
Fermilab

UIC University of Illinois at Chicago

# "Status of CMS"

R. Cavanaugh*
University of Illinois - Chicago & Fermilab

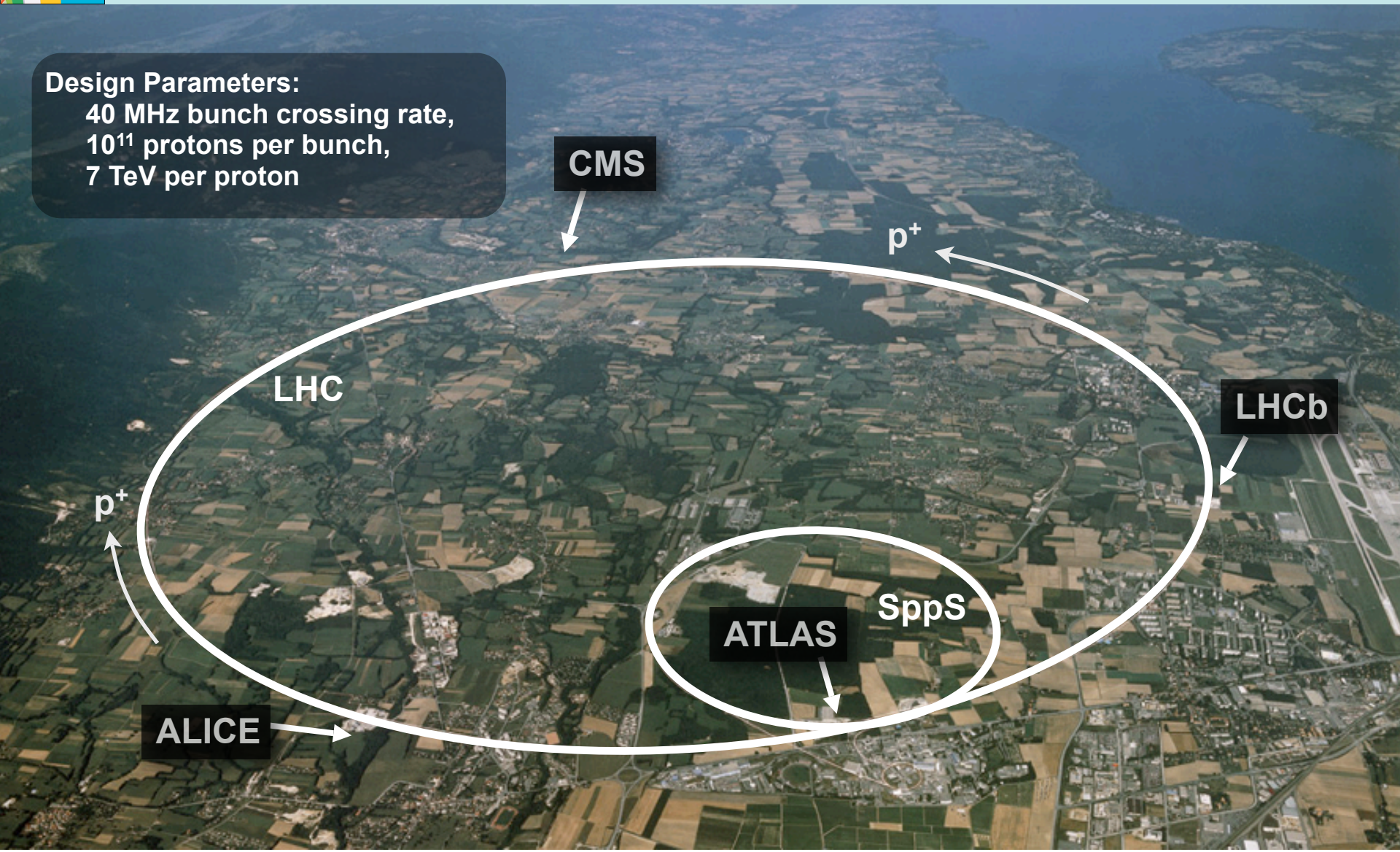
## Fermilab Users Meeting
## 4 June, 2009

- Introduction
- Detector Construction Finished
- Performance with Single LHC Beam
- Performance with Cosmic Rays
- ~~Performance with~~ 1st LHC Collisions

Preparations & Plans for

*On behalf of the CMS Collaboration

# The Large Hadron Collider



# Experimental Challenge

**Detector must be radically different from those of the previous generations**

## High Interaction Rate

pp interaction rate **1 billion interactions/s**
Data can be recorded for only ~$10^2$ out of 40 million crossings/sec
Level-1 trigger decision takes ~2-3 μs
⇨ **electronics need to store data locally (pipelining)**

## Large Particle Multiplicity

***Transparency from the early 90's***

~ <20> superposed events in each crossing
~ 1000 tracks stream into the detector every 25 ns
need highly granular detectors with good time resolution for low occupancy
⇨ **large number of channels (~ 100 M ch)**

## High Radiation Levels

⇨ **radiation hard (tolerant) detectors and electronics**

Slide taken from J. Virdee

# (CMS) Design Criteria

**Very good muon identification and momentum measurement**

Trigger efficiently and measure sign of TeV muons dp/p < 10%

**High energy resolution electromagnetic calorimetry**

~ 0.5% @ $E_T$ ~ 50 GeV

**Powerful inner tracking systems**

Momentum resolution a factor 10 better than at LEP

Slide taken from J. Virdee

**Hermetic calorimetry**

Good missing $E_T$ resolution

***Transparency from the early 90's***

**(Affordable detector)**

# CMS Detector

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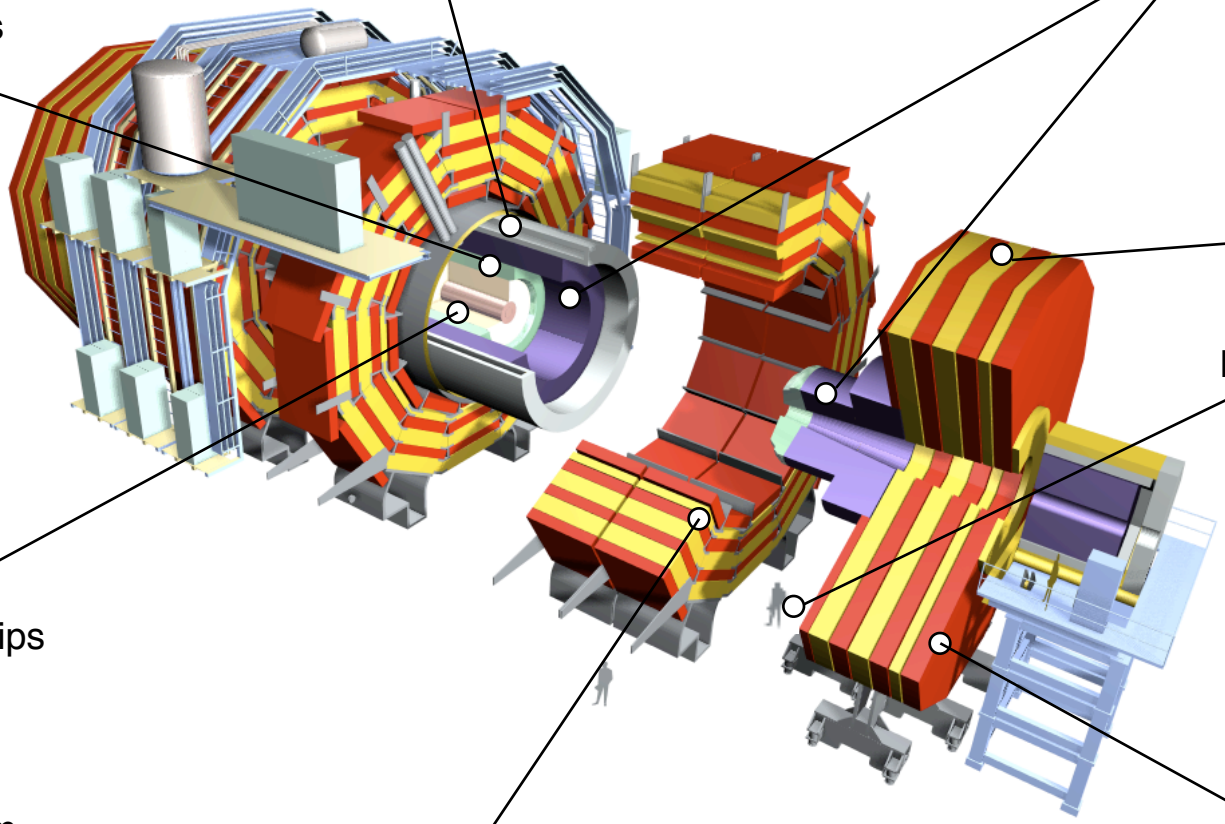
**HCAL**
Plastic scintillator/brass sandwich

**SUPERCONDUCTING COIL**

**ECAL**
Scintillating PbWO4 crystals




**Length: 21.6 m**
**Diameter: 15 m**
**Weight: ~12,500 tons**
**Magnetic Field: 4 Tesla**
**Length: 13m**
**Diameter: 6m**

# CMS Detector

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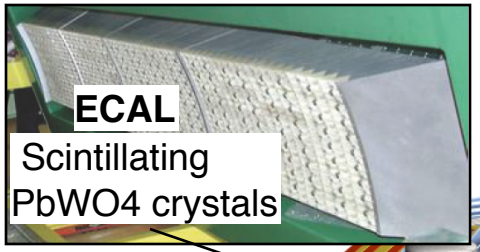
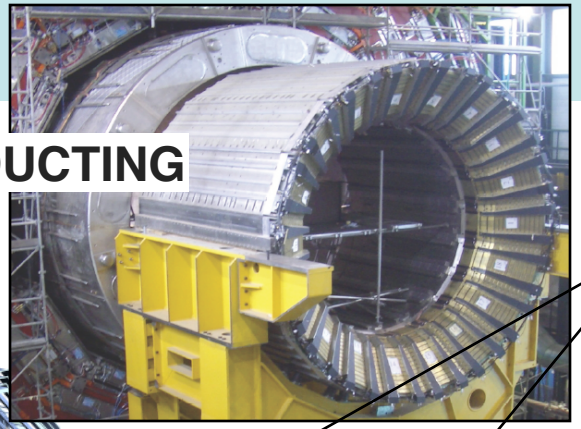


