Status and progress of TPC R&D for circular collider

Huirong Qi

On behalf of TPC detector subgroup

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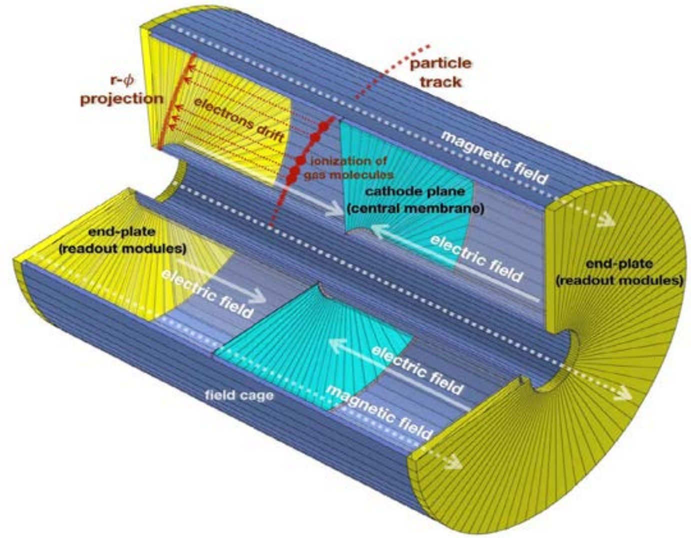
October, 26, CEPC2020, Shanghai

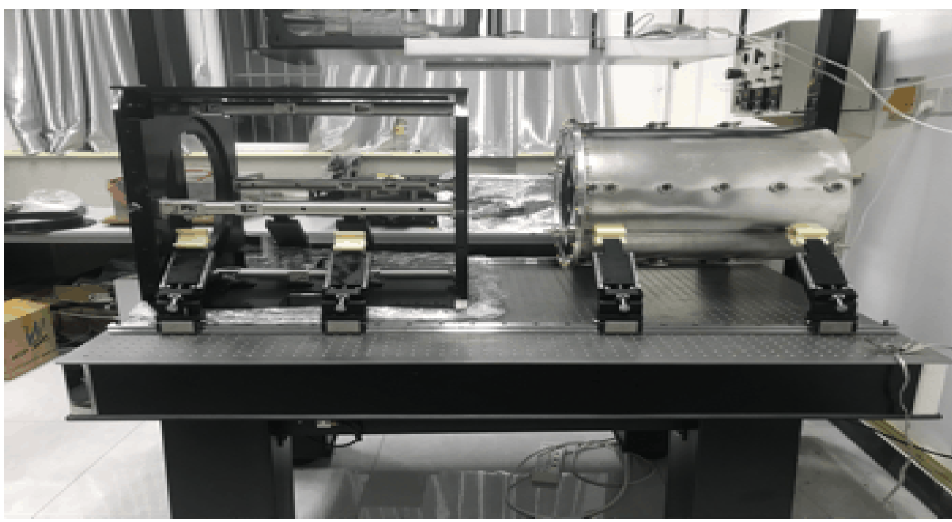
Outline

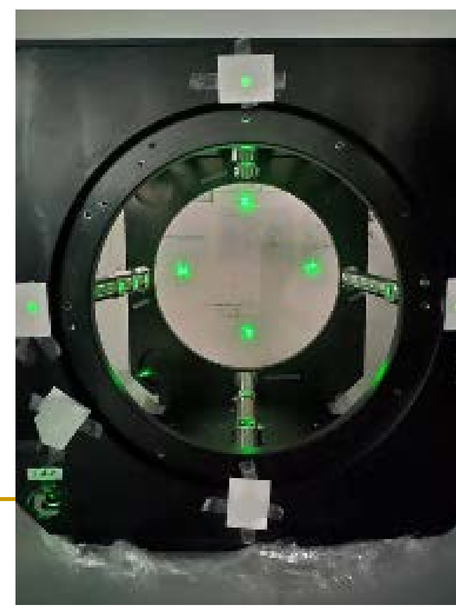
- Physics motivation
- Highlights of TPC R&D
- International collaboration
- Summary

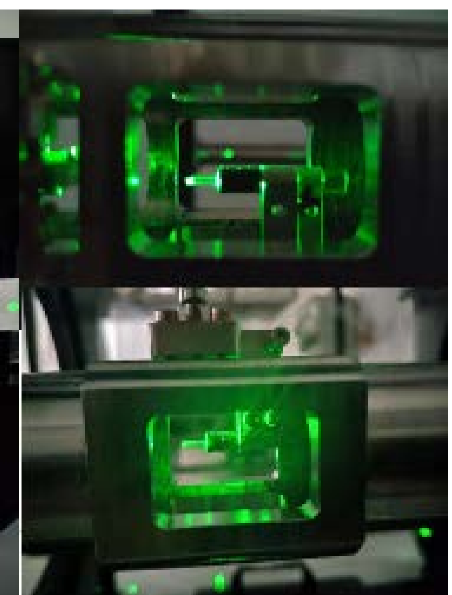
TPC technology R&D

- TPC track technology is as one the baseline options in CEPC CDR
  - TPC limitation items under the high luminosity
  - Ions back flow in chamber (MOST1 funding)
  - Calibration and alignment using UV lasers(NSFC funding)
  - Low power consumption FEE ASIC chip(MOST1)
- Pixel readout R&D as one possible option for circular collider









Physics motivation

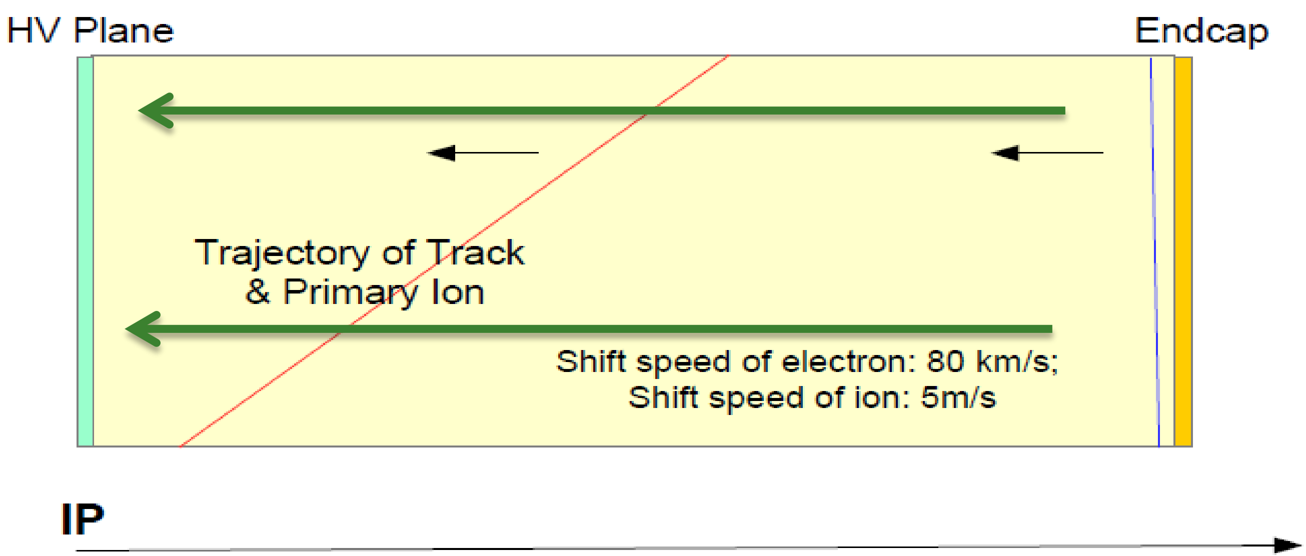
TPC limitations for Z

- Ions back flow in chamber MOST1
- Calibration and alignment NSFC
- Low power consumption FEE MOST1
  ASIC chip

Updated Parameters of Collider Ring since CDR

	Higgs		Z (2T)	
	CDR	Updated	CDR	Updated
Beam energy (GeV)	120	-	45.5	-
Synchrotron radiation loss/turn (GeV)	1.73	1.68	0.036	-
Piwinski angle	2.58	3.78	23.8	33
Number of particles/bunch N_e (10^{10})	15.0	17	8.0	15
Bunch number (bunch spacing)	242 (0.68μs)	218 (0.68μs)	12000	15000
Beam current (mA)	17.4	17.8	461.0	1081.4
Synchrotron radiation power /beam (MW)	30	-	16.5	38.6
Cell number/cavity	2	-	2	1
β function at IP β_x^* / β_y^* (m)	0.36/0.0015	0.33/0.001	0.2/0.001	-
Emittance $\varepsilon_x/\varepsilon_y$ (nm)	1.21/0.0031	0.89/0.0018	0.18/0.0016	-
Beam size at IP σ_x/σ_y (μm)	20.9/0.068	17.1/0.042	6.0/0.04	-
Bunch length σ_z (mm)	3.26	3.93	8.5	11.8
Lifetime (hour)	0.67	0.22	2.1	1.8
Luminosity/IP L (10^{34} cm^{-2}s^{-1})	2.93	5.2	32.1	101.6

