High granularity readout TPC for CEPC TDR

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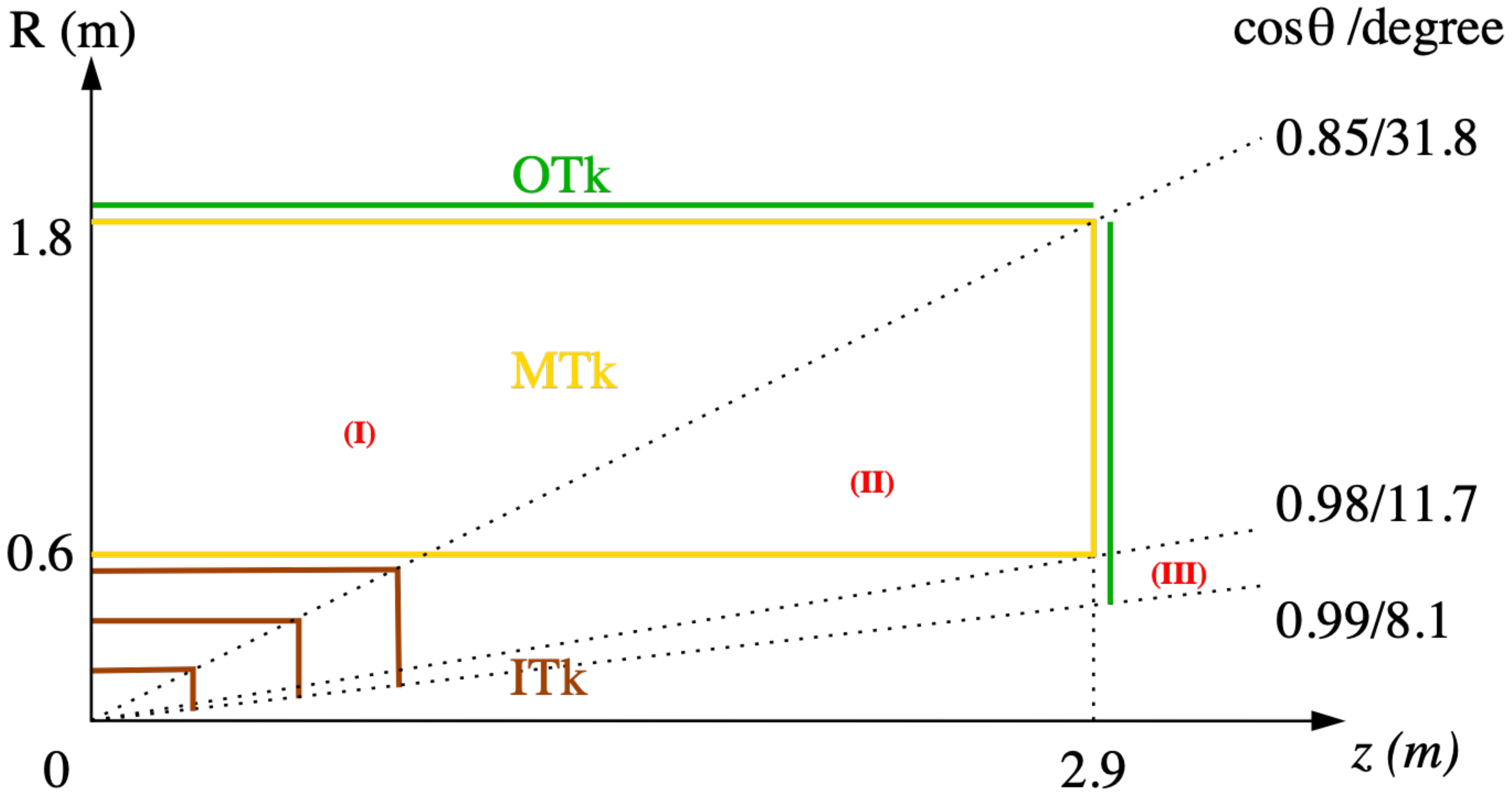
- **High granularity readout TPC for CEPC TDR**

Track detector system in CEPC Phy.&Det. TDR

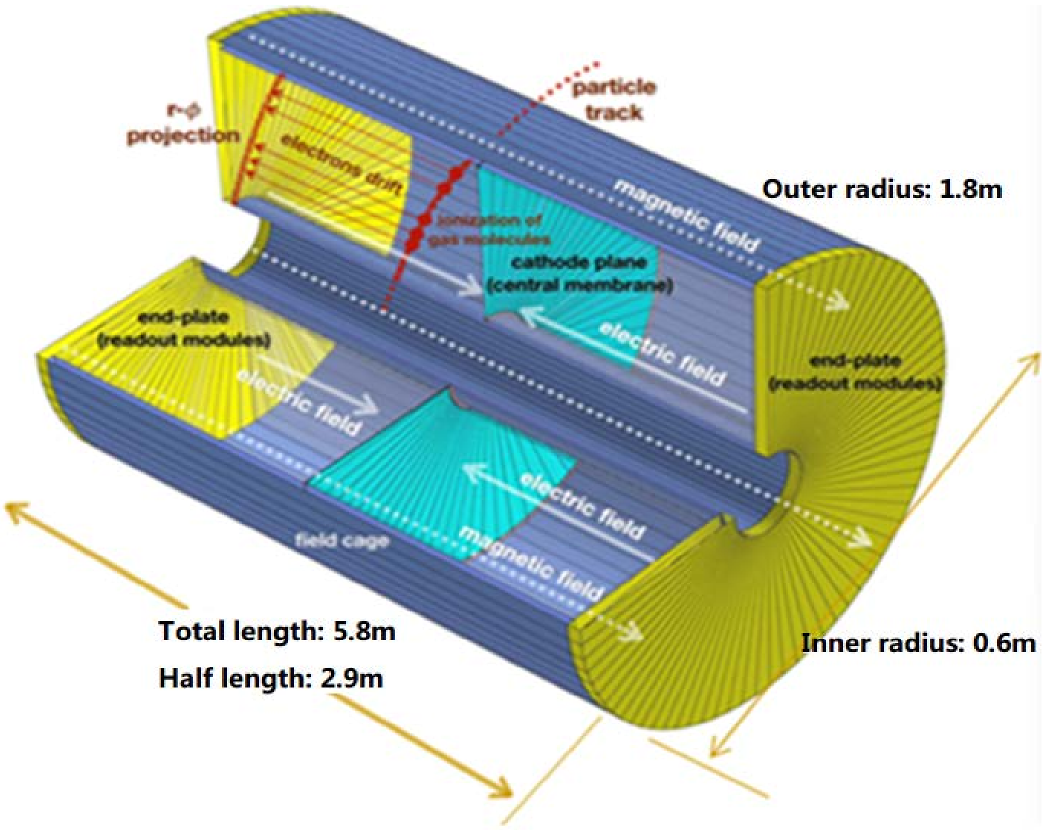
- The track detector system's geometry was finalized.
  - Converging geometries as quickly as possible in preparation for physics simulation
  - Geometry diagram almost finalized

