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

Alexander Camsonne[1], Yi Wang[2], Zhenyu Ye[3], Zhihong Ye[2]

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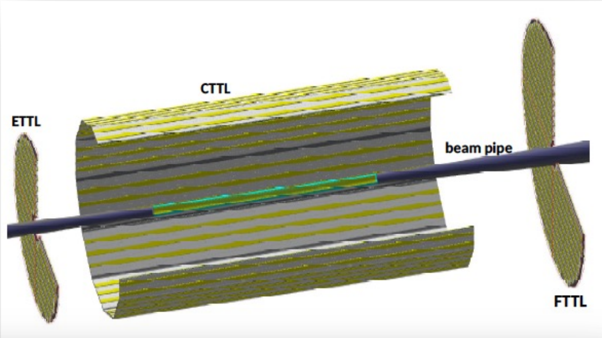
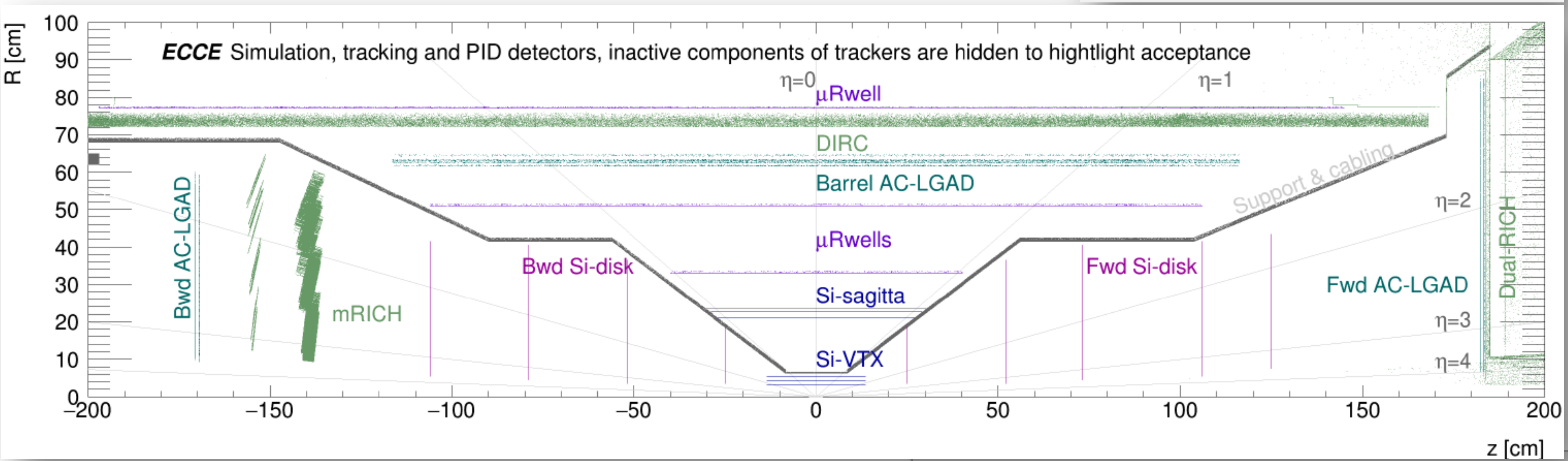
[1] Thomas Jefferson Lab
[2] Tsinghua University
[3] University of Illinois at Chicago

清華大學
Tsinghua University

TOF on EIC

- AC-LGAD as the TOF for ePIC
  - Goals: 25ps time + 30um spatial resolutions
  - Cost: ~$10M
  - Still under active R&D (possible risk)



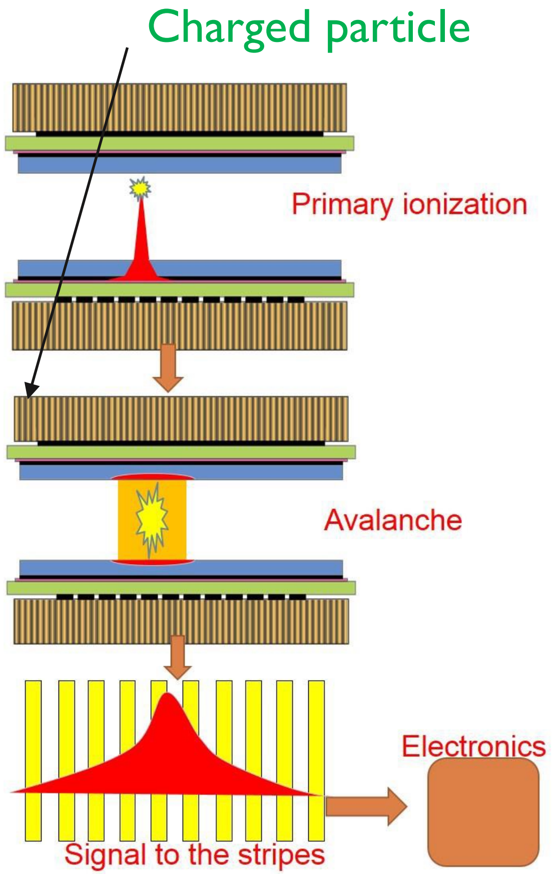


- Can any places be substituted?
- Alternative TOF solution?
- The second IP detector?

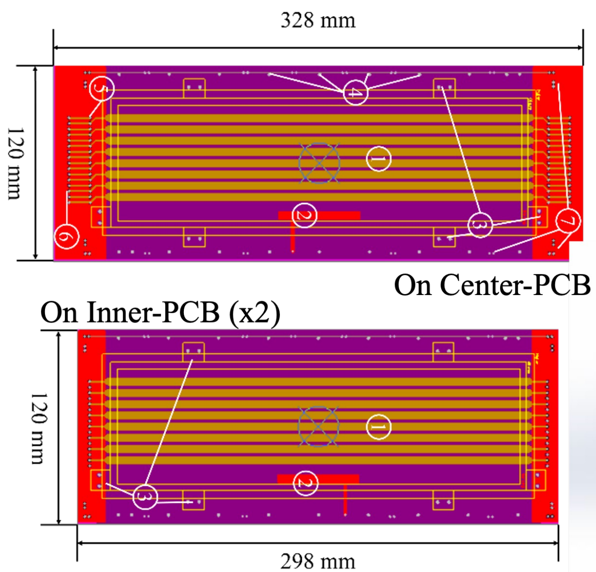
- Center Detector (most recent setup for ePIC):
  - ~~Electron Endcap → ~0.8 m² (R~70cm),~~
  - Hadron Endcap → ~2 m^2 (~~R~180cm,~~ R~65cm)
  - Barrel→ ~10 m^2 (R~64cm, Z~240cm)

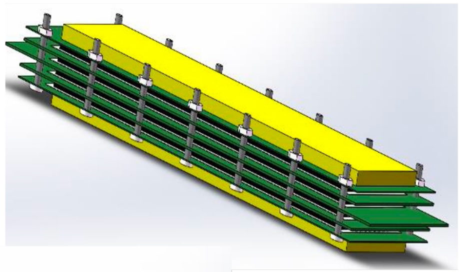
Multi-gap Resistive Plate Chamber (MRPC)

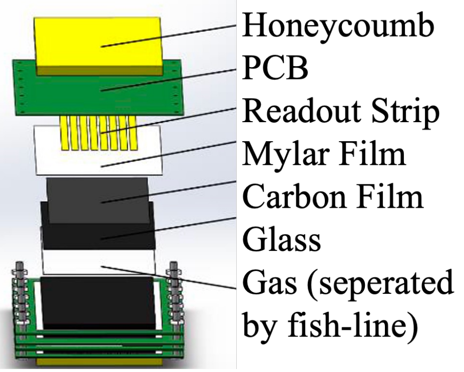
➢ General Princple

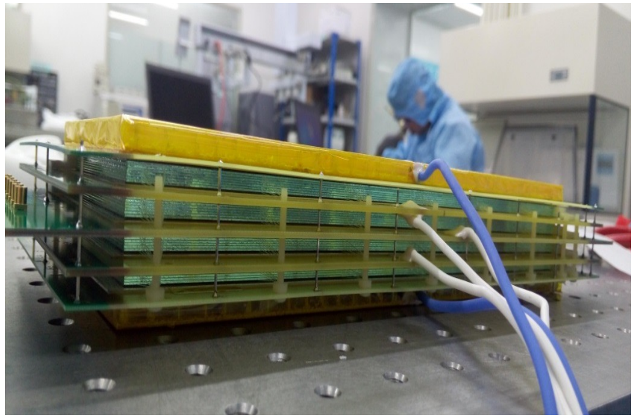


- ❑ Low-resistivity glass plates, Standard gas (95% F134a + 5% iso-butane), HV(~12kV)
- ❑ Good performances:
  time resolution, efficiency, rate capacity (>30kHz/cm^2), radiation-hard, magnet safe
- ❑ Certain spatial resolution (by strip pitch)
- ❑ Low cost, easy manufacturing, large sensitive area (up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



