Ultra-fast silicon (LGADs) for EIC detectors

Wei Li (Rice University)

for the LGADs consortium

ECCE workshop
February 11, 2021

LGADs consortium

– collaborative efforts on application of ultra-fast silicon for future HEP/NP detectors

- **EOI for EIC as a first cornerstone (LINK)**
  - 14 Institutes: ANL, BNL, OMEGA, FNAL, IFJ PAN, IJLAB, LANL, MIT, ORNL, Rice, Stonybrook, UCSC, UIC, KU
- **Interests in different detector concepts**
  - TOF, (4D) Tracker, Roman Pots, Preshower
- **Organize by areas of expertise/interest**
  - Physics Performance and Design
  - Silicon sensors
  - Front-end Electronics
  - System Design, Mechanics and Engineering
- **Meetings:** https://indico.bnl.gov/category/323/

Expression of Interest (EOI):
Fast timing silicon detectors for EIC detectors

LINK

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- Argonne National Lab (ANL)
- Brookhaven National Lab (BNL)
- Organisation de Micro-Électronique Générale Avancée (OMEGA), Ecole Polytechnique
- Fermi National Lab (FNAL)
- Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN)
- Laboratoire de Physique des 2 Infinis Irène Joliot Curie (IJCLAB)
- Los Alamos National Lab (LANL)
- Massachusetts Institute of Technology (MIT)
- Oak Ridge National Lab (ORNL)
- Rice University (Rice)
- Stonybrook University (Stonybrook)
- University of California, Santa Cruz (UCSC)
- University of Illinois, Chicago (UIC)
- University of Kansas (KU)

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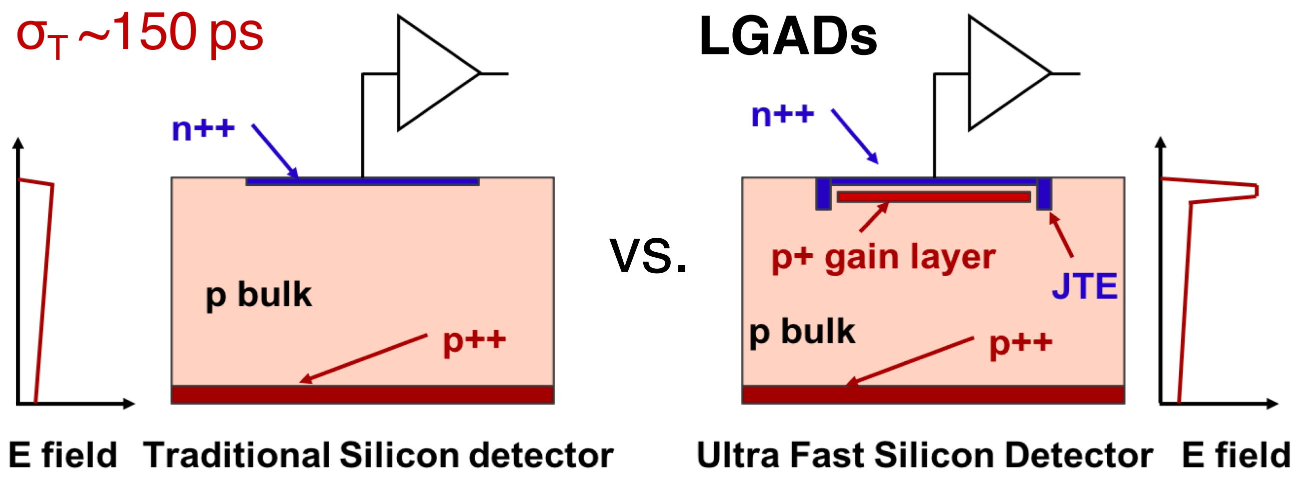
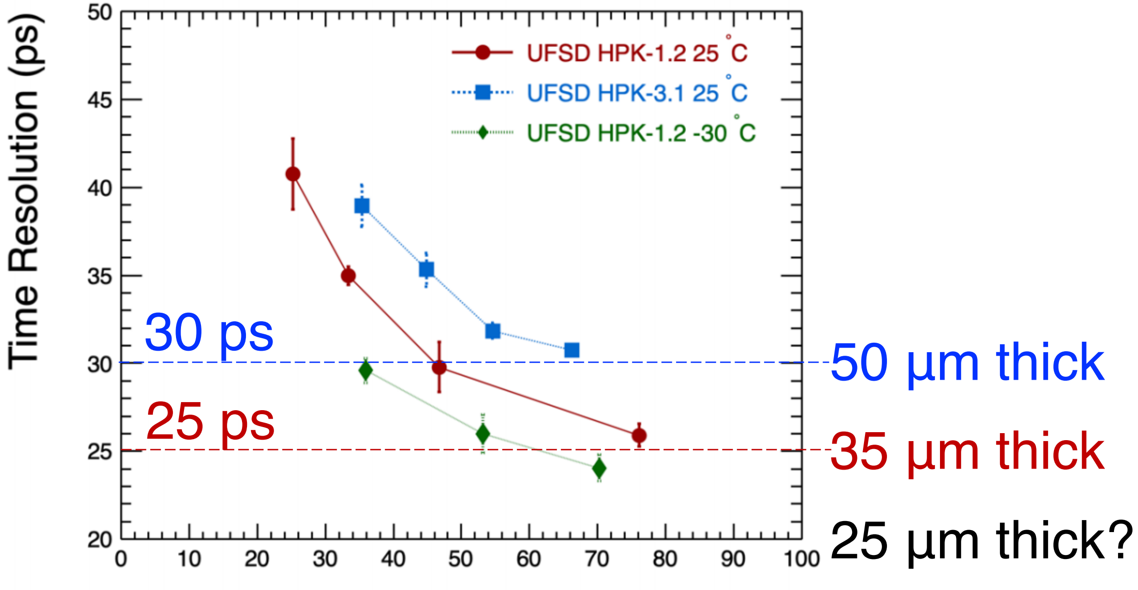
You are welcome to join!

Low-gain avalanche diodes (LGADs)



Internal gain layer

LGADs timing performance

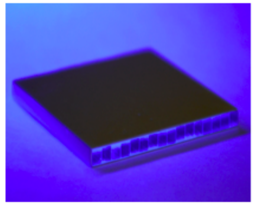


ANL/UCSC, arXiv:2010.02499

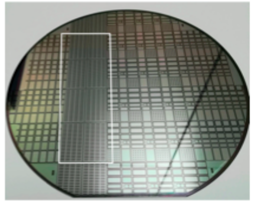
R&Ds for EIC aiming to achieve
σ_T ~ 20 ps with 20-25 μm sensors

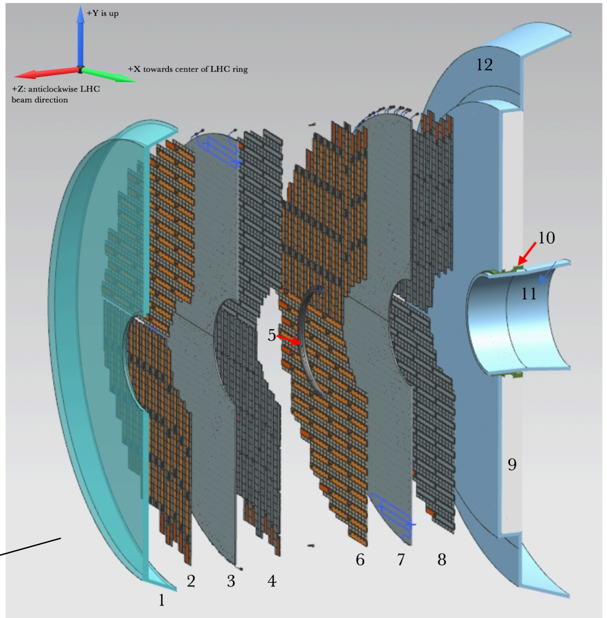
LGADs at the HL-LHC (2028)

