

Progress of high time resolution MRPC

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Outline

◆ Motivation

◆ MRPC Simulation using Geant4

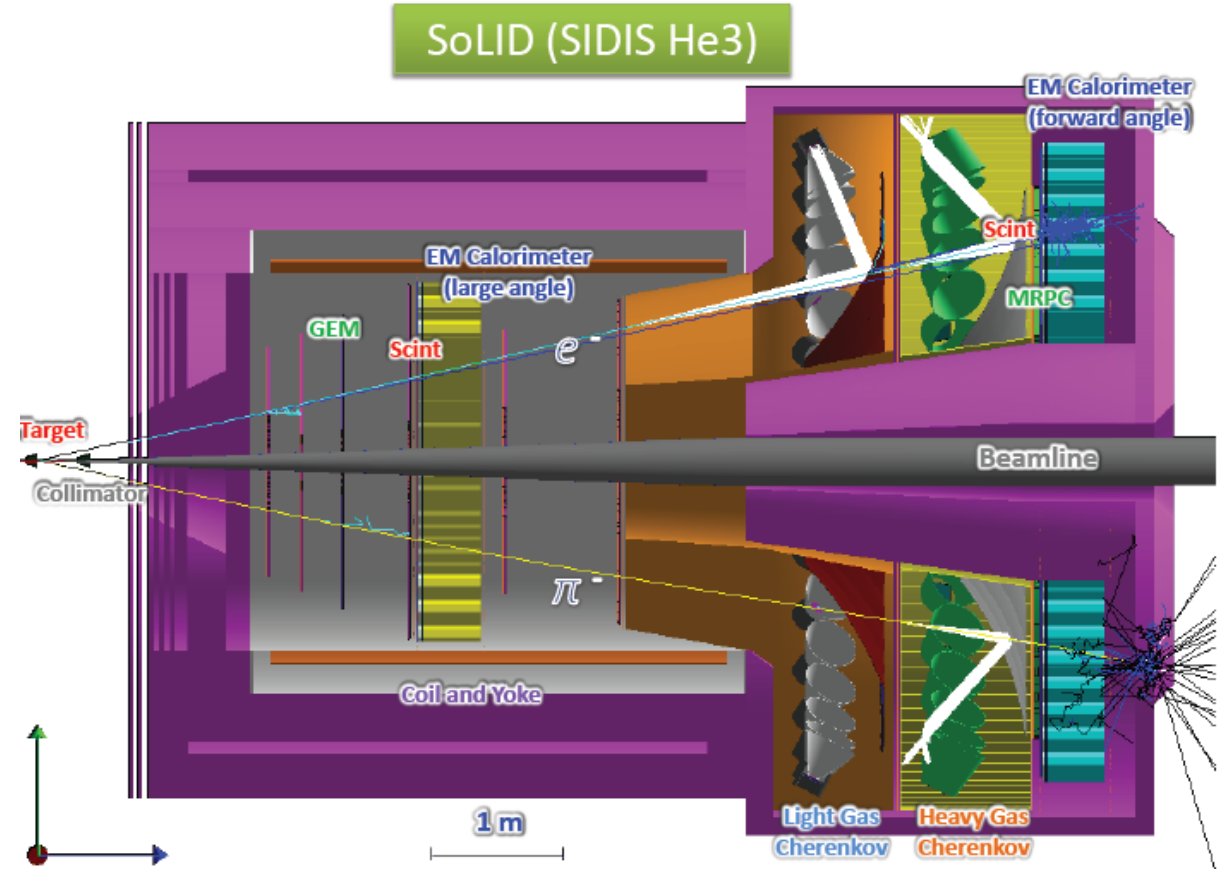
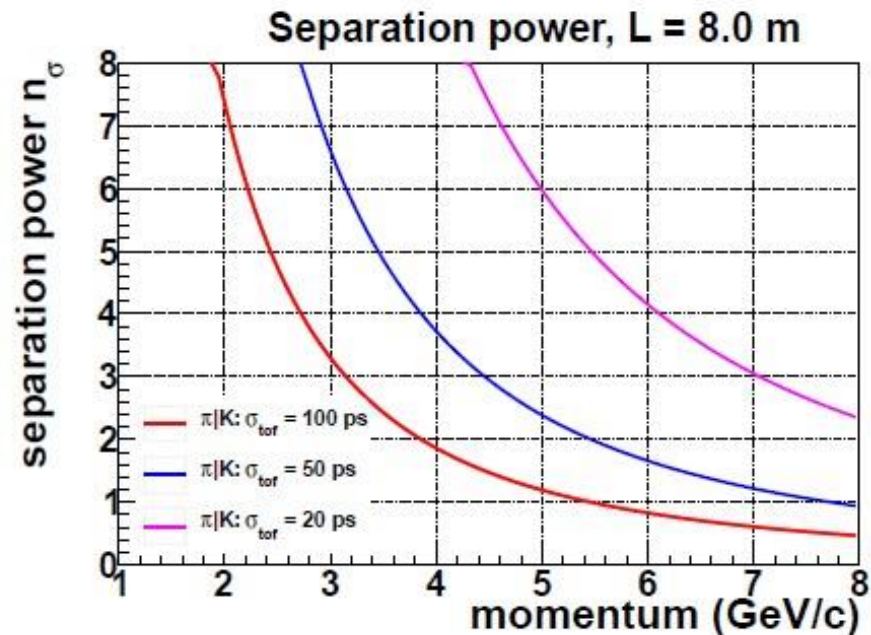
◆ Experiment

- The structure of the high time resolution MRPC
- Cosmic Test in Tsinghua
- Timing Method
- Preliminary Results

◆ Conclusion & Future Plan

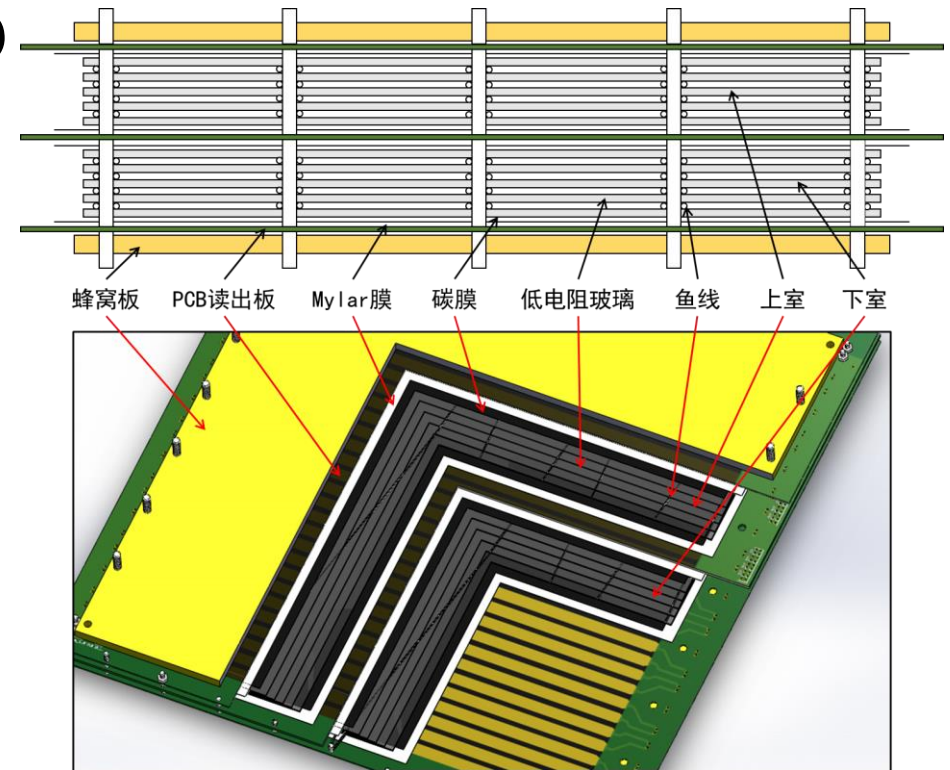
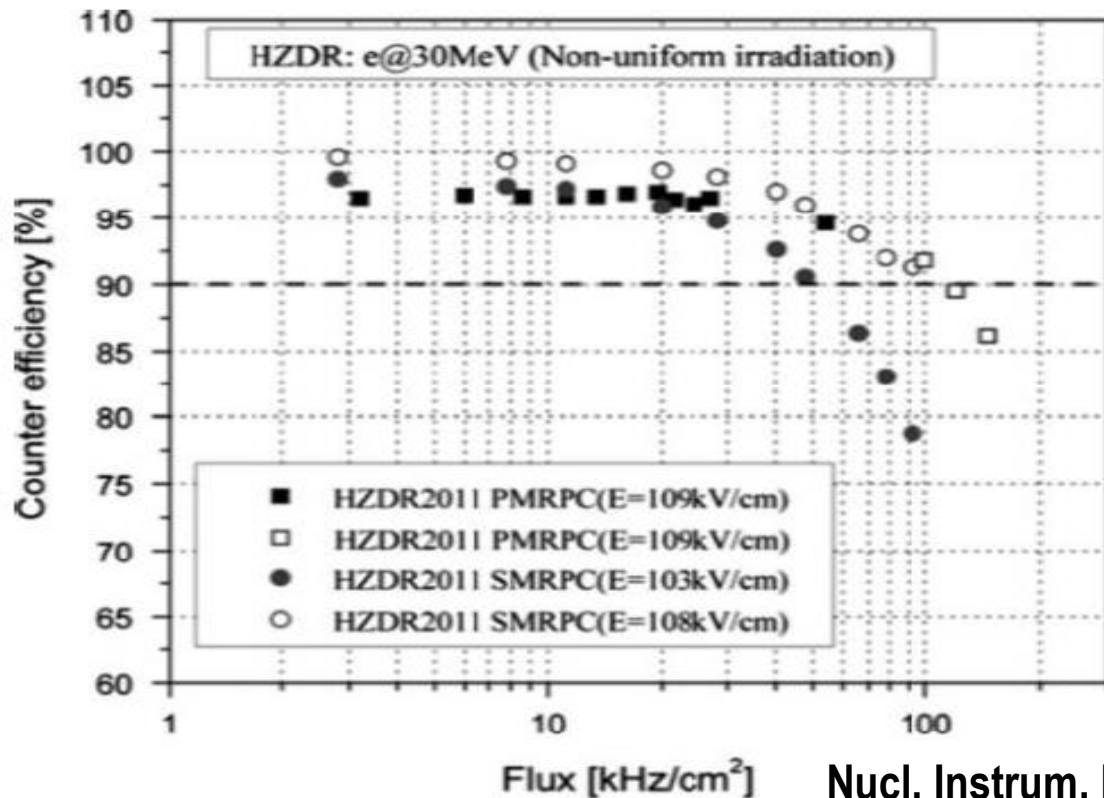
Motivation

- Jefferson Lab (JLab) 12 GeV Upgrade
- Solenoidal Large Intensity Device (SoLID)
- The requirements for the TOF system are:
 - ✓ π/K separation up to **7 GeV/c**
 - ✓ Time resolution **< 20 ps**
 - ✓ Rate capability **> 20 kHz/cm²**



Motivation

- The high time resolution & high rate MRPC for SoLID-TOF is proposed by Tsinghua
- High rate capability---- Low resistivity glass ($10^{10} \Omega\text{cm}$)
 - ✓ Rate capability $> 70 \text{ kHz/cm}^2$
 - ✓ Successfully used in CBM experiment (Germany)