Luminosity increase factor: × 1.8 × 3.2

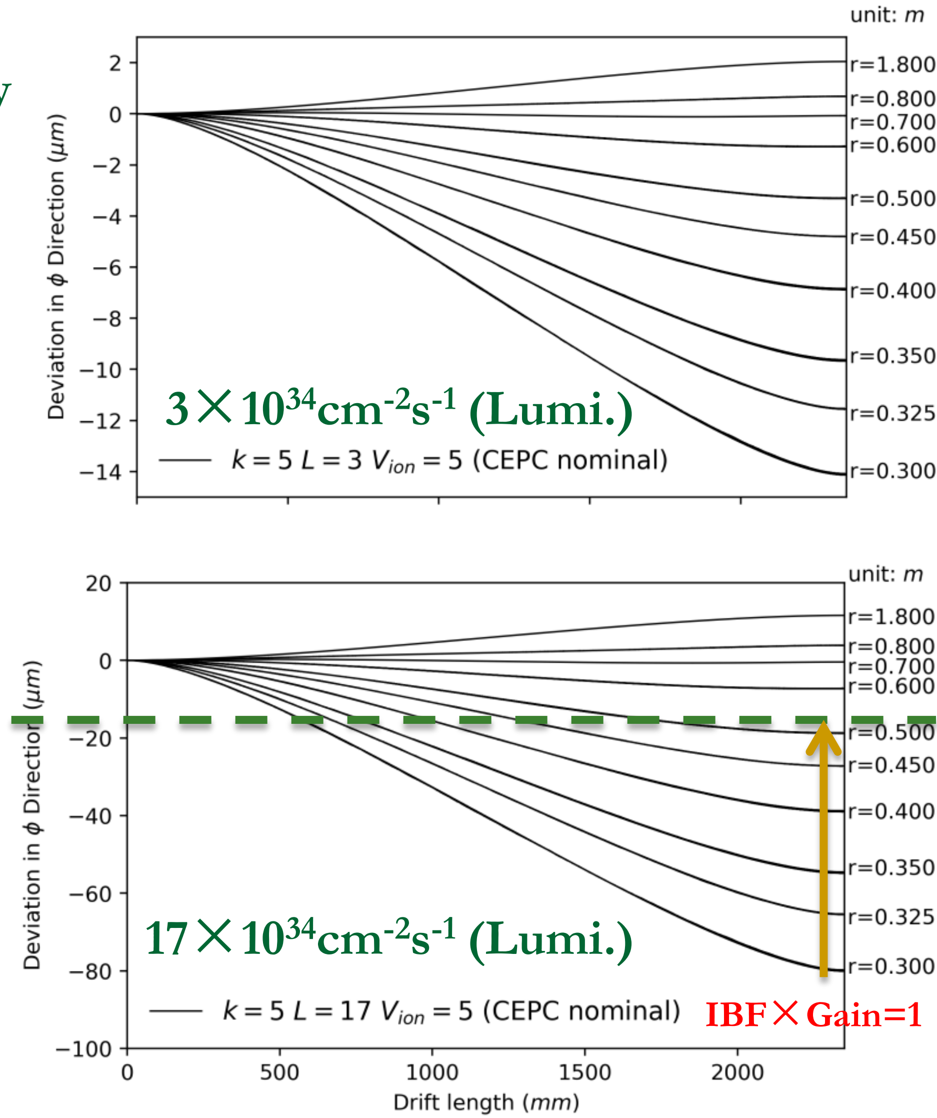


TPC detector concept

IBF simulation study at Z

DOI: 10.1142/S0217751X19400165, 2019
DOI: 10.1088/1748-0221/12/07/P07005, 2017

- Goal:
  - Operate TPC at higher luminosity
  - No Gating options
- Simulation
  - IBF × Gain default as the factor of 5
  - 9 thousand Z to qq events
  - 60 million hits are generated in sample
  - Average hit density: 6 hits/mm^2
  - Voxel size: 1mm × 6mm × 2mm
  - Average voxel occupancy: 1.33×10^{-8}
  - Voxel occupancy at TPC inner most layer: ~2×10^{-7}
  - Validated with 3 ions disks
  - Simulation of the multi ions disk in chamber under the continuous beam structure
  - Without the charge of the beam-beam effects in TPC

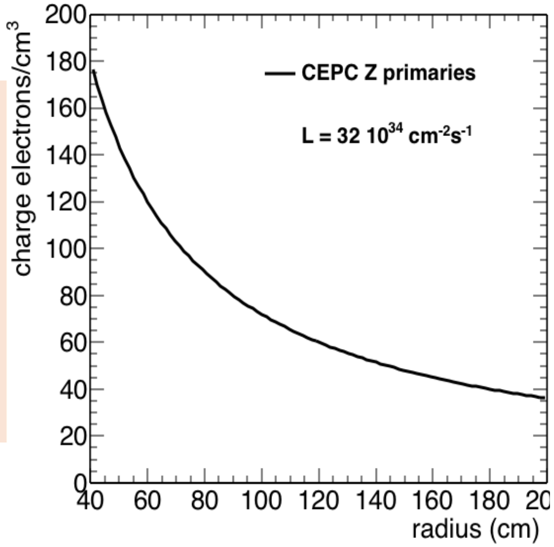


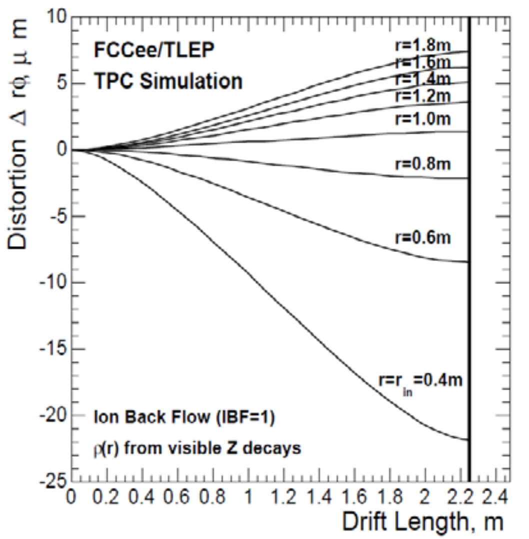
Deviation with the different TPC radius

Prospects for a TPC at Z

- Rough estimations at L = $35 \cdot 10^{35}$ cm^{-2} s^{-1} indicate primary ionisation at a ILC250 level
  ⇒ < 5 µm distortions (This equals 8 µm with IBF = 1) See Arai Daisuke
- Simulation from CEPC TPC with Gain × IBF = 1 and L = $32 \cdot 10^{34}$ cm^{-2} s^{-1}
  ⇒ < 16 µm distortions (Gain × IBF = 1 and L = $32 \cdot 10^{34}$ cm^{-2} s^{-1}) from Zhiyang Yuan
- FCCee/TLEP studies at Gain × IBF = 1 and 16.8 kHz hadronic Zs by Philippe Schwemling
  ⇒ < 22 µm distortions

Rough esitimation of primary ionisation
- 10 kHz Z event rate
- 500 ms will accumulate 5000 Z events
- 20 tracks / Z event and 10 000 e / track will make 10^8 ions in volume
- Volume is ~4 10^7 resulting in 25 e/cm^3
- Similar to ILC250 accumulated charge



