# CMS-RPC Project and Detector R&D in Peking University, China

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# Outlook:

## CMS-RPC Project:

- RPC at CMS and PKU's task
- R&D of RPC detector
- Production, assembly & test, installation and commission

## CMS $\mu$ system upgrade:

- low eta $4^{th}$ station RE4 project
- high eta GEM detector R&D

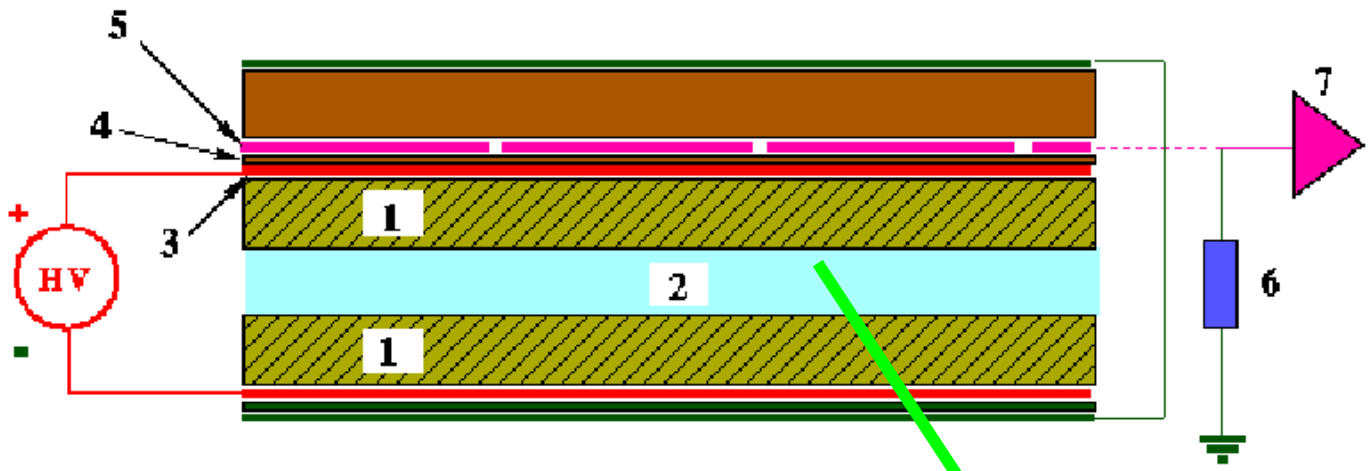
## Other detector R&D at PKU:

- multi-neutron correlation detector
- Cosmic $\mu$ tomographic imaging using glass RPC detector

## Summary

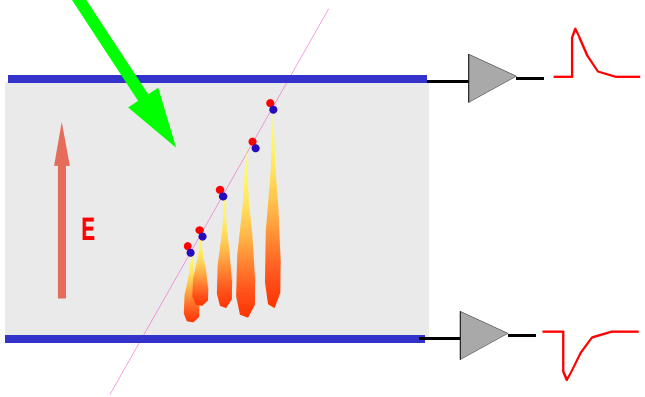
# ➢ CMS-RPC Project at PKU

## Basics of Resistive Plate Chamber




The chamber structure:

- Gap: 2 mm;
- HV electrodes : 100 μm graphite
- Gas pressure : ~ 1 Atm
- Gas mixture: ~ 95% F134a, ~ 4.5% Iso-Butane, 0.5%$SF_6$;
- bakelite resistivity $10^{10}$- $10^{12}$ Ωcm



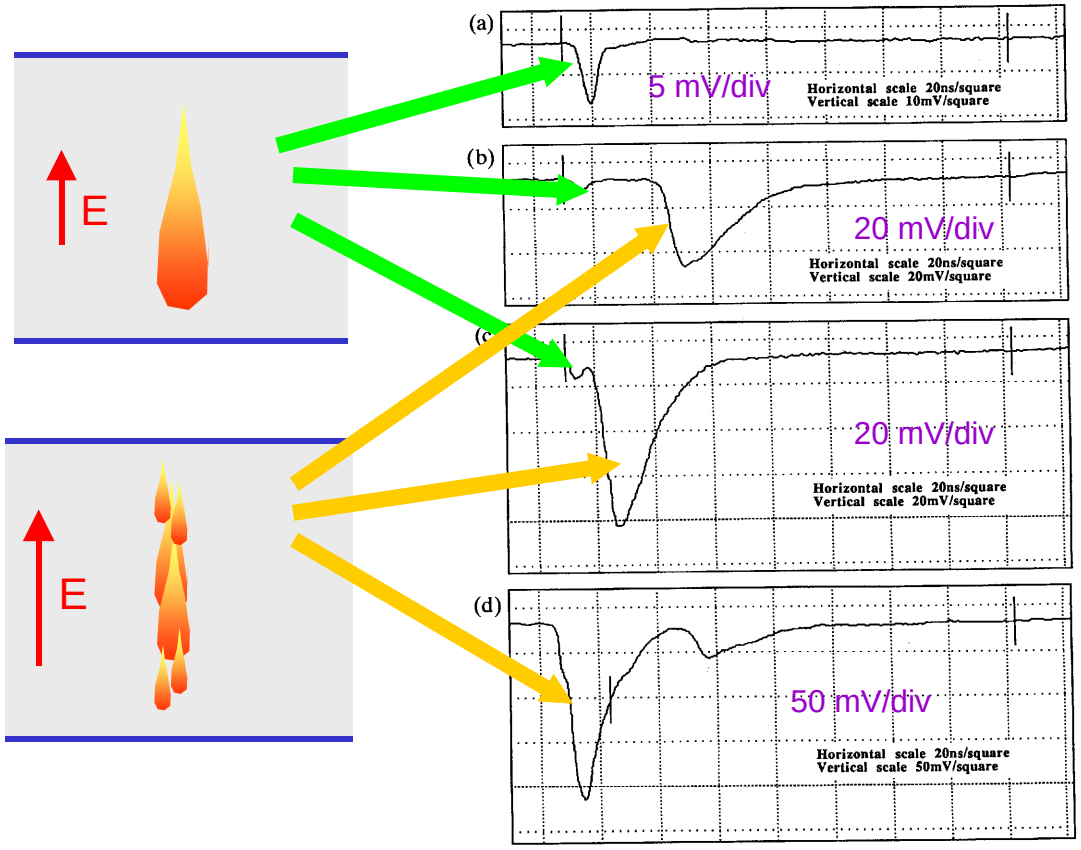

⇒The signal is induced on the read-out electrodes.

# Basics of Resistive Plate Chamber: working mode

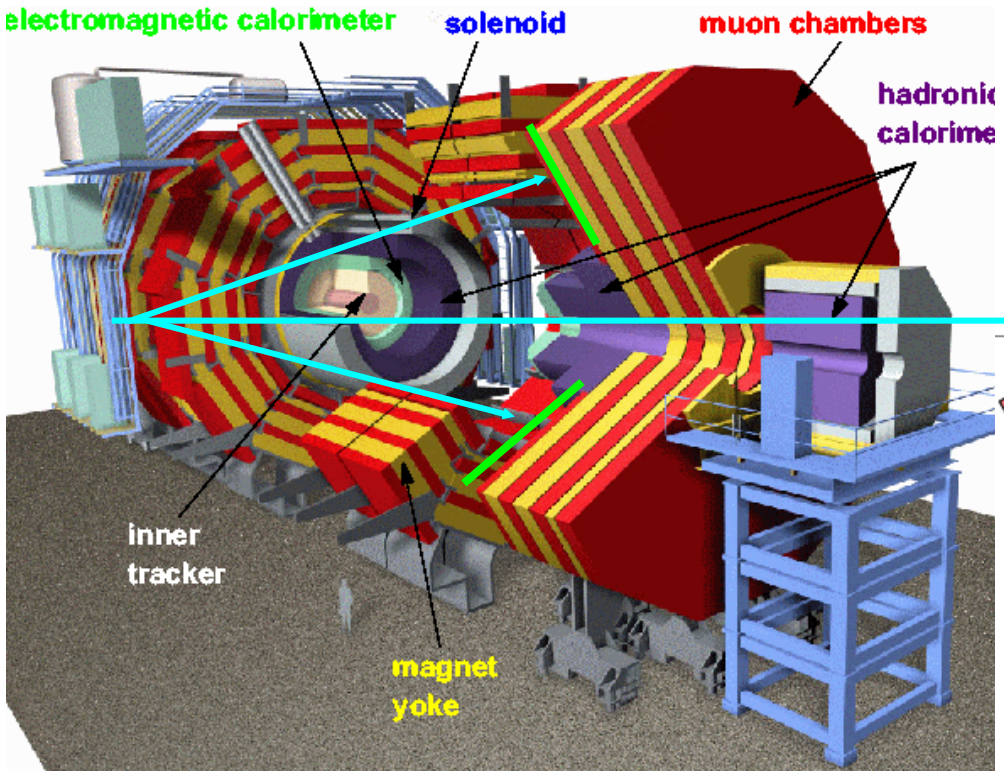
⇒ Avalanche:
The electric field is such that the electron energy is larger than the ionising potential

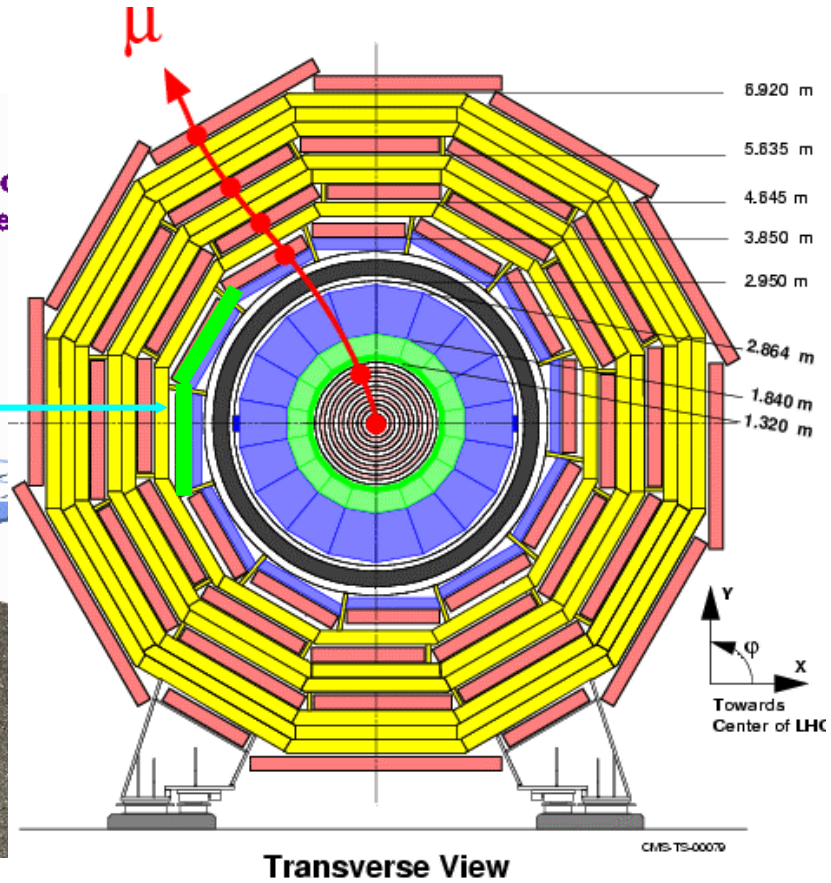
⇒ The separation avalanche-streamer decreases with increasing HV .

⇒ CMS-RPC will work at <u>avalanche mode</u>, to ensure the proper operation at very high rate.



# CMS-RPC Project: RPC system at CMS detector




China's share of task:

- RE1/2, RE1/3 of end-cap RPC (totally 144 detectors);
- RB1(in,out) of Barrel RPC (totally 120 detectors);

# History and milestone of CMS-RPC in PKU:

- 1996: PKU became CMS member; proposed to join CMS-RPC project;
- 1997: NSFC-CERN signed the cooperation agreement;
- 1998: RPC R&D and laboratory construction started; fund application for RPC approved by NSFC;
- 1999: China signed MoU with CMS;
- 2000: first RPC made of Chinese material beam tested successfully at CERN;
- 2001: full size RPC test assembled at CERN;
- 2002: full size, "thin" designed RPC assembled and tested successfully at CERN;
  barrel mechanics mass production started;
- 2003-2006: end-cap RPC mass production;
- 2006-2009: RPC installation and commission;
- 2009-2011: RPC operation and maintenance, low eta (RE4) and high eta RPC (GEM) detector upgrade R&D,
- 2012-: RE4 upgrade mass production

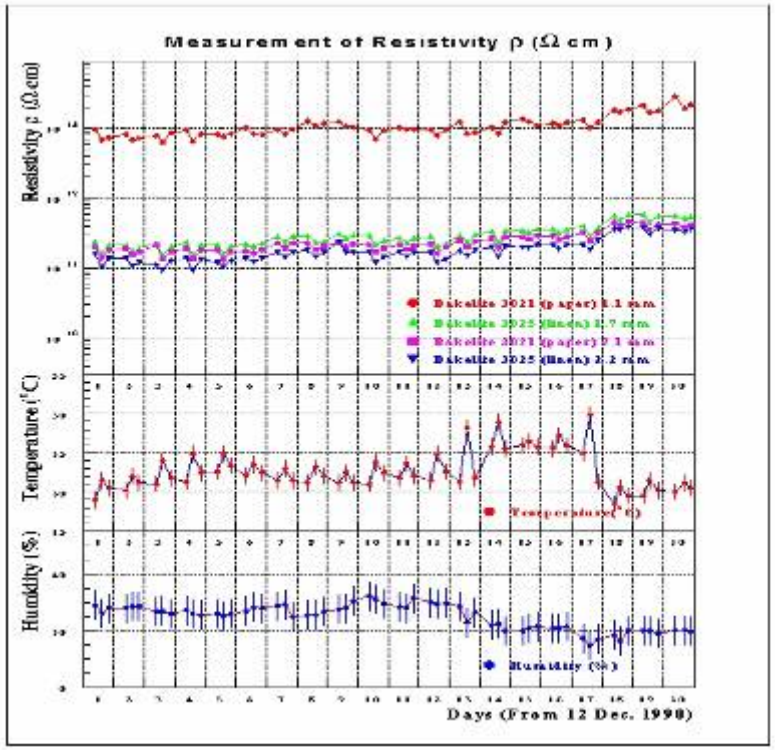
# Study of RPC detector at PKU

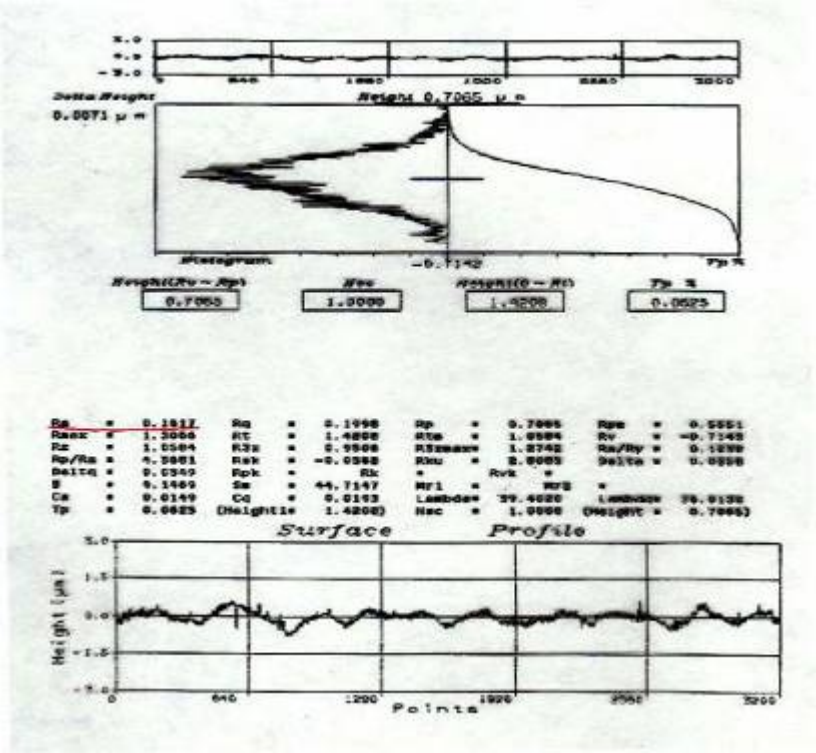
⇒To understand the characteristics and the technical details of the RPC detector, before we really start on the CMS-RPC project.

⇒ Using Chinese material to build a RPC: collaborated with the factory to fabricate resistive plate (bakelite + melamine).

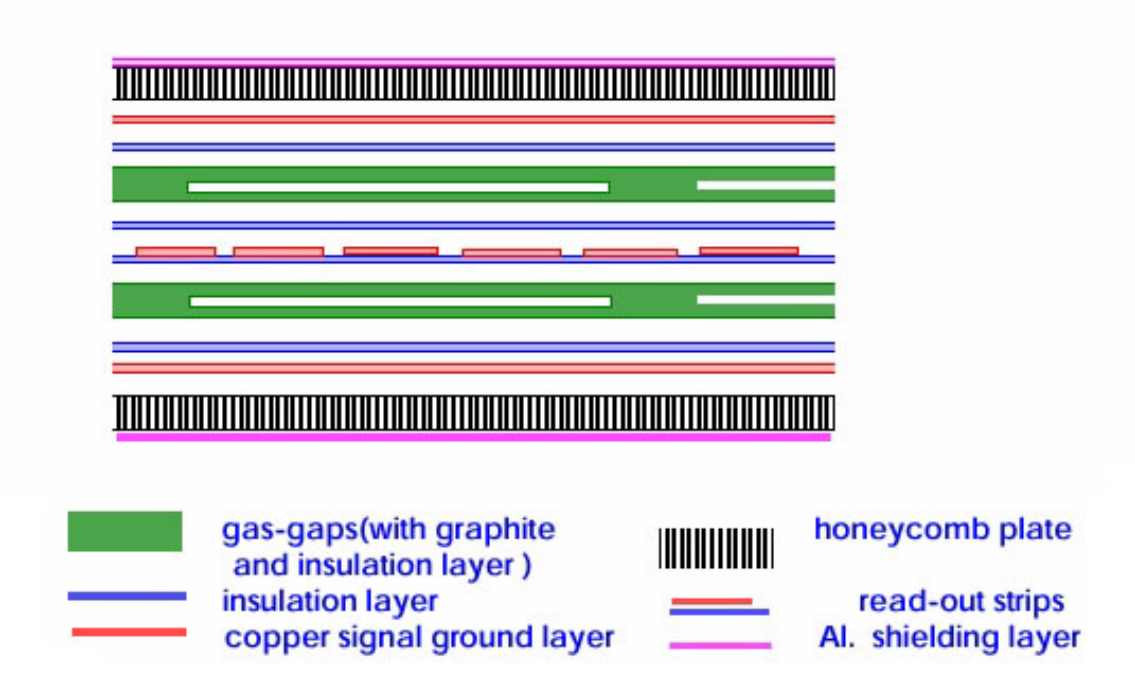
⇒ Two crucial characteristics affect the detector property:

Resistivity and surface smoothness.



