First LHC Beams in ATLAS

Peter Krieger
University of Toronto
On behalf of the ATLAS Collaboration

WIRED SCIENCE

First Beam Circles Large Hadron Collider Track

The Large Hadron Collider fired its first beam around the machine's full track at 10:28 AM local time (1:36 AM Pacific time).

No actual atoms were smashed today -- that won't start for weeks -- and no results are expected for months, at the earliest. Still, like first light in a telescope, the first beam in the particle accelerator is a landmark moment for a program that has spanned more than 20 years and involved tens of thousands of scientists.

"What has been shown today is that technically it all works," said Jos Engelen, chief science officer for CERN, the European scientific research agency directing the efforts, in a live webcast from Geneva.

The proton beams that raced around the 17-mile mile track begin a scientific relay that is likely to last for more than a decade. Scientists hope the discoveries made possible by the LHC will open new frontiers in physics and provide a new fundamental understanding of the universe.

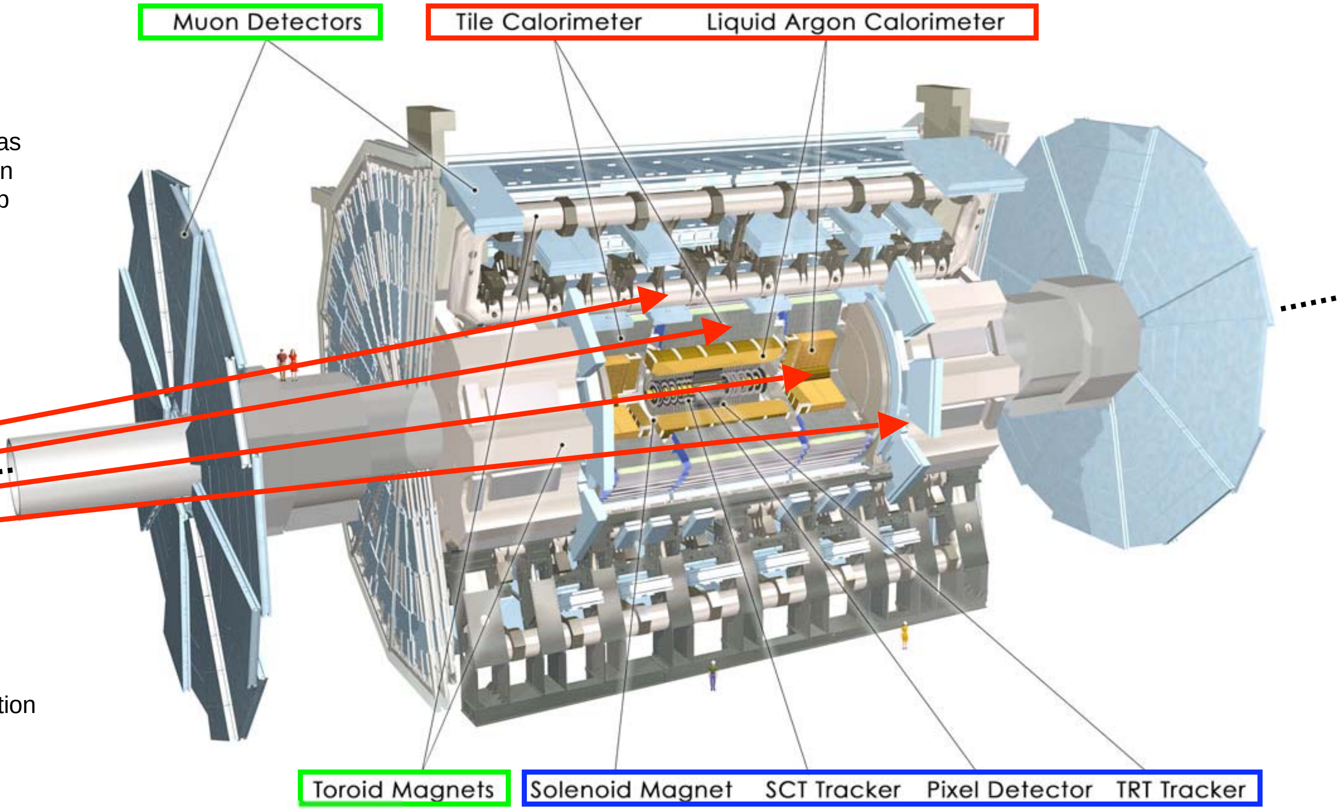
Next up for the collider is cranking up the energy of the proton beams to about 10 trillion electron volts, more powerful than other particle accelerators like Fermilab's Tevatron but still short of the proposed maximum collision energy of 14 trillion electron volts that the researchers hope to reach.

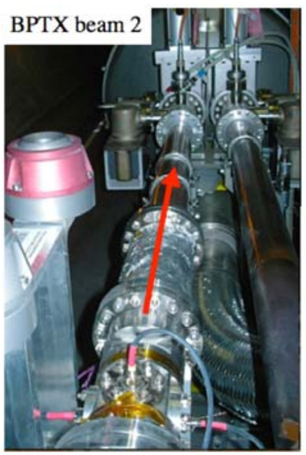
The next big moment will come when the first particle collisions occur. That had been tentatively scheduled for the official LHC unveiling on October 21, but the first beam firings could lead to an acceleration of that schedule.

"Based on today's evidence, things are going to move faster," said Mike Lamont, a member of CERN's beam operations team in the CERN webcast. "There's a remarkable number of systems working remarkably well -- the instrumentation, the magnets. There's still some hurdles to cross there, but we can anticipate collisions sooner than we planned."

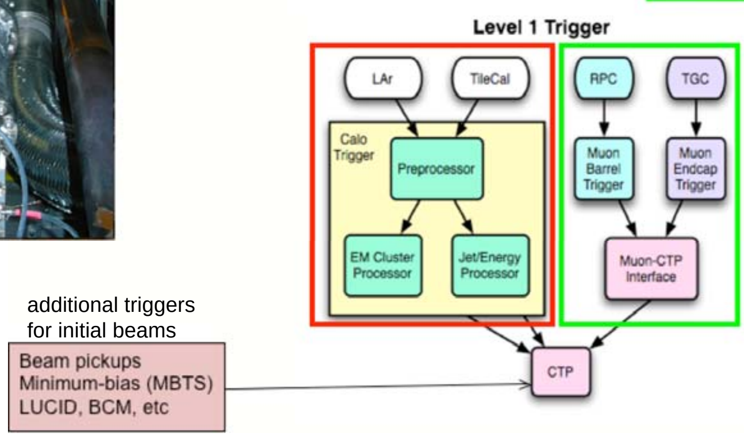
The ATLAS Detector & Trigger System

MBTS: minimum-bias trigger scintillator: on inner face of endcap calorimeter



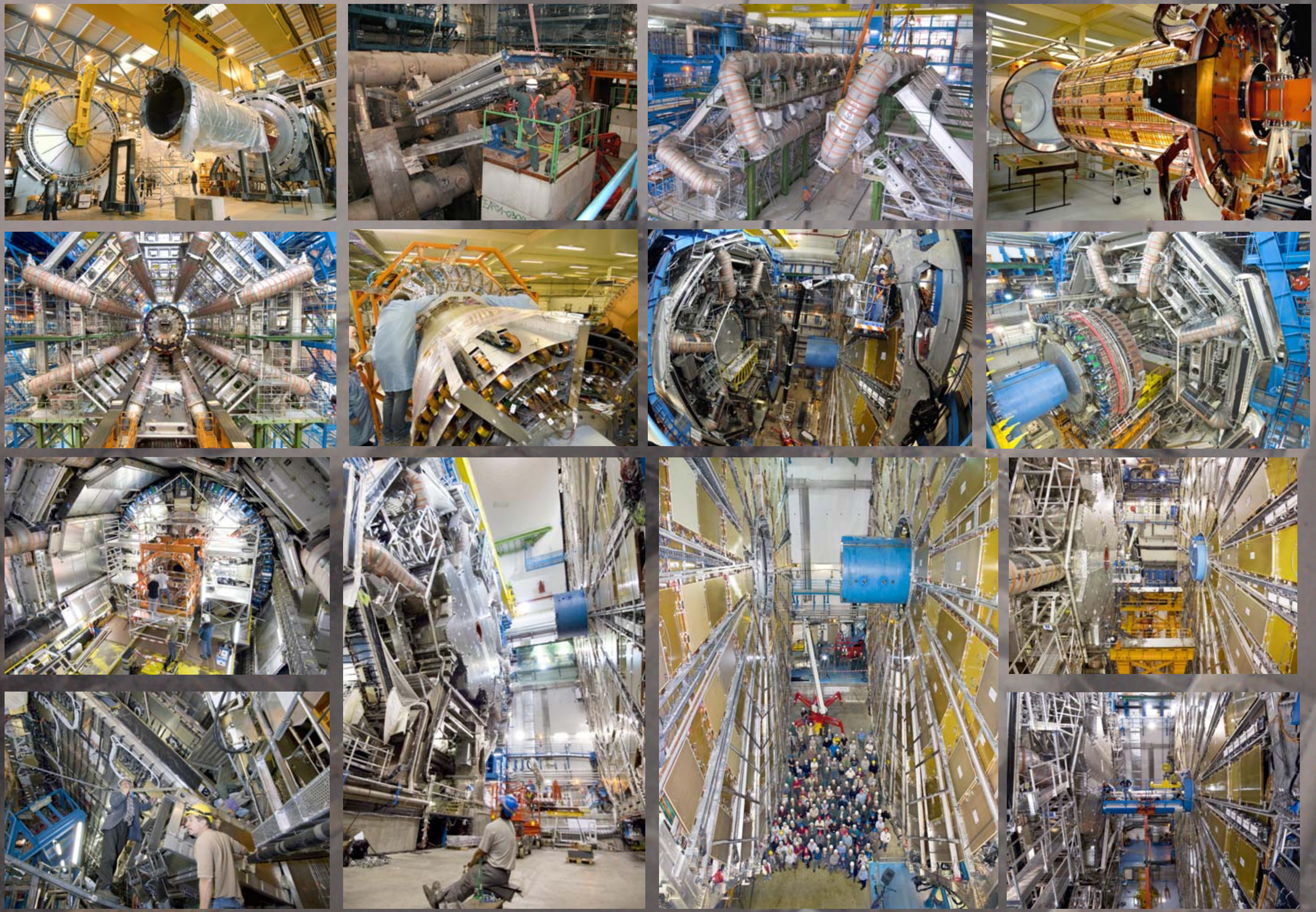


BPTX: electrostatic beam-pickup 175m upstream of interaction point



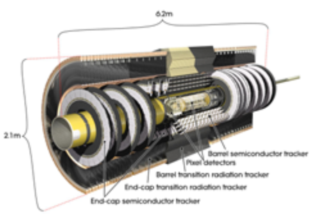
LUCID: 17m from interaction point. Luminosity monitor

UX15 ulx16 Wed May 21 17:11:15 2003 to closure of LHC beam-pipe (in ATLAS region) June 2008

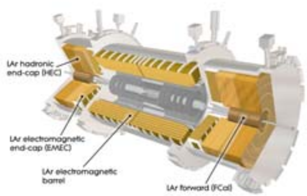


ATLAS Subsystems Readiness for Beam

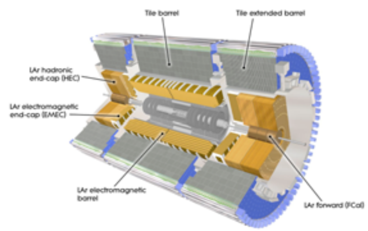
Years of ATLAS commissioning without beam described in talk earlier today by Joerg Dubbert.



