Status of the ATLAS Experiment

Valeria Perez Reale
(Columbia University)

Many thanks for direct input from Fabiola Gianotti, Beniamino De Girolamo, Isabelle Wingerter, Kevin Einsweiler, Howard Gordon, Mike Tuts, Emlyn Hughes, Jim Shank…

USLUO Users Meeting 2009
Berkeley, USA

Columbia University
in the City of New York

Outline

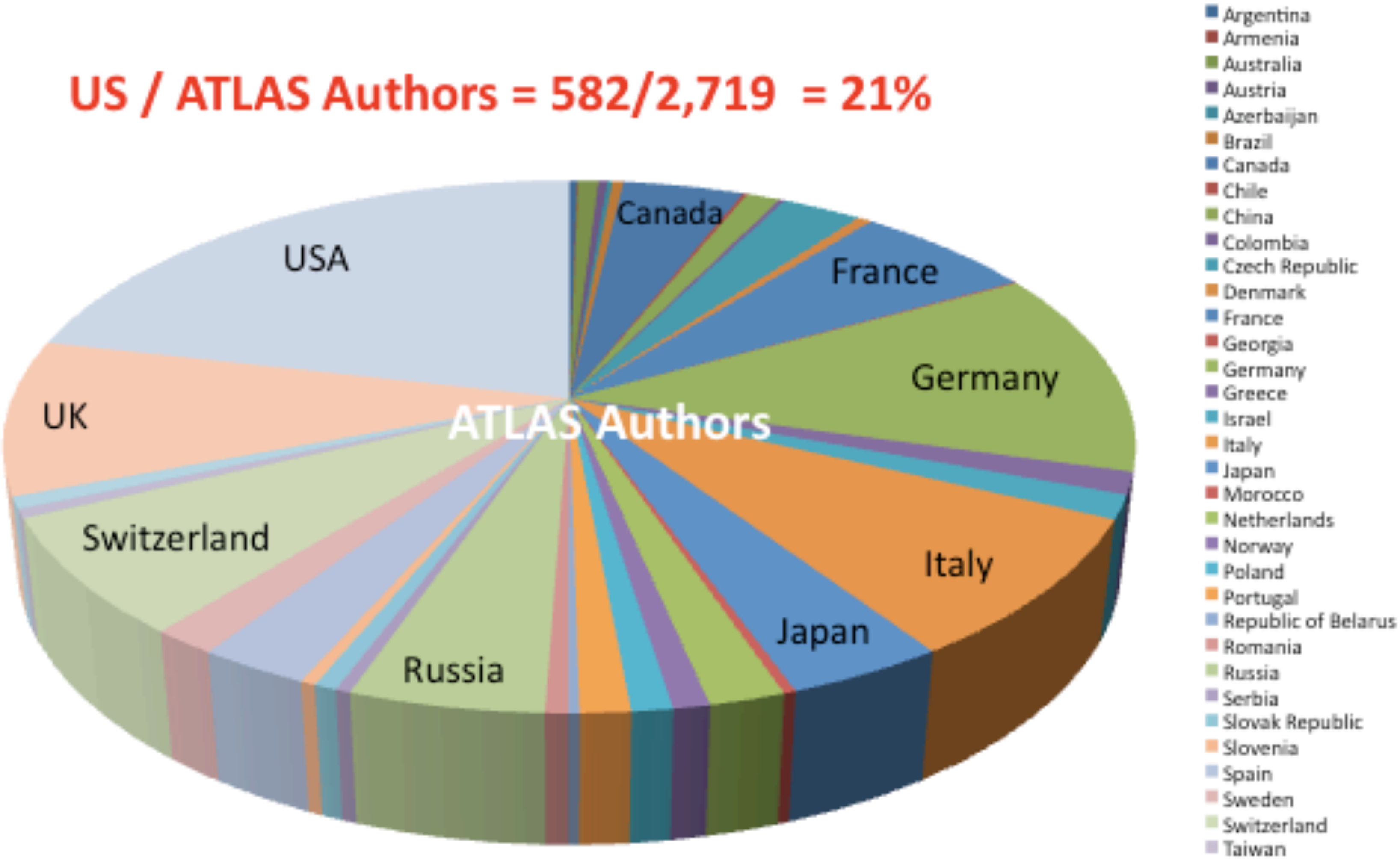
- ATLAS Detector status
- Detector commissioning with single-beam data and cosmic ray data
- Expected performance at day-1 and examples of first physics with first LHC data
- Summary

ATLAS COLLABORATION

37 Countries
169 Institutions
~2800 Scientific Authors
(~800 PhD students)

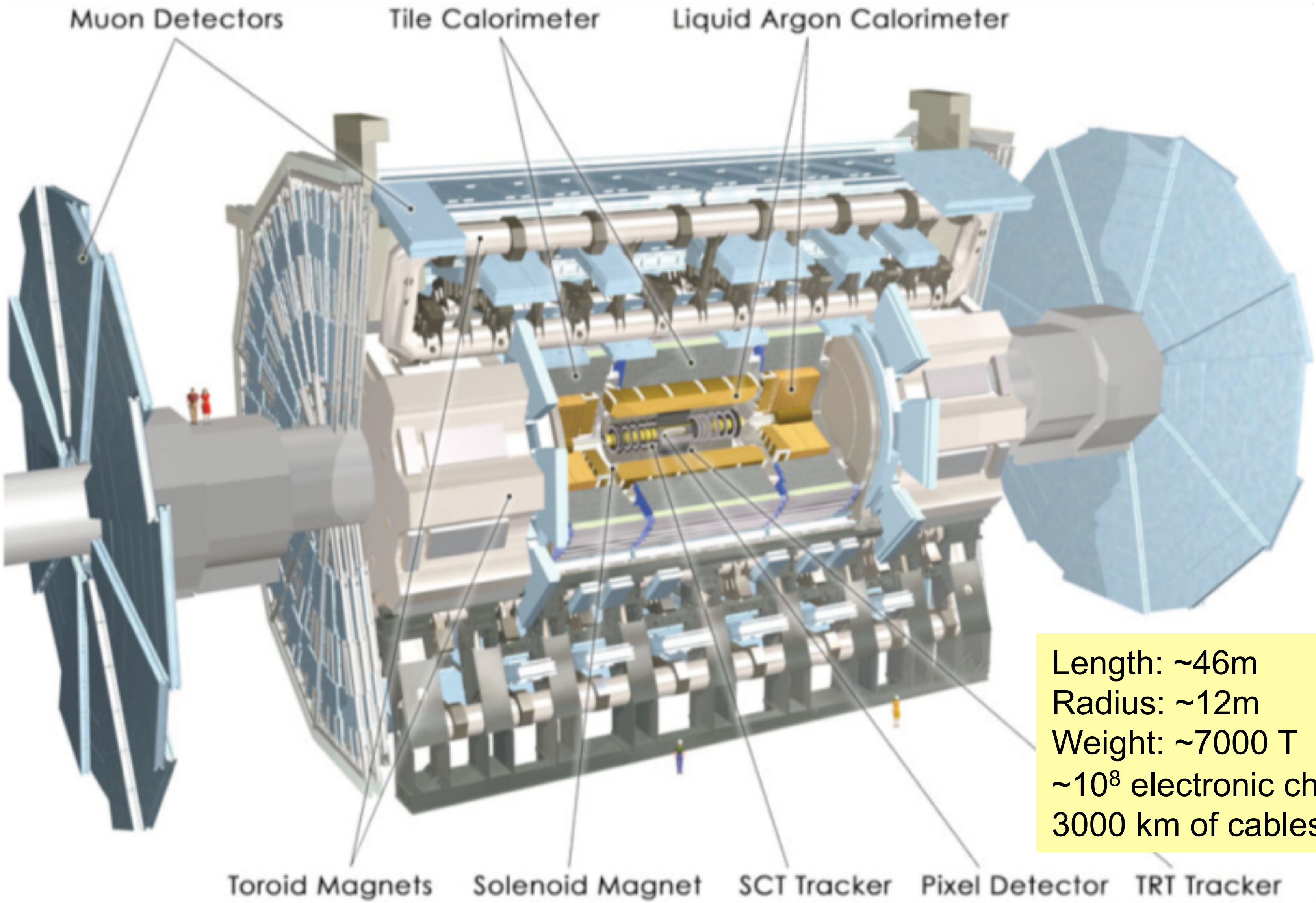
US ATLAS DEMOGRAPHICS

US / ATLAS Authors = 582/2,719 = 21%



US / ATLAS Grad Students = 169/849 = 20%

ATLAS DETECTOR

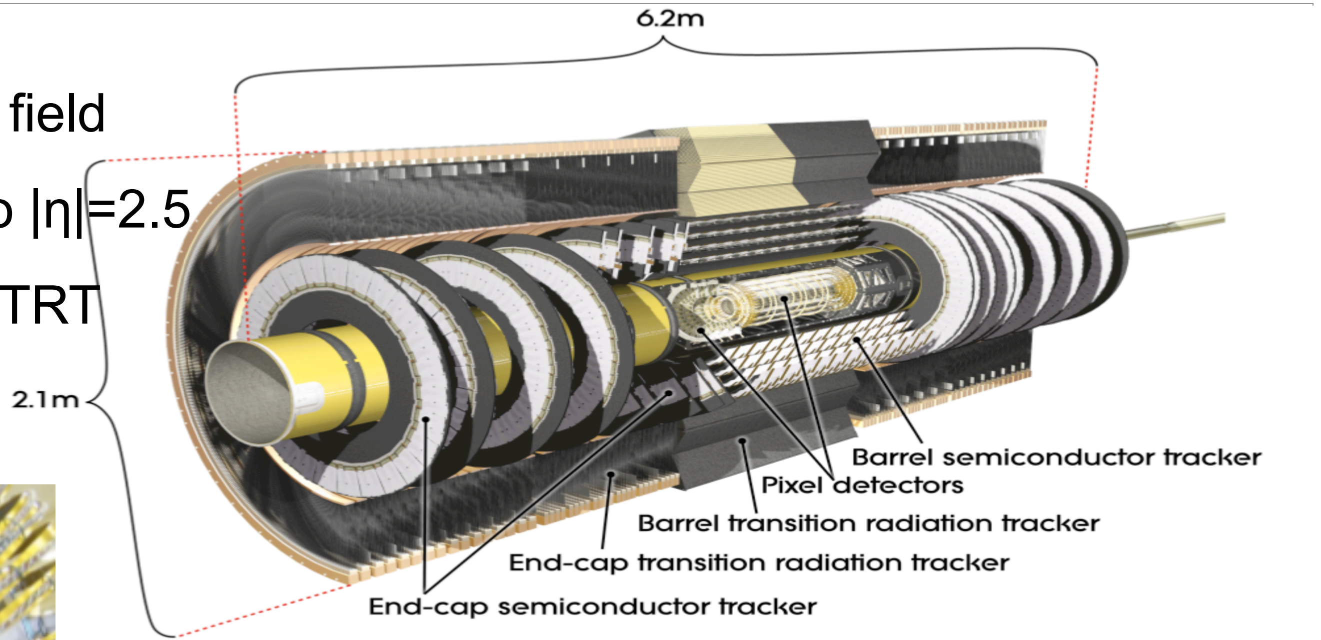


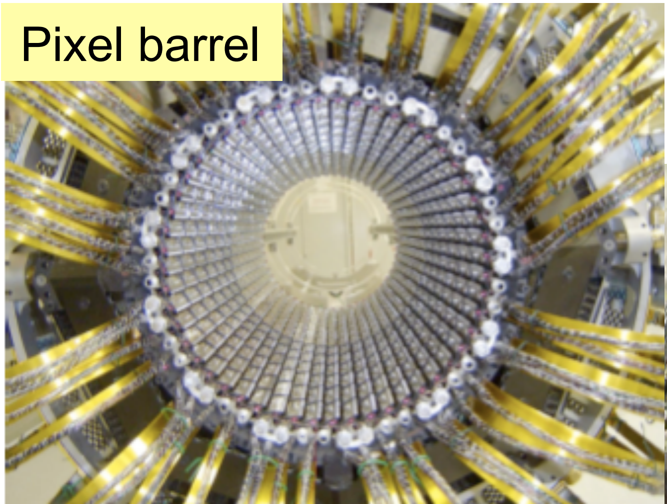
Length: ~46m
Radius: ~12m
Weight: ~7000 T
~10^8 electronic channels
3000 km of cables

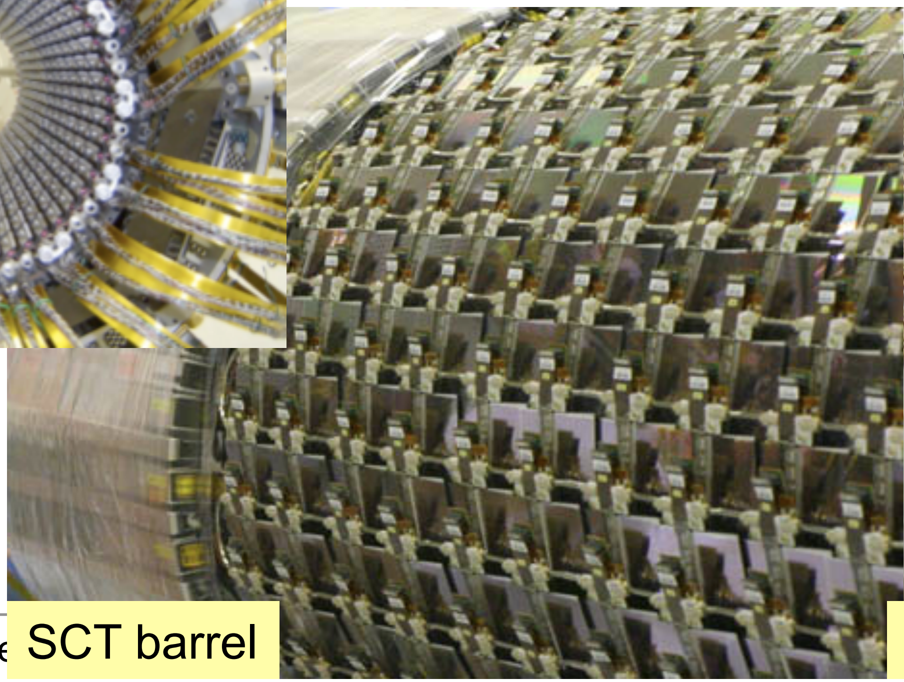
The ATLAS Collaboration, G. Aad et al., The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003

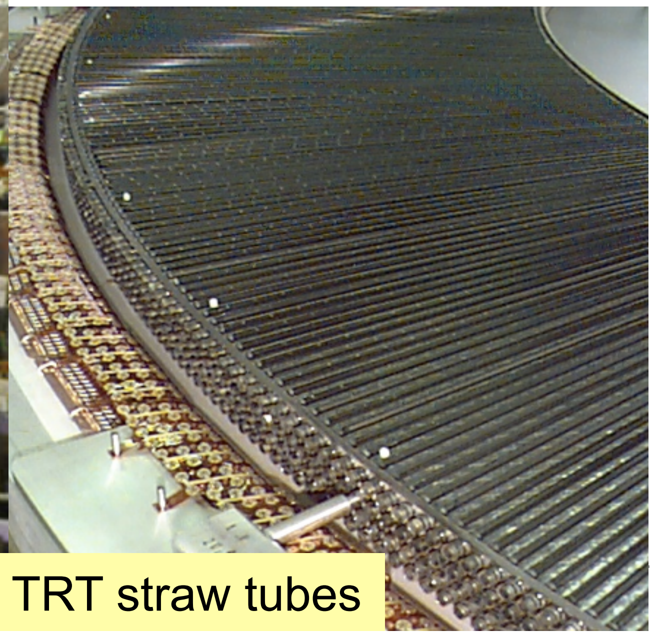
INNER DETECTOR (I)

- Located in 2 T solenoid field
- Tracking coverage up to |η|=2.5
- Consists of Pixel, SCT, TRT




Pixel barrel


SCT barrel


TRT straw tubes

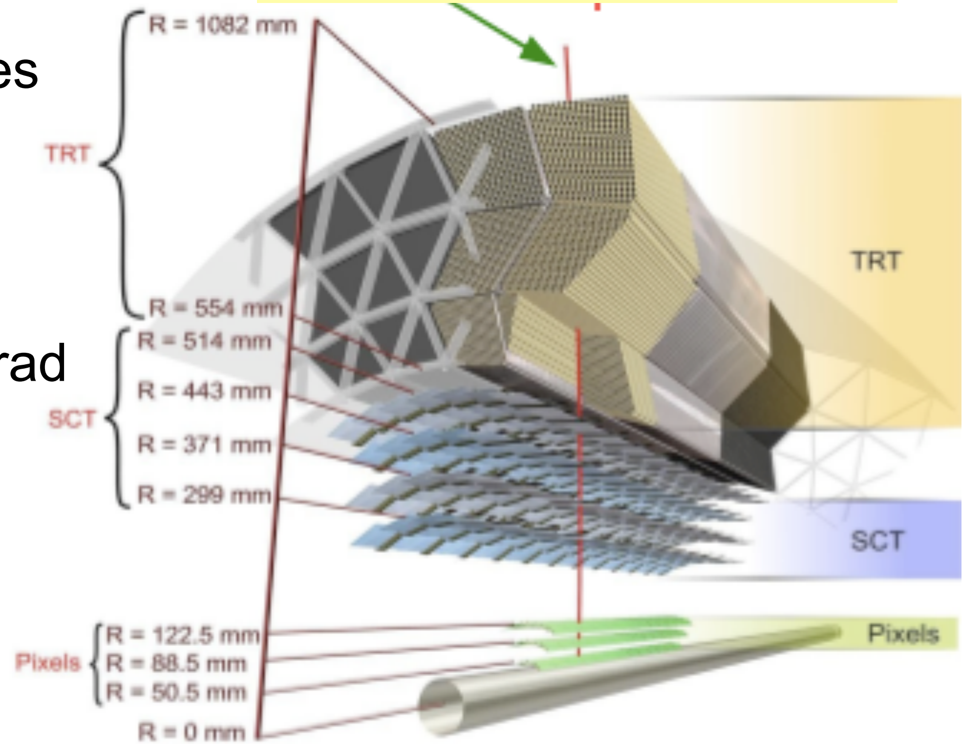
INNER DETECTOR (II)

TRT:
400k channels
4 mm straws (Xe) with 35μm anode wires
e/π separation 0.5 <E<150 GeV

SCT:
6.3M channels
~80μ strips, on 4088 modules with 40mrad stereo angle.

Pixels:
3 layers in barrel and endcap,
80M 50x400μ, on 1744 modules.

