Performance of the continuous ions suppression TPC prototype for circular collider

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On behalf of TPC detector subgroup
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Outline

- Physics requirements
- Simulation of IBF at Z
- TPC prototype R&D
- Summary

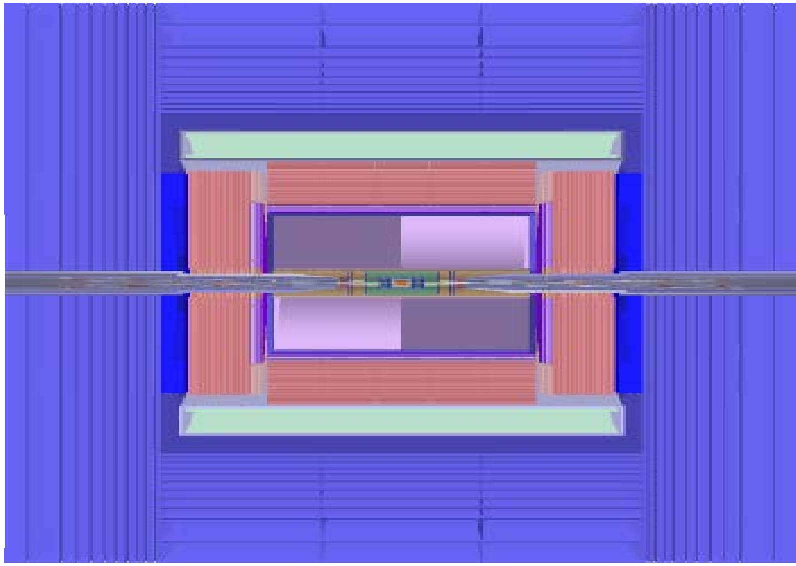
Three Detector Concepts (CEPC CDR)

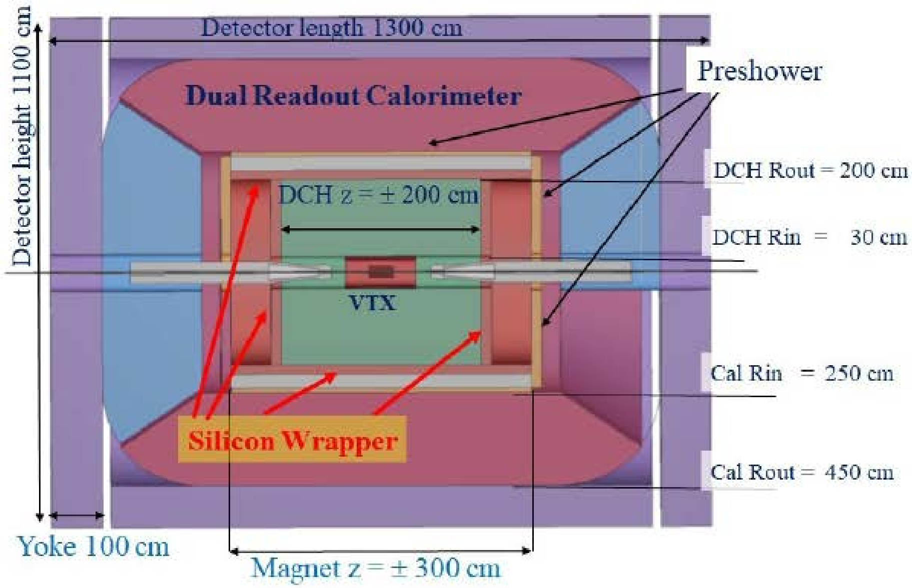
ArXiv:1811.10545

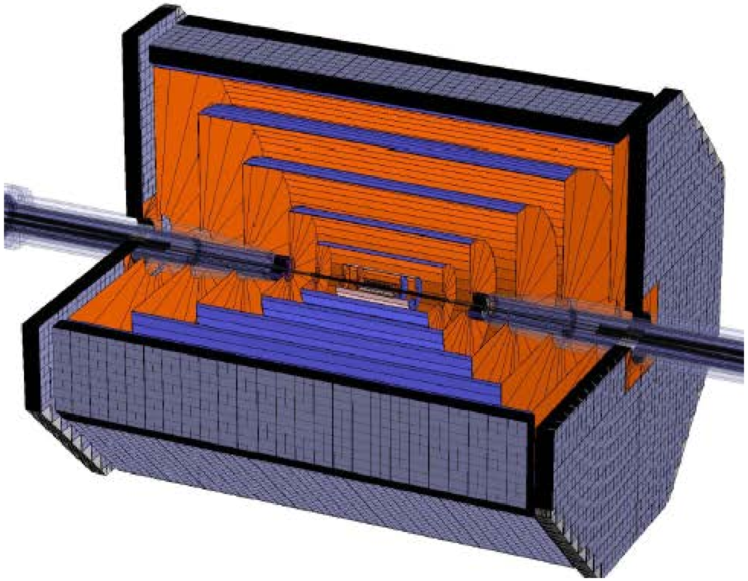
Operation mode	$\sqrt{s}$ (GeV)	L per IP (10^{34} cm^{-2}s^{-1})
H	240	3
Z	91.2	32 (*)
W^+W^-	158–172	10

- Baseline: Silicon + TPC
- FST: all-silicon tracker
- IDEA: Silicon+Drift chamber (DCH)

	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5 × 2			







Some update parameters of Collider

Joao's talk

Updated Parameters of Collider Ring since CDR

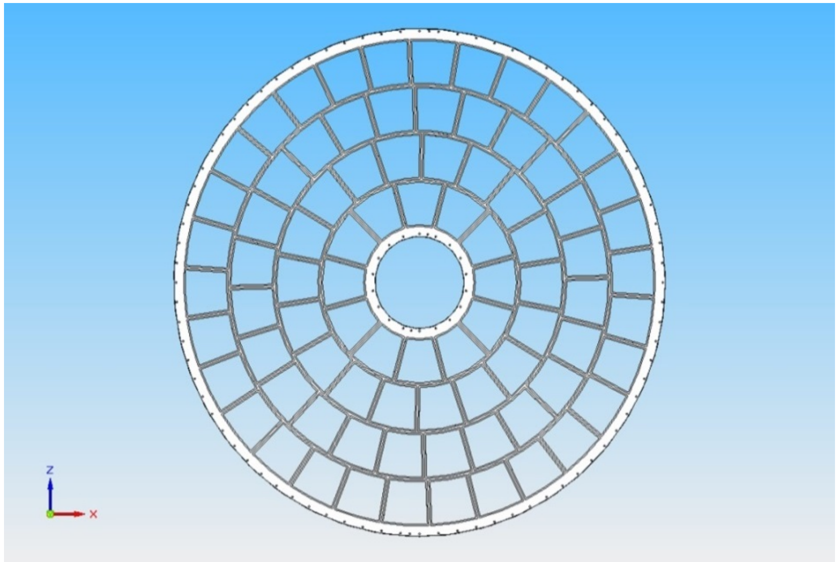
	Higgs		Z (2T)	
	CDR	Updated	CDR	Updated
Beam energy (GeV)	120	-	45.5	-
Synchrotron radiation loss/turn (GeV)	1.73	1.68	0.036	-
Piwinski angle	2.58	3.78	23.8	33
Number of particles/bunch N_e (10^{10})	15.0	17	8.0	15
Bunch number (bunch spacing)	242 (0.68μs)	218 (0.68μs)	12000	15000
Beam current (mA)	17.4	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