Motivation

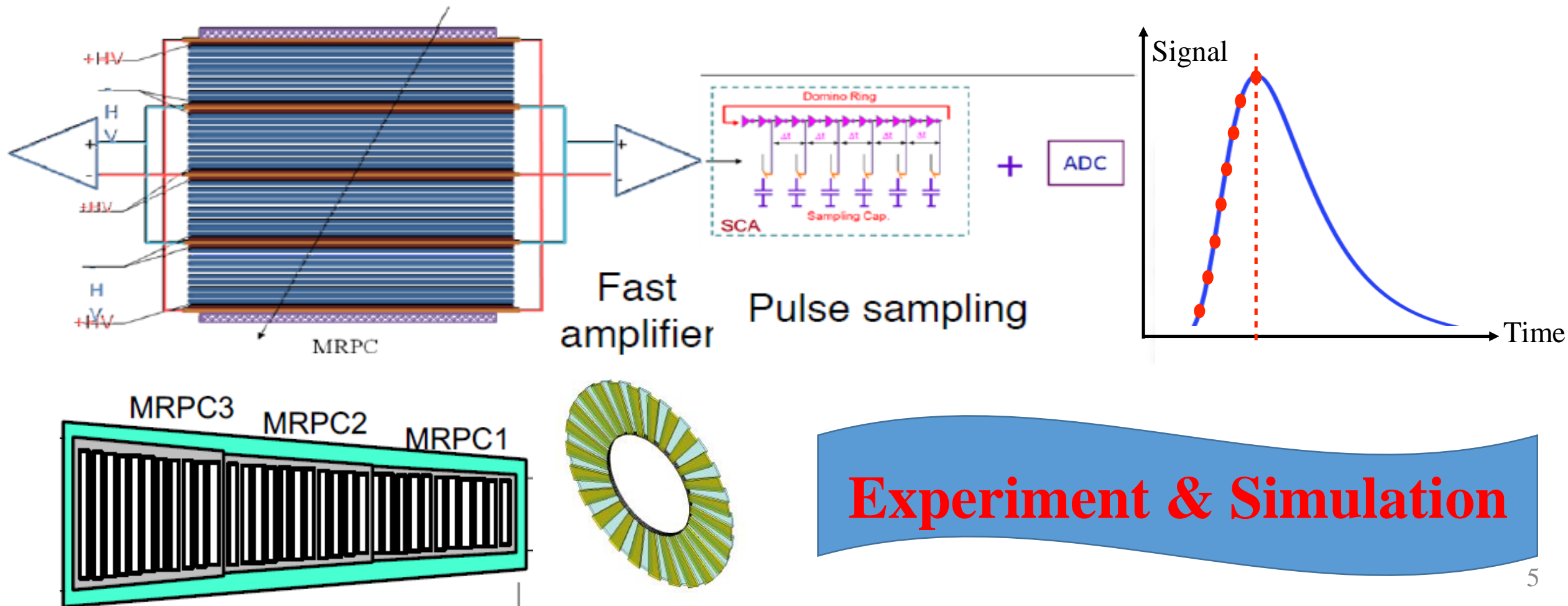
- Some typical MRPCs that are used in several high energy physics experiments

Experiment	StackNb	GapNb	Gap Thickness [um]	Working E [kV/cm]	Time resolution [ps]
ALICE	2	5	250	104	~60
STAR	1	6	220	114	~60
CBM	2	4	250	110	~60

Exp.	Electronic	Time jitter/ps
ALICE	NINO Amplifier	~20
	HPTDC	~25
CBM	PADI	~10
	GET4	~25

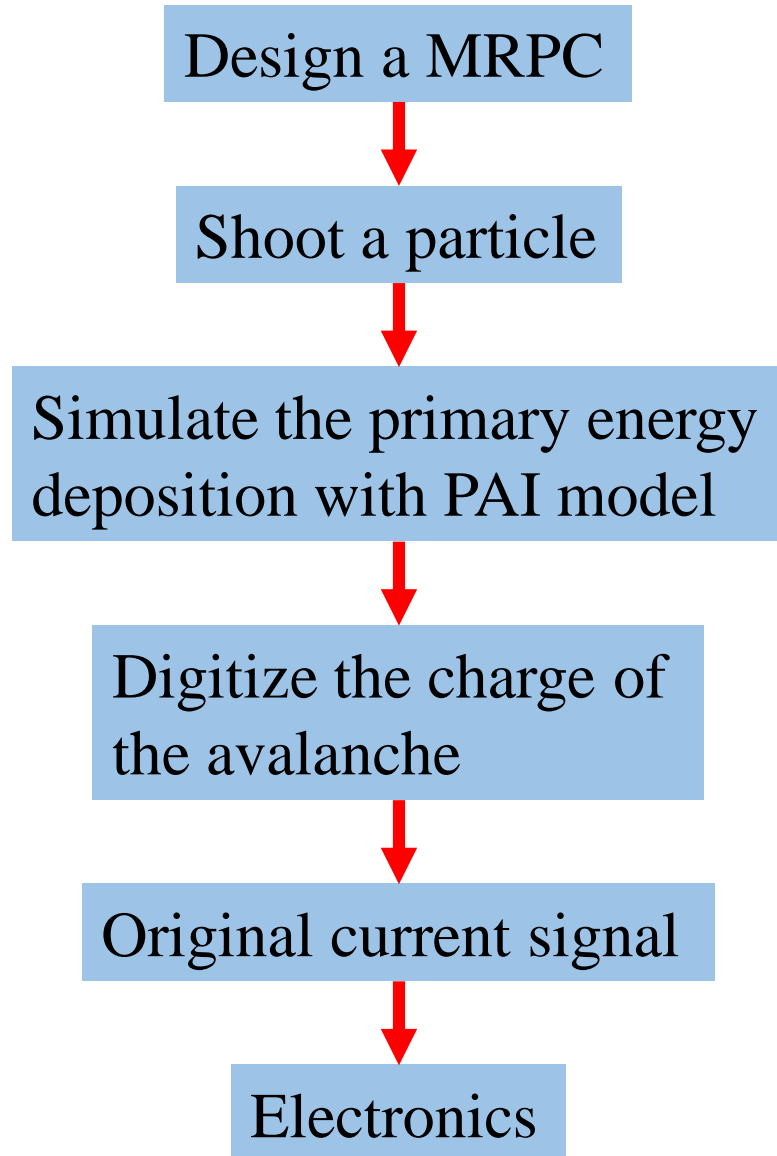
Motivation

- The high time resolution & high rate MRPC for SoLID-TOF is proposed by Tsinghua
- Thin gap MRPC + fast amplifier and waveform digitizer system (USTC)



Experiment & Simulation

MRPC Simulation



□ MRPC structure

- ✓ Materials
- ✓ Gap/glass thickness, stack/gap number
- ✓ Gas: **90% C₂H₂F₄ + 5% i-C₄H₁₀ + 5% SF₆**

□ Particle source: 4 GeV mu-

- ✓ perpendicular to the MRPC

□ **PAI** model is used to simulating the primary energy deposition*, rather than **Emstandard**

*W. Allison. Ann. Rev. Nucl. Part. Sci. 30 (1980) 253.
2018 JINST 13 P09007.

MRPC Simulation

Design a MRPC

Shoot a particle

Simulate the primary energy deposition with PAI model

Digitize the charge of the avalanche

Original current signal

Electronics

□ Primary energy loss

- ✓ Ionize electron-ion pairs
- ✓ $W = 30$ eV

□ Avalanche multiplication — **Townsend effect**

α : Townsend coefficient

β : Attachment coefficient (by **Magboltz**)

□ Electrons drifting in the electric field: induce a signal on the read out strips

□ ***Ramo theory:**

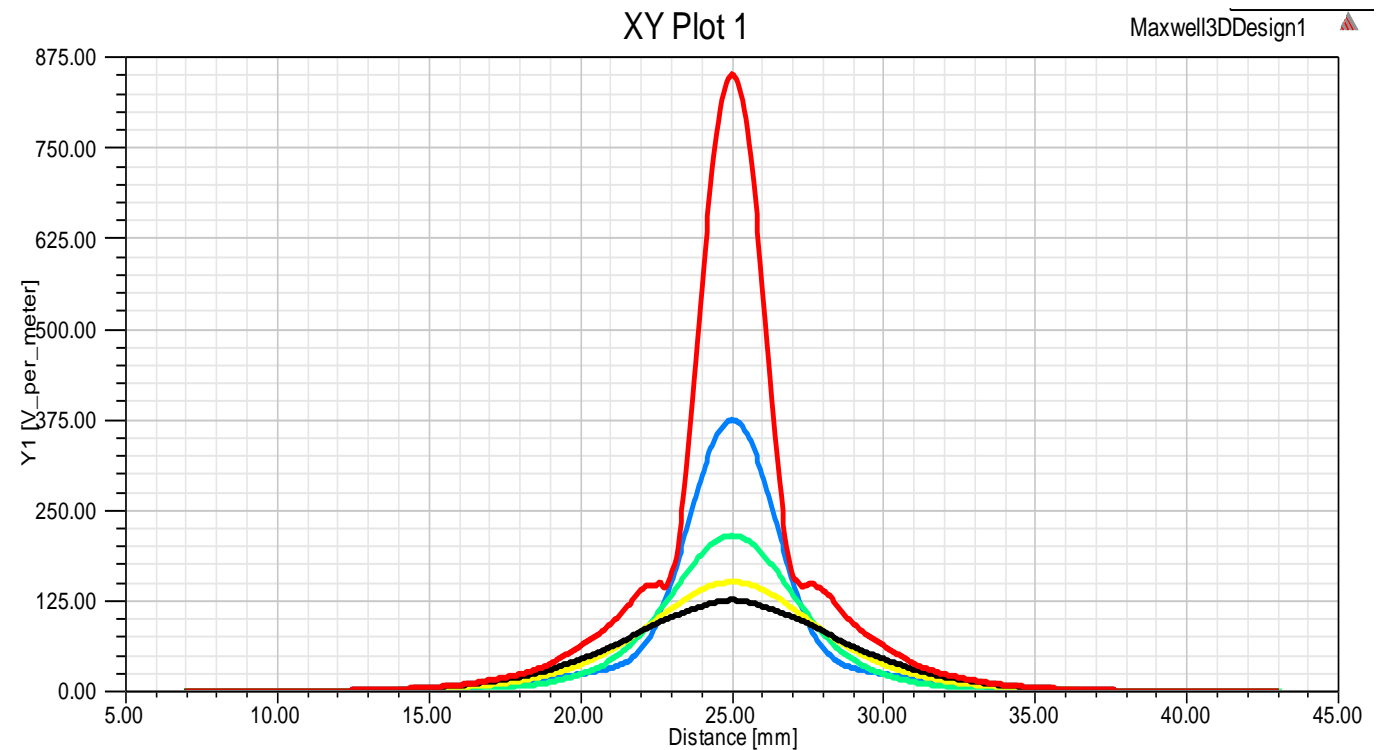
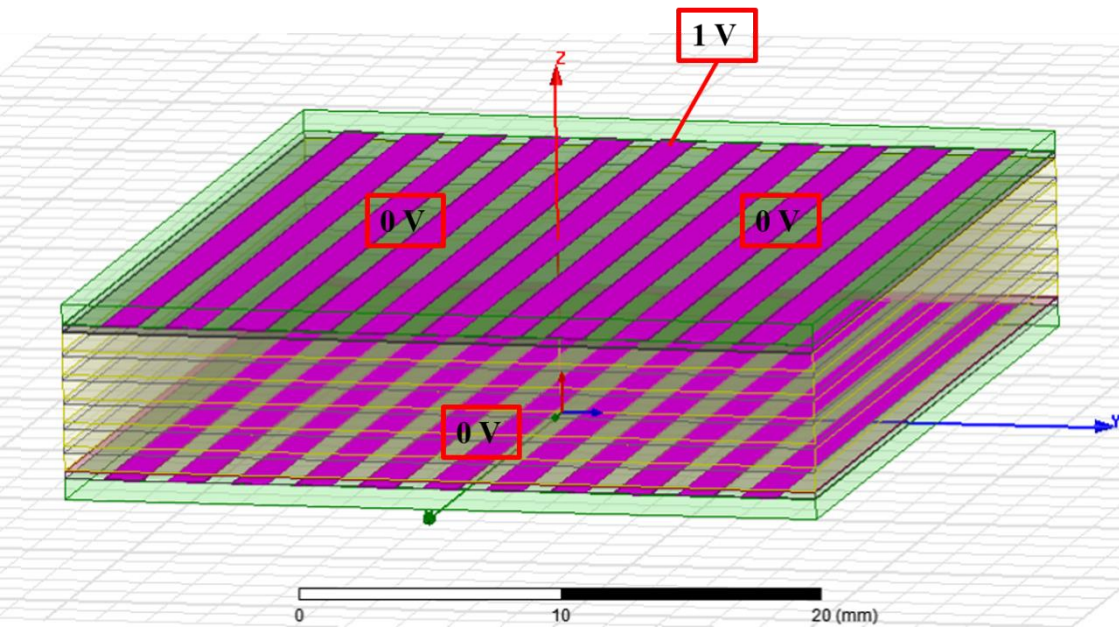
$$i(t) = \frac{E_W \cdot v}{V_W} e_0 N(t)$$

*S. Ramo, Currents induced by electron motion, Proc. IRE 27 (1939) 584.

MRPC Simulation

□ Weighting field

- ✓ E_W is the weighting field which is the electric field when setting the potential of the read out electrode to be V_W and others 0.



