Status of the Compact Muon Solenoid (CMS) Detector

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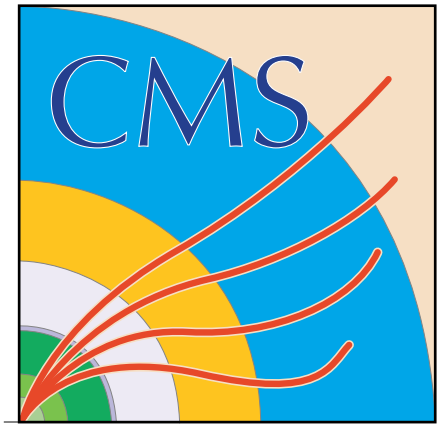


Division of Particles and Fields

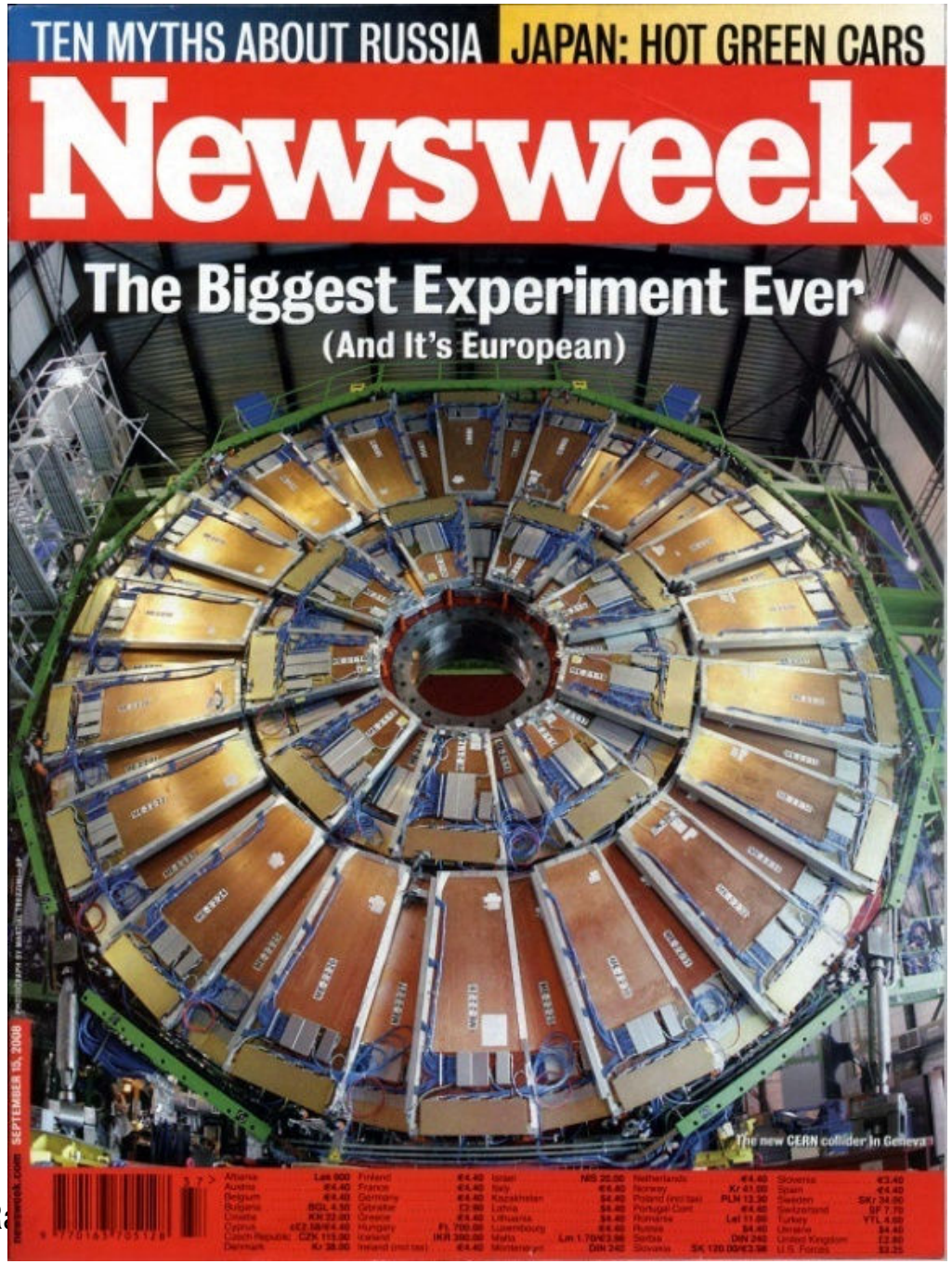
26 July 2009

Wayne State University

Outline

- Design of the CMS experiment
- Performance validation with cosmic rays
- What we saw during 10 minutes of beam in September 2008

… and how these data tell us that CMS is ready for physics…

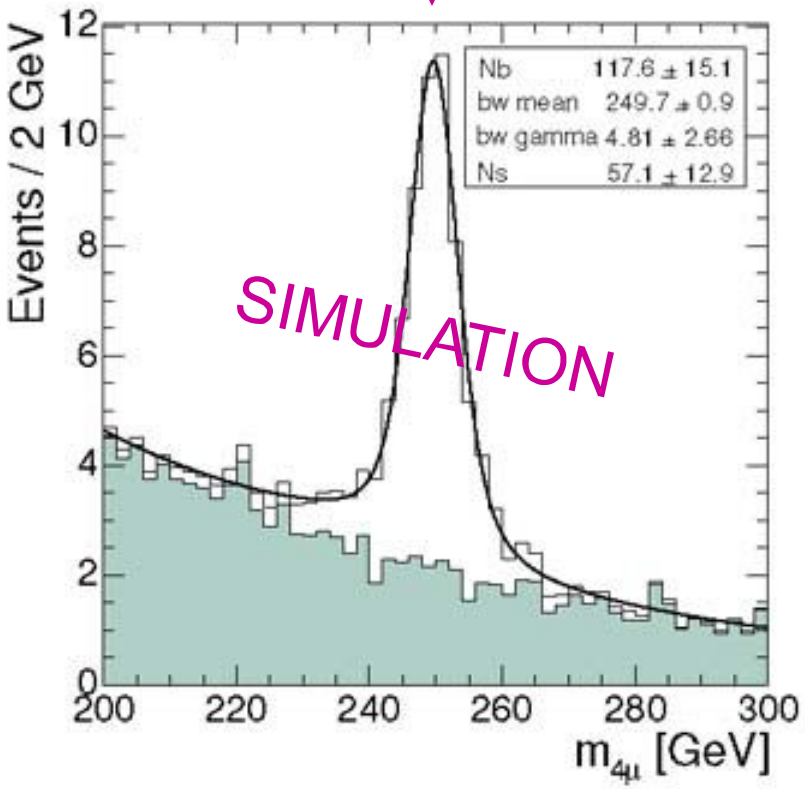


CMS Design: Discover New Physics

Some observables which must be detectable…

- $H \rightarrow Z + Z \rightarrow 4\mu$?
- $t + \bar{t} \rightarrow$ b-jet + $\bar{b}$-jet + 2μ
- $Z' \rightarrow e^+ + e^-$?
- $H \rightarrow \gamma + \gamma$?
- $H \rightarrow \tau + \tau \rightarrow l$ + jet?
- Missing E_T
- Di-jets
- Heavy Ions
- **… and more…**

CMS Collab. 2007, *J. Phys. G: Nucl. Part. Phys.* **34** 995–1579.



CMS is an experiment in the Large Hadron Collider

LHC parameters:

- Proton + proton collisions with center-of-mass energy **14TeV**
- Peak Luminosity **~ $10^{34}/cm^2/sec$**

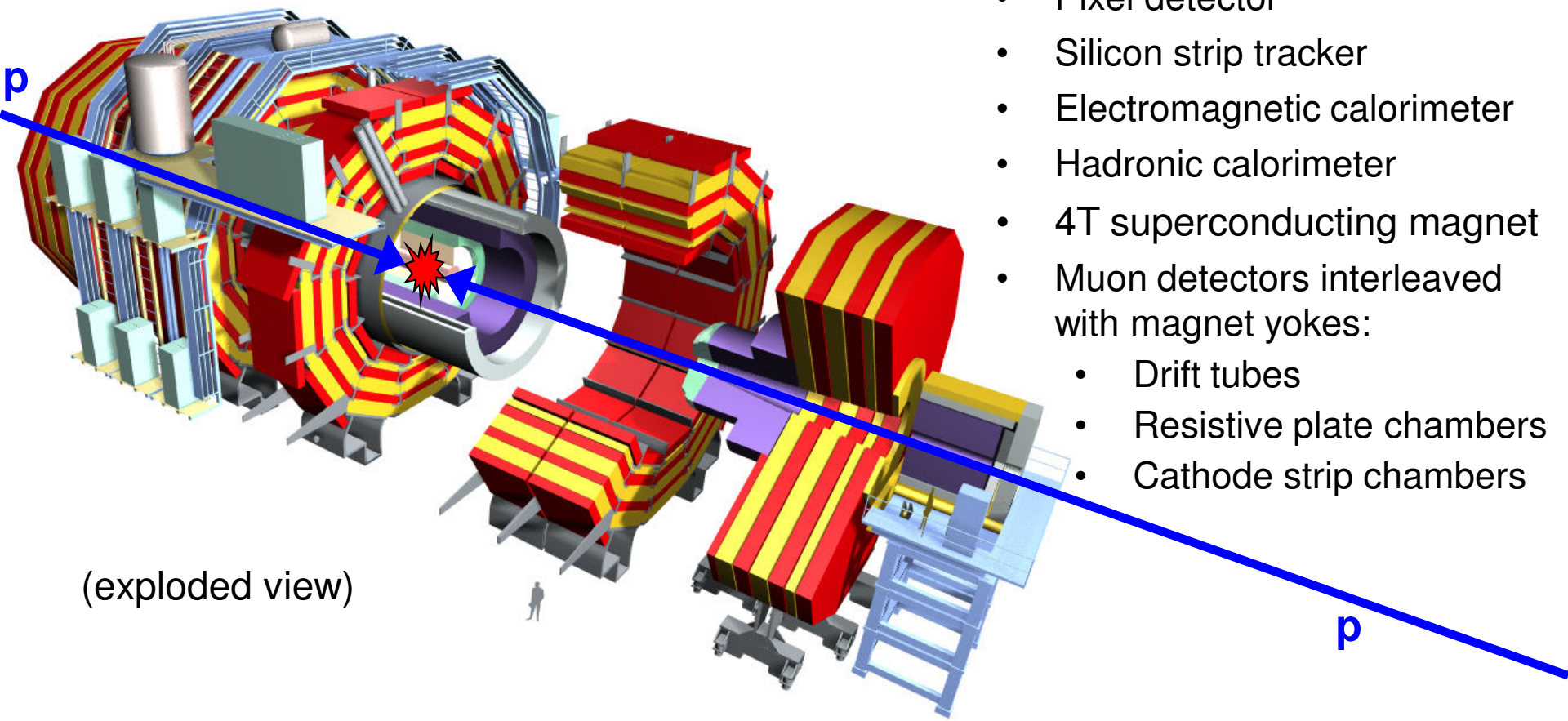
→ ~10^9 inelastic collisions/sec

→ ~20 events per crossing (40MHz)

