Some considerations and simulation of Pixel TPC for the High Luminosity Z Pole

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Outline

- Physics requirements
- Pad TPC and Pixel TPC
- Ion Back Flow
- Summary

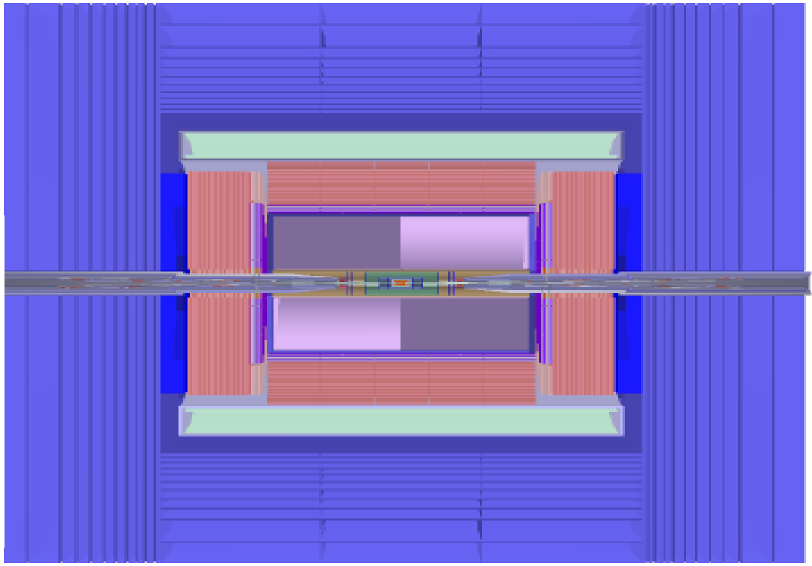
Three Detector Concepts (CEPC CDR)

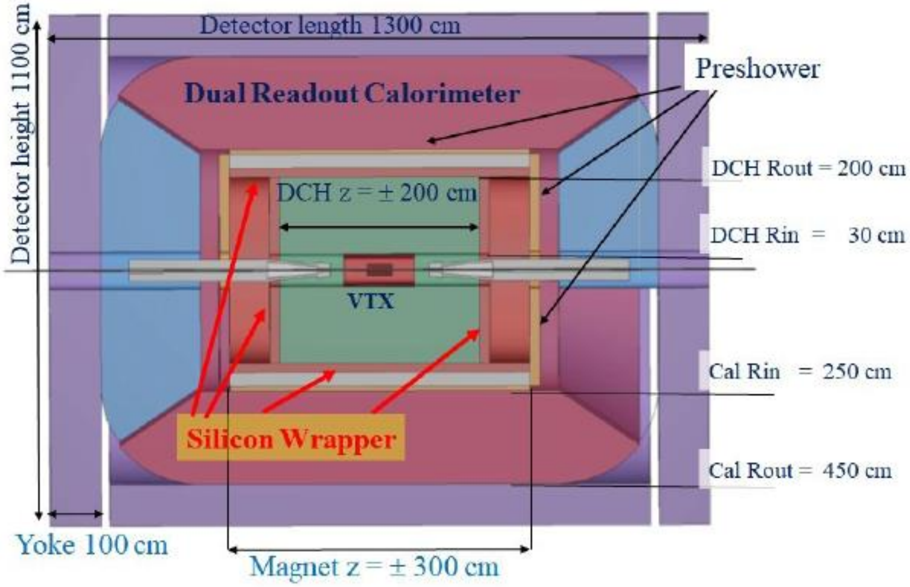
ArXiv:1811.10545

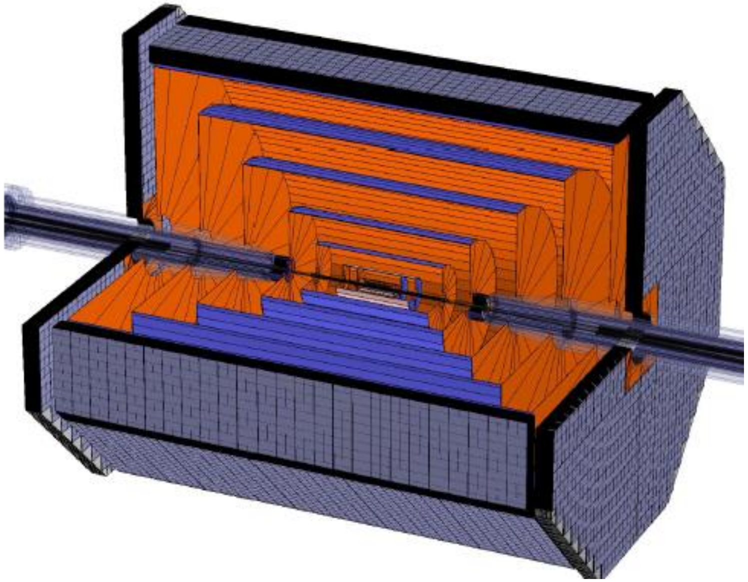
- Baseline: Silicon + TPC
- FST: all-silicon tracker
- IDEA: Silicon+Drift chamber (DCH)

