Title: CMS status at LHC and outlook for 2009

Date: Feb 13, 2009 01:00 PM

URL: http://pirsa.org/09020016

Abstract: Over the last two years, the Compact Muon Solenoid (CMS) detector has been installed in the tunnel of the Large Hadron Collider (LHC) at CERN and commissioned to its full functionality. The CMS detector successfully collected beam halo and beam dump data, while the beams were circulating in the LHC in September 2008. After the LHC incident, the commissioning of CMS continued with a one month campaign of continuous cosmic rays data taking at nominal magnetic field. This allowed further tuning of the detector, consolidation of its operation and characterization of its performances. In this talk, the status of the CMS detector and its performance, in view of LHC collisions in 2009, will be described.

outline

- CMS: the concept
- The installation
- Commissioning before beam
- September 2008
- CMS and beam
- CMS and cosmic rays
- prospects

LHC and CMS: history

LHC Timeline

1984 Workshop on a Large Hadron Collider in the LEP tunnel, Lausanne

1987 Rubbia "Long-Range Planning Committee" recommends Large Hadron Collider as the right choice for CERN's future

1990 ECFA LHC Workshop, Aachen

1992 General Meeting on LHC Physics and Detectors, Evian les Bains

1993 Letters of Intent (ATLAS and CMS selected by LHCC)

1994 Technical Proposals Approved

1996 Approval to move to Construction (ceiling of 475 MCHF)

1998 Memorandum of Understanding for Construction Signed

1998 Construction Begins (after approval of Technical Design Reports)

2000 CMS assembly begins above ground. LEP closes

2004 CMS Underground Caverns completed

2008 CMS ready for First proton-proton Collisions

T. Virdee

CERN ColloqDec07 tsv 7

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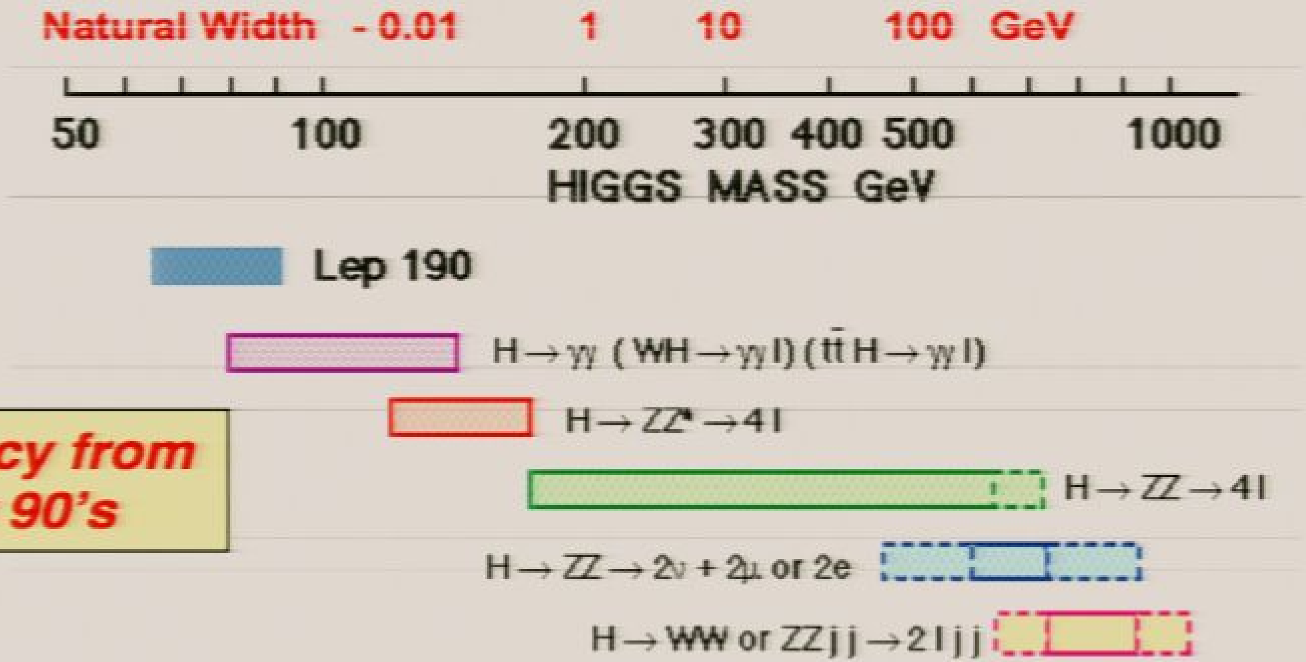
The CMS design criteria

- 1 Very good muon identification and momentum measurement
  - Trigger efficiently and measure charge sign of TeV muons, dp/p < 10%
- 2 High energy resolution for electromagnetic calorimetry:
  - 0.5% @ E_T ~ 50 GeV
- 3 Powerful inner tracking systems:
  - Momentum resolution a factor 10 better than at LEP
- 4 Hermetic calorimetry
  - Good missing Et resolution
- 5 (Affordable detector)

ORIGINAL POINTS DATING BACK TO THE **EARLY 90's**

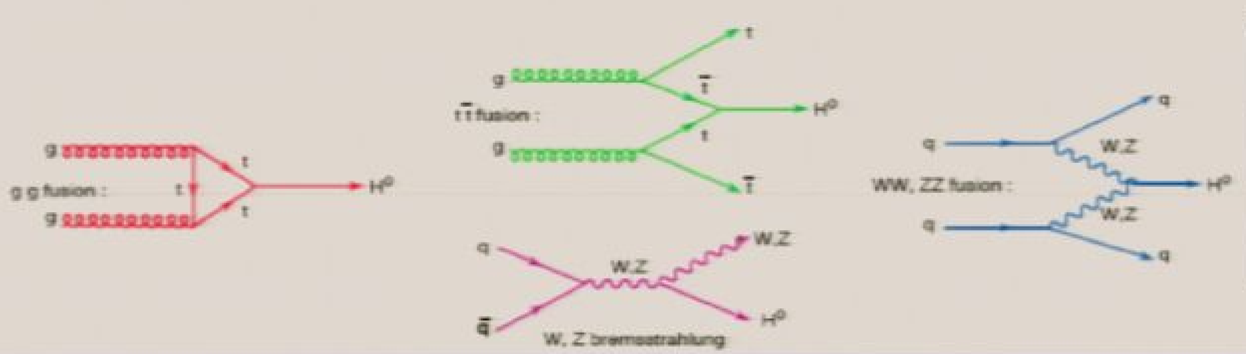
SM Higgs used as a benchmark

At the LHC the SM Higgs provides a good benchmark to test the performance of a detector



Transparency from the early 90's

T. Virdee



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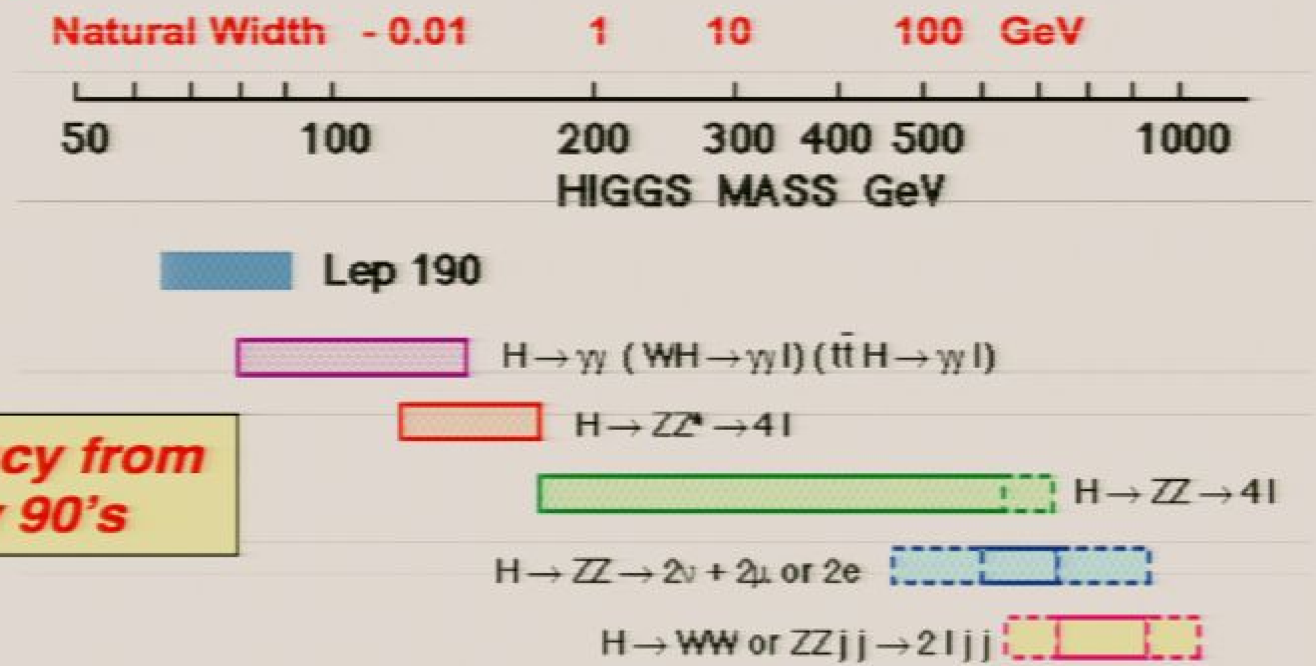

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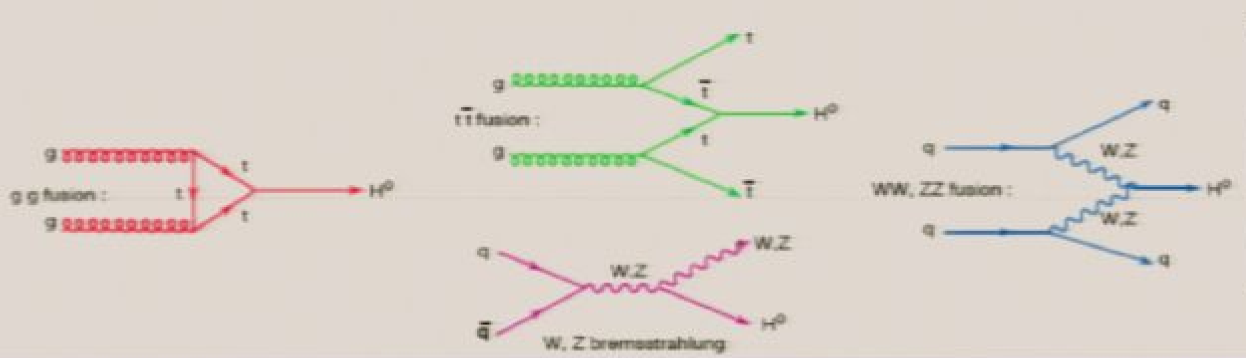
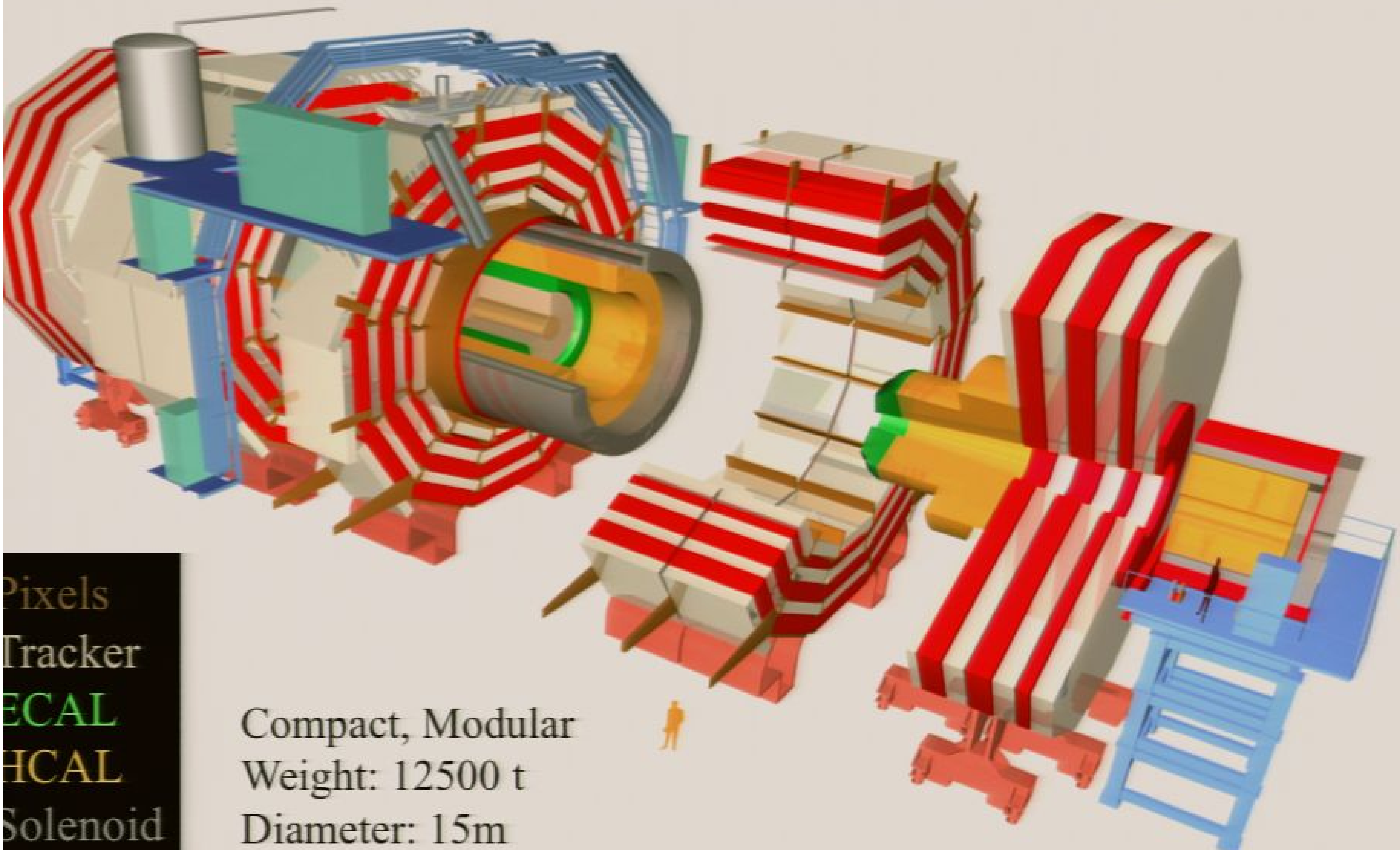


The CMS Detector

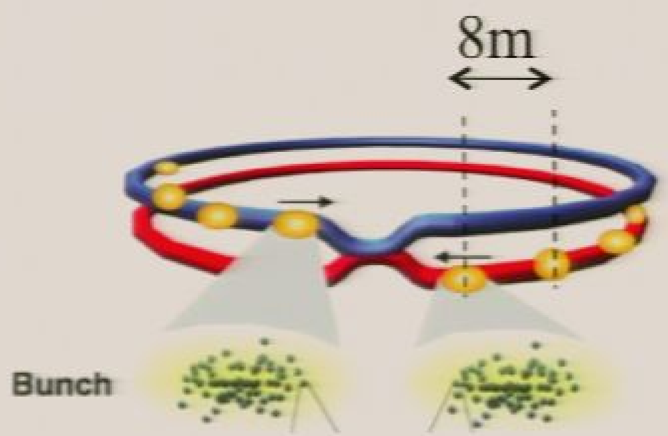


Pixels
Tracker
ECAL
HCAL
Solenoid
Muons

Compact, Modular
Weight: 12500 t
Diameter: 15m
Length: 21.6 m

Experimental challenges at LHC

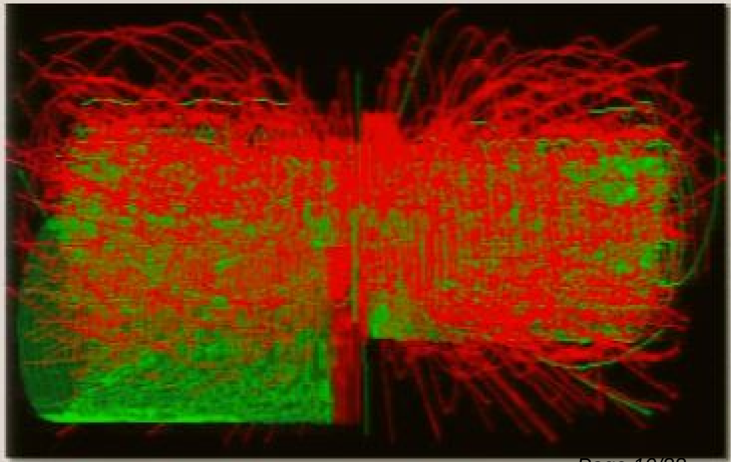
LHC Detectors (ATLAS, CMS) radically different from previous generations:



High Interaction Rate:

- 40MHz p-p bunch; you can record only ~10^2
- 1GHz p-p interactions
- Level-1 trigger decisions take ~2-3 μs, thus electronics need to store data locally

Large particle multiplicity



- ~<20> superposed events in each crossing
- ~1000 tracks into the detector every 25 ns
- ➔need highly granular detectors large number of channels (~ 100 M)

High Radiation Levels:

- rad-tolerant detectors and electronics

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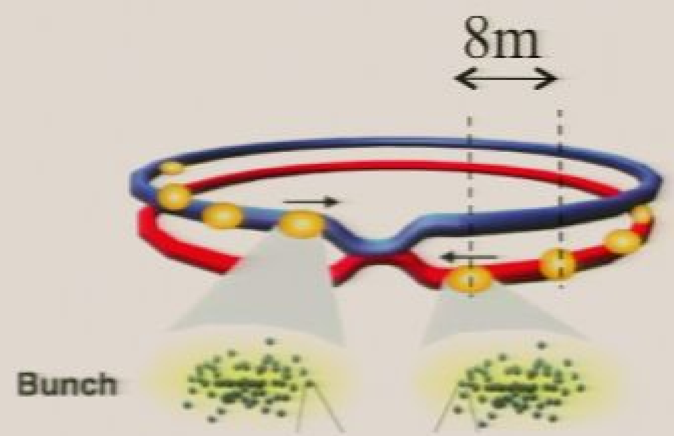

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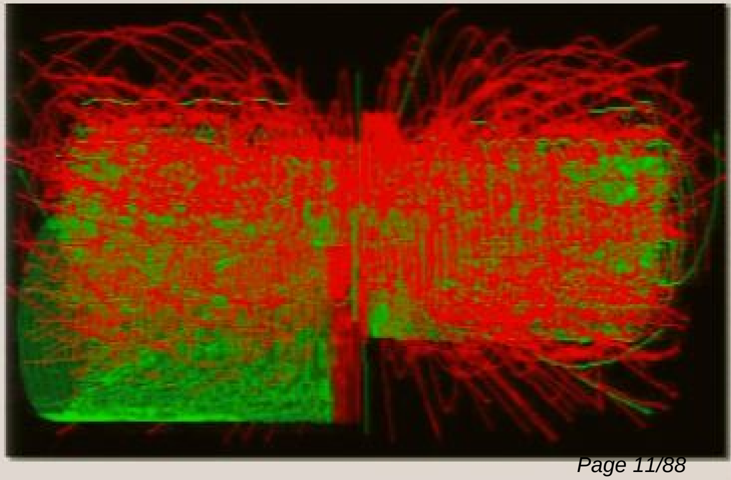

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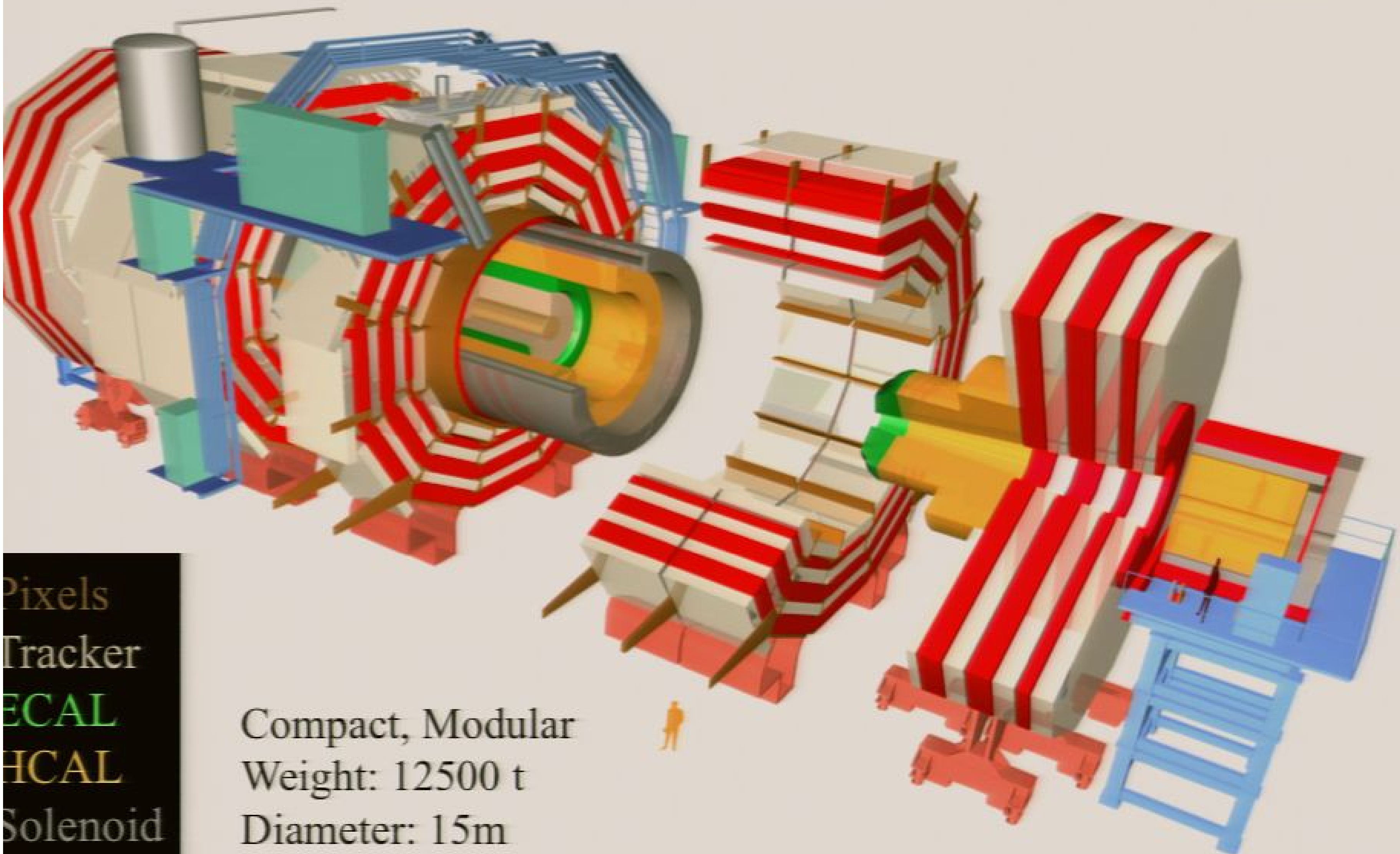

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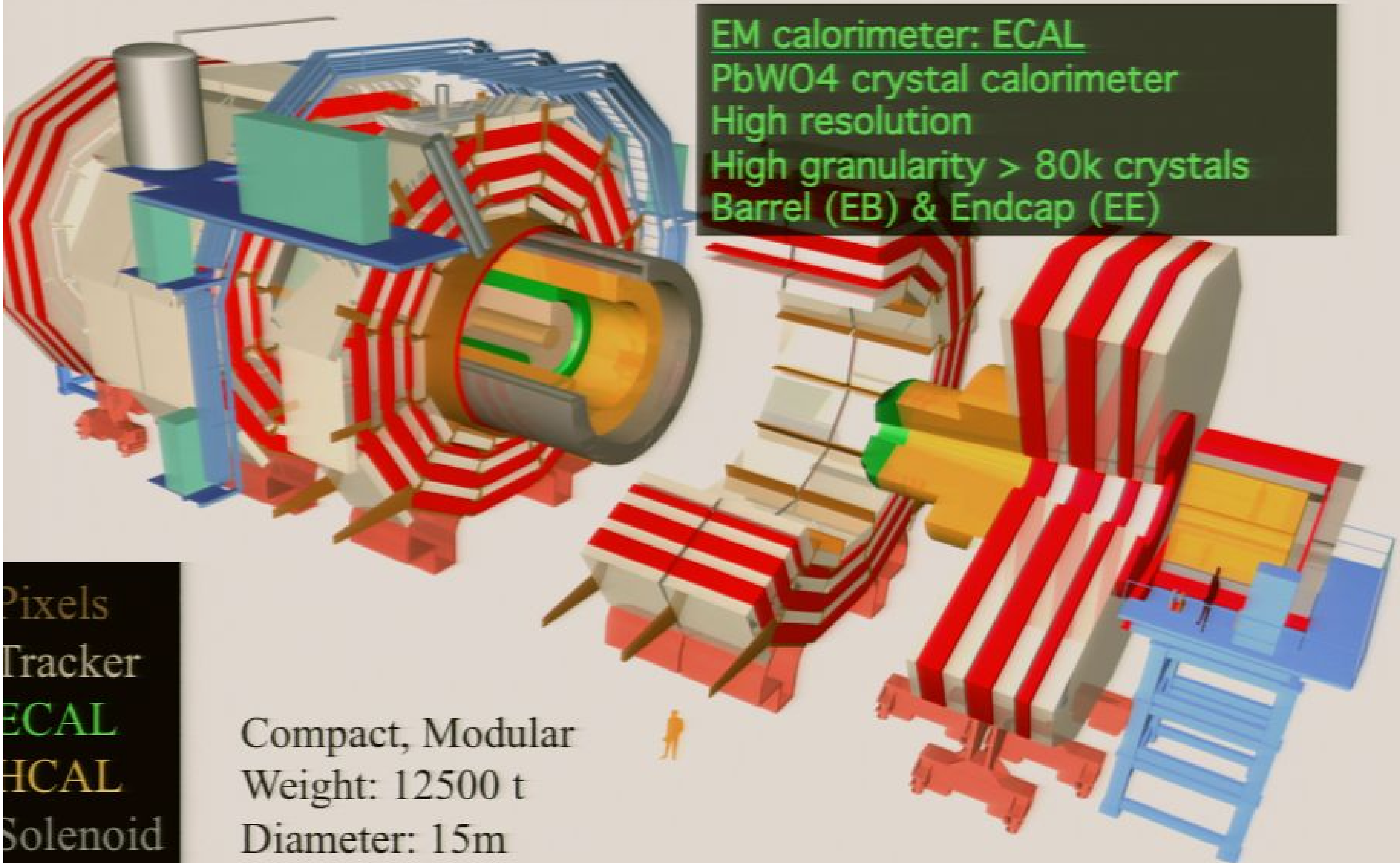
PbWO4 crystal calorimeter
High resolution
High granularity > 80k crystals
Barrel (EB) & Endcap (EE)



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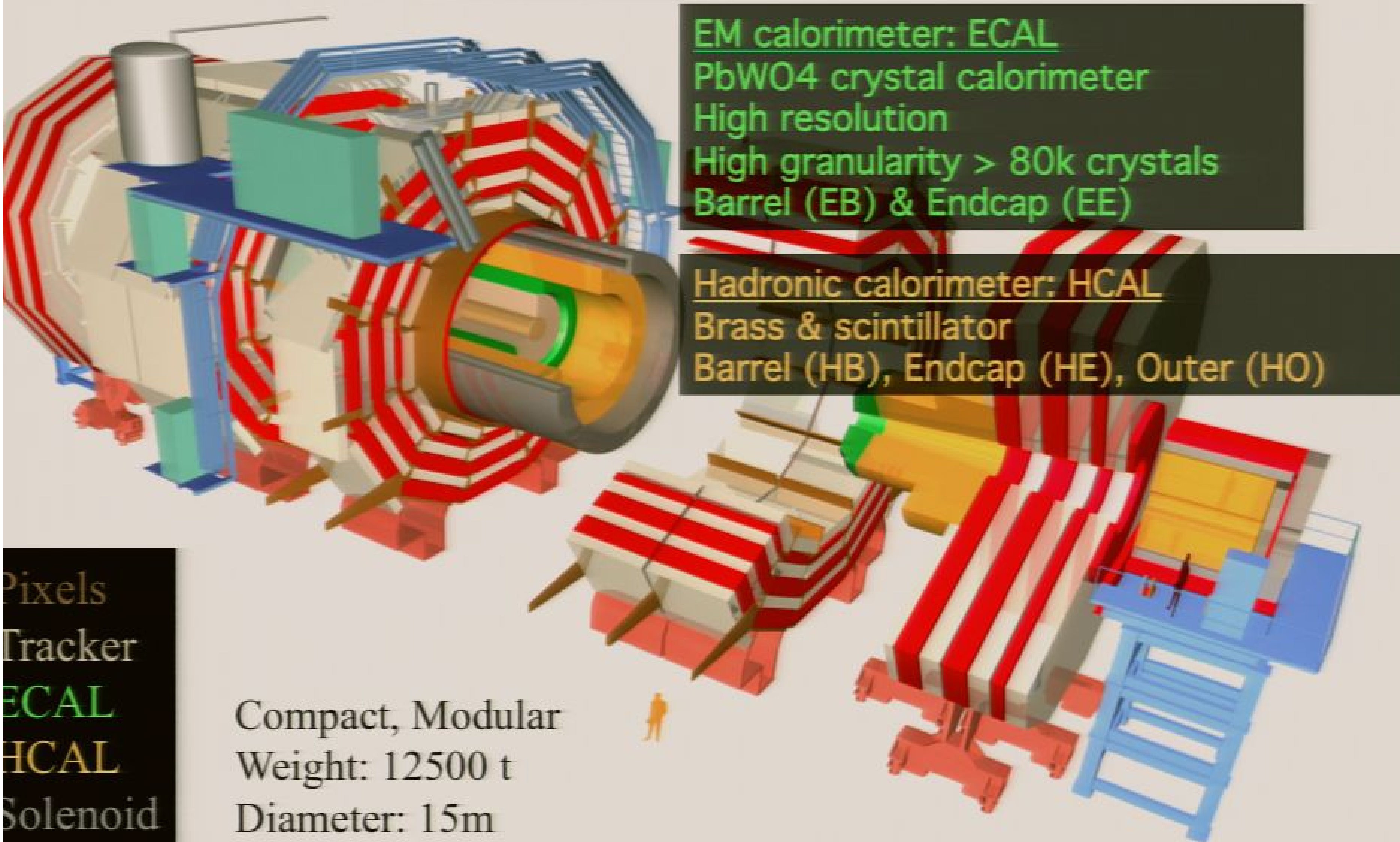

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Barrel (HB), Endcap (HE), Outer (HO)

