First LHC beams in CMS

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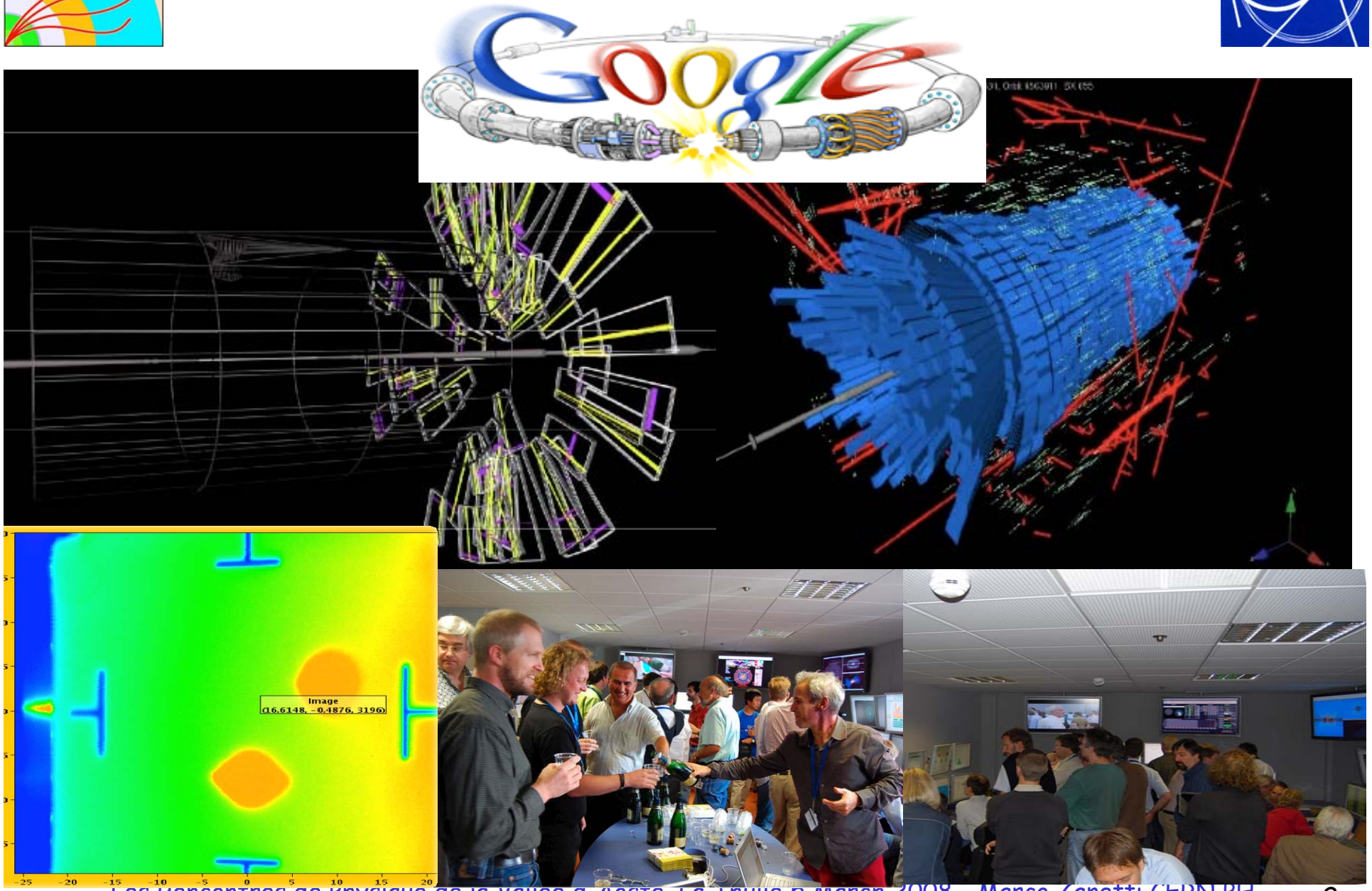
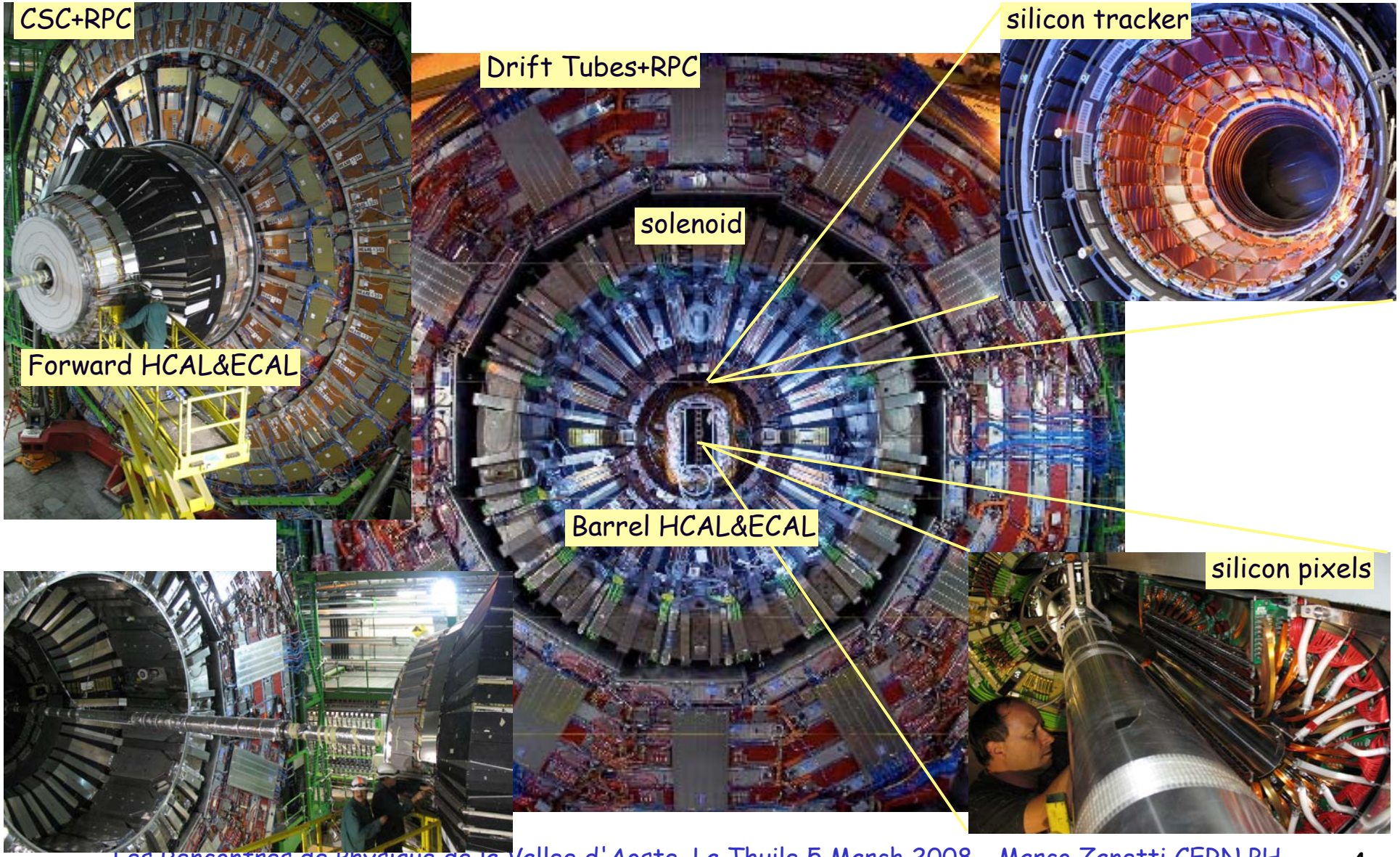
A spectacular incipit



Outline

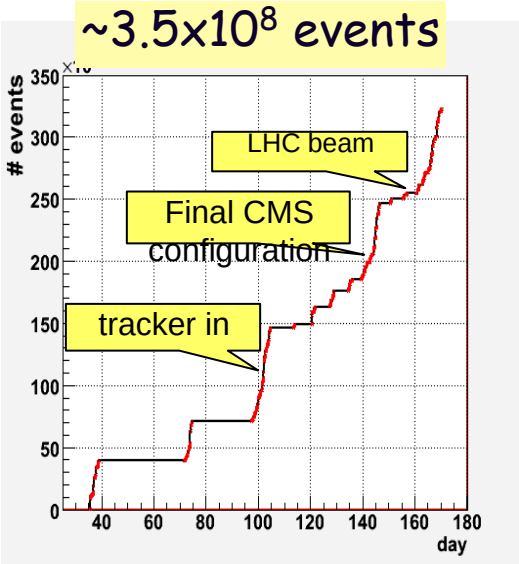
- ✓ Readiness of CMS for the beam
- ✓ Brief overview of LHC operations till September 18th
- ✓ CMS operations with LHC beam
- ✓ Results with beam data

CMS detector

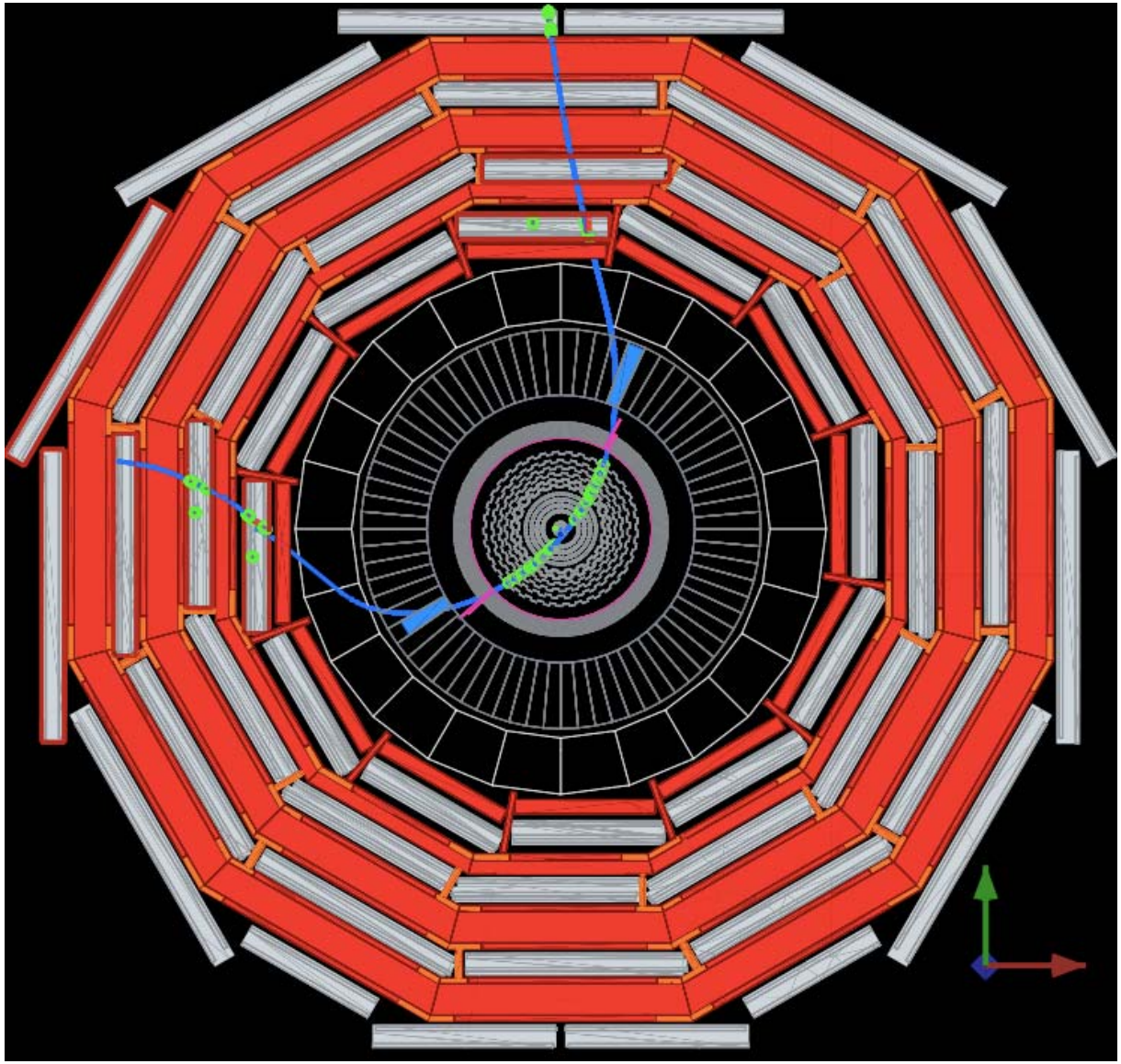


CMS commissioning with cosmic rays

- ✓ Magnet test in 2006 with detector still on surface
- Magnetic field maps up to 4 Tesla (3.8 T is the operational field)
- ✓ Since fall 2007 regular global data taking campaigns at B=0 to commission and integrate among themselves the detector subsystems
- Increasing fraction of sub-detectors read out, ~100% by the end of August
- Trigger both from muon system and from calorimeters. Whole chain fully operational
- ✓ DAQ capable of sustaining >60 kHz (nominal is 50 kHz) L1 accept rate
- full High Level Trigger menu deployed and tested online
- ✓ Synchronization procedures well established
- ✓ Detector alignment up to tens of microns
- ✓ m.i.p used to calibrate electromagnetic calorimeter up to 1%
- ✓ Computing operations: data processed at tier 0, re-processed at tier 1's and analyzed ad tier'2 via grid