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

	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

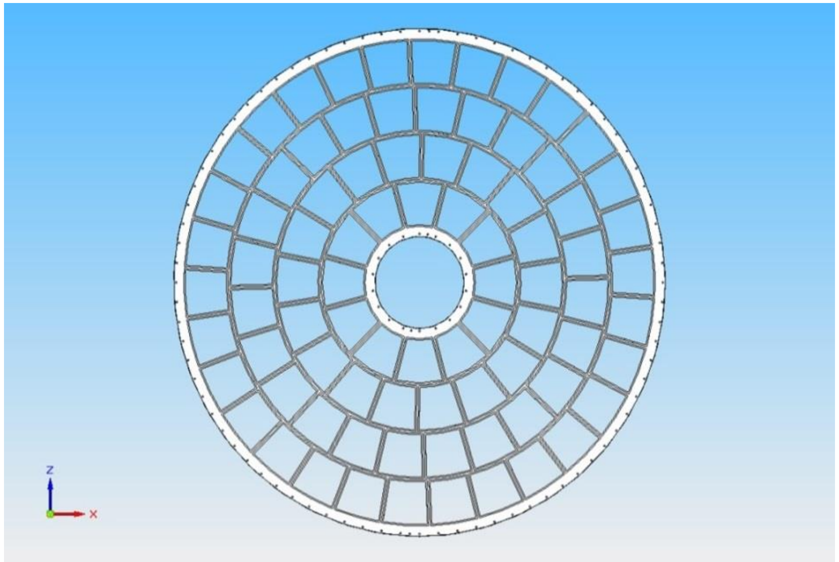
Some comments from CEPC workshop@2019.Nov.

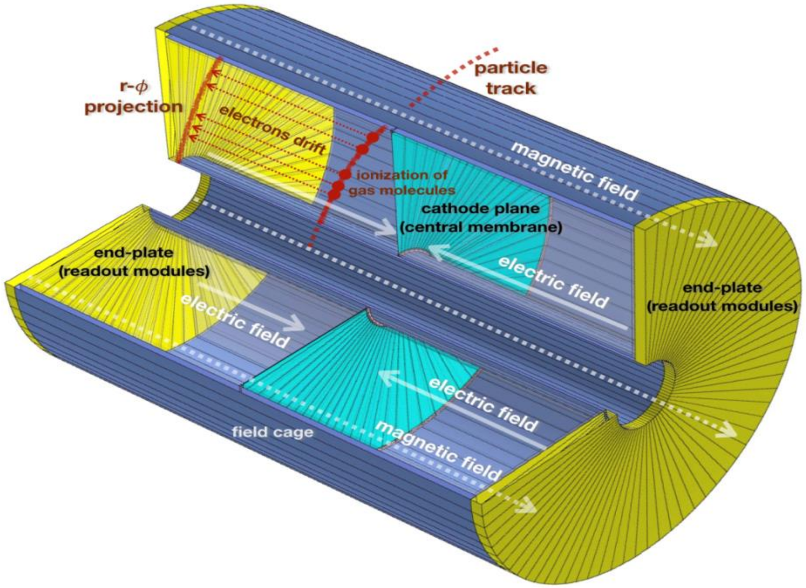
- Machine Detector Interface
- Luminosity meter (LumiCal)
- Tracker
  - Time Projection Chamber
    - Ion back flow and field distortion is a major problem to operate at the Z pole and 2 Tesla
  - Drift Chamber
    - Can it cope with the high rates at the Z pole? Enough resolution?
- Do we really need a 3 Tesla solenoid? Why?
  - Trade-off of luminosity versus resolution and particle identification needed?
  - Can the same physics goals be achieved some other way?

Overview: physics requirements

TPC detector concept:

- Under 2-3 Tesla magnetic field (Momentum resolution: $\sim 10^{-4}$/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