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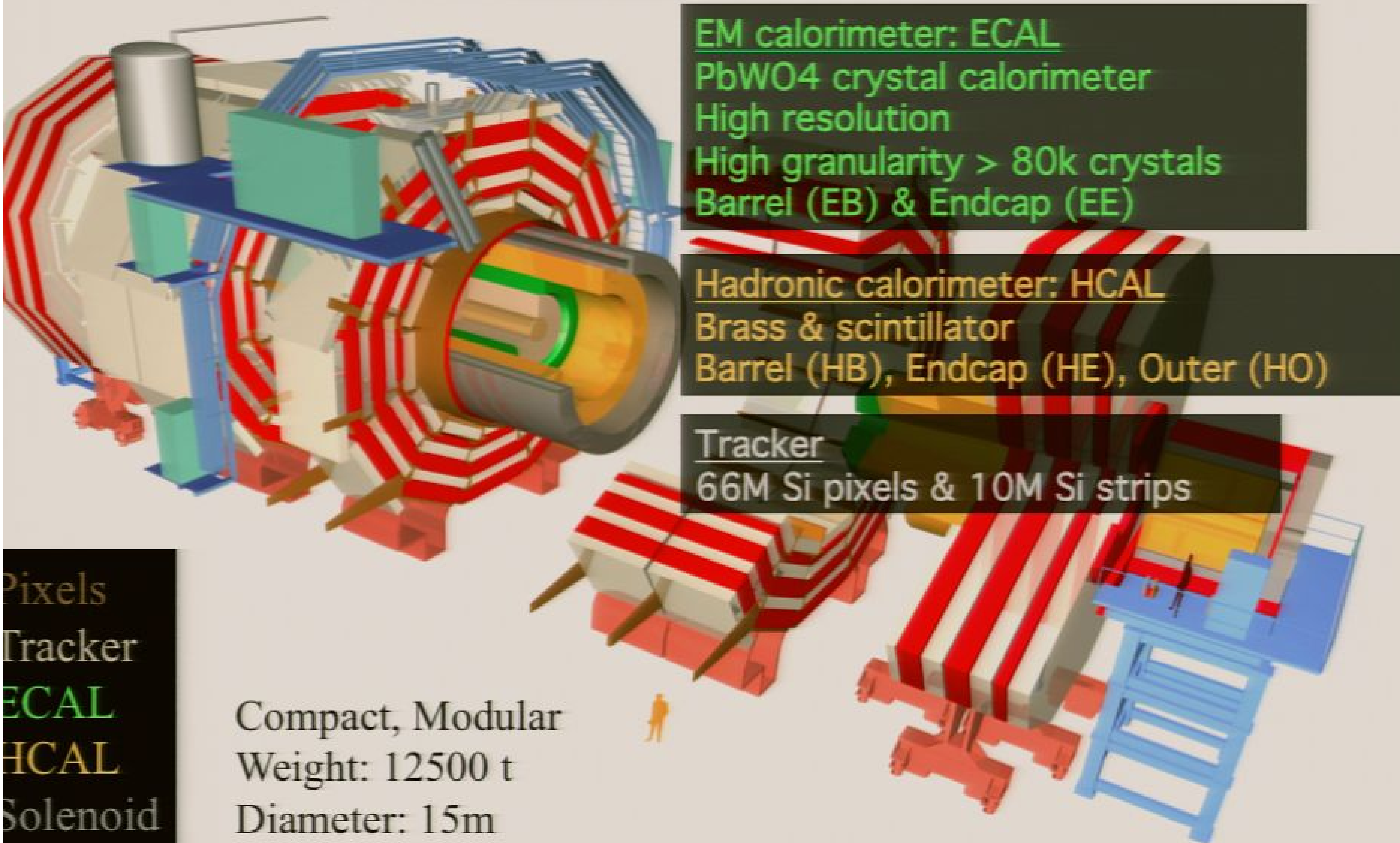

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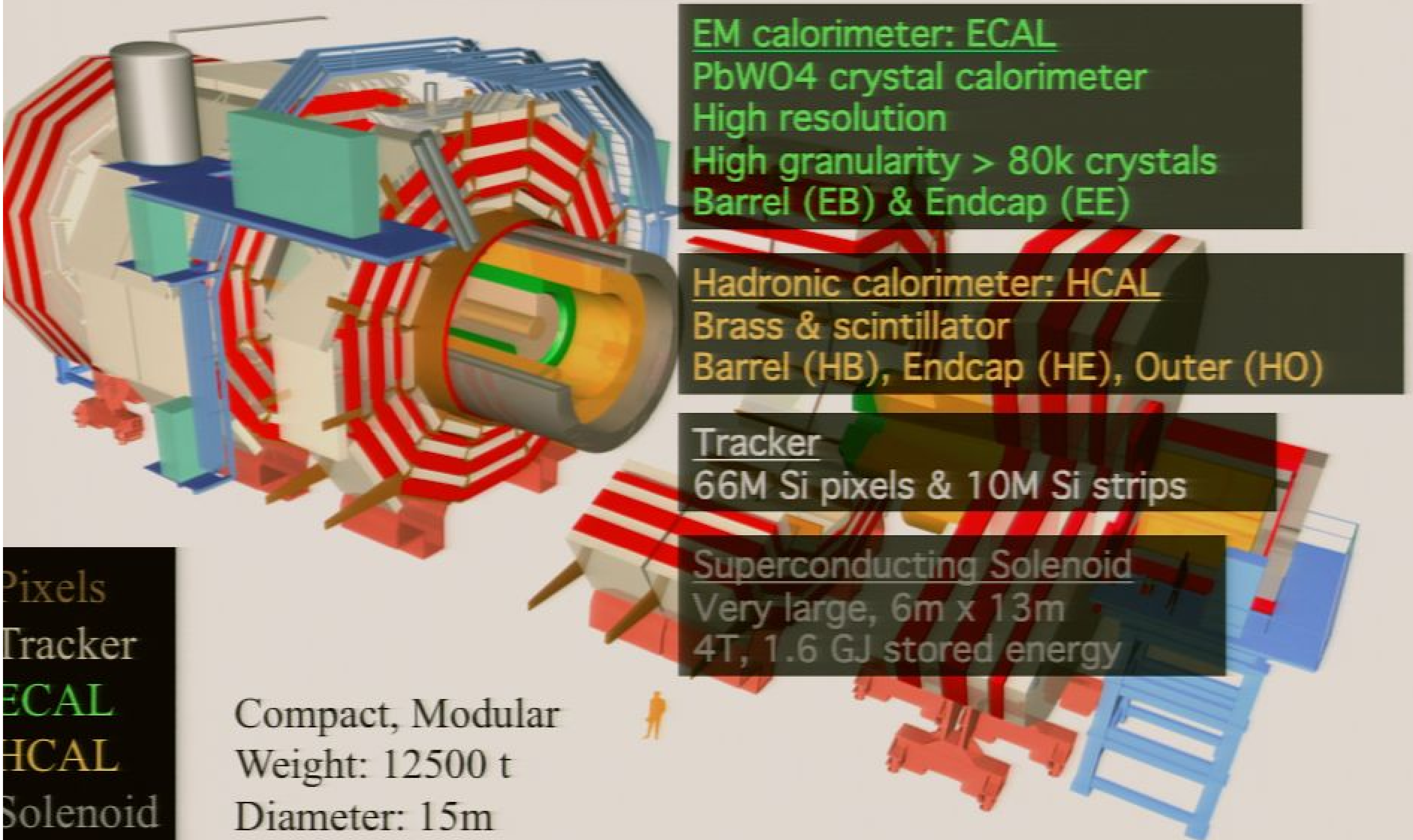

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Very large, 6m x 13m
4T, 1.6 GJ stored energy

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

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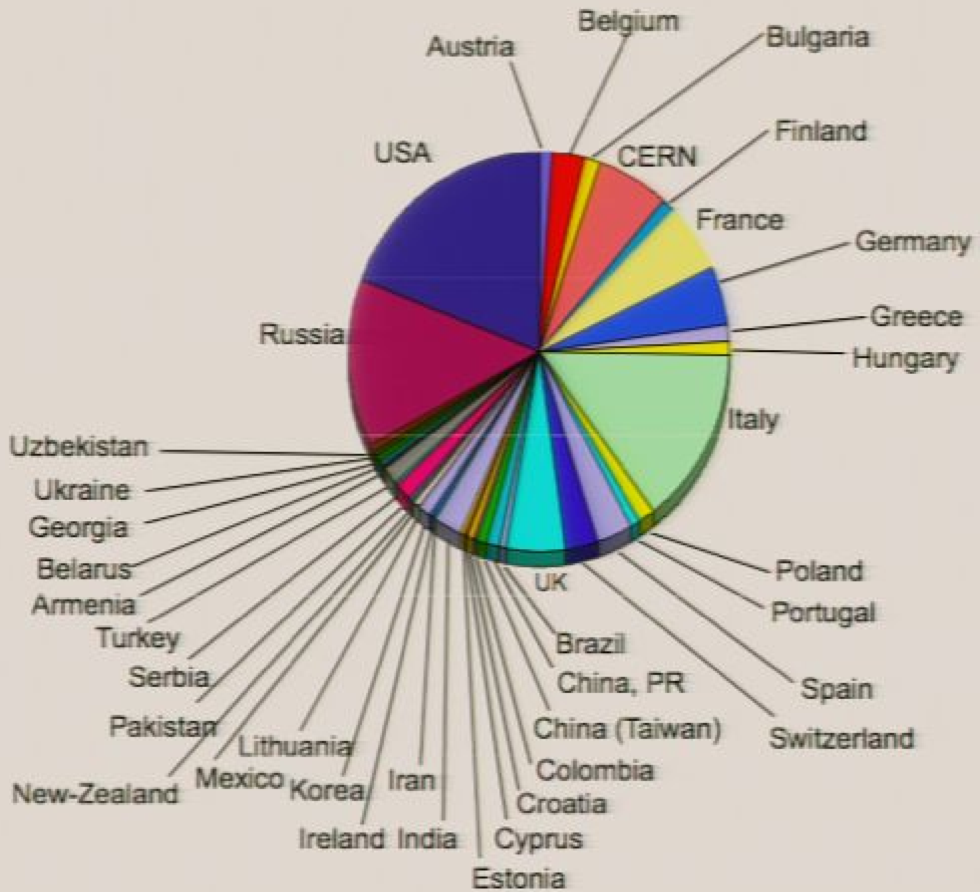
	Number of Laboratories
Member States	59
Non-Member States	67
USA	49
Total	175

	# Scientific Authors
Member States	1084
Non-Member States	503
USA	723
Total	2310

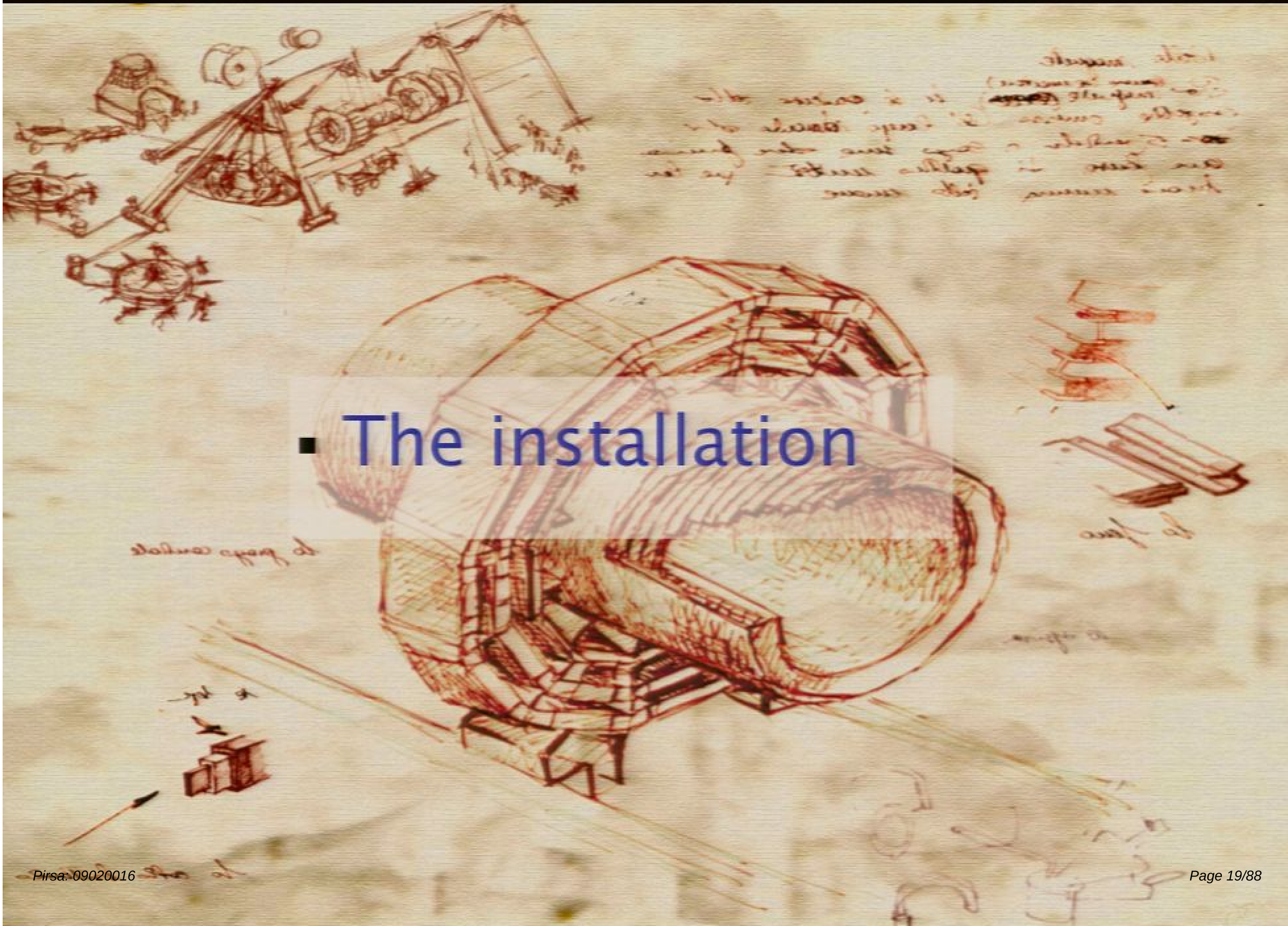
Associated Institutes	
Number of Scientists	62
Number of Laboratories	9



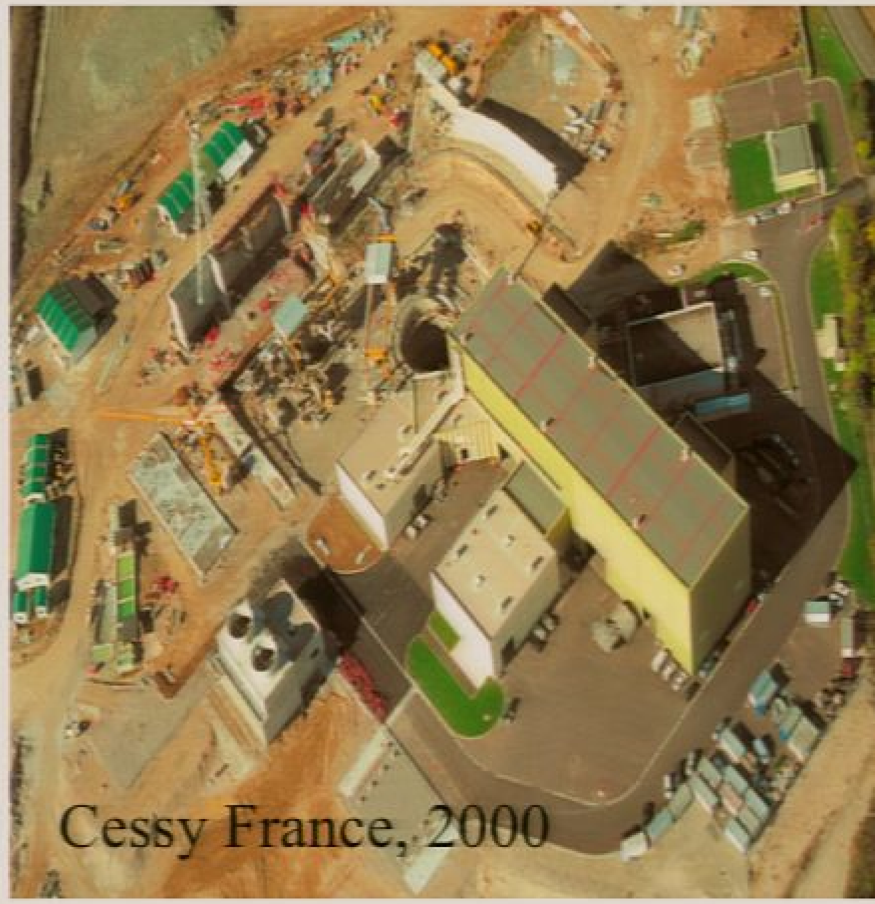
2310 Scientific Authors
38 Countries
175 Institutions

Oct. 3rd 2007/gm
T. Virdee

- The installation



Where are we?



Upstairs and downstairs: 2003

- CMS is the first large HEP detector that has been assembled, cabled and tested on the surface and then brought underground
- Work in parallel on the civil engineering and the detectors
- and the 'slicing' also meant that, through complicated loops of cable chains, water, gas and cooling leads, each piece remained accessible within the cavern

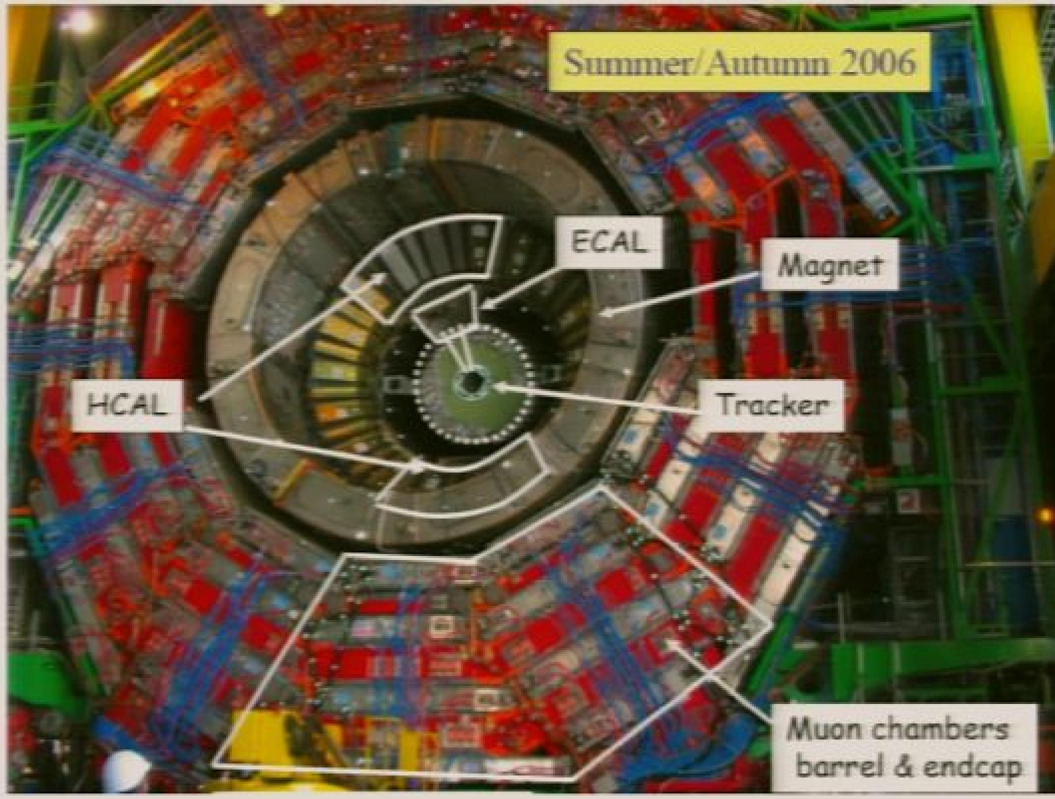
Upstairs and downstairs: 2005

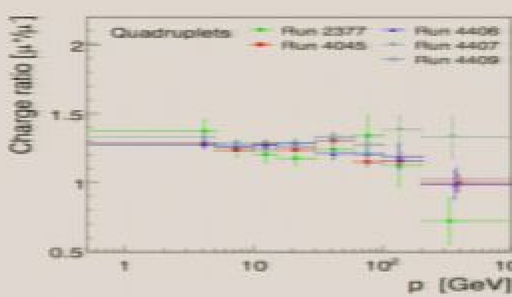
First elements of CMS were lowered
Into underground cavern in late 2006

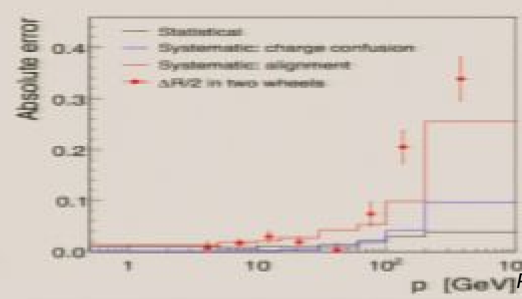
Safety: foam test

Magnet Test Cosmic Challenge: 2006

- First CMS integrated test: June/Nov 2006
- Field-mapping of solenoid magnet
- Integration test: elements of all subsystems plus central trigger & DAQ
- First CMS-wide team building experience
- First CMS measurement: cosmic muon charge asymmetry







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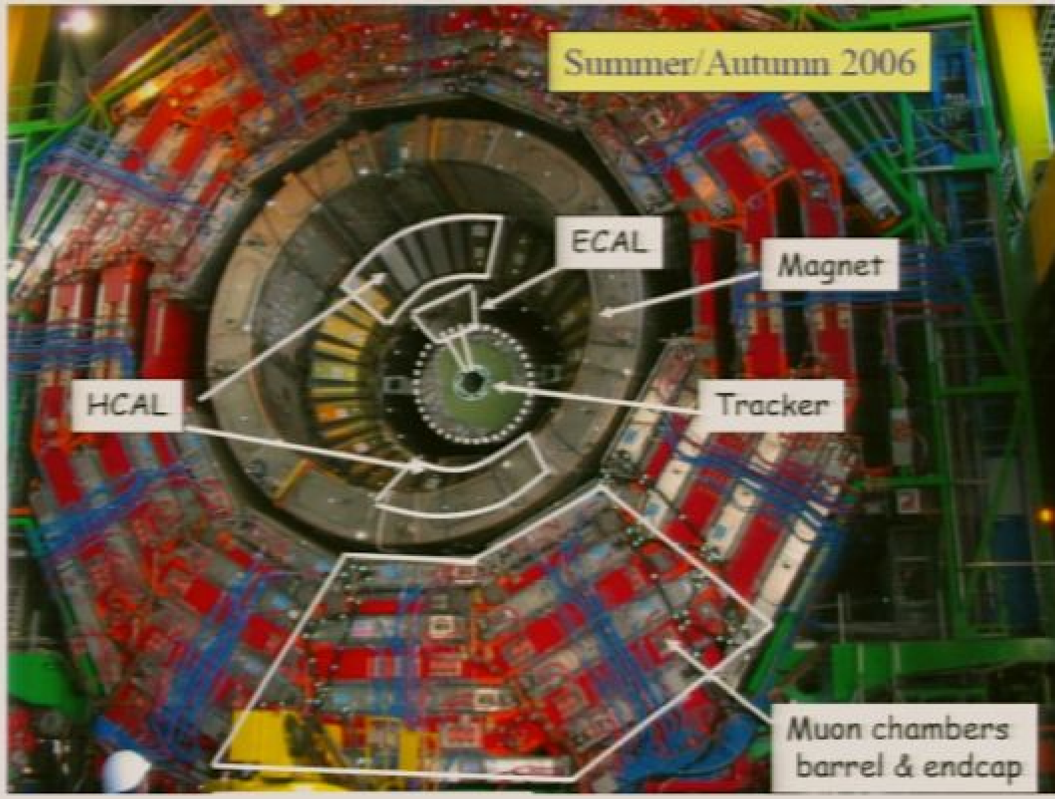
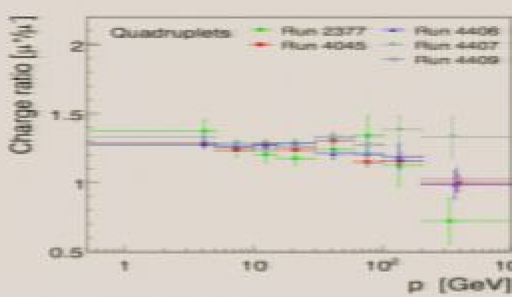
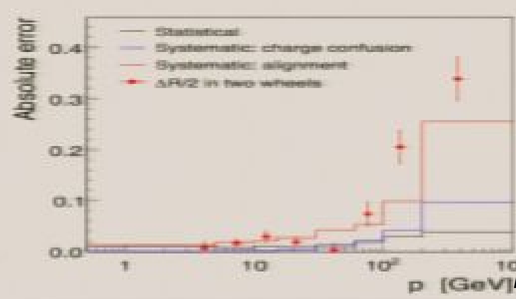


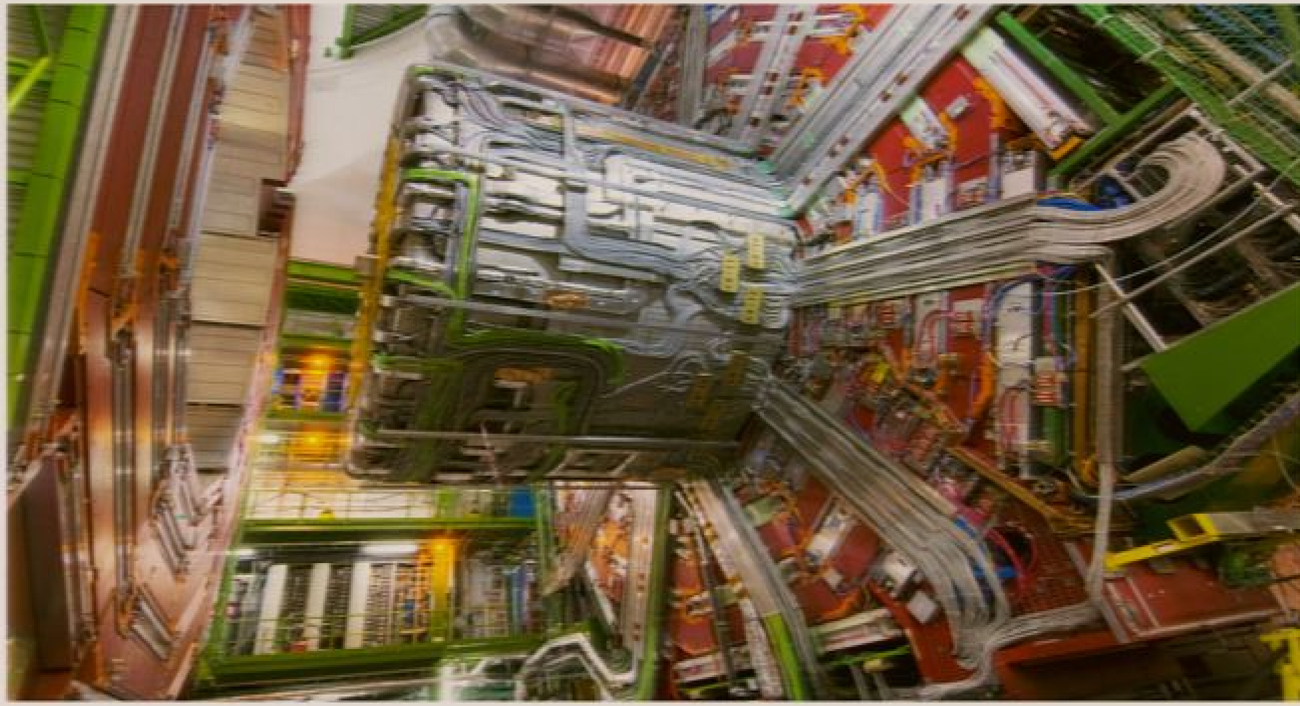




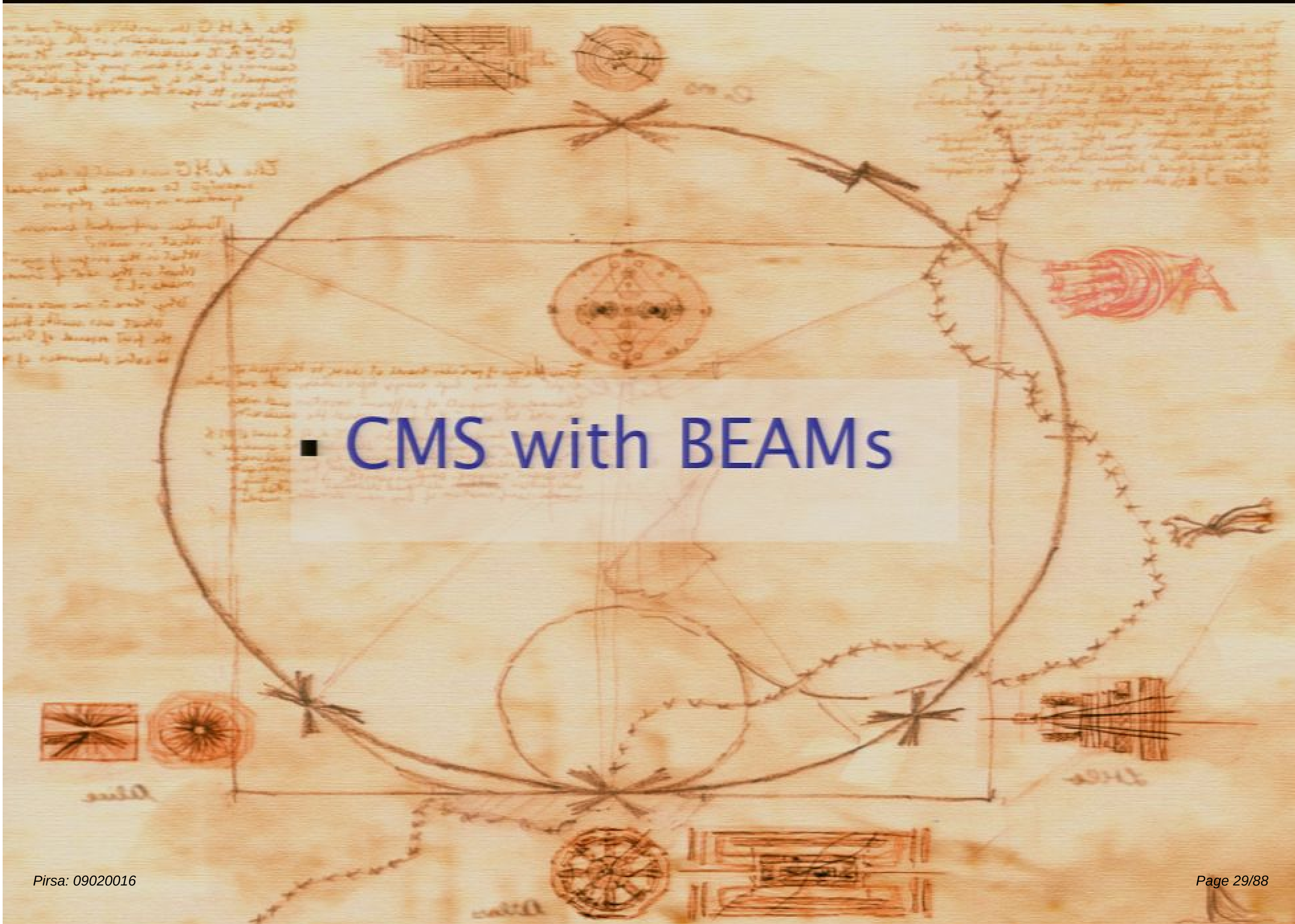
The heavy lowering

- Started Nov 11th, 2006 with the forward calorimeter (HF)
- Concluded on January 11th, 200, after 15 components lowered
- Central wheel w/ solenoid: 2500 tons; 11hs to go down ~90m

