Up-scope of the Forward RPCs for the CMS/LHC Experiment

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Forward RPC Collaboration

HIM, June 10, 2011

Outline

1. Introduction: Forward RPC system for CMS
   - RPCs System for the Compact Muon Solenoid
   - Collaboration works for Forward RPC system of CMS

2. Completion of the Forward RPC System
   - Current condition for the endcap-RPCtrigger
   - Upscope plans
   - R&Ds for RE1/1

3. Collaboration for the Forward RPC upgrades

4. Schedule and milestones

1. Introduction: Forward RPCs for CMS

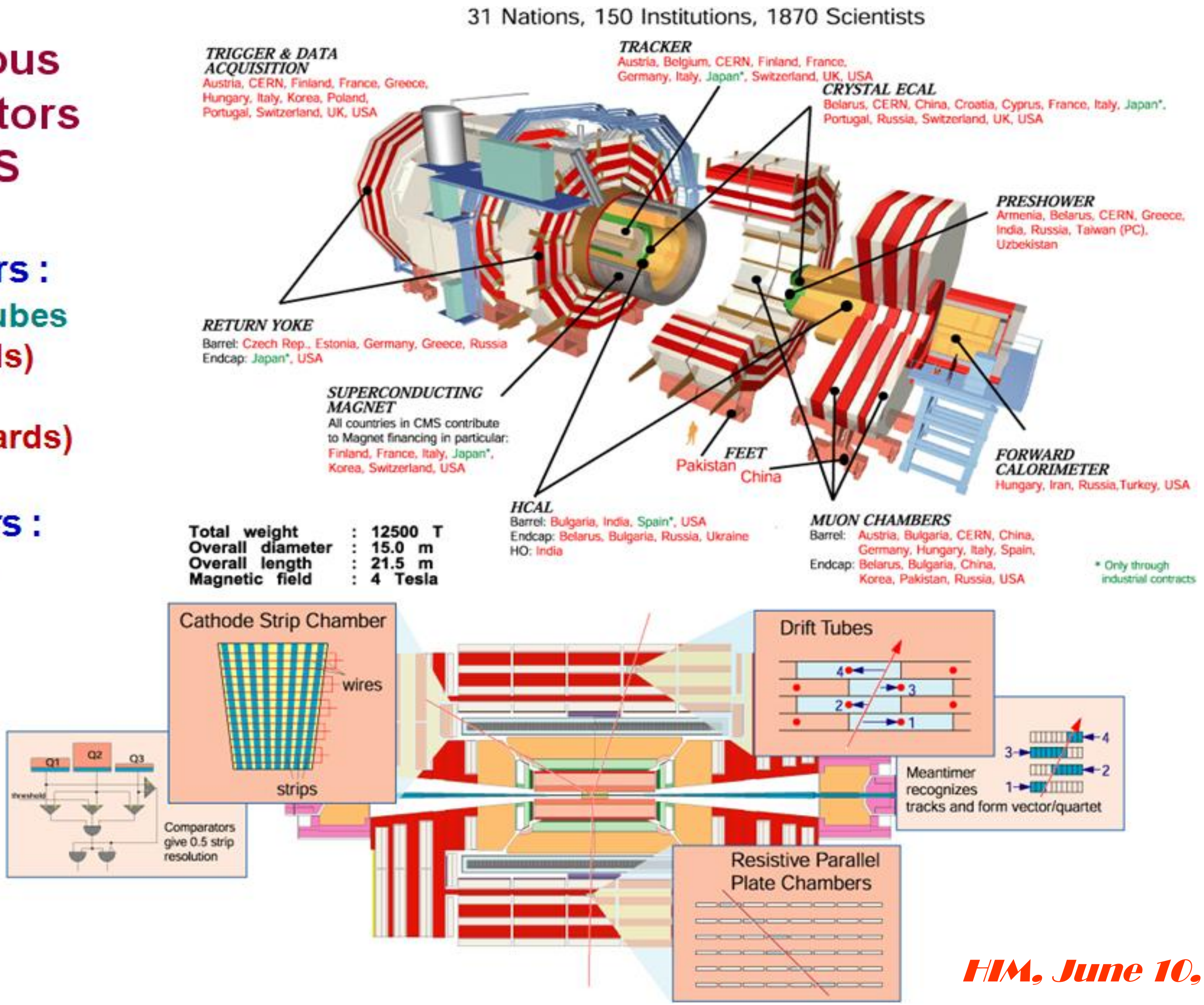
RPCs System for the Compact Muon Solenoid

- Detectors to select muon candidates for the CMS experiment

Gaseous Detectors in CMS

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

Triggers :
- RPCs



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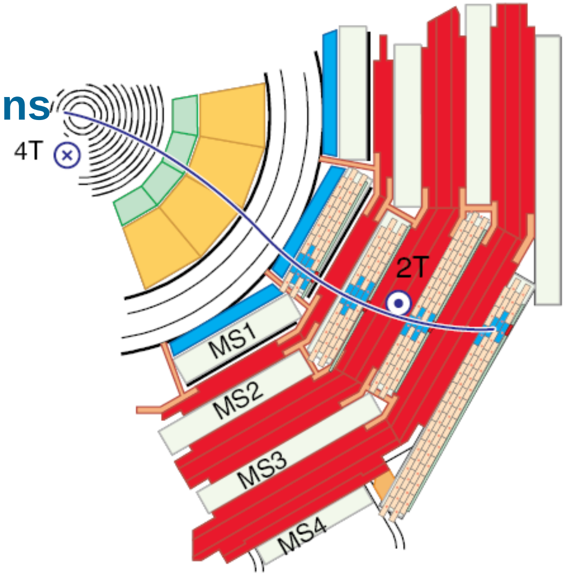
CMS RPCs, gas detectors in avalanche mode:

Fast time response (~ 10 ns) and resolution (~ 1 ns)

⇒ Suitable for tagging particles every 25 ns for LHC collisions

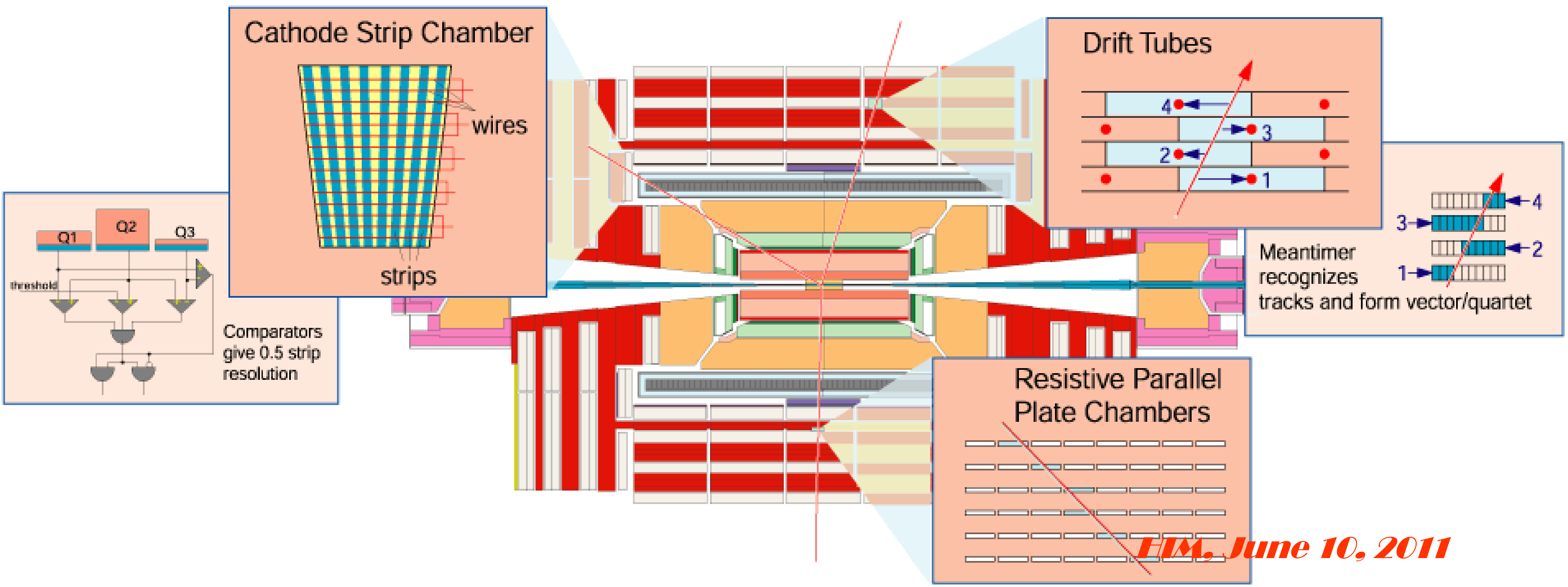
Thin panel detector structure of RPCs

⇒ Designed to provide L1 trigger information to trackers via PACT



Muon system

- Tracking : Drift Tubes + Cathode Strip Chambers
- Trigger : Resistive Plate Chambers



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

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

► Barrel RPCs

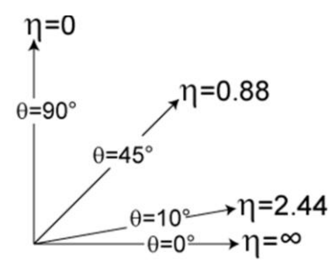
- 6 stations (layers)
- Fully covering up to η = 0.8
- Partially covering up to η = ~ 1.2

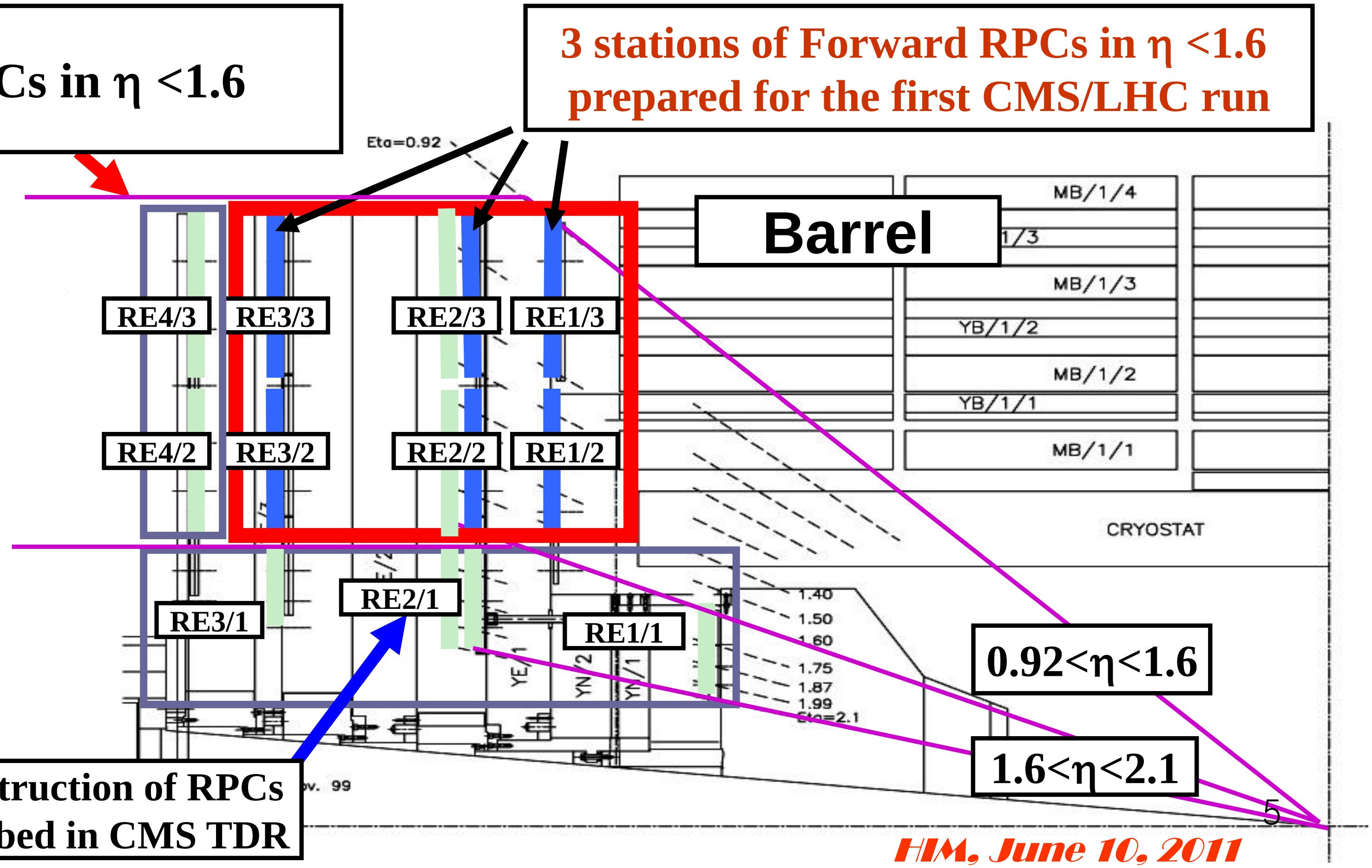
► Forward RPCs

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

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

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





CMS RPCs: 2-gap RPCs

The avalanche mode for RPCs lies near the end of the proportional mode (just below $\eta x \sim 20$)
→ 'Limited proportional mode'

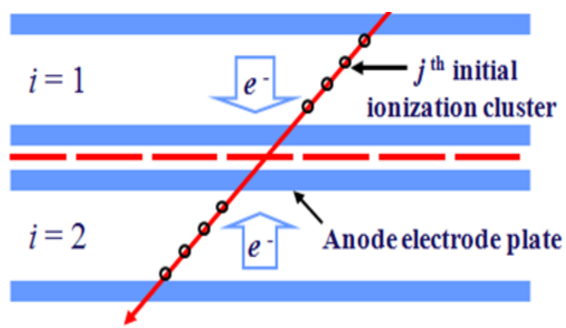
Thickness of each electrode : 2 mm

Anode readout by placing the strip panel at the GND side

Freon based gas mixture :
96.0% $C_2H_2F_4$ + 3.5% i-C_4H_{10} (+ 0.5% for SF_6)

Digitization of the pulse for the time information and to select the meaningful muon track from the hit pattern.

Important Characteristics	
Time resol.	~ 1 ns for MIP
Efficiency	> 95 % for MIP
Rate capability	> 2 kHz/cm^2
Noise rate	> 5 Hz/cm^2
Resistivity of HPLs	10^{10} Ohmcm
Strip multiplicity	1.5 – 3.0



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

$$dn = n\eta dx$$

$$n = n_0 e^{\eta x}$$

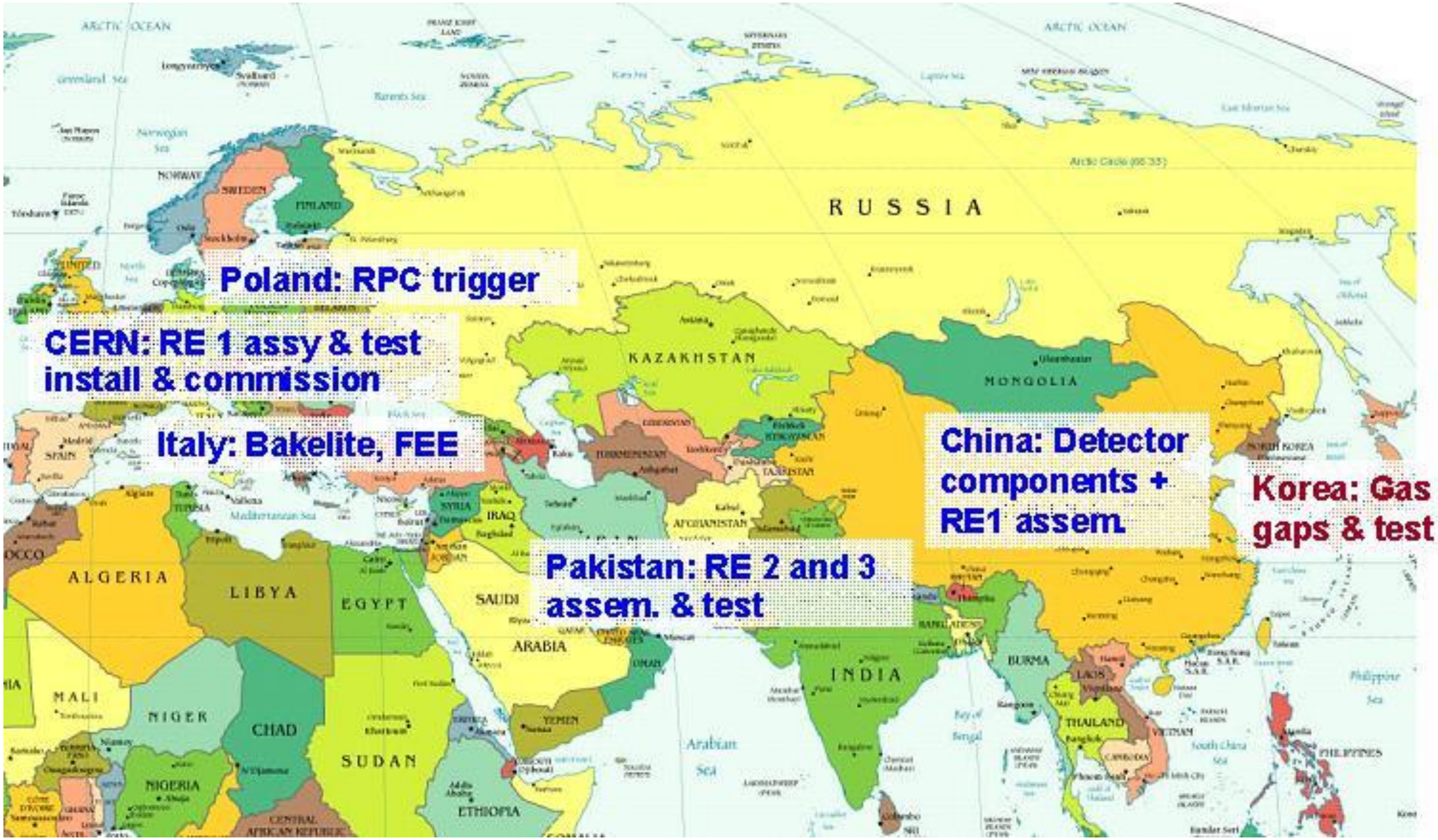
$$\frac{\eta}{p} = A e^{(-B\frac{p}{E})}$$

