Status and Challenges of CEPC Time Projection Chamber Detector

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On behalf of CEPC Tracking Subgroup

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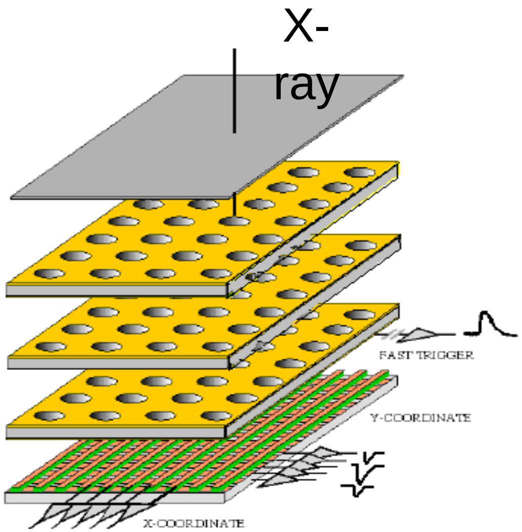
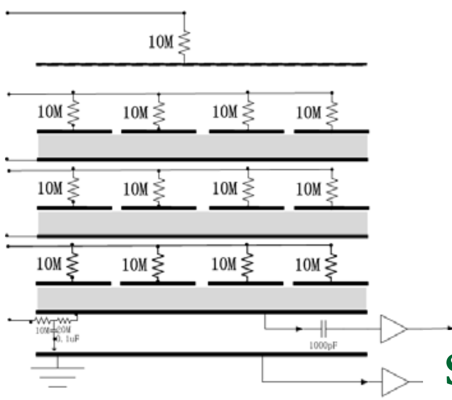
Content

- Status of GEM and TPC Detector
- Requirements and Concept design
- Preliminary Simulation
- Challenges
- Critical R&D

GEM Detector and TPC



- Trigger Signal from the bottom of third GEM
- Drift Distance: 14mm
- Transfer Space: 2mm
- Induction Space: 2mm
- HV power supply
- Seven Channels Independent
- $V_{gem1}:V_{gem2}:V_{gem3}=340V:330V:320V$
- $E_{drift}:E_{tran1}:E_{tran2}:E_{tran3}=3:2.5:2.5:2kV/cm$



Trigger

Strip Readout

Seven Channels HV

GEM Detector and TPC

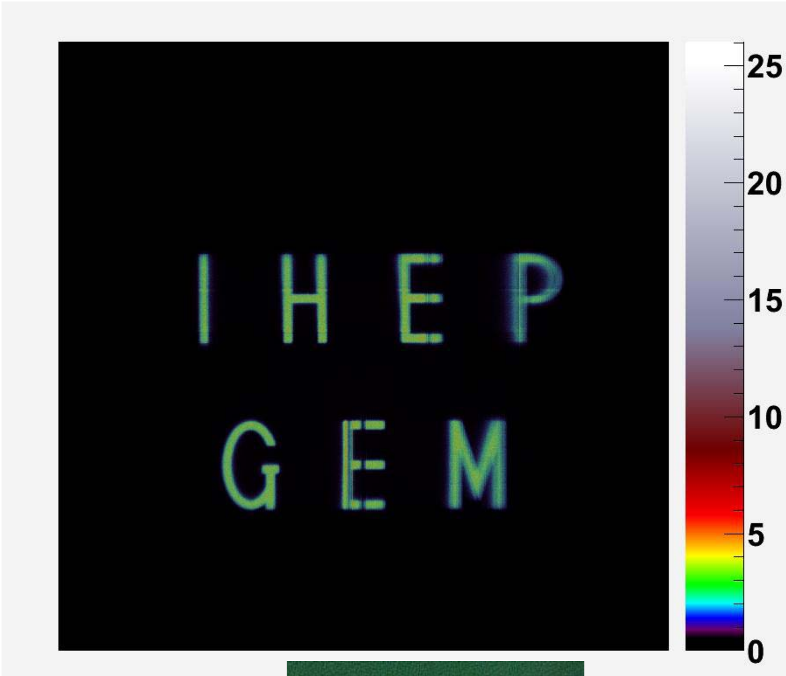


Image of Copper with 'IHEP GEM'

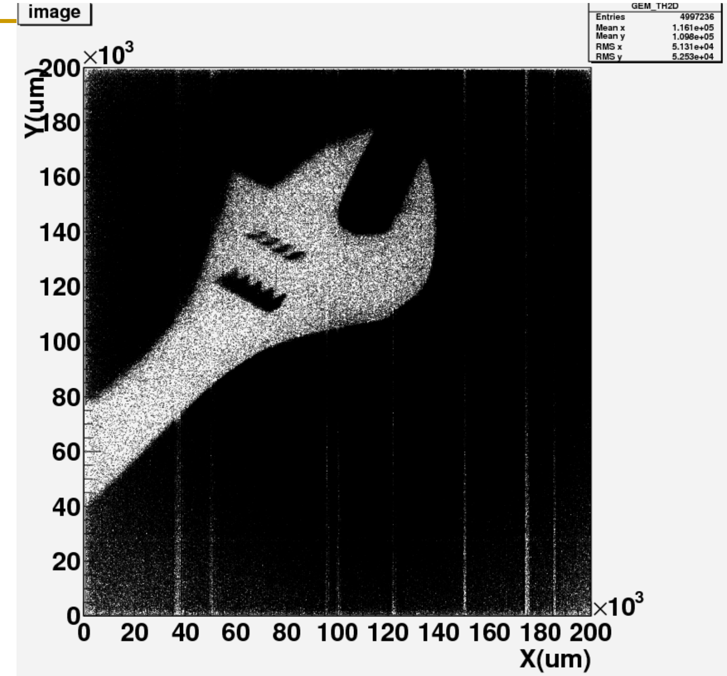
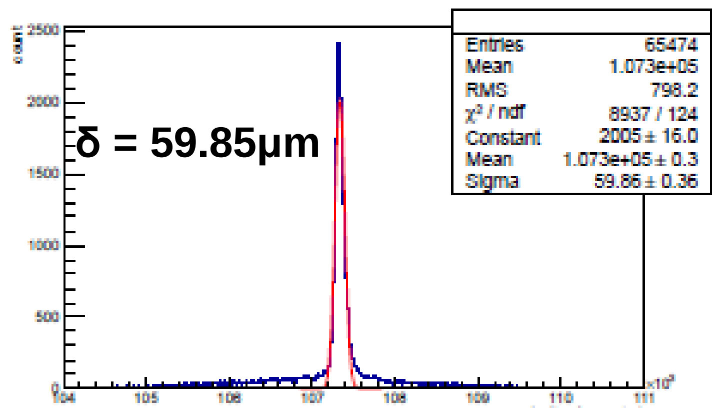


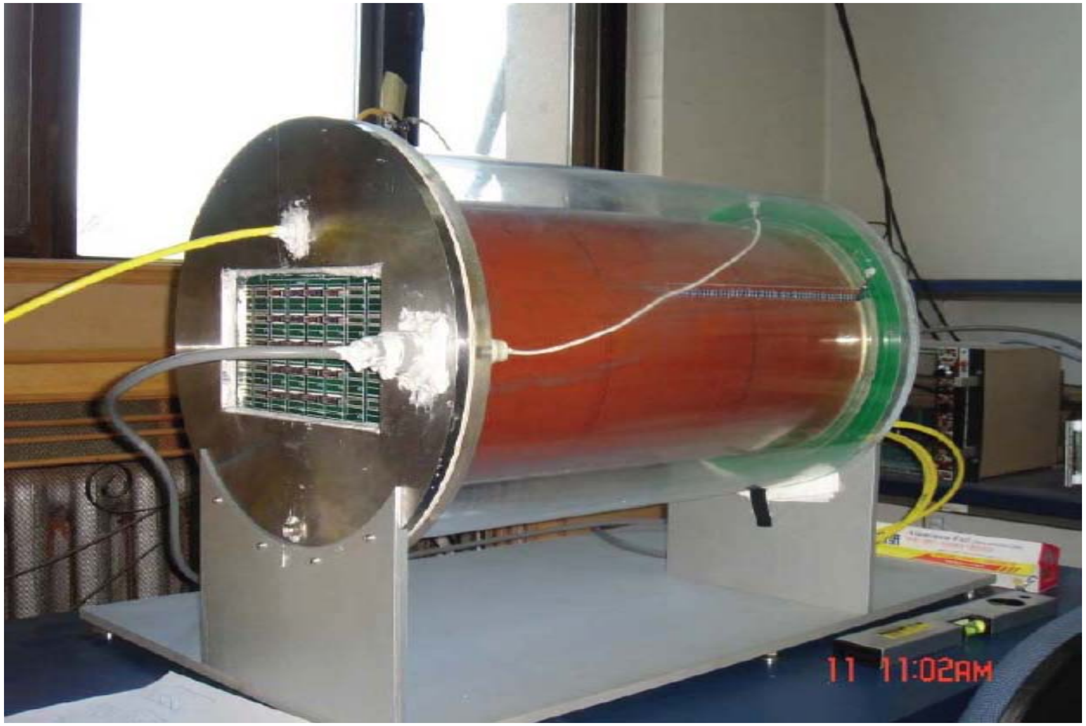
Image of Wrench
(Ten Minutes@30kHz count rate)