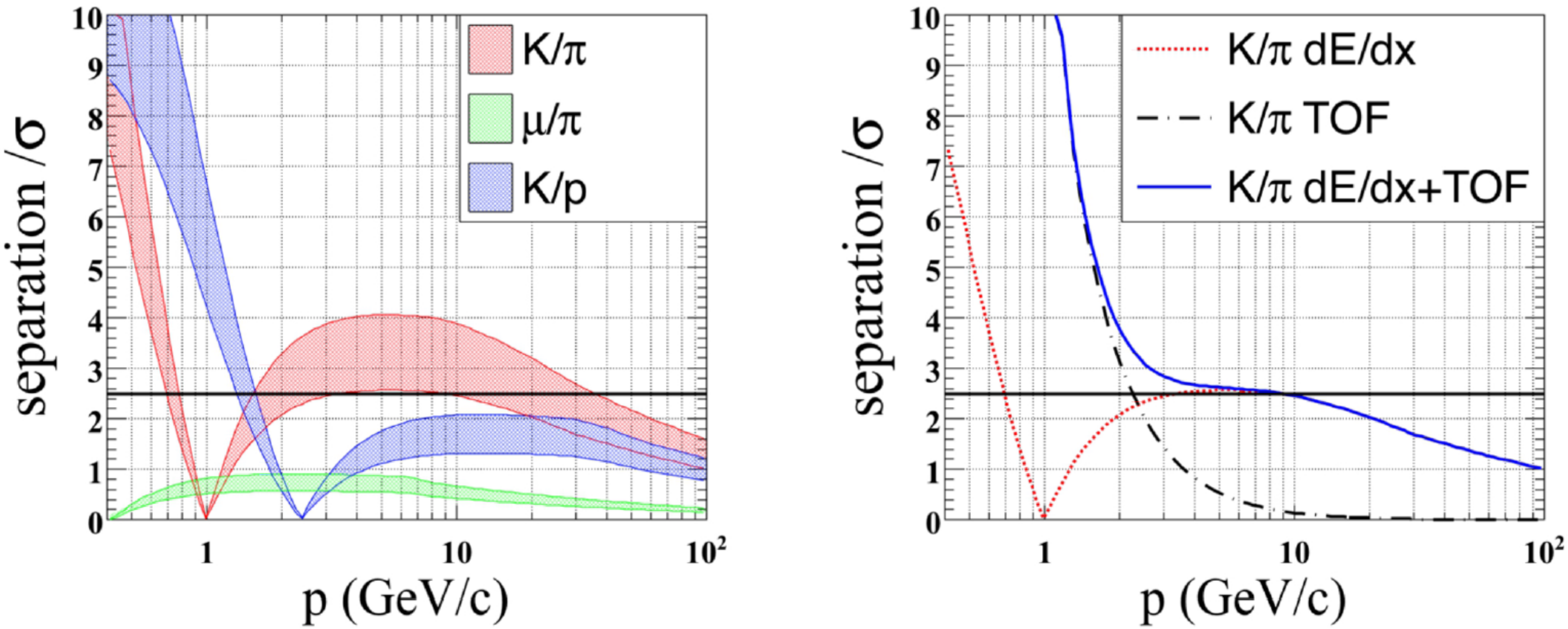


Slides@RD51 and TPC meeting 2020

PID requirements

Manqi@IAS2020 meeting

Kaon



Highly appreciated in flavor physics @ CEPC Z pole

TPC dEdx + ToF of 50 ps

At inclusive Z pole sample:

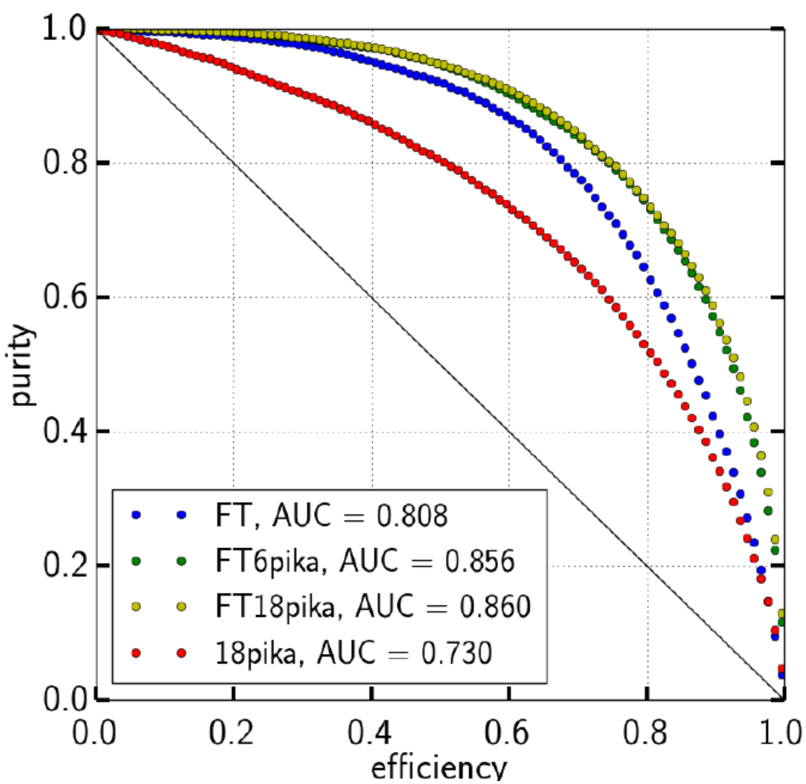
Conservative estimation gives efficiency/purity of 91%/94% (2-20 GeV, 50% degrading +50 ps ToF)

Could be improved to 96%/96% by better detector/DAQ performance (20% degrading + 50 ps ToF)

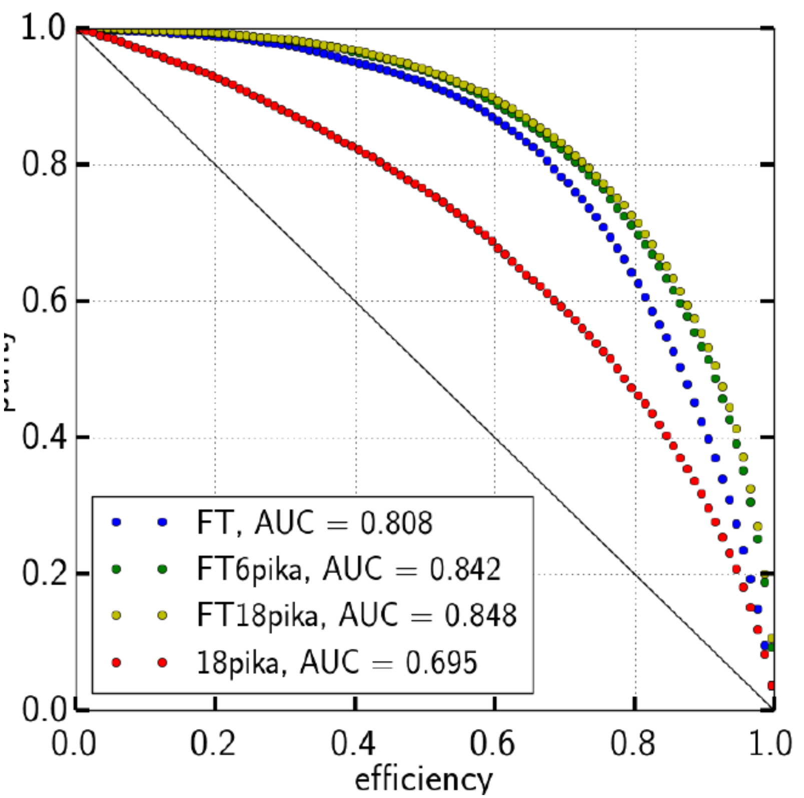
dE/dx of Flaver tag, pion, kaon

Uli Einhaus@ILD meeting

$\sigma_{dE/dx} = 2.6\%$



$\sigma_{dE/dx} = 4.5\%$



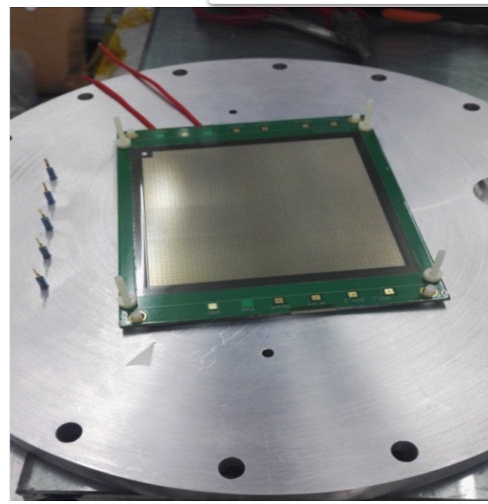
+ 20%

Highlights of TPC R&D

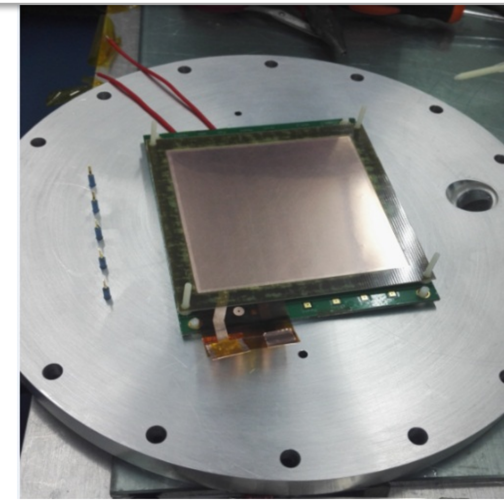
TPC detector module@ IHEP

DOI: 10.1088/1748-0221/12/04/P0401 JINST，2017.4
DOI: 10.1088/1674-1137/41/5/056003 , CPC,2016.11
DOI: 10.7498/aps.66.072901Acta Phys. Sin. 2017,7

