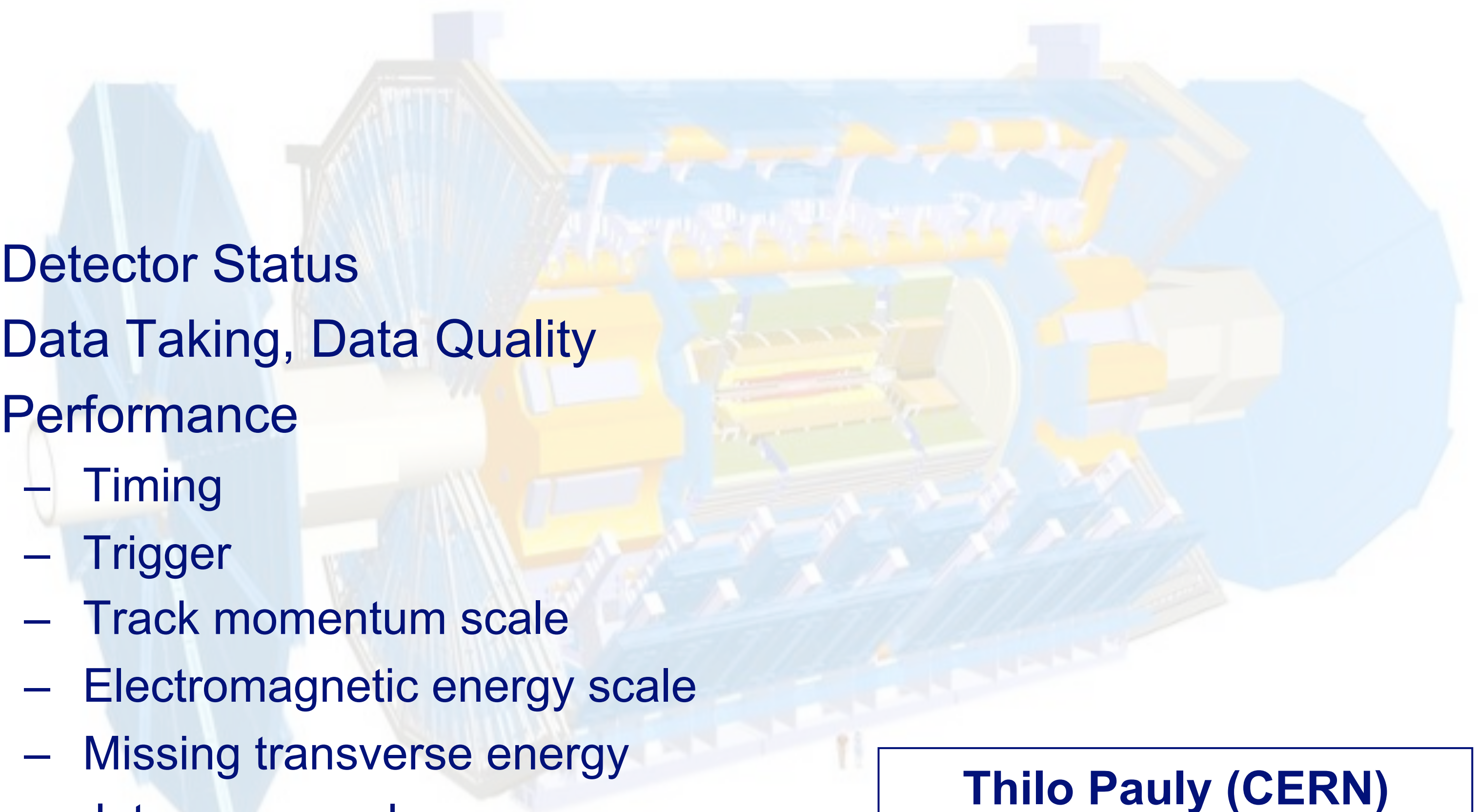
Performance of the ATLAS Detector and its Electronics under First Beam Conditions



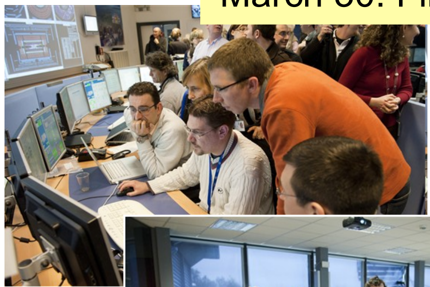
- Detector Status
- Data Taking, Data Quality
- Performance
  - Timing
  - Trigger
  - Track momentum scale
  - Electromagnetic energy scale
  - Missing transverse energy
  - Jet energy scale
  - Muon reconstruction

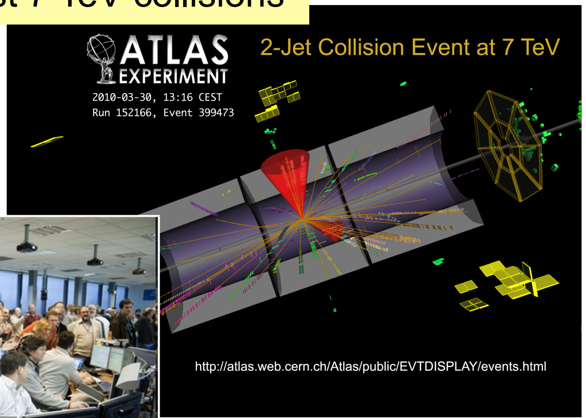
Thilo Pauly (CERN)