Position Resolution by 20μm slit collimator

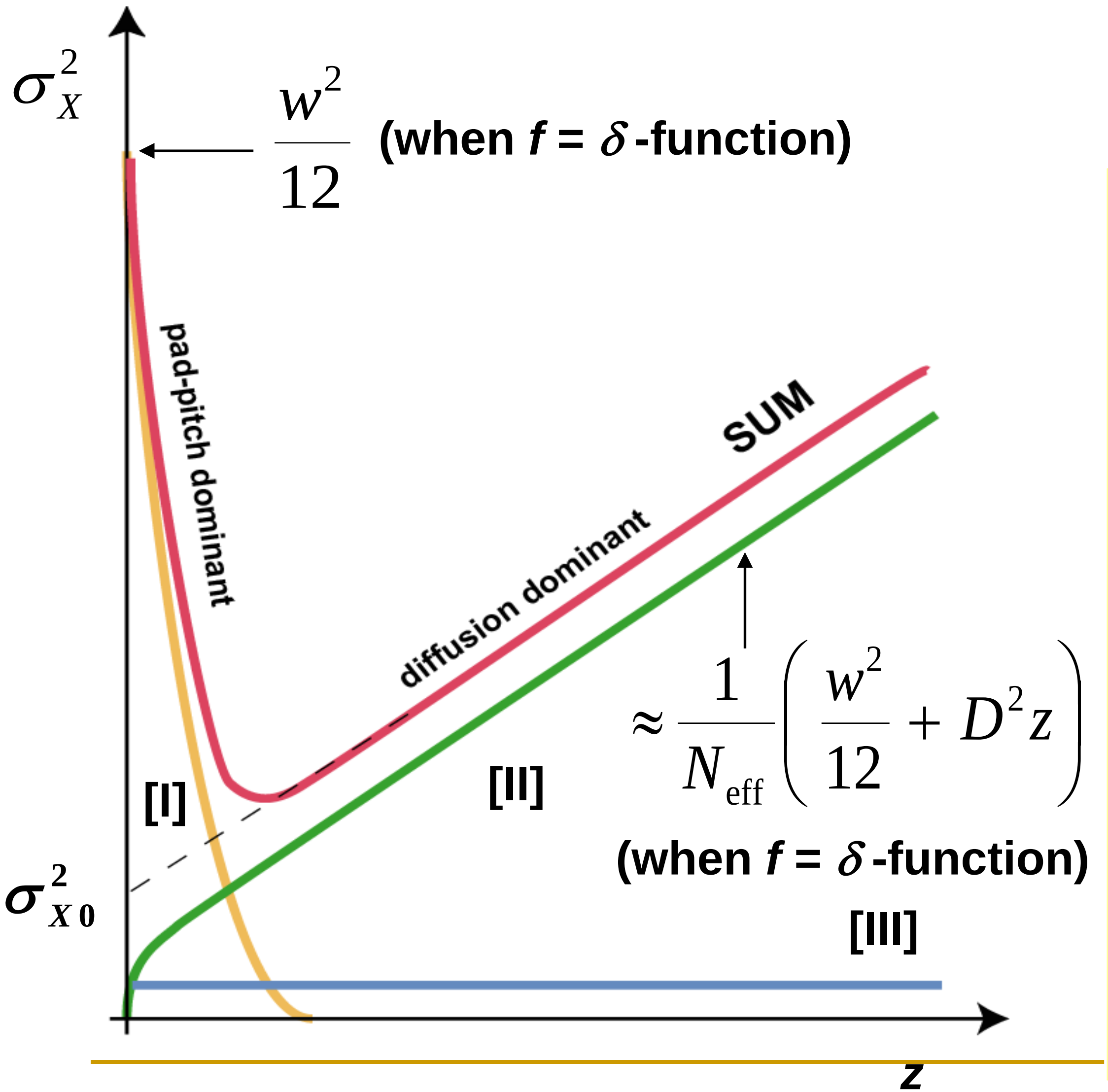
GEM Detector and TPC

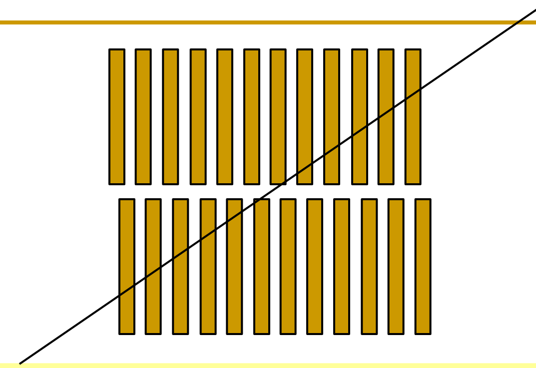
- Triple GEM readout
- Readout pad size: 9.5 mm ×1.5 mm
- Pitch: 10 mm ×1.6 mm
- Staggered 10 x 32 pads placed
- Field cage: 500mm
- Diameter: 320mm
- Only 10 x 32 pads read out due to the limitation of electronic channel number
- Scintillator+PMT coincidence trigger