**ECAL**
Scintillating PbWO4 crystals

**SUPERCONDUCTING COIL**



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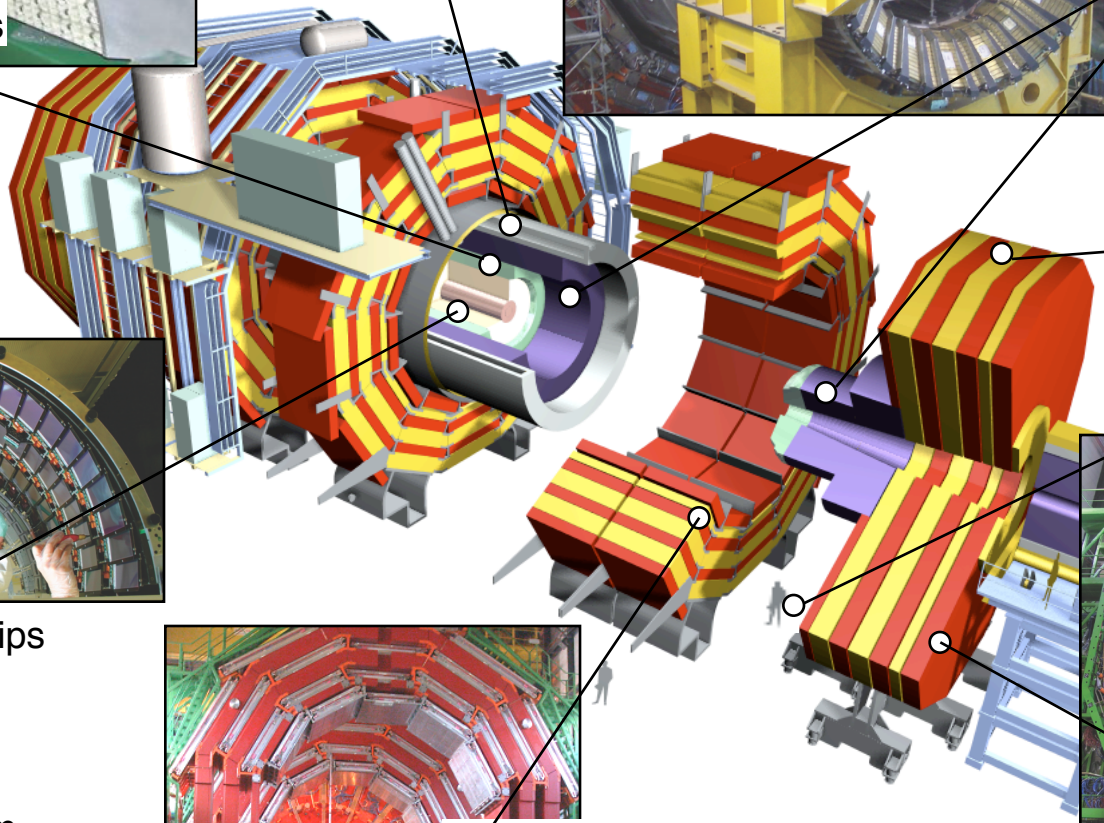
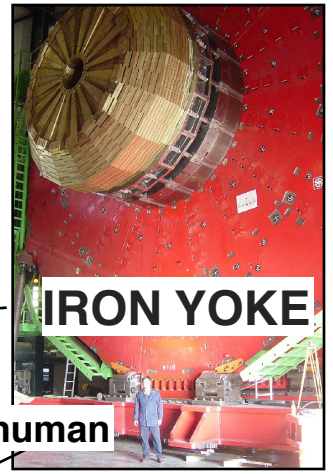


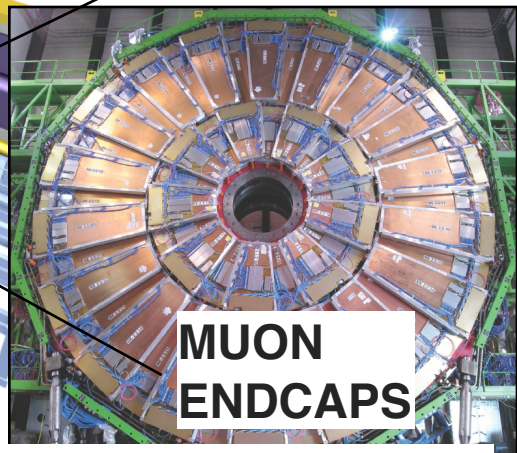


**IRON YOKE**

human

**TRACKER**

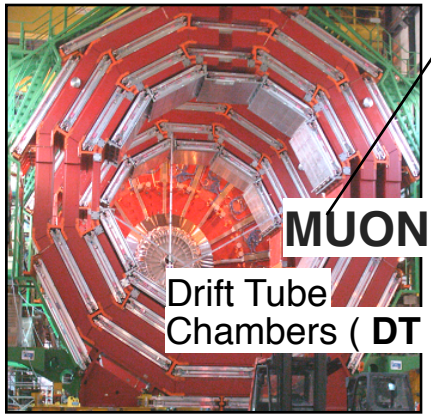
Silicon Microstrips
Pixels



**MUON ENDCAPS**

Cathode Strip Chambers (**CSC** )

Resistive Plate Chambers (**RPC**)



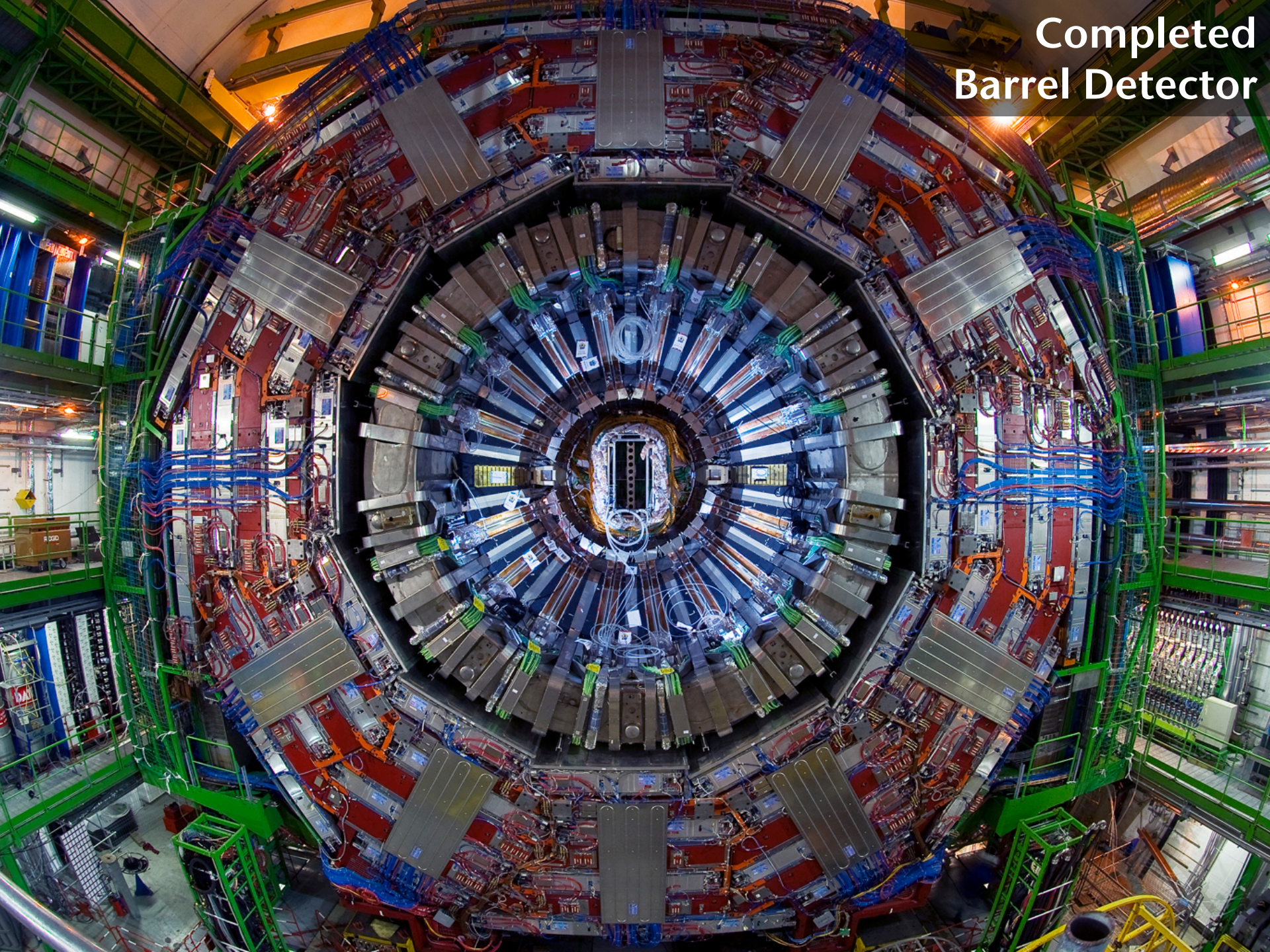
**MUON BARREL**

Drift Tube Chambers ( **DT** )

Resistive Plate Chambers ( **RPC** )

**Length: 21.6 m**
**Diameter: 15 m**
**Weight: ~12,500 tons**
**Magnetic Field: 4 Tesla**
**Length: 13m**
**Diameter: 6m**

# Modular Design : “Easy” Access


Completed
Barrel Detector

# 2008 CMS Run Summary

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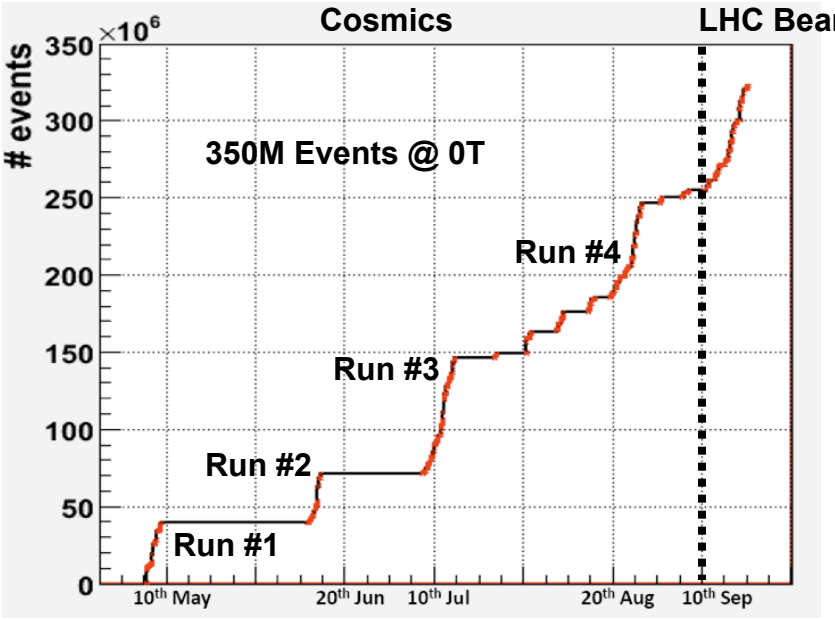
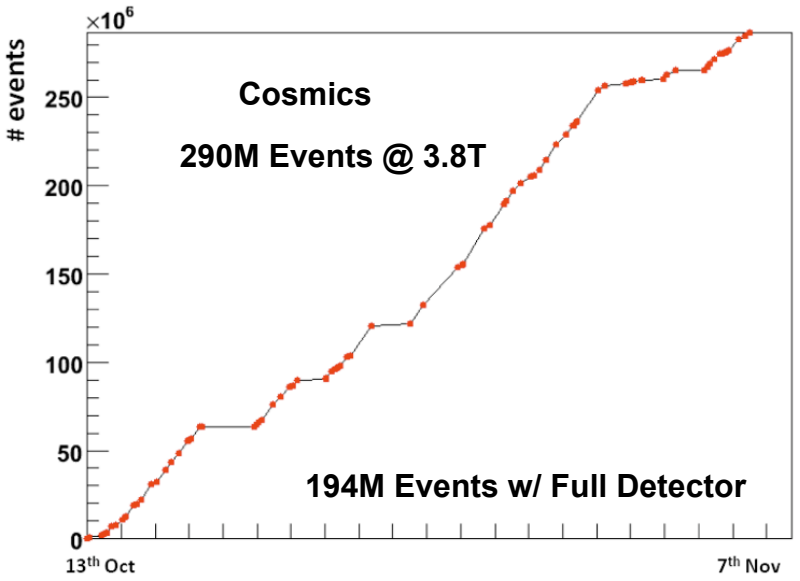
**CRUZETs**
(Cosmics RUn at Zero Tesla)
Detector Open - Magnet OFF

