Physics Studies for the CMS Muon System Upgrade with Triple-GEM detectors

PSD10: 10th International Conference on Position Sensitive Detectors,
7-12 September 2014, University of Surrey, London (UK)

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Outline

- **Introduction**
  - CMS Muon System
  - CMS Muon Trigger performance
  - Physics motivations
- **The GEM Project**
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  - Detector prototype development and tests
  - Integration into CMS
- **Impact on the Muon trigger**
- **Summary & Conclusions**

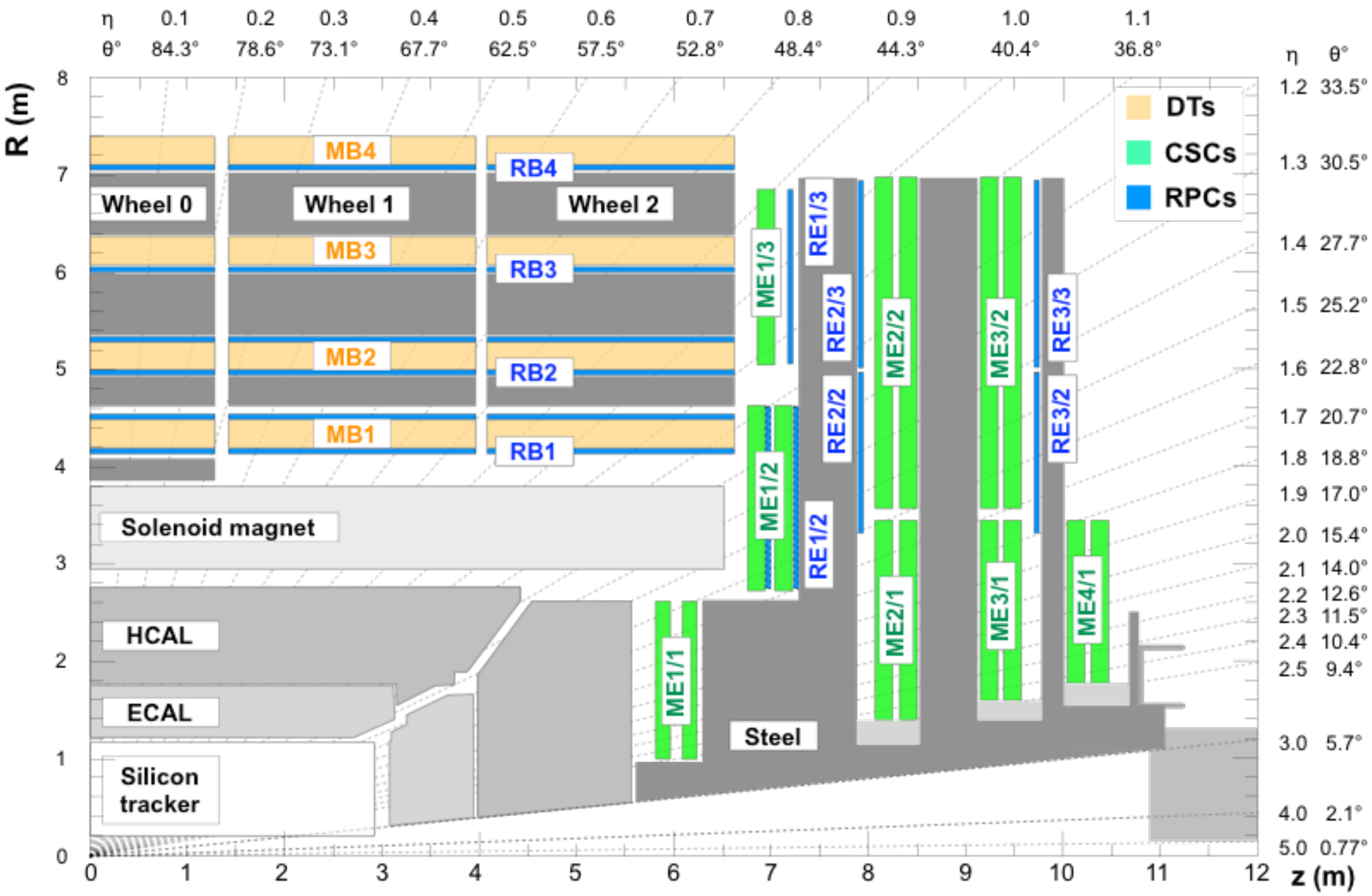
The CMS Muon System

3 technologies:

- Drift Tubes and Cathode Strip Chambers (for tracking and triggering)
- Resistive Plate Chambers (for triggering)

Goals:

- Robust, redundant and fast identification of the muons traversing the system
- Trigger capabilities and momentum measurement



Eta coverage:
|η| < 1.6: 4 layers of CSCs and RPCs
(ME4/2 and RE4 being installed during LS1)
|η| ≥ 1.6: CSCs only

New technology needed for **|η| > 1.6** region of muon system

- Present CMS RPC design not suitable for high rate environment
- Sustain O(MHz/cm²) environment
- Need for good spatial resolution O(100μm): muon tracking
- Need for good time resolution: muon triggering

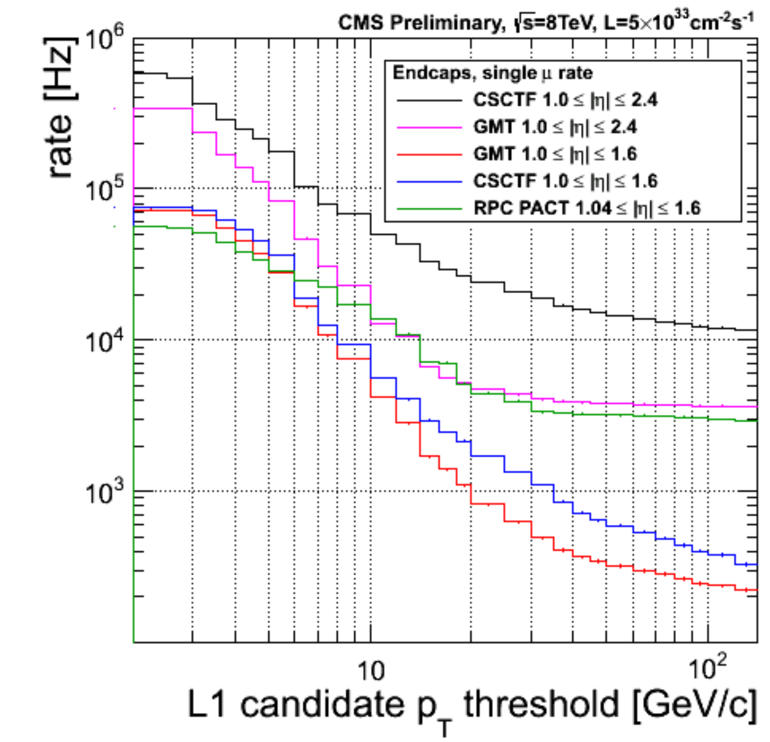
Muon Trigger Performance

Forward region trigger relies entirely on the CSC system (4 ME stations)

- Muon momentum from stub positions:

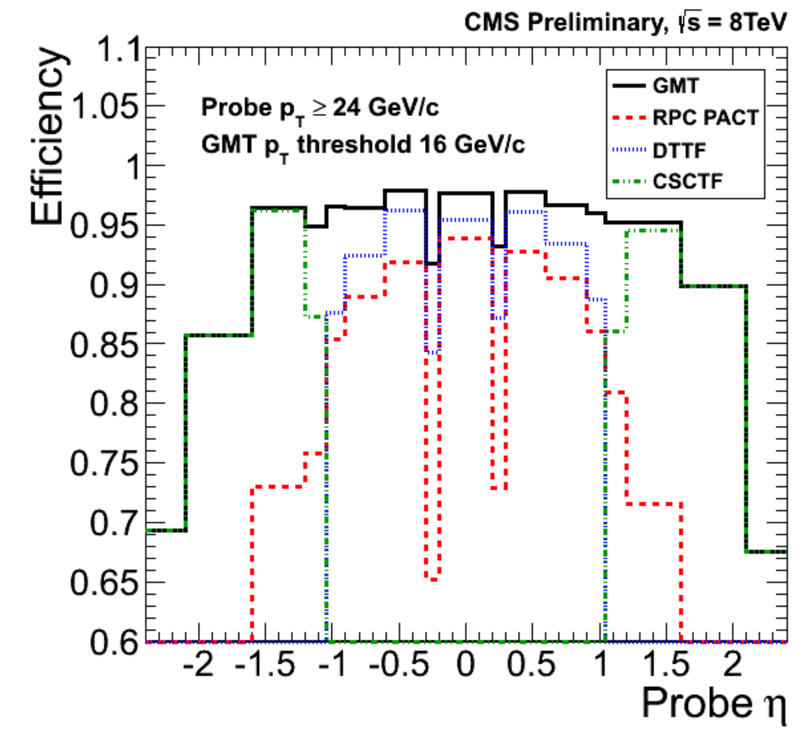
$$\Delta\Phi XY = \Phi(ME\text{-}X) - \Phi(ME\text{-}Y)$$