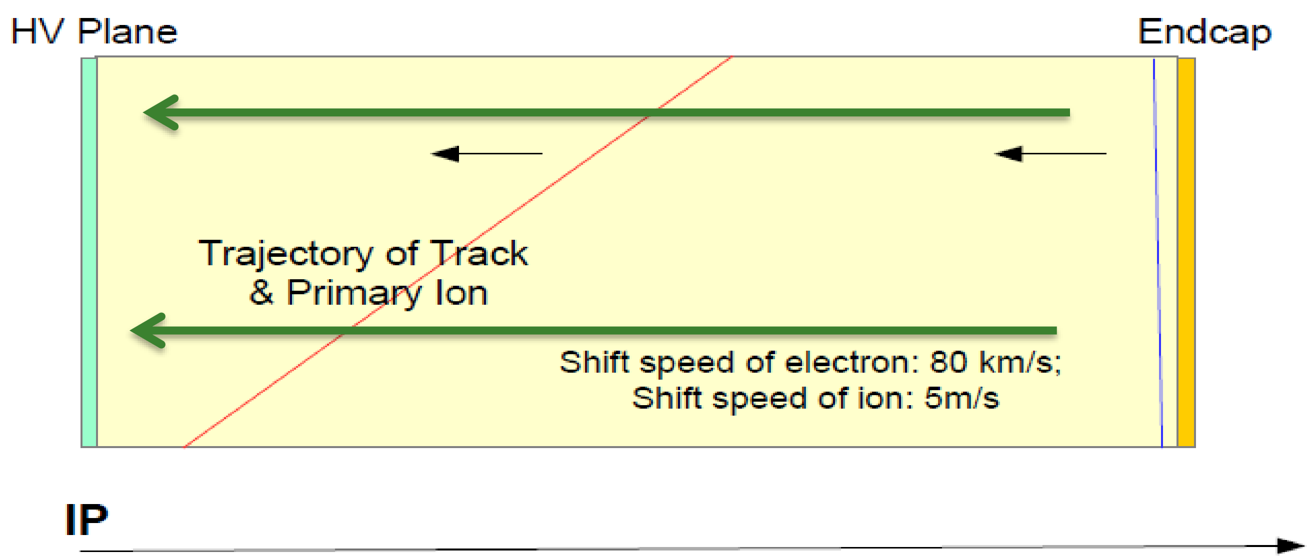
TPC detector endplate concept

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

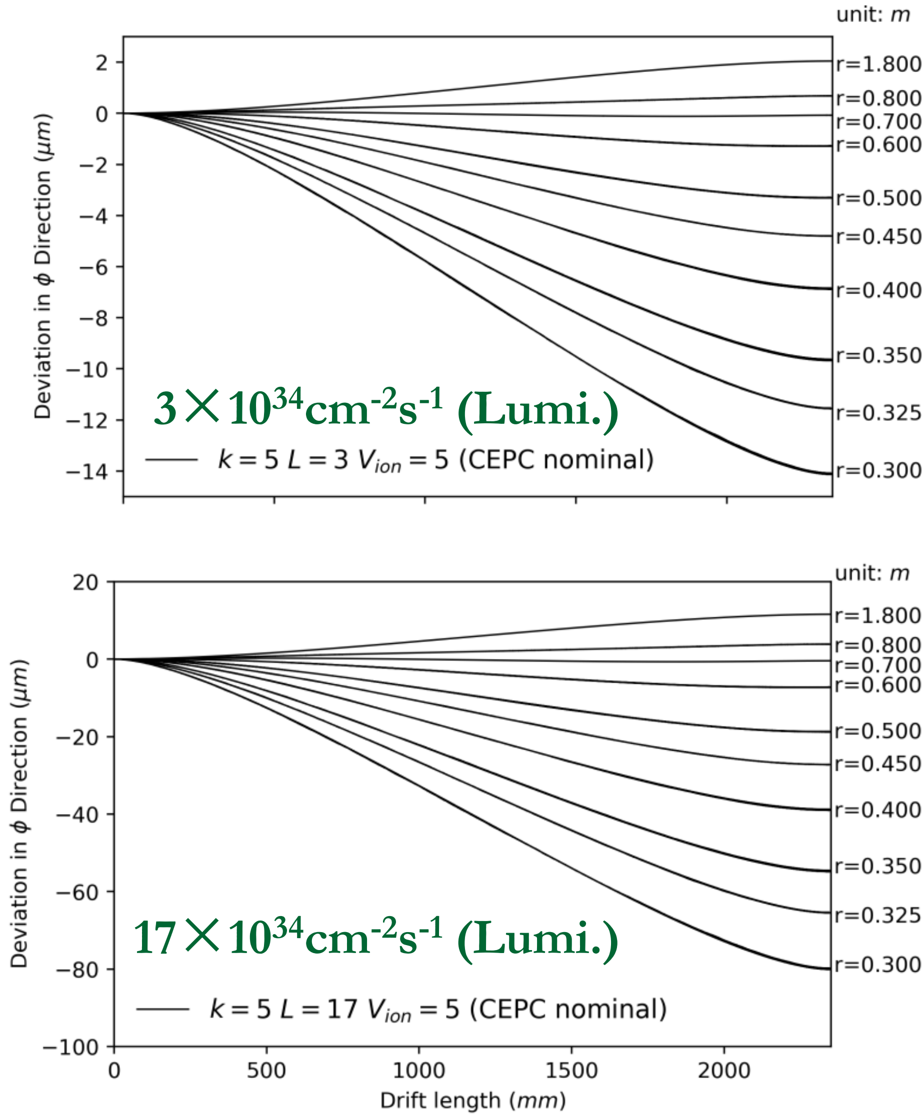


Compare with ALICE TPC and CEPC TPC

Simulation study at Z pole

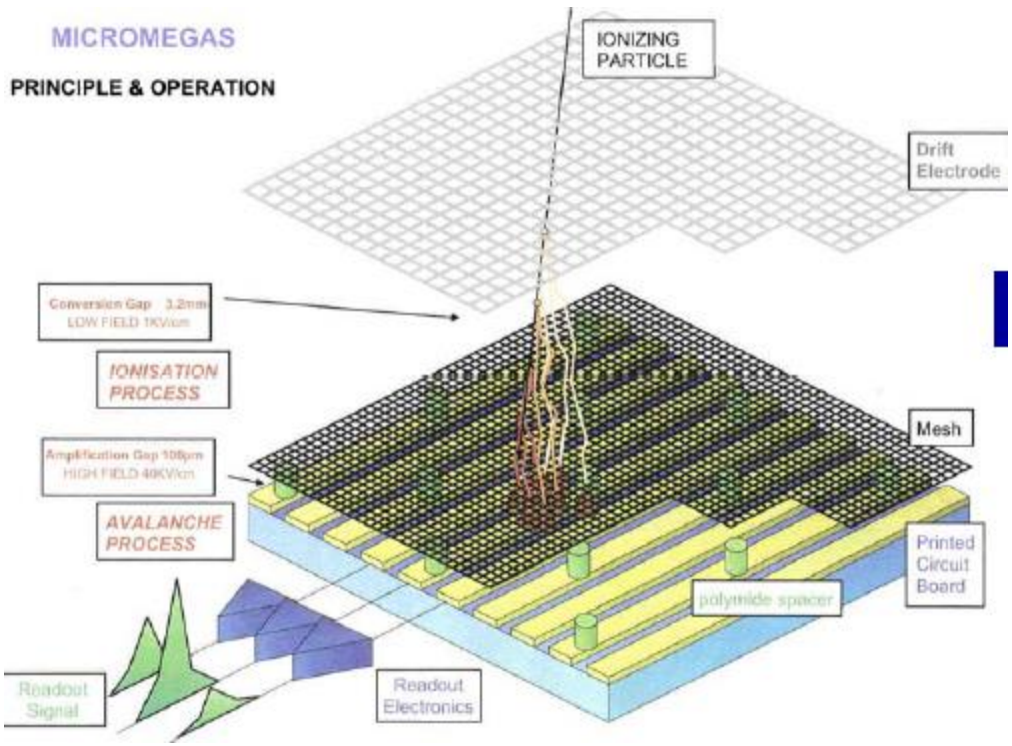
DOI: 10.1142/S0217751X19400165, 2019
DOI: 10.1088/1748-0221/12/07/P07005, 2017