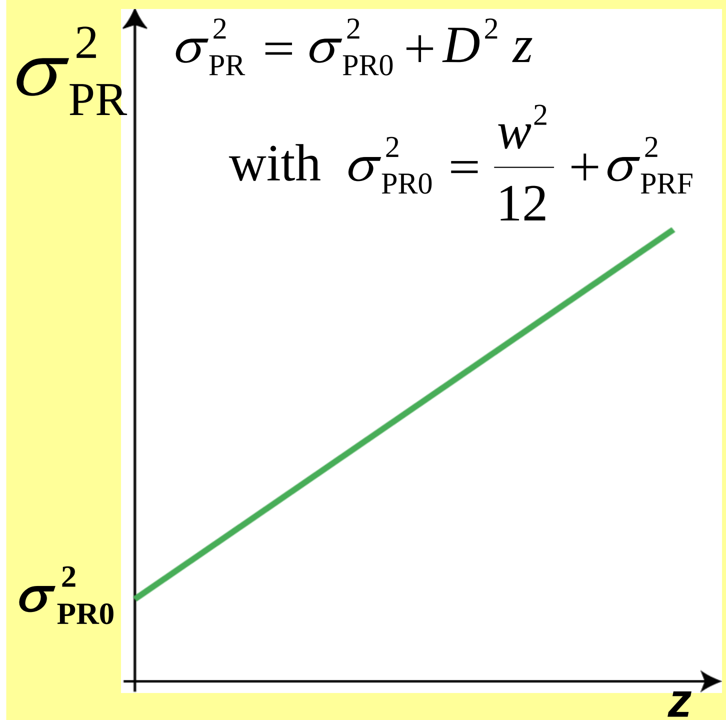
TU-TPC prototype

GEM Detector and TPC



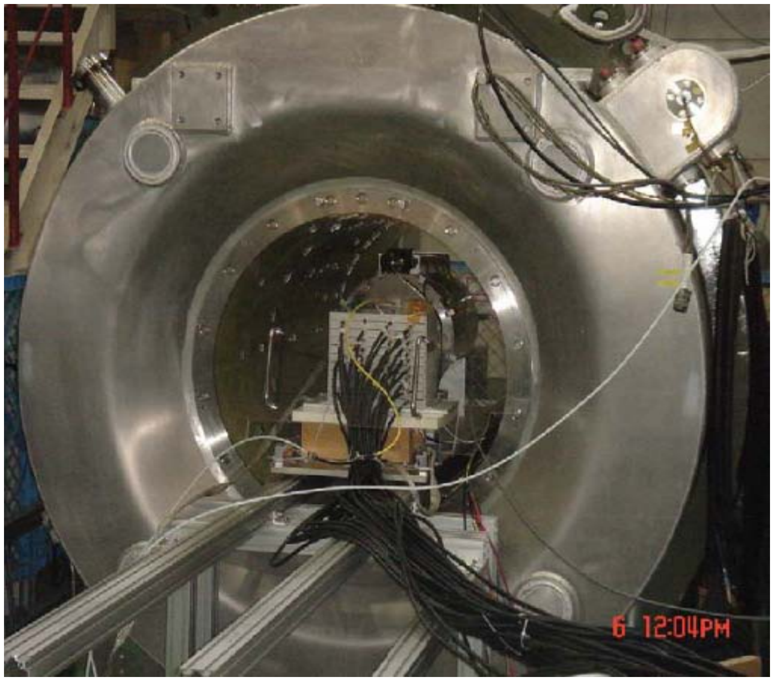


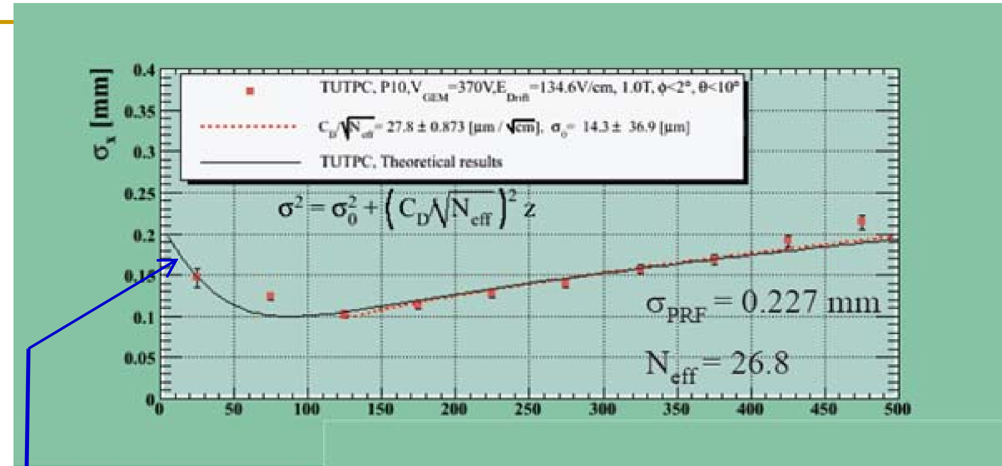
Pad Response

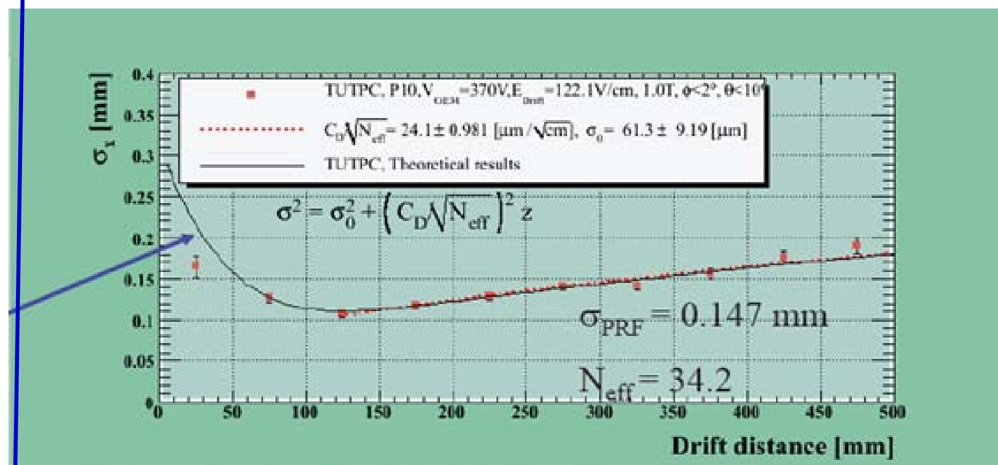


Hodoscope Effect in TPC

GEM Detector and TPC







Test @ KEK, Japan

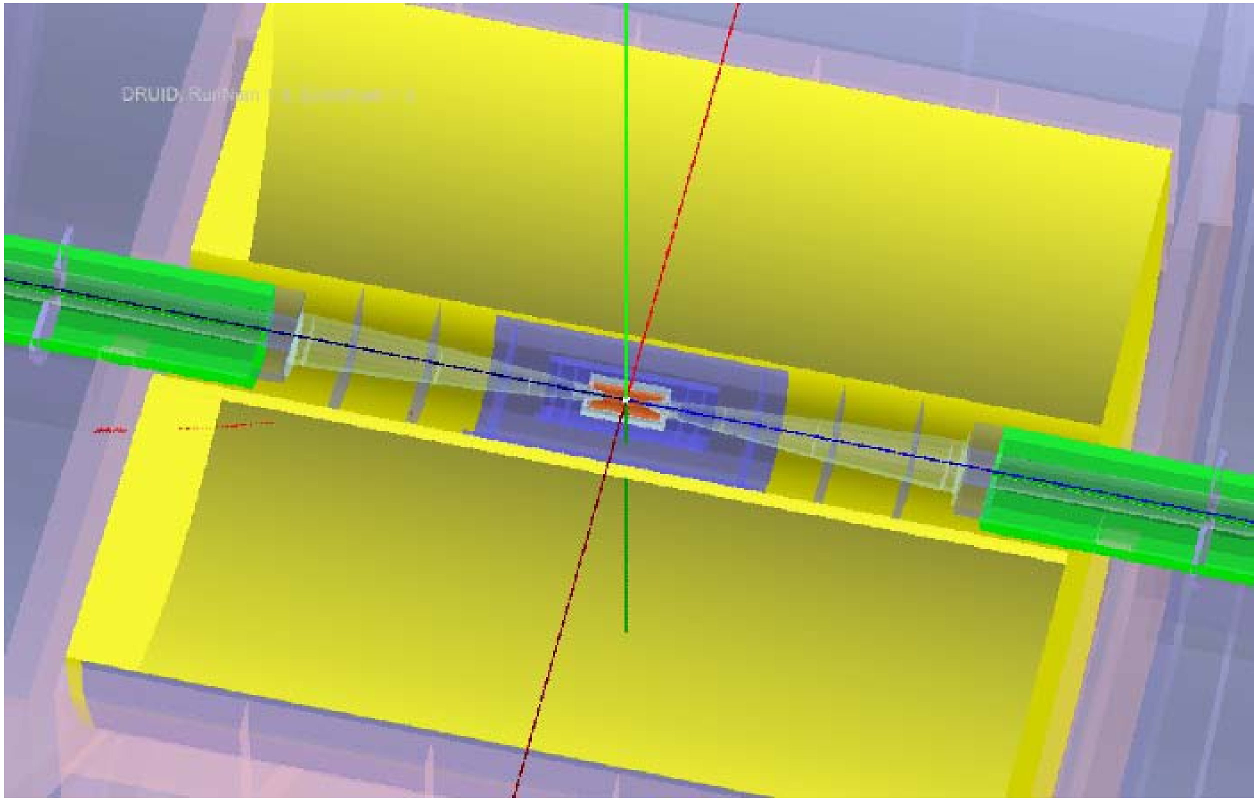
Measurement points fit the analytical formula very well

Hodoscope effect more obvious

Resolution can be as good as 100 μm@ Z ≈100 mm

Conceptual design need some information!

