Progress of the high time resolution MRPC

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Part Ⅰ
Study on the intrinsic time resolution of MRPC

Theoretical analysis

- Particles impinge on the MRPC detector
- Create the ionized electron-ion pairs
- The number of primary electrons and the following avalanches account for the final time resolution

Suppose there is an electron created at position $z = 0$ and drift along the z axis under the electric field. The probability for it to become n electrons at position z is $P(n, z)$*:

$$P(n,z) = \frac{1-k}{\bar{n}} e^{(k-1)\frac{n}{\bar{n}}} = \frac{1}{A'_{av}} e^{-\frac{A'}{A'_{av}}} \quad where \;\; A'_{av} = \frac{\bar{n}}{1-k}$$

$\bar{n}$ is the mean value of the number of electrons at z, and k is the ratio η/α

*Riegler W , Lippmann C , Veenhof R . Detector physics and simulation of resistive plate chambers[J]. Nuclear Inst& Methods in Physics Research A, 2002, 500(1):144-162.

Theoretical analysis

- The amplitude A_j of the signal caused by only 1 single electron follows an exponential distribution with a mean value of A_{av}

$$f(A_j) = \frac{1}{A_{av}} e^{-\frac{A_j}{A_{av}}}$$

- According to the Ramo theory, the induced current of m primary electrons is:

$$i = \sum_{j=1}^{m} A_j e^x = \left(\sum_{j=1}^{m} A_j \right) e^x = \mathrm{B} e^x \qquad x = (\alpha - \eta) vt = \alpha' vt$$

- The probability distribution function (PDF) of variable B can be obtained using $f(A_j)$

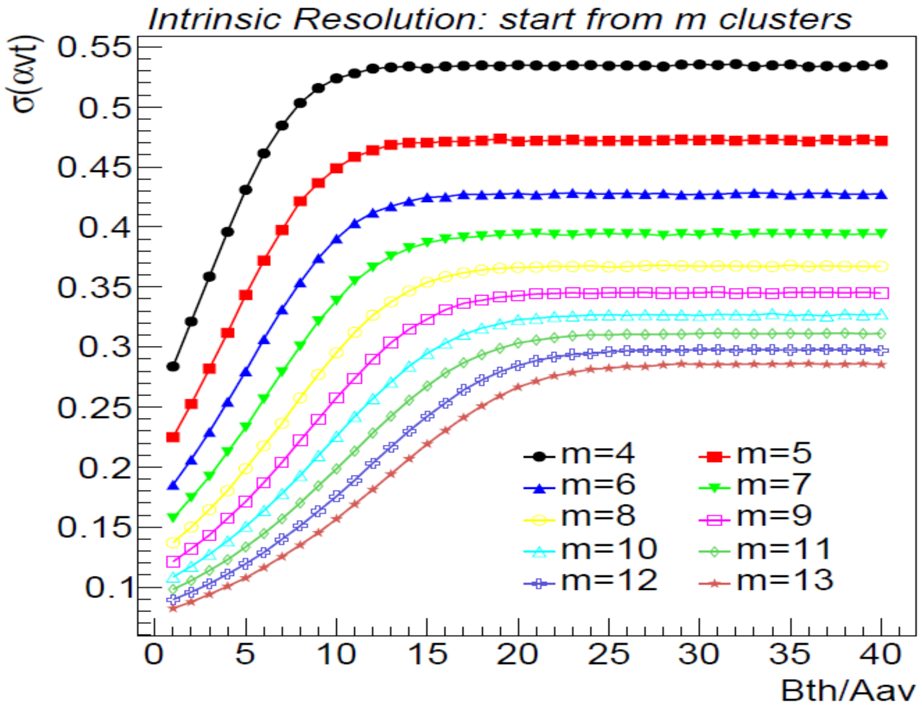
$$f(B) = f(A_1) \otimes f(A_2) \ldots \otimes f(A_m) = \frac{B^{m-1} e^{-\frac{B}{A_{av}}}}{(m-1)! A_{av}^m}$$

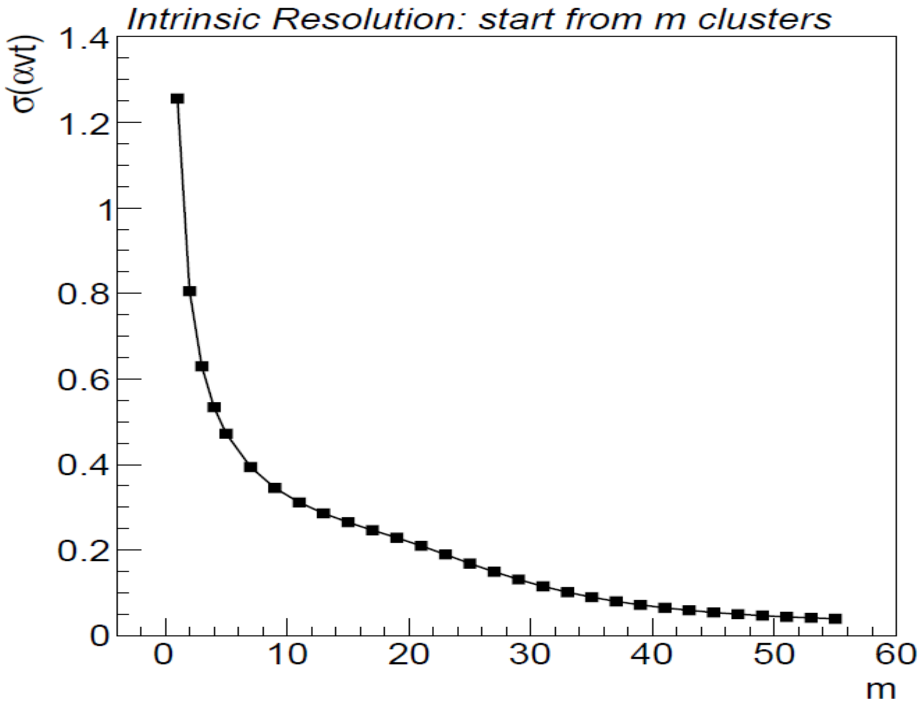
Theoretical analysis

- If a fixed threshold B_{th} is set to the current i
- Then the PDF of x can be obtained with $f(B)$ and the relationship between B and x

$$g(x) = f(B(x))\left|\frac{\mathrm{d}B}{\mathrm{d}x}\right| = \frac{r^m}{(m-1)!}\exp[-re^{-x} - mx] \quad where,\ r = \frac{B_{th}}{A_{av}}$$

- The standard deviation of $g(x)$ is the time resolution starting from m electrons in unit of $1/\alpha' v$.





