Simulation of the occupancy of TPC detector at Tera-Z

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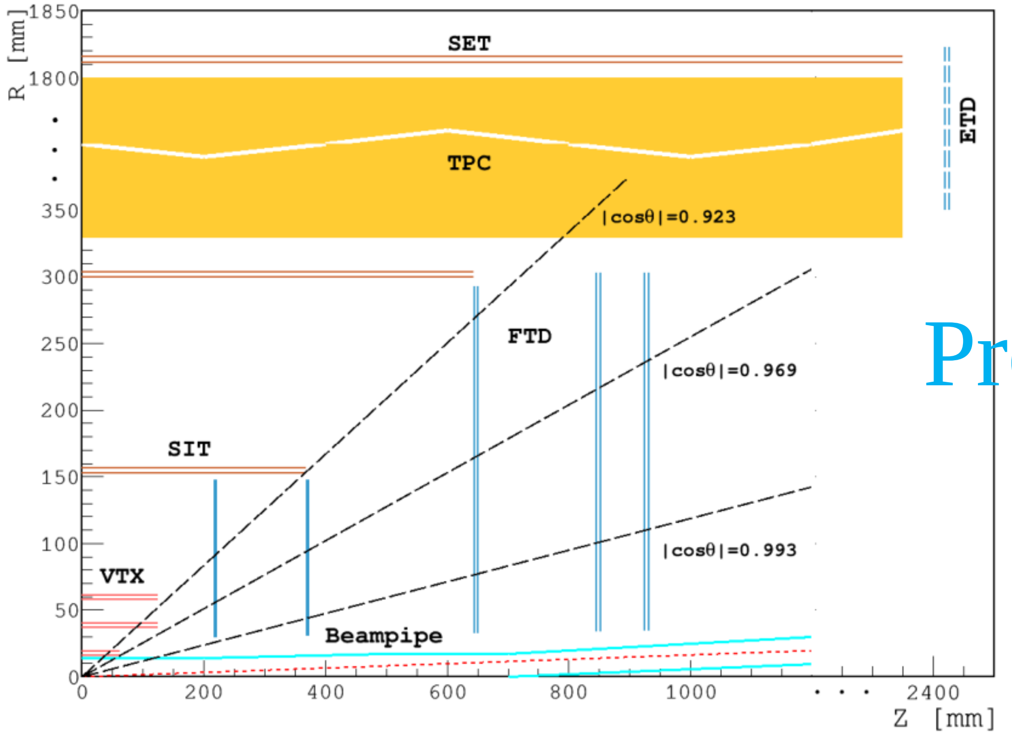
Content

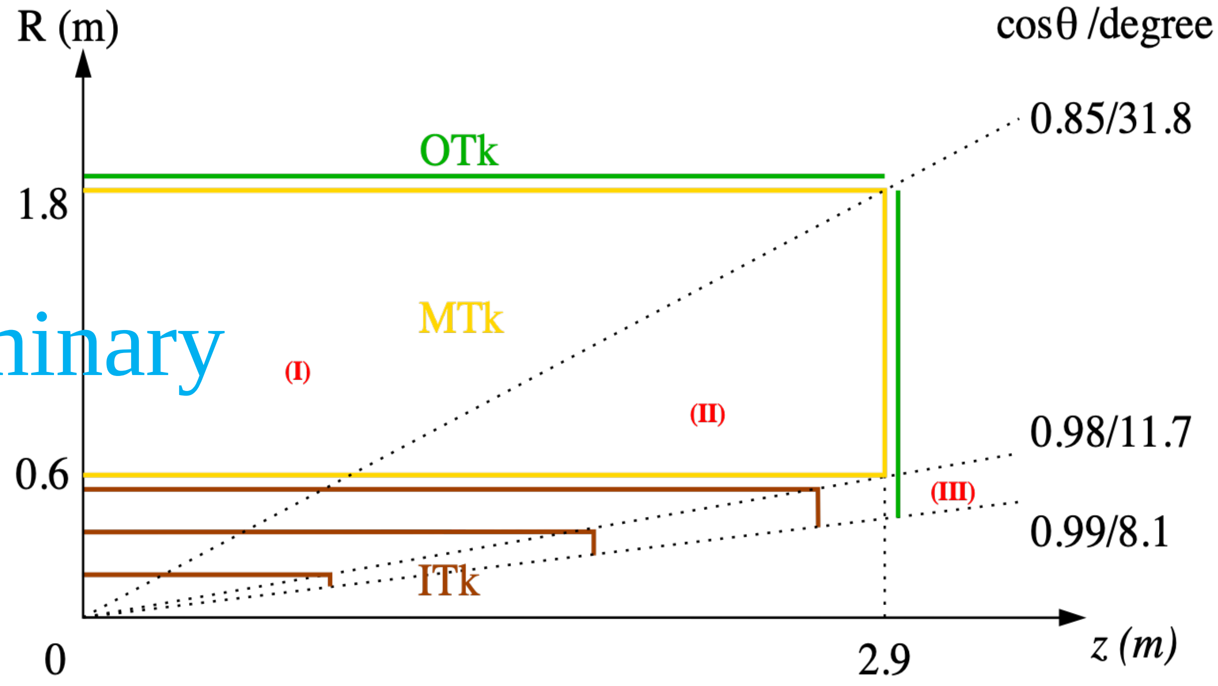
- **Motivation**

CEPC TPC parameters in TDR

TPC parameters updated in CEPC TDR:

- rMin:0.30m (CDR) → **0.60m (TDR)**
- rMax:1.80m (CDR) → 1.80m (TDR)
- maxDriftLen:2.35m (CDR) → **2.90m (TDR) , cosθ~0.98**

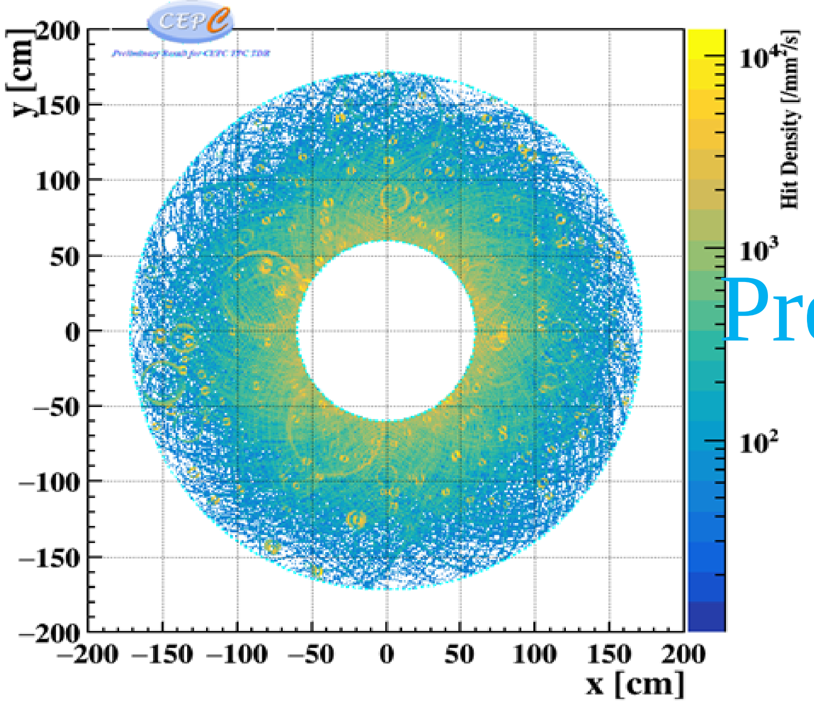


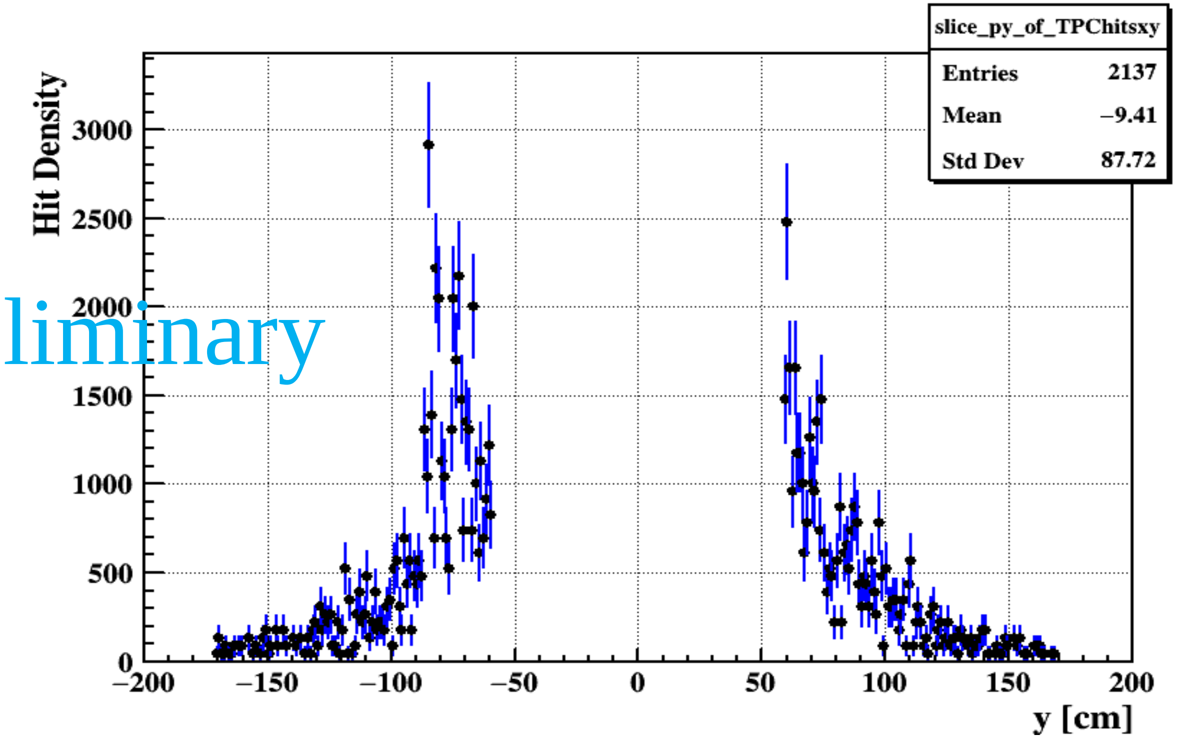


CEPC TPC layout in CDR(left) & CEPC TPC layout in TDR(right)

Hit density at the inner radius at Z pole 2T

- Hit density at the full simulation with the beam background (3T → 2T)
- At 2E36 (**Tera-Z**) with Physics event only, even bunch distribution(cite#2).
  - Pixelated readout much **LOWER** inner most occupancy (**even 0.6m inner radius**)
  - Pixelated readout can easily handle a high hits rate at Z pole. (cite#3/4)
  - The data at the inner radius @40M BX Z pole@1 Module ~0.05Gbps(Maximum).