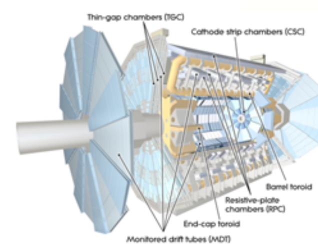
Inner Detector



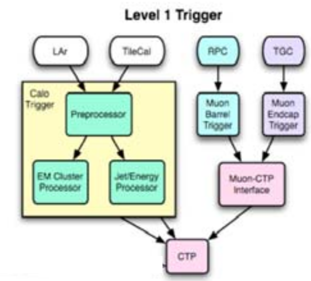
LAr Calorimeter



Tile Calorimeter



Muons



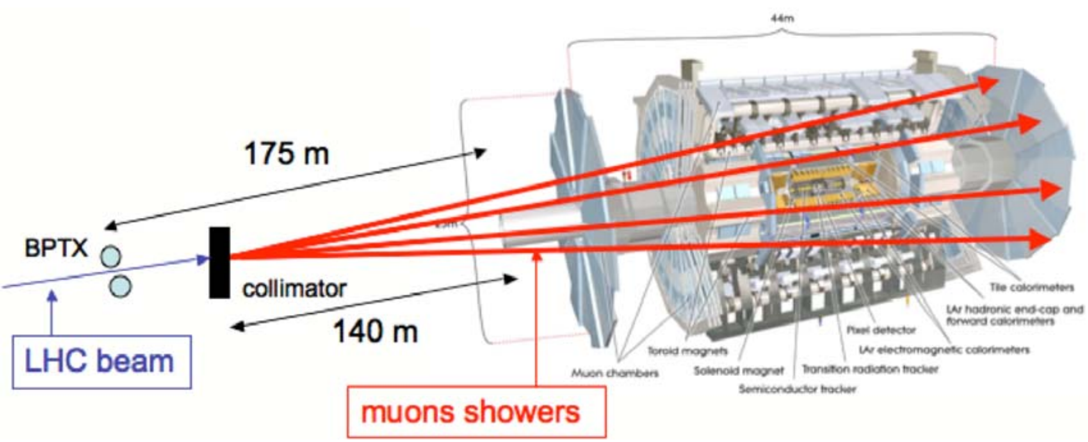
Trigger

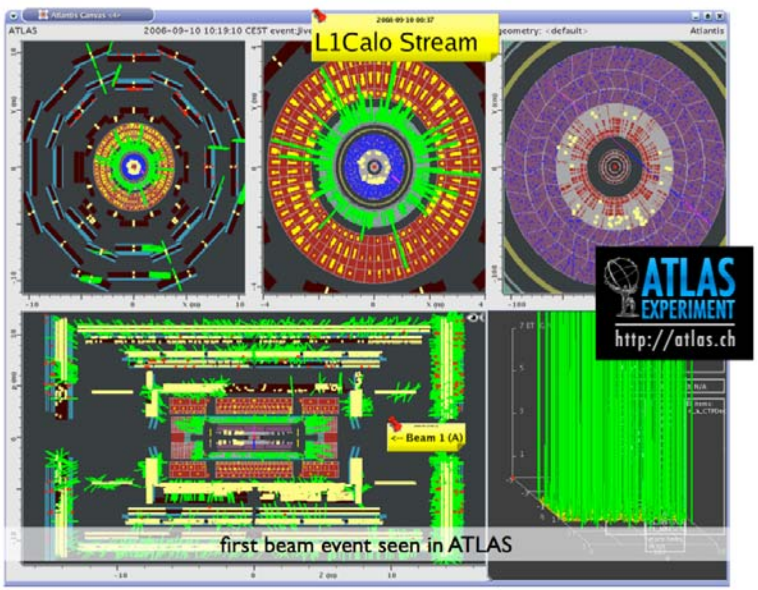
- Current status of detector presented in talk by Joerg Dubbert earlier today (will not repeat this).
- The situation on Sept. 10th was essentially the same: ATLAS was ready for data taking.
- Some subsystems were OFF or at reduced voltage during first beams (for safety). Briefly:
  - Inner Detector: Pixels OFF, Barrel SCT OFF, Endcap SCT at reduced HV, TRT ON (without Xe)
  - LAr Calorimeter: Forward Calorimeter (FCal) at reduced HV
  - Tile Calorimeter: Normal operation
  - Muons: Some regions at reduced HV (in region of high η)
- High level trigger was not run in real time for single beam running. Was used to stream the data from different Level1 triggers and has since been used to process single beam data offline.

First Single Proton Beams in ATLAS

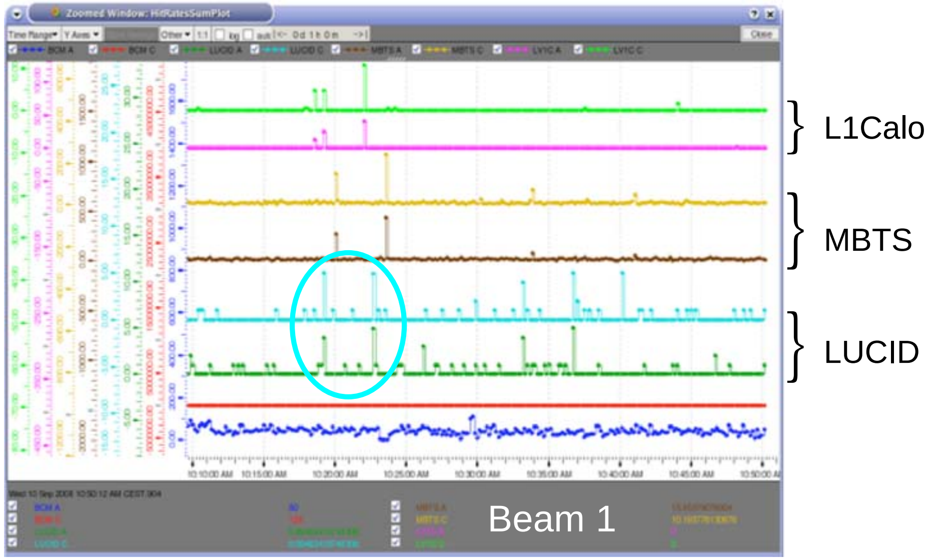
- First beam through ATLAS Sept. 10, 2008.
- Beam “splash” events with closed collimators (on relevant side).
  - Beam 1 from ATLAS A side
  - Beam 2 from ATLAS C side
- Calorimeter energy deposits of several TeV (up to ~1000 TeV).
- Circulating beams: typically lower energy deposits, depending on beam conditions (see *e.g.* run 87863 in table)

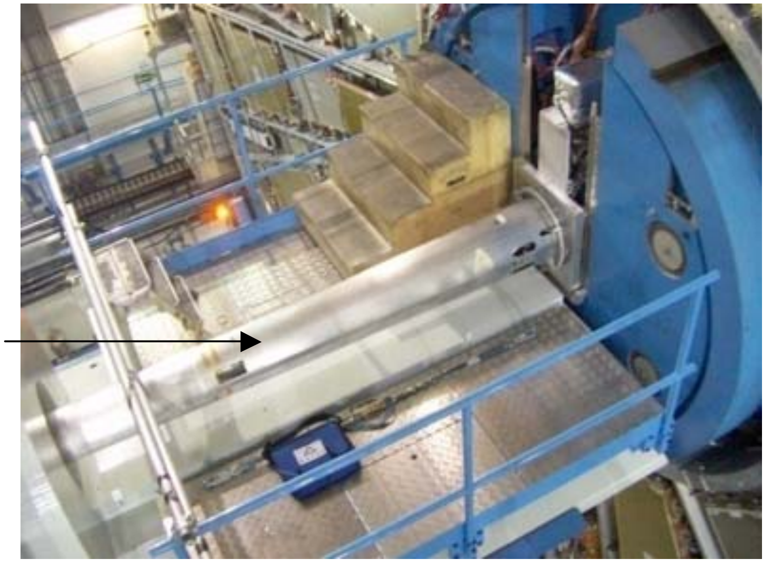
Run Number	LVL1 trg (#LVL1A)	Beam	Detector config
87764	BPTX (at end) (7) MBTS_BCM_LUCID (157634) L1Calo (41274)	Both directions, Splash events	LAr DSP conds pb Bad LVL1 trg timing for LAr
87851	BPTX (86)	Beam 2, Splash events	LAr ok in 5 samples
87860-2	BPTX (3)	Beam 2 No collimator splash evts – but some high Energy evts	LAr 32 samples
87863	BPTX (3948)	Beam 2 No splash events but some high Energy events Beam making 100s of turns by end	
88069	BPTX (155104) MBTS_BCM_LUCID (2006)	Beam 2 Injecting and circulating	TRT out from now (change gas), RPC out, LAr out
88128	BPTX (9860) MBTS_BCM_LUCID (5718)	Beam 2 Nearly stable beam	LAr 32 samples MBTS/BPTX in time
88153	MBTS_BCM_LUCID (34598)	Beam 2 after 15.25	
88234	MBTS_BCM_LUCID (3978)	Short beam period	

