dE/dx analysis of TPC detector prototype and new ASIC chip commissioning

Huirong Qi
ZhiYang Yuan, Yue Chang, Liwen Yu, Wei Liu, Jian Zhang, Hongliang Dai,
Zhi Deng, Yulan Li, Hui Gong

CEPC day, Jan. 29, 2022

Overview

1. TPC detector with UV laser
2. New electronic testing for TPC
3. Contributions for Snowmass and Summary

- dE/dx resolution of TPC detector with UV laser

Motivation- Particle identification

$$\sigma_{dE/dx} = \sigma_0 N_{hits}^{-k}$$

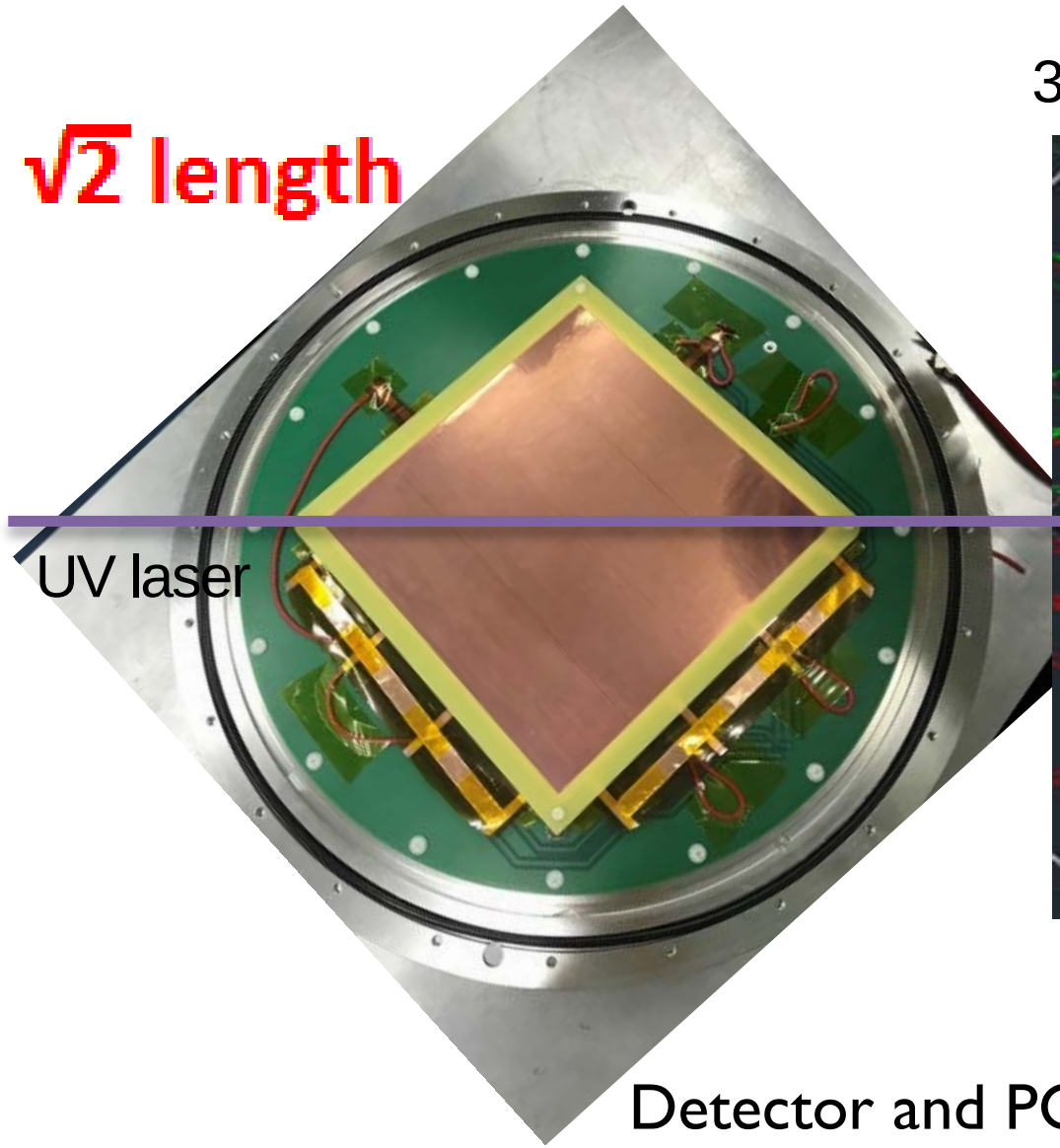
Experiment	Readout	Points	Sample	$p(GeV/c)$	$(\sigma_I/I)_{MC}$	$(\sigma_I/I)_{exp}$
	Pad (mm)					
PEP-4 TPC	4	183	e	14.5	2.6%	3.5%
TOPAZ TPC	4	175	π	0.4-0.6	3.8%	4.5%
DELPHI TPC	4	192	π	0.4-0.6	5.4%	6.2%
ALEPH TPC	4	344	e	45.6	3.0%	4.4%
STAR TPC	12, 20	13,32	π	0.4-0.6	5.3%	6.8%
ALICE TPC	7.5, 10, 15	63,64,32	π	6.0	3.3%	5.0%
TPC for CEPC	1mm×6mm	220	K	5.0	3.1%	
	Pixel(μm)					
GridPix TPC for ILD	55×55	9500	e	2.5	/	4.1%

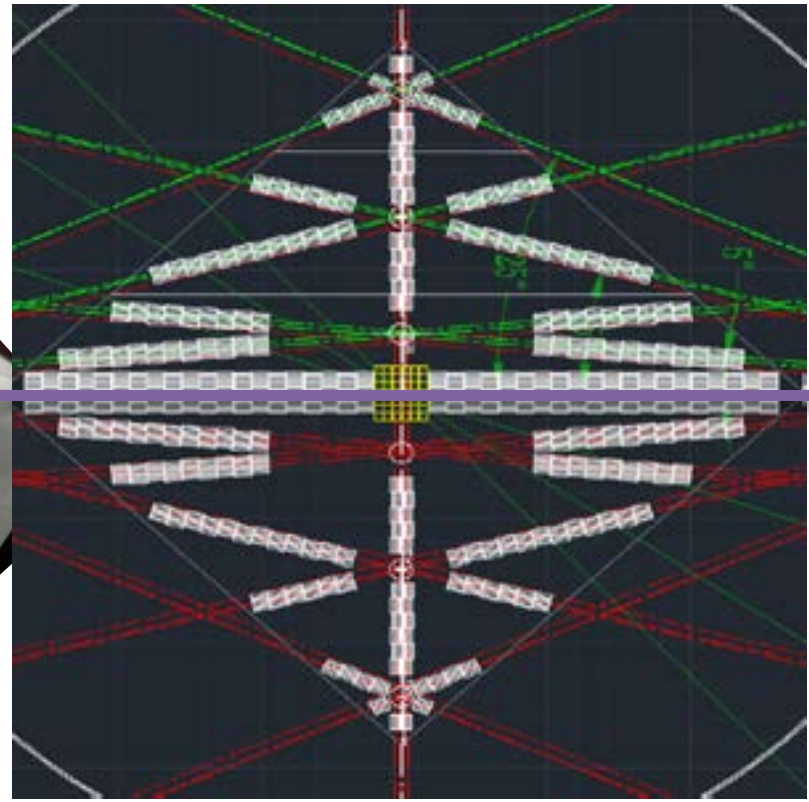
NO magnetic field
NO high energy particle testing beam

UV lasers (5 years R&D)

Pad TPC detector with UV laser

Pad size: 1mm × 6mm
38 hit points per track by UV laser





Detector and PCB readout board

Validation of UV laser with the mixture gases -Signal

The three operation gases for the detector compared with ILC DESY and KEK working gas

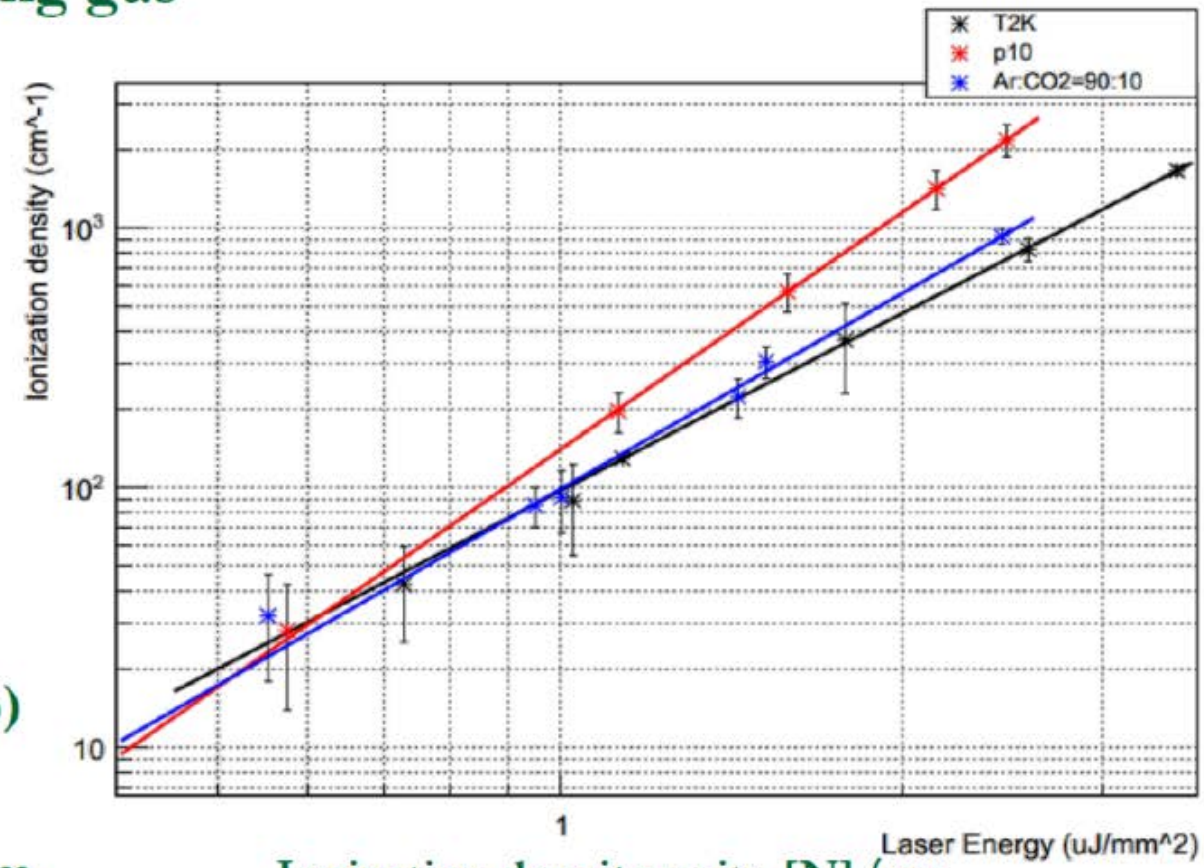
- T2K
- P10
- Ar/CO2=90/10

Gas purity

- Ar (99.999%)
- CO2 (99.999%)
- CH4 (99.999%)
- CF4 (99.999%)
- Isobutane (99.9%)