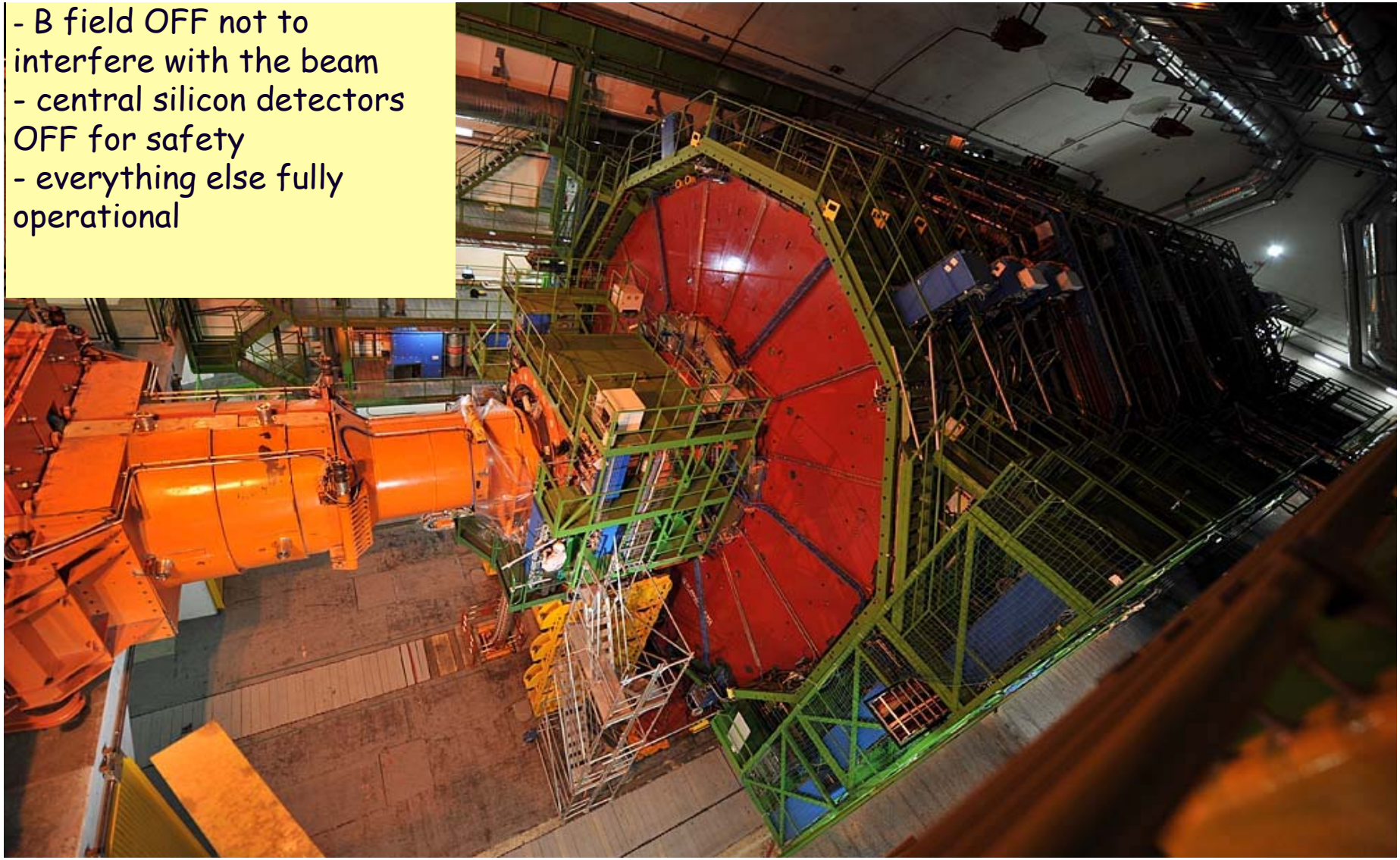


Cosmic muon event



CMS close and ready for beam: 2008 September 3rd 20.30

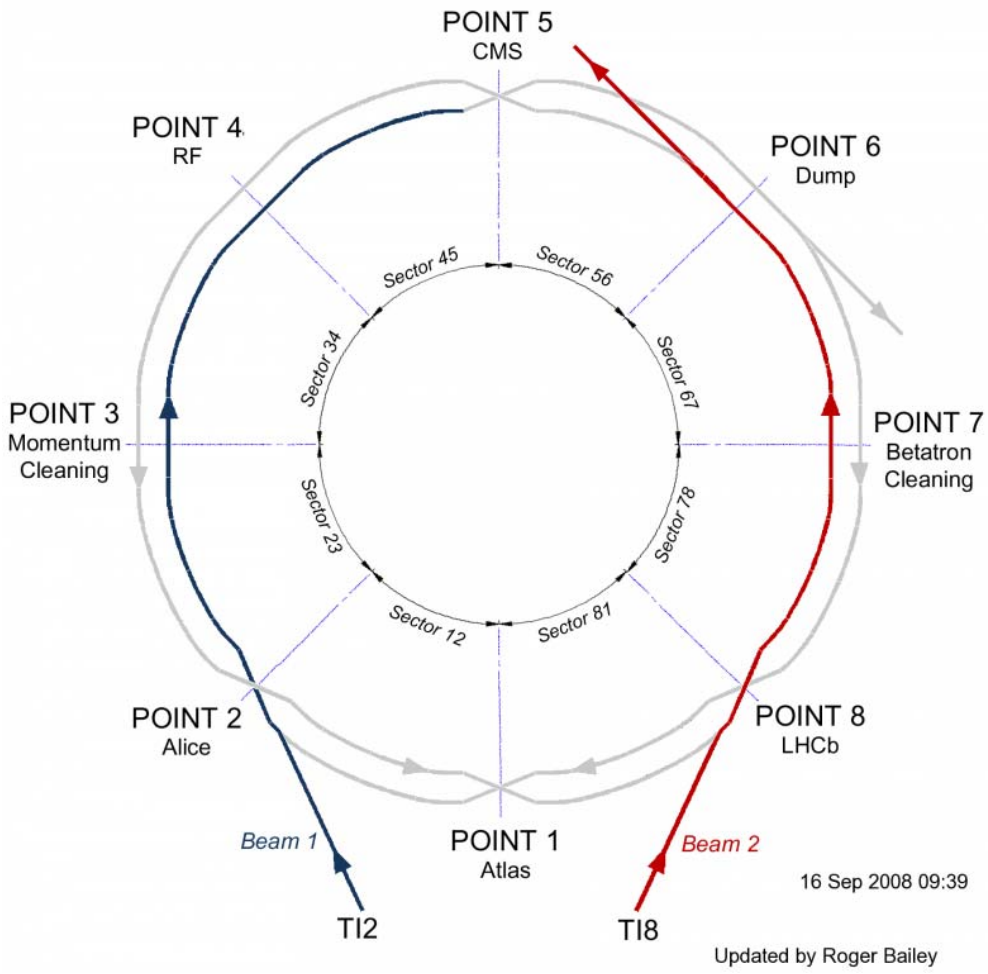
- B field OFF not to interfere with the beam
- central silicon detectors OFF for safety
- everything else fully operational



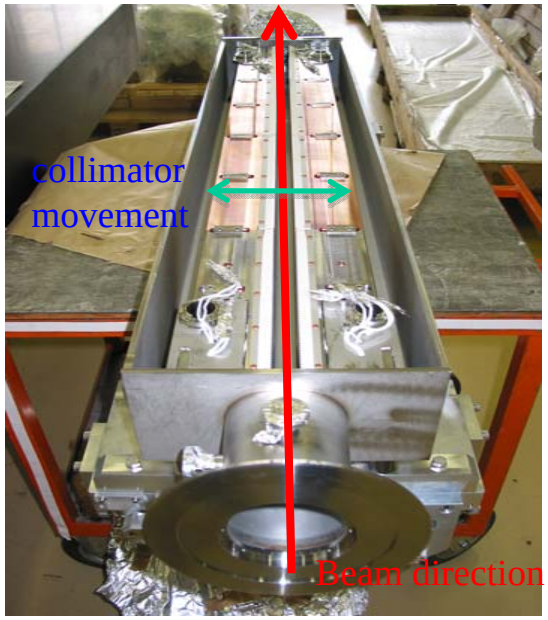
and the beam came

- ✓ "Synchronization" tests between 5 and 9 September
  - Beam 1 on CMS
- ✓ September 10th: circulating beams
  - 10:30 : Beam 1 around the ring (in ~ 1 hour), 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
- ✓ Night, Sept 11th: beam 2 captured by RF system
- ✓ Late evening of Friday Sept. 12th an old LEP HV transformer in point 8 failed, CMS provided a spare (the only available)
- ✓ Cryogenic back in service on the 19th morning. Ready for collisions
- ✓ September 19th, 11:06...

"Synchronization" tests, 5-9 Sept

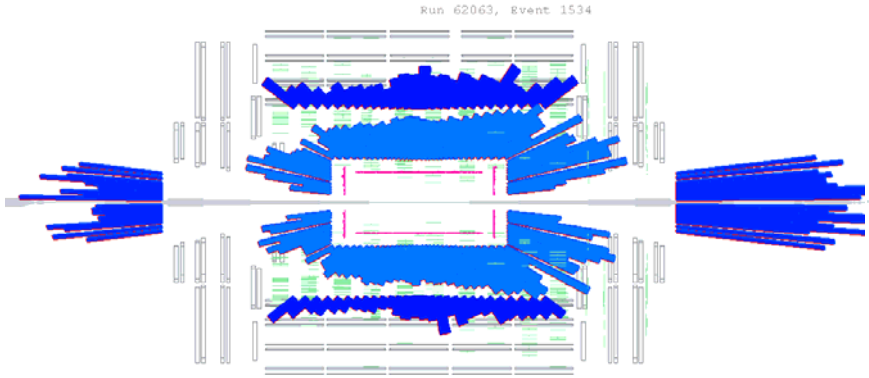


- ✓ collimators placed at 146 m away from the IP on each side of CMS to stop the beam
- ✓ Beam 1 at injection energy (450 GeV) shot towards CMS form z+
- ✓ Beam 2 tried the first time on Sept 10