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

- n_0 : initial size of clusters(electrons)
- n : size of of clusters(electrons)
- $\eta = \alpha - \beta$: effective Townsend coefficient
- β : attachment coefficient
- E : effective field
- P : gas pressure
- A, B : constants in Korff's approximation
- q_e : induced charge at signal pick-up strip
- μ : avarage initial size of clusters
- q_{el} : electron's charge
- d : gap width
- M : gain fluctuation factor
- $k = (\varepsilon_r d/s) / (\varepsilon_r d/s+2)$
- λ : average cluster density

Collaboration works for the Forward RPCs

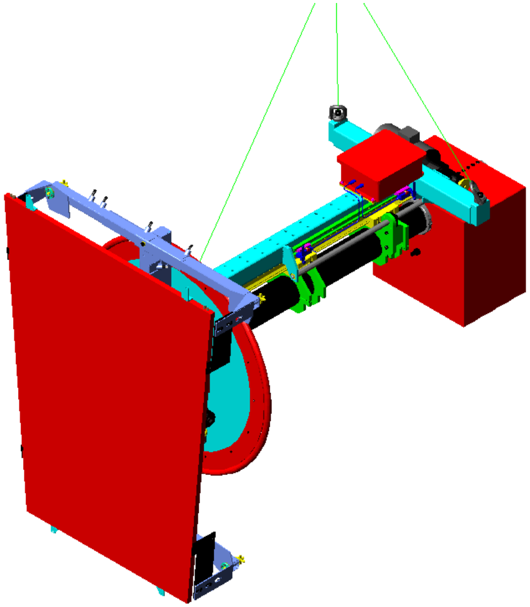
Korea, Belgium, CERN, China, India, Italy, Pakistan, Poland, Russia …



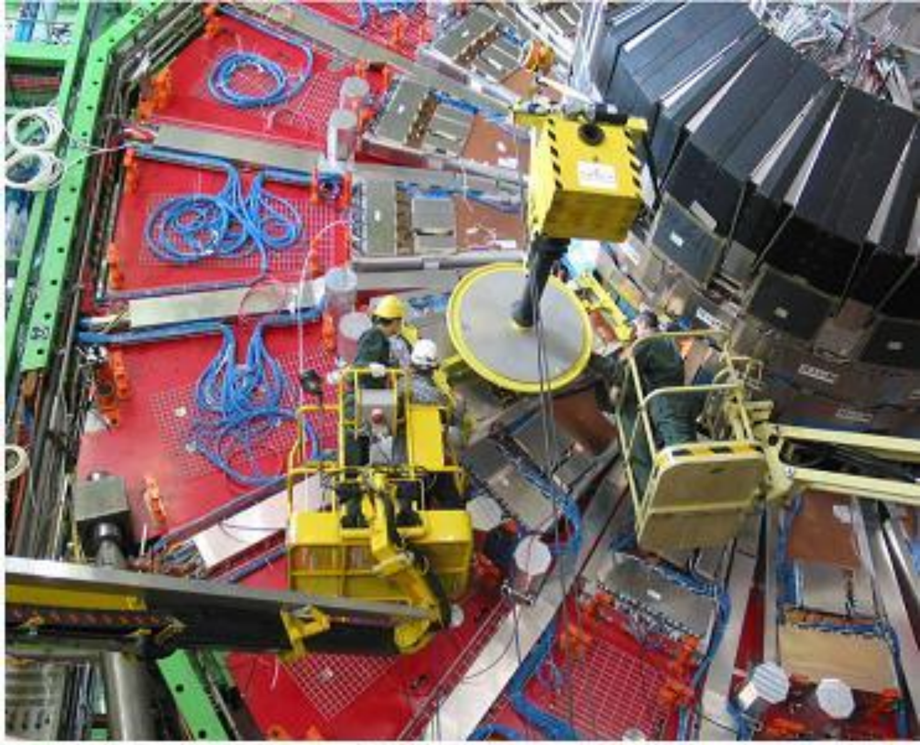
RE1 in $\eta < 1.6$

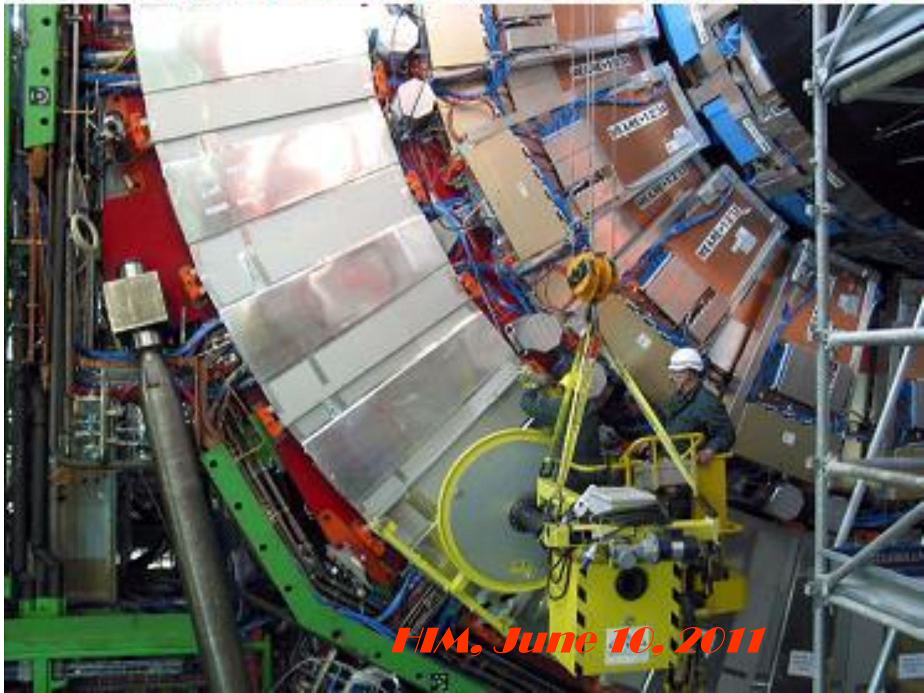
RE1/2 & RE1/3 : 144 RPCs

Installation of ME1/2-RE1/2 packages



Installation of RE1/3

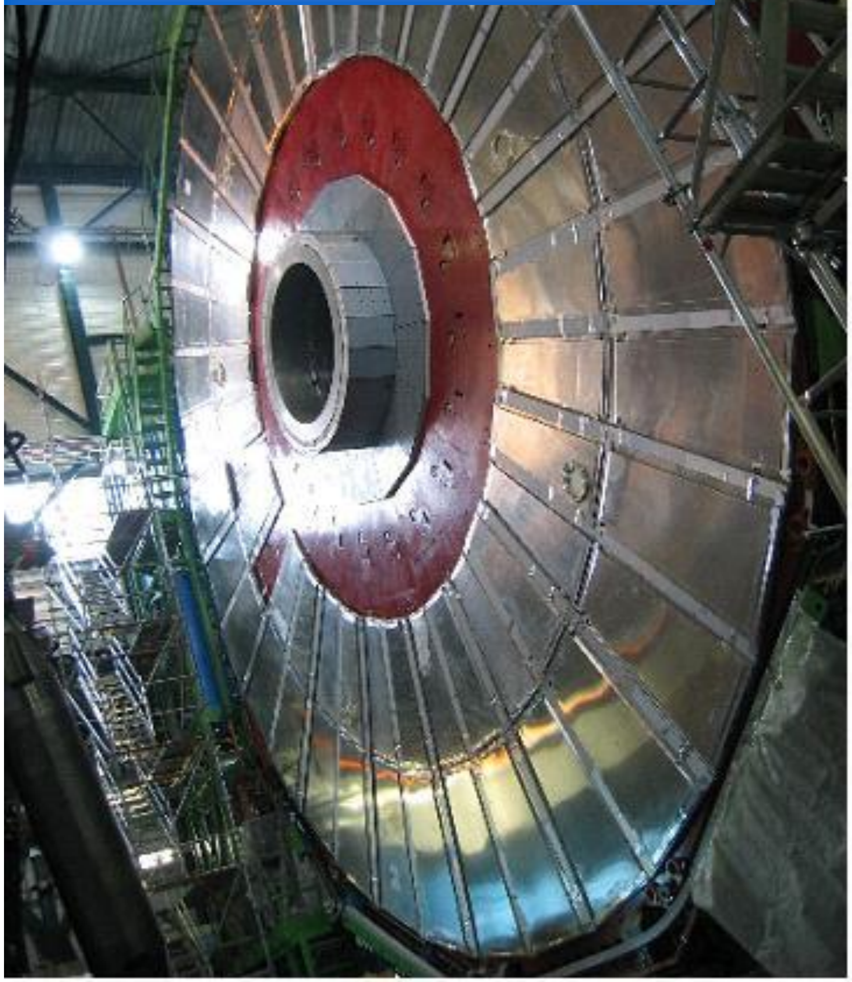




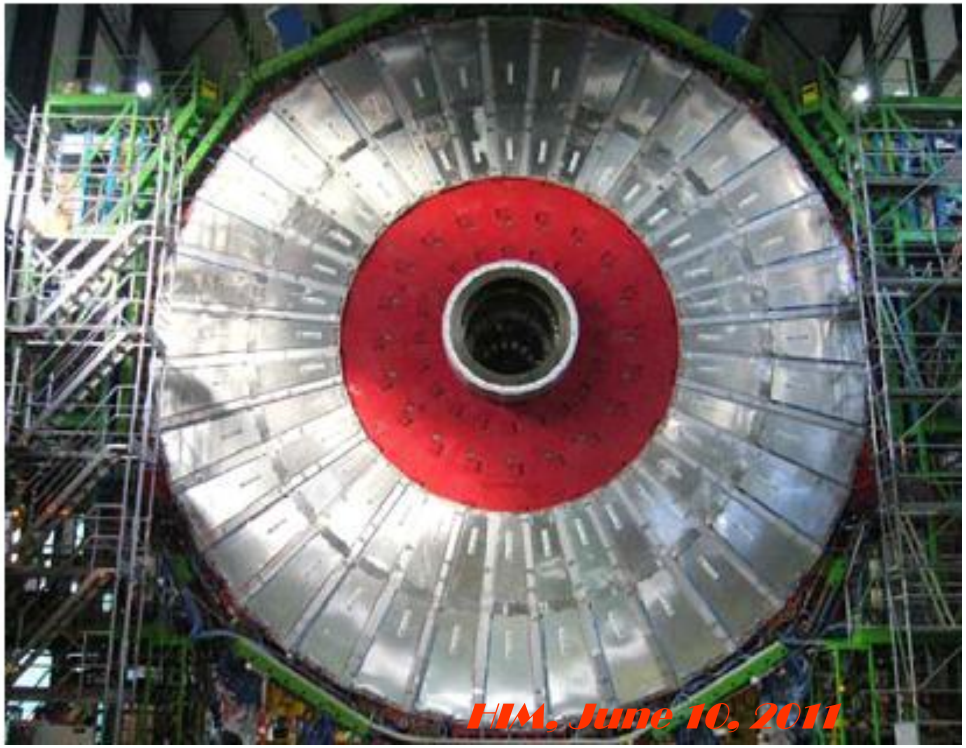
RE2 in $\eta < 1.6$

RE2/2, RE2/3, RE3/2, RE3/3 288 RPCs

**RE2/2 & RE2/3
on the back of YE1**



**RE3/2 & RE3/3
on the back of YE3**



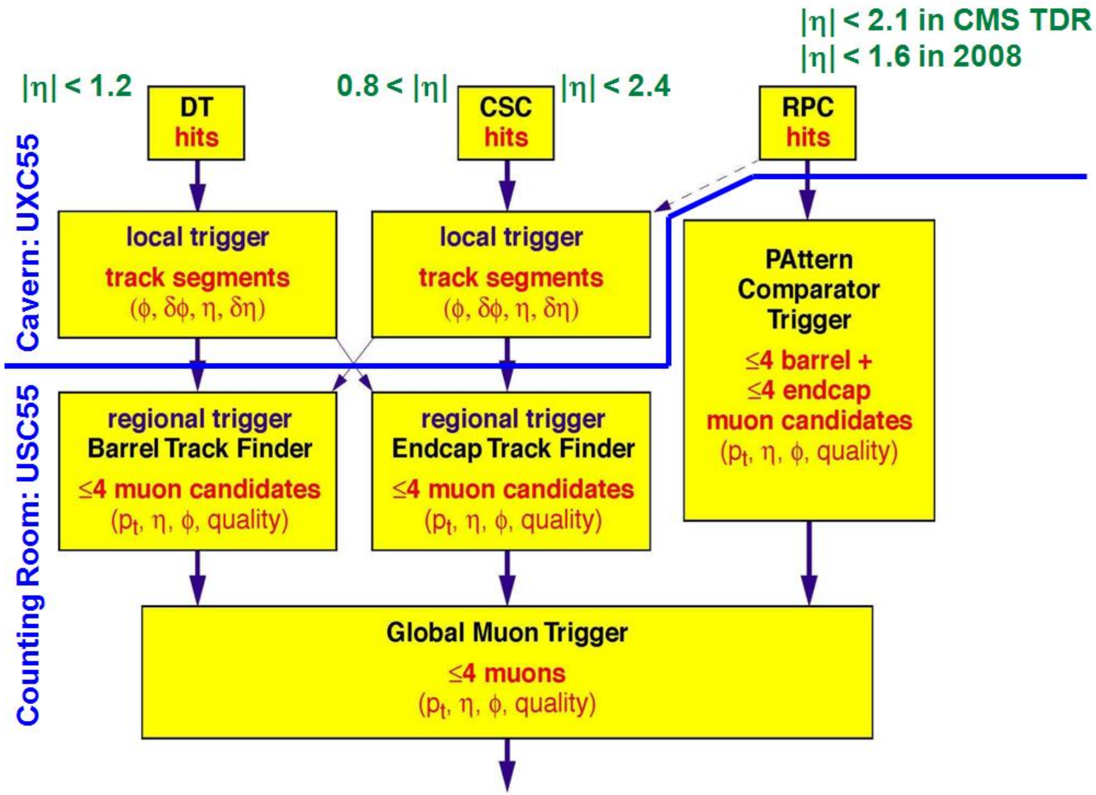
2. Completion of the Forward RPC System

► **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 < η.
- There is NO RPC muon trigger in 1.6 < η < 2.1.
- The current muon trigger efficiency in 1.6 < η < 2.1 ~ 70 % with the current system without high-η RPCs.

