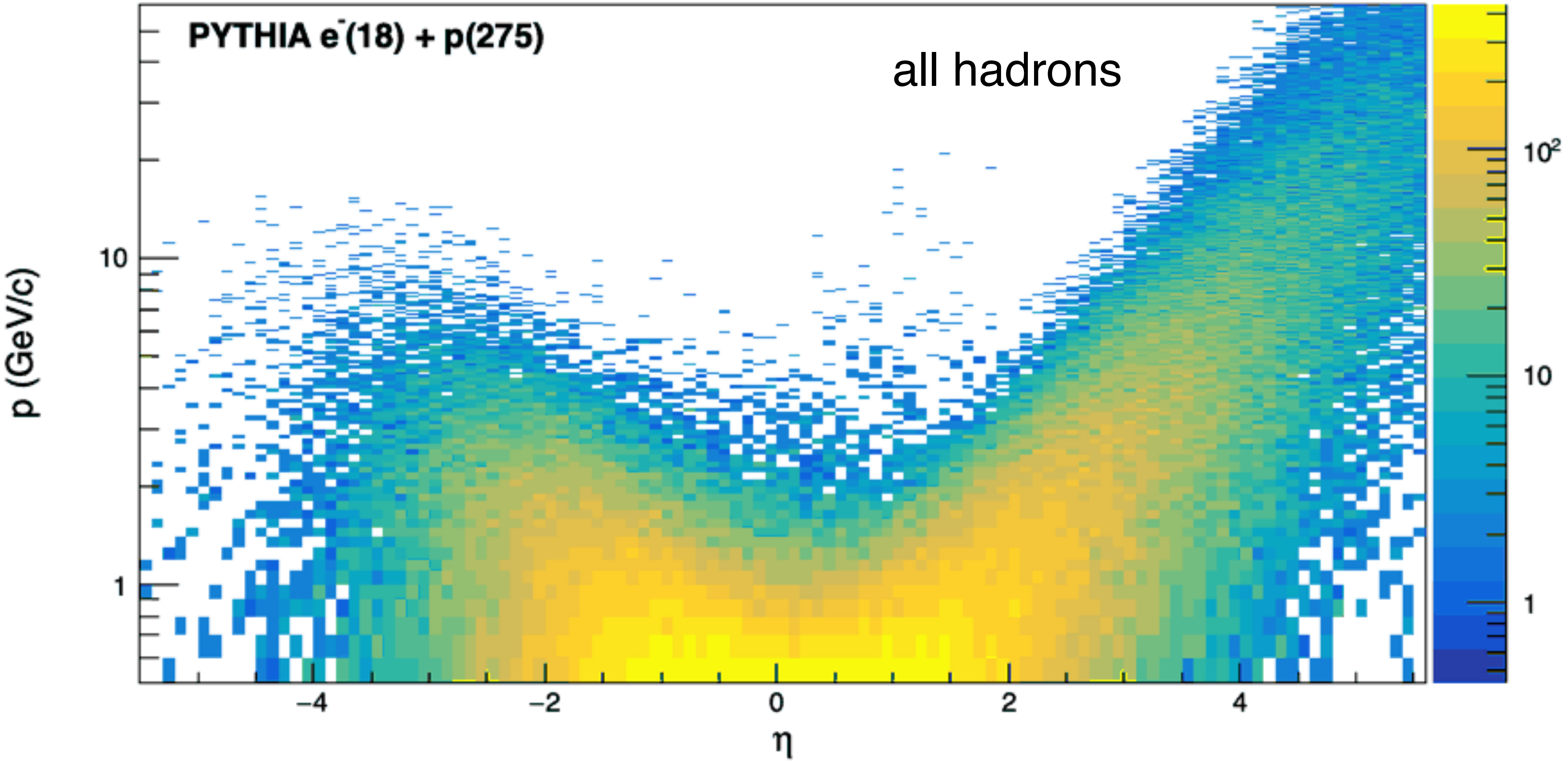
Particle identification (PID) at EIC

Physics:

- SIDIS
- Heavy flavor
- **Collectivity**
- …



	Backward (-4<η<-1.5)	Central (|η|<1.5)	Forward (1.5<η<4)
Low *p* (<3 GeV)	TOF	TOF, TPC, DIRC	TOF
Intermediate *p* (3-8 GeV)	TOF, RICH	TOF, DIRC	TOF, RICH
High *p* (8-50 GeV)			RICH