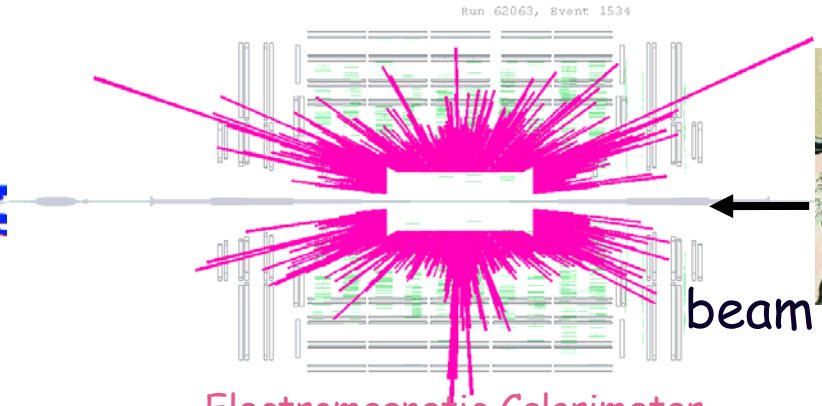


Beam Splash

2×10^9 protons per bunch on target: few 10^3 TeV downstream



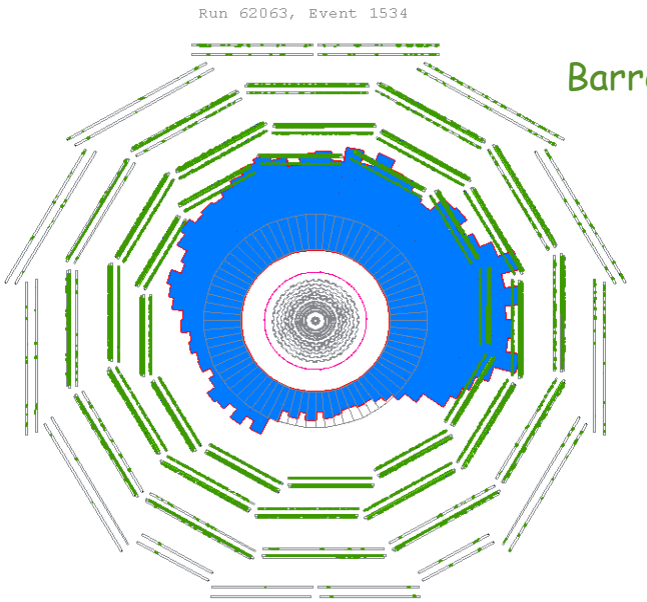
Hadronic Calorimeter

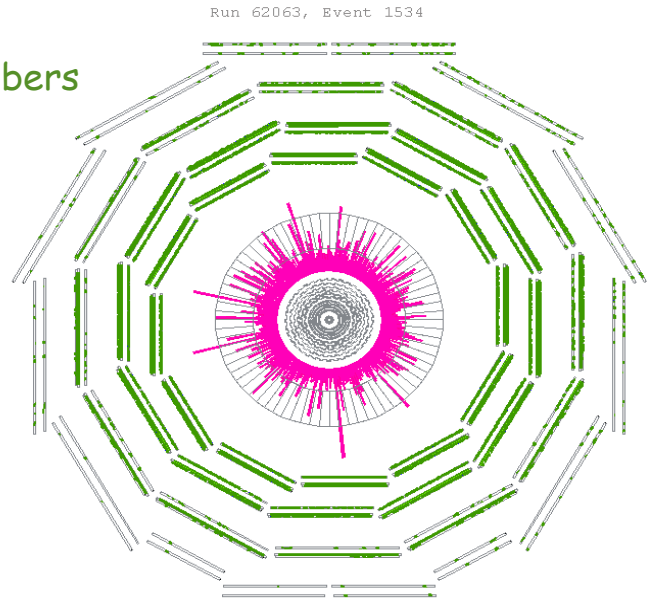


beam

Electromagnetic Calorimeter

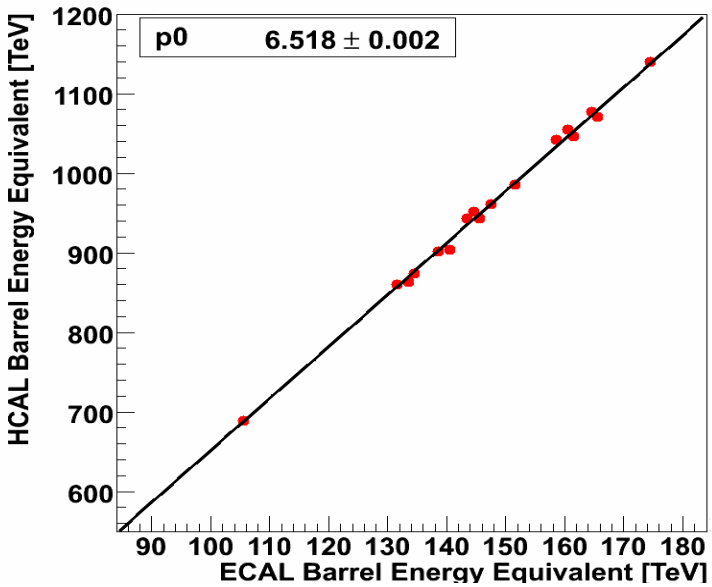
Barrel Muon Chambers

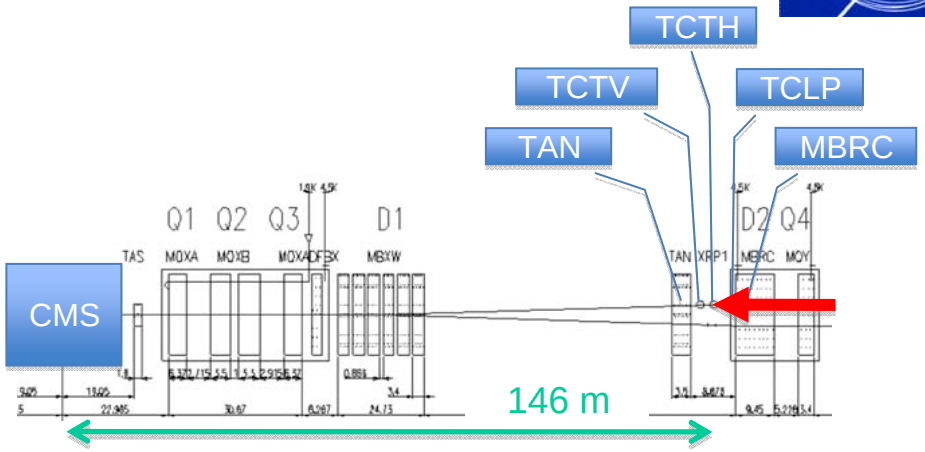




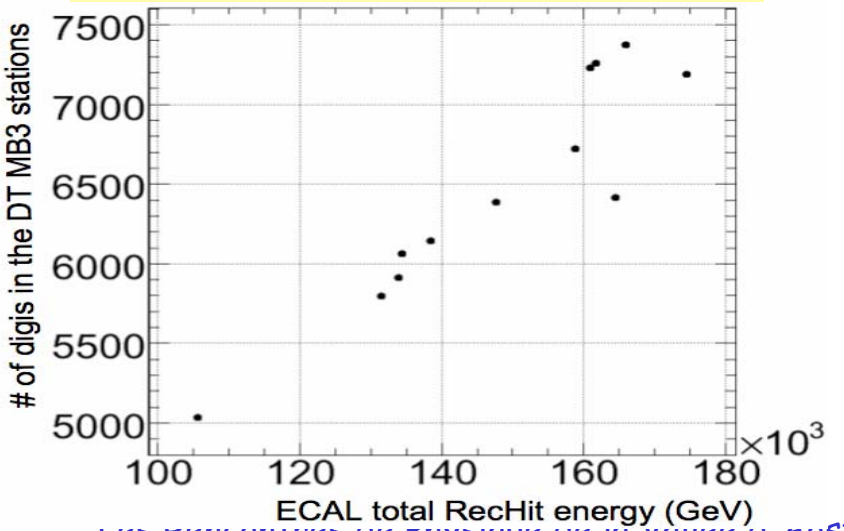
Beam Splash: energy measurement

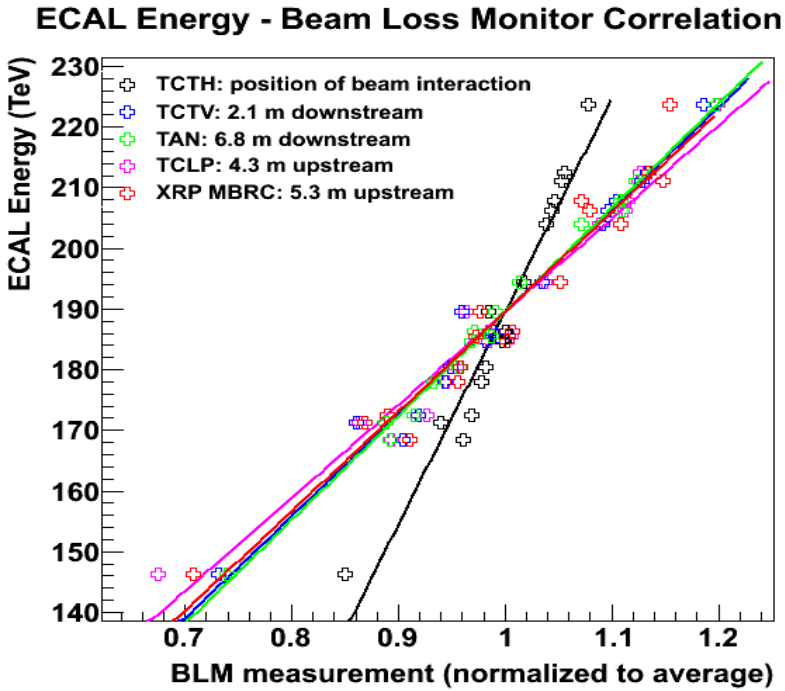
correlation among calorimeters





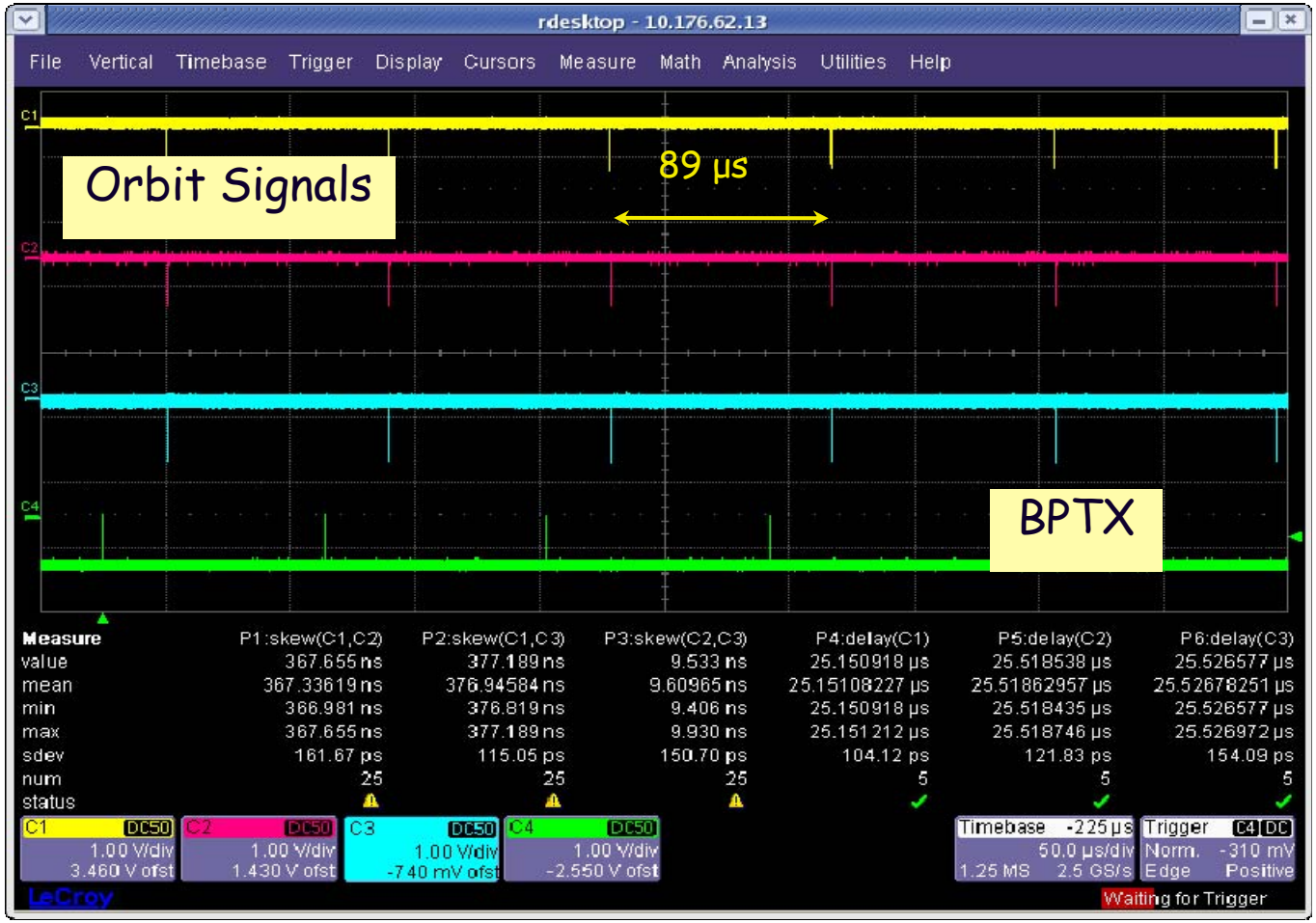
calorimeter muon chambers correlation



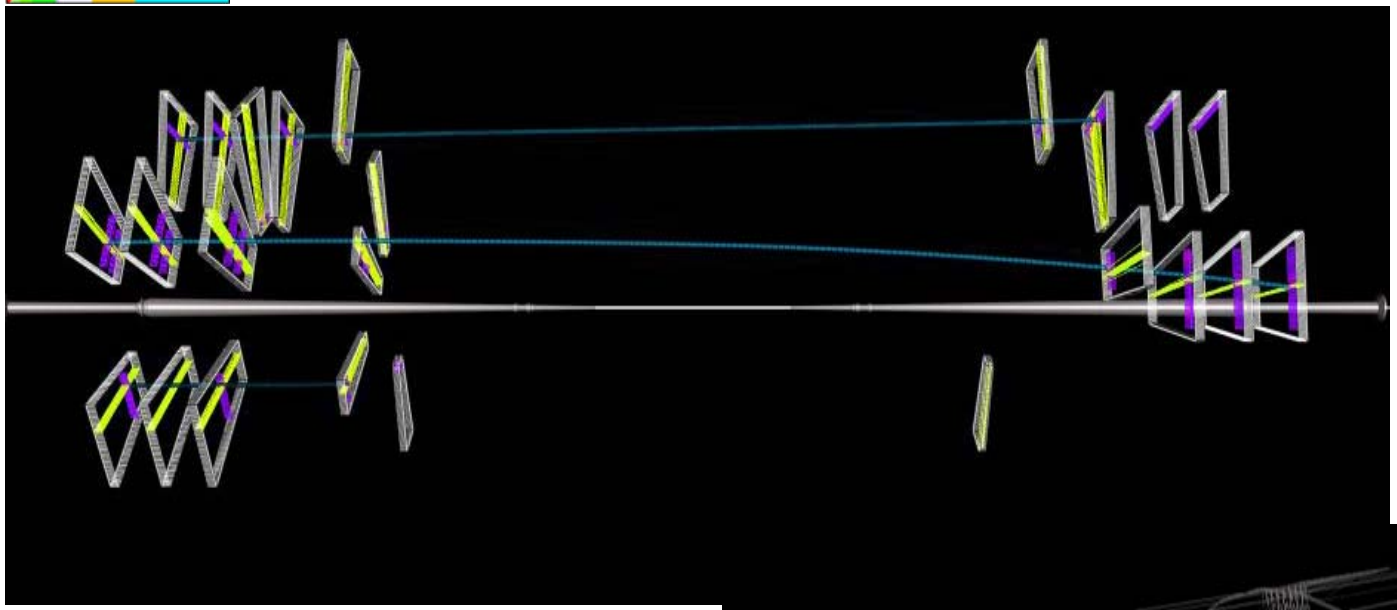


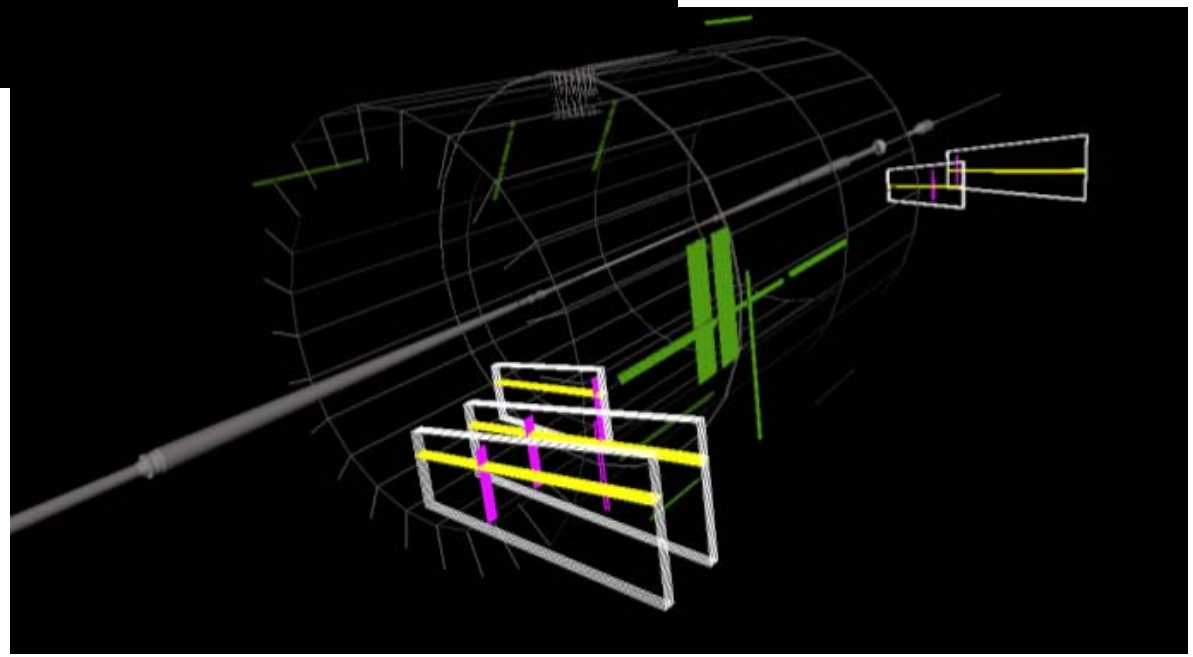
Circulating beam(s)