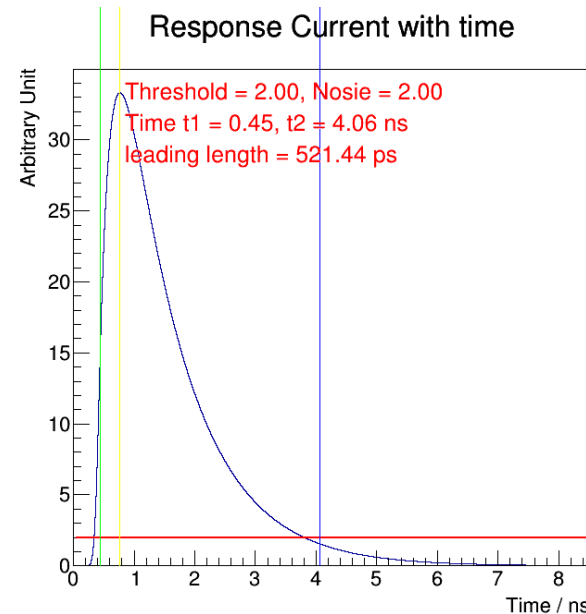
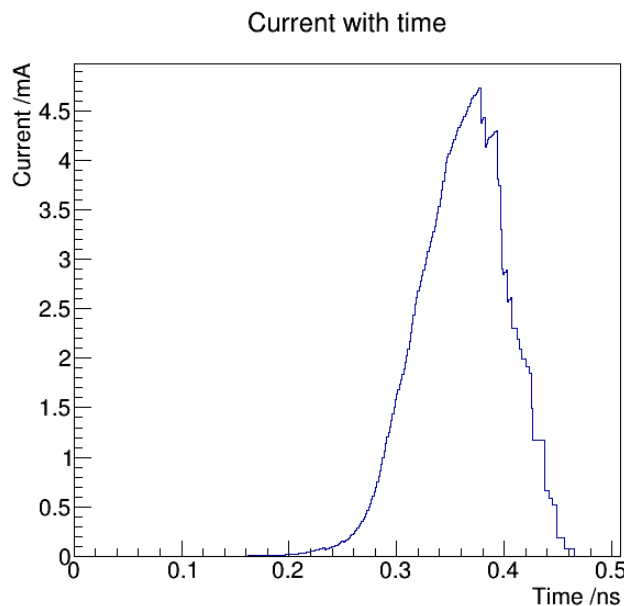
MRPC Simulation

Werner Riegler, Christian Lippmann. Nucl. Instrum. Meth. A 500 (2003) 144.

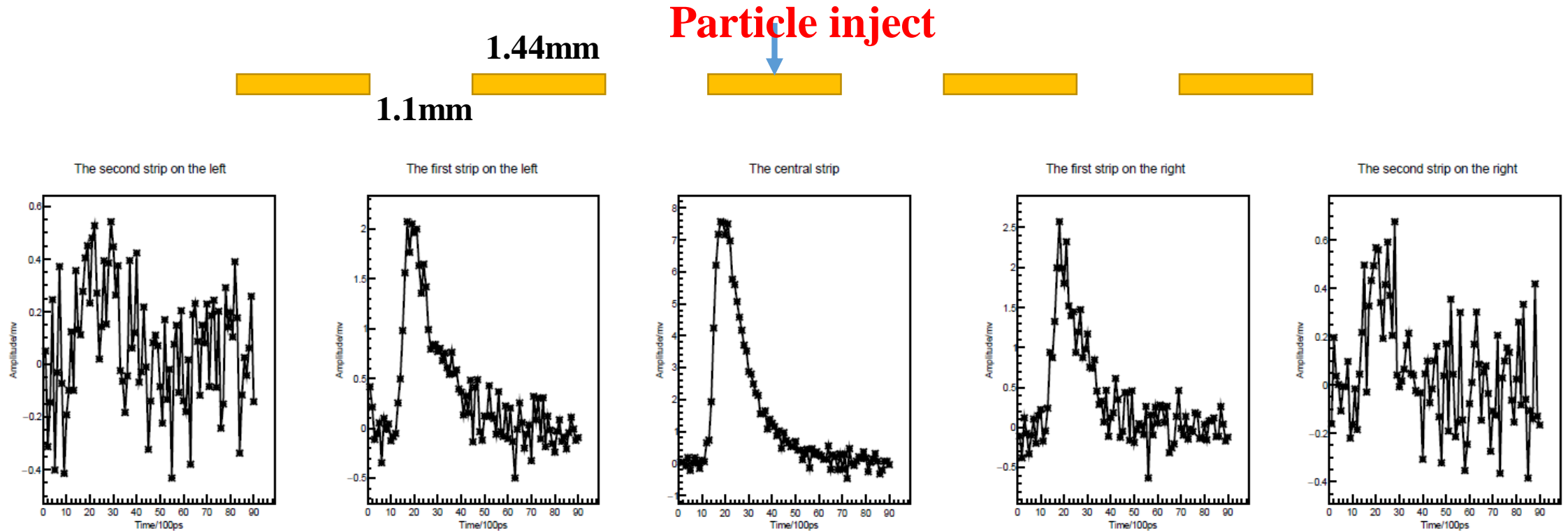
- ❑ Space charge effect: $\sim 10^7$ electrons
- ❑ Include the Front-end electronics response by convolving the original current with a simplified FEE response function:

$$f(t) = A(e^{-t/\tau_1} - e^{-t/\tau_2})$$

- ❑ Noise: by adding a random number sampled from Gauss(0, σ) to every time bin



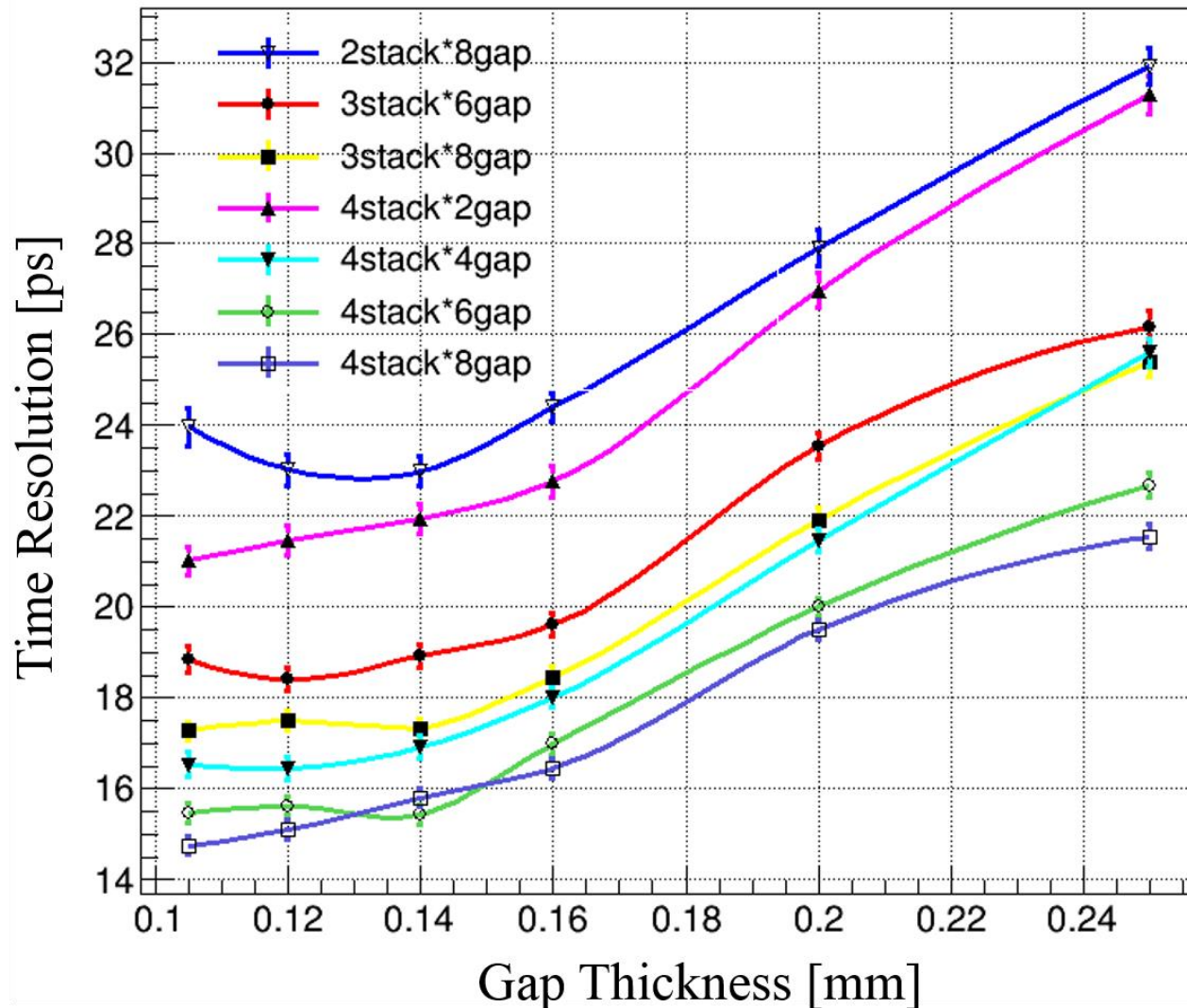
MRPC Simulation



- **Induced signals** generated by the energy deposition of **all sensitive areas**
- **Induced signals** on each readout electrode
- **Information** about time, charge, cluster size.....
- **Position resolution** -- with the center of gravity algorithm

MRPC Simulation

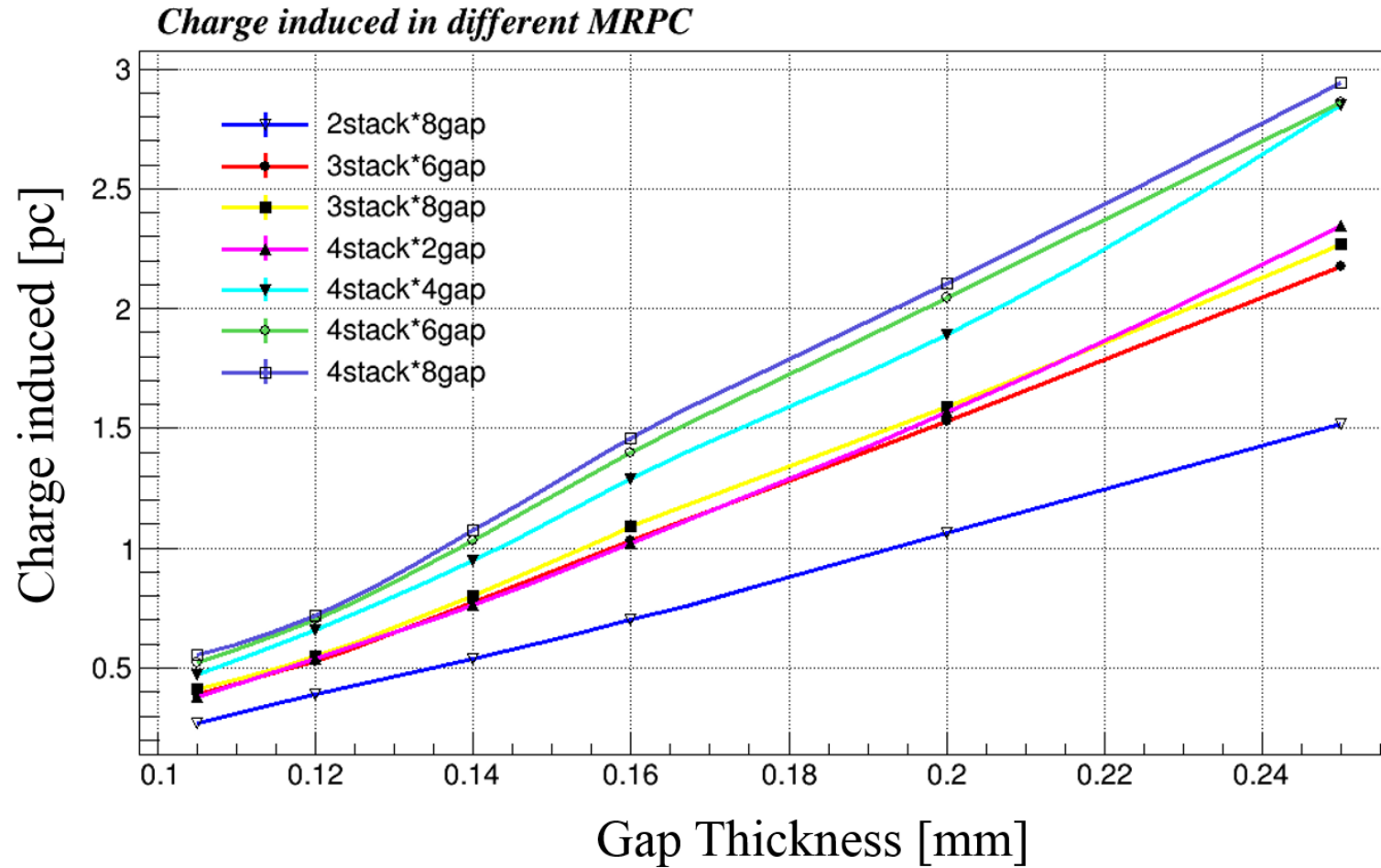
Time resolution for different MRPC: Electronics Noise $\sim 20\text{fC}$



In actual experiment, electronic noise and signal transmission should be considered carefully.