Preliminary

Simulation of Tera-Z/CEPC with the beamstruggle

Cite#2 https://doi.org/10.1088/1748-0221/12/07/P07005
Cite#3 Occupancy in the CLIC
Cite#4 GridPix detectors

- **Performance studies of the pixelated readout TPC for CEPC TDR**

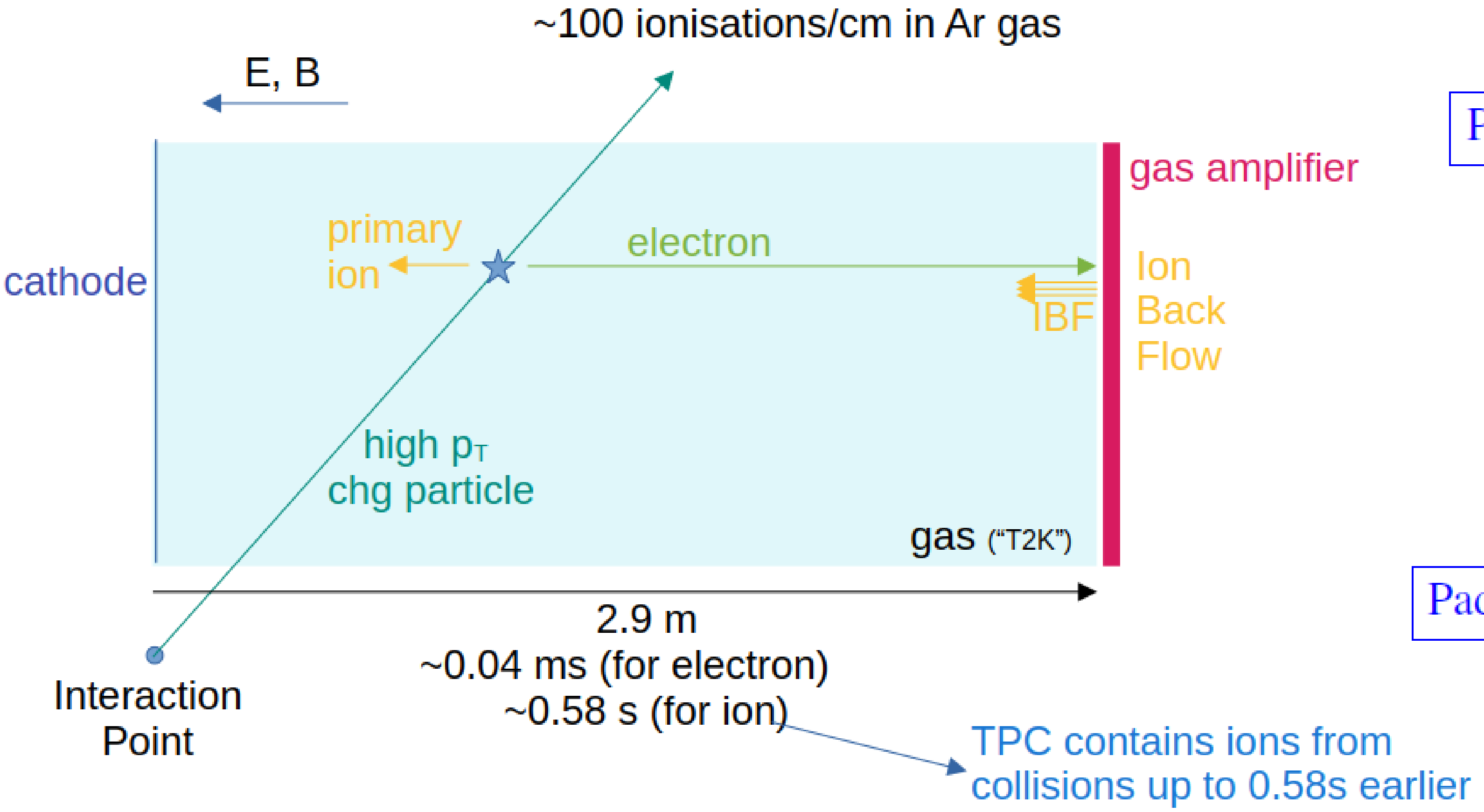
Critical key issues

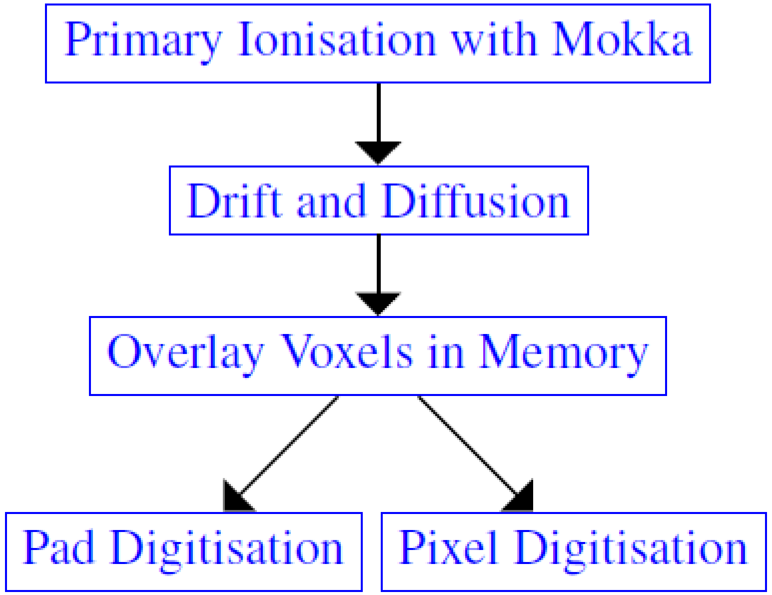
- **Material budget at endcape/barrel**
- **Occupancy and hit density (with Beamstruggle)**
- **Improved dE/dx+dN/dx for PID**
- **Ion backflow suppression**
- **Reasonable channels and power consumption**
- **Running at 2 Tesla**
- **Beamstrahlung and distortion**
- **Prototype validation**