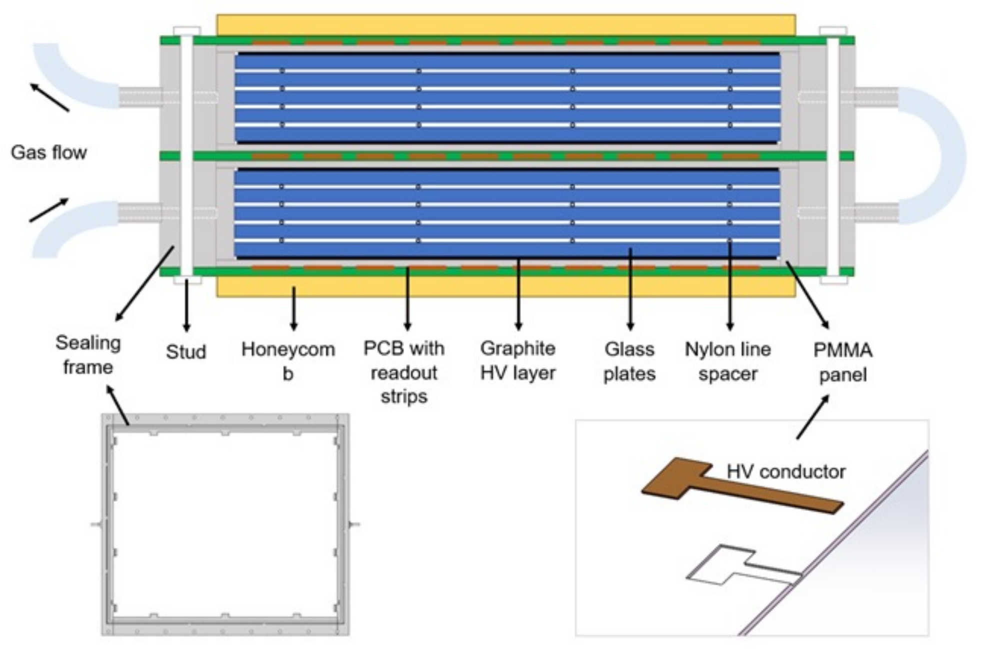




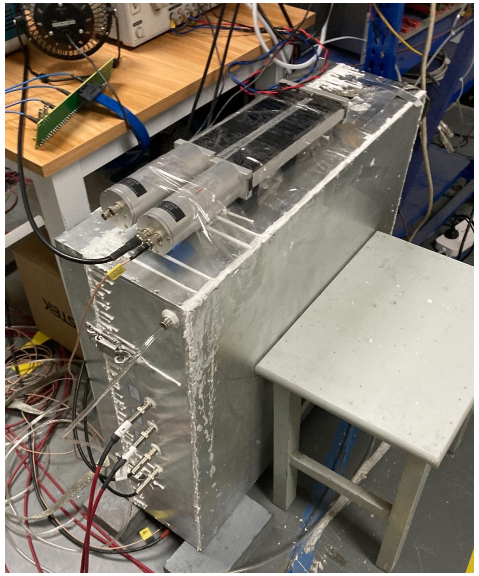


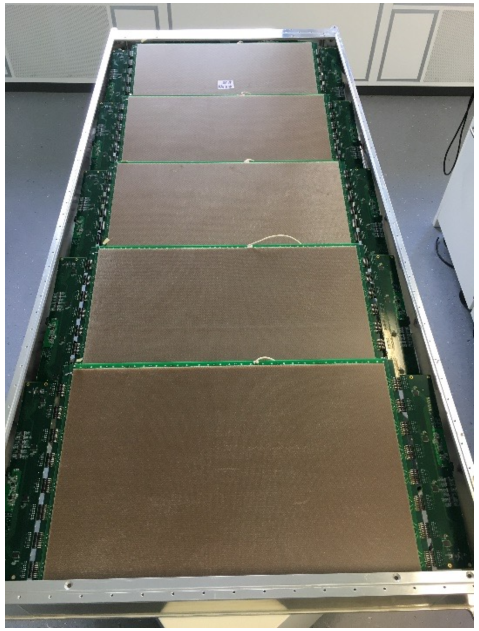
MRPC

- Tsinghua's new Sealed MRPC (sMRPC)
  - Gen3 MRPC with sealed gas → No more boxes!
  - More compact, less radiation length
  - Reduce greenhouse gas emmission (20cc/cm^2/min)

