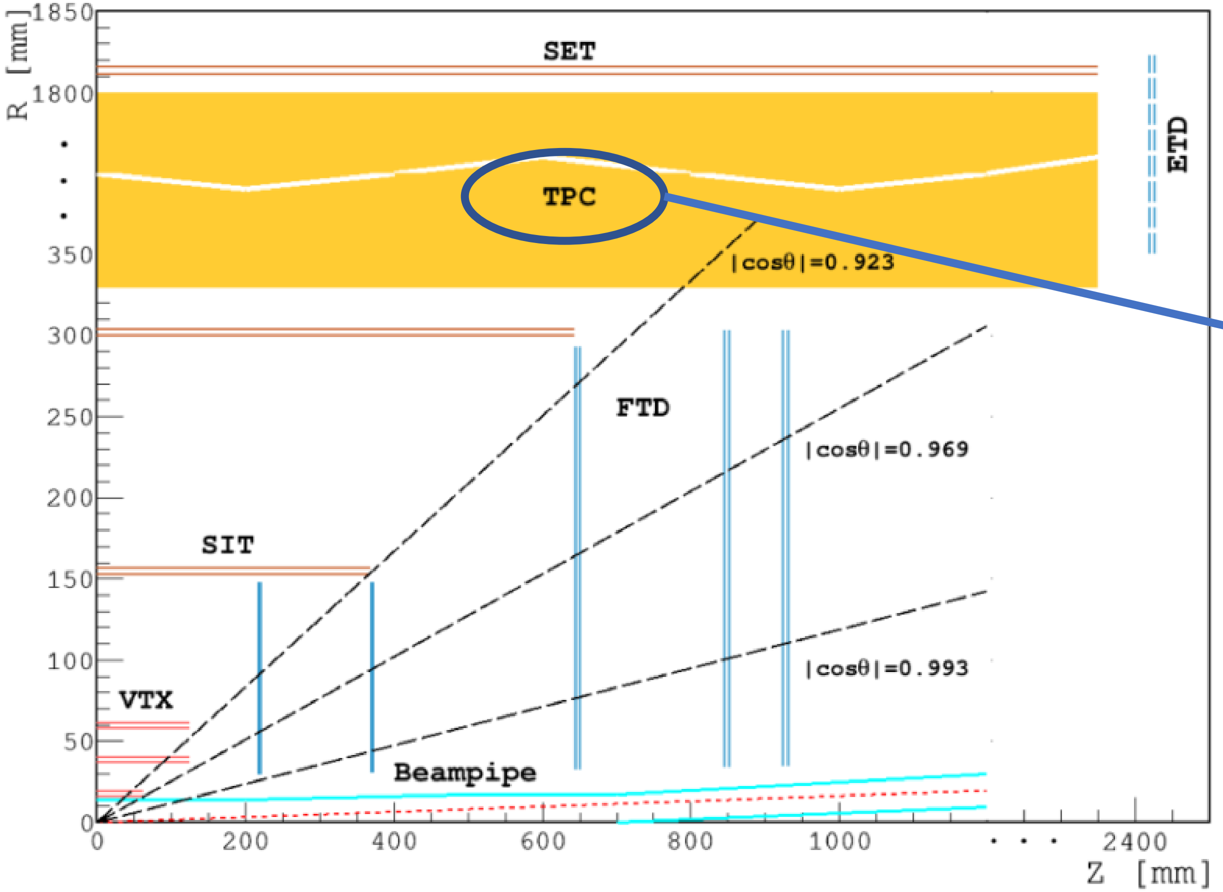
CEPC TPC

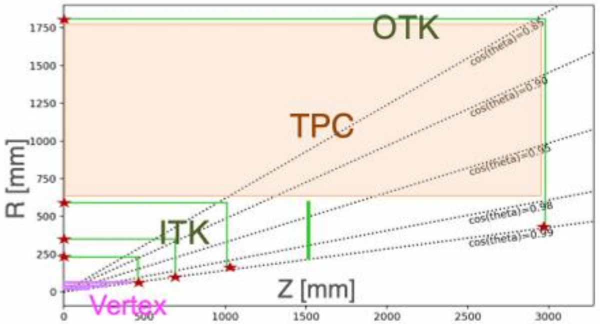
Role of CEPC TPC

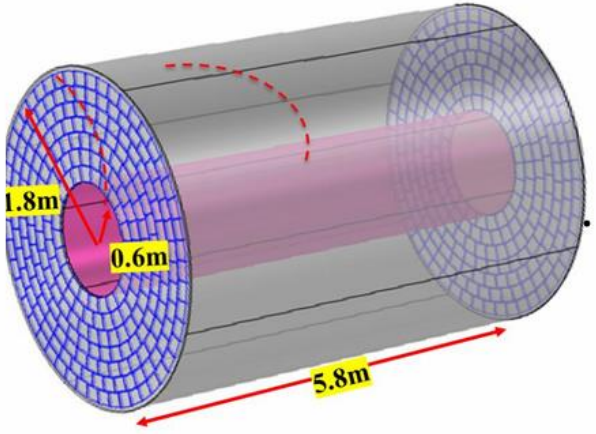


1. Momentum measurement
2. Particle Identification

Pixelated TPC Paramters

▹ **To improve performance and reduce the difficulty at high luminosity Z pole run. A pixelated TPC has been designed.**





Updated Geometry of TPC in TDR

- Granularity has improved in readout
  - TDR: pad (1mm x 6mm) → pixel (0.5mm x 0.5mm).
