Mechanical design progress of Time projection Chamber Detector for CEPC

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Outline

- Physics motivation
- Mechanical design of TPC prototype
- Some consideration of TPC for CEPC
- Summary

Physics Motivation

Baseline concept in CEPC CDR

❖ VERTEX: flavour tag, IP resolution (H → bb, cc ττ)
~1/5 $r_{beampipe}$,1/30 pixel size, ~1/10 resolution (ILC vs LHC

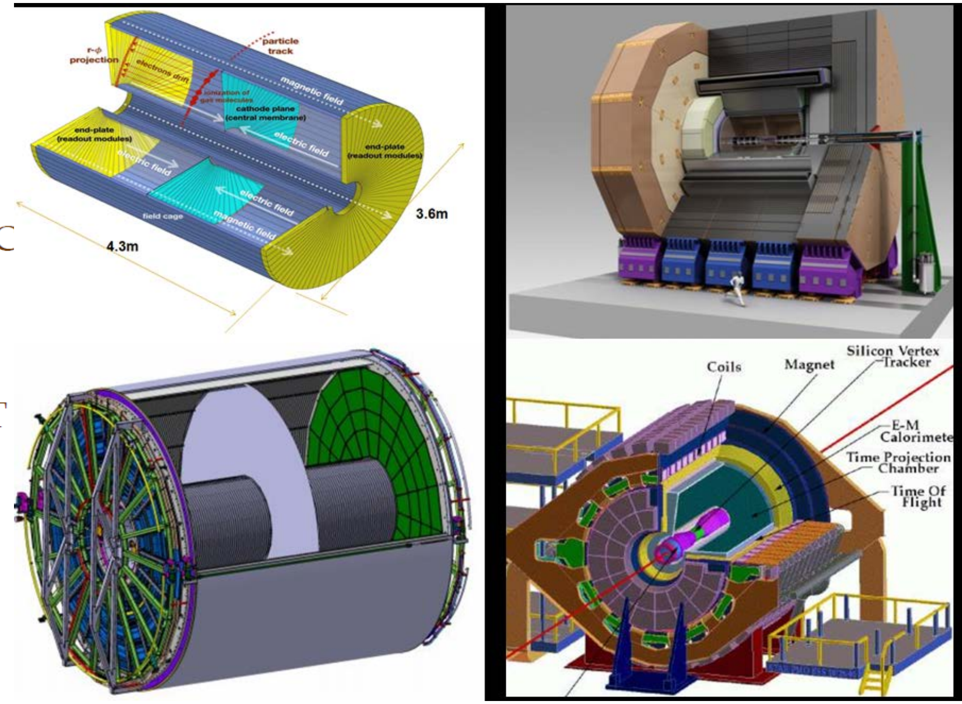
$$\sigma_{IP} = 5 \oplus \frac{10}{p\sin^{3/2}\theta}(\mu m)$$

❖ TRACKING: recoil mass to Higgs (e+e- → ZH → llX)
~1/6 material, ~1/10 resolution (ILC vs LHC); B = 3.5 – 5T

$$\sigma(1/p) = 2\times 10^{-5}(\mathrm{GeV}^{-1})$$

❖ CALORIMETRY: particle flow, di-jet mass resolution
1000x granularity, ~1/2 resolution (ILC vs LHC);
detector coverage down to very low angle

$$\sigma_E / E = 0.3/\sqrt{E(\mathrm{GeV})}$$



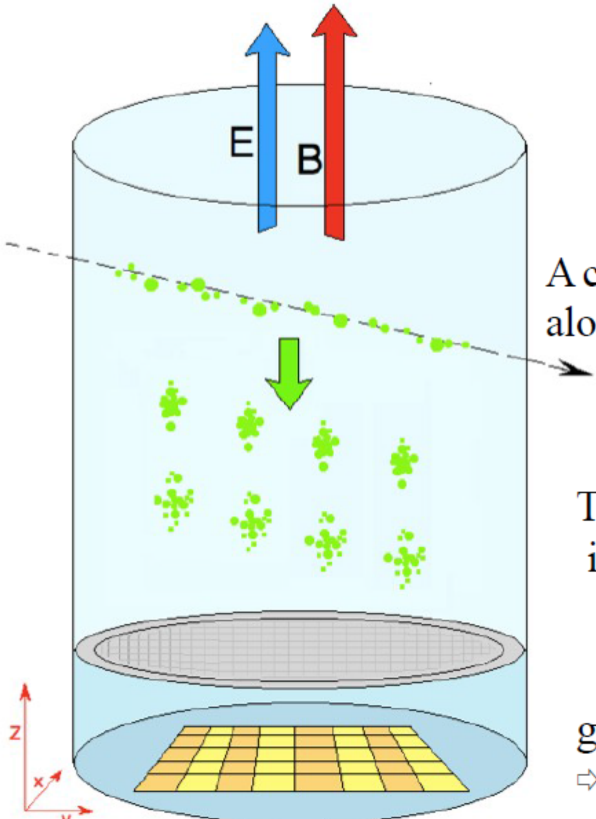
CEPC/ ILD/ ALICE/ RHIC-STAR

- **Large high-field solenoid and yoke**
- **Time Projection Chamber as a transparent central tracker**
- **Highly granular ECAL and HCAL optimized for particle flow**
- **Silicon envelope and inner tracker + vertex detector**
- **Forward calorimeter system**

TPC concept

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

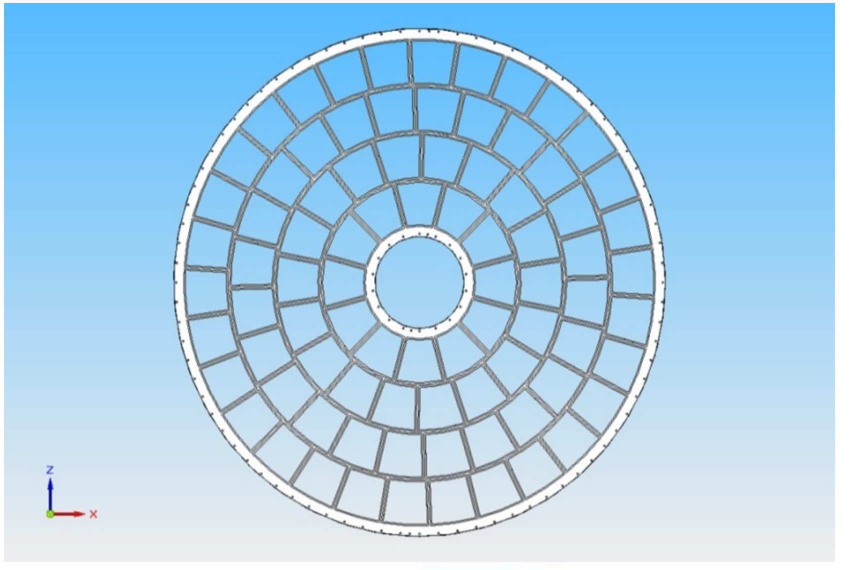
MPGD readout

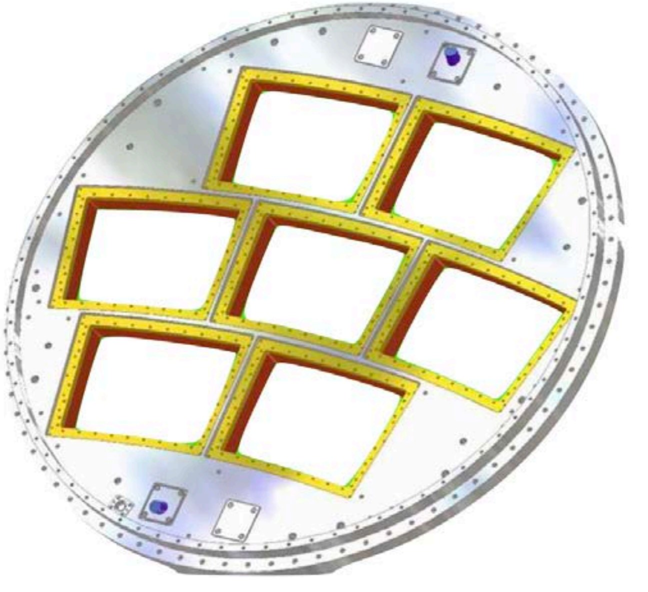
z component is obtained from drift time ⇨ 3-dimensional (x, y, z) information

