Update simulation and study of the pixelated TPC R&D for CEPC

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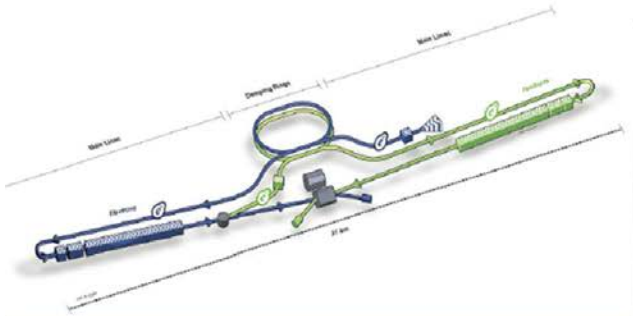
May 30, 2023

Content

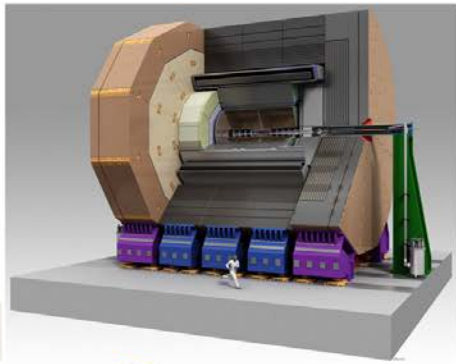
- **Motivation of pixel TPC detector**
- **Progress of the simulation and studies**
- **Updated status of the pixelated TPC**
- **Summary**

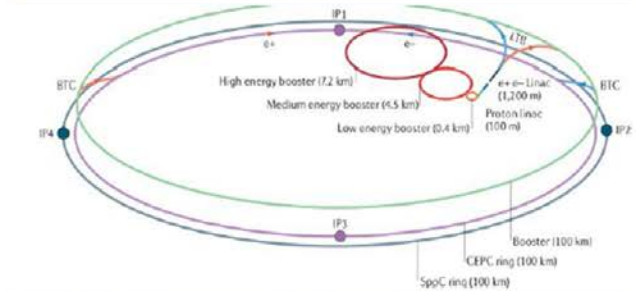
TPC technology for the future e+e- colliders

- A TPC is the main tracking detector for **some candidate experiments at future e+e- colliders**
  - Baseline detector concept of CEPC and ILD at ILC
- Pixel TPC is in the simulation package (MarlinTPC) **as the default track detector** in 2023
- TPC can provide hundreds of hits with high spatial resolution compatible, with PFA design (**very low material** in detector chamber)
  - $\sigma_{1/pt}$ ~10^{-4} $(GeV/c)^{-1}$ with TPC alone and σ_{point}<100μm in rϕ
  - Provide dE/dx and dN/dx with a resolution <4%

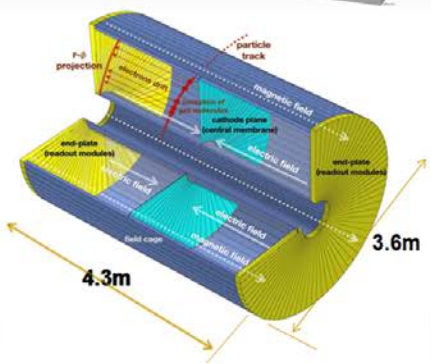


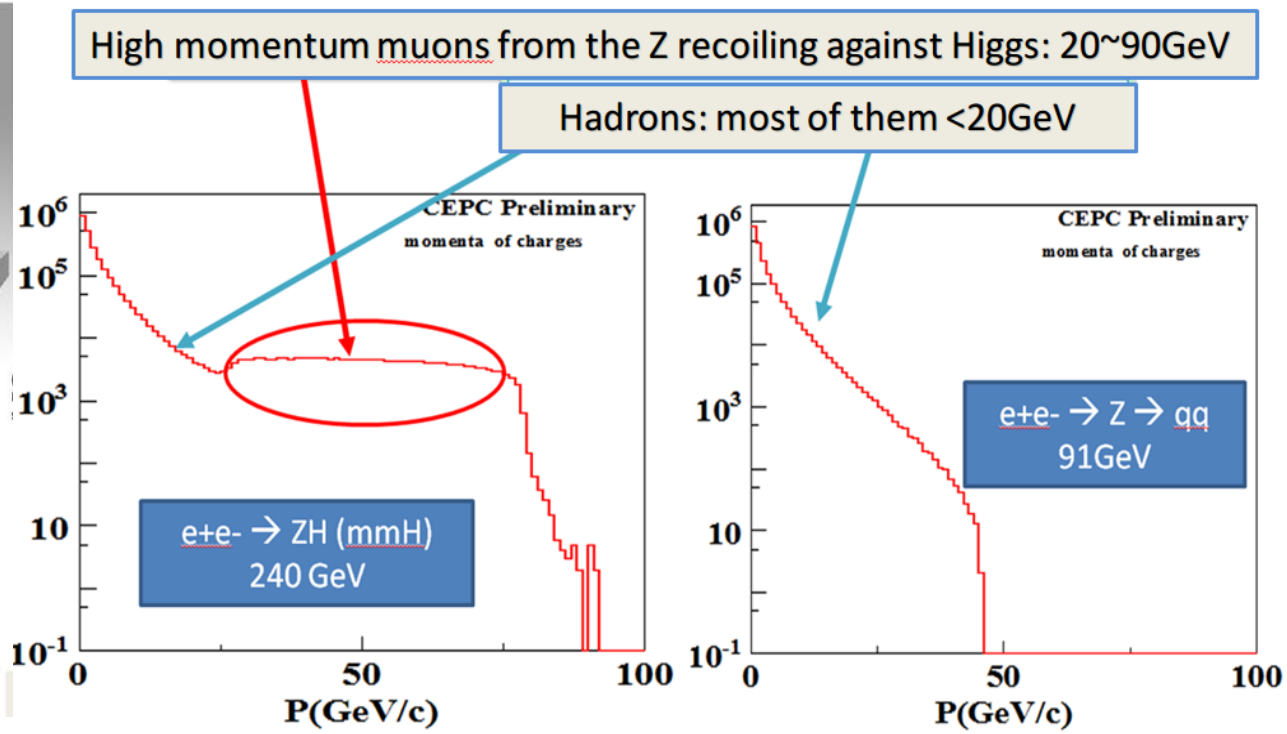
International Linear Collider (ILC)





Circular Electron Positron Collider (CEPC)





https://arxiv.org/abs/2203.06520

Investigation of the electrons/ions density at CEPC

- Simulation results based on CEPC's parameters (**High luminosity at Z pole: 10^{36}**)
- CEPC or others detector will meet the massive electrons/ions in the detector chamber
- To investigate and create the stable electrons/ions in the specific area to study the deviation
- Positive ion feedback in Z physics **(gain ~2000, IBF ratio ~0.1%, IBF × G ≤ 2)**

Electric field analysis

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\varepsilon} \longrightarrow$$

Cylindrical coordinates

$$\phi(r,\theta,z) = \sum_{m=-\infty,\infty} \phi_m(r,z) e^{im\theta},$$

$$\phi_m(r,z) = \int_{-\infty}^{\infty} \Phi_m(r,k) e^{ikz} dk,$$

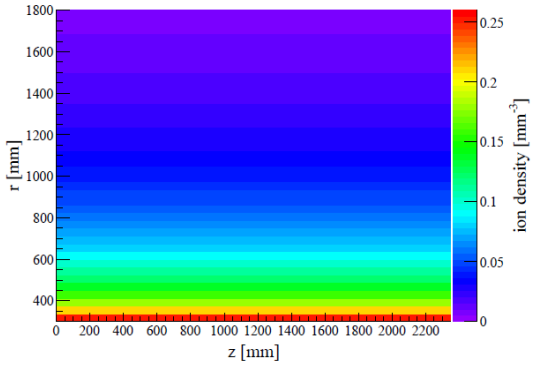
$$\Phi_m(r,k) = K_m(kr) \int_0^r R_m(r',k)\, I_m(kr')\, r'\, dr' + I_m(kr) \int_r^{\infty} R_m(r',k)\, K_m(kr')\, r'\, dr'$$

$$R_m(r',k) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \rho_m(r',z')\, e^{-ikz'} dz'$$

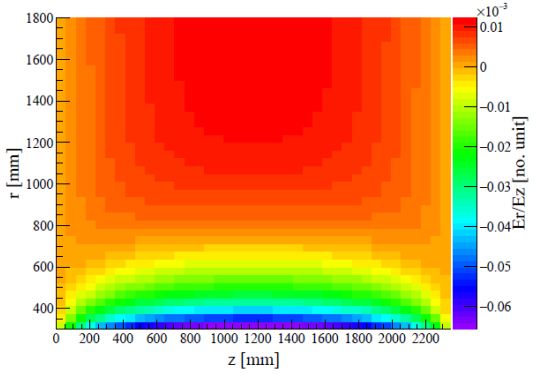
$$\rho_m(r',z') = \frac{1}{2\pi} \oint \frac{\rho(r',\theta',z')}{\epsilon_0} e^{-im\theta} d\theta'$$

Resnati F. Modelling of dynamic and transient behaviours of gaseous detectors[J]. 2017.