Track with p_T = 10 GeV

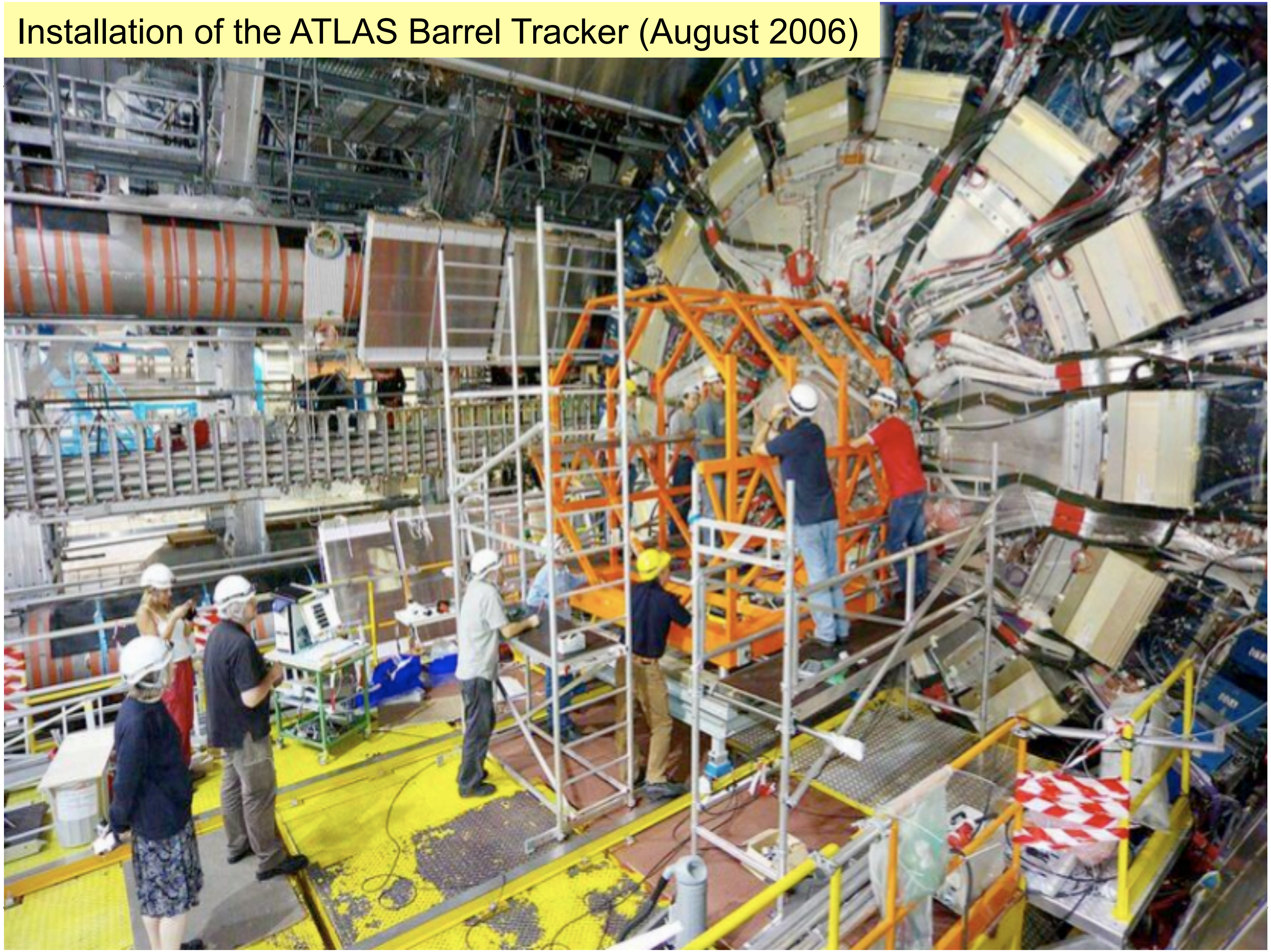


Barrel track passes:
- 36 TRT straws, 4x2 silicon strips and 3 pixels

Expect $\sigma/pT \sim 3.4\times10^{-4}\ pT(GeV) \oplus 0.015$

$\sigma_{d0} \sim 10 \oplus 140 / Pt\ (GeV)$ μm

Installation of the ATLAS Barrel Tracker (August 2006)



Electromagnetic Calorimeter |η|<3.2

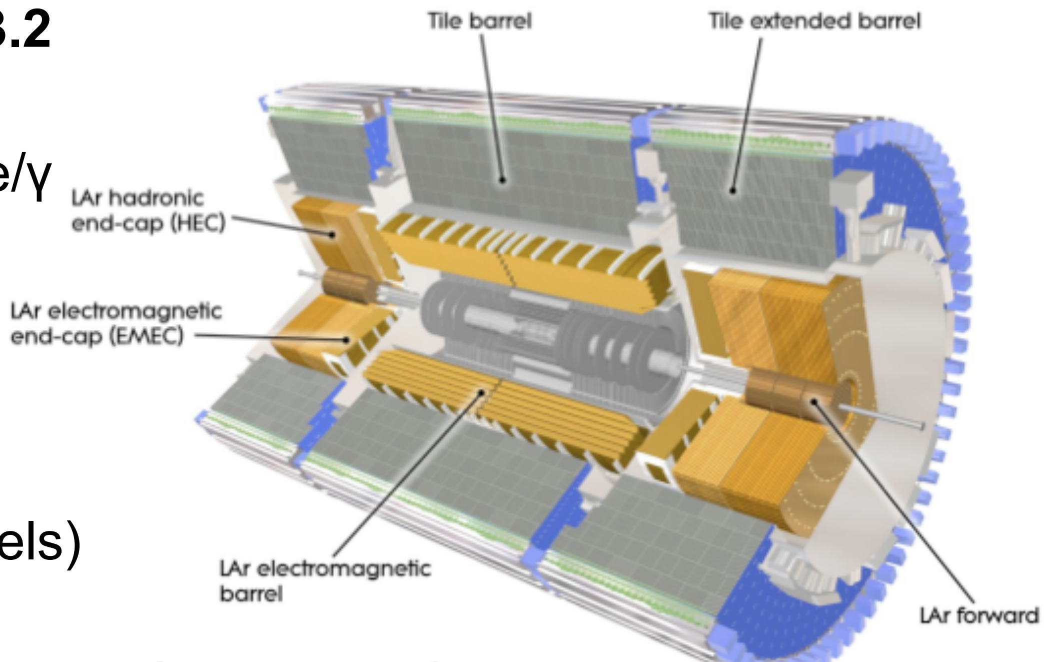
- Barrel, Endcap: Pb-LAr
- ~10%/√E ⊕0.7%energy resolution e/γ
- 170000 channels: longitudinal segmentation

Hadron Calorimeter Barrel |η|<5

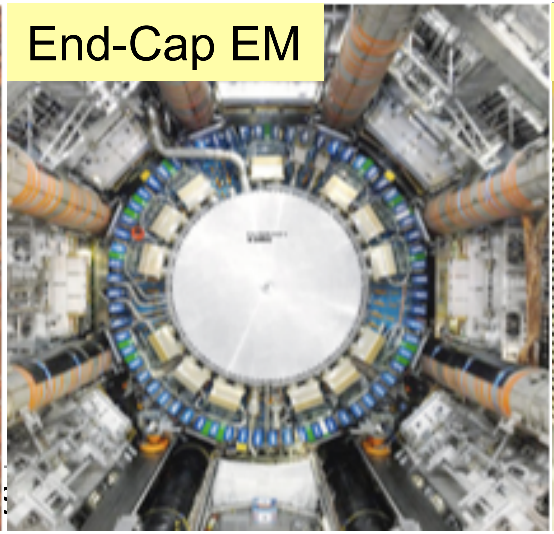
- Barrel Iron-Tile,
- EC/Fwd Cu/W-Lar (~19000 channels)

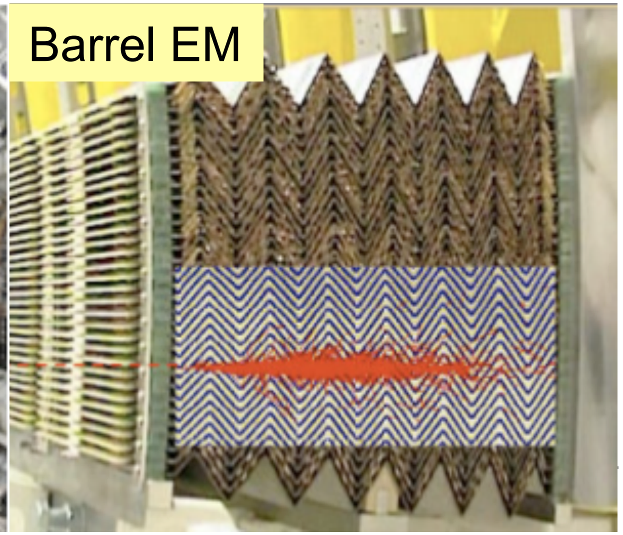
$\sigma(E)/E = 50\%/\sqrt{E} \oplus 3\%$ (|η| <3.2)

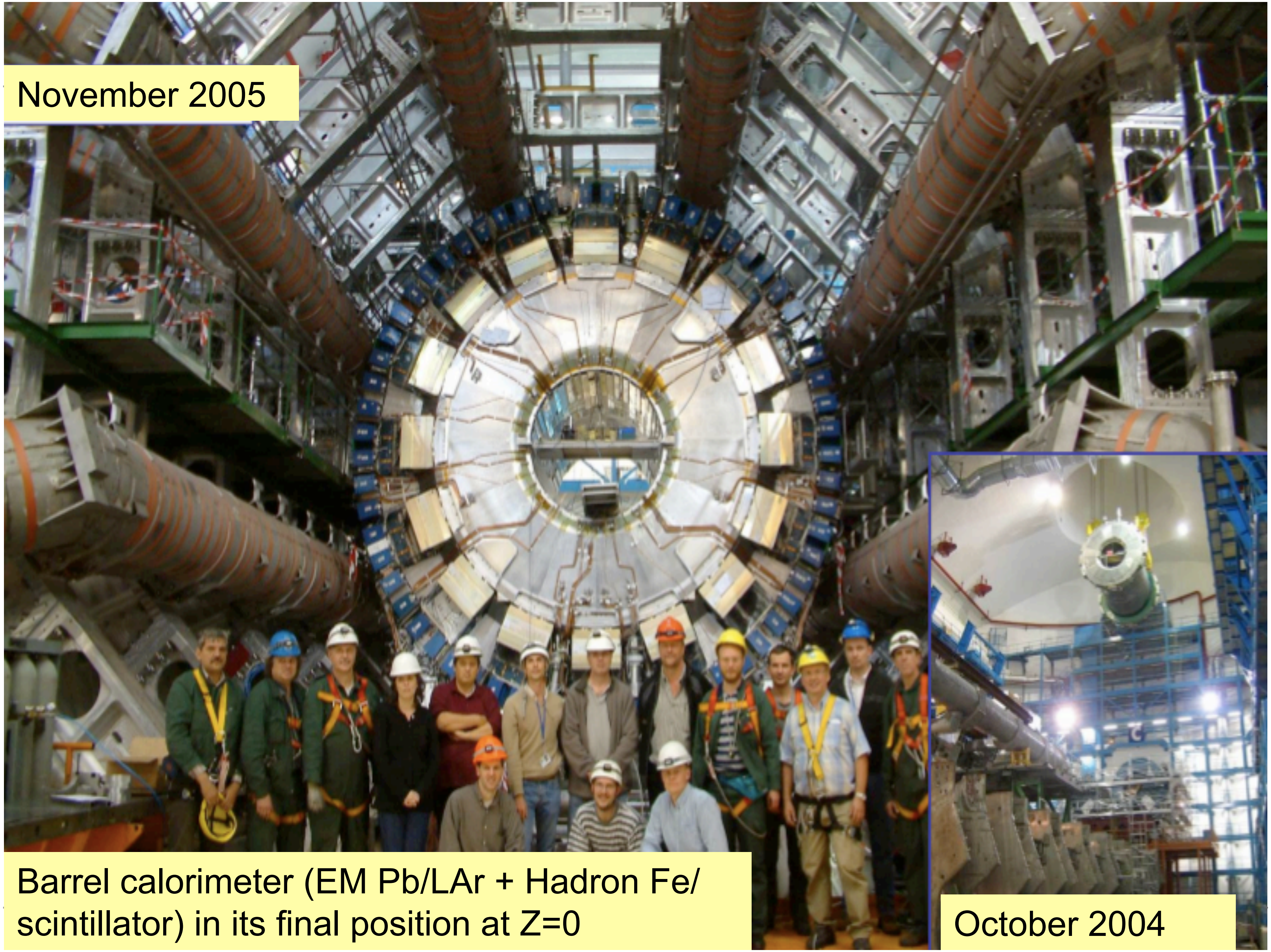
$\sigma(E)/E = 100\%/\sqrt{E} \oplus 10\%$ (|η| >3.1)



~12 m long, 4.3 m radius







Barrel calorimeter (EM Pb/LAr + Hadron Fe/ scintillator) in its final position at Z=0

MAGNETS

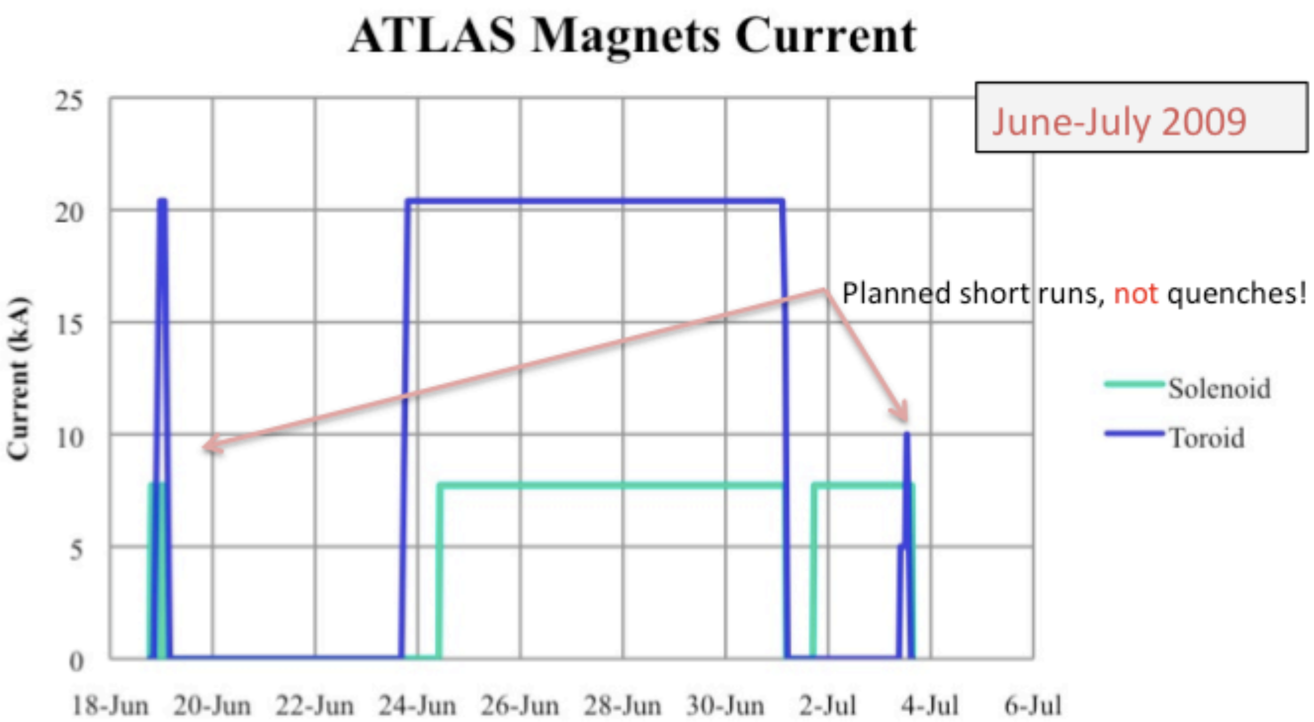
Solenoid:
- I=7.7 kA, T=4.5 K
- Uniform field 2 T

October 2005: full barrel toroid is in place

Barrel toroid:
- 8 superconducting coils, each, 100 tonnes.
- I=20.5 kA, T=4.5 K
- Typical field 0.5 T

Since August 2008, the full magnet system (barrel toroid, endcap toroids and central solenoid) has been operated at full current for long periods

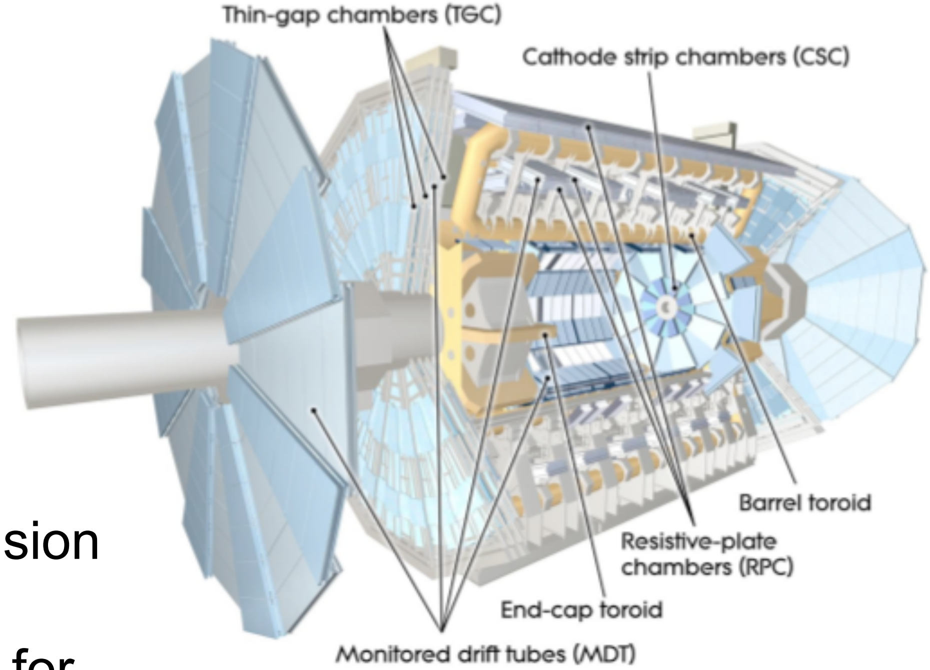
Endcap toroid (x2):
- I=20.5 kA, T=4.5 K



Muon system (I)

Stand-alone momentum resolution:
Δp/p = 10% at 1 TeV,
2-6 Tm |η|<1.3   4-8 Tm 1.6<|η|<2.7

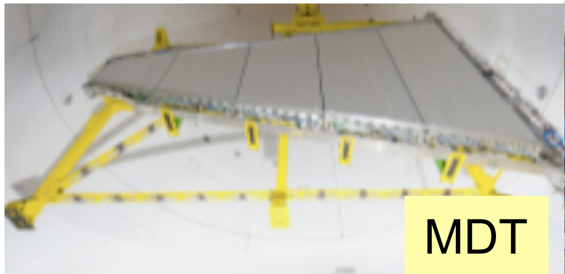
High Precision Muon Reconstruction

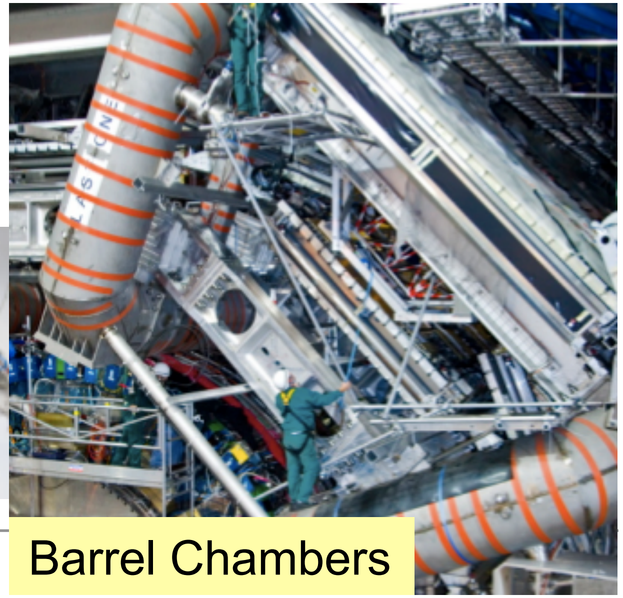


Barrel:

~650 **MDT** (Monitored Dria Tubes) precision chambers for track reconstruction
~550 **RPC** (Resistive Plate Chambers) for trigger Barrel chambers

- **Optical alignment system**: 12232 sensors


MDT


Barrel Chambers

Muon system (II)

Forward Detectors

Big wheels (and end-wall wheels):
~500 **MDT** precision chambers and ~3600 **TGC** (Thin Gap Chambers) trigger chambers

Small wheels:
32 **CSC** (Cathode Strip Chambers) precision chambers + ~80 **MDT**

Trigger & DAQ infrastructure

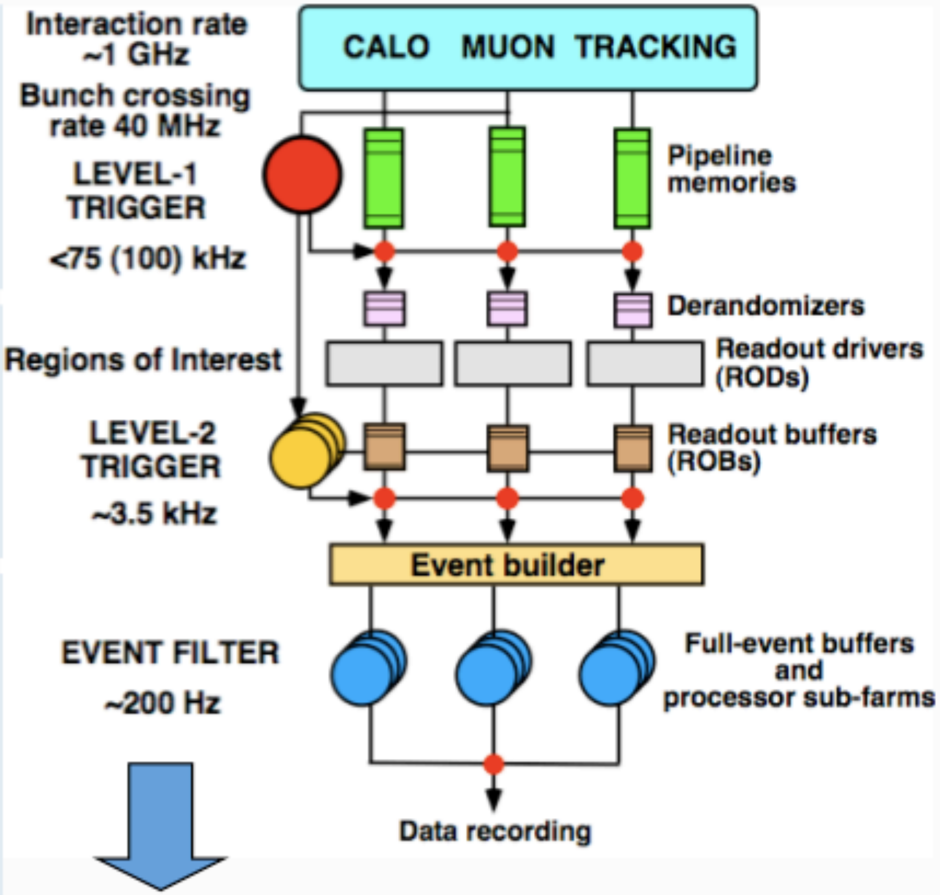
Three-level trigger architecture,exploiting the "region-of-interest" (RoI)