**CMS ready for BEAM**
Detector Closed - Magnet OFF

**CRAFT**
(Cosmics Run at Four Tesla)
Detector Closed - Magnet ON

May
Jun
Jul
Aug
Sep
Oct
Nov
Dec



# CMS Closed, Ready for Data

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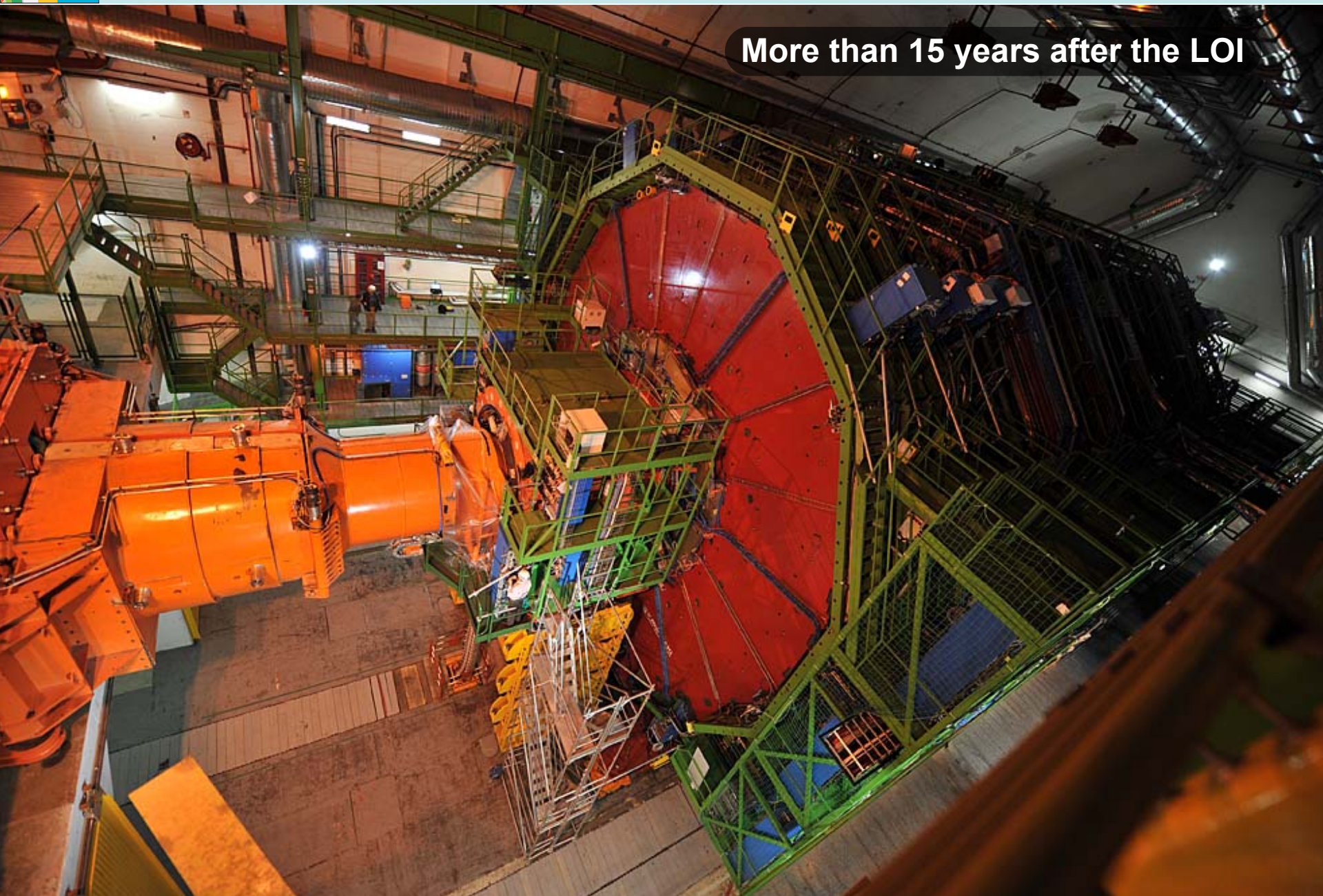
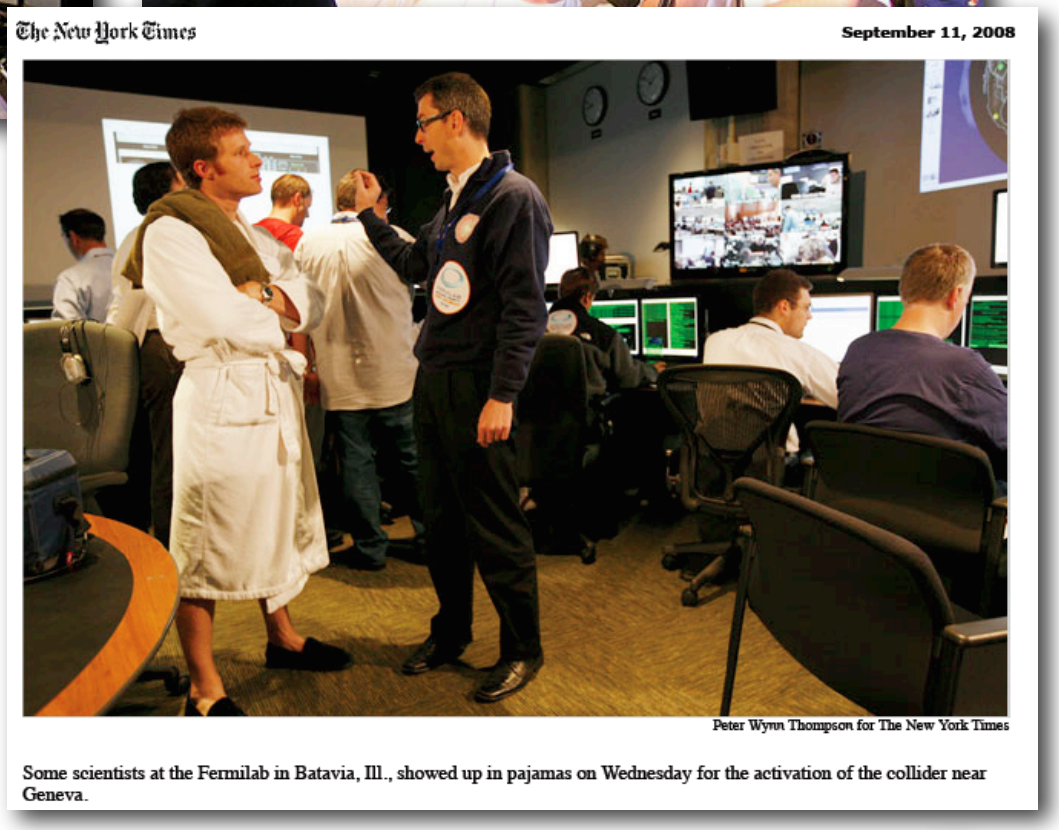


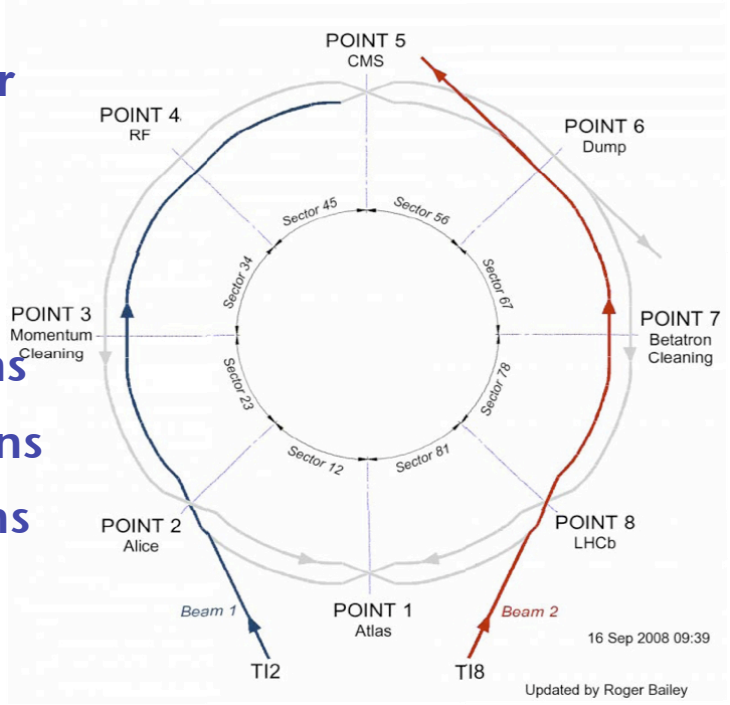





- Pajama Party at Fermilab
- LHC Progress Monitored by Fermilab ROC
- The LHC became a household word
  - Even the I-88 toll booth guy asked me about the "li'l boom-boom"

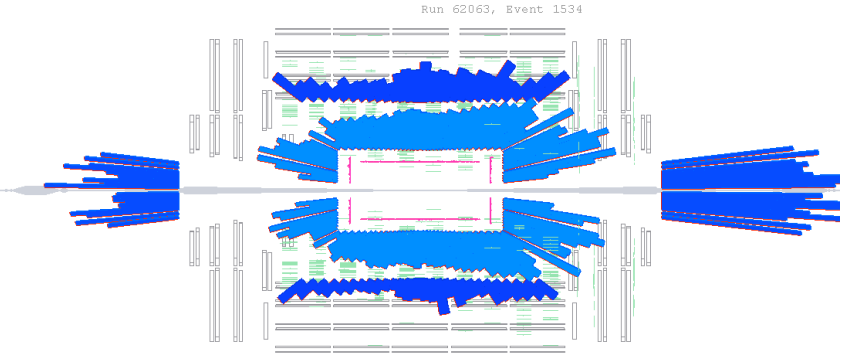
# First LHC Beam

- Synchronization tests (September 5-9)
  - Beam 1 (clockwise) “shots” onto a collimator 150 meters upstream of CMS
    - SPLASH EVENTS
- Circulating beams (September 10)
  - 10:30 Beam 1 around the ring, up to ~3 turns
  - 15:00 Beam 2 around the ring, up to 3-4 turns
  - 22:00 Beam 2 circulates for hundreds of turns
  - Beam protons interacting with Beam Gas
    - BEAM HALO EVENTS
- RF capture of beam (September 11)
  - All CMS systems on, except for Tracker and Magnet
    - ~40 HOURS OF BEAM