- Physics requirement?
- L* size?
- QD0 position?
- Out radius?
- Inner radius?
- Channels?
- Backgroud?
- Counting Rate?
- Particles?
- …



Preliminary layout design

Requirement for TPC part

Performance/Design Goals	
Momentum resolution[a] at B=3.5T	$\delta(1/p_t) \simeq 10^{-4}$/GeV/c TPC only
Solid angle coverage	Up to $\cos\theta \simeq 0.98$ (10 pad rows)
TPC material budget	$\simeq 0.05\,X_0$ including the outer field cage in r $< 0.25\,X_0$ for readout endcaps in z
Number of pads/timebuckets	$\simeq$ 1-2$\times10^6$/1000 per endcap
Pad pitch/no.padrows	$\simeq$ 1 mm$\times$4-10 mm/$\sim$200
σ_{point} in $r\phi$	$< 100\mu$m (avg for straight-radial tracks)
σ_{point} in rz	$\simeq 0.4 - 1.4$ mm (for zero – full drift)
2-hit resolution in $r\phi$	$\simeq$ 2 mm (for straight-radial tracks)
2-hit resolution in rz	$\simeq$ 6 mm (for straight-radial tracks)
dE/dx resolution	$\simeq$ 5 %
Performance	$>$ 97% efficiency for TPC only ($p_t >$ 1GeV/c) $>$ 99% all tracking ($p_t >$ 1GeV/c)
Background robustness	Full efficiency with 1% occupancy,
Background safety factor	Chamber prepared for 10–20% occupancy (at the linear collider start-up, for example)

[a]The momentum resolution for the combined central tracker is $\delta(1/p_t) \simeq 2 \times 10^{-5}$/GeV/c

Same as Main performance/ Design goals of ILD-TPC

Two options

Gluckstern Formula

δ_x : spatial resolution in the r-ϕ plane per point

n : the number of sampling points

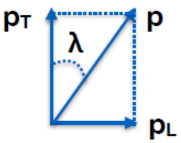
α : 333.56 (cm • T • GeV^{-1})

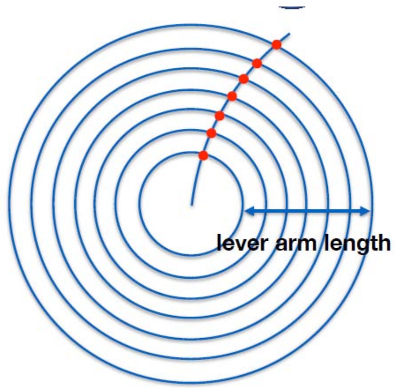
C : 0.0141 (GeV)

(X/X_0) : thickness measured in radiation length units

l : lever arm length (cm)

B : magnetic field (T)





Transverse momentum: P_T $k = 1/P_T$

$$\delta_k^2 = (\delta_k^{meas})^2 + (\delta_k^{MS})^2$$

Detector resolution:

$$\delta_k^{meas} \approx \left(\frac{\alpha\delta_x}{Bl^2}\right)\sqrt{\frac{720}{n+4}}$$

Multiple resolution:

$$\delta_k^{MS} \approx \left(\frac{\alpha C}{Bl}\right)\sqrt{\frac{10}{7}\left(\frac{X}{X_0}\right)} \bullet k$$

Total momentum:

$$p = p_T\sqrt{1+\tan^2\lambda}$$

- **SiD@ILC**
  - High B field
  - Excellent σ_x, but small the number of sampling points
  - Reasonably low material budget
  - Continuous data taking
- **ILD@ILC**
  - Large length
  - Large the number of sampling points
  - Moderate σ_x
  - Low material budget(gas)
  - dE/dx for low momentum particles
  - Good for calorimeter (particle flow algorithm)
  - Pictorial tracking by many space points
  - Less cost

Two options for CEPC

Performance comparison between
Silicon tracking and TPC (ILC)

	TPC in ILD	Silicon in SiD
Material	0.05X0 (vertical) 0.25X0 (forward)	0.10-15X0 (vertical) 0.2-0.25X0 (forward)
Magnet filed	3.5T	5T
dE/dx	5%	no
r_in	329mm	220mm
r_out	1808mm	1220 mm
Z	± 2350 mm	±1520
Cost (no contingency)	35.9MILCU (Jan 2012 US$)	95.7 MUS$

Does the design of ILC TPC work for CEPC?

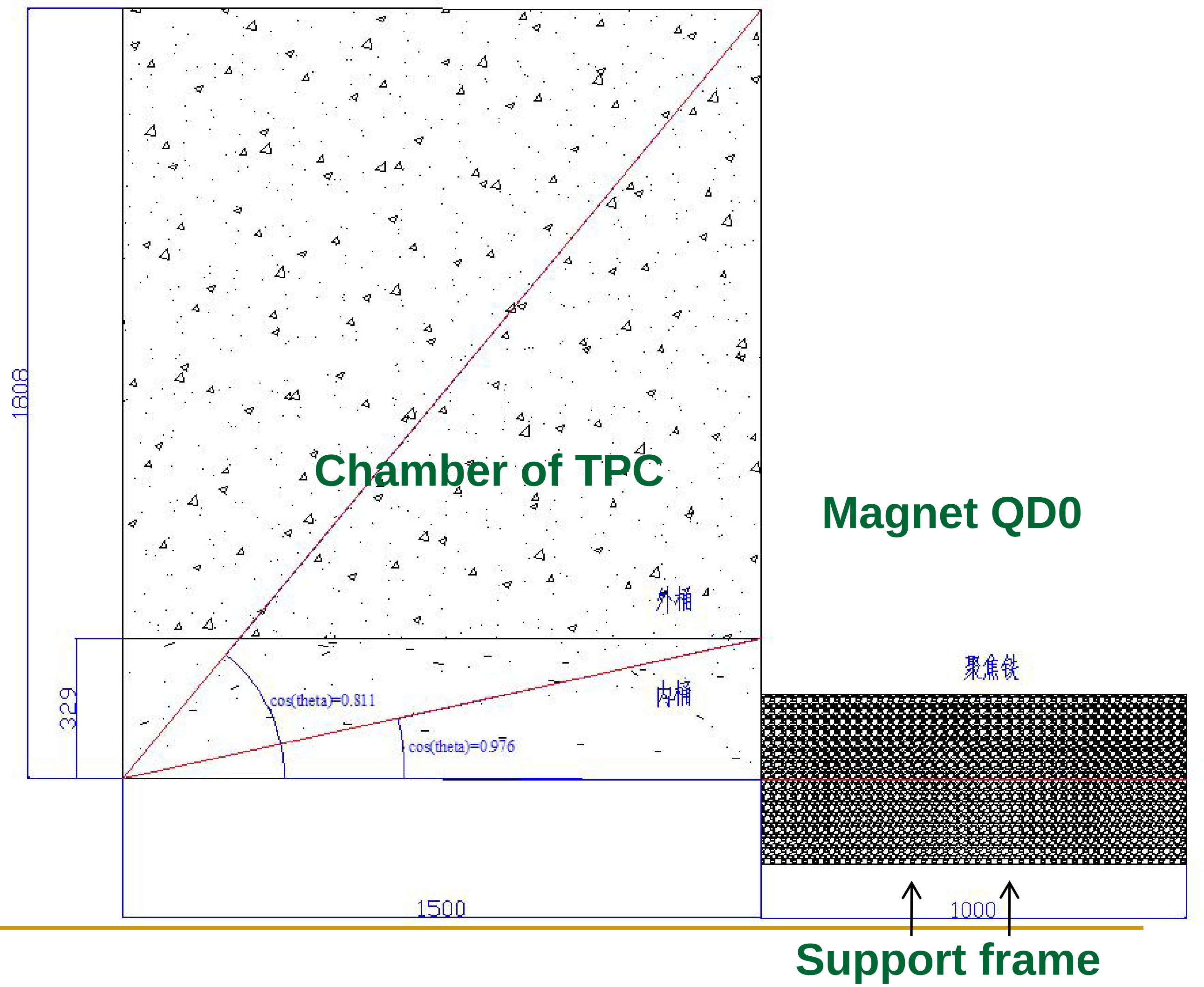
In principle, the answer is YES!

