Performance of the CMS Muon Spectrometer, Muon Reconstruction and Identification Performance

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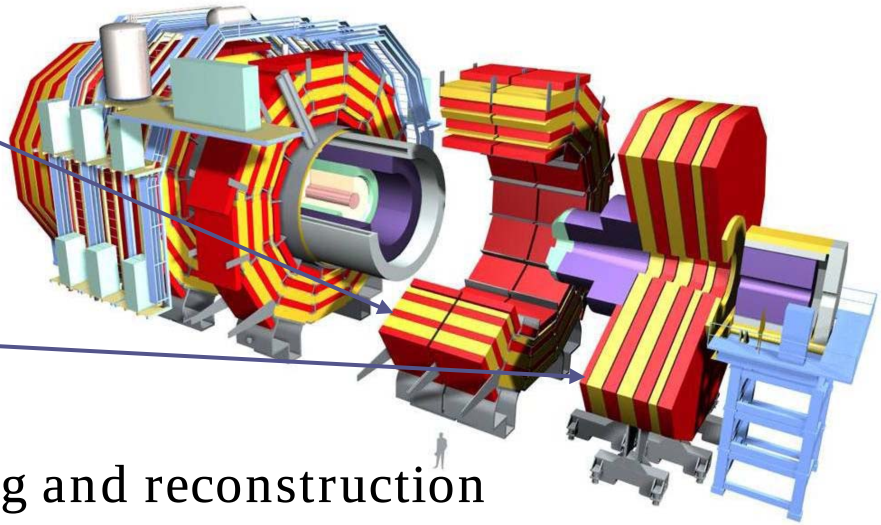
Outline

- Overview of the CMS muon spectrometer
  - Detector design and performance with cosmic ray muons
- Performance of muon reconstruction in cosmic ray events
  - Muon reconstruction and identification
  - Comparison data – Monte Carlo
  - Efficiency and resolution
  - Charge assignment
  - High Level Trigger
- Measurement of the charge asymmetry of atmospheric muons
  - First physics result with the CMS muon spectrometer
- Results with collisions data
  - First candidate display events and dilepton resonances
- Conclusions

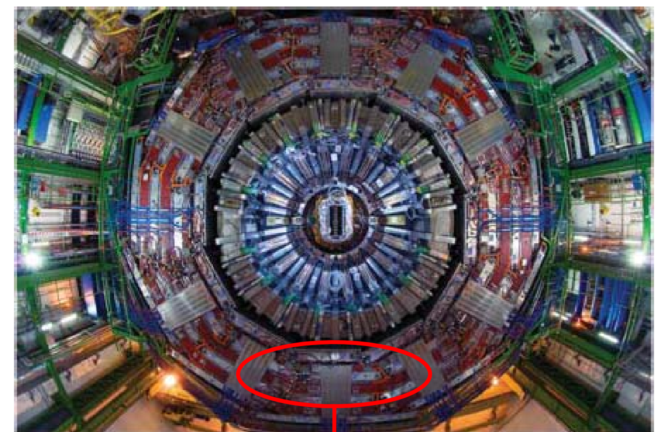
The CMS Muon Spectrometer

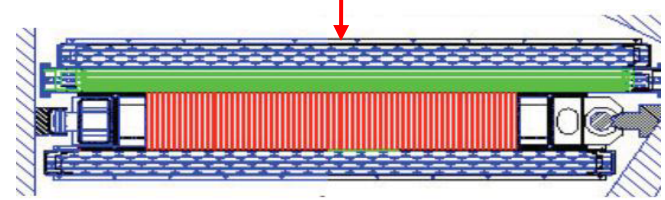
- Purposes of the CMS muon spectrometer:
  - □ Muon identification
  - □ Muon momentum measurement (~1 % at p_T~100 GeV, ~10% at 1 TeV, using tracker information)
  - □ Muon triggering
- Three technologies of gaseous detectors:
  - □ Barrel: 5 wheels ($|\eta|<1.2$)
    Drift Tube chambers (DT)
    Resistive Plate Chambers (RPC)
  - □ Endcap: 4 disks per side ($|\eta|<2.4$)
    Cathode Strip Chambers (CSC)
    RPC (up to $|\eta|<1.6$)
- All detectors used both for triggering and reconstruction



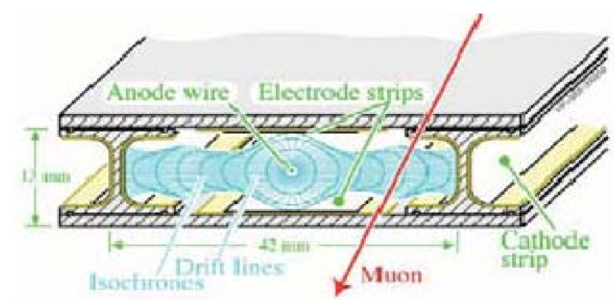
Barrel: Drift Tube Chambers (DT)

- 250 chambers arranged in 5 wheels, each with 4 stations forming concentric cylinders
  - ~172k read out channels
- Chambers made of staggered cell layers:
  - Two sets of 4 layers measure the bending coordinate $r\phi$ with ~100 μm precision
  - A set of 4 layers measure the z (θ) coordinate (only for the three innermost stations)
- Trigger on track segments with bunch-crossing identification at level 1