Sources that contributes to the intrinsic time resolution

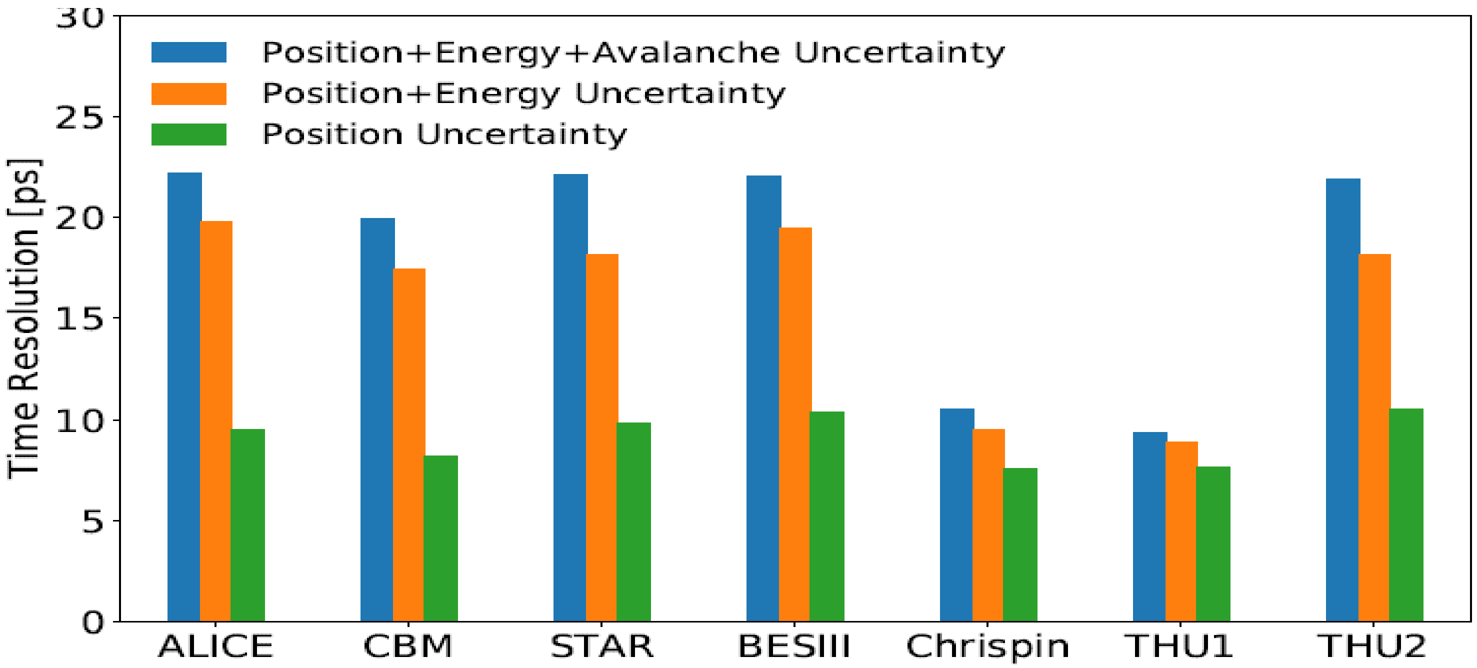
$$g(x) = f(B(x))|\frac{\mathrm{d}B}{\mathrm{d}x}| = \frac{r^m}{(m-1)!}\exp[-re^{-x} - mx] \quad where,\ r = \frac{B_{th}}{A_{av}}$$

- 3 main origins mainly contribute to the time resolution of the MRPC:
  - ✓ Uncertainty of the position where primary interactions take place
  - ✓ Uncertainty of the energy deposited and the number of ionized electrons created
  - ✓ Uncertainty of the avalanche multiplication

The Geant4 simulation framework built by Fuyue Wang:
*F. Wang, D. Han, Y. Wang, Y. Yu, Q. Zhang, B. Guo, Y. Li, A standalone simulation framework of the mrpc detector read out in waveforms, Journal of Instrumentation 13 (09) (2018) P09007.

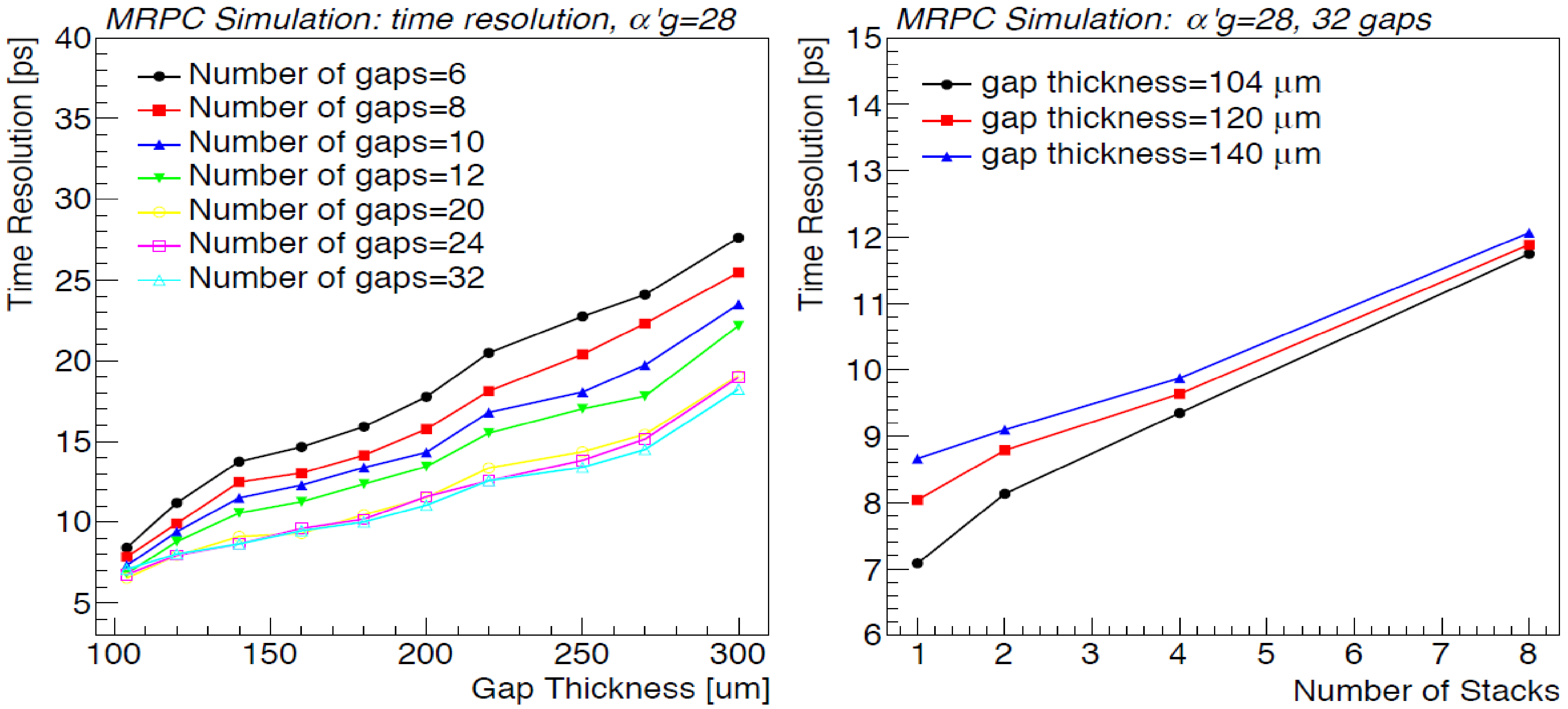
Sources that contributes to the intrinsic time resolution

Experiments	StackNb	GapNb	Thickness[μm]	Working E [kV/cm]
ALICE	2	5	250	104
CBM	2	4	250	110
STAR	1	6	220	114
BESIII	2	6	220	103
Chrispin	4	6	160	135
THU1	4	8	104	159
THU2	1	6	250	109



