Commissioning of the CMS Endcap Muon System

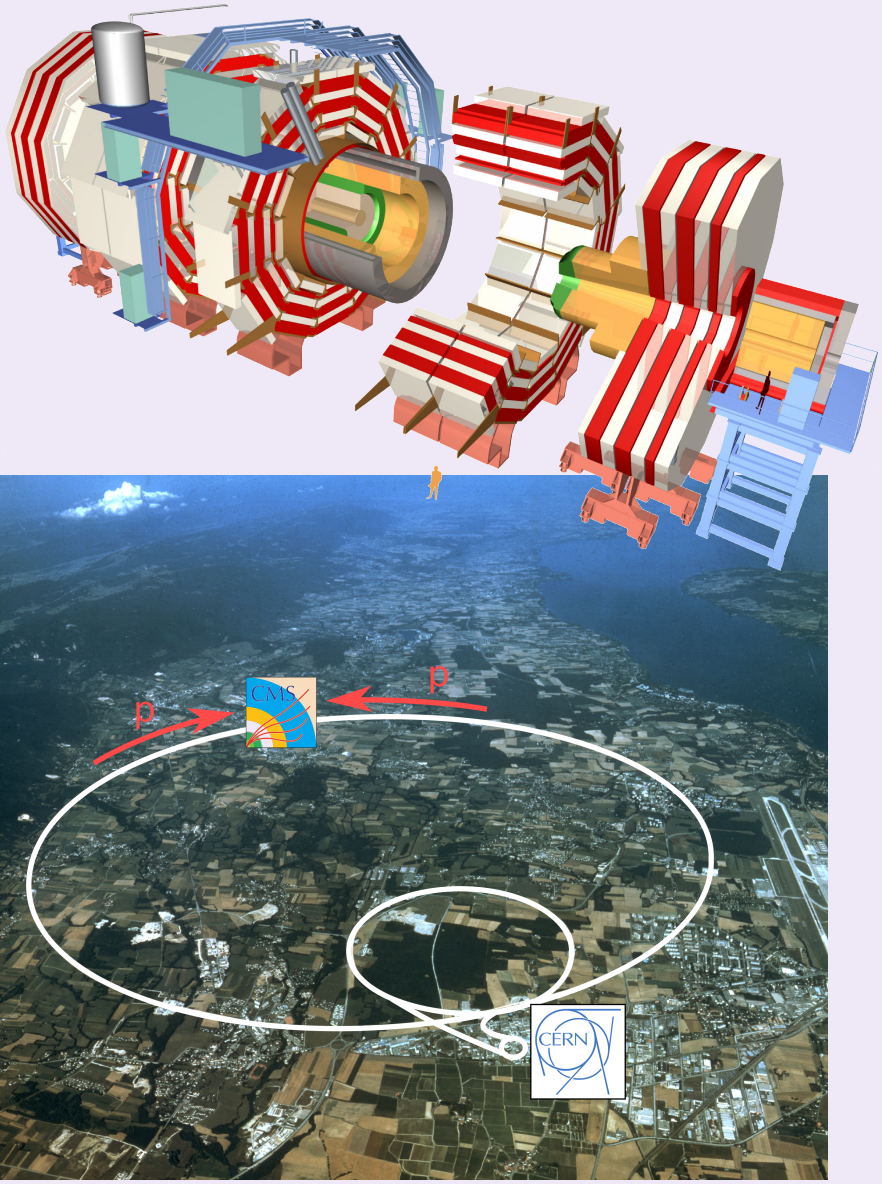
Phillip Killewald

The Ohio State University

Meeting of the Division of Particles and Fields
of the American Physical Society
July 2009

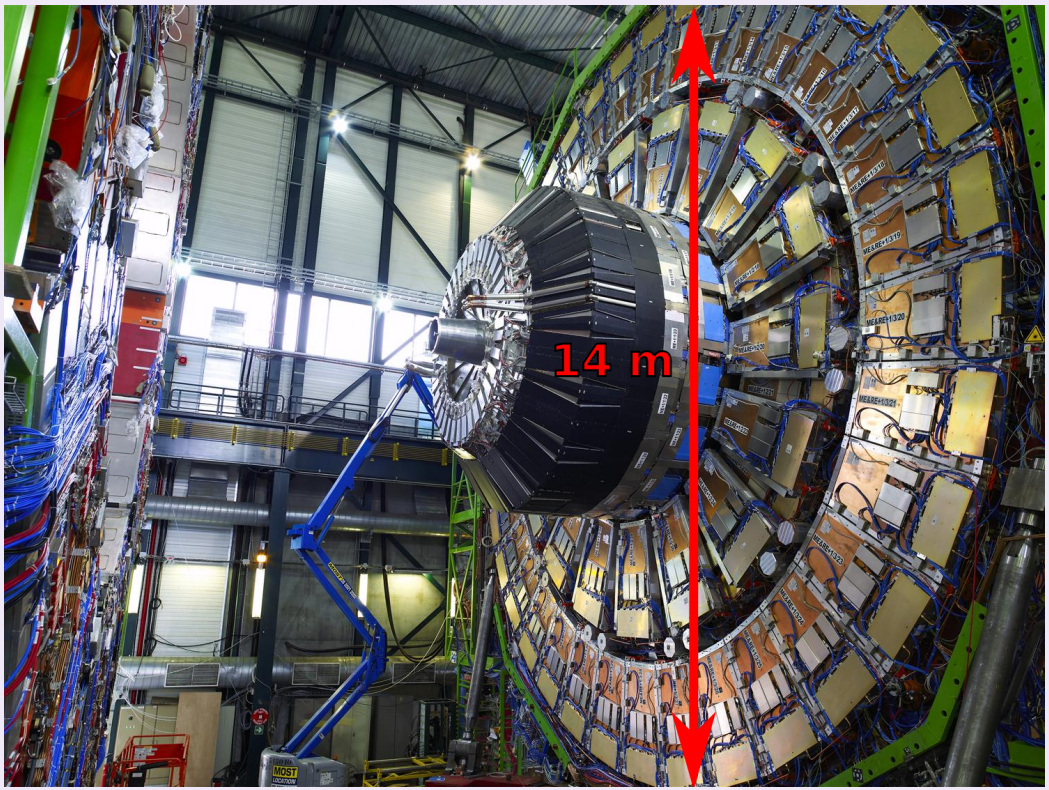
CMS: The Compact Muon Solenoid

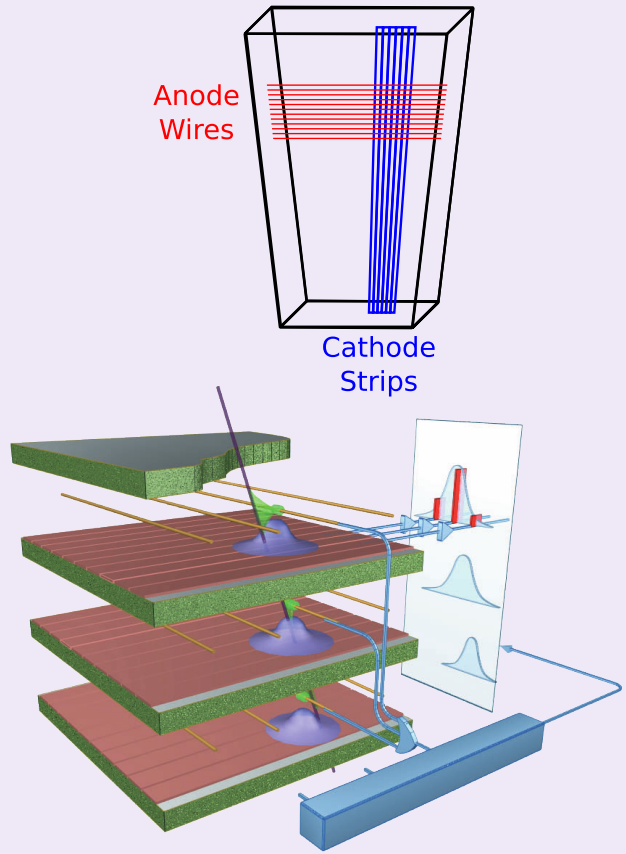
- General-purpose particle detector
- Centered around one of the interaction points of the Large Hadron Collider