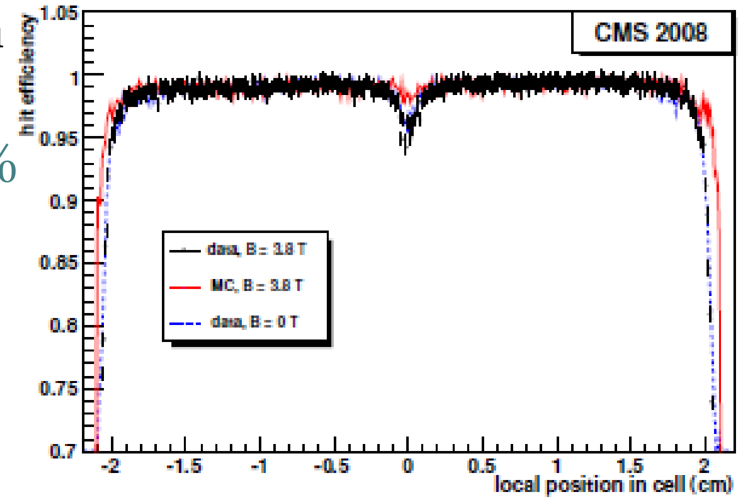


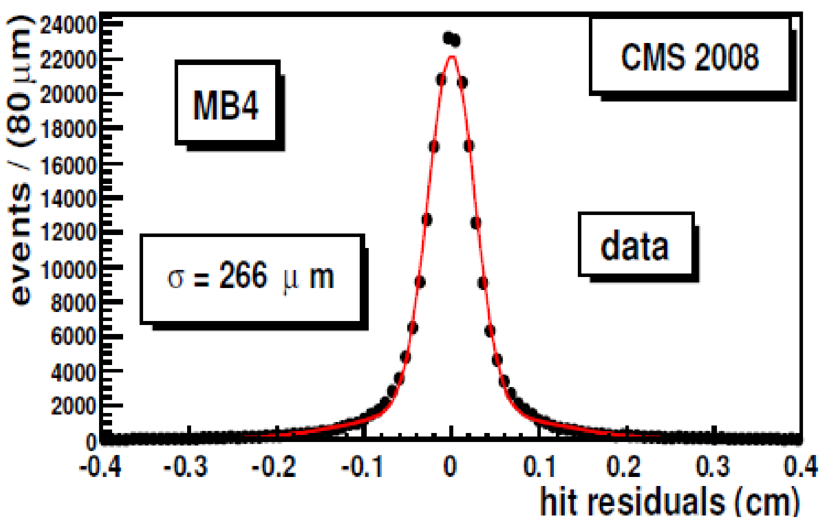
Gas mixture: Ar/CO_2 (85/15)%
Almost uniform drift velocity V_d~55 μm/ns
Maximum drift time ~380 ns
Cell resolution ~200 μm

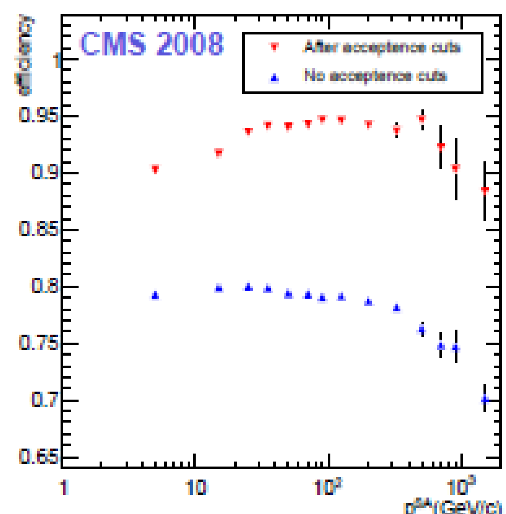


DT Performance with Cosmic Rays

- Hit reconstruction efficiency greater than 98% over a large part of drift volume
  - Segment reconstruction efficiency >99%
- Resolution on hit position ~260 μm
- Level 1 trigger efficiency reaches 95% for muon tracks in the fiducial volume

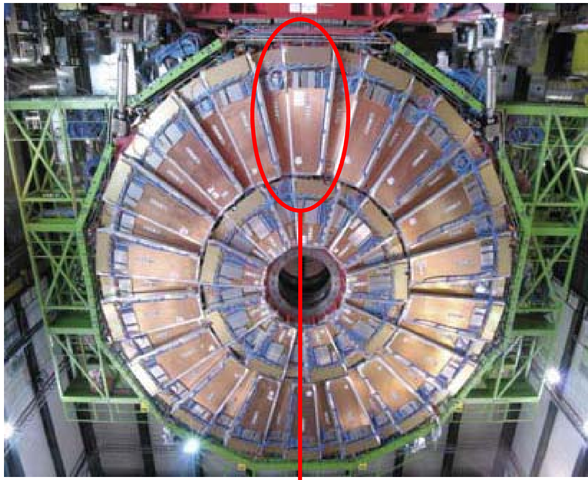


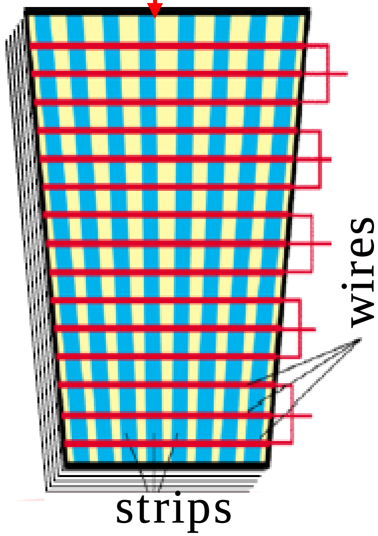




Endcaps: Cathode Strip Chambers (CSC)

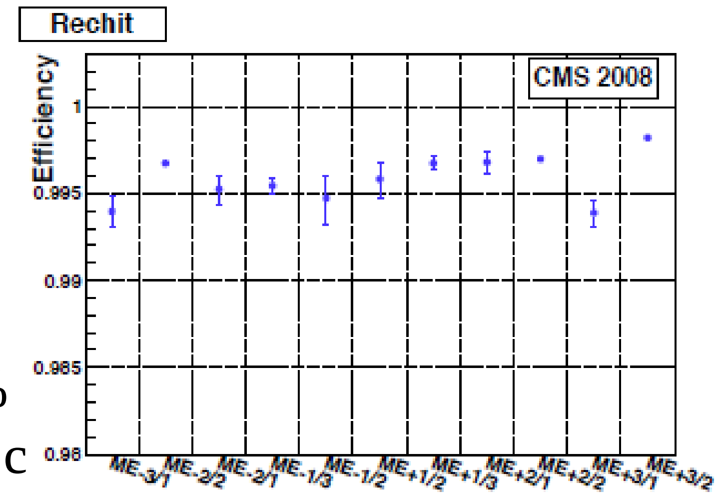
- 468 chambers arranged in 4 disks per endcap
  - □ 1, 2 or 3 rings per disk
  - □ 18, 36 or 72 chambers per ring
- Chambers composed by 6 gas gaps with a layer of staggered cathode strips and one of anode wires
  - □ Trapezoidal in shape and overlapped in ϕ
  - □ Gas mixture: $Ar/CO_2/CF_4$ (40/50/10)%
- Bending coordinate ϕ measured by strip centroid
  - □ Design resolution per chamber ~150 μm
  - □ 75 μm for chambers in the innermost ring
- Wire layers' signal:
  - □ Radial coordinate measurement
  - □ Fast response for bunch-crossing identification

