Pixelated readout TPC technology for CEPC Phy.&Det. TDR

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April 02, 2023

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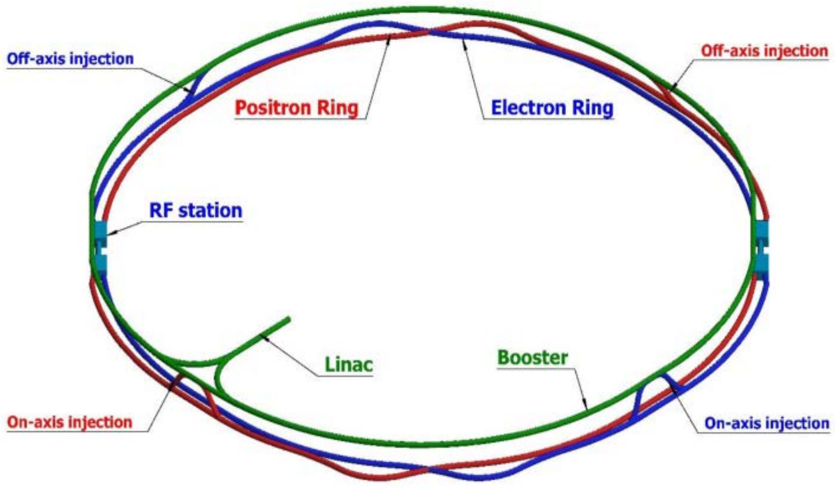
- **Motivation and physics requirements**
- **Pixelated readout TPC for CEPC TDR**
- **International collaboration**
- **Summary**

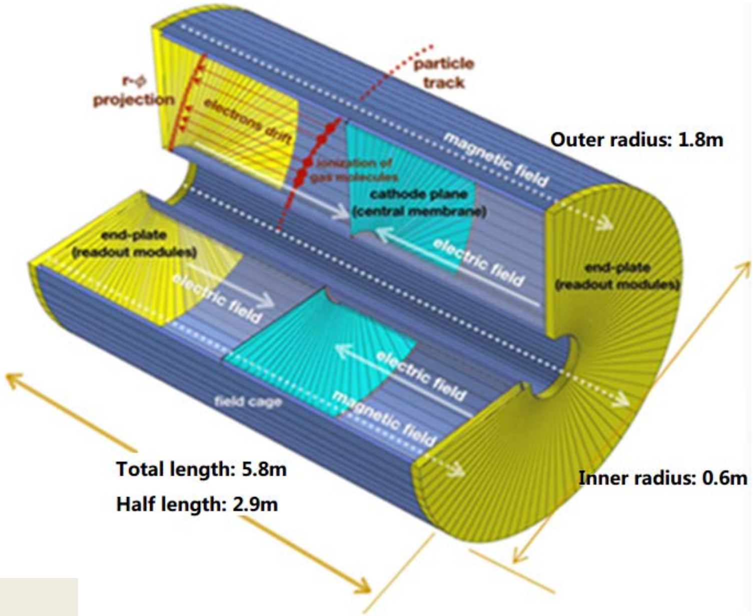
- **Motivation and physics requirements**

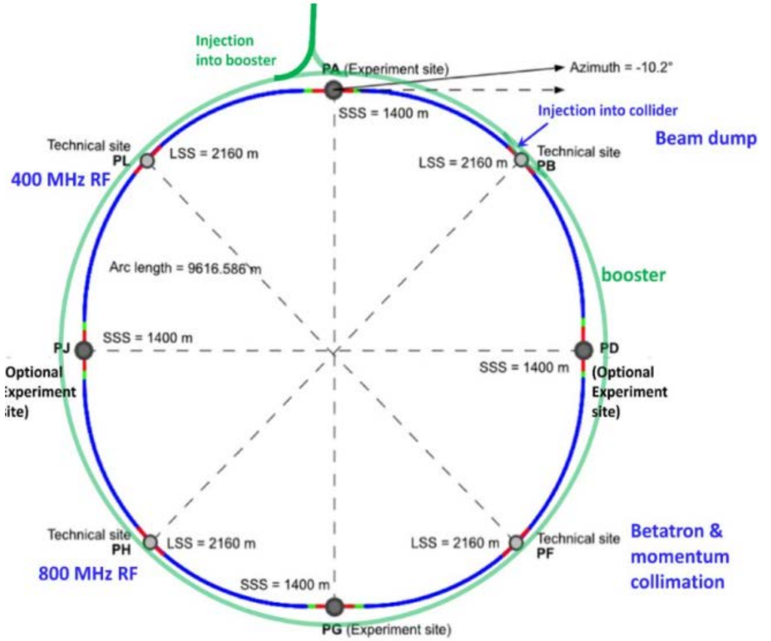
Motivation and physics requirements on e+e- collider

- A TPC is the main track detector for **some candidate experiments at future e+e- colliders**
  - Baseline detector concept of ALICE, STAR, CEPC CDR and ILD at ILC
  - TPC is a promised candidate as the main track detector in CEPC TDR
- TPC technology can be of interest for other future colliders (EIC, FCC-ee, KEKb…)
- Pixelated readout TPC is potential to **improve PID requirements of Flavor Physics** at e+e- collider.



Circular Electron Positron Collider (CEPC)





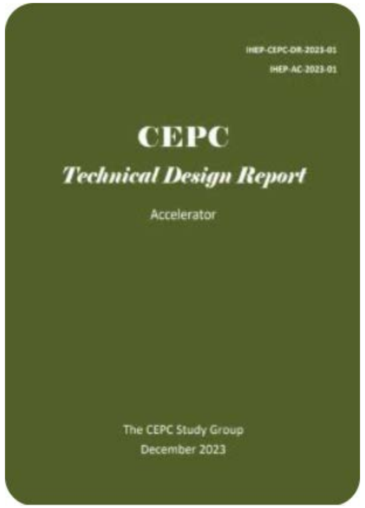
Future Circular Collider (FCCee)

https://arxiv.org/abs/1811.10545

https://arxiv.org/abs/2203.08310

Physics requirements of the track detector

- CEPC operation stages: **10-years Higgs → 2-years Z pole → 1-year W**
- CEPC phy./det. TDR (**preparation**)
  - Physics and detector concept designed under the principle.
  - **Requirements may be with regard to runs of Higgs and Z-pole separately**.
    - Mandatory requirements MUST be met.
    - Detector should primarily meet Higgs and run at Z also.



Chapter 3 of this report outlines that the CEPC is planned to be in operation for 8 months annually, totaling 6,000 hours. This operational schedule is used to calculate the cumulative absorbed doses for magnet coil insulations, as illustrated in Figure 4.2.4.16, considering a 10-year Higgs operation, 2-year Z operation, and 1-year W operation. Figure 4.2.4.17 displays the absorbed doses when an additional 5-year $t\bar{t}$ operation is included. These plots also include the upper limit for absorbed dose in epoxy resin, which is measured at 2×10^7 Gy [11].

CEPC- TDR p116

arXiv:2312.14363

Physics requirements on future circular e+e- collider

- **Phys. Requirements of the track detector**
  - TPC can provide thousands of hits with high spatial resolution compatible with PFA algorithm **(low X_0)**
- Beneficial for jet & differential at higher energy
  - BMR < 4% & pursue 3%
  - Highly requirements for excellent JOI & PID resolution (in Jets)
    - Provide **dE/dx + dN/dx** ~ 2-3%

	Processes @ c.m.s.	Domain	Total Det. Performance	Sub-D
H->ss/cc/sb	vvH @ 240 GeV	Higgs	PFA + JOI (Jet origin id)	All sub-D, especially VTX
Vcb	WW@ 240/160 GeV	Flavor	JOI + Particle (lepton) id	All
W fusion Xsec	vvH @ 360 GeV	Higgs	PFA + JOI	All
α_S	Z->tautau @ 91.2 GeV	QCD	PFA: Tau & Tau final state id	ECAL + Tracker material
B->DK	91.2 GeV	Flavor	PFA + Particle (Kaon) id	All, especially Tracker & ToF
Weak mixing angle	Z	EW	JOI	All
Higgs recoil	llH	Higgs	Leptons id, track dP/P	Tracker, All
H->bb, cc, gg	vvH	Higgs	PFA + JOI	All
	qqH	Higgs	PFA + JOI + Color Singlet id	All
H->inv	qqH	Higgs/NP	PFA	All
H->di muon	qqH	Higgs	PFA, Leptons id	Calo, All
H->di photon	qqH	Higgs	PFA, Photons id	ECAL, All
W mass & Width	WW@160 GeV	EW	Beam energy	NAN
Top mass & Width	ttbar@360 GeV	EW	Beam energy	NAN
Bs->vvPhi	Z	Flavor	Object in jets; MET	All
Bc->tauv	Z	Flavor	-	All
B0->2 pi0	Z	Flavor	Particle/pi-0 in jets	ECAL

Differential Efficiency.
Requirement: Pt threshold ~ o(100) MeV, |cos(theta)| < 0.99
Ref: CDR baseline design

Differential Material Budget.
Requirement: < 10%/50% X0 in Barrel/endcap
Ref: CDR baseline design + BMR & Material Dependence

Differential Resolution of 5 track parameters.
Requirement: In the barrel
δ(D0/Z0) ~ < 3 micro meter at 20 GeV
δ(Pt)/Pt ~ o(0.1%)
Ref: CDR baseline performance

Differential Pid Capability: eff*purity of Kaon id @ Z pole.
Requirement: eff*purity > 90% for all charged Kaon (@ Z pole)
~ relative resolution of dE/dx (or dN/dx) be better than 3%
ToF of 50 ps
Ref: Nuclear Inst. and Methods in Physics Research, A 1047 (2023) 167835

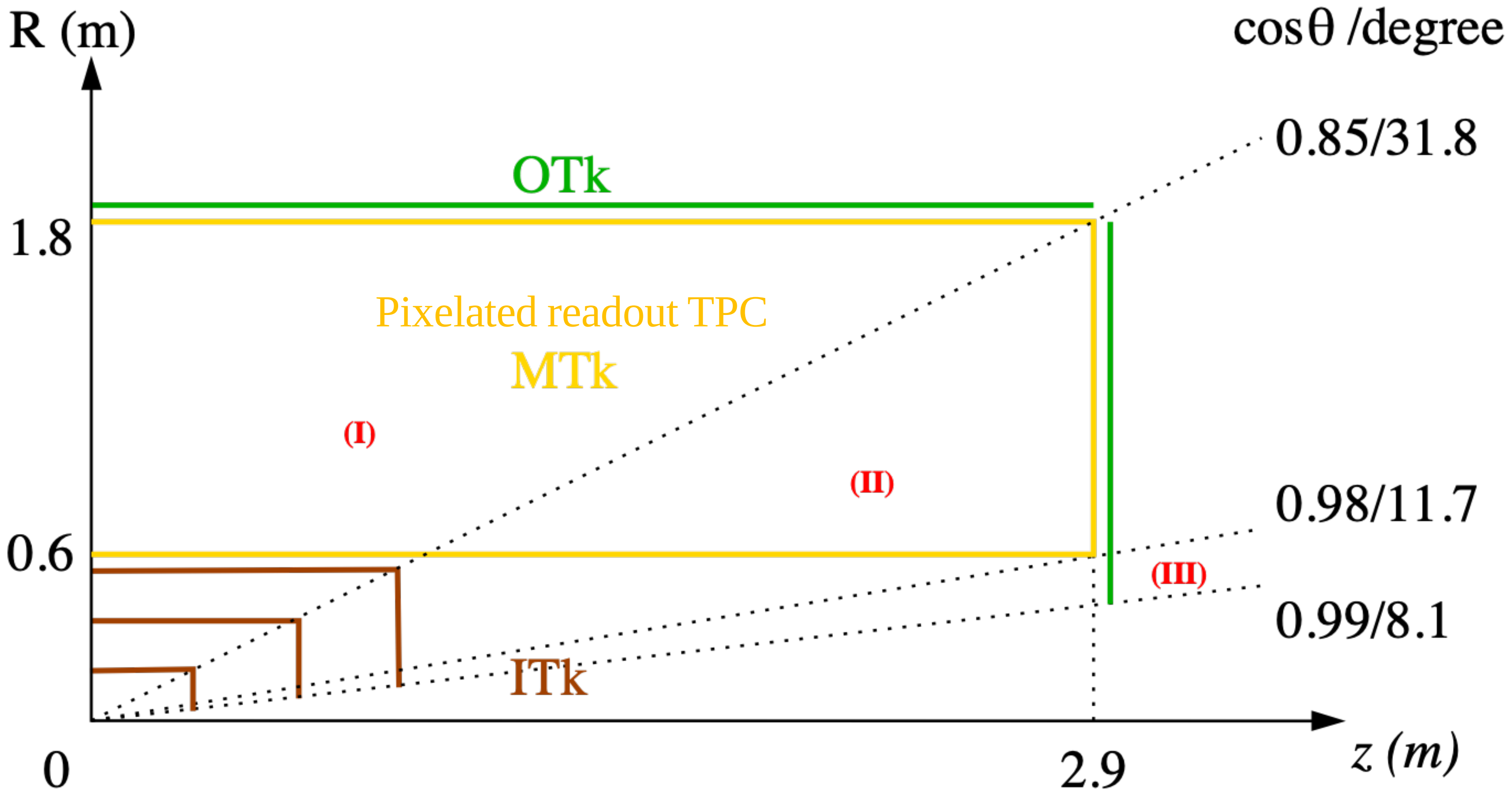
Sep. power: On 3 prong tau decay @ Z pole.
Requirement: efficiency > 99% at 3-prong tau
Ref: CDR baseline performance

Table from IAS2024 conference in January

- **Pixelated readout TPC for CEPC TDR**

Track detector system in CEPC Phy.&Det. TDR

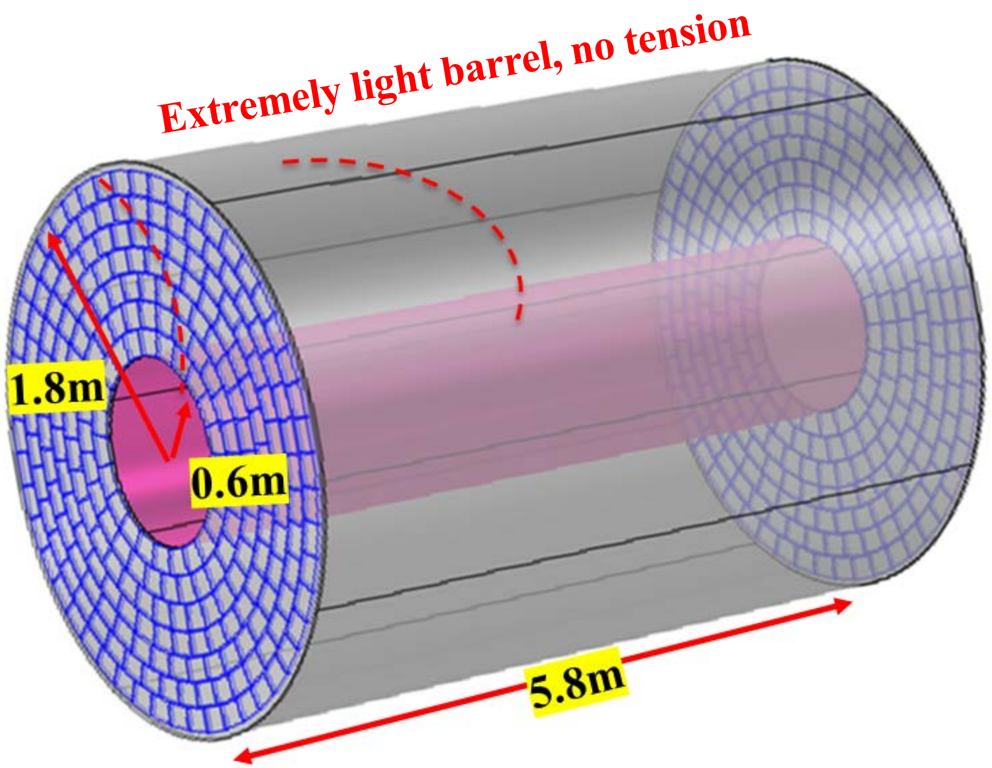
- The track detector system's geometry finalized.
  - All of physics simulation used the updated geometries for CEPC TDR document
  - Pixelated readout TPC as the **main track (MTK)** from radius of 0.6m to 1.8m