Multiple orbits detected by CMS beam monitoring system

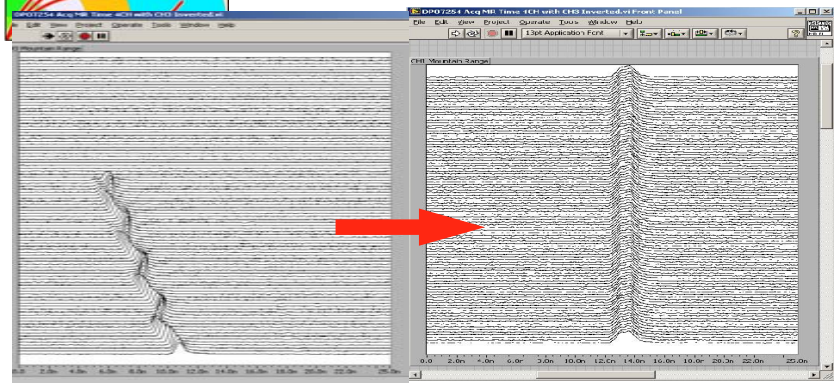


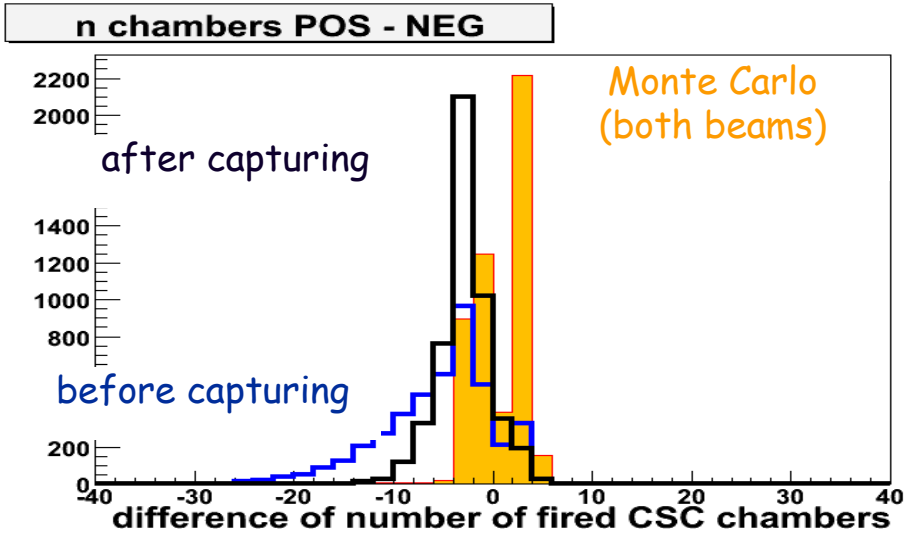
Beam Halo

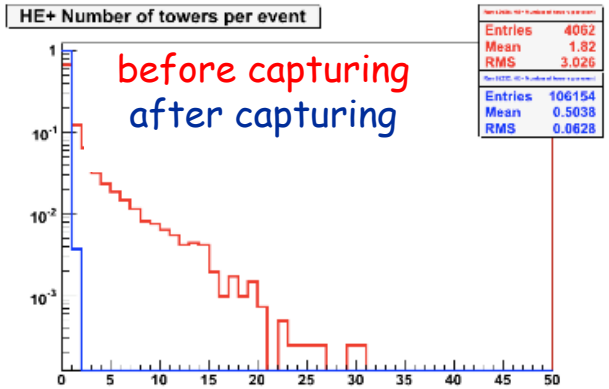


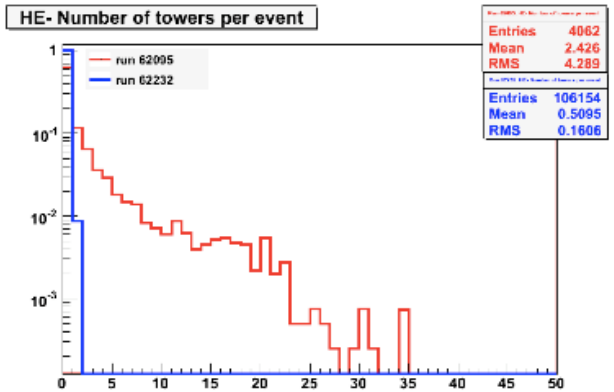


RF capture, cleaning of the beam

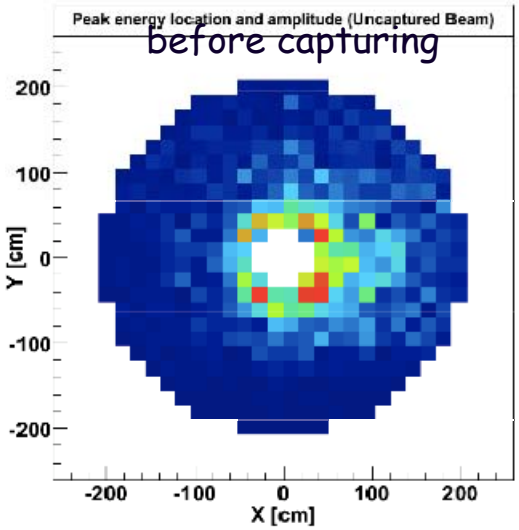


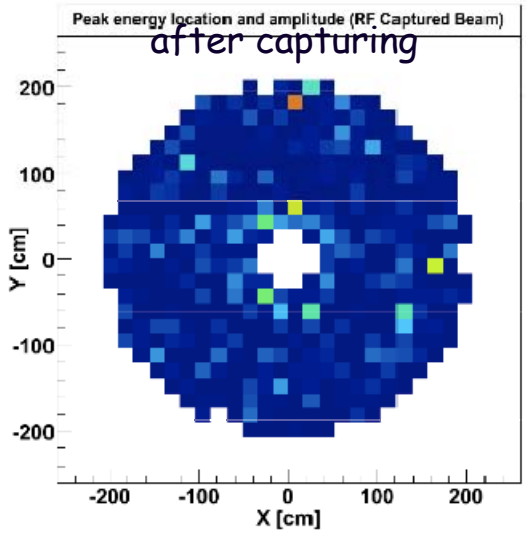




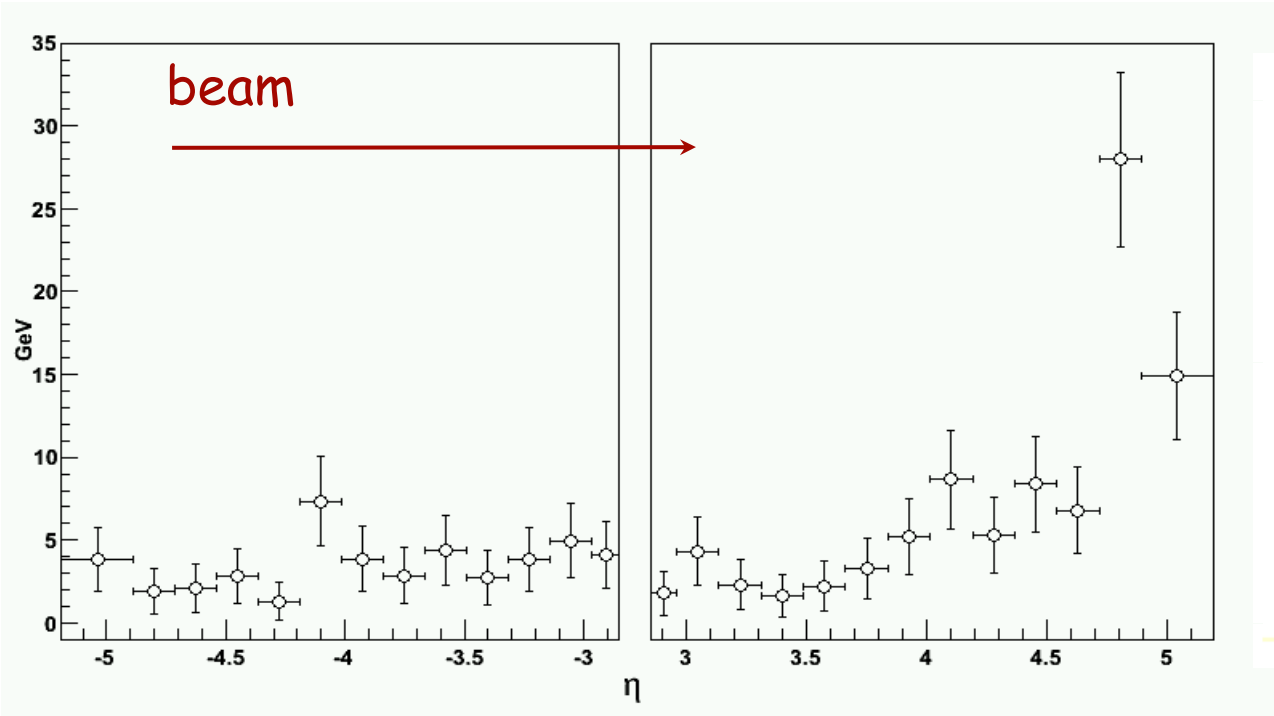


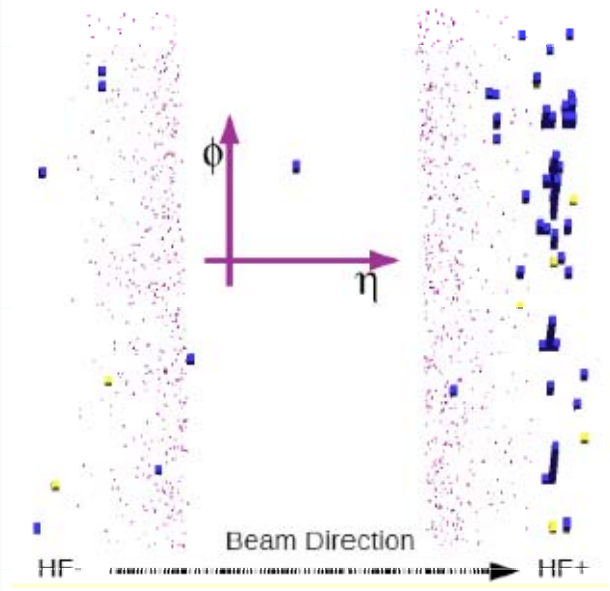
Energy in forward HCAL





Beam-gas collisions



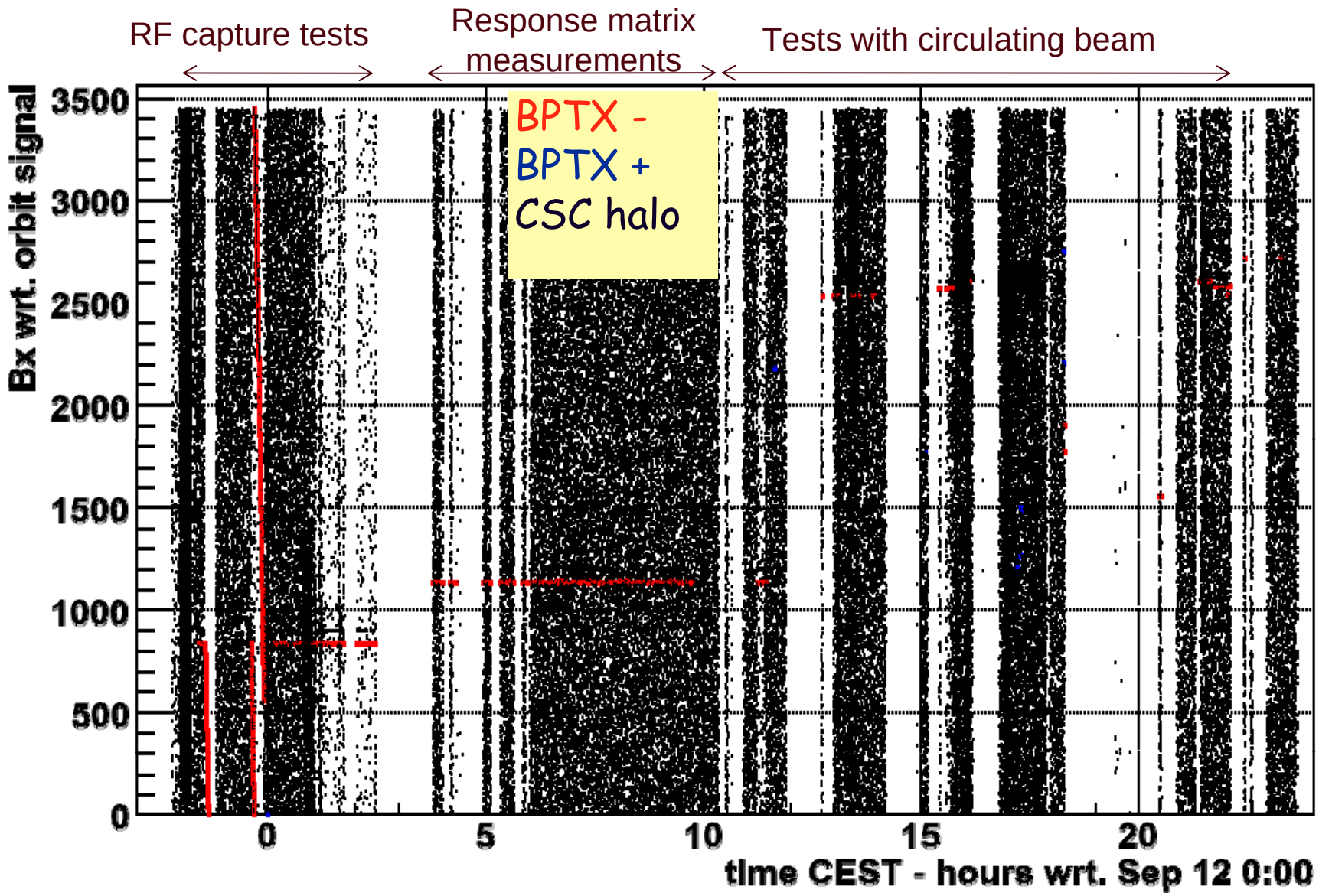


- ✓ Events triggered by forward HCAL, further selected by requiring >20 GeV energy deposition
- ✓ Compare the reading at different depths of the tower (short EM, long hadronic) to select hadronic depositions
- ✓ Deposits at high eta characteristic of beam-gas collision within the detector

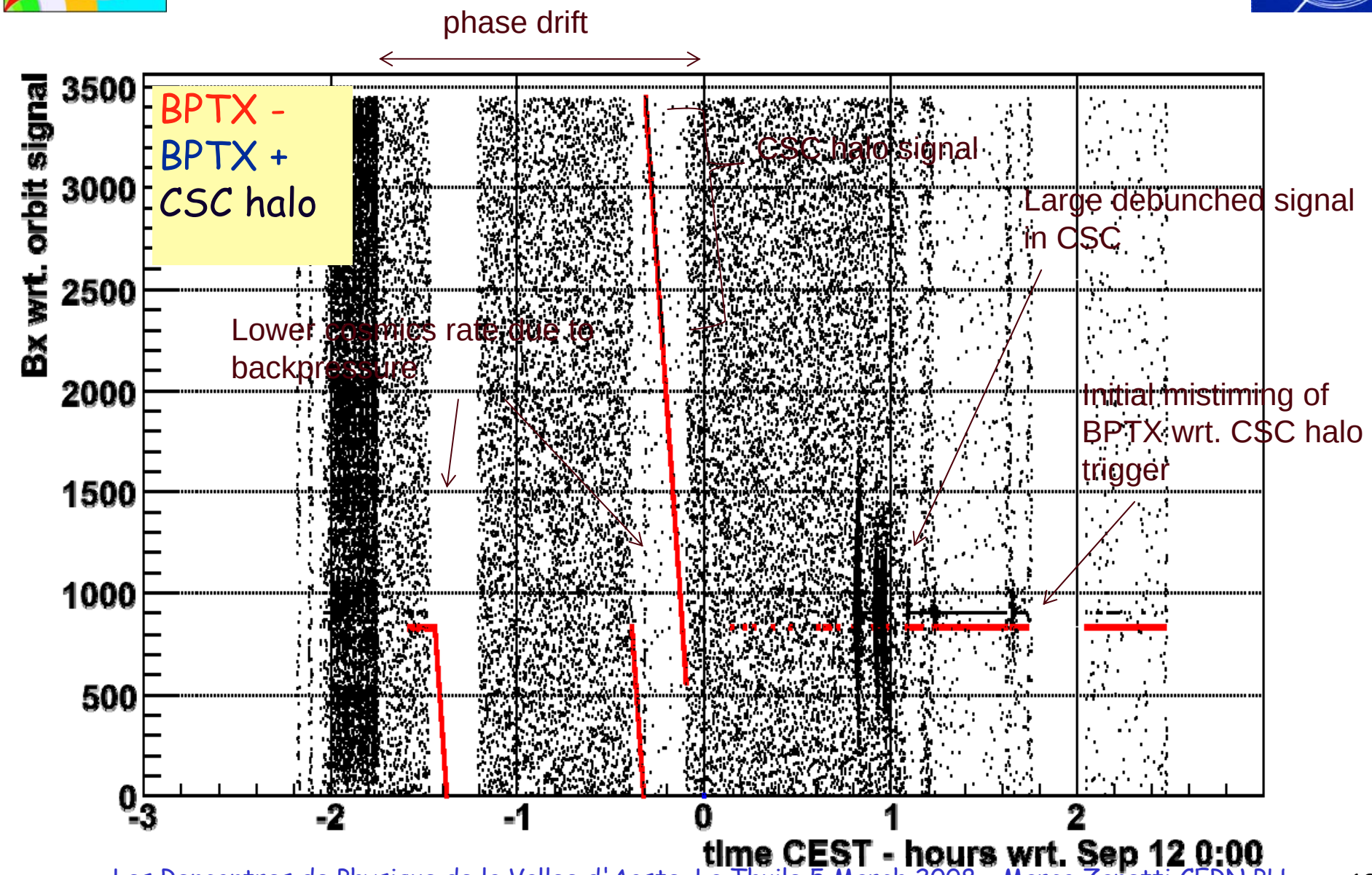
Triggering on the beam

- ✓ BPTX technical trigger
  - Most reliable source of trigger, to be synchronized with other trigger sources
  - Rate=beam revolution frequency=11 kHz
  - Efficiency going down as the beam weakens
- ✓ CSC beam halo trigger (special muon bit)
  - Very clean, noiseless trigger. Rate w/o beam ~2% due to cosmic muons
  - The trigger signal from the endcap facing first the beam delayed by 2 BX to keep the 2 disks in synch
  - Used also for beam splash, but chambers not in the read-out (gigantic events)
- ✓ Forward HCAL technical trigger
  - clean trigger, but typically beam halo too weak
- ✓ Non-filtering HLT
  - Though streaming events accordingly to L1 bit and performing basic reco

