Readiness of the CMS Detector for First Data

Emilio Meschi
CERN PH-CMD
For the CMS Collaboration

XLIV Recontres de Moriond
7-14 March 2009

Detector

Muon System
Barrel: Drift Tubes (DT)
Endcap: Cathode Strip Chambers (CSC)
Barrel & Endcap interleaved with Resistive Plate Chambers (RPC)

EM calorimeter: ECAL
$PbWO_4$ crystal calorimeter
High resolution
High granularity > 80k crystals
Barrel (EB) & Endcap (EE)

Superconducting Solenoid
Very large, 6m x 13m
4T, 1.6 GJ stored energy

Tracker
66M Si pixels & 10M Si strips

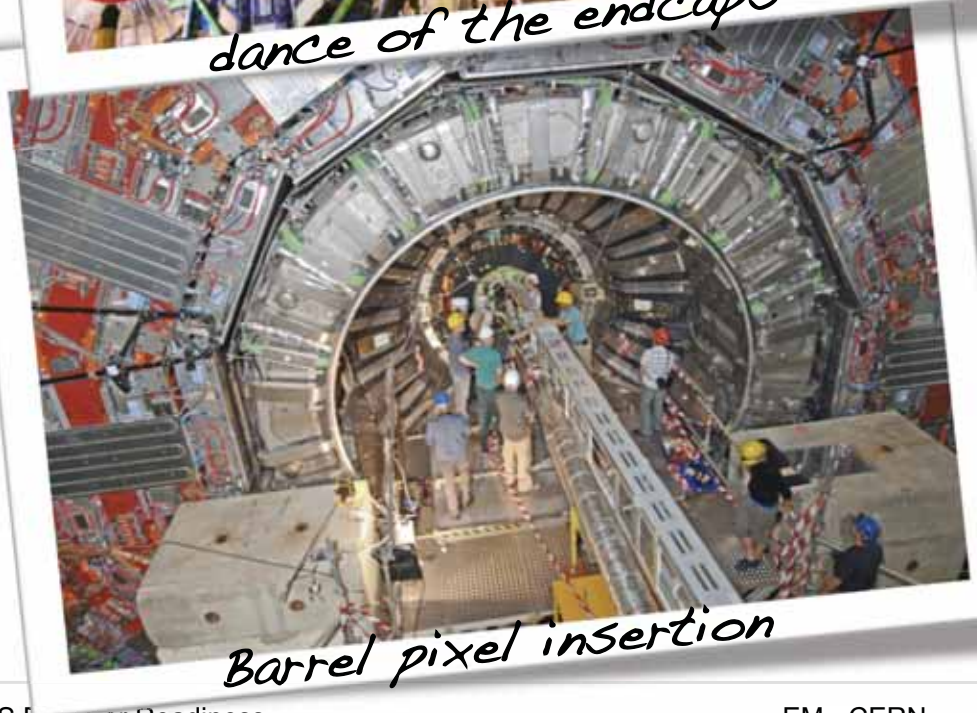
Hadronic calorimeter: HCAL
Brass & scintillator
Barrel (HB), Endcap (HE), Outer (HO)

Trigger/DAQ
Hardware Level-1 (100 kHz)
Tb/s Event Builder @ L-1 rate
Software High Level Trigger (HLT)
-> 300 Hz

Compact, modular design
12.500 t, 15 m diameter, 21.6 long

From the CMS Album

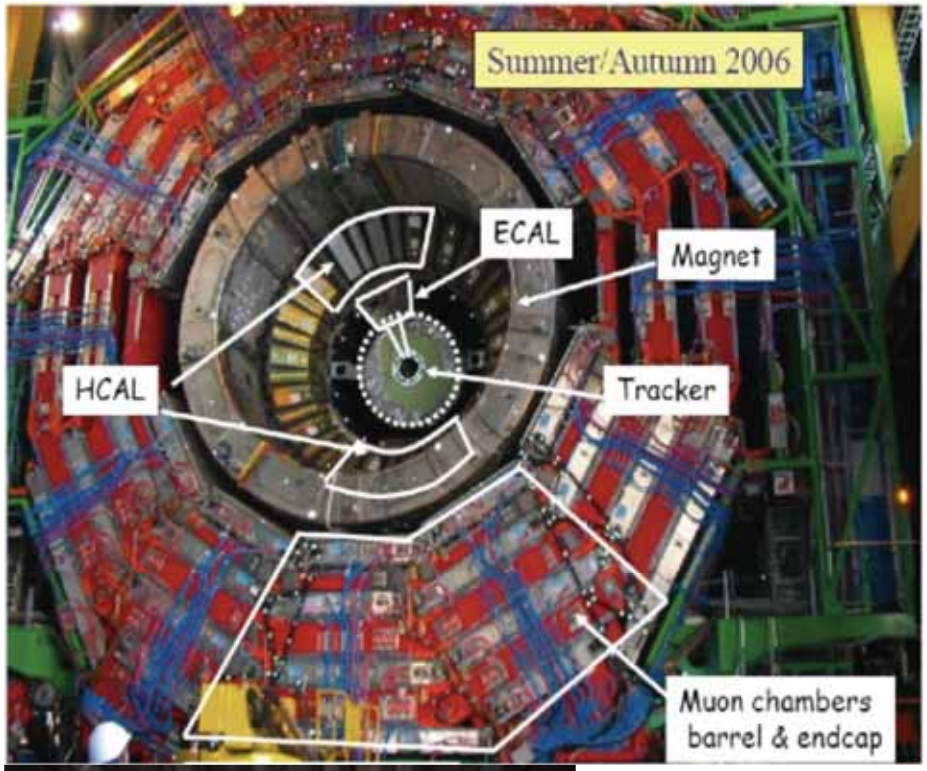
dance of the endcaps



Barrel pixel insertion

YE-1 lowering

MTCC: the Beginnings

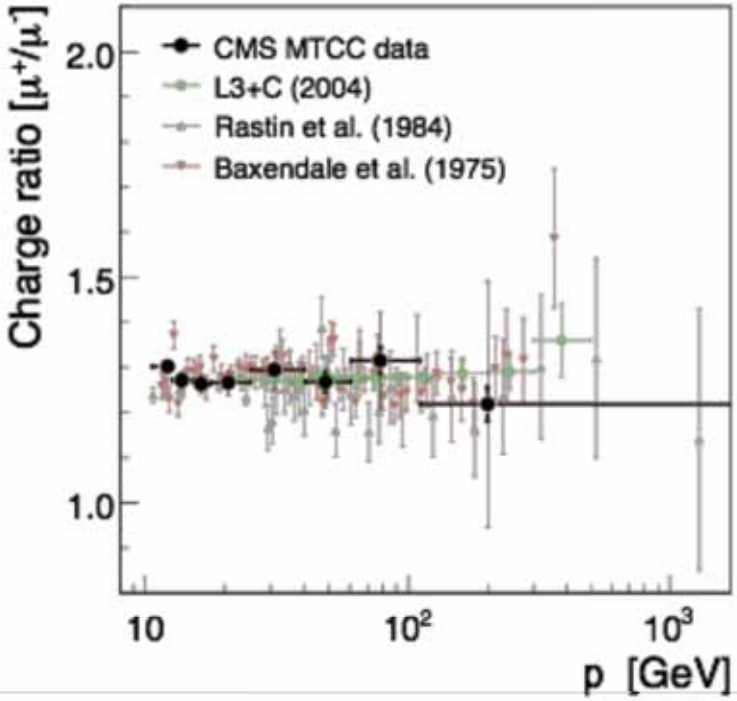


First system test

Scaled-down infrastructure

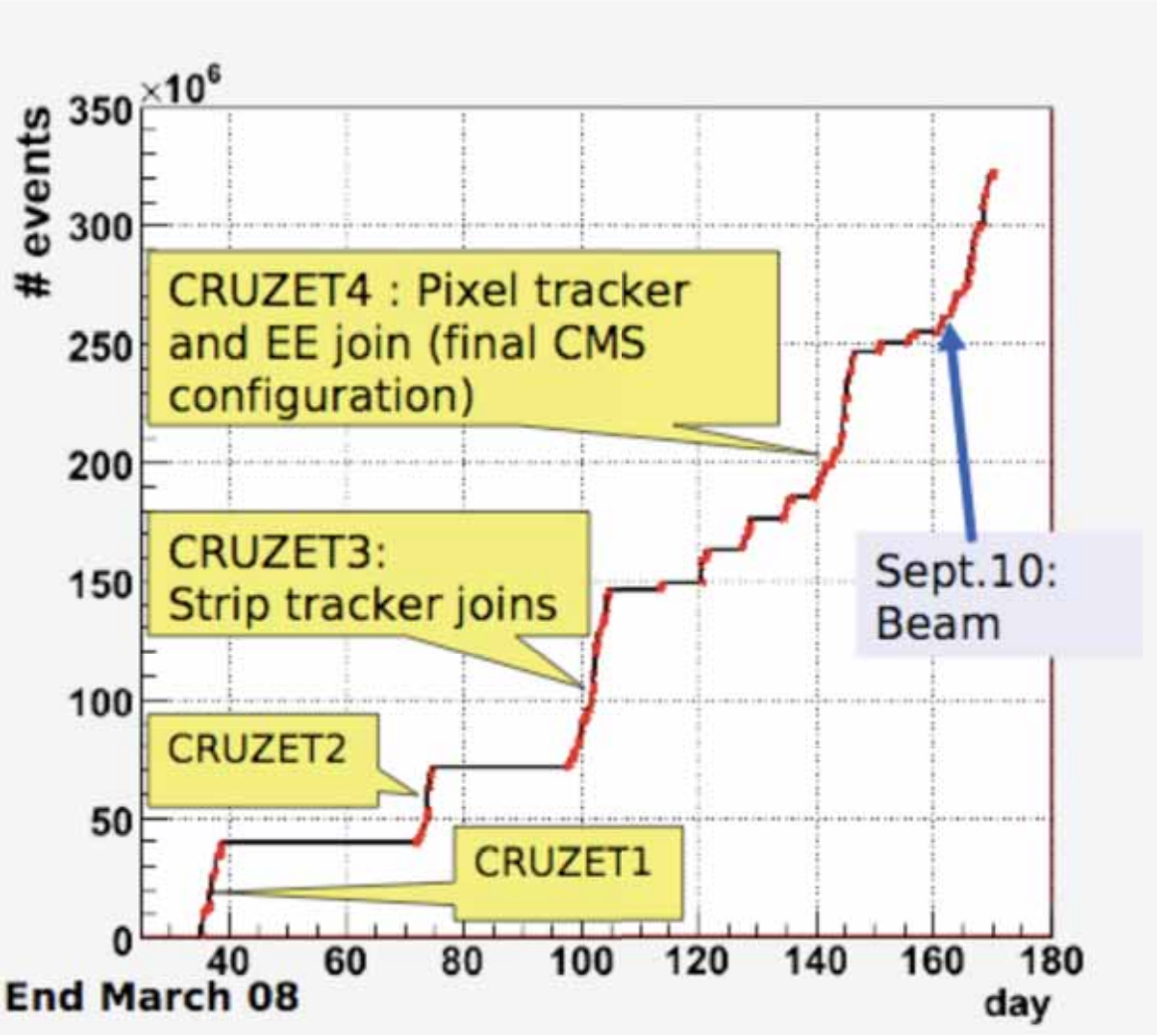
Slice of nearly all final components and DAQ

Parasitic to B-field measurements at 5 field values -> field maps for physics



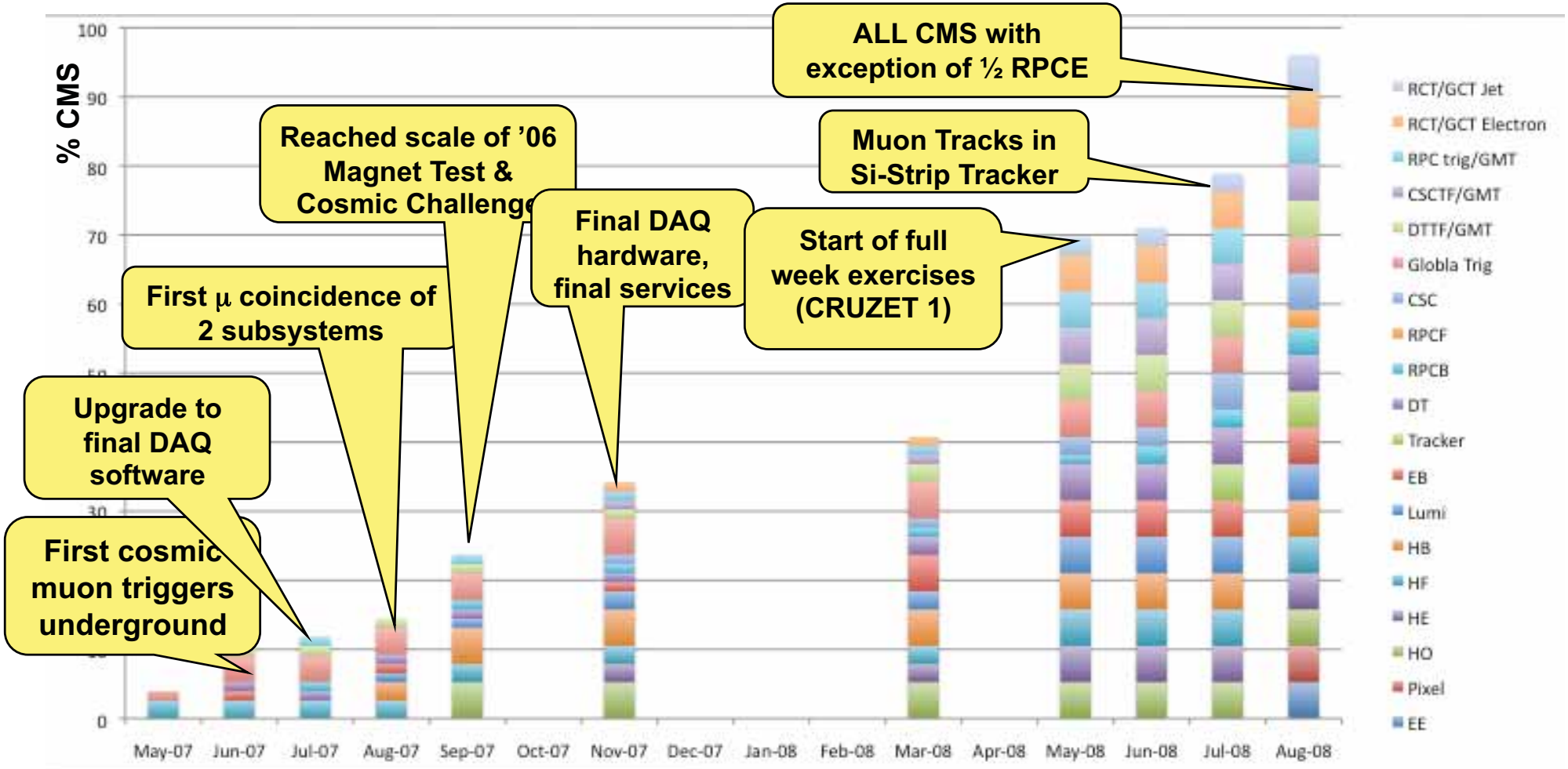
March-August 2008: Waiting for Beam

- Operate CMS as a single detector
  - Integration of new sub-detectors
  - Increase complexity maximize stability
  - Coordinate with installation schedule
- Infrastructure
  - DAQ, trigger commissioning
  - DQM, DCS, DSS
  - Control Room

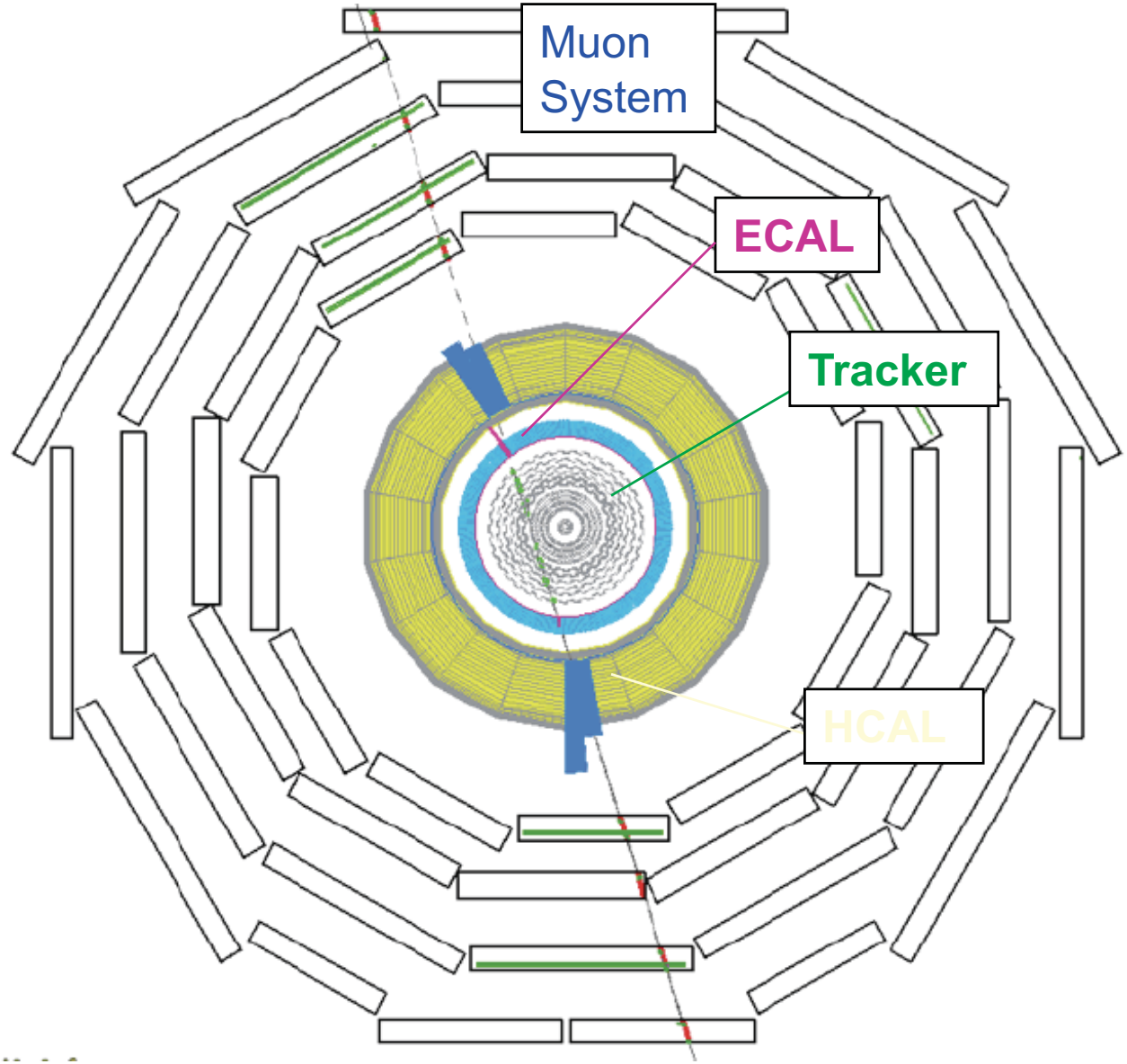


Global Runs

- **Subdetector and trigger considered separately - 19 items, each equally weighted - box size represents approx. fraction included (25%, 50%, 75%, 100%)**
- **With exception of some parts of RPC, all CMS detector and trigger system ready for LHC**



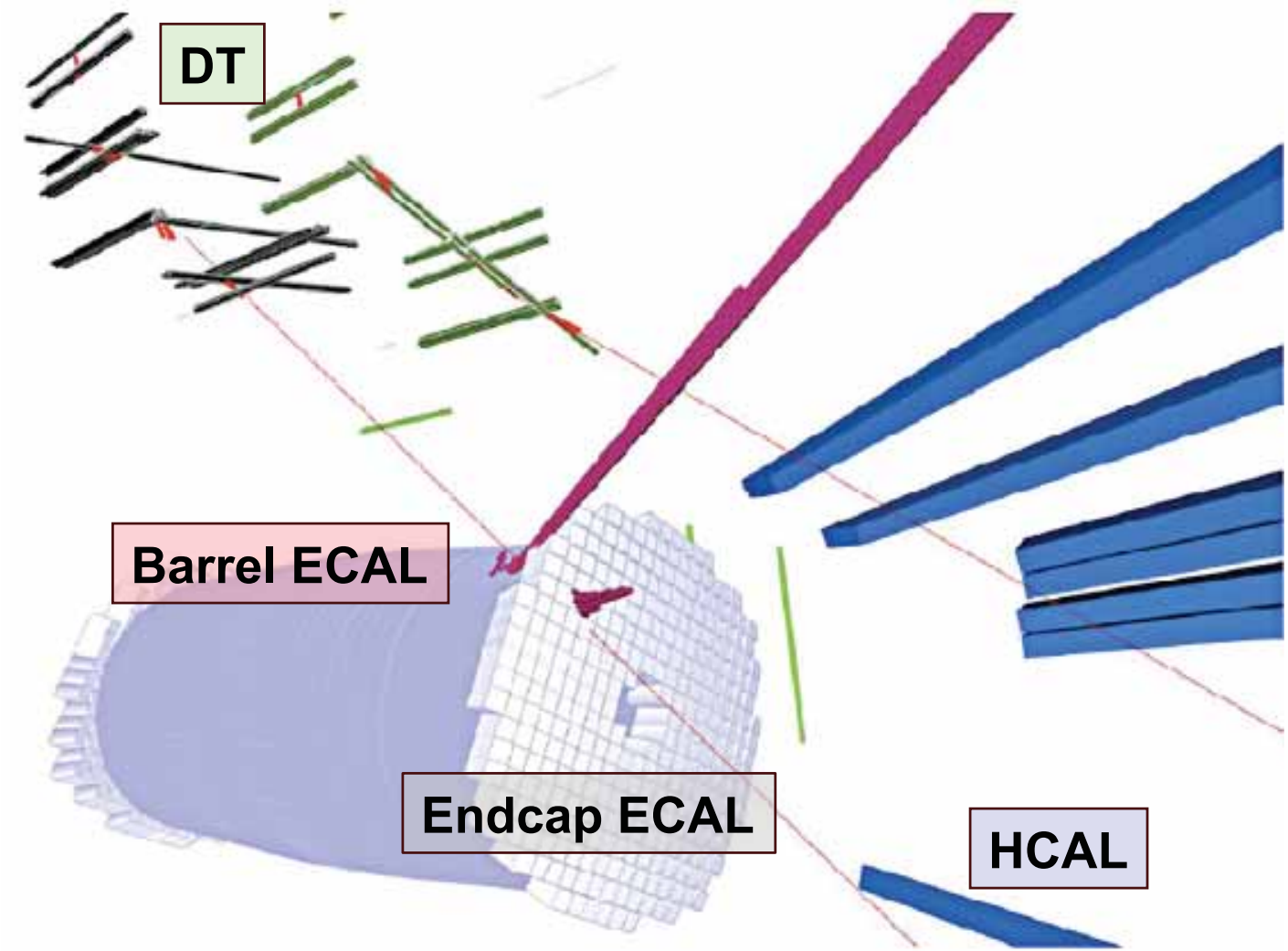
CRUZET3: Global Tracks



- Di-muon Trigger:
  - Drift-Tube coinc. in top+bottom, each ≥ 2 station segments
- Muon signals traced through
  - muon system
  - Tracker TOB+TIB
  - ECAL
  - HCAL
- Global track fit
- Data used for alignment