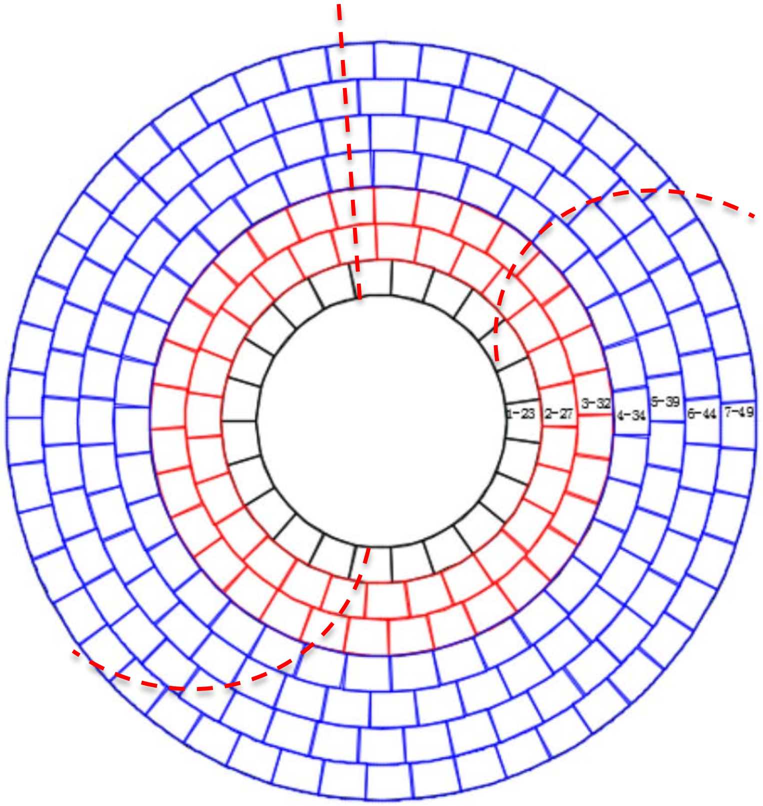


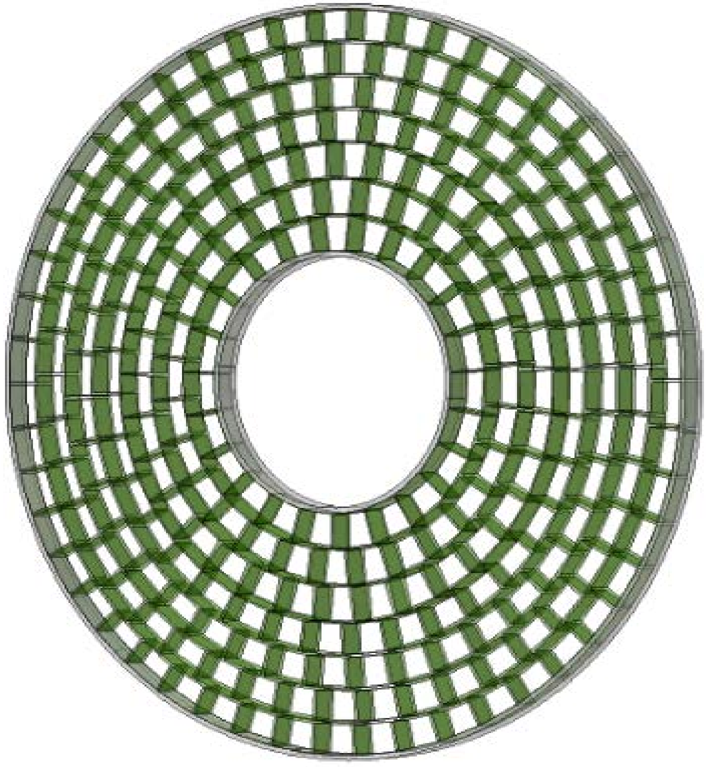
Geometry of the track detector system in CEPC TDR

Easy-to-install modular design of Pixelated readout TPC for TDR

- Pixelated readout TPC can operate at Higgs in **3.0T** and Tera-Z in **2.0T without any E×B effect**
- Easy-to-install modular design: optimized modules in the endcap
  - Modular installation and replacement, **extremely light** TPC barrel design along the drift length
  - Coverage of the sensitivity readout area increased **to 96% at the endcap**



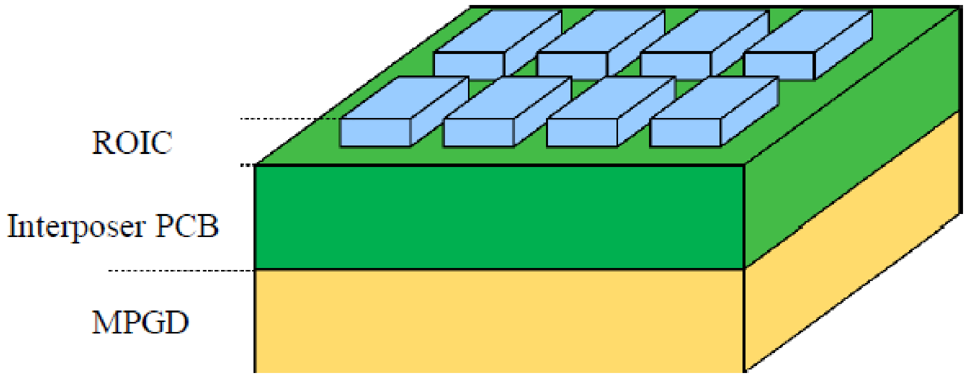


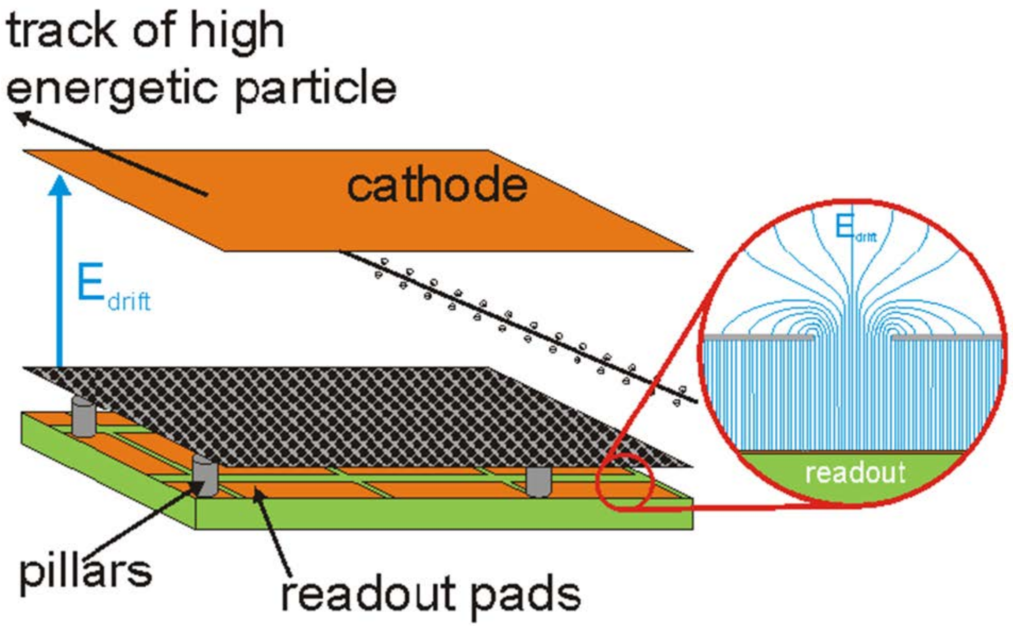


Optimization of Geometry of TPC detector and the Endplate

Pixelated readout TPC technology

- A pixelated readout TPC is a good option to provide realistic physics requirements and can work at high luminosity (2E36) on CEPC.
  - Pixelated readout→ **better resolution** → low gain → less distortion
- **Highlights** of Pixelated readout TPC technology for CEPC TDR
  - Can deal with high rates (MHz/cm^2)
  - High spatial resolution → better momentum resolution
  - PID: dE/dx + dN/dx (**In space**)
  - Excellent two tracks separation



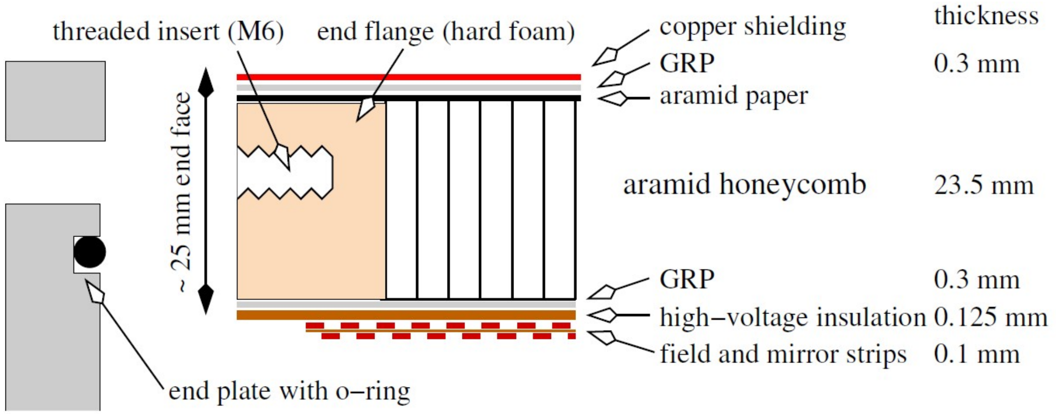


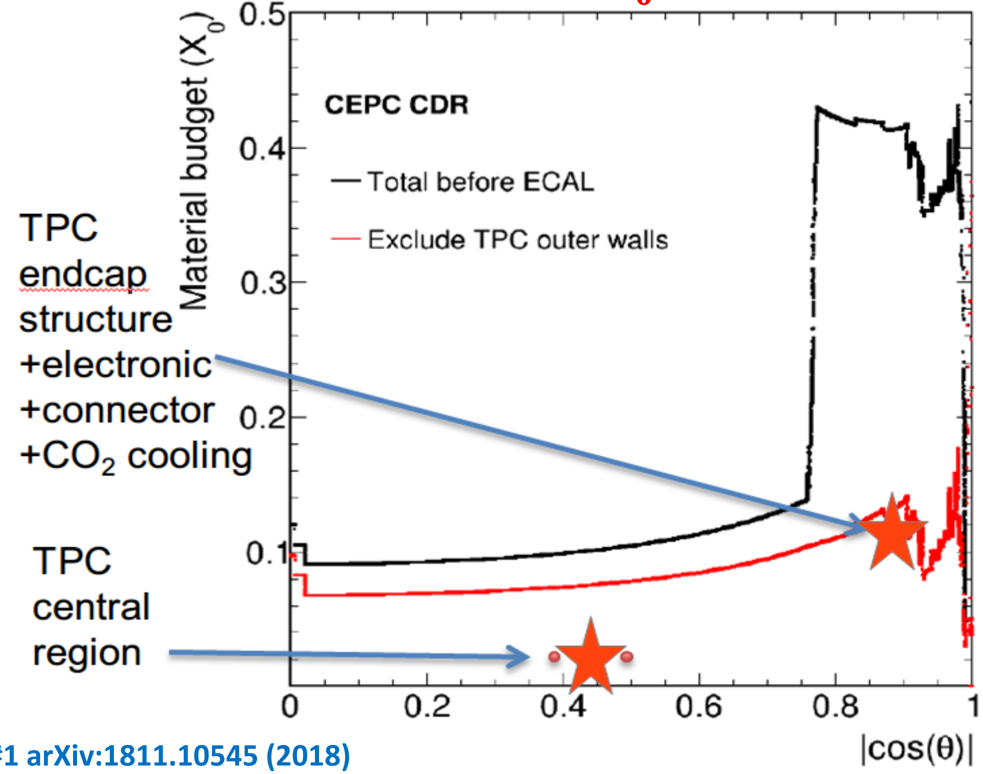
- **Feasibility studies of the pixelated readout TPC for CEPC TDR**
  - **Material budget at endcape/barrel**
  - **Occupancy and hit density**
  - **Improved dE/dx+dN/dx**
  - **Ion backflow suppression**
  - **Reasonable channels and power consumption**
  - **Running at 2 Tesla**
  - **Beamstrahlung and distortion**
  - **Cost estimation**
  - **International collaboration**

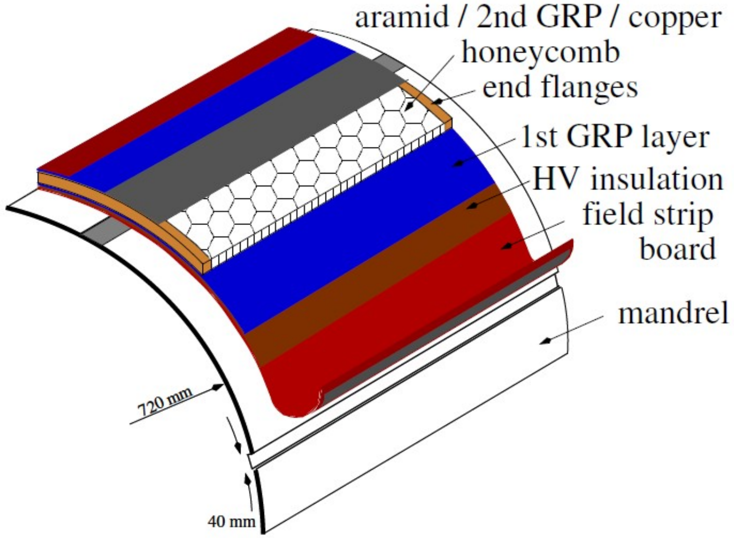
Critical key issues

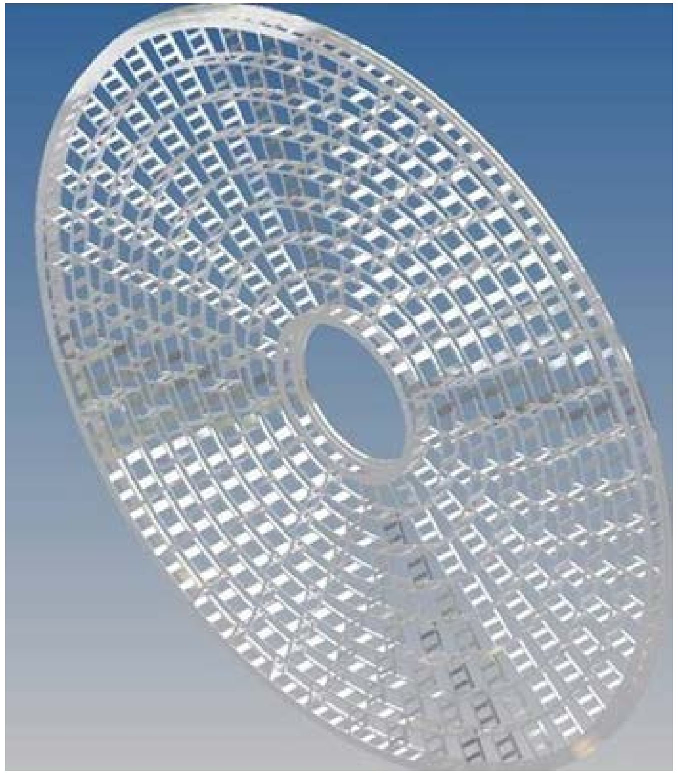
#1. Material budget at endcape/barrel √

- Barrel of the material budget
  - Material budget of **1.2%X_0** was reached
  - Operation gas (**negligible**): 1.2kg/m^3
- Endcap of the material budget
  - Readout plane, electronics, detector: <**5%X_0**
  - Cooling: <**2%X_0**
  - Power cables: <**10%X_0**





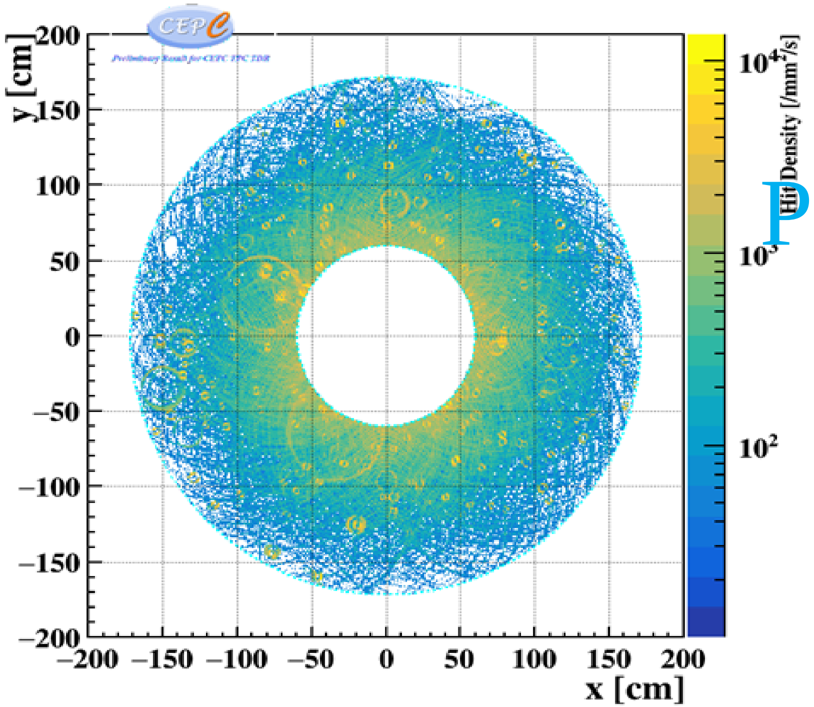


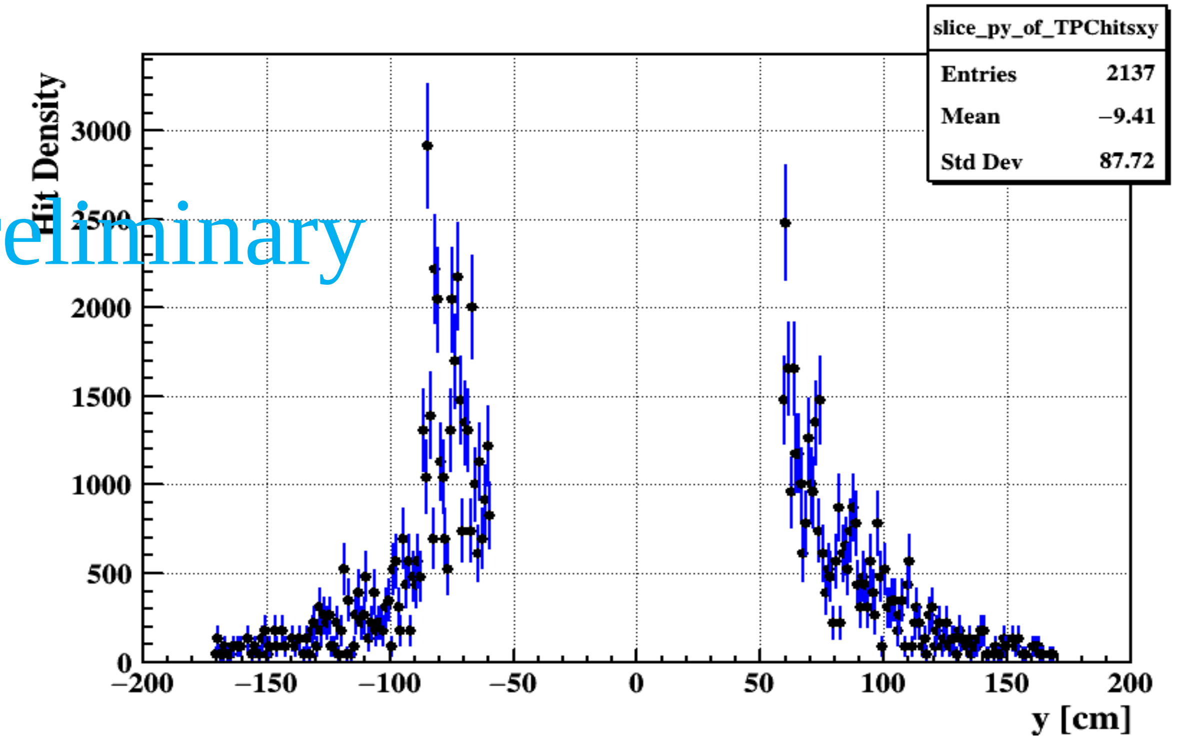


Cite#1 arXiv:1811.10545 (2018)

#2. Occupancy and hit density √

- **Low voxel occupancy** : 1E-5 to 1E-6 (cite#2)
- At 2 E36 with Physics event only, even bunch distribution(cite#3).
  - Pixelated readout much **LOWER** inner most occupancy (**0.6m inner radius**)
  - Pixelated readout can easily handle a high hits rate at Z pole. (cite#4)
  - The data at the inner radius @40M BX Z pole@1 Module ~0.05Gbps(Maximum).