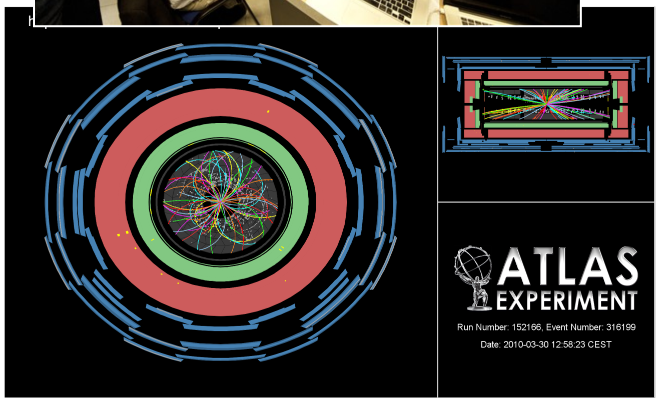
TWEPP 2010 Aachen

2010: An exciting year so far …

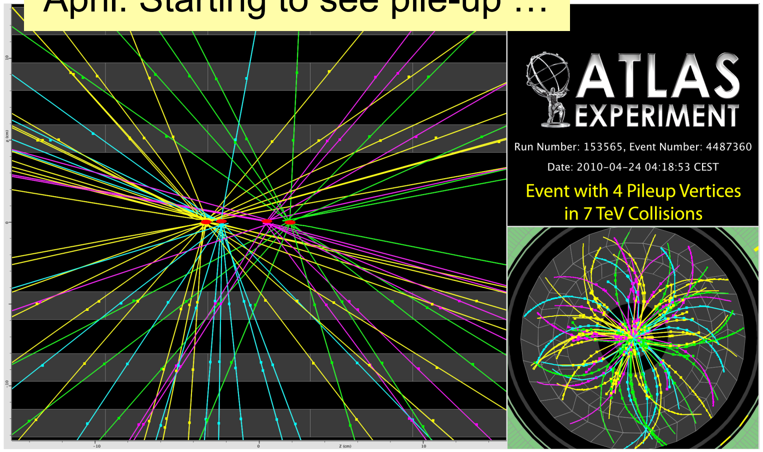
March 30: First 7 TeV collisions



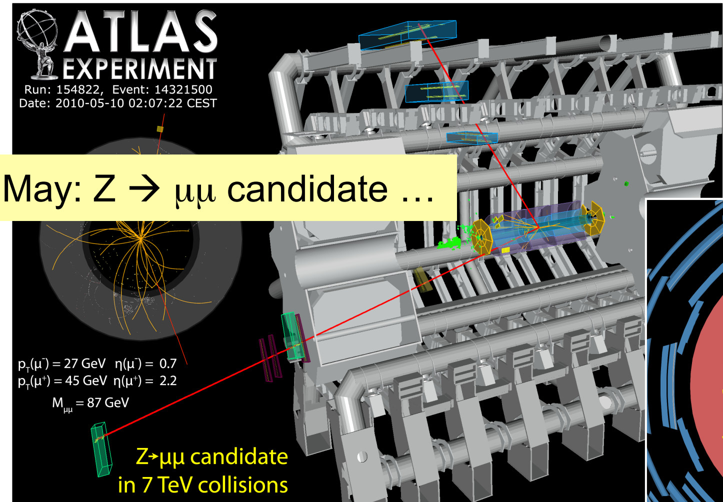


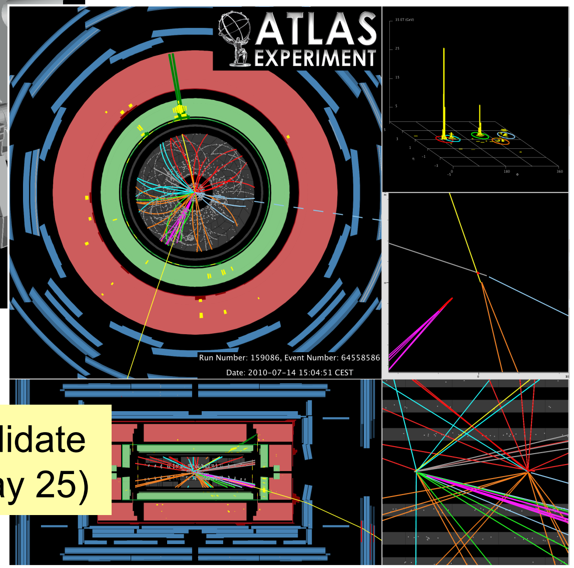


April: Starting to see pile-up …



End May: Z → $\mu\mu$ candidate …





July: t → jets + E_T^{miss} + e candidate
(first top candidate already May 25)

Thilo Pauly

ATLAS Detector …

Inner Detector: Silicon pixels, Silicon strips, Transition radiation detector, in 2T solenoidal field

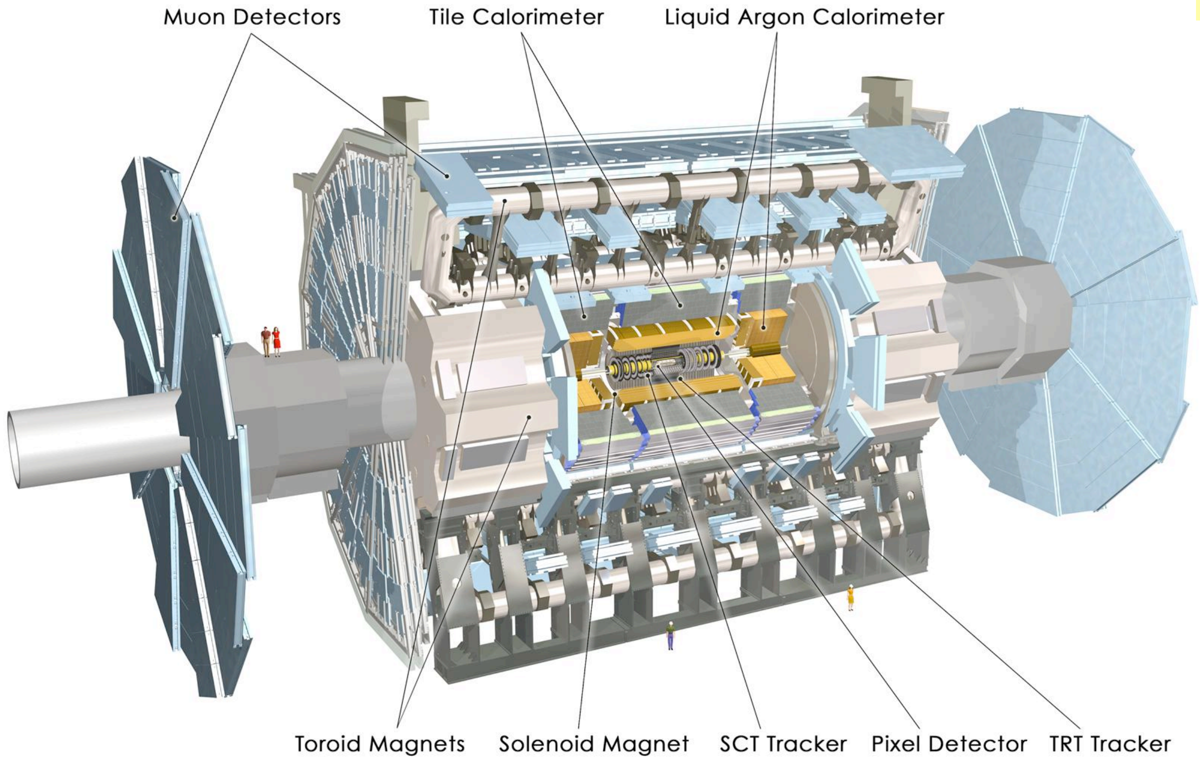
$\Delta p_t/p_t <= 0.05\% \; p_T \oplus 1\%$

Calorimeters

EM: LAr-Pb accordion $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$

HAD: Scintillator-Fe (central), LAr-Cu/W (endcap)

$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$



Muon spectrometer: 4 types of gas chambers (3 layers)

Trigger: $|\eta| < 2.4$

Reconstruction: $|\eta| < 2.7$

$\Delta p/p < 10\%$ up to 1 TeV

Toroidal Air-core Magnets

ATLAS Trigger …

Level-1: 40 MHz

- Implemented in hardware,
- Muon + Calo based, coarse granularity
- Selection on e/γ, τ/hadron, μ, jet candidates and on energy sums and E_T^{miss}
- Define regions of interest (ROIs)

<75 kHz

Level-2:

- Implemented in software
- Seeded by level-1 ROIs, full granularity
- Includes tracking information

~ 3kHz

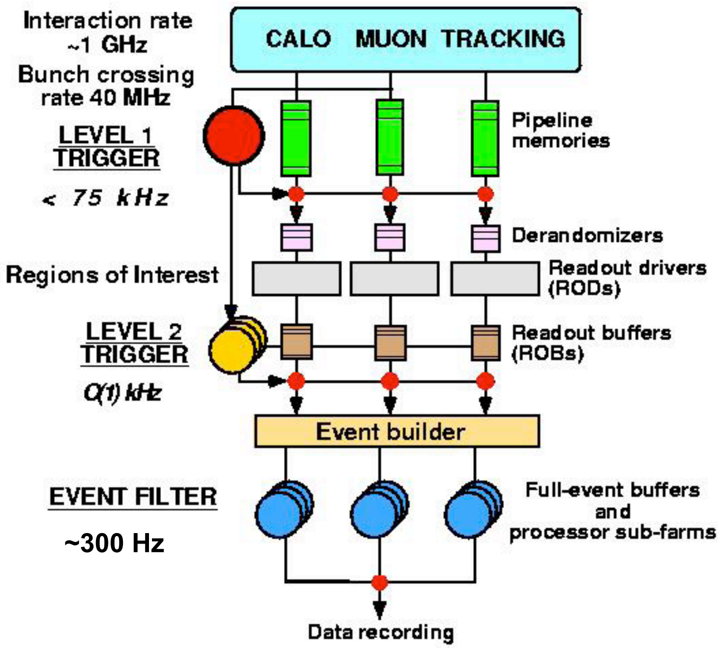
Event Filter:

- Implemented in software
- Full event building
- Refine Level-2 decision
- Offline-like algorithms for physics signatures

~300 Hz

High Level Trigger = **HLT**

Trigger and Data Flow Architecture



Detector Status …

Working fraction of the ATLAS detector end June '10:

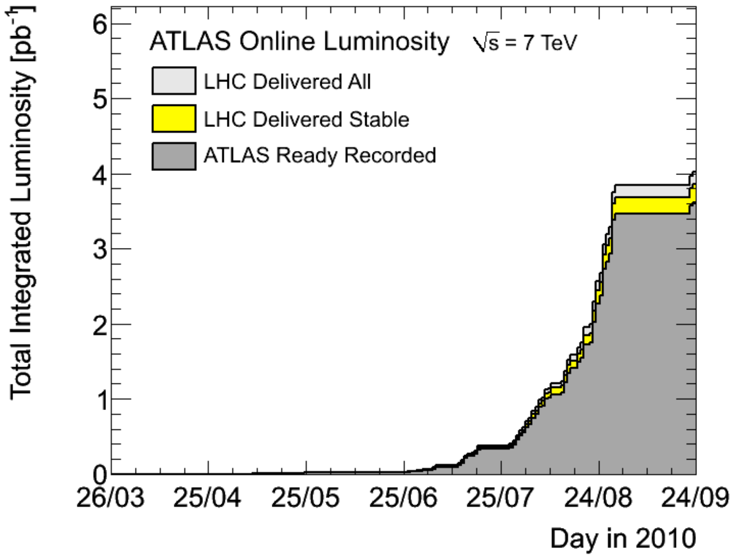
Sub-Detector	Number of channels	Approx. operational fraction (%)
Pixels	80 M	97.4
SCT Silicon Strips	6.3 M	99.2
TRT Transition Rad. Tracker	350 k	98.0
LAr EM Calorimeter	170 k	98.5
Tile Calorimeter	9800	97.3
Hadronic Endcap LAr Calorimeter	5600	99.9
Forward LAr Calorimeter	3500	100
LV1 Calo Trigger	7160	99.9
LV1 Muon RPC Trigger	370 k	99.5
LV1 Muon TGC Trigger	320 k	100
MDT Monitored Drift Tubes	350 k	99.7
CSC Cathode Strip Chambers	31 k	98.5
RPC Barrel Muon Chambers	370 k	97.0
TGC Endcap Muon Chambers	320 k	98.6

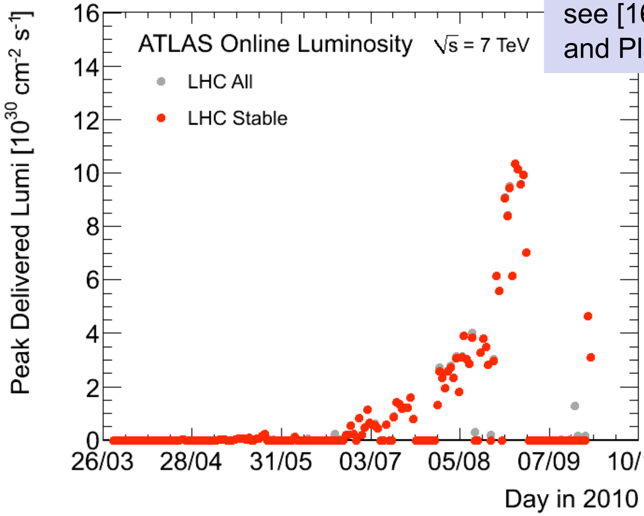
For all systems > 97% of channels are operational, in addition have built-in redundancy in most systems.
Overall detector is performing very well, but a few issues with component failures to watch out for …

see [188] T.Flick, VCSEL failures in ATLAS

see [113] T. LIU, Optical Link for ATLAS Liquid Argon Calorimeter

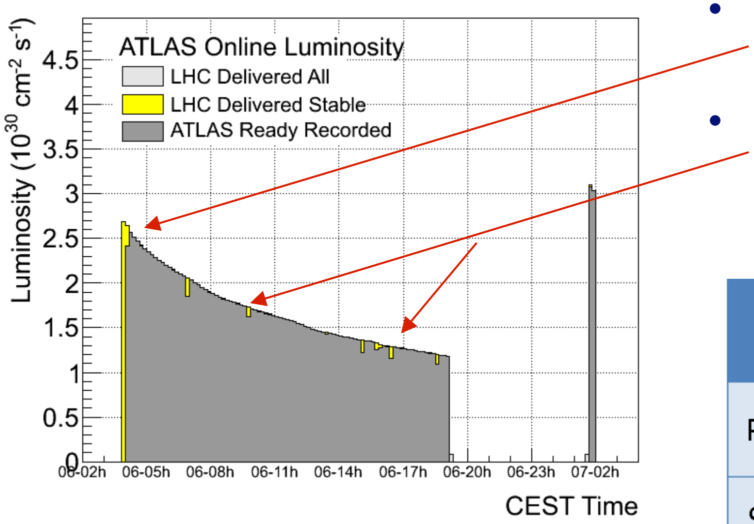
Data Taking and Data Quality …





see [168] R. Assmann, LHC project, Status, and Plans

Typical LHC fill … **Aug 6**



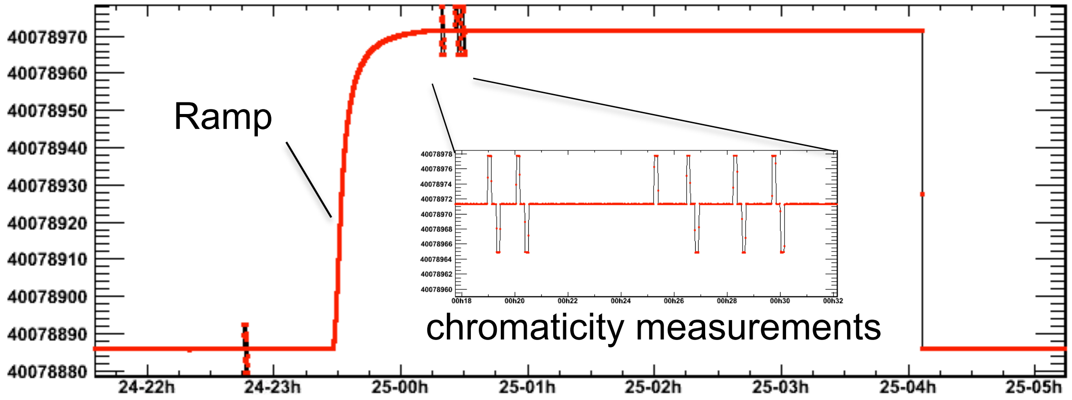
- Data Taking Efficiency very good
- Few minutes needed for tracking detectors (silicon and muons) to ramp HV when LHC declares stable beams
- Short ‘dips’ in recorded rate: recover “on-the-fly” modules which would otherwise give a BUSY blocking further events

Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	TGC	CSC
97.7	96.4	100	94.4	98.7	99.3	99.2	98.5	98.3	98.6	98.3

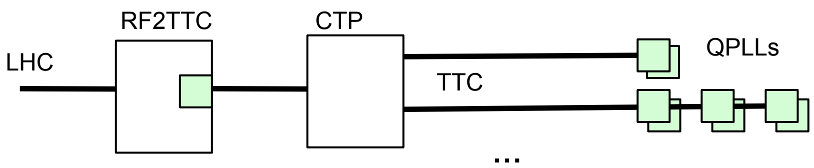
‘Good for Physics’ fraction with stable beams, constantly > 94%