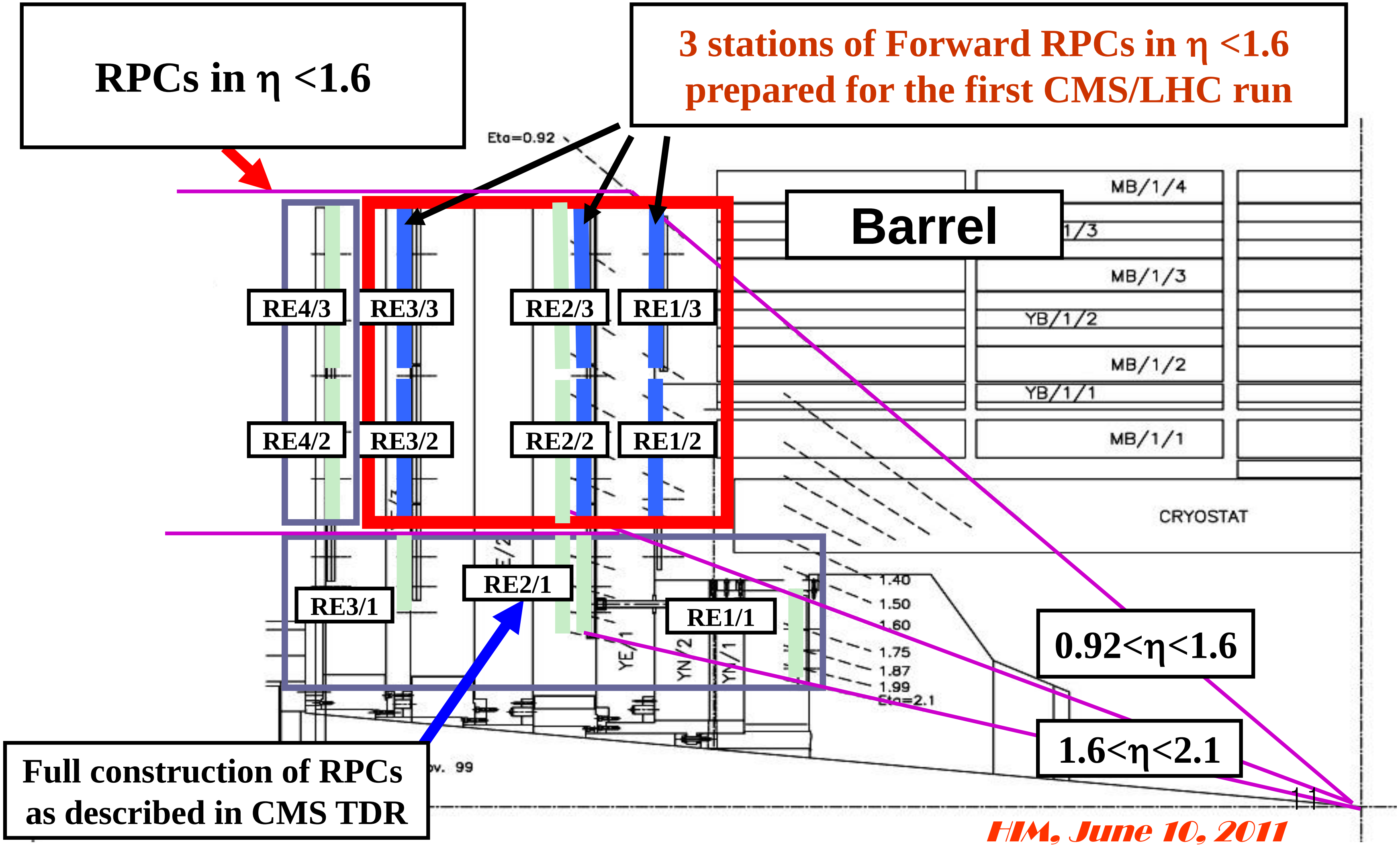
► **What we plan to do until the first shutdown of the LHC ?**

- 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 |η| < 1.6



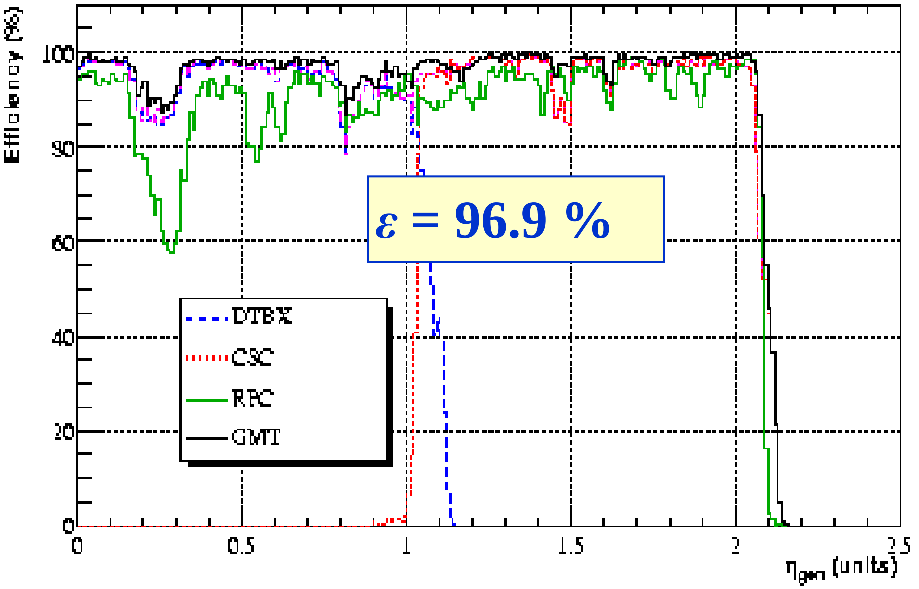
► **Barrel RPCs**
- 6 stations (layers)
- Fully covering up to η = 0.8
- Partially covering up to η = ~ 1.2

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



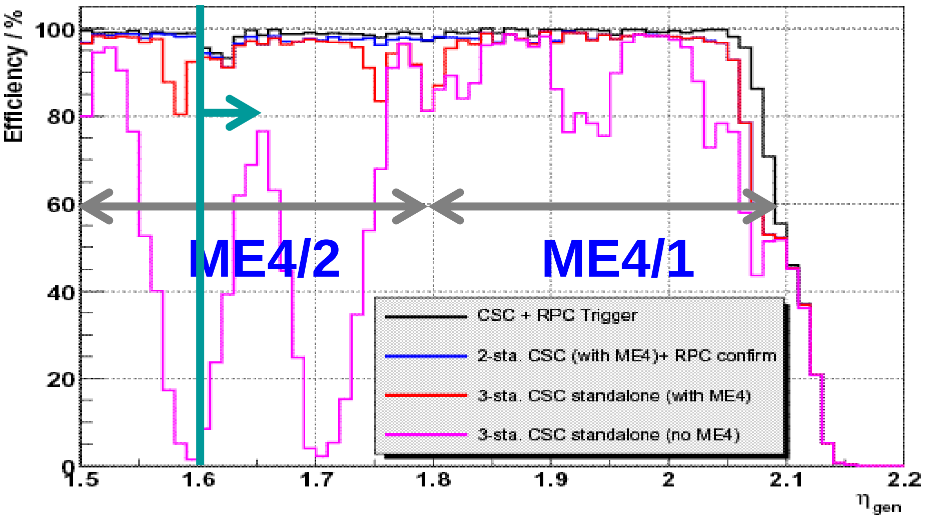
Trigger efficiency in the original design of the CMS Muon TDR (W. Smith)

Single-muon trigger ε vs. η



3-Station CSC Trigger Efficiency

Efficiency to find muon of any p_T in flat p_T =3-100 GeV sample



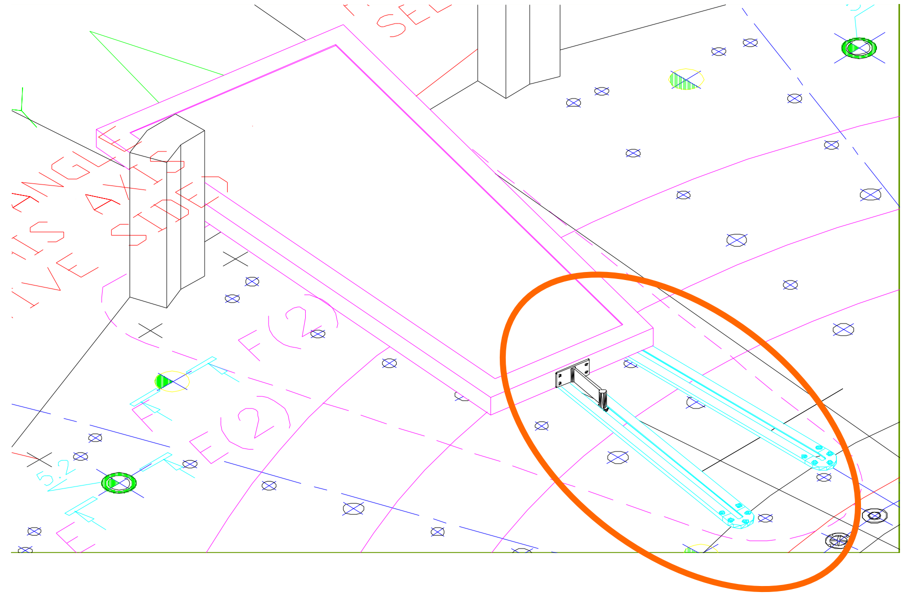
Requiring the RE1/1 trigger to enhance the efficiency in $1.6 < |\eta| < 2.1$

RE1/1 RPCs for high-η triggers

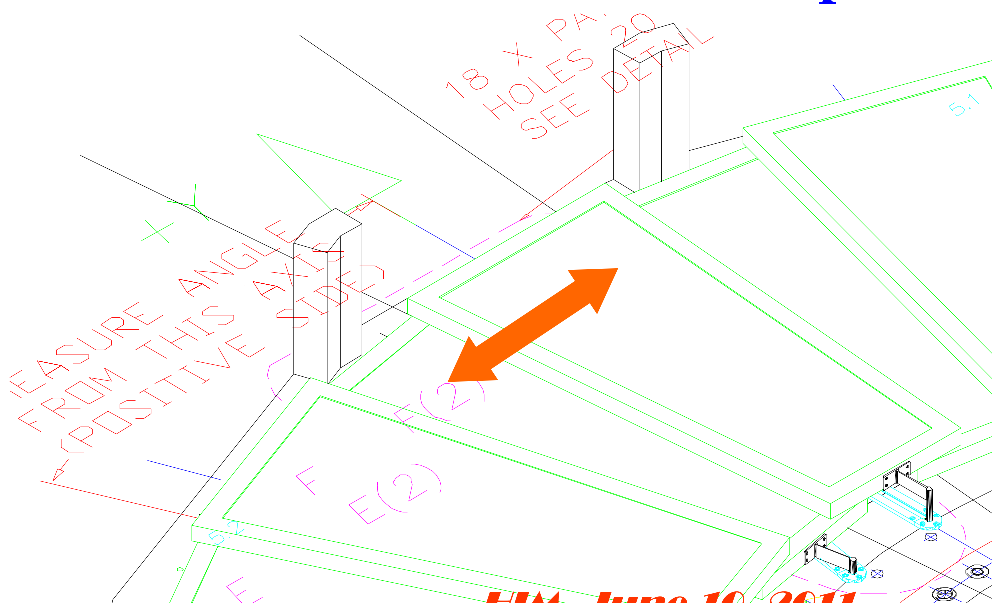
► **72 RE1/1 RPCs at YE1 :**

- 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.

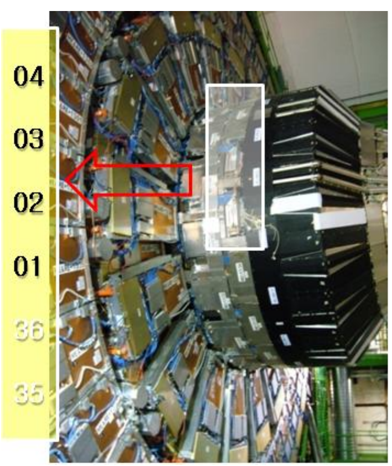
Insert via rails

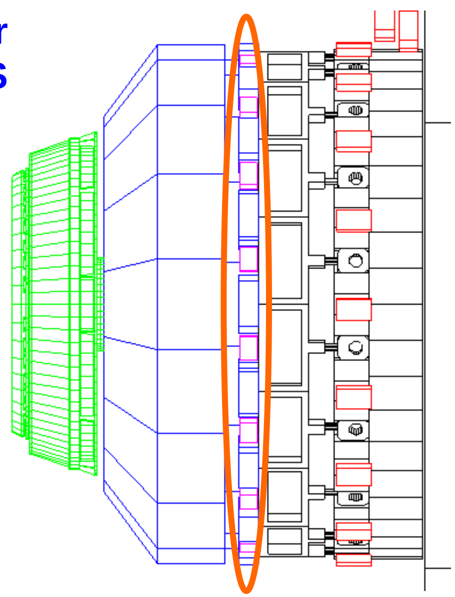


Rotate in place



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





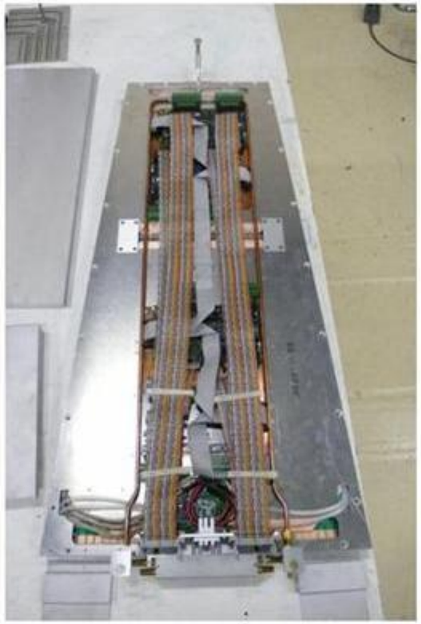
1) Standard 2-gap phenolic RPC: first six RE1/1 RPCs in CMS

Phenolic plate (~10^{10}Ωcm) instead of glass (~10^{13}Ωcm)
Expected maximum rate : 300 ~ 400 Hz/cm^2 @ L = 10^{34} cm^2 s^{-1}

1. **Standard procedure for the detector manufacture**
2. **Cosmic ray test for the detector quality assurance**

First 2-gap RE1/1 Detector at ISR

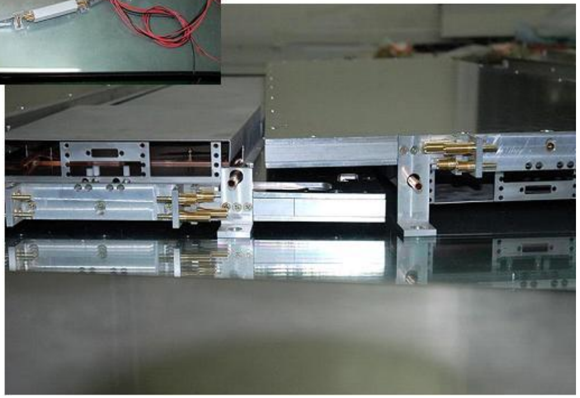
Covered by shielding box

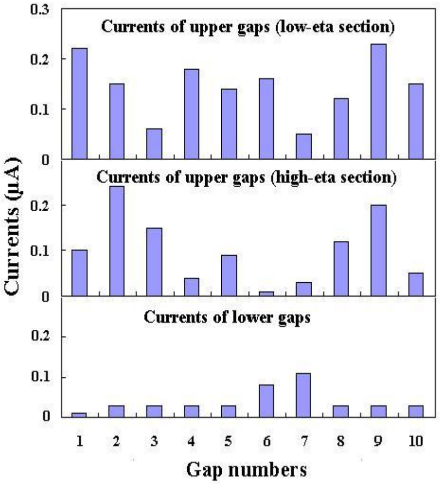


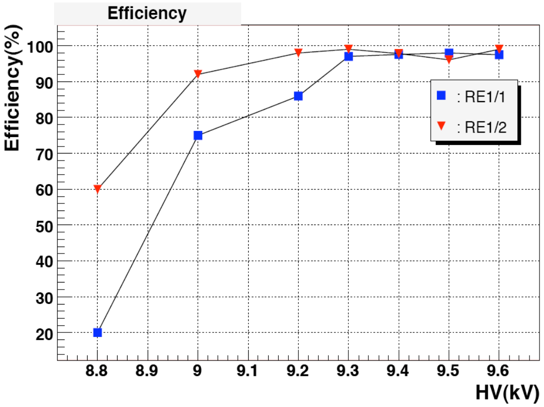
FEB flat cable layout

Signal cable layout

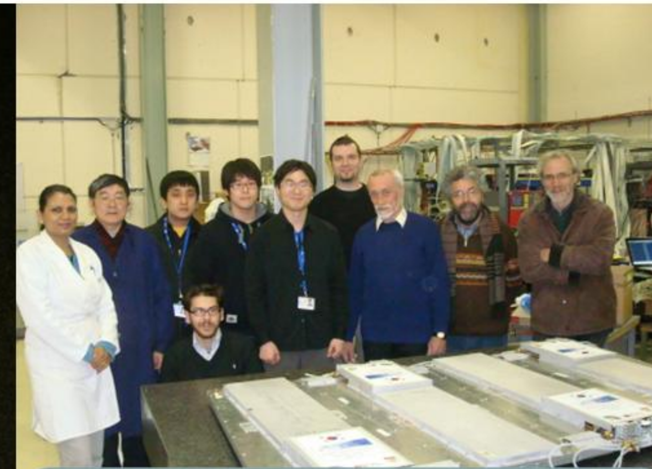
Configuration of 6 RE1/1 RPCs in a 60 degree sector