Level-1 Trigger
Calorimeter
Muon System
Hardware based
Coarse granularity

High Level Trigger (HLT)

Level-2 Trigger RoI
e/γ, μ, jet, ..
Full granularity in RoI
~ 500 PC (multi-core)

Event Filter
~1800 PC
(multi-core)
High bandwidth
Data Network



Front End Electronics

Readout Drivers

Readout System
Custom built
buffers in PC farm

Event Building
More PC farms
on Data Network

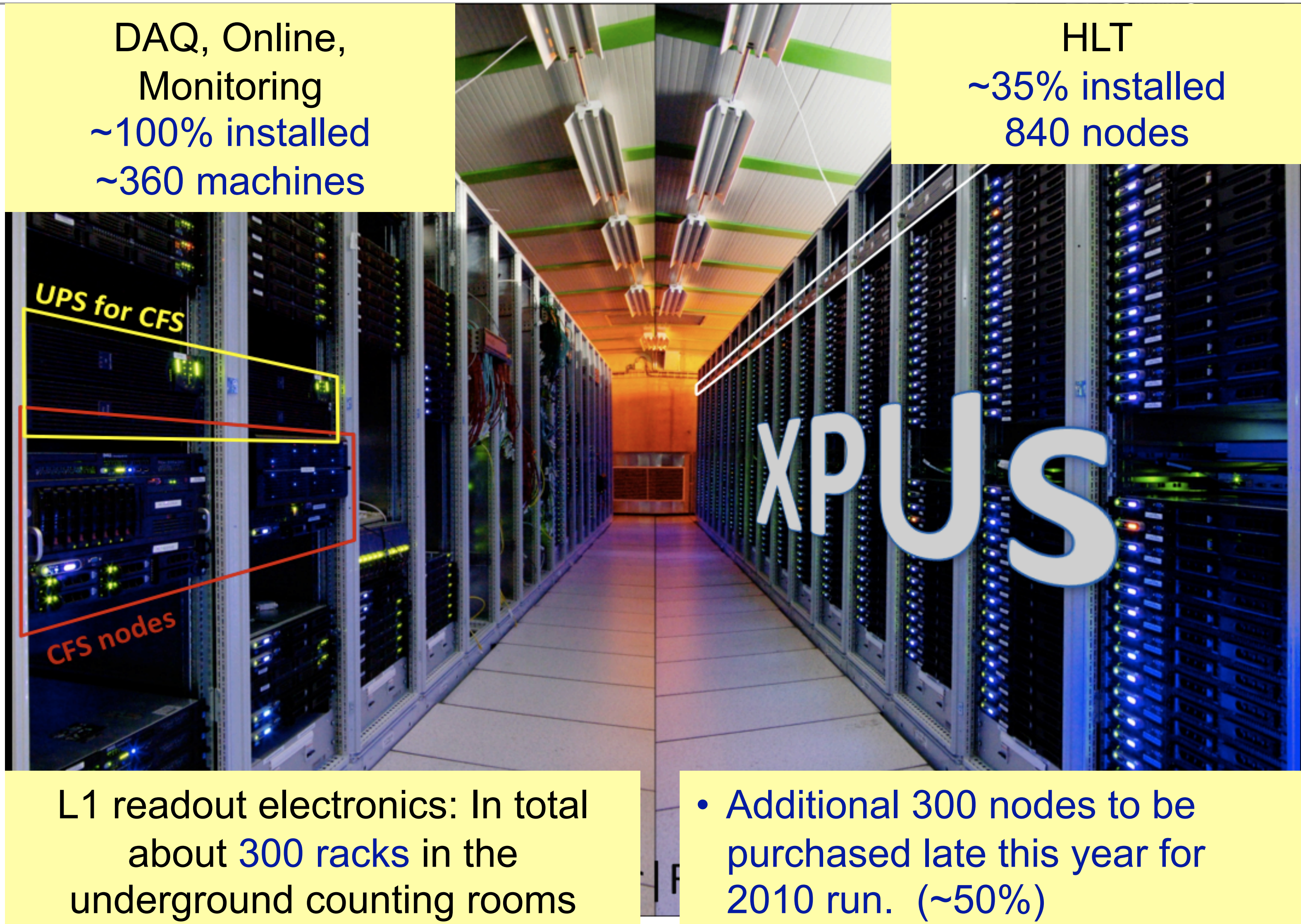
300 MByte/s
to Computer Center
~3 Pbytes stored / year

DAQ software
Control, configuration, monitoring
on Control Network

DAQ & HLT STATUS

DAQ, Online, Monitoring
~100% installed
~360 machines

HLT
~35% installed
840 nodes



L1 readout electronics: In total about 300 racks in the underground counting rooms

- Additional 300 nodes to be purchased late this year for 2010 run. (~50%)

The read-out electronics, trigger, DAQ and detector control systems have been brought into operation gradually over the past years, along with the detector commissioning

ATLAS COMMISSIONING TIME LINE

- October 2004: Combined Test Beam
- 2005-2008: technical runs and milestones with MC simulation and cosmics
- August 2008 –October 2008: Global cosmic data taking with full detector operational. More than 500M events recorded!
- August 2008: ATLAS ready for LHC data taking
- September 10th 2008: First LHC Beam. Single Beam events recorded
- October 2008: Detector Opened for maintenance, consolidation, repairs
- June 2009: Detector closed
- End of June 2009-Present:Cosmic runs (100M events recorded)

June 16th 2008: last piece the LHC beam pipe is installed

ATLAS STATUS

• Running efficiency ~83% for simulated LHC fills in June-July 2009
• Single hit efficiencies of each detector layer excellent for operational parts, but what fraction will be operational?

Detector System	Fraction of working
Pixel	98.5%
SCT	~99.5%
TRT	>98%
LAr EM	99.1%
LAr HEC	99.9%
LAr FCAL	100%
Tilecal	~99.5%
MDT	99.3%
TGC	>99.5%
RPC	~95.5%(aim >98.5)

Concerns are long-term reliability of some components:
• Low-voltage power supplies of Liquid-Argon and Tile calorimeters
• Liquid-Argon readout optical links
• Inner detector cooling.

• Back-up solutions being prepared for installation in future shut-down.

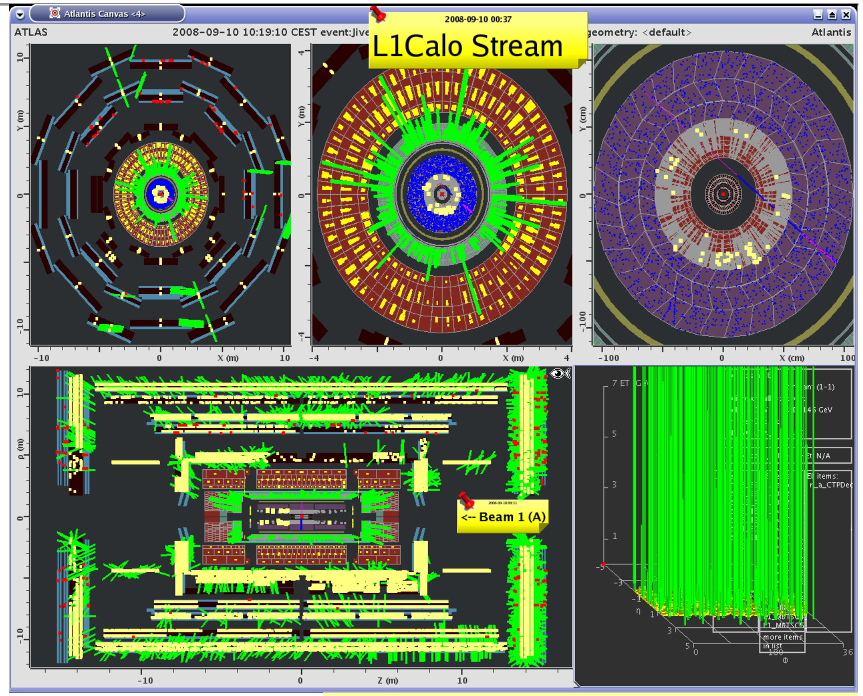
First LHC beams

10 September 2008, ~10h am: waiting for first beams

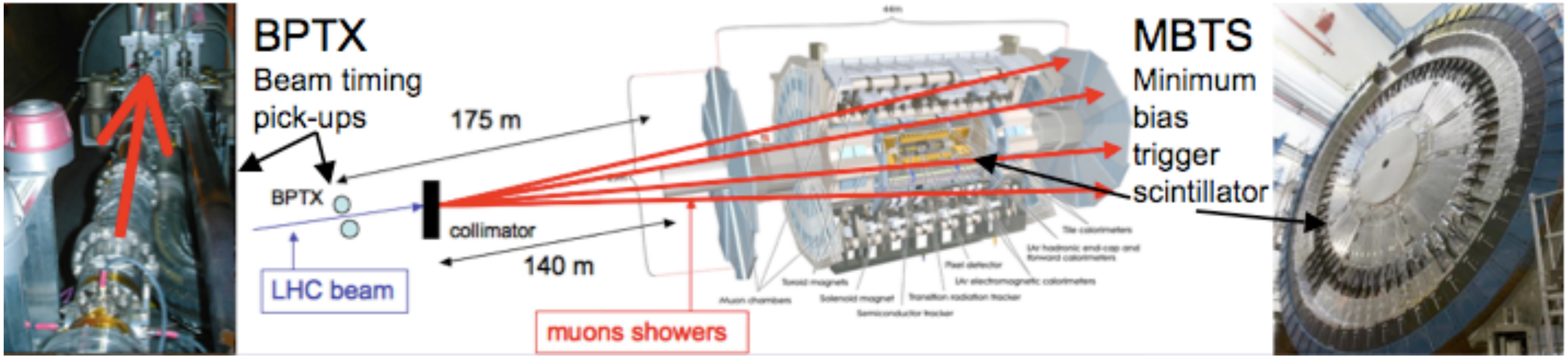
Commissioning with beam

Beam bunches $2x10^9$ protons at 450 GeV) stopped by (closed) collimators upstream of experiments:
→ "splash" events in the detectors (debris are mainly muons)

- Some parts of ATLAS at reduced HV or off for detector safety
- Calorimeter energy deposits of several TeV (up to ~1000 TeV), many tracks in tracking detectors



~100 TeV in detector

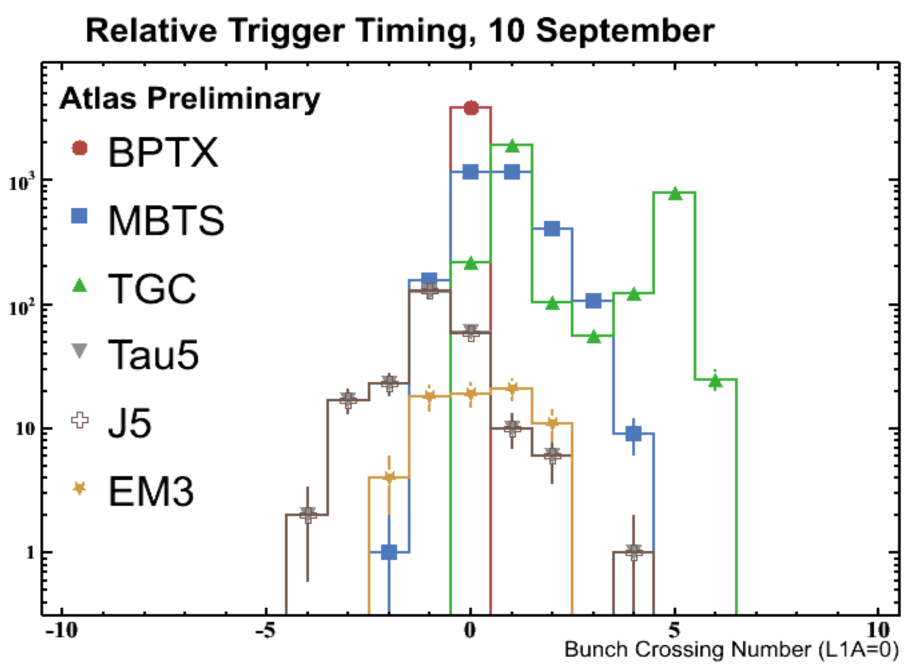


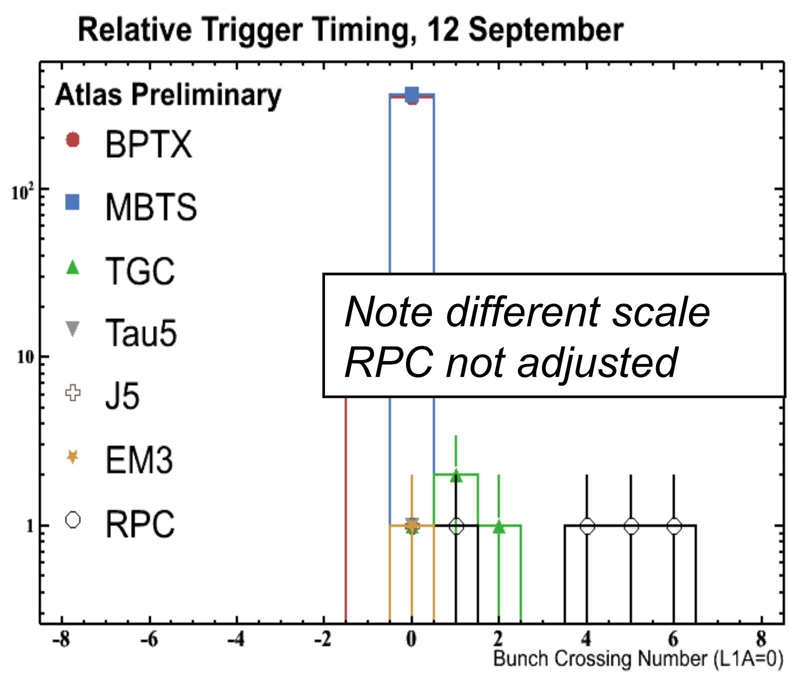
Trigger timing

Beam-splash events yield almost horizontal muons that were exploited to check the timing wrt to BPTX:

Remember: ATLAS is 6 LHC bunch crossings (25 ns each) across!!!

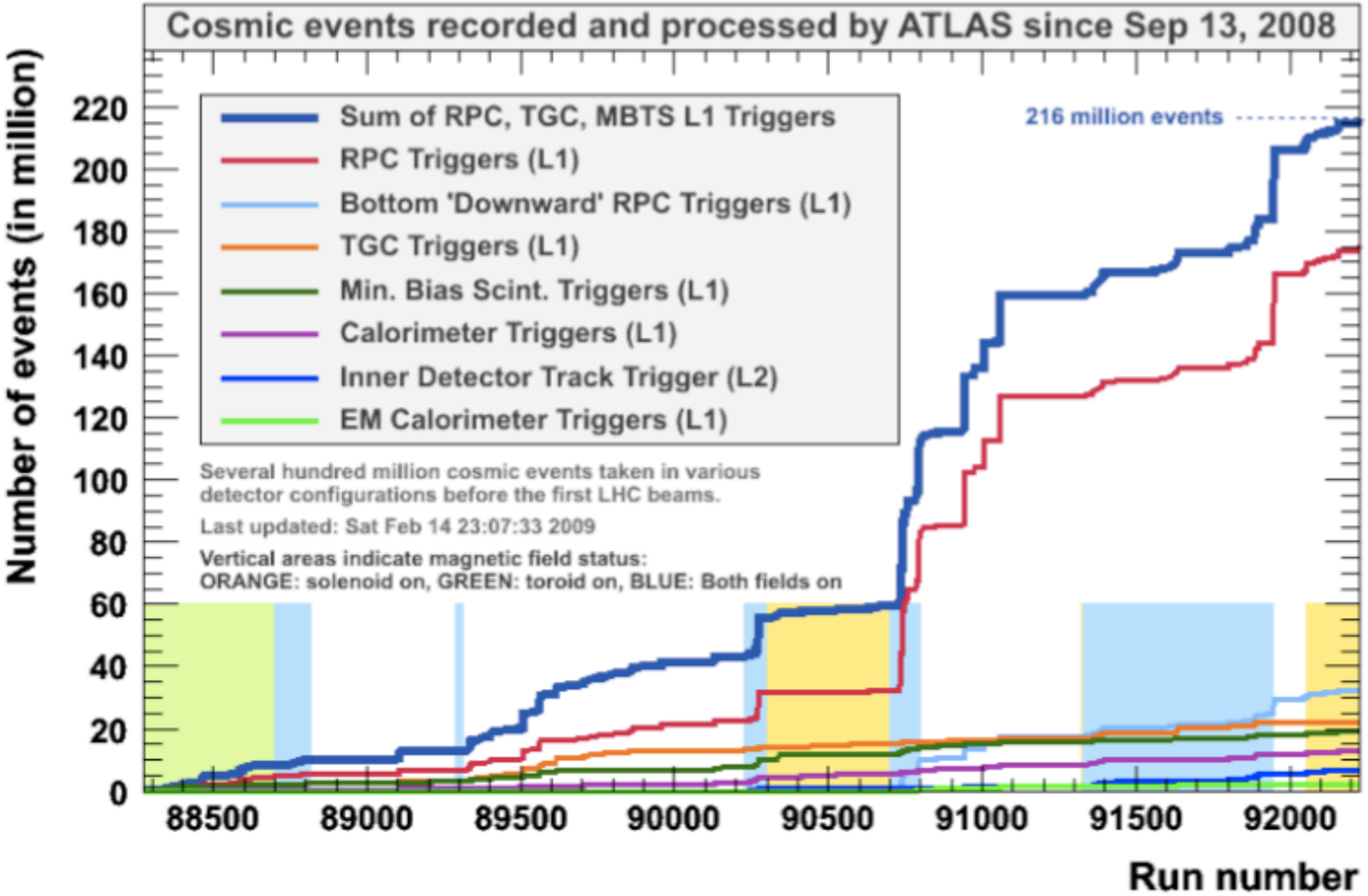
- Various systems **aligned in time** using beam pick-ups (BPTX) as reference
- Signal times of various triggers adjusted to match the BPTX reference
- Few splash events meant a jump in quality with respect to cosmic rays for detector timing!





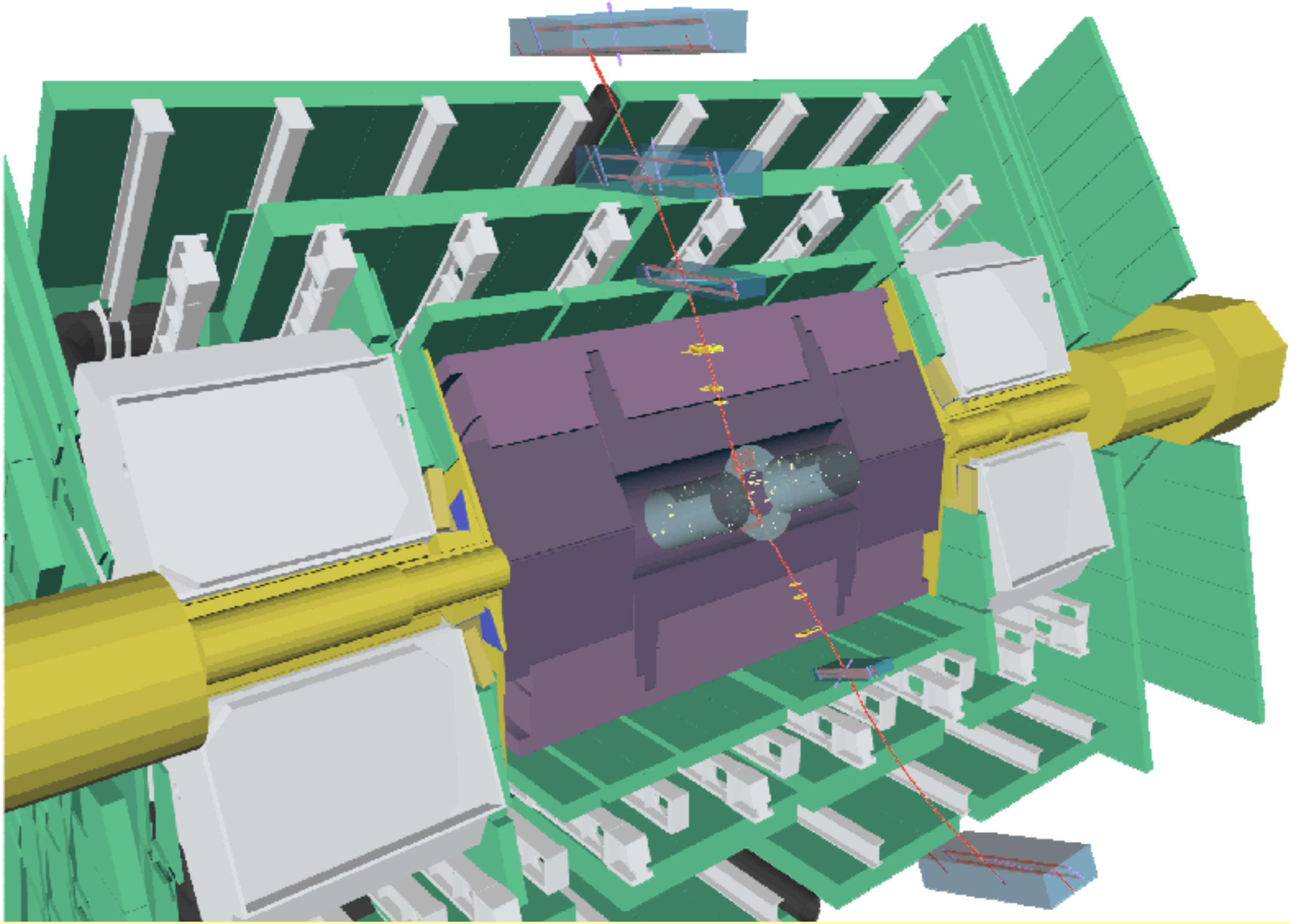
Commissioning with cosmic data

- Total of 216 million cosmic ray events in autumn 2008.
- Up to 700 Hz events in ATLAS. <1Hz in Pixel detector.