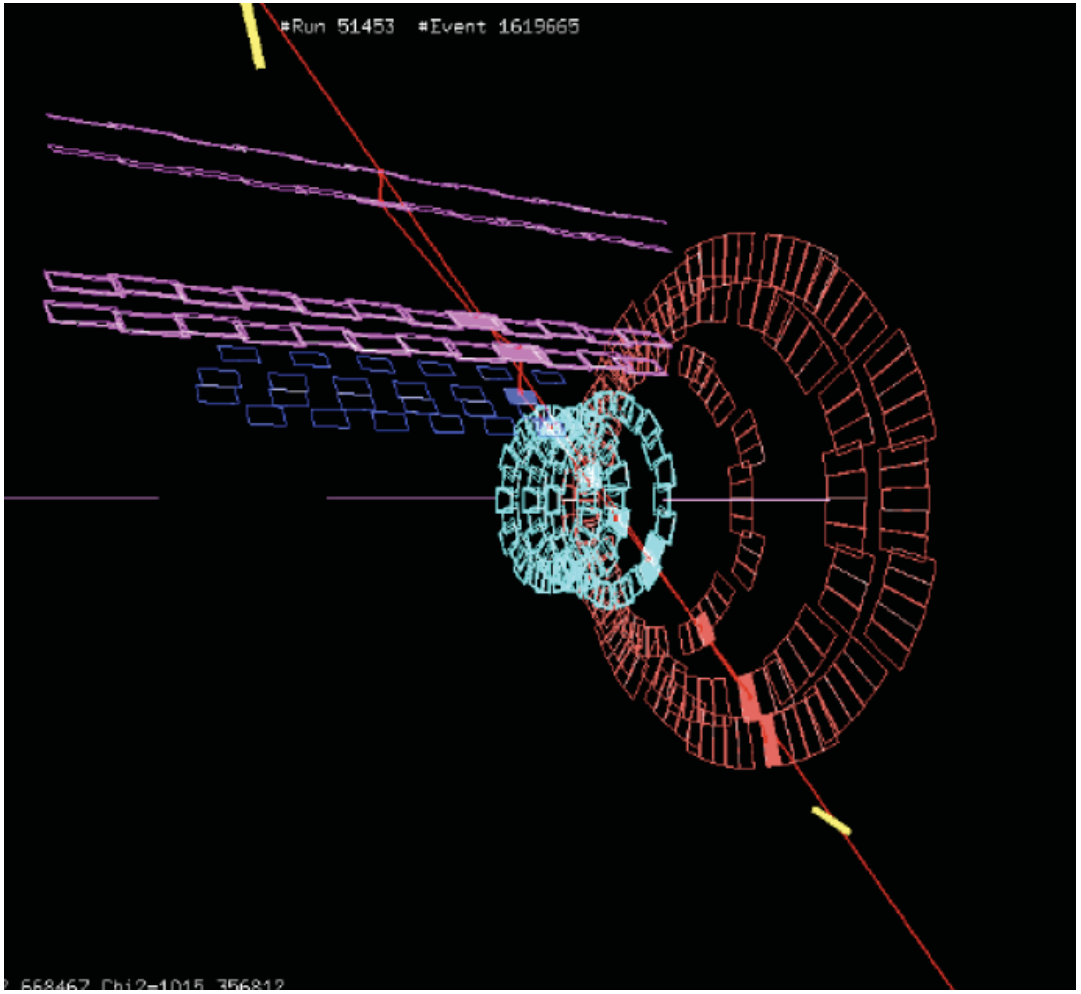
CRUZET4: Endcap ECAL

End of Aug08 – Endcap ECAL part of Global Runs

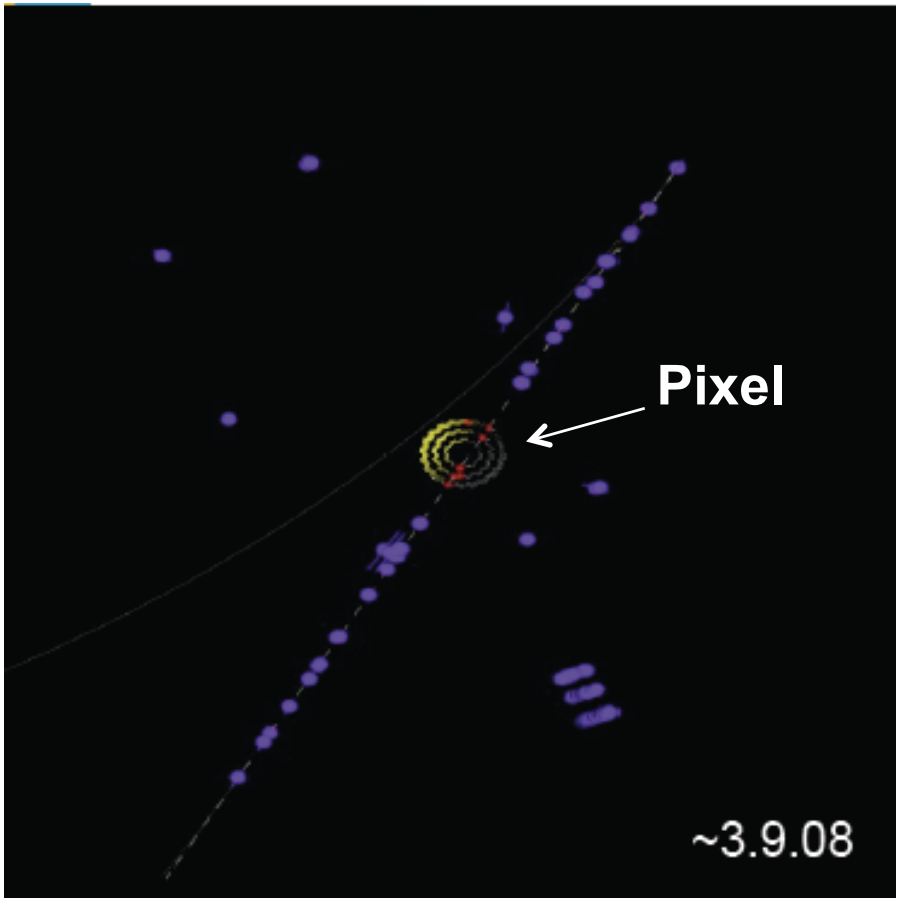


Tracker/Pixel

Aug08: all parts of Tracker integrated

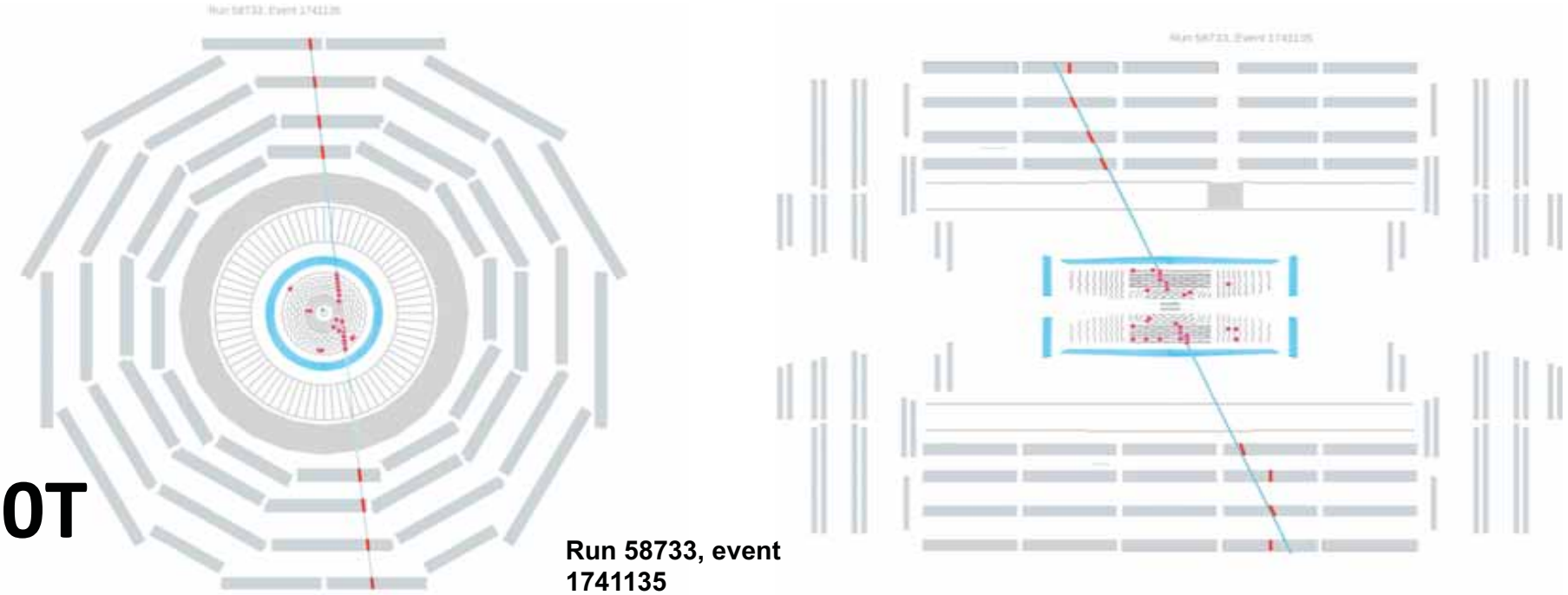


First cosmic tracks with Pixels



Testing the muon High-Level Trigger

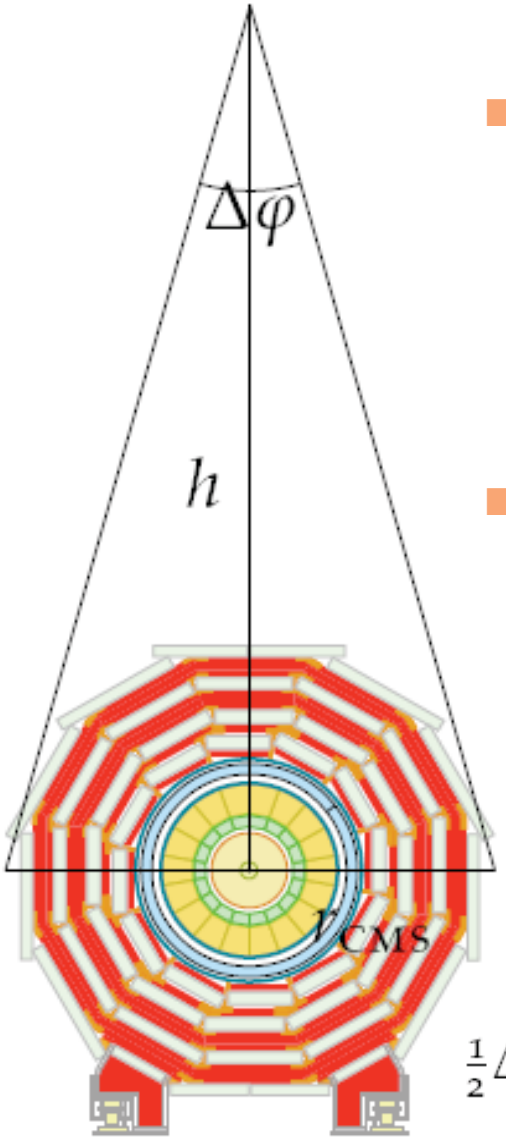
- Routinely running High-Level-Trigger menu (plus dedicated cosmic muon trigger path)
- Global fit with “L3” tracker track, seeded from “L2” muon track, seeded from “L1” trigger candidate:



0T

Run 58733, event 1741135

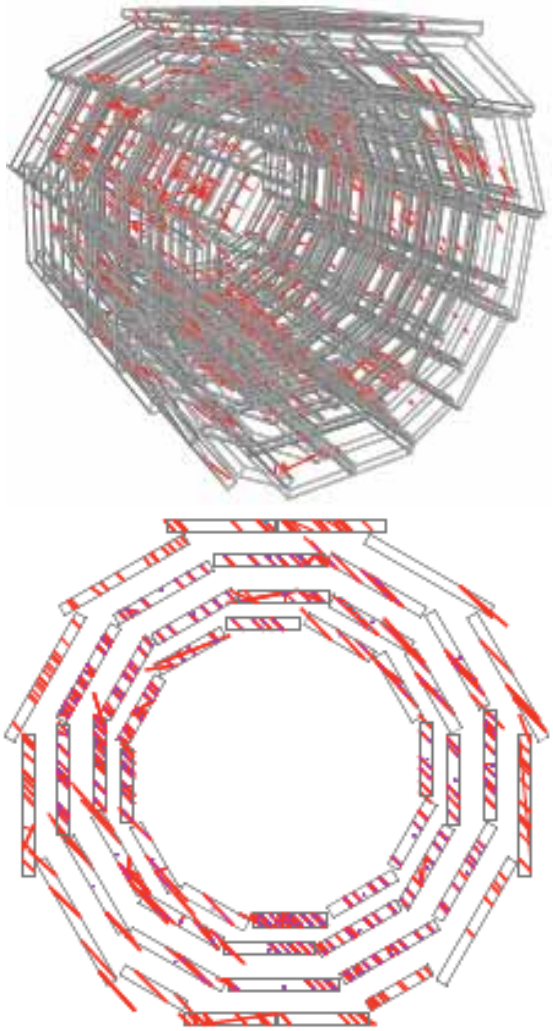
Cosmic Shower Events:



- 0.02% rate of events with >100 segments in ~10M cosmic events at 0T
- Event-by-event spread in phi compatible with multiple scattering → all events compatible with cosmic muon

$$\Delta\varphi \approx 0.01\pi$$
$$\Rightarrow \quad h \gtrsim 500\,\mathrm{m}$$

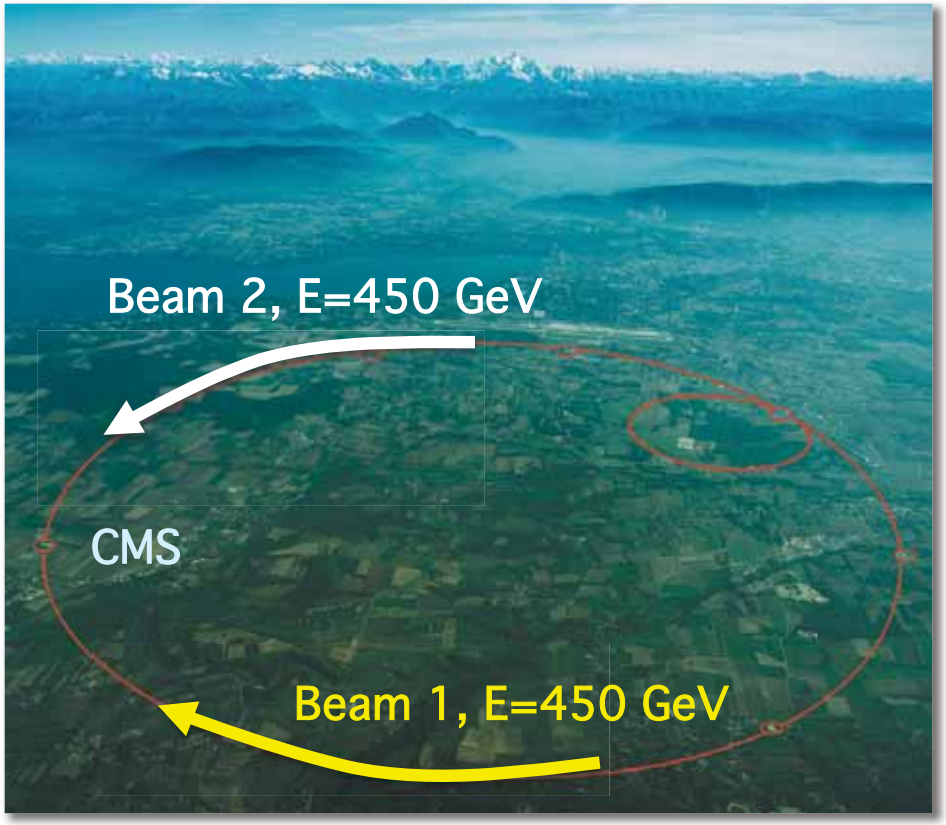
$$\tfrac{1}{2}\Delta\varphi \approx \tan\tfrac{1}{2}\Delta\varphi = \frac{r_{CMS}}{h}$$



- Run 50908
- event 1057286
- 541 segments

Calling the Shots: First LHC Beam

- September 7-12 2008
  - Beam1 on collimators (upstream of CMS)
- 10 September (D-day)
  - Beam 1, then Beam 2 circulating (hundreds of turns)
- 11 September: RF capture (millions of orbits)
  - Beam halo through CMS
  - Beam-gas events
- About 40 hrs beam at or through CMS
  - All systems active except Tracker and Solenoid



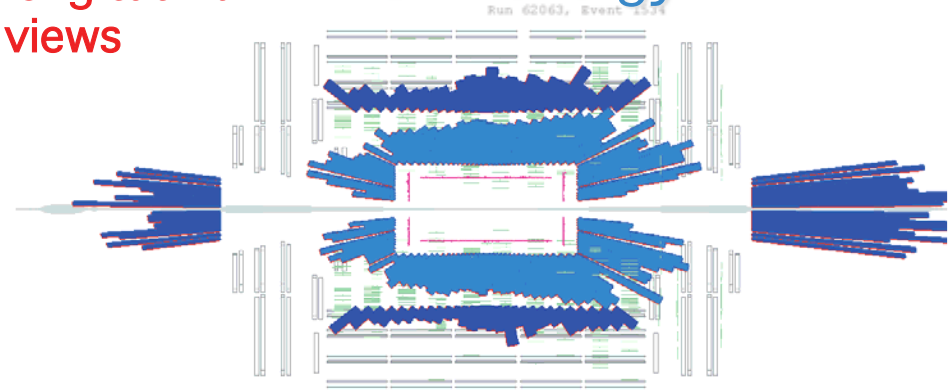
❑ CMS Trigger and DAQ fully functional: millions of beam events recorded