- **Voxel Occupancy using Pixelated Readout**

Pixelated readout TPC technology for CEPC TDR

- The pixelated readout TPC's occupancy is the **number of pixels with at least one active time sample** during the bunch train, divided by the total number of pixels of TPC.
    - On-going of the simulation

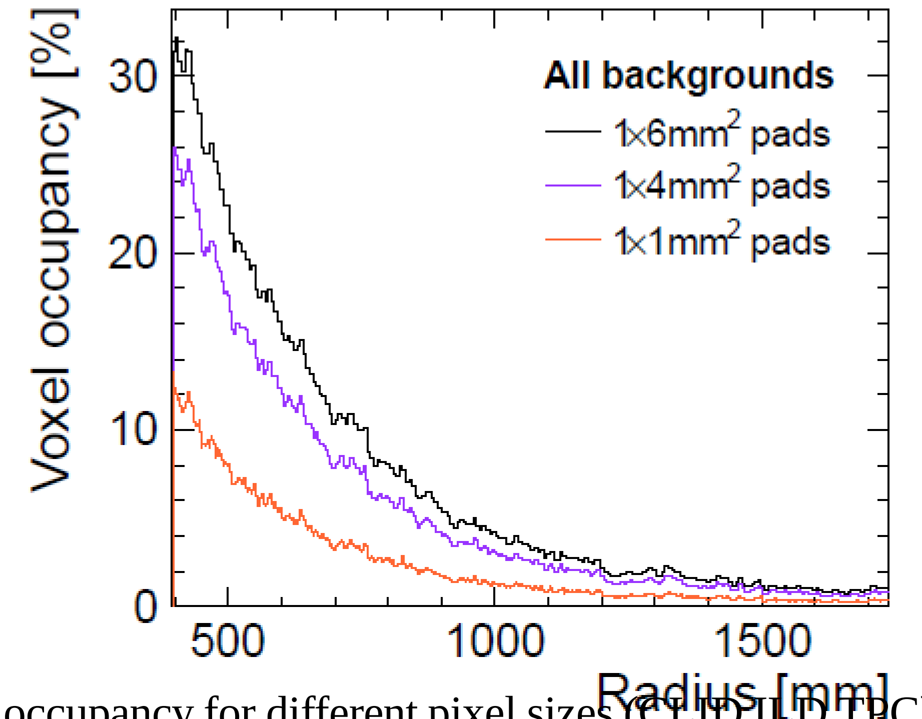




Voxel occupancy in TPC

- The voxel occupancy is the number of 3D readout cells (voxels) divided by all voxels in the TPC.
- A voxel has the size of pixel in the xy direction and the length of one time sample multiplied by the drift velocity in z direction.
  - Due to the shaping of the electronics, a single pulse occupies several voxels, even if the signal is just on one readout channel.
    - Typical drift velocity of **80mm/µs**
    - Readout frequency of **40 MHz** the voxel size in z is about 2 mm.