Timing ... LHC 40 MHz Clock Stability

- LHC clock not exactly stable:
  - Ramp (acceleration)
    - 87 Hz protons
    - 550 Hz ions
  - Frequency steps:
    - chromaticity measurements (+/- 6 Hz), loss map RF trims (+/- 90 Hz)
    - LHC resync
    - internal/external clock switch



- Many PLLs in ATLAS
  - most critical QPLL (Quartz Crystal Based Phase-Locked Loop for Jitter Filtering Application in LHC)
    - narrow locking range



- During data-taking, all QPLLs need to stay locked
  - otherwise data corruption, BUSY, readout inefficiencies
- Since data taking already starts before the ramp, we had unlocks at first
  - needed a revision of the configuration scheme for our QPLLs (thanks to S. Baron, P. Moreira)

- ATLAS' way to solve the problem:
  - use a well-defined frequency during configuration process (GPS-based function generator at injection frequency)
  - force a QPLL reset during configuration process, in the right order (top-to-bottom)
    - direct reset via reset pin
    - indirect reset: phase jump via TTCrx unlocks QPLL (automatic mode)
      - tried frequency jump, which didn't seem to work properly
  - for few sub-detectors: stop-less recovery, within a few seconds re-synchronize failing detector parts

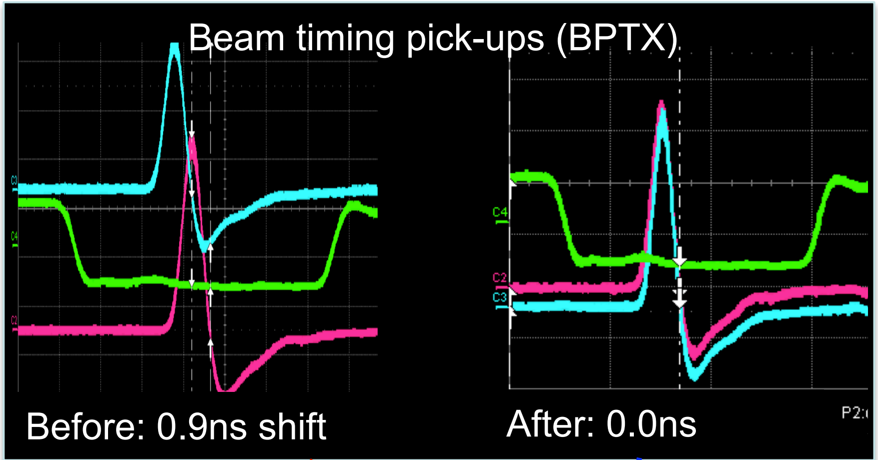
see [110] D. Olivito, ATLAS Transition Radiation Tracker

see [54] T. Hayakawa, ATLAS Endcap Muon Trigger

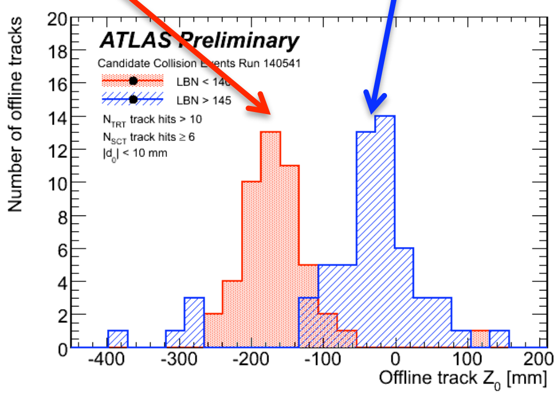
Timing ...

LHC timing

- RF cogging: phase rotation of beam 2 wrt beam 1 to longitudinally center the collision in the IP



12cm shift observed in tracking



Trigger timing

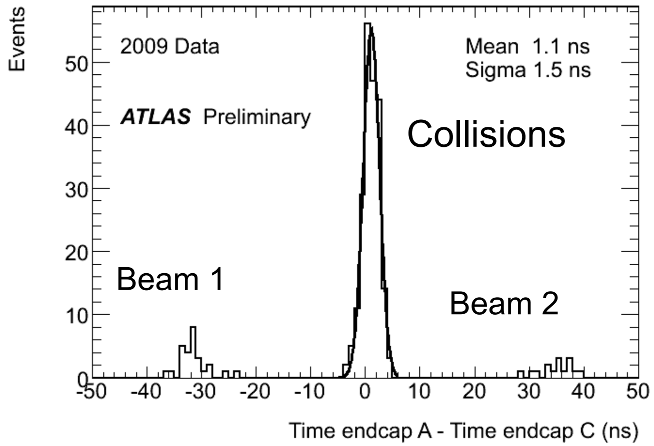
- most Level-1 triggers are timed-in within 1 BC or better

> see [54] T. Hayakawa, Performance of the ATLAS Endcap Muon Trigger
>
> see [78] J. Brancinik, ATLAS Level-1 Calorimeter Trigger

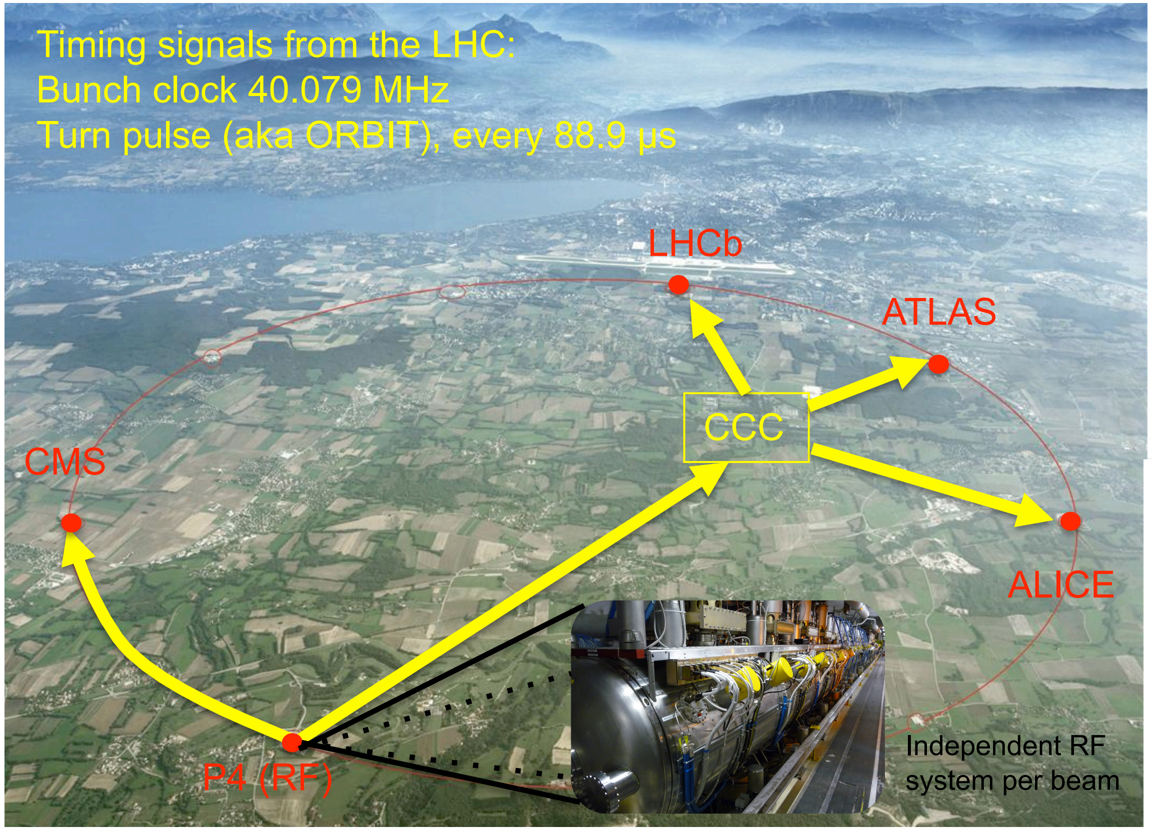
- few cases with +/- 1 BC
  - being improved, but OK for now with large bunch spacing
  - stretching to 3 BCs and forced coincidence with colliding bunches
- trigger latency (collision to trigger output): 1750ns