EIC Handbook; PID YR WG; R&Ds at eRD6 and 14

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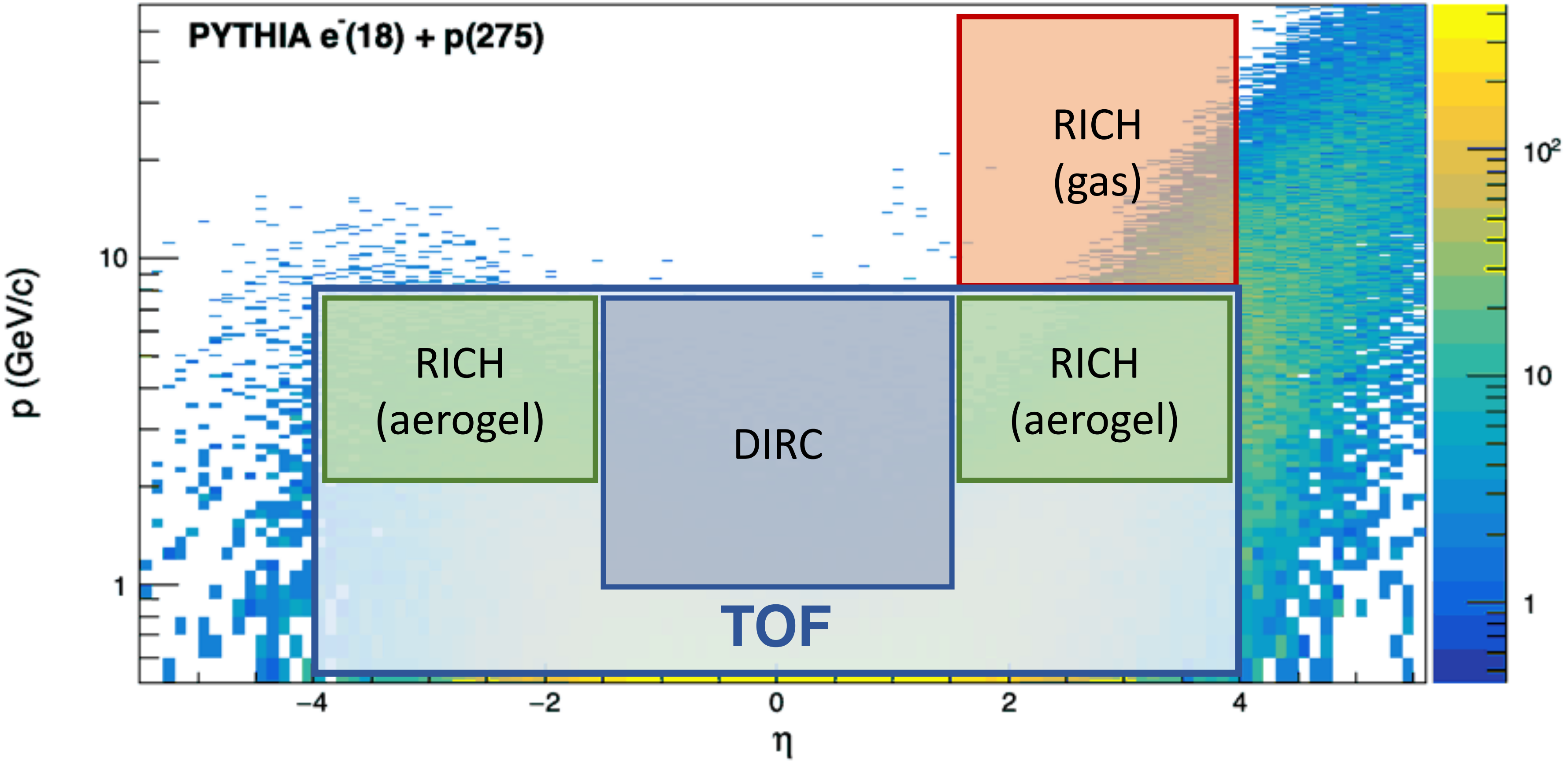

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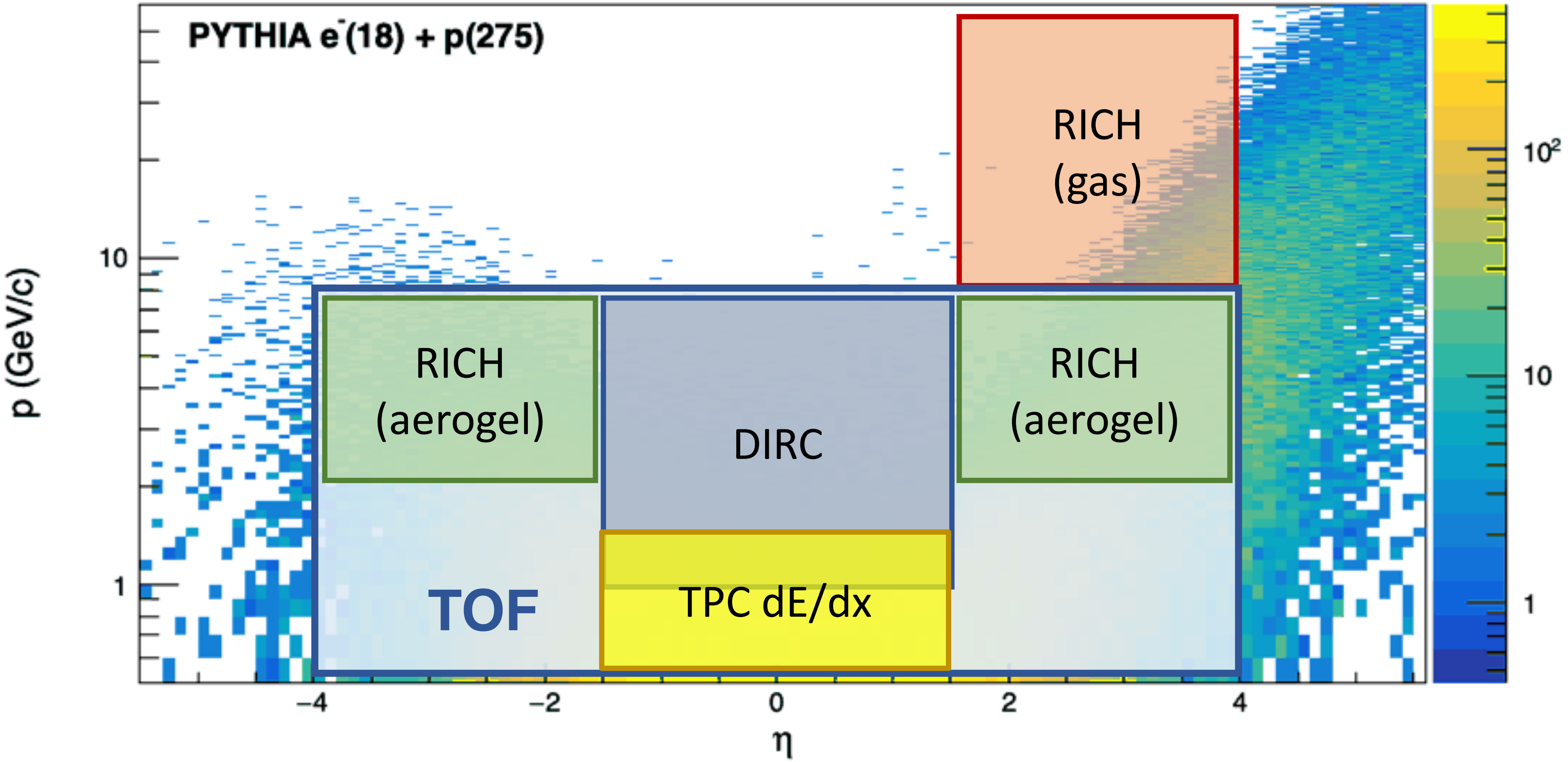

