Status of TPC R&D and estimation of the beamstrahlung background in Chamber

Huirong Qi, Xin She, Yue Chang, Zhi Deng, Jinxian Zhang, Liwen Yu
Haoyu Shi, Wei Xu, Gang Li, Manqi Ruan, Linghui Wu, Guang Zhao
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Institute of High Energy Physics, CAS

Content

- **Sources of Detector Backgrounds**
- **Estimation ions background of CEPC TPC**
- **Status and plan of TPC R&D**
- **Summary**

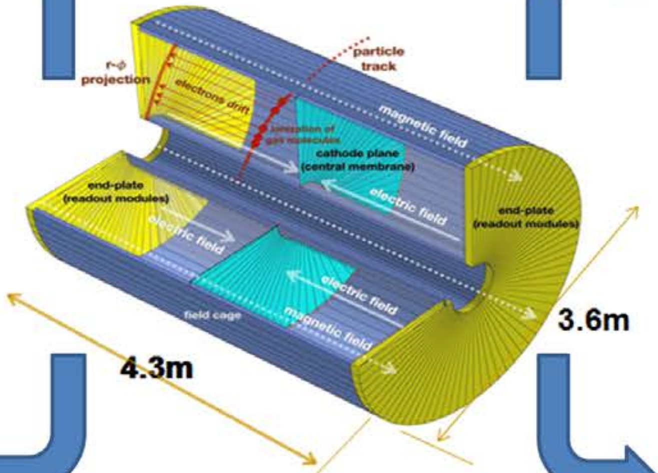
Motivation: TPC requiremetns from e+e- Higgs/EW/Top factories

- TPC can provide hundreds of hits with high spatial resolution compatible, with PFA design (**low X_0**)
  - $\sigma_{1/pt} \sim 10^{-4}\ (GeV/c)^{-1}$ with TPC alone and $\sigma_{point} < 100\mu m$ in $r\phi$
- **Provide dE/dx and dN/dx with a resolution** <4%
  - Essential for Flavor physics @ Tera Z run

TPC track detector for e+e- collider

Pad readout TPC
- To meet Higgs physics
- 1mm×6mm of Pad
- TPC module
- TPC prototype with UV laser

Pixelated readout TPC
- To meet Z physics
- ~500µm of Pad
- TPC prototype with UV laser track
- dN/dx+dE/dx study



Ion back flow study
- Simulation of Ion Backflow
- Test the UV light created the ions by photoelectric effect
- Experimental study

PID performance Study
- Simulation of the ionization cluster in space
- PID studies of the different readout TPC prototype
- Experimental study

Key issues of TPC technology for e+e- collider

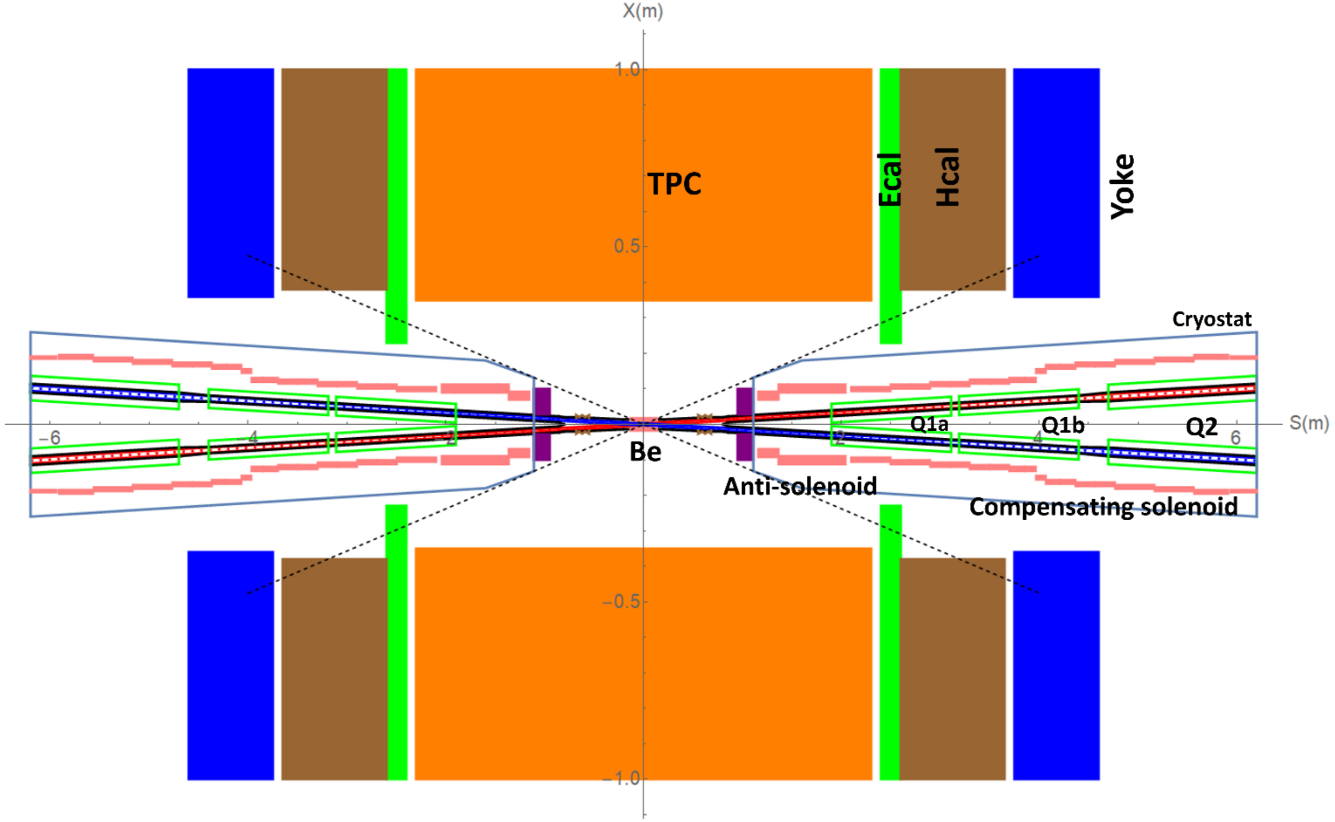
- **Estimation of the beamstrahlung background in Chamber**

e^+e^- colliders: Sources of Detector Backgrounds

- Beam-beam interactions (disrupted primary beam, **beamstrahlung photons,** e+e- and mu+mu- pairs and hadrons from **beamstrahlung** and gg interactions, and extraction line losses) and radiative Bhabhas
  - e+e- $\longrightarrow$ qq
  - beamstrahlung background

3.0T for Higgs

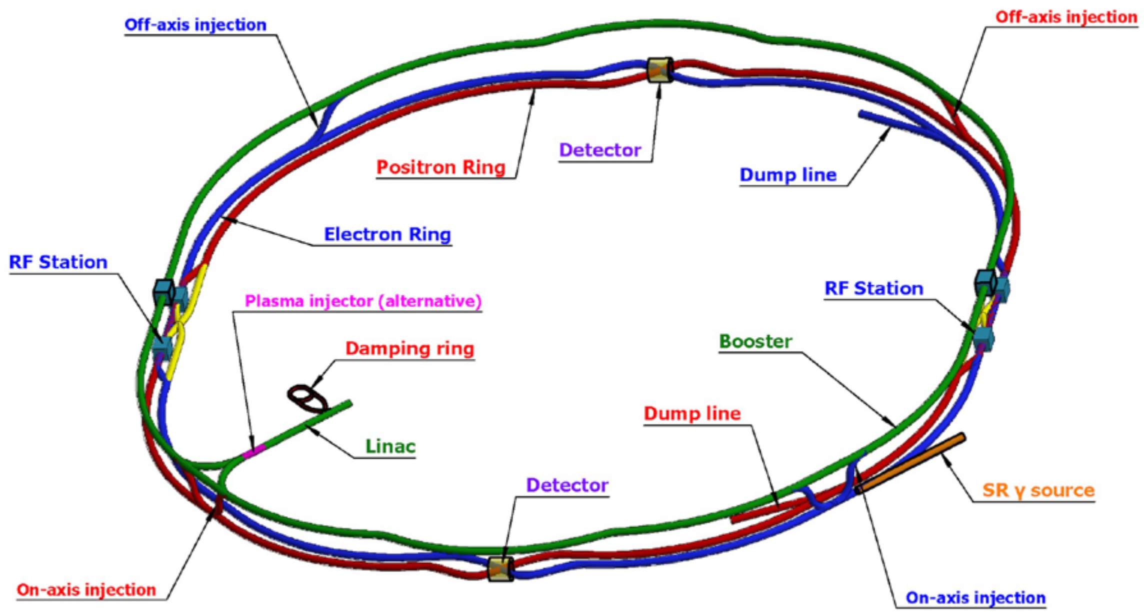
2.0T for Z
High luminosity (10^{36})
Beam crossing angle of 33mrad

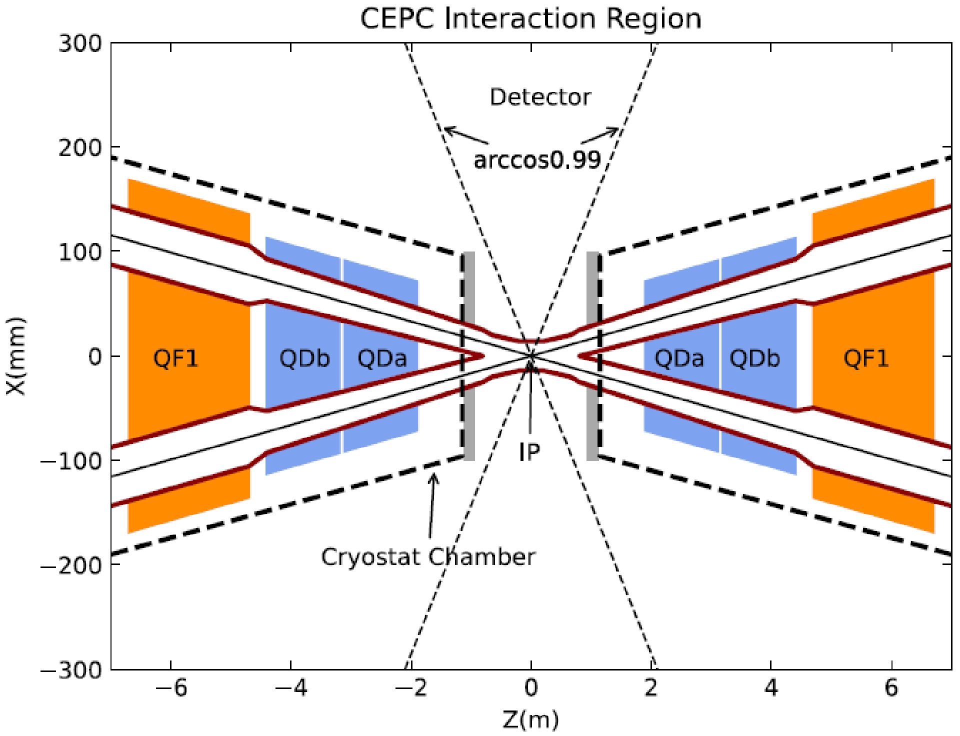


MDI of CEPC (TDR)

- MDI stands for ”Machine Detector Interface”
  - Interaction Region and other components
  - 2 IPs
  - 33mrad Crossing angle

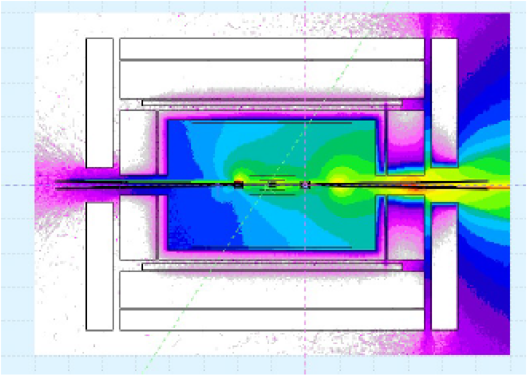
	ILC	FCCee
crossing angle	14 mrad	30 mrad
L* [distance from IP to last accel focusing quadupole magnet]	4.1 m	2.0 m
detector solenoid	3.5 T	2.0 T
additional B-fields	anti-DID (?)	- compensating - screening





Detector Simulation from CEPC

- The full detector simulation has been performed.
  - Baseline detector using Mokka/Marlin is updating.
  - 4th detector concept using CEPCSW is performing.
- The impacts on noise caused by beam backgrounds on detector performance need to be noticed.
  - ~50x of physics signal rates @ TPC z-pole