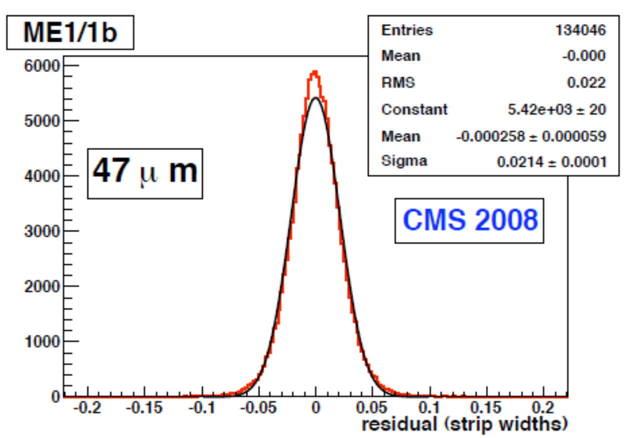


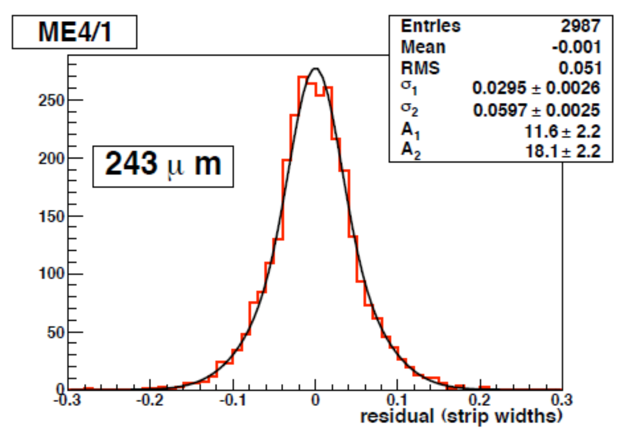


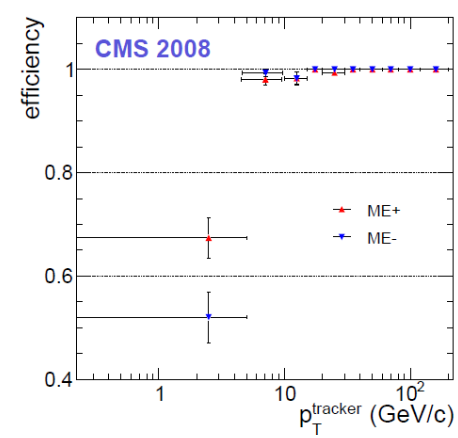
CSC Performance with Cosmic Rays

- Reconstruction efficiencies for hits and segments above 99%
- $R\phi$ resolution per chamber computed to range between 47 and 243 μm
  - $1/\sigma^2_{chamber} = 3/\sigma^2_{hit\_edge} + 3/\sigma^2_{hit\_center}$
- Level 1 trigger efficiency greater than 99% in both endcaps for muons of p_T>20 GeV/c



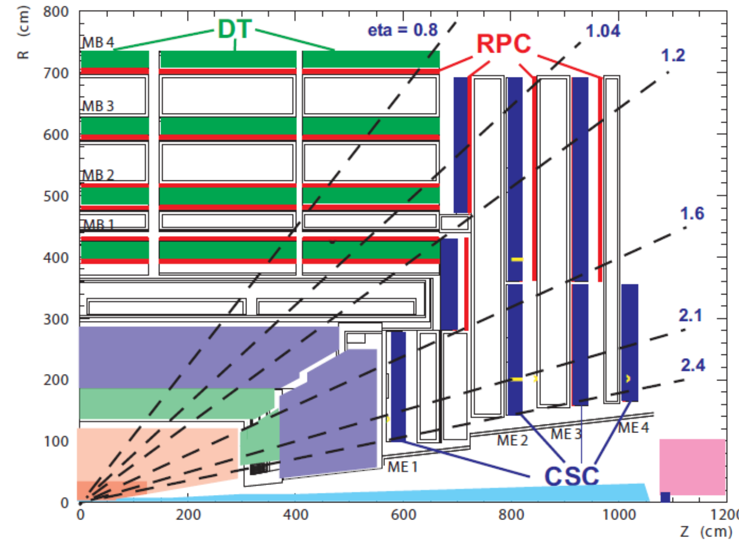


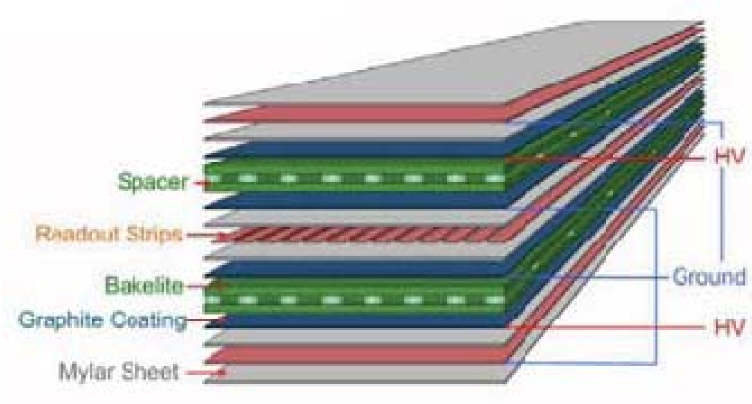




Resistive Plate Chambers (RPC)

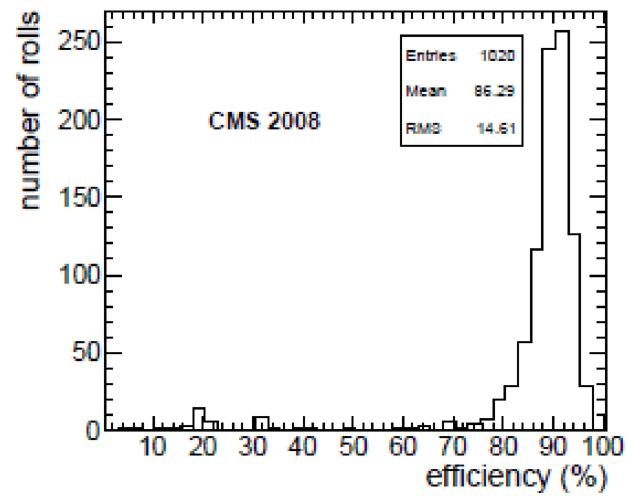
- Barrel: 480 chambers
  - 5 wheels with 6 concentric stations
- Endcap: 432 chambers
  - 3 stations/endcap covering up to $|\eta|<1.6$
- Double gap in avalange mode
  - Cope with hit rate up to 1 KHz/cm^2
  - Gas mixture: $C_2H_2F_4$/iso-C_4H_{10}/SF_6 (96.2/3.5/0.3)%
- Strips measure bending coordinate
  - Resolution ~1 cm
- Fast response; time resolution ~2ns
  - Unambiguous bunch-crossing identification at level 1

