UNIVERSITEIT GENT

FACULTY OF **SCIENCES**

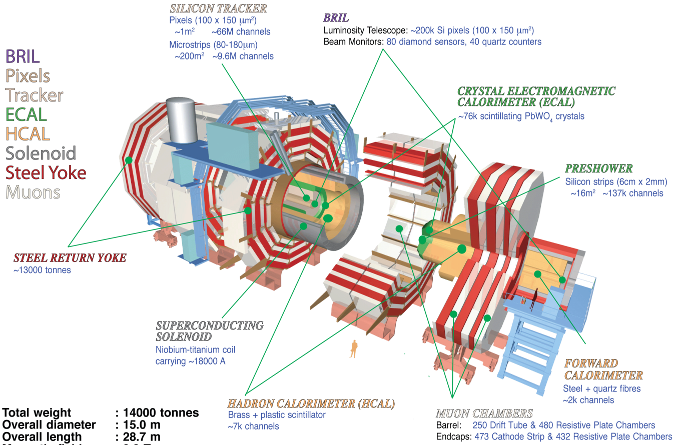
R&D towards future CMS RPC upgrades

Alexis Fagot

RPC 2016

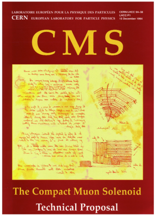
on behalf of the
CMS RPC Community

The Compact Muon Solenoid experiment



Total weight : **14000 tonnes**
Overall diameter : **15.0 m**
Overall length : **28.7 m**
Magnetic field : **3.8 T**

Muon system requirements[2]



CMS Technical Proposal (1994)[1]

The design goals of CMS were defined as follows:

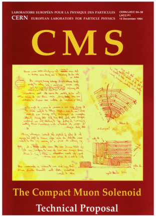
1) a very good and redundant muon system,
2) the best possible electromagnetic calorimeter (ECAL) consistent with 1),
3) a high quality central tracking to achieve 1) and 2),
4) a financially affordable detector.

In October 1992 a Letter of Intent signed by 443 members from 62 institutes was submitted to the LHC Committee (LHCC) [3]. The proposed muon system consisted of four muon stations and allowed three measurements of the muon momentum: inside the tracking volume, after the coil and in the flux return. These almost independent measurements make the muon identification very robust. The two measurements outside the coil are guaranteed at any luminosity.

Goals: Muon identification, muon trigger and (signed) muon p_T measurement

- **muon identification:** 16λ of material without acceptance losses
- **muon trigger:** combination of precise muon chambers (fast electronics) and fast dedicated trigger detectors provide unambiguous bx identification with sharp p_T thresholds
- **stand-alone muon p_T resolution:** $\Delta p_T/p_T$ = 8-15% at $10\ \mathrm{GeV/c}$ & 20-40% at $1\ \mathrm{TeV/c}$
- **global muon p_T resolution:** $\Delta p_T/p_T$ = 1-1.5% at $10\ \mathrm{GeV/c}$ up to 6-17% at $1\ \mathrm{TeV/c}$ *(matching track at <1 mm in bending plane (& <10 mm non-bending) at $1\ \mathrm{TeV/c}$)*
- **charge assignment:** 99% correct up to $1\ \mathrm{TeV/c}$
- **capability of withstanding high radiation background**

Muon system requirements[2]



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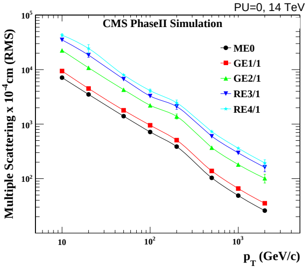
- **global muon p_T resolution:** $\Delta p_T/p_T$ = 1-1.5% at $10\ \mathrm{GeV/c}$ up to 6-17% at $1\ \mathrm{TeV/c}$ *(matching track at $<1\ \mathrm{mm}$ in bending plane (& $<10\ \mathrm{mm}$ non-bending) at $1\ \mathrm{TeV/c}$)*
- **Run-1:** $\Delta p_T/p_T$ = 1.3-2.0% (barrel) and < 6% (endcap) for $20 < p_T < 100\ \mathrm{GeV/c}$
- **Run-1:** $\Delta p_T/p_T$ < 10% (barrel) for $p_T < 1\ \mathrm{TeV/c}$ muons