- Measurement driven by internal chambers (ME1/1, ME2/1): least scattering and strong B field
- Resolution using outer stations is quite coarse (not enough bending)



Muon trigger issues

- High background rates in forward region: trigger rate is dominated by junk muons reconstructed as high pT muons (multiple scattering of soft muons in the iron yoke flattens the trigger rate curve)
- Muon trigger stub losses drive inefficiency
  - Dead electronics, spaces between chambers, but also algorithmic losses
  - Especially undesirable in station ME1/1, which is key for momentum resolution



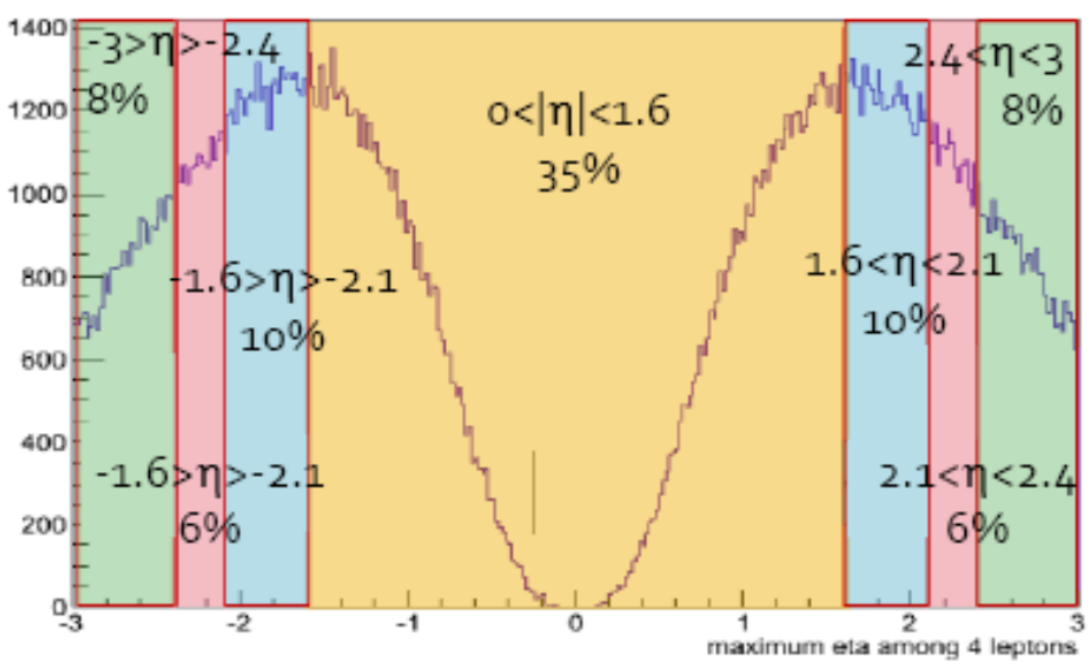
Physics motivations

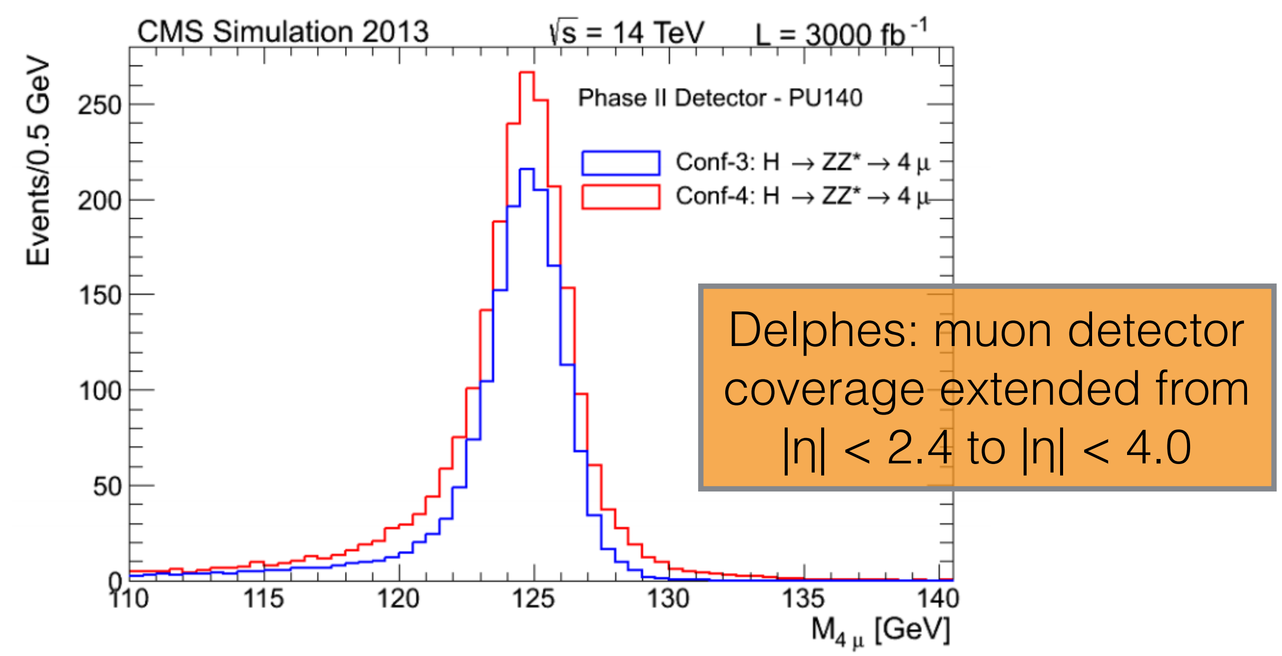
Muon system is **critical** for both **bosonic** and **fermionic couplings**:

- H → WW and ZZ are key to the precision measurement of H → VV couplings. In particular:

  H → ZZ → 4μ:

  - 20% of signal events falls in the eta region from 1.6 to 2.1 and can benefit from the improved muon detection
  - Gain up to 40% in signal selection efficiency with extension up to |η| = 4
- H → ττ is key for measuring fermion couplings H → ff
  - μ + τ_{had} is the most sensitive channel, fully relies on muon trigger
  - Fast falling muon momentum spectrum: requires an efficient muon trigger





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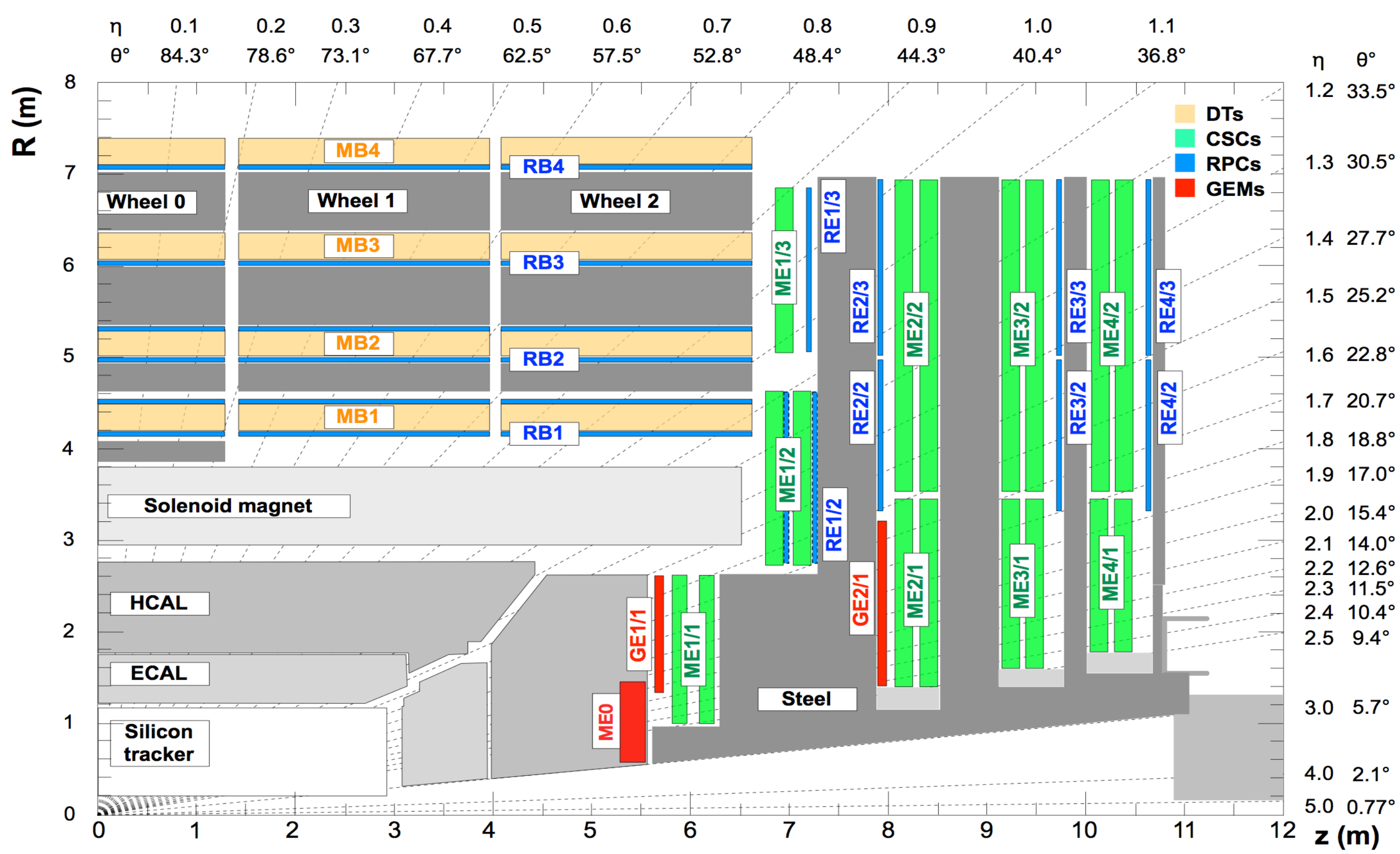
The GEM Project