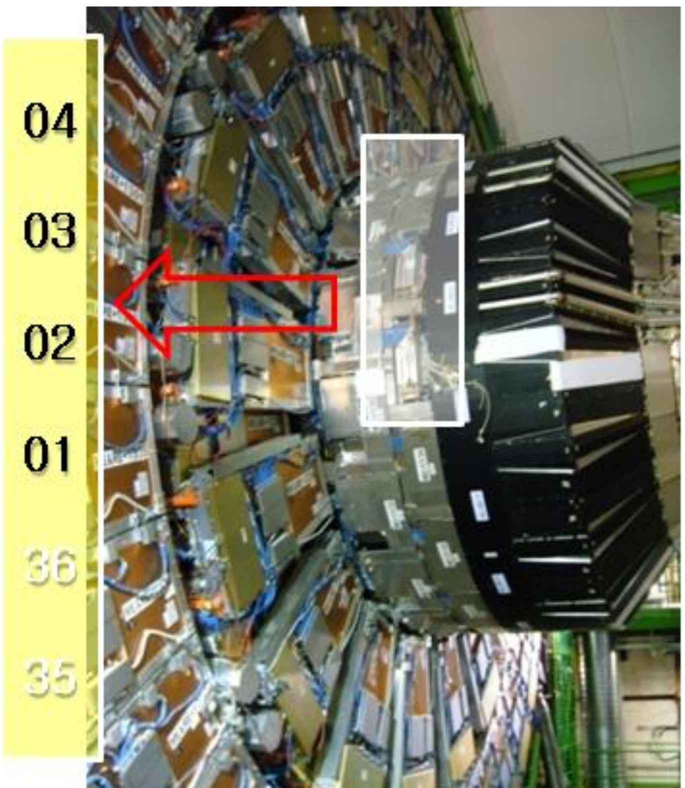


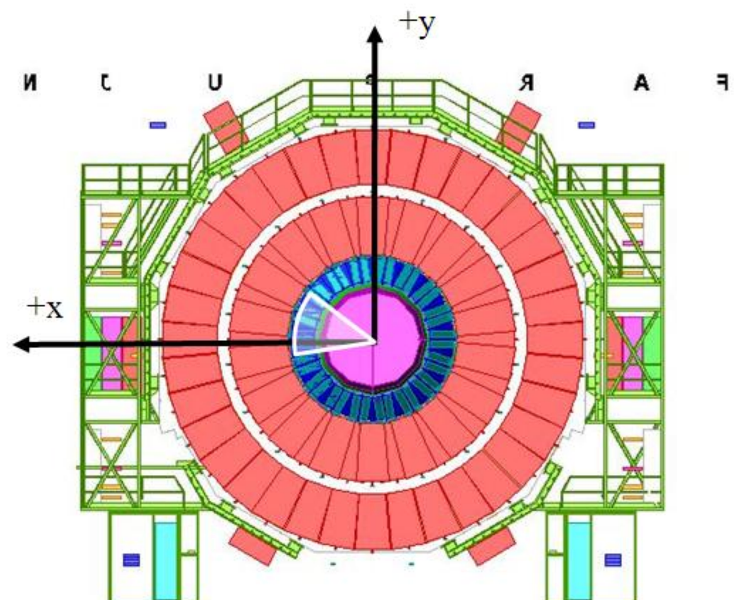


4 RE1/1 RPC module installed in the CMS nose-cone (2009)



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





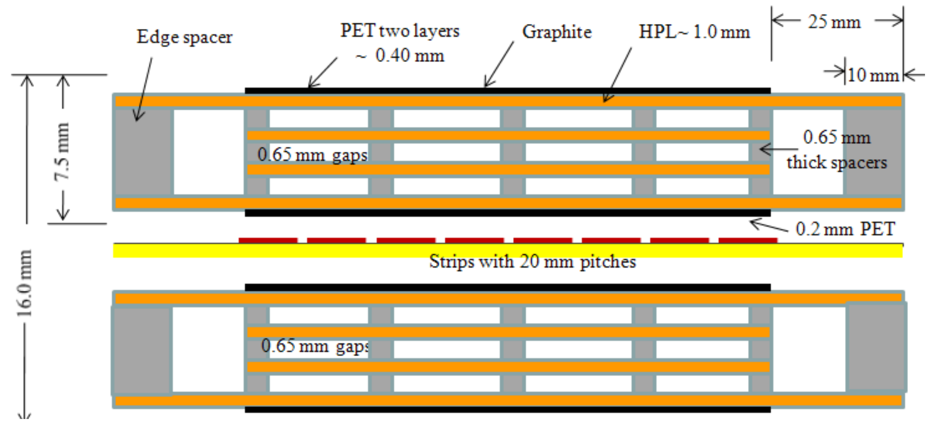
2) Multi-gap phenolic RPCs for RE1/1

HPL based 6-gap & 4-gap RPCs

Smaller detector pulses
- **Higher rate capability at RE1/1 of CMS**
- **Better radiation hardness**

Aiming for higher–rate trigger to enhance the future CMS/LHC trigger condition
Maximum rate expected ~ 2 kHz/cm²
@ L ~ 10^{35} Hz/cm²

6-gap RPC



	2-gap RPC	4-gap RPC	6-gap RPC
Thickness of each gap	2.0 mm	1.0 mm	0.65 mm
Total thickness of gap in RPC	4.0 mm	4.0 mm	4.0 mm
$\langle q_e \rangle$ in a working plateau	2.5 ~ 5.0 pC	1.3 ~ 2.0 pC	0.6 ~ 1.0 pC
Typical threshold	~ 200 fC	~ 150 fC	~ 100 fC
Resistivity of resistive plates	1 ~ 6 x 10^{10} Ωcm	1 ~ 6 x 10^{10} Ωcm	~ 1 x 10^{11} Ωcm
Maximum rate capability	< 2 kHz/cm²	~ 3 kHz/cm²	~ 5 kHz/cm²

Rate capability of RPCs ~ $1/\langle q_e \rangle$

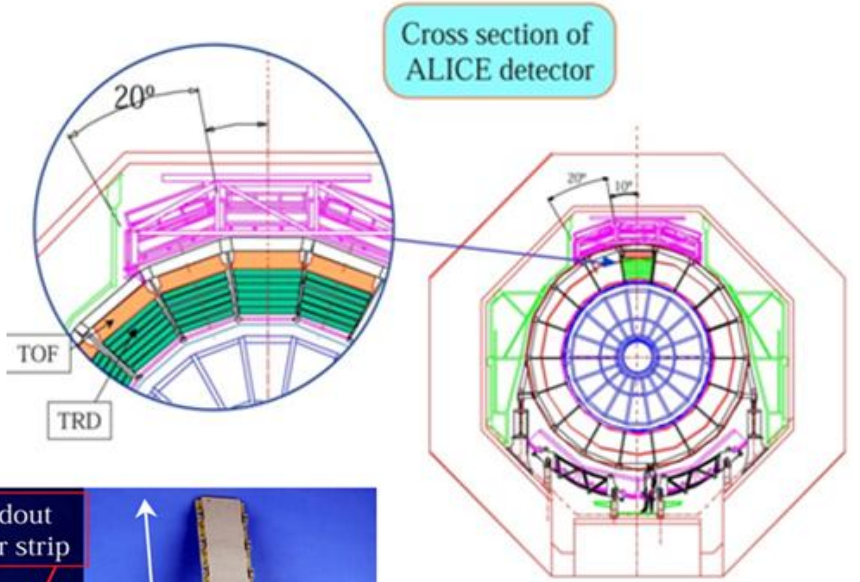
~ $1/\rho$

Time resolution

$\sigma \sim 1/d$, d: thickness of each micro-gap

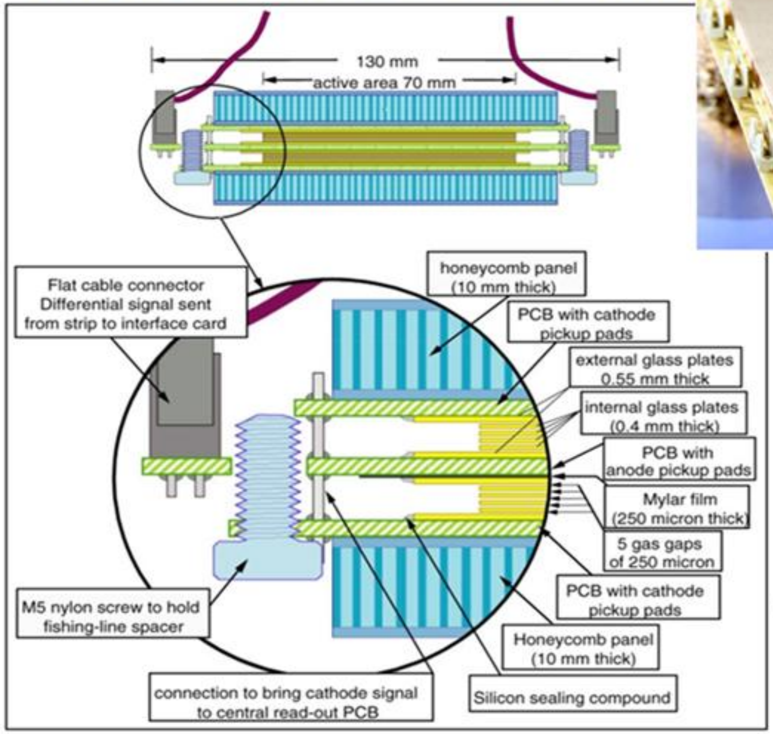
For CMS RPCs, d = 2 mm → $\sigma \sim 500$ ps

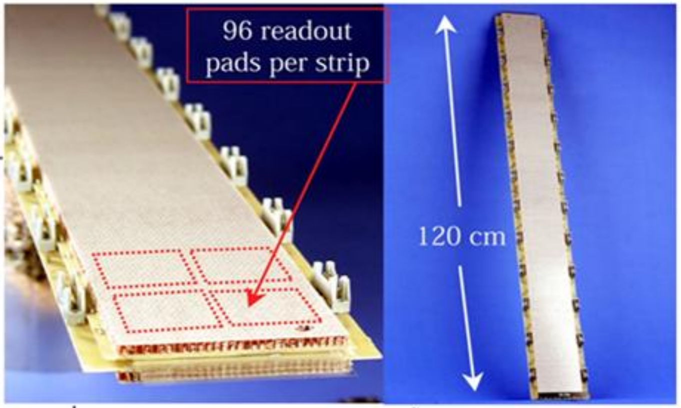
For d = 0.2 mm → $\sigma \sim 50$ ps

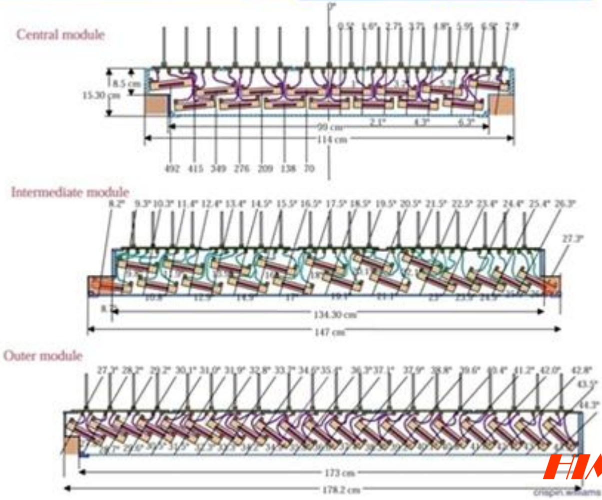


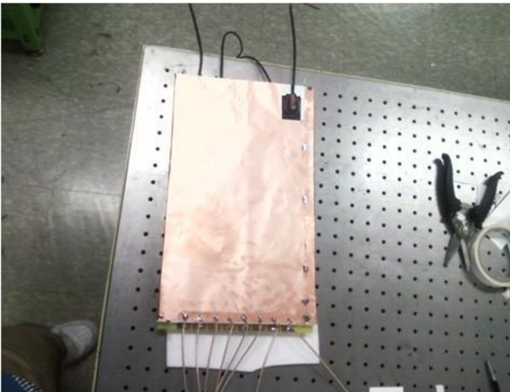
ALICE TOF RPCs (glass)

Cross section of double-stack MRPC - ALICE







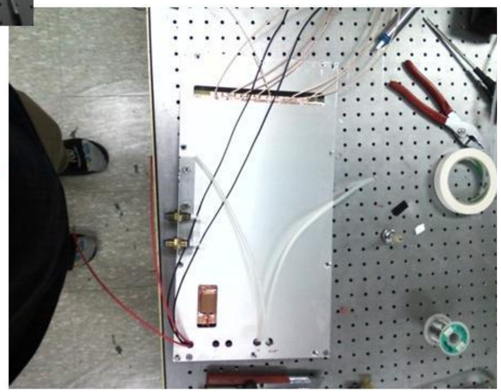


Two gas envelopes in copper GND sheet

Electronics

Gas system

Assembled 6-gap RPC



200 mCi Cs-137 source

A 200 mCi ^{137}Cs gamma source

A six-gap RPC installed with trigger plastic scintillators

ε & $<q_e>$ for a 6-gap RPC

TDC threshold = 1 mV

ADC thresholds = 80 ~ 150 fC

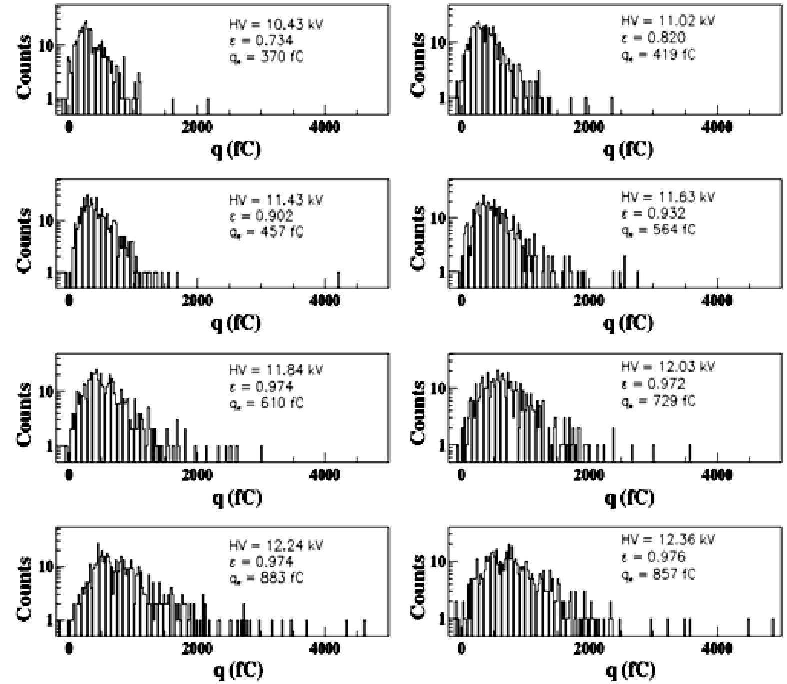
- For 2-gap RPCs ($2.5 < q_e < 5.0$ pC) :

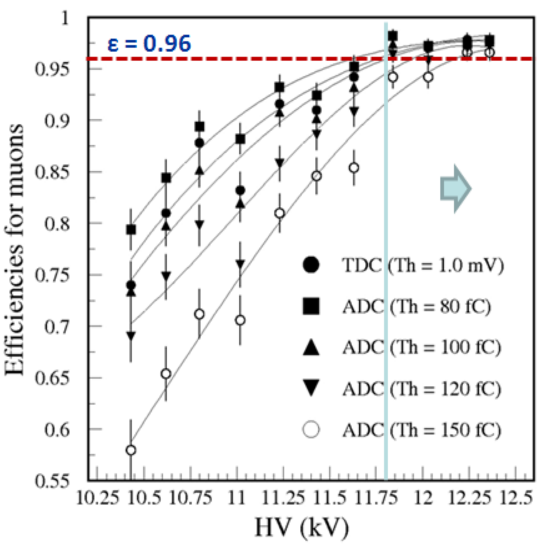
  q_{str} > 10 pC for CMS Barrel RPCs

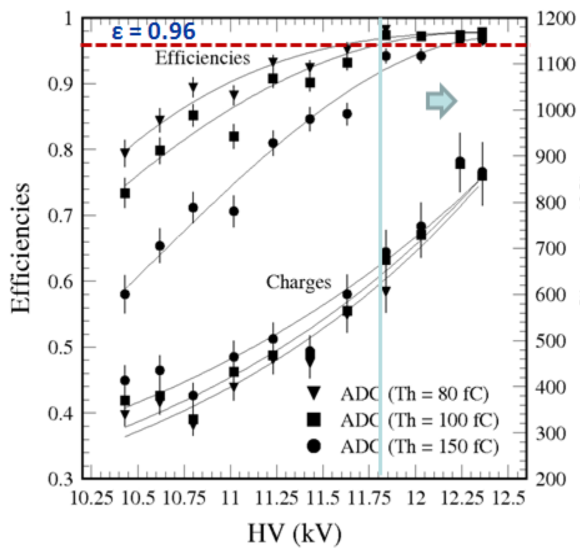
  q_{str} > 20 pC for CMS Forward RPCs

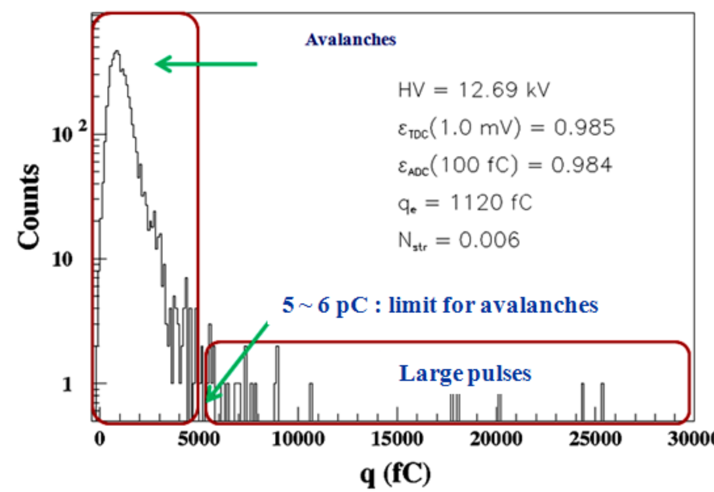
- For 6-gap RPCs ($0.6 < q_e < 1$ pC) :

