Progress of TPC detector and simulation towards CEPC ref-TDR

Huirong Qi

Guang Zhao, Lingwu Wu, Yue Chang, Xin She, Jinxian Zhang, Zhi Deng, Canwen Liu, Jianmeng Dong, Feng He, Jian Zhang, Gang Li, Manqi Ruan, Jinfei Wu, Chu Wang, Liwen Yu and some good inputs from LCTPC Collaboration

CEPC Day, September 27, 2024

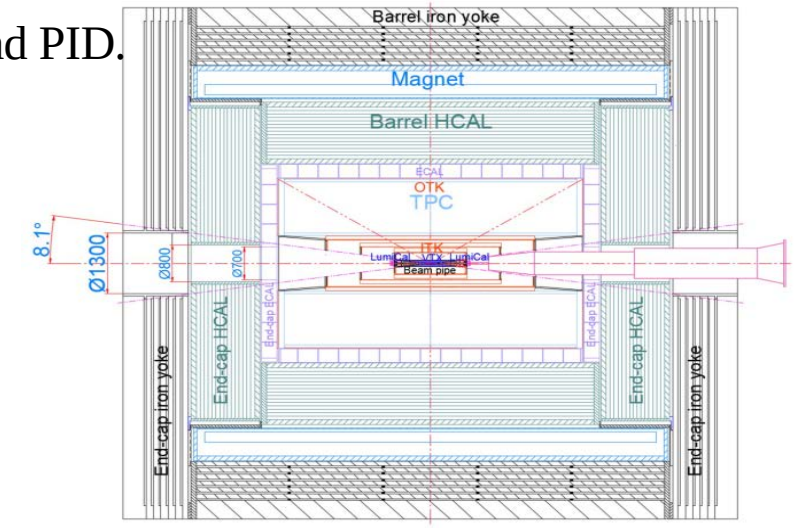
Content

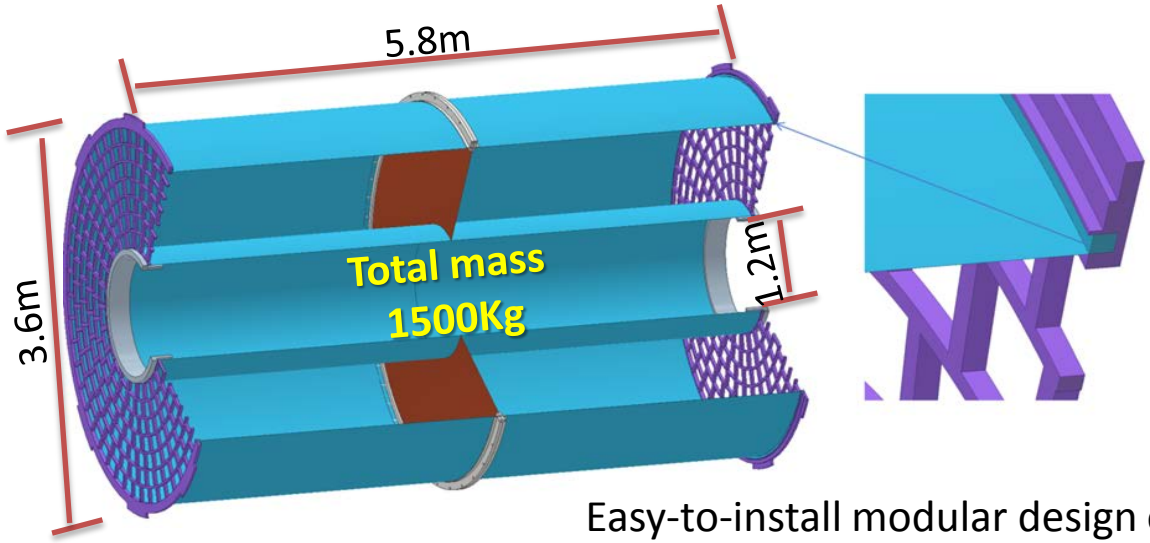
- **TPC detector for CEPC ref-TDR**
- **Update results of TPC simulation**
- **Status of the test beam with TPC module**
- **Summary**

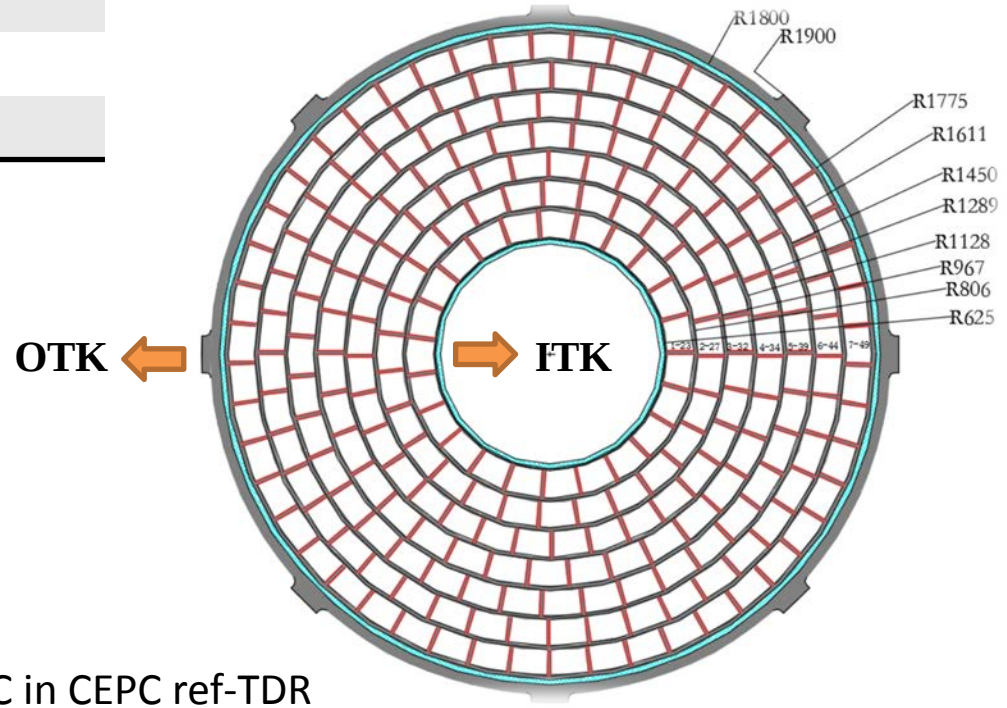
Updated design of TPC mechanics for ref-TDR

- Track detector system: **Silicon combined with gaseous detector** as the tracker and PID.
  - Pixelated readout TPC is as the baseline track detector in CEPC ref-TDR.

TPC detector	Key Parameters
Modules per endcap	248 modules /endcap
Module size	206mm×224mm×161mm
Geometry of layout	Inner: 1.2m Outer: 3.6m Length: 5.9m
Voltage of Cathode	- 62,000 V
Operation gases	T2K: Ar/CF4/iC4H10=95/3/2
Total drift time	34μs @ 2.75m
Detector modules	Pixelated Micromegas



