Prospects of RPC Triggers for CMS and PHENIX Experiments

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Contents

1. Introductions

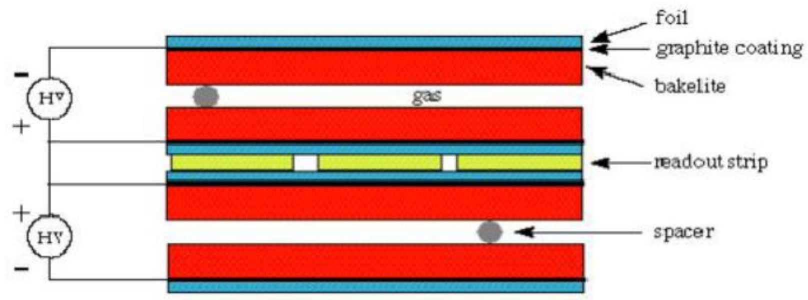
Why Resistive Plate Chambers for large detector systems in Nuclear & High-energy Physics ?

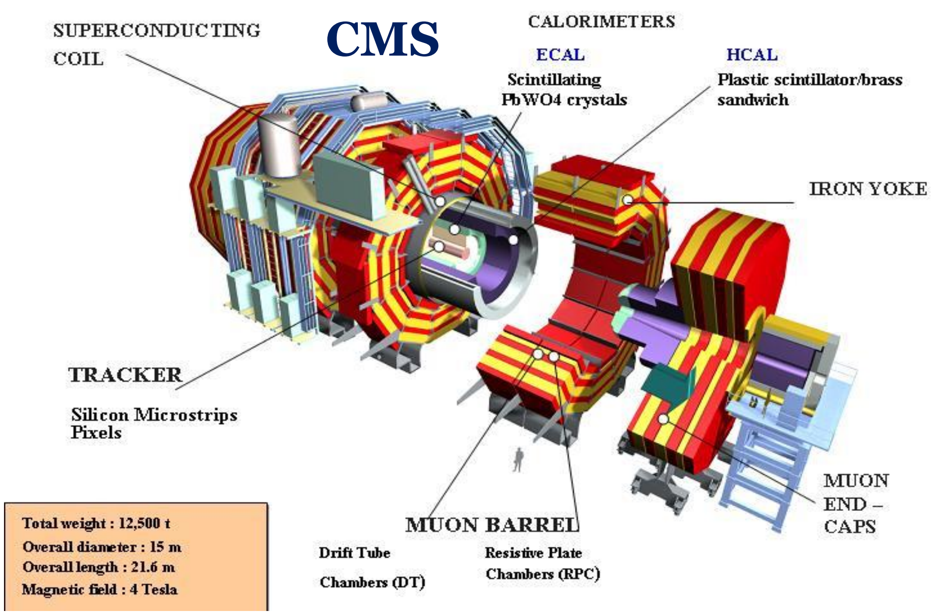
- **The fastest detector responses with fairly good time resolution for high-energy particle detections.**
- **Thin detector structure to cover a large detection area.**
- **Trigger detectors to be installed together with tracking chambers to obtain fast HIT response data for times and positions for particle tracking**
- **Small radiation thickness (thin detector thickness)**
  → minimally effect on the meaningful particle track to be reconstructed.
- **No wires used → relatively low costs**
- **Gaseous detectors → radiation hard for high-rate radiation environments**
  Guarantee reliable operation for long-period experiments

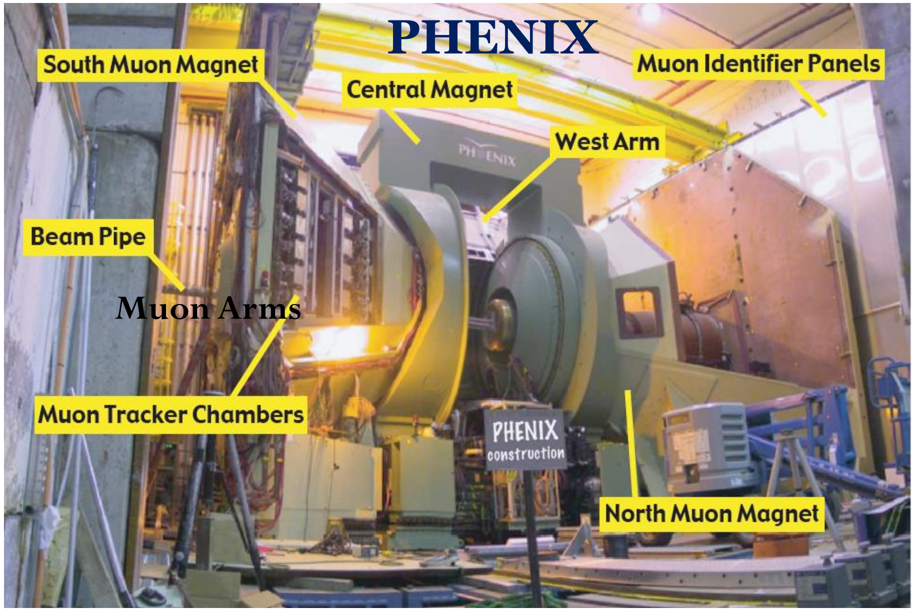
Large-area triggers for large area trigger detections

(CMS, ATLAS, & LHC-b in LHC, PHENIX in RHIC)

- 2-mm thick single or double-gap RPCs
- Required time resolution: 1 ~ 2 ns
- Less sensitive to neutral background particles
- Required rate capabilities: 10 ~ 1 kHz/cm²
- Digitization only for hits to provide fast hit data (measuring positions & times, no ADC)
- Resistive plate: HPL($\rho \sim 10^{10}\Omega$cm) or glass($\rho > 10^{12}\Omega$cm)

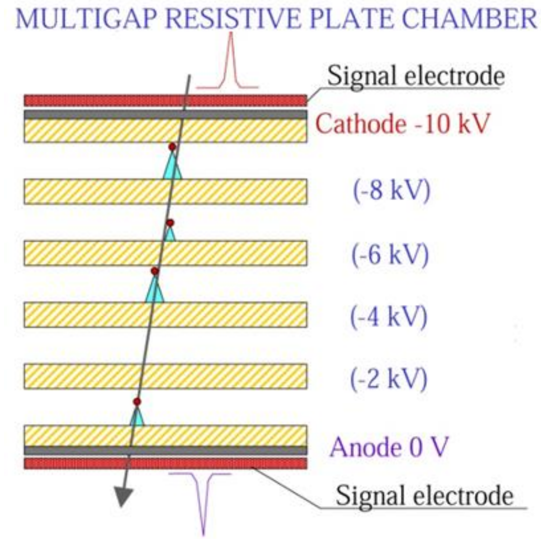


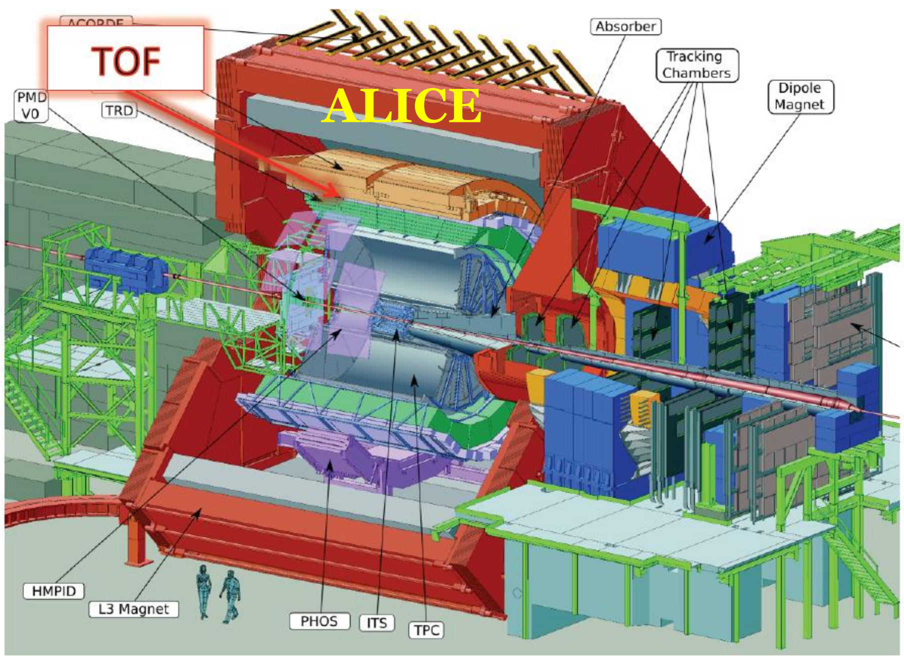


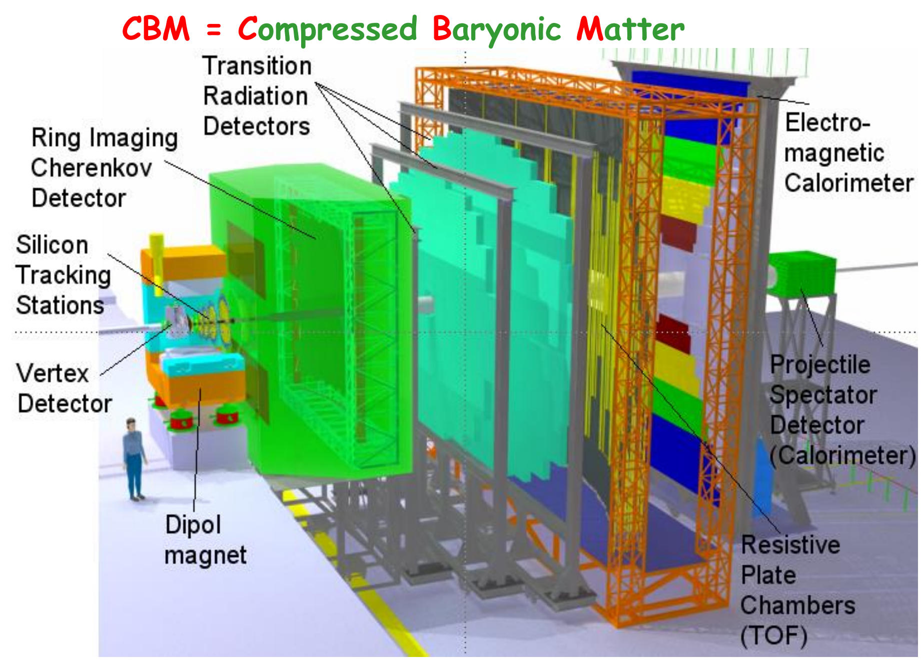


For TOF measurements (timing RPCs)
(ALICE in LHC, STAR in RHIC, and CBM @FAIR)

- ~ 0.25 mm thick multi-gap glass RPCs (6 or 8 gaps)
- Required fairly time resolution for TOF measurements:
  σ = 50 ~ 100 ps
- Rate capabilities:
  < 1 kHz/cm² with normal glass
  > 10 kHz/cm² with low resistive glass ($\rho \sim 10^{10}$ Ωcm)
- Digitization for times, positions, and charges
  (requiring both TDC and ADC measurements)



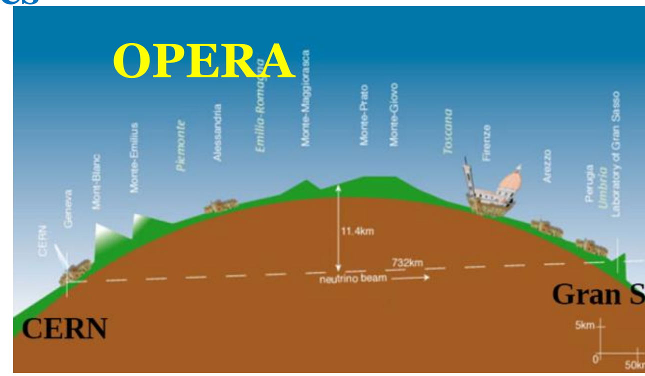


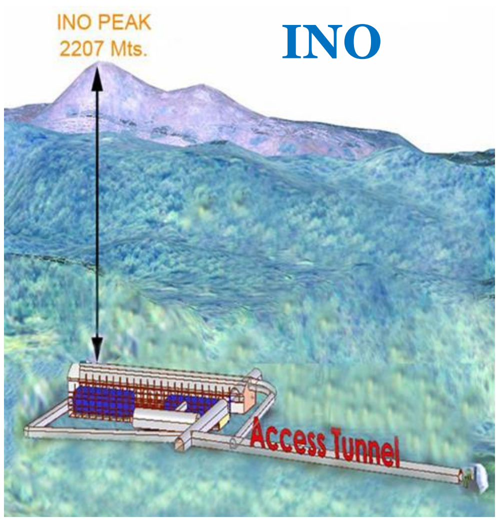


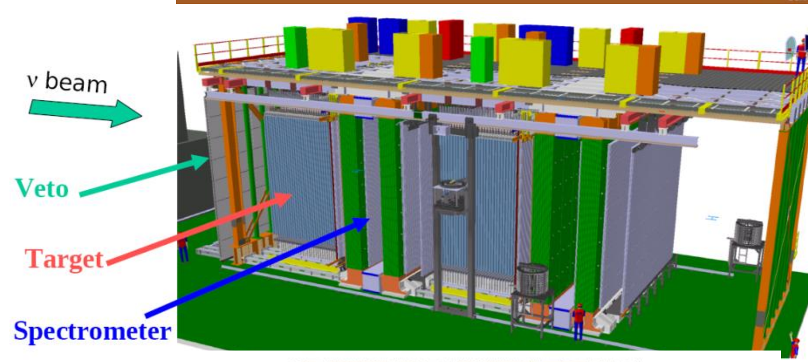
For measurements of neutrino oscillations (INO and OPERA)

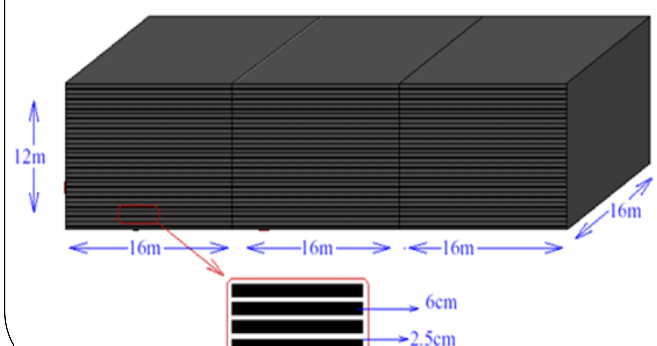
- **INO** (Indian Neutrino Observatory) measures neutrino oscillated muons (2018 ?)
  Deep inside a mine to suppress detection of cosmic muons
  High resistive normal glass single-gap RPCs to suppress noises
  Avalanche-mode operation

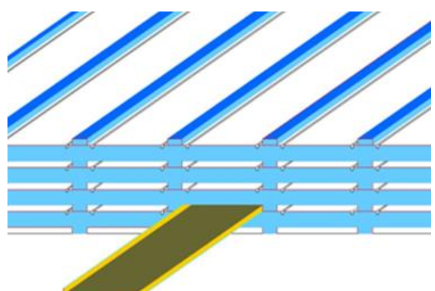
- **OPERA** (Oscillation Project with Emulsion tRacking Apparatus)
  measures neutrino oscillated τ's
  High resistive single-gap HPL RPCs
  Streamer-mode (avalanche-mode ?) operation

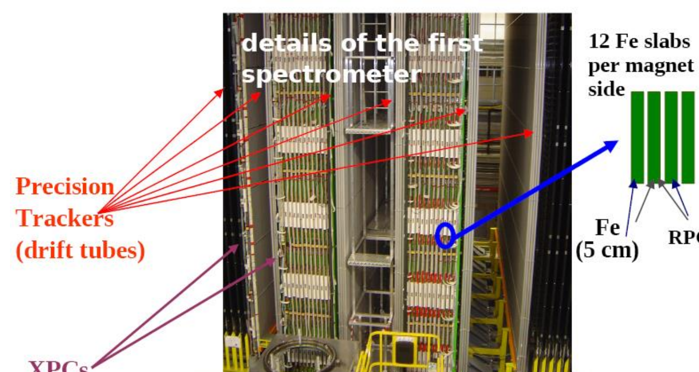






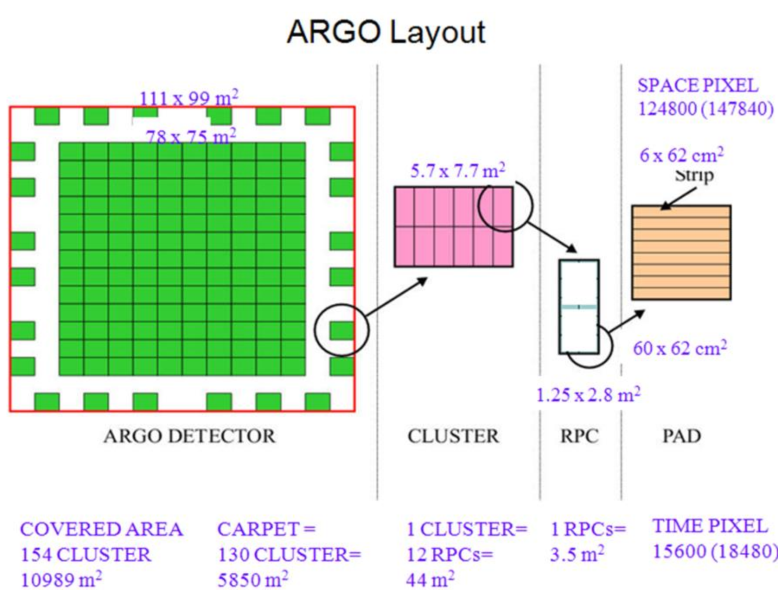






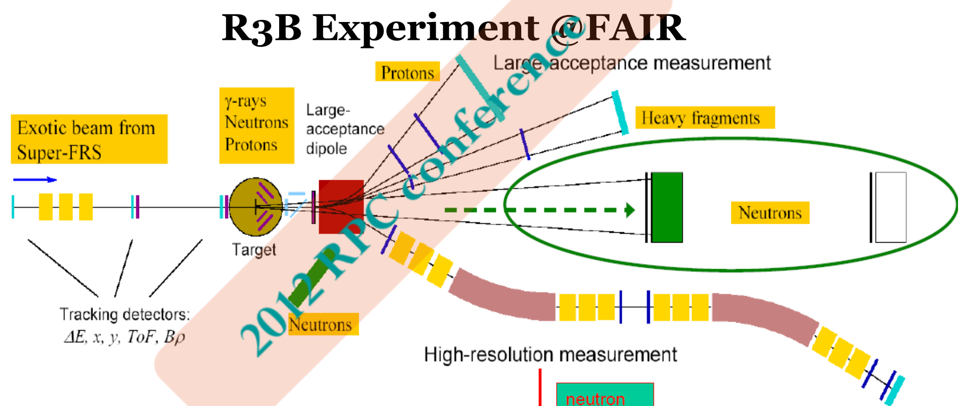
For measurement of cosmic rays (ARGO @YBJ)