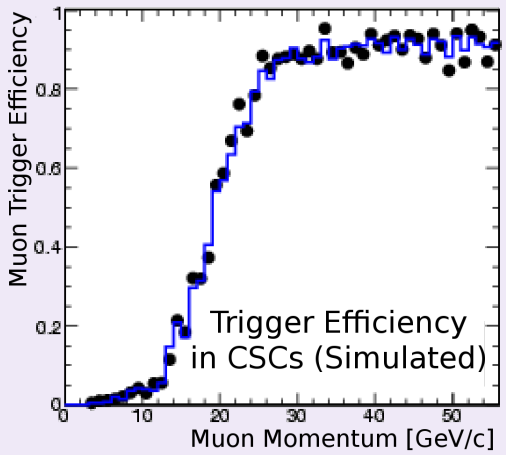


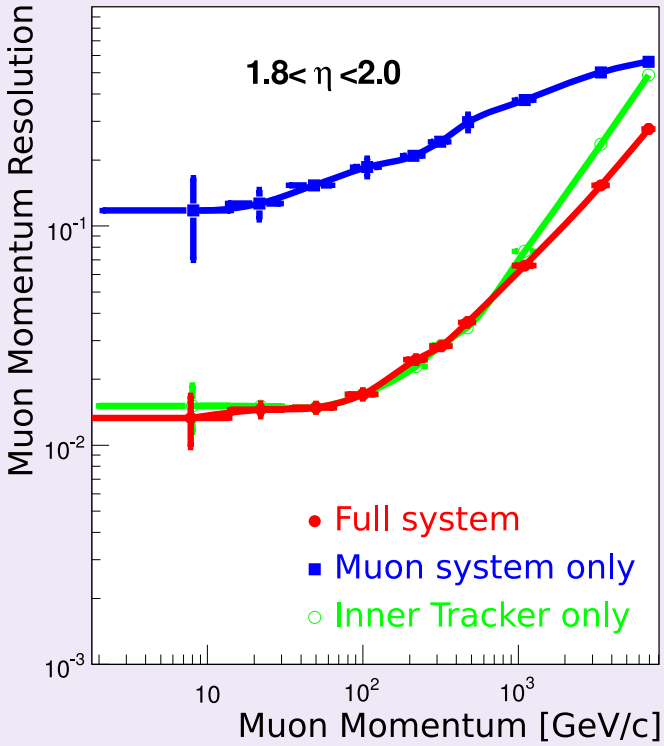
The CMS Endcap Muon System

- CMS uses 468 Cathode Strip Chambers as a muon spectrometer in the endcaps
- Each CSC has 6 layers of cathode strips and anode wires
- Each layer makes an independent 2D measurement of a through-going muon's position







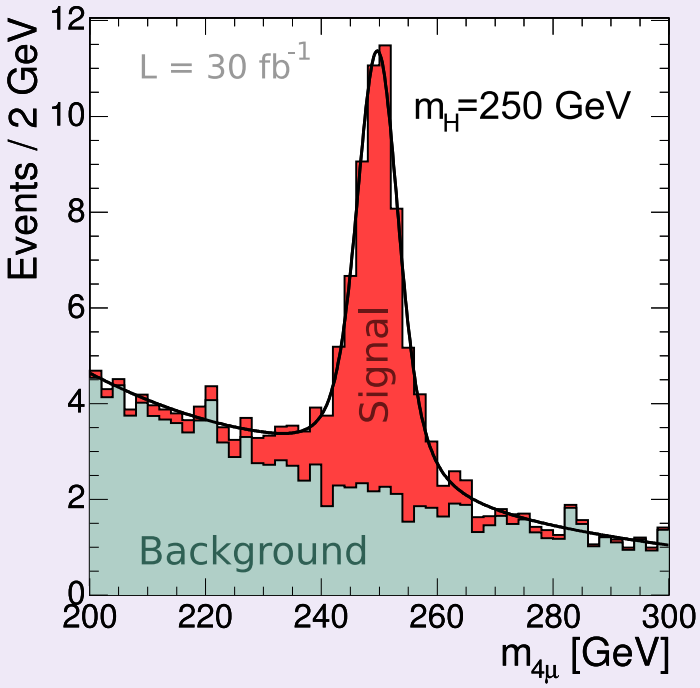


The CSCs are designed to provide:

- Reliable muon identification
- Efficient muon triggering
- Improved muon momentum resolution for $p > 500$ GeV

The CMS Collaboration 2006, CERN-LHCC-2006-001

The Importance of Muons in TeV Physics

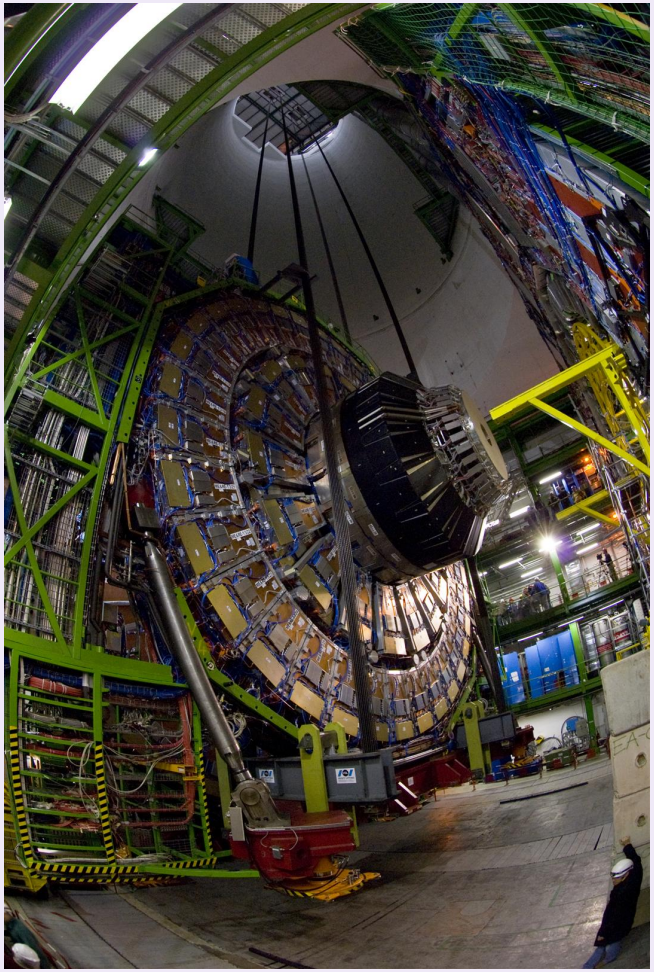


Muons are important in TeV-scale physics because they are:

- Easily identifiable with a clean experimental signature
- Present in many new physics signals
  - $H \rightarrow ZZ^{(*)} \rightarrow 4\mu$
  - $Z' \rightarrow 2\mu$
  - $W' \rightarrow \nu_\mu + \mu$
  - $\chi_2^0 \rightarrow \chi_1^0 + 2\mu$

The CMS Collaboration 2007, *J. Phys. G: Nucl. Part. Phys.* **34** 995-1579, doi:10.1088/0954-3899/34/6/S01