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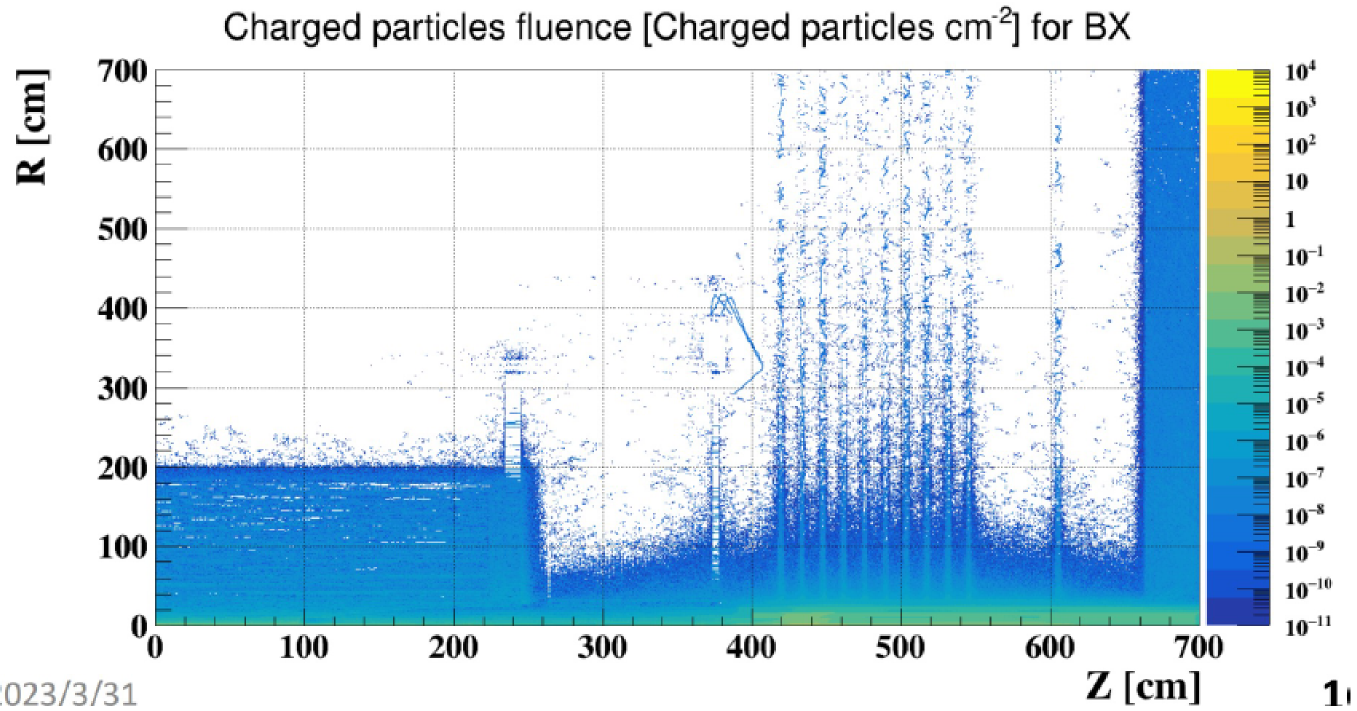
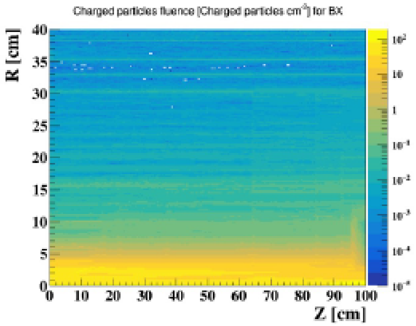


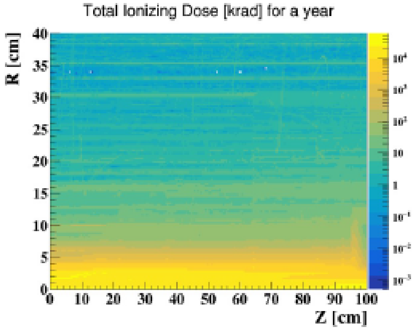
From the Beam-Gas scattering

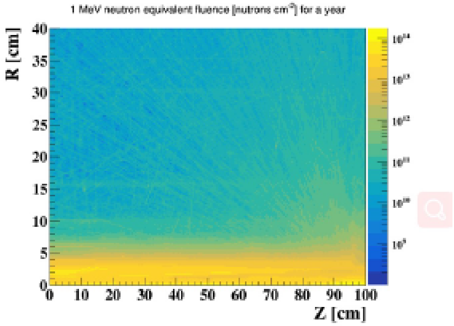
- for the Higgs mode

Fluence is flat along the Z axis

- Secondary scattering particles
- Backscattering

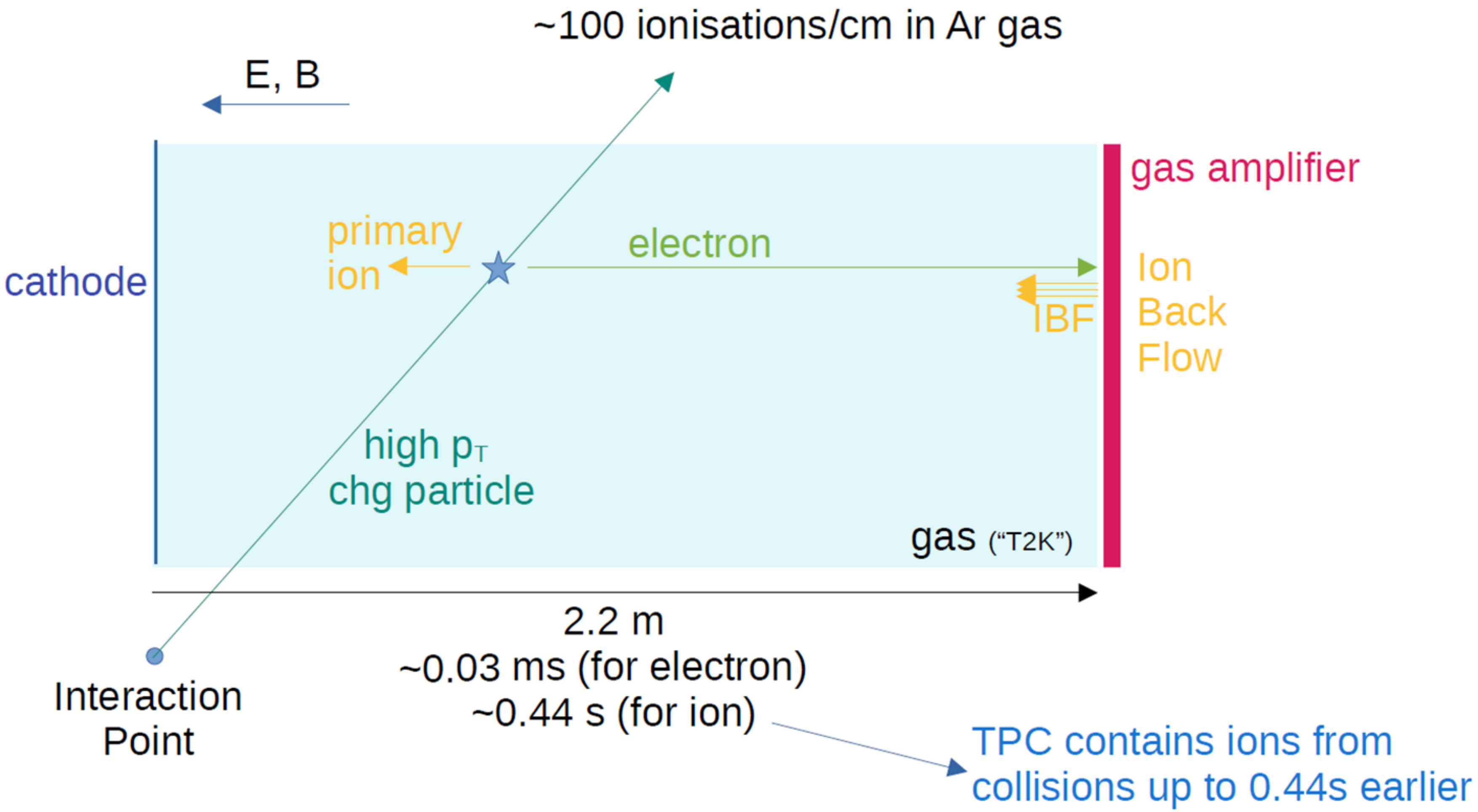






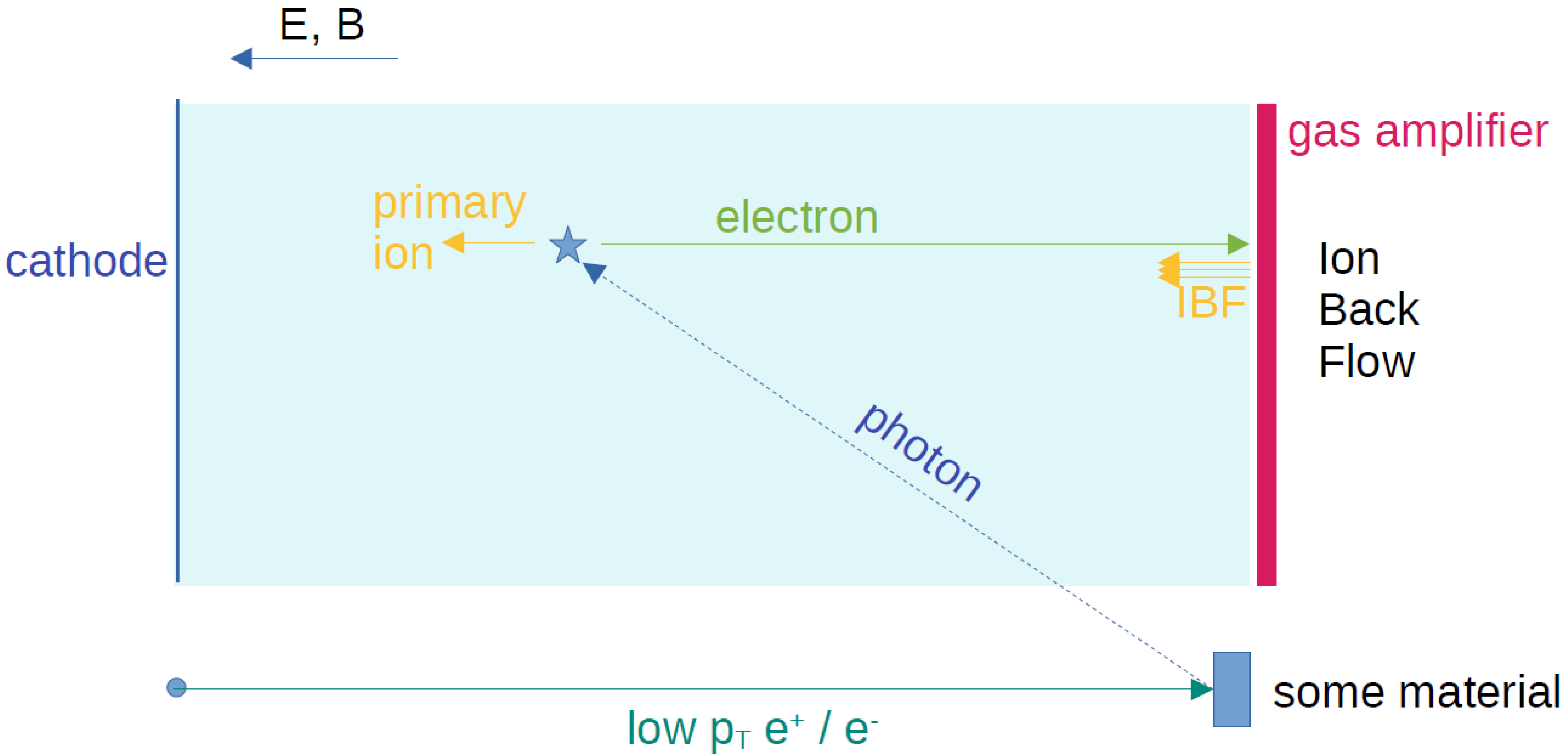
CEPC TPC operation

- CEPC TPC maximum drift length:2.225m Volume: 39.11m^3



Beam backgrounds in TPC

- Usually small $p_t \rightarrow$ particles do not reach TPC directly

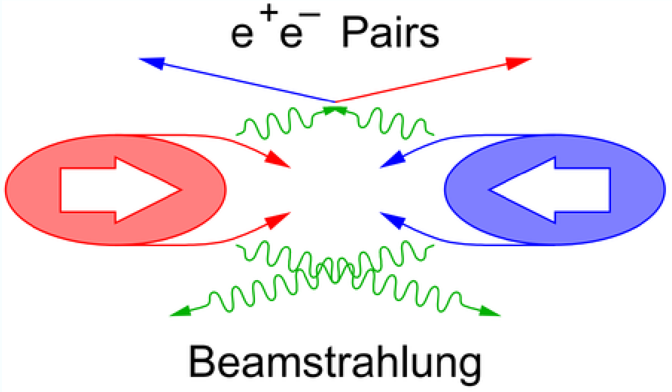


CEPC TPC本底效应模拟

- Beamstrahlung background in TPC
  - :**GuineaPig** Higgs@240GeV / Z-pole@91GeV
  - Version: CEPC_V4
  - Magnetic field： uniform 3 (Higgs run)/2T (Z pole run)
  - MDI
    - Optimization of LumiCal position
    - Optimization of the shield