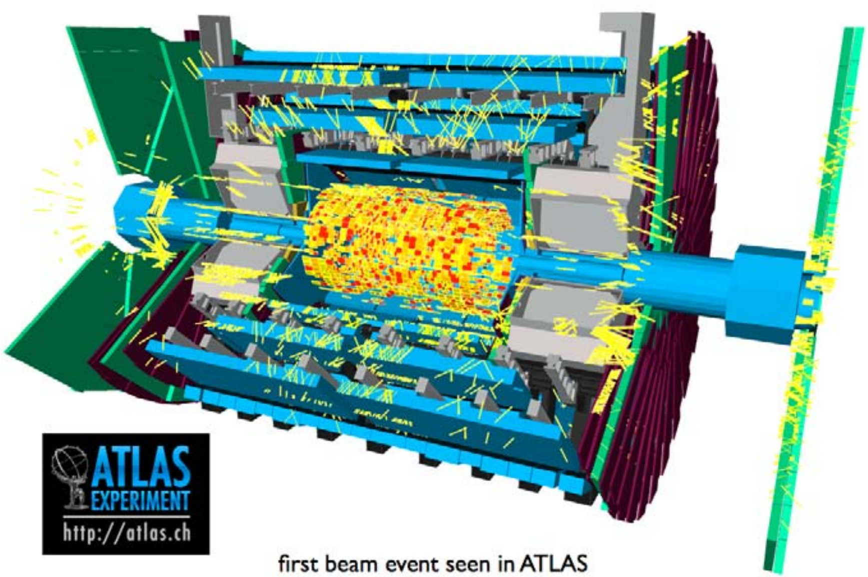


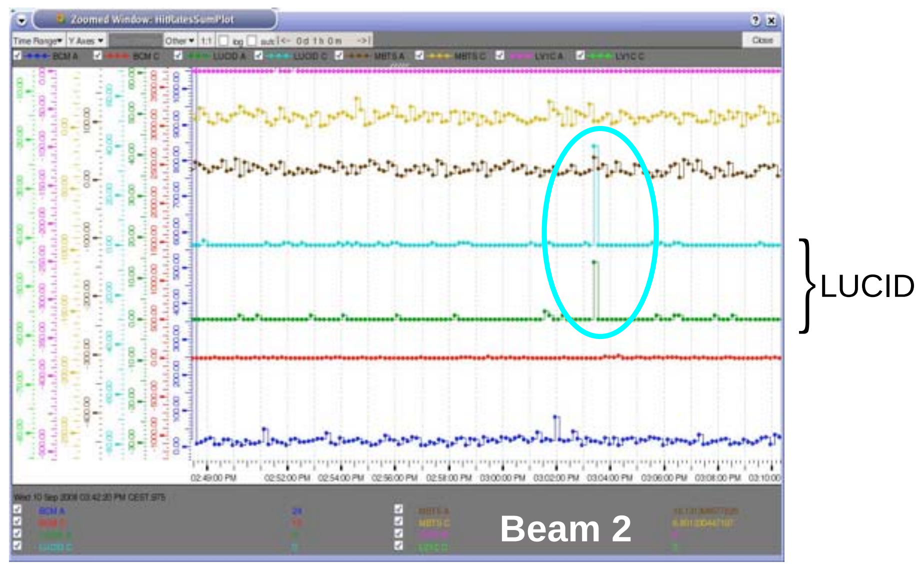


First Hits in LUCID Detectors, Sept 10.



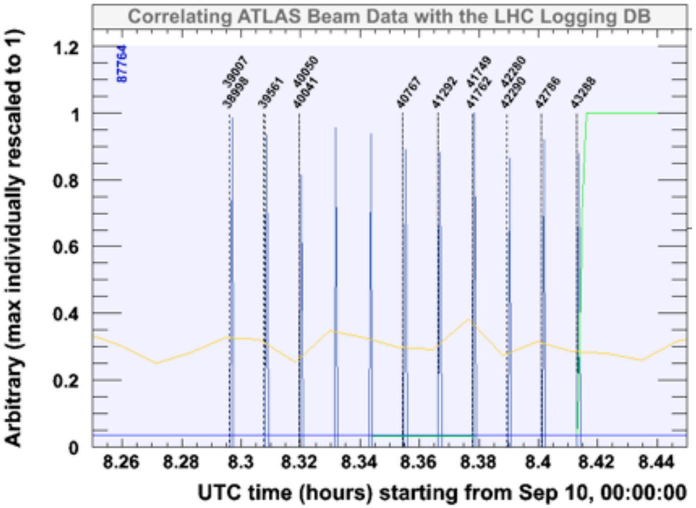




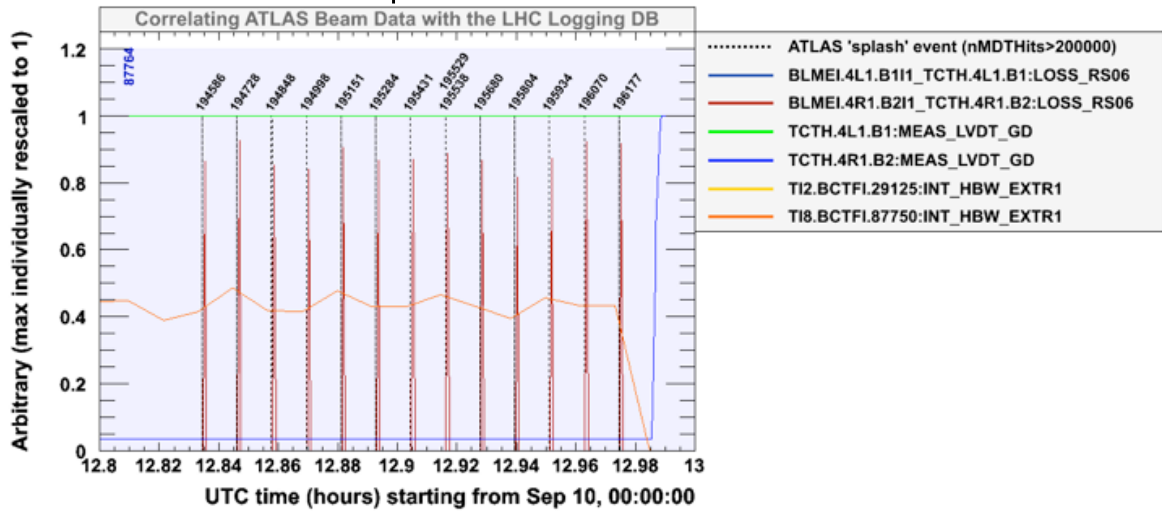


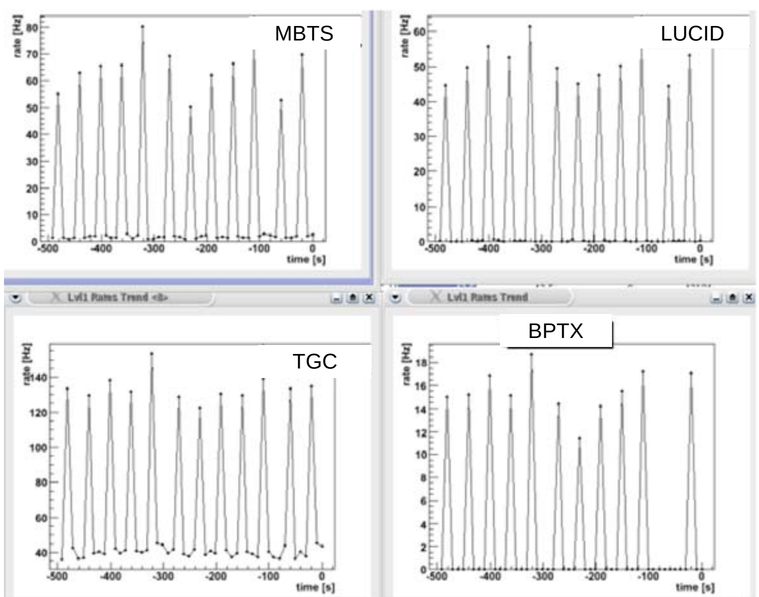
Beam Splash Events in ATLAS

Beam 1 splash events



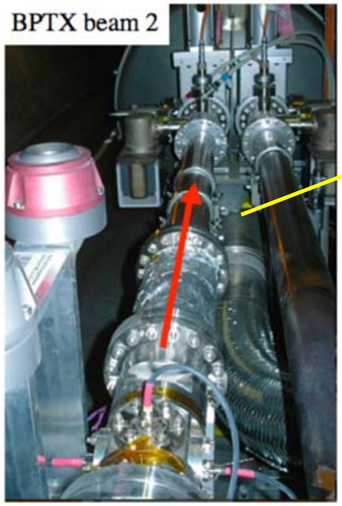
Beam 2 splash events



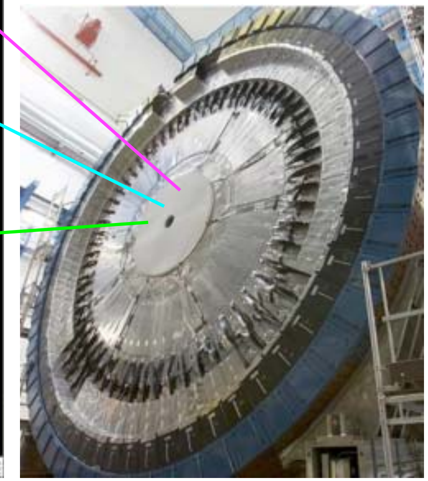


- Collimator “shots” every 42s
- Bunch intensities ~ 2x10^{9} p / bunch
- BLM lines show LHC beam-loss monitors after collimators on either side of ATLAS.
- Dotted lines are triggered beam splash events
- Can produce millions of muons through ATLAS

First Circulating Beam in ATLAS

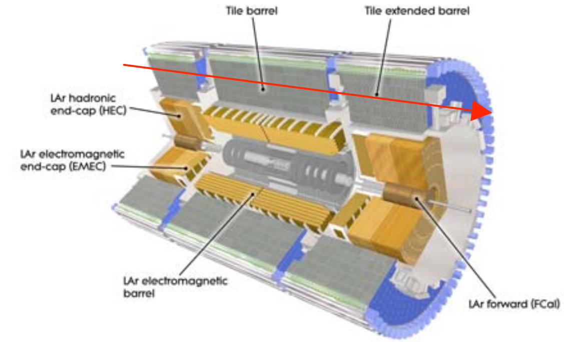


MBTS minimum-bias trigger scintillator on IP-side face of endcap calorimeter



Beam losses evident for last few turns where BPTX trigger signal disappears but MBTS triggers appear and continue for two more turns (every 89μs: single bunch, once per orbit)