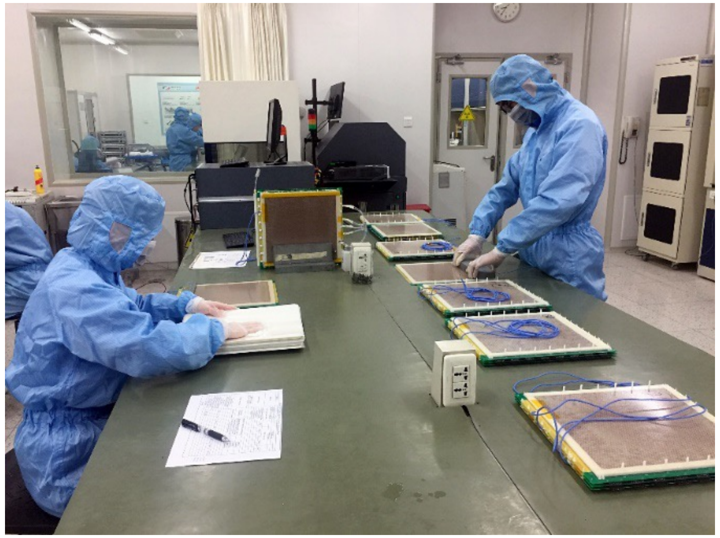


Y. Wang et al 2019 JINST 14 C06015



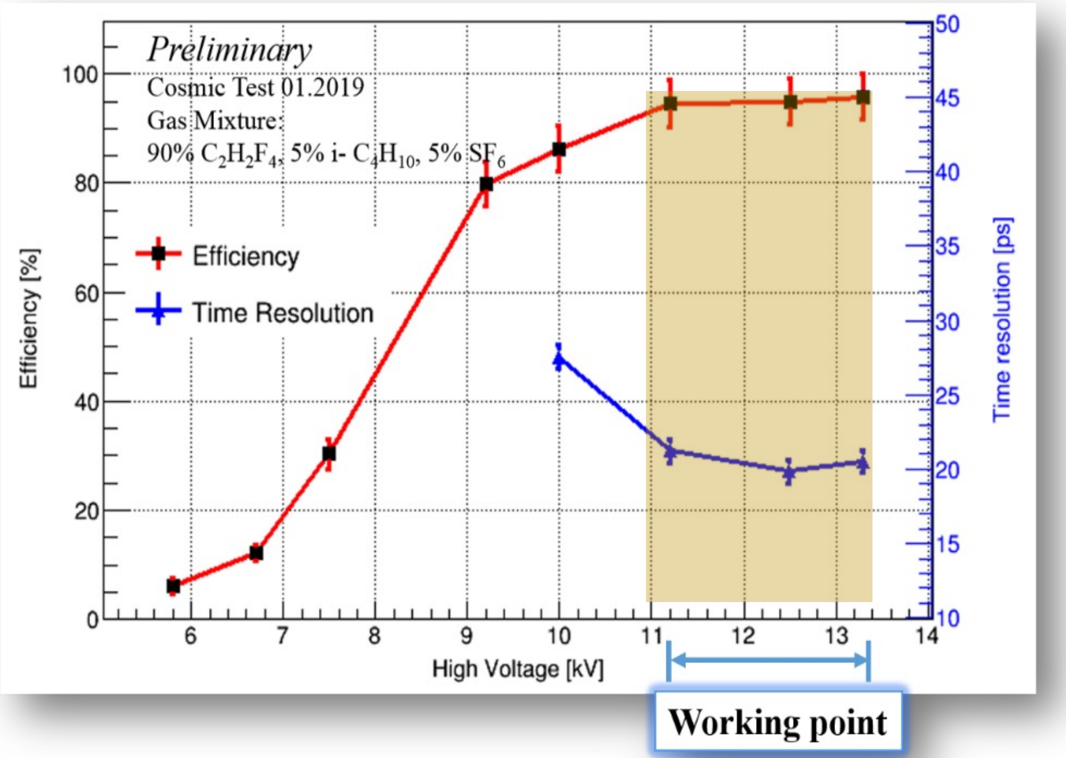


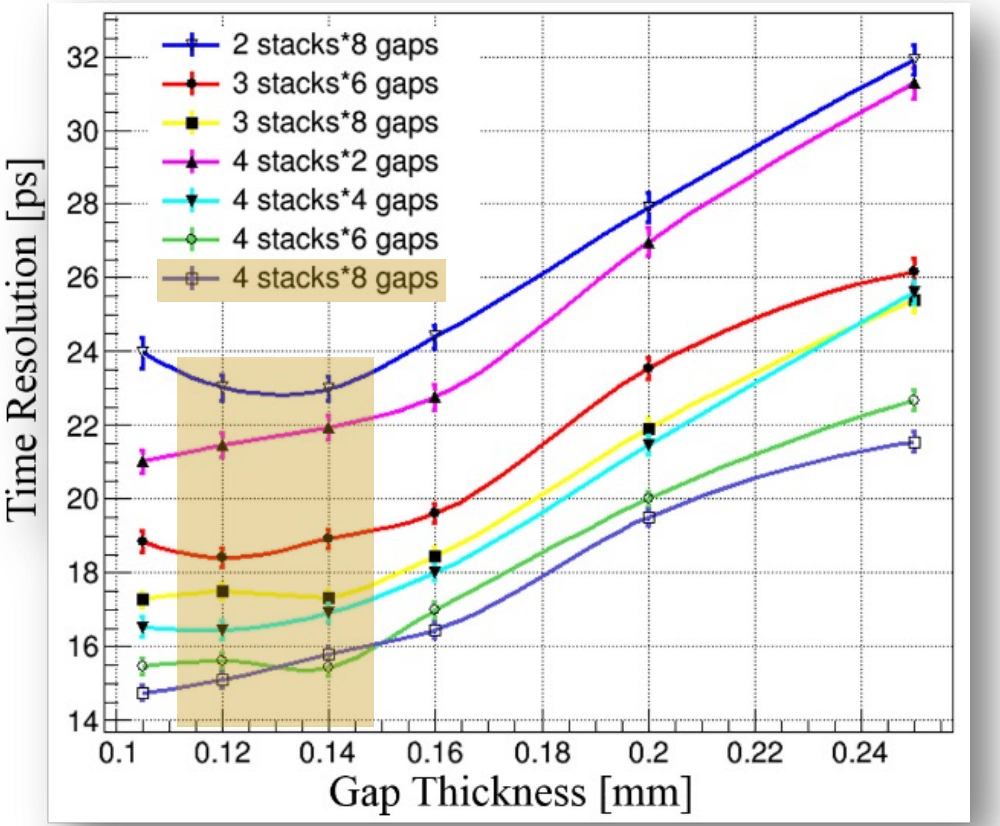
- To be used on CBM, CEE, SoLID, etc.
- Tsinghua's Miyun workshop is continousely conducting mass production of sMRPC for many projects



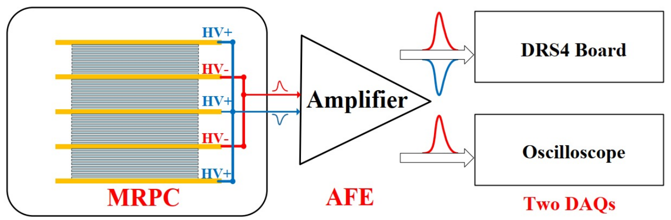
➢ Tsinghua's Sealed MRPC (sMRPC)

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





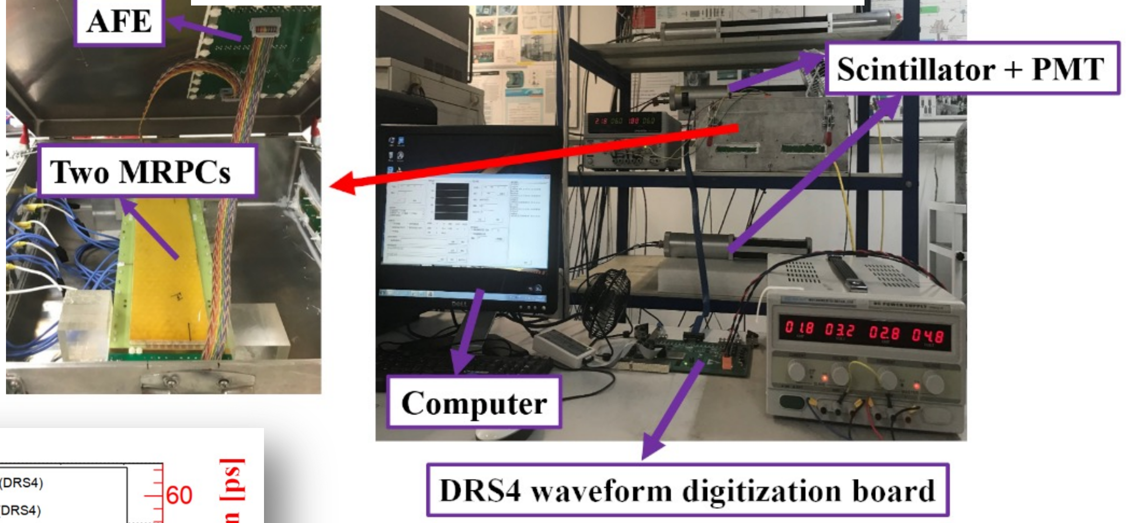
MRPC

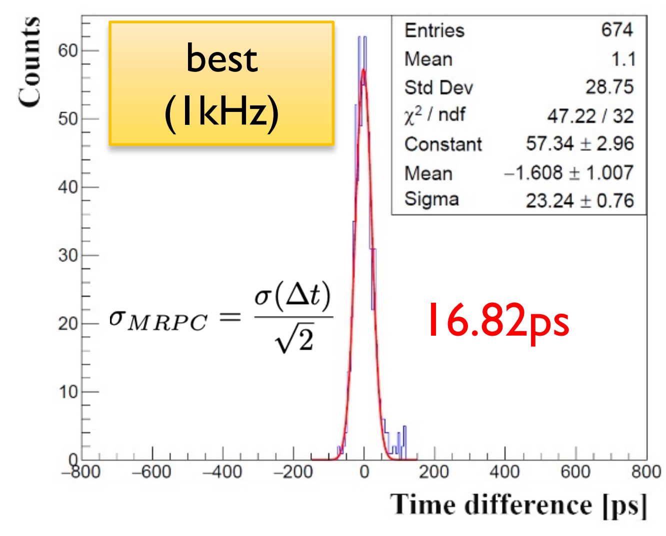


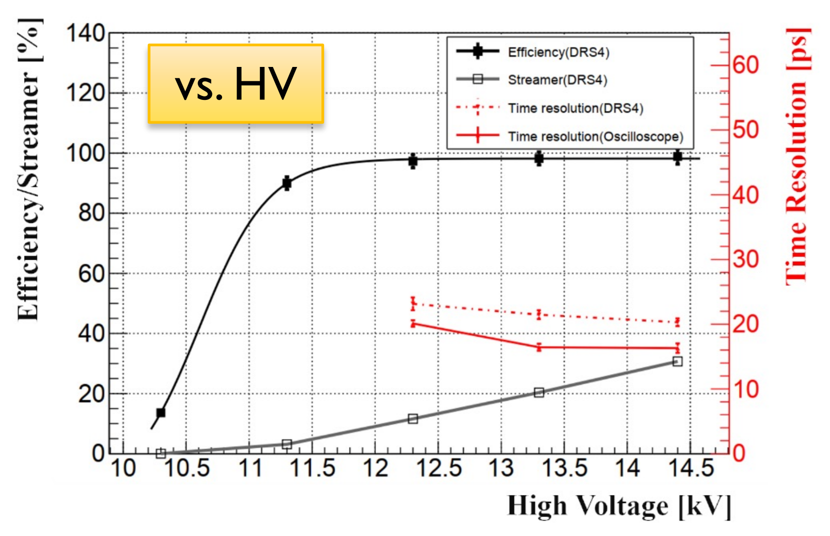
➢ Tsinghua's Sealed MRPC (sMRPC)

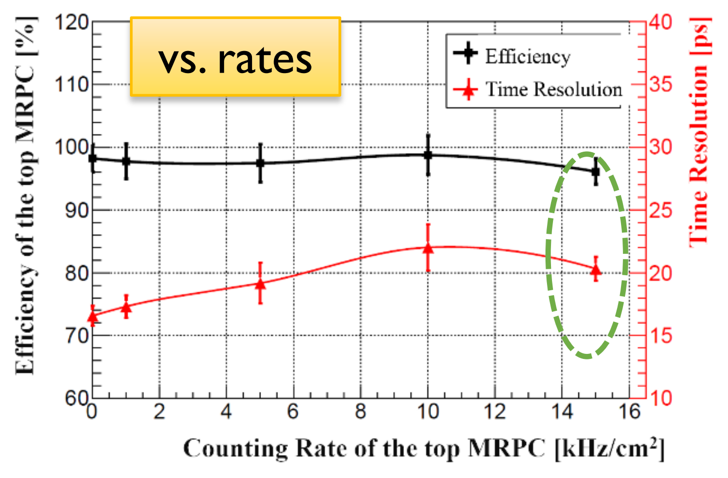
- ❑ Most recent tests: cosmic ray with x-ray background
  - ✓ 32-gaps (4 stacks), 400um thin glasses
  - ✓ 104um gas-gap + waveform-sampling → 20ps & 95% efficiency at 15kHz Y. Yu et al 2020 JINST 15 C01049
  - ✓ 128um gas-gap + ToT method → 20ps at 15kHz