- Debug the experiment → fix problems
- First calibration and alignment studies
- Gain global operation experience in situ

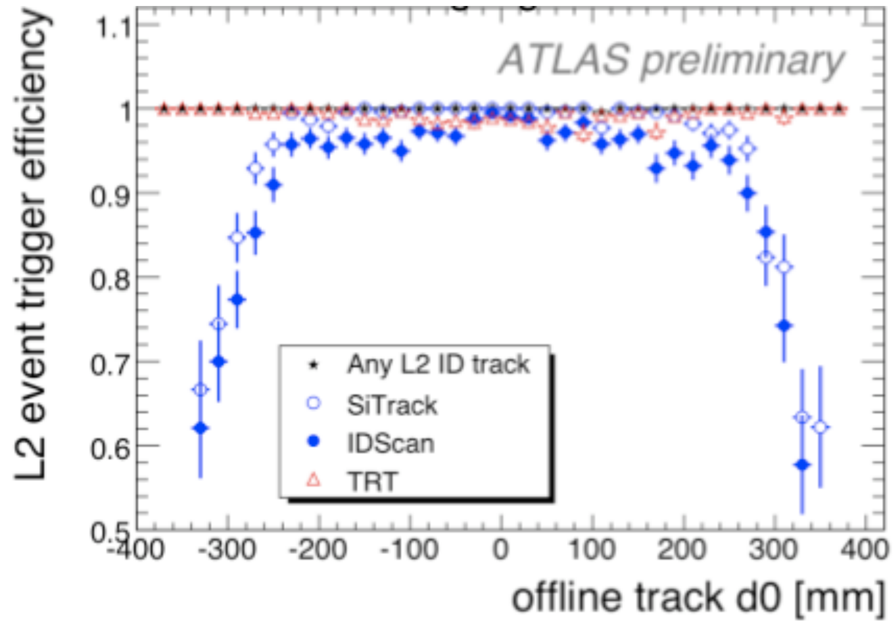
One "golden cosmic data event



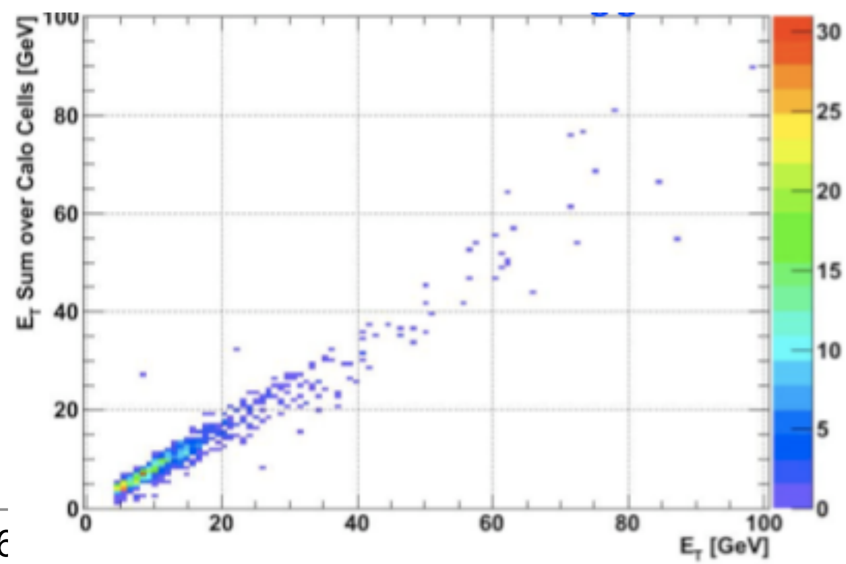
Achieved precisions far better than expectations at this stage

ATLAS L1 and HLT triggers have reliably collected, selected and rejected 100 s of millions of events!

Efficiency of the track trigger at level-two vs track impact parameter:
• ~ 5 M cosmics events selected by this trigger
• curve reflects geometrical acceptance

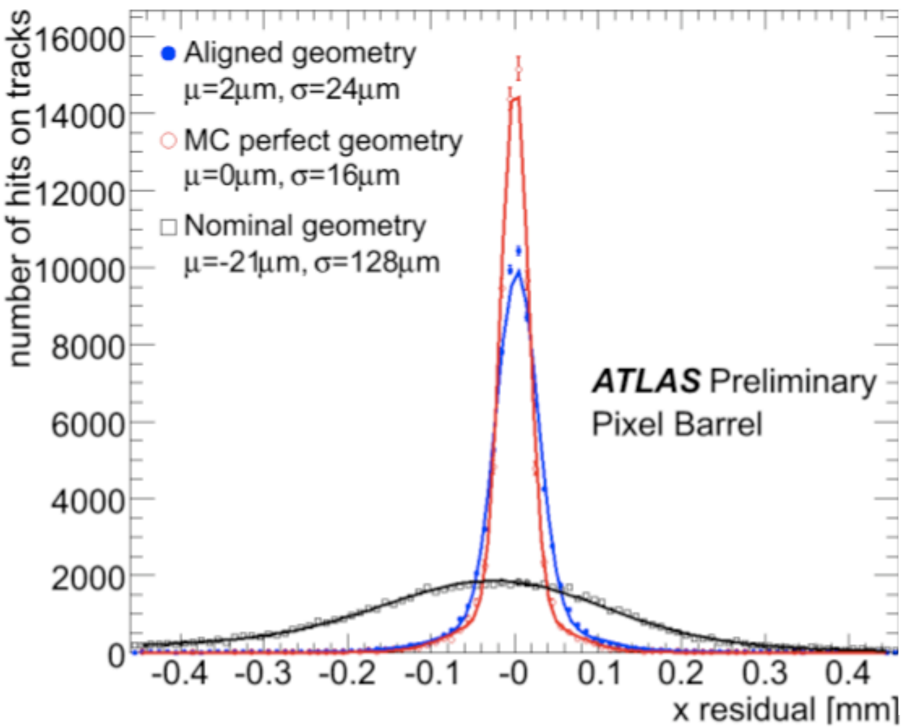


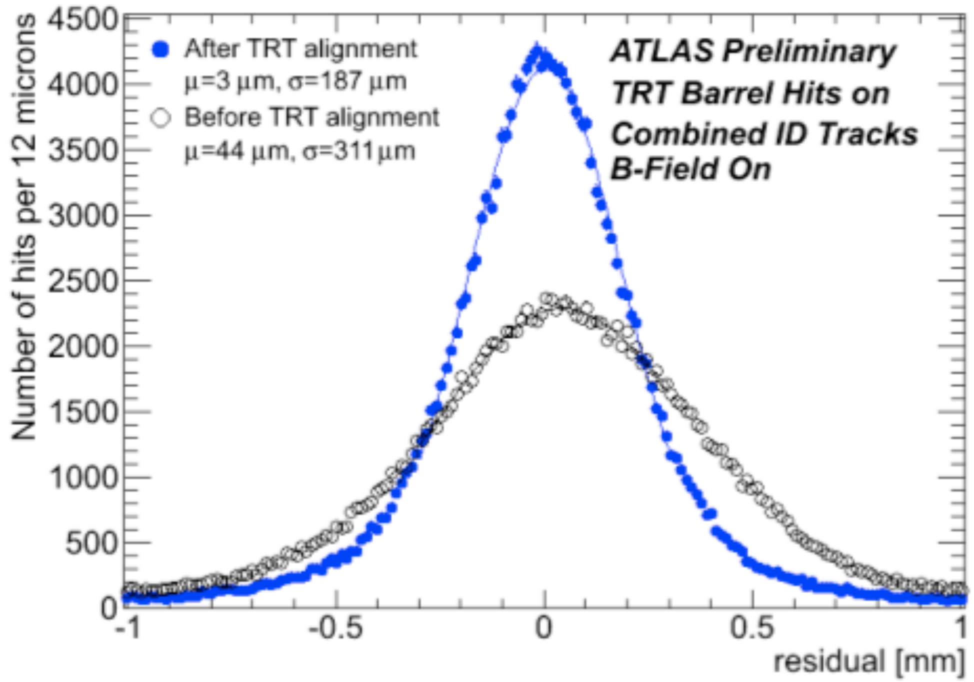
Muon (shower) energy measured with full calorimeter readout vs energy measured in trigger towers (ηxφ=0.1x0.1) by level1 calorimeter trigger.
[initial calibration: final one will reduce spread



ID ALIGNEMENT

- ID alignment fone with cosmic muons solenoid ON and OFF
- Alignment precision: ~ 20 μm (ultimate goal 5-10 μm)
- Alignment stability Oct-2008-June-2009: few microns
- Limited by statistics in the end-cap region





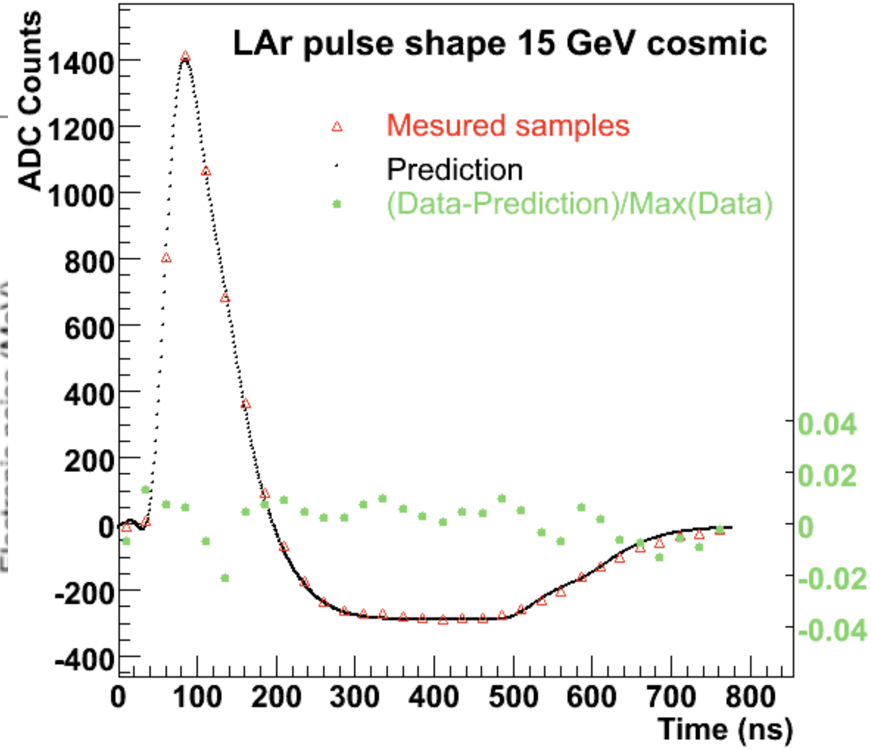
Calorimeter results

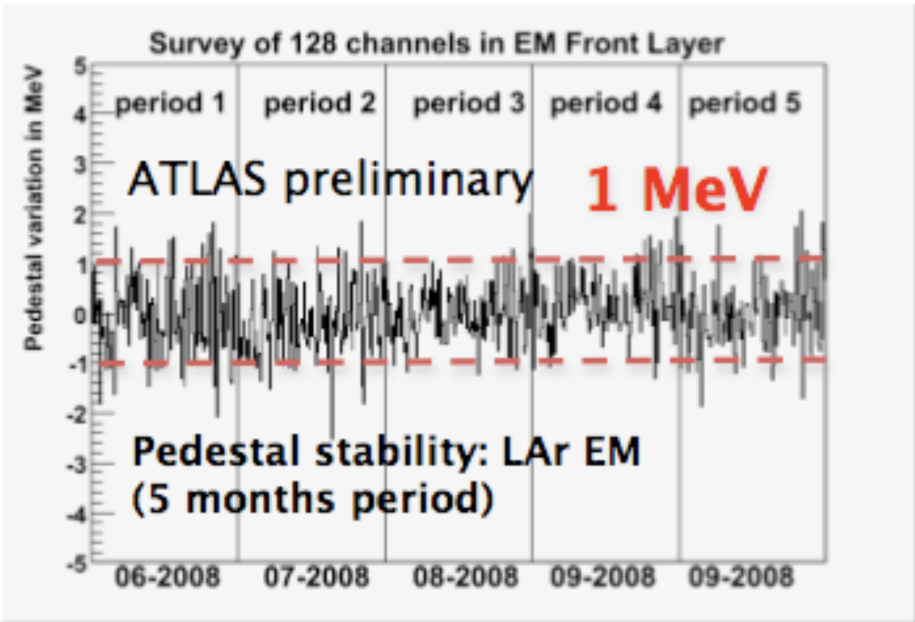
• Checked uniformity of response and stability.

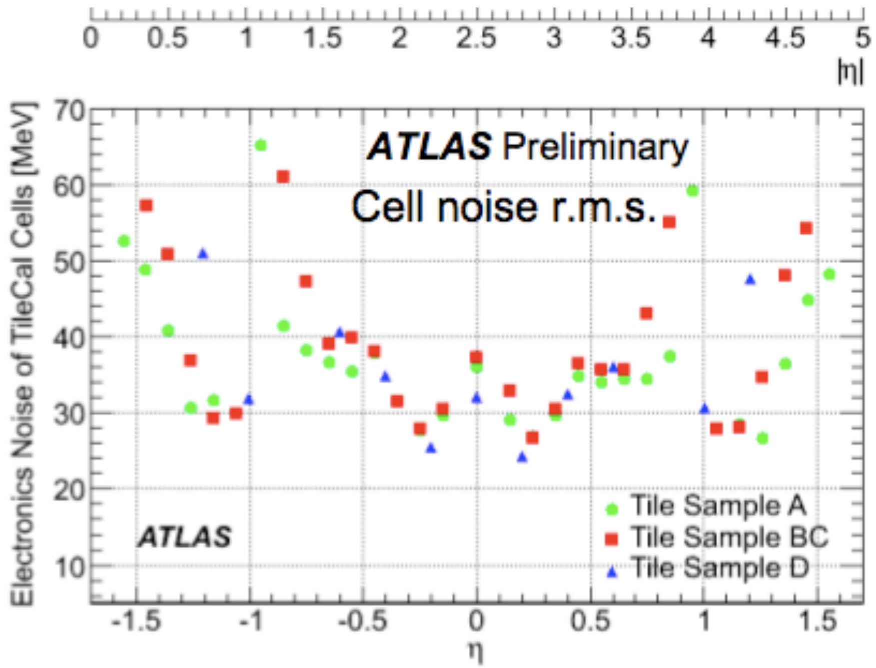
• Pulse shape distribution shows good agreement with prediction.

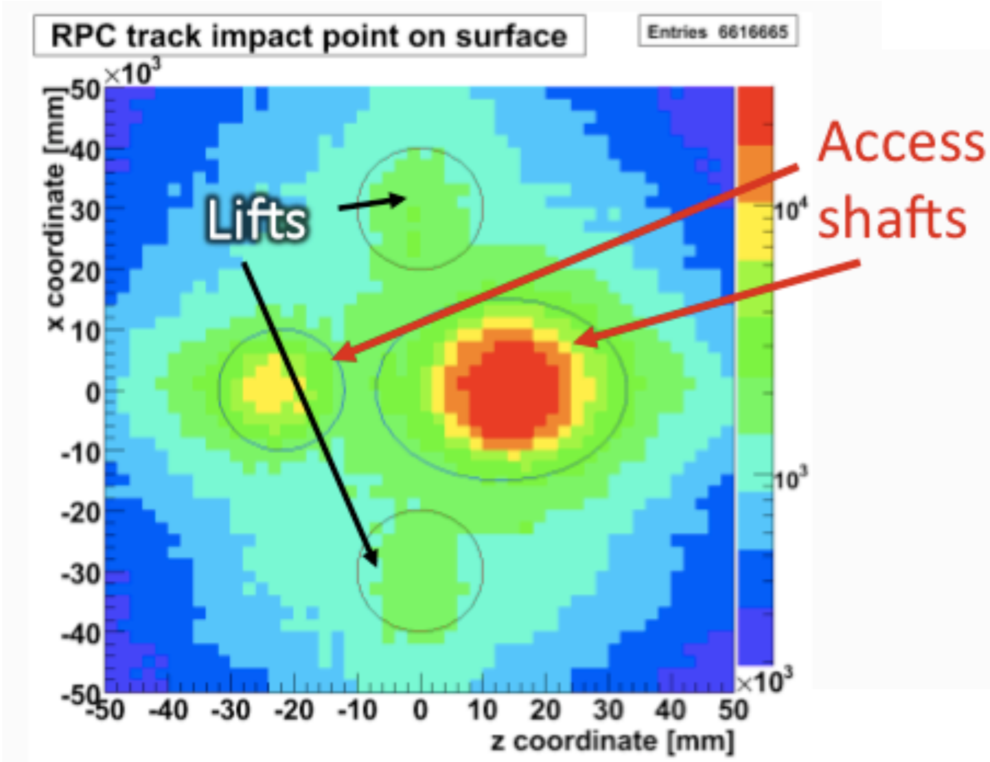
– Random triggers used to measure noise in calorimeters

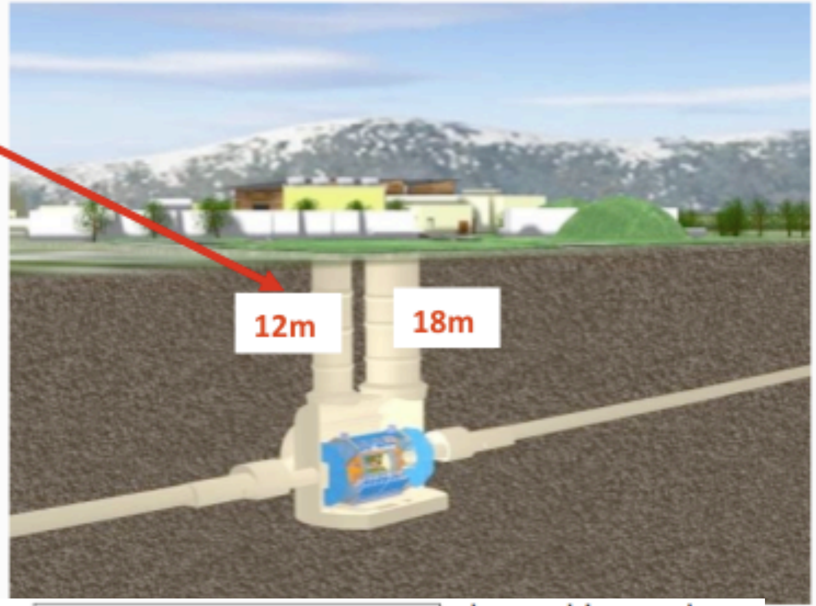
– High stability of read-out electronics and noise during months