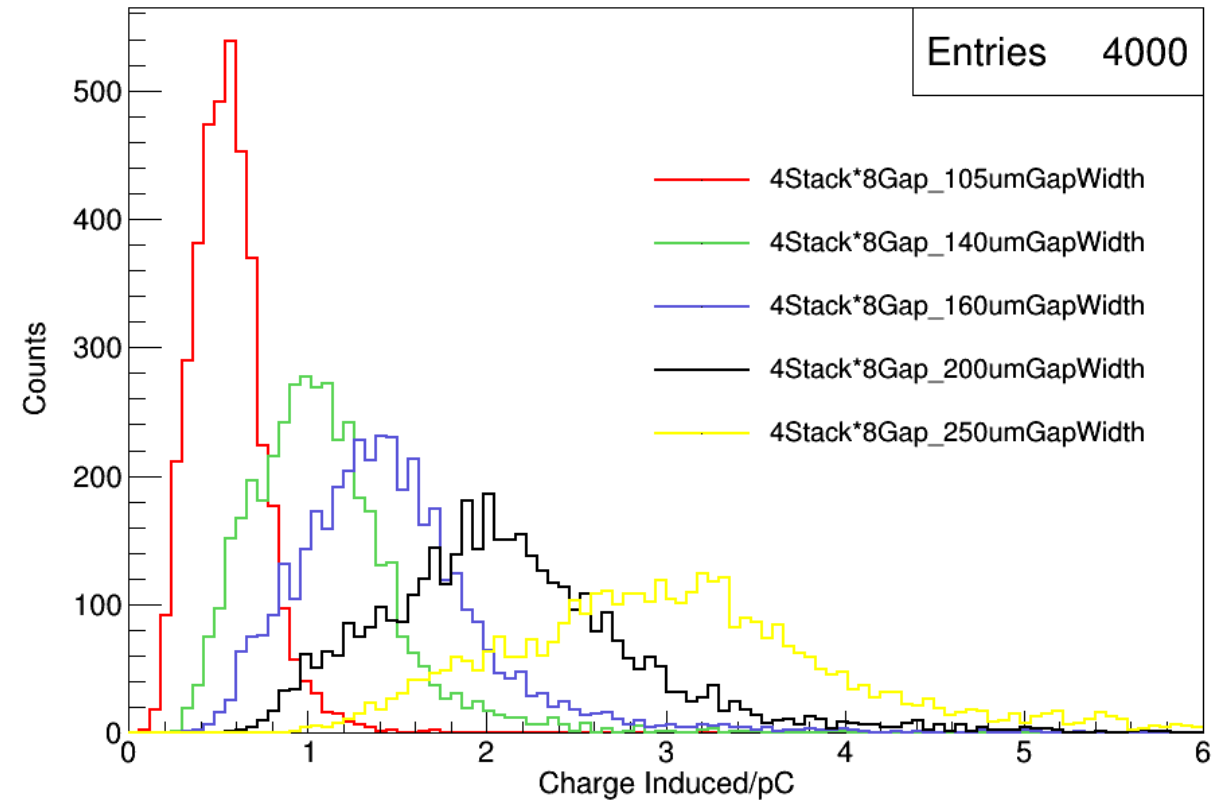
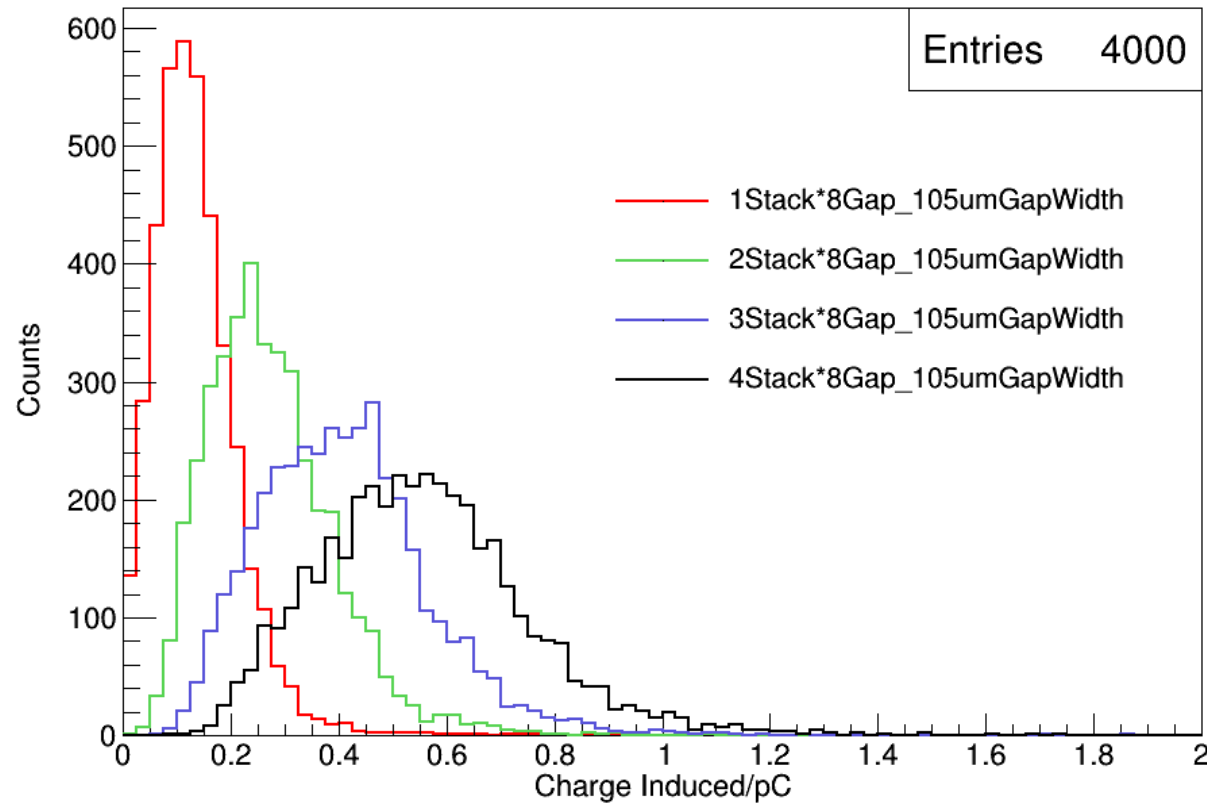
- Gap thickness below $160\ \mu\text{m}$, more than 3stacks, more than 4 gaps
→ 20 ps
- Thinner gap thickness, more gas gaps
→ better time resolution

MRPC Simulation



- The charge induced increases with the increasing gap thickness significantly.
- The number of stacks has a great influence on the charge.

MRPC Simulation



- Charge distribution.
- Small signals worsen the time resolution.

Experiment — MRPC Structure



Tsinghua Prototype	4-stack MRPC
Gas Gap Width	104 um (fishing line)
Number of Gas Gaps	4 stack \times 8 layers = 32 32
Float Glass Thickness	500 um
Readout strip	7 mm \times 270 mm (3 mm internal)
Readout	Single-ended

Equivalent noise charge:

$$\sigma_t = \frac{\sigma_V}{dV/dt} = \frac{t_{\text{rising}}}{V_{\text{signal}}/_{\text{noise}}}$$

- **Narrower gap width** \rightarrow fast charge dominant in the induced signal \rightarrow Better timing resolution
- **More gas gaps** \rightarrow Maintain the efficiency

Experiment — Electronics

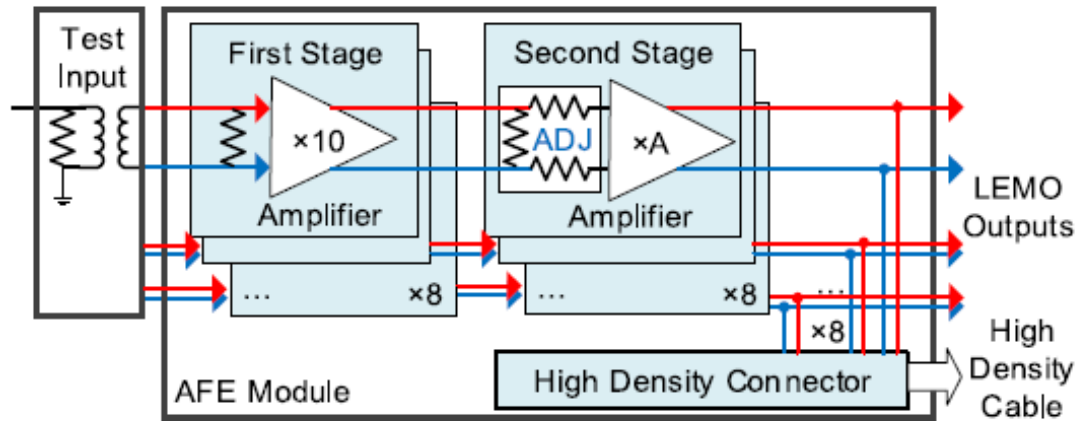
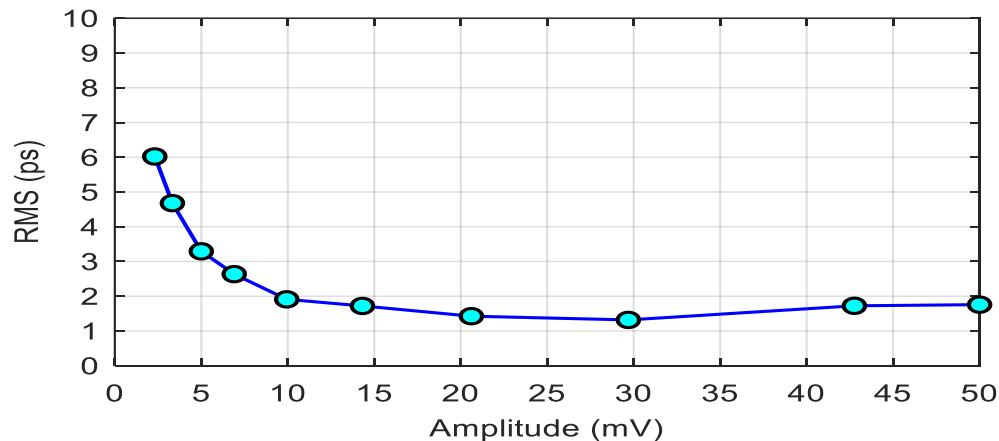
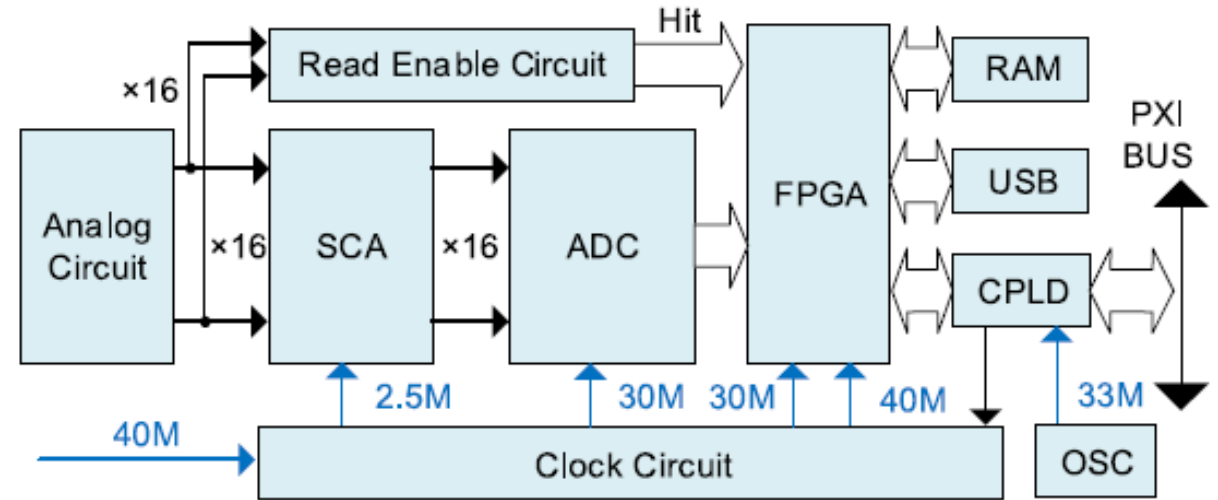