TPC is prefer one of the option.

Conceptual design plan

- L* = 1.5m

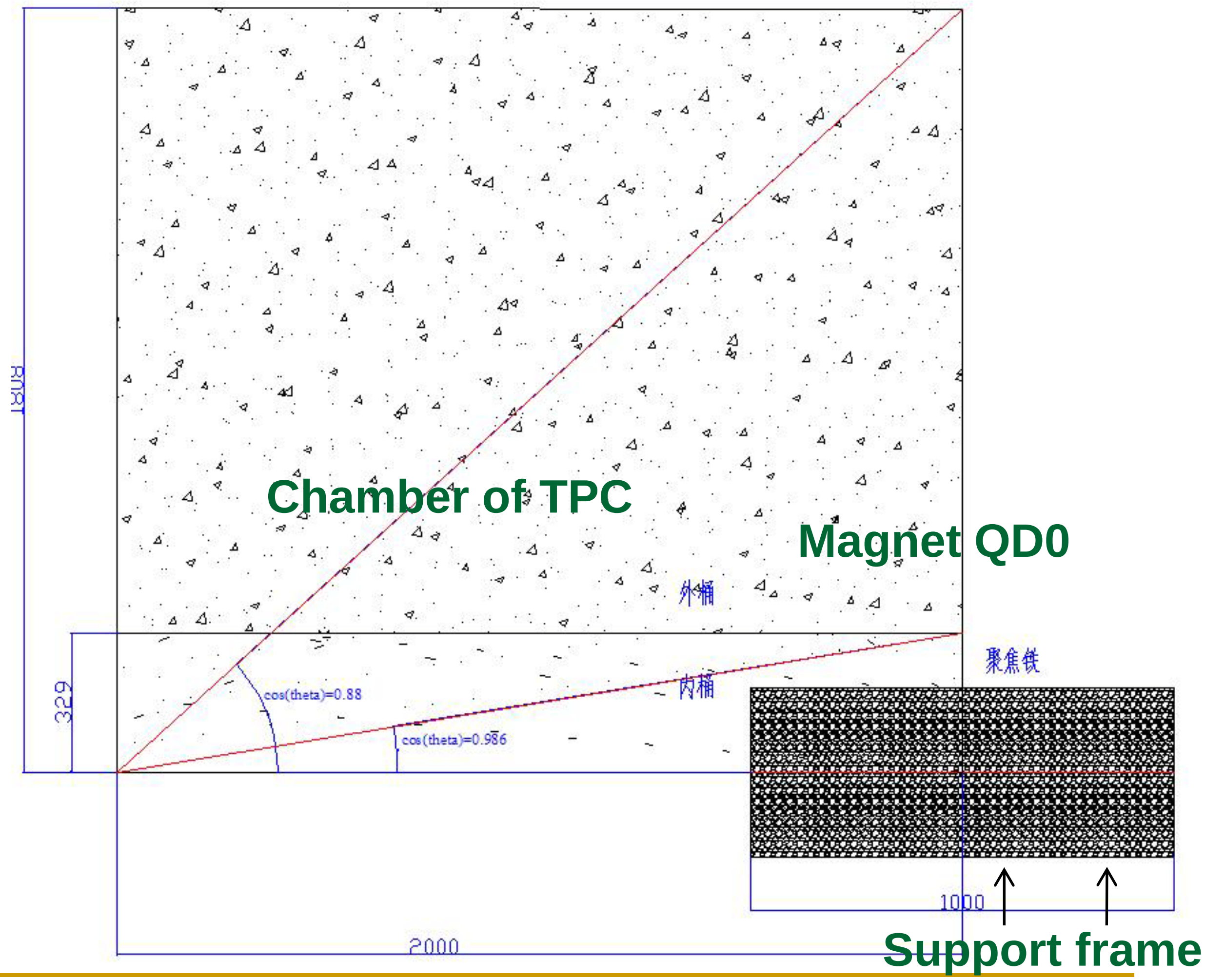
- Parameter of Chamber
  - Half Z=1.5m
  - r_in = 329 mm
  - r_out = 1808 mm
  - pad size: 1mm×6mm
  - Number of pads:~200
  - Easy to mount



Conceptual design plan

- L* = 1.5m

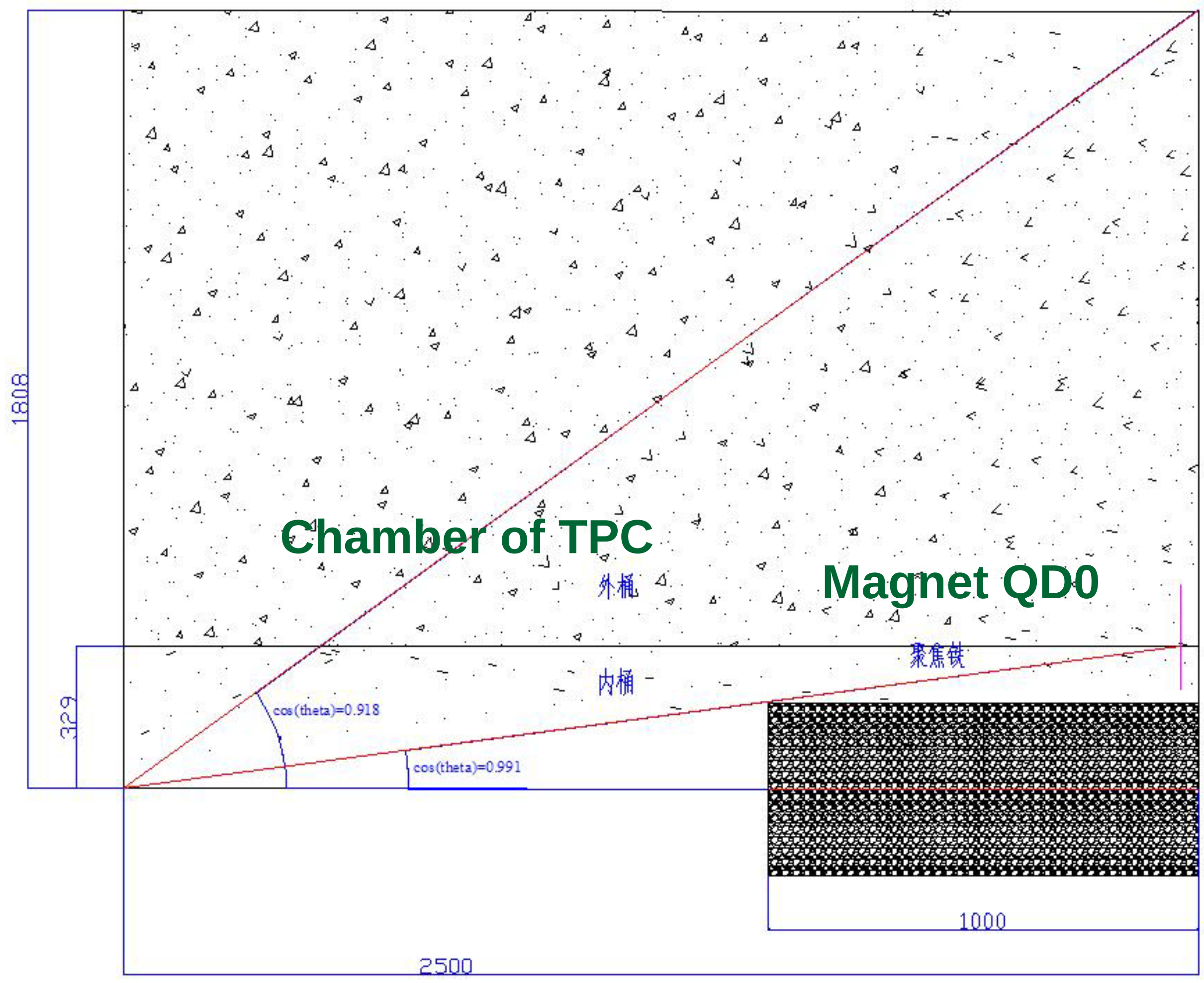
- Parameter of Chamber
  - Half Z=2.0m
  - r_in = 329 mm
  - r_out = 1808 mm
  - pad size: 1mm×6mm
  - Number of pads:~200
  - Easy to mount
  - Particle background



