Anatoli Romaniouk

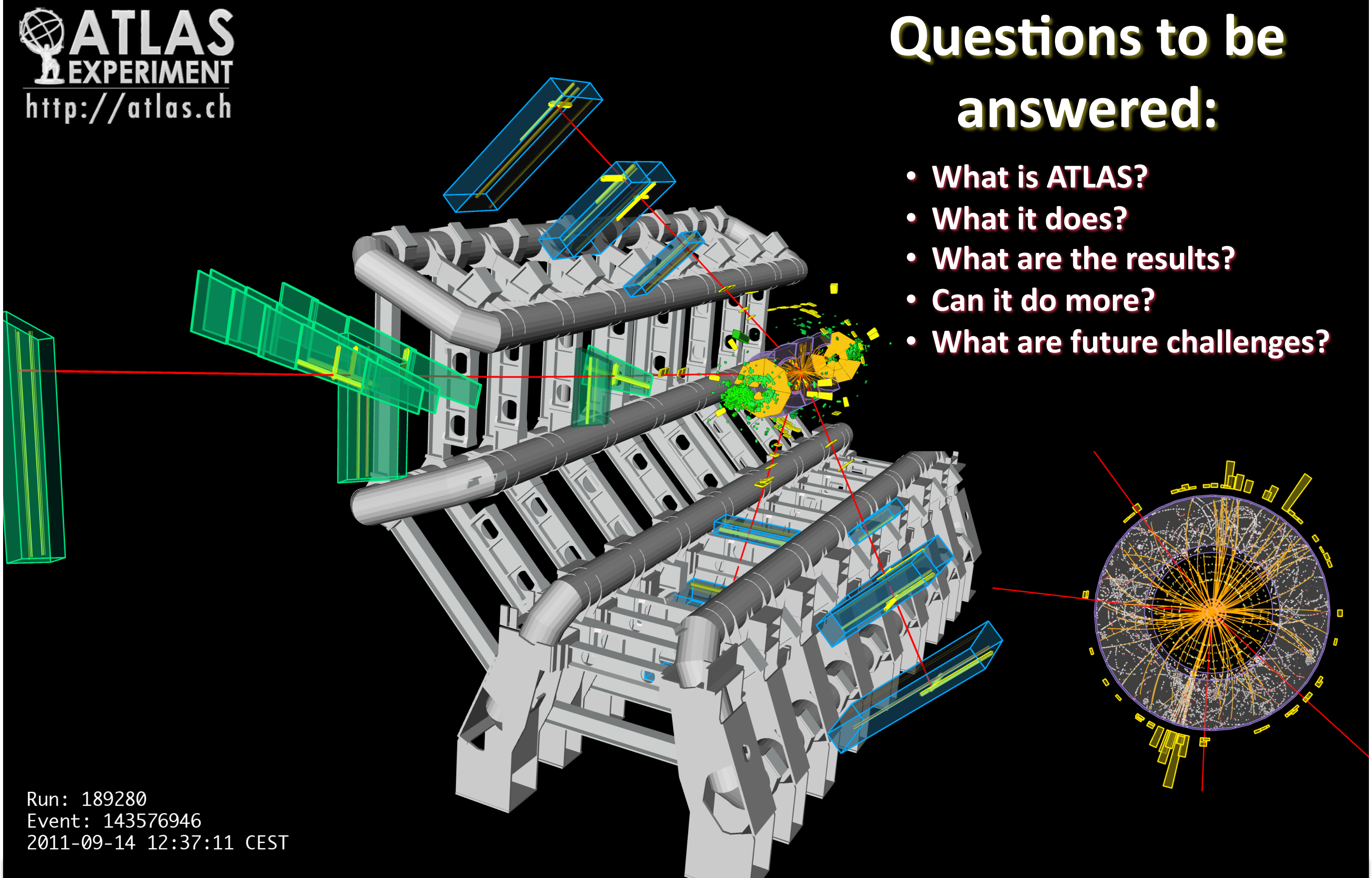
On behalf of the collaboration:

The ATLAS experiment at LHC: present status and future.