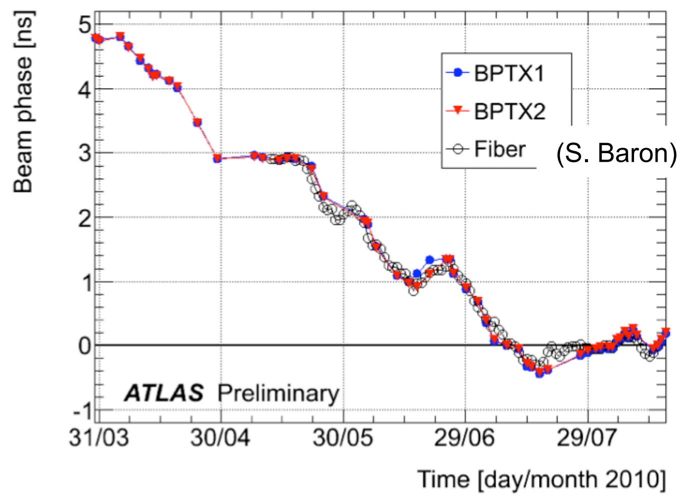
Sub-detector timing

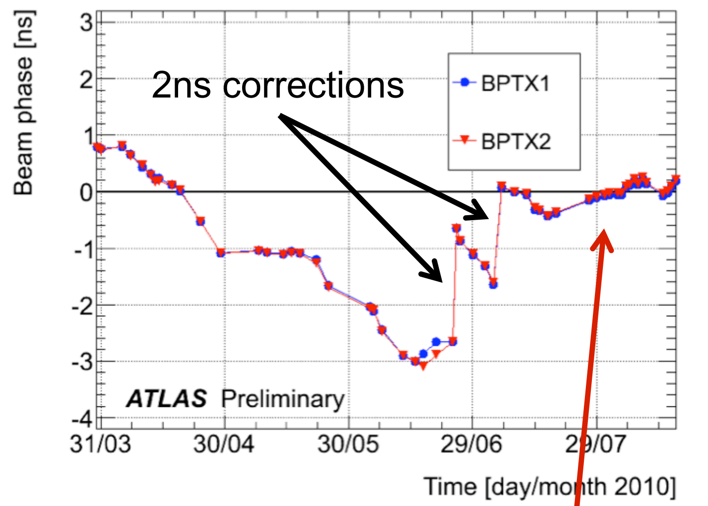
Example: LAr
•Timing resolution ~1 ns, goal 100ps
•Beam timing needs to be stable wrt LHC clock



Timing ... LHC Clock Drift







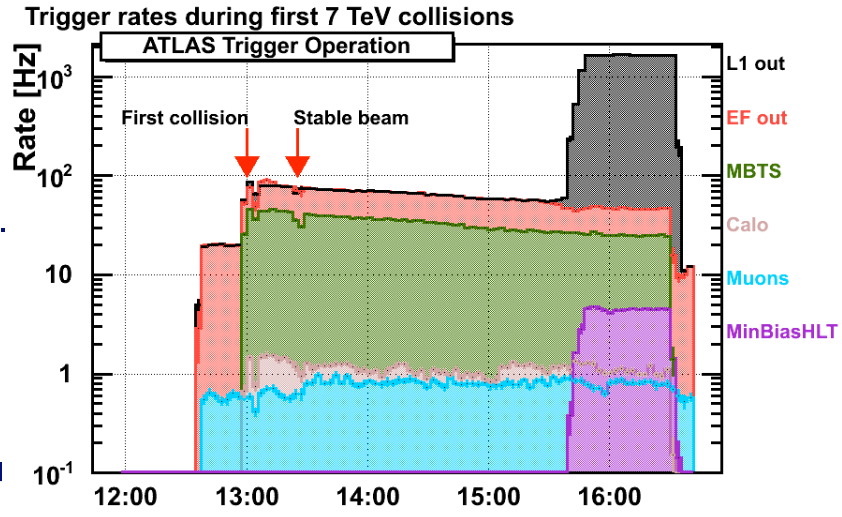
- Clock drift of 5 ns between April and July due to optical fiber (length variations with temperature)
- Many sub-detectors confirmed this
- Correction to keep within +/- 0.5ns using RF2TTC fine delay

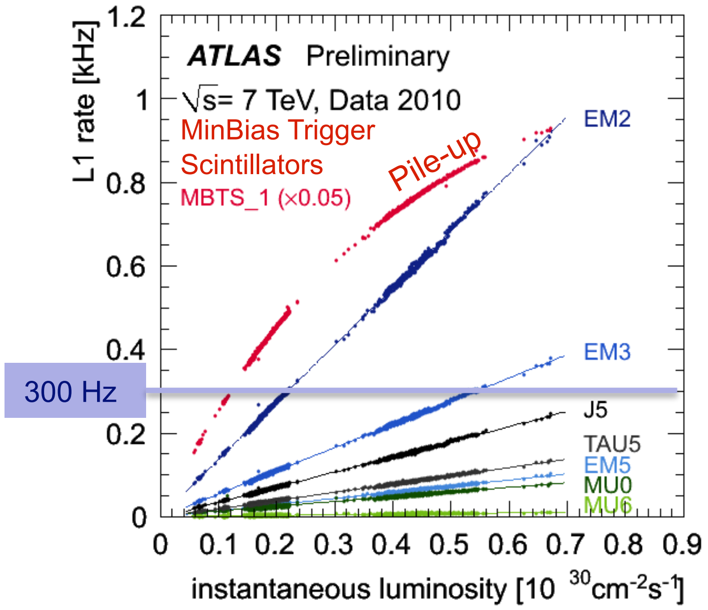
Keep phase stable within ±0.5ns

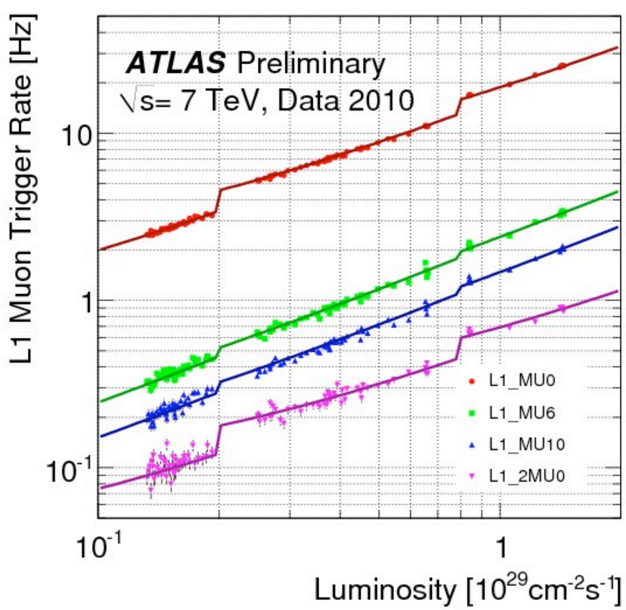
see [111] F. Alessio, LHCb timing and background monitoring

ATLAS Trigger ...

- Level-1 trigger rates evolve quickly with increasing luminosity
  → successively enable active rejection of events for various High Level Triggers (HLT)
  → Recorded physics rate during stable beams ~ 300 Hz.
- Validation of trigger algorithms with data is a crucial step before chains become actively rejecting!
- First high-level triggers to be run in activate rejection mode are low p_T electromagnetic chains, followed by tau and muon chains.