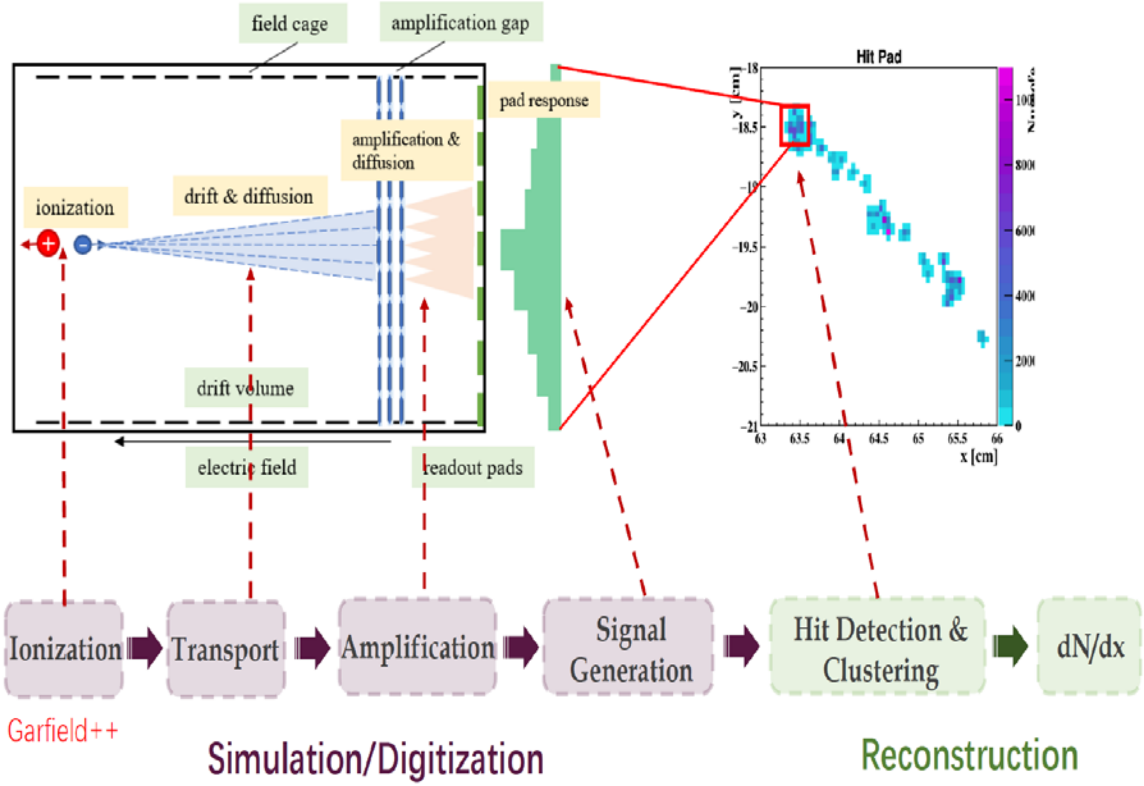
Simulation of Tera-Z/CEPC with the beamstruggle

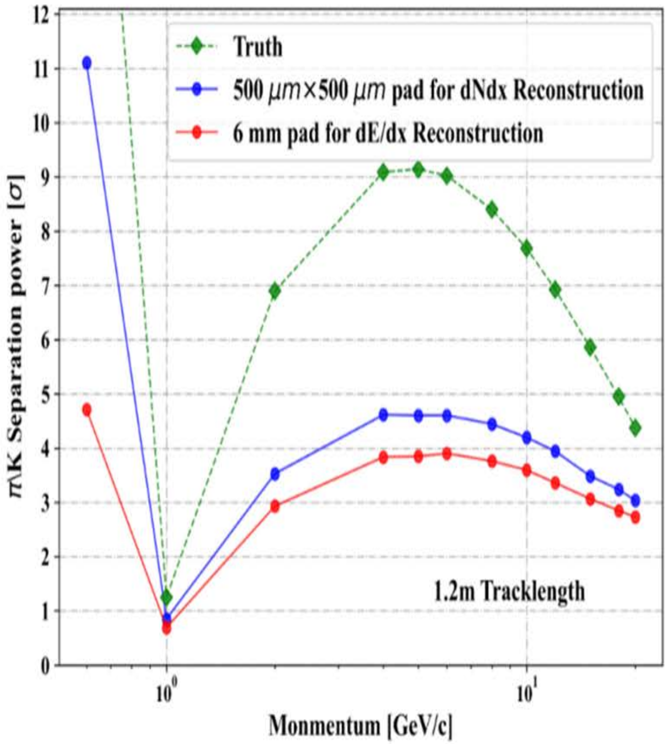
Cite#2 Occupancy in the CLIC
Cite#3 https://doi.org/10.1088/1748-0221/12/07/P07005
Cite#4 GridPix detectors

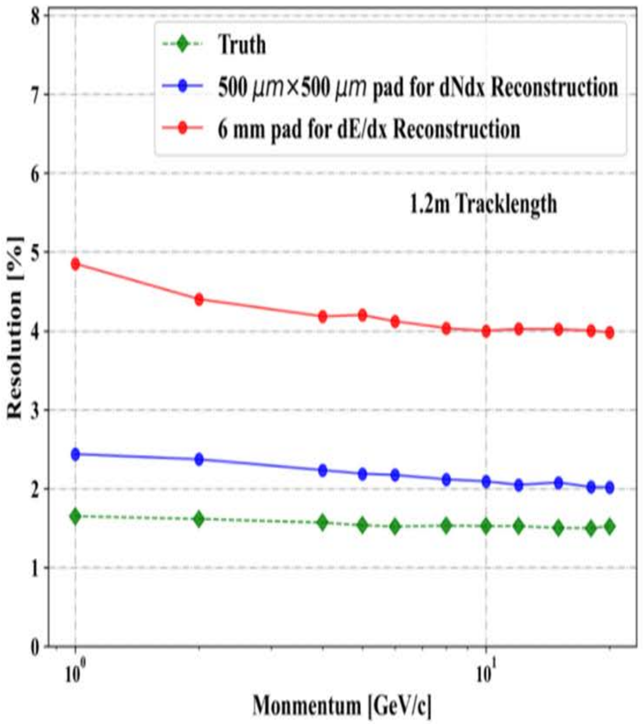
#3. Improved dE/dx+dN/dx √

- Full simulation framework of pixelated TPC developed using Garfied++ and Geant4 at IHEP
- Investigating the π/κ separation power using reconstructed clusters, **a 3σ separation at 20GeV** with 50cm drift length can be achieved
- dN/dx has significant potential for **improving PID resolution**

$$Sp = \frac{|\mu_A - \mu_B|}{\frac{\sigma_A + \sigma_B}{2}}$$







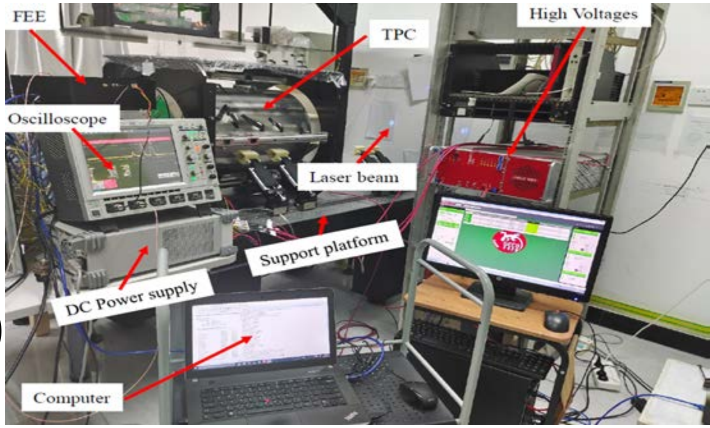
Cite#5 DOI: 10.22323/1.449.0553

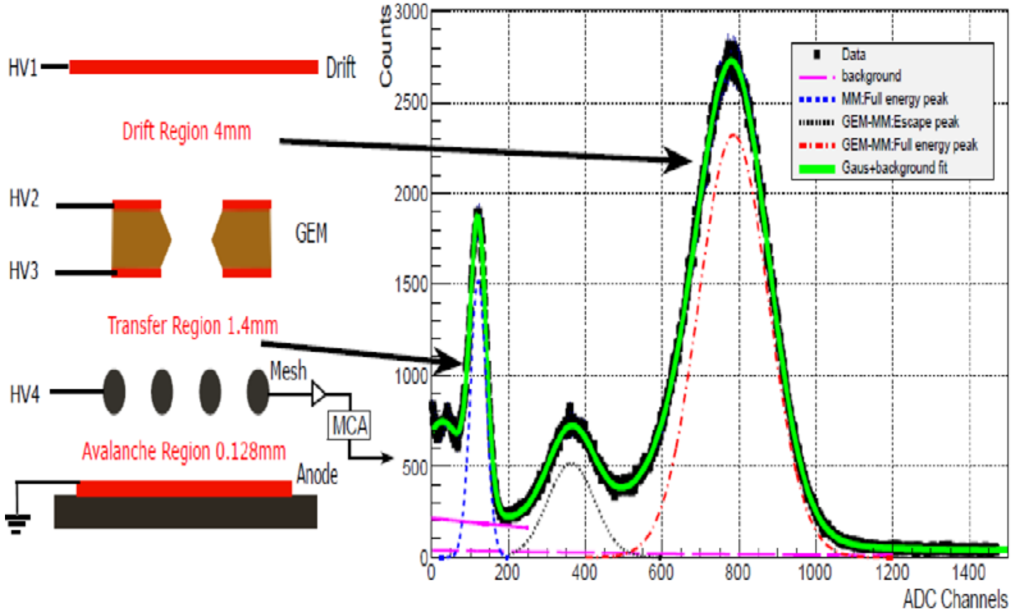
Cite#6 EPS-HEP 2023 talk by Yue Chang

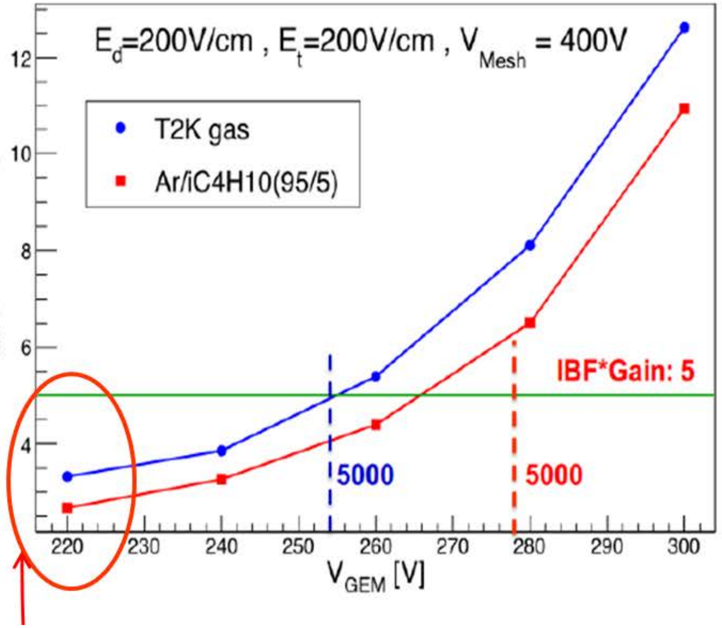
Simulation of TPC detector under 3T/2T and T2K mixture gas

#4. Ion backflow suppression √

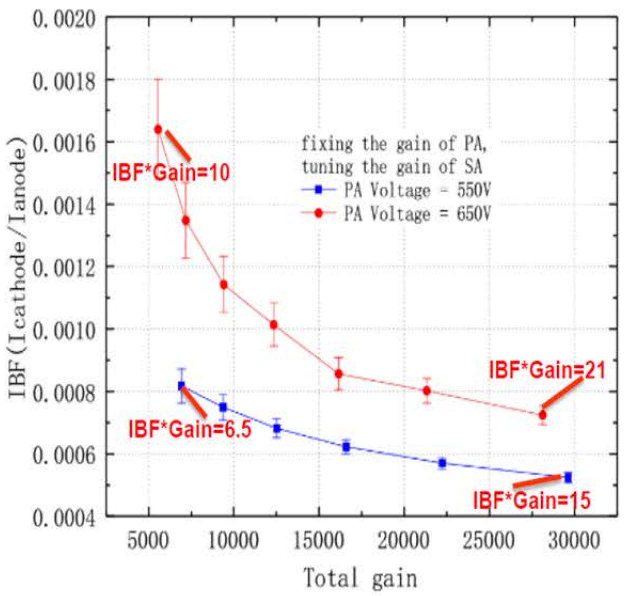
- Achievement by far from TPC module and prototype:
  - Supression ions hybrid TPC module
    - **IBF×Gain ~1 at Gain=2000 validation** with TPC module
  - Spatial resolution of **$\sigma_{r\varphi}$≤100 µm** by TPC prototype
  - dE/dx for PID: <3.6% (as expected for CEPC baseline detector concept)
  - Graphene foil suppression (on going @ Shangdong University)







IBF of double mesh MM @USTC/Jianbei Liu

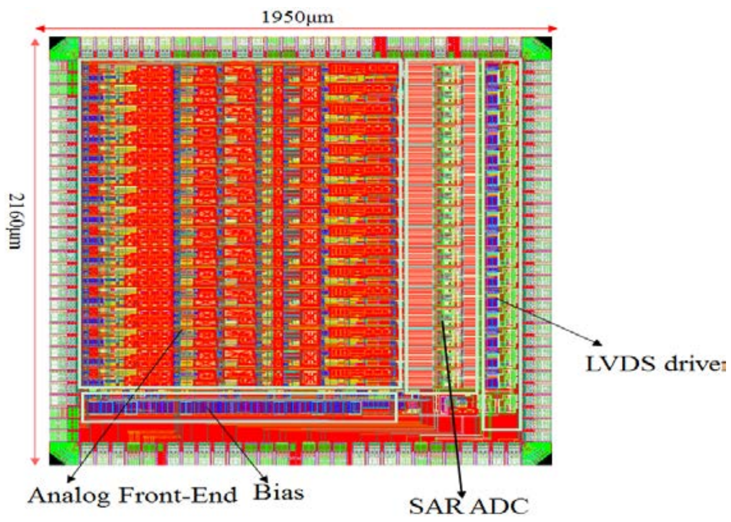


Cite#7: DOI:10.1016/j.nima.2020.164282
Cite#8: CERN-OPEN-2021-012. 2021
Cite#9: IJMPA 36.22 (20212142015

Hybrid TPC module and Double-mesh detector module

#5. Reasonable channels and power consumption √

- Power consumption relative with the high granularity readout
  - Pad readout TPC@1mm×6mm pad size
    - Total channels: **10^6** ; Total power: **<10 kW** using 2-phase CO_2 cooling
  - Pixelated readout TPC at the endcap
    - Total power: **<10 kW**
      - 2-Phase CO_2 cooling
      - **<100mW/cm^2**
  - ASIC chip and TPC prototyping R&D



	PASA+ALTRO	Super-ALTRO	SAMPA	WASA_v1
TPC	ALICE	ILC	ALICE upgrade	CEPC
Pad Size	4x7.5 mm^2	1x6 mm^2	4x7.5 mm^2	1x6 mm^2
No. of Channels	5.7× 10^5	1-2 × 10^6	5.7 × 10^5	2 x×10^6
Readout Detector	MWPC	GEM/MicroMegas	GEM	GEM/MicroMegas
Gain	12 mV/fC	12-27 mV/fC	20/30 mV/fC	10-40 mV/fC
Shaper	CR-(RC)^4	CR-(RC)^4	CR-(RC)^4	CR-RC
Peaking time	200 ns	30-120 ns	80/160 ns	160-400 ns
ENC	370+14.6 e/pF	520 e	246+36 e/pF	569+14.8 e/pF
Waveform Sampler	Pipeline ADC	Pipeline ADC	SAR ADC	SAR ADC
Sampling Rate	10 MHz	40 MHz	10 MHz	10-100 MHz
Sampling Resolution	10 bit	10 bit	10 bit	10 bit
Power: AFE	11.7 mW/ch	10.3 mW/ch	9 mW/ch	1.4 mW/ch
Power: ADC	12.5 mW/ch	33 mW/ch	1.5 mW/ch	0.8 mW/ch@40 MHz
Power: Digital Logics	7.5 mW/ch	4.0 mW/ch	6.5 mW/ch	2.7 mW/ch@40 MHz
Total Power	31.7 mW/ch@10MHz	47.3 mW/ch@40 MHz	17 mW/ch@10 MHz	4.9 mW/ch@40 MHz
CMOS Process	250 nm	130 nm	130 nm	65 nm