Compact Muon Solenoid (CMS)

From the Interaction Point → out:

- Pixel detector
- Silicon strip tracker
- Electromagnetic calorimeter
- Hadronic calorimeter
- 4T superconducting magnet
- Muon detectors interleaved with magnet yokes:
  - Drift tubes
  - Resistive plate chambers
  - Cathode strip chambers



(exploded view)

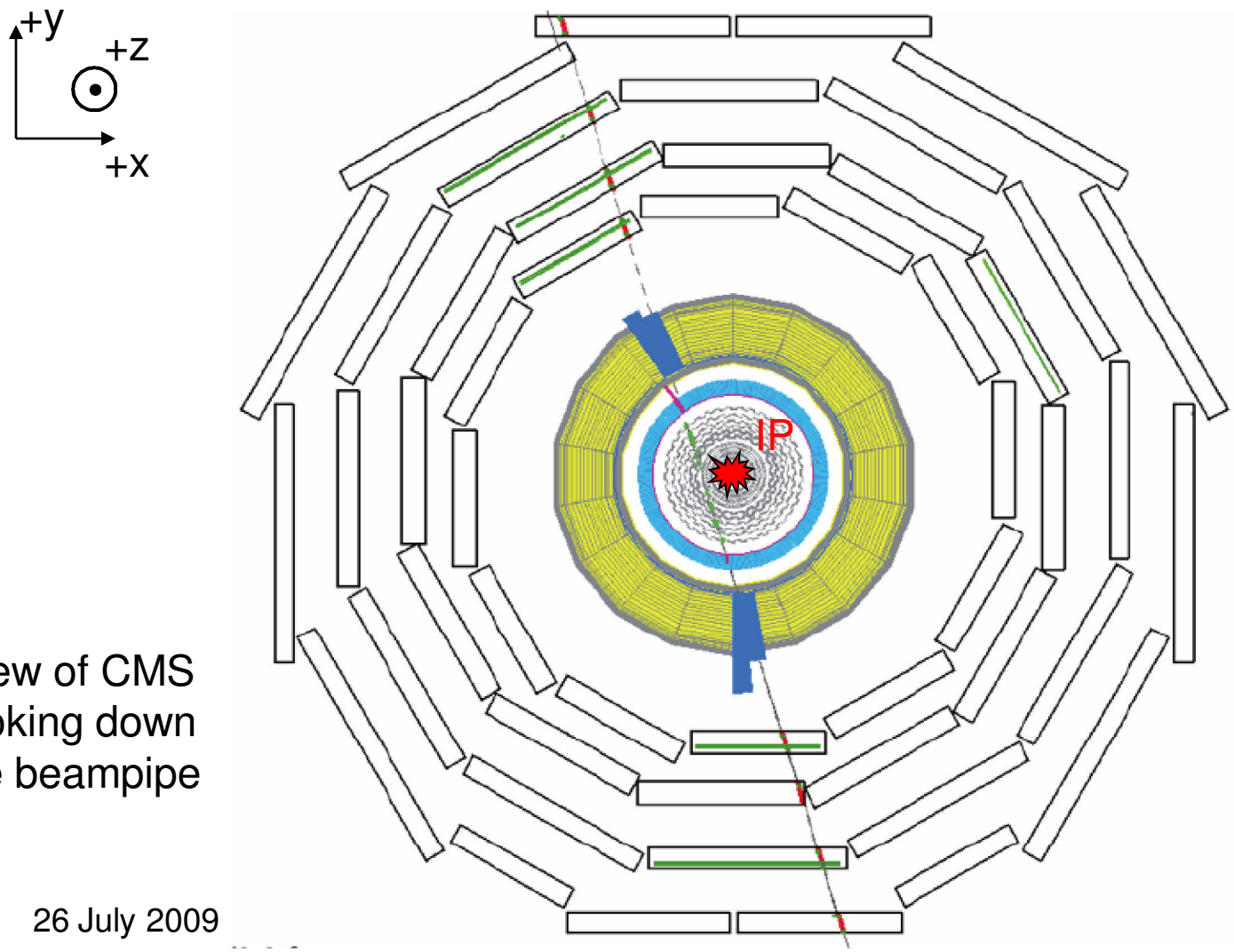
Detector requirements to extract the desired physics are specified in the Technical Design Report: CERN-LHCC-2006-001

It's been built. **Does it meet the specifications?**

Commissioning CMS: Response to Cosmic Rays

(Summer 2006 – now…)

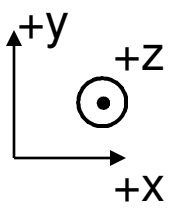
Event Display of Cosmic Ray with Magnetic Field OFF

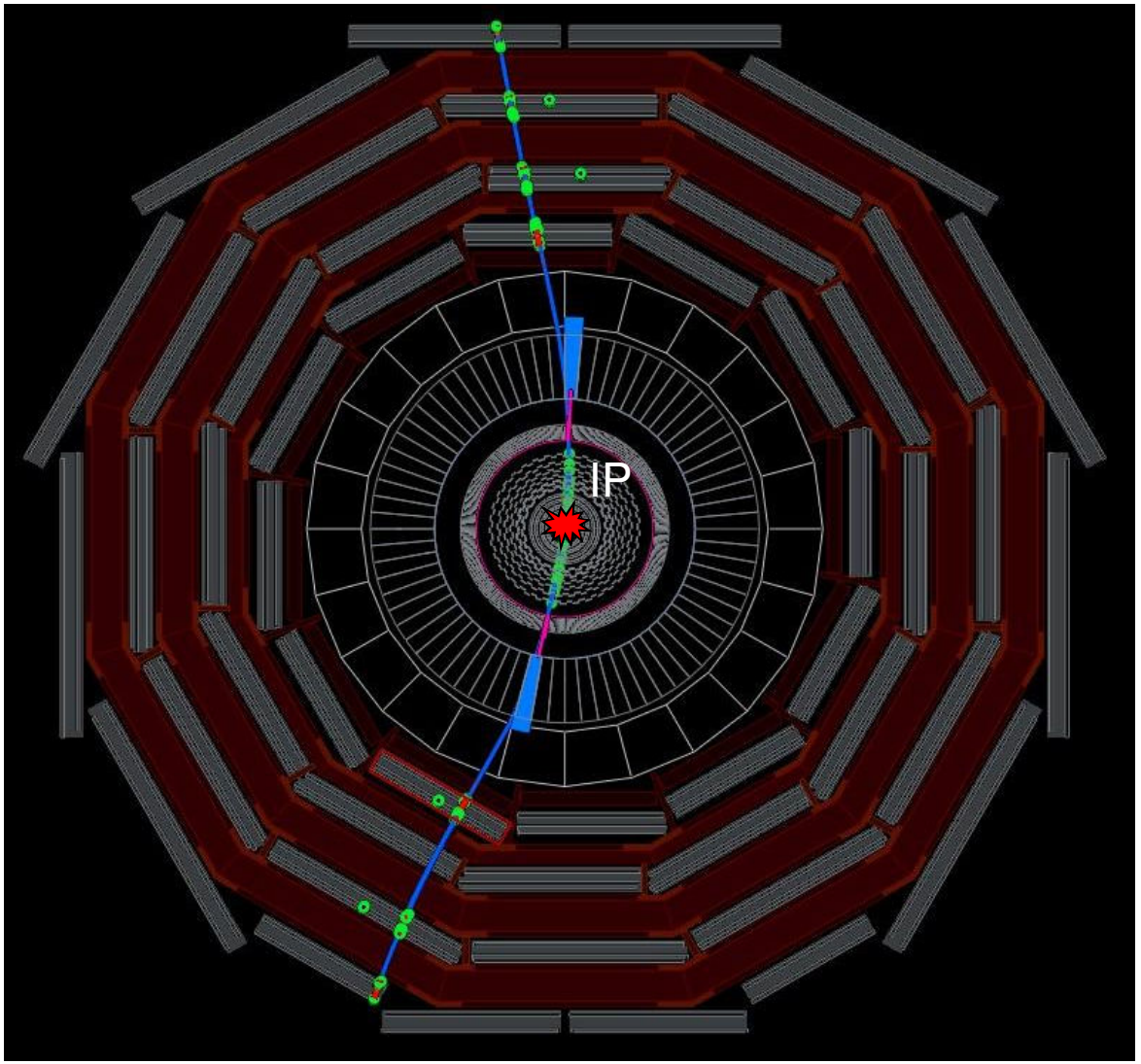


View of CMS looking down the beampipe

Cosmic ray enters CMS from the top (+y), passes near the Interaction Point (IP), exits CMS at the bottom (–y)

Event Display of Cosmic Ray with Magnetic Field ON (3.8T)