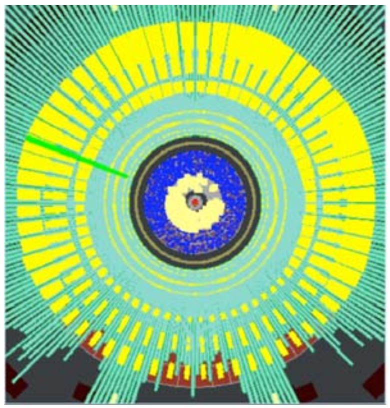
Energy Deposits in the Tile Calorimeter

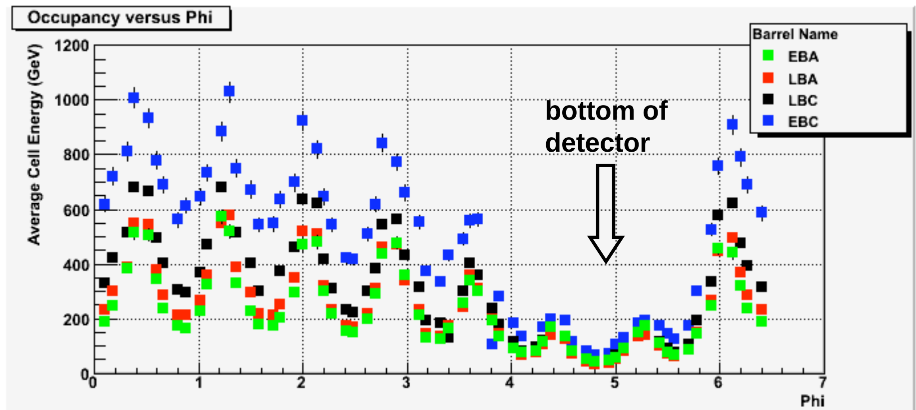


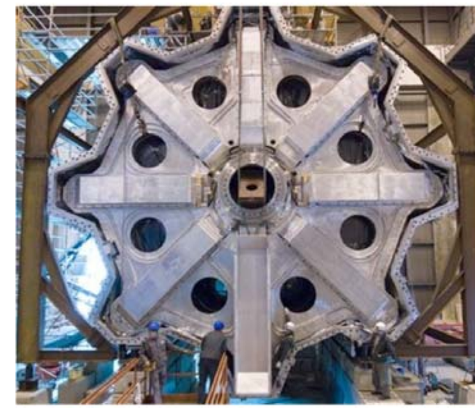
Energy deposits in TileCal from beam splash (collimator) events

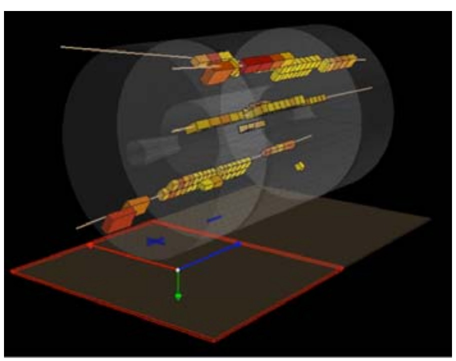
Also from beam-halo events (lower left)

Eight-fold structure in ϕ due to material of endcap toroid

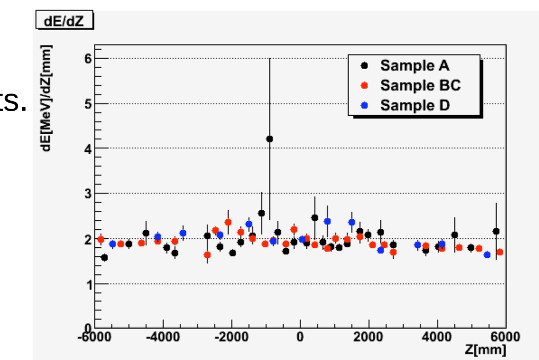






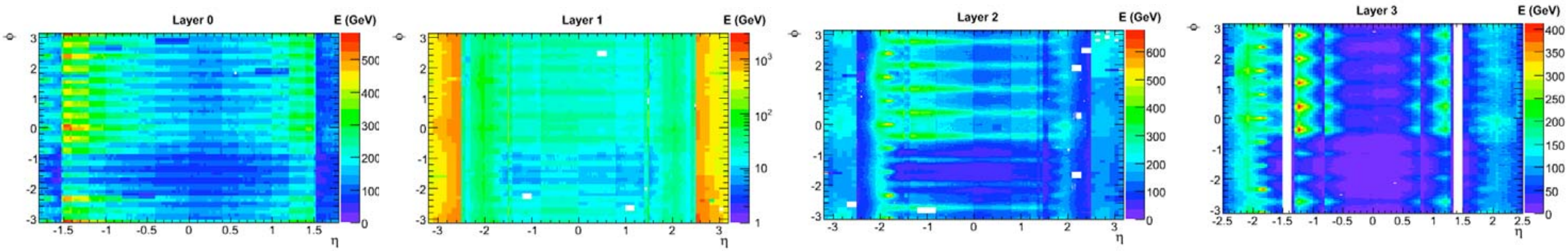


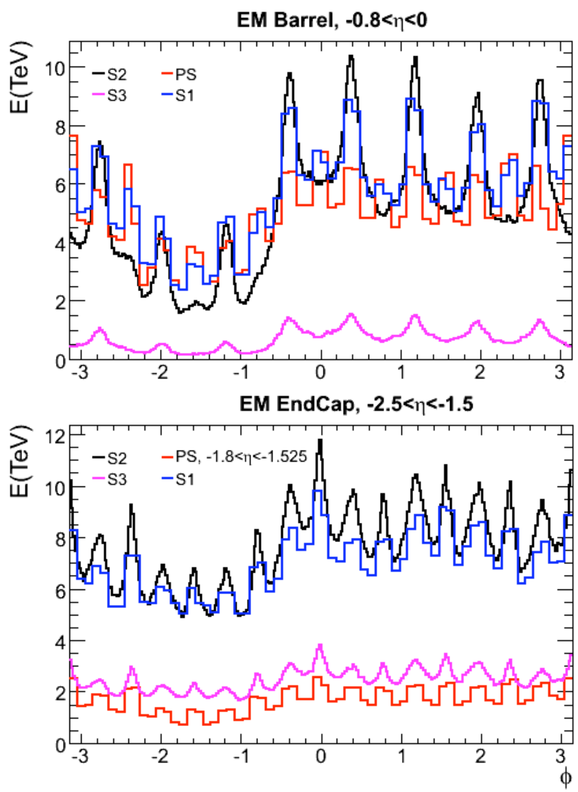
- Muon energy deposition from “scraping” or halo events.
- Consistent mean response validates Cesium cell response equalization procedure.
- Result consistent between partitions at the 6% level.



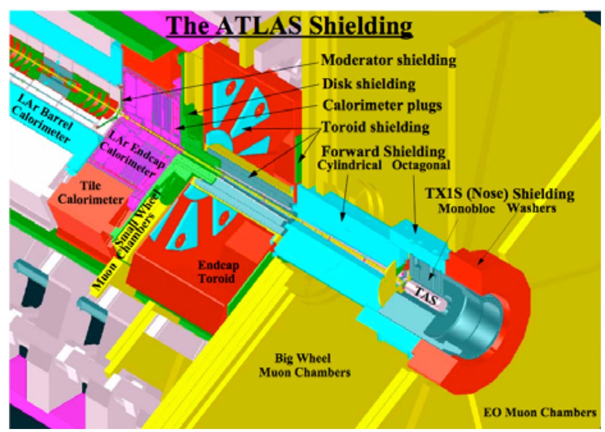
Energy Deposits in the LAr EM Calorimeter

Layer η-ϕ plots show EM Calorimeter coverage and exhibit the 8-fold structure also seen in Tile Calorimeter.

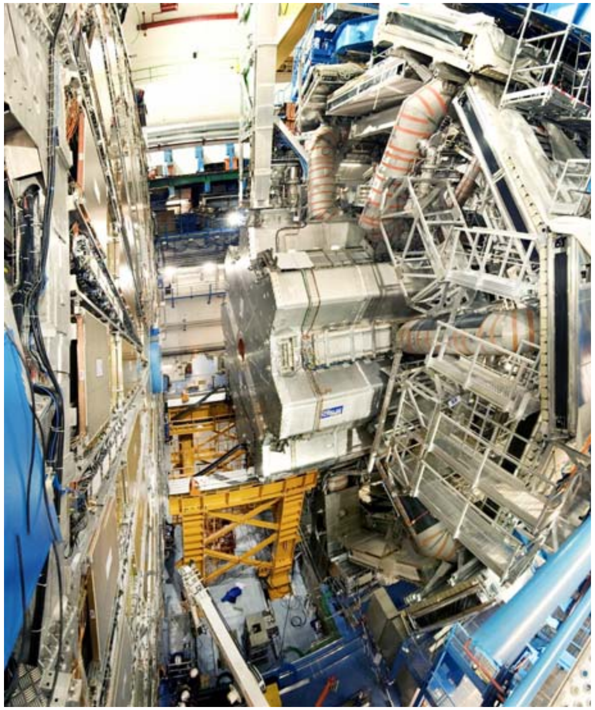




Energy vs ϕ plots display this more clearly. 16-fold structure also visible due to additional material.



