TPC tracking detector for CEPC

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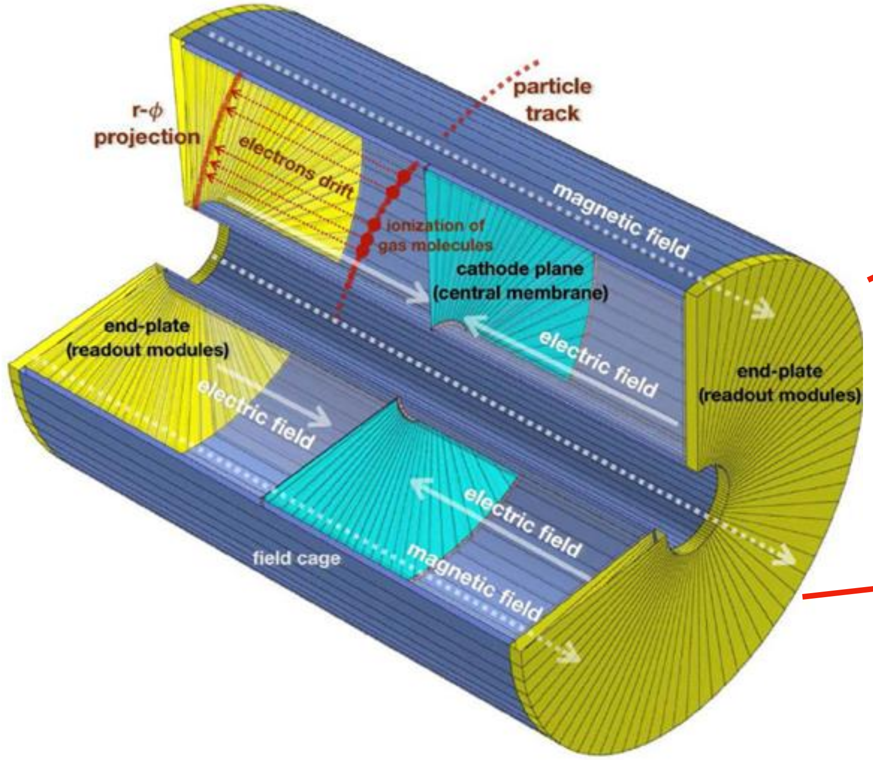
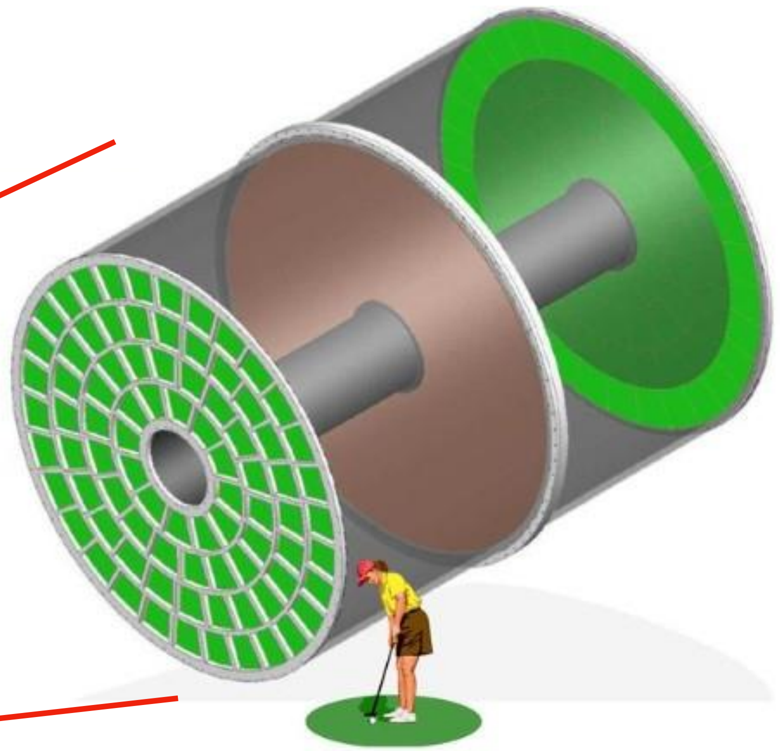
- **Overview of TPC detector**
- **Position resolution, dE/dx**
- **Status of TPC R&D**
- **Summary**

Time Projection Chamber (TPC)

