

# Commissioning of the ATLAS Experiment

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Galena, IL, USA



Commissioning of ATLAS  
Juergen Thomas, HCP 2008 Galena, 30 May 2008



# Outline:

- Introduction
- Calorimetry
- Muon Detectors
- Inner Tracking Detectors
- Trigger/DAQ
- Looking ahead

# Introduction

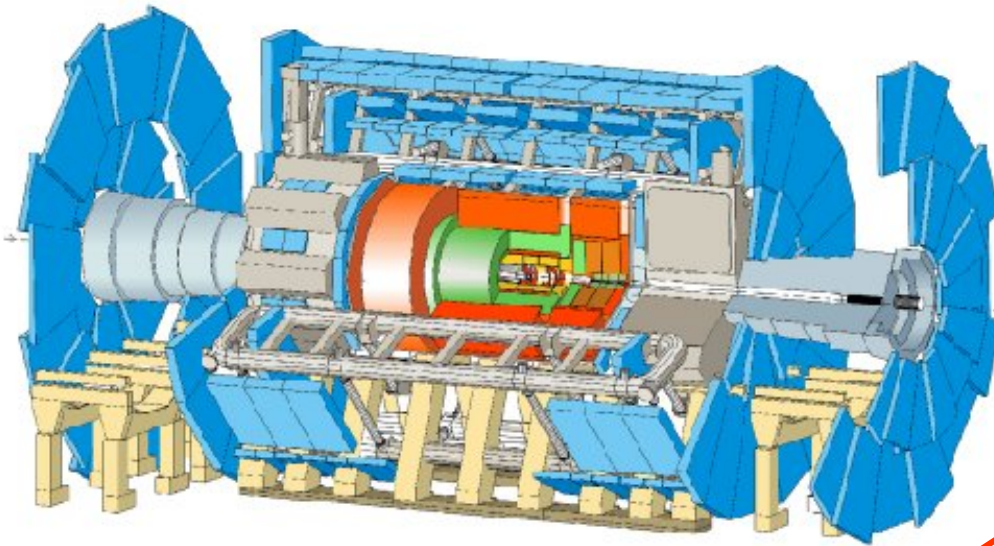
# The ATLAS Collaboration

- 1 Experiment
- 35 Countries (with collaborating institutes, many more countries of origin)
- 165 Institutes (as of July 2007)
- 1900 scientific authors

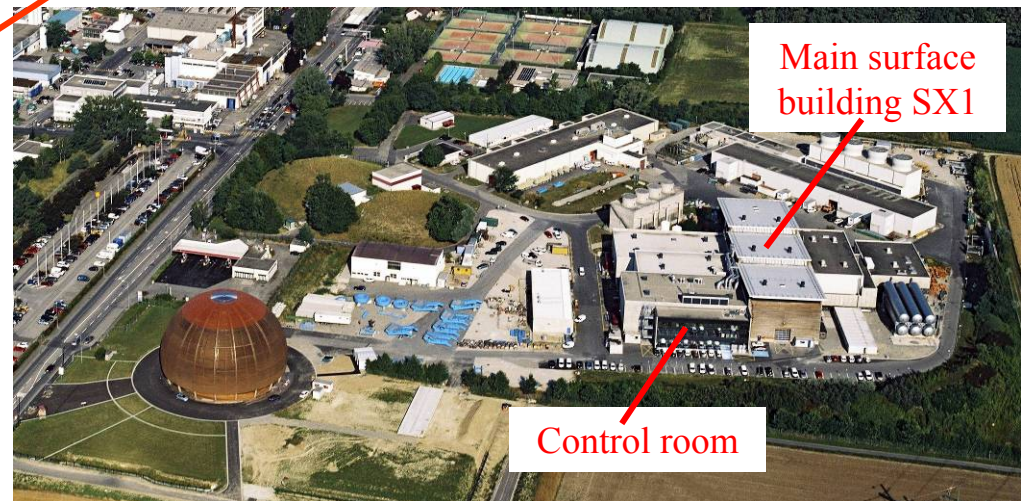
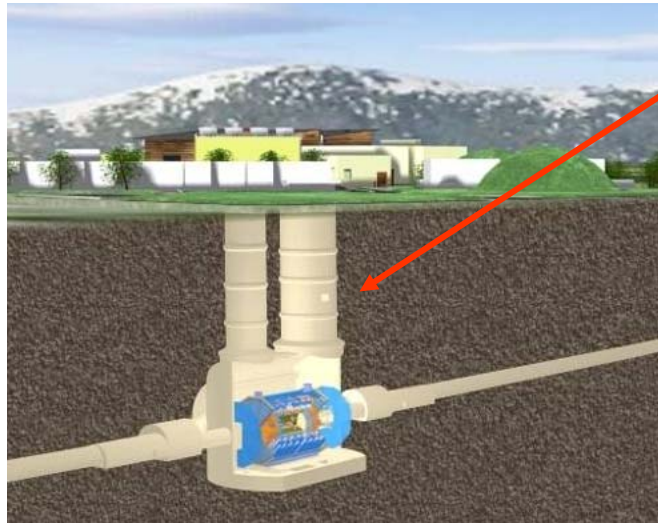


Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, Bologna, Bonn, Boston, Brandeis, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, Casablanca/Rabat, CERN, Chinese Cluster, Chicago, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Goettingen, LPSC Grenoble, Technion Haifa, Hamburg, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QM London, RH London, UC London, Lund, UA Madrid, Mainz, Manchester, Mannheim, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, FIAN Moscow, ITEP Moscow, MPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, UFRJ Rio de Janeiro, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine, Uppsala, Urbana UI, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Yale, Yerevan

# The ATLAS Detector



- 25m diameter
- 46m total length
- 7000t weight
- installed just across the CERN main site, 92 meters below ground
- ATLAS cavern: 55m long, 32m wide, 35m high: just large enough for the detector – ‘ship in a bottle’, assembled in situ



Commissioning of ATLAS

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# The Schedule: Working towards Data-Taking

- **Milestone weeks (Mx):** Dedicated effort bringing all experts together with defined targets:
  - Preparation days
  - Combined runs on weekends runs in different configurations with much of the detector
- Commissioning using cosmic muons, and integrated calibration systems
- Recently:
  - **M6:** 3-10 April 08, all subdetectors
  - **CaloWeek:** monthly, Calorimeters (LAr and Tile), and trigger (L1Calo). Results shown here from 31 March – 7 April
  - **M7** (now and on-going, all subdetectors)
- Technical Runs of Trigger/Data Acquisition (TDAQ) system: Full rate of 40 MHz



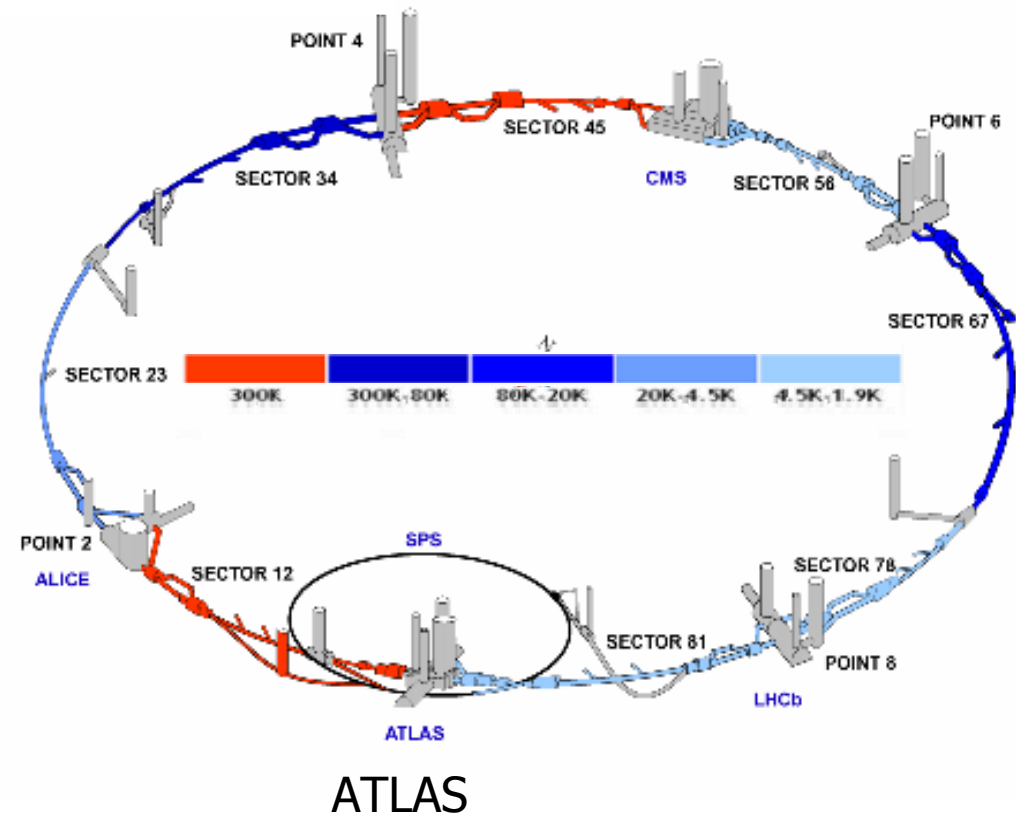
# Current LHC Start-Up Schedule

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

20 May 08

- ATLAS closes mid-July
- LHC currently cooling
- LHC startup:
  - First particles in LHC end-July
  - Aiming for first high-energy pp-Collisions by September (at 10 TeV)
  - Planning for a few weeks of stable operation in 2008 which could produce a few  $\text{pb}^{-1}$

*(Talk S8.2 by Peter Limon on Saturday)*



# Detector components

## Silicon **Pixel** detector

$1.4 \cdot 10^8$  channels, intrinsic  
resolution  $10 \times 110 \mu\text{m}$

## Silicon tracker - **SCT**

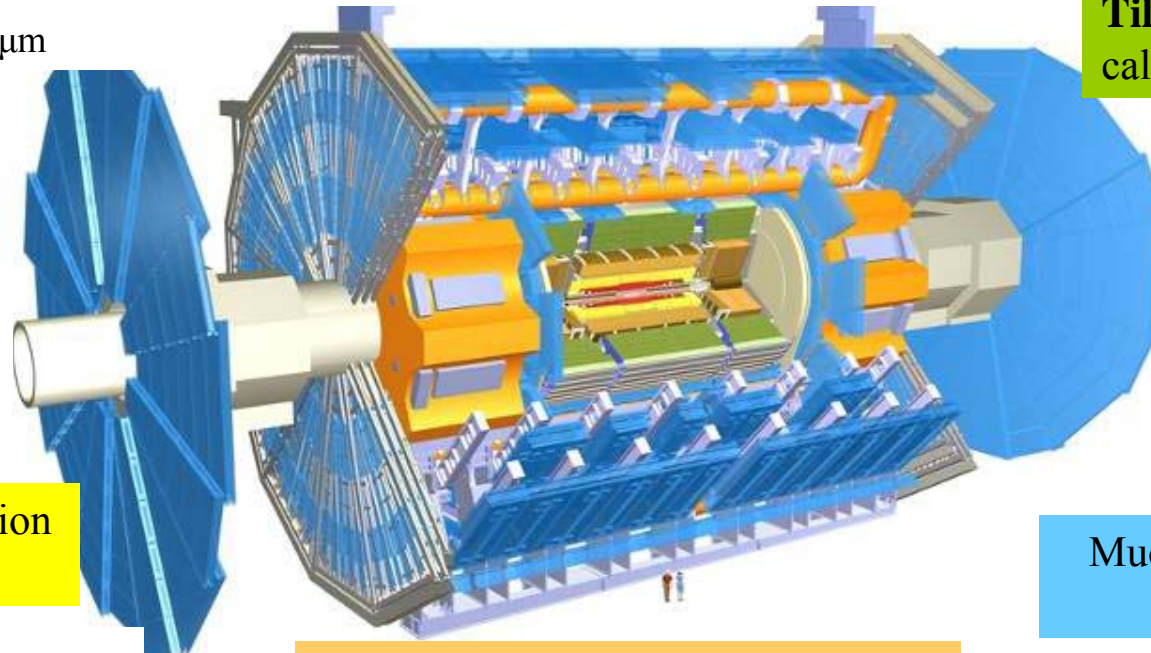
$\sim 6 \cdot 10^6$  channels  
80 $\mu\text{m}$  wide strips

## Transition Radiation Tracker - **TRT**

Xe-filled straw tubes,  
interleafed with PP/PE foil  
Electron - pion separation  
 $\sim 35$  hits/track for track  
reconstruction

## 4 super-conducting magnets: solenoid + 3 toroids

Solenoid field 2T in inner detector region  
toroid field peak strength 0.4T



## **TileCal** hadronic calorimeter (Barrel)

Sandwich structure:  
iron absorber + scin-  
tillator tiles  
 $\sim 10000$  channels

## **LAr** calorimeters (EM Calo, Had. EndCap)

$\sim 180000 + 10000$  channels (EMC, HC)  
 $10\%/\sqrt{E}$  energy resolution for  $e, \gamma$   
Trigger for electrons, photons and jets

## Muon spectrometer **MDT, CSC**

$\sim 1200$  precision chambers  
for track reconstruction  
 $\sim 600$  RPC and  $\sim 3600$  TGC  
trigger chambers  
Stand-alone momentum re-  
solution  $\Delta p_t/p_t < 10\%$  up to  
1 TeV