  - $2x3x10^7$ channels in readout endplate.
  - Divided into 248 modules/endplate in 21x17cm.
- Updated TPC will have:
  - More hits (~200 hits in TDR pad readout→~2000 hits in pixel)
  - High density readout make particle ID possible in ID algorithm.
  - 5 ns drift time resolution

- 漂移速度约80um/ns

漂移时间: (5800000 / 80) ≈ 72us

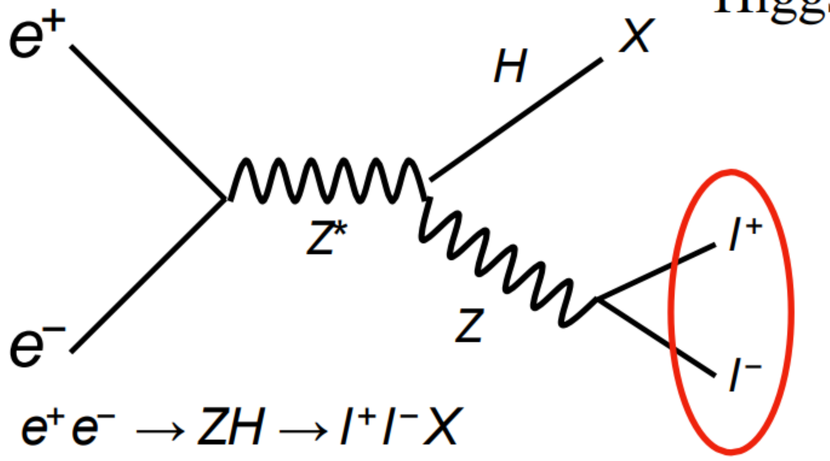
Momentum measurement

Momentum measurement

CEPC: "Higgs factory" Higgs precision measurement is a high-priority goal

"Recoil"