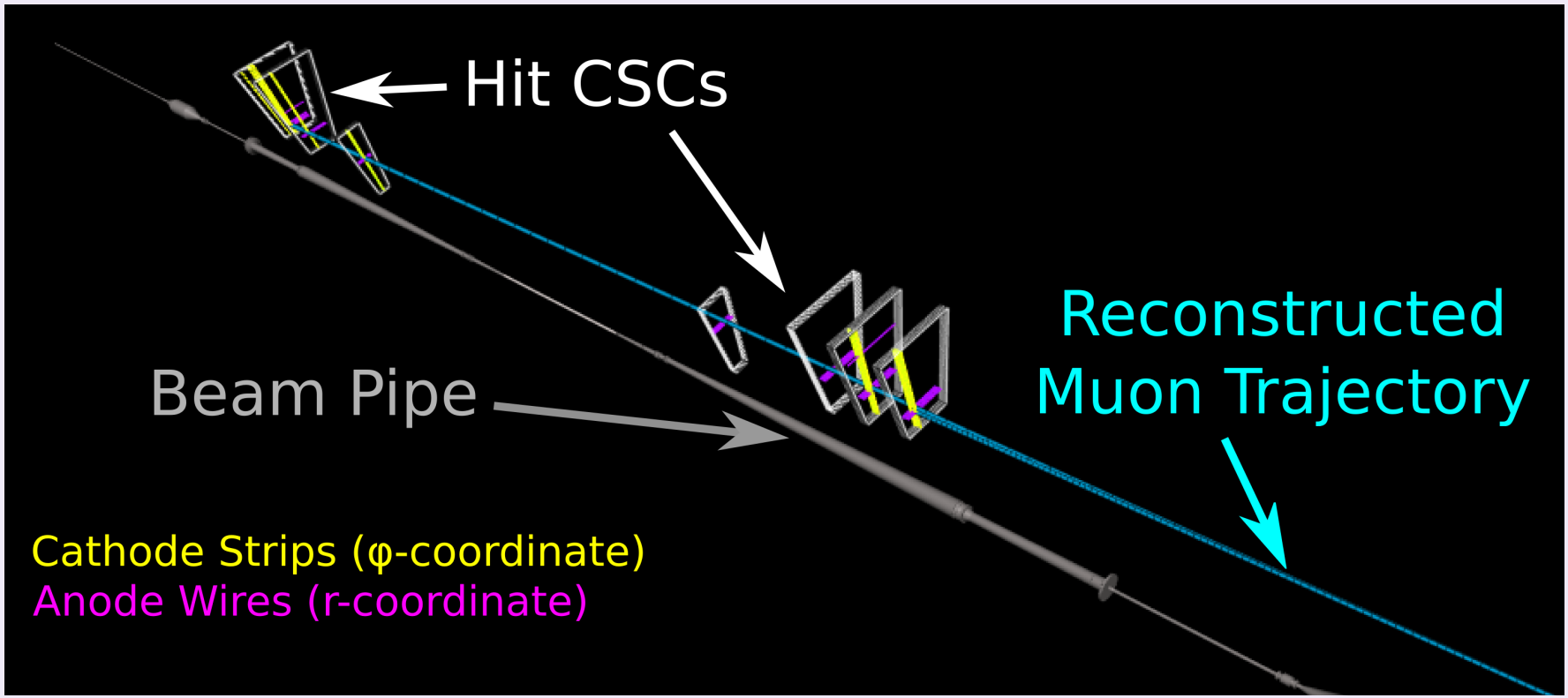
An Abbreviated Time Line

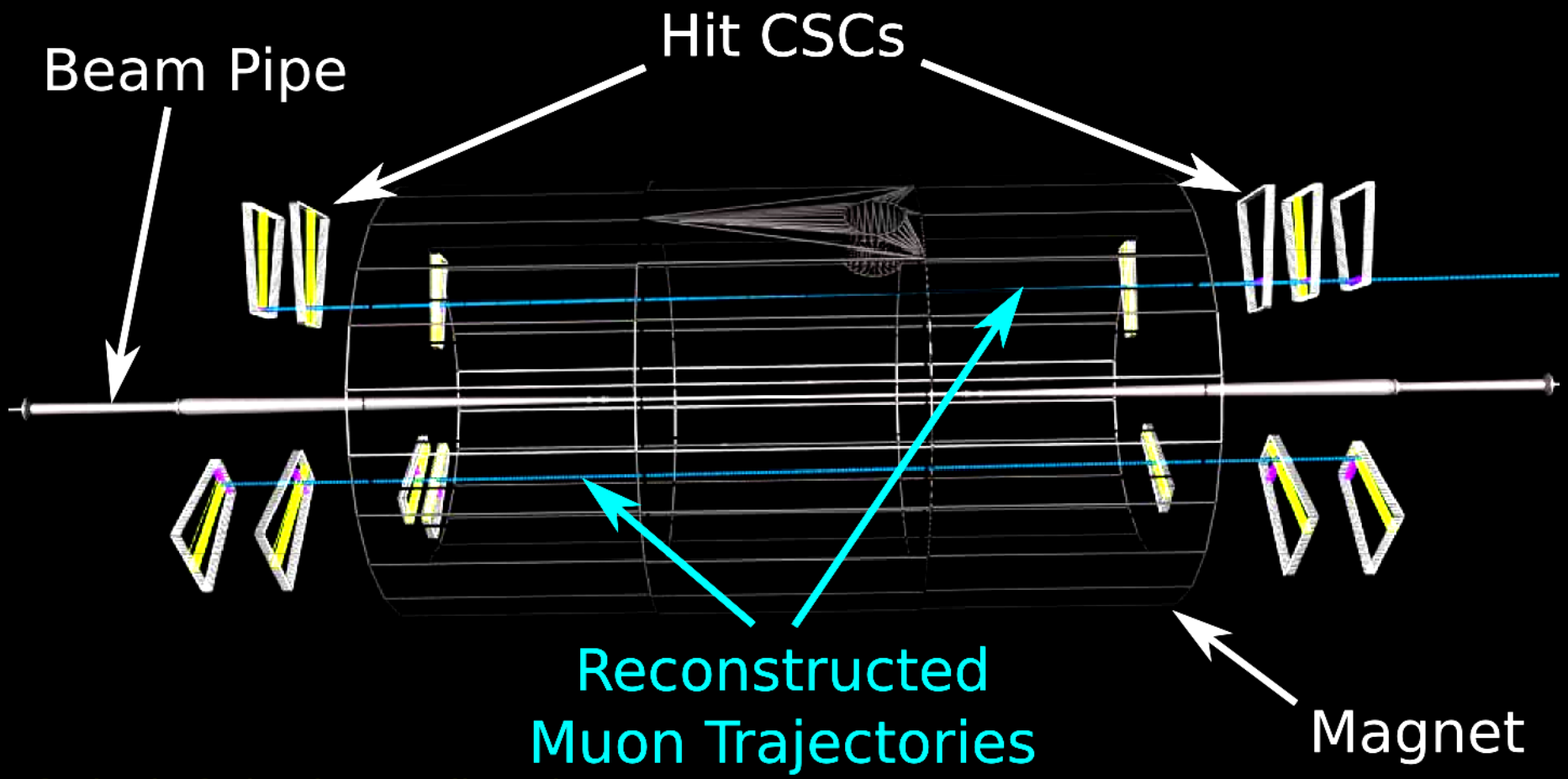


- Final CSC affixed to iron disk: February 2007
- Final disk lowered to underground cavern: January 2008
- First LHC beam: September 2008
  - Only 18 months to ready $\sim 4 \times 10^5$ data channels from $\sim 1.4 \times 10^4$ electronics boards!

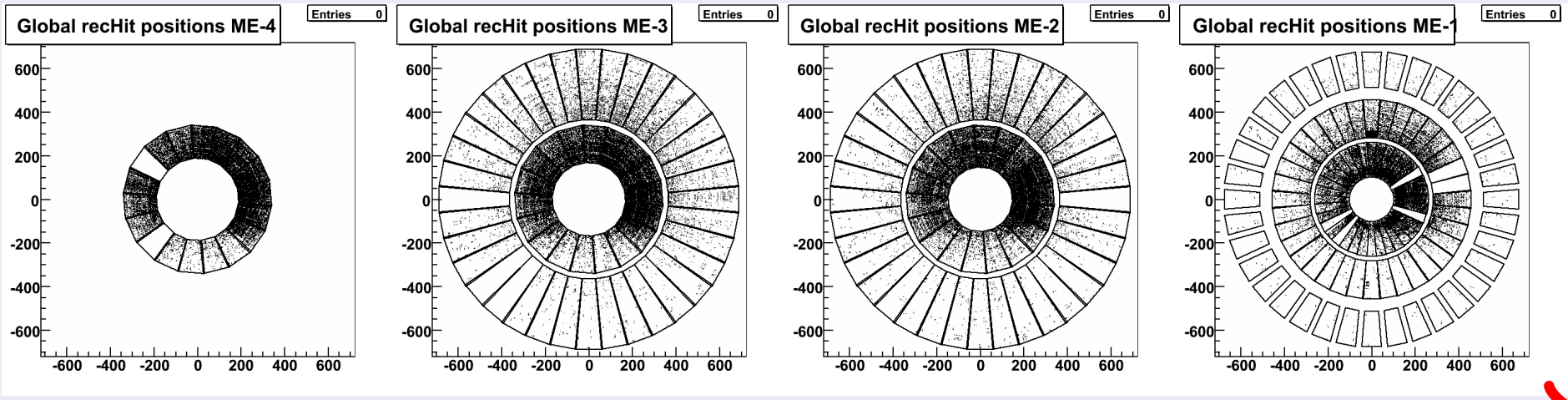
September 11, 2008

- LHC successfully captured and circulated a beam of protons in the anti-clockwise direction for a total of 12 minutes
- Collisions of protons with beam-pipe gas generates a "halo" of muons around the beam-pipe traveling nearly parallel to it