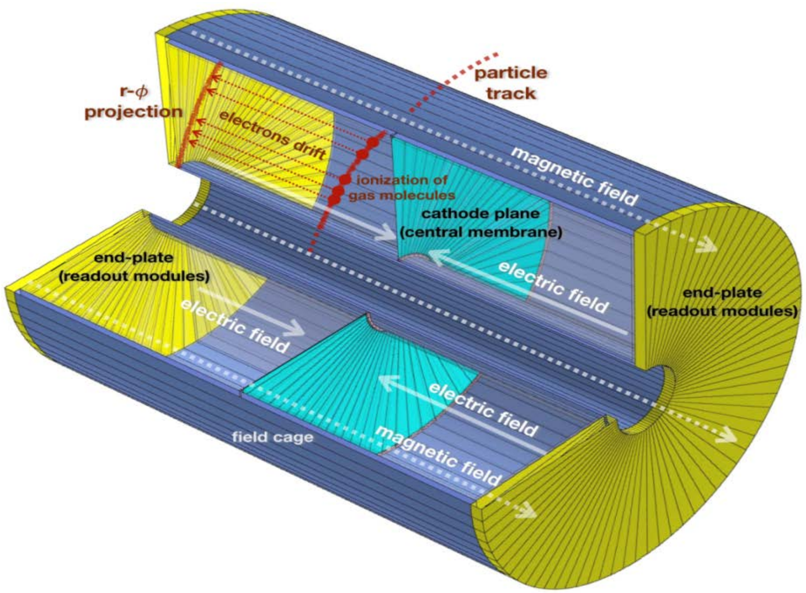
Luminosity increase factor: × 1.8 × 3.2

Overview: physics requirements

TPC detector concept:

- Under 2-3 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





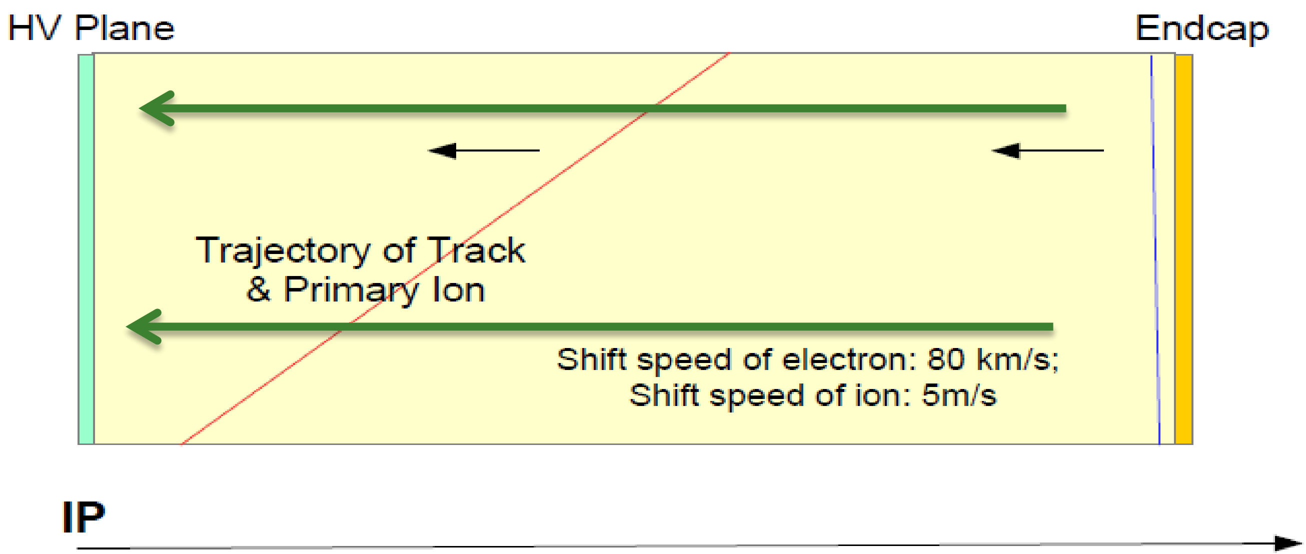
TPC detector endplate concept

Feasibility and limitations

TPC limitations for Z

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

	ALICE TPC	CEPC TPC
Maximum readout rate	>50kHz@pp	w.o BG?
Gating to reduce ions	No Gating	No Gating
Continuous readout	No trigger	Trigger?
IBF control	Build-in	Build-in
IBF*Gain	<10	<5
Calibration system	Laser	NEED