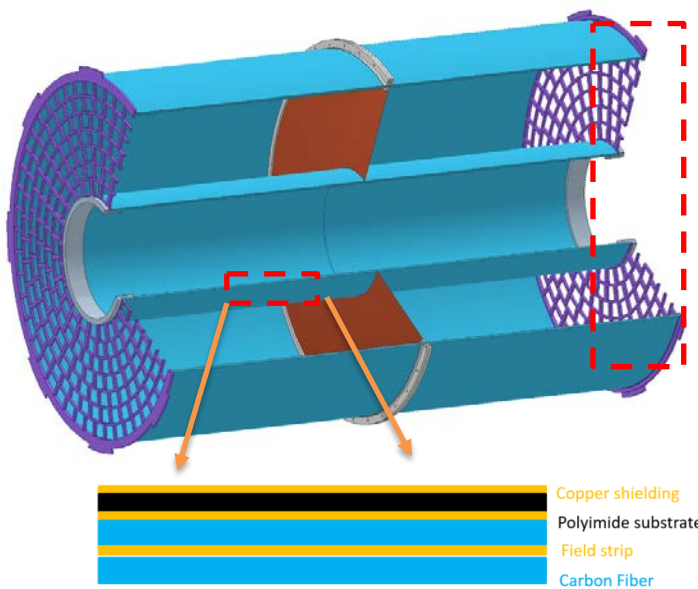


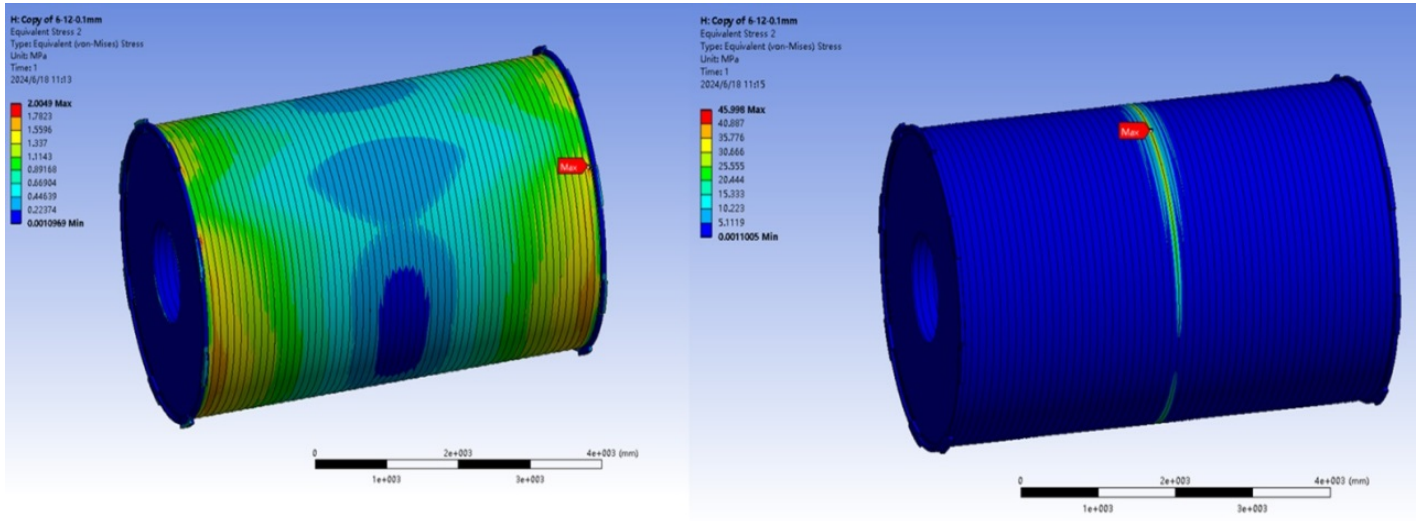


Easy-to-install modular design of TPC in CEPC ref-TDR

Ultra-light barrel and FEA analysis

- **Ultra-light material** of the TPC barrel (**QM55 CF**)
  0.59% X_0 in total
  - Carbon Fiber barrel instead of the honeycomb barrel (**~2% X_0**)
  - FEA preliminary calculation: 0.2mm carbon fibber barrel can tolerant of OTK (>100Kg)
  - Boundary dimensions are almost **finally defined.**
    - Mechanic, ITK, OTK





Ultra-light barrel and FEA analysis

Material budget of TPC barrel

Layer of the barrels	D[cm]	X_0[cm]	d/X_0[%]
Copper shielding	0.001	1.45	0.07
CF outer barrel	0.020	25.28	0.08
Mirror strips	0.003	1.35	0.19
Polyimide substrate	0.005	32.65	0.02
Field strips	0.003	1.35	0.19
CF inner barrel	0.010	25.28	0.04
Sum of the material budget			**0.59**

Update Chapter in TDR

- Update Chapter 5: Gaseous tracker
  Draft of content listed →
- Editing starting in October

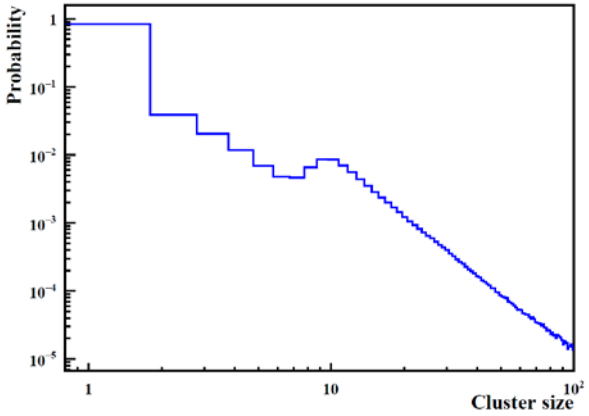
Chapter 5 Gaseous trackers

5.1 Physics requirements and detection technology . . . . . .
5.1.1 Physics requirements of Higgs and Tera-Z . . . . . .
5.1.2 Technology choice and the baseline track detector . . .
5.2 Pixelated readout TPC detection . . . . . .
5.2.1 TPC detector and readout electronics . . . . . .
5.2.2 Mechanical and cooling design . . . . . .
5.2.3 Challenges and critical R&D . . . . . .
5.2.4 Detector modules toward the validation prototype . . .
5.3 Performance of TPC tracker . . . . . .
5.3.1 Overall of the simulation framework . . . . . .
5.3.2 Spatial resolution and PID performance . . . . . .
5.3.3 Improvement using the machine learning algorithm . .
5.4 Alternative track detector of Drift Chamber in Tera-Z . . . . .
5.4.1 PID for high luminosity Z pole at 2T . . . . . .
5.4.2 Performance and critical R&D . . . . . .
5.5 Cost estimation . . . . . .

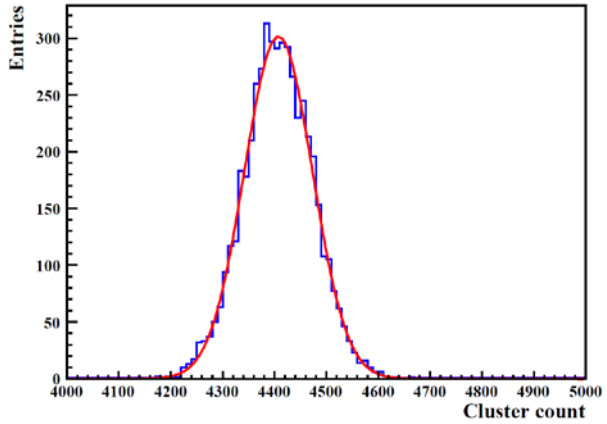
- **Update results of TPC simulation**

dN/dx measurement by Cluster Counting

- Direct cluster counting → Good method to measure dN/dx
  - Measure the number of ionization cluster of the incident particle
    - Minimized the cluster fluctuations
  - **< 3%** dN/dx resolution by cluster counting (statistical error only)
  - **5.4%** dE/dx resolution by charge measurement



Cluster size



distribution of cluster on the track

- Critical Challenges
  - How to achieve the individual clusters and count it?
    - **High cluster density**(**~30 cl./cm in Ar mixture for m.i.p → typical drift velocities 50 μm/ns**
      → 6 ~10 ns in between clusters → fast-shaping electronics (~ns needed) In time)
  - Need R&D with **high granularity or high time resolution** to meet the updated PID requirements.

Full Simulation of Pixelated readout TPC in TDR

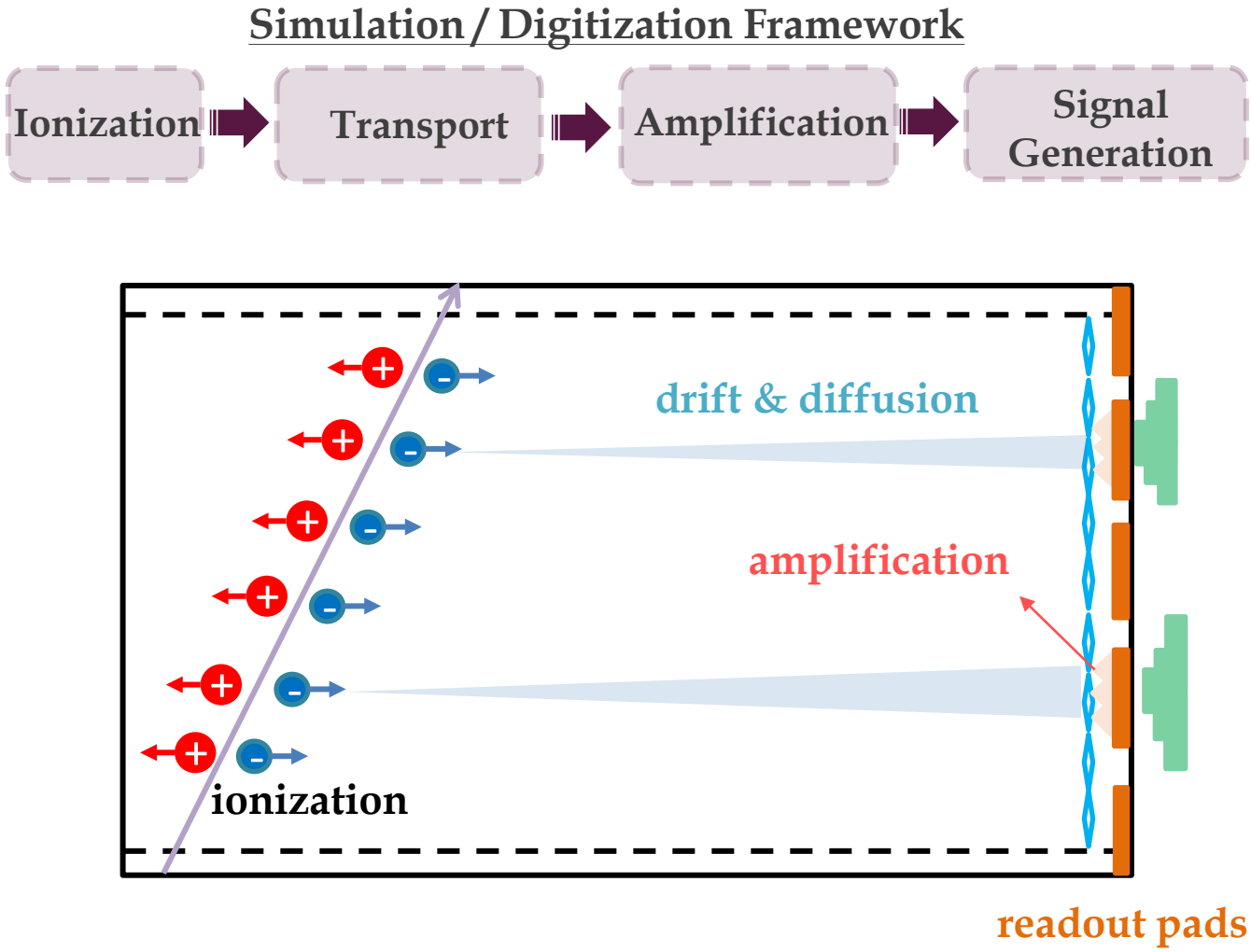
Guang Zhao, Linghui Wu, Yue Chang

Simulation:

- Full geometry TPC
- Ionization generation by Garfield++
- Drift and diffusion from parameterized model based on Garfield++ simulation