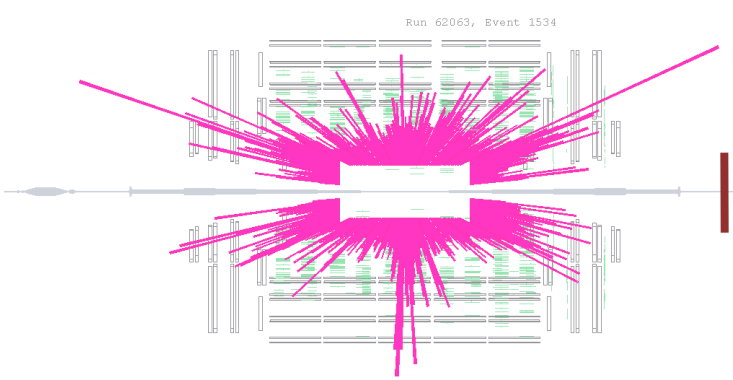


# Spectacular Beam Splash Events

HCAL Energy



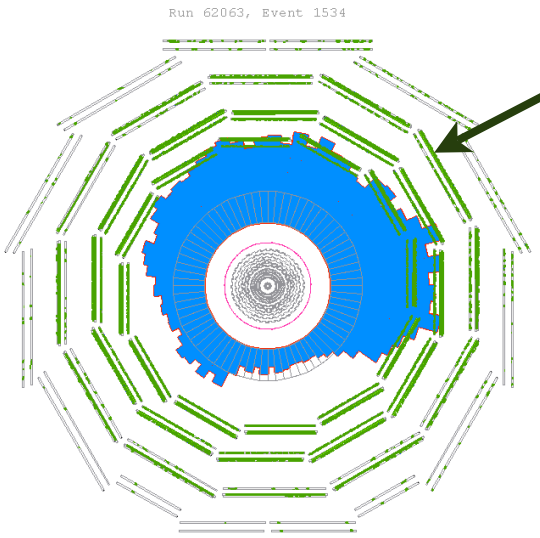

ECAL Energy

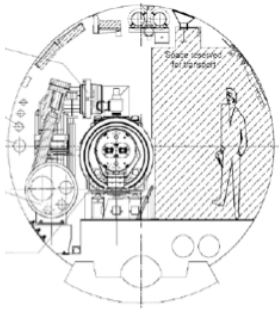



Collimators closed

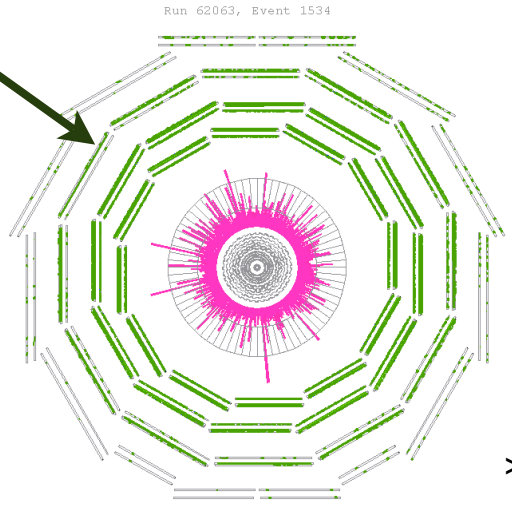
Beam 1
(2X10$^9$ protons)

Drift Tubes



Suggestive LHC tunnel profile



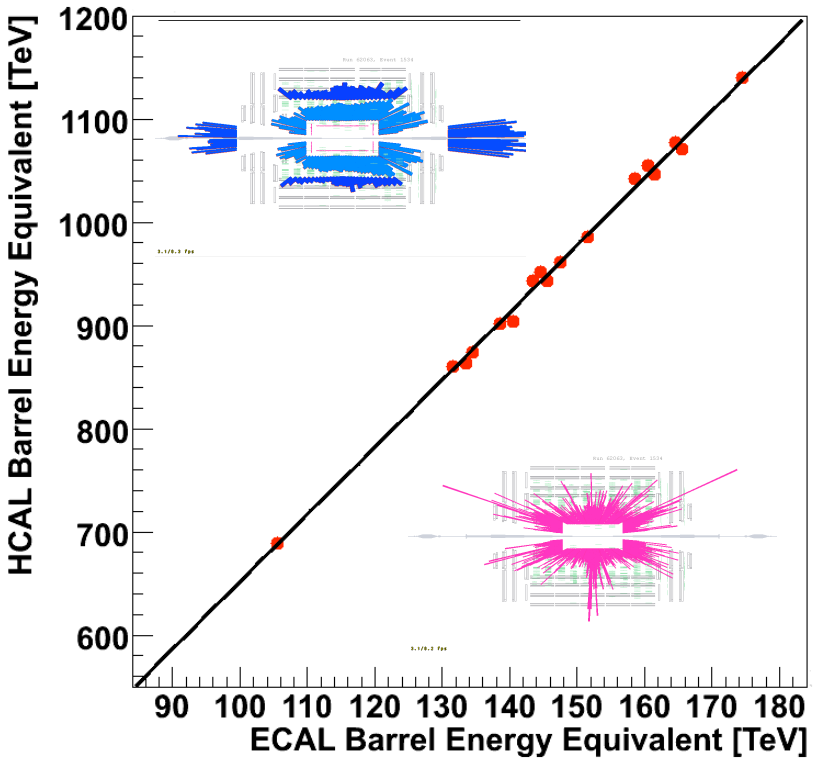

O(10$^5$) of muons passed through CMS per event.

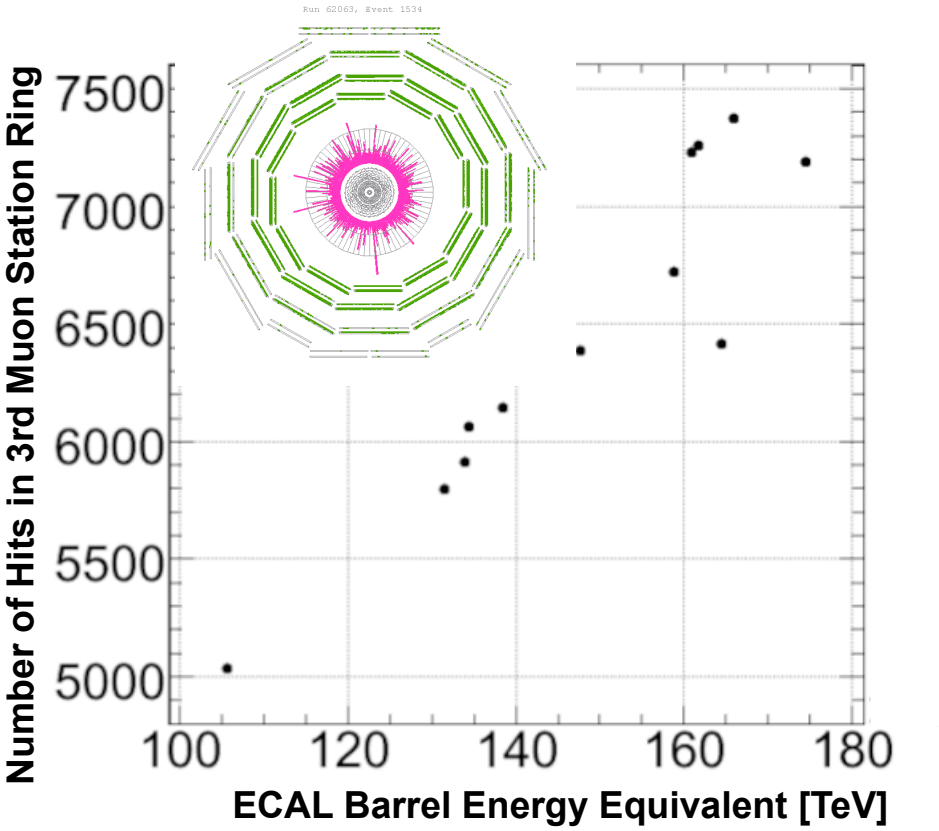
Enormous amount of energy deposited in calorimeters

>80% channels fired
→ 100-1000 TeV

Special Beam Triggers : endcap muon and forward calorimeter triggers were correctly timed in!