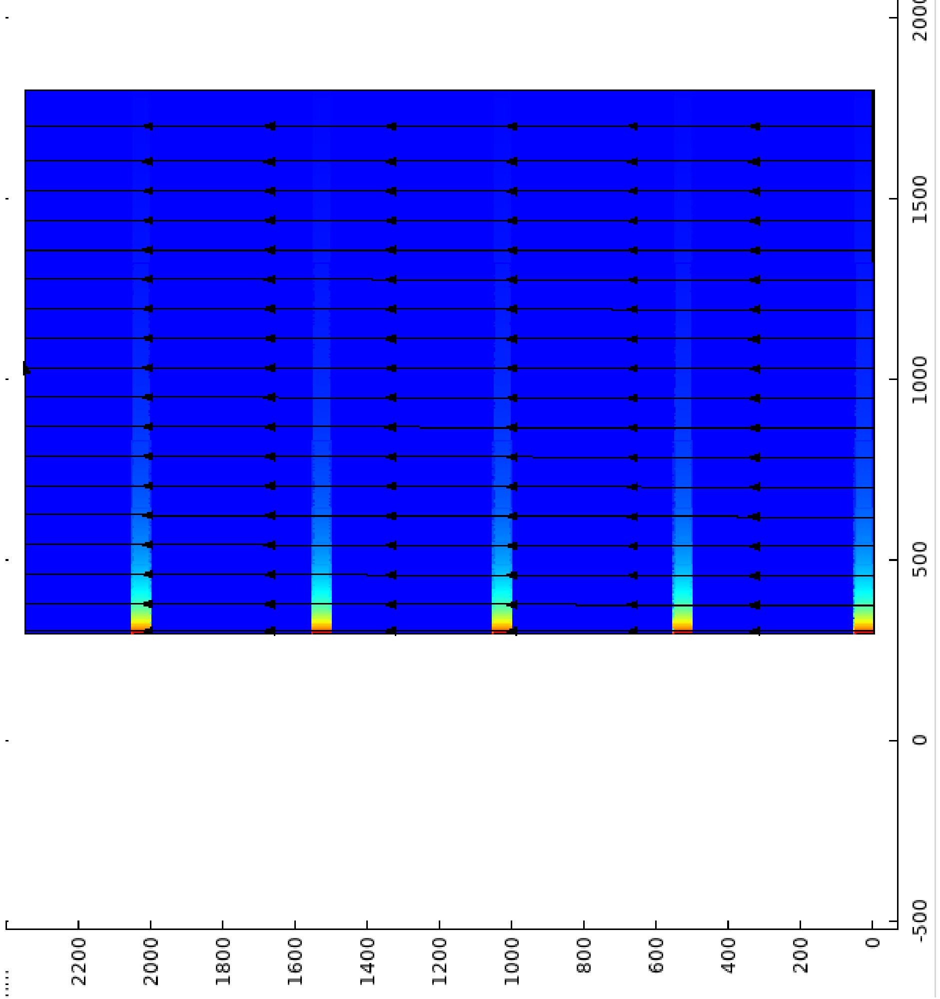


Compare with ALICE TPC and CEPC TPC

Simulation of IBF effect

Zhiyang Yuan

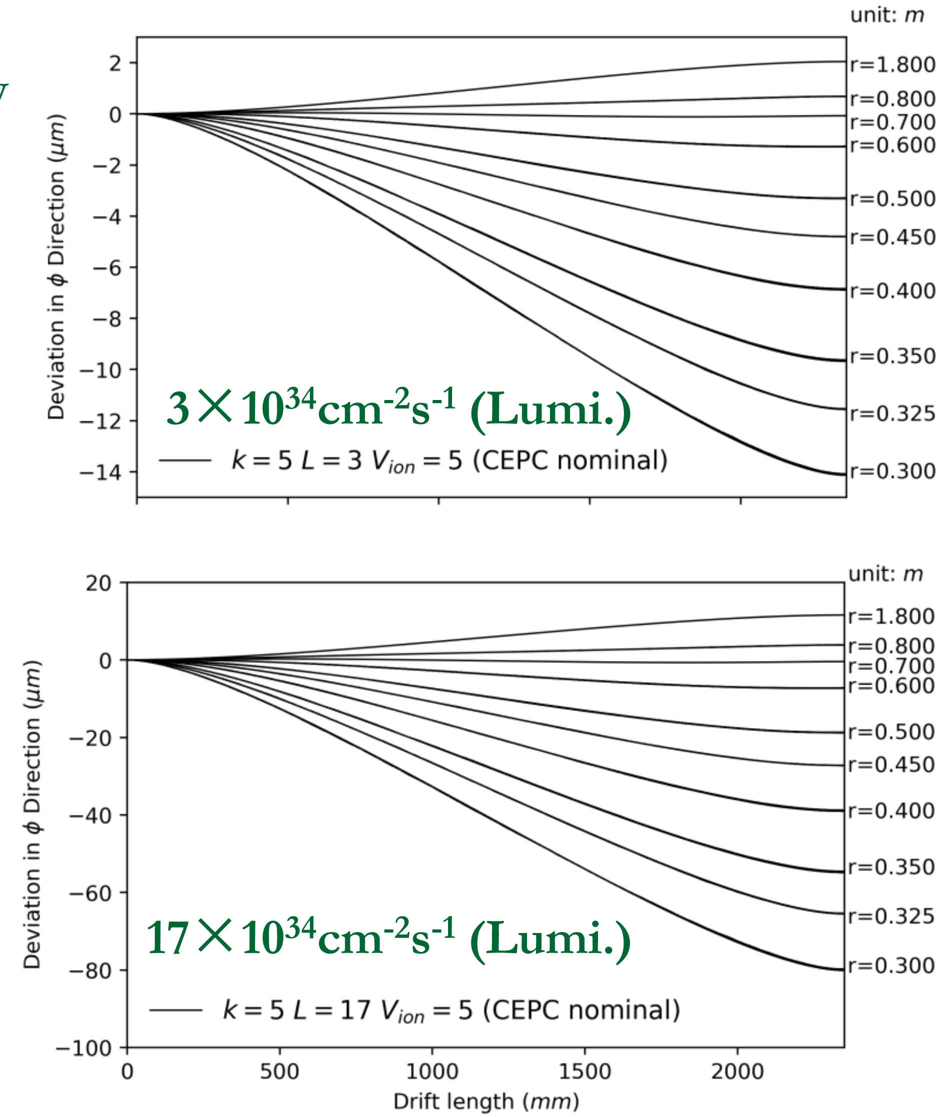
- Simulation
  - Re-established the model
  - Validated with 3 ions disks
  - Simulation of the multi ions disk in chamber under the continuous beam structure
  - Input from the full simulation data
  - IBF×Gain default as the factor of 5
  - Higgs run
  - Z pole run at the high luminosity
  - Without the charge of the beam-beam effects in TPC



Simulation study at Z pole

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: $\sim2\times10^{-7}$
  - 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

TPC module R&D

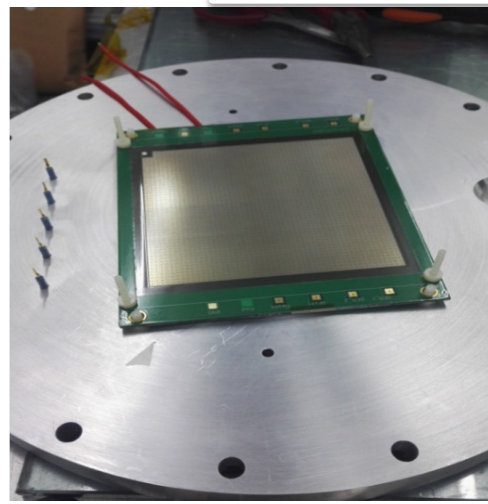
TPC detector module@ IHEP

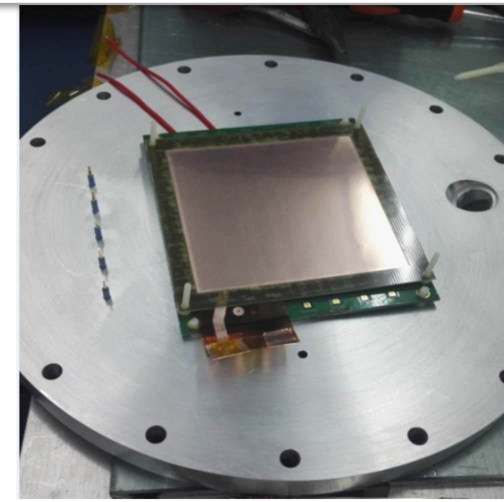
DOI: 10.1088/1748-0221/12/04/P0401 JINST，2017.4
DOI: 10.1088/1674-1137/41/5/056003 , CPC,2016.11
DOI: 10.7498/aps.66.072901Acta Phys. Sin. 2017,7

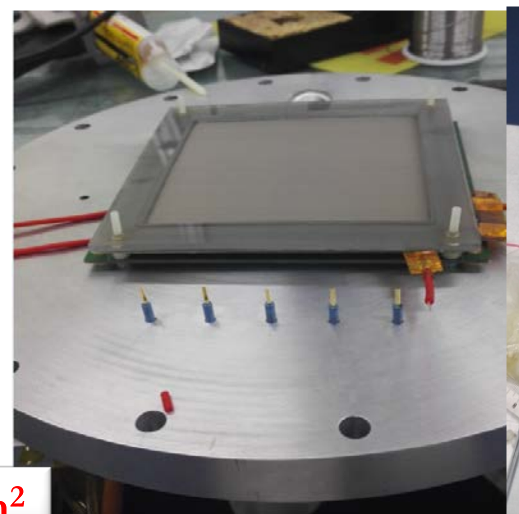
Preliminary R&D and first step

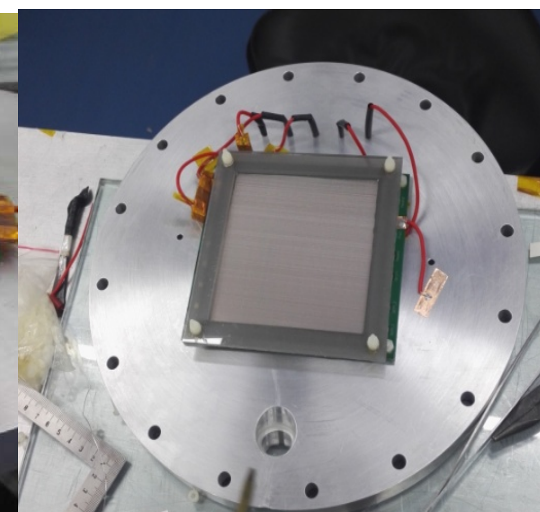
- Study with GEM-MM module
  - New assembled module
  - Active area: 100mm×100mm
  - X-tube ray and 55Fe source
  - Bulk-Micromegas assembled from Saclay
  - Standard GEM from CERN
  - Avalanche gap of MM:128μm
  - Transfer gap: 2mm
  - Drift length:2mm~200mm
  - pA current meter: Keithley 6517B
  -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