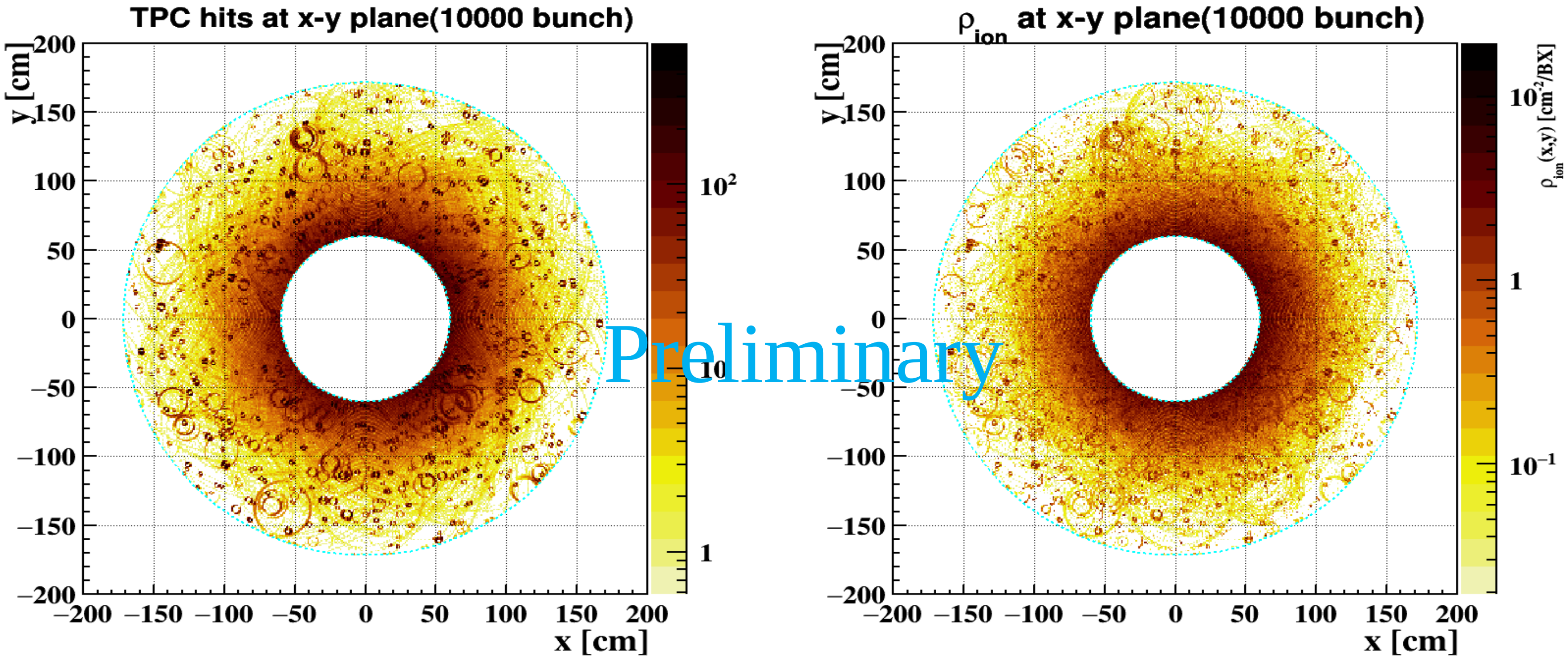
Occupancy and hit rates running CEPC at the Z.
Even, any track detectors,
Needed **carefully consider** with the background of MDI !!!



The pixel occupancy for different pixel sizes (CLID ILD TPC)

Beam background @ Higgs 3T

- Primary ions per bunch crossing in TPC
  - Edep: 10.21 GeV in total(10000BX)
  - Number of primary ions:
    - Edep/effective ionization potential of Ar [26eV] ~39.26k ions/BX
    - Primary ions in TPC at any time ~ 1.5×10^{10}
    - Average primary ion density ~0.05nC/m^3



Hits map (left) & Ion density(right) at x-y plane

Beam background of CEPC TPC simulation results

表 4.1: Summary (ionization efficiency $\eta \sim 90\%$)

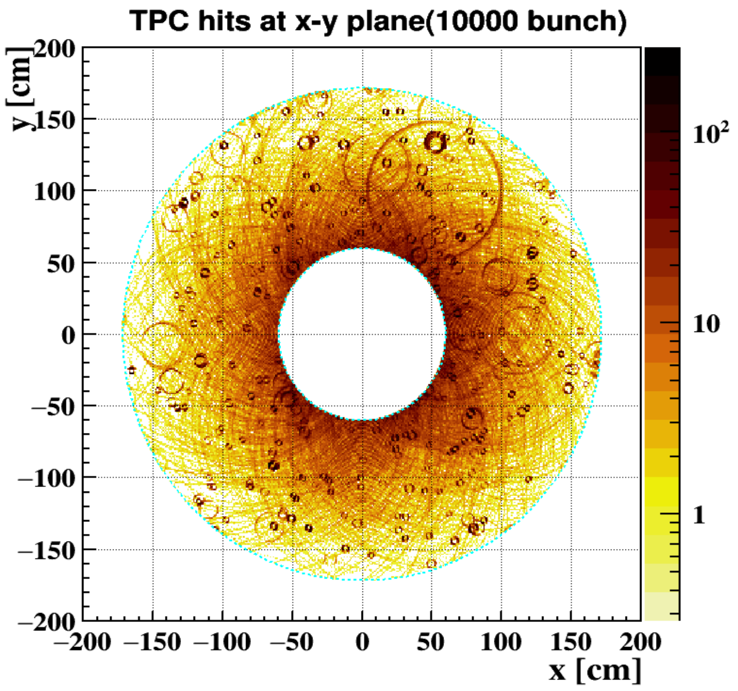
Collider Detector Model	CEPC_v4	CEPC_v4
Beamstrahlung pairs	CEPC Z-pole(91GeV)	CEPC Higgs(240GeV)
BX freq.	1/23 ns	1/680 ns
primary ions/BX	18.20 k	39.26 k
primary ions at any time	2.07×10^{11}	1.5×10^{10}
average primary ρ_{ion} [nC/m^3]	0.63	0.05
max (single BX) [nC/m^3/BX]	0.6×10^{-6}	1.8×10^{-6}
max (steady state) [nC/m^3]	5.46	0.62

