Status of the ATLAS detector

Oleg Solovyanov
On behalf of the ATLAS collaboration

ATLAS talks at this conference

- Status of the ATLAS detector – *Oleg Solovyanov*
- ATLAS upgrades towards the HL-LHC - *Hongbo Zhu*
- B-physics at ATLAS – *Vladimir Nikolaenko*
- Top physics at ATLAS - *Saverio D'Auria*
- SUSY and beyond SM searches at ATLAS - *Nathan Triplett*
- Electroweak physics at ATLAS - *Geraldine Conti*
- Higgs searches in various channels at ATLAS - *Simone Pagan Griso*
- Combined Higgs result at ATLAS - *Christian Schmitt*

Outline

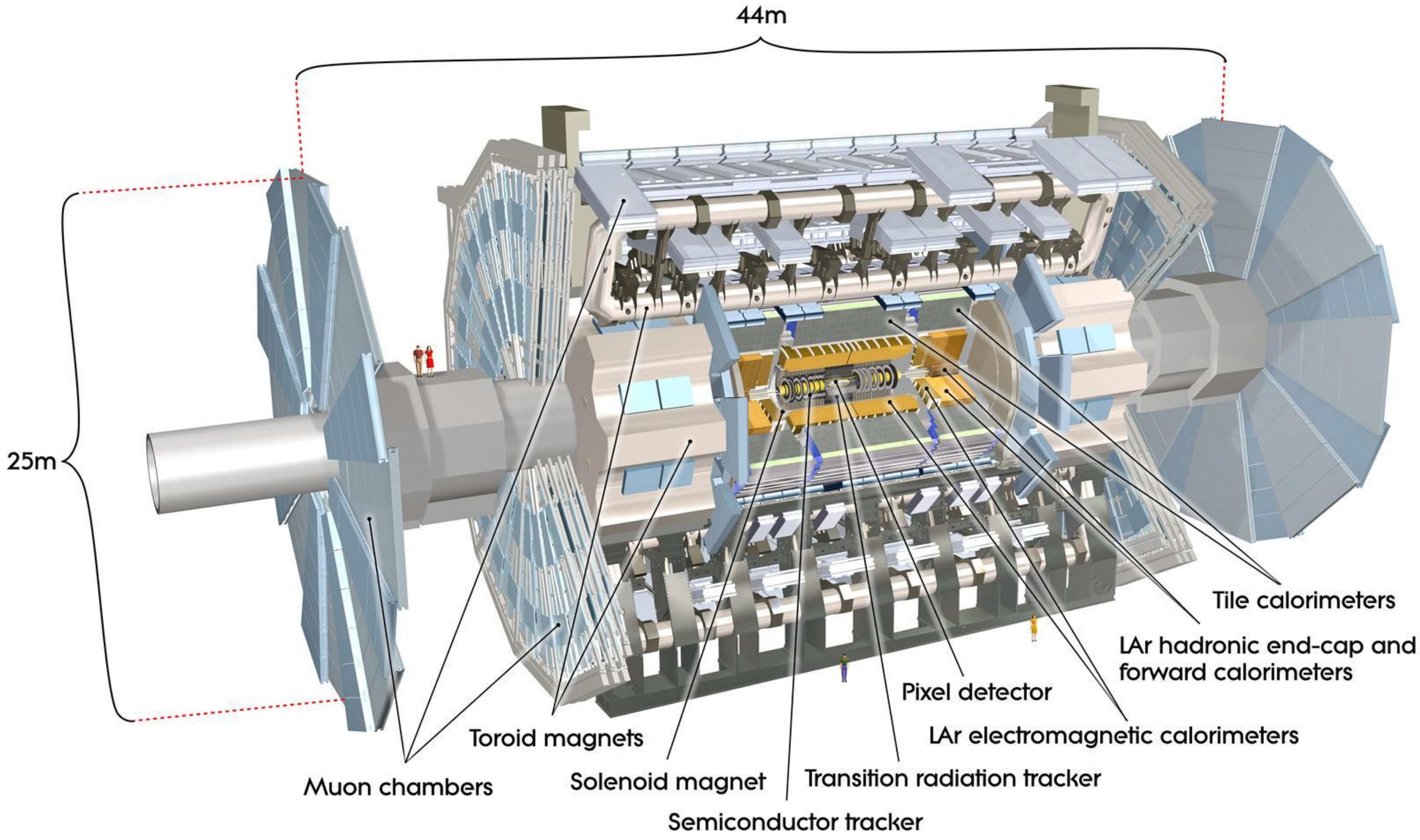
- ATLAS detector
- Data taking and trigger
- Sub-detectors status and performance
  - Forward/lumi detectors
  - Inner detectors
  - Calorimetery
  - Muon spectrometer
- Physics results
- Long shutdown and upgrade plans

ATLAS collaboration

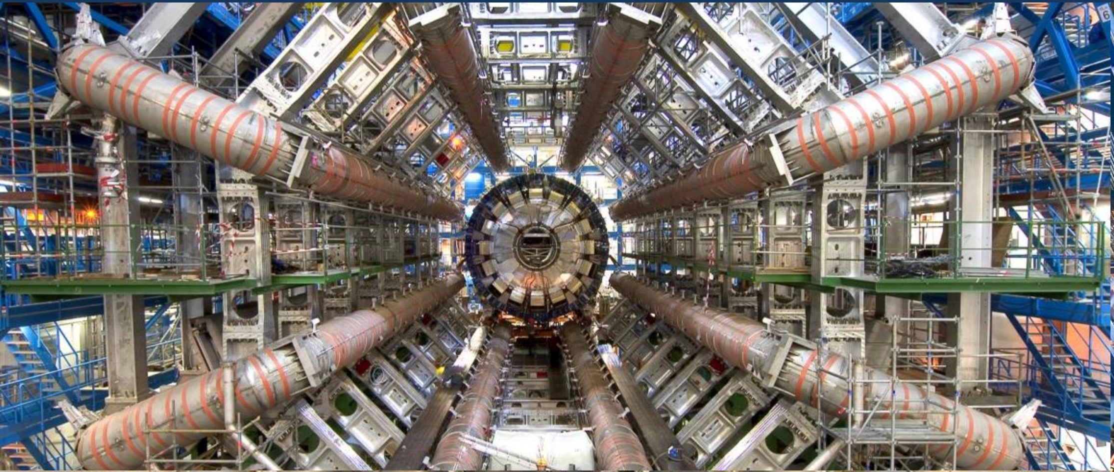
- More than 3000 physicists from 186 institutions of 46 countries
- Celebrating 20 years of ATLAS!
  - 1992 – letter of intent
  - 1996 – approval
  - 2008 – installation completed
  - 2009 – first collisions
  - 2010 – first collisions at 7 TeV
  - 2011 – data taking at 7 TeV
  - 2012 – data taking at 8 TeV

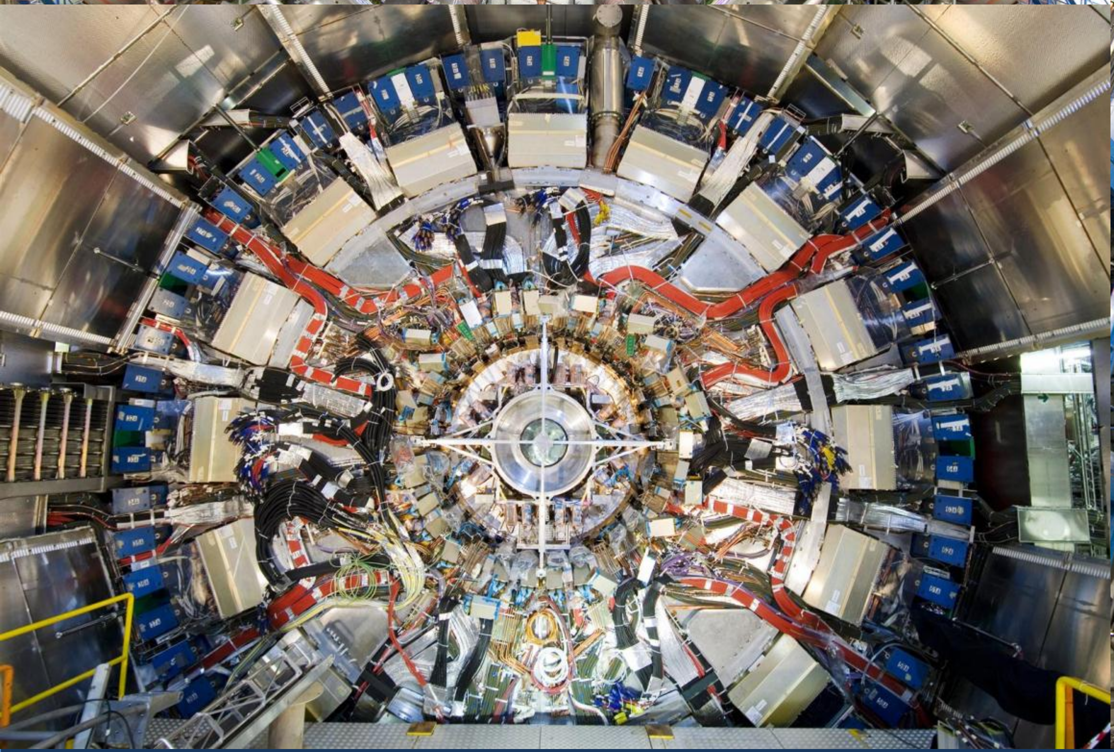
ATLAS site

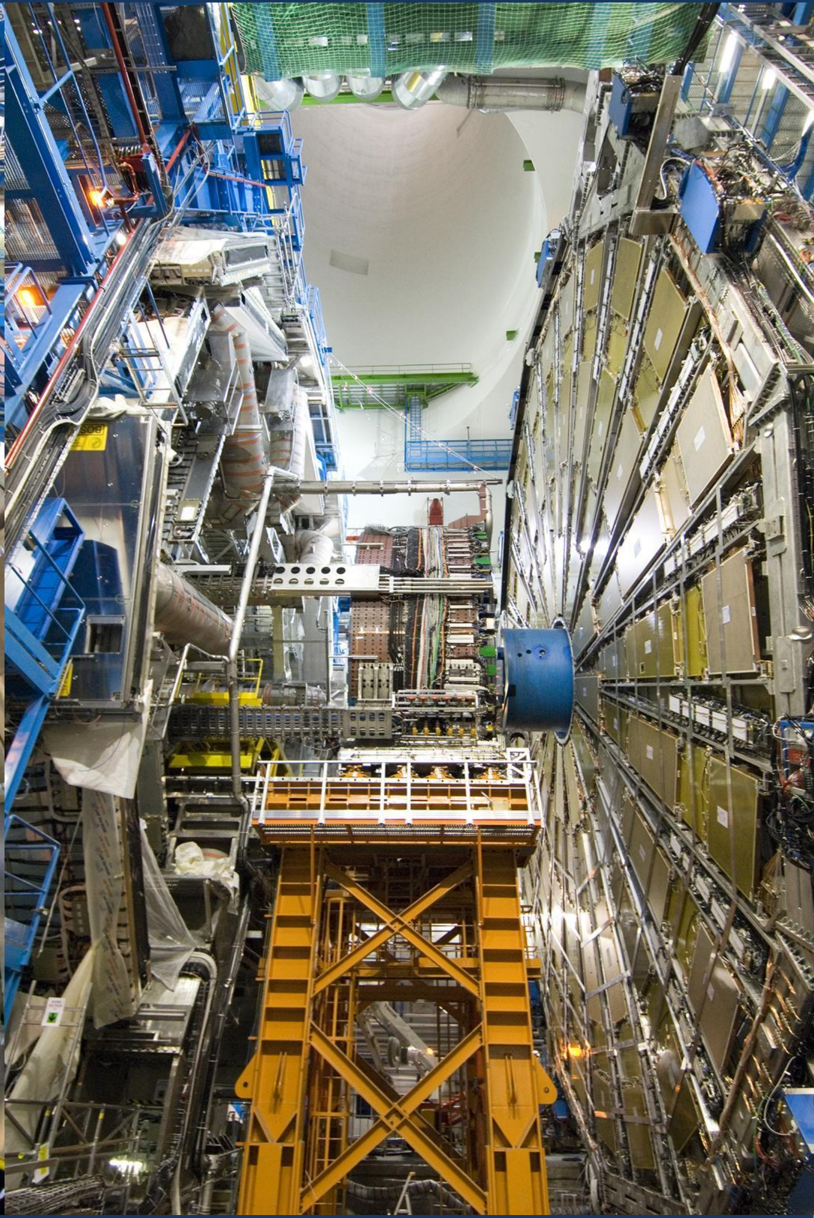
ATLAS detector



ATLAS detector: in the cavern





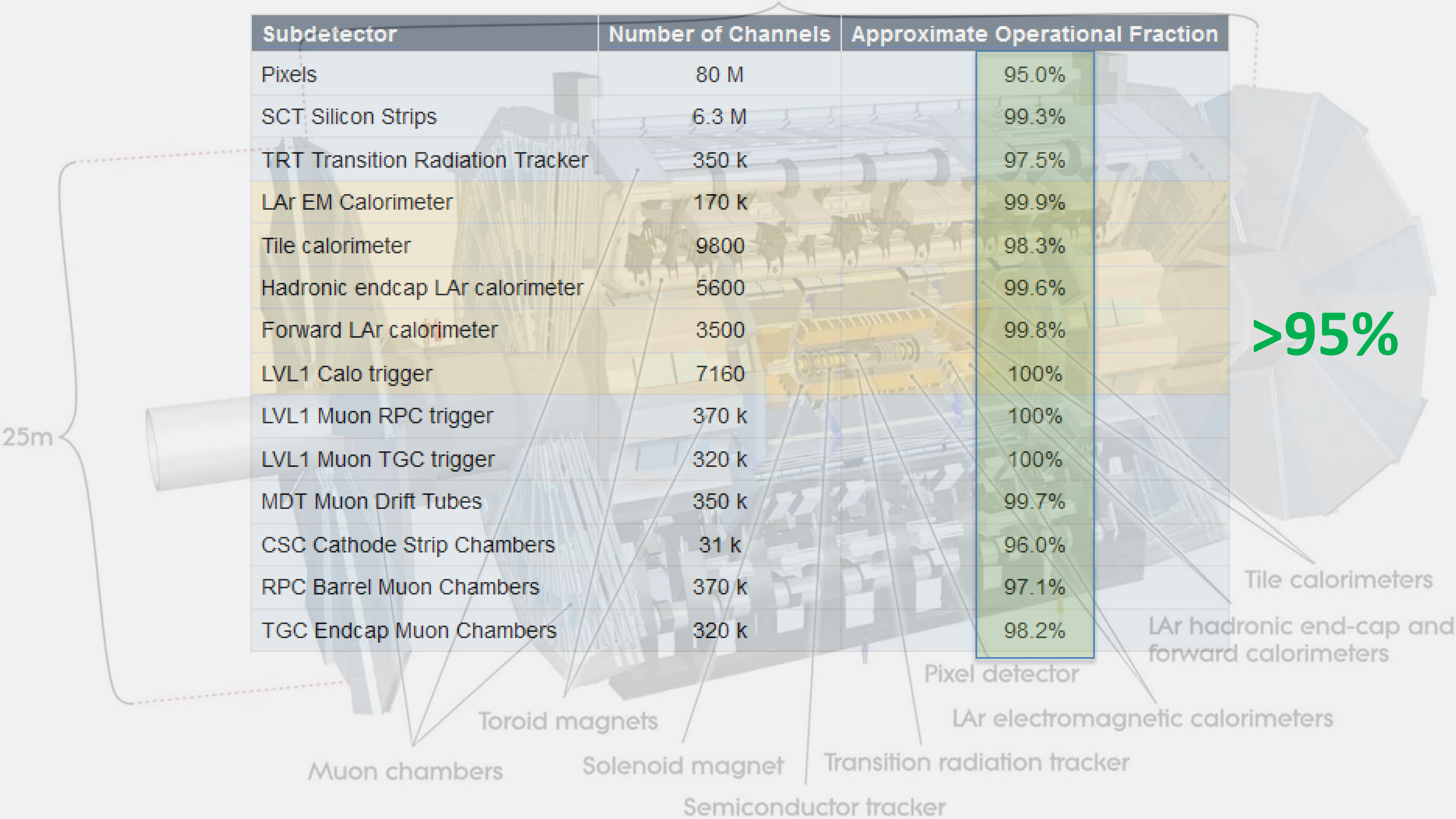


ATLAS detector hardware status

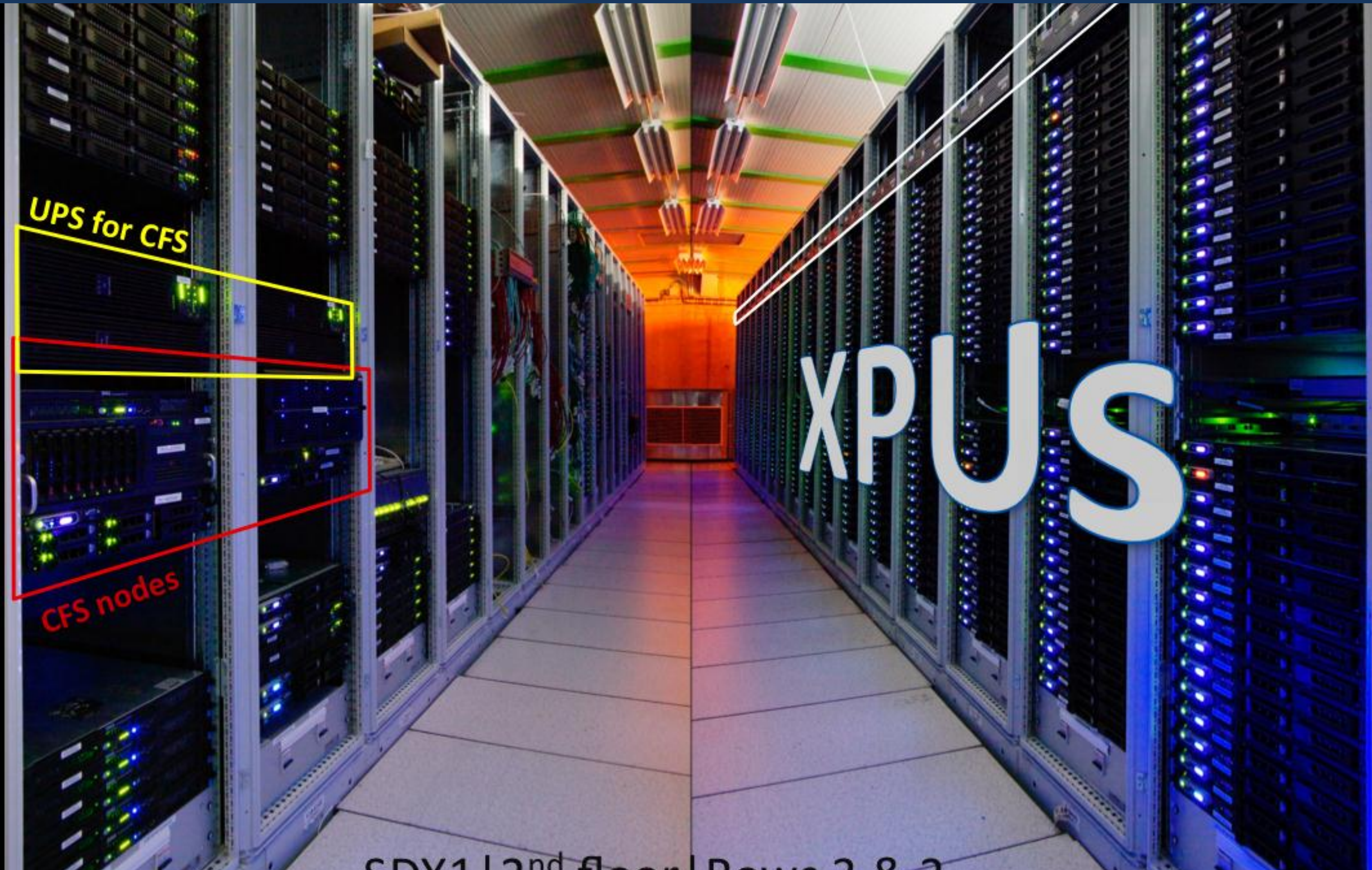
Fraction of operational channels is very close to 100% in most of the systems!