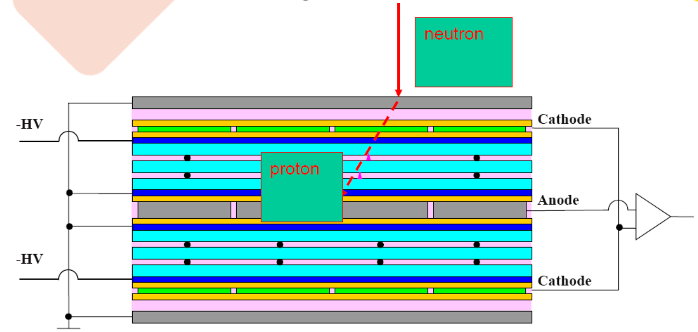
- ARGO measures muons, electrons, and gammas in cosmic-ray bursts
- High resistive double-gap HPL RPCs
- Streamer-mode operation



Neutron calorimeters

- Neutron measurements for RI reactions
- Detectable neutron energy: 0.2 ~ 1 GeV
  Expected ε > 90% for 400 MeV neutrons
- Steel converters + multi-gap RPCs
- Required time resolution ~ 100 ps
- Advantage of multi-neutron events over plastic scintillator arrays





2. Trigger RPCs in upgraded PHENIX

Motivation of RPC triggers

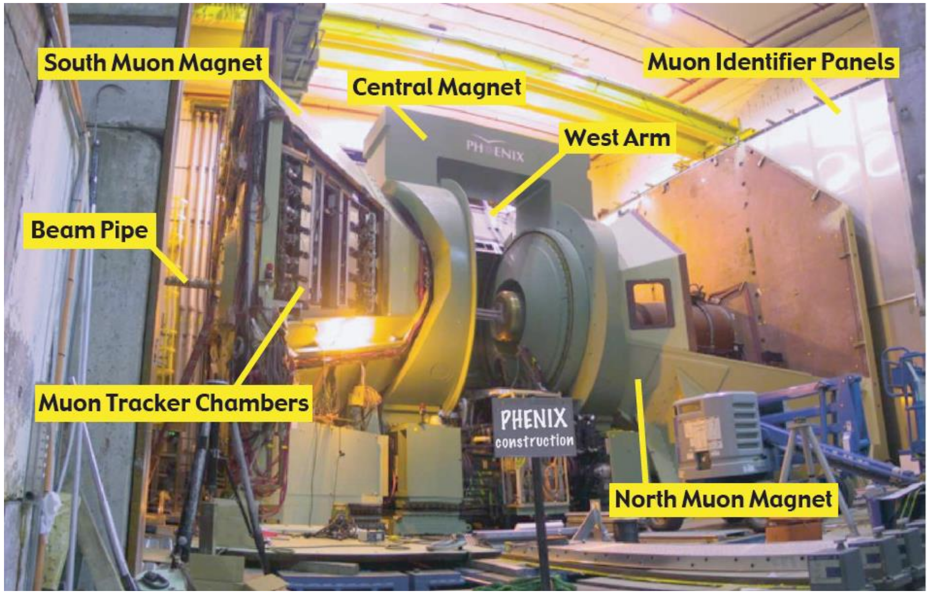
Upscope PHENIX TDR (2007)

The new spin physics with a higher energy requires more effective triggers in removing beam related backgrounds.

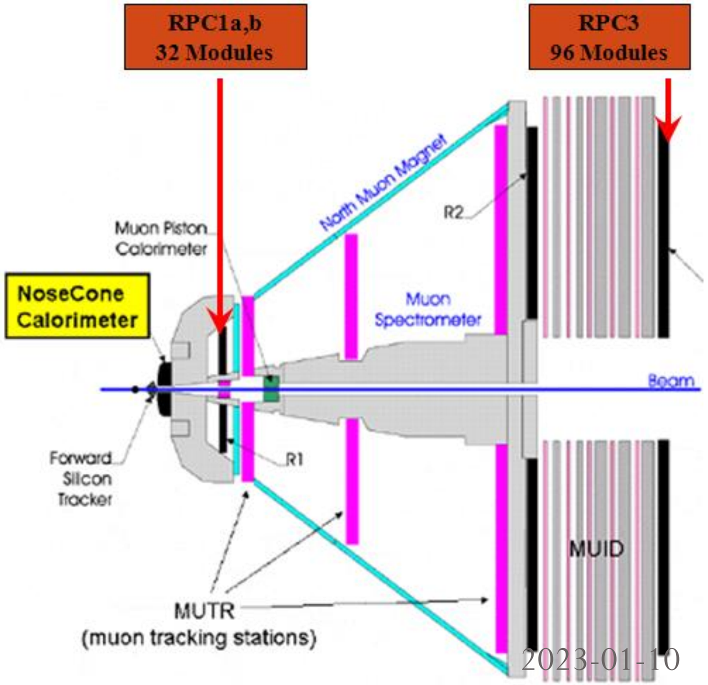
→ L = 1.6 x 10^{32} $cm^{-2}s^{-1}$ with a total cross section (60 mb) at $\sqrt{s}$ = 500 GeV
→ Needs **higher background reduction factor** ~ 10000 including safety factor 2.

RPCs in avalanche mode are enable to satisfy the condition

→ Time resolution (including electronics) < 2 ns.
→ Required rate capability < 1 kHz/cm^2.
→ Noise rate < 5 Hz/cm^2 in the detector level.

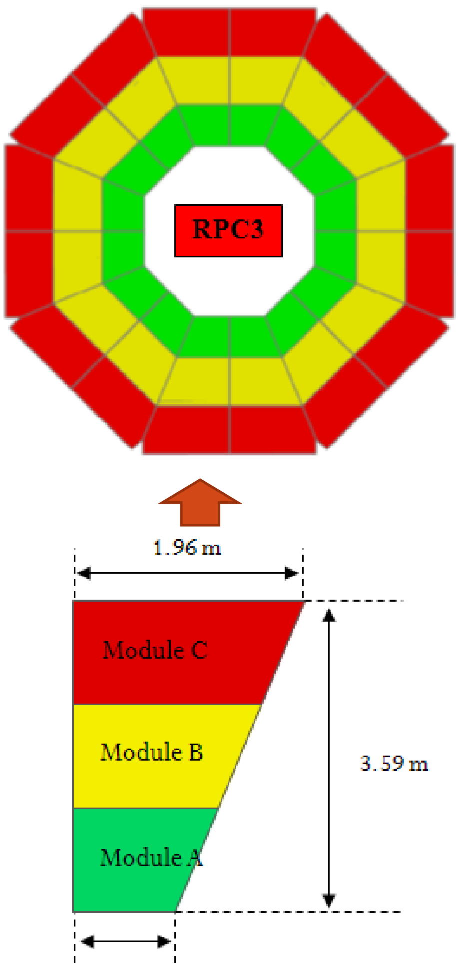


Coverage : 1.2 < η < 2.4 for North,
1.2 < η < 2.2 for South



RPC station 3

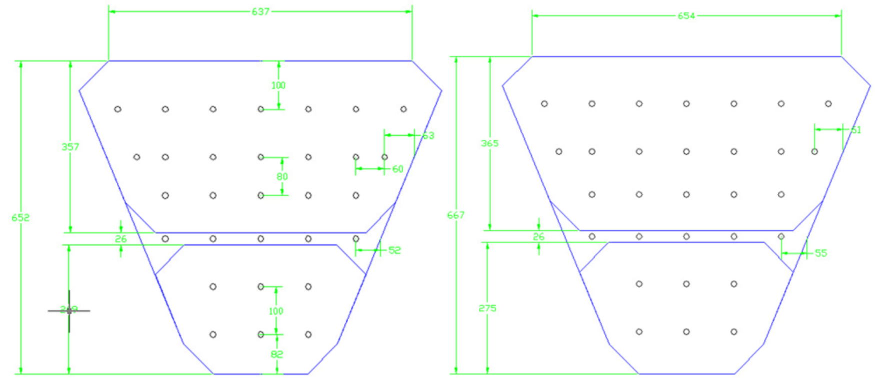
32 half octants (16 in each arm)
Three RPCs modules in a half octant
→ totally 96 double-gap RPC modules

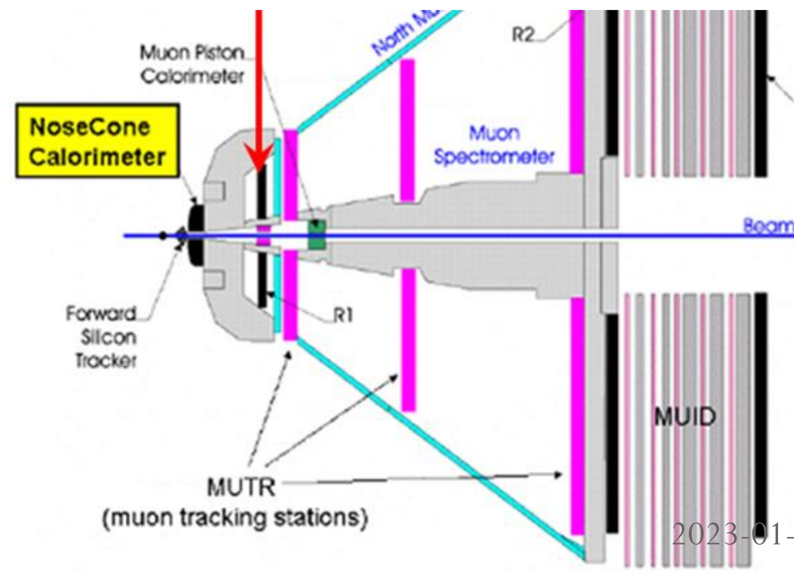


RPC station 1

16 half octants (8 in each arm)
One double-gap RPC module in a half octant
→ totally 16 double-gap RPC modules

N1A1 **N1A2**





Assembly of detector modules → QC test on each RPC module

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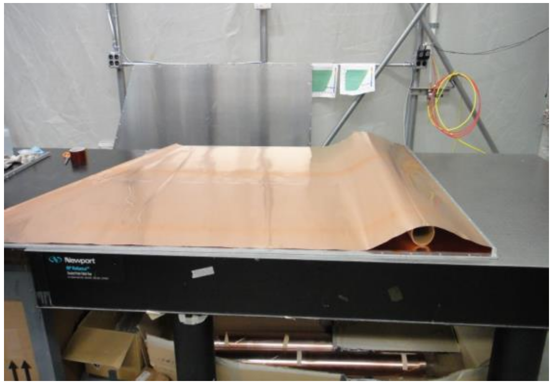
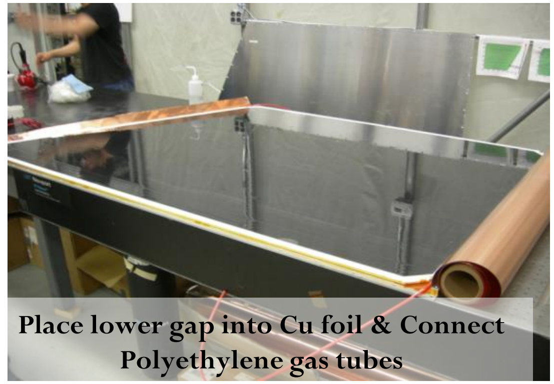
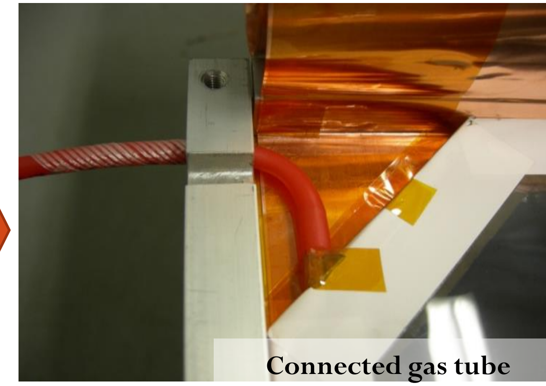
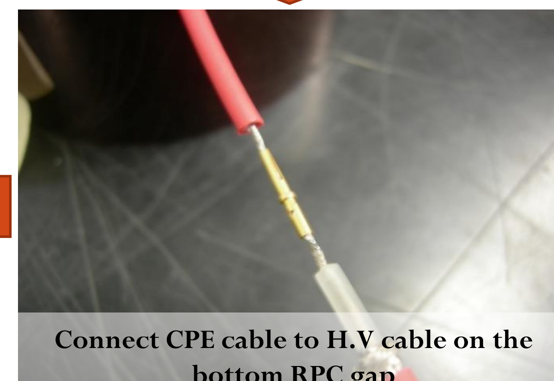




Place lower gap into Cu foil & Connect Polyethylene gas tubes

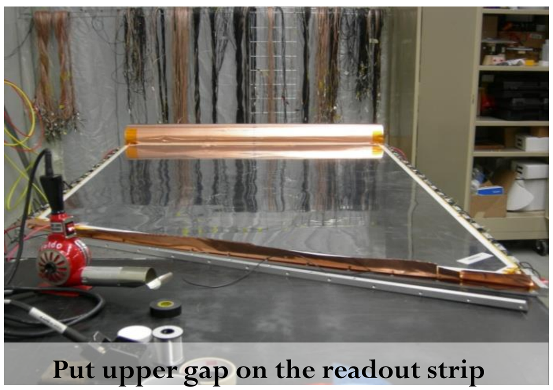


Connected gas tube

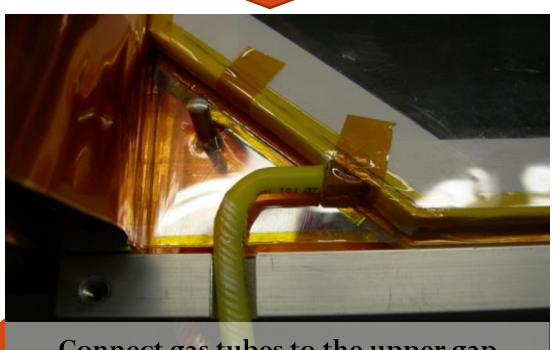


Connect CPE cable to H.V cable on the bottom RPC gap

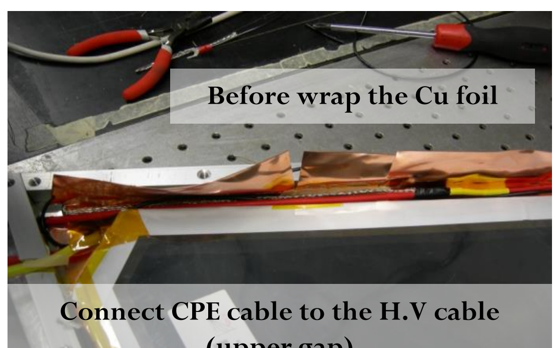
Put readout strip on the lower gap



Put upper gap on the readout strip

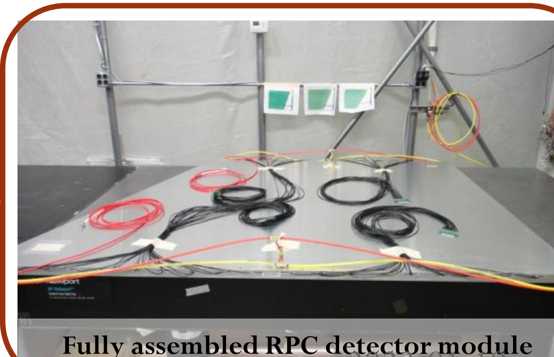


Connect gas tubes to the upper gap



Before wrap the Cu foil

Connect CPE cable to the H.V cable (upper gap)



Fully assembled RPC detector module

Assembly an half octant (super module) at RPC Station 3

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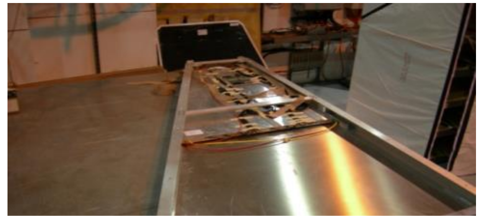
Route service lines of the module for the assembly


Insert prepared modules to the HO frame


Insert prepared modules to the HO frame (2)


Insert prepared modules to the HO frame (3)


Connect & Re-route service lines to the patch pannel


View from inside of patch pannel


RPC3N - installation (Nov. 11th, 2009)


RPC3S - installation (Sep. 22nd , 2010)

Assembly of an half octant at RPC Station 1

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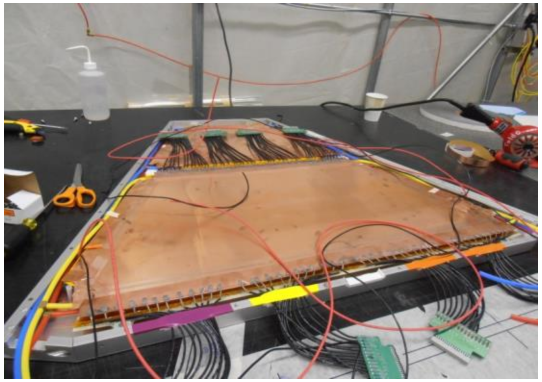
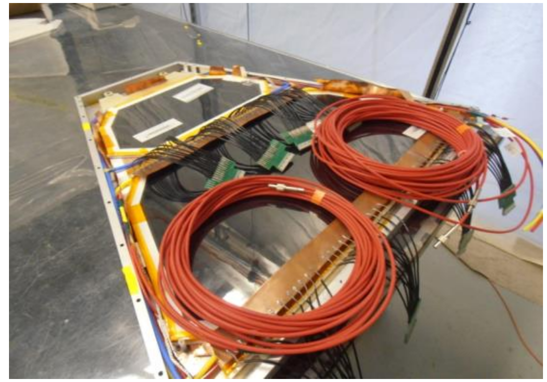
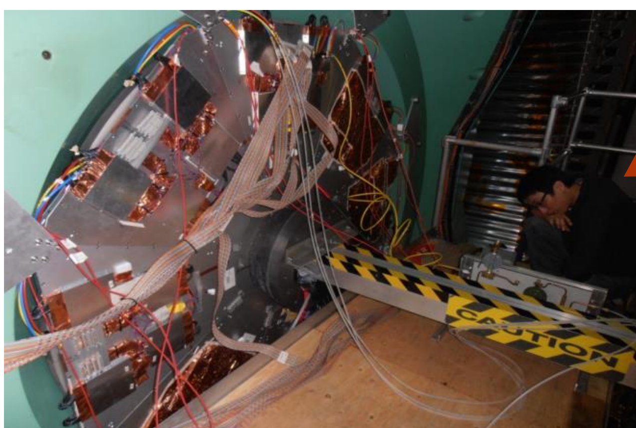