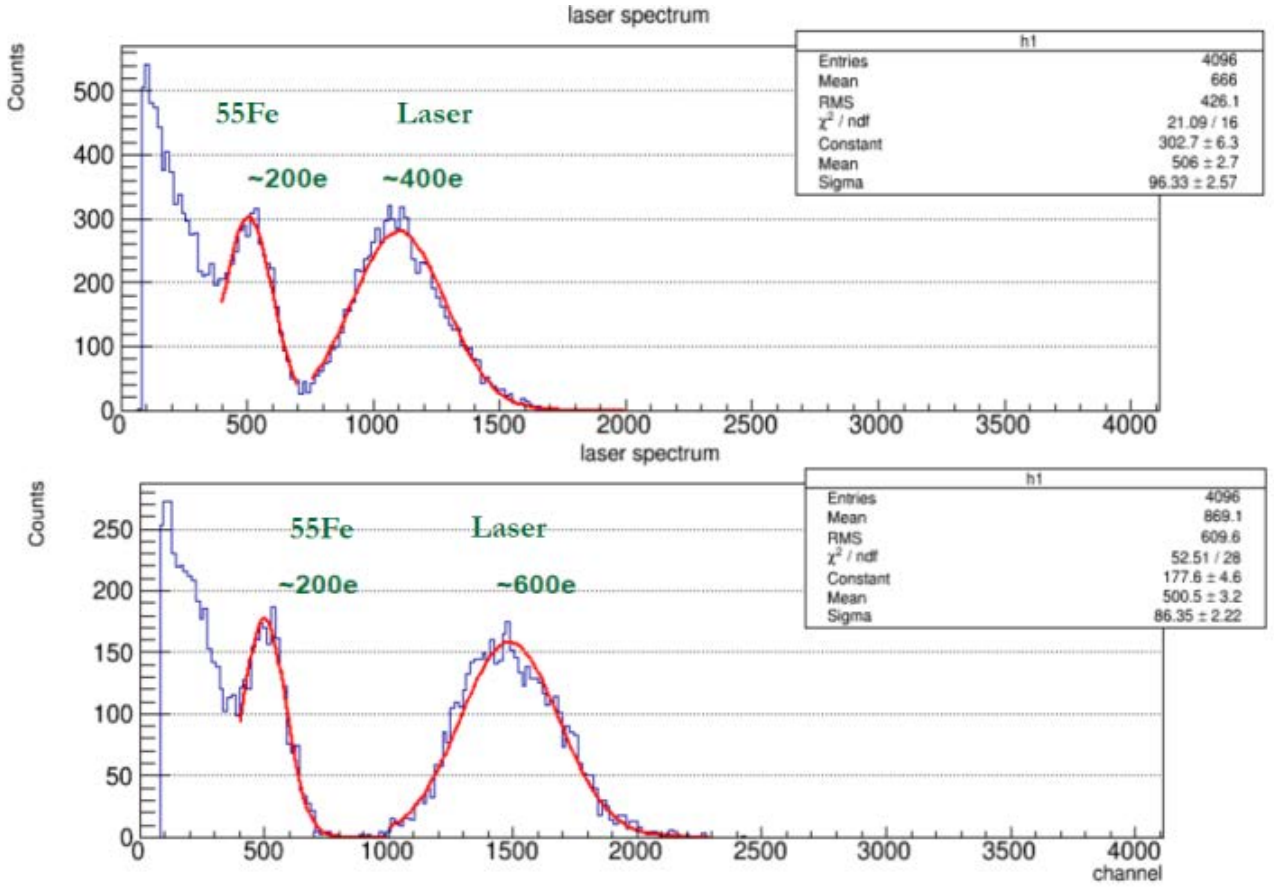
Ionization

- ~100 electrons/cm at ~1uJ/mm^2



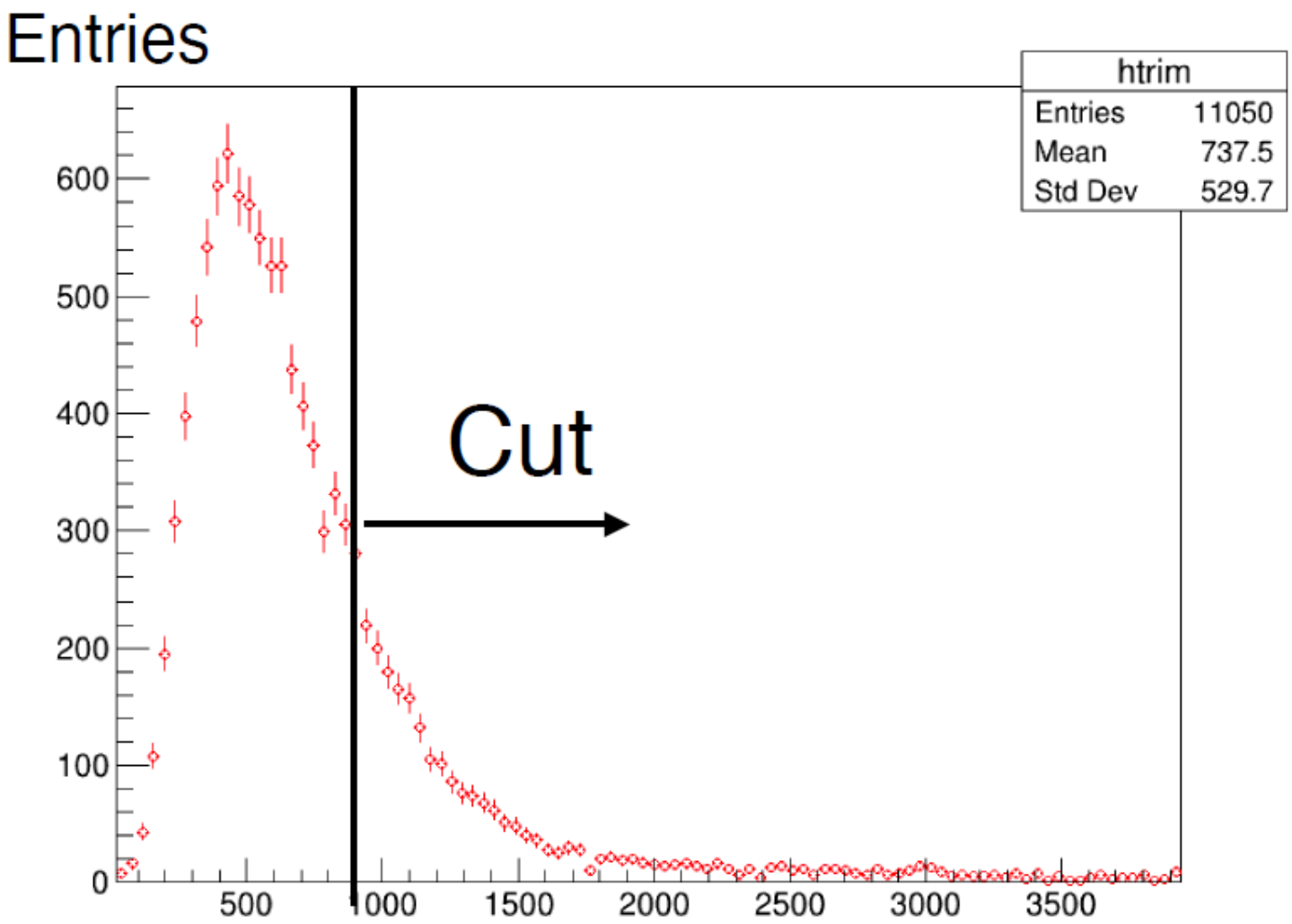
Ionization density unit: [N]/cm
(N is the primary electron number per 0.85mm^2)
Pad size: 0.9mm×6.0mm

Validation of UV laser and ^{55}Fe -Energy



- Same test conditions under the same working gases and high voltage
- The ionization results indicate that the number for Ar:CO2(90:10)-gas and T2K-gas are similar for the ionization density.
- About the gas purity, the experiment shows all mixture gas of the purity of isobutane is 99.9% despite other gases are 99.999%.