Higgs can be reconstructed indirectly

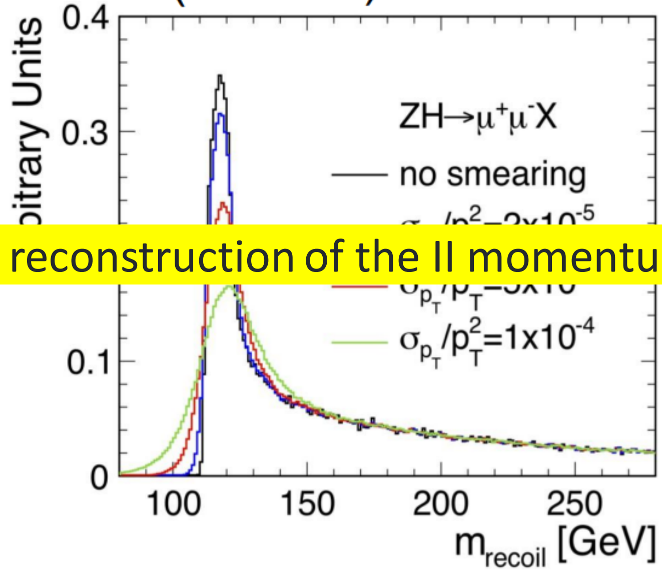


$e^+e^- \rightarrow ZH \rightarrow l^+l^-X$

$$P_h = P_{e^-} + P_{e^+} + P_Z$$

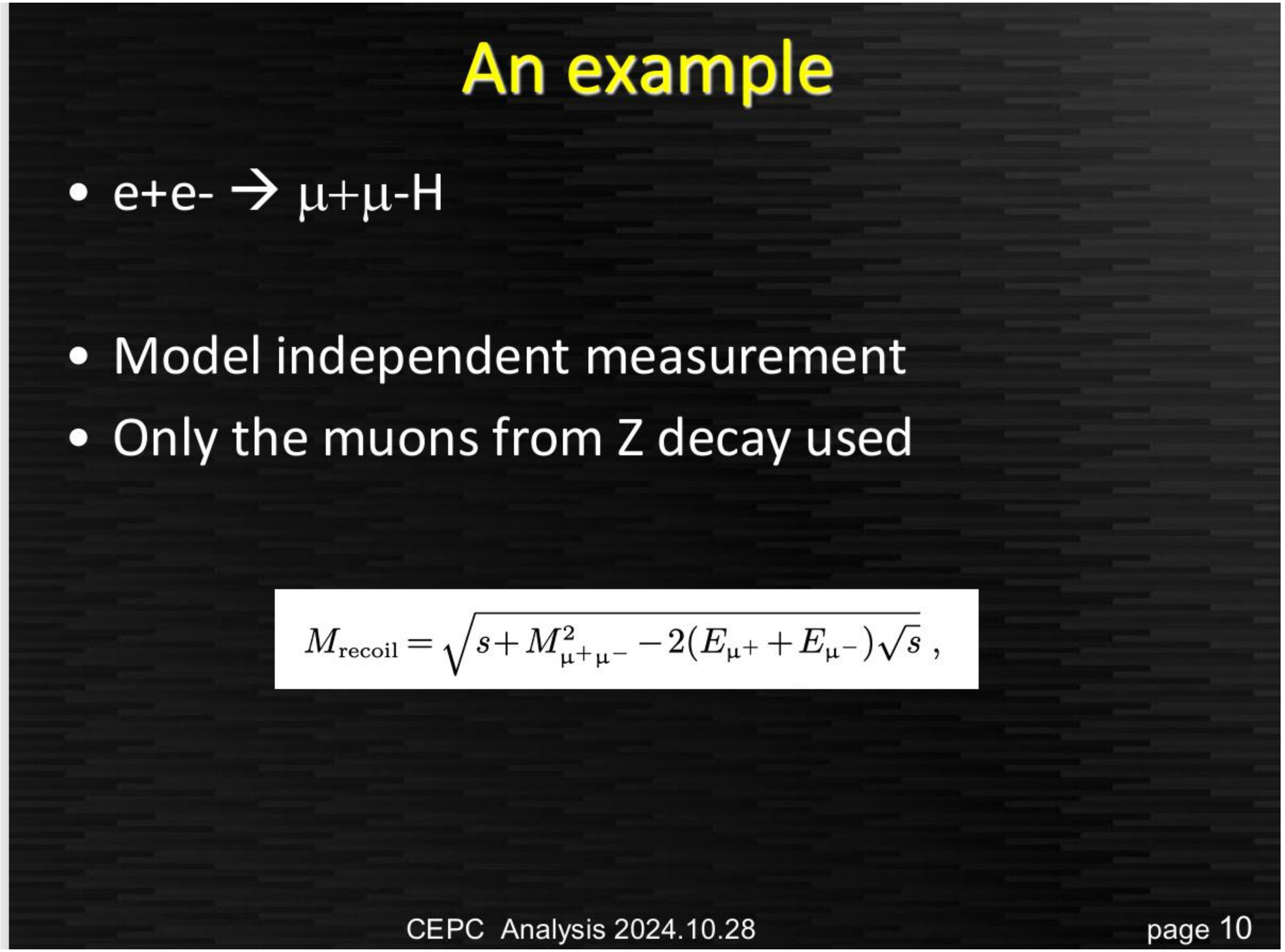
or

$$m^2_{recoil} = (\sqrt{s} - E_{ll})^2 - |P_{ll}|^2$$



Reconstructing the momentum of the Higgs through the reconstruction of the ll momentum

Reconstruction of $Z \rightarrow ll$ momentum resolution is crucial



Physics—view analysis points of at CEPC an analyze.