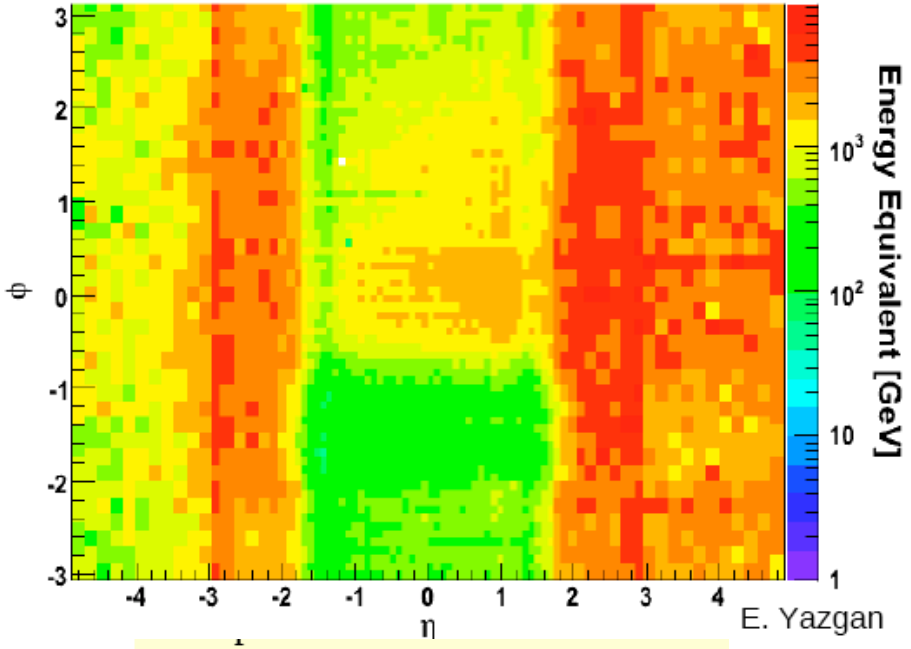
# Correlating Hits Across Detectors

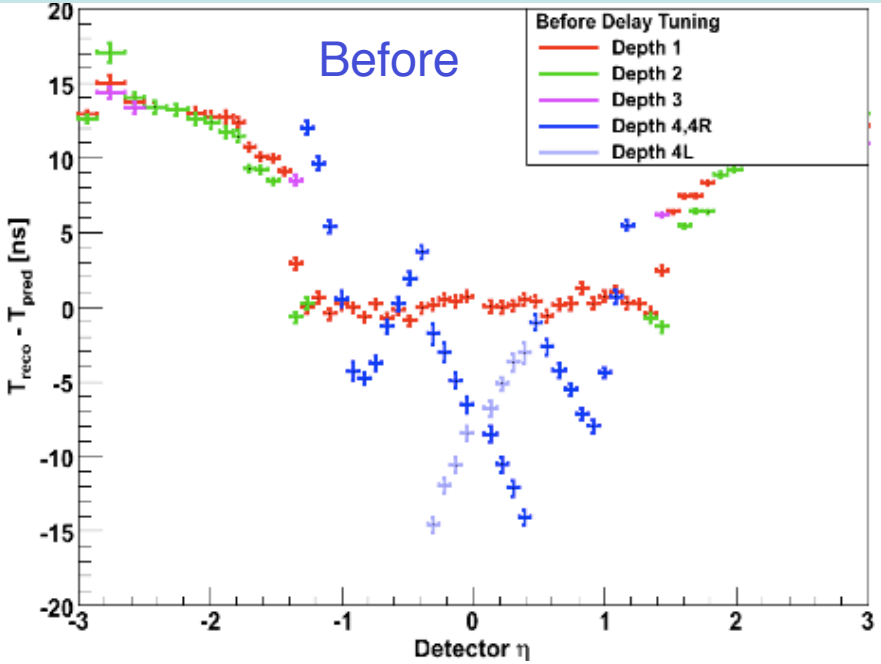


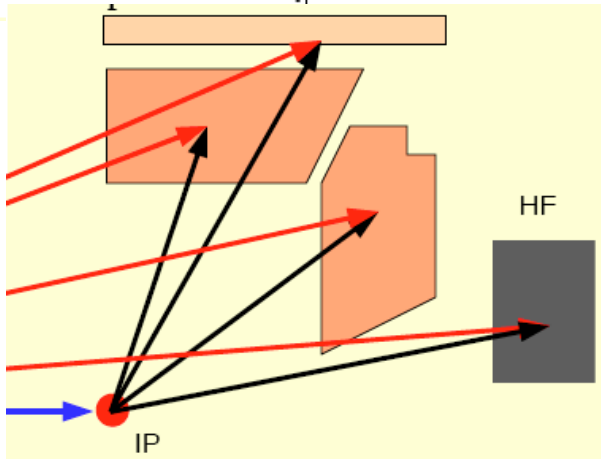



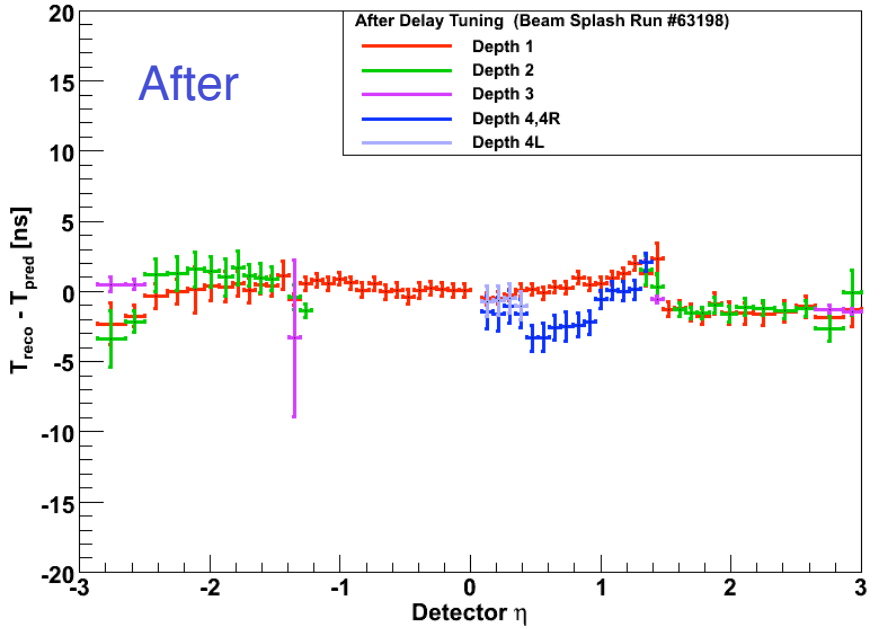

- 150 TeV deposited into ECAL and 1 PeV deposited into HCAL!
- Excellent Correlation between ECAL, HCAL, and Muon Barrel (Drift Tubes)

# Exploiting the 1st Data: Calibration & Timing



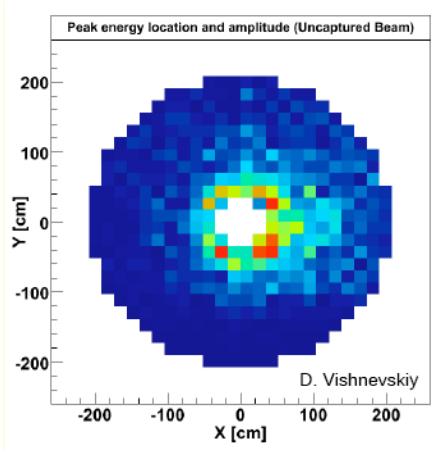



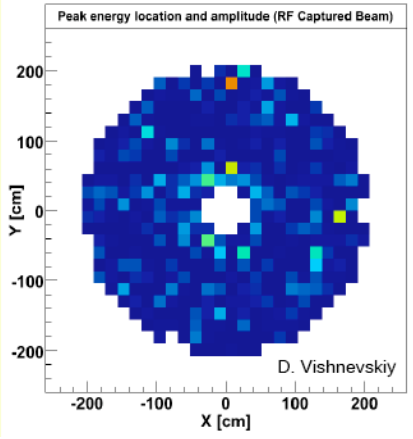




- **HCAL now timed in at nanosecond scale**
  - **(Parts of HCAL Barrel region timed in prior)**