Diagram of the **AFE** module



- Gain : 26 dB
- Bandwidth : 1.4 GHz
- Time resolution: better than 4 ps



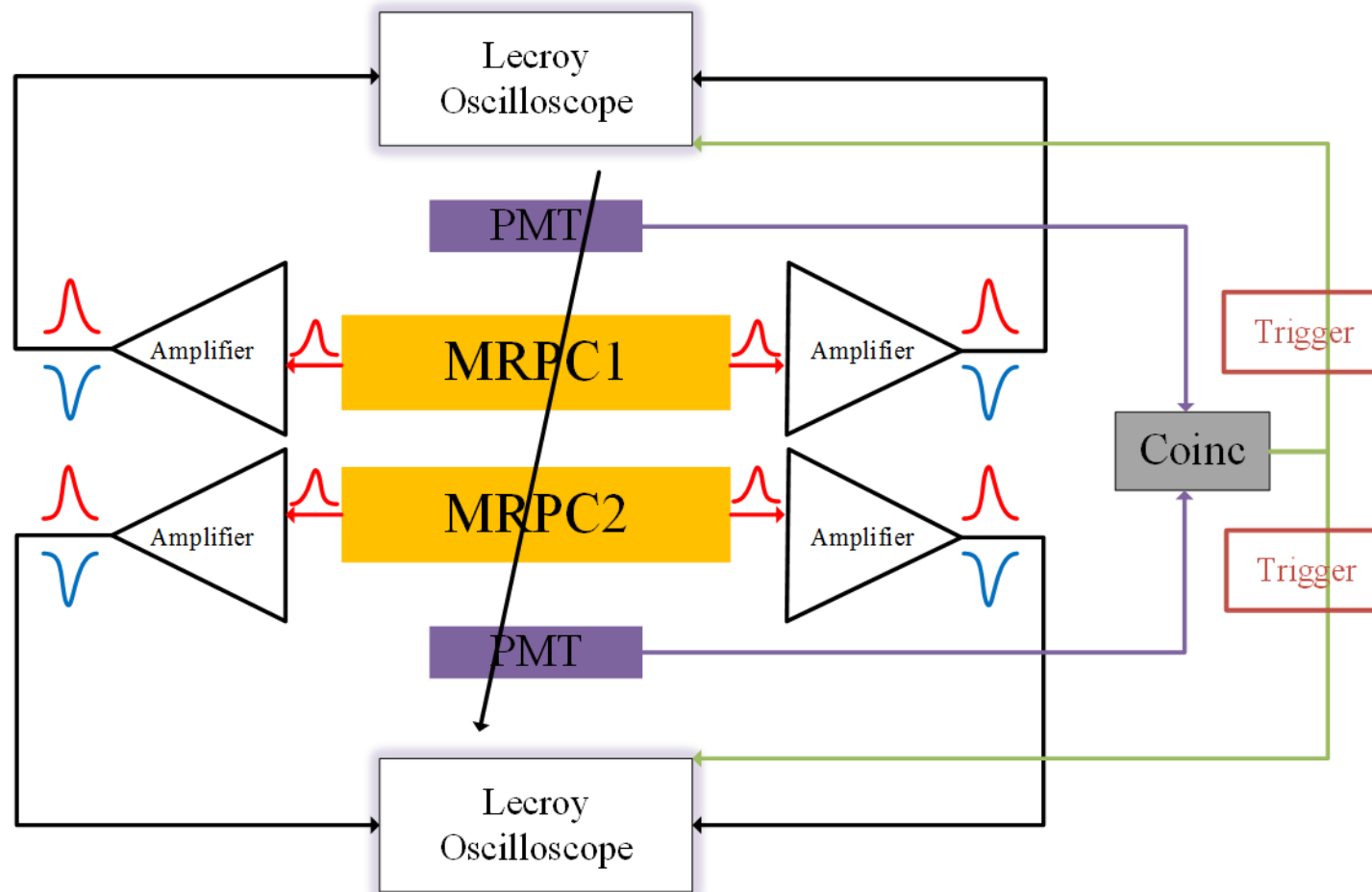
Block diagram of the **waveform digitization module**

Nucl. Instrum. Meth. A 925 (2019) 53.

- 1024 sampling capacitors of the Switched Capacitor Array (SCA)
- Sampling frequency of 5.12 GHz
- 0.5 mV rms & 3 ps time jitter
- DT5742 & Oscilloscope for the preliminary test and comparison

Experiment — Cosmic Ray Test

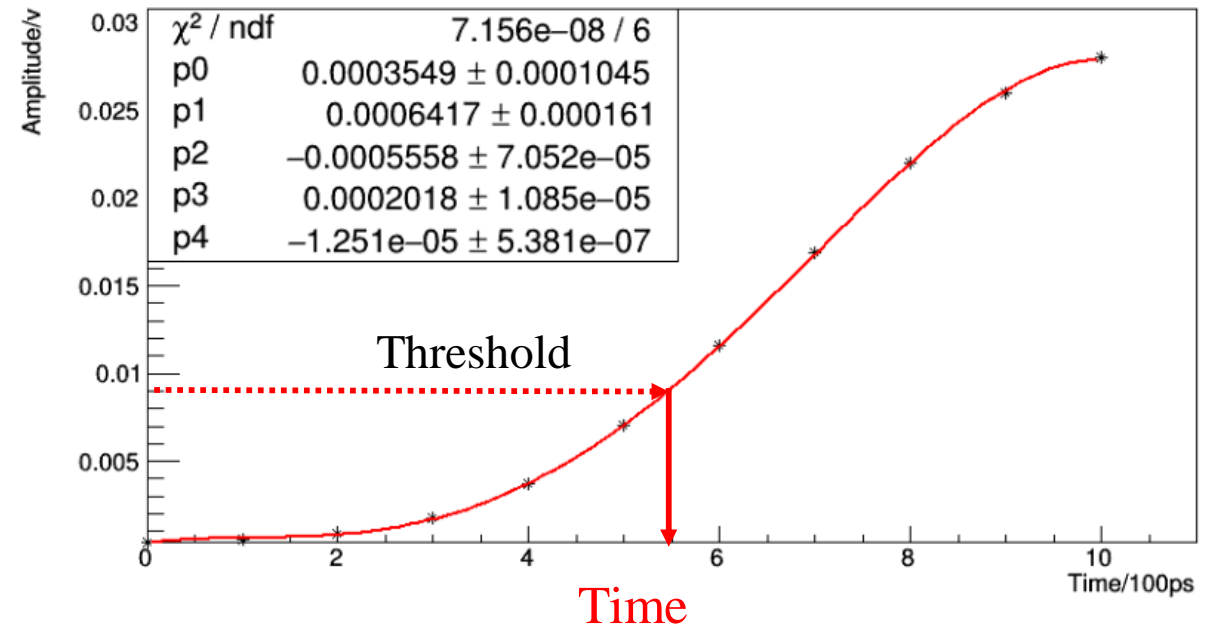
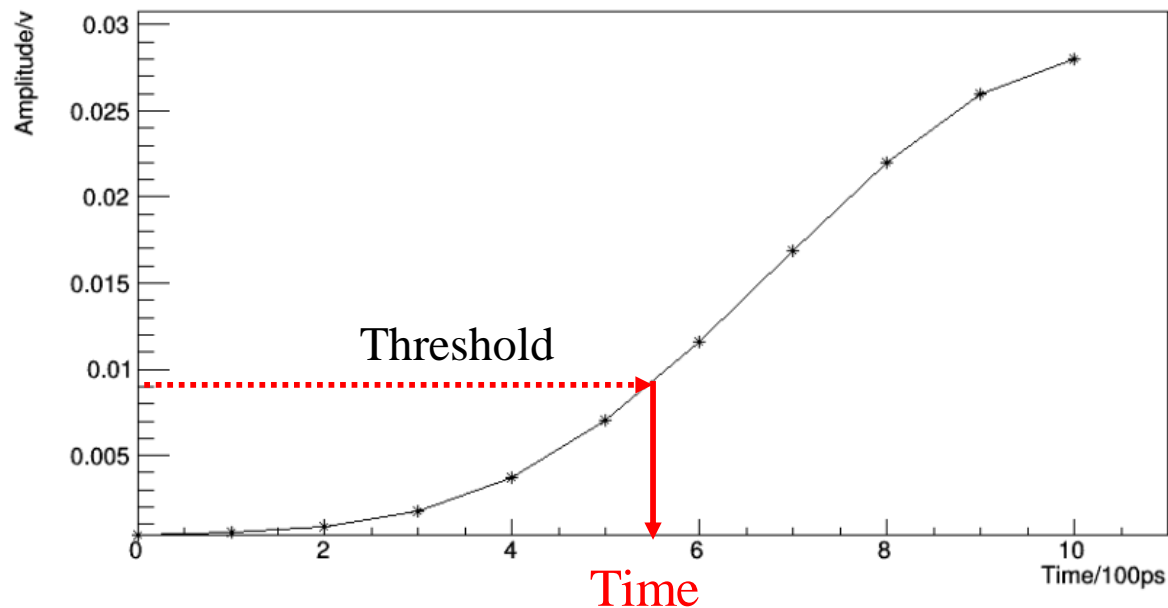
Gas component: 90% $\text{C}_2\text{H}_2\text{F}_4$ + 5% i- C_4H_{10} + 5% SF_6



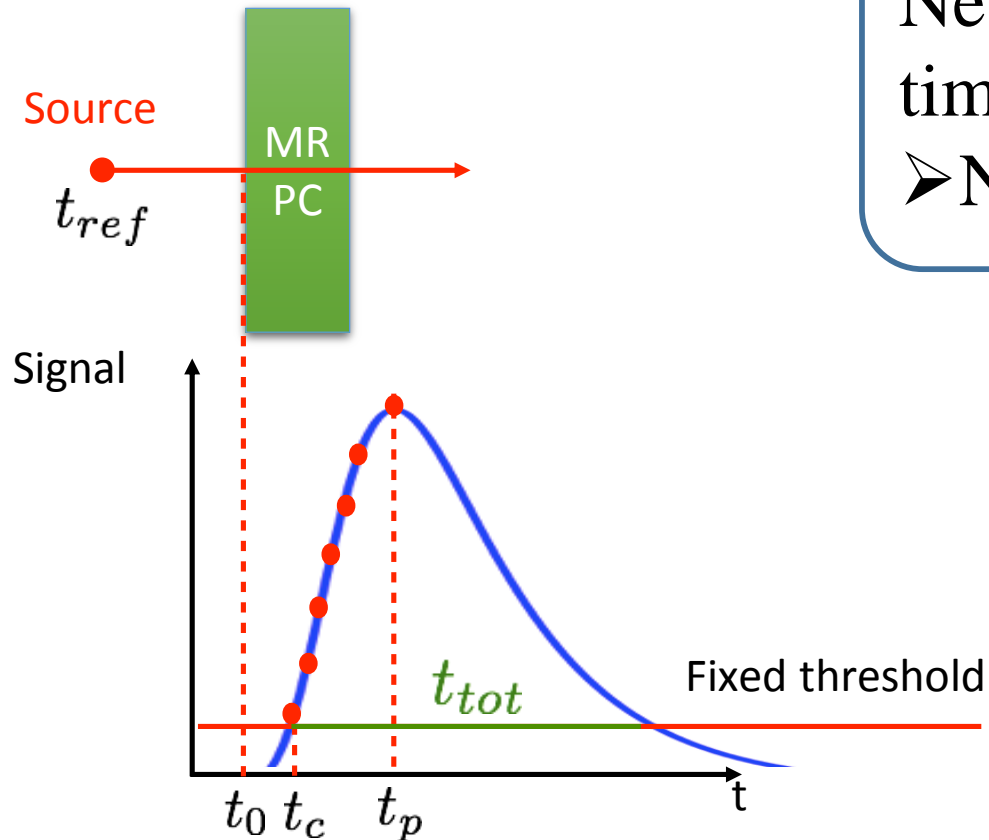
Timing Method — ToT Method

Algorithm to find the time (time over threshold)