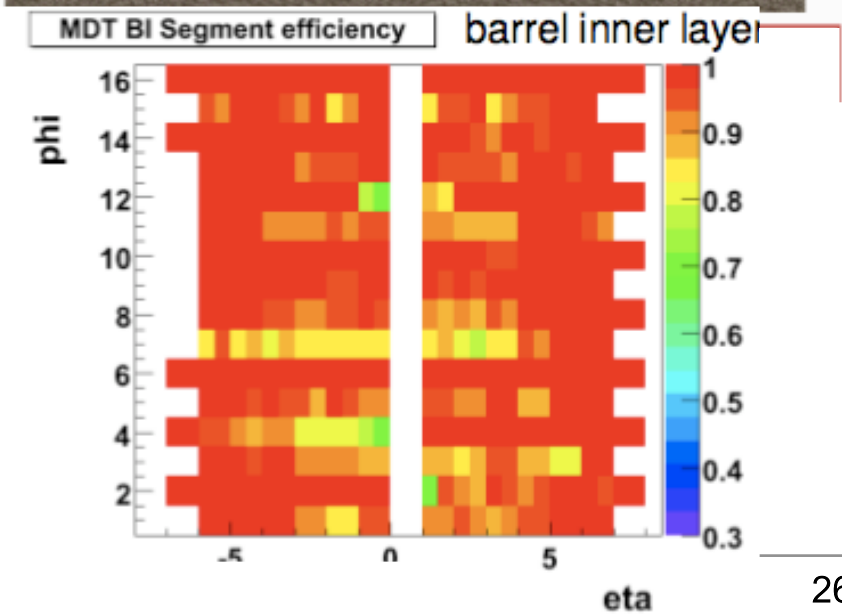








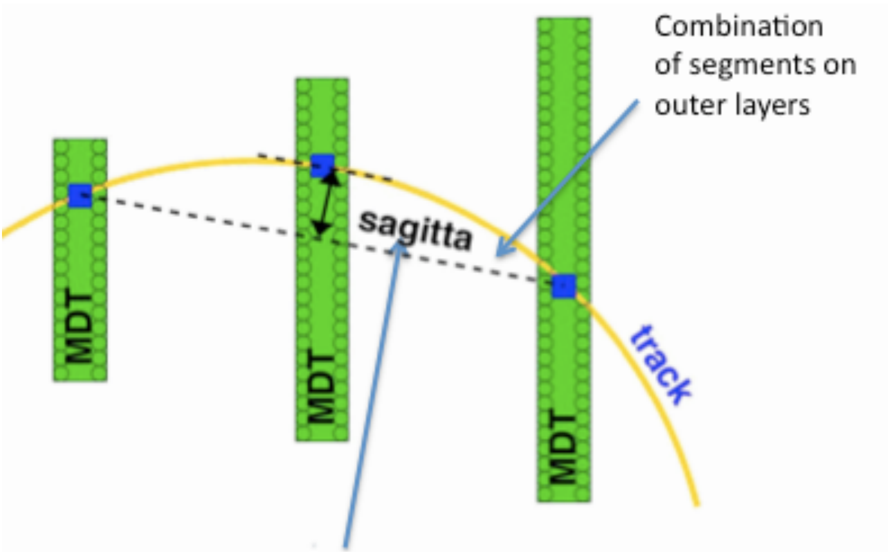


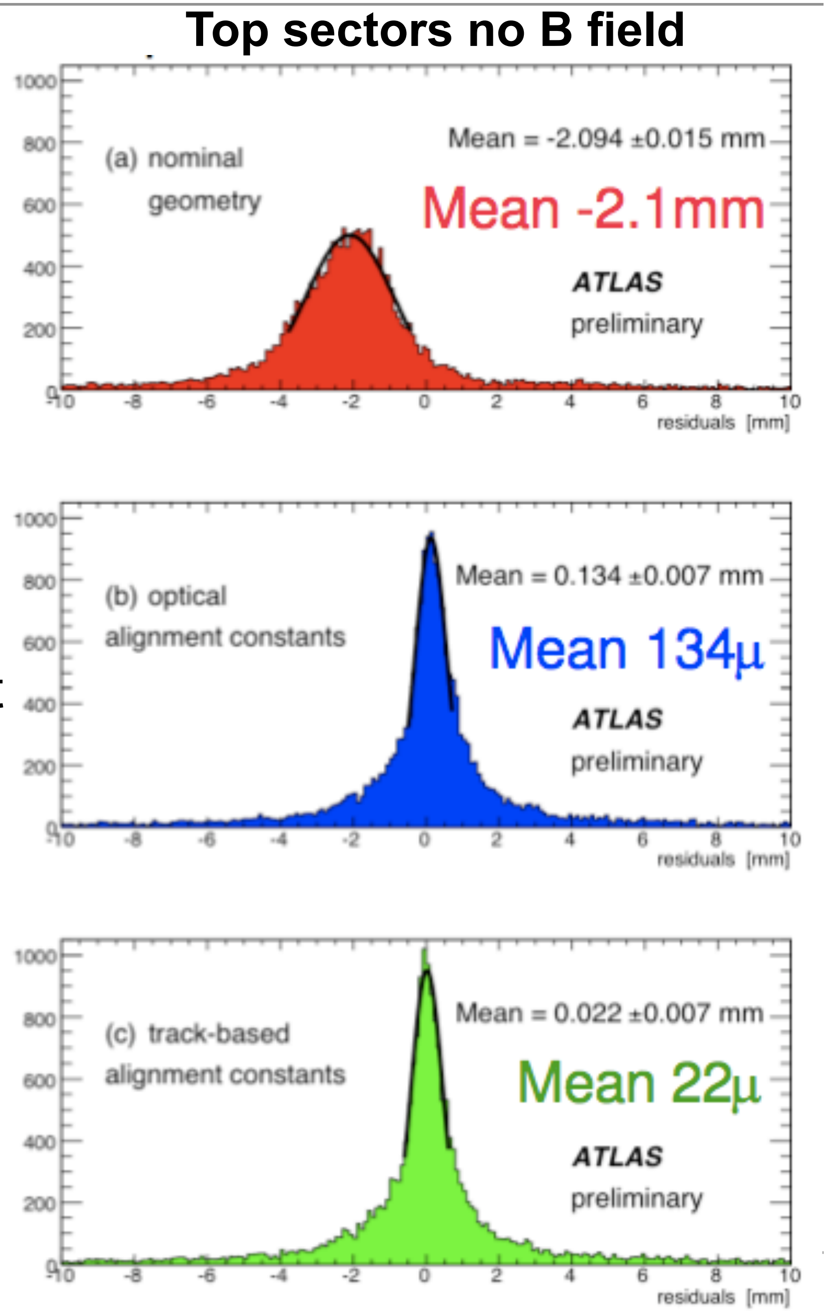


Extrapolation to the surface of cosmic muon tracks reconstructed by RPC trigger chambers

- Good efficiency

MUON ALIGNMENT

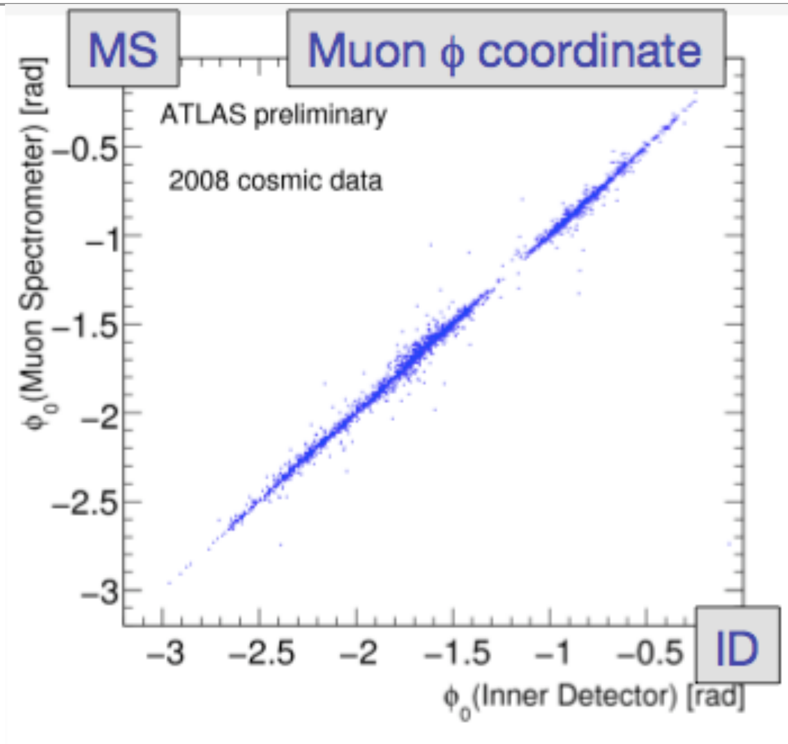


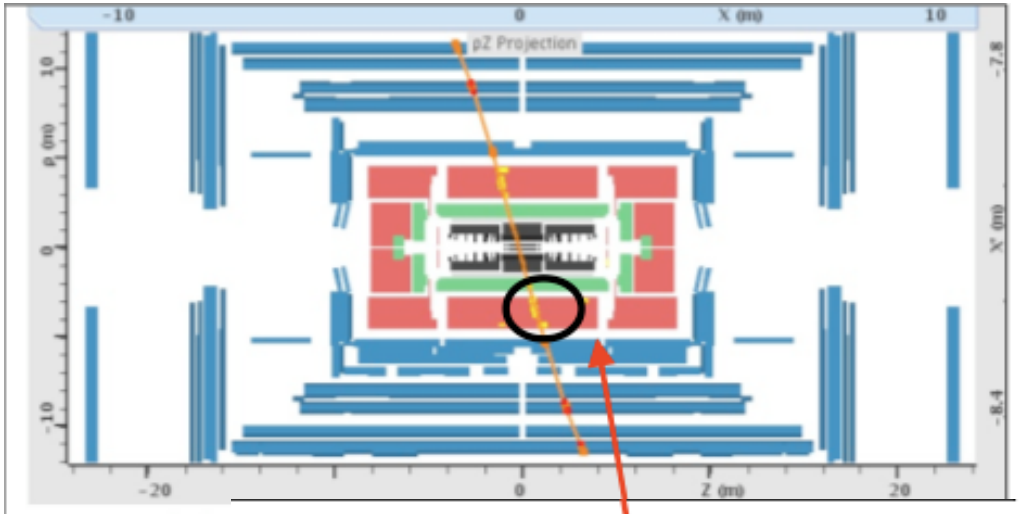


- Alignment with cosmic rays (no field, straight tracks):

–Measure sagitta, in the middle barrel chamber, and in the precision plane. (Sagitta for 1 TeV muon is ~500μm)
–Expected mean sagitta with good alignment is <30μ, to achieve 10% σ/p at 1 TeV.

Combined tracking



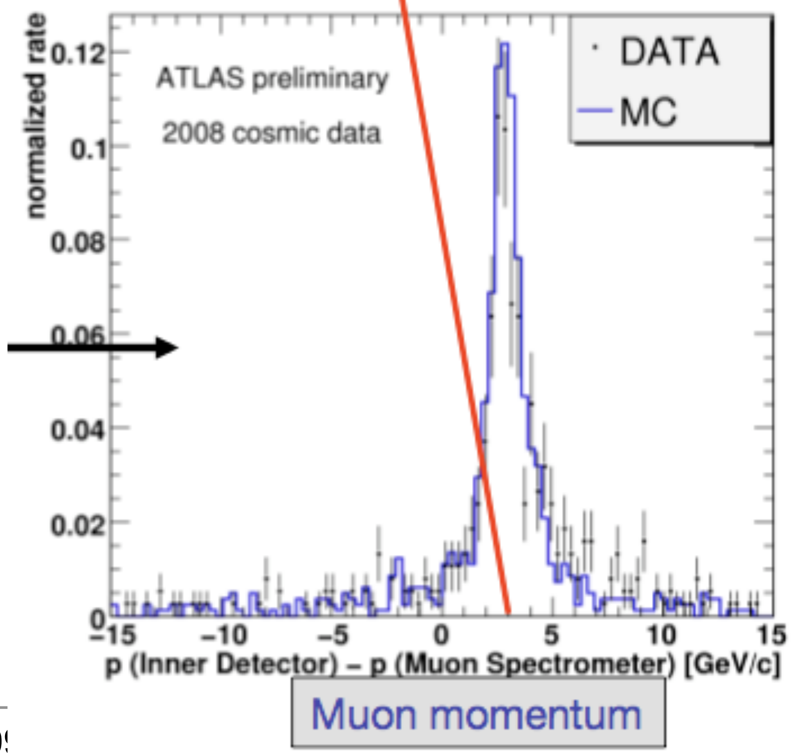


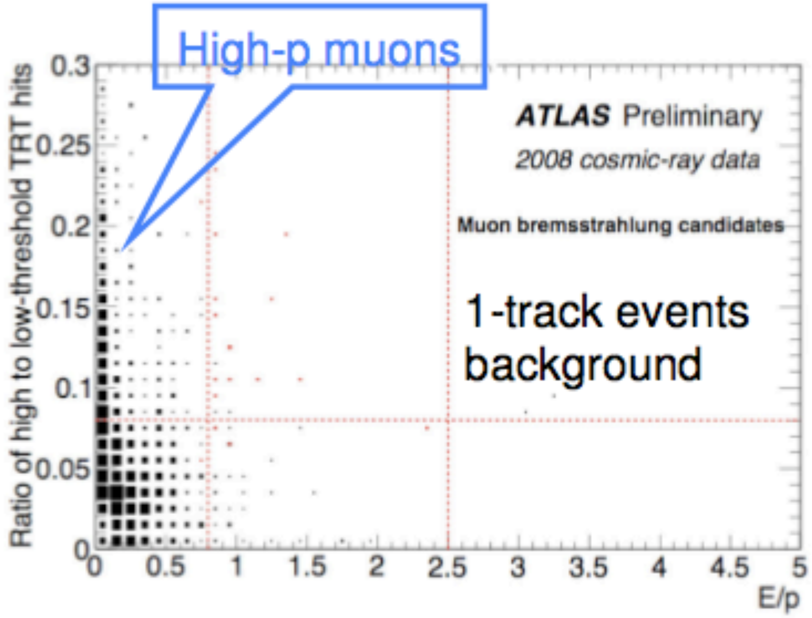
Cosmic muon tracks measured in the ID and in the muon system:

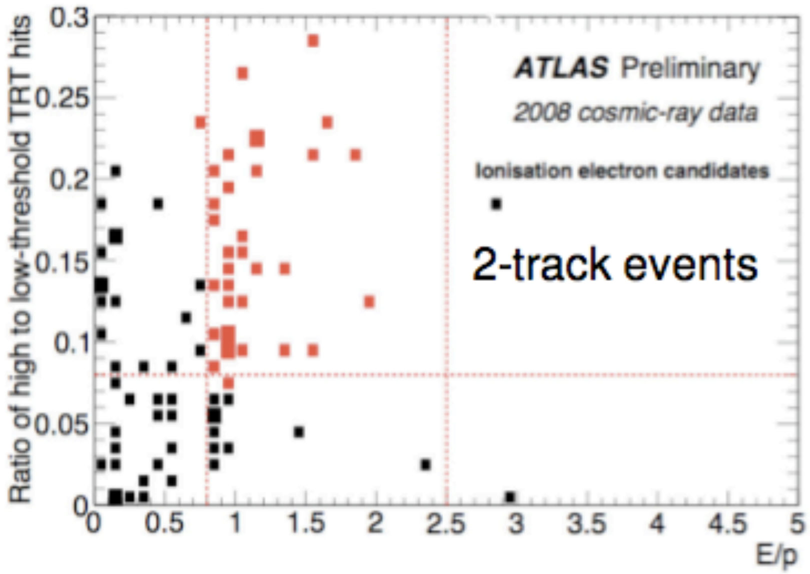
– Very good correlation between ID and muon system measurement

– Good agreement with MC studies!

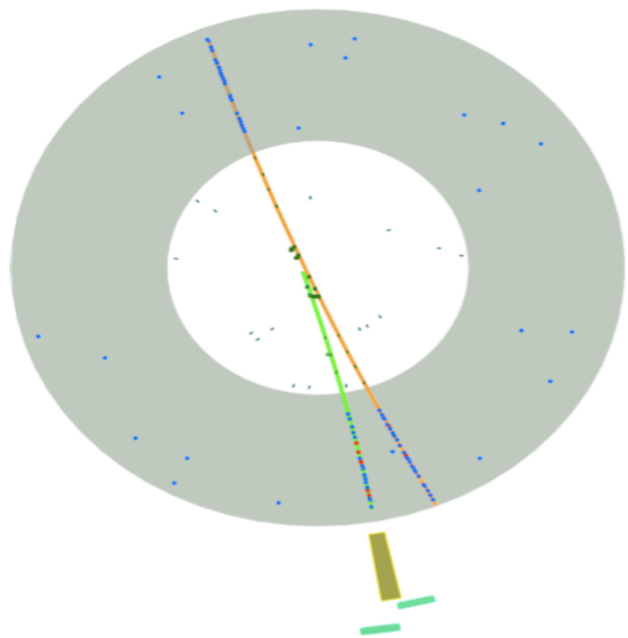
– Momentum difference of ~3GeV, which corresponds to the expected energy loss in the calorimeters



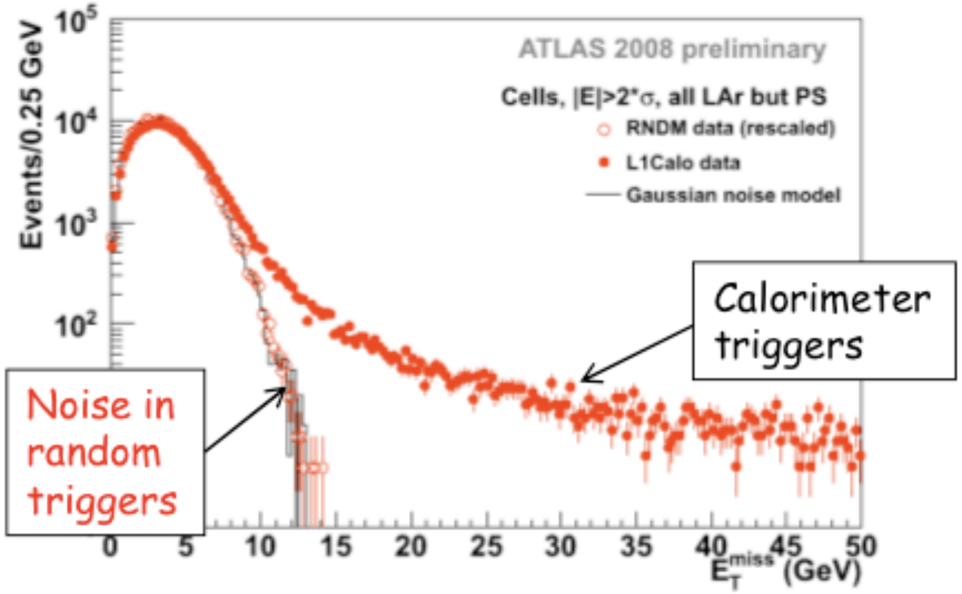




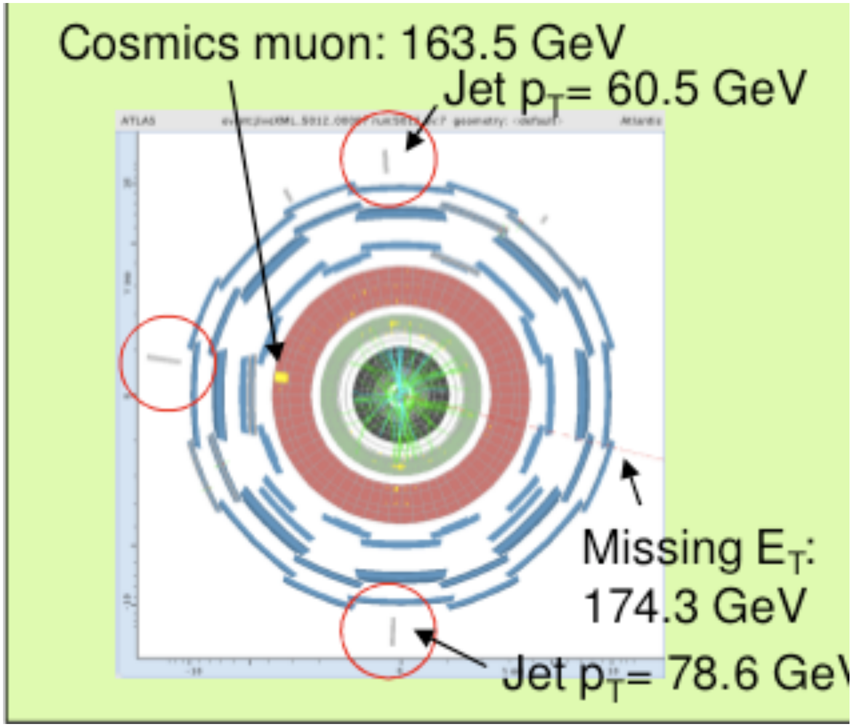
- Electrons produced by ionization (δ-rays)
- Require loose association between track and EM cluster with E>3 GeV
- Resulting samples:
  - electron "signal": events with 2 tracks
  - background: events with 1 track (γ – Bremsstrahlung by muons)
- Select on TRT signal and E/p ratio1-track events background