Track Reconstruction

TPC Reconstruction

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Institute of High Energy Physics
Chinese Academy of Sciences

- **Reconstruction Algorithm (clupatra):**
  - Clupatra is an algorithm developed by ILC, it works as follows:
    - Initial Clustering by Near-Neighbor-Clustering:
      - It will loop all hits, and merge the hist into one cluster with distance less than some criteria (eg. distance and angle)
    - Extend the cluster forward and backward using Kalman-fitter
      - Create track segments
    - Merge track segments based on criterion for R, tan(lambda)
  - In high granularity and high diffusion hits, the algo may:
    - Find multiple tracks, because of the diffusion.
    - Need to merge hits before clustering.

Hit merge

Implementation of ML-based clustering

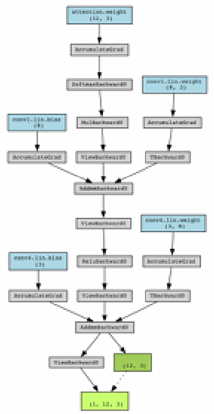
- **As the Pixelated TPC will have more than 2200 hits in all "layers"**
  - Large diffusions are observed in x-y plane.
  - To reduce the inefficiencies of track hits and improve the resolution of single hits. Need to merge hits, there are two possible ways to do so:
    - Calculate the mean value of the hits in multiple layers, where layers are defined as the ring with height=0.5mm in readout. If the curvature is large, the mean value will be biased.
    - Develop a Machine-learning based method to merge hits.
  - For the ML merging, we chosen a simple GCN model to collect informations from hits in multiple layers
    - To match the position of sim tracker hits

Hit merge

Machine learning based hits merging

Architecture of GCN model

- The graph was created by connect 11 nodes (hits) to one output node (hit).
- Each hit(node) has 3 features (r,phi,z)



Layer (type)	Output Shape	Param #
Linear-1	[-1, 1, 12, 8]	32
GCNConv-2	[-1, 1, 12, 8]	0
Linear-3	[-1, 1, 12, 3]	27
GCNConv-4	[-1, 1, 12, 3]	0

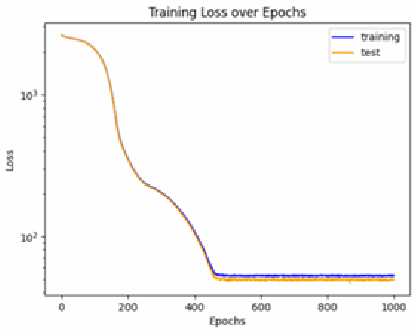
Total params: 59
Trainable params: 59
Non-trainable params: 0

Input size (MB): 0.00
Forward/backward pass size (MB): 0.00
Params size (MB): 0.00
Estimated Total Size (MB): 0.00

Structure of the Model

Training

- Trained with simulated samples in different:
  - pt: 1,3,15,100GeV
  - Theta: 60,85
  - Phi: randomized
- Loss: the distance between "output-node" and SimTrackerHit.

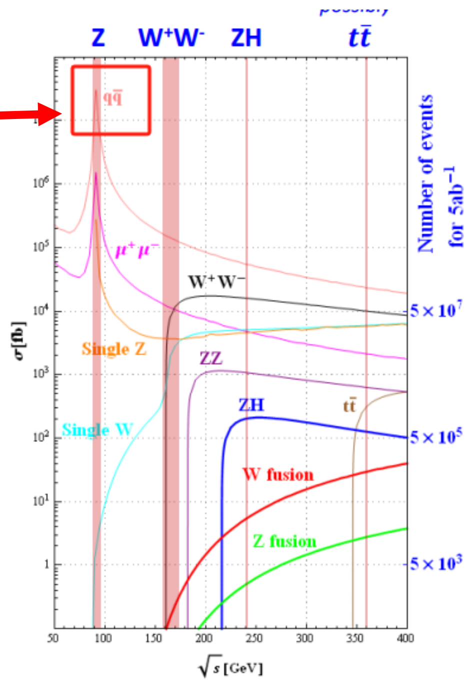


Loss vs Epoches

Particle Identification

The main scientific objective of the CEPC is the precise measurement of the Higgs properties. When CEPC operates as a Z-boson factory, trillions of generated $Z \to q\bar{q}$ events can provide a great opportunity for measuring flavor physics, where particle identification (PID) is essential.