  q_{str} > ~ 5 pC





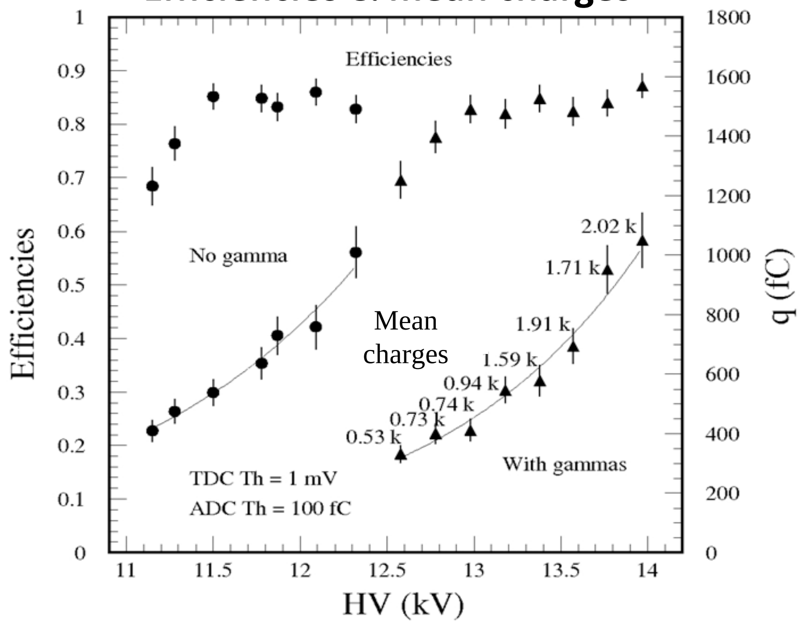




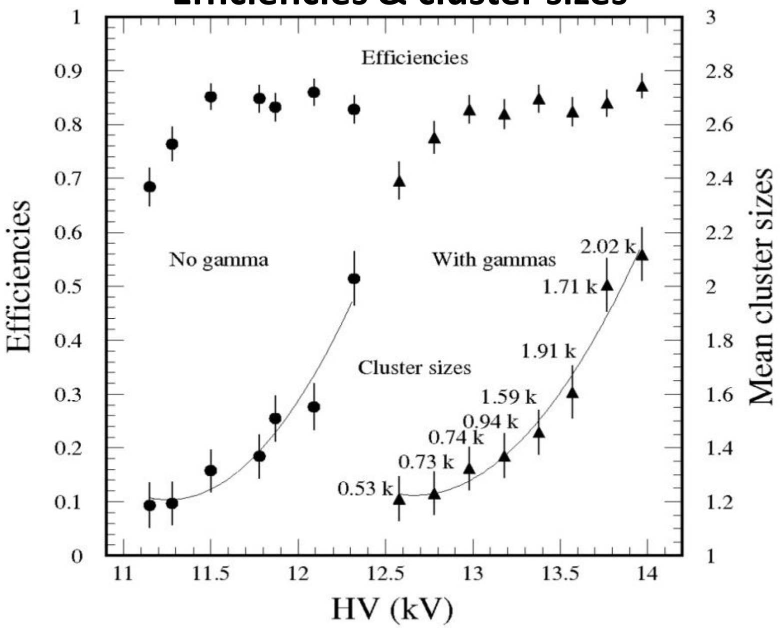
w/o and w. gamma-ray backgrounds

- Shifts in HV ~ 1.5 kV at 2.02 kHz/cm^2
- Caused by increase in resistivity of HPL
  ρ_{20} = (6.9 ± 3.5) × 10^{10} Ωcm (at H = 75%) in Jul. 15, 2009 (right after the production)
  ρ_{20} = (3.3 ± 0.8) × 10^{11} Ωcm (at H = 47%) in Jan. 6, 2010 (final measurement)
- Resistivity of the HPL should be ≤ 10^{11} Ωcm after fully polymerized.

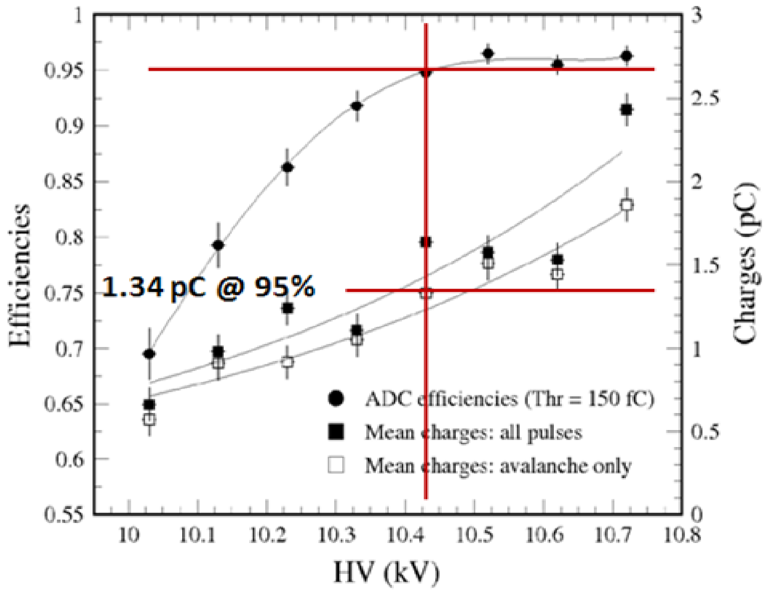
Efficiencies & mean charges

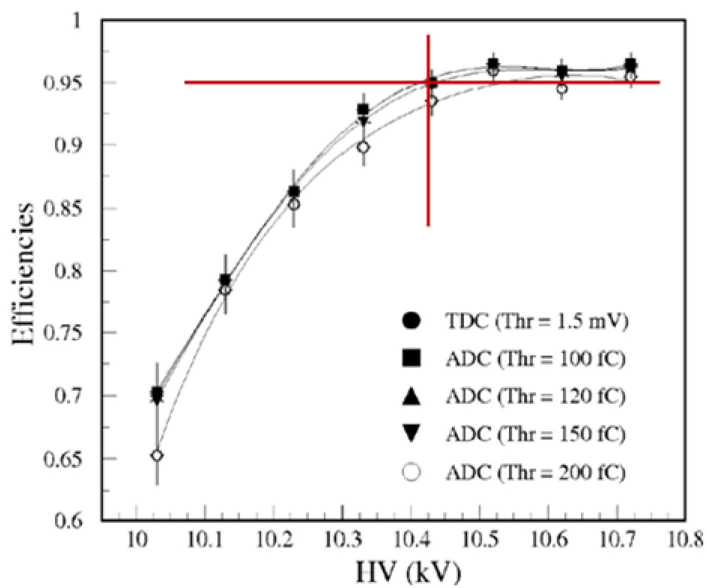


Efficiencies & cluster sizes

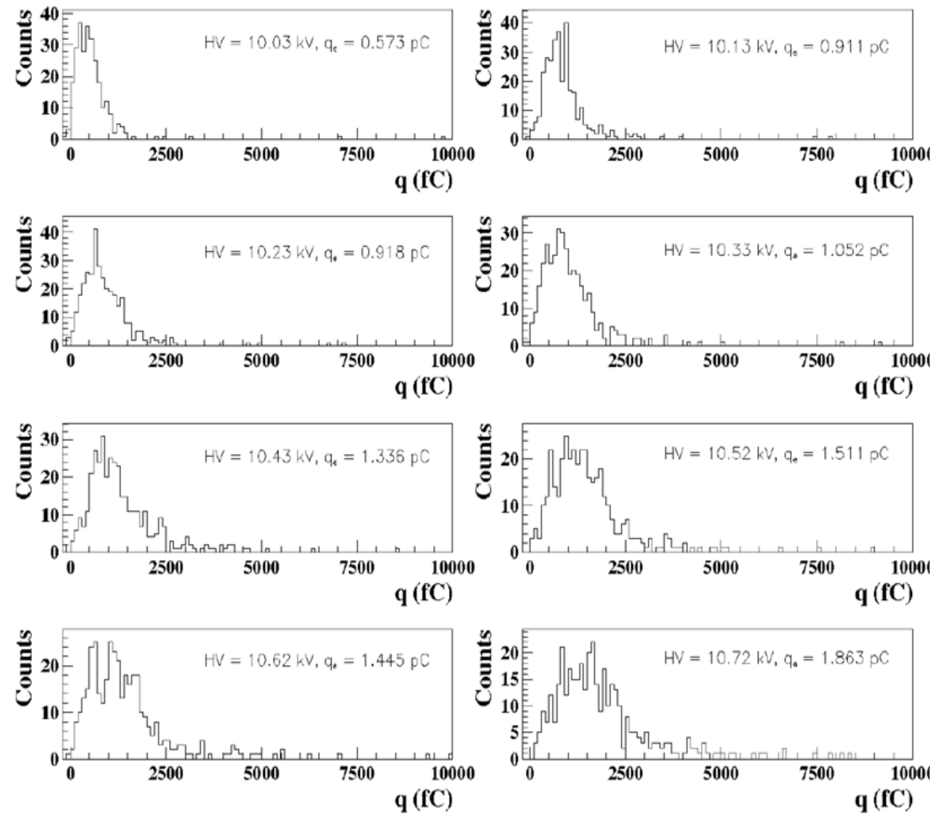


ε & $\langle q_e \rangle$ for a 4-gap RPC





For 4-gap RPCs (1.3 < q_e < 2.0 pC) :



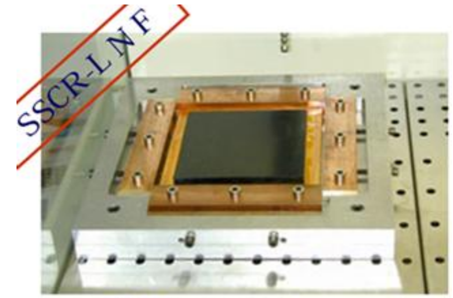
3) GEMs for RE1/1

- Compact detector structure
- Rate capability > 10^5/cm^2
- Tracking capability
- RE1/1: no access allowed
  → Radiation hardness
- Problem: too many channels
  # of ch/det. = 8960
  # of detector = 72

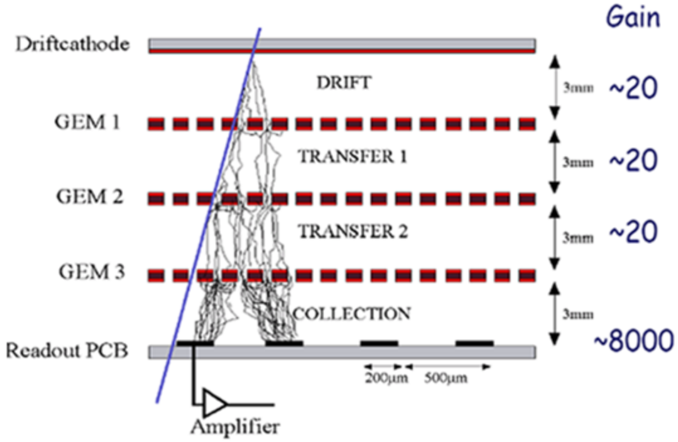
Basic structure

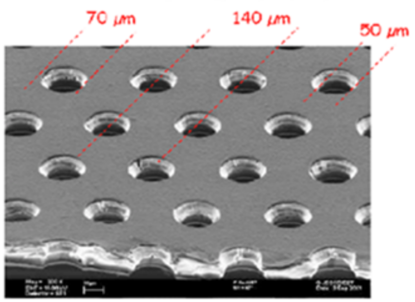
2 ~ 3 GEM plates : for the amplification of X-ray signals

Two dim. microstrips (~ 100 ㎛ spacing : to pickup the avalanche images)

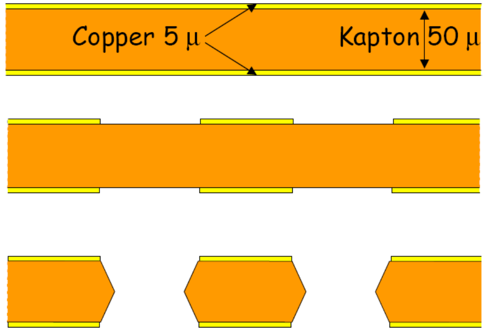


GEM stretcher



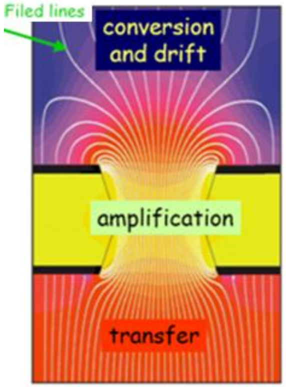


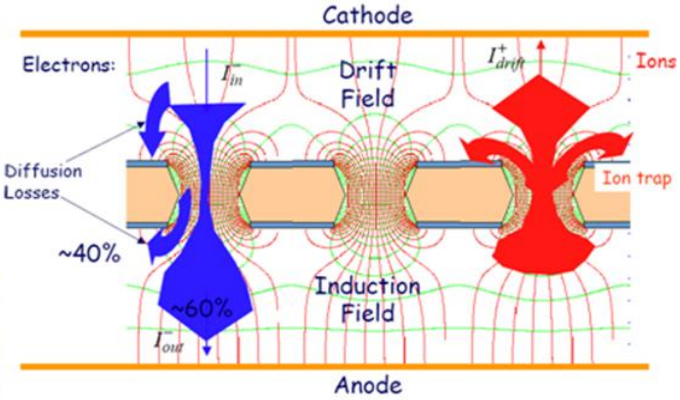
Photolithographic technology used for printed circuit board construction



Copper etching by chemical solution

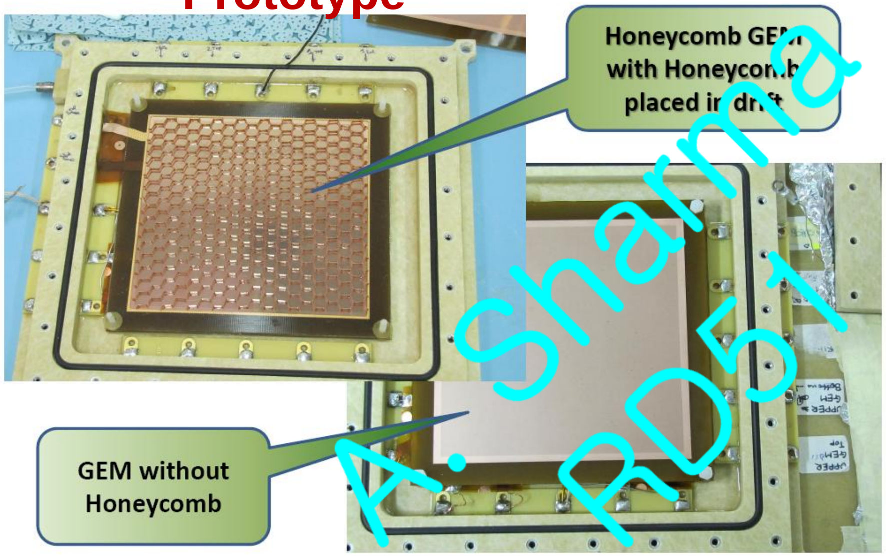
Kapton etching using the copper mask



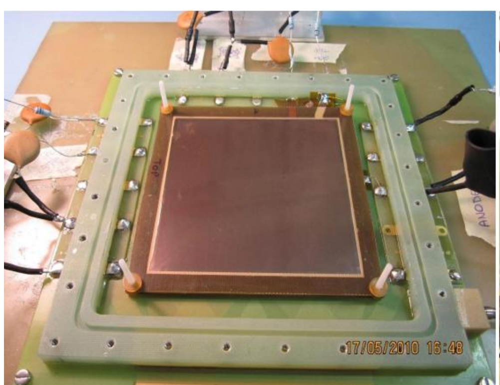


Honeycomb double mask single GEM

Prototype

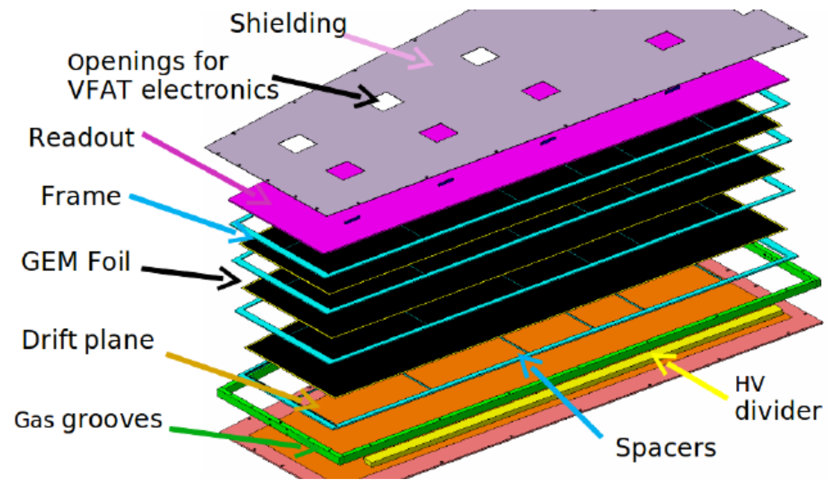


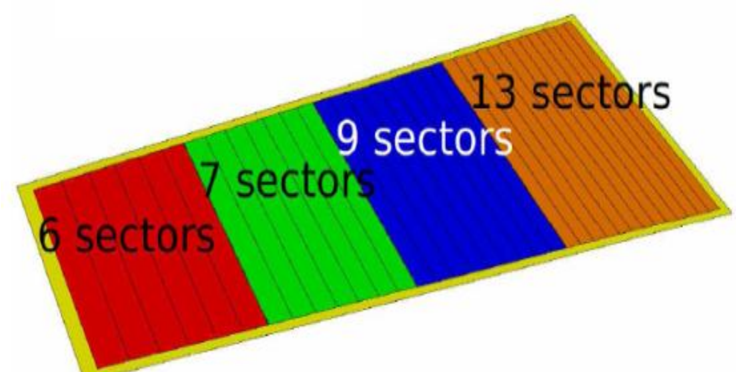
- Number of GEMs used = 1
- GEM active area: 10 x 10 cm²
- Gas mixture: Ar/CO_2 70/30
- Gas flow: ~ 5 l/h
- Water content: ~ 100 ppm H_2O
- Radiation source: Cu X−ray tube
- Cu X-ray @8.04 keV

