Detector Development for SoLID
from Chinese Collaborators

Zhihong Ye

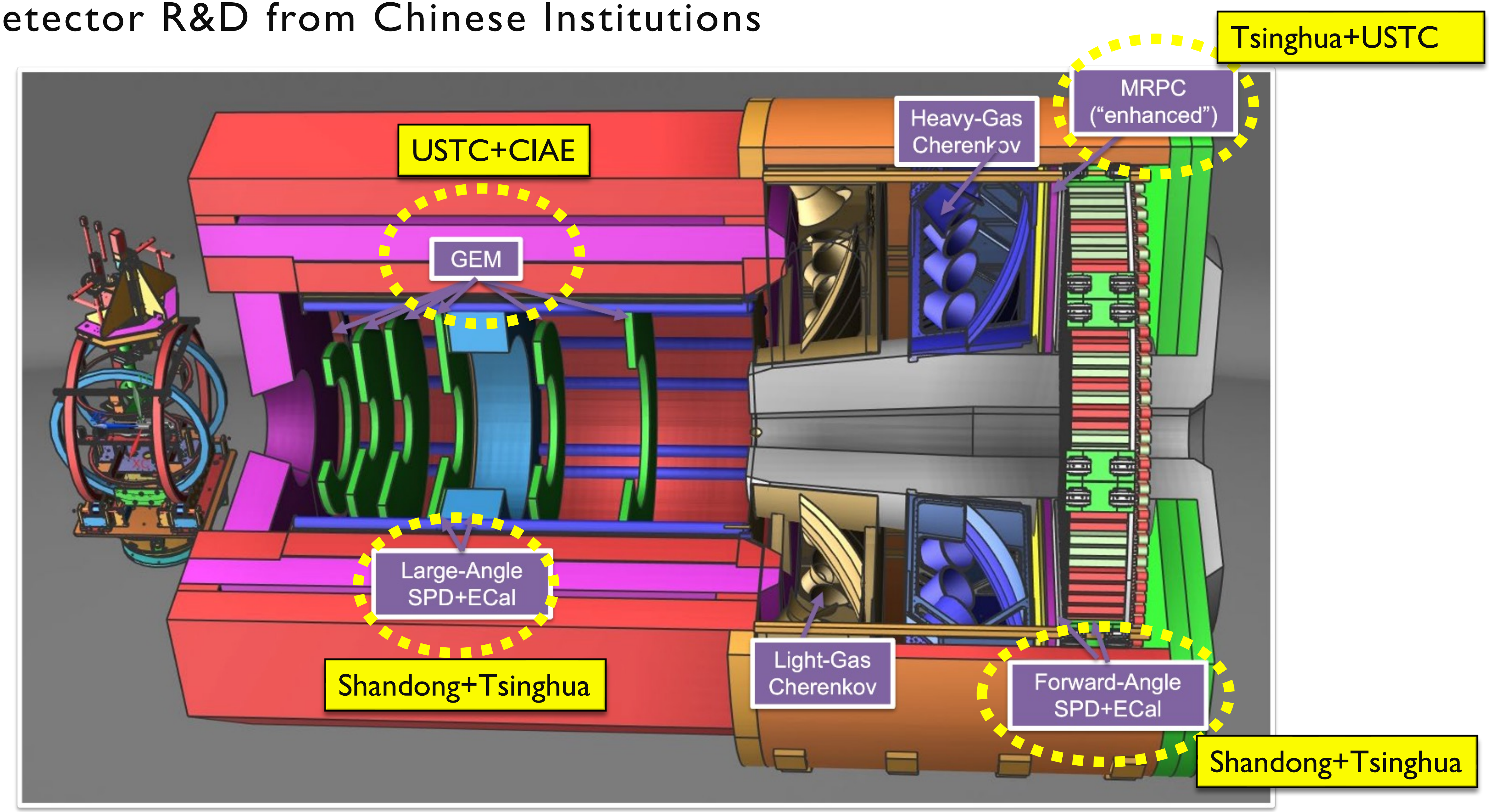
On behalf of Shandong Univ., Tsinghua Univ. and USTC

SoLID Collaboration Meeting, 12/08/2023

清華大學
Tsinghua University

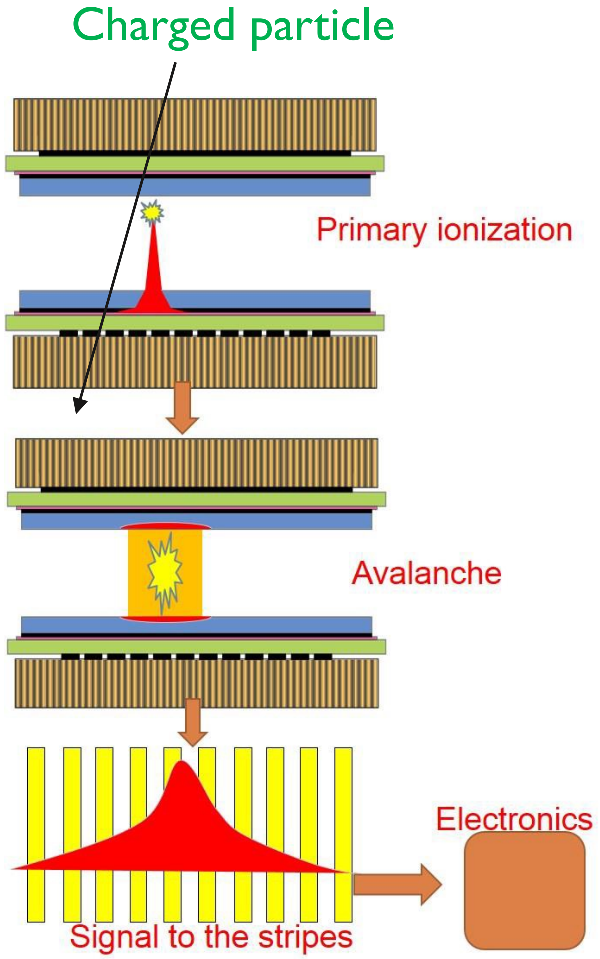
SoLID Detectors

- Detector R&D from Chinese Institutions

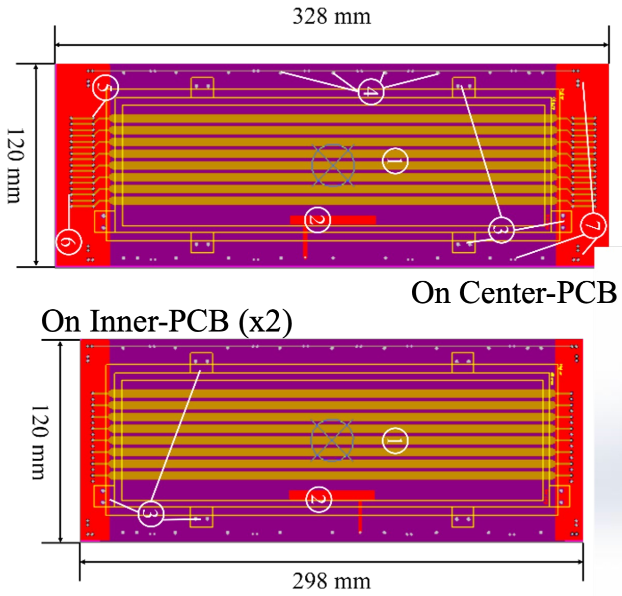


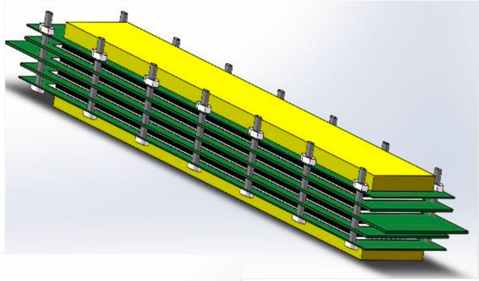
Multi-gap Resistive Plate Chamber (MRPC)

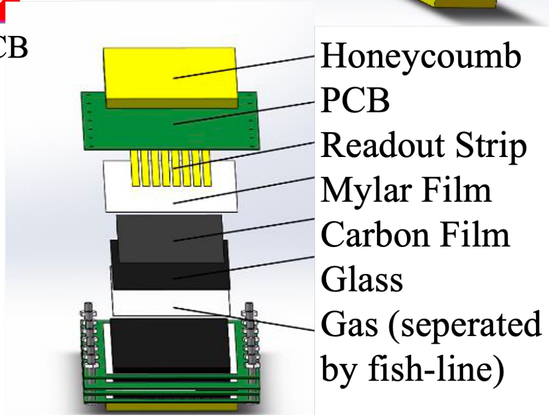
➢ General Princple

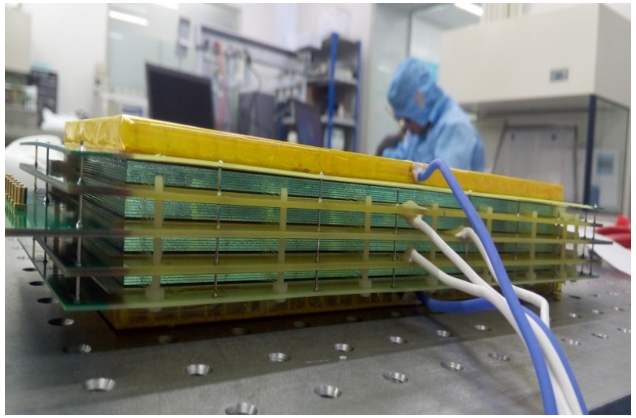


- ❑ Low-resistivity glass plates, Standard gas (95% F134a + 5% iso-butane), HV(~12kV)
- ❑ Good performances:
  time resolution, efficiency, rate capacity (>30kHz/cm^2), radiation-hard, magnet safe
- ❑ Certain spatial resolution (by strip pitch)
- ❑ Low cost, easy manufacturing, large sensitive area (up to 1.0mx0.5m)
- ❑ Used by ALICE, STAR, etc.





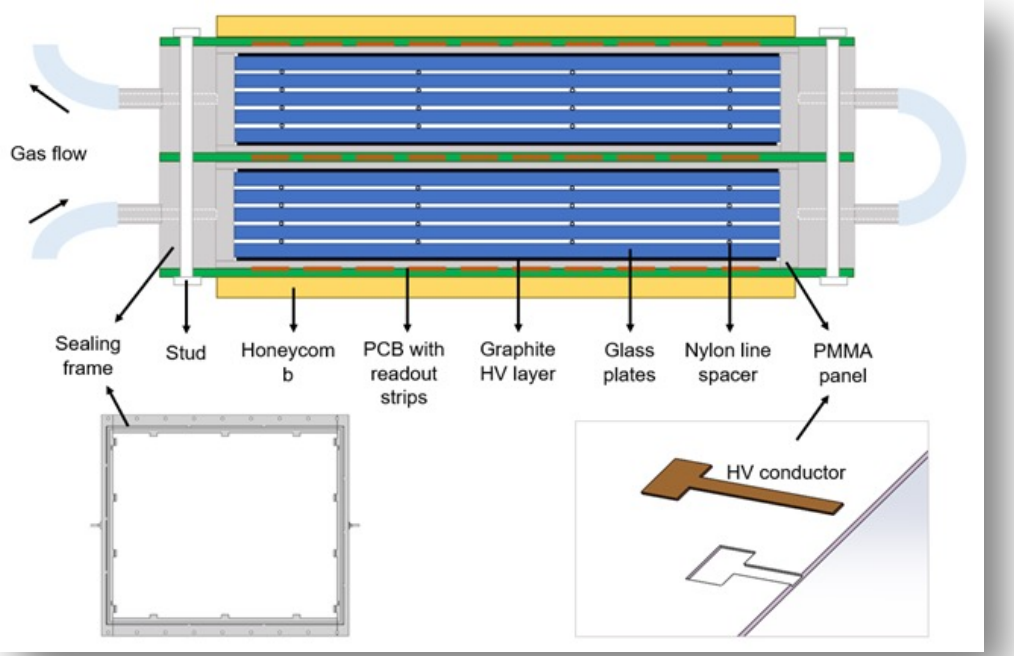




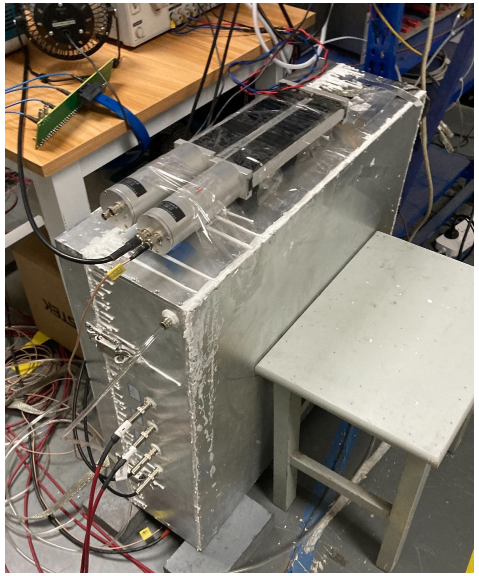
MRPC

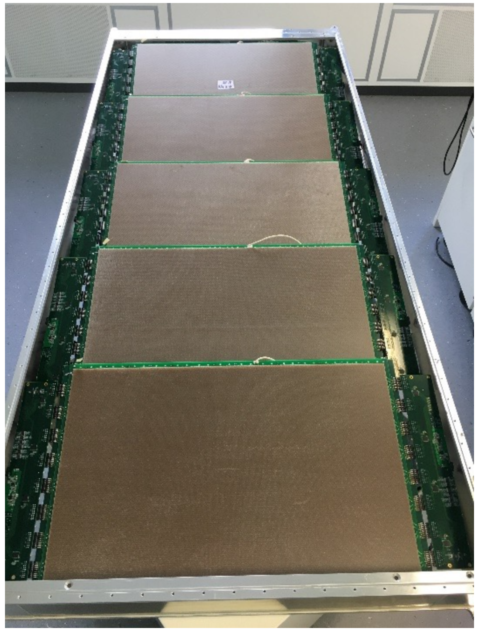
➢ Tsinghua's new Sealed MRPC (sMRPC)

- ❑ Gen3 MRPC with sealed gas → No more boxes!
- ❑ More compact, less radiation length
- ❑ Reduce greenhouse gas emmission (20cc/cm²/min)

