High rate and time resolution TOF for SoLID

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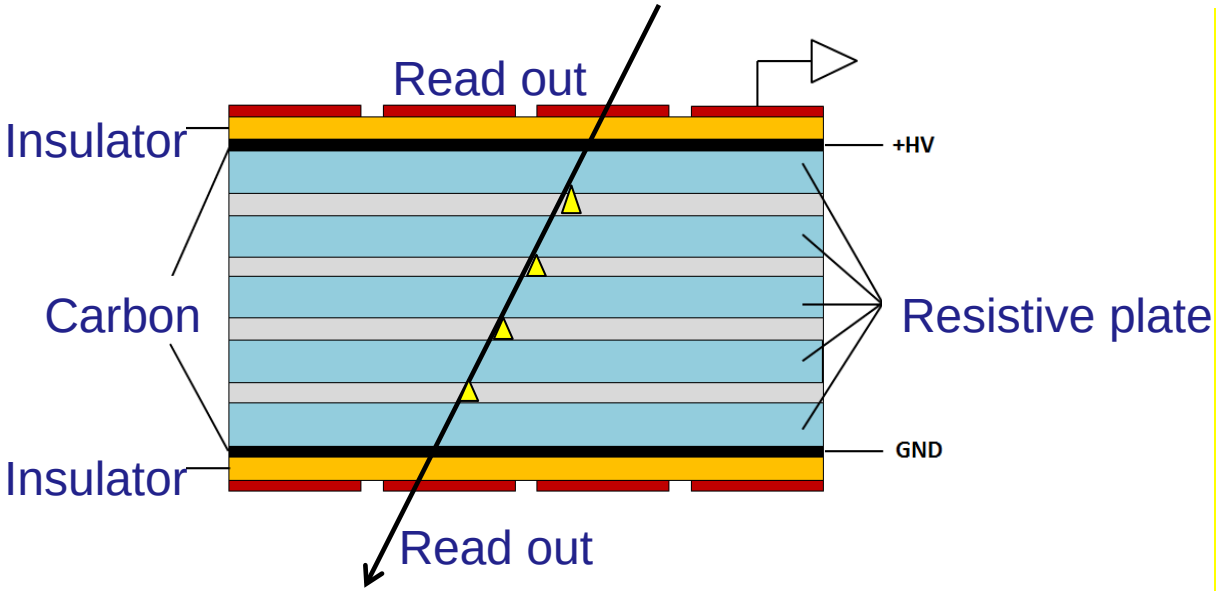
Outline:

- **Introduction MRPC-TOF and SoLID**
- **Development of high rate and high precision MRPC**
- **Next to do**
- **Conclusions**

Introduction of MRPC



- MRPC is made of thin glass, large area and cheap
- The inner glasses are floating, take and keep correct voltage by electrostatics. it is transparent to fast signals
- Thin gap->good timing
- Multi-gap-> high efficiency

Standard parameters:

Resistivity of glass: ~10^{12} Ω.cm

Time resolution <100ps

Efficiency >95%

Dark current: a few nA

Noise <1Hz/cm^2

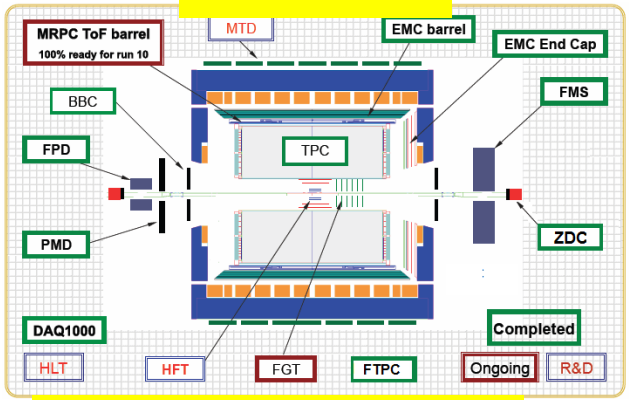
1. **Application in nuclear physics experiments**
2. **Application in industry（Muon tomography)**
3. **Application in medicine（TOF-PET）**

Three generation MRPC-TOF

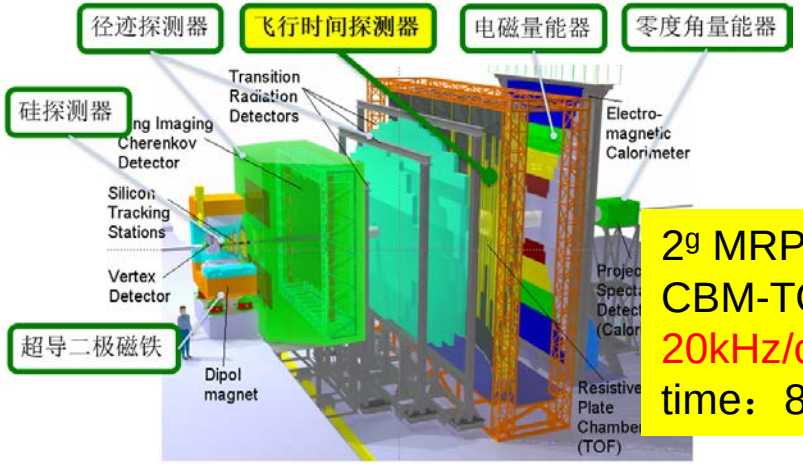
12 GeV Upgrade
Future Science at Jefferson Lab

With the increase of accelerator energy and luminosity, the requirement is also rigorous

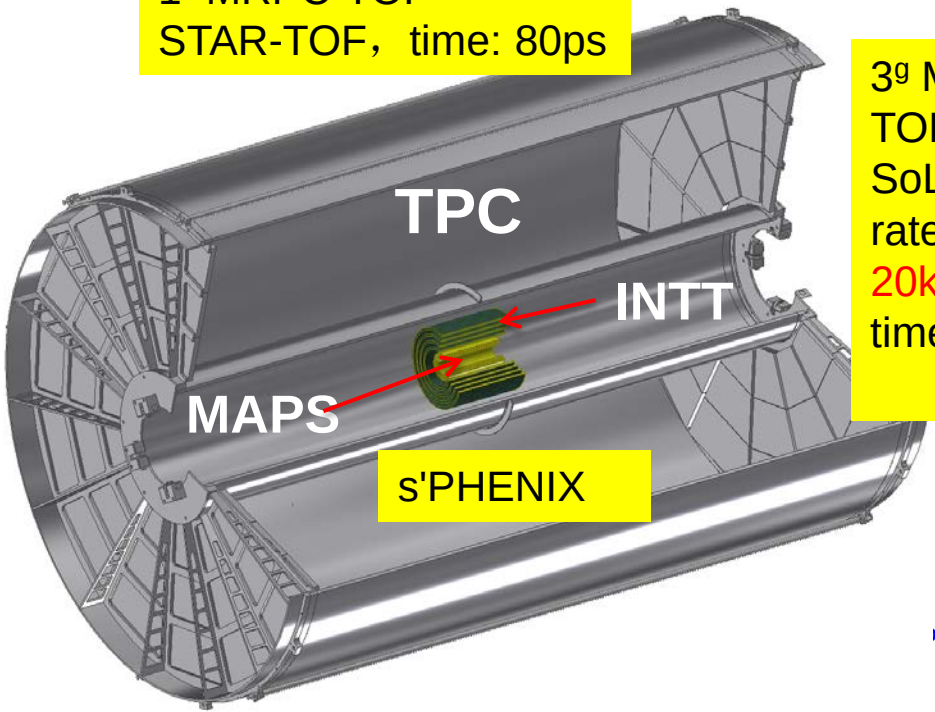
RHIC-STAR



1ᵍ MRPC-TOF
STAR-TOF，time: 80ps

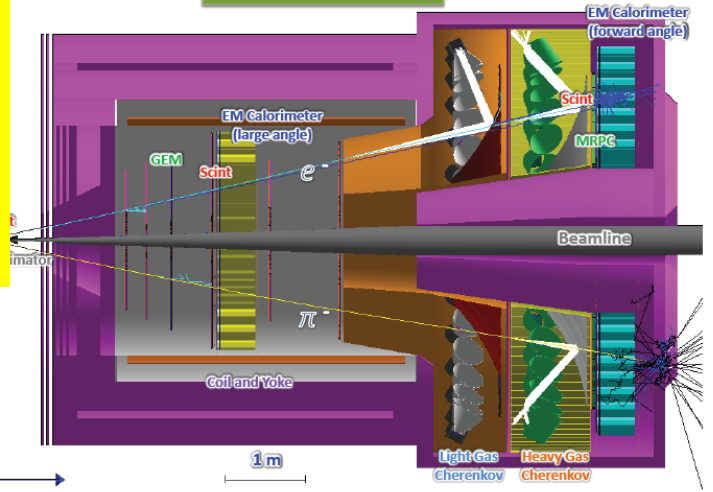


2ᵍ MRPC-TOF
CBM-TOF,rate：
20kHz/cm^2,
time：80ps



3ᵍ MRPC-TOF
SoLID-TOF,
rate：
20kHz/cm^2,
time：20ps

SoLID (SIDIS He3)



Motivation of 12 GEV Upgrade

- **JLab 6 GeV: precision measurements**

  high luminosity (10^{39}) but small acceptance (HRS/HMS: < 10 msr)

  or large acceptance but low luminosity (CLAS6: 10^{34})

- **JLab 12 GeV upgrade opens up a window of opportunities (DIS, SIDIS, Deep Exclusive Processes) to study valence quark (3-d) structure of the nucleon and other high impact physics (PVDIS, J/ψ, …)**

- **High precision in multi-dimension or rare processes requires very high statistics → large acceptance and high luminosity**

- **CLAS12: luminosity upgrade (one order of magnitude) to 10^{35}**

- **To fully exploit the potential of 12 GeV, taking advantage of the latest technical (detectors, DAQ, simulations, …) development**

→SoLID: large acceptance detector can handle 10^{37} luminosity (no baffles)

10^{39} with baffles

Overview of SoLID

Solenoidal Large Intensity Device

- Full exploitation of JLab 12 GeV Upgrade

  → A Large Acceptance Detector AND Can Handle High Luminosity (10^{37}-10^{39})

  Take advantage of latest development in detectors , data acquisitions and simulations