TPC requirements for CEPC

TPC detector concept:

- Under 3 Tesla magnetic field (Momentum resolution: ~10^{-4}/GeV/c with TPC standalone)
- Large number of 3D space points(~220 along the diameter)
- dE/dx resolution: <5%
- ~100 μm position resolution in rφ
  - ~60μm for zero drift, <100μm overall
  - Systematics precision (<20μm internal)
- TPC material budget
  - <$1X_0$ including outer field cage
- Tracker efficiency: >97% for pT>1GeV
- 2-hit resolution in rφ : ~2mm
- Module design: ~200mm×170mm
- Minimizes dead space between the modules: 1-2mm





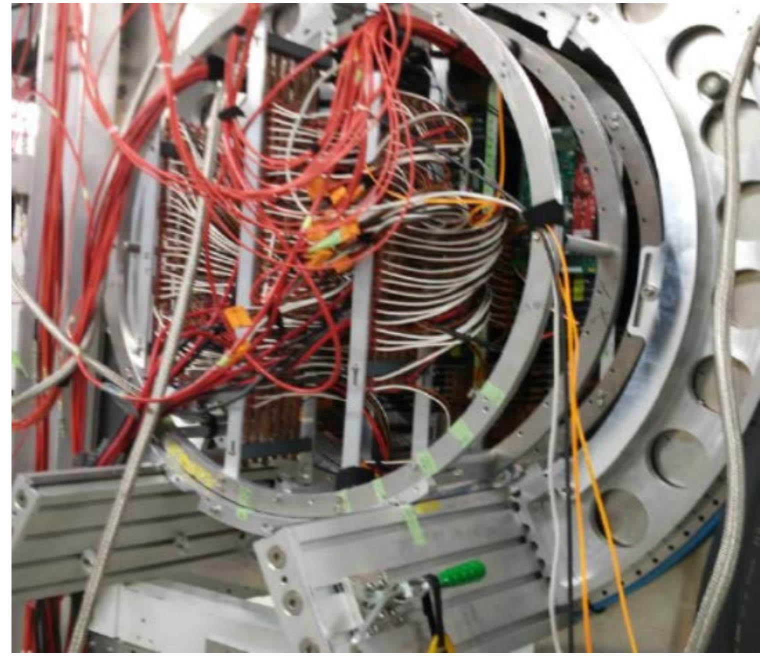
TPC detector endplate concept

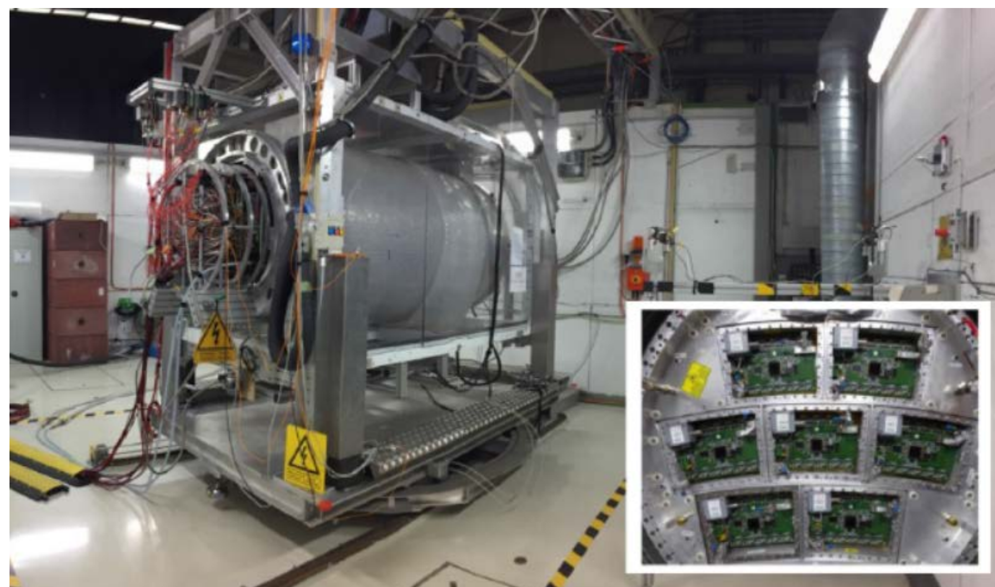
Some references

ALICE TPC (operation)

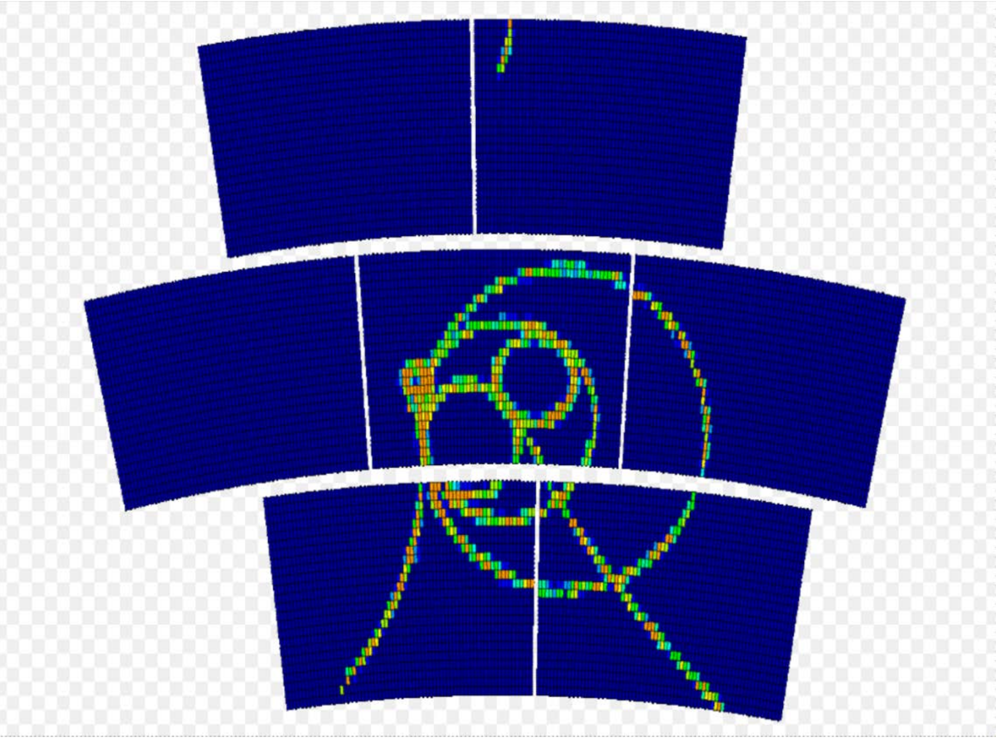
LCTPC collaboration R&D:

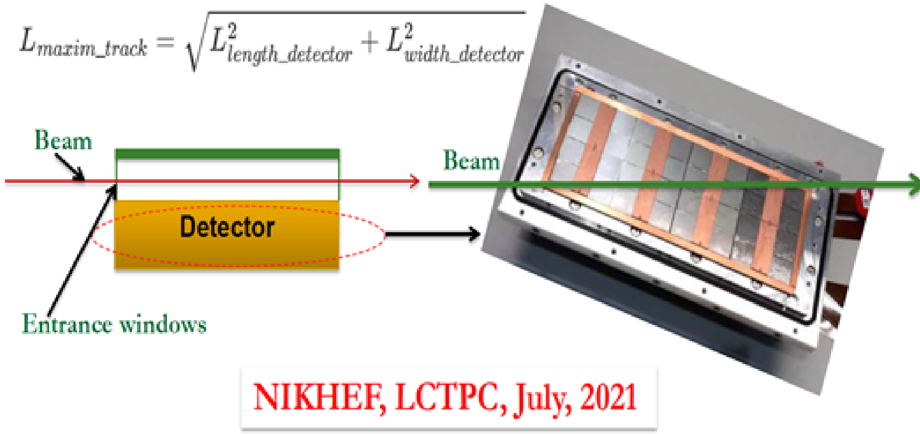
- As the key detector reference
- Phase#0: Small prototype
- Phase#1: Large prototype I
- Phase#2: Large prototype II
- Phase#3: Full size detector
- ……
- Technology collaboration
  - High voltage
  - Low voltage
  - Support layout
  - Gas system
  - Cooling system
  - Electronic system
  - ……

