Some considerations of TPC at High-Lumi. Z

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CEPC Day, March, 27, 2020

- In this talk presented issues with TPC running at High-Luminosity Z pole
    - Physics requirements
    - Pad TPC for IBF
    - Pixel TPC

Update beam parameters@27,March,2020

Main beam parameters

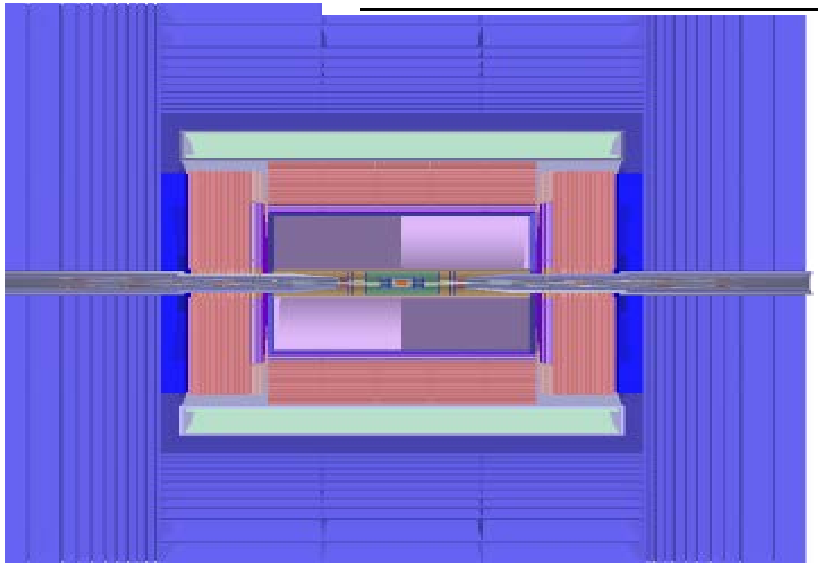
Parameter [unit]	Higgs-CDR	Higgs-High Lum	Z-CDR	Z-39MW
Beam energy [GeV]	120		45.5	
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.9	5.2	32.1	101.6
β_{IP} x/y (m)	0.36/0.0015	0.33/0.001	0.2/0.001	
Emittance (H/V) [nm]	1.21/0.0031	0.89/0.0018	0.18/0.0016	
Beam current [mA]	17.4	17.8	461.0	1081.4
Bunch number	242	218	12000	15000
Bunch Population [10^{10}]	15	17	8	15.0
Momentum compaction	1.11×10^{-5}	0.91×10^{-5} ↓	1.11×10^{-5}	
Natural bunch length σ_z (mm)	2.7	2.2 ↓	2.4	
Natural energy spread	1.0×10^{-3}		3.8×10^{-4}	
Betatron tune ν_x/ν_y	363.10/365.22	391.11/393.22 ↑	363.10/365.22	391.11/393.22 ↑
Synchrotron tune	0.065	0.066	0.028	
Radiation damping [ms]	46/46/23	47.6/47.6/23.8	843/843/436	849/849/424