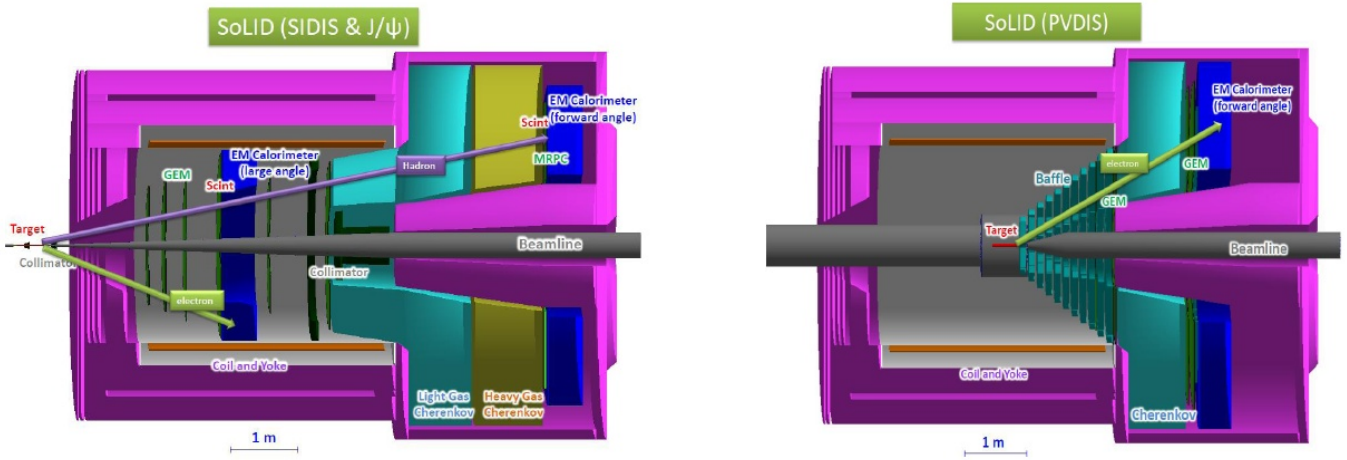
  Reach ultimate precision for SIDIS (TMDs), PVDIS in high-x region and threshold J/ψ

- 5 highly rated experiments approved (+3)

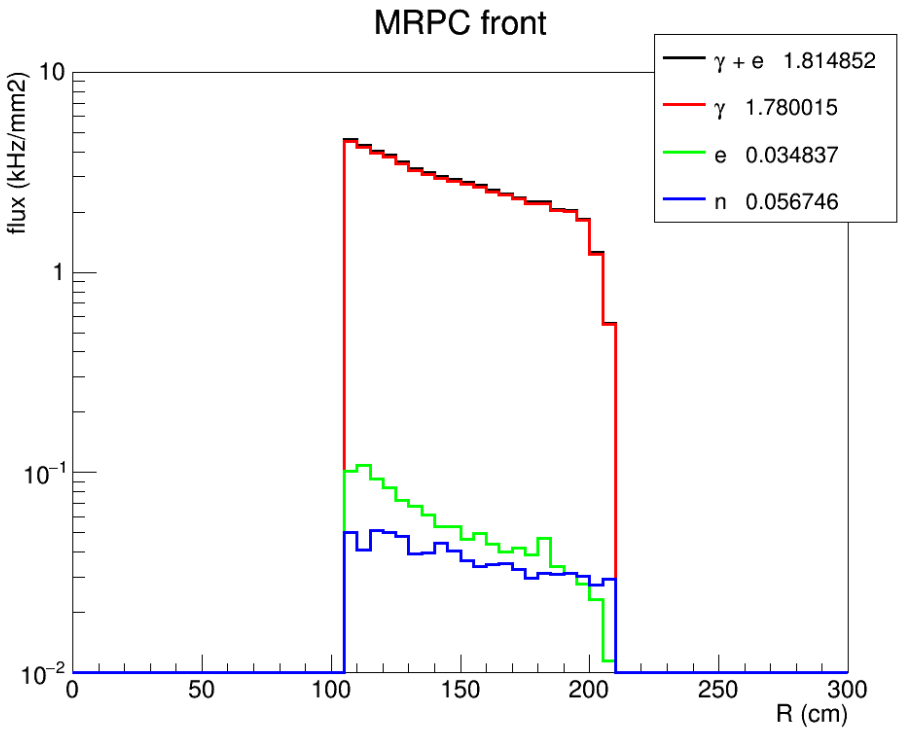
  Three SIDIS experiments, one PVDIS, one J/ψ production (+ three run group experiments)

- Strong collaboration (250+ collaborators from 70+ institutes, 13 countries)

  Significant international contributions (Chinese collaboration)



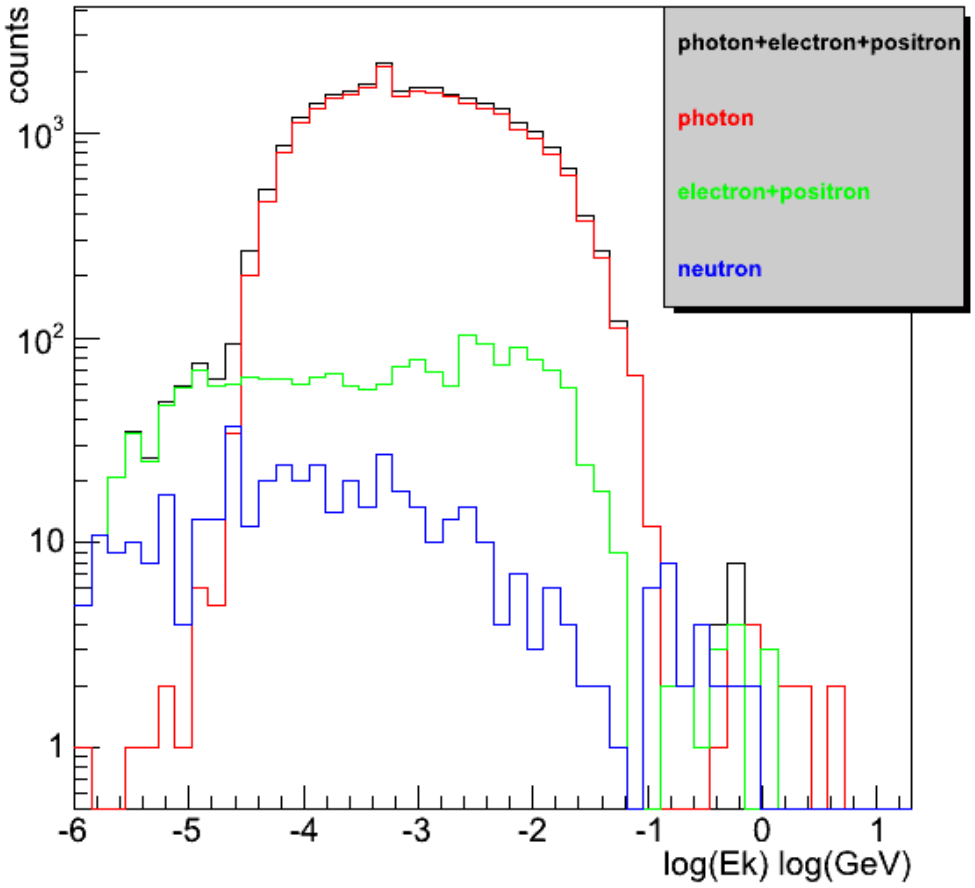
Particle rate entering MRPC



Particle rate in front of MRPC

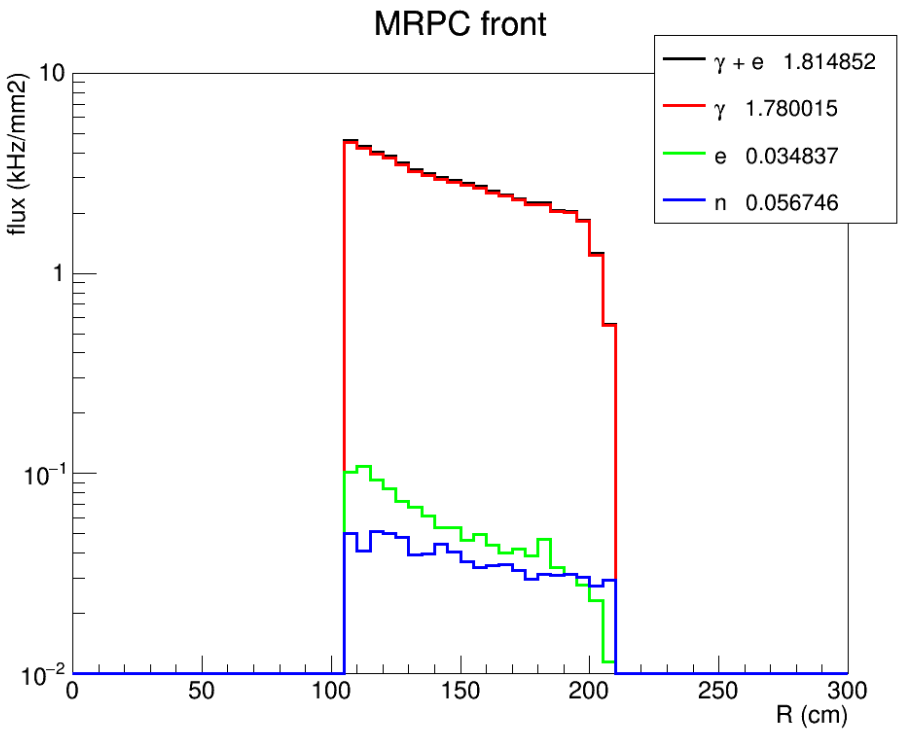
- Dominant by photon in MeV
- γ : 250kHz/cm^2
- e: 5kHz/cm^2
- n: 3kHz/cm^2

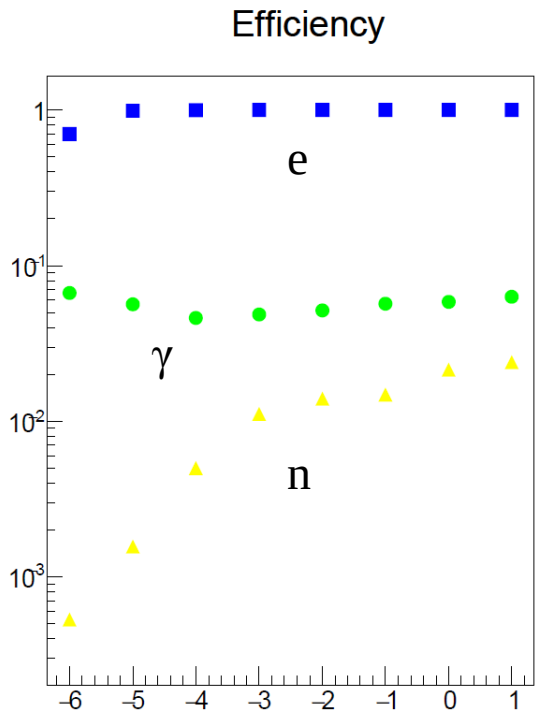
Energy of Photon, electron and neutron



- Energy range
- γ : 10^{-5} – 10GeV
- e: 10^{-6} – 10GeV
- n: 10^{-6} – 1GeV

Particle rate detected by MRPC





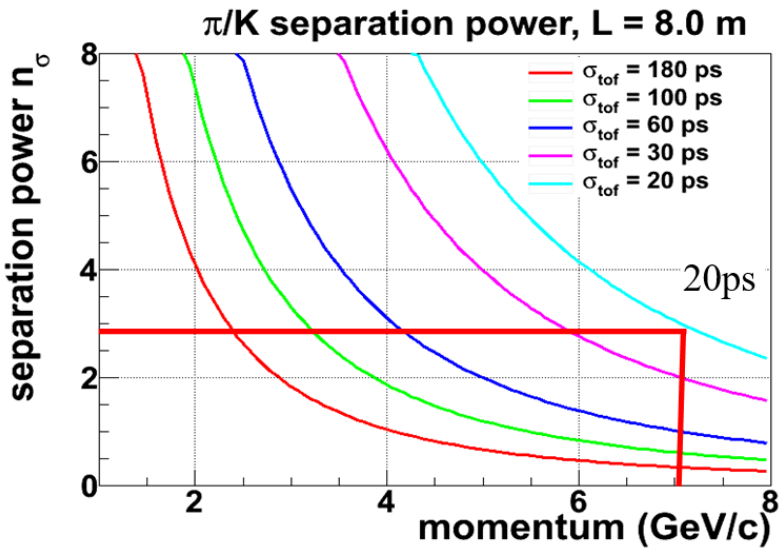
- Detected particle rate
- γ : 12.5kHz/cm^2
- e: 5kHz/cm^2
- n: 0.05kHz/cm^2

Total: 18kHz/cm^2

Main requirements for TOF

- The MRPC is developed for the TOF of SoLID
- Main Requirements for TOF:
  - π/k separation up to 7GeV/c
  - Time resolution < 20ps
  - Rate capability > 20kHz/cm^2

This is big challenge of MRPC-TOF!!