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

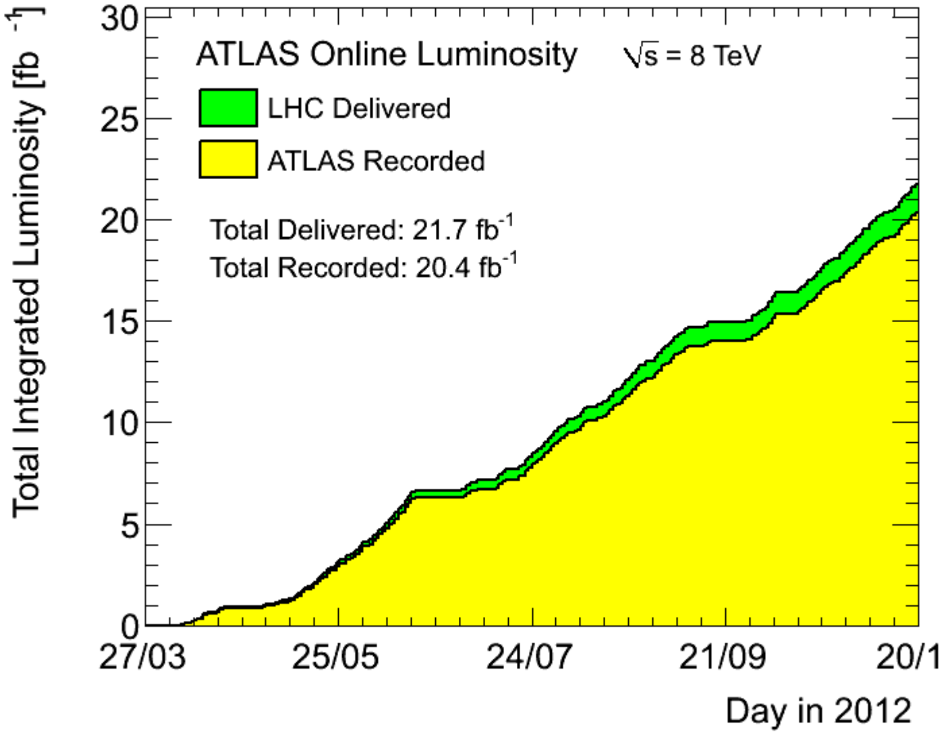
>95%

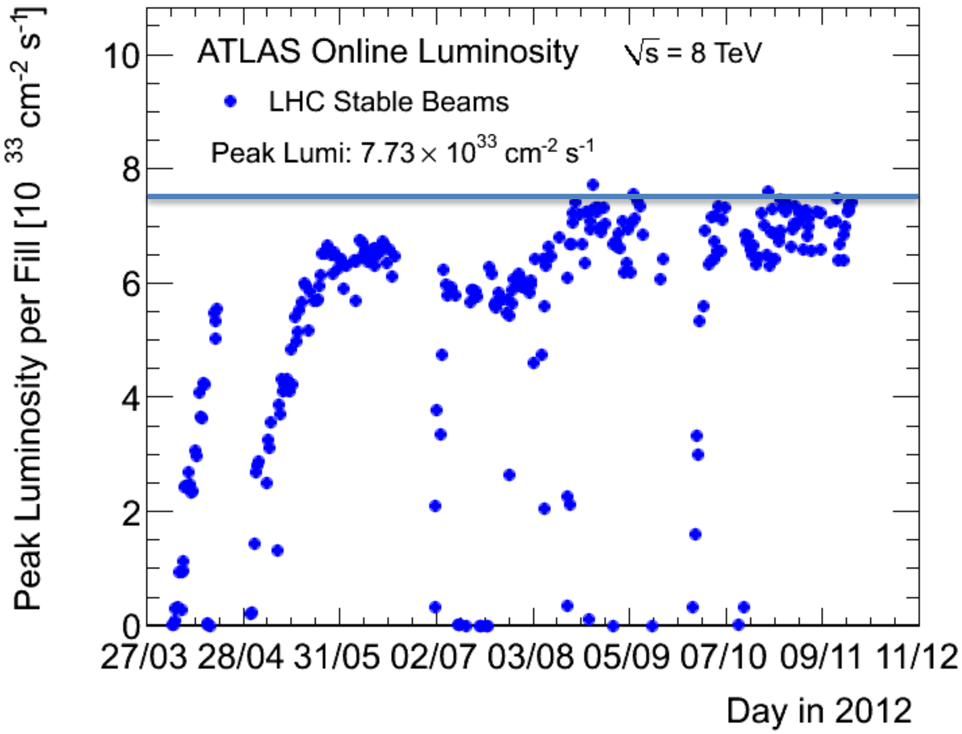


Data taking



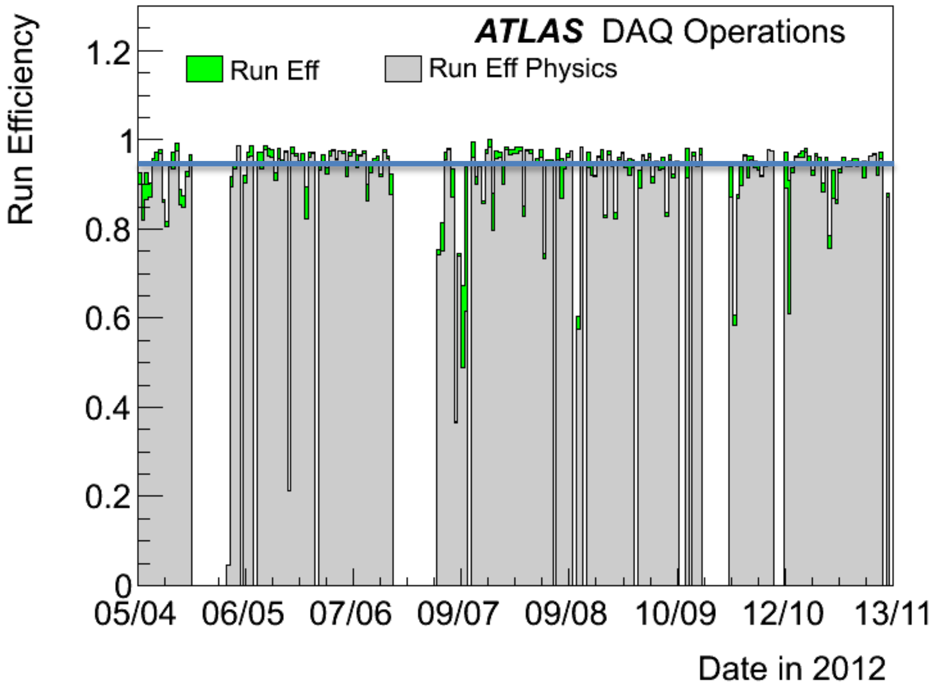
LHC performance

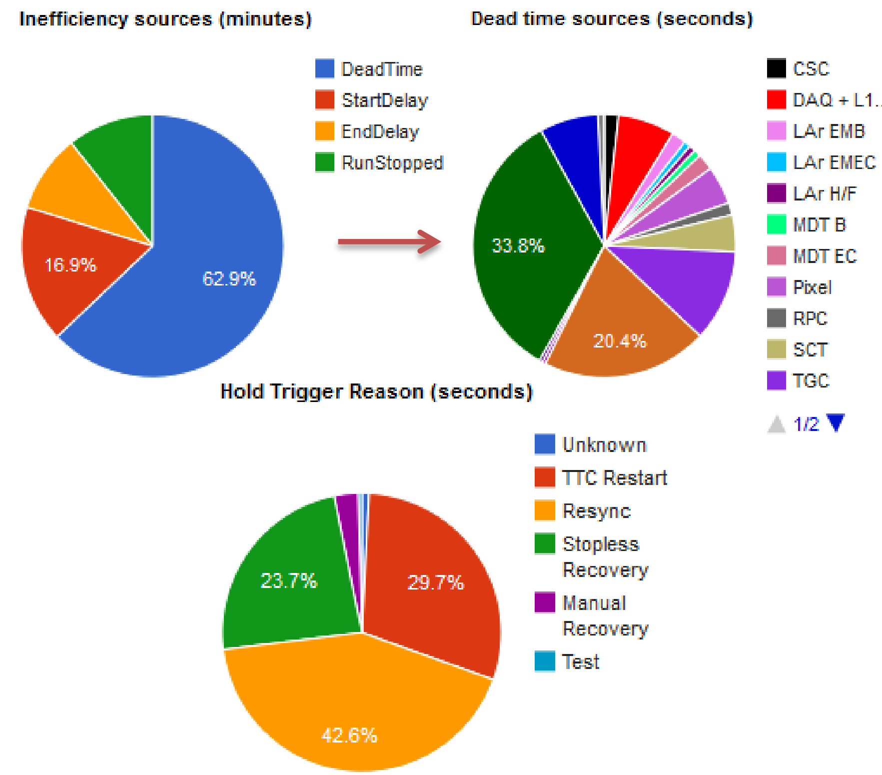




- Peak luminosities routinely reach 7.5×10^{33} cm^{-2} s^{-1}
- Regulary have a peak μ up to 35 and beyond

Data taking efficiency

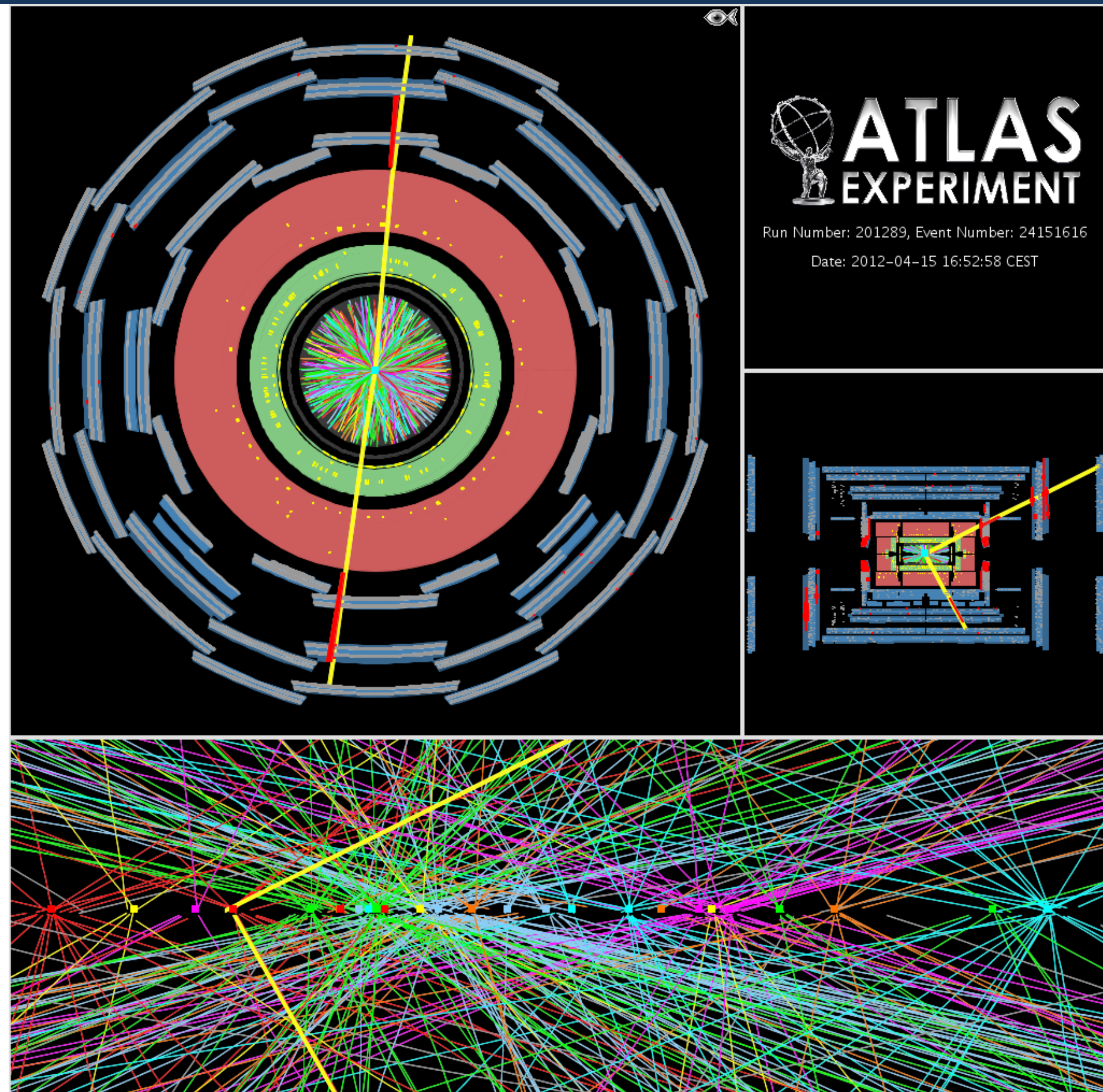




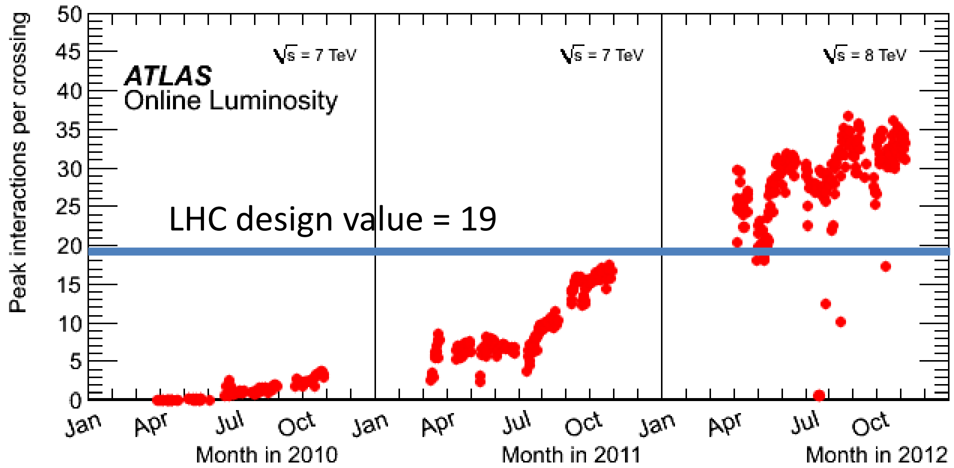
- Overall ATLAS data taking efficiency in 2012 is so far **93.7%**, similar to 2011
- Deadtime is the dominant inefficiency source
- Explicitly holding the trigger for recoveries also contributes for dead time
- Efficient implementations, parallel recovery mechanisms, when and what recovery is appropriate to perform are very important!

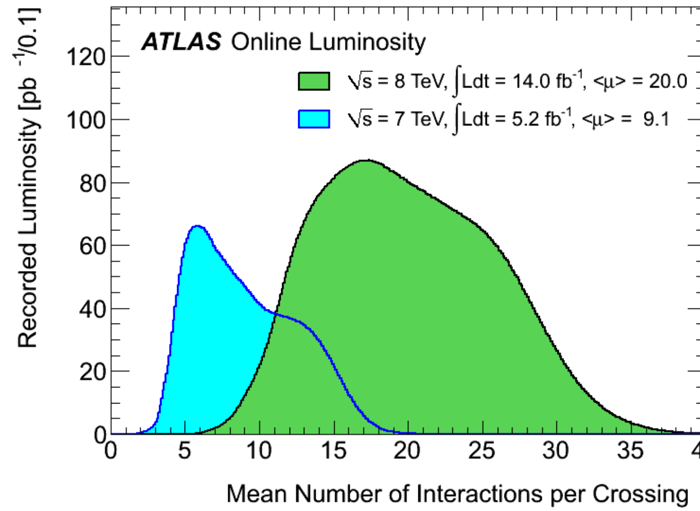
Event display: high pileup

- A candidate Z boson event in the di-muon decay with 25 reconstructed vertices.
- This event was recorded on April 15th 2012 and demonstrates the high pileup environment in 2012 running (when the beta* was reduced to 0.6m).
- For this display the track p_T threshold is 0.4 GeV and all tracks are required to have at least 3 Pixel and 6 SCT hits.
- The vertices shown are reconstructed using tracks with p_T greater than 0.4 GeV, but with tighter requirements on the number of hits on the tracks than in the 2011 reconstruction.

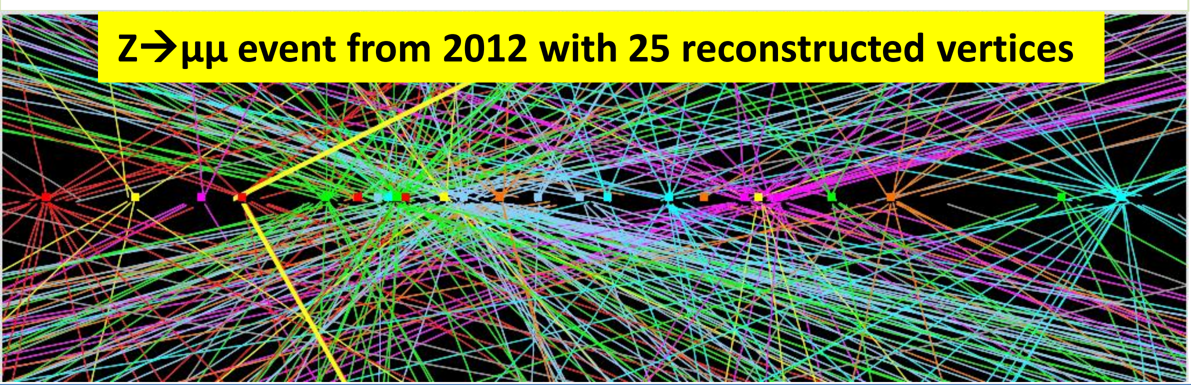


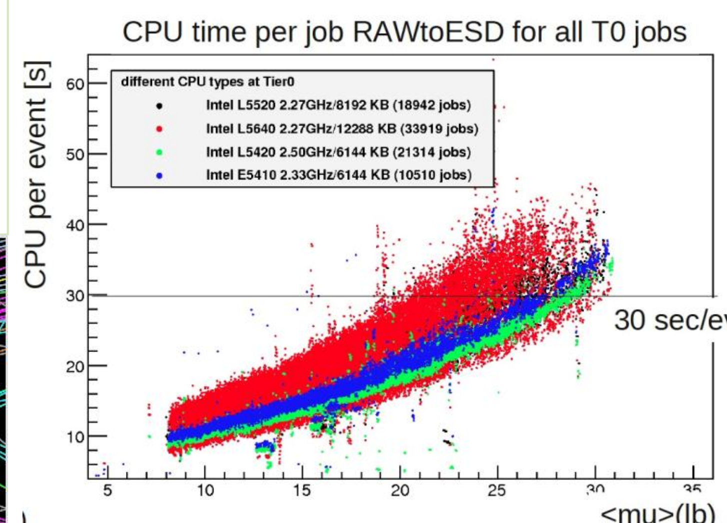
Pileup challenge





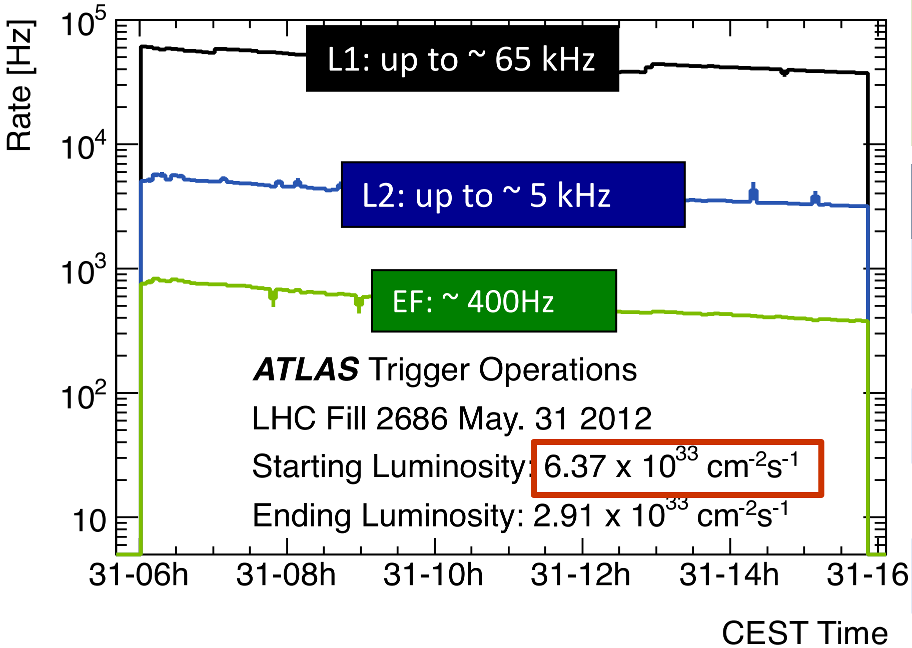
- Running with 50ns bunch spacing (instead of 25ns)
  - → double pile-up for same luminosity
- Has to be fought and mitigated at all levels:
  - Trigger, reconstruction of physics objects, isolation cuts, etc.
  - Data processing: CPU time for reconstruction…





Mean Number of Interactions per Crossing

Trigger



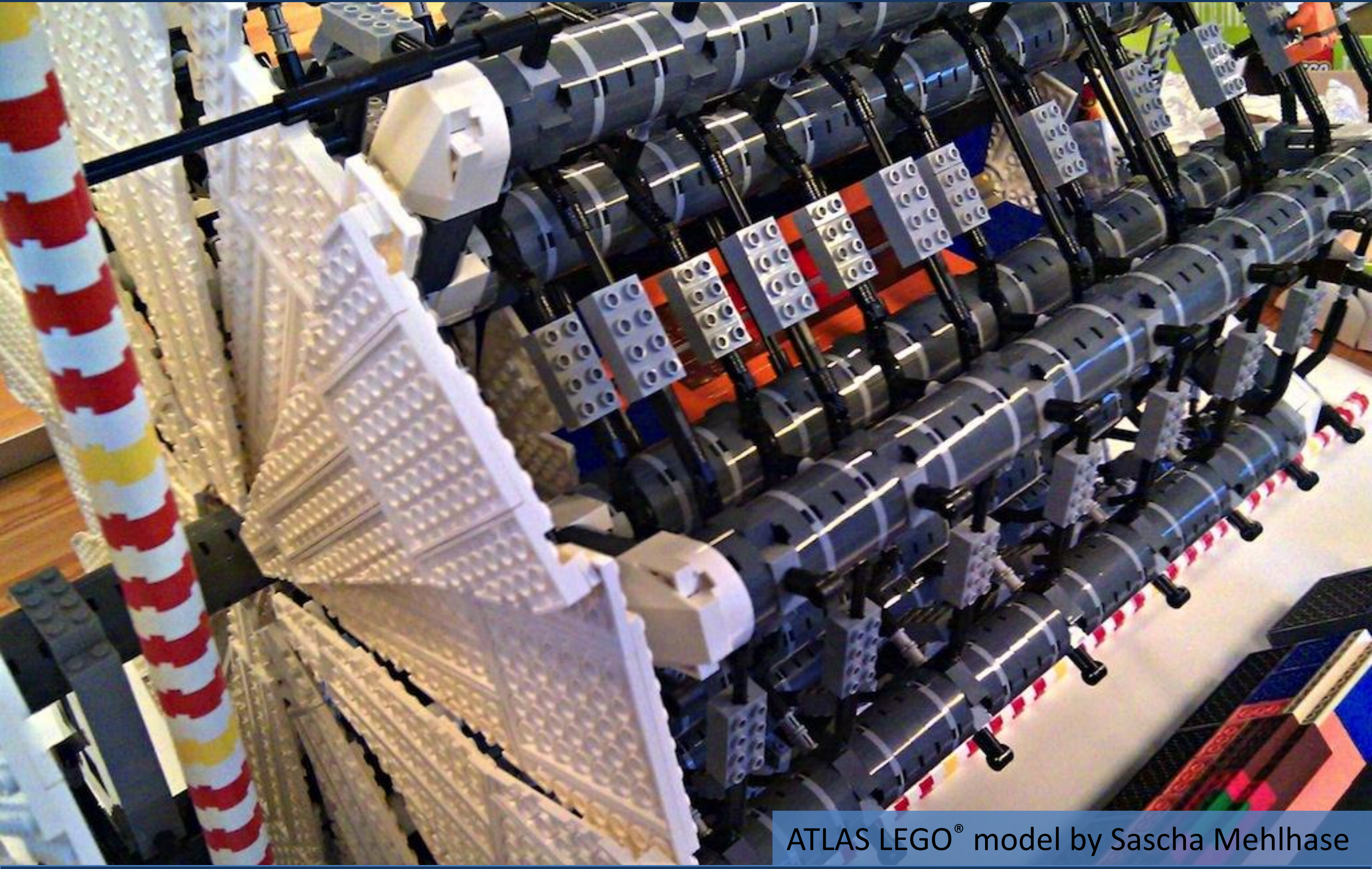
Managed to keep inclusive un-prescaled lepton thresholds within ~ 5 GeV over last two years in spite of the factor ~70 peak luminosity increase

Item	p_T threshold (GeV)	Rate (Hz) at $5x10^{33}$
Incl. e	25	70
Incl. μ	24	45
ee	12	8
μμ	13	5
ττ	29,20	12
γγ	35,25	10
E_T^{miss}	80	17
5j	55	8

Note: >550 items in trigger menu!