Central tracker of CDR concept





Detects reactions of charged particles in 3-dim as tracks

Role of TPC

Charged particle

<u>Track measurement</u>

Measure passing points along trajectory

→Directions of track

<u>Momentum measurement</u>

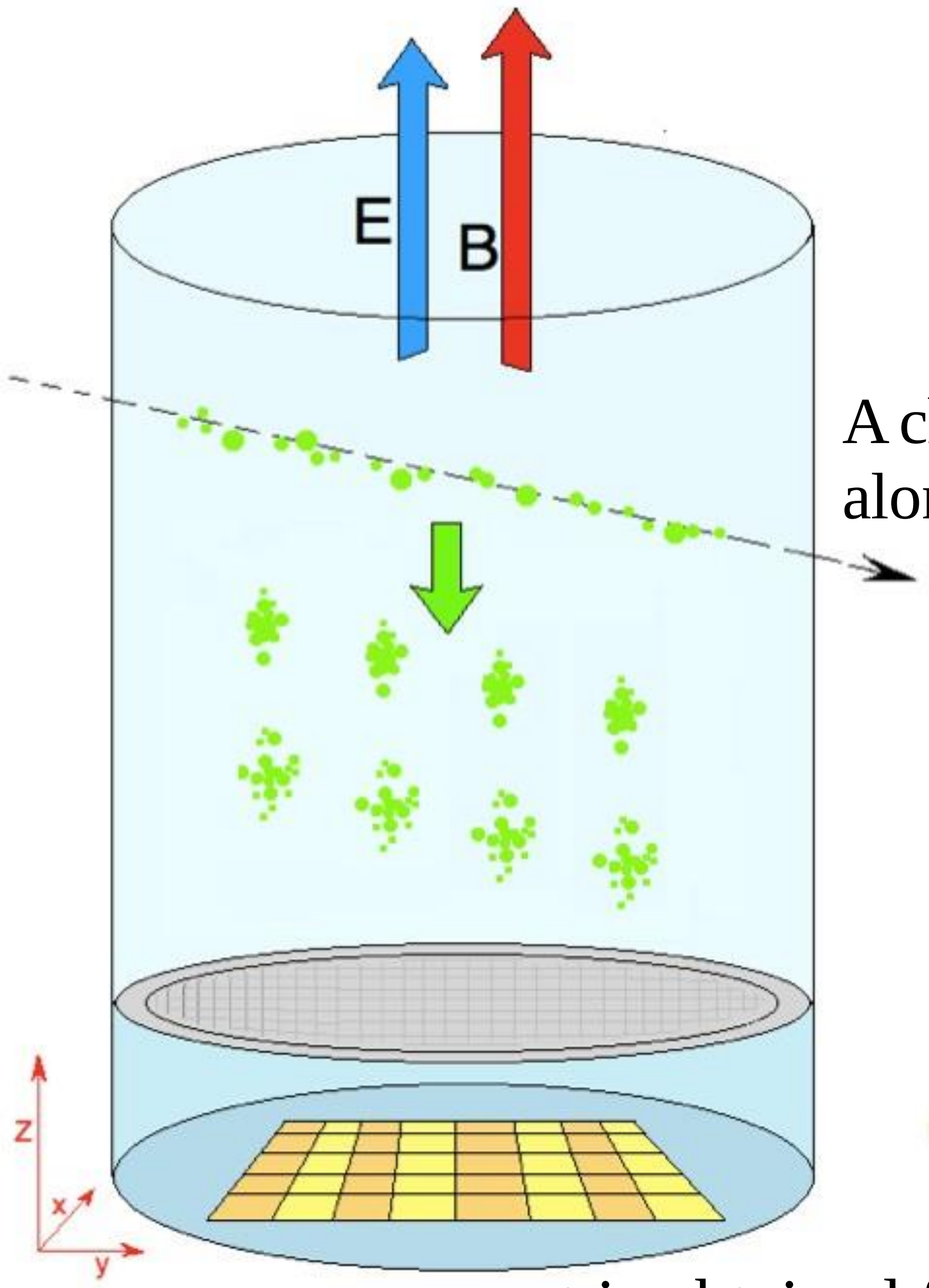
Measure the bend of tracks in B-Field

→Momentum of charged particle

<u>Particle Identification (PID)</u>

Operating principle of TPC

Electric field and magnetic field are applied in parallel in the TPC

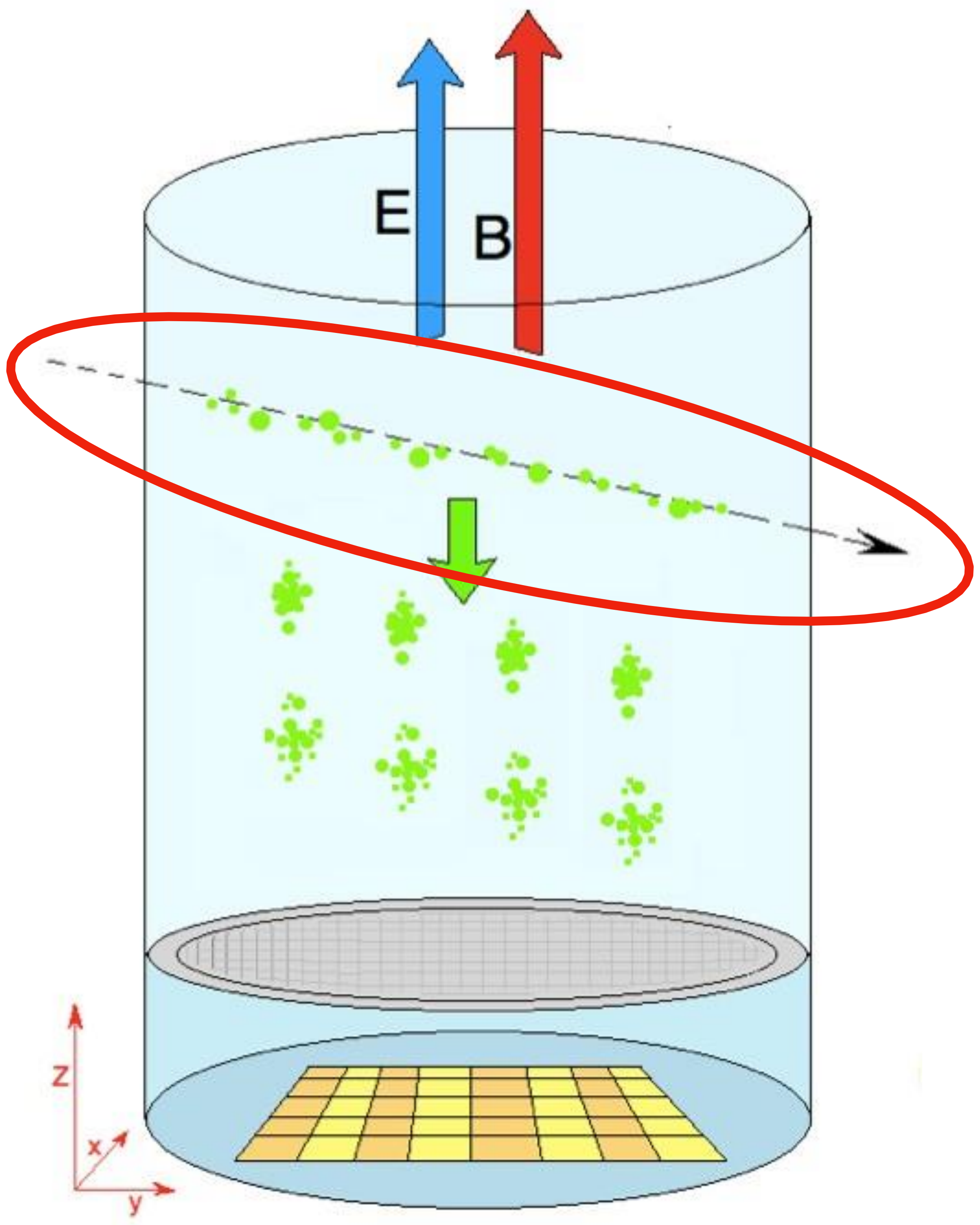


A charged particle ionizes the atoms of the gas mixture along its trajectory

The liberated electrons drift
in the E-field towards the readout pad

Gas-amplified and read as signal
⇨ 2-dimensional (x,y) information

z component is obtained from drift time ⇨ 3-dimensional (x, y, z) information



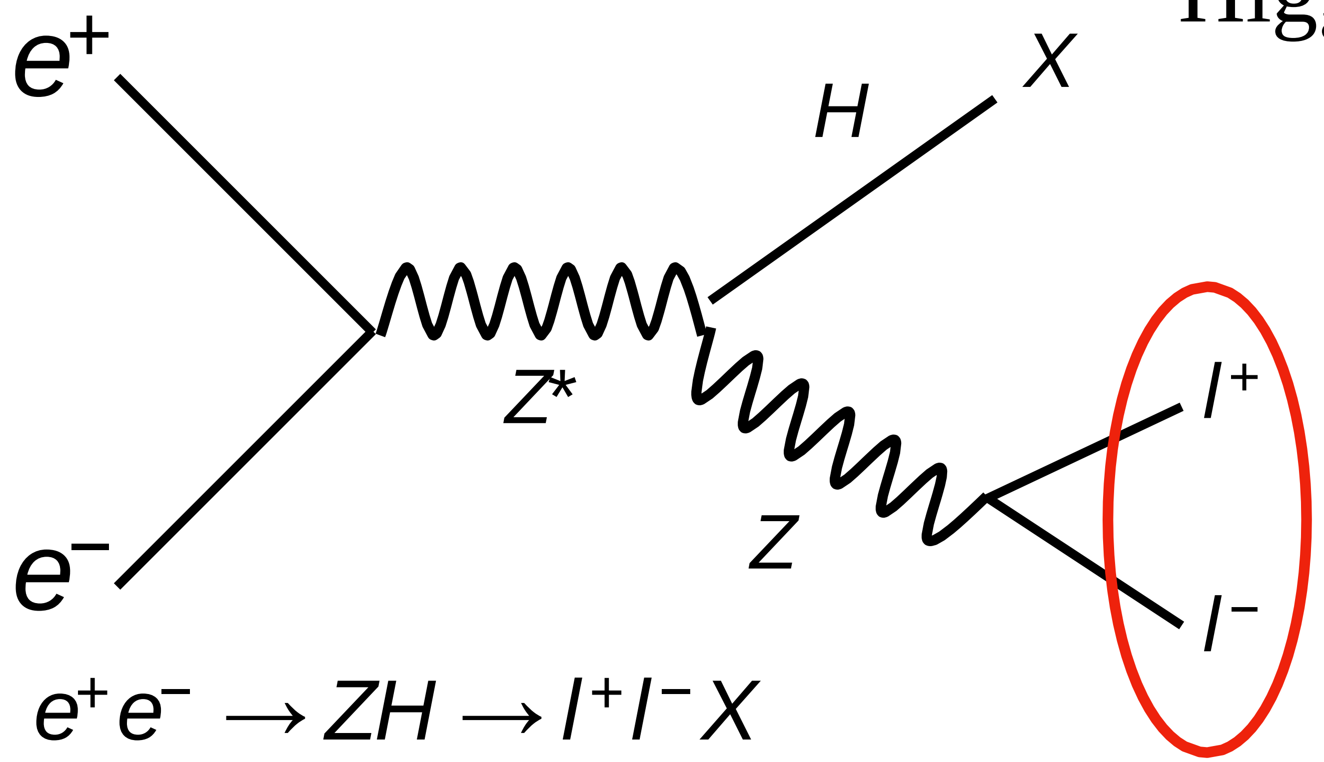
1. **Momentum measurement**
2. Particle ID and dE/dx
3. Readout module

Momentum measurement

CEPC: "Higgs factory"

Higgs precision measurement is a high-priority goal

"Recoil"