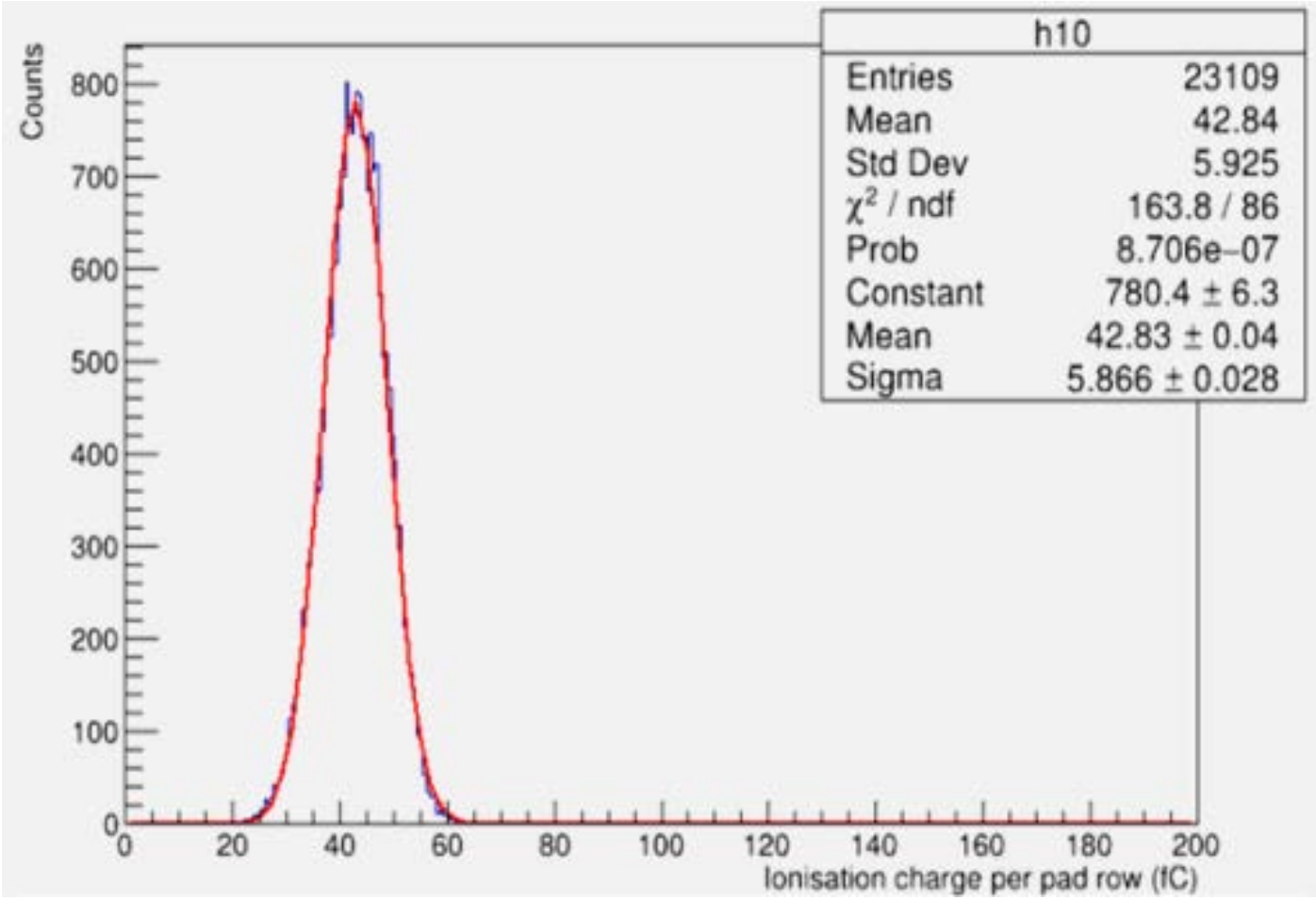
UV laser spectrum - **Charge correction**



- Take 70% trim average for upper bound
- Analysis without the contribution from the tail

UV laser spectrum - **Truncated method**

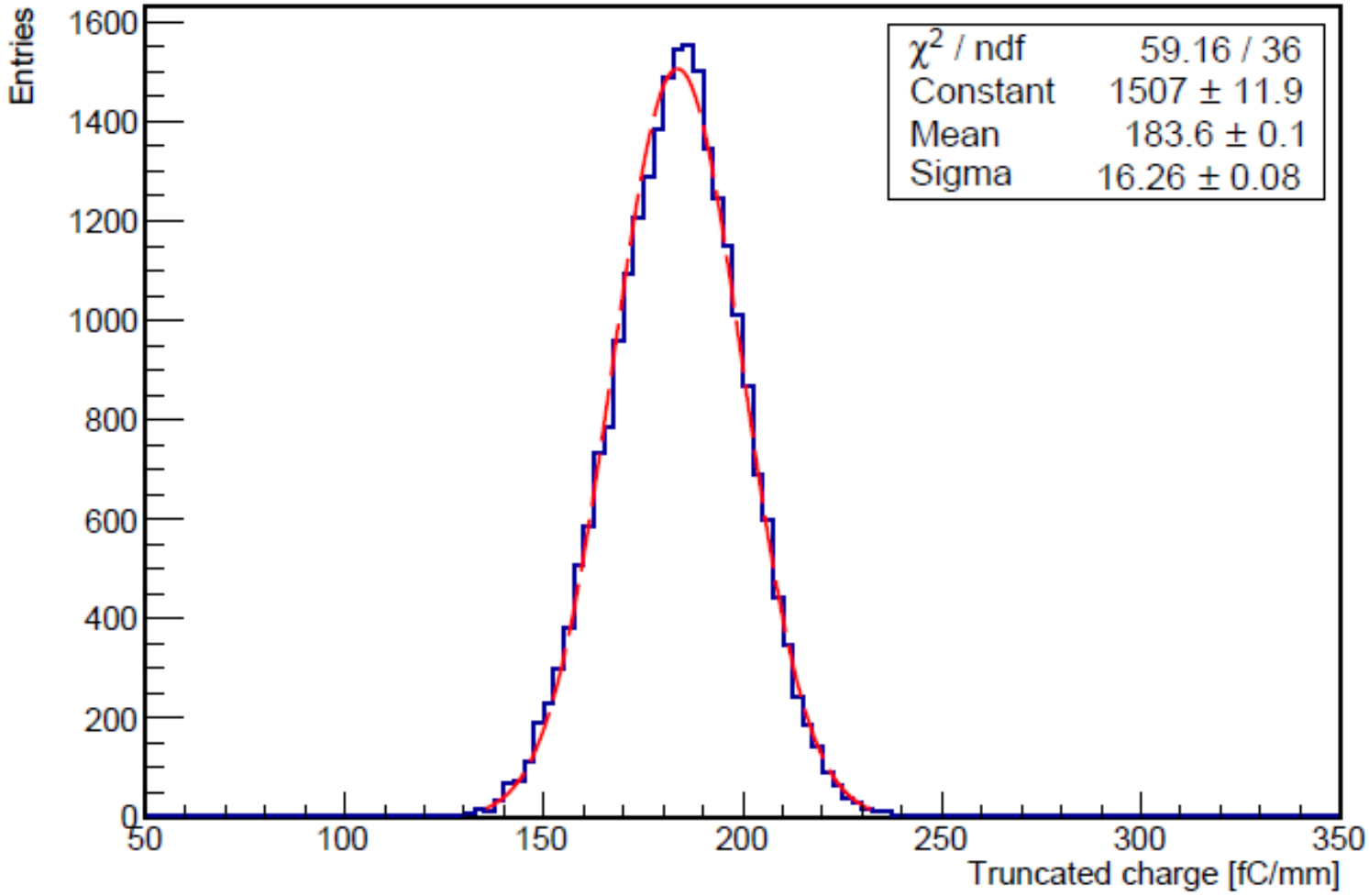
Energy cutting and correction by the events



Energy spectrum of UV

dE /dx resolution – **38 hit points**

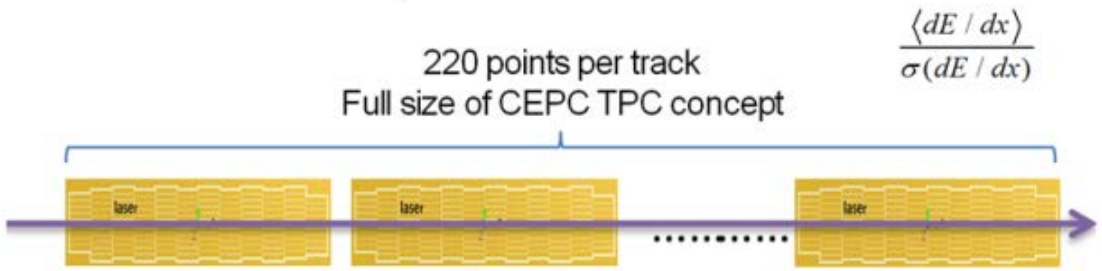
$$\sigma_{dE/dx} = (8.9 \pm 0.4)\,\%\textbf{(38hits)}$$

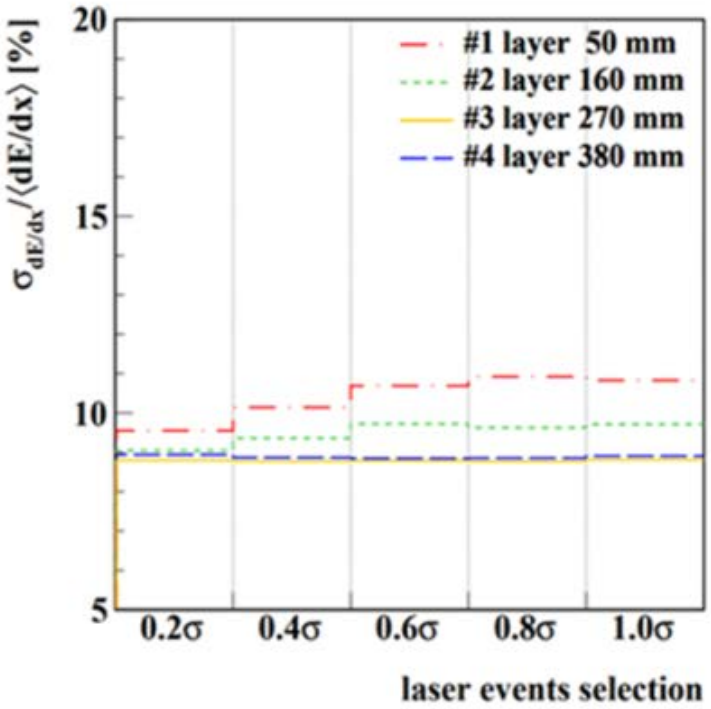


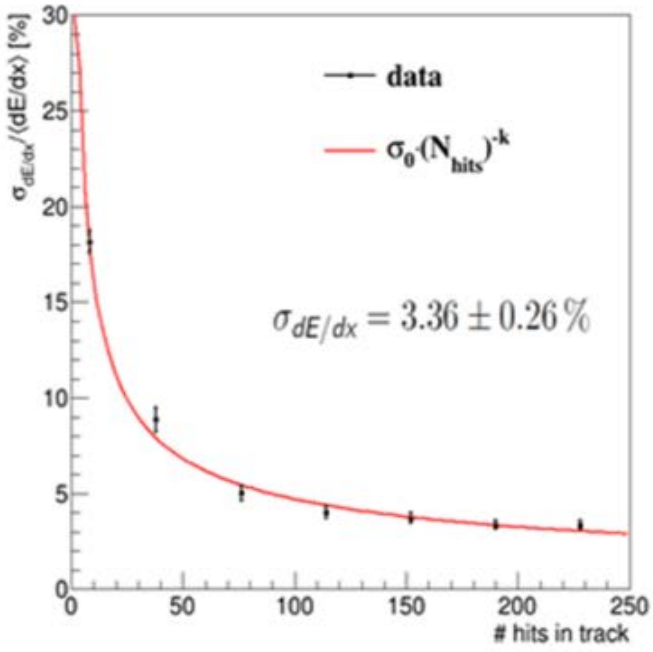
laser events using energy cutting and correction

dE /dx resolution - **pseudo-tracks using full size**

- dE/dx resolution achieved with pseudo-tracks of various lengths
- Comparison of simulation and experimental dE/dx
- Pseudo-tracks with 220 layers and dE/dx can reach to $3.36 \pm 0.26\%$