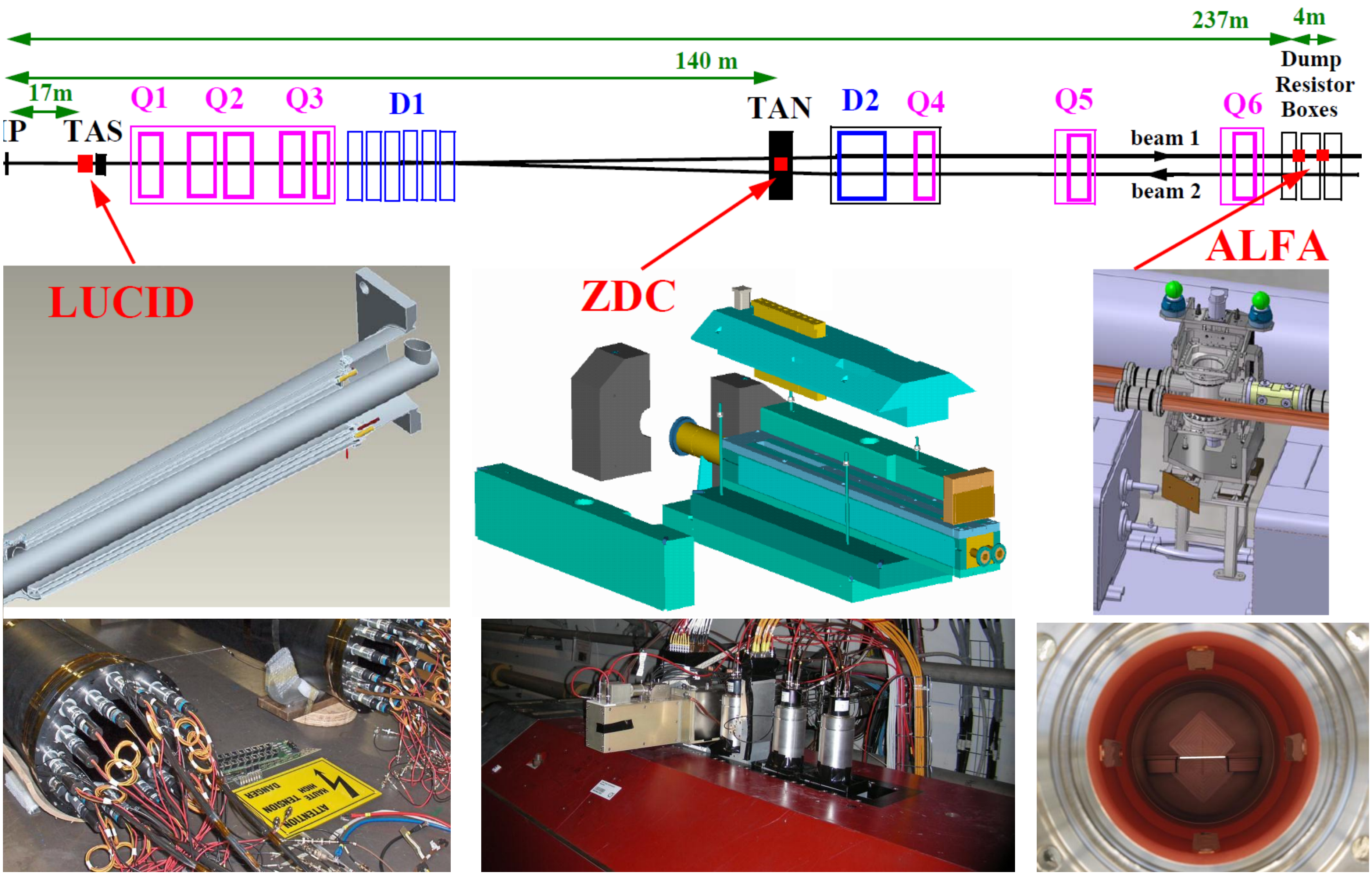
- Optimization of selections (e.g. object isolation) to maintain low un-prescaled thresholds (e.g. for inclusive leptons) in spite of x2 higher luminosity and pile-up than in 2011
- Pile-up robust algorithms developed (~flat performance vs pile-up, minimize CPU usage, ...)
- Results from 2012 operation show trigger is coping very well (in terms of rates, efficiencies, robustness, ..) with harsh conditions while meeting physics requirements

Sub-detectors



ATLAS LEGO® model by Sascha Mehlhase

Forward detectors

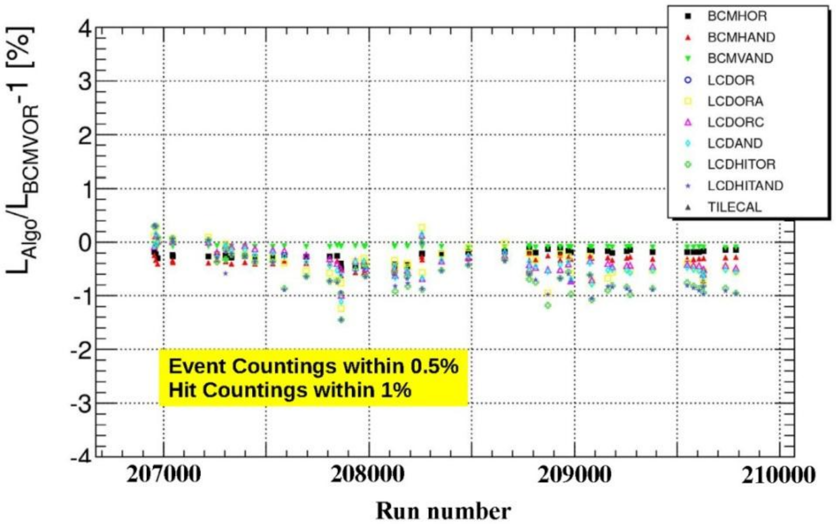


Forward detectors status

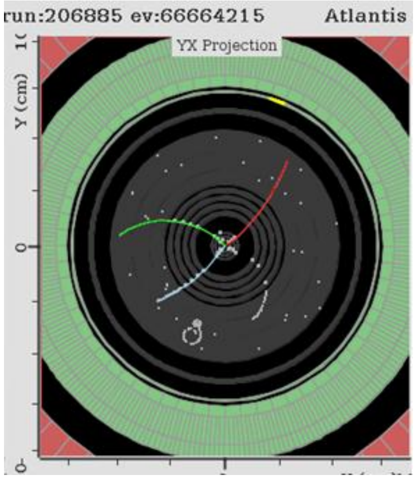
- **LUCID**
  - delivered luminosity measurement since beginning of the 2012 pp run
  - at higher μ-values serious problems for event counting due to saturation & migration
  - integrate the pulse charge per LB could replace traditional event counting method
  - will be taken out for repairs in LS1

- **ZDC**
  - suffered heavily from radiation, taken out after 2011 run for consolidation work
  - plan to be ready for HI run, but tight commissioning schedule

- **ALFA**
  - data taking at β* = 90m and β* = 1km for elastic and diffractive processes

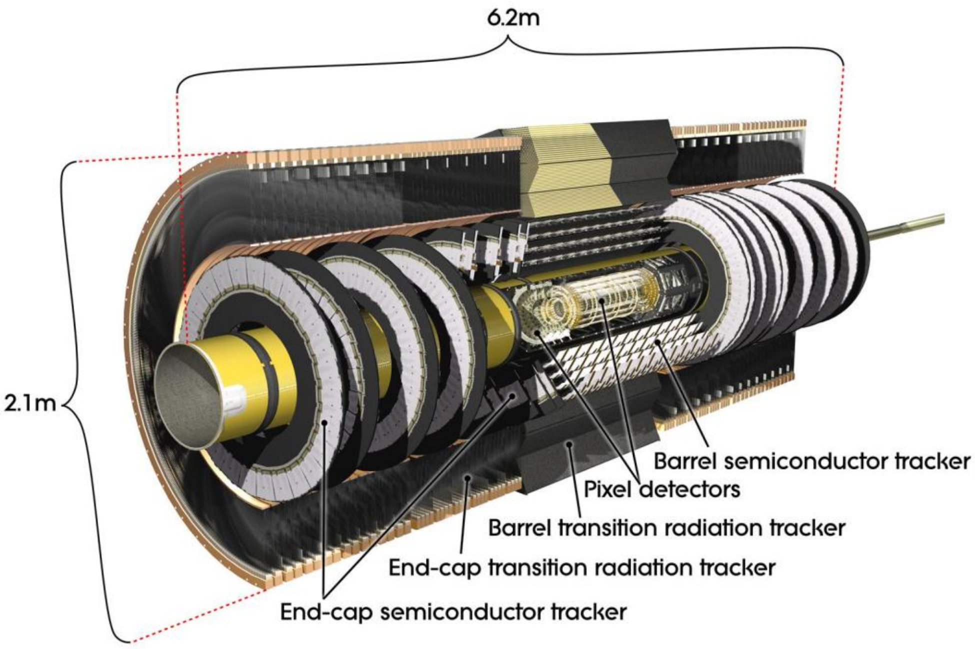


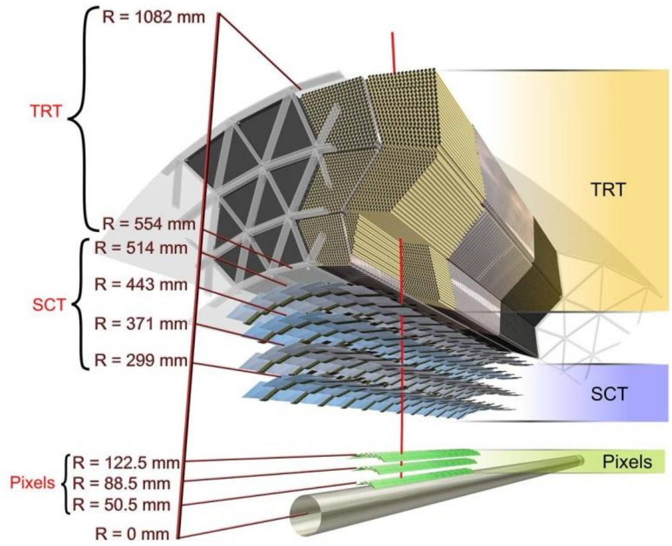
Comparisons of the integrated LUCID luminosity to BCM in runs with 1300 bunches shows an excellent stability



A typical single diffractive event at β* = 90m triggered by ALFA combined with ATLAS

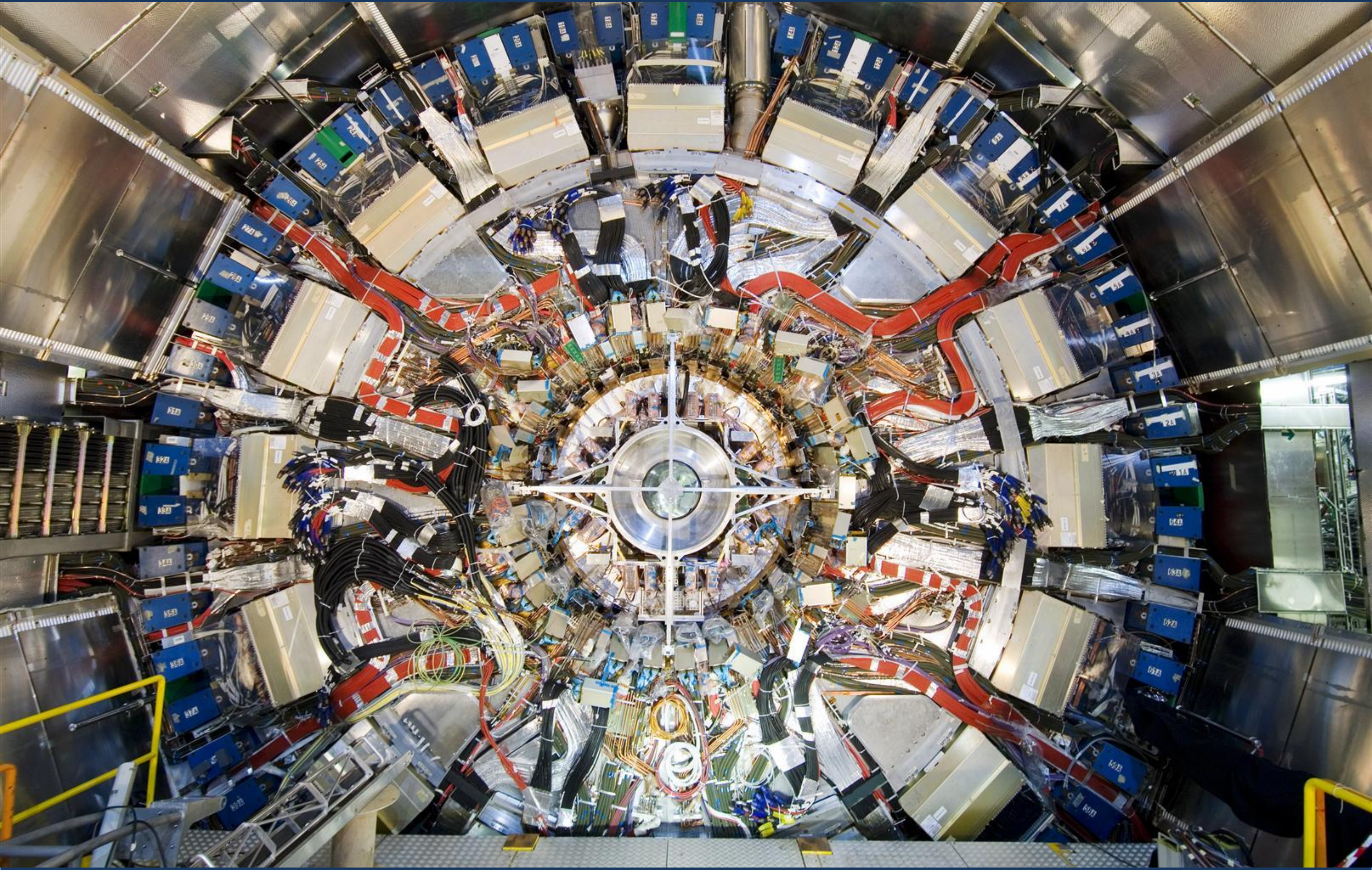
Inner detector



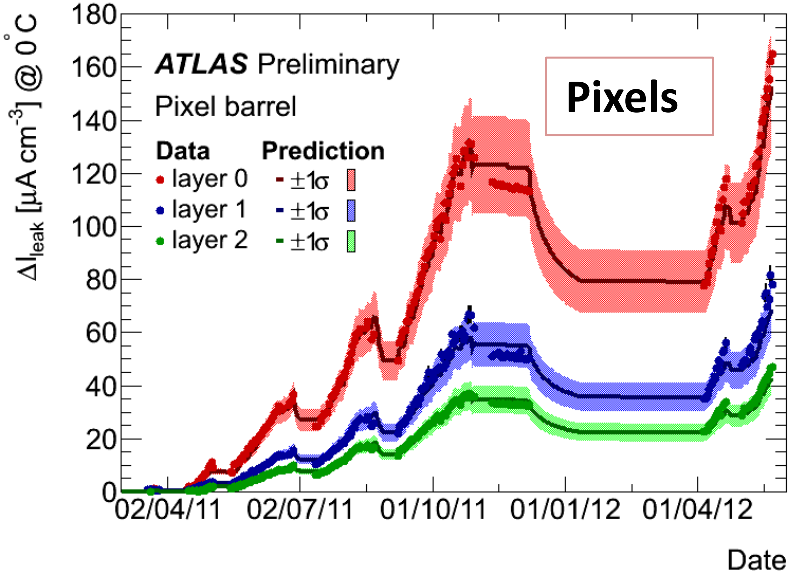


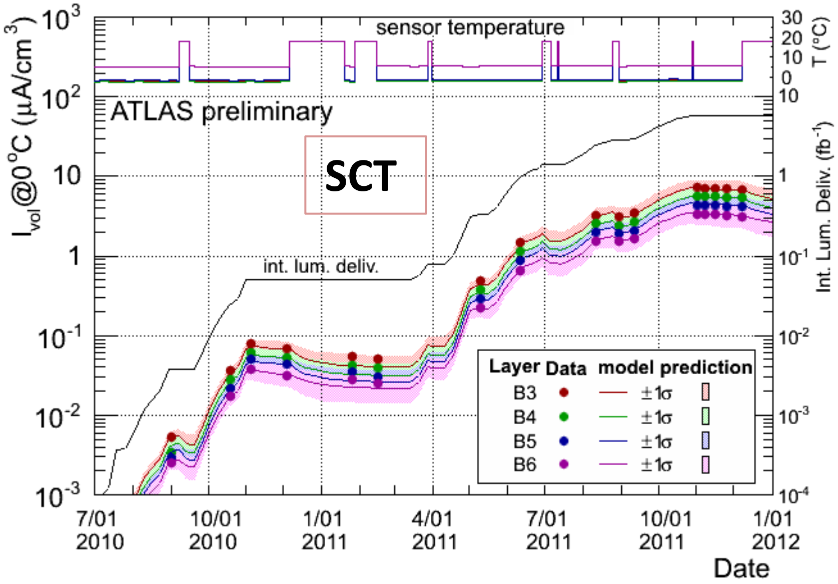
- Precise tracking and vertexing, e/π separation; coverage: $|\eta|<2.5$
- Powerful field (solenoid) = 2T
- Average number of hits in barrel ~ 3/8/30 pixel/SCT/TRT; $0.5X_0$ at $\eta=0$; 1.1 X0 at $\eta=1.8$
- $\sigma/pT = 0.038\%\ p_T(\mathrm{GeV}) \oplus 1.5\%$ (3.8% p_t= 100GeV ; <2% pt<35GeV)
- Impact parameter resolution (0.25<$|\eta|$<0.5) $\sigma(d_0) = 10\ \mu m \oplus 140\ \mu m / p_T$ [GeV/c]
- Si Pixels: 80M channels ; 3 layers and 3 disks ; $\sigma = 10\ \mu m\ [r\phi]$
- 10^6 Si strips (SCT): 6M channels; 4 layers and 9 disks ; $\sigma = 17\ \mu m\ [r\phi]$
- Transition Radiation Tracker (350k channels ; σ =120 μm/straw)

Inner detector: in the cavern



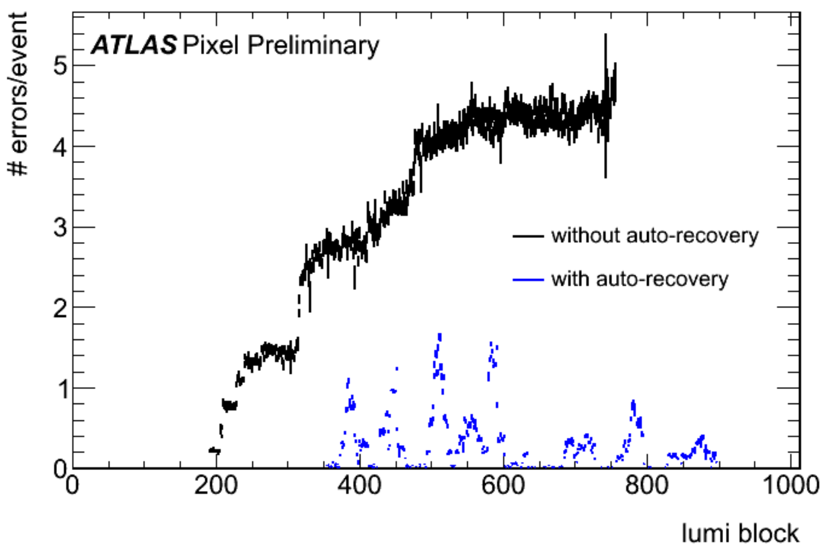
Inner detector status (J. Stahlman)



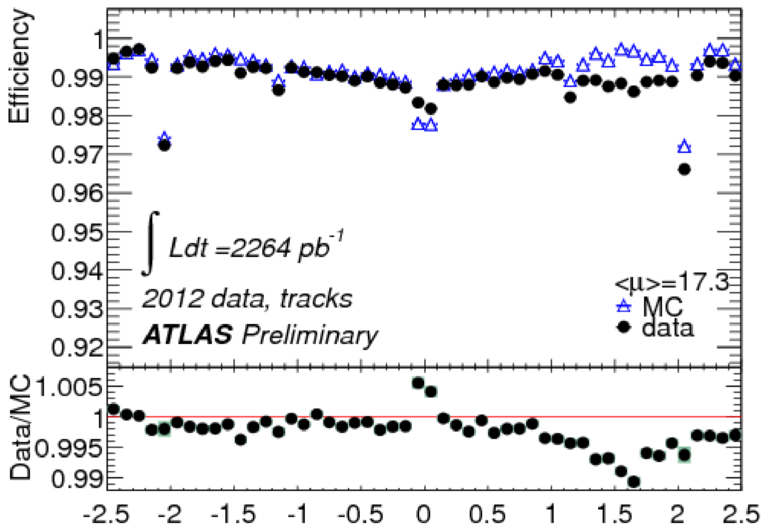


- **>99% efficiency data quality for all ID sub-detectors in 2012**

- Leakage currents are increasing in line with predictions from radiation damage model
- Work ongoing to further improve operations efficiency and understand detector behaviours/radiation effects:
  - Pixel: Reduction of ROD busies
  - SCT: Module re-configuration
  - TRT: Mediation of gas leaks