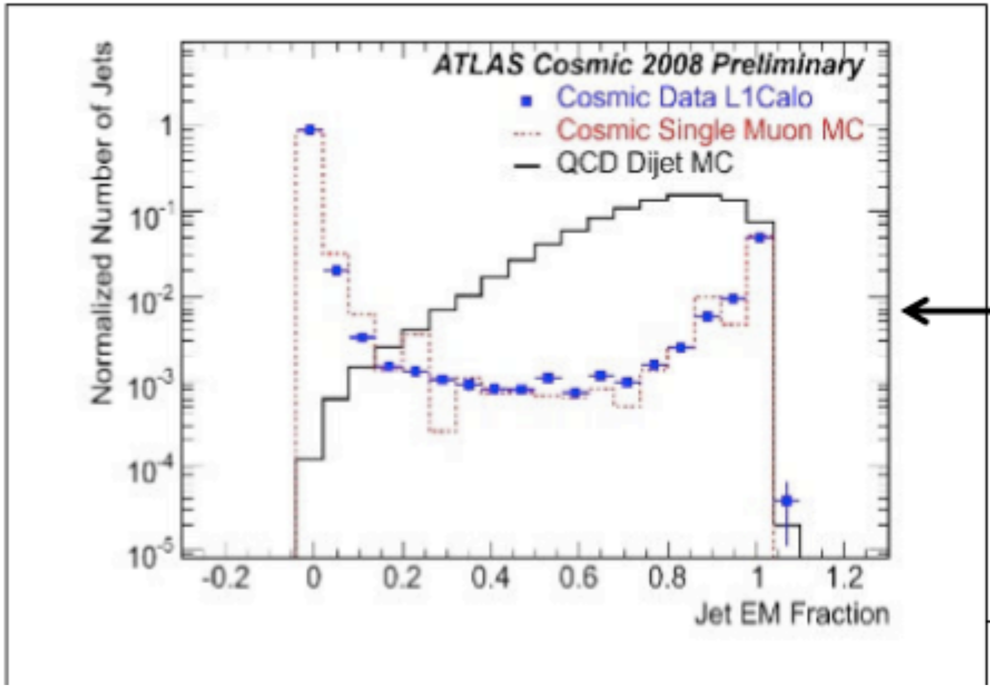


MISSING ENERGY AND JETS



Simulation of a cosmic muon overlap with a pp→ jet-jet event



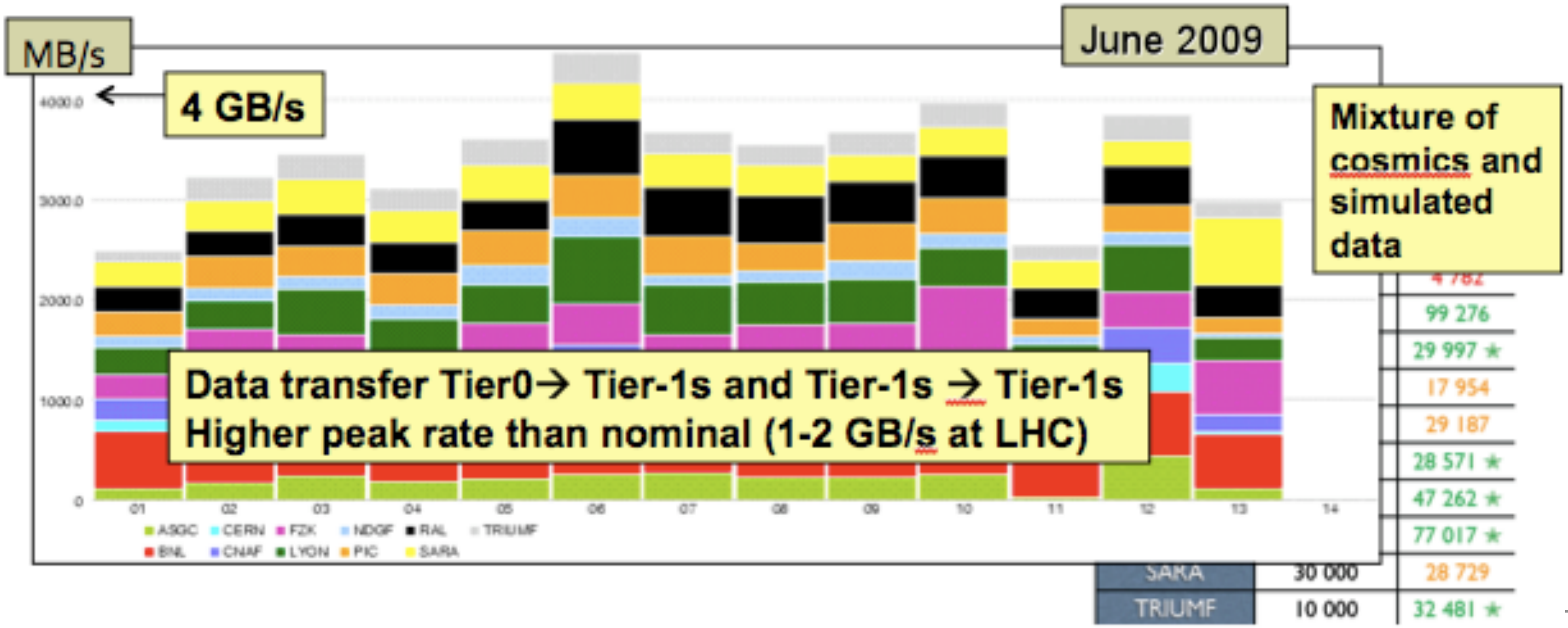


Variables to reject cosmics events (e.g. “jet” shapes) being studied

COMPUTING

ATLAS world-wide computing: ~ 70 sites (including CERN Tier0, 10 Tier-1s, ~ 40 Tier-2 federations)

Amazing operational challenges:
- ~ 50 PB of data to be moved across the world every year
- 10^9 raw events per year to be processed and reprocessed
- Operation and computing models have been stress tested and refined over the last years through functional tests and data challenges of increasing functionality, size, and realism



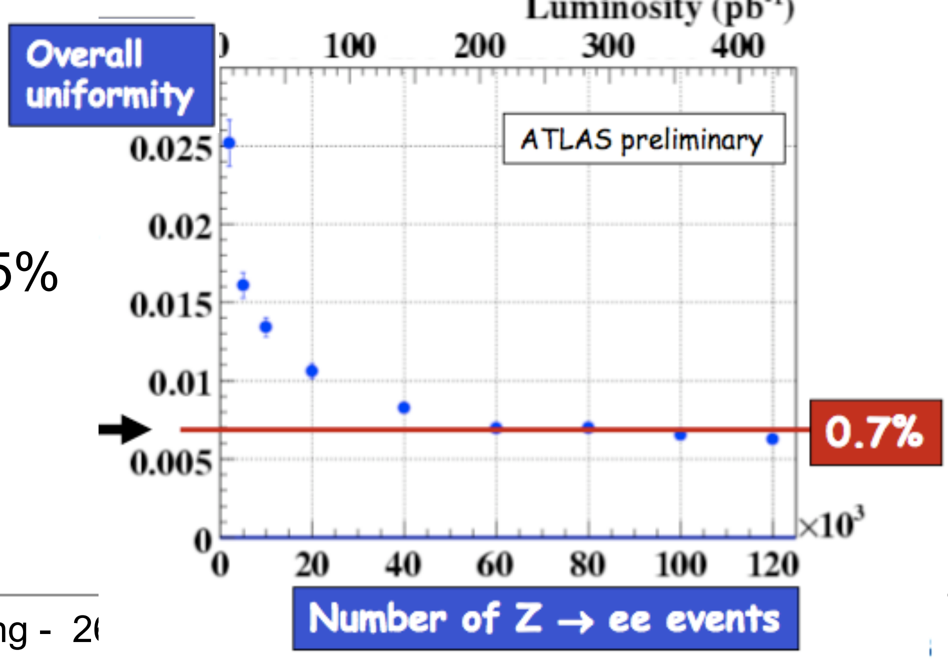
Detector expected performance

Expected knowledge of ATLAS on "day-1" (examples based on test-beam, simulation, and cosmics results)

	Day-1	Ultimate goal	Physics samples
ECAL uniformity	~2%	0.7%	Isolated electrons, Z→ee
e/γ E-scale	2-3%	<0.1%	J/ψ, Z →ee, electrons E/p
Jet E-scale	5-10%	1%	γ/Z + 1j, W →jj in tt events
ID alignment	20-200μm	5μm	tracks, isolated μ, Z →μμ
Muon alignment	40-1000μm	40μm	Straight μ, Z →μμ

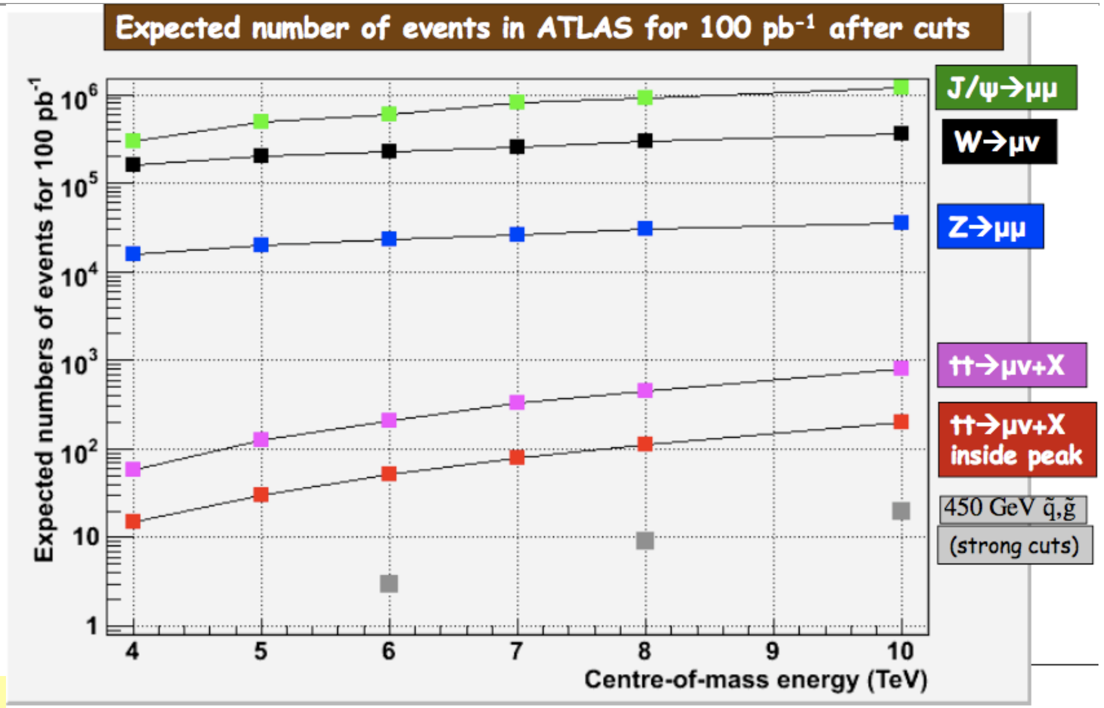
<ins>ECAL uniformity</ins>:

- local uniformity by construction/test: 0.5%
- residual long-range non-uniformities (upstream material, etc.): ~few %



Expected data samples vs. √s

Note: expect up to 200 pb^{-1} after first physics run at high energy



<u>Goals in 2010</u>:

1) Commission and calibrate the detector in situ using well-known physics samples e.g.

-Z → ee, μμ tracker, ECAL, Muon chamber calibration and alignment, etc.

-tt → blν bjj jet scale from W → jj, b-tag performance, etc.

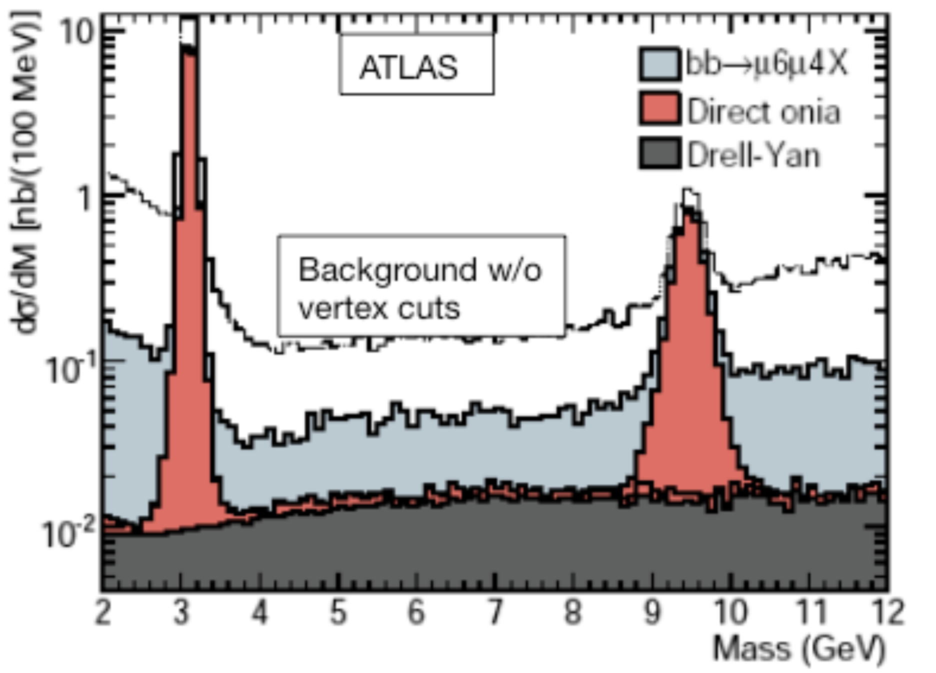
2) "Rediscover" and measure Standard Model at √s ~ 10 TeV:
W, Z, tt, QCD jets … (also because omnipresent backgrounds to New Physics)

3) Early discoveries ? Potentially accessible: Z', SUSY.. surprises ?

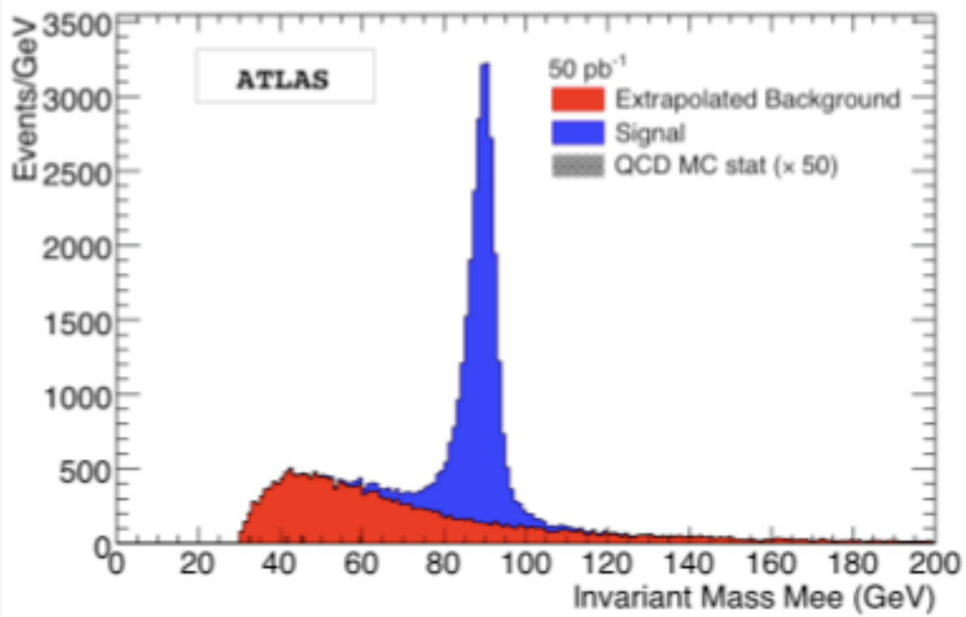
few pb^{-1} ↓ 50 pb^{-1} ↓ 100 pb^{-1} ↓

Early SM candle signals

First dilepton peaks ! with ~10 pb^{-1}



Z→ee, 50 pb^{-1}, 14 TeV



Estimated no of events after cuts per pb^{-1}:

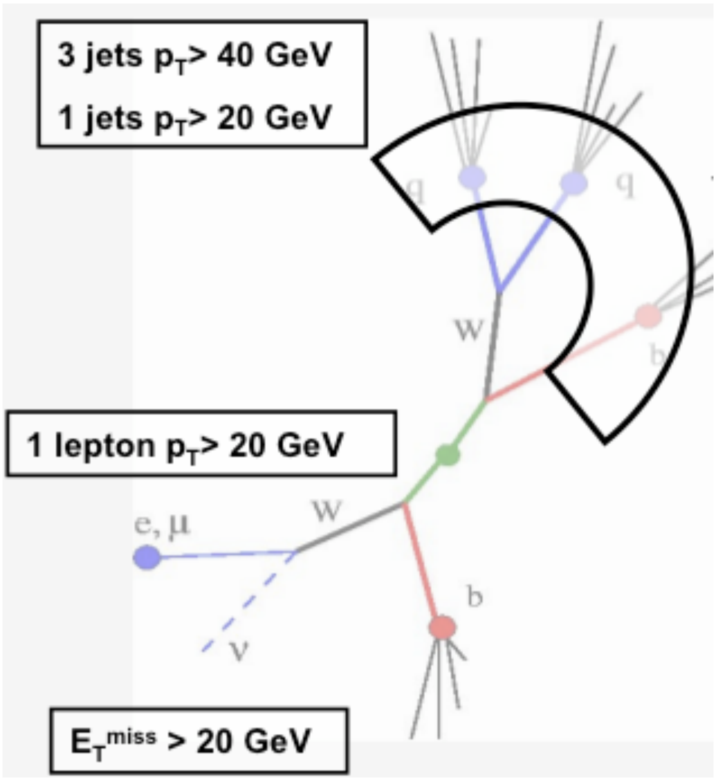
at 10 TeV: ~10000 J/ψ→μμ, 500 Υ→ μμ ~300 Z →μμ (and ~300 Z →ee)

at 7 TeV: ~7000 J/ψ→μμ ~200 Z →μμ (and ~200 Z →ee)

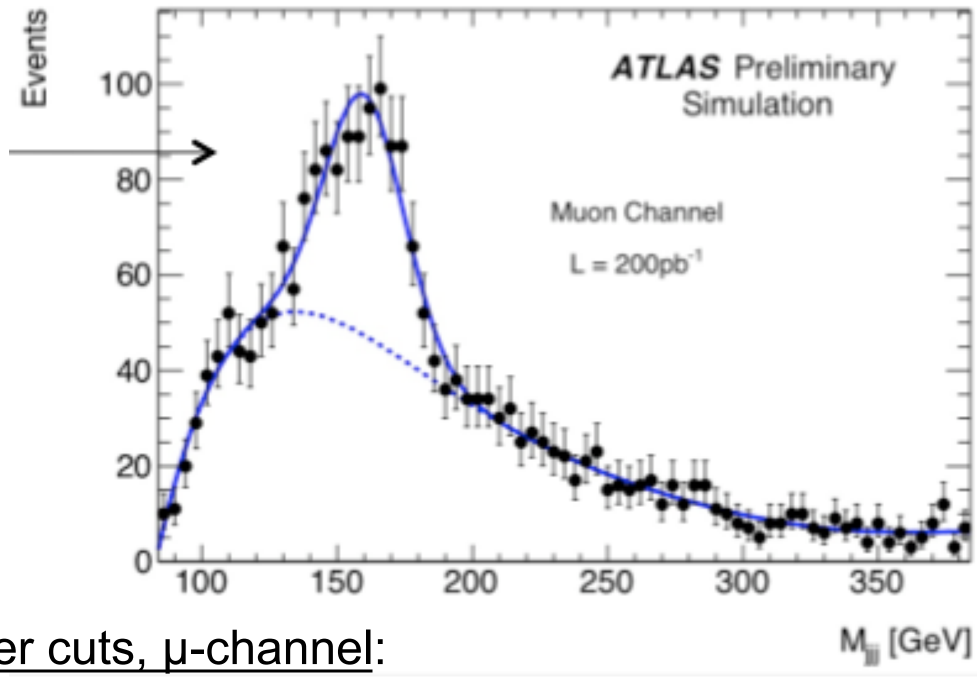
→Muon Spectrometer and ID alignment, ECAL calibration, energy/momentum scale of full detector, lepton trigger and reconstruction efficiency, …

EARLY TOP MEASUREMENTS

$t\bar{t} \to bW\, bW \to bl\nu\, bjj$



10 TeV, 200 pb $^{-1}$, μ-channel no b-tagging



After cuts, μ-channel:

$\sqrt{s}$ = 10 TeV, ~1600 ev. → expected uncertainty of cross section <20% (+luminosity uncertainty)

$\sqrt{s}$ = 7 TeV, ~600 ev.