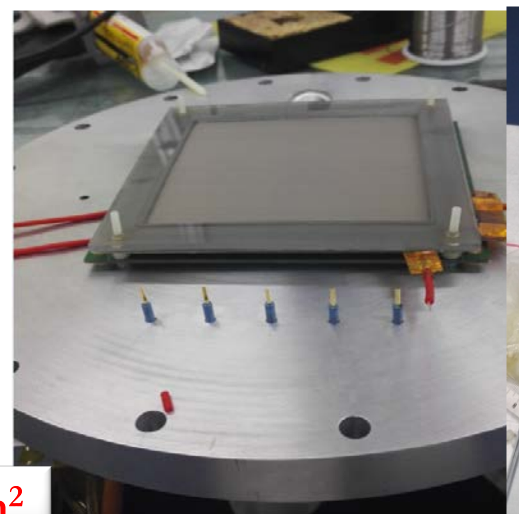
- Study with GEM-MM module
  - New assembled module
  - Active area: 100mm×100mm
  - X-tube ray and 55Fe source
  - Bulk-Micromegas assembled from Saclay
  - Standard GEM from CERN
  - Avalanche gap of MM:128μm
  - Transfer gap: 2mm
  - Drift length:2mm~200mm
  - pA current meter: Keithley 6517B
  - Current recording: Auto-record interface by LabView
  - Standard Mesh: 400LPI
  - High mesh: 508 LPI



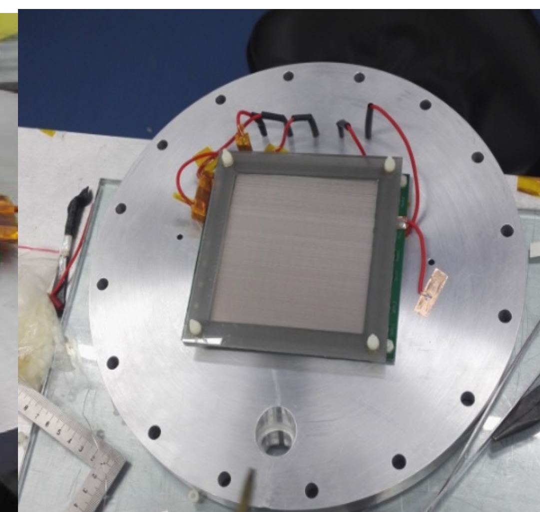
Micromegas(Saclay)



GEM(CERN)



Cathode with mesh



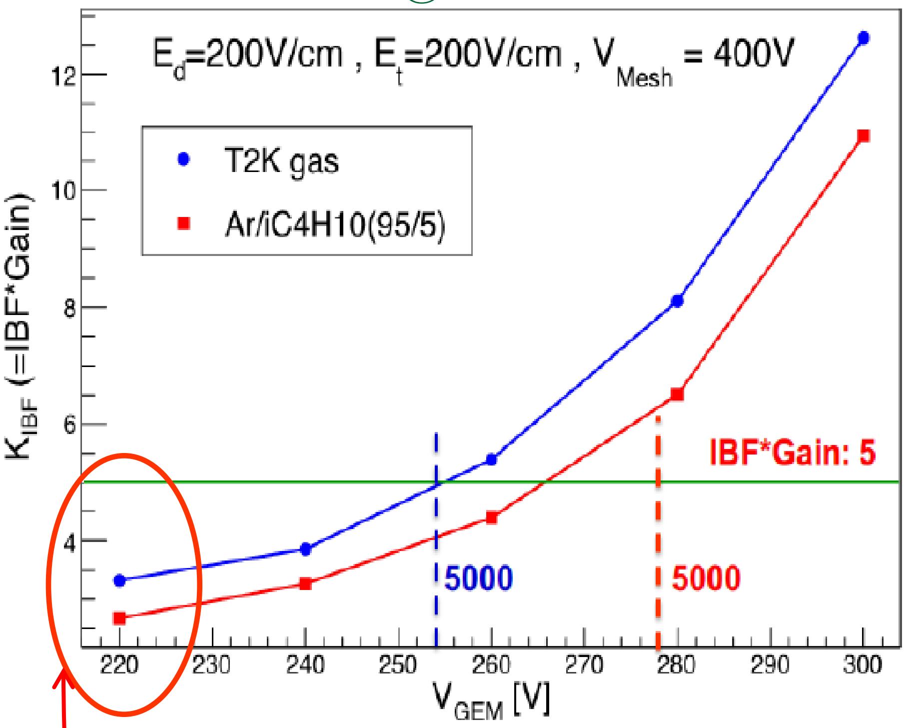
GEM-MM Detector

$50\times50mm^2$ 2015-2016 → $100\times100mm^2$ 2017-2018 → $200\times200mm^2$ 2019-2020

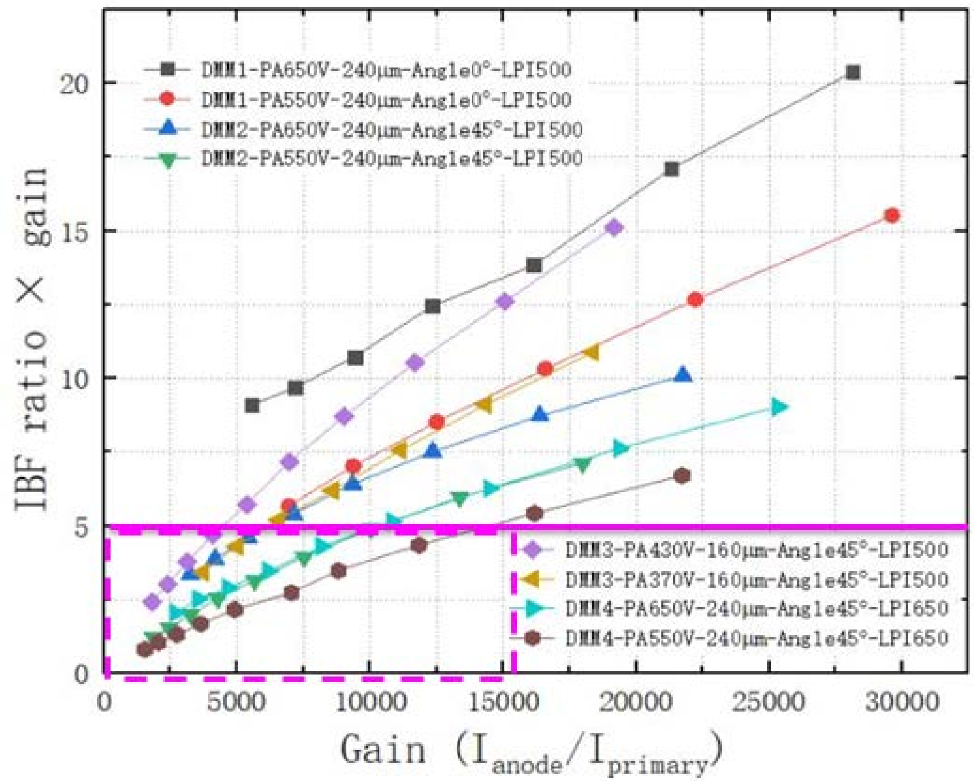
GEM+MM VS DMM@USTC

doi.org/10.1016/j.nima.2020.164282

Micronegas + GEM detector module @IHEP



IBF of double mesh MM @USTC/Jianbei Liu



- IBF × Gain has the limitation ratio from the detector R&D at high gain.
- Lower gain and lower IBF ratio