Spatial resolution of muon detectors[2]

CMS Muon Technical Design Report(1997)[3]

4.1.2.2 Off-line spatial resolution: φ-coordinate

Detailed Monte Carlo studies have been performed to identify the required CSC spatial resolution [4.4]. The optimization was done by requiring that the chamber spatial resolution contribution to the precision of muon momentum measurement (standalone muon system) be less or comparable to the contribution of multiple scattering. Muons with p_T<100 GeV were chosen as a reference since this range of momenta covers most of the plausible physics



Spatial resolution determined by MS

- $\sigma_{det} \ll$ MS limit (max 15% det.)

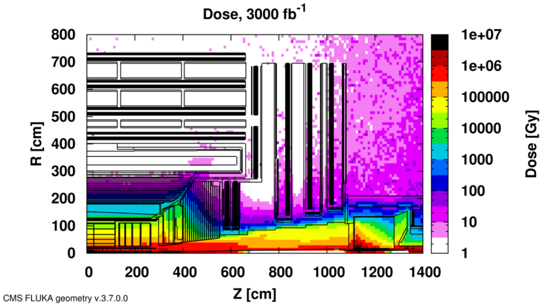
DT: 100 μm ($r-\varphi$) and 150 μm ($r-z$)

CSC: 75 μm (ME1/1 & ME1/2) and 150 μm

RPC: Correct BX-id is more important $\Rightarrow$ resolution of $\mathcal{O}$(1 cm)

- Spatial resolution ≈ MS (for a 100 GeV/c muon) gives deterioration of $\sqrt{2} = 40\%$

Background rates and dose during High Luminosity LHC



Overview[4][5]

- FLUKA simulations → mean rate around $0.5\ \mathrm{kHz/cm^2}$ in RE3/1
- At $0.5\ \mathrm{kHz/cm^2}$ and $\langle q \rangle$/avalanche of $20\ \mathrm{pC}$, integrated charge reach $\sim 0.6\ \mathrm{C/cm^2}$

→ Including safety factor 3, rate capability around $2\ \mathrm{kHz/cm^2}$ required

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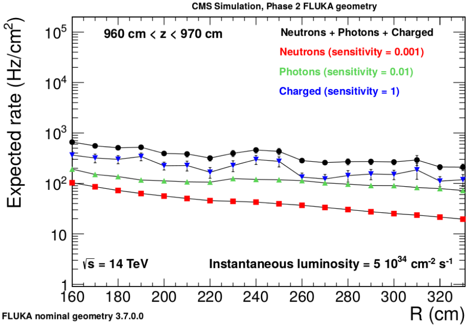

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- Reduced voltage drop on the electrode plates
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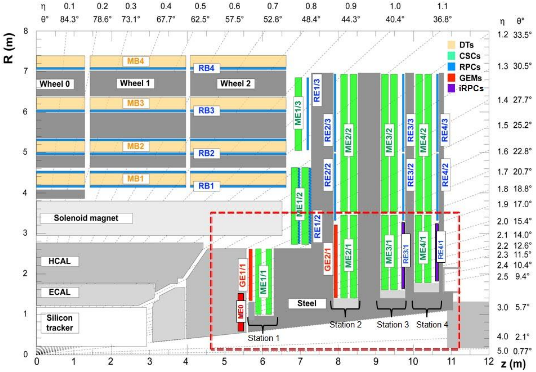
... changing the detector configuration

- Change the electrode thickness
- Change the number of electrodes
- Increase the ratio of the induced signal to the moving charge in the gap