Kim Young Jin
& many students



RPC1N - installation (Sep. 22nd , 2011)

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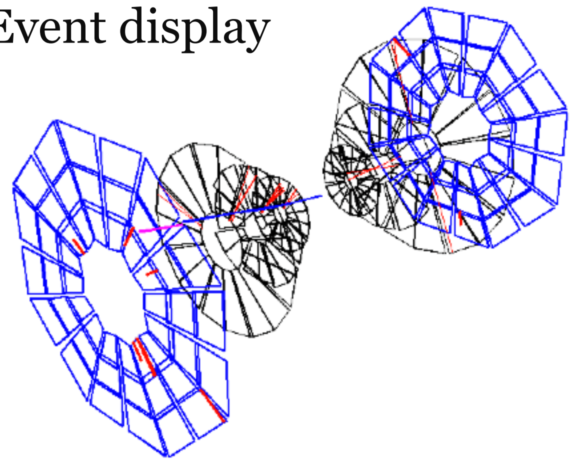
3D Event display



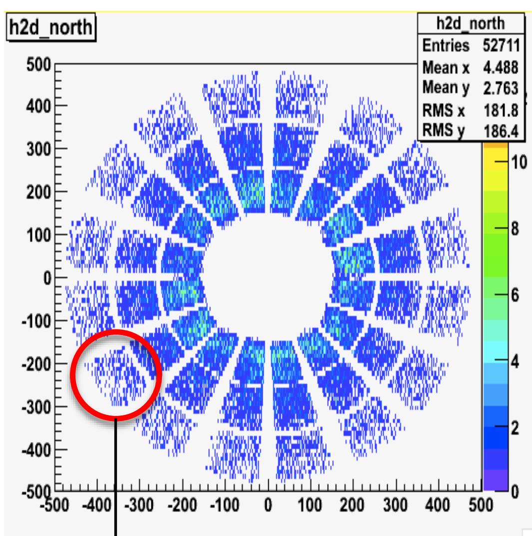
Measurement of RPC Station 3 data in RUN 11

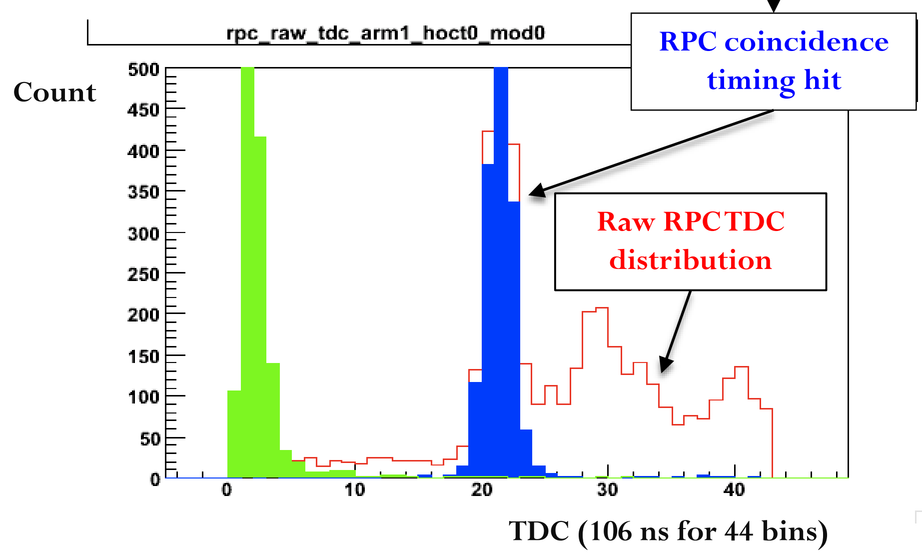
Relative efficiency calculation:

of hits on RPC / # of projected track on RPC
= # of RPC TDC count / # of Muons

Projected hits on RPC3

* Muon tracks at boundaries cut out





Efficiency in runs

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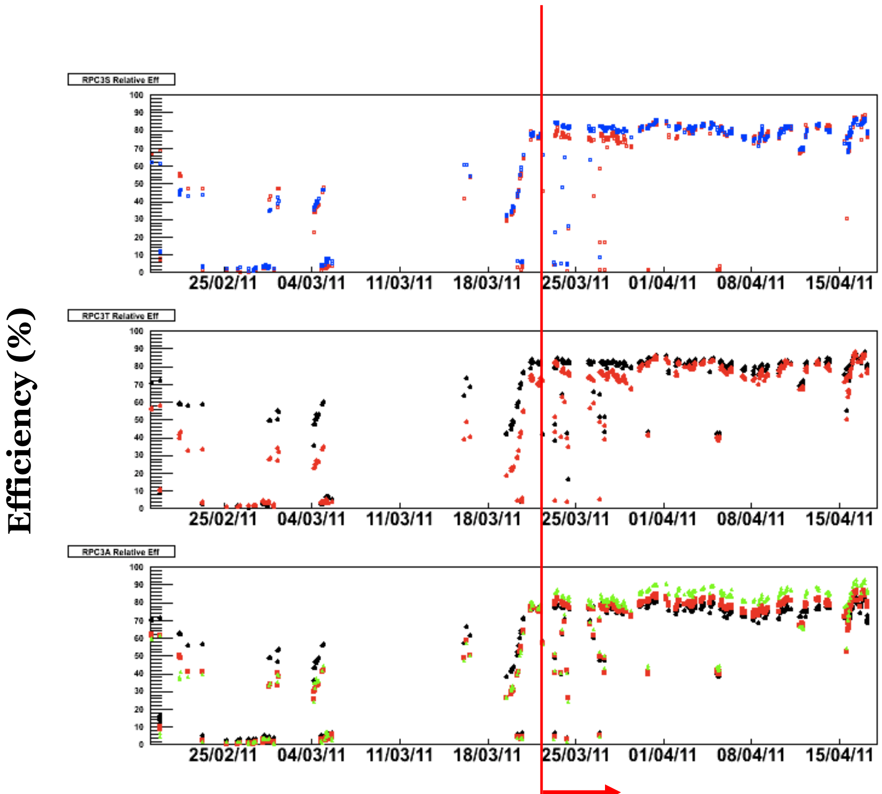
RUN 11, pp 500 GeV



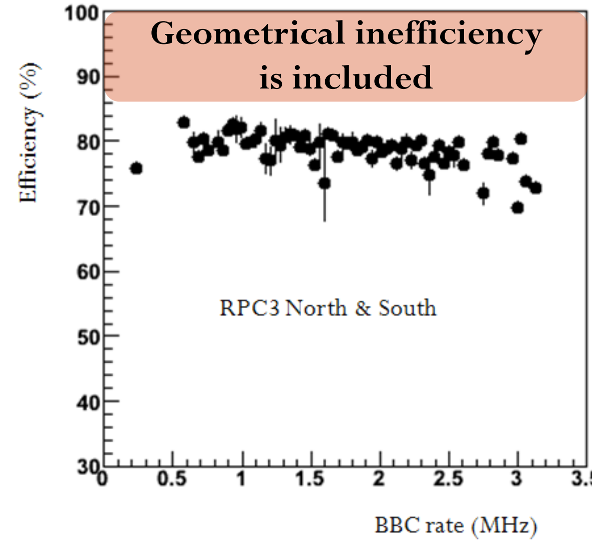
Blue: south
Red: north

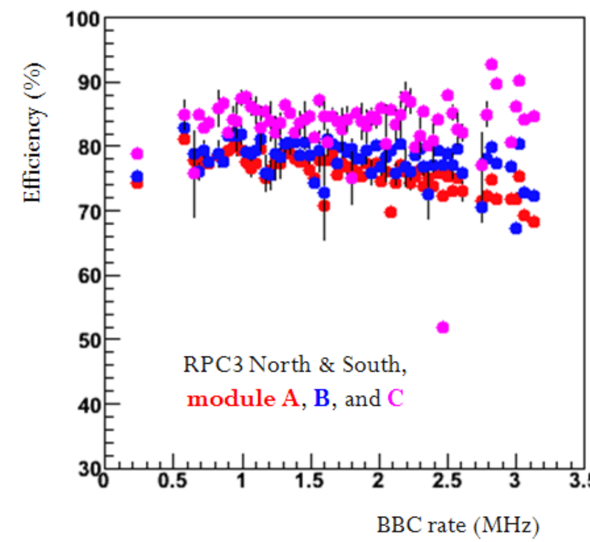
Black: top side
Red: bottom side

Black: module A
Red: module B
Green: module C

Before gas mixture optimization:
High dark current

After gas mixture optimization:
the dark current problem resolved





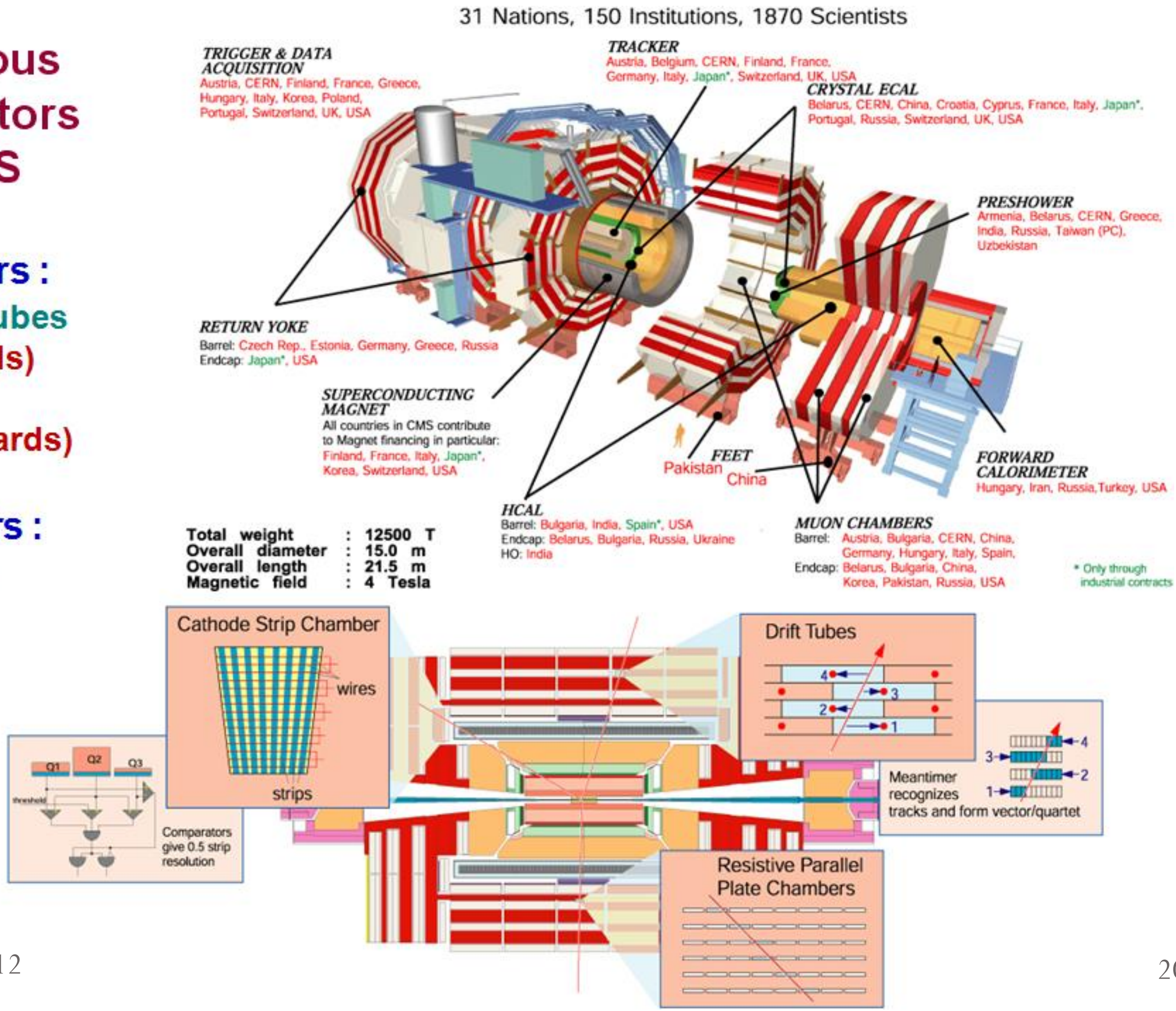
3. Upgrade of Trigger RPCs for CMS

Current RPC System for the Compact Muon Solenoid

Gaseous Detectors in CMS

Trackers :
- Drift Tubes (Barrels)
- CSCs (Forwards)

Triggers :
- RPCs



▶ RPCs System for the Compact Muon Solenoid (CMS/TDR LHCC/CERN 97-32)

- RPCs in Barrel + Endcap cover η < 2.1
- The angular coverage ~ 3 π

▶ Barrel RPCs

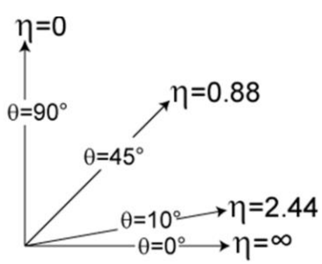
- 6 stations (layers)
- Fully covering up to η = 0.8
- Partially covering up to η = ~ 1.2

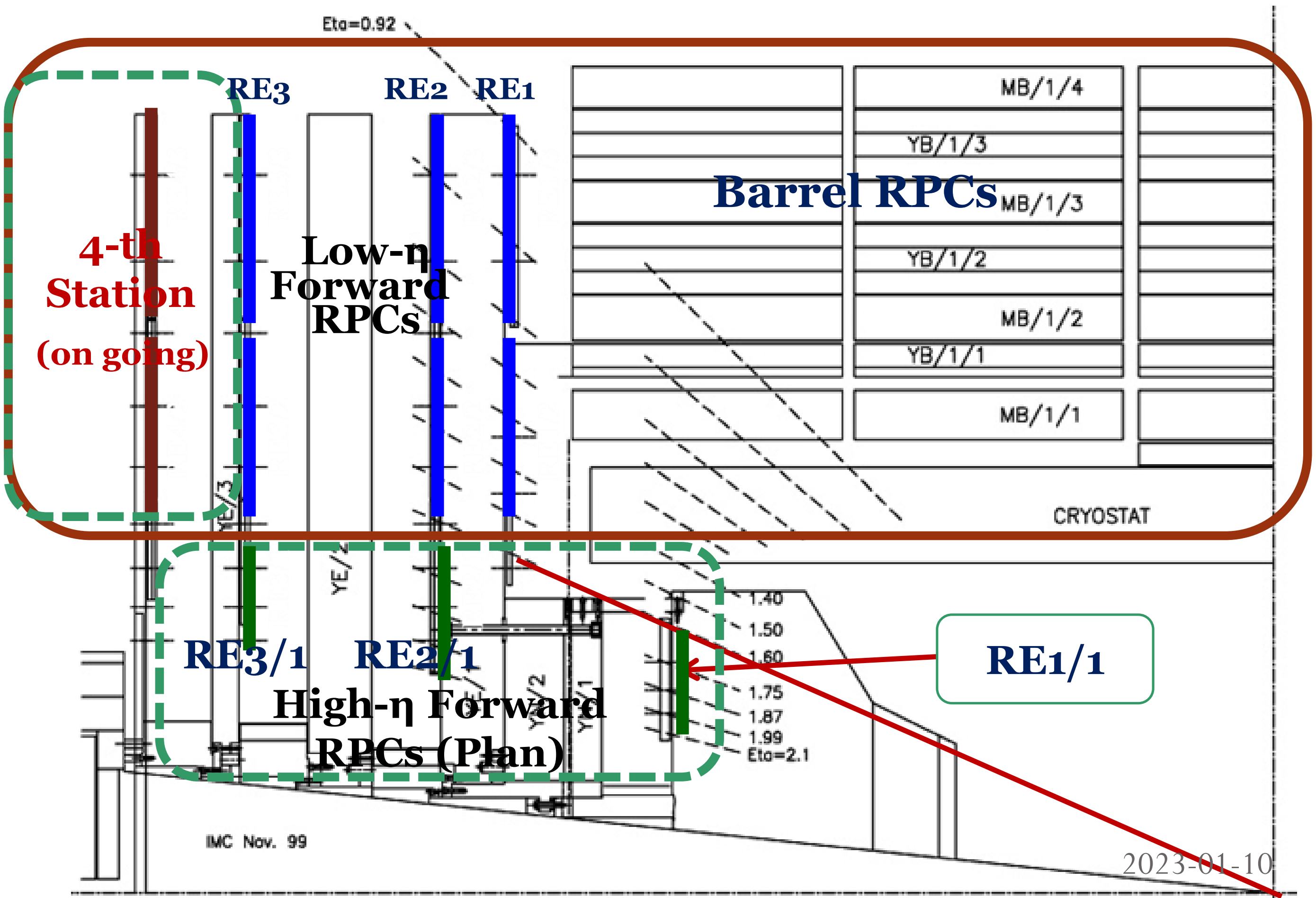
▶ Endcap RPCs

- 2 wings (RE+, RE-)
- 4 stations (RE1, RE2, RE3, RE4) in each wing
- Covering 0.92 < η <2.1

$$\eta = \frac{1}{2}\ln\left(\frac{|\mathbf{p}| + p_{\mathrm{L}}}{|\mathbf{p}| - p_{\mathrm{L}}}\right)$$