- Linear interpolation
- Polynomial fit



Timing Method — Neural Network Method



New Algorithm to find the first interaction time t_0

➤ Neural Network

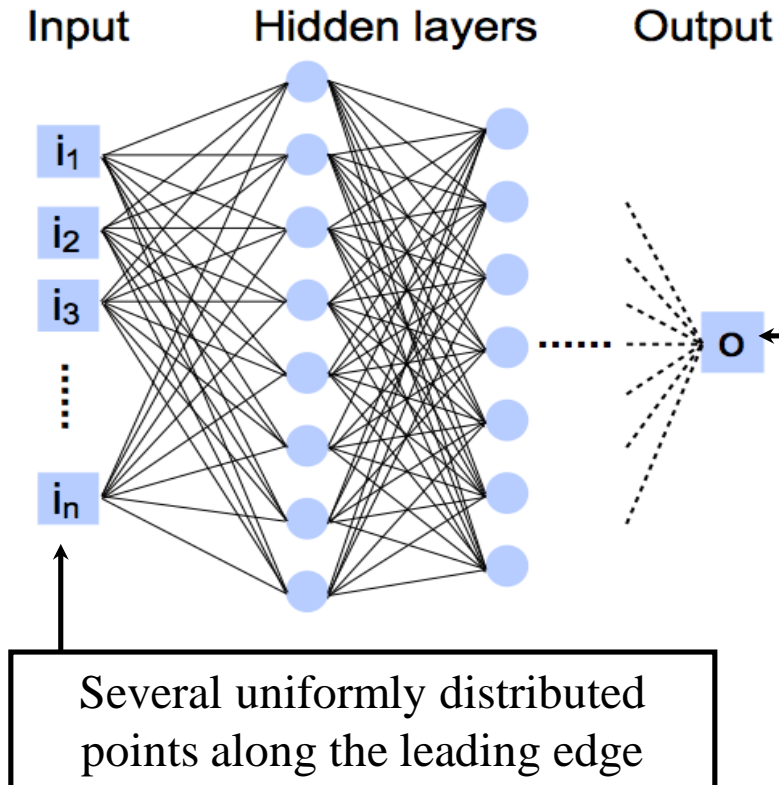
Simulation dataset :

1. t_0 : first interaction happens
2. t_p : the signal reach the peak
3. 7 uniformly distributed points along the leading edge

Timing Method — NN: MLP

➤ Multilayer perceptron (MLP)

$$\text{Output } F_i(\vec{x}) = h\left(\sum_j (\omega_{ij}^2 g(\dots g(\sum_k (\omega_{jk}^1 g(\sum_l (\omega_{kl}^0 \text{Input } x_l + \chi_k^0) \dots + \chi_j^1) + \chi_i^2))\right)$$

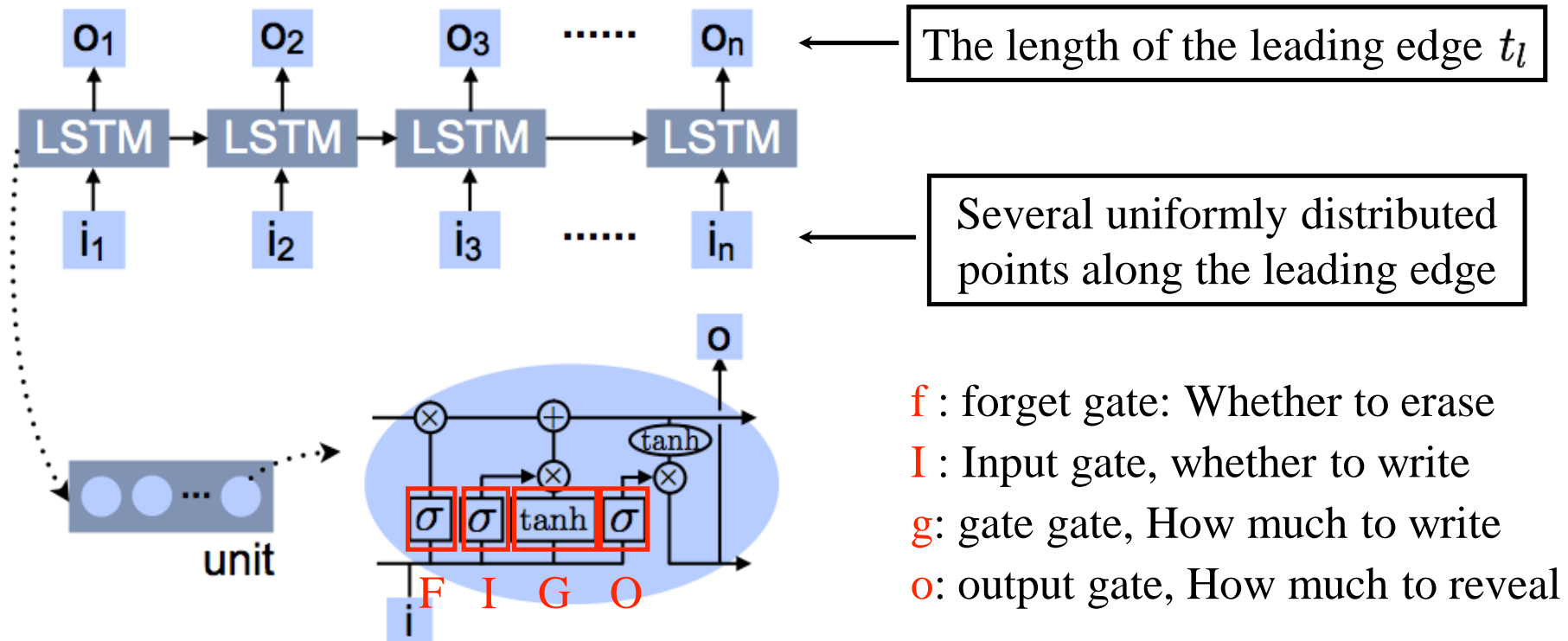


- Activation function: g and h — tanh
- Weights: $\omega^{0,1\dots}, \chi^{0,1\dots}$
- “Dropout”: avoid overfitting

- Train/validate/test set: 20/10/10 k
- Tensorflow & GPU: GTX 1080 Ti
- ~ 10 mins for training

Timing Method — NN: LSTM

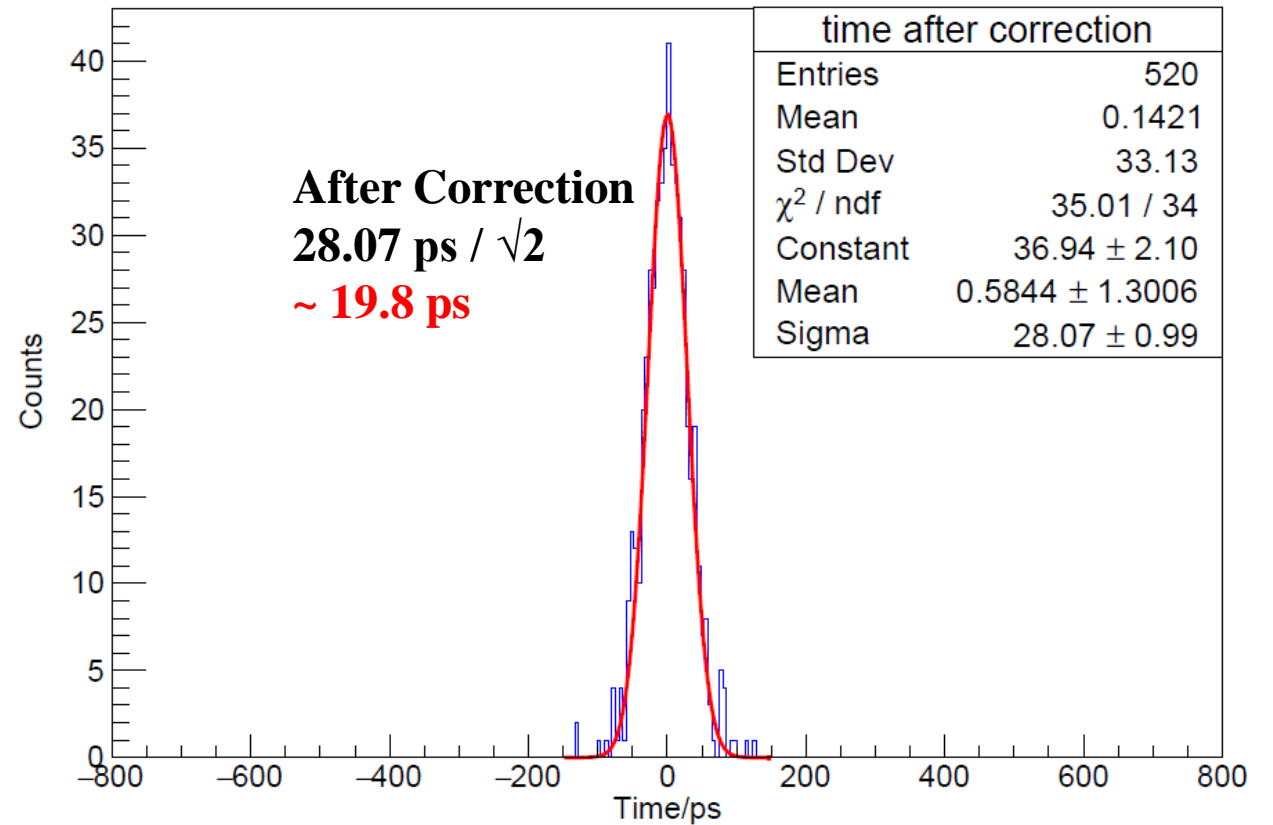
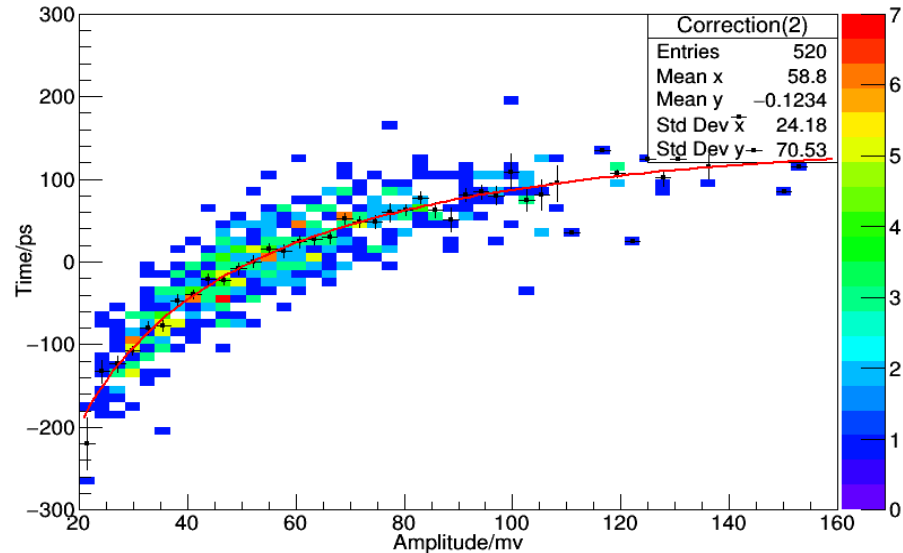
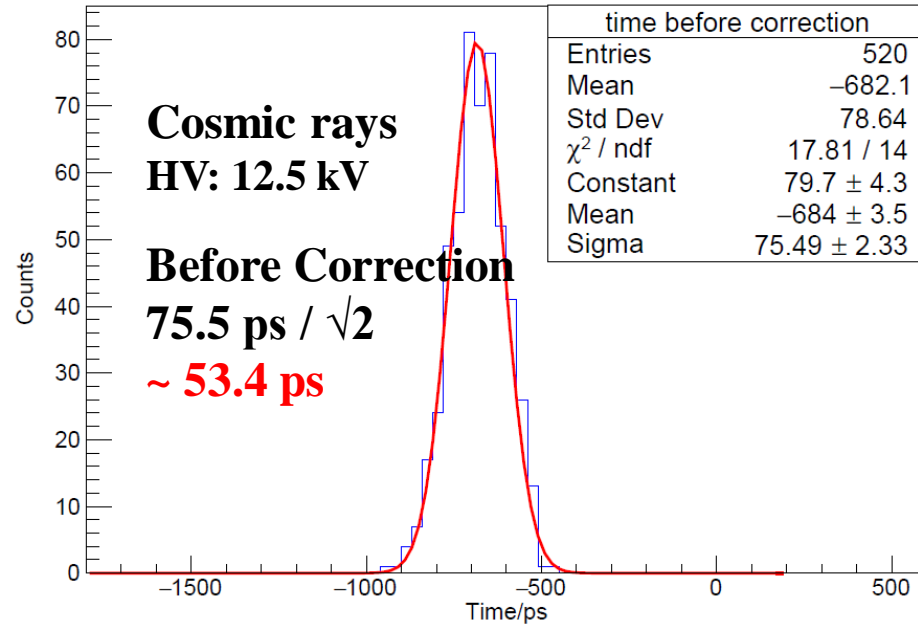
➤ Recurrent neural networks(RNN): Long Short Term Memory network (LSTM)