Forward RPC detectors RE3/1 and RE4/1



Detector overview [4]

- Complement existing ME3/1 and ME4/1 CSC stations → improvement of the L1 muon trigger

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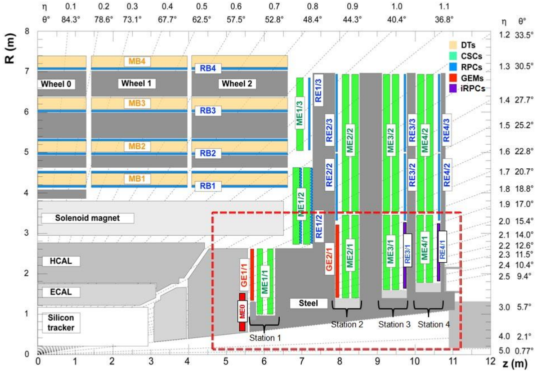

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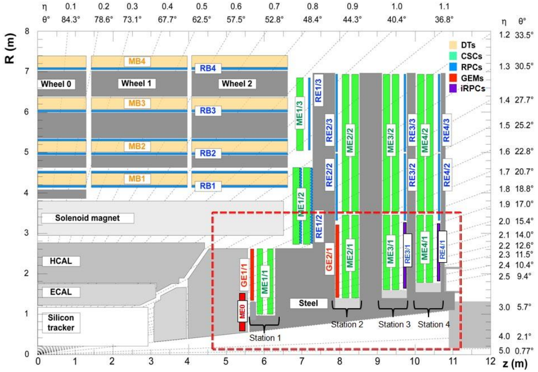

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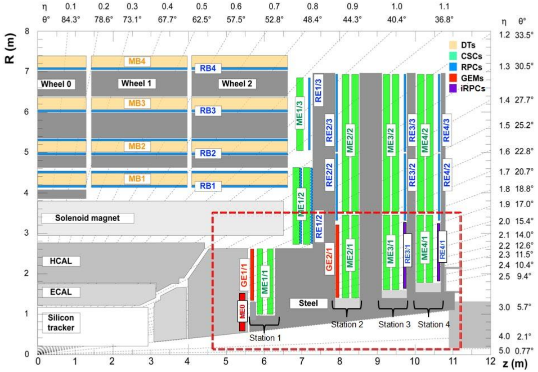

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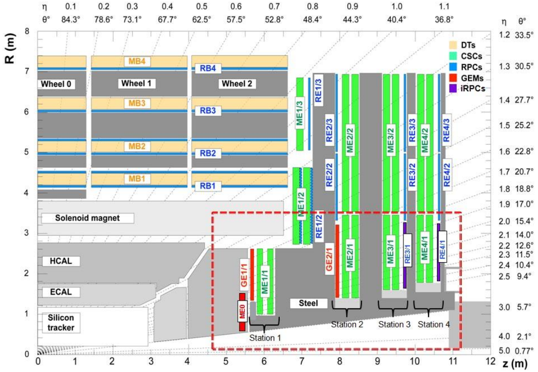

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- 192 read-out strips per η-partitions
- Pitch ranging from 0.30 to 0.62 cm (present endcap RPCs: 1.30 to 3.93 cm) → improvement of the spatial resolution

1. Forward RPC technologies under study
2. Forward RPC on-chamber electronics
3. Forward RPC R&D certification
4. Conclusion

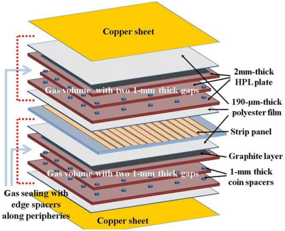
Low resistivity electrodes

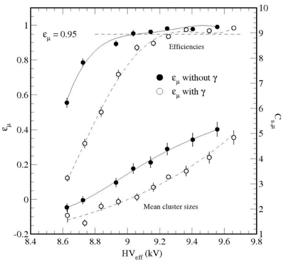
Electrode material	$\rho(\ \Omega\mathrm{cm})$	Institutes
HPL	$0.5 - 1 \times 10^{10}$	INFN
LRS glass	10^{10}	IPNL-LLR-Tsinghua[7][8]
Vanadate glass	10^{4} to 10^{16}	Coe College-ANL-University of Iowa[9]
SiC based ceramics	10^{7} to 10^{12}	HZDR[10]
Ferrite ceramics	10^{6} to 10^{13}	CSIC-USC[11]