Complexity



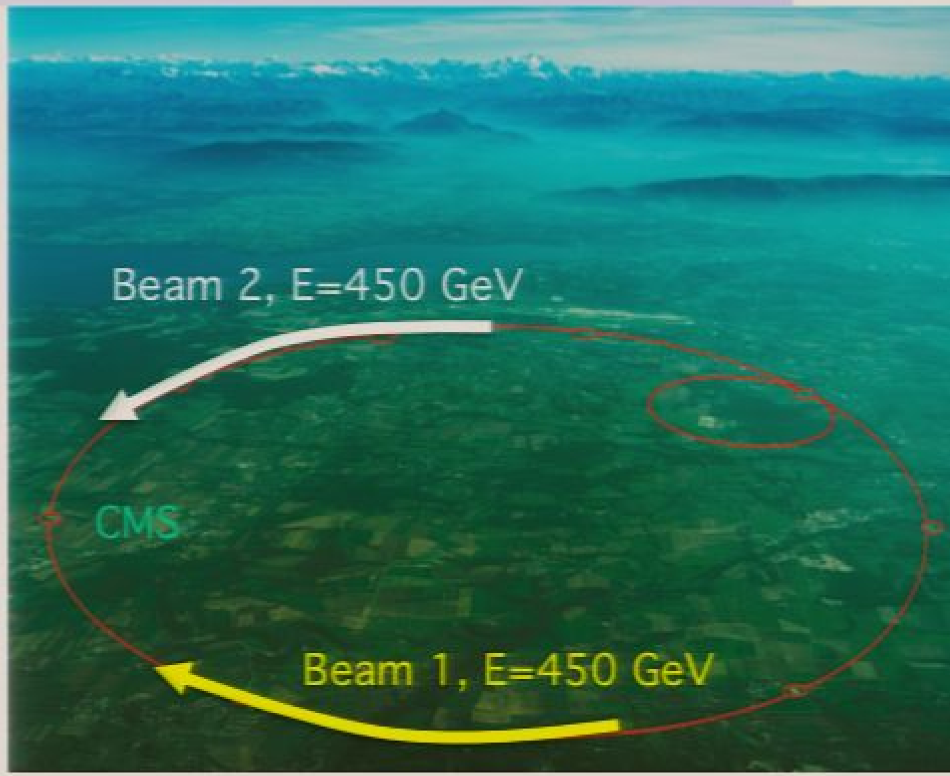
- All services for Pixel, Tracker, ECAL and HCAL have to go over the vacuum tank Approx.:
  - 250 Km cables, pipes and fibers
  - 6100 cables, 700 fibers,700 cooling pipes
  - 50000 hours of work in 8 months



- CMS with BEAMs

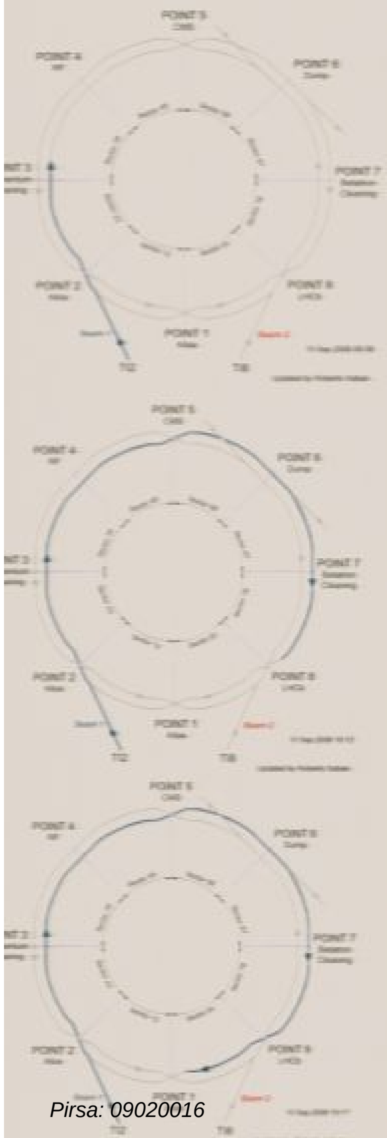
Timeline: First LHC Beams

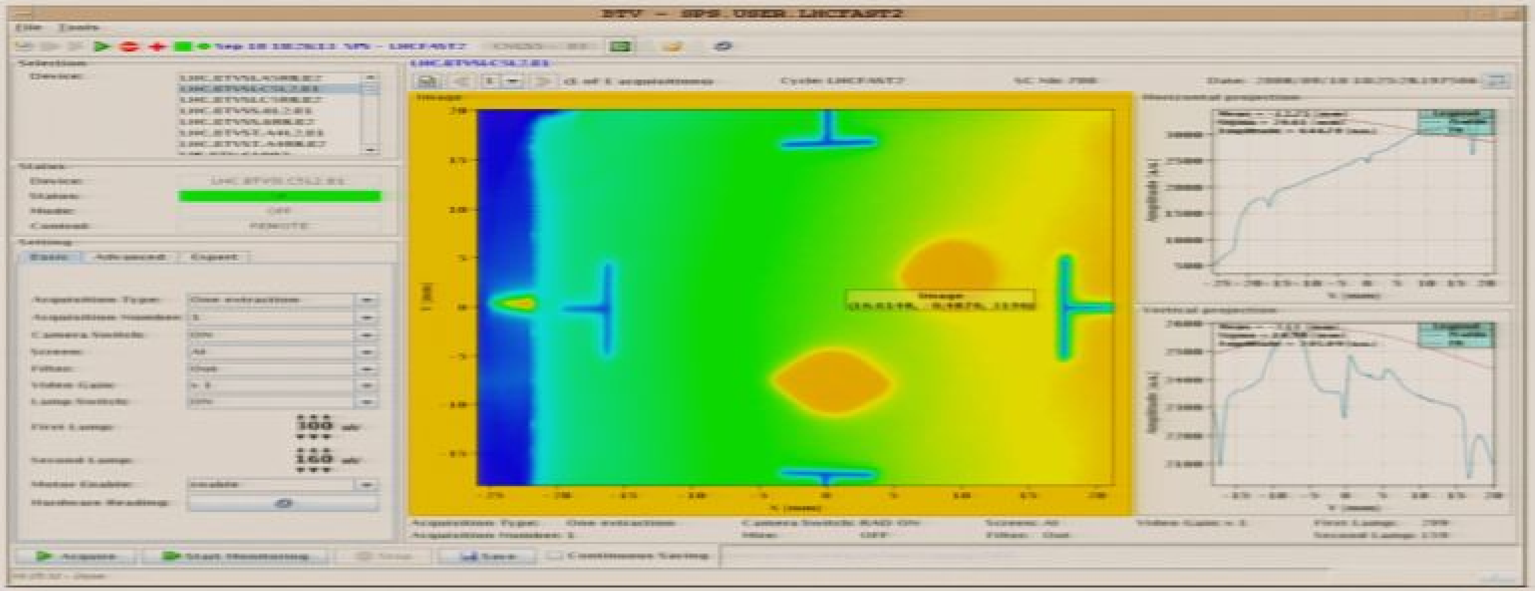
- **7-8 September**
  - Single shots of beam 1 onto closed collimator 150m upstream of CMS ('splashes')
- **9 September**
  - Additional single shots of beam 1 onto collimator
- **10 September (Media Day!)**
  - Beam 1 circulated in the morning, 3 turns by 10:40am (in 1 hour of work!)
  - Beam 2 circulated by 3:00pm, 300 turns by 11:15pm
- **11 September**
  - RF system captures beam at 10:30pm (millions of orbits)

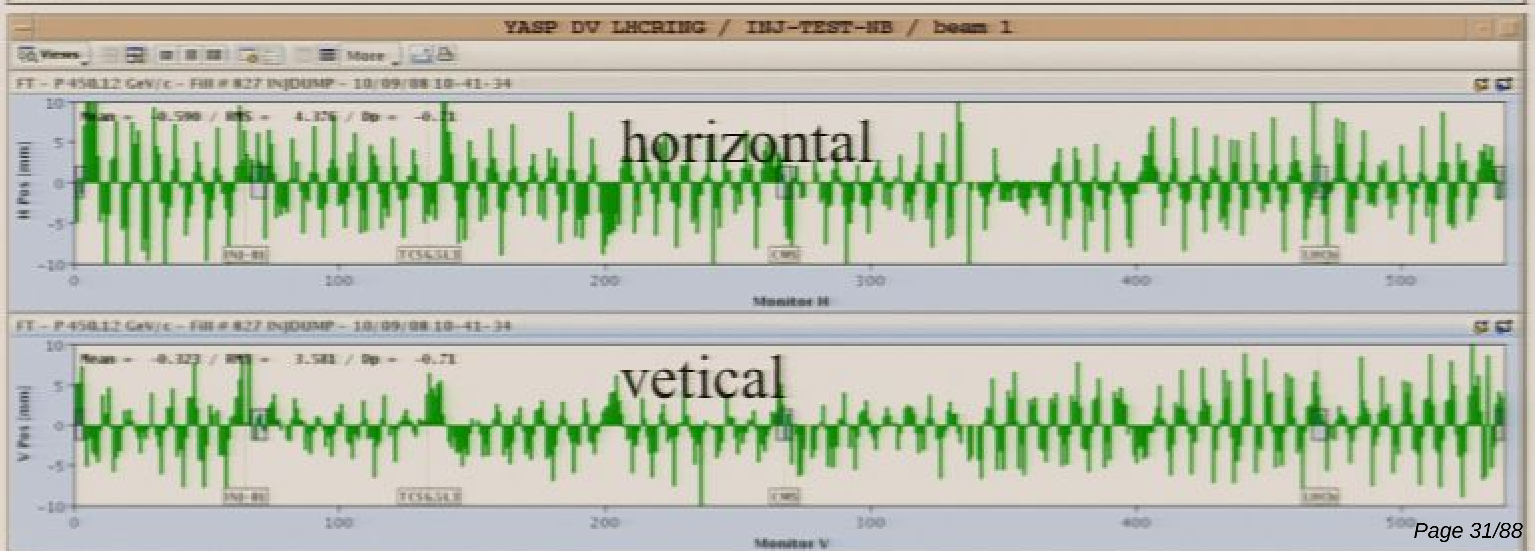


- **During all of these activities, CMS triggered and recorded data**
  - ~40 hours of beam to CMS
  - All systems on, except for Tracker and Solenoid

Sept 10th: beams find their way







September 10th excitement

L'ESPERIMENTO DEL CERN

Parte il test del Big Bang a Ginevra, festa e applausi per gli scienziati | Foto

08:44 | SCIENZE | Al via il progetto più ambizioso della fisica moderna, alla ricerca della «particella di Dio». I primi scontri tra nubi di protoni a novembre. Ma Monsignor Sgreccia frena gli entusiasmi sulla particella Higgs: «Dio non si può trovare con gli esperimenti» Caprara Video

- Scheda - Il ritorno alle origini dell'universo e le prime stelle
- Il Cosmo visto con gli occhi di Spinoza *di Giulio Giorello*
- Video - L'avventura di Lhc: ecco come funziona e a che serve
- L'Istituto di fisica nucleare: «Nel mondo miliardi di Lhc naturali»

Video Il blog - Guarda le vignette Vota

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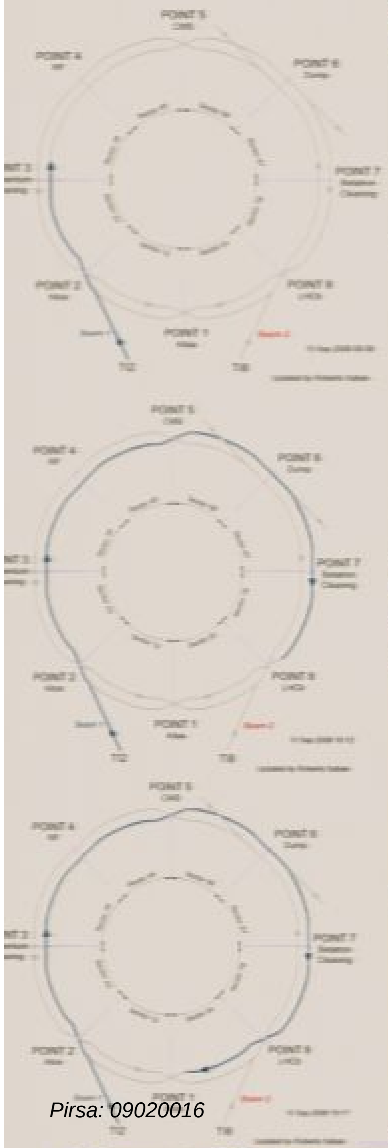

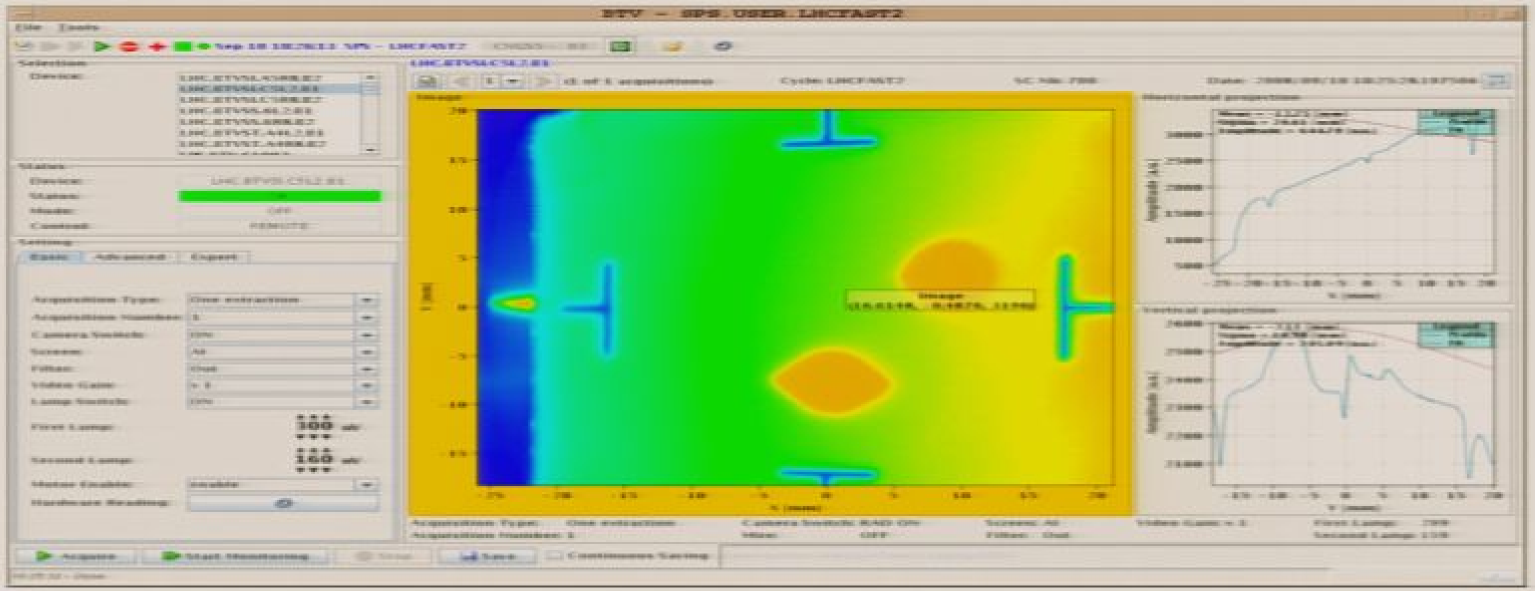

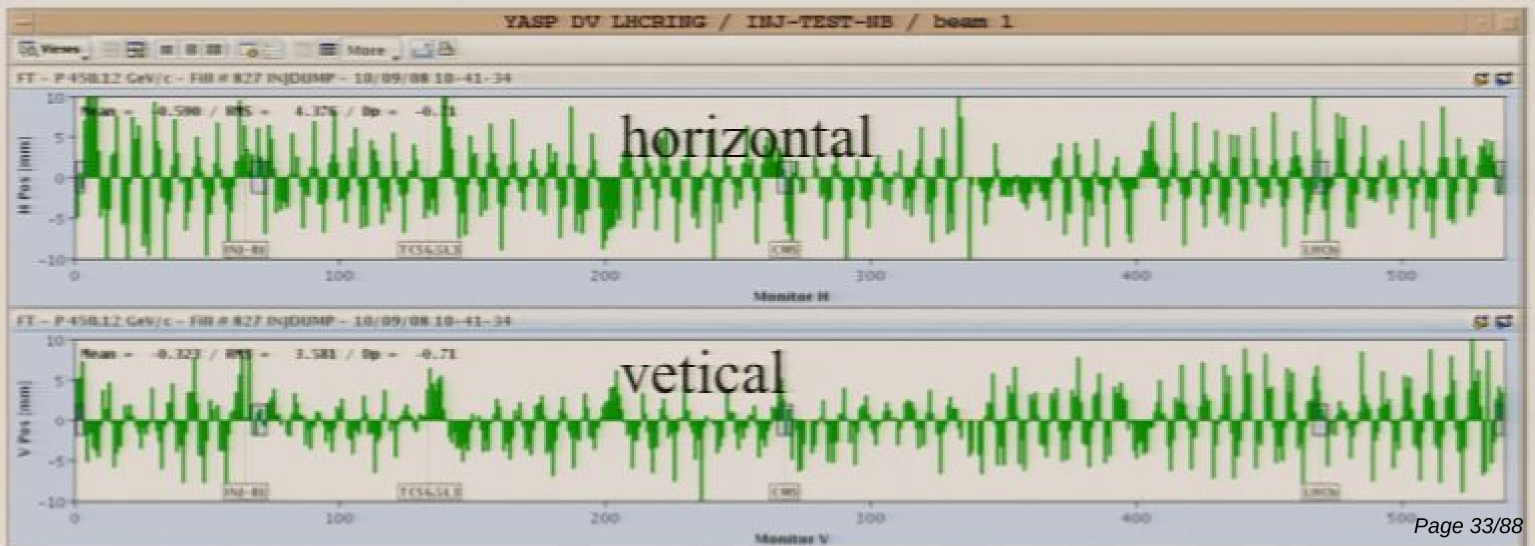

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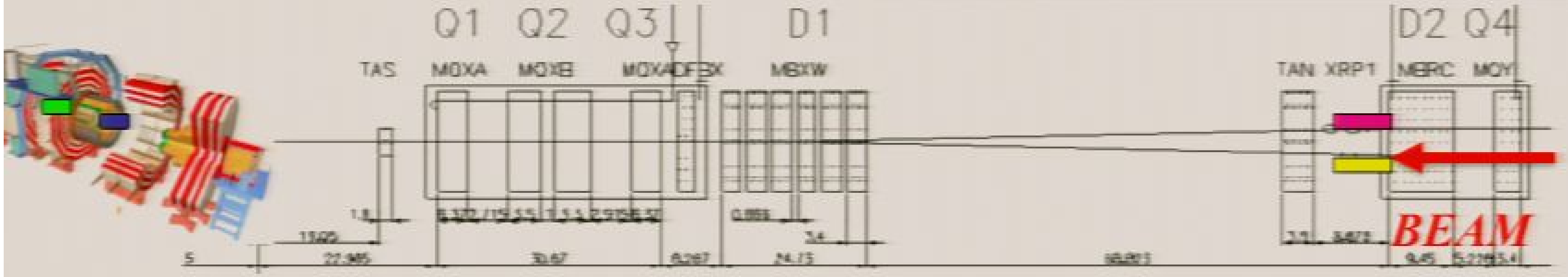
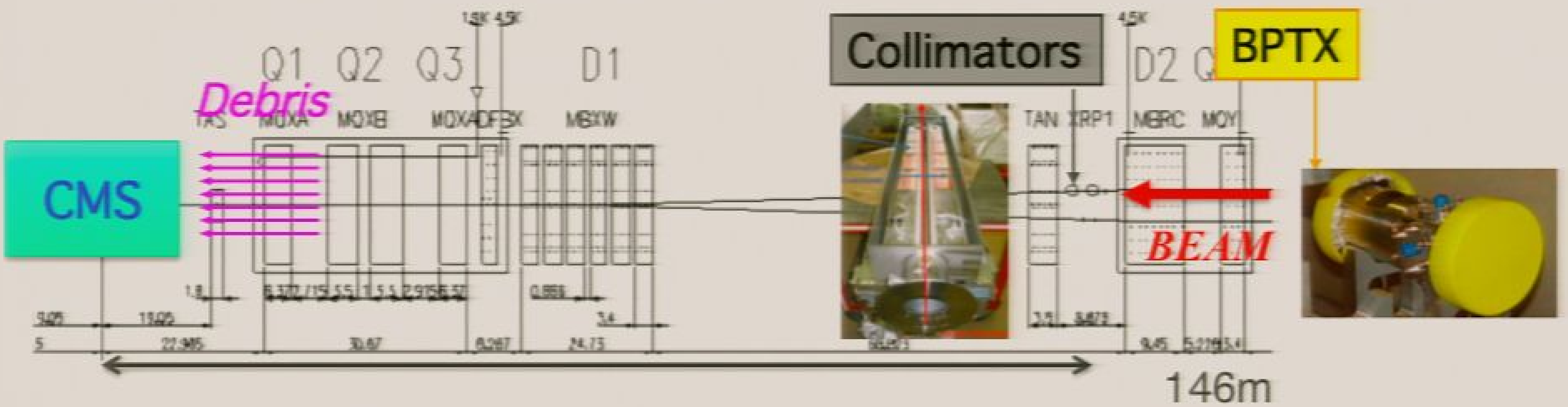
First Circulating Beam Through CMS



- *Beam pick up time*: e.m. induction from passing charge
- *Beam condition monitors*: at either side of the CMS pixel volume

Beam Splash Events

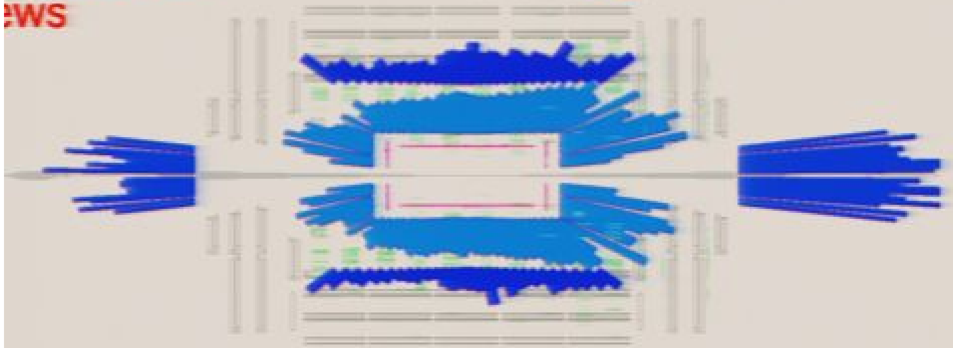
- **Single beam shots of $2*10^9$ protons onto closed collimators ~150m upstream of CMS**
  - Hundreds of thousands of muons pass through CMS per event
  - Enormous amount amount of energy deposited in calorimeters
- Allowed synchronization of triggers (previously with cosmic muons)
  - Muon end caps,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



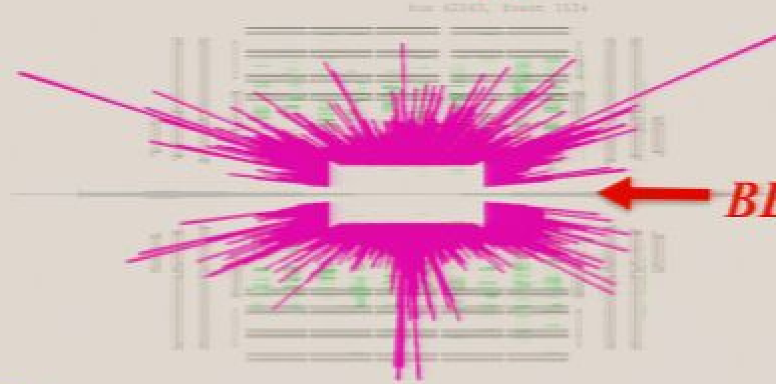
Beam Splash Event Display

ngitudinal
ews

HCAL energy



ECAL energy



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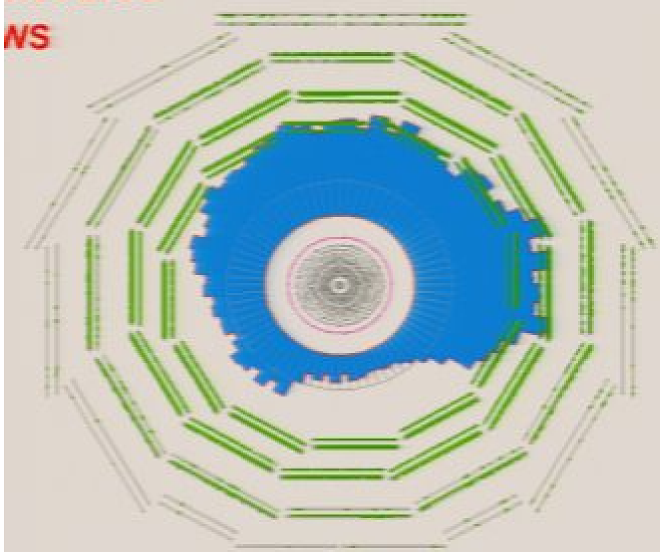
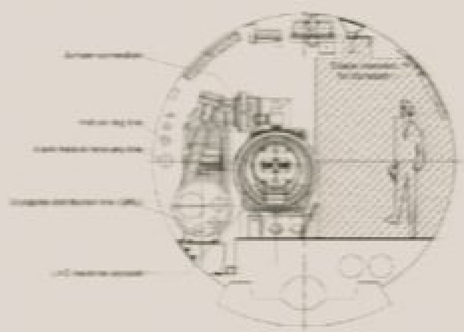
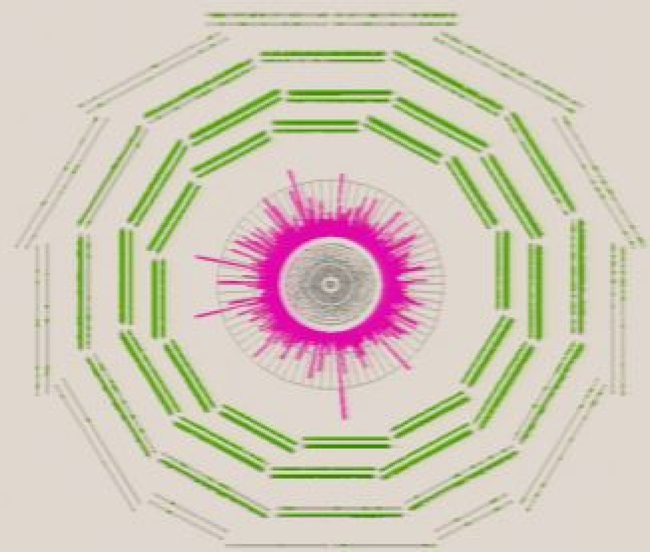


DT muon
chamber hits

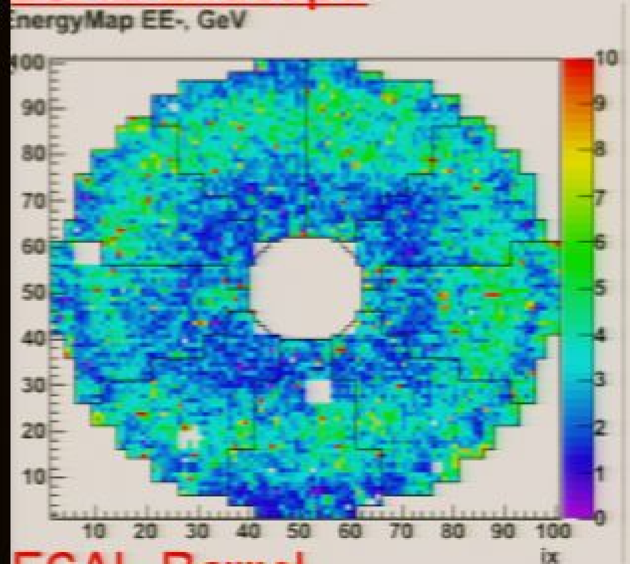


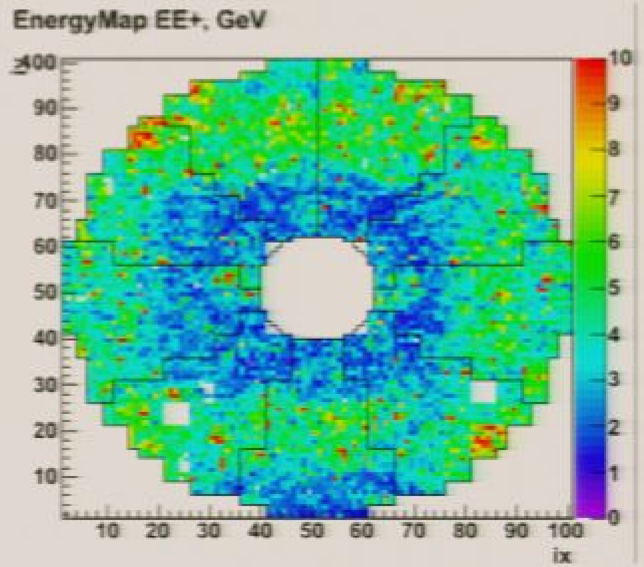
LHC Tunnel
profile visible



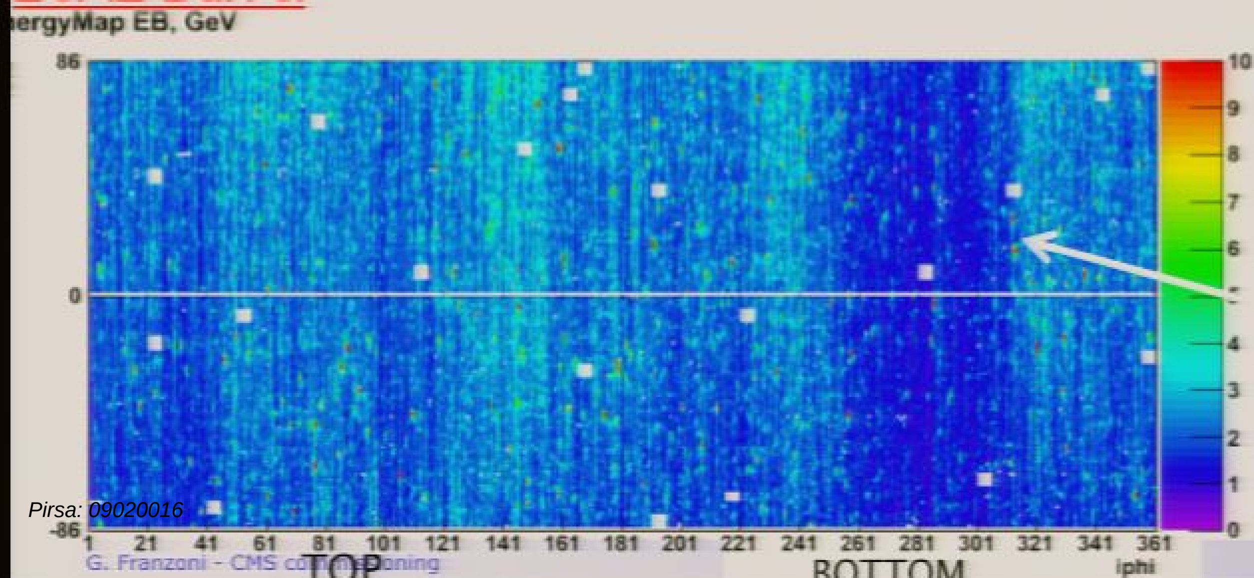
Beam Splash: ECAL Energy

ECAL Endcaps





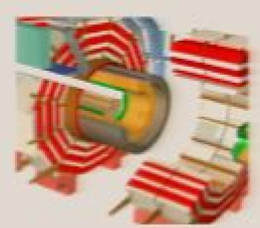
ECAL Barrel



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

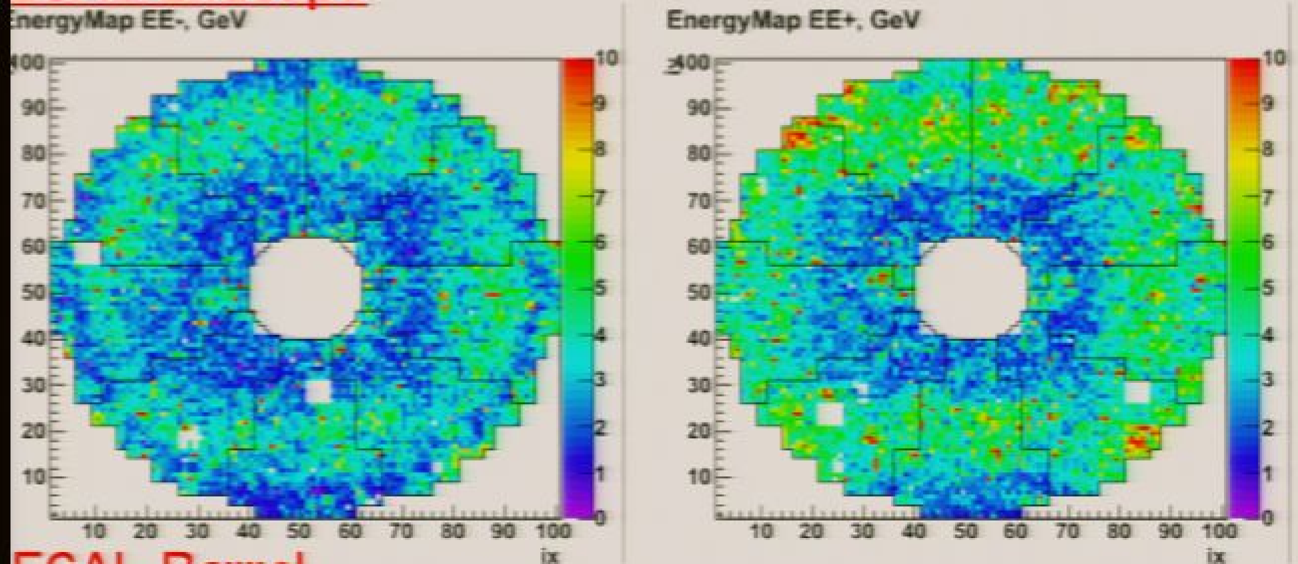
Beam (clockwise) came from plus side.