More information:

see [38] M. Stockton, ATLAS Level-1 Central Trigger

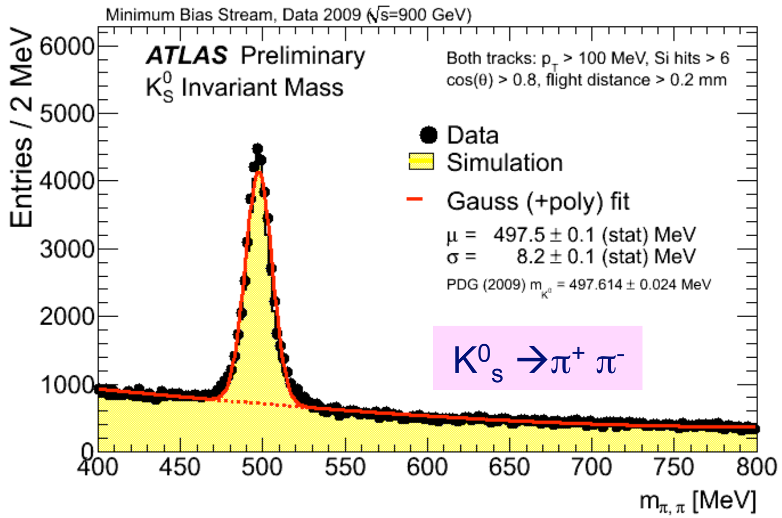
see [54] T. Hayakawa, Performance of the ATLAS Endcap Muon Trigger

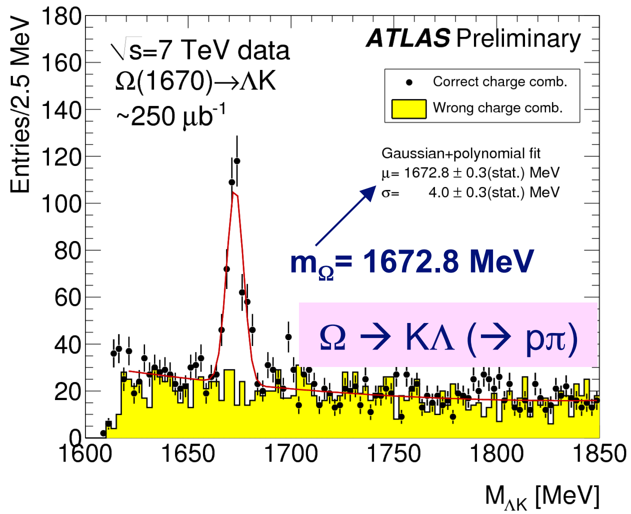
see [78] J. Brancinik, ATLAS Level-1 Calorimeter Trigger

see [144] T. Martin, Minimum Bias Triggers in ATLAS

Inner Detector Track Momentum Scale

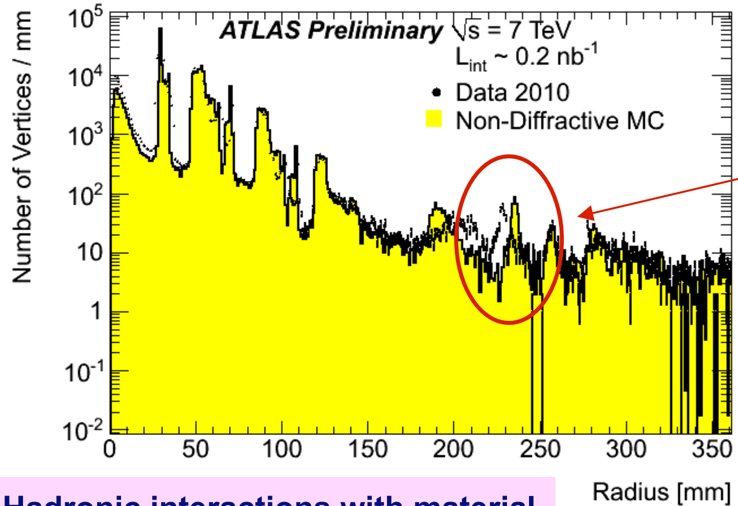
- At low p_T: large progress from early peaks few days after first collisions to cascade decays





- secondary/tertiary vertex reconstruct. By cascade vertex fitting approach
- PDG: m_Ω = 1692.45 MeV

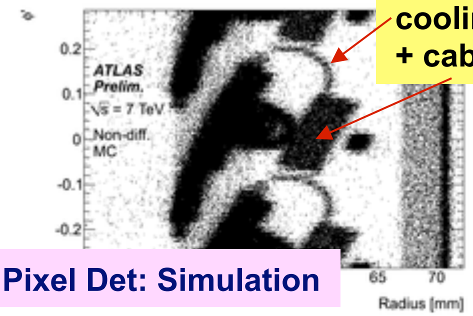
low-p_T momentum scale is known to few ‰ level, multiple scattering dominating resolution !



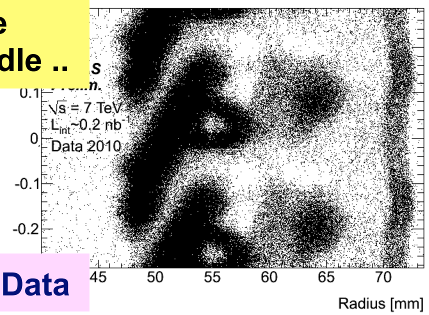
Hadronic interactions with material

- Today we know detector material distribution to ~ 10%
- Use $\gamma \rightarrow ee$ conversion + secondary hadronic interactions for mapping, already spotted few inconsistencies between data and MC ! Aim is ~% level

cooling pipe + cable bundle ..