Y. Yu et al 2022 JINST 17 P02005









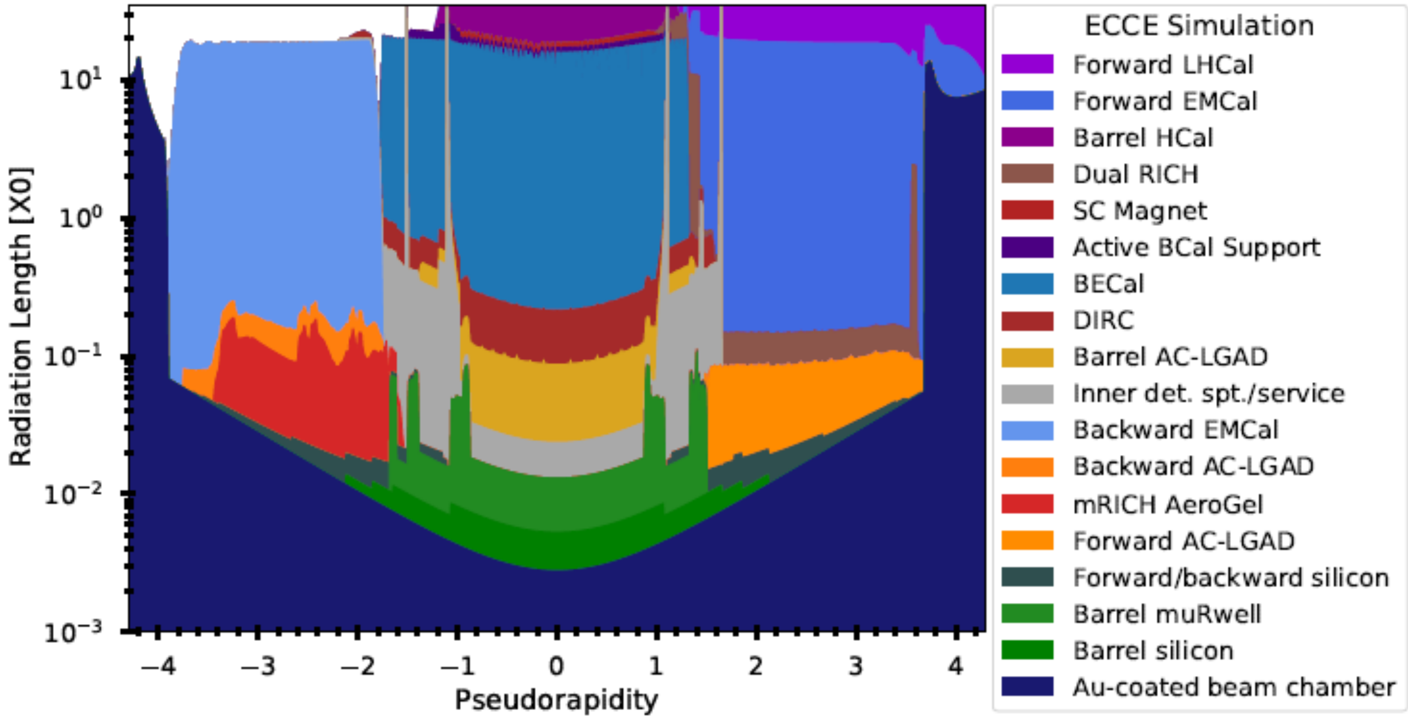
- ❑ No in-beam test yet

MRPC on EIC?

➢ sMRPC's Pros and Cons:

❑ **Pros:**

- ✓ Proved high-time resolution
- ✓ Radiation-hard, magnetic field safe
- ✓ Cost-effective
- ✓ Mass production
- ✓ No technical risk



❑ **Cons:**

- Thick (4cm for each plane)
- Large radiation length (32 layers=10% X_0)
- Limited spatial resolution
- Greenhouse gas

❑ Proposing R&D of sMRPC for EIC:

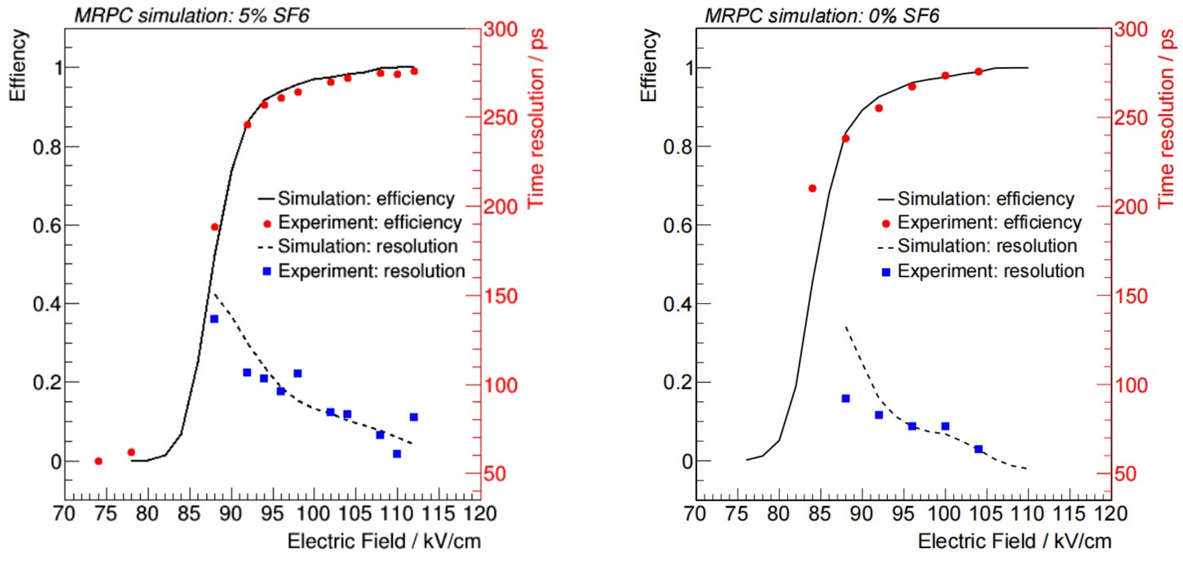
- Reduce thickness with fewer layers (time vs X_0)
- Ecofriendly gas (or gas-recycling system)
- Timing performance in high-energy beam
- Improve spatial resolution w/ finer strip pitch ($$$)