15th International Workshop **"What comes Beyond the Standard Model"** Bled, Slovenia, 9th-19th July 2012

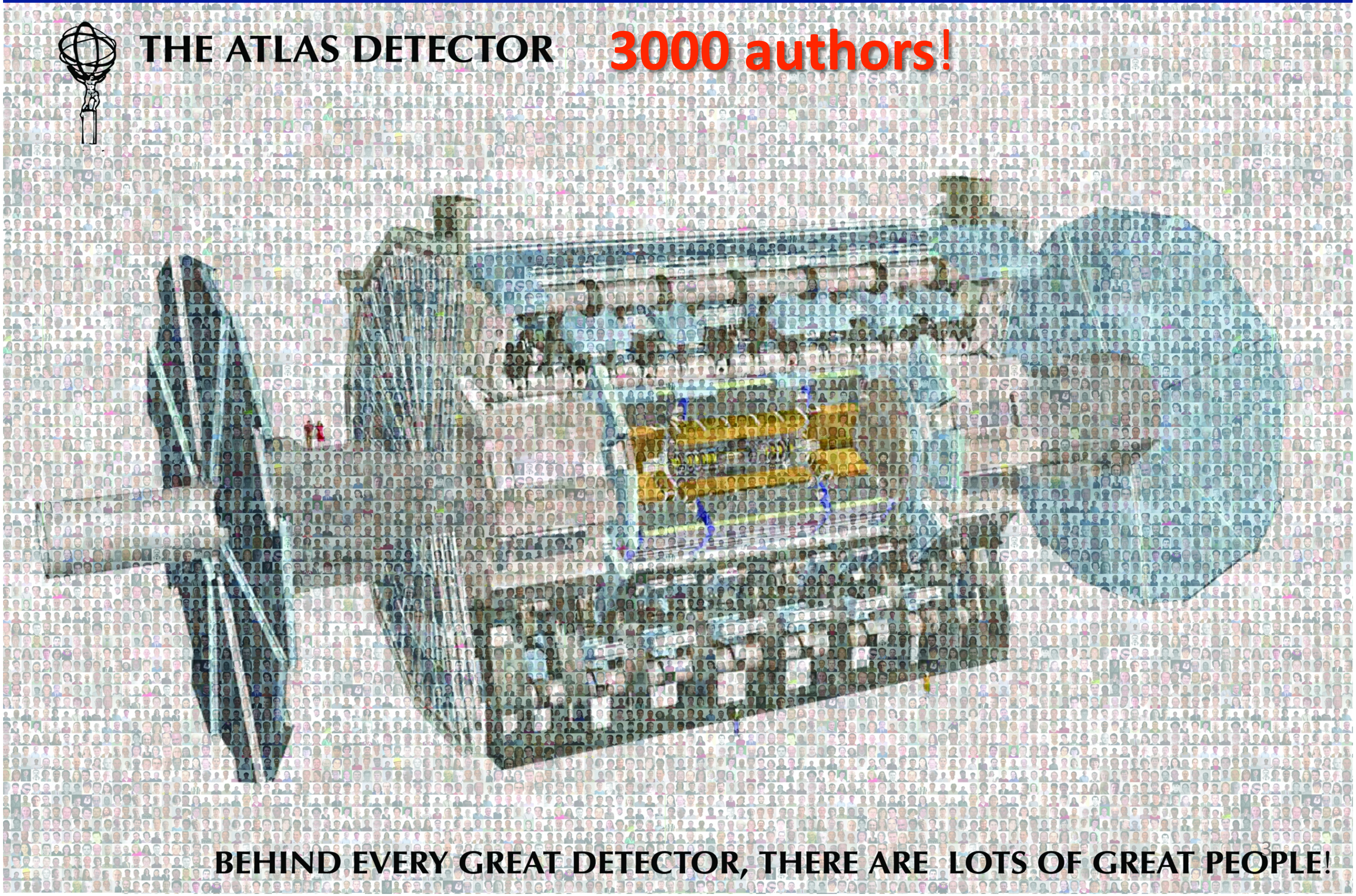
Questions to be answered:

- What is ATLAS?
- What it does?
- What are the results?
- Can it do more?
- What are future challenges?