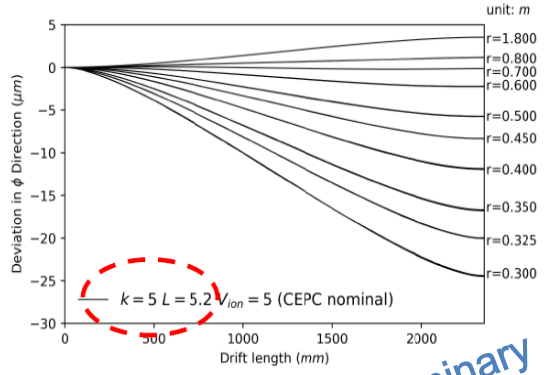
Ions density in chamber



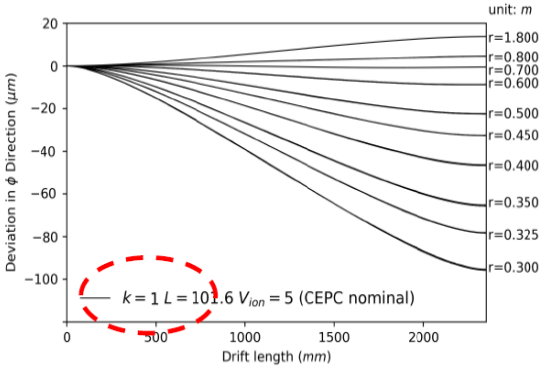
E_r/E_z



Higgs



Z Preliminary

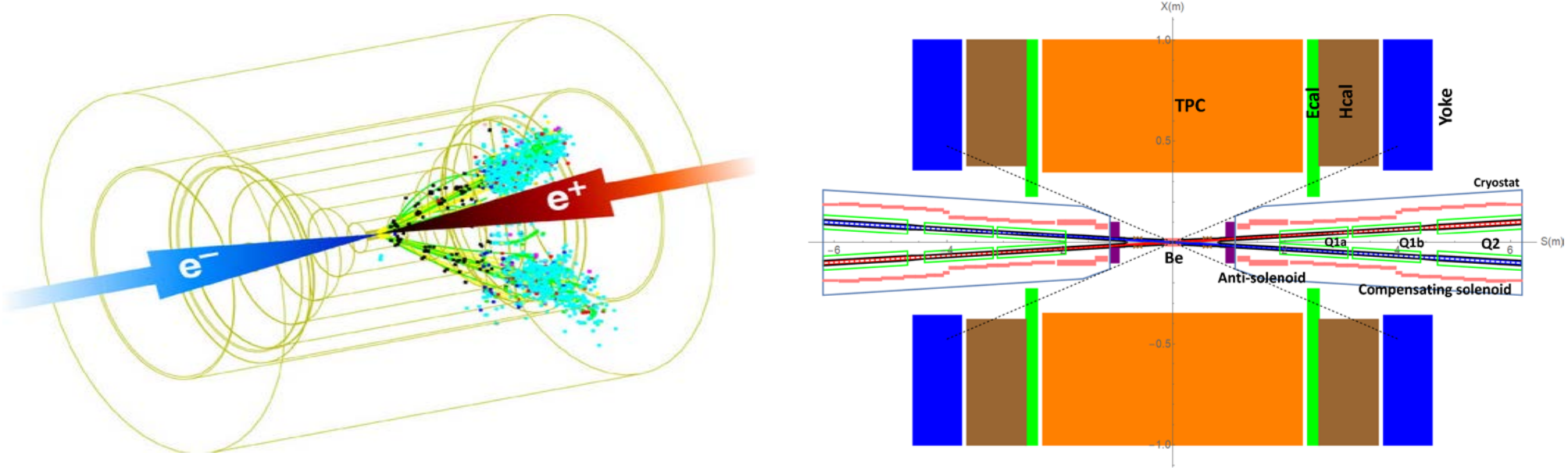


- Progress of the simulation and studies

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 γγ interactions, and extraction line losses) and radiative Bhabhas
  - $e^+e^- \longrightarrow e^+e^-\gamma$ electron-positron scattering

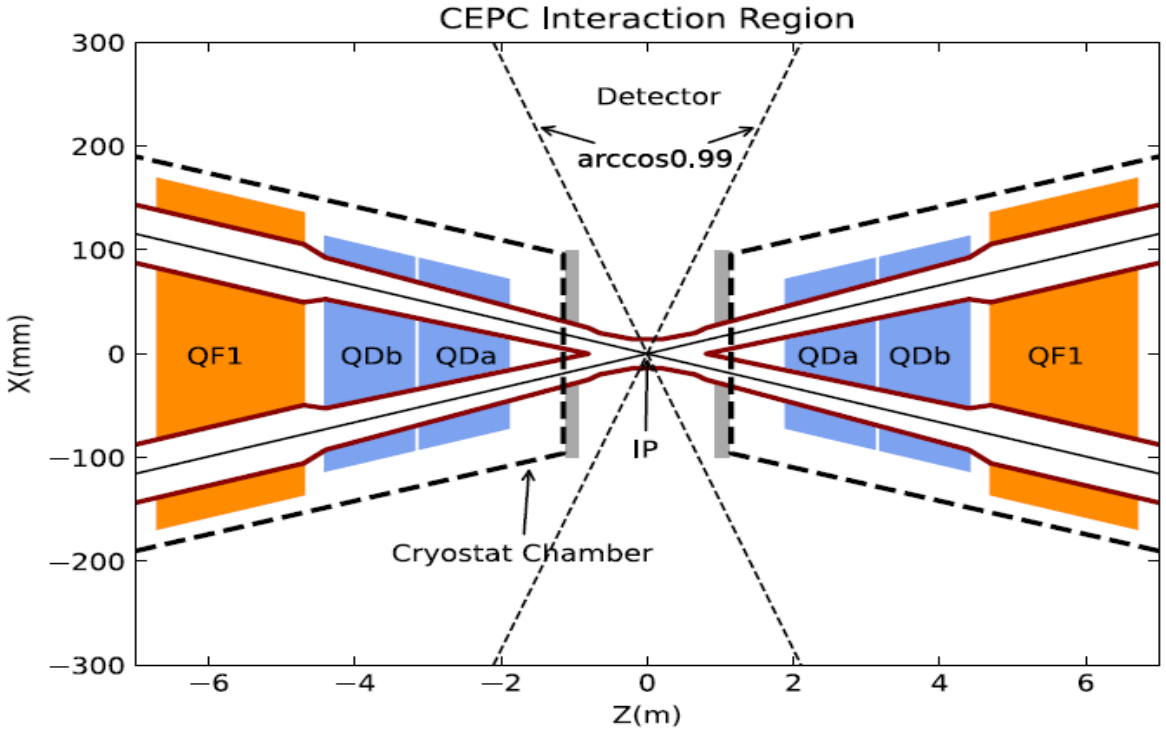
- From the standpoint of integrated background, e+e- circular collider is relatively '**very clean**' machines. Average integrated hadronic fluxes produced at the IP are about several orders of magnitude lower than the hadron collider. Also, high luminosity Tera-Z are similar.

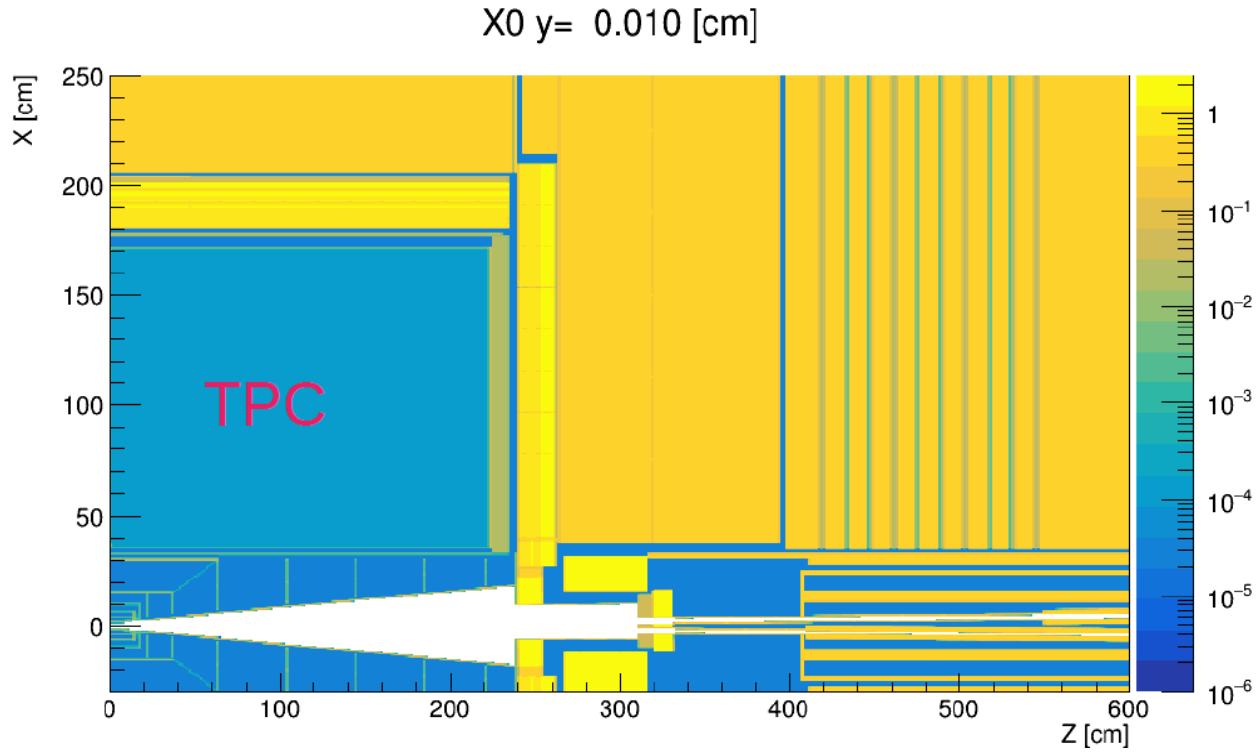


Concept of MDI region

e^+e^- colliders: sources of detector backgrounds at MDI

- In general, this source is well understood and under control: it scales with luminosity, one should transport interaction products away from IP and **shield/mask** sensitive detectors, and exploit detector timing
- 2.0T for Z pole run at CEPC， beam crossing angle of 33mrad in MDI design
- **Need to mimic the same level of the electrons density in TPC to study the performance**