- 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: ~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

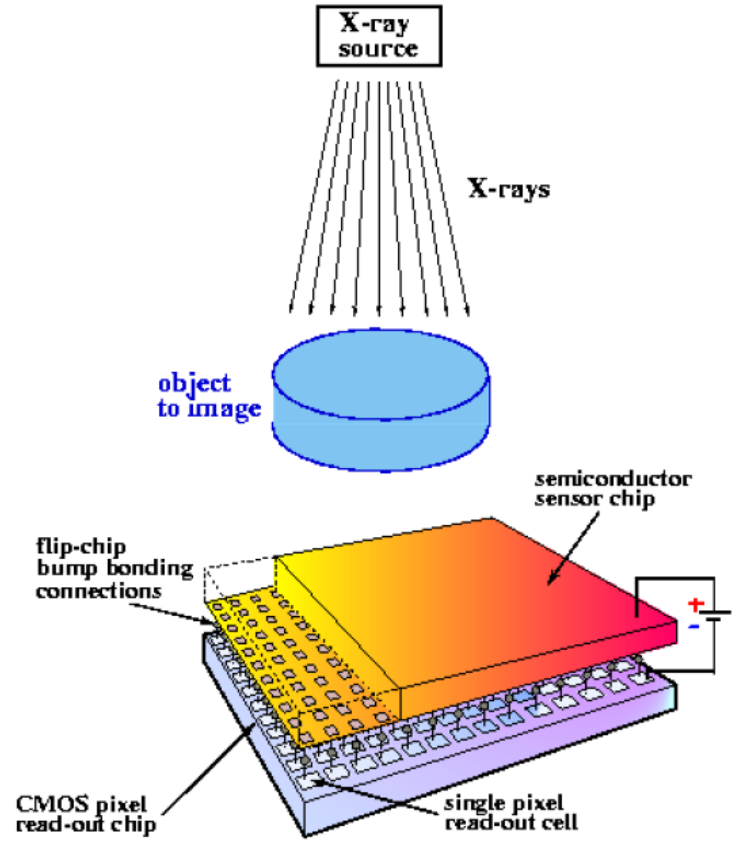


Deviation with the different TPC radius

Readout of TPC options



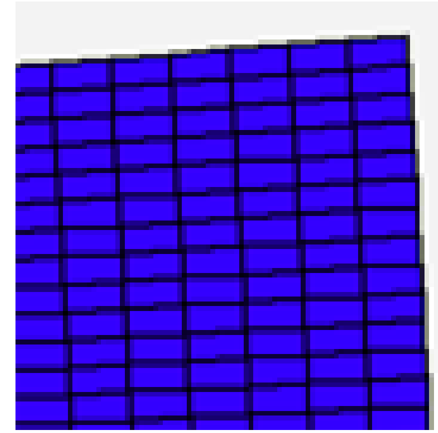
Standard charge collection

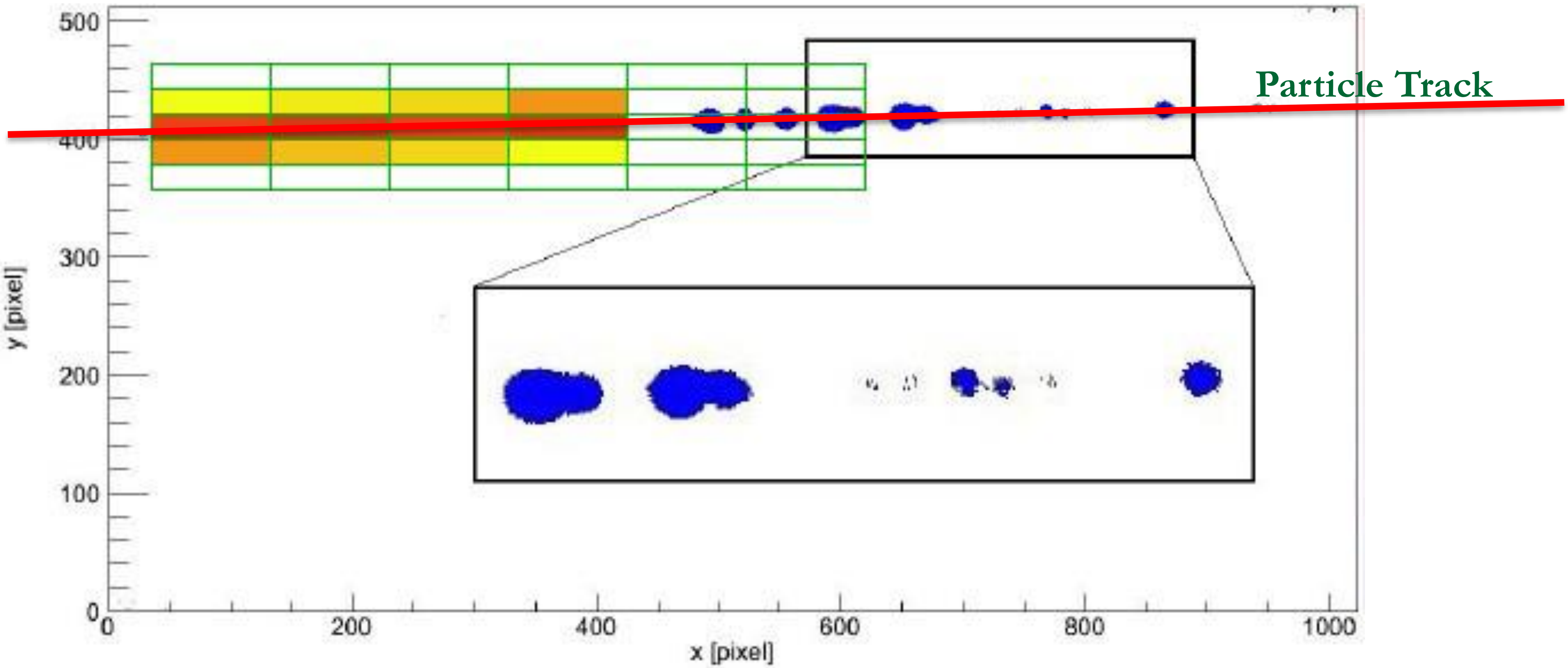


ASIC chip with sensors

Pad TPC and Pixel TPC

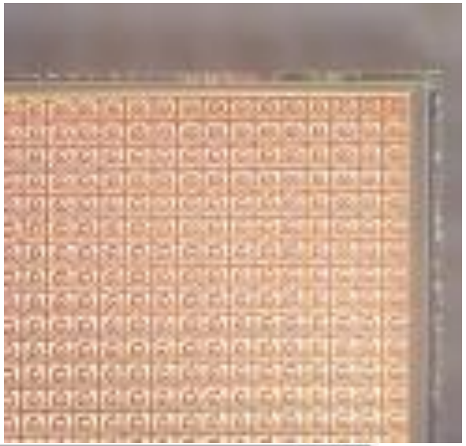
Standard charge collection
Pad: 1.0 x 6.0 mm²