CMS Magnet:
- 6m diameter
- 13m long
- 4T max field
- Stored energy = 2.5GJ

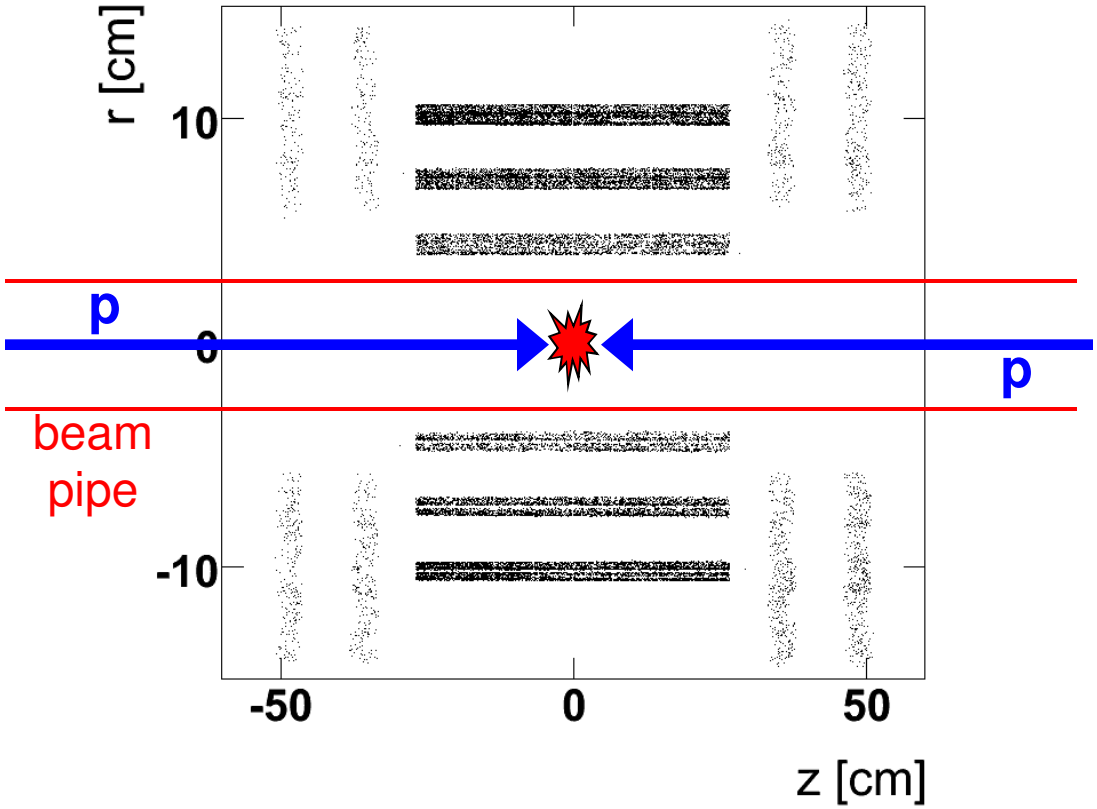
Solenoidal field in the z-direction bends the cosmic ray in the r-φ plane

View of CMS looking down the beampipe

CMS Pixel Detector

Physics example: find displaced vertices from
$t + \bar{t} \rightarrow b\bar{b}WW \rightarrow 2\ \text{jet} + 2\mu$

Hitmap of cosmic ray data in the pixel detector (B = 3.8T): ~75k events



66M pixels

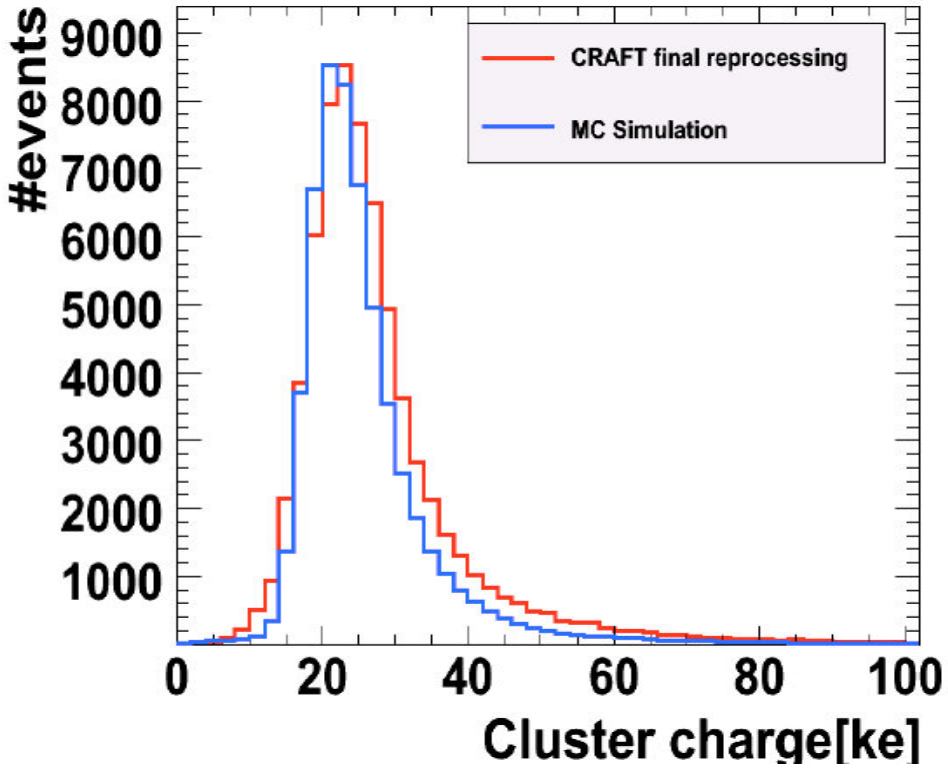
>99% operational

→ At full luminosity the pixel occupancy will be $<10^{-4}$/crossing

→ **Will be able to resolve individual tracks in a high multiplicity environment**

Response of CMS Pixel Detector to Cosmic Rays

Cluster charge associated with cosmic ray tracks:



→ Data calibrated for gains

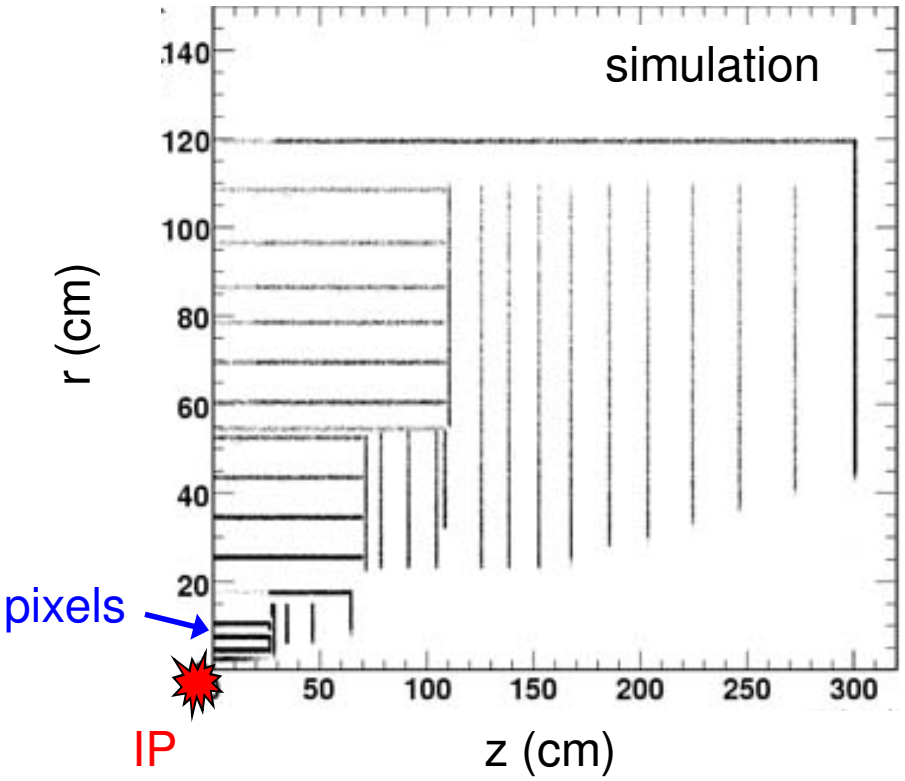
→ Simulation uses ideal gain calibration without charge smearing

→ **Pixel response to muons well described by a Monte Carlo simulation**

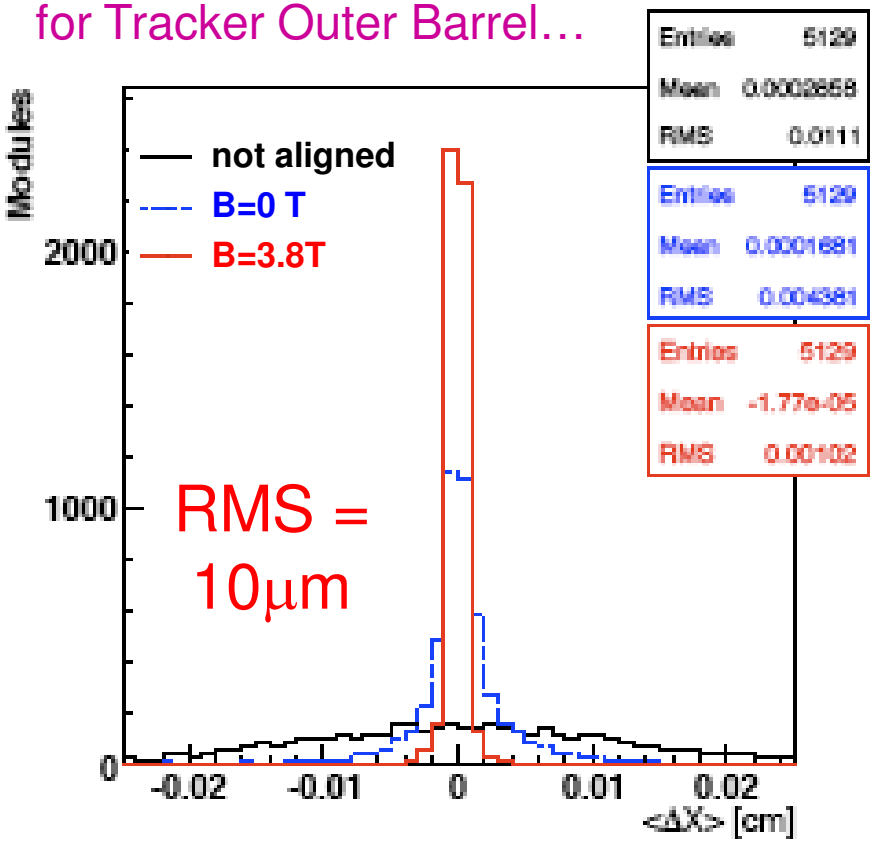
CMS Silicon Tracker

Physics example: accurately measure the large momentum of muons from $Z' \rightarrow \mu^+ + \mu^-$

Quarter r-z view of tracker:



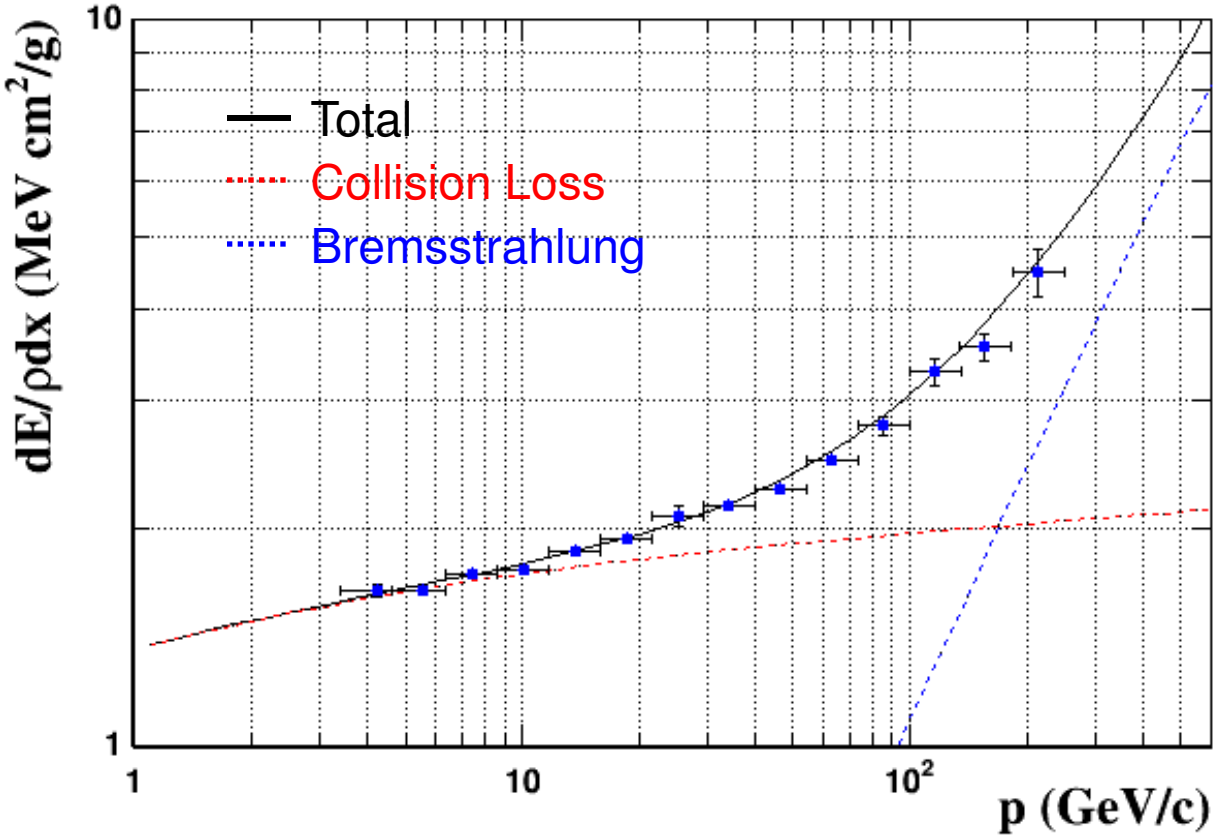
Cosmic rays: median of residuals for Tracker Outer Barrel…



→ **The quality of this cosmic ray alignment is comparable to what will be obtained with 10–50/pb of collision data**

CMS Electromagnetic Calorimeter

Physics example: H → γ + γ…



Energy loss per unit length for muons is well described by Particle Data Group's description of stopping power in $PbWO_4$

Demonstrates reasonable understanding of…

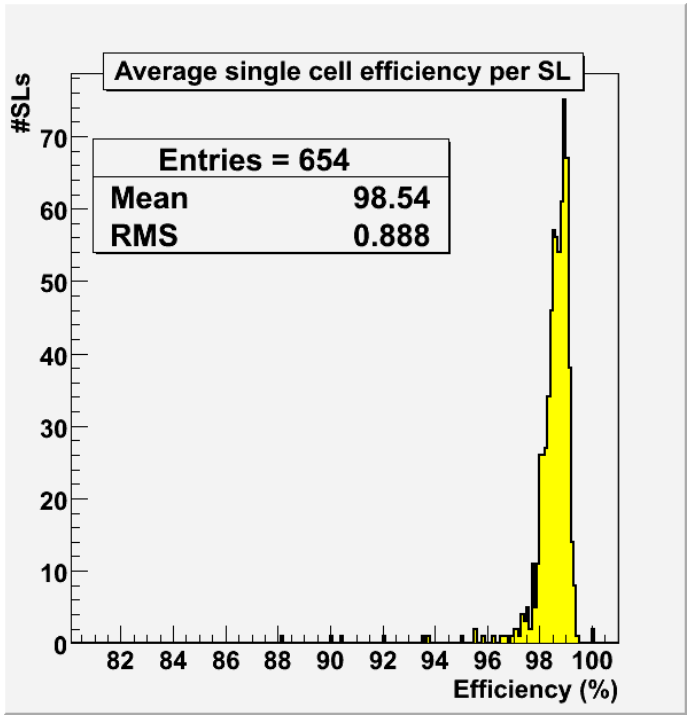
- **Momentum scale of tracker**
- **Energy scale of electromagnetic calorimeter**

CMS Muon Systems (Barrel): Drift Tubes and Resistive Plate Chambers

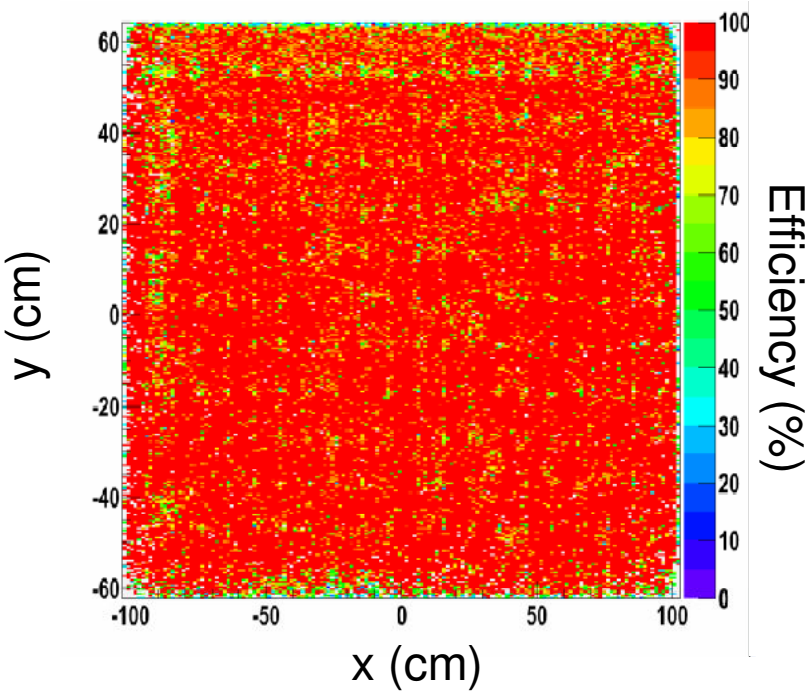
Physics example: trigger on W → μ (+ ν)

Measure efficiency with cosmic ray data (at 3.8T)…

Drift Tubes:



Resistive Plate Chambers:

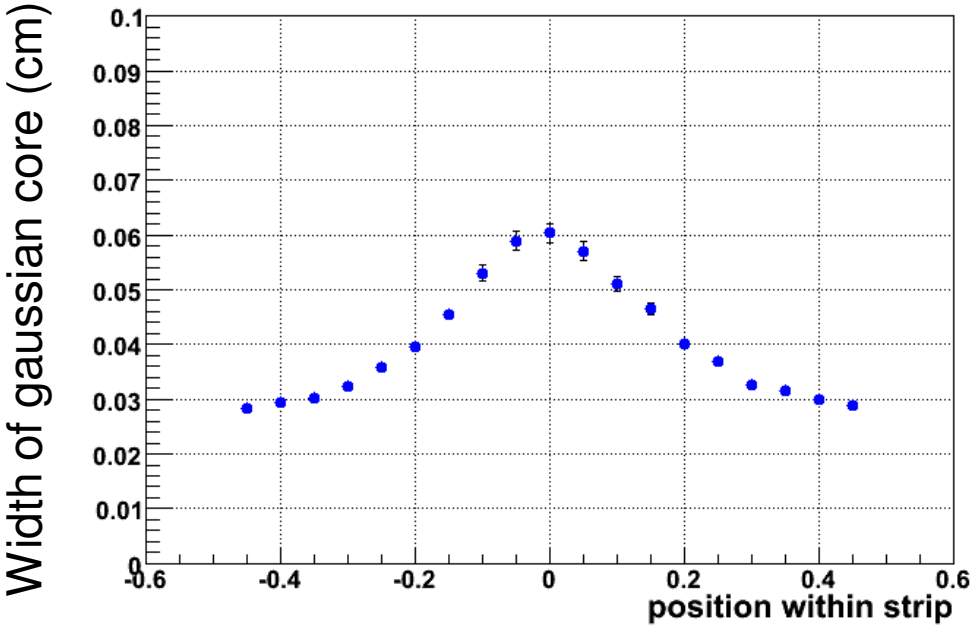


Conclusion: overlap of technologies → efficiency > 99%

CMS Muon Systems (Endcap): Cathode Strip Chambers

Physics example: trigger on H → μ + μ + μ + μ

Use cosmic ray data to measure residuals…



(Resolution is better at the edges of the strips because the charge is shared between strips)

Convoluting 6-layers of staggered strips gives

chamber resolution of σ = 160μm

(requirement for physics: σ ~ 150μm)

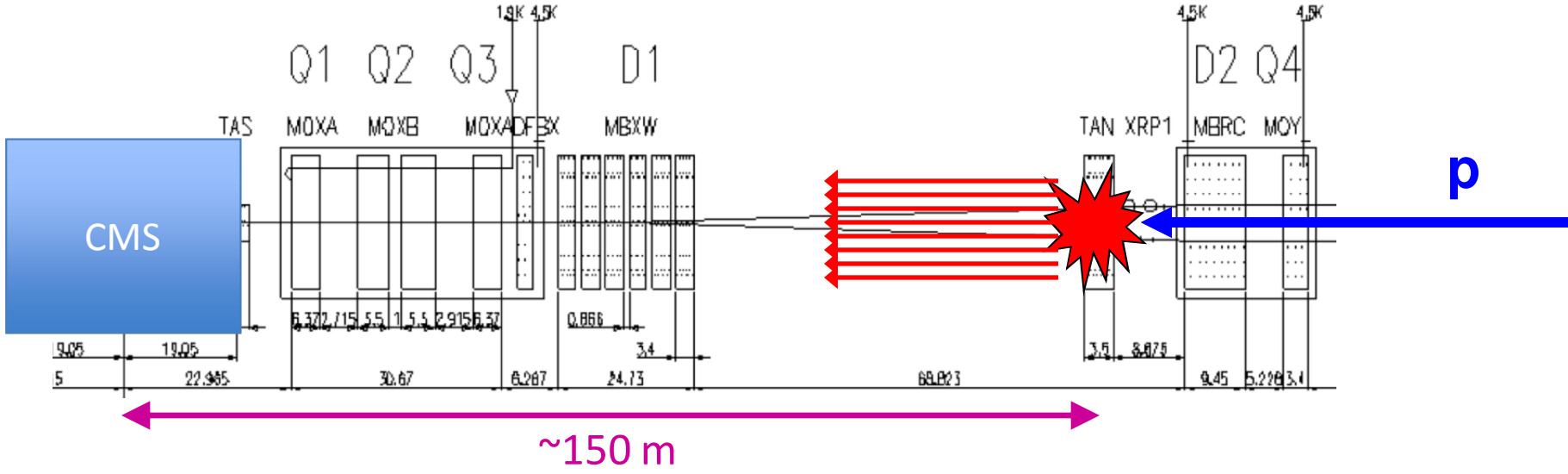
The response of CMS to cosmic rays looks good.