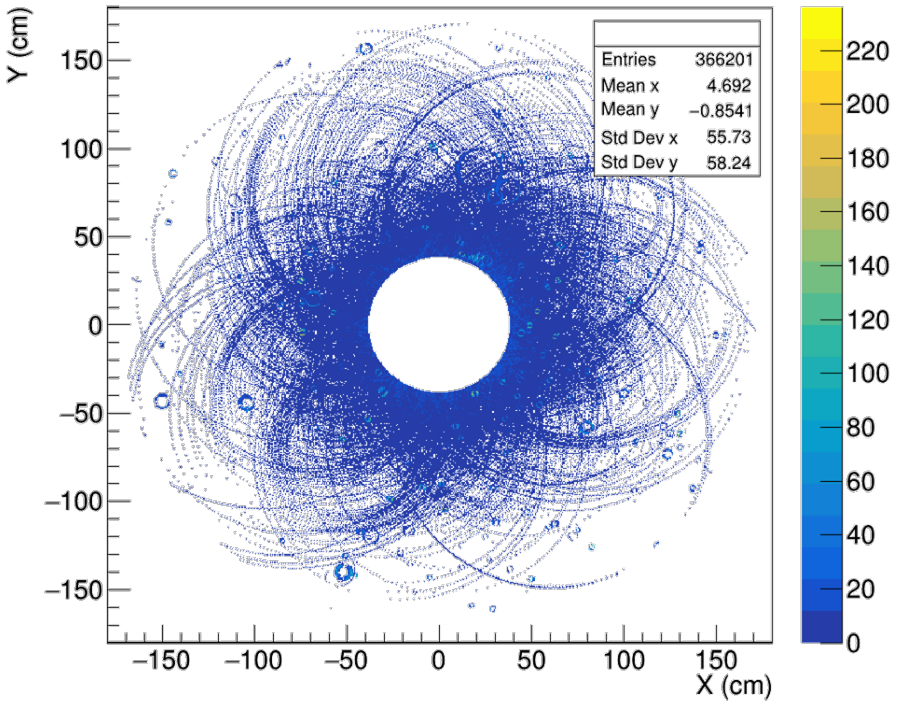




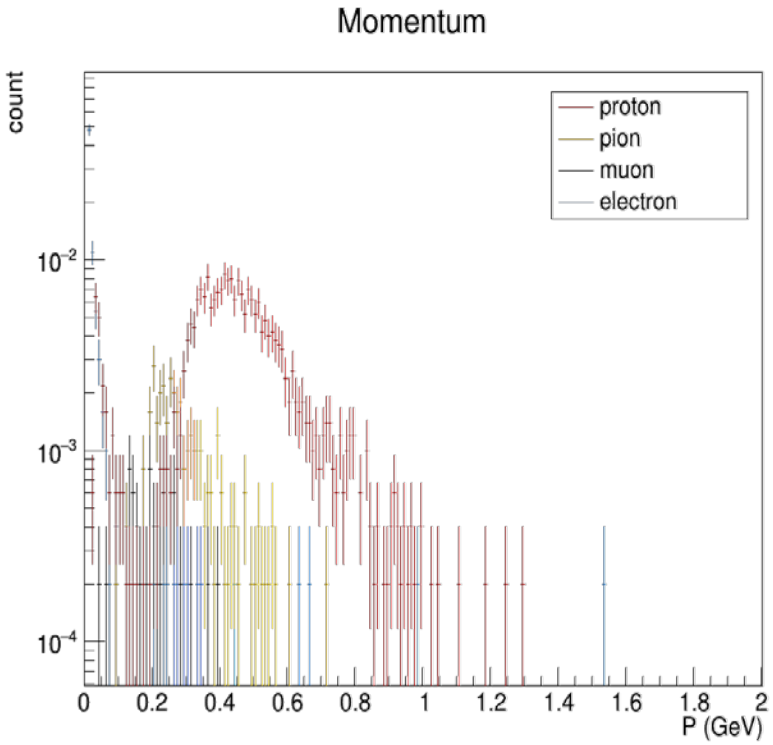
CEPC MDI region

Study the full simulation data of the high luminosity Z at CEPC

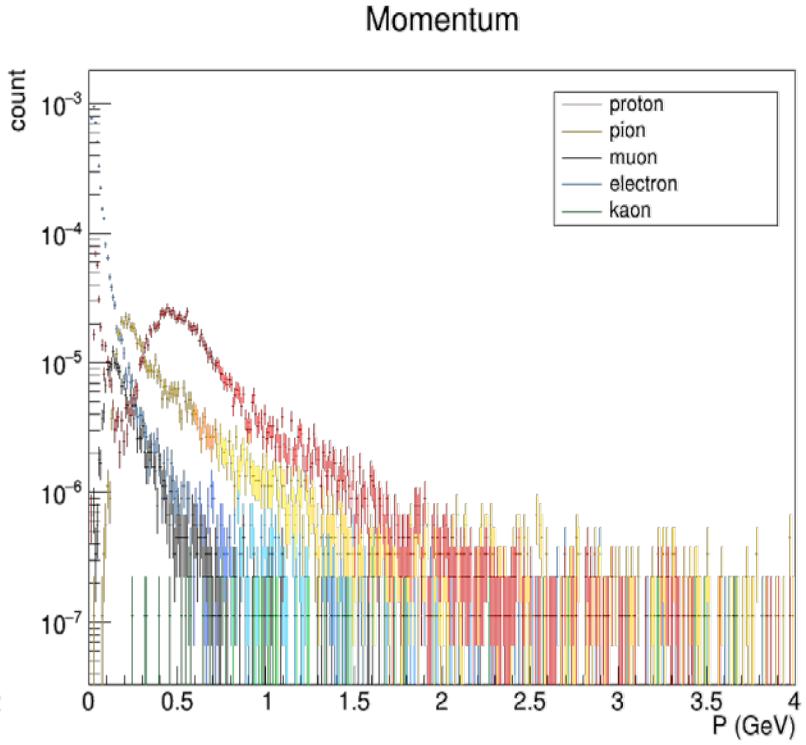
- All data from the full simulation of the **high luminosity Z pole run (2.0T) at CEPC**
- The pair production and beam-gas effect in TPC chamber have been consider to study
- Some particles have been analyzed using Proton, Pion, Muon and primary electrons with the different momentum in the TPC chamber



Hitting map of two-photon effect samples



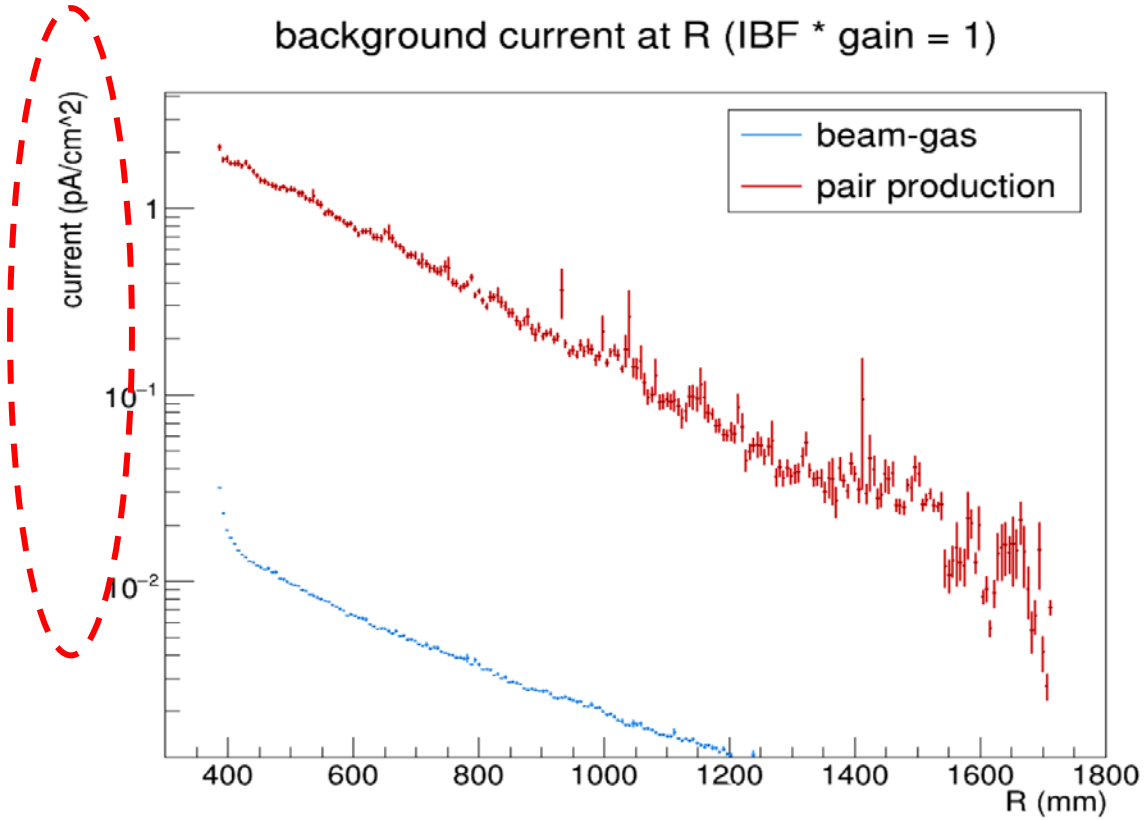
Pair production in TPC chamber



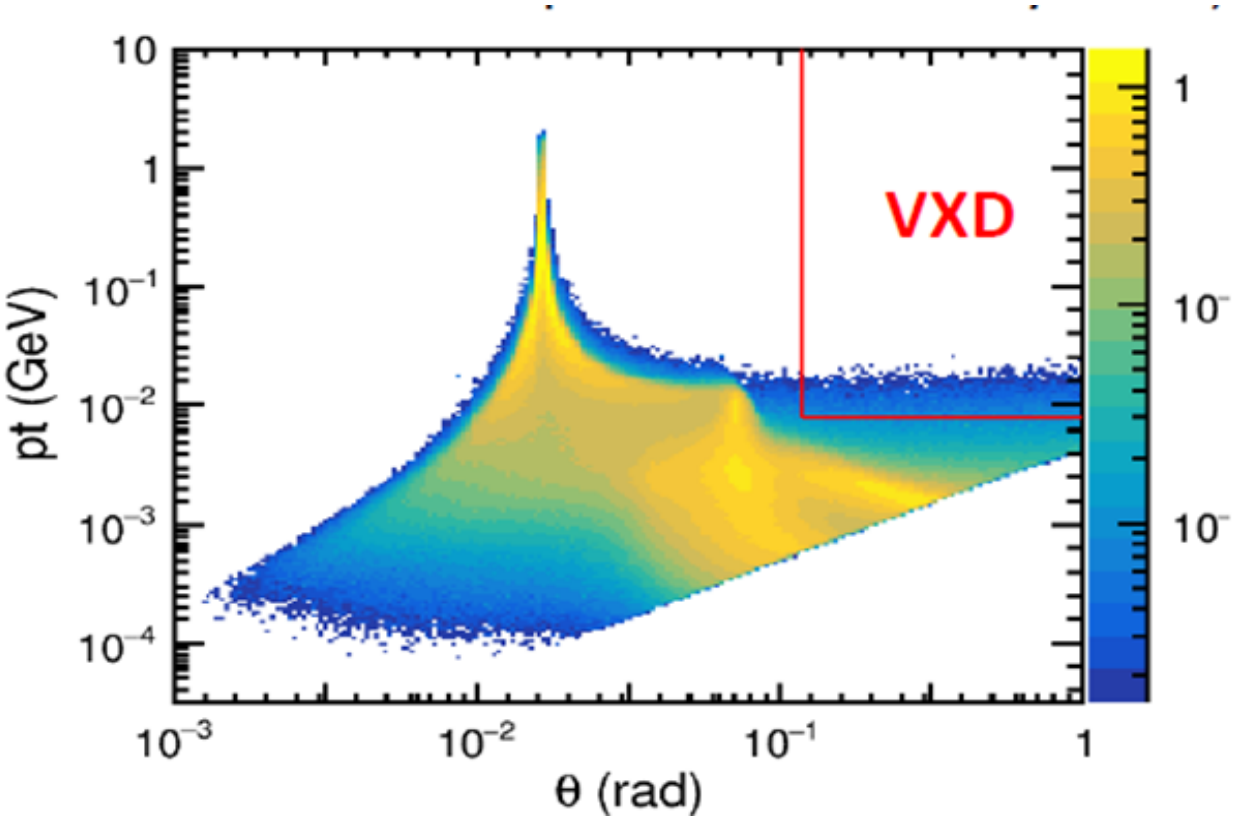
Beam-gas in TPC chamber

Study the full simulation data of the high luminosity Z at CEPC

- The currents of the electrons in TPC chamber reach to about 1pA/cm^2
  - IBF*Gain =1 at 2T
  - Beam-gas and pair production in the chamber
- The theta in the MDI region is pretty good to TPC chamber from the simulation results.