ECAL crystal is ~2x2x22 (~3x3x22) cm^3 in EB (EE)

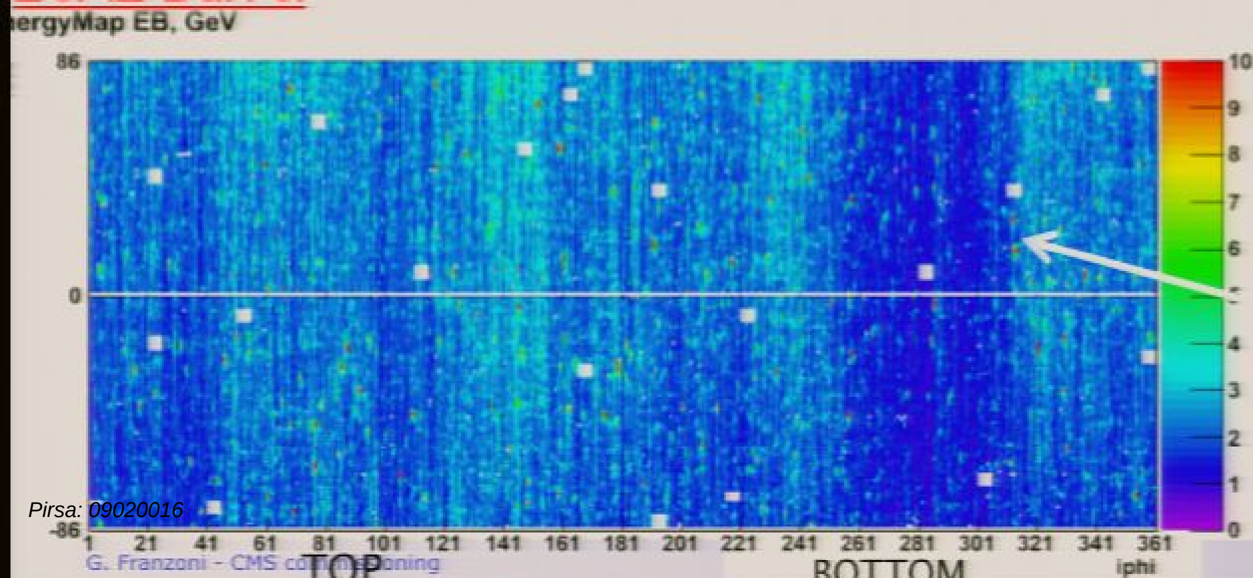


Beam Splash: ECAL Energy

ECAL Endcaps



ECAL Barrel



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

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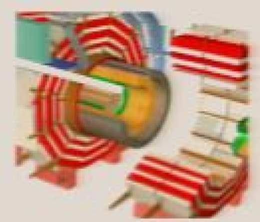
ECAL crystal is ~2x2x22 (~3x3x22) cm^3 in EB (EE)



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 time pick up, etc
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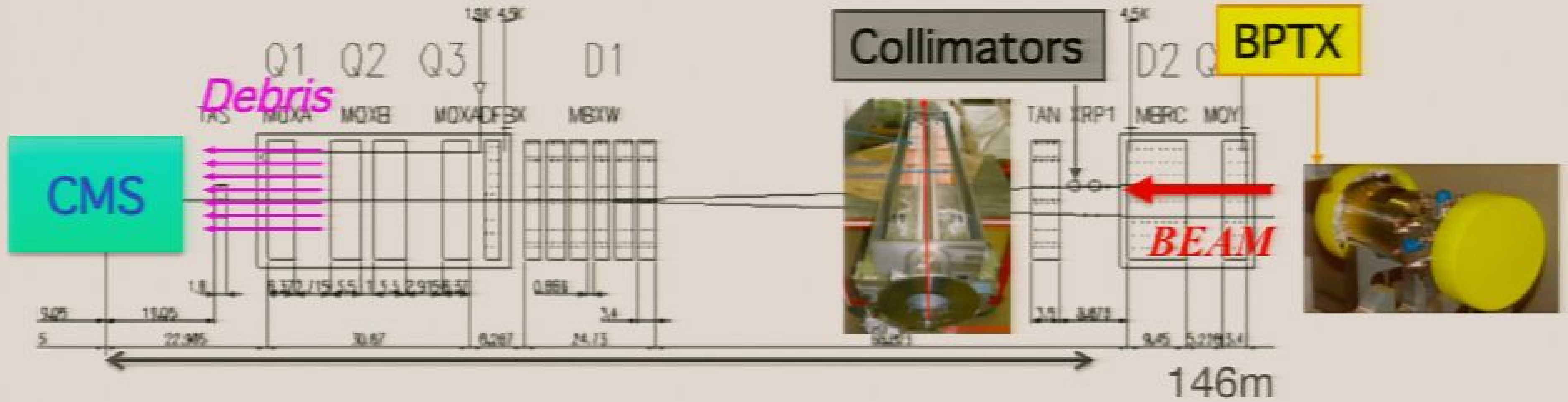
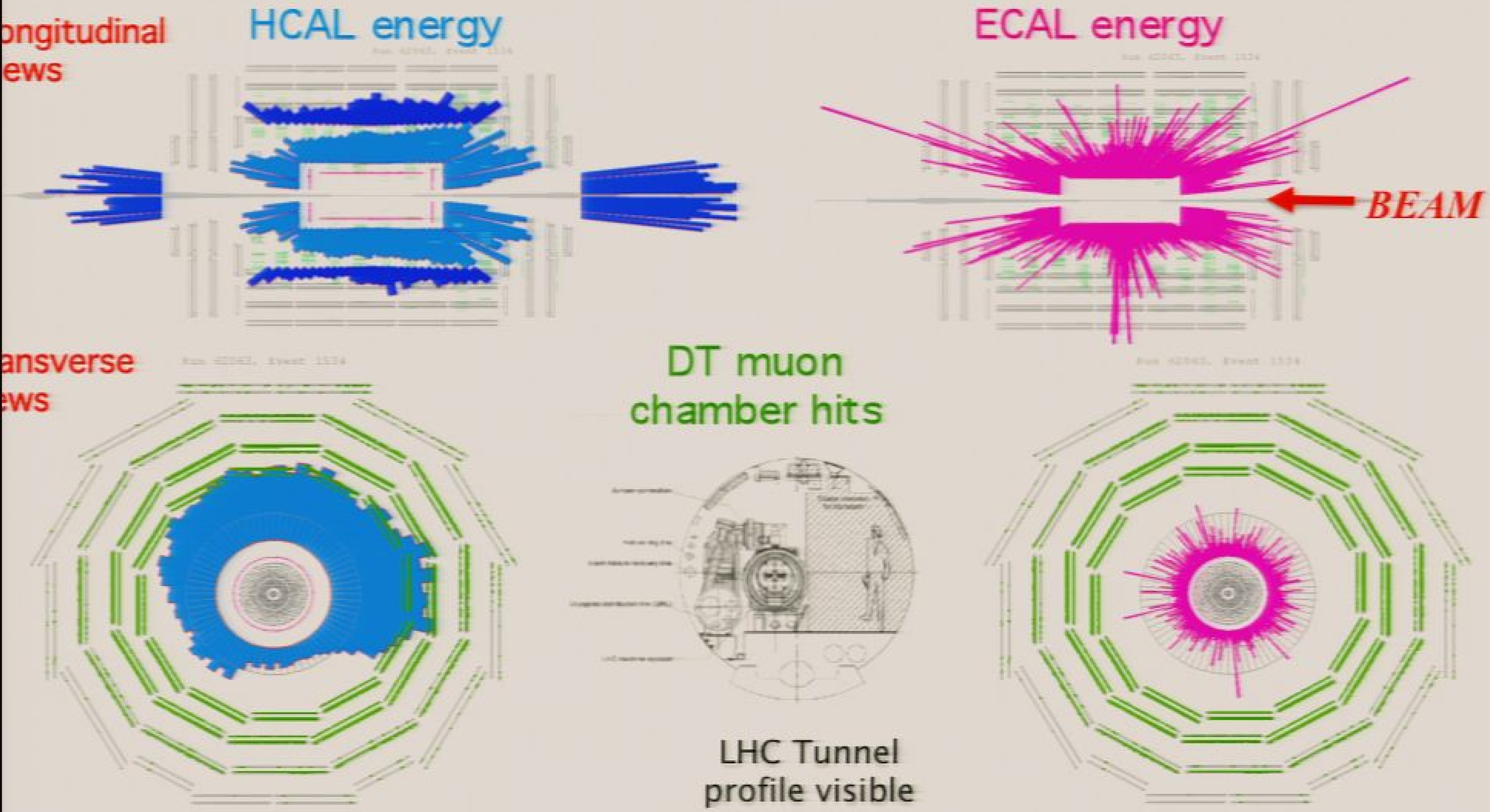


Beam Splash Event Display



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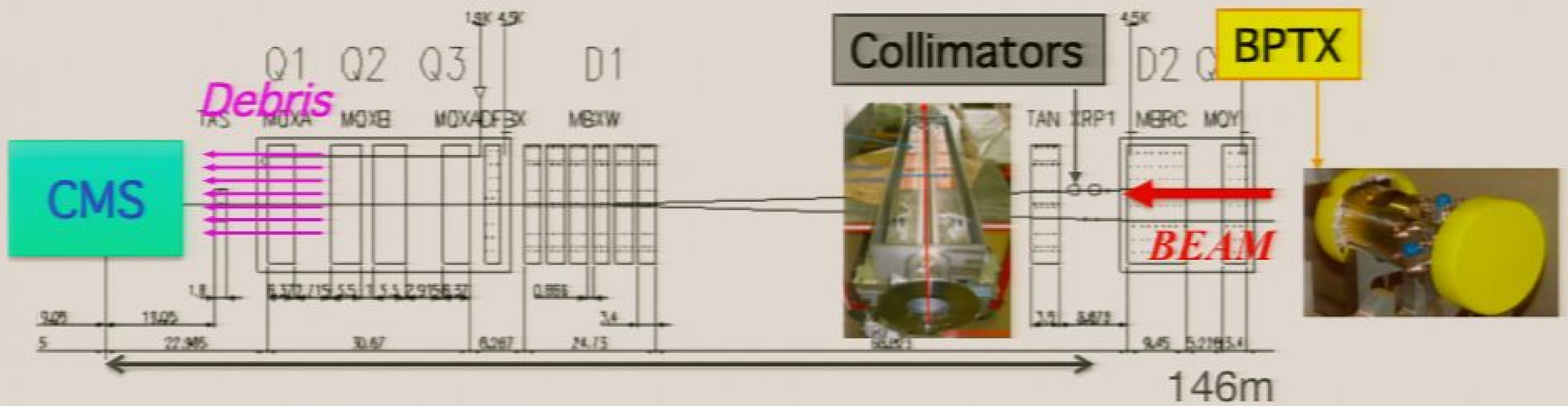
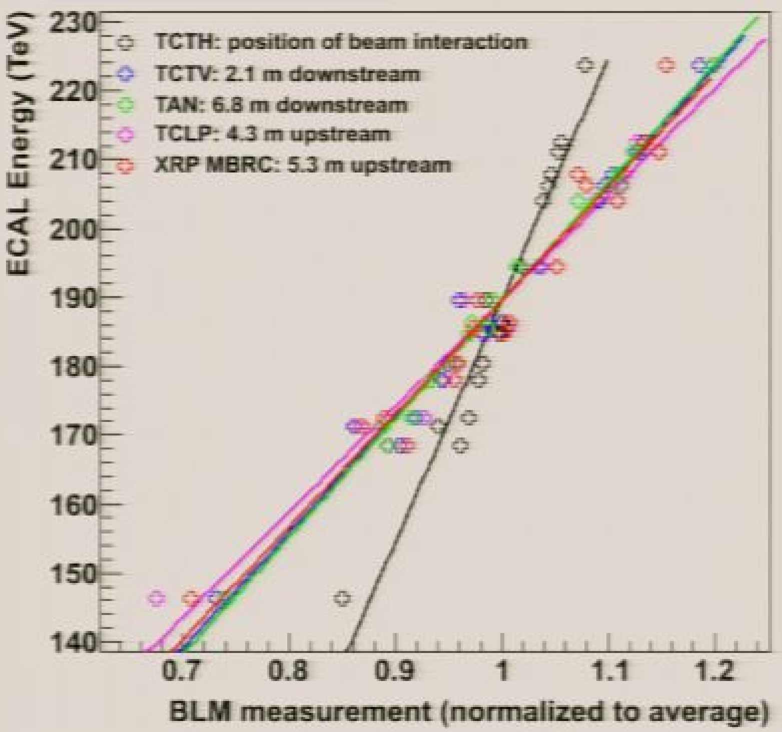
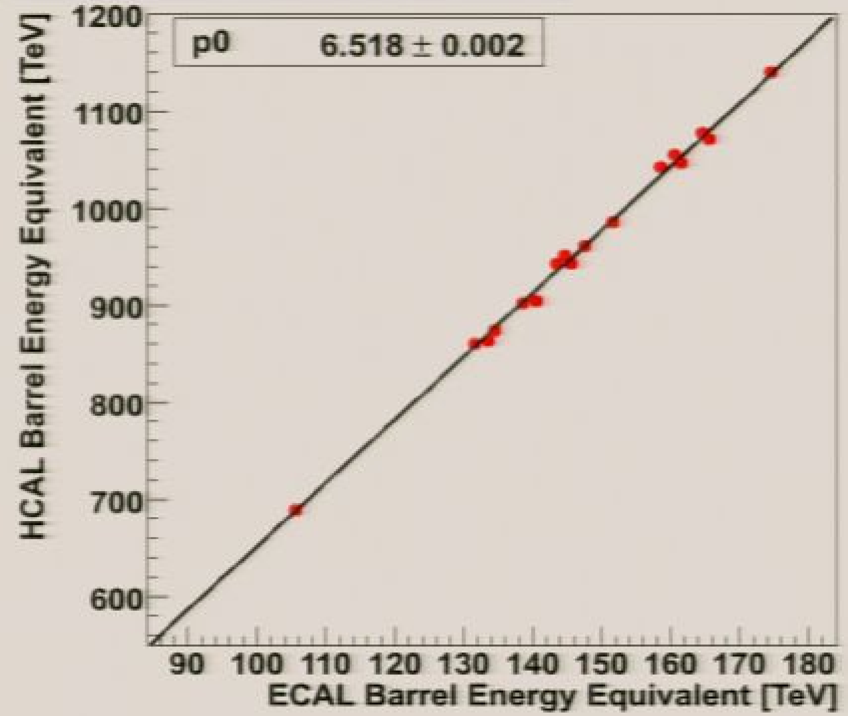


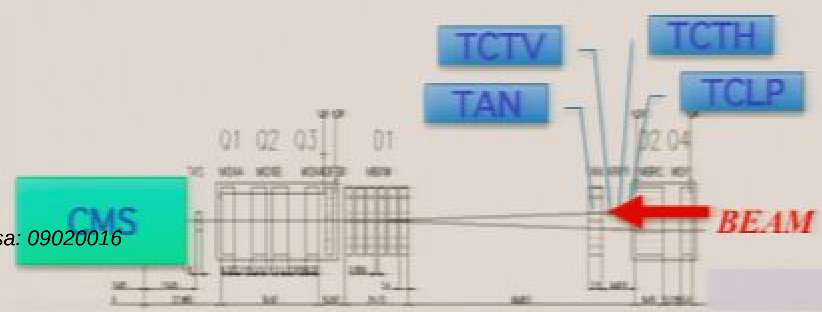
Beam Splash Correlations

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

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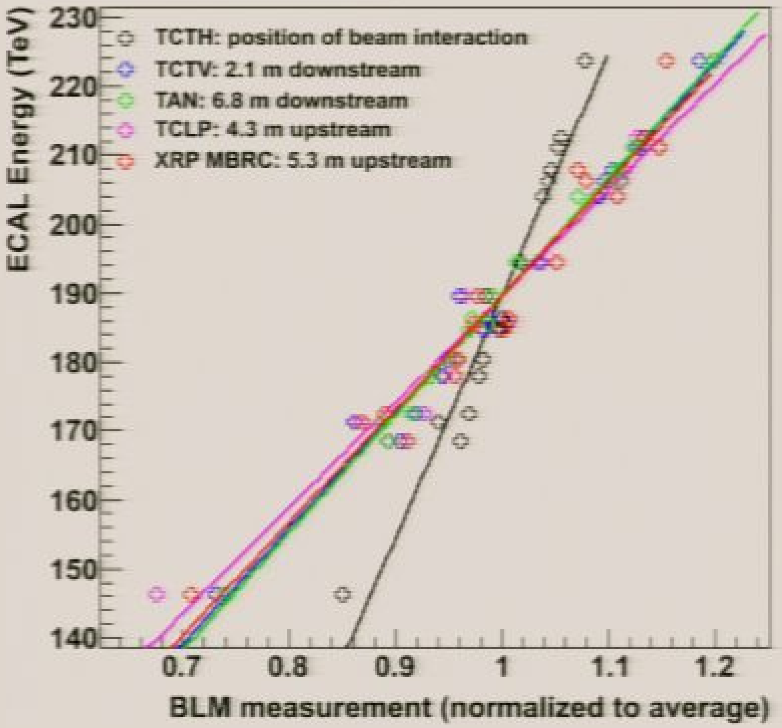

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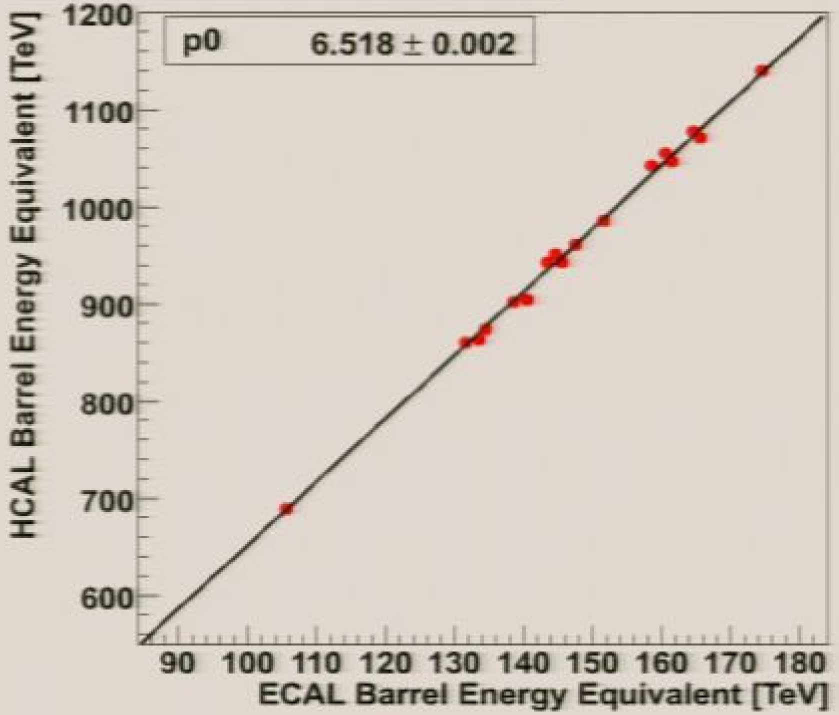

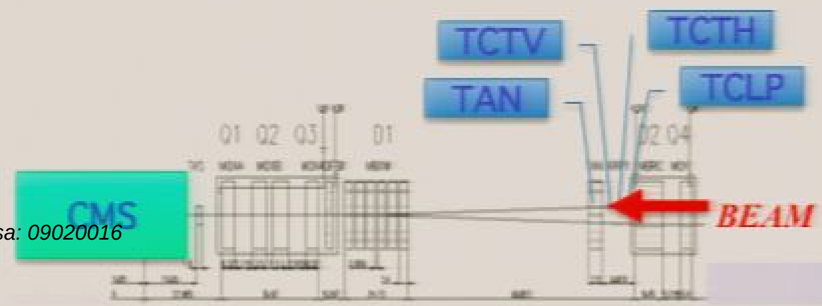

~150 TeV deposited in ECAL &
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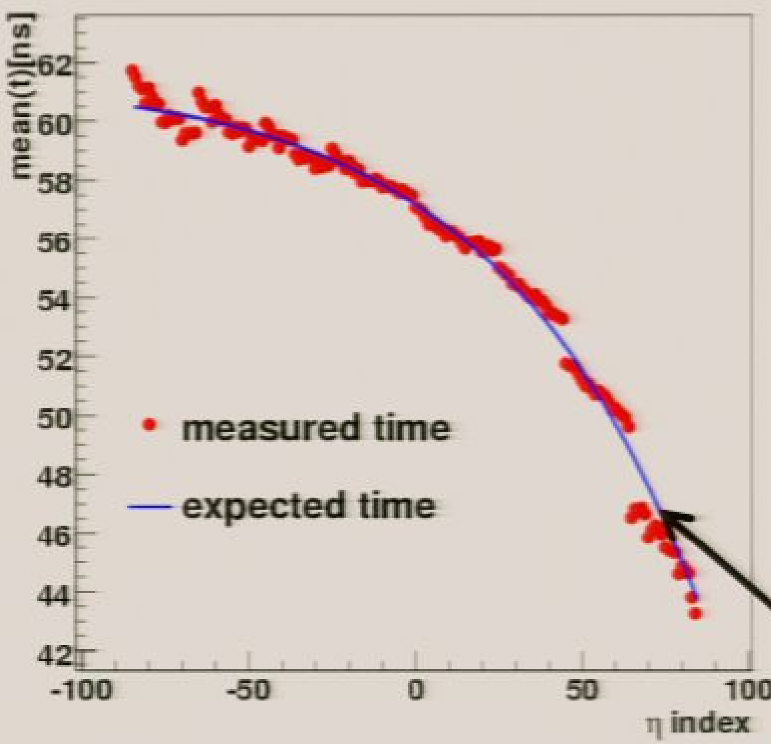
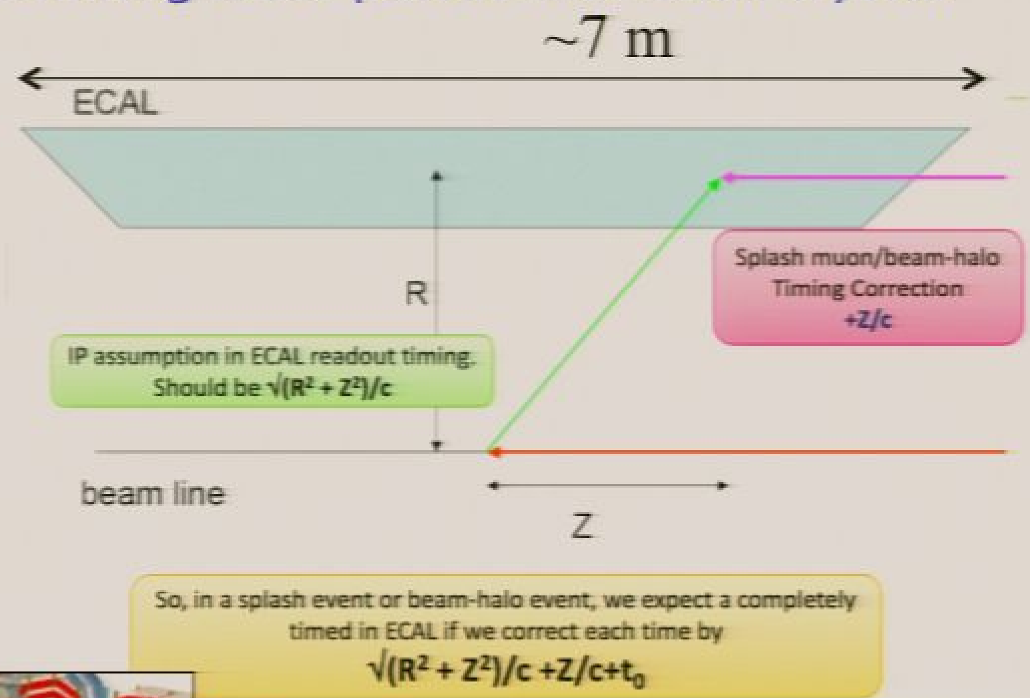
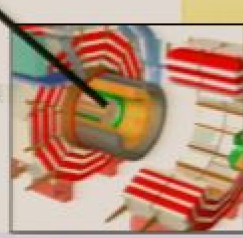
Tuning ECAL timing with Beam Splash

- The 61200 channels of the ECAL barrel are time-adjusted in groups of 5x5. Timing is set in the hardware such that clusters from collisions are all recorded at the peak of the scintillation pulse
- Initial timing settings obtained shining laser pulses into each crystal

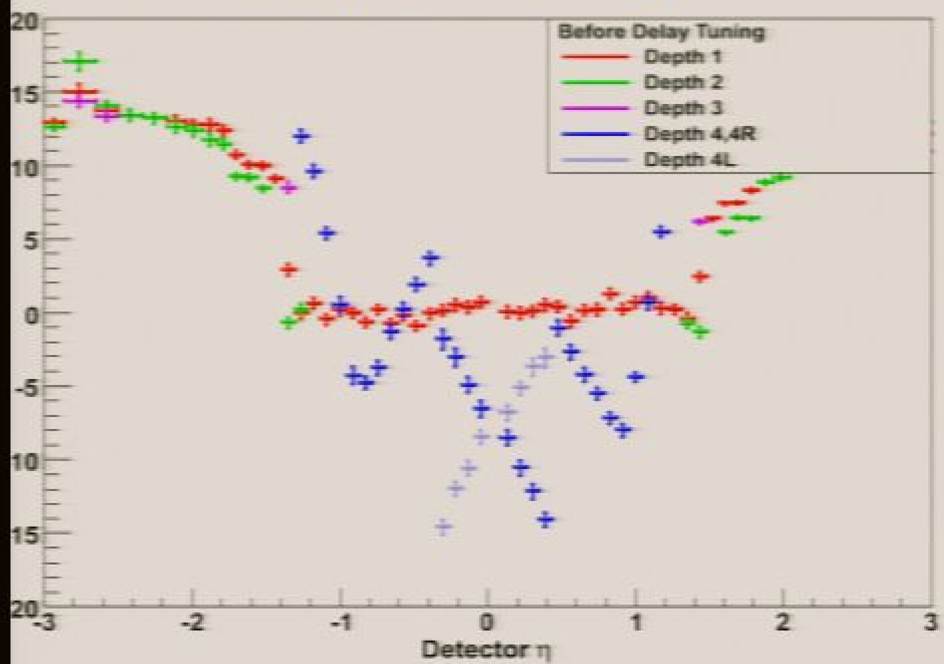






Tuning HCAL Timing with Beam Splash

ΔT Before Splash Tuning



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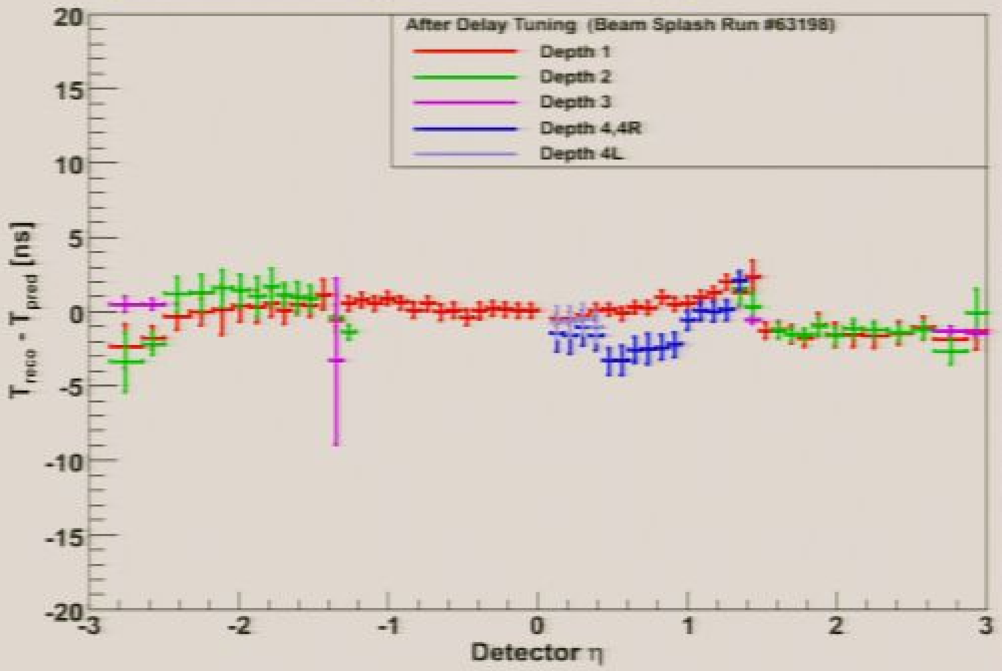
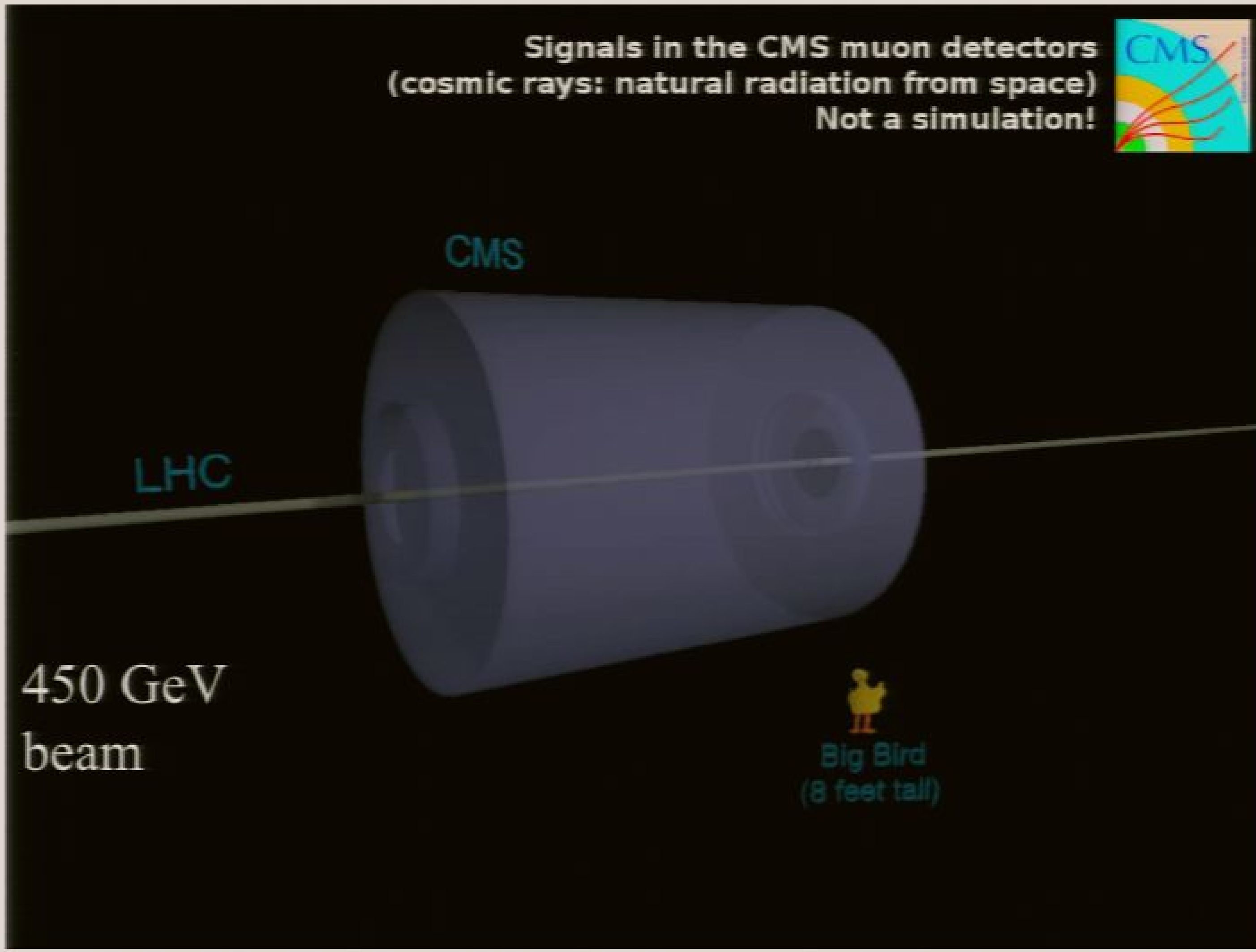


Time difference between predicted pulse arrival time and mean pulse arrival time for splash events, before and after using delays tuned from beam splash events.