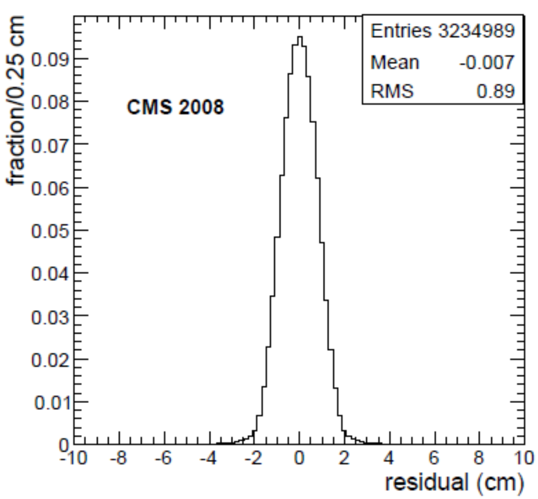


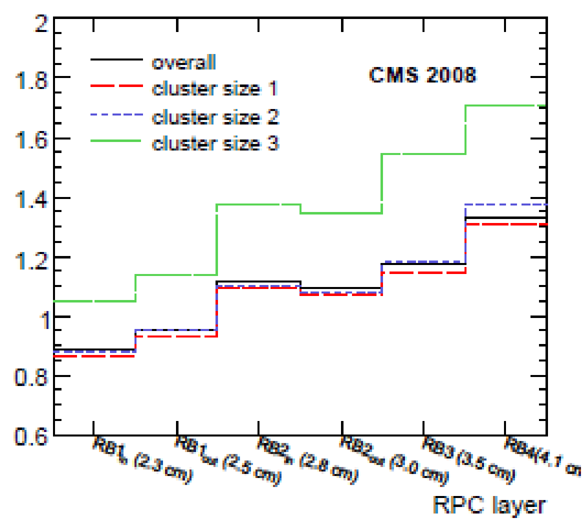


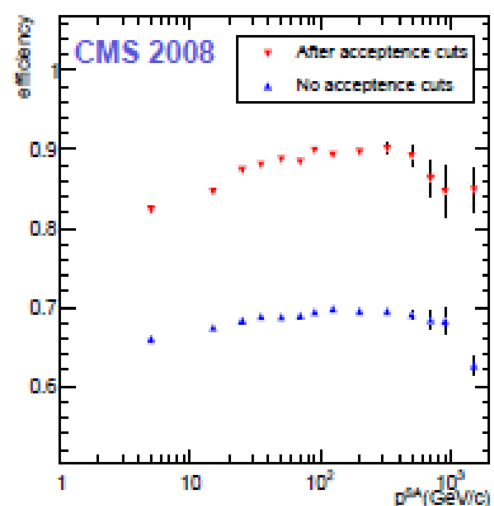
RPC Performance with Cosmic Rays

- Typical detection efficiency ~90%
- Spatial resolution ~1.1 cm
  - 0.89 cm for innermost barrel station
- Level 1 trigger efficiency between 80 and 90% for muons in the fiducial volume



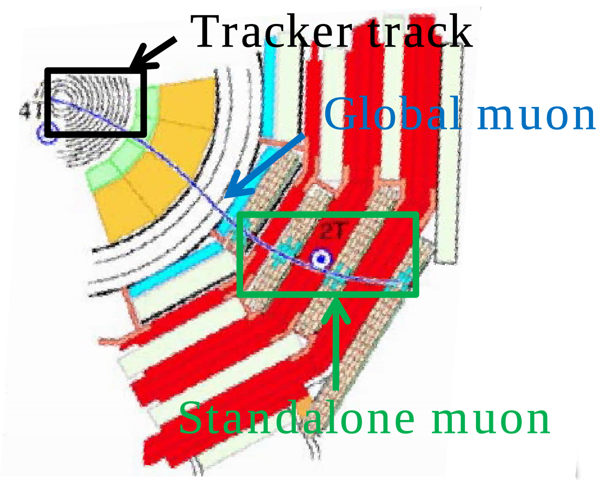


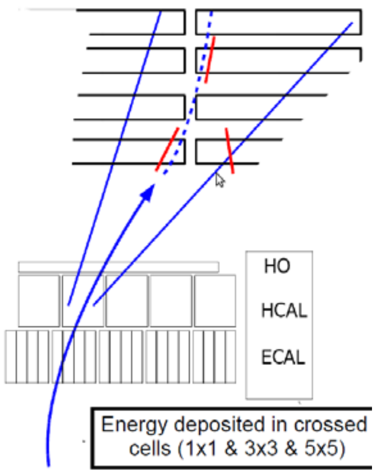




Muon Reconstruction and Identification

- Main muon reconstruction algorithms at CMS:
  - Standalone muons: only information from muon chambers used in the fit
  - Global muons: combined fit to hits in the muon system and in the inner silicon tracker
- Alternative approaches apply selections or cuts on the hits on muon chambers