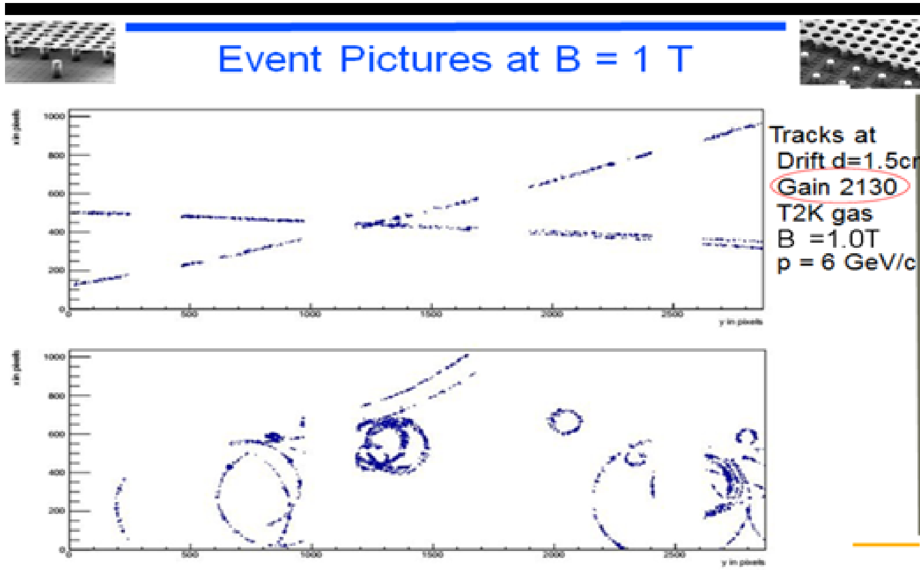




Update results-track reconstruction







两种读出结果事例显示（LCTPC）

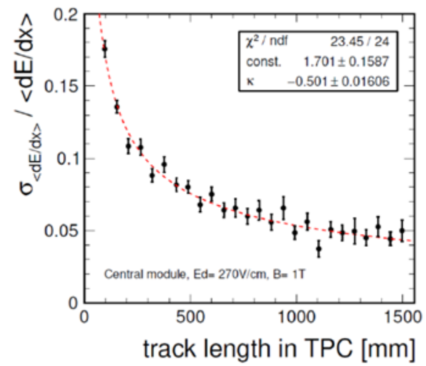
Update results-dE/dx

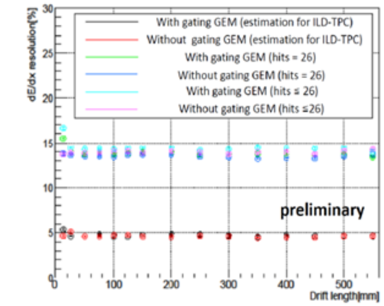
- Transformed to dE/dx resolution extrapolated to ILD
- GridPix, beam test at ELSA test beam @Uni Bonn
- 3.5 % by method 1: electron counting per 20-pixel intervals, 90 % truncated sum
- 3.4 % by method 2: cluster counting, by applying a weight w_i to every recorded electron, depending on the distance d_i to its sucessor; w_i extracted from simulation
- 3.26 % combined
  (numbers revised since publication of proceedings)

https://arxiv.org/abs/1902.01987

Beam test results@5GeV/1T/Pad TPC

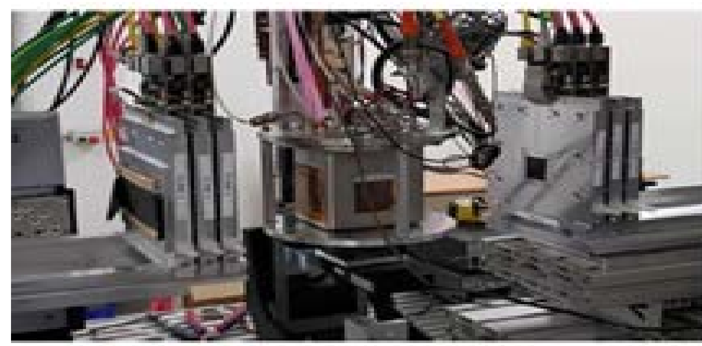
Jochen@ILD meeting





e average of dE/dx resolution expected from the ILD-TPC is 4.70 ± 0.02% (4.61±0.02%)
h (without) the gating GEM.

- dE/dx resolution extrapolated to ILD
- Pad-based systems, beam test @DESY II test beam facility:
  - 4.7 % (GEMs) https://arxiv.org/abs/2006.08562, paper in preparation
  - 4.6 % (GEMs) https://arxiv.org/abs/1801.04499
  - 5.0 % (Micromegas) https://agenda.linearcollider.org/event/7826/contributions/41602/



$$\mu' = \frac{1}{N_{\rm hits}} \sum_{i=0}^{N_{\rm hits}} w(d_i) d_i,$$

Update R&D at IHEP

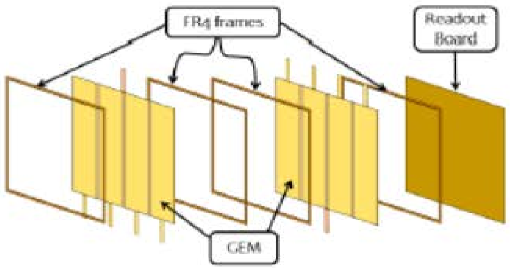
- Improved dE/dx by cluster counting
- Improved measurement for the low angle tracks
- Improved double track separation
- Much reduced hodoscope effect
  - Near to the endplate
  - Decreased the spatial resolution
- Lower occupancy in the high rate environments
- Fully digital readout

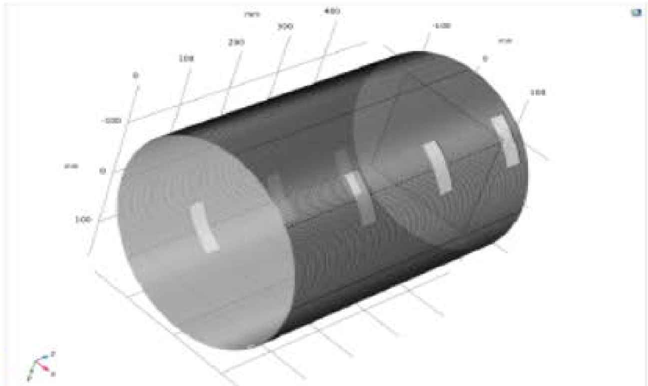
- **Mechanical design of TPC prototype (training)**

TPC detector prototype

- Main parameters
  - Drift length: ~500mm, Active area: 200mm²
  - Integrated 266nm laser beam with MPGD as the readout