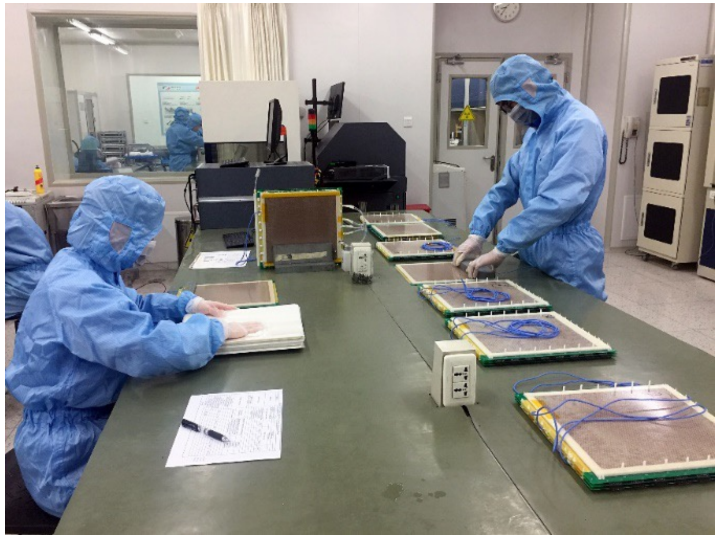


Y. Wang et al 2019 JINST 14 C06015





- ❑ Tsinghua's Miyun workshop: mass production of sMRPC

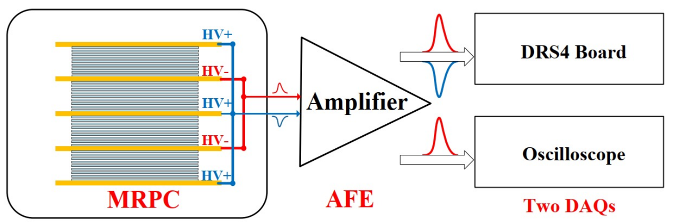


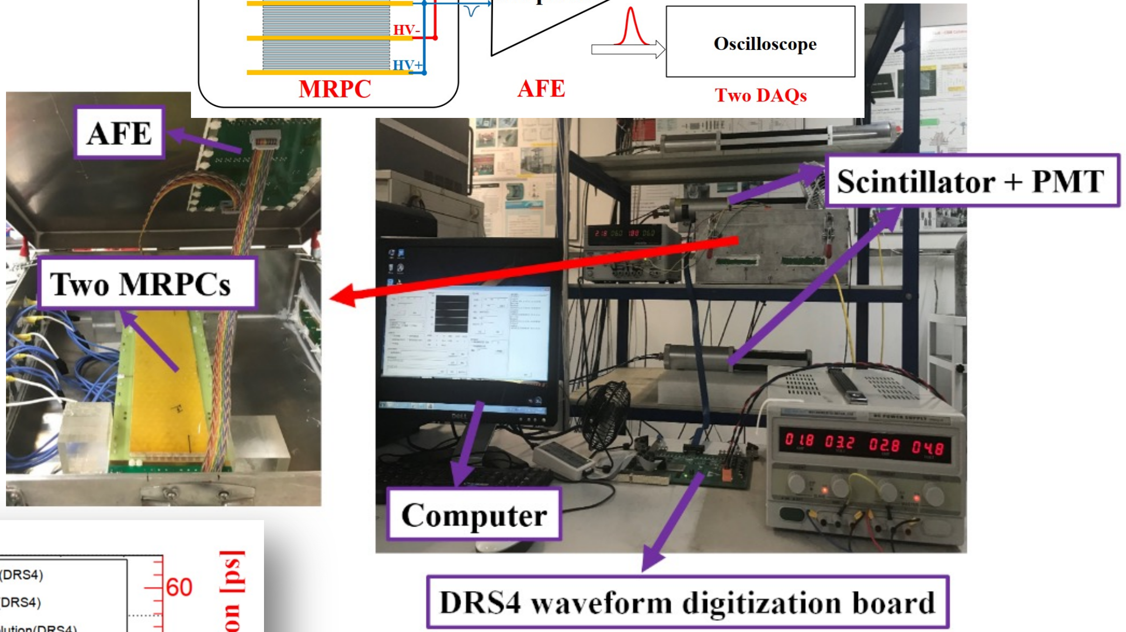
MRPC

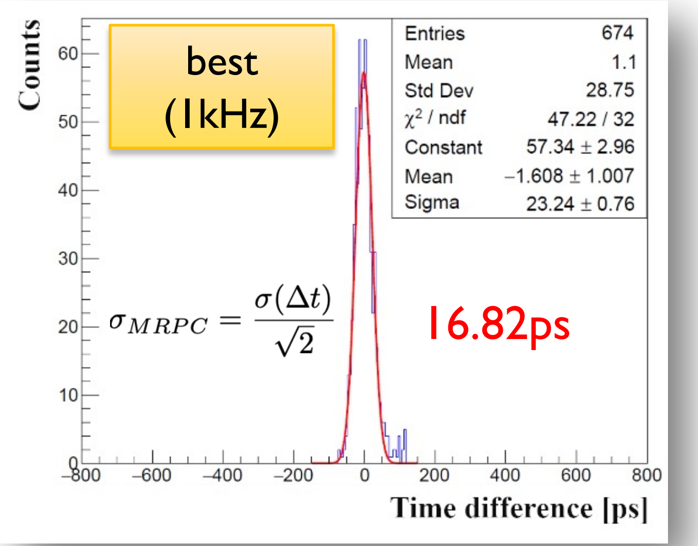
➢ Tsinghua's Sealed MRPC (sMRPC)

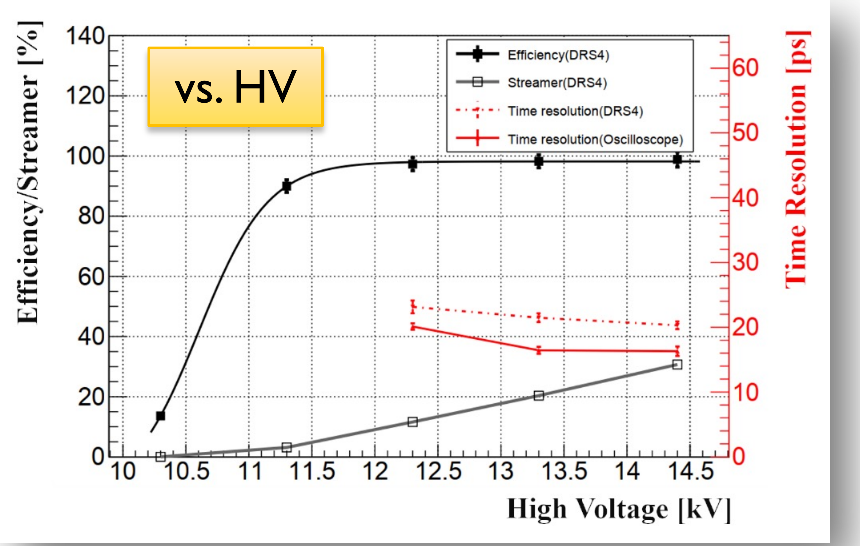
- ❑ Most recent tests: cosmic ray with x-ray background
  - ✓ 32-gaps (4 stacks), 400um thin glasses
  - ✓ 104um gas-gap + waveform-sampling → 20ps & 95% efficiency at 15kHz
  - Y. Yu et al 2020 JINST 15 C01049
  - ✓ 128um gas-gap + ToT method → 20ps at 15kHz

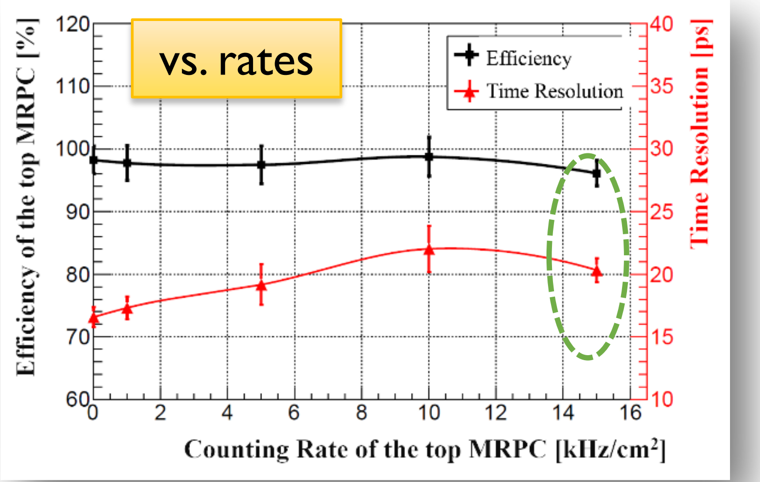
Y. Yu et al 2022 JINST 17 P02005







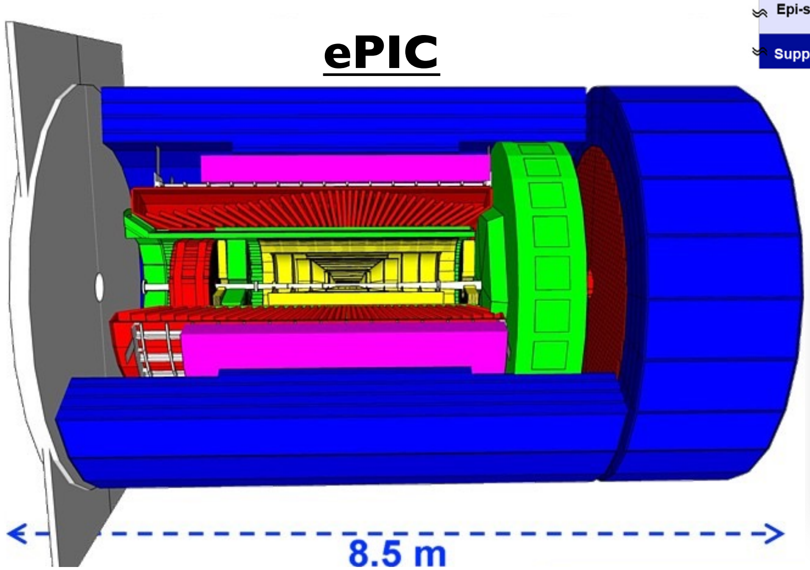


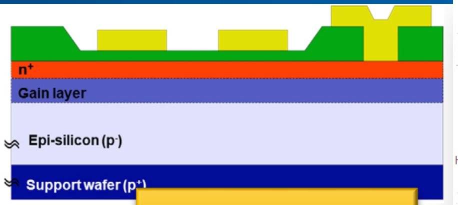


❑ Not proven in real beam!

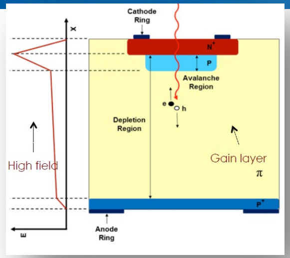
MRPC

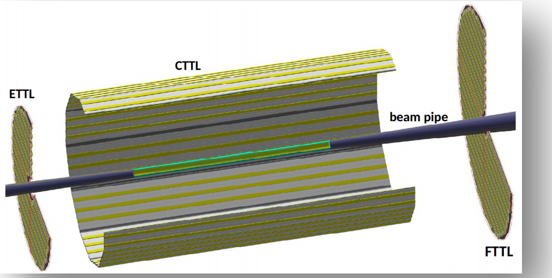
➢Synergy w/ US-EIC:





AC-LGAD





Development of High Precision and Eco-friendly MRPC TOF Detector for EIC

Alexandre Camsonne[1], Sanghwa Park[1], Yi Wang[2], Zhenyu Ye[*3], and Zhihong Ye[†2]

[1]Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA
[2]Department of Physics, Tsinghua University, Beijing 100084, China
[3]Department of Physics, University of Illinois at Chicago, Chicago 60607, USA

Submission date: July 14th 2023

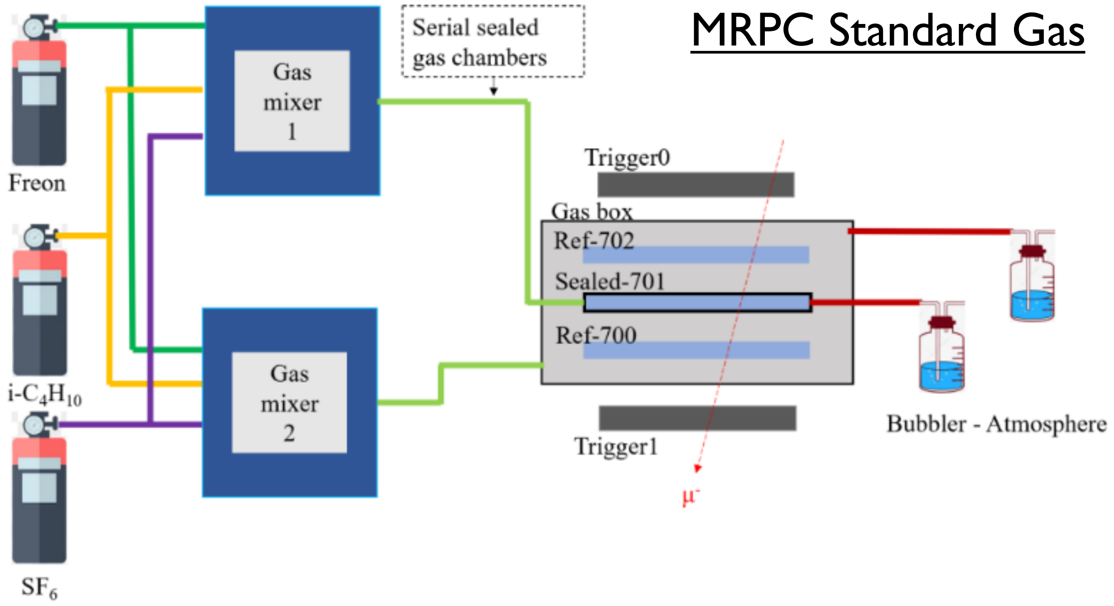
- ePIC chose AC-LGAD as the TOF
  - Goals: Time resolution~25ps, Tracking resolution ~100 um
  - MRPC vs. AC-LGAD:
    - thick (10% X_0), less position precision
    - Cost effective, radiation hard, no risk

- Generic R&D for EIC (#14, awarded $80K for 2024):
  - Possible for part of Detector#1 TOF, & Detector#2
  - Optimize thickness and position precision
  - Eco-friendly gas
  - In-beam performance
  - Readout electornics (synergic to AC-LGAD)

➢R&D Task#1: Eco-Friendly Gas Replacement

❑ Possible replacements of standard gas:

- ✓ C2H2F4 (R1234ze) + CO2
- ✓ Argonne + CO2
- ✓ Helium



❑ Cons:

- Expensive (C2H2F4)
- Impact to other detectors (Helium)
- Need ultra-high HV

❑ To-dos:

- Simulation with more gas mixtures
- Cosmic-Ray test with diff. gases (Tsinghua & UIC)
- Beam test for actual performance

MRPC

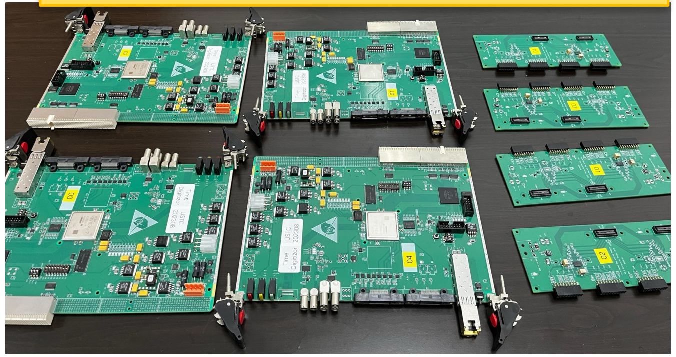
➢R&D Task#2: Readout Electronics

- ❑ 4 low-rate sMRPC at UIC (unfinished Fermi-Lab beam test)
- ❑ 2 high-rate sMRPC built at Tsinghua
- ❑ Goals: Test out front-end electronics options

- ❑ PreAmp + DIS
  - NINO (discontinued)
  - pico2023 (*NEW*)
- ❑ TDC
  - FPGA base (not rad. dard)
  - picoTDC (*NEW*)
- ❑ Waveform Sampler
  - DSR4 (slow)
  - SAMPIC
  - NALU AARDVARC

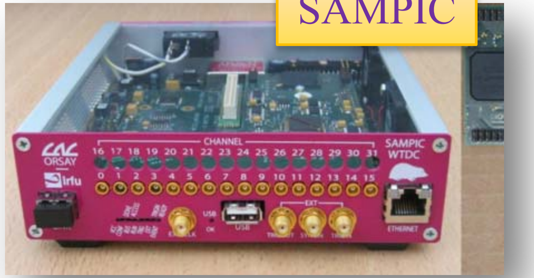
sMRPC at FermiLab (April 2022)

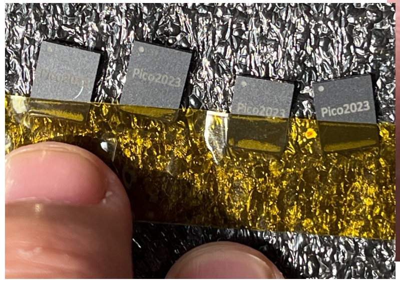
USTC FEE (NINO+FPGA-TDC)