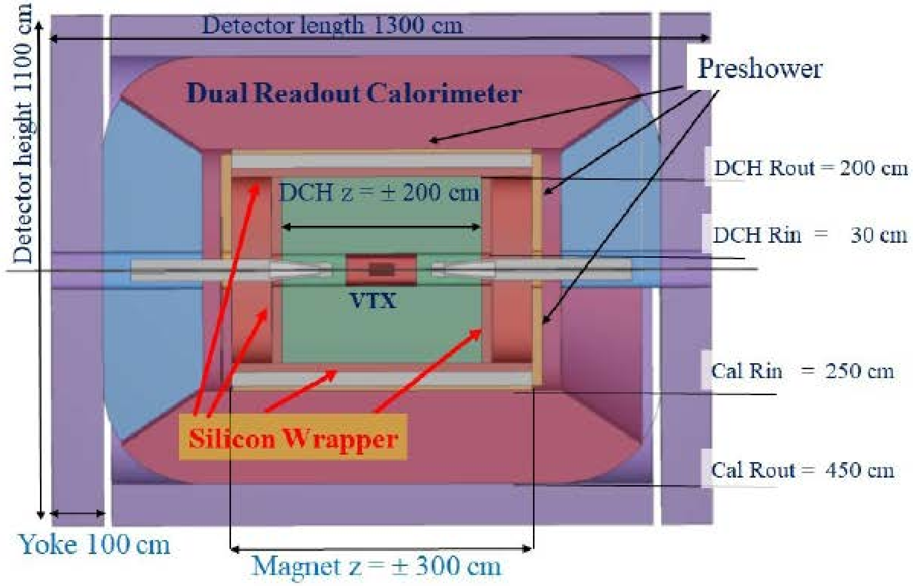
CEPC TPC Option

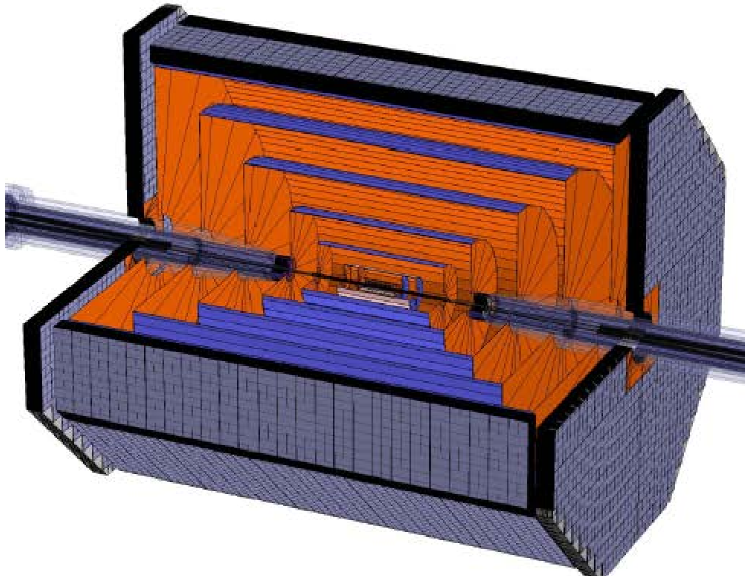
Operation mode	$\sqrt{s}$ (GeV)	L per IP (10^{34} cm^{-2}s^{-1})
H	240	3
Z	91.2	32 (*)
W^+W^-	158–172	10

- Silicon + TPC
- All-silicon tracker

	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			







CEPC IAC 2019

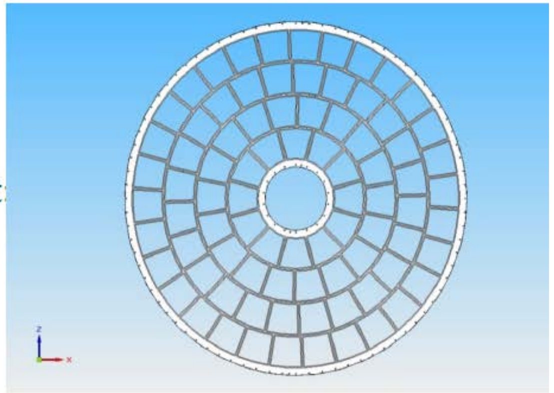
Recommendation 15:

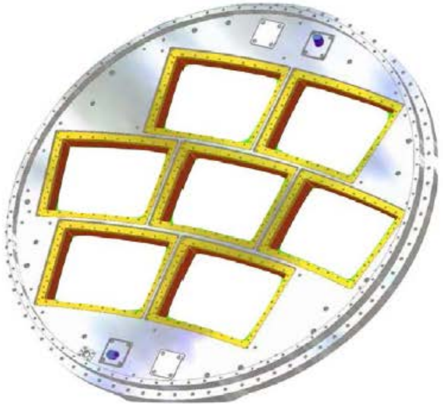
- *Engage engineering expertise to assess various engineering aspects of the detector options under study (supports, low mass aspects of the vertex and tracking detectors, heat dissipation and integration of cooling, low-mass services and service routing, influence of the magnetic field on the design, etc.). Engineering expertise helps also to enhance the credibility of the cost estimates.*
- *Reinforce detector studies in the forward region at the interface of the accelerator. Optimize the luminosity measurement, compatible with expected statistical errors on the physics, through optimal design, integration and alignment of LumiCal. Perform advanced engineering studies on the overall design of the complex forward MDI region, taking all constraints into account.*
- *Study whether the TPC is compatible with the high rates expected for operation at the Z-peak, including ion backflow, electronics readout and DAQ schemes.*
- *Study the impact of the choice of the solenoid field (2T or 3T) at all foreseen CEPC center-of-mass energies. Draw conclusions on the detector design and performance (in particular the TPC), taking the impact on the beams and the CEPC luminosity performance into account. Preferably make a final choice of the recommended magnetic field for both CEPC detectors at the earliest possible time.*
- *Continue to pursue studies of the solenoid yoke in view of magnetic stray fields and their influence on the booster beams and on other surrounding equipment.*
- *Reinforce efforts towards an engineering design of the IDEA detector (including engineering details of the dual readout calorimeter) and implement the corresponding design in the event simulation and reconstruction software.*