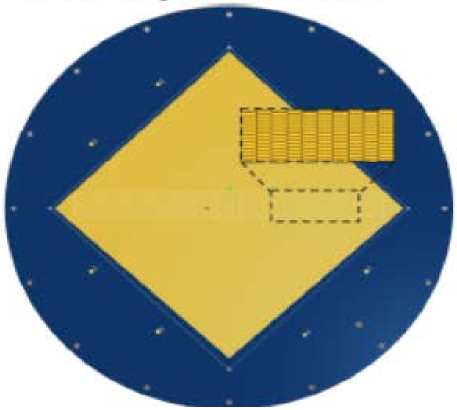
读出双层 GEM



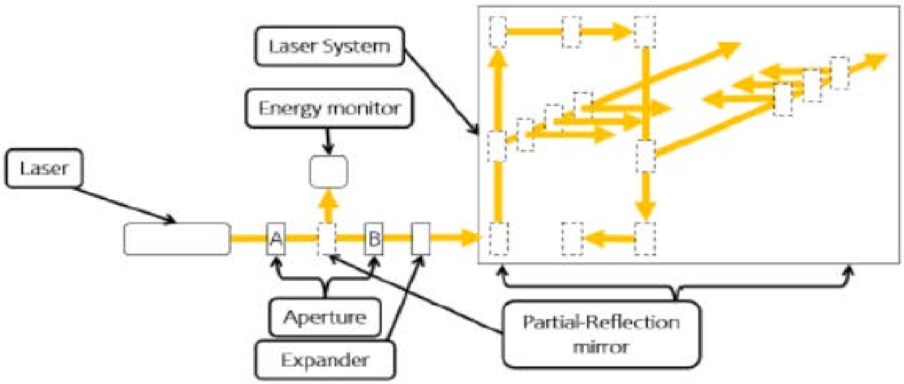


场笼

读出 pad 布局

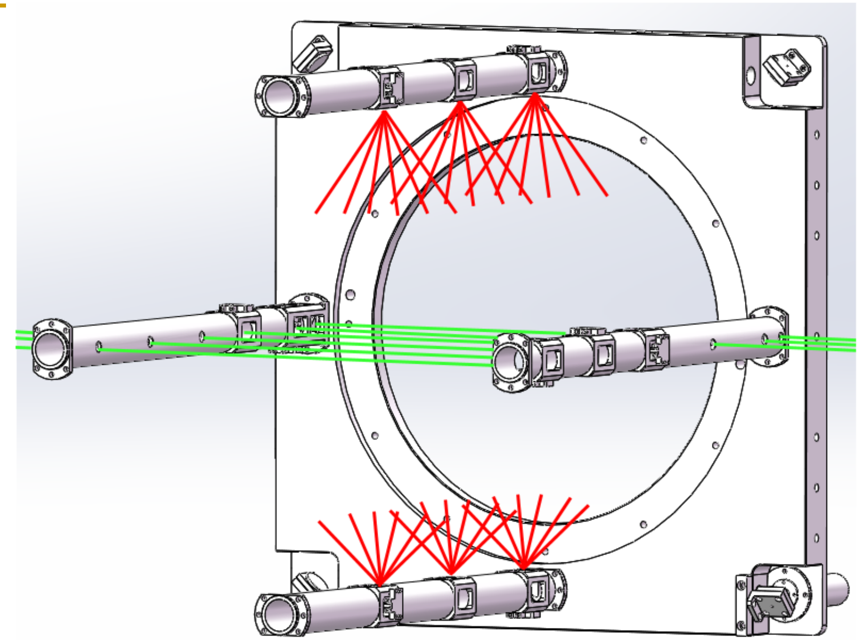


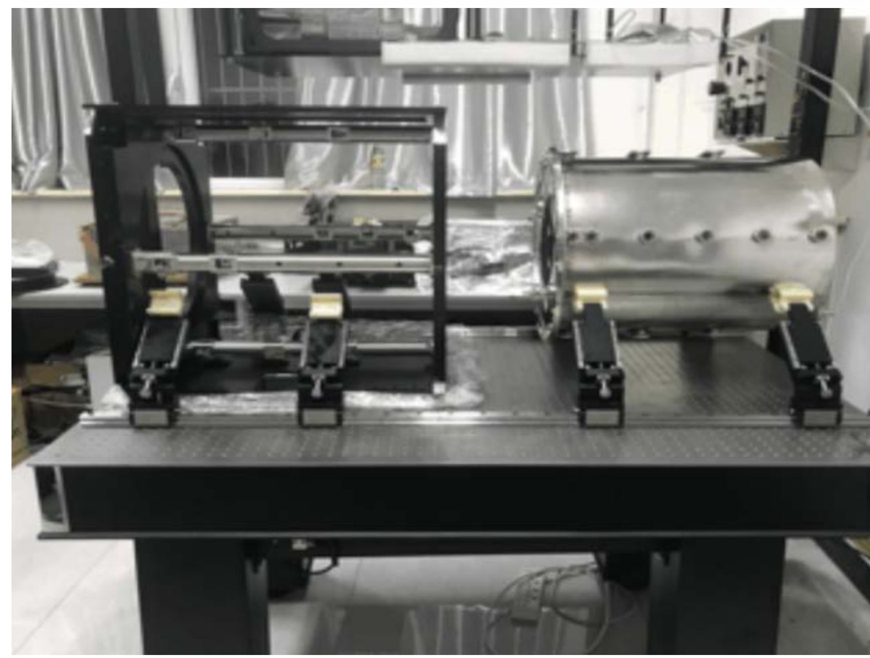
激光光路设计



TPC Prototype sketch

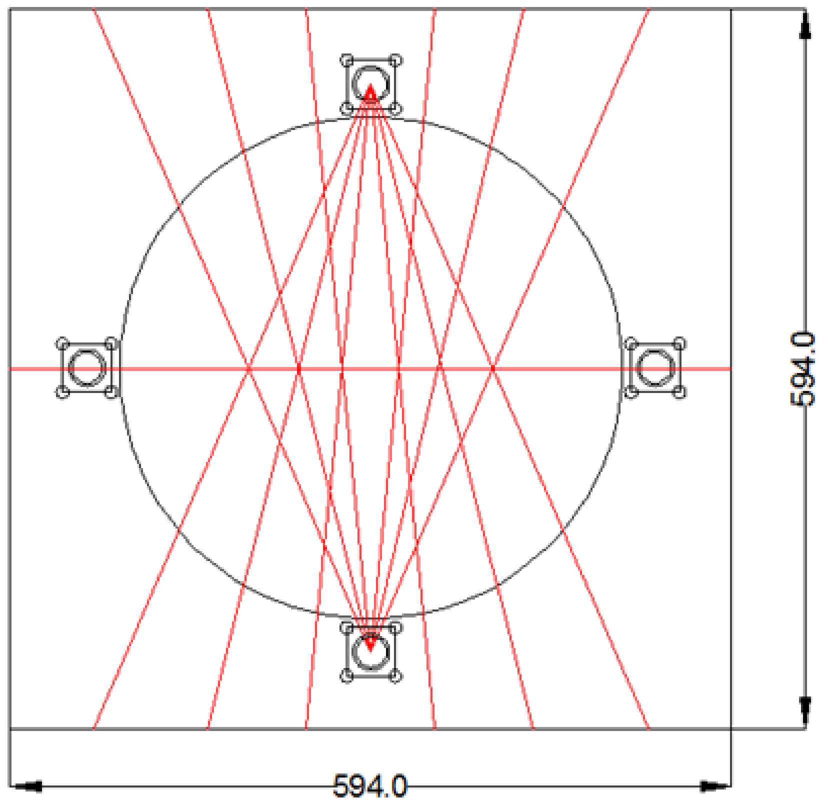
- Main parameters
  - Same test parameters in CEPC
    - Drift field=200V/cm
    - Relative gain: ≥2000
    - Readout pad(anode) is designed to 0V (Ground)
    - TPC detector system: Fieldcage+ Pads readout
    - Working mixture gas:
      - $Ar/CF_4/iC_4H_{10}$=95/3/2
      - Same purity
  - Specific prototype parameters
    - Drift length: ~500mm
    - Active area: 200mm^2
    - Integrated 266nm laser beam
    - MPGD detector as the readout
    - TPC cathode: -10kV
    - Readout Pads: 1280 channels