The GEM Project

- Restore redundancy in muon system for robust tracking and triggering
- Improve L1 and HLT muon momentum resolution to reduce or maintain global muon trigger rate up to $|\eta| = 2.4$
- Ensure maximum trigger efficiency in high PU environment
- Increase offline muon identification coverage up to $|\eta| = 3$ (calorimeter limit)

Install two layers (super-chambers) of triple-GEM (**GE 1/1 & GE 2/1**) chambers in the presently vacant positions in front ME1/1 (after LS2) and ME2/1 (after LS3), and a 6-layers of triple-GEM (**ME0**) near-tagger behind the future shortened hadron calorimeter (after LS3)



GEM features:
Rate capability: 10^5Hz/cm^2
Spatial/Time resolution: ~ 100 μm / ~ 4-5 ns
Efficiency: > 98%
Typical Gas gain: >10^4

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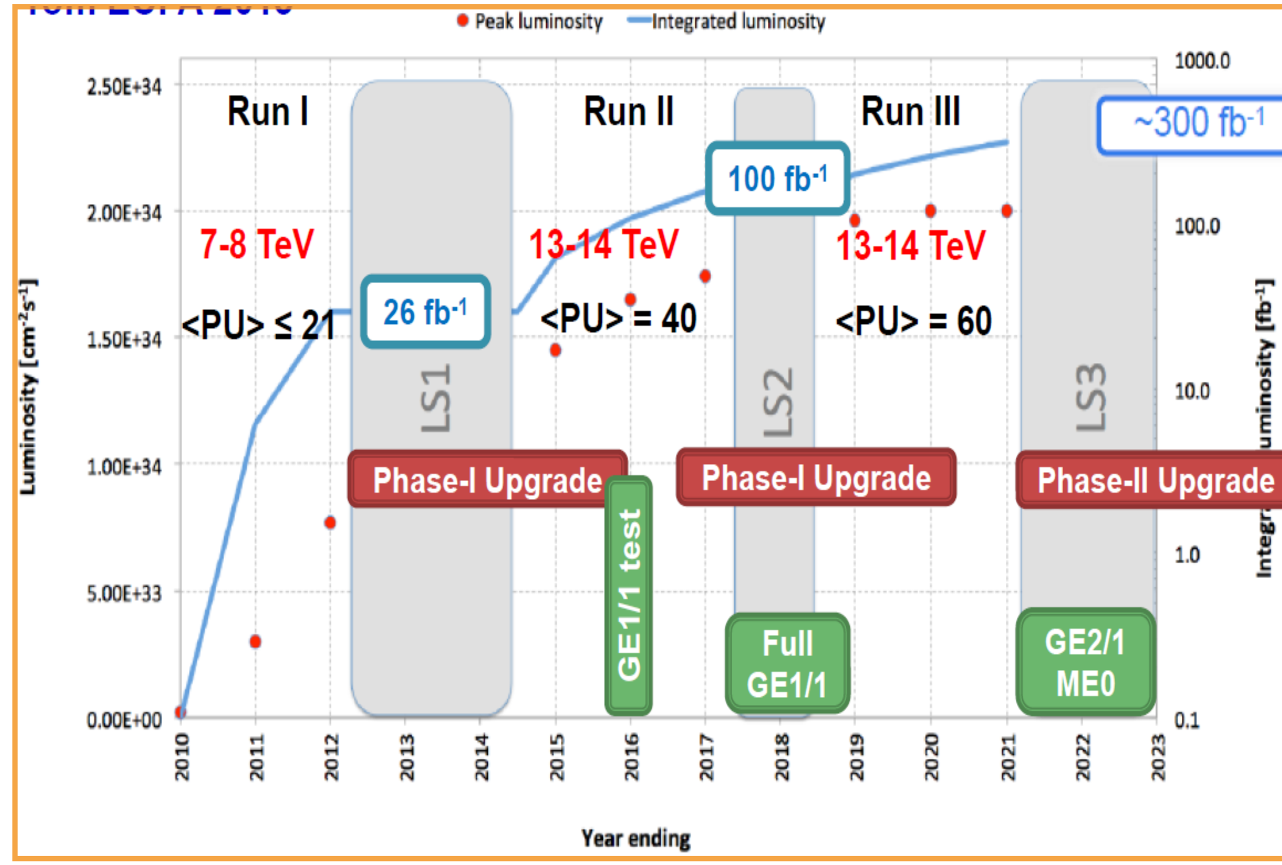
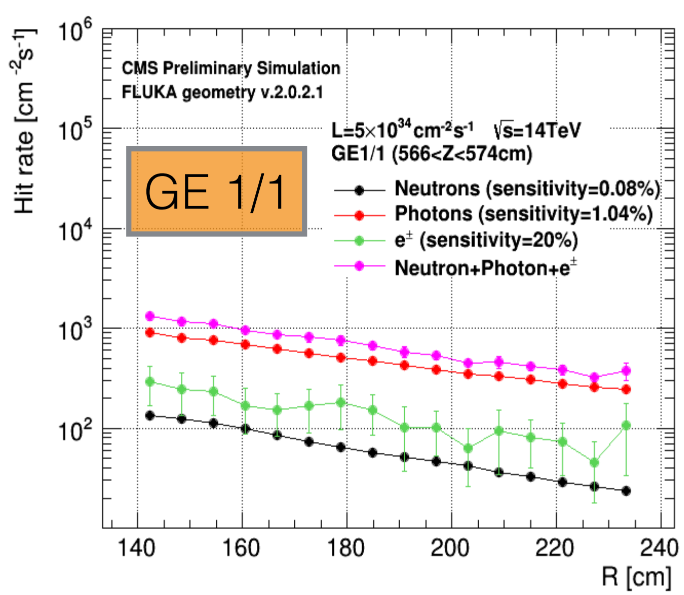
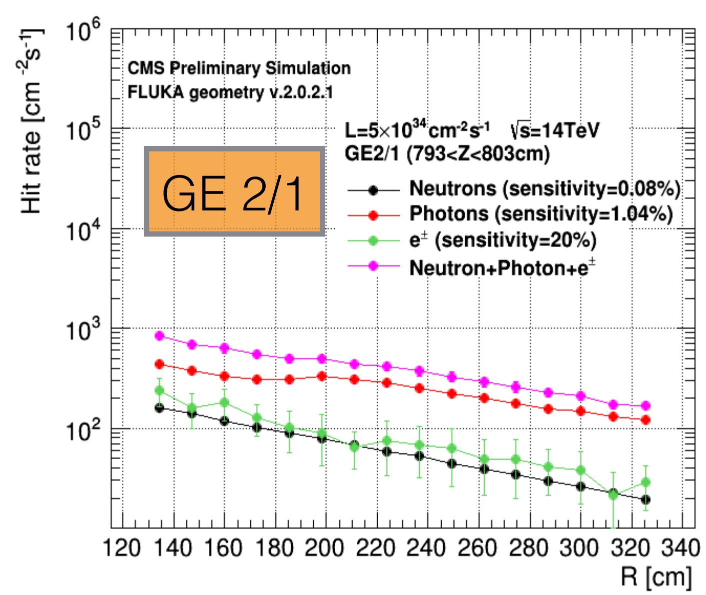
LHC and detector evolution