Key points

- High-Pressure Laminate is already industrially produced (lower cost, bigger surfaces)
- Glass and ceramics can achieve lower resistivity values than Bakelite
- Glass and ceramics have very smooth surfaces providing very consistent electric fields

Changes to the RPC detector configuration

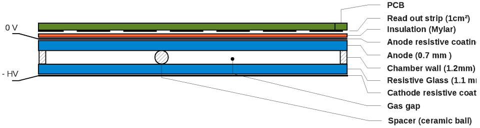


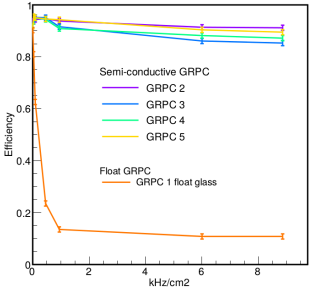


Multi-gap HPL[12]

- Modified standard bi-gap configuration using 2 double-gaps
- Thickness of the four gaps is $0.8\ \mathrm{mm}$
- Same electrodes and front-end electronics as standard CMS chambers
- Efficiency for cosmic muons vs. operating voltage (with and without irradiation via ^{137}Cs γ-ray source)

Changes to the RPC detector configuration





Single and Multi-gap glass RPCs[7][8]

- Tests performed with a rate capability exceeding $10\ \mathrm{kHz/cm^2}$
- Time resolution better than $100\ \mathrm{ps}$ for a multi-gap configuration

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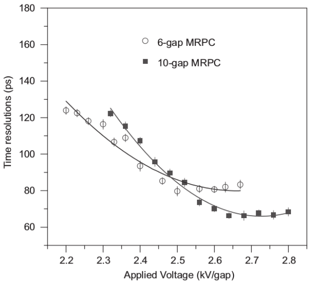

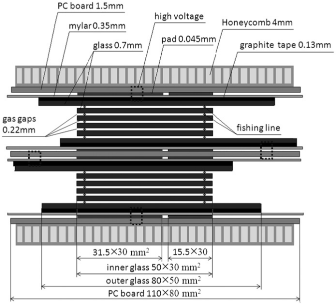

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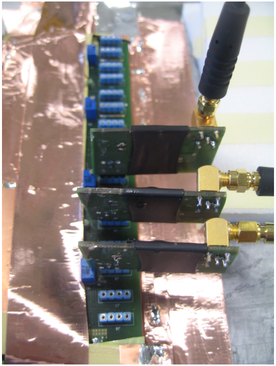
High-amplification electronics



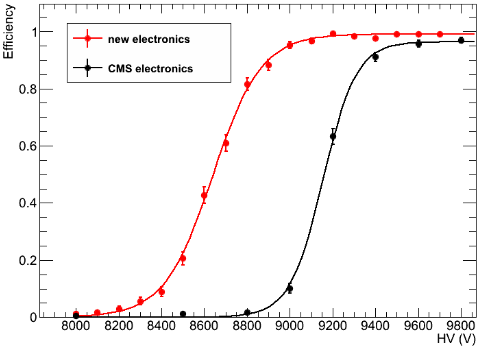
INFN SiGe low noise preamplifier[4]

- **Number of channel:** 3×1

→ new batch to cover full η-partition + gRPC prototype arriving

- **ASIC:** current CMS ASIC scheme
- **Preamplifier sensitivity:** $11\ \mathrm{mV/fC}$
- **Low offset discriminators:** autotrig down to $4\ \mathrm{fC}$
- **Power consumption:** $2\ \mathrm{mW/channel}$
- **Technology:** BJT transistor using SiGe