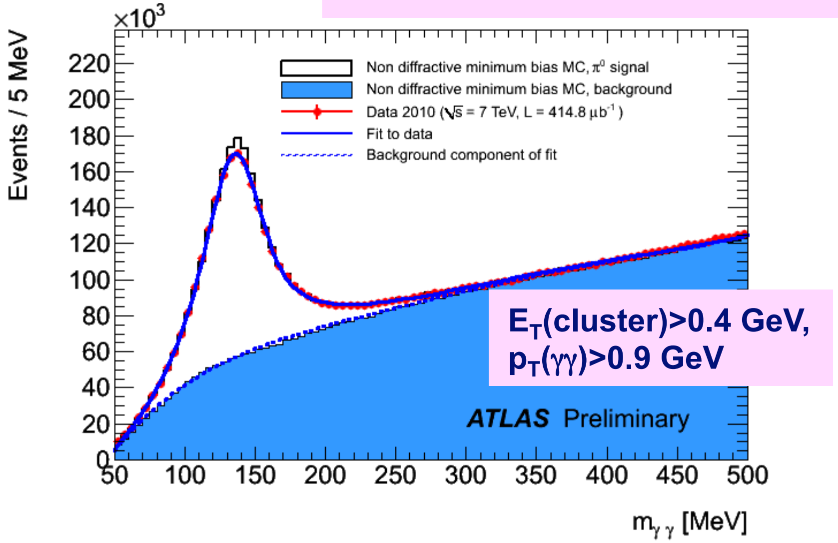
Pixel Det: Simulation

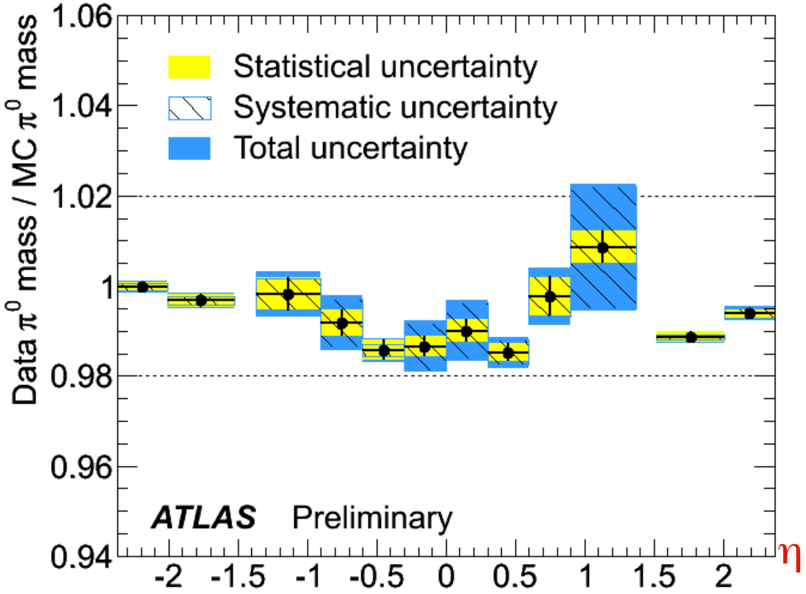


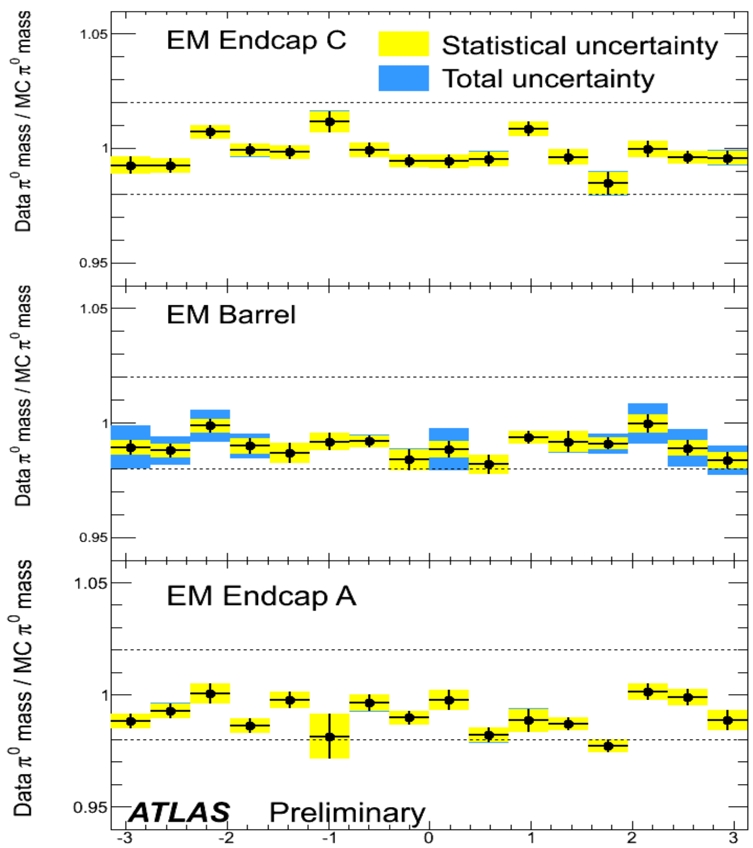
Data

Electromagnetic Shower Energy Scale …

Results from first 1 million $\pi^0 \rightarrow \gamma\gamma$





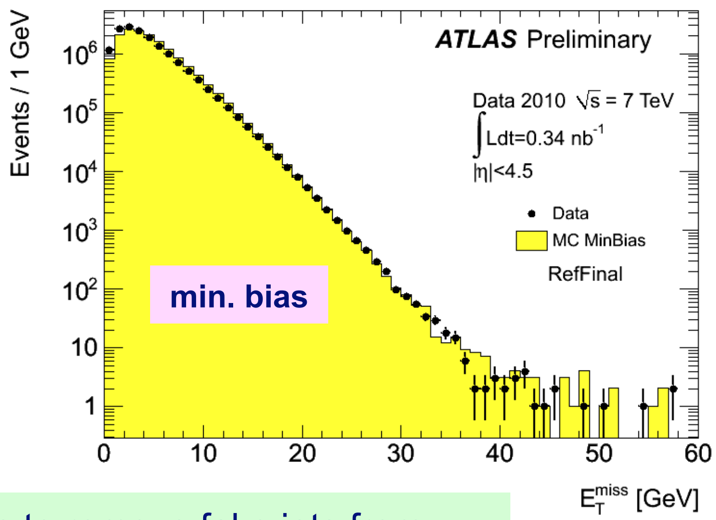


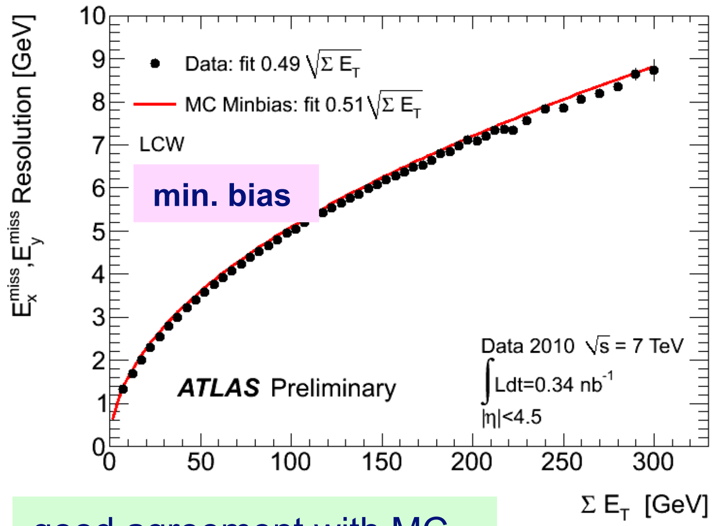
Uniformity of EM calorimeter response:
from π^0 EM energy scale known to better than 2%
over full η range, uniformity in φ <0.7%

Missing E_T

Missing E_T: Min. bias events and p_t-enhanced L1Calo samples, full calorimeter coverage

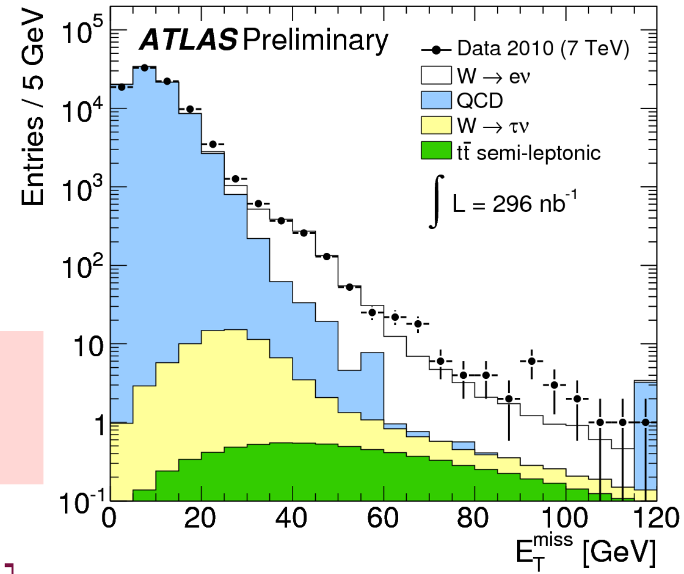
Important for SUSY searches !!





good agreement with MC

- Jet cleaning cuts to remove fake jets from noisy cells: no tails introduced into the distribution
- No tails introduced by improved calo calibration