Different concepts with IBF suppression

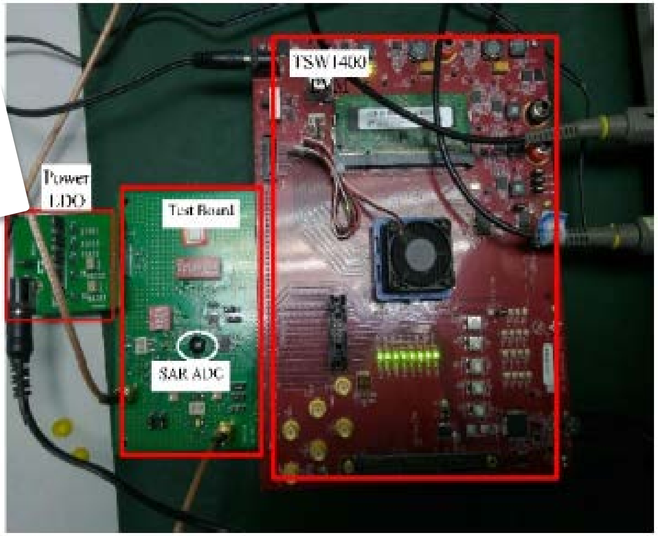
Pixel TPC with double meshes	Triple or double GEMs	Resistive Micromegas	GEM+ Micromegas	Double meshes Micromegas
IHEP, Nikehf	KEK, DESY	Saclay	IHEP	USTC
Pad size: 55um-150um square	Pad size: 1mm×6mm	Pad size: 1mm×6mm	Pad size: 1mm×6mm	Pad size: 1mm×6mm (If resistive layer)
Advantage for TPC: Low gain: 2000 IBF×Gain: -1	Advantage for TPC: Gain: 5000-6000 IBF×Gain: <10	Advantage for TPC: Gain: 5000-6000 IBF×Gain: <10	Advantage for TPC: Gain:5000-6000 IBF×Gain: <5	Advantage for TPC: High gain: 10^4 Gain: 5000-6000 IBF×Gain: 1-2
Electrons cluster size for FEE: About Ø200um	Electrons cluster size for FEE: About Ø5mm	Electrons cluster size for FEE: About Ø8mm	Electrons cluster size for FEE: About Ø6mm	Electrons cluster size for FEE: About Ø8mm
Integrated FEE in readout board Detector Gain：2000	FEE gain: 20mV/fC Detector Gain：5000-6000	FEE gain: 20mV/fC Detector Gain：5000-6000	FEE gain: 20mV/fC Detector Gain：5000-6000	FEE gain: 20mV/fC Detector Gain：5000-6000

Highlight progress of FEE R&D

- Low power consumption ASIC FEE chip for TPC detector using 65nm CMOS
- Two MWP finished
- Result of the power consumption of SAR ADC could tested less than 5mW/ch in total chip
- Three chips were exposed to the radiation source at a dose rate of 50 rad (Si)/s at room temperature with the total dose up to 1 Mrad(Si)
- All the performances of three chips remained almost the same after irradiation
- Preliminary requirement for CEPC track detector (<1 krad) from CDR

Liu Wei's talk
In this session

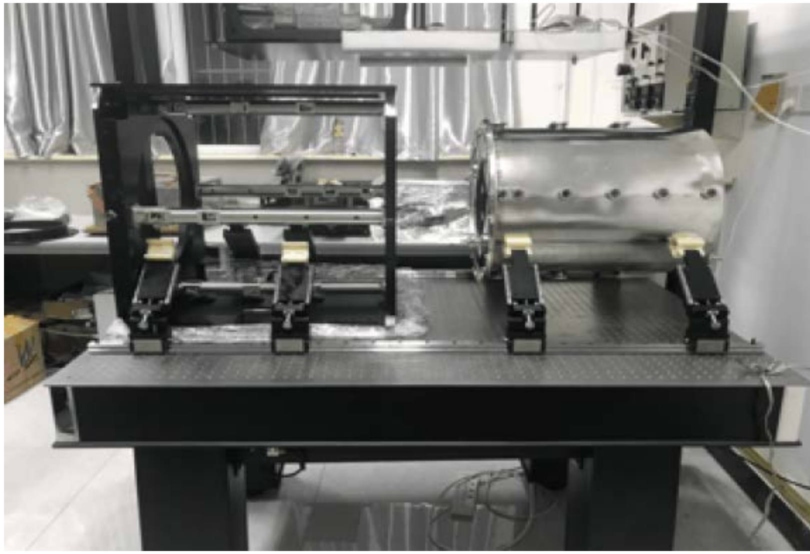
Module Name	Power (mW)
Total Chip	4.0
Reference Buffer	0.25
SAR ADC Core	1.0
Clock Generation	2.75



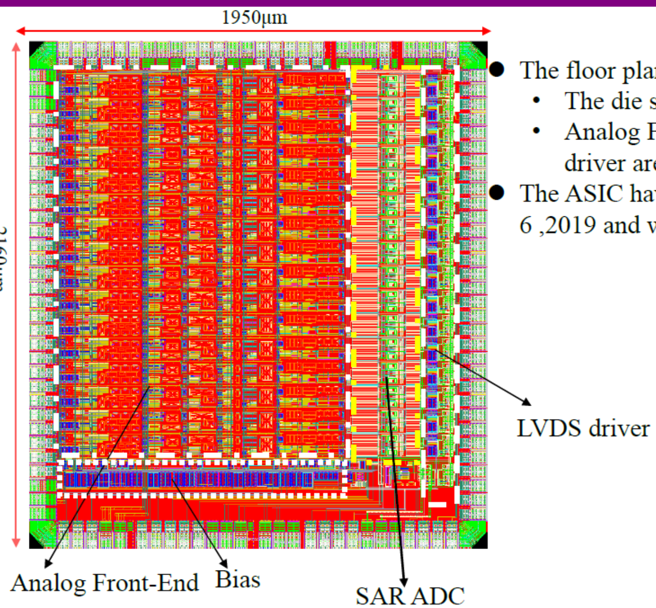
Study setup for AFE

TPC prototype R&D

- Main parameters
  - Drift length: ~510mm, Readout active area: 200mm×200mm
  - Integrated the laser calibration with 266nm
  - GEMs/Micromegas as the readout
  - Amplifier
    - CASAGEM chip
    - 16Chs/chip
    - Shape time: 20ns
  - DAQ
    - FPGA+ADC
    - 4 module/mother boar
    - 64Chs/module
    - Sample: 40MHz
    - 1280chs



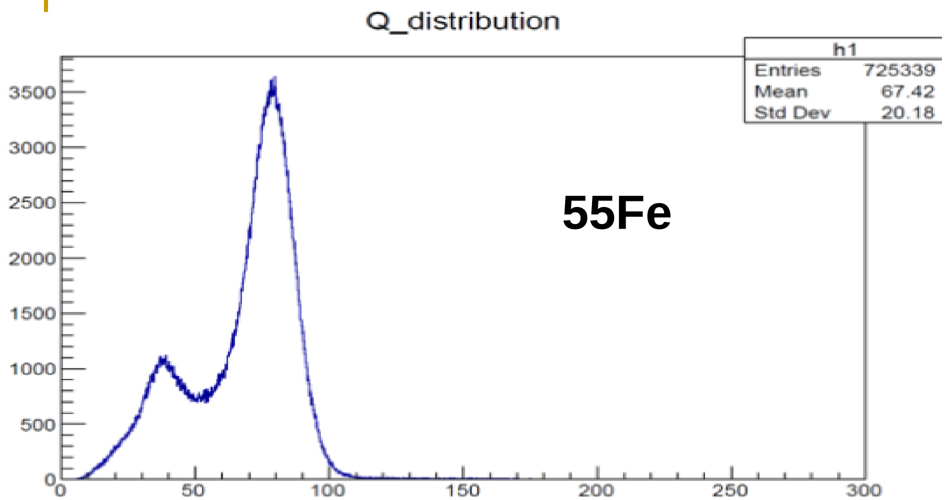
Layout of 16-ch TPC Readout ASIC

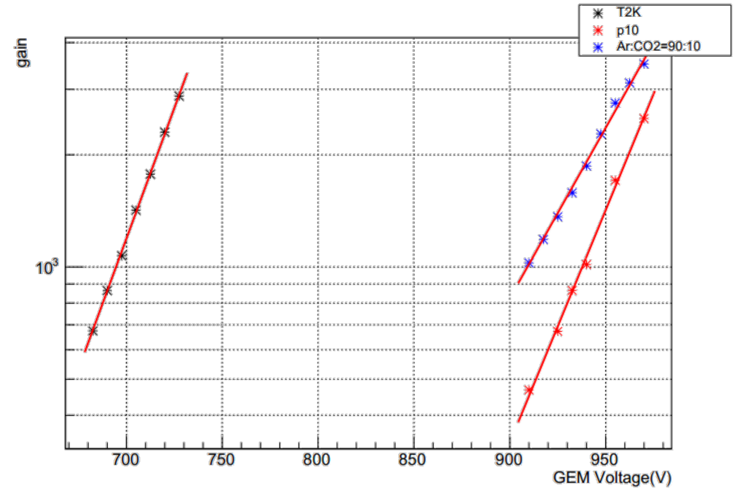


- The floor plan in layout：
  - The die size of 1950 μm x 2160 μm
  - Analog Front-End , SPI, SAR ADC, LVDS driver are supplied by separate power
- The ASIC have been taped out in November 6 ,2019 and will be evaluated in February,2020.