Deliveries#1

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

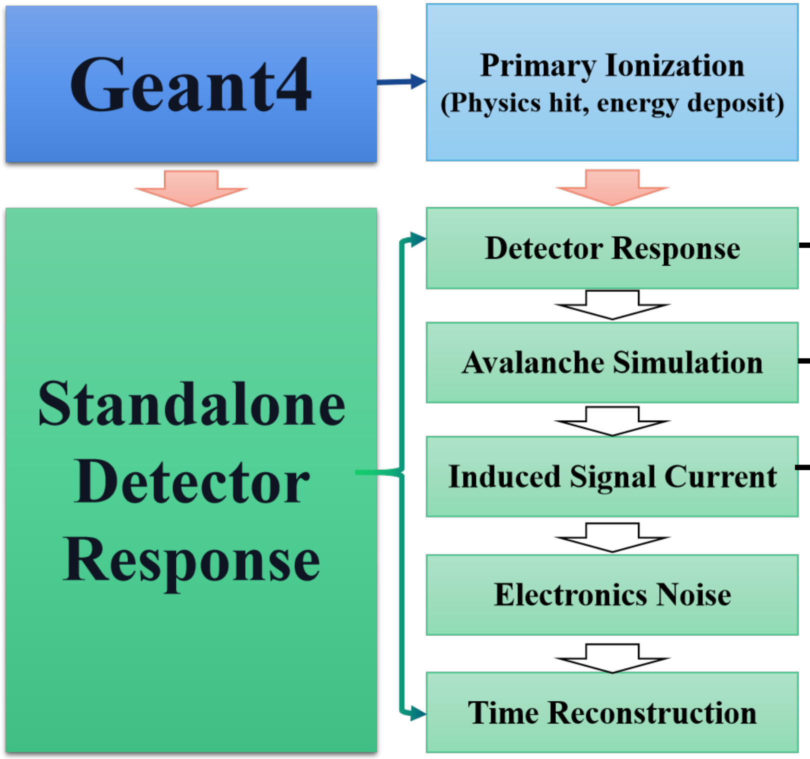
➢ Simulation Framework

- ❑ 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

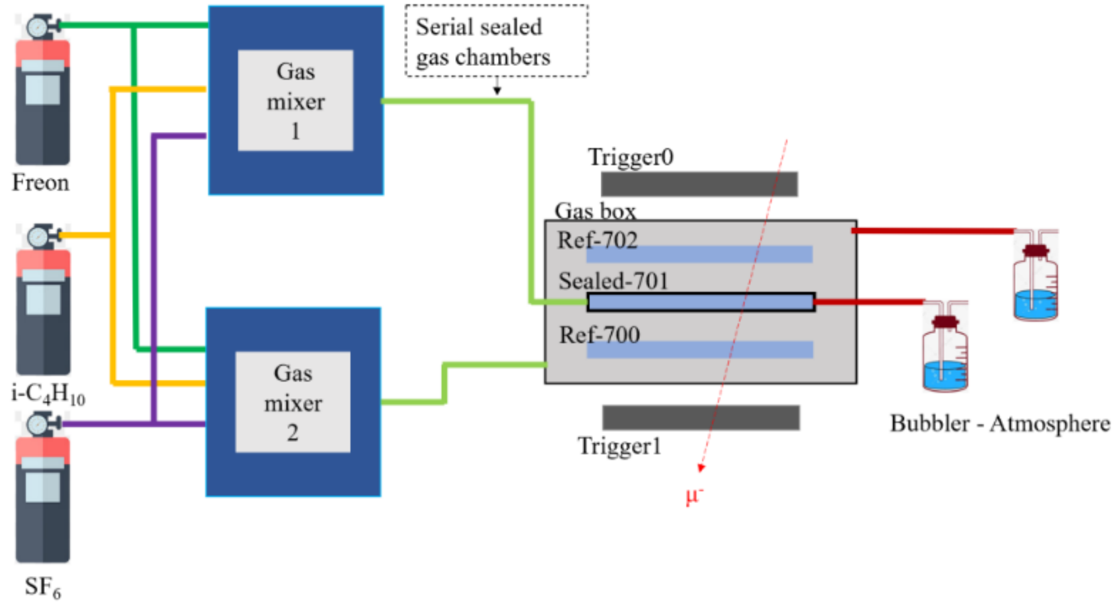
Deliveries#2

➢ 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

MRPC Standard Gas

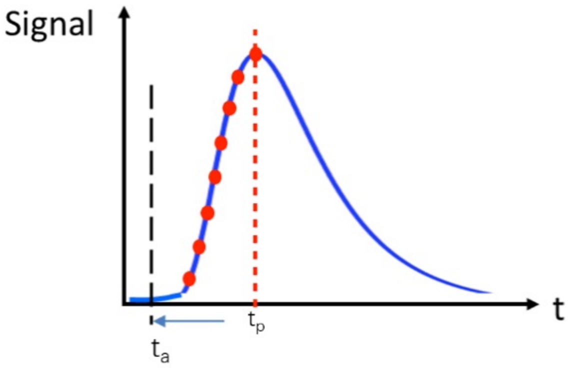


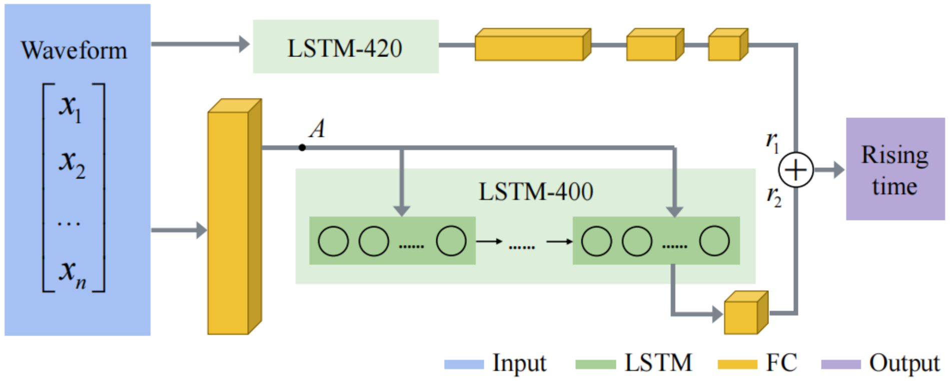
- ❑ To-dos:
  - Simulation with more gas mixtures
  - Cosmic ray and beam test for actual performance

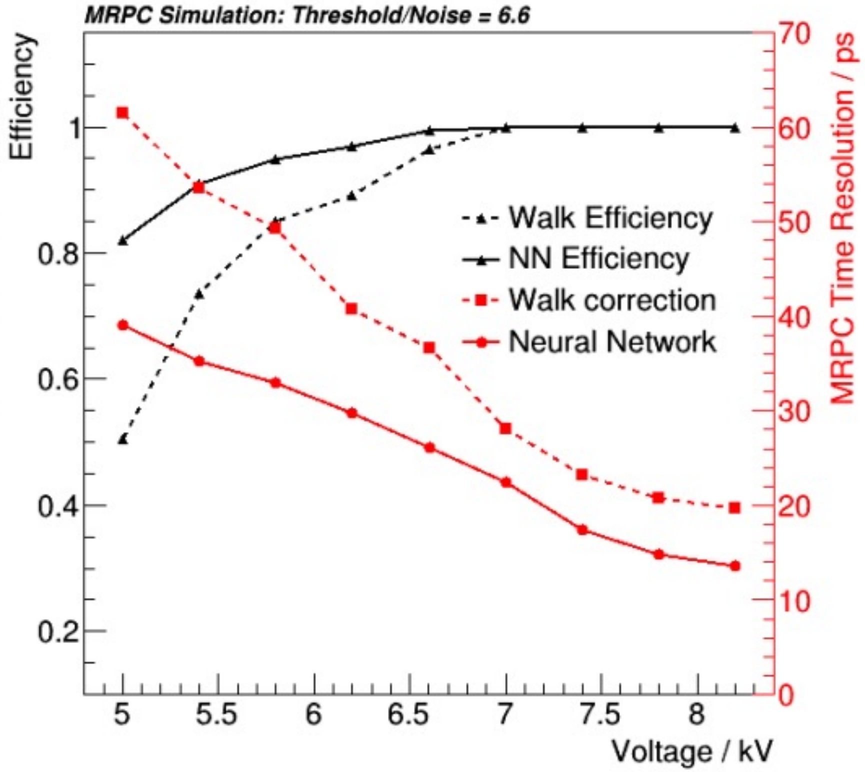
Deliveries#3

➢ 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

Deliveries#4

➢ Cosmic and Beam Test

❑ Goals:

- Validate simulation framework and machine-learning method
- Investigate different eco-friendly gas mixtures
- Study real performance with high-energy/high-rate background
- Test out front-end electronics

❑ To-dos:

- UIC local test with cosmic-ray + xray background

  2 planes of 16-layer sMRPC + SAMPIC
- Jlab/FermiLab beam test

  2 planes of 16-layer sMRPC + SAMPIC and NALU
- Tsinghua's local test with cosmic-ray + x-ray background

  2 planes of 32-layer sMRPC + USTC FEE

  + DT5742 (DSR4) and DT5202 (picoTDC)

Budget Request

	Software Develop-ment	Neural Network	Eco-friendly Gas	Cosmic& Beam Test	Sum
Tsinghua	$9K	$9K	-	$10K	$28K
UIC	-	-	$25K	$55K	$80K
JLab	-	-	-	$10K	$10K
Total					$118K

Table 2: Money Matrix.

- ❑ UIC: 1 FTE Grad. Student + Gas Circulation-System + Gas Mixtures + HVs + SAMPIC + Trip to Jlab
- ❑ JLab: local Gas Circulation-System + Mixtures + Accessories
- ❑ Tsinghua: 1 FTE Grad. Student + Travel to U.S.

❖ Additional contribution from Tsinghua

- ✓ 4 low-rate sMRPC with 16 gas-layers (at UIC now)
- ✓ 2 high-rate sMRPC with 32 gas-layers (ship soon)
- ✓ 2 picoTDC modules (128 channels)
- ✓ DT5742 (DSR4)
- ✓ USTC FEE

4.1 Detailed budget full funding

Tsinghua University	Graduate student 12 months	$18K
Tsinghua University	Travel	$10K
UIC	0.5 FTE student	$25K
UIC	HV supply	$10K
UIC	SAMPIC×2	$10K
UIC	Gas system and gas	$25K
UIC	Travel for beam test	$10K
JLAB	Gas supplies	$10K
Total		$118K

4.2 80 % budget scenario Tsinghua no trip to U.S.