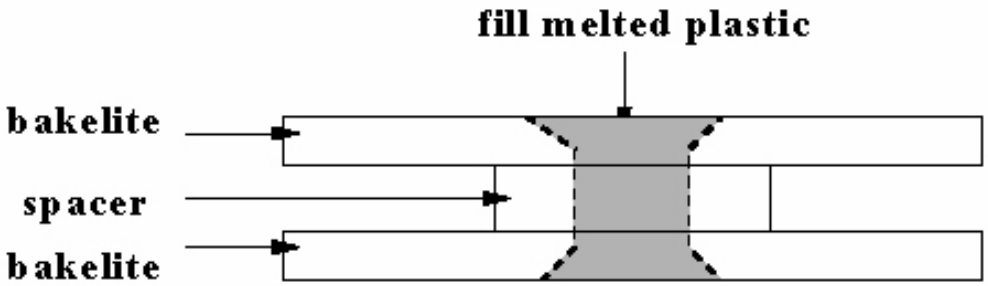
# RPC made of Chinese material:



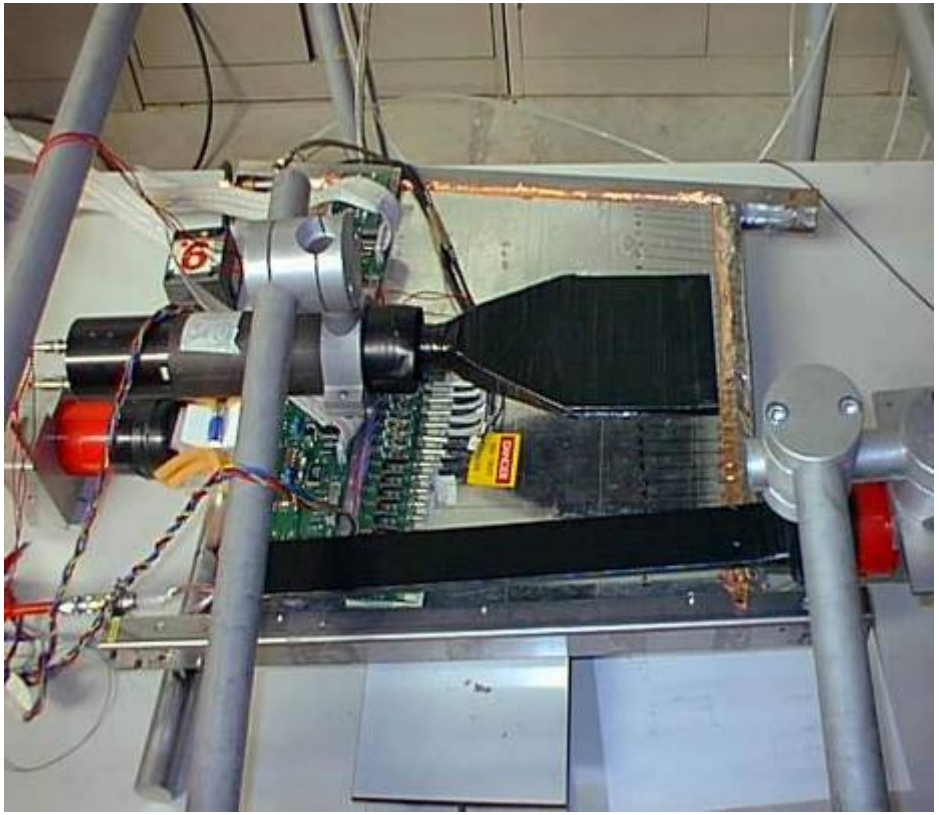

Detector structure:

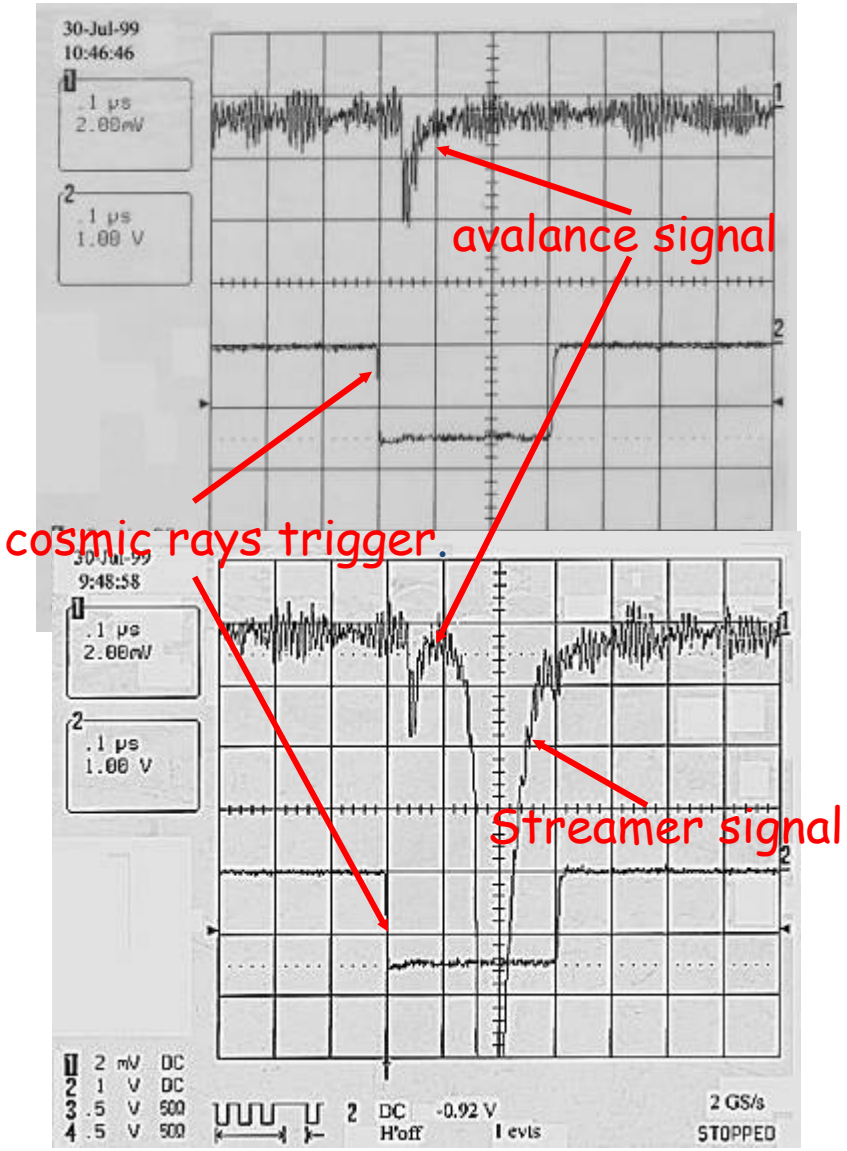
- Trapezoid shape, area ~ 0.6X0.6 $m^2$;
- Double gas-gaps: 2 mm;
- Read-out strip plane between the two gas-gaps;
- bakelite resistivity: ~ $10^{12}$- $10^{13}$ $\Omega$cm .

Special spacer structure: Try to make the chamber more robust.



# Cosmic ray test of the RPC prototype





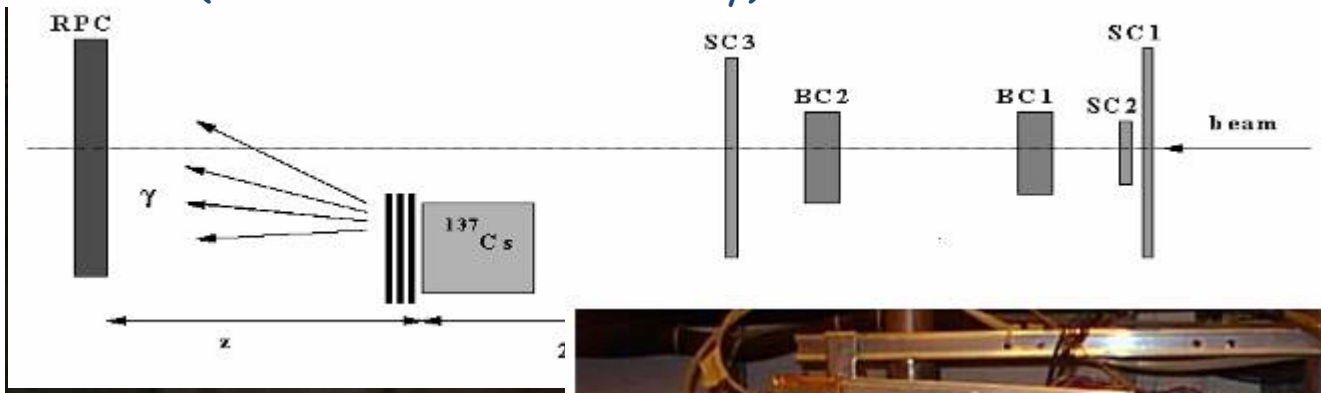

The RPC prototype was being tested by cosmic rays:

⇒ 3 layers of scintillator construct the cosmic-ray telescope.

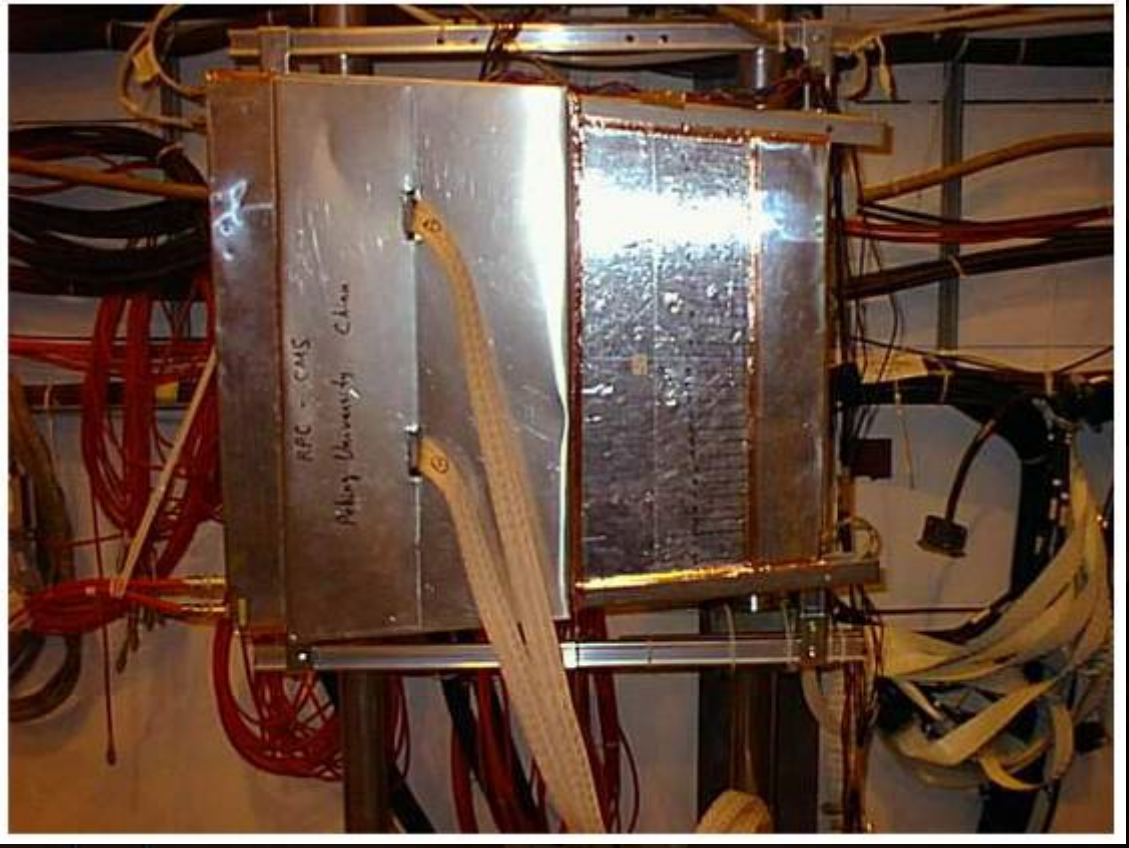
⇒ s small percentage of $SF_6$ killed the streamer signal .

# Beam test of Chinese RPC prototype at GIF of CERN

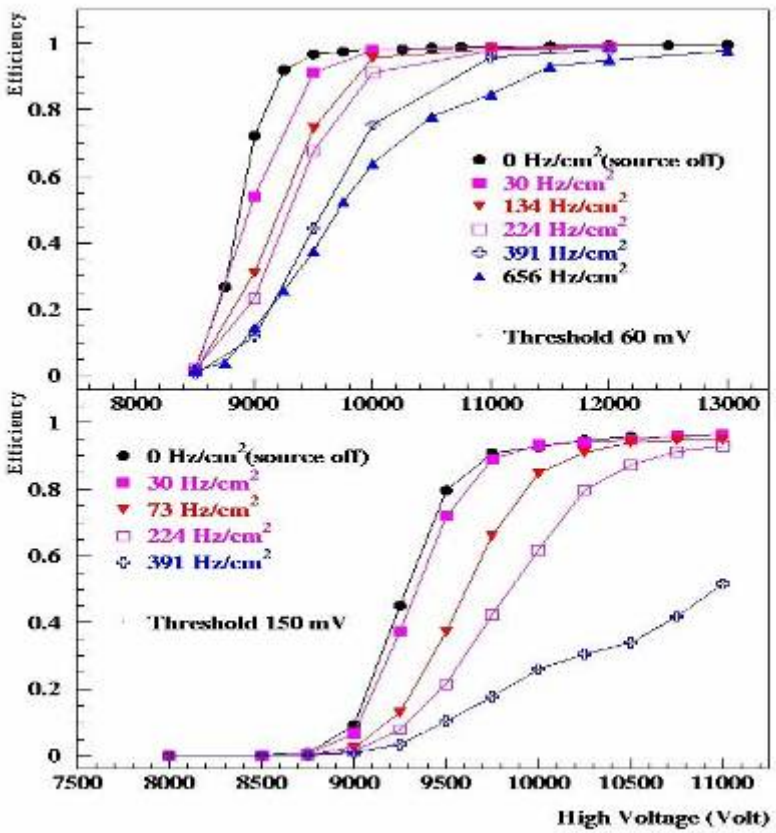
GIF(Gamma Irradiation Facility): simulate the irradiation environment at LHC.

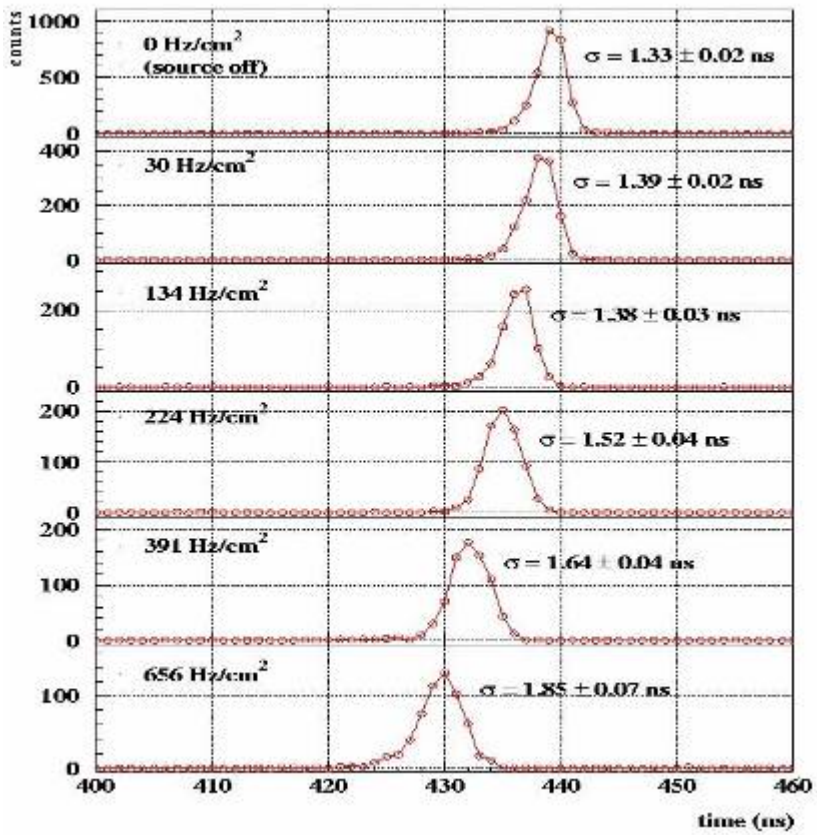


Chinese RPC prototype was being tested at GIF



# Beam test results of Chinese RPC prototype




Conclusion:

⇒The Chinese RPC prototype has good mechanical strength,gas-tightness and HV performances;

⇒The efficiency and time resolution are satisfactory;

⇒The efficiency at very high irradiation is limited due to the high resistivity of the bakelite.

The PKU-RPC group accumulated experience and technical know-how of RPC.

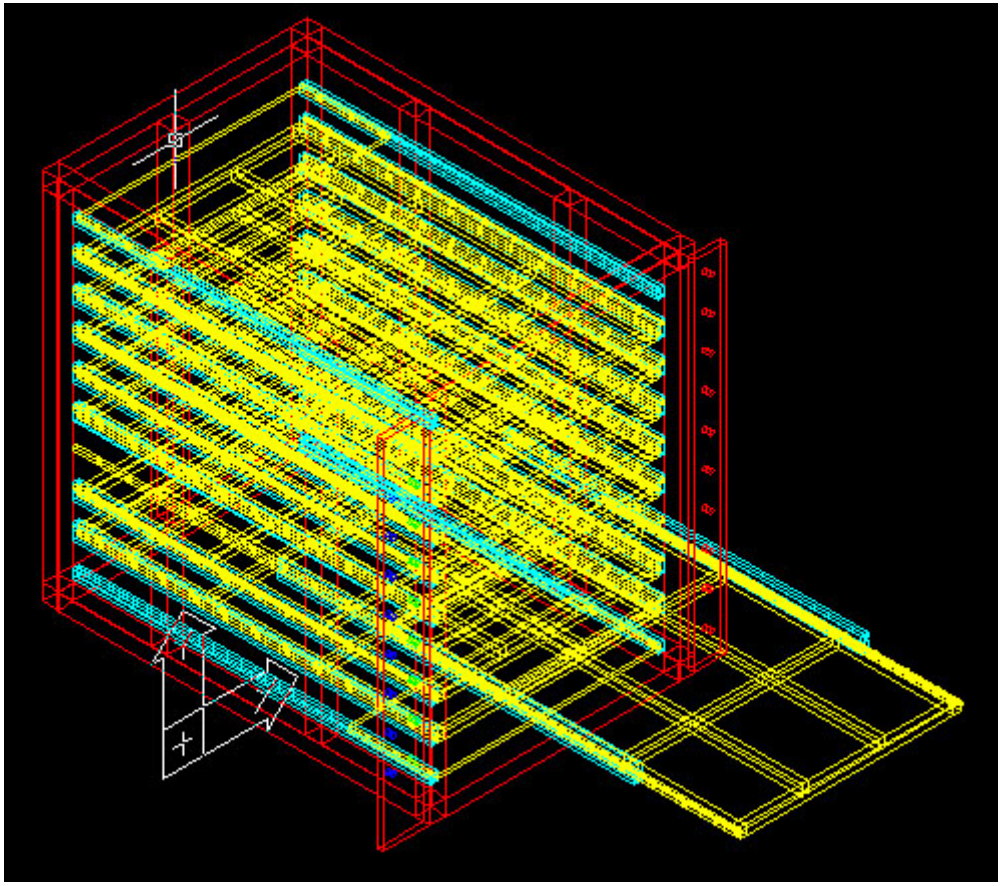
# Laboratory construction at PKU

Inside view of the new laboratory: equipped with crane, various tooling, gas and DAQ system.

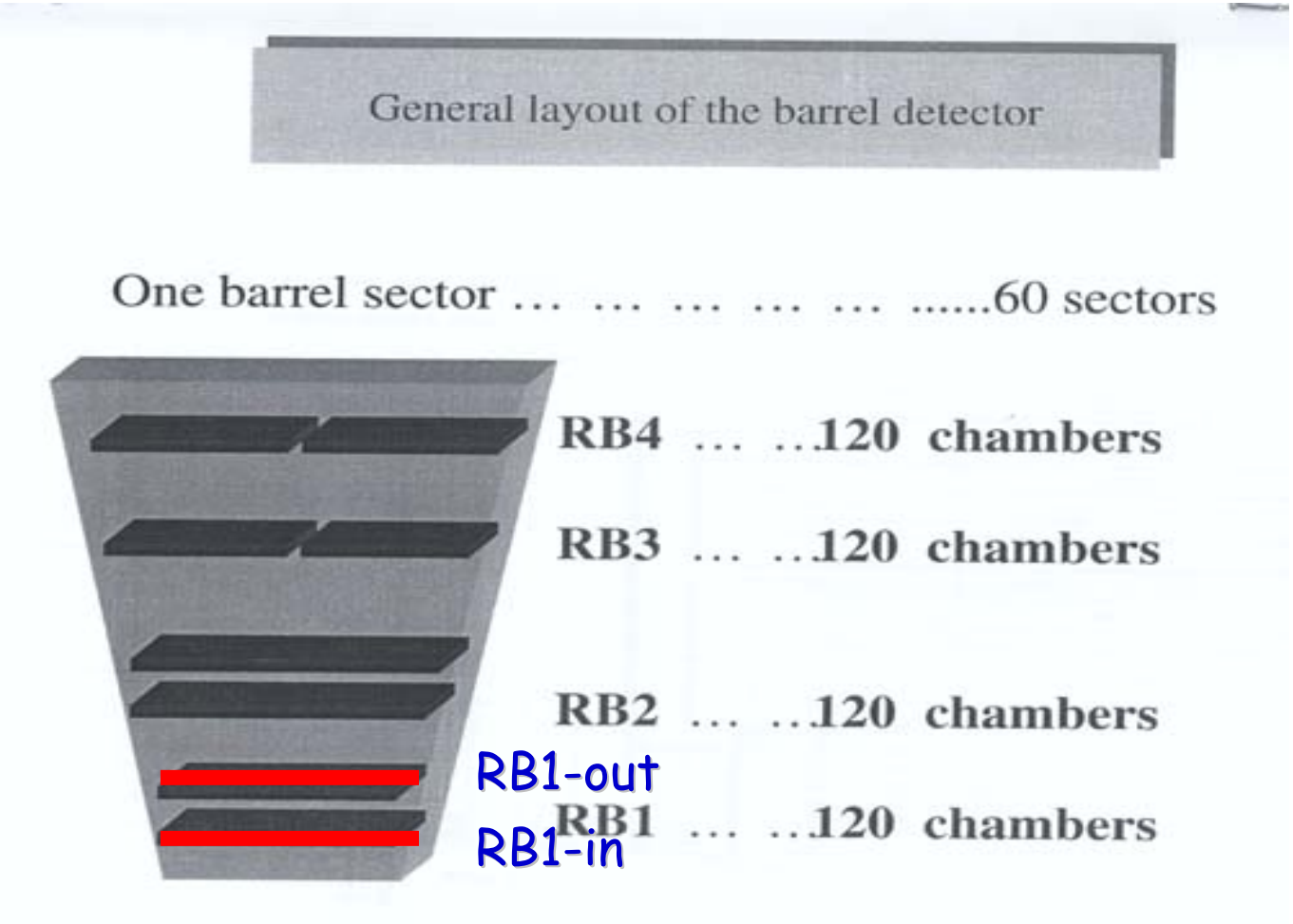
clean room: area ~16 $m^2$.

# Laboratory construction at PKU

The detector cosmic ray test stand: dimension 1.8X2X2 m;
10 slidable detector supporting layers, can test 6-8 RPC at the same time.