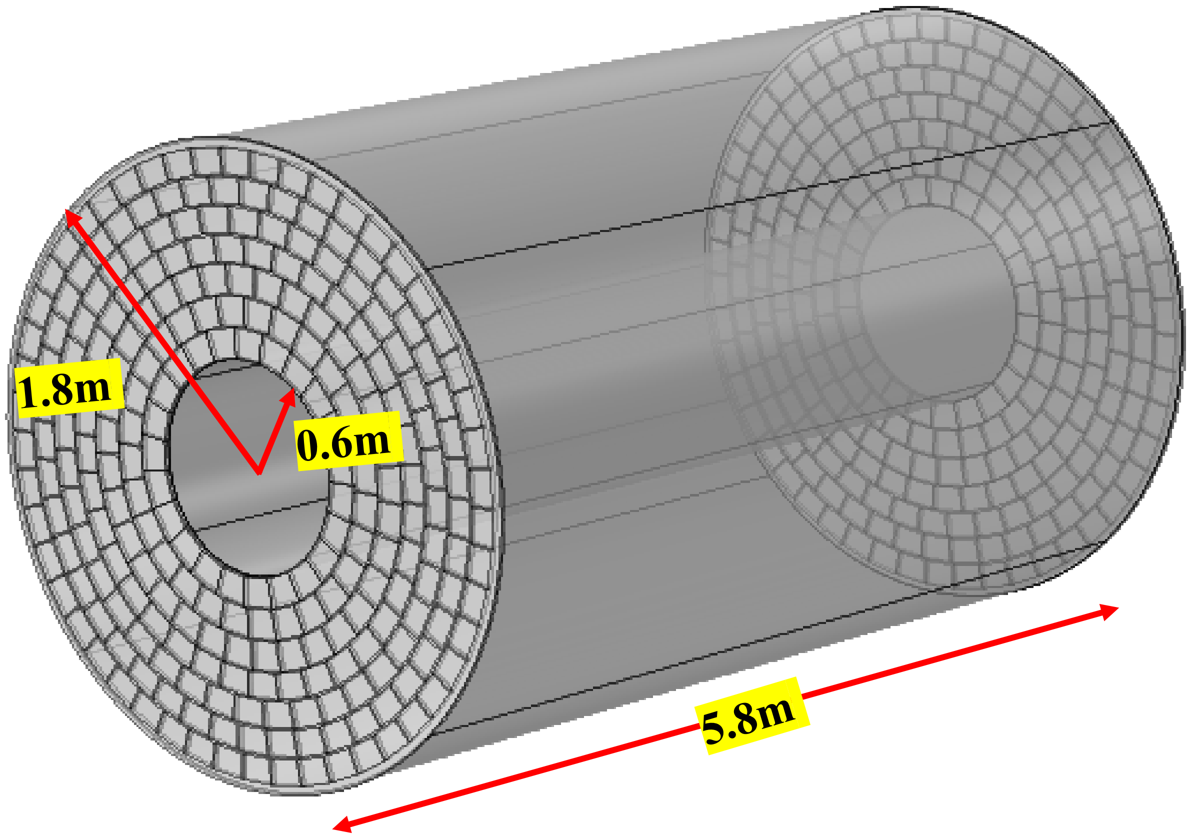


Almost finalized Geometry of the track detector system

General geometry of TPC detector

- General geometry of TPC and the optimization modules in endcap
- 3D optimization design on going

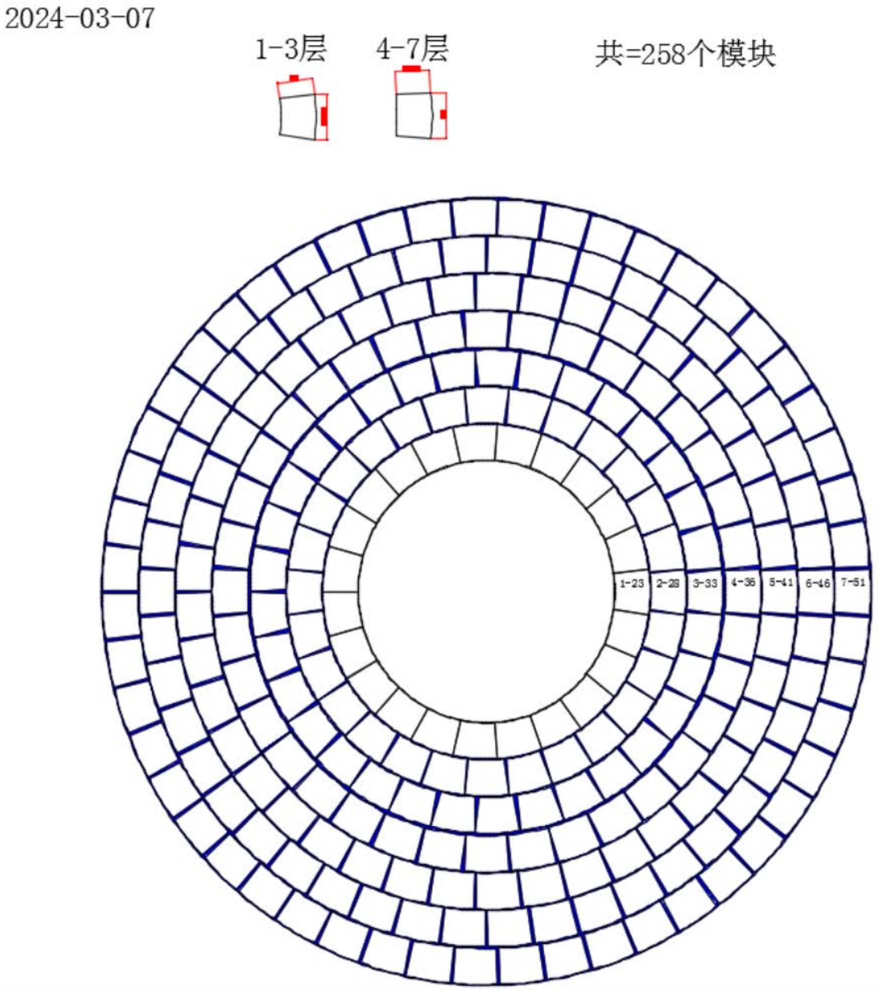


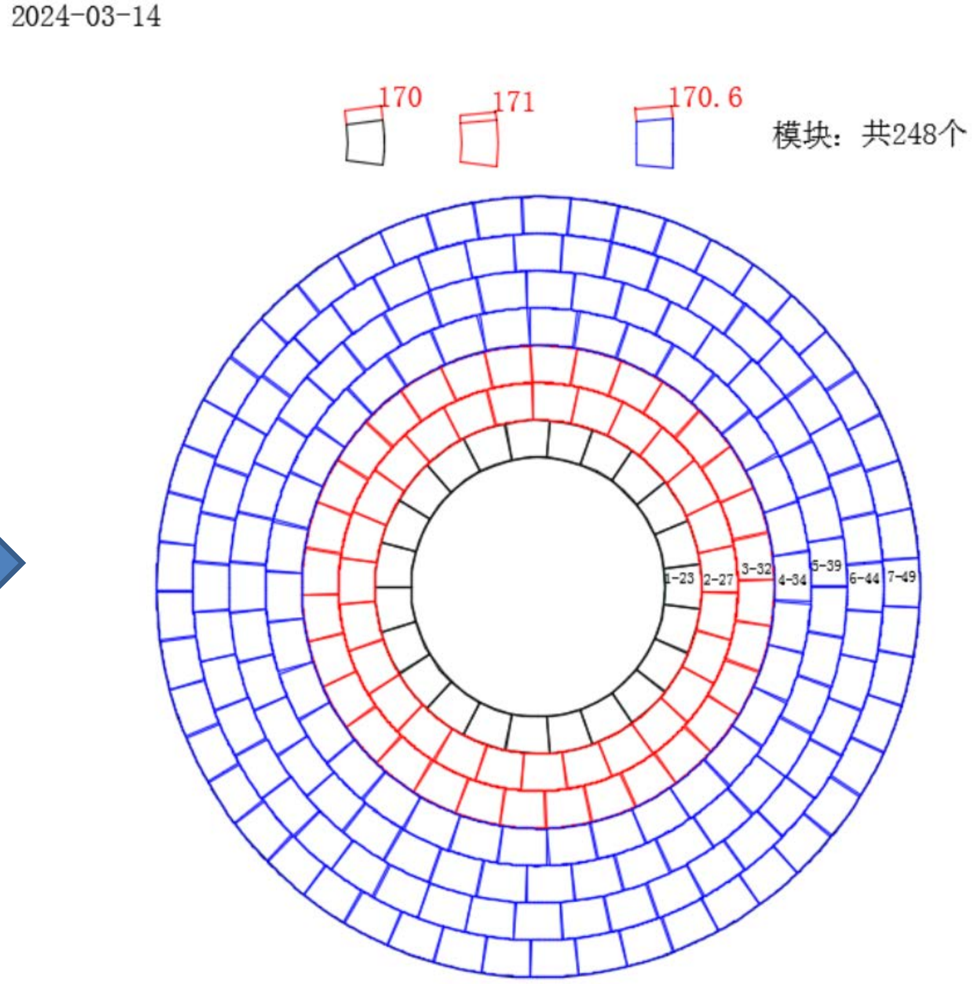


Almost finalized Geometry of TPC detector and the Endplate

Optimization the endcap of TPC

- Optimization modules in the endcap
  - ILD TPC: Coverage of the sensitivity readout area **~89%**
  - Coverage of the sensitivity readout area increased from **92% to 96%**