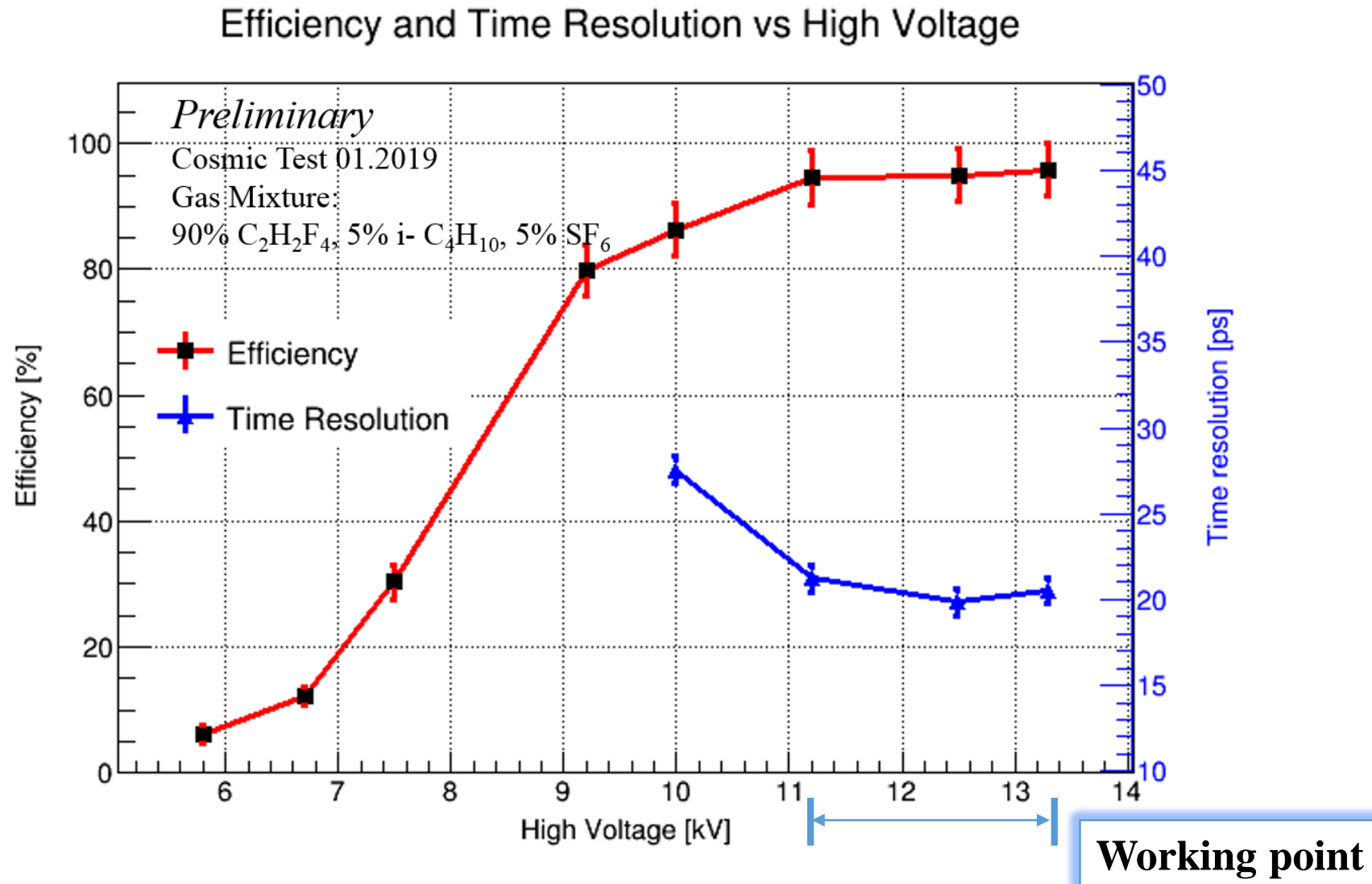
- Train/validate/test set: 20/10/10 k
- Tensorflow & GPU: GTX 1080 Ti

> 30 mins for training

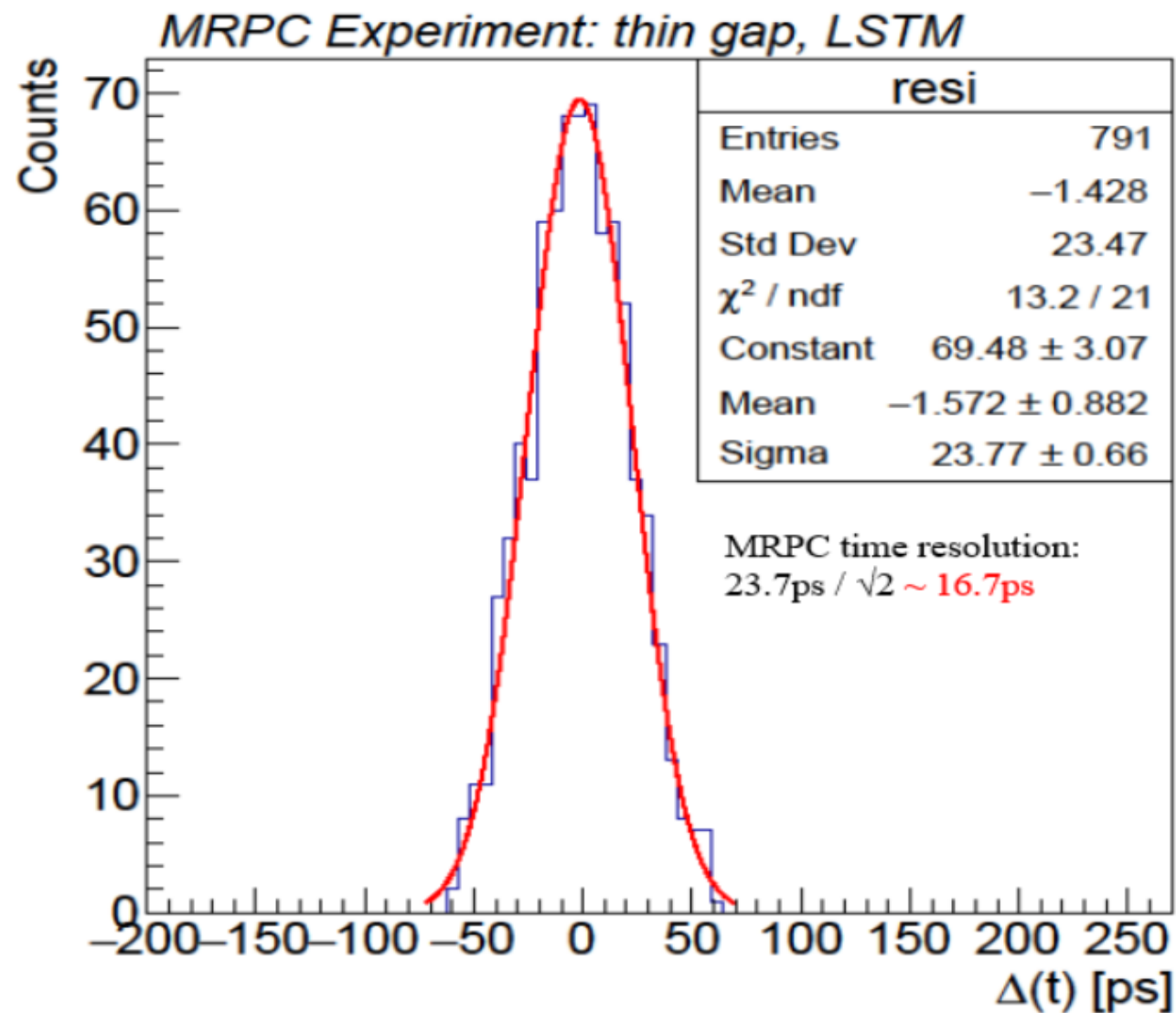
Preliminary Results — ToT



Preliminary Results — ToT



Preliminary Results — LSTM



Conclusion & Future Plan

Summary:

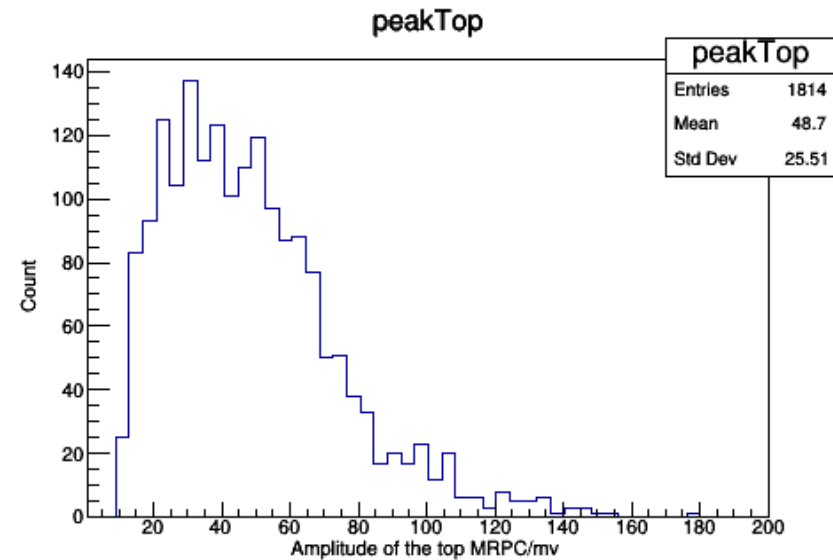
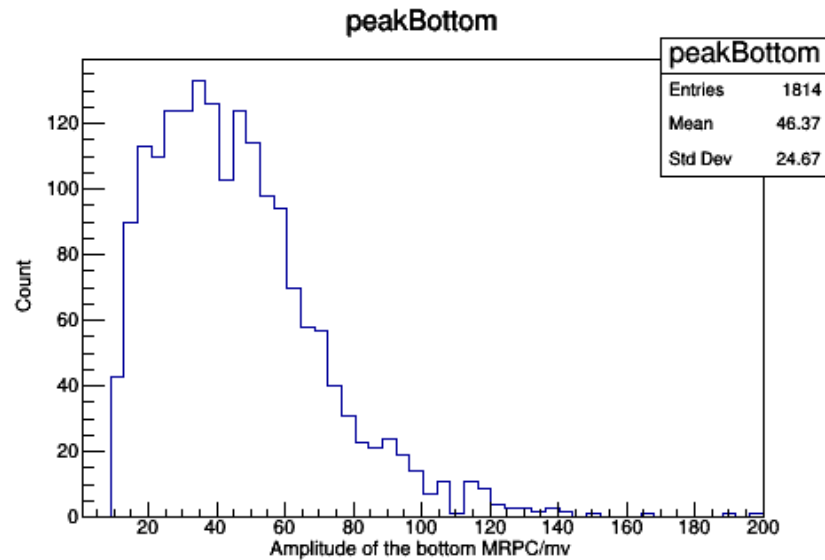
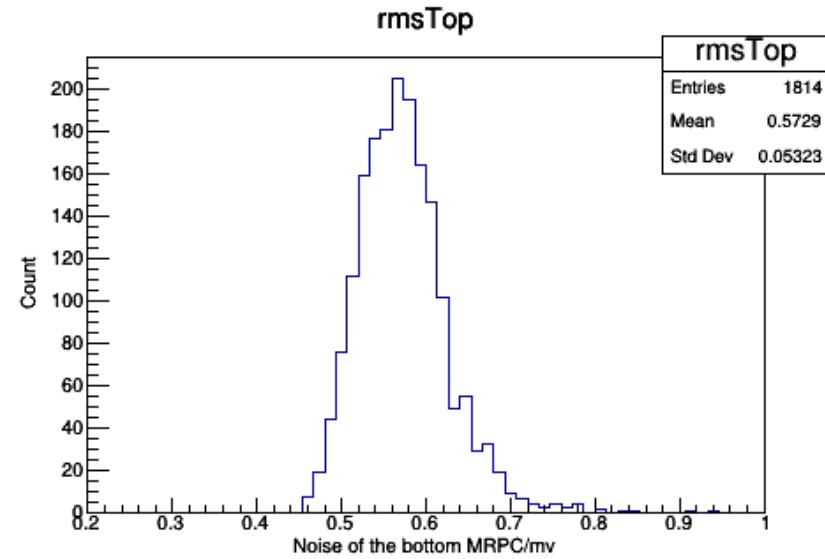
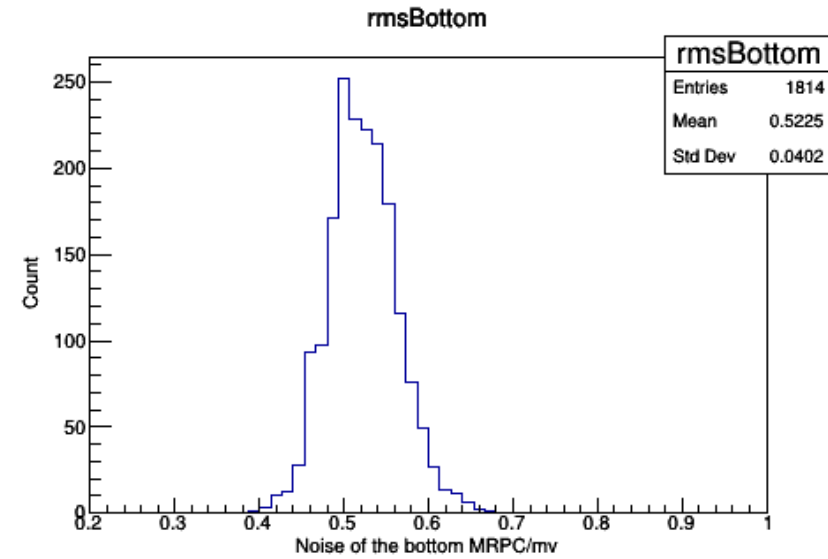
- The 32-gap MRPC prototype with gap thickness of $104\ \mu\text{m}$ has been developed.
 - ✓ Efficiency reaches 95% at $\pm 6250\ \text{V}$.
 - ✓ Time resolution around 20 ps.
- Detailed simulation of time resolution based on Geant4.
 - ✓ Different structure of MRPC.
 - ✓ Dependence on the thickness of gas gap.
- New analysis method such as deep learning technology will play an important role!