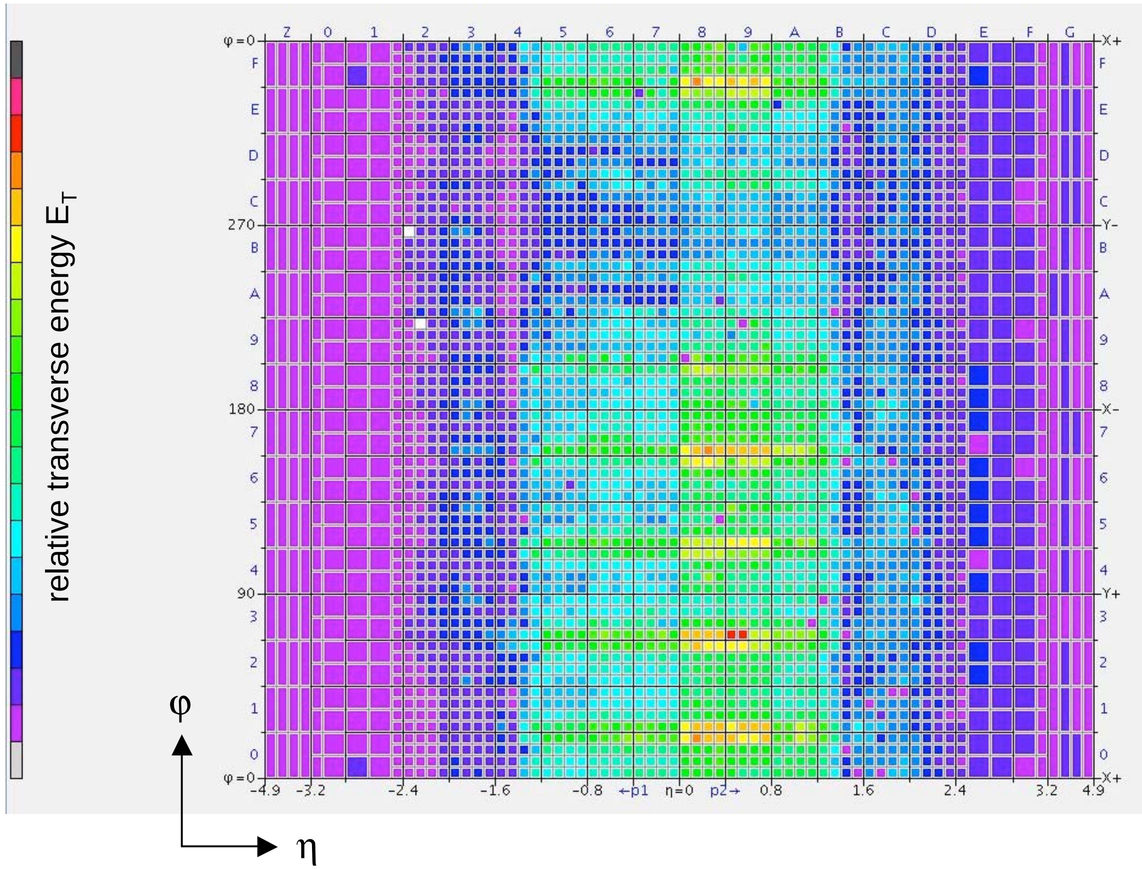
As in Tile Calorimeter, lower response around ϕ~ -π/2 due to additional material (mainly detector support structure)



LAr Level1 Calorimeter Trigger

Pattern of energy deposition and Level-1 Calorimeter trigger tower coverage also visible in the plot below: relative transverse energy in each trigger tower. Eightfold structure still apparent.

Observed asymmetry between A and C sides due to fact that timing for C-side was off the ideal value by 1 bunch crossing (BC). This was corrected as a result of this observation.



LAr Calorimeter Pulse Shape Studies

LAr energy reconstruction relies on *a priori* knowledge of the signal shape, for each channel. This is provided by the electronic calibration system. Performance requirements (for example $H\rightarrow\gamma\gamma$ mass resolution) dictate a constant term of < 0.7% in EM calorimeter energy resolution.

LAr EM calorimeter pulse shape studies (to check pulse shape predictions from calibration system) discussed in earlier talk (J.Dubbert). Single-beam events yield many more cells having high energy deposits (so good pulse shapes).

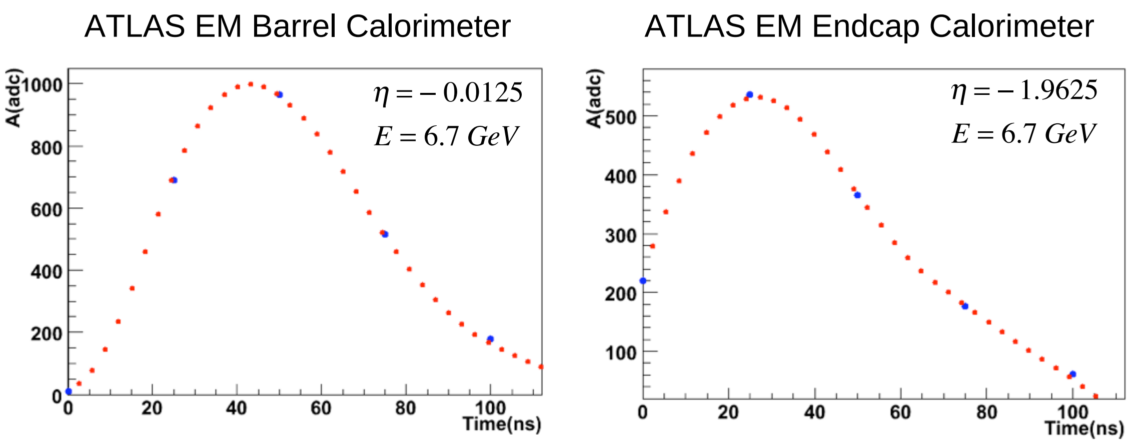
LAr data taken both in 5 sample (as in normal running) and 32 sample mode. Checks done with both samples. Extensive studies with 5 sample data from run 87851.

Run 87851

Beam 2 with BPTX trigger

86 events mainly from beam splash

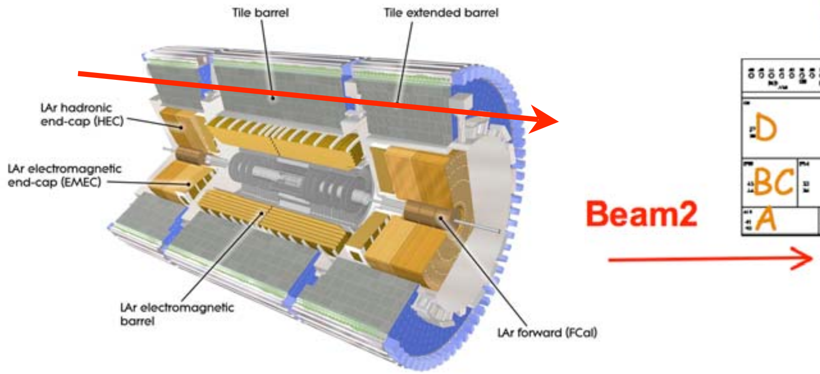
Red points show pulse shape prediction from calibration system.

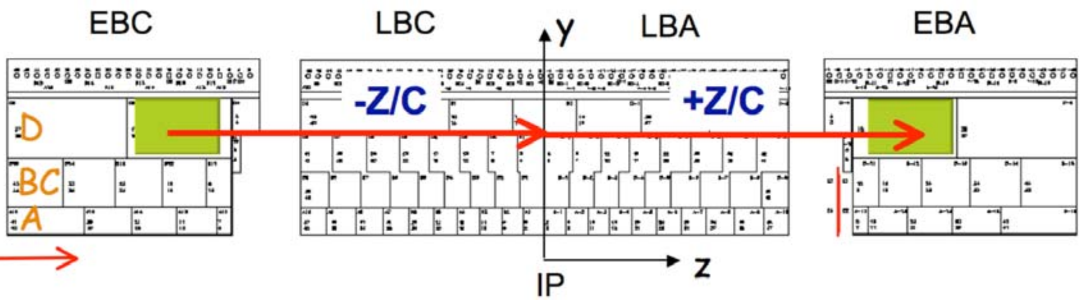


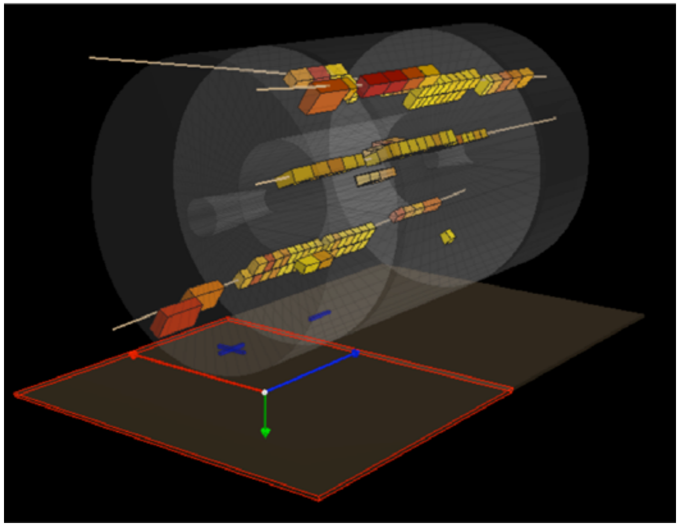
61% of all (~ 160K) EM Calorimeter cells have been examined so far.

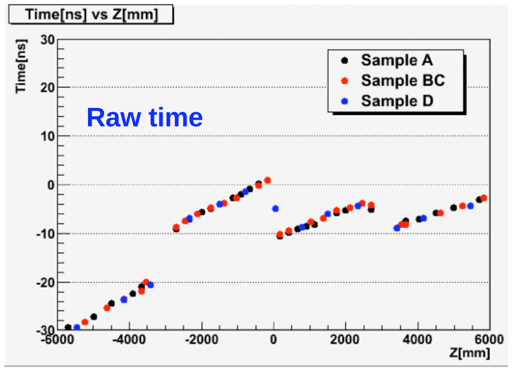
Timing Studies in the Tile Calorimeter

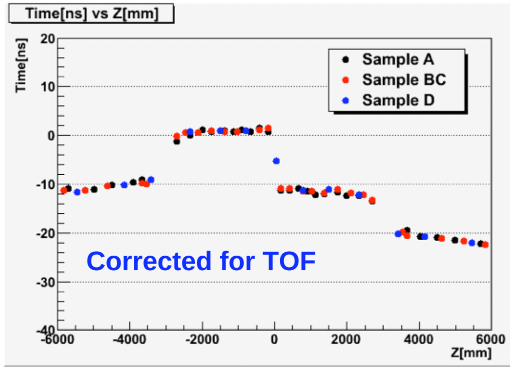
Beam-splash and beam halo events both yield ~ horizontal muons that can be exploited for checks of the timing