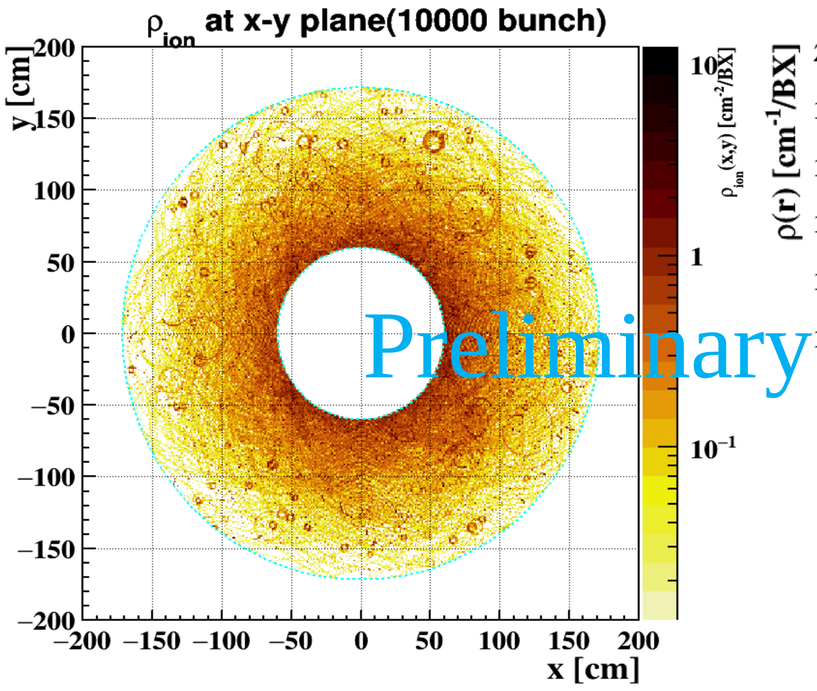
Max (steady state) ~ max(single BX) × BX freq. × max. drift time × 50% × η

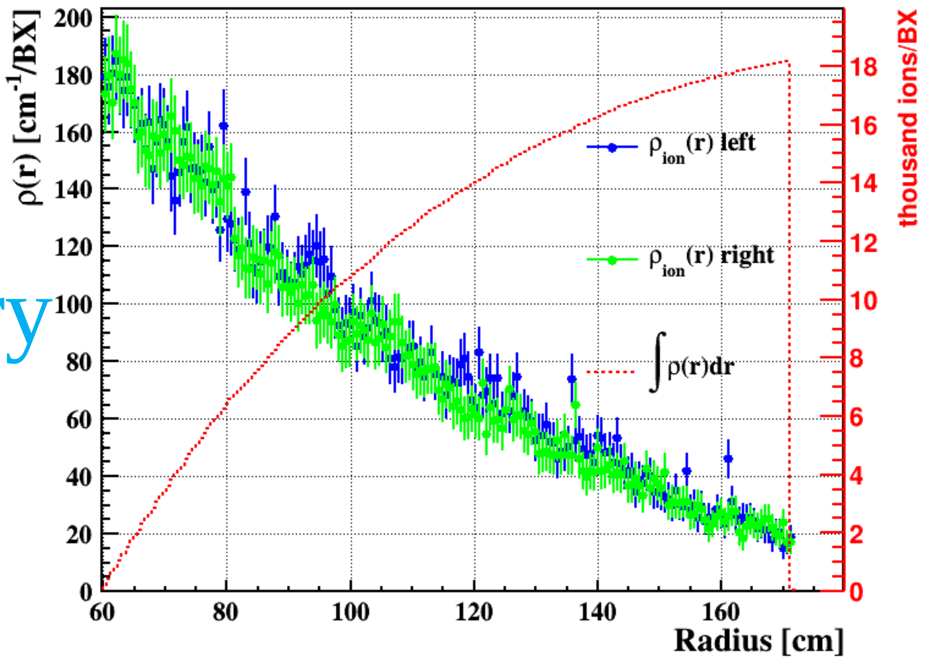
primary ions only

Beamstrahlung hit density calculation and estimation

- 18.2k ions/electrons per BX in total → per BX all energy lose/26eV (two chambers)
  - ions/electrons along r-direction at Tera-Z
  - Inner radius: 600mm， ions/electrons ~180 hits/cm, hit density~0.48 hits/cm^2/BX
- Total hits ~630 Hits/cm/cm in 30μs (drift time)
  - Readout: 500 μm×500 μm, the readout rate ~**31.5k hits/sec, Occupancy ~1.58%**
  - **The pixelated readout can handle that, obviously the pixelated readout occupancy is low.**







Running a pixelated readout TPC at high rates

- Comparison of the background rate with Z rate.
  - A readout with 500 μm×500 μm would work for the Zs with the **reasonable** the beam background.
  - Therefore it is **VERY important** to design a MDI reduces the background.

  - Comparing the ILD and the CEPC (FCC) MDI: backgrounds are a **factor 50 higher** for CEPC (FCC) .

			FCC-91	FCC-240	ILC-250
bunch crossing frequency			30 MHz	800 kHz	6.6 kHz
model	B-field [T]	MDI	thousand ions / bunch crossing mean $\pm$ RMS		
ILD_l5_v02	3.5 (uniform)	ILC	6.5 ± 19.9	14 ± 14	960 ± 150
ILD_l5_v02_2T	2.0 (uniform)	ILC	6.9 ± 11.1	15 ± 11	4700 ± 300
ILD_l5_v03	3.5 (map)	ILC	5.7 ± 7.9	14 ± 11	1100 ± 200
ILD_l5_v05	3.5 (map, anti-DID)	ILC	0.6 ± 1.5	3.7 ± 9.7	450 ± 110
ILD_l5_v11β	2.0 (uniform)	FCC-ee	390 ± 120	1000 ± 170	110000 ± 2400
ILD_l5_v11γ	2.0 (map)	FCC-ee	270 ± 100	800 ± 140	100000 ± 1900
removing BeamCal's graphite layer					
ILD_l5_v03	3.5 (map)	ILC			1300 ± 170
ILD_l5_v05	3.5 (map, anti-DID)	ILC			590 ± 120