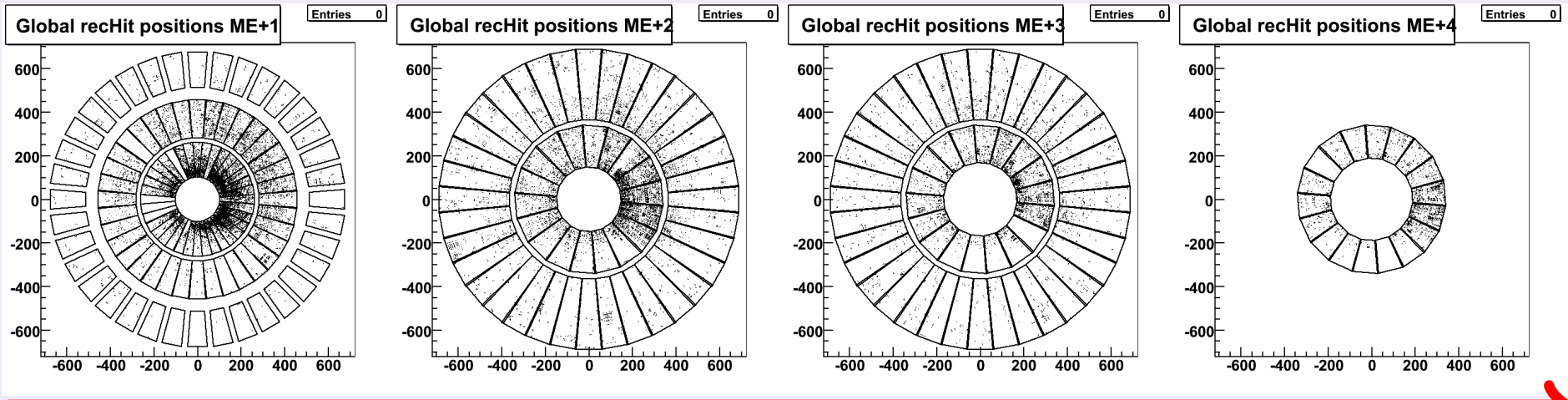

Beam Pipe
Hit CSCs
Reconstructed
Muon Trajectories
Magnet
Cathode Strips (φ-coordinate)
Anode Wires (r-coordinate)

-Z Endcap



Beam Direction

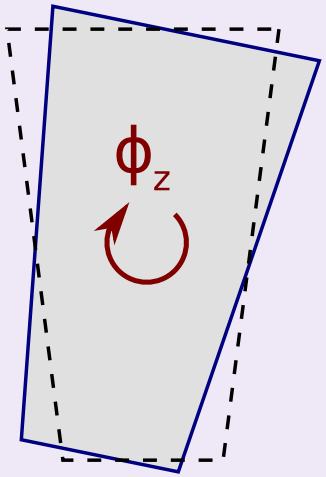
+Z Endcap

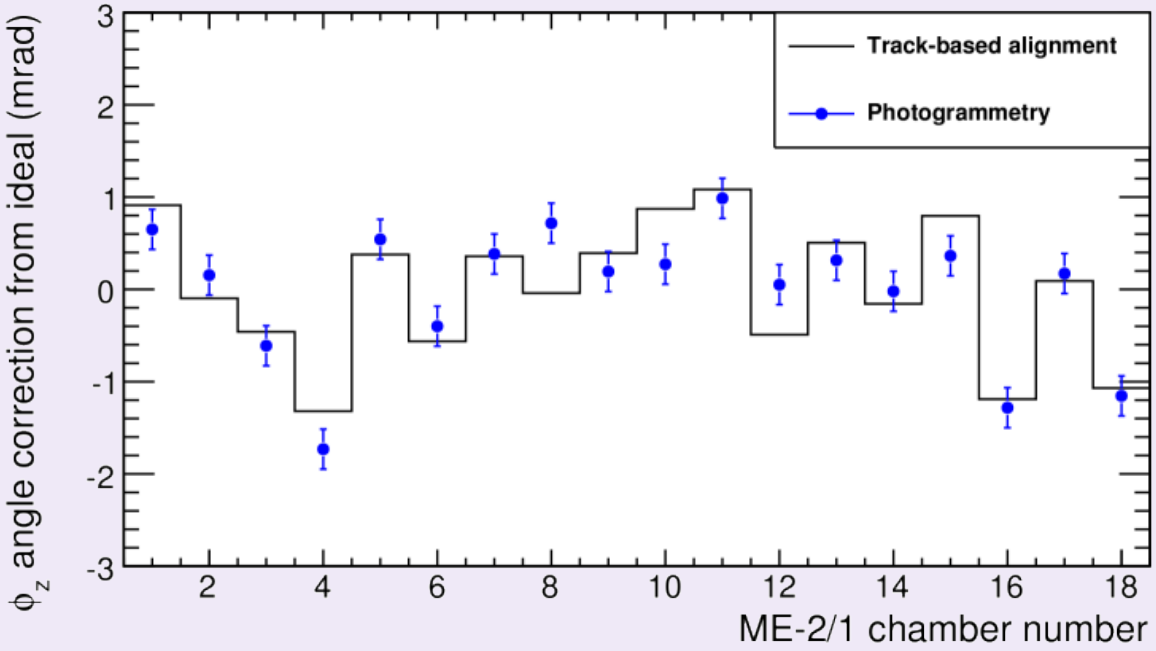


Beam Direction

CSCs employ two independent methods of spacial alignment:

- Hardware-based
  - Uses lasers and photogrammetry to align points on the CSCs to other points on the detector
  - Rough estimate of positions
- Track-based
  - Uses through-going muons to align overlapping detector regions to each other
  - Ultimate alignment method (using IP-muons)