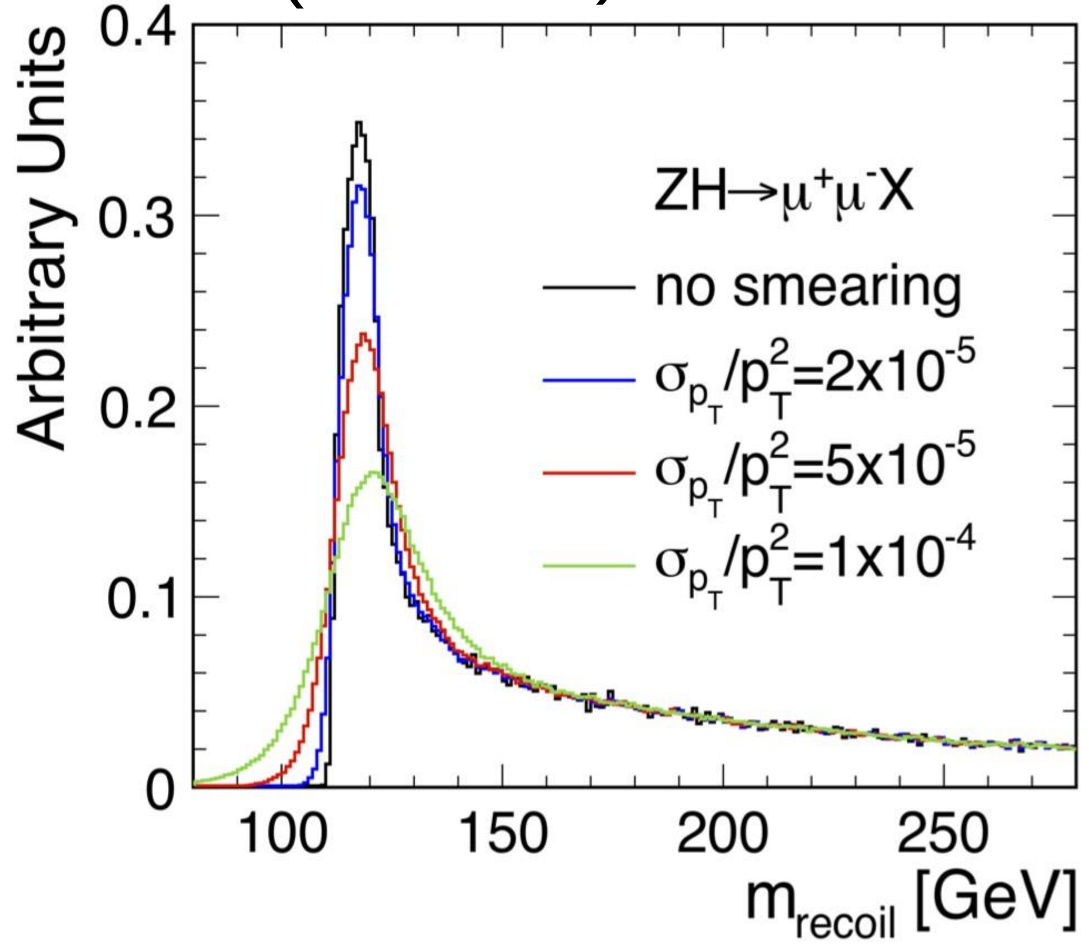
$e^+e^- \rightarrow ZH \rightarrow l^+l^-X$

Higgs can be reconstructed indirectly

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

or

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



Reconstruction of $Z \rightarrow ll$

momentum resolution is crucial

Momentum measurement

Momentum resolution

$$\frac{\sigma_{p_\perp}}{p_\perp} = \sqrt{\left(\frac{\alpha' \sigma_x}{BL^2}\right)^2 \left(\frac{720}{N+4}\right) p_\perp^2 + \left(\frac{\alpha' C}{BL}\right)^2 \frac{10}{7} \left(\frac{X}{X_0}\right)}$$

measurements multiple scattering

$p_\perp$: transverse momentum

σ_x : position resolution

B : strength of B-Field

N : # of measurement points

L : track detection length

$\frac{X}{X_0}$: radiation length of gas

α', C : constant

R.L. Gluckstern, NIM 24 (1963), 381

<u>Required momentum resolution of CEPC at Higgs run</u>

$$\frac{\sigma_{p_\perp}}{p_\perp} \approx 2 \times 10^{-5}$$

(including information of silicon tracker)

TPC only... $$\frac{\sigma_{p_\perp}}{p_\perp} \approx 1 \times 10^{-4}$$

Position resolution

$$\sigma_x = \sqrt{\sigma_0^2 + \frac{C_d^2 \cdot z}{N_{eff}}}$$

z: drift length
Neff: effective number of electron
Cd: diffusion constant of gas

depends on drift length

Small position resolution σ_x

$$\sigma_x \approx 100\ \mu m$$

Even at the large drift length of $2.2\ m$

- Strong magnetic field $B \sim 3.0\ T$
- Gas mixture with small diffusion constant

Gas mixture

T2K gas **Ar : CF4 : iC4H10 = 95 : 3 : 2**

<u>The isobutane</u>

act as a "quencher"

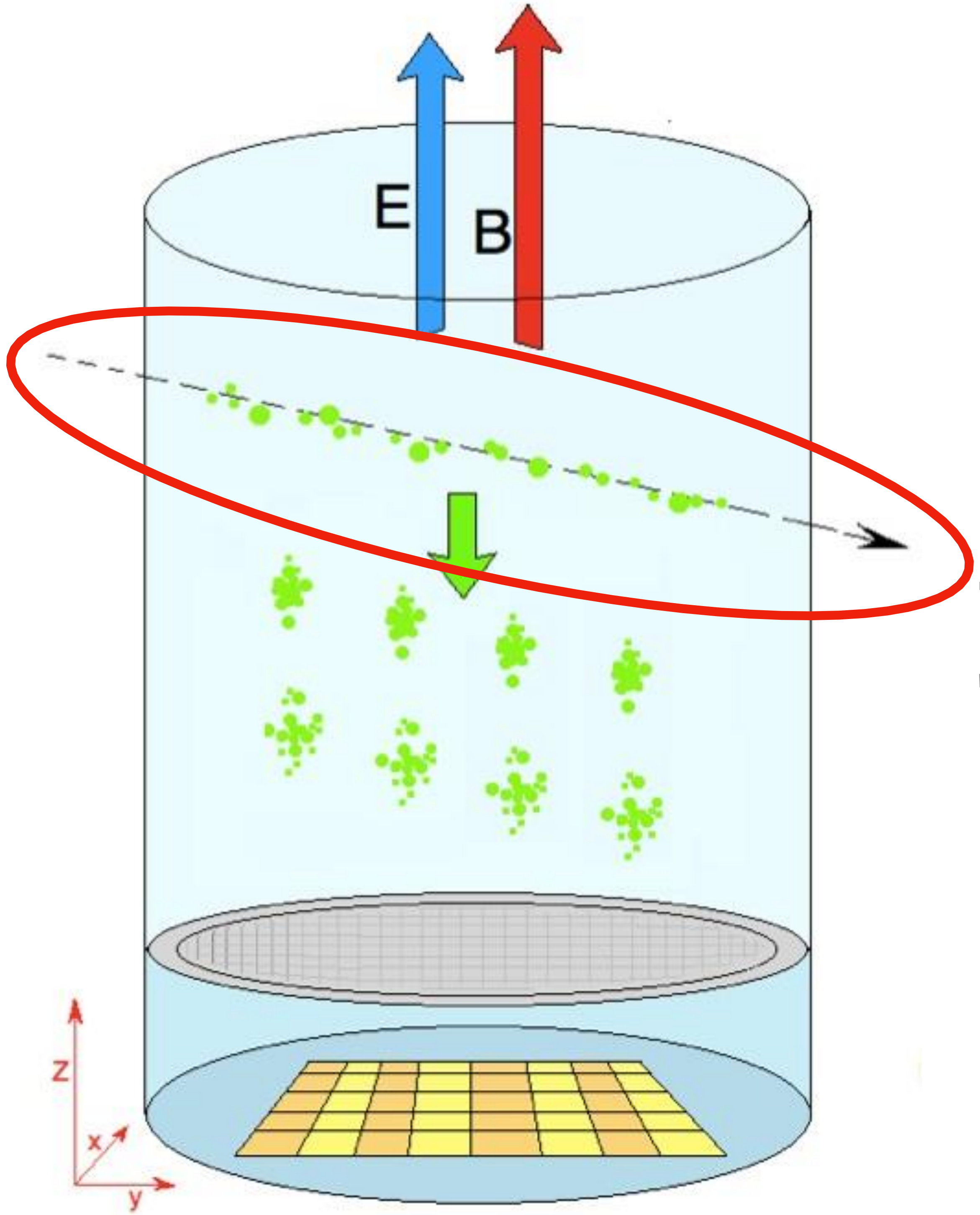
<u>absorb ultraviolet photons</u> from Ar molecules excited during avalanche process