How to reach high rate, high time

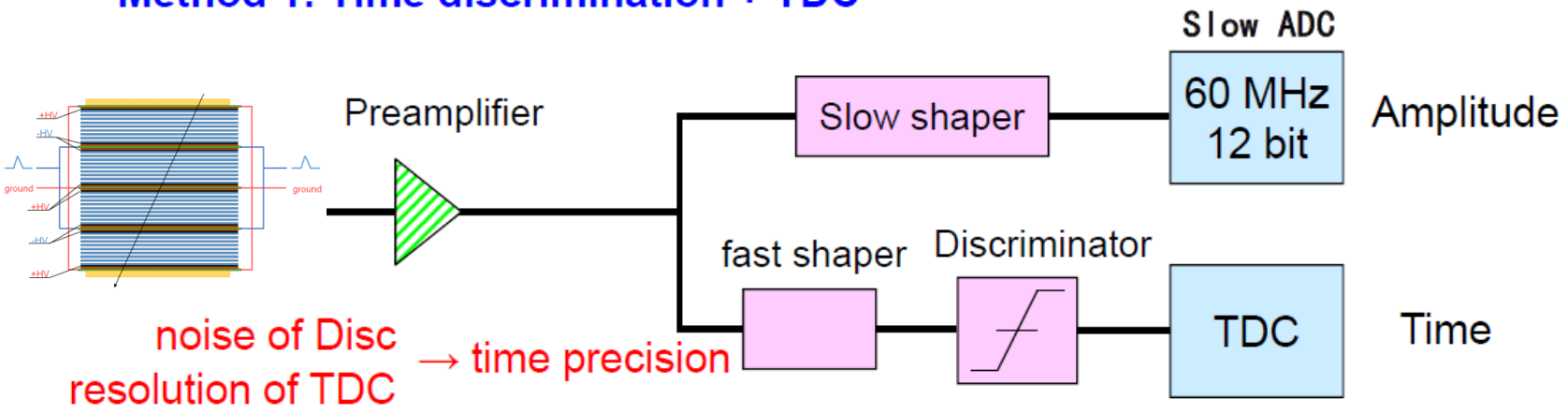
- **Increase rate：decrease the resistivity of glass**

$$\bar{V}_{drop} = V_{ap} - \bar{V}_{gap} = \bar{I}R = \bar{q}\phi\rho d$$

- **Improve TOF resolution**
  - **Reduce the width of gas gap** $\sigma_t = \frac{1.28}{(\alpha - \eta)v}$
  - **Improve precision of electronics**
    - **High speed pulse sampling**
    - **Fast discriminator+high precision TDC**

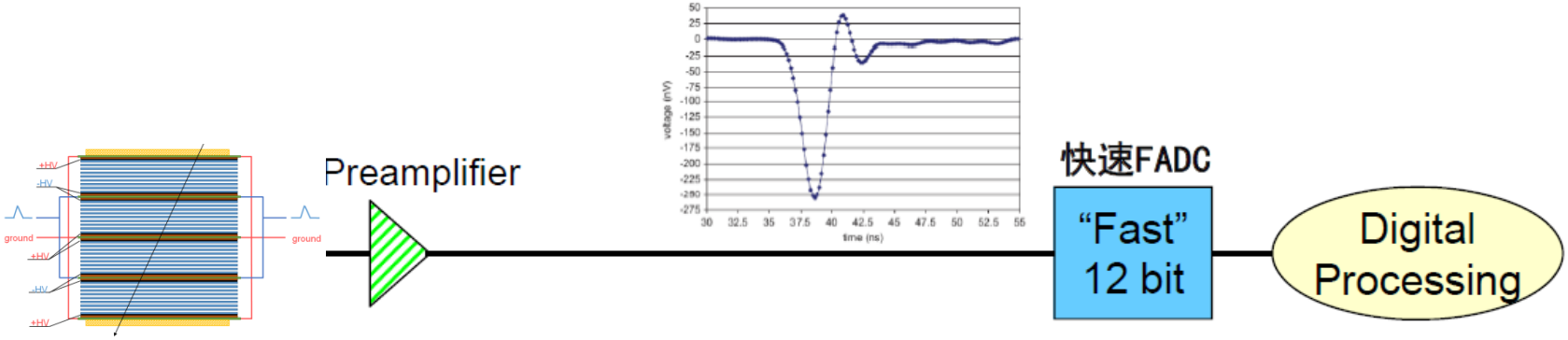
Two technologies

Method 1: Time discrimination + TDC



noise of Disc
resolution of TDC → time precision

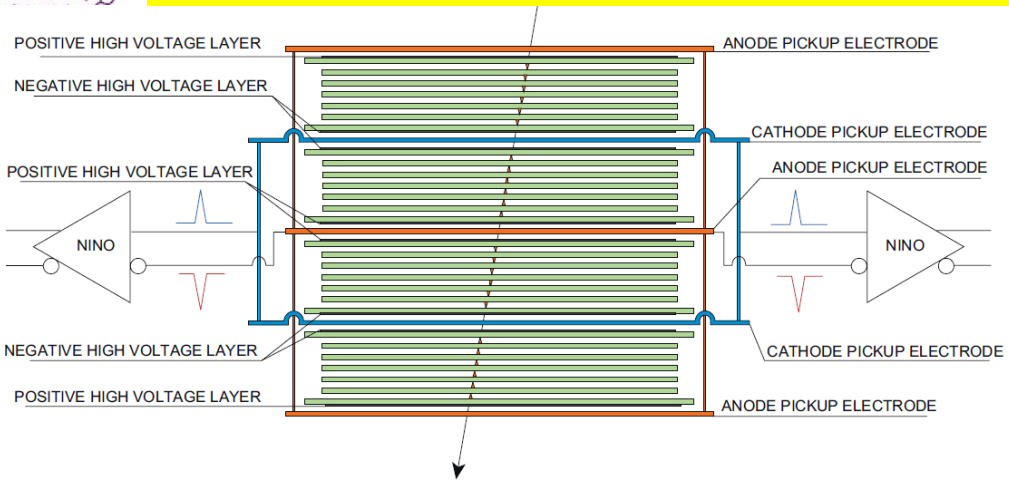
Method 2: Waveform digitization + Digital processing



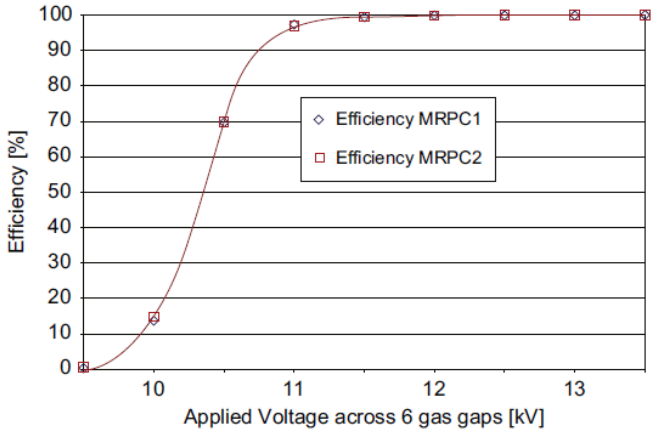
Flash ADC → Power consumption, density, cost

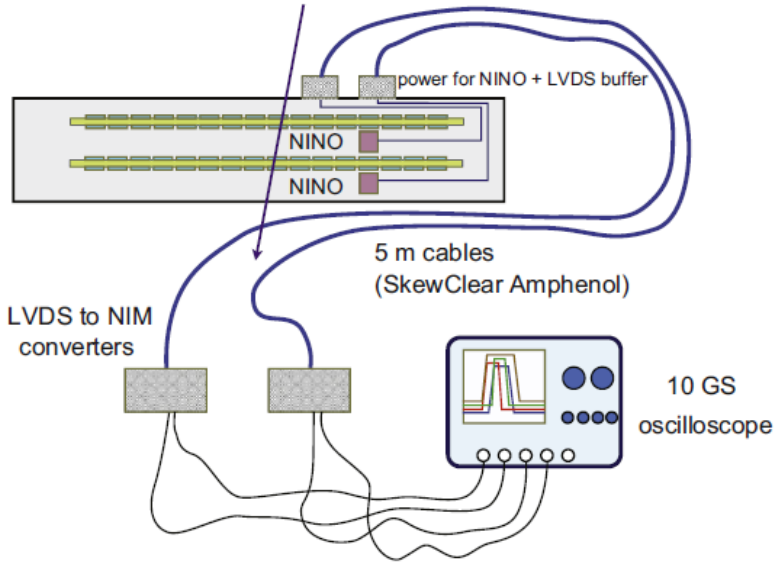
→ Switched Capacitor Array (SCA)

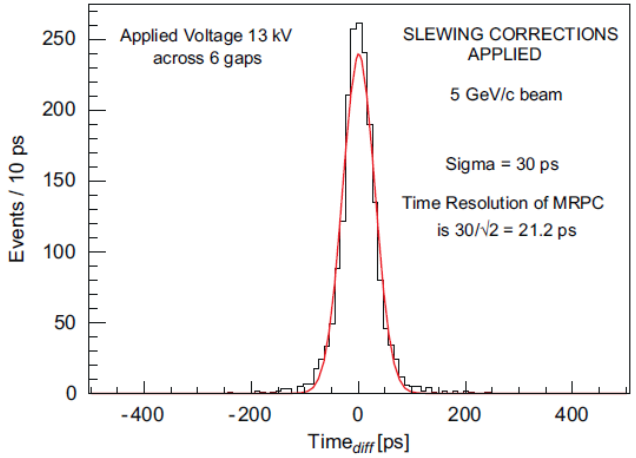
M.C.S Williams' work



M.C.S Williams, 24x160μm gaps, MRPC





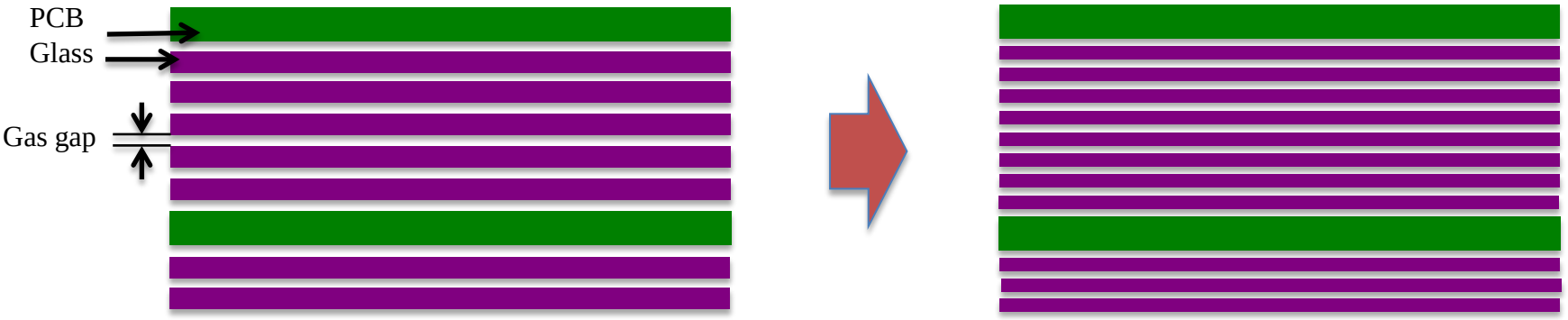


MRPC is assembled with float glass, it's rate <100 Hz/cm^2.