How about something more substantial?

CMS response to LHC "Beam Splash" events

(9 Sept. 2008)

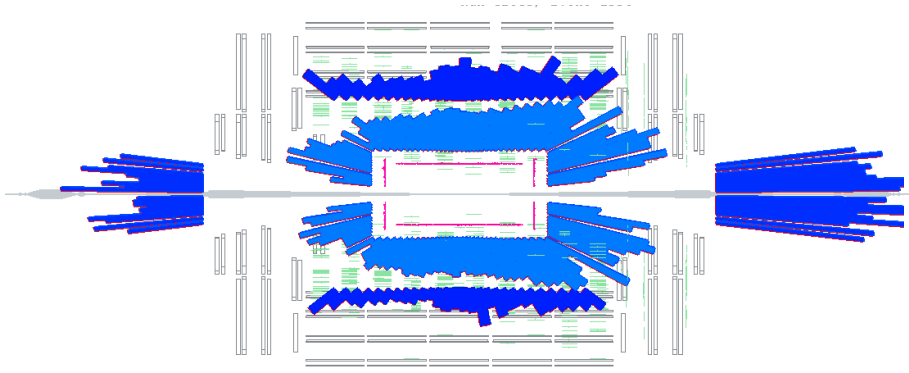
Beam splash = ~2 x 10^9 protons at 450 GeV/c incident on collimators ~150m upstream of CMS



BEAM SPLASH in CMS

Reconstructed segments in Cathode Strip Chambers…

Energy in Hadronic Calorimeter:



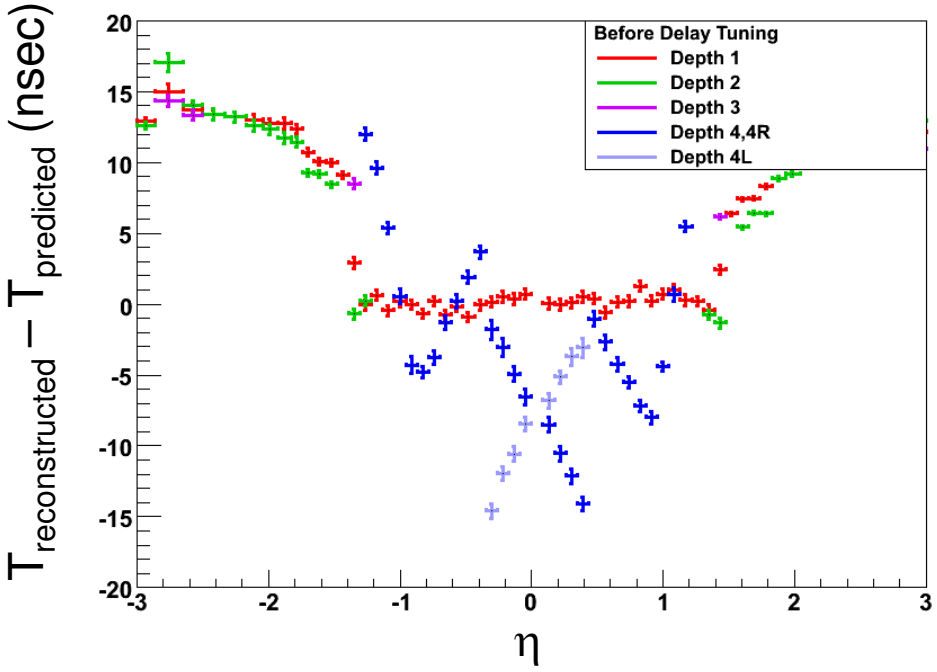
Energy in Electromagnetic Calorimeter:

CMS Hadronic Calorimeter

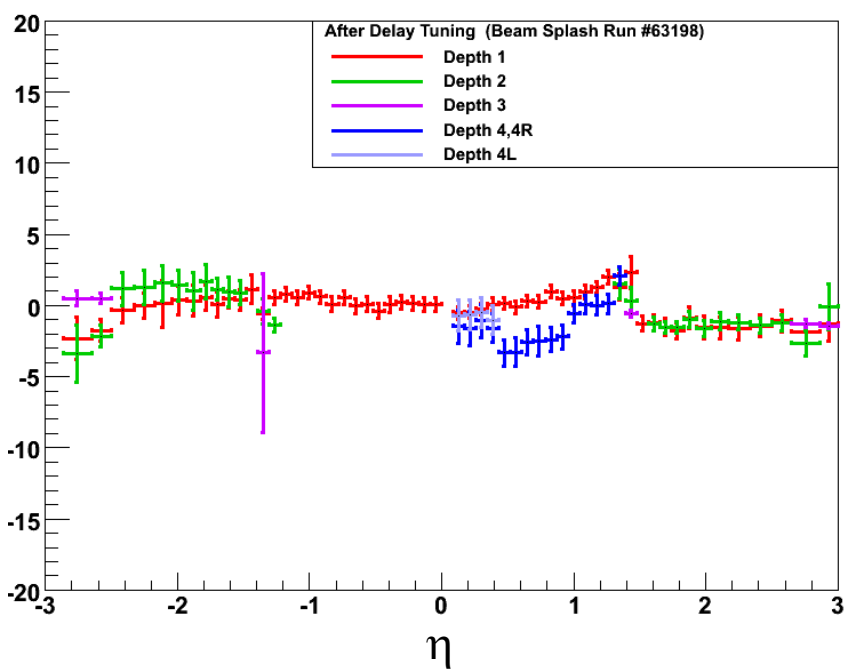
Physics example: accurately measure
SUSY particles → jets + "missing" transverse energy

Timing corrections from synchronous "Splash" events

Before corrections…



After corrections…



→ Nanosecond-scale synchronization will be achieved with collision events

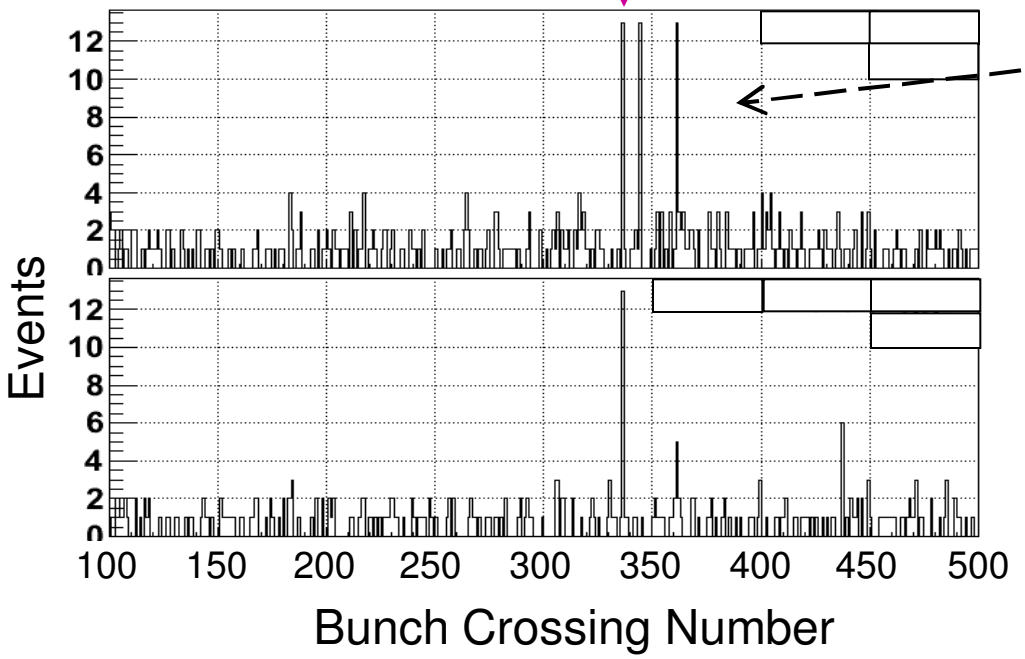
CMS Level-1 Trigger

Physics example: Readout 10^5 interesting events/second out of 10^9 interactions/second

"Beam Splash" events:

Hadronic Calorimeter

Cathode Strip Chambers



(Three pulses caused by afterpulsing in photodiodes filtered by CMS trigger rules)

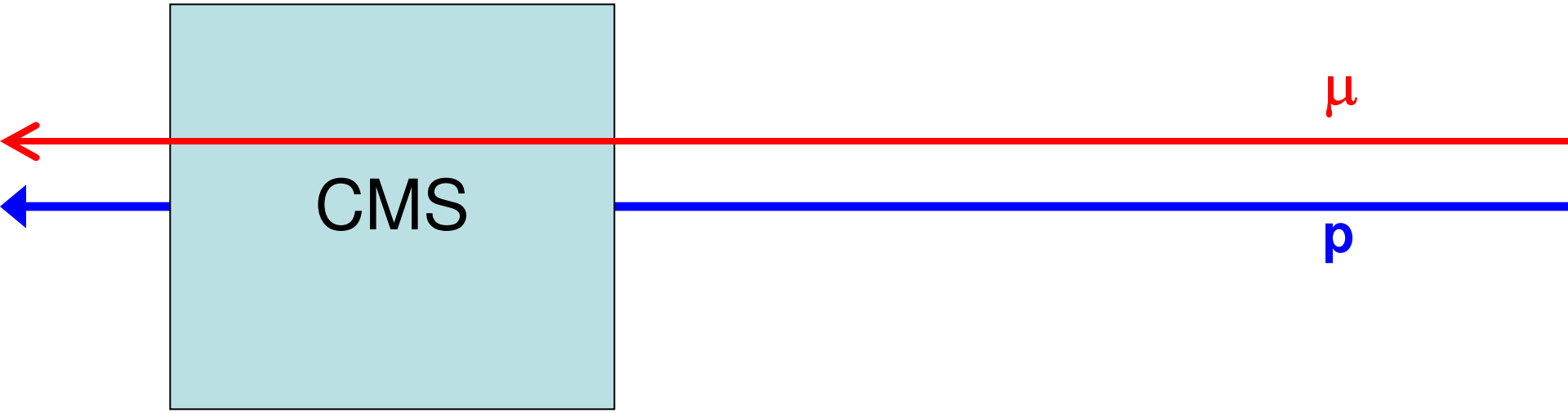
→ First synchronous signals ever seen from LHC