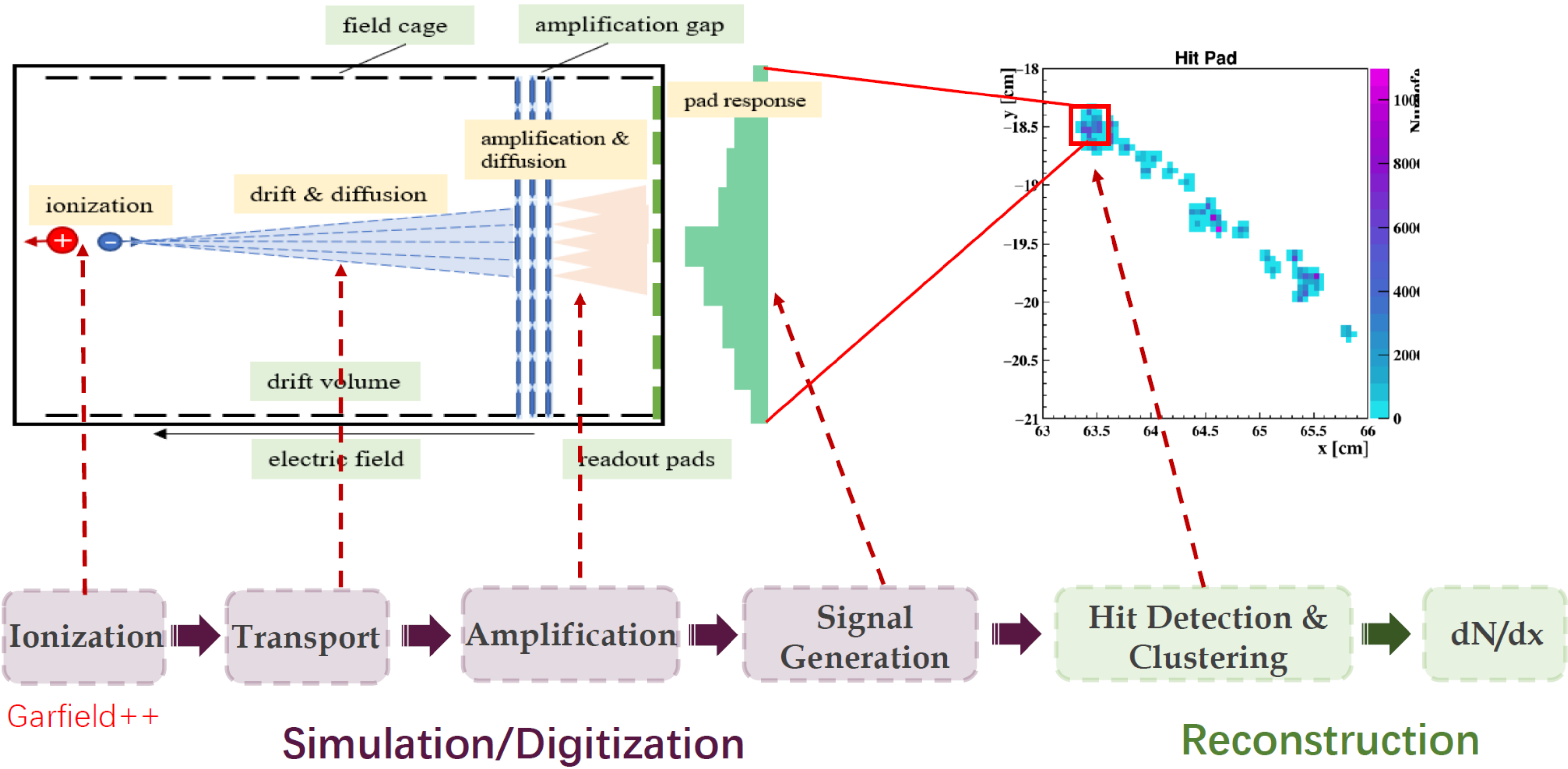
Optimization of Geometry of TPC detector and the Endplate

High granularity readout TPC @cosθ≃0.98

Parameters	Higgs run	Z pole run
B-field	3.0T	2.0T
Pad size (mm)/All channels	0.5mm×0.5mm /2×3×10^7	0.5mm×0.5mm /2×3×10^7
Material budget barrel	0.012 X_0	0.012 X_0
Material budget endcap	0.17 X_0	0.17 X_0
Points per track in rφ	2300	2300
σ_{point} in rφ	100μm (full drift)	400μm (full drift)
σ_{point} in rz	≃ 0.1 – 0.5 mm (for zero – full drift)	≃ 0.2 – 0.8 mm (for zero – full drift)
2-hit separation in rφ	0.5mm	0.5mm
K/π separation power @20GeV	3.2σ	3σ
dE/dx	3.2%	3.2%
Momentum resolution normalised: $\sigma_{1/pT} = \sqrt{a^2 + (b/pT)^2}$	a = 1.21 e -5	a = 2.69 e -5
	b = 0.60 e -3	b = 0.90 e -3

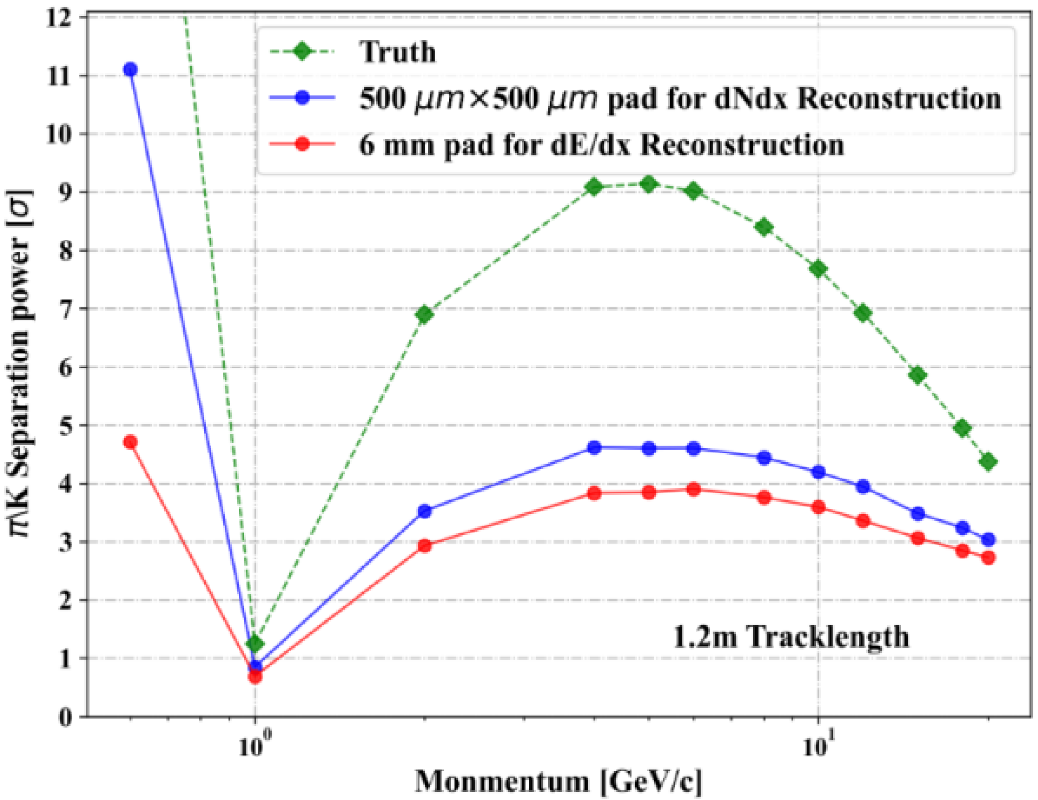
- **Performance and readiness of Simulation**