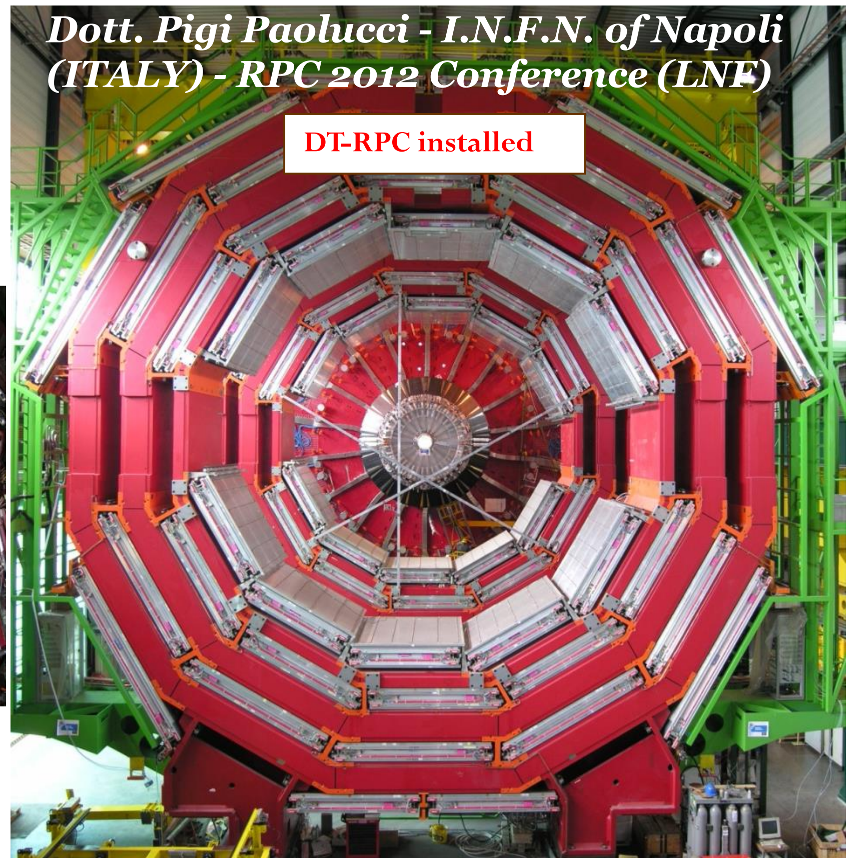
$$v \rightarrow c \qquad \eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$





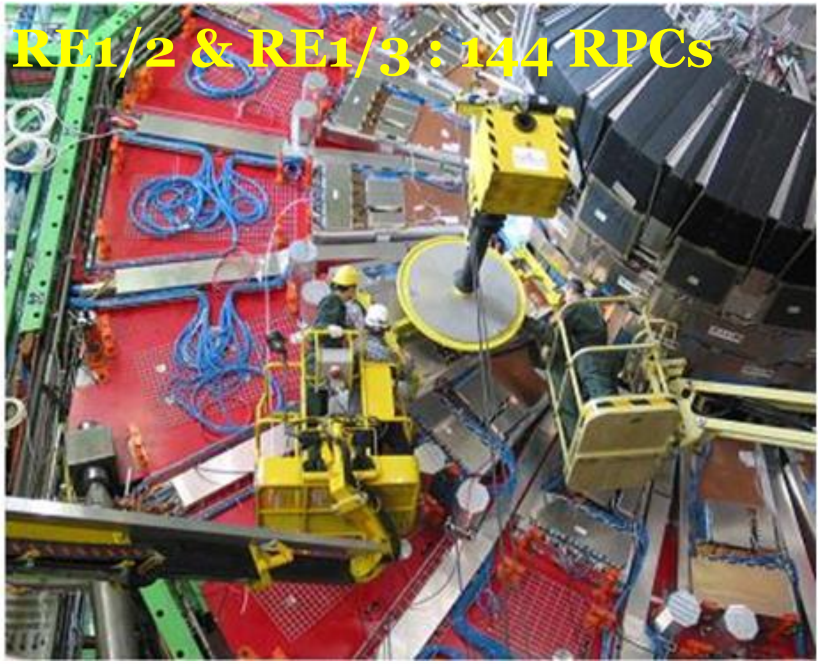
Installation of BARREL RPCs

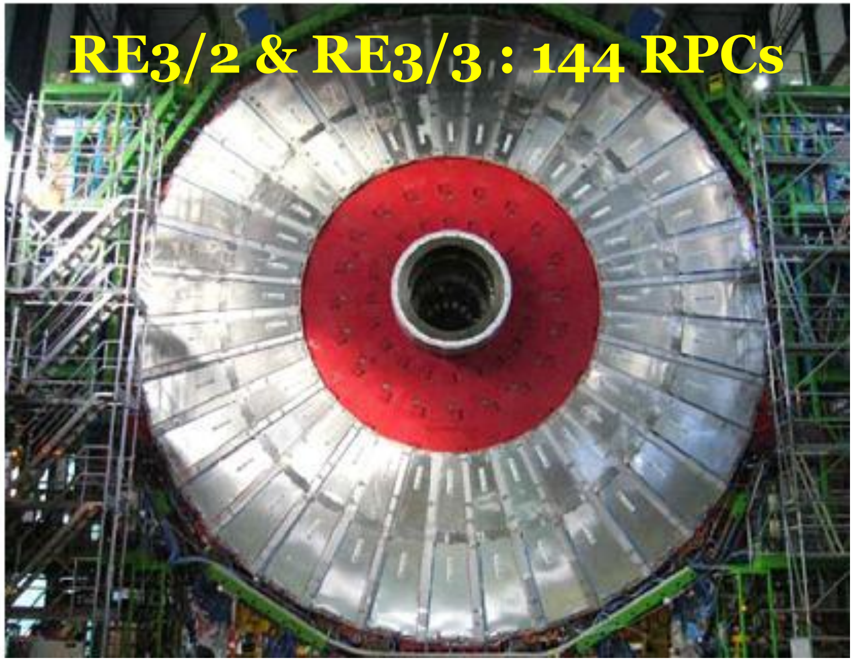
2004-2008



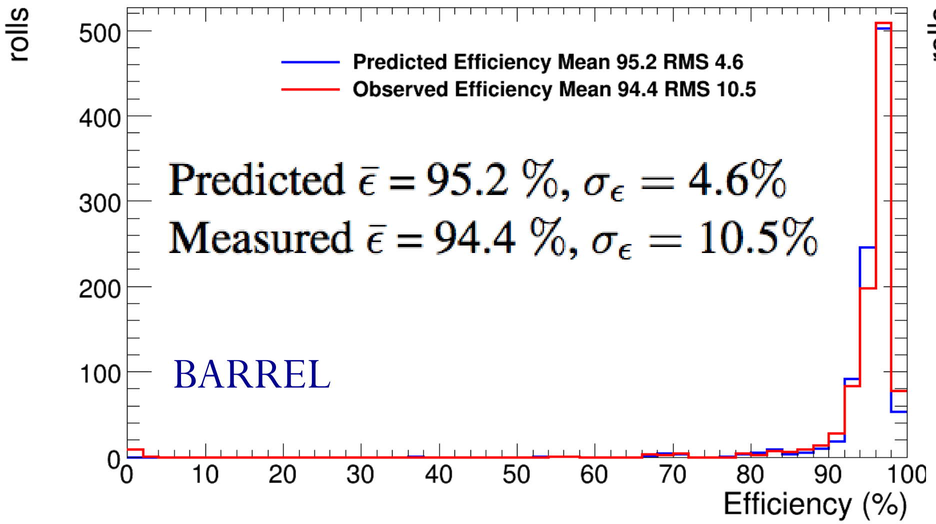
Installation of Endcap RPCs in |η| < 1.6

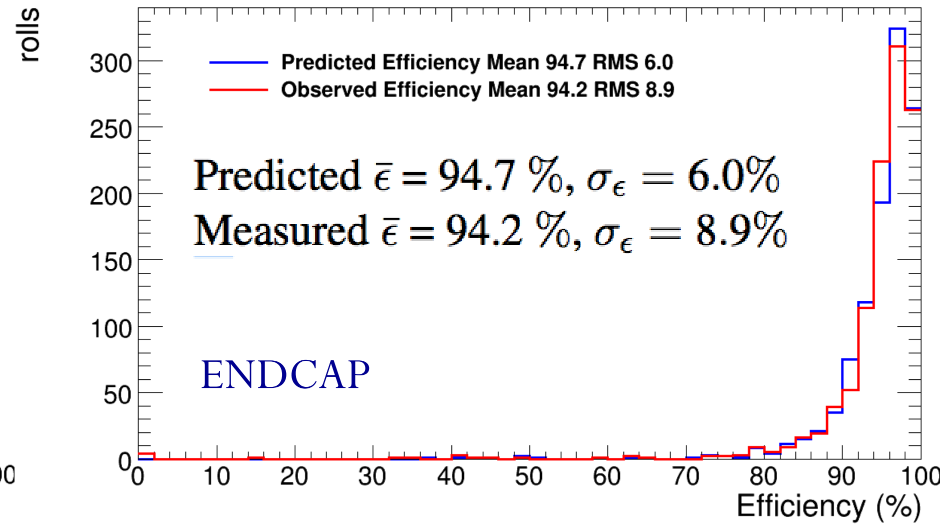
2007 - 2009



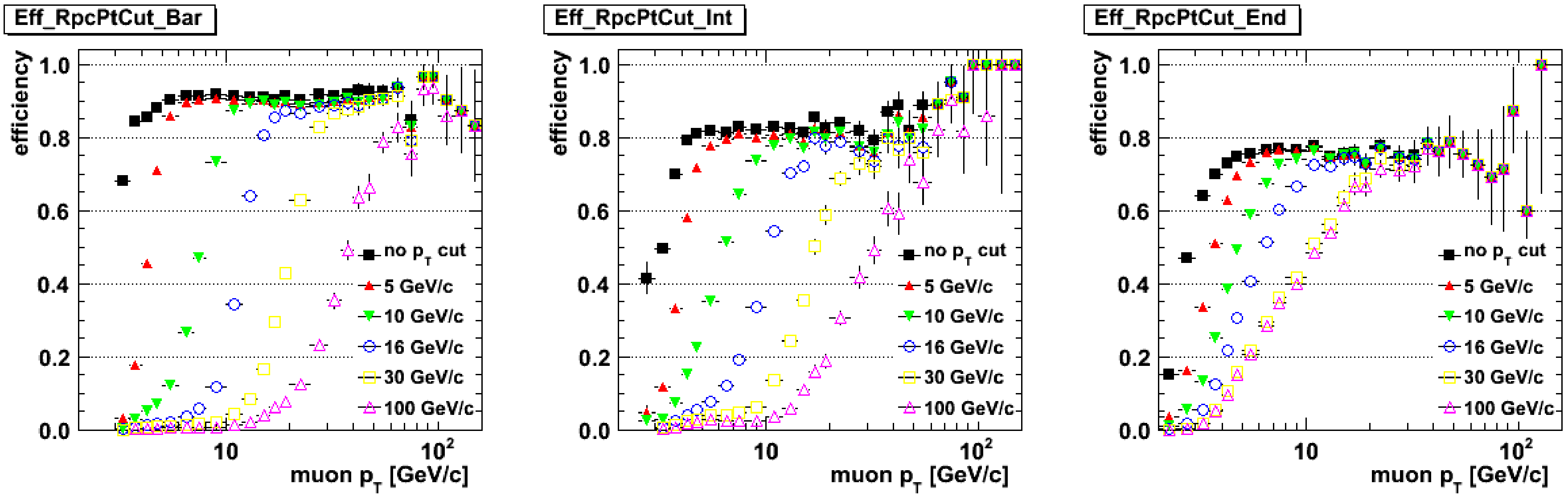


Trigger performances





Efficiencies for single muons for various p_T selections



Geometrical inefficiency is also included

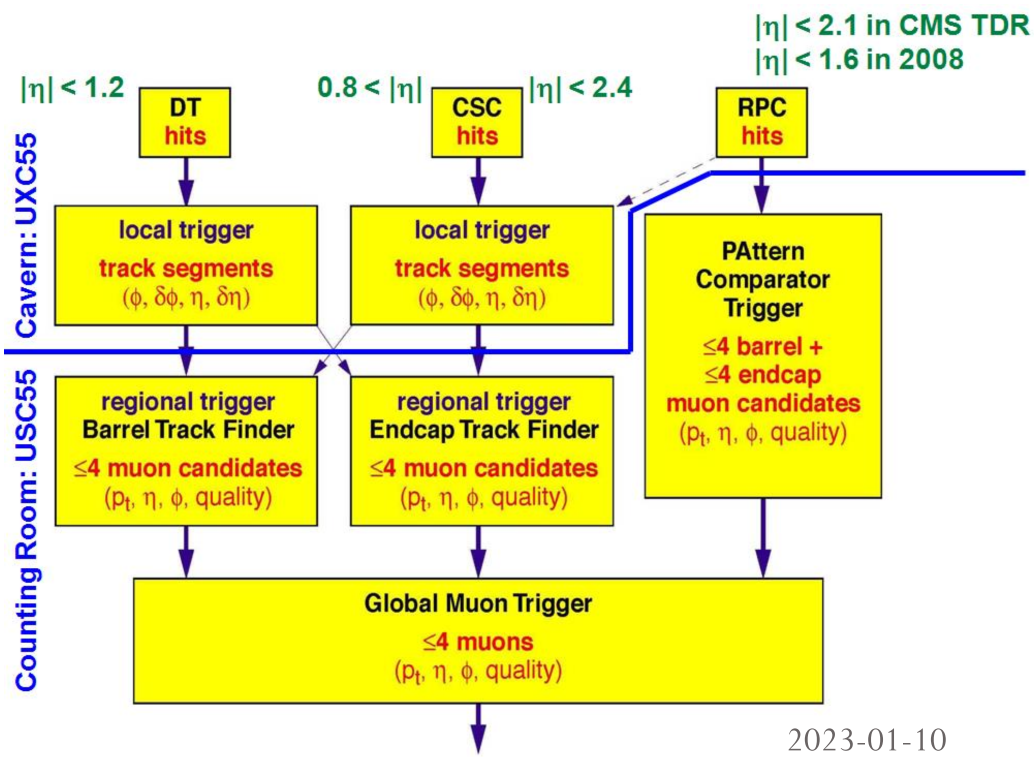
Upgrade of RPC triggers for the future CMS

► Why do we have to fully construct the Endcap RPC system ?

- The CMS was design to optimize detection of the muons from Higgs.
- Only 3 RPC stations in $1.6 < \eta$.
- There is NO RPC muon trigger in $1.6 < \eta < 2.1$.

► What we plan to do until the first shutdown of the LHC ?

- Planning the full construction of the endcap RPC system, as described in the CMS muon TDR (LHCC 97-32).
- First, installation of the missing RE4 in $|\eta| < 1.6$ (PHASE I)
- Second, extension of the RPC trigger coverage up to $|\eta| = 2.1$ (PHASE II)



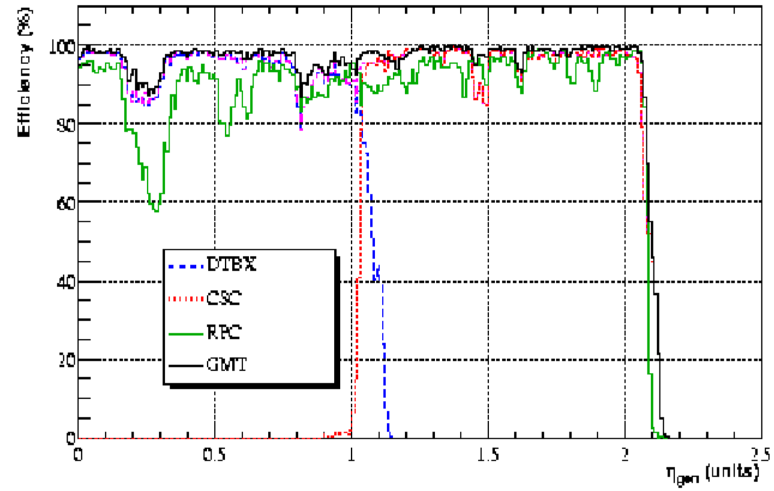
PHASE I: 4-th RPC station in Endcap RPC system

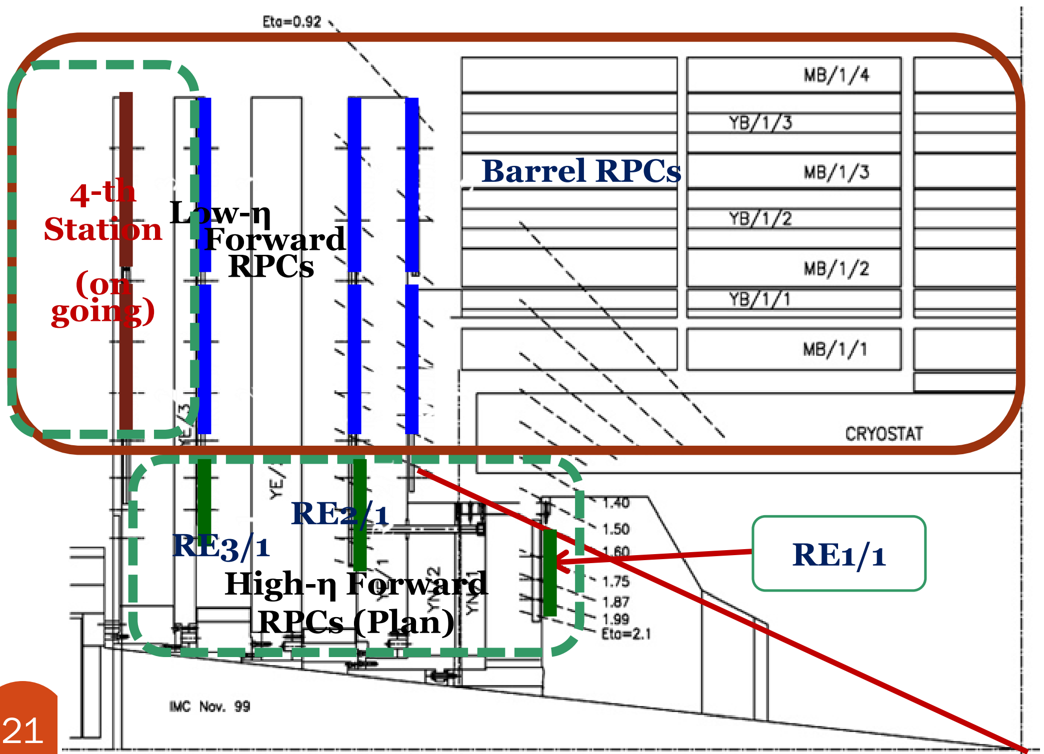
Installation RPCs proposed in the TDR LHCC-97-32
- 6 RPC stations in BARRAELs in $0.0 < |\eta| < 0.92$
- 6 layers overlapped in $0.92 < \eta < 1.1$
- 4 RPC stations in ENDCAP in $0.92 < |\eta| < 2.1$

In the Current ENDCAP composed of 3 RPC stations covering $0.92 < \eta < 1.6$ → Trigger requiring 3/3

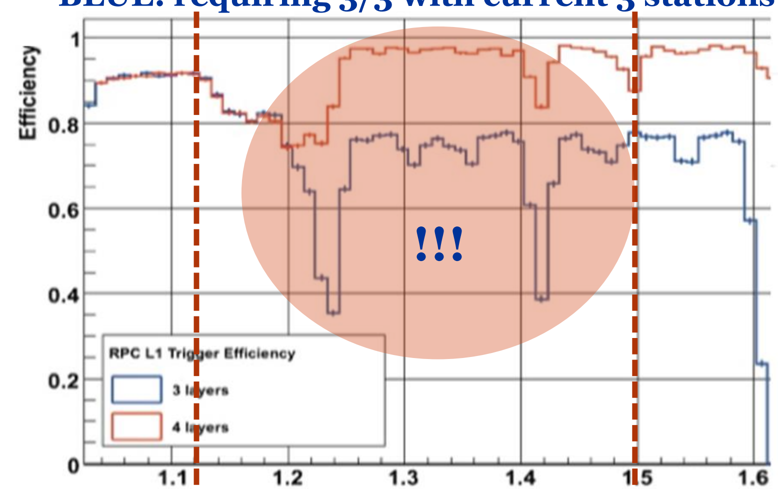
Trigger efficiency of the muon system is low due to
- Absence of the 4-th station (PHASE I)
- Absence of the RPC covering $1.6 < \eta < 2.1$ triggers. (PHASE II)

Global Muon Trigger efficiency proposed in the TDR LHCC-97-32





RPC Trigger Efficiencies
RED: requiring 3/4 with a new 4[th] station
BLUE: requiring 3/3 with current 3 stations



Roles:

Korea (KODEL Korea Univ., and Seoul Univ.)