→ **Detector synchronization much easier with synchronous beam**

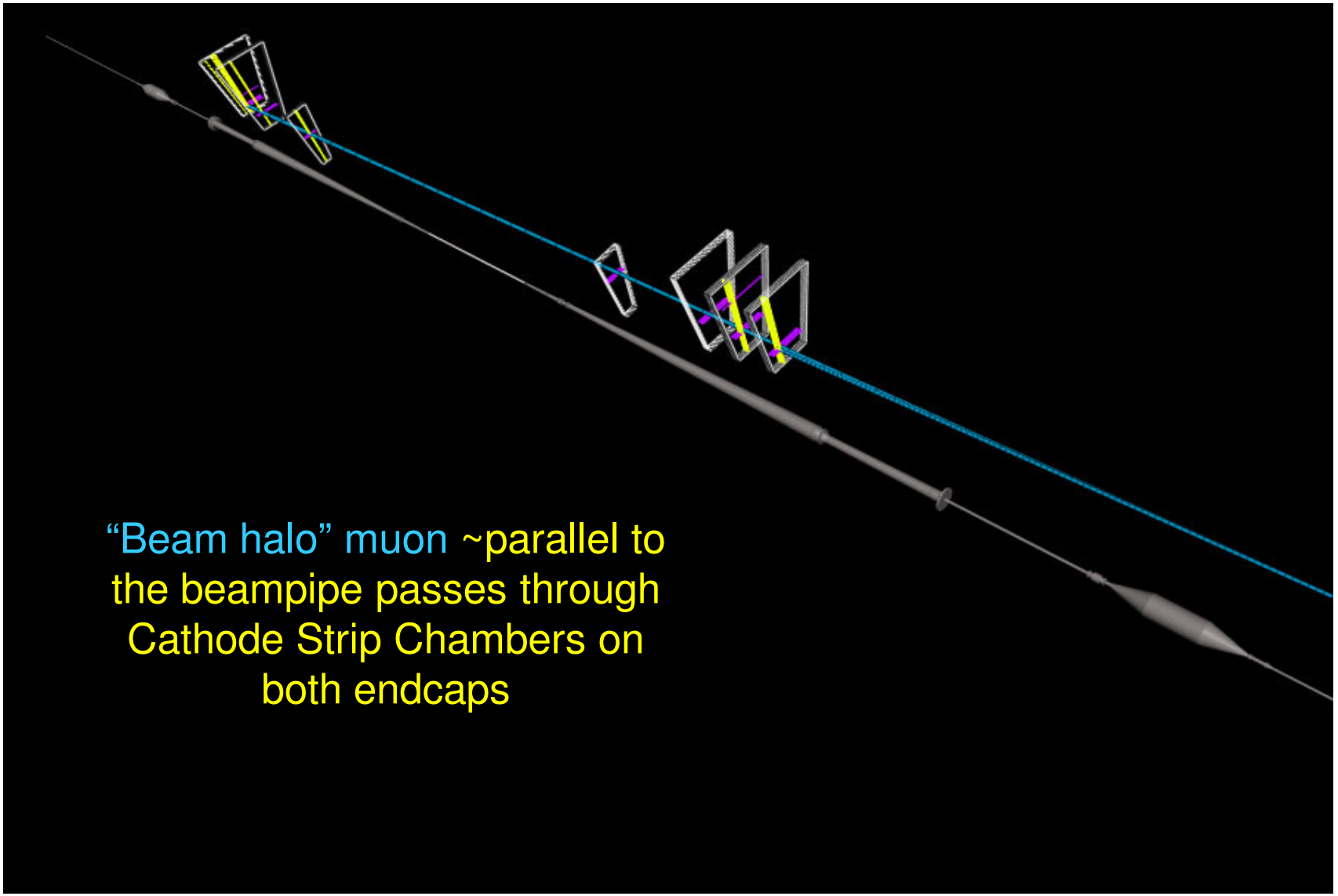
CMS response to LHC beam without collisions:

"Beam Halo"

(11 Sept. 2008)