Digitization (Refer to the TPC module and prototype**):**

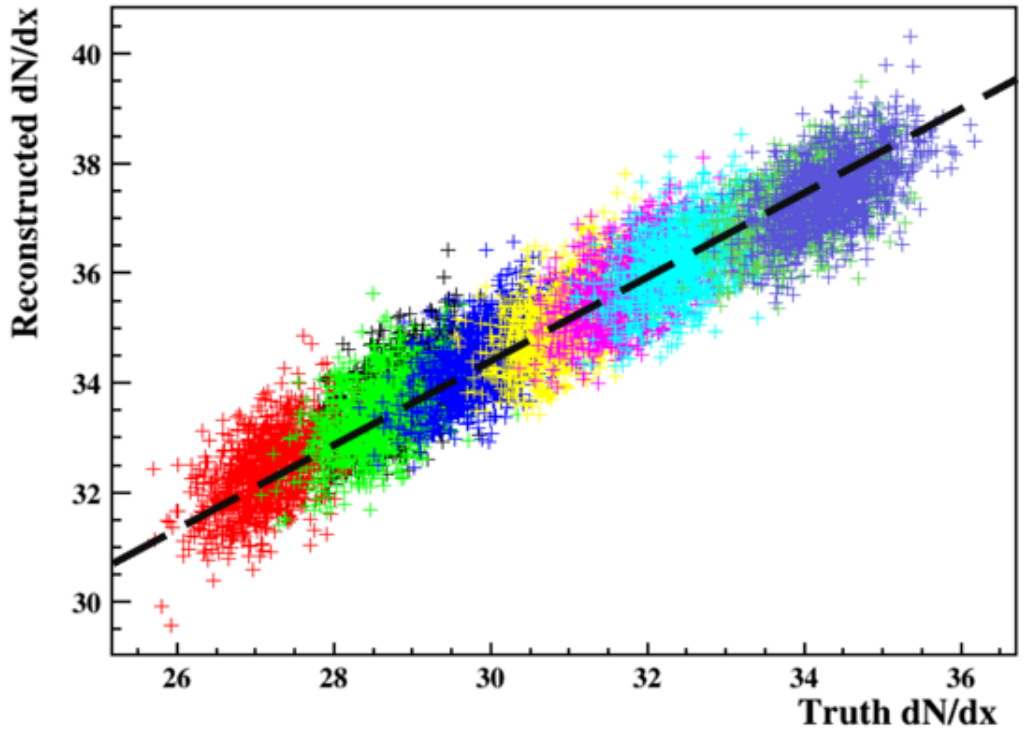
- Electronic noise: 100 e-
- Amplification:
  - Number of electrons: 2000
  - Signal size in space: 100 um



Reconstruction and preliminary PID performance

Reconstruction:

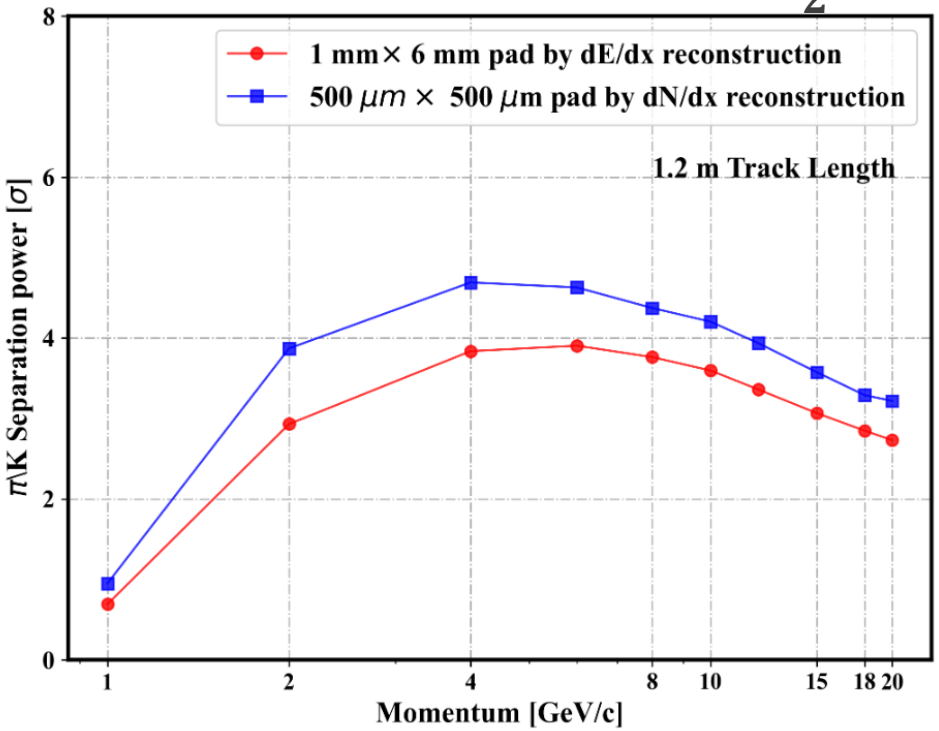
- Reconstruction by counting the number of fired pixels that pass a threshold
- **Reconstruction with good linearity and reliability**



Preliminary PID performance:

- 3σ π/k separation at 20 GeV with a 50 cm drift distance can be achieved

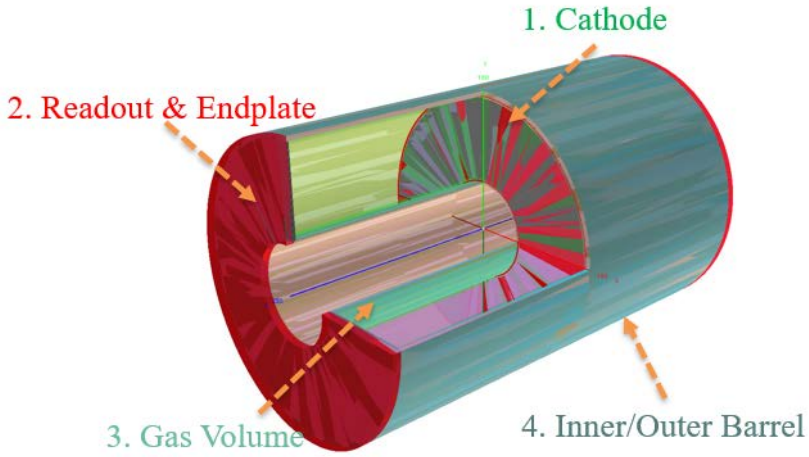
$$Sp = \frac{|\mu_A - \mu_B|}{\frac{\sigma_A + \sigma_B}{2}}$$



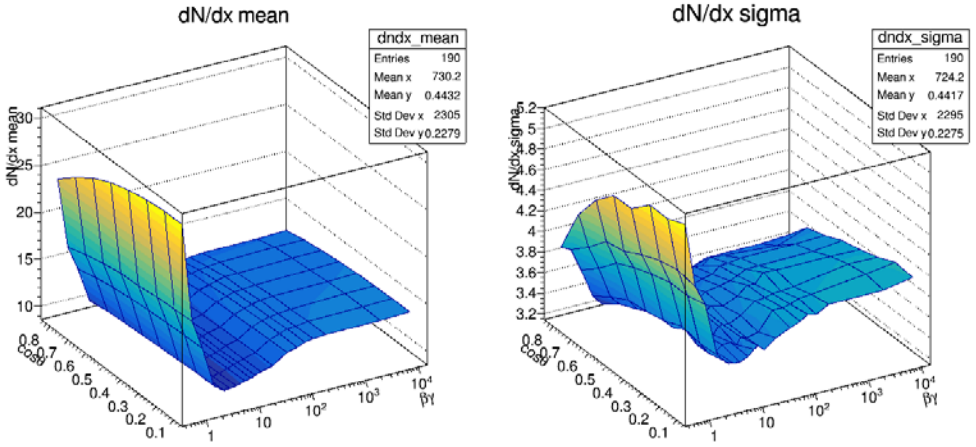
TPC software updated in CEPCSW (Available)

Xin She, Yue Chang, Guang Zhao, Linghui Wu

- **Geometry implementation based on CEPC Ref-TDR**
  - Cathode, micromegas readout and endplate, barrel, gas volume
- **PID: dN/dx implementation with a parameterized model**
  - Track-level dN/dx by parameterization from Garfield++-based full simulation
    - dN/dx mean vs. $\beta\gamma$ and cos θ
    - dN/dx sigma vs. $\beta\gamma$ and cos θ (for 1.2m track length)

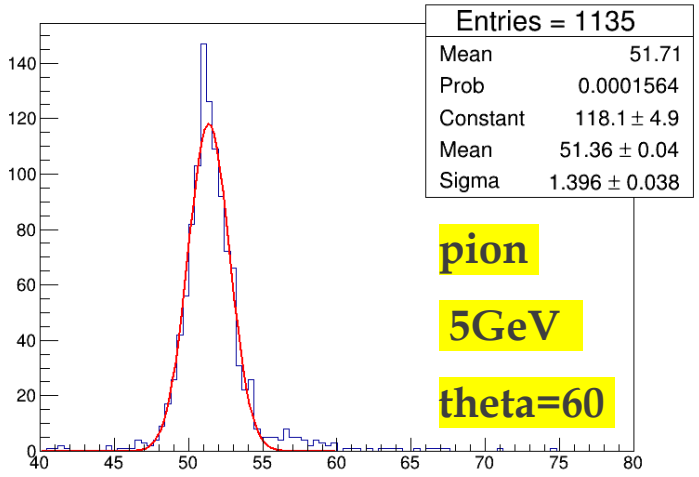


Parameterized dN/dx

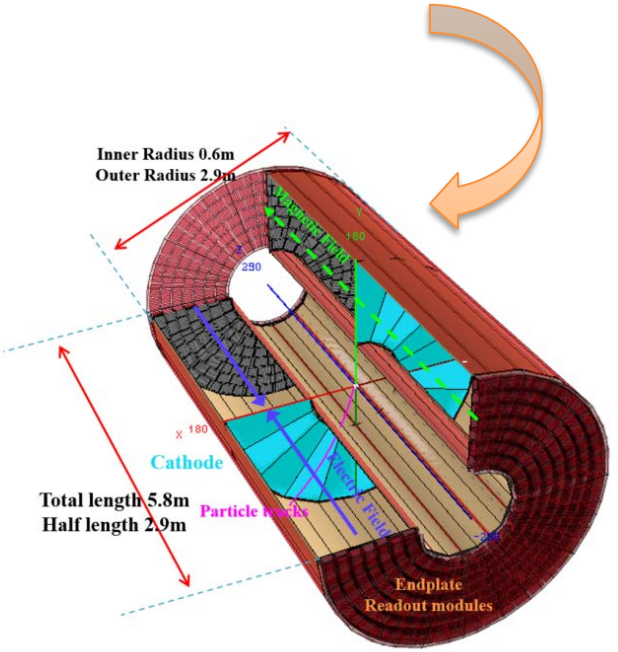


dN/dx mean dN/dx sigma

dN/dx simulation in CEPCSW



Relative resolution: ~2.7% (Sigma/Mean)