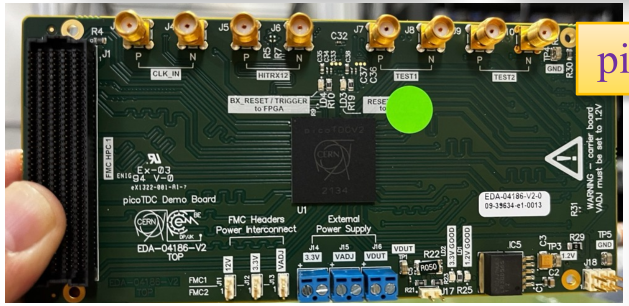
NALU

SAMPIC





Pico2023 (replacing NINO)



picoTDC

MRPC

Parameter	Value
Dimension	360 × 338 mm²
Height	26 mm
Weight	3.3 kg
Glass dimension	330 × 276 mm²
Gas gap number	2 × 4
Gas gap width	0.25 mm
Strip pitch	7 + 3 mm
Strip length	270 mm
Strip number	32

➢R&D Task#3: In-Beam performance

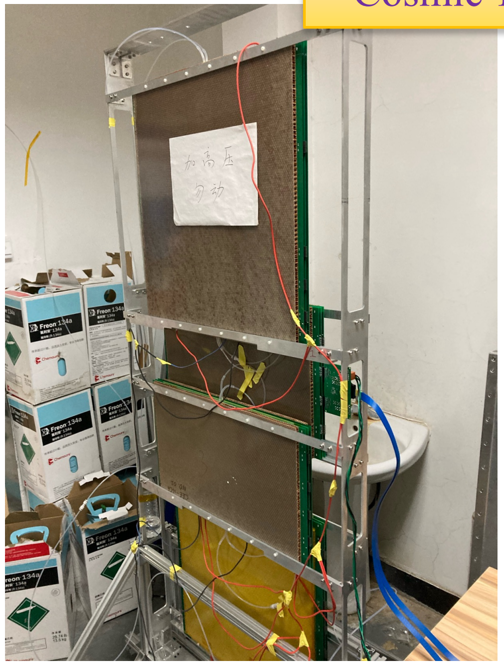
❑ Goals:

- Study performance of replacement gases
- Study timing performance with high-energy beam & high-rate background
- Radiation torrelance for modules and electronics

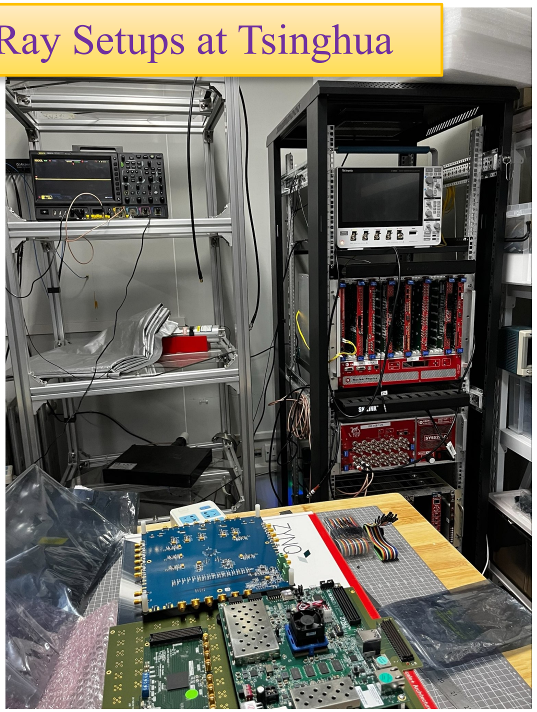
❑ To-dos:

- UIC local test with cosmic-ray + xray background
  - 2 planes of 16-layer sMRPC + SAMPIC & NALU
- Tsinghua's local test with cosmic-ray + x-ray background
  - 2 planes of 32-layer sMRPC + USTC FEE + DT5742 (DSR4) + pico2023 + DT5202 (picoTDC)
- Jlab beam test
  - 2(+2) planes of 16-layer sMRPC + SAMPIC & NALU

Cosmic-Ray Setups at Tsinghua

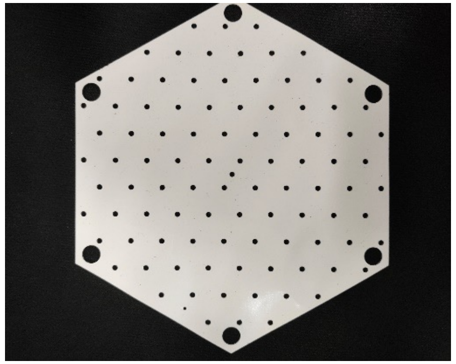


Wang's lab for Gas study

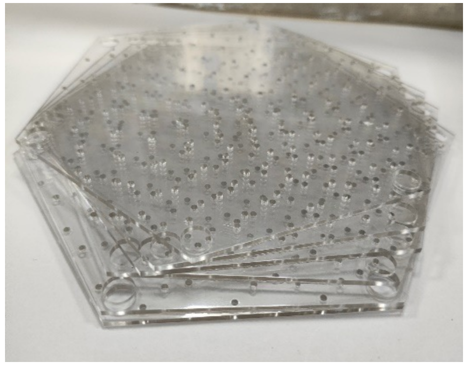


Ye's lab for FEE study

➢ Shashlyk ECal Material Overview:



lead sheet with reflective coating

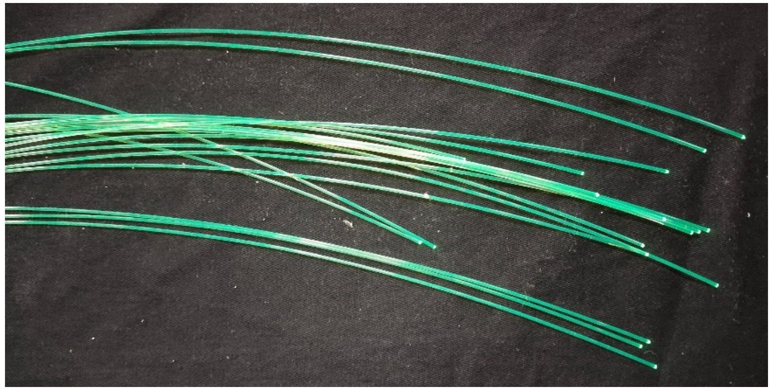


plastic scintillator

ESR with air coupling

optical reflective glue

Tyvek



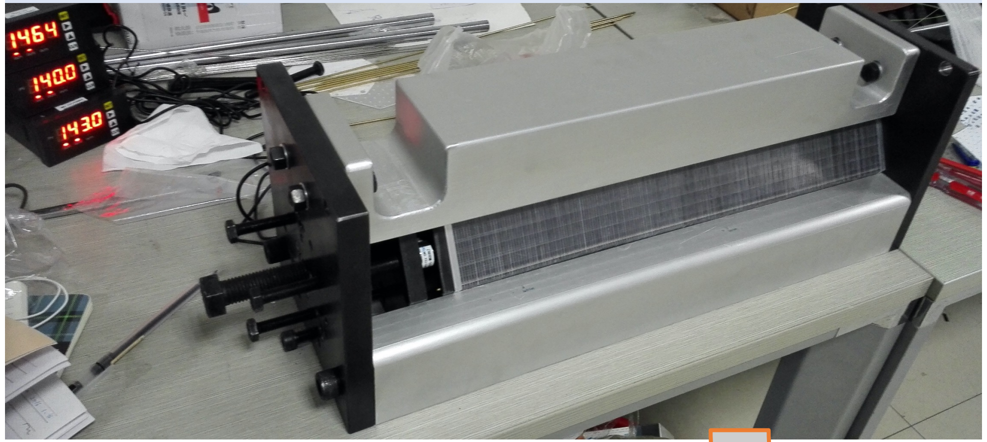
Wavelength-Shifting Fiber

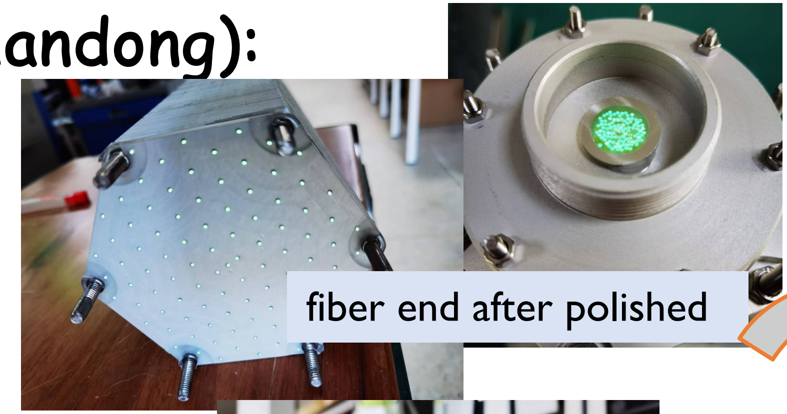
Part	Type/Material
scintillator	KEDI enhanced
WLS fiber	Y11 multi-cladding
outside surface	TiO2
fiber end reflector	ESR film
lead	paint TiO2*

*instead of reflective layer between lead

➤ Shashlyk ECal Assembly (by Shandong):

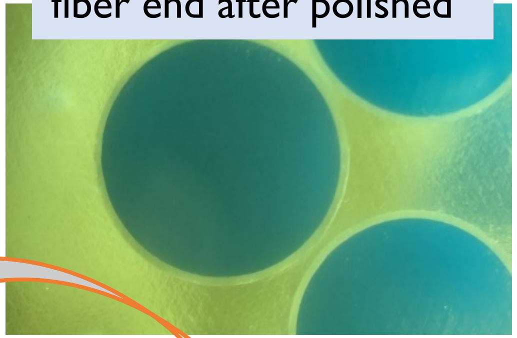
Scintillator tiles and leads are cross stacked in the mold, keeping pressure for one day.

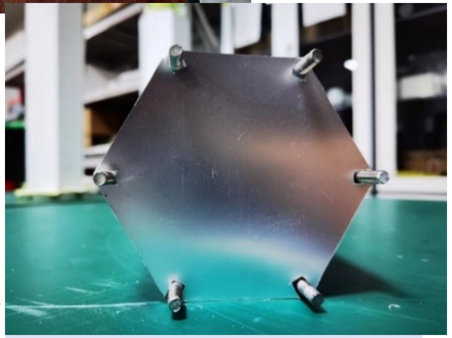




fiber end after polished

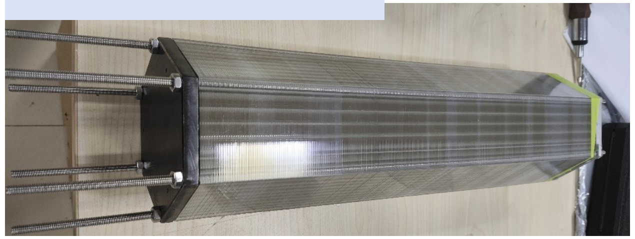
fiber end after polished



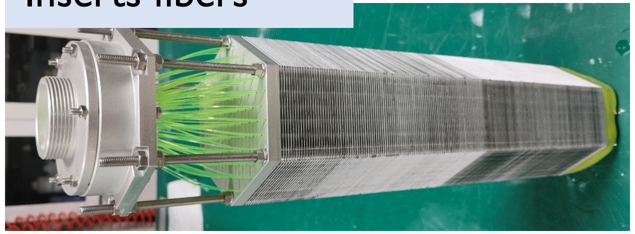


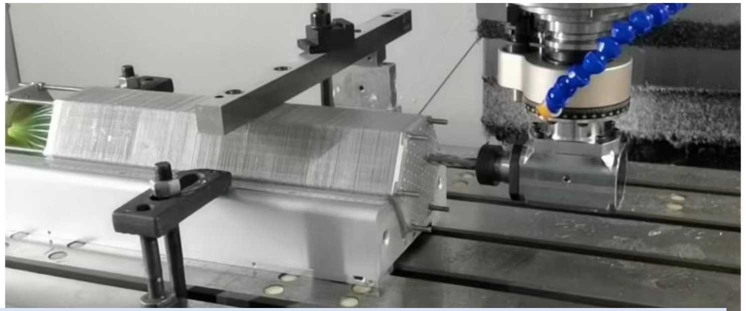
cover plate above ESR

Assembled module



Inserts fibers





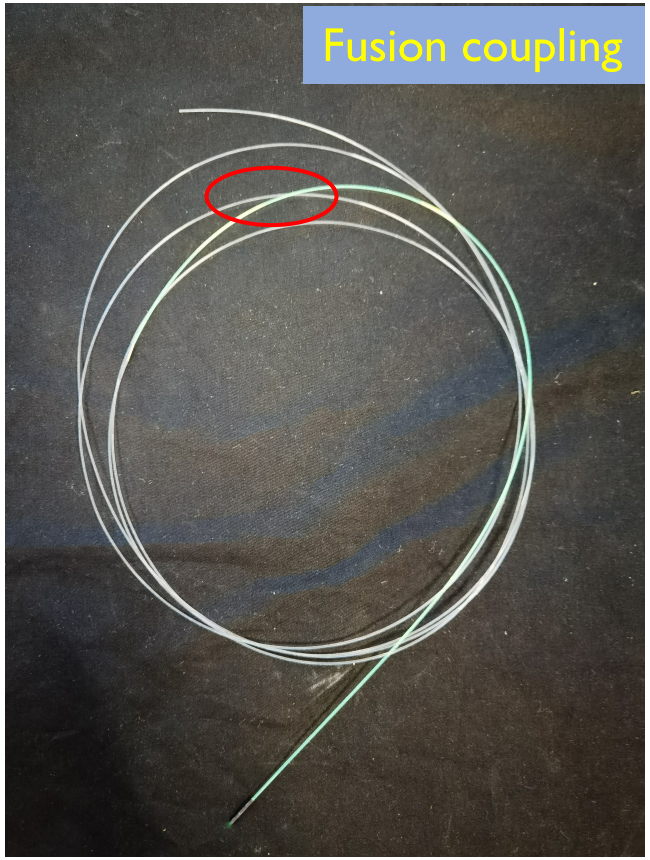
fiber polished with CNC milling machine

TiO2 reflective layer

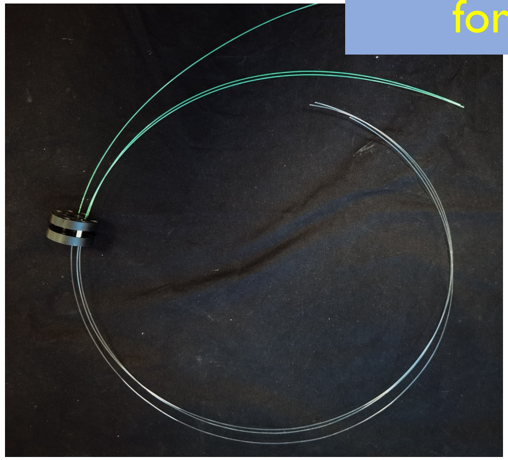
Tyvek

➢Shashlyk ECal Assembly (by Shandong):

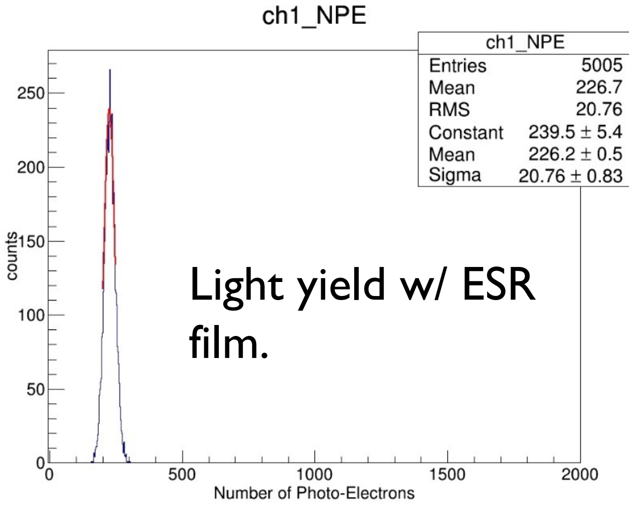
- ❑ The fiber coupling test is ongoing. The new adapter design is easy for assembling, still under study to improve the quality.