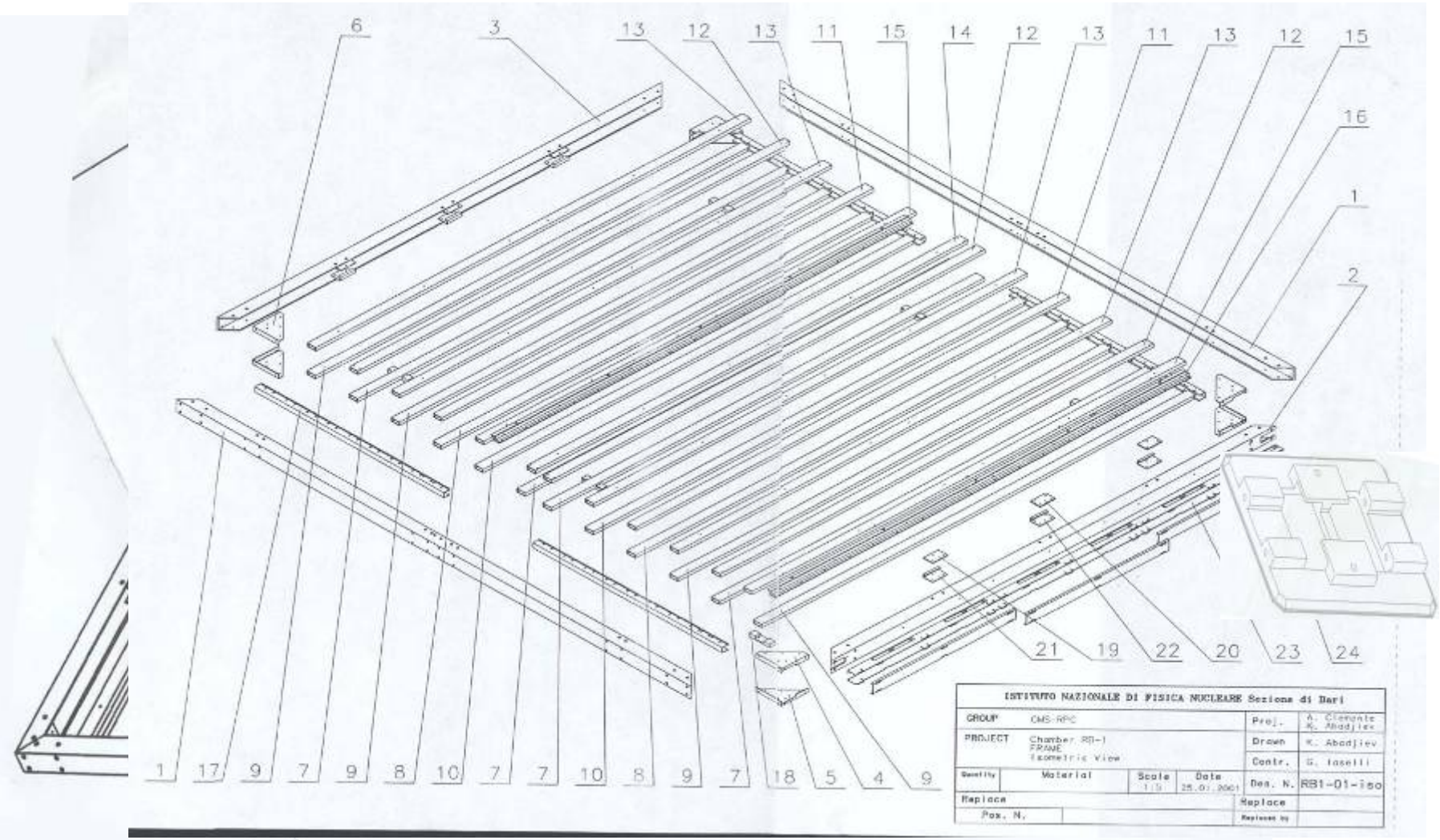
# Barrel RPC production: PKU's responsibility



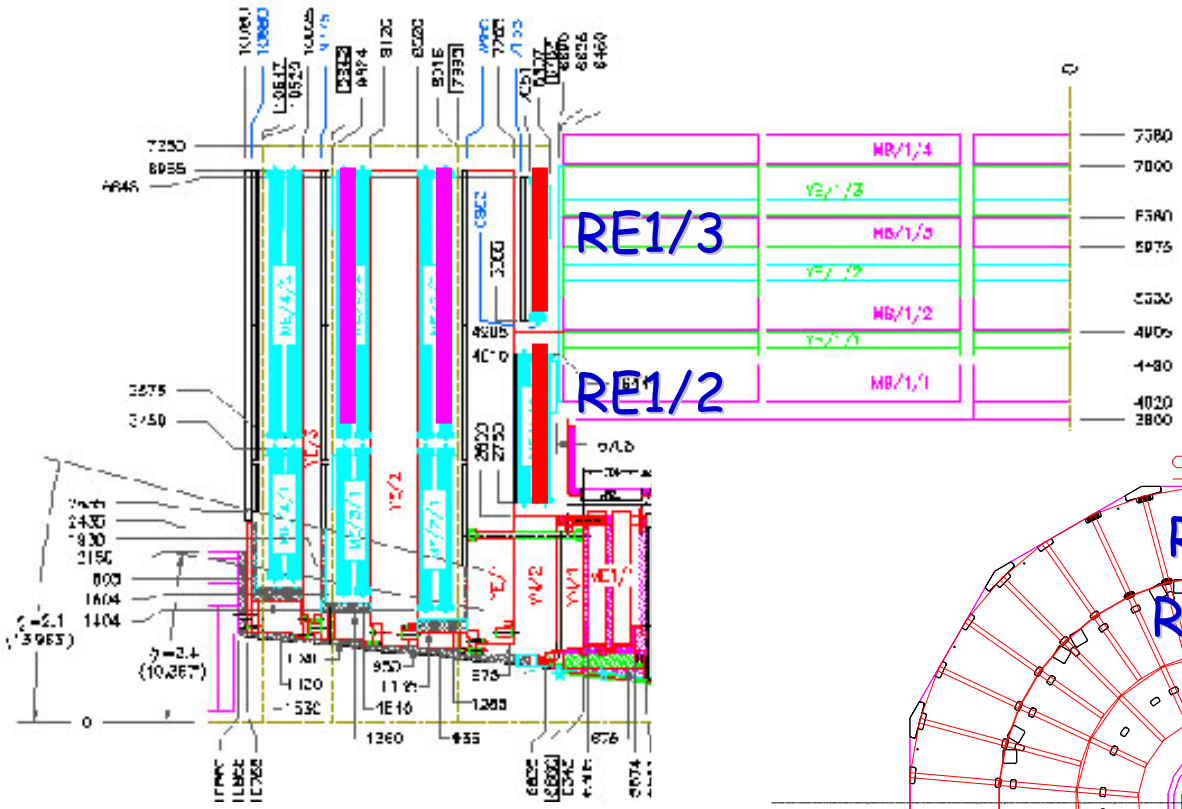

60 RB1-in + 60 RB1-out: totally 120 chambers.

# Barrel RPC production: RB1 Frames

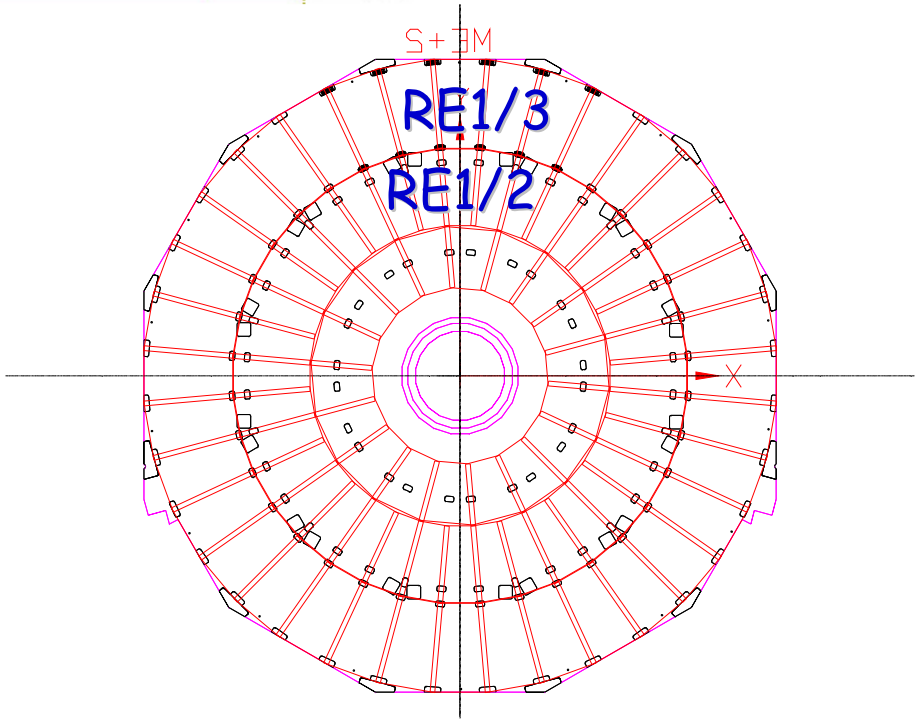
## RB1 mechanics: layout and isometric view



# End-cap RPC production: PKU's responsibility

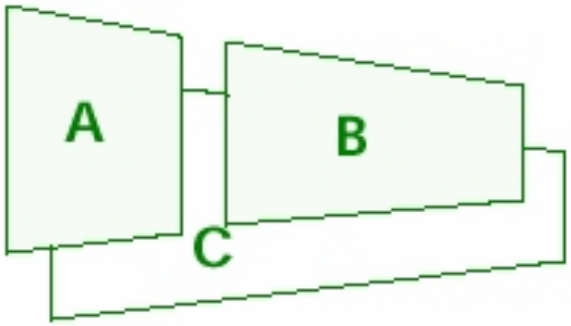


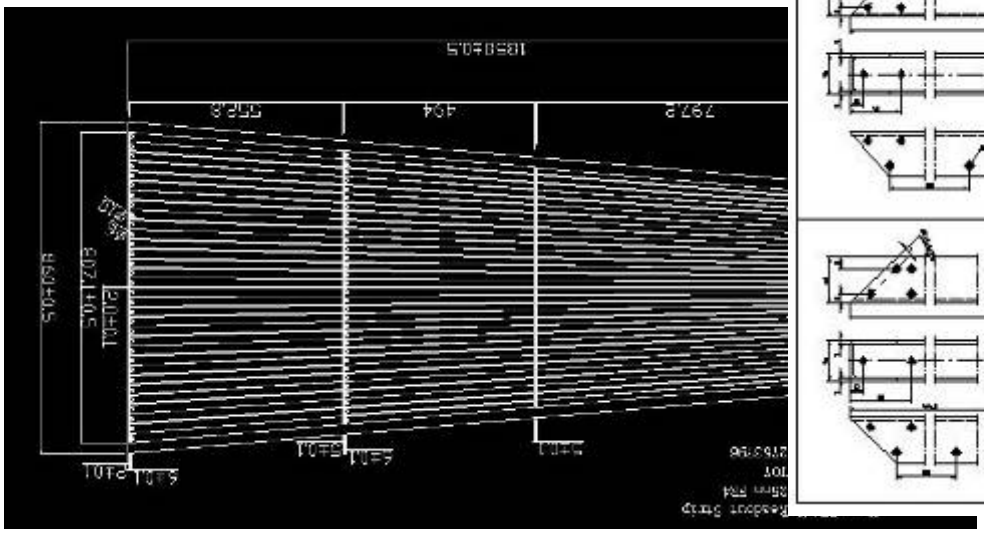

72 RE1/2 +
72 RE1/3:
totally 144 chambers.
Area of the chamber:
~2 $m^2$



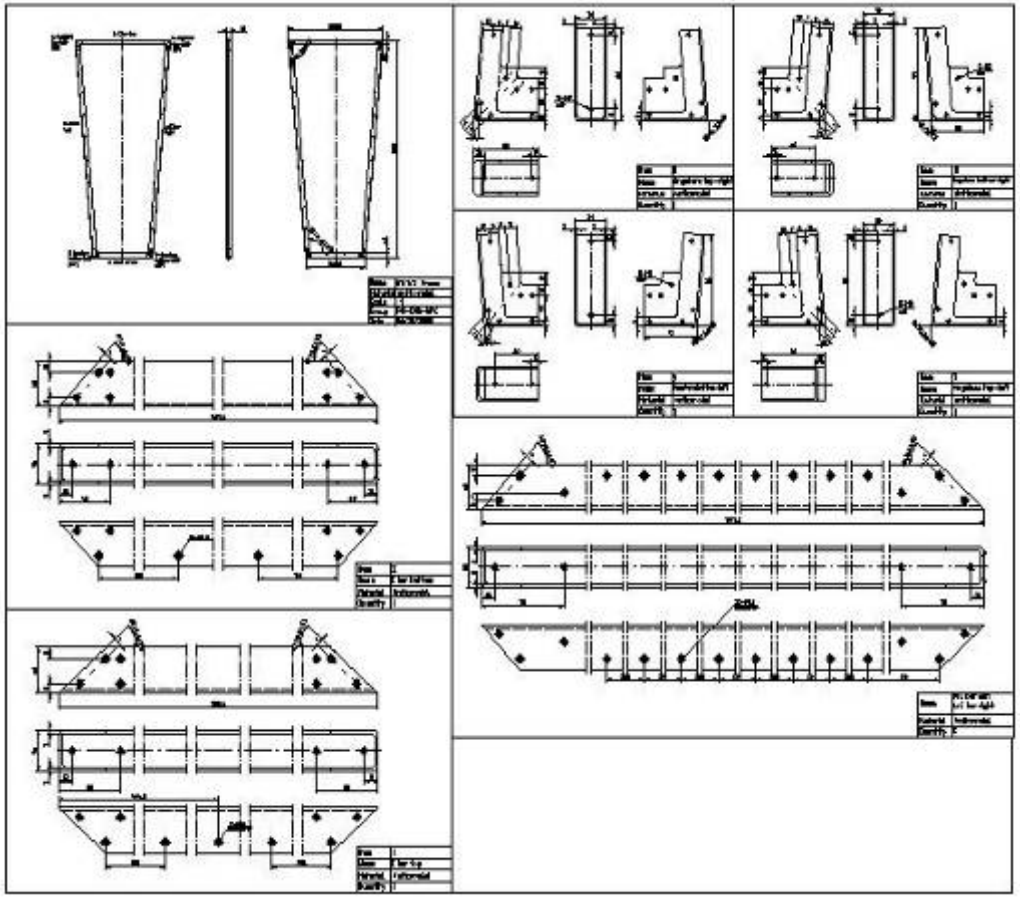

Gas-gaps will be produced
By Korea.
China's responsibility:
Chamber structure material,
Assembly and test.

# End-cap RPC mechanical design: development



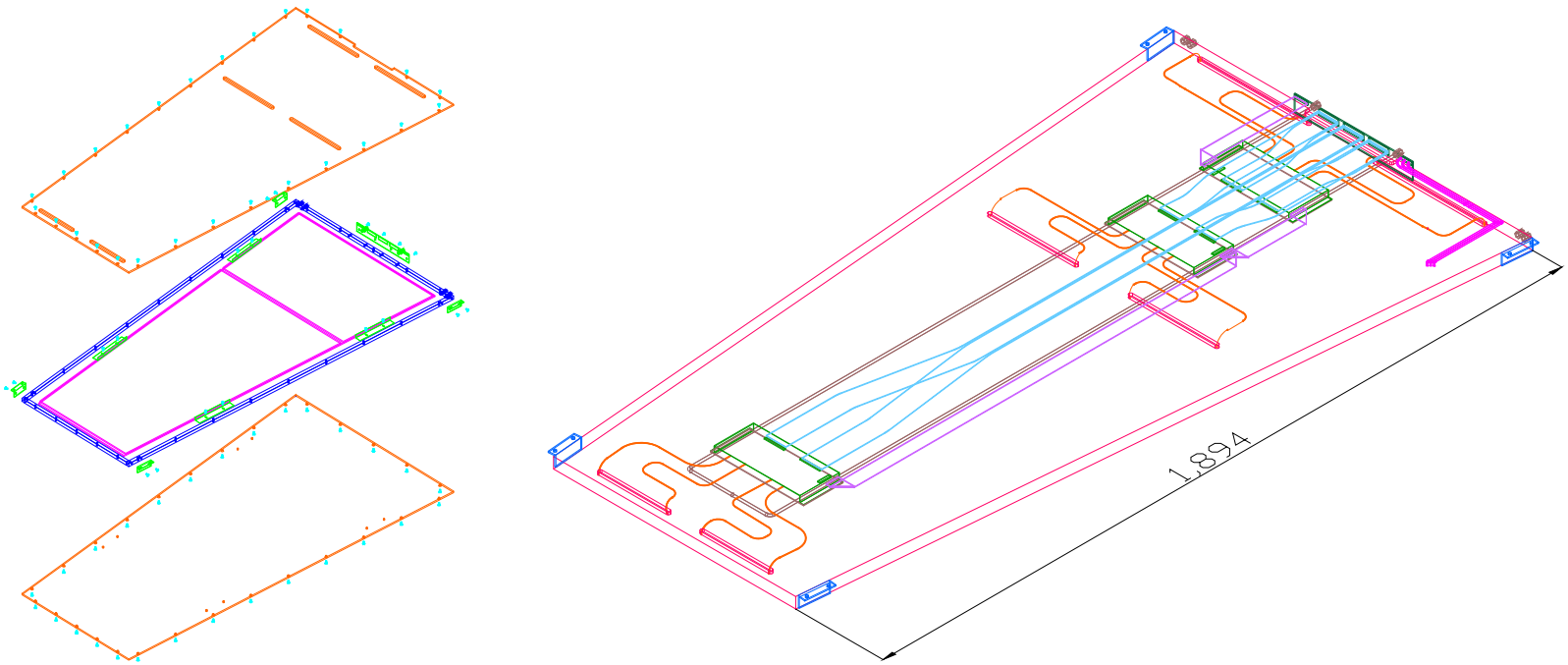



Each chamber has two upper, one bottom gas-gaps: read-out strips divided into 3 sections



Mechanical design in 2001: Aluminum C Profile + supporting plate

# End-cap RPC : "thin" chamber design

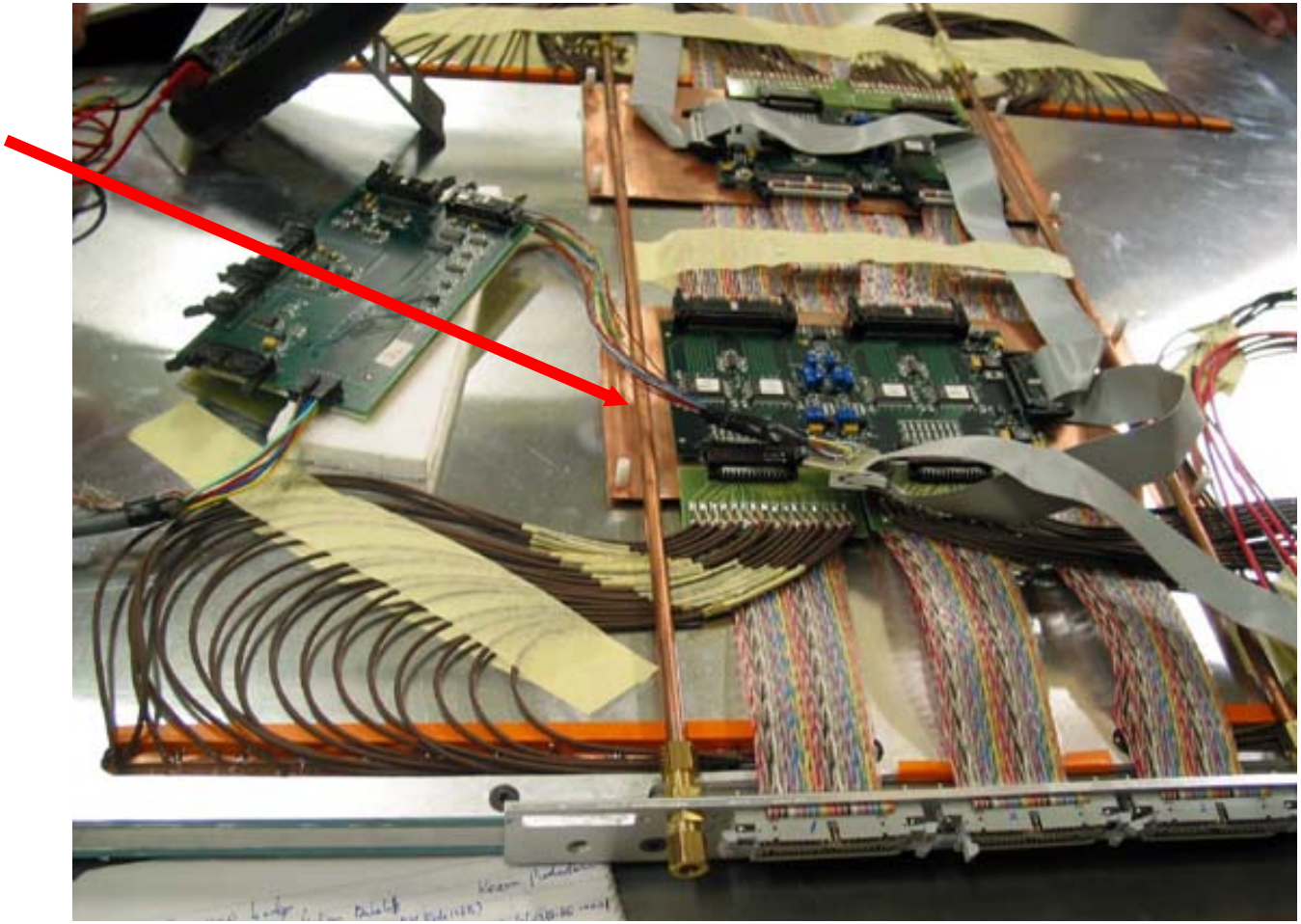



RE1/2 "thin" chamber design.

⇒ Thickness of RE1/2,1/3: 28mm(chamber)+20mm(Front End Elec.)
⇒ Simple structure: mainly composed of 2 honeycomb plates + 4 Al frames+ front patch panel;
⇒ relatively easy for fabrication, assembly and maintenance.

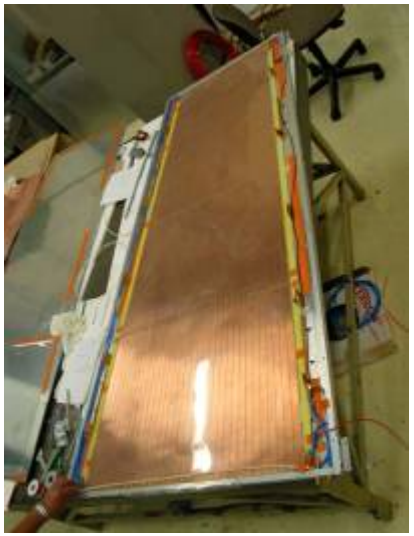
# Structure fabricated in China: cooling and screen box

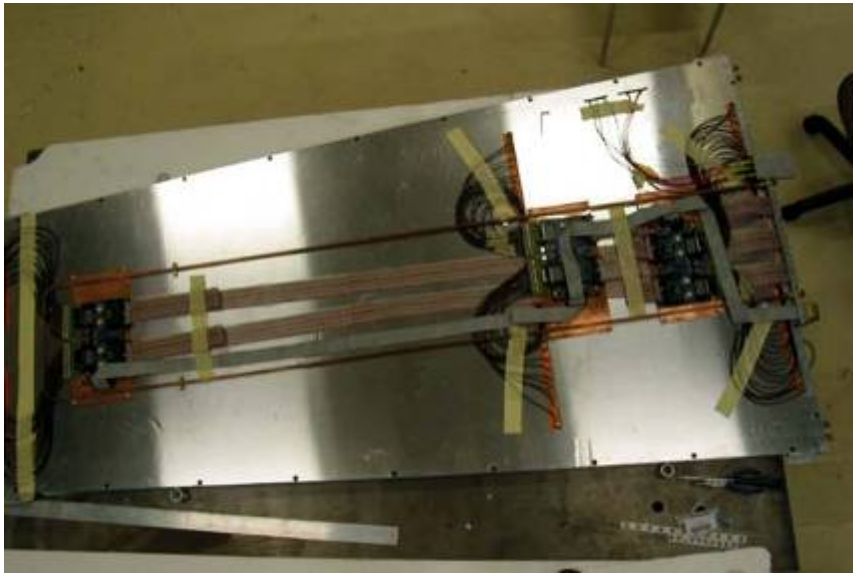
Production site: Beijing Sanli mechanical machining factory (北京三力机械加工厂)



- Cooling: cupper tube welded to the brace plates which will hold FEB;
- Screen box: cover all FEB and signal extraction wires.