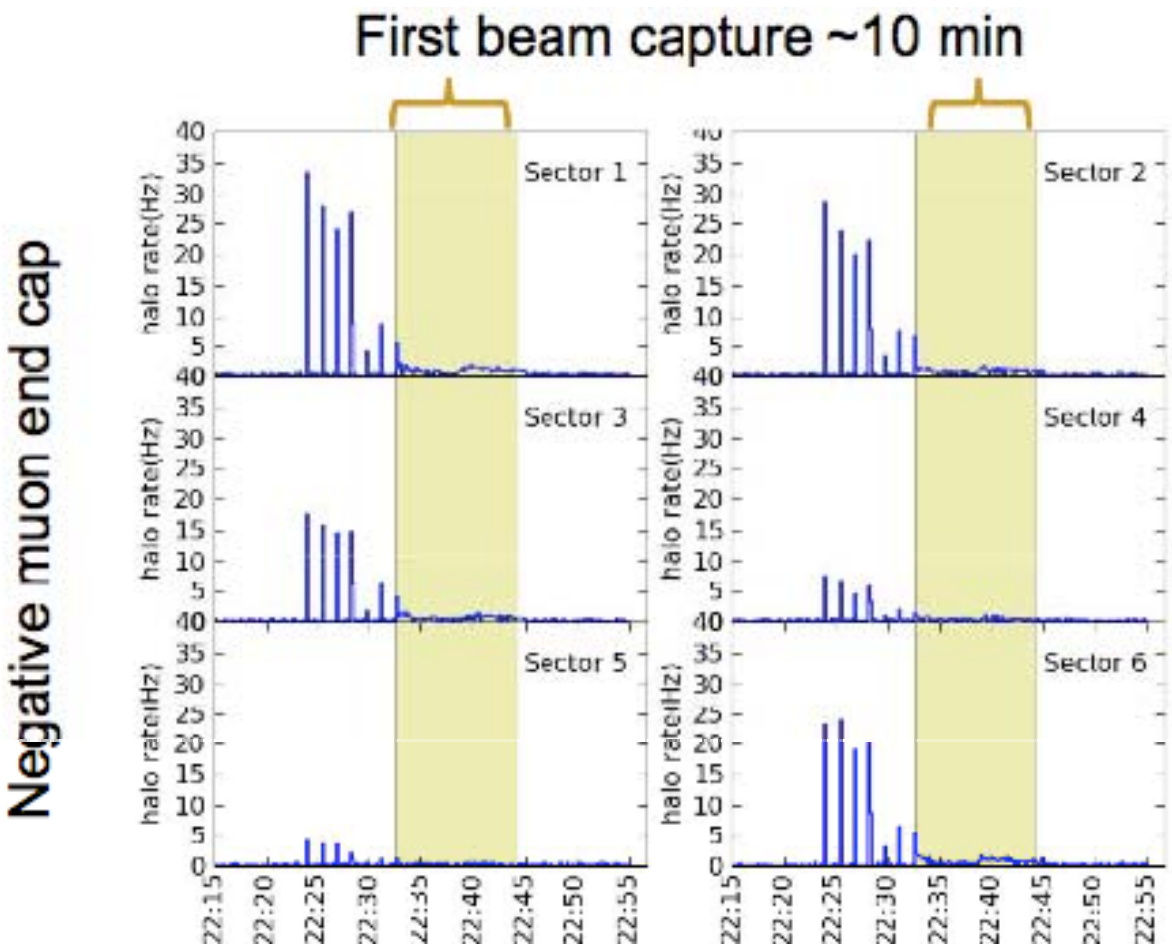
Triggering on the beam



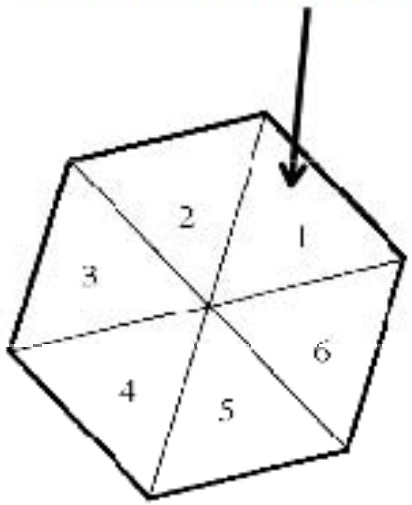
First RF capture attempts



CSC Halo trigger rate

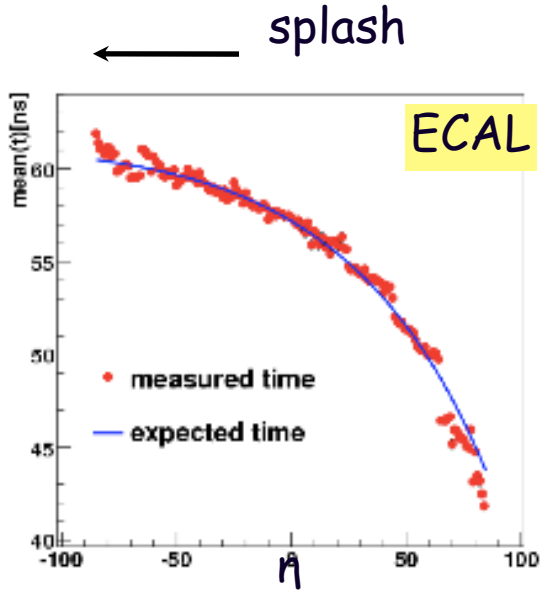


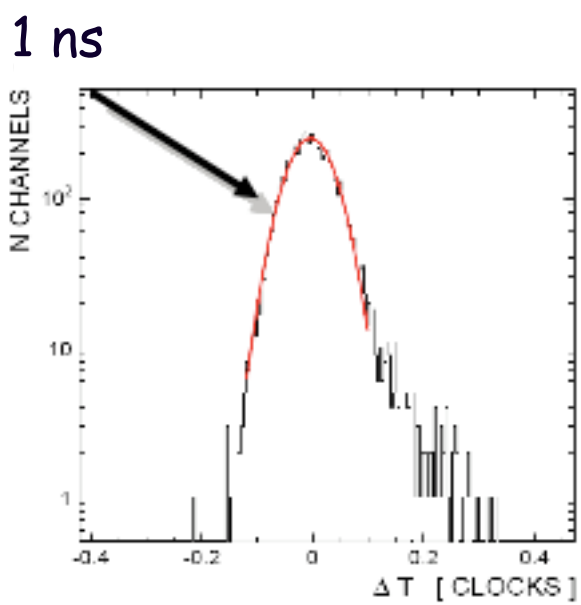
CSC trigger sectors viewed from the interaction point

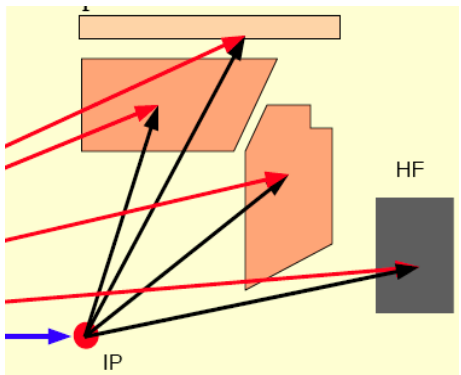


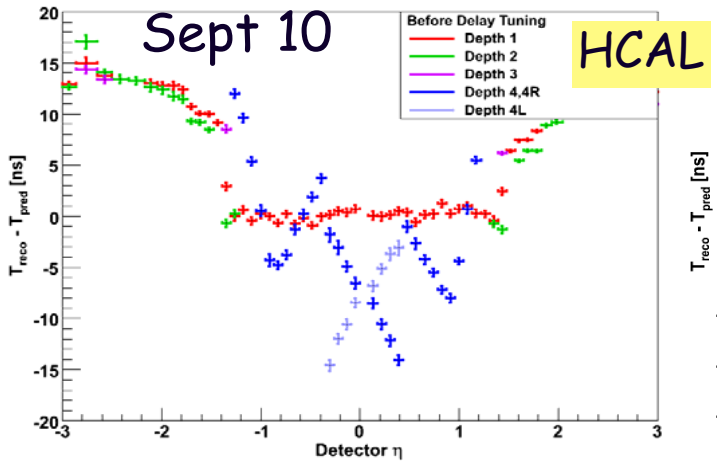
Calorimeters synchronization with beam splashes

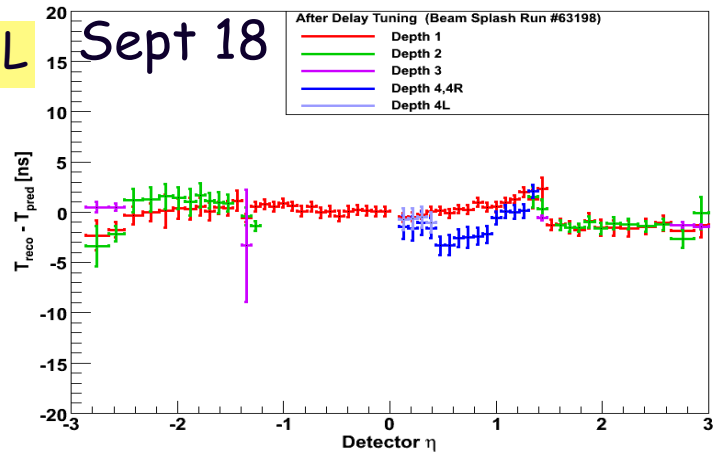
- ✓ In splash events ~all channels fires
- ✓ Signal time of arrival for beam splash events predicted on the basis of geometrical considerations
- ✓ data used to synchronize in one go all different parts of the sub-detector



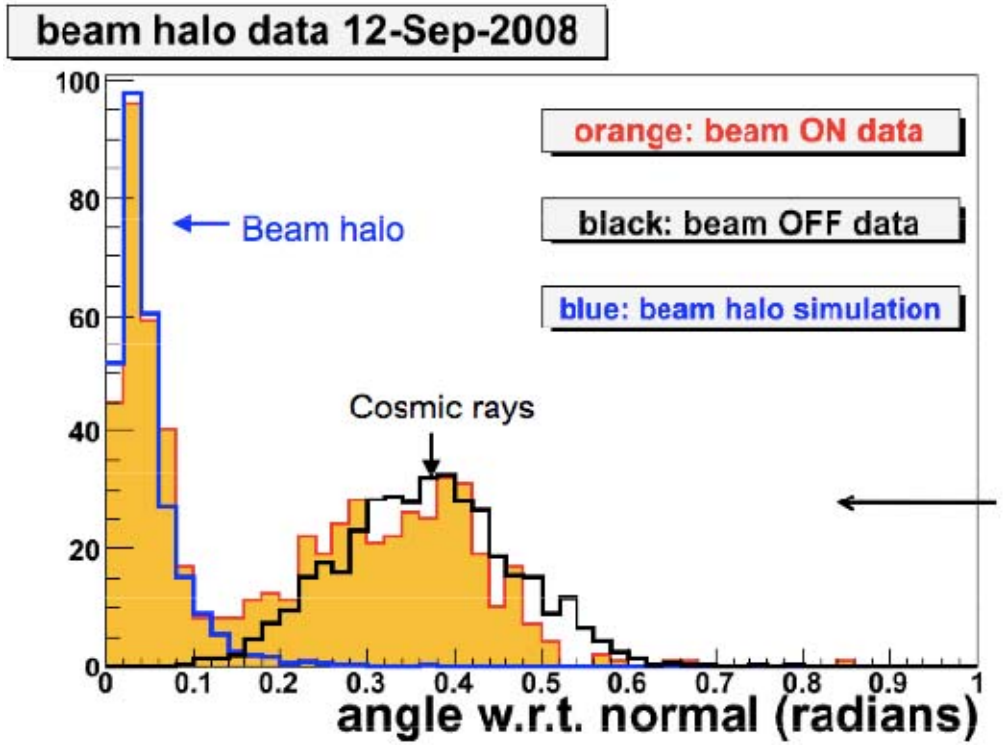






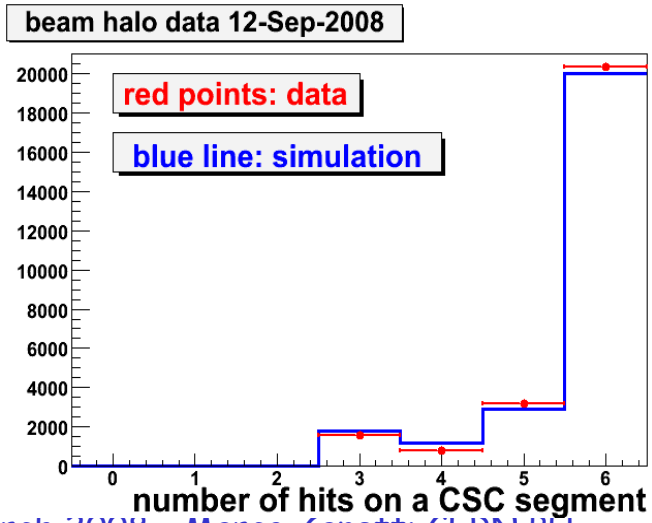


Comparison with simulation

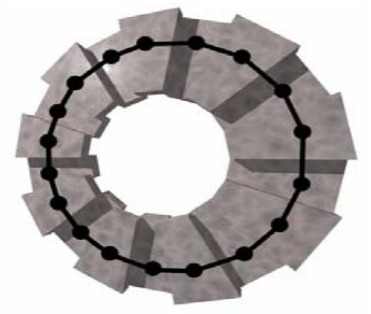


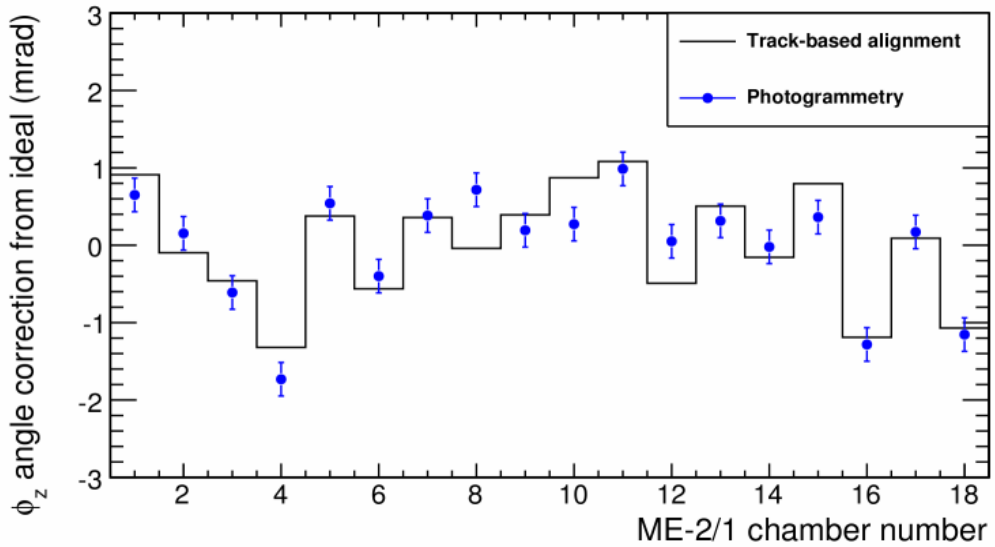
beam ON data:
combination of
- **beam halo**
- **cosmic rays**