Future plan:

- Waveform digitization module will be ready soon (from USTC).
- New **24-gap MRPC** is ongoing.
 - 4 stacks \times 6 gaps, gap width $\sim 140\ \mu\text{m}$.
 - **Low resistive glasses.**
- Cosmic test & Beam test.

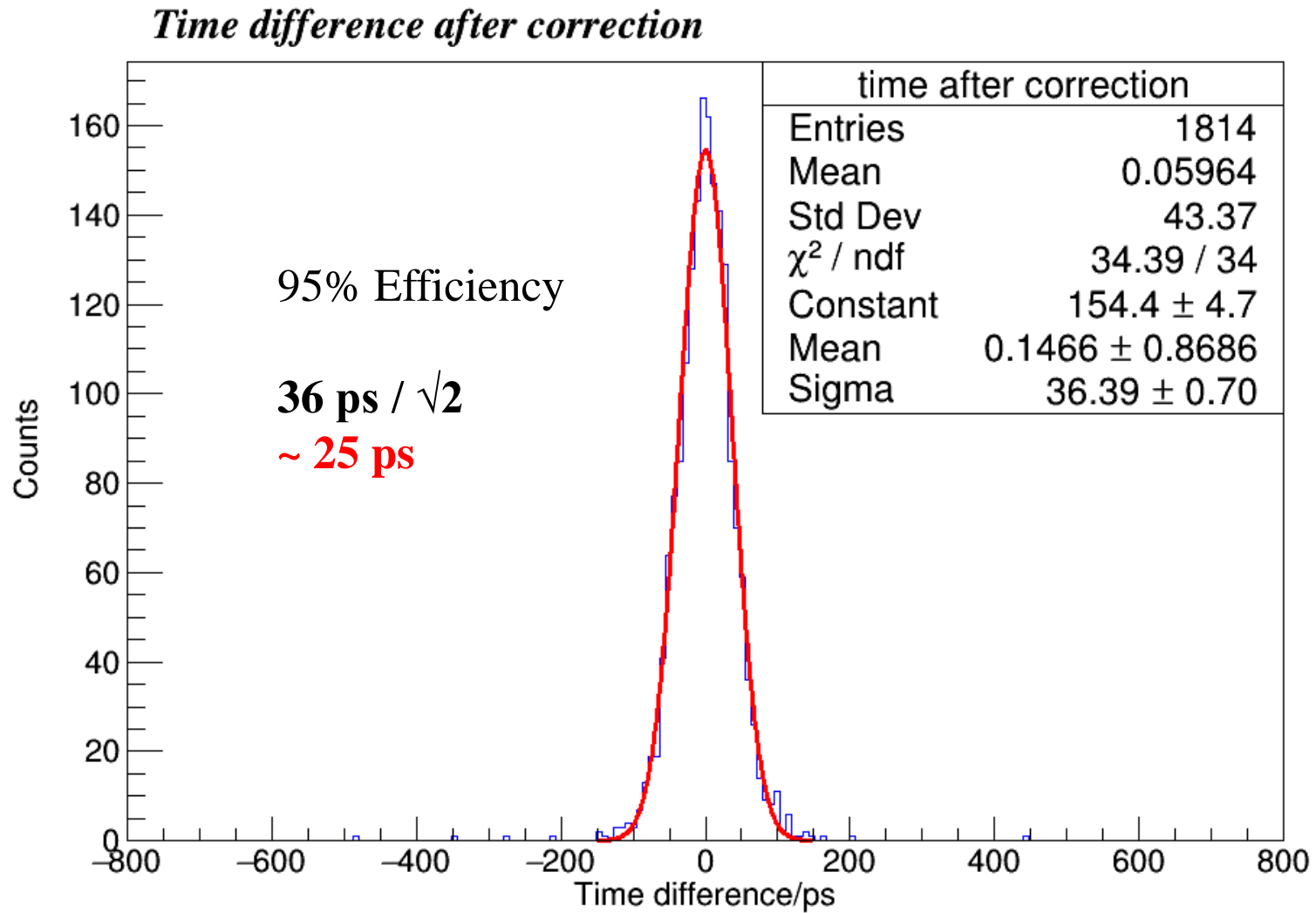
Thank you for your attention!

Backup



95% Efficiency:
20*SNR
1814events

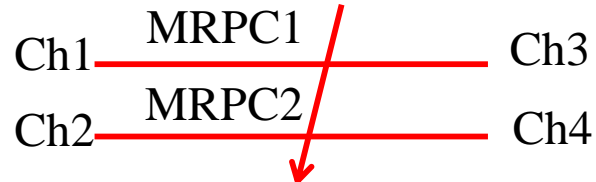
Backup



Experiment — Preliminary Results

$$\text{Time difference} = (T_{\text{ch1}} + T_{\text{ch3}}) - (T_{\text{ch2}} + T_{\text{ch4}})$$

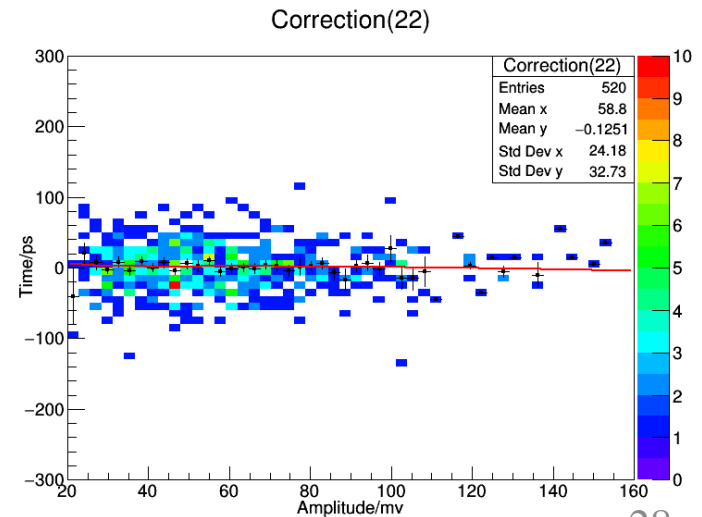
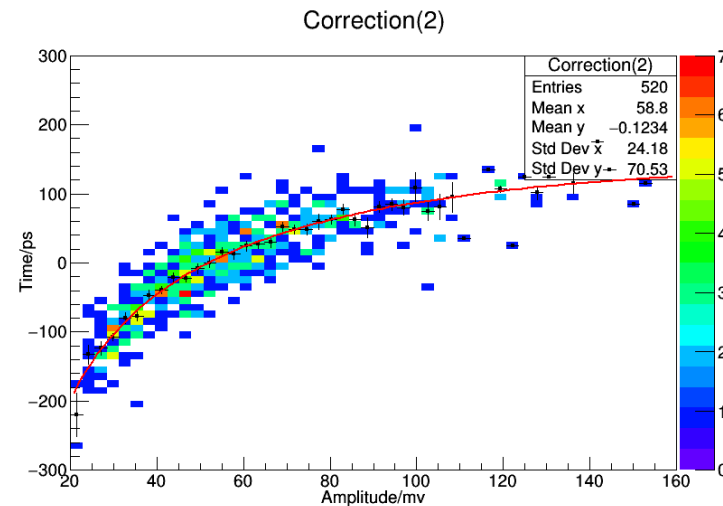
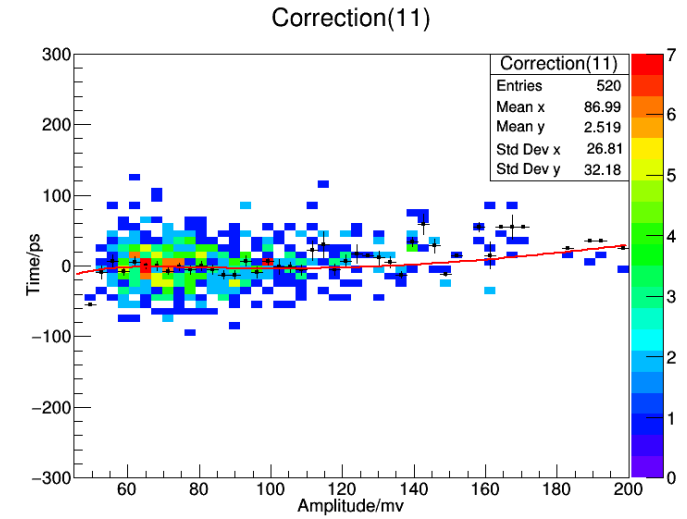
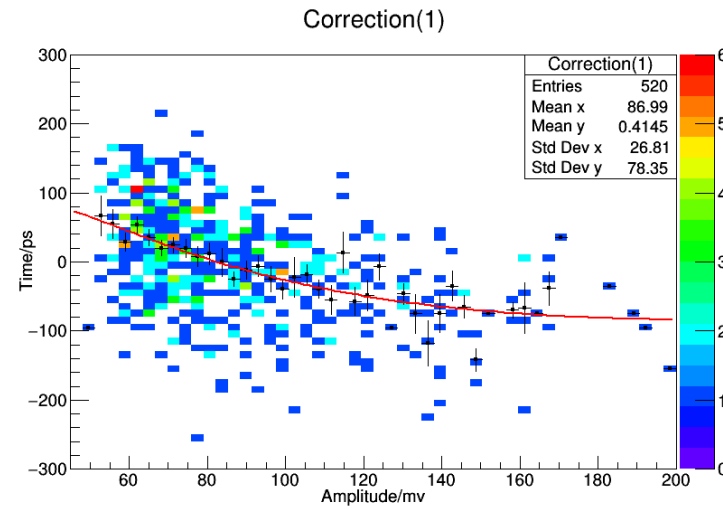
Channel Map



Cut:

$$(T_{\text{ch1}} - T_{\text{ch3}}) - (T_{\text{ch2}} - T_{\text{ch4}})$$

→ Angle of incident particle



Simulation— Multiplication

Multiplication in a small step:

- $P(n,x)$: Prob(one electron \xrightarrow{x} n electrons)

$$\begin{aligned} P(n, x + dx) = & P(n-1, x)(n-1)\alpha dx(1-(n-1)\eta dx) \\ & + P(n, x)(1-n\alpha dx)(1-n\eta dx) \\ & + P(n, x)n\alpha dx n\eta dx \\ & + P(n+1, x)(1-(n+1)\alpha dx)(n+1)\eta dx \end{aligned}$$

- Divide the gap into ~ 300 steps, and simulate the multiplication in every step
- Generate a random number according to $P(n,x)^*$:

$$n \begin{cases} 0, & s < k \frac{\bar{n}(x)-1}{\bar{n}(x)-k} \\ 1 + \text{Trunc}\left[\frac{1}{\ln(1-\frac{1-k}{\bar{n}(x)-k})} \ln\left(\frac{(\bar{n}(x)-k)(1-s)}{\bar{n}(x)(1-k)}\right)\right], & s > k \frac{\bar{n}(x)-1}{\bar{n}(x)-k} \end{cases} \quad \begin{aligned} k &= \frac{\eta}{\alpha} \\ s: & \text{uniform random number from } (0,1) \end{aligned}$$

- Finally, avalanche growth like: $e^{(\alpha-\eta)x}$