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# Trigger/DAQ architecture

## Level-1 Trigger

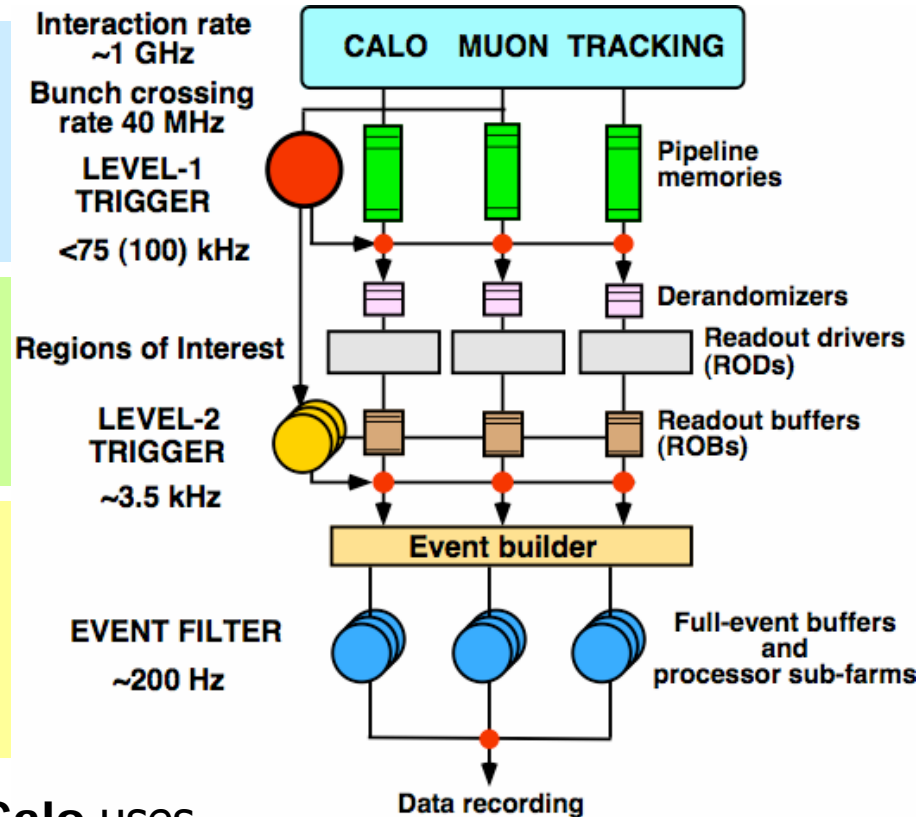
Custom Pipelined  
Hardware

## Region of Interest Builder

Custom Hardware

## High-Level Trigger

Large PC farm  
High data bandwidth  
Dedicated 'Data' Network



Detector Front

End Electronics

(Detector  
responsibility)

Detector RODs

## Readout System

Custom built buffers in  
ROS PC farm

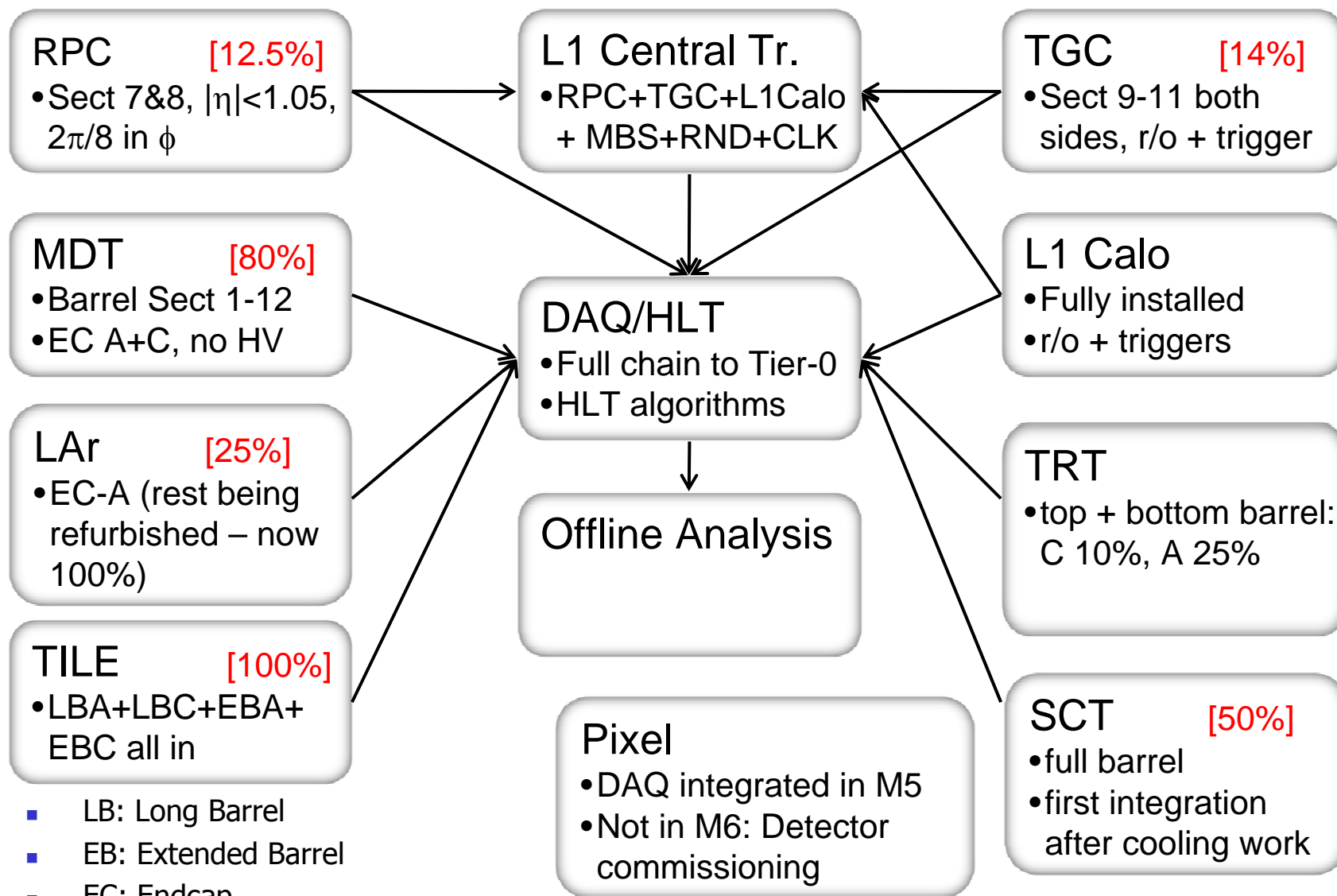
## Event Building

More PC farms  
on 'data' network

- Level-1 Trigger: **Calo** uses calorimeter towers, **Muon** has dedicated trigger chambers inside muon spectrometer (RPC in barrel, TGC in endcap)

- DAQ software – control, configuration, monitoring (control network)

# M6 setup (April): Detector Coverage



- LB: Long Barrel
- EB: Extended Barrel
- EC: Endcap
- A or C: which side

# Calorimetry

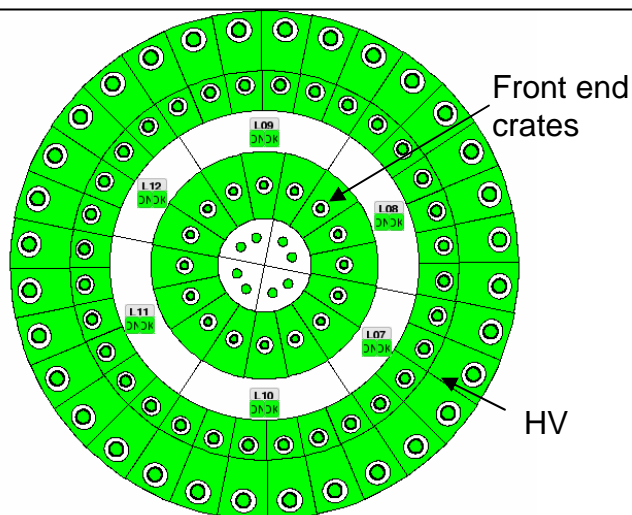
# Calorimeter Commissioning: LAr

- M6 April '08: Only EndCap A participating
  - EndCap C was being filled with LAr
  - Barrel: refurbishment of front end boards going on at that time
- CaloWeek April '08:
  - HV switched on (nominal HV) for the full LAr system
  - First muon runs with the full LAr calorimeter at nominal HV
  - Cosmic muon data taking in 32 sample transparent mode (nights and weekend) and test in 5 sample physics mode
  - Timing with respect to Level-1 Calo and Tile trigger
  - Monitoring, DQ tools, HLT studies
- M7 May '08:
  - Running with full LAr calorimeter system, 100% read-out and working as expected

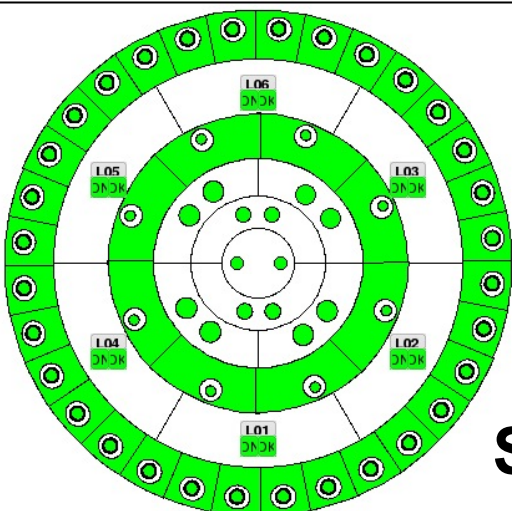
# Status of LAr Calorimeter System

- 100% of the detector switched on, participating at April CaloWeek data taking (HV, LV, ...). Remaining crate operational since Friday 2<sup>nd</sup> May.

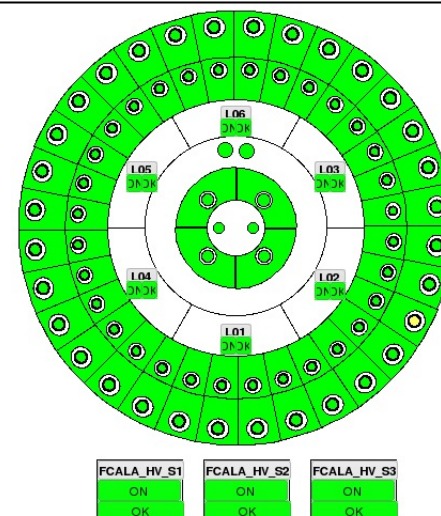
## EM Barrel Cal.



## EM-EndCap Cal.

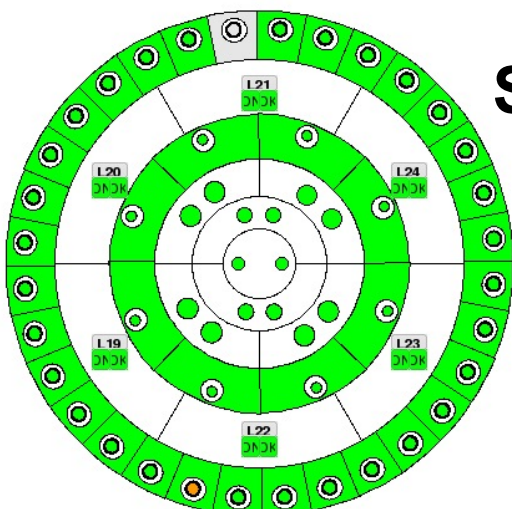
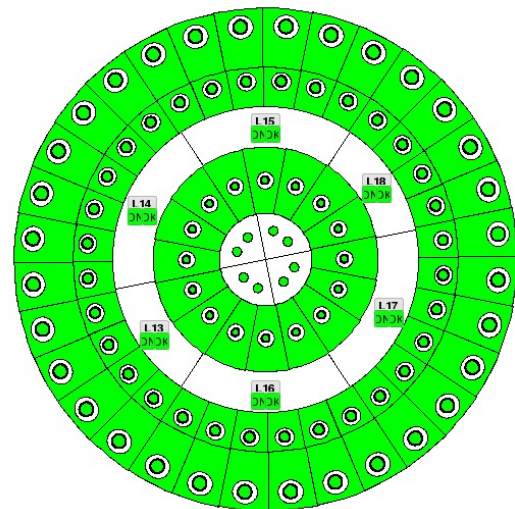


## Had. EndCap & Forward Cal.

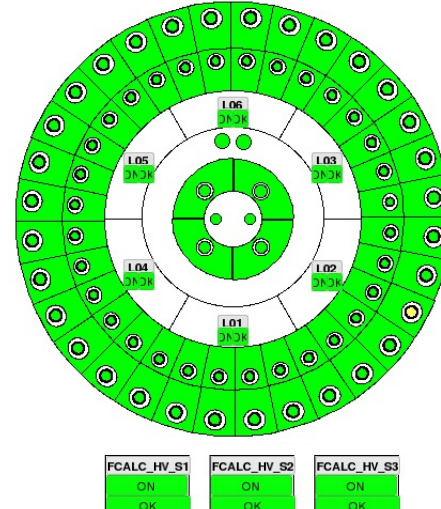


## Side A

FCALA_HV_S1	FCALA_HV_S2	FCALA_HV_S3
ON	ON	ON
OK	OK	OK



## Side C



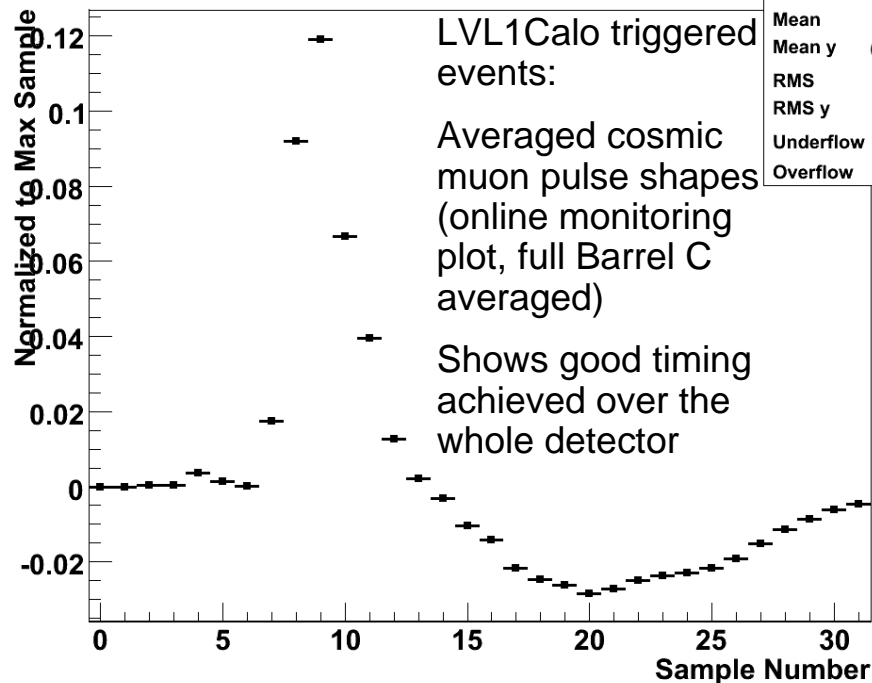
FCALC_HV_S1	FCALC_HV_S2	FCALC_HV_S3
ON	ON	ON
OK	OK	OK



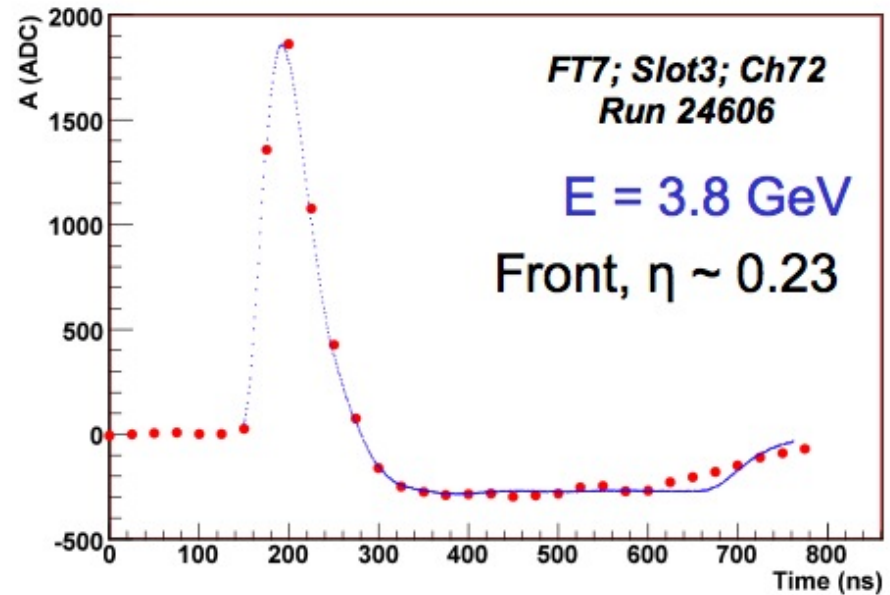
# LAr: Analysis of Cosmics from April CaloWeek