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Particle identification (PID) at EIC – TOF

TOF-PID depends on time resolution and flight distance

(b) Complementarity of different TOF technologies

	LGADs	MRPC	LAPPD
Time resolution	20ps	20 ps	5ps
Spatial resolution	a few to hundreds μm	a few mm to 1 cm	1 mm
Overall thickness	2cm	10cm	2cm
High B field tolerant	Yes	Yes	No
Cost	High	Low	High

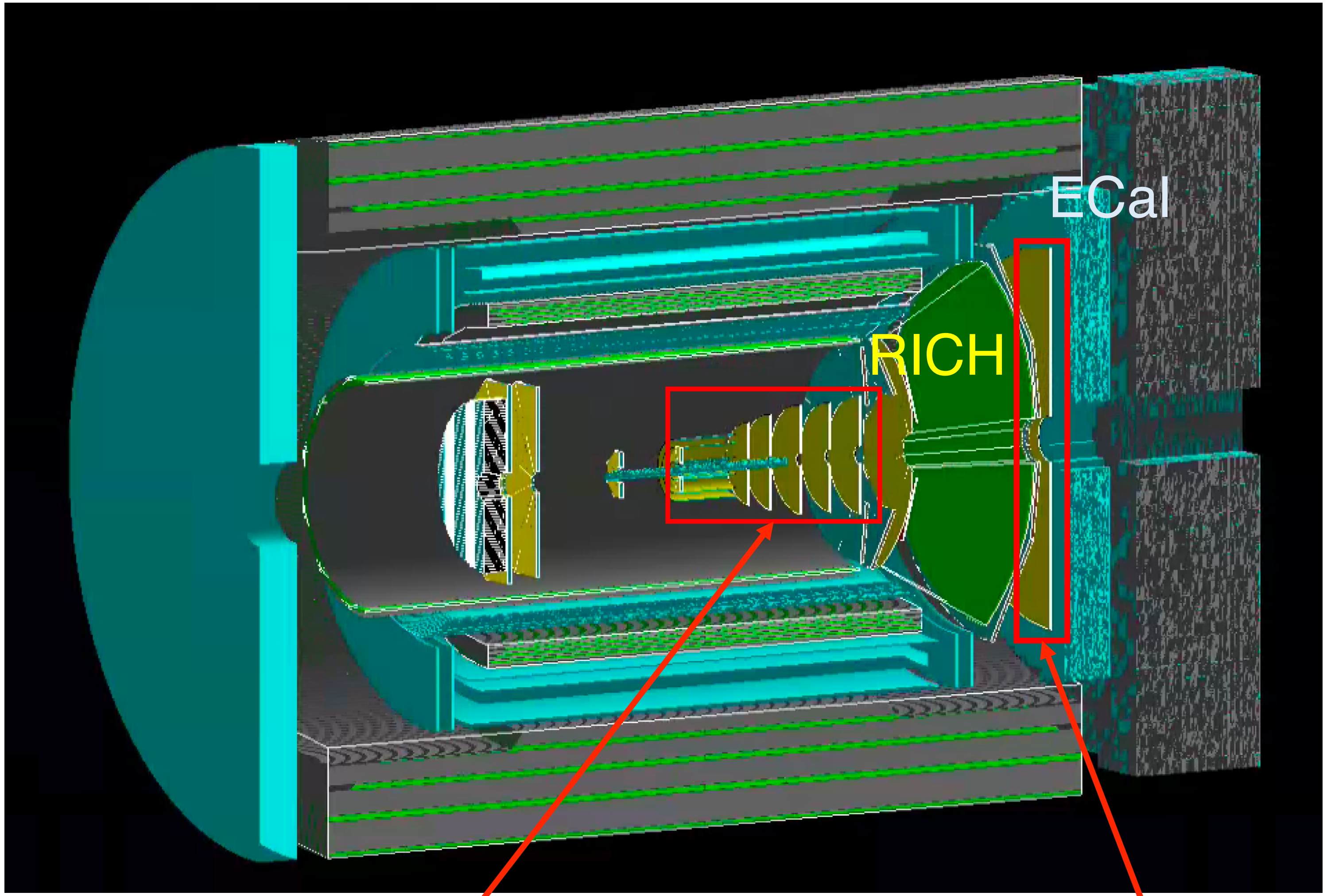
LGADs:

- Potential to combine TOF and (partially) tracker in one system
- Lots of R&Ds at the HL-LHC to synergize

Rough cost estimate (based on CMS ETL): ~ total of $10 M for 15 m^2

Performance studies based on Fun4All from sPHENIX

as an example



Silicon tracker
(Barrel + Forward from LANL)

LGAD TOF

Focus on forward for now!