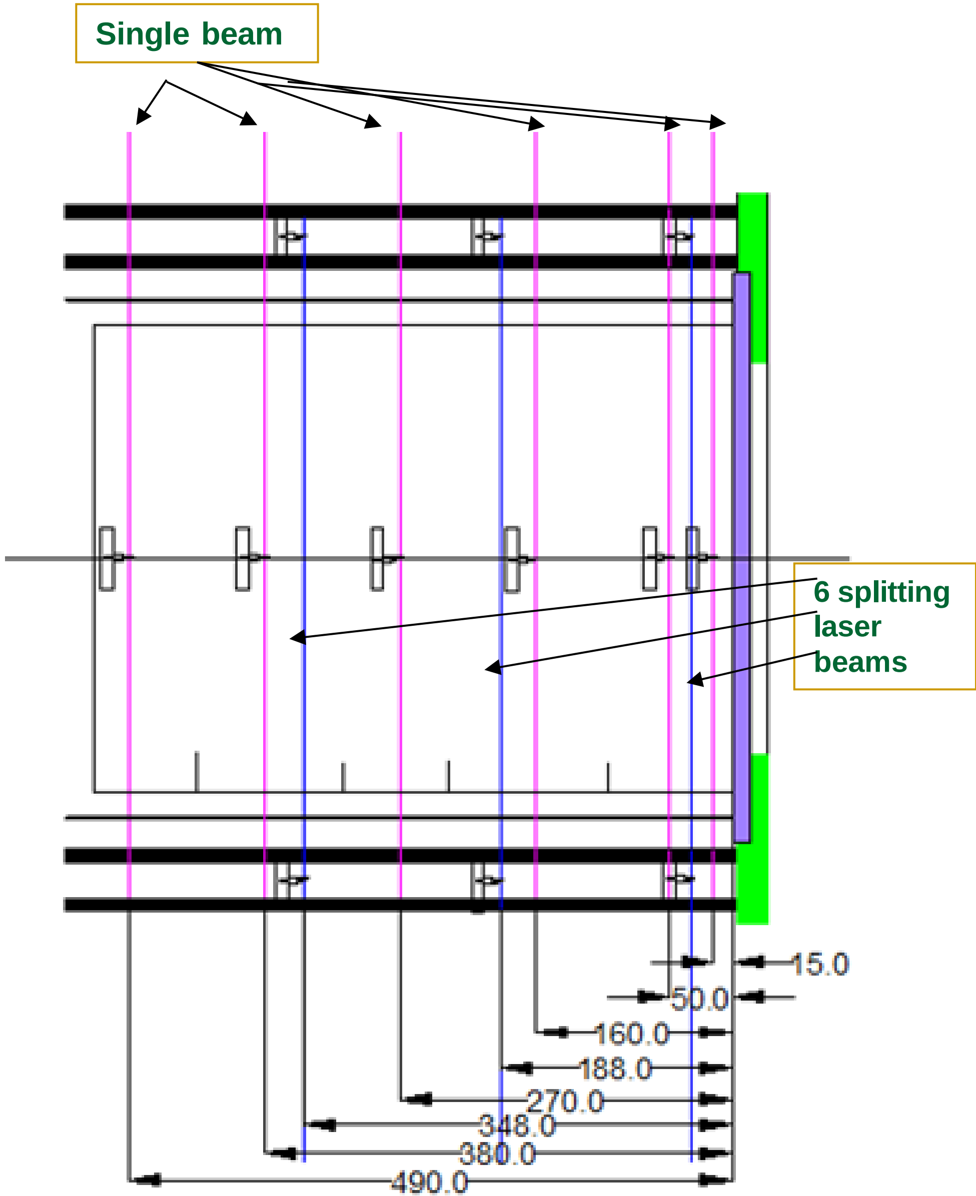


TPC prototype

Layout of UV beams



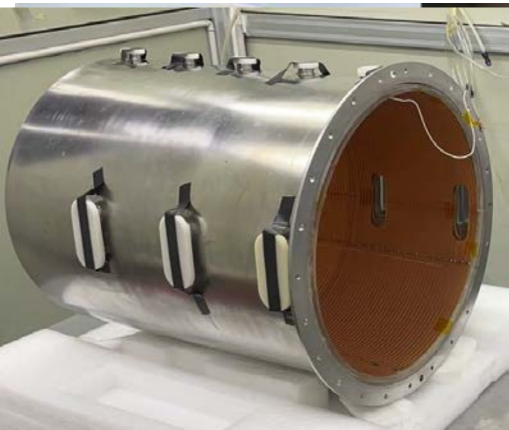
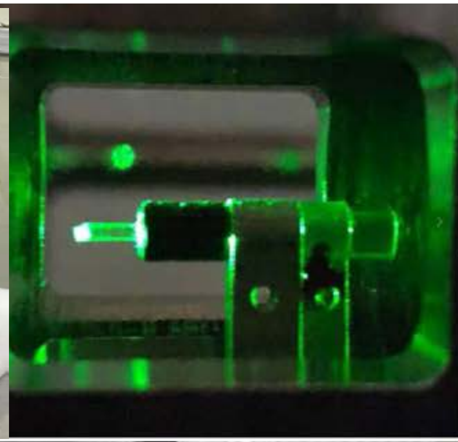
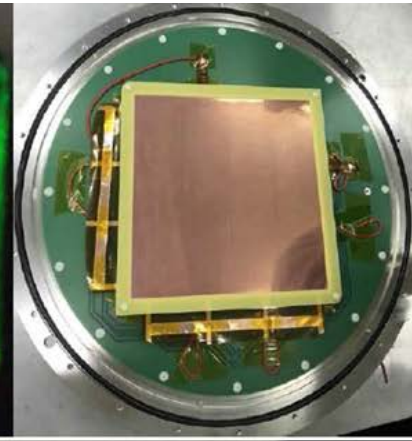
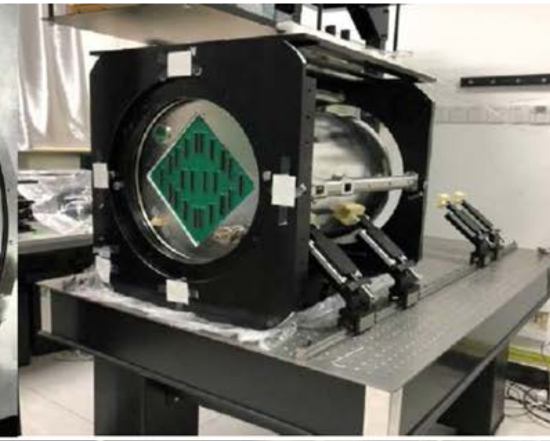
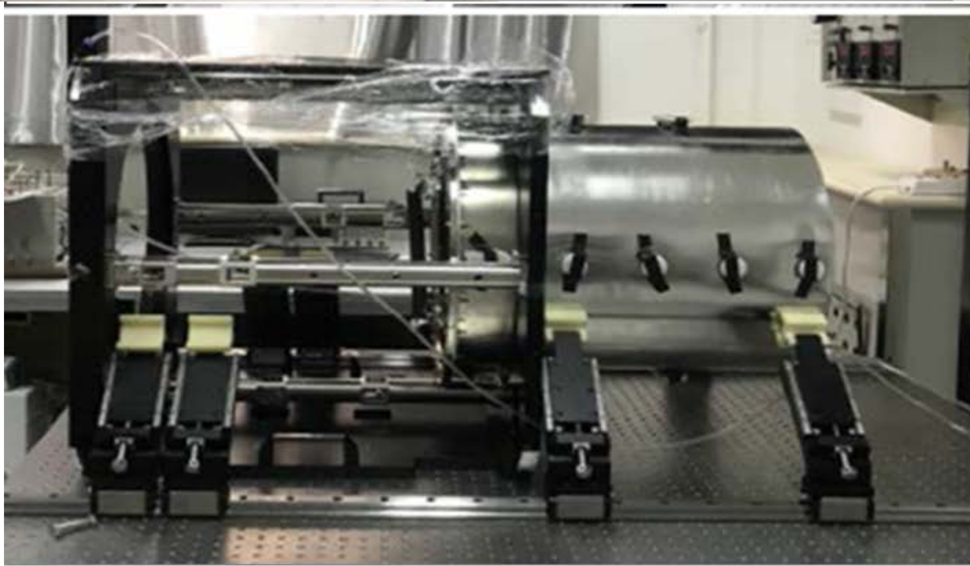
Laser map in X-Y direction