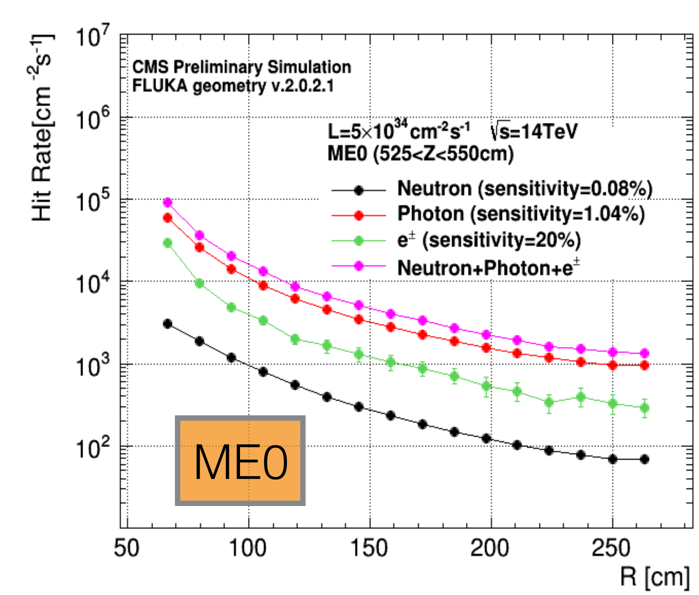
Background (from FLUKA + GEANT4):

- Hadronic interactions lead to activation of materials and give rise to neutron backgrounds
- Long living neutrons can interact with nuclei and produce photons which further decay to electrons/positrons with some possibility to generate fake signals
- Background rates expected in each chamber normalized to 5×10^{34} Hz/cm^2





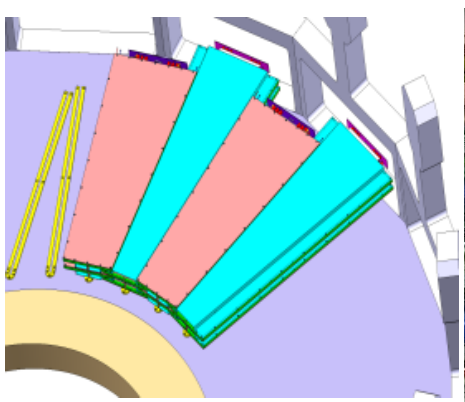




The GEM Project

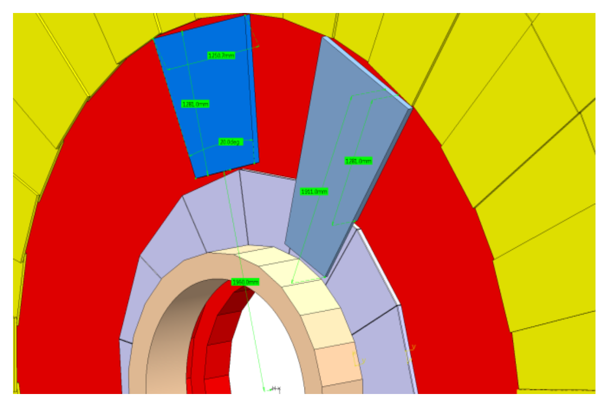
GE1/1: baseline detector for GEM project

- $1.55 < |\eta| < 2.18$
- 36 staggered super chambers, super-chamber (2 layers), each chamber spans 10°
- Several prototype designs with different number of eta partitions
- Short and long super chambers for maximum coverage in pseudo-rapidity



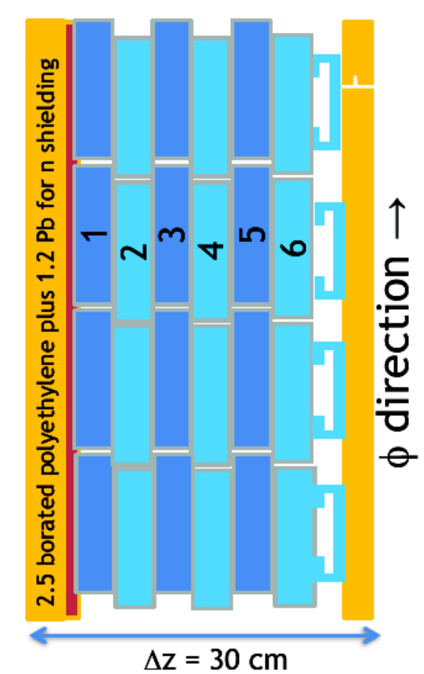
GE2/1: station 2 upgrade

- 1.6 < |eta| < 2.49 - Chambers spanning 20°
- Looking into possibility of installing 2 rings of two layers of triple GEMs (1 ring with short, 1 ring with long super chambers)



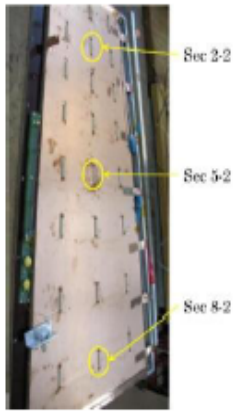
ME0: near-tagger to be installed behind new HCal

- 6-layers of triple-GEM detectors
- $2.0 < |\eta| < 3.0$ - 20° chambers
- Additional 6 points of measurements extending in high eta (for neutron background rejection): R&D on-going



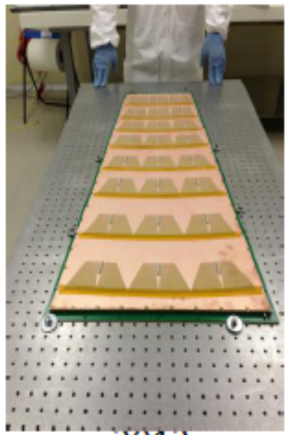
Large GEM prototype evolution


2010



2011


2012


2013


2013/14

GENERATION VI
Latest version currently compliant with CMS

GENERATION I
The first 1m-class detector ever built but still with spacer ribs and only 8 sectors.

Ref: 2010 IEEE
(Also RD51-Note-2010-005)

GENERATION II
The first large detector with 24 readout sectors (3x8) and 3/1/2/1 gaps but still with spacers and al glued.

Ref: 2011 IEEE
(Also RD51-Note-2011-013)

GENERATION III
The first large detector without spacers, but with outer frame still glued to drift

Ref: 2012 IEEE

GENERATION IV
The first large detector evolved from previous generation without spacers and any glue.

Ref: 2013 IEEE2013

GENERATION V
Tuned version of CMS detector, to be produced in two versions (long and short)

The CMS GEM collaboration has undertaken a 5-year long R&D process:

- Test of performance on small prototypes
- Development of 6 generations of large-area GEM prototypes
- Intense prototype testing on bench top and in beam tests