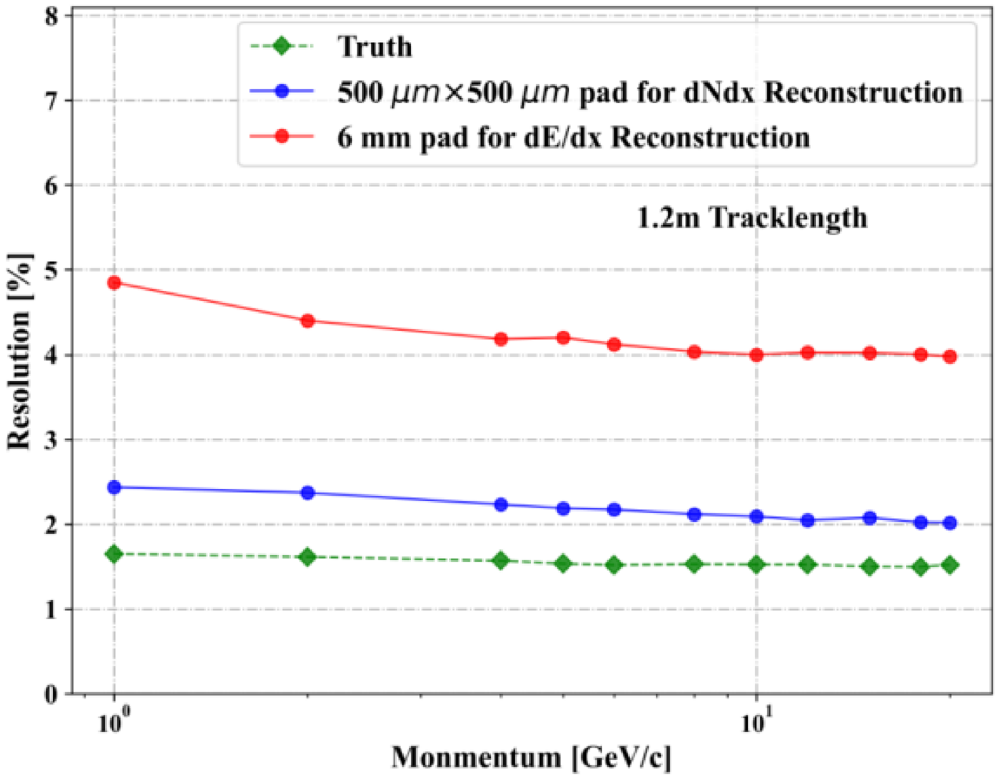
Simulation framework developed by Garfield++ and Geant4 @IHEP



PID Performance using dN/dx

- Investigating the π/K discrimination capability using reconstructed clusters, a 3σ separation at 20GeV with a 50cm drift distance can be achieved
- dN/dx has significant potential for improving resolution

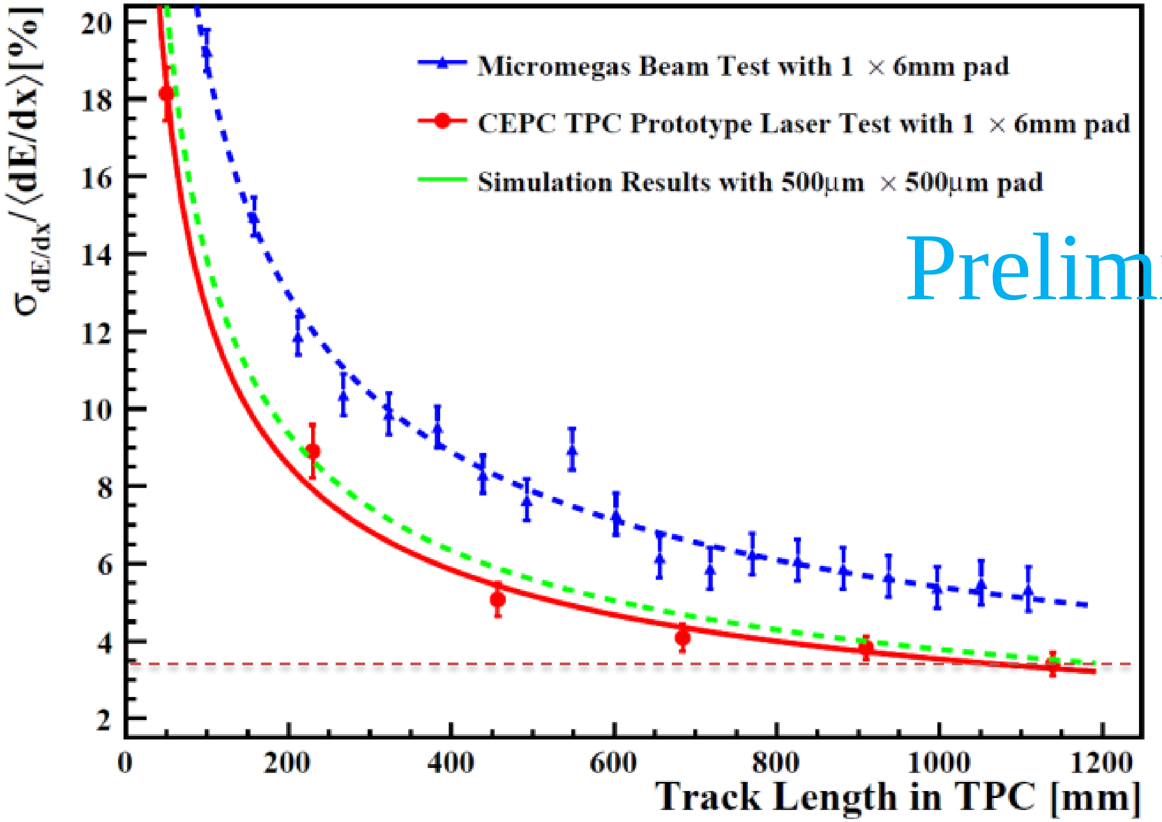




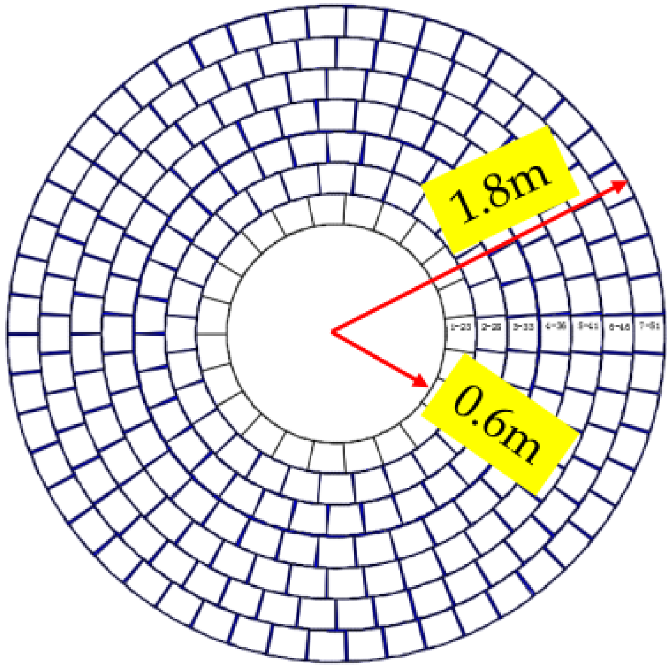
PID Performance using dE/dx

- A higher granularity is also very helpful for improving dE/dx.
- According to simulation results, for a pad size of 500um, with the current 1.2-meter track length of CEPC, the dE/dx can reach 3.2%.