# Circulating Beam: Halo Events

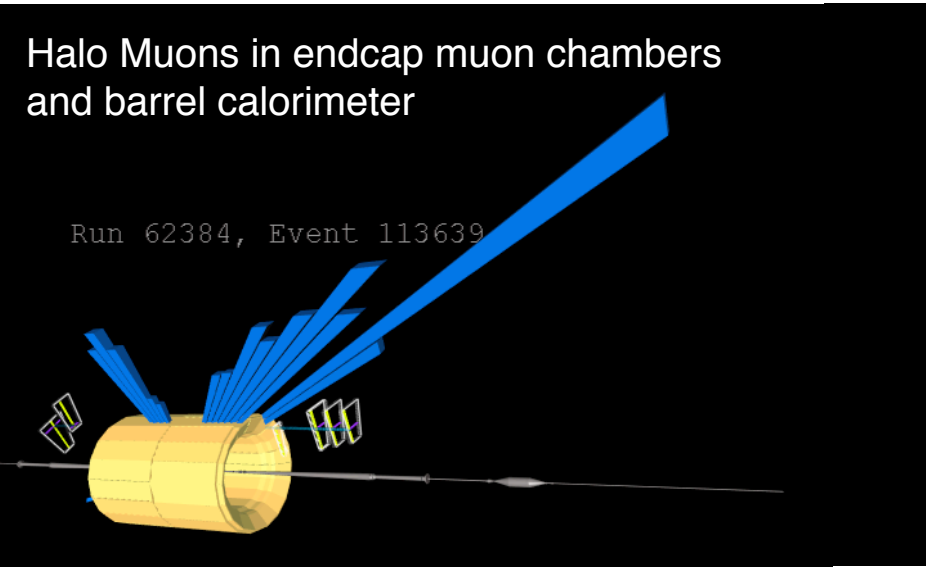



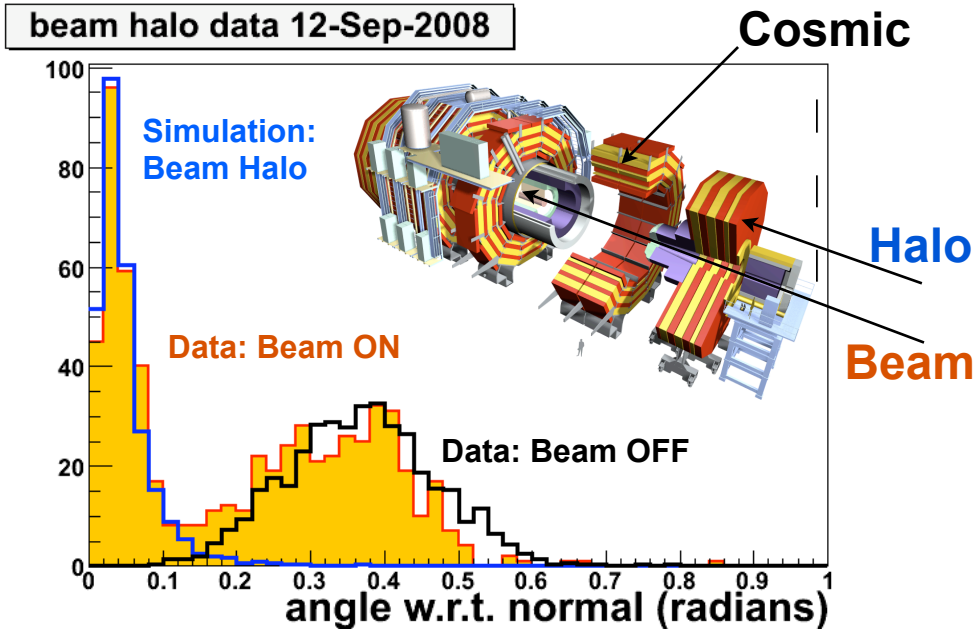




**Un-captured (left) and Captured beam (right)**

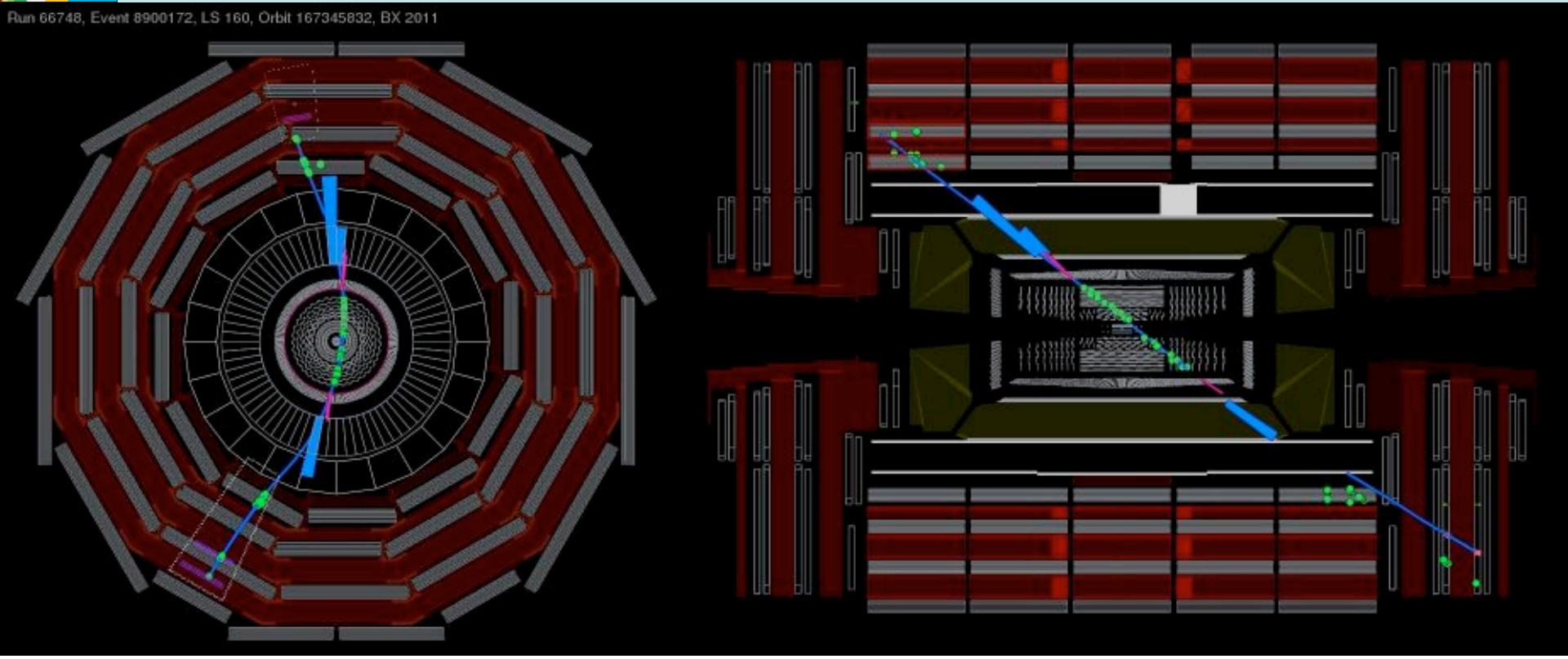
**RF Captured Beam ⇒ LHC much cleaner**

Halo Muons in endcap muon chambers and barrel calorimeter



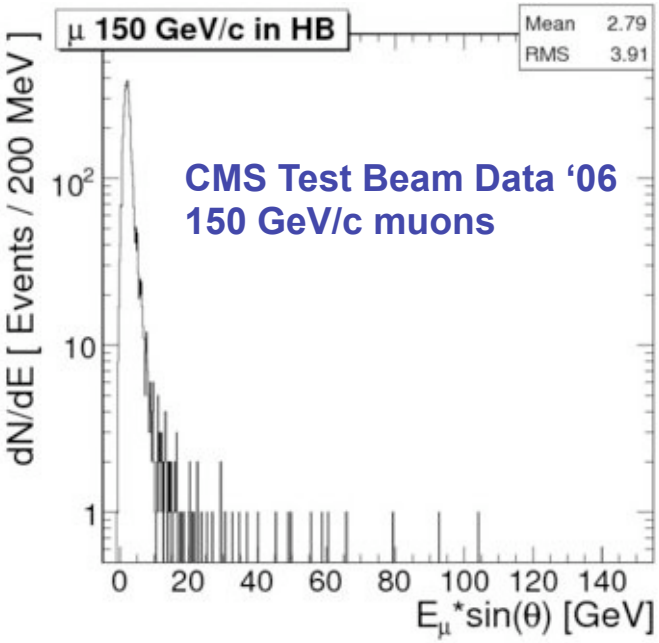
# Cosmic Ray Global CMS Runs

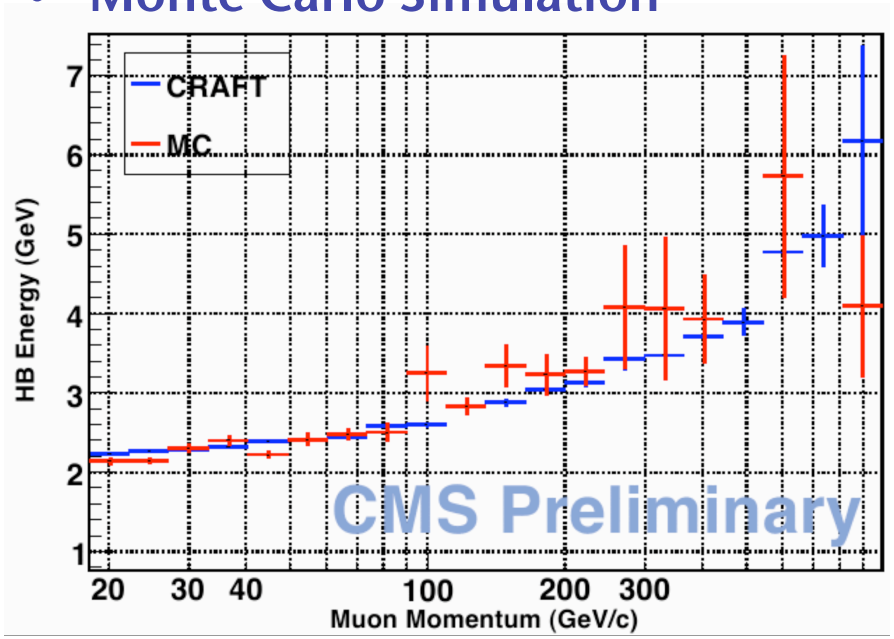


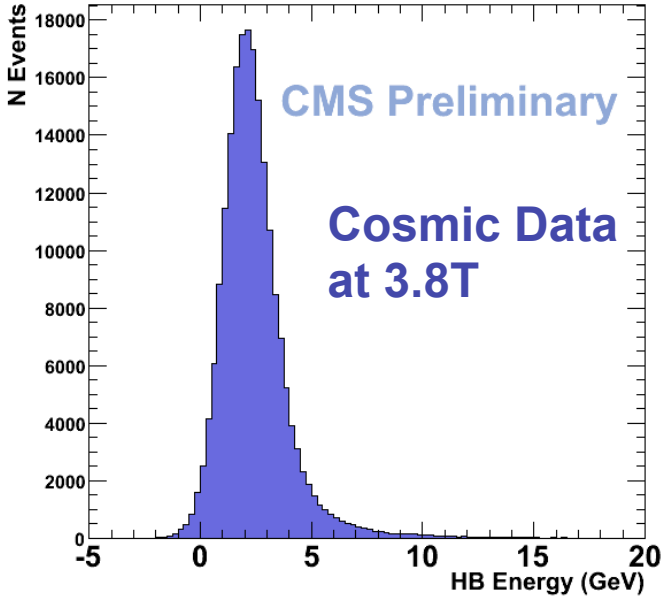

- Large amount of data at 0T (350M events) and 3.8T (290M events)
  - Tremendously valuable source for detector & software commissioning
- Commissioning of detector, online-to-offline, reconstruction chain
  - Many aspects now understood at level estimated only after 20-50 $pb^{-1}$
    - Efficiencies, alignments, B-field effects being addressed
  - Events span five orders of magnitude in muon multiplicity
    - Robustness of detector & software

# Cosmic Muons and HCAL

- Muon MIP energy in HCAL: Typically 2-3 GeV
  - Muon-Barrel & Tracker matched to HCAL Cells
    - Energy corrected for path length
    - muon momenta: 20 GeV to 1 TeV
  - 200K events in Data; 15K events in MC
- Good agreement Between
  - Test Beam Data taken in 2006.
  - Cosmic Muon Data
  - Monte Carlo Simulation

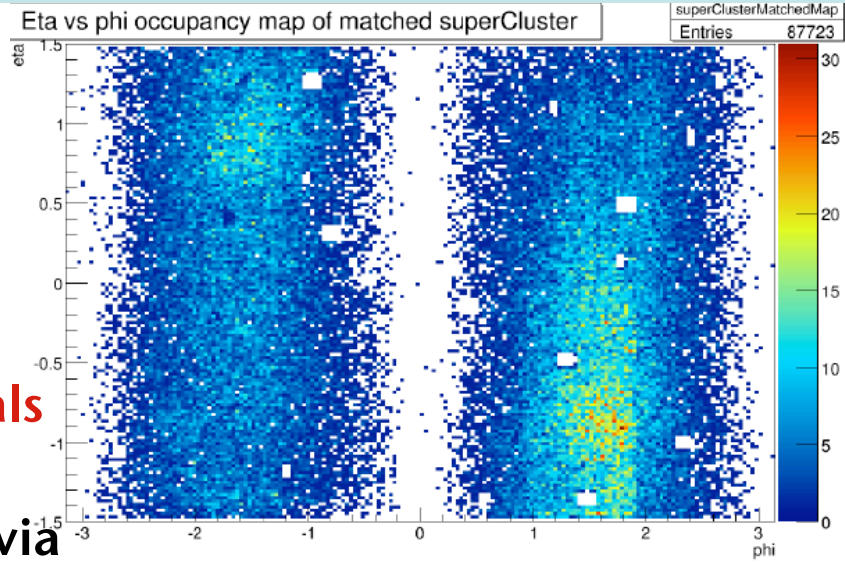


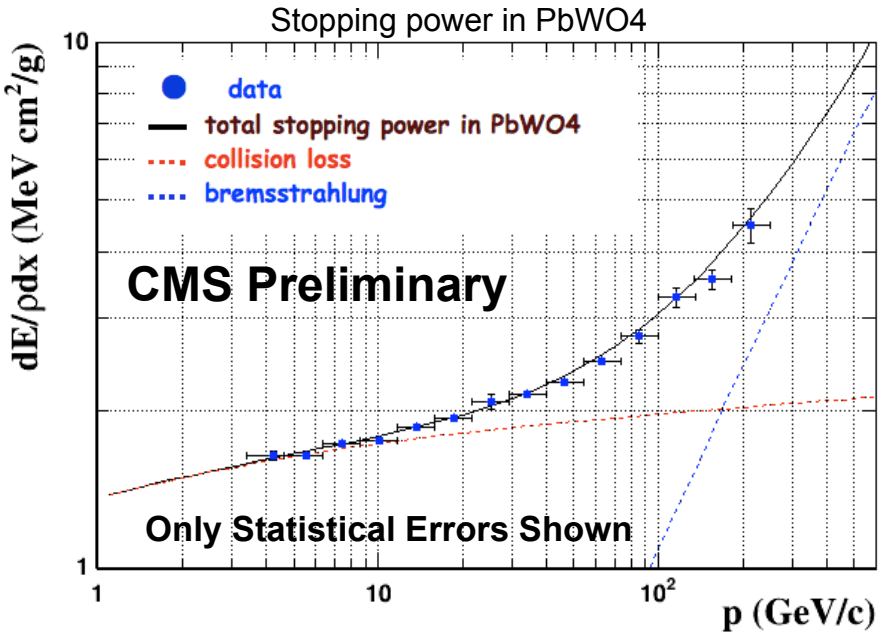



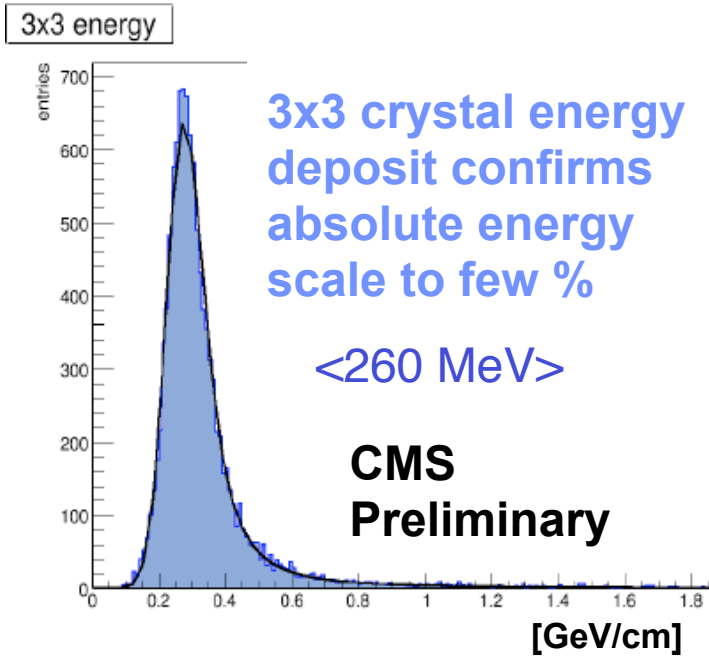



# Cosmic Muons and ECAL

- e/γ trigger tested by triggering on MIP
- Muon stopping power in ECAL Barrel.
  - Momentum measured in the tracker
  - <dE/ρdx> = cluster energy
    - matched to muon track
    - corrected for path length in crystals
- Good agreement of tracker momentum scale with ECAL energy scale (calibrated via test beam)