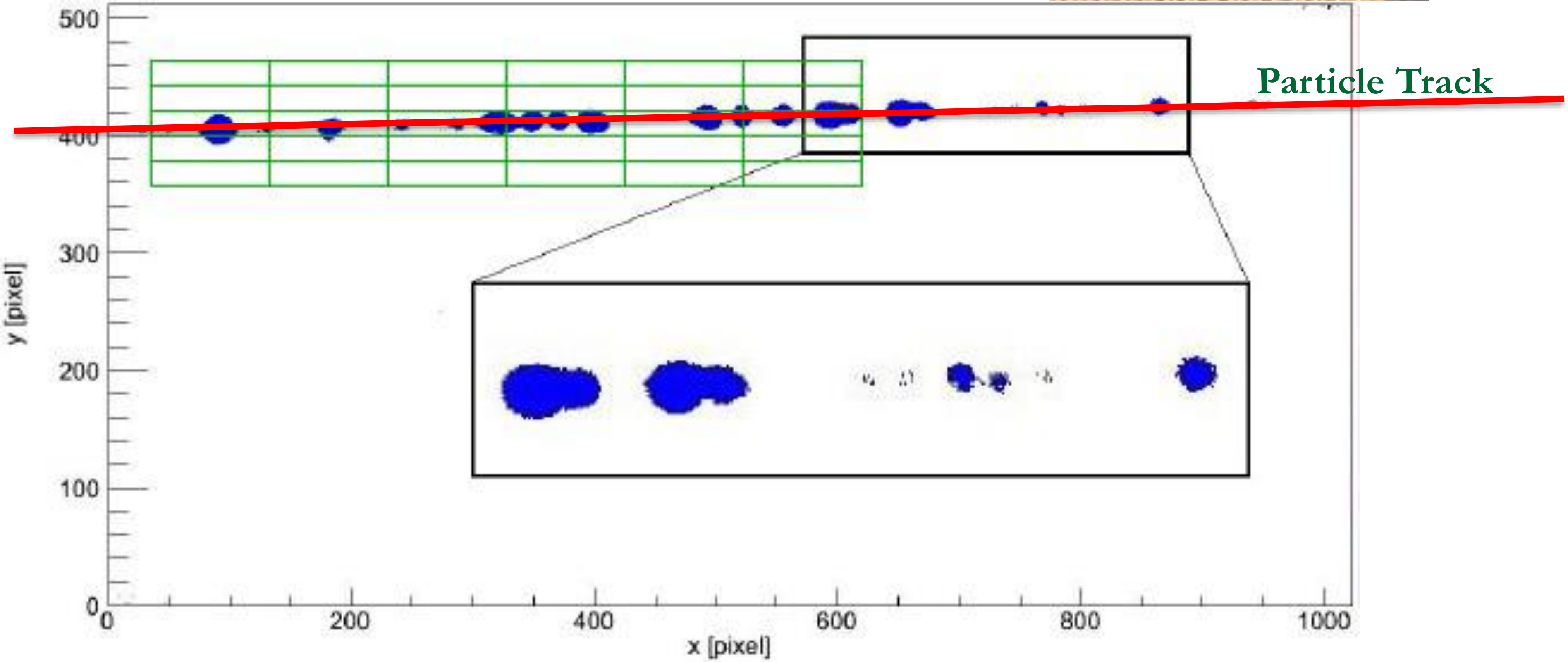




Pad TPC and Pixel TPC

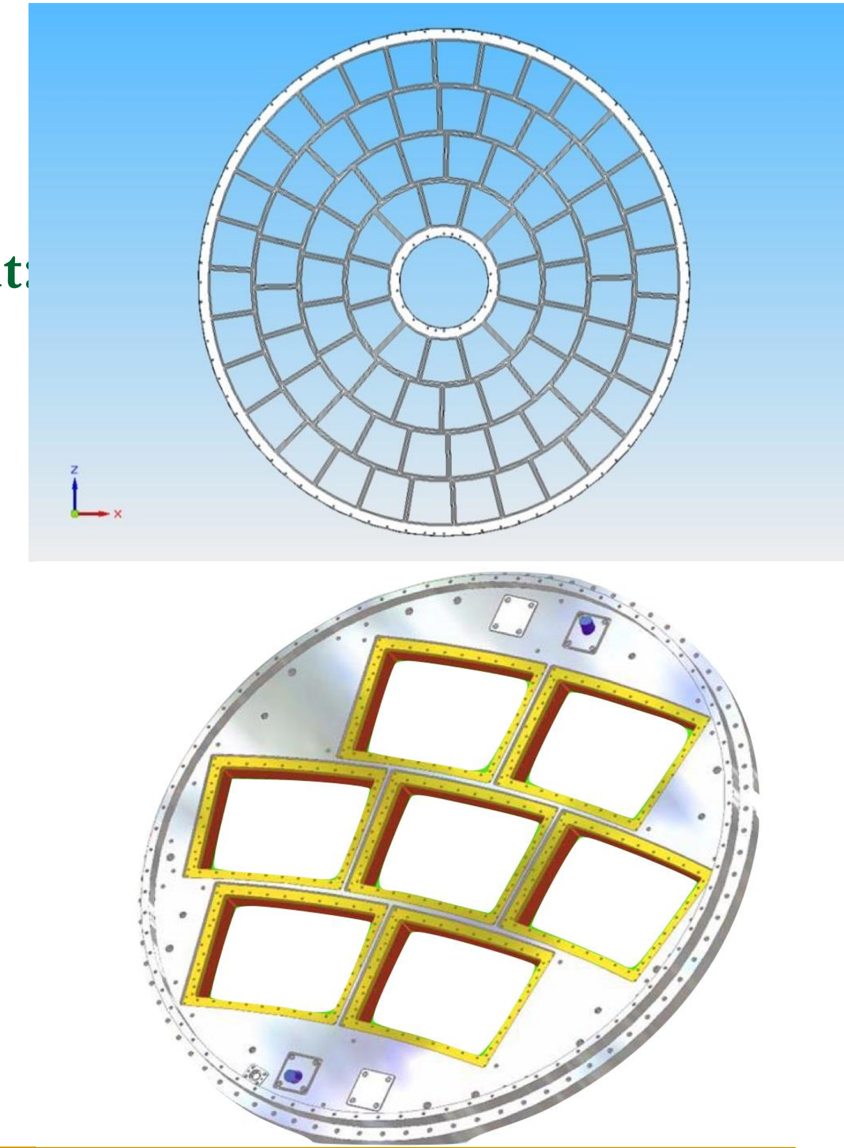
Pixel: 55x 55 μm²





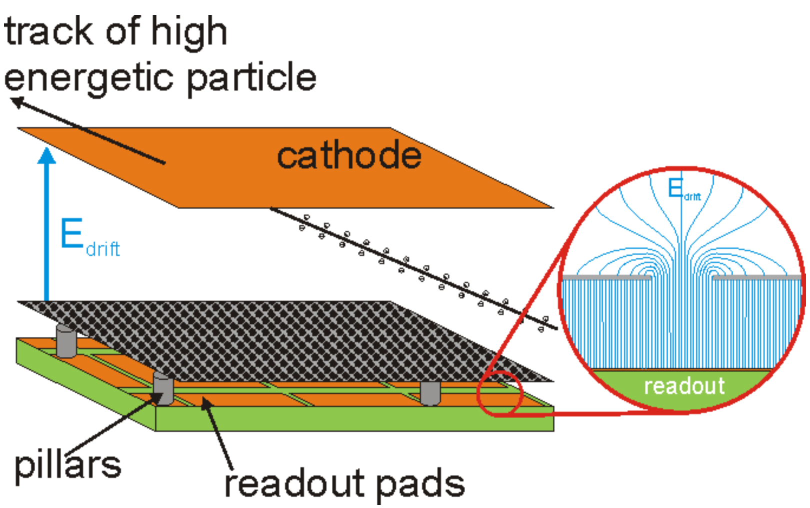
Pad TPC for collider

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



TPC detector endplate concept

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

Feasibility of Pixel TPC at Z running

- The conditions for CEPC running
  - High(est) luminosity CEPC L = 32-50 (17-32) $x10^{34}$ $cm^{-2}s^{-1}$ at 2 T from CDR.
    - 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 25 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 takes 30 μs