The geometry effects on the intrinsic time resolution

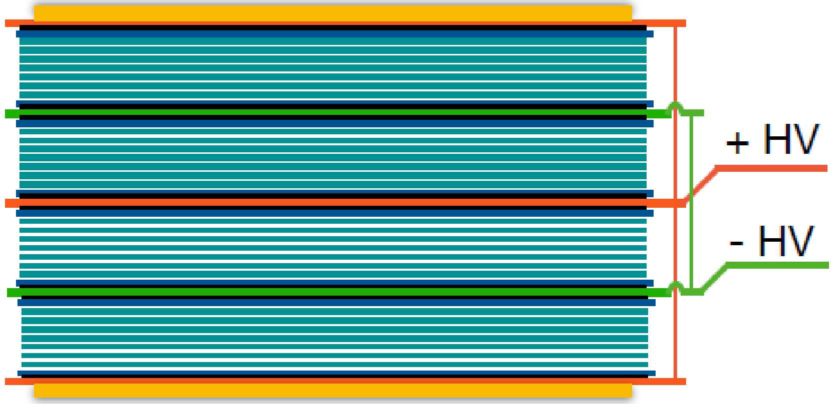
- To control the final avalanche size and avoid streamers, the effective Townsend coefficient times the gap thickness are fixed at $\alpha g = 28$

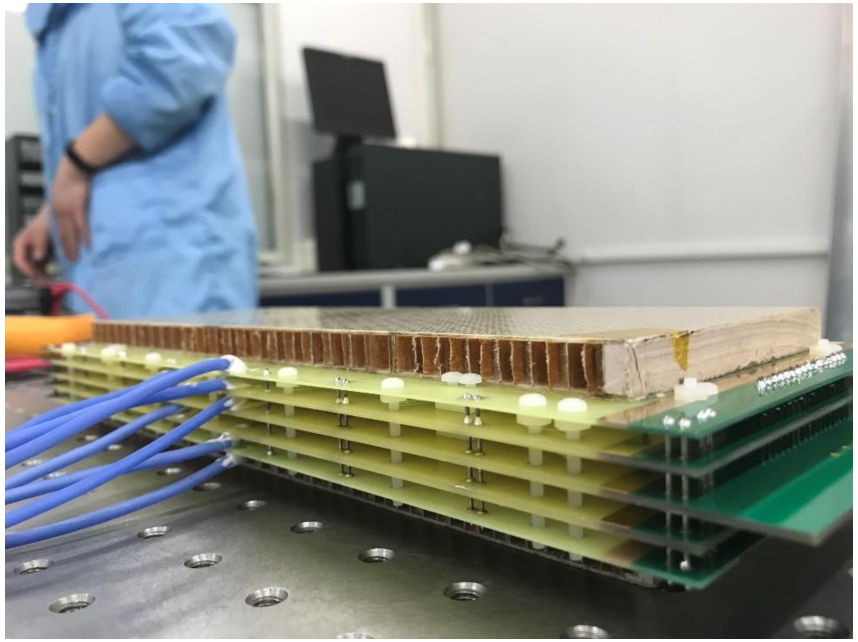


- The possible choices for nMRPCs are only the designs with gap thickness below 140um