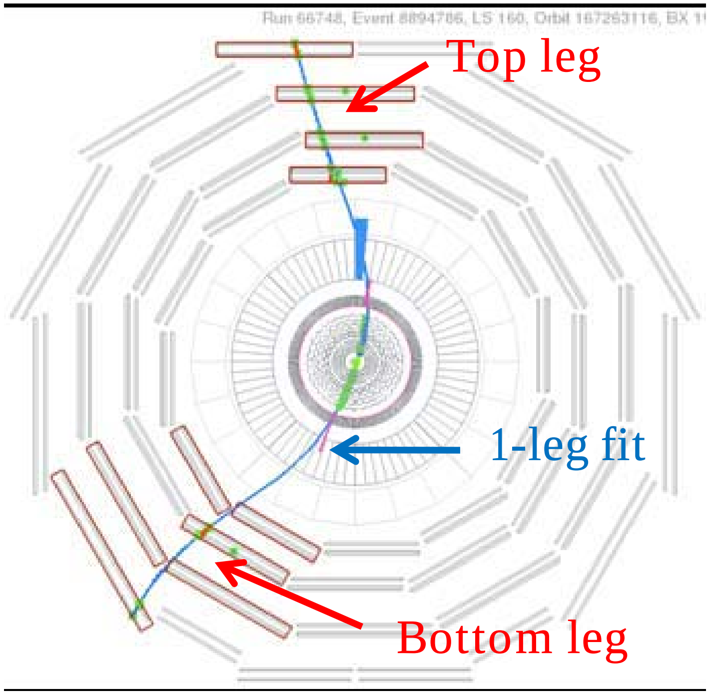




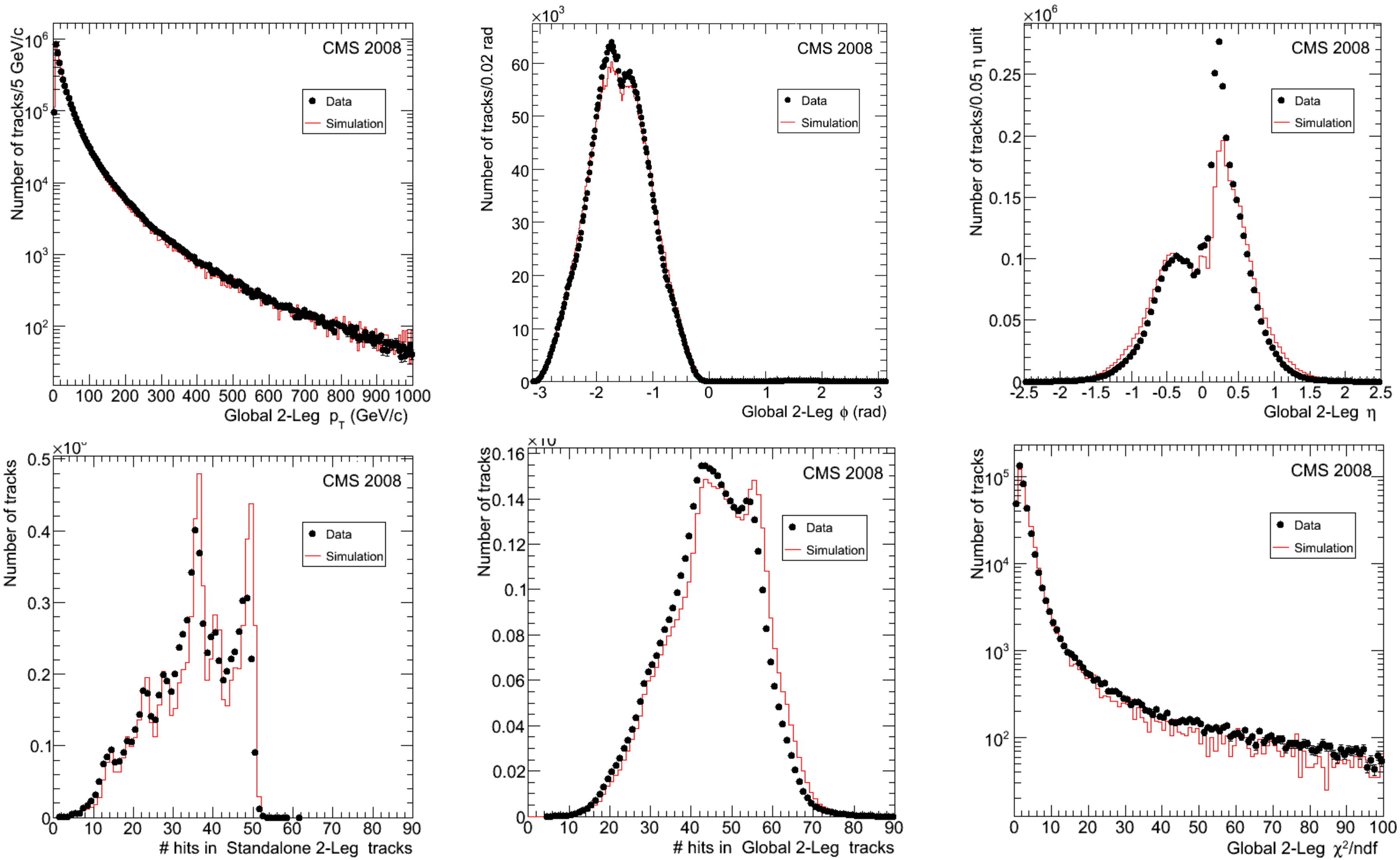
- Muon identification at CMS:
  - Tracker track extrapolated to muon system
  - Requirements applied to select muon candidates
- Two main sets of requirements studied:
  - Compatibility: based on calorimeter and muon system information
  - LastStation: well matched segments in last station

Cosmic Muon Reconstruction

- Cosmic Run At Four Tesla (CRAFT):
  - 270 million events collected in Oct. 2008
  - Full detector operative
  - Nominal magnetic field
- Cosmic rays offer many handles to probe muon system performance:
  - Redundancy of track algorithms
  - Comparison of top and bottom legs of a single cosmic muon
  - 1-leg fit of top and bottom sectors together: best possible resolution

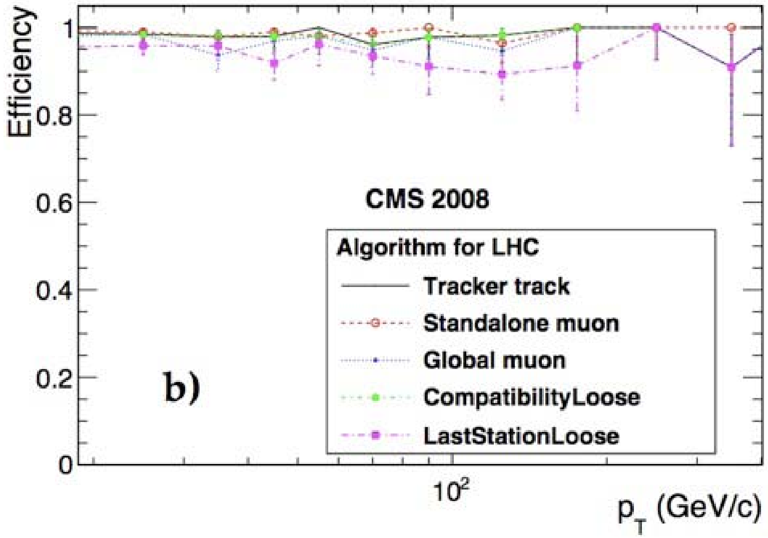


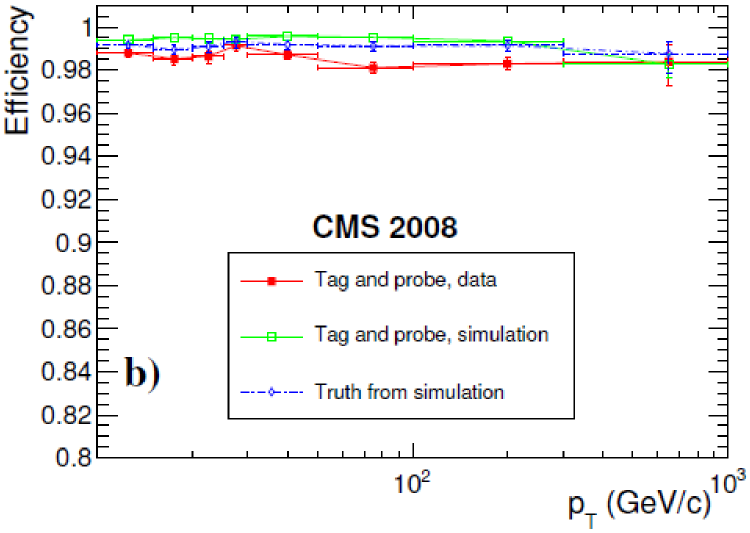
Data-Monte Carlo Comparison



Efficiency

- Tag&Probe method:
  - Muon tagged in one detector hemisphere and probed in the opposite
- To test standard LHC algorithms, use collision-like cosmics
  - Minimal distance to the interaction point: r<4 cm, Δz<10 cm
- Standalone muon efficiency: tag from good quality tracker tracks
  - Good agreement between data and simulation



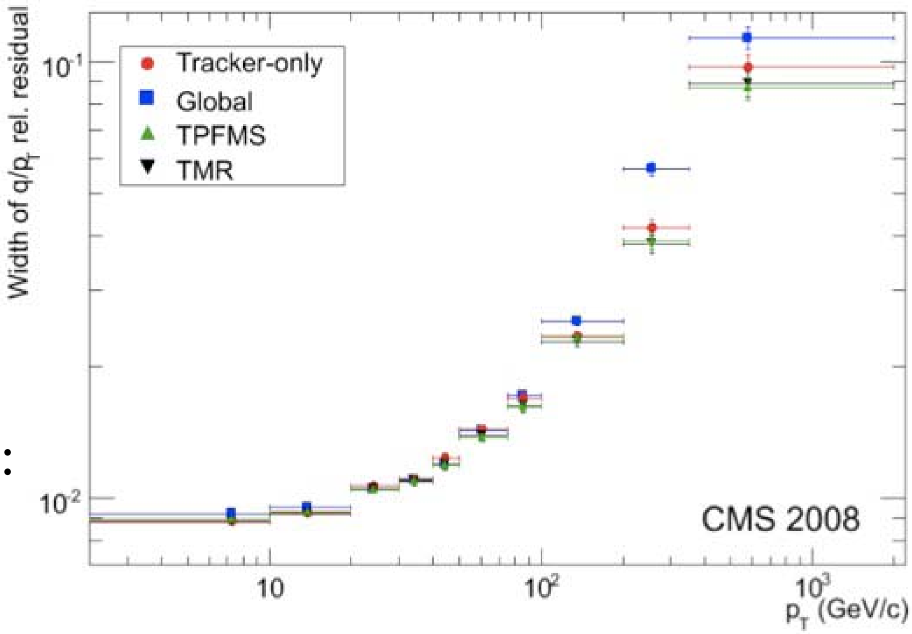


Momentum Resolution

- Using 2-legs collision-like muons
- Relative q/p_T residual:

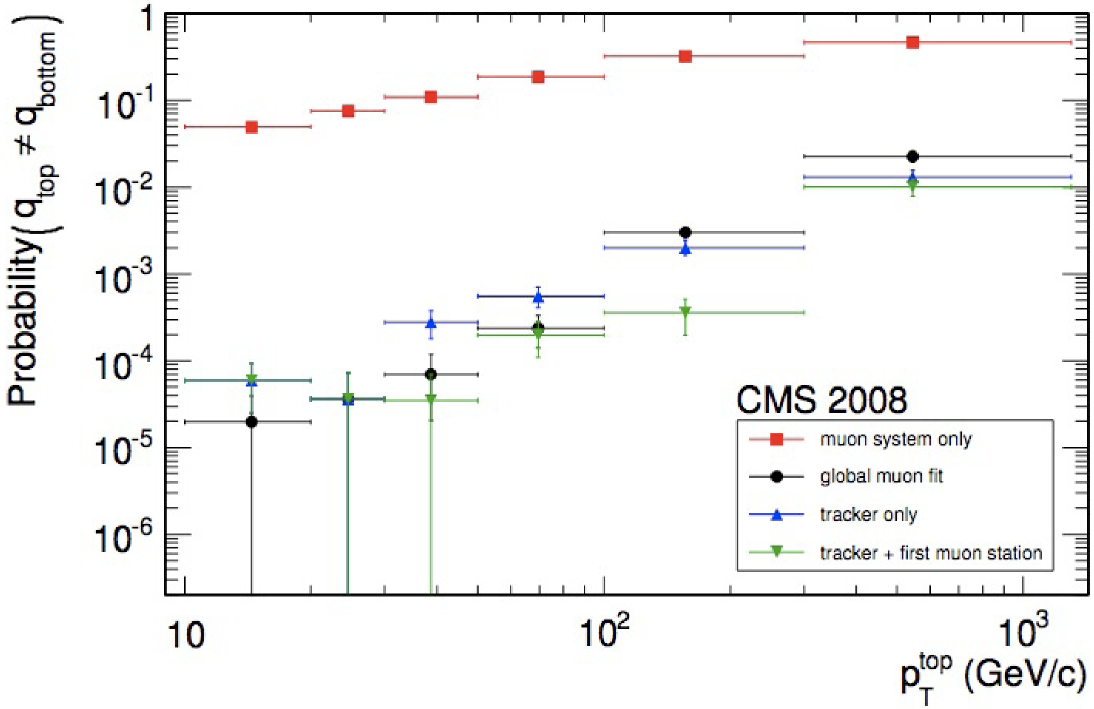
$$R(q/p_T) = \frac{(q/p_T)^{\mathrm{top}} - (q/p_T)^{\mathrm{bottom}}}{\sqrt{2}(q/p_T)^{\mathrm{bottom}}}$$

- Widths of $R(q/p_T)$ distribution for:
  - □ Tracker tracks
  - □ Global muons
  - □ Tracker Plus First Muon Station fit
  - □ Truncated Muon Reconstructor: best between tracker and TPFMS fits



Muon Charge Assignment

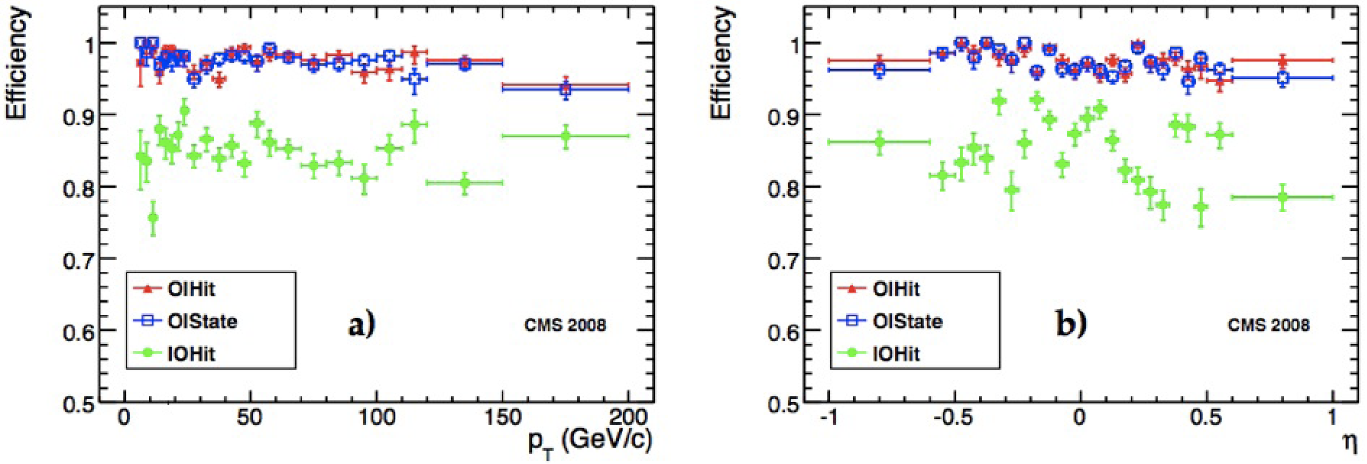
- The rate of charge mis-assignment is measured by the fraction of times the charges in the top and bottom legs of a muon disagree



- Crucial effect at high p_T when the muon trajectory is nearly straight

Muon High Level Trigger

- Three level 3 algorithms using different seeds:
  - Inside-Out Hit-based: using innermost tracker (pixel) hits as seeds
  - Outside-In Hit-based: using outermost tracker hits as seeds
  - Outside-In State-based: using level 2 muons as seeds
- Efficiencies tested on collision-like tracker tracks
  - IOHit algorithm performance strongly depends on pixel efficiency