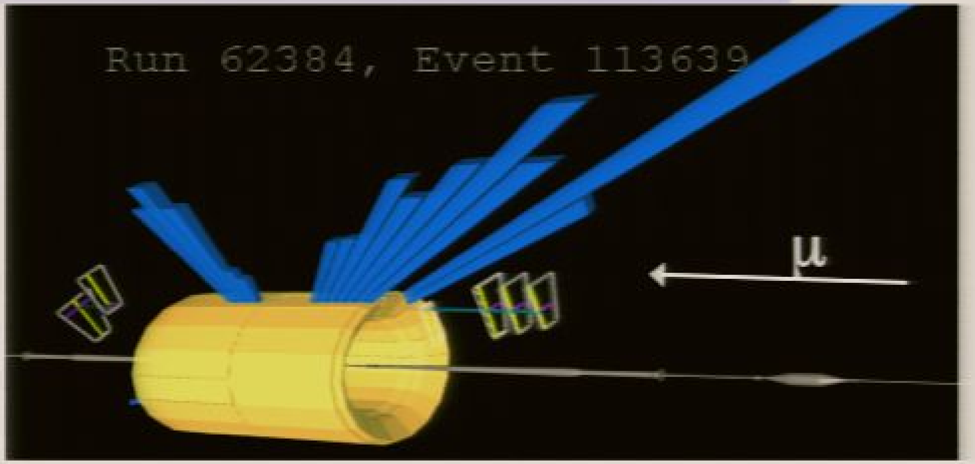
- Note that HCAL Barrel region was already tuned with prior data.
- HCAL now timed in at nanosecond scale

Beam halo events

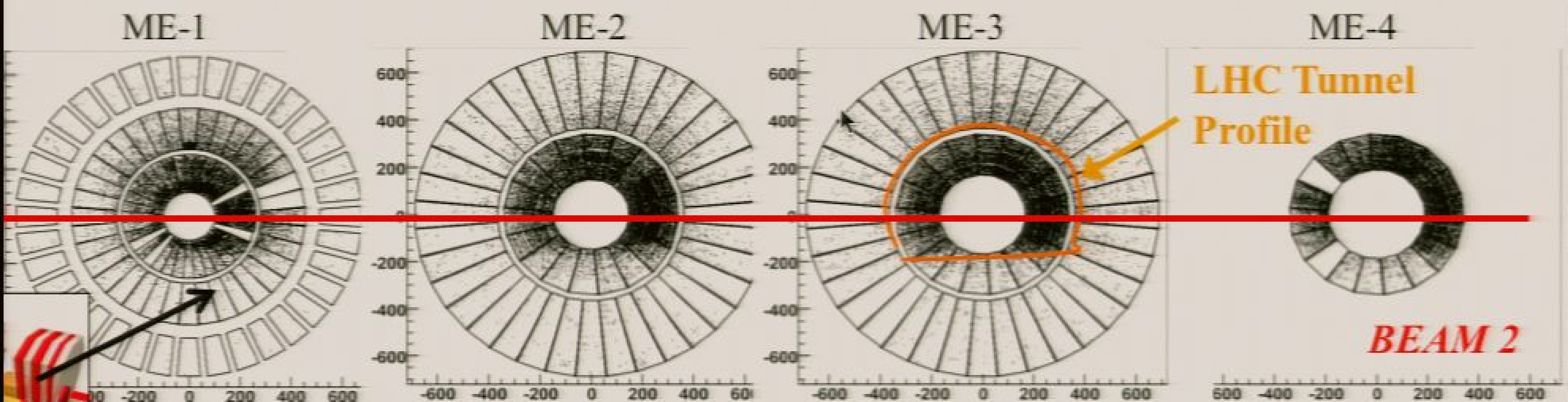


Beam Halo Muons

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



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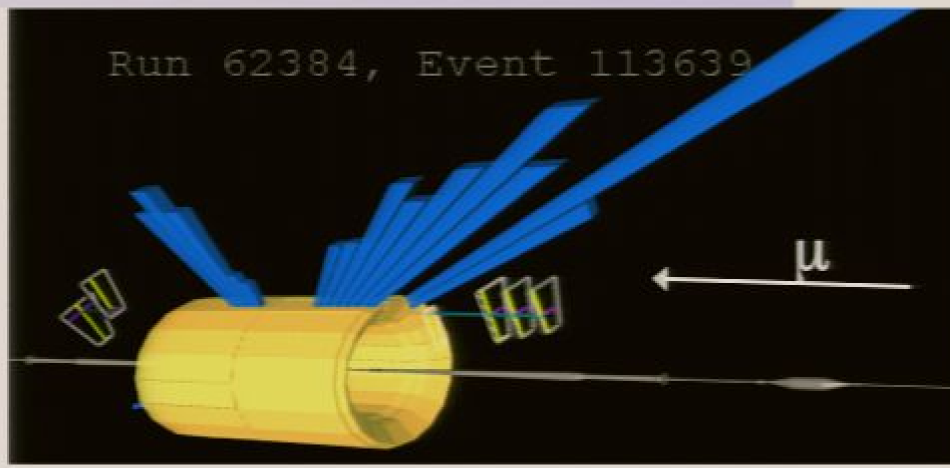

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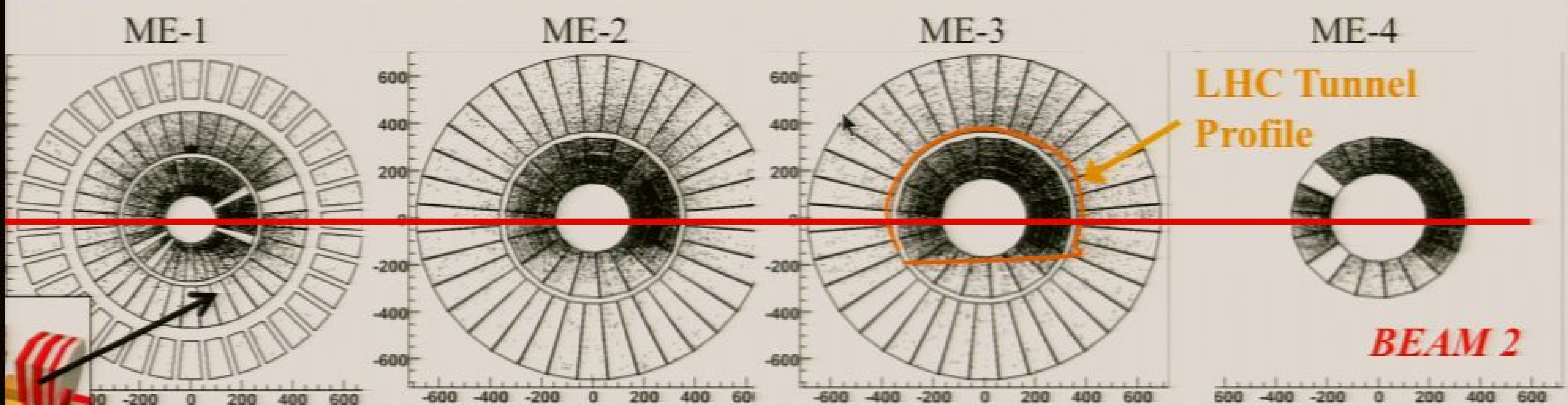

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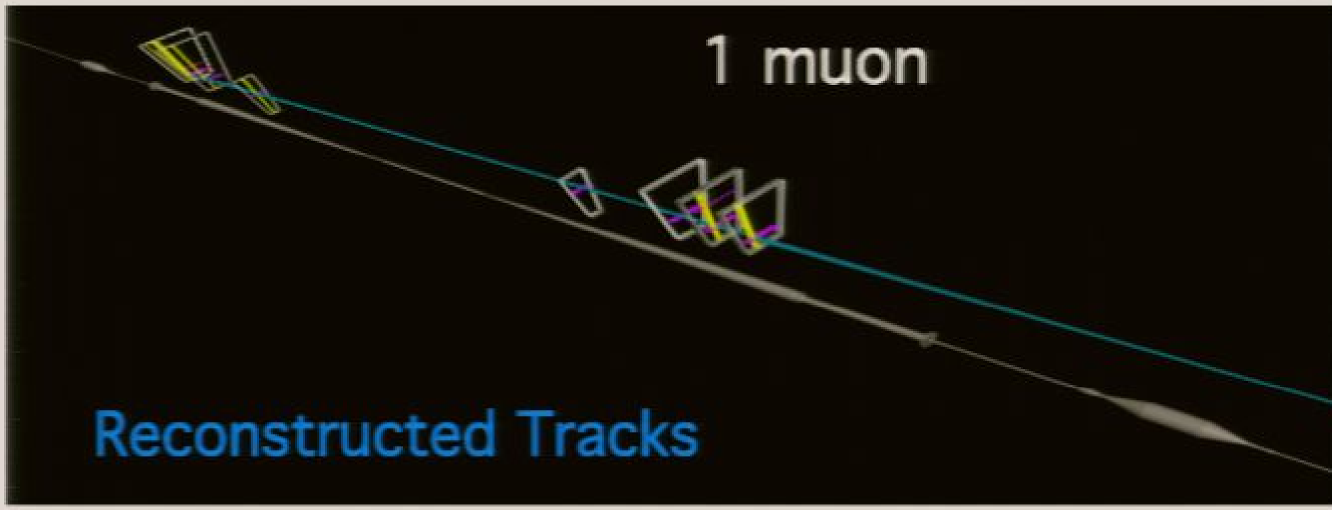
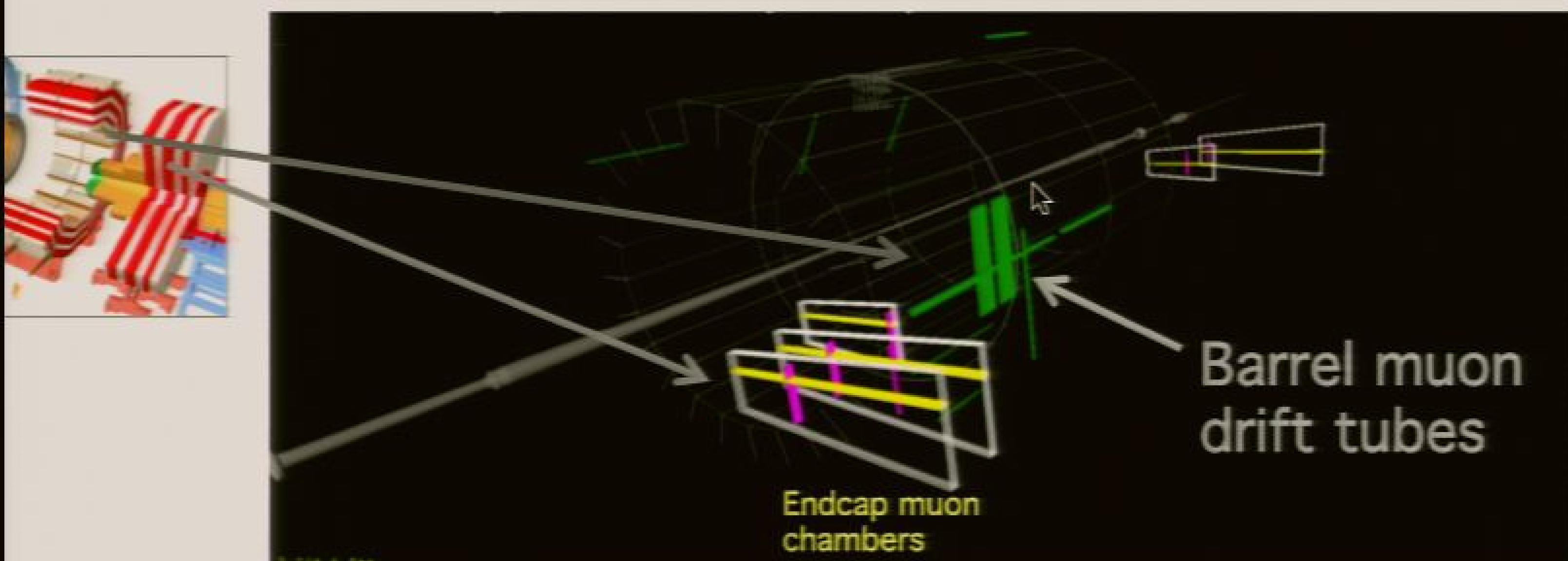
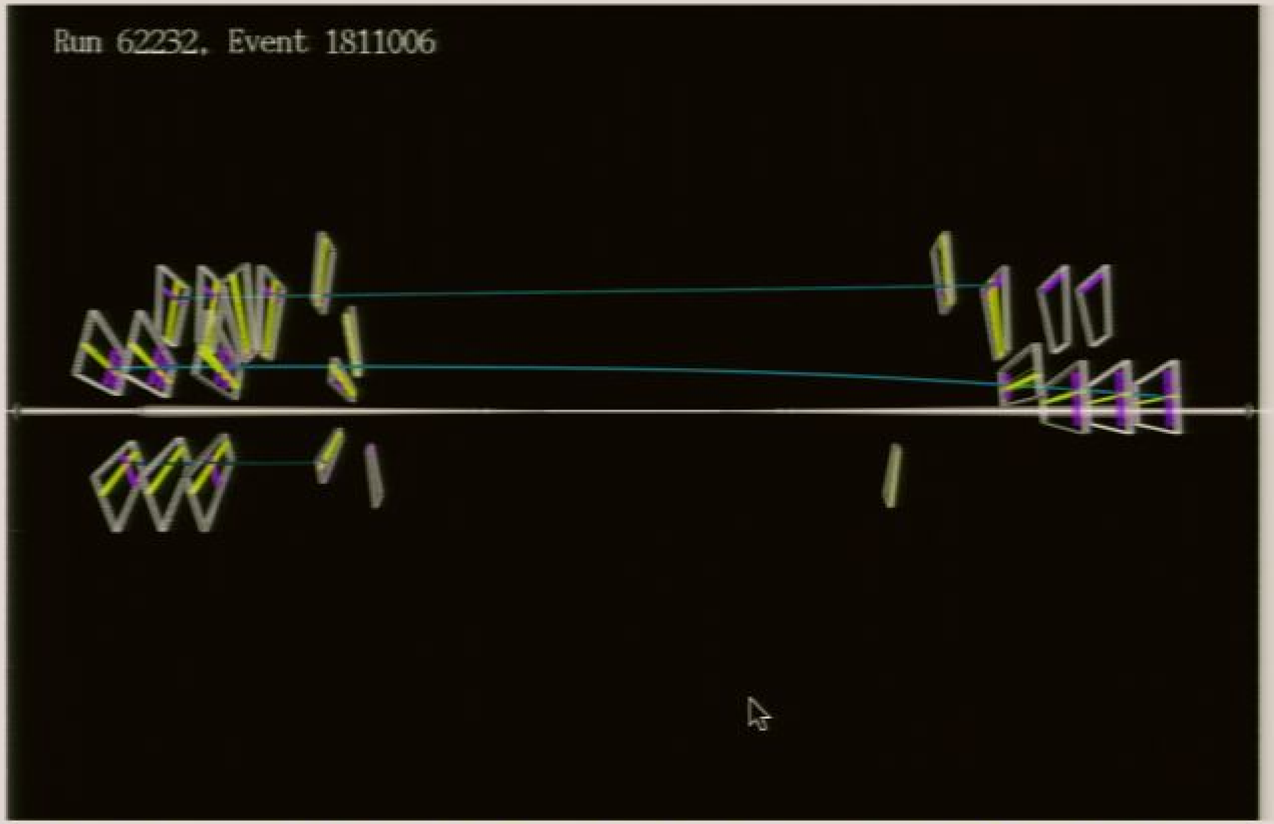


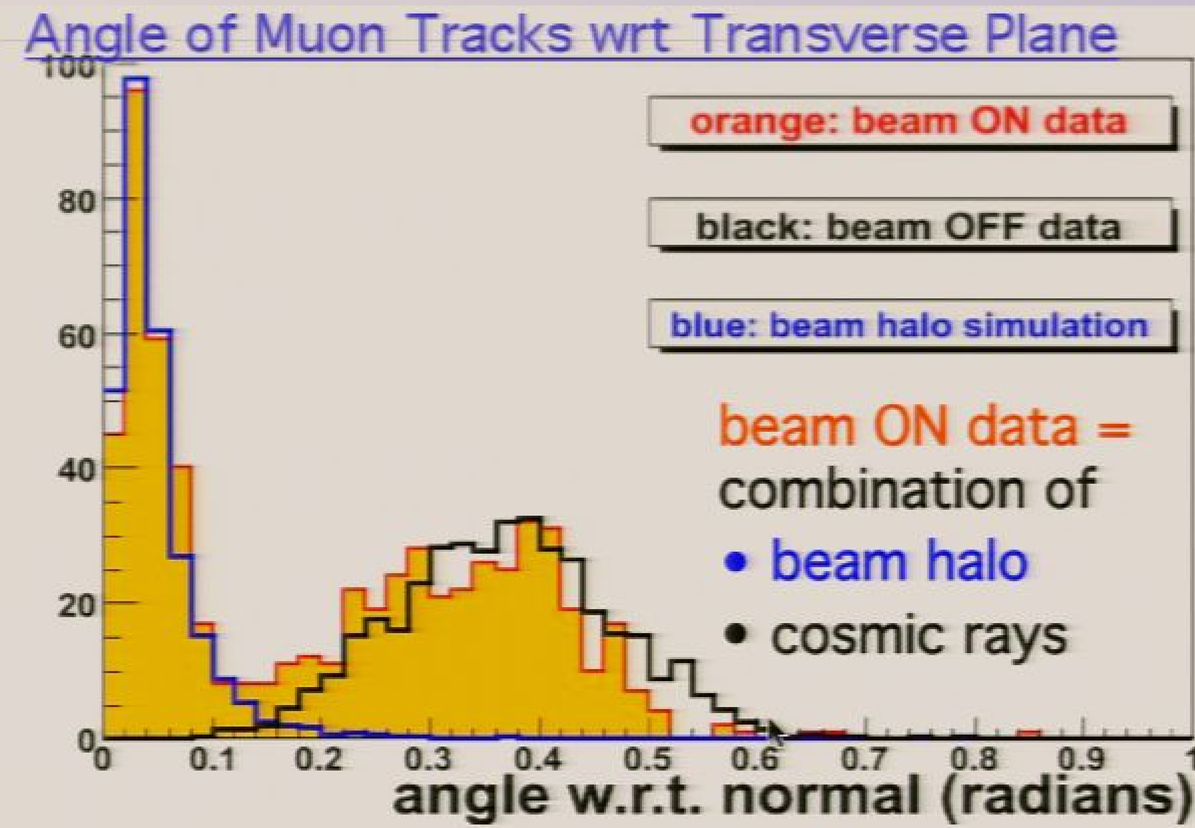


Beam Halo Muons Reconstructed in CSCs



- Three muons are reconstructed in the Cathode Strip Chambers (CSC's). The chambers with hits are shown as trapezoidal volumes in white, with yellow strips running in the radial direction, and purple wires running in the azimuthal direction. The long blue lines threading several chambers represent muon trajectories reconstructed offline. One line appears to be bent due to multiple scattering of the muon in the calorimeter.
- This particular beam halo / beam gas event is unusual in having three reconstructed muons; most events have one.

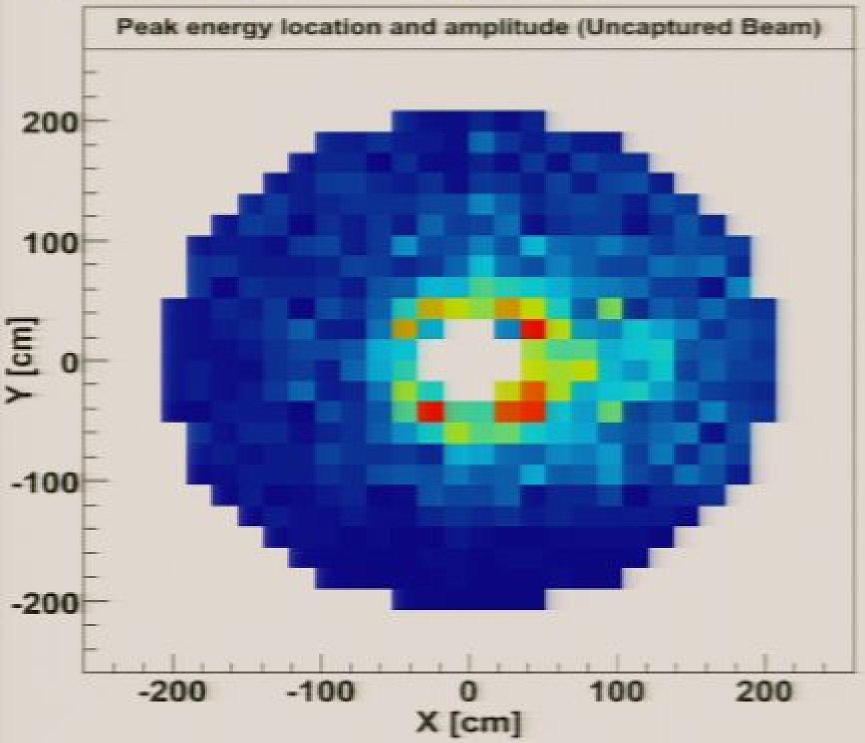
Halo and Cosmic Muon Angles



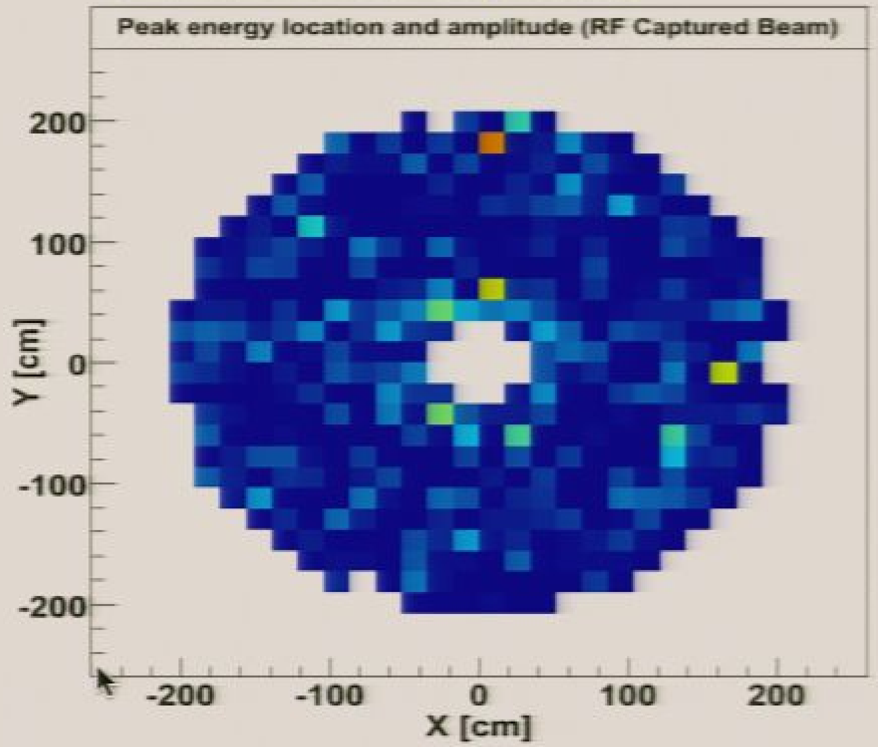
- Beam halo muons to make a small angle
- Cosmic Ray muons pass through the CSCs at a more oblique angle
- Beam-on distribution consists of two pieces, one resembling cosmic rays and the other matching the beam halo simulation.

HCAL Endcap Energy and Beam Capture

Before Beam Capture



After Beam Capture



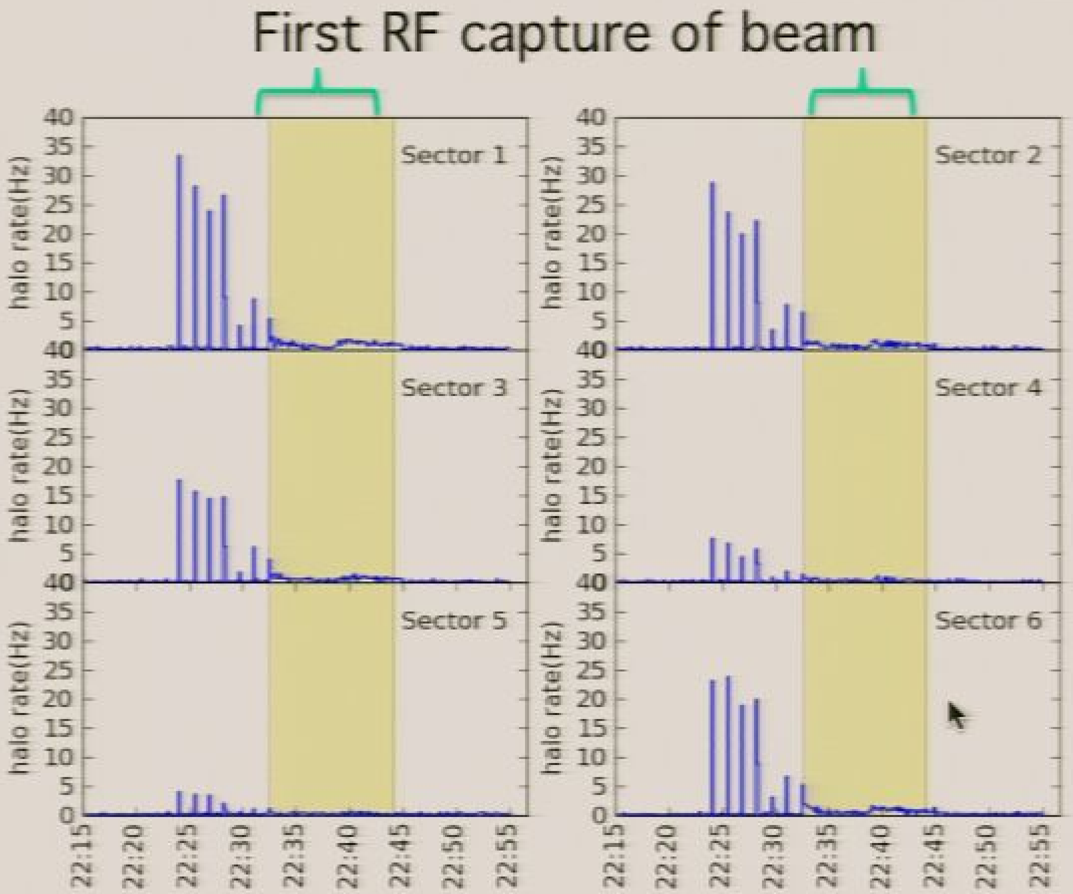
Capture: phase of the circulating beam Radio Frequancy cavities

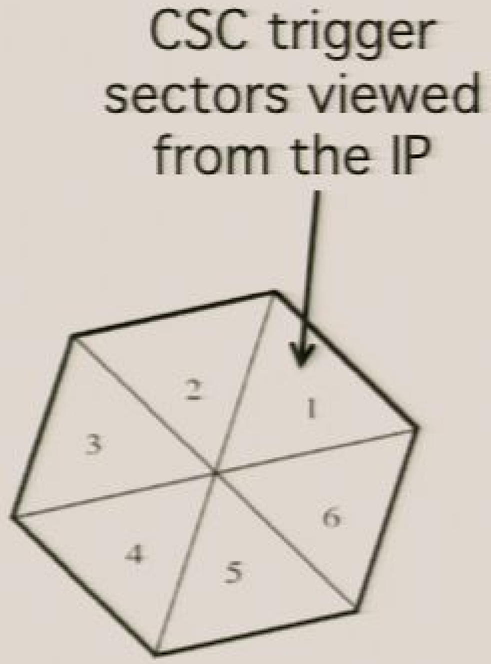
- Compensating for synchrotron radiation energy loss

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.