EIC R&D Prototype MRPC

Crispin Williams, CERN, 2010
Gas gap width : 160um

BNL&UIUC Prototype, 2015
Gas gap width : 105um

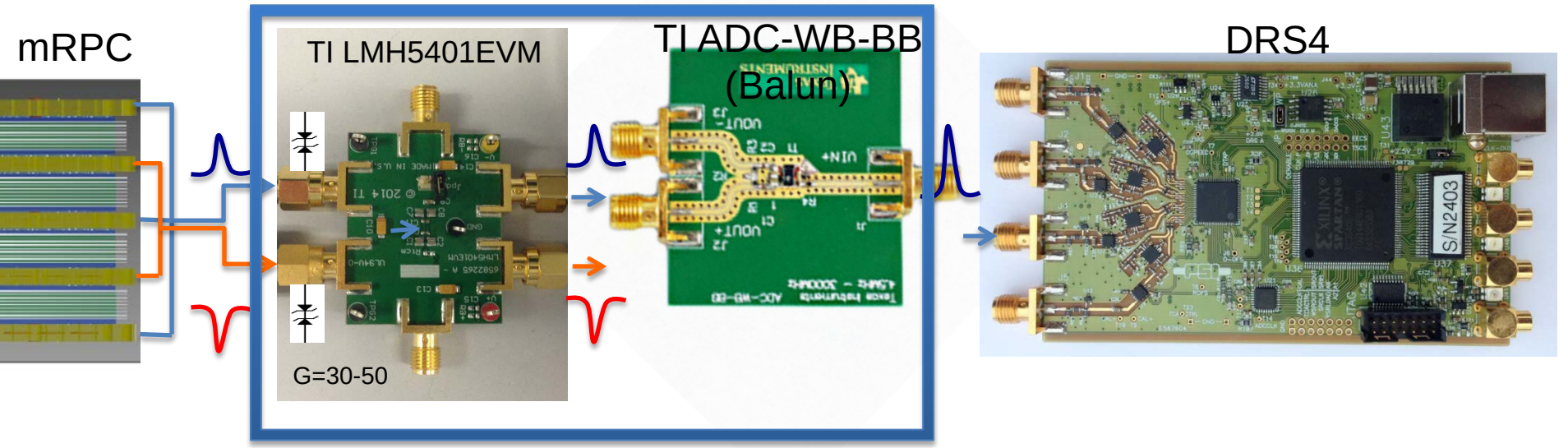


- *Narrower gap width -> fast charge dominant in the induced signal -> Better timing resolution*
- *Efficiency will be recovered by adding more gas gaps*

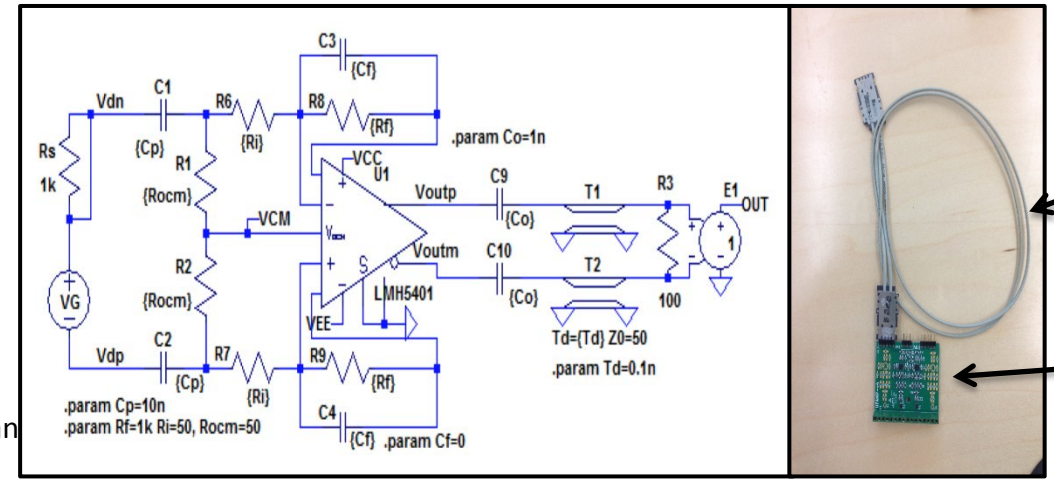
	MRPC (C. Williams et al.)	MRPC (UIUC & BNL)
Gas Gap Width	160um (fishing line)	105um (diameter of fishing line)
# of Gas Gaps	4 stack x 6 gas gaps = 24	4 stack x 9 gas gaps = 36
# of thin glass layers	4 stacks x 5 layers = 20 (250um thick glass)	4 stack x 8 layers = 32 (210um thick glass)
Preamplifier	Differential type, NINO chip (3GHz bandwidth)	TI LMH6554 2.8-GHz Evaluation Board
TDC and DAQ	Oscilloscope (Sampling speed of 10Gs)	DRS4-V5 (5 GSPS) + PC
Time resolution	30 ps with cosmic ray / 16 ps at T10 beam test CERN	??, Cosmic ray test / Beam halo test at COMPASS

Electronics development

- Current test readout chain, using off the shelf electronic components
- Currently with DRS4, only 1-2 channels at a time can be read out
- Need 2 detectors for timing, reading out both ends, so test of 1 ch needs 4 readout ch



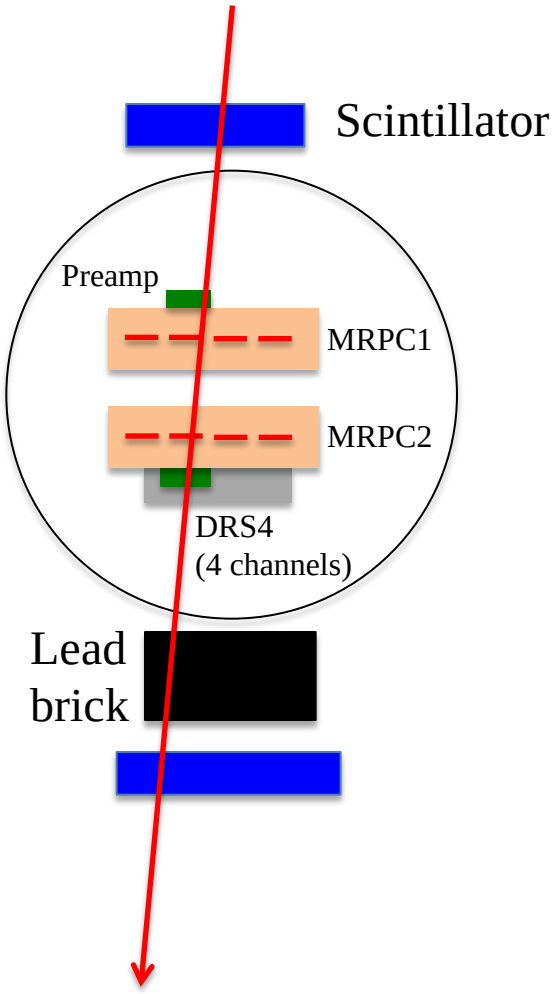
- Custom BNL fast preamp under testing, will help allow many more channels to be read