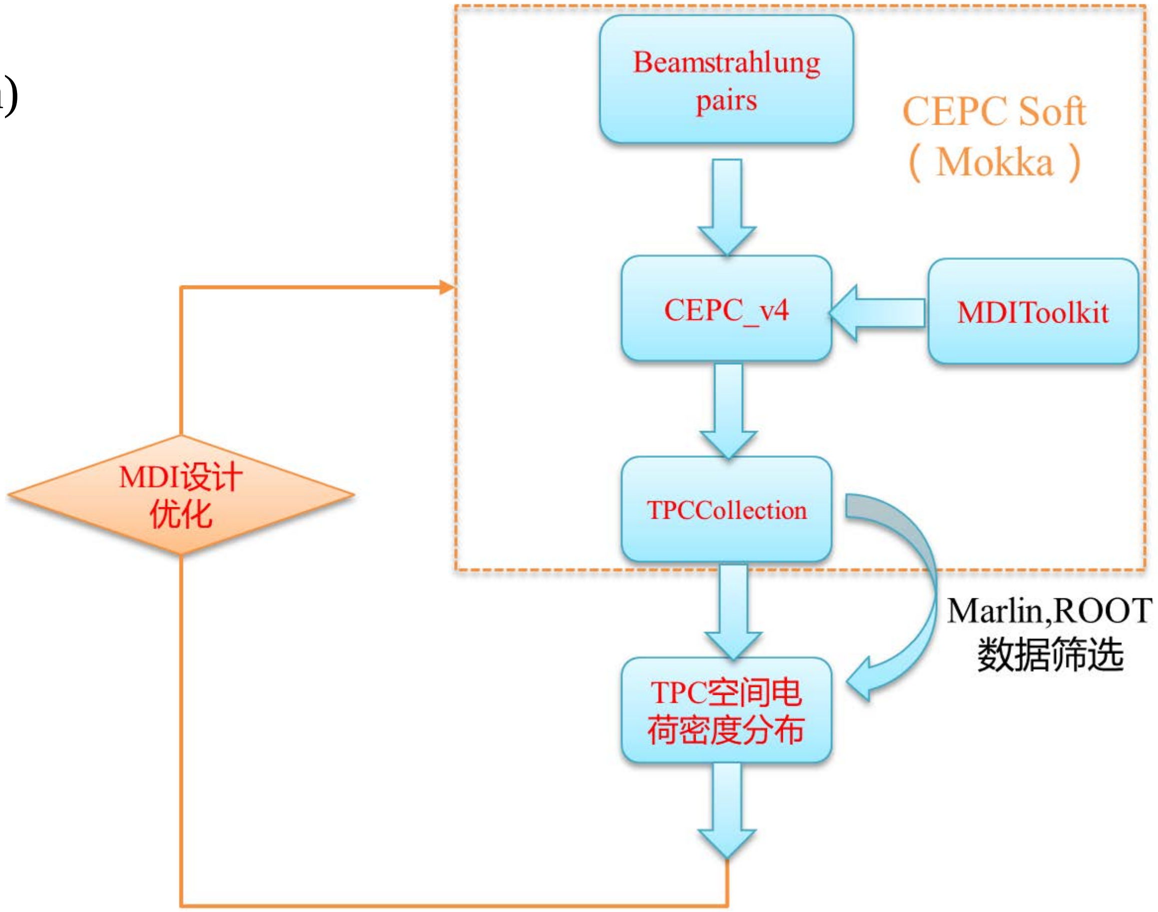
Beamstrahlung

In order to achieve the required luminosity ($1.8\times10^{34} cm^{-2} s^{-1}$) at CEPC, the section size of electron and positron beam will be squeezed to be very small at the interaction point. As a consequence, the trajectories of the electrons/positrons in each bunch will be bent significantly by the electromagnetic field that is formed by the beam particles of the opposite charge inside the crossing bunch. During this process, a particular kind of synchrotron radiation, called "beamstrahlung", will be emitted.



The emitted photons might further interact with each other through pair production and hadronic processes. The pair production was considered to be the dominant backgrounds induced by beamstrahlung.

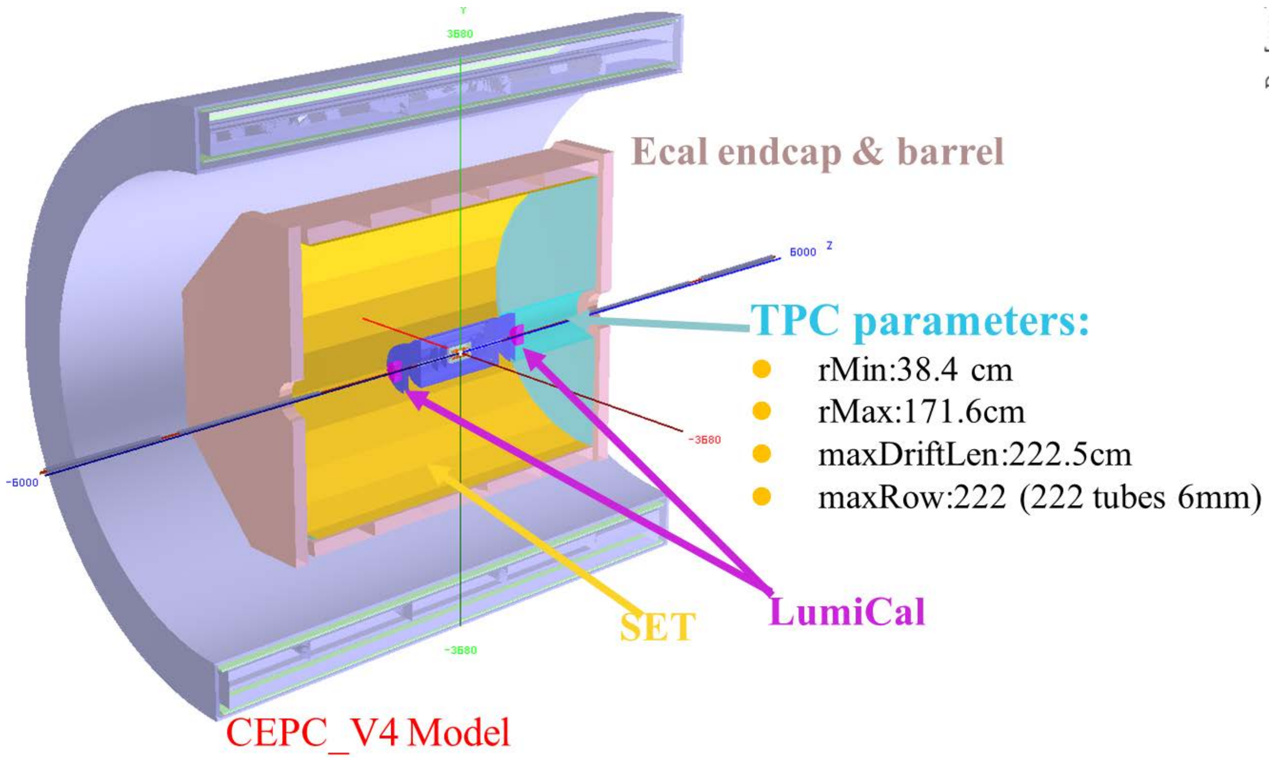
- **Pair Production**
- **Hadronic Backgrounds**

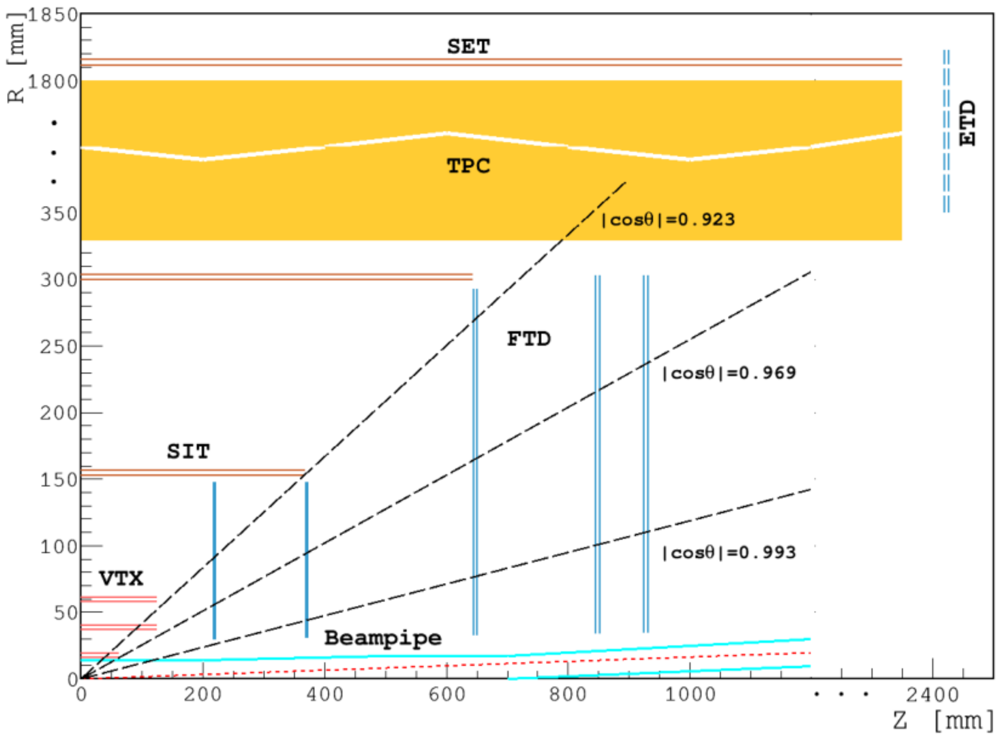


estimate number of **primary ions** produced in the TPC per bunch crossing
→ geant4 energy deposit / effective ionisation potential of Ar [26 eV]

CEPC Machine Detector Interface

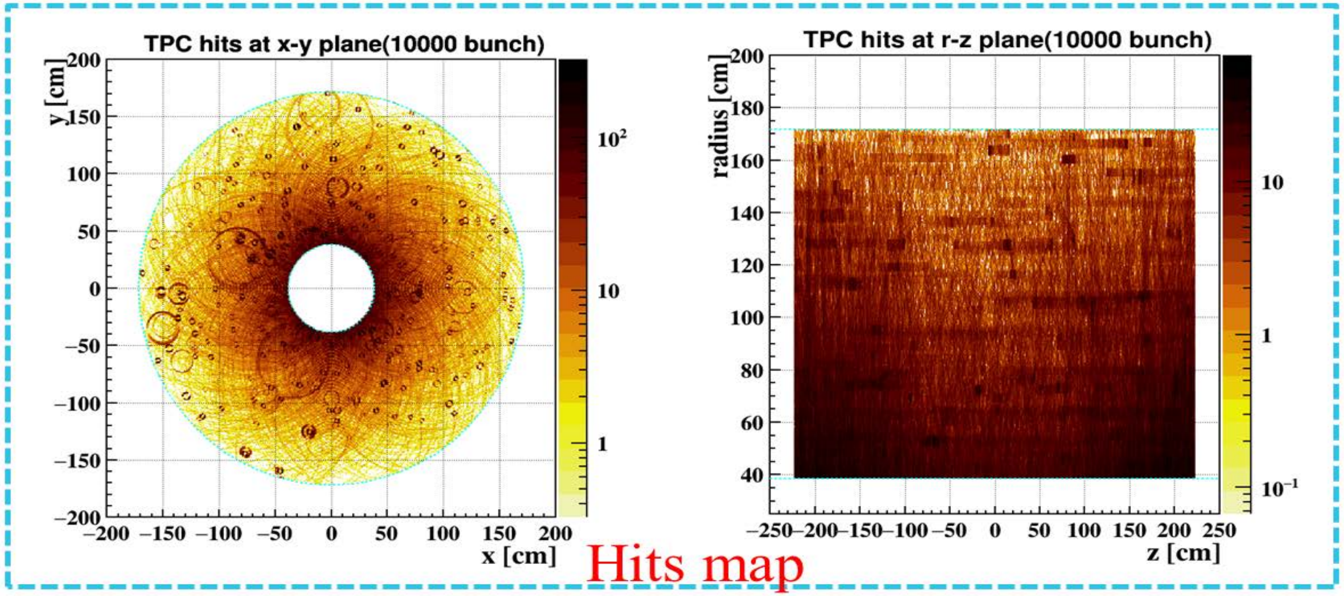
- Detector Concept
  - CEPC_v4 @ Z-pole 91GeV
  - Magnetic field: 2T (uniform), with QD0,QF0
  - TPC inner detector: with VTX,SIT,FTD,LumiCal(z=1.016m)
  - TPC outter detector: with SET,ECal,ETD,Coil