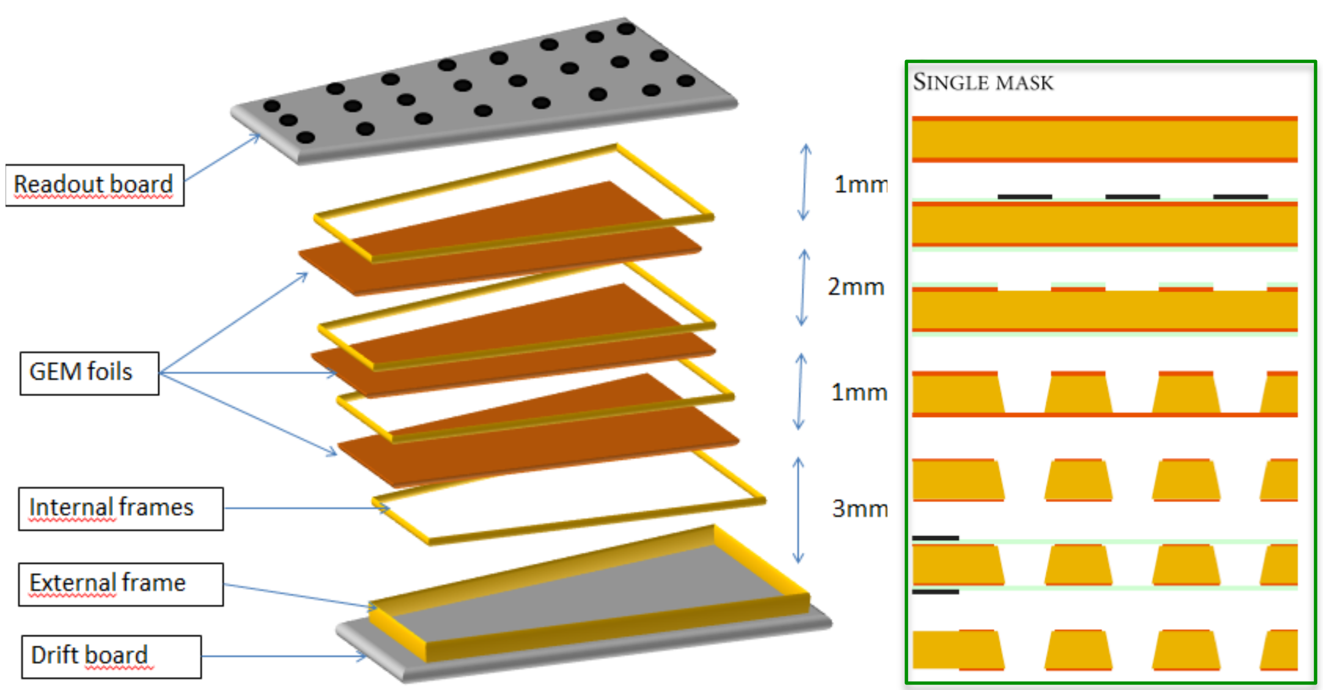
GE1/1 detector layout

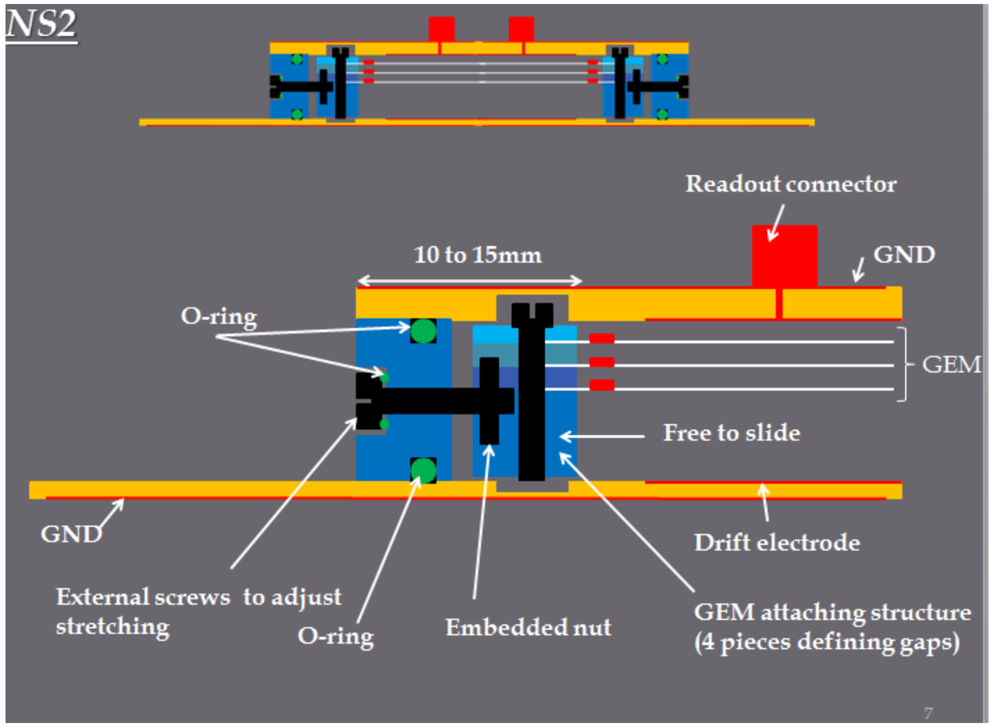
Main detector layout features:

- Single-mask
- Gap sizes: 3/1/2/1 mm
- Sectors : 3 columns x (8-10) η partitions
- Strip pitch: 0.6-1.2mm (trapezoidal chambers)
- 1D readout with 384 channels

Self-stretching assemply (**NS2**):

- Tightening the horizontal screws tensions the GEMs & seals gas volume
- Allows re-opening of assembled detector for repairs if needed
- Assembly time reduced (2 hours)



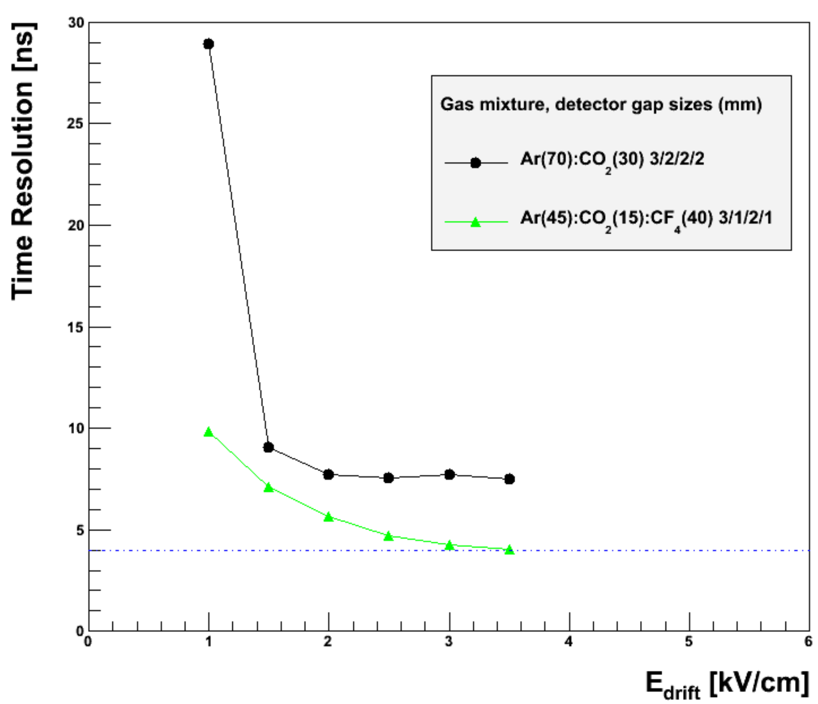


GEM project achievements

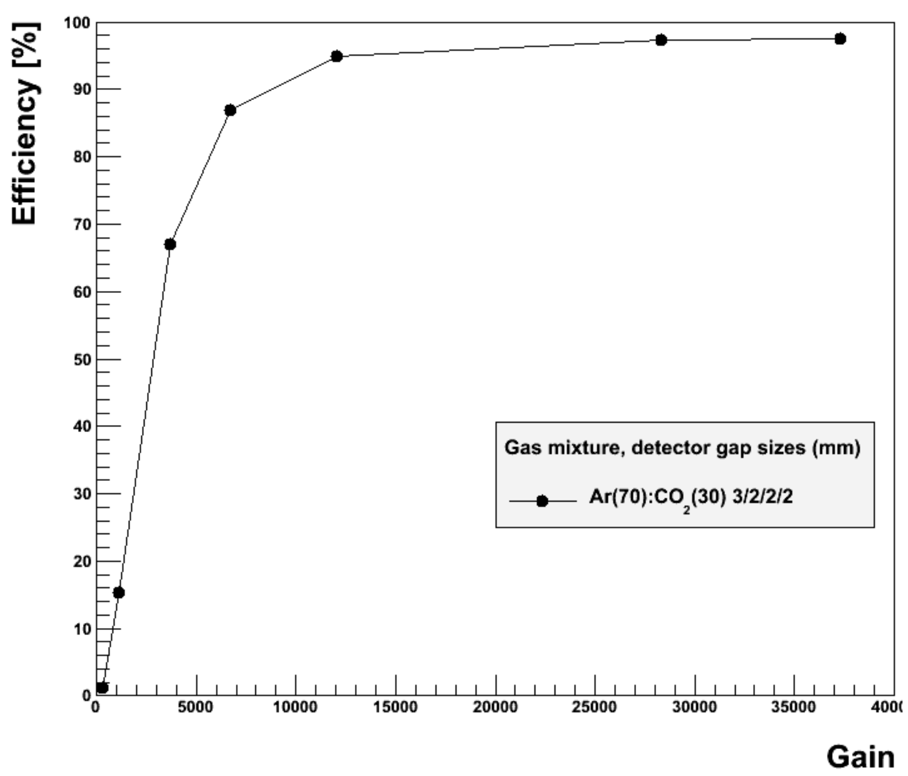
Performance from Test-Beams:

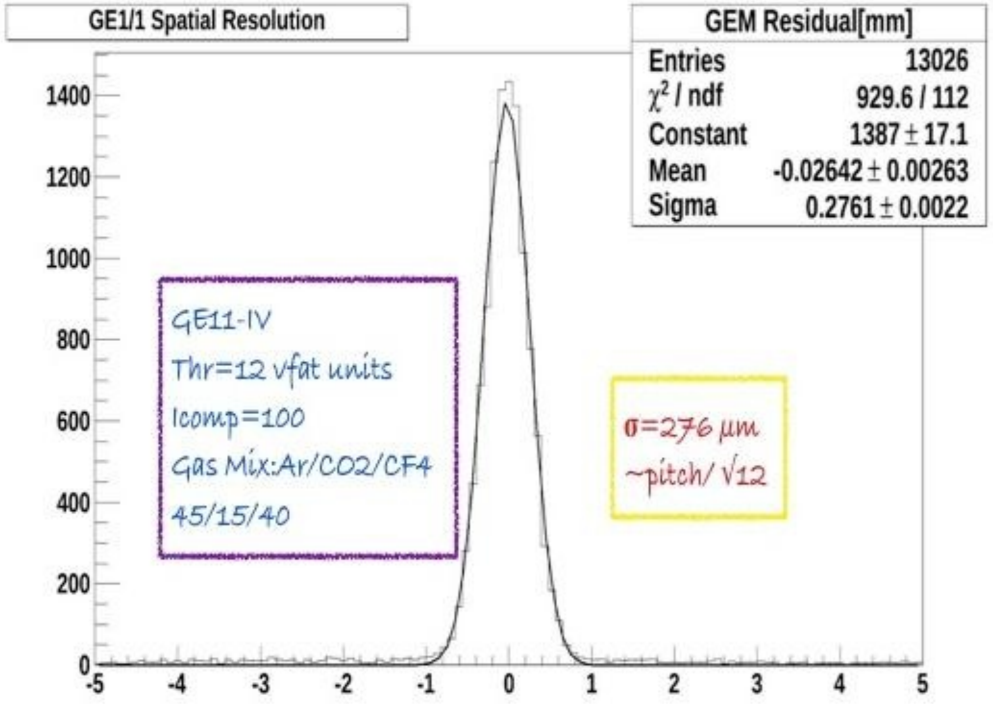
- Detector **efficiencies**: > **98%** + **Time resolution**: **~4ns**
- **Spatial resolution** of about **276µm** with VFAT2 (digital) and **< 104µm** APV (analog) readout chip
- Operation of GEMs in **magnetic field**
- Gas mixture: Ar/CO2/CF4 (45/15/40)
- Rate capability: **~10^5 Hz/cm^2**
- Good performance in test-beams at CERN SPS/FNAL

Standard GEM Timing Performance



Single Mask GEM performance





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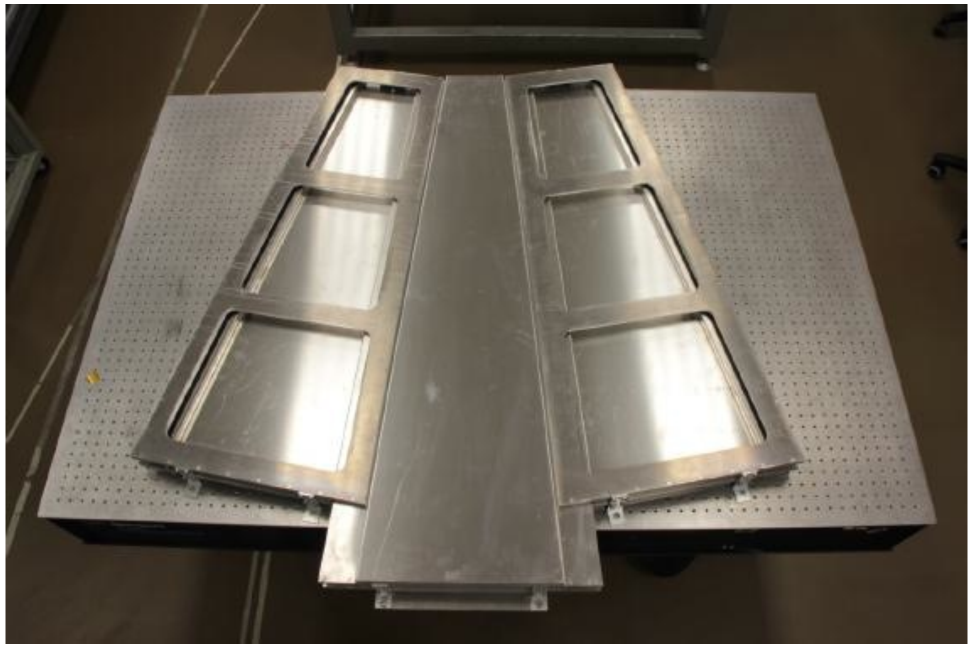
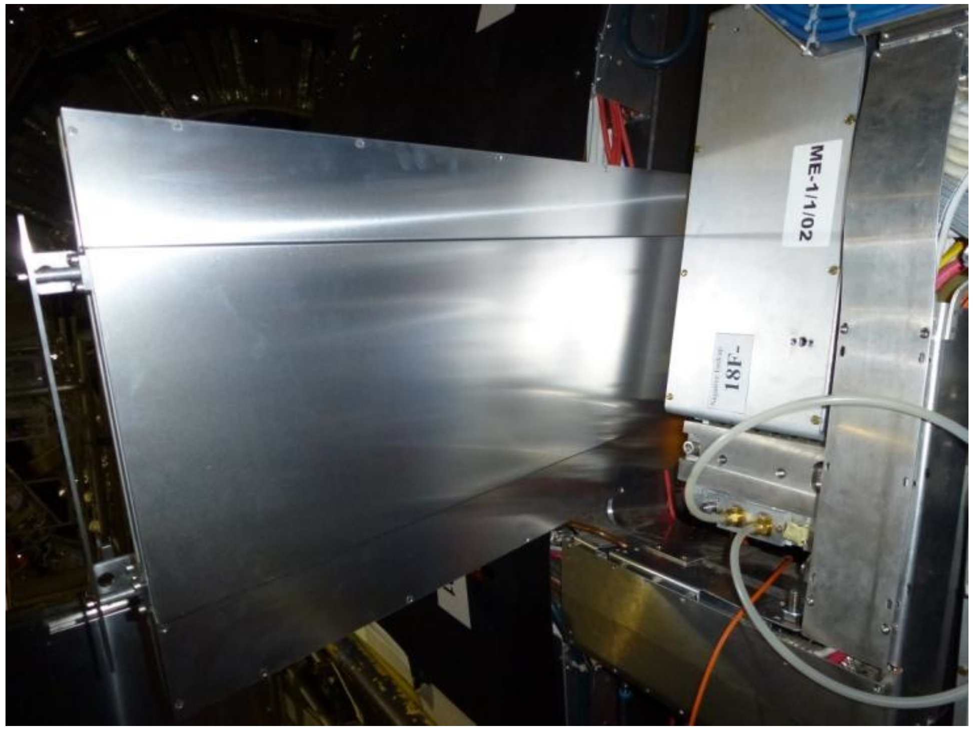
GEM project achievements



Technology and assembly

- Validation of **single-mask** technology
- Production of **large area GEM foils** (GE1/1-type)
- **NS2 technique** for GEM assembly



Integration

- **Successful** trial **installation** of **dummy super chambers** to optimize design and to perform trial insertion into CMS
- No detector and no electronics inside
- All positions for gas, cooling and electronics connections at the right place
- Same weight and dimensions as a real super chamber
- Trial installation of 1st set in Summer 2013
- Trial installation of 2nd set (short and long chambers) in March 2014

Impact on the Muon Trigger

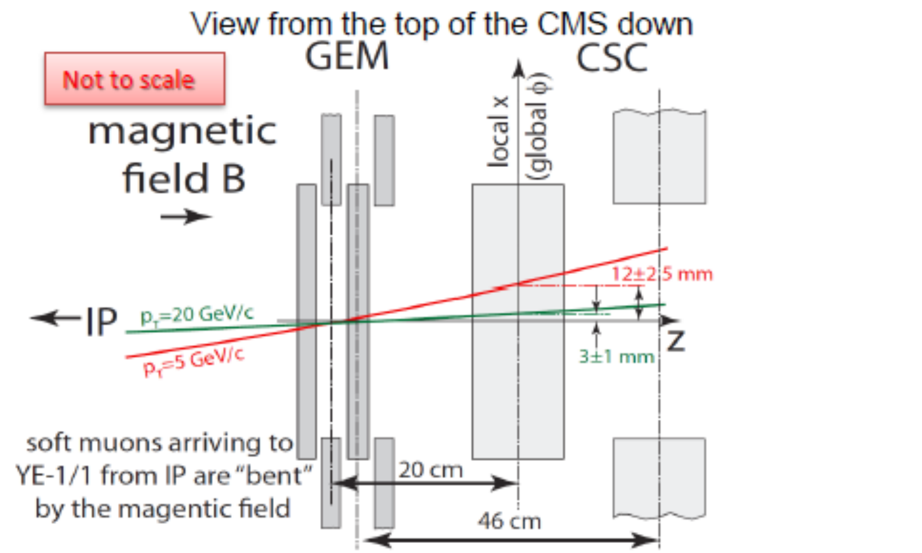
Impact on the trigger: bending angle

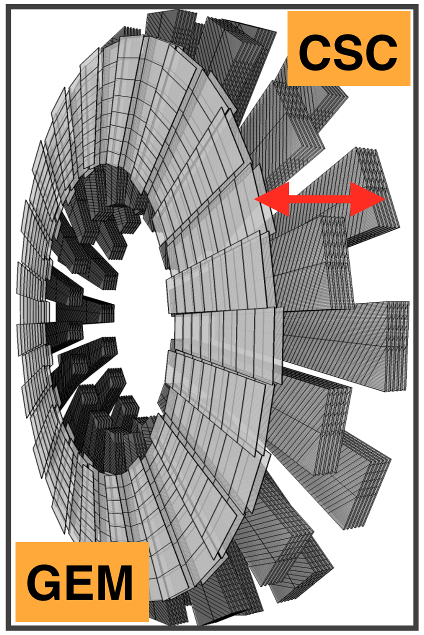
GEM-CSC Bending Angle

Scattering of soft muons due to multiple-scattering in the iron yoke flattens the trigger rate curve:

promotion of low-pT muon to high-pT

L1 muon momentum resolution can be improved with a second detector if we can measure the "bending angle".