- Production & QC of single gaps

CERN

- Integration of the new Endcap RPC system
- RPC assembly & test for QA

Italy (INFN + GT)

- Integration of the upscope project
- Qualified HPL plates for RPC gaps
- New Front-End-Electronics and the technical support

Belgium Group (Vrije Univ. etc…)

- Integration of the new Endcap RPC system
- RPC assembly & test for QA

Chinese Group

- Parts for detectors (Honeycomb panels, frames …)
- Participation in the assembly and test for the high-η RPCs

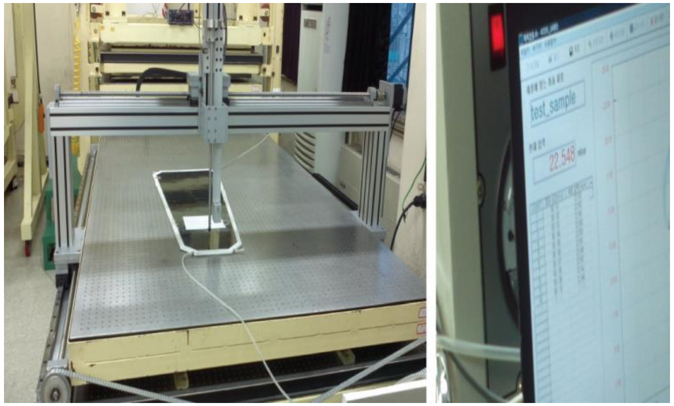
Indian Group (NPD-BARC, Panjab Univ.)

- RPC assembly and the test for QA

KODEL

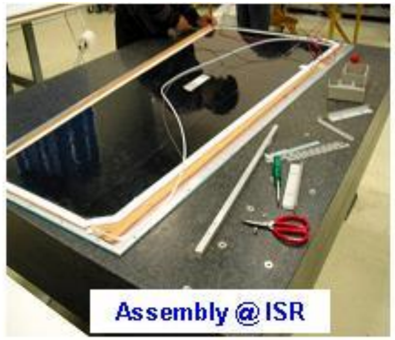
Gap production facilities used for the previous CMS & PHENIX RPCs

New Facilities of glue dispense and leak test for QC

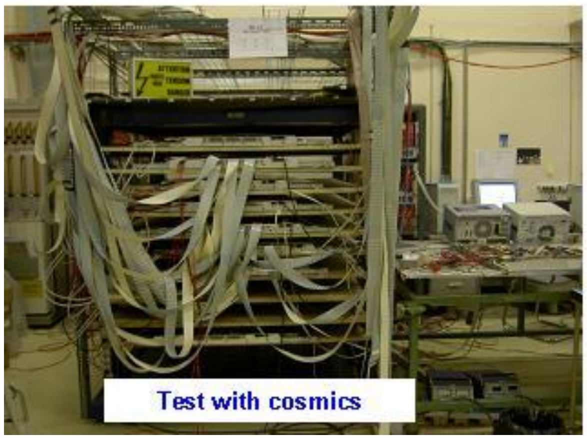


CERN


Parts from China


Assembly @ ISR


Mass production


Test with cosmics


Ready for installation

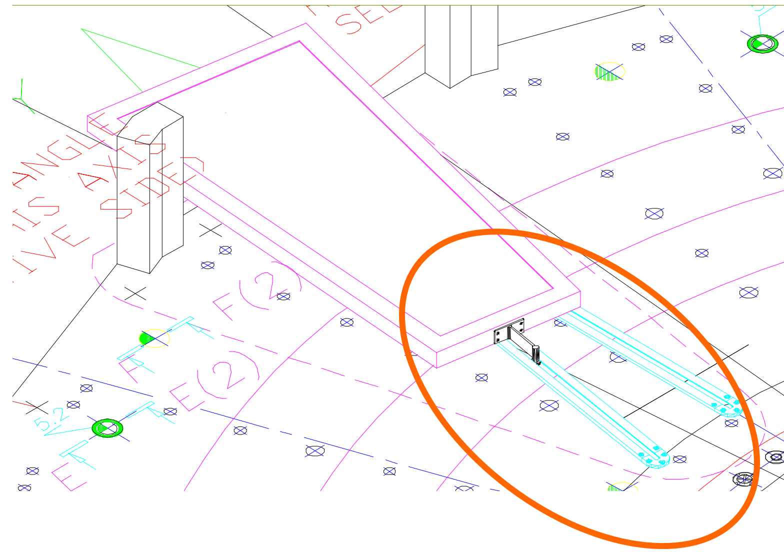
Assembly & test facilities at the old spacer in the ISR tunnel were moved to a new in BLD 904.

Detector assembly site: Facilities of assembly & test at NPD-Barc, India

PHASE II: high-η RPCs in Endcap RPC system

(Many R&Ds and proposals)

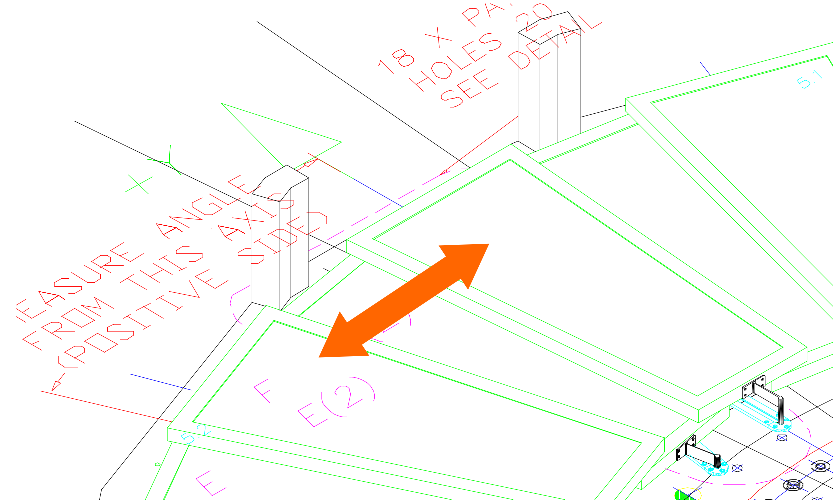
Insert via rails



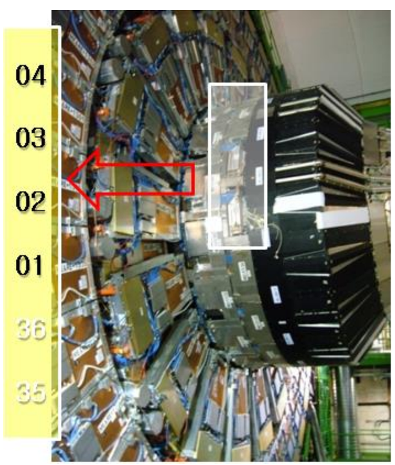
▶ **RE1/1 RPCs at YE1 :**

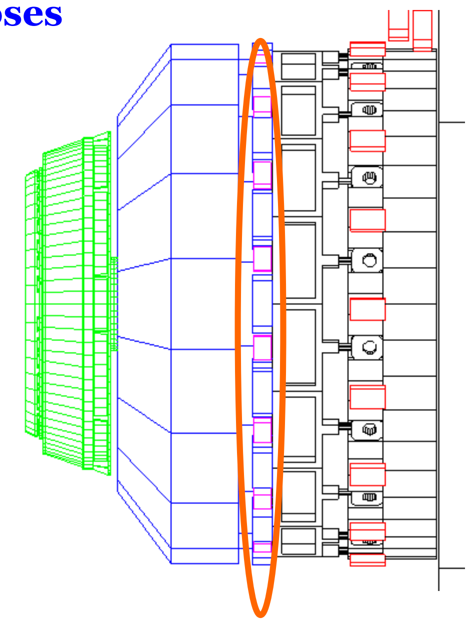
- High priority among RPCs in $1.6 < \eta < 2.1$
- Advantage of RE1/1 : RPCs closest to *pp* collision vertex with presence of strong magnetic fields.
- Expect an effective rejection of the beam-related backgrounds (Gammas, neutrons, charged pions…) for the muon triggers.

Rotate in place



Have to insert trigger detectors in the CMS end-cap noses



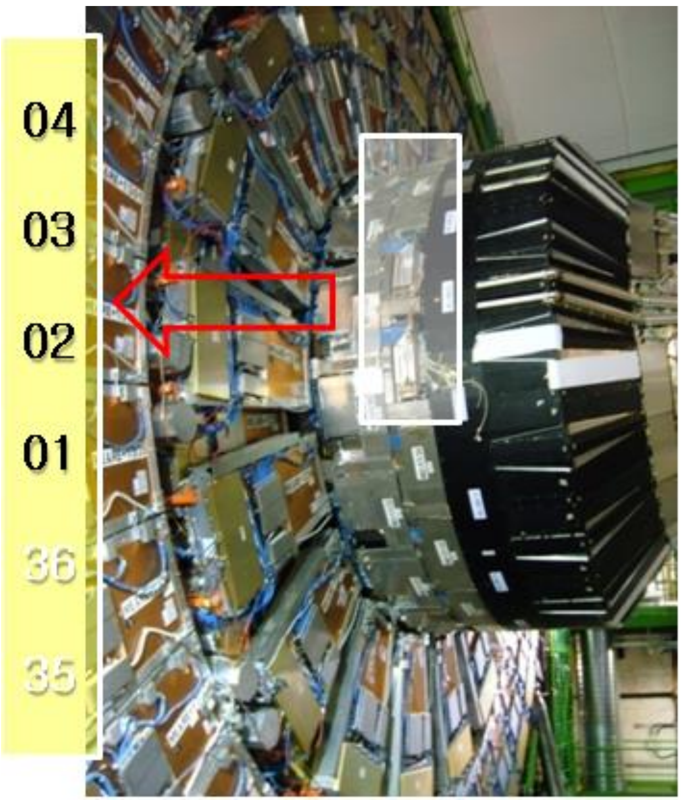


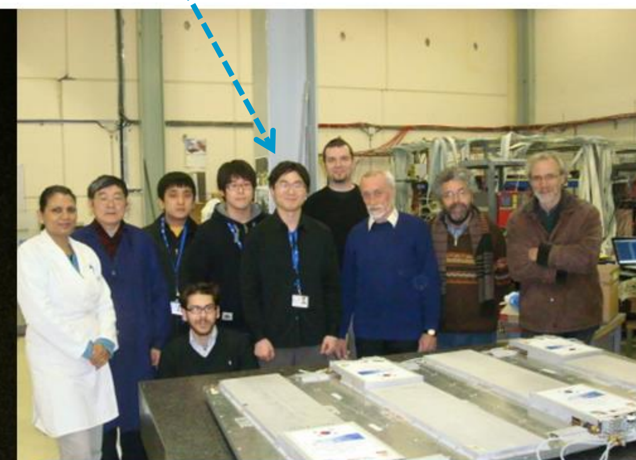
Kim Hyuncheol, Cho Sung Woong, Jung Min Soo

1) Standard double-gap phenolic RPC

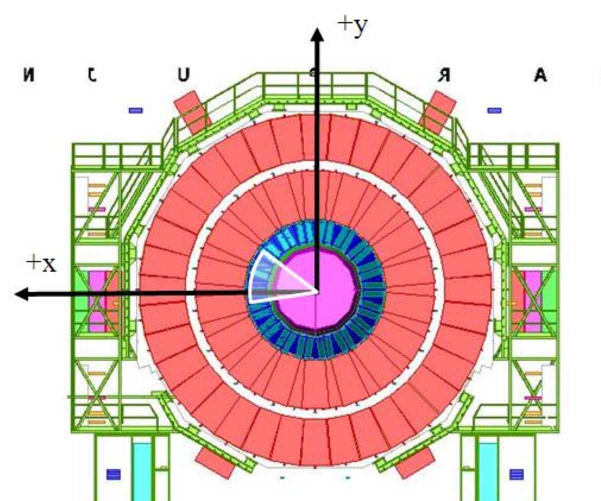
Double-gap RPCs are VALID for RE1/1 when maximum rate ~ 400 Hz/cm² @ $L = 10^{34}$ cm² s⁻¹

4 RE1/1 RPC modules installed in the CMS nose-cone (2009)





- Final result : Chamber 1,2,5,6 is OK
- Chamber 3,4 were rejected because of high and unstable current of bottom gap



2) Multi-gap RPCs

Shin Seung Su

R&D aiming to develop HPL multigap panel-type RPCs working with max. background rates ~ 3 kHz cm^{-2} @ L ~ 10^{35} cm^{2} s^{-1}

Direction → Smaller detector charges

1. To reduce aging at high rate background
2. To enhance high rate capability

$$q_e = \sum_{i=1}^{2}\sum_{j=1} \frac{q_{el}}{\eta d} n_{0ij} M_{ij} k [e^{\eta(d-x_{ij})} - 1]$$

Higher rate capability ← lower avalanche charge

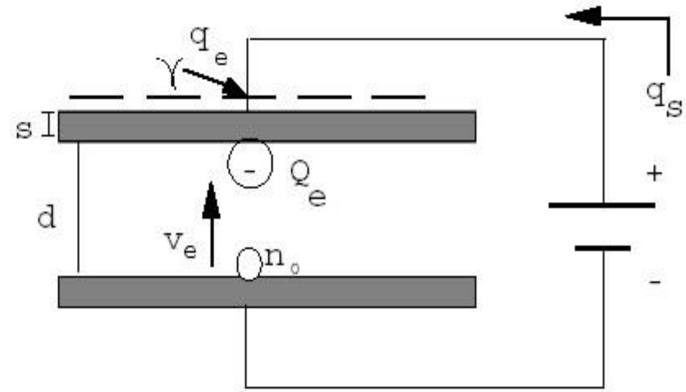
- Rate capability ~ 1/ ρ
- Smaller q_e → higher rate capability (actually related to the ion charge Q)

$$< q_e > = 2\sum_{j=1} \frac{q_{el}}{\eta d} \mu k e^{\eta d} \left(\frac{\lambda}{\lambda+\eta}\right)^j$$

$$< Q_e > = \frac{\eta d}{k} < q_e > \qquad k = \frac{\epsilon_r d/s}{\epsilon_r d/s + 2}$$

Typical glass multigap RPCs

- q_e < 1 pC (~ 0.5 pC)
- ρ = 10^{12} ~ 10^{13} Ω cm for normal glass
  = 10^{9} ~ 10^{10} Ω cm (ceramic & low res. glass)



Then, what if multi-gap RPCs with high-pressure laminated (HPL) plates ?

- q_e ~ 1 pC
- Phenolic HPL → ρ = 10^{10} ~ 10^{11} Ω cm
- Oiling required to reduce noises

4- or 6-gap RPCs in high-η region of the CMS ?