BTL: LYSO bars + SiPM readout:
- TK / ECAL interface: |η| < 1.45
- Inner radius: 1148 mm (40 mm thick)
- Length: ±2.6 m along z
- Surface ~38 m^2; 332k channels
- Fluence at 4 ab^{-1}: 2x10^{14} n_{eq}/cm^2

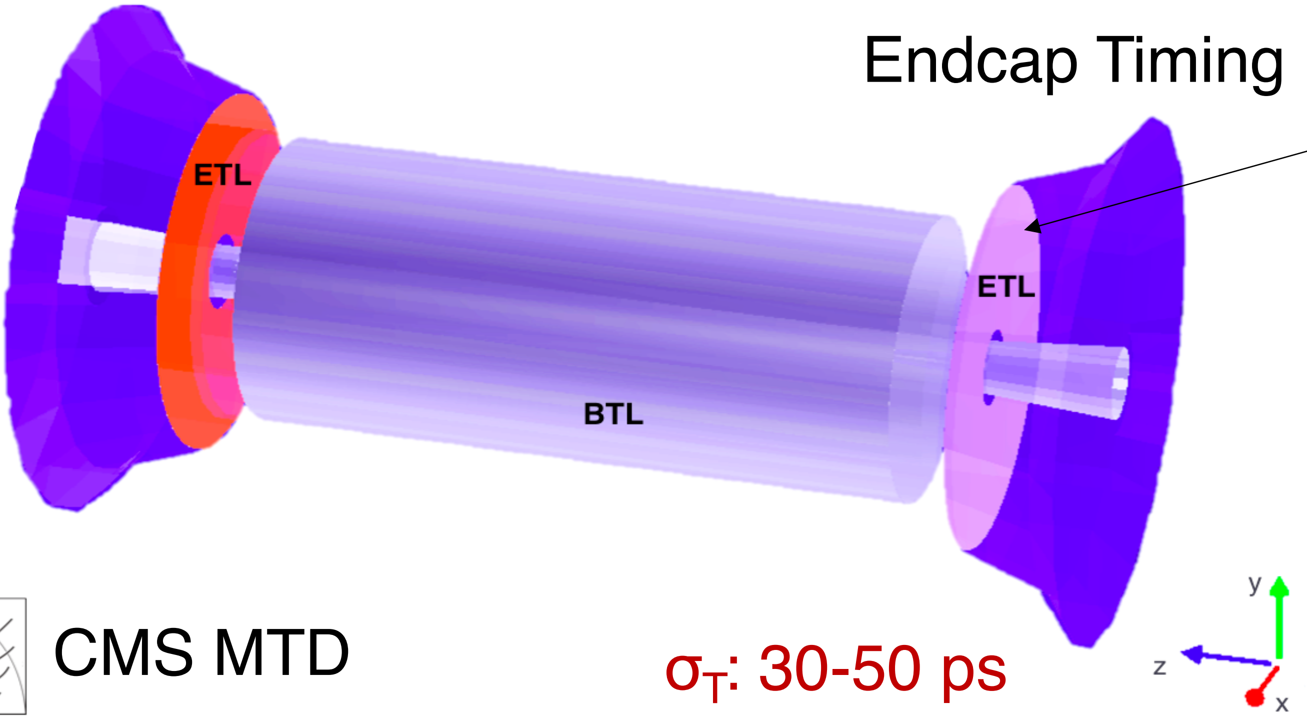


ETL: Si with internal gain (LGAD):
- On the CE nose: 1.6 < |η| < 3.0
- Radius: 315 < R < 1200 mm
- Position in z: ±3.0 m (45 mm thick)
- Surface ~14 m^2; ~8.5M channels
- Fluence at 4 ab^{-1}: up to 2x10^{15} n_{eq}/cm^2