- First data taking with the full LAr detector (100% since 2<sup>nd</sup> May)
- Many quantities available in the online monitoring:
  - Digits, Noise, Timing, Cells, Clusters

Normalized signal shape - Sampling 2 - EM - Barrel C



MuonShapeEBCECALDigits	
Entries	812192
Mean	15.5
Mean y	0.001275
RMS	9.233
RMS y	0.08259
Underflow	0
Overflow	0



Single cosmic muon pulses fitting very well to the predicted pulse shape

ATLAS 2008-03-09 01:32:52 CET event:JiveXML\_43864\_622704 run:43864 ev:622704 geometry:<default> Atlantis

M6 event  
RPC trigger

Images from Atlantis Event Display

HEC pulse shape

Real pulse shape

ADC counts

bunch crossing

HEC cell: 4/2/2/1/0/4/29

Mcalo event  
LVL1Calo trigger

Real pulse shape

ADC counts

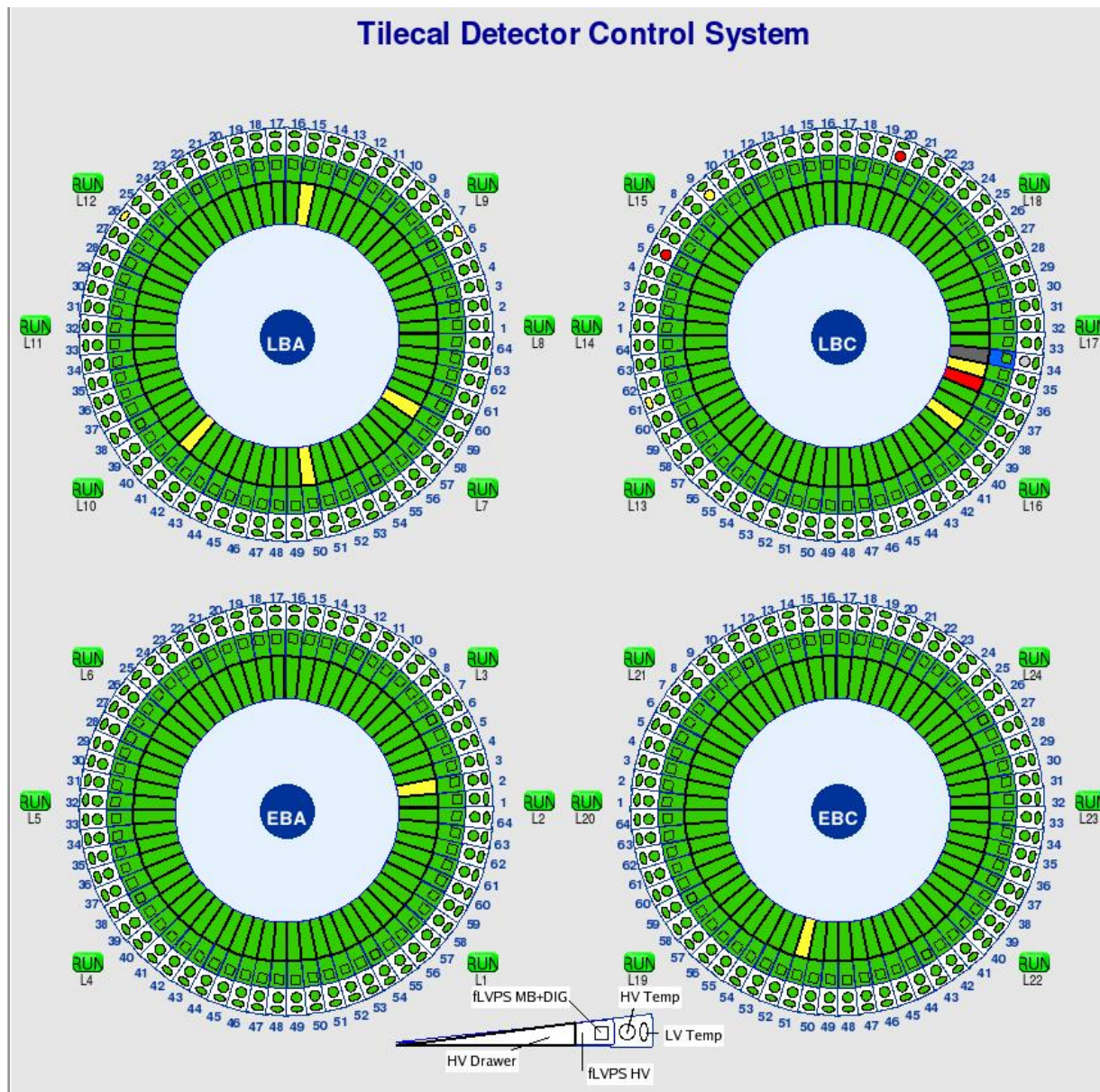
bunch crossing

LAr cell: 4/1/-1/2/0/14/144

Juergen Inomas, HCP 2008 Gaiena, 30 May 2008

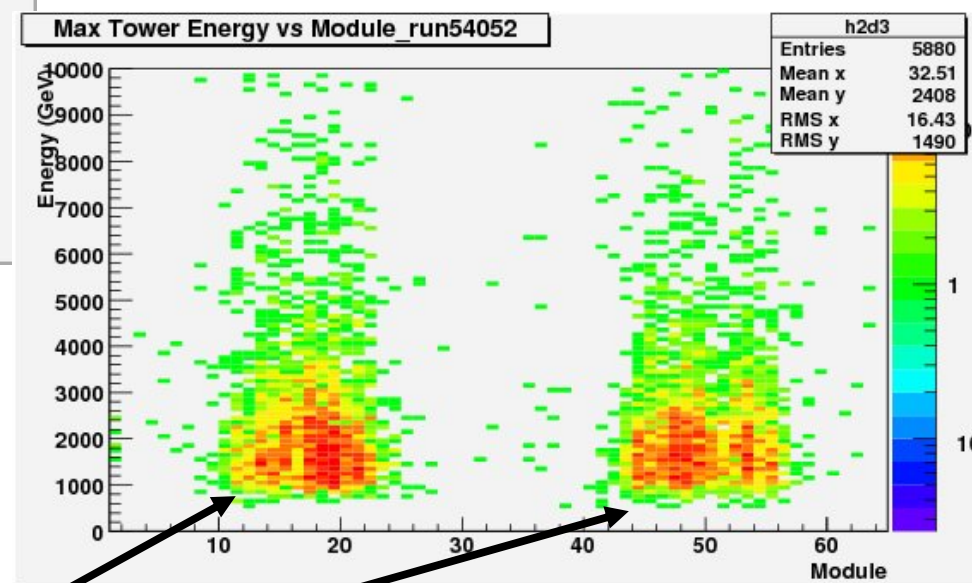
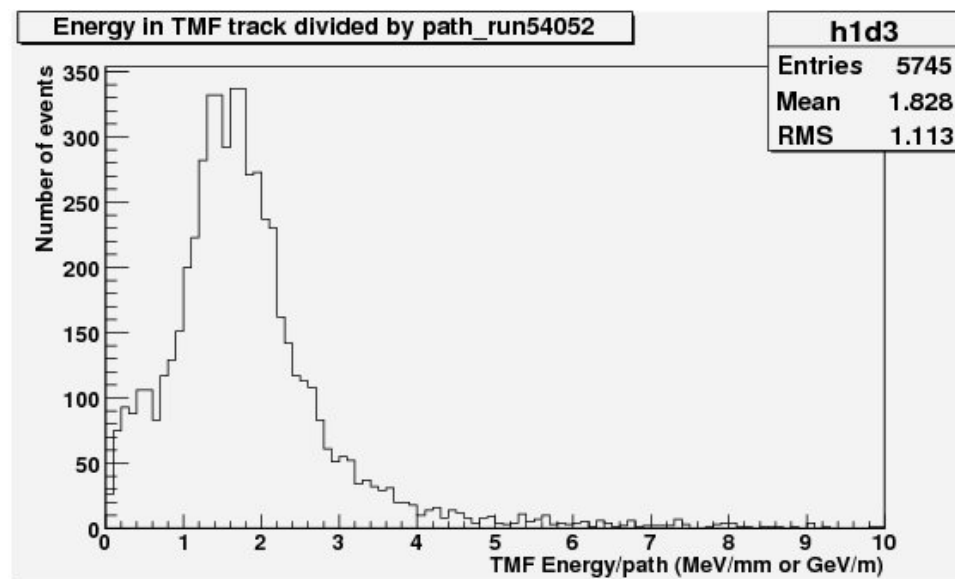
ATLAS

# Tile Cal: Coverage



- Almost full coverage (Image shows status 15th May):
  - 95% barrel
  - Some modules still in refurbishment (power supply)

# Tile Cal: Energy in Calo Week (April)

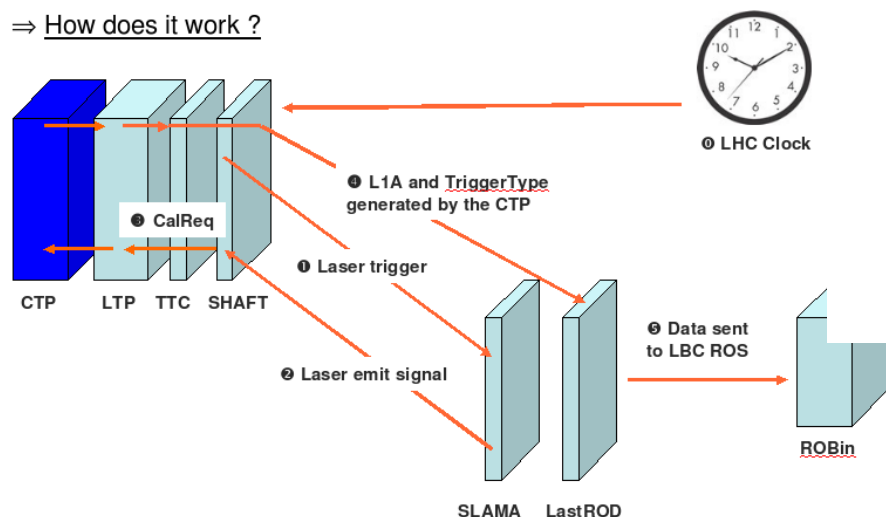
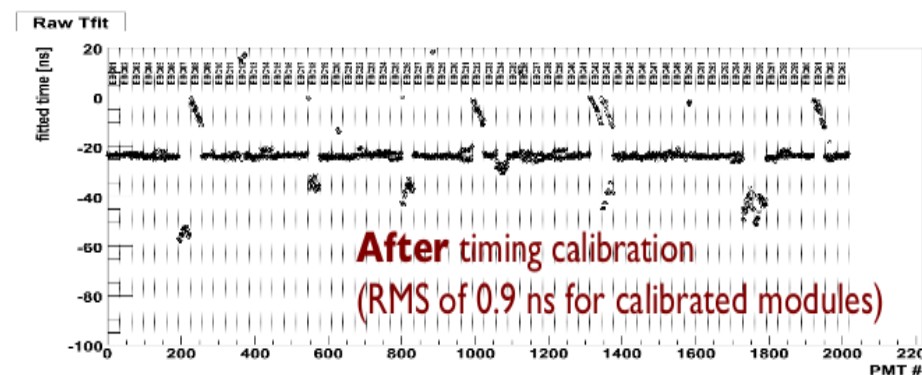
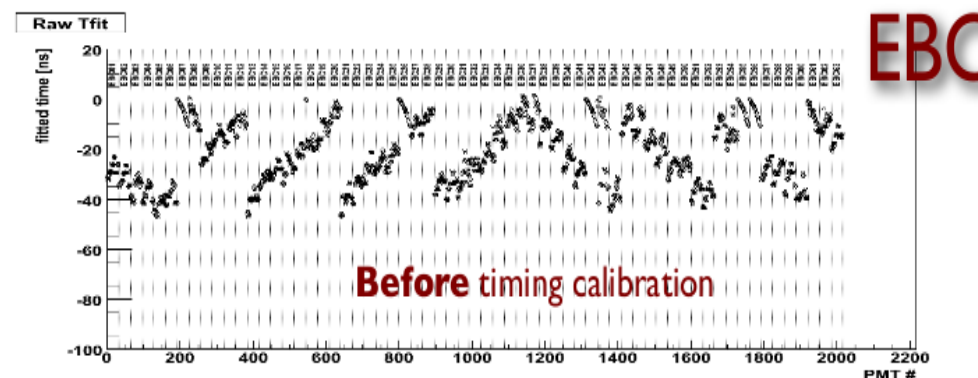


- Good energy density peak
- No top-bottom bias:
  - $\phi$  segmented into modules 1-64
  - cosmics muon depositing similar energies passing top (module 17/18) to bottom (module 48/49)