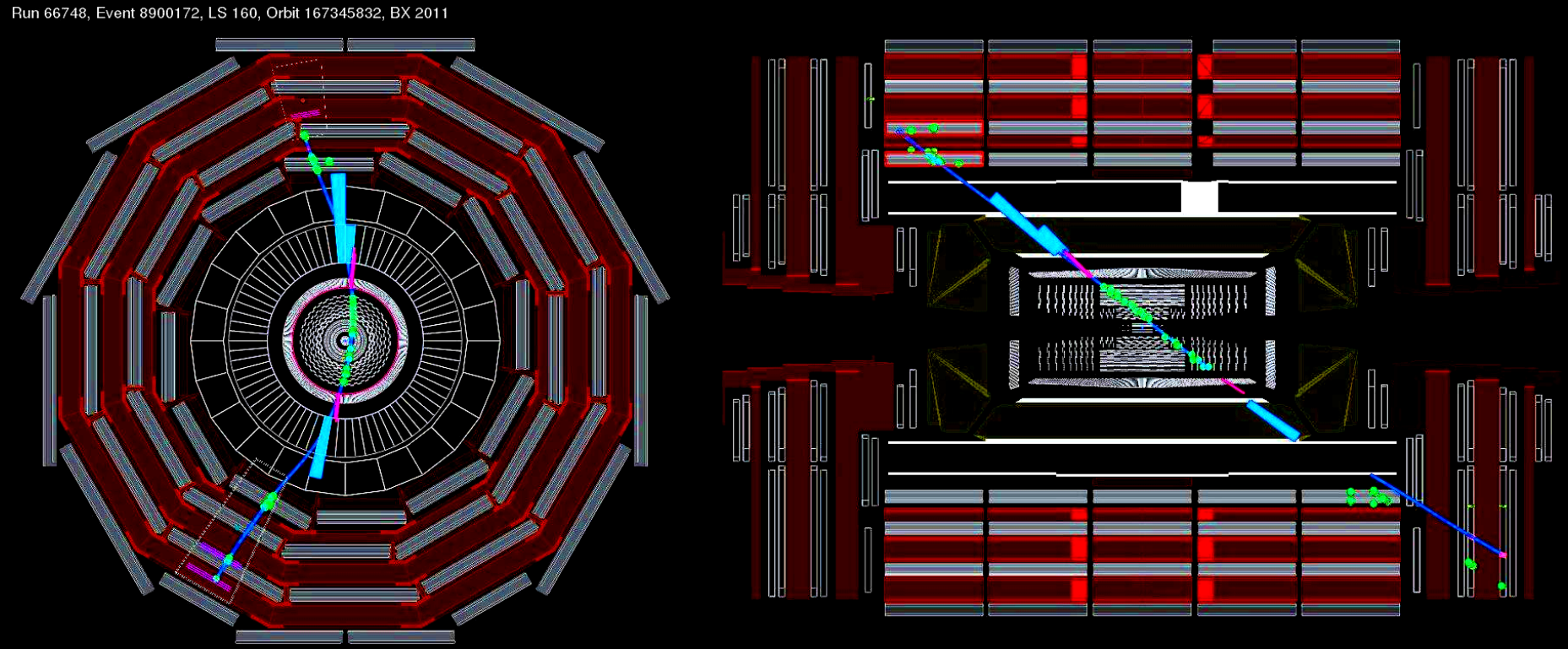


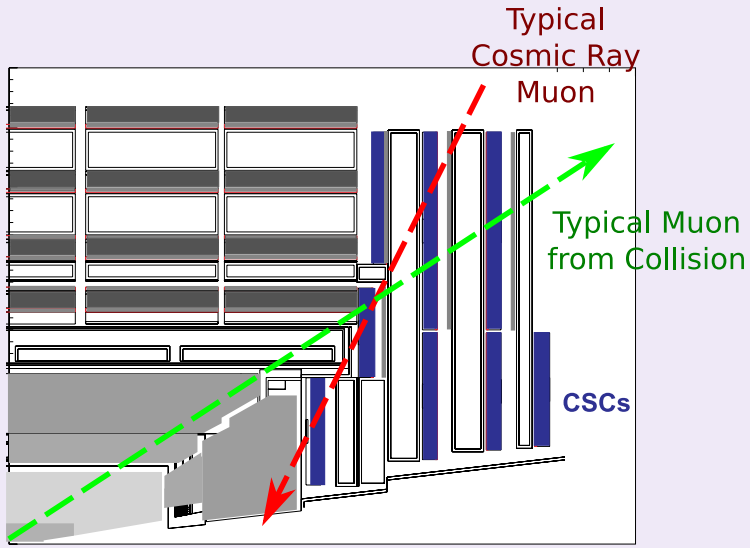


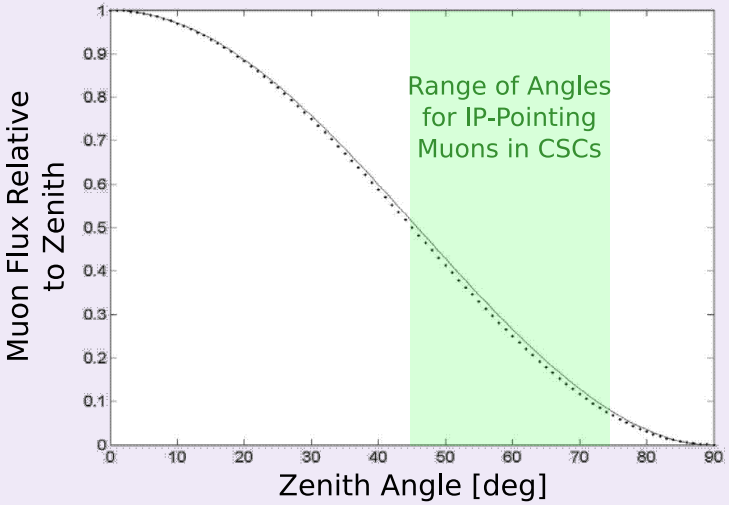
- Track-based method agrees with photogrammetry to ~ 0.5 mrad

Jim Pivarski (Texas A&M)

- Since the LHC incident on September 18, 2008, CMS had only cosmic ray muons to use for commissioning...
- From October 13 to November 11, all of CMS participated in a global cosmic ray data-taking run dubbed "CRAFT":
  - $\sim 3.7 \times 10^8$ cosmic ray events recorded
  - $\sim 2.9 \times 10^8$ of those with an operating magnetic field at 3.8T
  - $\sim 1.4 \times 10^7$ of those with muons reconstructed in the CSCs
  - $\sim 1.2 \times 10^5$ of those with muon trajectories that take them close to the interaction point (IP-pointing)


Run 66748, Event 8900172, LS 160, Orbit 167345832, BX 2011





The CMS CSCs were designed for muons...

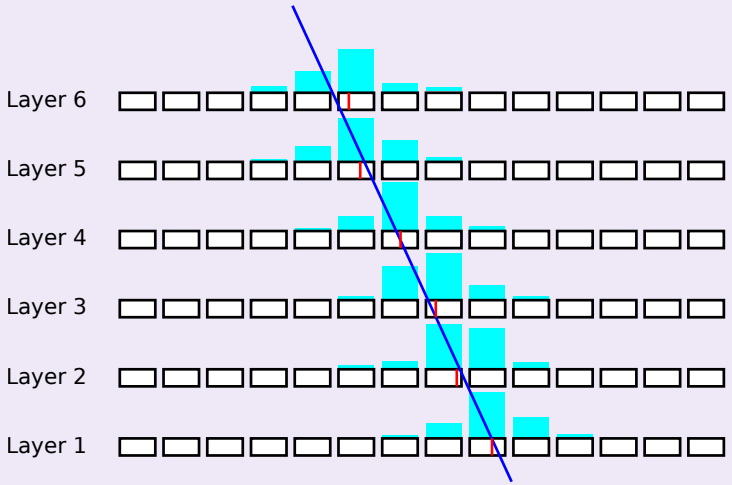
- coming from the interaction point
- at a rate of $\sim 10^4$ Hz

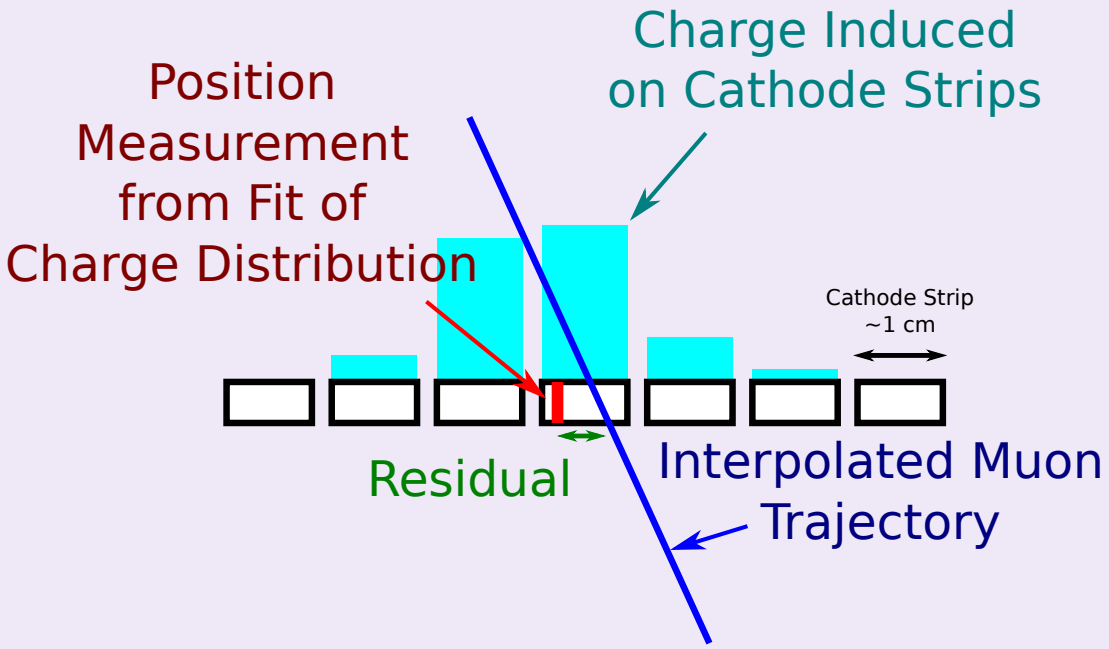
Cosmic rays give us muons...