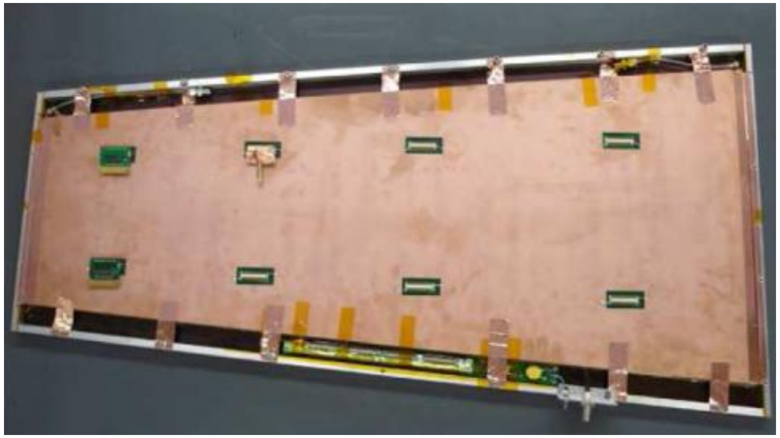


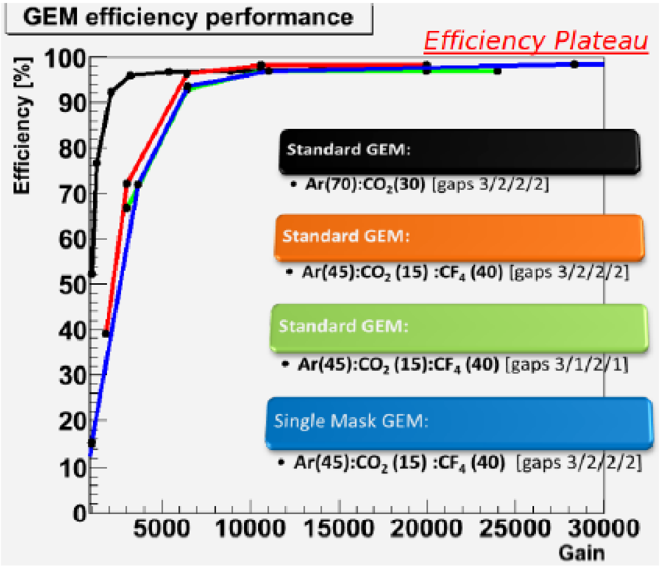
Real size:GE1/1

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

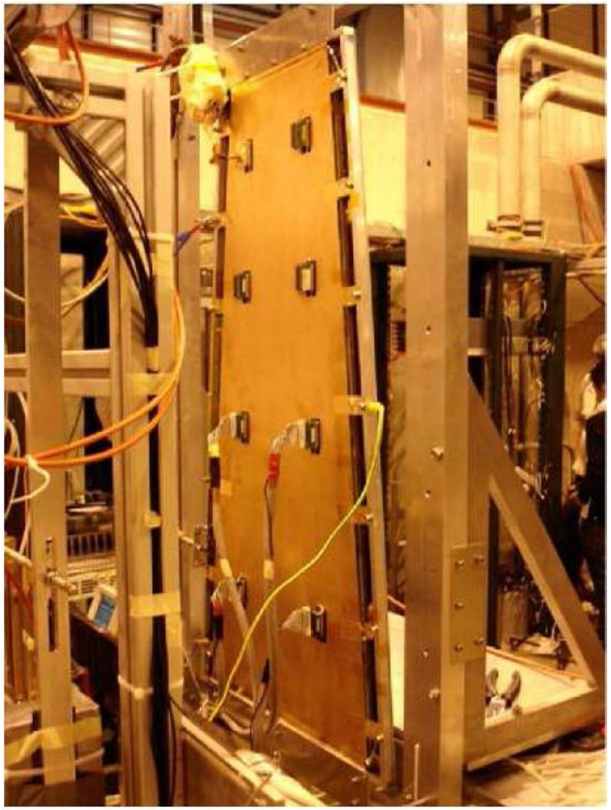




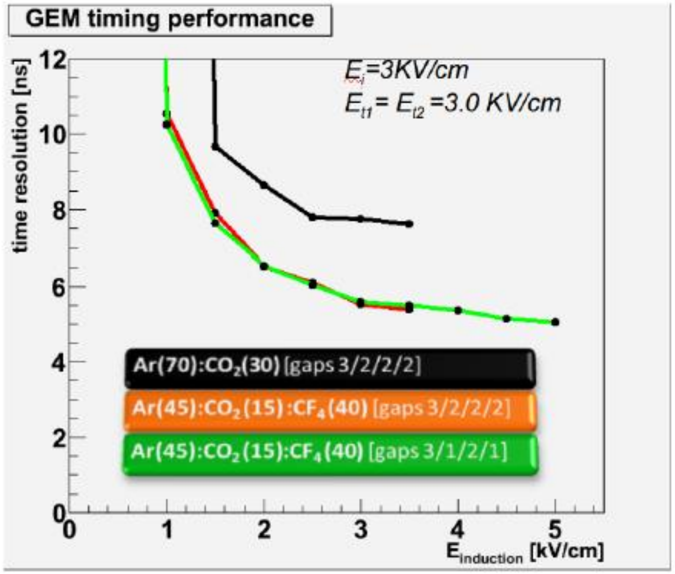




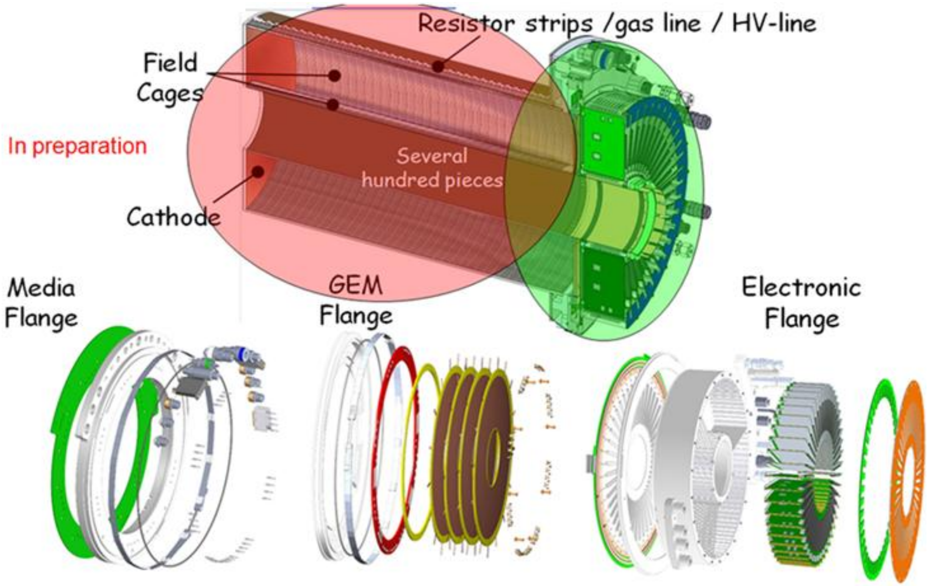
Muon-beam test at GIF/CERN



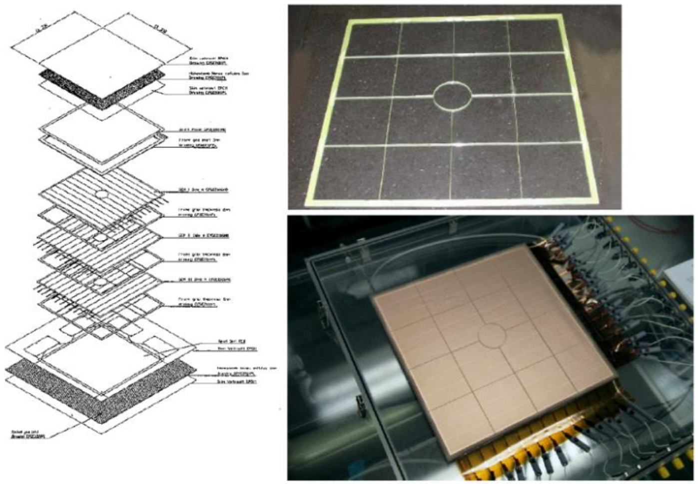
Time resolution ~ 5 ns

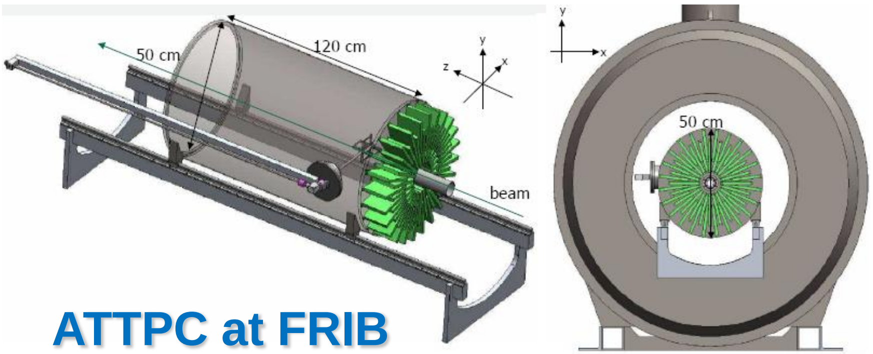


PANDA TPC: vertex tracker

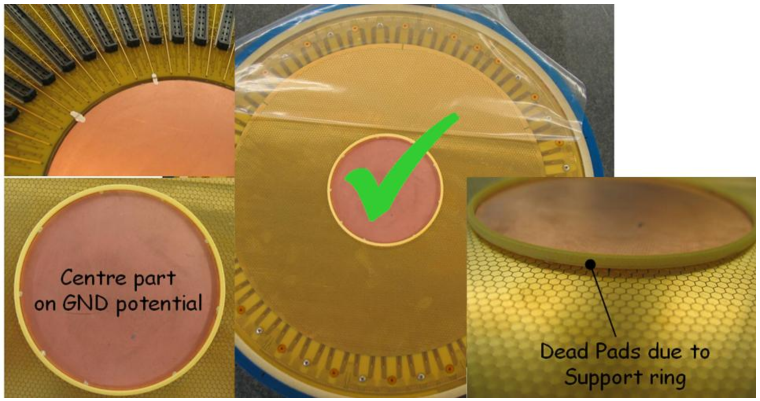


GEM trackers for COMPASS

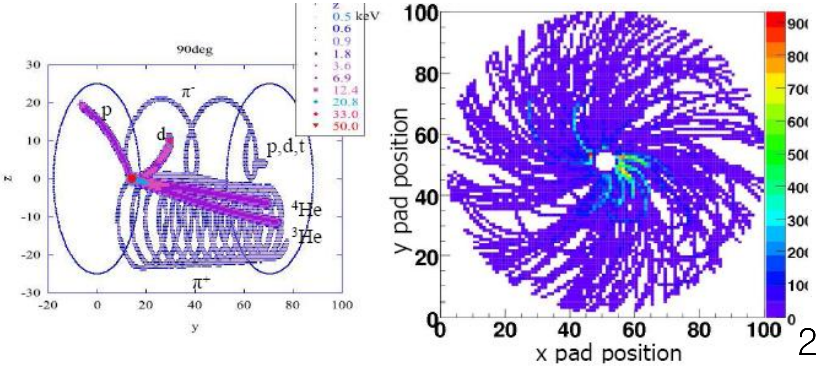




Hexagonal readout pads



ATTPC at FRIB



HIM, June 10, 2011

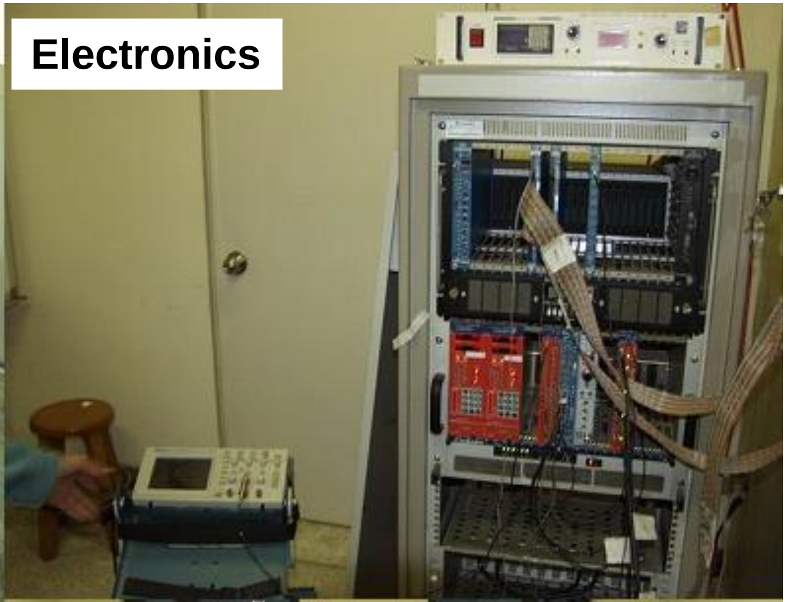
3. Collaboration for the Forward RPC upgrades

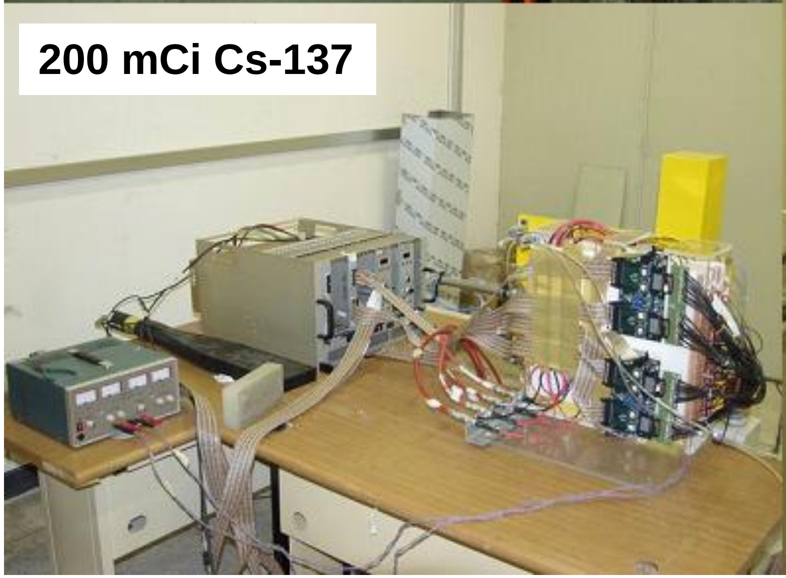
Korean Group :

1. **Production and the tests for RPCs gaps (Phase I)**
2. **Participation of the detector assem. for high η RPCs**

Will use the current detector production site and the facilities in Korea University (used for the previous production for the RE).

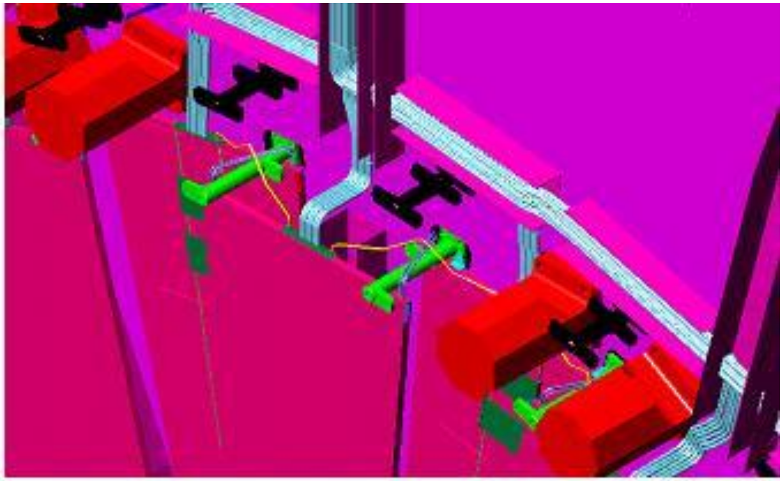
TEST facilities

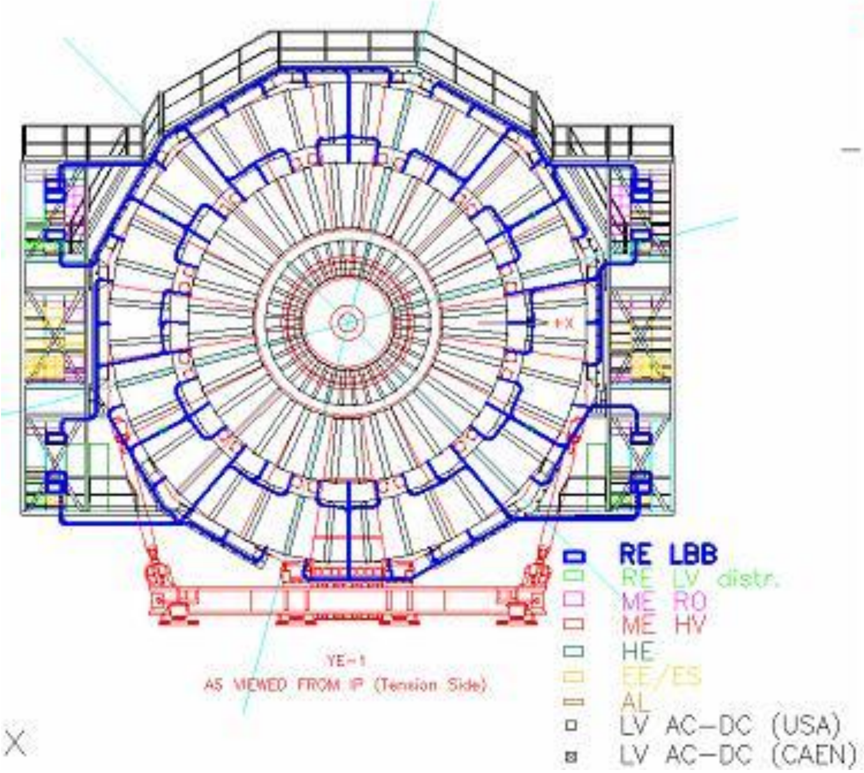


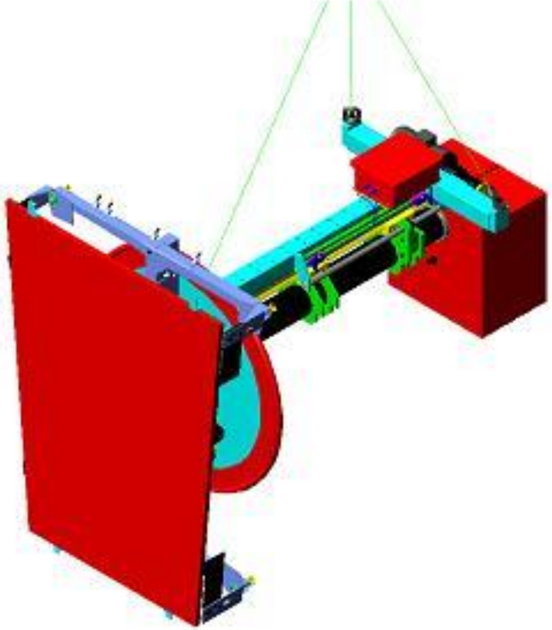


CERN Involvement

1. Project steering & coordination
2. Integration of the detectors
3. RPC assembly & test for the QA
4. Logistics
5. Finances
6. Installation & commissioning







Belgium Group (Vrije Univ. etc...)