Conceptual design plan

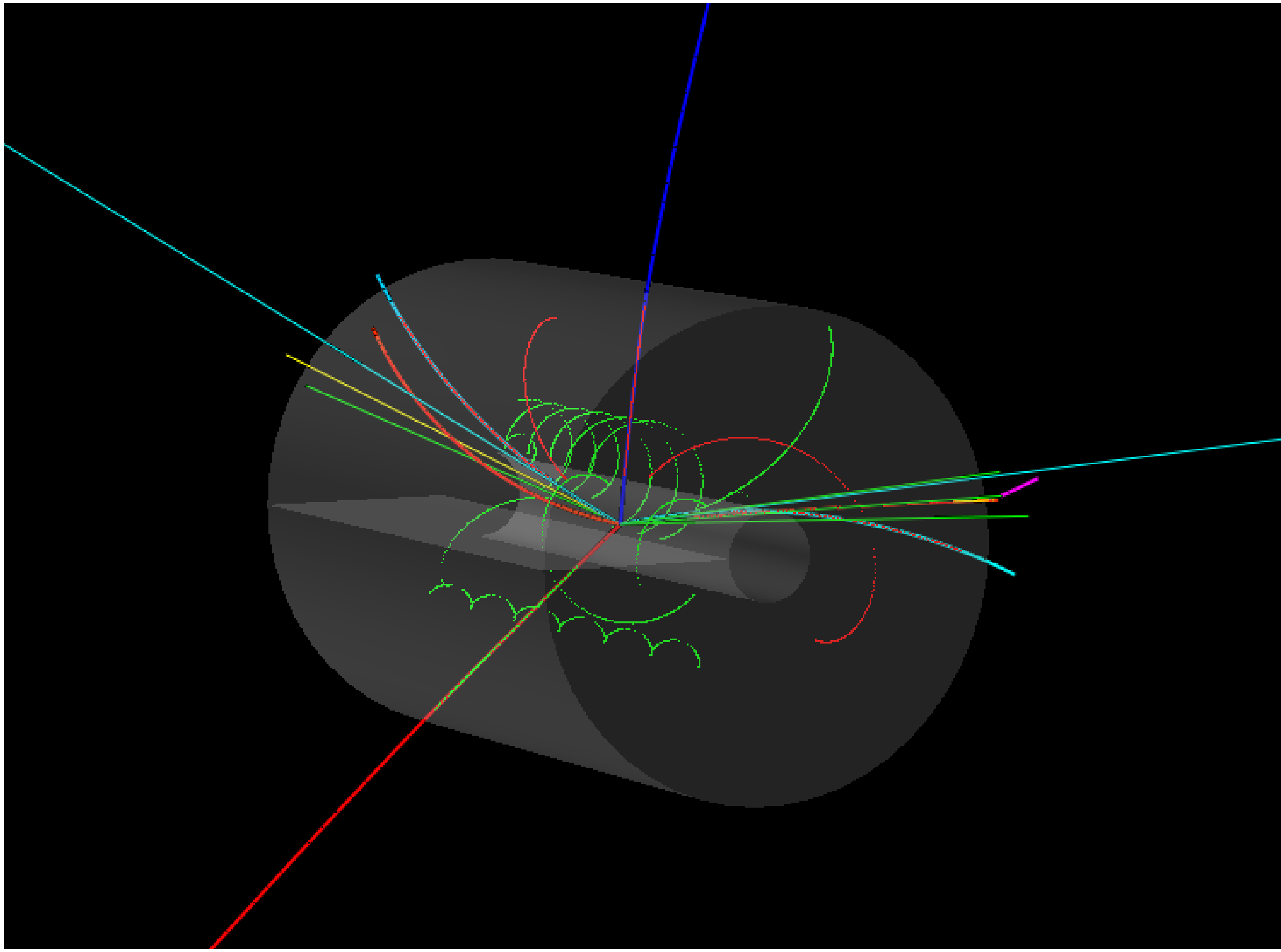
- L* = 1.5m

- Parameter of Chamber
  - Half Z=2.0m
  - r_in = 329 mm
  - r_out = 1808 mm
  - pad size: 1mm×6mm
  - Number of pads:~200
  - Hard to mount
  - Particle background



Preliminary Simulation

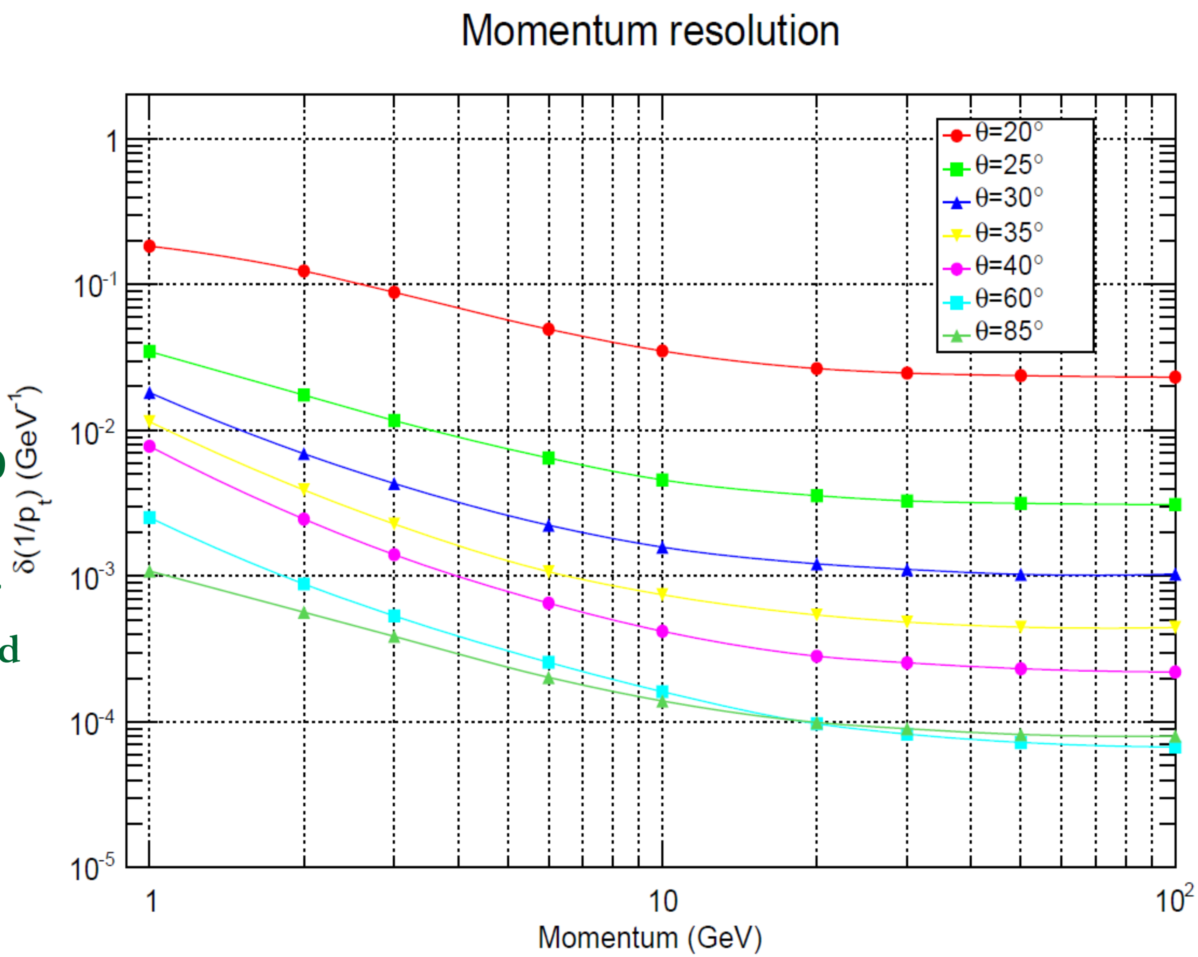
- Parameter of Simu.
  - Half Z=2.35m
  - r_in = 329 mm
  - r_out = 1808 mm
  - pad size: 1mm×6mm
  - Number of pads:~200
  - B = 3.5 Tesla
  - With multiple scattering
  - Position resolution based on ILD-TPC with smearing of 100μm