- Same gas system → same gas mixture
- Same electronics → same front-end-electronics (FEE) and so on

Timing RPCs ← q_e

Other characteristics → 2-mm thick 2-gap RPCs

Construction method → 2-mm thick 2-gap RPCs

Electronics → 2-mm thick 2-gap RPCs

	2-gap RPCs	4-gap RPCs	6-gap RPCs
Each gap thickness	2.0 mm	1.0 mm	0.66 mm
Total gap thickness	4.0 mm	4.0 mm	4.0 mm
$\langle q_e \rangle$ at ~ mid of plateau	4.0 pC (Thr~200 fC)	1.5 pC (Thr~150 fC)	0.9 pC (Thr~100 fC)
Type of resistive plates	HPL	HPL	HPL
Thickness of HPL	2.0 mm	2.0 mm	1.0 mm
Resistivity of HPL	1 ~ 6 x10^{10} Ωcm (for CMS)	~ 10^{10} Ωcm (Italian HPL)	~ 10^{11} Ωcm (Korean HPL)

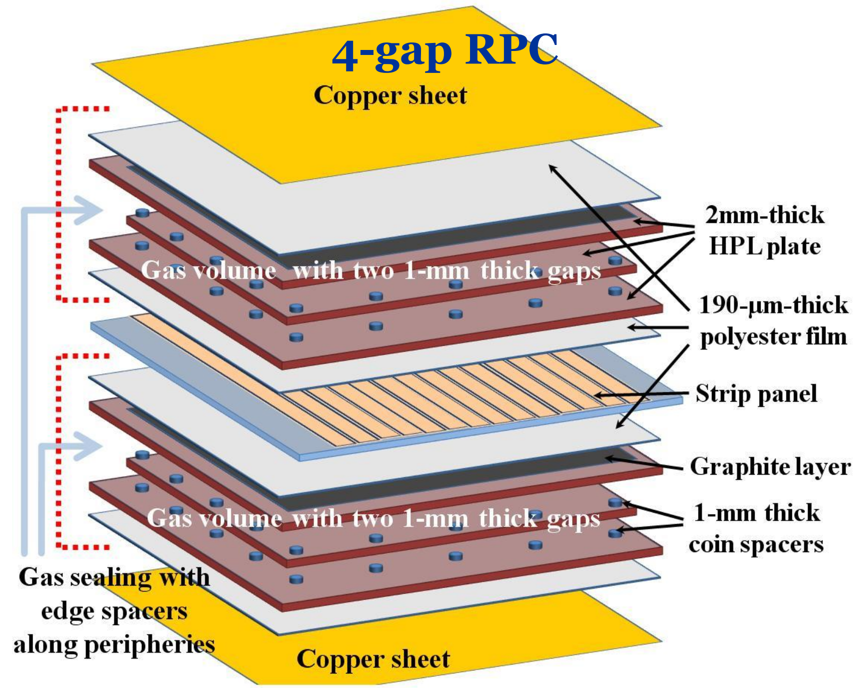
Constructions of prototype detectors

Detector structures

Oiled Phenolic HPL Multigap Panel-type RPCs for CMS high-η triggers

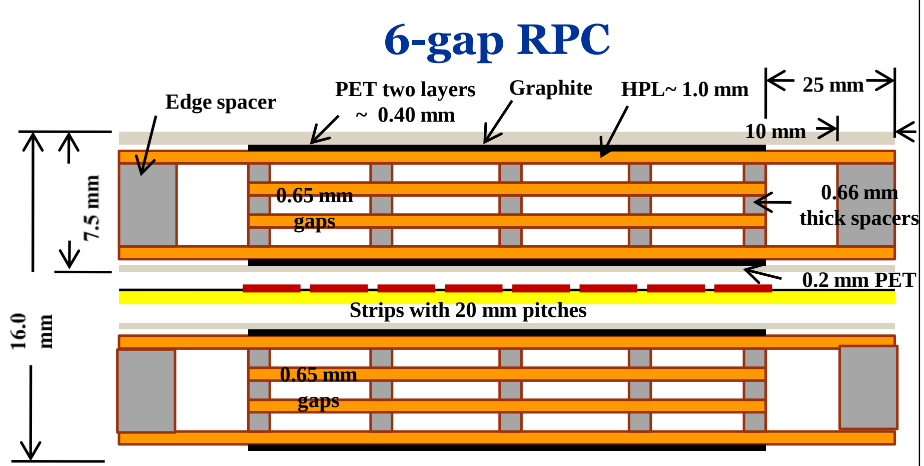
Panel-shape multigap RPCs

~ Two separated gas envelopes + a strip panel
Each gas envelope ~ 2 gaps in 4-gap RPCs
3 gaps in 6-gap RPCs



Prototype detectors

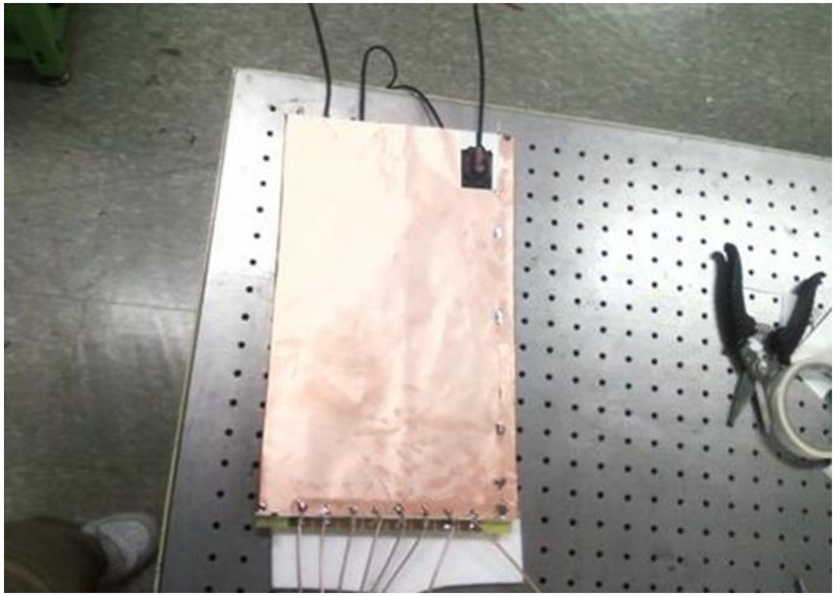
4-gap RPC: 45 x 45 cm² (active area)
- HPL : 2 mm
- Coin spacers : 1000 ± 10 μm (Polycarbonate)
- Strip pitch = 27 mm



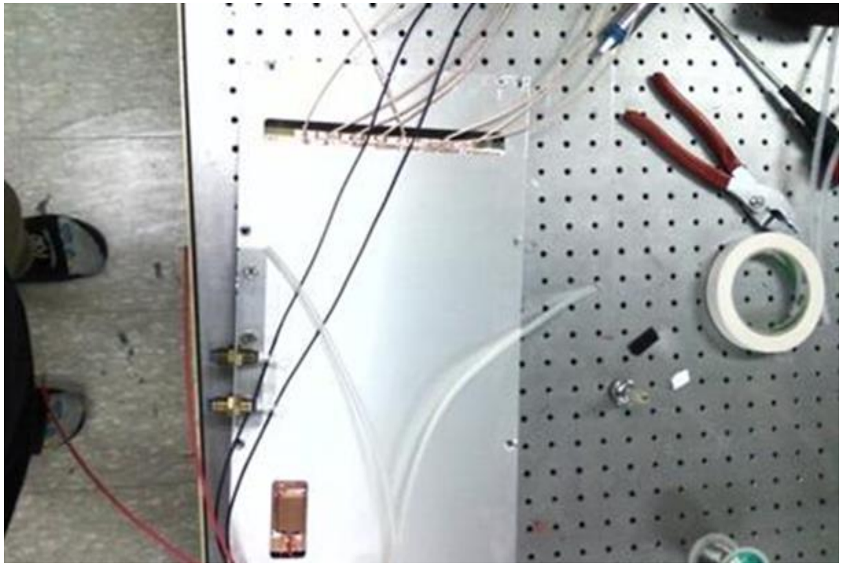
6-gap RPC: 15 x 29 cm² (active area)
- HPL : 1 mm
- Coin spacers : 660 ± 10 μm (Polycarbonate)
- Strip pitch = 20 mm

Constructions of prototypes

6-gap RPC



4-gap RPC



Efficiencies & mean fast charges

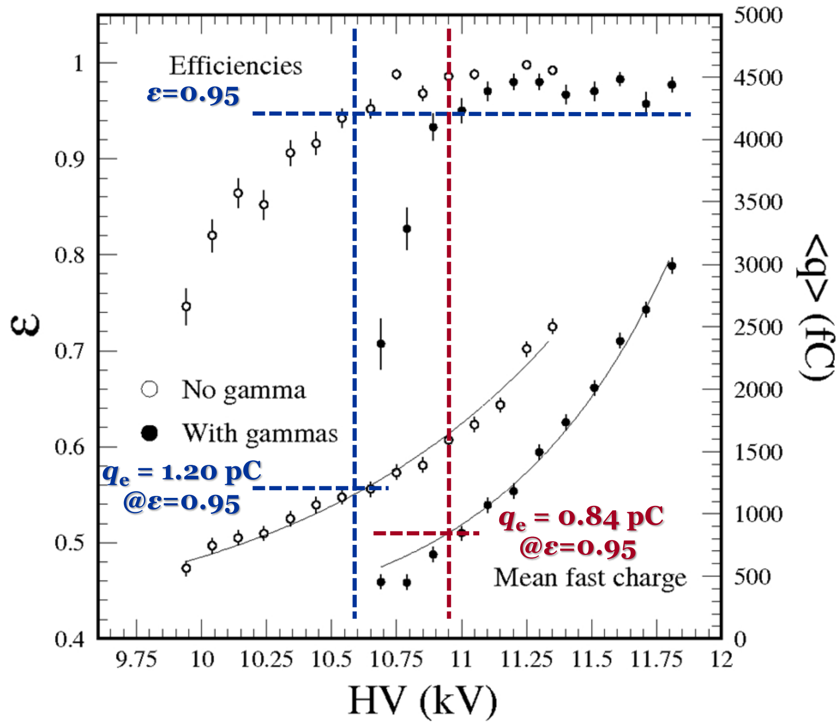
Mean q_e (avalanches only) at the efficiency plateau region

4-gap RPC: q_e = 1.51 ± 0.06 pC with ε = 0.98 (by TDC) at 10.95 kV

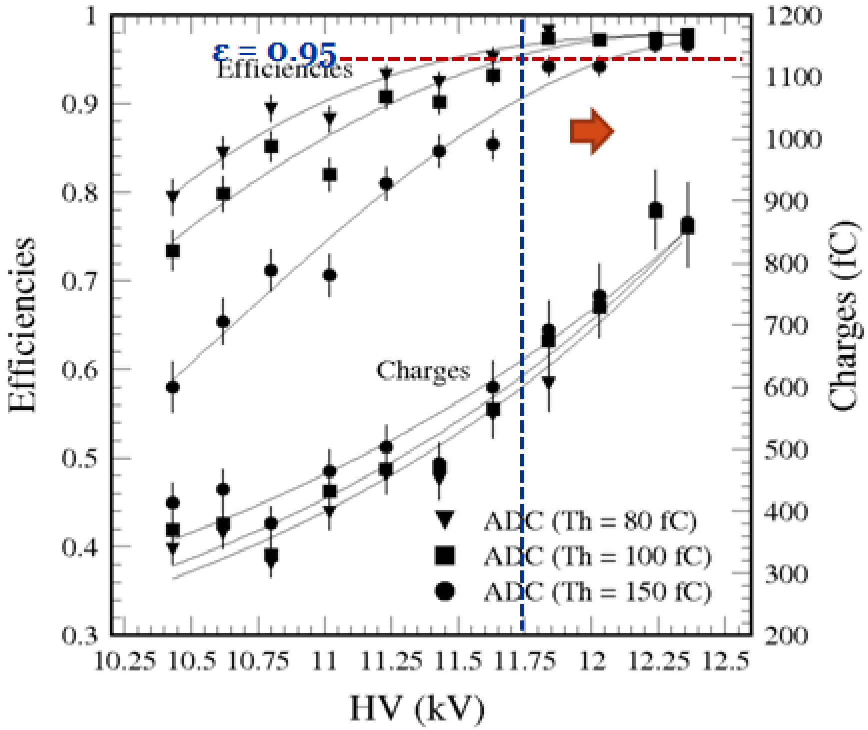
6-gap RPC: q_e = 0.88 ± 0.05 pC with ε = 0.98 (by TDC) at 12.24 kV

<-> ~ 4.0 pC for a standard double-gap RPCs

4-gap RPC

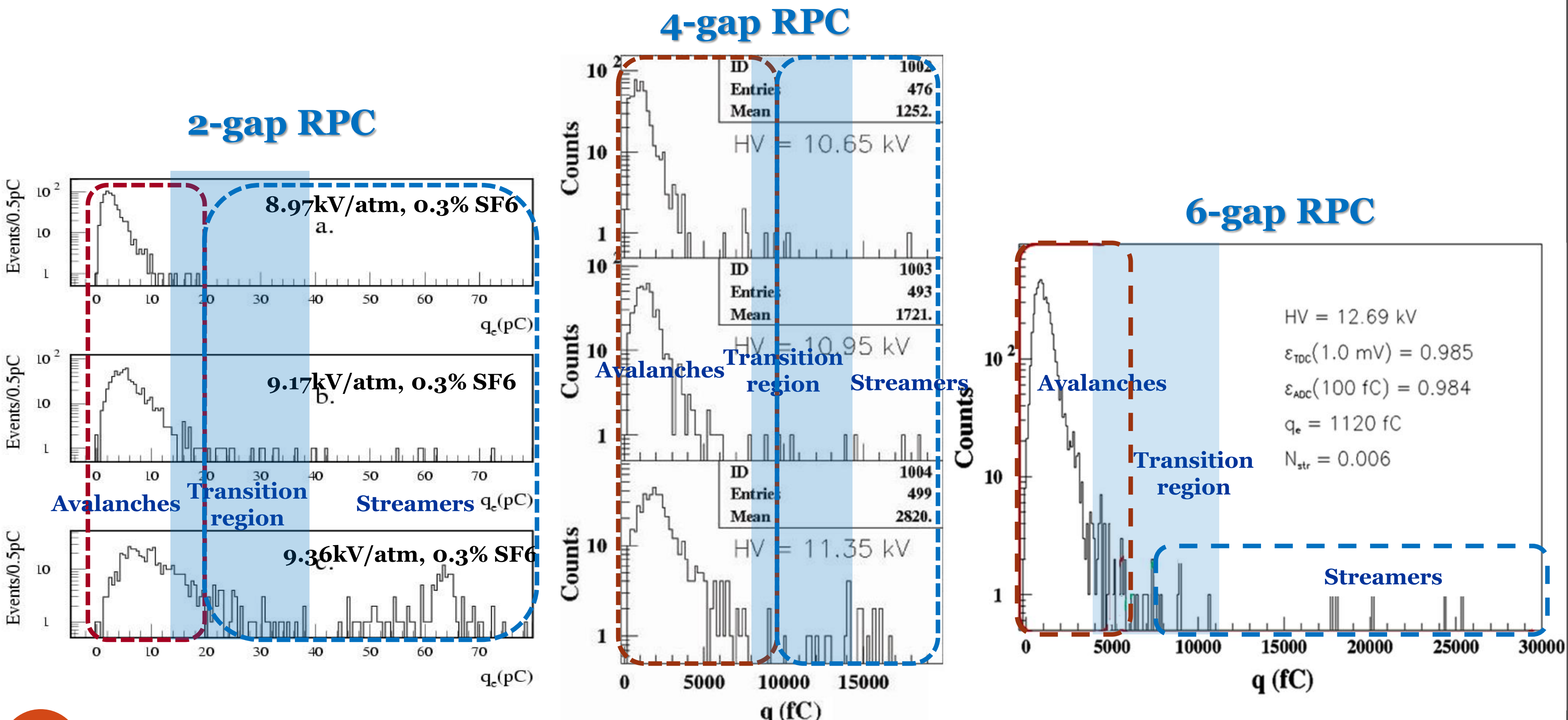


6-gap RPC



Pulse distributions

- For 2-gap RPCs
  - q_e < 10 pC for CMS Barrel RPCs
  - q_e < 20 pC for CMS Forward RPCs (no termination)
- For 4-gap RPCs: q_s < 10 pC (no termination)
- For 6-gap RPCs: q_e < 5 pC (no termination)



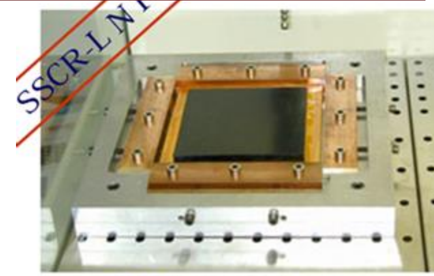
3) GEMs at RE1/1 both for triggering & tracking

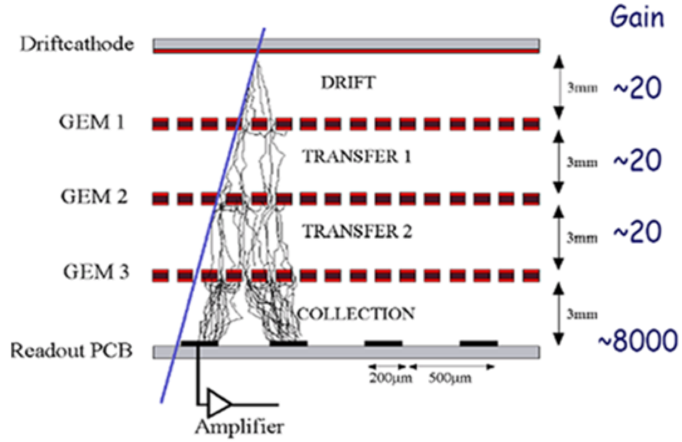
RD51 & A. Sharma

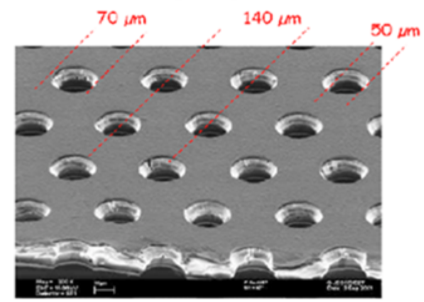
- Compact detector structure
- Rate capability > 10^5/cm²
- Tracking capability
- RE1/1: no access allowed
  → Radiation hardness
- Problem: too many channels
  # of ch/det. = 8960
  # of detector = 72

Basic structure

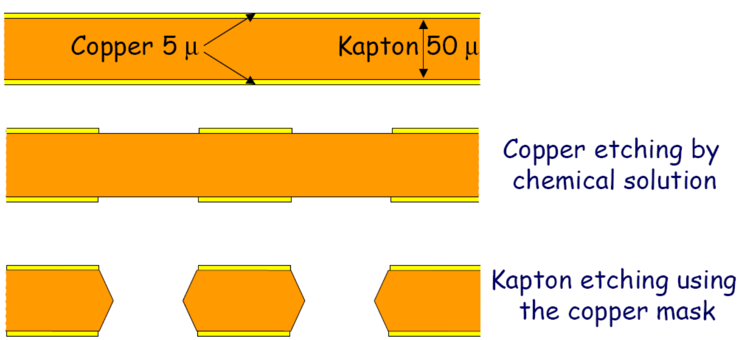
2 ~ 3 GEM plates : for the amplification of X-ray signals
Two dim. microstrips (~ 100 ㎛ spacing : to pickup the avalanche images)