$$\sigma_{dE/dx} \sim L^{-0.47} \times G^{-0.13}$$

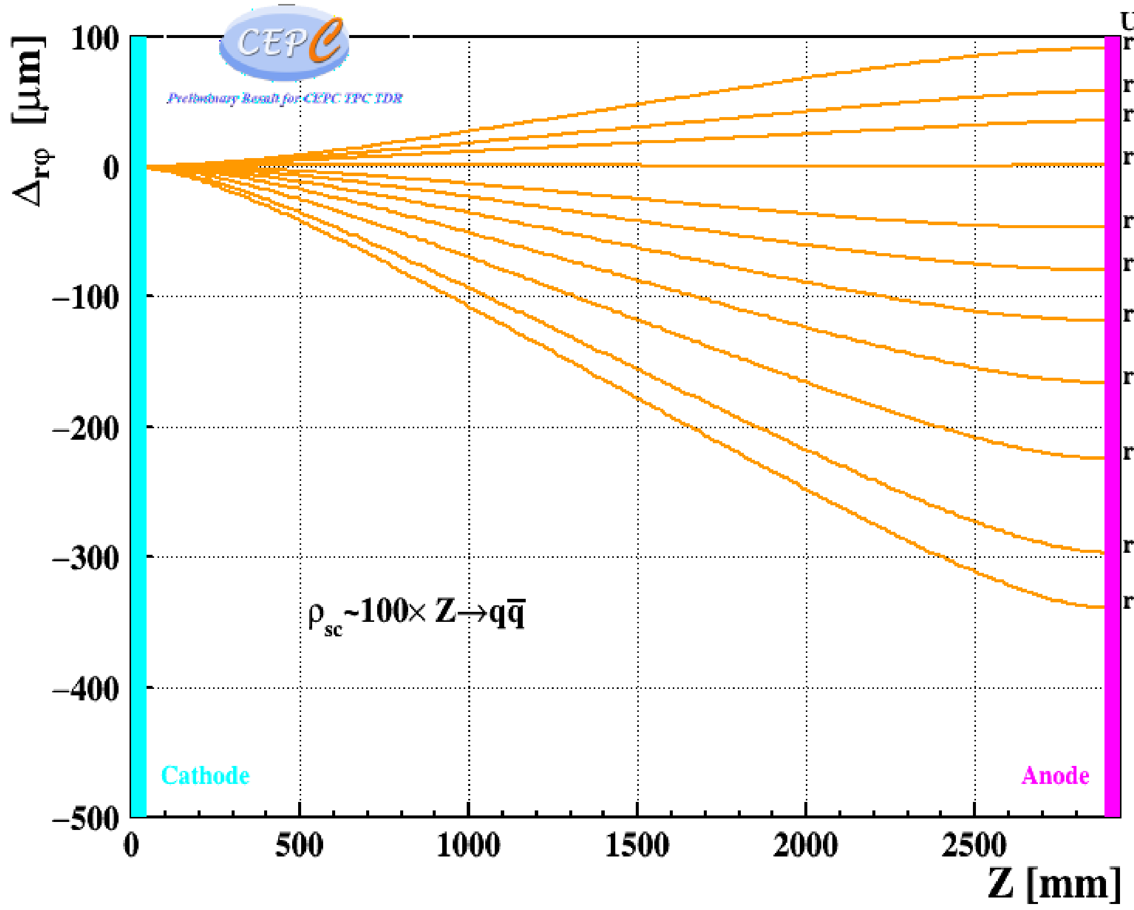


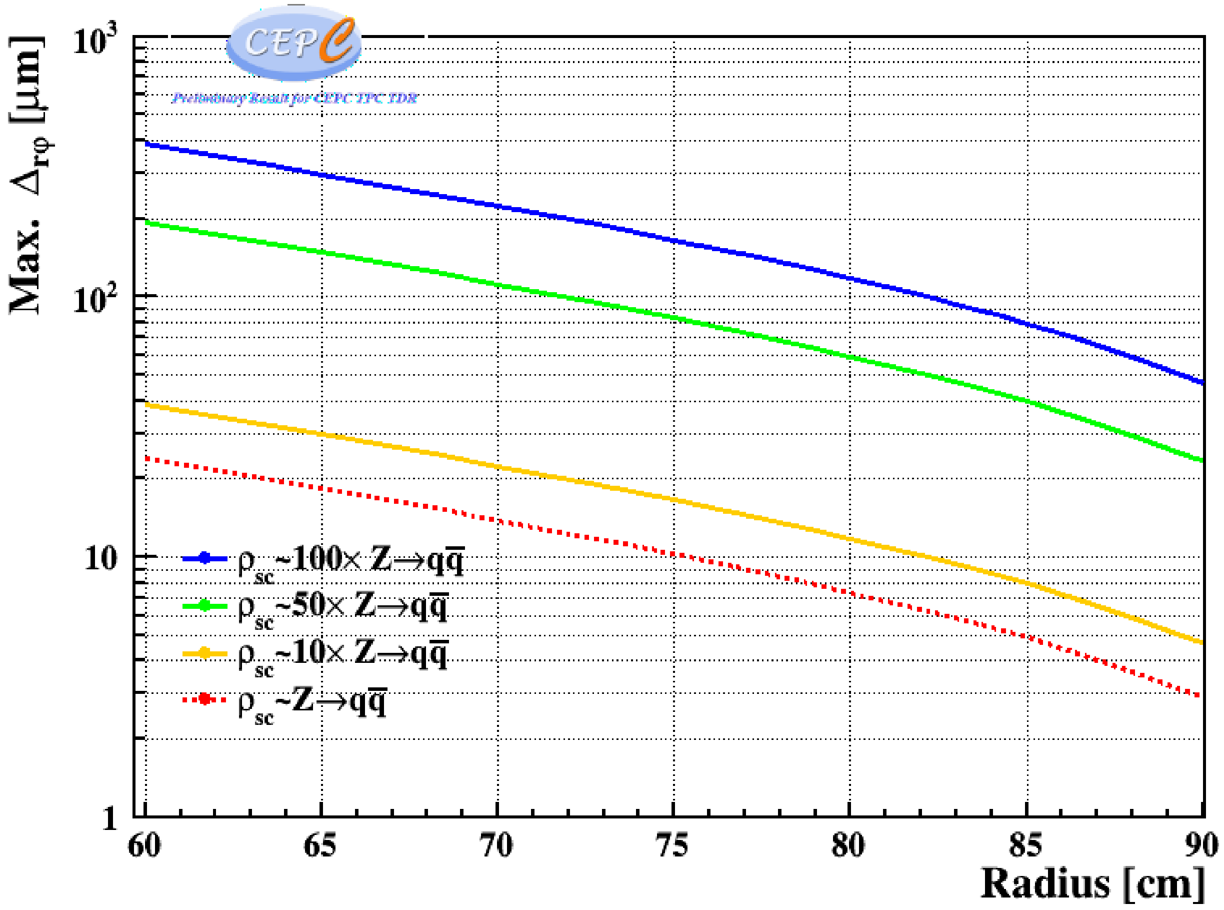
Preliminary



Maxim distortion calculation using new geometry

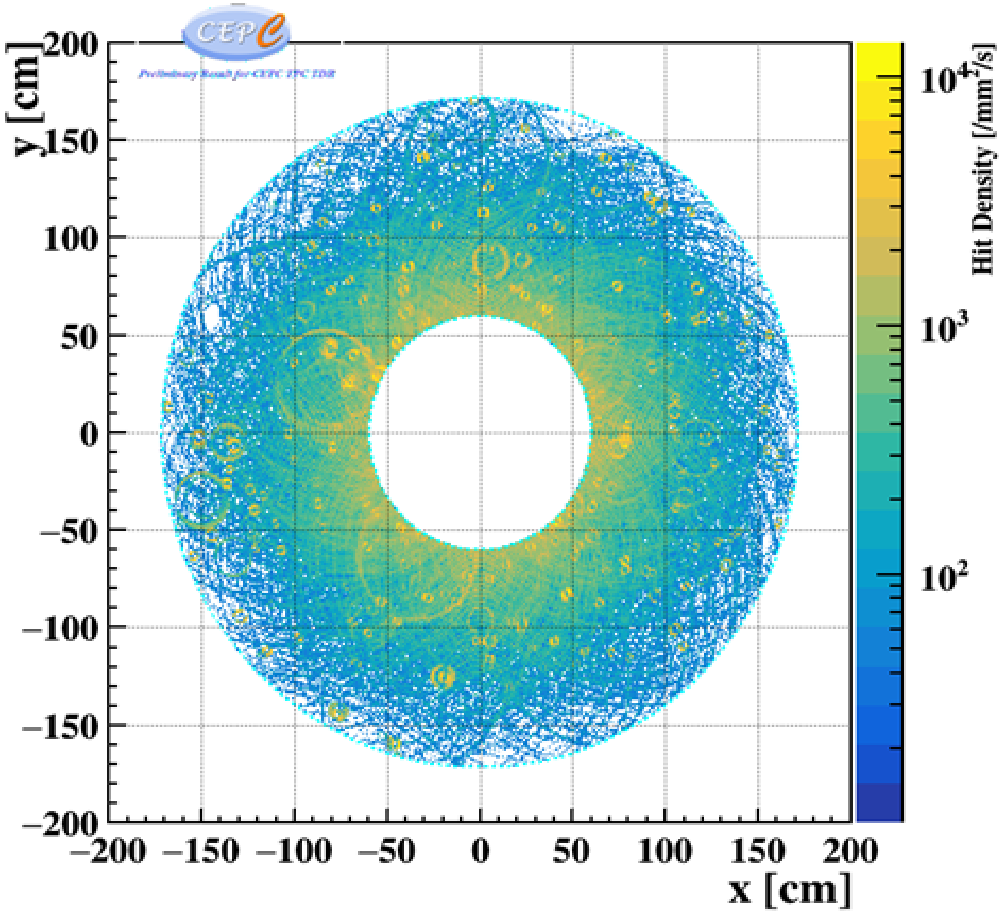
- **Maxim distortion with e+e- to qq at Z pole (物理事例的畸变影响)**
- **Maxim distortion under the different Beamstruggle background (物理事例×10、 ×50、 ×100倍本底的影响)**

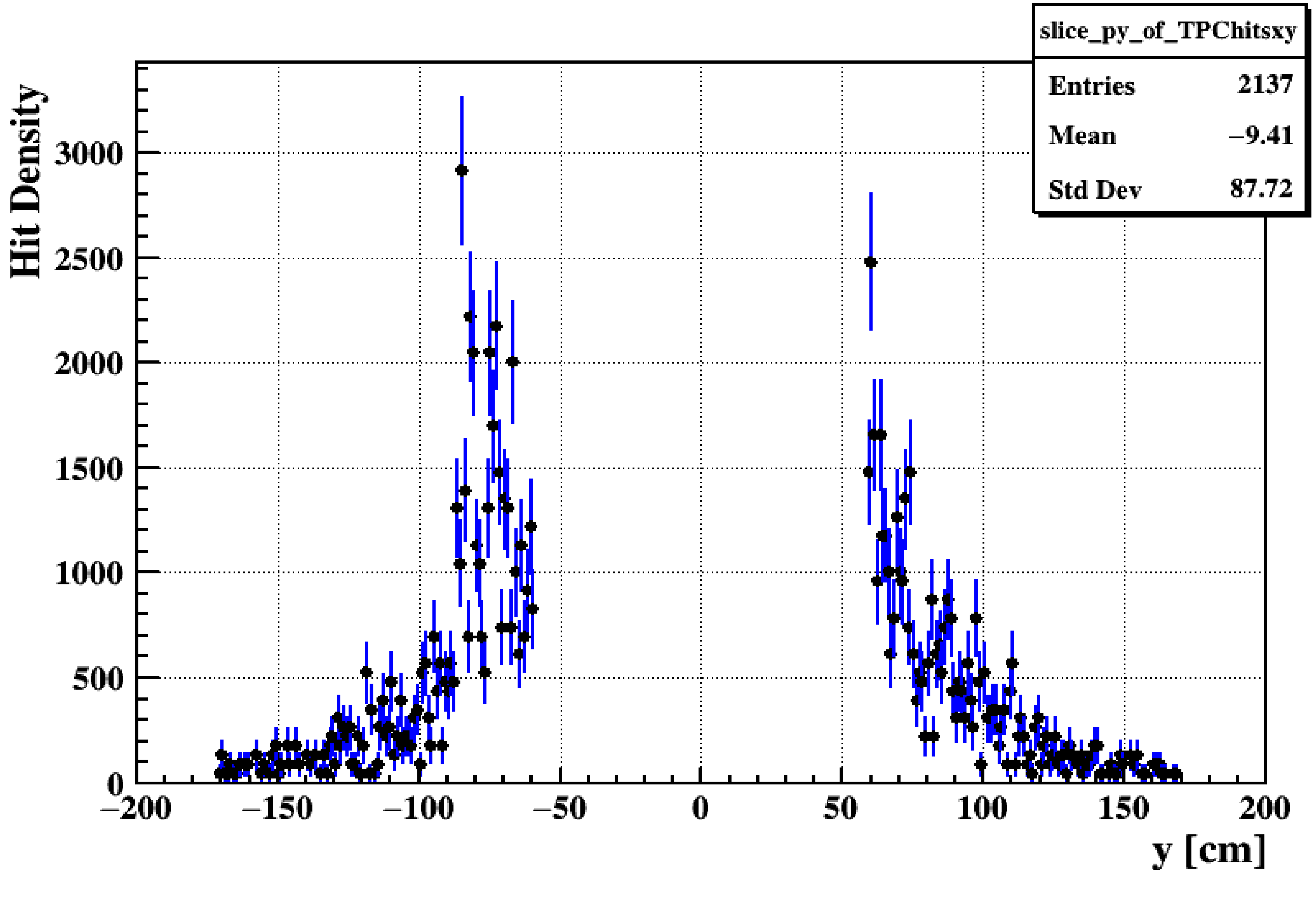




Hit density at the inner radius at Z pole 2T

- Inner radius (0.6m) hit density validation