- **Status of the test beam with TPC detector**

Status of the prototype of pixelated TPC for TDR

- **R&D on Pixelated TPC readout for CEPC TDR**
  - The **TOA and TOT** can be selected as the initiation function in the ASIC chip
    - 500μm×500μm pixel readout designed
    - Noise of FEE: 100e
    - Time resolution: **14bit** (5ns bin)
    - **Power consumption: <1mW/pixel (2nd prototype)**
      - **~100mW/cm^2**
    - Technology: 180nm CMOS -> 60nm CMOS
    - High metal coverage: 4-side bootable

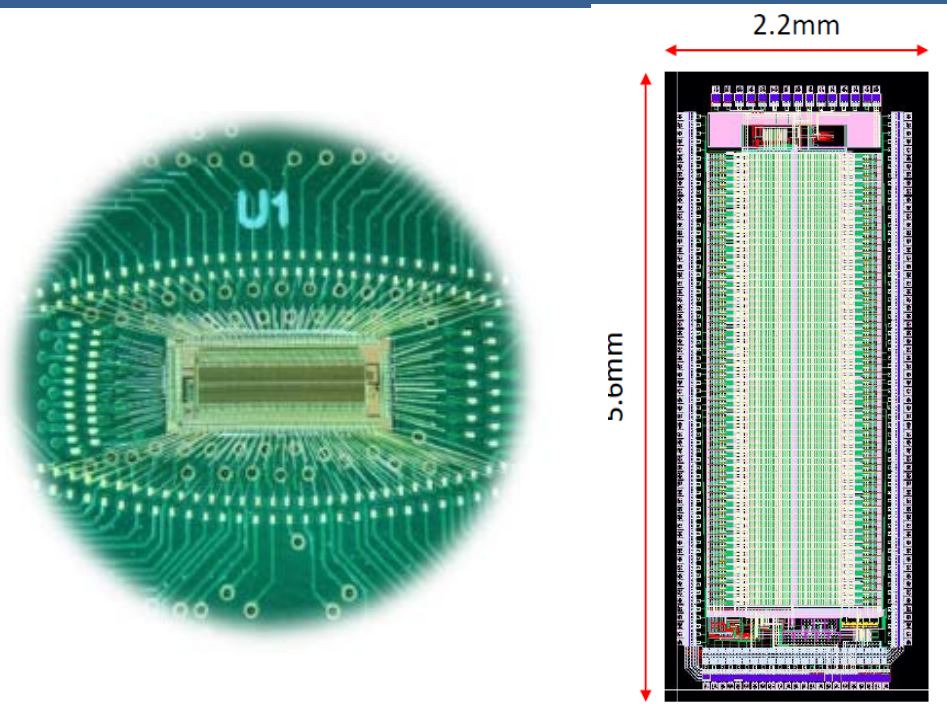
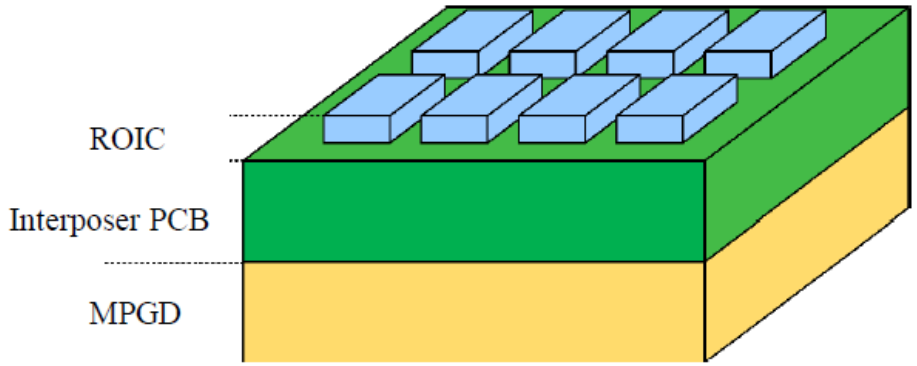


Photo and layout of ASIC Chip R&D for TPC

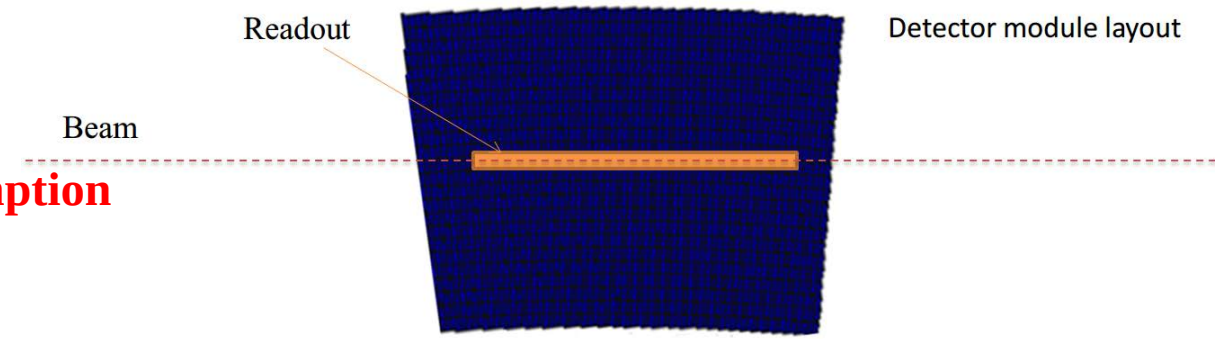
- **Prototyping pixelated TPC detector using the chips**
  - Principle of the prototype is no problem for testing
  - The validation of the prototype preparation ongoing



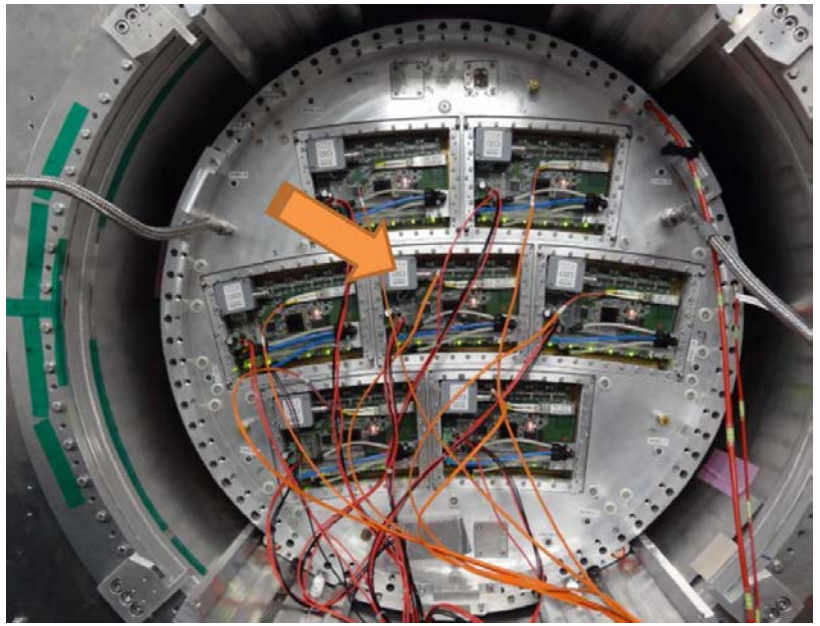
Prototyping pixelated TPC detector using the chips

Some critical simulation and validation

- **Pixelated readout TPC can be as a realistic and promised track detector in CEPC TDR, some key issues will be simulated and validated.**
  - **Occupancy and hit density**
  - **Improved dE/dx+dN/dx**
  - **Ion backflow suppression**
  - **Reasonable channels and power consumption**
  - **Running at 2 Tesla**
  - **Beamstrahlung and distortion**