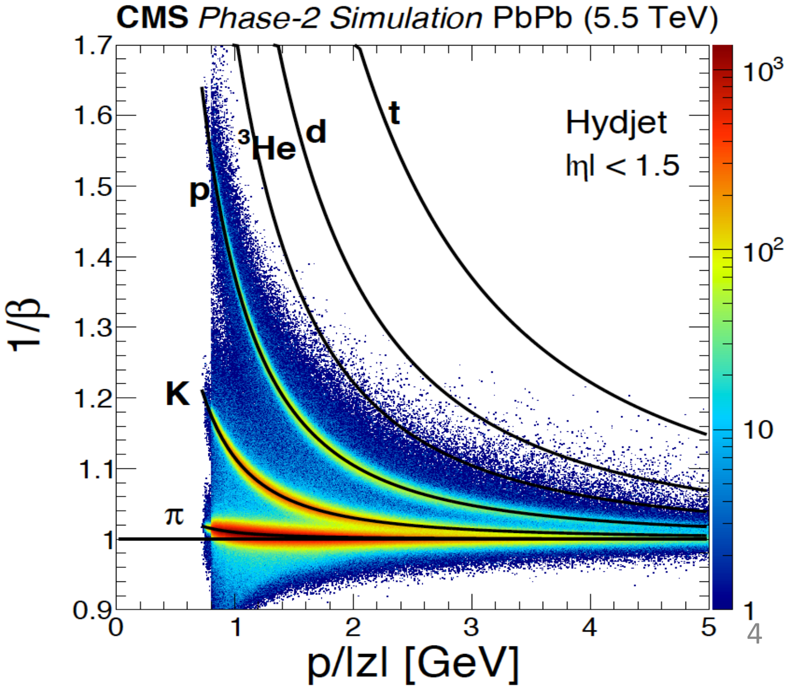
Endcap Timing Layer



CMS MTD

σ_T: 30-50 ps

Particle ID in HI

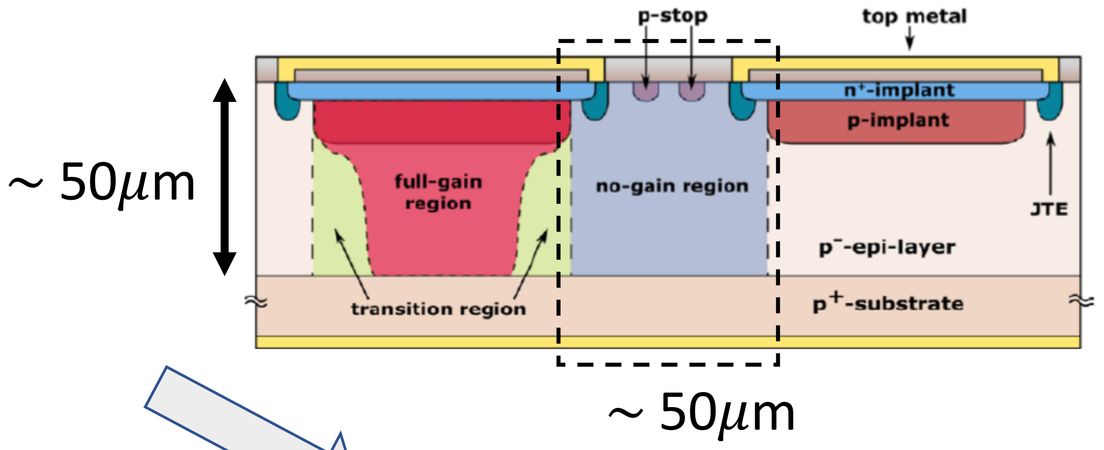


Lots of synergies to leverage for EIC

Position resolution for LGADs

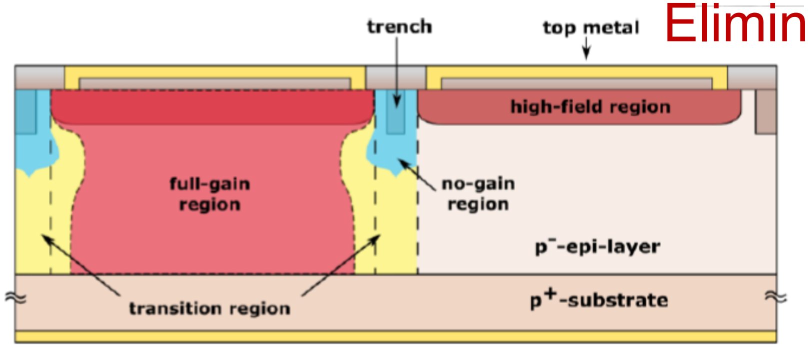
Standard LGADs at HL-LHC

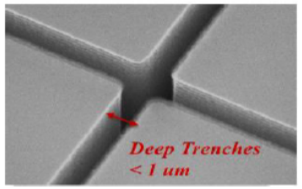
- **Pixel: 1.3x1.3 mm^2**
- ~ 50 μm intrapad dead zone