PID in TPC focus on Z->qq.



is investigated based on Monte Carlo (MC) simulation. PID will play an important role in measurements of the bottom (b) and charm (c) hadron decays in heavy flavor physics. It can also be exploited to enhance the flavor tagging of the b/c-jets in Higgs and precision electroweak measurements. We study the PID of kaons, pions and protons in hadronic

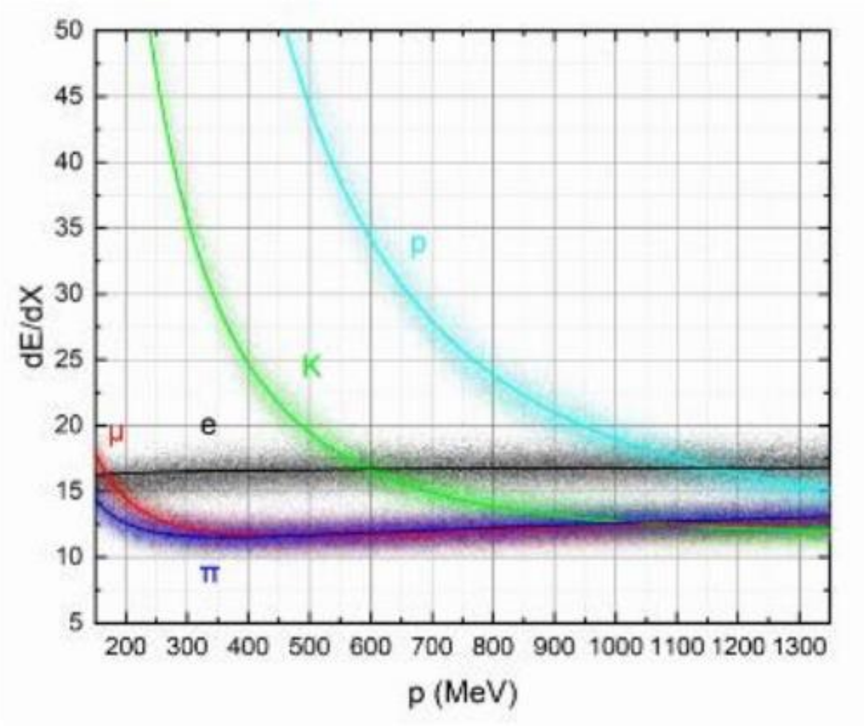
PID is used to study flavor physics by observing these particles.

Particle Identification

Traditional method: dE/dX

Different particles lose energy at different rates as they pass through the TPC.

Different particles can be identified through dE/dX.