Tile: Laser Calibration System

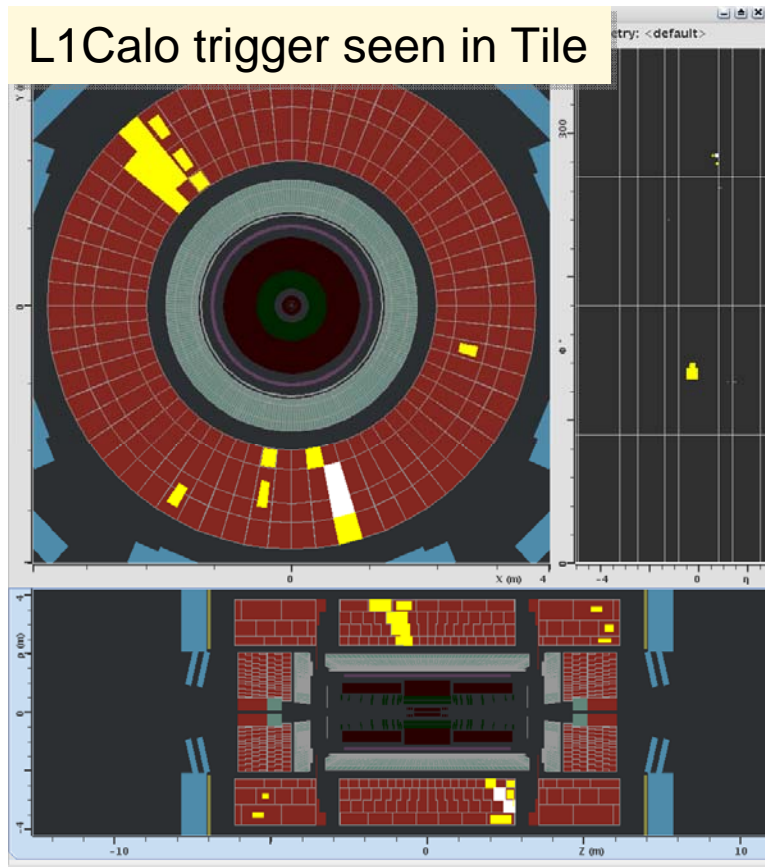
- Commissioning of Laser system is in advanced state.
- Laser used routinely in commissioning data taking to send light to PMTs
- Laser data essential for timing intercalibration of TileCal readout.
- Tests with CTP and TDAQ done in January
- Work ongoing in order to integrate laser with Online and DCS monitoring



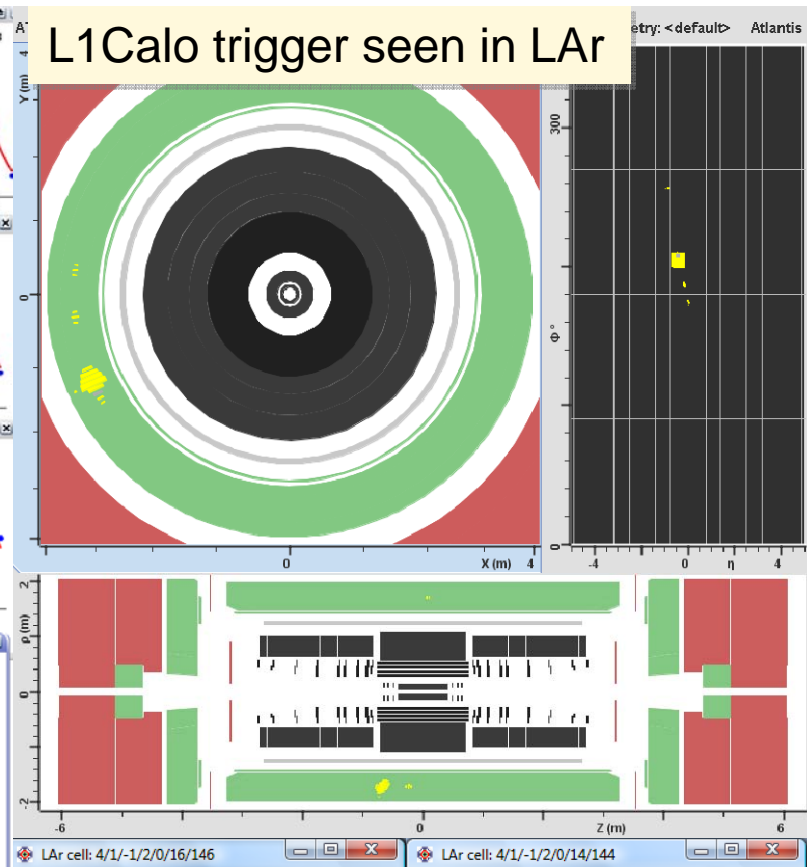


# Calorimeter commissioning

L1Calo trigger seen in Tile

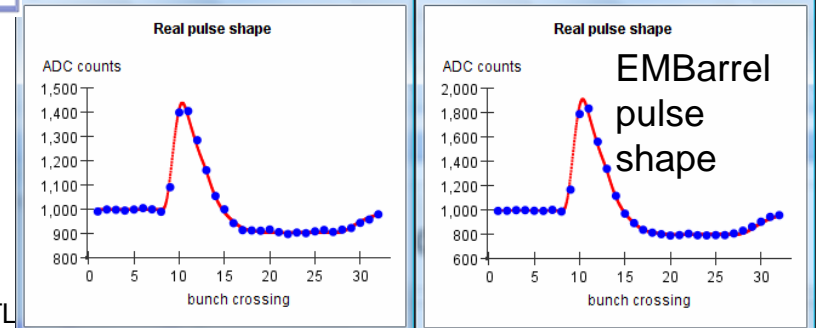


L1Calo trigger seen in LAr



ADC counts vs. bunch crossing

Extensive testing of Calorimeters and L1Calo during M6 and after, including trigger timing studies



Commissioning of ATLAS

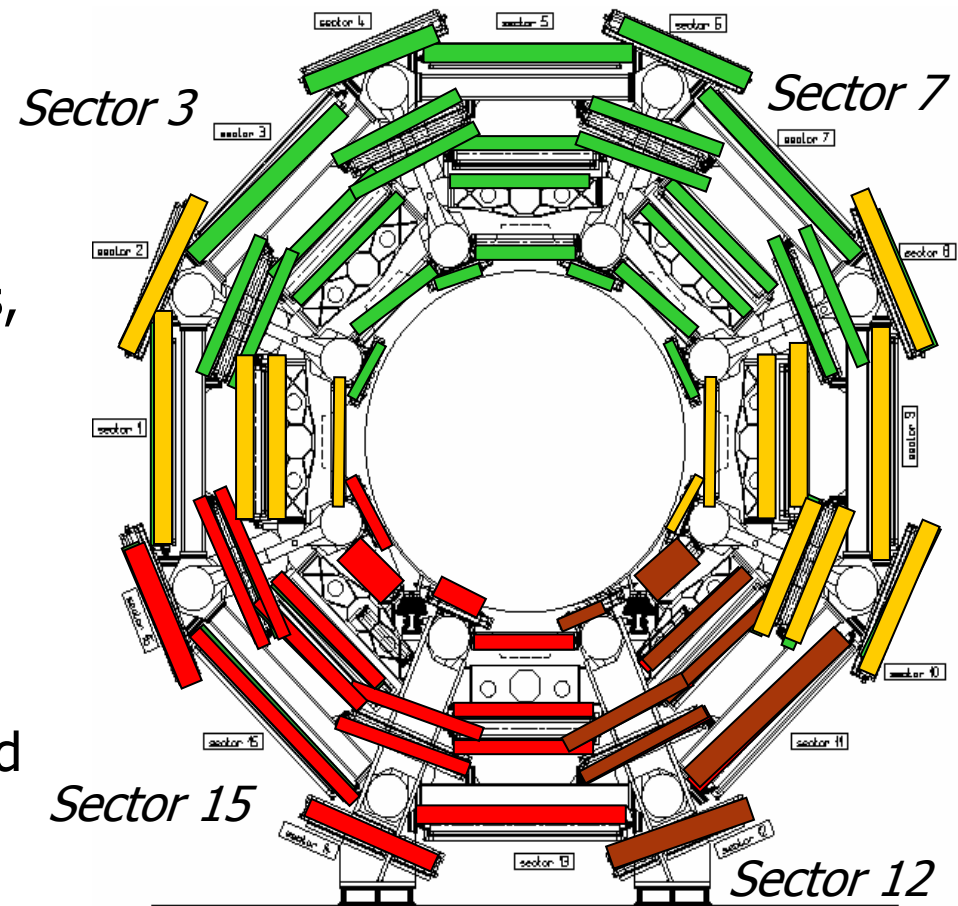
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# Muon Detectors

# Muon Barrel Commissioning: Sectors

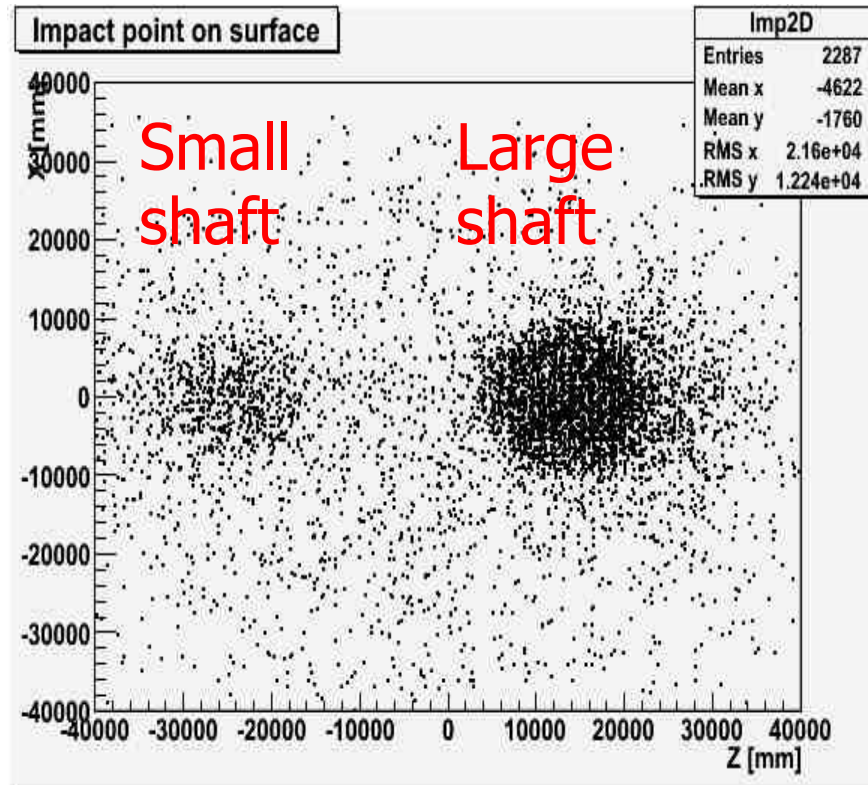
## ■ Muon Spectrometer Barrel (MDT):

- Consists of 16 sectors
- LV power on in all barrel sectors, early all chambers
- HV power on, apart from lower sectors (supplies)
- Sectors from 3 to 8 commissioned with Cosmic rays
- Sectors 11-12 under test
- Many problems found and solved
- Installation issues: Access for other detectors

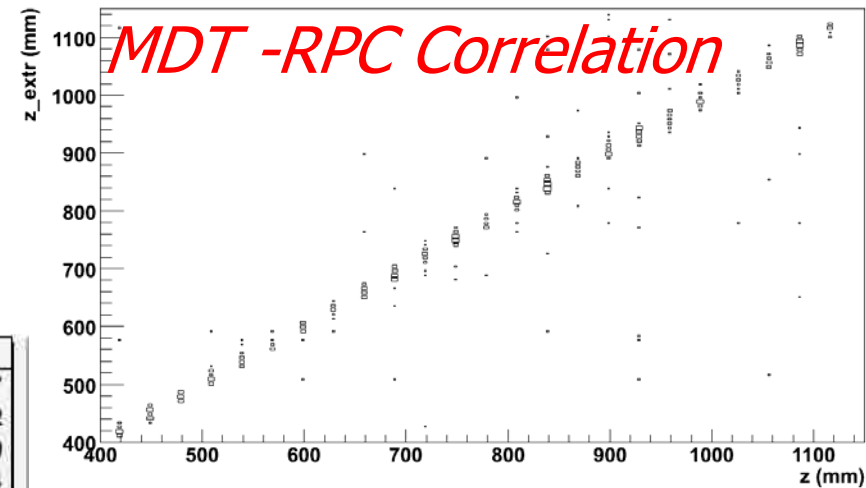


# Muon Barrel Sector Commissioning: RPC

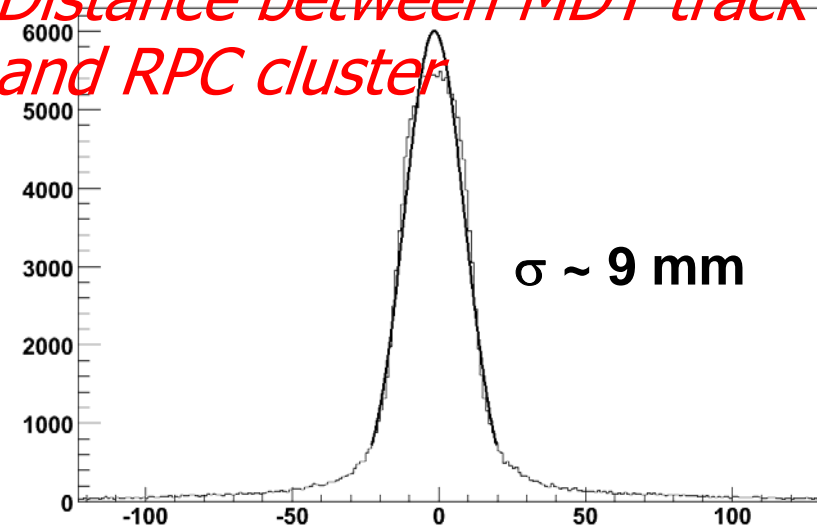
RPC (Level-1 Muon Trigger):  
Standalone Tracking:  
Triggered Cosmic Rays impact  
point at surface