(1) Trench-Isolated (TI) LGADs

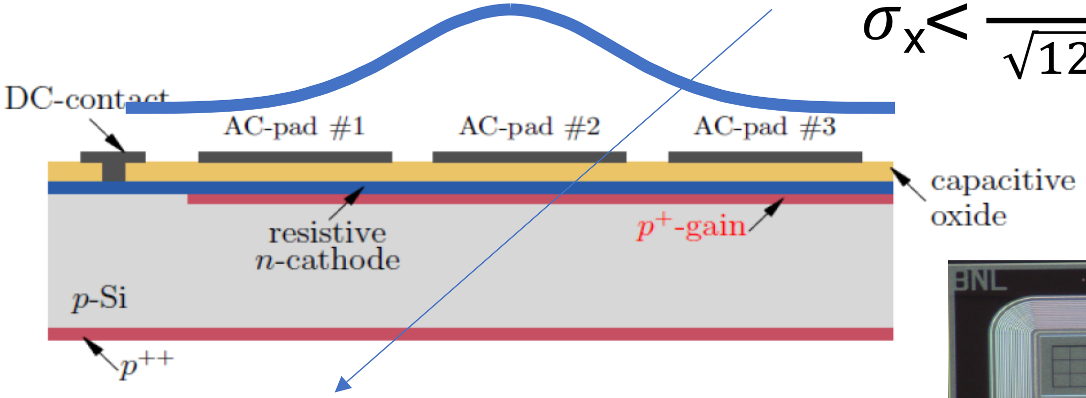
Eliminate dead zone



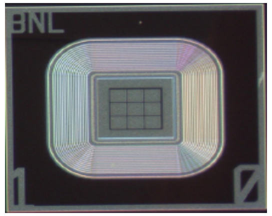


(2) AC-coupled LGADs

$$\sigma_x < \frac{\text{Pitch}}{\sqrt{12}}$$



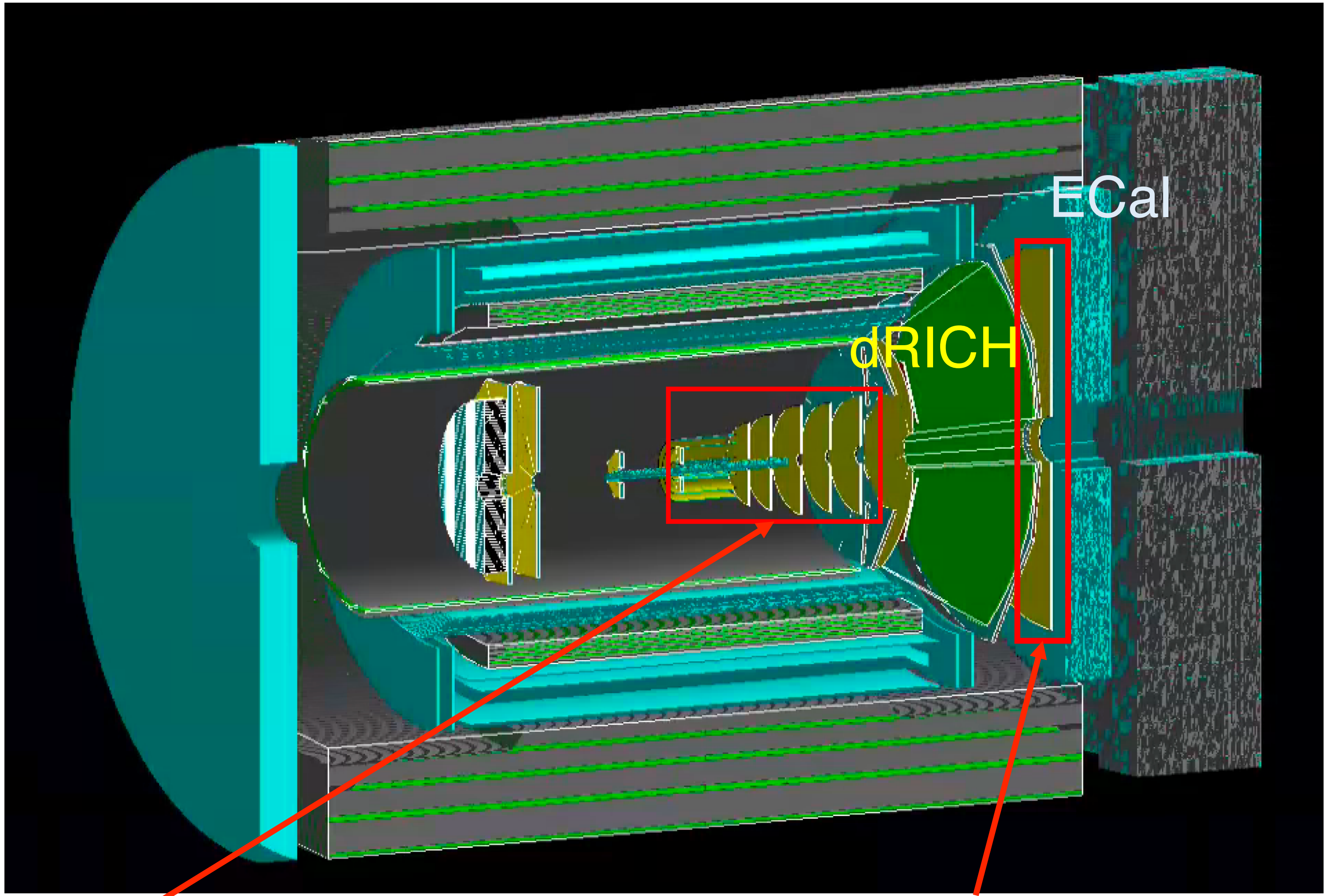
BNL



Fine pixelization (~ 100-200 µm) achievable for tracker

Performance studies in Fun4All

BNL-eRD29

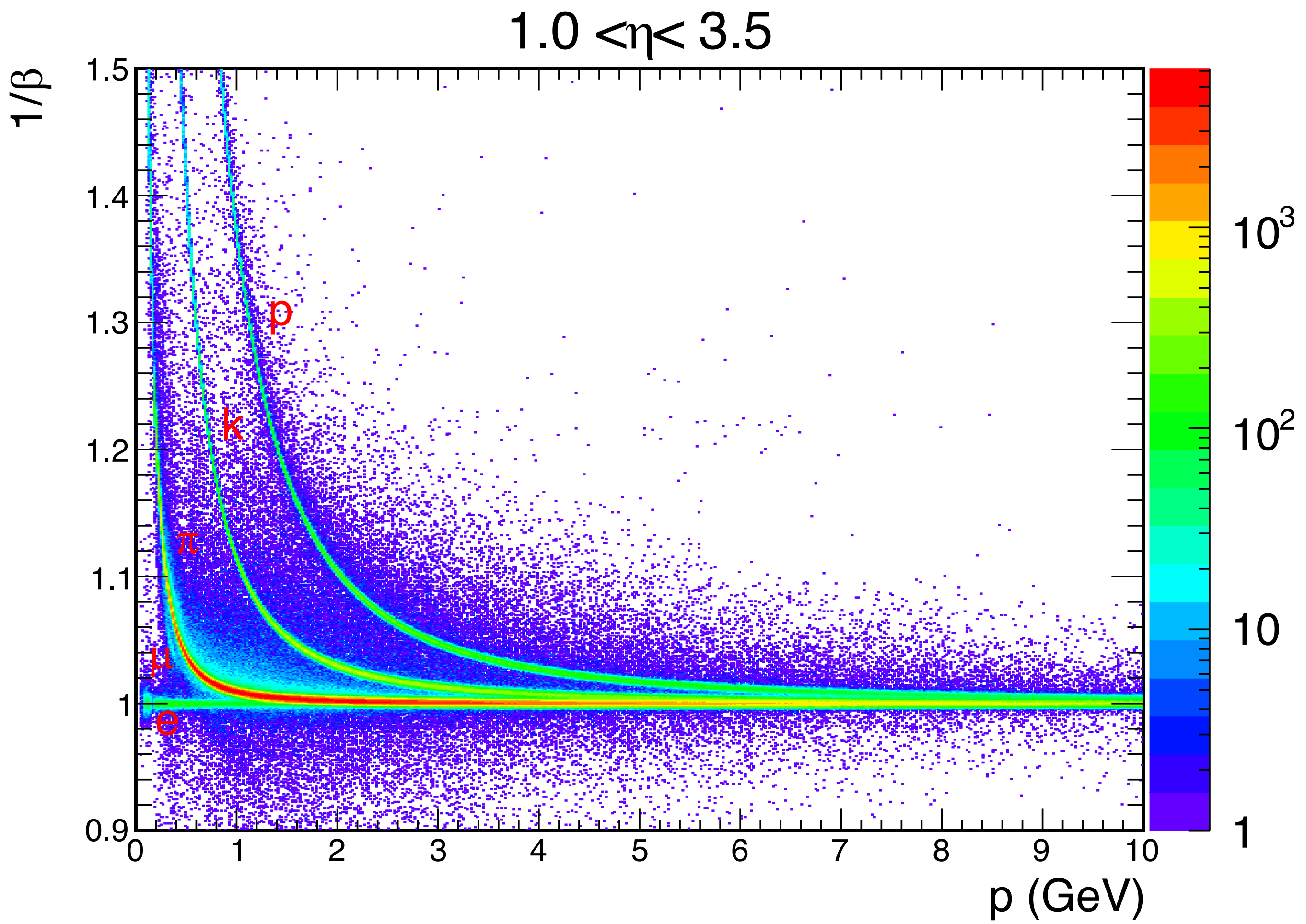


Silicon tracker
(Barrel + FST from LANL)

Forward LGADs layer(s) behind dRICH: z=2.8m — farther the better to maximize flight distance

PID performance $1/\beta$ vs. p

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

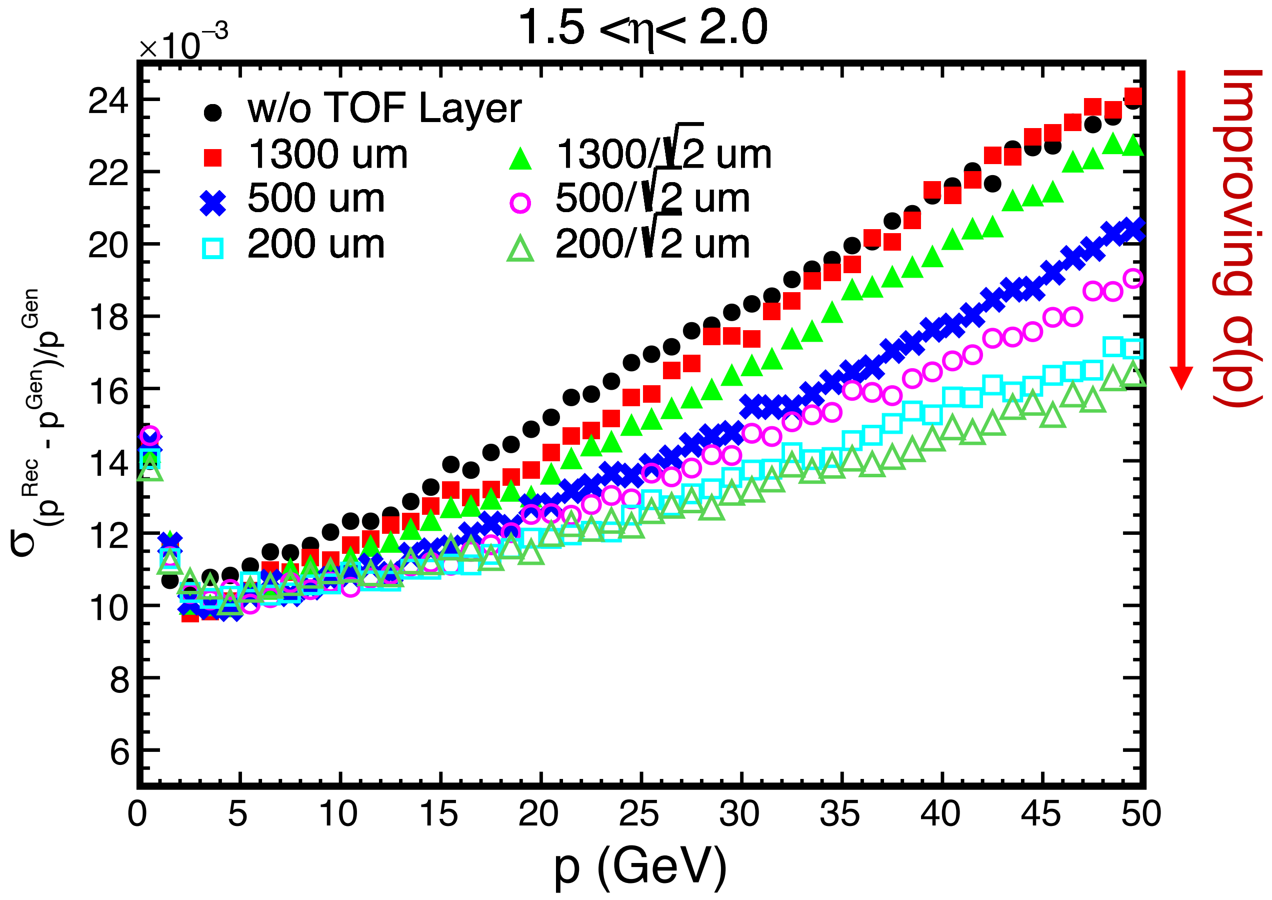


Two layers: $\sigma(p_T)$ ~ 20ps/layer

- π/k: 0.1~4-5 GeV; k/p: 0.1~7-8 GeV
- Start-time (T_0) contribution being studied