Part Ⅱ
Next-Gen MRPC R&D

nMRPC design

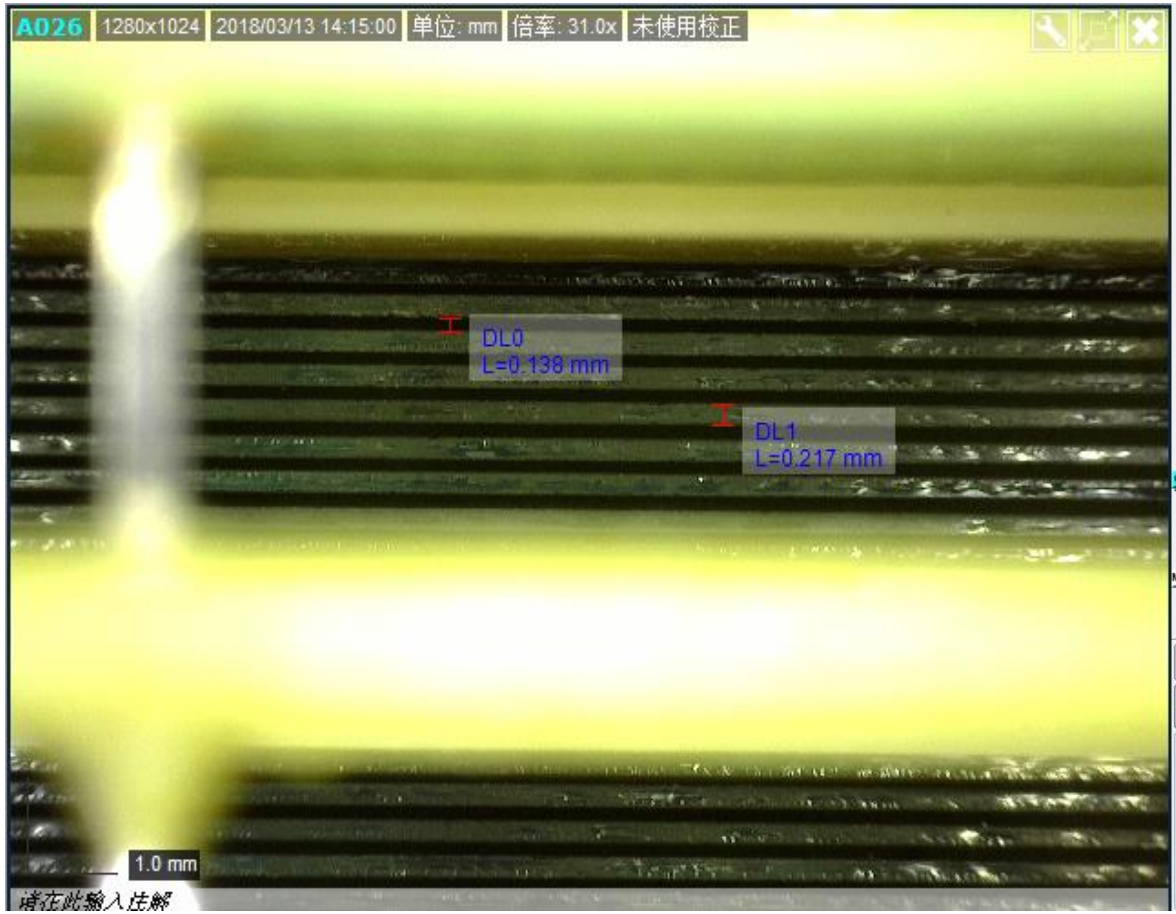




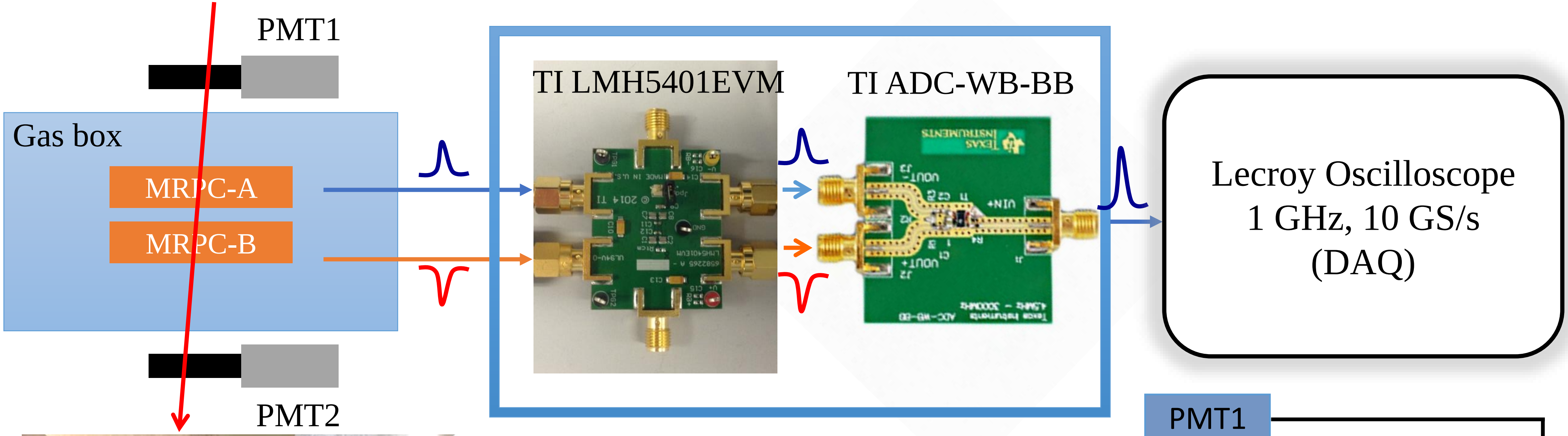
- **Narrower gap width** →fast charge dominant in the induced signal → Better timing resolution
- **More gas gaps** → Efficiency will be recovered

	Tsinghua nMRPC, 2018
Gas Gap Width	128 um (fishing line)
Number of Gas Gaps	4 stack x 8 layers = 32
Float Glass Thickness	230 um
Readout strip	3 mm x 268mm(3 mm internal)
Readout	differential, both ends

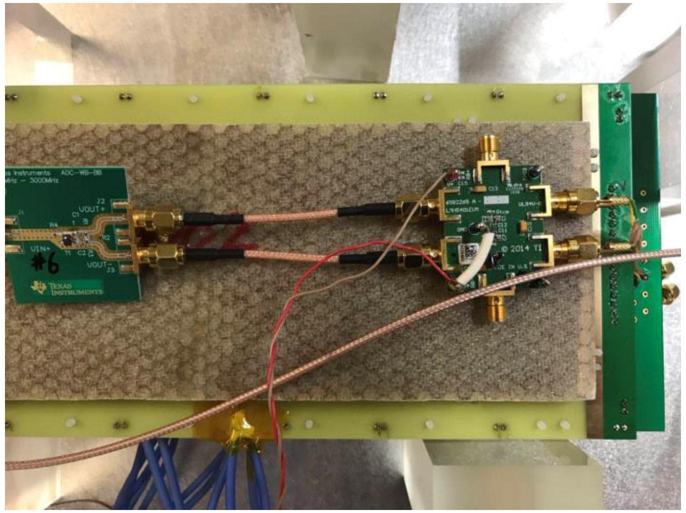
nMRPC design

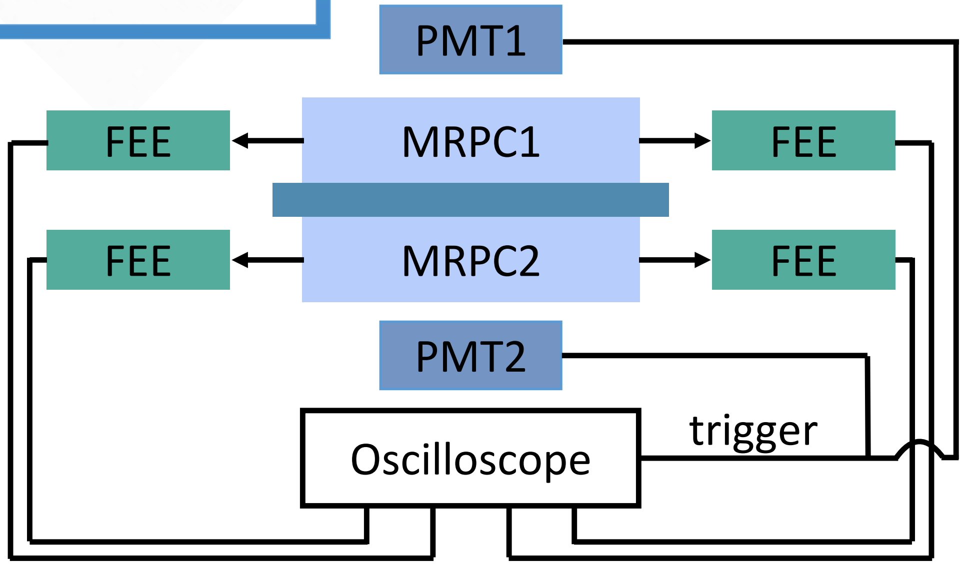


Setup



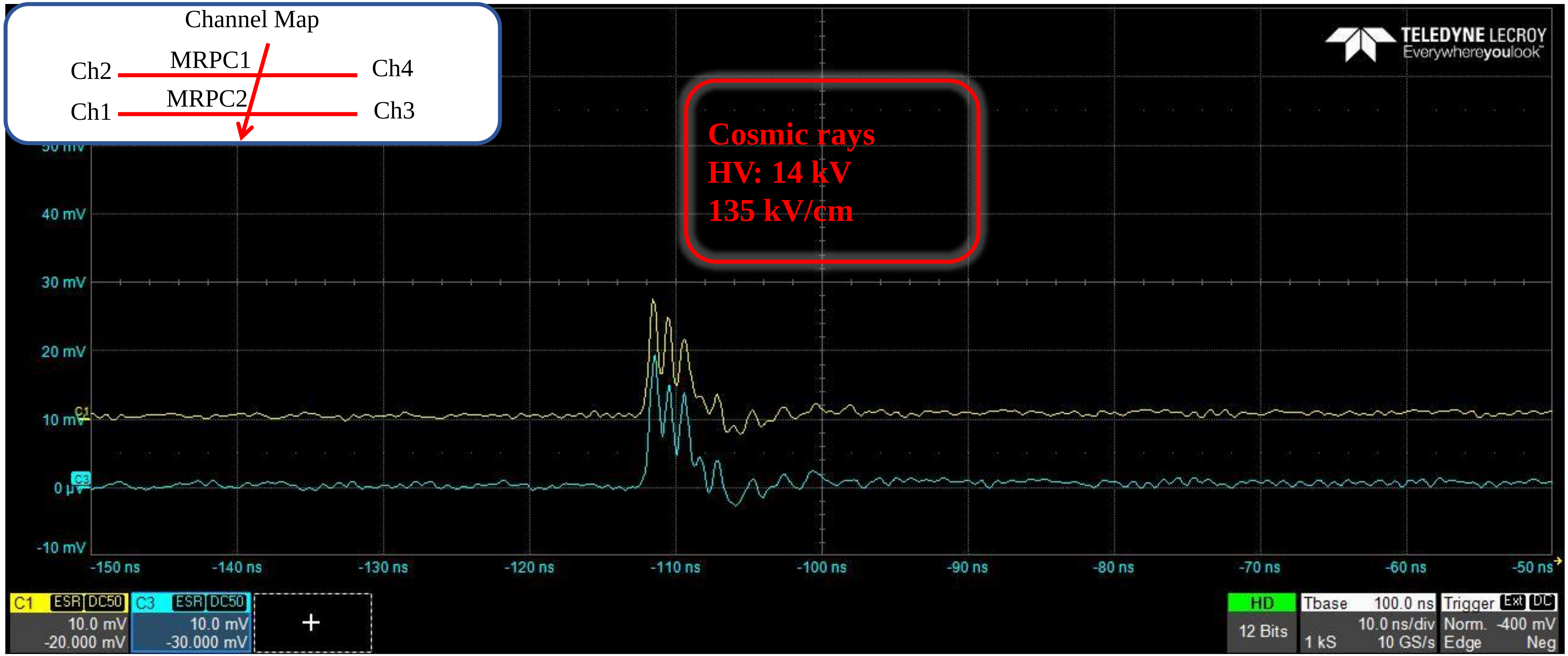
PMT1
Gas box
MRPC-A
MRPC-B
PMT2
TI LMH5401EVM
TI ADC-WB-BB
Lecroy Oscilloscope
1 GHz, 10 GS/s
(DAQ)