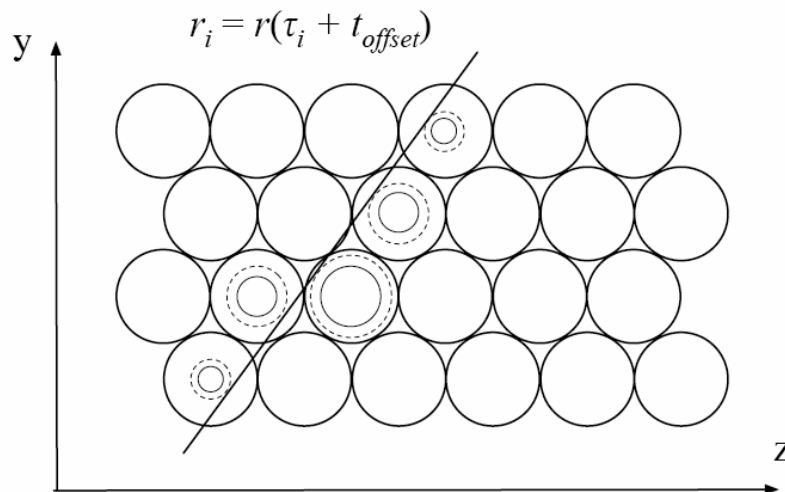
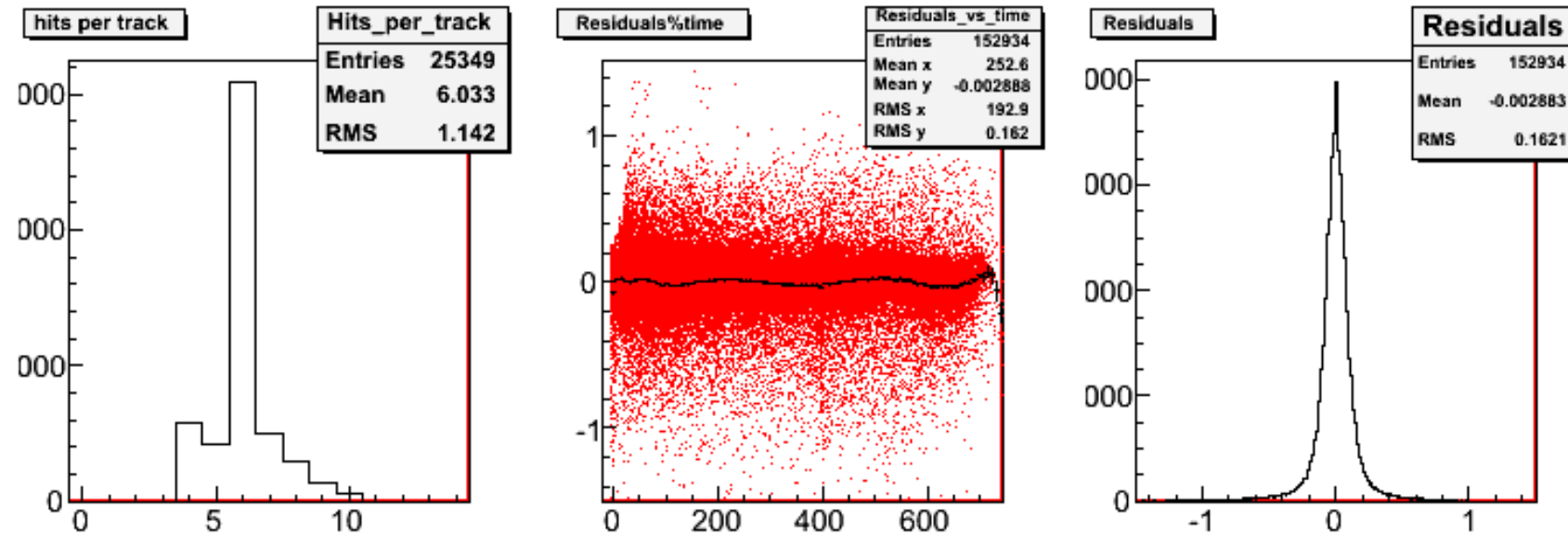
(Shafts into ATLAS cavern)



*Distance between MDT track  
and RPC cluster*



# Muon Barrel Sector commissioning: MDT Results



MDT shows very good track quality for cosmics:

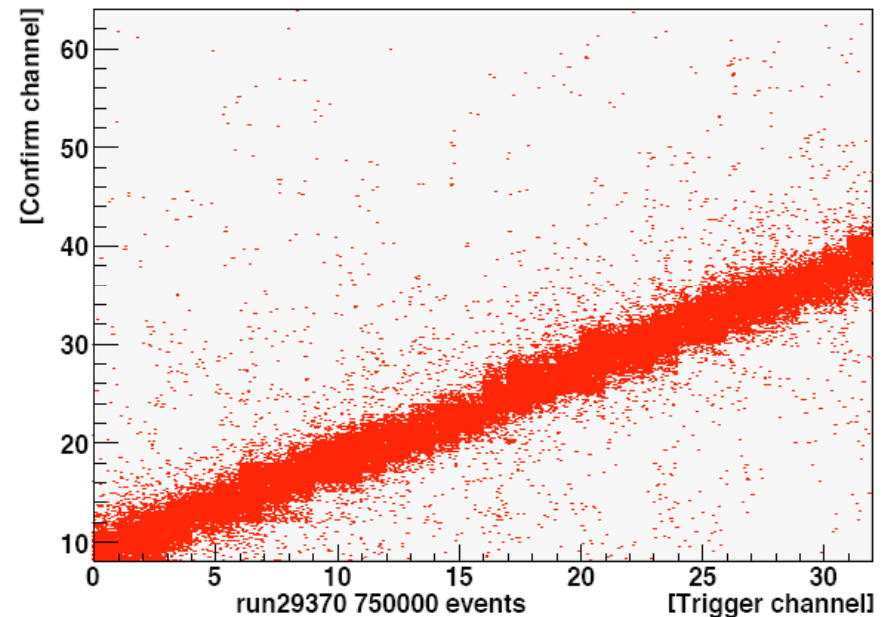
- 6 hits per track
- Residuals centered at 0
- Residuals RMS  $\sim 160 \mu\text{m}$



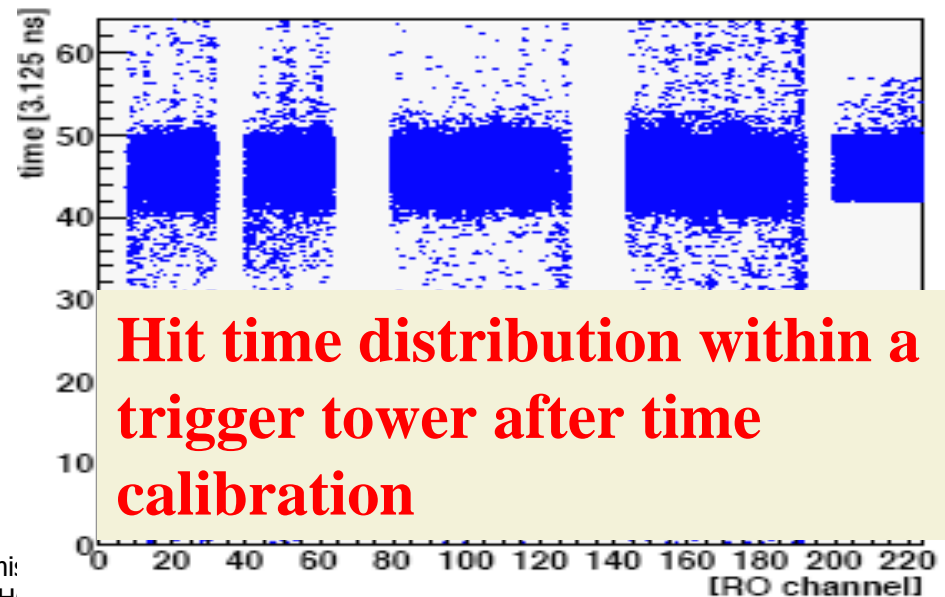
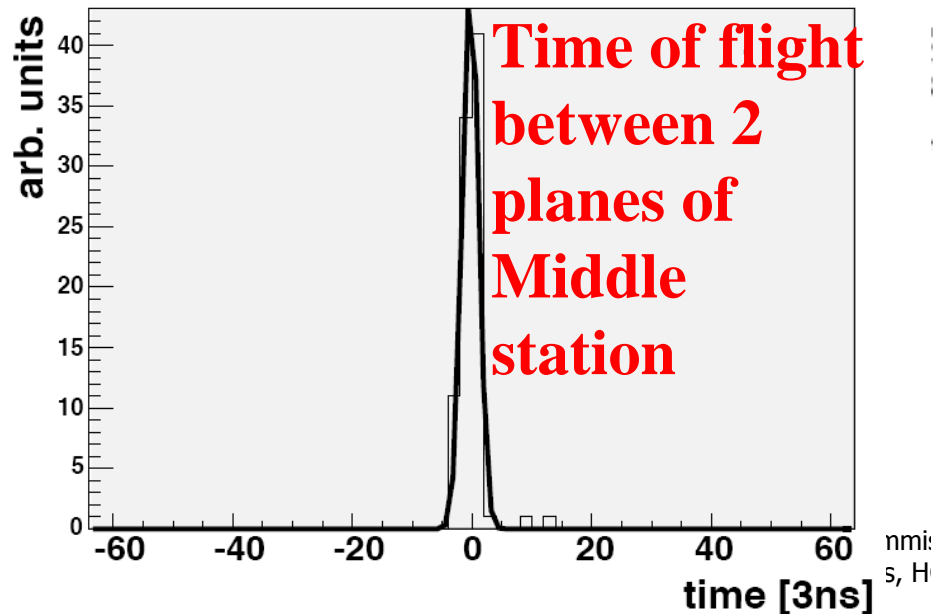
# Barrel Commissioning: Level-1 Muon Trigger

- Check of the trigger road settings: Width of correlation band between clusters on middle layer RPCs corresponds to the trigger road
- Trigger time Calibration: Fit the time of flight distribution between 2 planes and derive the time offset per layer

ConChvsTrigCh\_SL39\_Tower5\_CM0



Time-of-flight, middle station

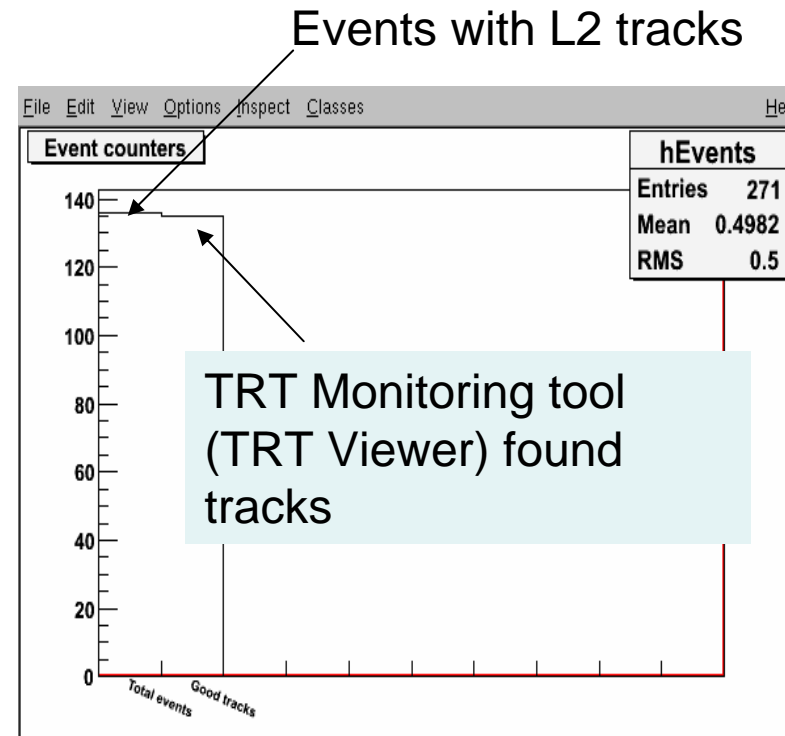
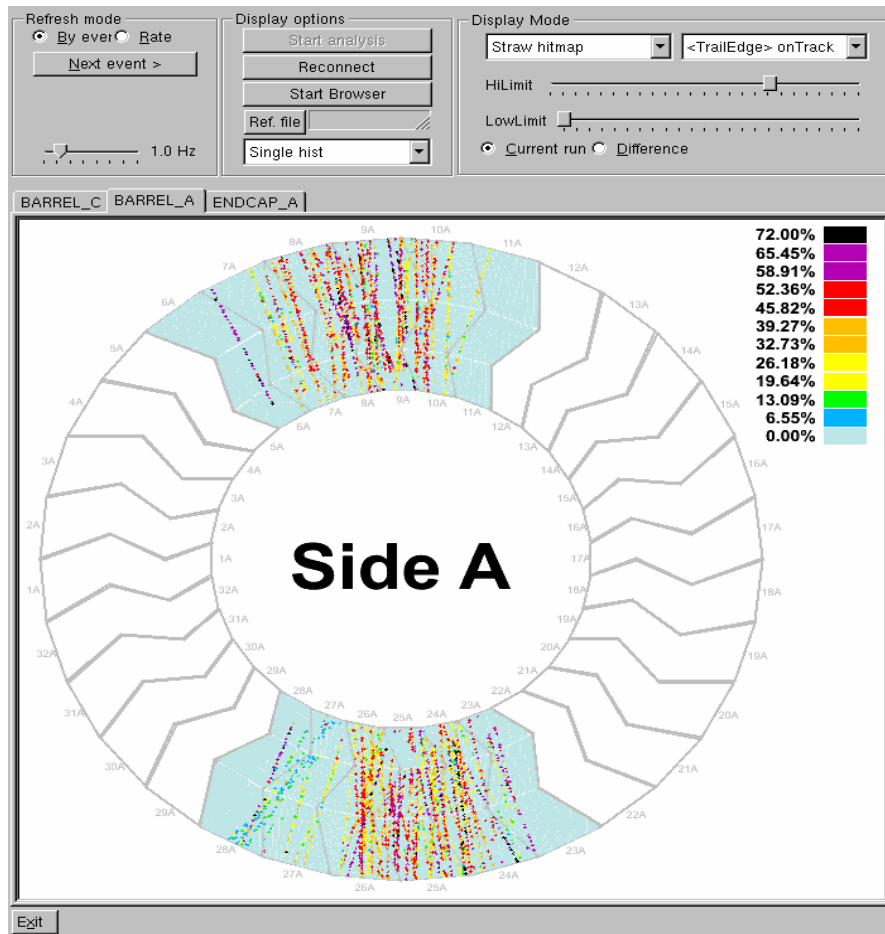


# Inner Tracking Detectors

# Inner Detector Installation Status

- Inner detector consists of: Pixel, SCT, TRT
- Commissioning of the Pixel and SCT had major setback on 1 May, due to break-down of compressors for the evaporative cooling system after only 5 days of testing of Pixel detector
- Compressors have been dismantled and are being repaired
- The failure resulted in contamination of coolant (C3F8) and entire cooling plant must be cleaned before cooling can be restarted.
- Cleaning, repair, and restarting of cooling plant will take until at least mid-June.
- Bakeout of central section of beam pipe in ATLAS requires cooling plant to be operational, and at least innermost layer (plus some disks) of Pixels detector to be cooled
- This failure means that Pixel sign off tests before closing ATLAS were severely reduced, and has major impact on SCT and Pixel commissioning time