Daniels from KEK

- **Rates and operation gas for TPC**

Alternative gases even the higher BK MDI

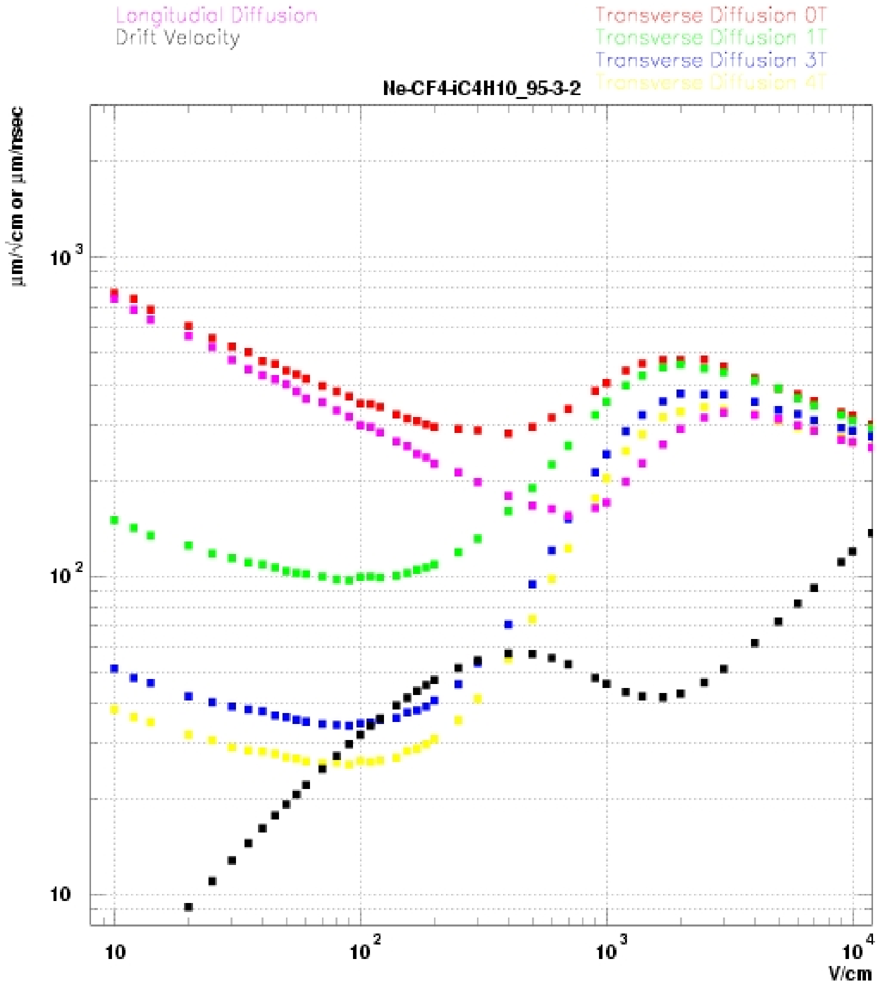
- The idea is use in the TPC not the T2K gas.
  - Another gas mixture that gives less hits.
  - Less sensitive to the beam background.
- One could think of a He or Ne based gas.
  - The advantage would be: the number of electrons /cm is lower by a factor of about **8 (Ne 2.5**) w.r.t. the T2K gas.
  - The probability that the photons (from the beam-beam background) interact with Helium is also a factor of **9 (Ne 5)** lower.

Daniels Jeans from DESY

T2K gas → Ne:CF4:iCH4H10 95:3:2

Alternative gases even the higher BK MDI

Neon version of T2K gas: Ne:CF4:iCH4H10 95:3:2 and still reach low transverse diffusion: of about $D_T = 70\ \mu m/\sqrt{cm}$ at 2 T. Drift field 200 V/cm.