Cite#10: DOI: 10.1088/1748-0221/15/02/T02001
Cite#11: DOI: 10.1088/1748-0221/15/05/P05005

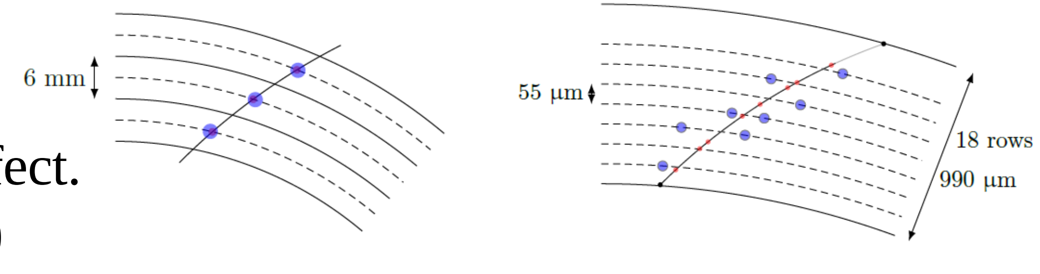
Option: Pixelated readout TPC @cosθ≃0.98

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	120μm (full drift)	400μm (full drift)
σ_{point} in rz	≃ 0.1 – 0.4 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 σ	3 σ
dE/dx	3.2%	3.2%
Momentum resolution normalised: $\sigma_{1/pT} = \sqrt{a^2 + (b/pT)^2}$	a = 1.210 e -5	a = 2.69 e -5
	b = 0.589 e -3	b = 0.90 e -3

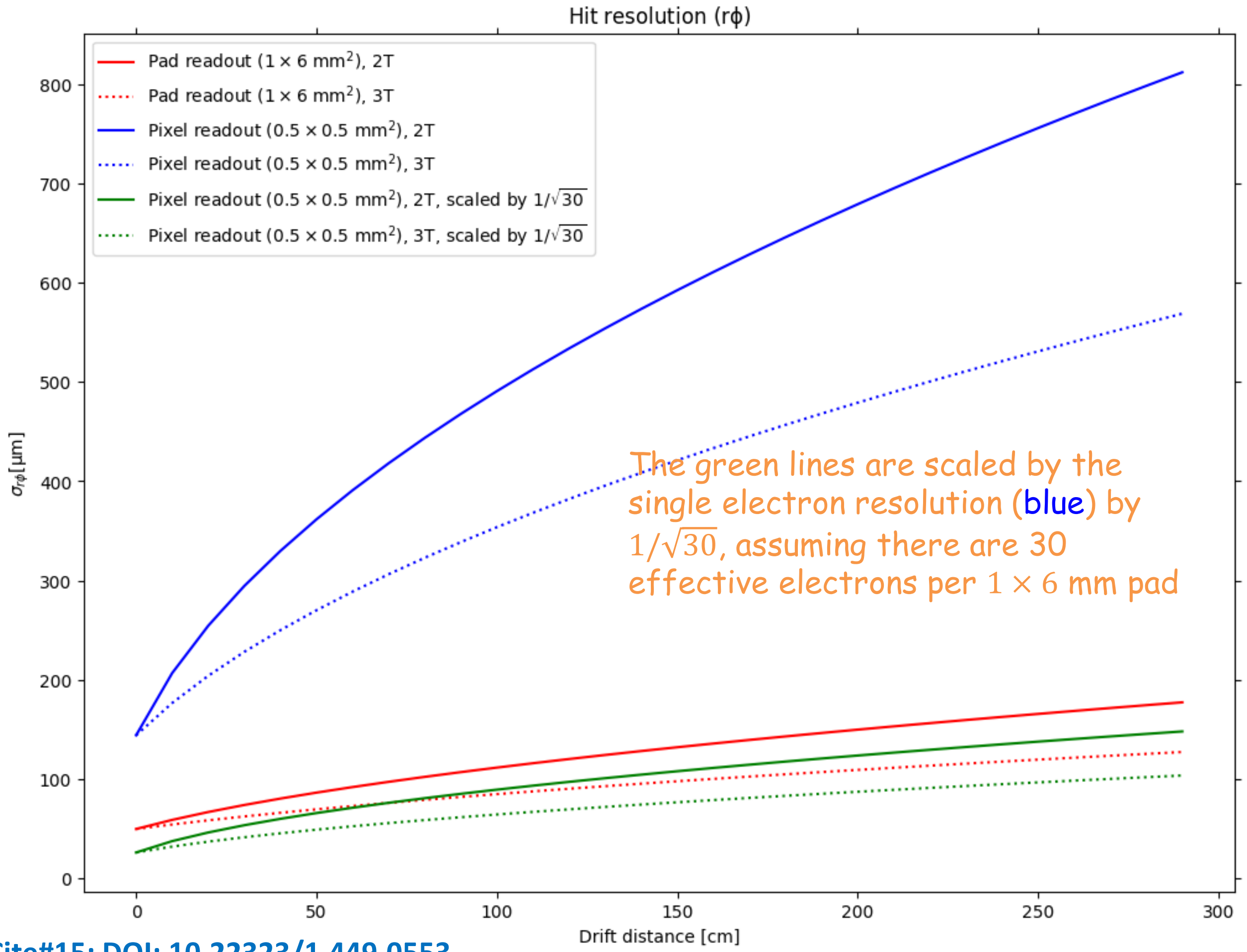
#6. Running at 2 Tesla √

Estimation of the **spatial resolution using pixelated readout**.

- The granularity and the transverse diffusion considered.
- TPC can work well at the 2T B-field **without any E×B** effect.
- Distortion will be considered proportionally at Z (on going)



(a) Pads (b) Pixels



Pad readout:

$$\sigma_{r\phi}^{\text{pad}} = \sqrt{(\sigma_{r\phi 0}^{\text{pad}})^2 + \sigma_{\phi 0}^2 \sin^2(\phi_{\text{track}}) + L\frac{D_{r\phi}^2}{N_{\text{eff}}}\sin(\theta_{\text{track}})\left(\frac{6\text{ mm}}{h_{\text{pad}}}\right)\left(\frac{4.0\text{ T}}{B}\right)^2}$$

- $\phi_{\text{track}} = 0°, \theta_{\text{track}} = 90°$
- $\sigma_{r\phi 0} = 50\mu\text{m}$
- $N_{eff} = 22$
- $D_{r\phi} = 46.9\mu\text{m}/\sqrt{\text{cm}}(2\text{T}), 32.3\mu\text{m}/\sqrt{\text{cm}}(3\text{T})$

Pixel readout:

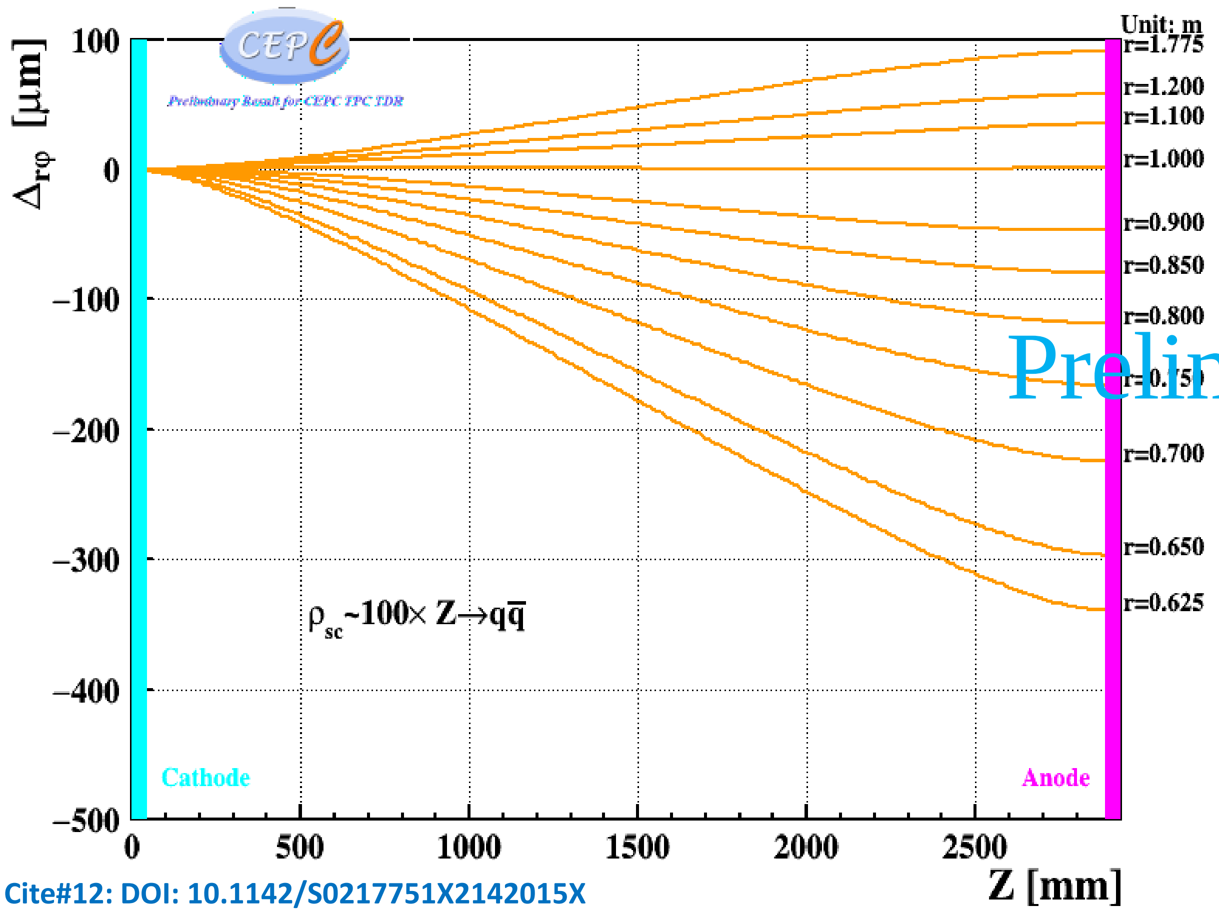
$$\sigma_r^{\text{pixel}} = \sigma_{r\phi}^{\text{pixel}} = \sqrt{(\sigma_{r\phi 0}^{\text{pixel}})^2 + LD_{r\phi}^2\left(\frac{4.0\text{ T}}{B}\right)^2}$$

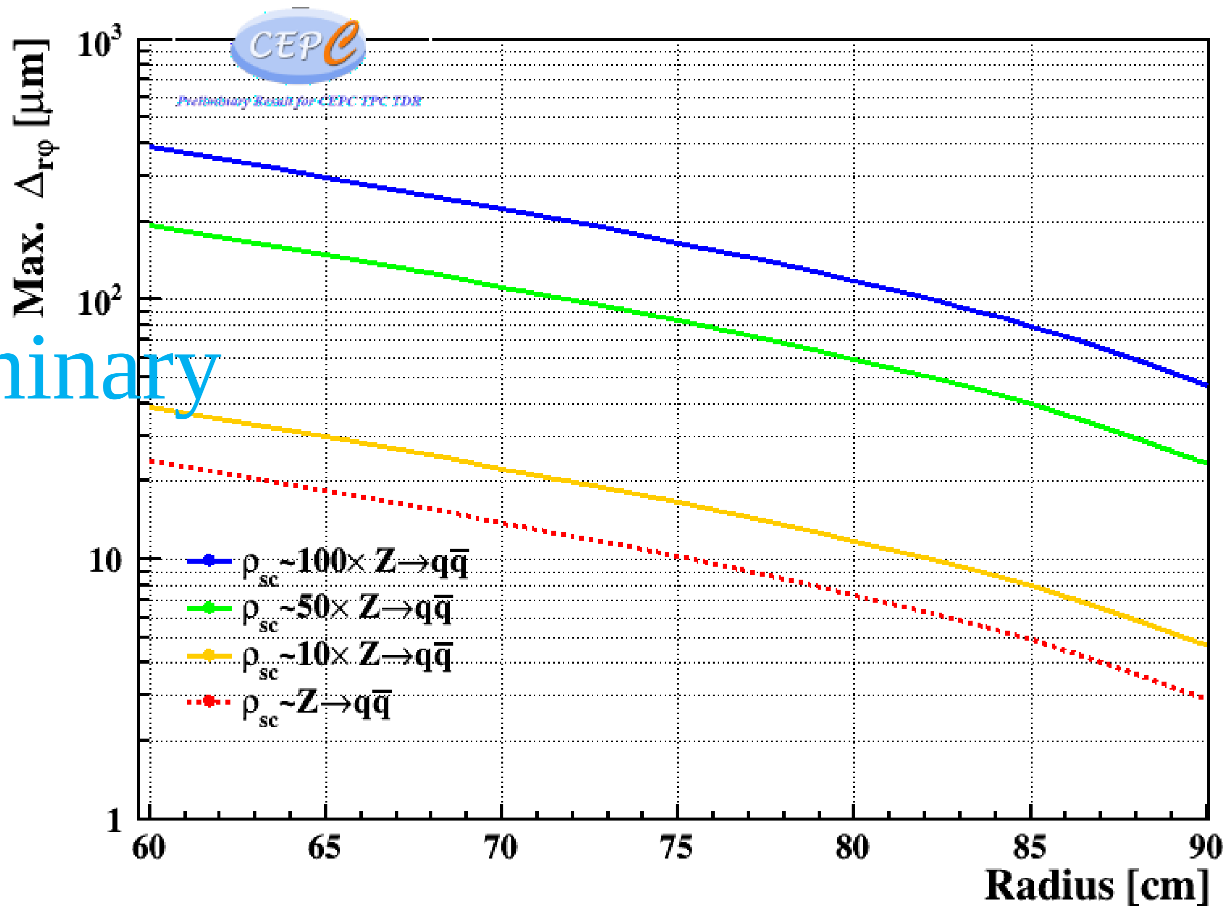
- $\sigma_{r\phi 0} = \frac{500}{\sqrt{12}} = 144\mu\text{m}$
- $D_{r\phi} = 46.9\mu\text{m}/\sqrt{\text{cm}}(2\text{T}), 32.3\mu\text{m}/\sqrt{\text{cm}}(3\text{T})$

Cite#15: DOI: 10.22323/1.449.0553

#7. Beamstrahlung and distortion √

- Maximum distortion with e+e- to qq at Z pole (Physics events only)
- Maximum distortion under the different Beamstrahlung background (×10, ×50 , ×100 times Physics events)
  - MDI design at Z need carefully optimized with MDI group in CEPC





Cite#12: DOI: 10.1142/S0217751X2142015X
Cite#13: DOI: 10.1016/j.nima.2022.167241
Cite#14: DOI: 10.1088/1748-0221/12/07/P07005

#8. Cost estimation √

- **Cost estimation**: ~170 Million RMB (Detector 80 Million + Electronic/DAQ 90 Million)

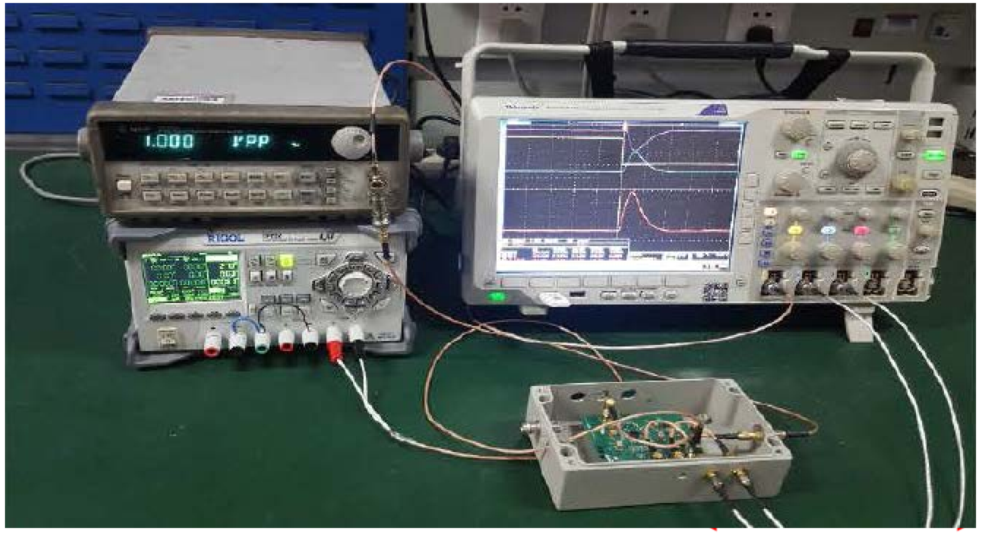
TPC COST ESTIMATION (Unit: *10K CNY)							
			Detector concept/ Detector items	Unit	Unit cost (CNY)	Quantity	total cost (CNY)
Number			CEPC				
3.2			Time Projection Chamber				17000.00
	3.2.1		**Chamber**				**3600.00**
		3.2.1.1	Fieldcage		1200.00	1	1200.00
		3.2.1.2	Connector		800.00	1	800.00
		3.2.1.3	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**				**9000.00**
		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	4000	1200.00
		3.2.3.6	Crate and controller		20.00	20	400.00
		3.2.3.7	TPC cooling system		1500.00	1	1500.00
	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	Testing bef. Assembly		200.00	1	200.00