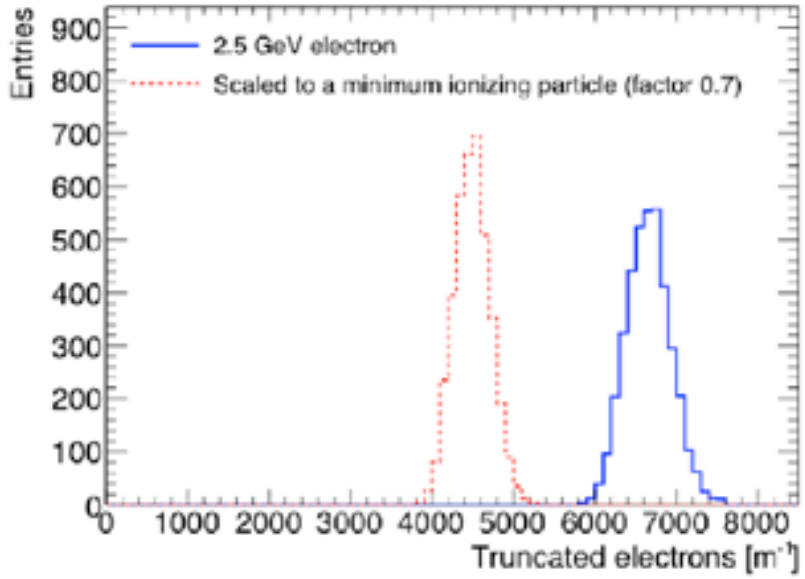


Peter's talk on IAS HEP Hong Kong 2022

Pixel dE/dx performance

- dE/dx resolution with truncated mean
  - From the single chip tracks; 1 m long tracks are made;
  - nr of electrons counted in slices of 20 pixel and reject 10% highest slices
  - Distances along track are scaled by 1/0.7 to get an estimation for the dE/dx of a MIP
  - Resolution is 4.1% for a 2.5 GeV electron and 4.9% for a MIP
- Separation $S = (N_e - N_{MIP})/\sigma_e$
- 8σ MIP-e separation for a 1 meter track

- A pixel readout can in principle within the resolution (diffusion) separate primary from secondary clusters. dE/dx can be measured by cluster counting and performance separation enhanced.

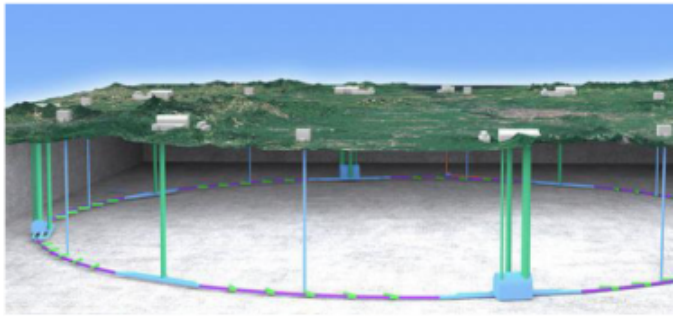


A Pixel TPC at the CEPC?

CEPC running above the Z (WW, Higgs) there are no critical issues

A Pixel TPC can deal with the high beam rates at the CEPC

- At the Z pole the CEPC with L = 34 10^{34} cm^{-2} s^{-1} will produce Z bosons at ~10 kHz
- Link speed of Timepix3 (in Quad) is 80 Mbps: 2.6 MHits/s per 1.41 × 1.41 cm^2
- Excellent time resolution: time stamping of tracks < 1.2 ns
- Power consumption ~2W/chip depends on hit rate
  - No power pulsing possible at the CEPC
  - Good cooling is important
- Ion back flow of the quad is measured to be 1.3% at a gain of ~2000. So IBF*Gain is ~25.



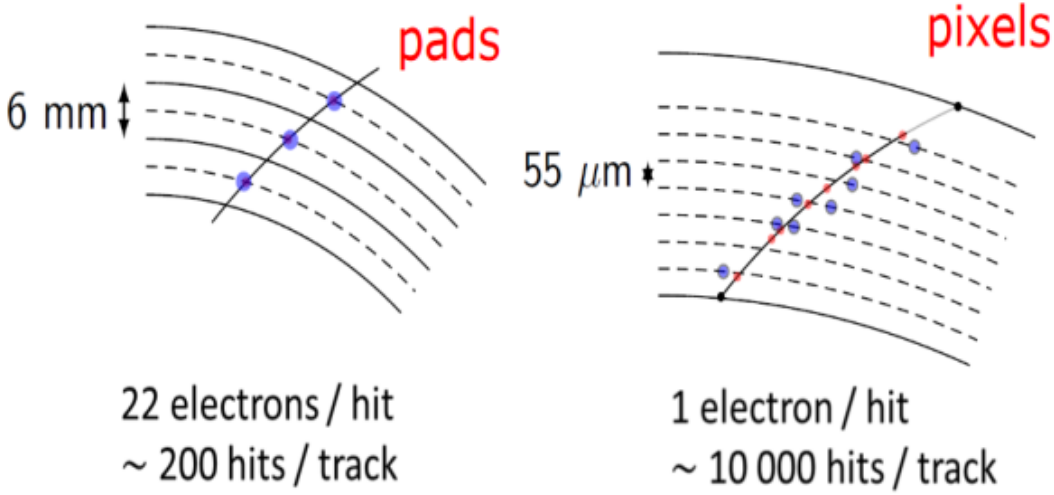
NB: to limit the distortions in de drift volume one needs to achieve < 4

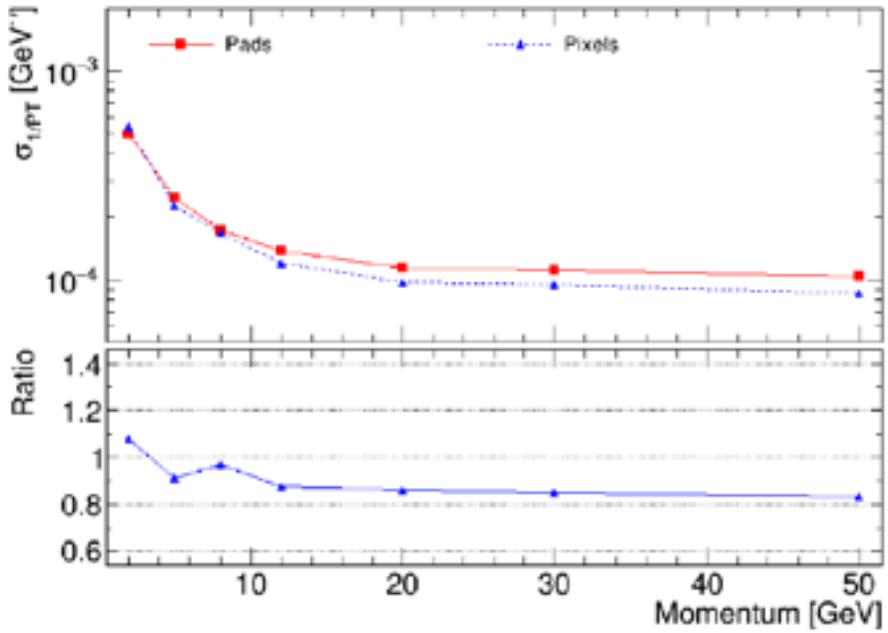
LCWS 2019 Sendai talk Huirong Qi

Collaboration: PID analysis of pixel TPC data starting

Performance of Pixel TPC at 2 Tesla

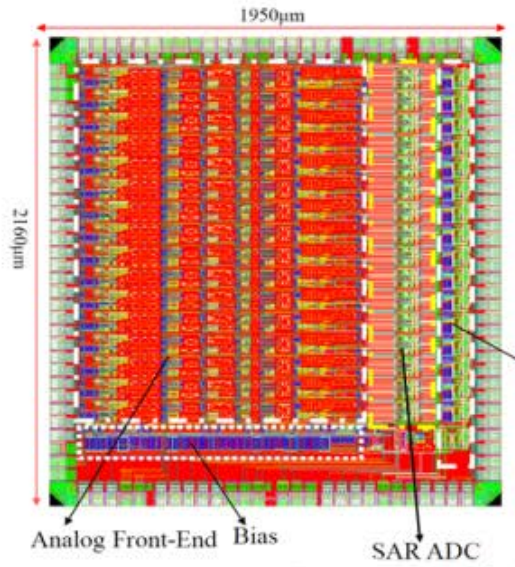
- From the full simulation the momentum resolution can be determined at 2-3 Tesla
- Momentum resolution is about **15%** better for the pixels with realistic coverage(with the quads arranged in modules 59%) compared with the pad TPC option at 3 Tesla
- Starting to check the beam data and collaborate analysis momentum resolution (preliminary showing the fine results) **/IHEP & Bonn Univ.**