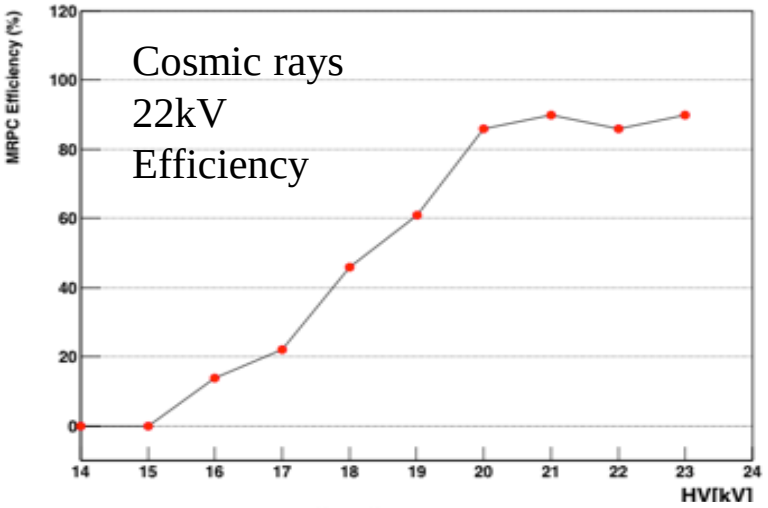


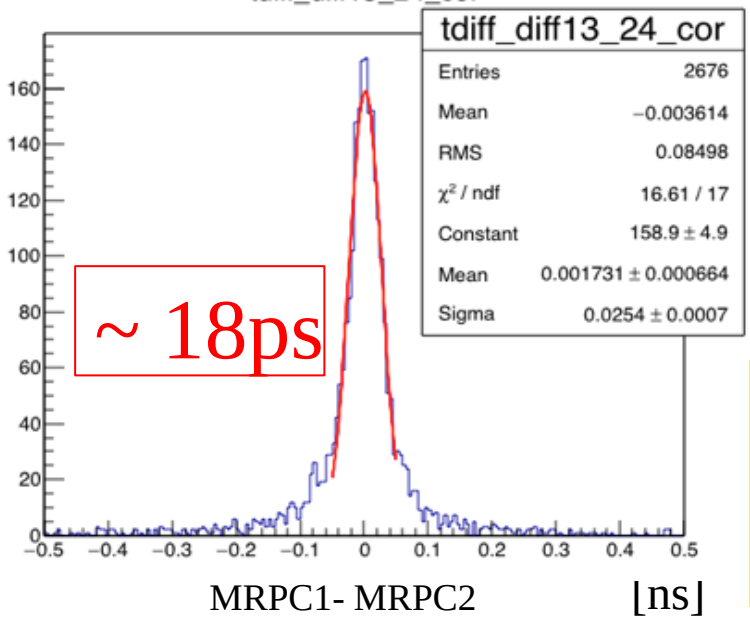
Hard metric 100Ω differential cables

BNL "UFAMP"
4 channel
100Ω differential
900 MHz, 8x gain

Cosmic ray test





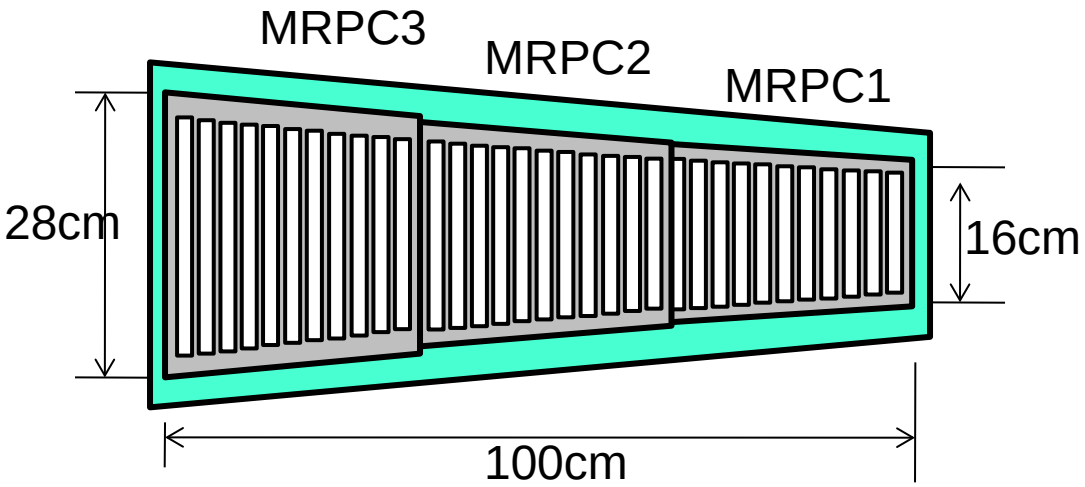


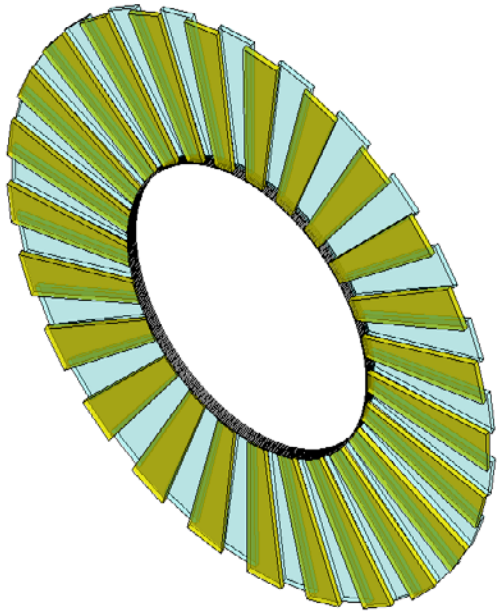
MRPC is assembled with float glass, it's rate <100 Hz/cm^2.

Conceptual design of SOLID-TOF

eV Upgrade
e Science at Jefferson Lab

MRPC TOF wall we designed contain 150 MRPC modules in total, with 50 gas boxes and 3 counters in each box, covering the area of 10m².

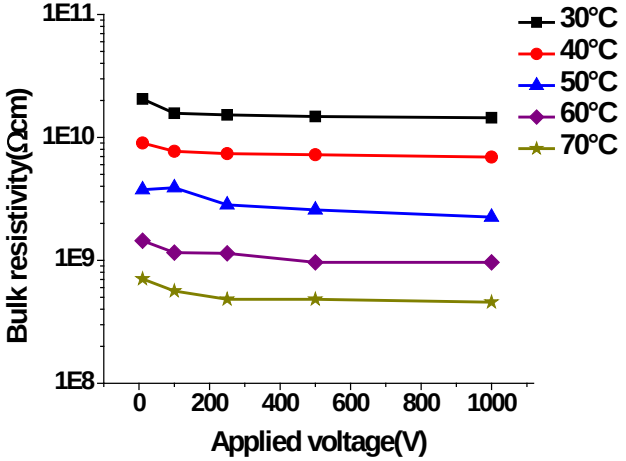




Total channel ~3600

Performance of low resistive glass

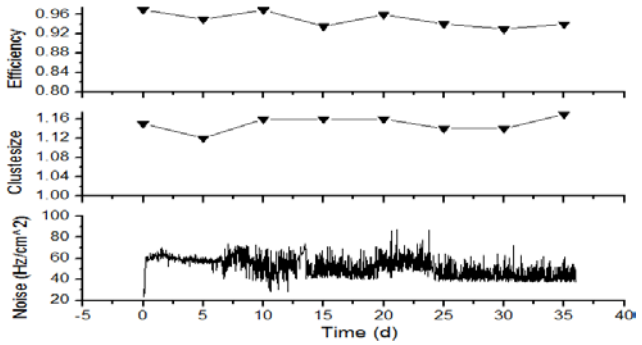
Dimension	33 x27.6cm^2
Bulk resistivity	~$10^{10}\Omega$cm
Standard thickness	0.7, 1.1mm
Thickness uniformity	20μm
Surface roughness	<10nm
Dielectric constant	7.5 - 9.5
DC measurement	Ohmic behavior
	stable up to 1C/cm^2



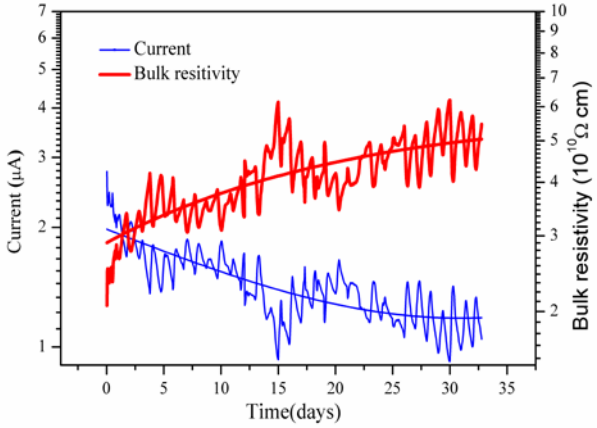
Aging test of the glass

This glass was applied with 1000V for about 32days, integrated charge: 1 C/cm^2

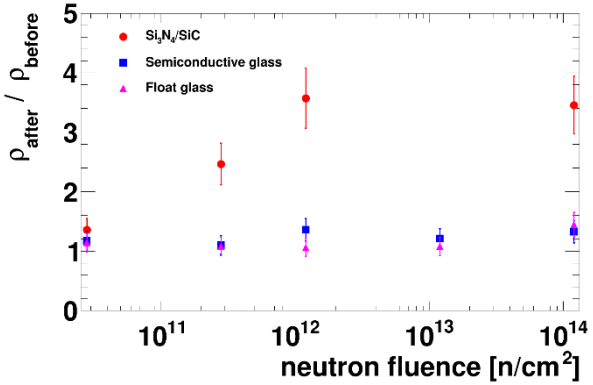
--roughly corresponding to the SoLID life-time over 5 years operation at the maximum particle rate.