PMT1
FEE
MRPC1
FEE
FEE
MRPC2
FEE
PMT2
trigger
Oscilloscope

Setup


Channel Map
Ch2
MRPC1
Ch4
Ch1
MRPC2
Ch3
Cosmic rays
HV: 14 kV
135 kV/cm
TELEDYNE LECROY
Everywhereyoulook
40 mV
30 mV
20 mV
10 mV
0 µV
-10 mV
-150 ns
-140 ns
-130 ns
-120 ns
-110 ns
-100 ns
-90 ns
-80 ns
-70 ns
-60 ns
-50 ns
C1 ESR DC50
10.0 mV
-20.000 mV
C3 ESR DC50
10.0 mV
-30.000 mV
HD
12 Bits
Tbase 100.0 ns
10.0 ns/div
1 kS 10 GS/s
Trigger Ext DC
Norm. -400 mV
Edge Neg

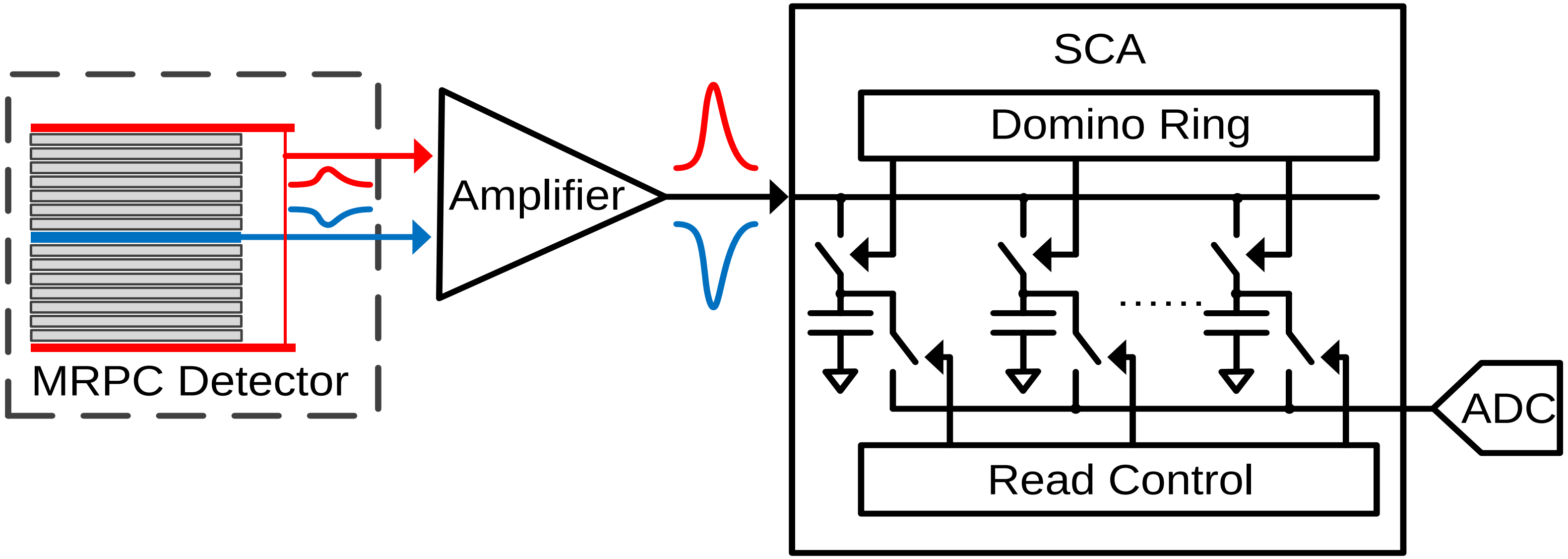
Next

Next…

- ✓ Figured out the noisy channel(ch2)
- ✓ Rebuilt the test platform, now gas fluxing
- ☐ Cosmic test for the 32-gaps MRPC
- ☐ Considering the reason of the reflections