- Design of the double-layered RE2
- Integration of the new FRPC 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

Italy (INFN + GT)

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

Facilities of assembly & test at NPD-Barc

4. Conclusions & Milestones

1) Upscope plans

► PHASE I (by mid of 2013) :

- RE4 station on YE3 in $\eta < 1.6 \Rightarrow$ RE4/2(72) and RE4/3(72)

► PHASE II (~ 2016 ?) :

- Construction and installation detectors in $1.6 < \eta < 2.1$
  RE1/1 (RPCs or GEMs), RE2/1 and RE3/1 (RPCs) in $1.6 < \eta < 2.1$

2) Detector production for PHASE I

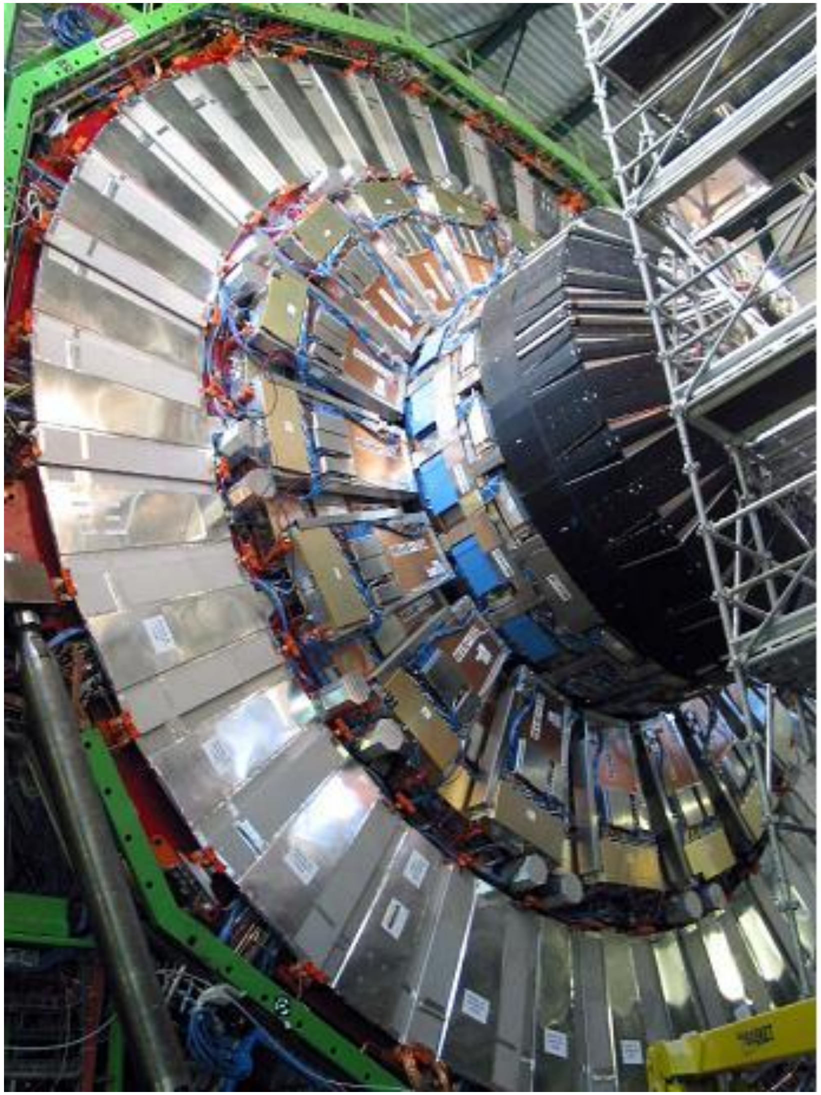
- Detailed designs for RE4 RPCs completed.
- First delivery of HPLs ~ July 2011 to detector production from Aug. 2011.
- Completion of gaps ~ July of 2012.
- Completion of RPC module ~ end of 2012.
- Installation ~ mid of 2013.

3) R&D for RE1/1 (in PHASE II): options are still in an open question

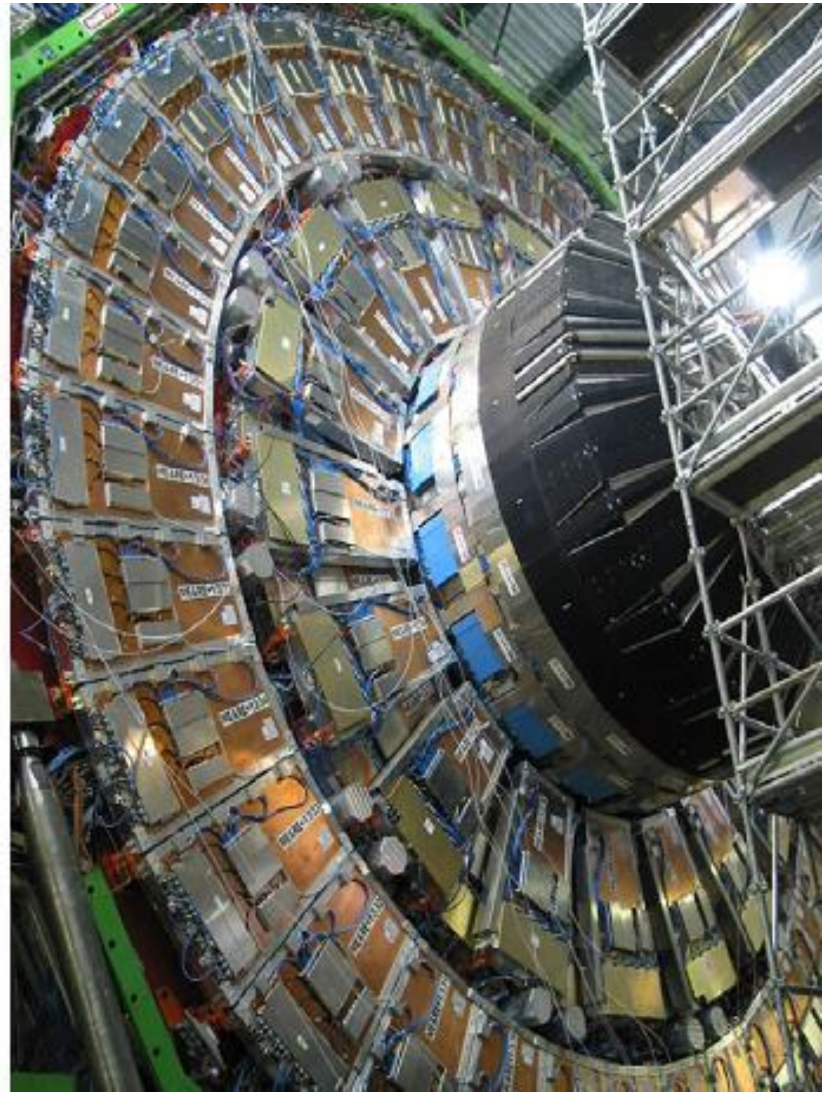
- Standard 2-gap RPCs (same as the other RPC trigger detectors)
- Multi-gap RPCs (need a new detector mass-production technology)
- GEM (triggering + tracking)

BACKUPS

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



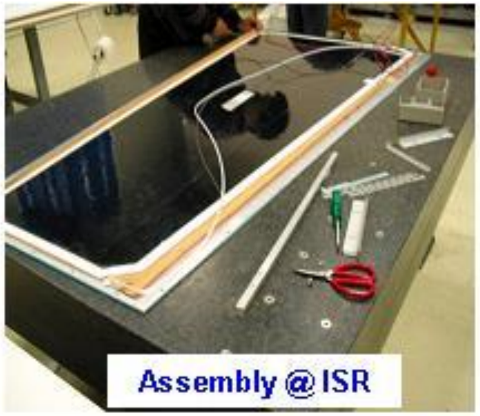
The ME1/3 CSC's now cover the RPC outer ring and hence complete the first muon station on YE+1.

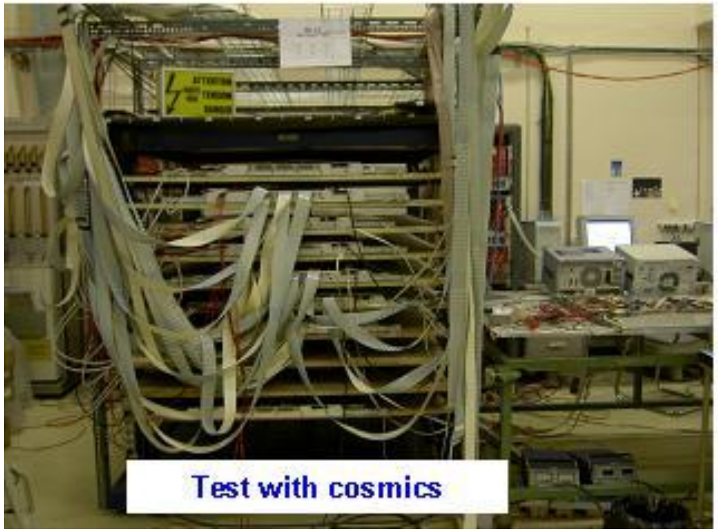


W. Vandoninck

At CERN

Cosmic tests for the new RPCs at the site in the ISR (used for the previous detector assembly and tests)





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.

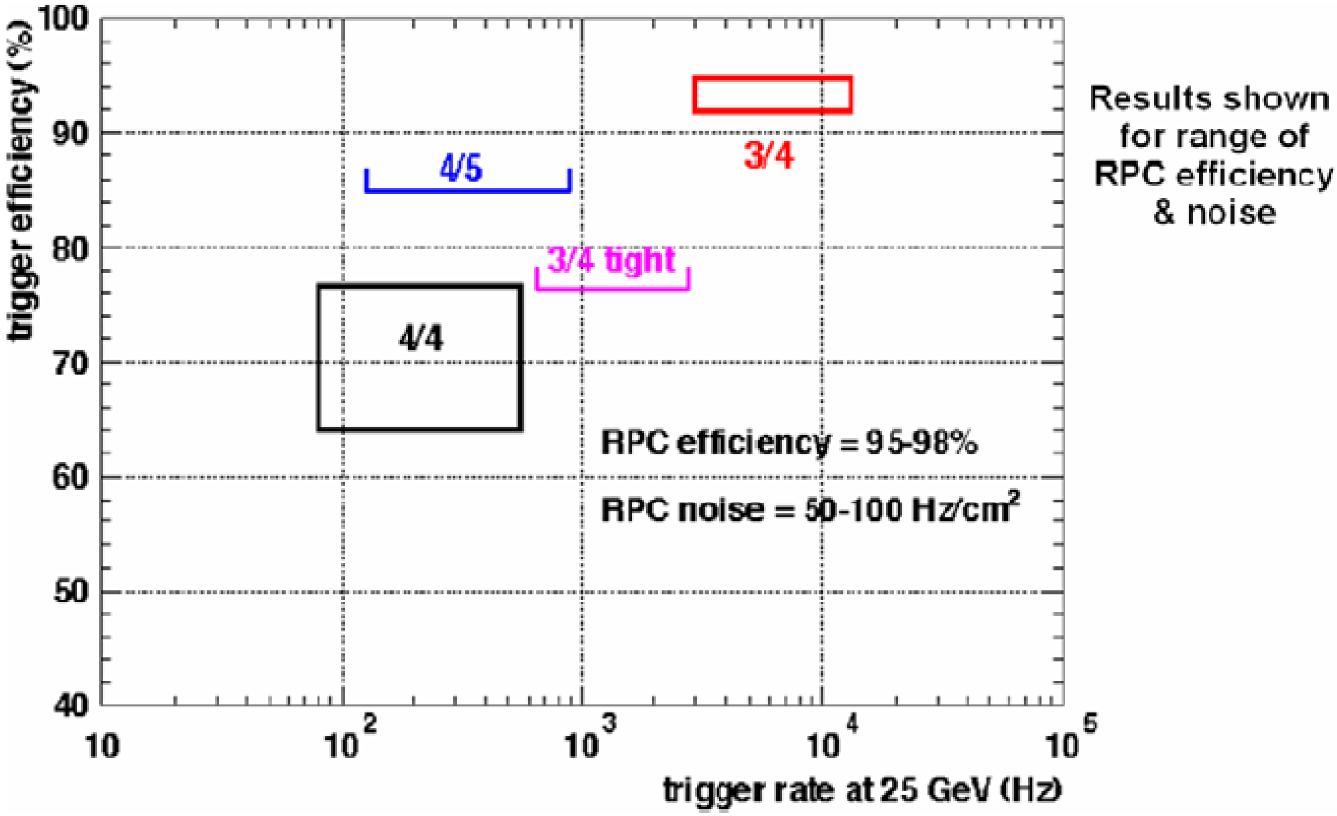
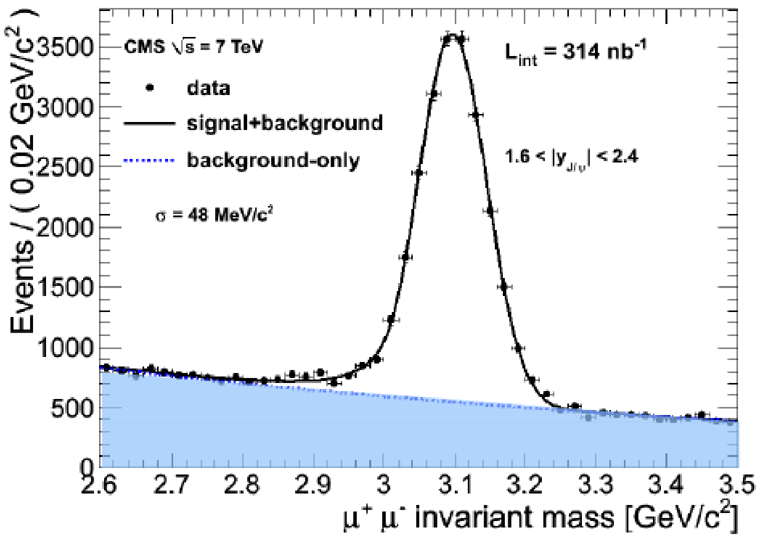


Figure 1.3: results of a simulation study on first level trigger performance of the RE system.