X ray irradiation

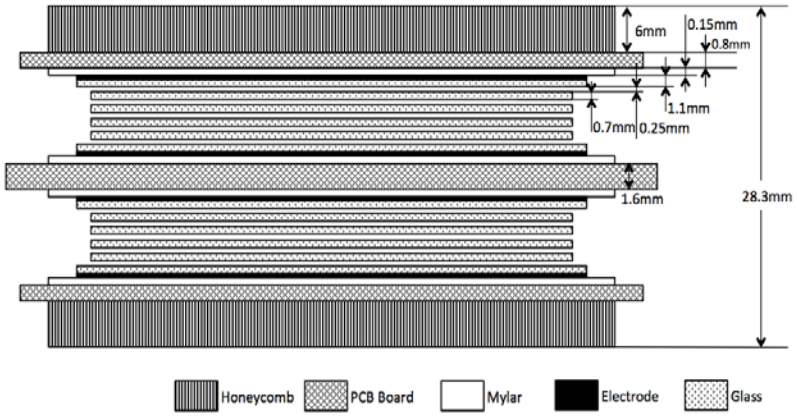


HV test on glass

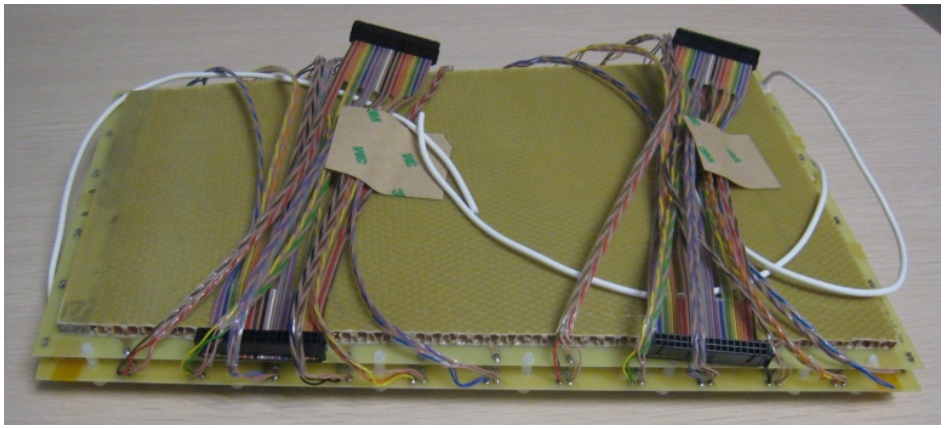


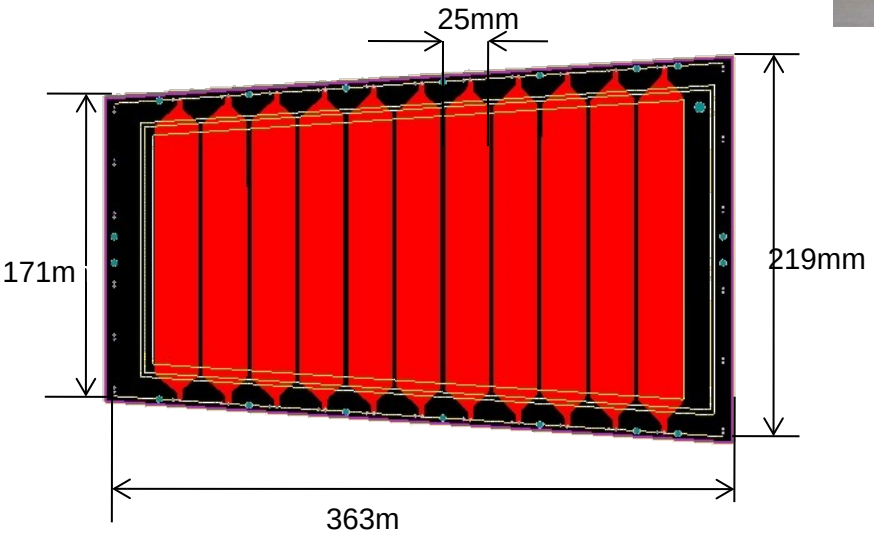
Neutron irradiation

A 2g MRPC prototype for SoLID-TOF



Volume resistivity: ~$10^{10}\Omega$.cm

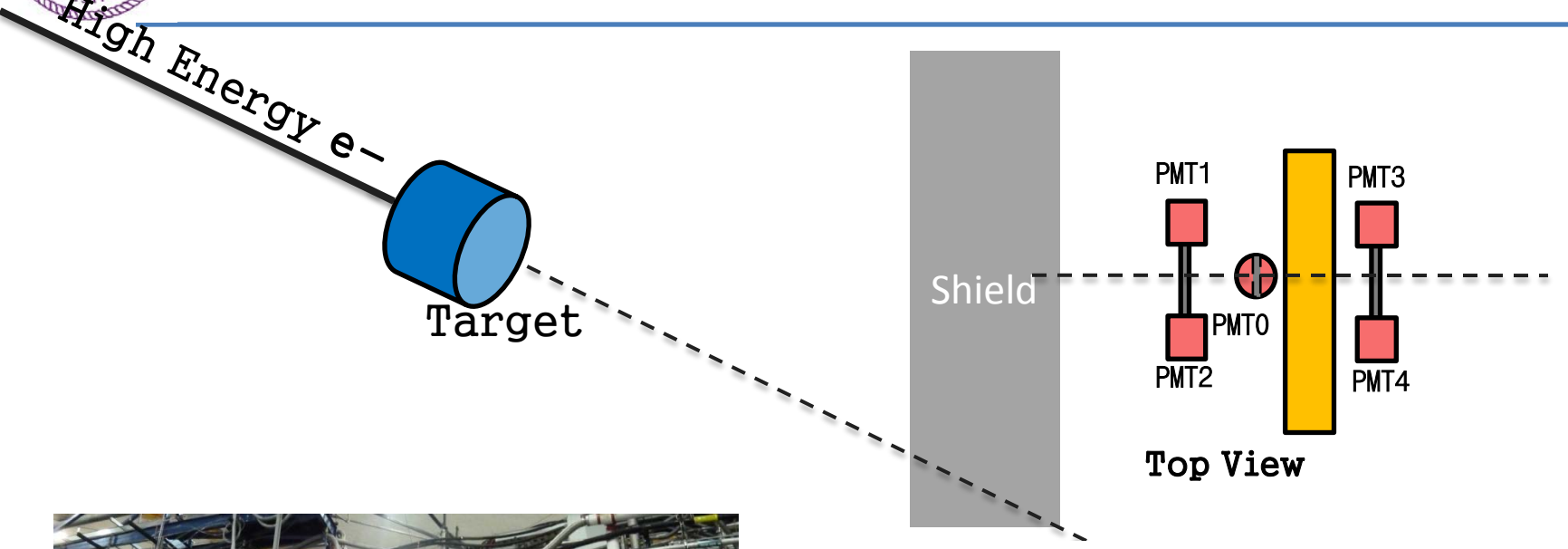




Material dimensions

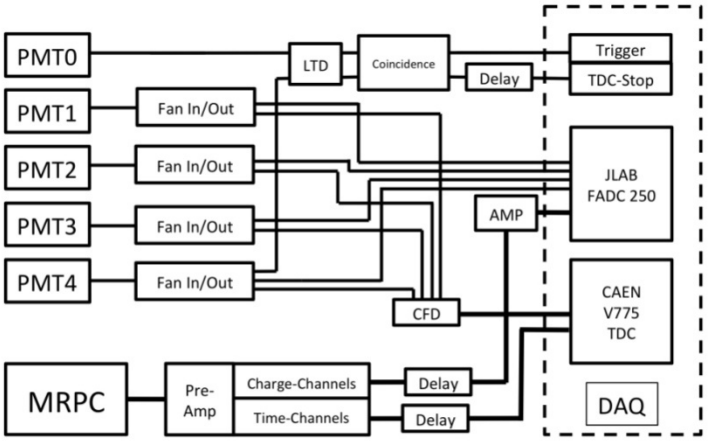
	Length/mm	Width/mm	Thickness/mm
Gas gap	-	-	0.25×10
Inner glass	320	130-171	0.7
Outer glass	330	138-182	1.1
Mylar	335	153-198	0.18
Inner PCB	350	182-228	1.6
Outer PCB	350	172-218	0.8
Honeycomb	330	153-198	6