Beam Halo Rates in Muon Endcaps

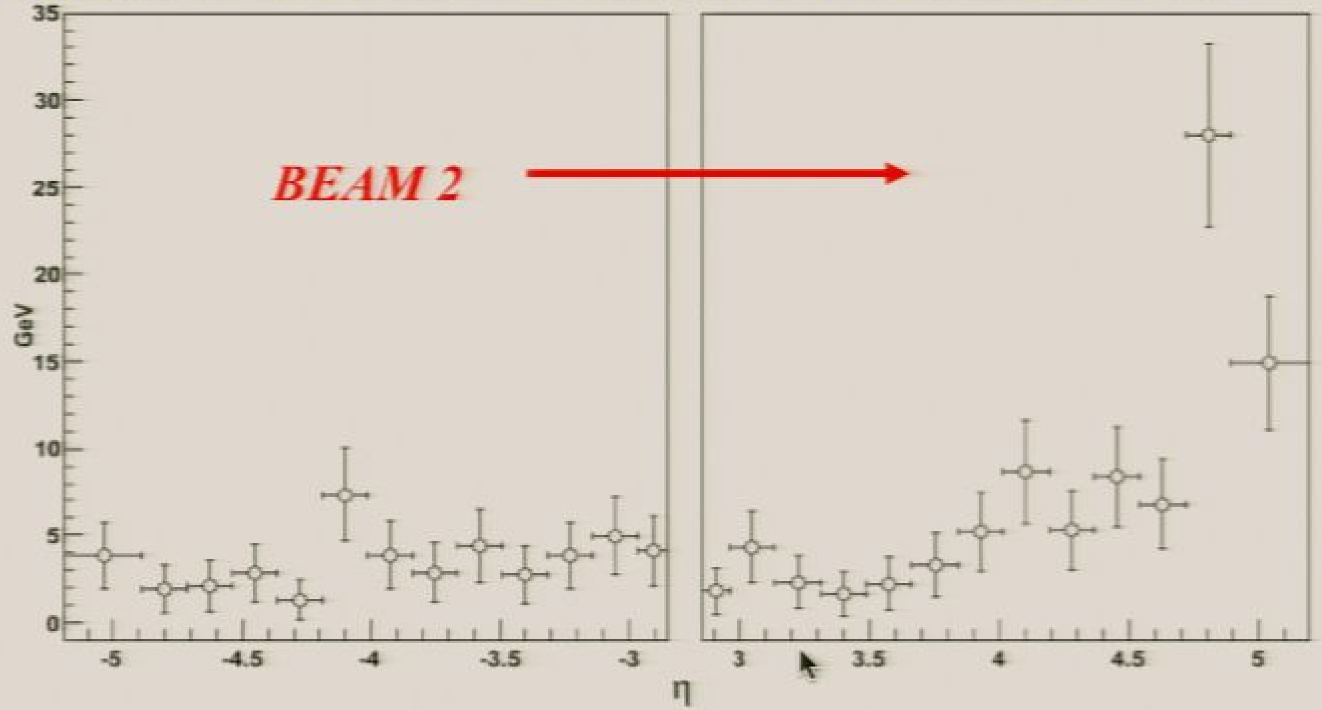




- CSC halo trigger rate in the minus endcap as a function of time.
- First successful capture lasted for 10 min and ended with beam abort
- One sees rate jumps preceding this due to earlier capture attempts.

Evidence for Beam Gas Collisions

Energy in the Forward Hadronic Calorimeter (HF)



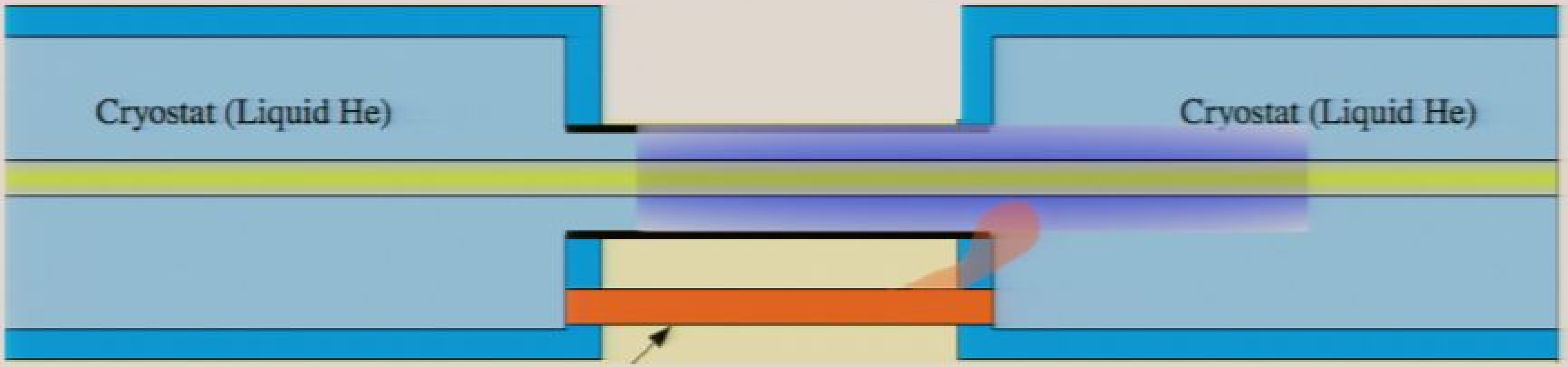
- Average energy as a function of eta in HF for circulating beam 2
- Events triggered by HF
- Peak in energy towards positive pseudo-rapidity is a signature of beam-gas interactions near or within the detector; the remnants of beam-gas interactions will have small p_T and larger p_L from the initiating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

September 10-19th

- In a few days the beam group had done ***marvellous*** progress:
  - Both beams injected
  - Splashes provided to the experiments
  - Both beams circulated for several hundreds turns
  - RF locking
- The magnet circuits in the seven other sectors of the LHC had been fully commissioned to their nominal currents (***9.3*** kA, corresponding to beam energy of 5.5 TeV) before the first beam injection on 10 September 2008
- Only sector 3-4 was left.
- While replacing a power converter (which took few days), commissioning of sector 3-4 was re-scheduled before the first collisions at sqrt(s) = 900 GeV/c^2

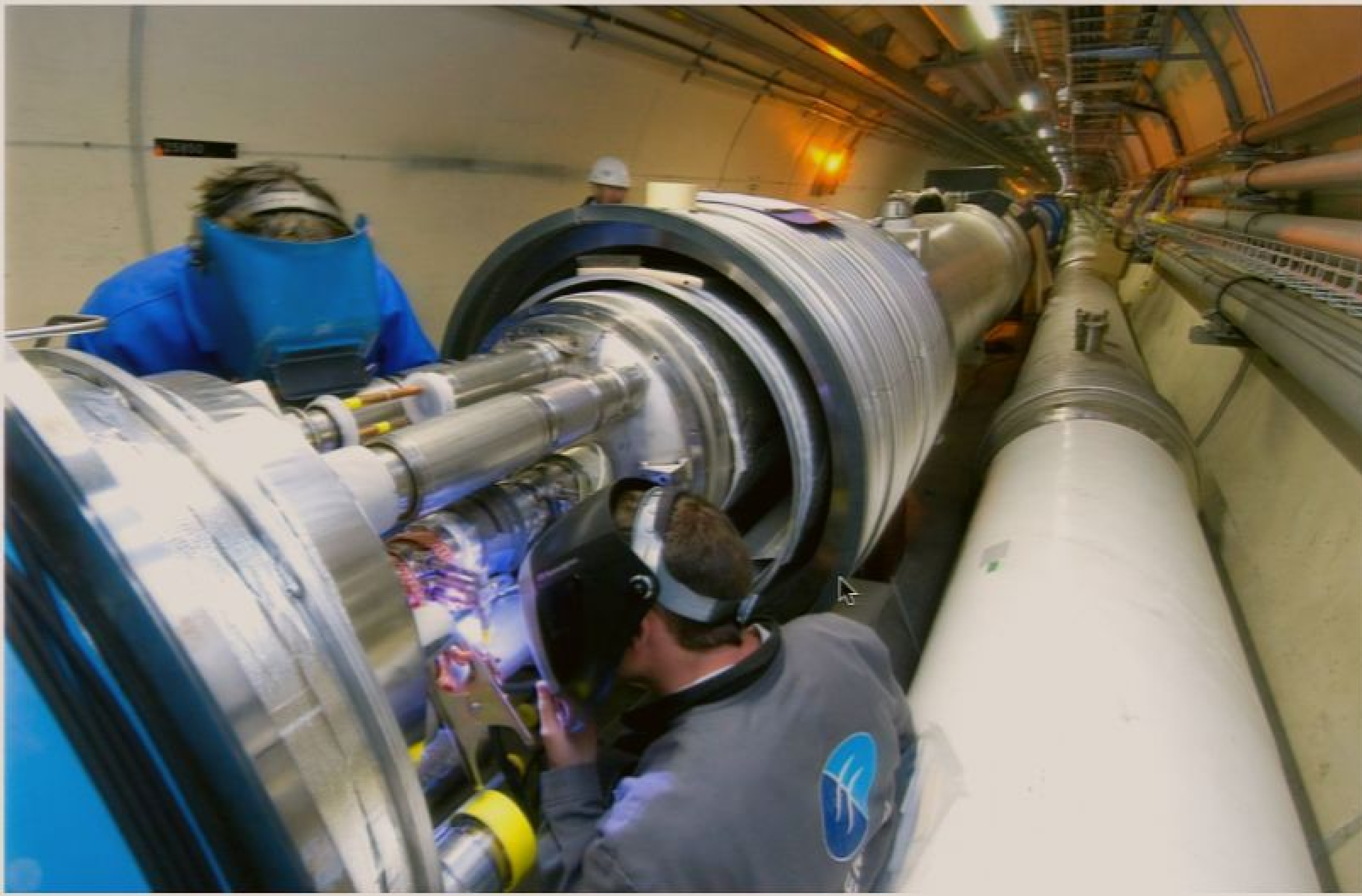
September 19th, 11:18:36 CEST

Sequence of events

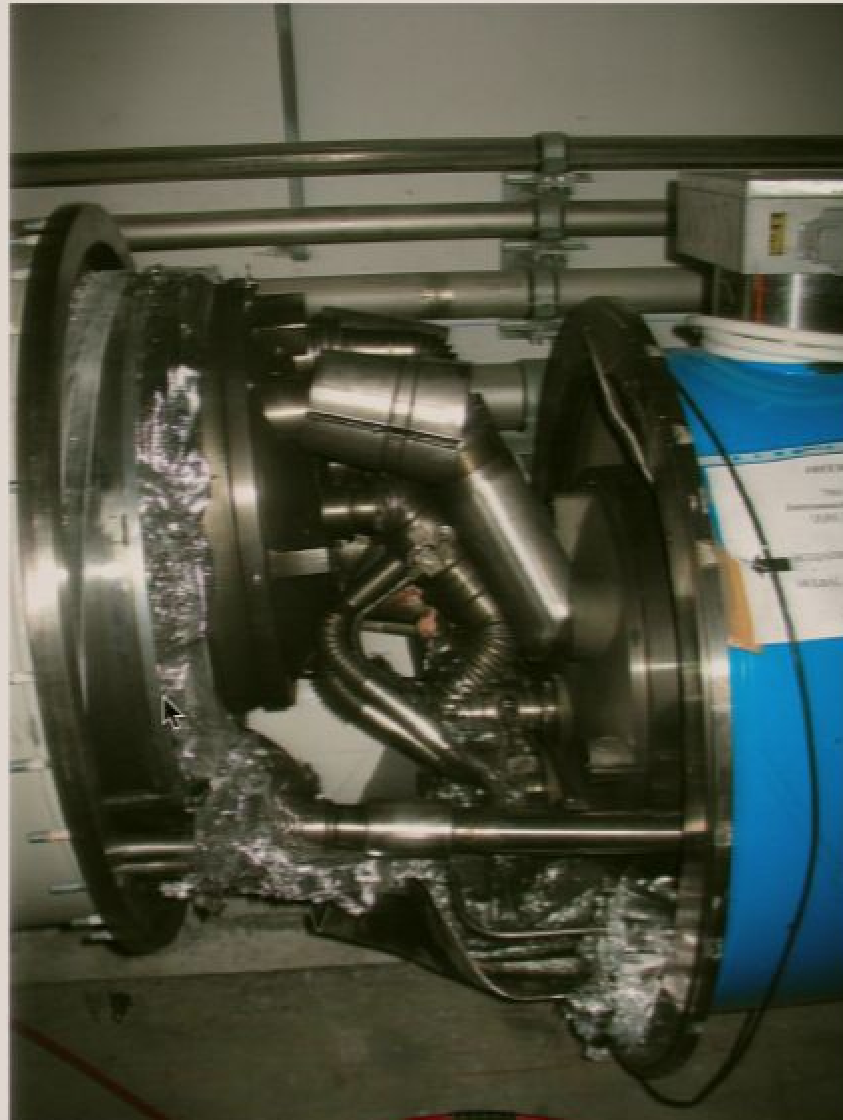


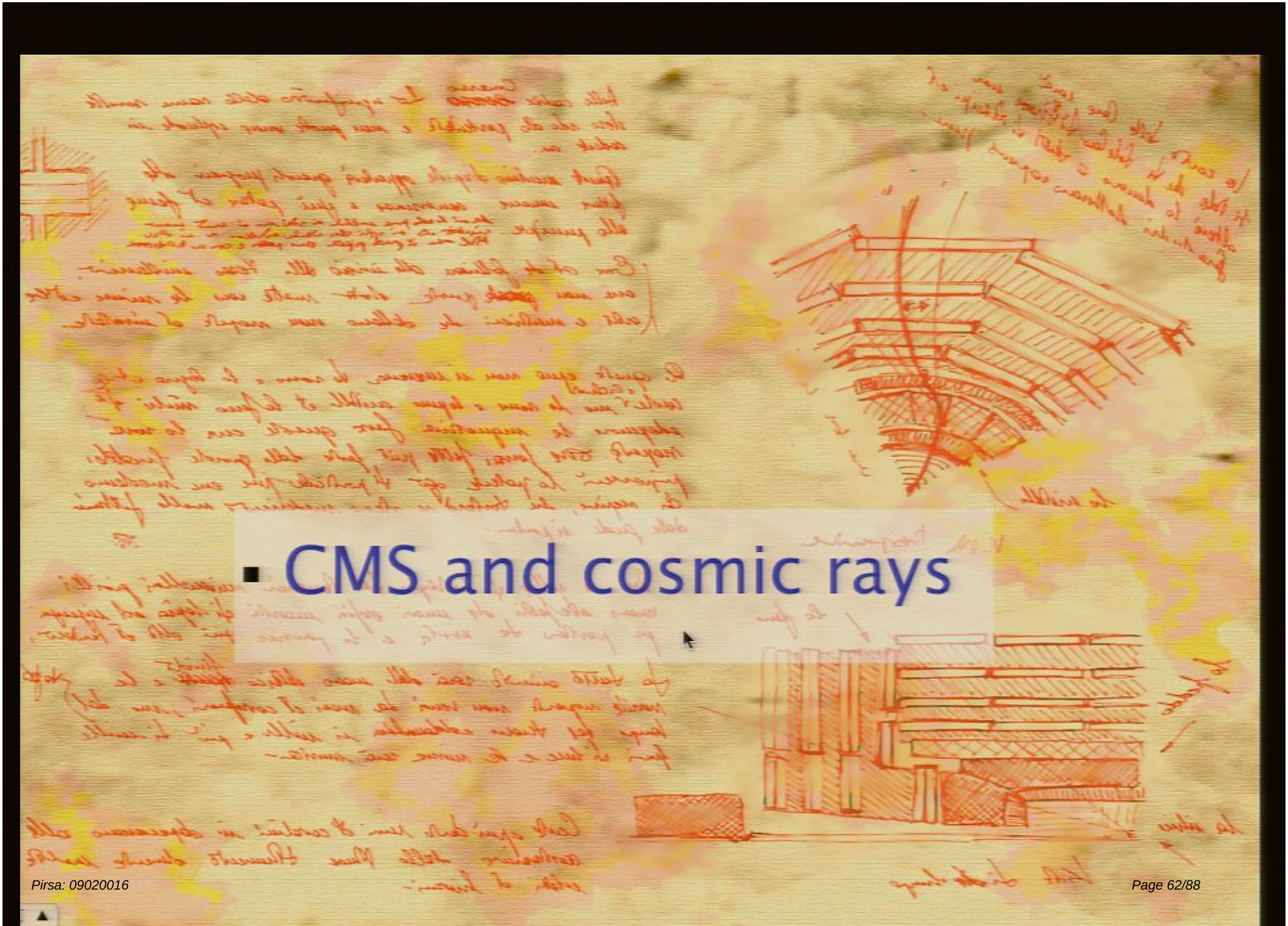
- Splice becomes highly resistive with *8.7 kA* of current flowing through it
- Local heating causes the splice to melt explosively, ejecting molten metal which punctures the cryostat
- The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus relieving the helium to the tunnel. They were however unable to contain the pressure rise below the nominal 0.15 MPa absolute in the vacuum enclosures of subsector 23-25, thus resulting in large pressure forces acting on the vacuum barriers separating neighboring subsectors
- Rapid heating and expansion of the liquid helium creates a shockwave

Dipoles



The most displaced dipoles

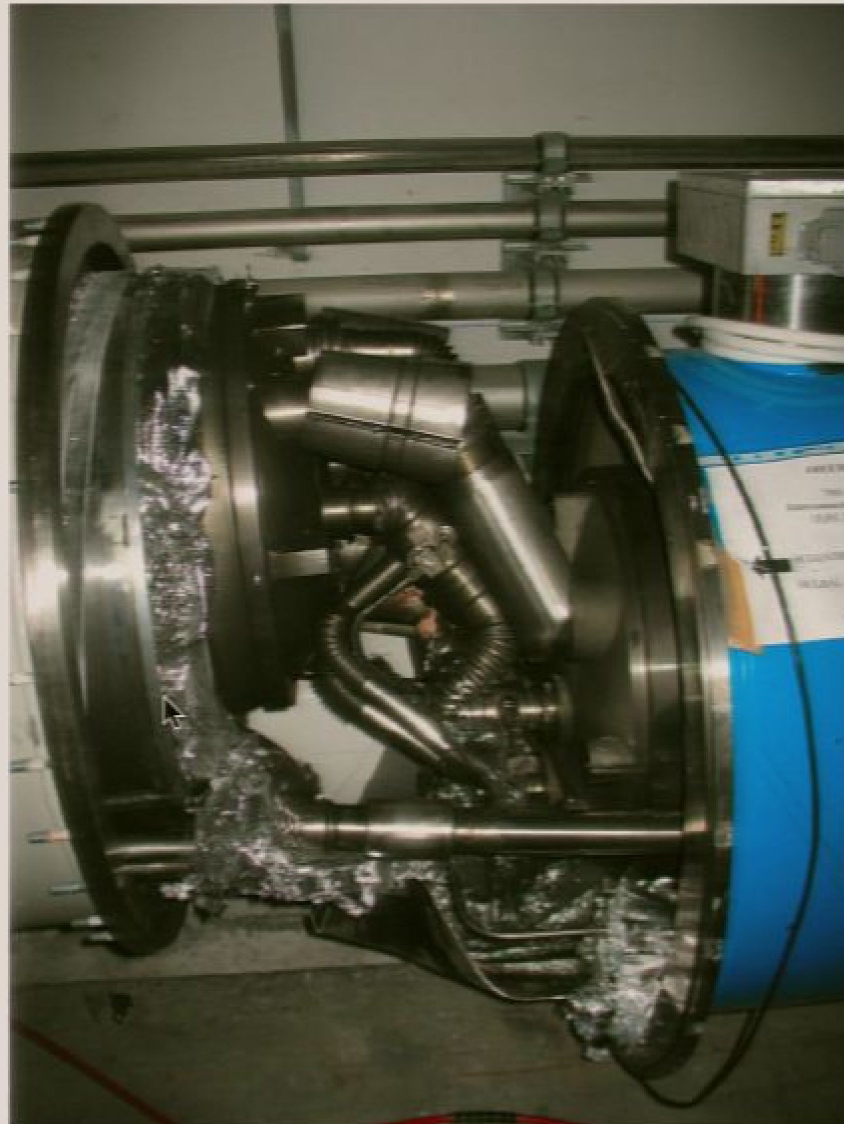



CMS and cosmic rays

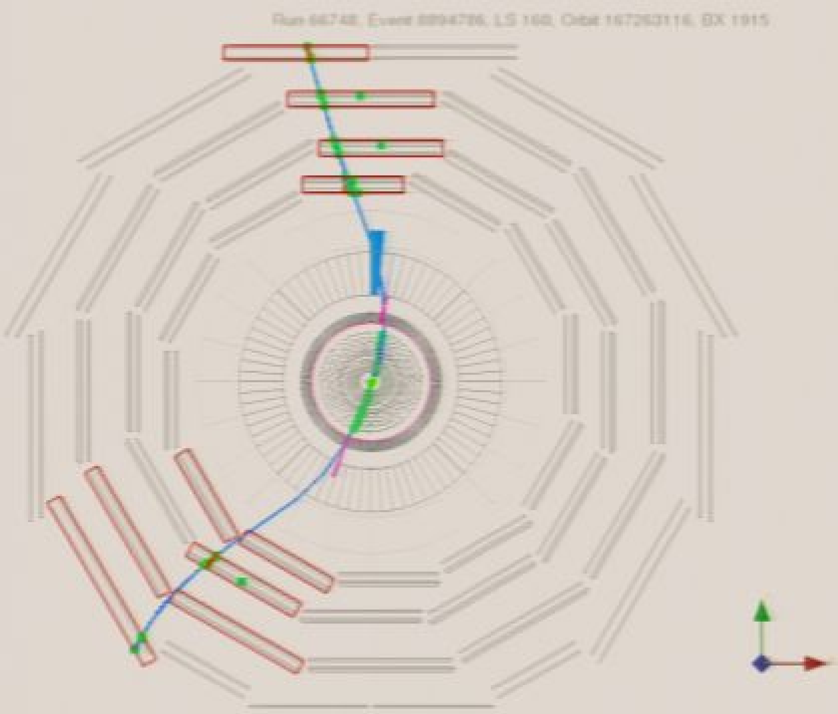
What do we do after Septermber

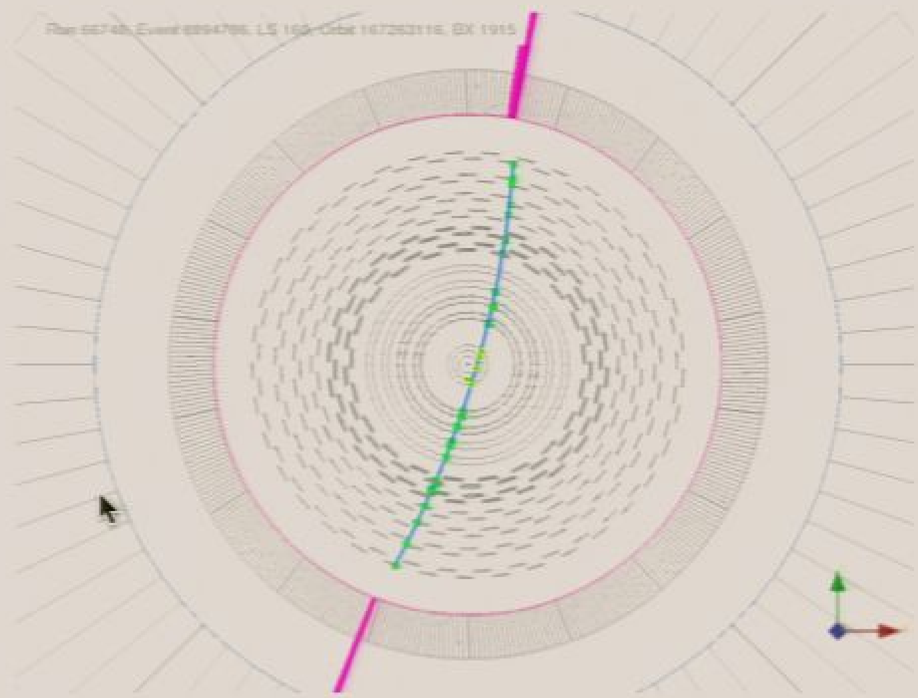
- Though the detector was ready for collisions, plenty of aspects could still be improved / solidified by running for extended amount of time in presence of magnetic field
- So we did: one month of cosmic rays data taking at 3.8T

The most displaced dipoles



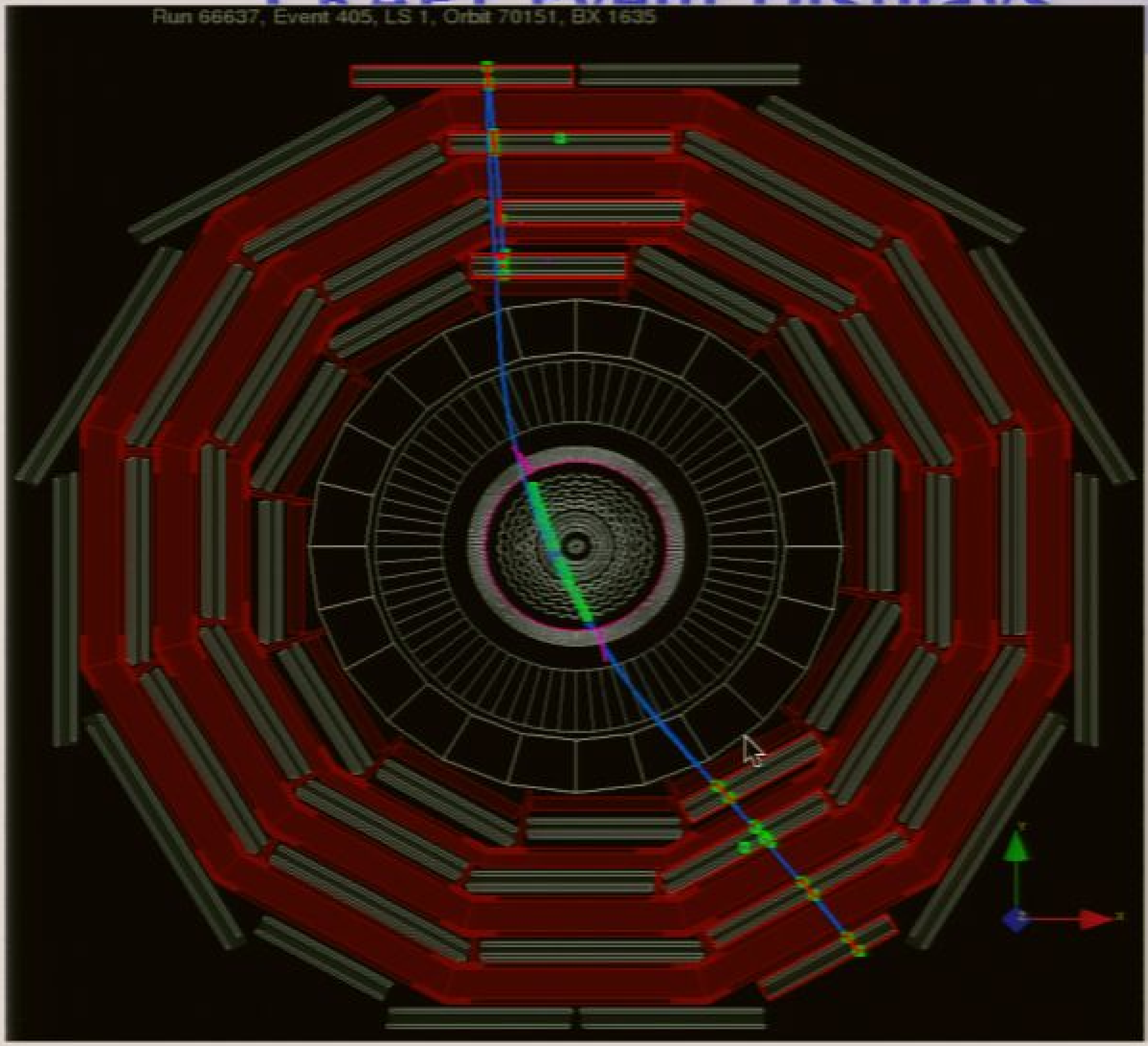
Traversing Pixel Detector





- ECAL in magenta, HCAL in blue, tracker and muon hits in green

CRAFT Event Displays



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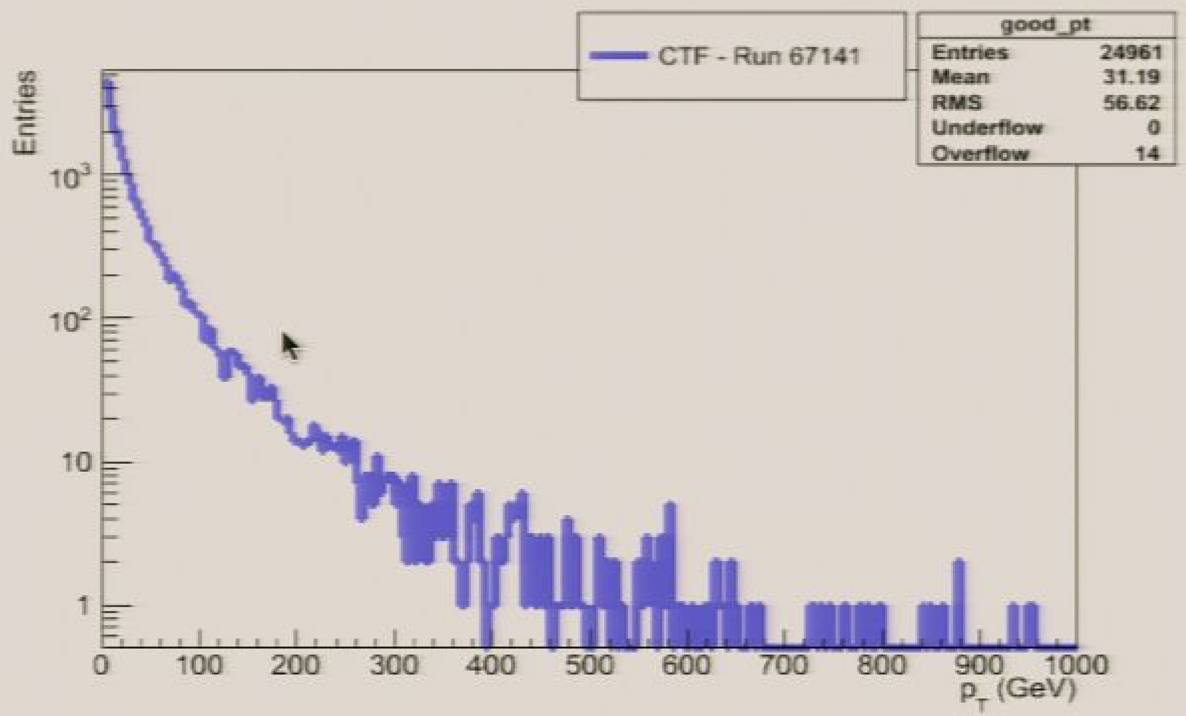
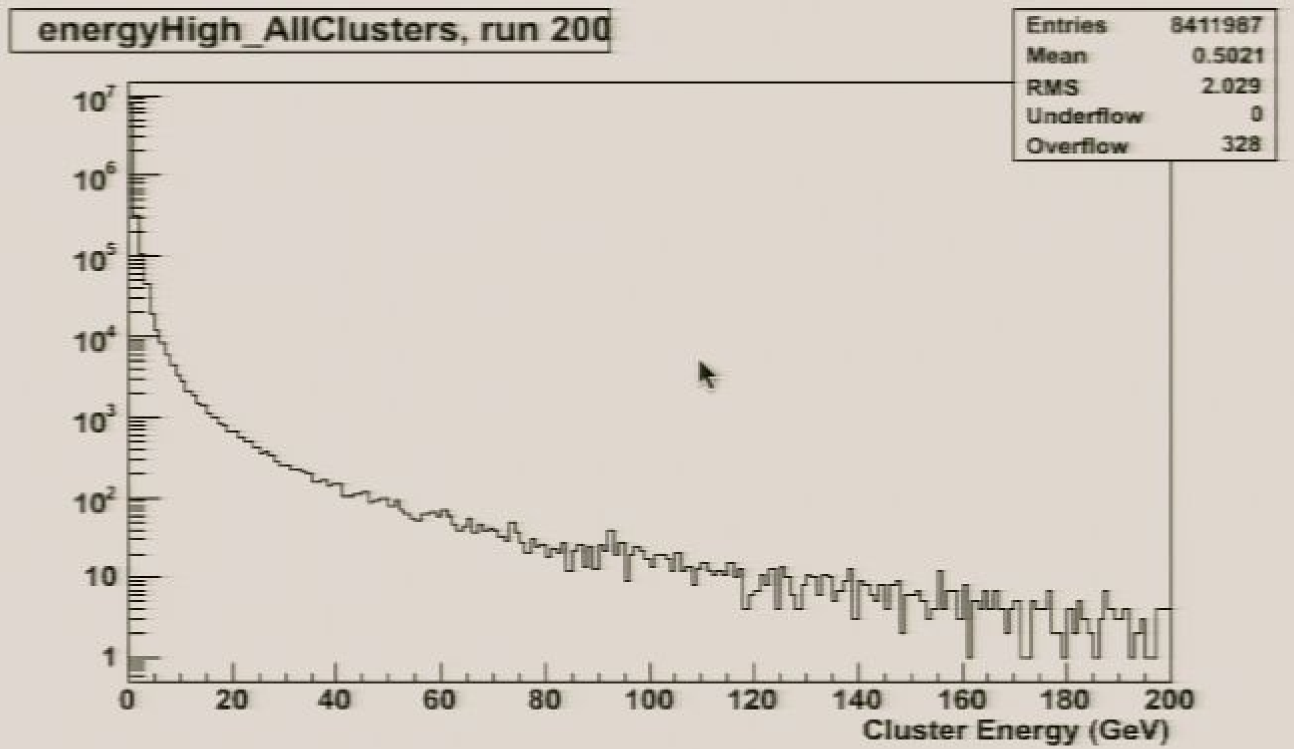
Cosmic Tracking using Tracker