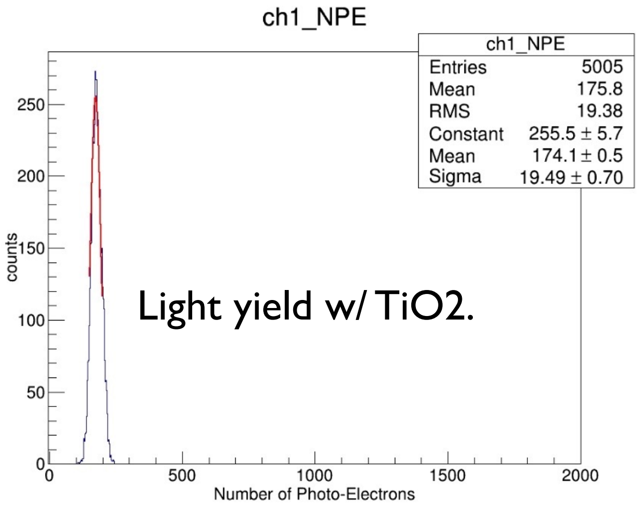


New designed adapter for 100 fibers

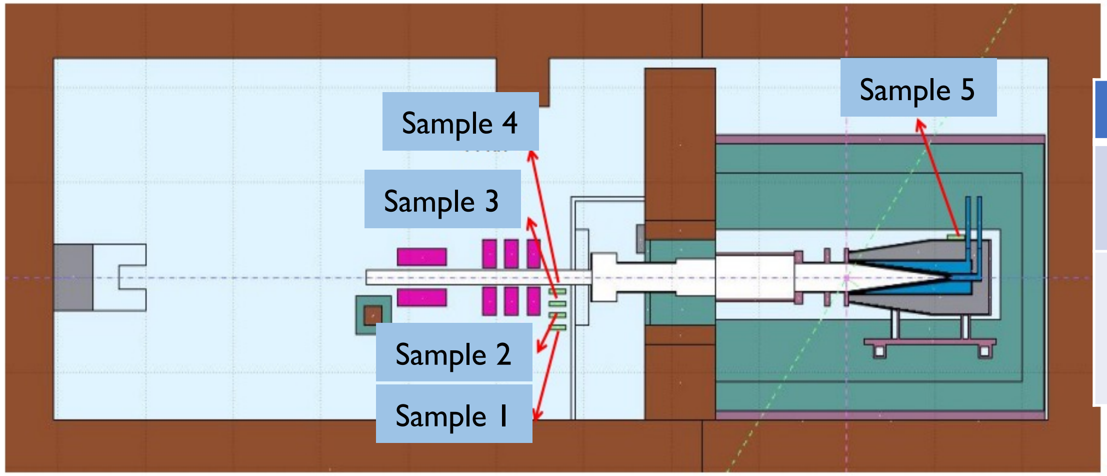


- ❑ The reflectivity of ESR film is better than TiO2 painting



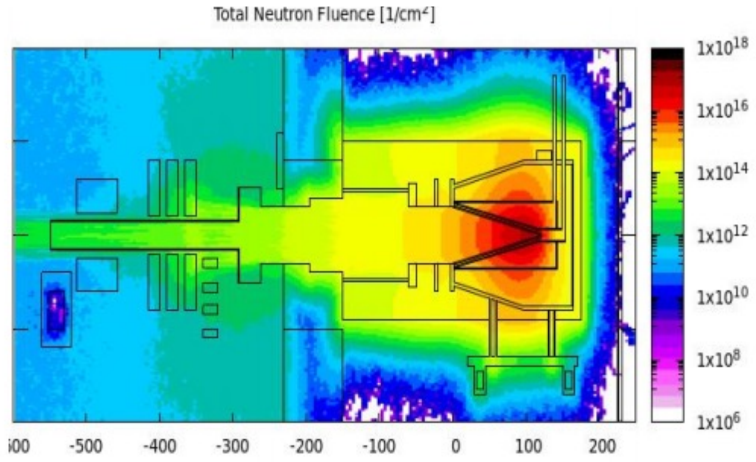


➢Shashlyk ECal Assembly (by Shandong): :

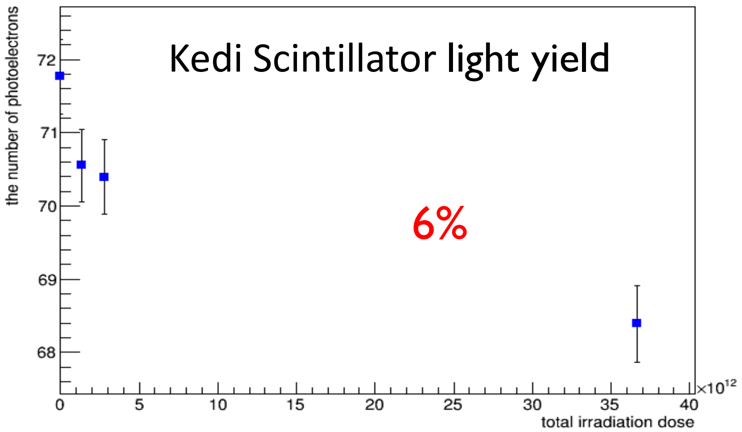


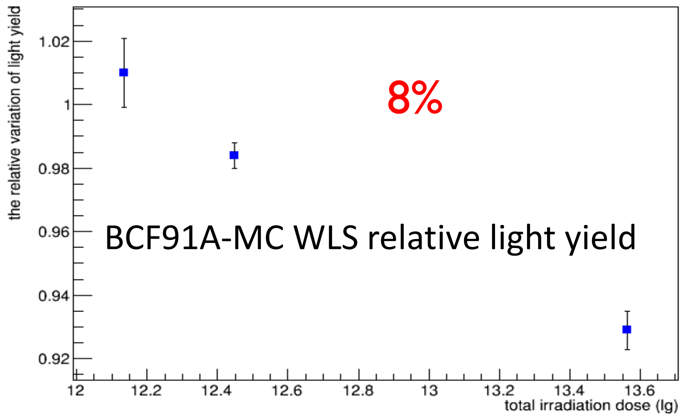
❑ Irradiation resistance test at IMP

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Total Irradiation(MeV/cm^2) by simulation (uncertainty 10%)	8.6E+11	1.4E+12	2.8E+12	3.7E+13	1.1E+14 **(Not tested)**
Test material	clear fiber	clear fiber BCF91A-MC scintillator	clear fiber BCF91A-MC scintillator	clear fiber BCF91A-MC scintillator	BCF91A-MC scintillator



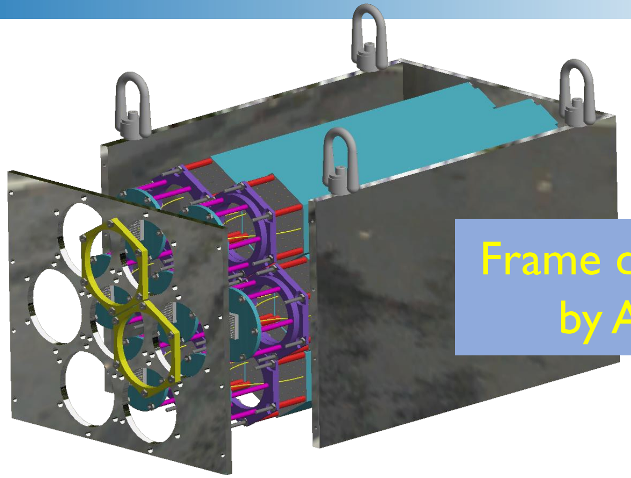
❑ Satisfy radiation resistance requirement



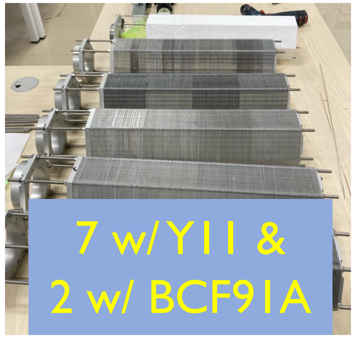


ECAL

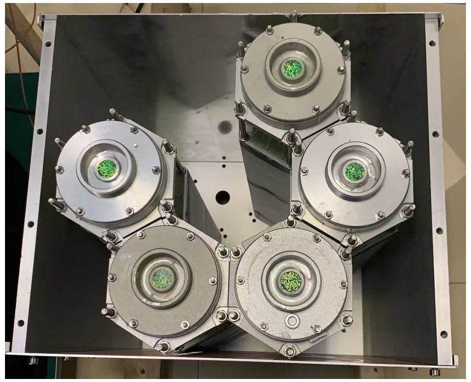
- **Shashlyk Supermodules:**
  - Goals:
    - ✓ Performance of a full shower development
    - ✓ Photo-sensor options (clear fiber+MaPMT, or MCP)
    - ✓ Assembly process, deformation, quality-check, and calibration, etc.
    - ✓ Optimizing supporting structure design (by ANL)
    - ✓ Slow control development (HV, LED, …)
    - ✓ In-beam performance (moving to Tsinghua now, then to Jlab in 2024)

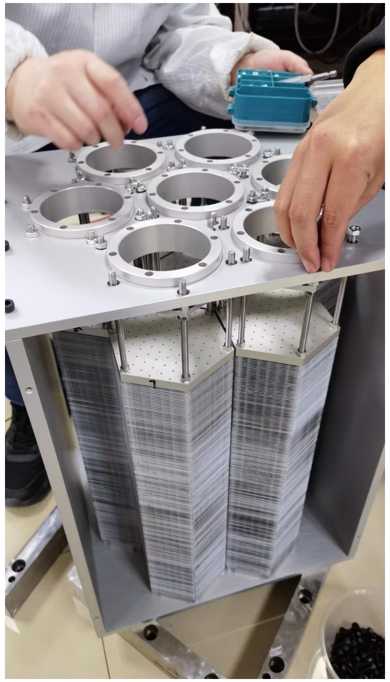


Frame designed by ANL

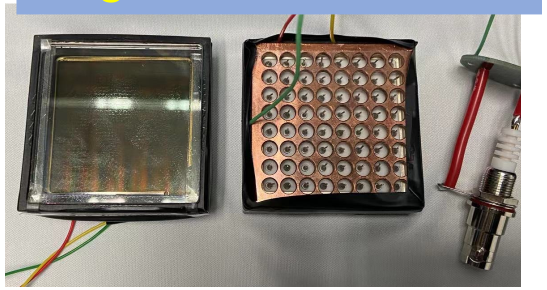


7 w/Y11 & 2 w/ BCF91A





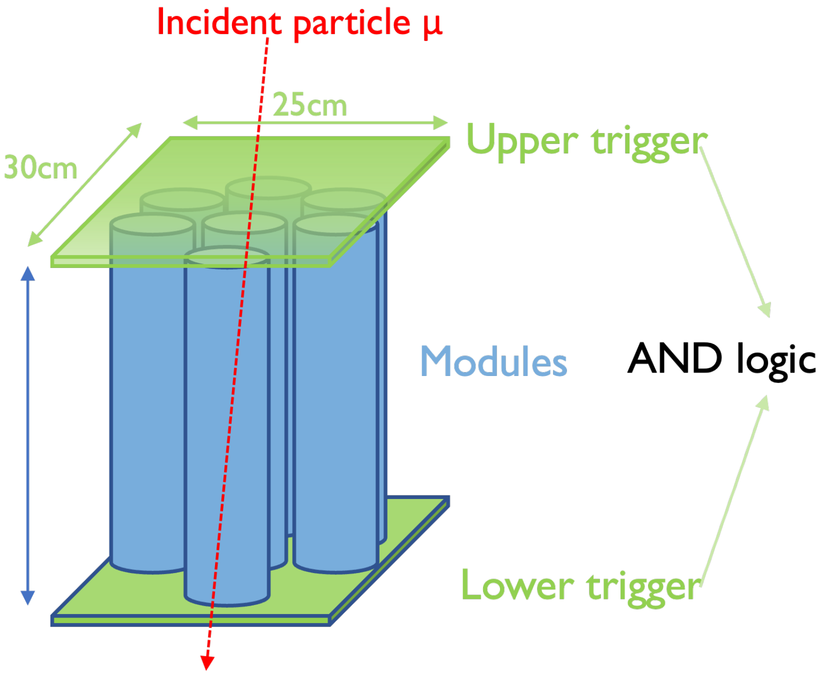
Single&Mutil-Anod MCP



ECAL

➢ Shashlyk Supermodules:

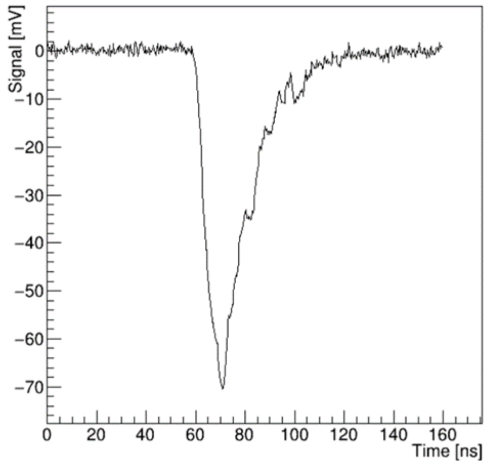
❑ Cosmic ray test at Shandong Univ.