Tsinghua University	Graduate student 12 months	$18K
UIC	0.5 FTE student	$25K
UIC	HV supply	$10K
UIC	SAMPIC×1	$5K
UIC	Gas system and gas	$25K
UIC	Travel for beam test	$5K
JLAB	Gas supplies	$10K
Total		$98K

4.3 60% budget scenario No beam tests

Tsinghua University	Graduate student 12 months	$18K
UIC	0.5 FTE student	$25K
UIC	HV supply	$10K
UIC	SAMPIC×1	$5K
UIC	Gas system and gas	$25K
Total		$83K

Address Questions

Q#1: Please respond to the observation that the emphasis of this proposal is on simulations and gas optimizations while the proponents have not demonstrated that they have a scalable electronics readout solution that can deliver the performance that they need.

Answer:

- For the first year of R&D w/ requested budget, the simulation and eco-friendly gas study will be the main tasks:
  - Optimize the MRPC for different EIC needs (timing resolution, spatial resolution, radiation length),
  - Study neural network methods for precision timing
  - Study the replacement of green-house gas with eco-friendly gas

- Besides, we will also perform cosmic-ray and beam tests to evaluate the realistic in-beam timing resolution of the sMRPC with background, using different layers and different gas mixtures.

- We have multiple readout solutions for the cosmic ray and beam tests to achieve our goals:
  - Existing: used by previous tests: DT5742 based on DSR4, USTC FEE, 10GS/s Oscilloscope
  - New: SAMPIC, NALU, and picoTDC

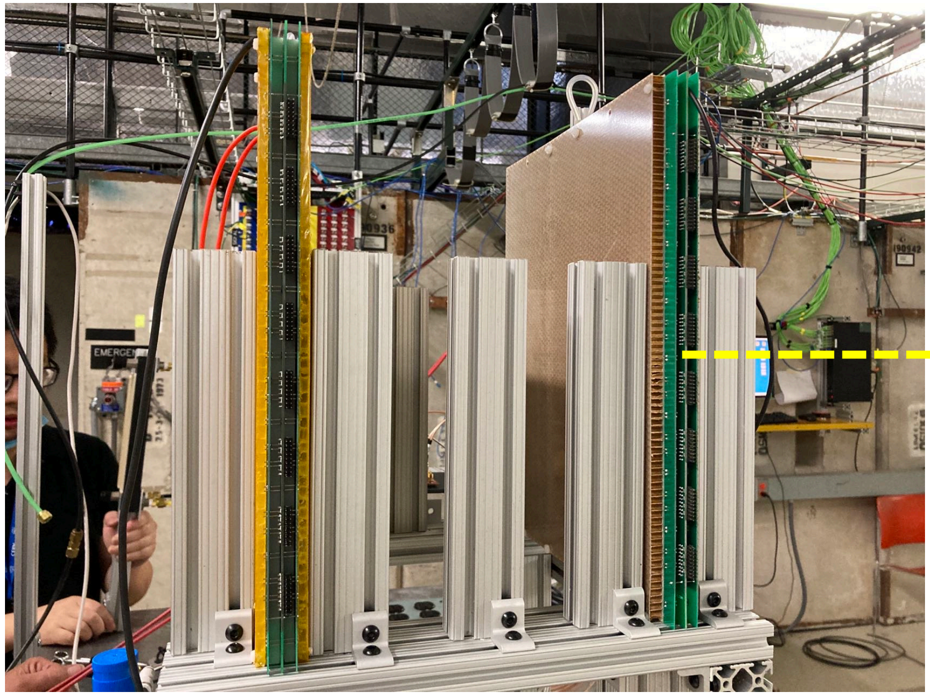
- Future R&D:
  - A scalable electronics readout solution for sMRPC on EIC detectors
  - ~20ps time resolution from beam-test w/ optimized sMRPC+Eco-gas

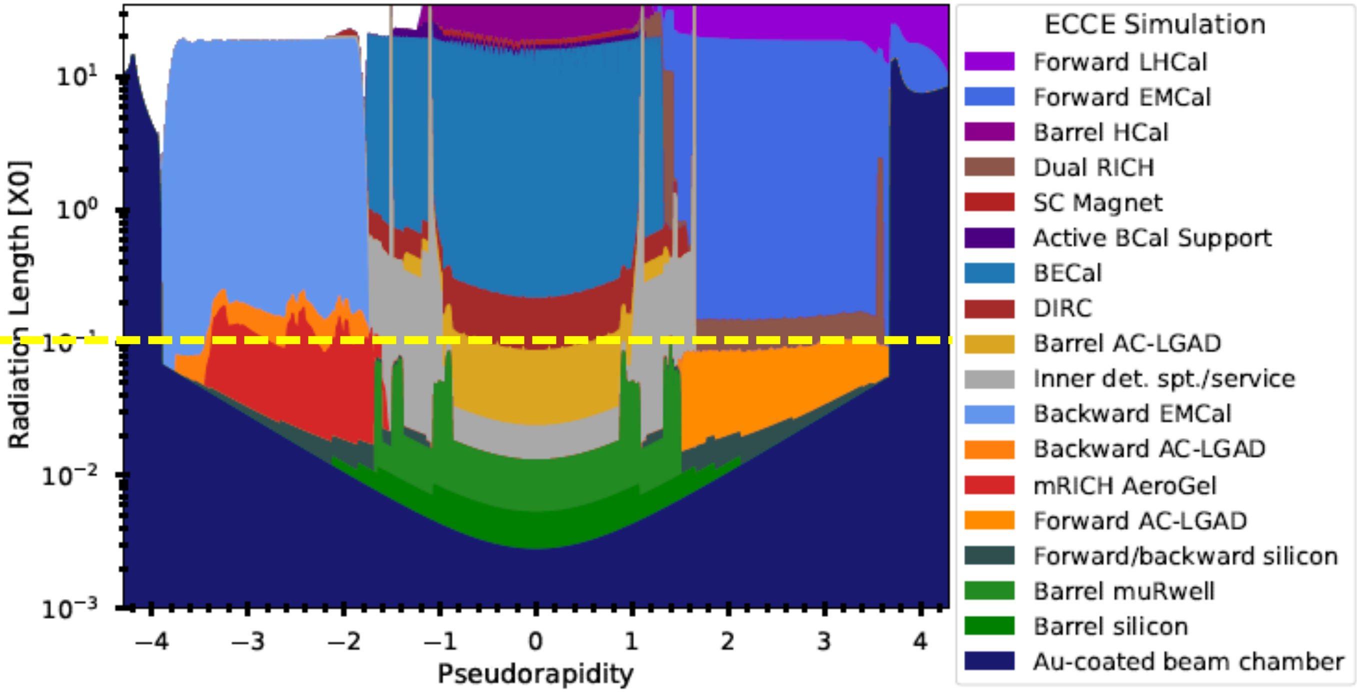
Address Questions

Q#2: Can you make a rough comparison of the radiation length of MRPCs vs AC-LGAD's? (Include services such as cooling

Answer:

- MRPC: 5% X_0 for 16 layers (30~40ps); 10% X_0 for a 32-layer one (20ps) → including all materials, no cooling needed
- AC-LGAD: 1% X_0 for ePIC Barrel; 8% for Endcaps





Address Questions

Q#3: Can you also roughly compare the cost for instrumenting the same area with MRPCs vs AC-LGAD's?

- ❑ AC-LGAD: ePIC estimated cost is $\$1M/m^2$
- ❑ MRPC: ~$\$310K/m^2$
  - $\$30K/m^2$ for 32-layers (~\$20K for 16-layers)
  - Readout: $\$280K/m^2$ for a 5mm strip-pitch and 1-dimension readout

Q#4: What is the expected position resolution of the MRPCs in this proposal?