  - So events are separated in the TPC
- Running at the Z with a pixel TPC?
  - Large potential in terms of rate capabilities
  - Pattern recognition profits from high granularity of 55x55 μm^2 pixels
  - IBF, Rates and occupancies

Feasibility of Pixel TPC – Occupancies

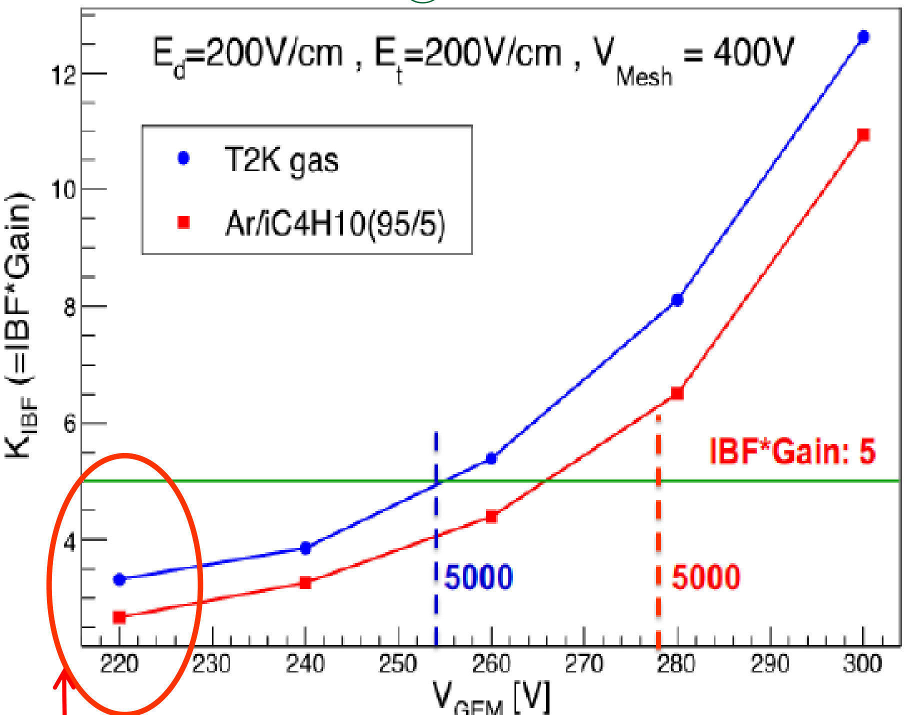
- Z rates@L = 32×10^{34} $cm^{-2}s^{-1}$ and occupancies
  - Data is produced at a large rate of 300 k hits/s/chip (at R=40 cm)
  - In the test beam it has been demonstrated that the TPX3 can handle a rate that is a factor 10 higher
  - Occupancies are less than 1% at low radii
- Pattern recognition 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