Current of the electrons in TPC chamber



The theta in MDI region

Experimental studies: create the massive electron in the chamber

UV laser: Two-photon ionization method (>10uJ/cm^2)

- Some gas can absorb the energy of 2 photons from UV laser and ionized
- Wavelength of UV laser: 266nm (almost: 4.66eV×2)
- Threshold of the ionization energy: **>10uJ/cm^2 @MIP**
- **To mimic the stable laser tracks in chamber**

→ **UV Laser TPC prototype R&D**
Without B field

UV light: Photoelectric effect method (<10uJ/cm^2)

- Explanation of photoelectric effect by A.Einstein
- Each photon carries energy proportional to its frequency $E_\gamma = hf = hc/\lambda$
- One electron absorbs only one photon
- Energy of UV can less than 10uJ/cm^2
- **To study of the stable current of photoelectric**

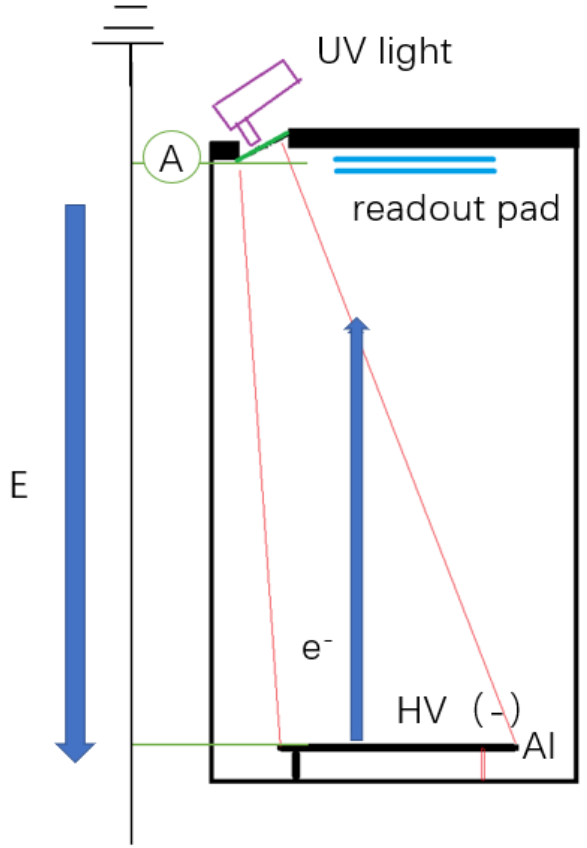
→ **Massive electrons R&D**
Without influence working gas

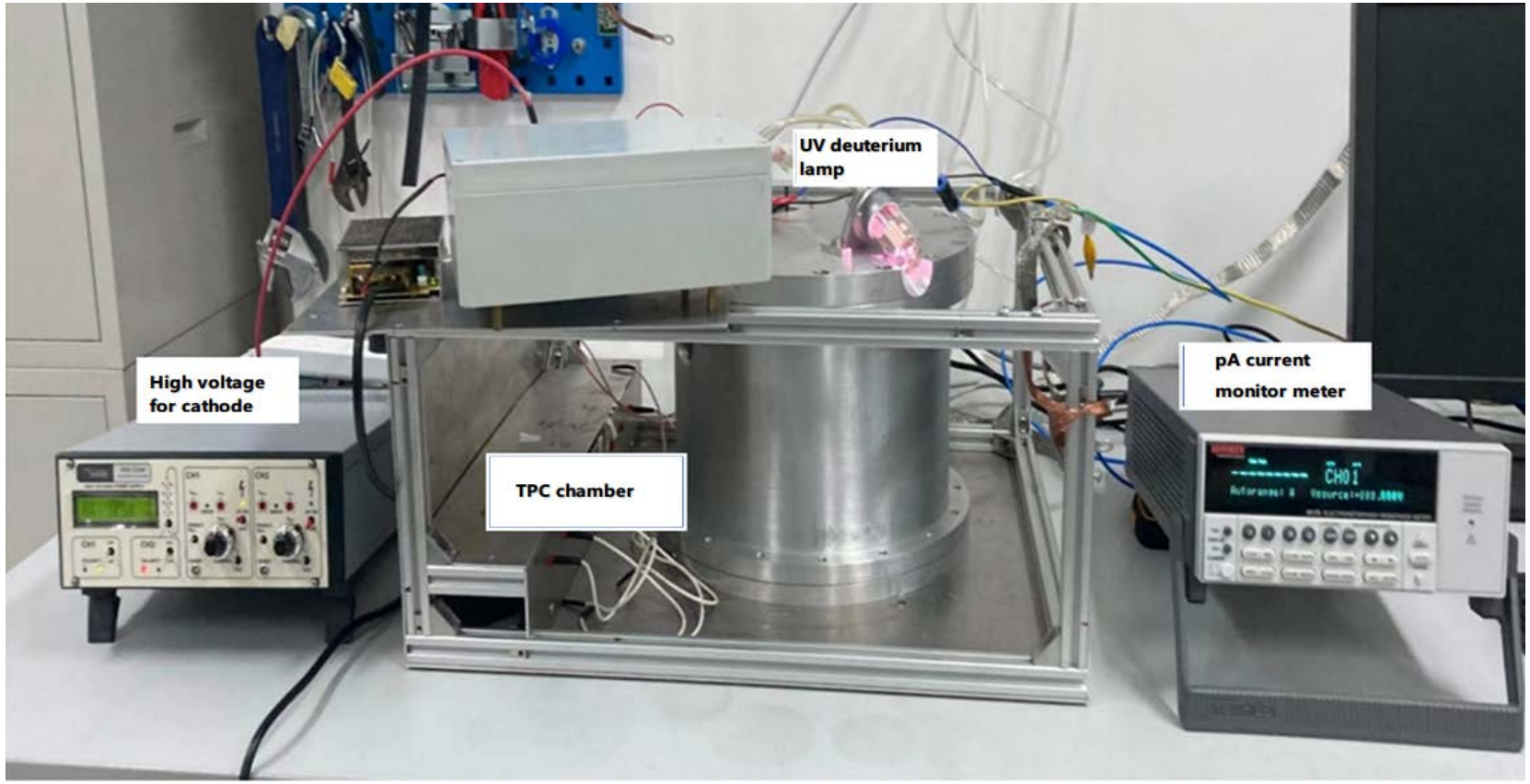
→ **Study the deviation of the tracks**
under the high luminosity

Testing the UV light created the massive electrons by photoelectric effect

UV light created the massive primary electrons

- Ions will fill in the drift chamber of TPC to mimic the ions distortion
- **Metal mesh polished Aluminum**: 600/800/1000/1200/1400/2000 (**LPI: Linear Pair)**
- Experimental testing of the current at record detector layers