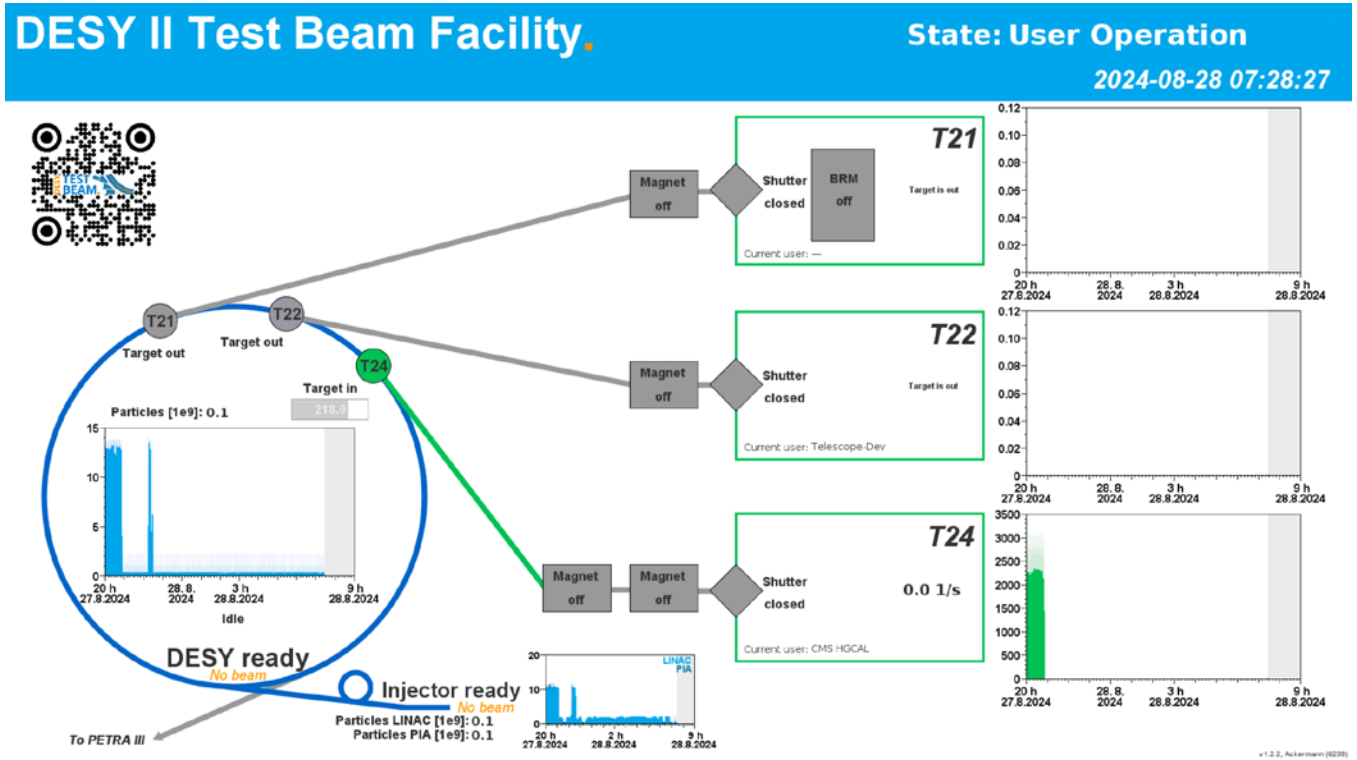


- **LCTPC (Lepton Collider Time Projection Chamber) collaboration will continue to push this technology to e+e- collider.**



DESY beam plan

- Some time slots available for the test beam
- Test bam hall for TPC surrounded 1.0T
  - TB241
  - **Contacted with Ralf** in charge of this hall



DESY TEST BEAM.

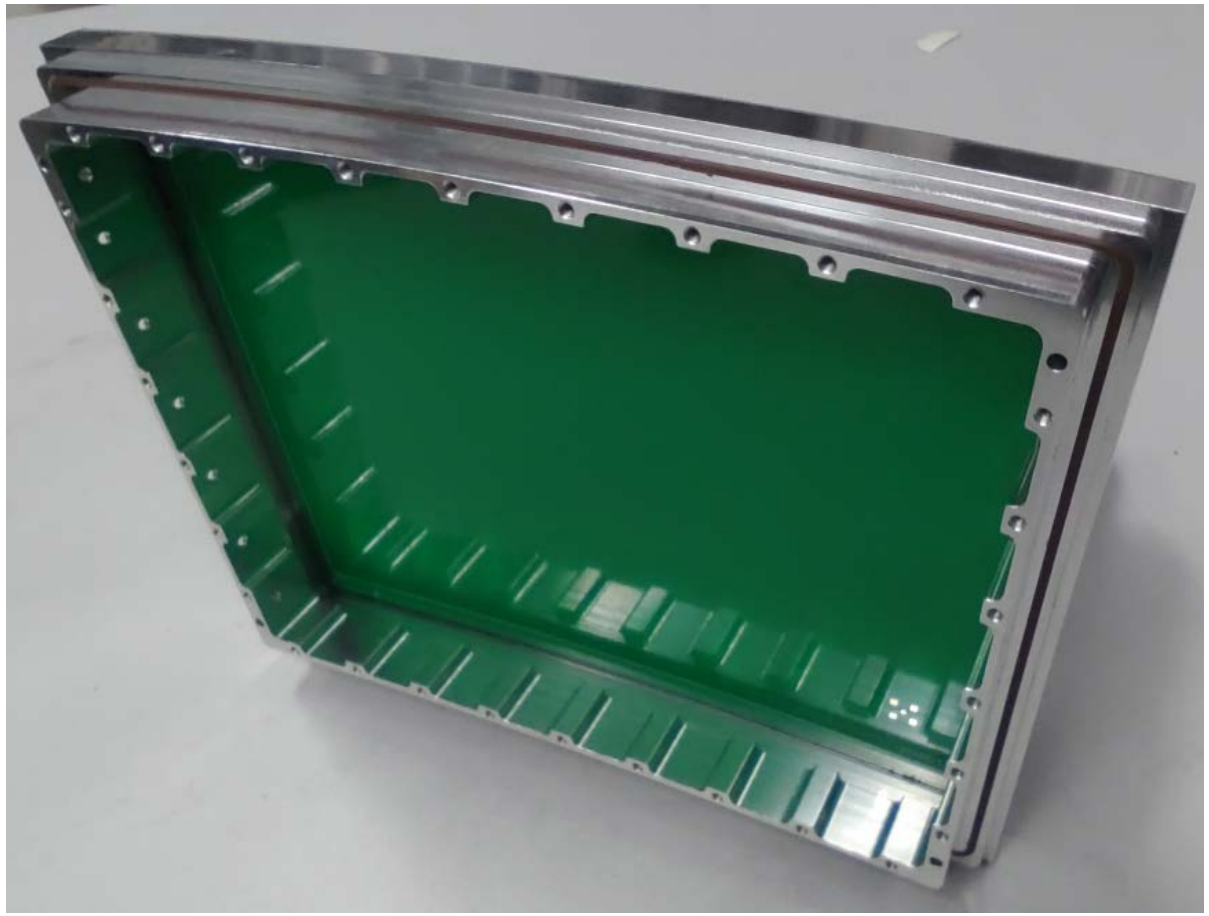
DESY 2 Test Beam Schedule 2024 – Status from 28/AUG/2024

DESY 2 Test Beam Coordinators: Ralf Diener, Norbert Meyners, Marcel Stanitzki

Startdate	Week.	TB21	T	TB22	T	TB241	T	TB24	T
01.01.2024	1	Shutdown		Shutdown		Shutdown		Shutdown	
08.01.2024	2	Shutdown		Shutdown		Shutdown		Shutdown	
15.01.2024	3	Shutdown		Shutdown		Shutdown		Shutdown	
22.01.2024	4	Shutdown		Shutdown		Shutdown		Shutdown	
29.01.2024	5	Startup		Startup		Startup		Startup	
05.02.2024	6	CMS Outer Tracker	X	dSiPM	X			CMS–HGCAL	X
12.02.2024	7	CMS Outer Tracker	X	Mu3e	X			AidaInnova–WP6	X
19.02.2024	8	CMS ETL ETROC	X	Mu3e	X			AidaInnova–WP6	X
26.02.2024	9	CMS ETL ETROC	X	TelePix	X			ATLAS HGTD	
04.03.2024	10	ITk Pixel Dortmund	X	ATLAS–ITk–Strips	X			ATLAS HGTD	
11.03.2024	11	CMS Inner Tracker	X	LHCb–MightyPix	X			CMS ETL	X
18.03.2024	12	CMS Inner Tracker	X	LHCb–MightyPix	X			SHiP–SHADOWS–ECAL	X
25.03.2024	13	Maintenance		Maintenance		Maintenance		Maintenance	
01.04.2024	14	Maintenance		Maintenance		Maintenance		Maintenance	
08.04.2024	15	DESY Heidelberg TB School	X	Tangerine	X			DESY Heidelberg TB School	
15.04.2024	16	Schwartz–Reisman School		Tangerine	X			ALICE–ITS3	
22.04.2024	17	MDI–2		RD50–MPW4	X			CalVision	X
29.04.2024	18	CMS ETL ETROC	X	CMOS Strips Detectors	X			Telescope–Dev	X
06.05.2024	19	CMS ETL ETROC	X	HD HV–MAPS	X			IPHC–CE65_v2	
13.05.2024	20	Maintenance		Maintenance		Maintenance		Maintenance	
20.05.2024	21	MDI–2		dSiPM	X			CMS HGCAL	
27.05.2024	22	ATORCH		Tangerine	X			CMS HGCAL	
03.06.2024	23	CMS ETL ETROC	X	Tangerine	X				
10.06.2024	24	CMS ETL ETROC	X						
17.06.2024	25	CMS ETL ETROC	X	DCRSD	X				
24.06.2024	26	CMS Inner Tracker	X	ATLAS–ITk–Strips	X				
01.07.2024	27	Maintenance		Maintenance		Maintenance		Maintenance	
08.07.2024	28	MONOPIX2	X	Telescope–Dev	X				
15.07.2024	29	Belle–II CMOS	X	CMS–HGCAL	X			MIMOSIS	
22.07.2024	30			TelePix	X				
29.07.2024	31	BL4S preparation		TelePix	X				
05.08.2024	32	Shutdown		Shutdown		Shutdown		Shutdown	
12.08.2024	33	Shutdown		Shutdown		Shutdown		Shutdown	
19.08.2024	34	Shutdown		Shutdown		Shutdown		Shutdown	
26.08.2024	35			Telescope–Dev				CMS HGCAL	X
02.09.2024	36								
09.09.2024	37	BL4S	X						
16.09.2024	38	BL4S	X						
23.09.2024	39	BL4S	X	Tangerine	X			UHH–LGAD	X
30.09.2024	40			RD50–MPW4					
07.10.2024	41	Maintenance		Maintenance		Maintenance		Maintenance	
14.10.2024	42	ATORCH		ATLAS–ITk–Strips	X			DDR6–CALICE SiW–ECAL	X
21.10.2024	43			Tangerine	X			CalVision	
28.10.2024	44	MONOPIX2	X	Tangerine	X			EEEMCAL	
04.11.2024	45	MONOPIX2	X	UHH–LGAD	X			EEEMCAL	
11.11.2024	46	Maintenance		Maintenance		Maintenance		Maintenance	
18.11.2024	47	CMS HGCAL	X	ATLAS HGTD	X			LHCb–ECAL	
25.11.2024	48	CMS Inner Tracker	X	ATLAS HGTD	X			LHCb–ECAL	
02.12.2024	49	CMS Inner Tracker	X	ATLAS–ITk–Strips	X			CMS ETL ETROC	X
09.12.2024	50	LHCb–MightyPix	X	DCRSD	X			CMS ETL ETROC	X
16.12.2024	51	LHCb–MightyPix	X	Telescope–Dev	X			EXFLU	
23.12.2024	52	Shutdown		Shutdown		Shutdown		Shutdown	