→ might cause discharge and destabilise chamber operation.

bonus

A small amount of isobutane is added to obtain a high gas gain at low voltages

⇨ **Penning effect**



1. Momentum measurement
2. **Particle ID and dE/dx**
3. Readout module

Particle identification

Charged particle pass ->detect as track

main charged particle on the detector

- **π**
- **K**
- **e**
- **μ**

From the direction of bending by a B-Field

<u>charge</u> can be identified

particle <u>type</u>

dE/dx:Energy loss per unit length

Bethe-Bloch formula

$$\left\langle -\frac{dE}{dx} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

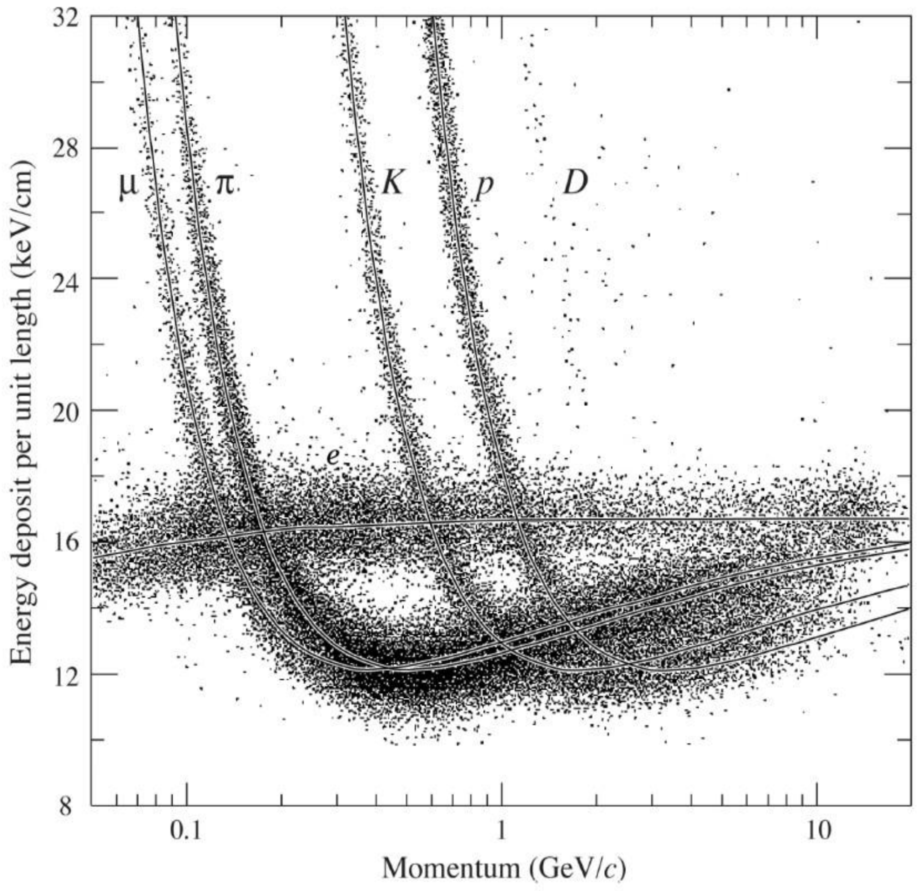
The value of <dE/dx> depends on particle species at a given momentum

→particle <u>type</u> can be identified

Particle identification

Function of $\beta\gamma = p/M$ **: <u>same distribution</u>**
regardless of **<u>particle type</u>**

Plot with function of $p = M\beta\gamma$
shift according to **<u>particle type</u>**

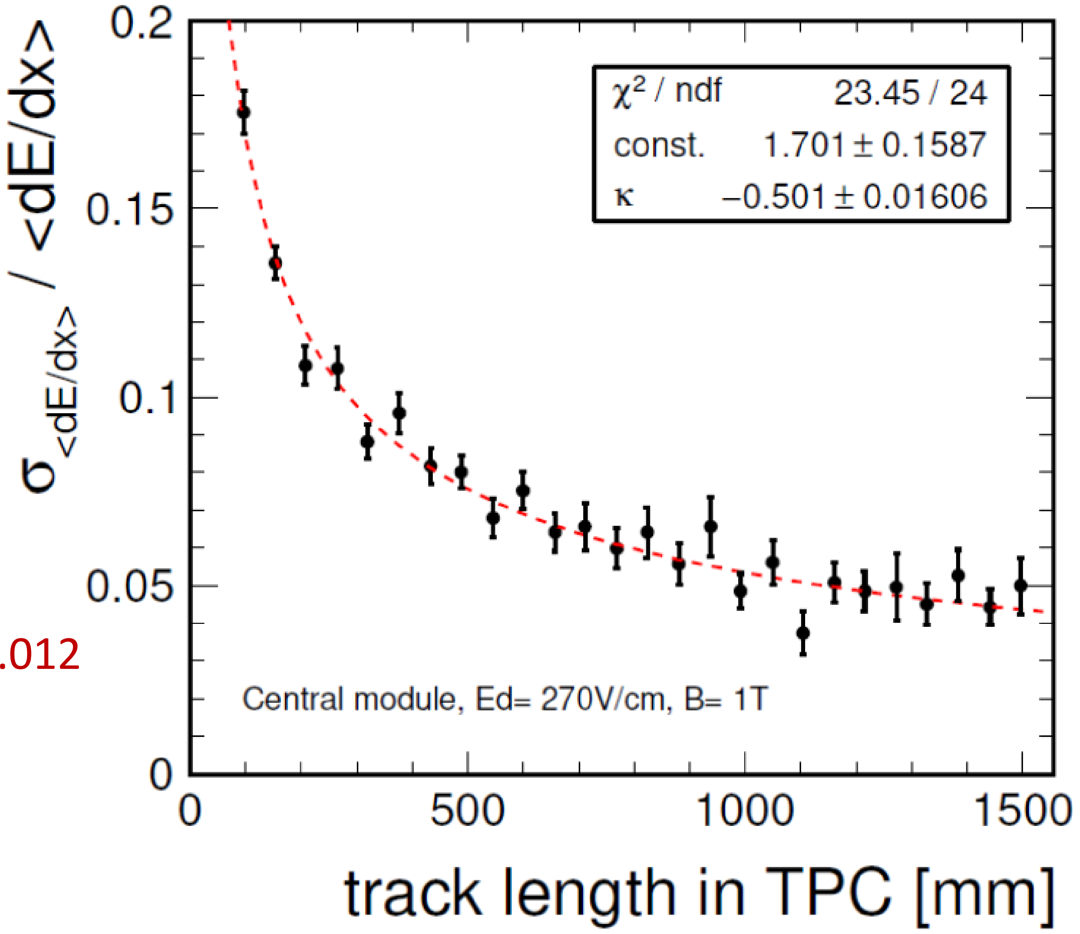


Particle ID using the specific ionization loss is possible at LOW MOMENTUM

(PEP4/9-TPC energy deposit measurement)
Physics Letters B667 (2008)
1 available on the PDG