Part Ⅲ
Progress of high time precision electronics
----From USTC

System Framework

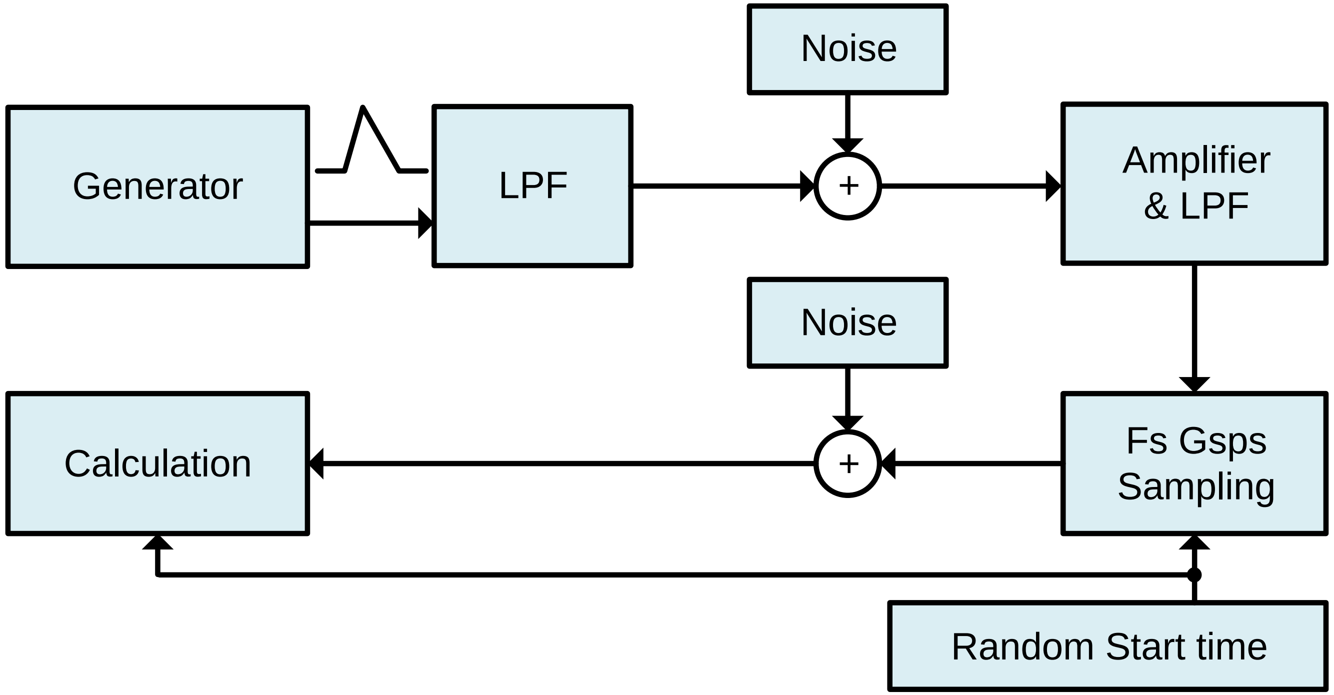


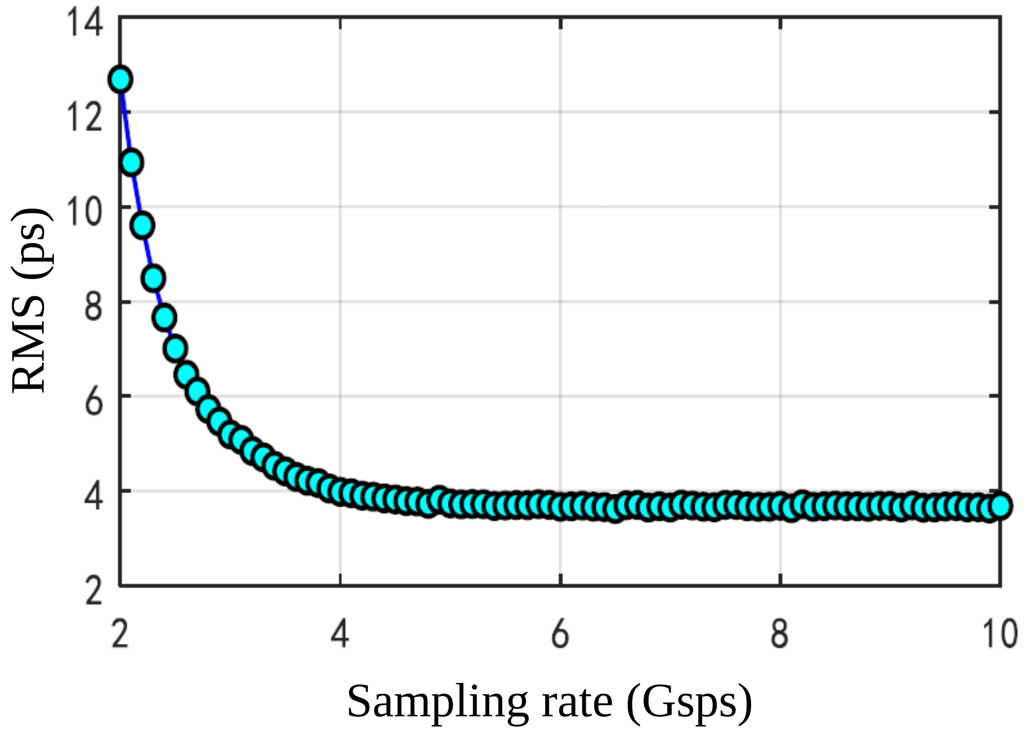
- ➢ Preamplification + High speed Waveform-to-Digital Conversion(WDC)
- ☐ Analog Front-end Electronics(AFE) requirements:
  - ✓ High bandwidth

    Leading edge of the MRPC signals is ~300ps → -3dB bandwidth needs to be 1.16GHz
  - ✓ High gain (20-40dB)

    The amplitude of input signals to WDC >100mv
  - ✓ Impedance matching
  - ✓ Reach around 10ps time resolution

System Framework



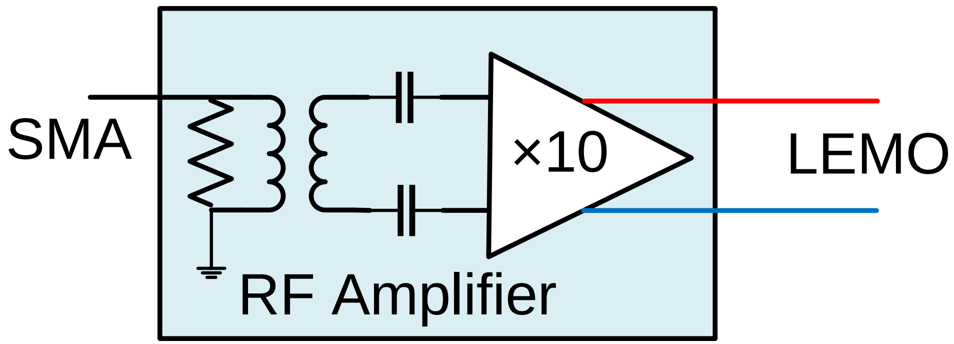


- ➢ Preamplification + High speed Waveform-to-Digital Conversion(WDC)
- ◻ WDC requirements:
  - ✓ Sampling rate > 4Gsps
  - ✓ 14bits resolution ADC
  - ✓ Sampling depth is 1024 points
  - ✓ Reach below 10ps time resolution