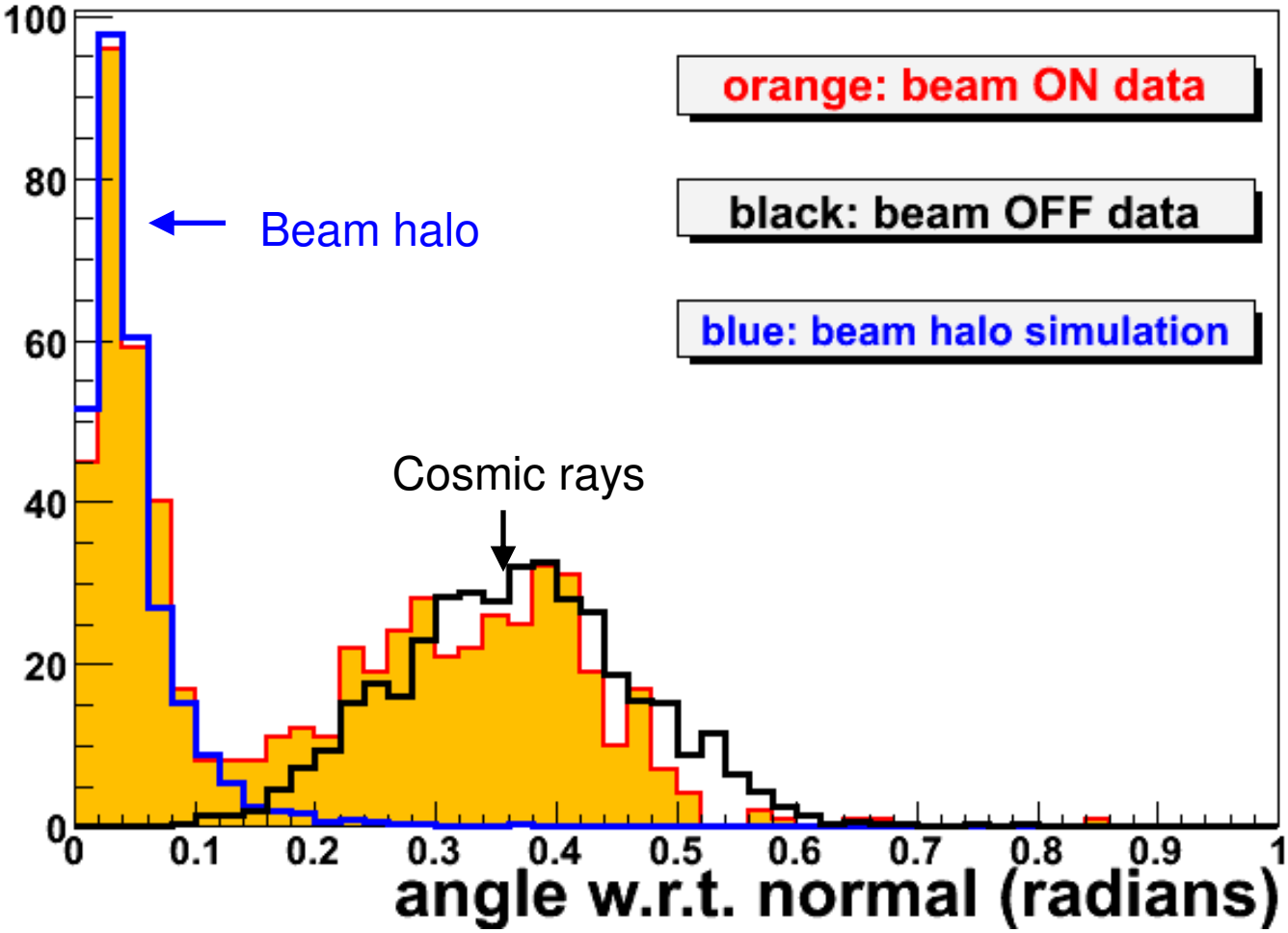


“Beam Halo” Muon Traversing CMS



Orientation of beam halo events

Tracks reconstructed in the cathode strip chambers



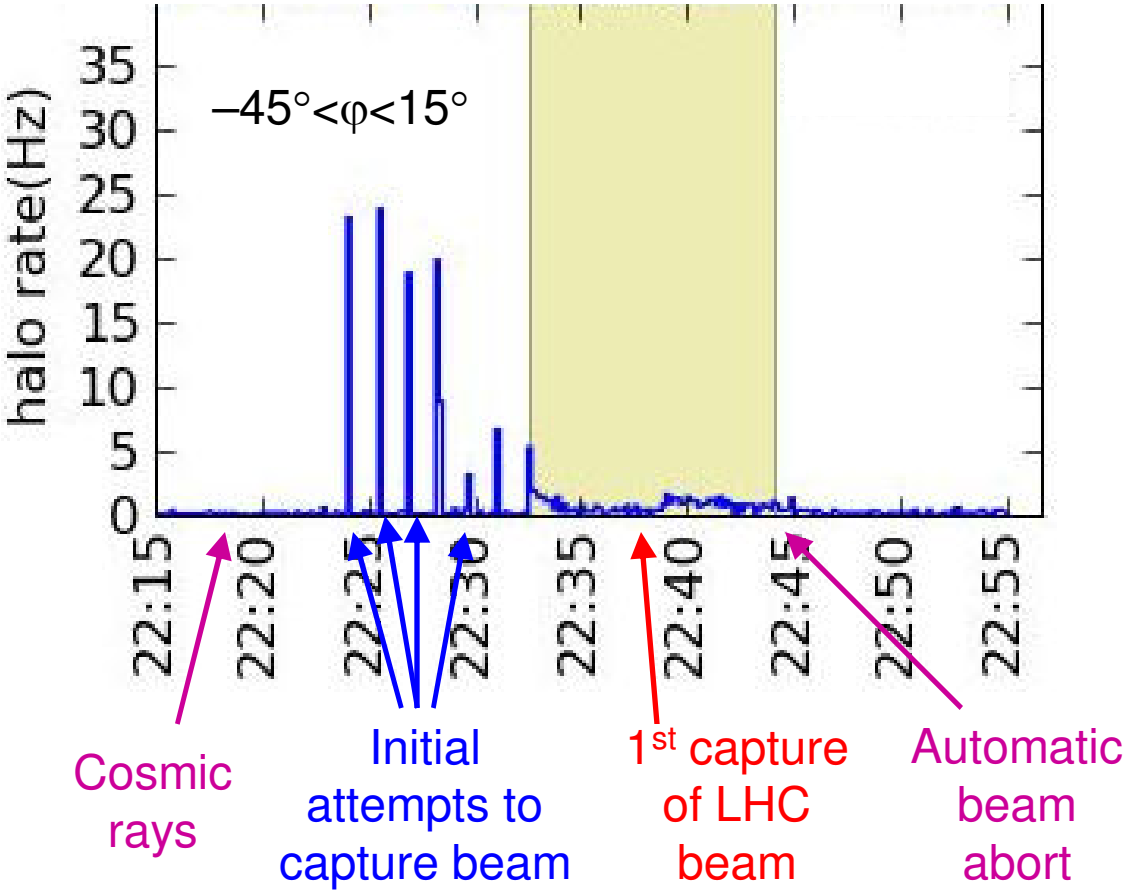
(Separate normalization of blue and black curves → not quantitative…)

Reasonable description of beam ON data: combination of

- **beam halo**
- **cosmic rays**

First LHC Beam Capture Seen at CMS

Trigger rates for “Beam-halo” (i.e., “straight-through”) muons in one endcap of the Cathode Strip Chambers



11 Sept. 2008

LHC beam control established within minutes of first attempt

First beam in 2008 was incredibly exciting

It will only get better with collisions…

Early Physics Program of CMS

10/pb: Commission the detector…

- Detector synchronization and alignment
- In-situ calibration
- Commission trigger
- Start "physics commissioning"
  - Jet and lepton rates; observe W, Z, top
  - And, first look at possible extraordinary signatures…

100/pb: Measure the Standard Model…

- 10^6 W → l + ν; 10^5 Z → l + l; 10^4 $t\bar{t}$ → μ + X
  - Improve understanding of physics objects; jet energy scale; extensive use (and understanding) of b-tagging
  - Measure/understand backgrounds to SUSY and Higgs searches
- Initial MSSM (and some SM) Higgs sensitivity
- Early look for excesses from SUSY, Z′, di-jet resonances…

1000/pb: Higgs discovery era…

- In addition: explore large part of SUSY and resonances at ~few TeV…

Summary

CMS is ready for physics

We are eagerly anticipating proton collisions in the LHC…

(next slide…)

CMS Talks in DPF Parallel Sessions

- **Beyond the Standard Model**
  - Search for Supersymmetry at the CMS in All-Hadronic Final State – **G. Lungu** (Rockefeller)
  - Search for a Heavy Top Partner at the LHC – **A. Avetisyan** (Brown)
  - Search for Extra Dimensions in the Diphoton Channel – **S. Esen** (Brown)
  - Searching for Majorana Neutrinos in the Like-Sign Dilepton Final – **W.J. Clarida** (Iowa)
  - Exotic Searches with Complex Final States – **T. Bose** (Boston)
- **Computing in HEP**
  - The CMS Computing System: Successes and Challenges – **K. Bloom** (UN-Lincoln)
- **Detectors**
  - Upgrade of CMS HCAL for SLHC – **B. Klima** (FNAL)
- **Electroweak Physics (W/Z)**
  - Towards the First Measurement of the Drell-Yan Dimuon Differential Cross Section with CMS – **C. Liu** (Purdue)
  - Inclusive W/Z productions at CMS – **P. Tan** (FNAL)
- **First Results from LHC**
  - Cosmic Muon Analysis with the CMS detector – **C. Liu** (Purdue)
  - Commissioning the CMS pixel detector with Cosmic Rays – **A. York** (U. Tenn.)
  - First Alignment of the CMS Tracker and Implications for the First Collision Data – **Z. Guo** (Johns Hopkins)
  - Alignment of the CMS Muon System with Tracks – **J. Pivarski** (Texas A&M)
  - Commissioning of the CMS Endcap Muon System – **P. Killewald** (OSU)
- **Higgs Physics**
  - SM Higgs searches at CMS with an integrated luminosity of 1/fb – **A. Drozdetskiy** (UF)
  - Search for the Standard Model Higgs Boson produced in Vector Boson Fusion and decaying into tau pair in CMS with 1/fb of luminosity – **R. Rahmat** (U. Miss.)
- **Top Quark Physics**
  - Reconstruction of high transverse momentum top quarks at CMS – **G. Giurgiu** (Johns Hopkins)
  - Prospects for studying the ttbar invariant mass spectrum and spin correlations at CMS – **B. Klima** (FNAL)
  - Prospects for the first ttbar cross section measurement in the semileptonic and dilepton channels at CMS – **A. Kumar** (SUNY)
  - Probing the heavy flavor content in ttbar events and using ttbar events as a calibration tool at CMS – **R. Volpe** (INFN-Perugia)

Backup slides

Cosmic Rays 100m Below Ground

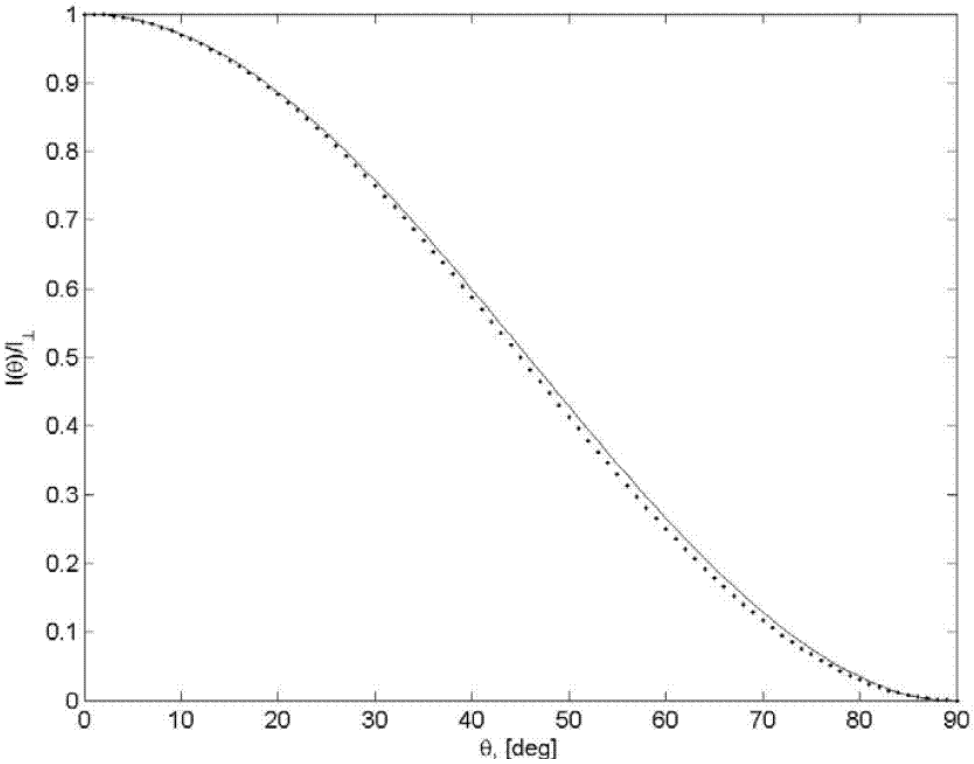
The LHC (and CMS) is located under ~70m of rock

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

→ **Angular distribution of cosmic ray muons is similar beneath 100m solid rock to that on the surface…**