reconstructed track angle w.r.t. to the normal to transverse plane

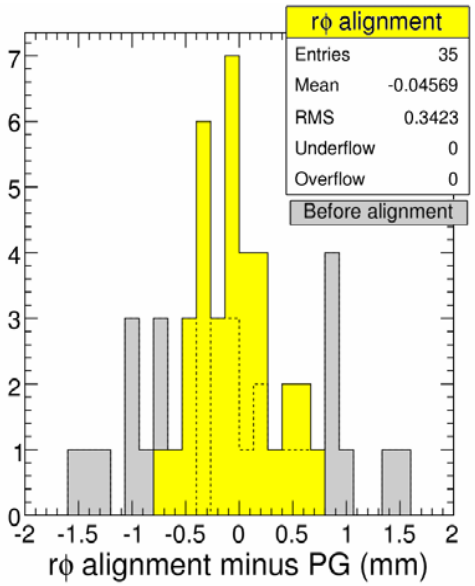


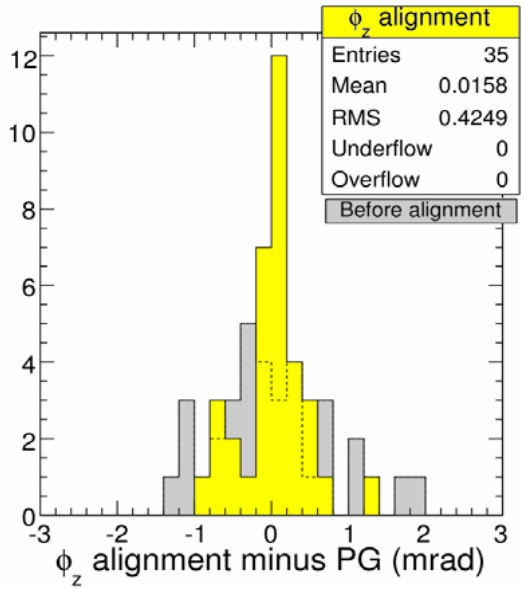
CSC alignment





- ✓ tracks crossing overlapping muon chambers can be used for alignment
- ✓ 11,000 beam halo events (out of a total of ~500 k) useful for alignment collected in 9 min of LHC running
- ✓ 300 microns accuracy achieved





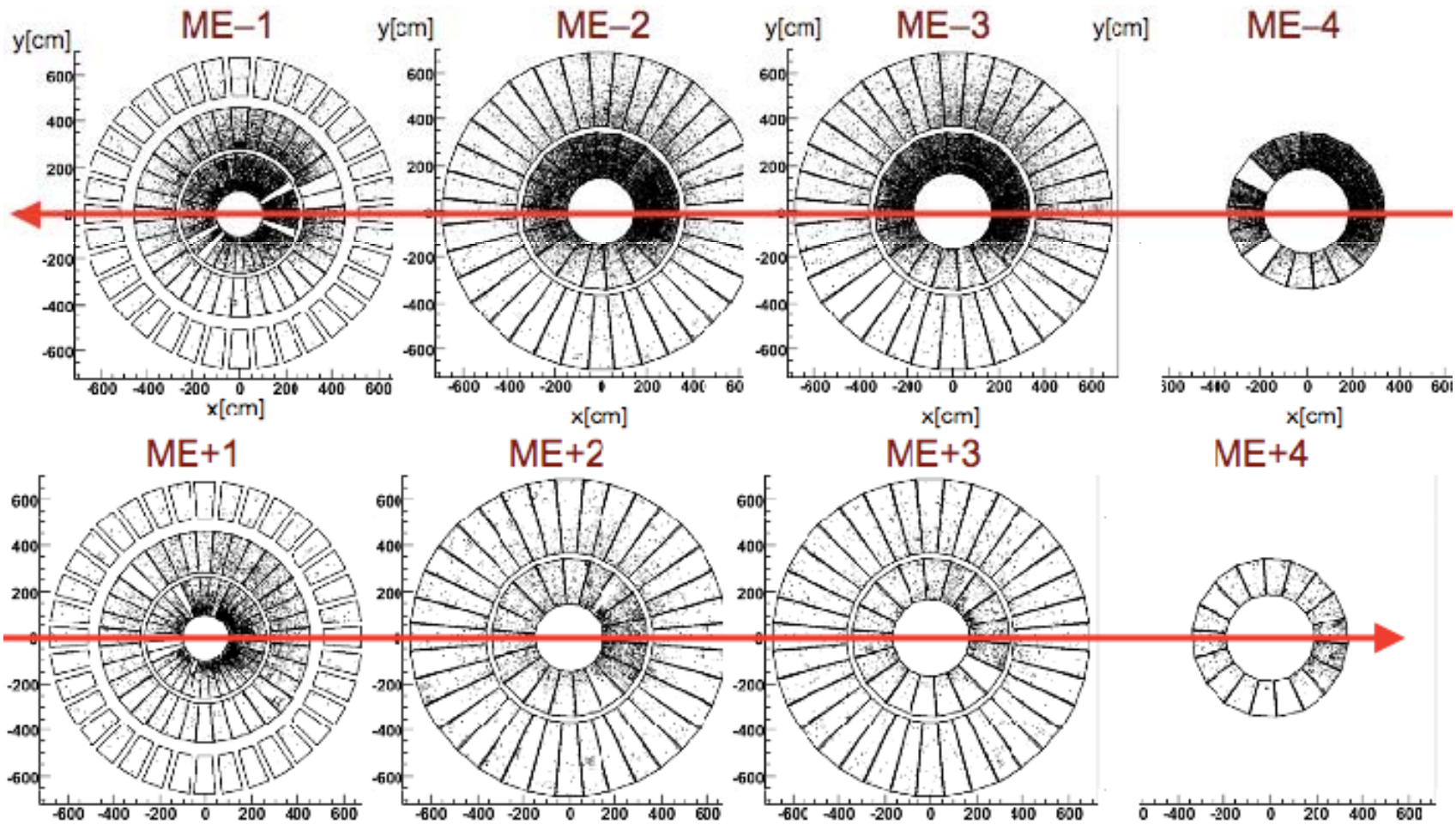
Conclusions

- ✓ Impressive startup of LHC beam operations. Too bad it lasted so little
- ✓ After ~20 years, R&D, construction, installation and commissioning of CMS are over. The result is a magnificent detector
- ✓ All the experiment components (sub-detectors, trigger and DAQ, software and computing, offline analysis, and human collaboration) performed wonderfully. ~100% efficiency beam events
- ✓ We were and still are ready for the beam
- ✓ Give us the beam back as soon as possible, please