Laser map along drift length

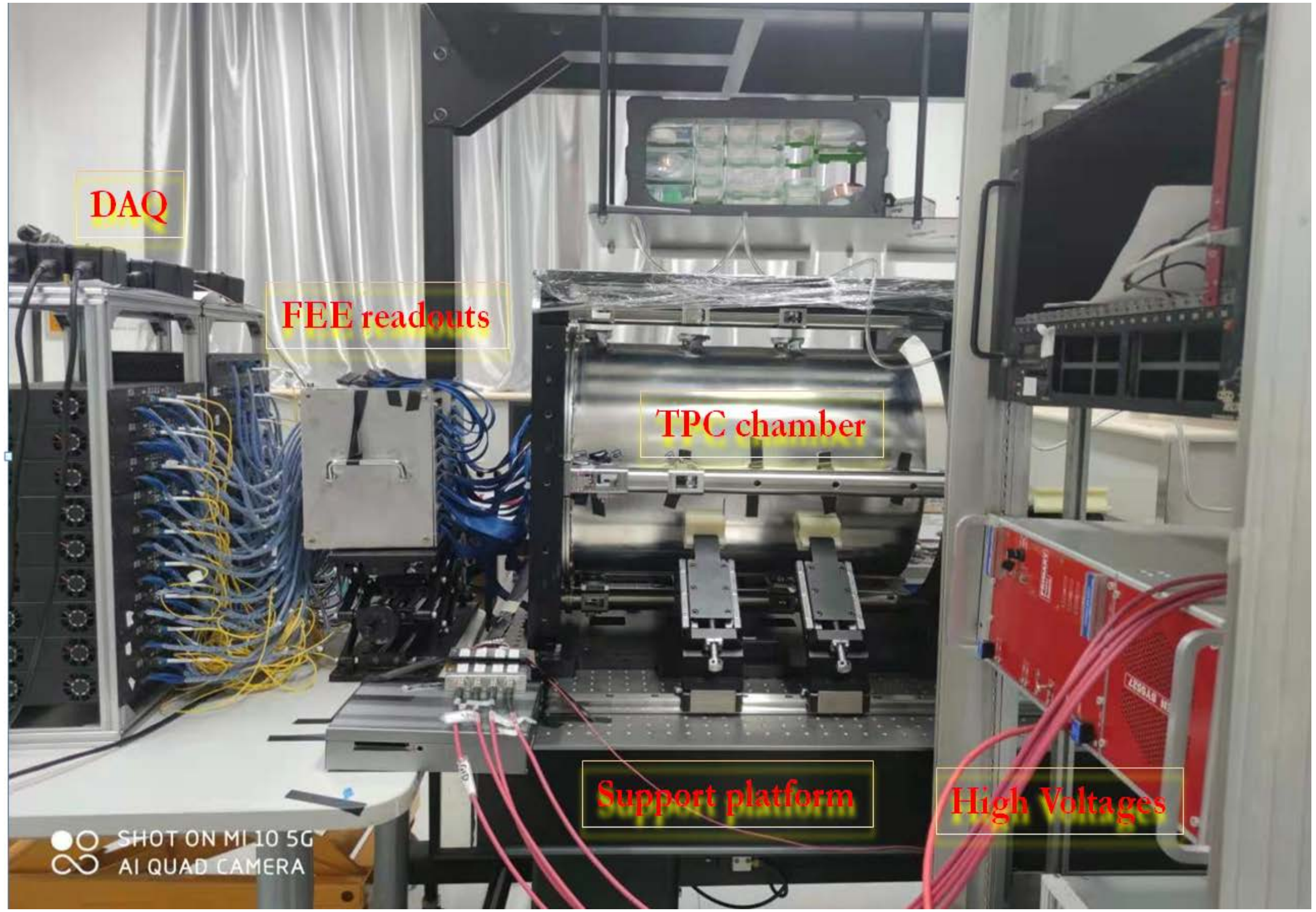
Fieldcage

- GEM detector as the endplate with 200mm²
- Cylindrical flexible circuit board with 0.15mm thickness
- 500mm drift length with 20000V high voltage
- Integration of the 266nm UV laser tracks in the chamber

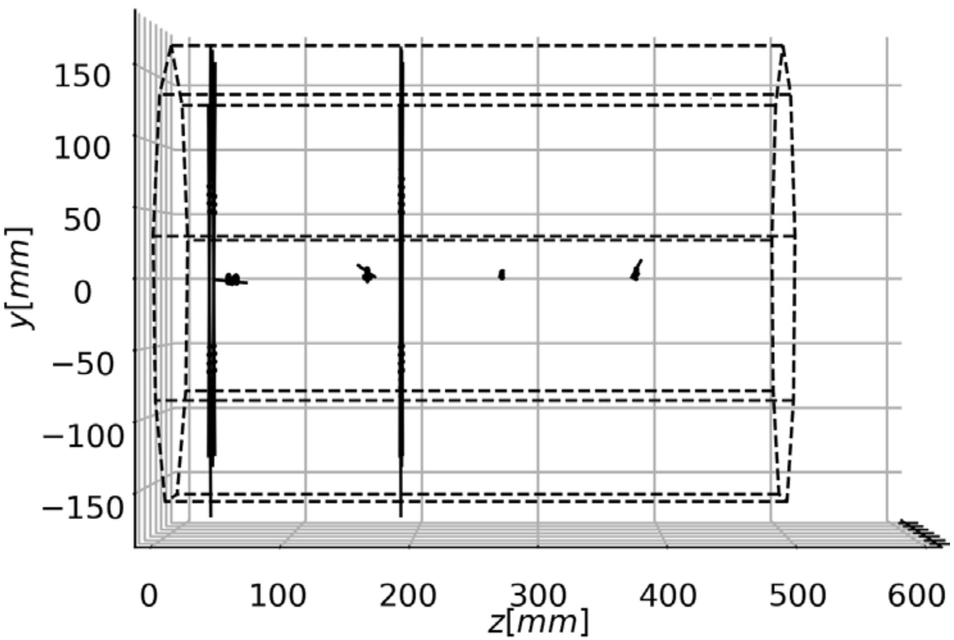

Status of TPC prototype

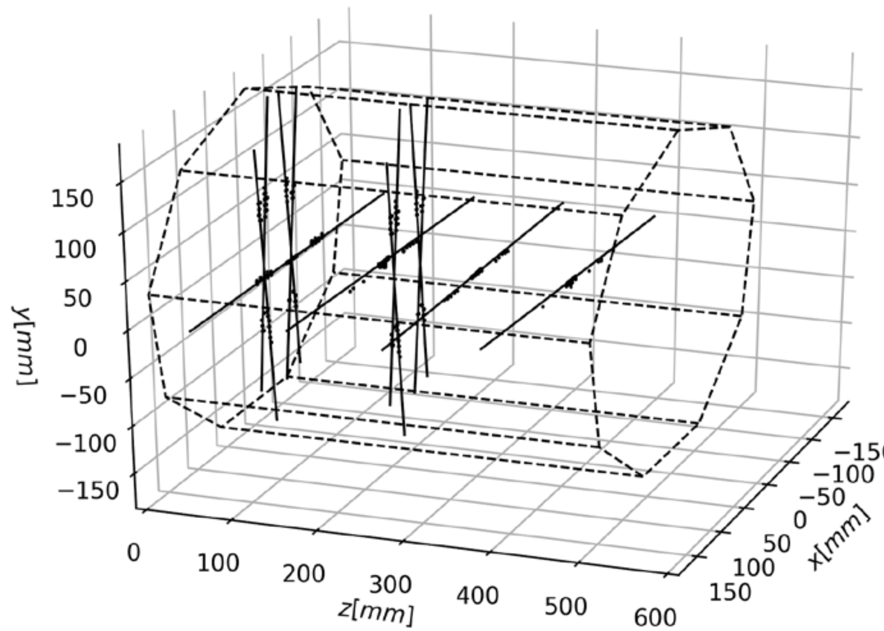
- Detector prototype was done and successfully operated
- Commissioning: Huirong Qi, Zhiyang Yuan, Yiming Cai, Yue Chang, Jiang Zhang, Yulan Li, Zhi Deng
- Data taking and more analysis on going