What are the signatures of a new physics which are note considered?

First of all the ATLAS are people who proposed it, made R&D, designed and built it, developed sophisticated SW tools, operate it and carry out the data analysis!

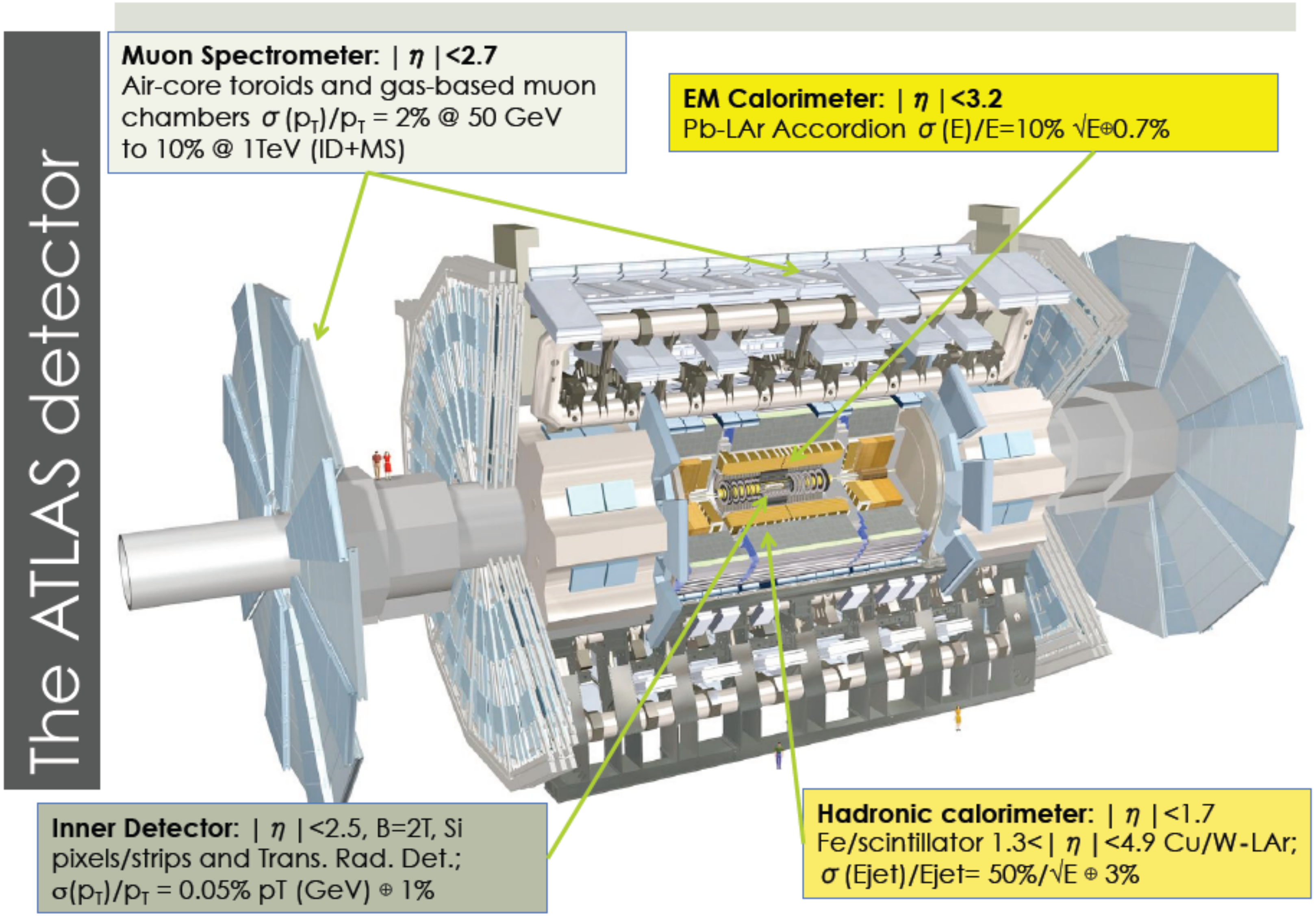


38 countries, 174 universities and laboratories, 1000 students

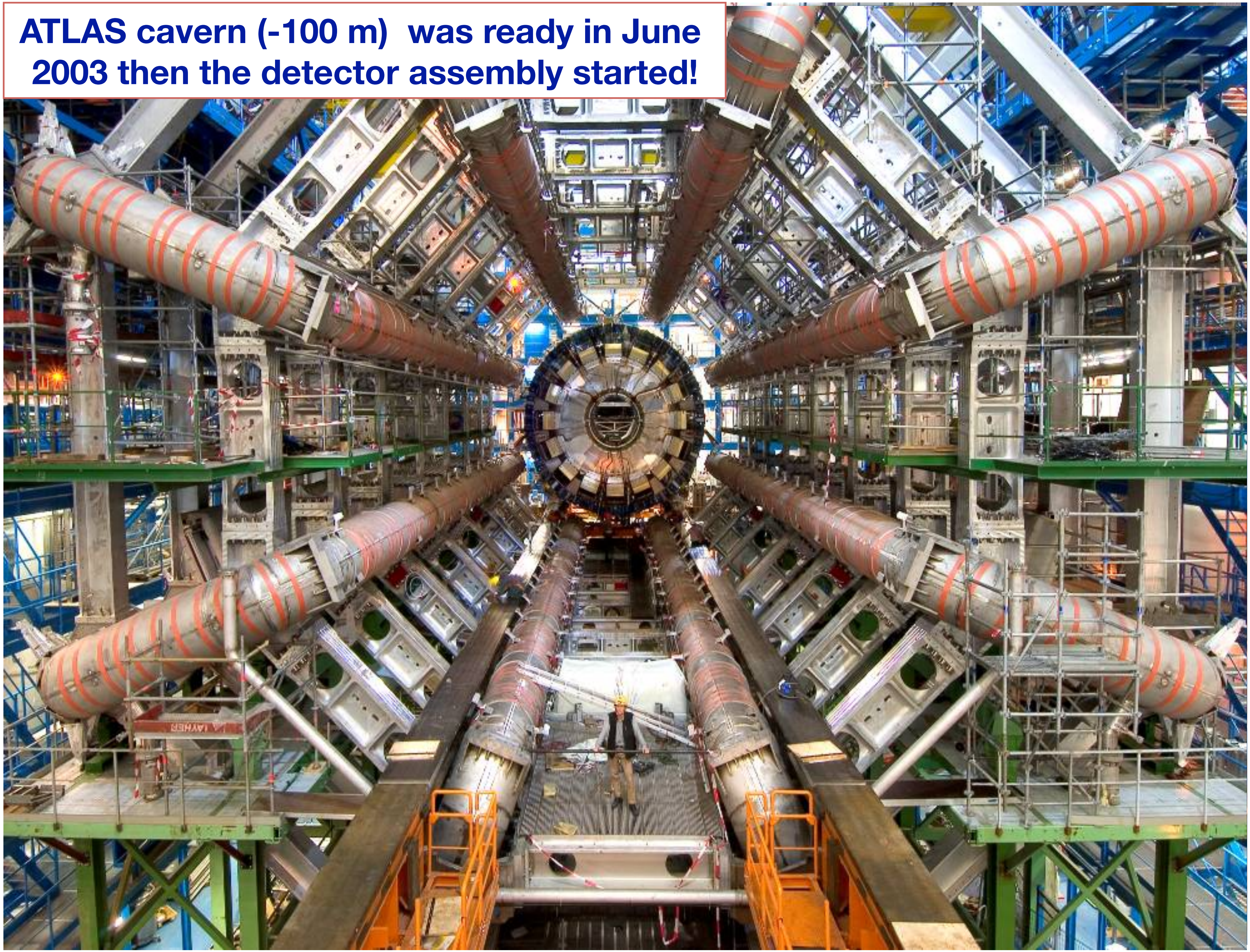
ATLAS (A Toroidal LHC ApparatuS)

The Largest High Energy Physics Experiment

45 meters long, 25 meters high, 7000 tons.