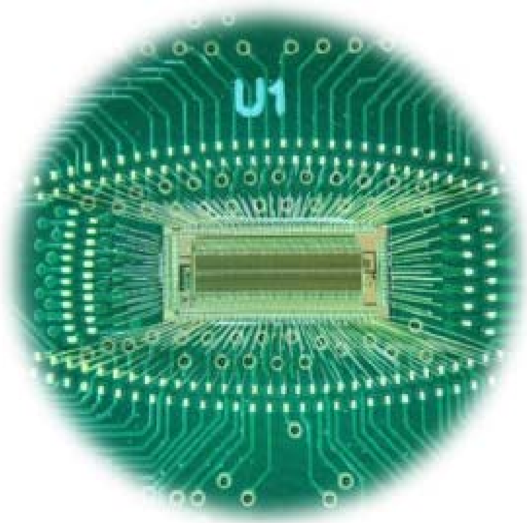
Cite#16: Cost estimation of ILD concept

Status of the prototype of pixelated TPC for TDR √

- **R&D on Pixelated TPC readout for CEPC TDR**
  - Macro-Pixel TPC ASIC chip was started to developed and **2nd prototype wafer has done** and tested
  - The **TOA and TOT** can be selected as the initiation function in the ASIC chip
    - 500μm×500μm pixel readout designed
    - Noise of FEE: 100e
    - Time resolution: **14bit** (5ns bin)
    - **Power consumption: <0.3mW/pixel (2nd prototype)**
      - **~100mW/cm²**
    - Technology: 180nm CMOS -> 60nm CMOS
    - High metal coverage: 4-side bootable

- **Prototyping pixelated TPC detector using the chips**
  - Principle of the prototype is no problem for testing
  - The validation of the prototype in April and May





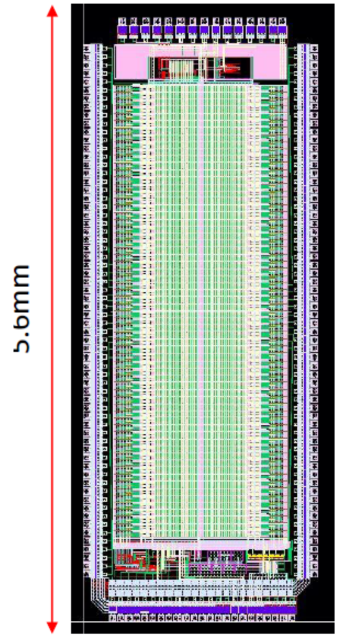


Photo and layout of ASIC Chip R&D for TPC

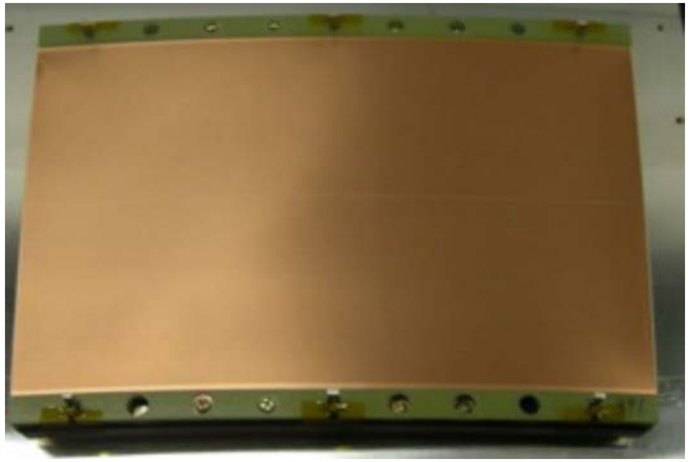
Cite#17: ILD conference 2024 January by Zhi Deng

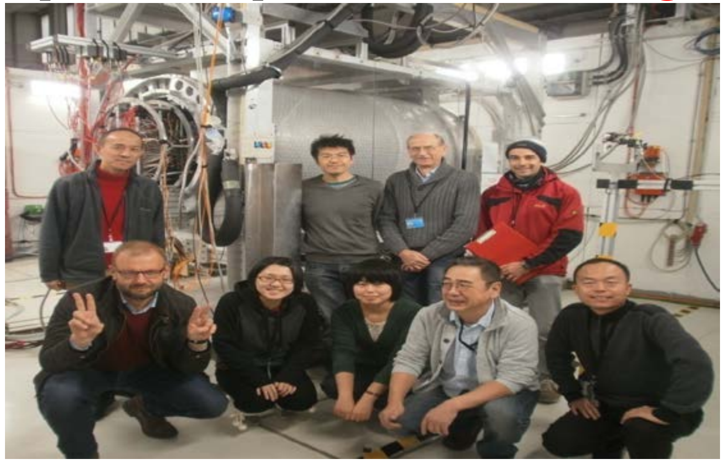
- **International collaboration**

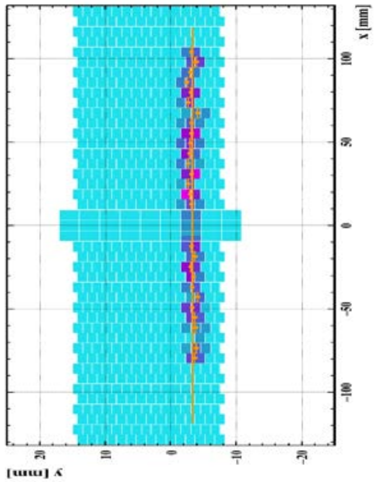
Activity international collaboration - TPC technology R&D

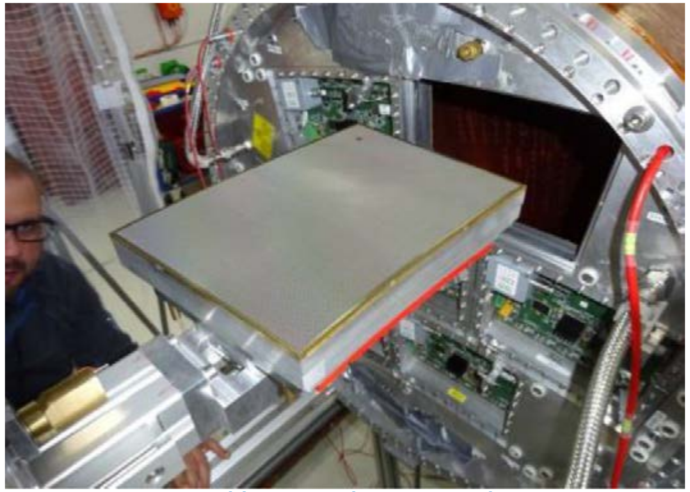
- Large Prototype setup have been built to compare different detector readouts for Tera-Z
  - PCMAG: B < 1.0T, bore Ø: 85cm, Spatial resolution of σrϕ≤100 μm
  - Pad readout and Pixelated readout from **IHEP and LCTPC collaboration**
  - Collaboration want to implement improvements in a **new generation of modules**

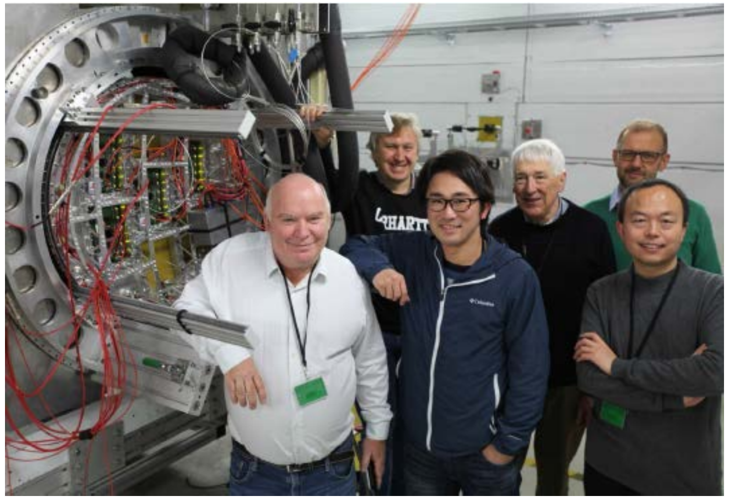
ArXiv. (2023)2006.08562
NIM A (2022) 167241
ArXiv (2022)2006.085
JINST 16 (2021) P10023
JINST 5 (2010) P10011
NIM A608 (2009) 390-396

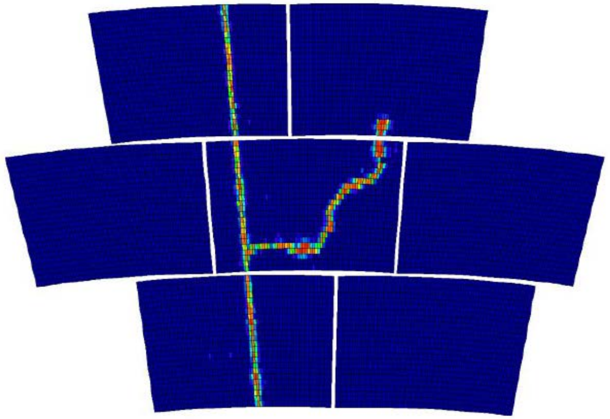








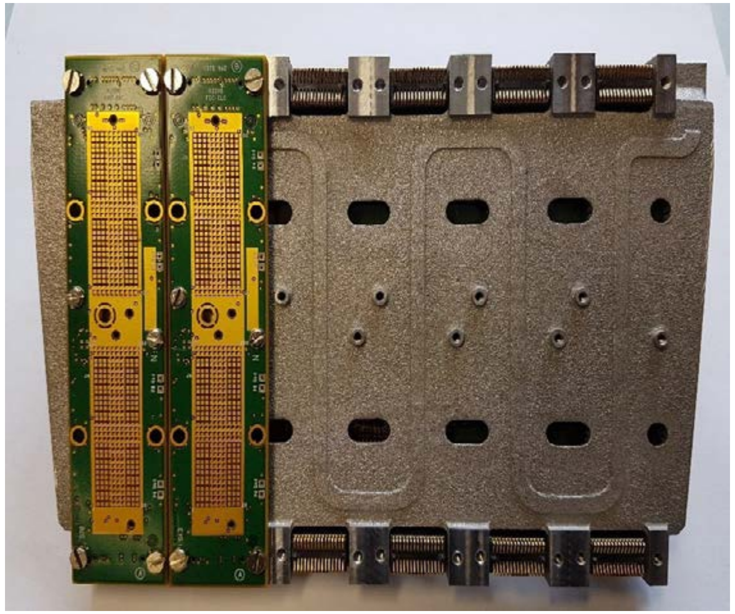


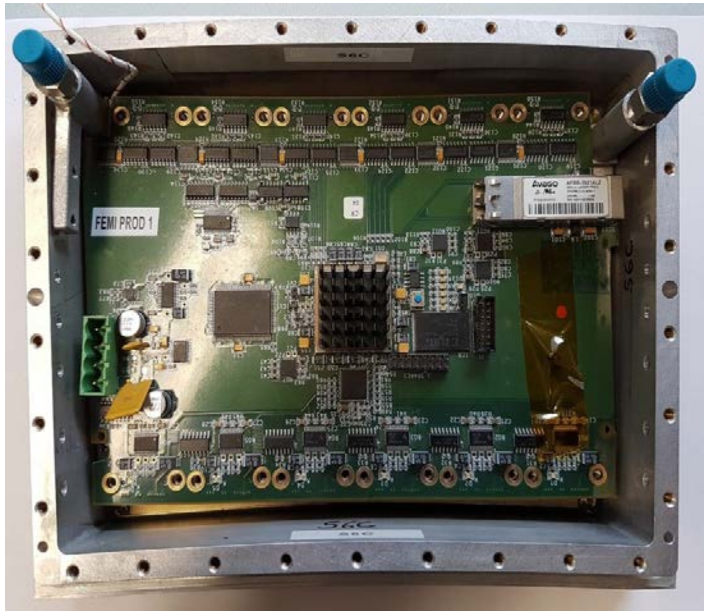


Cite#18: https://doi.org/10.48550/

Validation cooling system for the readout electronics

- Readout electronics will require a cooling system. **2-phase CO2-cooling** is a very interesting candidate.
  - A fully integrated AFTER-based solution tested on 7 Micromegas modules during a test beam.
- To optimize the cooling performance and the material budget **3D-printing of aluminum** is an attractive possibility for producing the complex structures required.
  - A prototype for a full module is **validated at LCTPC**.

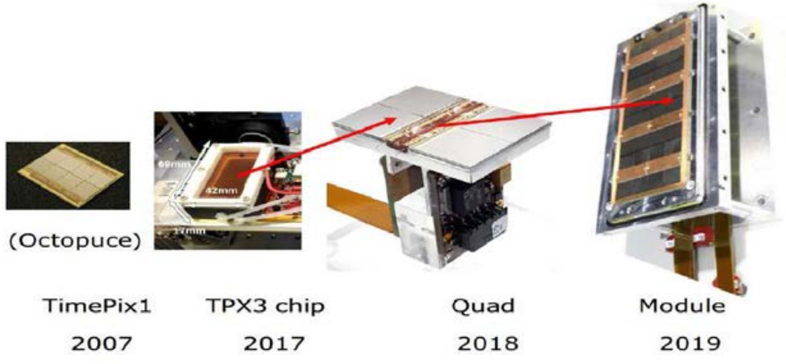




Cite#19: DOI 10.48550/arXiv.1403.7717
Cite#20: DOI 10.1088/1748-0221/10/08/P08001
Cite#21: DOI 10.1088/1742-6596/2374/1/012149

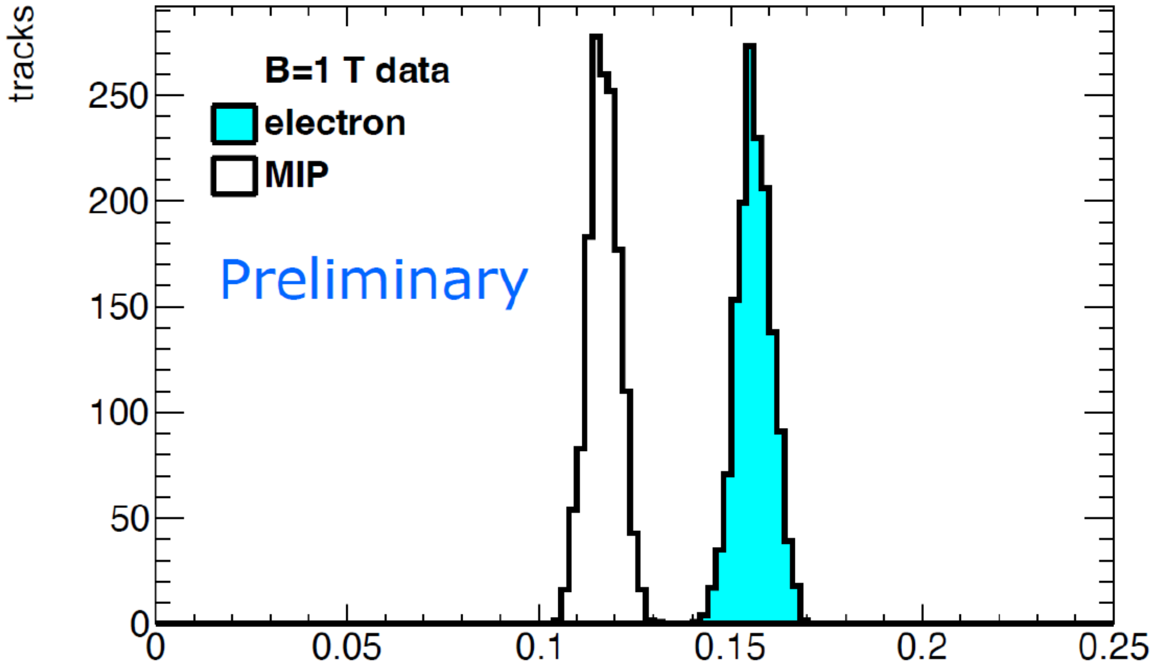
Pixelated readout TPC beam test for PID

- Pixelated readout TPC is **a good option** at high luminosity Z on circular e+e- collider (2x36 $cm^{-2}s^{-1}$)
  - High spatial resolution **under 2T or 3T magnetic field**
  - Better momentum resolution
  - High-rate operation (MHz/cm^2)
  - dE/dx and Cluster counting (**in space**)
  - Very low voxel occupancy



Electron resolution 2.9%
1 m track 60% and coverage
Linearity MIP-e = 1.07

Ideally this is 1. A number larger than 1 means that the resolution is +7% larger



Pixelated TPC for PID by Peter

Summary

- **Pixelated readout TPC can be as a realistic and promised track detector for CEPC TDR.**
    - **Material budget at endcape/barrel √**
    - **Occupancy and hit density √**
    - **Improved dE/dx+dN/dx √**
    - **Ion backflow suppression √**
    - **Reasonable channels and power consumption √**
    - **Running at 2 Tesla √**
    - **Beamstrahlung and distortion √**
    - **Cost estimation √**
    - **LCTPC international collaboration √**

We kindly acknowledge the following funding agencies, collaborations:

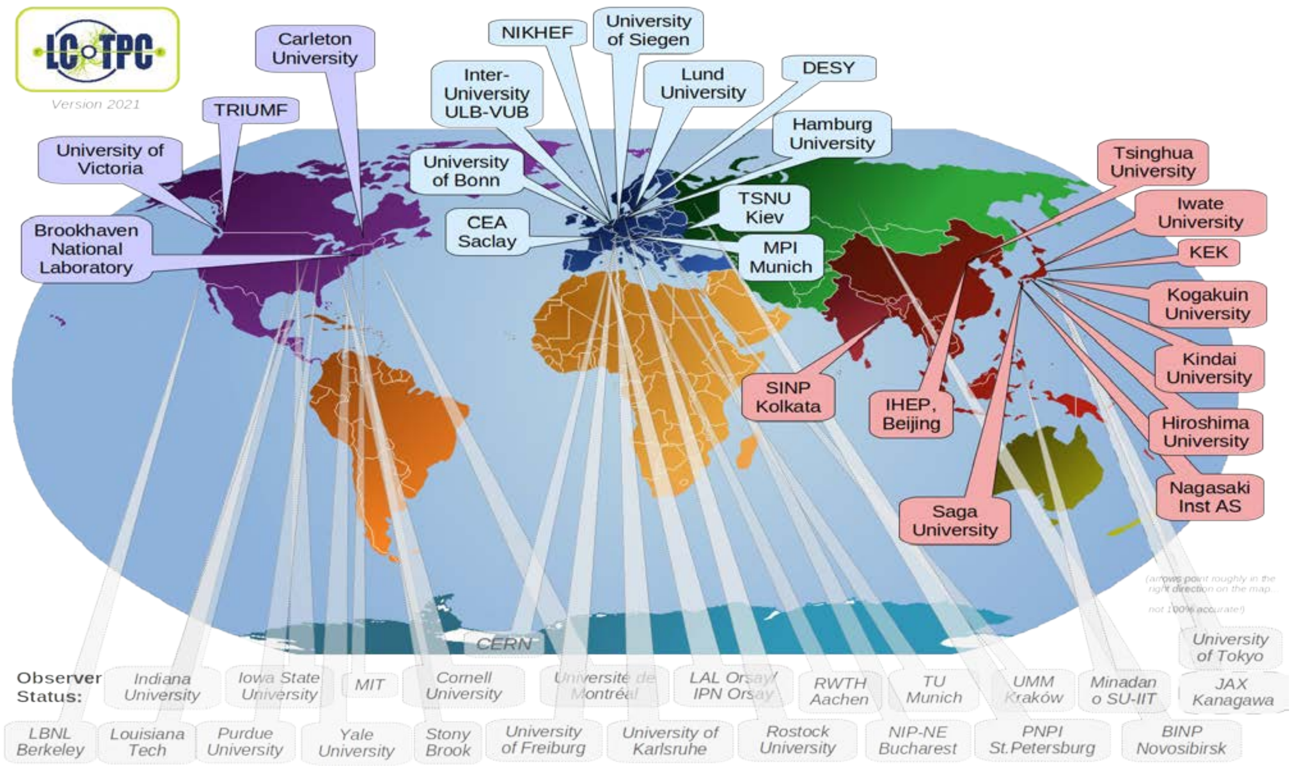
- National Key Programme for S&T Research and Development (Grant NO.: 2016YFA0400400)
- National Natural Science Foundation of China (Grant NO.: 11975256)
- National Natural Science Foundation of China (Grant NO.: 11535007)
- National Natural Science Foundation of China (Grant NO.: 11775242)
- National Natural Science Foundation of China (Grant NO.: 11675197)

Many thanks!