# Assembly procedure of RE1/2 RPC





# Beam test at GIF 2002

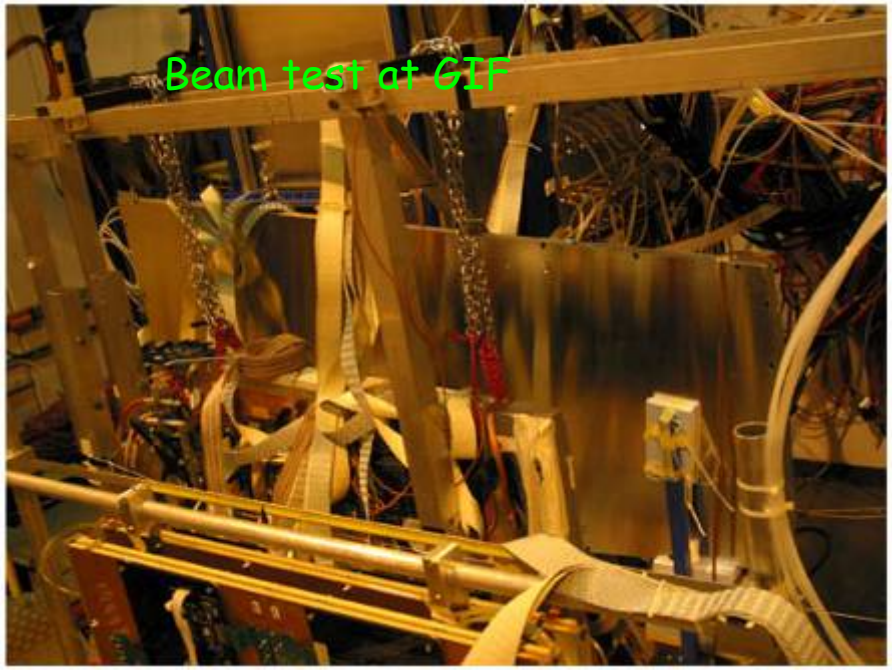
Beam test at GIF

Our chamber at Building-40 for the exposition during autumn CMS-Week after successful beam test.

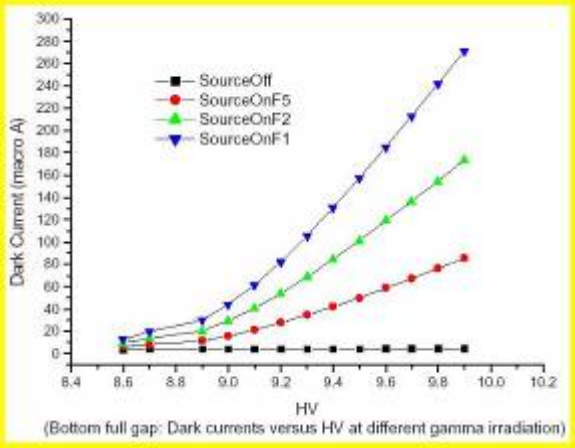
- It's the first full size "thin" designed chamber;
- first chamber with Chinese honeycomb mechanics.

⇒ Test results: the chamber has good gas-tightness, HV and efficiency performances.

# Beam test at GIF 2003

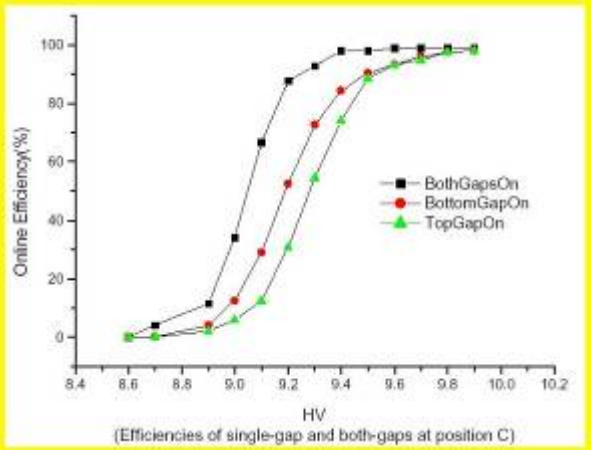



- First oiled gas-gaps made by Korea;
- more Chinese structure material used in assembly (cooling, insulation etc…)

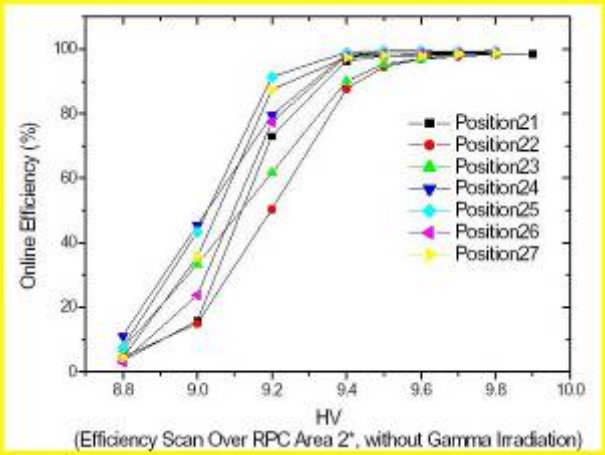


(Bottom full gap: Dark currents versus HV at different gamma irradiation)

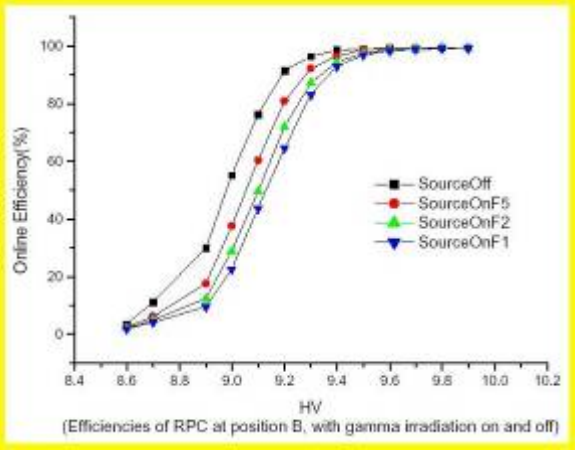
Results:
- the detector worked properly with satisfactory efficiency and lower noise rate.



(Efficiencies of single-gap and both-gaps at position C)



(Efficiency Scan Over RPC Area 2*, without Gamma Irradiation)

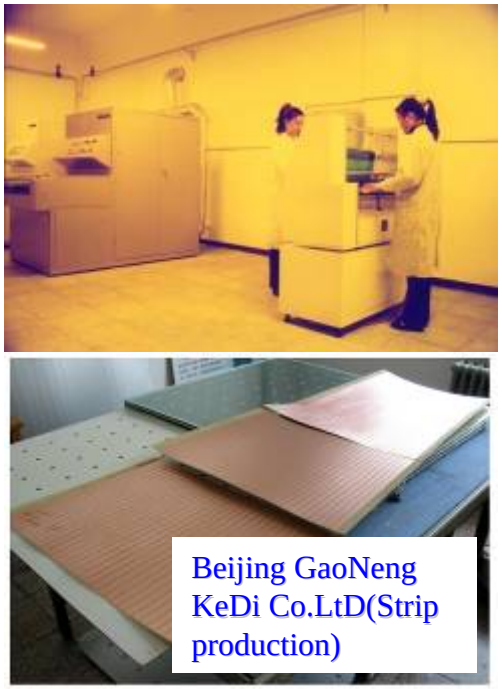


(Efficiencies of RPC at position B, with gamma irradiation on and off)

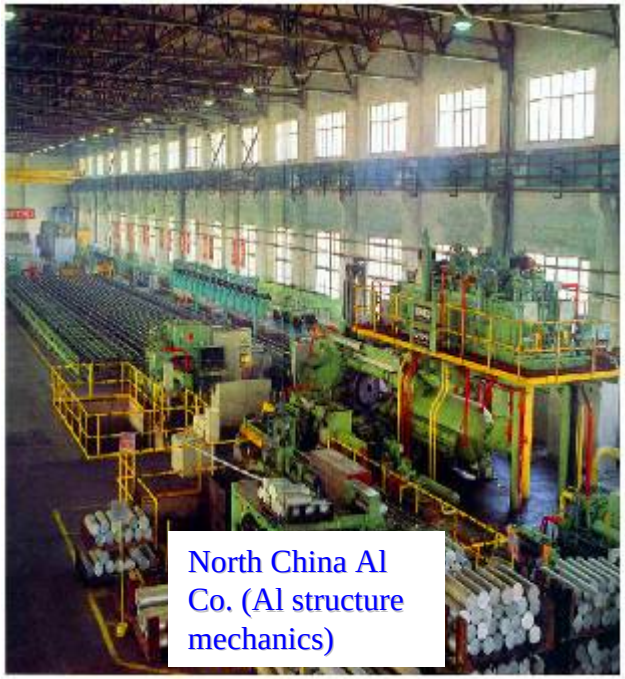
# Structure mechanics production sites in China

- we have long term collaboration with Chinese firms , successfully developed CMS-RPC structure components (honeycomb box, readout strips, copper-Mylar Farady cage, screen box etc.).
- Beam test at CERN proved that RPC components produced in China functioned well, satisfy all requirements.
- All CMS end-cap RPC use the structure mechanics produced in China .

Beijing HoneyTec. Co. (honeycomb panel production)



Beijing GaoNeng KeDi Co.LtD(Strip production)

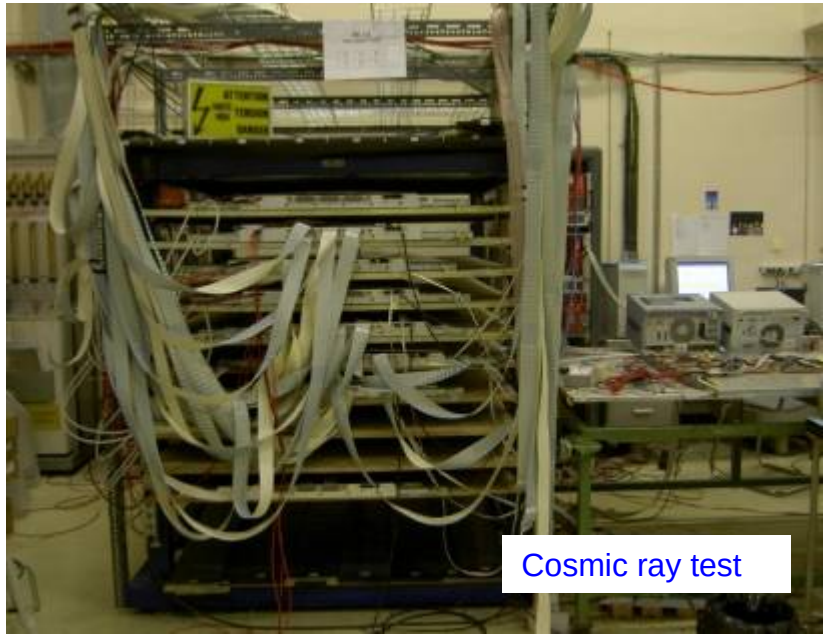


North China Al Co. (Al structure mechanics)

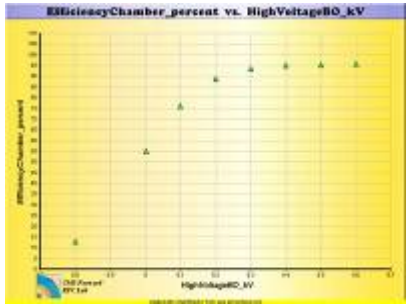
# Test and assembly of endcap RPC

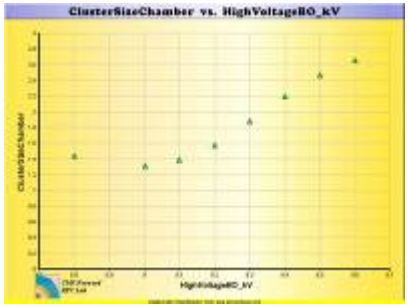
- Endcap RPC mass production started in 2004,
- by 2006 all 160 chambers have been assembled and tested

Completed detectors, ready to go



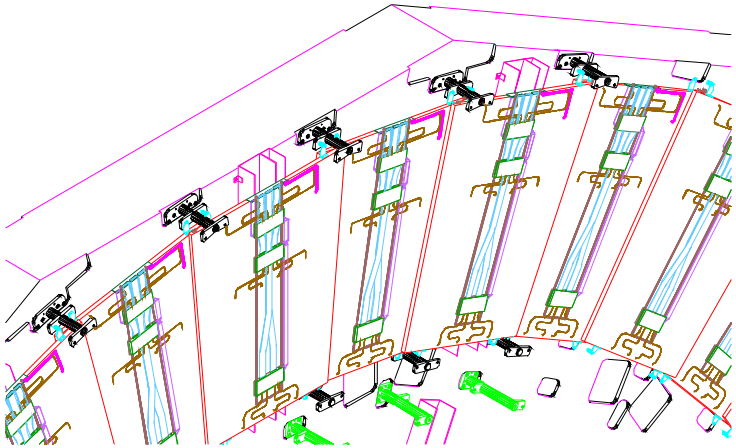
Cosmic ray test

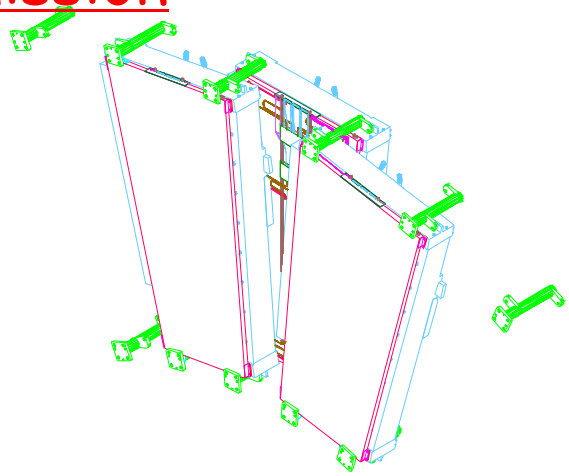


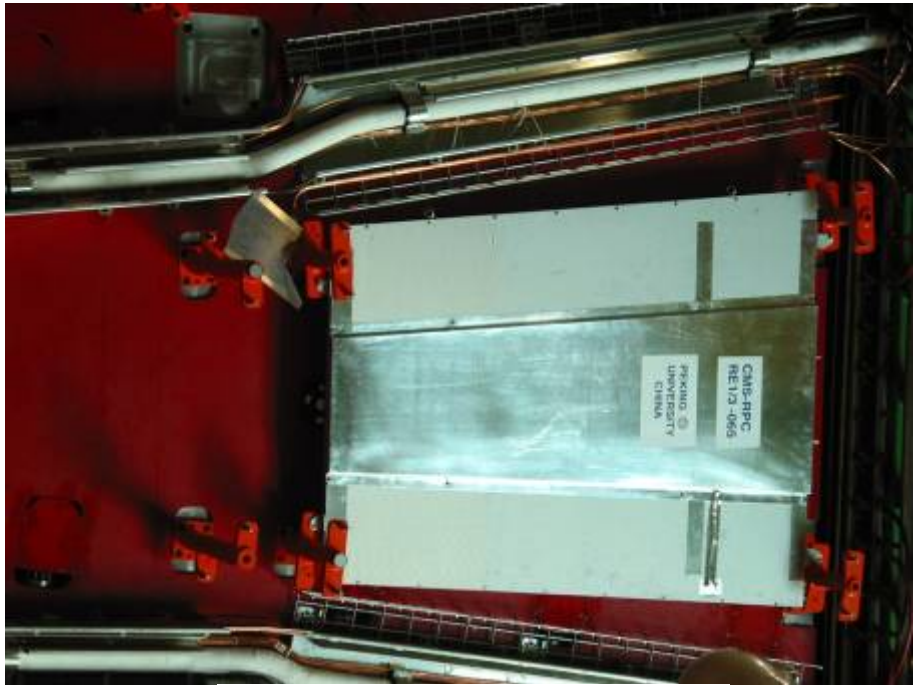




Efficiency curves and dark current

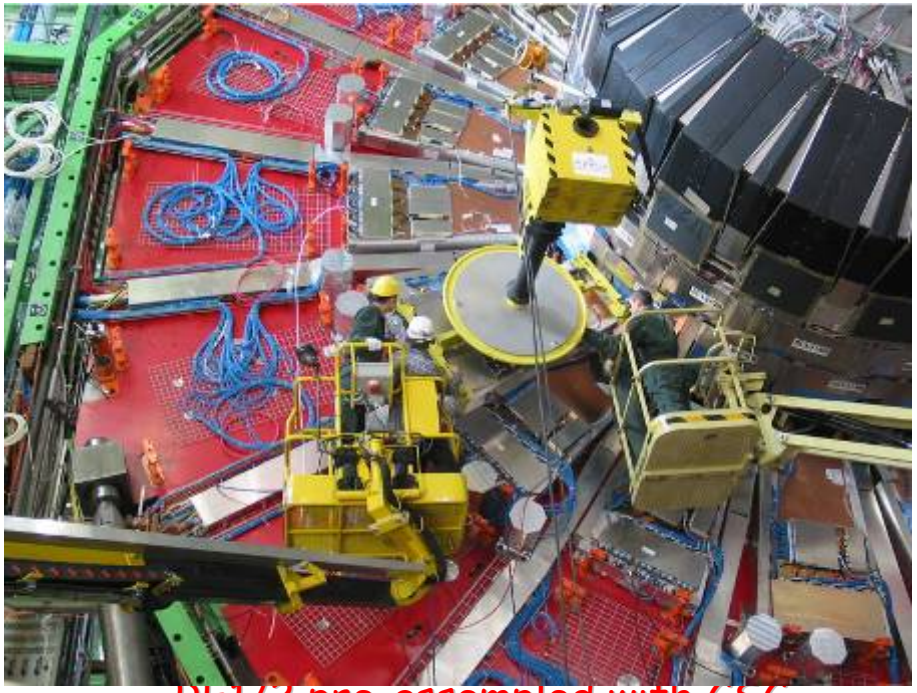
# Endcap RPC installation and commission