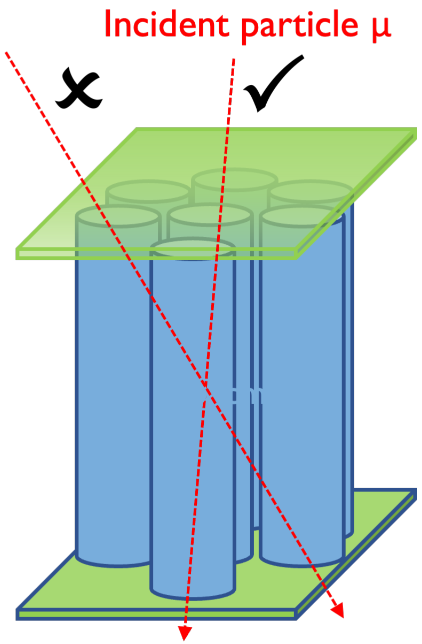


test system simplified diagram

3.2GS/s Digitizer

waveform of one event in one module





event selection

➢ Calculate number of photo-electrons(NPE)

- Perform an integral over the entire waveform
- Subtract the baseline from the waveform integral
- NPE = charge / (1.6 * 10^-19) / gain

➢ Select vertical muon events

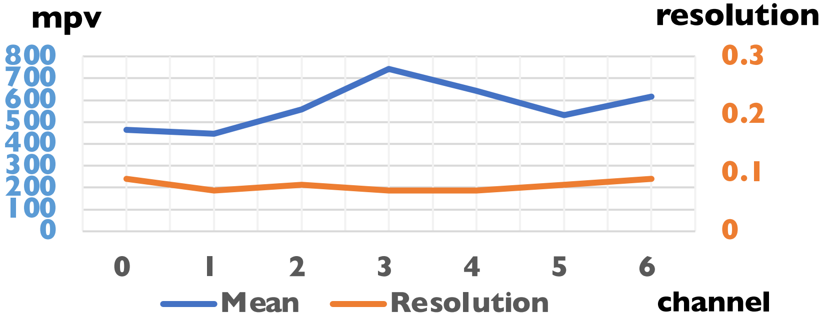
- Only one out of 7 modules has a signal, indicating nearly vertical incidence

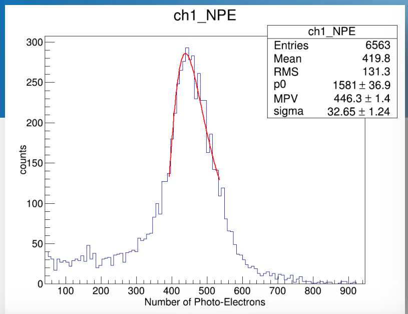
ECAL

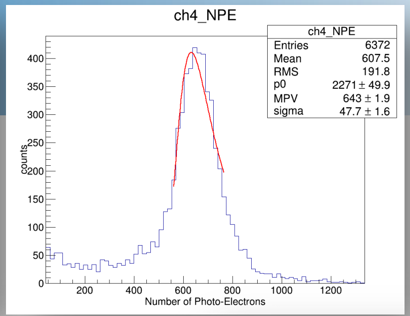
➢ Shashlyk Supermodules:

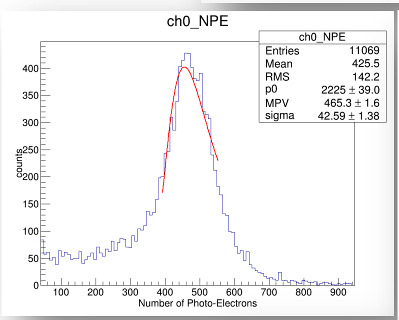
❑ NPE & Resolution

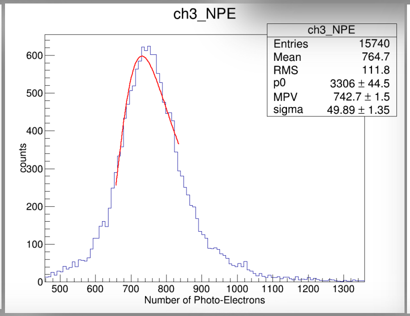
Resolution = sigma/mpv

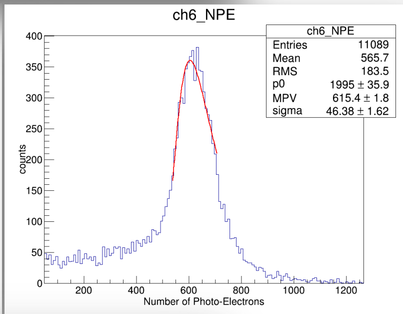


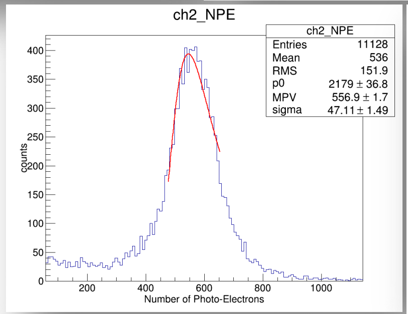


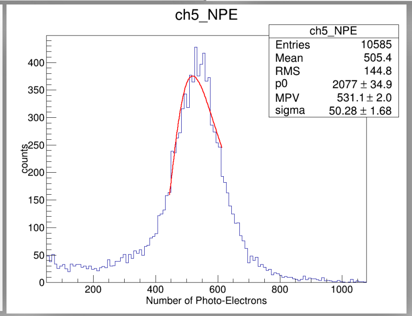






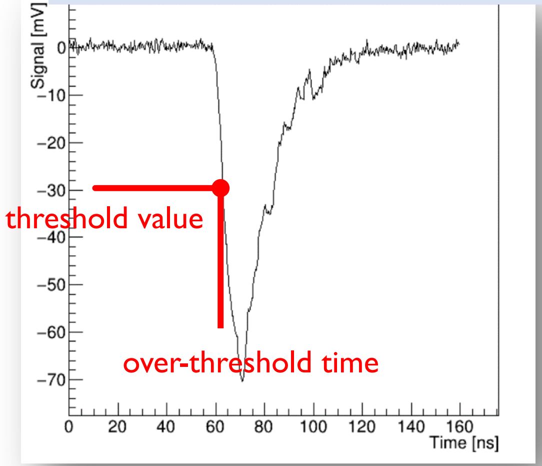




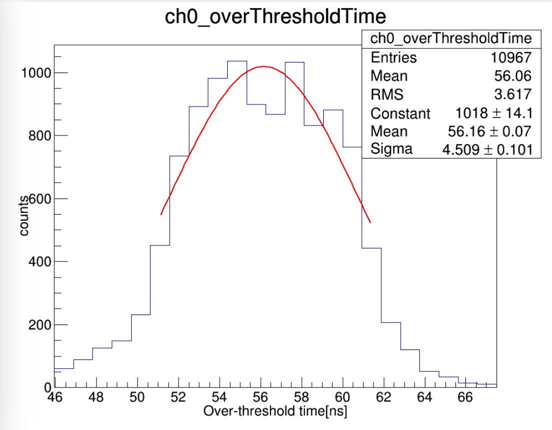


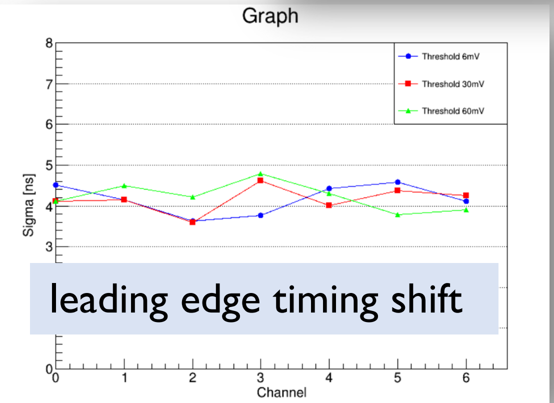
❑ Time Performance

leading edge timing to determine over-threshold time



over-threshold time histogram example



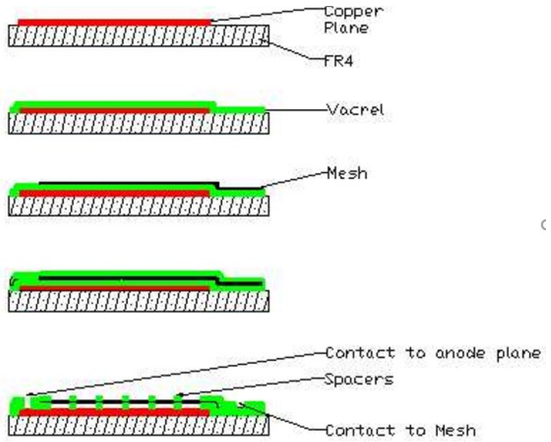


leading edge timing shift

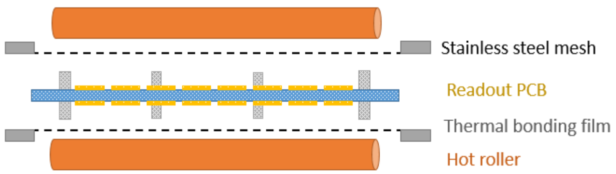
Micromegas & uRWELL R&D by USTC

- USTC is moving away from GEM technology

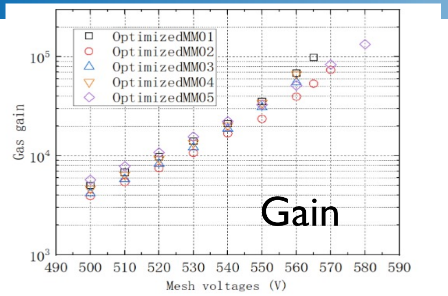
Micromegas in a Bulk

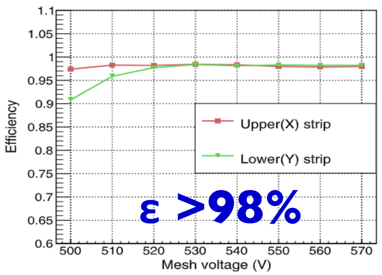


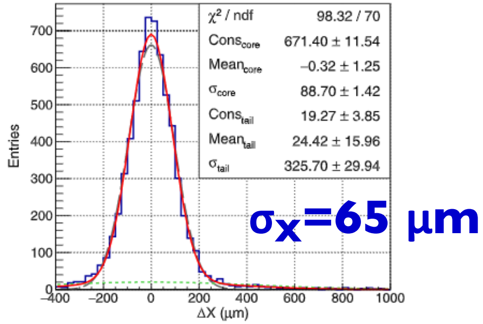
Thermal bonding processing

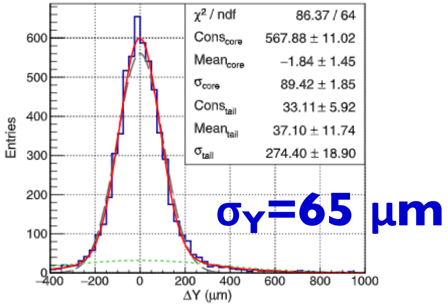


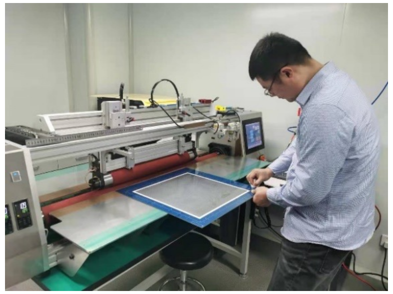
- No etching, no pollution
- Easy to handle at lab
- Easy to make new structures
- Low cost
- Φ0.5mm- Φ1mm spacers, ~1cm pitch
  - ➔easy to clean for large area
  - ➔less than 1% spacer area



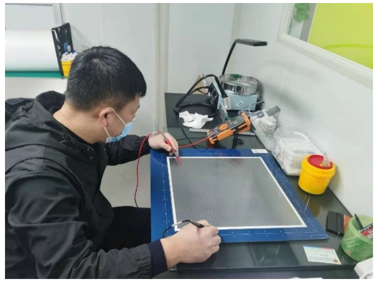


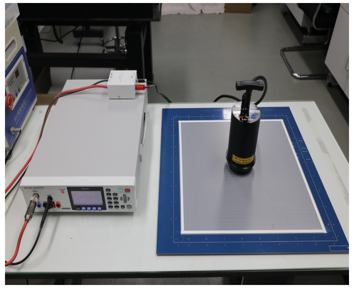


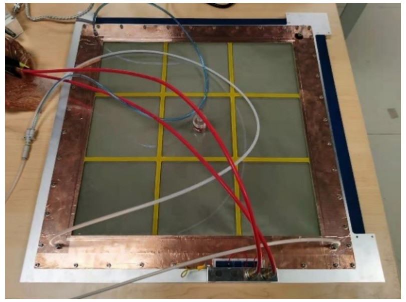




- Thermal bonding method (TBM) for Micromegas detectors: concise and etching-free mass-productive process
- A complete set of equipment, mature fabricating process, mass production capability for m^2 size micromegas





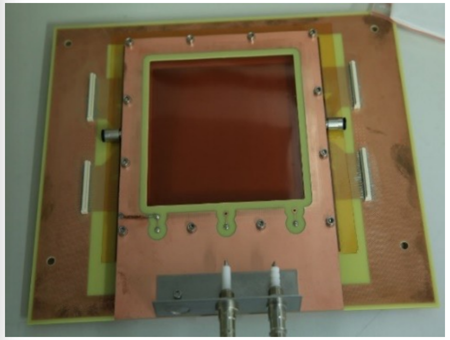


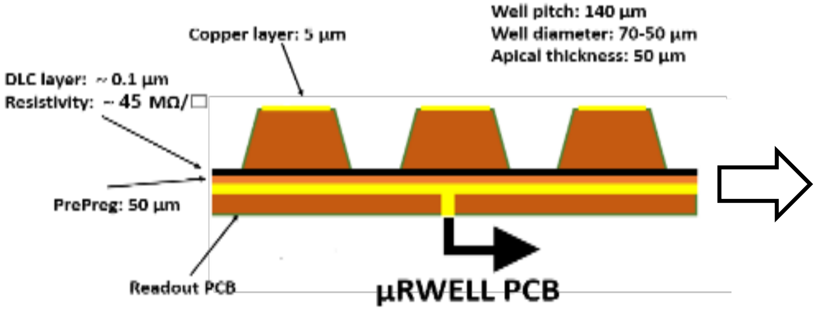
MPGD

➢ Micromegas & uRWELL R&D by USTC

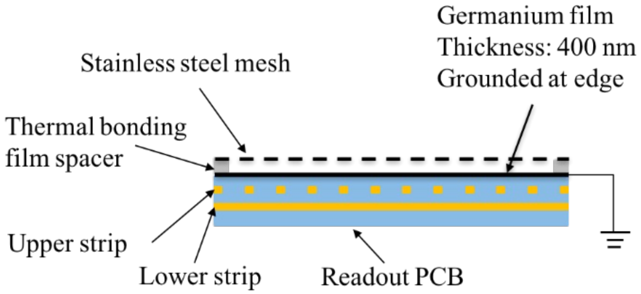
❑ USTC is exploring high rate & spatial-resolution uRWELL technology

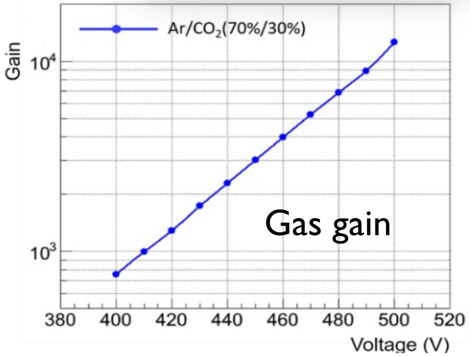
- Compact structure: 50 -100 um avalanche structure tightly attached on the PCB
- < 100 µm spatial resolution
- ~M Hz/cm2 rate capability
- X-Y 2D readout design
- Promising to make a large area

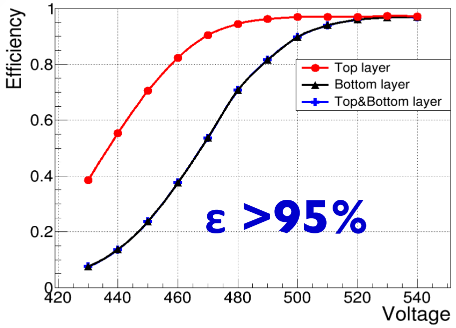


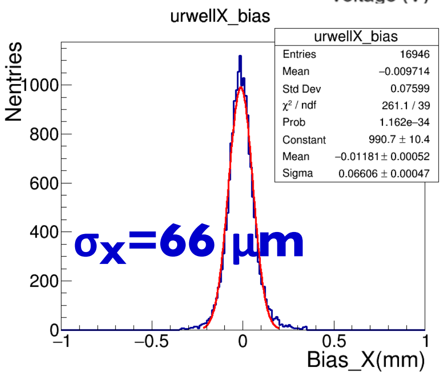


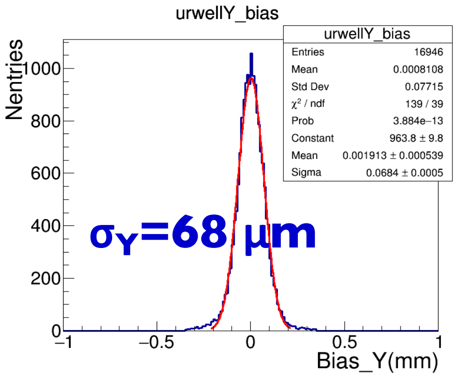
two orthogonal layers of strips were set in the inner layer of the readout PCB