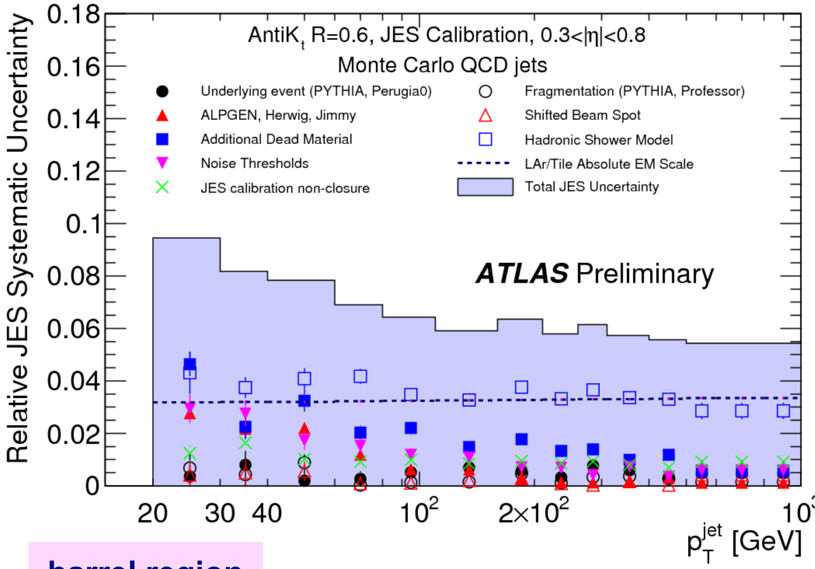


Detailed Understanding from W's ..

Jet Energy Scale

MC-based p_T, η dependent Jet Energy Scale:

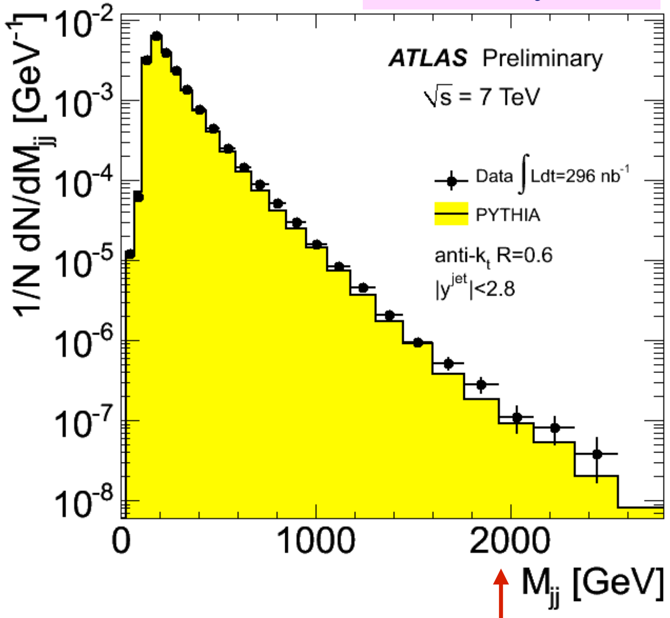
- Uncertainties 10% for low p_T, 7% for p_T>100 GeV
- validated with test-beam and collision data



barrel region

p_T(jet1)>160 GeV, p_T(jet2)>40 GeV

integrated data ~ mid July



Tevatron $\sqrt{s}$=1.96 TeV !!

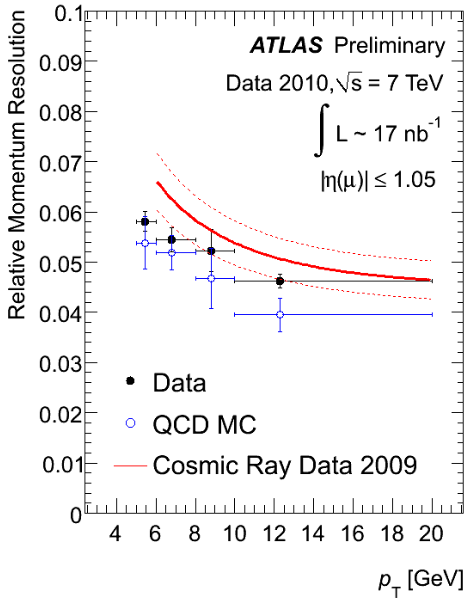
~ 3.5 months after start of LHC physics running @ 7 TeV: enter new territory above Tevatron reach !

Muon Reconstruction

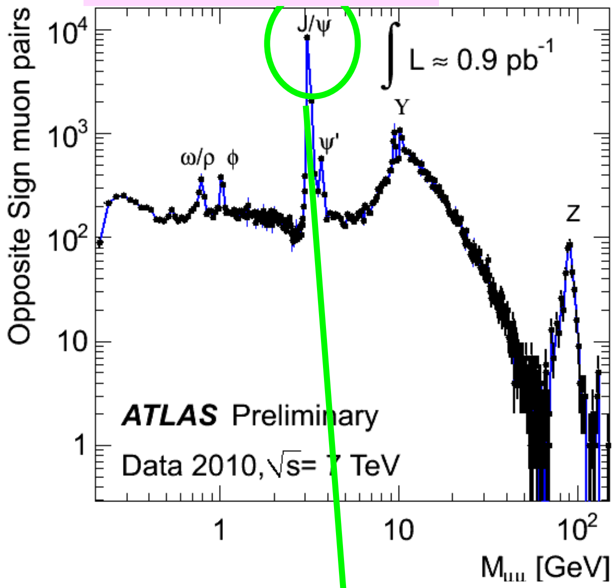
- Expected momentum resolution at high p_T is

  $\Delta p_T/p < 10\%$ up to 1 TeV

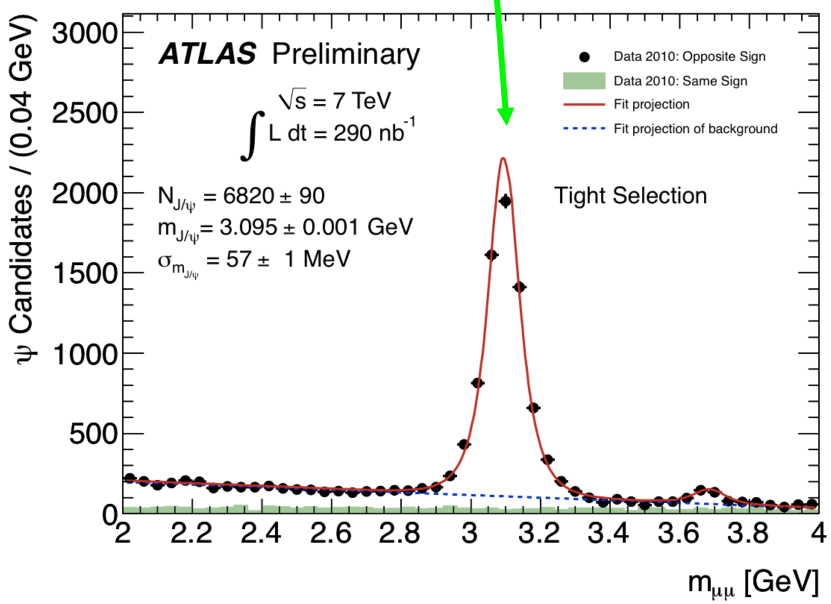
- Comparison between tracks in Muon Spectrometer and Inner Detector
- Initial understanding of the detector from analysing cosmics data, agrees well with collisions results



Di-muon resonances



- At low p_T, expected resolution is ~ 2%, dominated by multiple scattering:
  - From J/ψ di-muon mass peak: absolute momentum scale known to ≈ 0.2%, momentum resolution known to ≈ 2% for few GeV



Summary and Outlook

- First few months of LHC running @ 7 TeV has already yielded a wealth of physics results
- All ATLAS sub-detectors are working very well, no show-stopper, good data quality and data taking efficiency of > 94 %
- High level trigger algorithms enabled for active rejection in many of the main trigger chains
- Rapid progress in understanding the detector performance, employing more and more data-driven methods in addition to data-MC comparison

Rest of 2010 promises to be as exciting as the previous months …