Detector setup

Barrel	Radius (cm)	Z range (cm)	η range	Pitch size (μm)
Layer 1	3.64	(-20, 20)	(-2.4, 2.4)	20
Layer 2	4.81	(-20, 20)	(-2.1, 2.1)	20
Layer 3	5.98	(-25, 25)	(-2.1, 2.1)	20
Layer 4	16	(-25, 25)	(-1.2, 1.2)	36.4
Layer 5	22	(-25, 25)	(-1.0, 1.0)	36.4

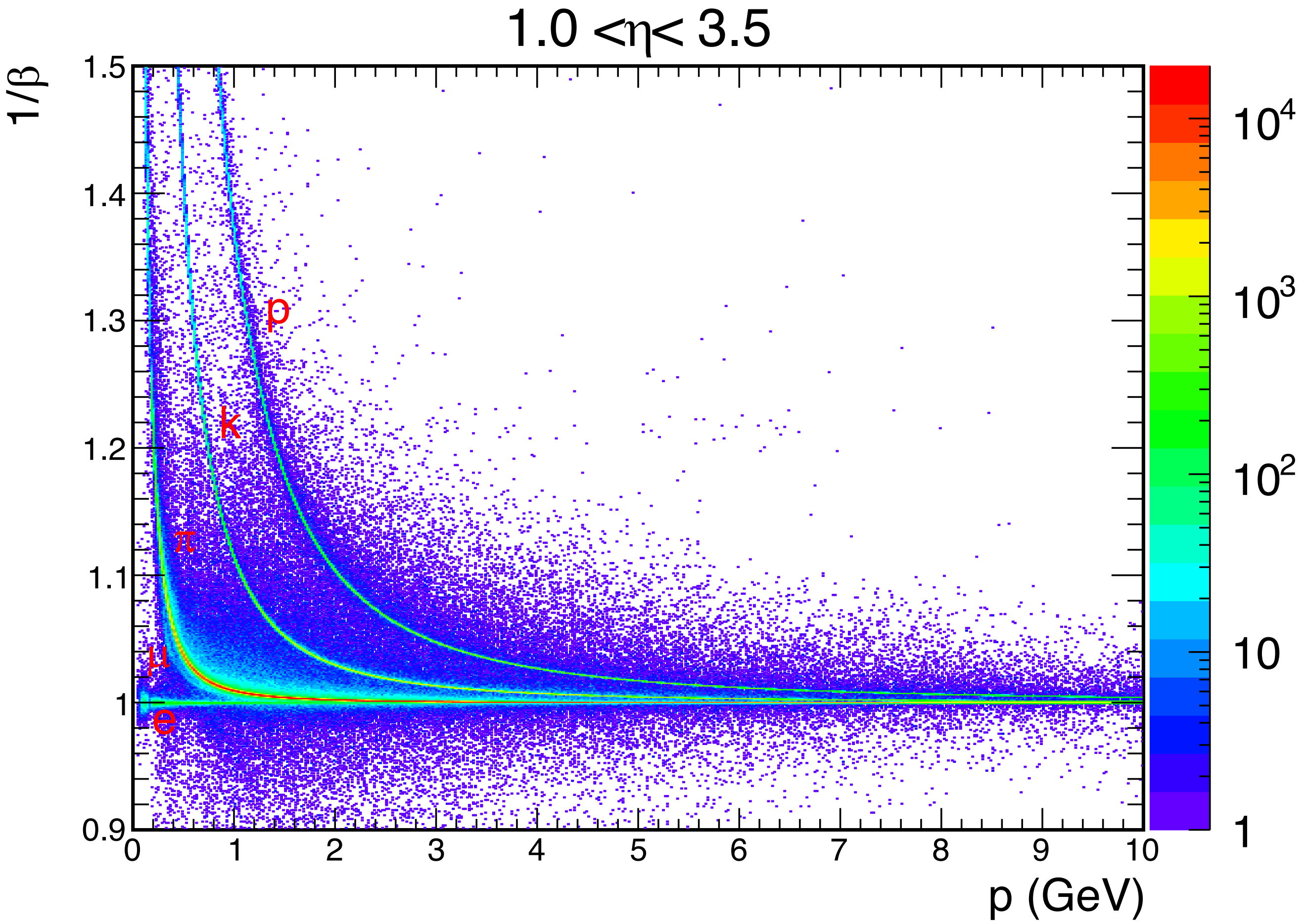
Forward	Radius (cm)	Z position (cm)	η range	Pitch size (μm)
Layer 1	(4.0, 25)	35	(1.1, 2.9)	20
Layer 2	(4.5, 42)	62.3	(1.2, 3.3)	20
Layer 3	(5.2, 43)	90	(1.5, 3.6)	20
Layer 4	(6.0, 44)	115	(1.7, 3.7)	36.4
Layer 5	(6.5, 45)	125	(1.8, 3.7)	36.4
LGADs-TOF	**(15, 141)**	**280**	**(1.4, 3.6)**	**TBD**

LGADs time resolution: 20 ps/layer with ultra-thin sensors (e.g., 25μm) ($1/\sqrt{2}$ if double layers)

Using LGADs for Layer 1-5 in sPHENIX config. do not help TOF-PID because of too short flight distance

$1/\beta$ vs. p

Pythia6: e (10 GeV) + p (250 GeV)