Pixelated TPC

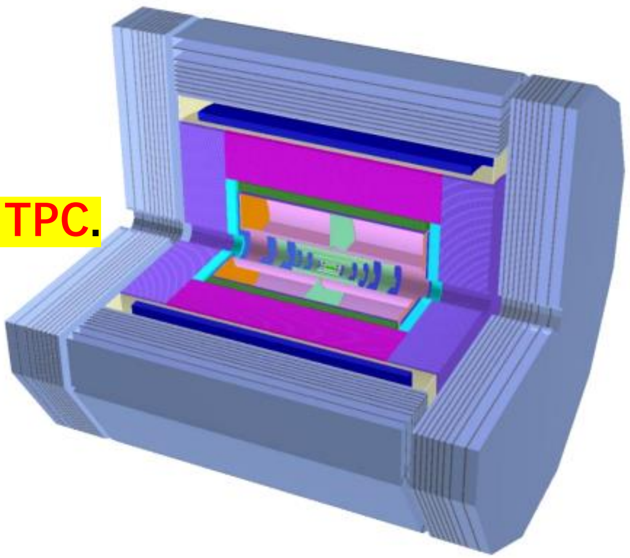
Technologies For Ref-TDR

System	Technologies		
Beam pipe	Φ20 mm		
LumiCal	SiTrk+Crystal		
Vertex	CMOS+Stitching	CMOS Pixel	SOI
Tracker	SPD ITrk		
	Pixelated TPC	PID Drift Chamber	
	AC-LGAD OTrk	SSD OTrk	SPD OTrk
		LGAD ToF	
ECAL	4D Crystal Bar	Stereo Crystal Bar	
	GS+SiPM	PS+SiPM+W	SiDet+W
HCAL	GS+SiPM+Fe	PS+SiPM+Fe	RPC+Fe
Magnet	LTS	HTS	
Muon	PS Bar+SiPM	RPC	
TDAQ	Conventional	Software Trigger	
BE electr.	Common	Independent	

R

Baseline | For Comparison

Baseline is Pixelated TPC.



- The CEPC study group worked hard since Jan 2024, to compare different technologies.
- The baseline and comparison technologies were decided based on multiple factors: performance, cost, R&D efforts, technology maturity, …

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Aug. 7th, 2024, CEPC Detector Ref-TDR Review

Pad readout vs Pixel readout

像素型读出应用于CEPC-TPC

- 像素型读出对于高亮度下的CEPC-TPC极具优势
  - ✓ dE/dx + dN/dx提供良好的粒子鉴别能力
  - ✓ 2T/3T下提供高空间分辨
  - ✓ 高计数率
  - ✓ 卓越的双径迹分辨

Pad型读出	Pixel 读出
读出面积 2×10 m^2	读出面积 2×10 m^2
微结构气体探测器读出	微结构气体探测器读出
单Pad尺寸 1 mm×6 mm	~~单pixel尺寸 55 μm×55 μm~~
10^{6}个读出单元	10^{9}个读出单元
84个读出模块	480个读出模块
快电子学读出	快电子学读出
CO_2冷却	CO_2冷却
	更好的计数率>900 kHits/s

CEPC-TPC两种读出方式比较

- 经典的电荷求和(传统的大尺寸Pad读出)

优势：技术成熟

不足：受大的波动敏感、

对dE/dx已无大幅提升空间

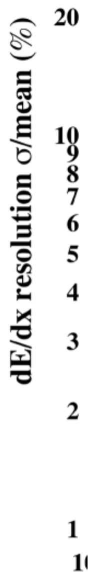
- 新型簇团计数(小尺寸的像素读出)

优势：不受波动影响

dN/dx实现更好的分辨能力

技术难点：缺乏验证理论 → 模拟验证

技术实现难度较大 → 实验验证



关键：利用像素型读出技术实现簇团计数

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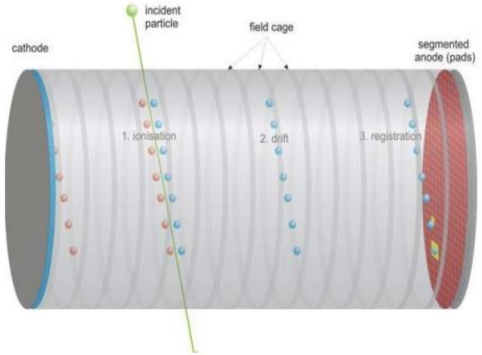
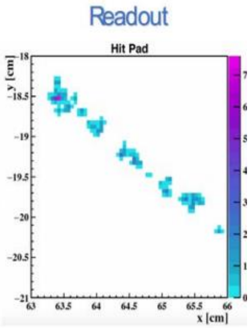
dN/dX vs dE/dX

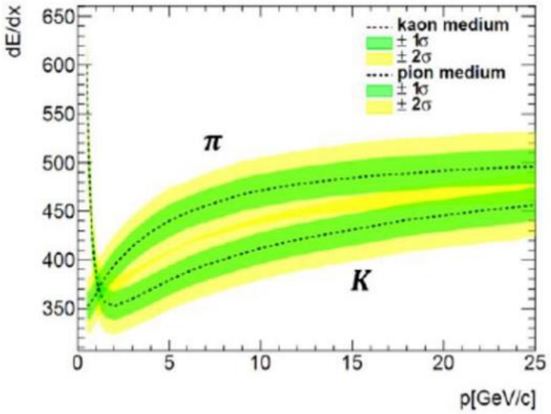
- 初步结论：像素尺寸在300 μm ~ 500 μm，即可实现对每个电离簇团的计数