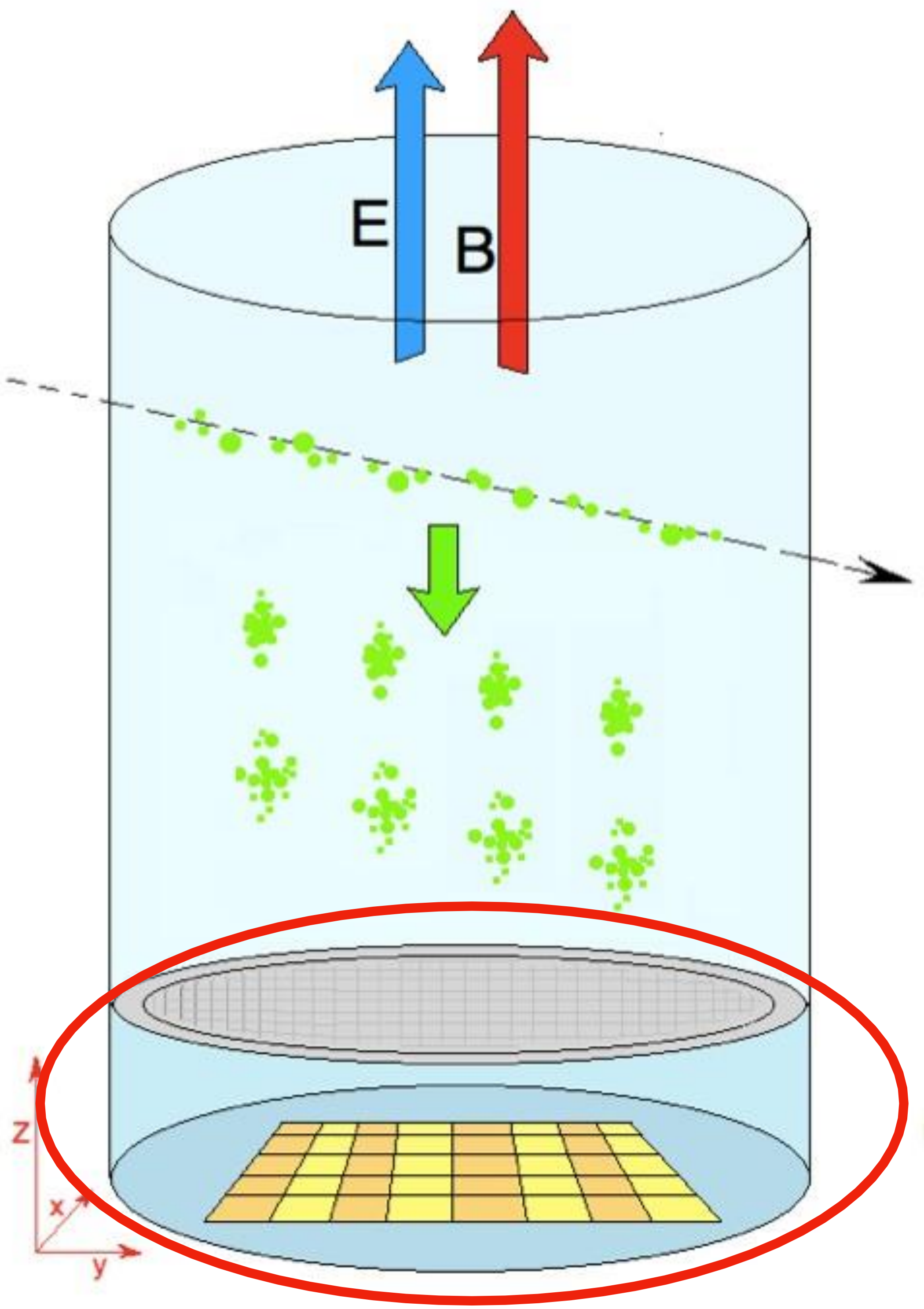
Pixel TPC dE/dx resolution can reach 2.7%

DOI:10.1016/j.nima.2018.08.012



5GeV e- beam at DESY

TPC detector with GEMs readout Micromegas readout



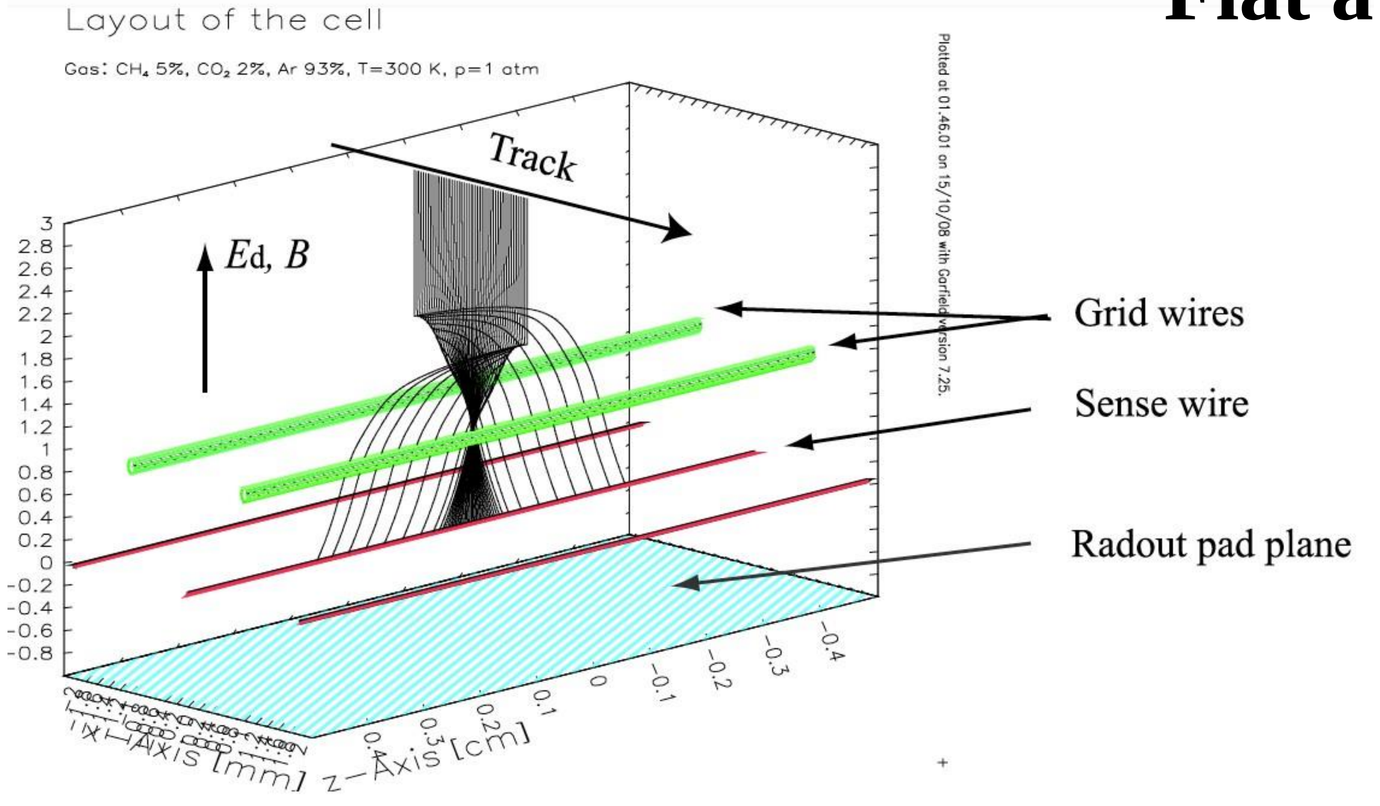
1. Momentum measurement
2. Particle ID and dE/dx
3. **Readout module**