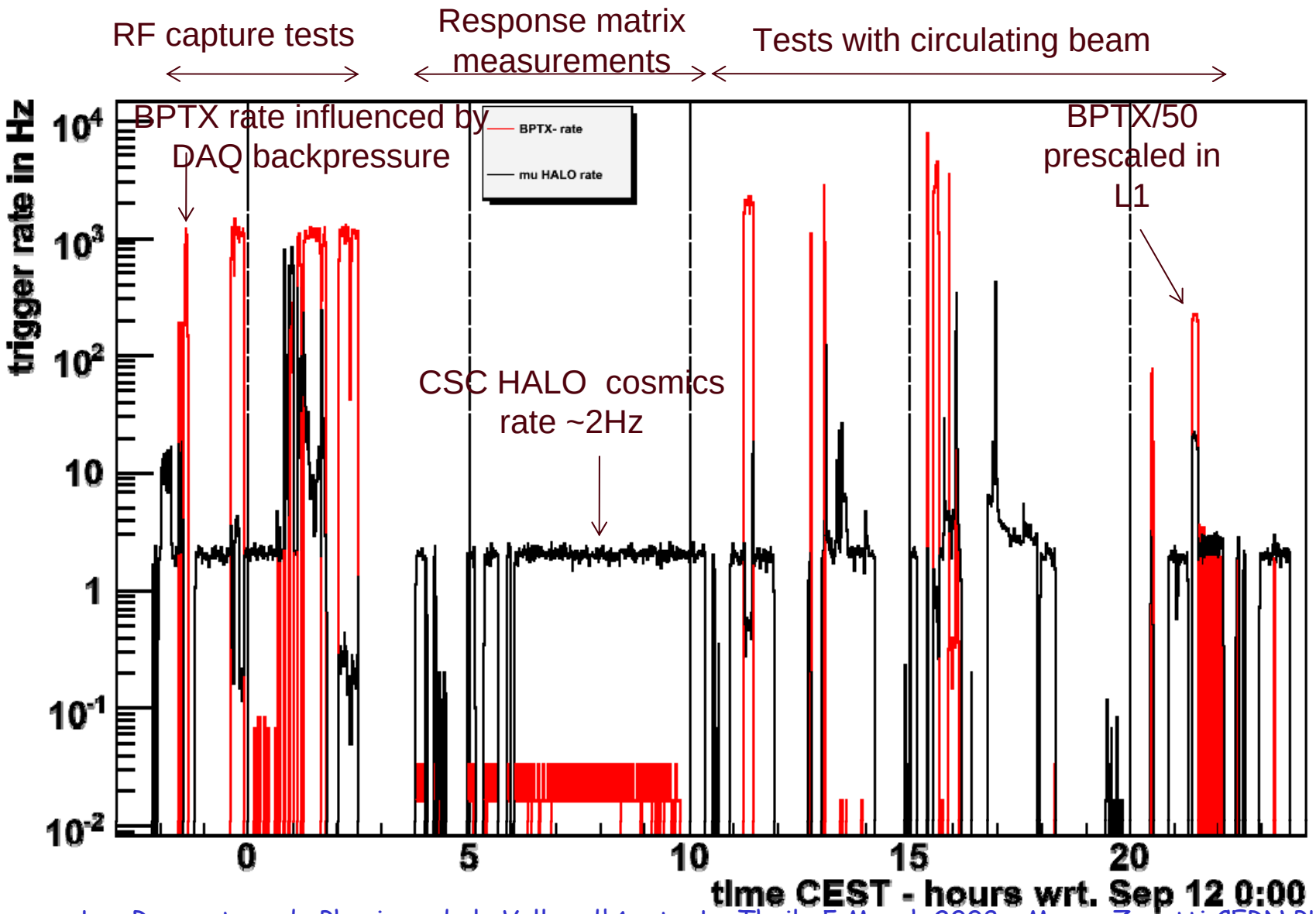
BACKUP

Beam Halo hits distribution

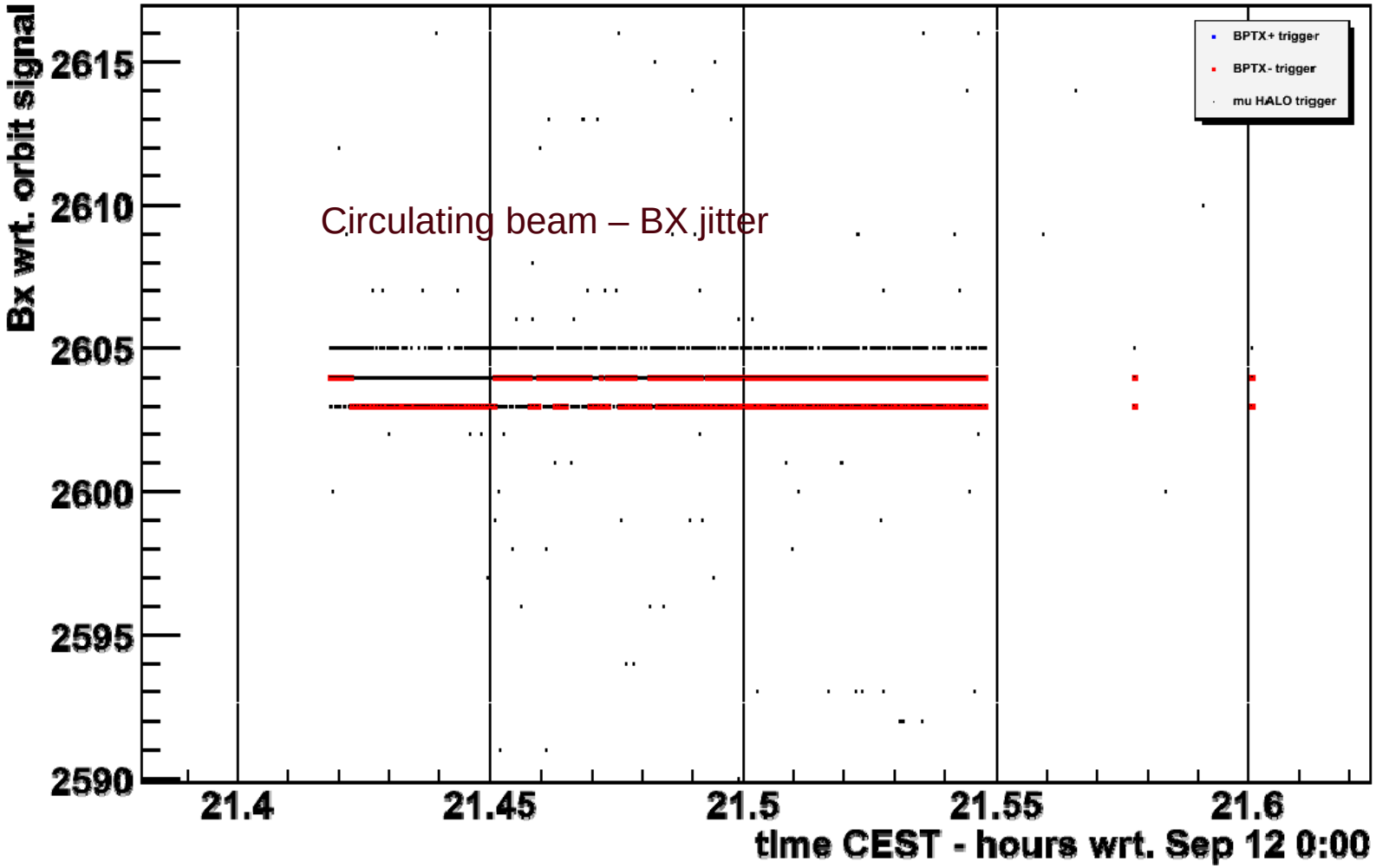
Muon Endcap disks hits occupancies



Trigger rates

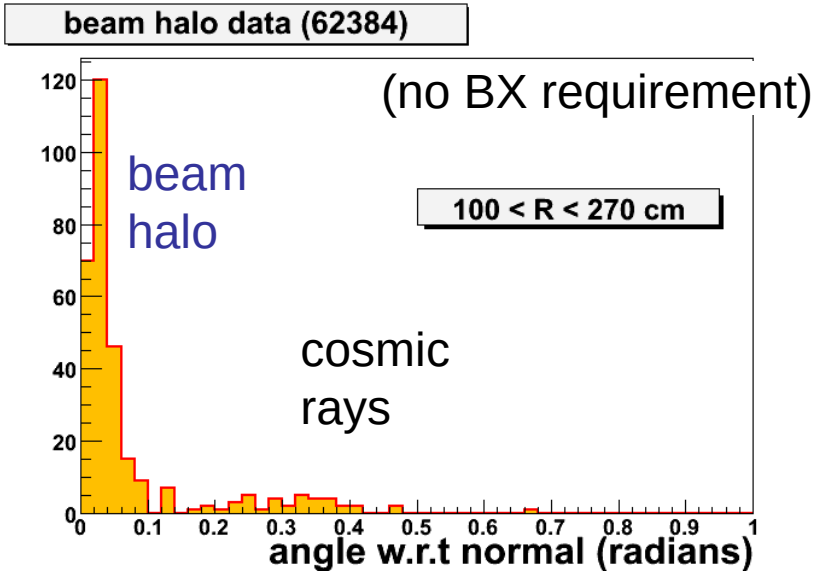


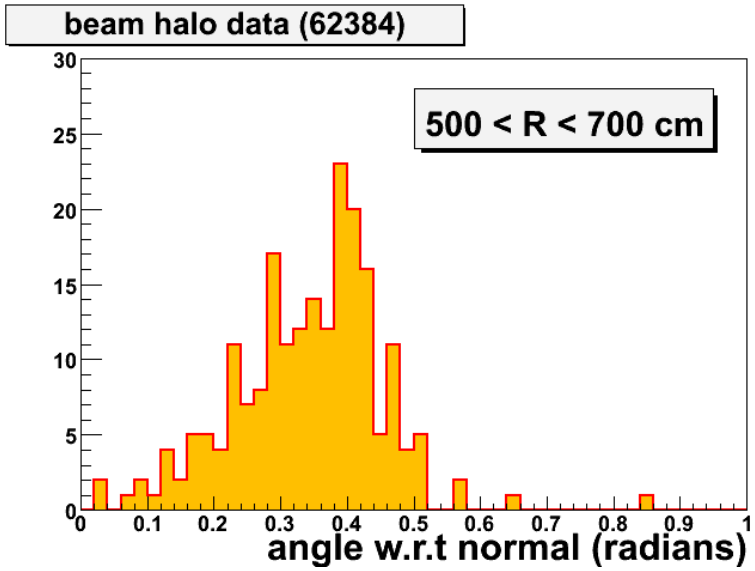
Beam jittering?

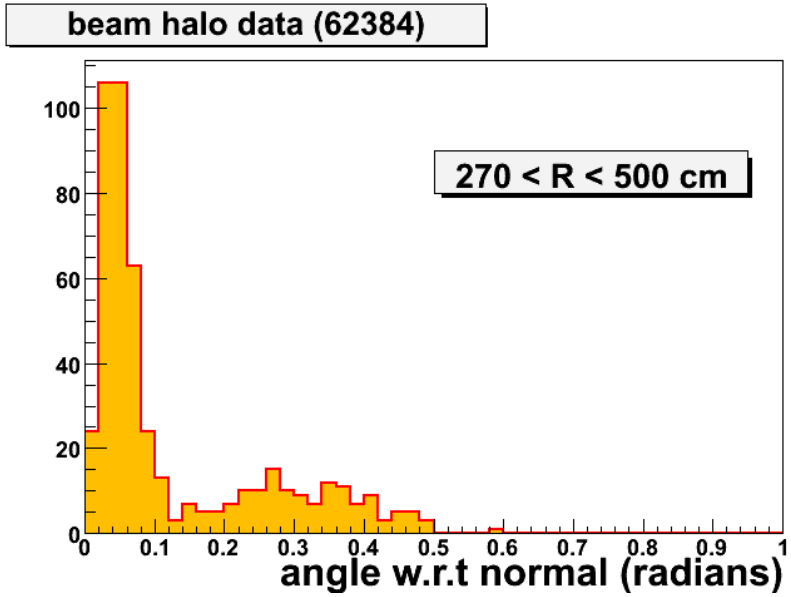


Halo features

Study the angle w.r.t. the normal by selecting regions in R (radius from the beam line)

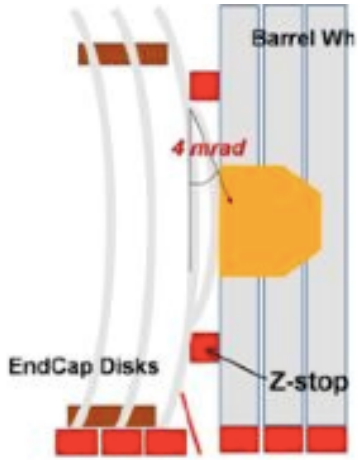


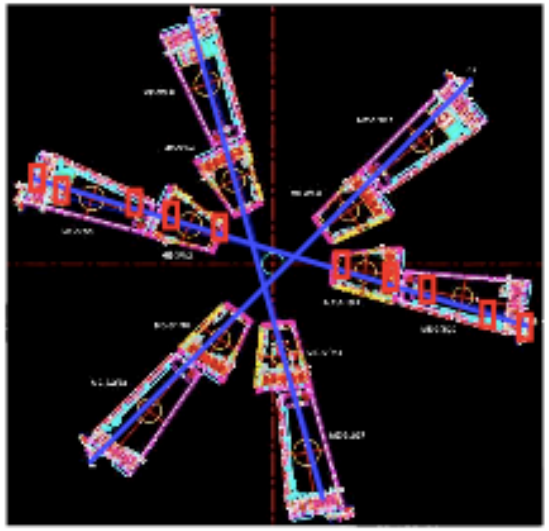




Clearly the large radius is dominated by cosmic rays and the small radius is beam halo, as expected.

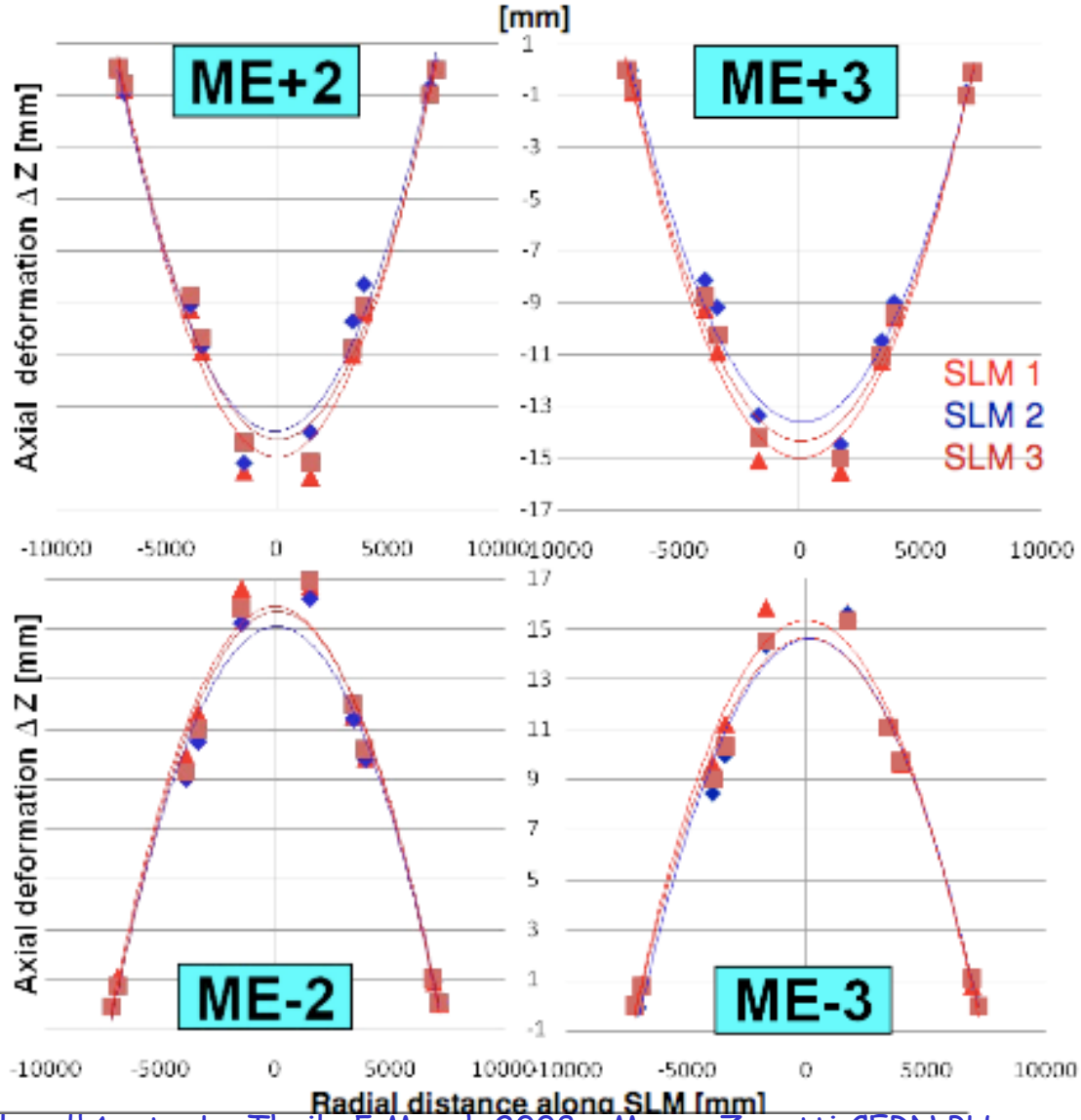
Endcap disk deformation



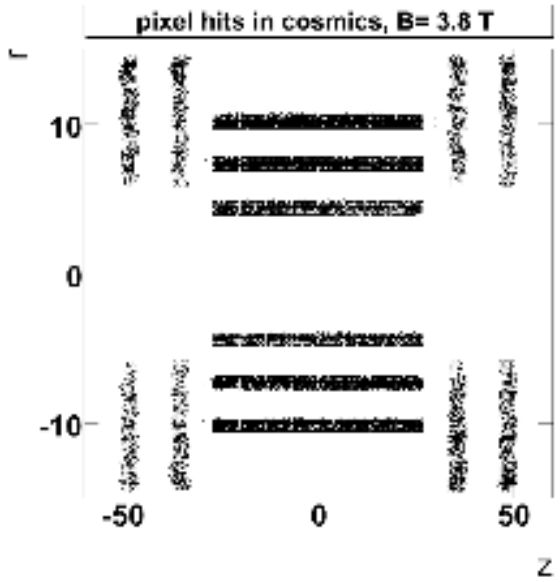


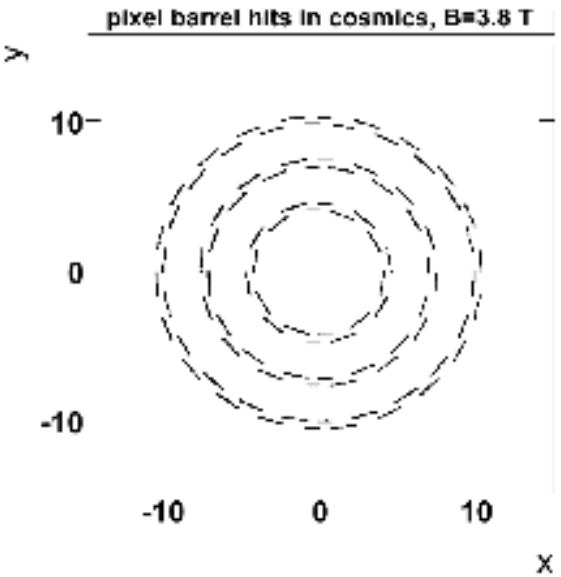
3 Straight Line Monitor (SLM) Laser Lines per Muon Endcap Station