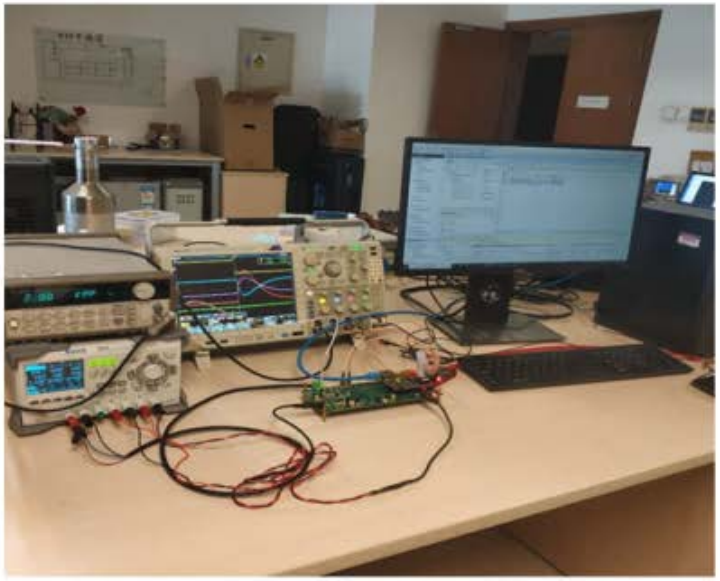
- new ASIC chip commissioning

Low power ASIC chip



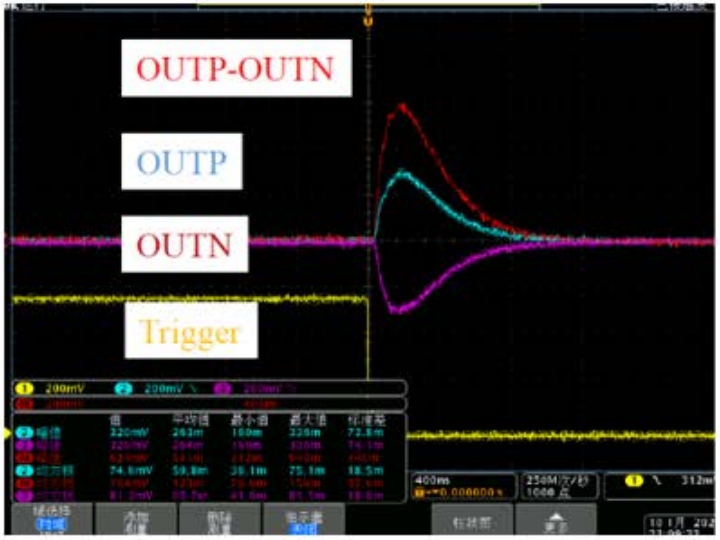
- The floor plan in layout :
  - The die size of 1950 μm x 2160 μm
  - Analog Front-End , SPI, SAR ADC, LVDS driver are supplied by separate power
- The ASIC have been taped out in November, 2019 and is being evaluated

Layout of ASIC chip



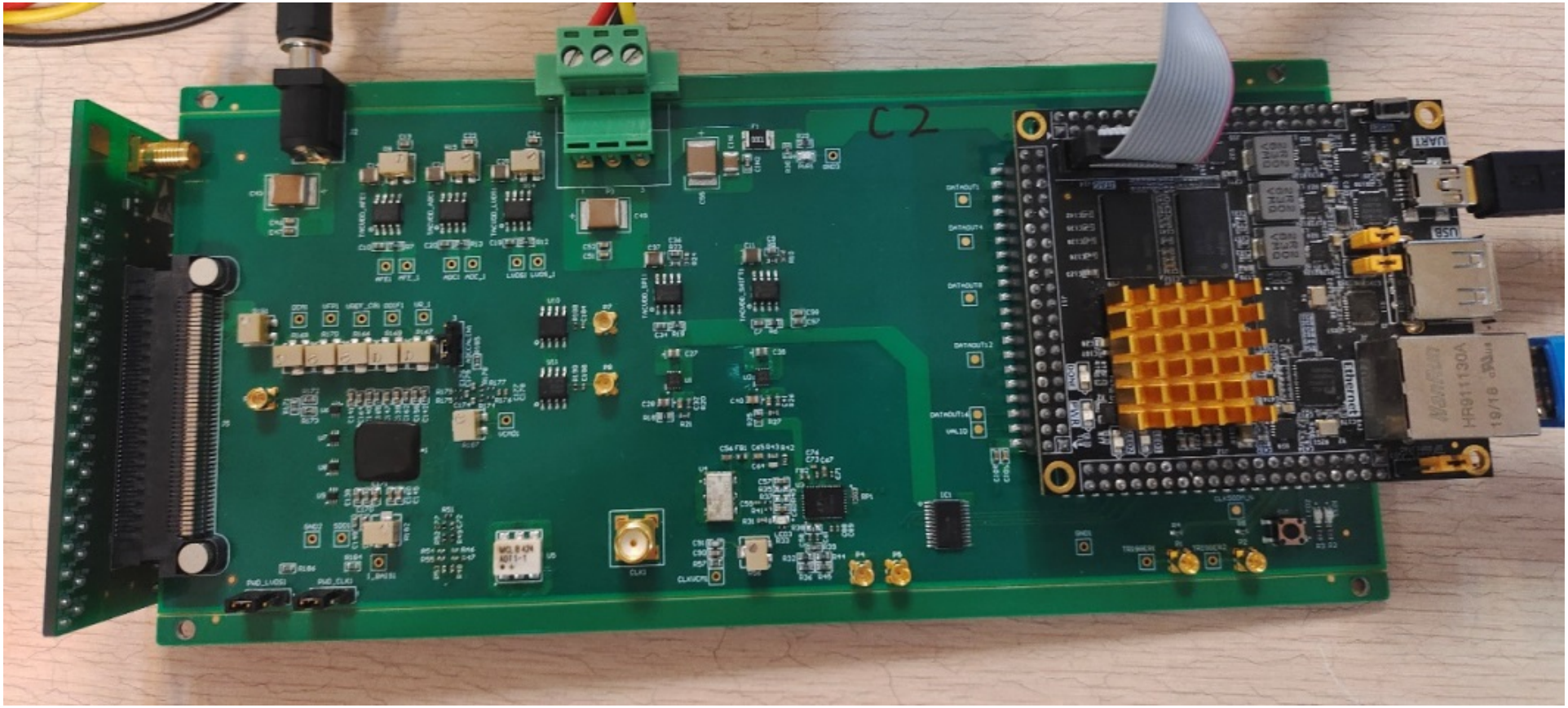
ASIC chip for TPC readout have been developed

- The power consumption is 2.33 mW/channel
  - P_{AFE} = 1.43 mW/channel
  - P_{ADC} = 0.9 mW/channel @ 40M/s
- ENC =852e @Cm = 2pF, gain =10 mV/fC and can be reduced to 474e using digital trapezoidal filter



Test of the signals

Low power ASIC chip- WASA_V0 testing board



Channels：≤128channels (**only 4×16 =** 64 channels available)

External power supply: ±5V, ± 12V, ± 24V

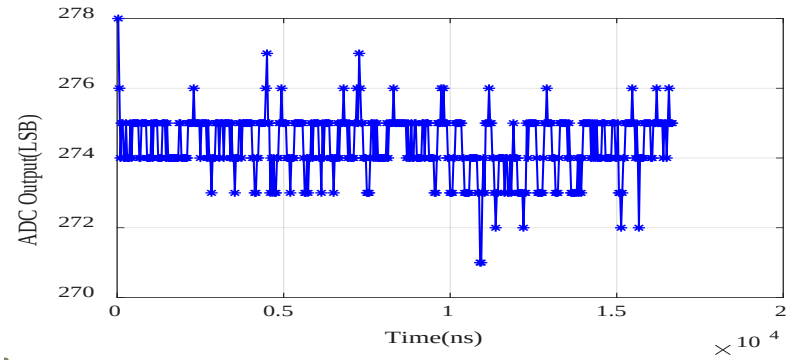
Low power ASIC chip- WASA_V0 testing

Testing parameters：

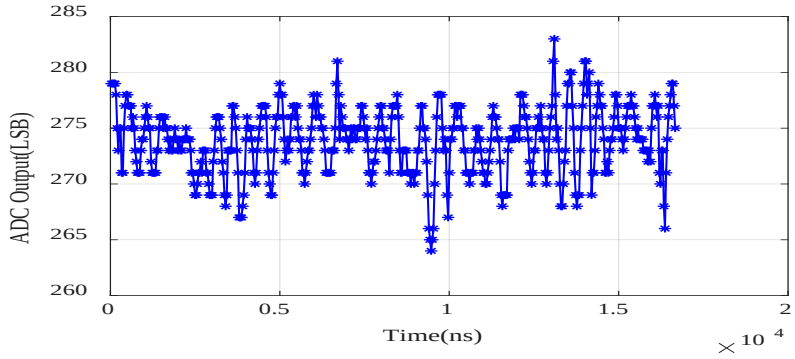
- GEMs detector: 280V-310 V
- E_{drift}： ≤280 V/cm
- Operation gases： $Ar/CF_4/iC_4H_{10}$ 95/3/2 (T2K)
- Radioactive source： ^{55}Fe@ 1mCi

Low power ASIC chip- Baseline of the noise

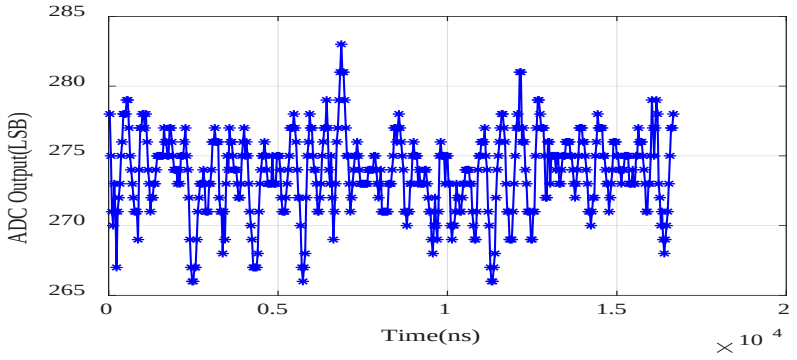
Baseline of the noise
without detector connecting