Combining with dRICH, PID over full *p* range covered

Tracking performance: *p* resolution



Pitch size:

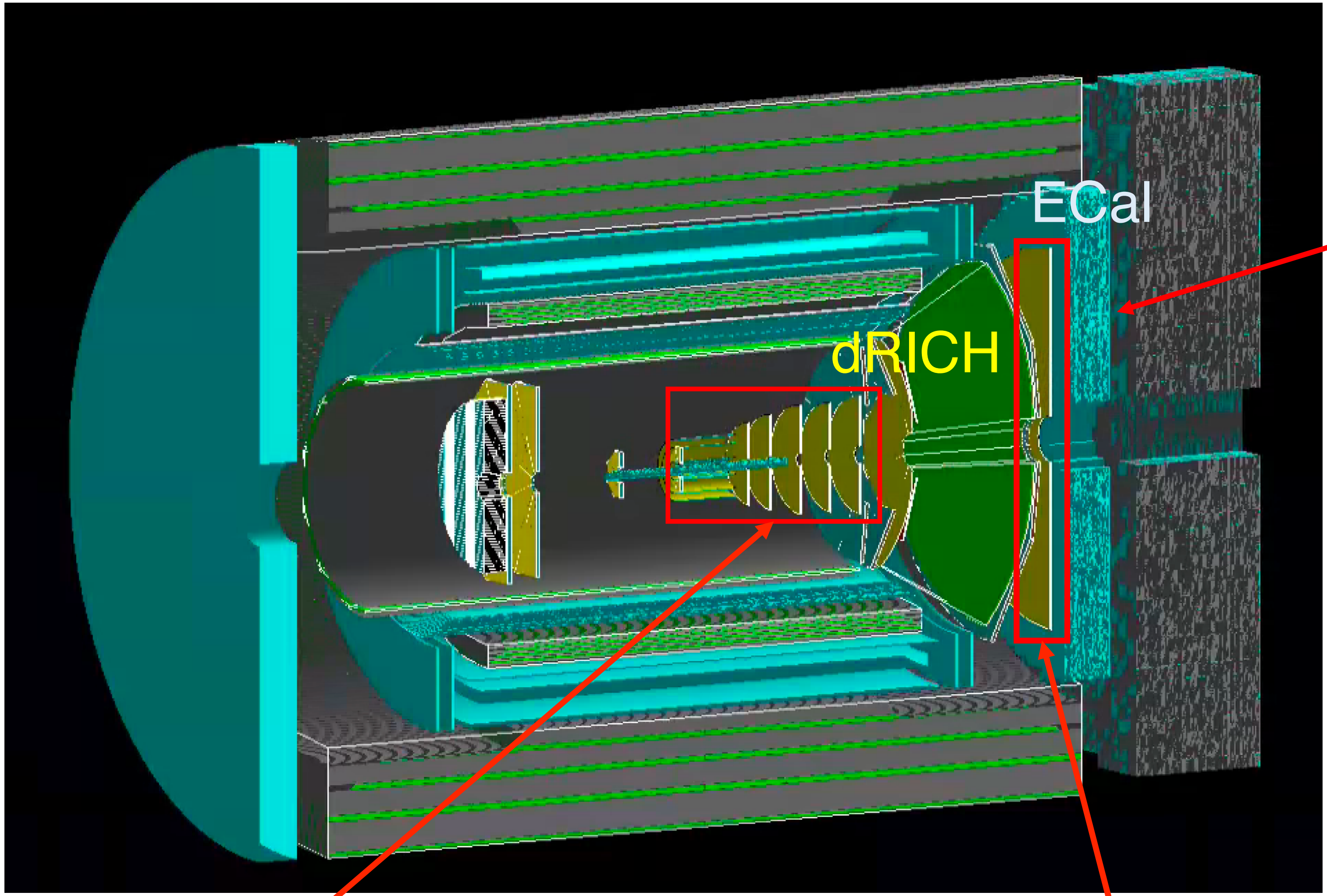
- 1300 μm: CMS/ATLAS
- 500 μm: optimistically achievable
- 200 μm: significant R&Ds on ASICs

$\sigma_{x(y)}$: (pitch) / $\sqrt{12}$ per layer

- Better than 1/ $\sqrt{12}$ using AC-LGADs

Improved *p* resolution with LGADs as outer tracker (after dRICH)

Future development in progress



Silicon tracker
(Barrel + FST from LANL)

Forward LGADs layer(s) behind dRICH: z=2.8m

Performance and design

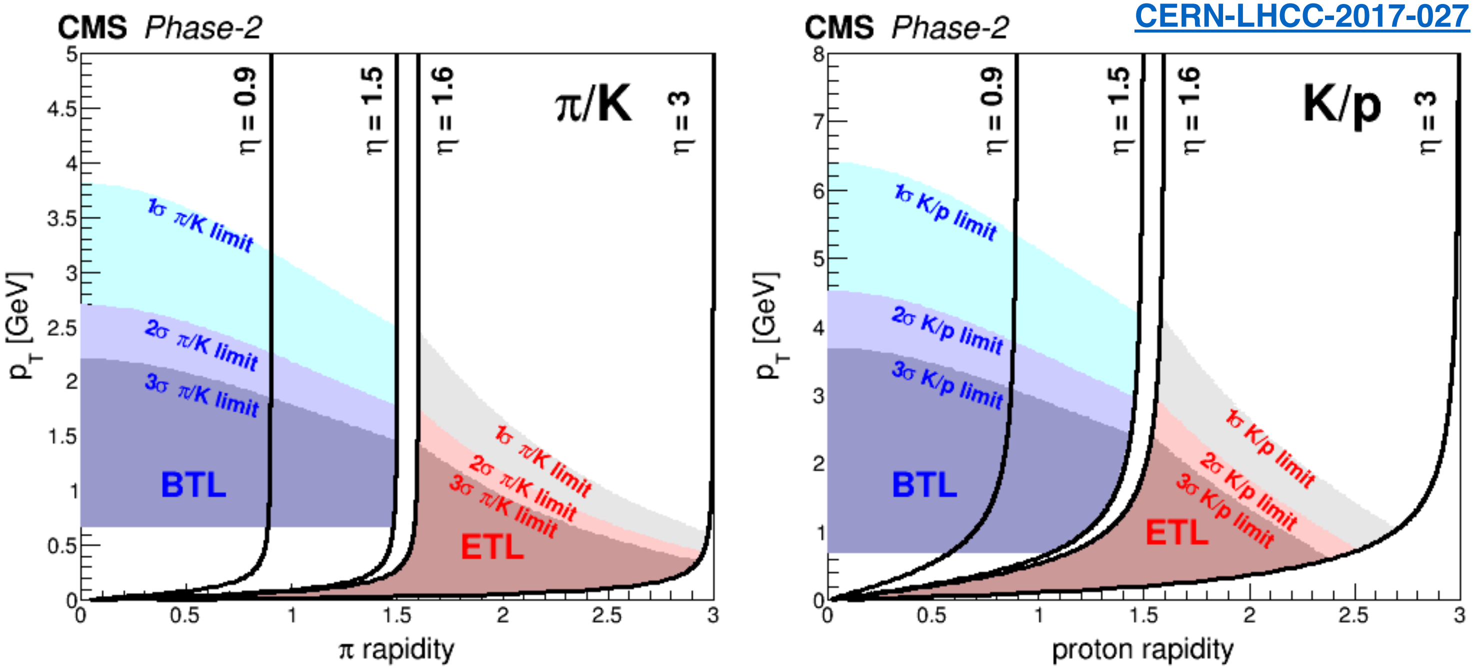
- Layers between ECal and Hcal?
- Add backward/central coverage
- Test with different tracker design (e.g., LBNL)
- T_0 determination strategy