  - Hit density at the full simulation with the beam background (3T → 2T)
  - The data at the inner radius @40M BX Z pole1 Module ~0.05Gbps

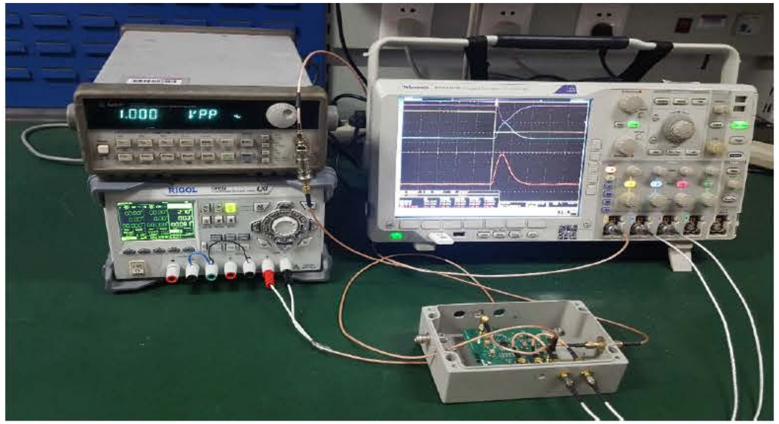




- **Performance and readiness of TPC detector R&D**

Power Consumption – TPC - Validation

- High granularity readout TPC： **3×10^{7}**
- Total power: <10 kW to need the power consumption **<100mW/cm^2**



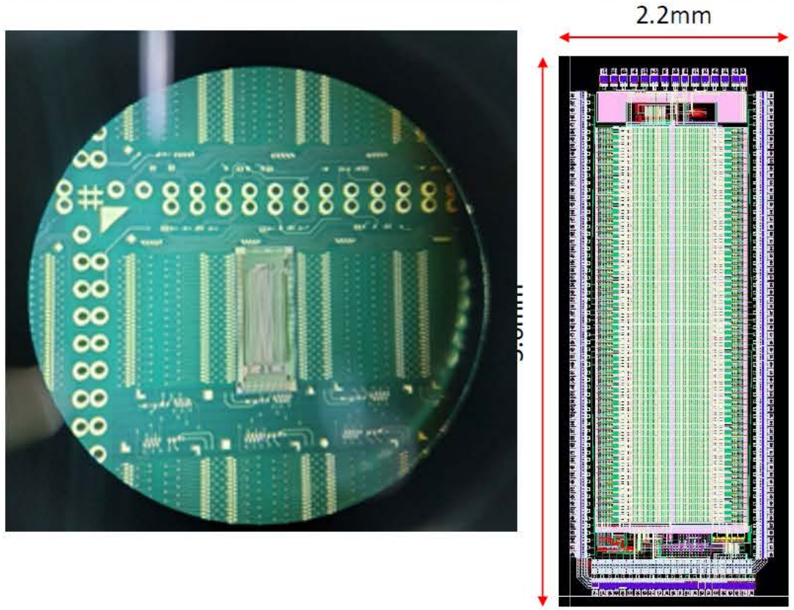
■ R&D on pixel TPC readout for CEPC

Pixel TPC ASIC chip was started to develop in 2023 and 1st prototype wafer standalone tested in May.