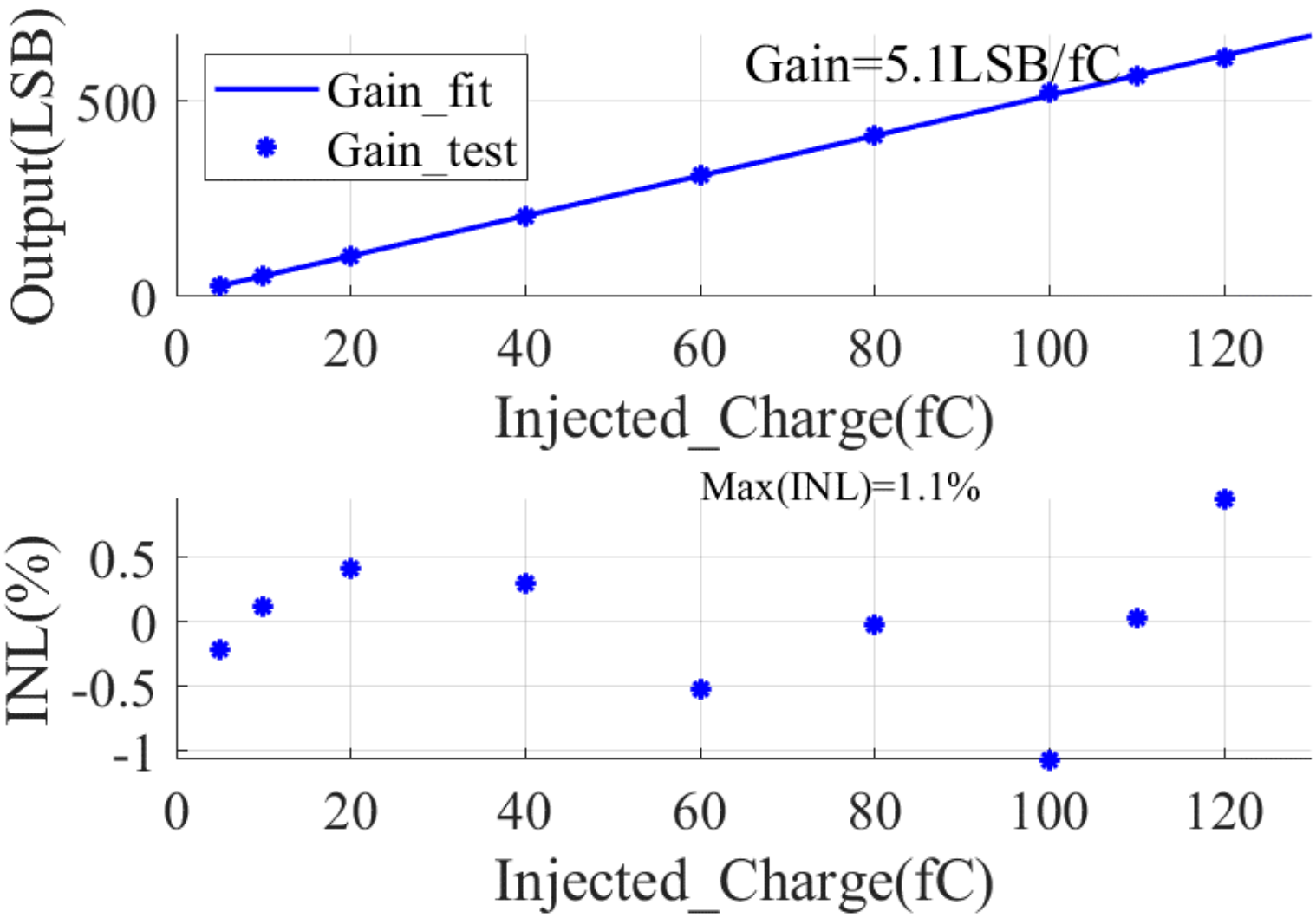
Baseline of the noise
with TPC detector connecting
@ V_{GEM}=0V@E_{drift}=0V/cm



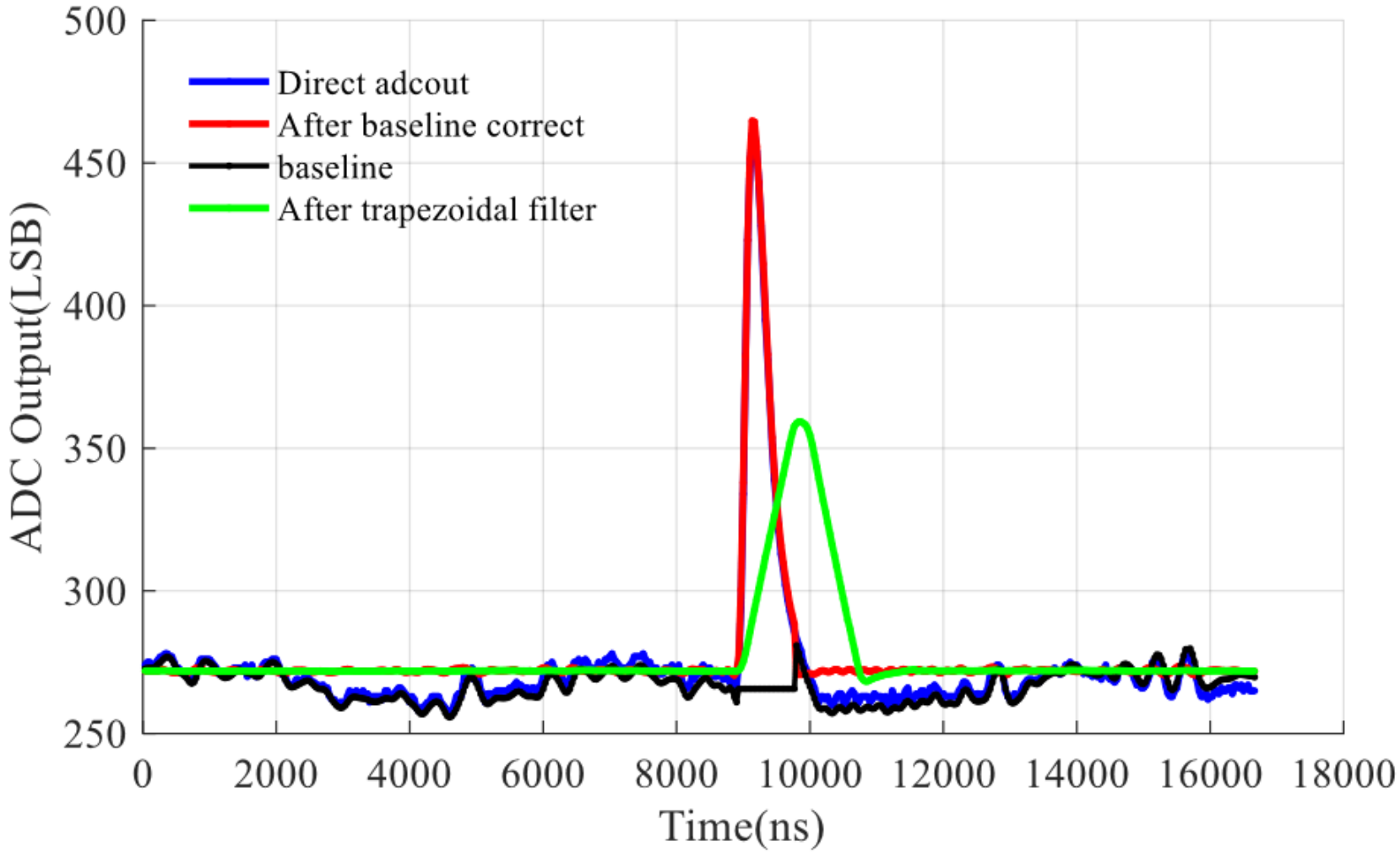
Baseline of the noise
with TPC detector connecting
@ V_{GEM}=310V@E_{drift}=290V/cm