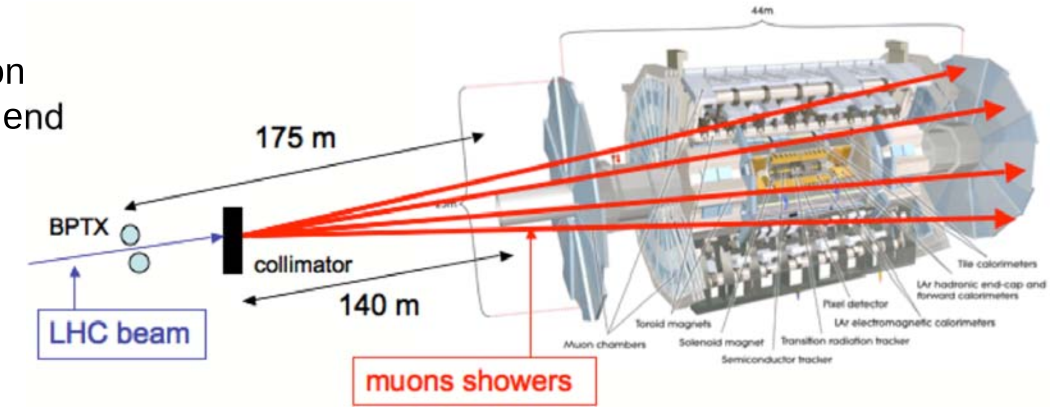




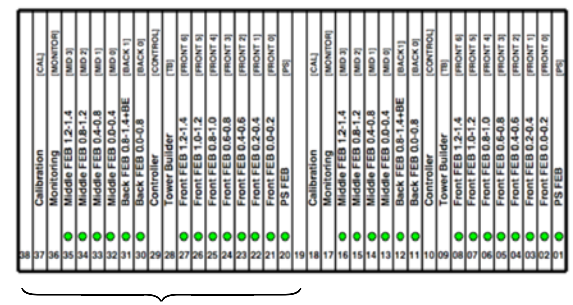
- Time dispersion in each partition ~2ns.
- Offsets between partitions well within 1 BC

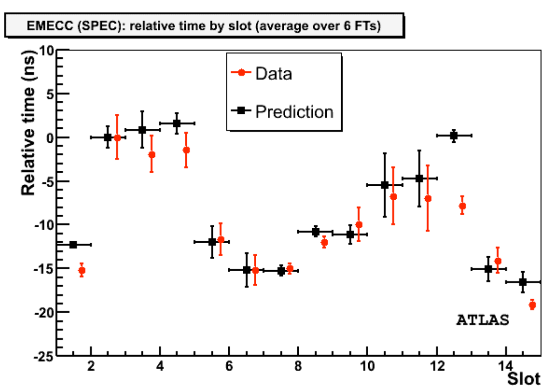
LAr EM Calorimeter Timing Studies

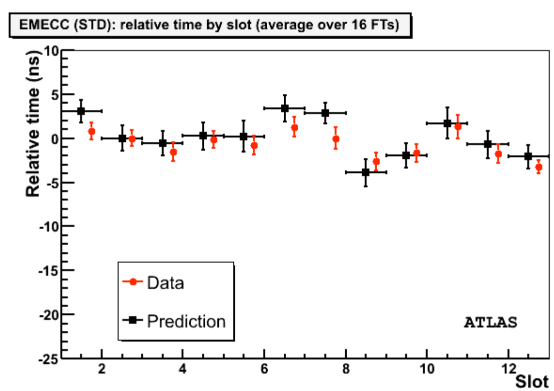
- Difference between physics and the calibration timing extracted per cell and per type of front end board:
  - start with measured signal time (BPTX trigger)
  - apply time of flight correction (to get time equivalent to collision)
- Compare to calculation of this offset due to different cable lengths.
- 1 Delay adjustable by Front End Board (FEB)
- Adjust to sample physics pulses at the maximum on average over the FEB.
- Predict set of FEB delays for “day 1” of collisions

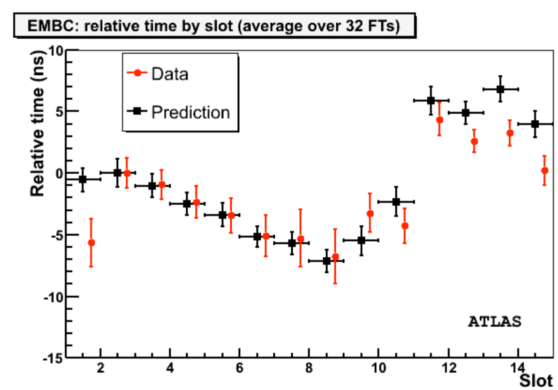


LAr EM Barrel Front End Crate

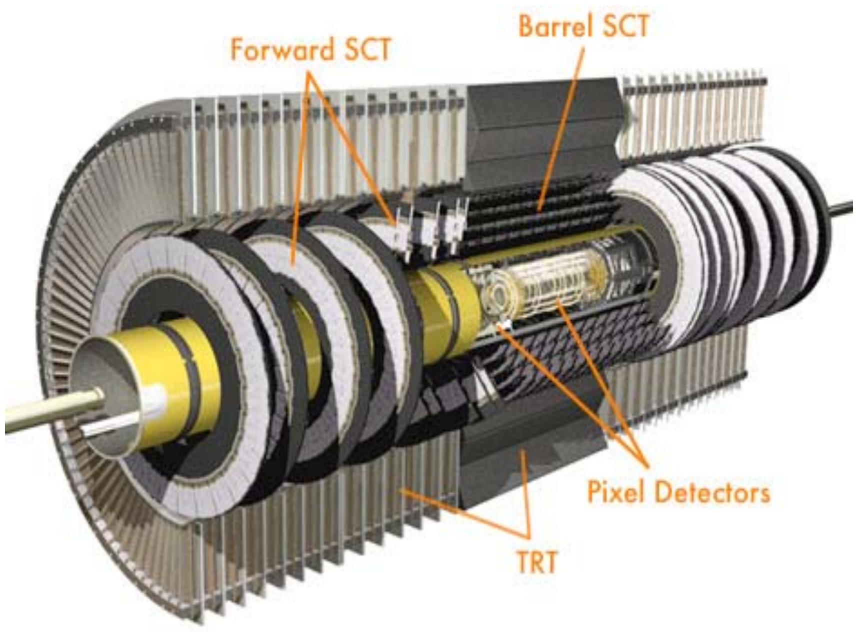


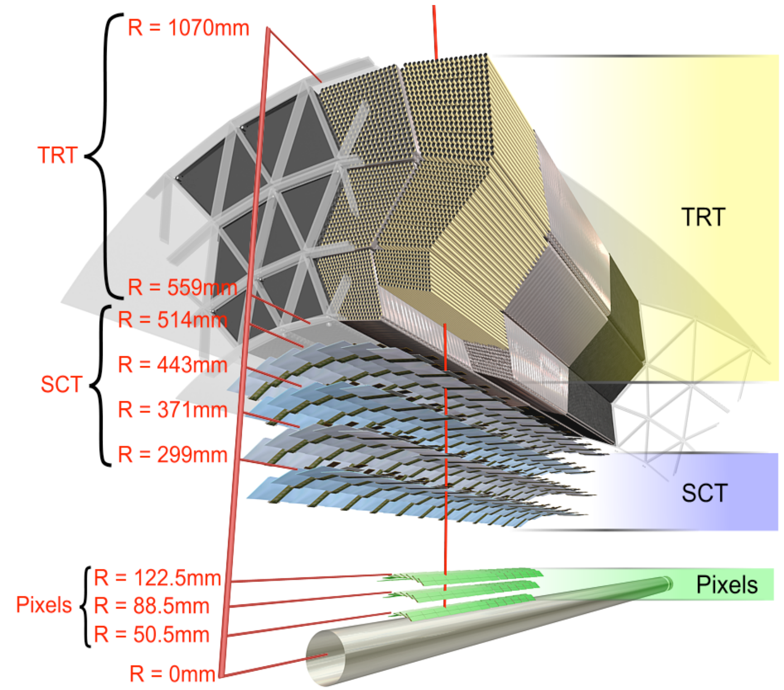






The ATLAS Inner Detector

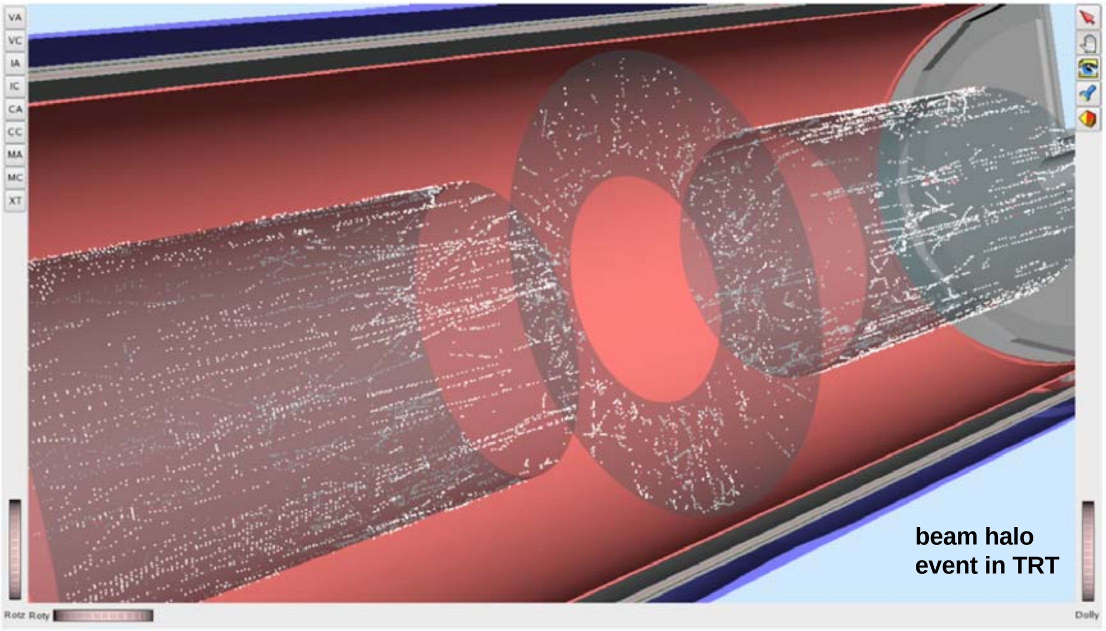




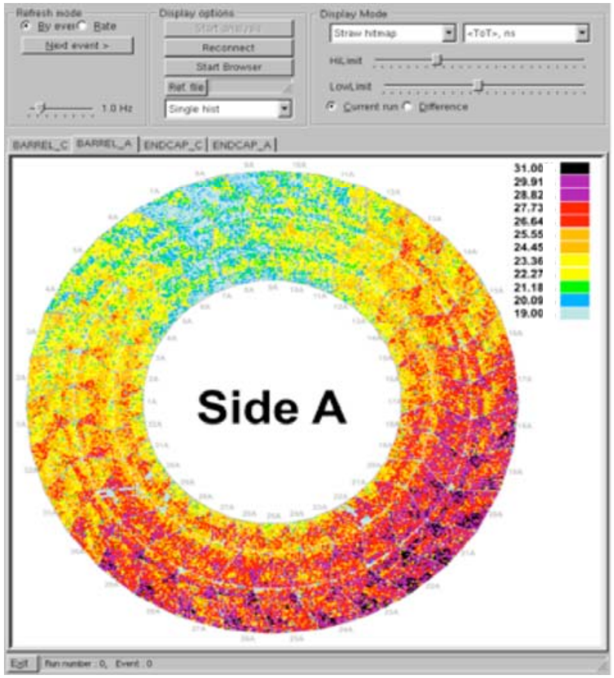
Three subsytems	Status for single beam running
• Pixel Detector	OFF
• Silicon Tracker (SCT)	Barrel OFF, Endcaps ON at reduced HV
• Transition Radiation Tracker (TRT)	ON (gas mixture without Xe)