- **Backup slides**

TPC Technology R&D in LCTPC Collaboration

- **All research will be integrated with DRD1 of CERN from 2023**
- MPGDs for TPC readout is a **baseline solution and further R&D** features many benefits:
  - Small pitch of gas amplification regions => strong reduction of E×B-effects
  - No preference in direction => all 2 dim. readout geometries possible
  - **Ion backflow** can be reduced significantly (Gating, Hybrid structure…)
  - Continue electronics, cooling, UV laser track and low power consumption FEE development



LCTPC-collaboration studies MPGD detectors for the ILD-TPC and e+e- ollider R&D:
24 Institutes from
11 countries
+ 24 institutes with observer status

Various **gas amplification stages** are studied: GEMs, Micromegas, GEMs with double thickness and GridPixes.

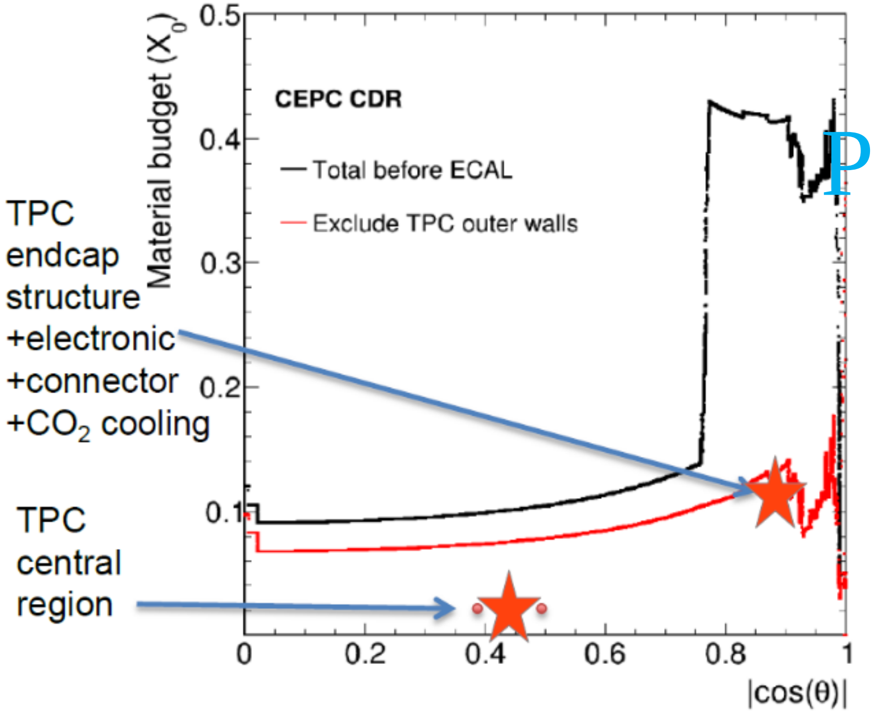
https://www.lctpc.org/

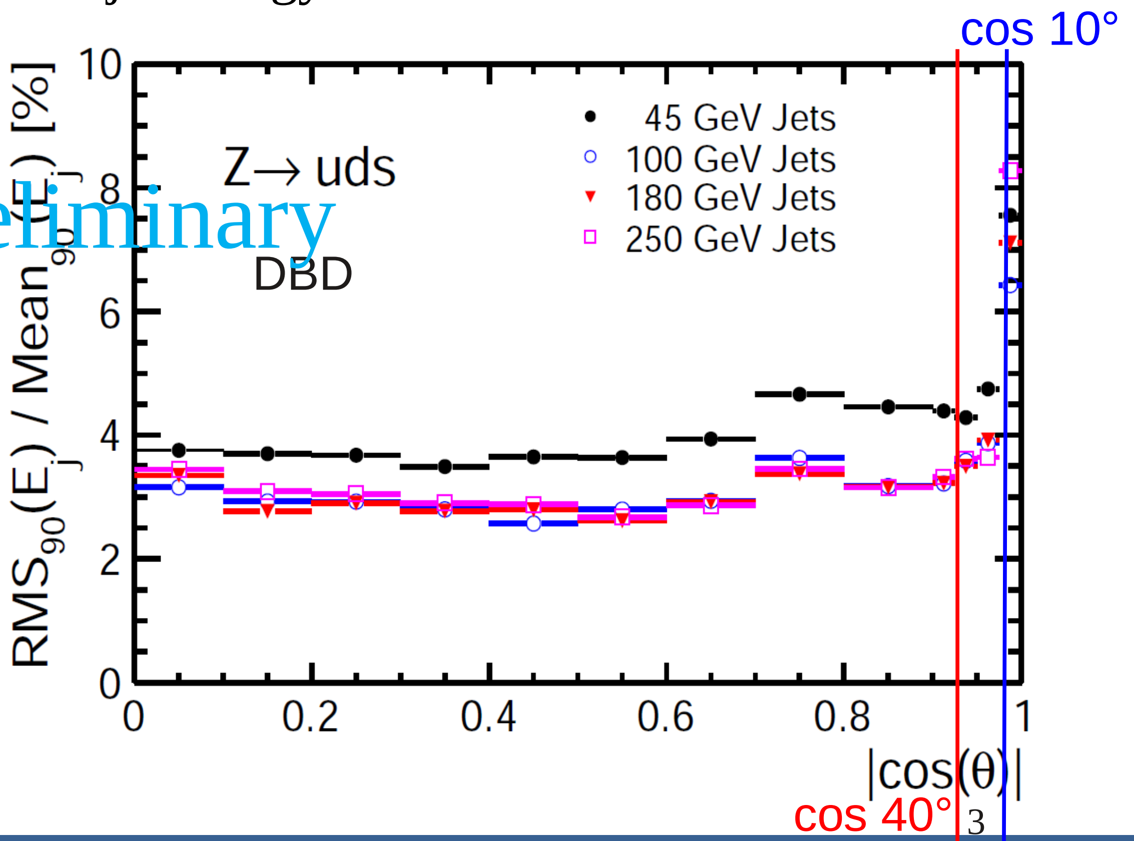
Material Budget – TPC – Very light

- **TPC as the main tracker detector**
  - A low material budget is a strong argument for a TPC
    - $\leq 5\% \ X_0$ in the barrel region
    - $\leq 25\% \ X_0$ in the endcap region
  - Increased material in endcap has no impact on jet energy resolution

	45 GeV	100 GeV	250 GeV
$15\%X_0$	0.28 ± 0.01	0.32 ± 0.01	0.47 ± 0.02
$30\%X_0$	0.30 ± 0.01	0.31 ± 0.01	0.47 ± 0.02
$45\%X_0$	0.30 ± 0.01	0.32 ± 0.01	0.52 ± 0.02
$60\%X_0$	0.32 ± 0.01	0.33 ± 0.01	

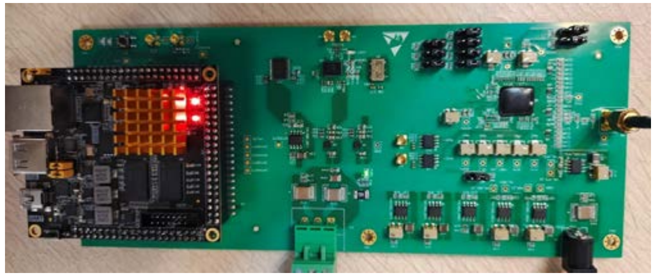
TPC – PRC2010 report

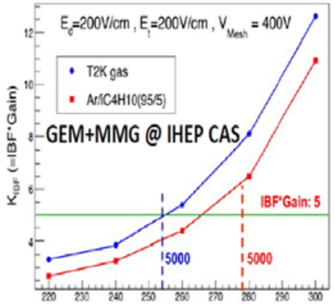


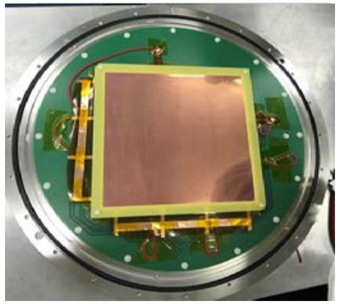


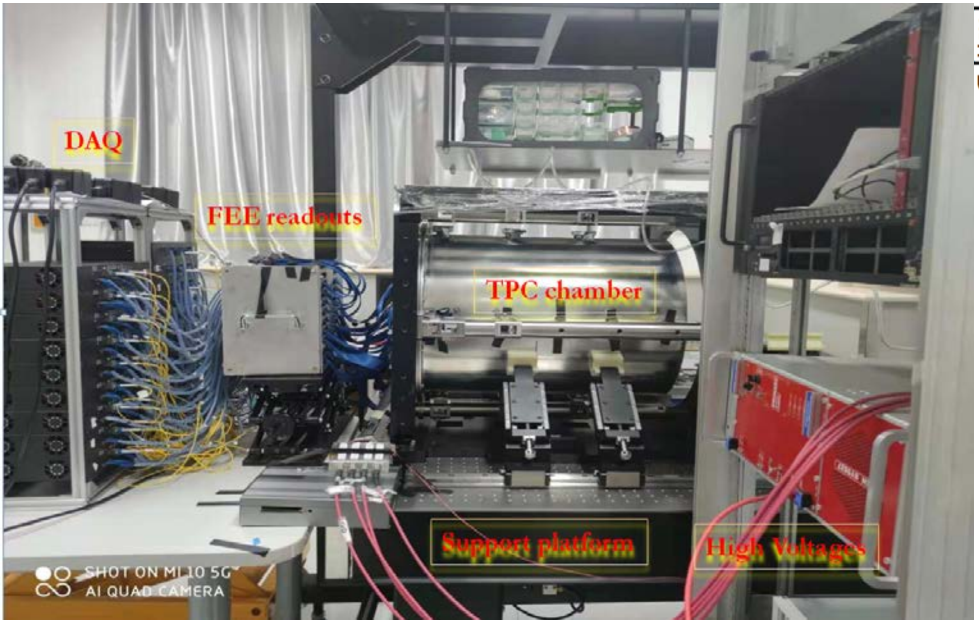
Pad readout TPC – Low power consumption and hybrid readout @IHEP

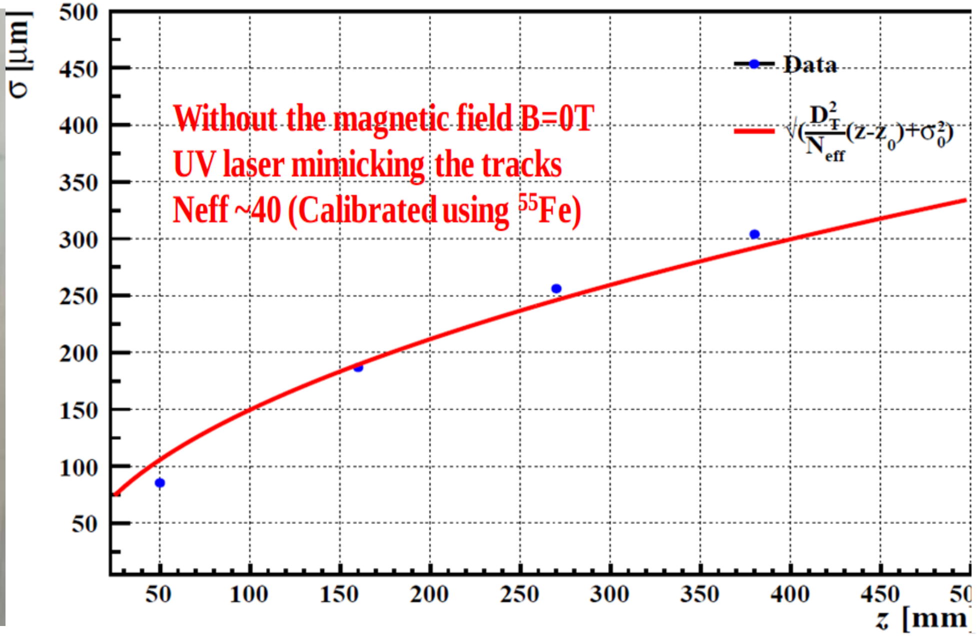
- **Low power consumption ASIC has been developed for TPC readout.**
  - Low power consumption FEE ASIC (**~2.4 mW/ch** including ADC)
- **Hybrid readout module has been developed:**
  - IBF×Gain **~1 at Gain=2000** validation with GEM/MM readout
  - Spatial resolution of **$\sigma_{r\varphi} \leq 100$ μm** by TPC prototype
  - Pseudo-tracks with 220 layers (**same as the actual size of CEPC baseline detector concept**) and dE/dx is about 3.4 ± 0.3%

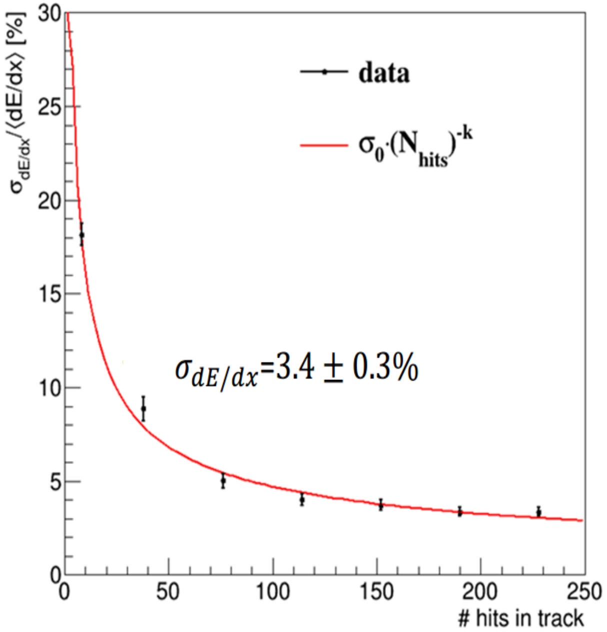








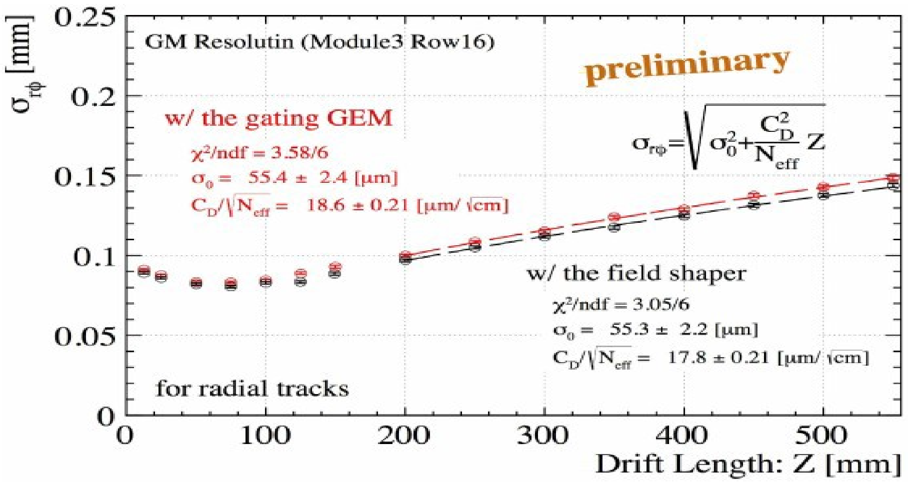


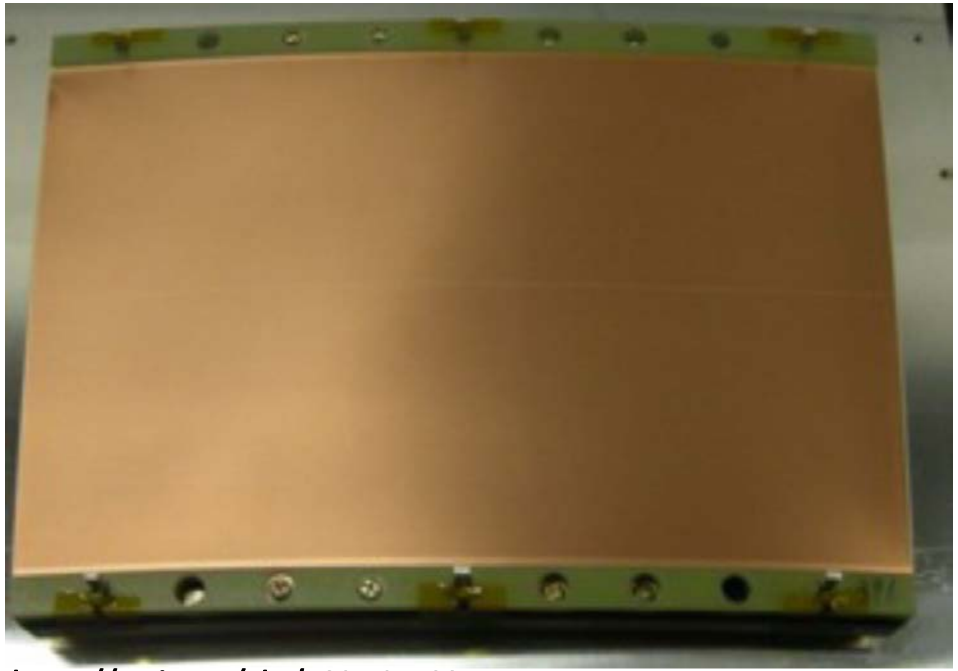


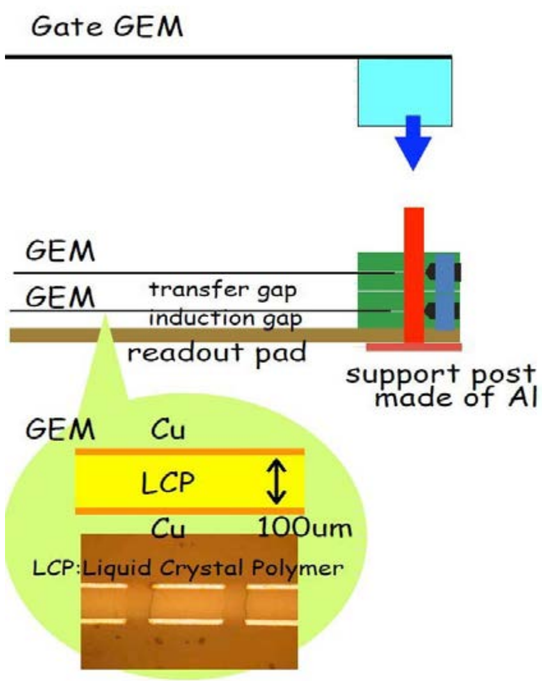
https://doi.org/10.1016/j.nima.2022.167241