Pad TPC and Pixel TPC

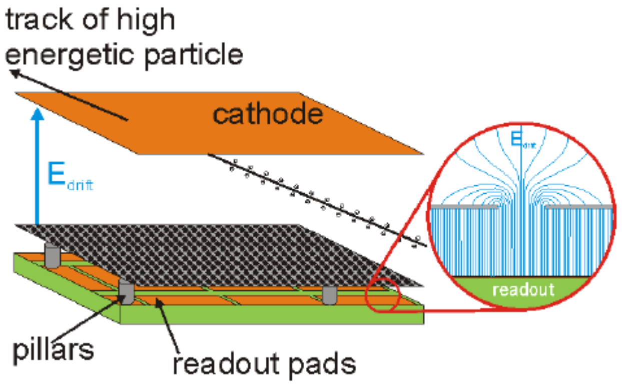
Pad TPC for collider

- 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

Pad TPC

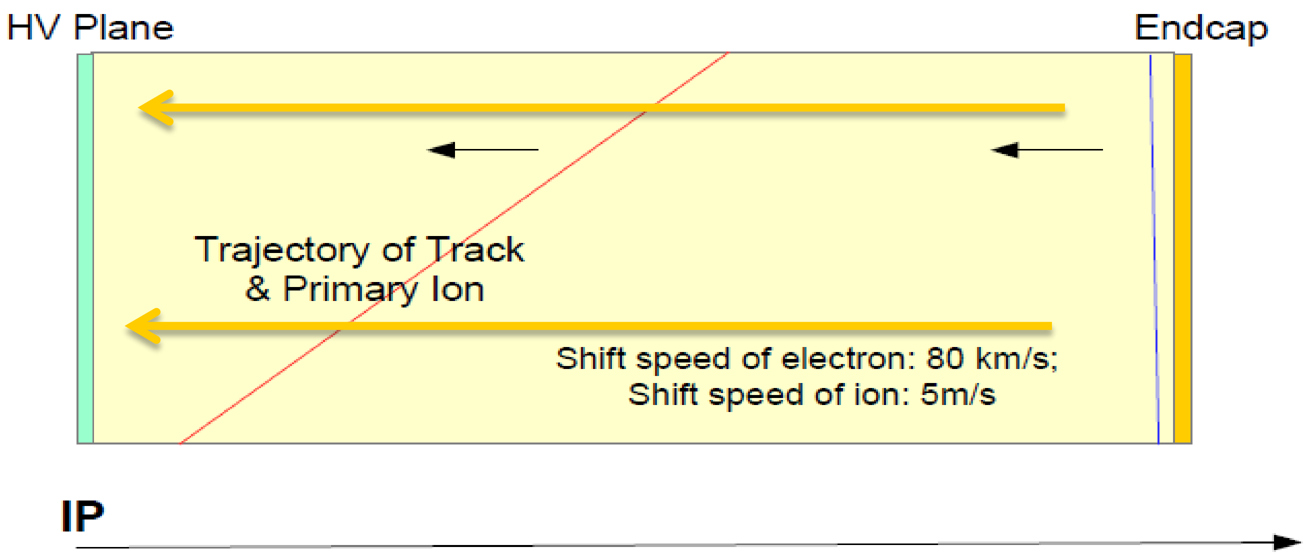
Advantages:

- 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
  - <1X0 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