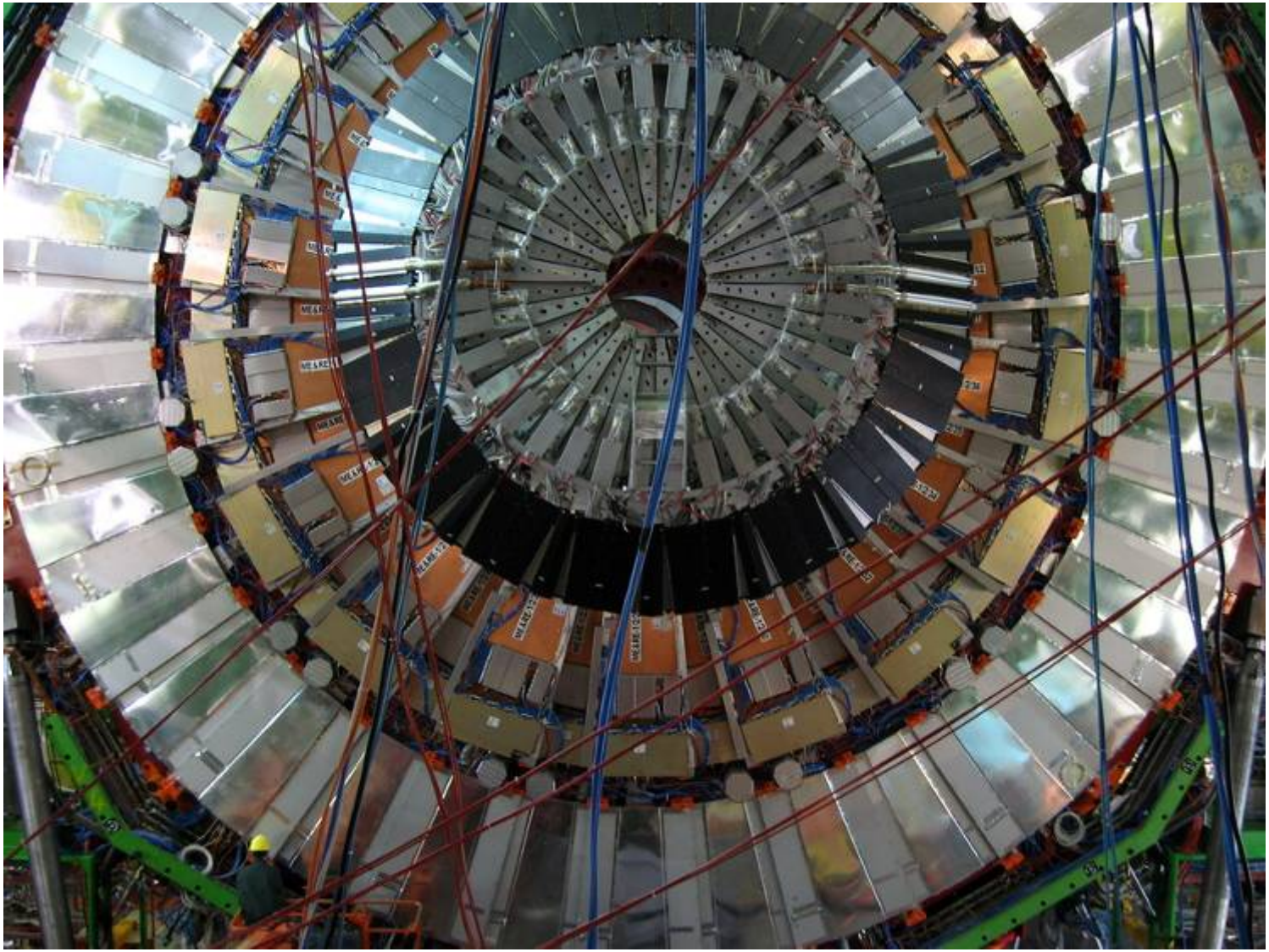



1st installed RE1/3 RPC

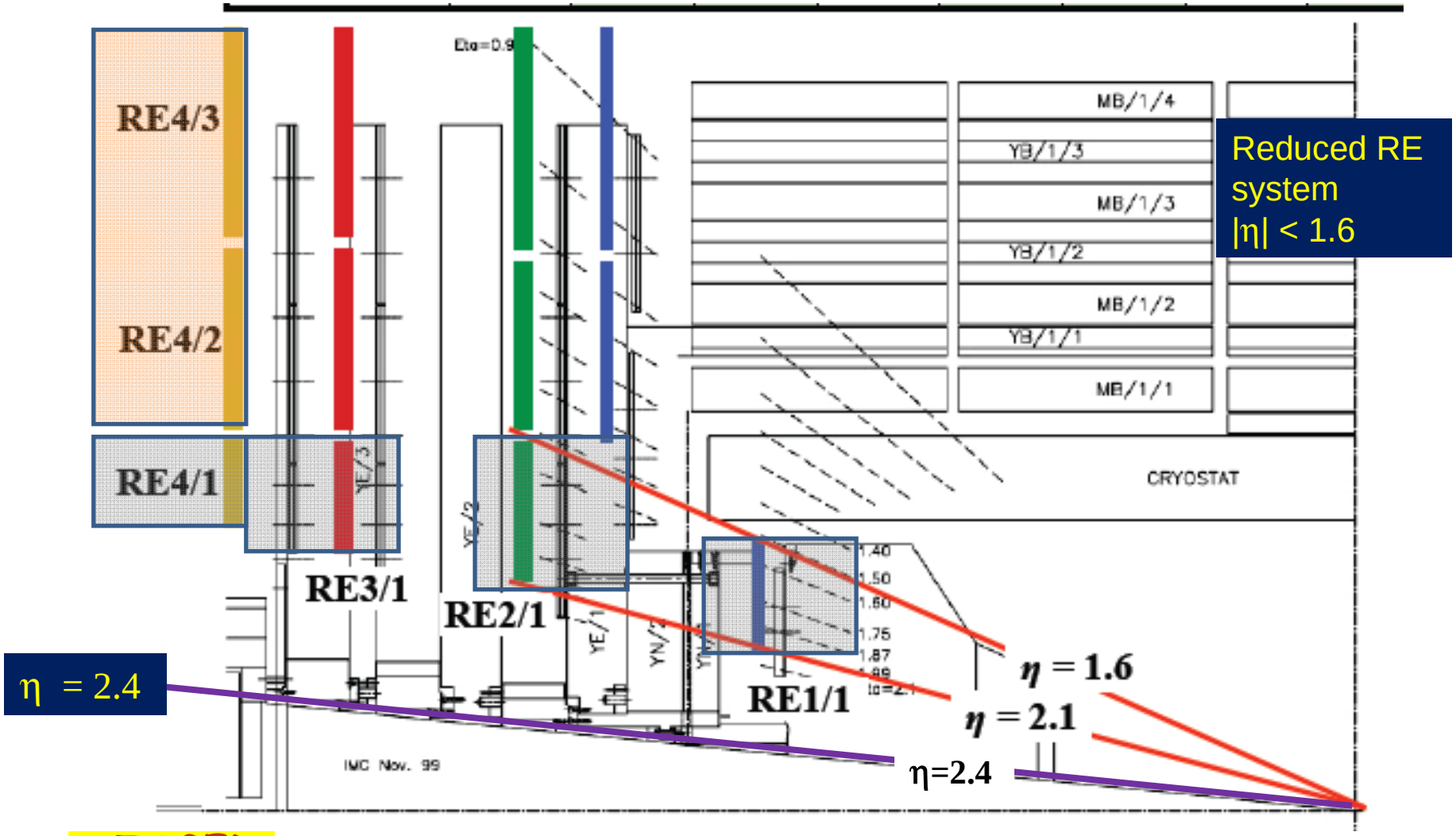


RE1/2 pre-assempled with CSC,
then installed on the yoke

# Endcap RPC installation and commission



# ➢ CMS $\mu$ system upgrade:

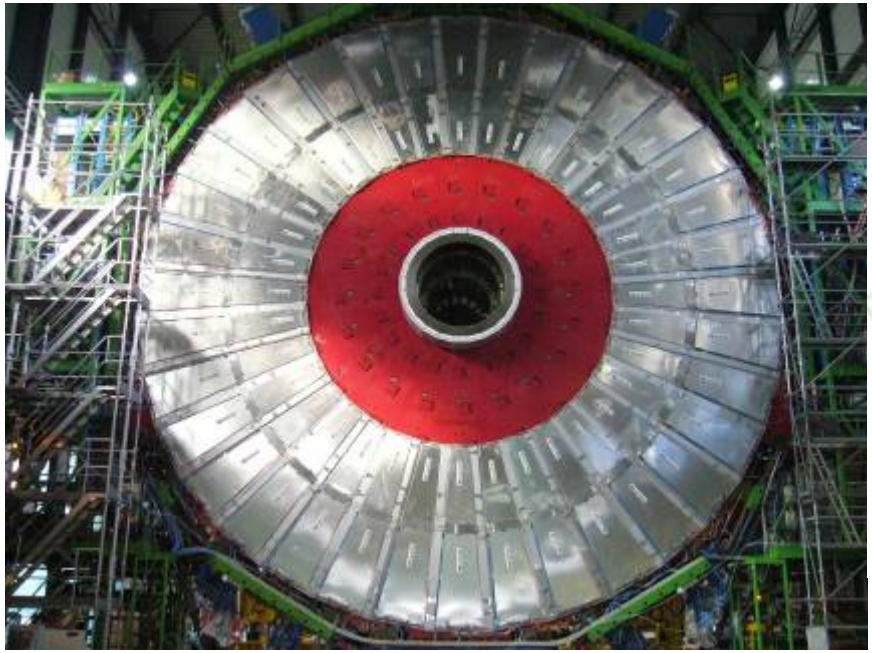


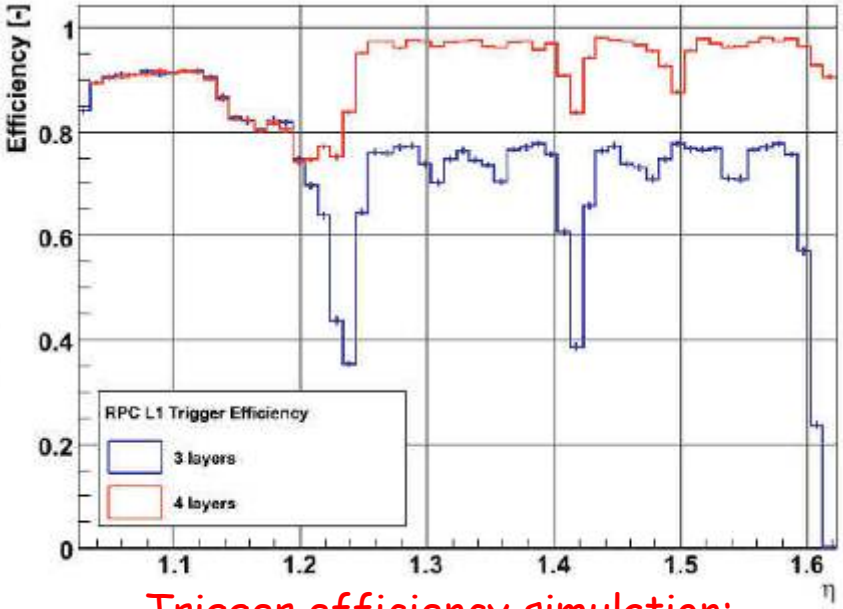

STAGED

| | RE 1/1 | RE 1/2 | RE 1/3 | RE 2/1 | RE 2/2 | RE 2/3 | RE 3/1 | RE 3/2 | RE 3/3 | RE 4/1 | RE 4/2 | RE 4/3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of chambers | 36*2 | 36*2 | 36*2 | 18*2 | 36*2 | 36*2 | 18*2 | 36*2 | 36*2 | 18*2 | 36*2 | 36* |

# phase 1 upgrade: 4th station RE4 (low eta) project

installed RE2, the upgrade RE4 will have similar structure



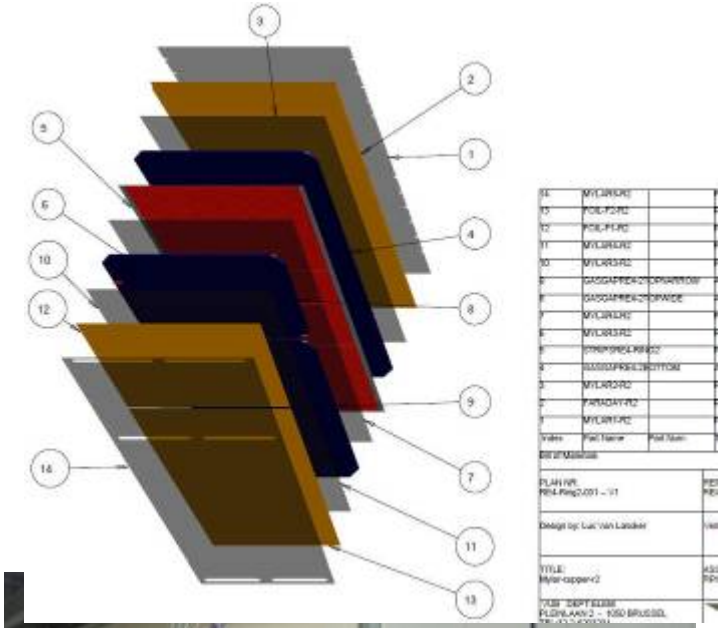


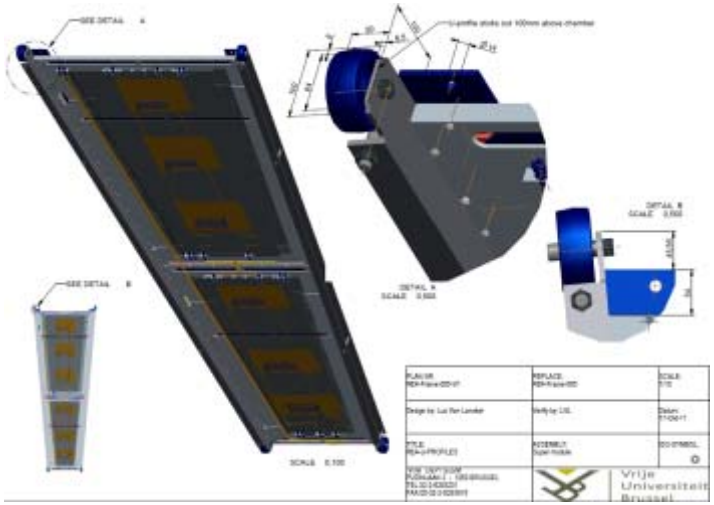

Trigger efficiency simulation:
Blue curve: present system
Read curve: 4th station added

Task share:
CERN: bakelite procurement, cable, service preparition; INFN Italy: bakelite QC, trigger electronics, detector monitor; Korea: gas-gap production; India: assembly and test of part of RPC, cooling circuit production, part of power procurement. ; Pakistan: FEB,signal cable, : assembly and test of part of RPC, ; Belgium: : assembly and test of part of RPC,HV module and other service:
Peking University: structure mechanics production, assembly and test of part of RPC.

# phase 1 upgrade: 4th station RE4 (low eta) project

- 2008-2010: detector design and R&D
- 2010/09 :sign contracts with the production firms. 6 full size prototypes shipped to CERN in Oct., for QC and test assembly
- 2010/11, design finalized, structure component mass production started.
- 2011/12, structure component mass production , shipped to CERN and other sites in batches
- 2012/01, test assembly of the super-module.





RE4 Super module design and assembly

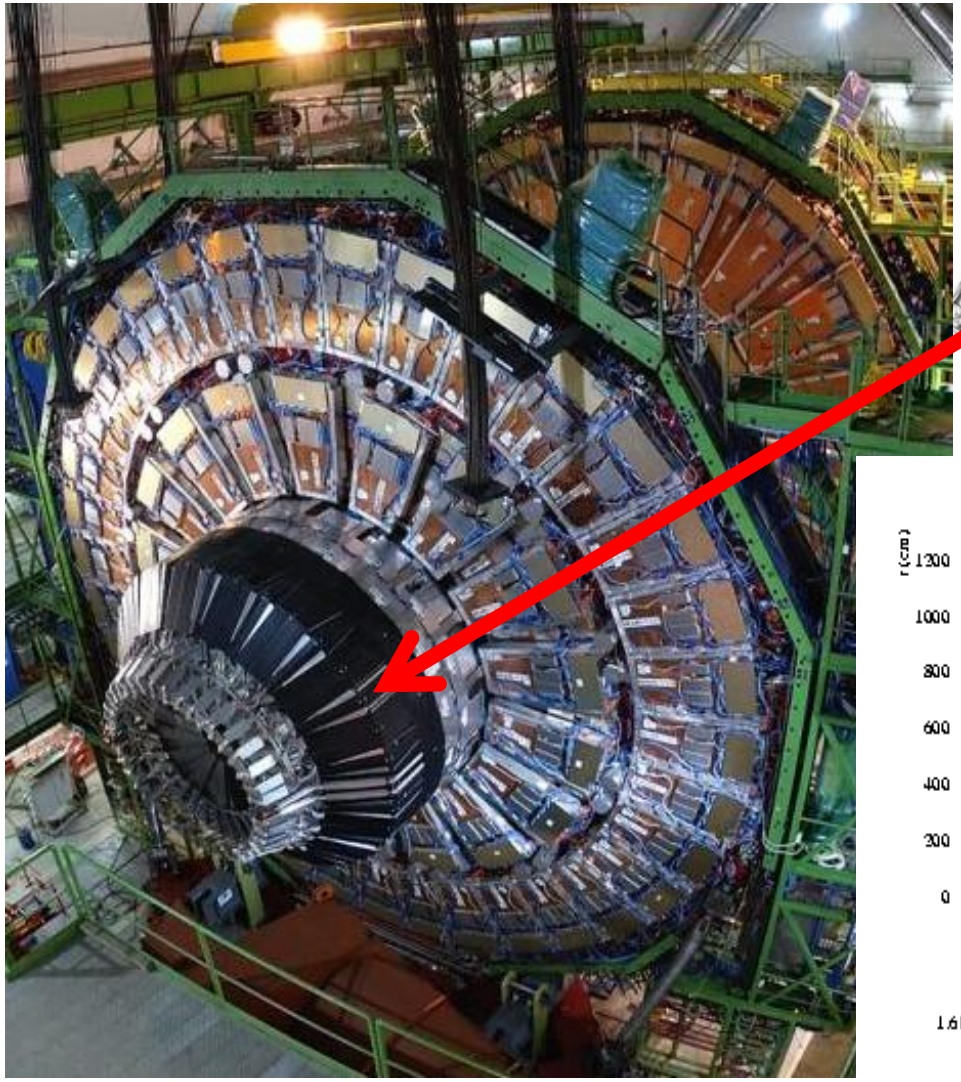
# phase 1 upgrade: CERN production lab.

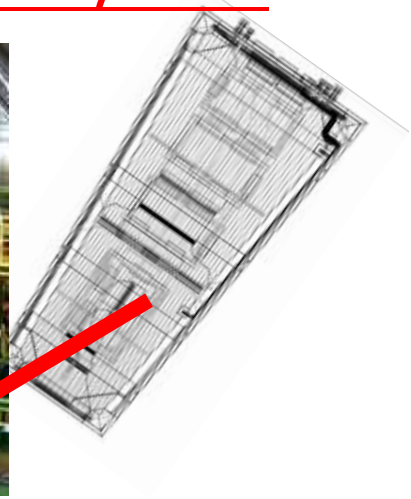
Structure components produced in China arrived CERN

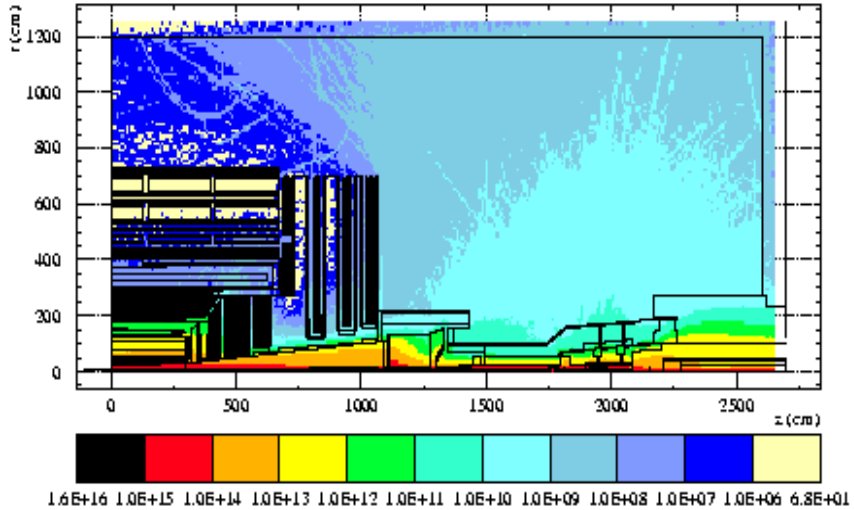
CERN RPC assembly and test lab.

- 200 detectors will be assembled and tested, 144 chambers will be installed, half of the chambers will be produced at CERN.
- We'll participate assembly and test at CERN, and installation and commission.

# phase 2 upgrade: high eta muon system

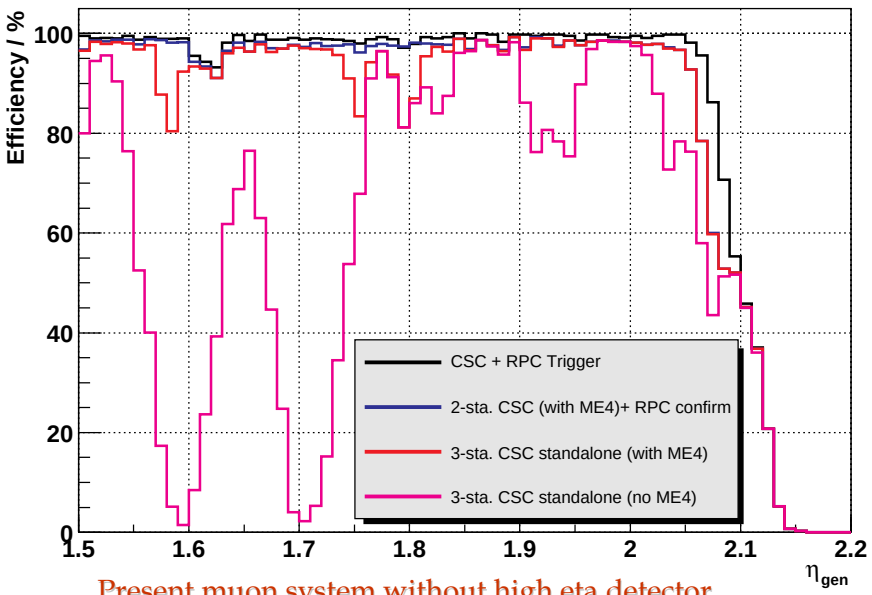




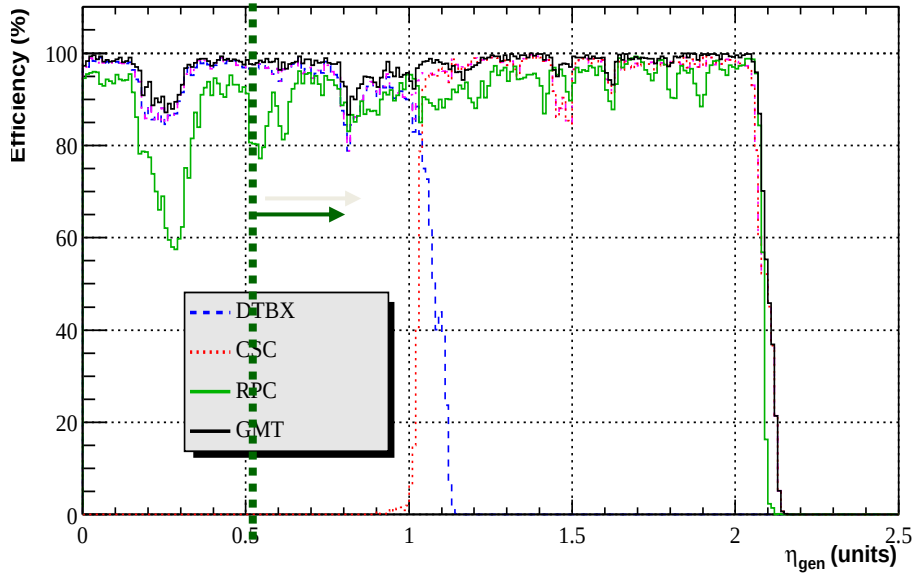



Radiation strength at different region of the detector

# phase 2 upgrade: high eta muon system (2016-)




Present muon system without high eta detector



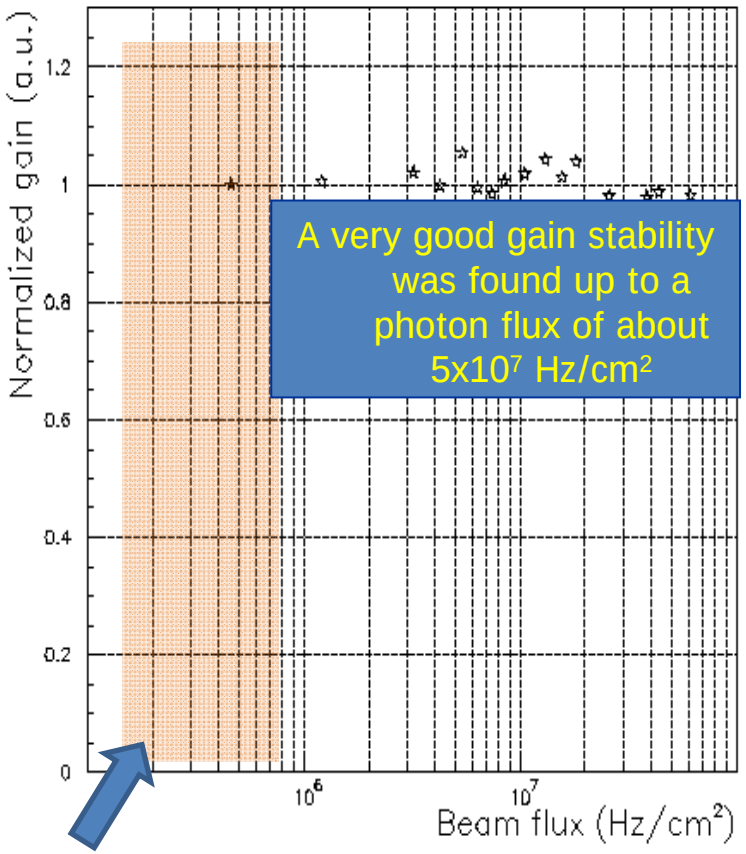

With high eta detector installed

- Proposal: use GEM technique for high eta muon detector.
- since 2009, CMS-GEM group formed, different designed GEM detector constructed and tested.
- present CMS-GEM members: CERN CMX Group, Detector Technology Group, Electronics Group: expertise and facility; Florida Institute of Technology: electronics and DAQ; INFN-Frascati: online-offline software、detector production; Gent University in Belgium: detector R&D, test and analysis; Wayne State University: electronics, test and operation; Korea, India. Total 35 institutes, 180 researchers.
- PKU joined CMS-GEM group in 2009, engaged in detector R&D, assembly and test, test beam analysis, software development etc.