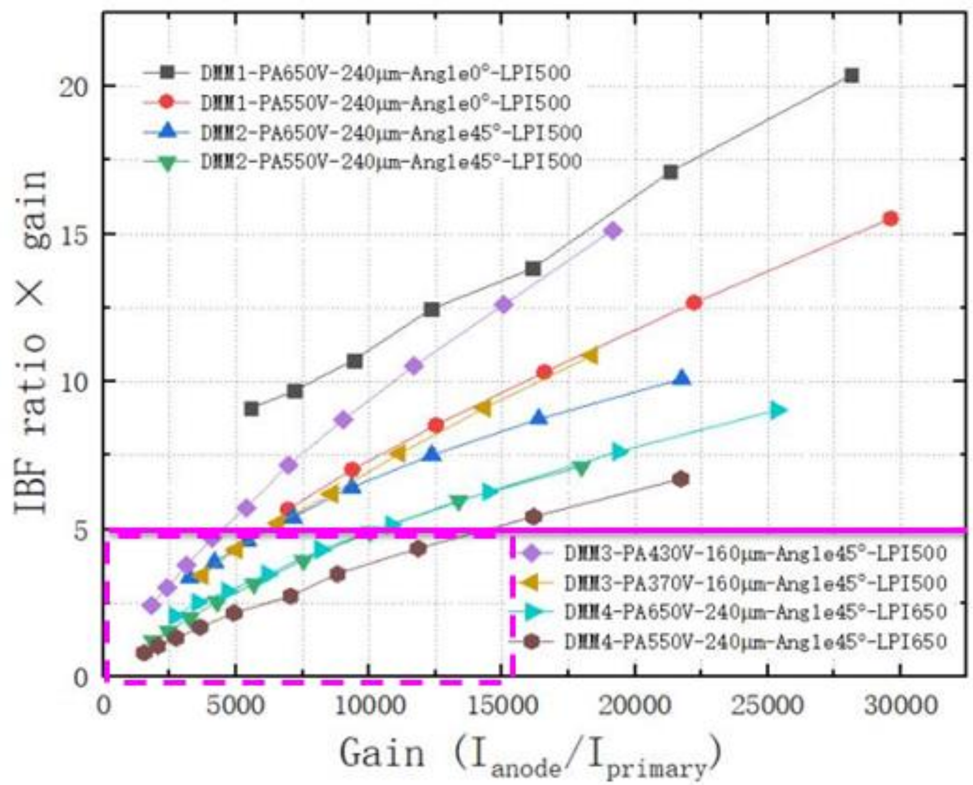
- Situation for a pixel TPC
  - Large potential in terms of rate capabilities
  - Pattern recognition high granularity works in high Z rate
  - Question: what is the IBF for our GridPix?
    - O(0.1%) It will be measured with IHEP and Nikehf's collaborations.
- Can TPC apply in Z collisions?
  - High(est) luminosity CEPC L = 32-50 (17-32) $\times 10^{34}$ $cm^{-2}s^{-1}$ 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

GEM+MM VS DMM@USTC

Micronegas + GEM detector module @IHEP

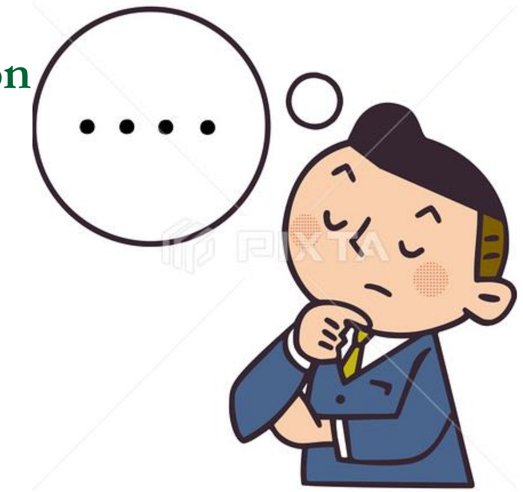


IBF of double mesh MM @USTC/Jianbei Liu



- IBF×Gain has the limitation ratio from the detector R&D at high gain.
- How to do it next ? Any new ideas? (Lower gain and no IBF)

Idea: intermediate solution between pads and pixels for CEPC at Z



- Clusters contain the primary information of the ionisation
- Can we find a solution to resolve clusters?
- Some R&D for pixel TPC:
  - What is the optimal pad size to
    - – improve double hit and double track resolution
    - – do cluster counting for improved dE/dx?
    - → Pixel size:(200μm or large), significant reduce cost
- Almost without IBF (Gain< 2000)
- Micromegas + ASIC Chips (Our option)
- Pixel TPC can handle the large data rates during CEPC Z running. The pixel occupancies are low and the pattern recognition will have no problem to separate events and find the tracks
- Estimates have been presented for deformations coming from charges from primary Z events and Ion Back Flow. (Need updated background parameters from MDI).