Preliminary Simulation

Change the length of TPC

- Parameter of Simu.
  - Half Z=1.5m
  - r_in = 329 mm
  - r_out = 1808 mm
  - cos_theta = ~ 0.95
  - pad size: 1mm×6mm
  - Number of tracker:~200
  - B = 3.5 Tesla
  - With multiple scattering
  - Position resolution based on ILD-TPC

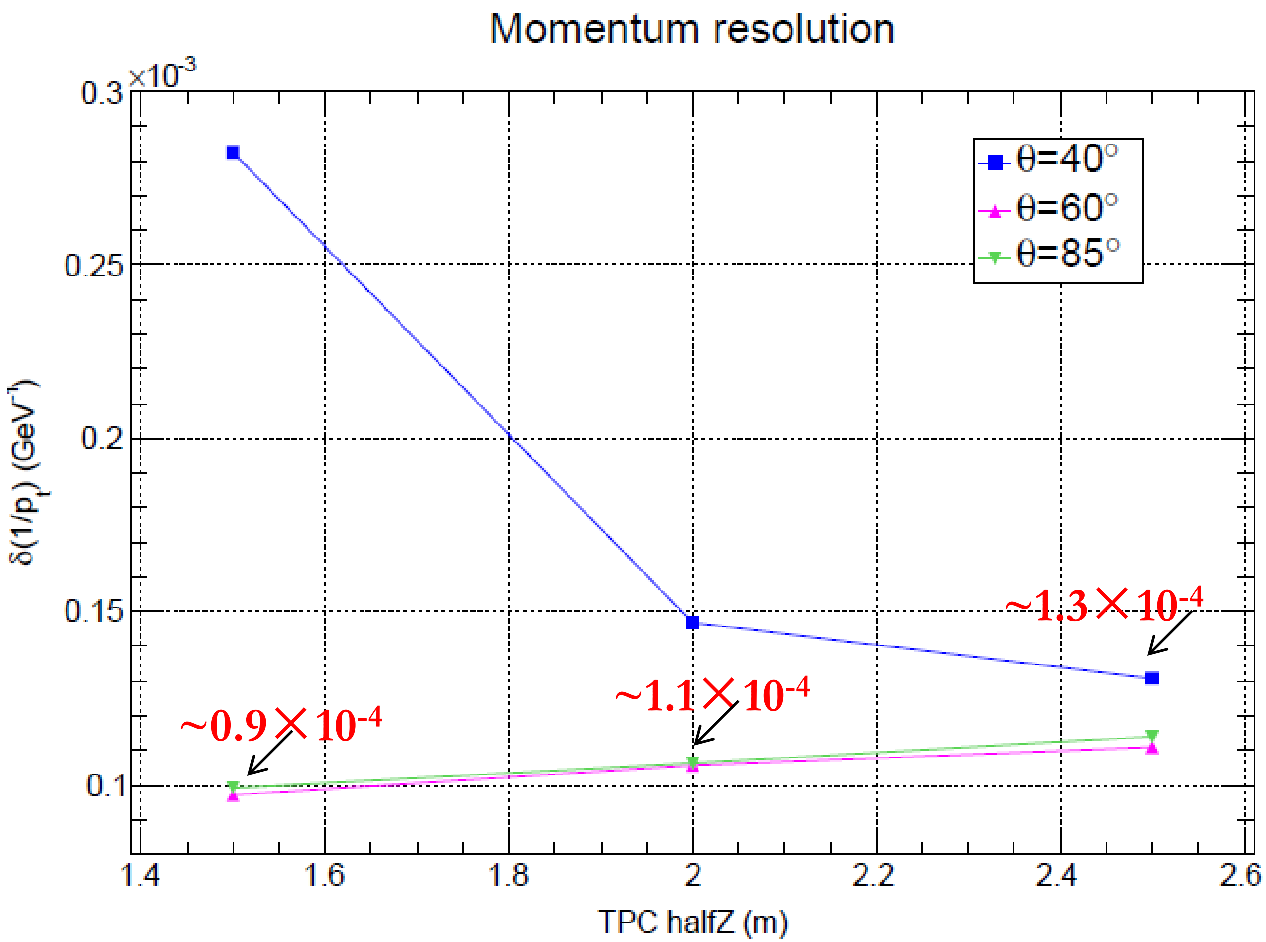


TPC
$$\sigma^2_{r\phi} = \left(50^2 + 900^2 \sin^2\phi + \left((25^2/22)\times(4T/B)^2 \sin\theta\right)(z/\mathrm{cm})\right)\mu\mathrm{m}^2$$
$$\sigma^2_z = \left(400^2 + 80^2\times(z/\mathrm{cm})\right)\mu\mathrm{m}^2$$
where ϕ and θ are the azimuthal and polar angle of the track direction

Preliminary Simulation

- Parameter of Simu.
  - Half Z=1.0m,2.0m,2.5m
  - r_in = 329 mm
  - r_out = 1808 mm
  - pad size: 1mm×6mm
  - Number of pads:~200
  - B = 3.5 Tesla
  - With multiple scattering
  - Position resolution based on ILD-TPC with smearing of 100μm