On 10th September

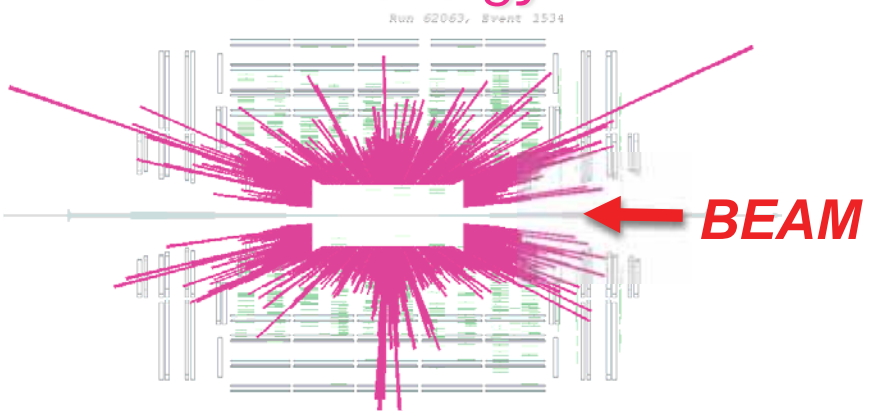
Beam Splash Event Display

Longitudinal views

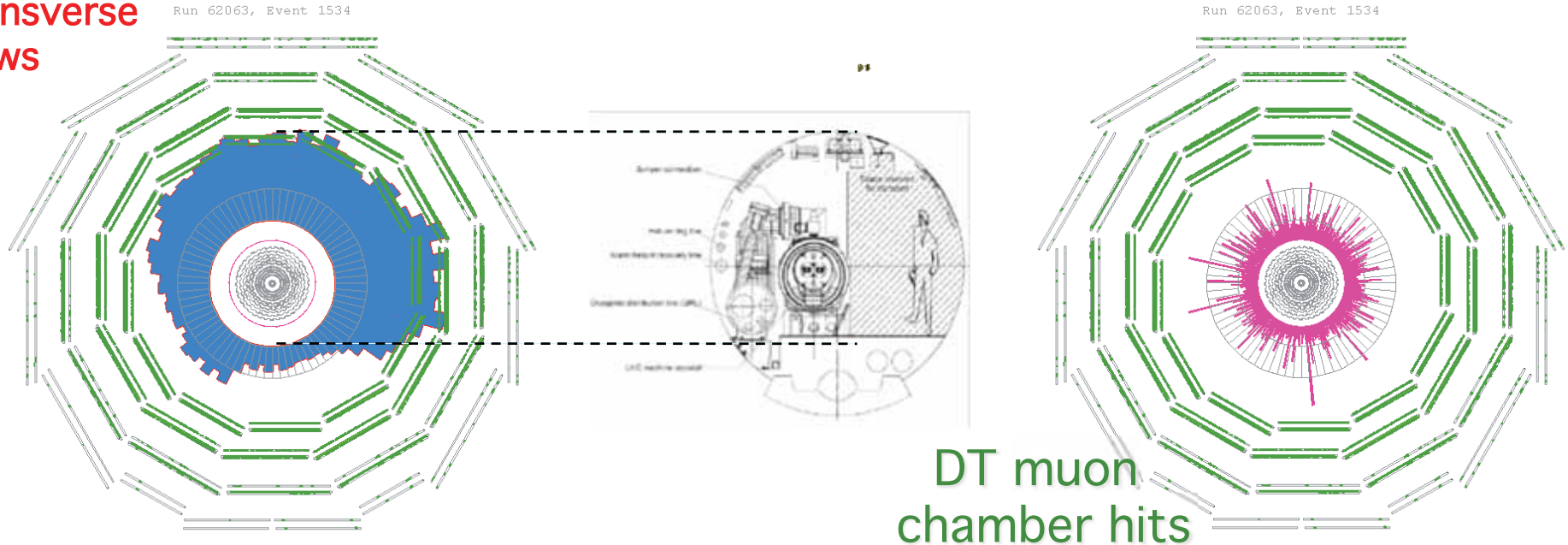
HCAL energy



ECAL energy



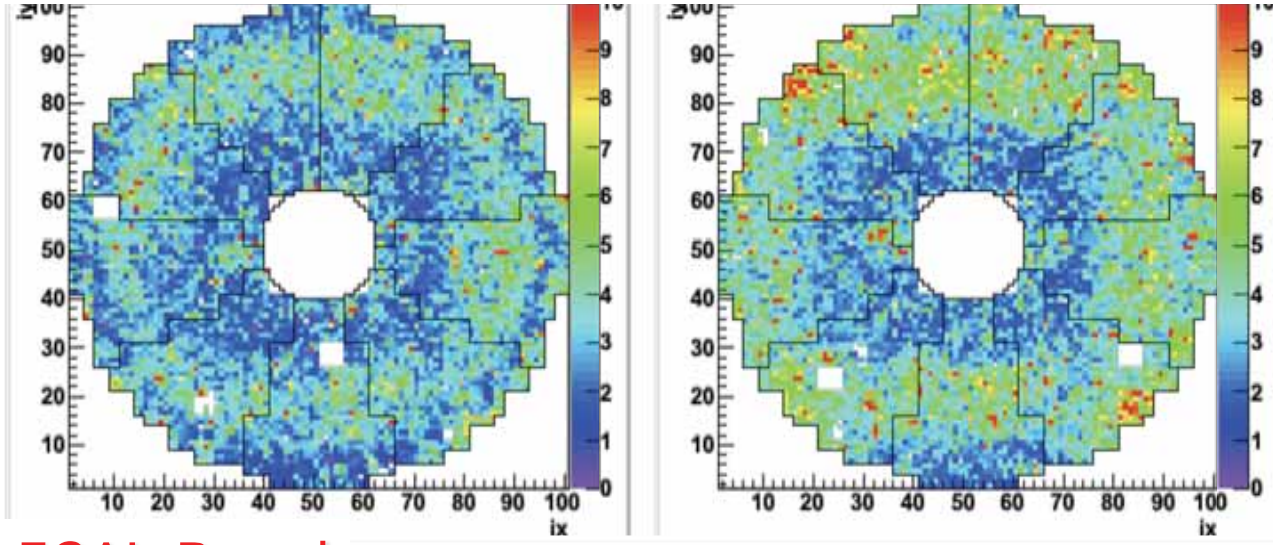
Transverse views



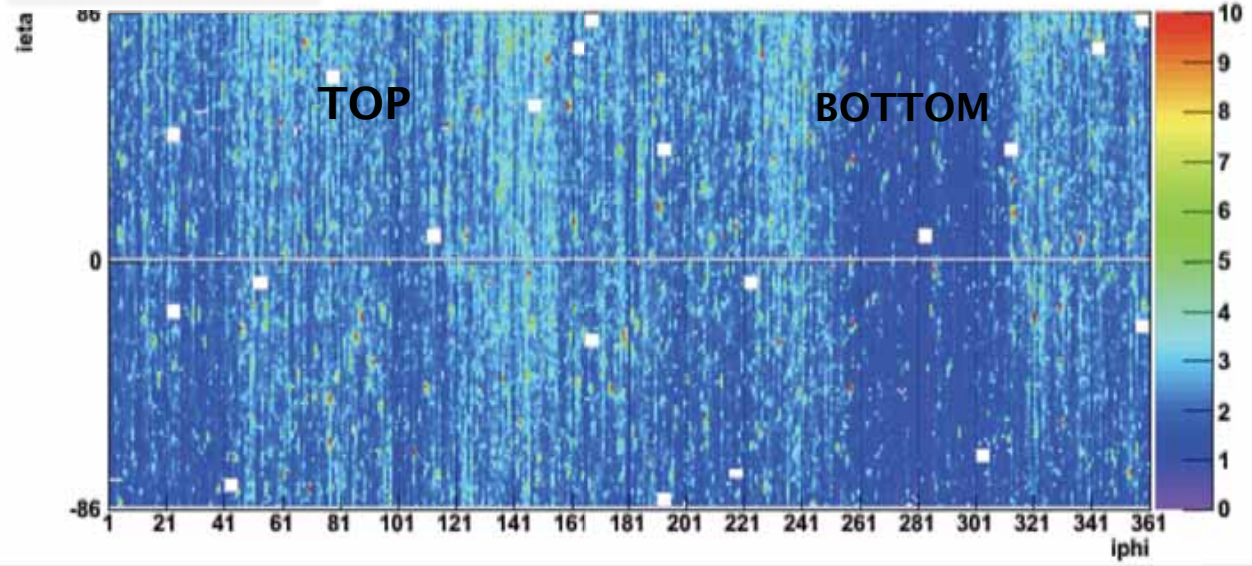
DT muon chamber hits

Beam Splash: ECAL Energy

ECAL Endcaps



ECAL Barrel



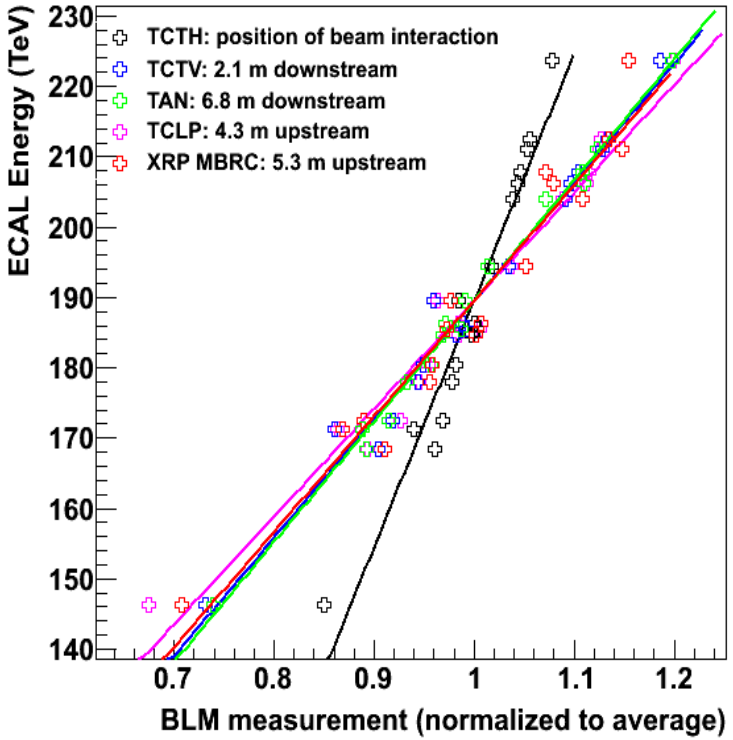
> 99% of ECAL channels fired and ~200 TeV energy deposited in EB+EE

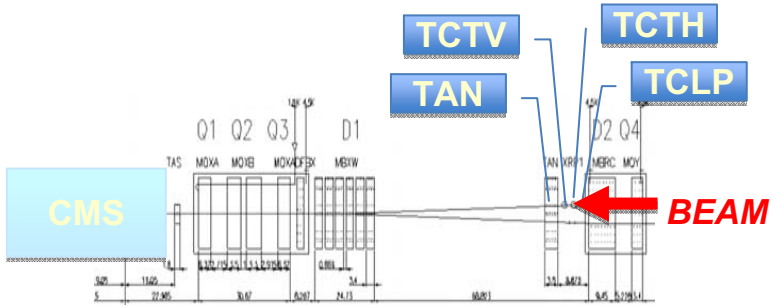
Beam (clockwise) came from plus side.

Endcap calibrations were not yet applied (lowest gain near the beam pipe).

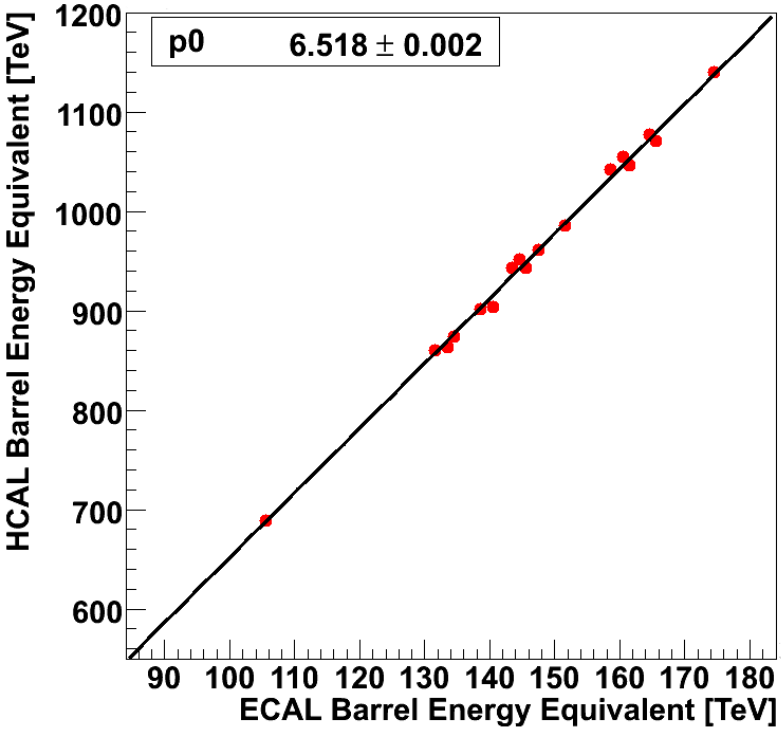
Beam Splash Correlations

Correlation between ECAL & Beam Loss Monitors





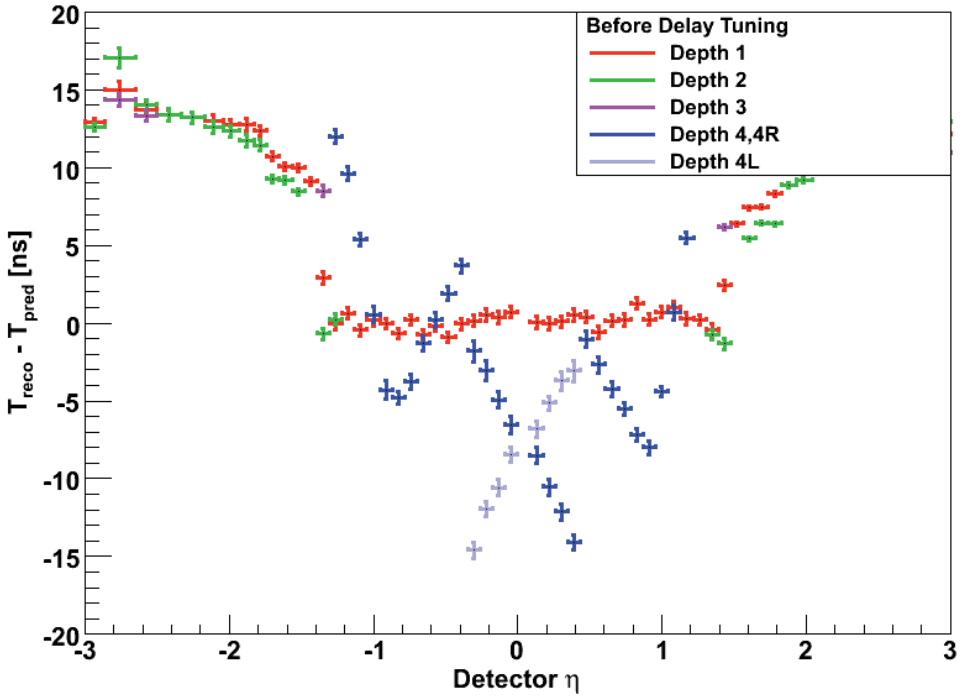
Correlation between Energies in barrel HCAL and ECAL



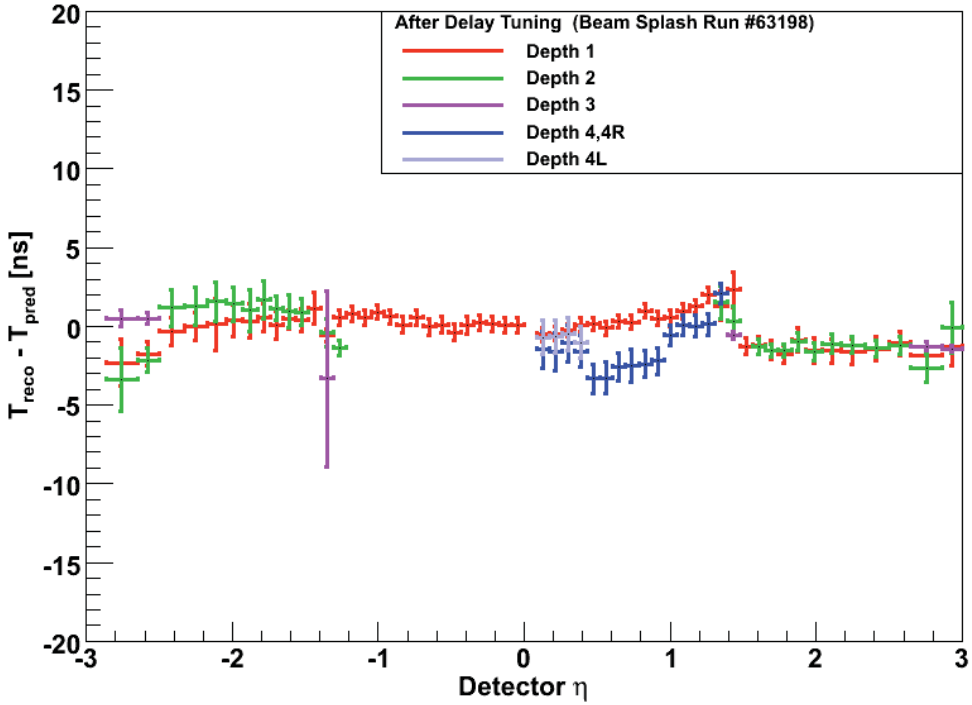
~150 TeV deposited in ECAL & ~1000 TeV deposited in HCAL per splash event

Tuning HCAL Timing with Beam Splash

ΔT Before



ΔT After

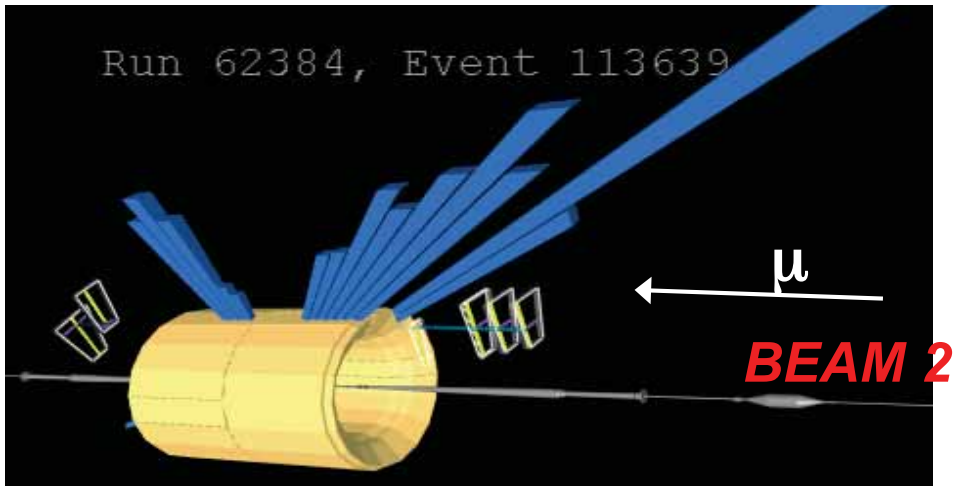


Time difference between predicted pulse arrival time and mean pulse arrival time for splash events, before and after using delays tuned from beam splash events.

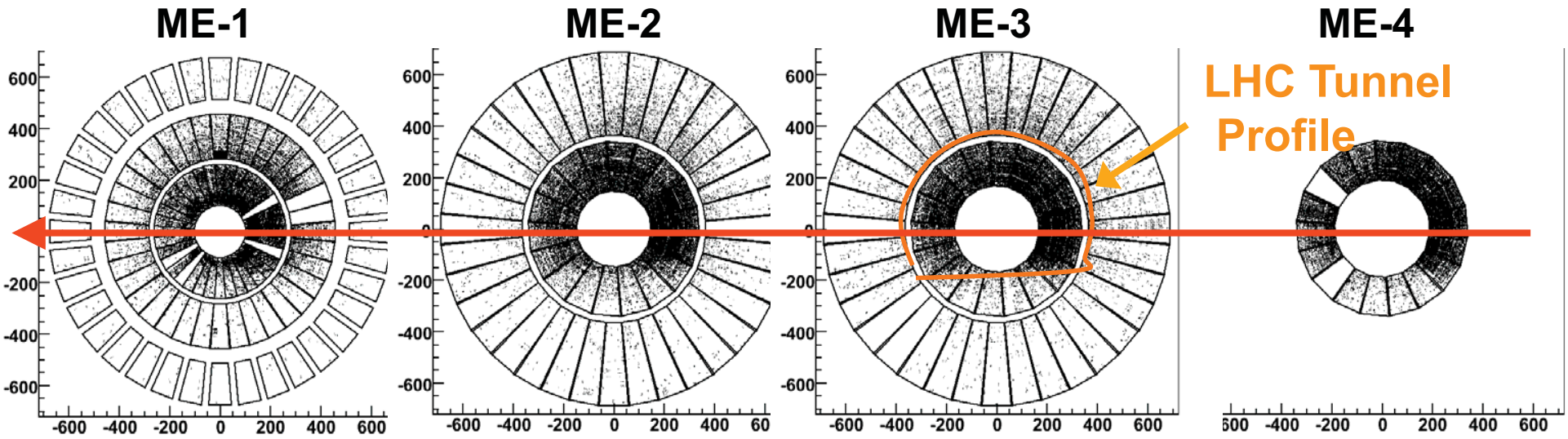
- Note that HCAL Barrel region was already tuned with prior data.
- HCAL now timed in at nanosecond scale

Beam Halo Muons

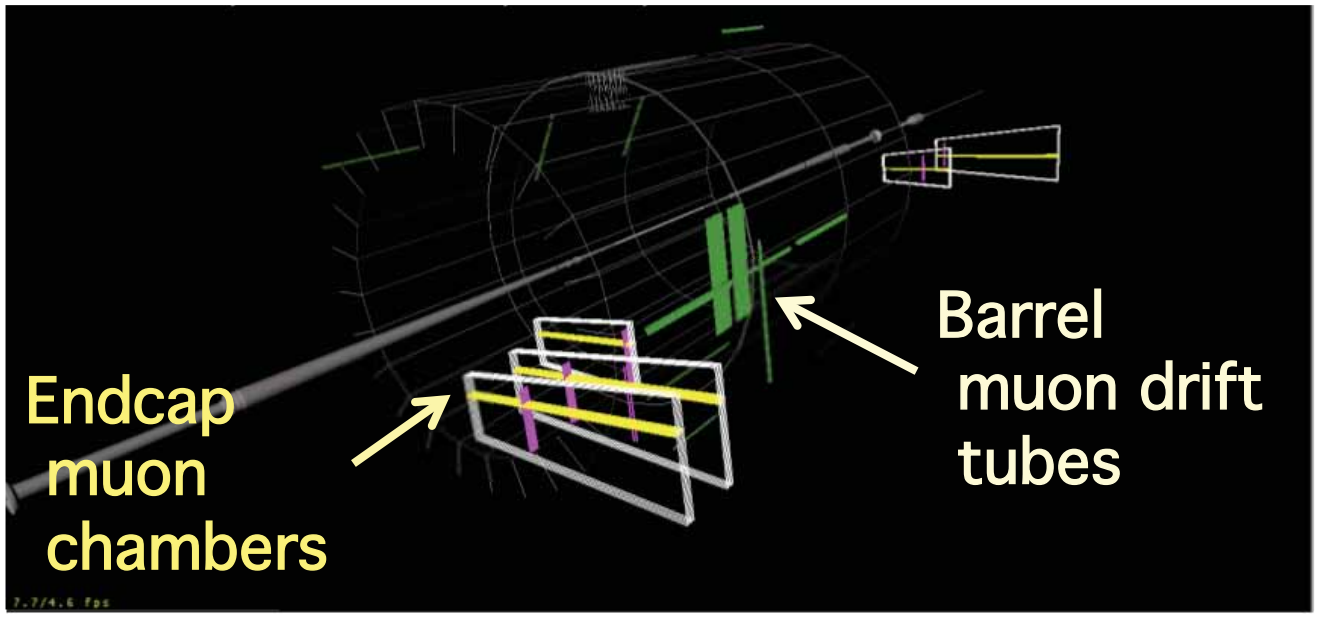
Beam Halo: Muons outside of beam-pipe, arising from decays of pions created when off-axis protons scrape collimators or other beamline elements