➢ Velocity with ONLY pathlength uncertainty

- non-negligible effect from tracking

$1/\beta$ vs. p

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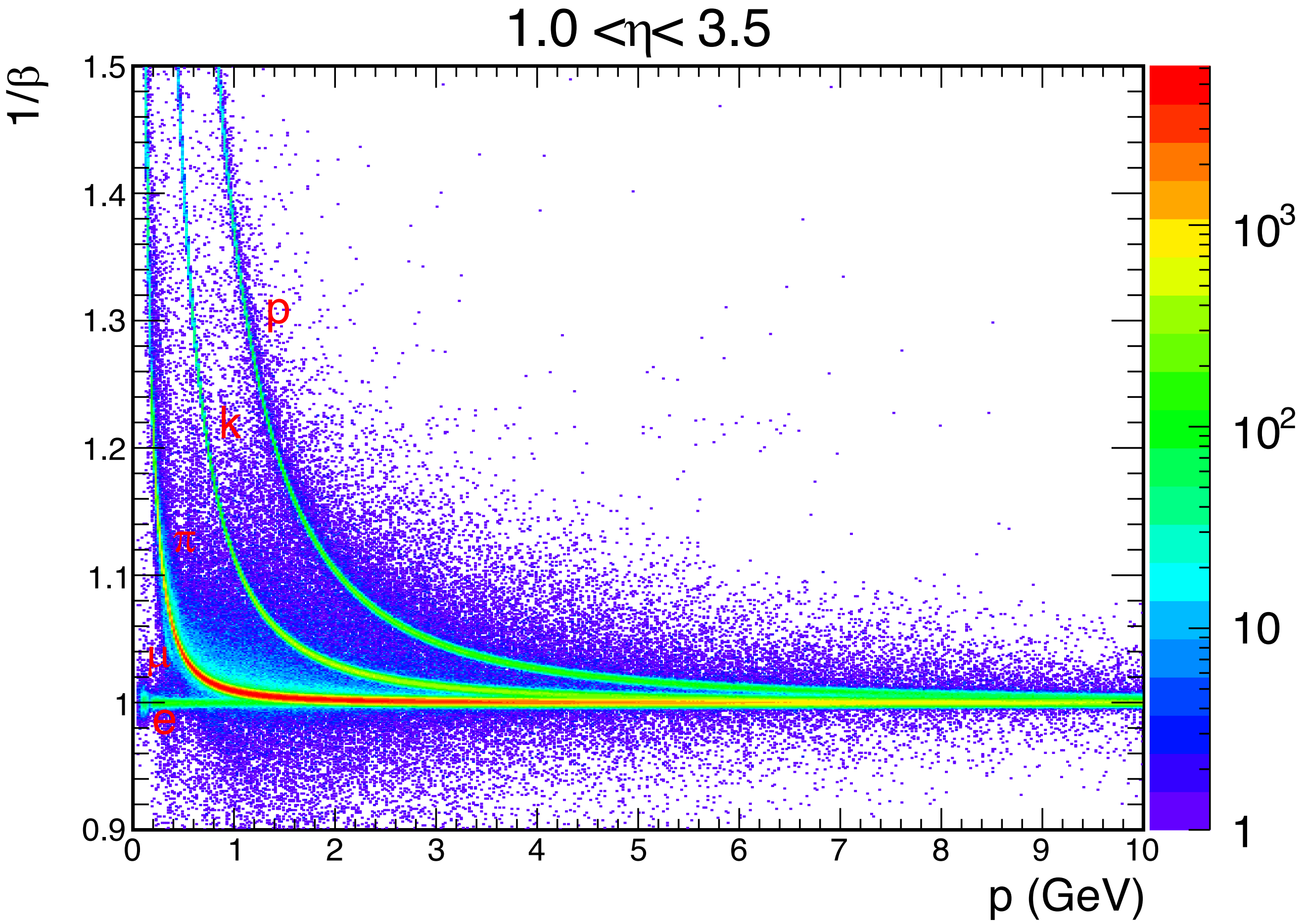


➢Velocity with pathlength and timing (two layers, $20/\sqrt{2}$ ps) uncertainty

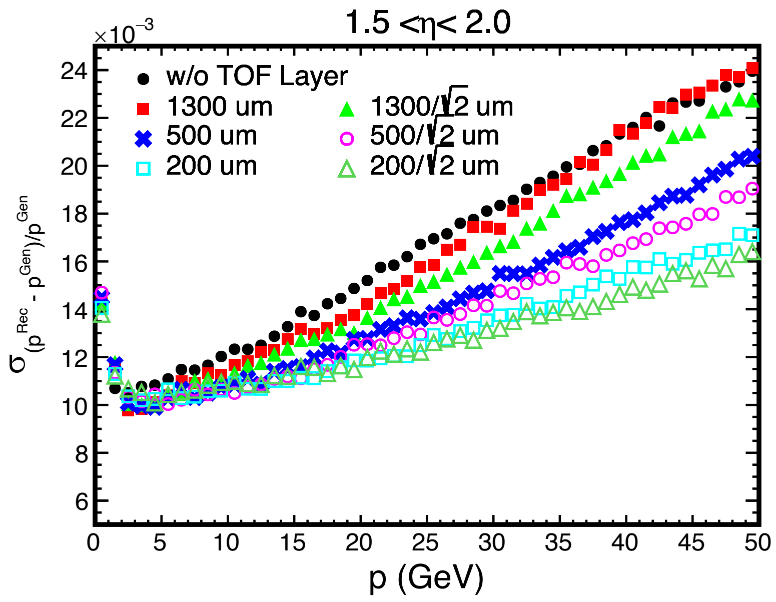
- π/k separation: 0.1~4-5 GeV; k/p separation: 0.1~7-8 GeV
- No start-time (T_0) contribution

Tracking performance with LGADs-TOF layer(s)