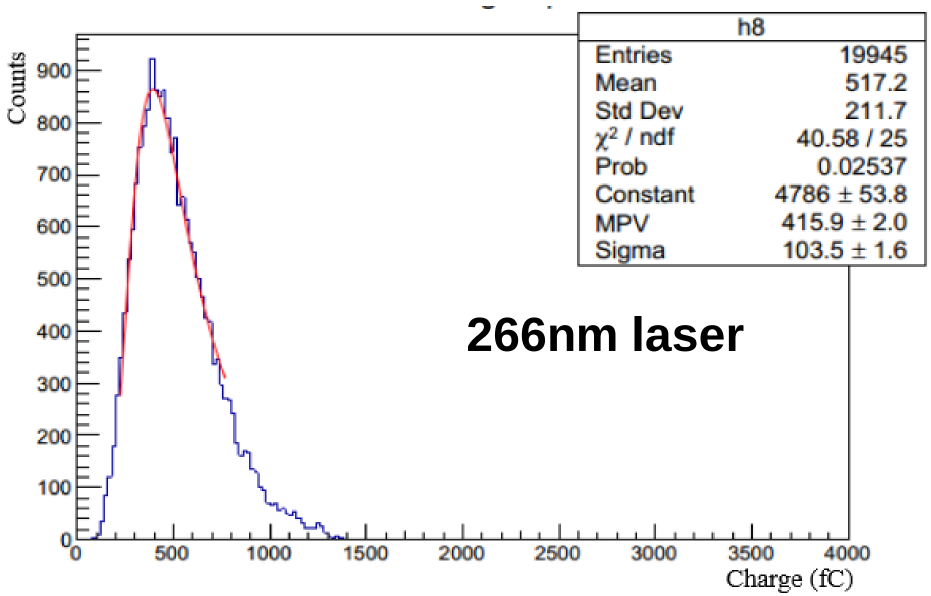
Diagram of the TPC prototype with the laser calibration system