- ❑ MRPC's position resolution depends on the readout strip pitch (e.g., 5mm/sqrt(2))

Summary

- ❑ MRPC is a good candidate of TOF detectors for modern particle experiments (SoLID, EIC)
  - ✓ Mature technology, high-performance, low-cost
  - ✓ A good alternative TOF option for EIC
- ❑ Tsinghua's new sealed MRPC (20ps at 15kHz/cm^2, cosmic ray + Xray) meets EIC-TOF requirements

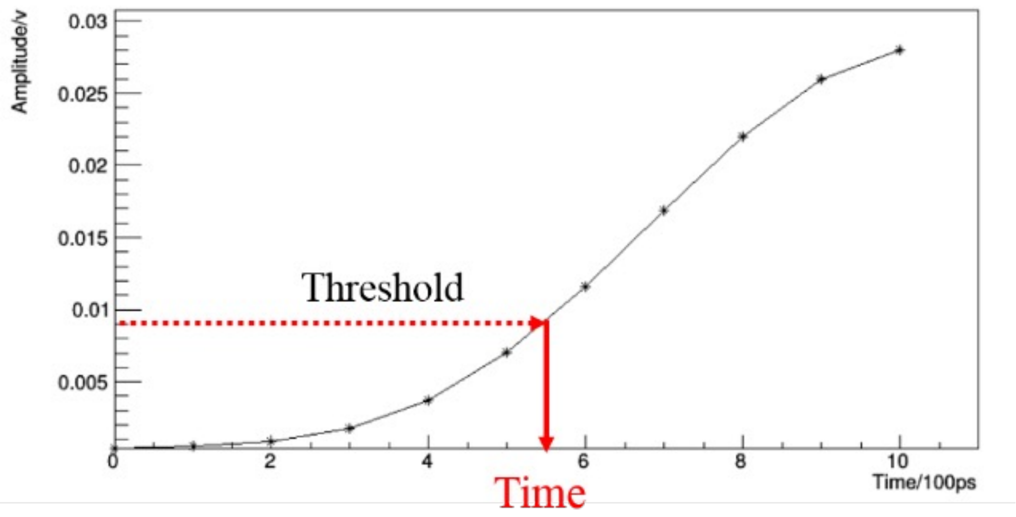
- ❑ Proposal of new sMRPC R&D on EIC (ePIC endcaps and/or second IP):
  - ✓ Reduce thickness (less space, less material budget)
  - ✓ Replacement of Eco-friendly gas
  - ✓ Improve spatial resolution
  - ✓ Readout electronics (partially explore)

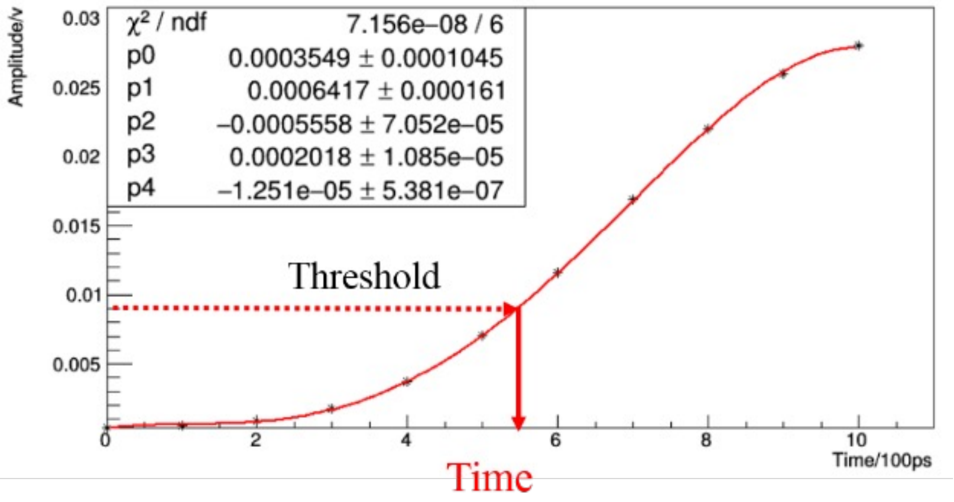
➢ A formally supported EIC R&D program for sMRPC will encourage more funding supports from China

BACKUP

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

➢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)

Hadron Endcap mRPC-TOF

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

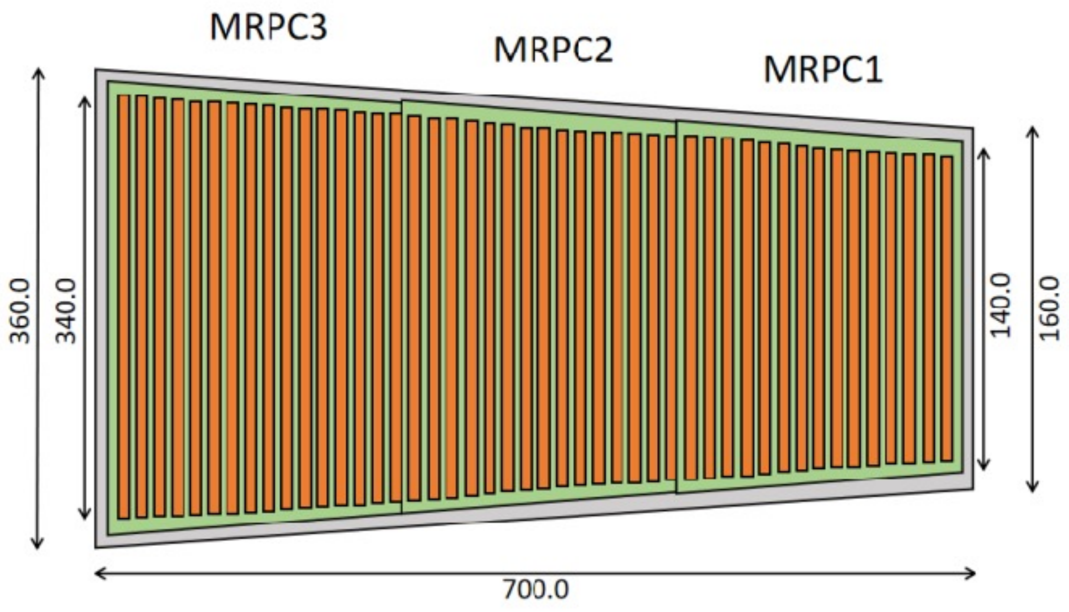
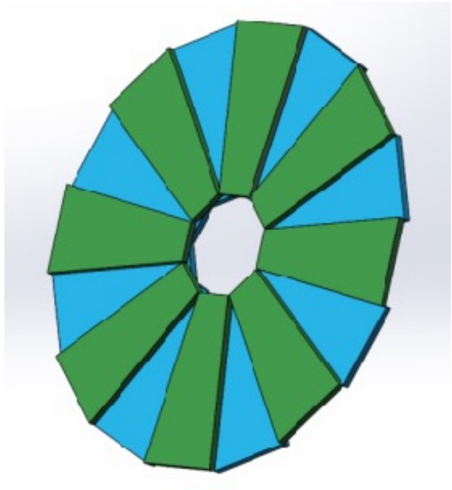
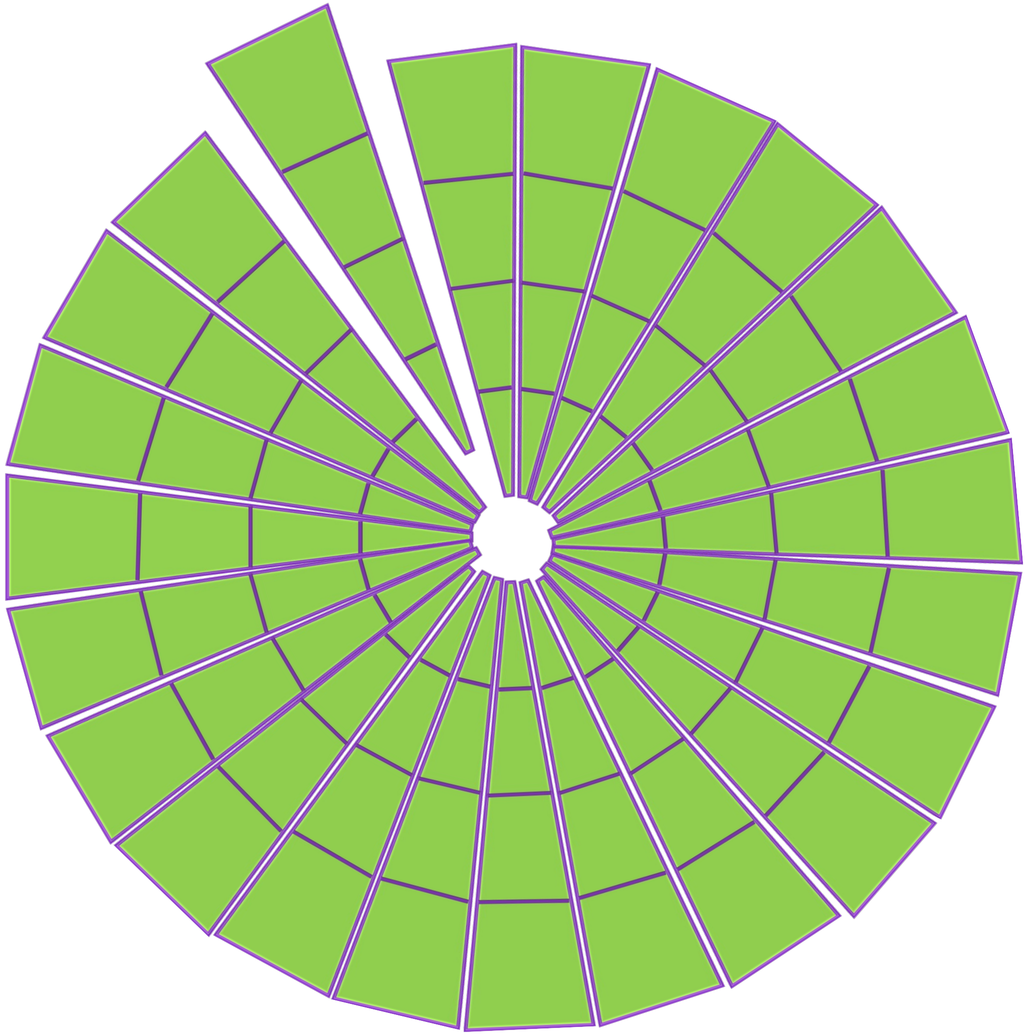


Figure 1.3 Arrangement of MRPCs inside the box in the End-cap.