Assembled module of the beam test

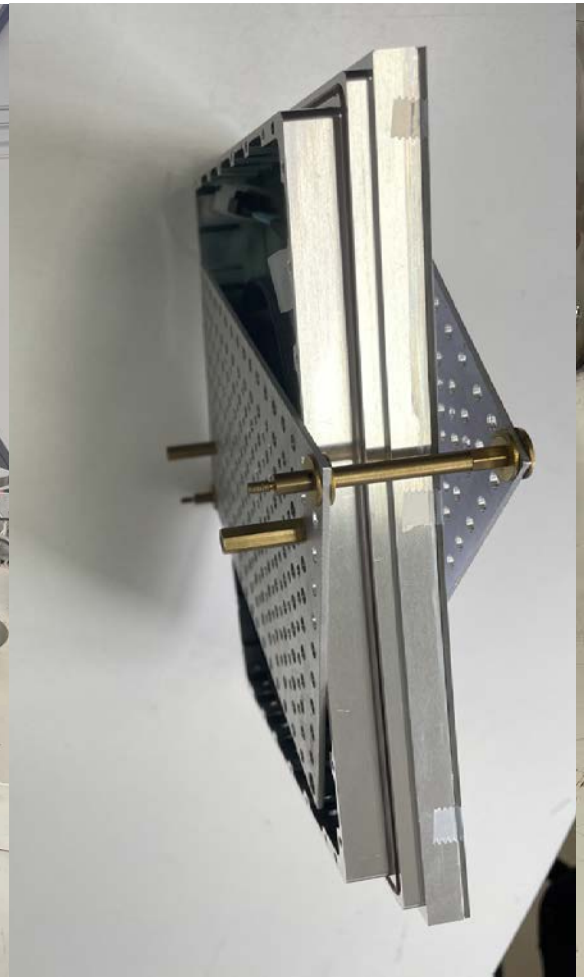
- Two Aluminum back frames have been done.
  - One assembled module delivered to Tsinghua.
  - **O ring has been selected using 2.3mm**



Magnetic field validation

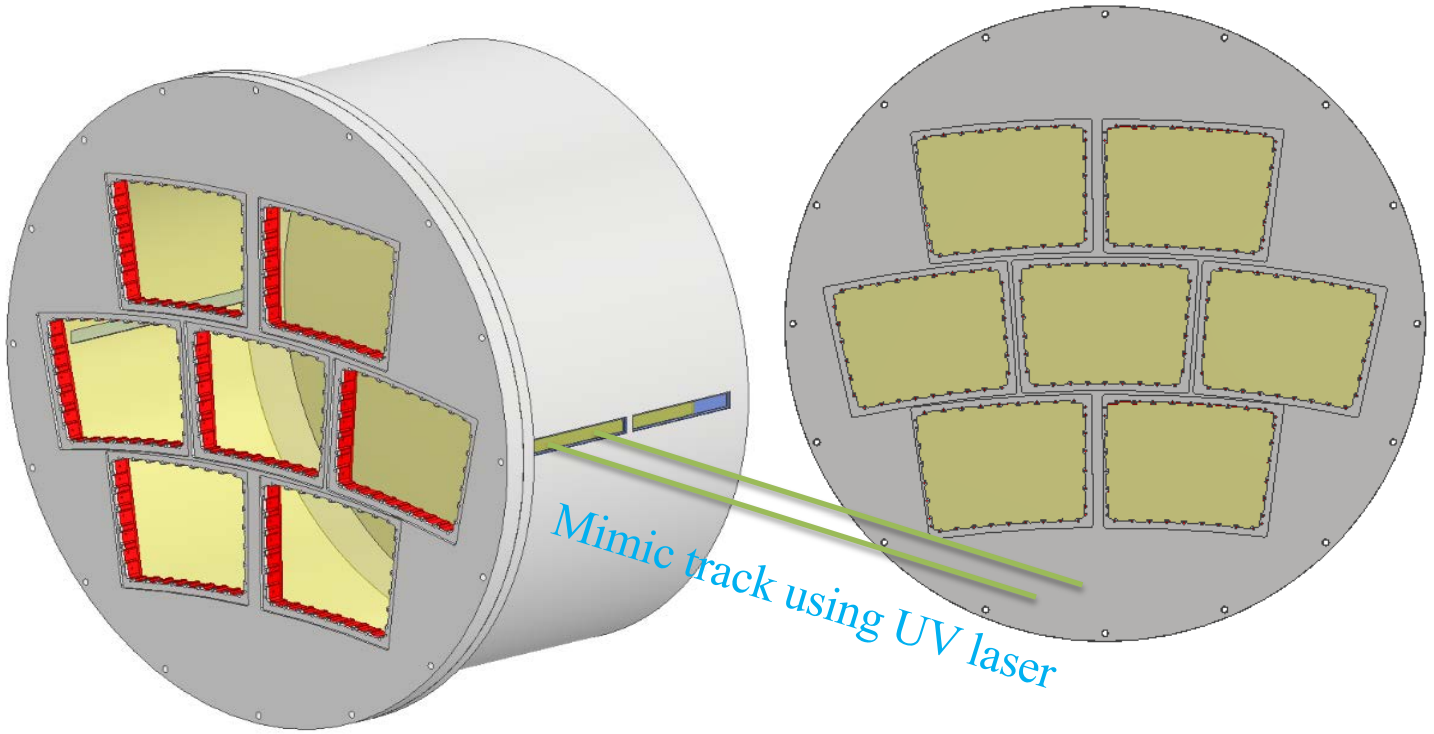
- The materials of the cables and connects have been studied surround the magnetic field of 1.2T.
  - The uniformity magnetic field **too smaller not to fit to study** TPC module.
  - All cables and connects confirmed to meet 1.2T (**Thanks to Feipeng's warm helpings**)