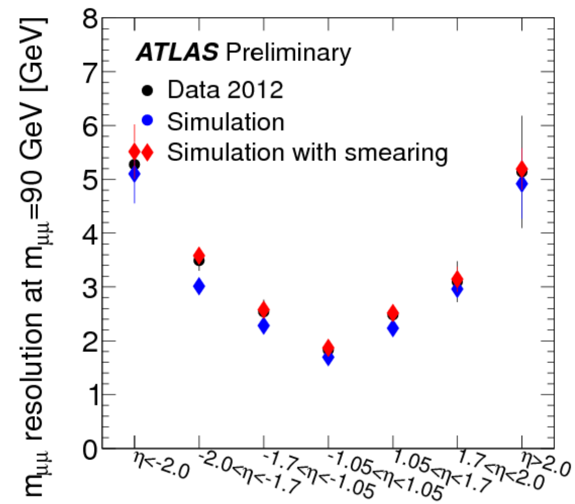


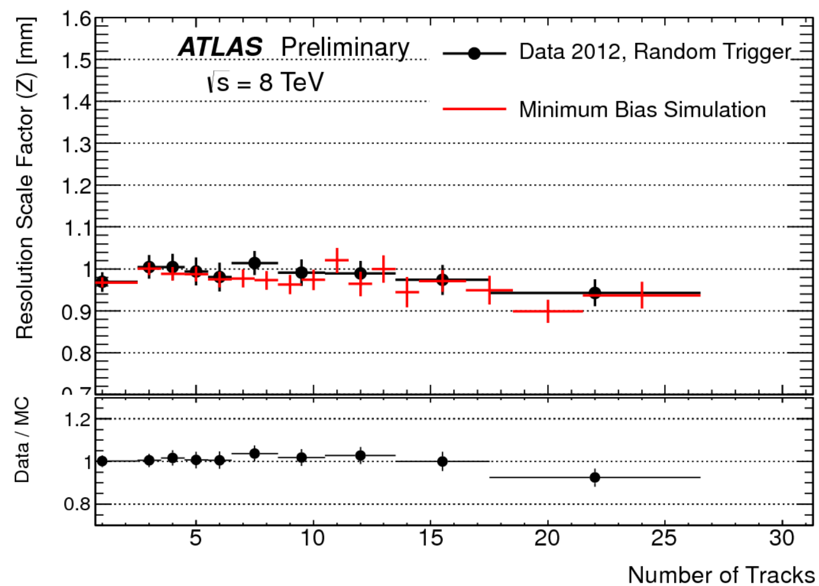
Inner detector performance



Reco. efficiency versus the muon pseudo-rapidity

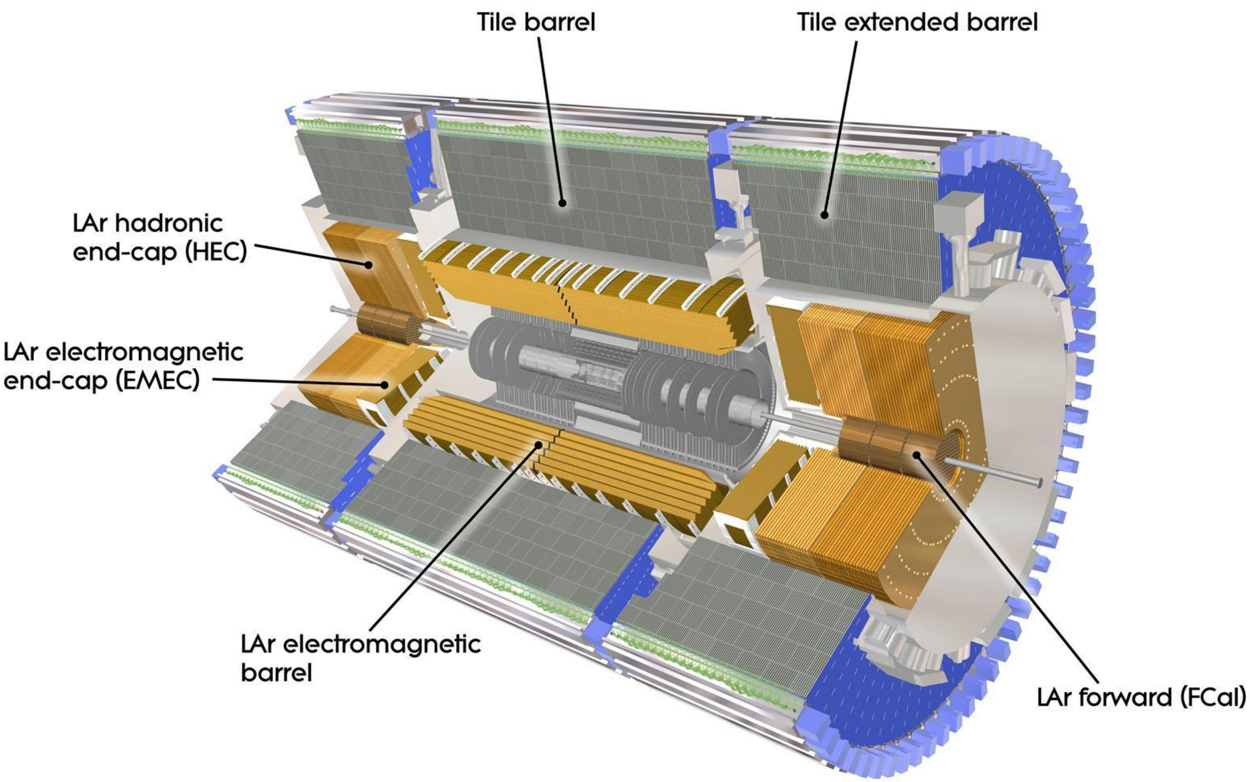
Di-muon mass resolution for muons from Z decays





- Excellent detector performance
- High reconstruction efficiency
- Simulation correctly represents data

Calorimetry



EM (LAr) calorimeter ($|\eta|<3.2$):

- e/γ trigger, identification; measurement
- $\sigma/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
- Granularity: 0.025x0.025 ; $22X_0$
- 3 long. layers + presampler($0 < |\eta| < 1.8$)
- $180\text{x}10^3$ channels

Hadron calorimeter (LAr,Tile):

Trigger;measure jets; E_{tmiss}:

- σ/E~50-60%/$\sqrt{E} \oplus 3\%$ central
- σ/E~90%/$\sqrt{E} \oplus 7\%$ in fwd
- $\sigma(E_{T,miss}) / \Sigma E_T \approx 55\ \%$

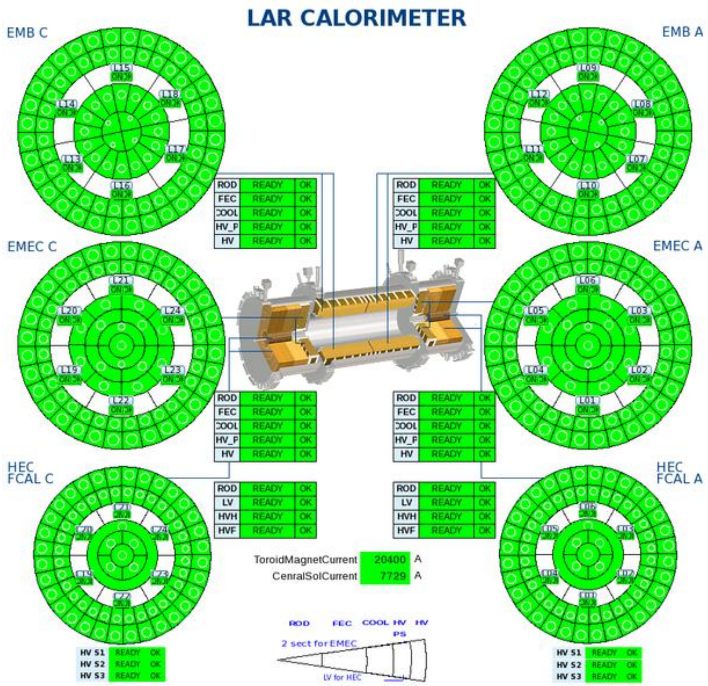
- $|\eta|<1.7$: Fe/scint. Tiles (Tilecal)
- $3.2 < |\eta| < 1.5$: Cu-Lar (HEC)
- $3.1<|\eta|<4.9$: FCAL Cu/W-Lar

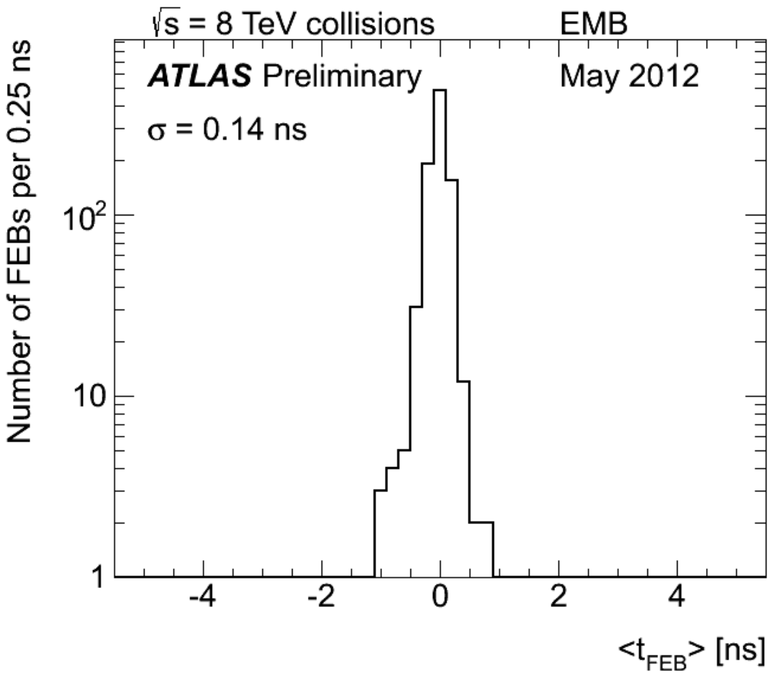
- $|\eta|<4.9$
- 10λ at $|\eta|=0$
- $\Delta\eta\times\Delta\phi$: 0.1x0.1 up to $|\eta|<2.5$
- 3-4 Longitudinal layers
- $20\text{x}10^3$ channels

Calorimetry: in the cavern

Moving the calorimeter on side A
of the ATLAS cavern

Calorimetery: LAr

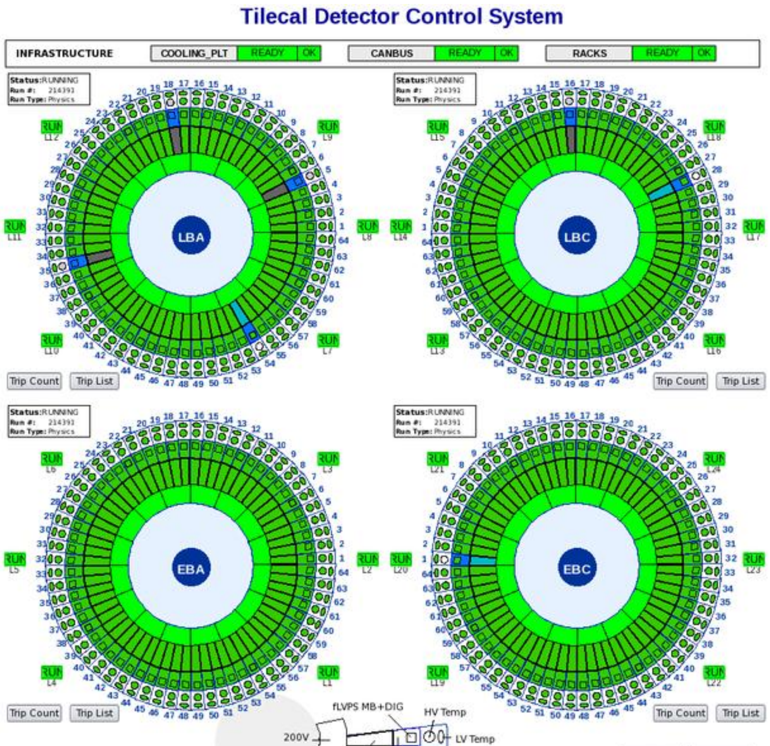


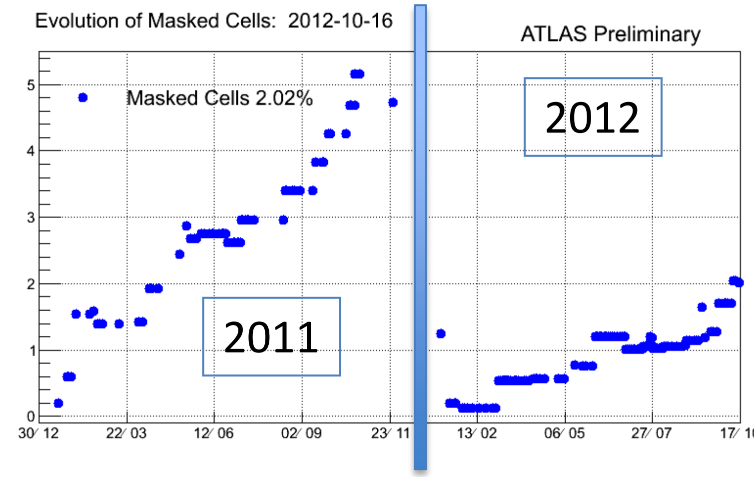


- LAr detector is very stable, no major problems in data taking
- Data quality efficiency in all-time high, improving constantly
- Most of LAr related inefficiency and small problems will be corrected off-line, during reprocessing
- LAr is mostly ready to tackle the data taking conditions after the LS1 (5->4 samples readout change)

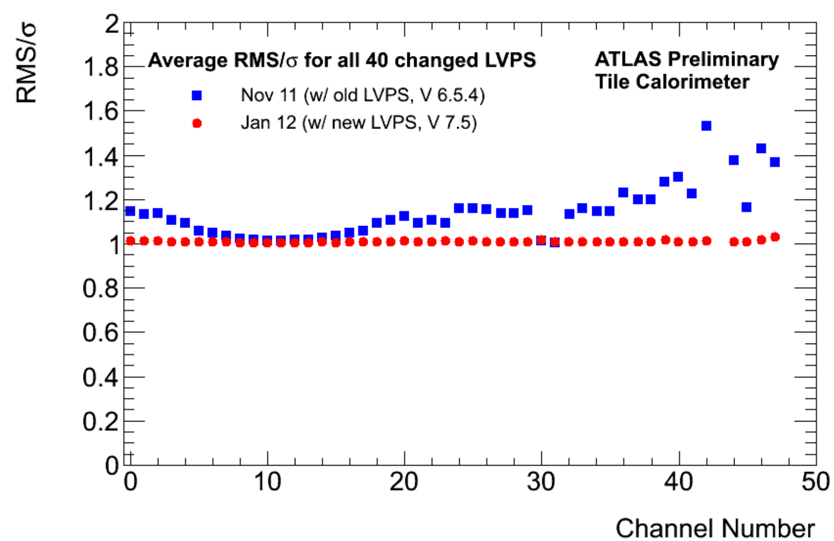
- Average time per Front End Board in EM Barrel (EMB) with 8 TeV data
- With the increased statistic available in each run of 2012, the 896 EMB Front End Boards (FEB) have been aligned.

Calorimetery: Tile

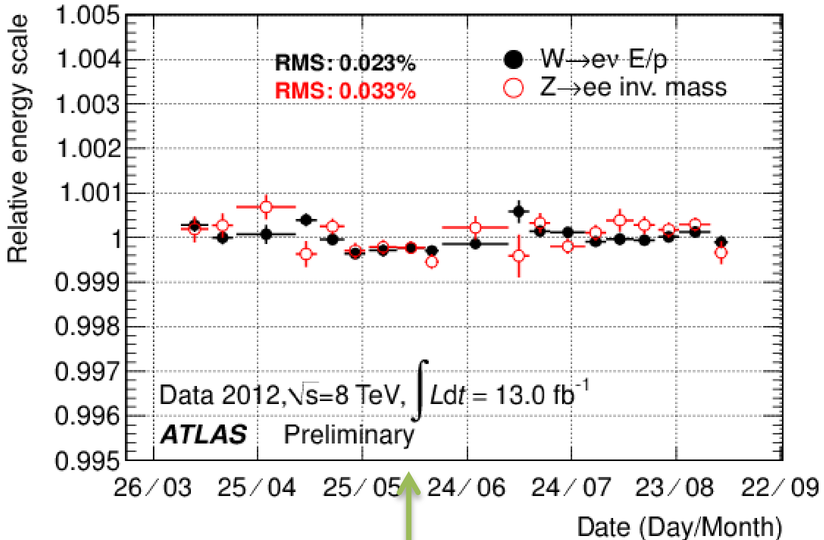


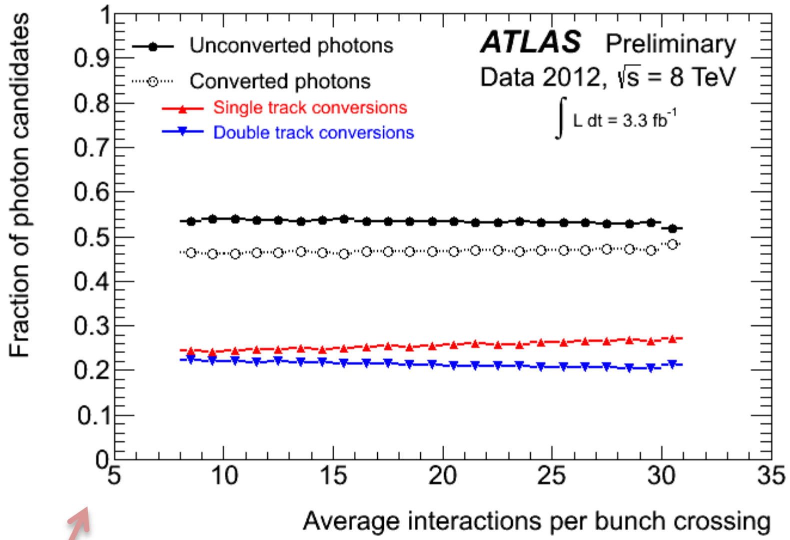


- Tile is performing well, number of masked cells is ~2%, mainly due to 4 dead LV power supplies
- Tile DAQ had improved automatic online recovery procedures after the trips of power supplies
- The 40+ new LV power supplies are stable (only one trip) and have lower noise



Calorimetry: e/γ performance

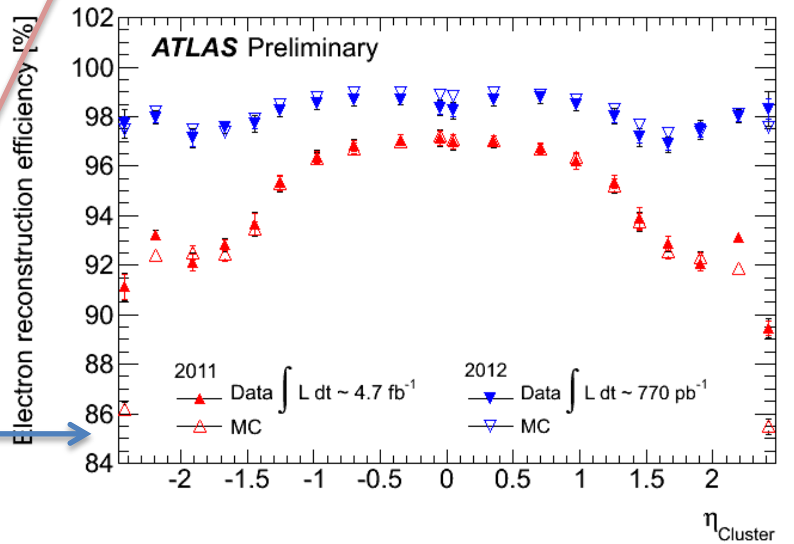




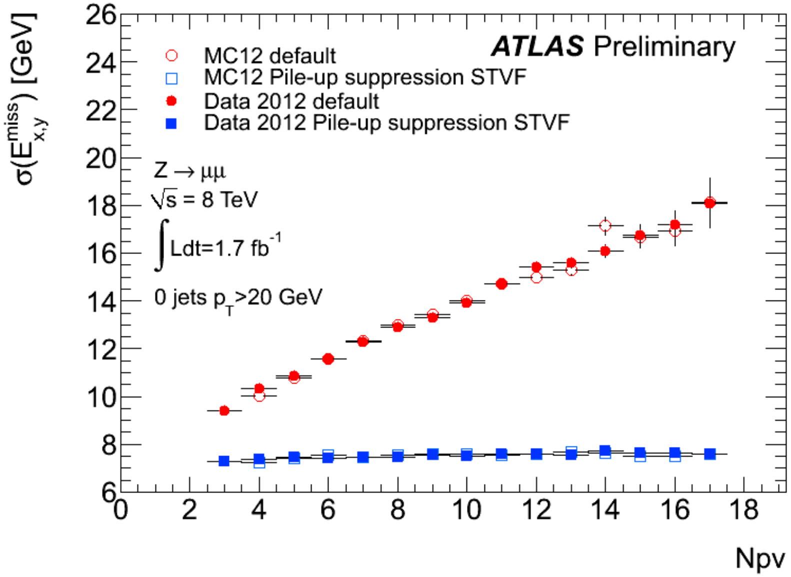
Electron energy response shows excellent stability with respect to increasing pile-up in 2012 data

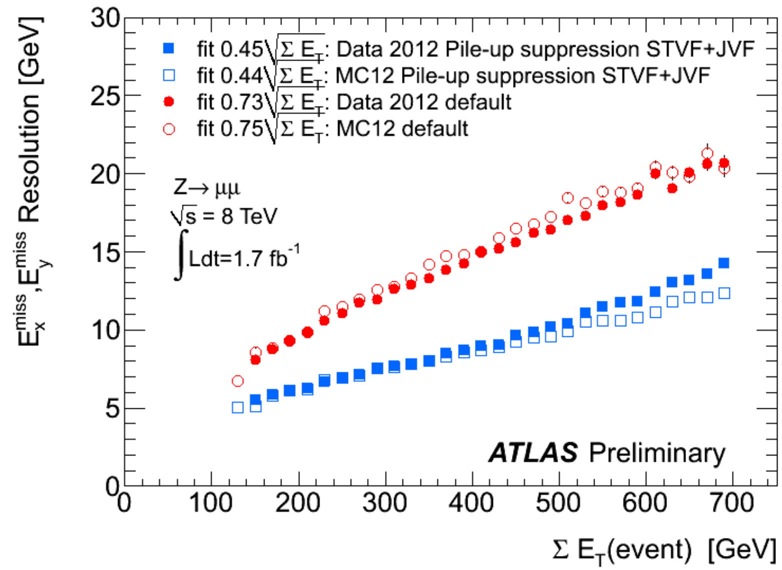
Stability of photon conversion reconstruction is also good

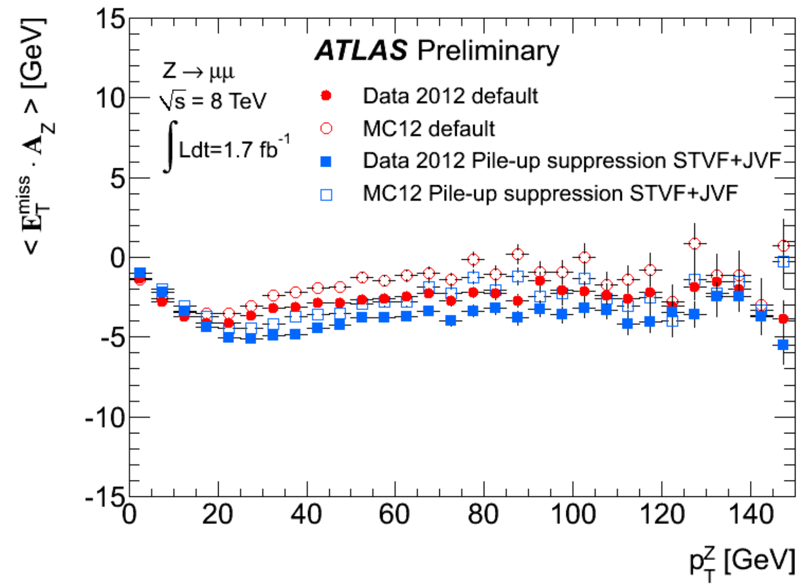
For the 2012 data taking, the electron reconstruction algorithm has been improved with respect to 2011 for both data and MC: ~1% in the barrel region of the calorimeter and ~5% in the endcaps



Calorimetry: Jet/Etmiss performance







- Missing ET reconstruction performs quite well under harsh pile-up conditions of 2012 data
- Stable resolution performance with respect to increasing pile-up
- Improvements in pile-up corrections
- Good description of data by simulation
- Expect higher pile-up after LS1!