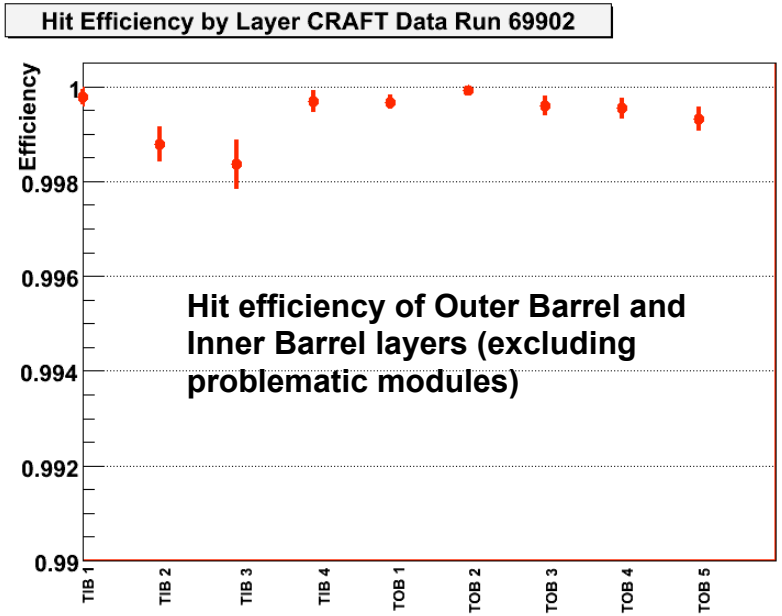


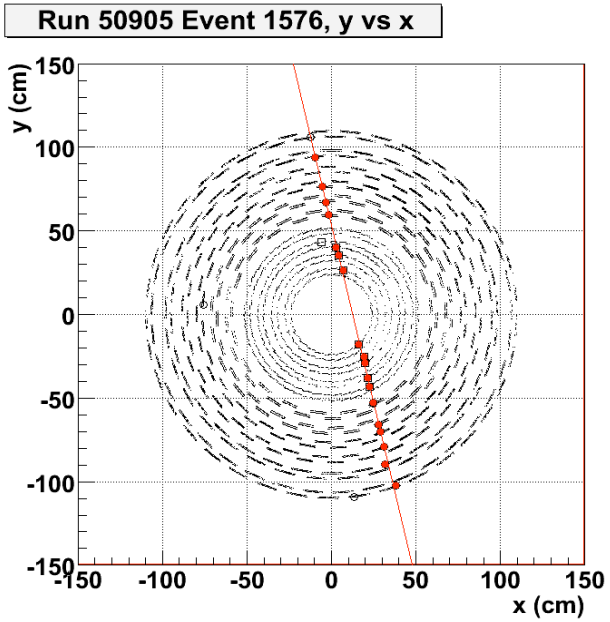



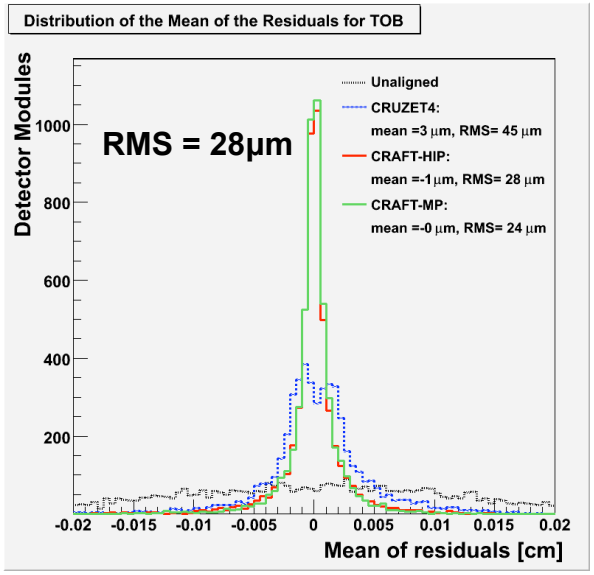



# Cosmic Muons and Si Tracker

- Health of Si Strip Tracker
  - Outer Barrel: 98.2% (0.6% recoverable)
  - Inner Barrel: 96.9 % (1% recoverable)
  - + End Cap: 99.2%
  - - End Cap: 97.8 % (1.7% recoverable)
- Aligned to 25-30μm using cosmic data !
  - Only modules with > 30 hits considered
- Track-hit finding efficiency > 99.8%

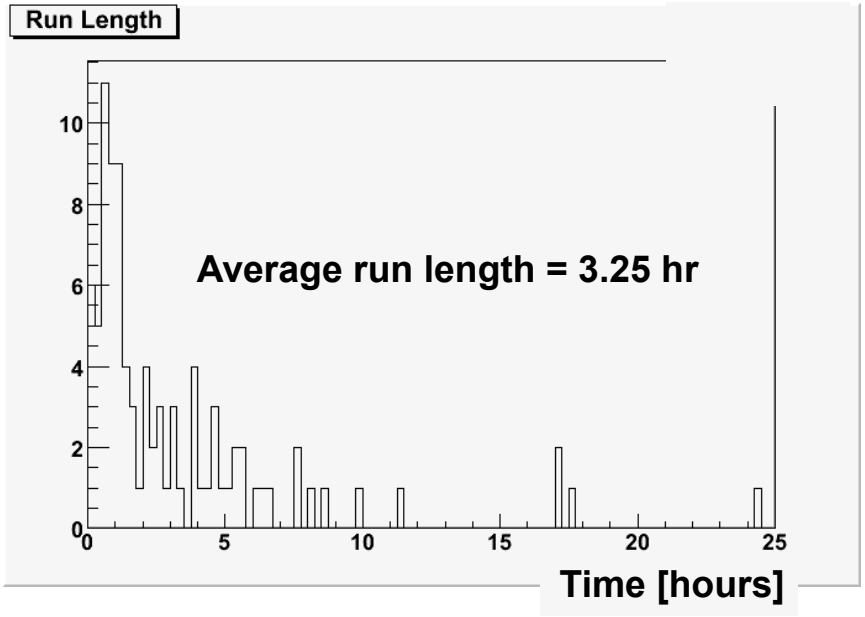


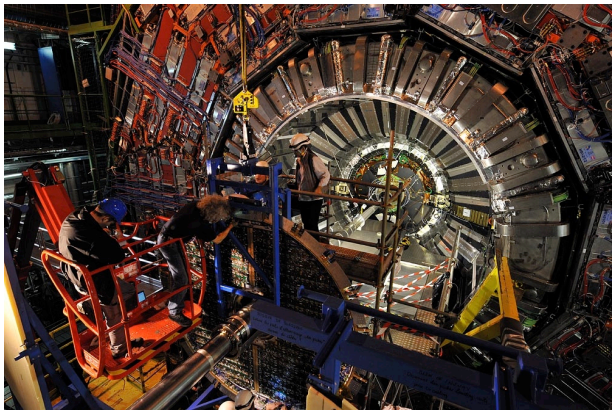
# Performance: Global Runs during Oct/Nov 08

- Four weeks of continuous running 13-Oct to 11-Nov
  - 19 days with B = 3.8T
- 370M cosmic events collected
  - 290M with B = 3.8T, Si Tracker & Muon Barrel in Readout
  - 194M with all components in
- Average data-taking efficiency
  - 60%, with periods of up to 24h at 100% efficiency
    - Earlier CRUZET (B = 0T) efficiency was about 50%
  - 10% inefficiency due magnet cooling (leading to ramp down)
  - 30% inefficiency for problems encountered between runs
- Crucial for Learning how to operate the Experiment
  - Efficiency improving; automation increasing; control centralizing
  - Shift rules and documentation evolving



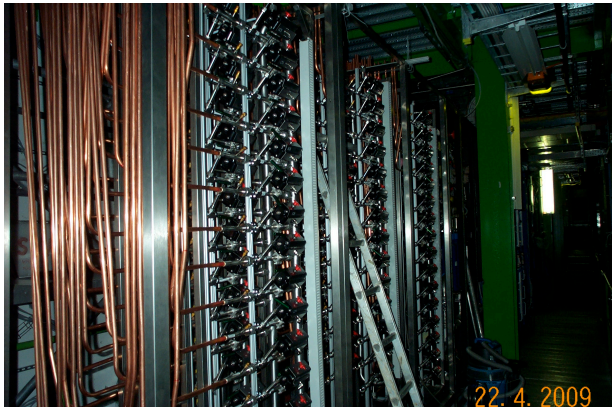
# Main activities during the shut-down

- Installation of Preshower (ES) detector (1)
- Extraction, repair and re-insertion of the forward pixel detector (2)
- Refurbishment of the tracker cooling plants (3)
- Miscellanea intervention on muon chambers (DT, CSC and RPC) (4)
- Final commissioning of the endcap RPC (neg. side).
- Main infrastructure (power, cooling, network, etc.) maintenance

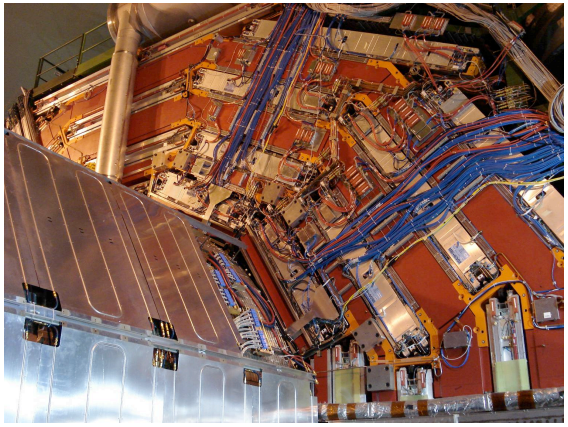


(1)

(2)




(3)



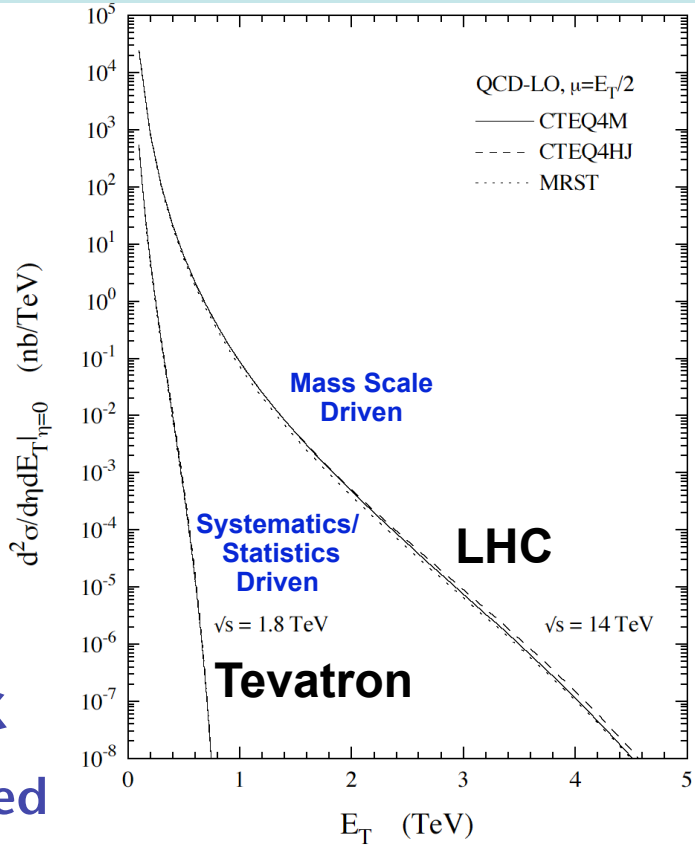
(4)

# Broad Stroke Plans for Beam

| Maintenance & Operation | | Software, Computing & Physics Analysis |
|---|---|---|
| | Jan | |
| | Feb | Release Software Version For Data (limited validation) |
| Install Pre-Shower 1<br>Install Pre-Shower 2 | Mar | |
| | Apr | |
| Tracker Cooling Plant Revised | May | ↕ Full validation of Software (and large scale production) |
| Close CMS | Jun | |
| Magnet Tests | | |
| Cosmic Run At Four Tesla (CRAFT) ↕ | Jul | ↕ Exercise Software widely across all of CMS (prepare early physics analyses) |
| | Aug | |
| CRAFT Contingency & pre-beam maintenance | | |
| CMS READY for Beam | Sep | CMS READY for Beam |
| | Oct | |

# LHC Opens up the Mass Terascale

- 20 years of operations: CDF & D0 are instruments of amazing precision:
  - Single Top, W Mass, Flavour Physics, ..
- For many searches, CMS needs to understand Detector & Bkgs only well enough, not more!
  - TeV dijets ≈ 10% energy scale OK
  - TeV dileptons ≈ 10% PT resolution OK
  - 0.25 TeV MET ≈ 10% HT energy scale OK
  - Improve systematic understanding as needed




- CMS Gearing up to robustly explore with imperfect knowledge
  - Exploit any/all data: Cosmics, single-beam, min-bias, dijets, etc
  - Use redundancy, calibrate to candles, use ratios & shapes,...
- Detector Understanding already quite good!