TPC prototype in the lab

Laser tracks in chamber@T2K gas





- Same of working gas@T2K, same of high voltage, same of test conditions
- Different of GEMs@ 320V
- Triple GEMs to double GEMs
- No discharge

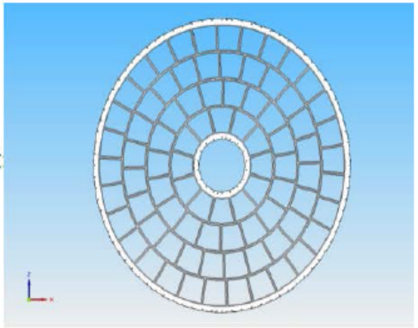
- **Some consideration of TPC technology for CEPC (planning)**

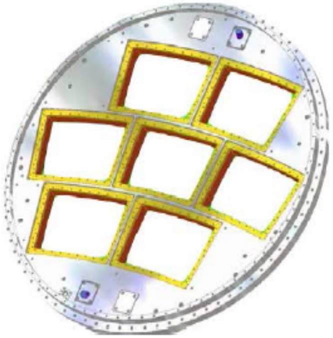
Two readout endplate options

Pad TPC and Pixel TPC

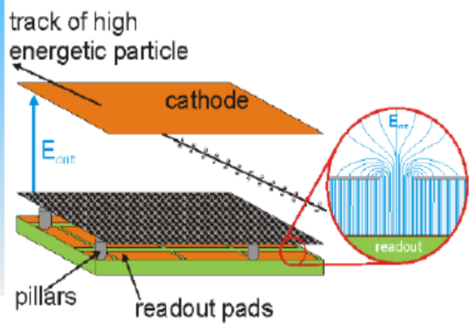
Pad TPC for collider

- Active area: 2×10m^2
- One option for endplate readout
  - GEM or Micromegas
  - 1×6 mm^2 pads
  - 10^6 Pads
  - 84 modules
  - Module size: 200×170mm^2
  - Readout: Super ALTRO
  - CO_2 cooling





Pixel TPC for collider



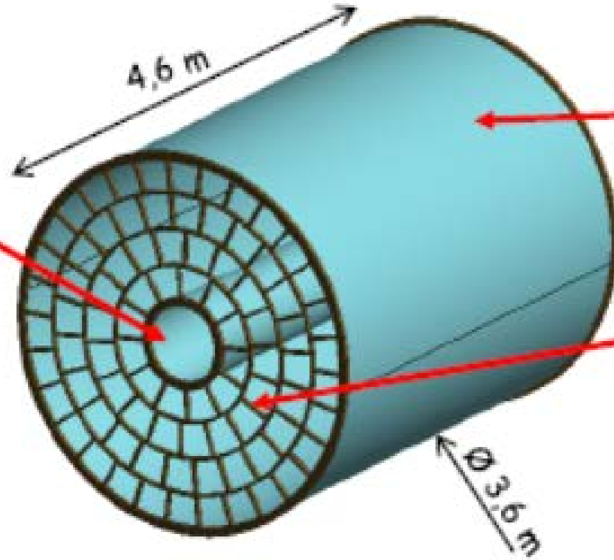
For Collider @cost:
But to readout the TPC with GridPixes:
→100-120 chips/module
240 modules/endcap (10 m^2)
→50k-60k GridPixes
→ 10^9 pixel pads

Benefits of Pixel readout:

- Lower occupancy
  - → 300 k Hits/s at small radii.
  - → This gives < 12 single pixels hit/s.
  - → With a read out speed of 0.1 msec (that matches a 10 kHz Z rate)
  - → the occupancy is less than 0.0012
- Improved dE/dx
  - → primary e- counting
  - Smaller pads/pixels could result in better resolution!
  - Gain <2000
  - Low IBF*Gain<2
  - CO_2 cooling

TPC detector chamber

INNER CAGE
- MATERIAL : Composite
- FEA ELEMENTS : shell
- THICKNESS : 25 mm



OUTER CAGE
- MATERIAL : Composite
- FEA ELEMENTS : shell
- THICKNESS : 60 mm

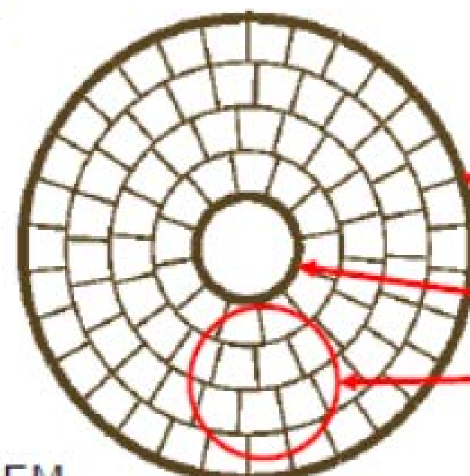
ENDPLATE
- MATERIAL : aluminum alloy
- FEA ELEMENTS : beam

Number of modules mounted on the 2 endplates (2 x 84 PCB) :

- PCB1 : 2 x 12
- PCB2 : 2 x 18
- PCB3 : 2 x 24
- PCB4 : 2 x 30

→ Size of the modules ≈ 300 x 330 mm

1 module = 1 MicroMegas or 4 GEM



Cross sections of the endplate components :

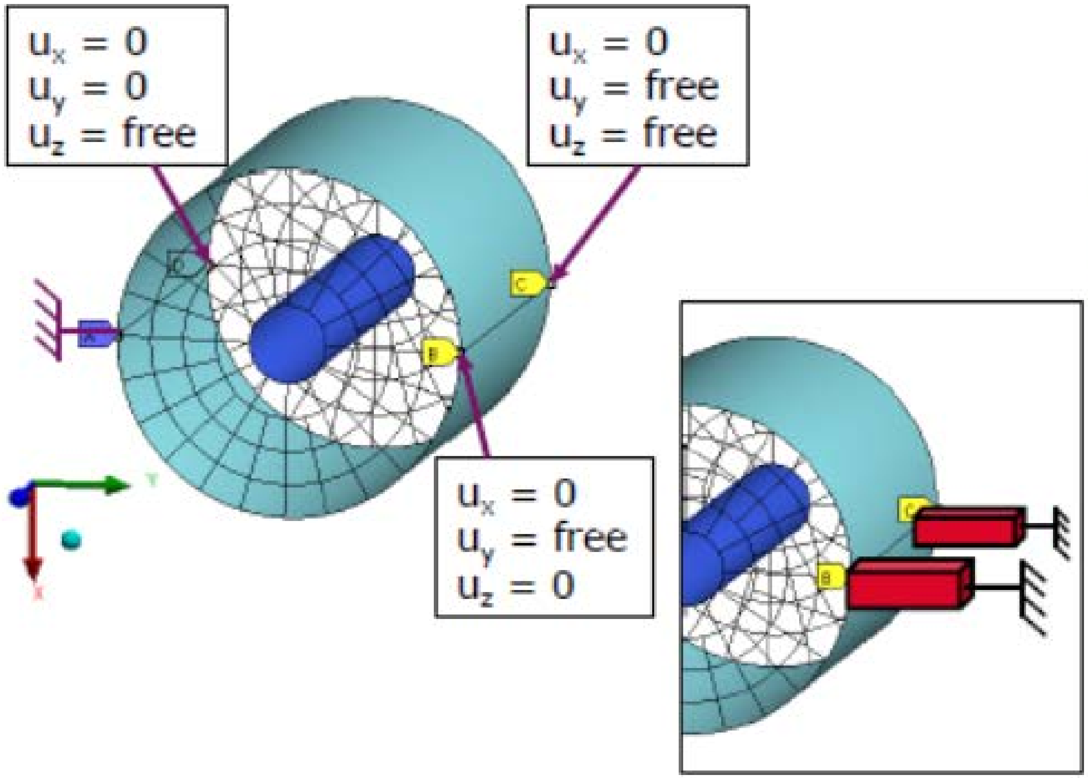
85 x 50 mm (outer ring)