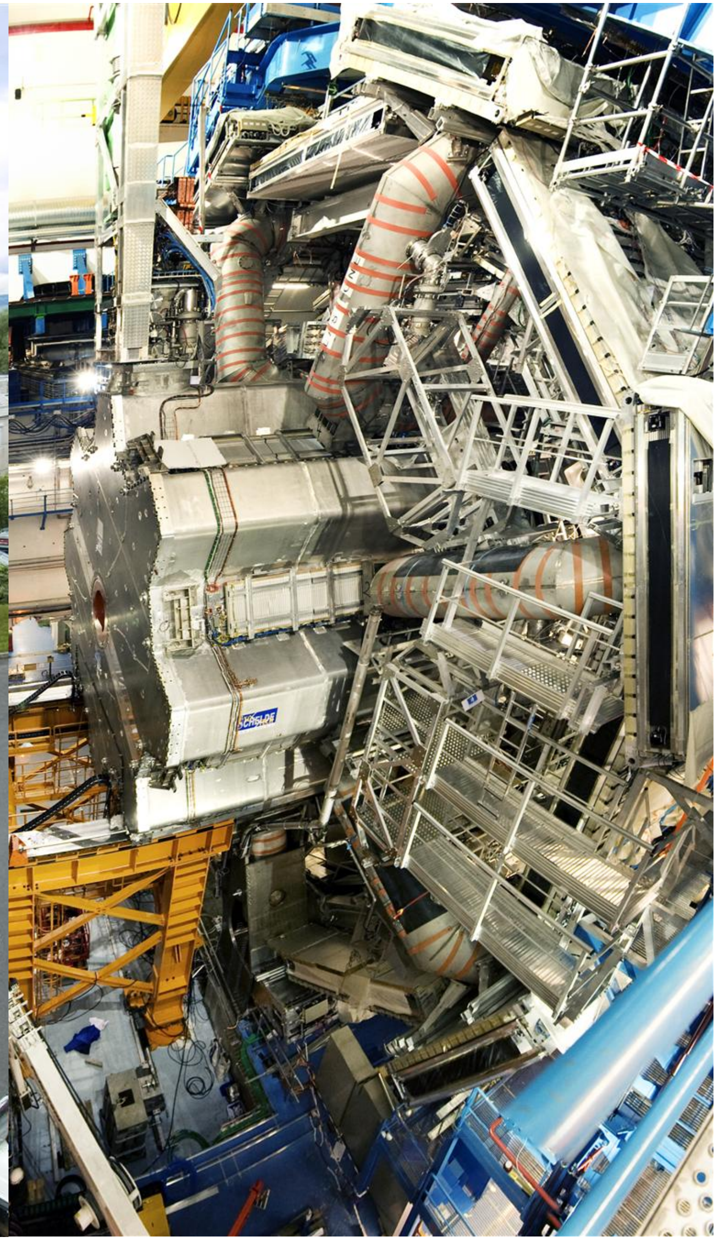


ATLAS cavern (-100 m) was ready in June 2003 then the detector assembly started!