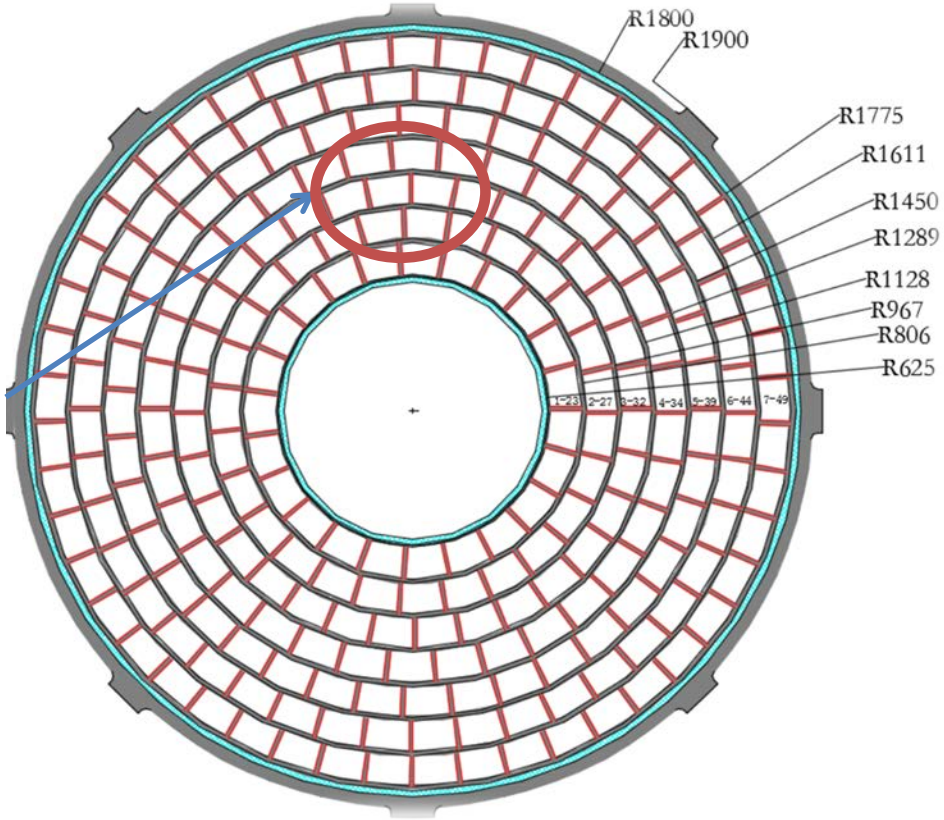





Preparation for Beam test - multi modules validation

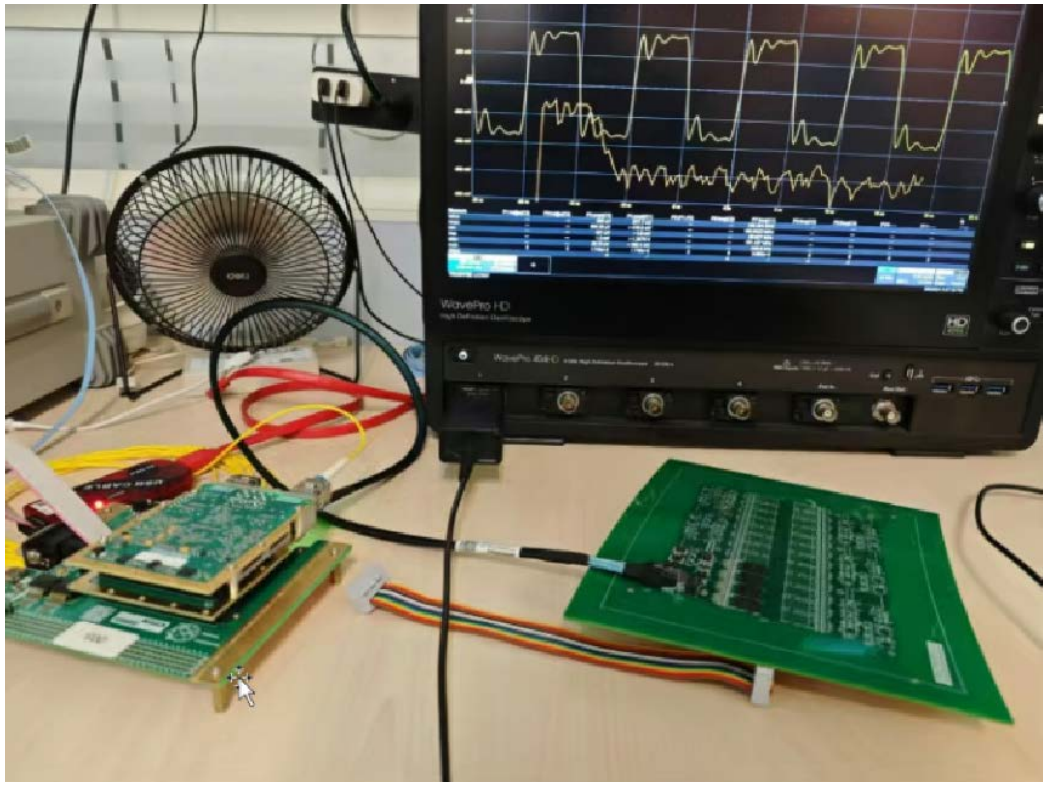
- Detailed design validated the final design of TPC readouts modules.
  - Junsong Zhang, Quan Ji, Jian Zhang, Huirong Qi
- Tested and studied at lab before the beam test.
  - Prototype will be **done in the middle of October**.

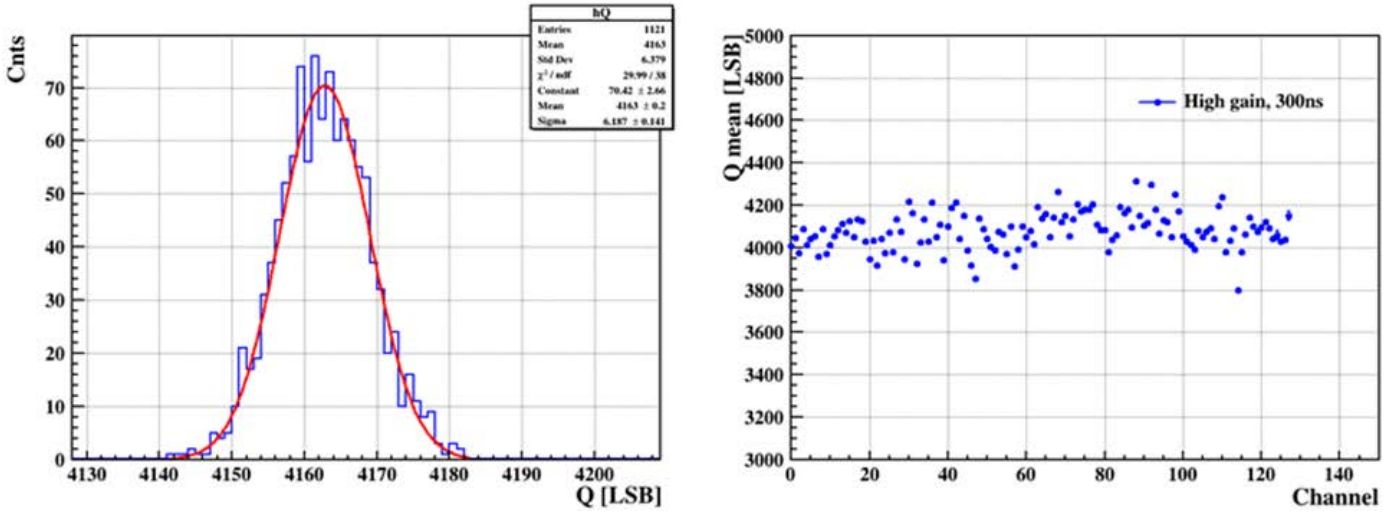




Updated results of the TPC module testing

- Completed testing of TEPIX, a pixel-based readout chip to **determine that the chip is operational**.
  - Inputted square wave signals, external trigger mode
  - Chip outputs data functional and the data taking per channel
    - This steps are working well, and the detector will be assembled in next weeks.



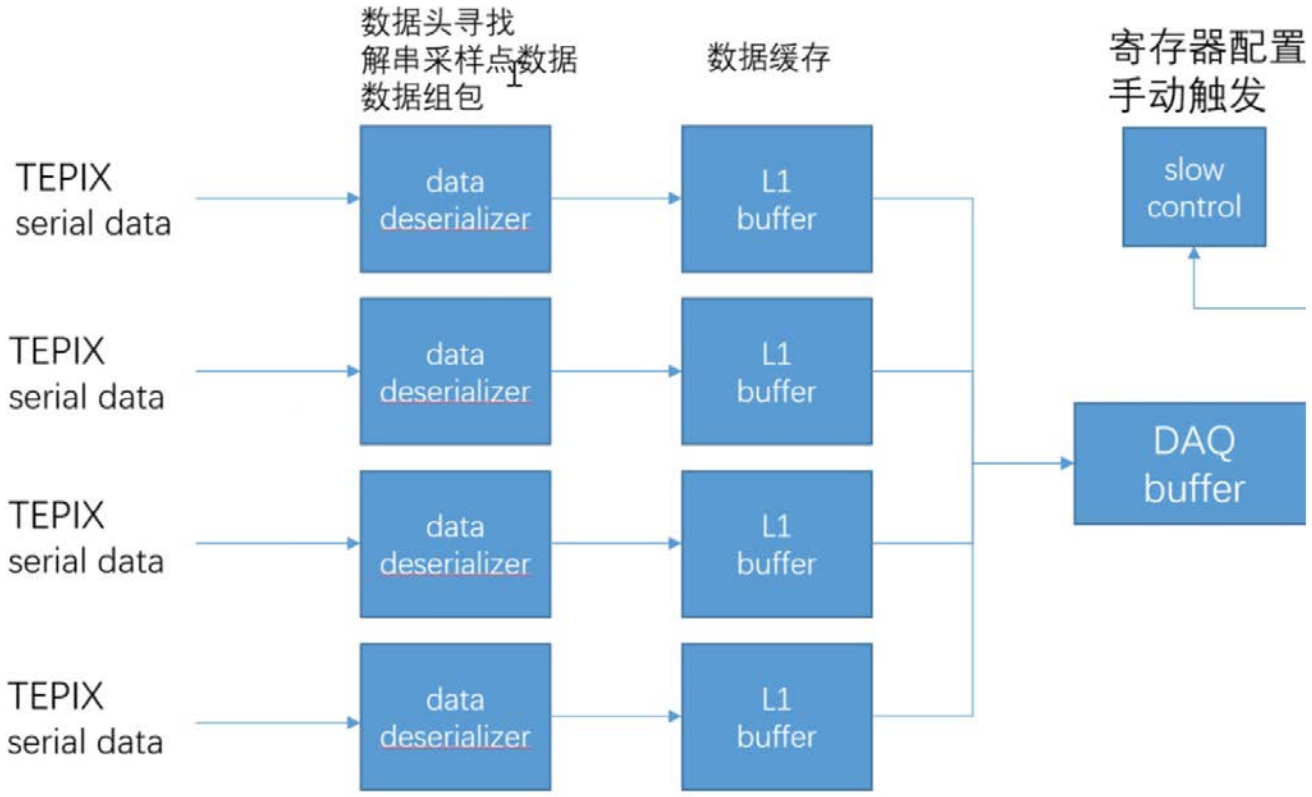


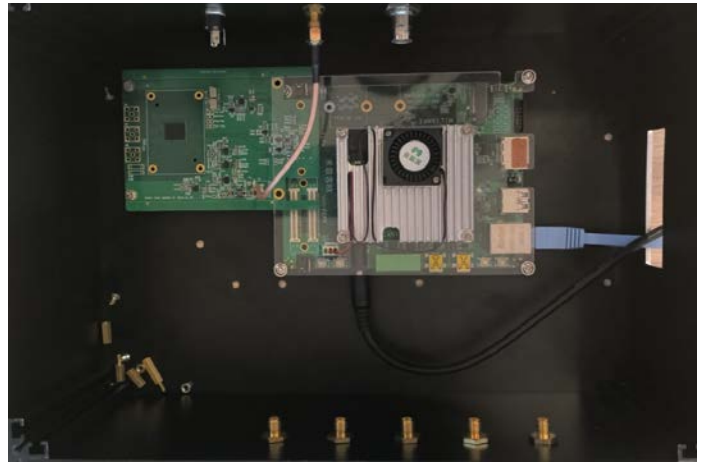
Amplitude distribution per channel(left) and Uniformity per channel (right)