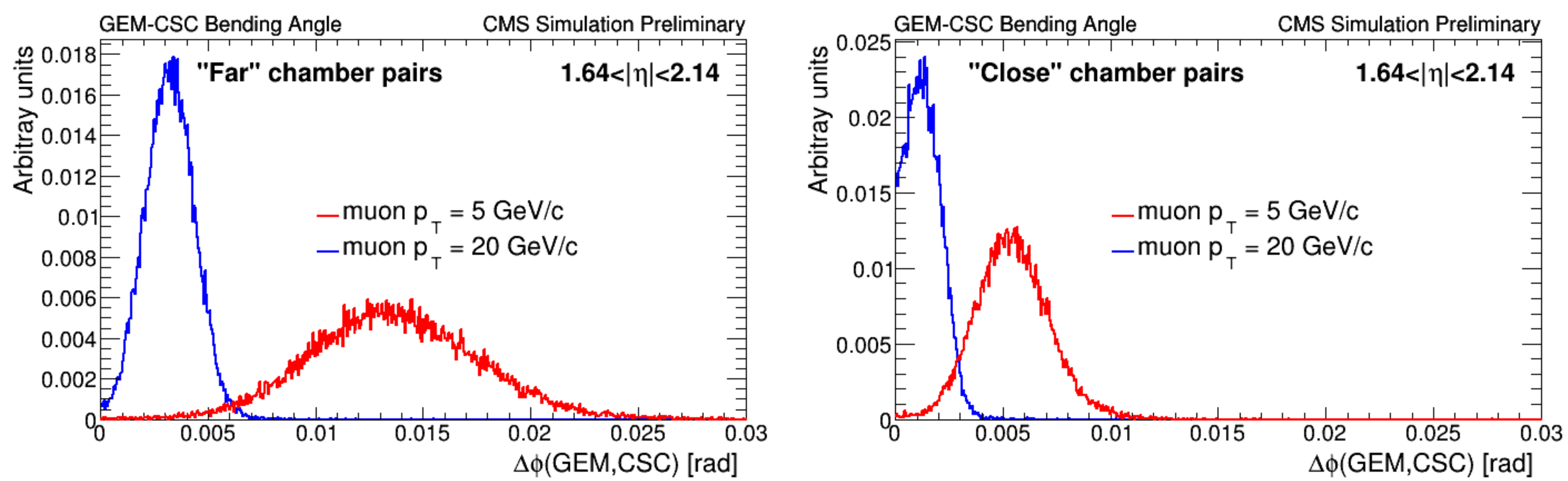




CSCs are too thin (11 cm) to see the bend with sufficient resolution (around 0,5 mrad) to discriminate 5 GeV from 20 GeV muons.

GEM detector in front of CSC can measure muon bending angle in magnetic field:

- increase "lever arm";
- high point resolution of GEM detector improve over the limited pt resolution.



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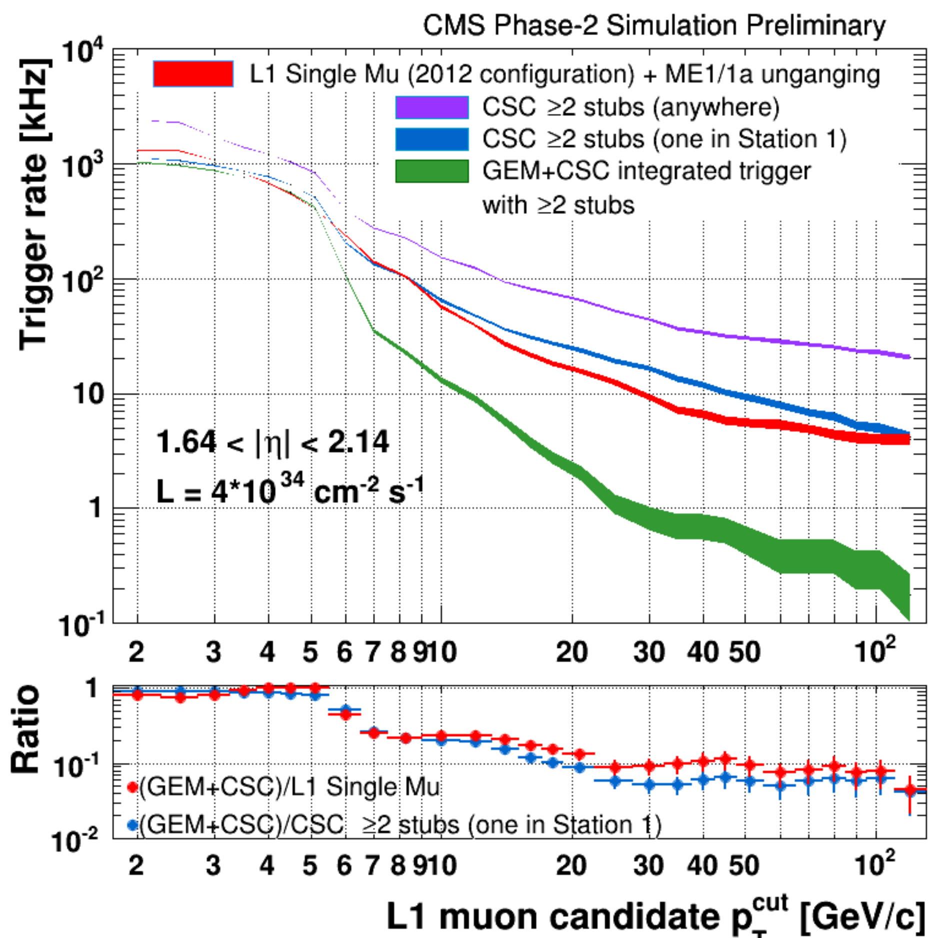
Impact on the trigger: rate

CSC only: at least 2 CSC stations with hits + presence of a track in ME1/1:

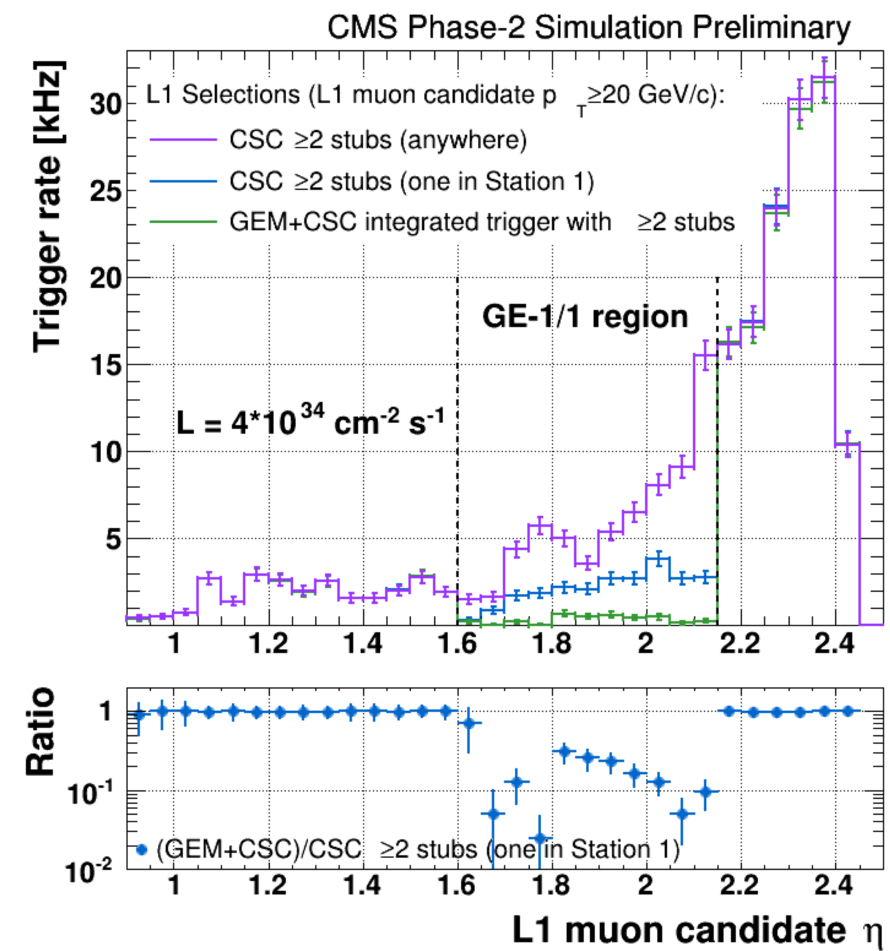
- Muon L1 rates increase with |η|, as the momentum resolution decreases

GEM+CSC integrated local trigger (GEM hits as additional input for CSC stub generation):

- better discrimination of high momentum using the bending angle measured;
- can lower pt threshold increasing efficiency in GE1/1 region.