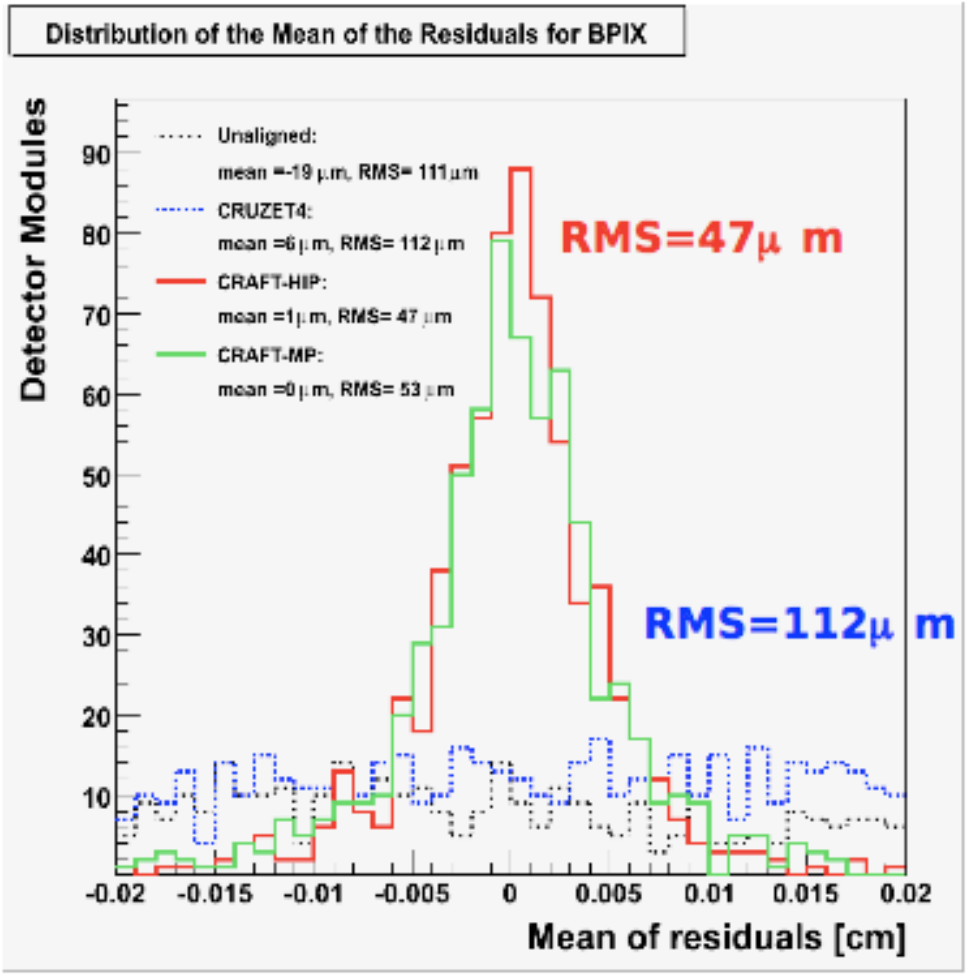
10 optical CCD sensors per SLM



Pixel alignment







- ~75K tracks yielding 200-300 hits per module in Barrel
- Barrel aligned at module level and endcap at disk level

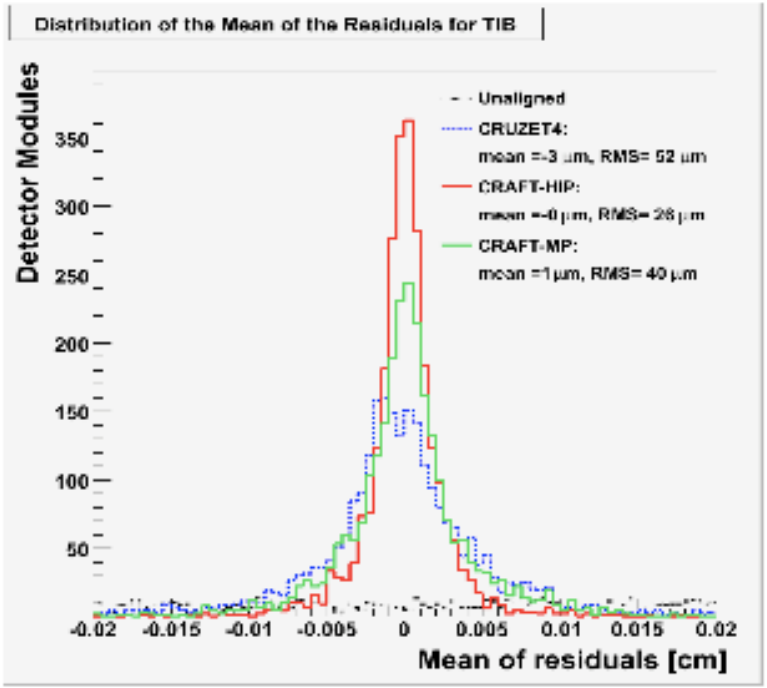
Tracker alignment

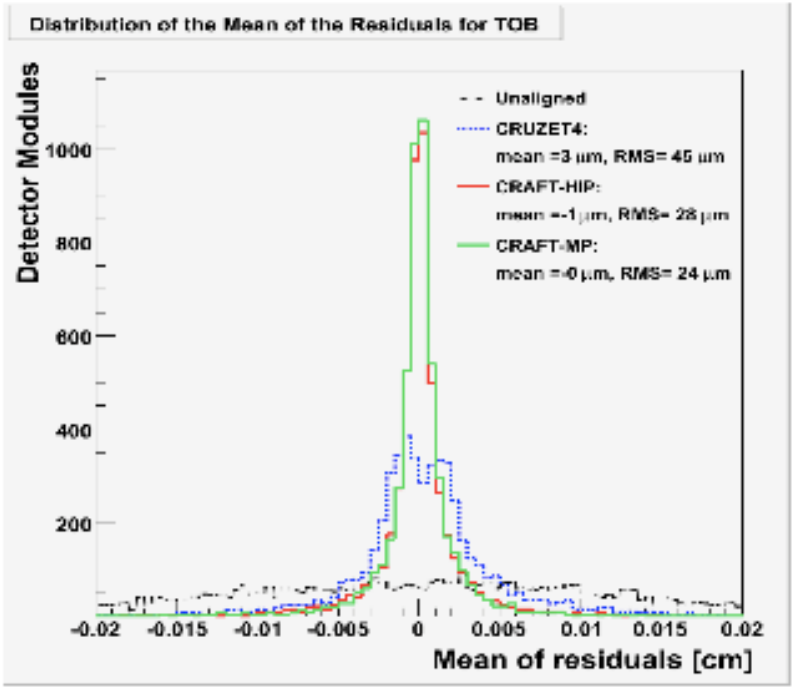
- Use 4M tracks for alignment and 1M for validation
- The second update on alignment constants delivered 1 day after CRAFT ended

Mean of residual distributions (cm), sensitive to module displacements

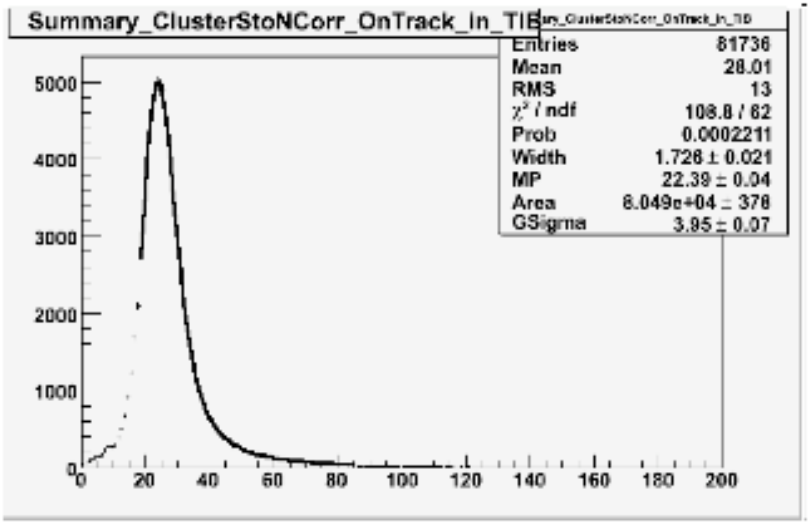
- Only modules with >30 hits considered
- Tracker Inner Barrel RMS = 26µm

Tracker Outer Barrel RMS = 28µm



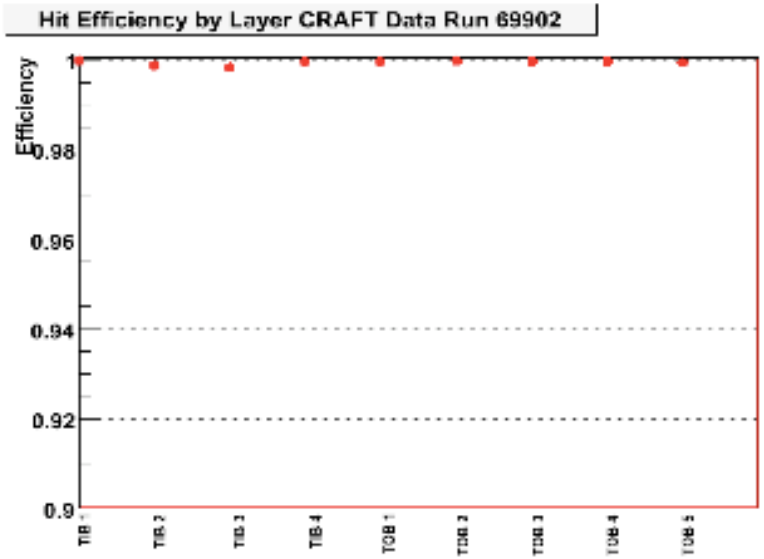


Tracker performances



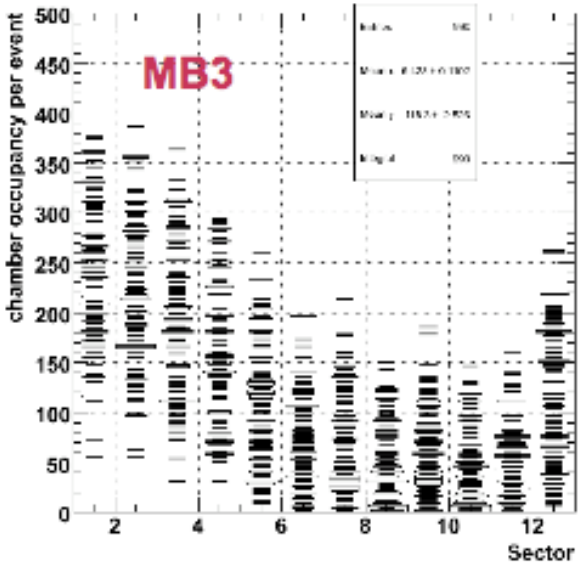
On track Strip clusters S/N ratio in peak mode of the read-out chip, corrected for the track angle

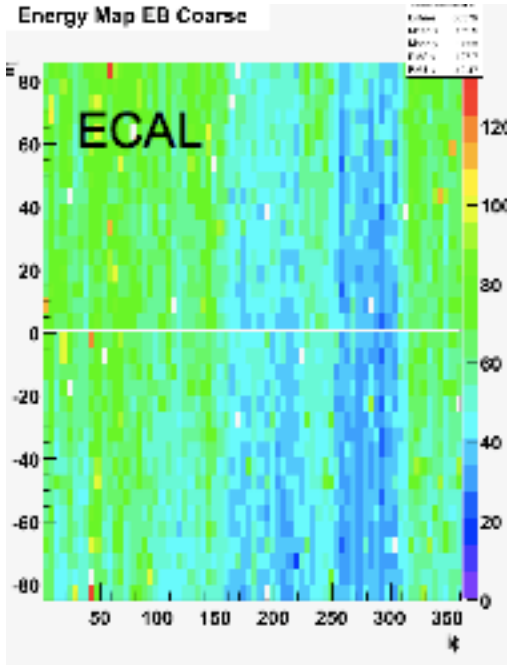
- **TOB thick sensors : S/N = 32**
- **TIB/TID thin sensors : S/N = 27/25**
- **TEC (mixed thickness) : S/N = 30**

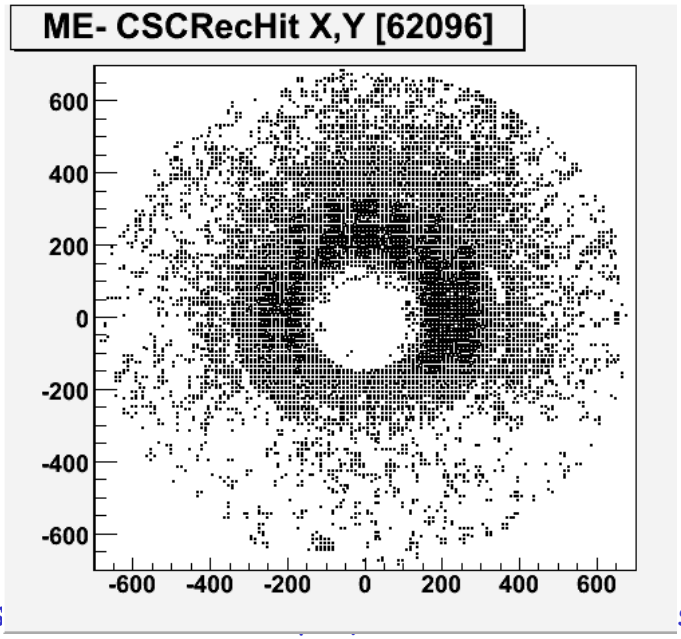


Track hit finding efficiency of TIB and TOB layers, excluding modules not in operation

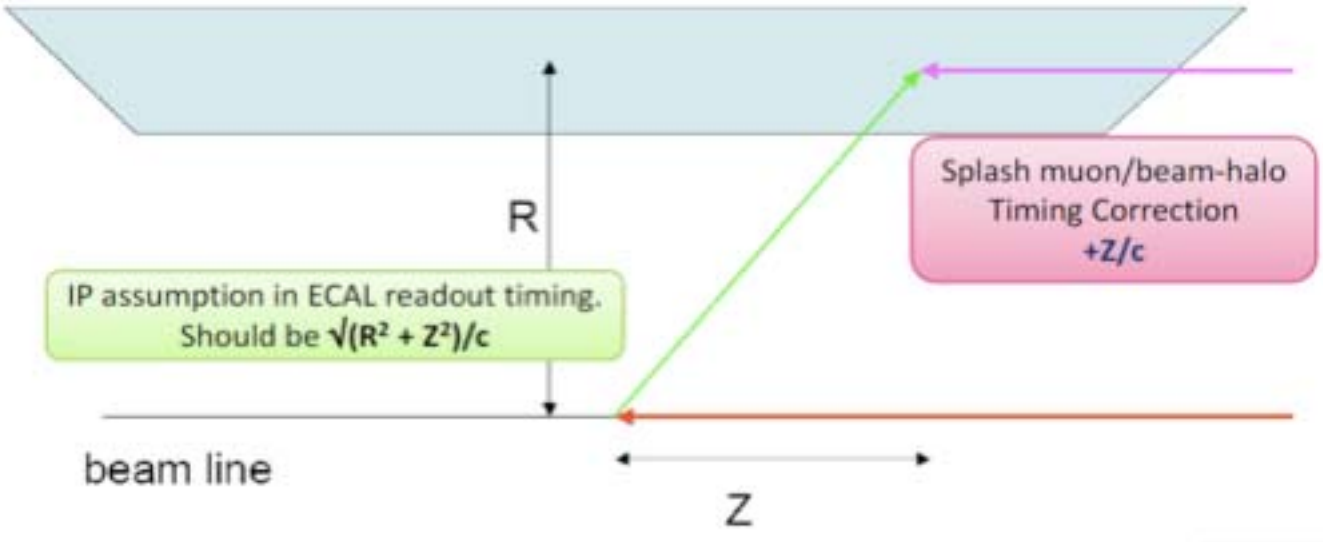
phi asymmetry







Beam Halo Timing



So, in a splash event or beam-halo event, we expect a completely timed in ECAL if we correct each time by

$$\sqrt{(R^2 + Z^2)}/c + Z/c + t_0$$