Chip selection

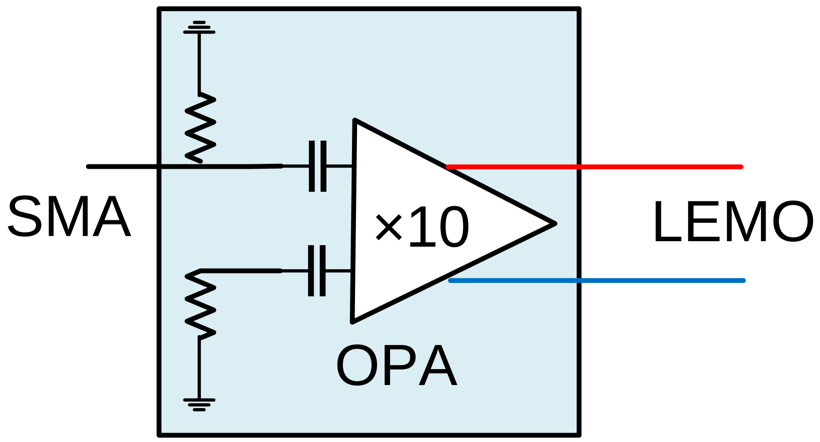
RF Amplifier

LTC6430-20

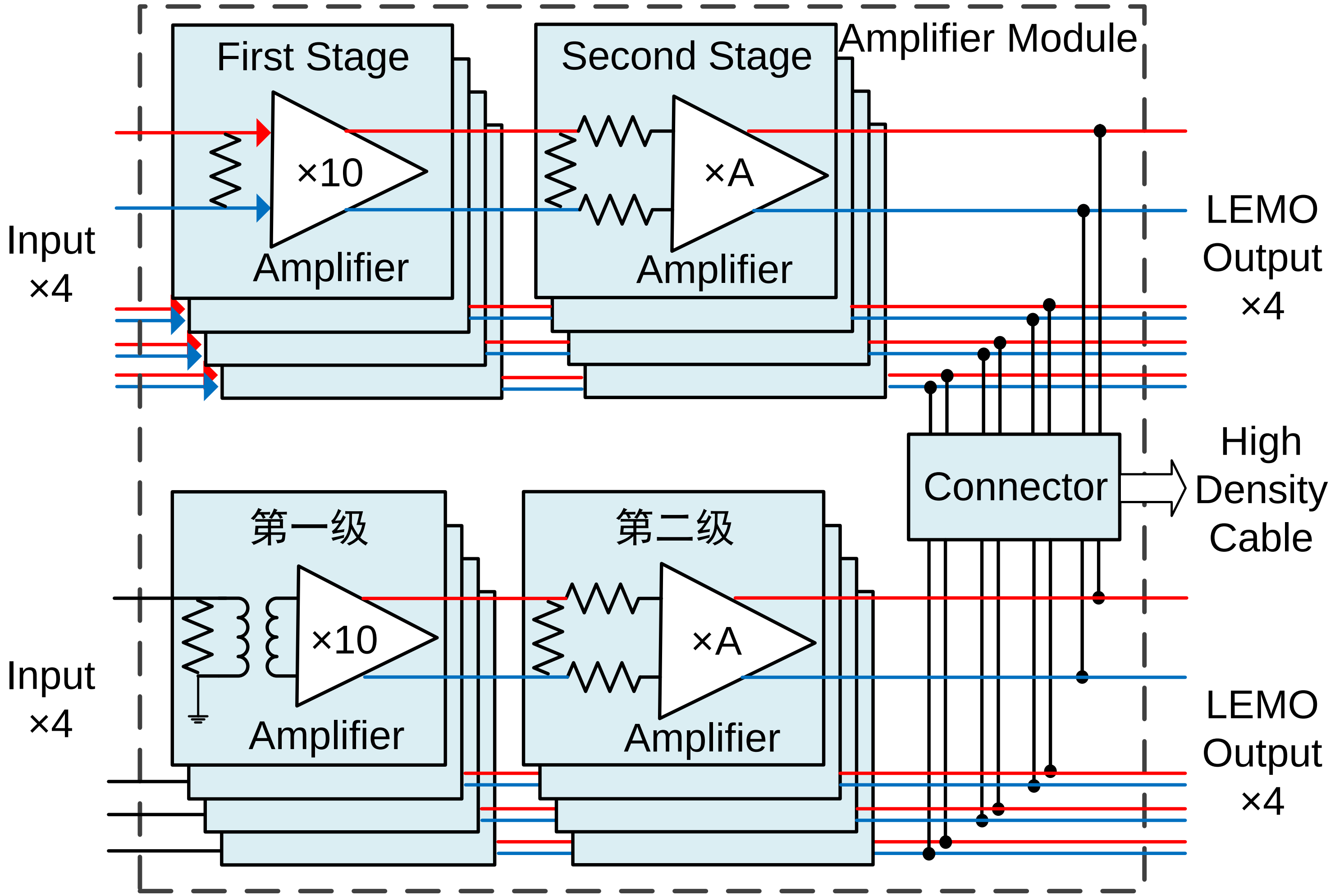


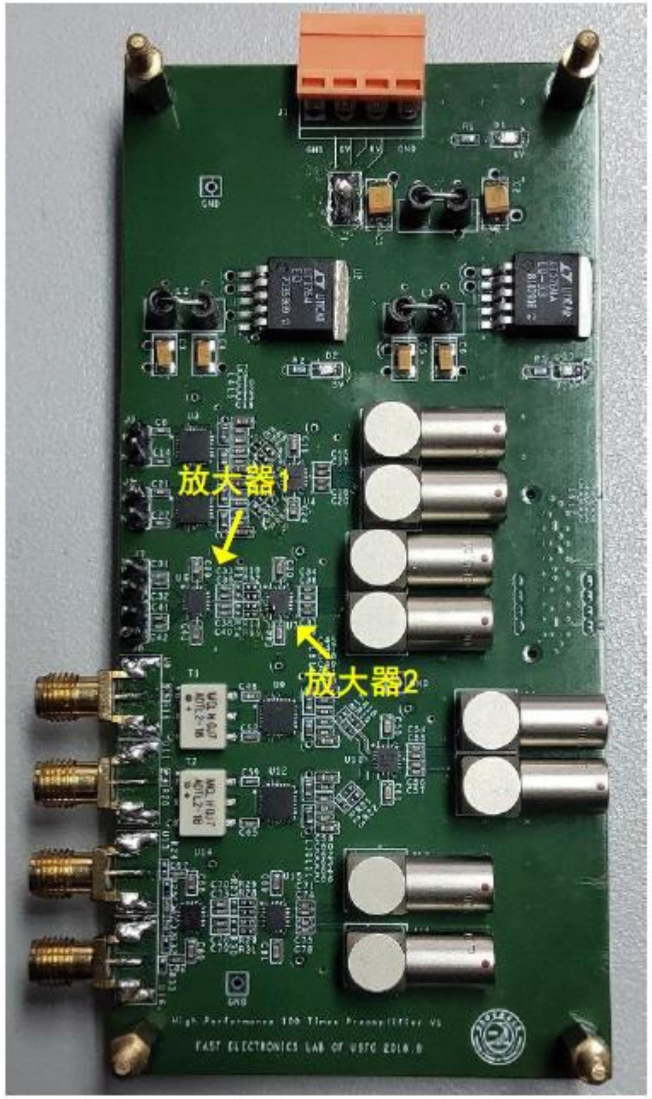
Operational Amplifier(OPA)