- 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 distributior statistics)
  - 8 hits
  - 1 hit in TIB L1/L2
  - 1 hit in TOB L5/L6
  - ~70K tracks expected out of full CRAFT statisti with P_T>100 GeV



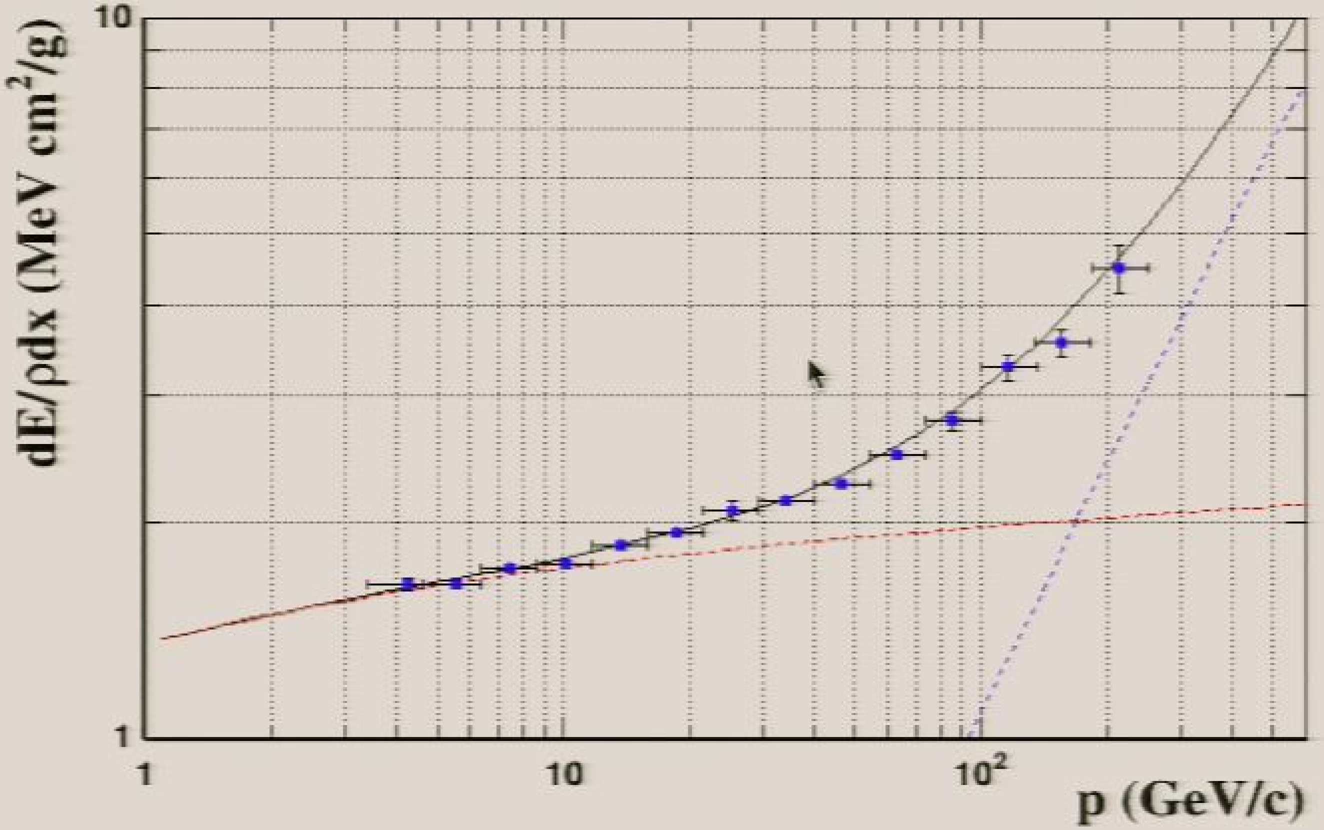
Energy spectrum

The figure shows the spectrum of energy deposits in the ECAL barrel in cosmic muon runs with the magnetic field at 3.8T and the APD gain set to 200 (x4 the LHC conditions). Clusters are seeded either from a single crystal above 15 ADC counts (≈130 MeV) or from two adjacent crystals above 5 ADC counts (≈2x43 MeV). Energy is obtained summing the energies of all the crystals belonging to a cluster.

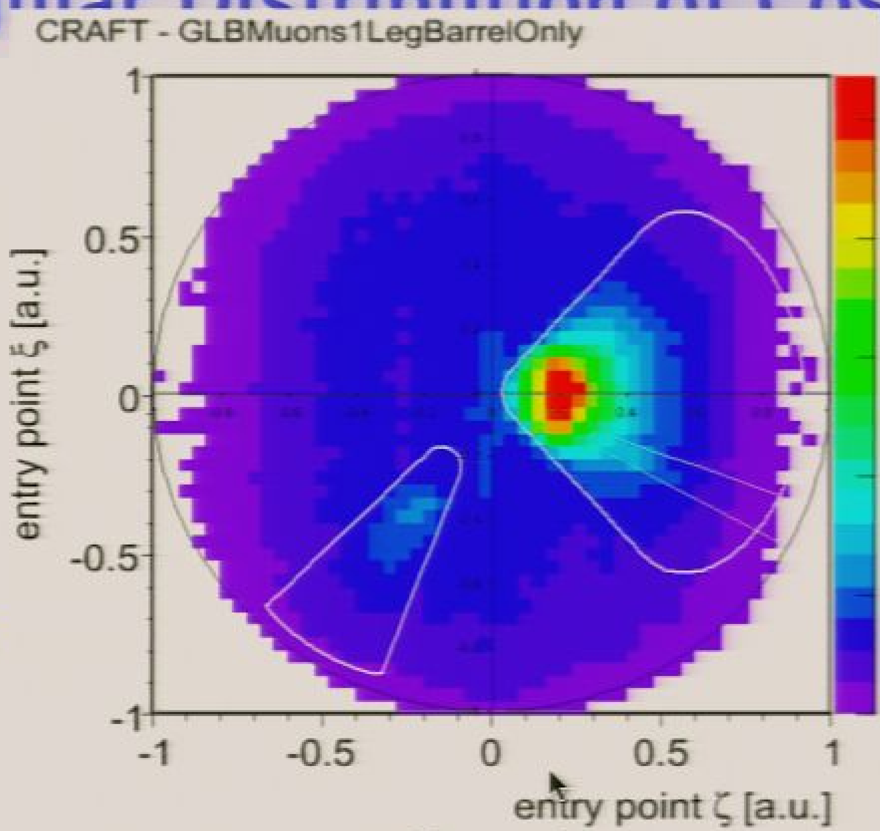


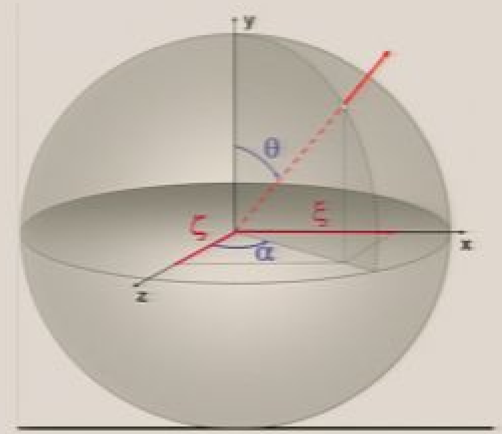
Stopping power

The figure shows the stopping power of cosmic muons traversing ECAL as a function of the muon momentum as measured in the tracker. In ECAL the energy deposit is measured by the cluster energy matched to the track; the track length is estimated from track propagation inside ECAL crystals. Loose selection on the distance of closest approach of the track to the centre of CMS is applied. Experimental data (dots) are compared to the total stopping power ($dE/\rho dx$) in $PbWO_4$ (black continuous line). The dashed lines are the contributions due to collision loss (red) and bremsstrahlung radiation (blue). Data are displayed in the momentum range where sufficient number of events survive the selections. Errors on the vertical scale are statistical only; error bars on the momentum represent the bin width.
Results indicate the correctness of the tracker momentum scale and of the energy scale in ECAL calibrated with electron at test beams.

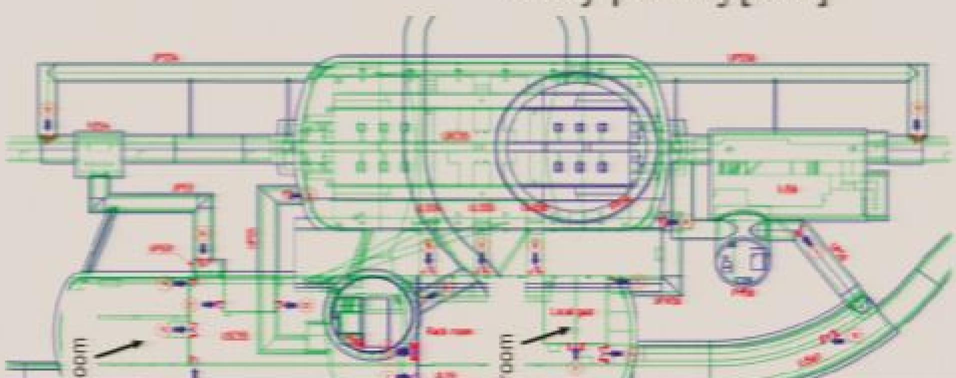


Angular Distribution of Cosmics



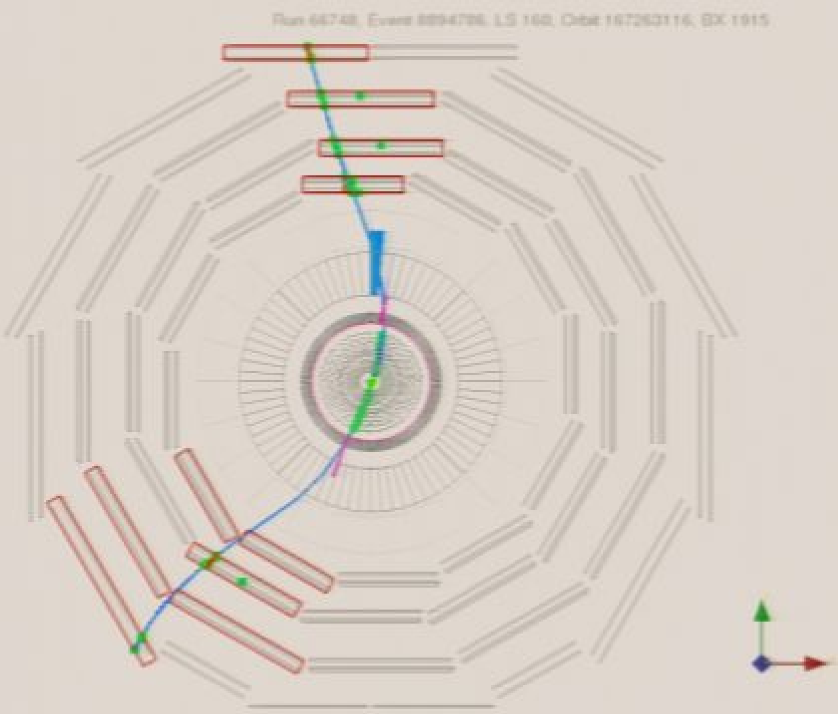


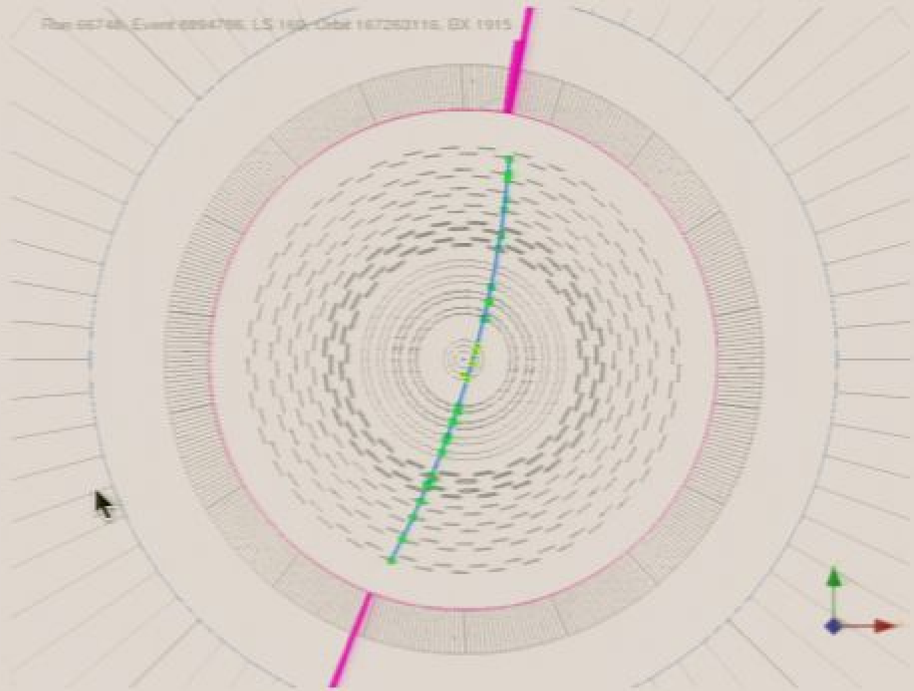
Reconstructed angles of cosmic rays indicate increased acceptance through the 3 access shafts of CMS



- n.b. CMS is

Traversing Pixel Detector





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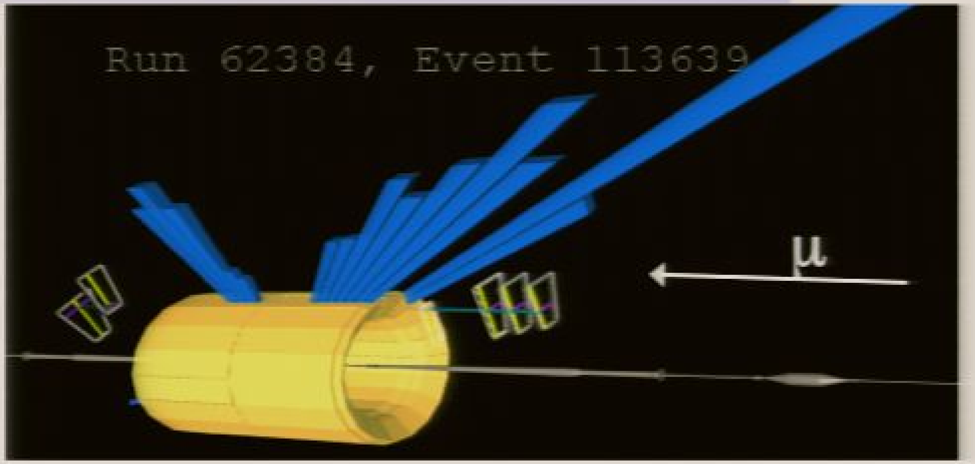
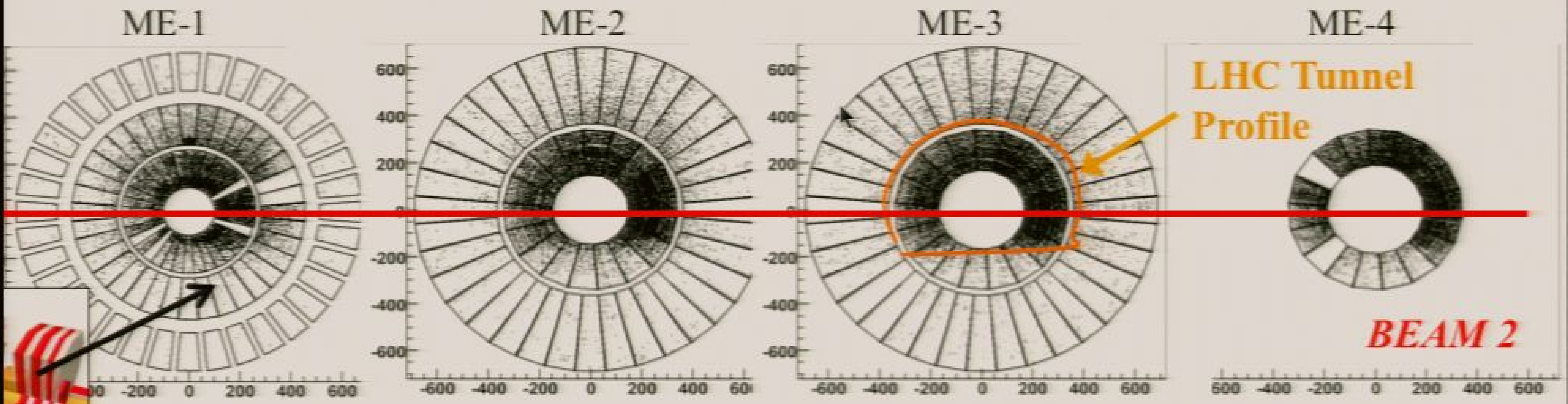


CSC Hit Distribution from Beam Halo Events



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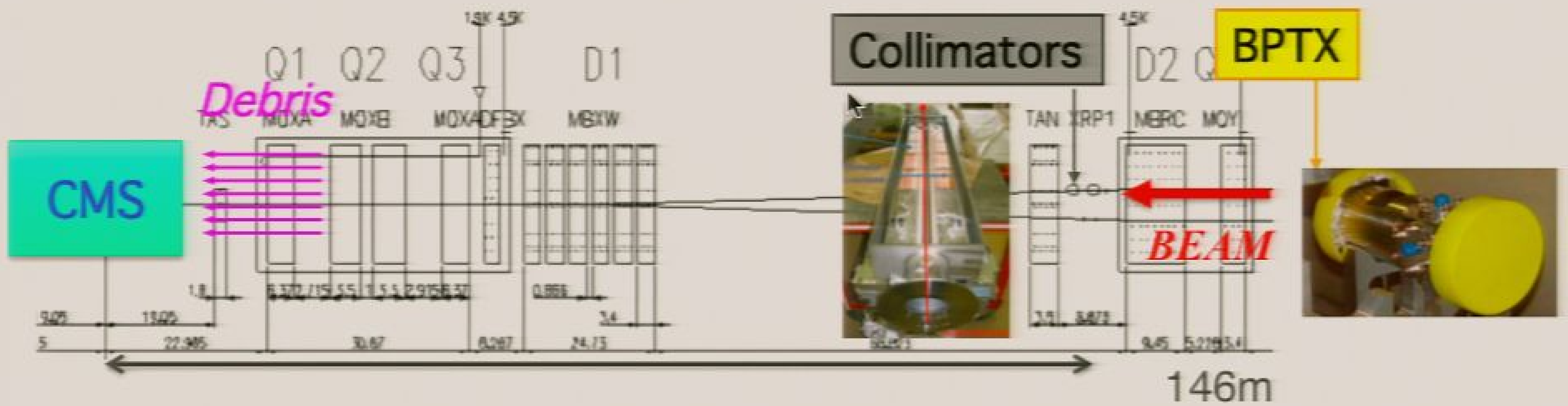
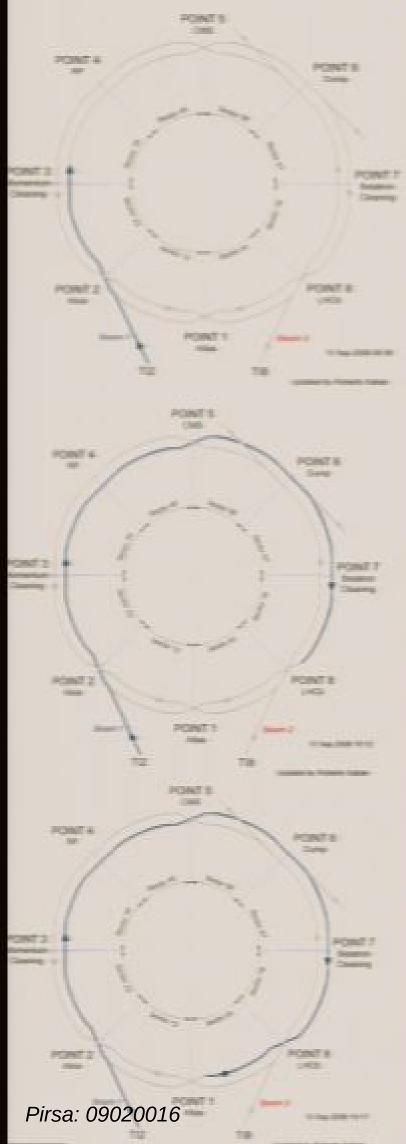
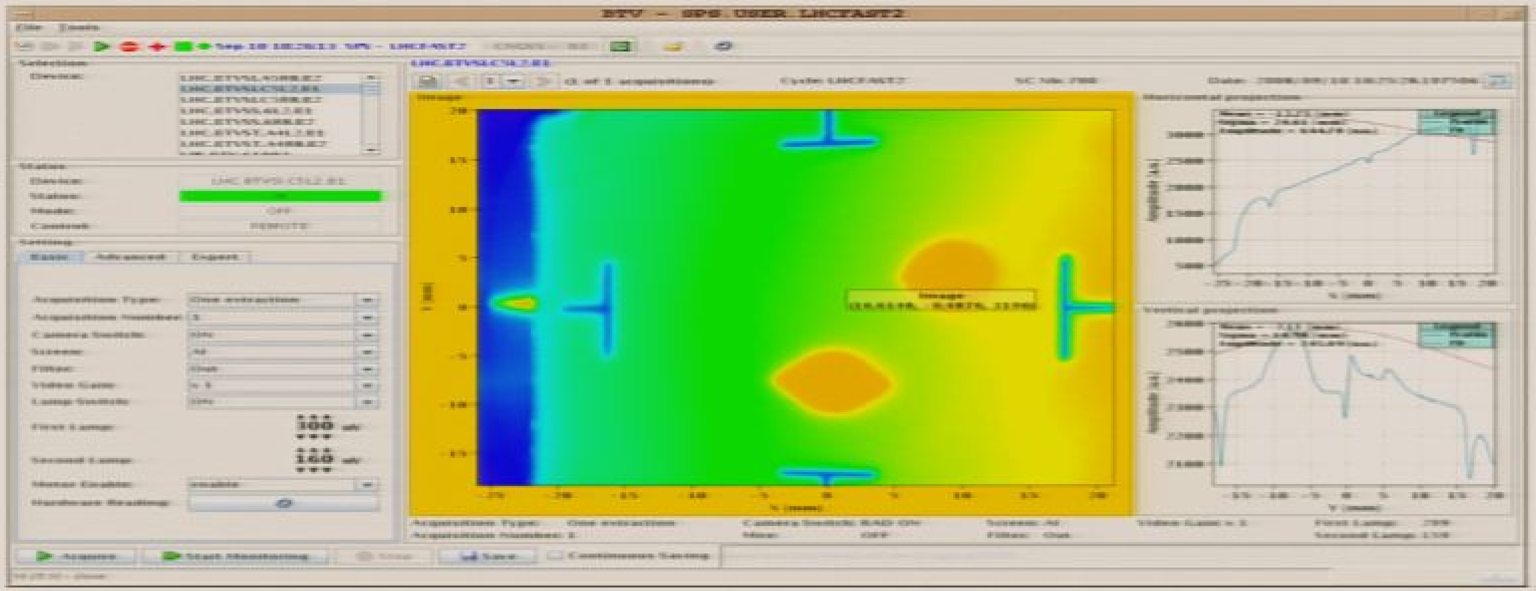
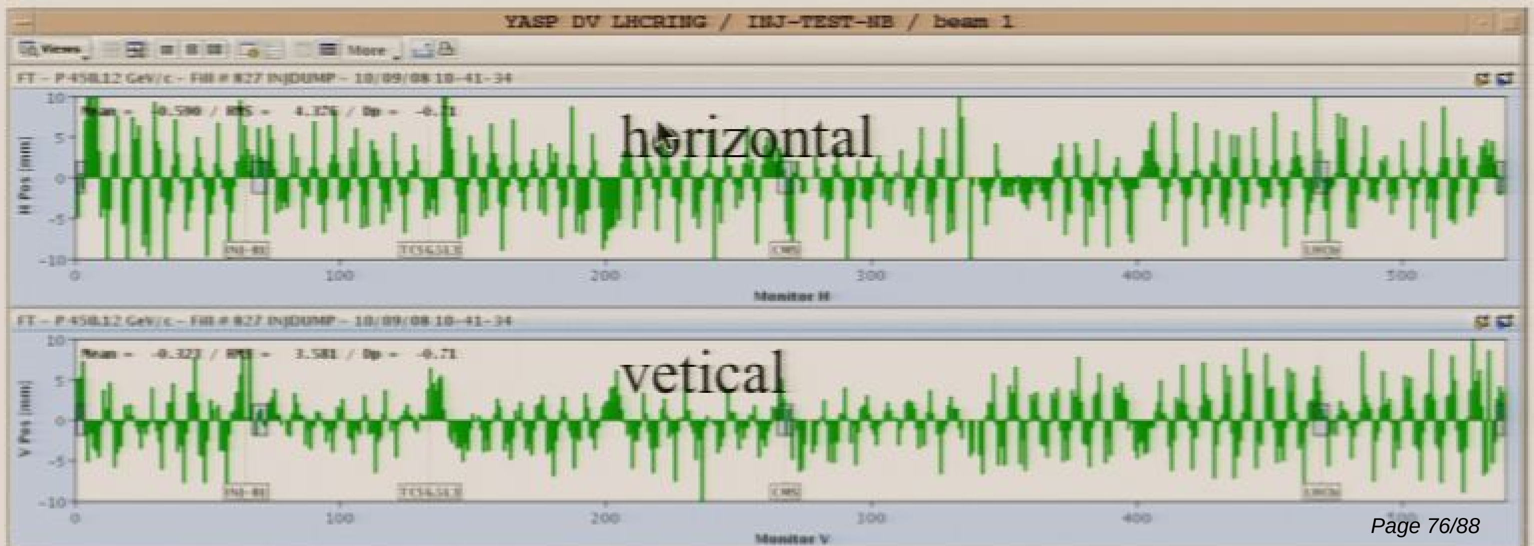