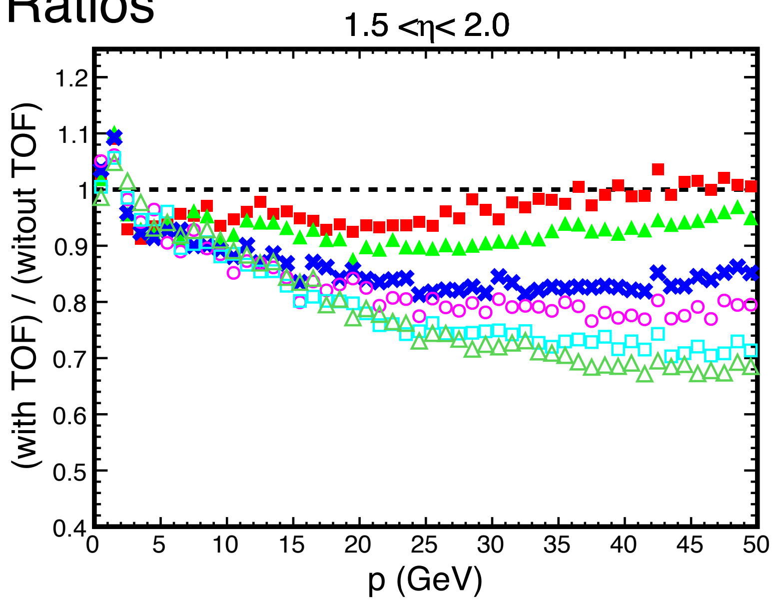
- Particle gun
  - Pion with flat p_T : 0.1 – 20 GeV
  - $1.5 < \eta < 3.5$
- Spatial resolution: (pitch size) / $\sqrt{12}$
  - 1300 μm: CMS/ATLAS timing layer
  - 500 μm: optimistically achievable
  - 200 μm: requires significant R&D esp. on ASICs

  (1/$\sqrt{2}$ if double layers)