ADL5569

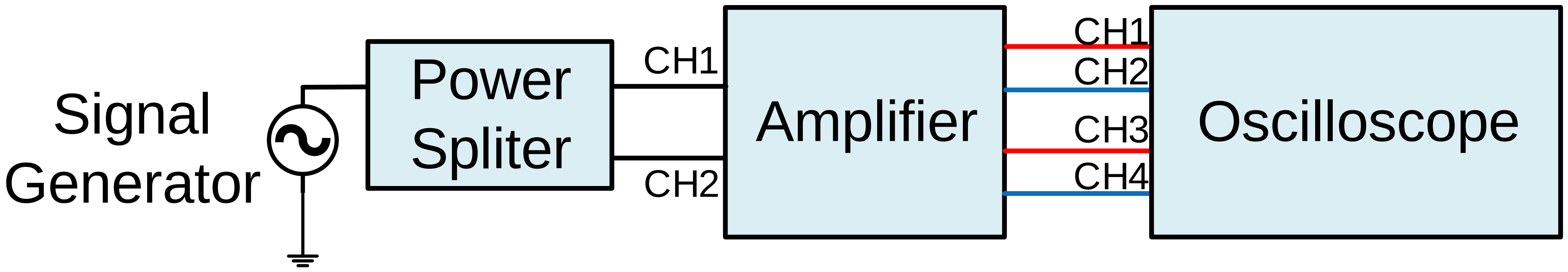


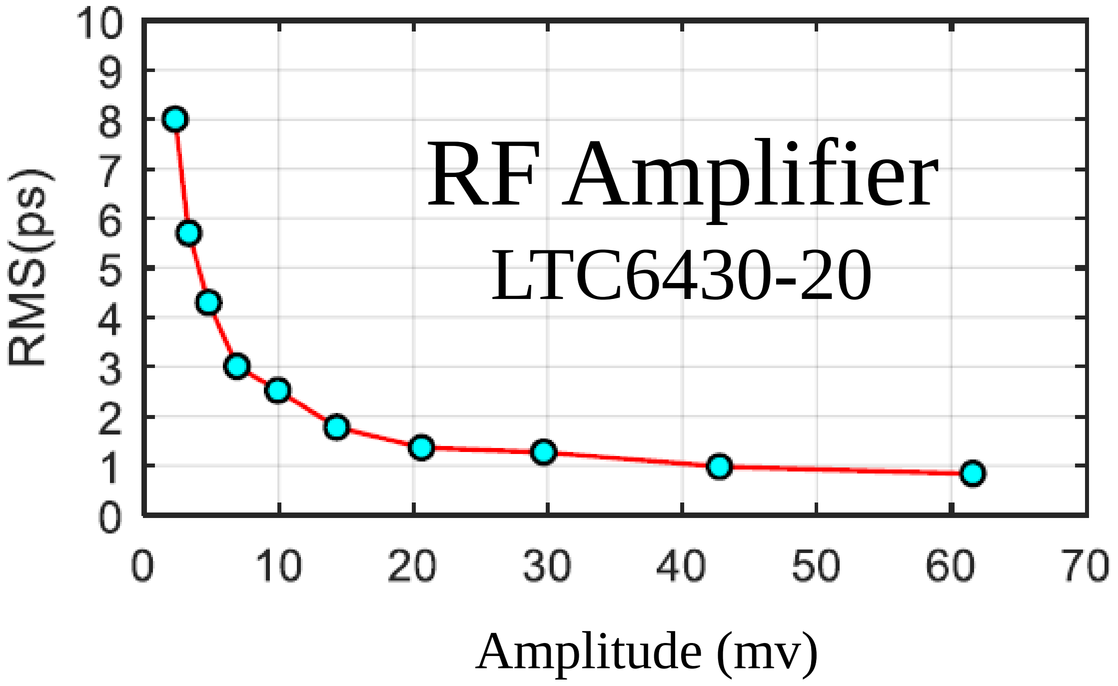
AFE Module Structure

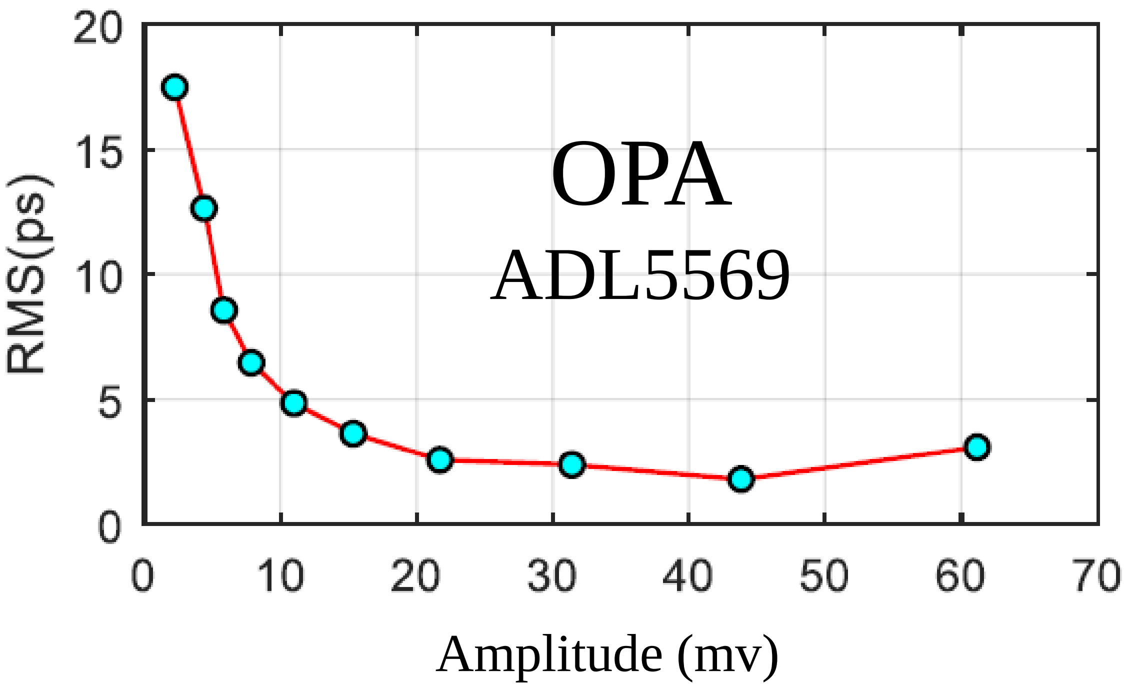




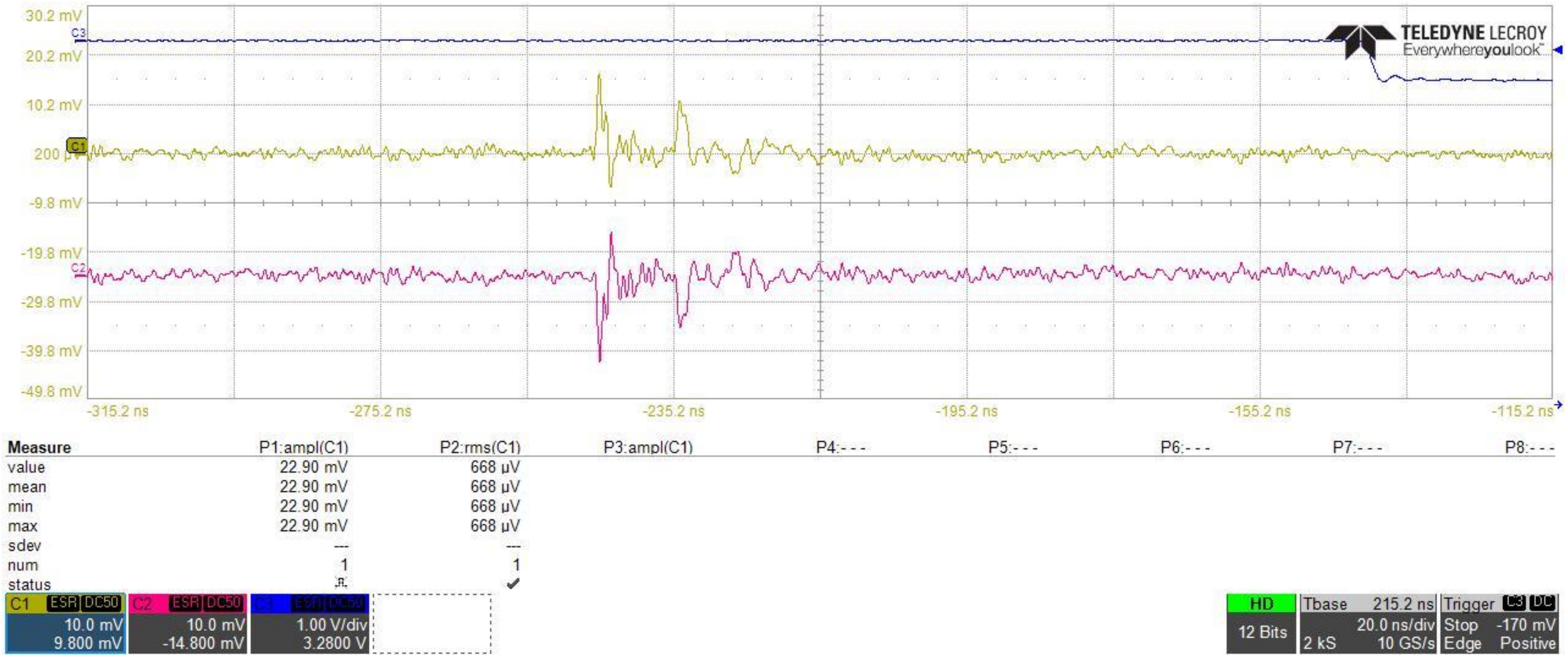
Test in the lab







Next



- ✓ Two PhD students from USTC just came to Tsinghua.
- ✓ The 32-gap MRPC are ready for test.
- ☐ Test the AFE module with MRPC detector.
- ☐ Take some data, analyze the performance of the MRPC and AFE.

Thank you for your attention!