Readout module

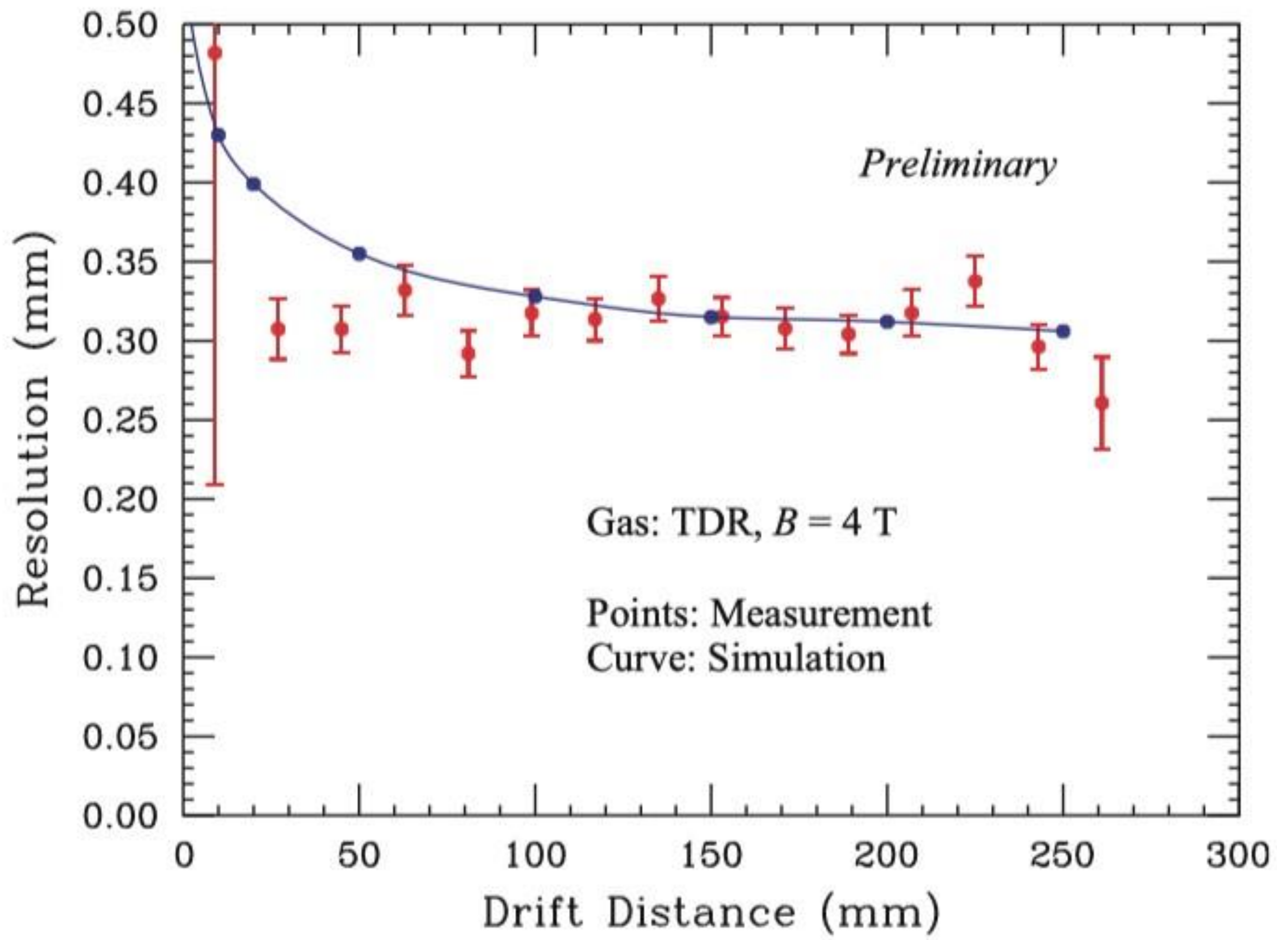
MWPC (Multi-Wire Proportional Chamber)
has been used in various experiments

CEPC: B-field ~ 3.0T
→E×B effect: bend the electron drift path near the wire
the spread of drift electron is VERY LARGE under a strong axial B

TPC using MWPC



Flat at position resolution of about 300 μm



MWPC can not achieve $\sigma_x \approx$ **100 μm**

A study with a small prototype TPC for the international linear collider experiment

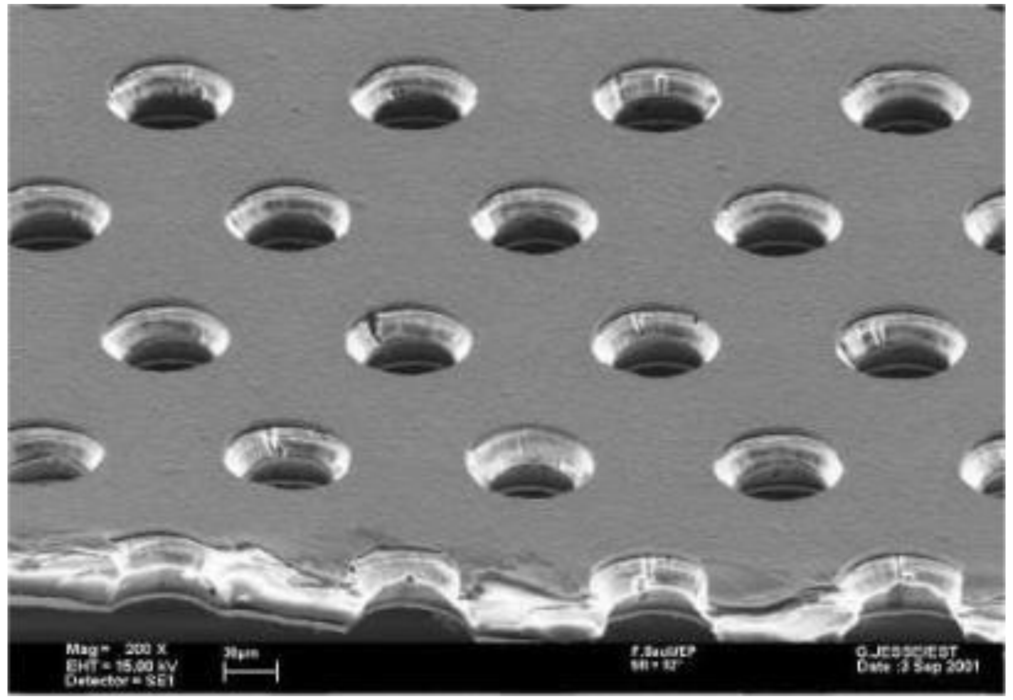
Readout module

MPGD (Micro-Pattern Gas Detector)