J/ψ in pp collisions



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

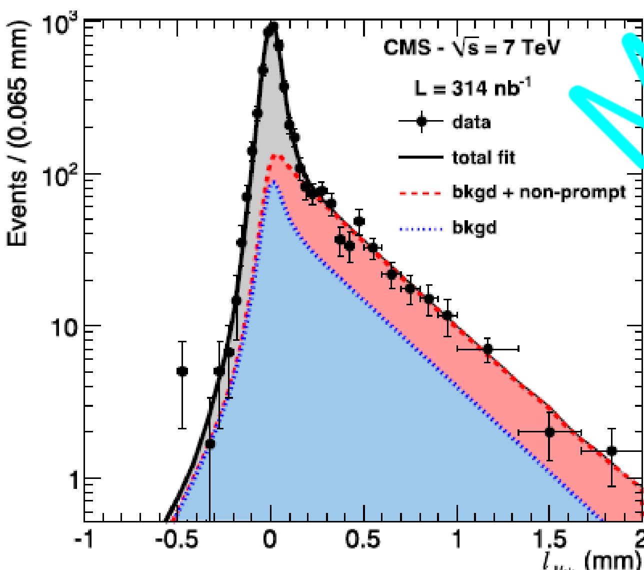
THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

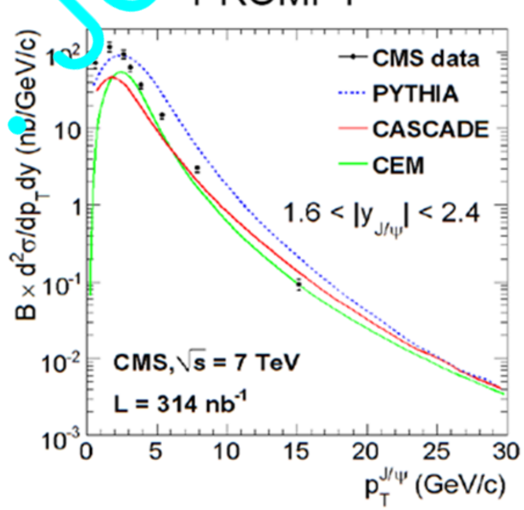
Prompt and non-prompt J/ψ production in pp collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration*

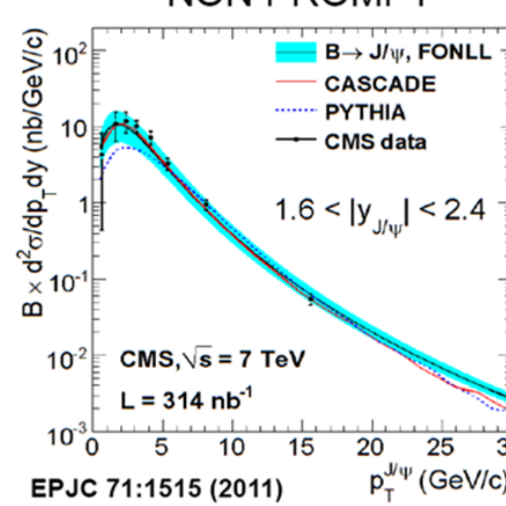
Received: 18 November 2010 / Revised: 10 January 2011 / Published online: 22 March 2011



PROMPT

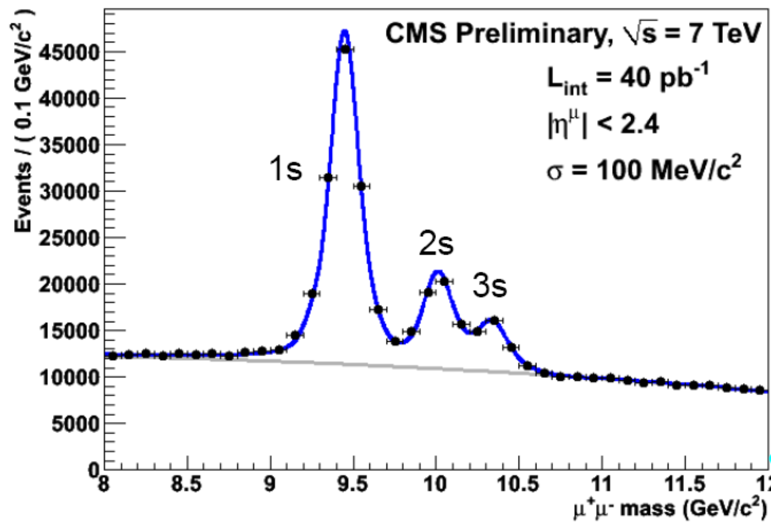


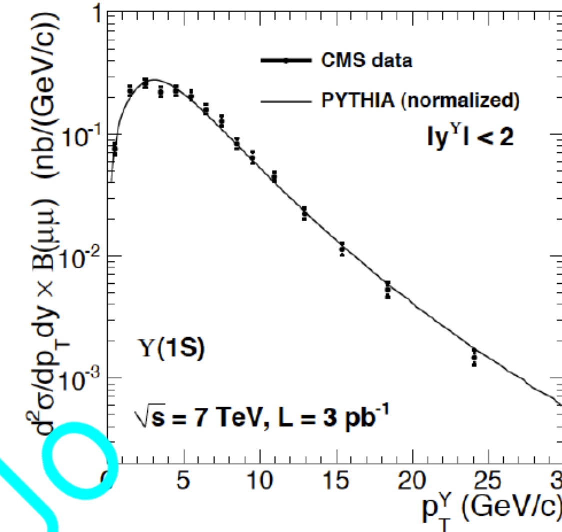
NON PROMPT



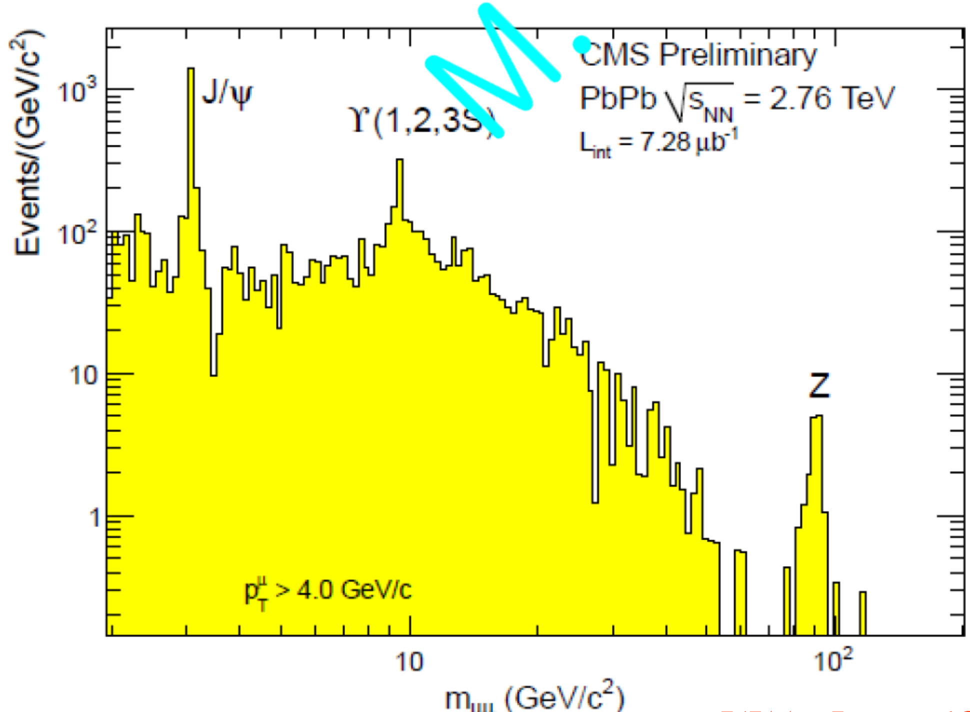
EPJC 71:1515 (2011)

ϒ in pp collisions



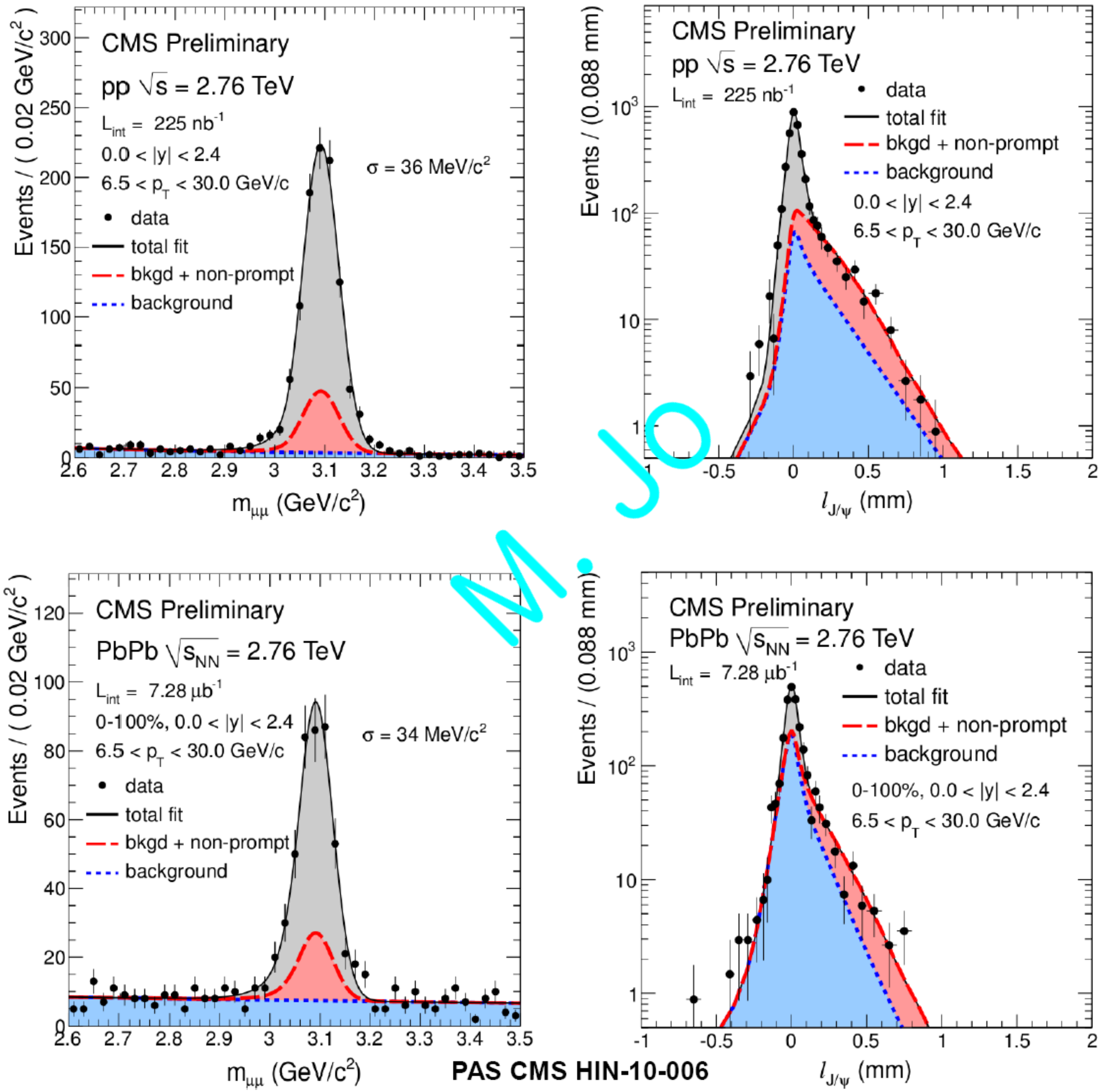


Dimuons in Pb-Pb Collisions



J/ψ in pp and Pb-Pb collisions

1 week run
at $\sqrt{s}$ = 2.76 TeV
in Mar 2011
Separate prompt
& non-prompt J/ψ



PAS CMS HIN-10-006

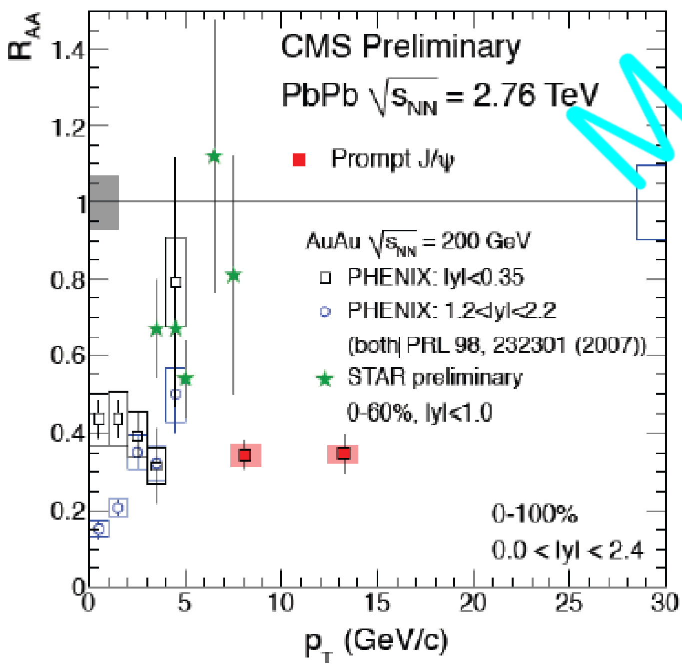
HIM, June 10, 2011

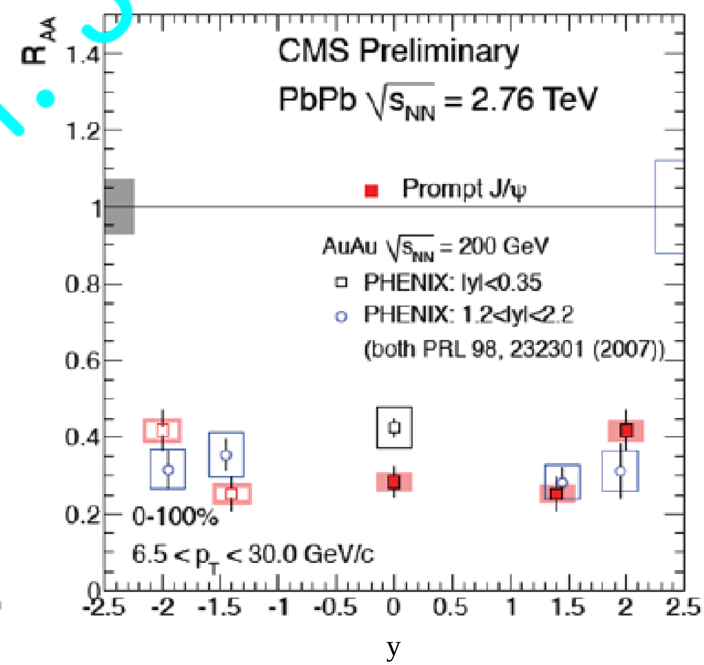
$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{\mathrm{MB}}} \frac{N_{\mathrm{PbPb}}(J/\psi)}{N_{pp}(J/\psi)} \frac{\varepsilon_{pp}}{\varepsilon_{\mathrm{PbPb}}(\mathrm{cent})}$$

Preliminary results for prompt dimuons

CMS $p_T > 3$ GeV/c
$R_{AA} = 0.39 \pm 0.06 \pm 0.03$
p_T=10 up to x_1~0.02(x_2~5.10^{-4})

ALICE low $p_T^{J/\psi}$
$R_{AA} = 0.49 \pm 0.03 \pm 0.11$
p_T=0 up to x_1~0.06(x_2~2.10^{-5})

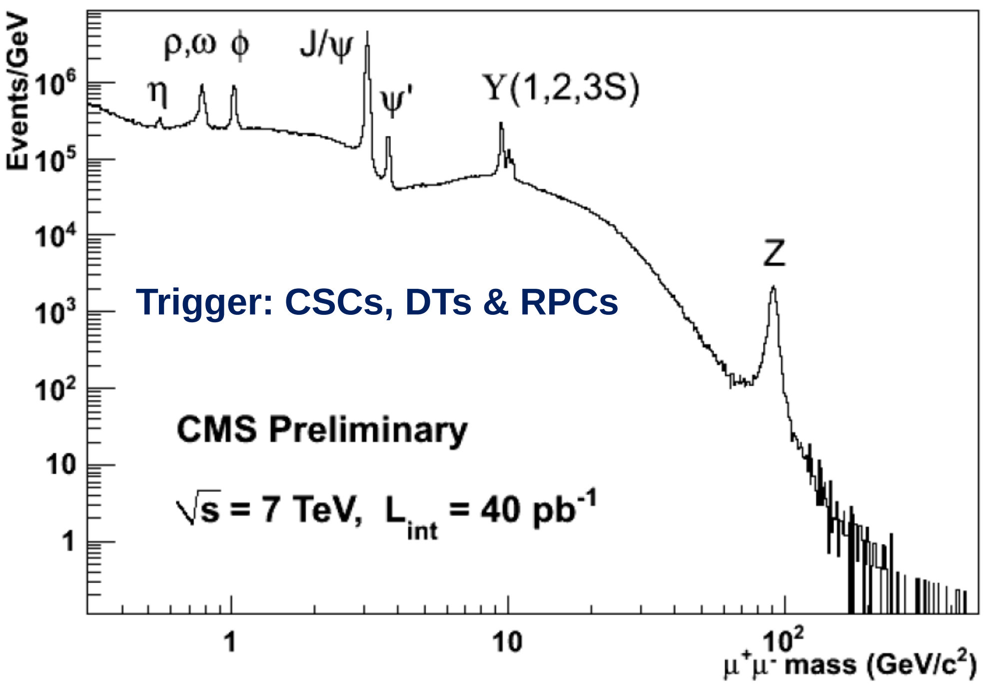




Quarkonia at CMS/LHC

Mass, BE, and radius

	J/ψ	χ_c	ψ (2s)	ϒ (1s)	ϒ (2s)	ϒ (3s)
M (GeV/c²)	3.10	3.53	3.69	9.46	10.0	10.36
ΔE (GeV)	0.64	0.20	0.05	1.10	0.54	0.20
r_0 (fm)	0.25	0.36	0.45	0.28	0.56	0.78



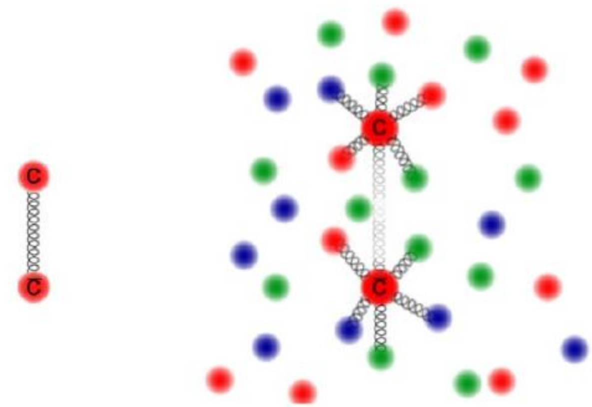
Proving QGP with pp and HI collisions

Debye screening: characterized by a debye radius λ_D where its eff. charge drops ~1/e.

In QGP > T_c, the screening suppresses formation J/ψ.

λ_D decreases as the T of the collision system.

cc−bar bound state with potential



$$V(r) = \kappa r - \frac{\alpha_{eff}}{r} \qquad V(r) = -\frac{\alpha\, e^{-r/\lambda_D}}{r}$$