Beam test @ Hall A



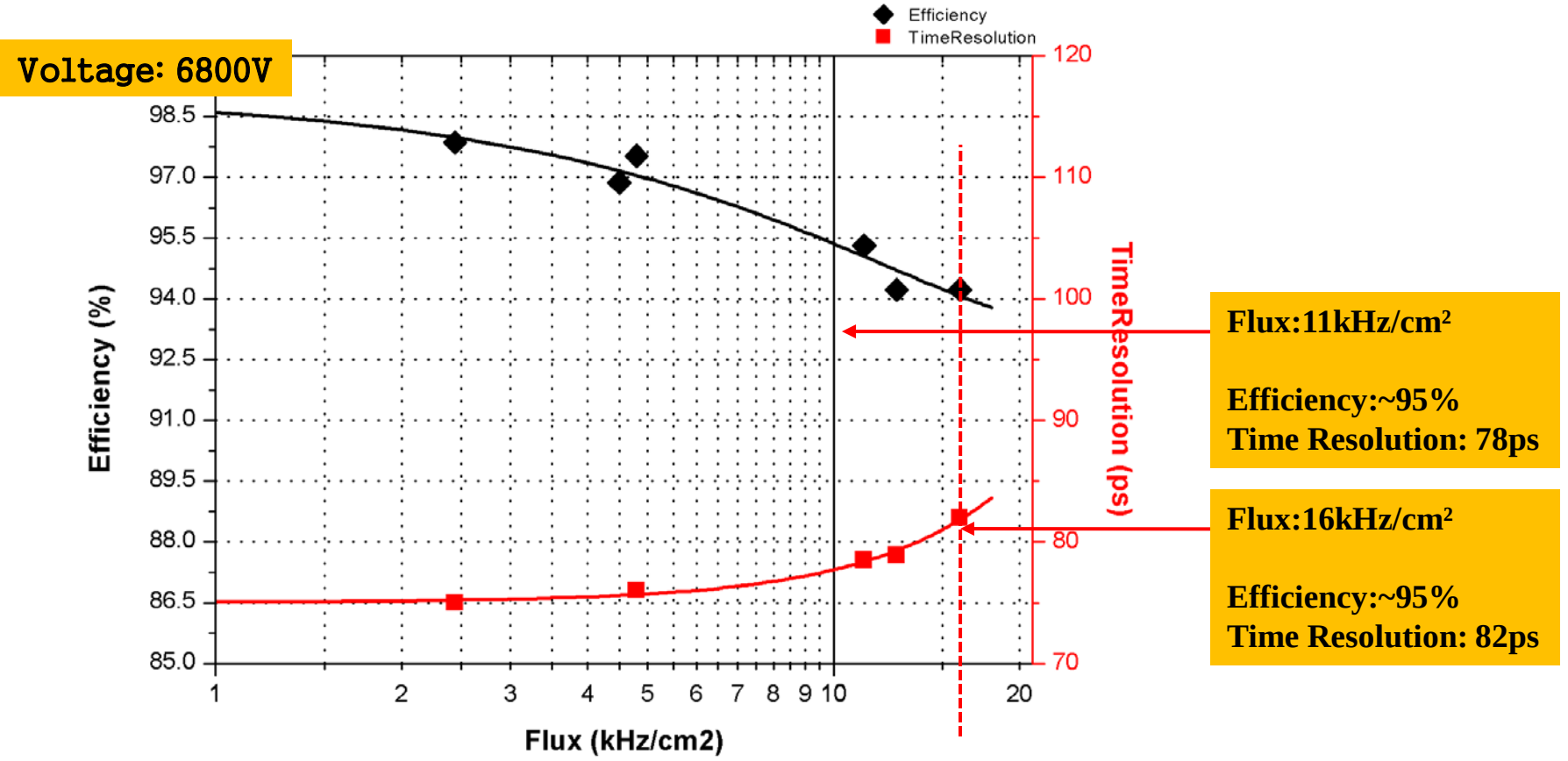
Target

Test setup



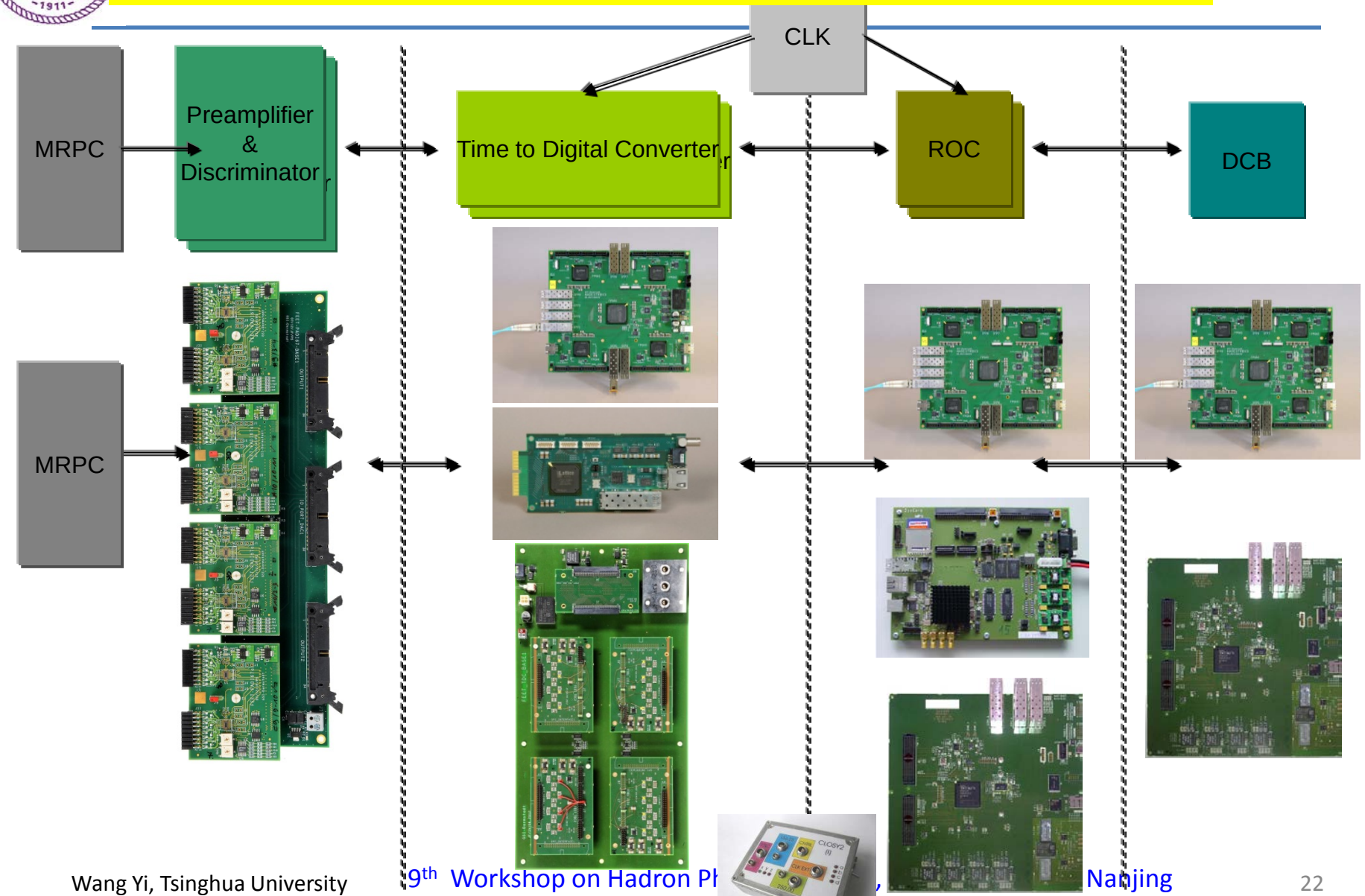
The diagram of DAQ system

Rate Performance



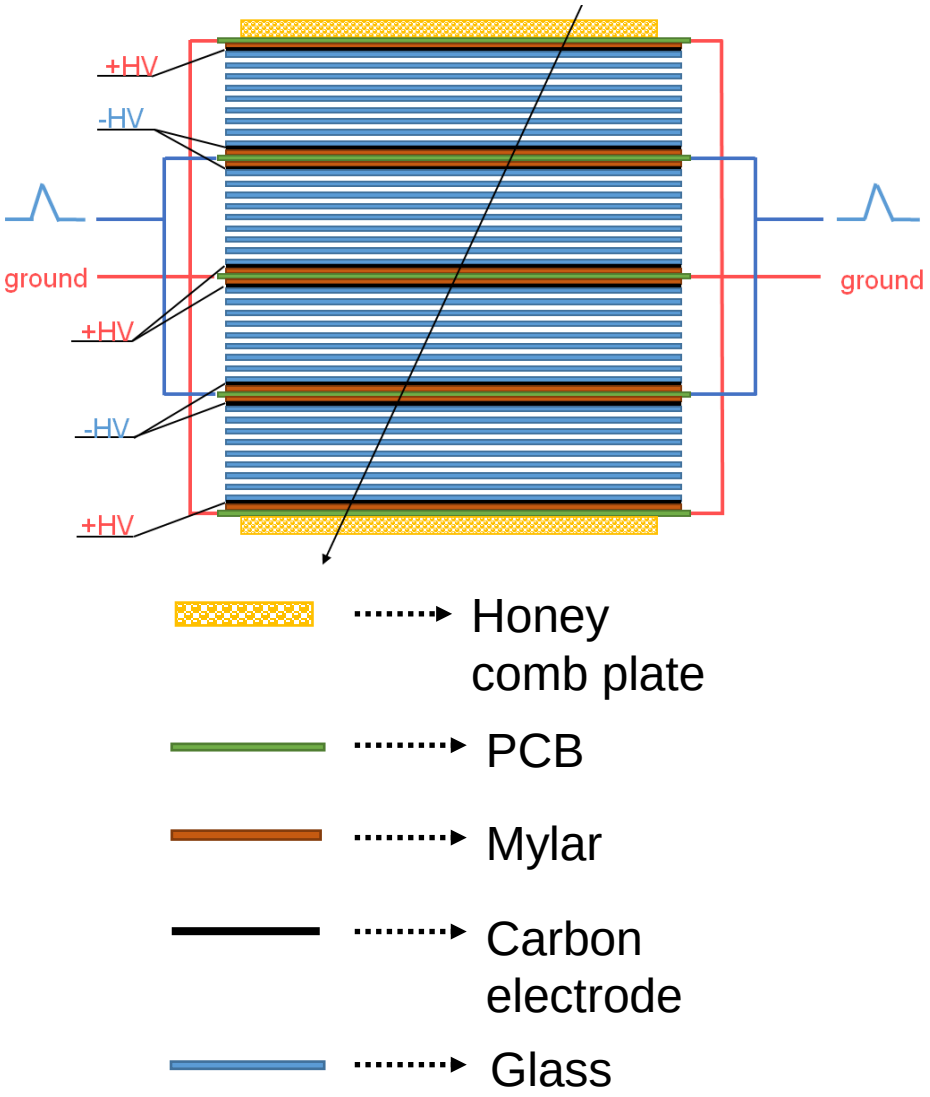
Wan Yi. A MRPC prototype for SOLID-TOF in Jlab. 2013_JINST_8_P03003

TOF readout chain with PADI and GET4

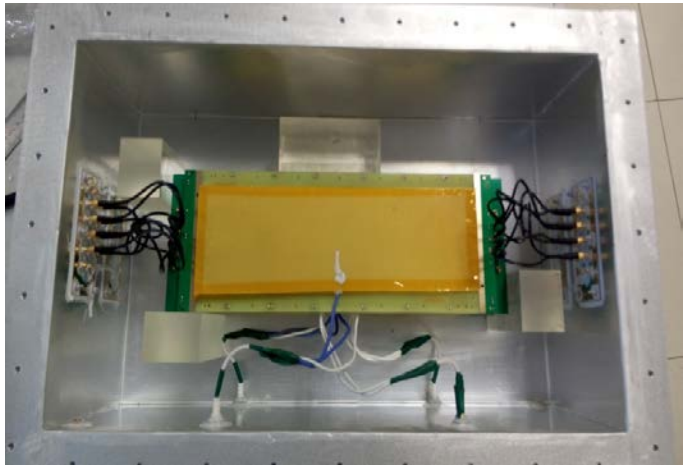


Design of 3g MRPC for SoLID

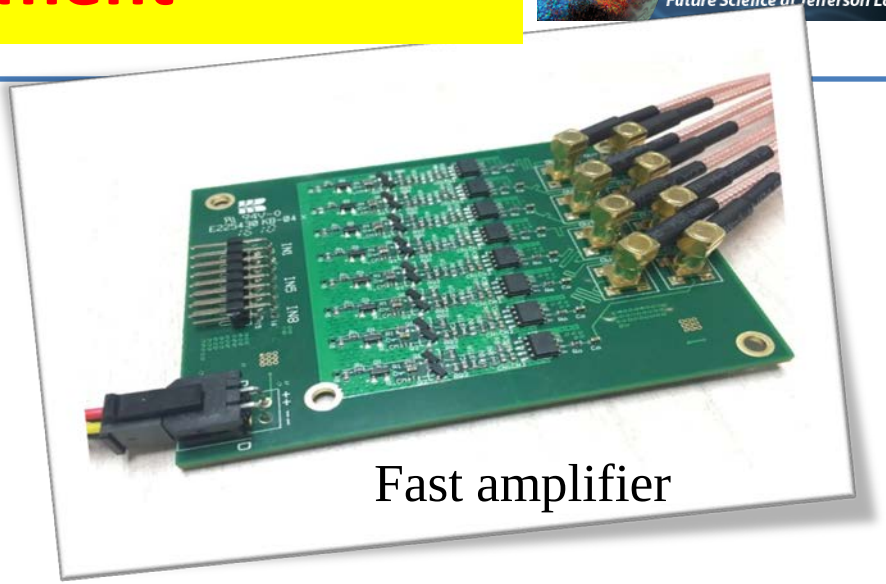
Item	dimension/mm
Honeycomb	90×265×7.5
Outer PCB	120×298×0.6
Middle PCB1	120×298×1.2
Middle PCB2	120×328×1.2
Strip length	268
Strip width	7
Mylar	90×268×0.25
Glass	80×258×0.5
Carbon	72×250
Gas gap width	0.104
Number of gas gap	32



Test equipment



Gas box

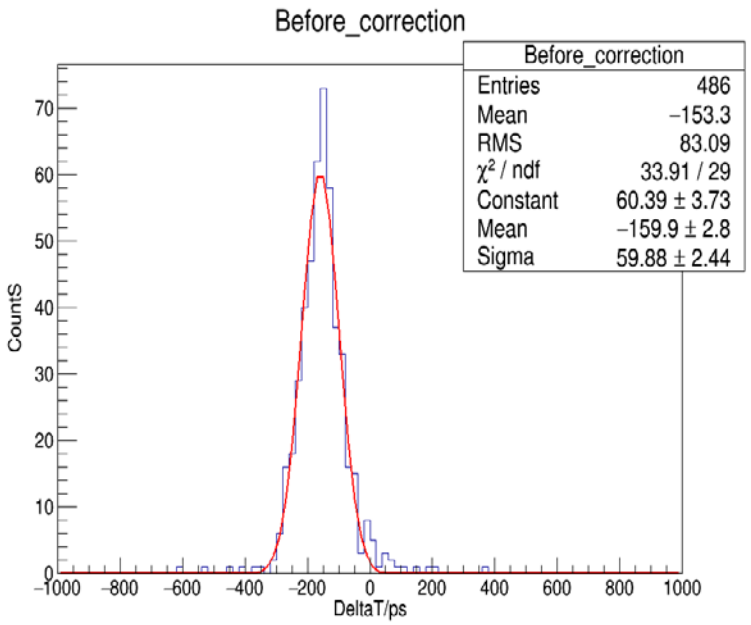


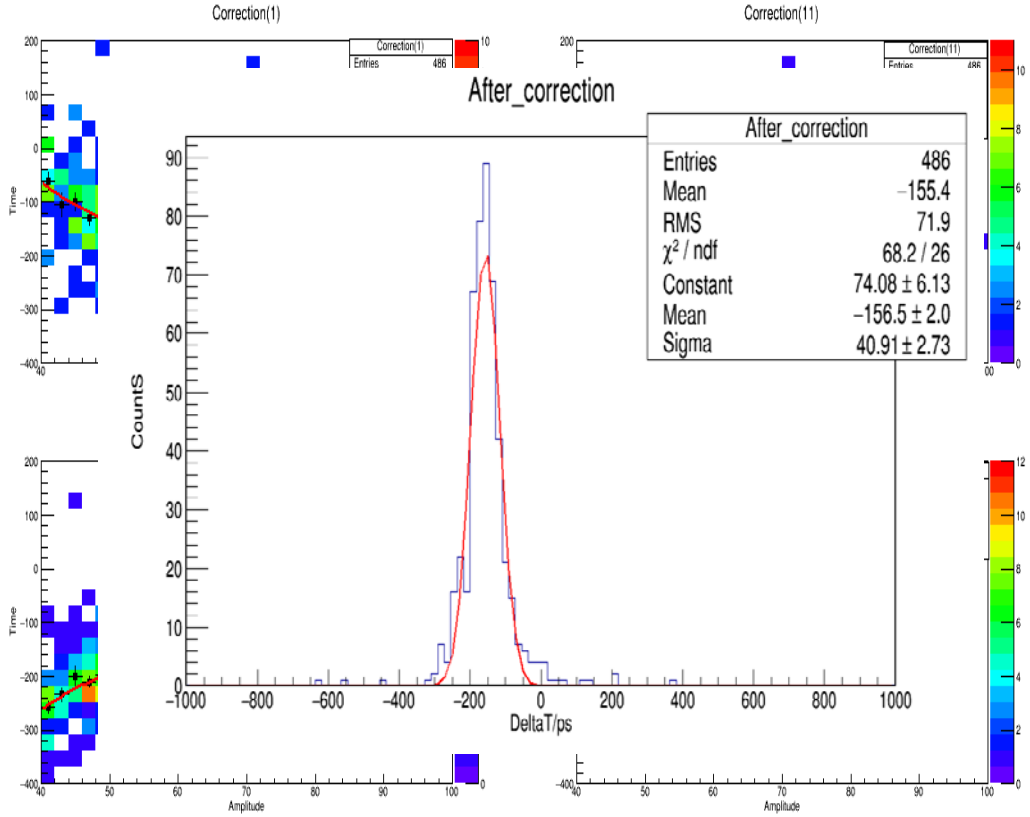
Fast amplifier

Waveform Digitizer DT5742

- DRS4-V5 chip
- 16 channels
- 12bit 5GS/s
- 5 points for leading edge of MRPC

Time resolution





$$\sigma_{MRPC} = {}^{\sigma_t}/_{\sqrt{2}} = {}^{40.91}/_{\sqrt{2}} = 28.93ps$$

Next to do

- **NSFC key project: Development of high rate and high time resolution TOF**
  - **Simulation to get : Width of gas gap→ time resolution**
  - **Development of high rate 15ps resolution MRPC**
  - **Development of 15ps jitter SCA, fast amplifier and TDC**
  - **Impedance math**