Pad TPC

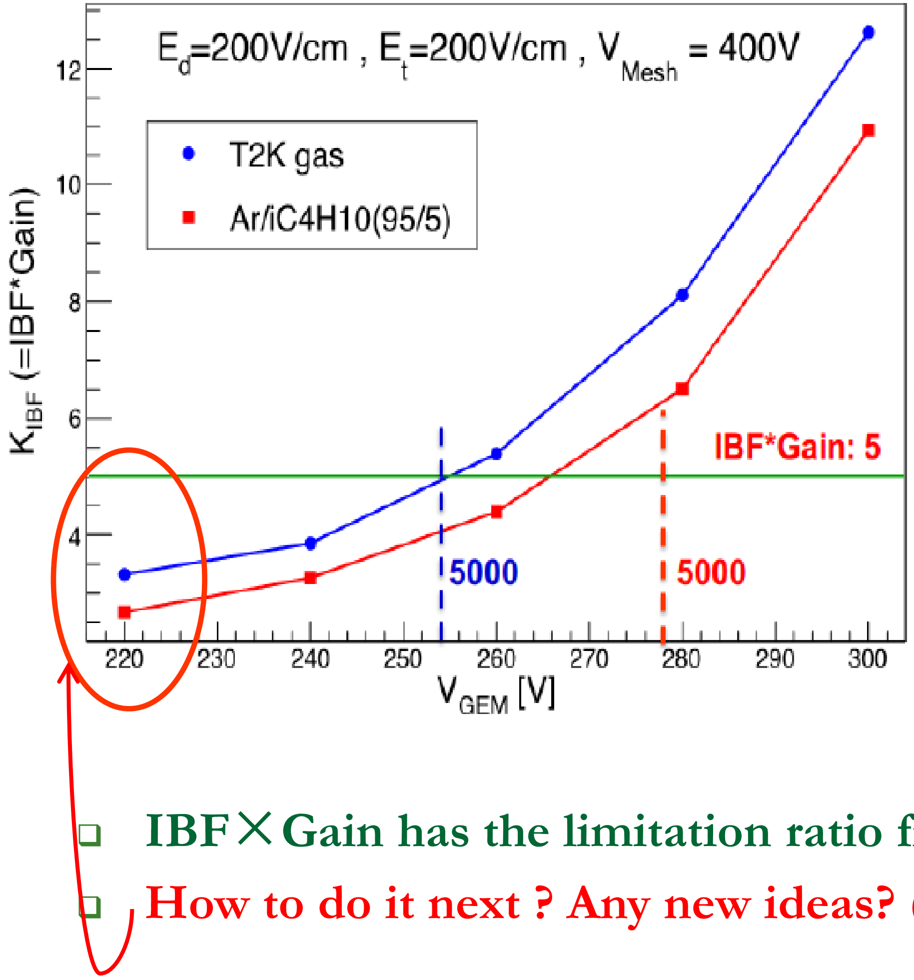
Limitations

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

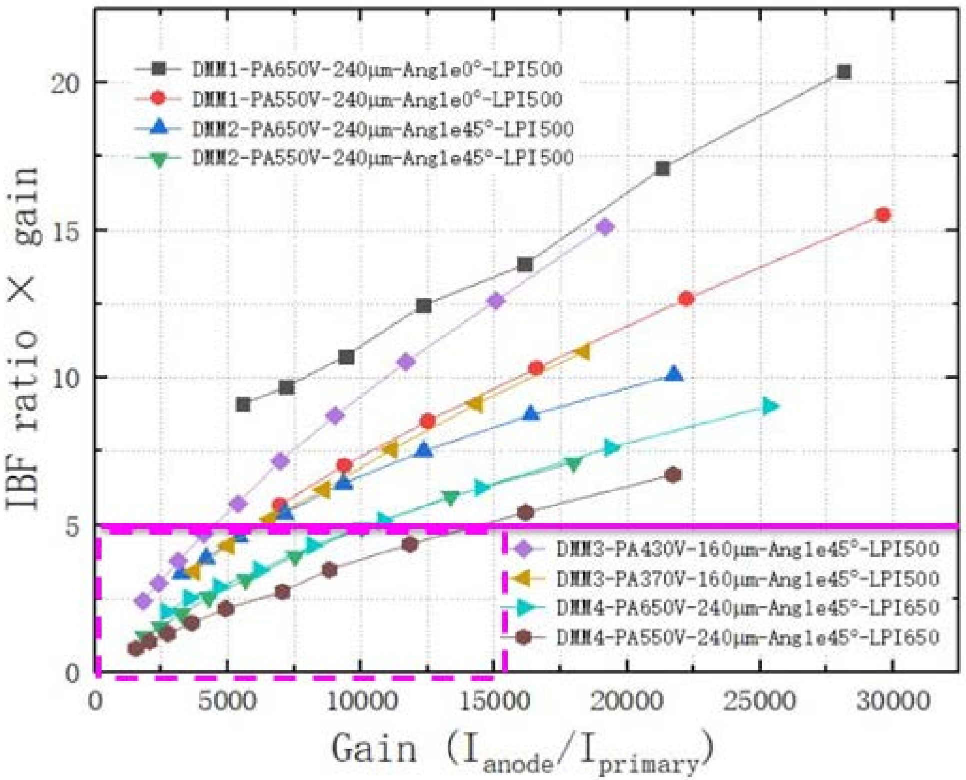


TPC module R&D – **Ions backflow**

Micronegas + GEM detector module@IHEP



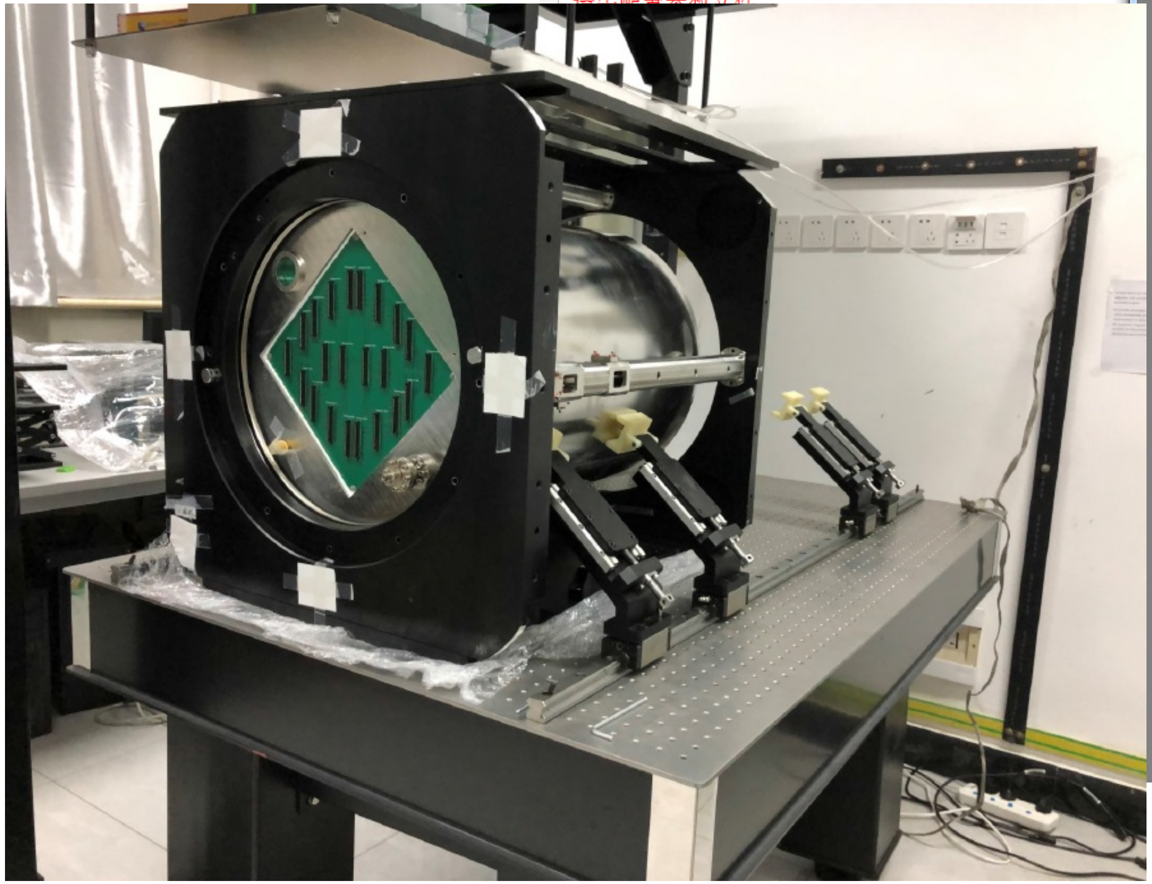
IBF of double mesh MM @USTC/Jianbei Liu

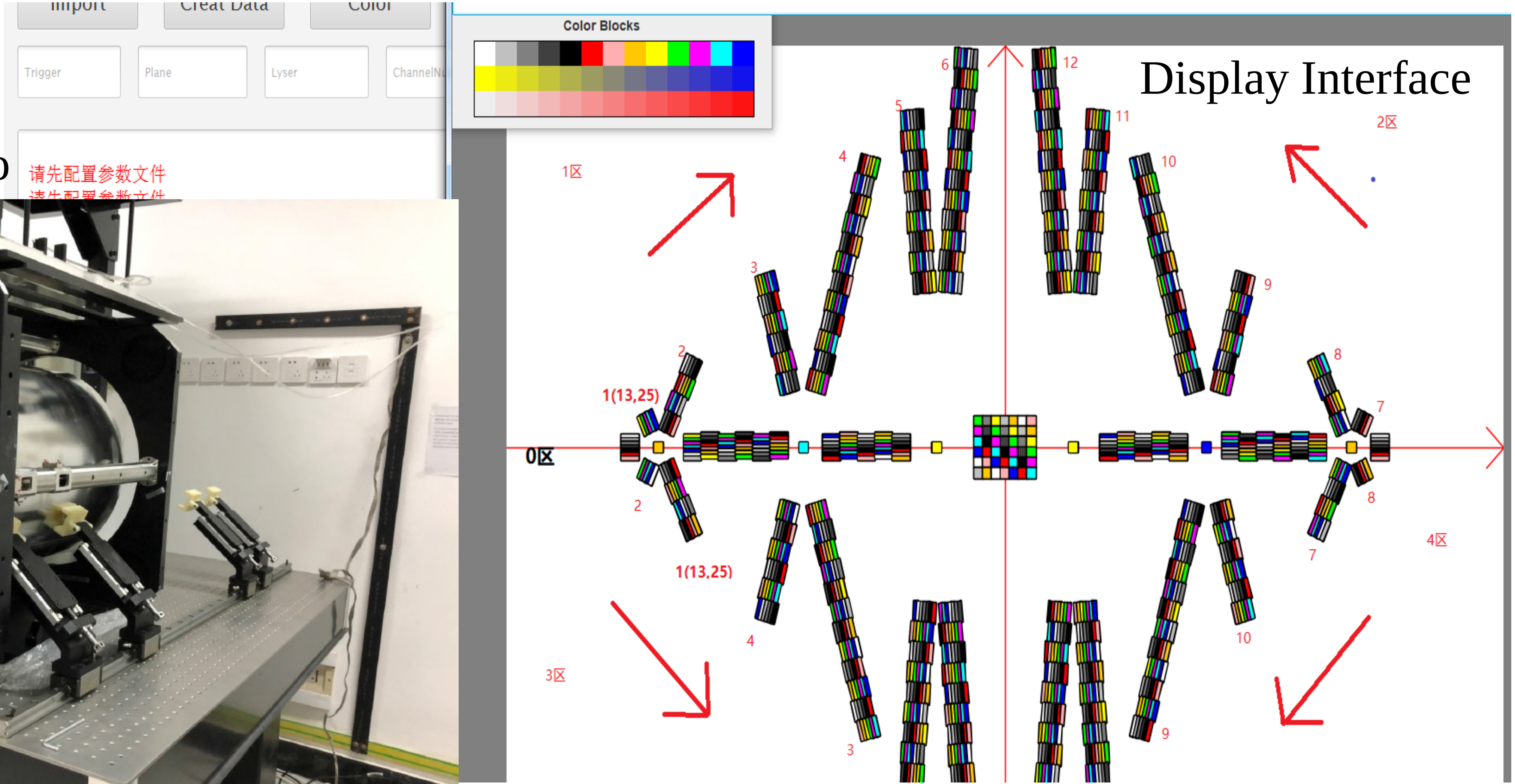


- IBF×Gain has the limitation ratio from the detector R&D at high gain.
- How to do it next ? Any new ideas? (Lower gain and no IBF)

TPC prototype R&D at IHEP

Prototype of Photo





Display Interface

Simulation of pad and pixel TPC (on going)

Preliminary results – Diffusion and Hit resolution

- Using DDTPCDigiProcessor of Marlin TPC
  - r-phi resolution are simulated by smearing the hits by the experiments using MPGD
  - Diffusion resolution are simulated by smearing the hits by the expected
  - E=220V/cm
  - Drift length <2.0m

- Momentum resolution...
- Tracking Efficiency...