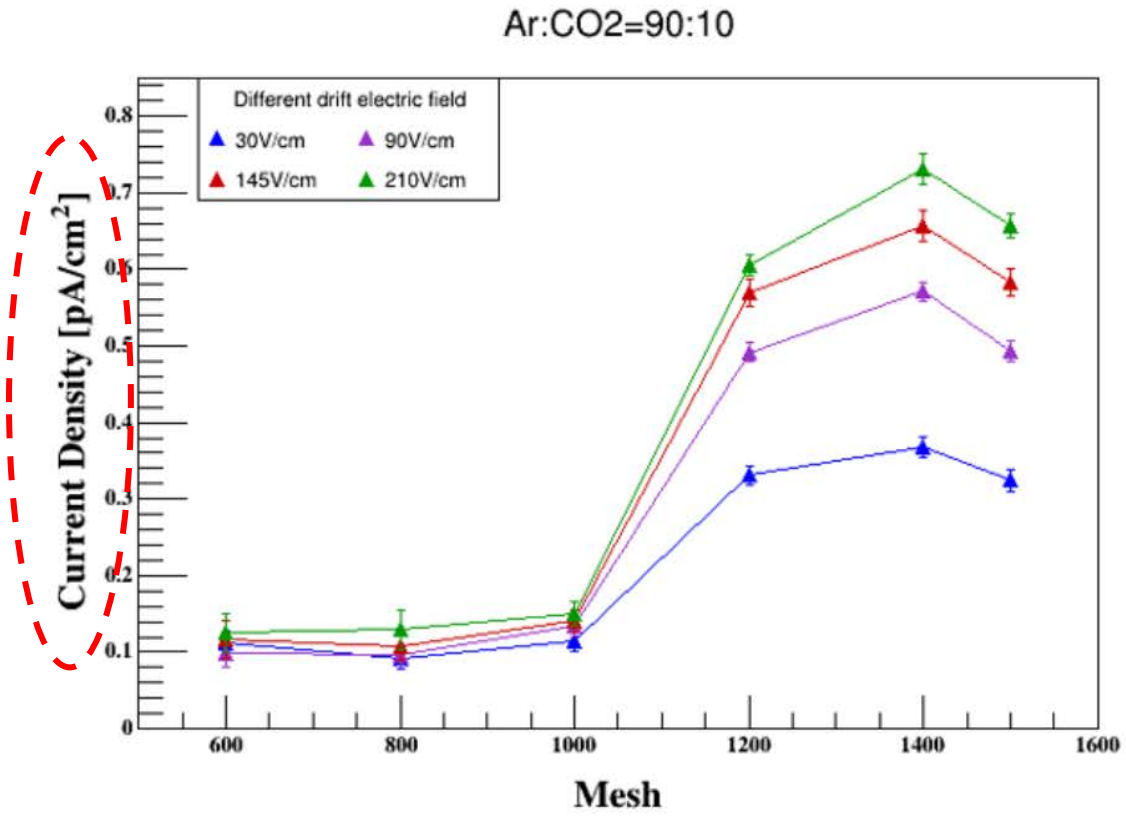


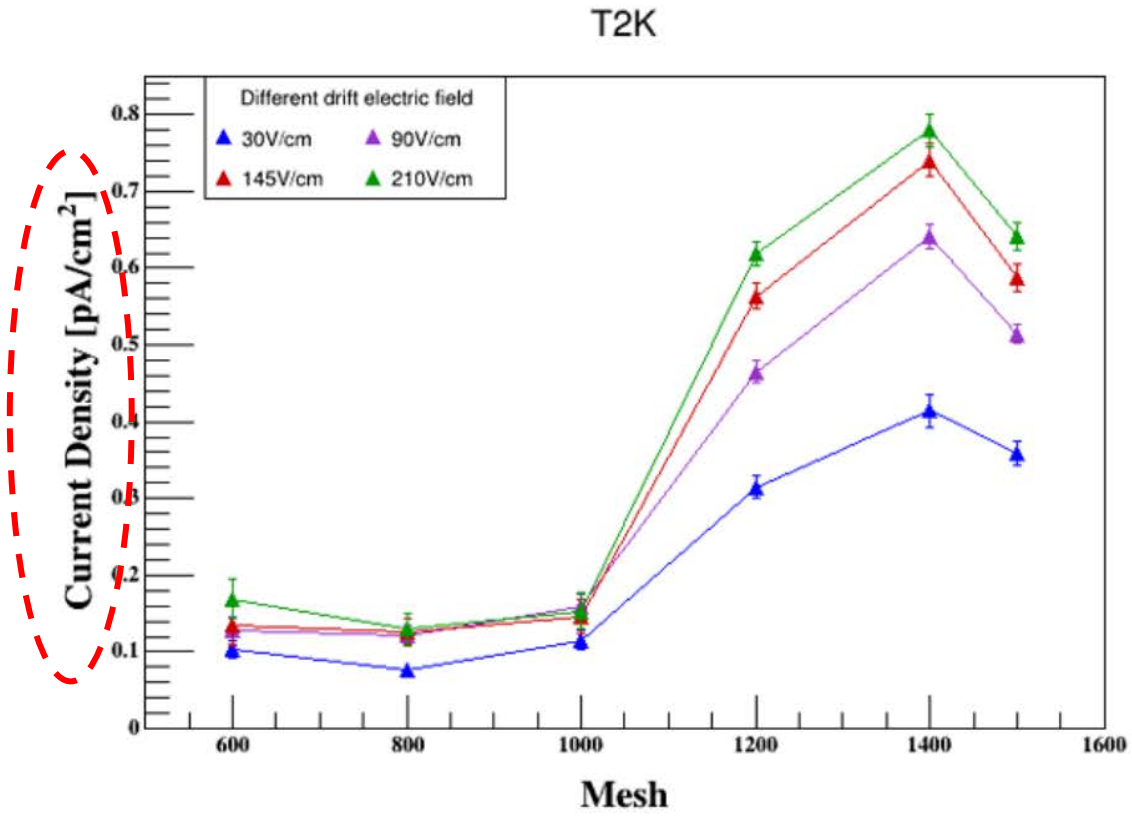


Concept and photo of the experimental study using UV deuterium lamp

Testing the UV light created the massive electrons by photoelectric effect

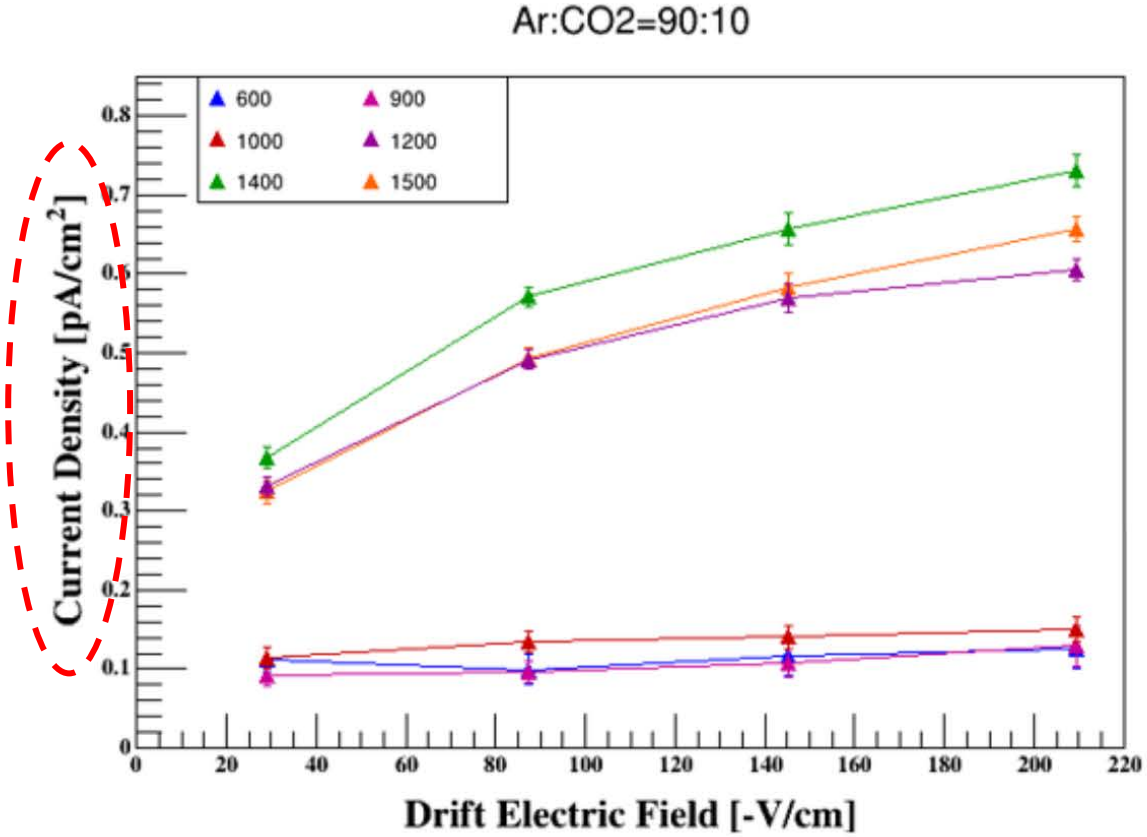
- The different LPI Aluminum's surface tested the stable current
- The maximum current reached at 1400LPI Aluminum's surface (**Very stable**)
- Detector has been studied under the two different mixture gases
  - Very similar trends **from 30V/cm to 210V/cm (Electric field of drift)**
- The novel method **can meet to study the current** of the electrons using the prototype (**Max.~1pA/cm^2**)

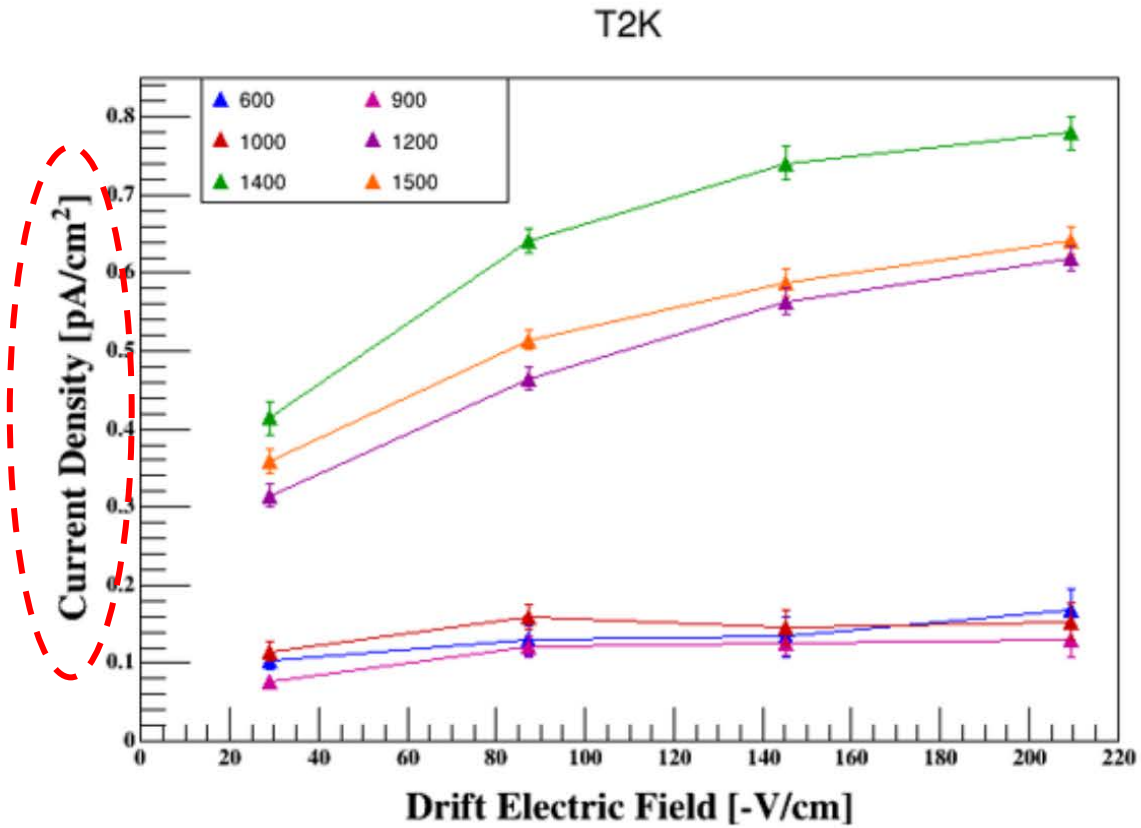




Testing the UV light created the massive electrons by photoelectric effect

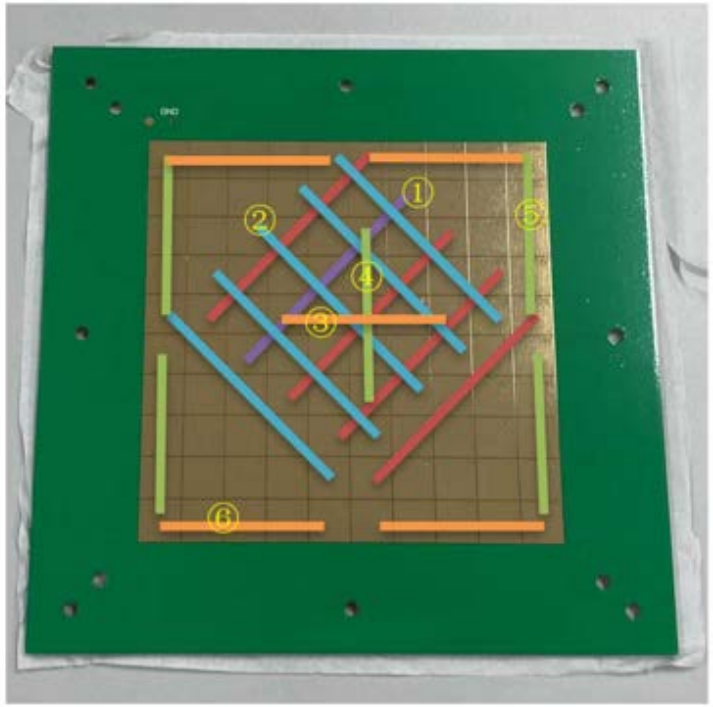
- The different LPI Aluminum's surface tested the stable current
- Detector has been studied under the two different mixture gases
  - The current with the different electric field of drift was recorded.
  - **Same trend as the saturation** of the drift velocity in the two mixture gases.
- The studies of the **avalanche electrons/ions** of the GEM+Micromegas module are ongoing.