→ **Rate is smaller by factor of ~100**

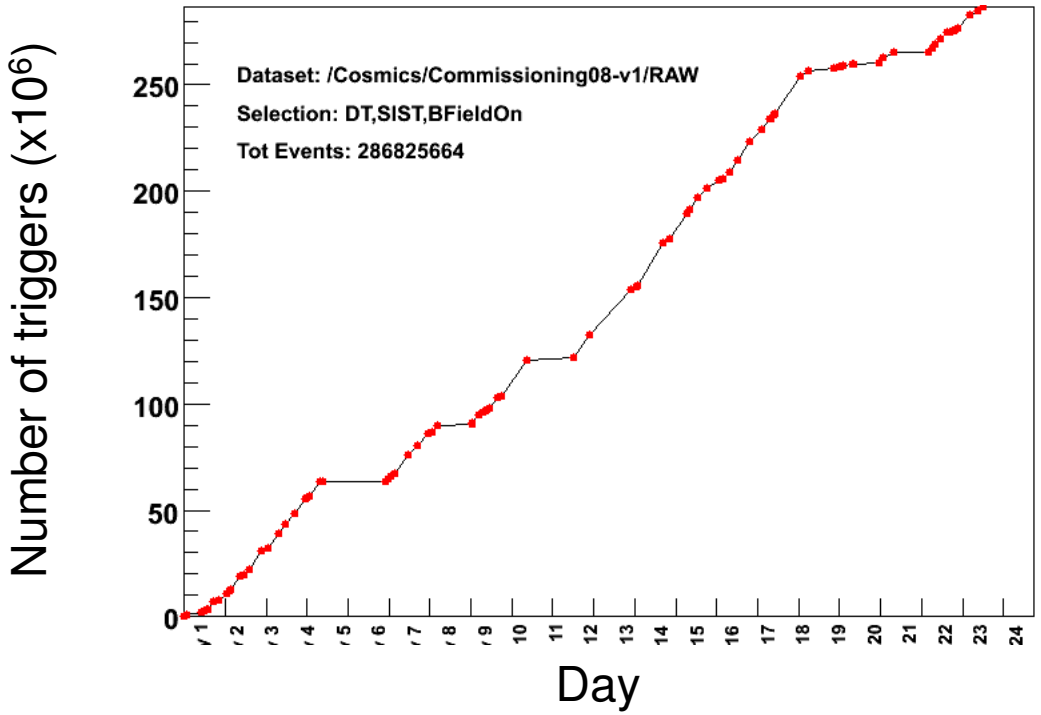
→ **Cosmics are asynchronous**



Most cosmic rays are vertical: go through CMS from Top → Bottom

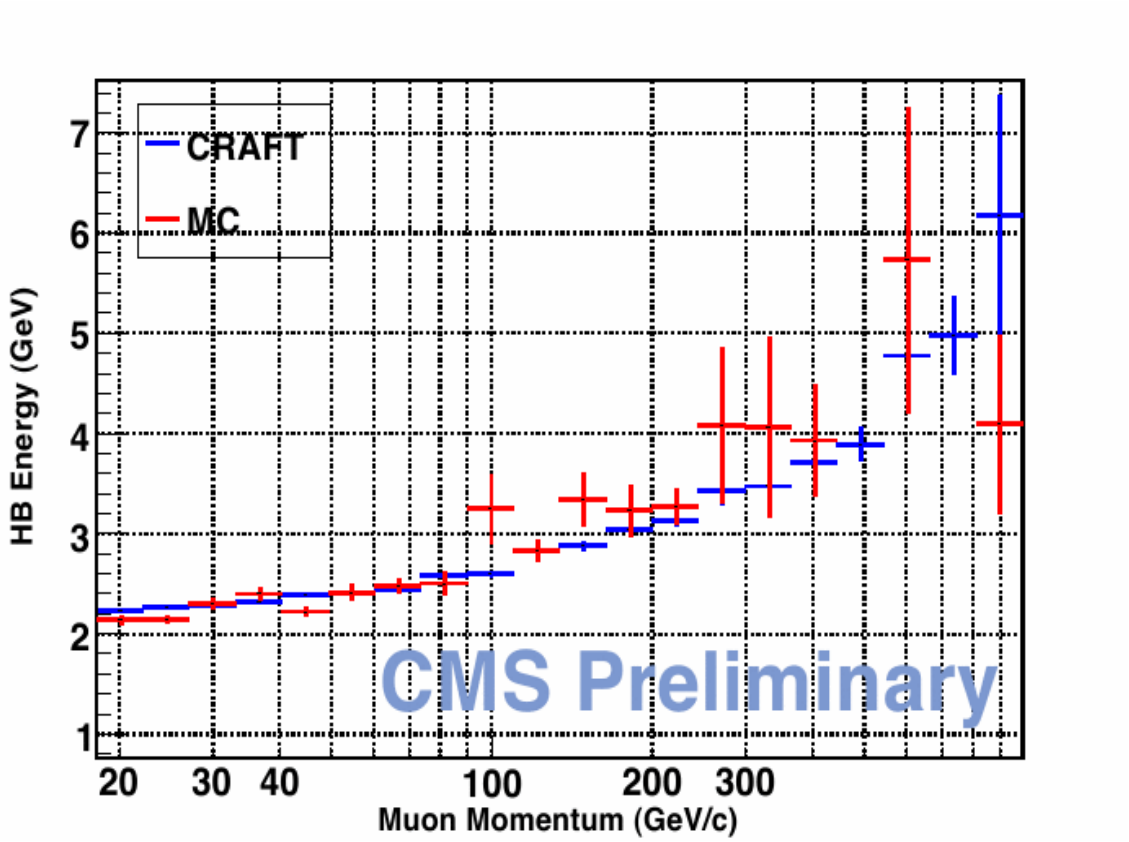
Cosmic Ray Data Accumulated

- Operated CMS for 3 weeks continuously with magnetic field at 3.8T
  - October – November 2008



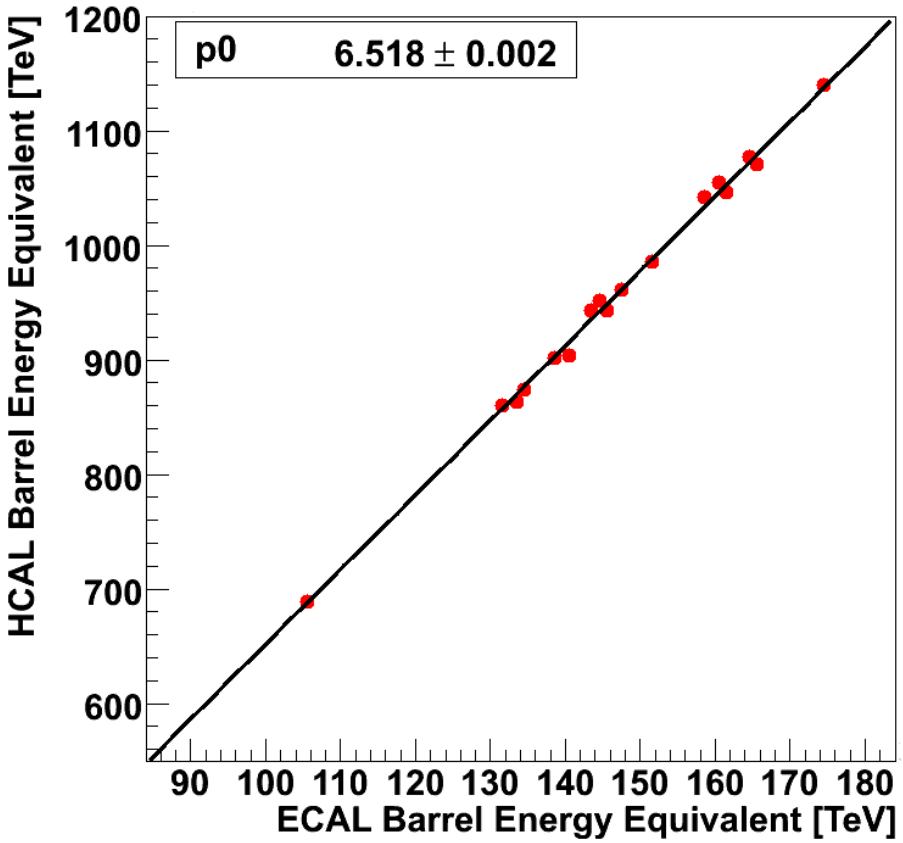
Note: Months of cosmic ray running is equivalent to a few minutes of LHC collisions…

CMS Hadronic Calorimeter



Hadronic calorimeter response to muons well described by a Monte Carlo simulation

Significant Energy Deposition in CMS Calorimetry

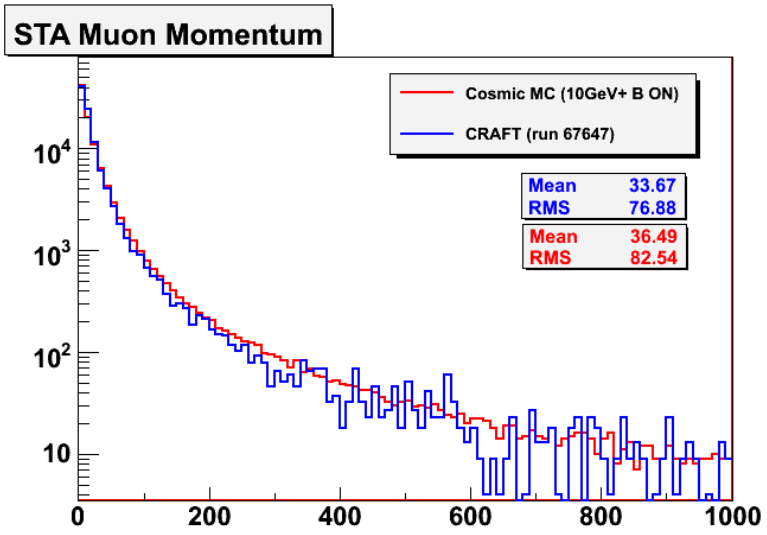


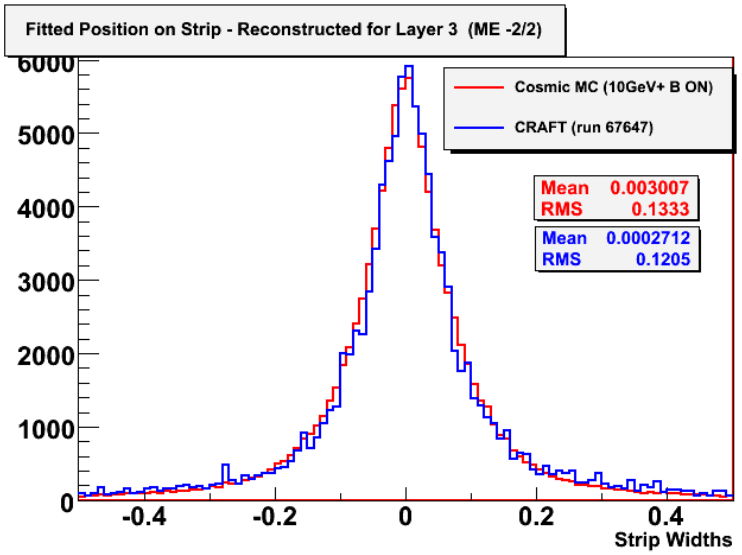
Linear correlation observed between hadronic and electromagnetic energy deposited in CMS from Beam Splash events

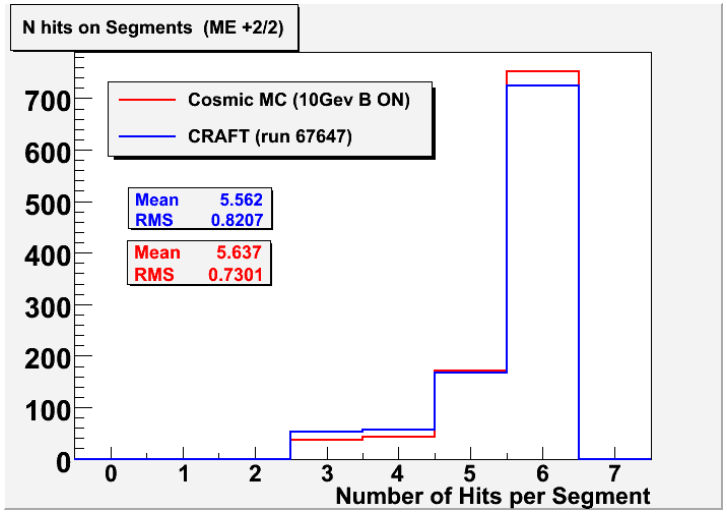
~10^6 GeV of energy seen in the Hadronic Calorimeter…

(c.f. "normal" cosmic rays ~ 1 GeV…)

Data vs. Simulation Comparisons of Cosmic Muons in Endcap







Cathode Strip Chamber response to cosmic ray muons are well described by a Monte Carlo simulation