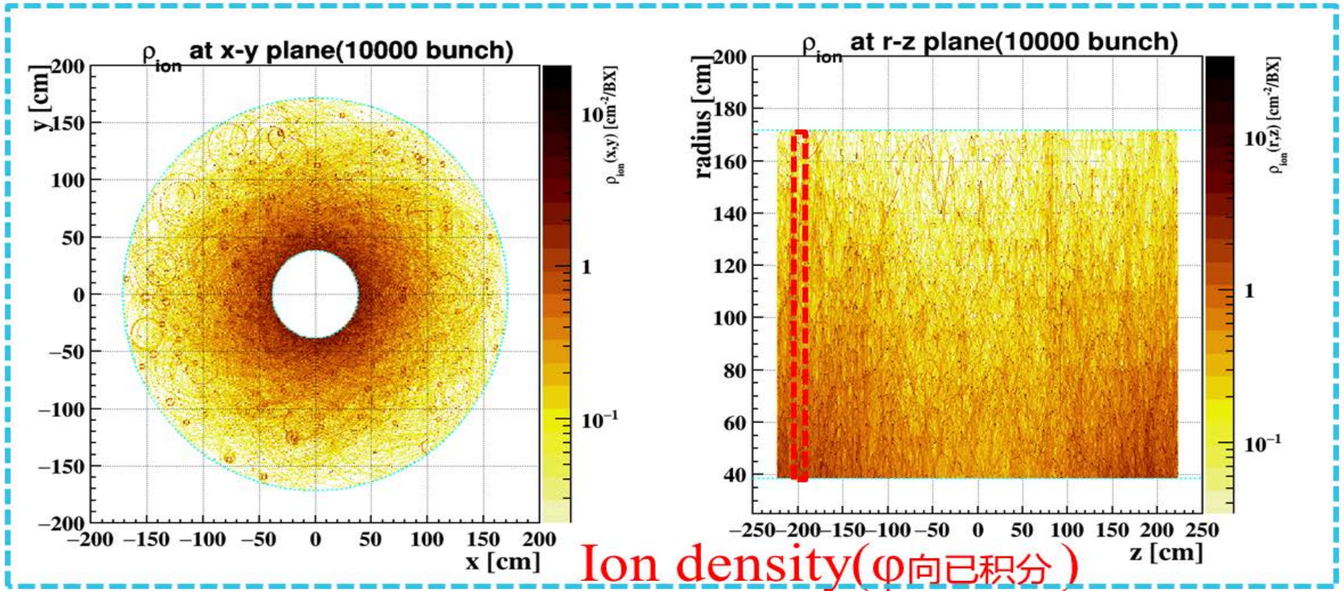




TPC hits/BX & ion density/BX@Z-pole

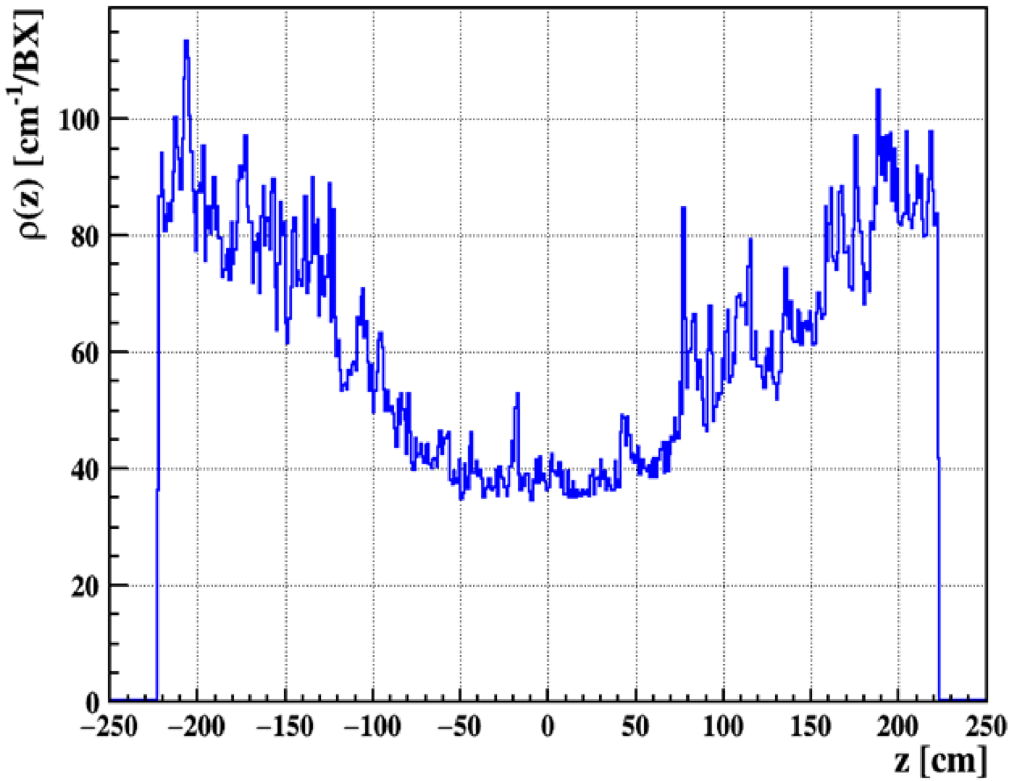
- Primary ions per bunch crossing in TPC
  - **10000 bunchs crossing**, ~3.8k tracks,~1e+6 hits in total
  - Edep ~7.12GeV in total
  - Number of primary ions:
    - Edep/effective ionization potential of Ar **[26eV]**
      ~27.37k ions/BX

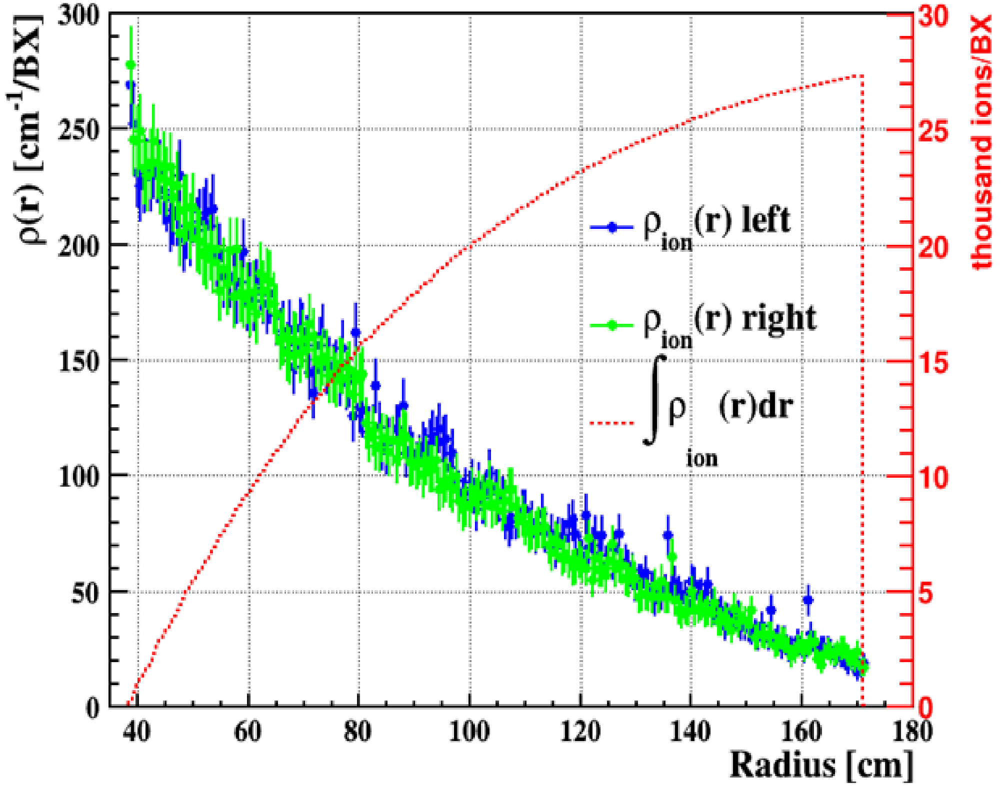




TPC hits/BX & ion density/BX@Z-pole

- **Primary ions** per bunch crossing in TPC
  - Ion density in TPC chamber
    - Same in the left and right chambers of the TPC chamber
    - Each bin (6 mm) represents the ion number density of the TPC per sample of delta-r





$\rho_{ion}(z), \rho_{ion}(r)$ distribution

Estimate number of primary ions produced in the TPC per bunch crossing

- TPC integrates over many collisions; maximum ion drift time ~ 2.225m/(5cm/ms)=0.044s
- Roughly estimate number of primary ions in the CEPC TPC volume at any time, taking account of different collision rates
  - Number of Ions ~Primary ion/BX · BX $frequency$ · 50% [ion already reached cathode]
  - BX $frequency$ = 1/23ns ~43.5MHz
  - Primary ions in TPC at any time 5.95×10^{11}
  - Average primary ion charge density 2.43 nC/m^3 (Reference of Daniel's talk)

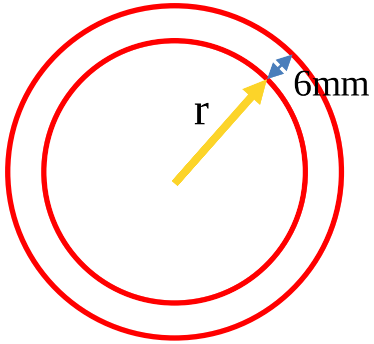
Collider Detector Model	CEPC_v4 with LumiCal
Beamstrahlung pairs	CEPC Z-pole (91GeV)
BX freq.	1/23 ns
primary ions/BX	27.37 k
primary ions in TPC at any time	5.95×10^{11}
average primary ρ_{ion} [nC/m^3]	2.43

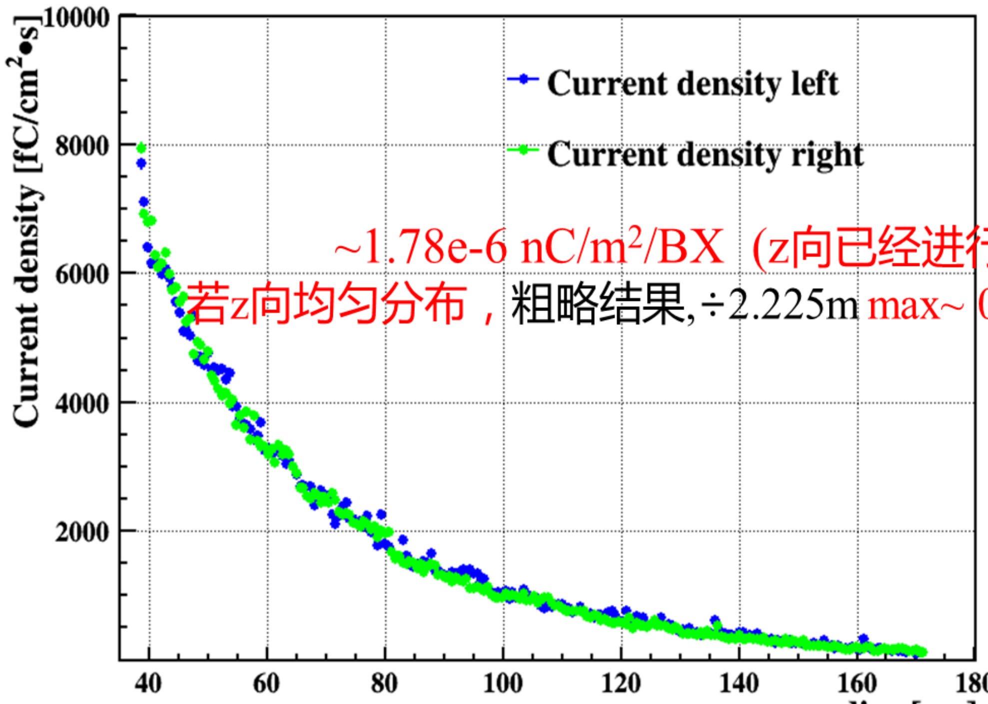
Estimation of Ion charge density/BX @ Z-pole (91 GeV 2T)