- coming mostly from the vertical direction
- at a rate of ~ 60 Hz

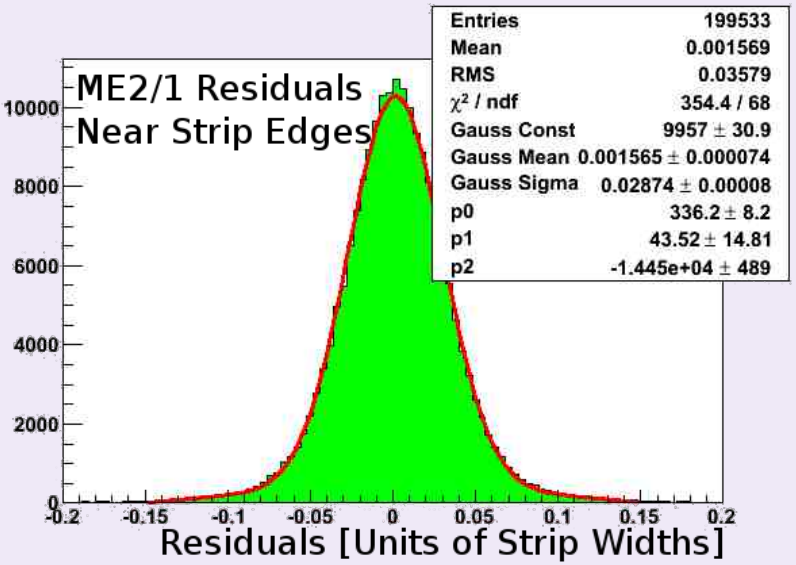
L.N. Bogdanova, et al., *Phys. Atom. Nucl.* **69** (2006) 1293; arXiv:nucl-ex/0601019v1

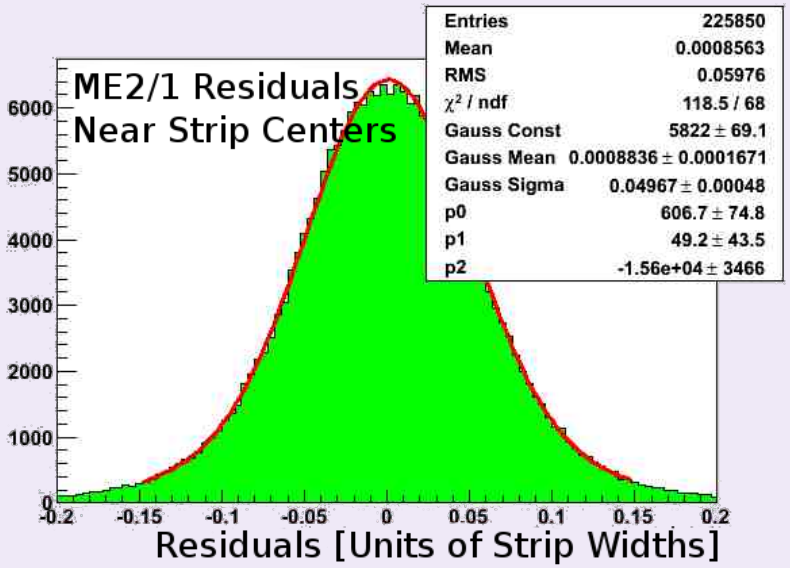
Local Position Resolution



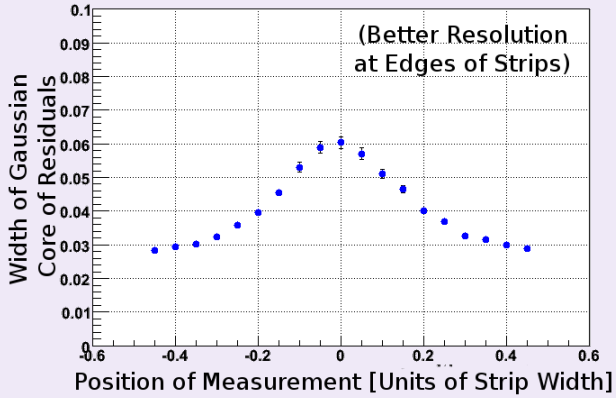


- Each CSC has six planes of anode wires and cathode strips
- The intersection of a strip and a wire group produces an independent 2D measurement (a "hit") of a point on the muon's trajectory in each layer
- Use hits from layers 1, 2, 4, 5, and 6 to interpolate where the hit in layer 3 should be and calculate residual



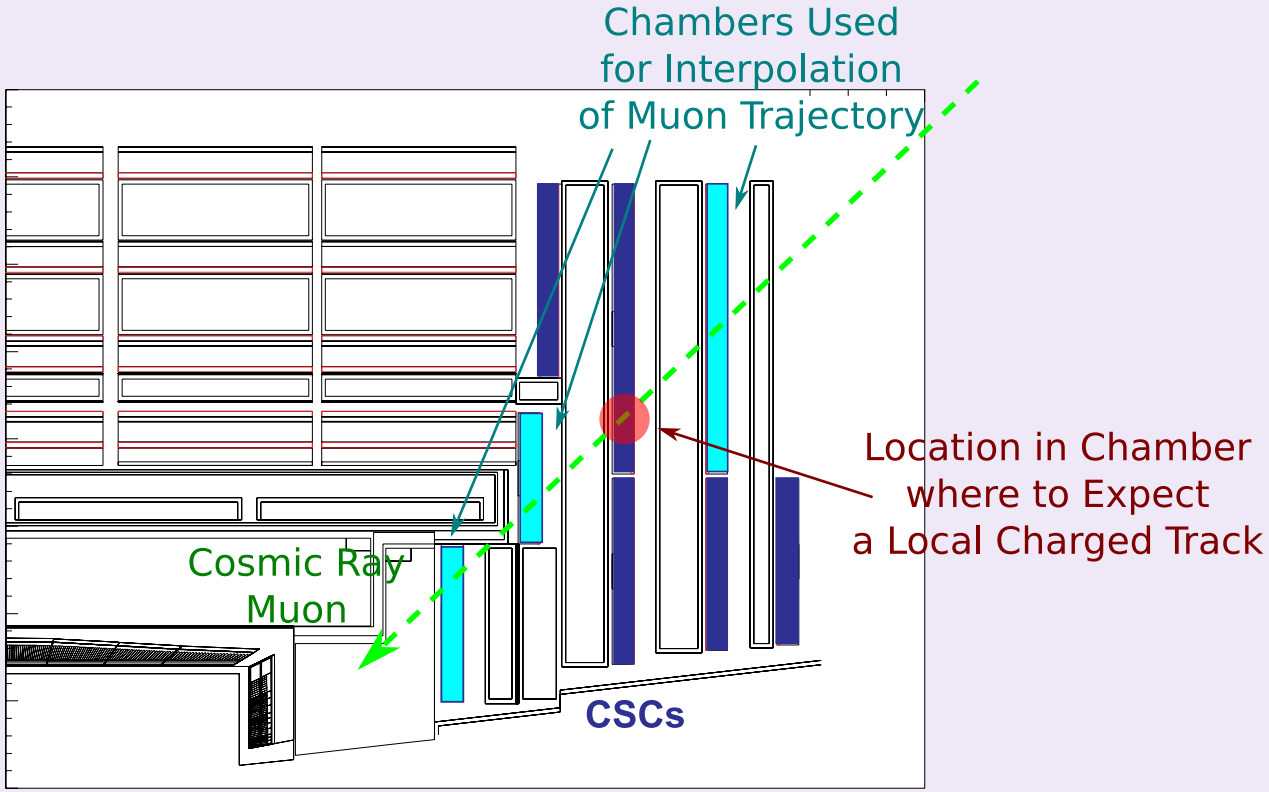


- $\sim 161\ \mu\mathrm{m}$ chamber resolution (after convolution of gaussians)
- Hits near strip edges have better resolutions because of the shape of the fit