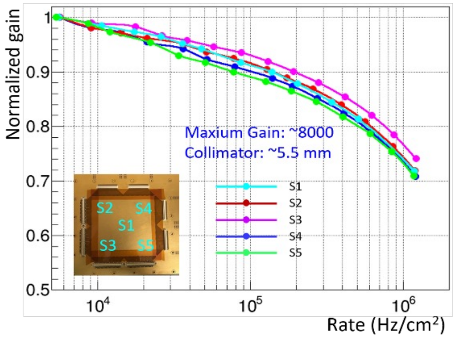


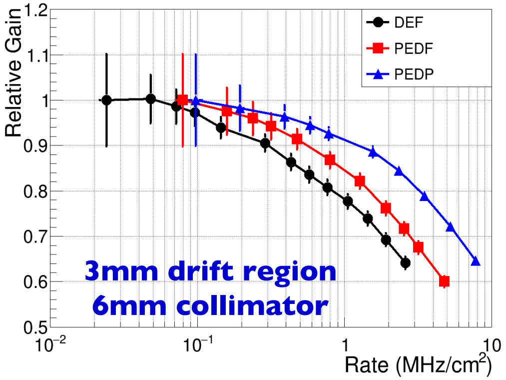






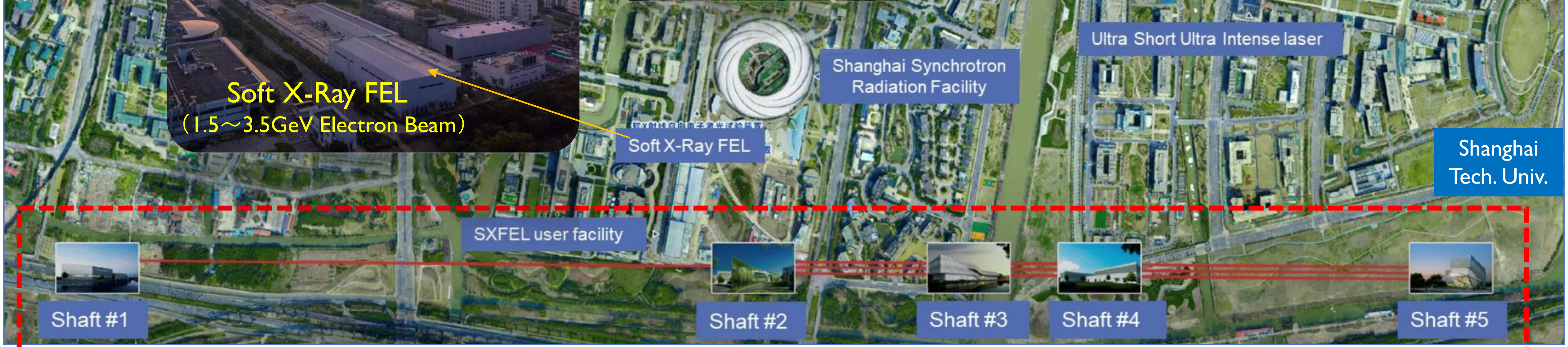
❑ Normalized gain vs. Rate





Beam Tests

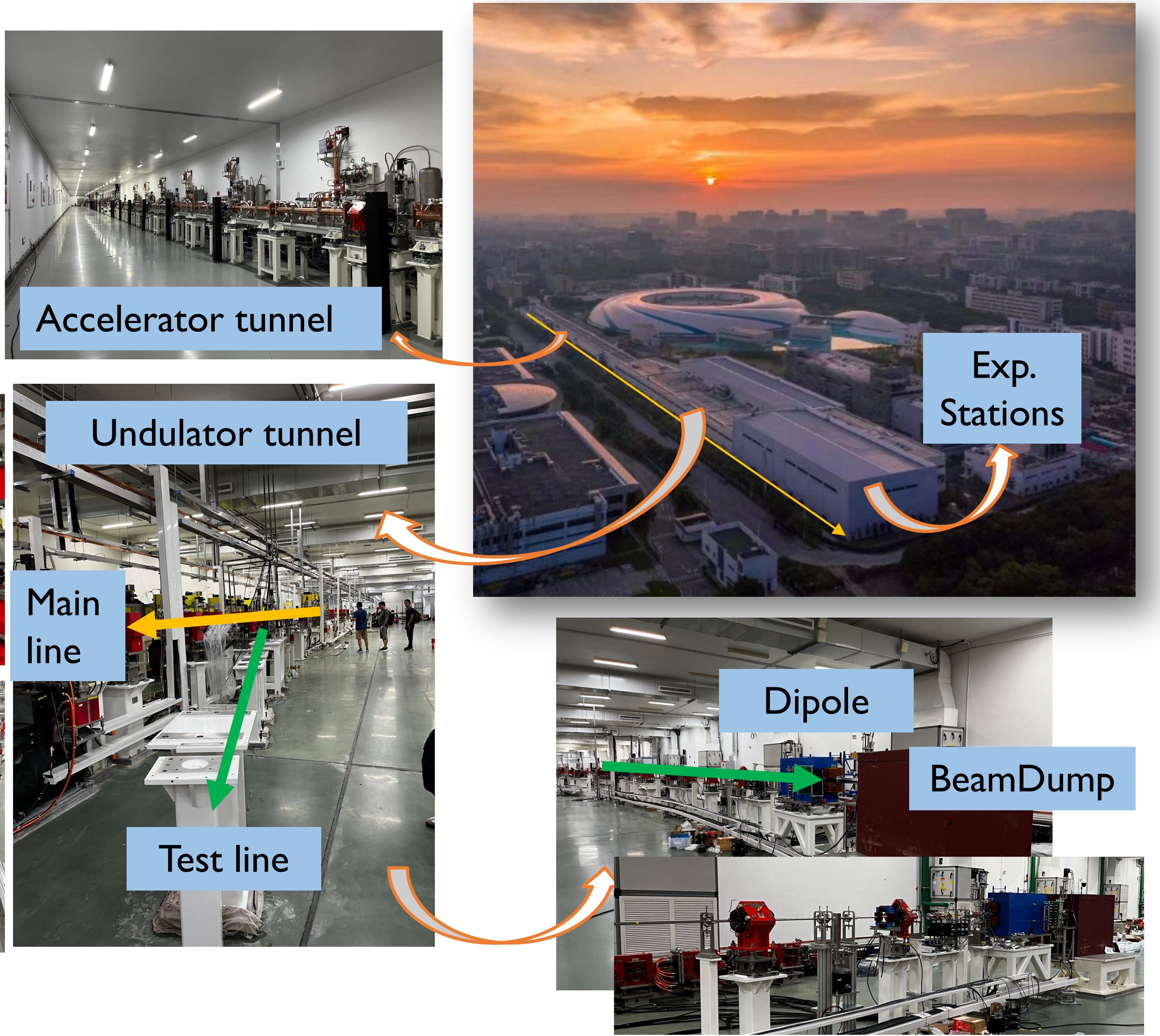
- **Shanghai Advanced Research Institute (SARI):**

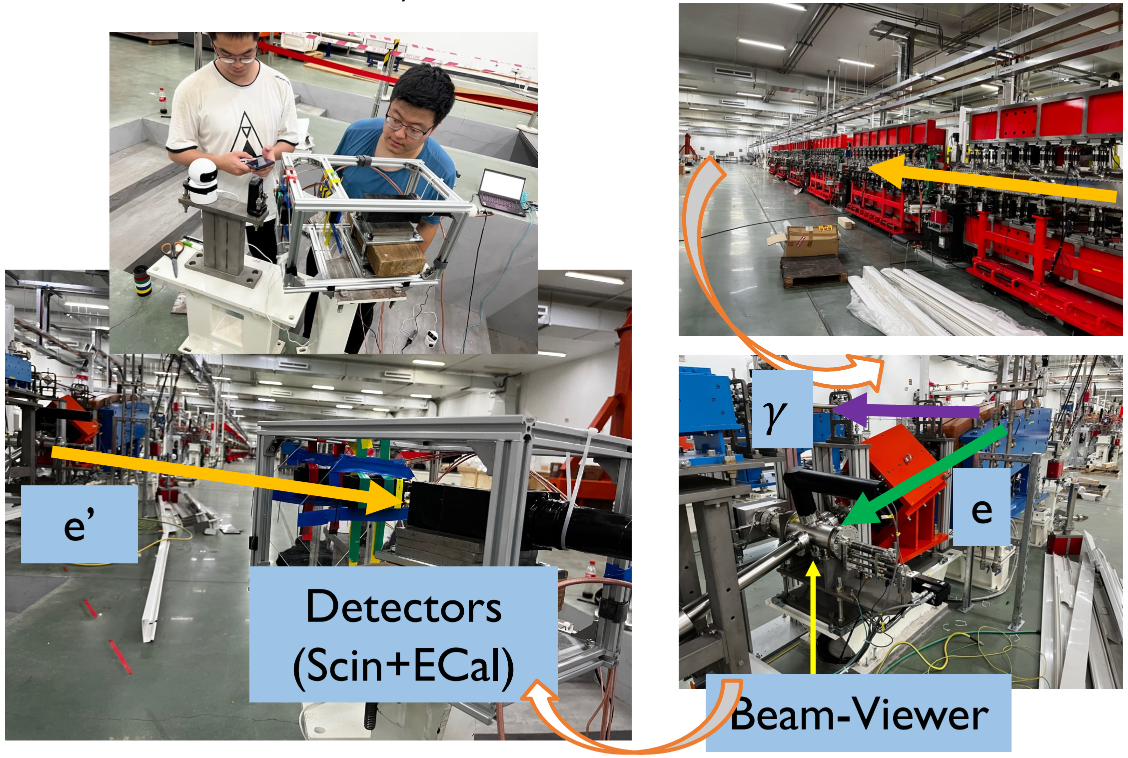


Shanghai High Repetition Rate X-ray FEL and Extreme Light Facility (SHINE)
（8 GeV, 10 exp. Stations, operation in 2024）

Beam Tests

- **Soft X-Ray FEL (SXFEL):**
  - 1.5 GeV electron (10Hz, 500pC/p, 2ps-width)
  - Summer 2023 Test:
    - ✓ 4 scintillators as trigger, see electron signals in ECal (W-power) → saw huge "overflow" signals!
    - ✓ Detectors in the tunnel (not easily accesible)
  - Spring 2024: SoLID ECal+Trackers+MRPC
  - Aim for a dedicated experimental station (need beam-line modification)





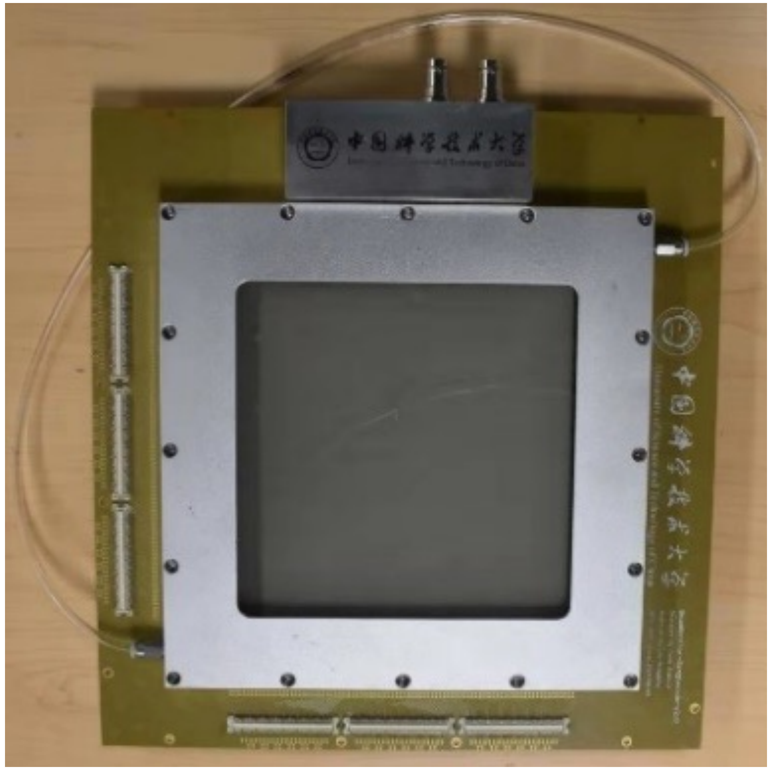
Beam Tests

➢ Jefferson Lab:

- ❑ Move 2 low-rate MRPC from UIC to Jlab; Ship 2 high-rate MRPC from Tsinghua to Jlab;
  - Develop test stand (gas circulation system, FEE, DAQ)
  - In-beam time resolution & efficiencies with different FEE (Hall-A or Hall-C?)
  - Radiation hardness of MRPC and FEE
  - Used in Hall-C Hypernuclear experiment (sMRPC+pico2023+picoTDC)?

- ❑ ECAL supermodule from Tsinghua to Jlab
  - Energy resolution of a full shower (Hall-D beam?)
  - Mounting and Supporting (need local engineer support)
  - Photo-sensors and FEE in magnetic field (200G ~ 1.5T)
  - Radiation hardness of modules and long clear-fibers

- ❑ Under discussion: beam test of USTC's micromegas & uRwell w/ optimized design (flexible PCB backplane)
  - Two micromegas ($20x20cm^2$) to be installed at Tsinghua

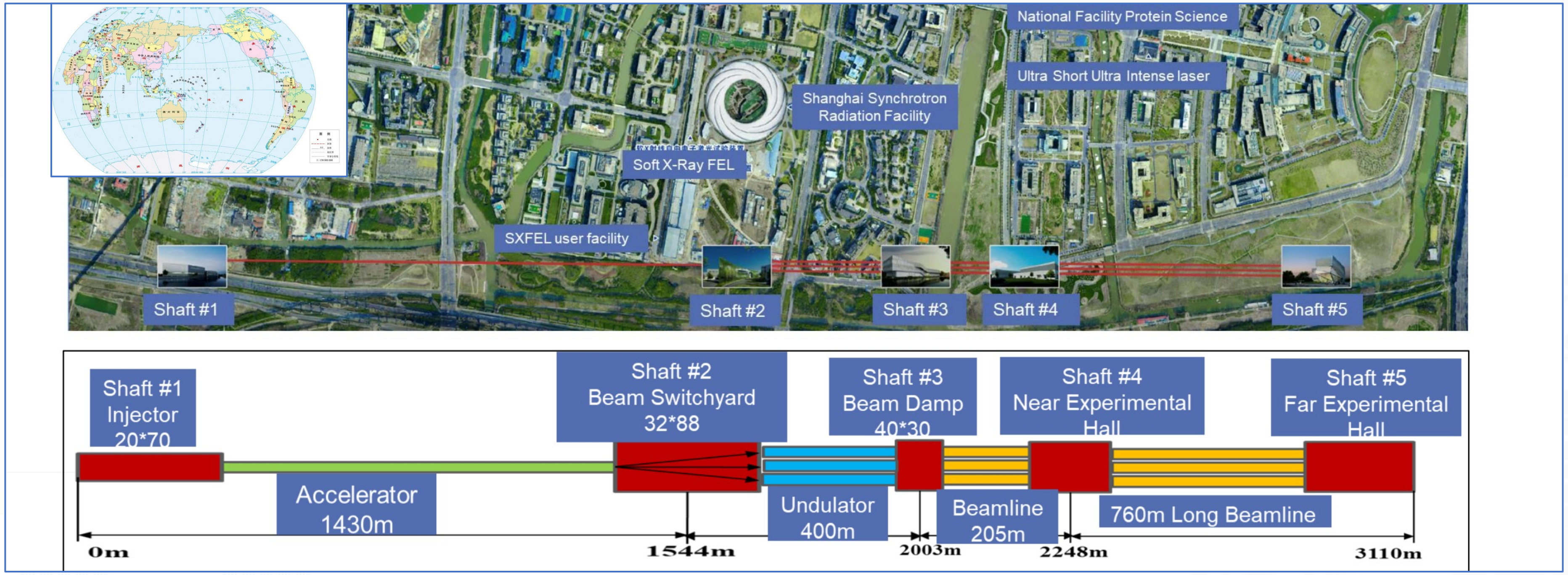


Summary

- **MRPC** by Tsinghua aims for improving TOF down to 30ps
  - 4 modules at UIC & Jlab; 2 high-rate modules at Tsinghua
  - Exploring FEE options
  - Support from EIC R&D funding
- **Shashlyk ECal** by Shandong and Tsinghua
  - A super-module with 7 modules has been assembled (+2 spares)
  - Exploring photo-sensor options
  - Developing calibration method, slow control
  - Synergic w/ EIC? Apply 2024 EIC R&D Funding?
- **MPGD** by USTC
  - Moving away from GEM; Mass production capability for micromegas; R&D on uRWELL
  - 2 micromegas moduels at Tsinghua for MRPC and ECal testing;
- Shanghai SARI e-beams at 1.5 GeV (SXFEL) and future 8 GeV (SHINE) → dedicated e-beam station?
- Beam tests at Jlab (MRPC, ECAL, MPGD) → Local support needed!
- **How to move forward with formal US-China collaboration on SoLID?**