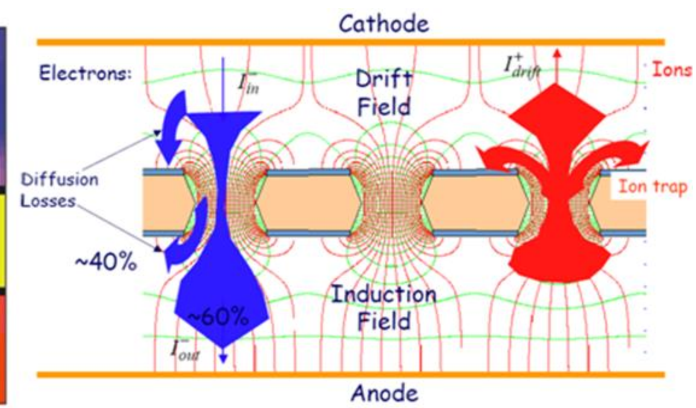

GEM stretcher

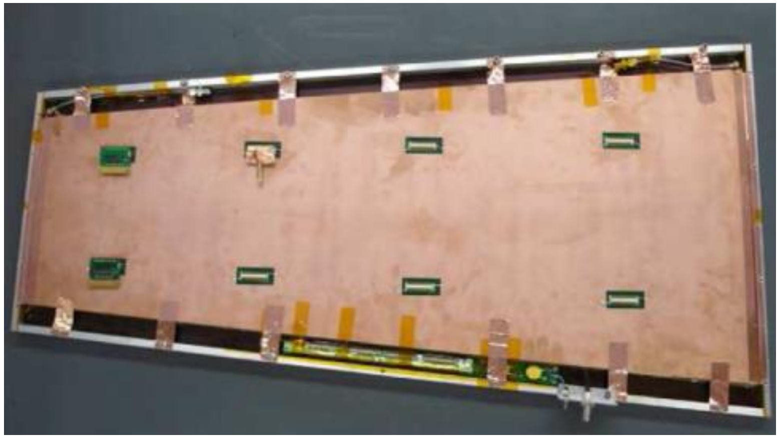


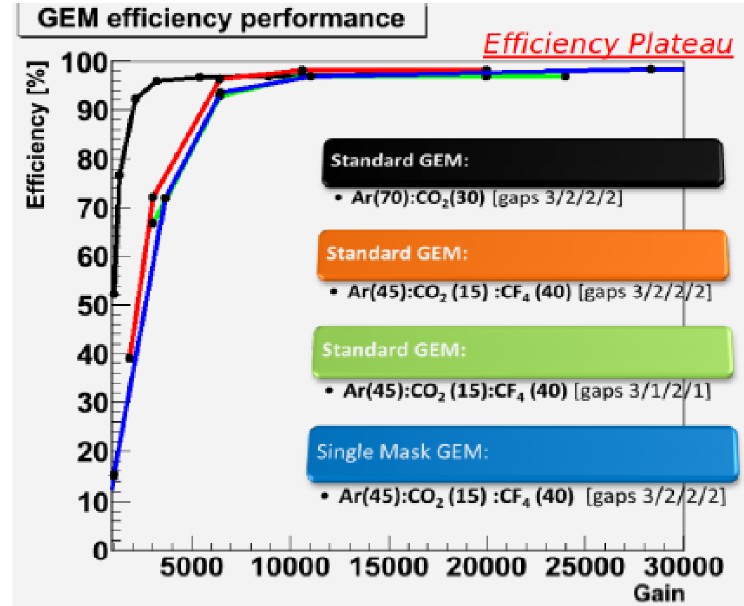


Photolithographic technology used for printed circuit board construction

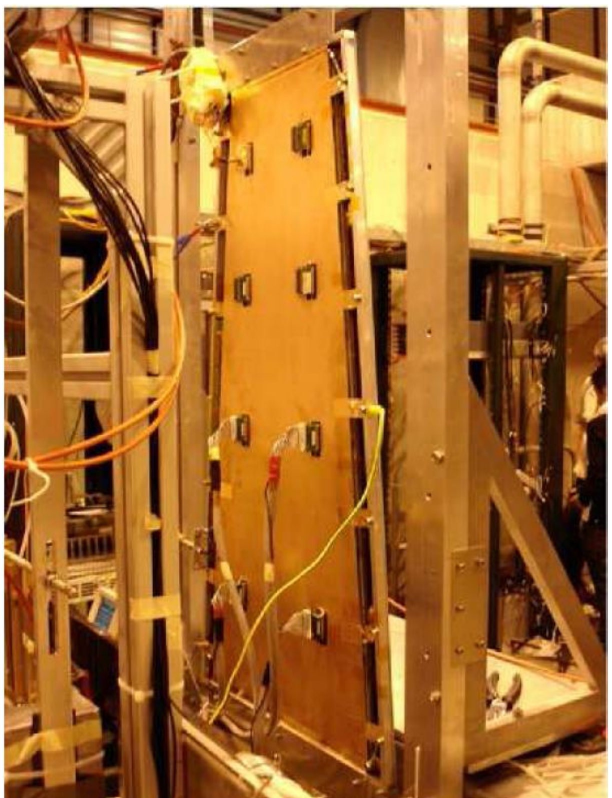


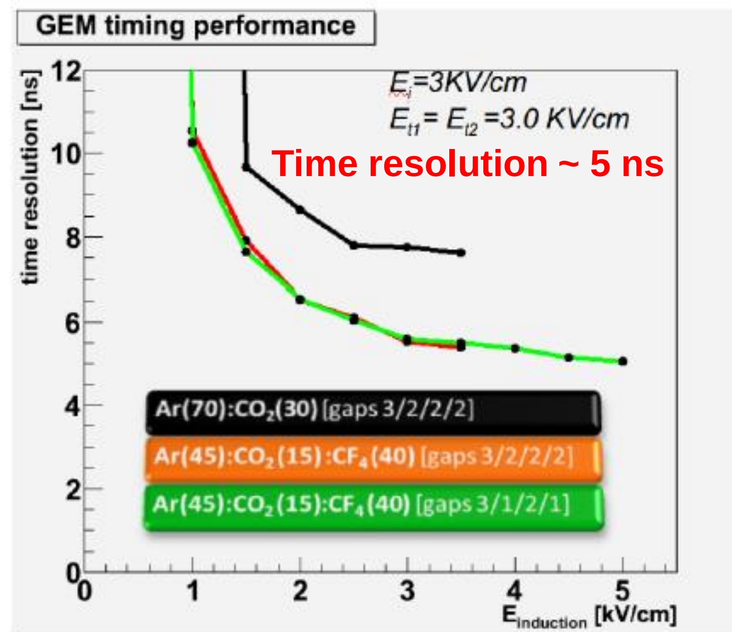






Muon-beam test at GIF/CERN





4. Summary

1) The current RPCs in PHENIX

- The operation & performance have been optimized through RUN11&12.

2) Upscope of CMS RPCs

- The current system works with a minimal coverage for muons
- PHASE I upgrade (2012 ~ 2014) :
  RE4 station to enhance the single muon efficiency in $\eta < 1.6$
- PHASE II upgrade (from 2015 ?) :
  Trigger/tracker detectors in $1.6 < \eta < 2.1$

3) PHASE I project for CMS

- Completion of gaps ~ April 2013.
- Completion of RPC module ~ end of 2013.
- Installation ~ mid of 2014.

4) PHASEII project for CMS: detector options are still in an open question

Plans will be discussed in March CMS week.

- Standard double-gap RPCs -> NOT adequate for SLHC
- Multigap HPL RPCs -> promising (also reasonable for sPHENIX ?)
- GEM (triggering + tracking) for the innermost RE1/1 -> promising but too expensive

BACKUPS

1. Physics motivation of the fast muon trigger upgrade for the PHENIX muon Arms

Exclusive reactions by using polarized protons

Fundamental questions lying in the proton spin

- Nucleon structure by measuring polarized quark & gluon distributions, and transverse spin effect

2. W-production to probe polarized Sea and Valence quark distributions

3. $W^{\pm}$ prod. ratio → Flavor asymmetry of light sea quarks in nucleons

4. Dimuon measurement for J/ψ suppression in HI physics to probe QGP

$$q(x) = q^{\rightarrow}(x) + q^{\leftarrow}(x)$$

$$\Delta q(x) = q^{\rightarrow}(x) - q^{\leftarrow}(x)$$

Helicity dependent quark distribution

$$g(x) = g^{\rightarrow}(x) + g^{\leftarrow}(x)$$

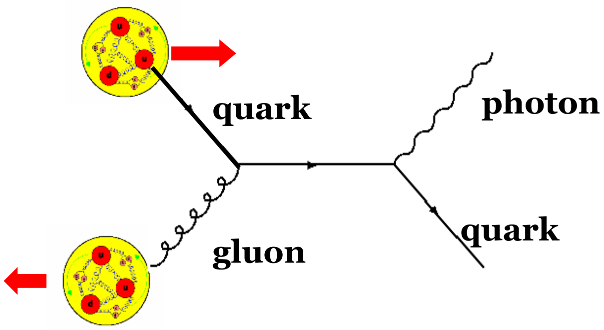
$$\Delta g(x) = g^{\rightarrow}(x) - g^{\leftarrow}(x)$$

Helicity dependent gluon distribution

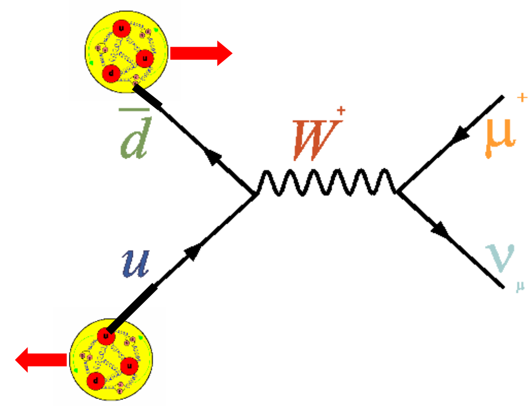
Upscope PHENIX TDR (2007)

Figures obtained from Matthias Grosse Perdekamp U. of Illinois U. C.

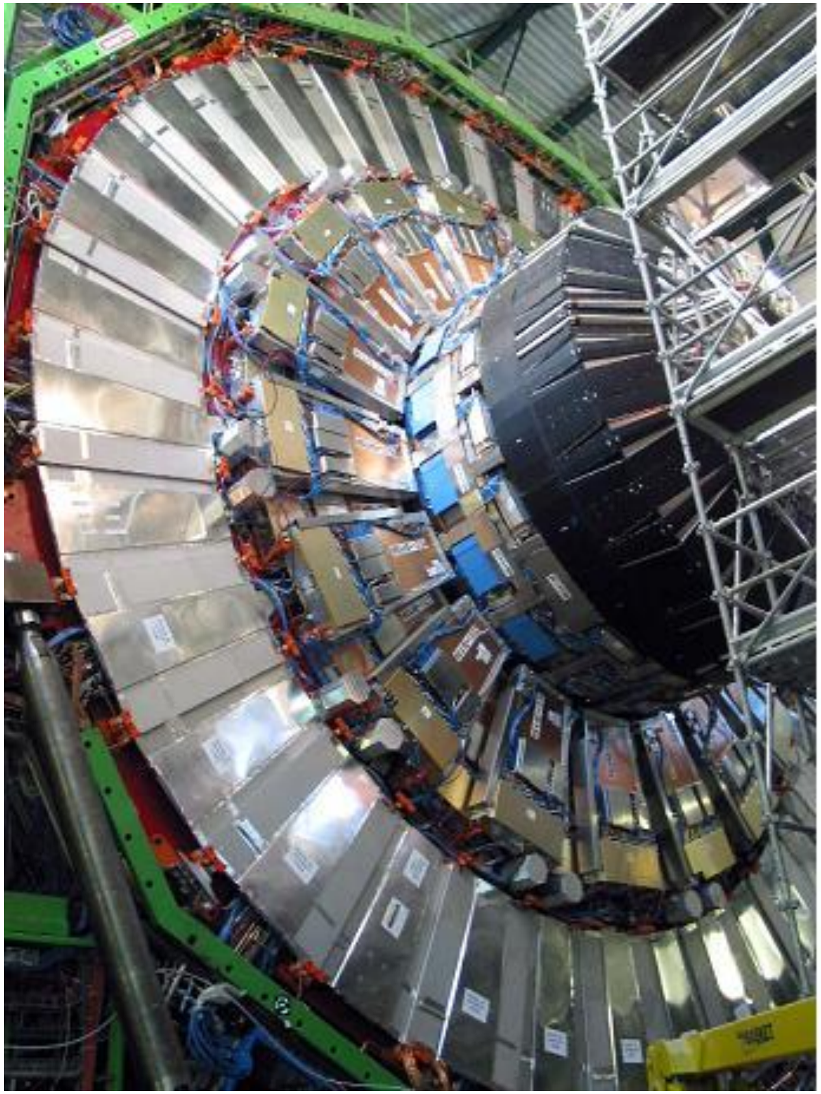
Direct photon production
(probe gluon content with quark probes)



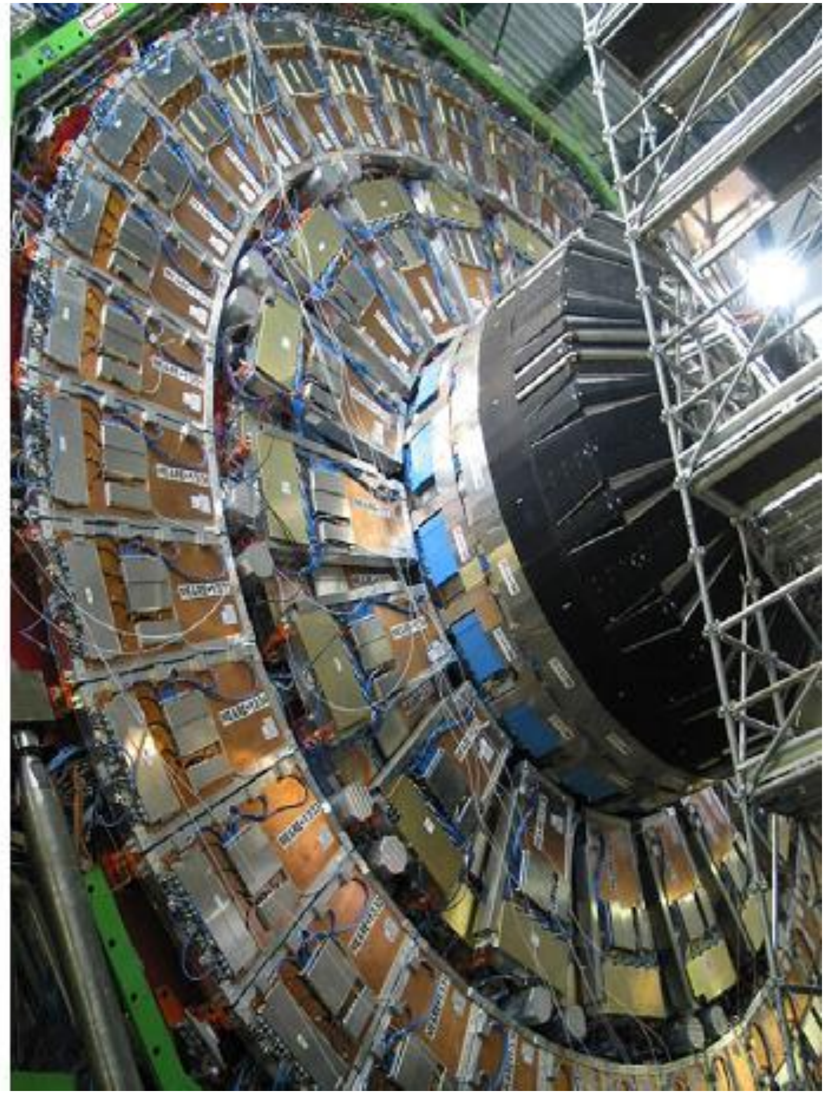
W-boson production



On YE+1 yoke equipped with CSC/RPC packages (inner ring) and RE1/3 RPC's (outer ring).



The ME1/3 CSC's now cover the RPC outer ring and hence complete the first muon station on YE+1.



Gamma-induced currents/unit area

↔ Q_e (avalanche charge)

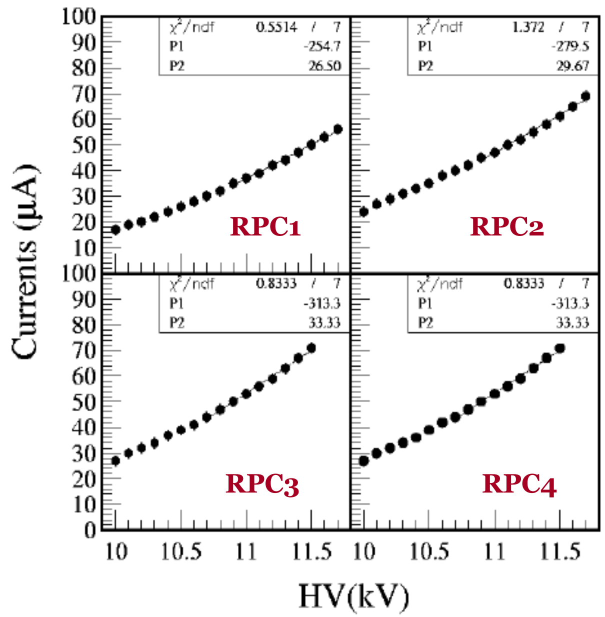
At ~ 1.0 kHz cm^{-2}

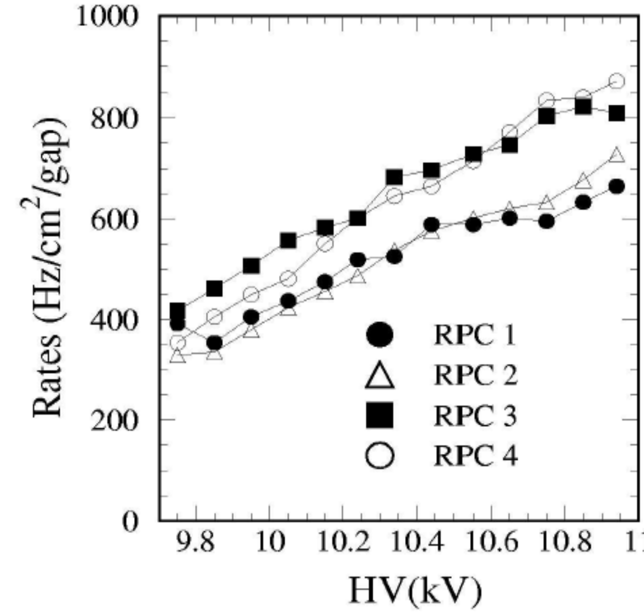
~ 105 μA m^{-2}
for 4-gap RPCs
→ *i* ~ 200 μA in a 2-m² RPC