- **Primary ions** charge density/BX
  - TPC inner detector: with

Current density = $\rho_{ion}(r) \cdot 6mm \cdot e \cdot$ BX $frequency \cdot 10^{15}/(2\pi r \cdot 6\text{mm})$ [fC/cm^2·s]

  - BX $frequency = 1/23ns \sim 43.5MHz$
  - **Max. Current density ~ 8 pA/cm^2**

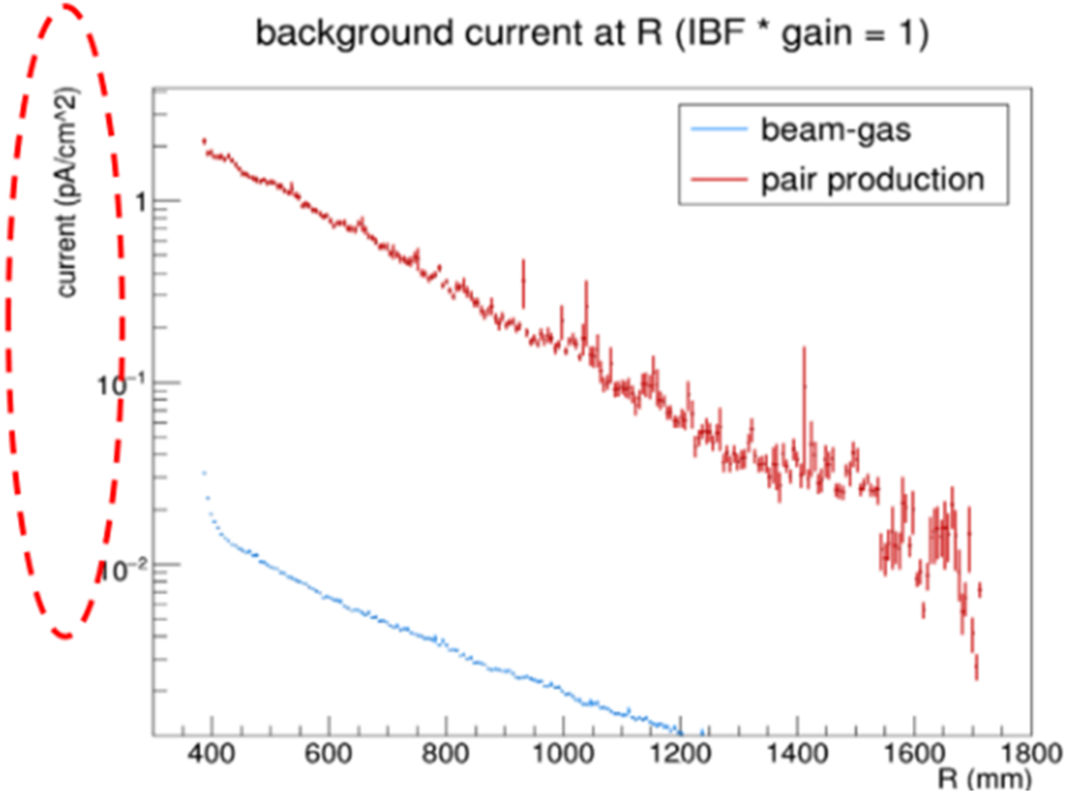




~1.78e-6 nC/m^2/BX (z向已经进行积分)

若z向均匀分布，粗略结果,÷2.225m max~ 0.8e-6nC/m^3/BX

Ion current density distribution



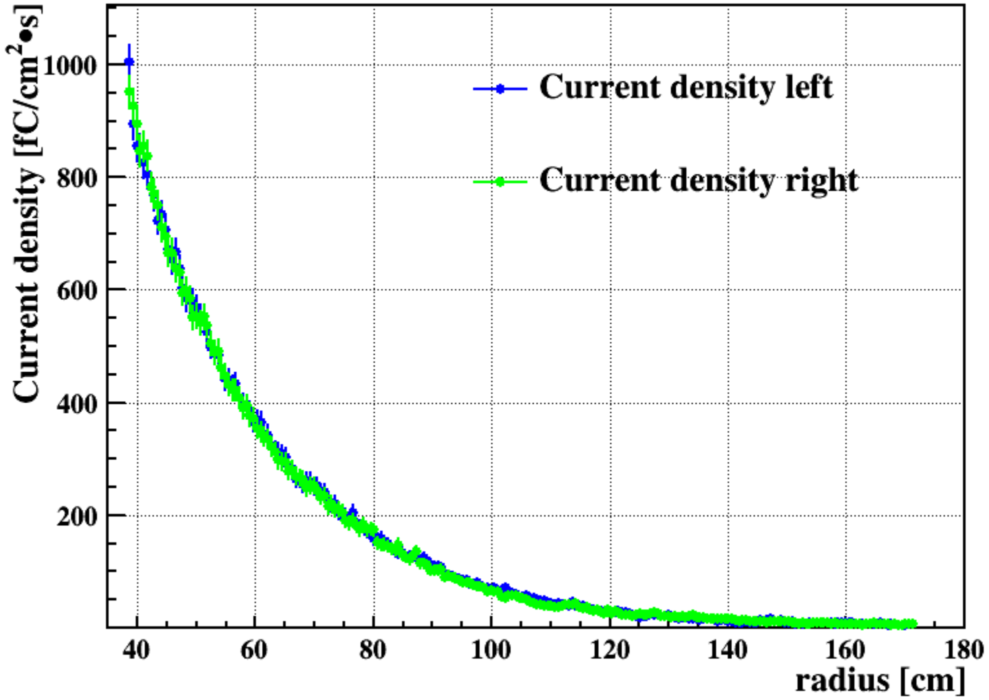
电离效率70%+Gain*IBF估算结果

Estimation Ion charge density @ Higgs (240 GeV 3T)

- **Primary ions** charge density/BX
  - Each bin: 6mm width

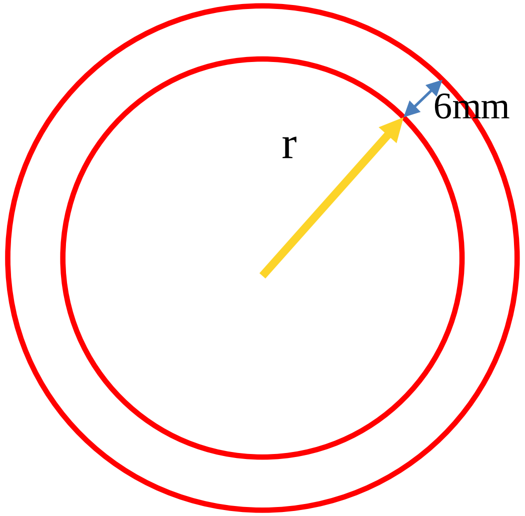
Current density = $\rho_{ion}(r) \cdot 6mm \cdot e \cdot$ BX $frequency \cdot 10\text{^}15/(2\pi r \cdot$6mm) [fC/cm^2·s]

  - BX $frequency$ = 1/680ns
  - **Max. Current density** <1 pA/cm^2



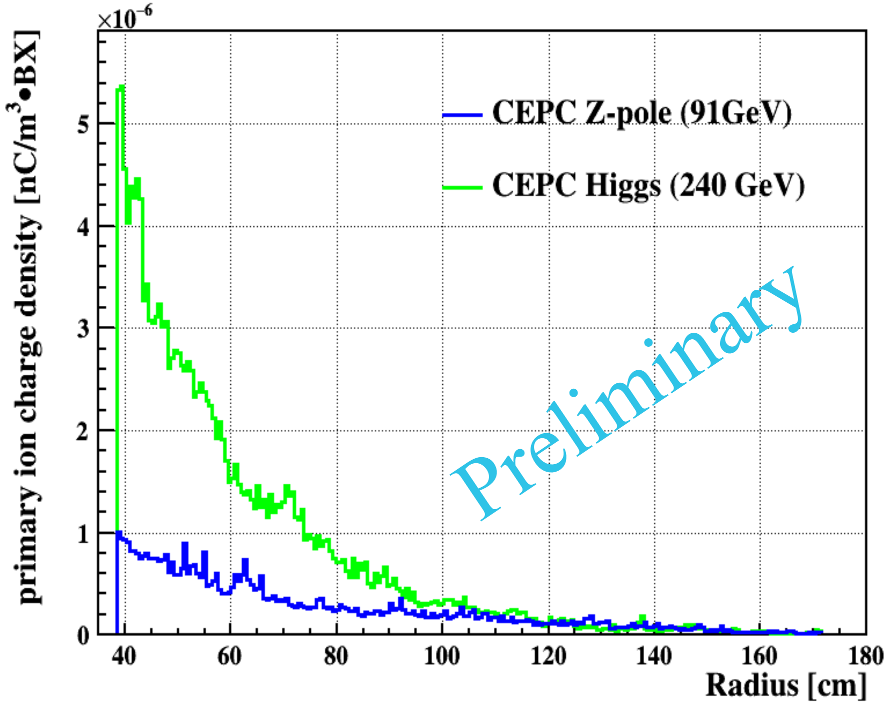
~6.58e-6 nC/m^2/BX (z direaction)

Estimation result: ÷2.225m max~ 2.96e-6nC/m^3/BX



Results of the estimation ion charge density

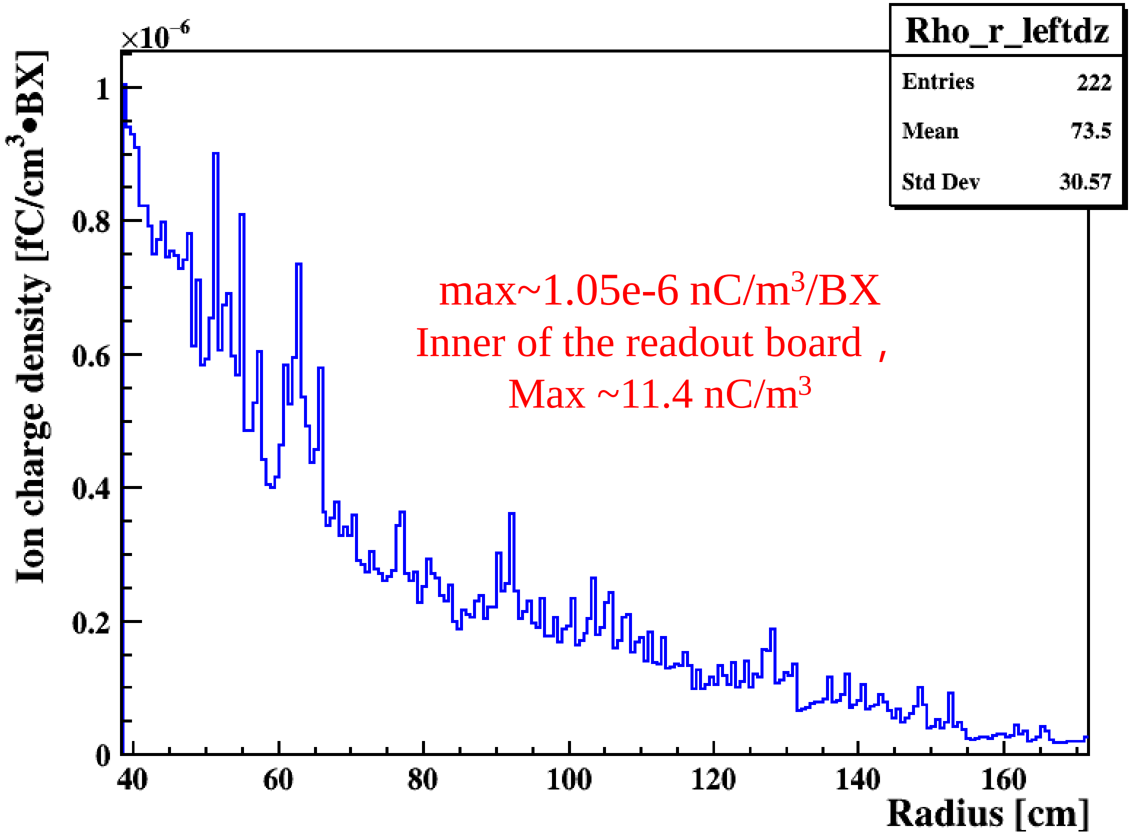
- **For Higgs run, no problem detector factor for TPC**
- **For Z pole run**
  - **TPC with IBF*Gain=1 at CEPC-91**
    → at best, less or similar space-charge as at ALICE