Gas detector using PCB(Printed Circuit board) etching technology

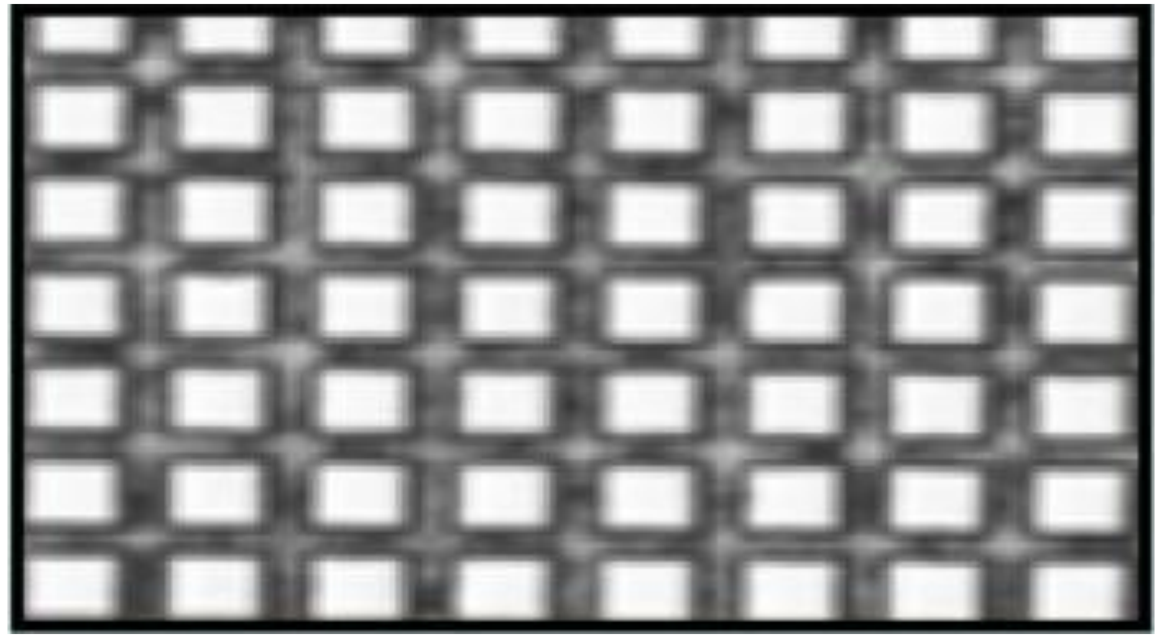
Example of MPGD

GEM



F.Sauli, NIM A 386(1997)531

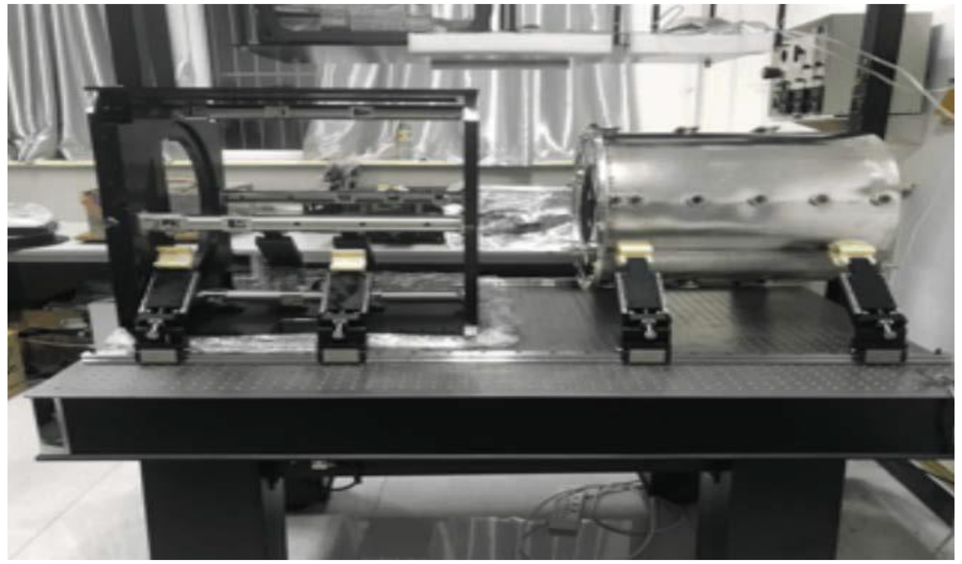
MICROMEGAS

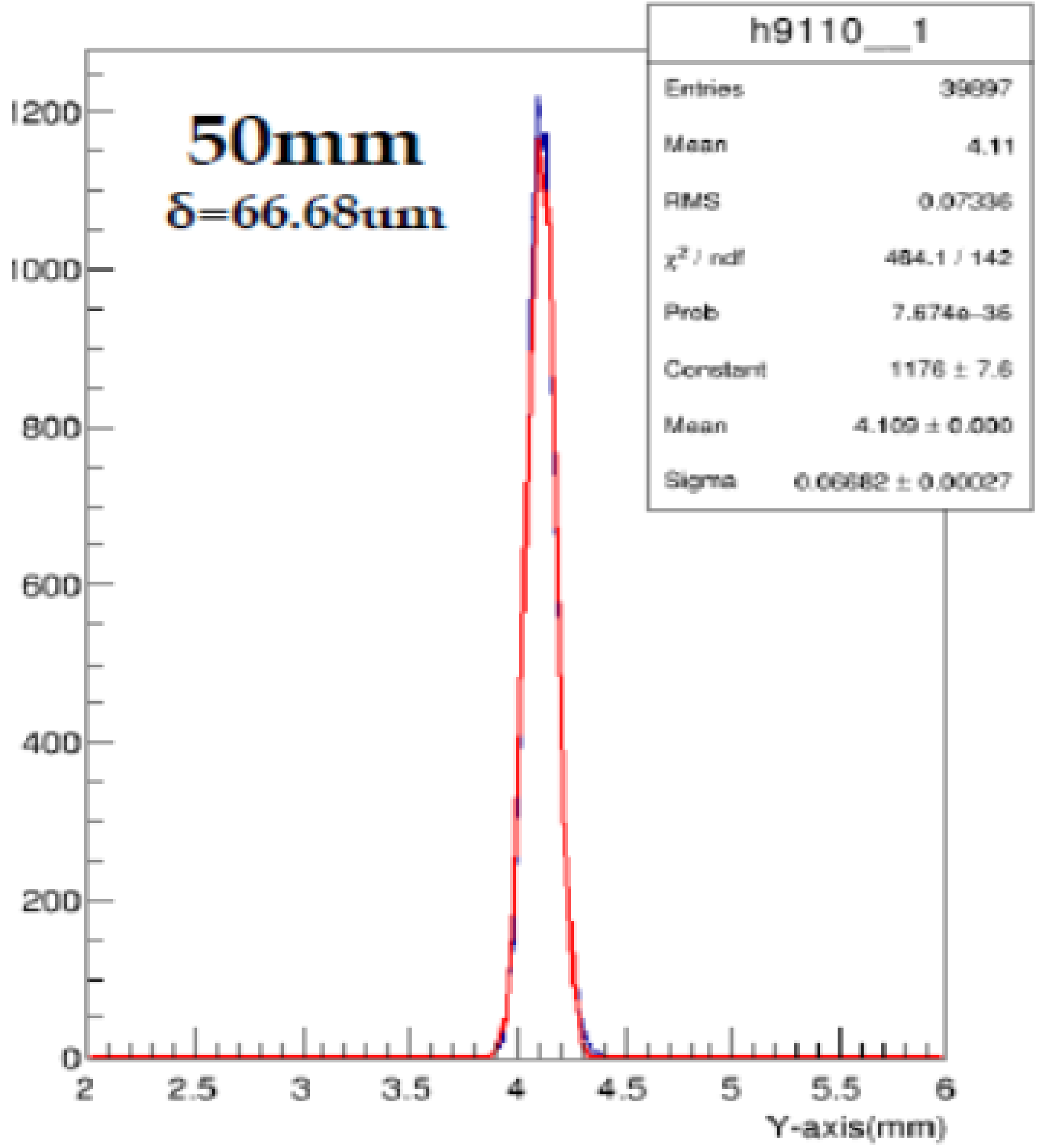


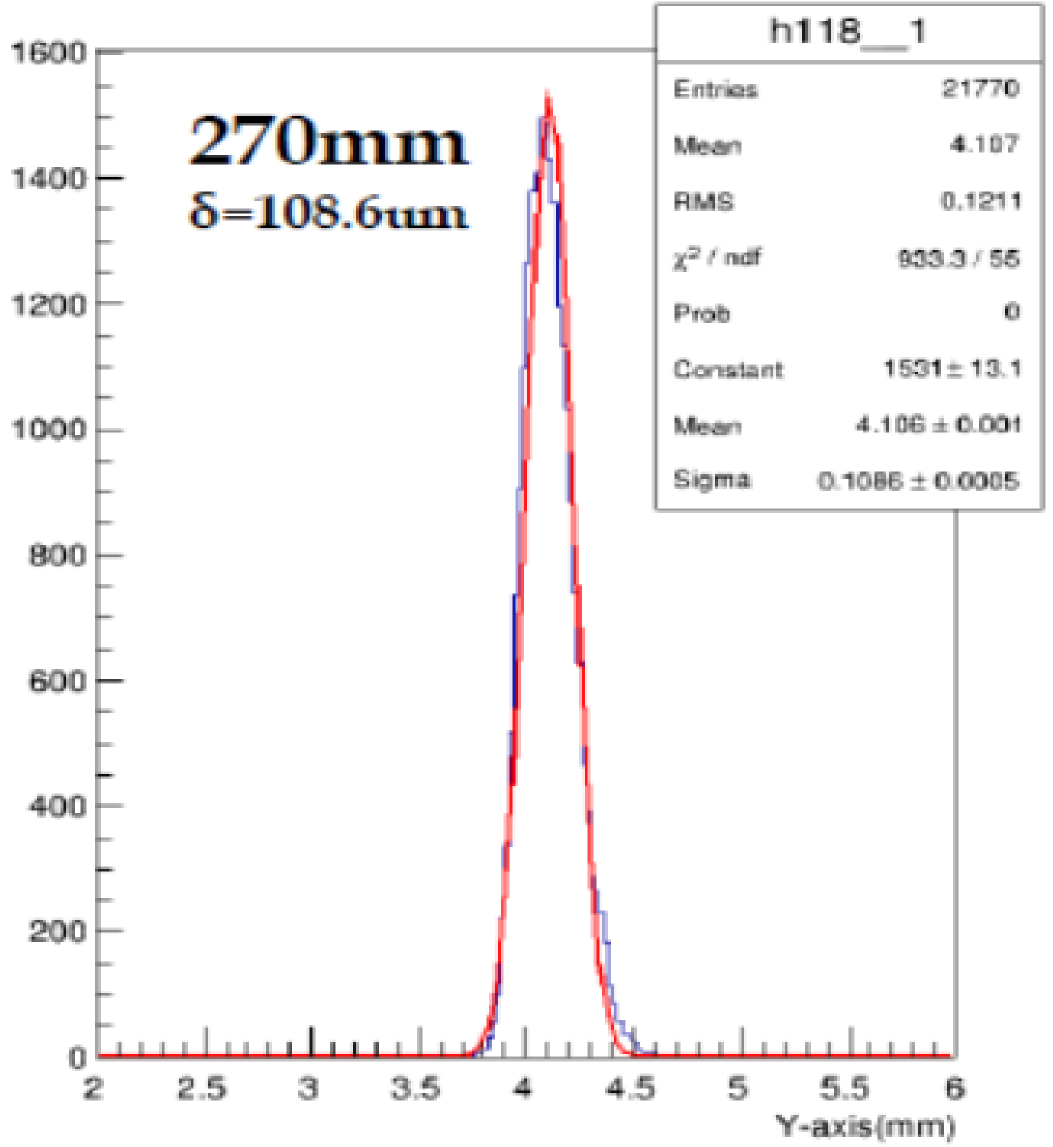
<u>E×B effect</u> is suppressed even in a high B-Field

The position resolution is good!