High-amplification electronics



INFN SiGe low noise preamplifier[4]

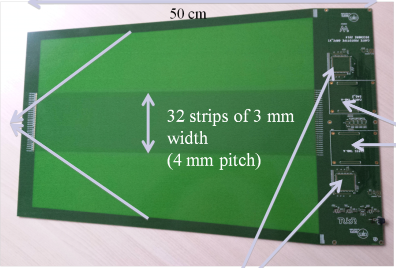
- Developed in the framework of the muon system upgrade of the ATLAS experiment
- Performance comparison of CMS chambers with standard CMS electronics and an early prototype

→ Shift of about 460 V in the efficiency curves

→ Average charge for 90% efficiency is reduced from 20 pC to about 3 pC

High-amplification electronics

We conceived and produced a PCB to host : Pickup strips, 2 PETIROC, 2 TDC



Return strips outside the detector

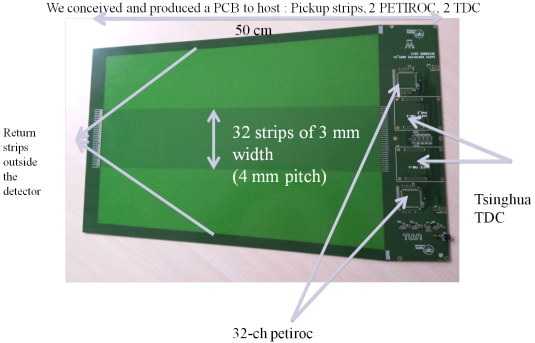
Tsinghua TDC

32-ch petiroc

PET TIme-of-flight Read-Out Chip[13]

- **ASIC:** 16 channels - SiGe
- **Fast low impedance preamplifier:** variable gain (8 bits/channel)
- **Semi-digital readout:** 3 thresholds
- **Low offset discriminators:** autotrig down to 10 fC up to 10 pC
- **Power consumption:** 1 μW/DAQ

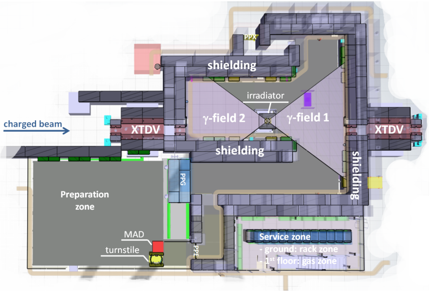
High-amplification electronics



PET TIme-of-flight Read-Out Chip[13]

- Front-end electronics originally designed for time-of-flight measurements to readout silicon photomultipliers (SiPMs)
- Combines a very fast and low-jitter trigger with an accurate charge measurement
- Has already been used for testing glass RPCs
- Interface to the CMS DAQ chain is under investigation

Forward RPC R&D certification



The Gamma Irradiation Facility (GIF++)

- Performance tests with high radiation background
- Longevity tests on CMS present muon system detectors and new R&D efforts
- Irradiation for ∼ 17 months with an acceleration factor 2

Life-time could depend on

- The integrated charge
- The long-term operation of RPCs with a fluoride-rich gas (HF production[14])
- The material and component degradation

→ The first results will be presented during S. Carrillo's talk (4:50pm 25/02)

Outlooks

- The RPC community is moving forward into conceiving and testing new RPC prototypes using different electrode materials, geometries or electronics.
- A worldwide effort is put into making new specific electrode materials for RPCs as examples mentioned *(this workshop is a chance to have status report from the research teams).*
- The final technique adopted may combine the benefits of the different approaches.
- Although, it is needed to urgently address the issue of the installation of REX-1 in LS3.
- Moreover, we need to test several options for the electronics and to establish contact with CMS electronics and trigger groups.
- The first GIF++ test beam results are appearing.

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