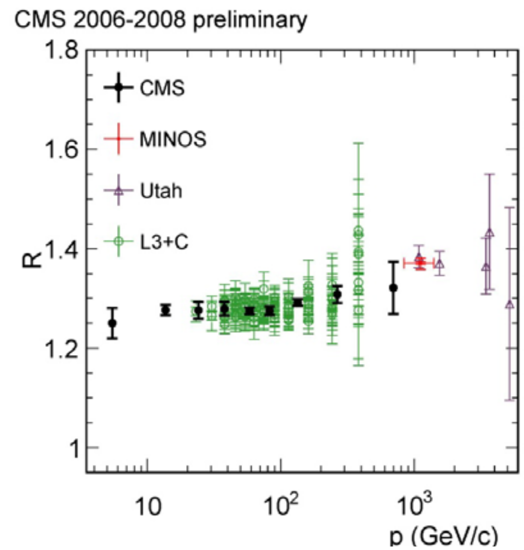


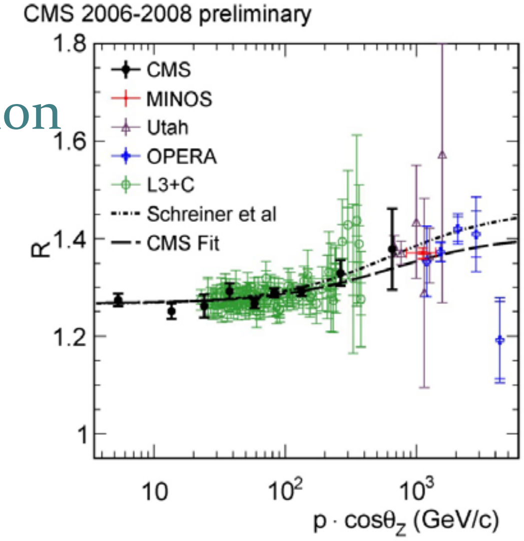
Charge Asymmetry of Atmospheric Muons

- Flux ratio of positive to negative muons in cosmic rays measured as a function of the muon momentum
- Combining different samples ...
  - Magnet Test Cosmic Challenge events collected in 2006
  - CRAFT 2008 data
- ... and reconstruction algorithms:
  - Global tracks
  - Standalone muons
- Raw charge ratio measured by CMS corrected for several effects:
  - Energy loss in the earth
  - Moment resolution
  - Mis-assignment of the charge

Charge Asymmetry of Atmospheric Muons

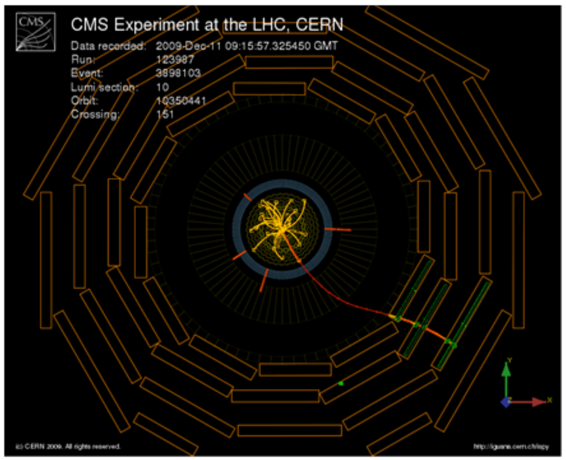
- Charge ratio measured for muons in a large momentum range: 3 GeV/c to 1 TeV/c
- Constant flux observed below 100 GeV/c:
  - $$R = 1.2766 \pm 0.0032\ (\text{stat}) \pm 0.0032\ (\text{syst})$$
  - World most precise measurement
- Increase of charge asymmetry at high moment
  - Good agreement with models of muon production in cosmic ray showers
  - Compatible with previous measurements

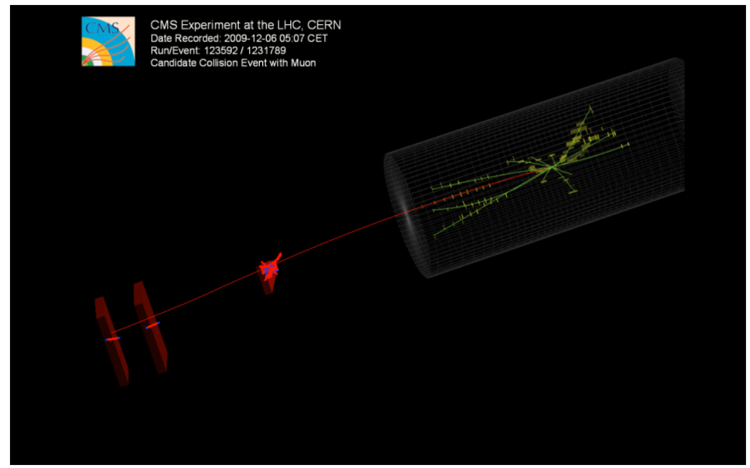




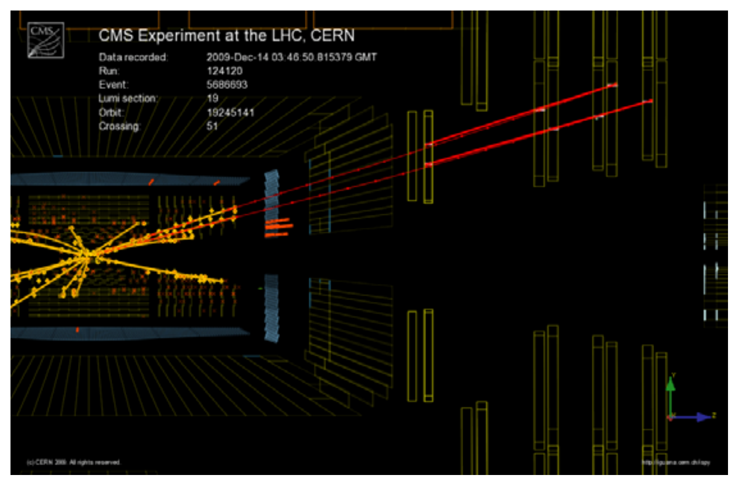
Muons in Collisions at 900 and 2360 GeV

- First muons from pp collisions observed in barrel and endcap





- J/ψ candidate in the endcap:
  - $p_T(\mu_1)$ = 3.6 GeV/c
  - $p_T(\mu_2)$ = 2.6 GeV/c
  - $m(\mu\mu)$ = 3.03 GeV/c^2