$$\sigma_{r\phi}^{\text{pads}} = \sqrt{\sigma_{r\phi 0}^2 + \sigma_{\phi 0}^2 \sin^2(\phi_{\text{pad}}) + \frac{D_{r\phi}^2}{N_{\text{Eff}}} \sin(\theta_{\text{pad}}) \left(\frac{6\text{ mm}}{h_{\text{pad}}}\right) \left(\frac{2.0\text{ T}}{B}\right)^2 L}$$

$$\sigma_{r\phi}^{\text{pixels}} = \sqrt{\sigma_{r\phi 0}^2 + D_{r\phi}^2 \left(\frac{2.0\text{ T}}{B}\right)^2 L}$$

$$\sigma_z = \sqrt{\sigma_{z0}^2 + D_z^2 L}$$

	Pad TPC	Pixel TPC
$\sigma_{r\varphi 0}$	0.06mm	0.0016mm
σ_{z0}	0.35mm	0.17mm
$\sigma_{\varphi 0}$	0.9mm	/
$D_{r\varphi}$	0.025mm/$\sqrt{cm}$	0.025mm/$\sqrt{cm}$
D_z	0.08mm/$\sqrt{cm}$	0.256mm/$\sqrt{cm}$
N_{eff}	26	/

Pixel TPC discussion from LCTPC Collaboration Meeting at DESY in January 2020

Pixel TPC

- At a circular collider CEPC there is place for different experiments, one of them could use a TPC as the main tracker

- Why is a pixel TPC a serious and realistic option?
  - For Higgs and top running no problem for all TPC read out technologies