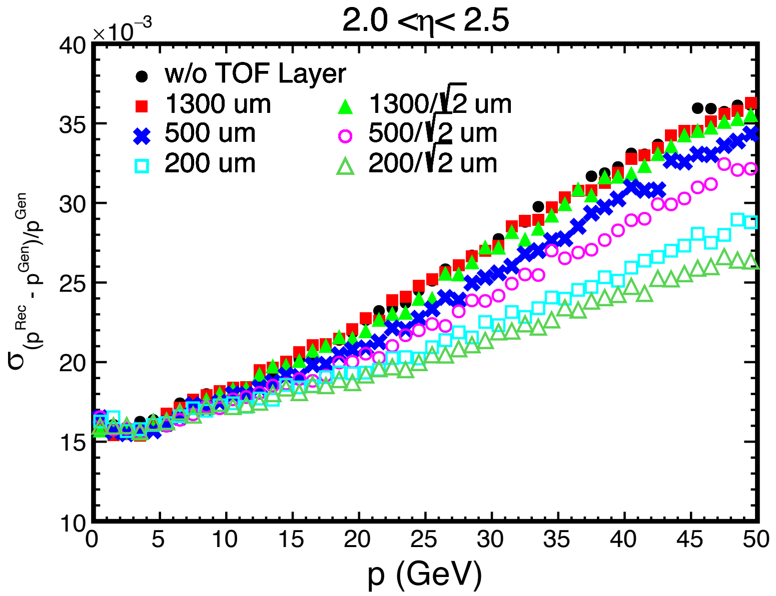
Track p_T resolution with pion guns

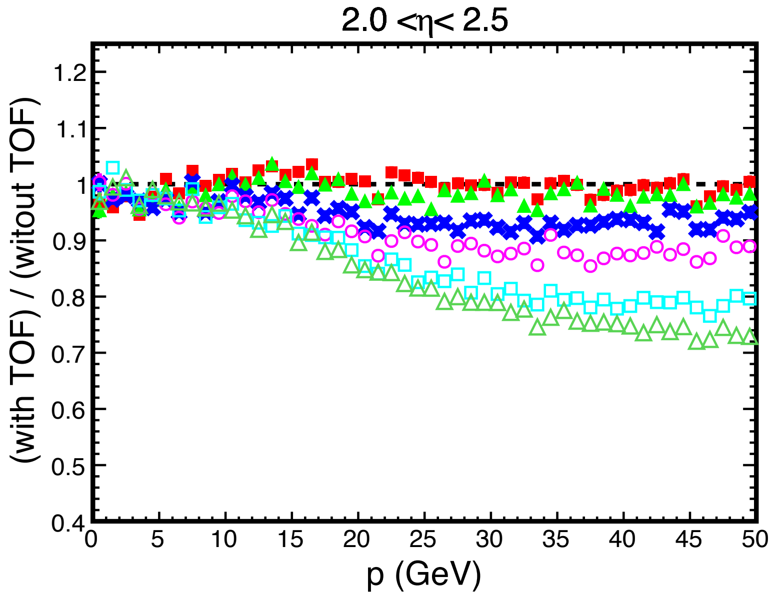


Ratios

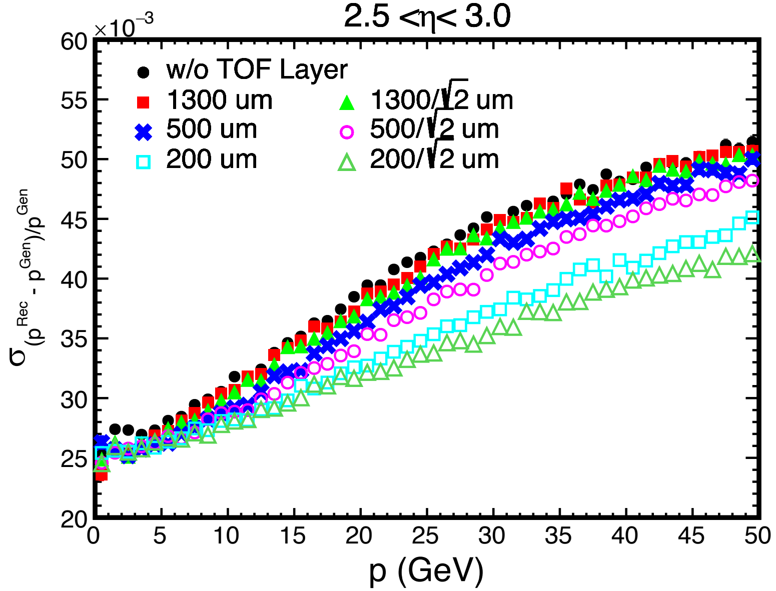


1.5<η<2:
~ 50% of disk area

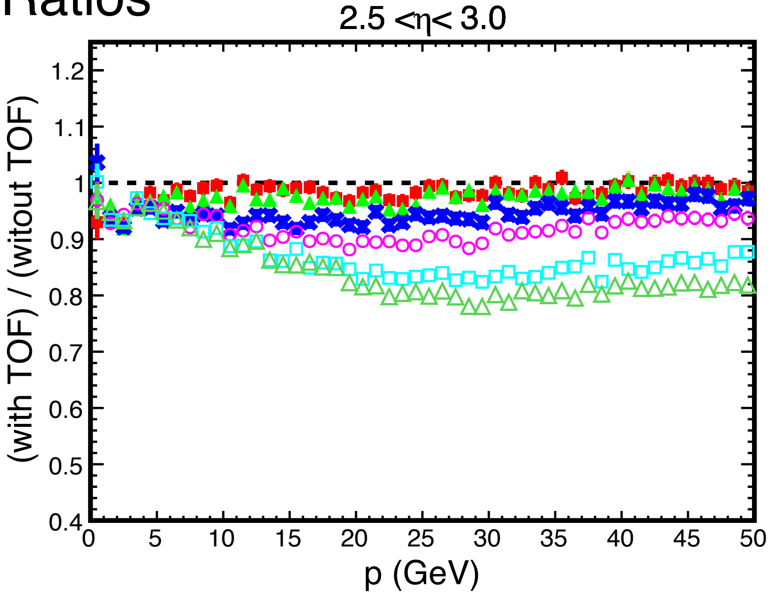


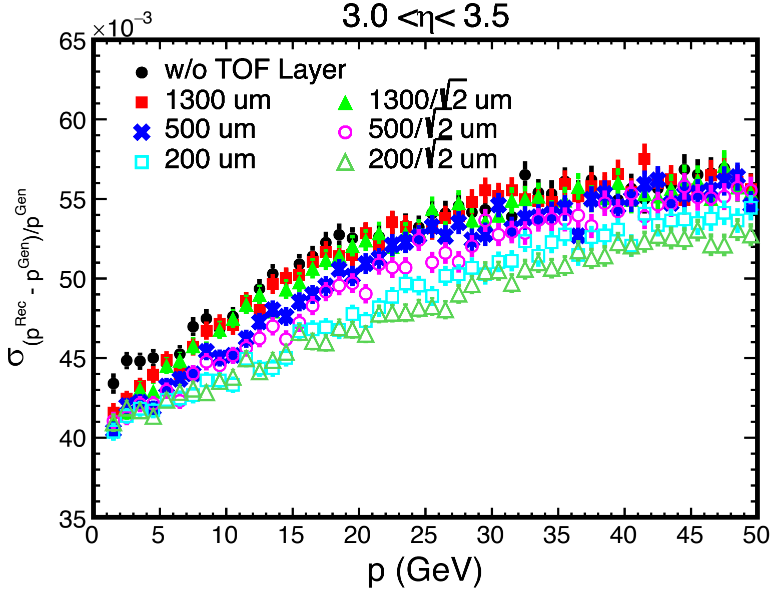


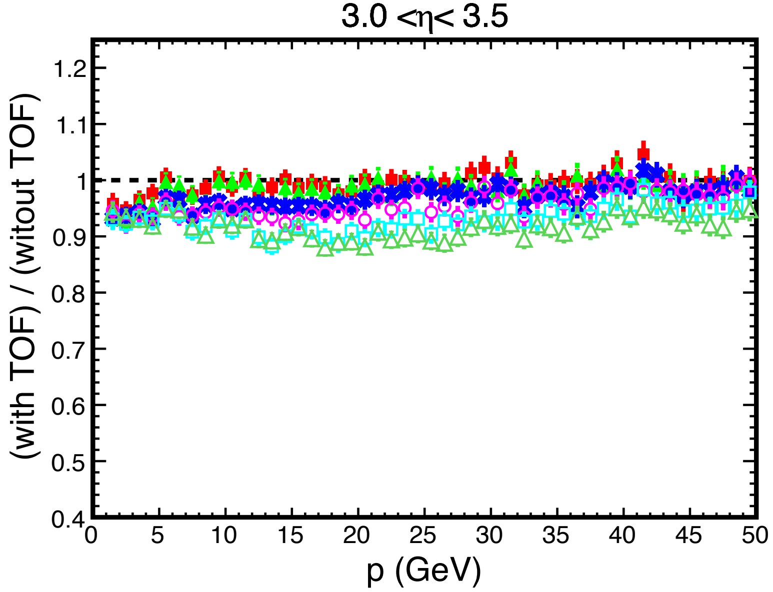
Track p_T resolution with pion guns



Ratios







Conclusion and next steps

Considered design of all silicon tracker + outmost LGADs layers (4-D)

(i) LGADs for TOF-PID

- Single-layer time resolution of ~20 ps (total) required
- Performance dominated by farthest layer(s): L > ~3 m is desired in forward
- Path length uncertainty non-negligible: coupled with the tracker

(ii) LGADs for tracking (at outer layers)