- **Study "ecological" gas mixture for high rate MRPC**

The "ecological" gas issue

- **The European Community has prohibited the production and use of gas mixtures with Global Warming Power > 150 (GWP(CO_2) = 1)**
  - ✓This is valid mainly for industrial (refrigerator plants) applications
  - ✓Scientific laboratories would be excluded
  - ✓CERN could require to stick to these rules anyhow
- **$C_2H_2F_4$ is the main component of the present RPC gas mixture:**
  - ✓GWP($C_2H_2F_4$) = 1430, GWP(SF_6) = 23900, GWP(iC_2H_{10}) = 3.3
- $C_2H_2F_4$ and SF_6 Crucial to ensure a stable working point in avalanche
- To test molecules similar to $C_2H_2F_4$ but with lower GWP

  $C_3H_2F_4$ – tetrafluoropropene (GWP=4)

  ✓**Should replace $C_2H_2F_4$ as automotive air-conditioning refrigerant**

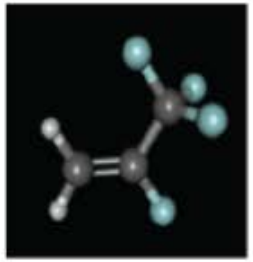
✓other possibility could be CF_3I – Trifluoroiodomethane with GWP ~ 0 & ODP ~ 0

Possible eco-gas Replacements

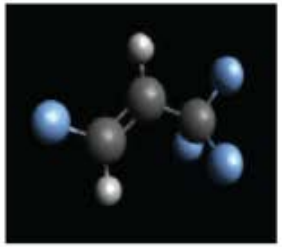
Tetrafluorepropene ($C_3H_2F_4$)

It cames in two allotropic forms

HFO-1234ze



HFO-1234yf



Molecule	CCl_2F2	CF_4	R134a
Ionization energy (eV)	10.24	12.81	12.40
Molecule	R152a	HFO1234ze	HFO1234yf
Ionization energy (eV)	10.78	9.34	9.37

Molecule similar to R134a ($C_2H_2F_4$) BUT

HFO-1234 GWP=4

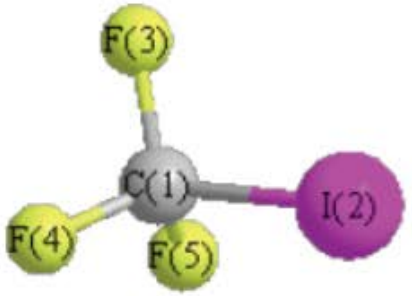
R134a GWP = 1430

HFO-1234yf HMIS code =2
(moderate flammability)

In this talk we concentrate on HFO-1234ze

(HFO in the labels will mean HFO-1234ze)

Trifluoroiodomethane (CF_3I)

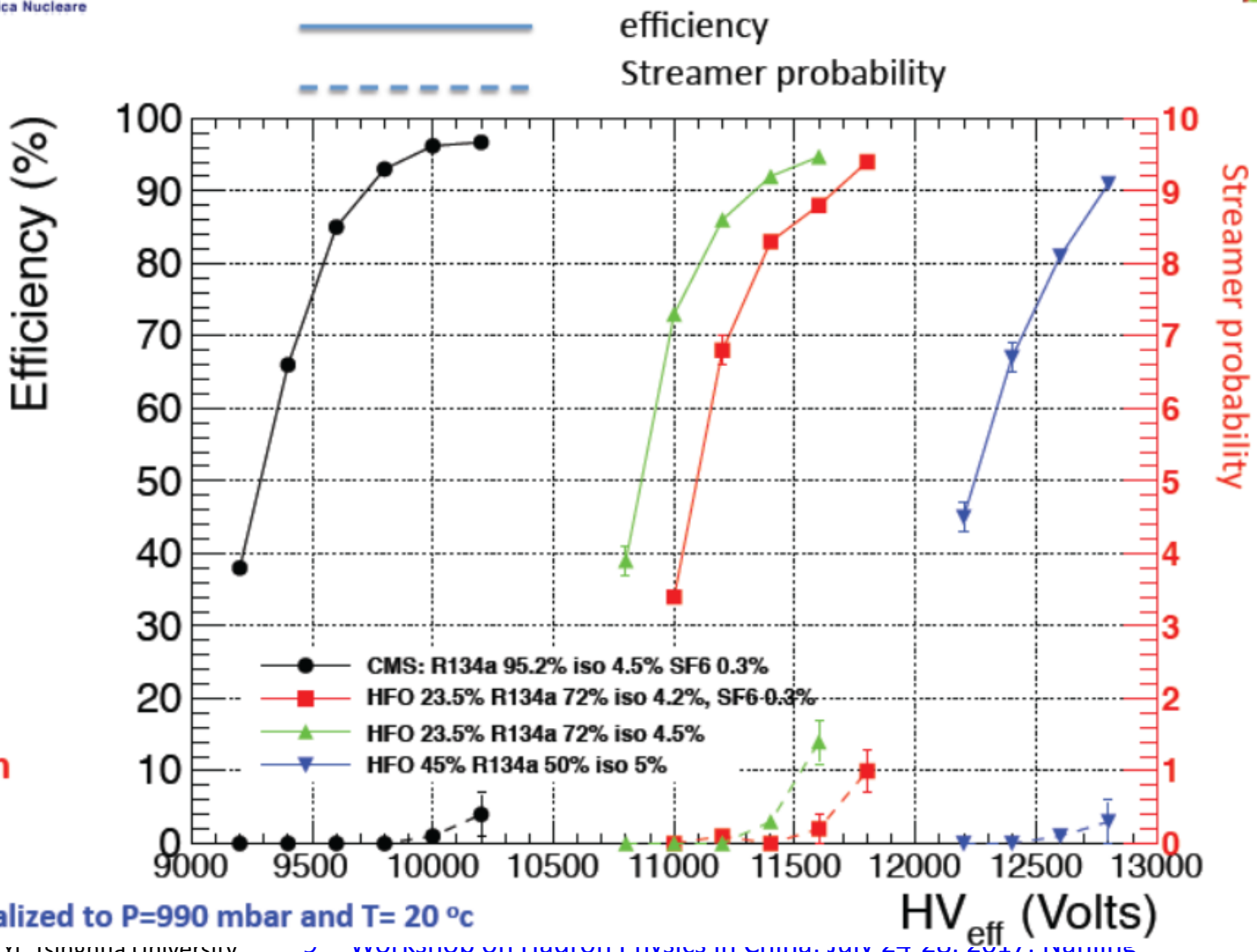


GWP and ODP close to 0

High quenching power

Very expansive ! We were able to buy just a small bottle of 0.5 kg for very few preliminary tests

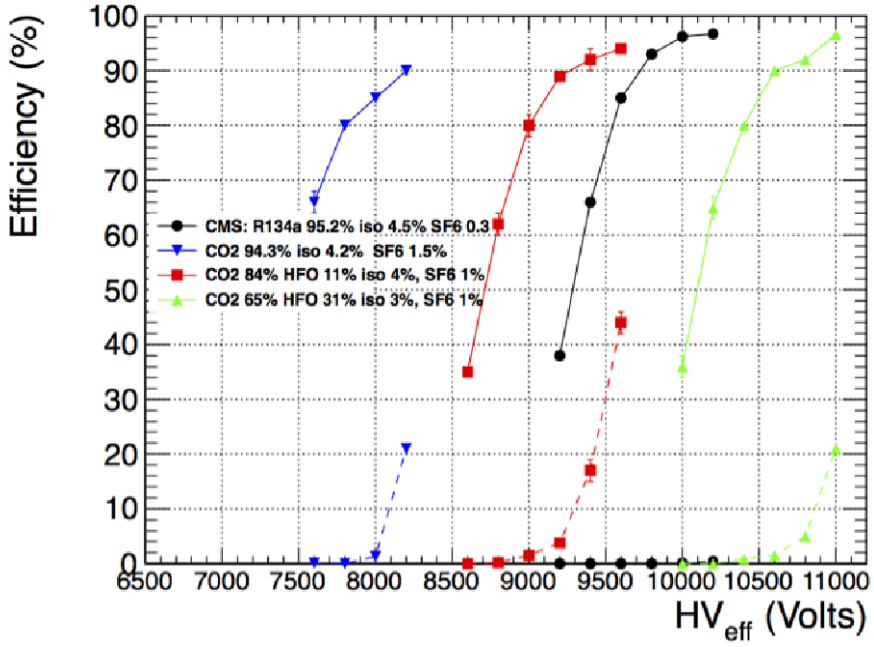
Replacing R134a with HFOze

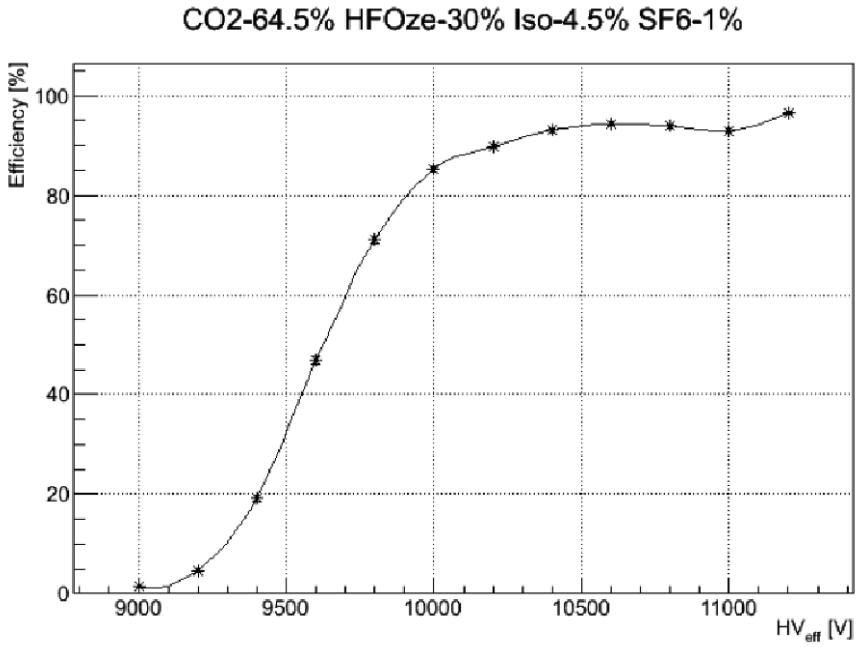


LNF Test station

HV normalized to P=990 mbar and T= 20 °c

- Eco-gas candidate is 4-component mixture:
  - CO_2 / HFOze / Isobutane / SF_6





Conclusions

- **3g MRPC-TOF is high rate (20kHz/cm^2) and high time resolution (20ps).**

  The time resolution of MRPC: <15ps

  Time jitter of electronics: <15ps

  This technology is a big challenge

- **Search ecological gas mixture is meaningful and urgent**

Thanks for your attention !