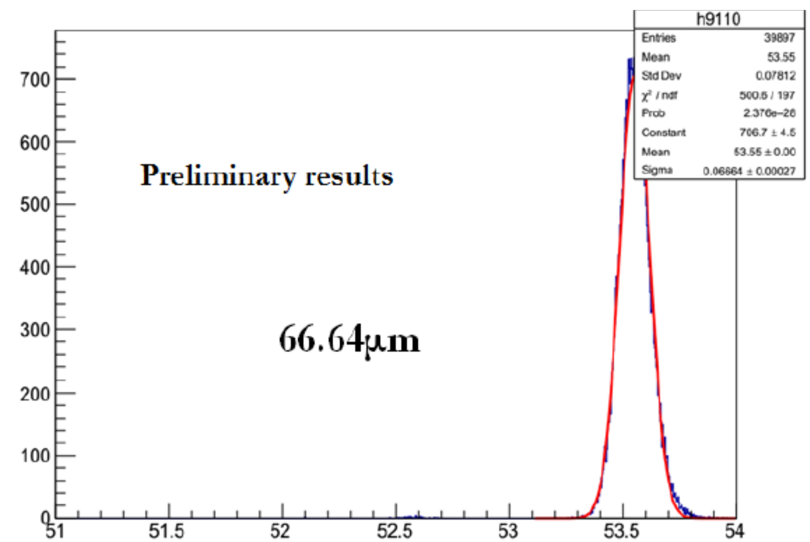
Test results using 266nm laser





Gain at T2K, P10, Ar/CO2





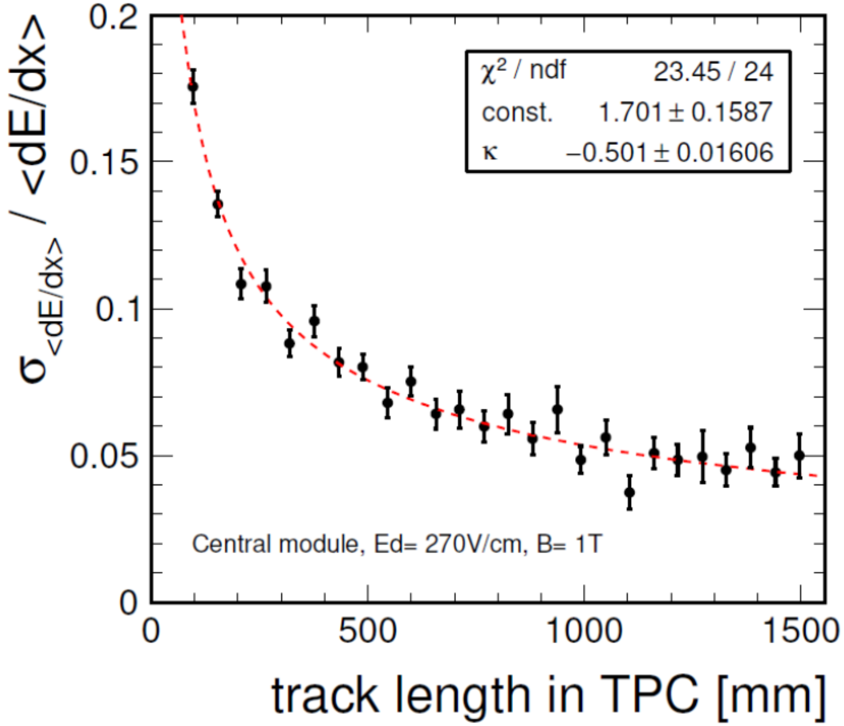
Energy spectrum of 55Fe and the laser

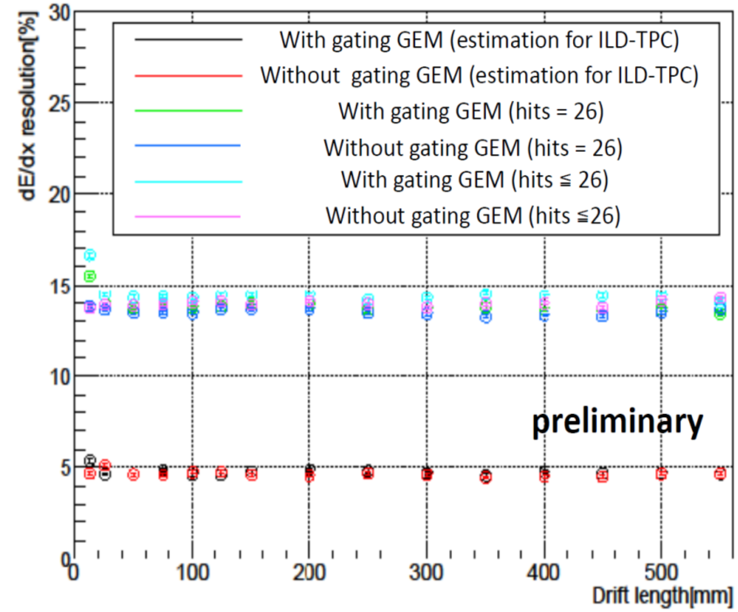
Results of position resolution with PRF

dE/dx R&D

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

Jochen@ILD meeting



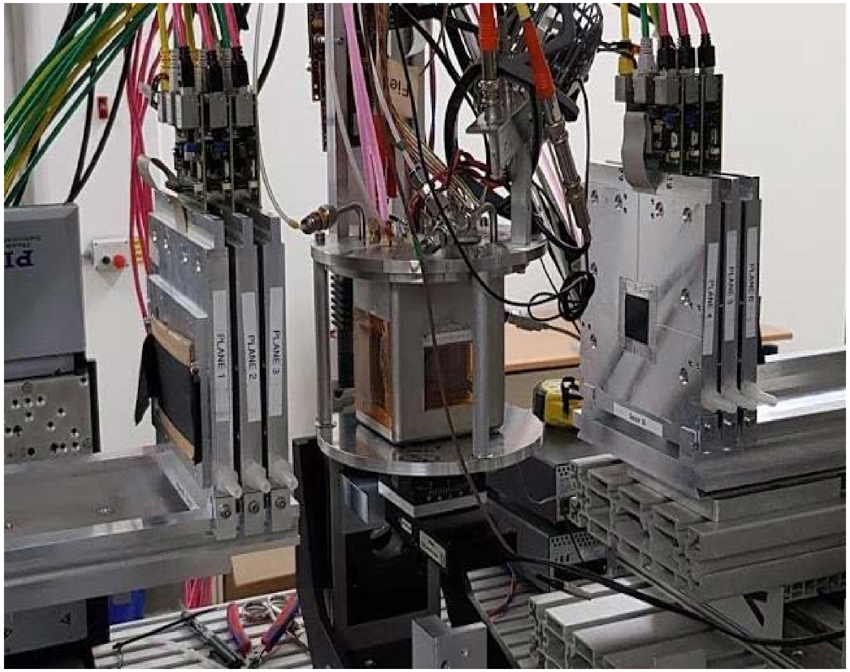


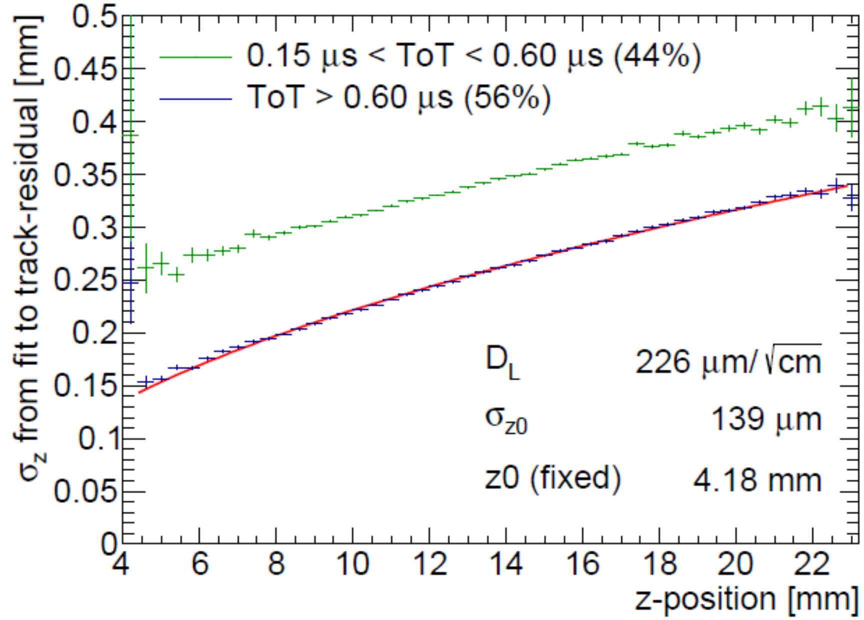
ıe average of dE/dx resolution expected from the ILD-TPC is 4.70 ± 0.02% (4.61±0.02%) th (without) the gating GEM.

- 5GeV e- beam at DESY
- TPC detector with GEMs readout Micromegas readout

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

Peter@ILD meeting

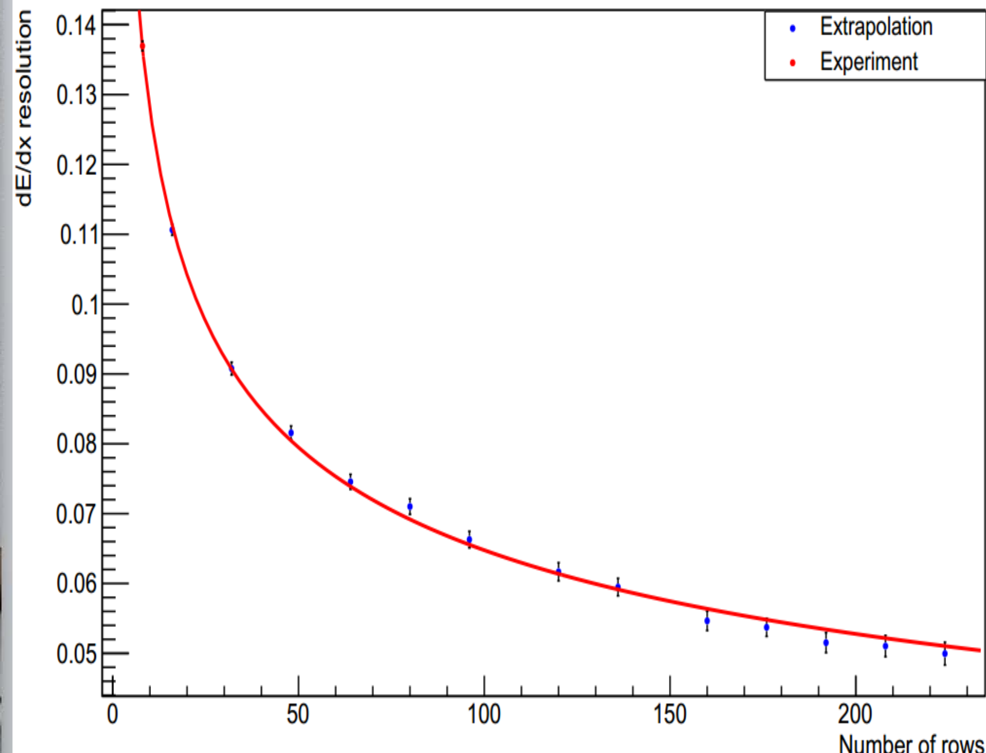




2.7% resolution is within prospects of PixelTPC [arXiv:1902.01987]