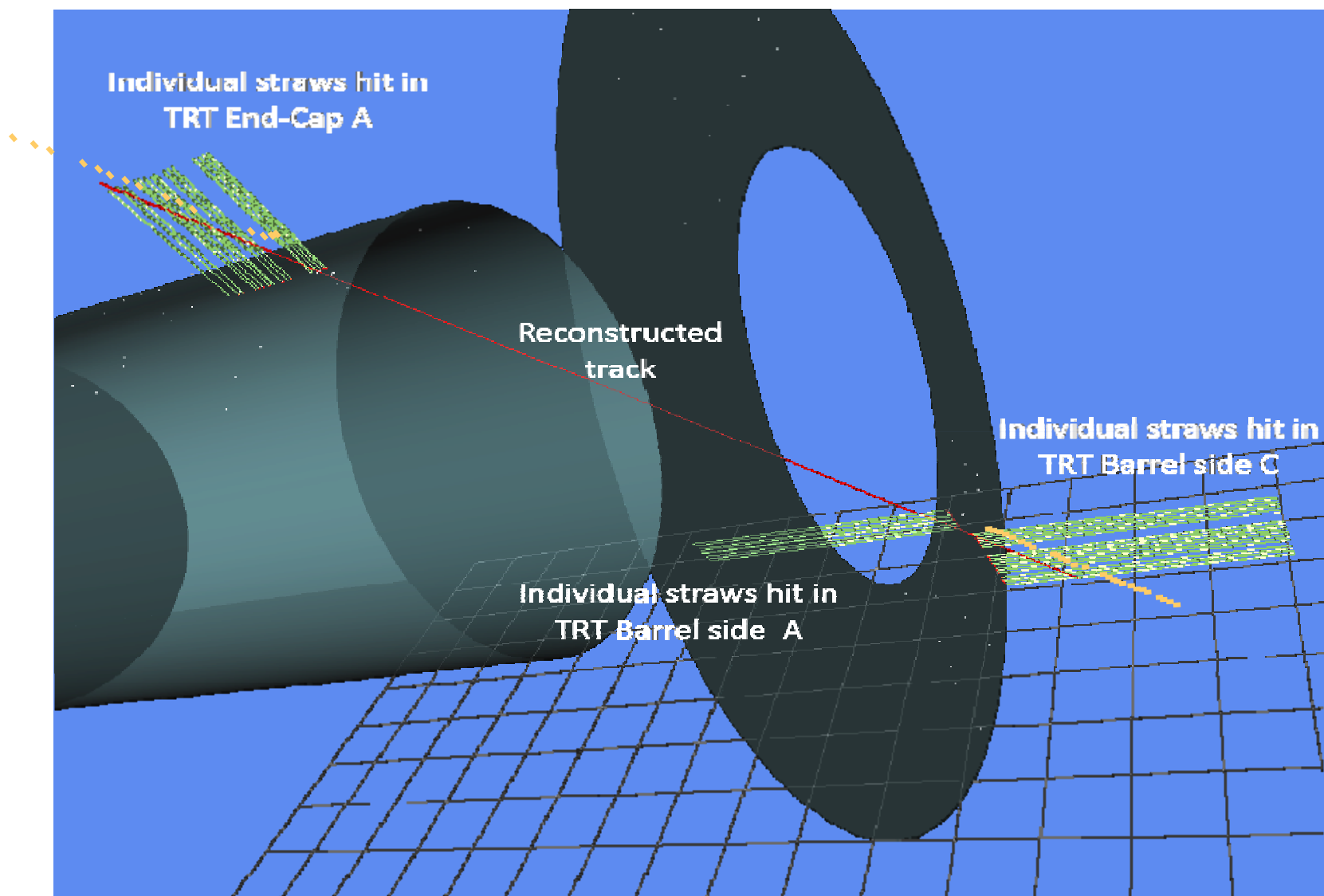
# TRT: Event in Barrel and End-Cap-A



- Efficiency of the L2 tracks with respect to TRT monitoring tool

Trigger from scintillation counter (2ns jitter) and tile calorimeter

# TRT: Event in Barrel and End-CapA

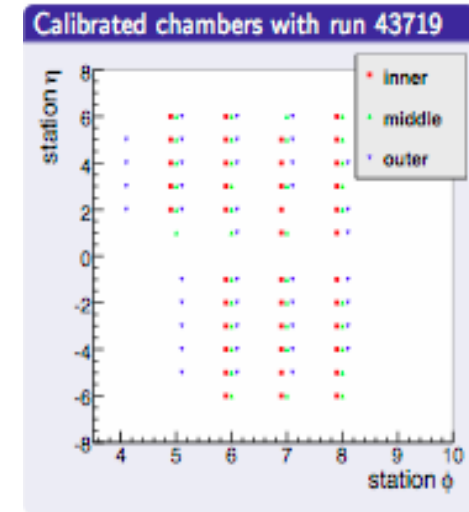




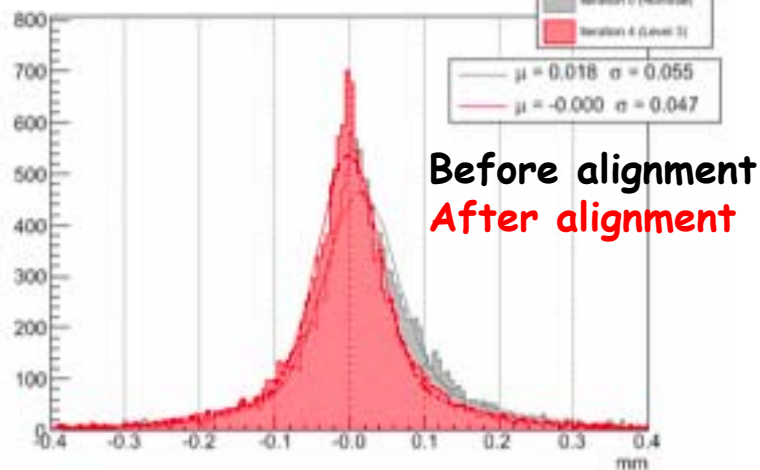
# Cosmic data analysis: TRT+SCT

- Detailed studies performed for each sub-system have been performed, in particular:
  - ID alignment and calibration
  - Muons calibration
  - List of bad channels
  - Tile laser timing updated

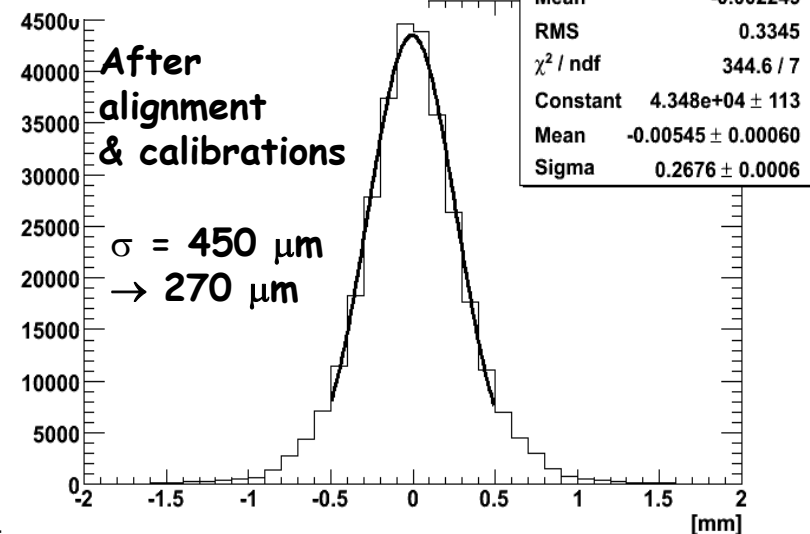
## Muons calibrated chambers



## SCT residuals

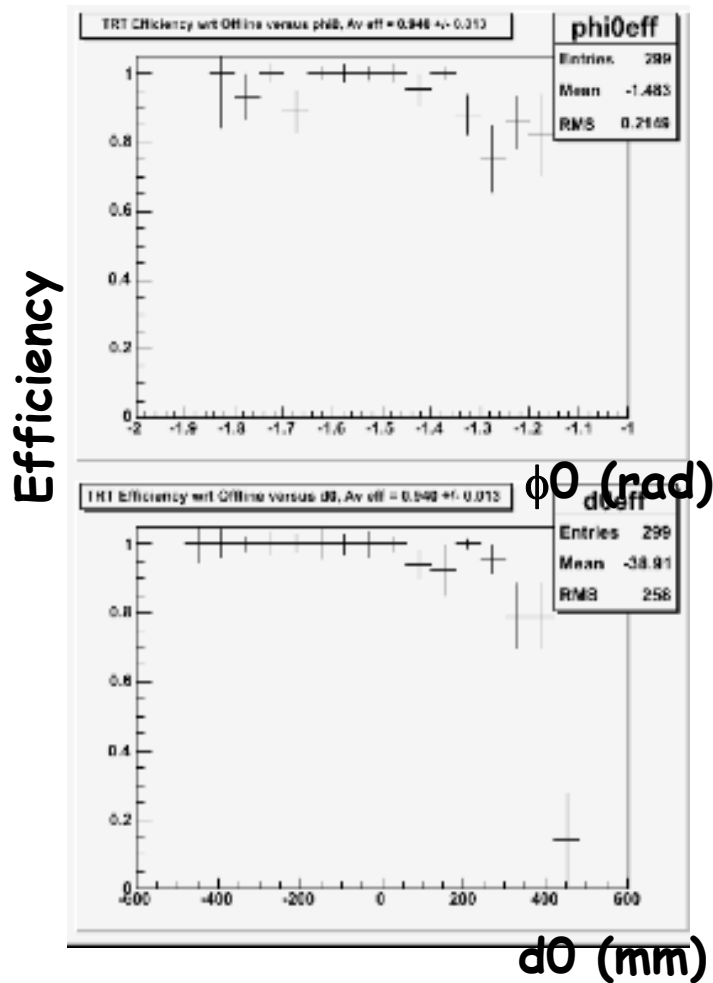


## TRT residuals



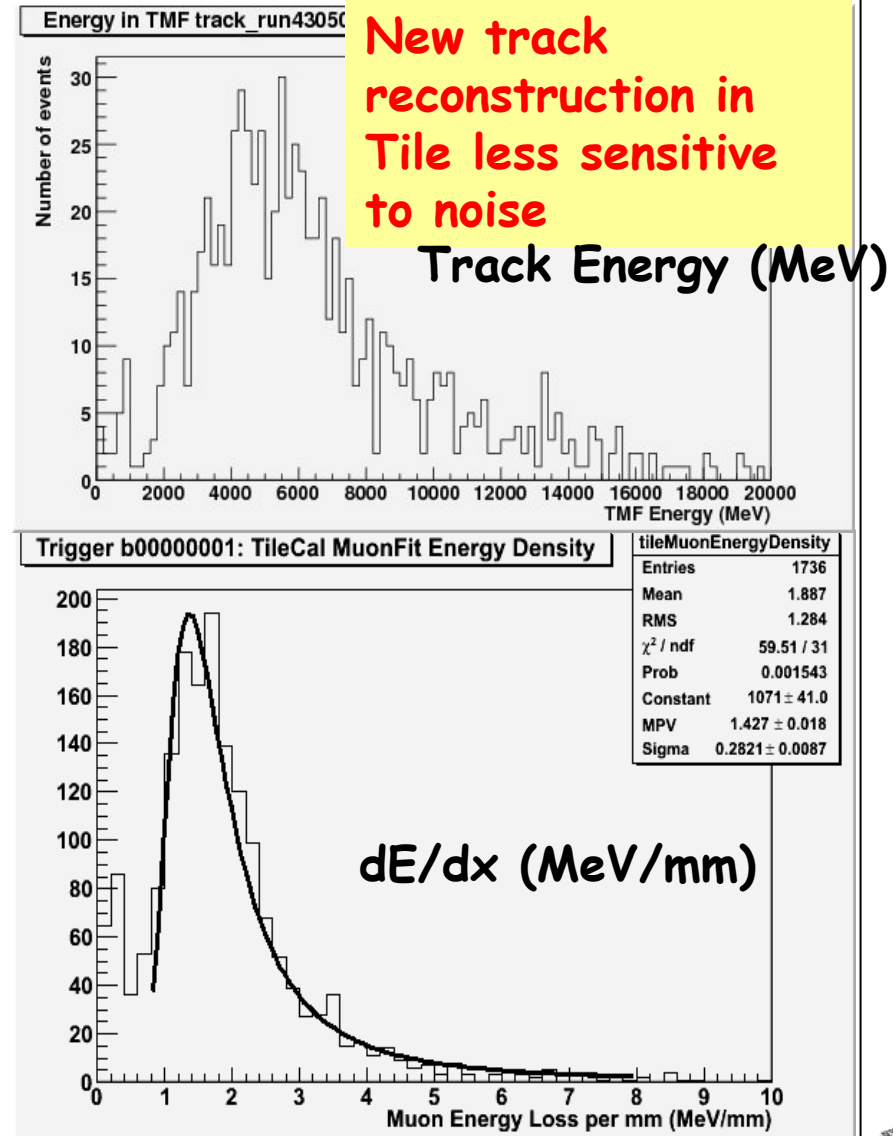
# Cosmic data analysis (TRT+SCT and Tile Cal.)