Firmware and data structure of DAQ

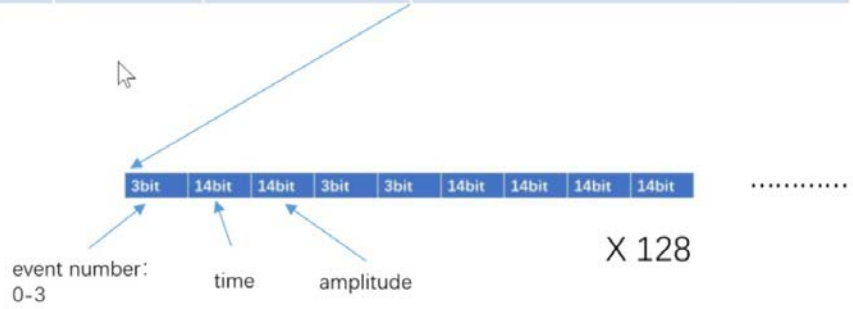
Zhi Deng, Jianmeng Dong

- Firmware construction block diagrams and data structures are defined.
  - All functional modules are under development.
- **It's going well but still needs some time to debug**.





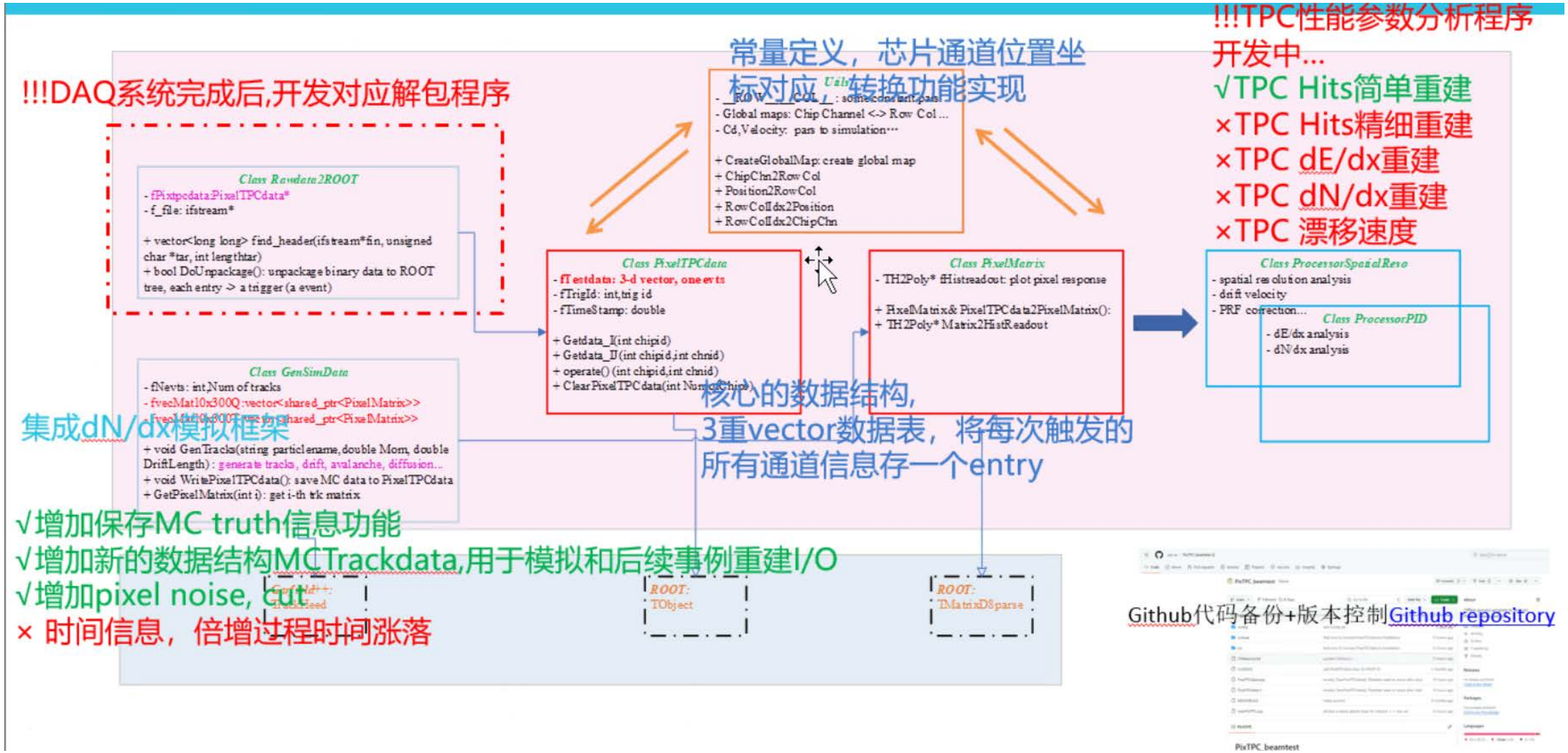
Head	Channel number	timestamp	Trigger number	Payload data
0xff	4MSB->port, 4LSB->chip	64b	32b	Vary length



Development of the data analysis (ongoing)

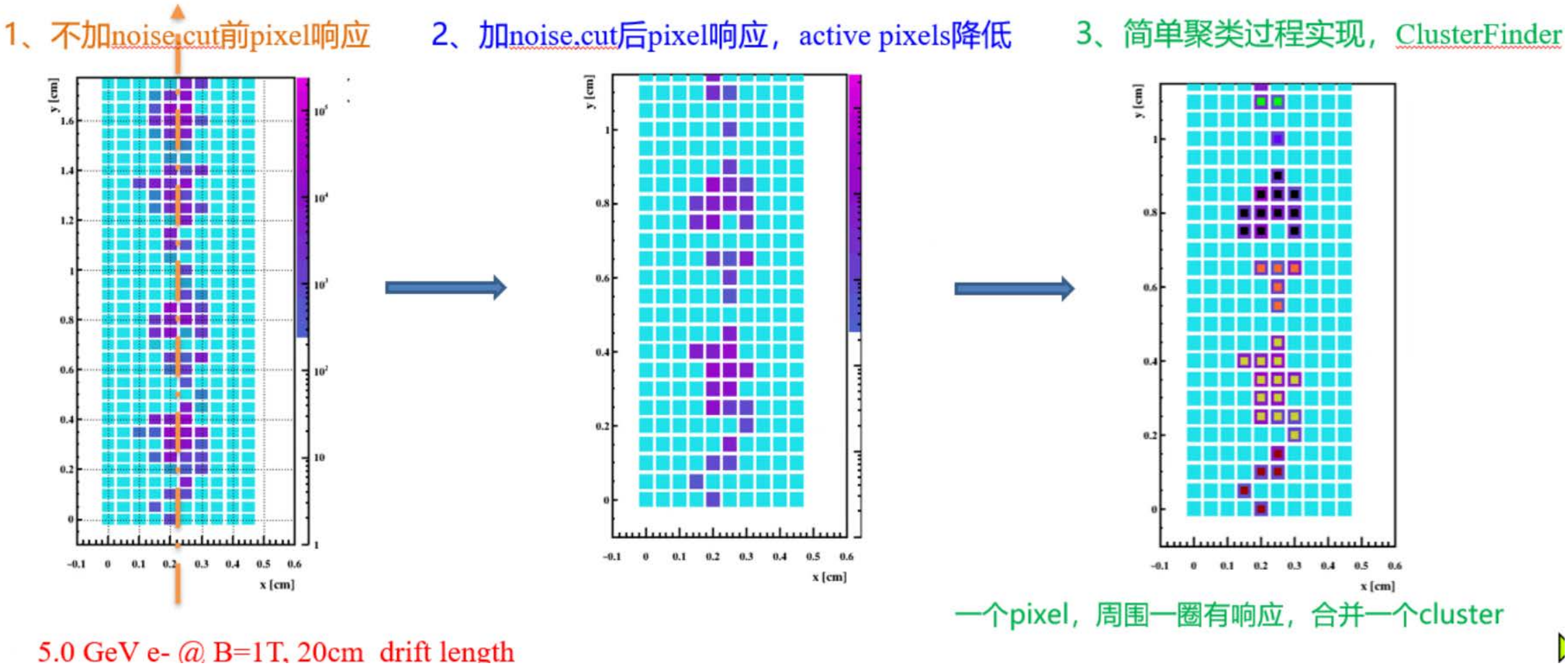
Xin She, Jianmeng Dong

- Firmware construction block diagrams and data structures are defined.
  - The data analysis are under development.(Kalman filter and CEPCSW)



Development of the data analysis: Cluster Finding (ongoing)

- The preliminary simulation data analysis are under development including the drift, diffusion and avalanche of the detector.



Summary

- **TPC detector prototype R&D using the pad readout towards the pixelated readout for the future e+e- colliders, espial to the high luminosity Z pole run at future e+e- collider.**

- **Pixelated TPC is choose as the baseline detector as main track in CEPC ref-TDR. The simulation framework has been developed using Garfied++ and Geant4 at IHEP, and all new updated parameters have been integrated in CEPCSW software.**

- **Some validation of TPC module and prototype for the test beam in DESY have been studies and developed the analysis software in last several months.**


CEPC TDR像素型时间投影室TPC
探测器束流测试合作讨论会
Thanks for all !
2024.4.26