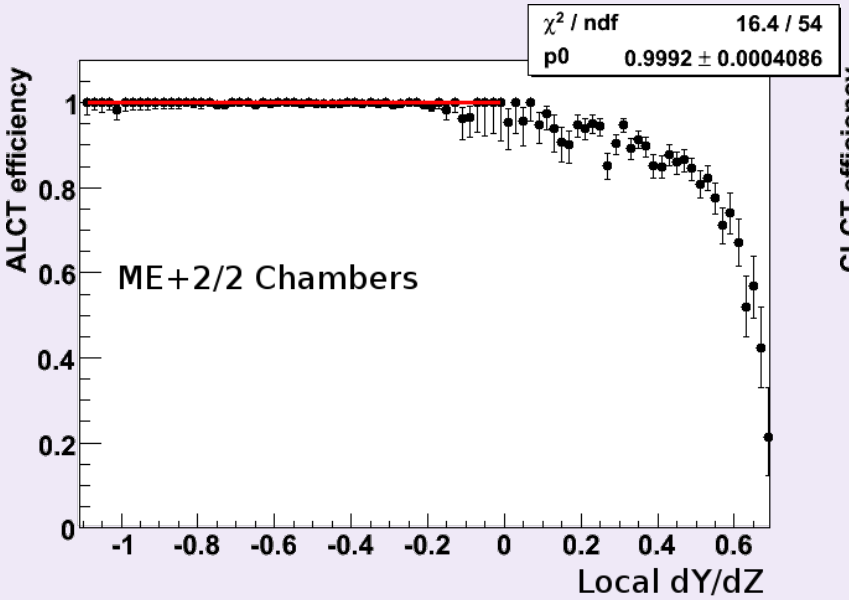
Vladimir Palchik (JINR)

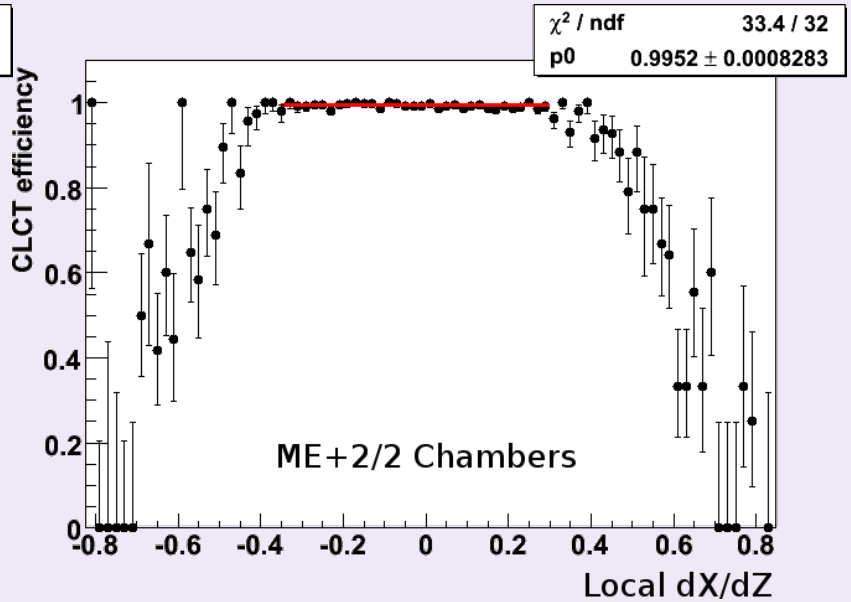
Local Charged Track (LCT) Efficiencies

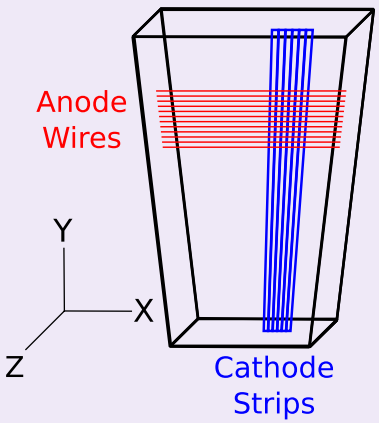


- Use 3/4 stations in a given endcap to interpolate where the muon trajectory should pass through the 4th station
- Look for local charged tracks (trajectory segments) in that neighborhood

Results

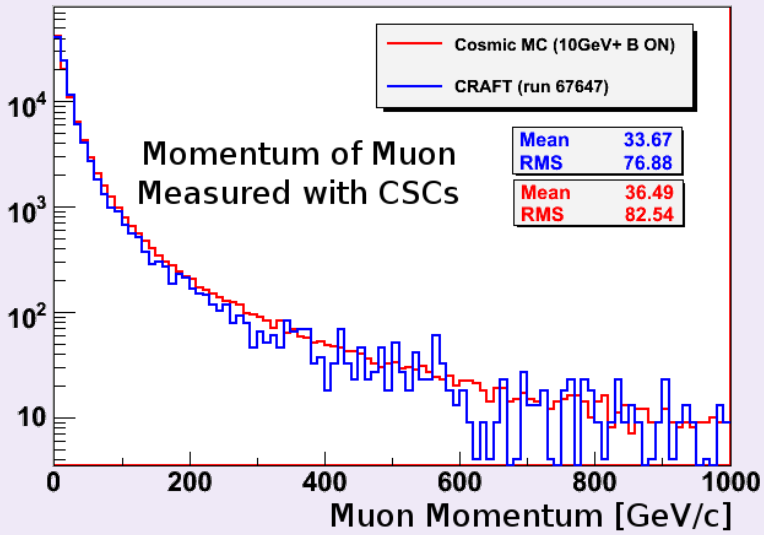


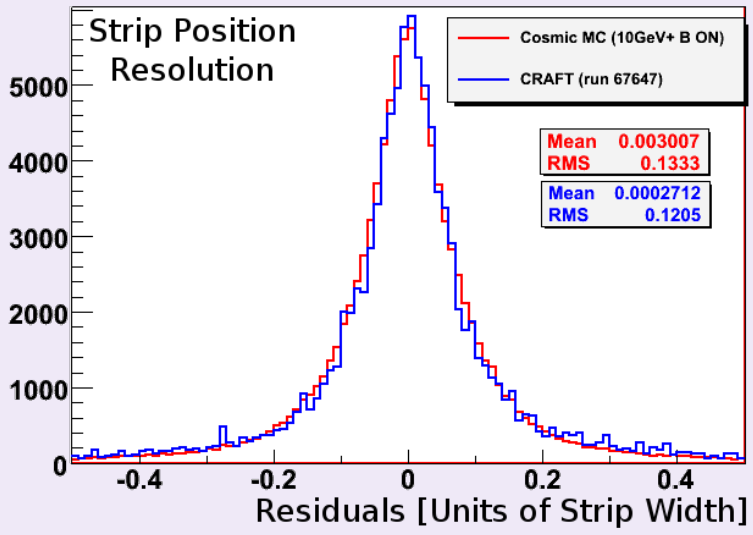




- $>$ 99.5% trigger efficiency in trigger window (IP-pointing, high-p_T)

Stoyan Stoynev (Northwestern)





- Cosmic ray muon MC run through a full CMS detector simulation
- Similarity in comparison demonstrates a good understanding of the detector

Andy Kubik (Northwestern)