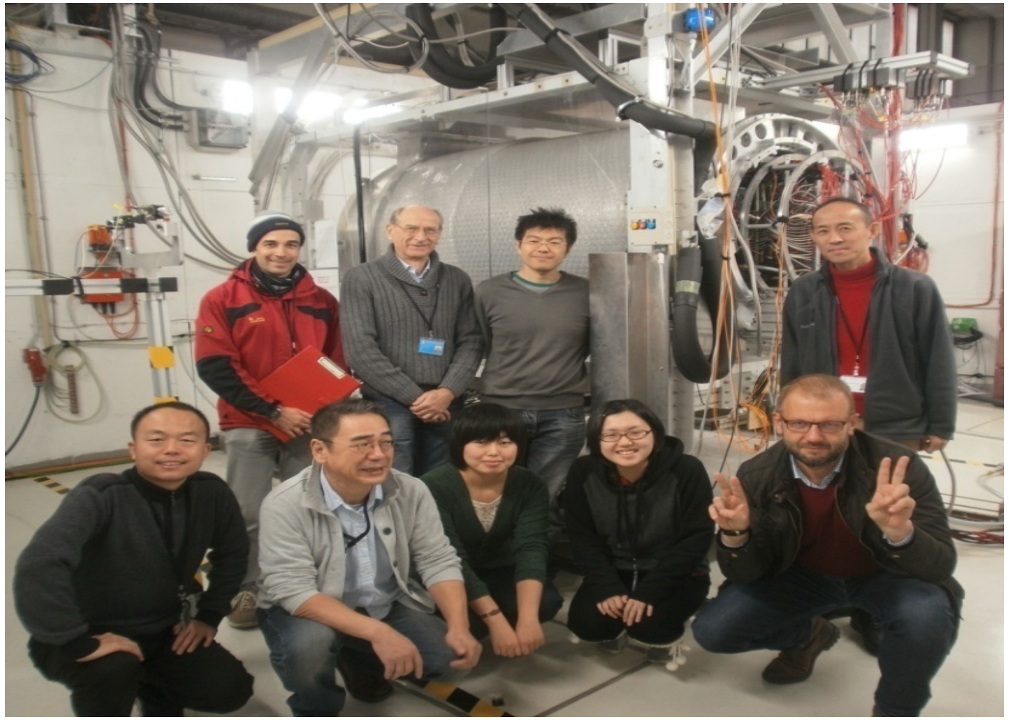
Pad readout TPC technology – GEMs readout @LCTPC

- **TPC prototype have been studied the beam under 1.0T.**
  - GEMs with 100μm LCP insulator
  - Standard GEM from CERN
- Design idea of the GEM Module:
  - **No frame** at modules both sides
  - Spatial resolution of $\sigma_{r\phi} \leq 100$ μm, more stability by the broader arcs at top and bottom





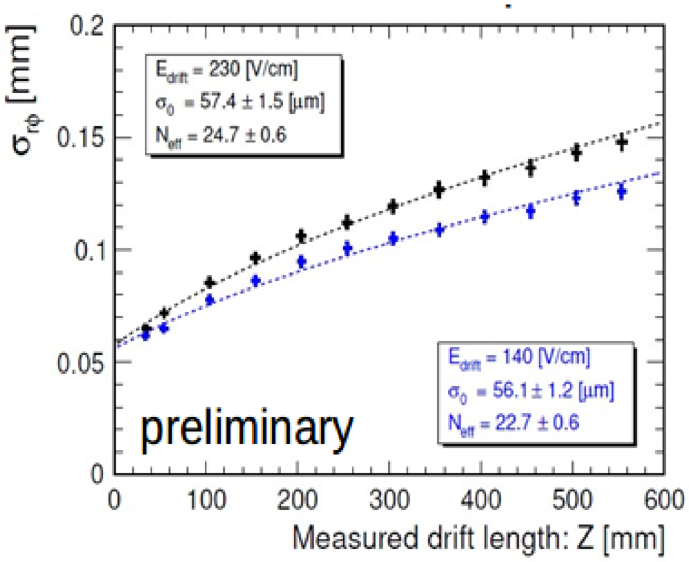


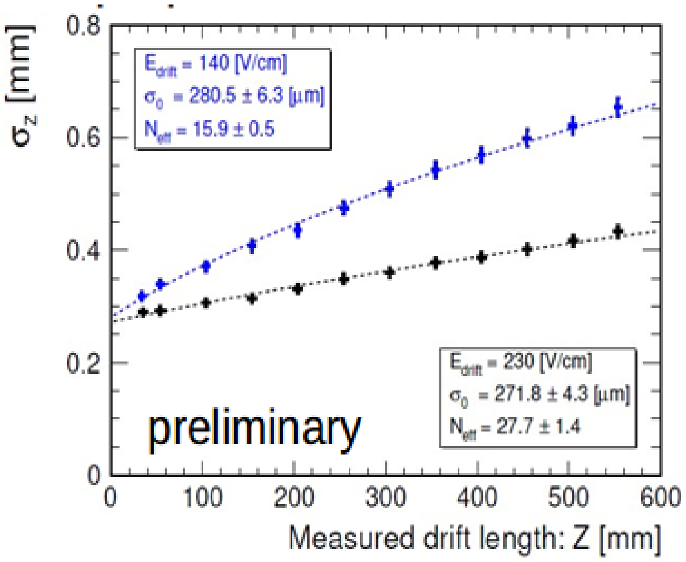


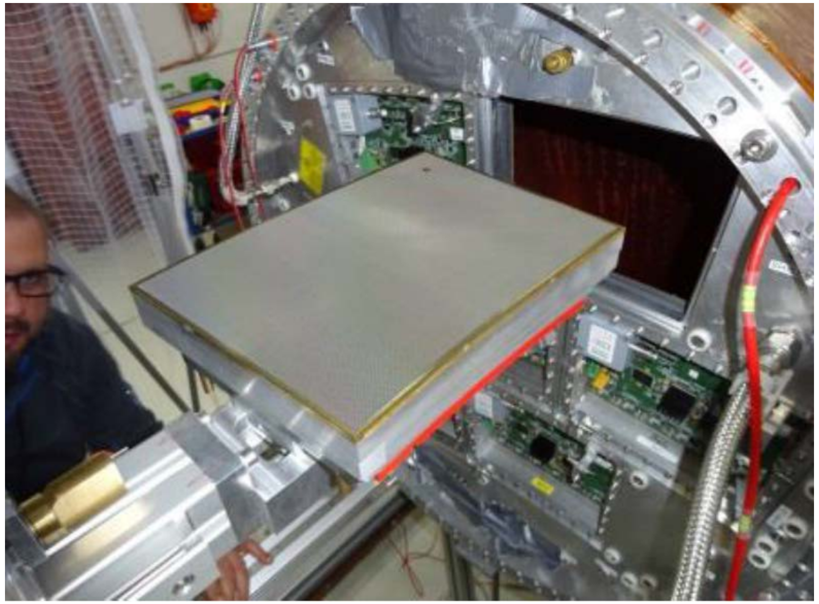
https://arxiv.org/abs/1801.04499

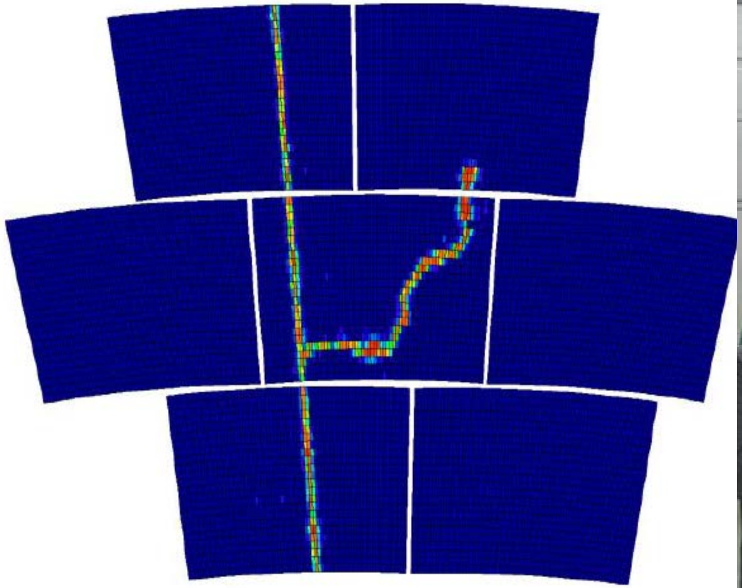
Pad readout TPC technology – Resistive Micromegas readout @LCTPC

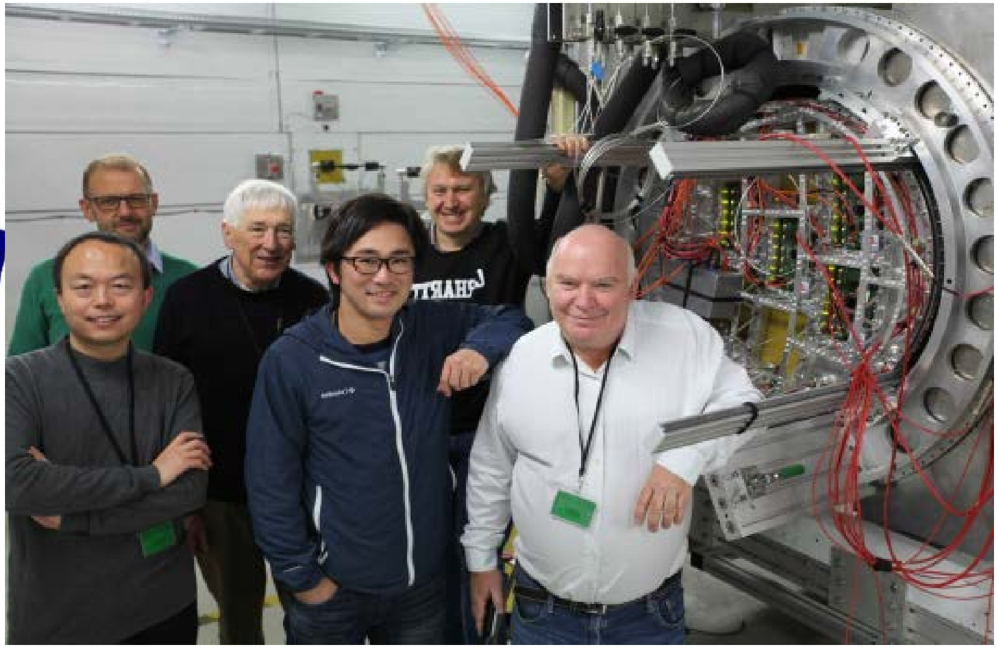
- **Resistive Micromegas has been studied by the beam under 1.0T.**
  - Bulk-Micromegas with 128 µm gap size between mesh and resistive layer.
- HV scheme of the module (ERAM) places grid on ground potential
  - Spatial resolution of $\sigma_{r\phi} \leq 100$ µm









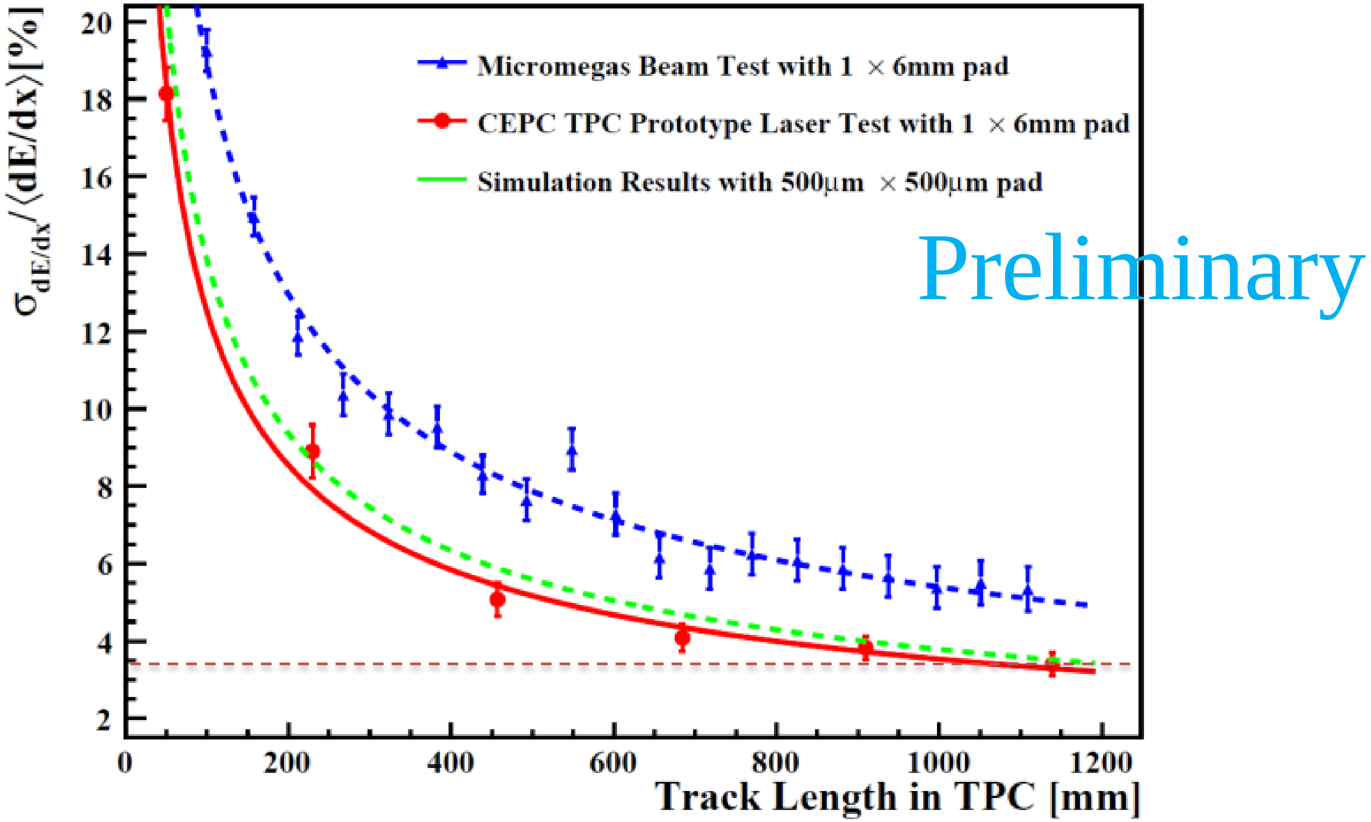


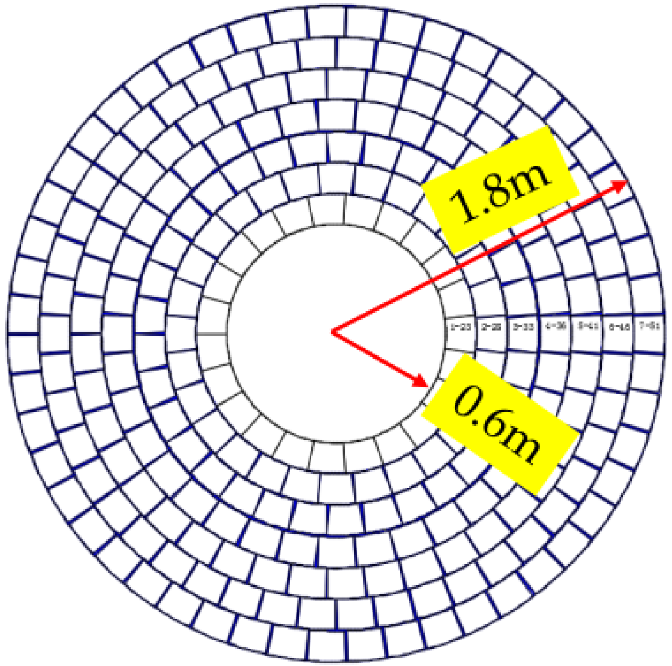
https://doi.org/10.1016/j.nima.2019.162798

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%.