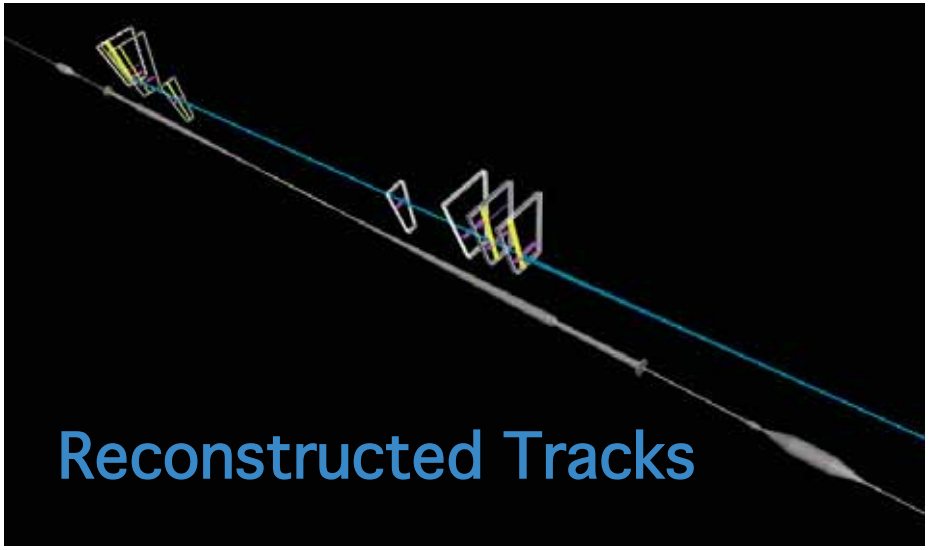


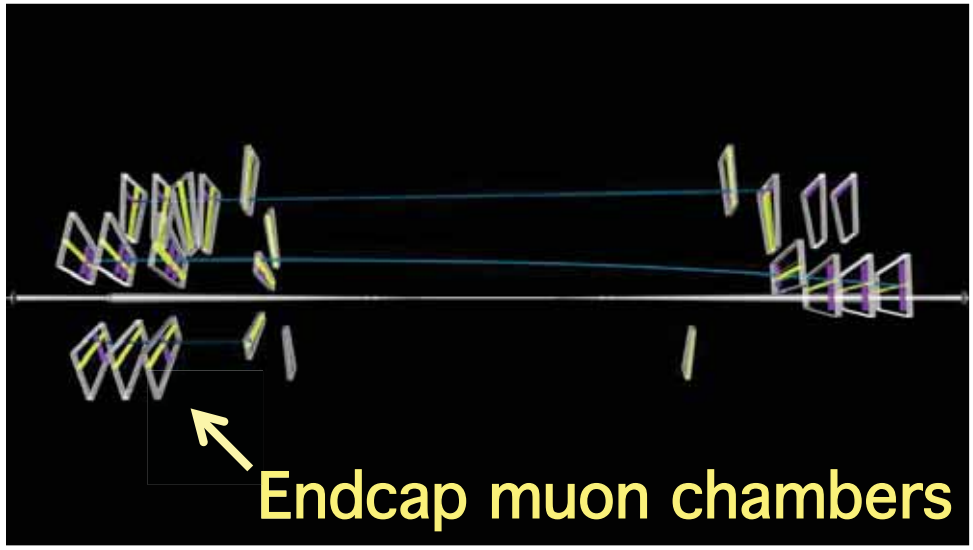
CSC Hit Distribution from Beam Halo Events



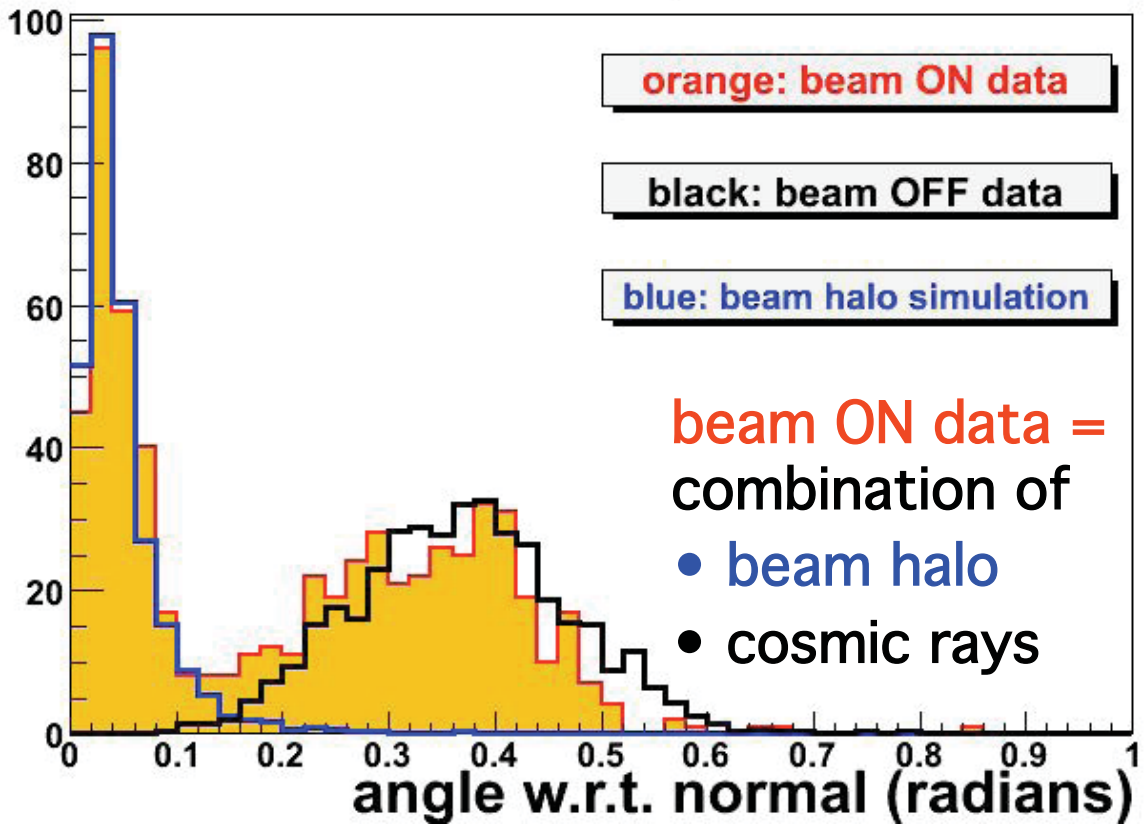
Halo Muons


Endcap
muon
chambers
Barrel
muon drift
tubes


Reconstructed Tracks

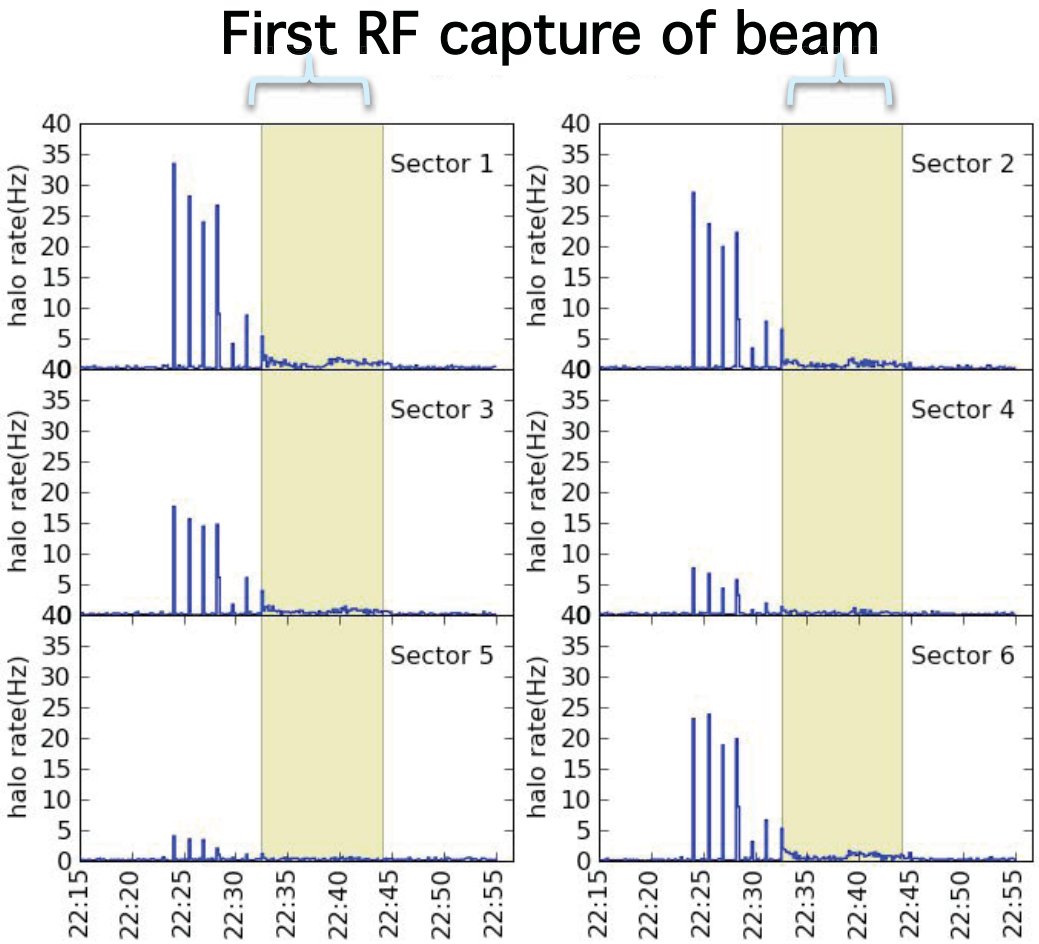

Endcap muon chambers

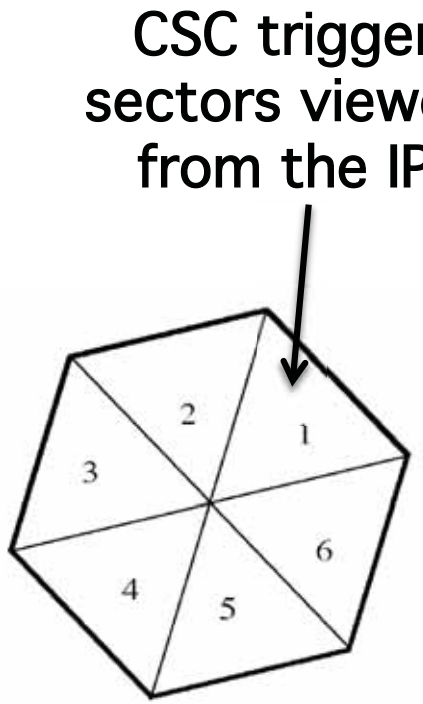
Halo and Cosmic Muon Angles



- Beam halo muons parallel to beam tangent (small angle)
- Cosmic Ray muons pass through the CSCs at a more oblique angle
- Beam-on distribution consists of two pieces, one resembling cosmic rays and the other matching the beam halo simulation.

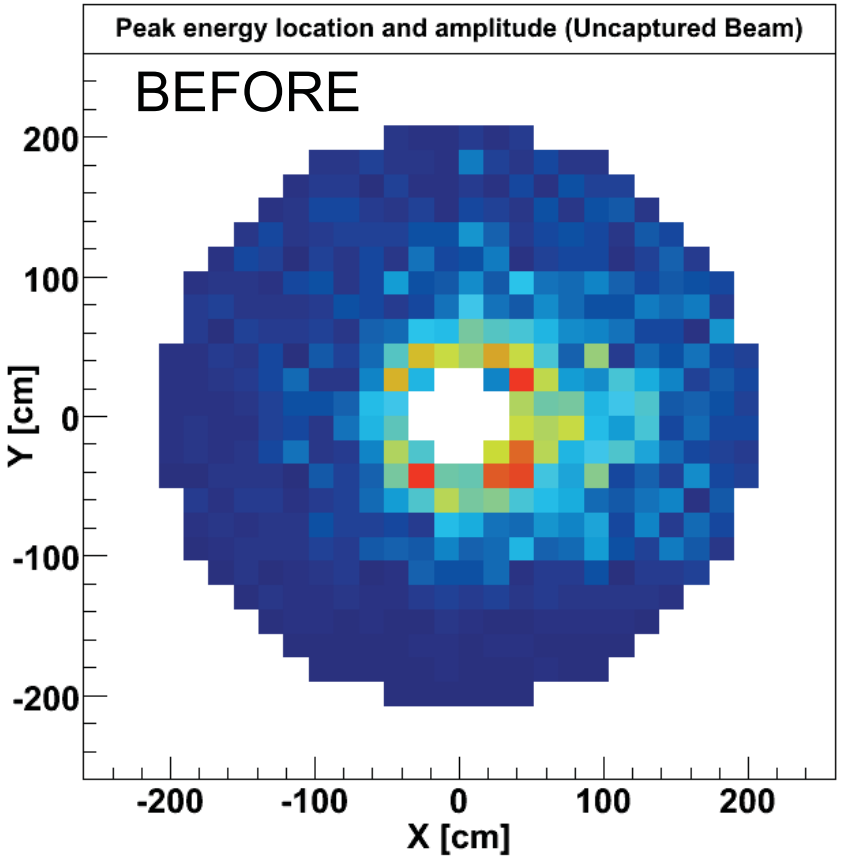
Beam Halo Rates in Muon Endcaps

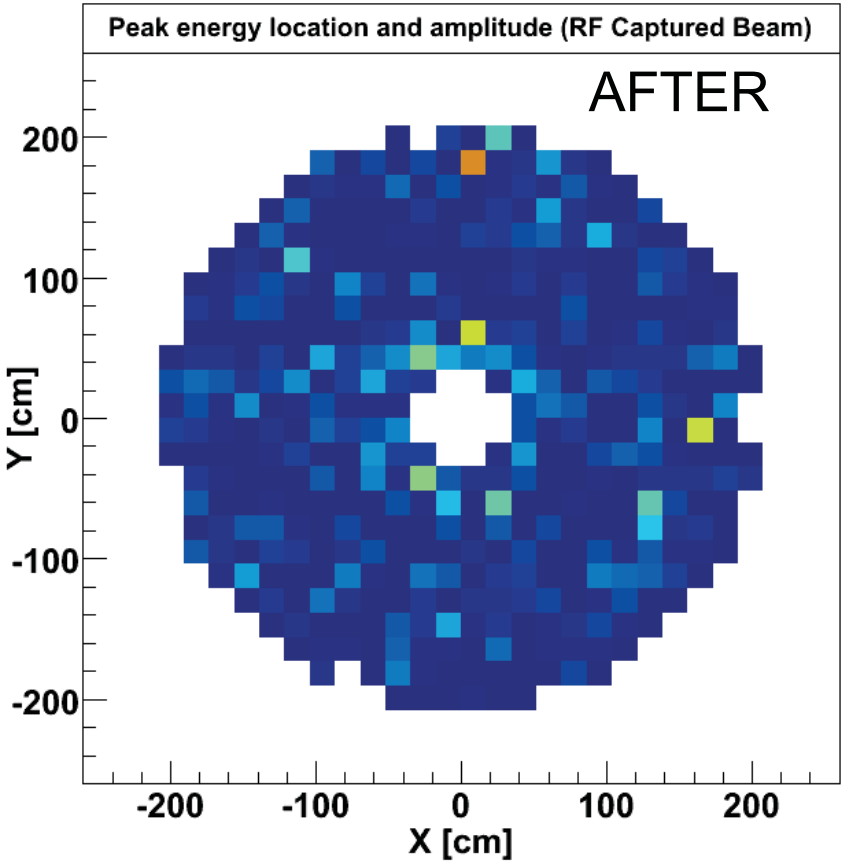




- CSC halo trigger rate in the minus endcap as a function of time.
- First successful capture lasted for 10 min and ended with beam abort
- Rate jumps preceding this are visible, due to earlier capture attempts.

HCAL Endcap: Beam Capture

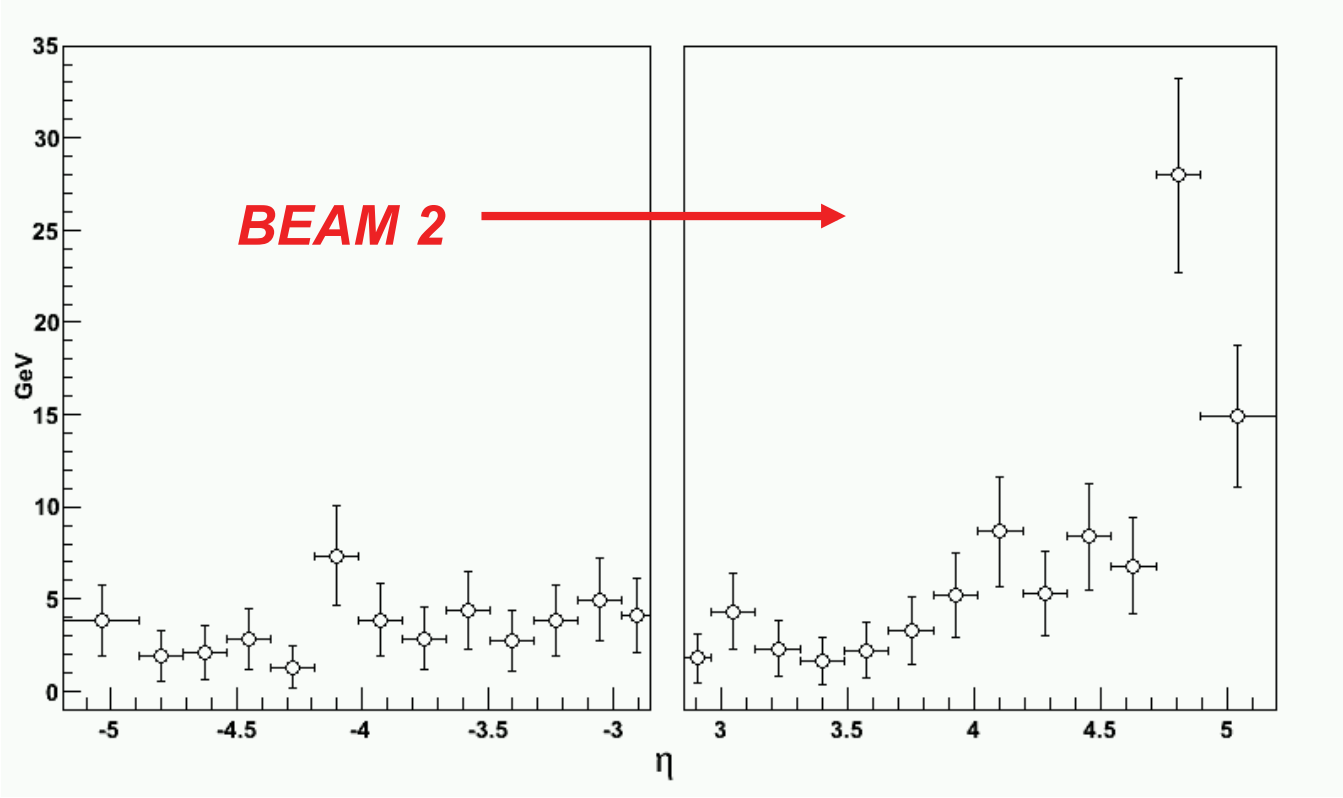




- HCAL Endcap energy before and after RF capture of the beam.
  - Before, high rate of energy deposition near beamline.
  - After, beam is cleaner, depositing less energy in HE.