Pirsa: 09020016

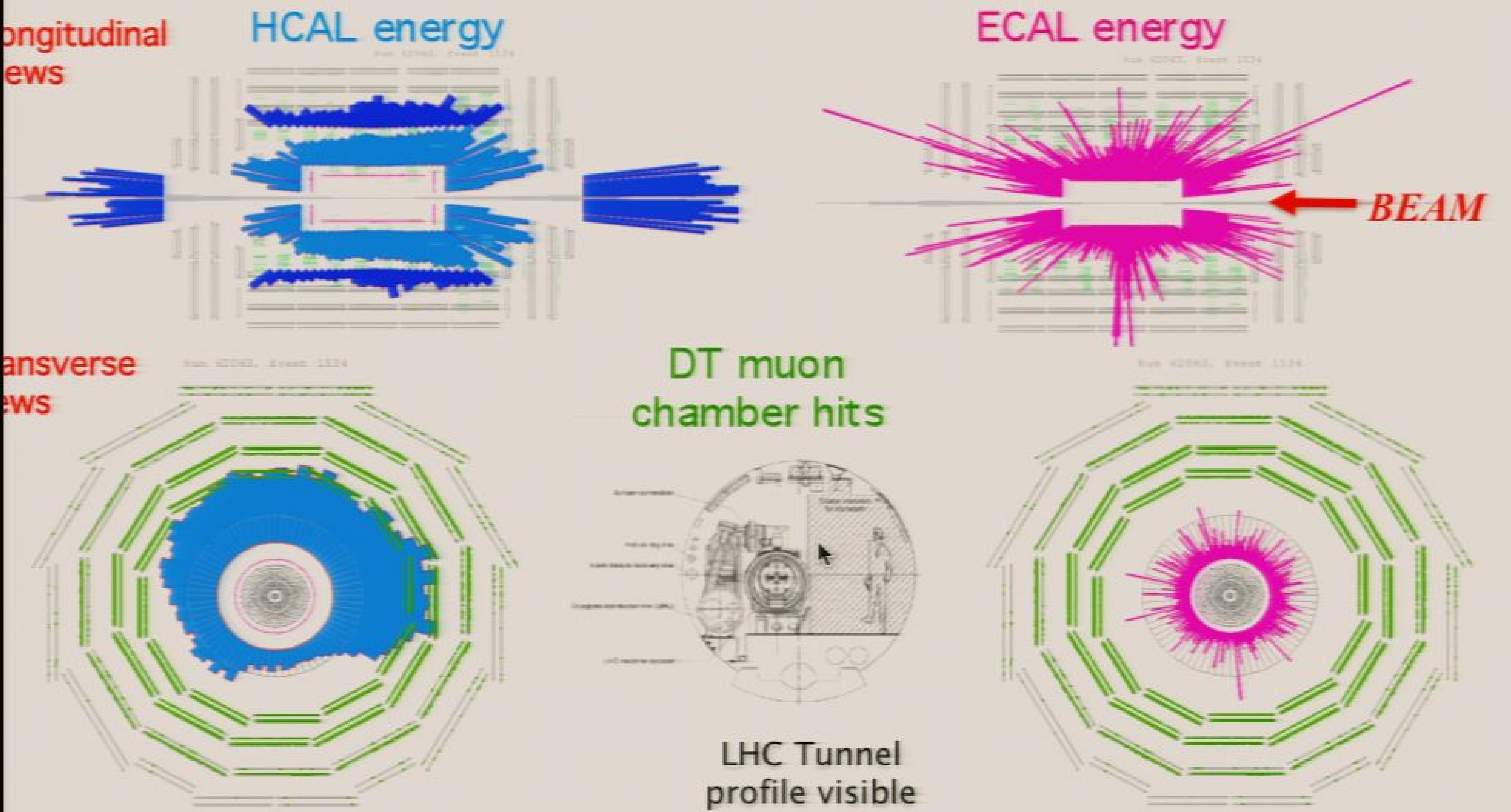
Sept 10th: beams find their way



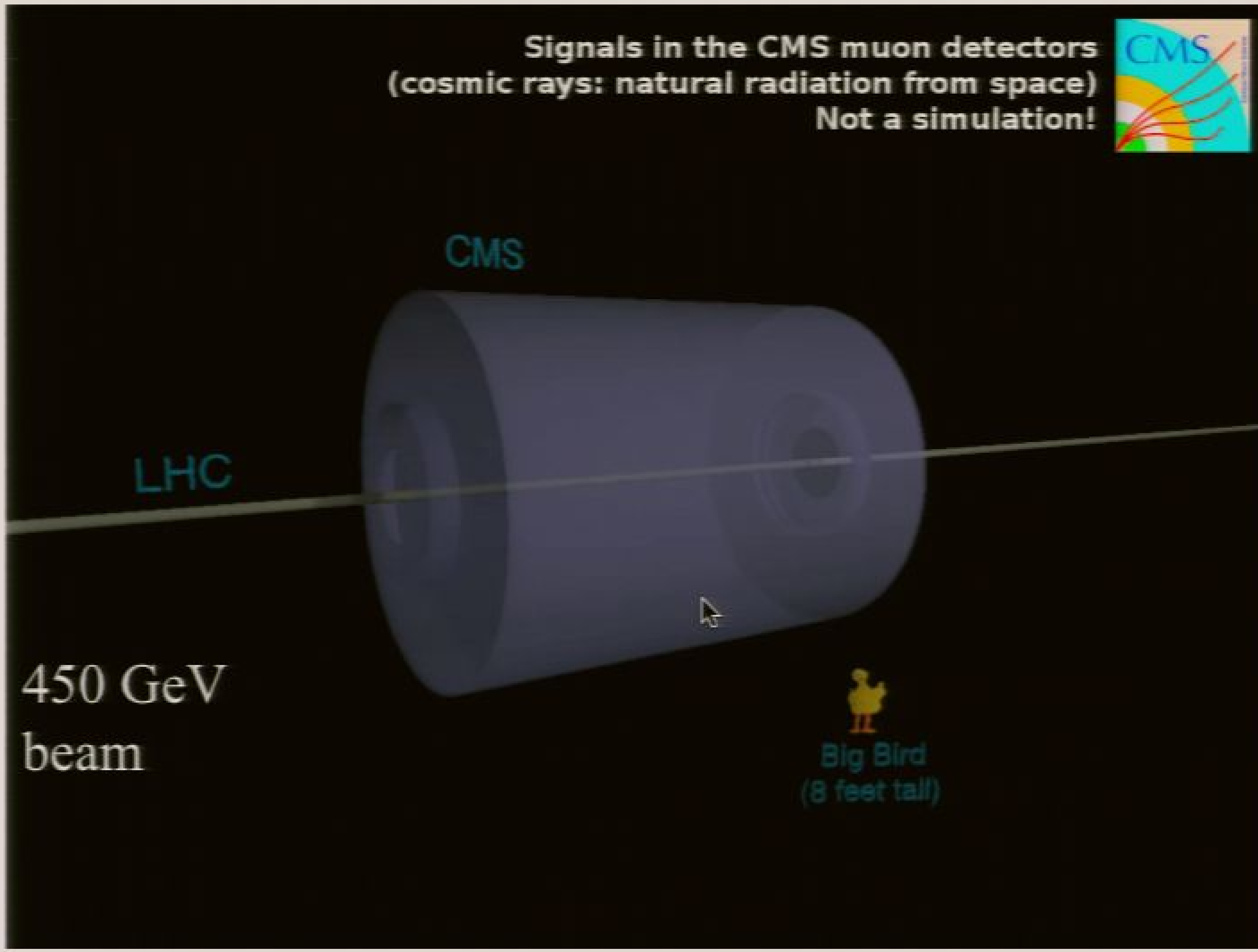




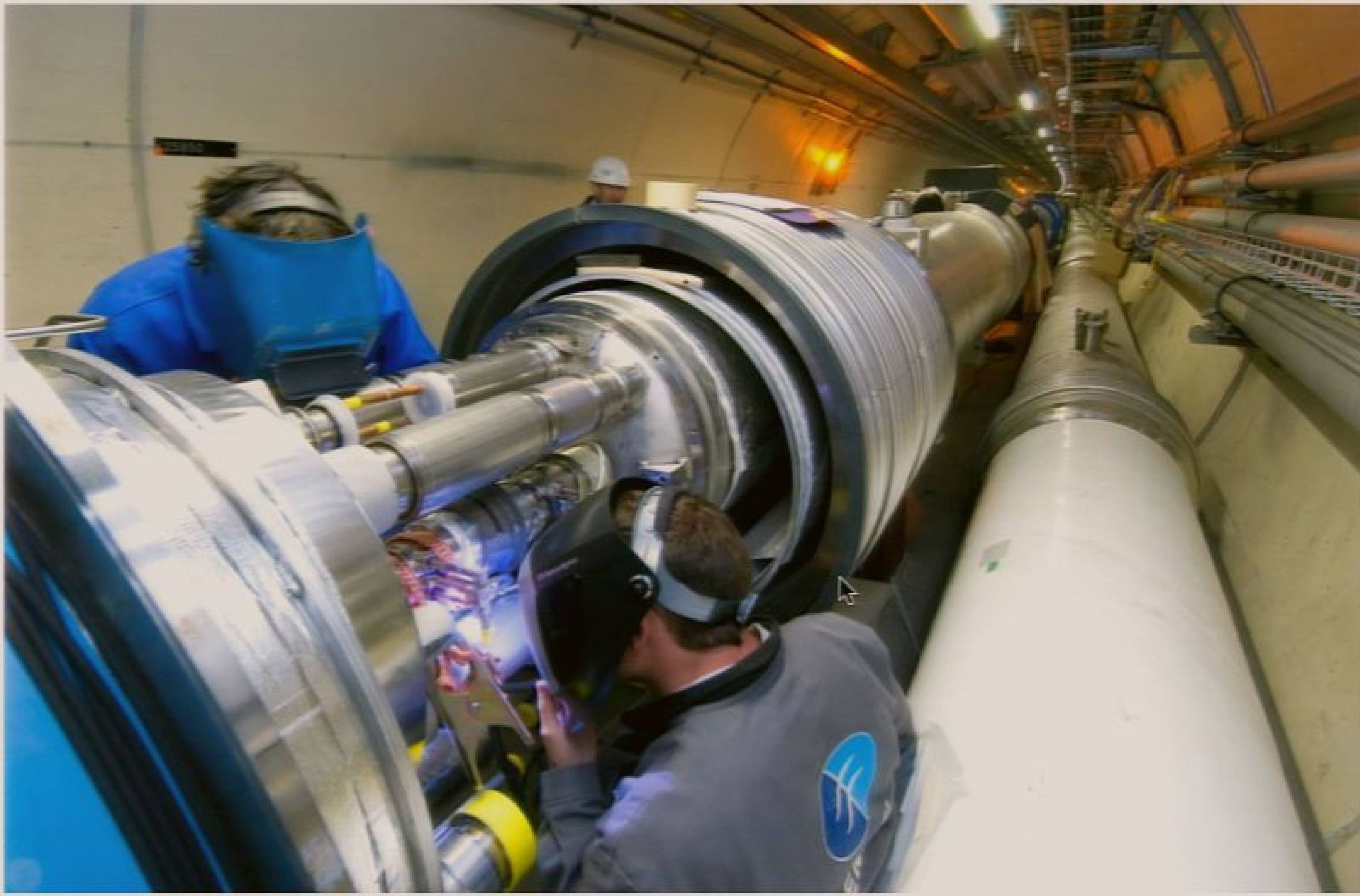
Beam Splash Event Display



Beam halo events

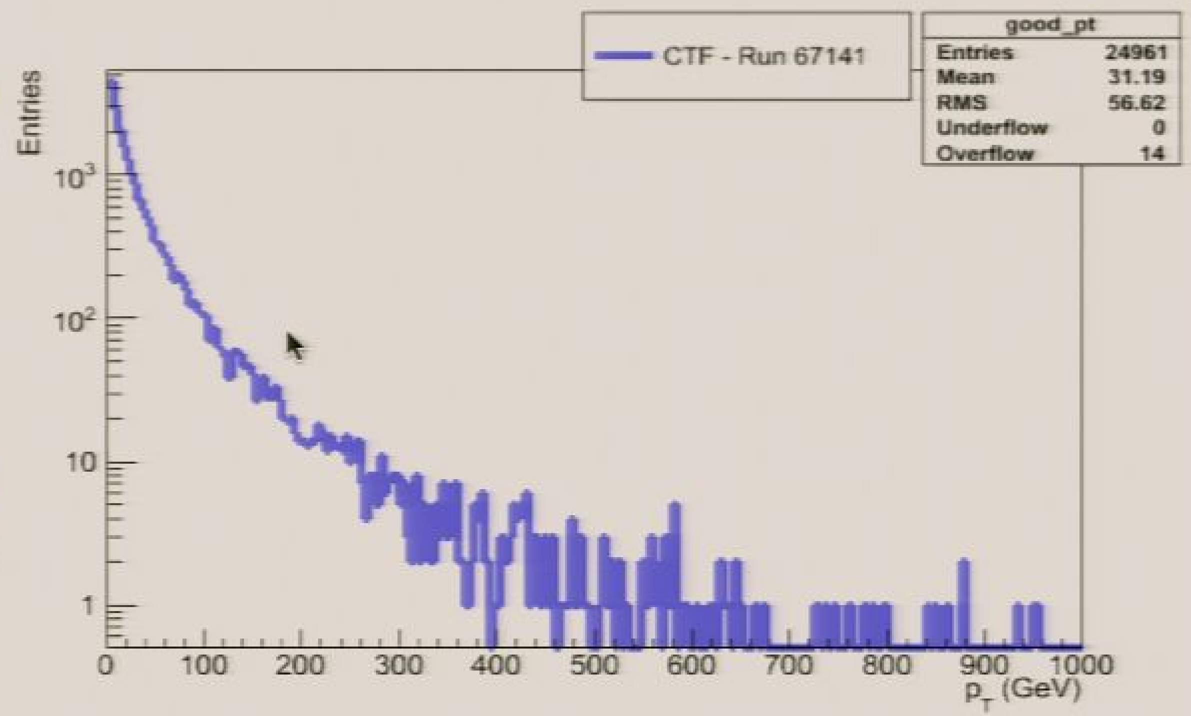


Dipoles

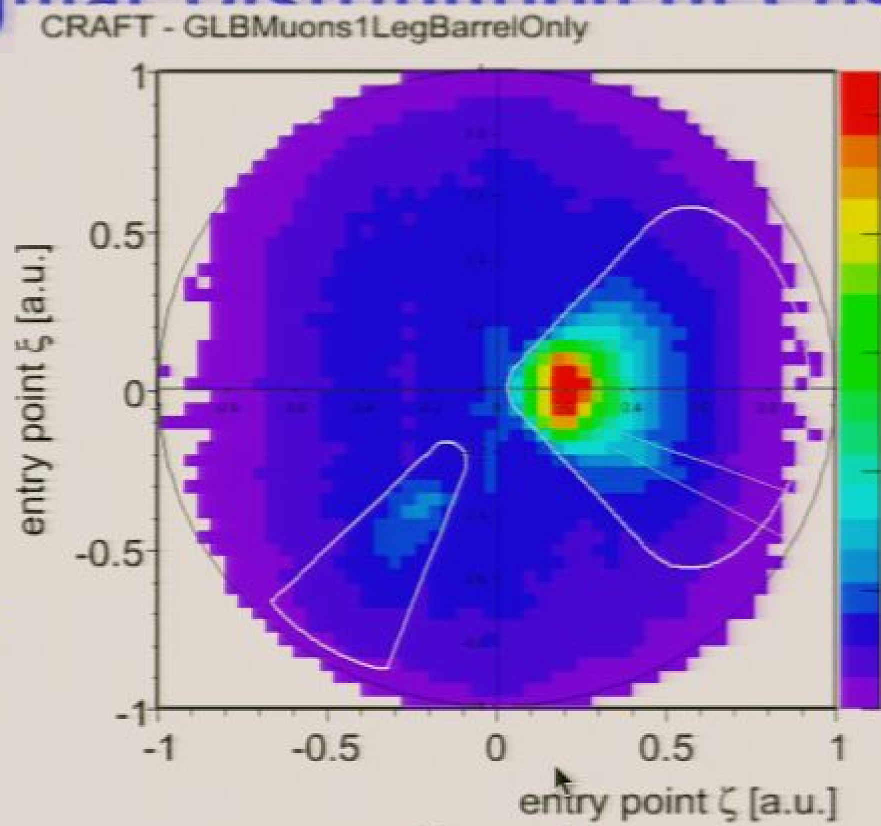


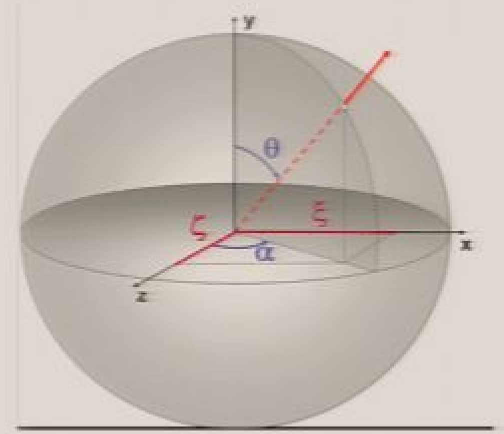
Cosmic Tracking using Tracker

- 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 distributio[n] statistics)
  - 8 hits
  - 1 hit in TIB L1/L2
  - 1 hit in TOB L5/L6
  - ~70K tracks expected out of full CRAFT statisti[cs] with P_T>100 GeV



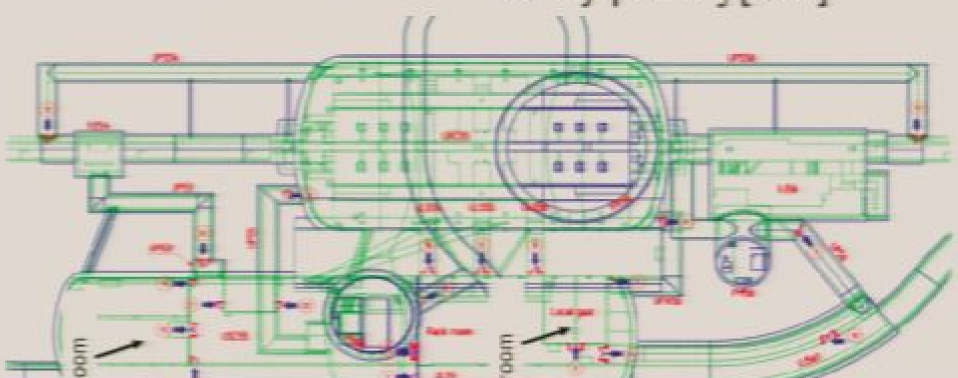
Angular Distribution of Cosmics

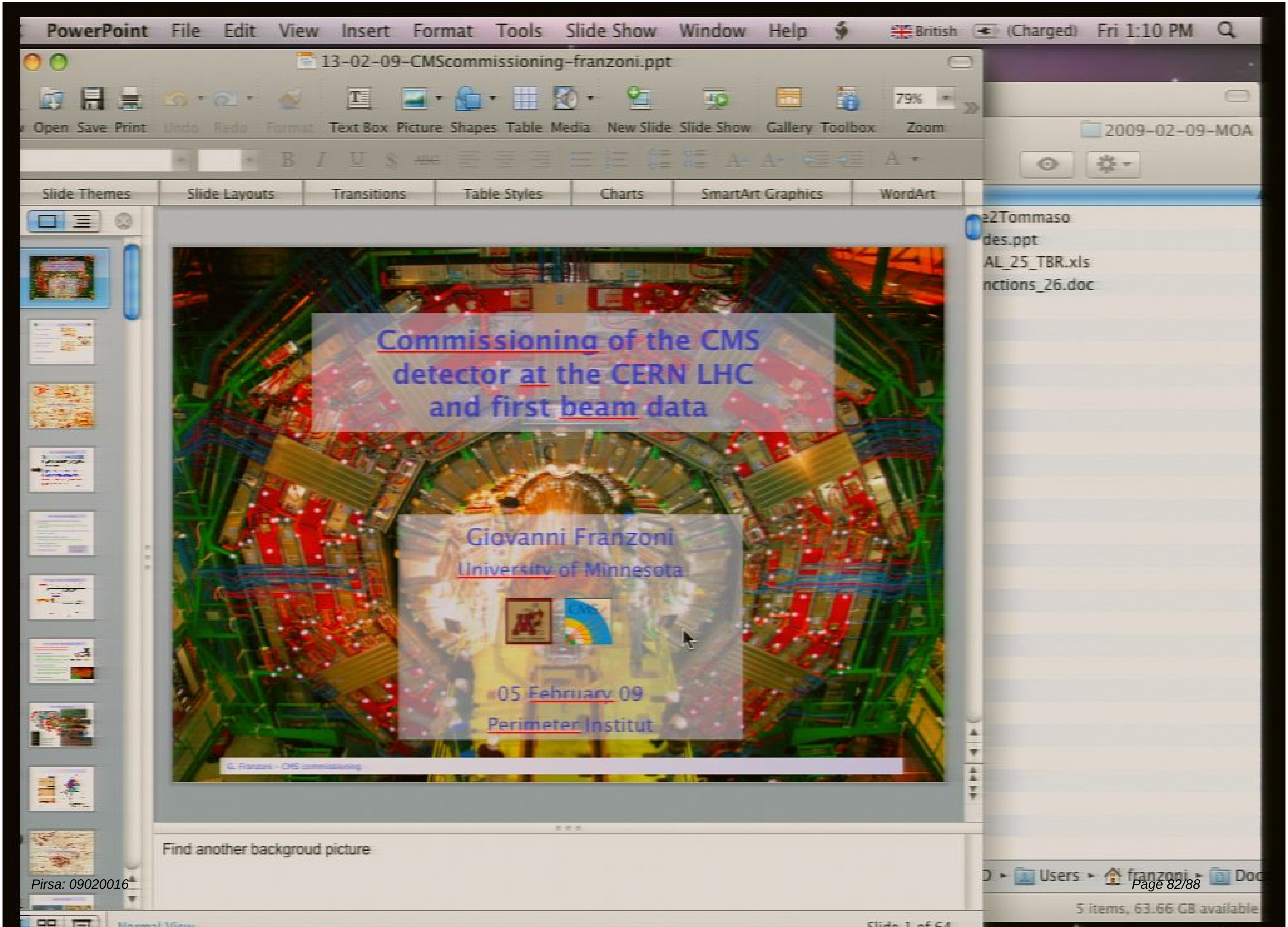




Reconstructed angles of cosmic rays indicate increased acceptance through the 3 access shafts of CMS

- n.b. CMS is

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Giovanni Franzoni
University of Minnesota
05 February 09
Perimeter Institut
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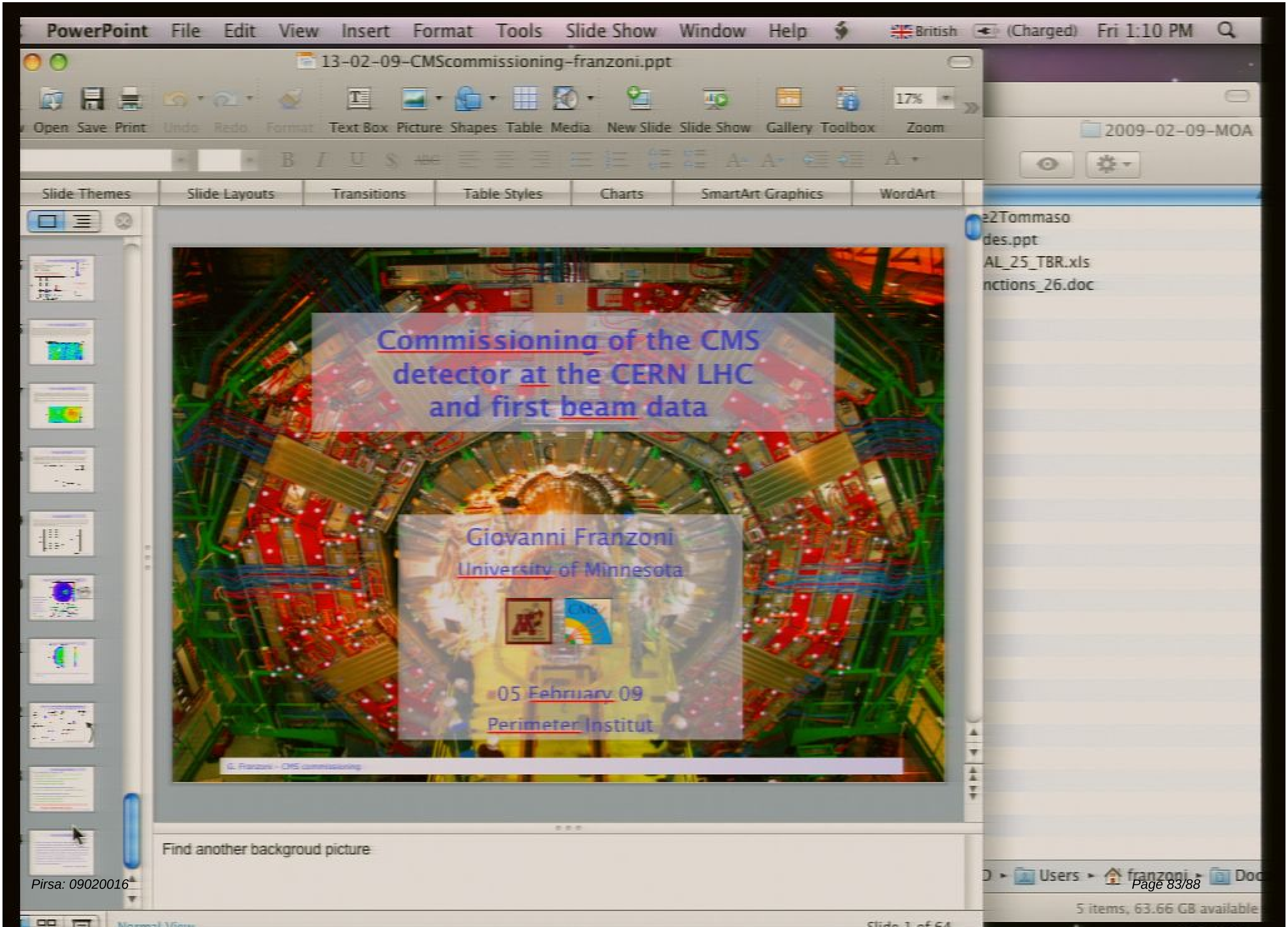
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CMS Detector Status

- Since beginning of September 2008
  - All installed CMS sub-detectors in global readout routinely
  - All triggers operational
  - 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 Full Tesla, > 300M cosmic ray events
- Detector opening started on Nov 17th Nov
  - Interventions/repairs for problematic channels (order of ~1%)
  - CMS cooling system maintenance
  - Installation of Preshower detector
- Plan to continue global data-taking operations with cosmics this
- Physics behind the corner

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- **Physics behind the corner**

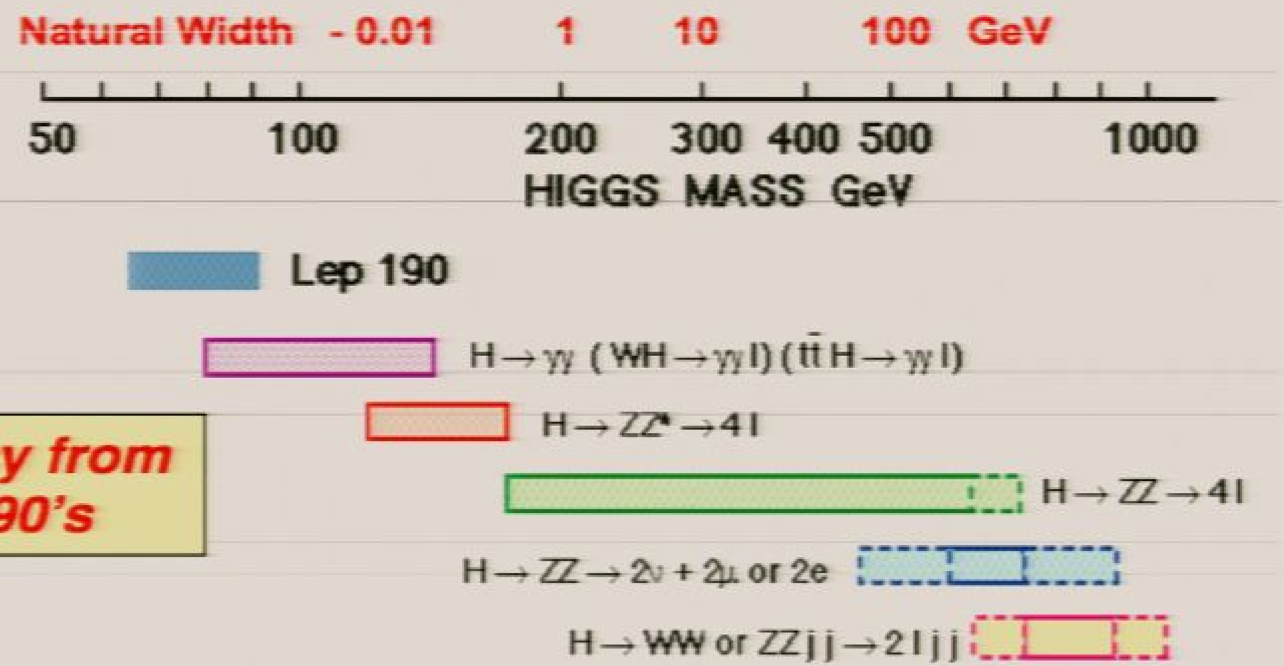
Chamonix meeting

- Under a proposal submitted to CERN management, we will have physics data in late 2009, and there is a strong recommendation to run the LHC through the winter and on to autumn 2010 until we have substantial quantities of data for the experiments. With this change to the schedule, our goal for the LHC's first running period is an integrated luminosity of more than 200 pb-1 operating at 5 TeV per beam, sufficient for the first new physics measurements to be made. This, I believe, is the best possible scenario for the LHC and for particle physics.

Rolf Heuer, Feb 6th 2009

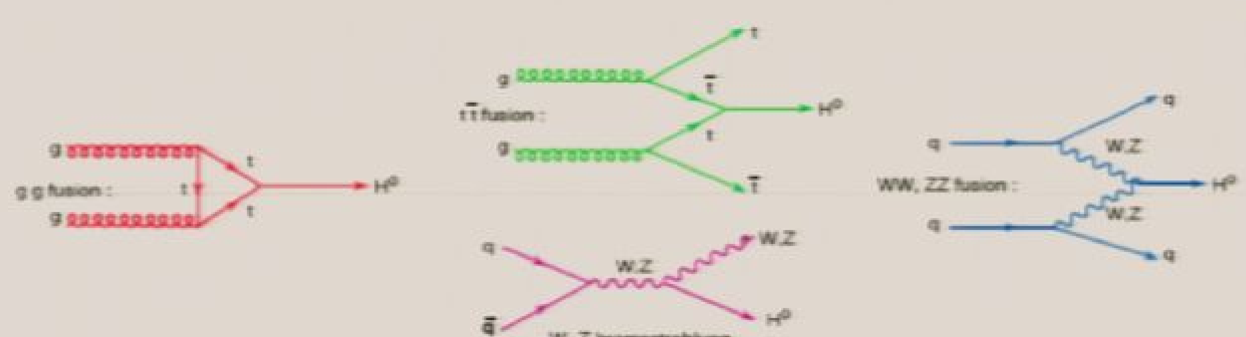
SM Higgs used as a benchmark

At the LHC the SM Higgs provides a good benchmark to test the performance of a detector

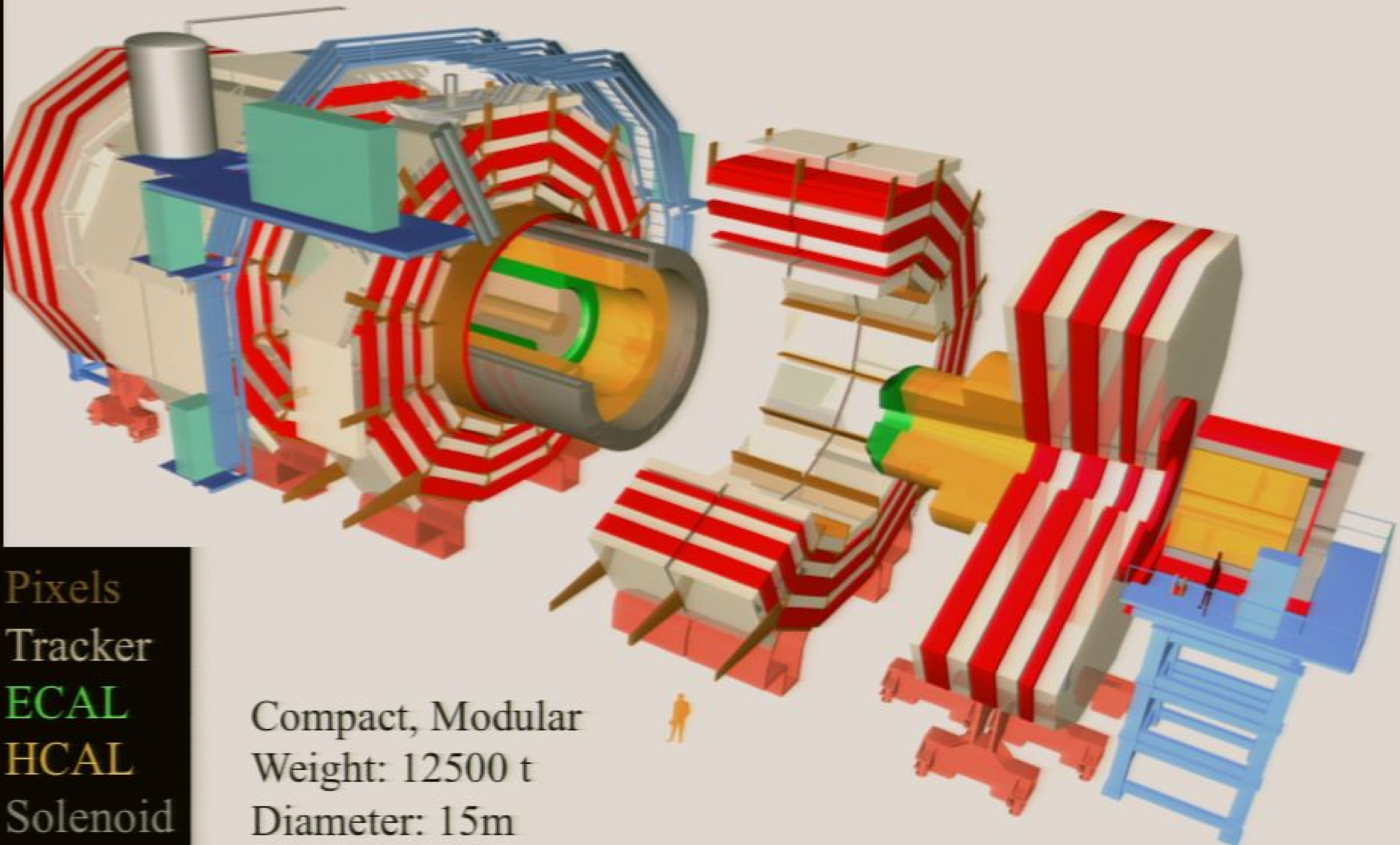


Transparency from the early 90's

T. Virdee



The CMS Detector



Pixels
Tracker
ECAL
HCAL
Solenoid
Muons

Compact, Modular
Weight: 12500 t
Diameter: 15m
Length: 21.6 m