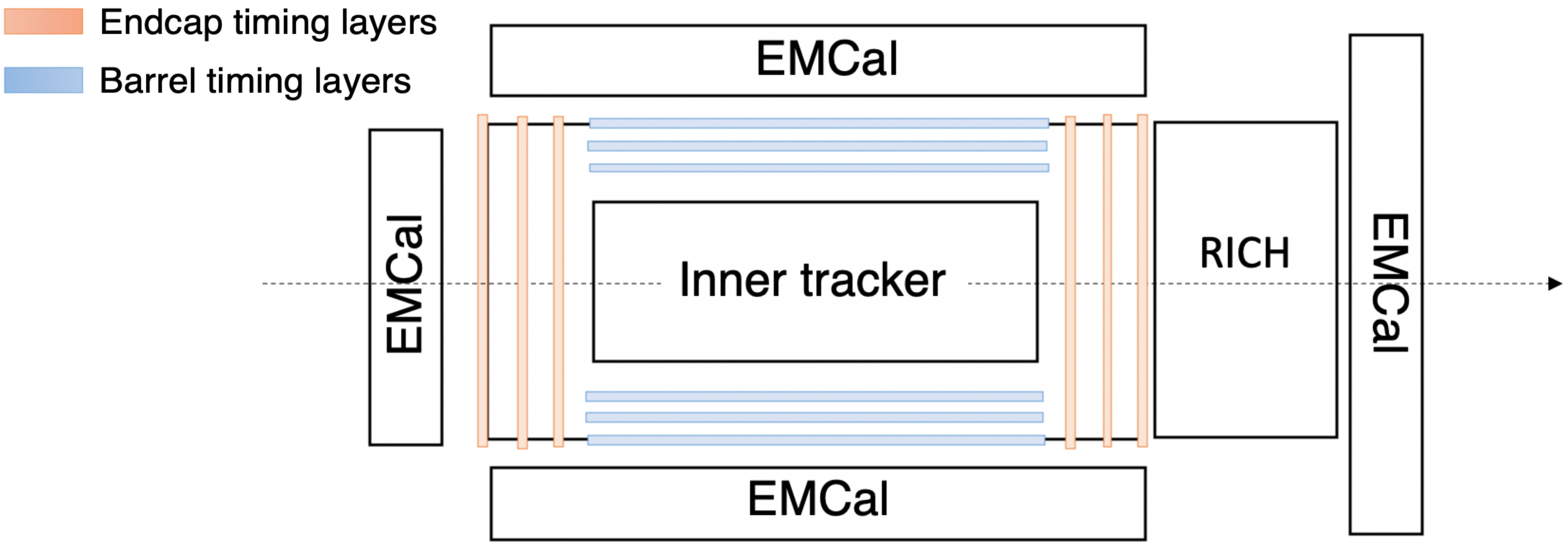
- Standard pitch size (1.3x1.3 mm^2) does not degrade $\sigma(p_T)$
- Pitch size of 0.5x0.5 mm^2 to 0.2x0.2 mm^2 can improve high p_T $\sigma(p_T)$ by 10-20%
- Effect on track impact parameter to be investigated

Toward a full 4π (cost-effective) design of LGADs-TOP

- Backward kept similar to Forward but no need of finer pitch size
- Mid-rapidity?
  - r > 1.5m desired: is there enough space?
  - Larger area to cover: can we afford it?

Backups

TOF-tracker PID with LGADs at EIC

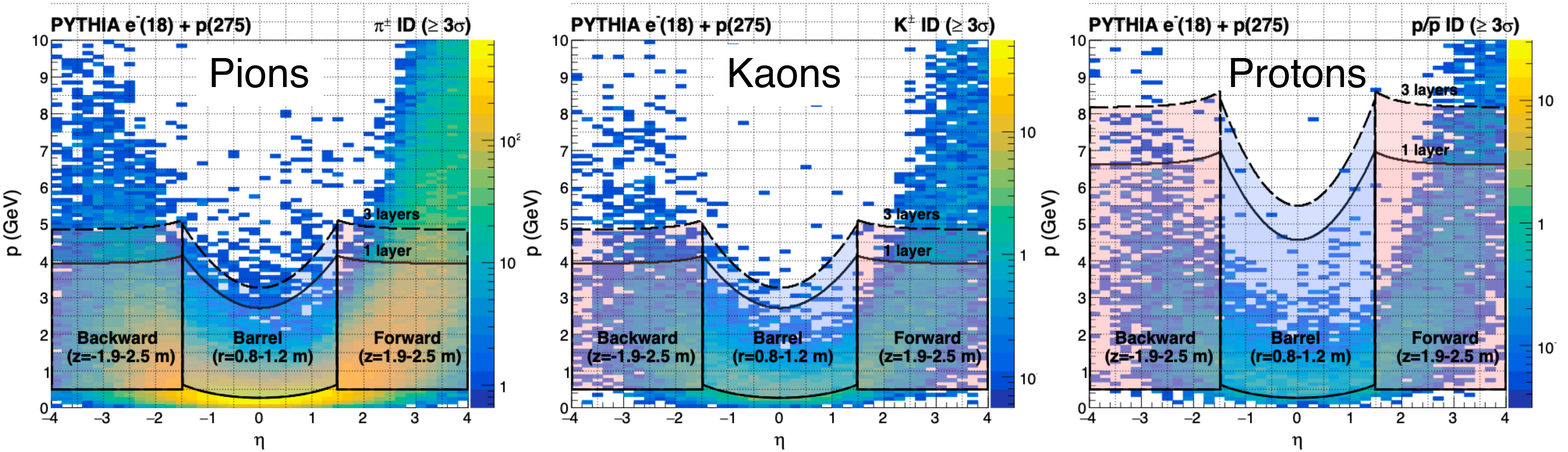


Timing layers outside inner tracker as both TOF and outer tracker

- presently not considering timing layers for the inner tracker due to too short flight distance and the requirement of low material budgets

TOF-tracker PID with LGADs at EIC

- Time resolution: σ_T = 20 ps / layer
- Flight distance: L_{half} ~ 2 m, r ~ 1m



Cover a wide phase space of PID required at the EIC

EIC Detector Requirements

Table 2: Physics requirements for a an EIC detector

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-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 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 1:10^4	≤ 7 GeV/c	≥ 3σ	~50%/√E	
-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	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	$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								

Electron-Ion Collider Detector Requirements and R&D Handbook