# phase 2 upgrade: CMS-GEM project

## Rate capability

Measured with an X-ray (5.9 keV) tube;
$Ar/CO_2/CF_4$ (60/20/20) Gain of about $2x10^4$;




CMS high η - maximum rate

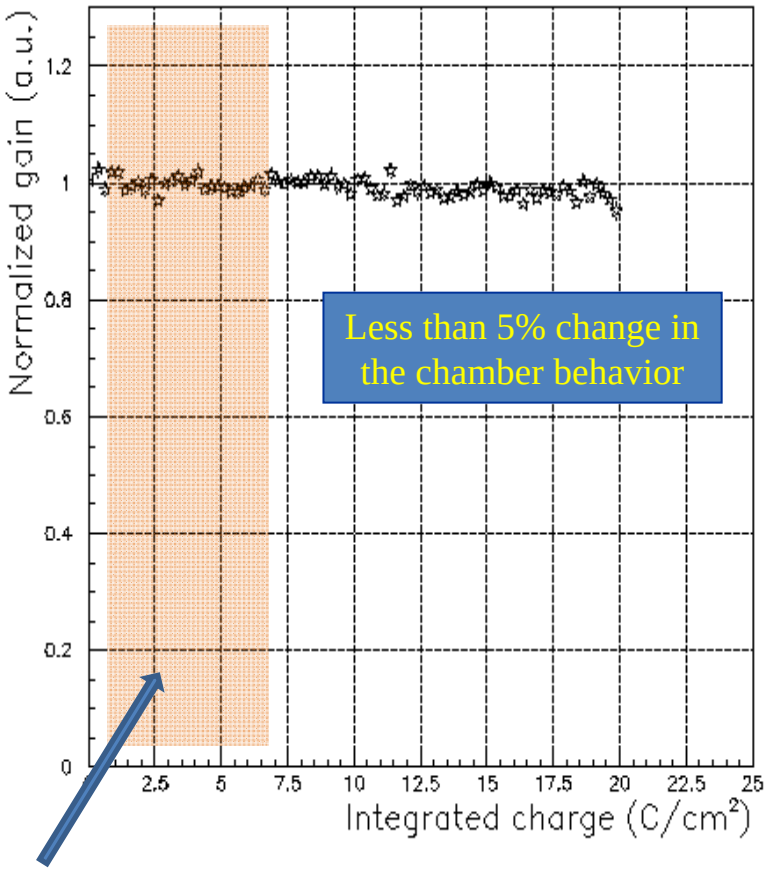
LHCb meas

## Triple GEM Ageing test

Gain of $2x10^4$

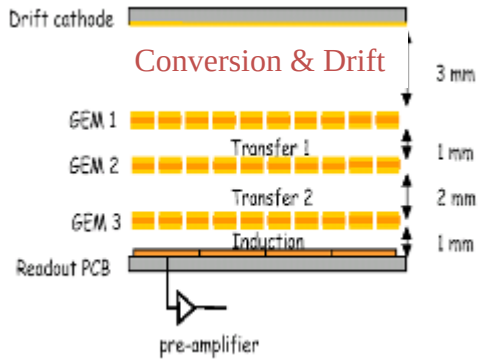
Total integrated charge of 13 C/cm$^2$ is expected in 10 years of operation in LHCb

50 MHz/cm$^2$ X-rays, in 10 days a total charge of 20 C/cm$^2$ was integrated;



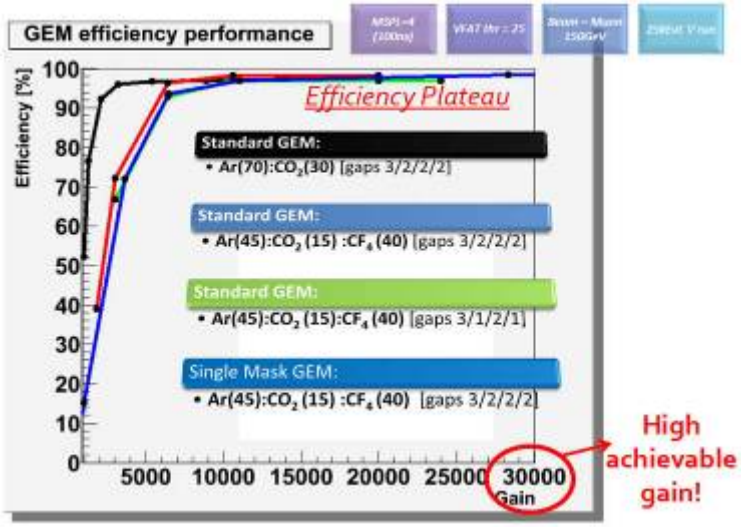

CMS high η - maximum integrated charge

# phase 2 upgrade: CMS-GEM project

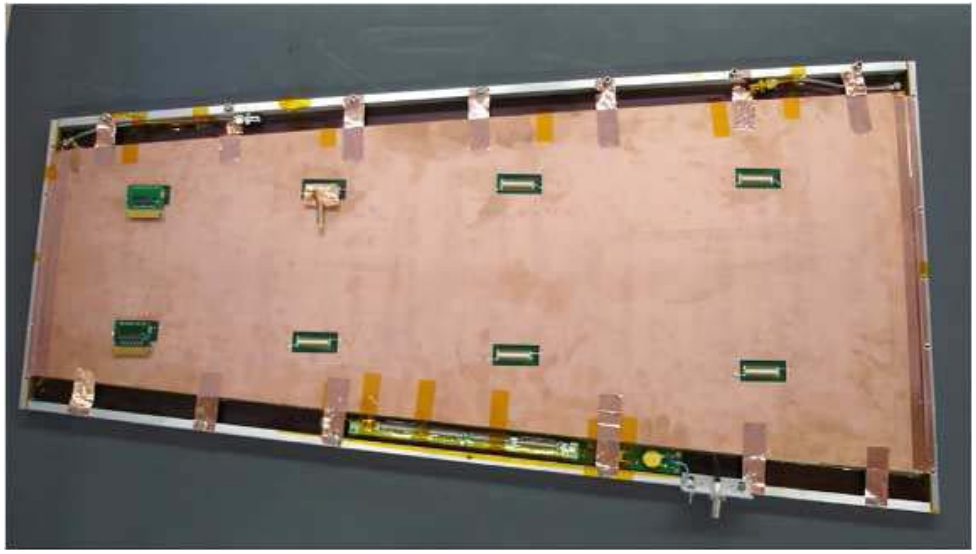



Structure of CMS-GEM detector

- spatial resolution of GEM could reach 100 μm, efficiency 98%, could be used for trigger and track reconstruction simultaneously. 。
- GEM could be operated stably at high rate（$10^4$Hz/cm2), time resolution also satisfy LHC-CMS requirement.
- 2010-2011， we have taken part in triple GEMCMS-RE1/1fullsize prototype construction，x ray、cosmic ray and beam test. The results show the prototype can maintain high gain at 1.5 Tesla and operated with high efficiency.




2010-2011 beam test results

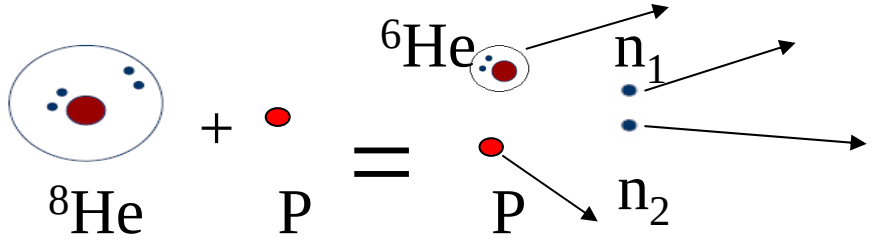


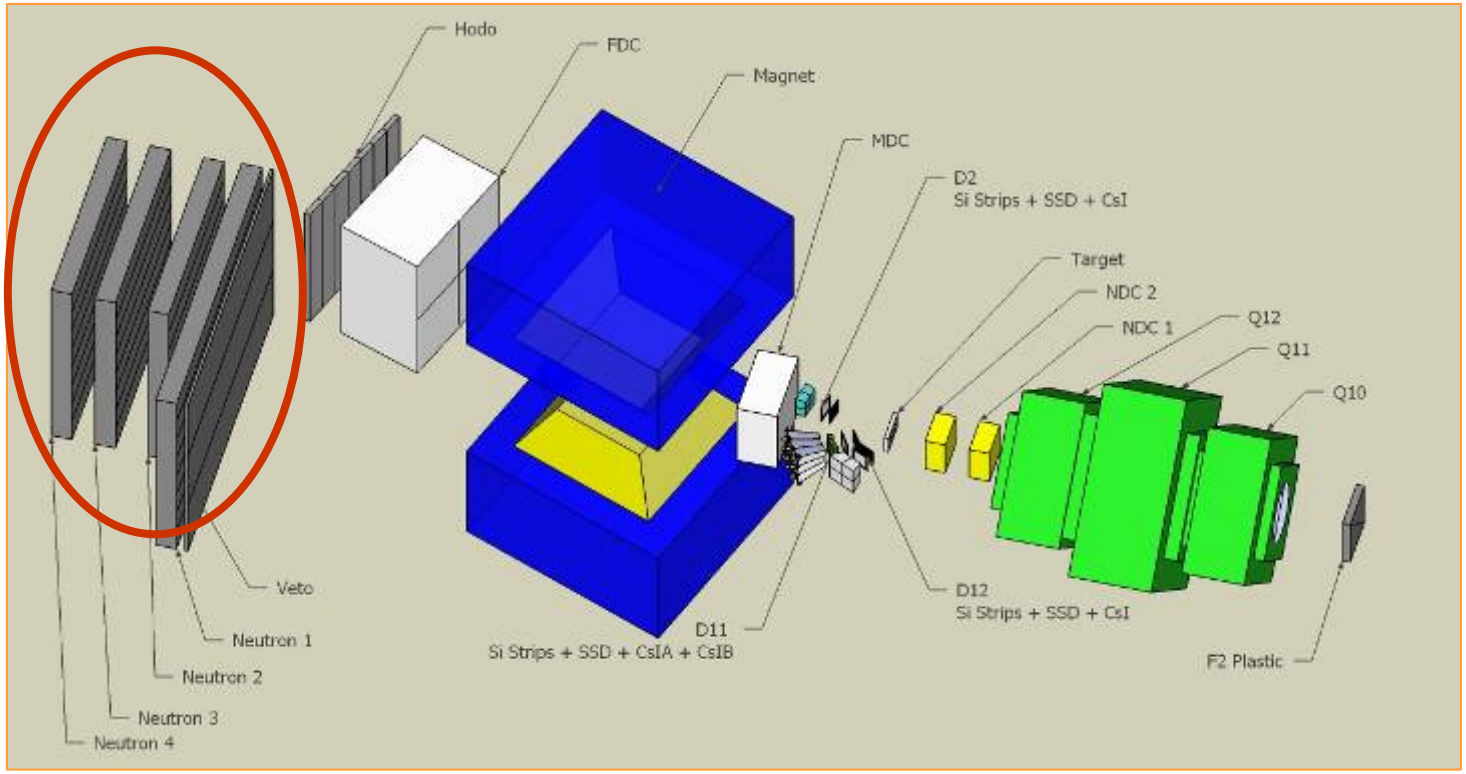
Full size CMS-GEM prototype

# Other detector R&D at PKU

## ➢ Multi-neutron correlation spectrometer

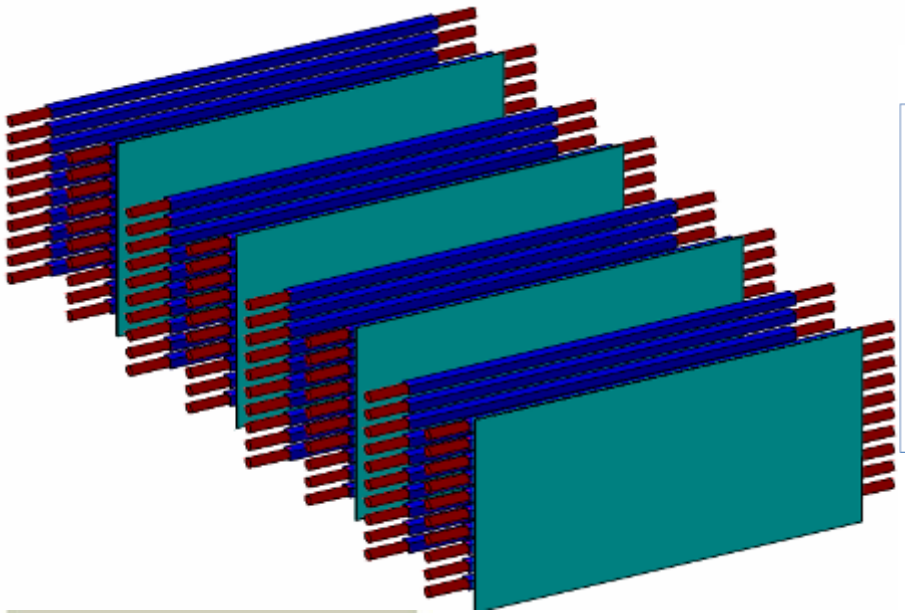
- Used in radioactive-beam nuclear reaction experiment,
- measure the energy, momentum and correlation of neutrons.



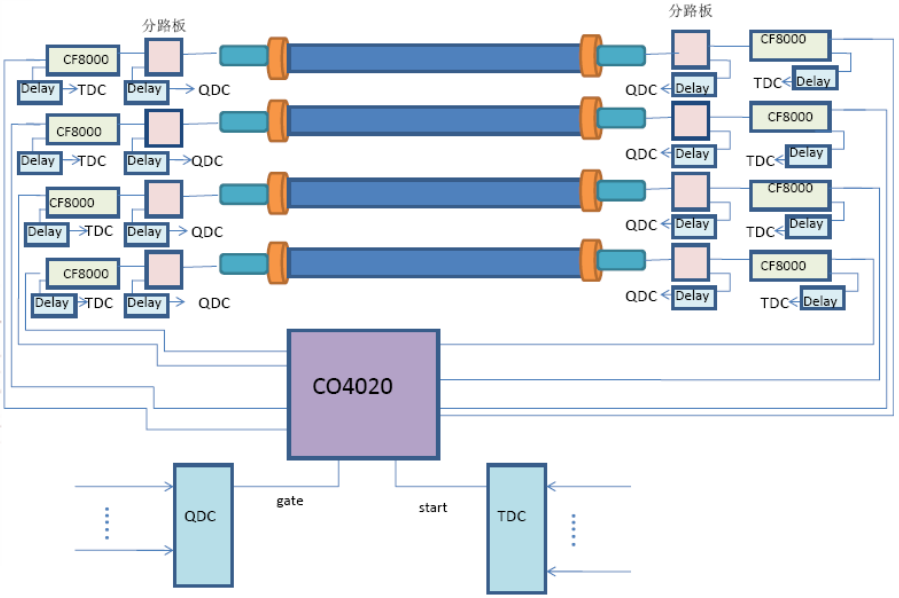



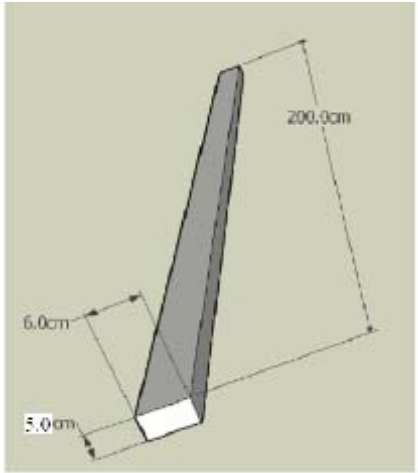
# Overview of multi-neutron correlation spectrum

## Set up of neutron detection system

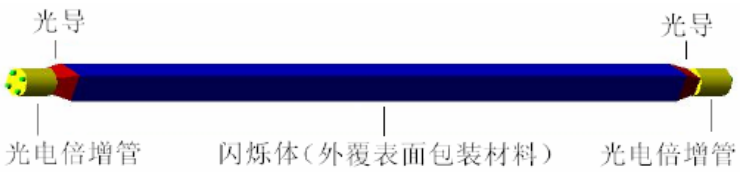


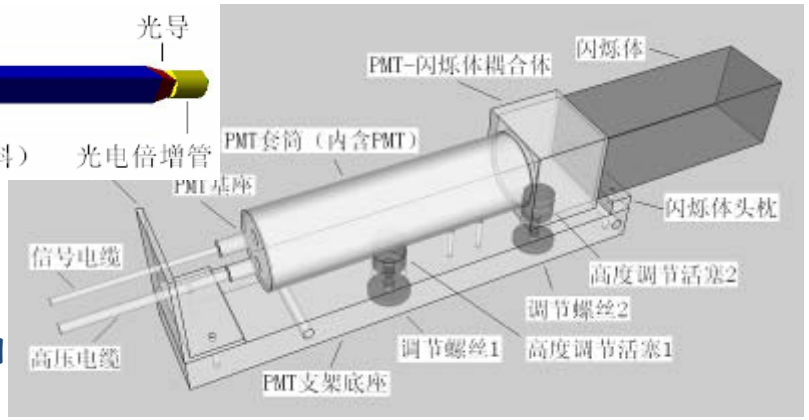
## Electronics and DAQ




北京大学中子谱仪探测器单个闪烁体几何尺寸设计



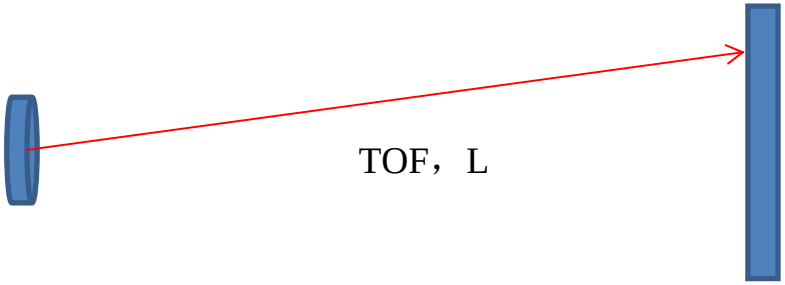




## Detector unit:

200cm*5cm*6cm BC408 scintillator + Hamamatsu R1828-01 PMT

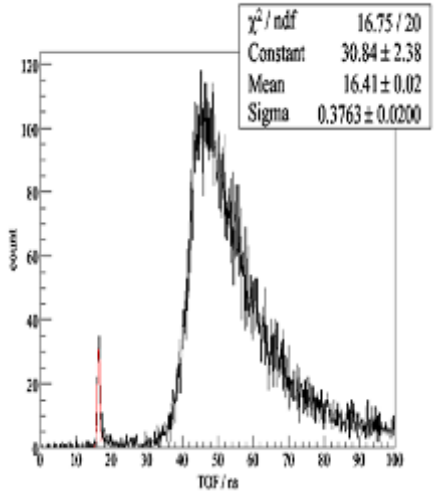
# Neutron TOF measurement:

Using gamma produced in beam - heavy target reaction measure TOF and calibrate time zero

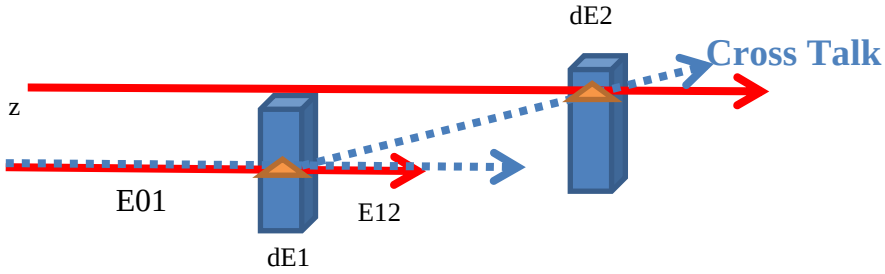



$$\begin{cases} TOF_n = T_n + T_0 \\ \beta_n = \frac{1}{c}\frac{L}{TOF_n} \\ E_n = M_n\left(\frac{1}{\sqrt{1-\beta_n^2}} - 1\right) \end{cases}$$

$$\begin{cases} T_n = TOF_n + T_0 \\ T_\gamma = TOF_\gamma + T_0 = \frac{L}{c} + T_0 \end{cases}$$