SiTrack LVL2 tracking  
Efficiency w.r.t. to Offline



New track  
reconstruction in  
Tile less sensitive  
to noise

Track Energy (MeV)

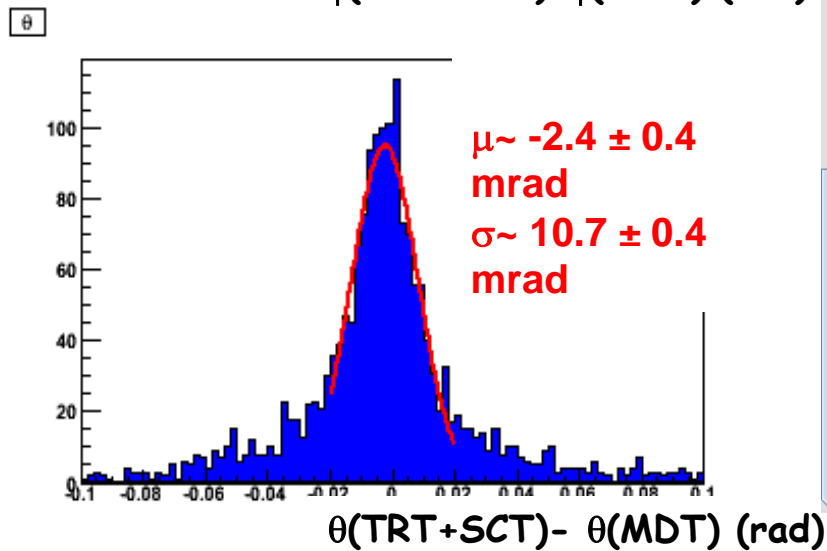
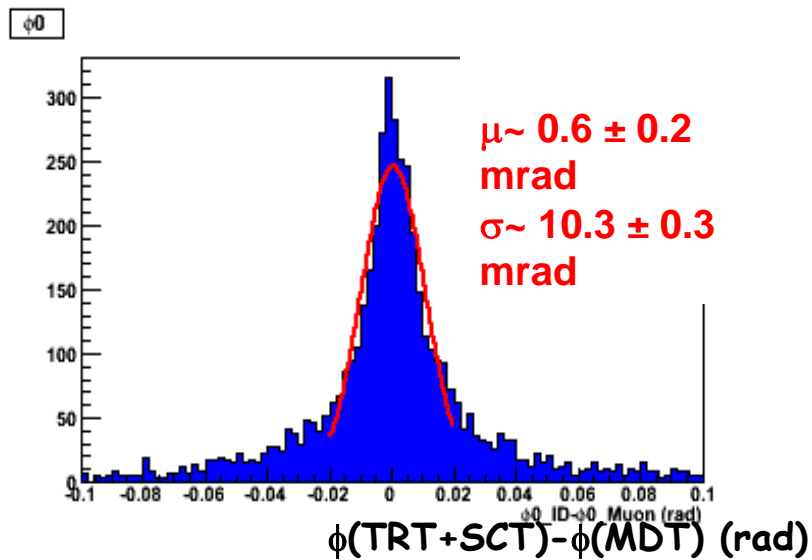


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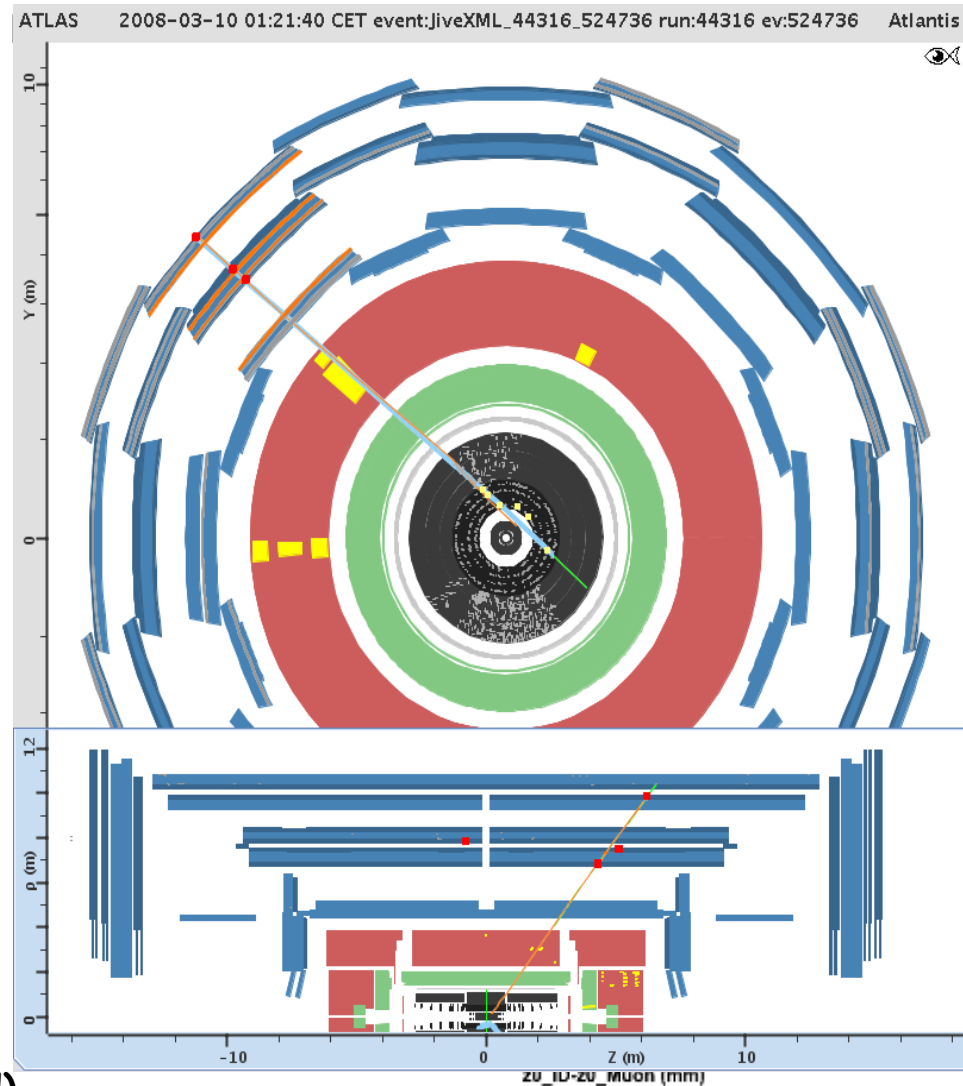
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# Cosmic data analysis: TRT+SCT and Muon



Difference of track position ( $\eta, \phi$ )  
 TRT+SCT vs. Muon (MDT)



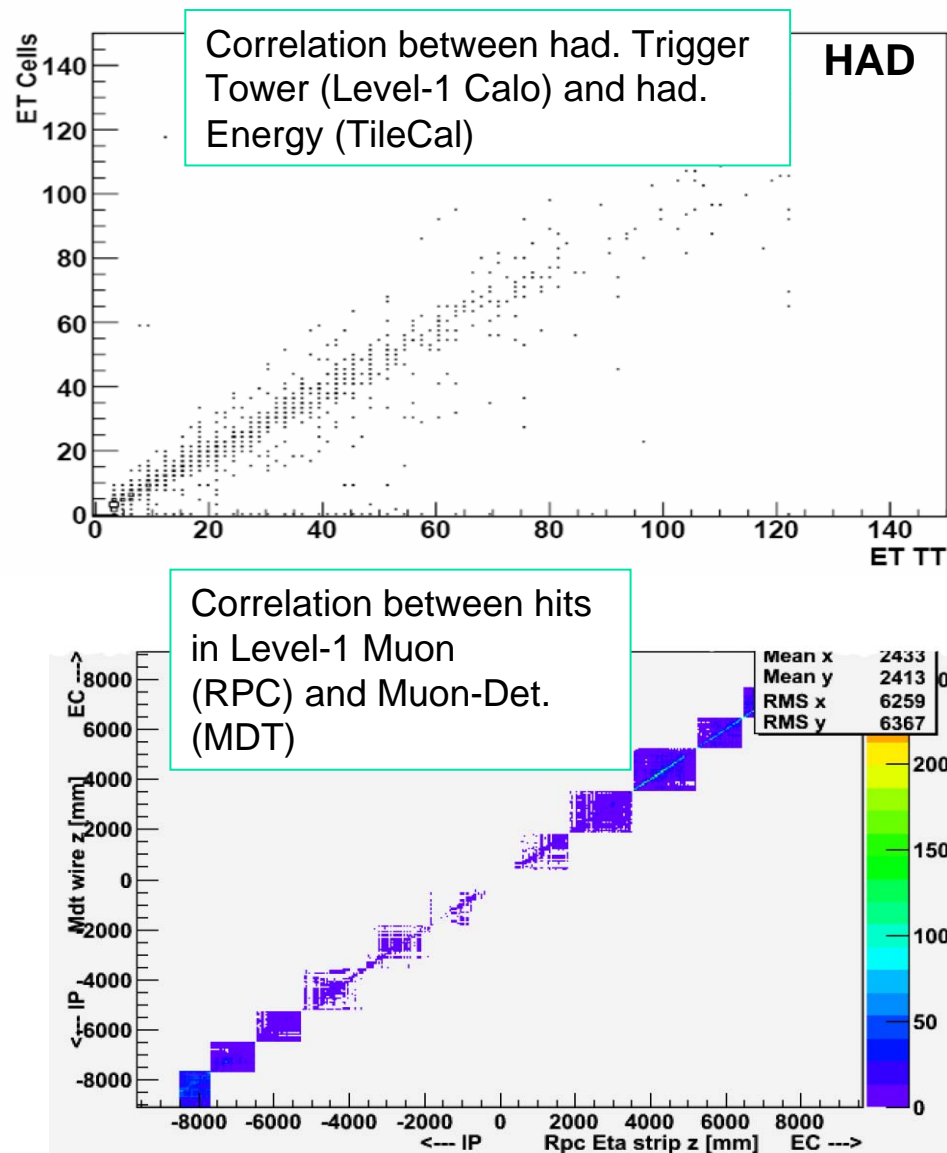
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# Trigger and Data Acquisition (TDAQ)

# Level-1 Trigger Commissioning

- Calorimeter trigger signals are thoroughly tested before access disappears
- Muon trigger commissioning done sector by sector (Availability of gas and power supplies)
- Timing being addressed
  - Require all triggers to have same timing w.r.t. (non-existent) bunch-crossing
  - Complete system needs to be available (Calo and Muon)



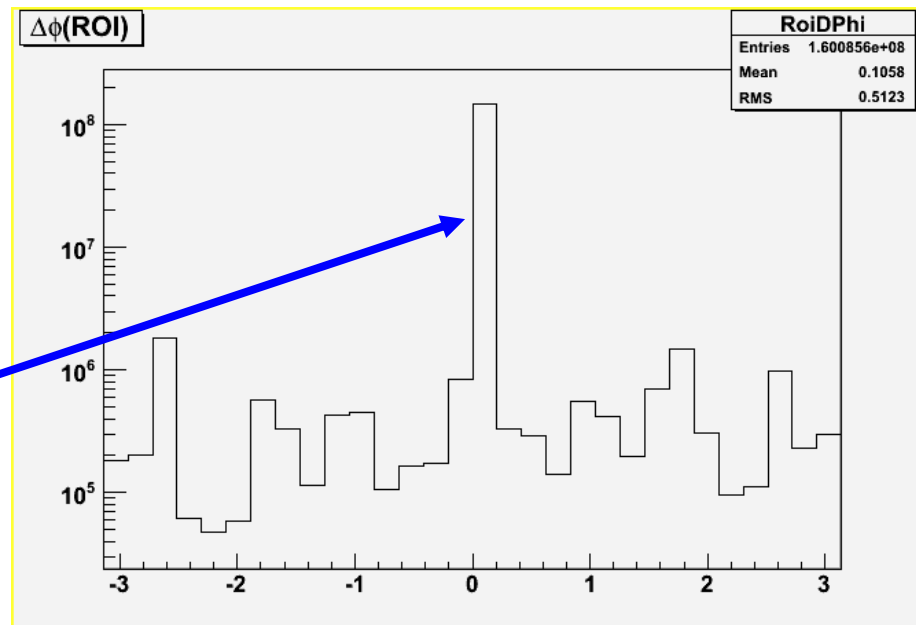


# Level-1 Calo Triggering in April CaloWeek

- Setup for combined running:
  - L1Calo, LAr, Tile
  - TDAQ
- Triggering on (in collisions):
  - electron/gamma trigger
    - At > 5 GeV
  - jet trigger at
    - At > 20 GeV
  - tau trigger at
    - At > 15 GeV
- Regions
  - LAr: EM-Barrel, EM-Endcap (EMEC), Had. Endcap (HEC)
  - Tile: Barrel, Extended-Barrel
- Spacial correlation ( $d\phi$ ) of interesting regions flagged by L1Calo (ROI) compared to Calo (LAr and Tile) (in *log* scale)

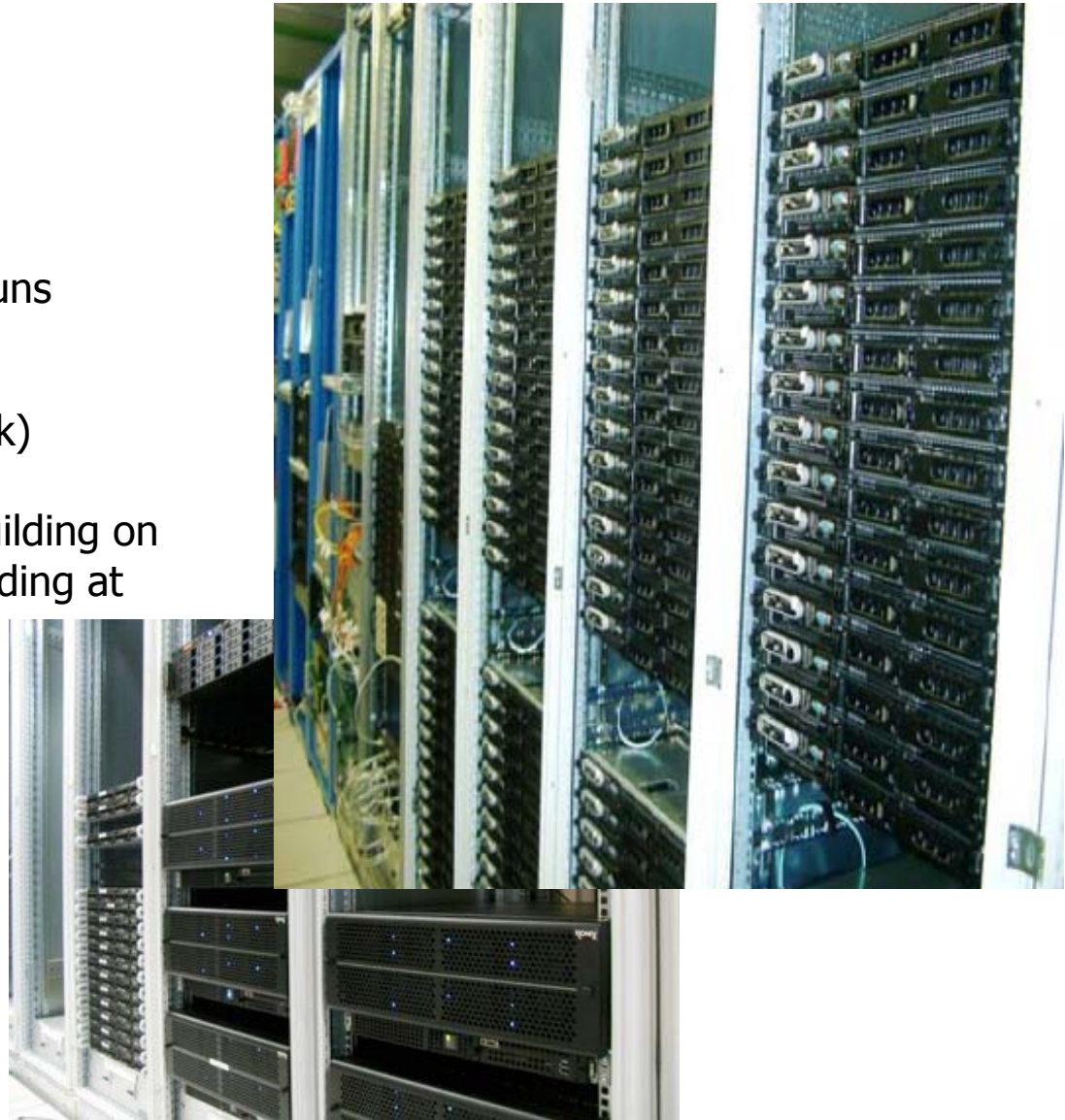
CTP Items, retrieving data from: LumiBlock.LB\_CTP\_54046\_00010