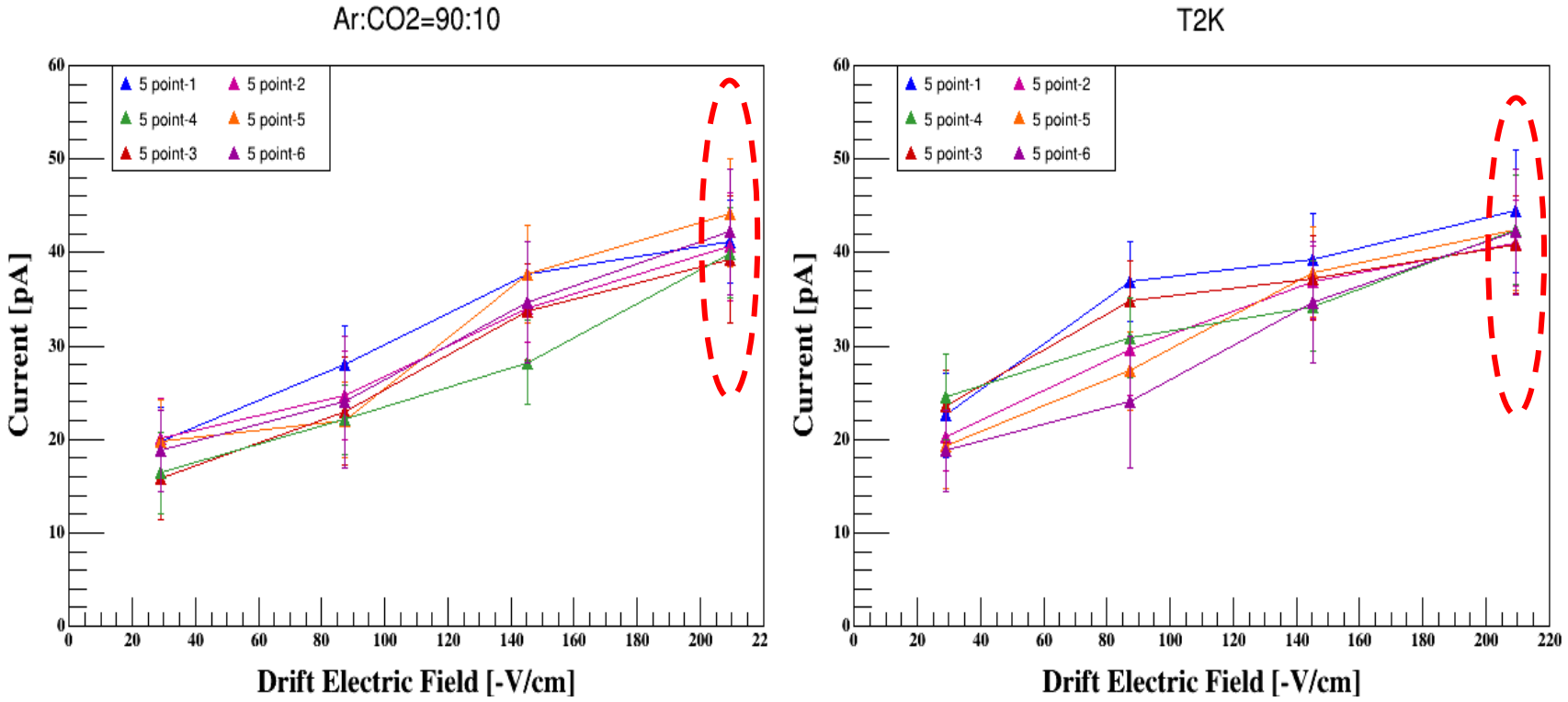




Uniformity of the current in the TPC readout

- Uniformity of the TPC readout plane
  - Studies of the primary electron distribution on the readout plane by the current
  - Studies of the different groups of series-connected five pads in the readout board
- **Uniformity of electron distribution** by the photoelectric effect in the cathode of Al
  - **better than 96 %** in 100cm^2 (pretty good)





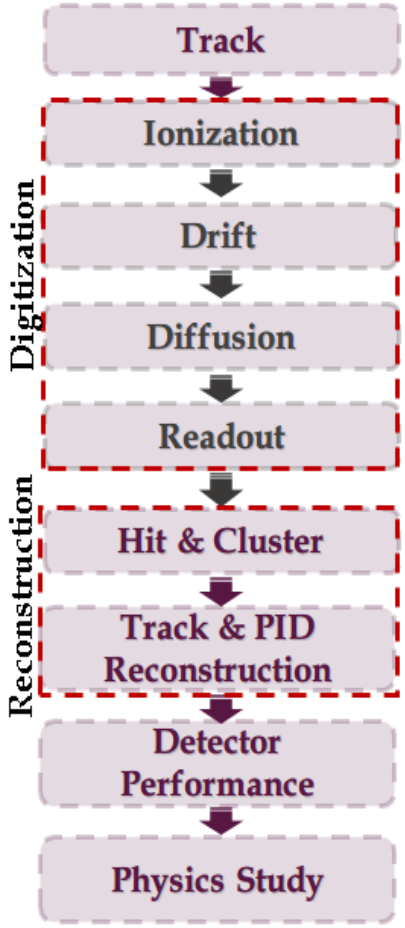
Concept and results of the uniformity of the current in the TPC readout

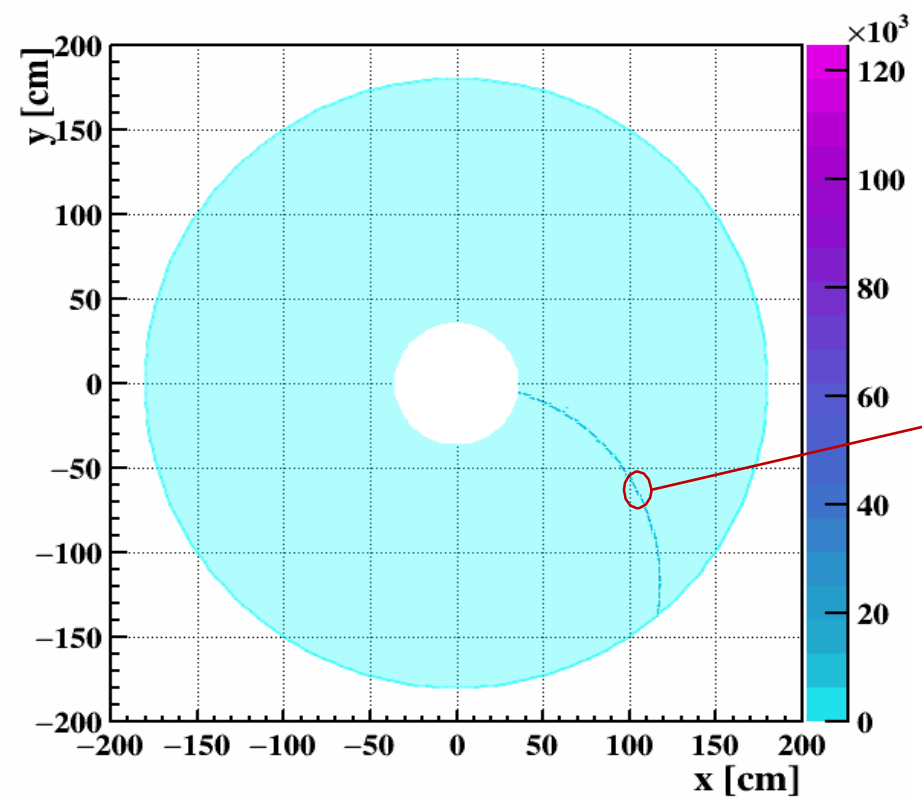
- Updated status of the pixelated TPC R&D

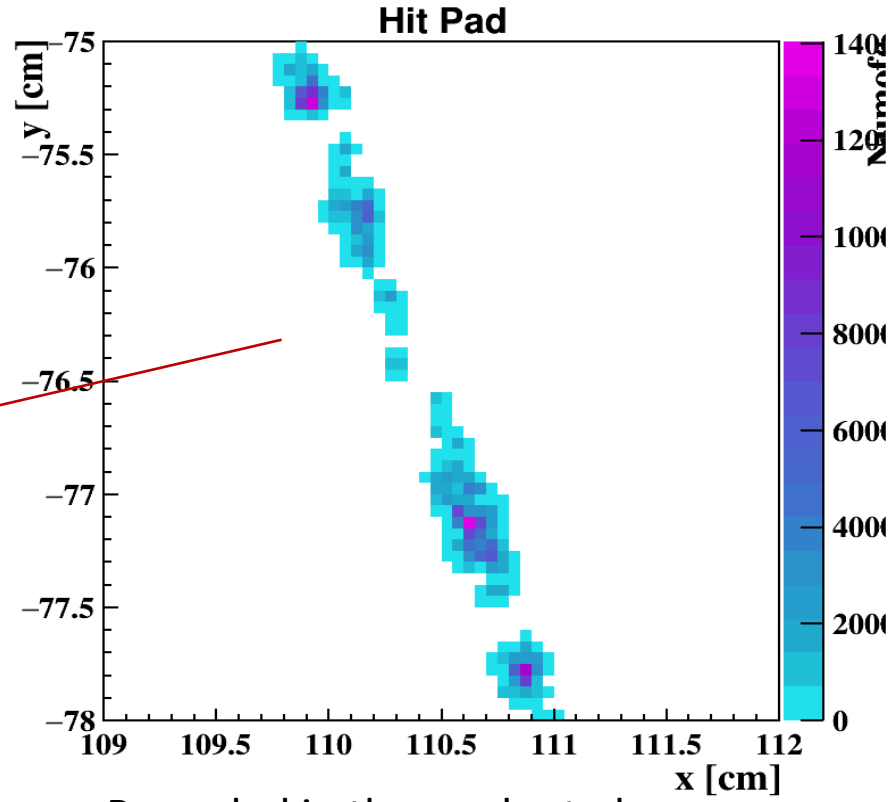
Simulation of the pixelated TPC - ongoing

- 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
  - Progress presentaion will be prepared soon

Yue Chang,
Guang Zhao,
Linghui Wu, Gang Li







Recorded in the readout plane:
Drift distance = 150mm
Pixel size: 500μm×500 μm

Same goal: Low power consumption pixelated TPC technology IHEP/LCTPC

- R&D @ IHEP based on **0.5×0.5 mm^2 pixels and electronics uses a power of <0.2mW/channel**.
  - For all the active area of 160 000 cm^2 one has 64 M channels and **<1.2 kW** power consumption
  - > 89% coverage in the endplate

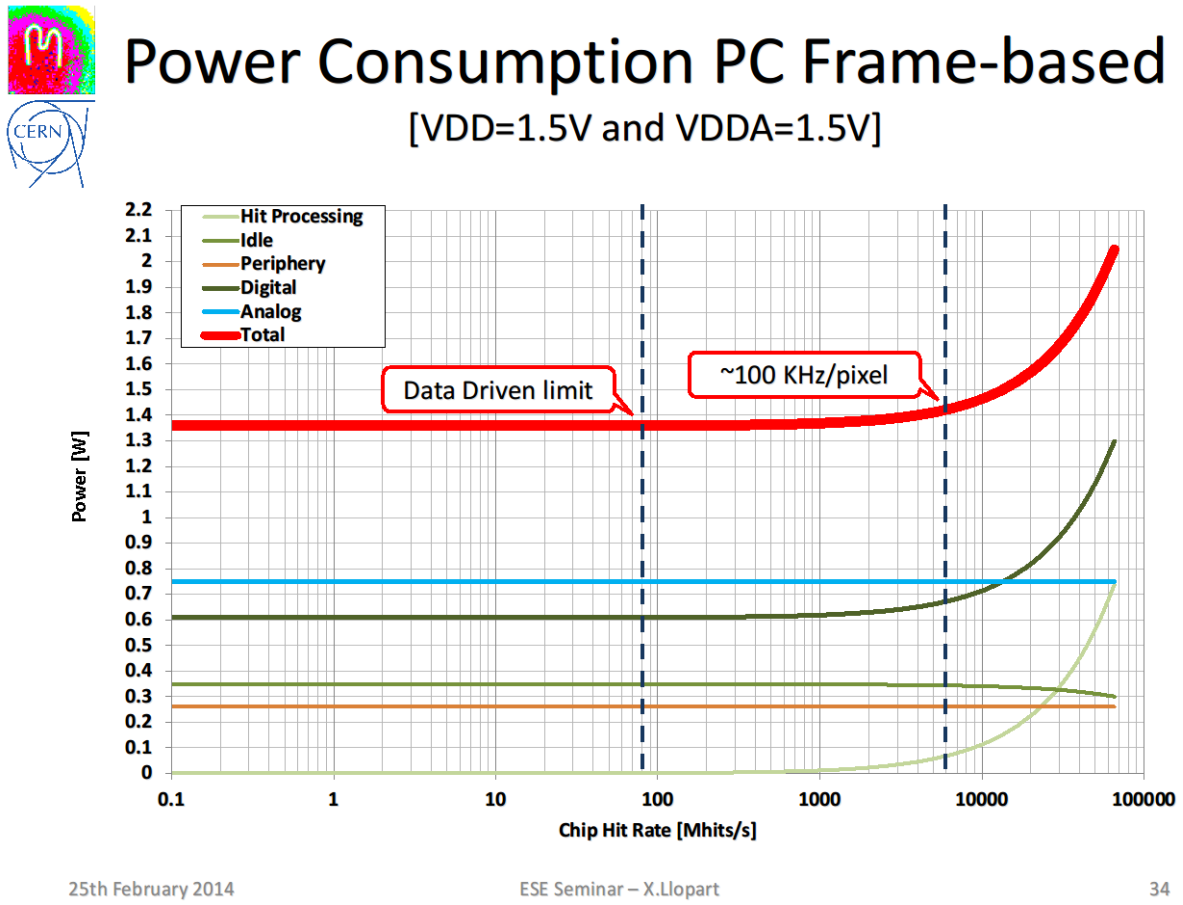
- Current TPX3 chip has 256×256 channels and a surface of 1.41×1.41 cm^2
- Power consumption ~2W/chip; this means 30 mW/channel
- A full pixel TPC in the detector will have a total area 160 000 cm^2
  - For full coverage one needs 80 000 chips
  - With the current TPX3 chip one reaches about 60% coverage
  - For the pixel TPC the total power is 160 kW (so 80 kW per endcap)