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	27.37 k	72.36 k
primary ions at any time	5.95×10^{11}	5.32×10^{10}
average primary ρ_{ion} [nC/m^3]	2.43	0.22
max (single BX) [nC/m^3/BX]	1.05×10^{-6}	5.4×10^{-6}
max (steady state) [nC/m^3]	11.4	1.98

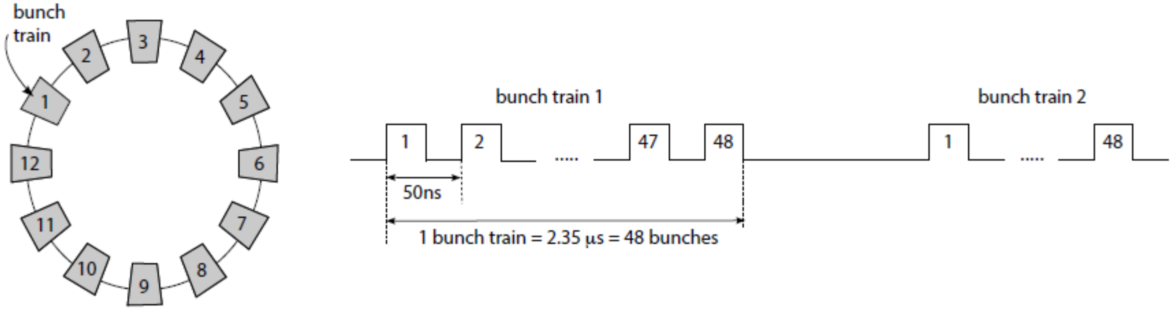
Compare to ALICE-TPC environment

- Calculation of TPC radial ion space charge density: z=-200cm， (dz=10cm，dr=6mm)
  - $d\Omega = 2\pi r\, dr\, dz$; $\rho_{ion} = \frac{n_{ion}}{d\Omega}$
- Each BX~ **1.05e-6 nC/m³/BX**，0.2e-6 nC/m³/BX (compared to uniformly distributed)
- Stable Max~ 1.05e-6 nC/m³/BX × 1/23ns × 50% × η = 11.4 nC/m³ (Only primary ions, η ionization efficiency)



ALICE TPC upgrade TDR: CERN-LHCC-2013-020

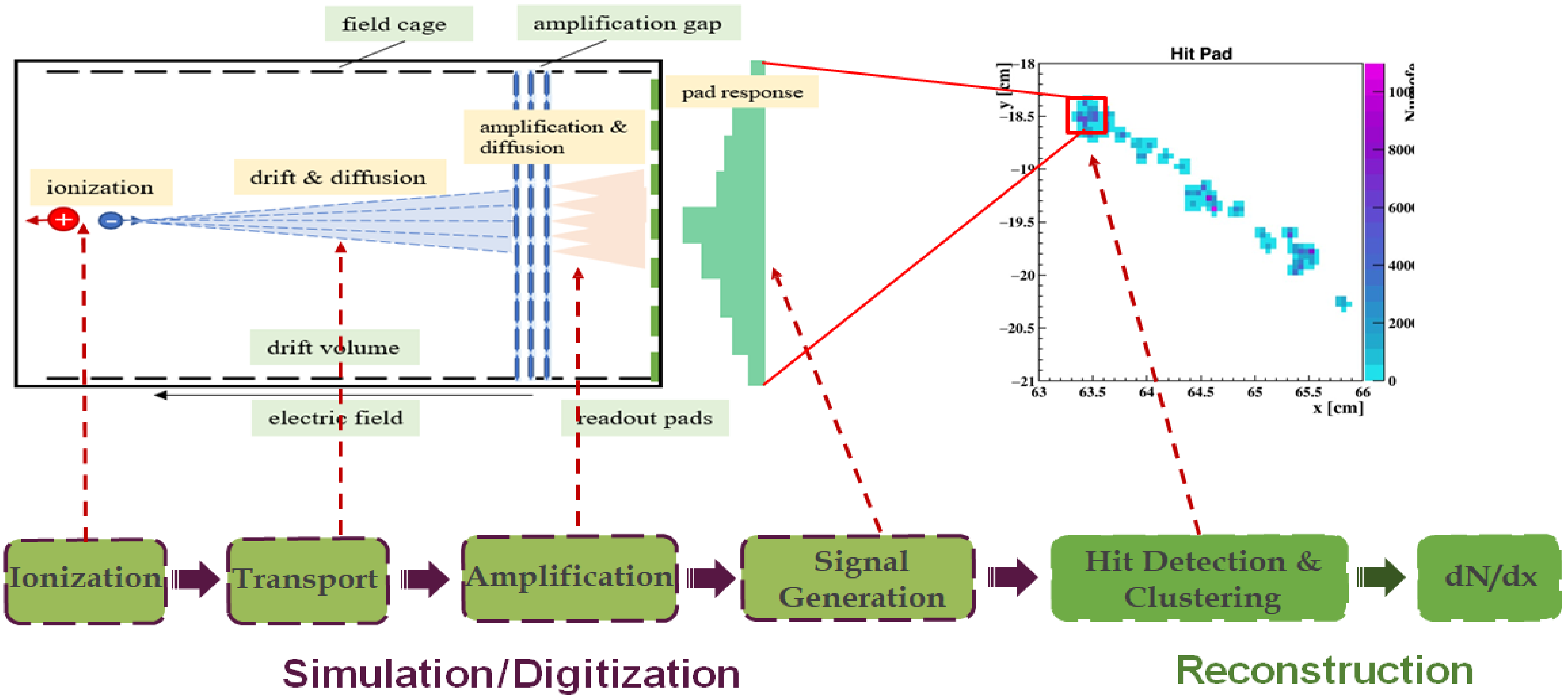
	max (single BX)	BX freq	max (steady state)
ALICE		50k	120 nC/m³ with IBF=20



- **Status and Plans of TPC R&D**

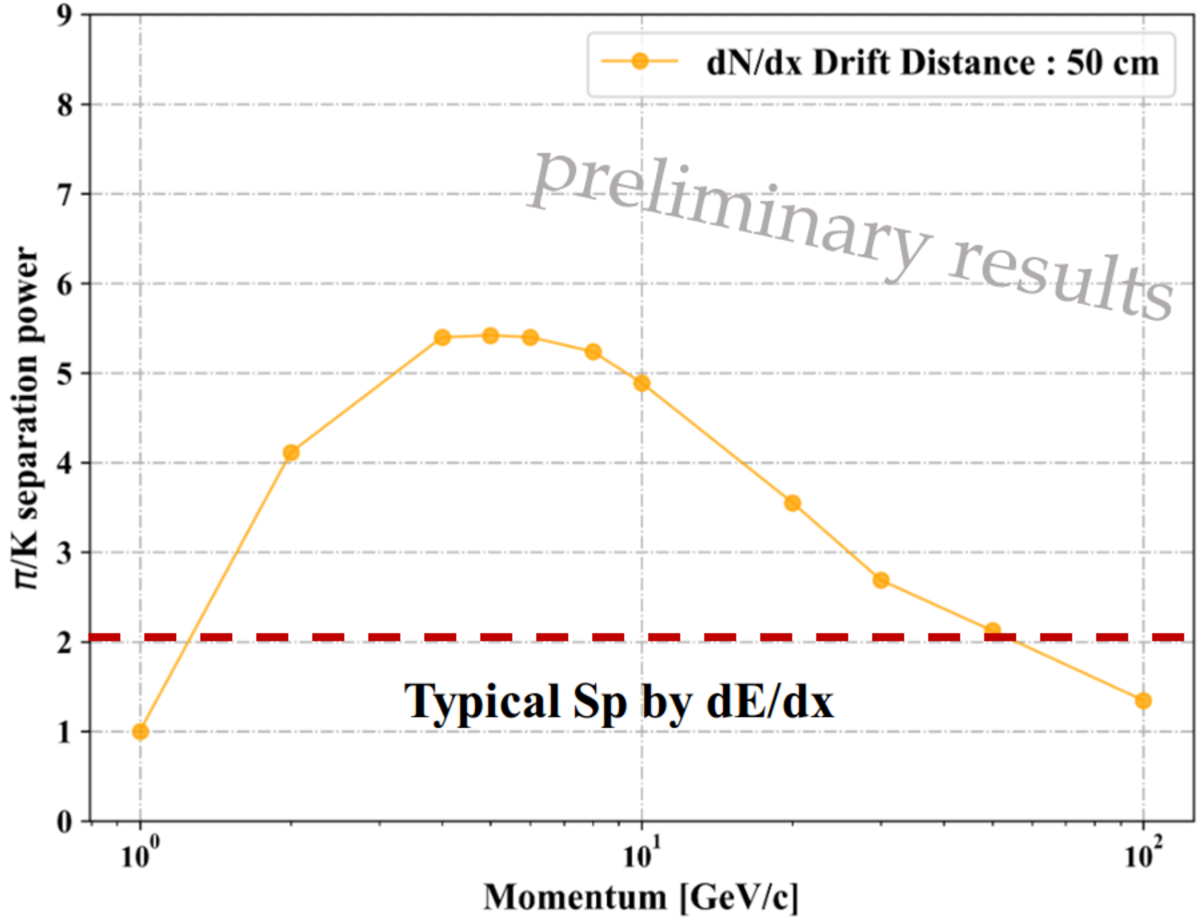
Simulation of the pixelated TPC - ongoing

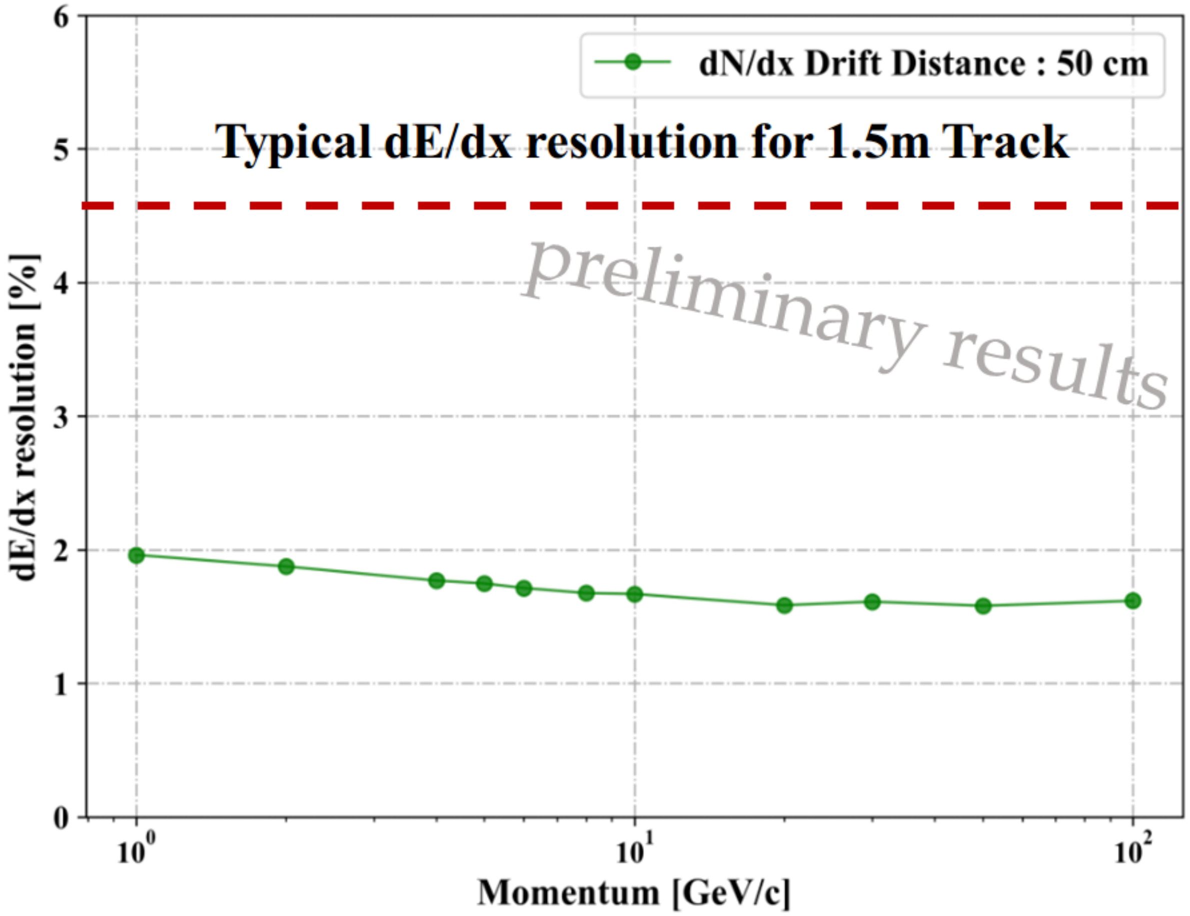
- All detailed simulation **starting** at IHEP using Garfied++ and Geant4
  - Setup the new simulation framework
  - TPC detecror module simulated **under 2T and T2K gas** from CEPC CDR