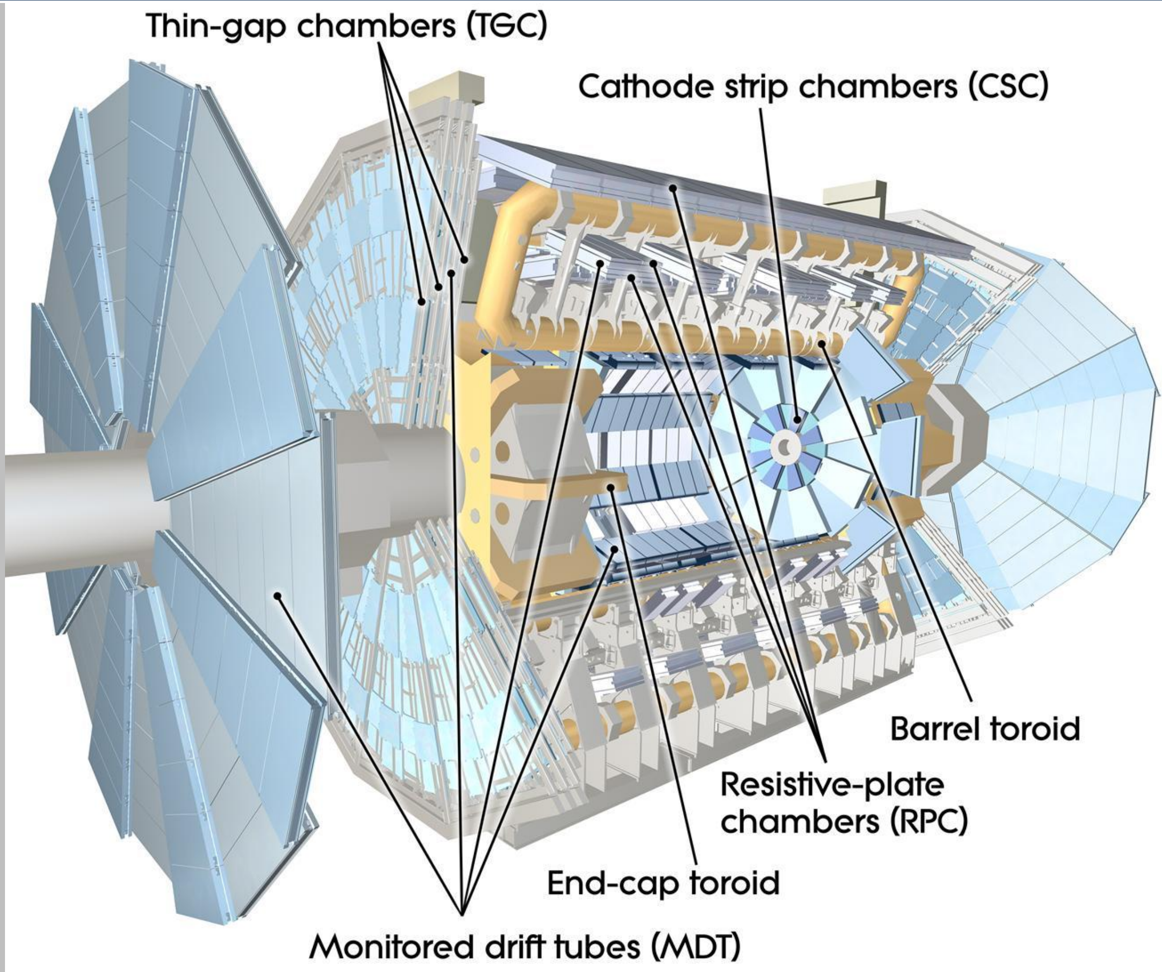
Muon spectrometer

4 chamber types gas based
($|\eta|<2.7$)
1.1×10^{6} channels ; 12000 m^3

Precision chambers : MDT ; CSC
Trigger chambers (LVL1): RPC ; TGC

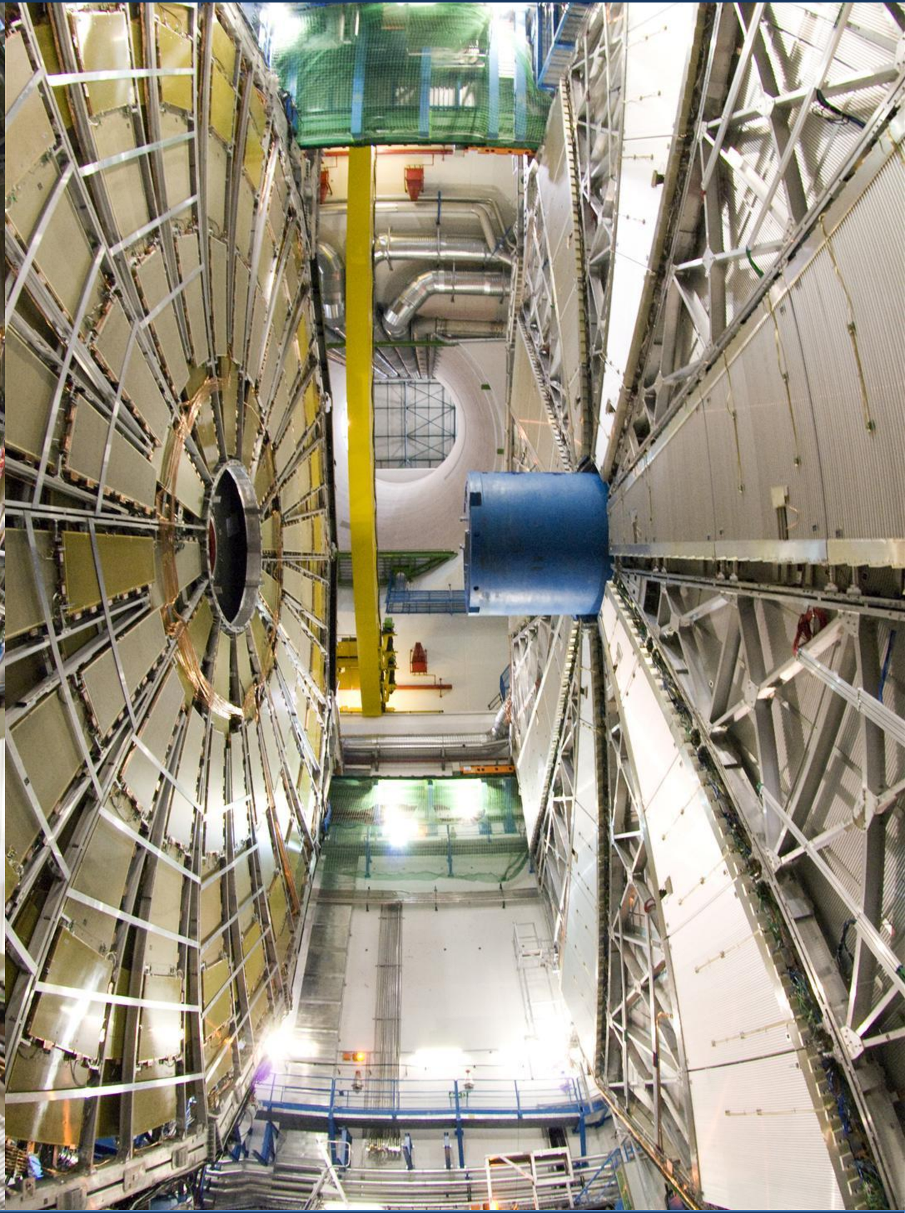
Muon trigger and measurement
Alignment accuracy: ~ 30-40 μm
MDT resolution = 80μm ($|\eta|<2$)
CSC resolution =60μm ($2<|\eta|<2.7$)

Momentum resolution (ID+MS)
$|\eta|<1.1$:
$\sigma p_T/p_T$ ~10% (p_T ~ 1 TeV)
$\sigma p_T/p_T$ ~2% (p_T =50 GeV)

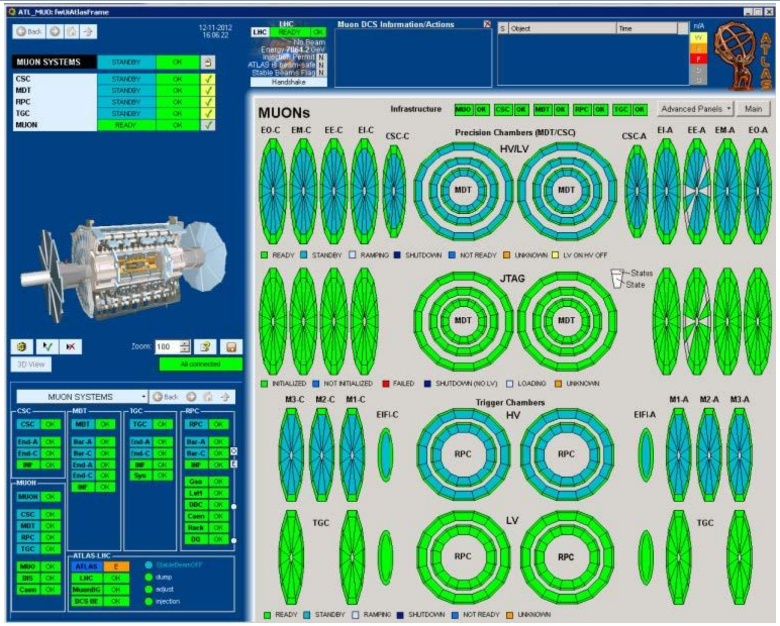


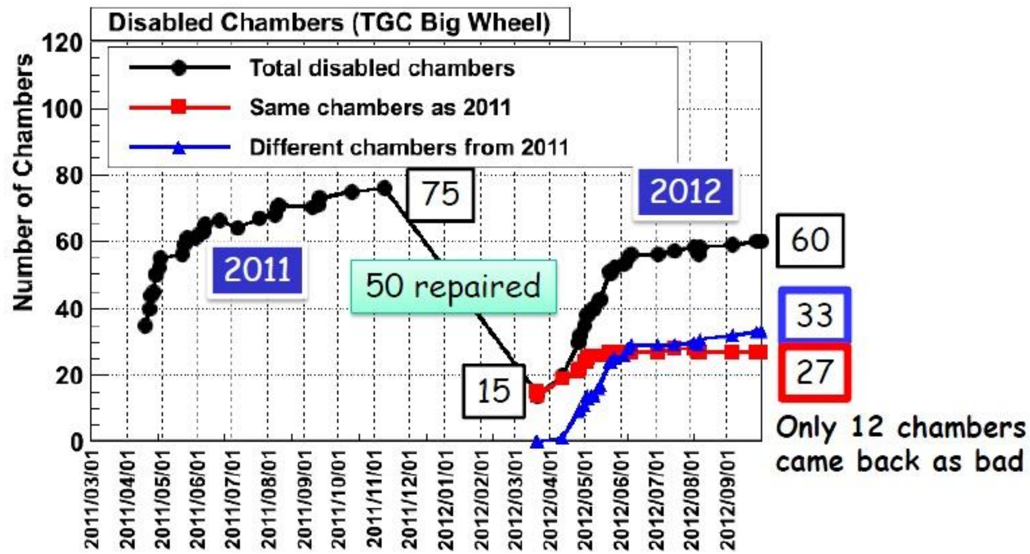
4 Superconducting magnets:
- Solenoid around ID (B=2T;7.6 kA)
- 3 Air core Toroids (with 8 coils each): 22kA, B_{toroid} ~0.5-1T

Muon spectrometer: in the cavern

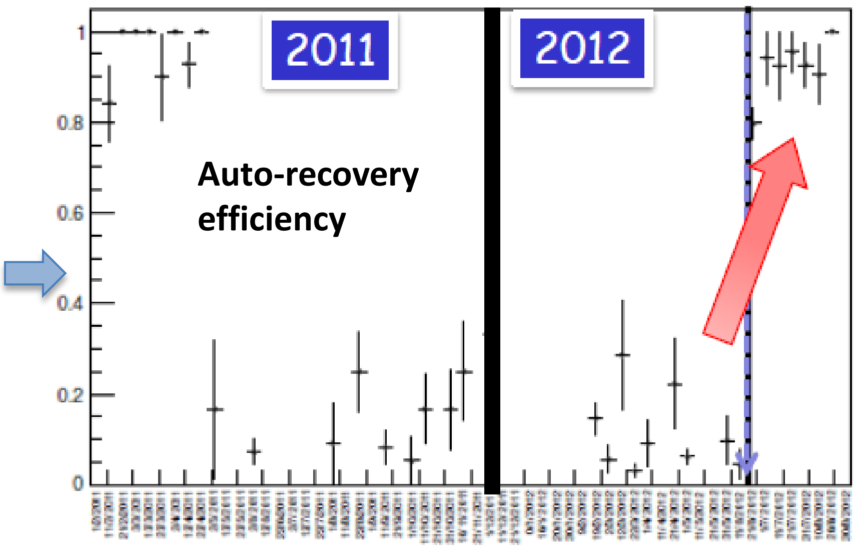


Muon spectrometer status

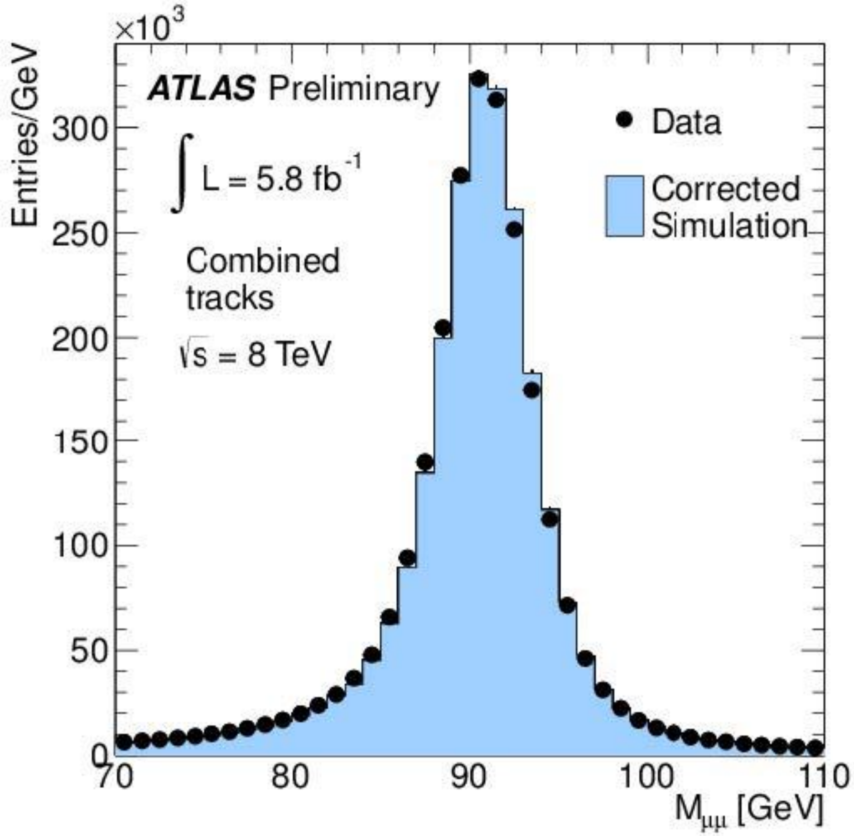




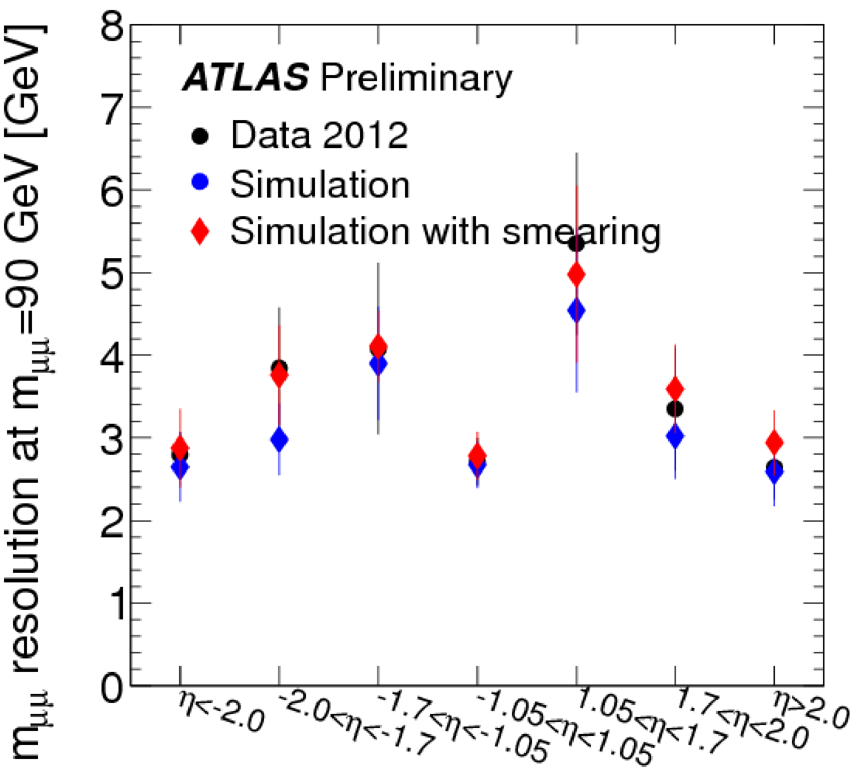
- Muon spectrometer is in good shape
- Generally smooth running with occasional hiccups
- TGC ROD busy improved auto-recovery minimizes downtime while the causes are being investigated
- Alignment with toroid-off collision data
- Very good results thanks to a lot of efforts



Muon spectrometer performance



Good agreement between data/MC for di-muon resolution

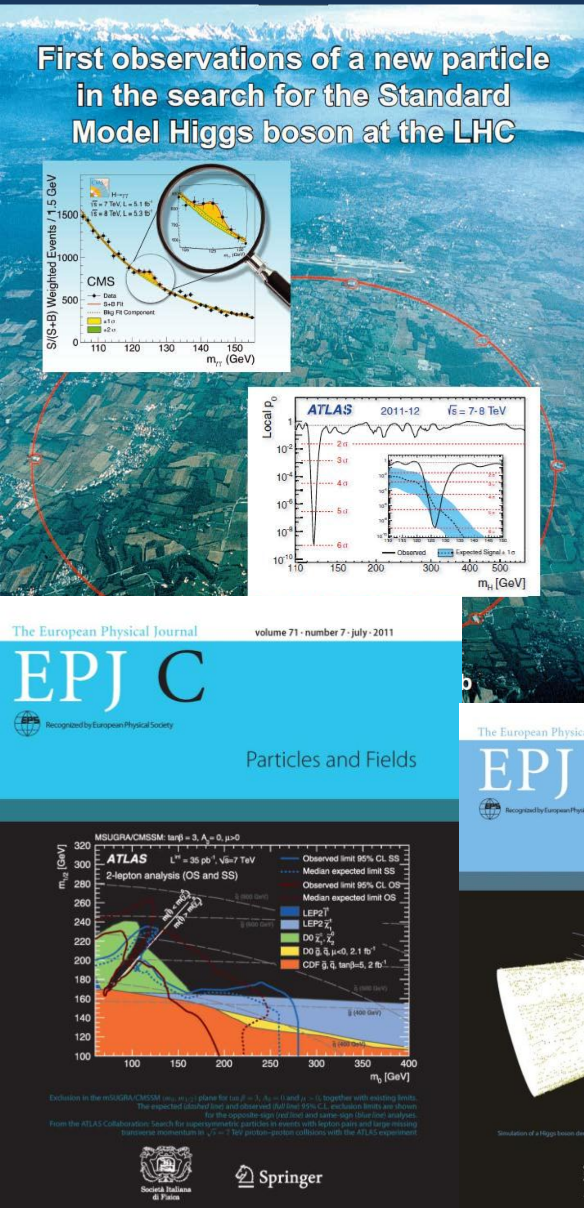


Di-muon mass resolution for muons from Z boson decays using the momentum measurements in the muon spectrometer corrected for the energy loss in the calorimeters