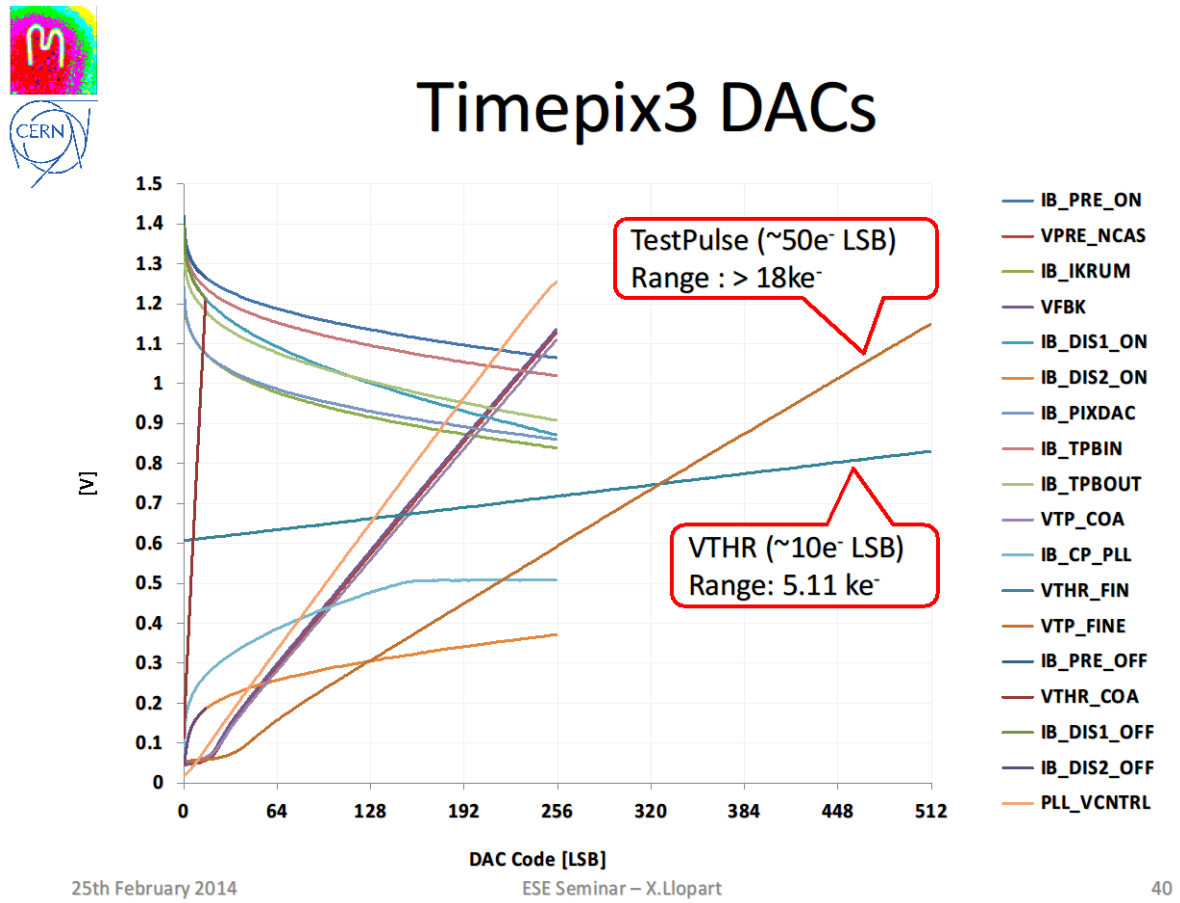
- Low power consumption **is the first requirement** for the pixelated TPC technology to LCTPC
  - TPX3 Gridpixes in low power mode reduces the power consumption for a pixel TPC to **8 kW per endcap** at the cost of a worse time resolution.

- Ref1 https://iopscience.iop.org/article/10.1088/1748-0221/14/01/C01024
- Ref2 https://iopscience.iop.org/article/10.1088/1748-0221/14/01/C01001

Low power pixelated TPC technology – LCTPC collaboration

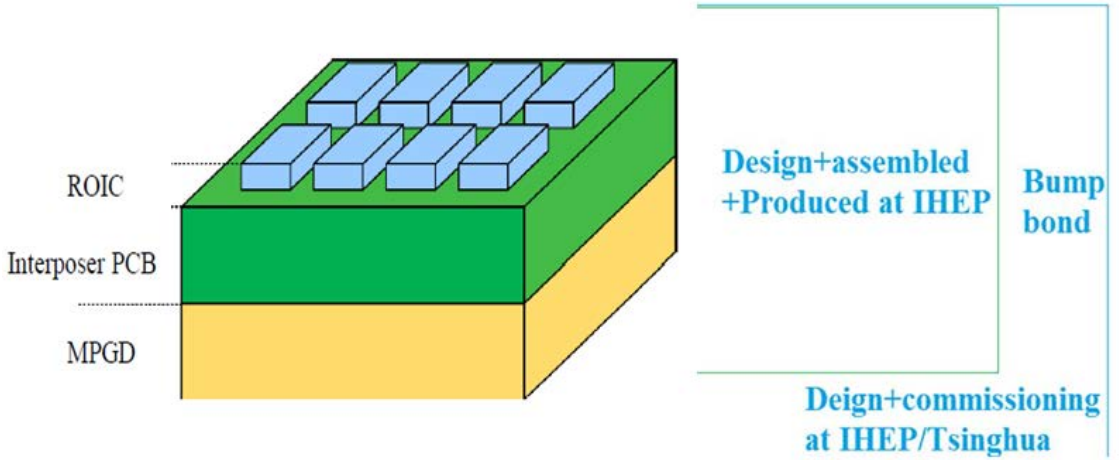
- The Medipix collaboration (CERN and Czech groups) **carefully investigated the possibilities** of the reduction of the power consumption for the TPX3 chip and TPX4 chip
- For EIC, a set of low power DAC (Digital Analogy Converter) settings has prepared in Bonn

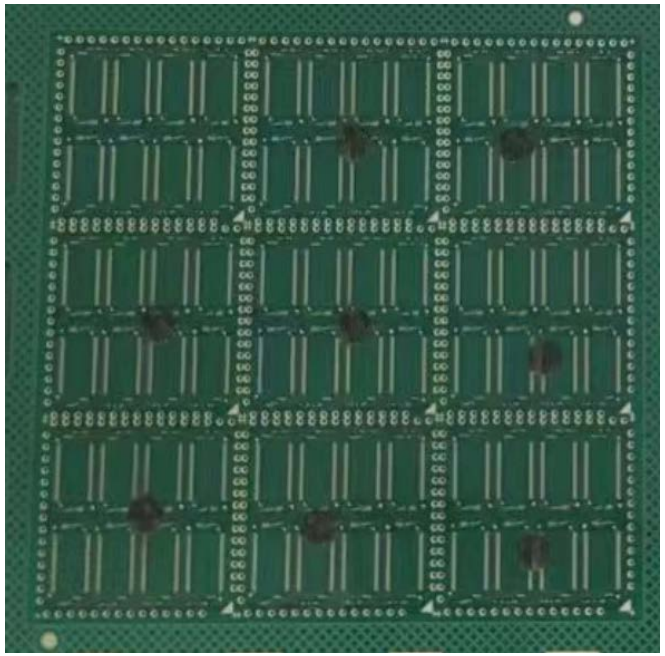




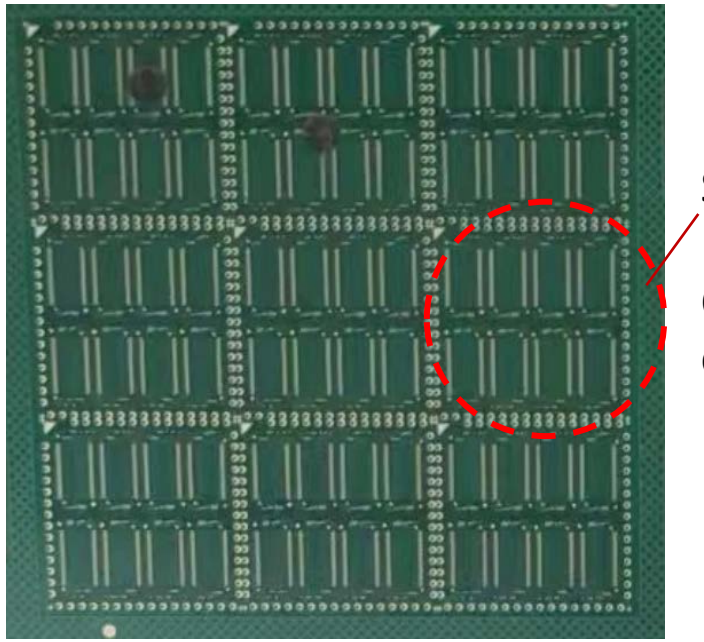
Current R&D effort: Pixelated TPC R&D for CEPC

- **R&D on interposer PCB integrated with ROIC**
  - 3×3 the interposer PCB board designed and produced.
  - There are some tests of short circuits in the first version (Marked in PCB).
  - The **circuit connections have been improved** and the second version is good.