Simulation of the pixelated TPC - ongoing

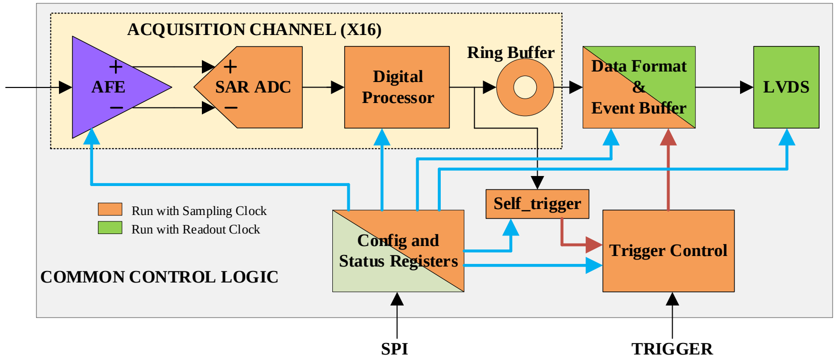
- Separation power was obtained based on the current reconstruction algorithm as well as the results of the resolutionSetup the optimaztion simulation framework.
- π/K resolution **is better than 3σ at 20 GeV and 50 cm drift distance**.
- The dN/dx has an **good potential** to improve the resolution.

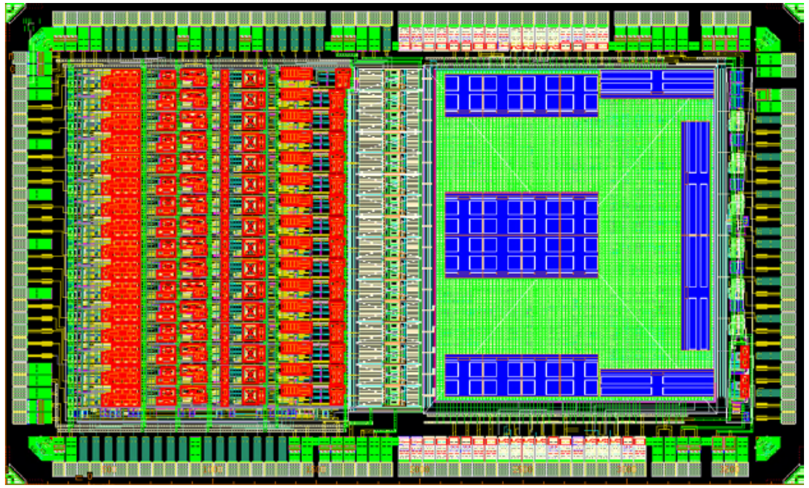


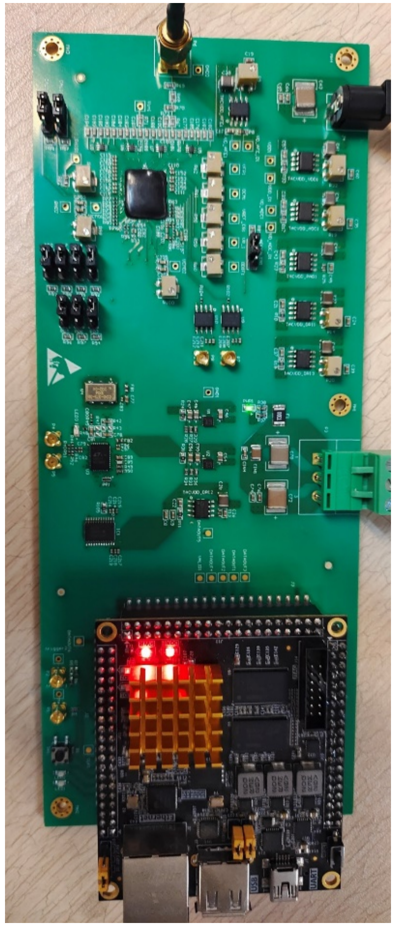


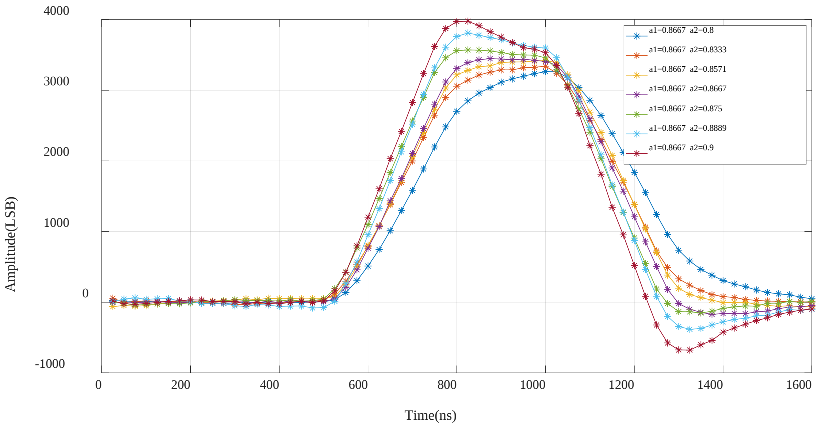
Progress on the : low power FEE ASIC

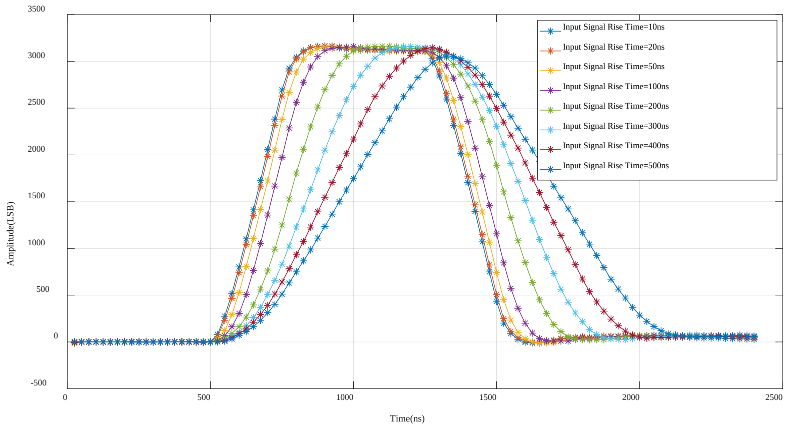
- WASA: waveform sampling front-end up to 40MSPS, 10bit, less than 5mW/ch
- More electronics tests in 2023 such as programmability on digital shaping