Low power ASIC chip- Integral Nonlinearity



Transient Waveforms After Digital Filter

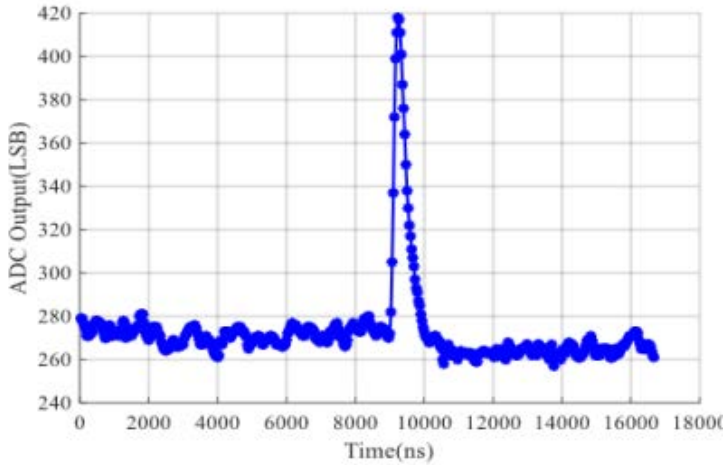


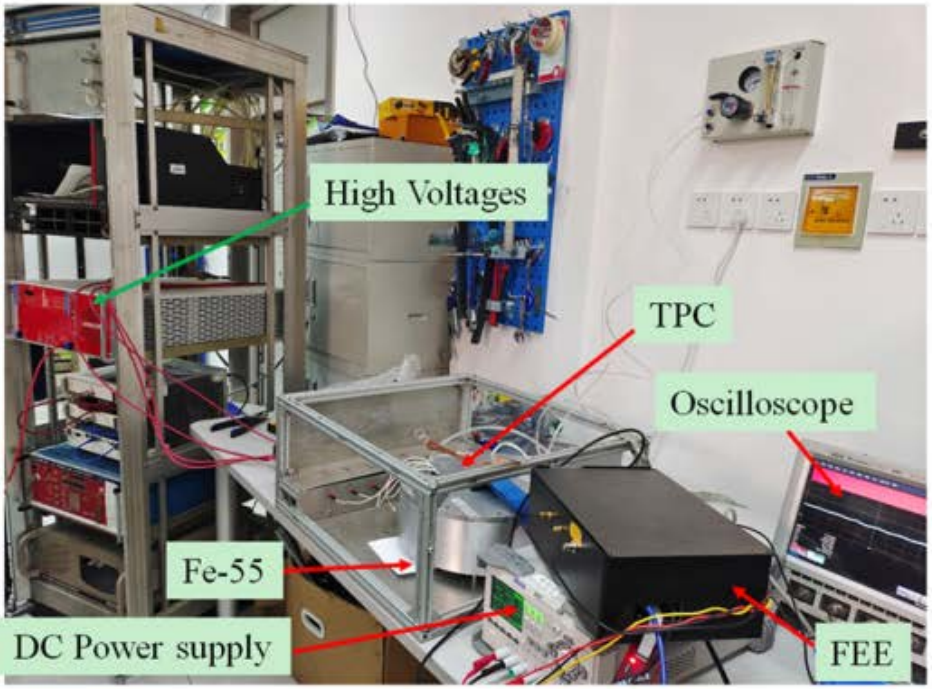
New electronics testing with the module

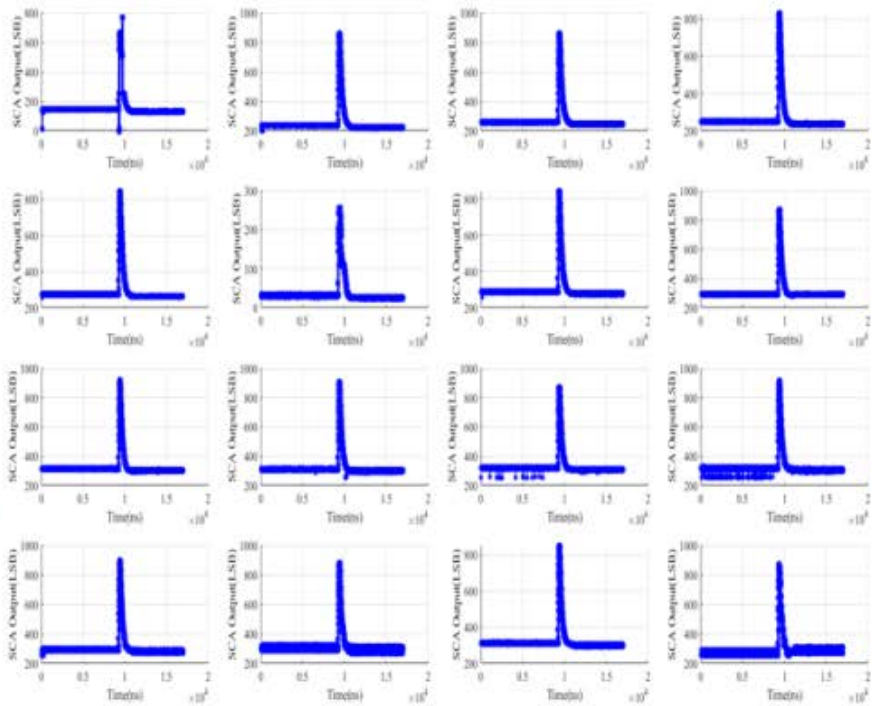
^{55}Fe testing

Testing parameters:

- **GEMs detector: 280V-310 V**
- **E_{drift}: ≤280 V/cm**
- **Operation gases: $Ar/CF_4/iC_4H_{10}$ 95/3/2 (T2K)**
- **Radioactive source: ^{55}Fe@ 1mCi**
- **Successfully commissioned and collected signals using DAQ**



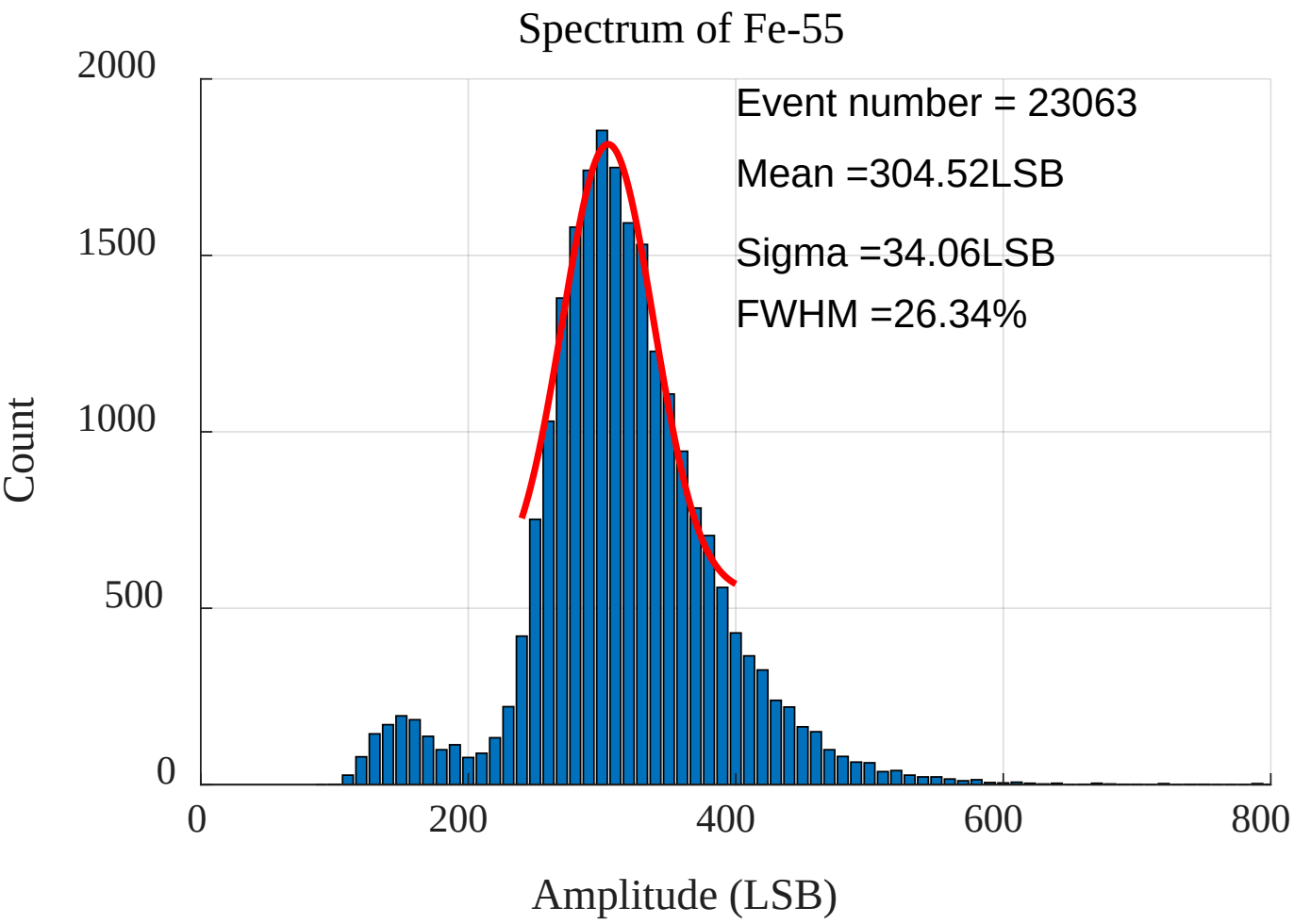




Low power ASIC chip- preliminary results

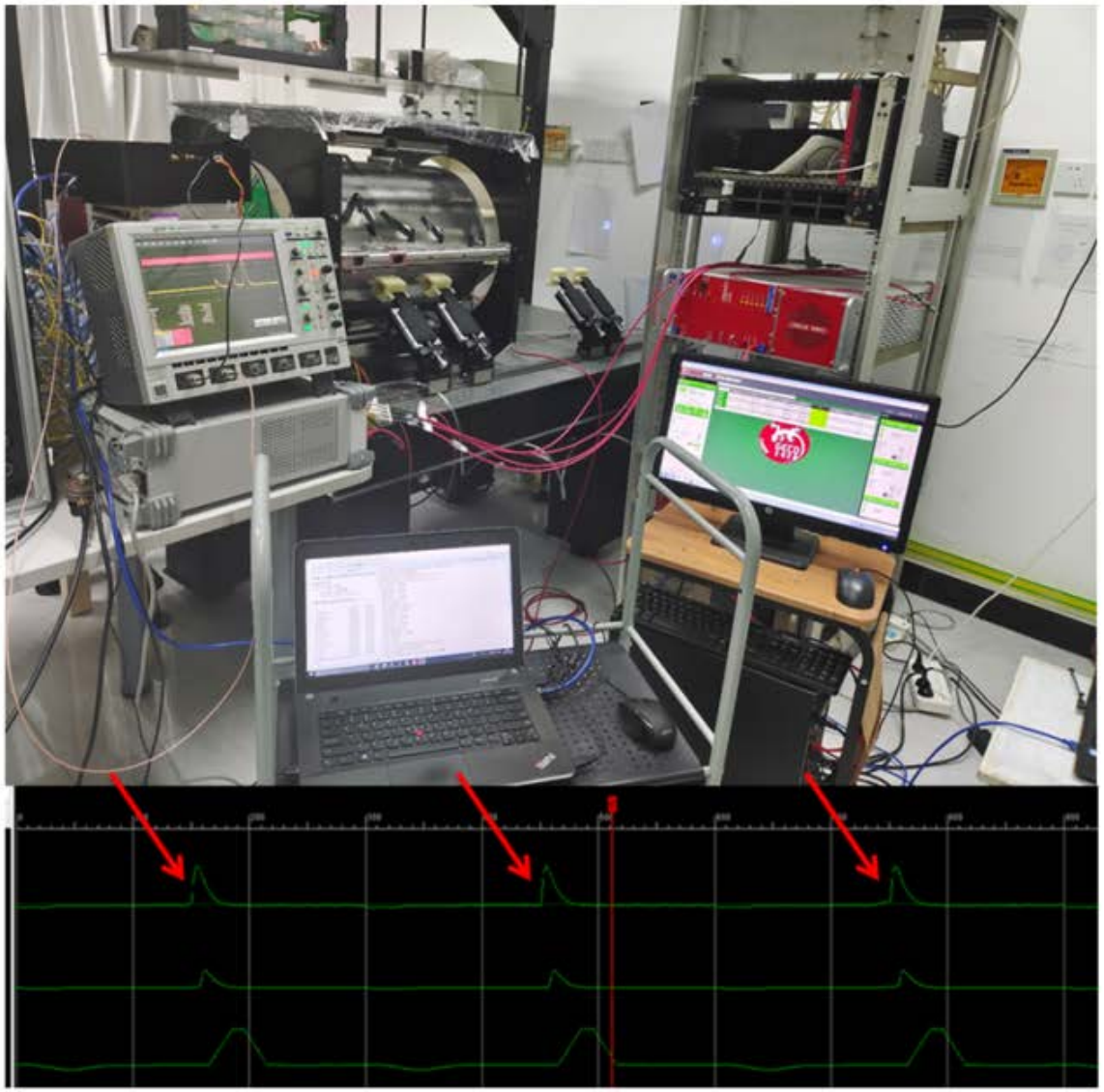
^{55}Fe testing:
Successfully commissioned and collected signals using DAQ