dE/dx by 266nm UV laser@IHEP

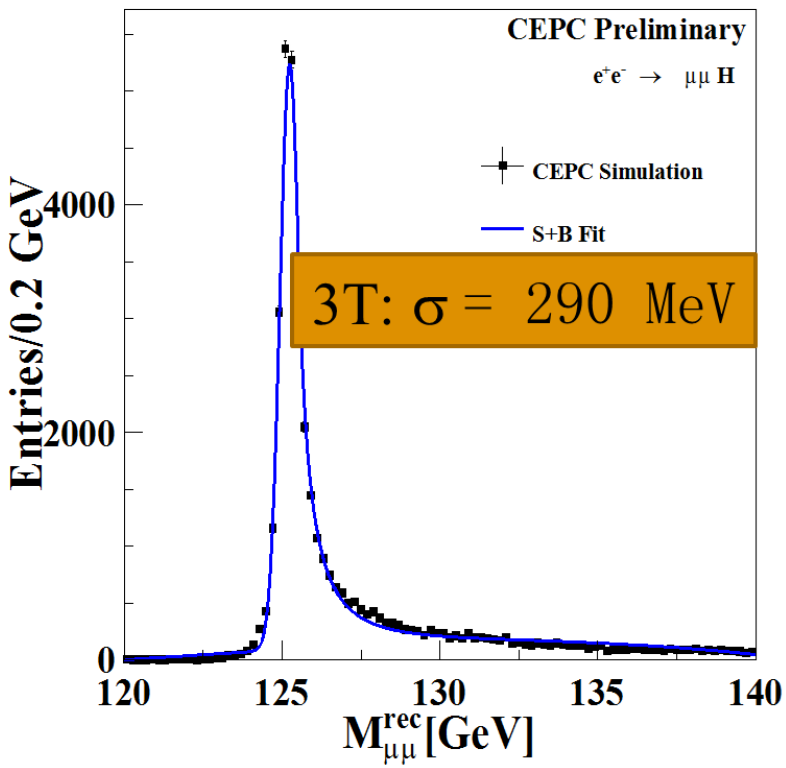
Yiming Cai, Zhiyang Yuan@ILD meeting

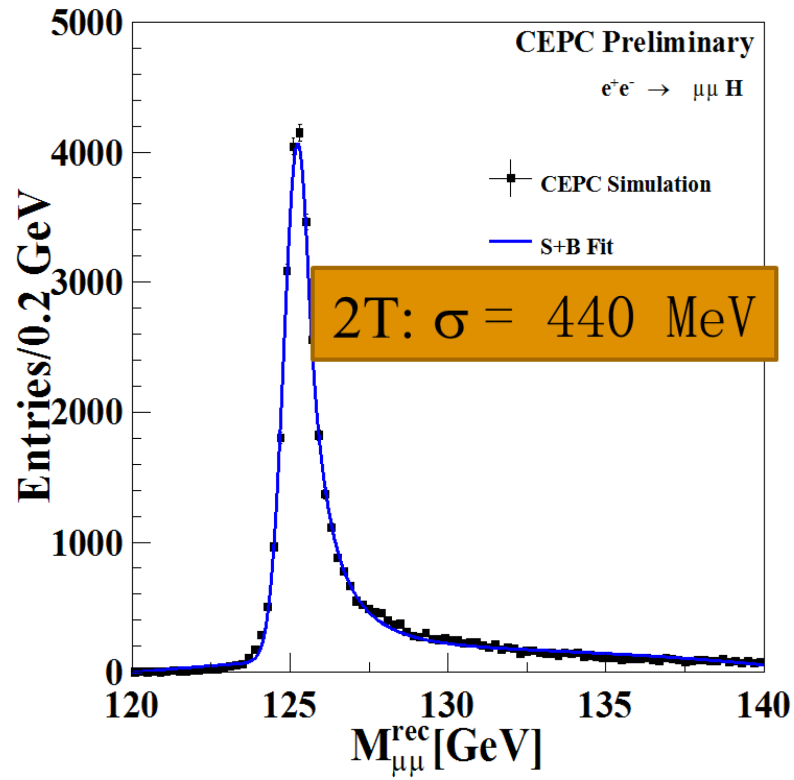


Experimental study result using laser and expanded to CEPC TPC

Full simulation @3 Tesla vs. 2 Tesla @240 GeV

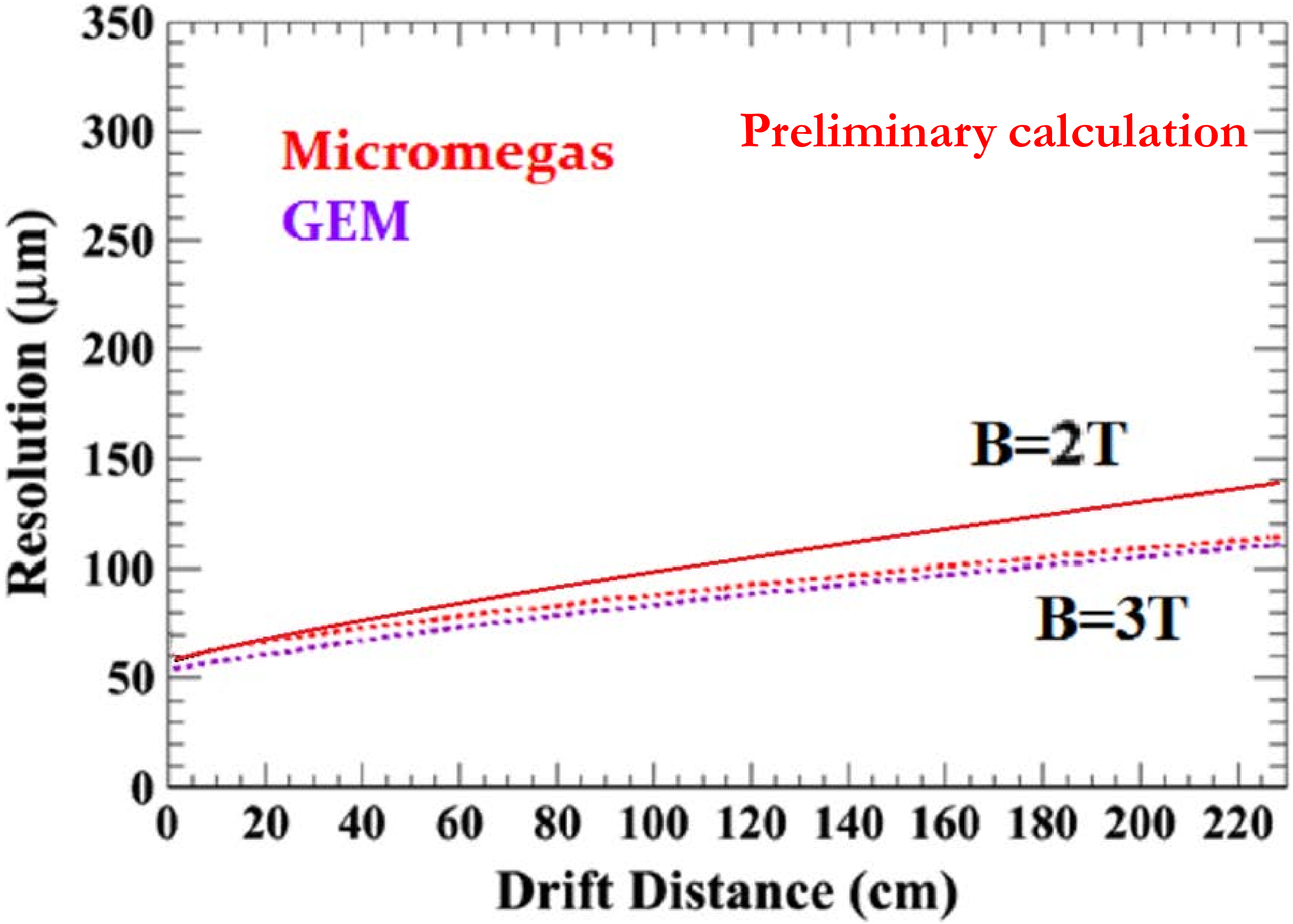
Preliminary simulation Gang Li and Zhiyang Yuan





- The δ_m of μμ recoil mass increases ~50% as expected when B = 2 T
- It needs at least 125% more data to get the same δ_m at 3 T

TPC transverse rφ resolution

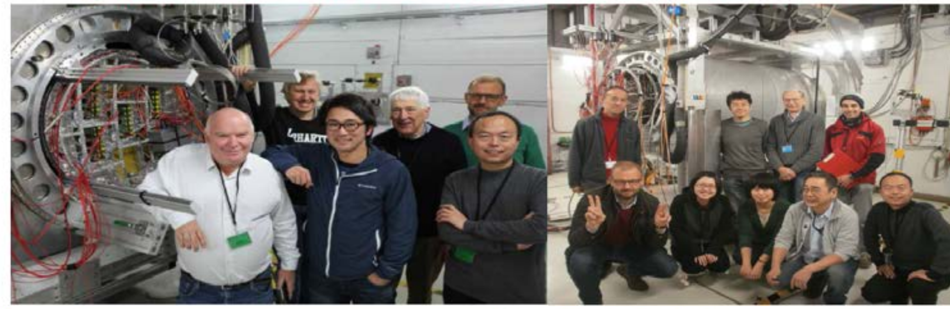


International collaboration

- **IHEP Signed MOA and joined in LCTPC collaboration@ Dec. 14, 2016**
- **IHEP participated in IDR LCTPC documents in 2019**
- **IHEP participated in LOI Snowmass LCTPC documents in 2020**
- **Participated the beam test at DESY in 2016 and 2019**

International cooperation

- LCTPC collaboration group (LCTPC)
  - Singed MOA and joined in LC-TPC collaboration @Dec. 14,2016
  - As coordinator in ions test and the new module design work package
  - CSC funding: PhD Haiyun jiont CEA-Scalay TPC group(6 months)
  - Joint beam test in DESY with our hybrid detector module in 2019



TPC prototype cooperated with Tsinghua

International cooperation

- CEA-Saclay IRFU group (FCPPL)
  - Three vidyo meetings with Prof. Aleksan Roy/ Prof. Yuanning/ Manqi and some related persons (2016~2017)
  - Exchange PhD students: Haiyun Wang participates Saclay's R&D six months in 2017~2018
  - Bulk-Micromegas detector assembled and IBF test
  - IBF test using the new Micromegas module with mor 590 LPI
  - UV+ laser tracker

Summary

Requirements and critical challenges for the high luminosity motivation:

- **IBF*Gain should be considered at the high luminosity**
- **Some motivations of TPC detector for collider at Z pole run listed.**

TPC module and prototype R&D:

- **TPC can meet most requirements of PID and moment resolution, and others should be optimized and R&D**
- **Concerning TPC technology R&D in ILD collaboration, IHEP will continuously collaborated with LCTPC**
- **The calibration and alignment methods of the narrow UV laser beam considered for further R&D**
- **IHEP and Nikehf will collaborated in pixel TPC to significantly reduced the issue of IBF at high luminosity in collider**

10:30 - 12:00

Gaseous Detector

Conveners: Silvia Dalla Torre (CERN), Mr. Imad LAKTINEH (IPNL), Dr. Huirong Qi (Institute of High Energy Physics, CAS), Hongyu ZHANG (EPC, IHEP, CAS, China)

Location: Grand Ballroom A (Online Meeting Room: https://weidijia.zoom.com.cn/j/68389800454)

10:30 **Status and progress of CEPC TPC R&D** *18′*

Speaker: Dr. Huirong Qi (Institute of High Energy Physics, CAS)

10:48 **65nm ASIC FEE for TPC** *18′*

Speakers: 伟 刘 (清华大学), Dr. 智 邓 (清华大学)

11:06 **Development of the uRWELL detector for large area application** *18′*

Speaker: Dr. You Lv (USTC, CAS)

Material: Slides

11:24 **High time presion MRPC for CEE** *18′*

Speaker: Dr. Botan Wang (Tsinghua University)

Material: Slides

11:42 **RPC FEE** *18′*

Speaker: Weihao Wu (Shanghai Jiao Tong University)

Thank you for your attention !

16:30 - 18:30

Gaseous Detector

Conveners: Silvia Dalla Torre (CERN), Mr. Imad LAKTINEH (IPNL), Dr. Huirong Qi (Institute of High Energy Physics, CAS)

Location: Grand Ballroom A (Online Meeting Room: https://weidijia.zoom.com.cn/j/68389800454)

16:30 **Pixel TPC Technology R&D** *20′*

Speaker: Peter Kluit (NIKEHF)

16:50 **MPGD technology** *20′*

Speaker: Florian Brunbauer (C)

17:10 **Drift chamber** *20′*

Speaker: Marco Chiappini (INFN-Pisa)

17:30 **sPHENIX TPC** *20′*

Speaker: Dr. Klaus Dehmelt (Stony Brook U.)

17:50 **RPC new readout** *20′*

Speaker: Prof. imad laktineh (IPNL)

Material: Slides

18:10 **Status of the gaseous detector on jet studies with PID** *15′*

Speaker: Dr. Zhiyang Yuan (IHEP)