Position resolution of TPC prototype using GEM detector module at IHEP







Status of CEPC-TPC R&D

TPC R&D

To develop a high-performance TPC as a detector for CEPC

Our detector technology meets some critical challenges

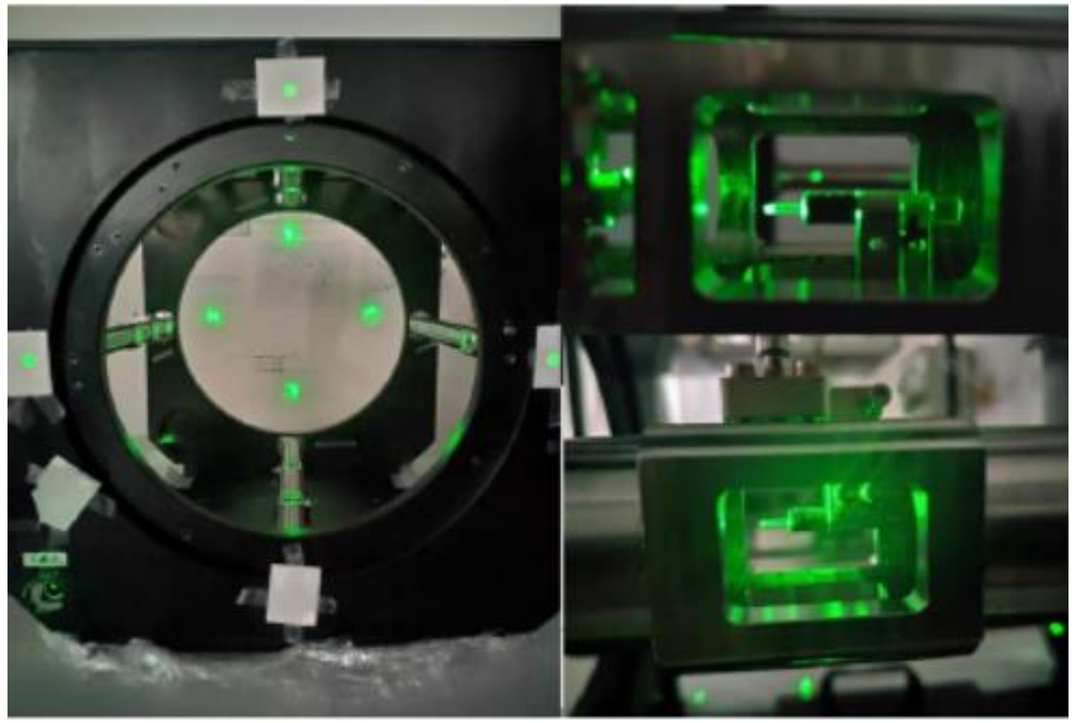
— Reduced the ions to control Ion back flow
— Calibration using UV laser
— Low power consumption ASIC chip readout

One solution to solve them to use our module and prototype

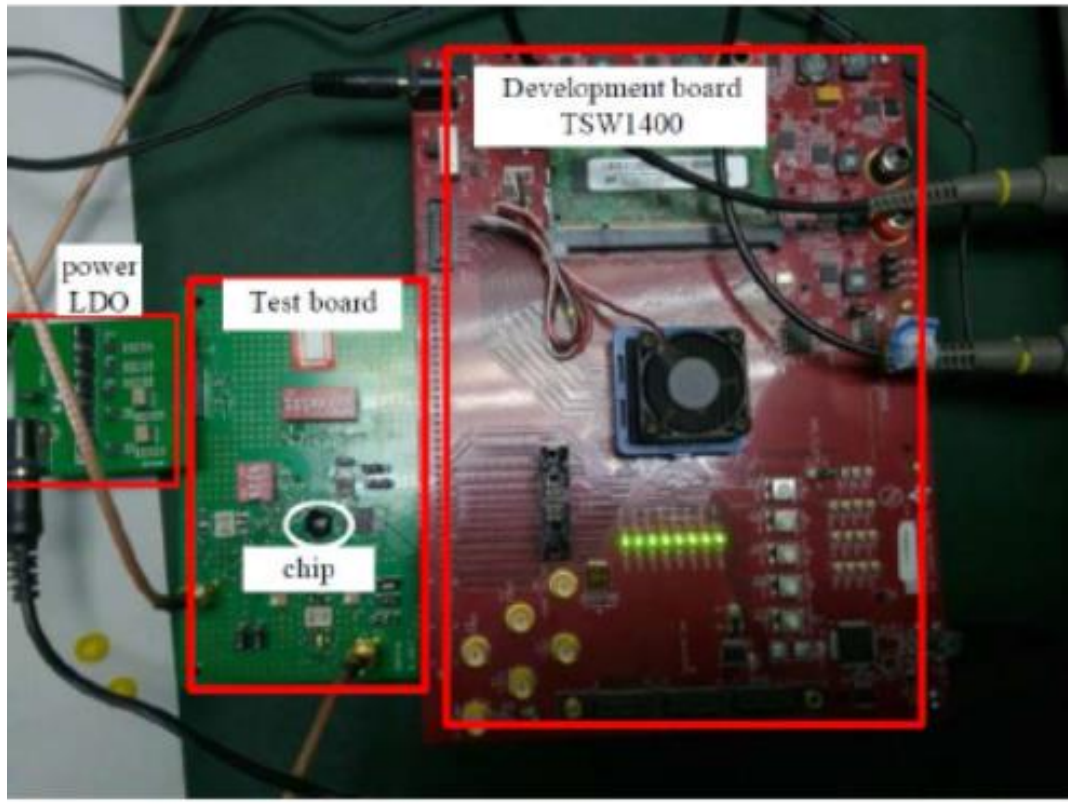
TPC R&D

Highlight progress of TPC R&D:

- **Simulation from CEPC TPC with IBF**
  - Position $< 20\ \mu m$ distortion ($Gain \times IBF = 1\ and\ L = 32 \times 10^{34}\ cm^{-2}s^{-1}$)
  - Study of TPC module and prototype
  - Lower gain and lower IBF ratio
  - $Gain\ \times\ IBF$ could reach to 1 @Gain/2000
  - TPC prototype integrated UV laser beams
- **Study of low power consumption FEE chip**
  - Using more advanced 65nm CMOS process
  - AFE SAR ADC *<5mW/ch* @ Chip prototype
- **Key issues and potential solutions:**
  - Double meshes Pixel TPC option R&D with the lower IBF ratio
  - Calibration and alignment studies at Z pole using UV laser beams
  - Most requirement of dE/dx and momentum resolution, and others should be optimized



TPC Prototype integrated UV laser beams



FEE ASIC Chip using 65nm CMOS

Summary

– The CEPC TPC is a high-performance central tracker operated in a strong B-field, featuring MPGD readout modules.

– The TPC provides excellent track pattern recognition capability with small 3-D voxels, along with good position, momentum, and dE/dx information of each track in jets, which are indispensable for the Particle Flow Analysis.

– We have successfully developed a detector module and prototype that meets the requirements, and are now working on the R&D.

– Some new considerations of TPC technology will be developed to meet the high luminosity of Z pole run in CEPC.