Using collimator for the radioactive source
and taking data from 128 channels



New electronics testing with the prototype

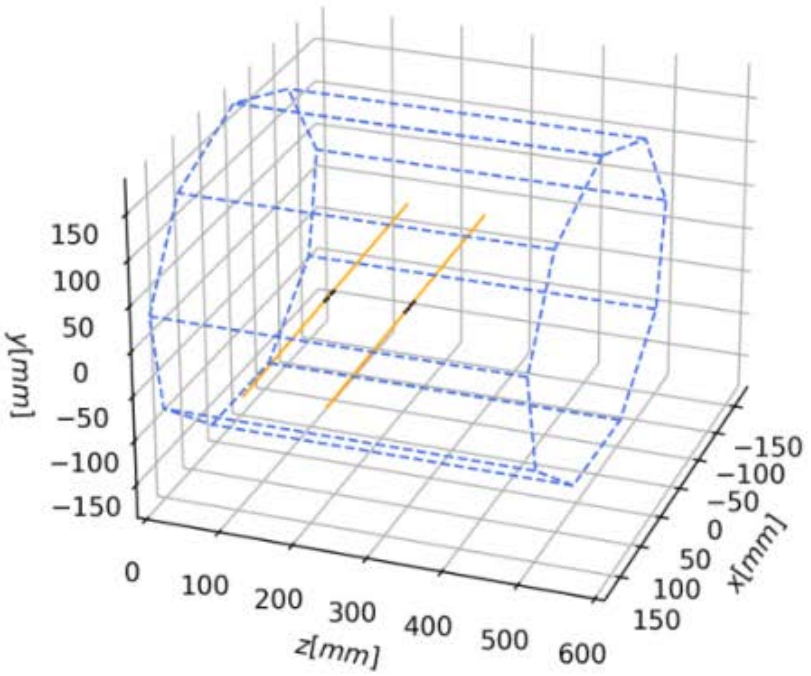
- Successfully realized the joint test of low-power ASIC chip and TPC prototype
- ASIC+TPC parameters
  - TPC:
    - GEM: 280 V
    - Drift length: 500mm
    - E_drift: 180 V/cm
    - Gas: Ar/CF4/iC4H10 95/3/2 (T2K)
    - UV laser: 7.2 mJ @20 Hz
    - Laser tracks: 3 layers along drift length
  - Electronics:
    - Trigger by UV laseer
    - Gain: 20 mV/fC
    - Sample frequency: 30 MS/s



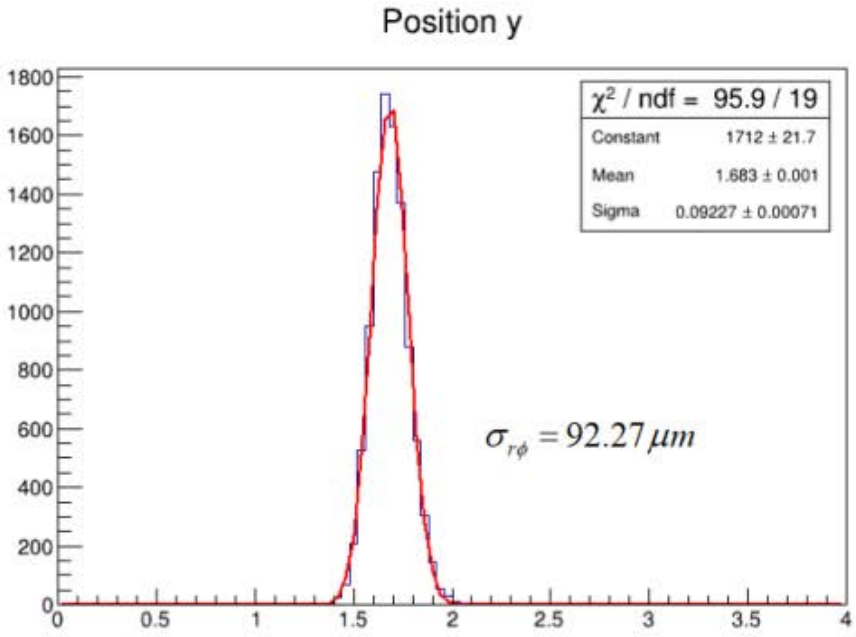
65nm ASIC + TPC prototype

Track & Position Resolution

- Laser Tracks



- Position Resolution



- Some contributions for Collaboration from IHEP 2021

Some contributions for LCTPC Collaboration Group/2021

TPC Development
by the LCTPC Collaboration
for the ILD Detector at ILC

2021 IEEE NSS/MIC Conference (Oct. 16-23):
https://nssmic.ieee.org/2021/
H. Qi

2021 IEEE NSS/MIC Conference
Presentation & Proceeding

Some contributions for ECFA Detector R&D Roadmap/2021

TPCs at future lepton and lepton-hadron colliders

(large volume gaseous detectors: TPCs, drift chambers,)

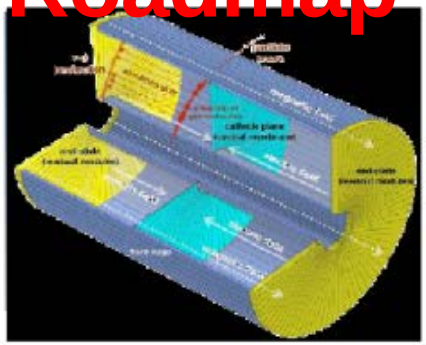
ECFA

European Committee for Future Accelerators

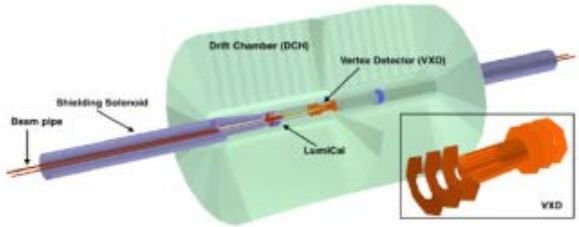
ECFA Detector R&D Roadmap
Symposium of Task Force 1
Gaseous Detectors

ECFA Detector R&D Roadmap

- TPCs
  - MPGD amplification technology,
  - Pad vs. Pixel TPC
  - IBF reduction (together with other operational parameters optimisation)
  - Mechanical structure, static distortions
  - Low-power FEE development



- DCs
  - Mechanical structure, feed-through-less wiring
  - New wire materials
  - PID via d*N*/d*x* (FEE development)



Some contributions for MPGD Snowmass white paper/2021

IF5: Micro Pattern Gas Detectors (MPGDs)
January 16, 2022

MPGDs for TPCs at future lepton colliders

A. Bellerive

Department of Physics, Carleton University, Ottawa, ON, K1S 5B6, Canada

ABSTRACT

This submission will focus on advancements and advantages of Micro Pattern Gas Detector (MPGD) technologies together with their applications for the construction of a dedicated [illegible] excellent main tracker for any multipurpose detector that can be foreseen to operate at a future leptons collider. The first portion of the report will be the 1.5 page executive summary. It will be followed by sections detailing on applications of MPGDs specifically for the construction of the LCTPC for the ILD at ILC, for a possible upgrade of the Belle II detector and for the design of a TPC for a detector at CEPC. MPGD technologies offers synergy with other detector R&D's and several application domains; a few examples will be provided in the context of the long range planning exercise in the USA. Link to industrial partnership and work with institutions in the USA will be highlighted when appropriate.

Submitted to the Proceedings of the US Community Study
on the Future of Particle Physics (Snowmass 2021)

H. Qi

3 TPC for CEPC

The Circular Electron Positron Collider (CEPC) has been proposed as a Higgs/Z factory in China (CEPC Study Group 2018). The baseline design of CEPC tracking system consists of a vertex detector with three concentric double-sided pixel layers, a high precision (about 100μm) large volume time projection chamber (TPC) and a silicon tracker on both barrel and end-cap regions. The tracking system has similar performance requirements to the ILD detector in ILC detectors but without power-pulsing, which leads to additional constrains on detector specifications, especially for the case of machine operating at Z-pole energy [illegible] luminosity. Until a decision on a tracker for a future circular collider in China can be reached, a number of tasks are still remaining regarding the TPC research. Such tasks include the full simulations of the TPC performance in the CEPC environment, further design of the low power [illegible] electronics, UV laser calibration methods and and cooling [illegible] challenges to be addressed in the near future is the physics requirements for the TPC performance towards the inclusive CEPC physics program. MPGD technology, though quite far advanced [illegible] effort [illegible] Nonetheless, [illegible] are very similar than the ones described for the ILD TPC, and thus achievable with existing possible MPGD technologies. R&D activities in actively ongoing in China and could potentially lead to partnership with the USA.

Overall, the TPC at CEPC has been inspired by the ILC-TPC development. Contrary to the ILC, Z-pole running at CEPC with the high luminosity of about $32\times10^{34}\text{cm}^{-2}\text{s}^{-1}$ prevents gating mode TPC operation. Hence, one area of research specific to CEPC is low-gain, lower ion back flow (IBF) hybrid gaseous structure and the key factor of the Gain multiply by the IBF suppression ratio of them shows good promise(Yuan et al. 2021; Zhang and Qi 2020). In this situation, GridPix is also an attractive option, which provides the high granularity needed to resolve individual electron clusters and to determine energy loss by the cluster counting technique. The CEPC TPC requires transverse ($r-\phi$) single-hit space-point resolutions of less than 100μm and longitudinal (Z) time resolution of about 100 ns. The physics goals requires dE/dx resolution of less than 5% and particle identification separation at about 2% level with cluster counting. Most conditions set by the CEPC tracking systems can be met by MPGDs as proven by LCTPC effort. Such detector development offers a possibility for partnership between the LCTPC collaboration group and

January, 2022
From LCTPC CB Discussion
IF5 Submitted to Snowmass 2021

Summary

- dE/dx study used TPC detector using 266nm UV laser
- Pseudo-tracks with 220 layers and dE/dx can reach to 3.36 $\pm$ 0.26% of dE/dx by Pad size (1mm $\times$ 6mm)
- Successfully testing and collected signals using the new electronics with the lower power consumption chips
- Some contributions for the international collaboration group from IHEP

Thanks