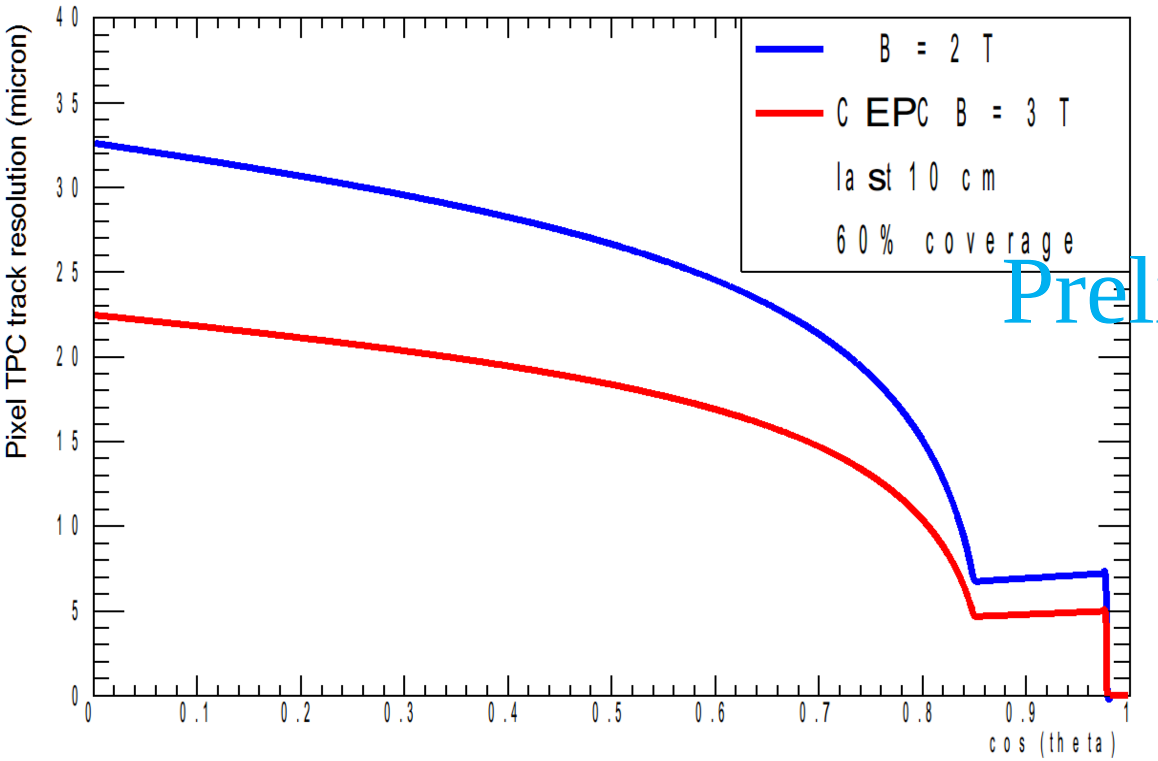


	clusters/cm	primary	total
Ne:CF4:iCH4		16.04	46
T2K		26	100

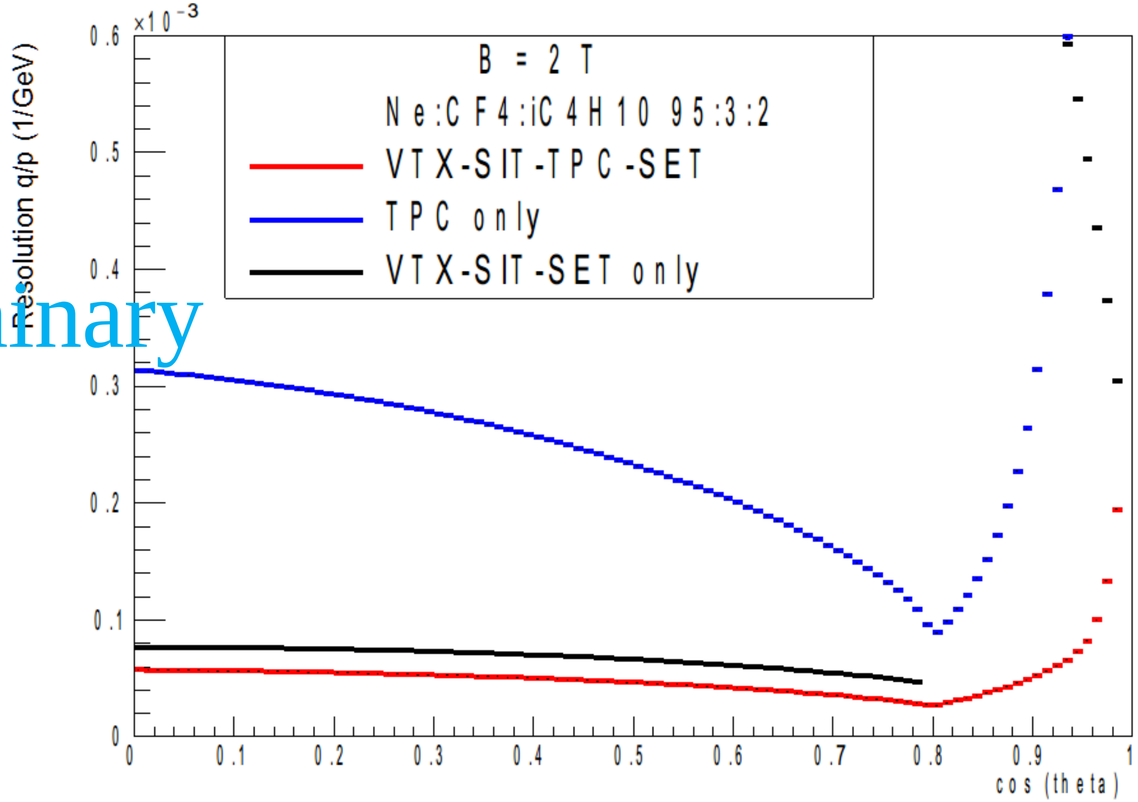
http://cepcsoft.ihep.ac.cn/tpc/gassimu/gas.html

Performance of alternative gases even the higher BK MDI

- Ne:CF4:iCH4H10 95:3:2 gas with $D_T = 70\ \mu m/\sqrt{cm}$ at 2T.
  - Combined s(1/p) at cosθ=0 is 3.9 (Ne 5.7) 10^-5 /GeV
- **TPC can be optimized, even to meet the higher BK MDI at CEPC.**



Preliminary



Summary

- From the calculation and estimation of Beamstrahlung hit density, the preliminary results shows :
  - The pixelated readout can handle that, obviously the pixelated readout occupancy is low.

- Even operation at the higher BK MDI at CEPC TDR
  - TPC can be optimized and be operated to meet the higher BK MDI at CEPC using the alternative mixture gases.

Many thanks!