- Top signal observable with O(10 pb-1), no b-tagging and simple analysis even at intermediate energy steps as low as 4 TeV
contain most physics objects: leptons, jets, ETmiss , b-jets
- background to ~ all searches

→ when top measured, experiment is ready for discovery phase

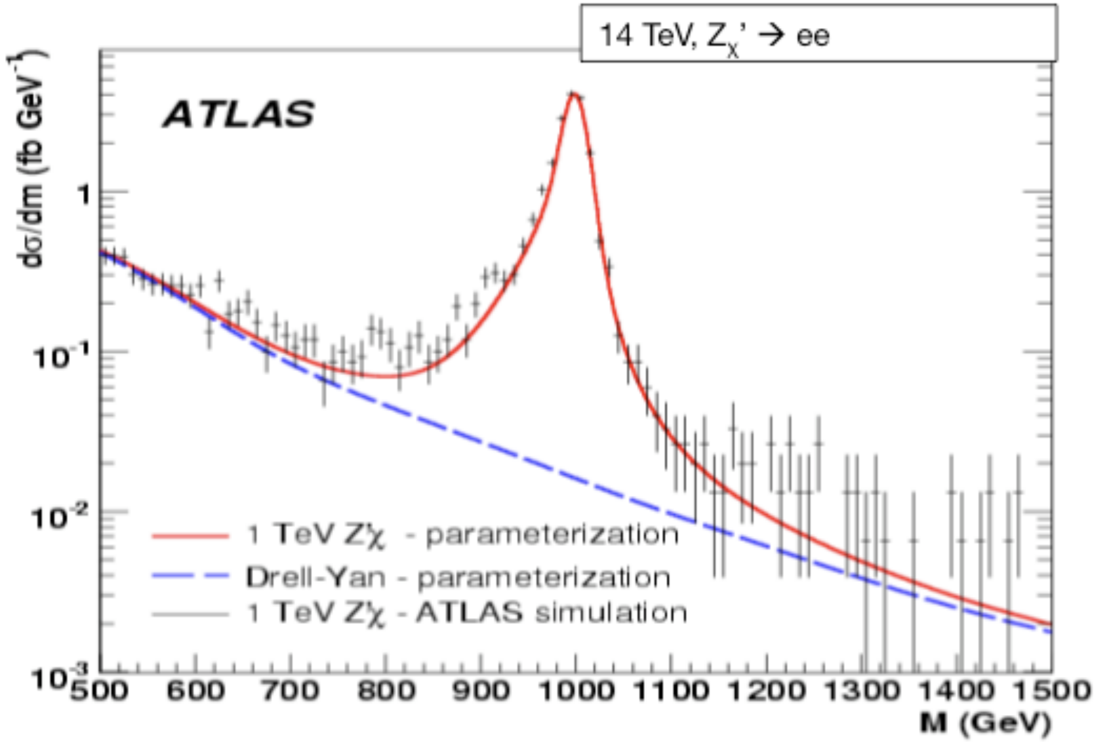
A FIRST SURPRISE?

Z’ → ll, mass ~ 1 TeV

Is this a manifestation of new forces or new dimensions ?

From angular distribution of leptons can disentangle Z’ (spin=1) from ! G (spin=2).

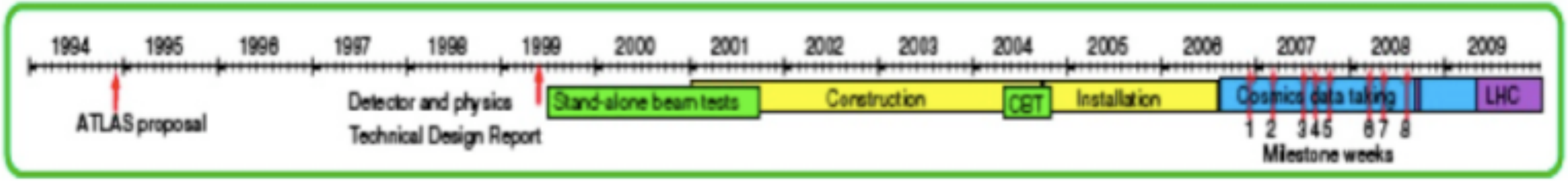
Requires more data …



- Signal is (narrow) mass peak above small and smooth SM background
- Does not require ultimate EM calorimeter performance
- Sensitivity beyond Tevatron limits with 200 pb-1 and √s ≥ 7 TeV !   (100 pb-1 at 10 TeV)

→perhaps sometime in 2010 ?

SUMMARY



The ATLAS experiment is in excellent shape

- The fraction of non-working channels is on the per mille level
- Analysis of ~600 M cosmics events, as well as single beam data in Sept 2008, shows better detector performance than expected at this stage
- Software and computing have proven to be able to cope with simulation, analysis and world-wide distribution of massive amounts of data
- After 20 years of efforts building all aspects of the experiment: **ATLAS is eagerly waiting for LHC collisions data …**

First one delivered...

Bottles of champagne to be offered by ATLAS to the LHC accelerator team

BACK-UP SLIDES

Work during shutdown

Inner Detector:

- Evaporative cooling for the ATLAS silicon detectors: system upgraded.
- Refurbished distribution racks, more flexible control system, new reserve tank which can take all fluid.
- Replaced Optical Transmitters of the Pixel and SCT. Upgrade of HV boards for the SCT
- Increased reliability of the Beam Condition Monitor. ATLAS Beam Loss Monitors installed.
- CO2 straw cooling for TRT: tests done, additional CO2 extraction lines being tested.

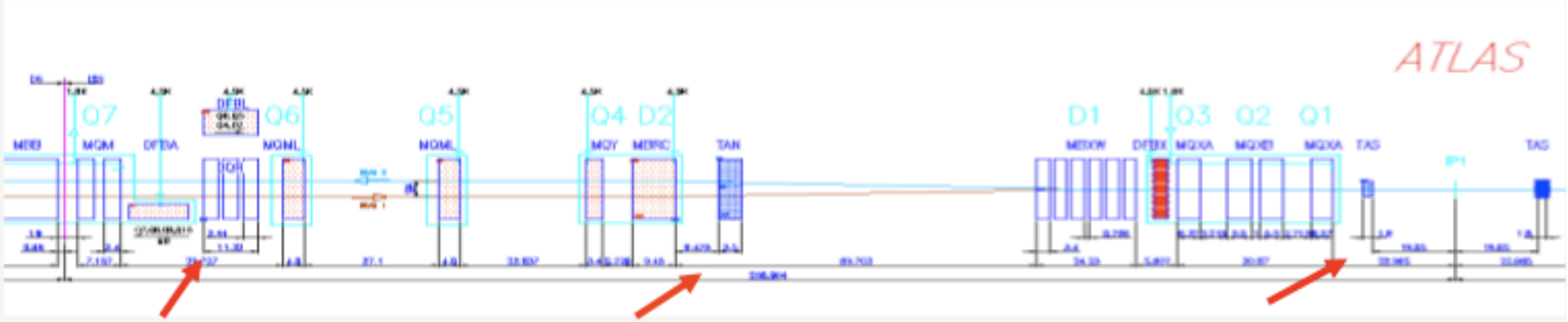
Calorimeters:

- All Liquid Argon power supplies were repaired and re-installed
- Front end boards optical transmitters, 12 out of 1600 dead
- Repairs carried out on 81/256 Tile HCal electronic drawers

Muon Spectrometer:

- Additional precision muon chambers (EE) installed
- Repairs of 7 Thin Gap Chambers that had been damaged by overpressure incident
- RPC operational fraction increased from 70% to 97%
- Improved temperature control for the RPC ″ Still concern for the Cathode Strip Chambers rate performance

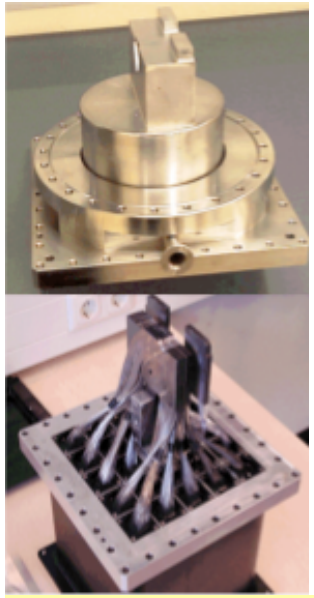
Forward detectors



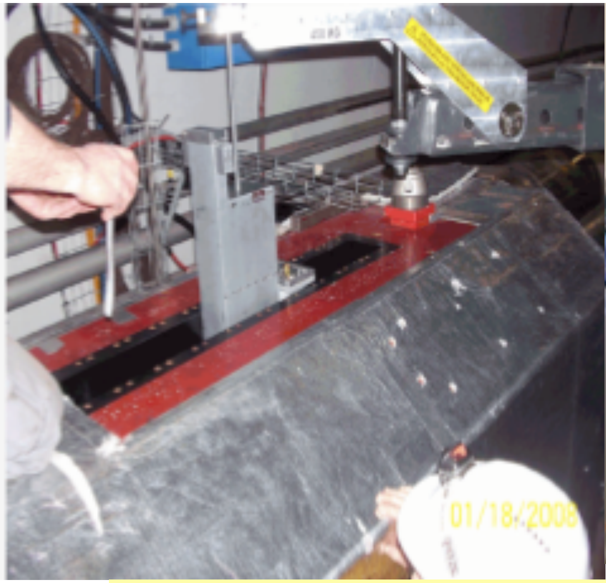
ALFA at 240 m

ZDC at 140 m

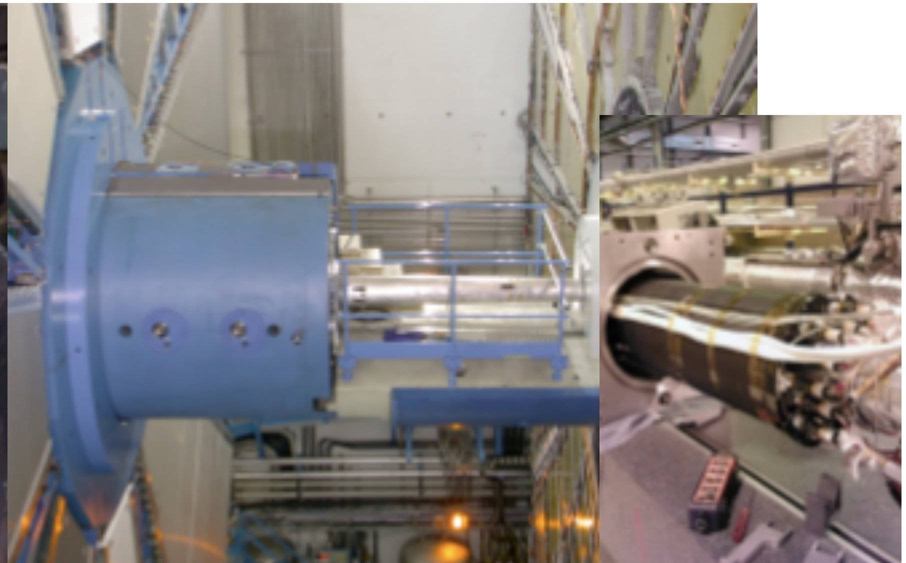
LUCID at 17 m



Absolute Luminosity for ATLAS Installation 2010



Zero Degree Calorimeter (Data taking in 2009)



Luminosity Cerenkov Integrating Detector

LoI for Forward Proton detectors at 220 and 420 m (AFP): ongoing ATLAS review

Detector status

TRT running smoothly already for months
2.2% dead channels, confident to recover 0.2%
TRT noise occupancy set to 2%
SCT 98% of detector operated
After all repairs should be 99.6%
SCT noise occupancy < 10-5
Pixels:
Up to 98% of detector operated
Pixel noise occupancy < 10-9

Silicon hit efficiency >>99%, TRT >97%

- **L1 Calorimeter**

–Dead channels: < 0.4% (+0.3% recoverable in shutdown) of a total of 7200 analogue channels
–Channel-to-channel noise suppression allows ET=1 GeV cut (aim: 0.5 GeV)

– Muon **Optical alignemnt system:** 99.7% (barrel), 99% (end-cap)

LAR: –0.0186% dead channels
-0.75% dead readout
Noisy channels: 0.003%bad calibration <0.2%
Electronic calibration procedure operational (calibration constants used online)

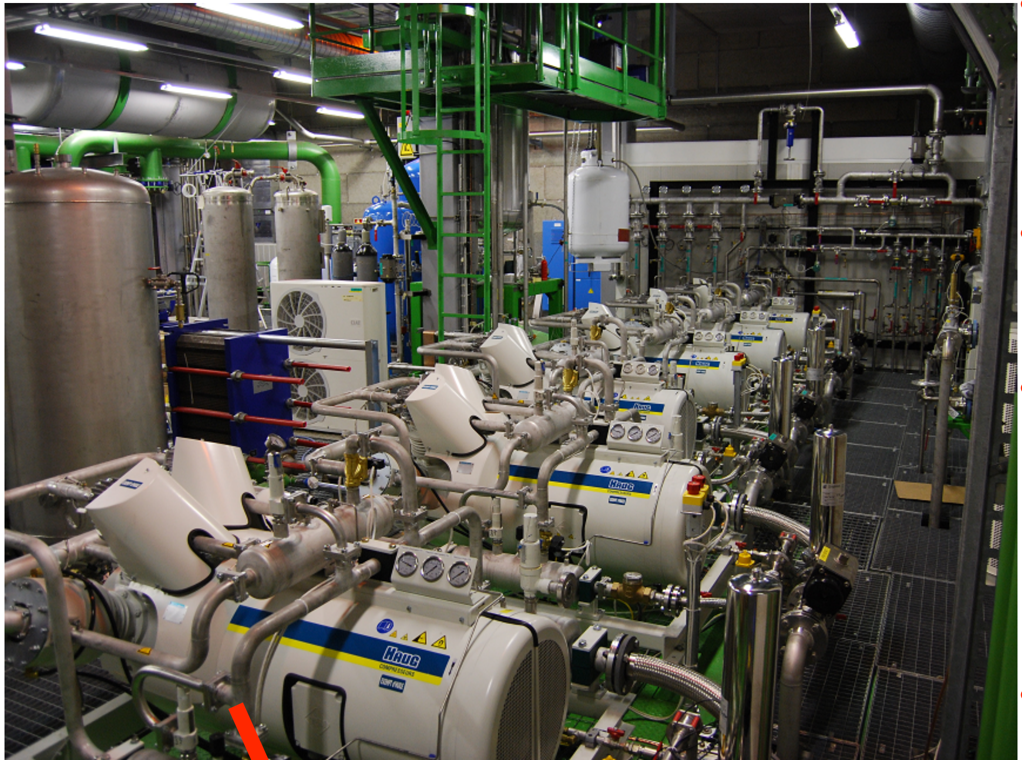
Hadronic:–<1.4% dead cells in 2008 treated during shutdown, reduced to 0.5%
–Calibration system operational (Cs source, Laser, charge injection)

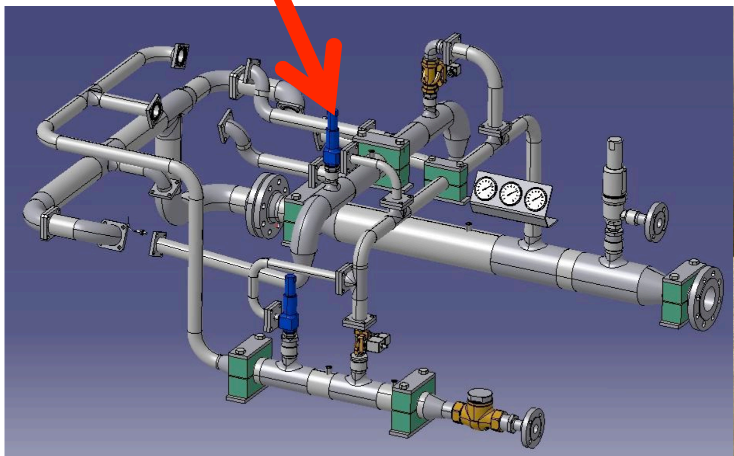
MDT: – >99 % of chambers operational
– Dead channels: 0.5 %
– Noisy channels: < 0.2 % with 5% occupancy

RPC:95.5% (plan to be at 98.5% for beam
– Dead strips < 2% -Hot strips/spots < 1%

TGC:– 99.8% of chambers operational
– Dead channels < 0.01%
– Noisy channels <0.02% with >5% occupancy

Evaporative cooling

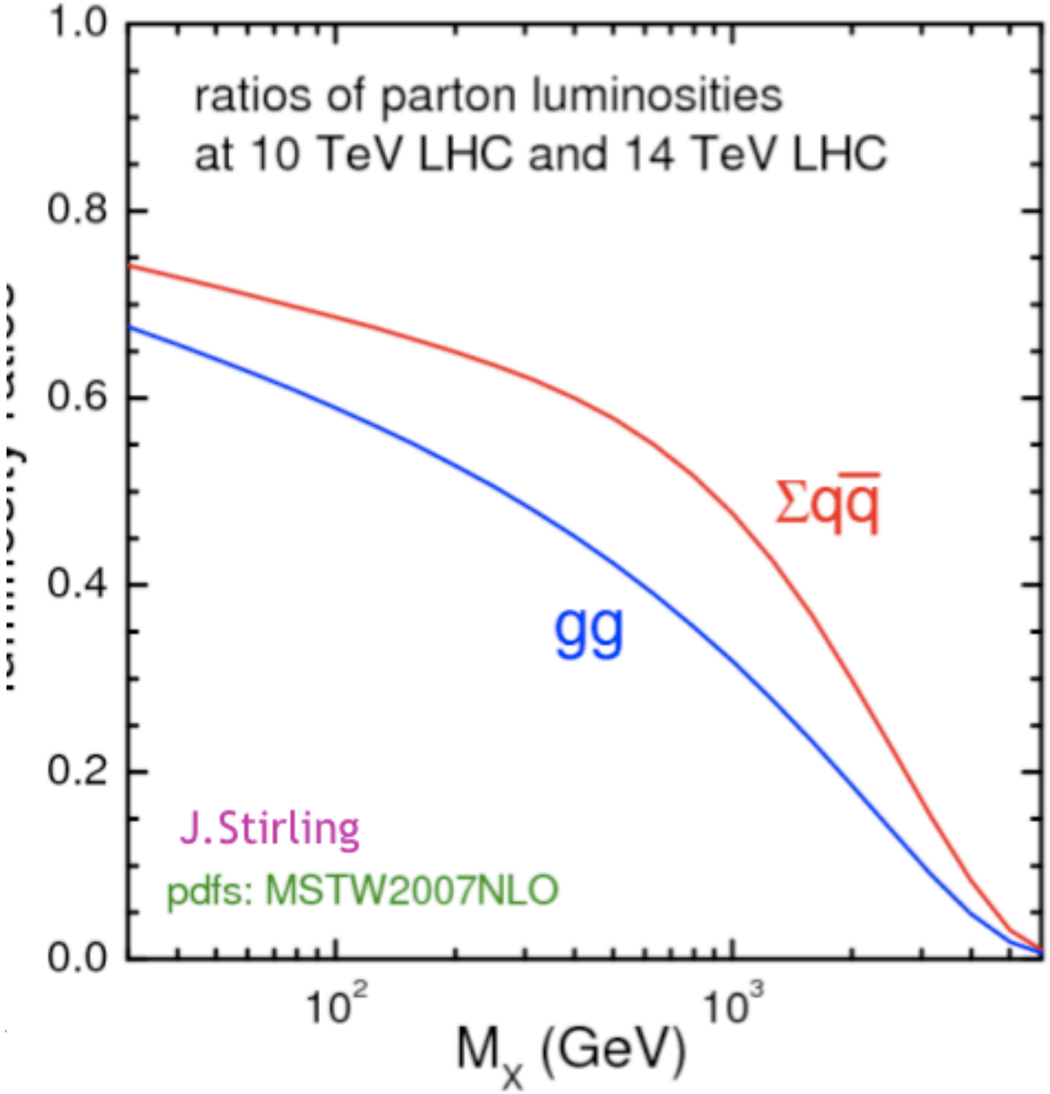




- From end of July to beginning of November '09 the installation has been running for 96% of the time for an overall of 2.629 hours
- Major events occurred in October (after ~2000 h): four cracks on compressor
- The mechanical problems where associated to stress due to vibration & excitation of pipes and collectors by pressure oscillations of the gas at the rotational frequencies
- All compressors were send back to the producer for a major rework of the piping and their welding, after a major review of the piping geometry and their welding qualification
- 7/7 compressors are back in place, reinstalled and operational. The system was put in operation in June 2009

14 TeV vs. 10 TeV

Ratios of cross-sections at 10/14 TeV for processes induced by *gg* and *qq*

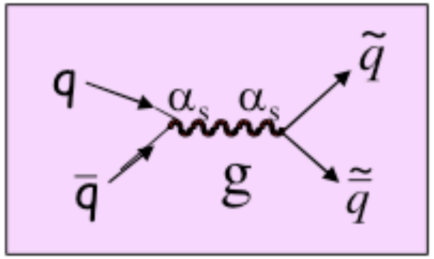


Channel	σ(10)/σ(14)
W,Z	~ 0.7
J/Psi, Υ	~ 0.8
Higgs	~ 0.6
t-tbar	~ 0.5
1 TeV $\tilde{q},\tilde{g}$	~ 0.25
Jets p_T> 0.5 TeV	~ 0.4
Jets p_T > 1 TeV	~ 0.25

Note: acceptance increases slightly at 10 TeV (physics is more central at lower energy)

SUPERSYMMETRY?