# Readiness for Early LHC Physics

- Extra time Improved Computing, Software & Physics Preparations
  - Continued exercise of Data Operations
    - from Trigger to DAQ to T0 to T1 to T2
  - Simulation Faithfulness of Real Detector
    - Testbeam, Cosmics, other known issues, …
  - Reconstruction Algorithms
    - Robustness, Redundancy
  - Object Calibrations Strategies:
    - tag & probe; dijet, photon-jet, Z-jet balancing; b-tag
  - QCD, EWK & Top
    - Establish Control Regions, Template fitting, MC-tuning, etc
  - Data Driven Searches
    - Many methods transferred from wealth of Tevatron expertise
  - Even Publication Review process exercised/streamlined

- We're not starting from zero! Far from it, in fact!

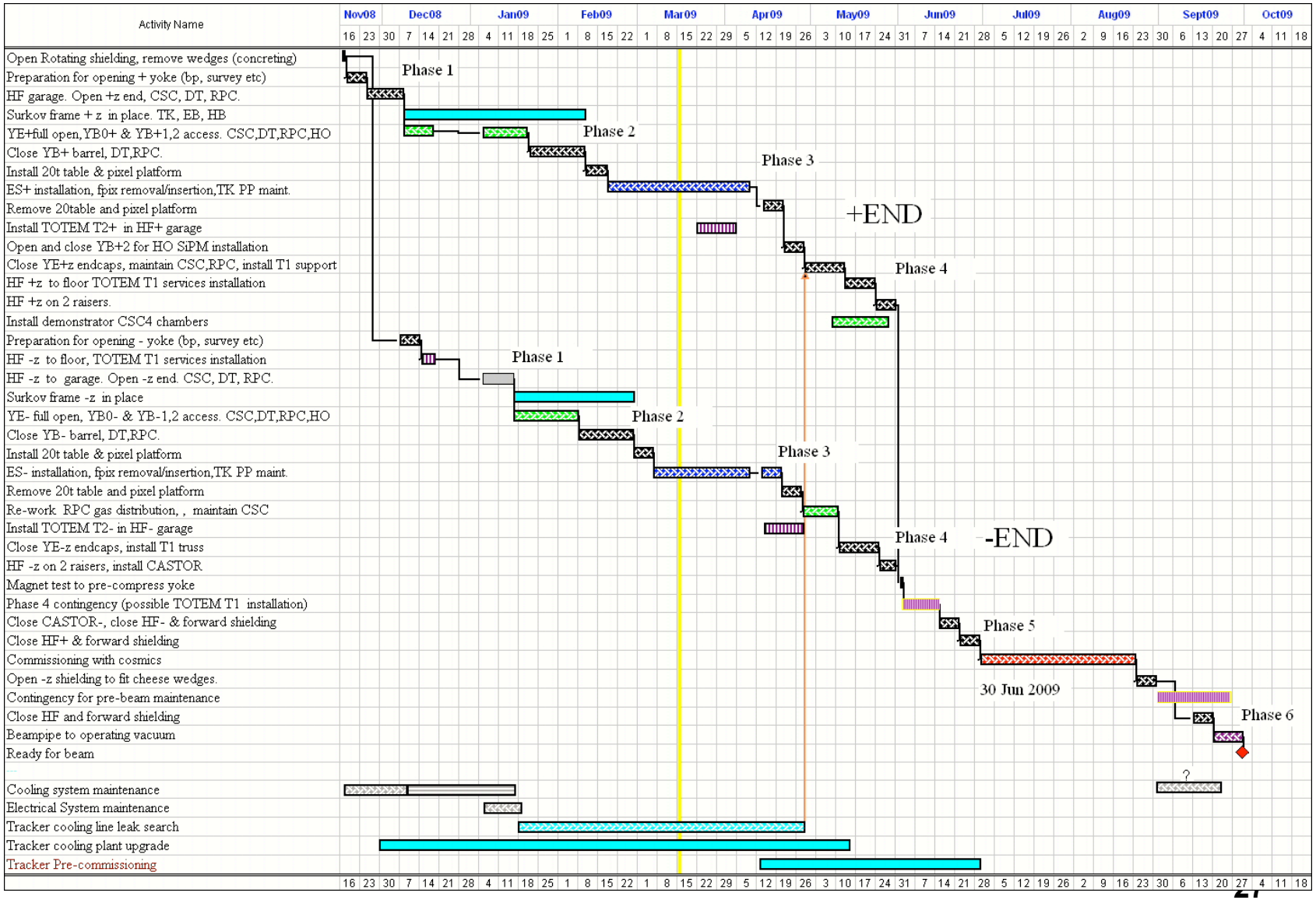
# Conclusion

- After 20 years of R&D, construction, and integration
  - CMS Commissioning is essentially finished
  - Result is a truly beautiful Detector
- All major components fully integrated and operational
  - Missing channels at few % level or less
  - Synchronization at few ns level or better
  - Trigger operational & DAQ stable
- CMS was ready for first LHC Beam
  - Delivered data maximally exploited
- Cosmic Ray Runs proven crucial
  - Online Operations, Detector Alignment & Response, etc
- Good use made of extra time
  - Debug remaining issues, improve efficiency, Physics Prep.

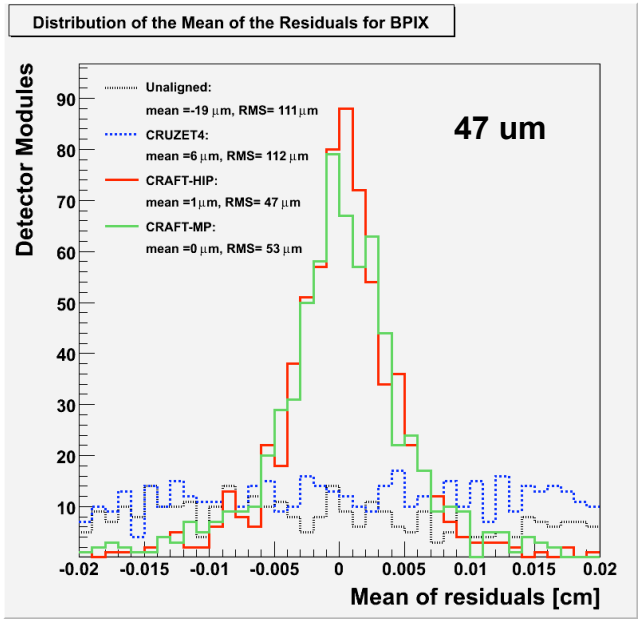
**CMS is in Excellent Shape!**

# Backups

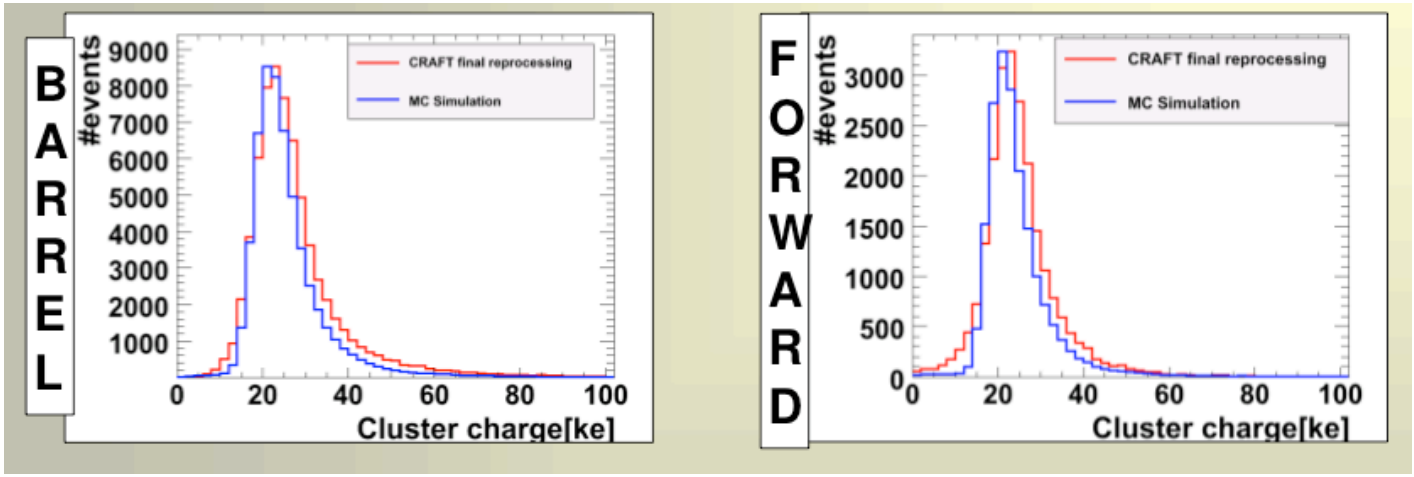
# Schedule: details



# Cosmic Muons and Pixels

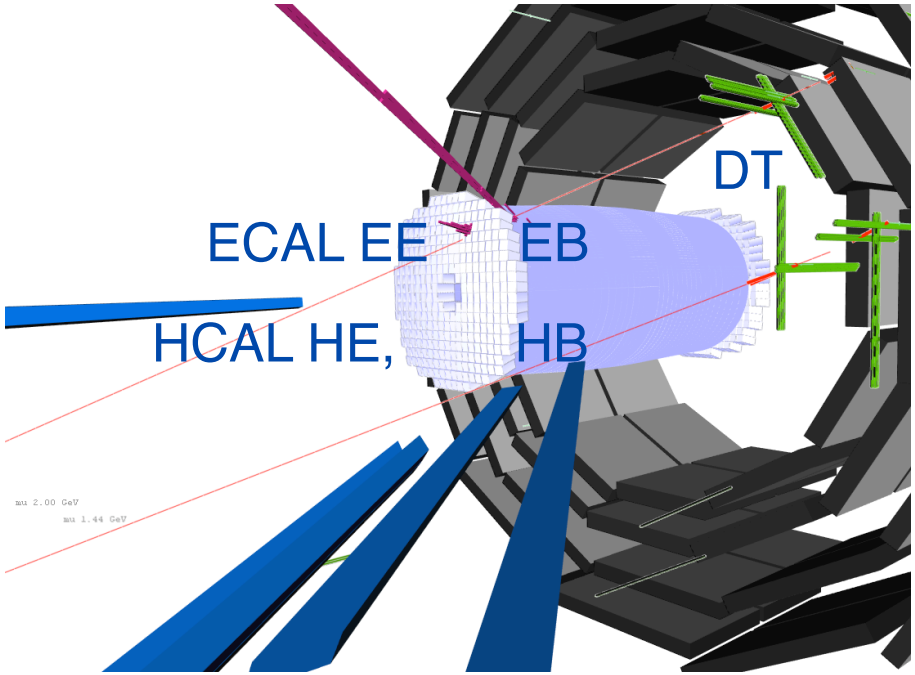


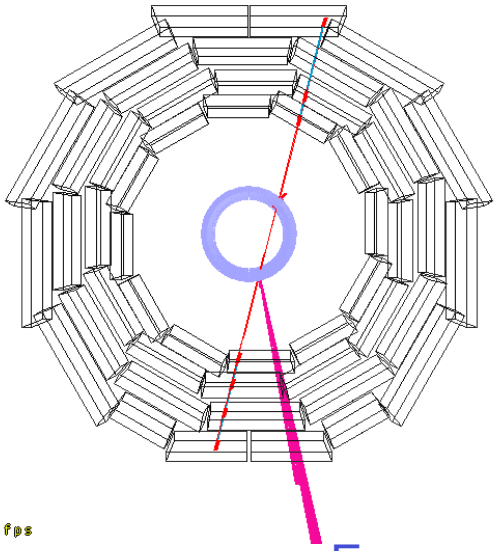

- Pixels
  - Barrel pixels: 99.1%
  - Forward pixels: 94.0% (addressed during this shutdown)
- Enough data in the barrel to align to 50um




- Cluster charge distribution understood for both barrel and forward

# Muon Brem in ECAL




Energy: 250 GeV