  - Momentum:20GeV

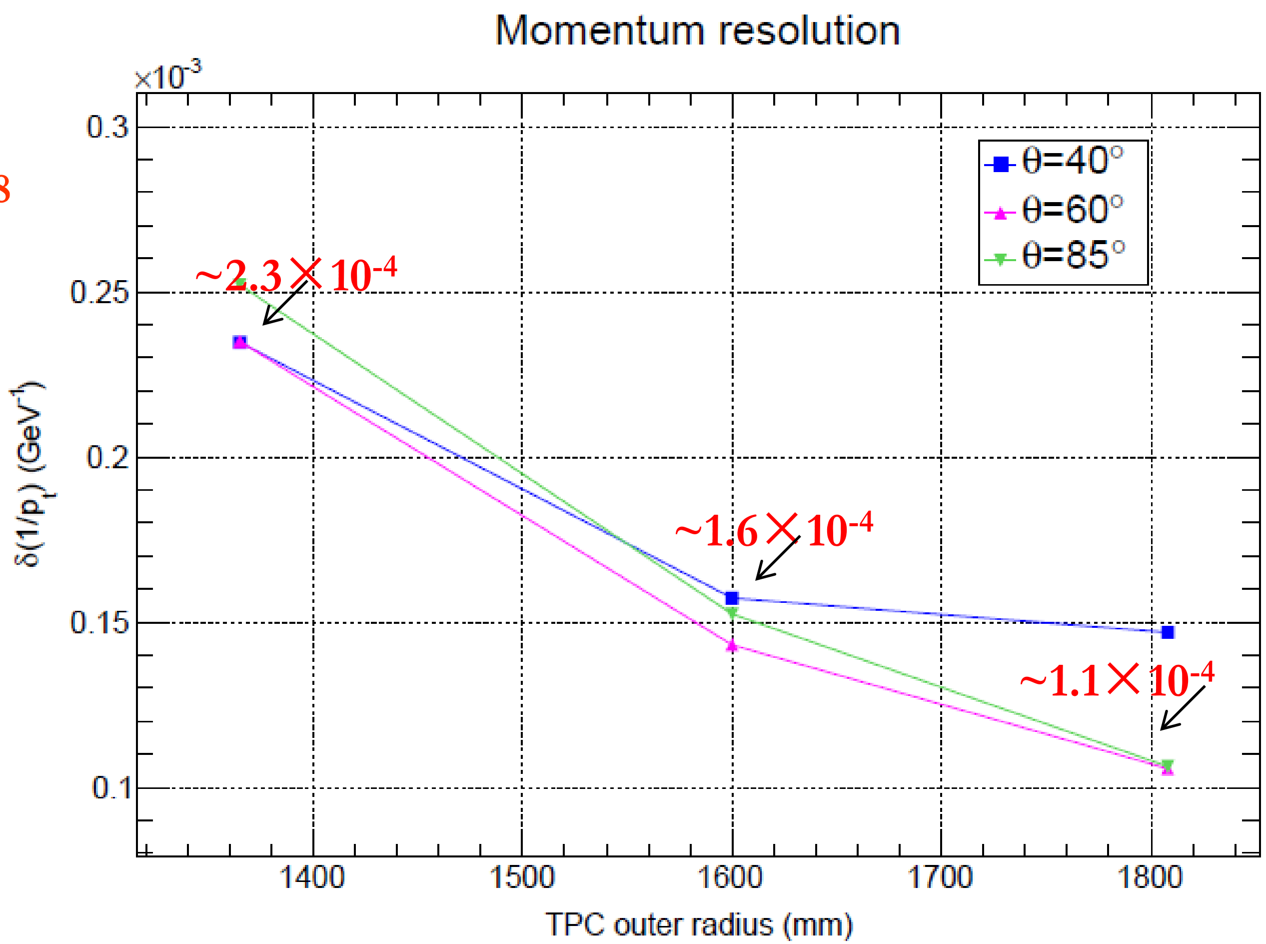


To change the length of TPC

Preliminary Simulation

- Parameter of Simu.
  - out_radius=1365,1600,1808
  - Half Z=2.0m
  - r_in = 329 mm
  - pad size: 1mm×6mm
  - Number of pads:~200
  - B = 3.5 Tesla
  - With multiple scattering
  - Position resolution based on ILD-TPC with smearing of 100μm

  - Momentum:20GeV



To change the out radius of TPC

Ion backflow at CEPC

- Different with ILC-ILD
- In CEPC, the bunch spacing is 3.6us
- NO Gating in TPC
- The ions generated from the ionization in the drift volume and from the avalanche multiplication in gaseous detector
- Ions into the drift region will introduce the field distortion
- Deduce the TPC counting rate capability

Ion backflow estimation

- **Total charge density** $\rho = \dfrac{eRGL\varepsilon}{v_I}$

  e is the charge of electron, Gε is the number of ions appear in the drift space for each electron , vI is the ion drift velocity, L is the length of TPC drift region. **R is the rate density.**

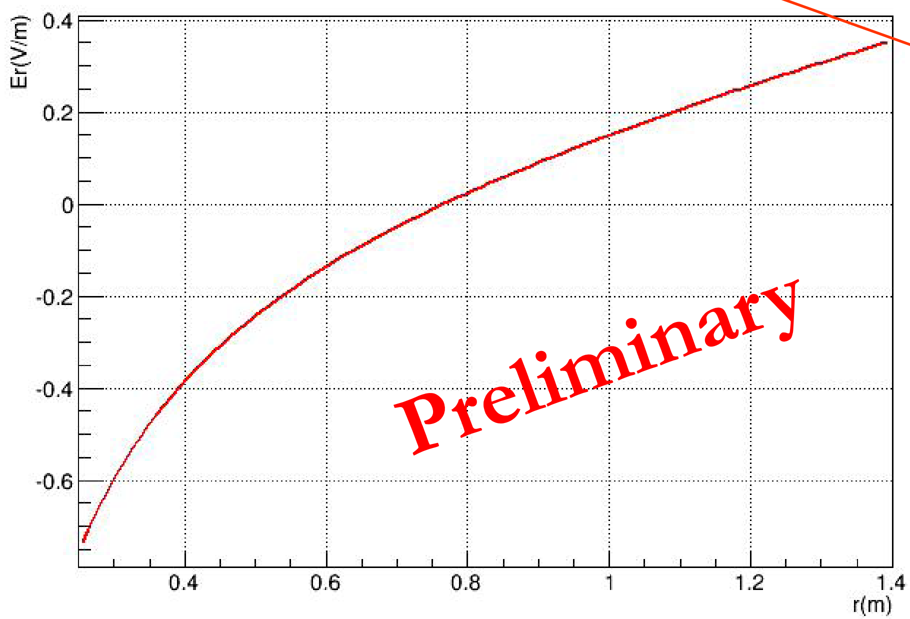
- **Radial distortion of electric field**

$$E_r(r) = \frac{\rho_0}{2\varepsilon_0}\left(r - \frac{1}{2r}\frac{r_2^2 - r_1^2}{ln(r_2/r_1)}\right)$$

R is uniformity in the drift region and is as constant *p0*. For TPC with inner radius r1 and outer radius r2.

Ion backflow estimation

- $G = 10^4$, $G\varepsilon = 0.1\%$, $V_I = 1m/s$ @ $E = 200V/m$, $L=2.5m$, $r1=0.3m$, $r2=1.4m$
- we expect the electron distortion to be less than 1%($E_r(r) < 2V/m$)
- R must be less than $5.3 \times 10^6 /s/m^3$



For Z pole
Challenge!

Radial distortion of electric field produced by a uniform charge distribution at CEPC

Challenges for R&D

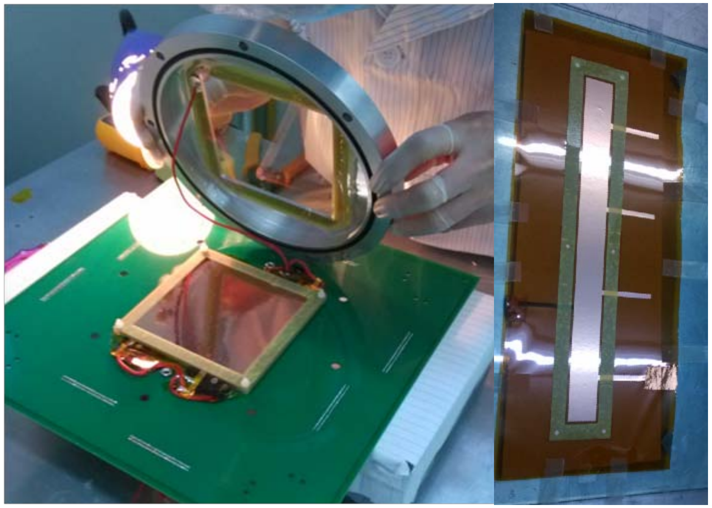
- Field distortion near boundaries
  - Insulator surface facing drift volume should be removed; Avoid charge up effects in GEM detector
  - Electric field distortion near module boundaries should be shaped away
- High B-field performance
  - Is Neff at B=3.5T the same as at B=1T?
  - Is electron attachment by CF4 in amplification region negligible?
  - Tracking in non-uniform B-field: ExB and deviation from helix
- Positive ions and Gate
  - Develop ion gate: transparency, distortion, ion leak
  - Is primary positive ion effect really negligible? (effects of heavy micro-curlers?)
  - Establish distortion correction method
- Z measurement
  - Hodoscope effect?
  - Angular effect? (primary ionization statistics)
- Neutron BG
  - Is gas mixture with a hydrocarbon molecule such as iso-C4H10 OK?
- P/T control of gas volume
  - 2P CO_2 cooling of the whole gas volume?

Manpower and starting project in next 3 years

- Manpower

Tsinghua University	Gao Yuanning, Li Yulan, Li Bo, Deng zhi
IHEP	Li Jin, Qi Huirong, Zhang Yulian
Shandong University	Zhu Chengguang
UCAS	Zheng Yangheng, Liu Qian, Wang Binlong
Lanzhou University	Hu Bitao, Zhang Yi

- Starting project supported by IHEP
  - Simulation and optimize the geometry of TPC
  - Simulation and design the system of alignment and calibration by laser
  - Design and assembled low material detector modules for prototype
  - Measurement the detector modules and optimize performance
  - Simulation and design the alignment and calibration TPC prototype detector
  - Solved key issues technology for modules



GEM Detector for Module

Critical R&D plan

- Background and physics requirement @CEPC
  - Goals for performance and design parameters
  - E/B field
  - Counting rate and Ion back flow
  - The time structure of the beam
- Simulation based on ILD-TPC and optimized the performance
  - Diameter of chamber
  - Working gas selection
  - Tracking distortion
  - Size of Pads
  - GEM and Micromegas detectors
- R&D
  - Large prototype design, assembly
  - Laser calibration and alignment device design, assembly
  - Detector readout module
  - Readout electronics: pulsing power, cooling

Thanks