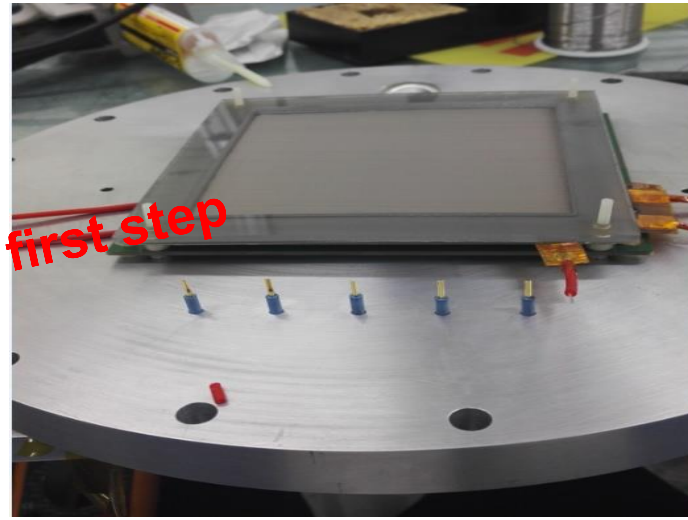
Some progress of TPC R&D

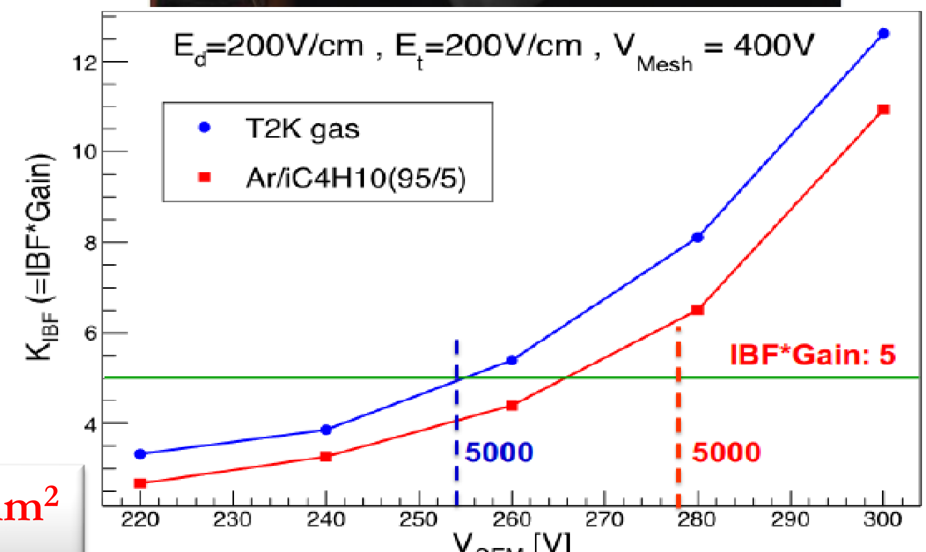
TPC detector module R&D

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

Preliminary R&D and first step

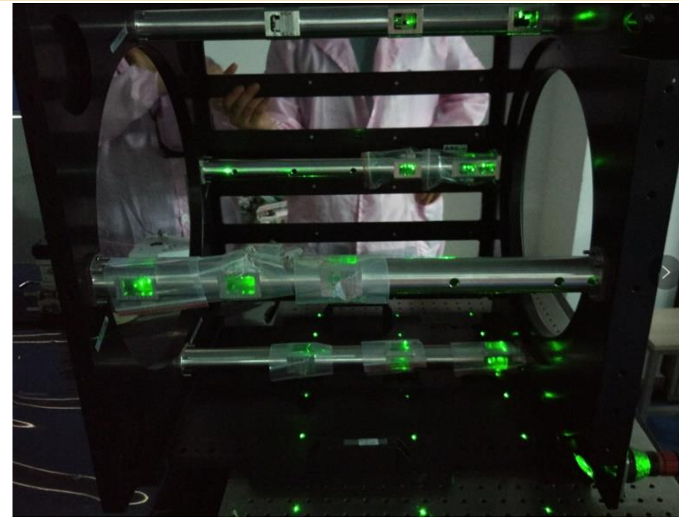




Micronegas + GEM detector module

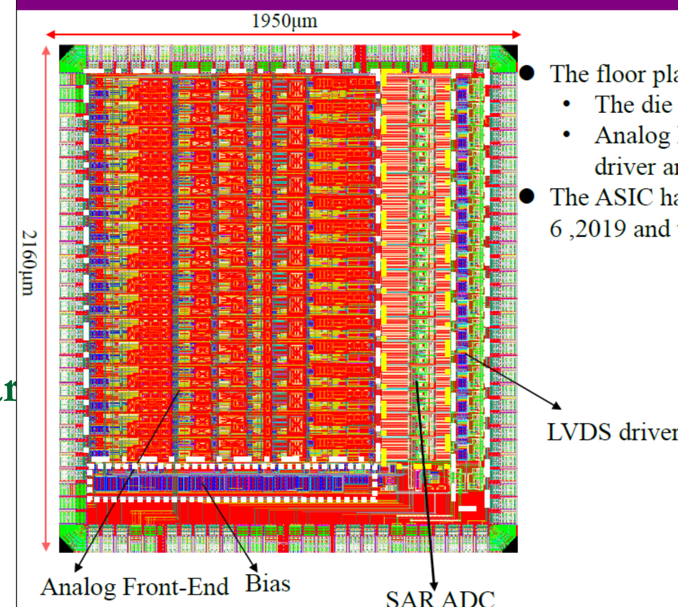
50×50mm^2 2015-2016 → 100×100mm^2 2017-2018 → 200×200mm^2 2019-

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

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 prototype integrated UV laser system 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**

Many thanks for your attention.