Evidence for Beam Gas Collisions

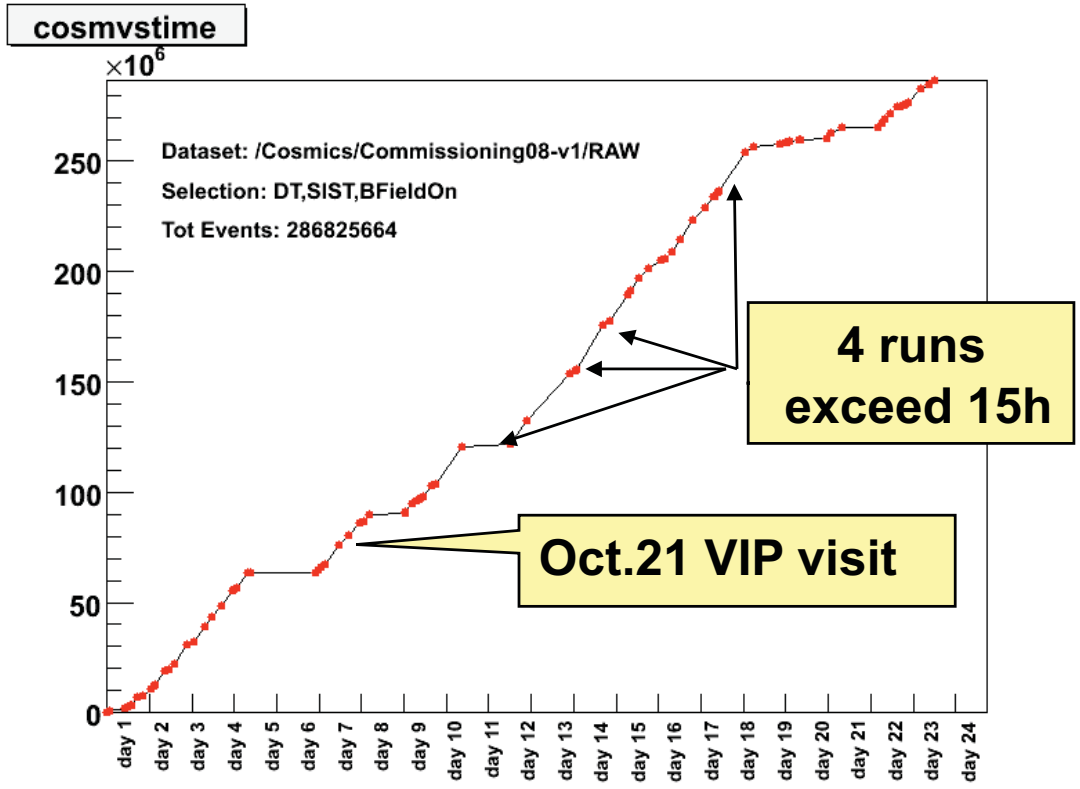
Energy in Forward Hadron Calorimeter (HF)



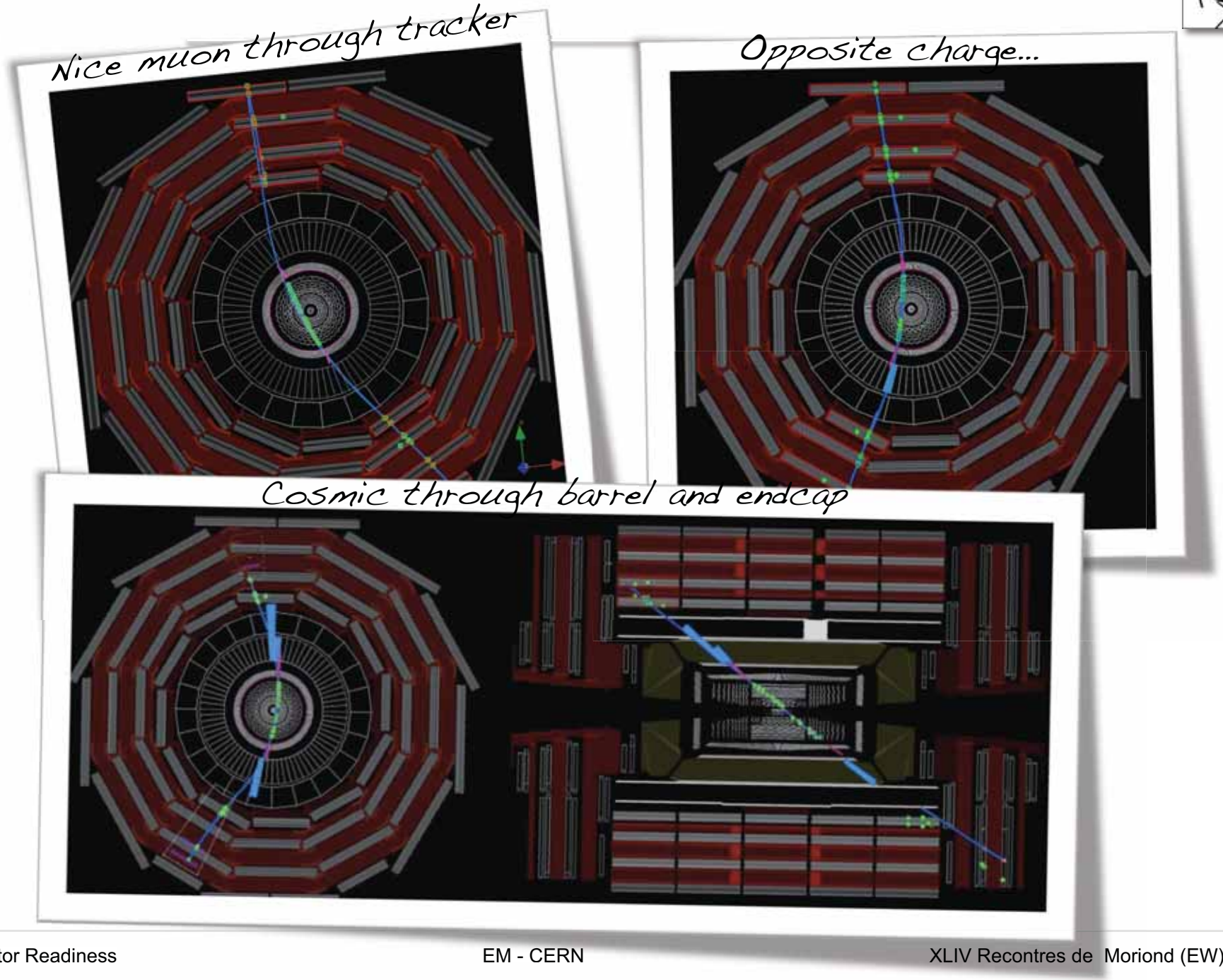
- Average energy as a function of eta in HF for circulating beam 2
- Events triggered by HF
- Peak in energy towards positive pseudo-rapidity is a signature of beam -gas interactions near or within the detector; the remnants of beam-gas interactions will have small p_T and larger p_L from the initiating proton.

CRAFT

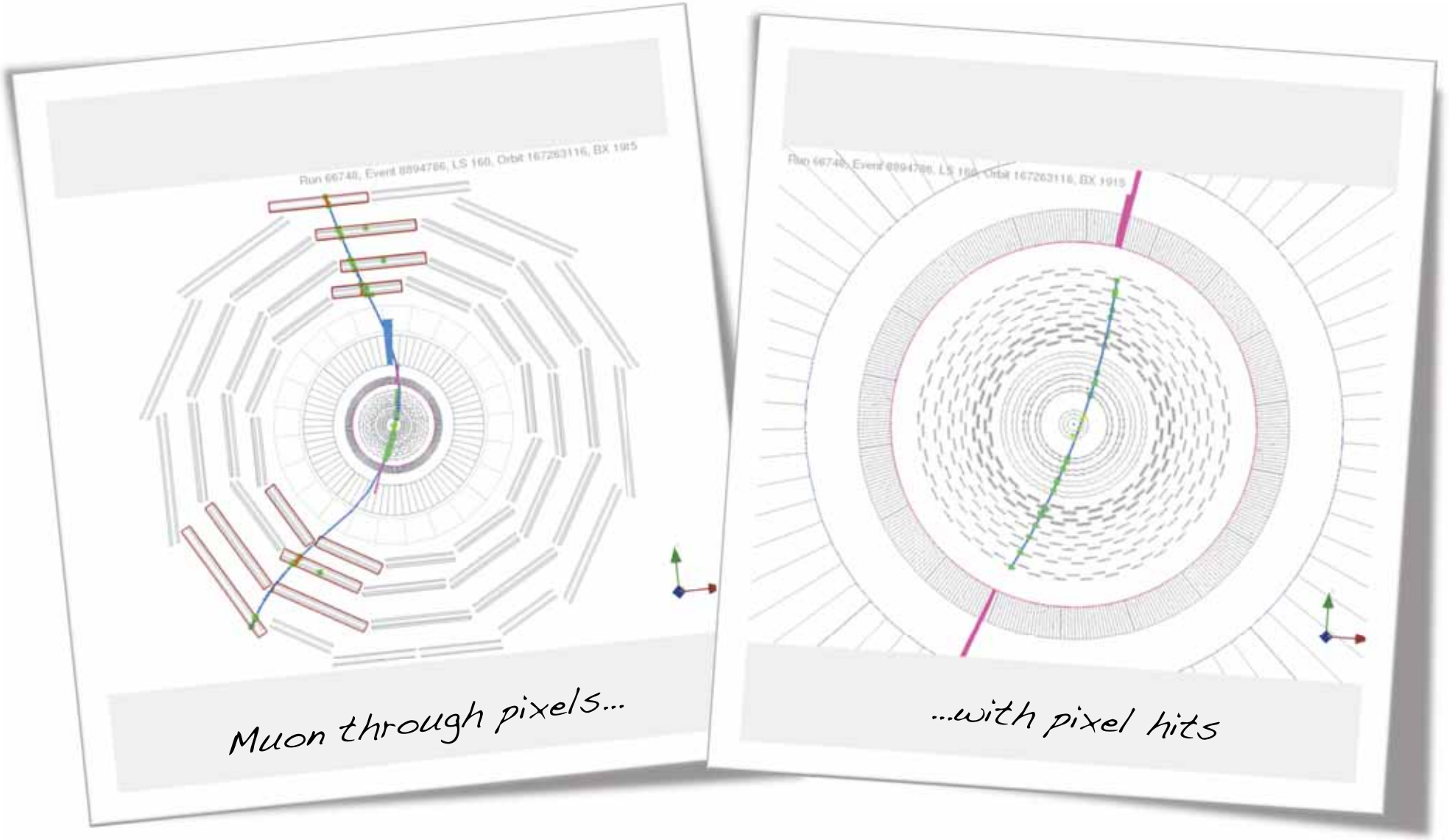
- Four weeks continuous running: target @ 70% eff.
  - 19 days with B=3.8 T
  - gain operational experience w 24/7 operation and identify areas of concern, understand efficiency
- 370M cosmic events, 290M with B=3.8T, and Tk on
  - 87% events with muon track
  - 3 % also have strip tk hits
  - 0.03% have pixel hits
- Data Operations
  - 600 TB transferred
  - Prompt reconstruction within 6 hrs



From the CMS Album



From the CMS Album



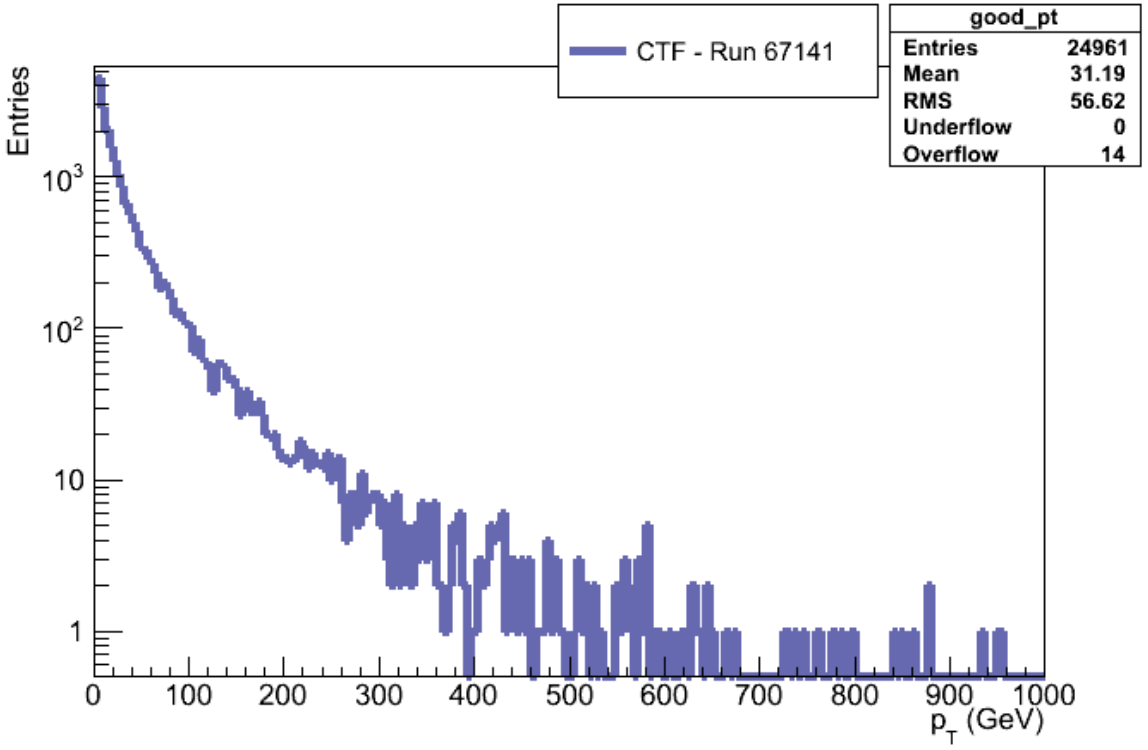
Strip and Pixel Tracker: Status

- Strip Tracker
  - TOB: 98.2% (0.6% recoverable)
  - TIB/TID: 96.9 % (1% recoverable)
  - TEC+: 99.2%
  - TEC-: 97.8 % (1.7% recoverable)
- Pixels
  - Barrel pixels: 99.1%
  - Forward pixels: 94.0%
    - Dominated by some readout chips without bias voltage and others without low voltage
    - Repair ongoing

Cosmic Tracking using Tracker

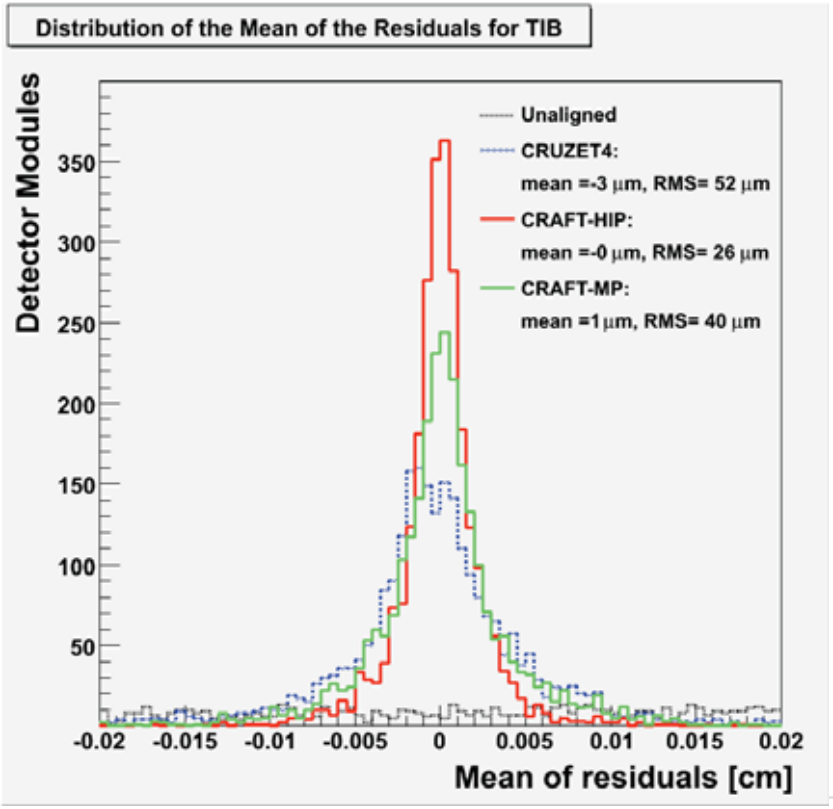
- Three tracking algorithm used for track reconstruction, with different acceptance for cosmics:
  - Combinatorial Track Finder (CTF standard algorithm for collisions)
  - Road Search
  - Cosmic Track Finder
- Momentum distribution for high quality tracks (partial statistics)
  - 8 hits
  - 1 hit in TIB L1/L2
  - 1 hit in TOB L5/L6
  - ~70K tracks expected

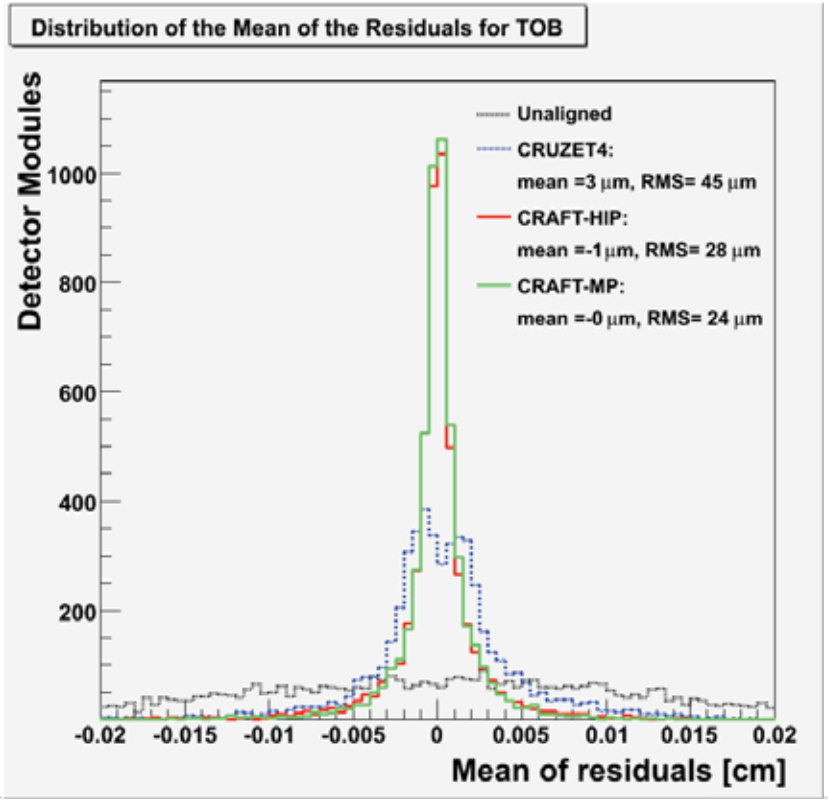
  out of full CRAFT statistics with P_T>100 GeV



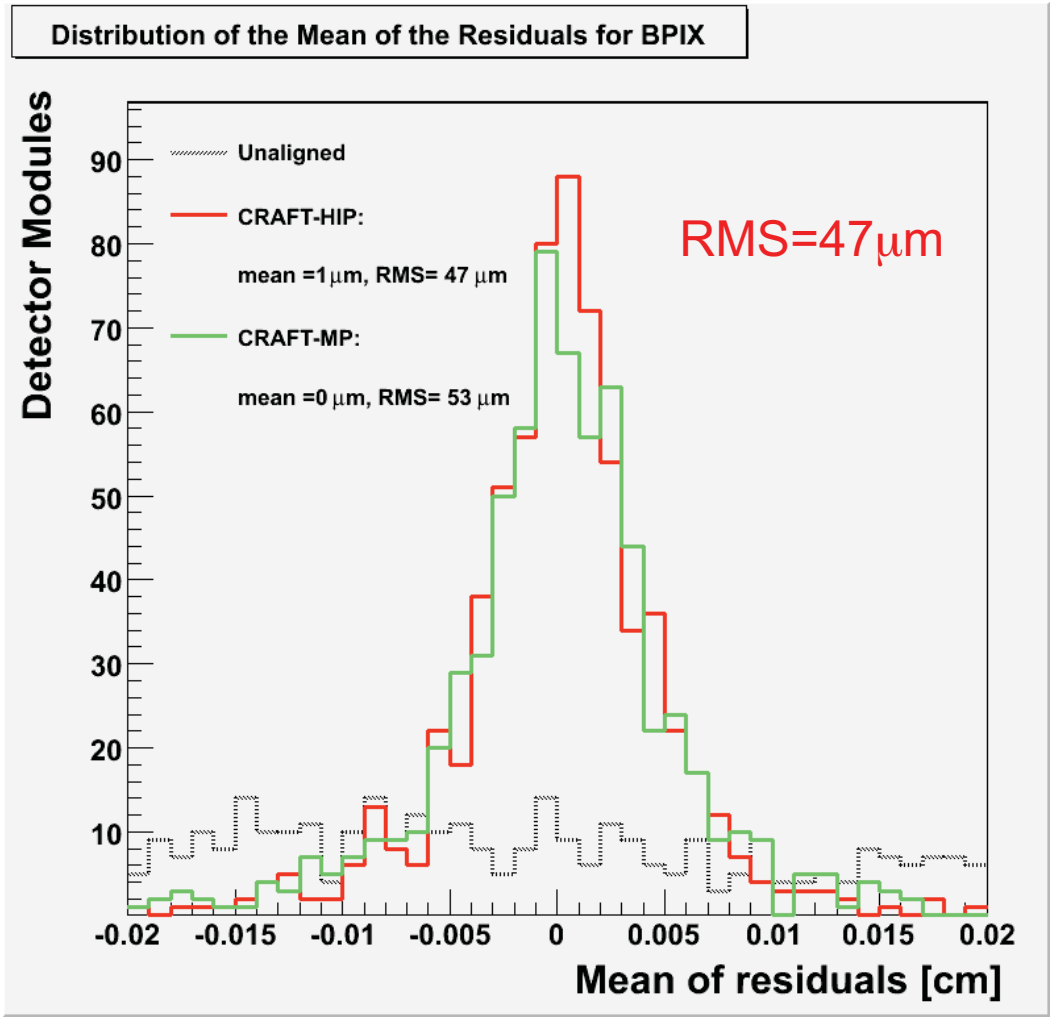
Tracker Barrel Alignment

- Mean of residual distributions (cm)
  - Sensitive to module displacements
- Only modules with >30 hits considered
  - TIB 96%, TID 98%, TOB 98%, TEC 94%
- HIP algorithm : TIB RMS = 26μm TOB RMS = 28μm





Pixel Barrel Alignment



- Barrel aligned at module level (200-300 hits, 89%)
- Endcap aligned at half-disk level (8)

HCAL Barrel Muon Reponse

Event selection:

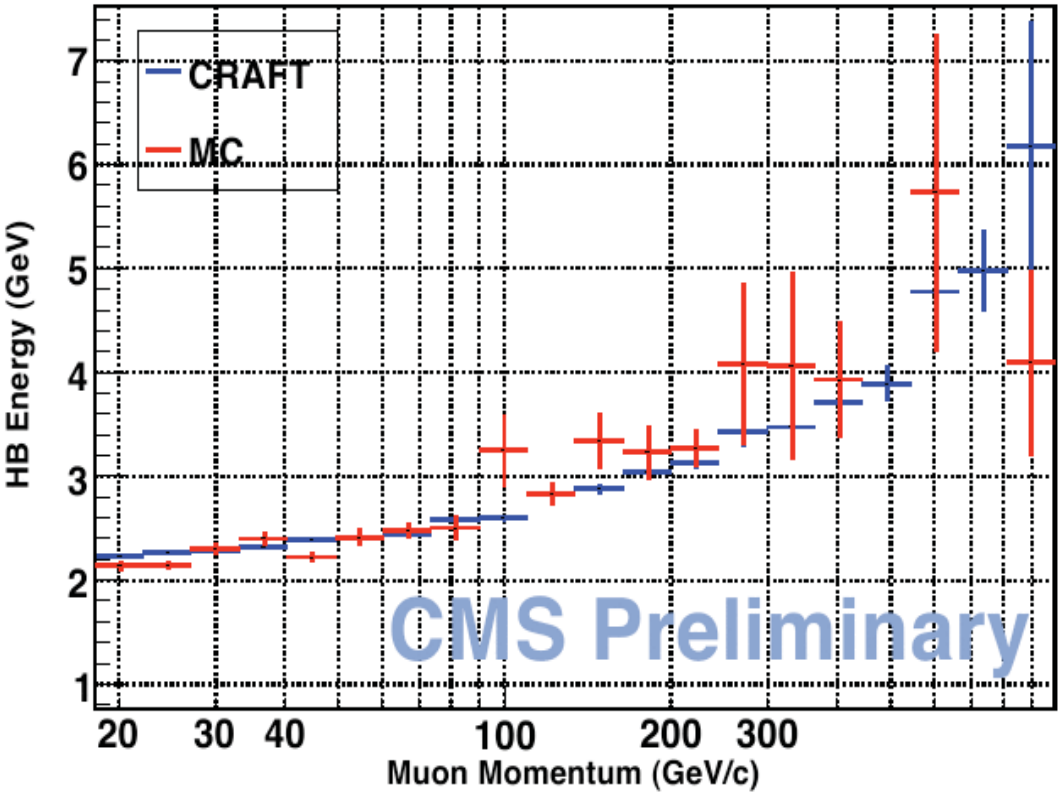
Muon track matching in DT and Tracker

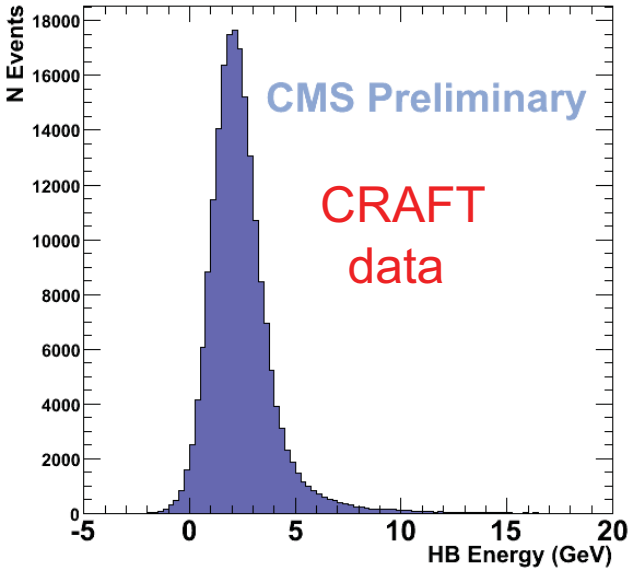
20 GeV/c < P_μ < 1000 GeV/c

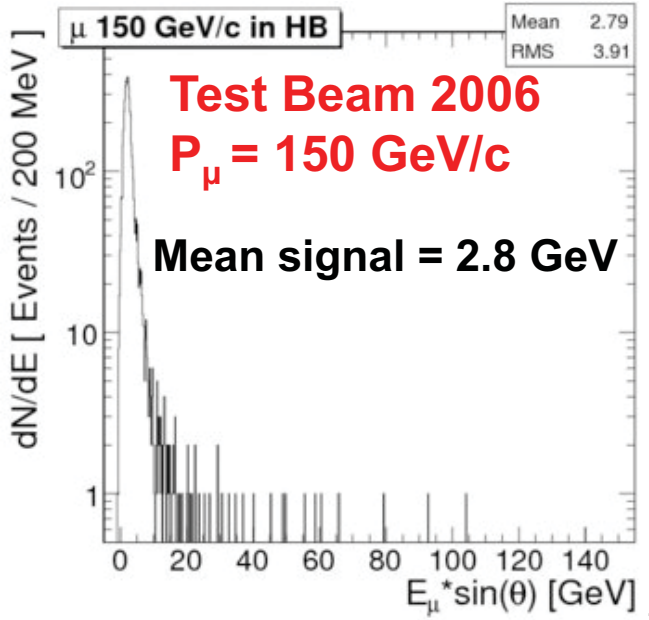
CRAFT: 200 K events

MC: 15 K events

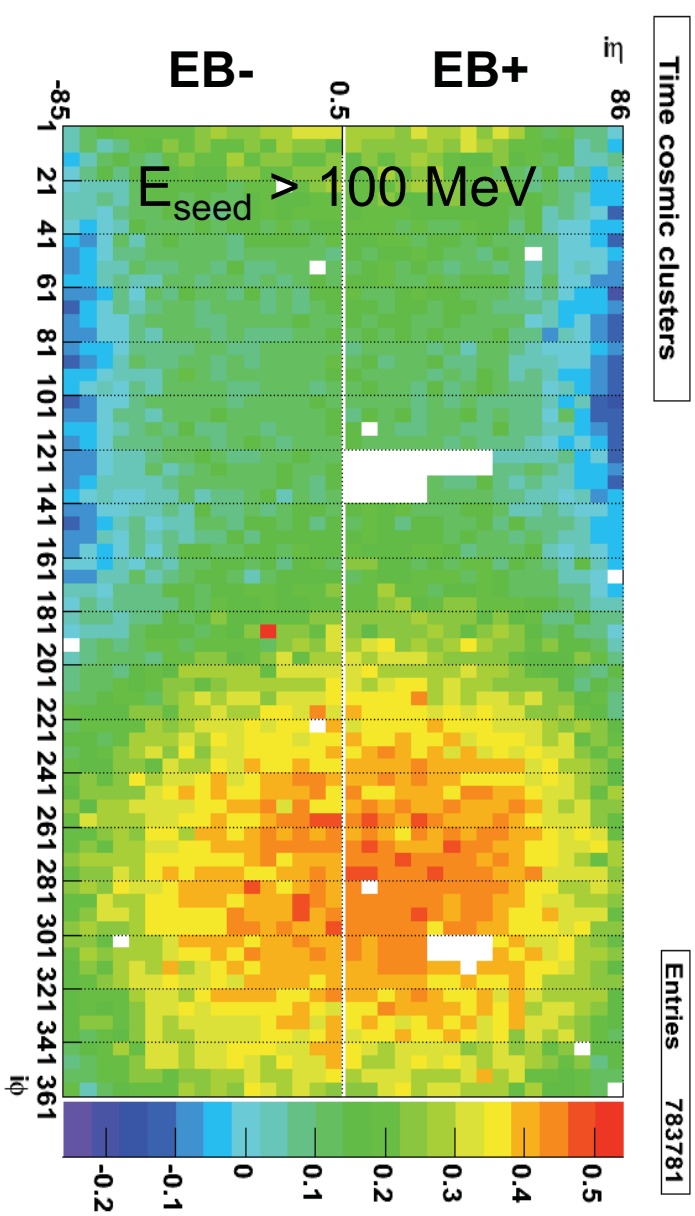
HB energy: signal from HB towers corrected for muon path length in HB





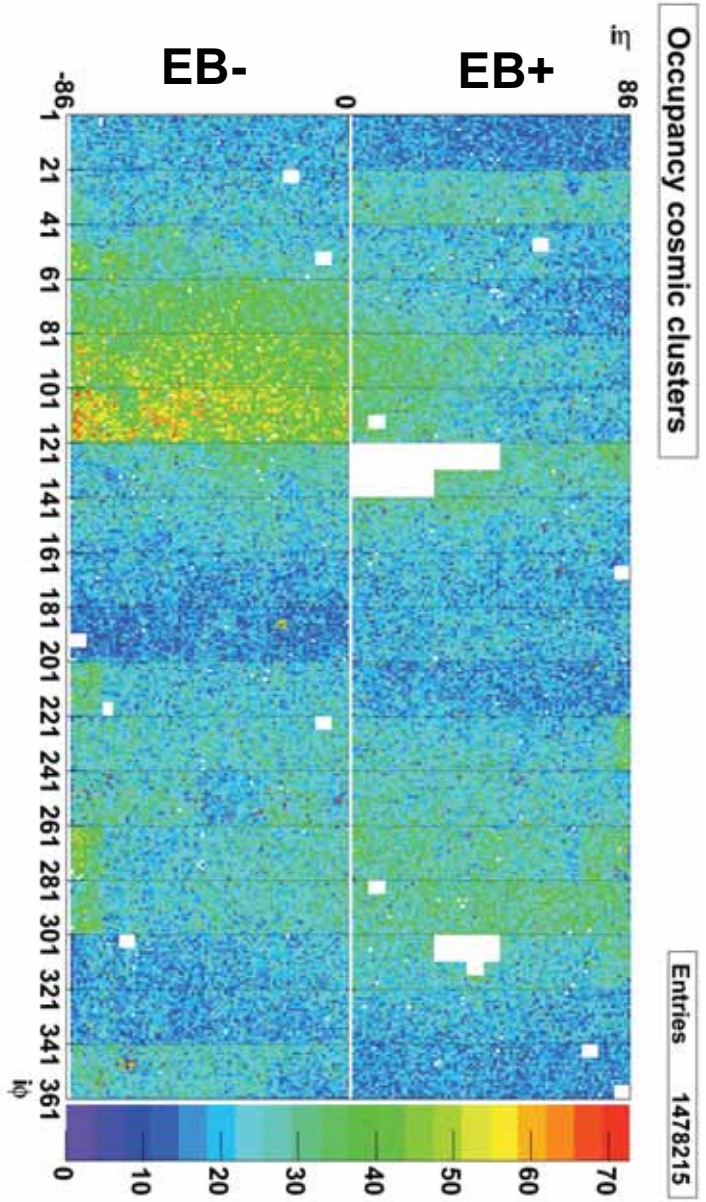


ECAL Occupancy and Timing

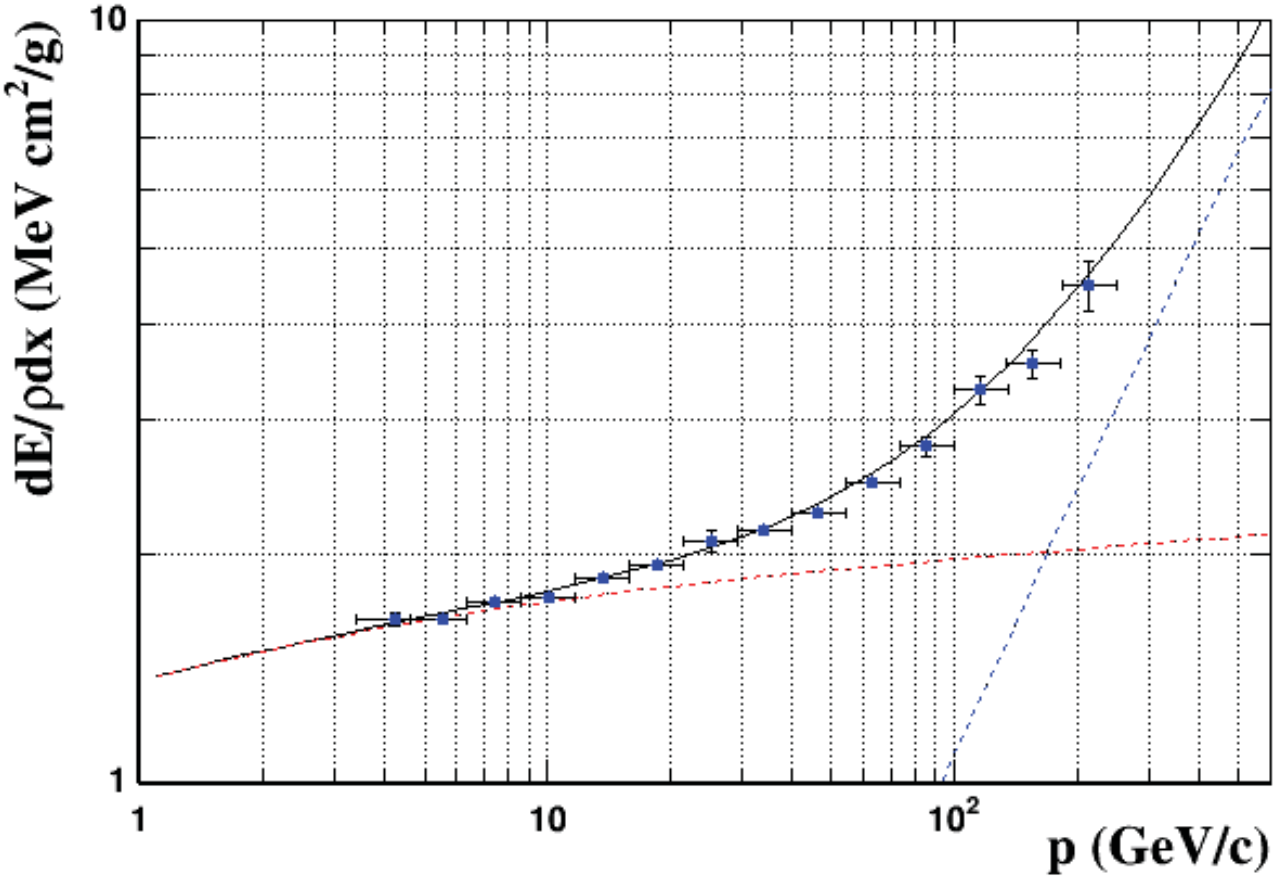


TOP

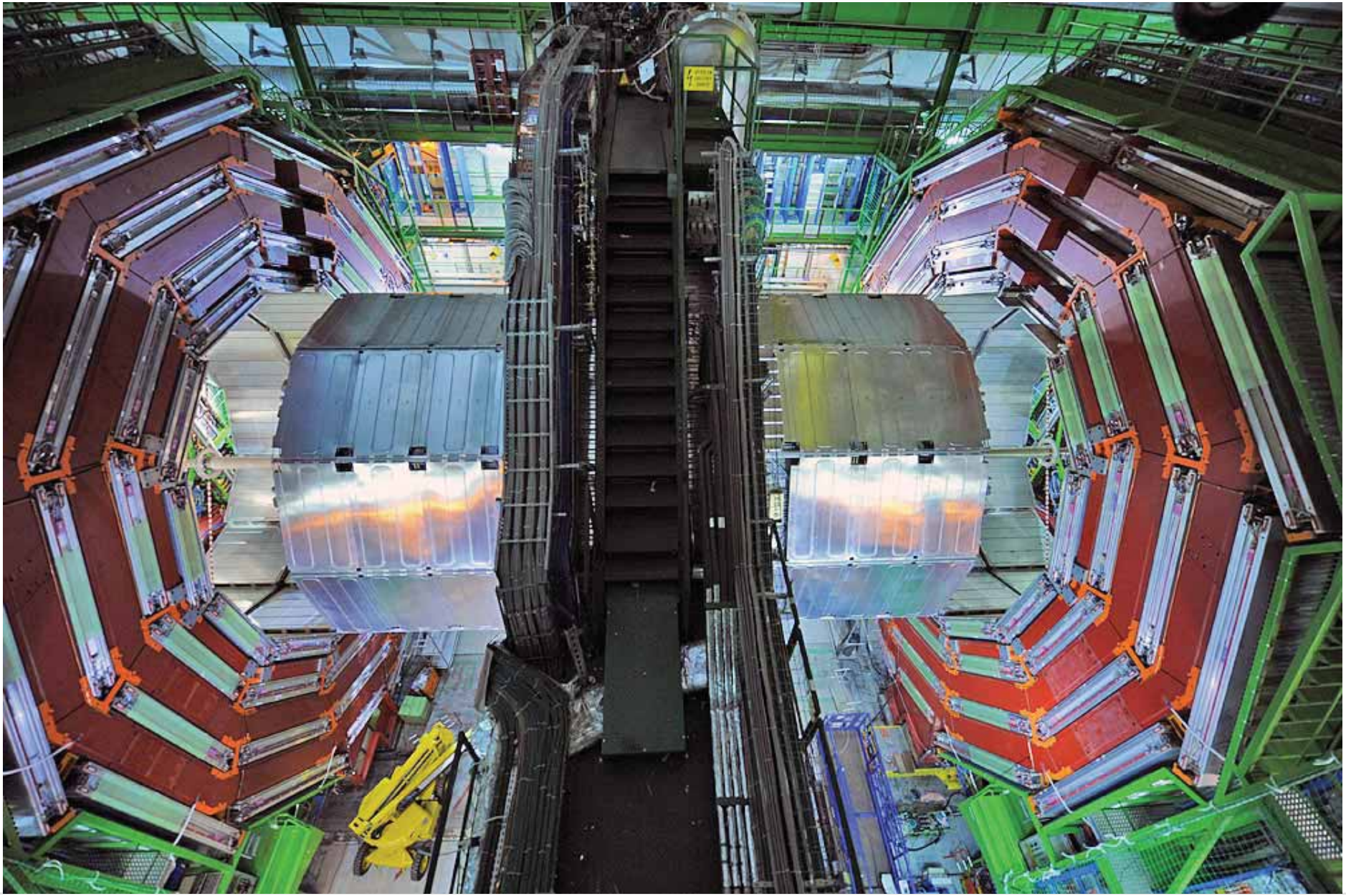
BOTTOM



Stopping power



Current Status



CMS Detector Status

- Since beginning of September 2008
  - All installed CMS sub-detectors in global readout routinely
  - All triggers operational, DAQ commissioned, high L1 rates tested
  - Stability of running with all CMS components proven
  - LHC clock and orbit signals tested
  - Synchronization to few ns or better
- Have continued global data-taking with cosmics
  - CRAFT: Cosmic Run at “Four” Tesla, > 300M cosmic ray events
- Detector opening started on Nov 17th
  - Interventions/repairs for problematic channels (order of ~1%)
  - CMS cooling system maintenance
  - Installation of Preshower detector
- Plan: continue global data-taking operations with cosmics this spring to prepare for beam this fall.

Point 5: Shutdown Activities

Shutdown Activities: Status

- Tracker Cooling Plant refurbishment
  - Plan reviewed: green light to proceed.
- Repair 6% of Fpix with lost LV
- HCAL: replaced faulty HPDs
- Muon DT/RB: ~ 10/250 chambers needed repair
  - (few per mille of channels) YB0, YB+1 completed.
- CSCs - repaired ~10/468 known faulty chambers
- Endcap RPCs: some chambers showed increasing leakage current – progress being made.
- ECAL LV lost on 200 channels – now repaired.
- Field Map
- Forward Region: TOTEM, ZDC, CASTOR

"We are within a few days of the schedule defined mid-November"

ECAL Preshower

All 4 Dees assembled and tested warm and cold.