Targeted R&Ds being planned in the consortium

Backups

Performance for PID with CMS-MTD

CERN-LHCC-2017-027



- p_T coverage comparable to STAR/ALICE
- **Unique wide η coverage**

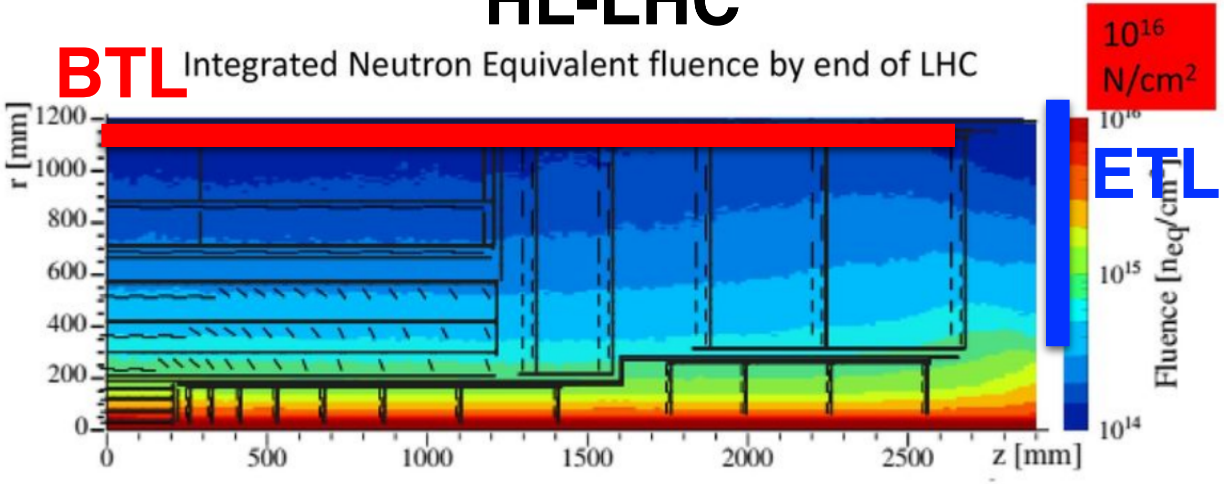
A large coverage, LGAD-based TOF(-track) at EIC

- Significant synergies to leverage with the HL-LHC upgrade
- Advantage of no radiation constraints at the EIC

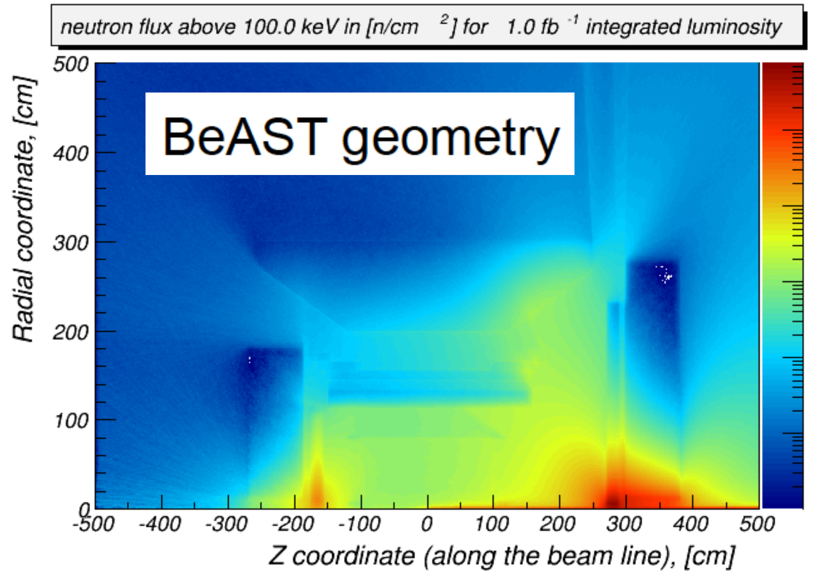
EIC: the next QCD frontier

Radiation fluence

HL-LHC



EIC



~ $2\text{x}10^{14}$ n_{eq}/cm^2 for BTL

~ $2\text{x}10^{15}$ n_{eq}/cm^2 for inner radius of ETL

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

Synergies between LHC and EIC but also different challenges:

- No radiation constraints for EIC – good for the entire lifetime
- Optimize for better time and position resolutions

EIC Detector Requirements

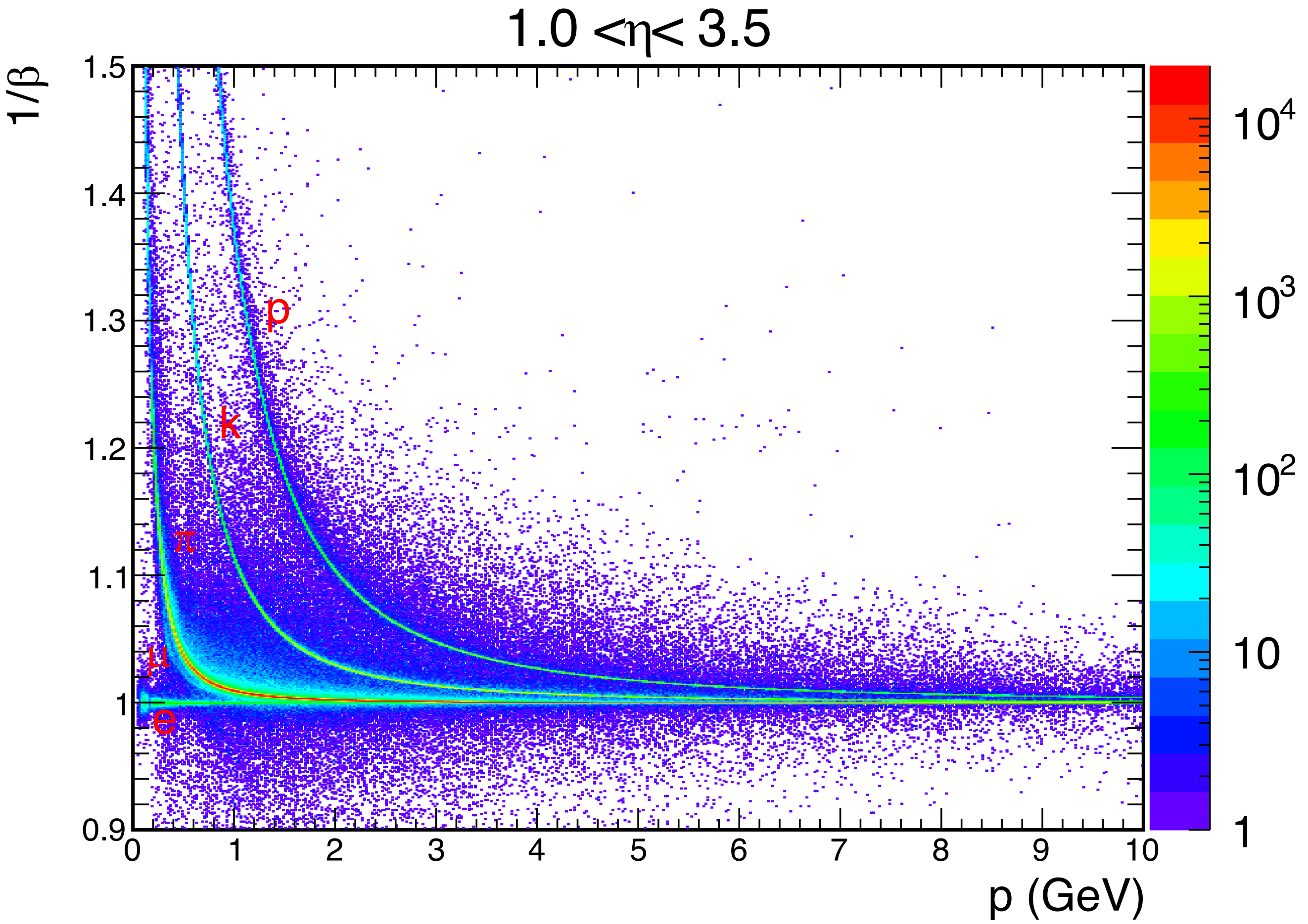
Table 2: Physics requirements for a an EIC detector