50×50mm² 2015-2016	→	100×100mm² 2017-2018	→	200×200mm² 2019-


Micromegas(Saclay)

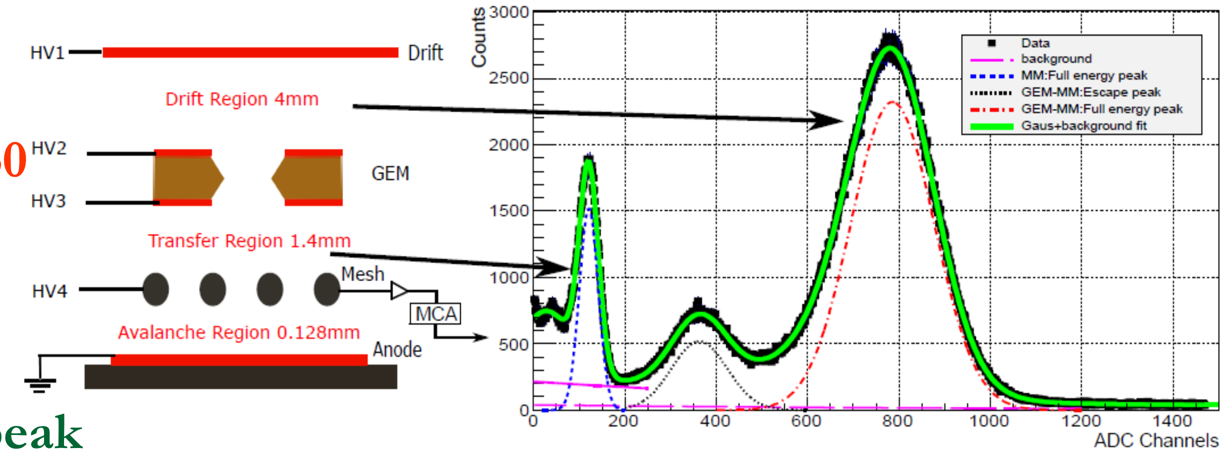

GEM(CERN)


Cathode with mesh


GEM-MM Detector

GEM+MM VS TPC@ALICE

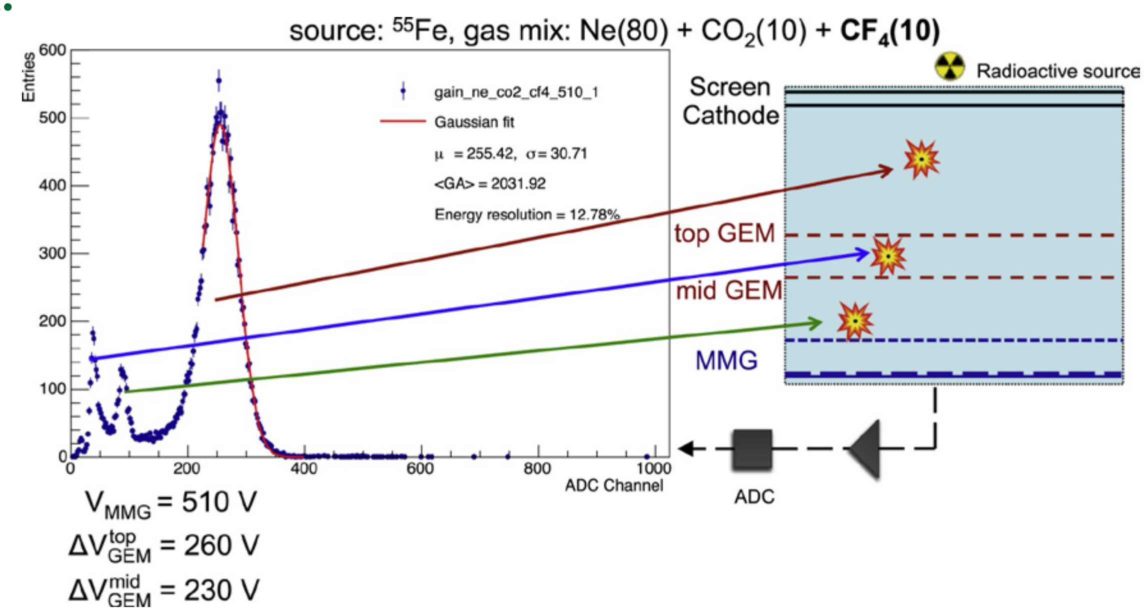
For e^+e^- machine
Primary N_{eff} is small: ~30
Pad size:1mm×6mm



GEM+MM IBF suppression detector@55Fe

GEM+MM module:
Photo peak and escape peak are clear!
Good electron transmission.
Good energy resolution.

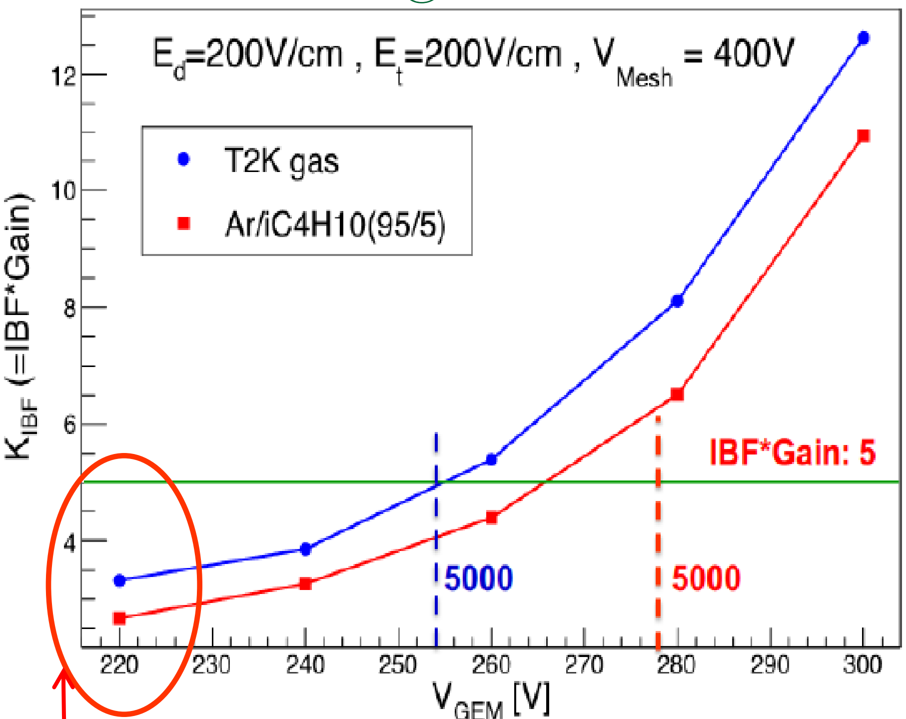
One option for ALICE TPC
GEM+GEM+MM
Gain of mid GEM: ×0.5