Approach, connection and moving of ES-Dees completed successfully

Completing LV, HV, control and readout

Transport and lowering started

About 3 weeks required for each endcap for underground assembly, installation and check-out

Prospects for 2009-2010 Run

Month	Comment	Turn around time	Availability	Max number bunches	Protons/Bunch	Min beta*	Peak Luminosity $cm^{-2}s^{-1}$	Integrated Luminosity
1	Beam commissioning							First collisions
2	Pilot physics, partial squeeze, gentle increase in bunch intensity, 40%	Long	Low	43	3×10^{10}	4 m	1.2×10^{30}	100 - 200 nb^{-1}
3		5	40%	43	5×10^{10}	4 m	3.4×10^{30}	~2 pb^{-1}
4	2.5% nominal beam intensity	5	40%	156	5×10^{10}	2 m	2.5×10^{31}	~13 pb^{-1}
5		5	40%	156	7×10^{10}	2 m	4.9×10^{31}	~25 pb^{-1}
6	9% nominal beam intensity, 75 ns	5	40%	936	3×10^{10}	2 m	5.1×10^{31}	~30 pb^{-1}
7	15% nominal beam intensity, 75 ns	5	40%	936	5×10^{10}	2 m	1.4×10^{32}	~75 pb^{-1}
8	*15% nominal beam intensity, 75 ns**	*5*	40%	936	5×10^{10}	2 m	1.4×10^{32}	~75 pb^{-1}
9	15% nominal beam intensity, 75 ns*	5	40%	936	5×10^{10}	2 m	1.4×10^{32}	~75 pb^{-1}
10	Ions							
							TOTAL	**~300 pb^{-1}**

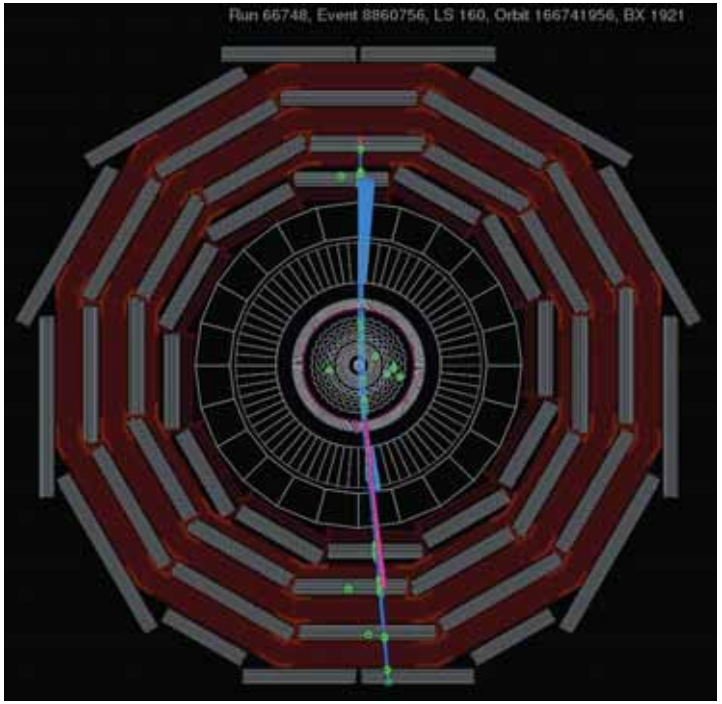
- With first collision data:
  - Understand reconstruction performance of physics objects: muons, electrons, photons, jets ... b-tagging, taus, missing transverse energy
- With few pb-1:
  - Hadron spectra, low-mass resonances, underlying event

Prospects for 2009-2010 Run

- 10 pb-1
  - Standard candles: W, Z, top x-sections at 10 TeV
  - Jet energy corrections
  - Searches using high-Et jets
- 100 pb-1
  - Precision measurements of SM
  - W', Z'
  - JES from top
  - Heavy stable charged particles
  - SUSY searches
  - …
- 2-300 pb-1
  - at 10 TeV ⇒ start competing with Tevatron for Higgs masses around 160 GeV

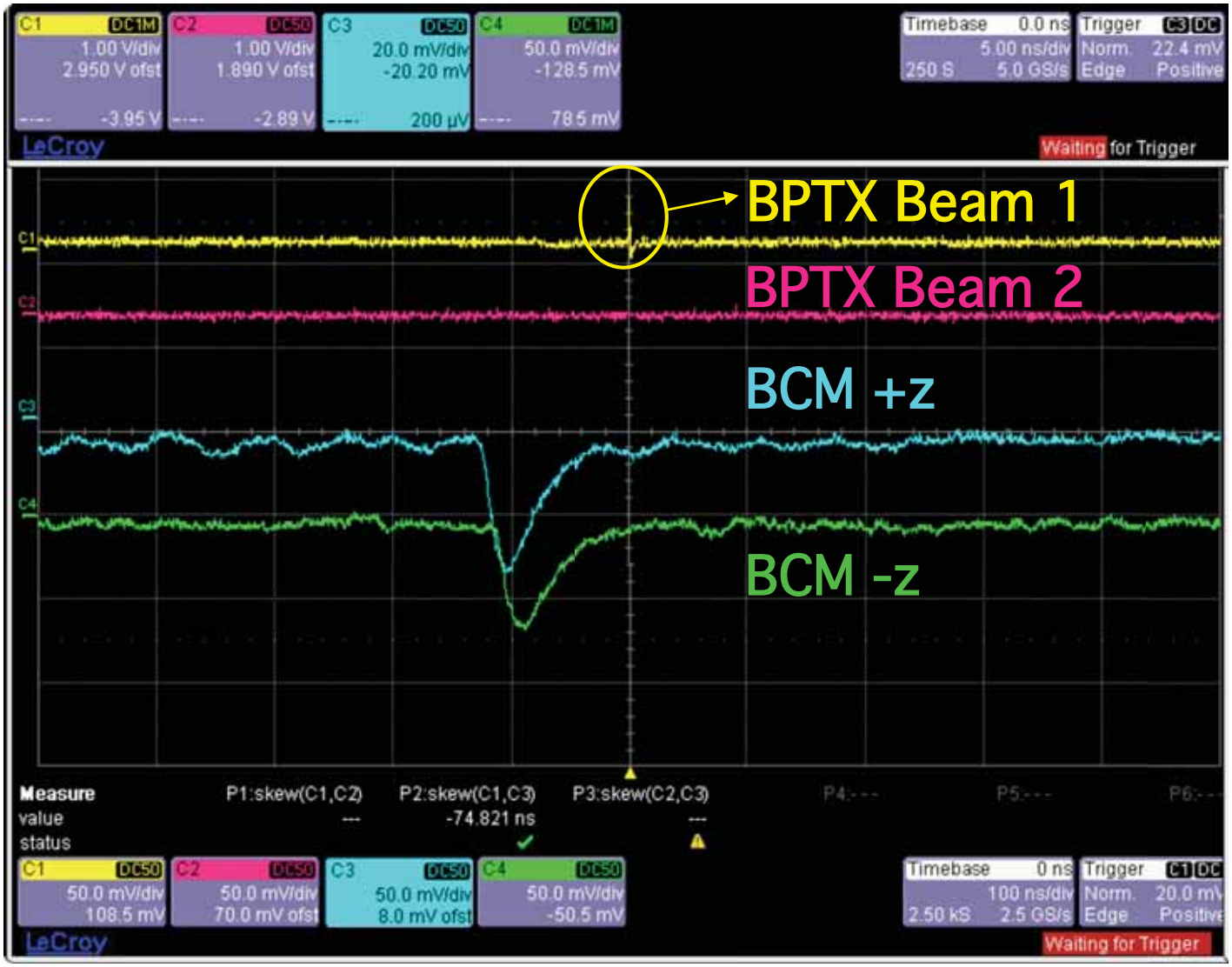
Conclusions

- CMS is commissioned and has collected first data with LHC
  - It's just been ~20 years
- After the unfortunate LHC incident, we are using the time for remaining issues and "final touches"
- See you next year with the "First Physics with the CMS Detector"



- Backup slides

First Circulating Beam Through CMS



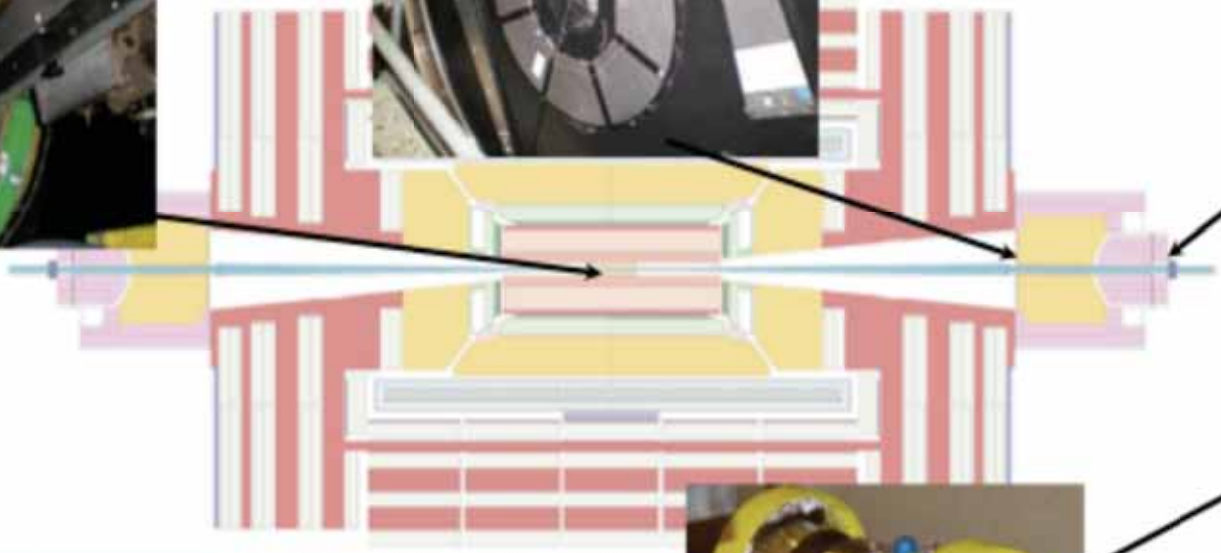
Beam1 arrives at +z monitor ~15ns before -z monitor (TOF)

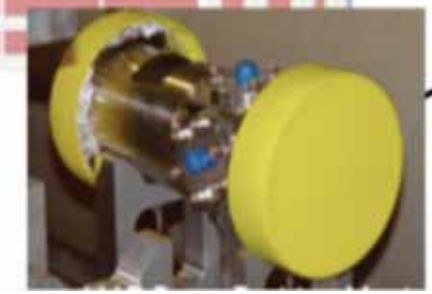
Beam Detectors

BCM1 L/F diamonds
Z=± 1.9m, r=4.3cm

BSC1: scintillators
Z=± 10.9 m, r=4.3cm

BCM2 diamonds &
BSC2 scintillators
Z=± 14.4m, r=29cm



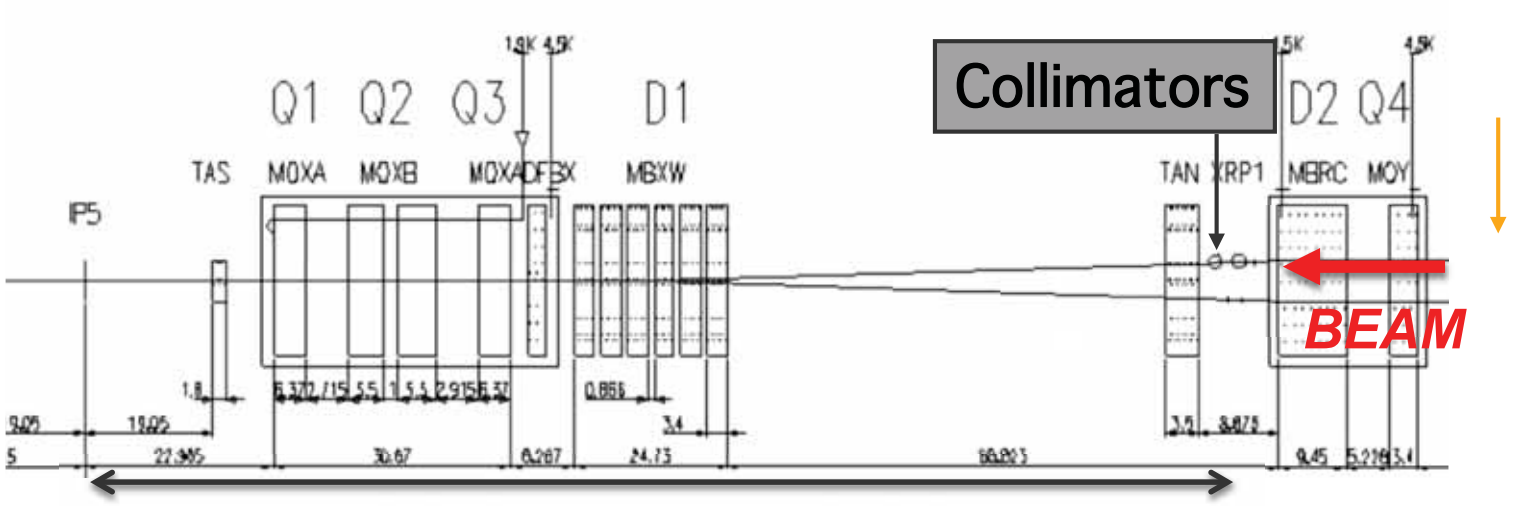


BCM1 L/F and BCM2
PROTECTION of CMS

BPTX beam pickup
Z=± 175m

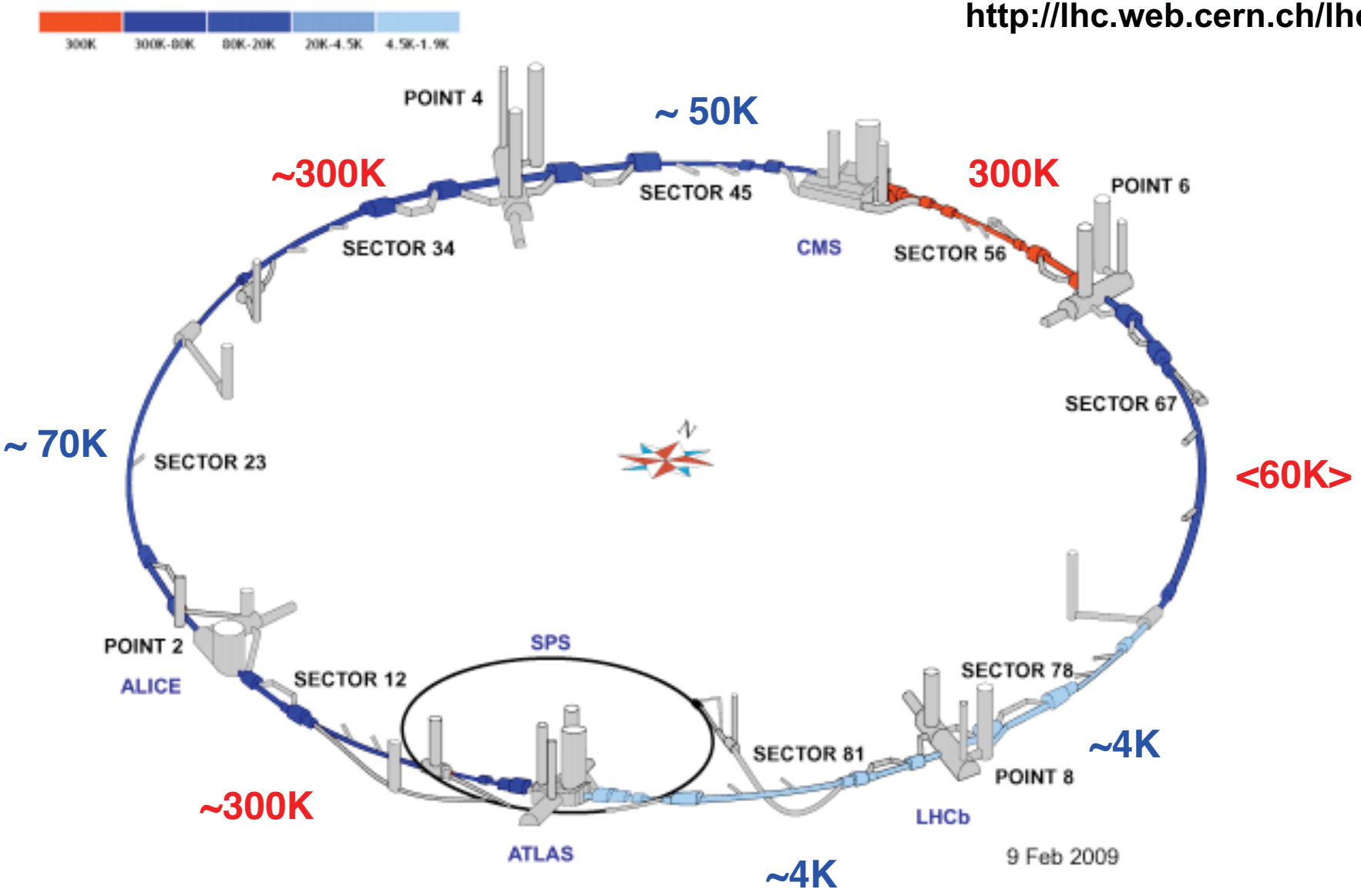
“Beam Splash” Events

- Single beam shots of 2×10^9 protons onto closed collimators ~150m upstream of CMS
  - Hundreds of thousands of muons pass through CMS per event
  - Enormous amount amount of energy deposited in calorimeters
- Allowed synchronization of triggers (previously with cosmic muons)
  - Muon end caps, BPTX beam pick up, etc
- Internal synchronization of sub-detectors



Status of the Machine

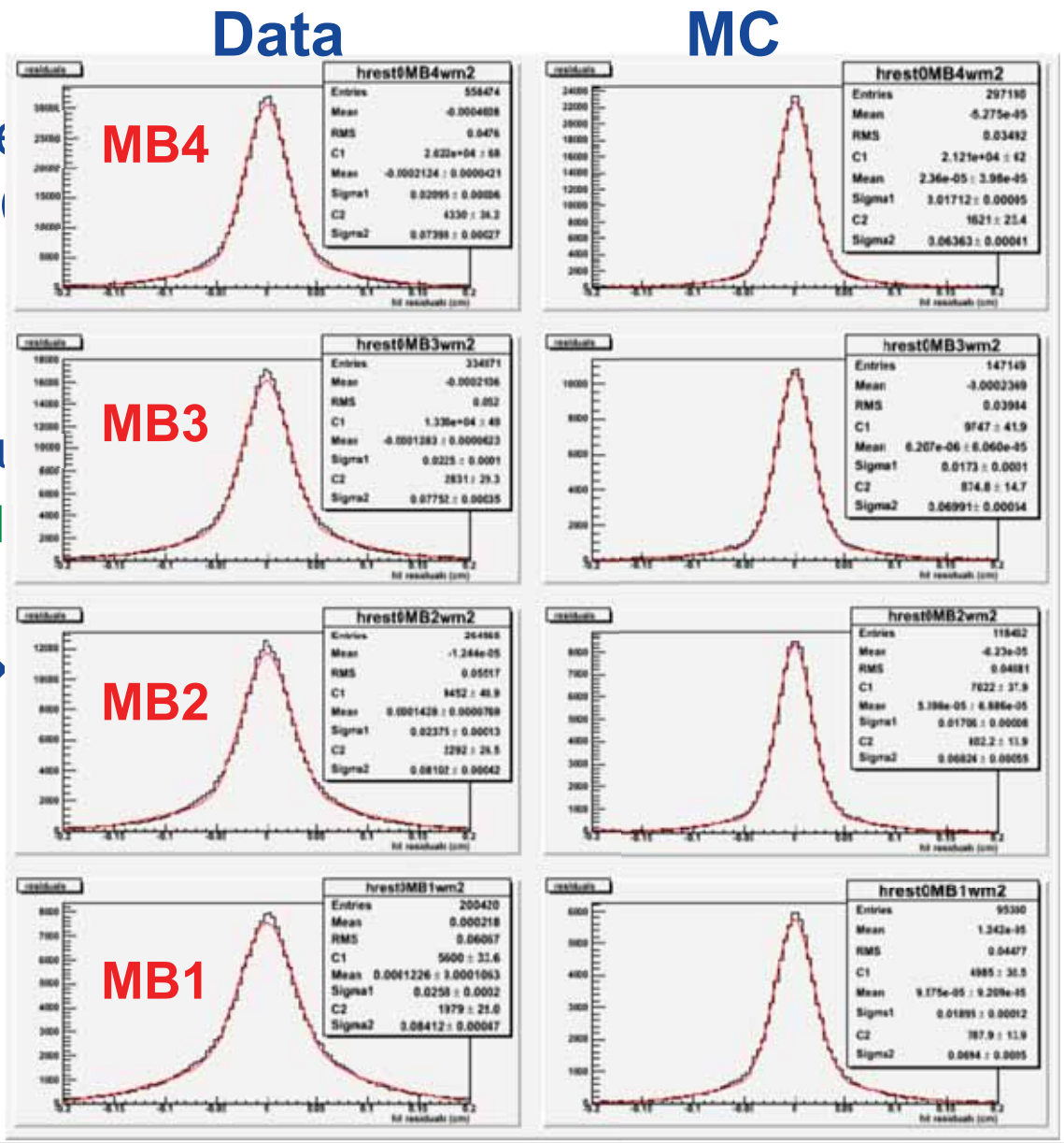
http://lhc.web.cern.ch/lhc/



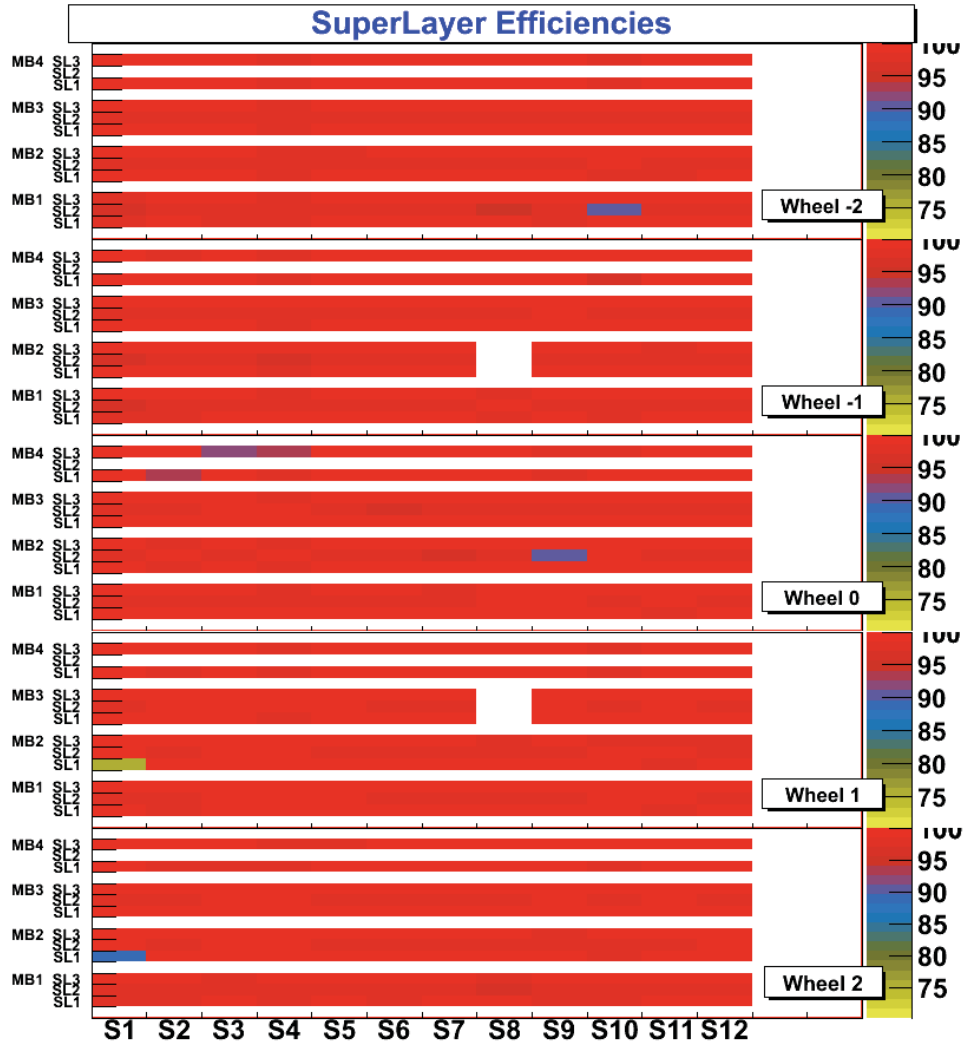
Drift Tube Muon System at CRAFT

- Residuals
  - Reasonable agreeme between data and M after cosmic muon arrival time fit
  - Sigma ~ 200 – 260 μ
    - B field degrades MB1 in wheels +/-2
  - Sector 4, wheel -2 →