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-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 1:10^4	≤ 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

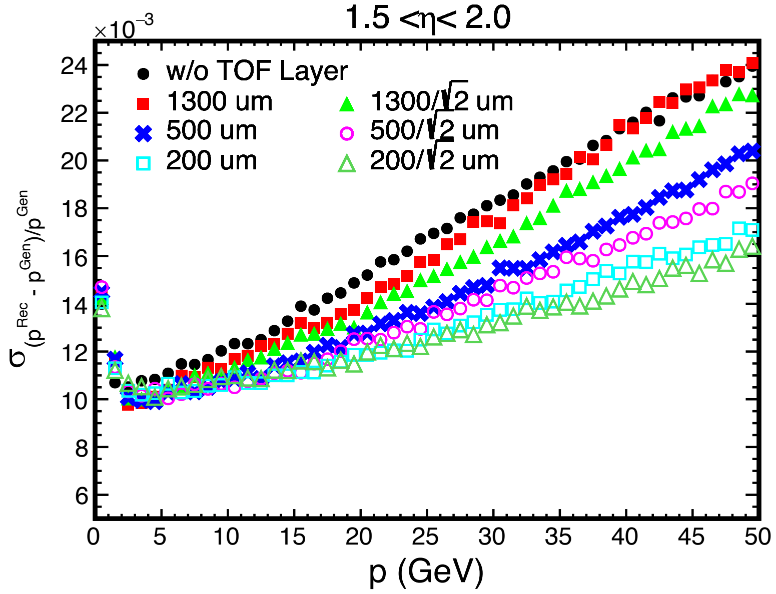
$1/\beta$ vs. p

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

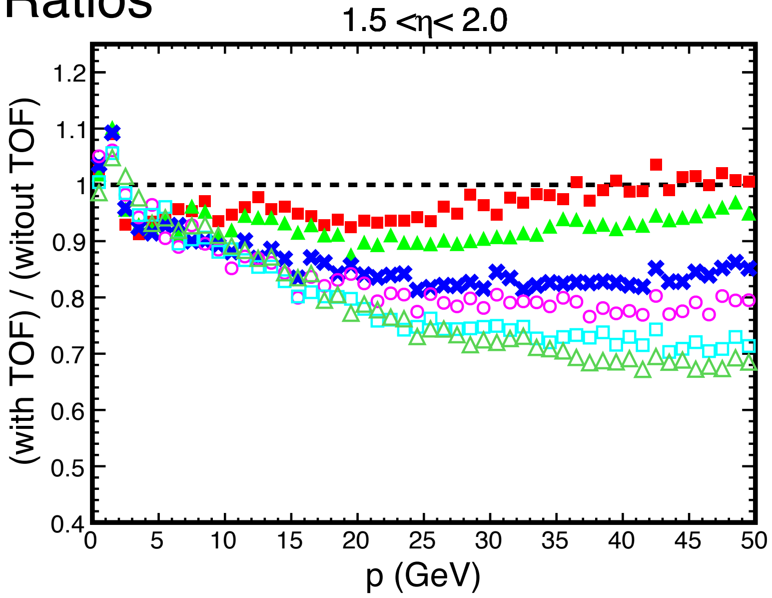


- ➢Velocity with ONLY pathlength uncertainty
  - non-negligible effect from tracking