  - For W running probably no issue either
  - Running at the Z with high luminosities and high rates is however problematic for current micromegas and pad technologies. Tracks will overlap in the read-out plane and the occupancy at low radii will become too high

- A pixel TPC is a realistic option at the CEPC and provides:
  - High precision tracking in the transverse and longitudinal planes
  - dE/dx by electron and cluster counting
  - Excellent two track resolution
  - Digital readout that can deal with high rates

Pixel TPC

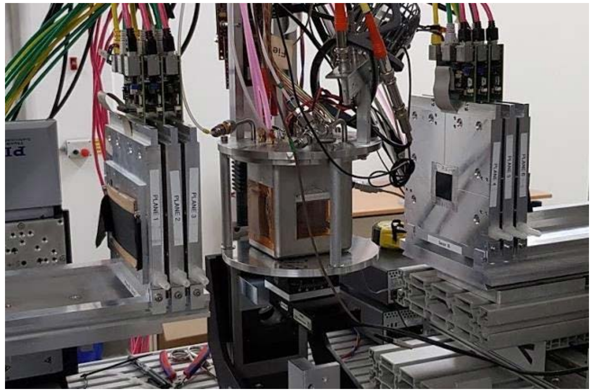
Limitations

- Running at the Z with a pixel TPC?
  - Large potential in terms of rate capabilities
  - Pattern recognition profits from high granularity of small($55x55\mu m^2$) pixels

- Will go through different aspects of CEPC Z running
  - Rates and occupancies
  - Distortions in a pixel TPC from primaries and Ion Back Flow
    - Low detector gain to reduce IBF
    - Gating device to reduce IBF