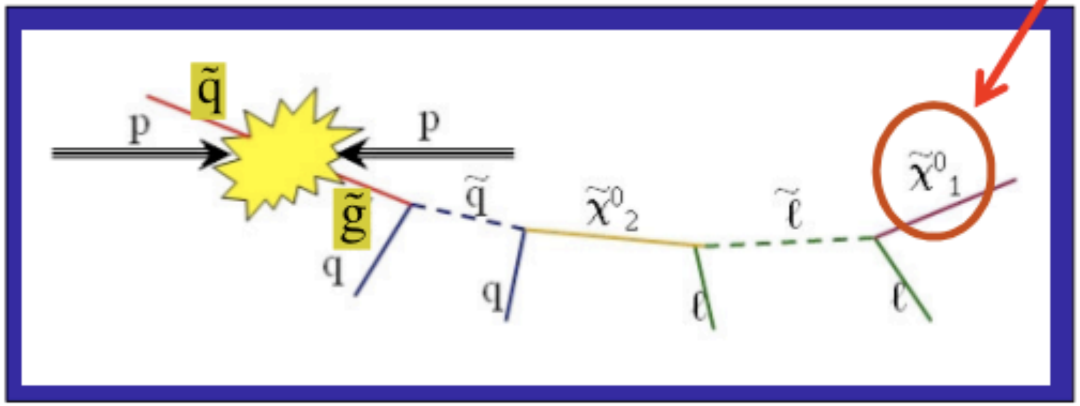
If it is at the TeV mass scale, it could be found "quickly" …. thanks to:

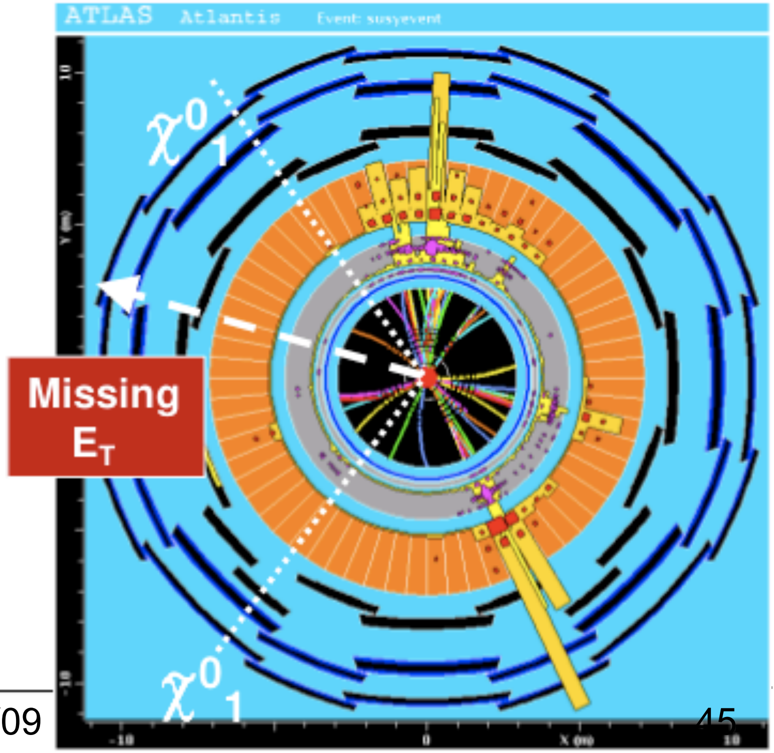


- Huge production cross-section for $\tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{g}\tilde{g}$ production

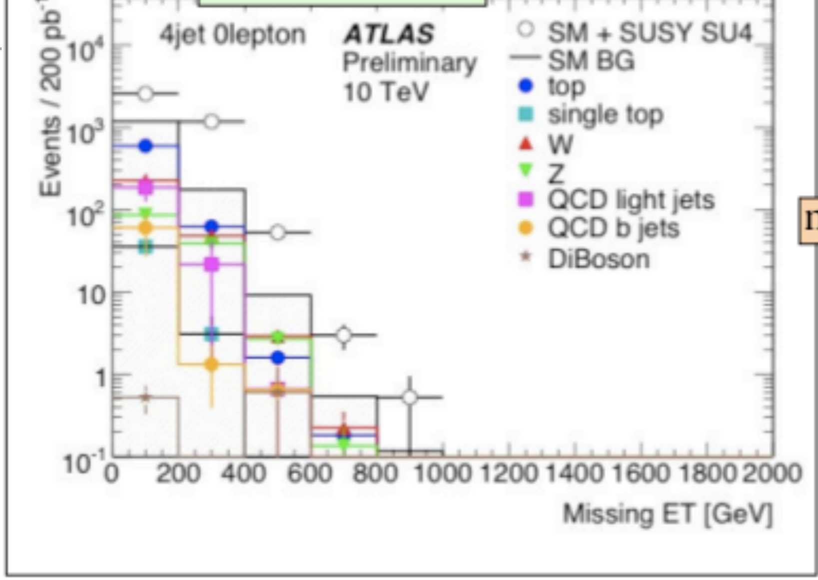
  For $m(\tilde{q},\tilde{g}) \sim 1$ TeV
  expect 1 event/5 days at 10 TeV and $L=10^{31}$ cm^{-2} s^{-1}

- Spectacular final states (many jets, leptons, missing transverse energy)





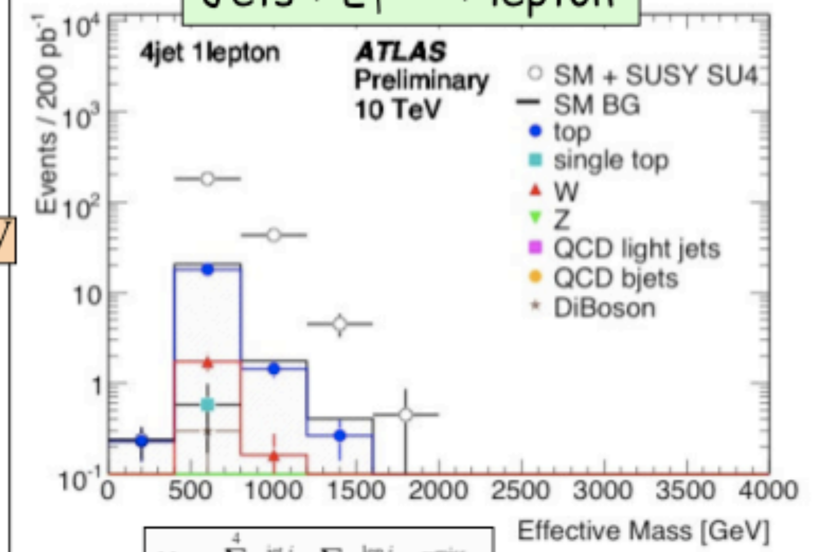
Jets + E_T^{miss}



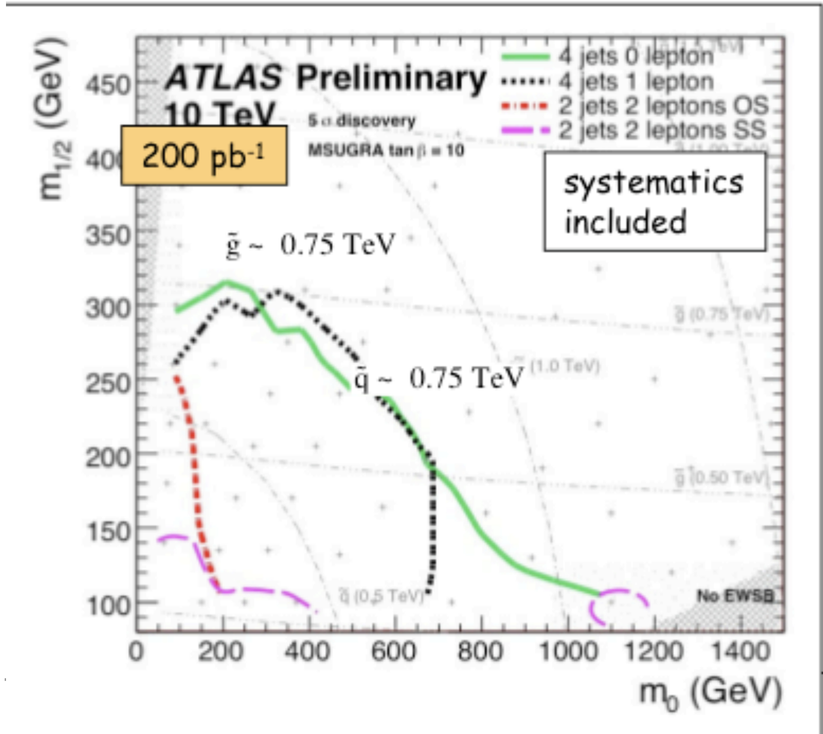
$\sqrt{s}$ = 10 TeV
200 pb^{-1}

$m(\tilde{q},\tilde{g}) \sim 410$ GeV

Jets + E_T^{miss} + lepton



$$M_{\rm eff} \equiv \sum_{i=1}^{4} p_T^{{\rm jet},i} + \sum_{i=1} p_T^{{\rm lep},i} + E_T^{\rm miss}$$



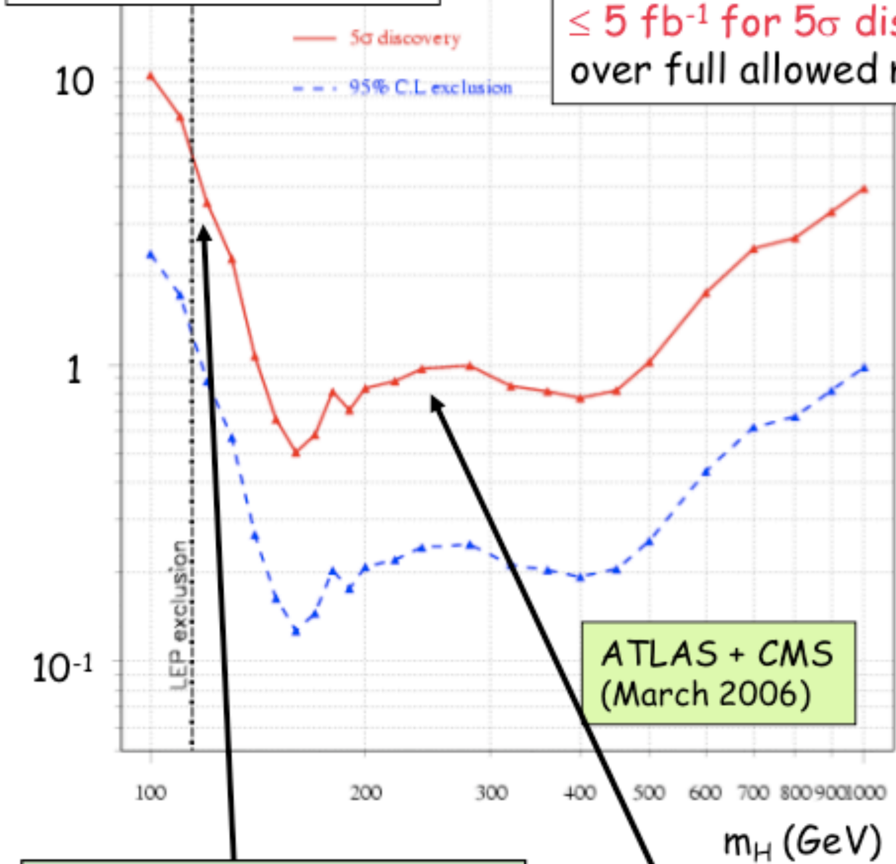
Jets + E_T^{miss} channel: highest reach
1-lepton channel: more robust against B uncertainties

- Discovery up to m ~ 750 GeV with 200 pb^{-1} at $\sqrt{s}$ =10 TeV
- With 200 pb^{-1}, ATLAS discovery reach beyond expected Tevatron exclusion (~400 GeV) if $\sqrt{s} \geq 7$ TeV
- However: understanding the (tricky) backgrounds, in particular fake missing transverse energy coming from instrumental effects (cracks, noise, ..), will take time
- Ultimate LHC reach: $m(\tilde{q},\tilde{g}) \sim 3$ TeV

Higgs discovery potential

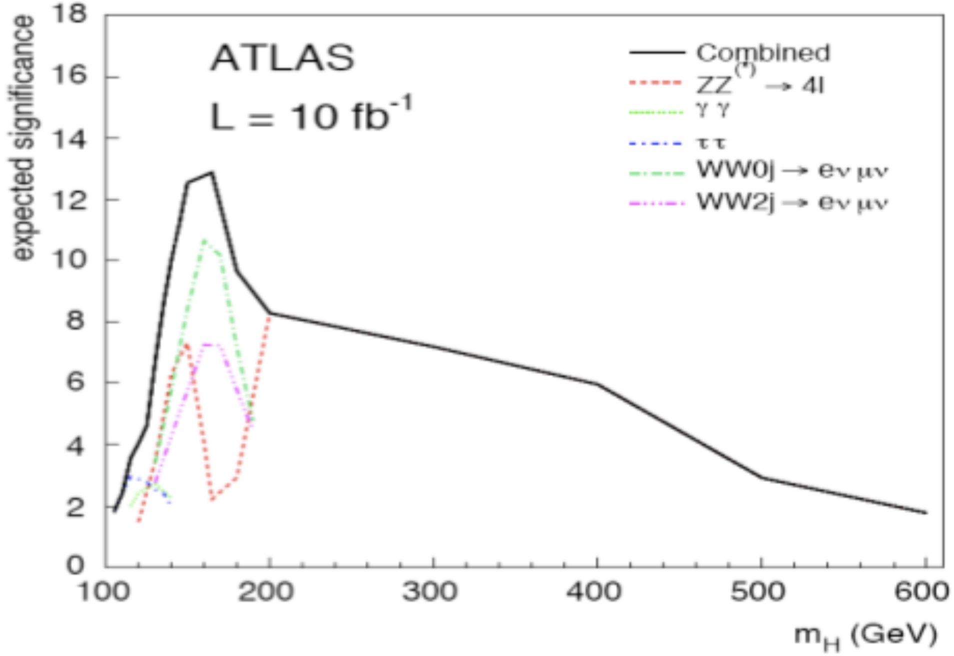
Needed ∫Ldt (fb^{-1}) of well-understood data per experiment

≤ 1 fb^{-1} for 95% C.L. exclusion
≤ 5 fb^{-1} for 5σ discovery
over full allowed mass range



Most difficult region: need to combine several channels (e.g. H → γγ, qqH→qqττ) with small S/B or S

Easier region: H → 4l



Important changes w.r.t. previous studies:

- H → γγ sensitivity of ATLAS and CMS comparable
- ttH → tt bb disappeared in both ATLAS and CMS studies:

Higgs: LHC vs. Tevatron

Combining ATLAS and CMS, √s = 14 TeV:
0.1-1 fb-1 of good data for 95% C.L. exclusion
~0.5-5 fb-1 of good data for 5σ σσ σdiscovery depending on the Higgs mass
√s = 10 (7) TeV: need ~1.6 (~3) more luminosity

Tevatron:
"analyzable" luminosity: ~ 80% of delivered → 5.5 fb^{-1} in 2009
7.4 fb^{-1} in 2010
10 fb^{-1} in 2011

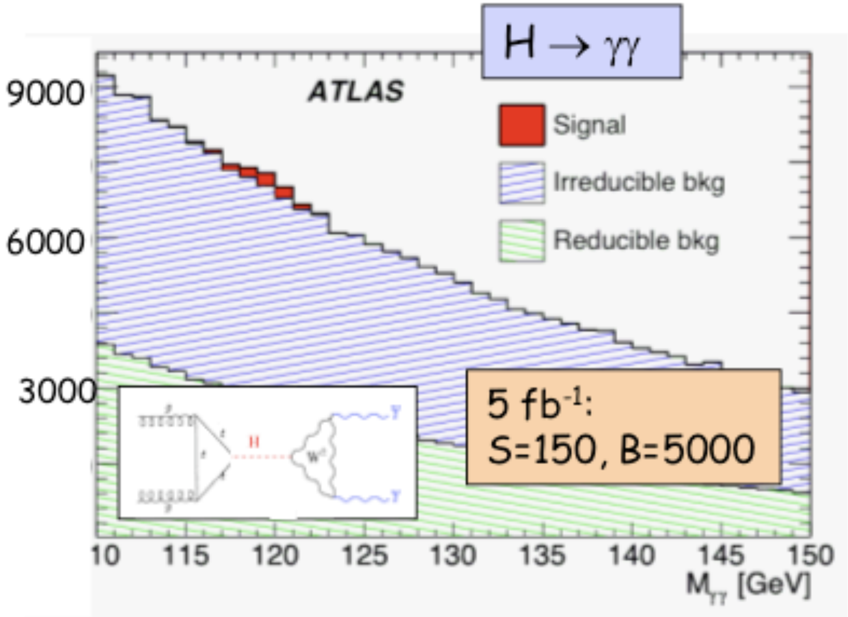
Note:
160-170 GeV
excluded already

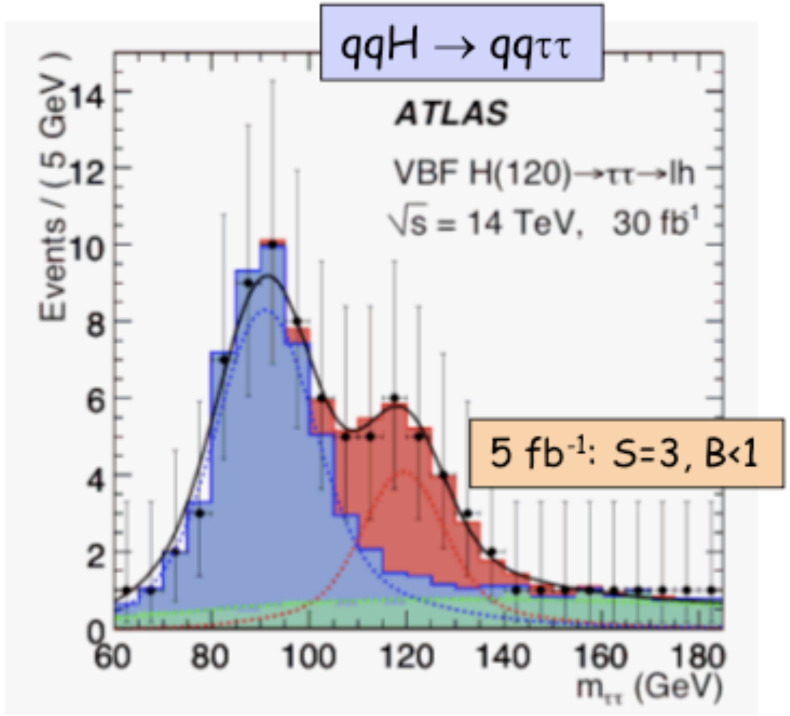
	95% C.L exclusion	3σ
Tevatron 2009 (5.5 fb^{-1})	full range ≤180 except 118-146	156-170 GeV
Tevatron 2010 (7.4 fb^{-1})	full range <200 except 128-134	153-178 GeV
Tevatron 2011 (9.6 fb^{-1})	full range <180	<117, 148-185 GeV
LHC (1-2 fb^{-1})	full range < 1 TeV	> 125 (5σ: 140-500)

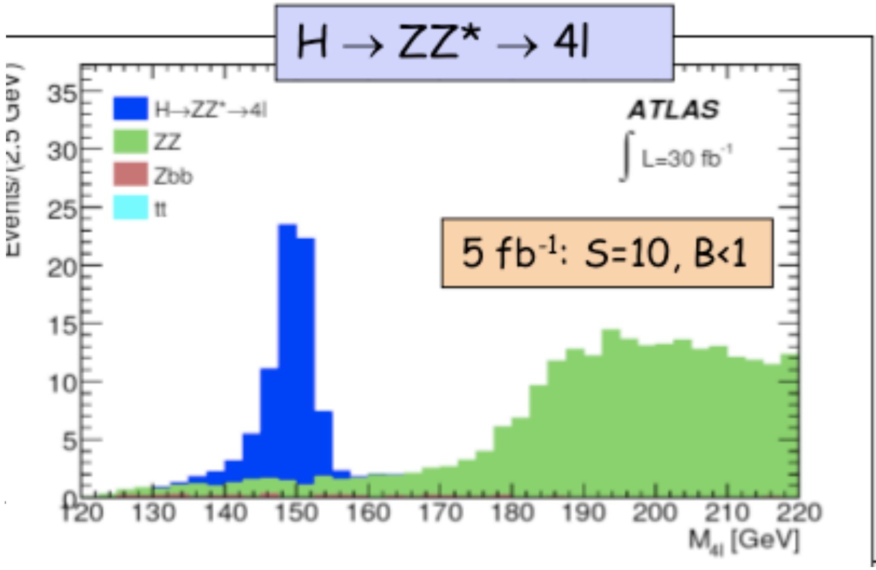
- No competition for exclusion: if the Higgs is not there, Tevatron will exclude almost all mass range below 200 GeV in 2010
- 2010: Tevatron has 3σ sensitivity ± 8 GeV window around the presently excluded region
- LHC becomes competitive (and ultimately takes over) starting with ~ 1 fb^{-1} (2011)

Light Higgs

30 fb^{-1}







- m_H < 130 GeV: most difficult region: need to combine many channels with small S or S/B
- m_H > 130 GeV: discovery easier with $H \to 4l$ (narrow mass peak, small B)
- $H \to WW \to l\nu l\nu$ (dominant for 160-185 GeV) is a counting experiment (no mass peak)