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

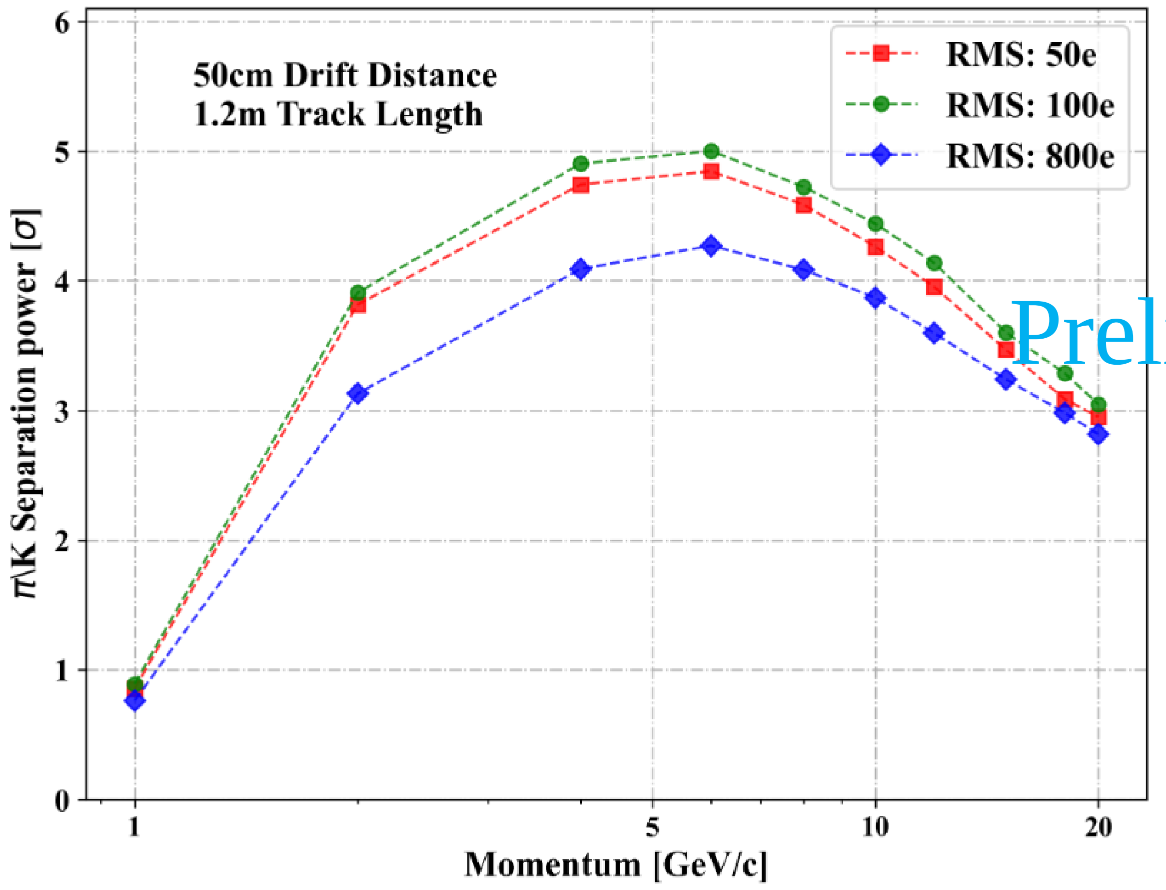




Noise of FEE VS Separation power

Estimation of the **FEE readout** using Micromegas.

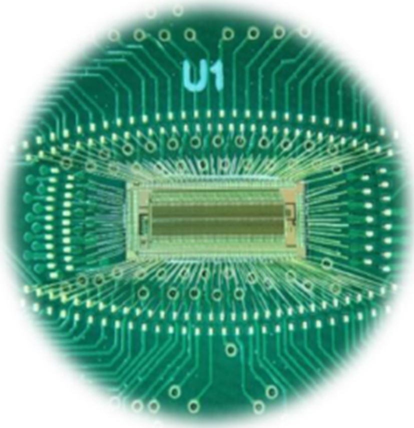
- The noise of the FEE should be kept the lower to keep the reasonable gain of the detector (-2000).
- The noise of the FEE reached to 100e.



R&D on Pixelated TPC readout for CEPC TDR

Preliminary

- Macro-Pixel TPC ASIC chip was started to developed and **2nd prototype wafer has done** and tested
- The **TOA and TOT** can be selected as the initiatic function in the ASIC chip
  - 500μm×500μm pixel readout designed
  - Noise of FEE: ~100e
  - Time resolution: **14bit** (5ns bin)
  - **Power consumption: <1mW/pixel (2nd prototype**
    - **~100mW/cm²**



Pad size optimization

- Pad size optimization ongoing.
  - Optimized the pad size to validate the PID performance

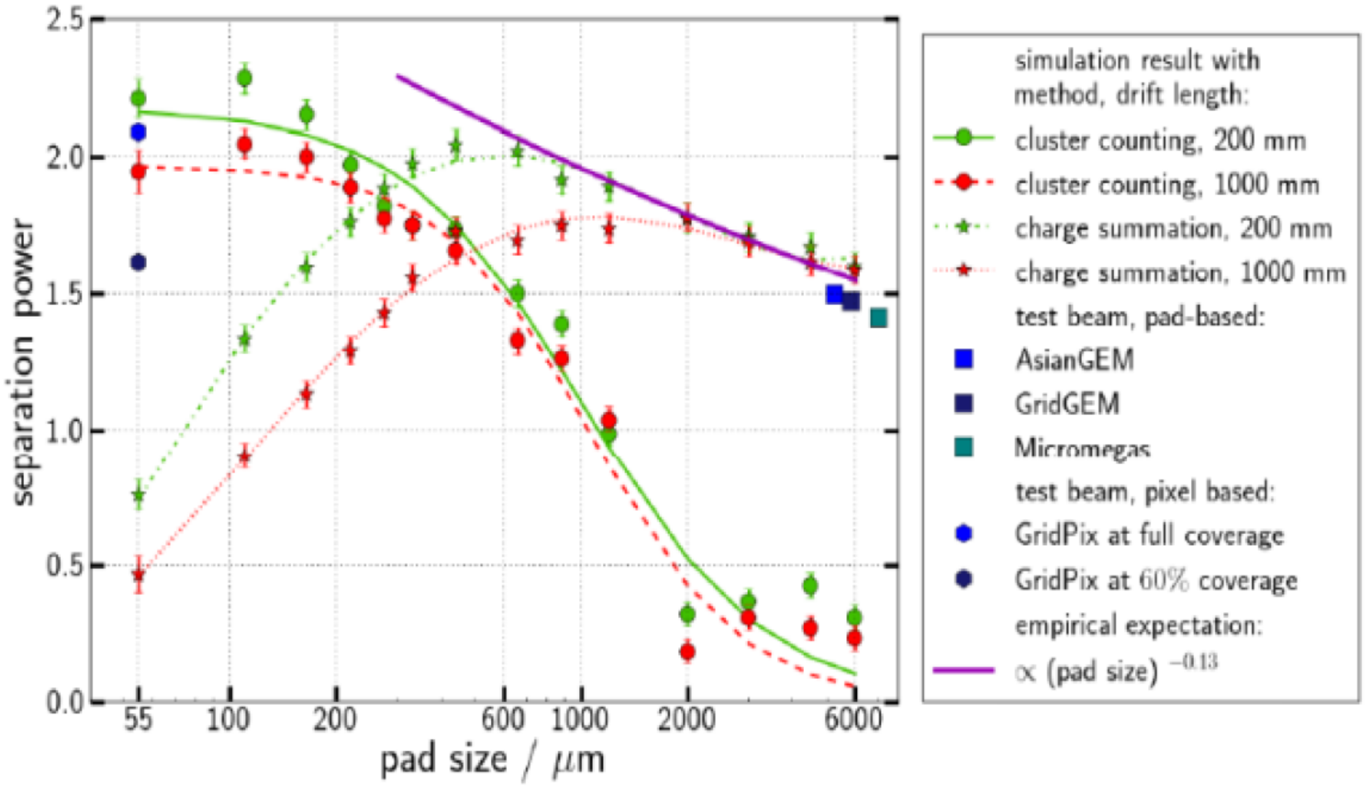
- **dN/dx (and tracking) can be beneficial from smaller pad size**

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

(To detect single e^-)

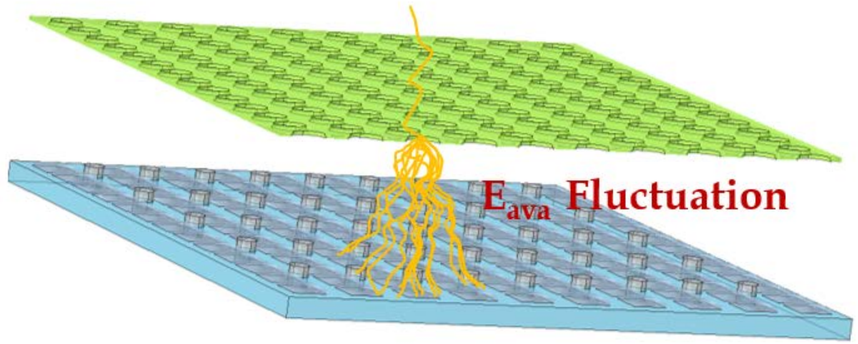
- **Need to find out the optimal pad size considering cost/power consumption**

Simulation with 30 cm track length



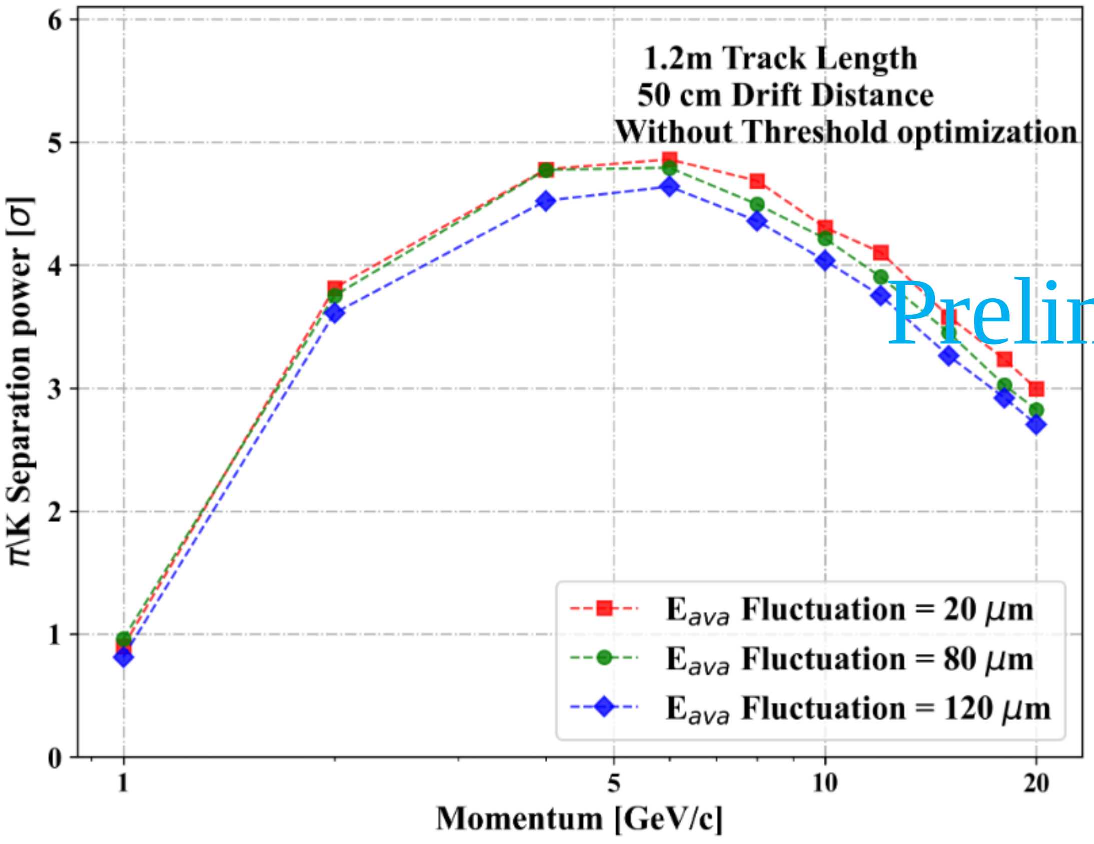
https://doi.org/10.1088/1748-0221/17/11/P11027

e_{ava} fluctuation VS Separation power

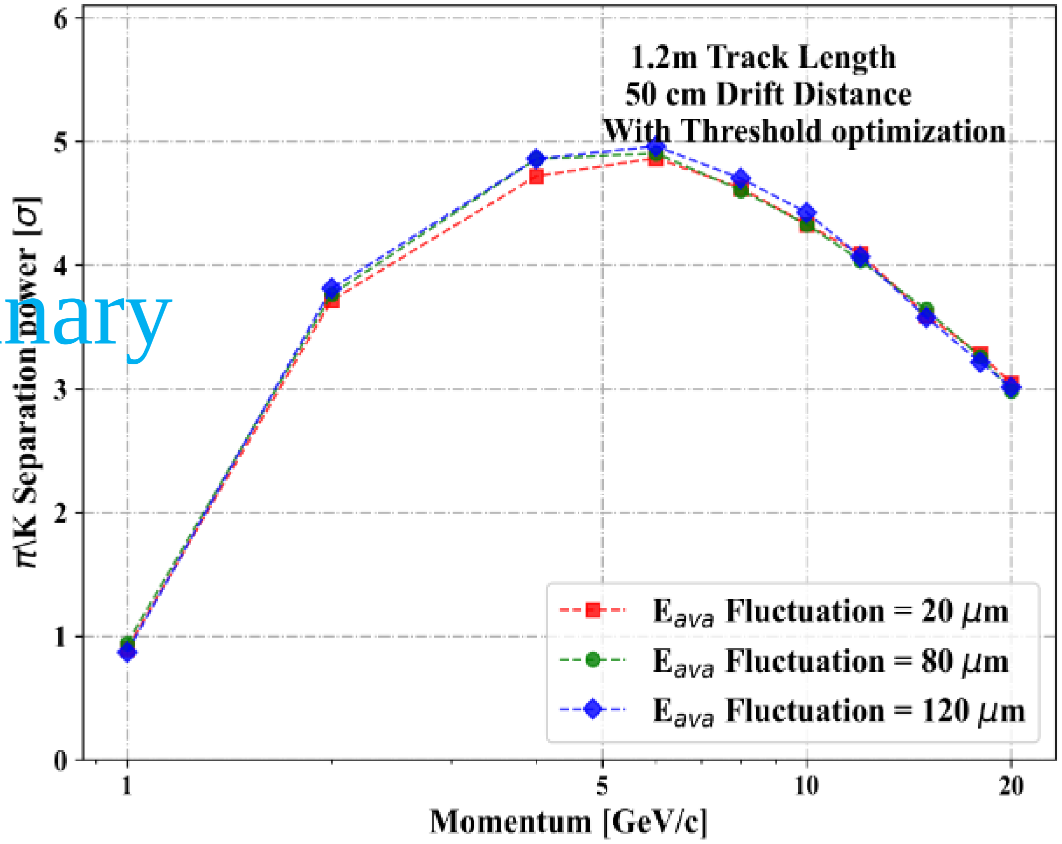


Estimation of the **pixelated readout** using Micromegas.

- Electrons of the avalanche's fluctuation simulated the relative with the separation power w/o threshold optimization.
- **No significant impact** to the separation power.



Preliminary



High granularity readout -1 @cosθ≃0.98

Parameters	Higgs run	Z pole run
B-field	3.0T	2.0T
Pad size (mm)/All channels	1.0mm×6.0mm /2×10^6	1.0mm×6.0mm /2×10^6
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	200	200
σ_{point} in rφ	≤ 100µm (full drift)	≤ 400µm (full drift)
σ_{point} in rz	≃ 0.4 – 0.6 mm (for zero – full drift)	≃ 0.5– 0.8 mm (for zero – full drift)
2-hit separation in rφ	< 2mm	< 2mm
dE/dx	≤ 3.6%	≤ 3.6%
Momentum resolution normalized: $\sigma_{1/pT} = \sqrt{a^2 + (b/pT)^2}$	a = 1.82 e -5	a = 3.32 e -5
	b = 0.60 e -3	b = 0.92 e -3

High granularity readout -2 @cosθ≃0.98

Parameters	Higgs run	Z pole run
B-field	3.0T	2.0T
Pad size (mm)/All channels	0.110mm×0.110mm /2×6×10^8 (TPX4)	0.110mm×0.110mm /2×6×10^8 (TPX4)
Material budget barrel	0.012 X_0	0.012 X_0
Material budget endcap	0.20 X_0	0.20 X_0
Points per track in rφ	22000	22000
σ_{point} in rφ	120µm (full drift)	400µm (full drift)
σ_{point} in rz	≃ 0.1 – 0.4 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 σ	3 σ
Momentum resolution normalised: $\sigma_{1/pT} = \sqrt{a^2 + (b/pT)^2}$	a = 1.210 e -5	a = 2.69 e -5
	b = 0.589 e -3	b = 0.90 e -3

High granularity readout -3 @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	120μm (full drift)	400μm (full drift)
σ_{point} in rz	≃ 0.1 – 0.4 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 σ	3 σ
dE/dx	3.2%	3.2%
Momentum resolution normalised: $\sigma_{1/pT} = \sqrt{a^2 + (b/pT)^2}$	a = 1.210 e -5	a = 2.69 e -5
	b = 0.589 e -3	b = 0.90 e -3