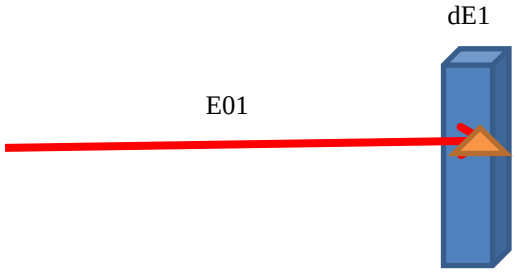



# Cross talk suppression:

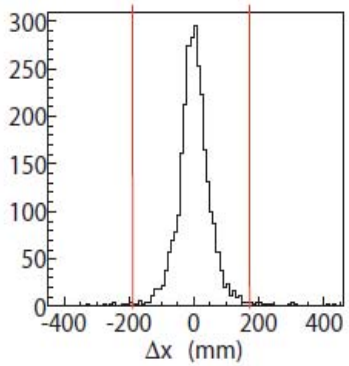


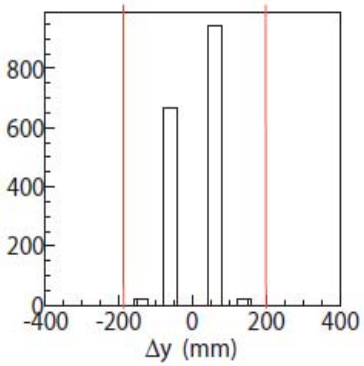

Suppression condition:
Space criteria + energy criteria

# Neutron energy measurement:

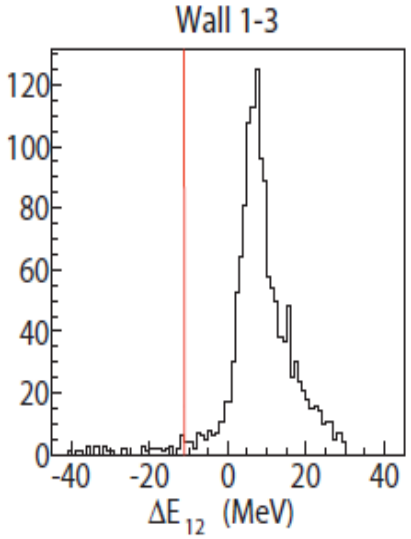


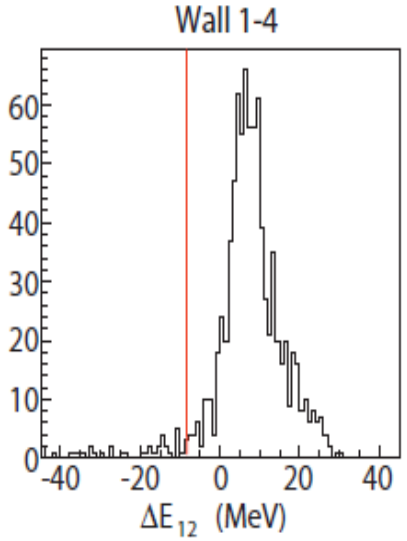
# Cross-talk treatment

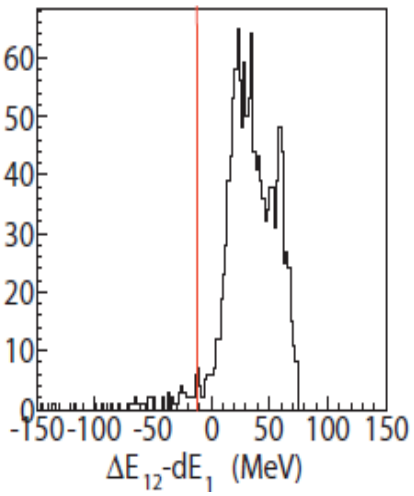


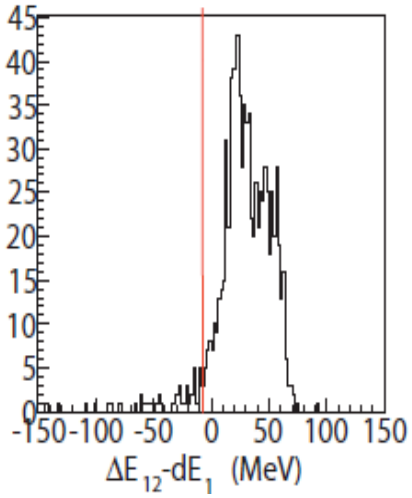




Same wall: reject track with x distance < 200mm and y distance < 150mm



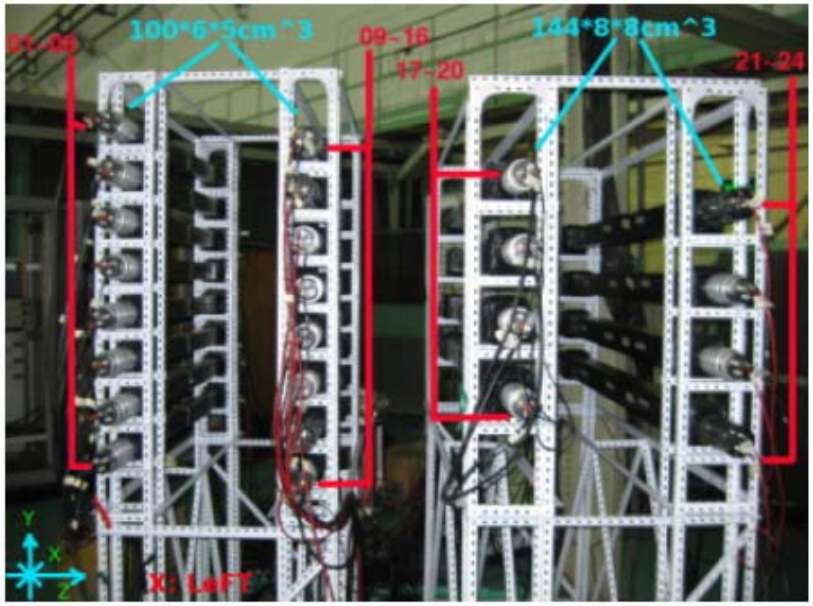



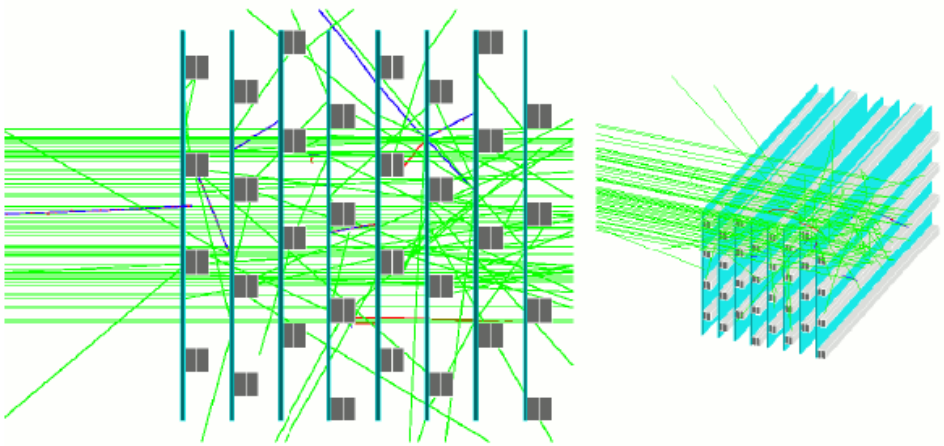



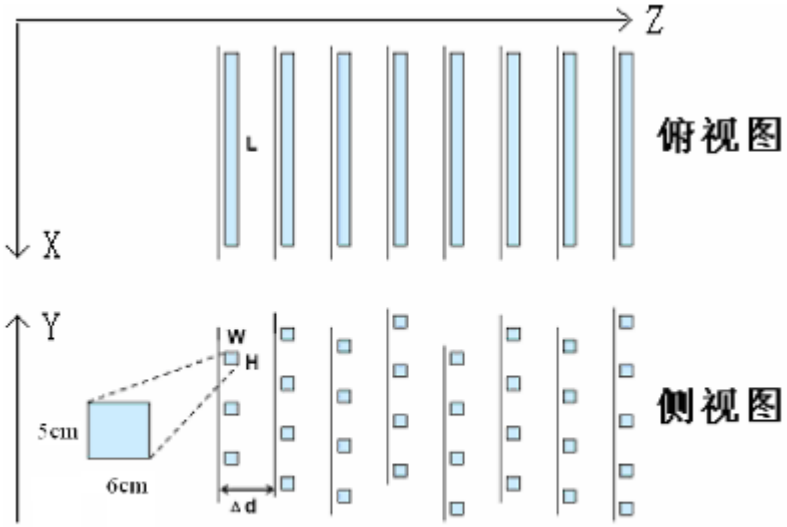

Different walls:
Apply kinematics criteria according to the measured space and energy

# Layout of Multi-neutron correlation spectrometer



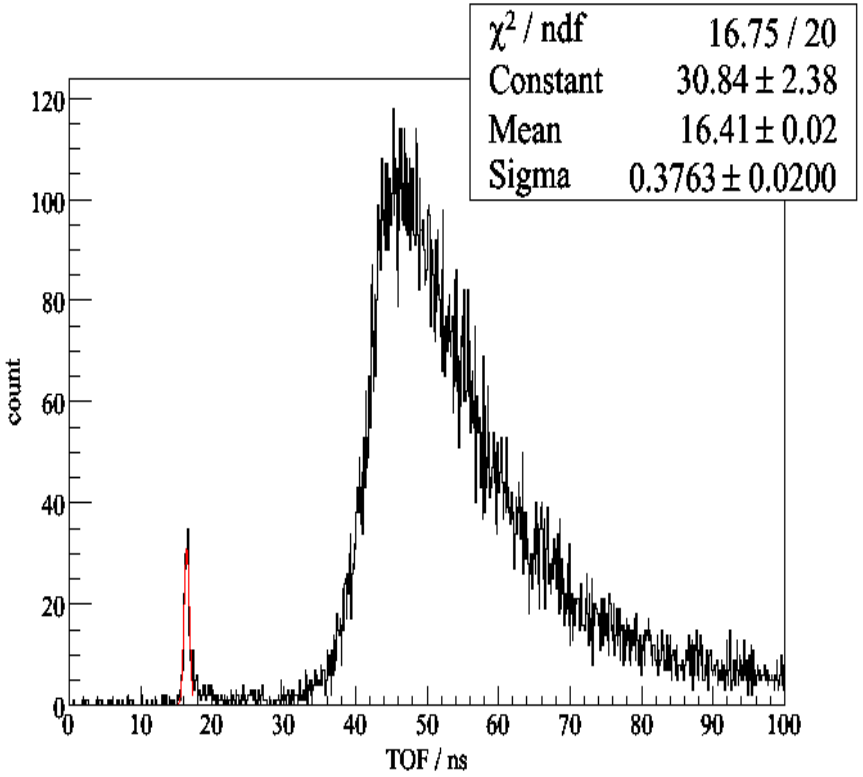



Neutron track simulation

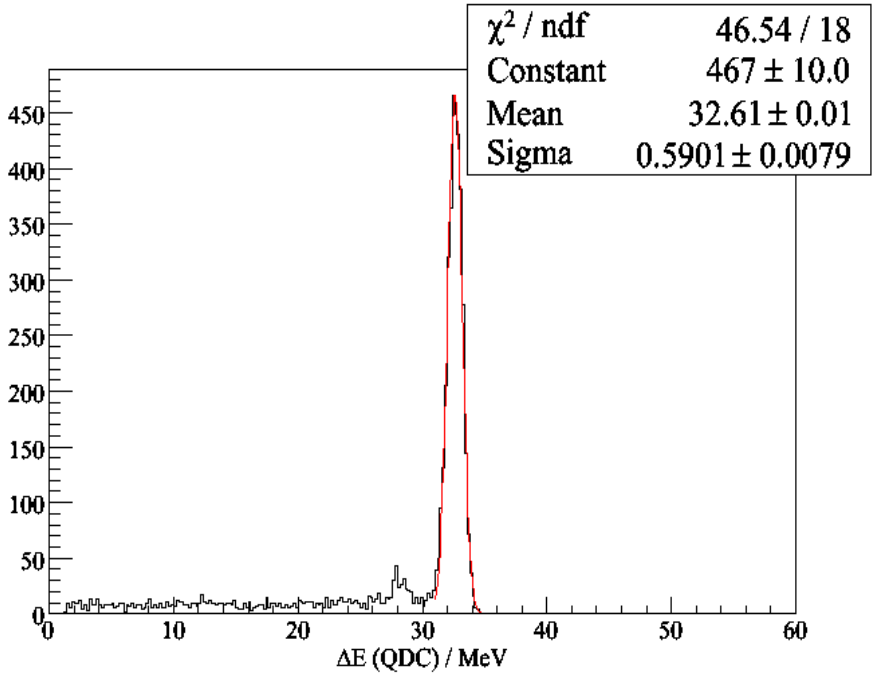



Multi-Neutron Correlation Spectrometer at Forward Angles for Radioactive Nuclei Beam Experiments

# Some measurements from data




measured TOF resolution for gamma is 900ps(FWHM)

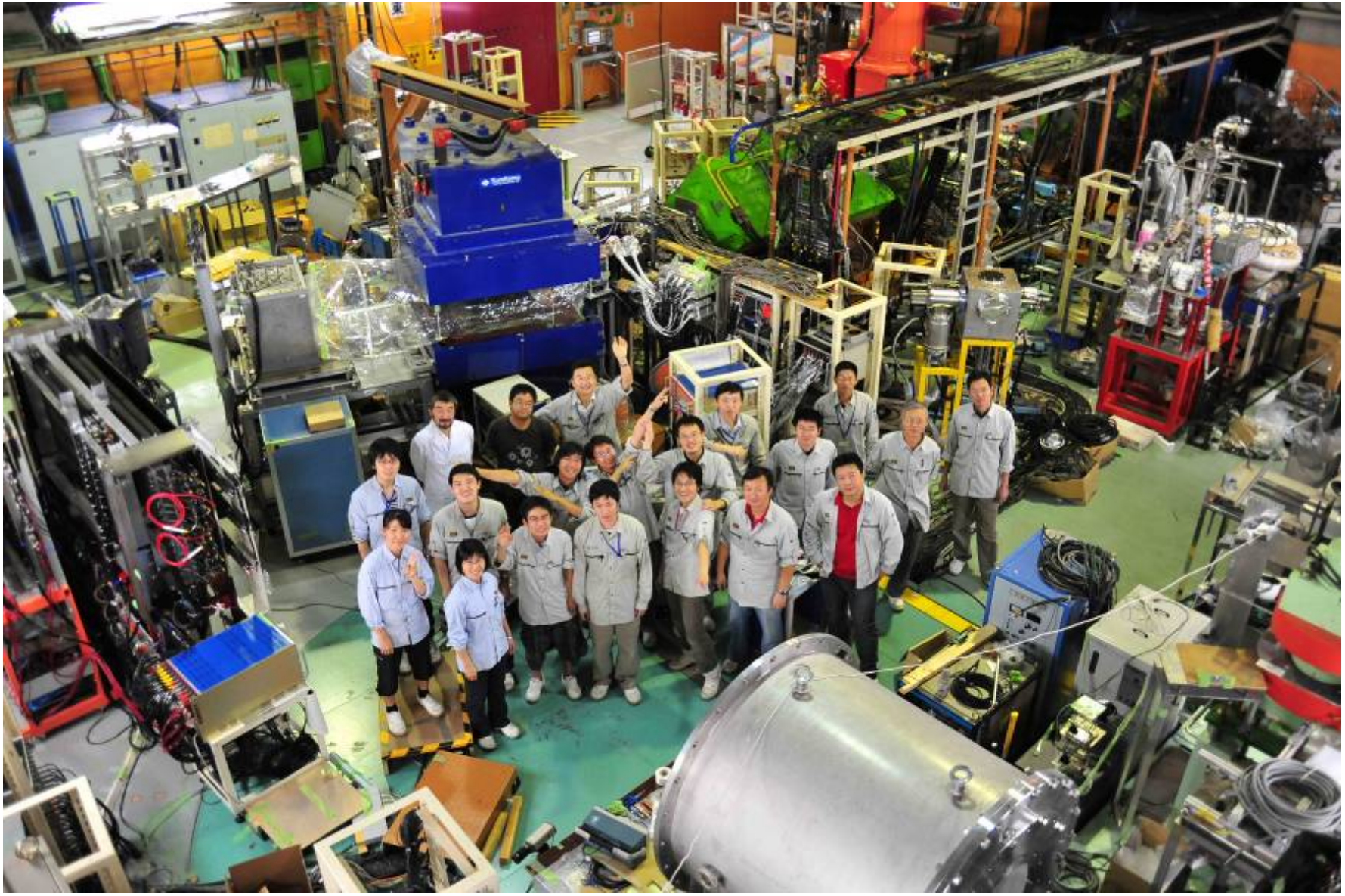



Using fixed energy neutron from 7Li(p,n)7Be reaction, the measured resolution for energy loss is about 4%（FWHM）

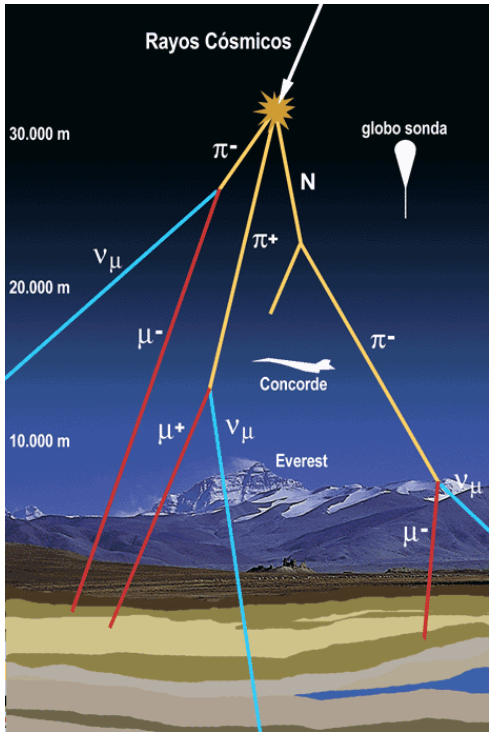
# Criteria of multi-neutron correlation spectrum

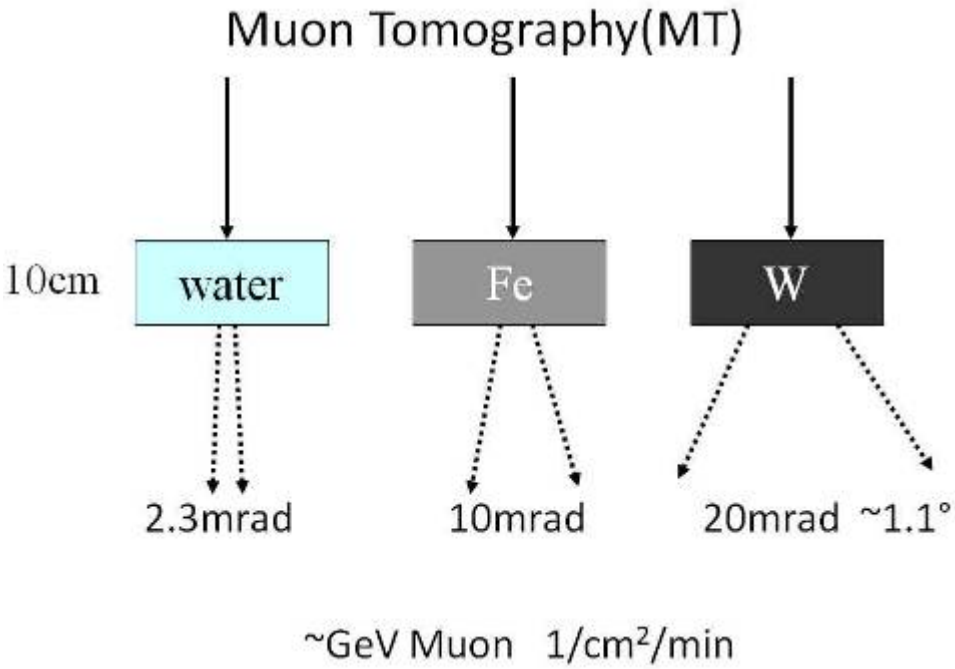
- For neutrons with energy between 30 – 100 MeV, the detection efficiency is around 70%
- Spatial resolution 3cm FWHM
- Time resolution 190ps
- Energy resolution 0.5%
- with current detector layout and using multi-scattering tracing method, the cross talk suppression rate > 90%, efficiency loss < 10%
- Angular coverage (distance to target 4m): longnitudinal $\pm 10^\circ$ ; transverse $\pm 14^\circ$
- A thin layer (1cm) of scintilatior was placed in front of the neutron spectrometer to reject charged particles using anti-coincidence method. The rejection rate > 98%

# The spectrometer in $^{8}He$+C/H experiment at RIKEN, Japan



# ➢ Muon Tomographic Imaging using Glass RPCs

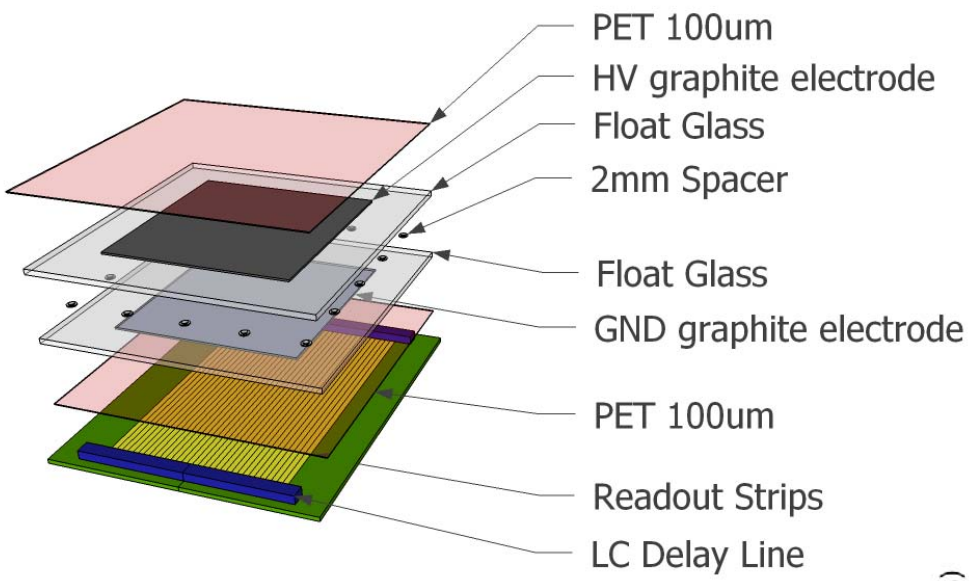


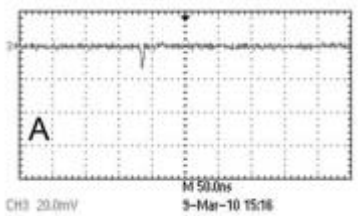
Detector requirement:

- ➢ Large Area (~1m²)
- ➢ High Detction Efficiency (>90%)
- ➢ High Spatial Resolution (<1mm)
- ➢ Cost-effective

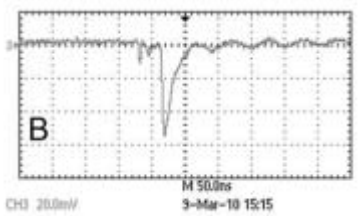
# Detector structure:
# Combination of glass RPC & Delay-line Readout




Avalenche Signal

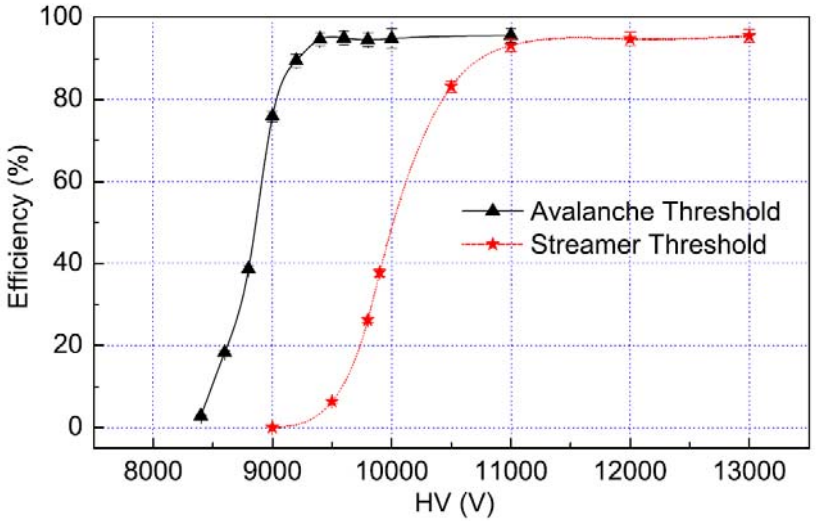



Avalenche +Streamer Signal



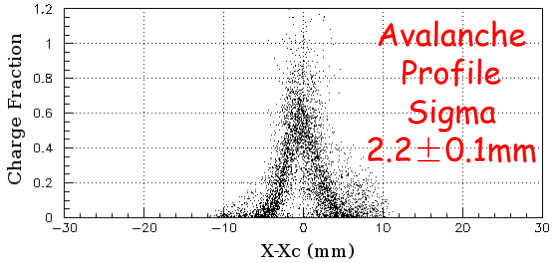

Working gas composition:
90% F134a+9% $C_4H_{10}$+1% $SF_6$

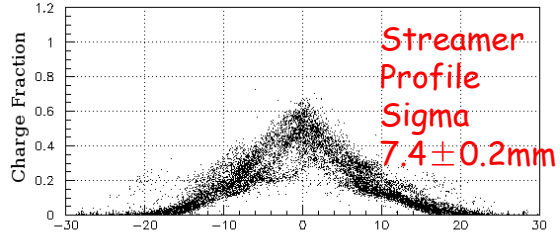
Gas flow: 50ml/Min

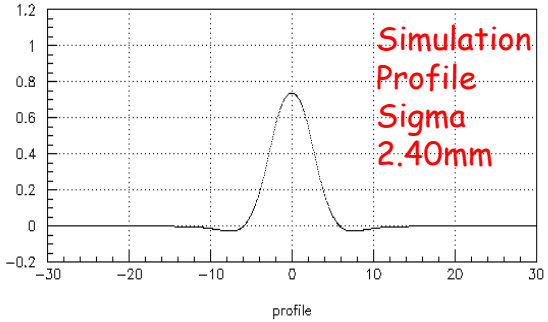


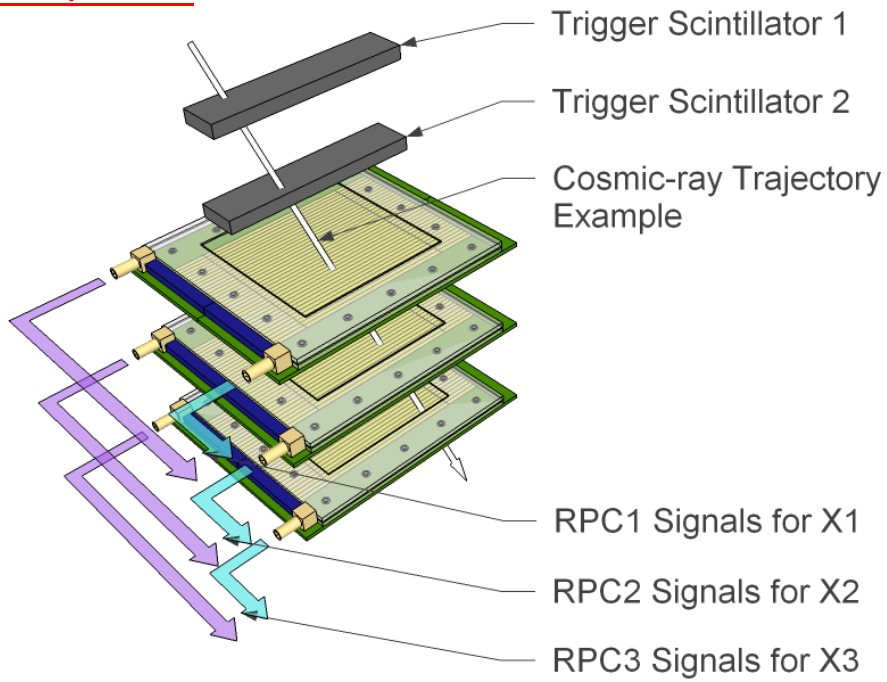

Detection Efficiency

# Spatial Resolution Measurement



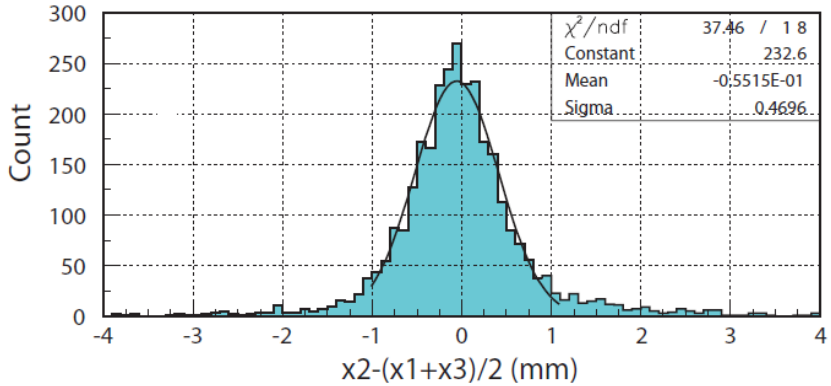

## Residual Method: $\Delta X = X_2 - (X_1 + X_3)/2$

$$f = X_2 - (X_1 + X_3)/2$$

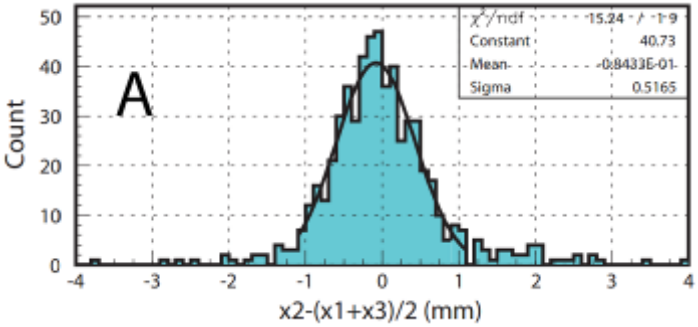
$$\sigma^2 = \sigma_{x2}^2 + (\frac{1}{2})^2 \sigma_{x1}^2 + (\frac{1}{2})^2 \sigma_{x3}^2 = \frac{3}{2}\sigma_x^2$$

$$\sigma_x = \sqrt{\frac{2}{3}}\sigma = 0.816 \bullet 0.470mm = 0.384mm$$

$$FWHM_x = 2.35\sigma_x = 0.90mm$$

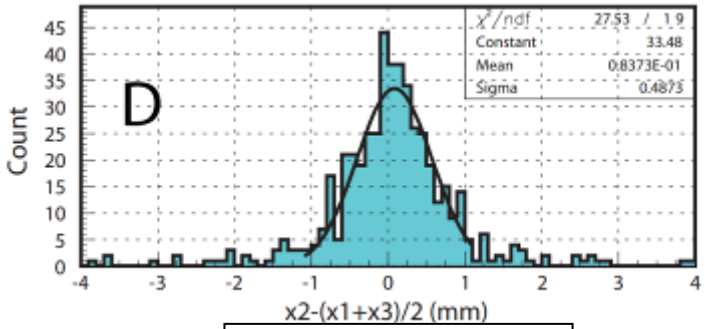


# Uniformity of spatial resolution



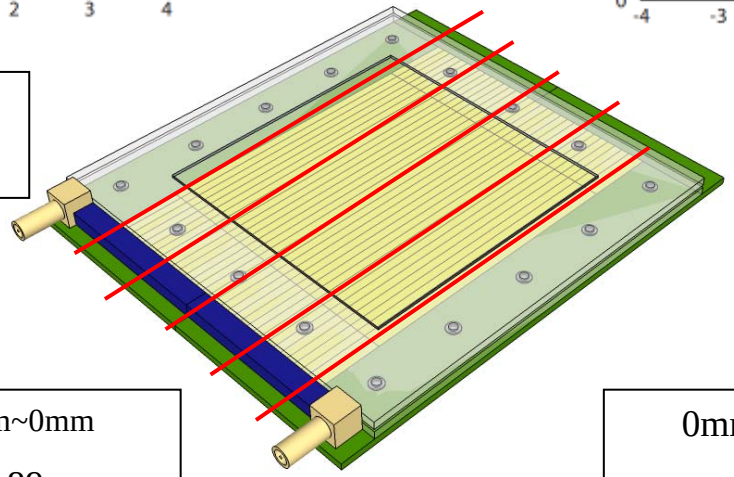

-50mm~-25mm

Res=0.99 mm




25mm~50mm

Res=0.94 mm

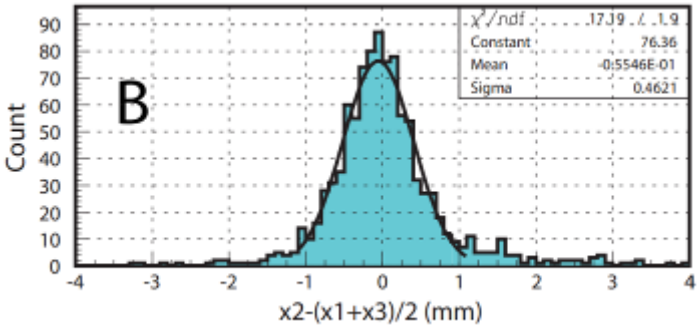


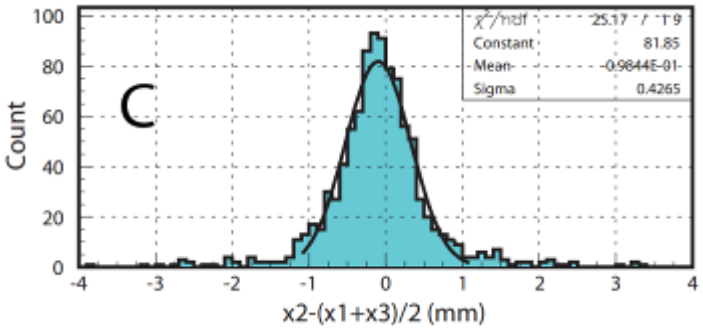
-25mm~0mm

Res=0.89 mm

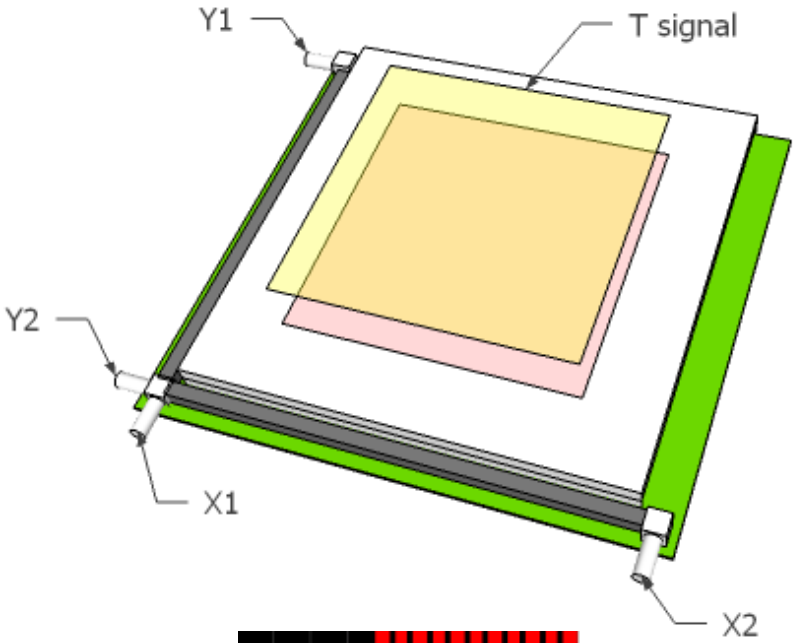
0mm~25mm

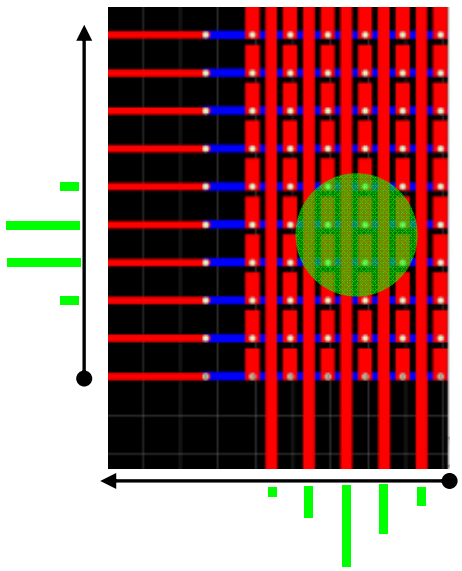
Res=0.82 mm



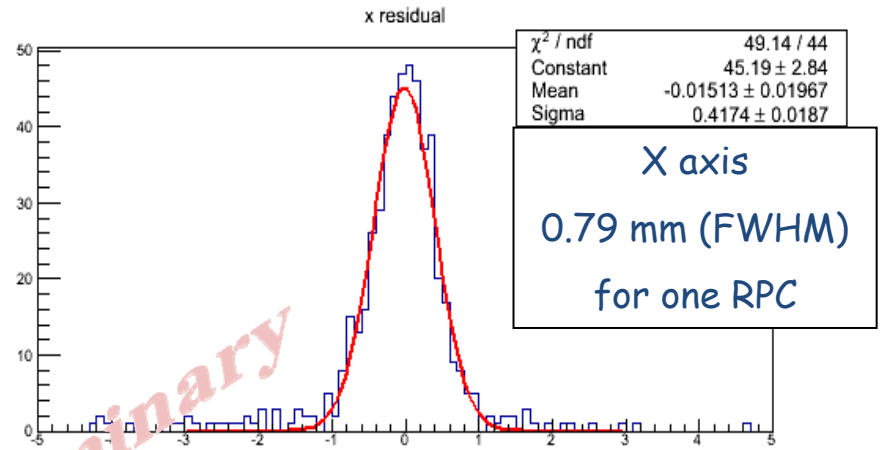



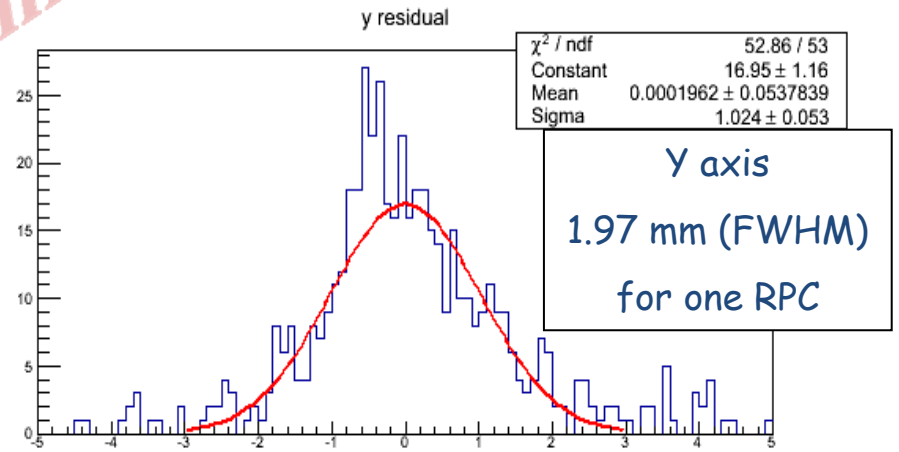
# X, Y and T readout in ONE RPC



Spatial resolution in both direction:

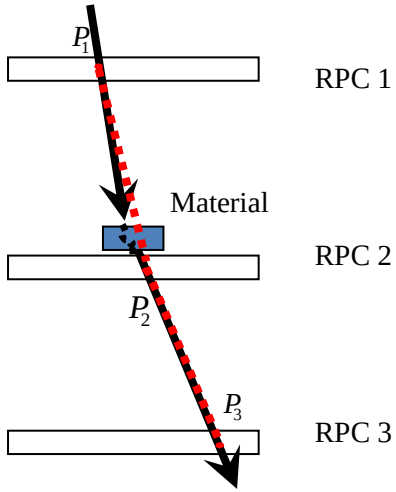


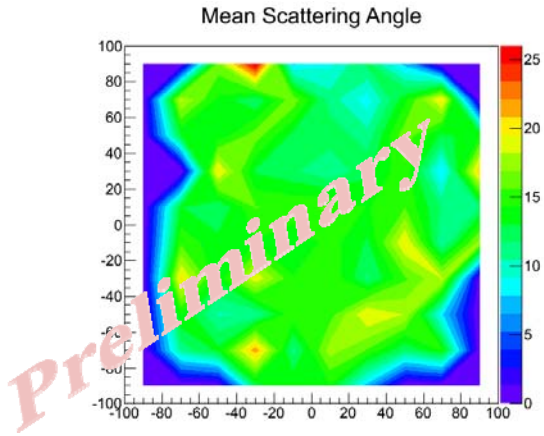




Preliminary

# MT Station with three 2D-Glass RPCs, 12+2 channels

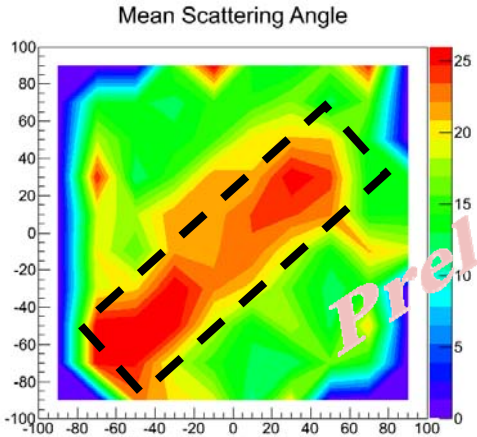
Set up of 3 layer glass RPC MT station



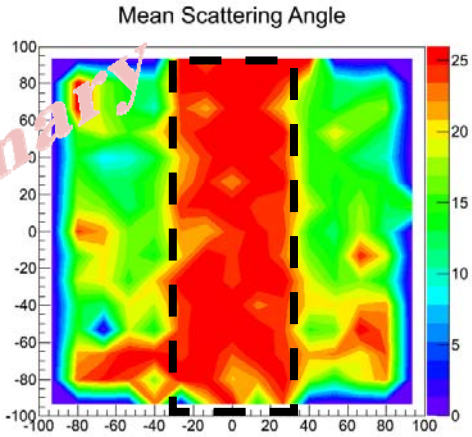




Empty target

- Mean angle ~15 mrad
  - Position/Alignment error
    - ~8 mrad
  - RPC box, framework
    - ~10 mrad




Pb brick 1 15cm*5.5cm*3.5cm

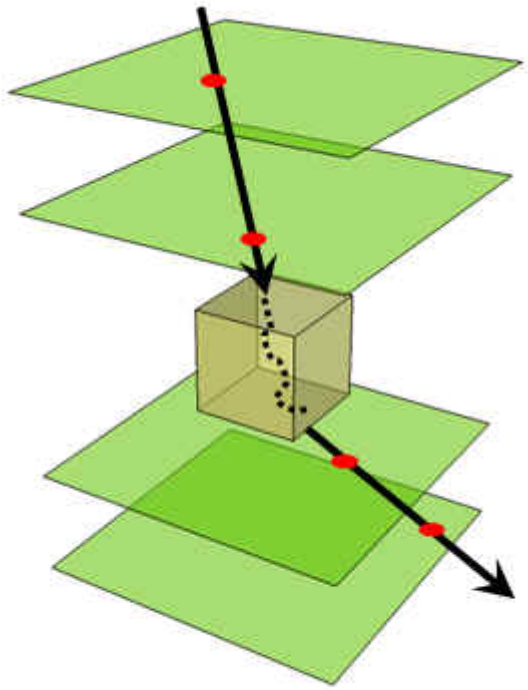



Pb brick 2 24cm*7cm*6cm

# MT Station with Glass RPCs: summary

- Glass RPCs with LC Delay-line Readout
  - Simple structrue, stable performance
  - Efficiency 95~98%
  - Charge profile measurement
    - <1mm(FWHM) in avalenche mode
  - Ideal detectors for MT

- MT Station using three 2D-Glass RPCs
  - Preliminary Test (detection area: 20cm*20cm)
  - Sensitive to ~cm Pb



MT station with 4 RPCs
3D Imaging
→ Coming Soon

# Summary

- We have made concreate contribution to the construction of CMS-RPC system. During the collaboration process, we've also accumulated expertise and experience in detector R&D, mass production QC, installation, commission and software developt. Our detector research laboratory also developed during the CMS-RPC project.
- Our nuclear physics group has stuff members working full time on detector R&D. For major project, we also share man-power and recourse.
- We'll continue working on CMS upgrade project, we are also interested in possible future collaboration opportunities.

Thanks you!