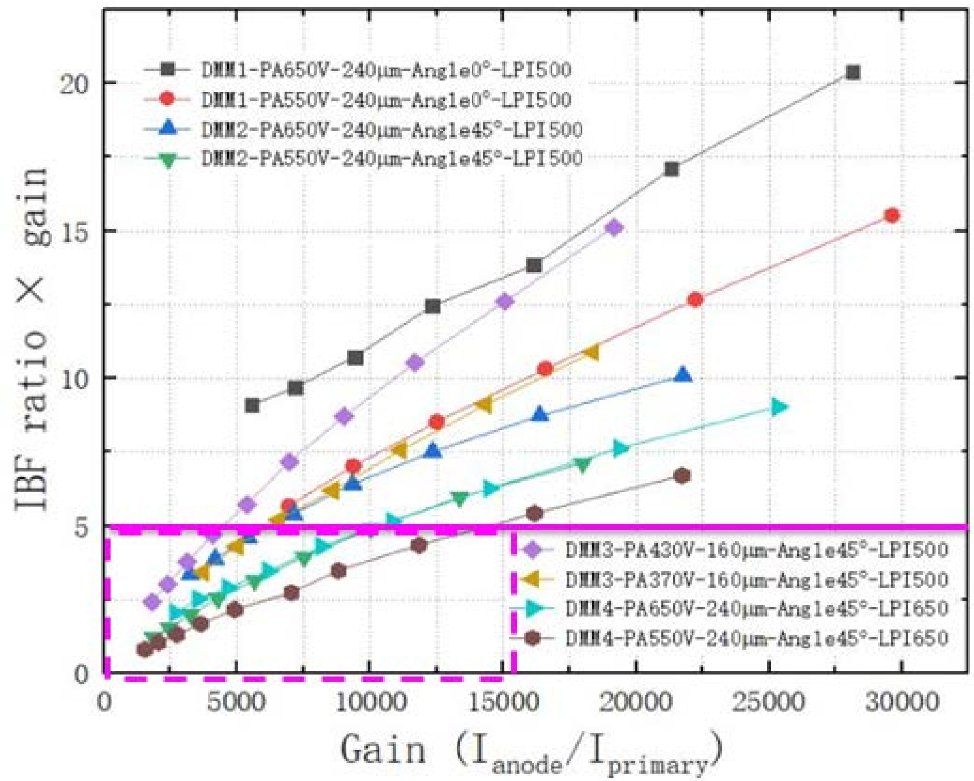
2GEM+MM IBF suppression detector@55Fe

GEM+MM VS DMM@USTC

Micronegas + GEM detector module @IHEP



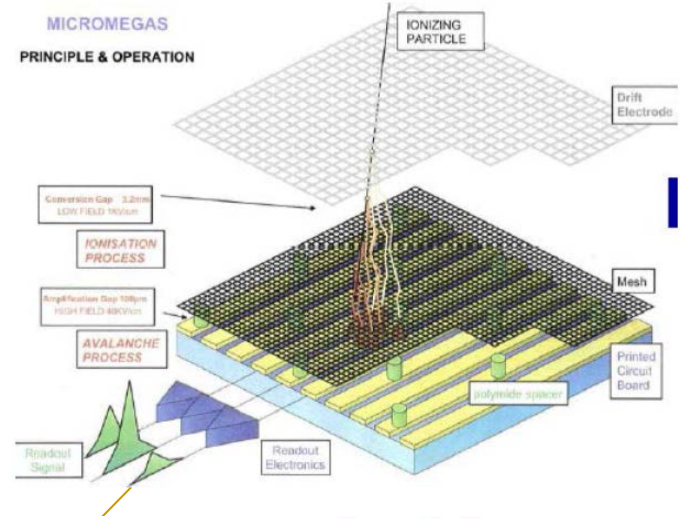
IBF of double mesh MM @USTC/Jianbei Liu

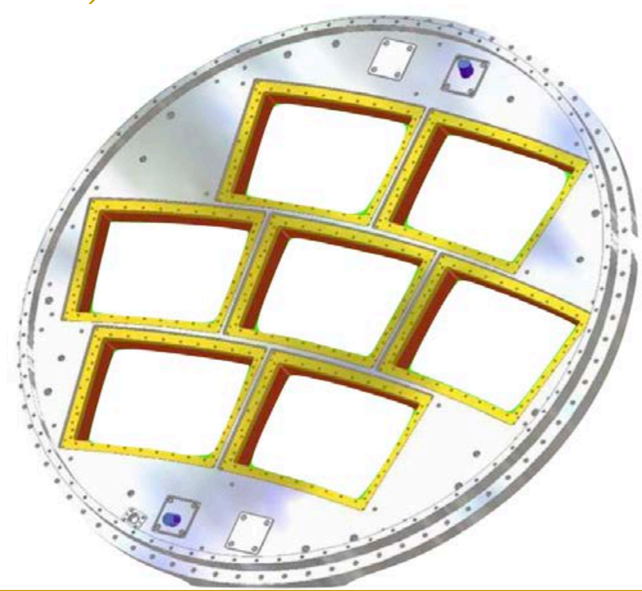


- IBF×Gain has the limitation ratio from the detector R&D at high gain.
- Lower gain and lower IBF ratio

Options #1: Pad TPC for collider

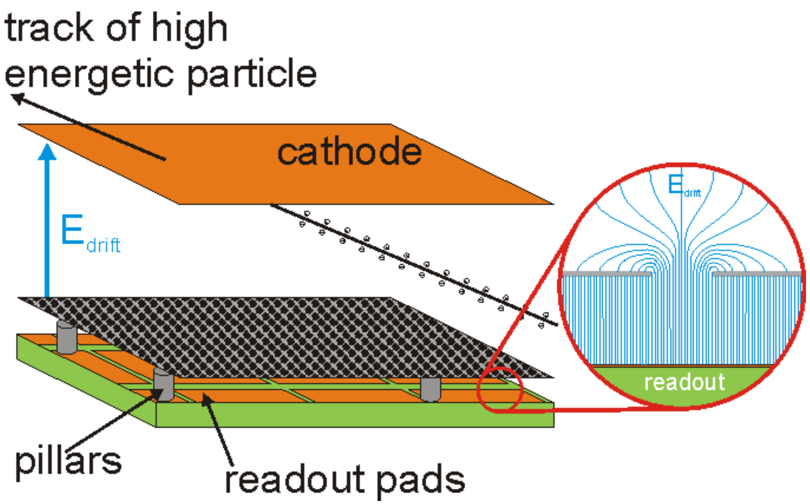
- Active area: 2×10m^2
- One option for endplate readout:
  - – GEM or Micromegas
  - – 1×6 mm^2 pads
  - – 10^6 Pads
  - – 84 modules
  - – Module size: 200×170mm^2
  - – Readout: Super ALTRO
  - – Gain: 4000-6000
  - – CO_2 cooling





TPC detector endplate concept

Option #2: 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)

