Some considerations and plan for TPC at Tera Z

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In this talk presented issues with a TPC running at Tera Z Physics requirements Pad TPC for IBF Pixel TPC

CEPC TPC Option



- 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: 2×10m²
- One option for endplate readout
 - GEM or Micromegas
 - $-1 \times 6 \text{ mm}^2 \text{ pads}$
 - 10⁶ Pads
 - 84 modules
 - Module size: 200×170mm²
 - 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
 - $\rightarrow 10^9$ pixel pads

Benefits of Pixel readout:

- Lower occupancy
- $\rightarrow 300~k$ Hits/s at small radii.
- \rightarrow This gives < 12 single pixels hit/s.
- \rightarrow With a read out speed of 0.1 msec (that
- matches a 10 kHz Z rate)
- \rightarrow the occupancy is less than 0.0012
- Improved dE/dx
 - \rightarrow primary e- counting
 - Smaller pads/pixels could result in better resolution!
 - □ Gain <2000
 - Low IBF*Gain<2</p>
 - \Box CO₂ 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%
- \sim 100 µm position resolution in r ϕ
 - ~60µm for zero drift, <100µm overall
 - Systematics precision (<20µm internal)</p>
- TPC material budget
 - <1X0 including outer field cage</p>
- Tracker efficiency: >97% for pT>1GeV
- **2**-hit resolution in $r\phi$: ~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)



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(55x55µm²) 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 $L = 32-50 (17-32) 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ 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
- 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 μm²)
 - 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 cm².



Pixel TPC: Z running

- Summary of Z rates @ $L = 32 \ 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ 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
 - 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 corrected for
- 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.
- 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 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

Cost and Power consumption

Total: 184 Millions RMB

2019 cost (Micromegas option)

2019.11

				1	Detector concept /						associated unit labor	r
Colonne1	Colonr	Colonne:	Colonne4	Colonn	detector items	Unit	Unit cost (€)	Quantity	total m&s	Home/Industry	(FTE.year)	labor cost
WBS/Nun	nber	////	////		N/N///////////////////////////////////	///////////////////////////////////////	//////	/////	////////	////////	///////////////////////////////////////	//////
					Time projection							
	1.2				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 (AI)		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

Pad TPC R&D

Module and prototype

- LCTPC collaboration in January
 - Pixel TPC option for CEPC/FCC circular collider @ one day meeting
 - TPC module: Bean test and measurement
 - Pixel TPC module: IBF study
 - Cooling study of the readout
 - Two phase CO2
 - Cost estimation