BACKUP

GeV electron beam at SHINE

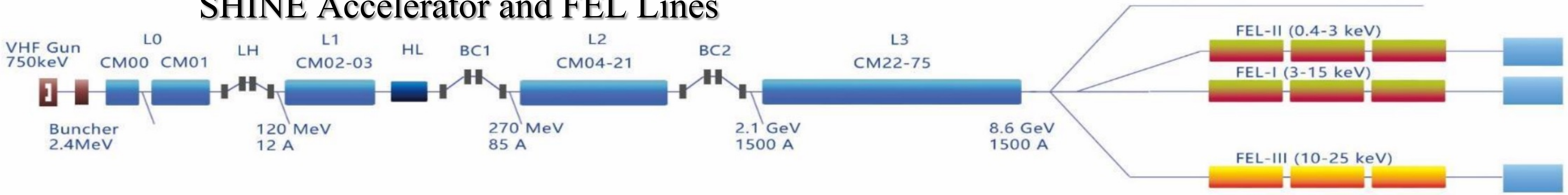


- Total Length: 3.1km
- 29m Underground
- 5 Shafts Down
- Over 10B RMB

- e, 8GeV, Frq=1MHz
- FEL: 0.4—25keV
- Pulse width: 1---10fs
- 3 X-ray beamlines
- 10 exp stations

GeV electron beam at SHINE

SHINE Accelerator and FEL Lines



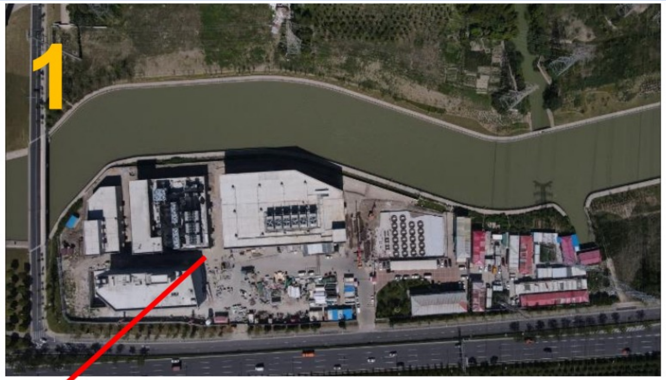
	Nominal	Range
Beam energy/GeV	8.0	4-8.6
Bunch charge/pC	100	10-300
Max rep-rate/MHz	1	up to 1
Beam power/MW	0.8	0 - 2.4
Photon energy/keV	0.4-25	0.4-25
Pulse length/fs	20-50	5-200
Peak brightness	5×10^{32}	1×10^{31}-1×10^{33}
Average brightness	5×10^{25}	1×10^{23}-1×10^{26}
Total facility length/km	3.1	3.1
Tunnel diameter/m	5.9	5.9
2K Cryogenic power/kW	12	12
RF Power/MW	2.28	3.6

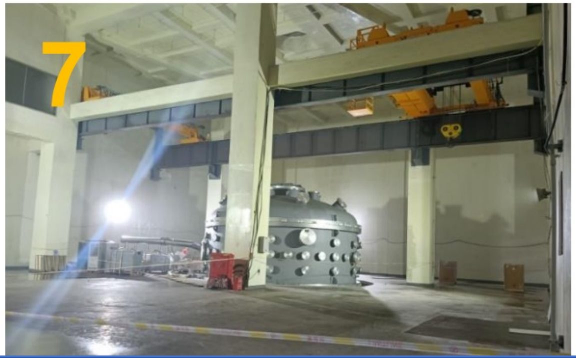
FEL Line	Nominal	Objective
FEL-I		
Photon energy/keV	3-15	3-15
Photon number per pulse @12.4keV	$>10^{10}$	$>10^{11}$
Max pulse repetition rate/MHz	0.66	1
FEL-II		
Photon energy/keV	0.4-3	0.4-3
Photon number per pulse @1.24keV	$>10^{12}$	$>10^{13}$
Max pulse repetition rate/MHz	0.66	1
FEL-III		
Photon energy/keV	10-25	10-25
Photon number per pulse @15keV	$>10^{9}$	$>10^{10}$
Max pulse repetition rate/MHz	0.66	1

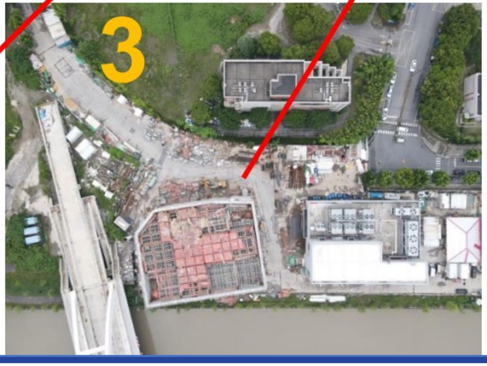
GeV electron beam at SHINE

Civil Construction

1. Shaft #1,　2. Shaft #2
3. Shaft #3,　4. Shaft #4
5. Shaft #5,　6. Linac Tunnel
7. Target Chamber in #5-B5



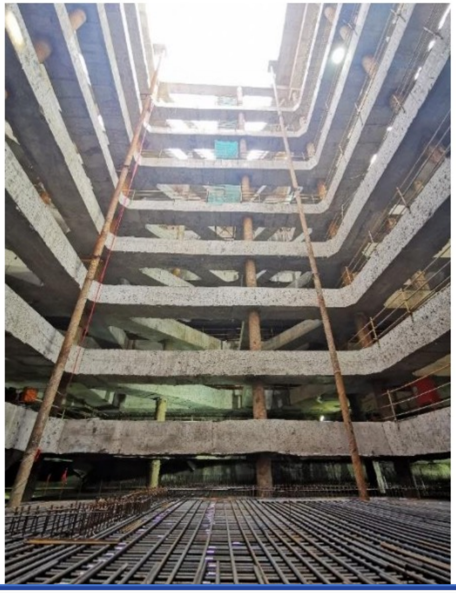


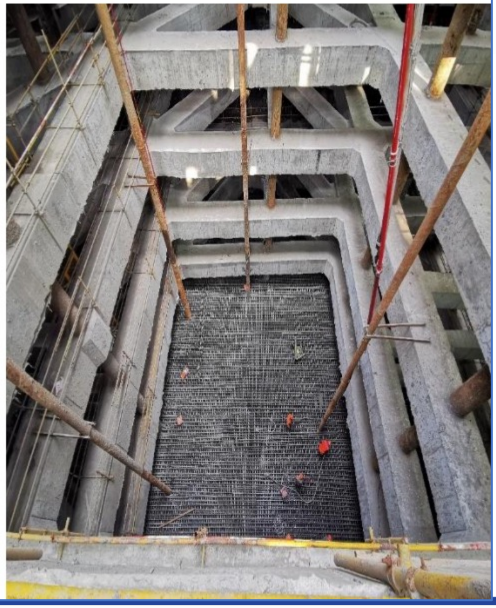


GeV electron beam at SHINE

- ➢ Till March 2023, ten tunnels between shaft No#1to No#5 have been all constructed.

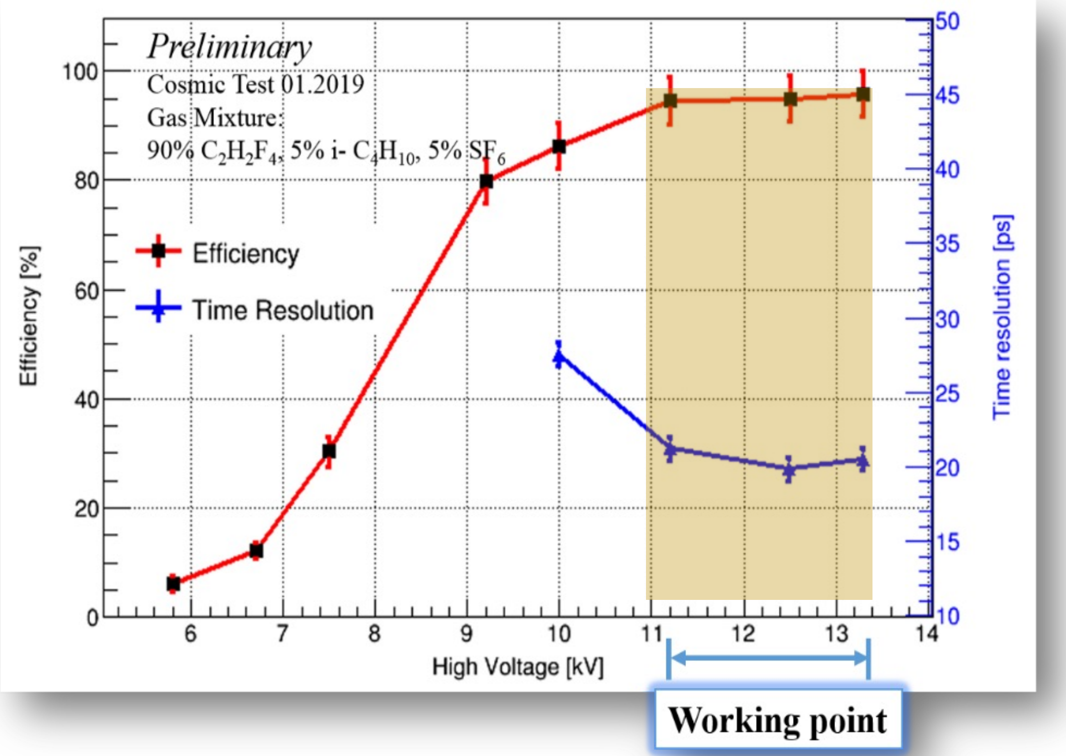
- ➢ Non-circular structure of shafts
- 5 shafts have been constructed
- Shafts No.#1 to #3 adopted opposite braces and diagonal braces
- Shaft No. #4 & #5 adopted opposite braces and side braces, 9 or 10 supporting beams are used along the depth of the foundation pits.

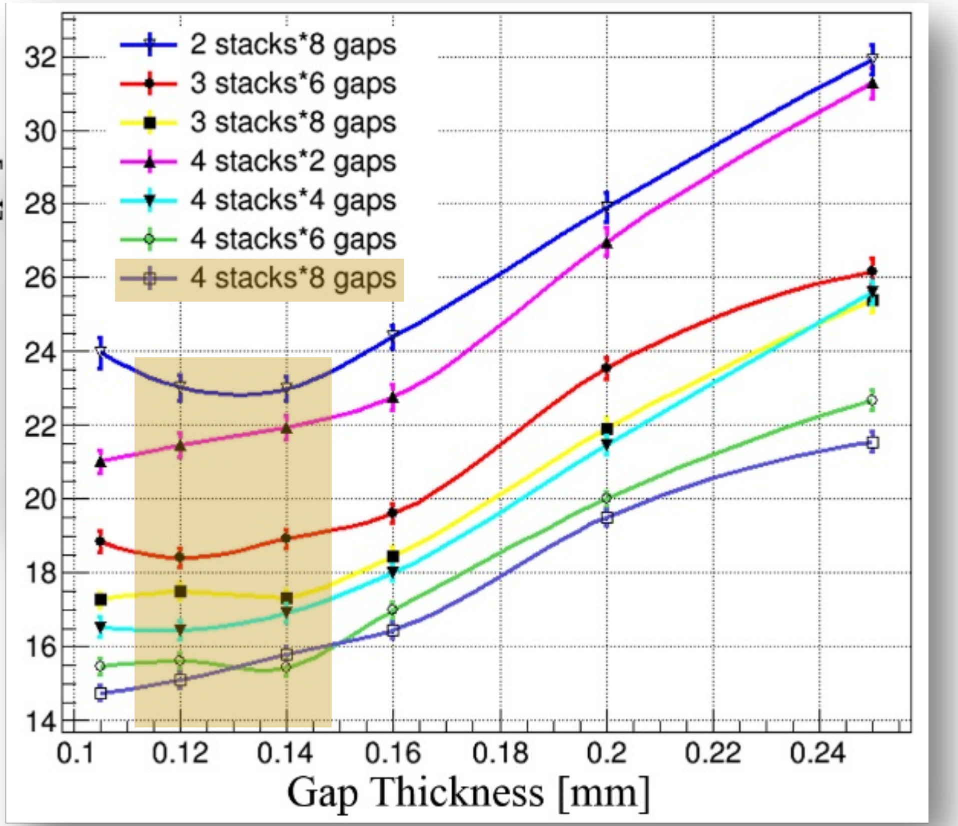




➢ Tsinghua's Sealed MRPC (sMRPC)

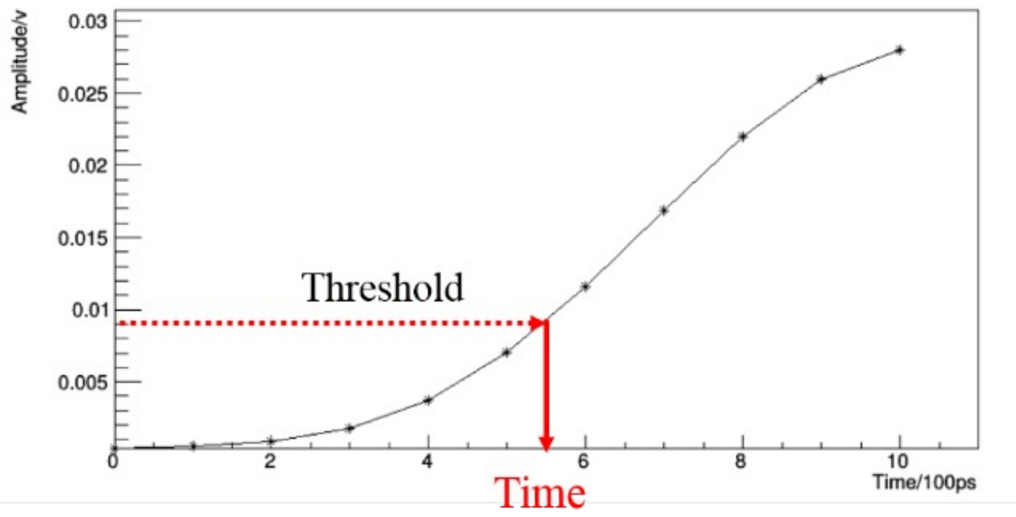
- ❑ Tunable performance of Gen3 sMRPC
  - ✓ Gaps, layers and HVs can be optimized for different needs
  - ✓ BEST: 32-layers, 400um glass, 128um gap, 12kV