TRT Studies with Single Beams

TRT barrel hits collapsed into rϕ, endcap hits into zϕ

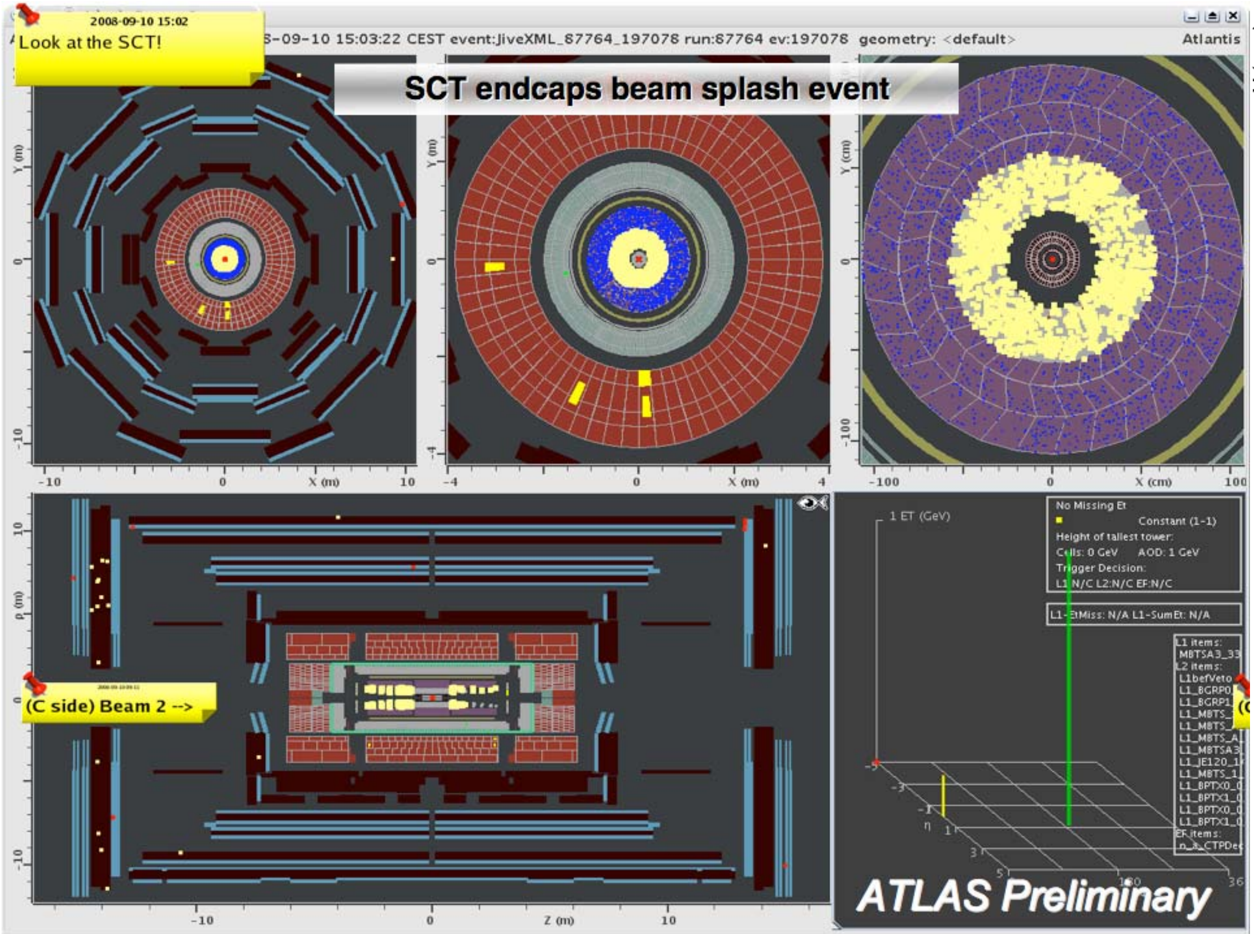


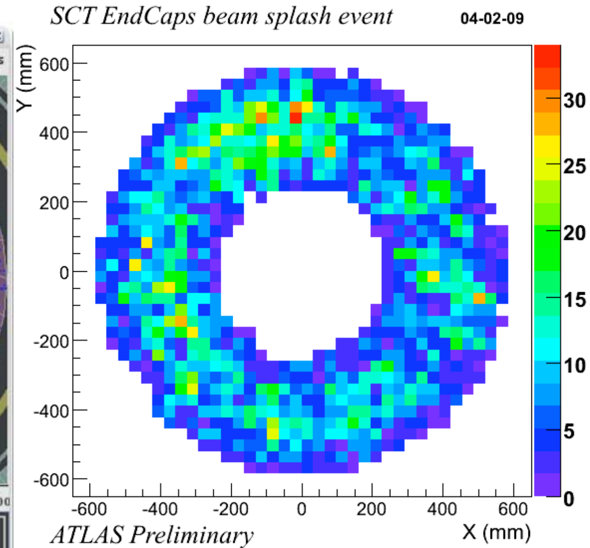
- Beam-splash events: estimate 10-100 particles/straw. Can time in detector with a single event!
- 5 splash events used. Timing offsets agree at 0.3*ns* level.
- TRT barrel timed in a ~1*ns* level.
- TRT endcap at few *ns* level.

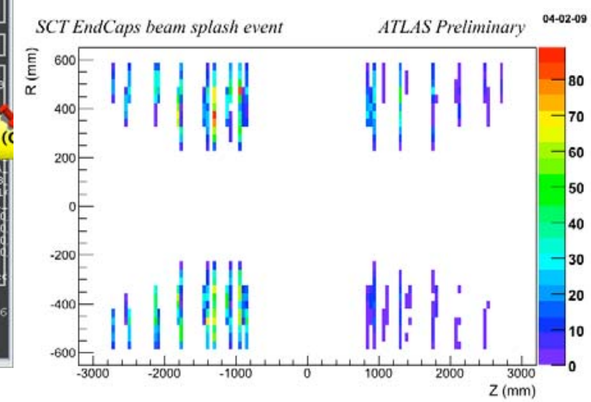


- TRT (Barrel A) timing for one beam splash event (in *ns*).
- Pattern from top left to bottom right arises from the use of cosmic rays for setting of initial timing offsets.
- Timing differences consistent with time of flight for cosmic ray muons. New offsets now calculated for collisions.

First Beams in ATLAS Semiconductor Tracker



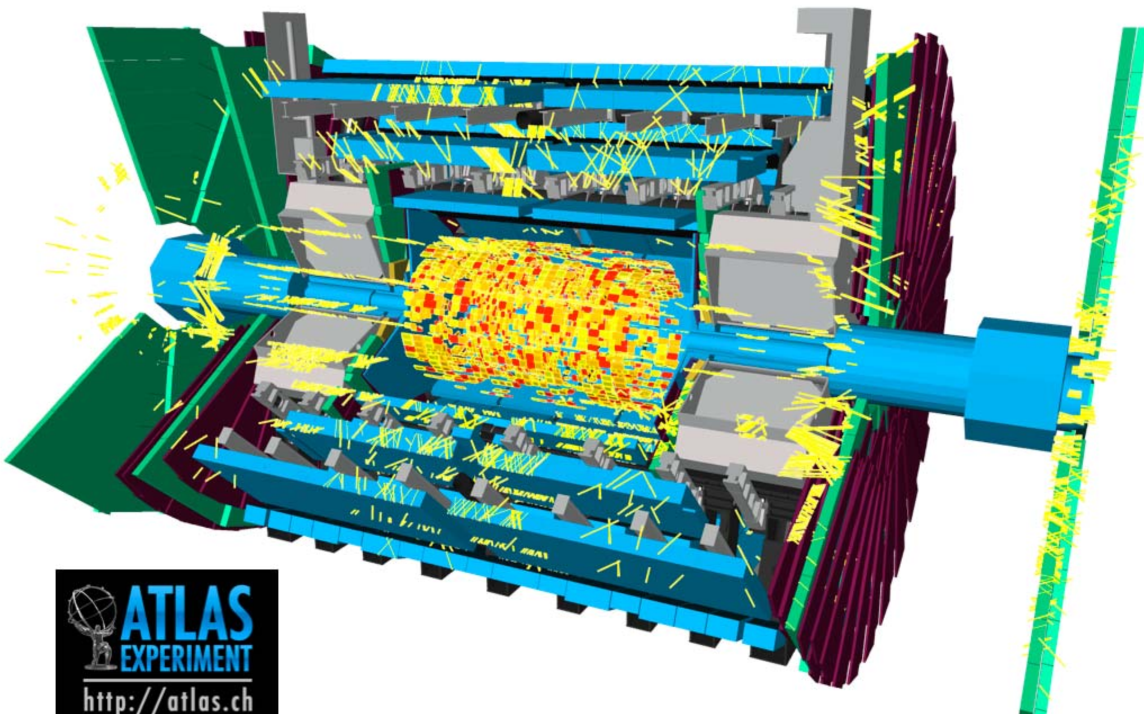




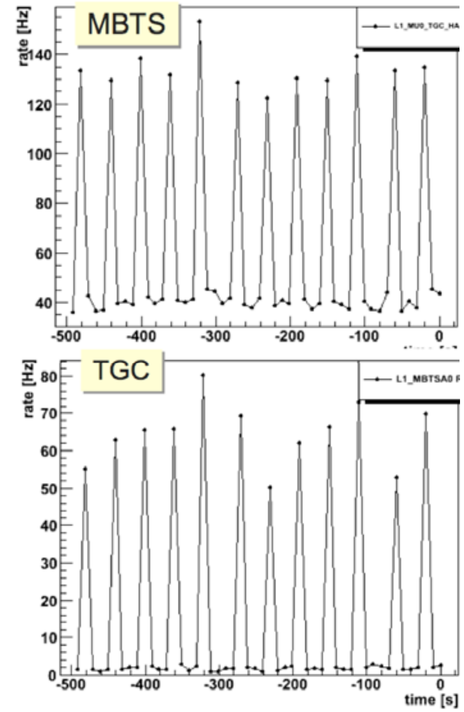
Event displays (xy, rz views) show numbers of hits.