Physics results

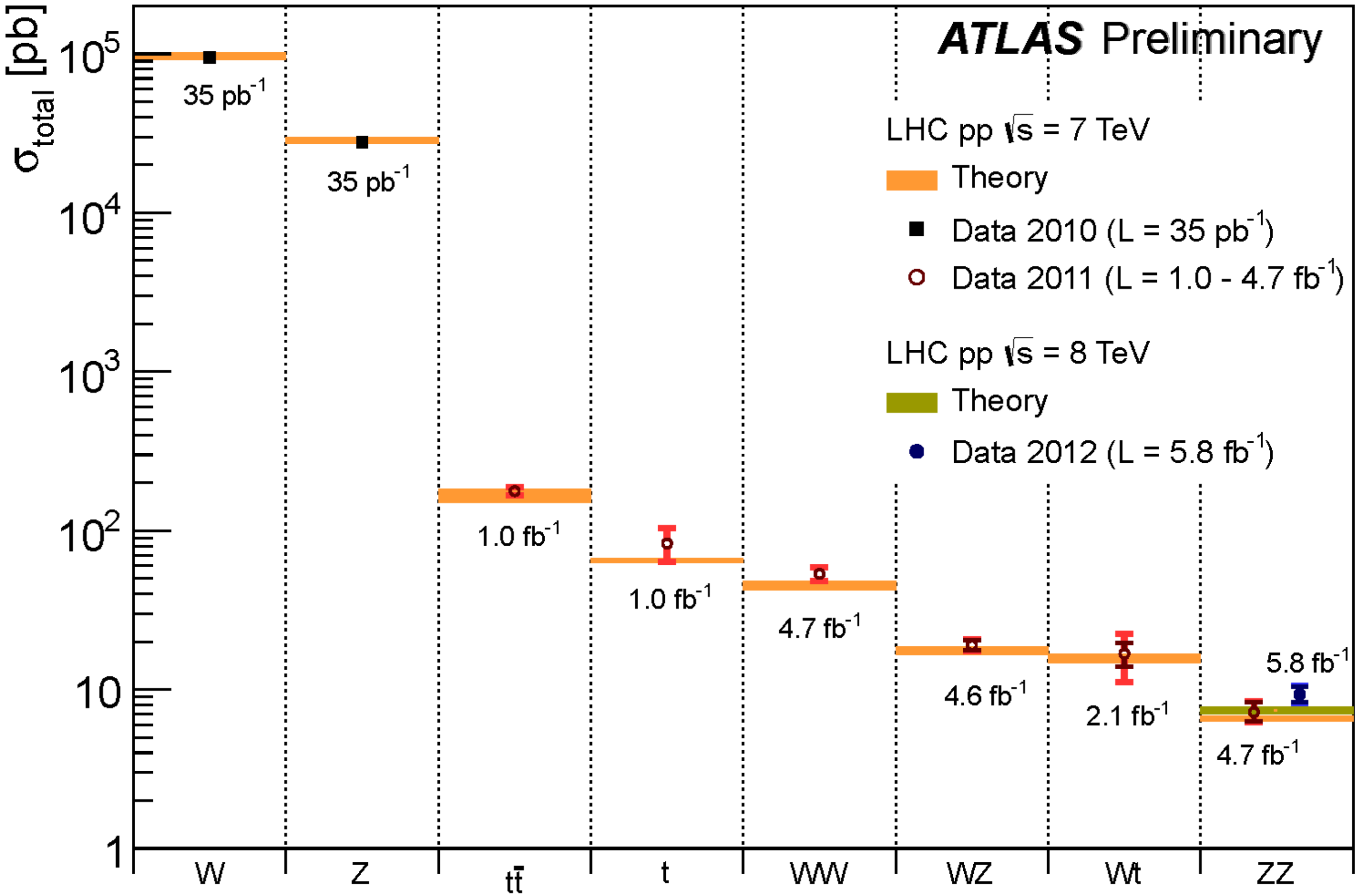
Physics publications

ATLAS submitted/published
200+ physics papers, 400+ conference notes All ATLAS results available at
https://twiki.cern.ch/twiki/bin/view/AtlasPublic

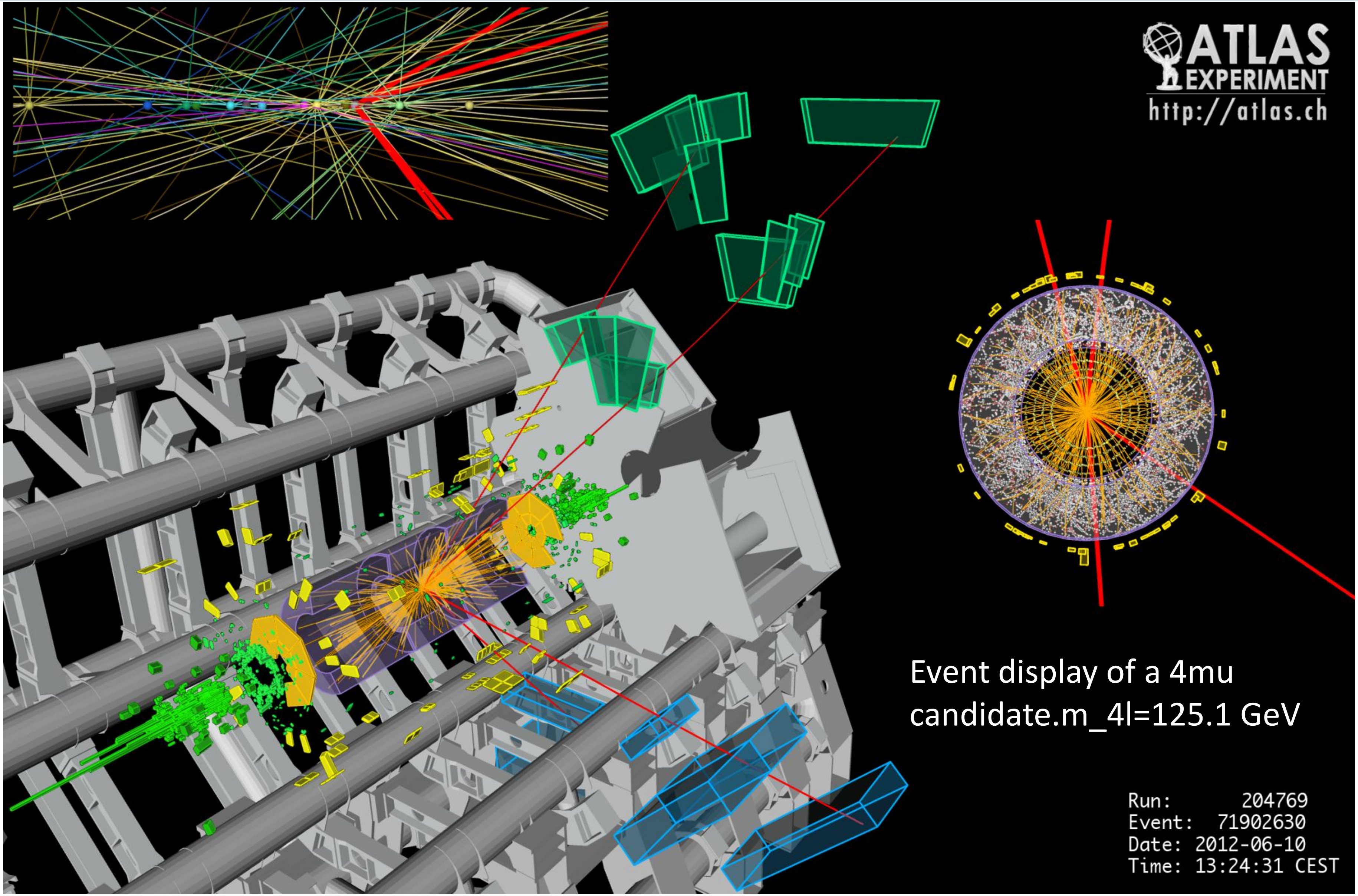


Physics results: Standard Model

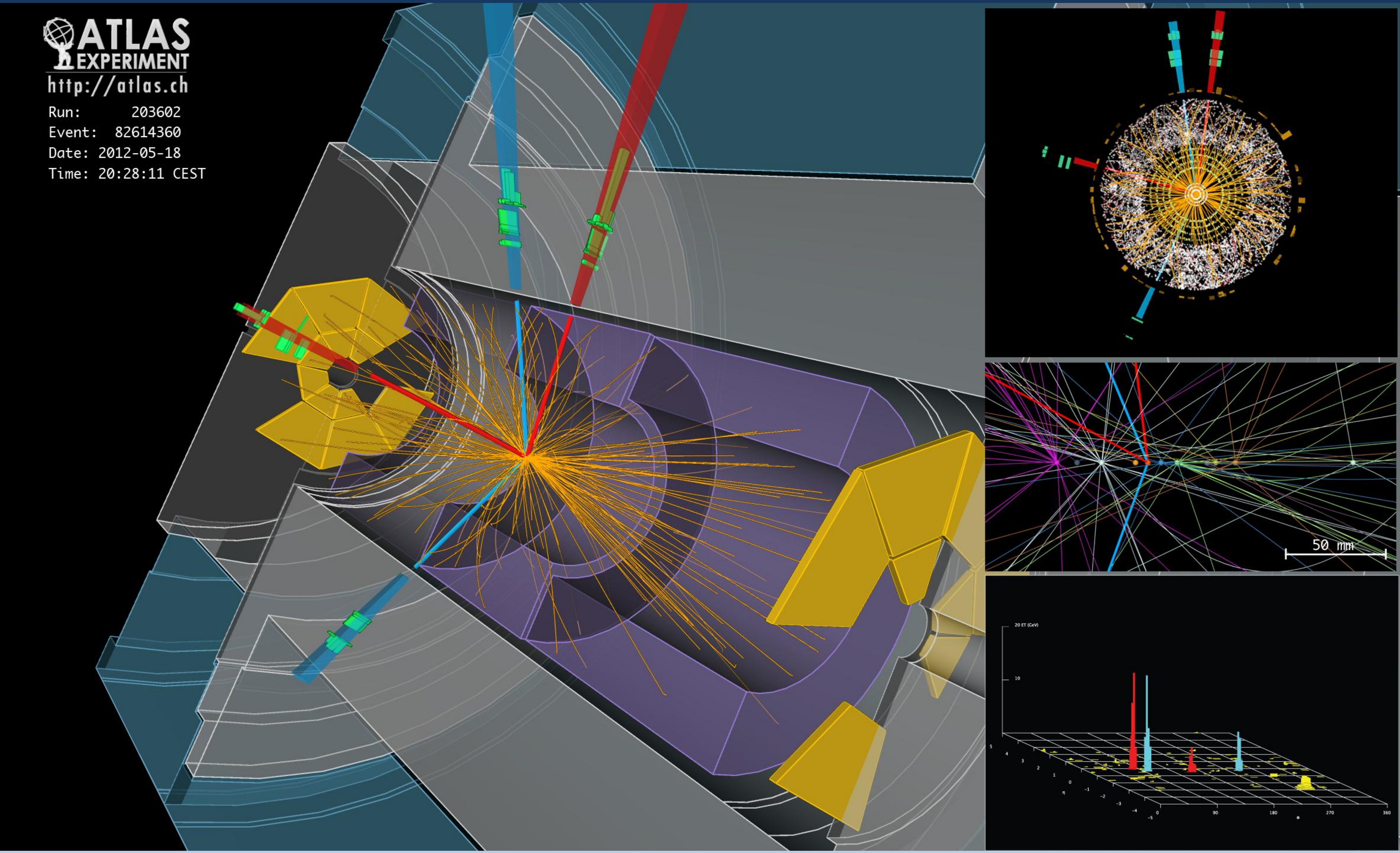
Cross-section measurements from inclusive W, Z to ZZ production. Foundation of SM.
- tests of the SM & probing new physics
- backgrounds for searches and precision measurements



Event display: H->ZZ->4μ

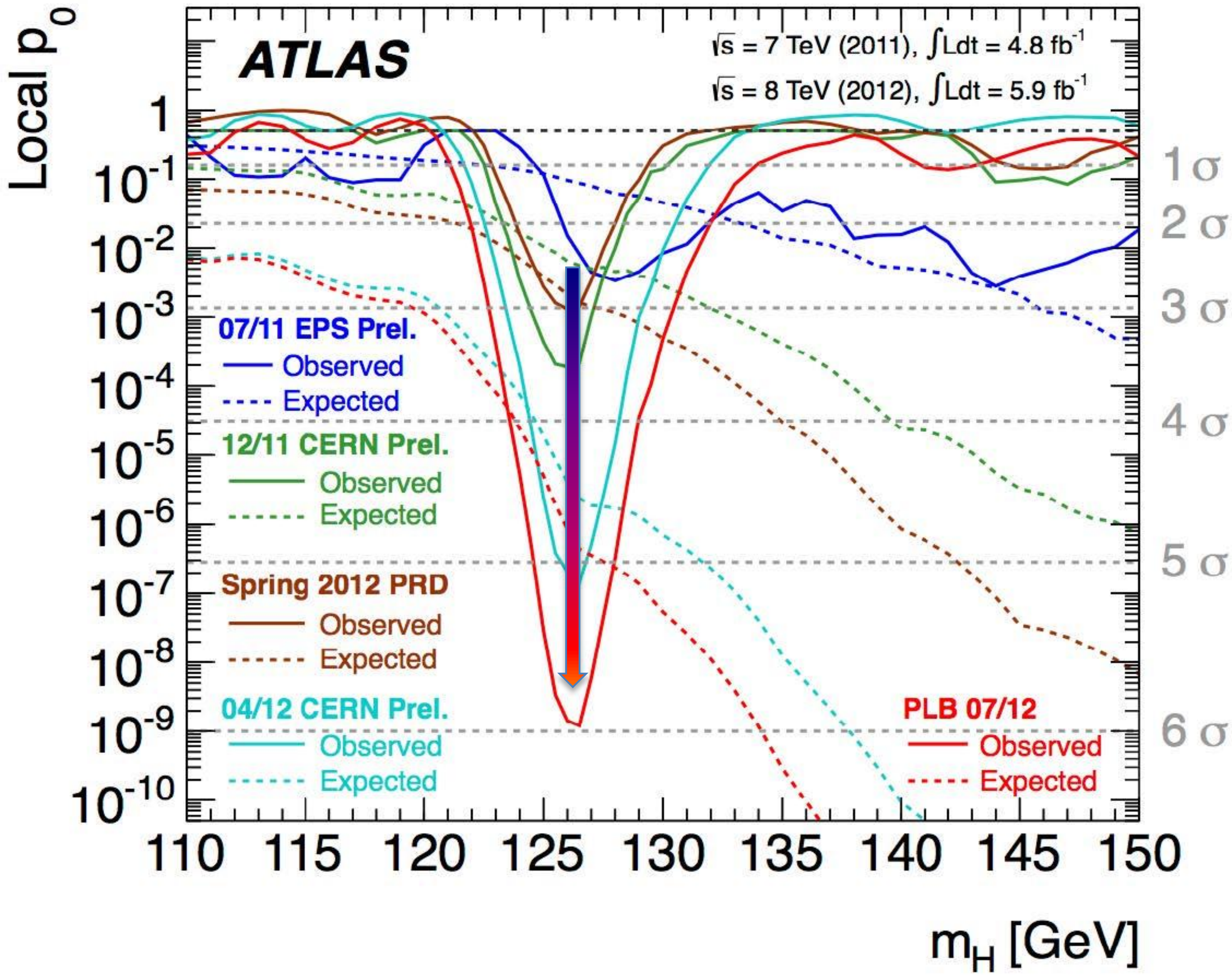


Event display: H->ZZ->4e



Event display of a 4e candidate. m_4l=124.6 GeV

Physics results: Higgs evolution



Significance increase from 4th July to the PLB from including H-> WW* search for 2012 data (from 5.2 to 5.9 σ)

Physics results: SUSY searches

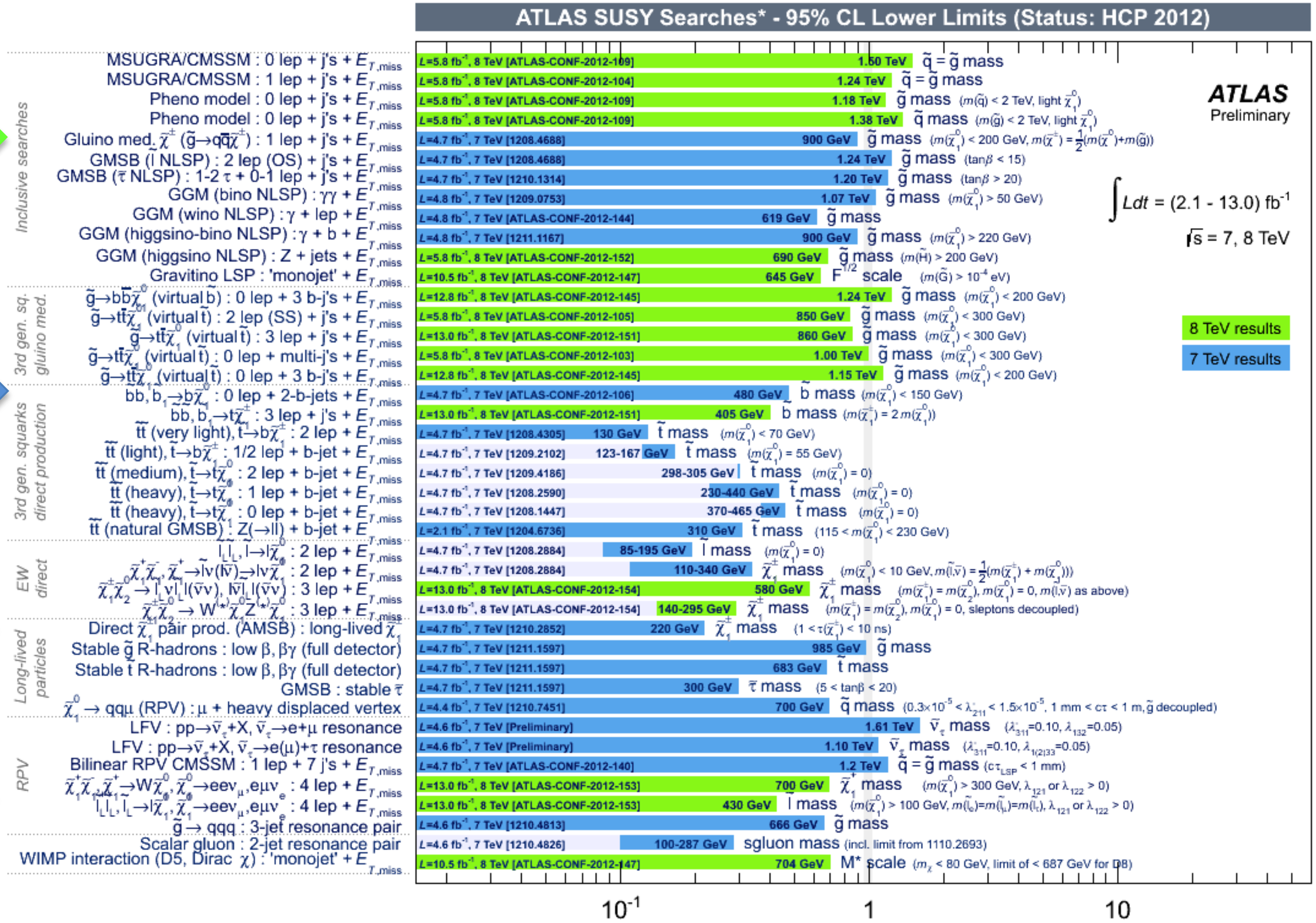
ATLAS seriously attack the weak scale SUSY between 100 GeV and 1 TeV