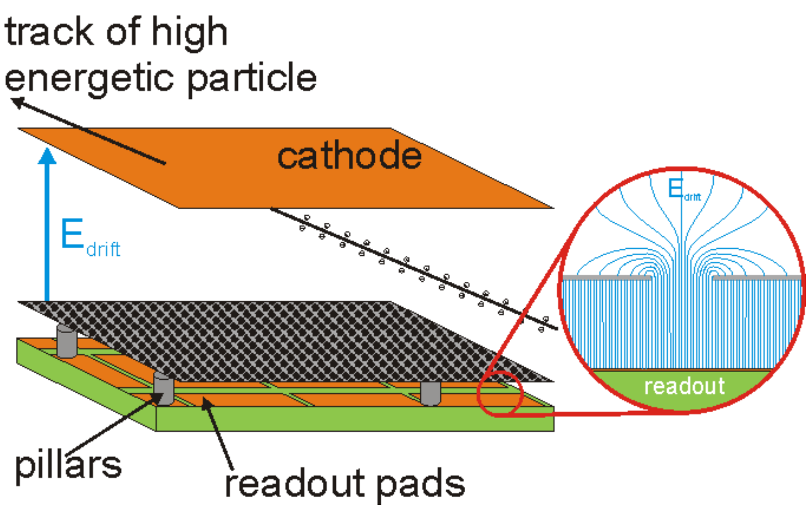
→ the occupancy is less than 0.0012

- Improved dE/dx

→ primary e- counting

- Smaller pads/pixels could result in better resolution!
- Gain <2000
- Low IBF*Gain<2
- CO_2 cooling

Pad and pixel TPC for collider



- Standard charge collection:
  - Pads of several mm2
  - Long strips (l~10 cm, pitch ~200 μm)
- Instead: Bump bond pads are used as charge collection pads

Benefits of GridPix readout:
● Lower occupancy → better track finding
● Improved dE/dx→ primary e- counting

- Smaller pads/pixels could result in better resolution!
- Gain <2000
- At Nikhef the GridPix was invented from 2003.

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

Feasibility of Pixel TPC – Occupancies

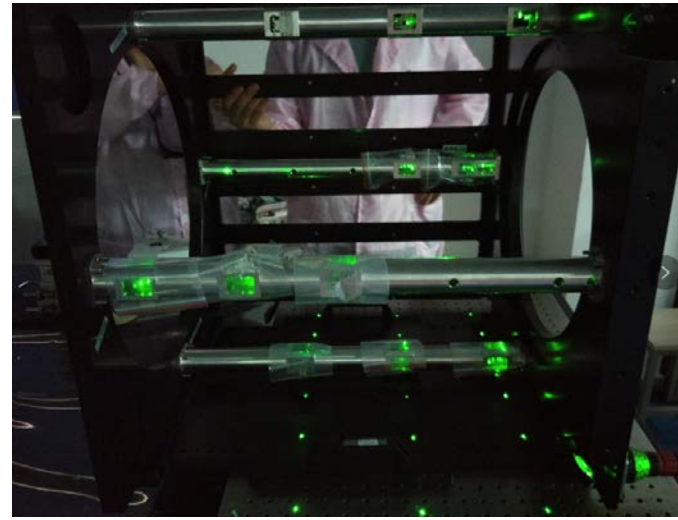
- Z rates@L = 32 1034 cm-2s-1 and occupancies
  - Data is produced at a large rate of 300 k hits/s/chip (at R=40 cm)
  - In the test beam it has been demonstrated that the TPX3 can handle a rate that is a factor 10 higher
  - Occupancies are less than 1% at low radii
- Pattern recognition will be no problem
  - The occupancies in the pixel plane are low
  - The time between the Z interactions is large 120 μs. The time will be measured by each pixel.
  - The resolution is dominated by longitudinal diffusion. It amounts to less than about 20 nsec.
  - Different Z events can be easily separated in time.

Feasibility of Pixel TPC – Ions backflow

- **Situation for a pixel TPC**
  - Large potential in terms of rate capabilities
  - Pattern recognition high granularity works in high Z rate
  - Question: what is the IBF for our GridPix?
  - O(0.1%) It will be measured with IHEP and Nikehf's collaborations.
- **Can TPC apply in Z collisions?**
  - High(est) luminosity CEPC L = 32-50 (17-32) 1034 cm-2s-1 at 2 T.
  - CEPC Ring length 100 km with 12 000 bunches and a hadronic Z rate of 10-15 (5-10) k Hz (cross section 32 nb).
  - Beam structure rather continuous 14 ns spacing.
  - Note that this Luminosity gives about 60-120 (30-60) G Zs per running year
  - Time between Z interactions 120-60 (200-100) μs
  - TPC drift time takes -30 μs
  - Need IBF suppression and IBF*Gain <2