- **dN/dx: Number of primary ionization clusters per unit length**
  - Ideal measurement of ionization, clean in statistics
  - Reasonable pixel reveals the underlying cluster structure in 3D
    - Resolve clusters **in space** by high granularity TPC
  - Small fluctuation ➔ **Potentially, a factor of 2 better** than dE/dx

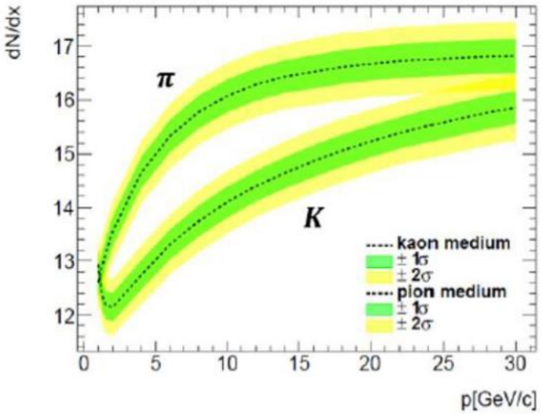




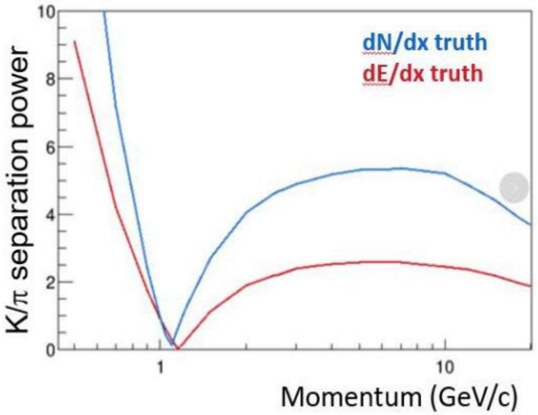
dE/dx



dN/dx



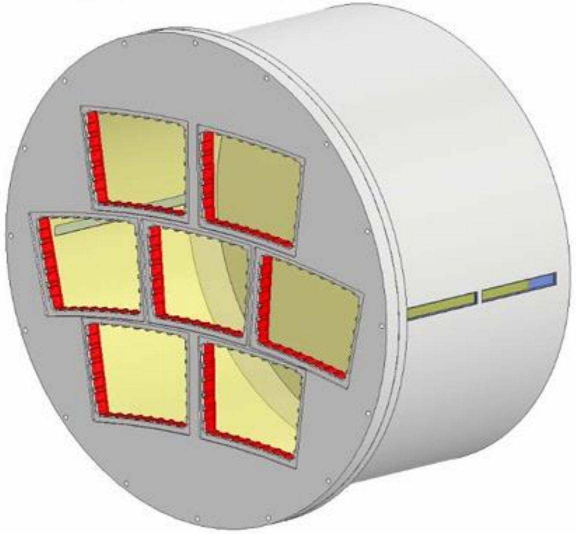
K/π separation power
dN/dx vs dE/dx



Work Plan

Work plan

- Short term work plan (**before June, 2025**)
  - Optimization of TPC detector for CEPC ref-TDR
  - Prototyping R&D and validation with the test beam
    - mechanics, manufacturing, beam test, full drift length prototype
  - Performance of the simulation and Machine Learning algorithm
- Long term work plan (**next 3-5 years**)
  - Development of pixelated TPC prototype with low power consumption FEE
    - Collaboration with LCTPC collaboration on beam test
  - Development of the full drift length prototype
    - Drift velocity. Attachment coefficient, T/L Diffusion, etc.



Milestones achieved	Before June, 2025	Beyond TDR
Ion backflow suppression	IBF×Gain<1 (Gain=2000)	Graphene technology
Pixelated readout prototype	Validation with beam test	Prototype with Multi-modules
Power consumption ASIC	~100mW/cm^2 (60nm ASIC)	Optimization 330µm - 500µm
PID resolution	3% (dN/dx)	<3% (dN/dx)
Material budget (barrel)	Carbon Fiber	Full size prototype