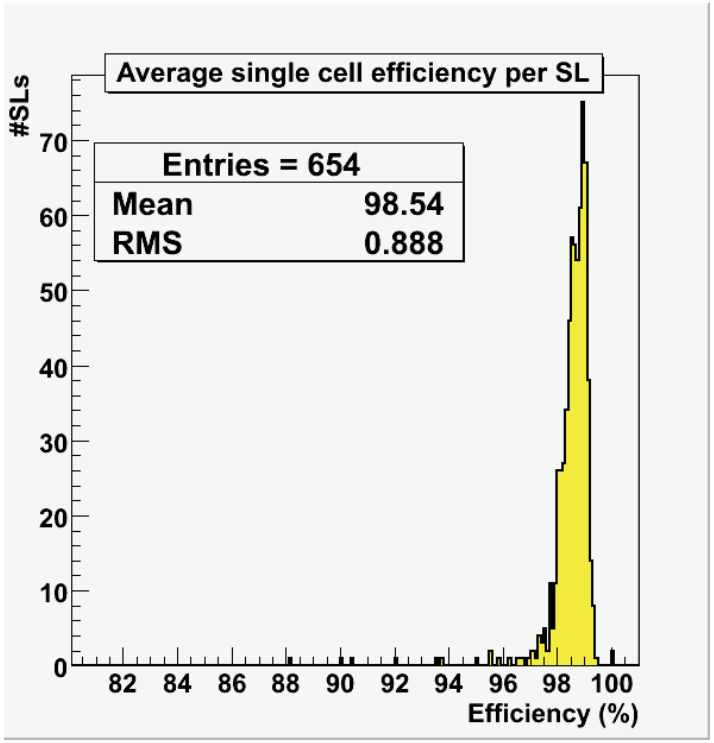
Clean up statistics boxes



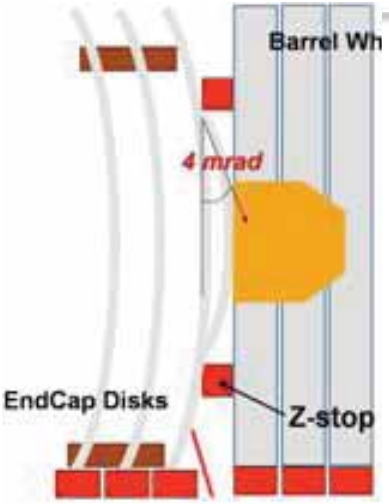
Average of single DT cell efficiency per SuperLayer

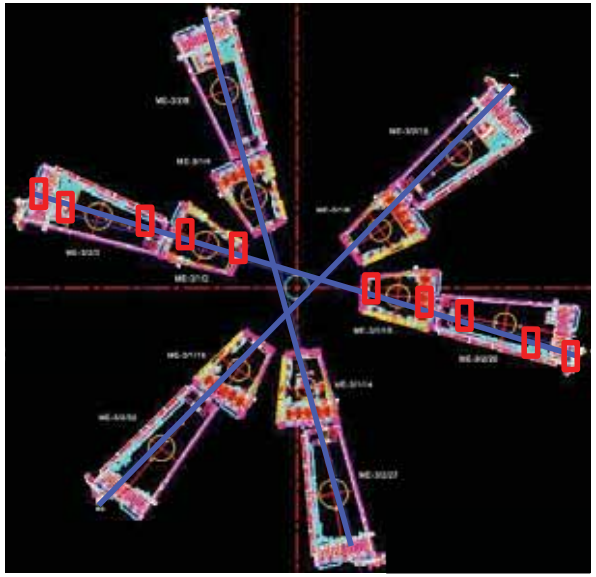


Lower values correspond to Superlayers with some group of disconnected (temporary) channels



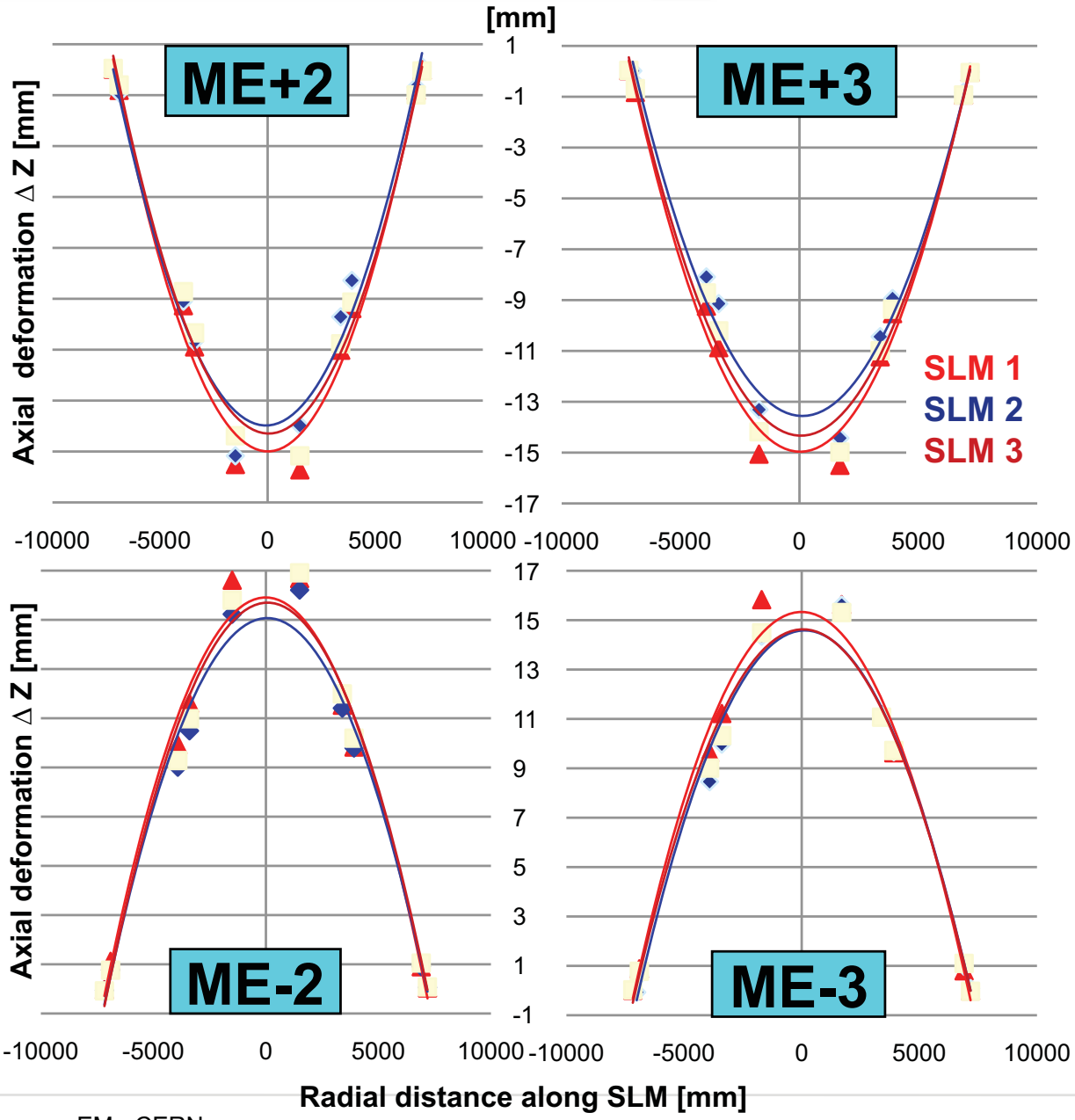
Measured Endcap Deformation at 3.8T





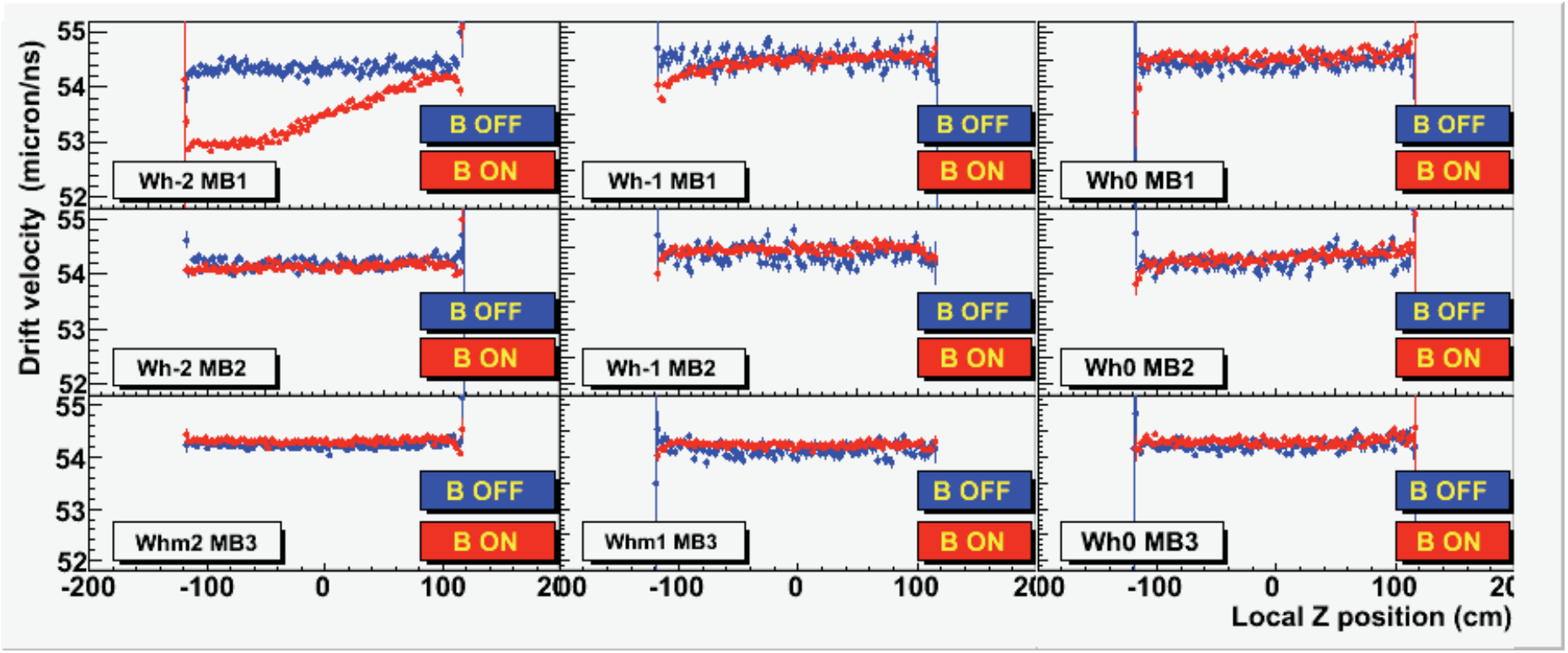
3 Straight Line Monitor (SLM) Laser Lines per Muon Endcap Station

10 optical CCD sensors per SLM

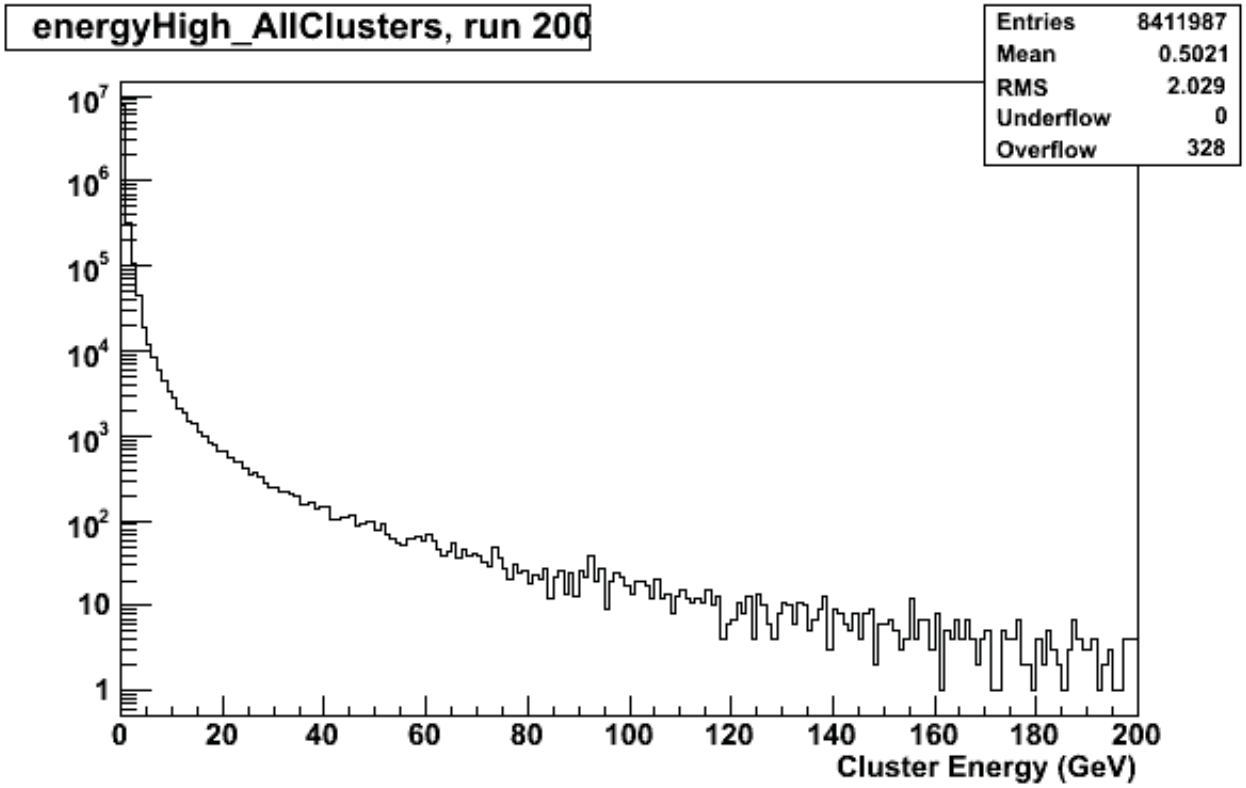


DT Drift Velocity Along Z, Field On/Off

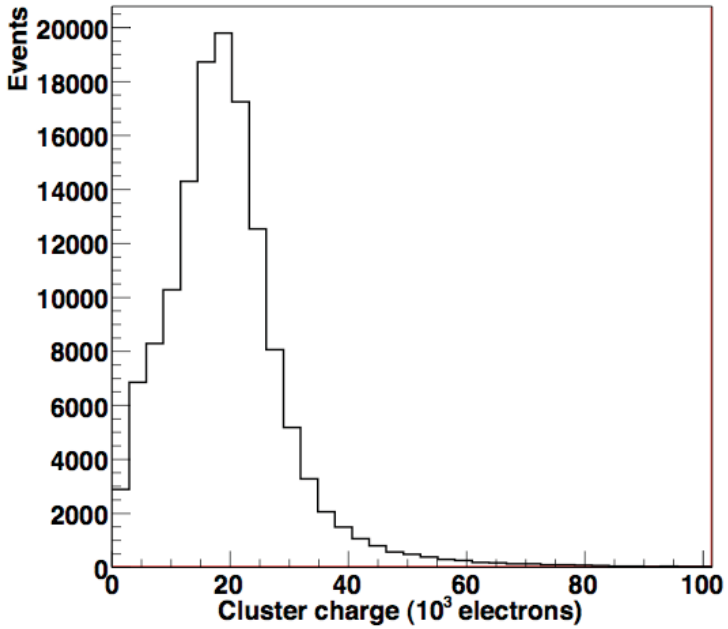
- Innermost stations on outer wheels have largest radial field
- Maximum difference in drift velocity is 3%



Energy spectrum

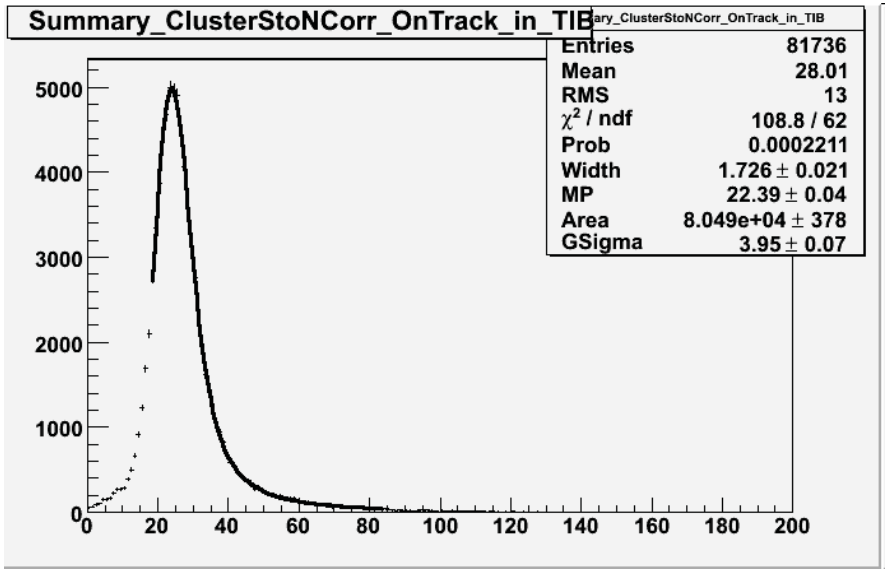


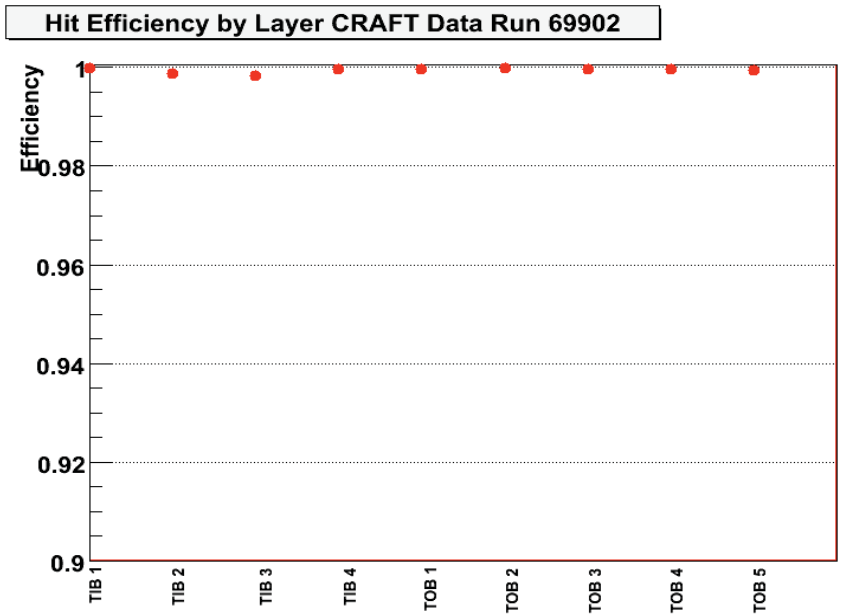
Pixel Signal



Barrel Pixel cluster charge corrected for the track angle

Tracker Signal/Noise





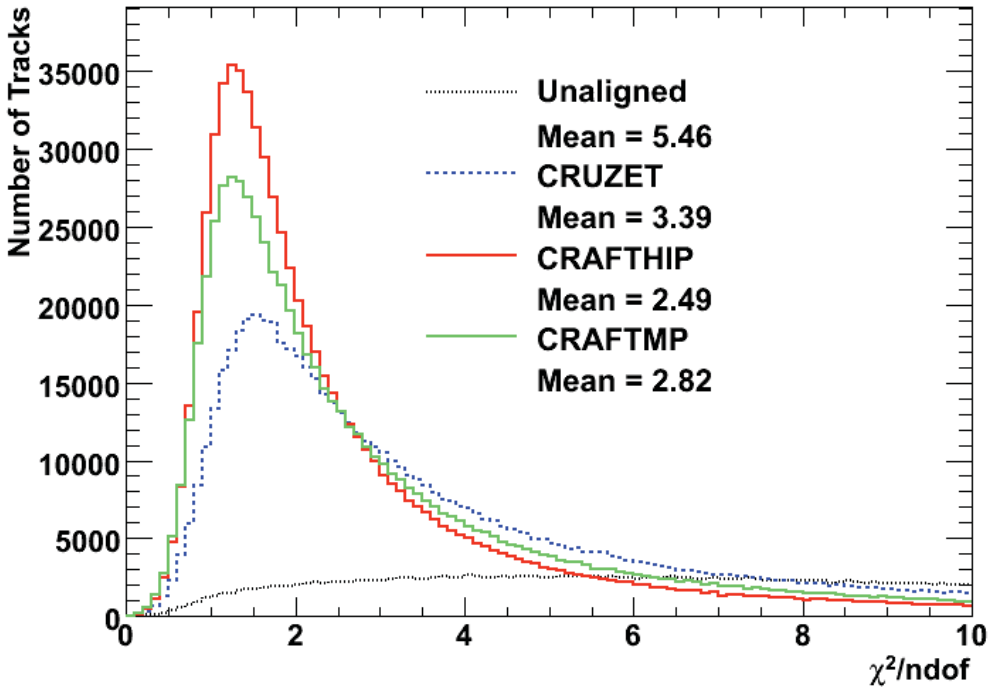
On track Strip clusters S/N ratio in peak mode of the read-out chip, corrected for the track angle

- TOB thick sensors : S/N = 32
- TIB/TID thin sensors : S/N = 27/25
- TEC (mixed thickness) : S/N = 30

Track hit finding efficiency of TIB and TOB layers, excluding modules not in operation

Tracker Alignment

χ^2/ndof



Pixel Occupancy Maps