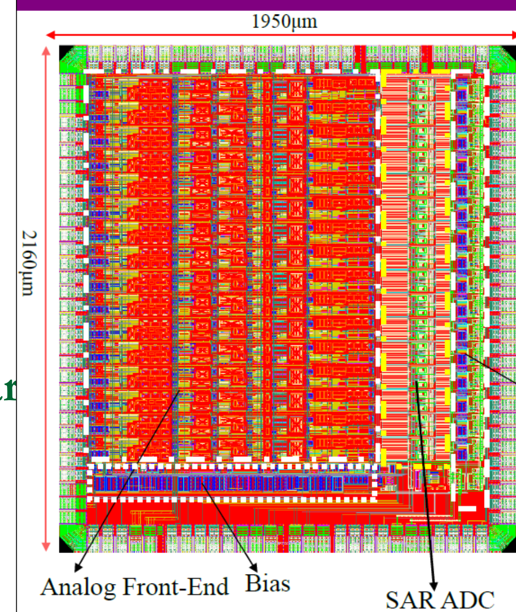
TPC prototype R&D

TPC prototype and FEE R&D



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

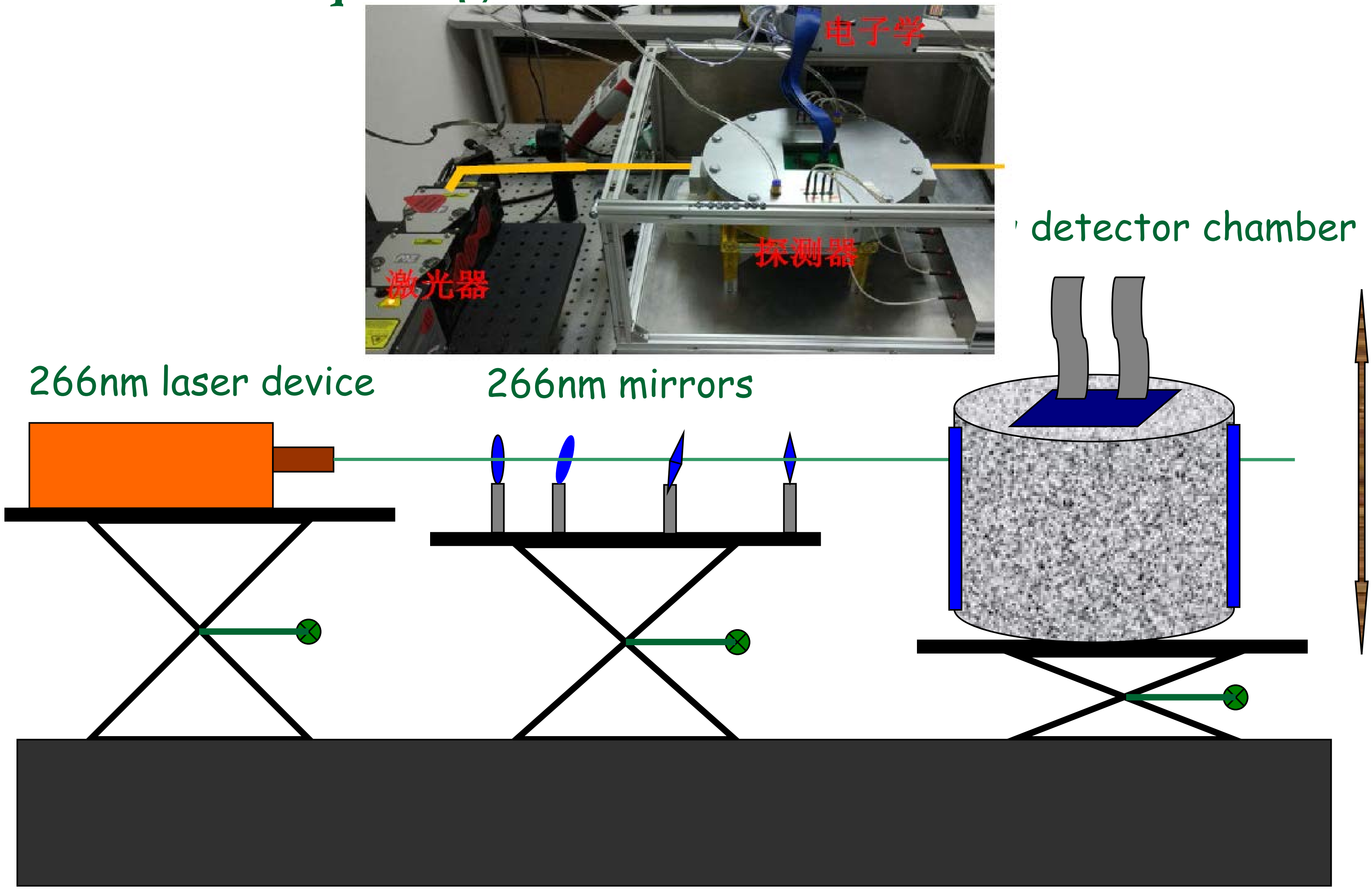
Layout of 16-ch TPC Readout ASIC



- 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.

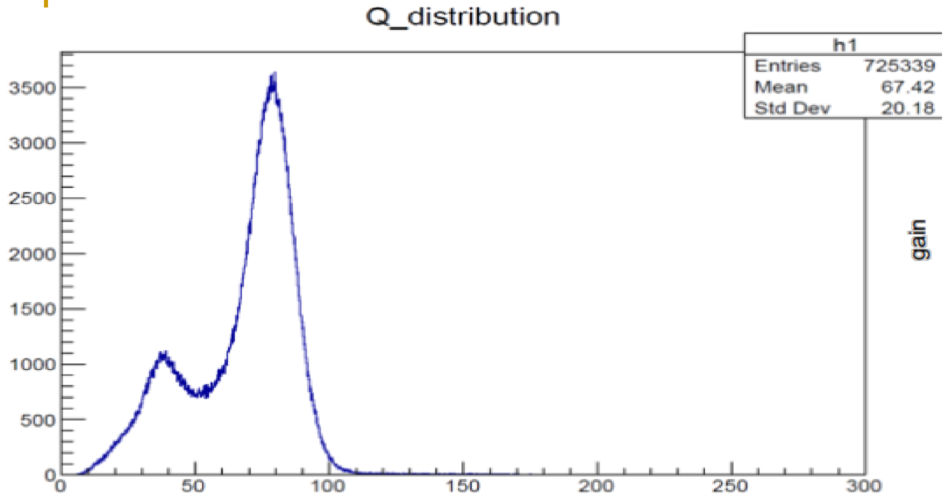
Diagram of the TPC prototype with the laser calibration system