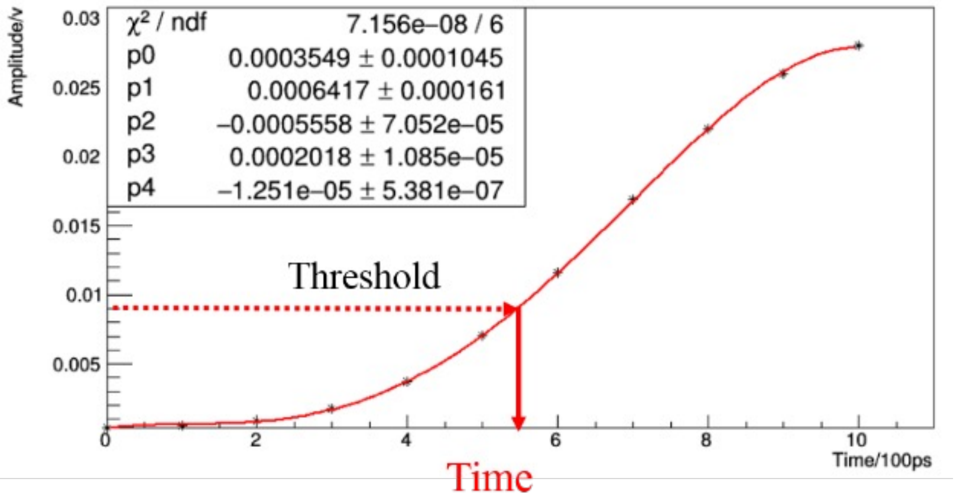




Time Correction

➢ToT Method vs. Sampling





❑ ToT Method:
- ✓ Fixed threshold by DIS
- ✓ Use ADC for walk-correction
- ✓ Fewer requirements on front-ends
- ✓ Affected by signal amplitude

❑ Sampling Method:
- ✓ Capture waveform of raise-edge
- ✓ Need fast sampling front-ends
- ✓ Good for high-precision timing
- ✓ Good for large noise and varying amplitudes

MRPC

➢Tsinghua's Sealed MRPC (sMRPC)

❑ Parameters of Gen3 sMRPC (32-layers, 400um glass, 128um gap)

MRPC Module	L x W x T (mm)
Honeycoumb Board(x2)	265 x 90 x 7.5
Outer PCB (x2)	298x120x0.6
Inner PCB (x2)	298x120x1.2
Center PCB (x1)	328x120x1.2
Readout Strip (on PCB)	268x5(8 line, 2mm gap)
Mylar film (x2*4)	268x90x0.25
Carbon Electrode (x2*4)	250x72x0.005
Resistive Glass (x9*4)	258x80x0.4
Gas Layer (x8*4)	0.128
Active Area	258 x 80
Total Size	328 x 120 x 40.3 （0.1 X_0)

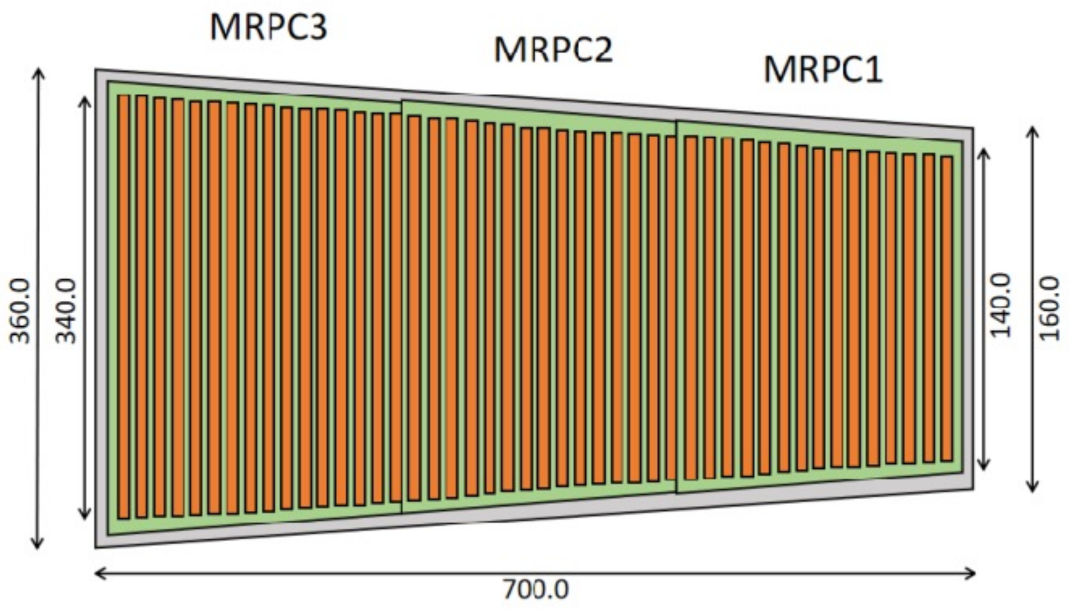
Pulse signal before PreAMP: 2mV (integrated charge ~ 4pC)

❑ 4 mRPC at UIC and 2 new ones at Tsinghua

Parameter	Value
Dimension	360 × 338 mm²
Height	26 mm
Weight	3.3 kg
Glass dimension	330 × 276 mm²
Gas gap number	2 × 4
Gas gap width	0.25 mm
Strip pitch	7 + 3 mm
Strip length	270 mm
Strip number	32

Hadron Endcap mRPC-TOF

Endcap TOF consists of 16 modules and each module consists of 3 sealed MRPC.



Total overlapped thickness= 60mm

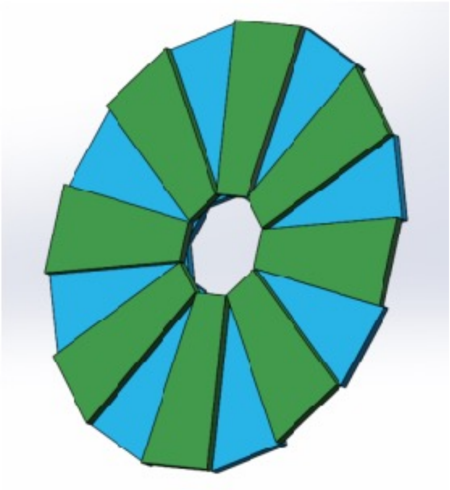


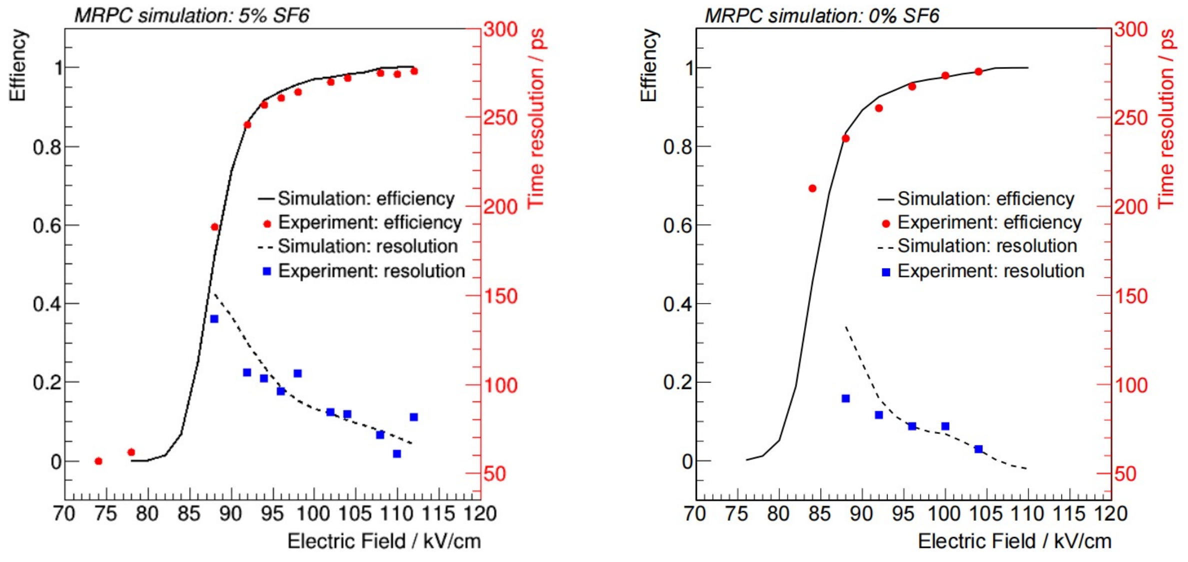
Figure 1.3 Arrangement of MRPCs inside the box in the End-cap.

MRPC

F.Wang, JINST, 13(09):P09007, 2018.

➢ R&D Task#1: Simulation Framework

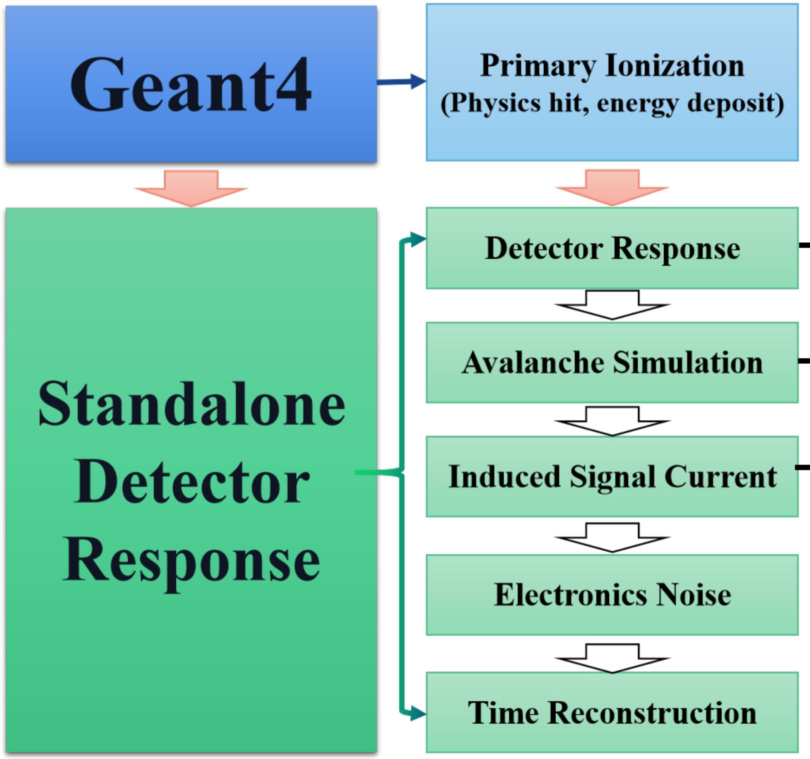
- ❑ Tsinghua has developed an efficient MRPC simulation tool



(a)

(b)

- ❑ Improvement for future study
  - o Eco-friendly gas
  - o Reduce gaps (less radiation length)
  - o Improve spatial resolution

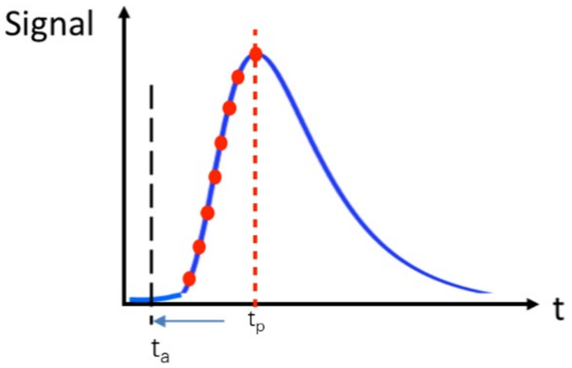


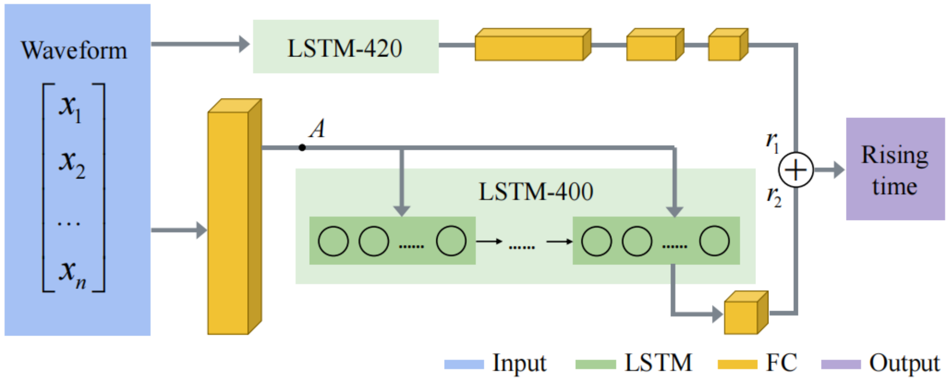
now	future	goals
Magboltz	→ Betaboltz	→ Better Gas Property Simulation
1D E-Field	→ 3D E-Field	→ Study Space-Charge Effect
Single-Strip	→ Multiple-Strip	→ Strip Optimization

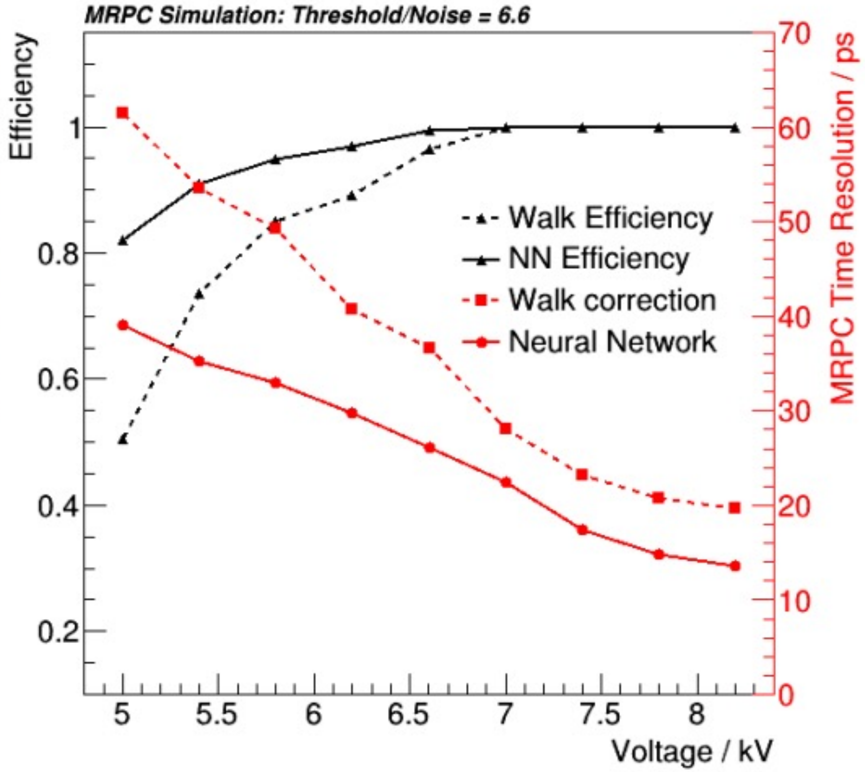
Deliveries#3

➢ Time-Correction with Machine-Learning

- ❑ ToT method is limited by pulse height, noise, and TDC resolution
- ❑ Limited improvement by offline time-walk correction (w/ ADC info)
- ❑ Waveform Sampling →higher precision
- ✓ Further improvement w/ ComLSTM neural network model







F. Wang, JINST, 14(07):C07006, 2019

- ❑ To dos:
  - ✓ Use modern machine-learning tools
  - ✓ Train with new simulation data
  - ✓ Check with beam-test data