First version of the interposer PCB

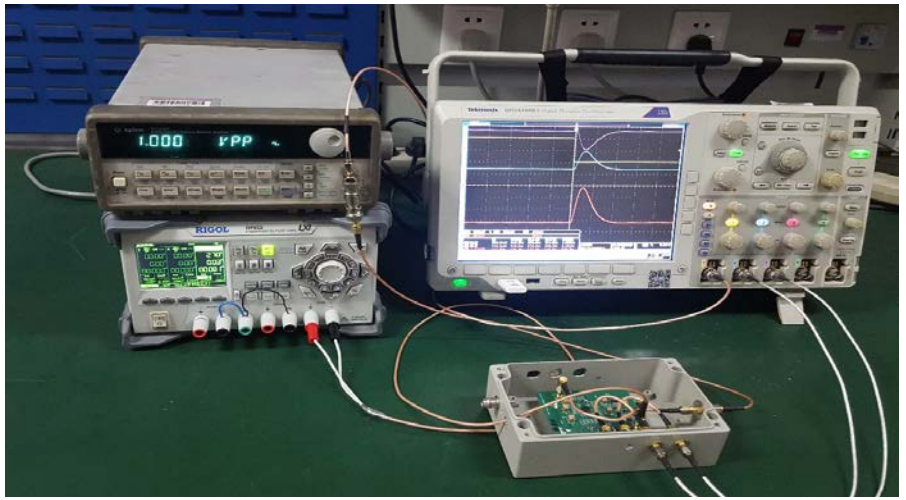


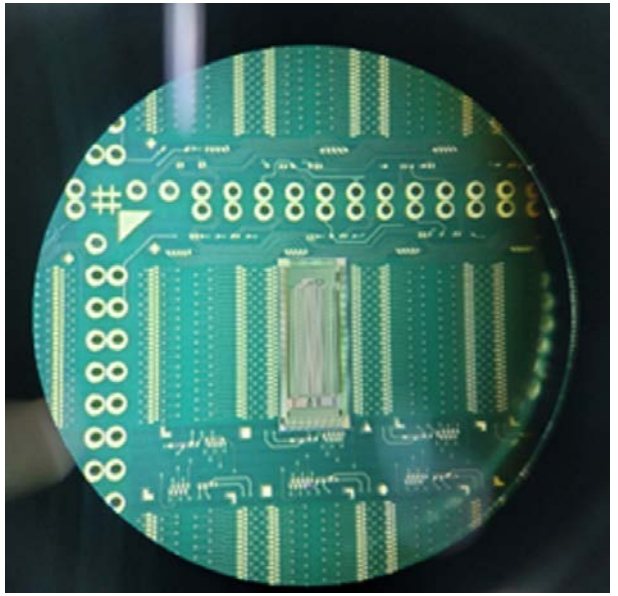
Size: 16mm×16mm
Pixel: 500μm×500μm
Connected: 2×4 ROIC chips

Second version of the interposer PCB

Current R&D effort: Pixelated TPC R&D for CEPC

- **R&D on pixel TPC readout for CEPC**
  - Pixel TPC ASIC chip was started to developed in 2023 and 1st prototype wafer standalone tested in May.
    - **Power consumption: <1.1mW/ch (1st prototype)**
      - **<400mW/cm^2 (Test)**
  - 2nd prototype wafer design done (simulation power: 0.2mW/ch)
    - **< 100mW/cm^2 (Goal and final design)**
  - The TOA and TOT can be selected as the initiation function in the ASIC chip.
    - 1mm×6mm → 500μm×500μm pixel readout → 330μm
    - Higher precision and higher rate (MHz/cm^2)
    - Gain of the amplification: >40mV/fC
    - Channels: 32
    - Time resolution: **14bit** (5ns bin)
    - Time discriminator: TOA (Time of Arrival)
    - Technology: 180nm CMOS -> 60nm CMOS
    - High metal coverage: 4-side bootable

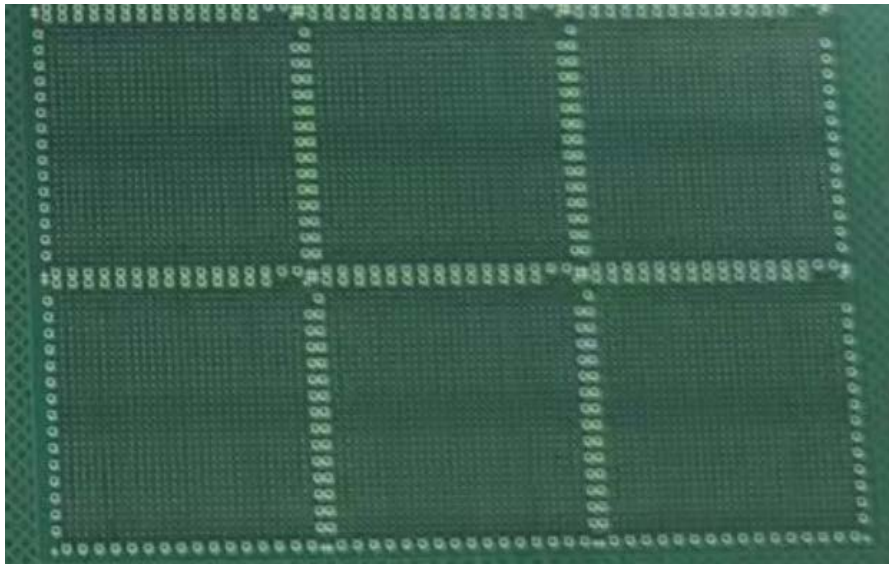




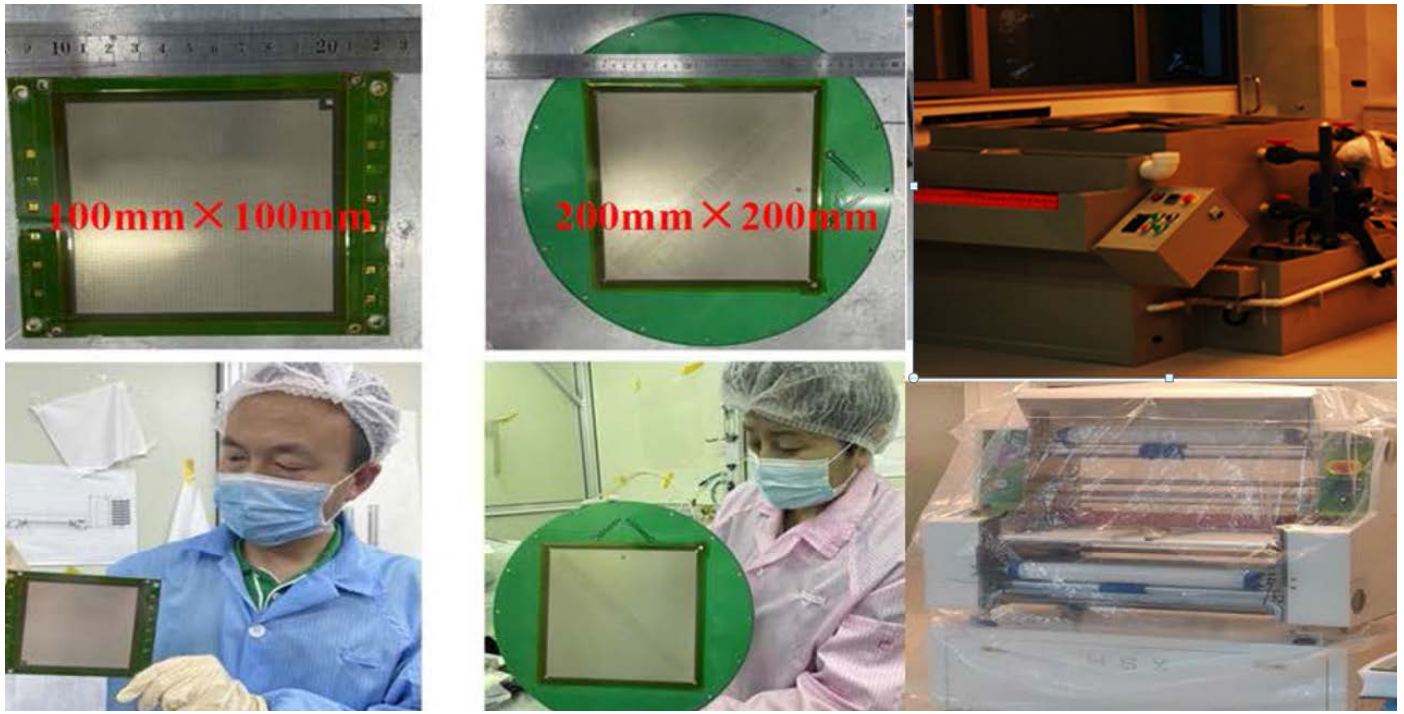
1st readout PCB board and the ASIC layout

Current R&D effort: detector production integrated with PCB and ROIC

- R&D on detector production integrated with PCB and ROIC will be assembled.
  - **All are ready**, and some good discussion and inputs from LCTPC collaboration.
    - We will meet Bonn's staffs in person at Hamburg in August (EPS meeting)
  - First step: the Micromegas was produced using the raw interposer PCB
  - Second step: Bump boding the ROIC with the interposer PCB to collaborate with Tsinghua

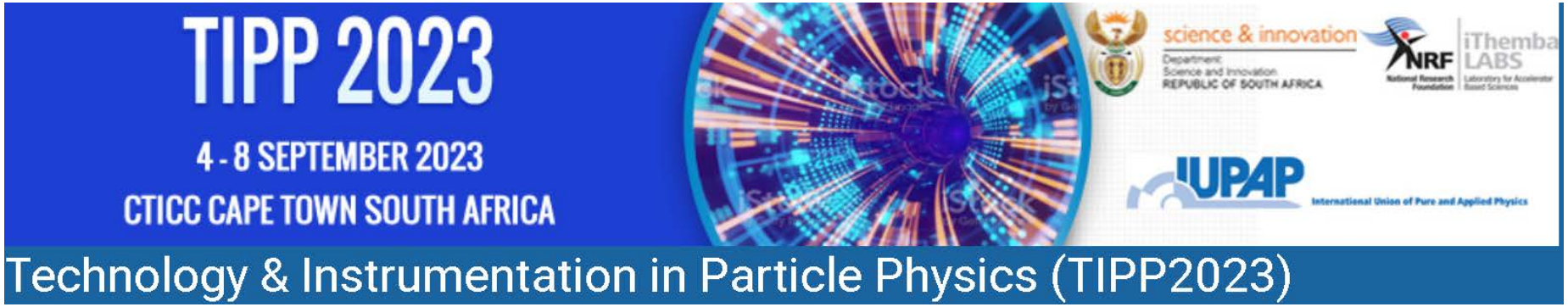


Raw interposer PCB



Detector production in the laboratory

Two oral talks to TIPP2023 (Acceptance)



Oral Presentations

High spatial resolution of Time Projection Chamber R&D at high luminosity Tera-Z on CEPC

Huirong Qi, Yue Chang, Xin She, Liwen Yu, Zhi Deng, Jinxian Zhang, Jianchun Wang, Jian Zhang

Oral Presentations

Status of TPC development for the ILD detector at future e+e- collider

Huirong Qi, Xin she, Maxim Titov on behalf of LCTPC collaboration

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, the background current of the electron density in TPC chamber. And, some update results of TPC prototype have been studies, UV light can created the enough massive primary electrons in the chamber to study.**
- **Pixel TPC is in the simulation package (MarlinTPC) as the default track detector in 2023. The requirements of the low power consumption pixelated TPC technology became as the general proposal from LCTPC collaboration and IHEP. The updated progress on the interposer PCB integrated with ROIC are ongoing.**
- **Two oral talks are accepted in TIPP2023.**

Many thanks!