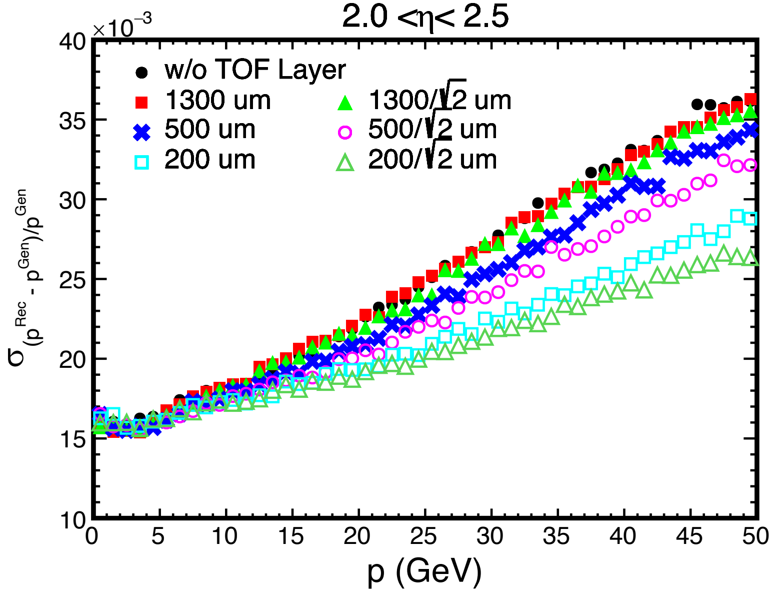
Track p_T resolution with pion guns

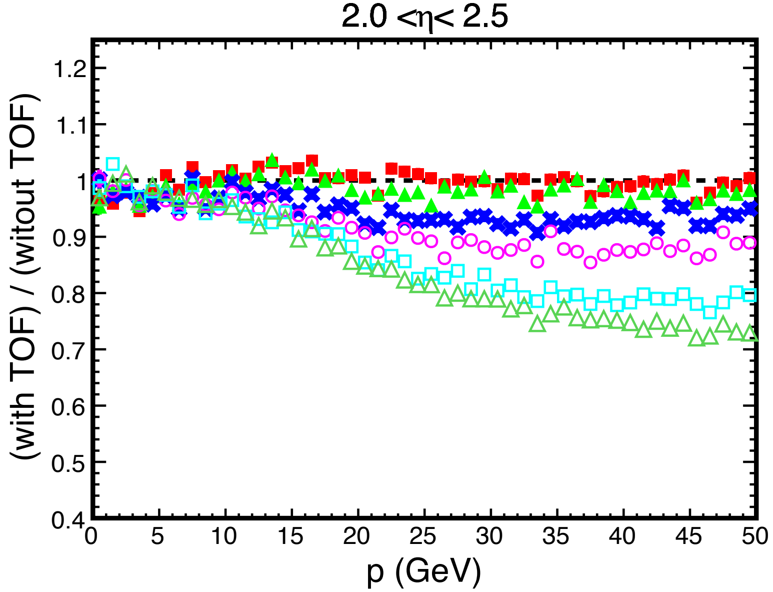


Ratios

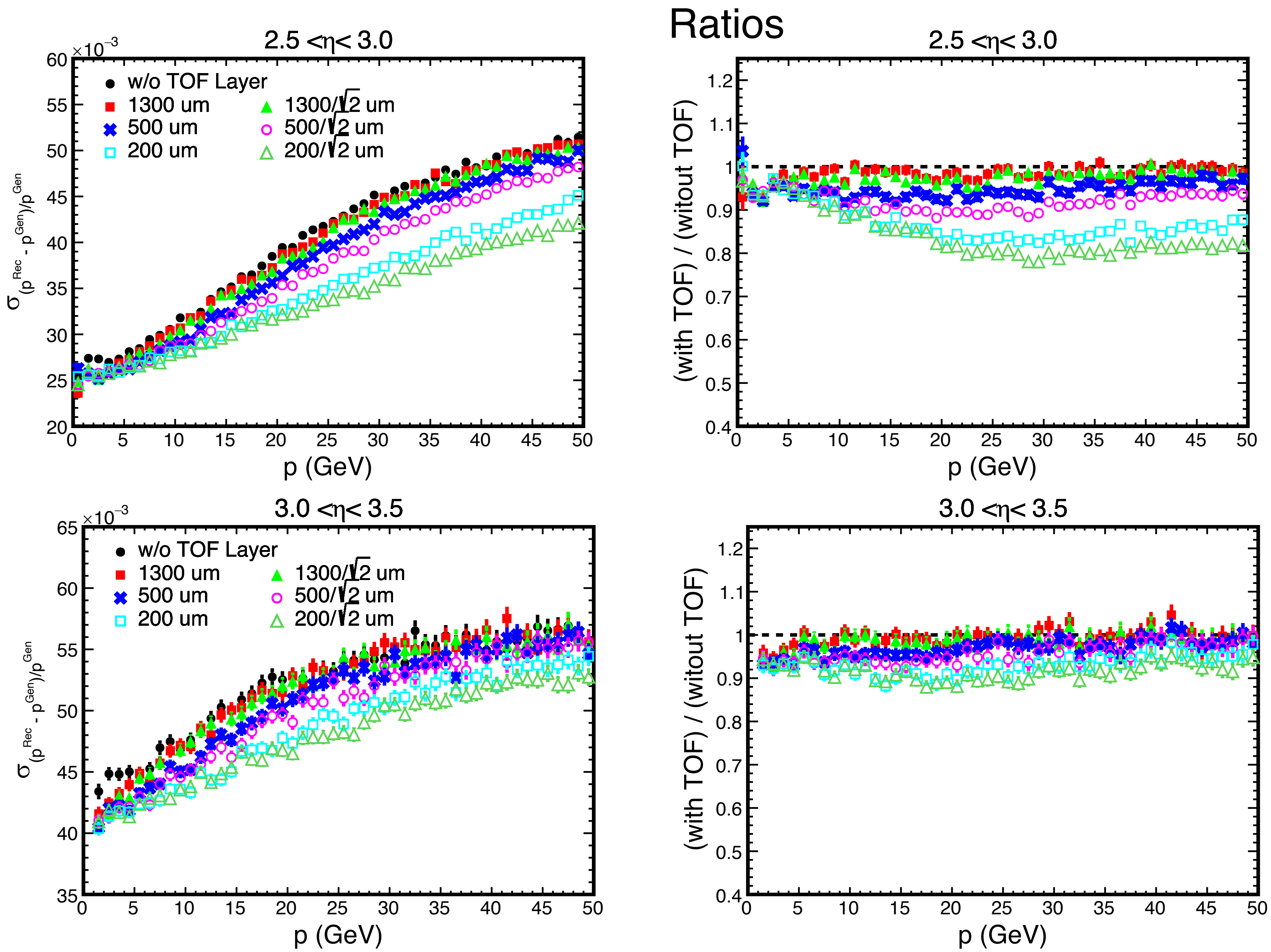


1.5<η<2:
~ 50% of disk area





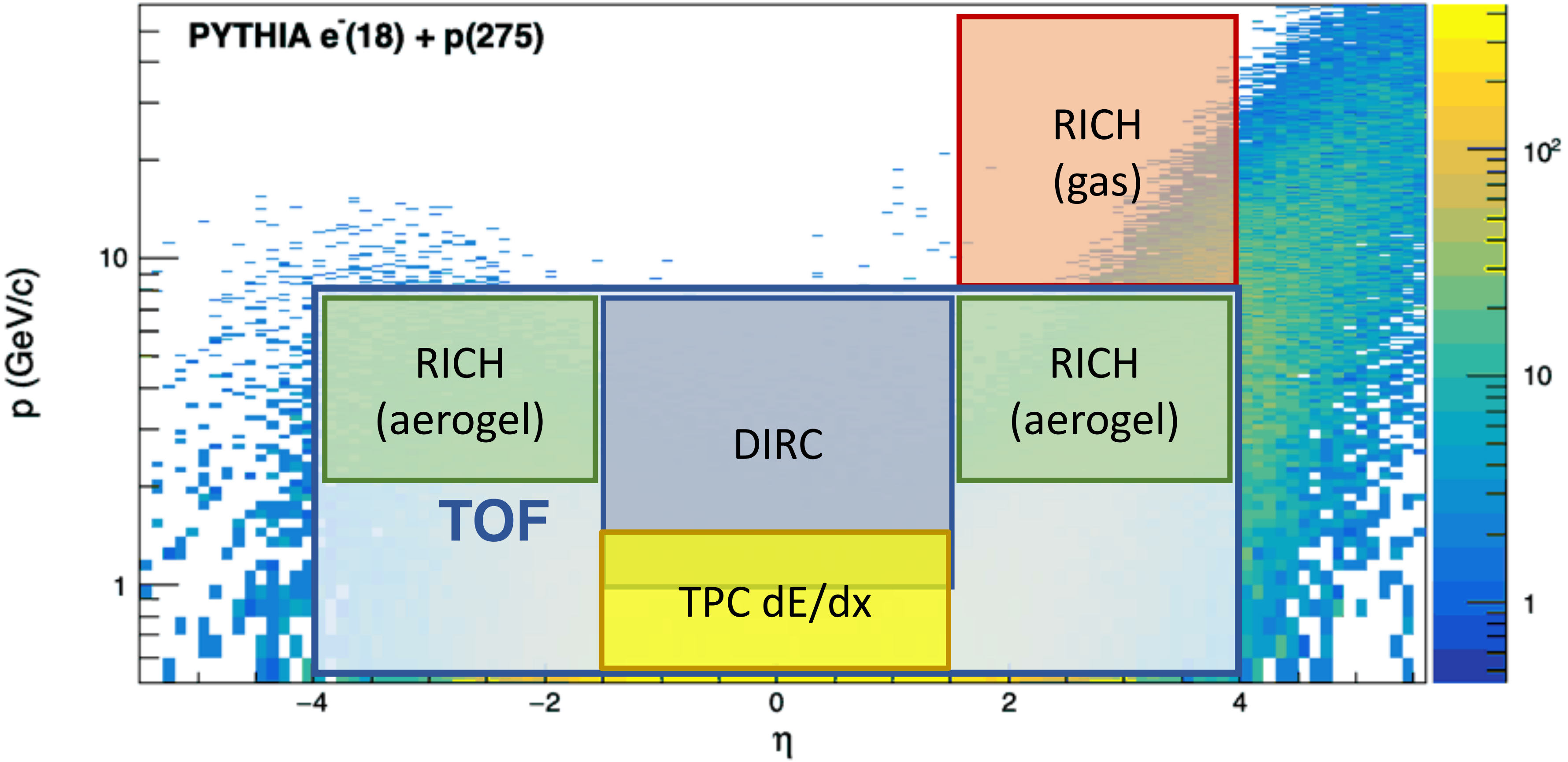
Track p_T resolution with pion guns



Particle identification (PID) at EIC

Physics:

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



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

	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

Particle identification (PID) at EIC – TOF

(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 silicon sensor: low gain avalanche diodes

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