Endcap SCT timing (initially set using cosmics) checked at level of ~25*ns* (1BC) with splash events.

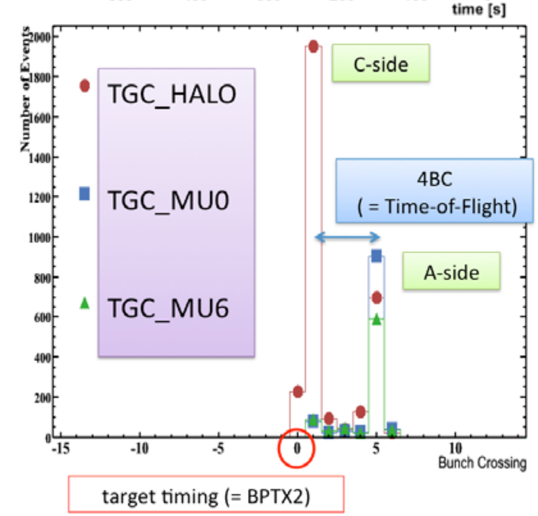
Beam Splash Events in Muon System



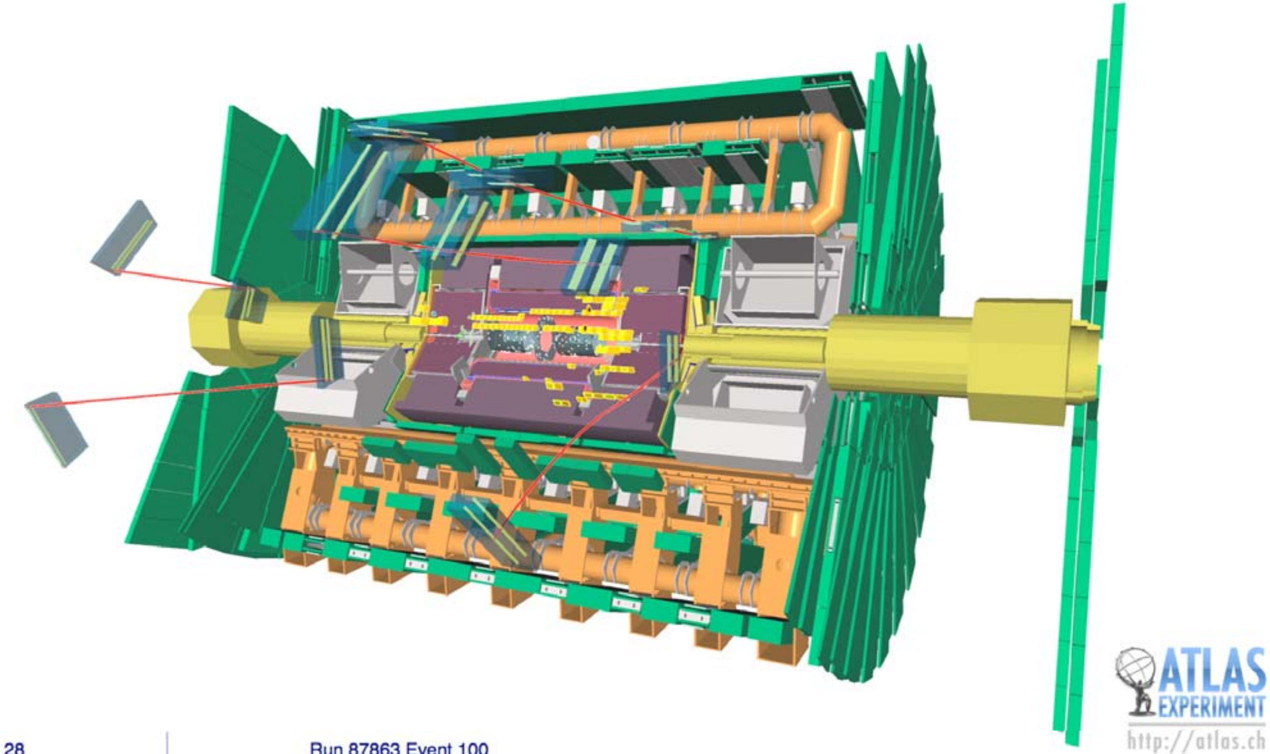
first beam event seen in ATLAS



Beam from C-side to A side, so TGC timing shift of -5BC provides correct for collisions. Narrow spread of two peaks indicates that timing is otherwise good at ~1BC level.



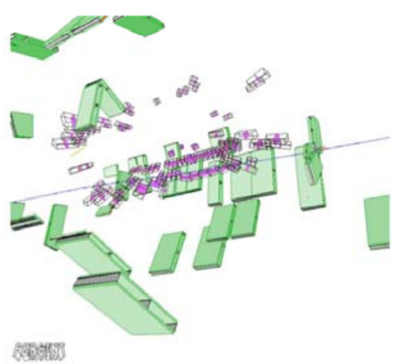
Beam Halo Events in Muon System



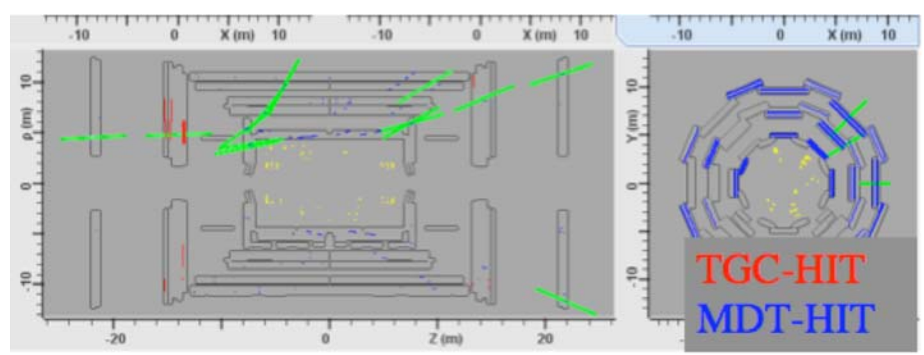
Run 87863 Event 28

p = 4.0 GeV

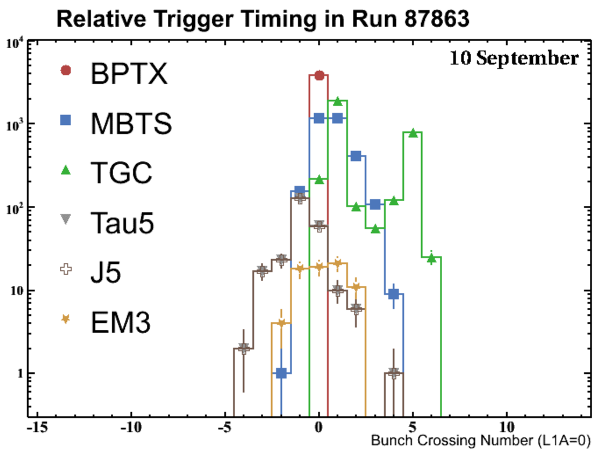
Run 87863 Event 100



p = 9.6 GeV

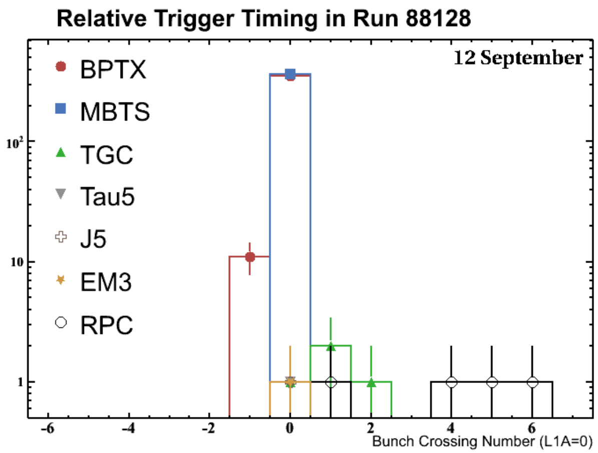


Trigger Timing with Single Beams



Timing distribution of L1 triggers, Sep. 10th run 87863

- BPTX trigger for stable time reference (BC 0)
- Run 87863 was with collimators open but poor beam quality leading also to large numbers of muon and calorimeter triggers.
- Two peak structure visible in TGC (as previously shown).



Timing distribution of L1 triggers, Sep. 12th run 88128

- Triggered by MBTS (BC 0) which had been timed in w.r.t BPTX (good overlap observed here)
- Run 88128 was with collimators and relatively good beam quality leading rather few additional triggers. Note that the RPC trigger was not completely timed in prior to this run.

Trigger operated very well right from the start, and quick progress was made in the refining of trigger timings over the three days of single beam running.

Summary

- First beam provided valuable operations experience to the detector communities (and was exciting despite the later disappointment).
- Energy deposition patterns in calorimeters useful as qualitative check of coverage and response.
- Beam events useful for timing studies for
  - sub-detectors
  - triggers

  (which are difficult with cosmic-ray muons).
- Halo events in Tile Calorimeter allow checks of calibration / channel equalization.
- Checks of LAr pulse shapes in beam splash events provide tests of LAr electronic calibration procedures.
- Continue to examine these data to extract everything we can from them.
- Waiting until later this year for collisions.