	CTP ID	Item Name	Before Prescale	After Prescale	After Veto
1	61	NIM8	14.7708	1.46875	1.46875
2	26	1EM2	1.51042	1.51042	1.44792
3	9	1J4	1.46875	1.46875	1.33333
4	10	1J5	1.02083	1.02083	0.927083
5	36	1TAU4	0.927083	0.927083	0.833333
6	63	NIM10	4.04167	0.395833	0.395833
7	53	NIM0	0.364583	0.364583	0.260417
8	62	NIM9	0.583333	0.0625	0.0625
9	27	1EM3	0.0833333	0.0833333	0.0520833
10	64	NIM11	0.145833	0.0208333	0.0208333
11	242		0	0	0



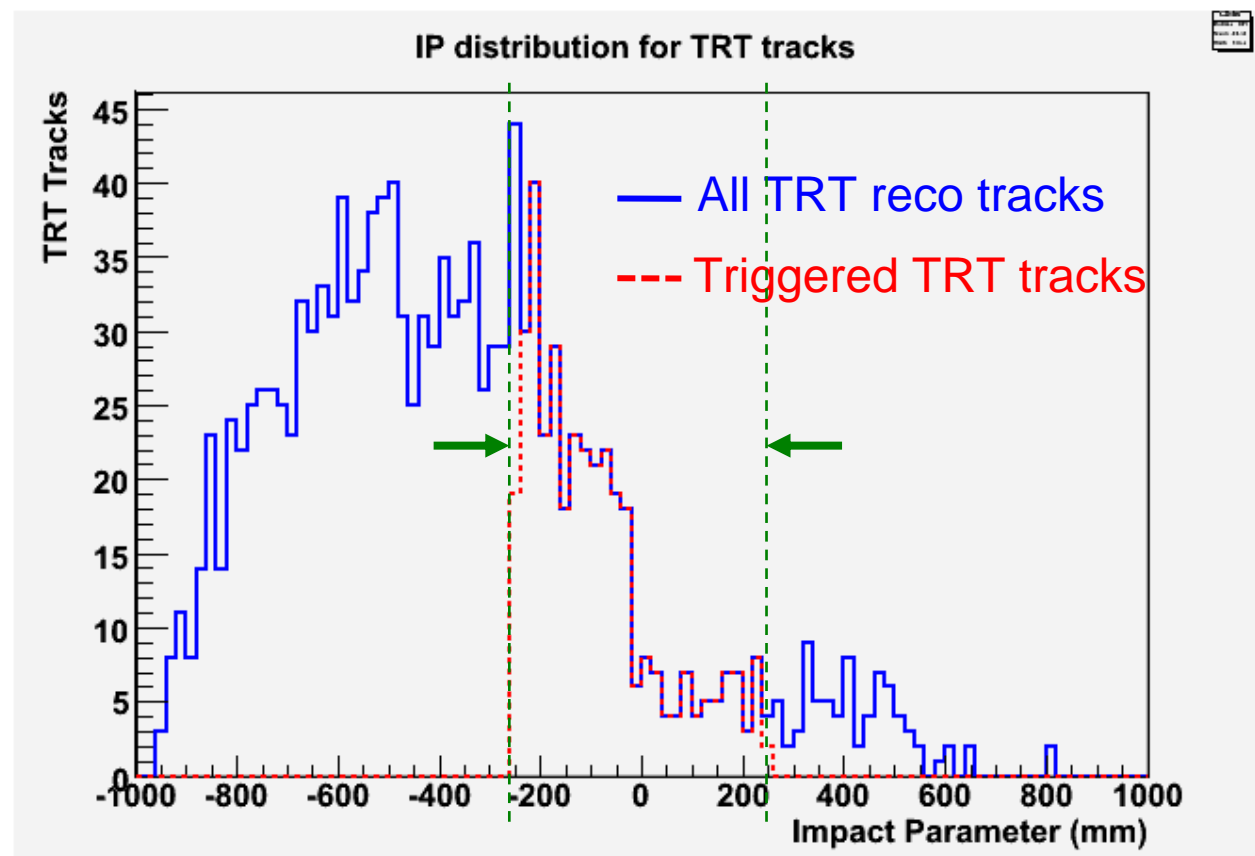
# High Level Trigger Infrastructure

- **HLT nodes** consist of:
  - Level-2 Supervisors
  - Level-2 Processing Nodes
  - Event Filter Nodes
- 1U rack mounted dual quad core
- Regularly used in commissioning runs
- Expansion to 830 nodes
  - 35% of foreseen system
- Rapid installation (3 racks per week)
- **Sub Farm Inputs** perform Event Building on Level-2 selected events, Event building at  $\sim 3\text{kHz}$  (event size 1.5 Mbyte)
- **Sub Farm Outputs** write Event Filter-selected events to disk
  - Write to separate streams
  - 6 available (final number)
  - 300 Mbyte/s to computer centre



# High Level Trigger: Track Trigger

High Level  
Trigger



- Analysis of one M6 cosmics commissioning run taken in March 2008
  - Trigger is requiring TRT tracks reconstructed online within pixel volume (equivalent to  $d_0 \leq 250$  mm)
  - Triggered events (red) end up in one stream file, non-triggered events (blue) into another one: proves trigger and streaming are working

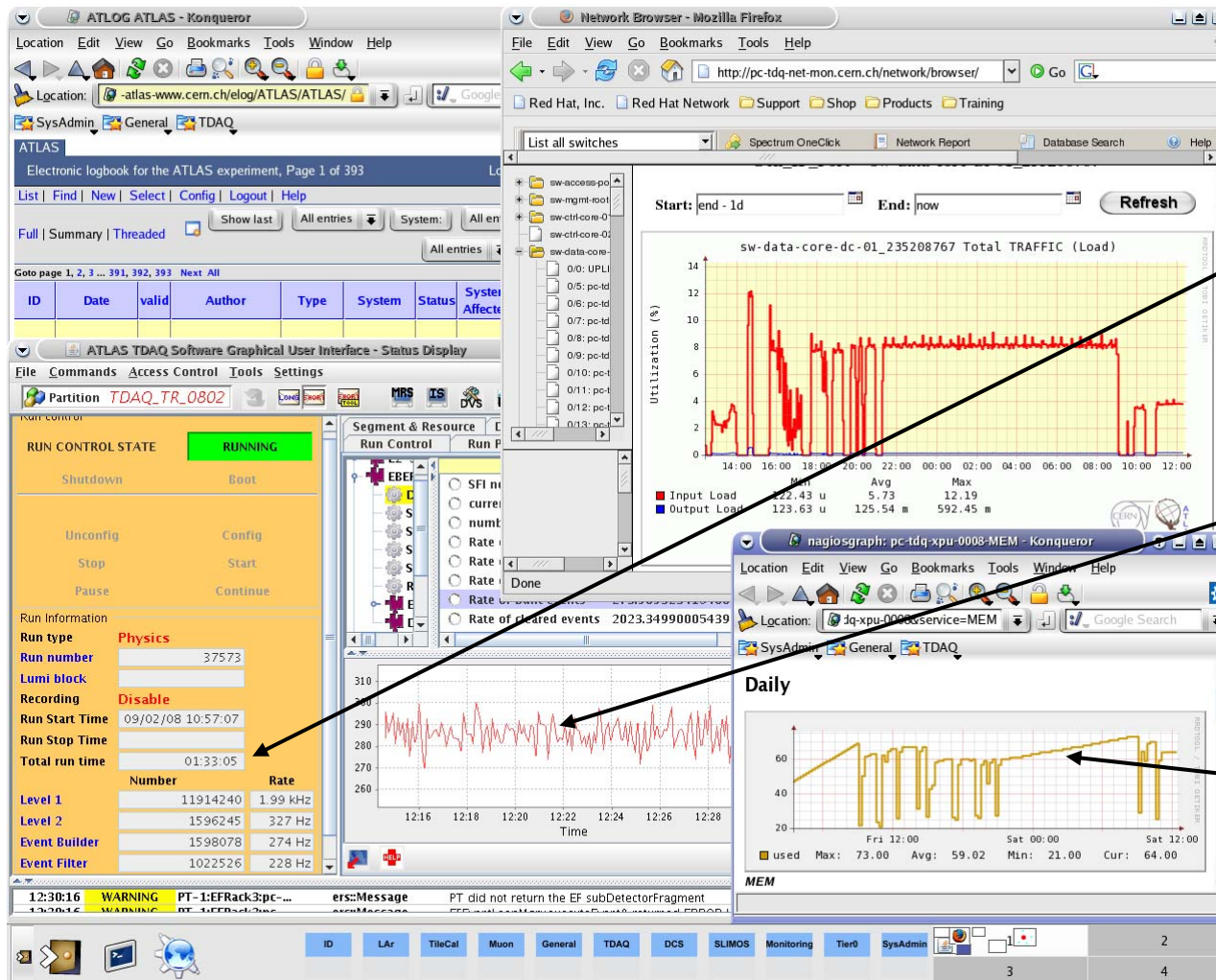
# Technical Runs

- Series of tests of TDAQ-only at nominal rate (40 MHz input). Using busy events e.g. ttbar from MC.

Most recently in April '08:

- Concentration on stress tests: Stress data flow at all levels
- Achievements:
  - Stable running (several hours without intervention)
    - Event sizes from 1 MB to 10 MB
    - Event Building and Data Writing ran at Gbit link limits
  - Controlled ~1500 applications over 350 nodes
    - Successful, though some tweaks needed in error handling
  - Playback of M4, M5 and Monte Carlo data to test all algorithm slices
  - Generated data set for luminosity  $10^{31}$  used to test HLT menu for initial running

# Technical Run Display



1.5 hour  
running time

stable  
trigger rate

memory  
leak spotted





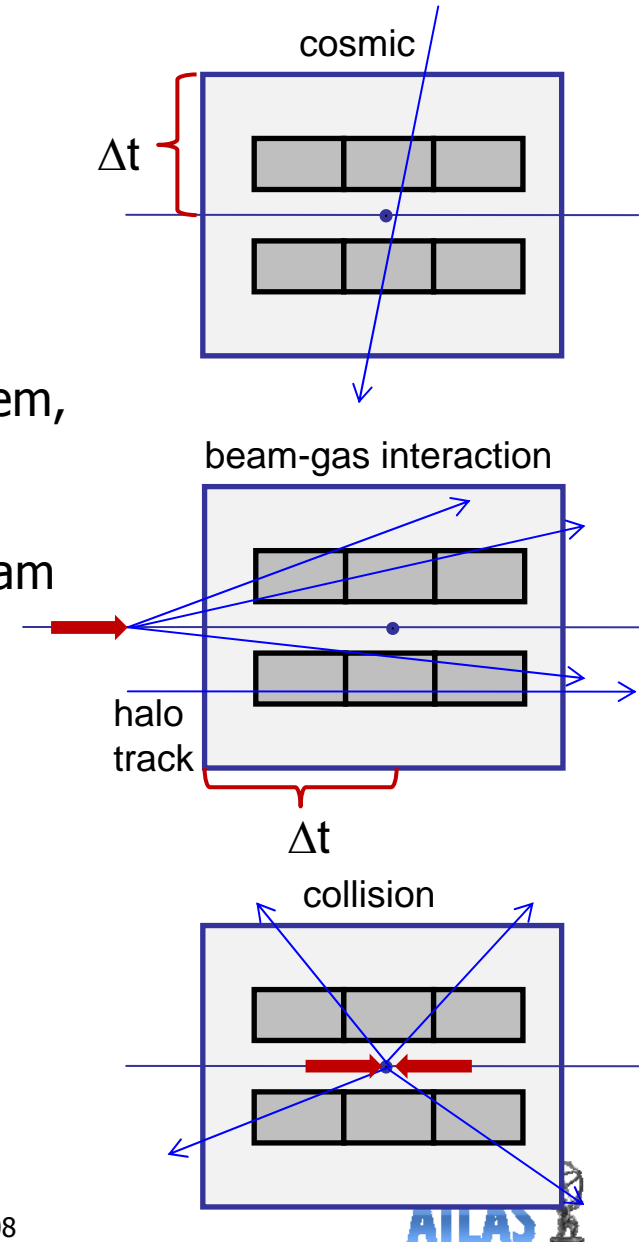
# Looking ahead...

# Looking ahead: Commissioning with beam

Activities during Beam Commissioning  
(expected end-July):

- Calibration triggers
  - Detector characterisation, timing
- Cosmic triggers
  - Exercise whole system, HLT, read out, TTC system,
  - Alignment data, coarse timing, synchronisation,
  - Monitoring, exercise reconstruction/ Tier 0
  - Verification of experiment protection without beam
- Single beam triggers
  - Validation of beam protection systems
  - Feedback to machine,
  - First synchronization with LHC
- Collision triggers
  - Full synchronization with LHC
  - Understanding of full detector
  - Physics ...

*(Talk S6.4 today by Tetiana Hryn'ova)*



# Conclusions

- ATLAS detector is fully installed in the cavern
- Last hardware work being done before beam-line closes, esp. in Muon (MDT) and Inner Detector (SCT and Pixel cooling) area
- Milestone weeks with cosmic, calibration and technical runs on-going:
  - Combined analysis
  - 'Real' triggers used
  - TDAQ integrating all subsystems
- Online and Offline software maturing, computing infrastructure being tested
- Moving into continuous runs and 24/7 shifts
- *Ready and waiting for collisions!*