Inclusive searches

Natural SUSY

Long lived particles

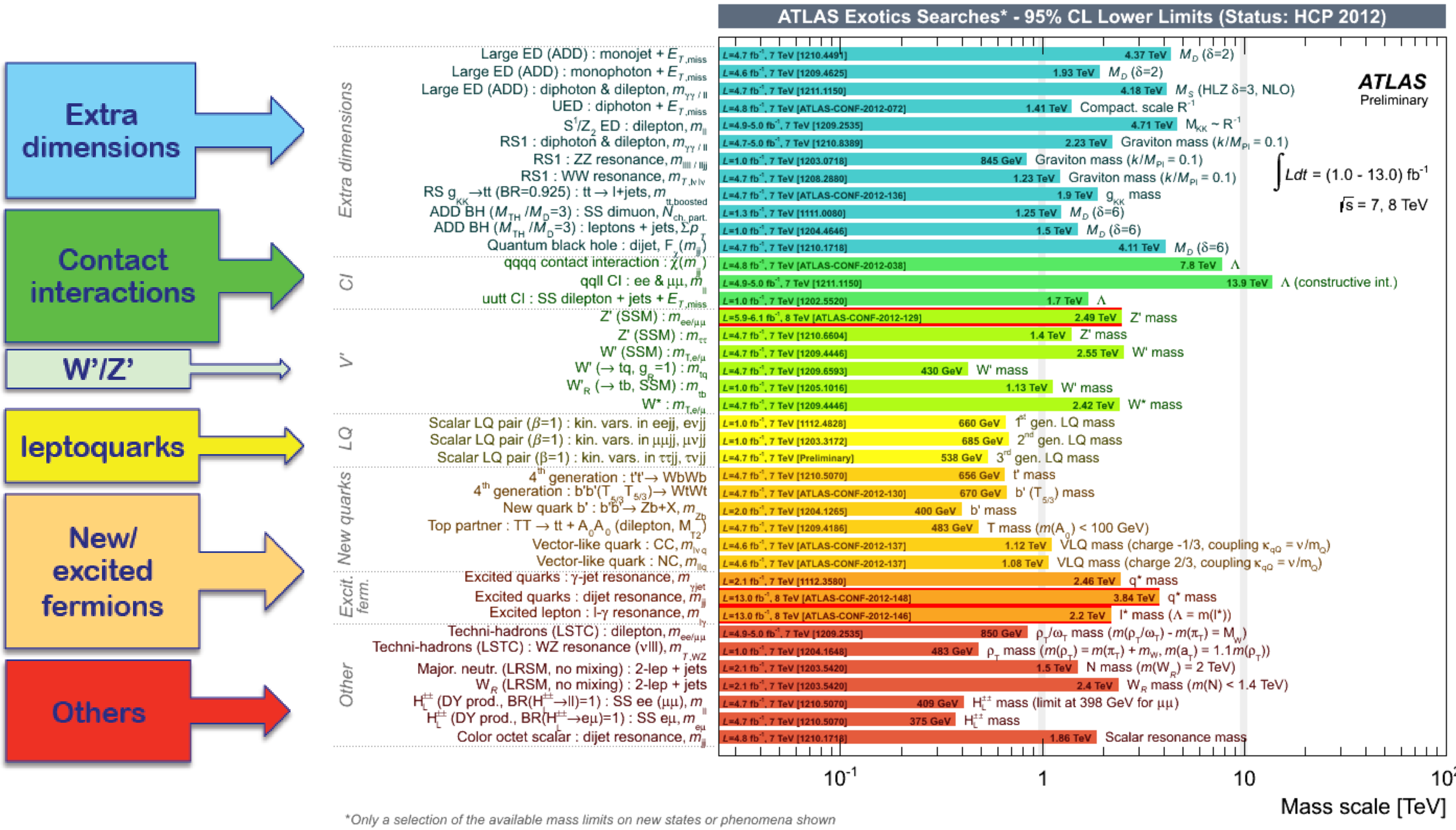
RPV



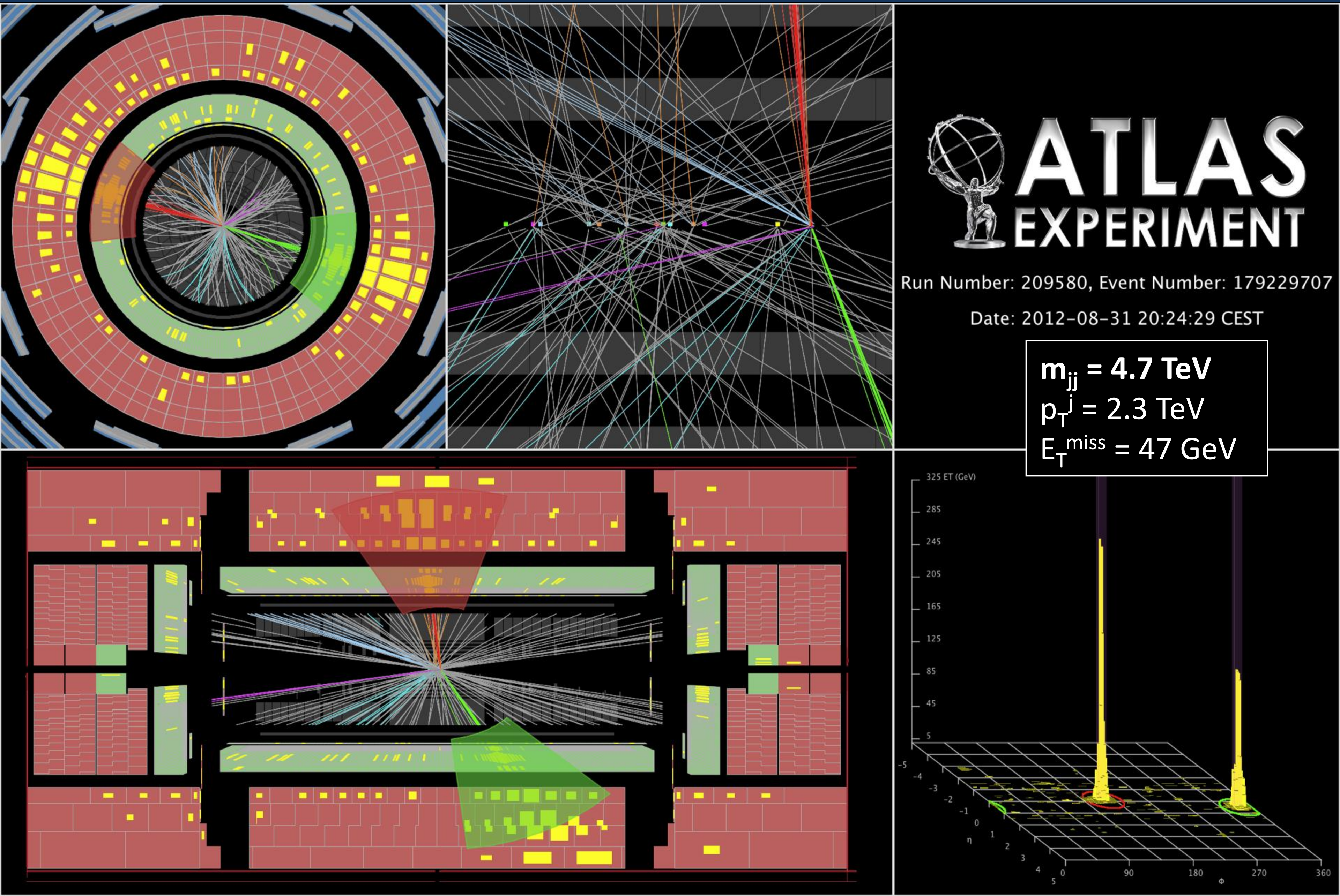
*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Physics results: exotics searches

No signs of the new physics so far … but lots of the 8 TeV analyses in the pipeline



Event display: hi-mass di-jet

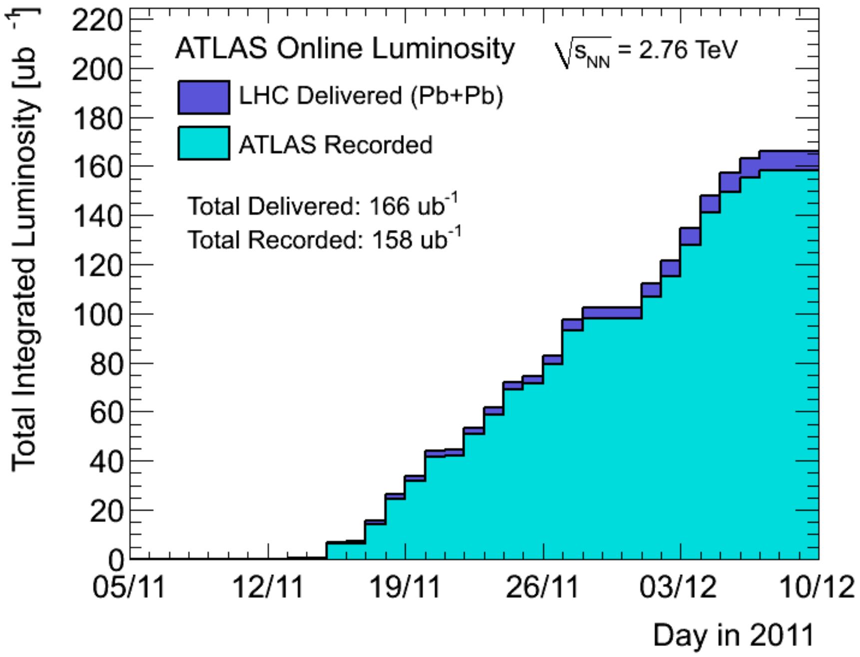


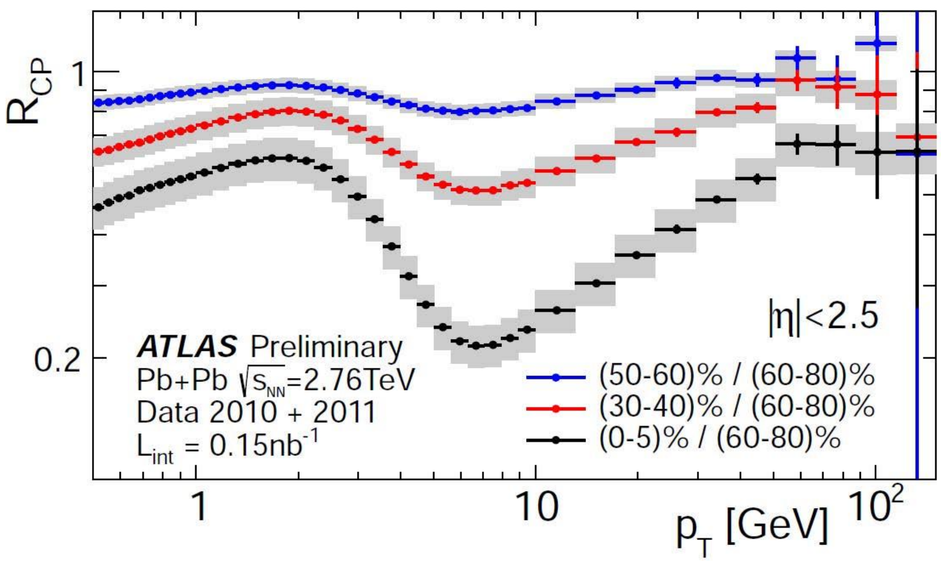
Physics results: heavy ions

2011: 160 µb-1

- >97% detector efficiency
- triggers: MB, e, µ, γ, jets, UPC
- ~1 billion events

2012: No new Pb+Pb, but 2 million p+Pb events from pilot run!
p+Pb run in early 2013; next Pb+Pb data in 2015





Charged particle suppression: compatible with previous measurements and with jet results
2011 data provides important new statistics at high pT

LHC upgrade timeline

Year	Shutdown	Event / parameters	Integrated luminosity
2009		LHC start up, $\sqrt{s}$ = 900 GeV	
2010–2012		$\sqrt{s}$ = 7-8 TeV , L = 6 to $8 \cdot 10^{33} cm^{-2} s^{-1}$, bunch spacing **50 ns**	~25 fb^{-1}
2013	LS1	Go to design energy, nominal luminosity	
2014–2017		$\sqrt{s}$ = 13-14 TeV, L = $1 \cdot 10^{34} cm^{-2} s^{-1}$, bunch spacing **25 ns** **(likely to be more)**	~50 fb^{-1}
2018	LS2	Injector & LHC Phase I upgrade to full design luminosity	
2019–2021		$\sqrt{s}$ = 14 TeV, L = $2 \cdot 10^{34} cm^{-2} s^{-1}$, bunch spacing **25 ns** **(likely to be more)**	~300 fb^{-1}
2022	LS3	HL-LHC Phase-2 upgrade, crab cavities?, IR	
2023–2030?		$\sqrt{s}$ = 14 TeV, L = $5 \cdot 10^{34} cm^{-2} s^{-1}$, bunch spacing **25 ns** **Plan for 50% more**	~3000 fb^{-1}

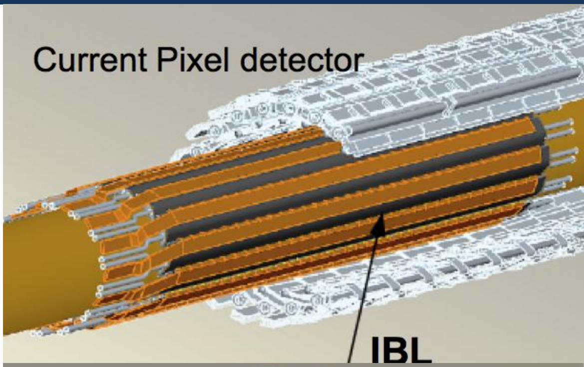
ATLAS LS1 upgrade plans (2013-1024)

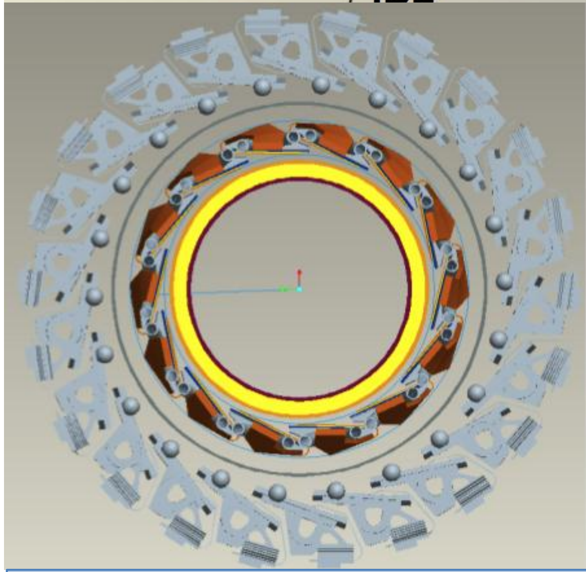
Phase 0 Upgrade – Some major improvements to physics capabilities

- New small Be beam pipe
- New insertable pixel b-layer (IBL)
  - drives shutdown schedule for ATLAS

- Completion of the installation of the endcap extra (EE) muon chambers (staged in 2003) and some additional chambers in the feet and elevator regions

- Add topological processing at level 1 trigger
- Increase maximum level 1 trigger accept rate to 100kHz





IBL preserves current physics performance at very high pileup

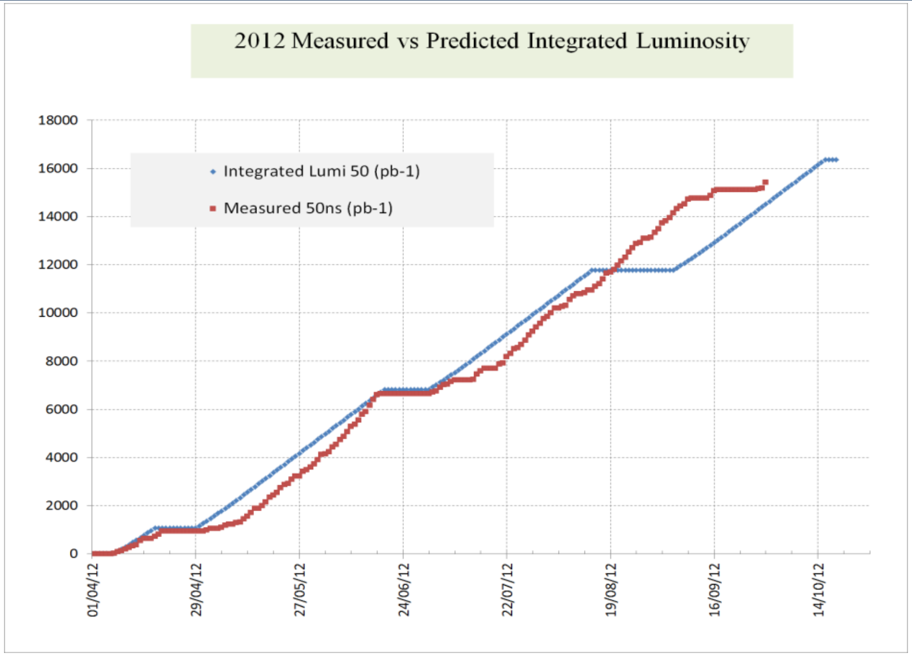
Summary

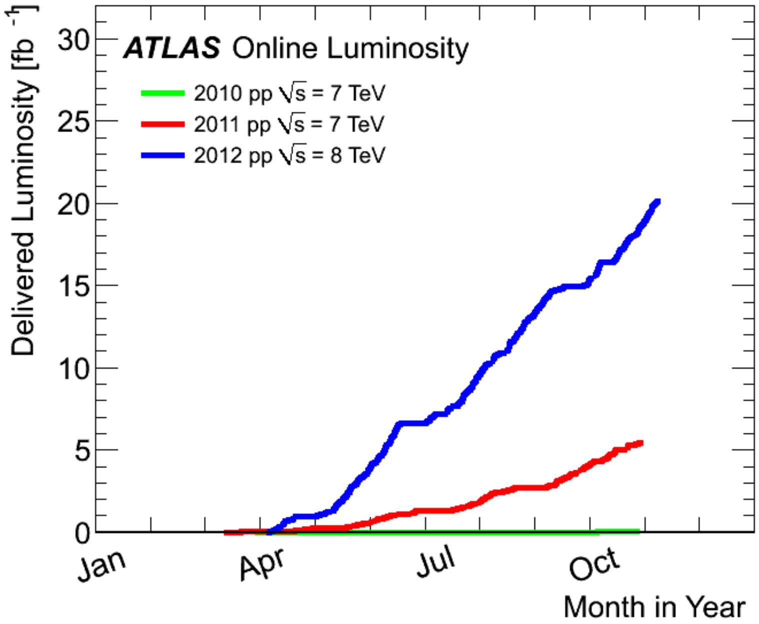
- During 2012 run successfully recorded more than 20fb^{-1} of good quality data at 8 TeV with ~94% efficiency
- The ATLAS detector is performing quite well, in good agreement with simulation, coping with increasing luminosity and large pile-up using optimized trigger
- More than 200 physics papers using collision data have been published, including the most important one:
  - "First observations of a new particle in the search of the Standard Model Higgs boson at the LHC"
- The upgrade R&D and projects are well advanced and running at full speed

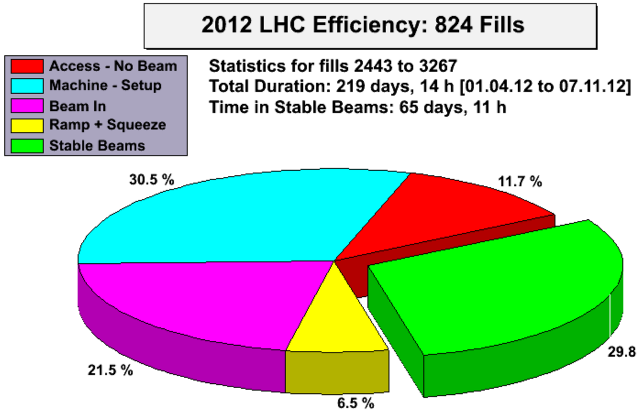
Many thanks to LHC machine and all ATLAS collaboration for their amazing performance!

Backup slides

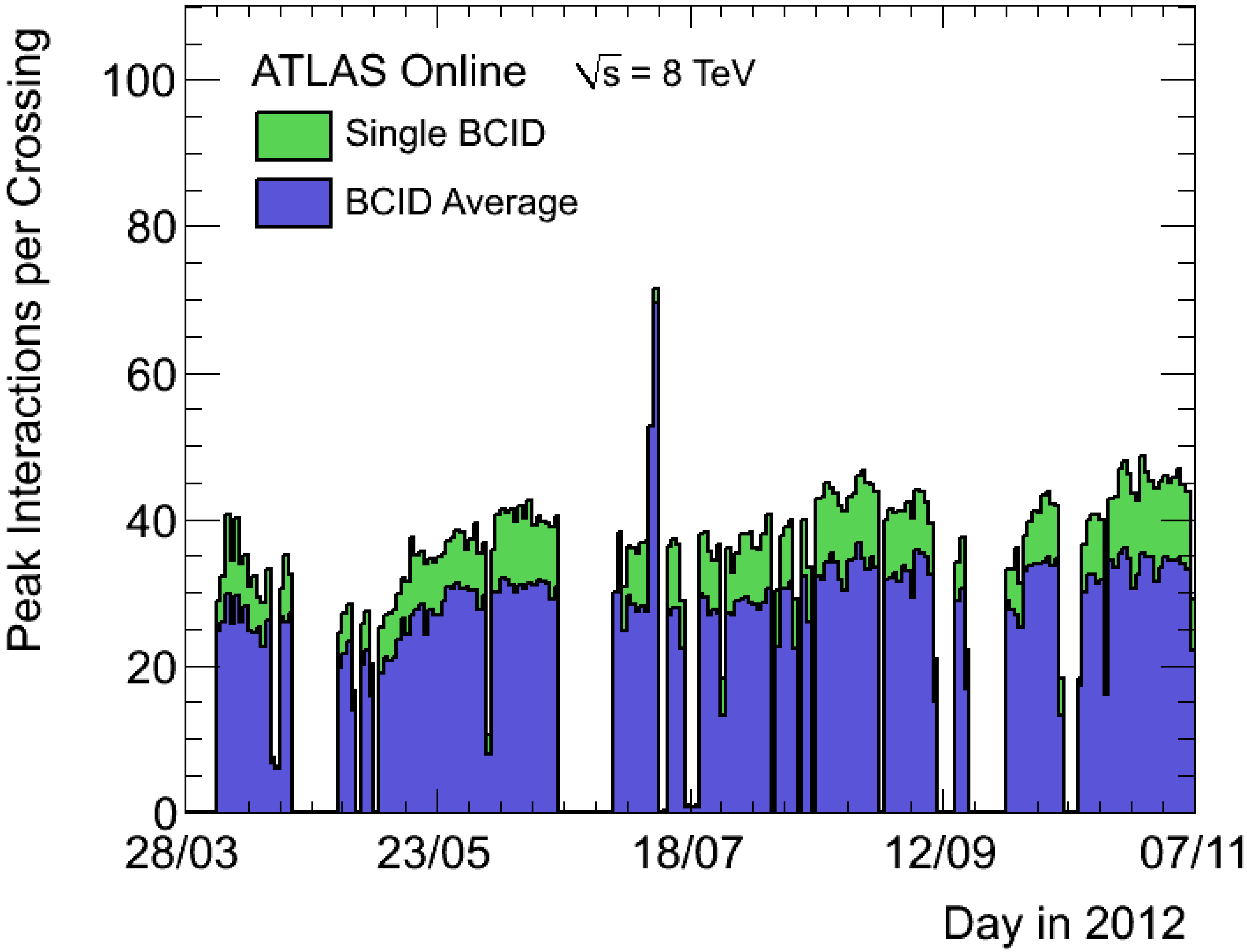
LHC performance







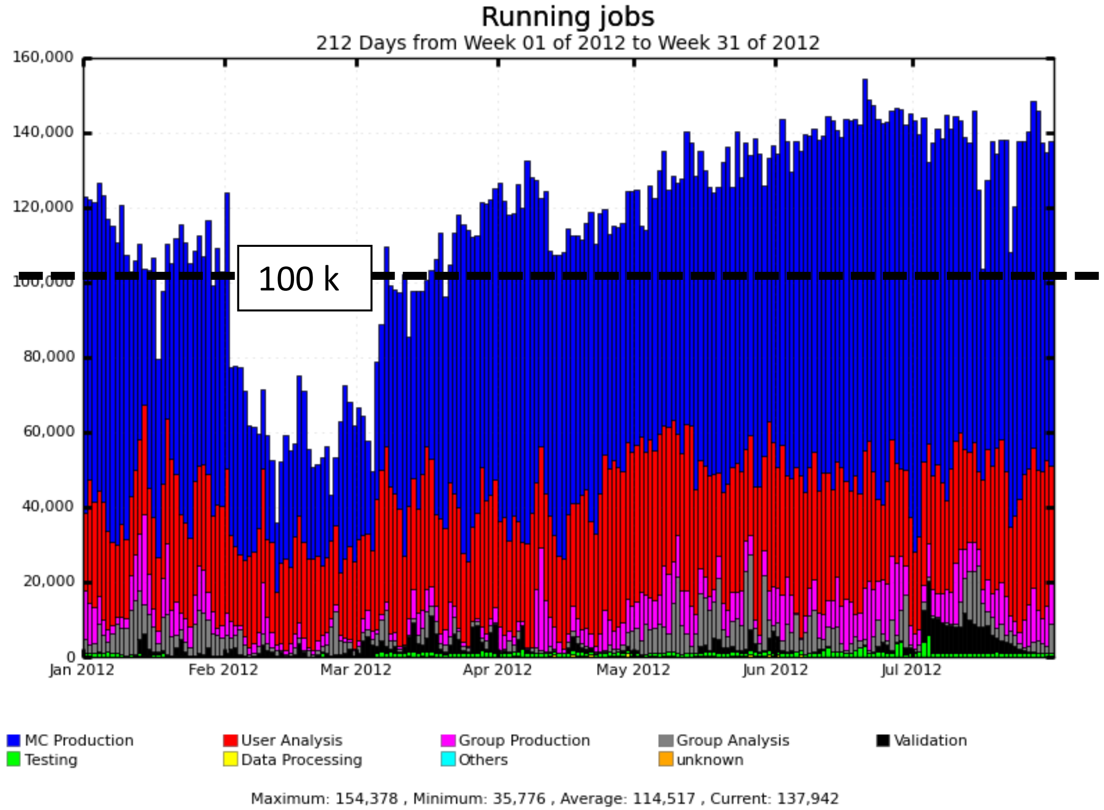
ATLAS pileup



The maximum mean number of events per beam crossing versus day. It is determined for each bunch as described above. The online luminosity measurement is used for this calculation as for the luminosity plots. In this plot both the maximum pileup for any bunch is shown in green, as well as the maximum pileup averaged over all the colliding bunches (shown in blue).