Pixel TPC: Z running

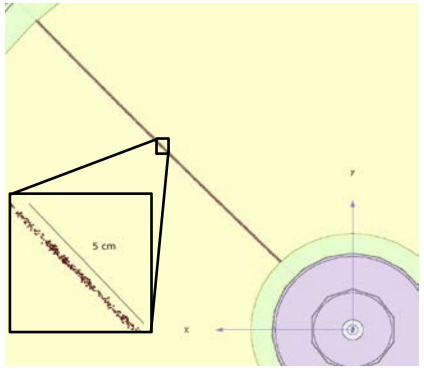
- The conditions for CEPC running
  - High(est) luminosity CEPC L = 32-101 10^{34} $cm^{-2}s^{-1}$ at 2 T from CDR.
    - CEPC Ring length 100 km with 12 000 bunches and a hadronic Z rate of 10-32 k Hz (cross section 32 nb). Beam structure rather continuous 25 ns spacing.
    - Note that this Luminosity gives about 60-185 G Zs per running year
  - Time between Z interactions 200-70 μs
  - TPC drift takes 30 μs
  - So events are separated in the TPC



- High rate capabilities of GridPix pixel chip TPX3
  - Bonn test beam was 5 kHz electrons for a quad
  - Link speed 80 Mbps per chip (256x256x 55 x 55 μm^2)
  - Test beam 2018 1.3M hits/s per chip could be read out
  - In 2019 the link speed doubled to 2.6M hits/s per 1.42x1.42 cm^2.

Pixel TPC: Z running

- Summary of Z rates @ L = 32-101 10^{34} $cm^{-2}s^{-1}$ and occupancies
  - Data is produced at a large rate of 300-900 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 safe factor 10 higher
  - Occupancies are less than 1% at low radii
  - One needs to design a DAQ system to collect all data



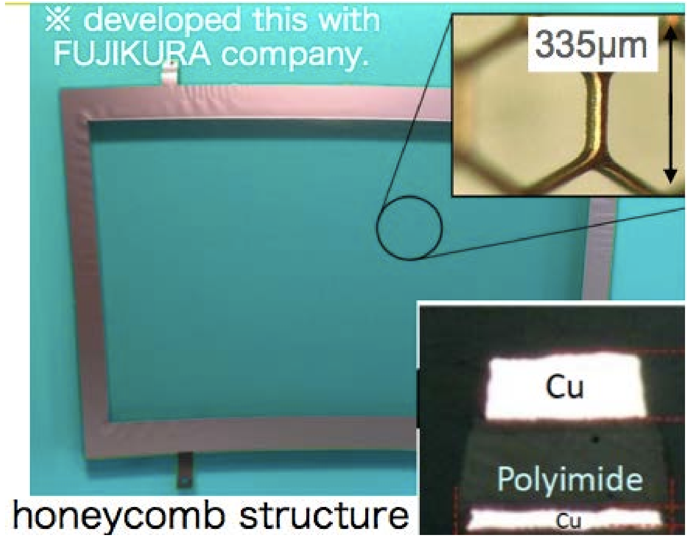
- Pattern recognition will be no problem
  - The occupancies in the pixel plane are low. The time between the Z interactions is large 120 μs. The time will be measured by each pixel. The resolution is dominated by longitudinal diffusion. It amounts to less than about 20 nsec. Different Z events can be easily separated in time.

CEPC Pixel TPC NO gating

- Depending on the IBF, the distortions could also be measured and calibration using the UV laser tracker
- Due to the large Z data set it will be possible to correct for the distortions in a timely manner. Suppose one has distortions that correspond to IBF = 15 (applying a safety factor 10). The maximum deviation will be 130 μm at small radii. It is realistic to assume that one can measure this number with a precision of 13 μm (factor 10) using the vertex detector.
- Need the update background parameters
- This means that one can reach the precision requirements of the ILD TPC: the systematics in the bending plane will be less than 10-20 μm
- NB for the W and Higgs runs it is important to install and use a gating device

CEPC Pixel TPC with gating

- Possible CEPC triggered gating scheme
  - Time between Z collisions is 120 μs. So one can think of gating
  - Make a GEM gating device a la ILD (see picture) but now at 1-5 mm above the grid
  - Gating in a triggered mode;
    - if a hadronic Z interaction in TPC start gating "stop the ions".
  - Gate length of e.g. 30-60 μs would stop the ions in Z triggered mode
    - the price is dead time, reduced efficiency
    - Trade off between IBF reduction 0 and efficiency 100%
  - This might work and will reduce IBF and distortions
- NB: ILC gating can exploit bunch structure: Gate opens 50 μs before the first bunch and closes 50 μs after last bunch. Close time between bunches 200 ms. Device 1 cm above grid.



Yumi Aoki @ LCWS2019

CEPC Pixel TPC backgrounds and distortions

- Important to estimate the charge in the TPC as it can cause distortions
  - Physics events like Zs
  - Other backgrounds γγ background and incoherent pairs from beam-beam interactions that produce hits
    - At ILC beam-beam effects are dominant over the physics interactions.
    - Reasonable: FCCee studies show that e.g. γγ background are very small at the Z. Also the incoherent pair production is several orders smaller than at the ILC. CEPC's situation is same likely.
    - To reduce: As Adrian Vogel (DESY-thesis-08-036) showed the detector - machine design is important to reduce the number of back scattered photons. See plot below.