Total overlapped thickness= 60mm



Hadron Endcap mRPC-TOF



mRPC Modules:

- $30K per m^2 for 32 gas-layers with regular low-resistive glasses
- For a 180cm outer radius and 10cm inner radius disk, it takes 10m^2 of mRPC
- Total cost: $0.3M

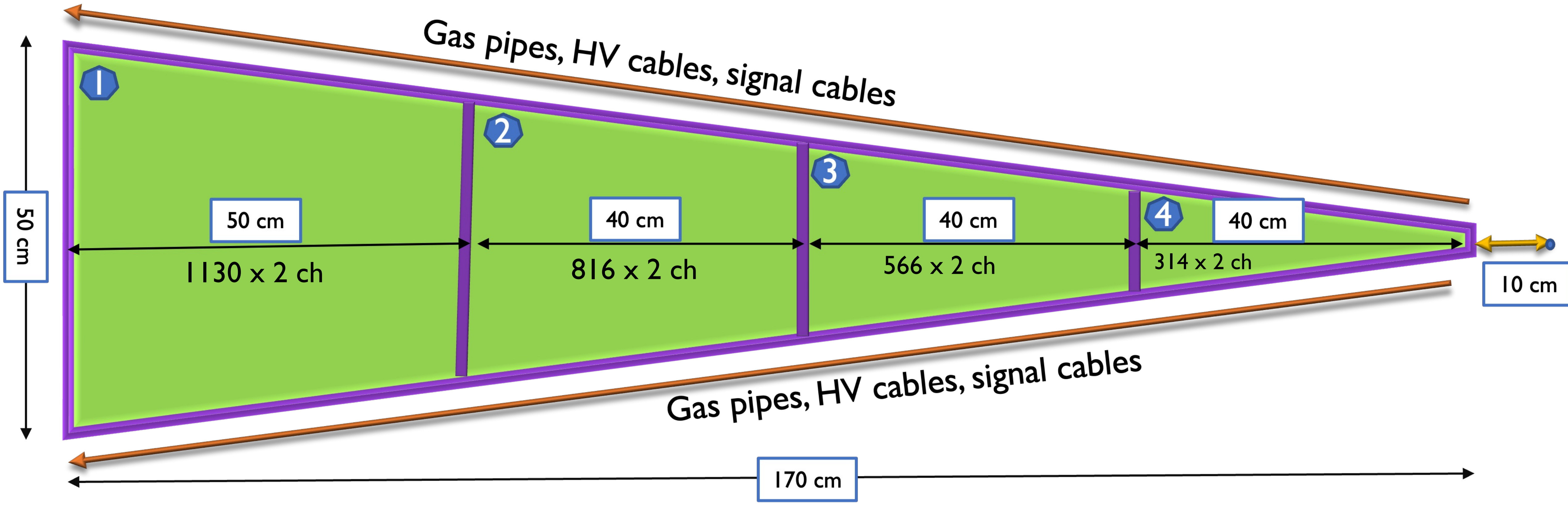
Readout Electronics:

- 1cm for each channel, read from both ends along the radial direction
  - Module#1: 51 x 2 channels
  - Module#2: 37 x 2 channels
  - Module#3: 25 x 2 channels
  - Mudule#4: 14 x 2 channels
- Total channels of each sector: 254 channels
- Total 22 sectors → 5588 channels ~ 5600 channels
- Total cost: $500 for each channel → $2.8M for readout electronics

HV Supplies:

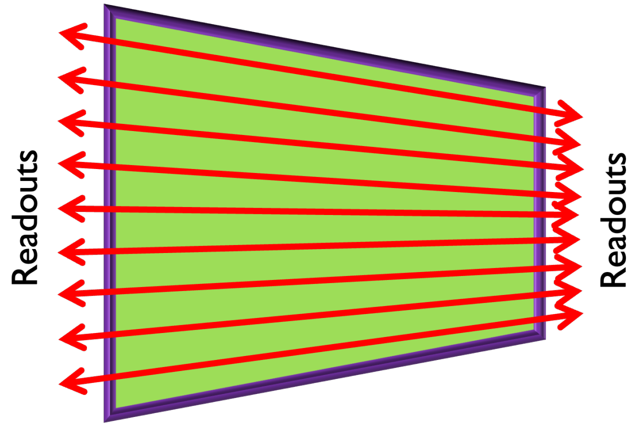
- CAEN AG524P → 6 HV outputs, quote $6K for each board
- Two module power one sector (positive + negative polarity)
- Total 44 HV boards
- Nee two frames that house the HV boards → $8K for each
- Total: $280K for HV power supplies
- Cables: $??K

Hadron Endcap mRPC-TOF

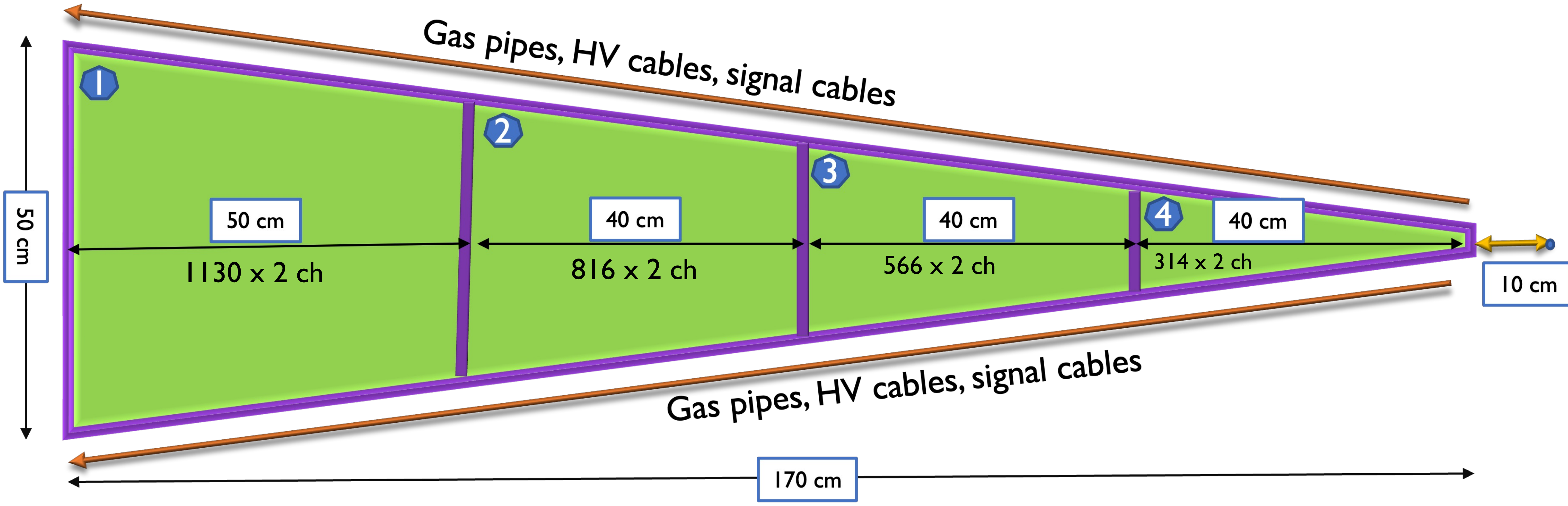


Each mRPC Super-Module:

- Divide the total disk into 22 sectors
- Each sector contains a super-module with 4 individual mRPC modules with different sizes
- For each mRPC module, read the signal from both ends along the radius direction



Hadron Endcap mRPC-TOF



Each mRPC Super-Module:

- Divide the total disk into 22 sectors
- Each sector contains a super-module with 4 individual mRPC modules with different sizes
- For each mRPC module, read the signal from both ends along the radius direction
- Alternatively: Chain the strips of two (or all four) neighboring mPRCs to save more readouts → How much timing resolution we will lost?