Pt_cut=30 GeV/c:
L1 single Mu rate **10 kHz**
GEM+CSC rate >2 stubs **1 kHz**



Typical trigger rate reduction for 20GeV muon: **20kHz to 2kHz**

Impact on the trigger: rate

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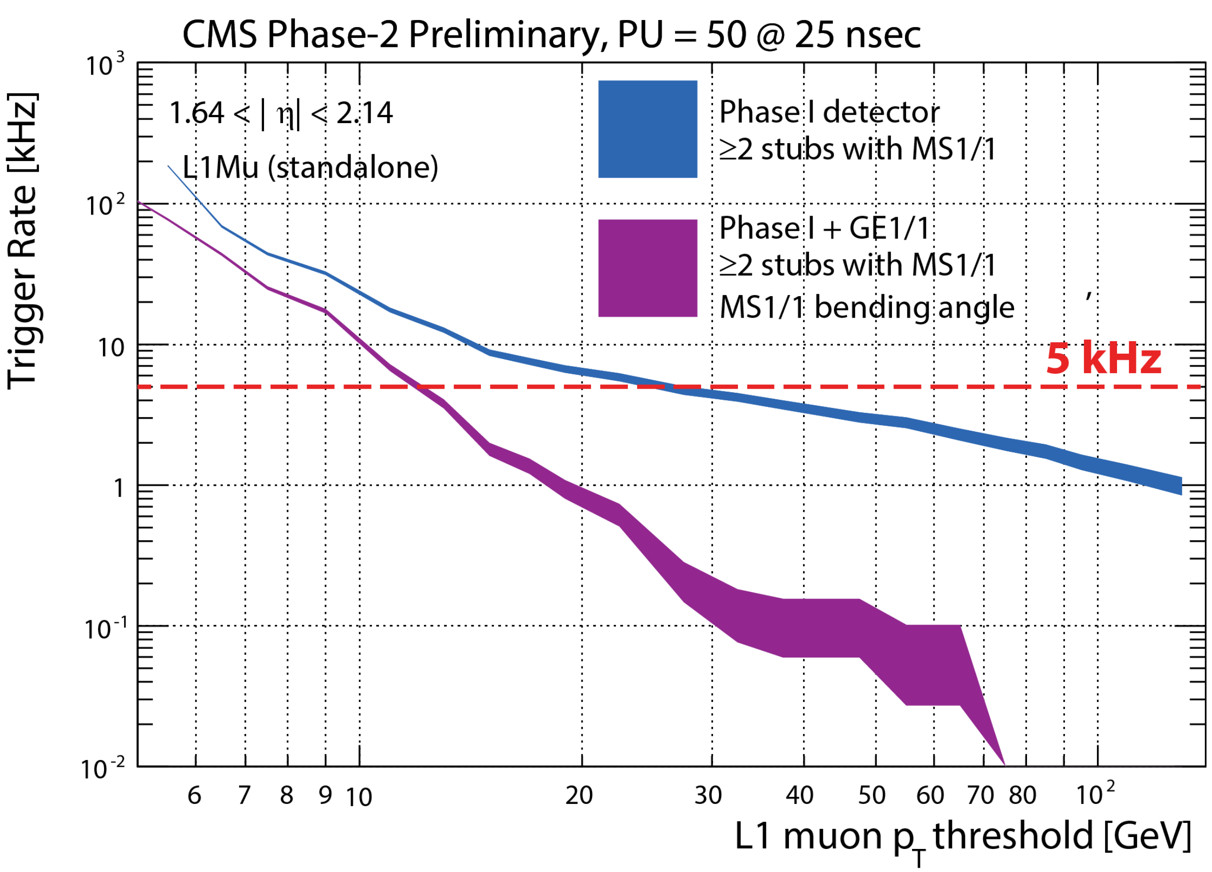

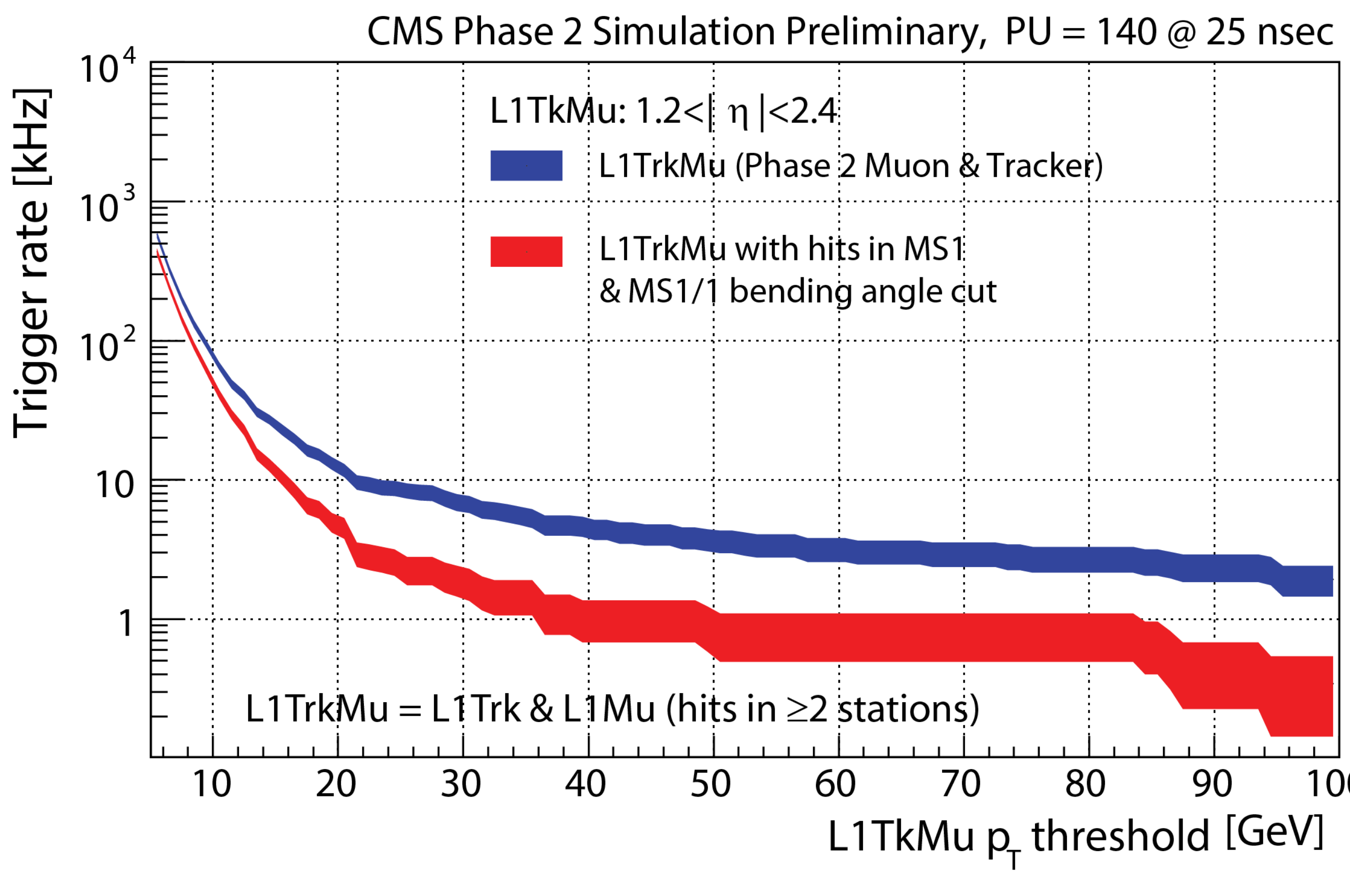

Excellent handle for trigger in Run 3

Summary & Conclusions

- **CMS GEM Project** has been developed since 2009
- Present scope of the project includes new **GE1/1** (LS2), **GE2/1** and **ME0** (LS3) stations
- Triple-GEMs provide a **excellent solution** for the **CMS muon trigger** and **tracking** needs in the LHC Phase-II era
- Good performance in test beams:
  - **Detector efficiencies**: ~98%; **Time resolution**: 4-5ns
  - **Spatial resolution** of about **100-250μm** with analog and digital
- Design of the GE1/1 chambers for installation in CMS close to final
  - Production and test of 10 full-size GE1/1 chambers
- During **LHC 2016-2017** Year-End **Technical Stop** 40° slices (four **triple-GEM** super chambers) will be **installed** inside **CMS**, in YE1/1
- **Full GE1/1** installation during **LHC LS2**
  - Production sites being commissioned
- Preparing CMS (Muon) Phase-II Technical Proposal and GE1/1 Technical Design Report to be submitted to LHCC

Thank you for your attention!