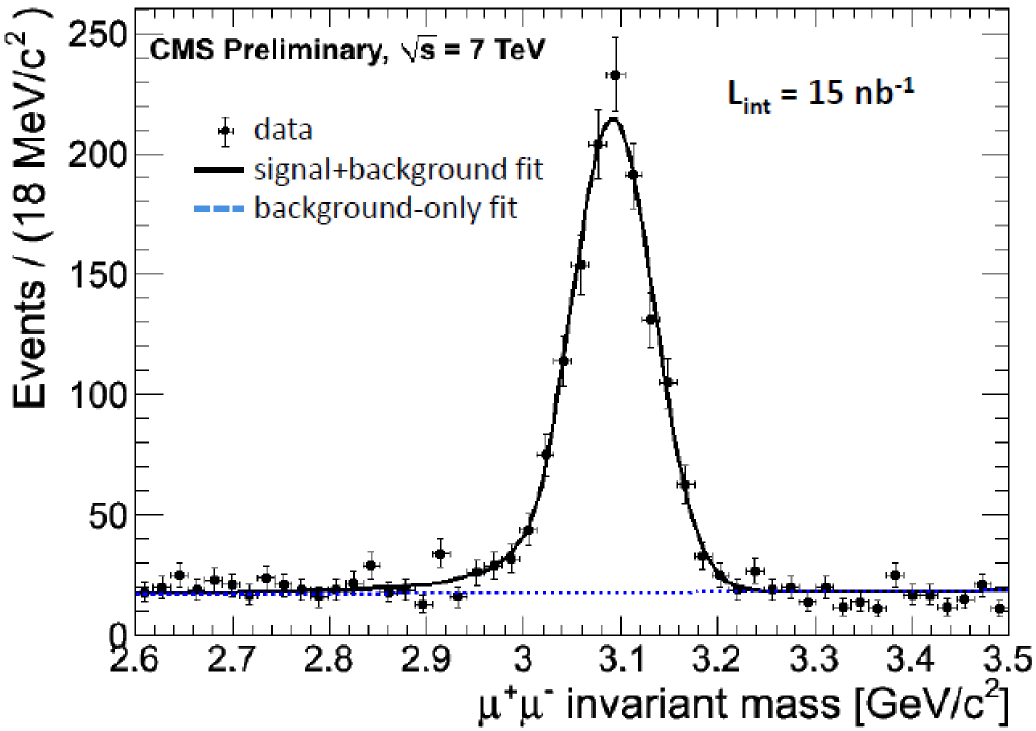


Dilepton Resonances at 7 TeV

- Invariant mass of dimuons in 0.985 nb of pp collisions
  - J/ψ resonance measured

    $N_{sig} = 1230 \pm 47$
    $m_{J/\psi} = 3092 \pm 1$ (stat.) $\mathrm{MeV/c^2}$
    $\sigma = 42.7 \pm 1.5$ (stat.) $\mathrm{MeV/c^2}$

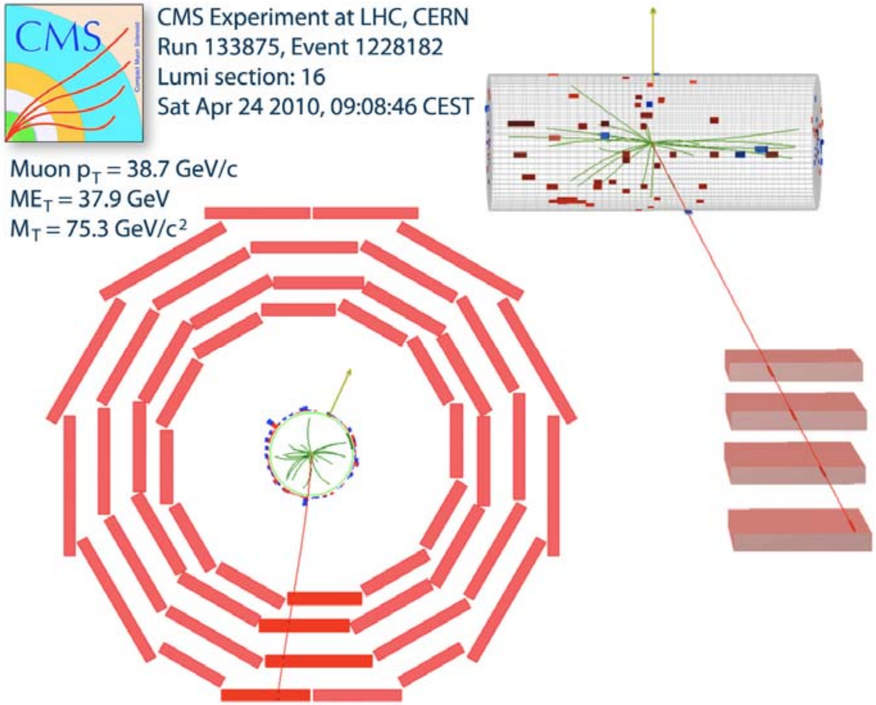
  - More on this subject from Mario Pelliccioni next Friday



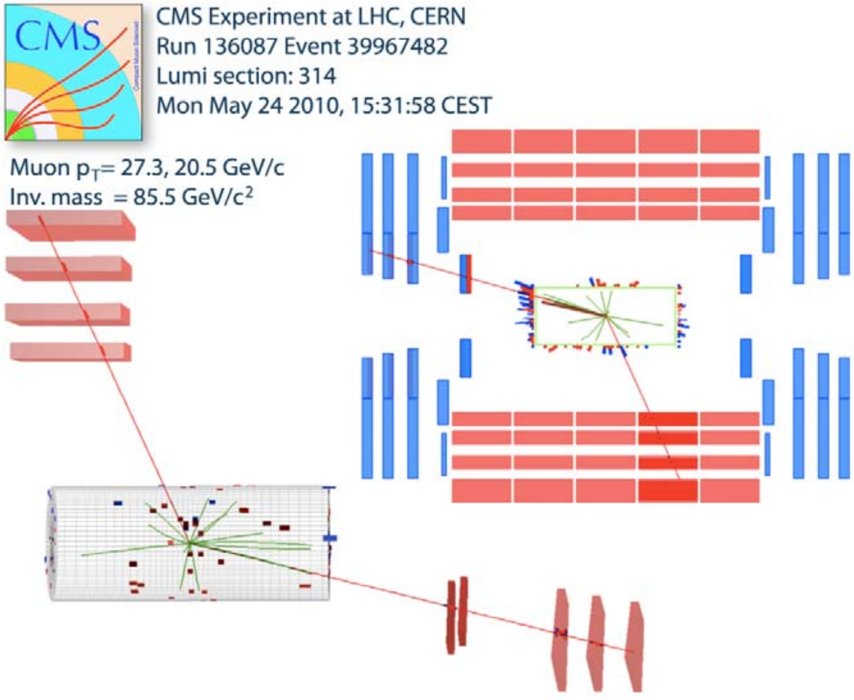
- Looking for Upsilon and Z boson resonances

First W and Z Boson Candidates

- $W \rightarrow \mu\upsilon$ candidate



- $Z \rightarrow \mu\mu$ candidate



□ More details on Emanuele Di Marco's talk next Thursday

Conclusions

- The design of the CMS muon spectrometer and its performance on cosmic rays has been presented
- Efficiency of various high level trigger, identification and reconstruction algorithms have been measured
  - Good agreement with expectations from Monta Carlo simulation
- The CMS muon spectrometer proved to improve the momentum resolution and charge assignment of reconstructed tracks at high p_T
- CMS has measured the charge asymmetry of cosmic muons in the momentum range from 3 GeV/c to 1 Tev/c
- For muon momenta below 100 Gev/c, the flux ratio is measured to be a constant 1.2766 ± 0.0032 (stat) ± 0.0032 (syst)
  - Most precise measurement to date
- First muons detected in pp collisions
  - J/ψ resonances measured, looking for Upsilon and Z boson signals
  - Vector boson candidates observed