- ✓ Power consumption: <1.1mW/ch (1st prototype)
- ✓ <400mW/cm^2 (Test)

- 2nd prototype wafer design done
  - ✓ < 100mW/cm^2 (Goal and final design)

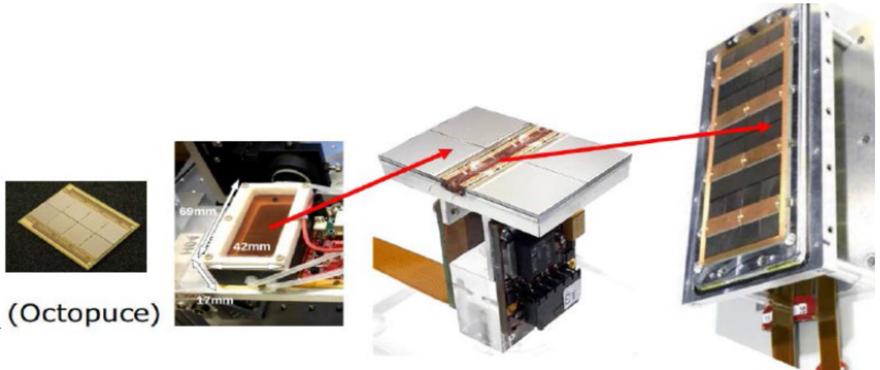
■ The TOA and TOT can be selected as the initiation function in the ASIC chip.



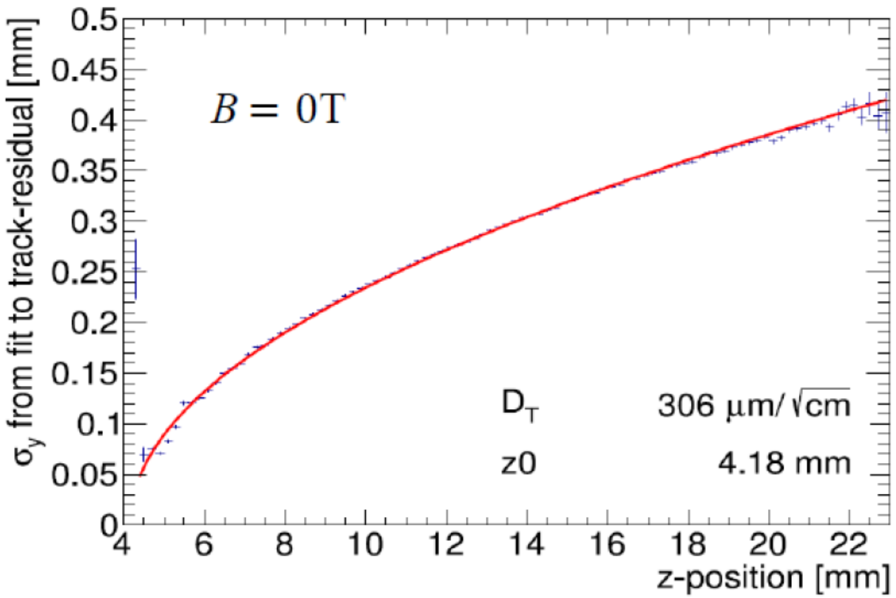
1st readout PCB board and the ASIC layout

GridPixes Pixel TPC Readout

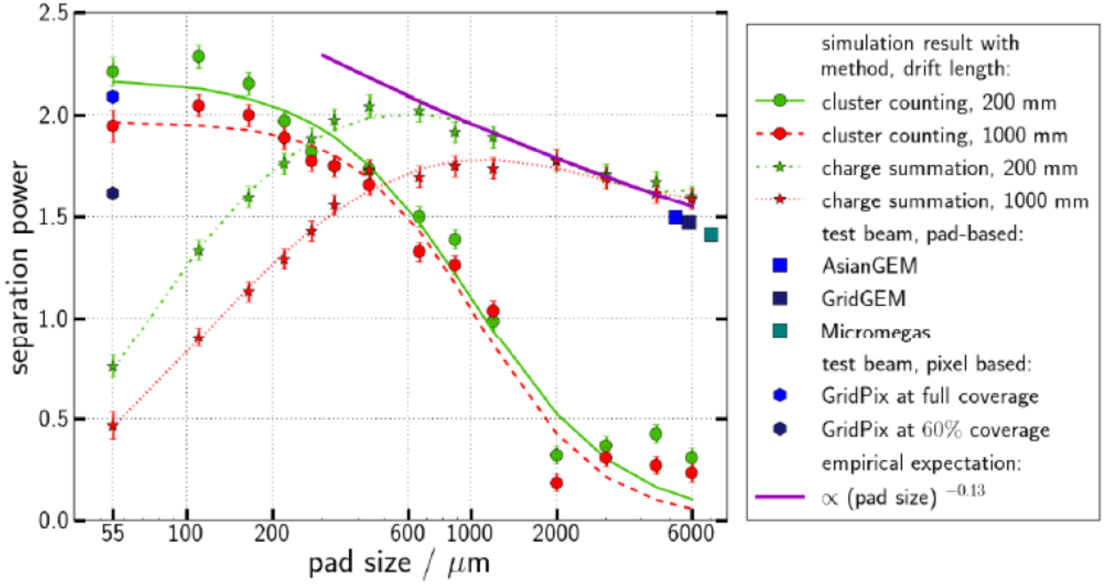
- Tests with single and quad devices have been successfully done.
- ~4.1% dE/dx resolution at B = 1.0T at DESY
- For very small readout pads the cluster counting method yields a very good separation power



TimePix1 2007 | TPX3 chip 2017 | Quad 2018 | Module 2019



https://doi.org/10.48550/arXiv.1902.01987



https://doi.org/10.1088/1748-0221/17/11/P11027

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Cost – TPC

- **TPC cost estimation**
  - Chamber
  - Endplate
  - Electronics
  - Alignment
  - HV and Gas system
- **Electronics and DAQ sections re-estimated and reduced**

TPC COST ESTIMATION (Unit: *10K RMB)							
			Detector concept/ Detector items	Unit	Unit cost (RMB)	Quantity	total cost (RMB)
Number			CEPC				
3.2			Time Projection Chamber				18000.00
	3.2.1		Chamber				3600.00
		3.2.1.1	Fieldcage		1200.00	1	1200.00
		3.2.1.2	Connector		800.00	1	800.00
		3.2.1.3	Barrel		600.00	1	600.00
		3.2.1.4	HV test bef. Assembly		400.00	1	400.00
		3.2.1.5	Support board		600.00	1	600.00
	3.2.2		Endplate				2500.00
		3.2.2.1	MPGD detector		800.00	1	800.00
		3.2.2.2	Support board		600.00	2	1200.00
		3.2.2.3	Readout bef. Assembly		2.50	200	500.00
	3.2.3		Electronics				10000.00
		3.2.3.1	FEE ASIC readout		0.012	200000	2400.00
		3.2.3.2	Cables		0.03	50000	1500.00
		3.2.3.3	Optical driver		0.03	50000	1500.00
		3.2.3.4	Optical link, connectors		1.00	500	500.00
		3.2.3.5	DAQ system		0.30	5000	1500.00
		3.2.3.6	Crate and controller		20.00	50	1000.00
		3.2.3.7	Cooling system		1600.00	1	1600.00
	3.2.4		Alignment and calibration				500.00
		3.2.4.1	Calibration system		500.00	1	500.00
	3.2.5		HV and Gas system				1400.00
		3.2.5.1	HV and low power		600.000	1	600.00
		3.2.5.2	Gas system		300.00	1	300.00
		3.2.5.3	Slow control system		300.00	1	300.00
		3.2.5.4	Shipping bef. Assembly		200.00	1	200.00

Many thanks!