Conclusions

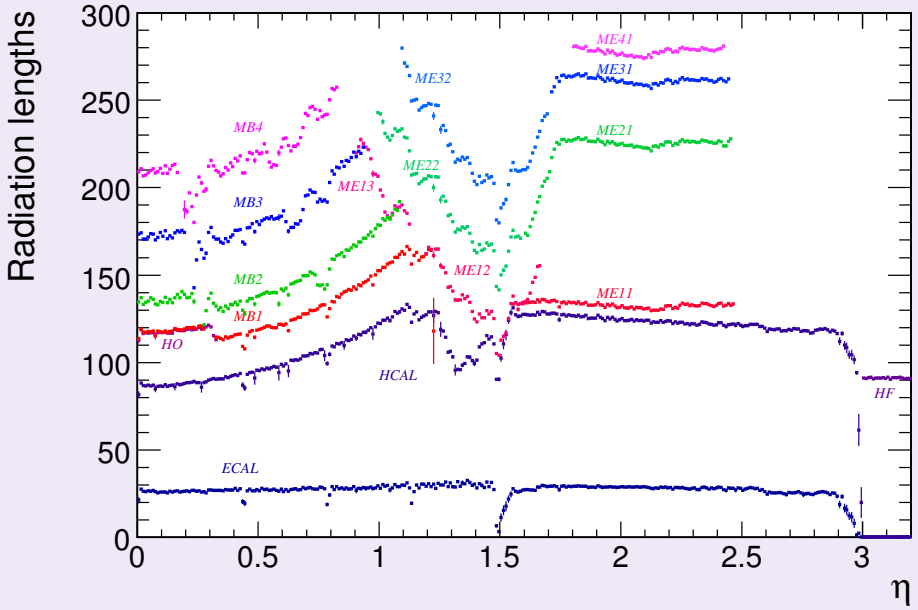
- We have built and deployed the world's largest cathode strip chamber muon spectrometer, and it works!
  - Efficient triggering
  - Improved momentum resolution
- We have been performing commissioning and performance studies on the CSCs using 12 minutes of beam halo data and 1 month of cosmic ray data
- These results show we have a strong understanding of the response of the system to real muons
- We are learning more every day how to maximize the CSCs' usefulness for the upcoming LHC beam

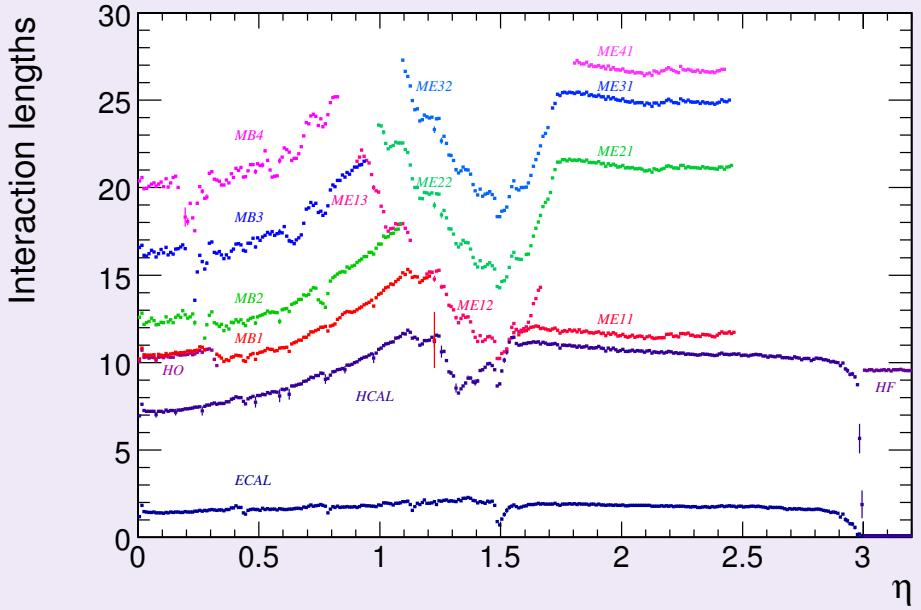
The success of this commissioning effort is due to the incredible work of the dedicated physicists, engineers, and graduate students of the CMS CSC collaboration.

Thank you.

Backup Slides

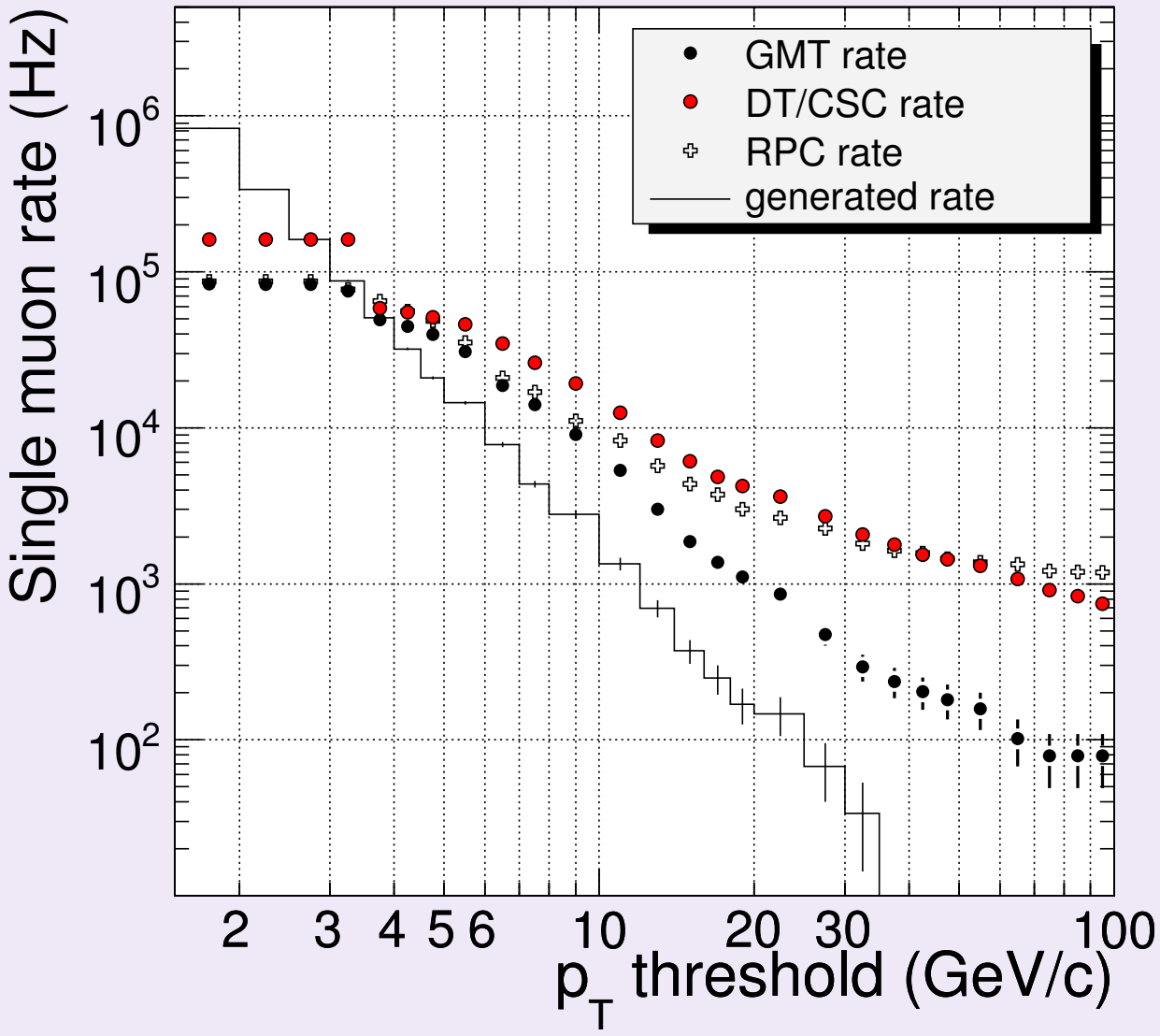
Radiation & Interaction Lengths





The CMS Collaboration 2006, CERN-LHCC-2006-001

Trigger Rates



The CMS Collaboration 2006, CERN-LHCC-2006-001