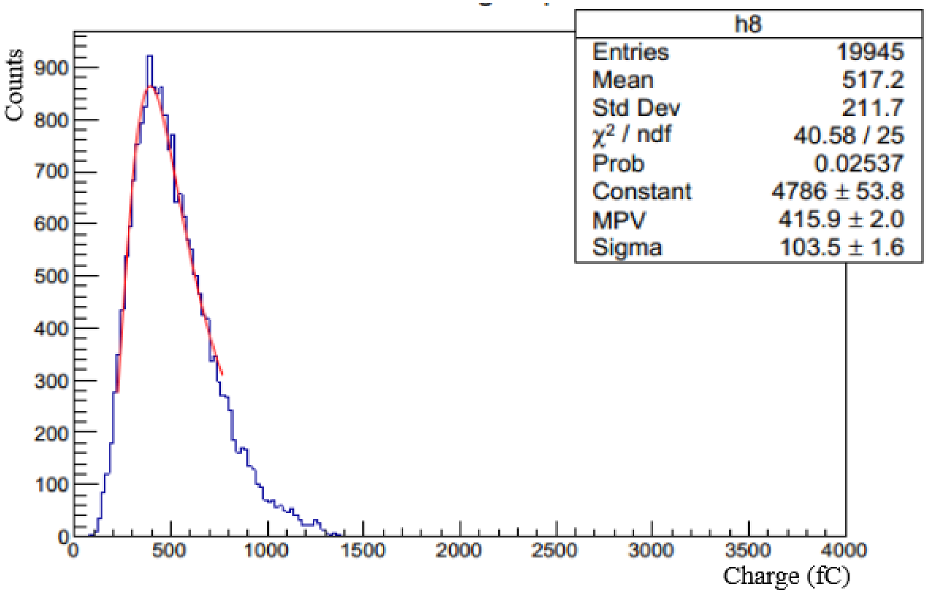
Detector setup diagram



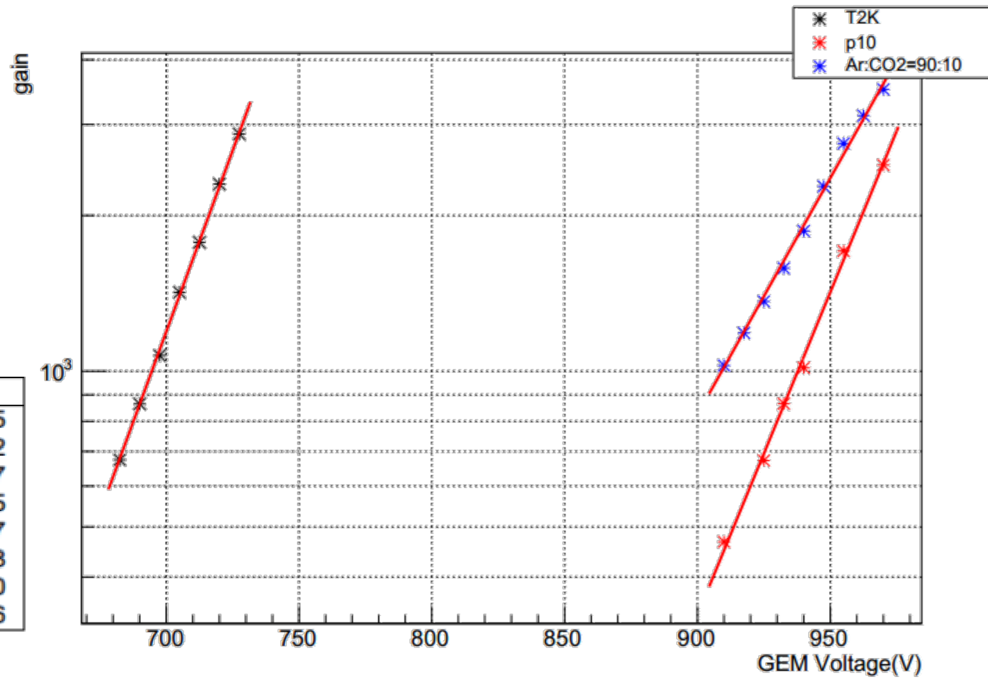
Setup and photo of the detector module

Energy spectrum and gain



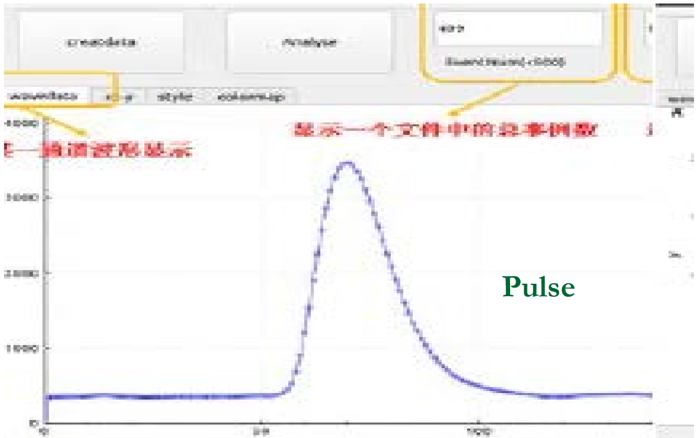


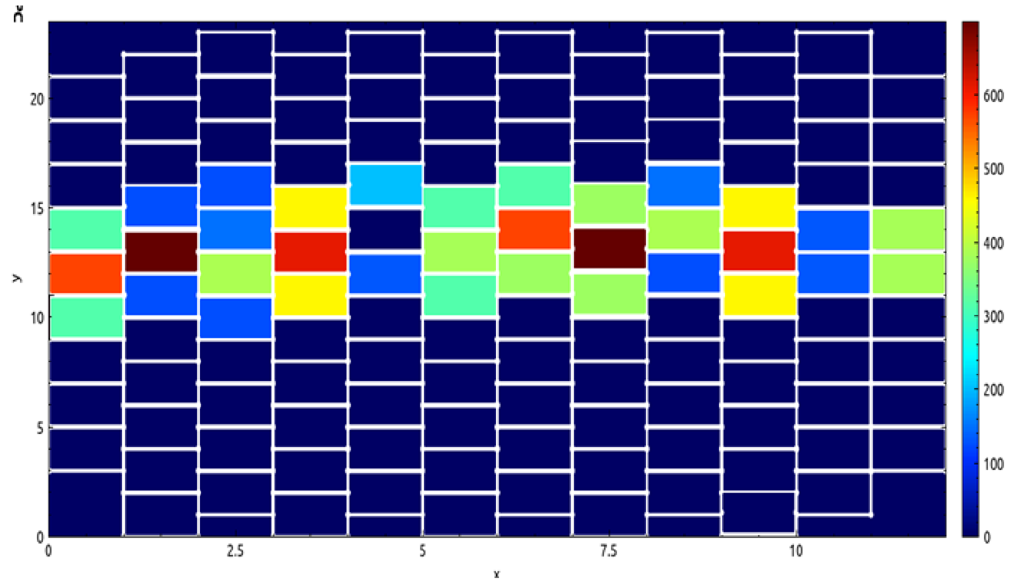
Energy spectrum of 55Fe and the laser

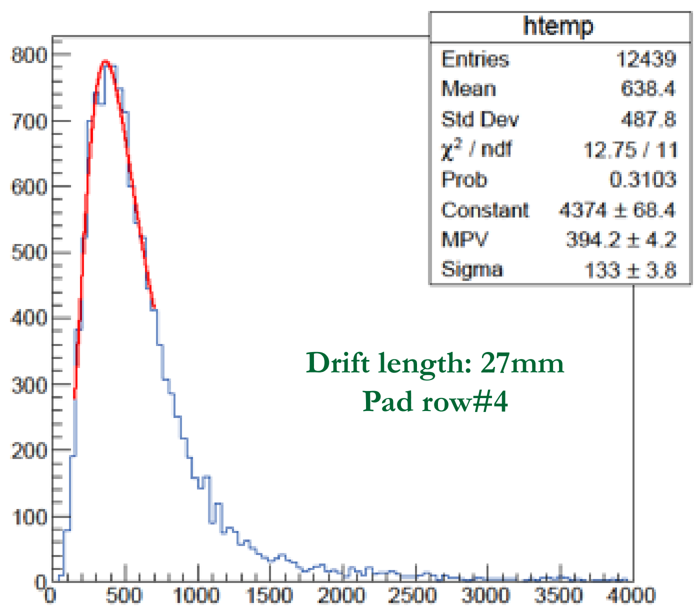


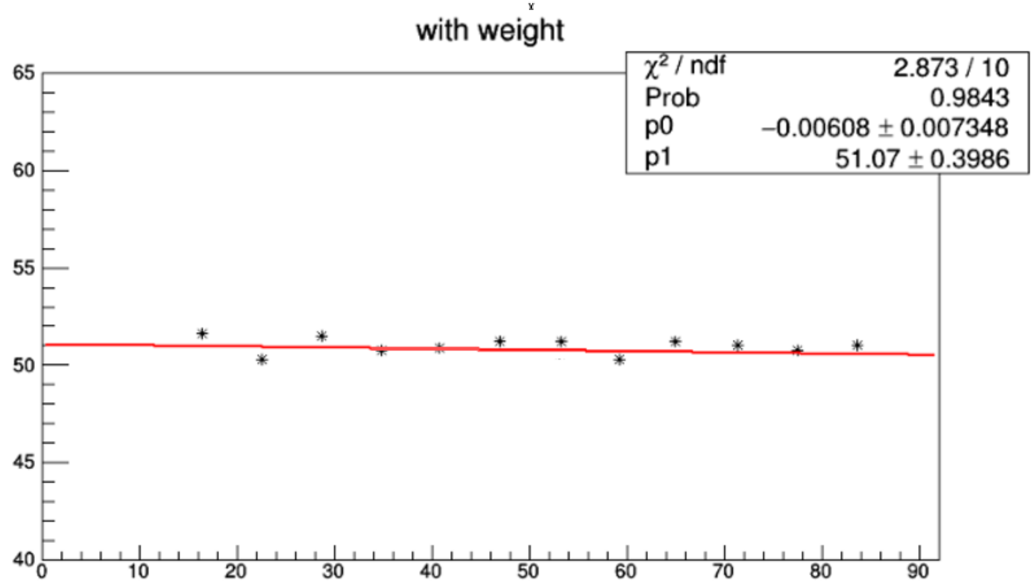
Gain at T2K, P10, Ar/CO2

Laser track test@128chs









Preliminary results of Laser tracker energy spectrum and tracker

Summary

Requirements and critical challenges for the high luminosity:

- **High momentum resolution and position resolution**
- **IBF*Gain should be considered at the high luminosity**
- **It needs very sophisticated calibration in order to reach the desired physics performance at Z pole run**
- **Simulation and experiment studies give some parameters for the detector**

TPC module and prototype R&D:

- **TPC prototype has been designed with UV laser system and developed at IHEP and Tsinghua University.**
- **UV laser beam have been assembled and tested, some test parameters have been obtained.**
- **The beam test plan with TPC prototype under 1.0T magnetic field will be realized**

Thank you for your attention !