To do (I): Pad size optimization

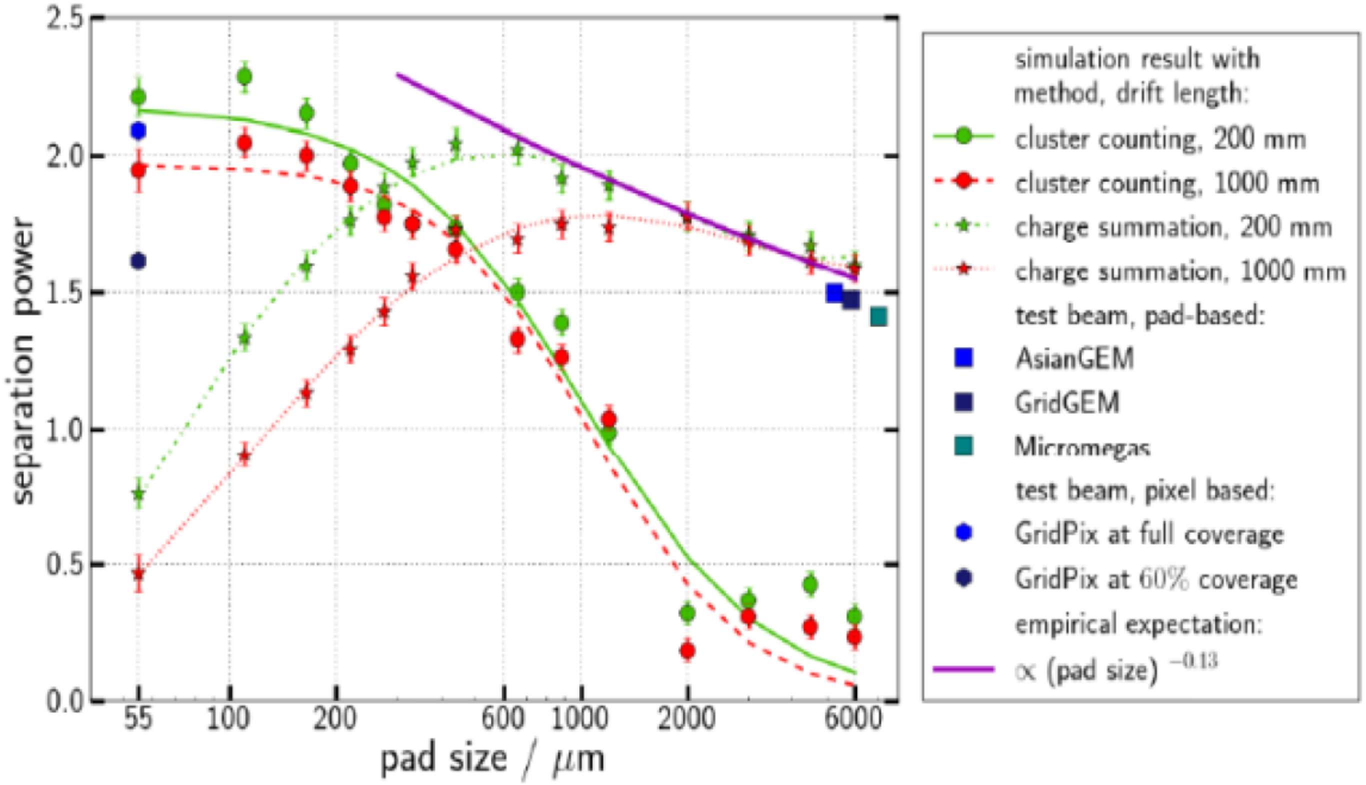
- dN/dx (and tracking) can be beneficial from smaller pad size

$$\rho_{cl} \approx 30cm^{-1} \Rightarrow Pad\ size \approx 300\mu m$$

(To detect single e^-)

- Need to find out the optimal pad size considering cost/power consumption

Simulation with 30 cm track length



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To do (II): Understand the 2021 DESY test beam

Need to understand their results and tune our simulation!

Extremely powerful PID performance:

- **> 6σ** @ 20 GeV/c, 1.4 m track length

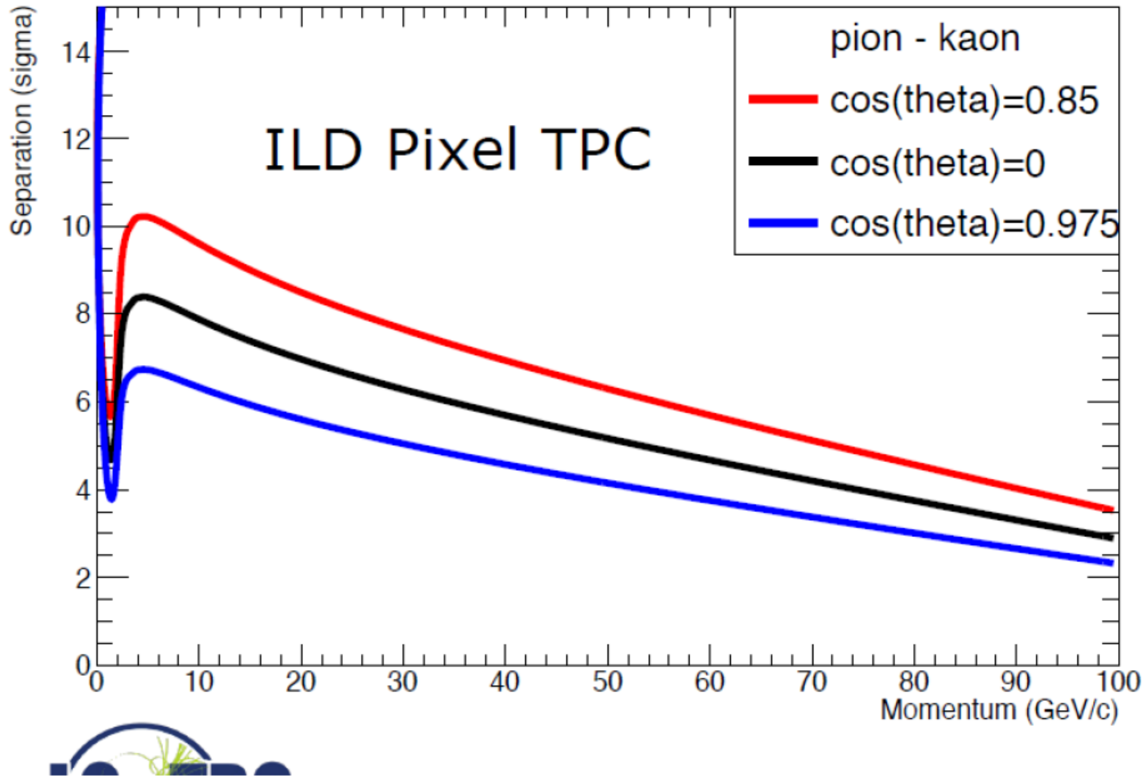
ILD detector

rInner = 329 rOuter = 1770 mm

MIP resolution = 3.6% at $\theta=\pi/2$

electron resolution = 2.5%

Assume Pixel TPC performance at
B = 1 T at p = 5,6 GeV/c



- Separation pion kaon
  $|\langle Eloss\ \pi\rangle - \langle Eloss\ K\rangle| / \sigma_\pi$
- Separation pion kaon for different cos(theta) values due to the track length dependence
- For cos(theta)=0 till 0.95 the separation lies between the black and red curves. Only above 0.95-0.975 the separation drops till the blue curve.
- Excellent performance over very large polar angle range