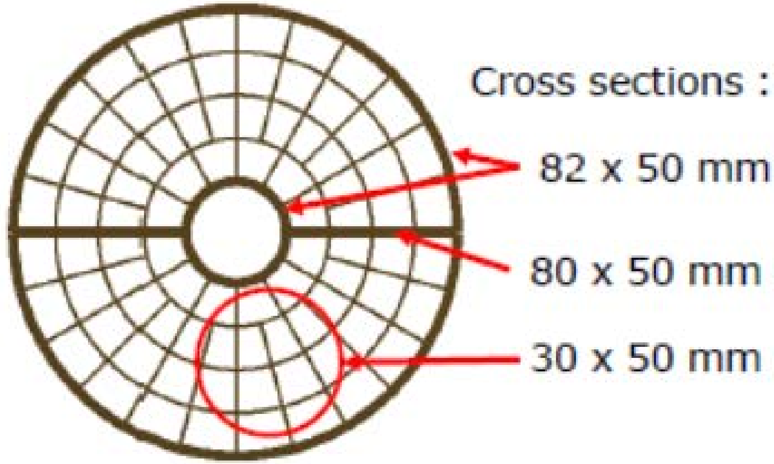
82 x 50 mm (inner ring)

32 x 50 mm (intermediate rings and spokes)

Optimization structure

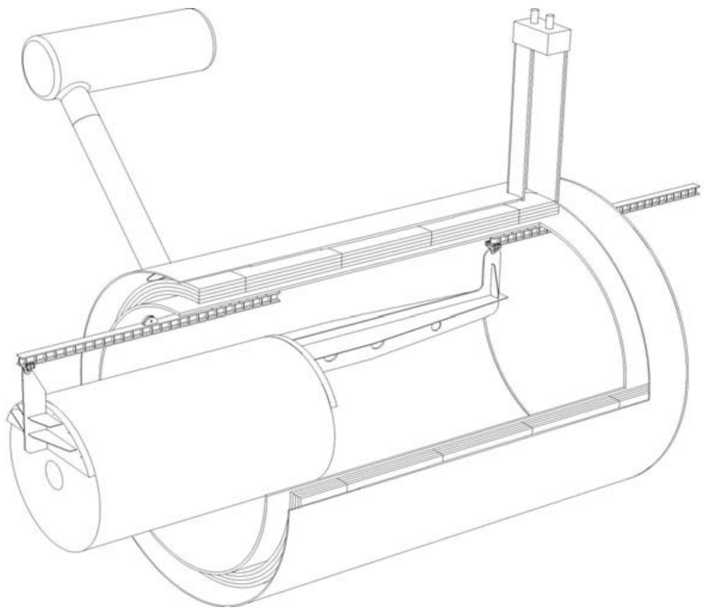
- The best structure found so far has this characteristics :
  - Support in the median plane
  - Aligned spokes for an easier production and for lower deformation
  - Horizontal spokes reinforced for a gain of deformation, especially in the endplate planes





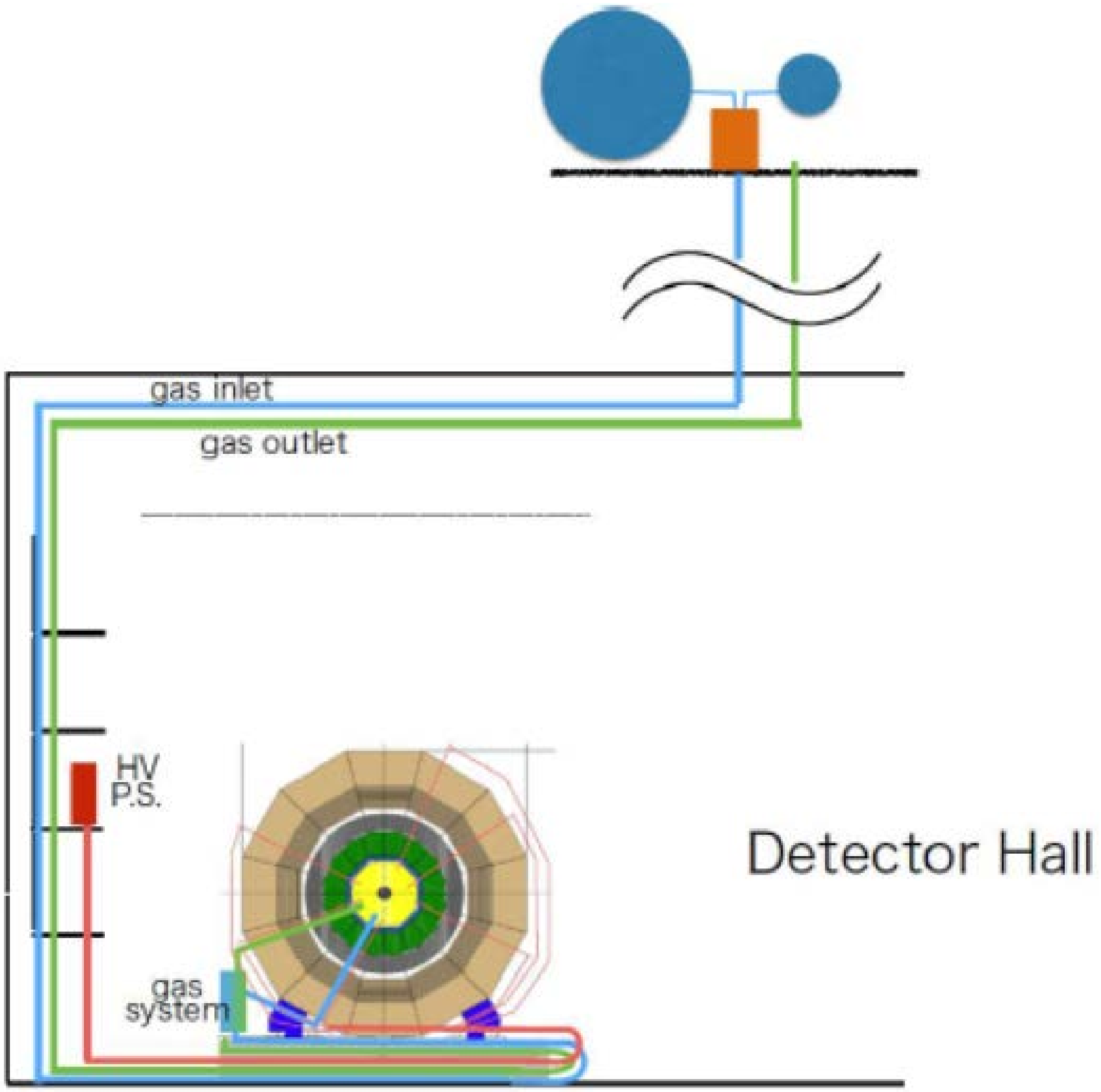
TPC mechanical detector design

- The time projection chamber(TPC) is inserted into the electromagnetic barrel calorimeter.
- The chamber is fixed to the inner wall of the magnet cryostat at both ends with spokes located in the gap between barrel and end cap calorimeter.
- For installation and removal the TPC can be connected to a temporary support mechanism and decoupled from the spokes. The removal is necessary to allow access to the inner sub detectors.
- The TPC support frame move on rollers running on the girders



TPC mechanical detector design

- TPC detector system
  - High voltage
  - Low voltage
  - Support layout
  - Gas system
  - Cooling system
  - Electronic system
  - ……



No conclusion and open questions:

- What are the update physics requirements or technical performance?（对于不断更新的物理性能需求？）
- On the X-Y plan precision and stability, somewhat less than 50/20/10um? Displacement absolute or relative? Each direction or in total? (对于技术上性能需求？)
- Commissioning of the interaction and machine studies should be completely independent (对于设计安装和维护的技术需求？)

Thanks!