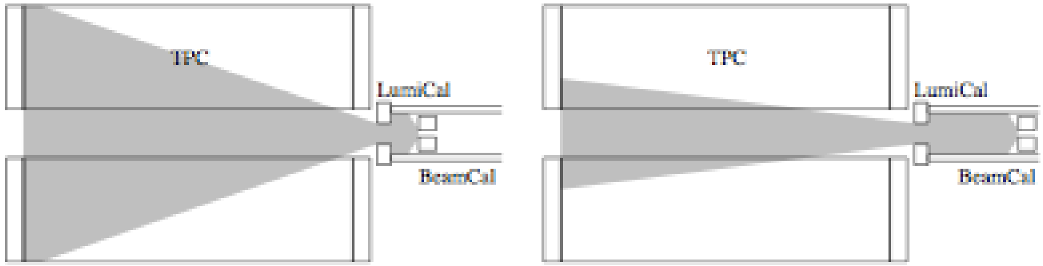


Figure 7.32: A larger distance between LumiCal and BeamCal reduces the backscattering of photons into the TPC.

Cost and Power consumption

Total：184 Millions RMB

2019 cost (Micromegas option) 2019.11

Colonne1	Colonn	Colonne	Colonne4	Colonn	Detector concept / detector items	Unit	Unit cost (€)	Quantity	total m&s	Home/Industry	associated unit labor (FTE.year)	labor cost
WBS Number					ILD							
	1.2				Time projection Chamber				23, 638, 740. 00			
		1.2.1			Field cages				5,800,000.00			
			1.2.1.1		inner fieldcage		860000	1	860,000.00			
			1.2.1.2		outer fieldcage		4300000	1	4,300,000.00			
			1.2.1.3		central membrane		300000	1	300,000.00			
			1.2.1.4		hanging and damping				30,000.00			
			1.2.1.5		HV test bef. Assembly				10,000.00			
			1.2.1.6		shipping				300,000.00			
		1.2.2			Endplates			2	540,000.00			
			1.2.2.1		base material (Al)		10, 000. 00	2	20,000.00			
			1.2.2.2		machining		40, 000. 00	2	80,000.00			
			1.2.2.3		Fixtures		10, 000. 00	2	20,000.00			
			1.2.2.4		Module jigs		500. 00	120	60,000.00			
			1.2.2.5		shipping				300,000.00			
			1.2.2.6		assembly				60,000.00			
		1.2.3			Modules (20 spares)			140	2,042,800.00			
			1.2.3.1		back-frames	frame	1, 000. 00	140	140,000.00			
			1.2.3.2		PCBs	PCB	2, 000. 00	140	280,000.00			
			1.2.3.3		mesh and DLC	detector	4, 000. 00	140	560,000.00			
			1.2.3.4		connectors	connector	45. 00	13440	604,800.00			
			1.2.3.5		storage boxes	box	200. 00	140	28,000.00			
			1.2.3.6		shipping		70, 000. 00		70,000.00			
			1.2.3.7		Mounting and test				360,000.00			
		1.2.4			Ancillaries				2,256,400.00			
			1.2.4.1		CO2 compressor	compressor	65, 000. 00	14	910,000.00			
			1.2.4.2		CO2 comp. Shipping	compressor	7, 000. 00	14	98,000.00			
			1.2.4.3		Gas mixer				400,000.00			
			1.2.4.4		Gas analyser				100,000.00			
			1.2.4.5		laser system				540,000.00			
			1.2.4.6		HV power supplies	supply	6, 000. 00	12	72,000.00			
			1.2.4.7		HV racks	rack	5, 000. 00	2	10,000.00			
			1.2.4.8		LV power supplies	8-channel supply	7900	16	126,400.00			
		1.2.5			Cables and pipes				49,540.00			
			1.2.5.1		HV cable (60m) x120	60m HV cable	130. 00	120	15,600.00			
			1.2.5.2		LV cable	cable	25. 00	120	3,000.00			

- The total cost of a pad or a pixel read out is pretty similar; all readout options need cooling and electronics and that drives the read out cost.
- For the prototype, E.g. for 1 module of 100 chips that need 1 wafer 3000 euro plus post processing 3000 euro，It will go down substantially because of prices going down for large numbers.
- All the costing done for ILD is more realistic for TPC concept.

Summary

- Update parameters from the high luminosity of Z
- Pad TPC R&D
  - Module and prototype R&D
  - Some limitation issues

- Pixel TPC discussion from LCTPC collaboration in January
  - Pixel TPC option for CEPC/FCC circular collider
    - TPC module: Bean test and measurement
    - Pixel TPC module: IBF study
    - Rates and occupancies
    - Cost estimation