GRID usage

- Available resources fully used/stressed (beyond pledges in some cases)
- Massive production of 8 TeV Monte Carlo samples
- Very effective and flexible Computing Model and Operation team → accommodate high trigger rates and pile-up, intense MC simulation, analysis demands from worldwide users (through e.g. dynamic data placement)
- **It would have been impossible to release physics results so quickly without the outstanding performance of the Grid (including the CERN Tier-0) (F. Gianotti)**

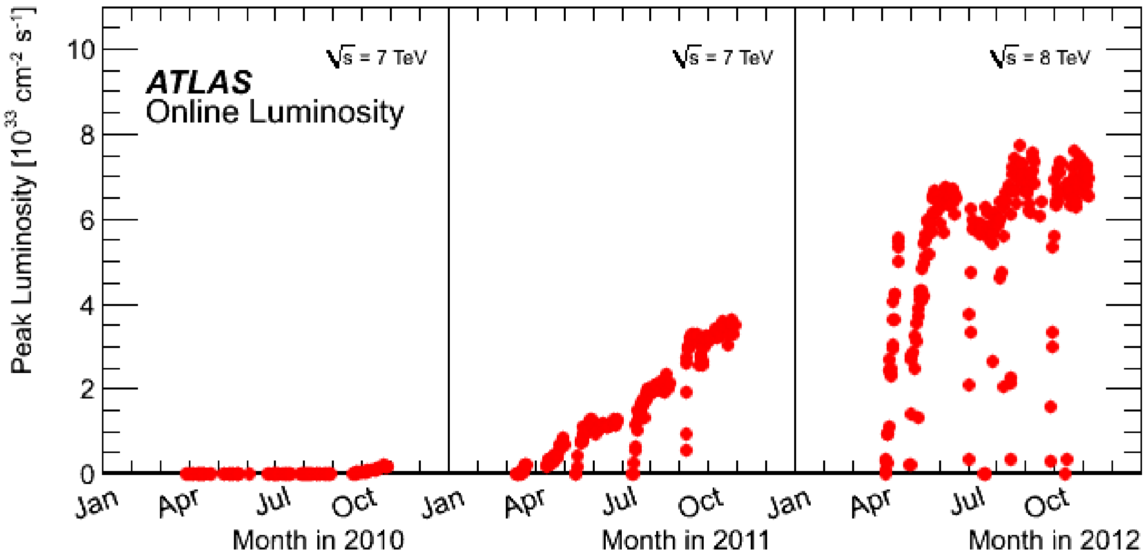


Number of concurrent ATLAS jobs

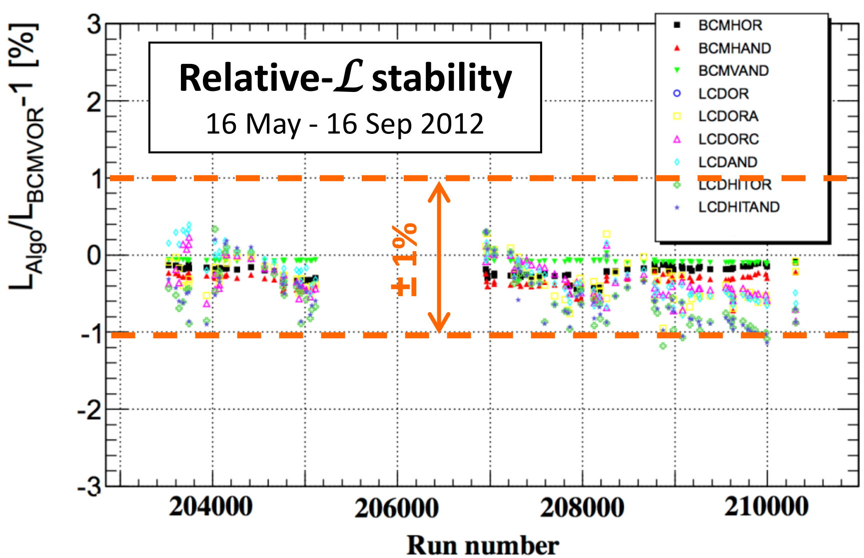
Includes MC production, user and group analysis at CERN, 10 Tier1-s, ~ 70 Tier-2 federations → > 80 sites

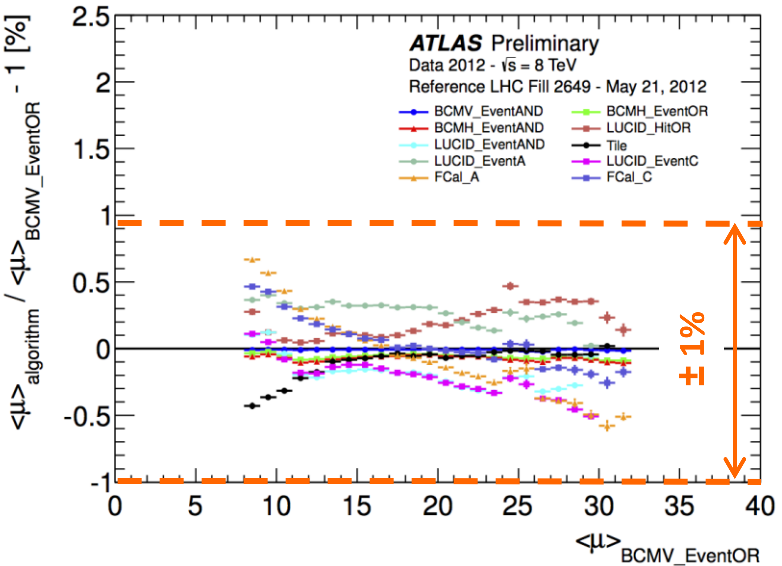
> 1500 distinct ATLAS users do analysis on the GRID

ATLAS luminosity measurements

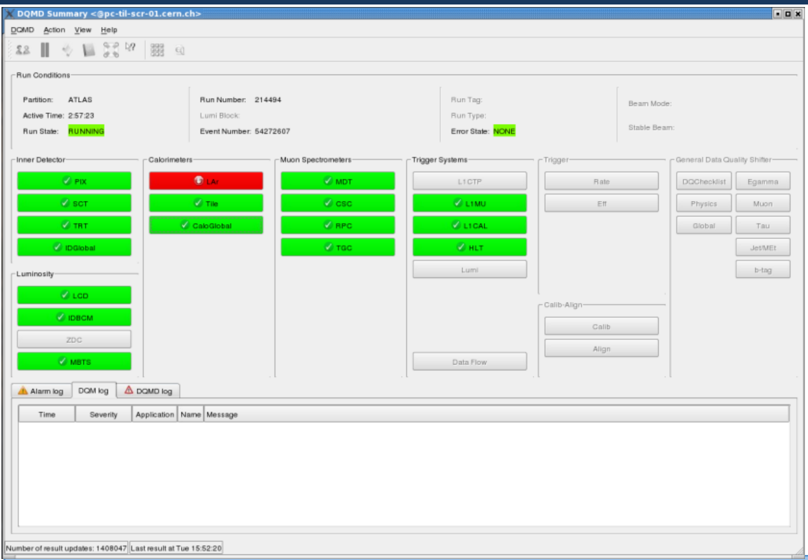


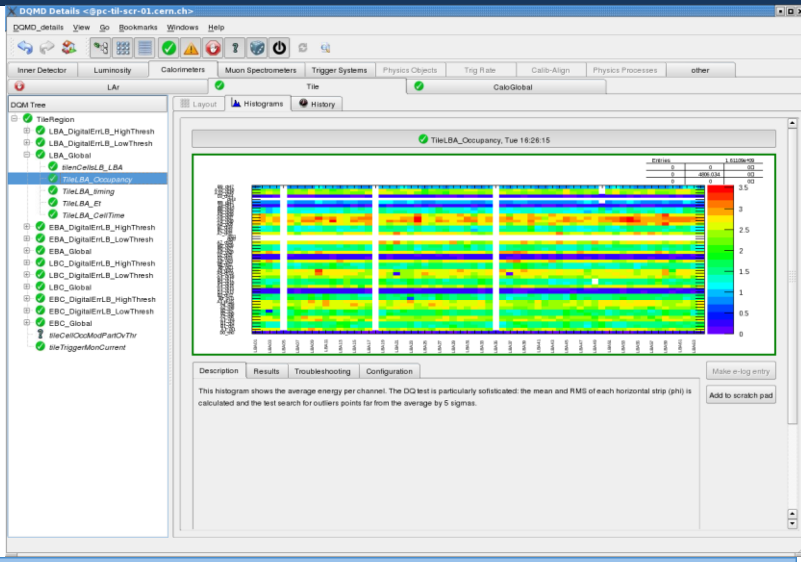
- Assumption that $\mathcal{L}$ distribution is factorizable in {x, y} appears to be violated
- Compelling evidence that this is caused by the beams themselves





Data quality





ATLAS p-p run: April-Sept. 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.3	99.5	97.0	99.6	99.9	99.8	99.9	99.9	99.7	99.2
All good for physics: 93.7%										

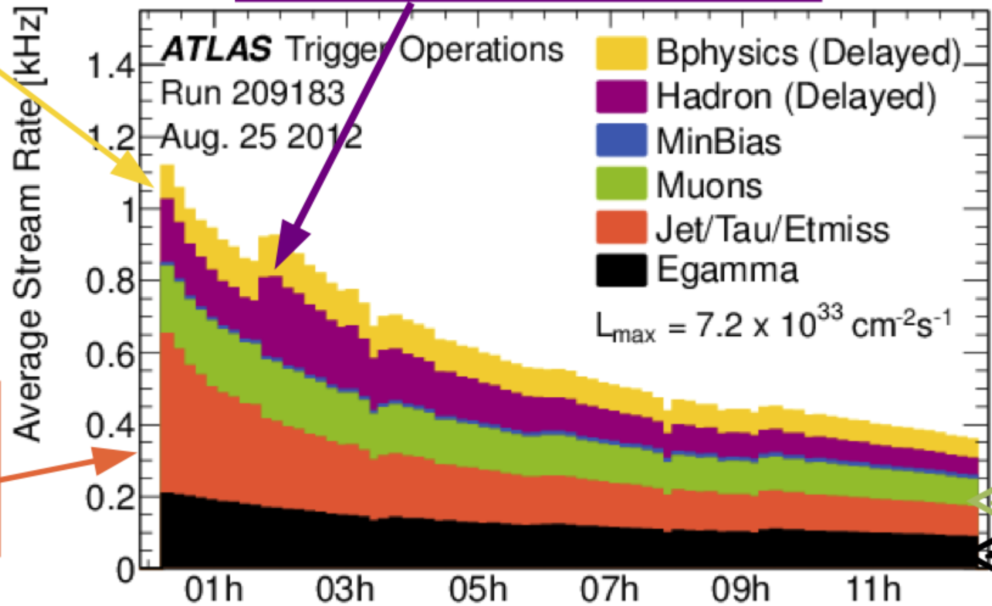
Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at $\sqrt{s}$=8 TeV between April 4th and September 17th (in %) – corresponding to 14.0 fb^{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.

Trigger: stream rates

Low-threshold dimuon triggers disabled at highest L due to Level 1 constraint of ~75kHz

Lower (60 GeV) threshold ETMISS trigger below ~ 6 $10^{33}/cm^2/s$

Trigger optimized to make full use of current ressources



Jet/ETMiss baseline triggers expected to hold till end of the year

Single lepton threshold correspond to offline cuts pT >25 GeV (unchanged during 2012)

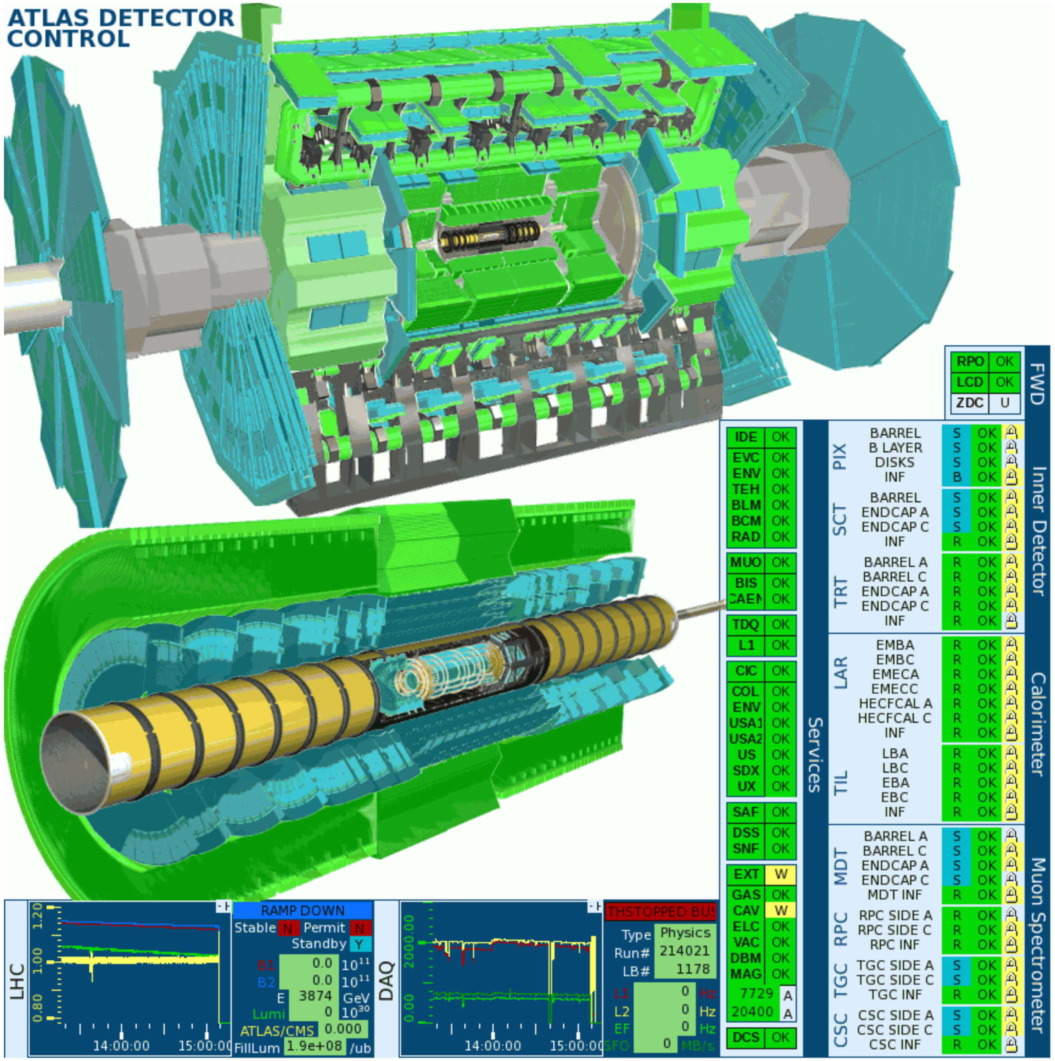
(Main) streams sizes up to 3rd technical stop:

Stream	Egamma	Muons	JetTauEtmiss	Total prompt	Hadron delayed	Bphysics delayed	Total Delayed
Events (10^9)	0.47	0.48	0.54	**1.62**	0.22	0.23	**0.47**
Average Rate [Hz]	110	110	120	**370**	50	50	**110**

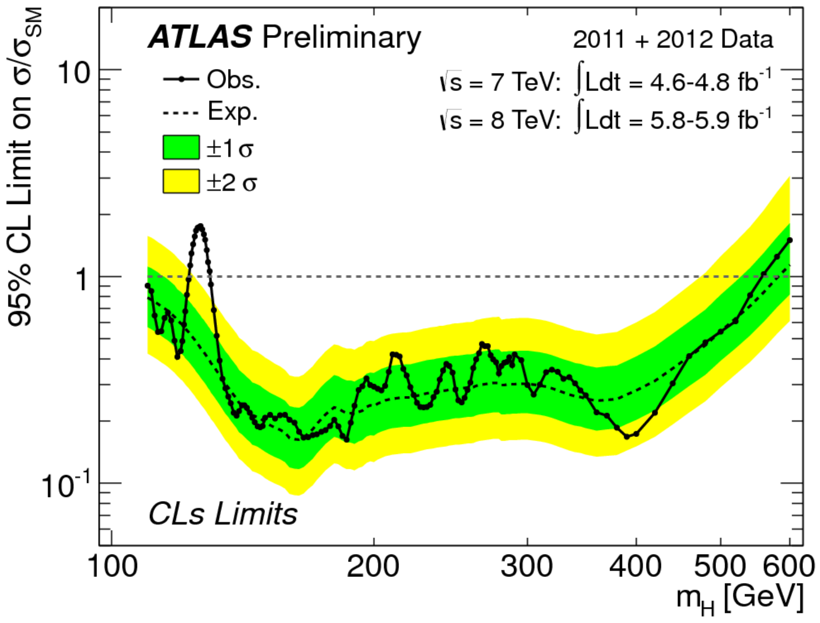
H. Bachacou, CEA-Saclay/CERN LHCC, 26/10/2012 4

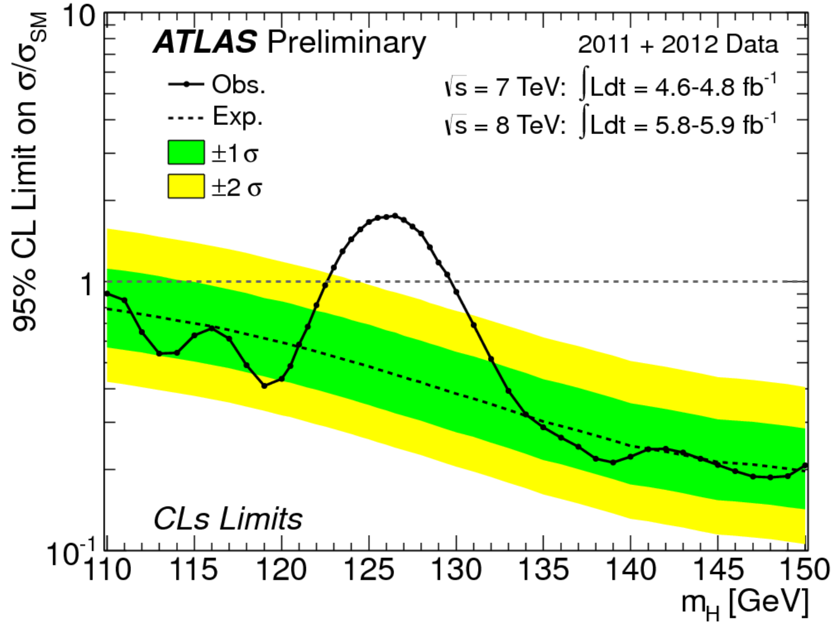
DCS

- DCS runs very smoothly
- Lots of consolidation work in the sub-systems to follow and support operation
- Established a homogeneous online documentation for shifters/experts based on FSM and alarms
- Major improvements in DCS Back-End Monitoring
- New version of DCS data viewer deployed:
  - allows to store plots on web server and then access them later, send plot link via email or embed them in web pages
- Lots of DCS projects migrated from Windows to Linux



Physics results: Higgs





Excluded masses at 95% CL :
- Observed : 112-122 GeV and 131-559 GeV
- Expected : 110 GeV to 582 GeV

Maximum excess observed at
mH=126.5 GeV
- Local significance 5.9σ
- Expected: 4.9σ

(Global significance: ~ 5.2 σ)
Probability of background fluctuation to the observation: 1.7 x 10-9