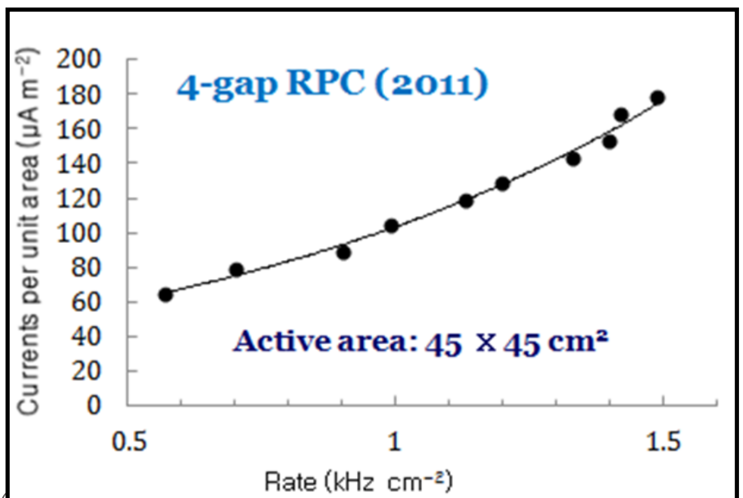
~ 330 μA m^{-2}
for 2-gap RPCs
→ *i* ~ 600 μA in a 2-m² RPC

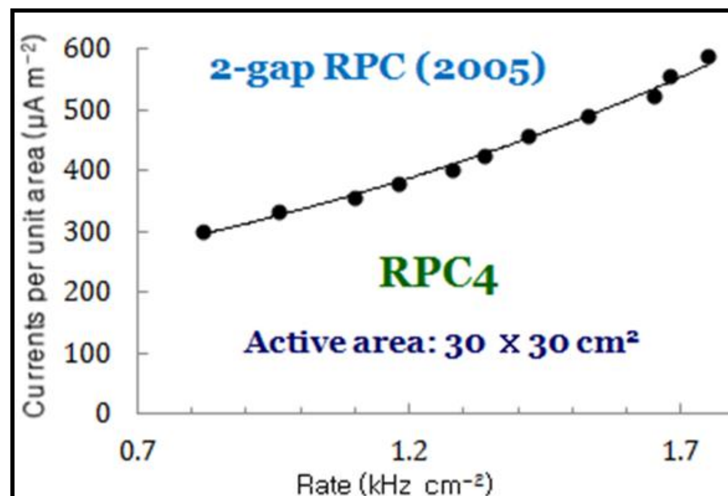
2-gap RPC data measured in 2005

96.2% $C_2H_2F_4$ + 3.5% iC_4H_{10} + 0.3% water, Active area: 30 x30 cm²



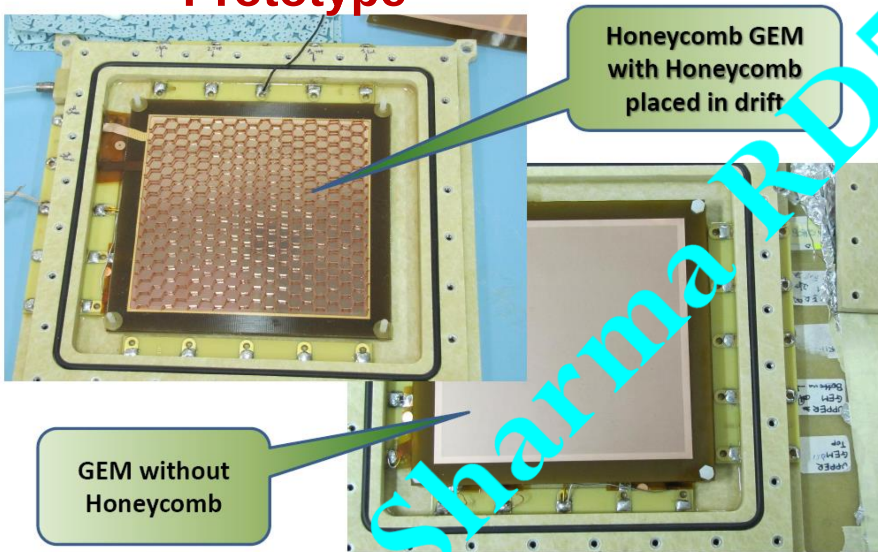


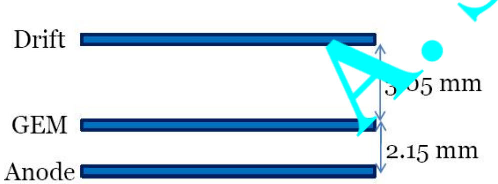




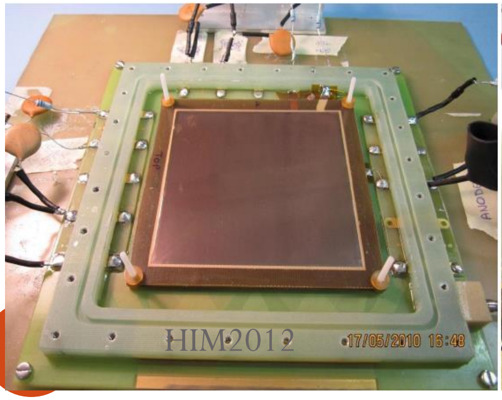
Honeycomb double mask single GEM

Prototype



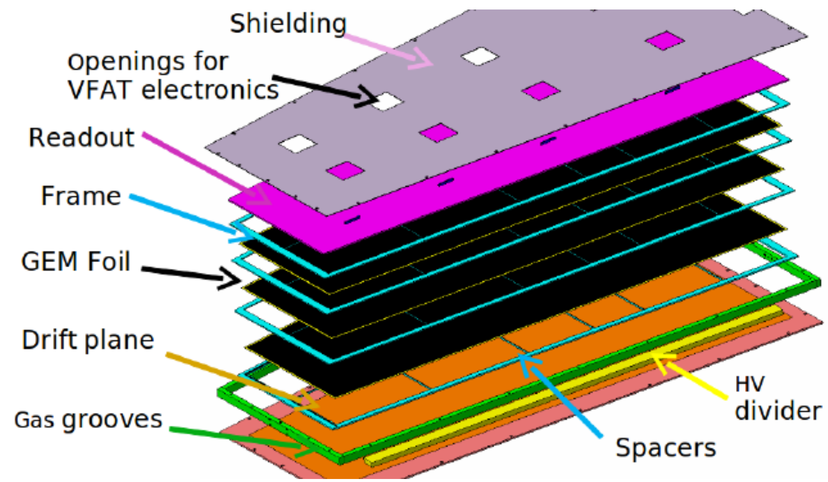


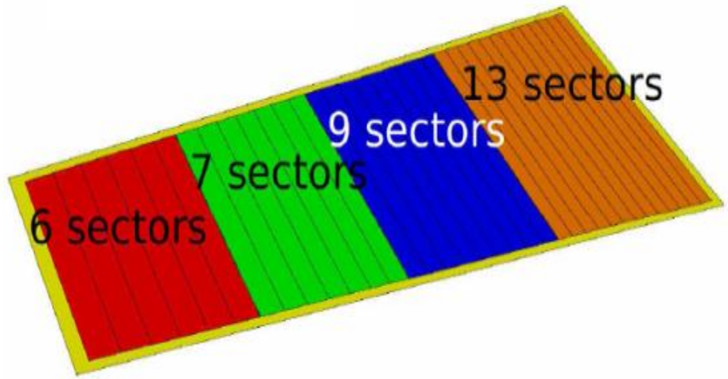
- Number of GEMs used = 1
- GEM active area: 10 x 10 cm²
- Gas mixture: Ar/CO_2 70/30
- Gas flow: ~ 5 l/h
- Water content: ~ 100 ppm H_2O
- Radiation source: Cu X–ray tube
- Cu X-ray @8.04 keV



Real size:GE1/1

arXiv:1012.1524v2 [physics.ins-det] 9 Dec 2010





For the low-η trigger ($|\eta| < 1.6$) of the RE system,

1. The trigger of requiring 4 hits out of 5 stations will provides us high trigger efficiencies with low trigger rates.
2. The logic 4/5 for the low η RE can more effectively remove ghost hits for the CSC tracking system.

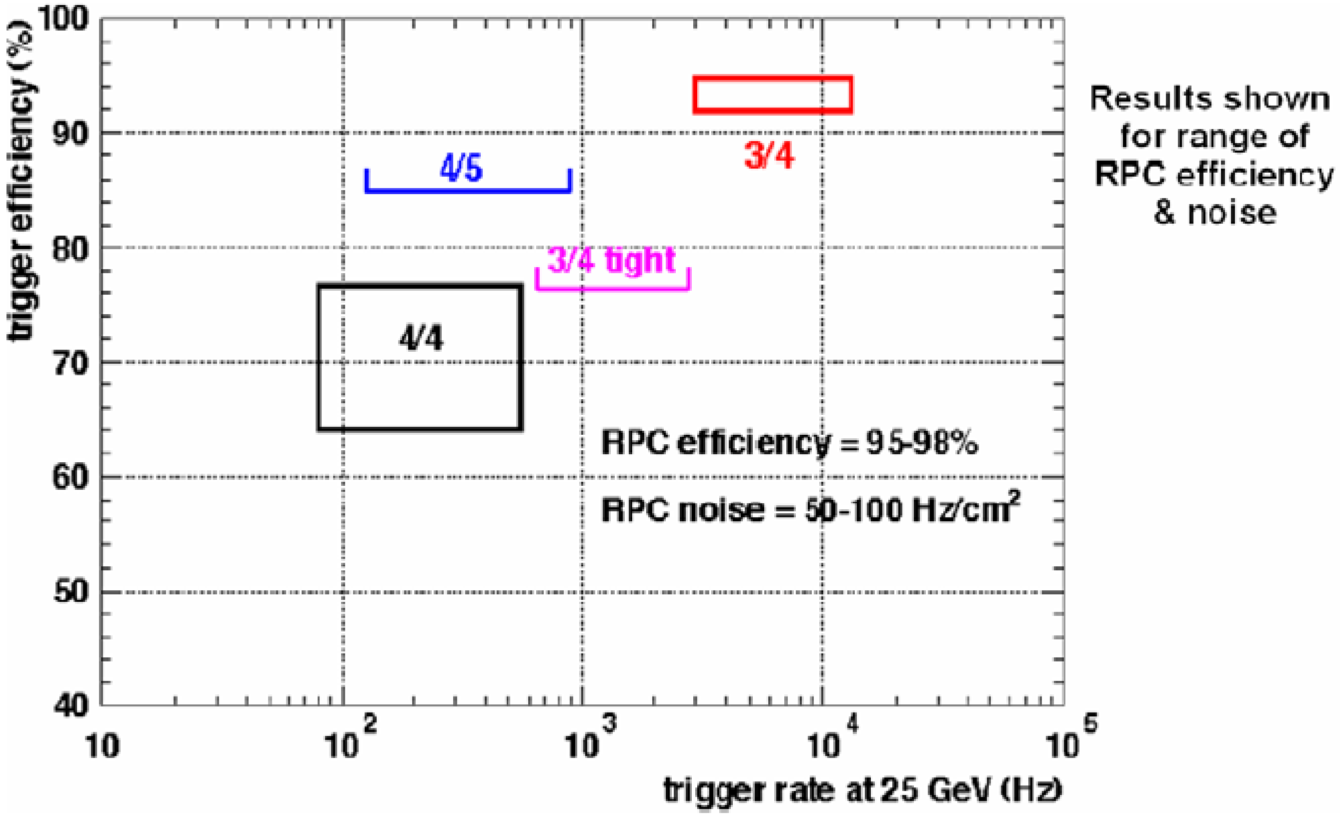
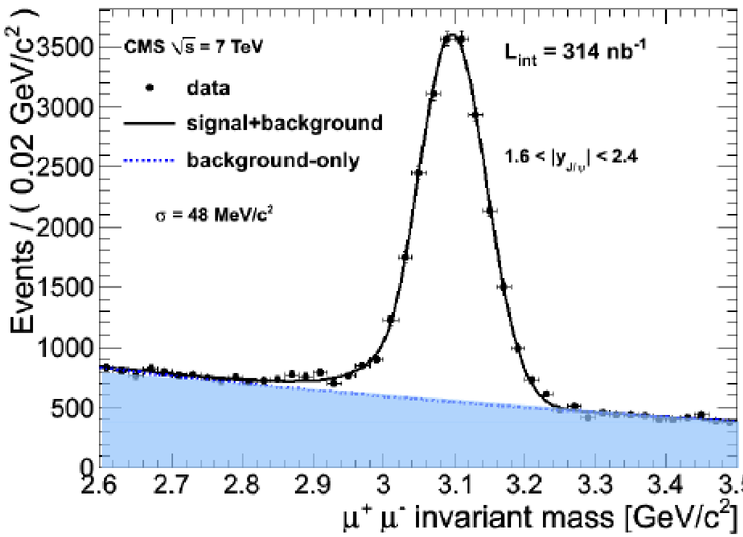
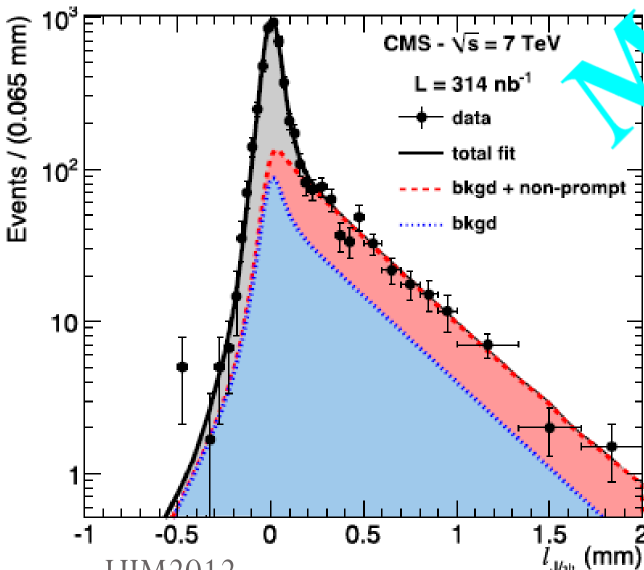


Figure 1.3: results of a simulation study on first level trigger performance of the RE system.

J/ψ in pp collisions





Eur. Phys. J. C (2011) 71: 1575
DOI 10.1140/epjc/s10052-011-1575-8

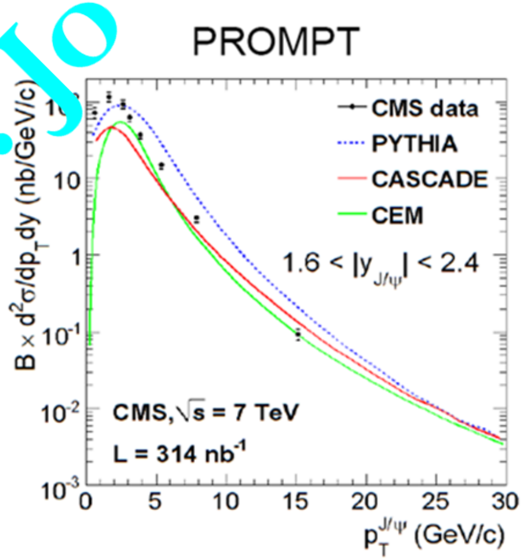
THE EUROPEAN PHYSICAL JOURNAL C

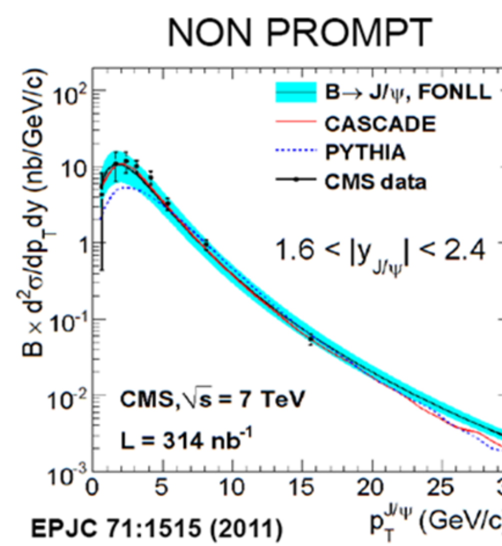
Regular Article - Experimental Physics

Prompt and non-prompt J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV

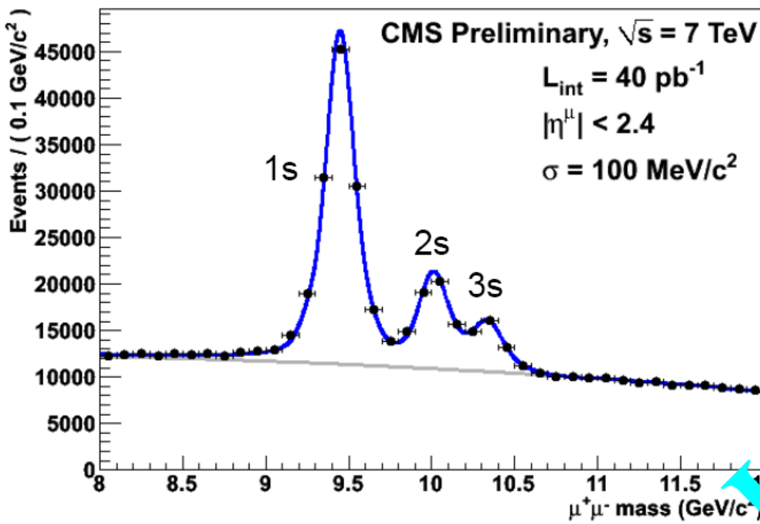
The CMS Collaboration*

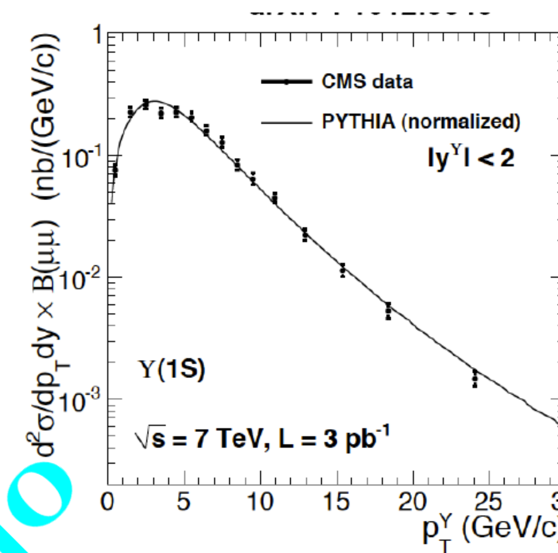
Received: 18 November 2010 / Revised: 10 January 2011 / Published online: 22 March 2011





Υ in pp collisions





Dimuons in Pb-Pb Collisions