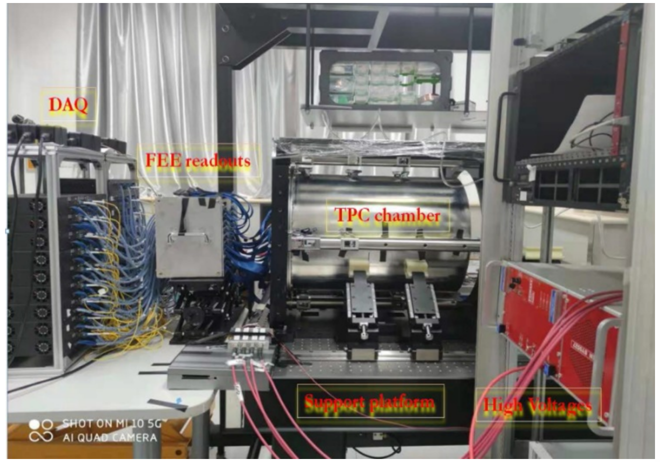


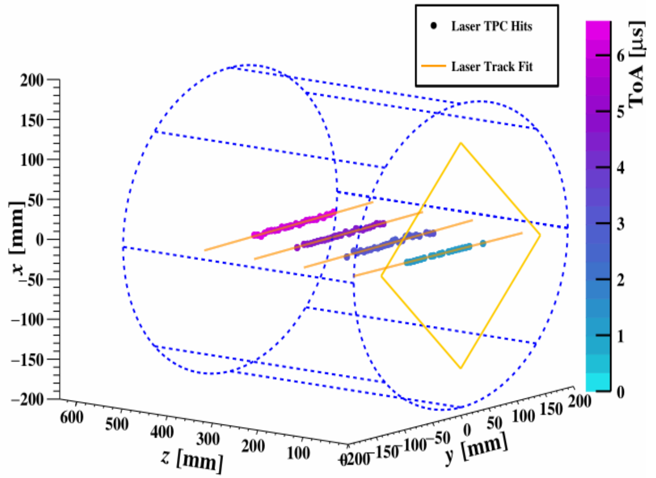


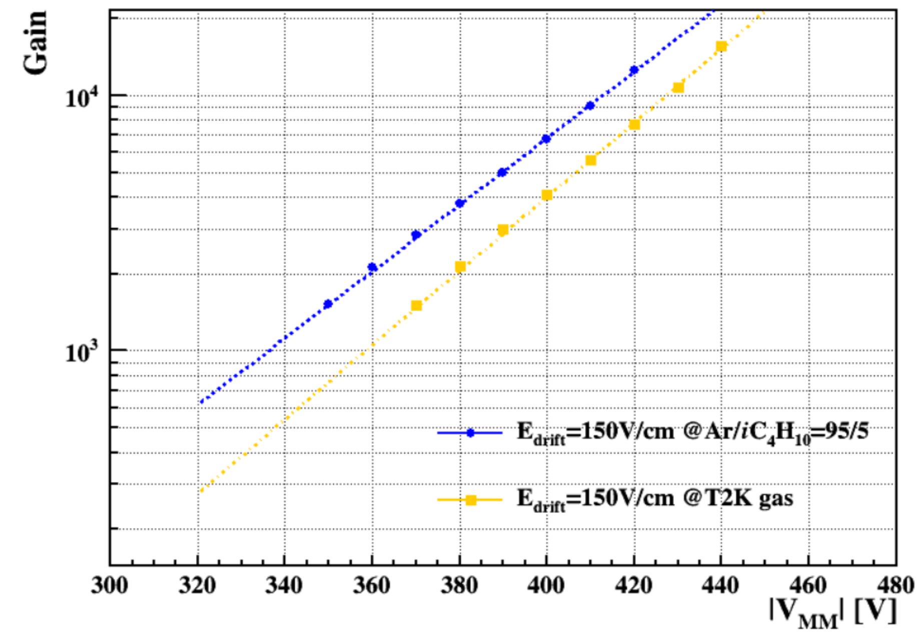


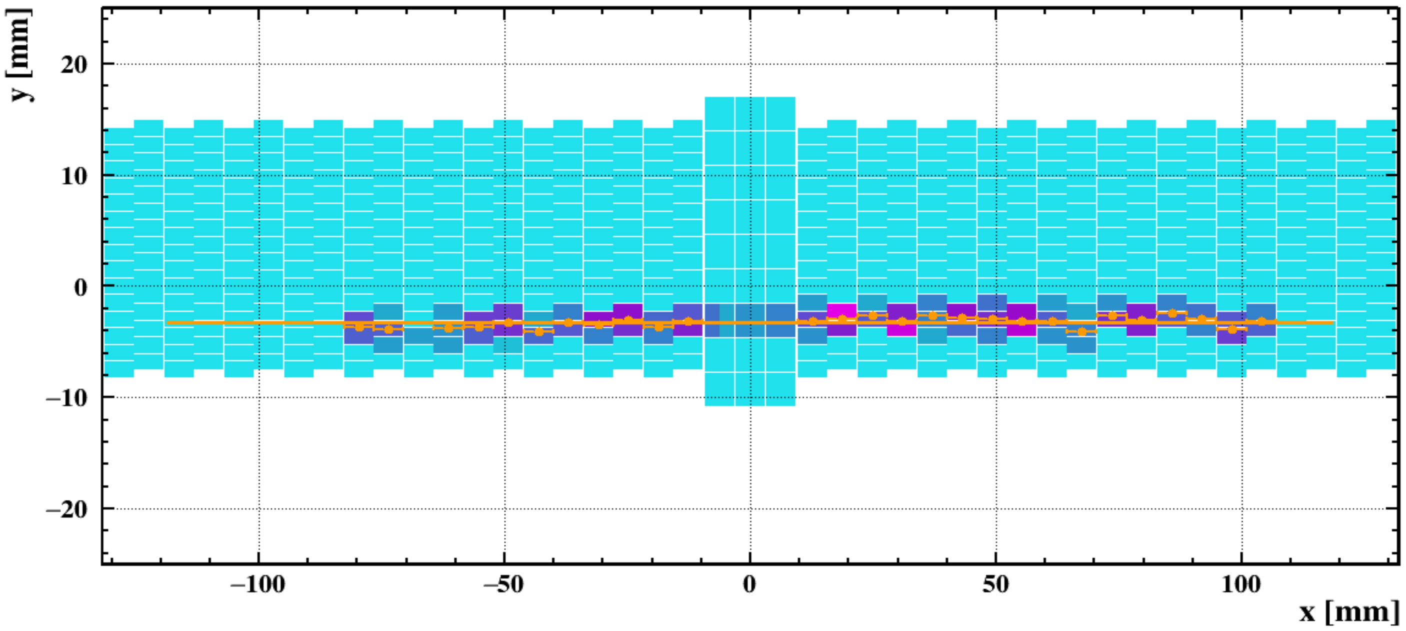
Progress on UV laser track at TPC prototype

- New **Micromegas detector as the readout** with the pad readout electronics (>1000 channels)
- **Gain and the 266nm UV laser track** studies have been completed using the TPC prototype
  - Operation gain at <2000
  - T2K gas and Ar/Iso gas





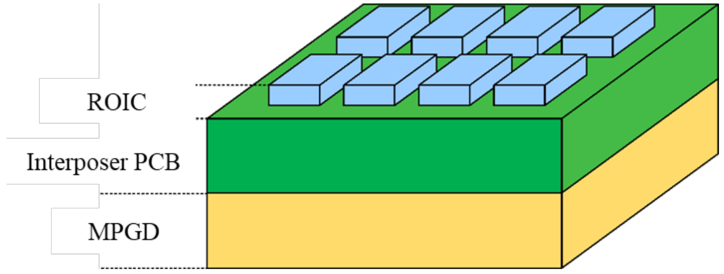


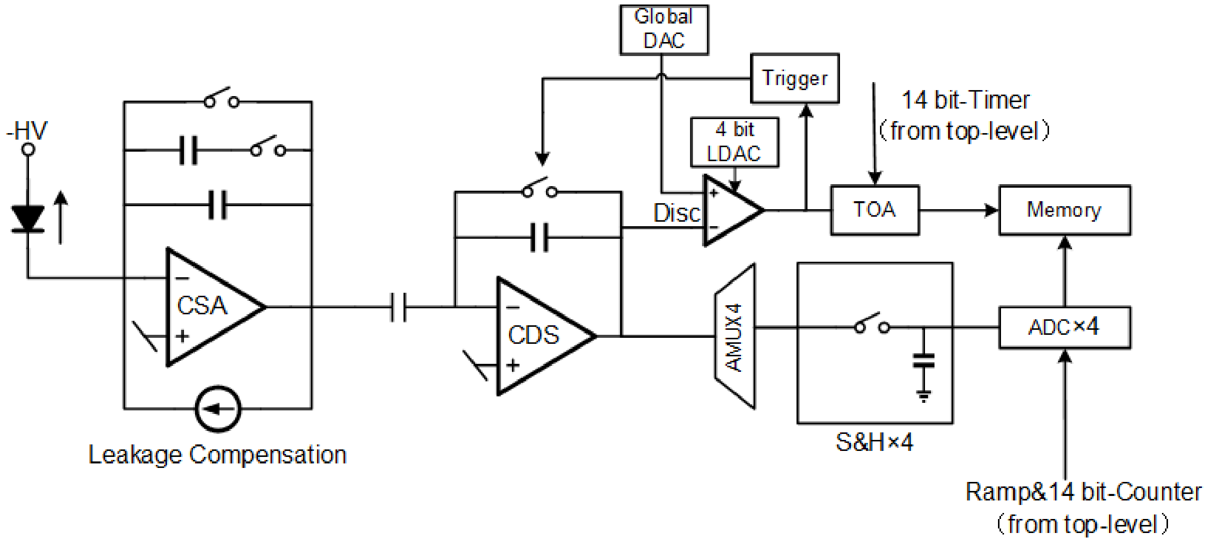


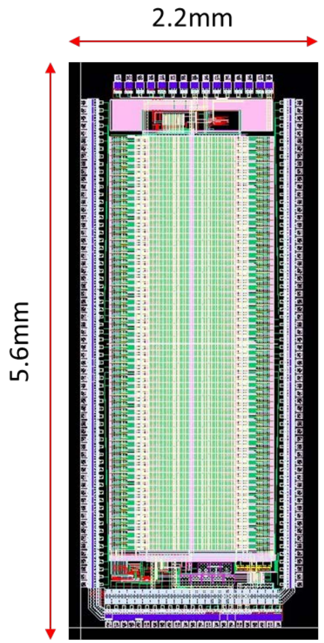
Gain and 266nm UV laser track at TPC prototype

Progress on pixel readout electronics in 2023

- **Pixel readout R&D started and the design and testing of two versions of the chip completed.**
- ROIC +Interposer PCB as RDL
    - High metal coverage, 4-side buttable
    - Low power Energy/Timing measurement ASIC
    - **~100 e noise**
    - 5 ns drift time resolution
    - **<100 mW/cm2**
- 2nd version chip arrived and the tests are onging.



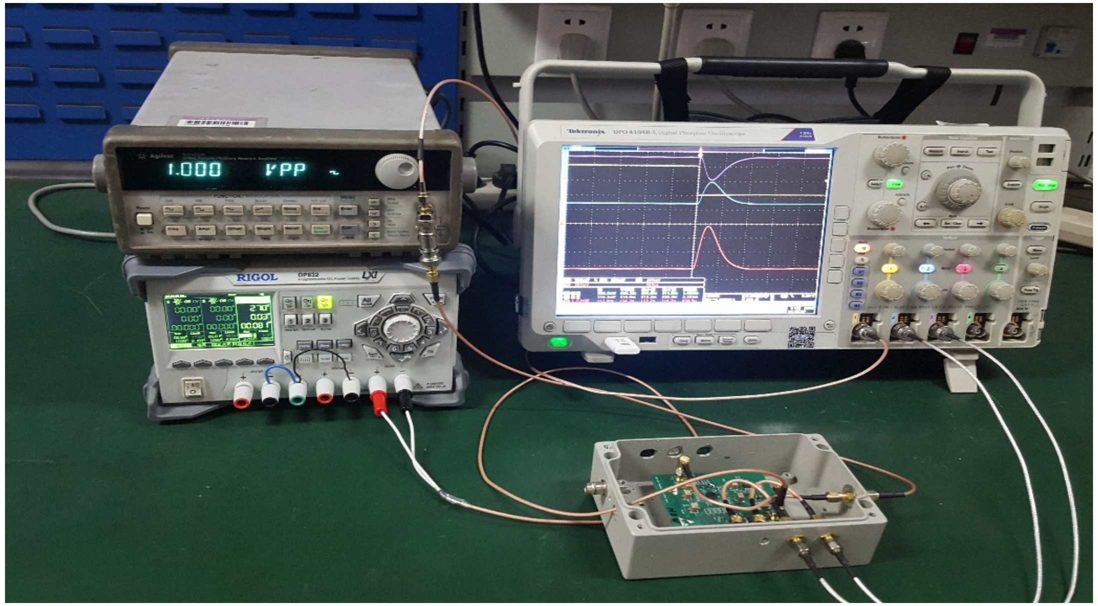


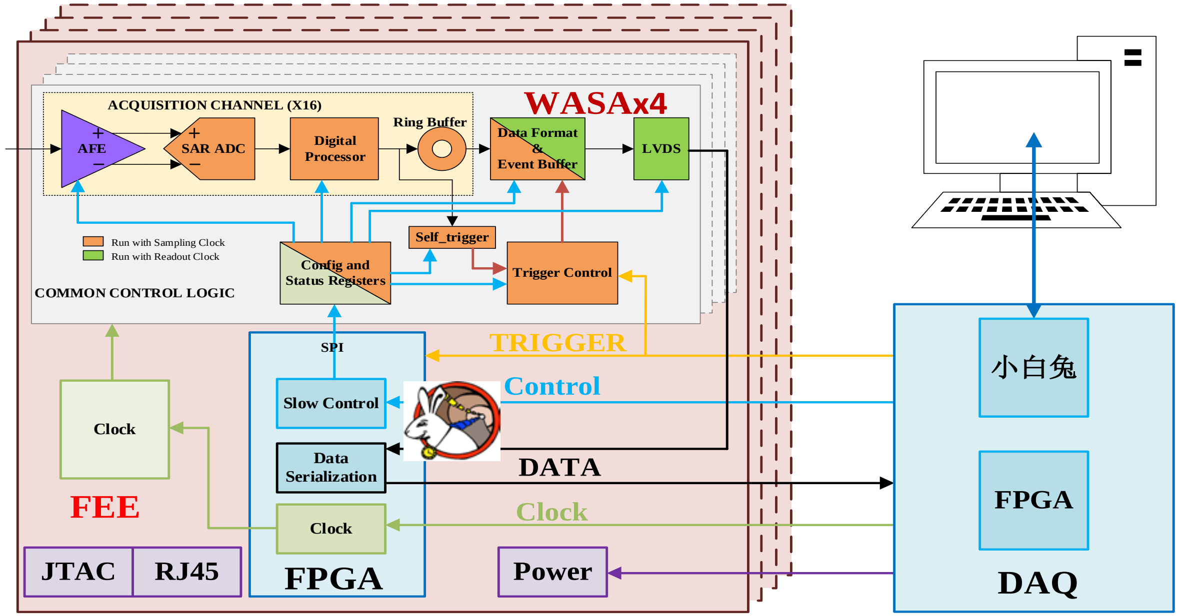


TPC R&D toward CEPC Phy.&Det. TDR

- Simulation and experiments studies needed for **CEPC TDR**.
  - MDI region optimized, lower Gain×IBF and reach the same level primary ions(Gain: 2000, IBF: ~0.1%)
  - TPC with IBF at Tera-Z with **quasi continuous collisions** @ CEPC/FCCee
    - Apply Micromegas+GEM , mutil-mesh Micromegas
    - Nano-material through which ions can be controlled
      - Ion backflow R&D with the **Grapheme foil** → Collaboration: CEA-Saclay, Shandong University

- Low **power consumption** readout R&D of TPC FEE board based on WASA.
- Tests Low power Energy/Timing chip of the pixel readout chip. → Collaboration: Tsinghua University





Summary

- In CEPC TPC study group, TPC detector prototype R&D using the pad readout towards the pixelated readout for the future e+e- colliders.
  - To analyze the simulation data of the high luminosity Z pole run at CEPC, some update results of TPC prototype have been studies.

- TPC background from beamstrahlung:
  - same order per BX at ILC250 and CEPC
  - Average BX frequency: 4.5k times higher at CEPC\
  - CEPC-91 looks less or similar to ALICE-TPC environment

- For CEPC, we assume that gating will not be possible, so we need an ion back flow suppression without gating R&D (double or triple mesh/mutil-Mesh, graphene membrane...)
  - SDU/THU/USTC collaboration for CEPC Phy.&Det. TDR

Many thanks!