Toroid magnets for muon system

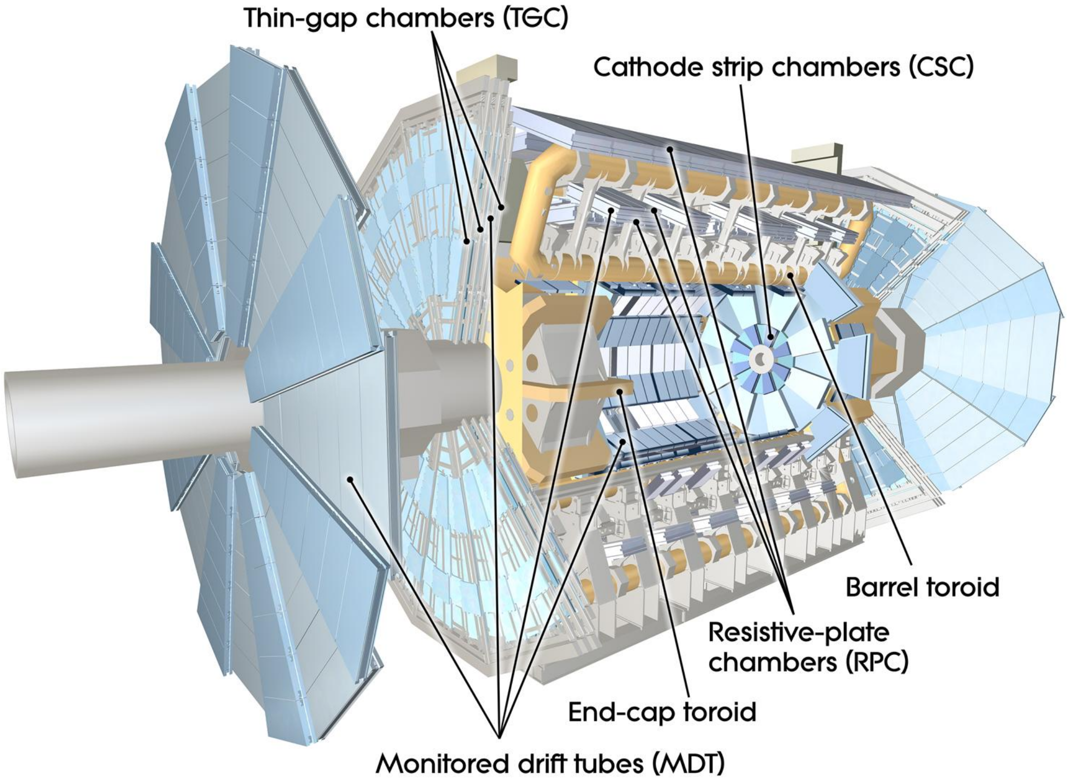
Field integral 2-6 Tm $|\eta|<1.3$ 4-8 Tm $1.6<|\eta|<2.7$

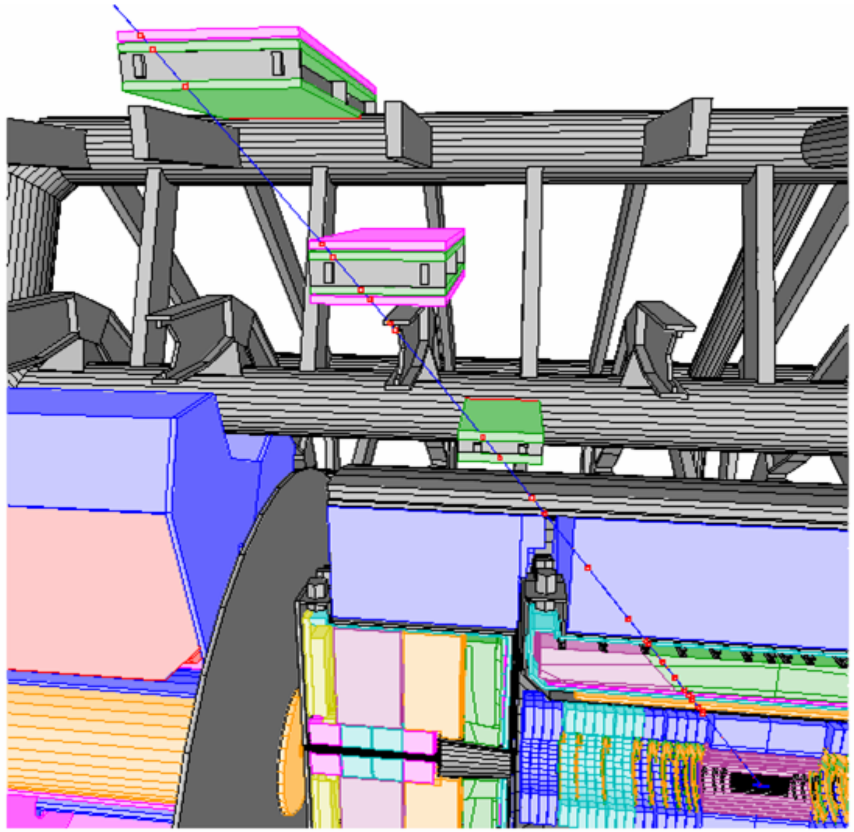


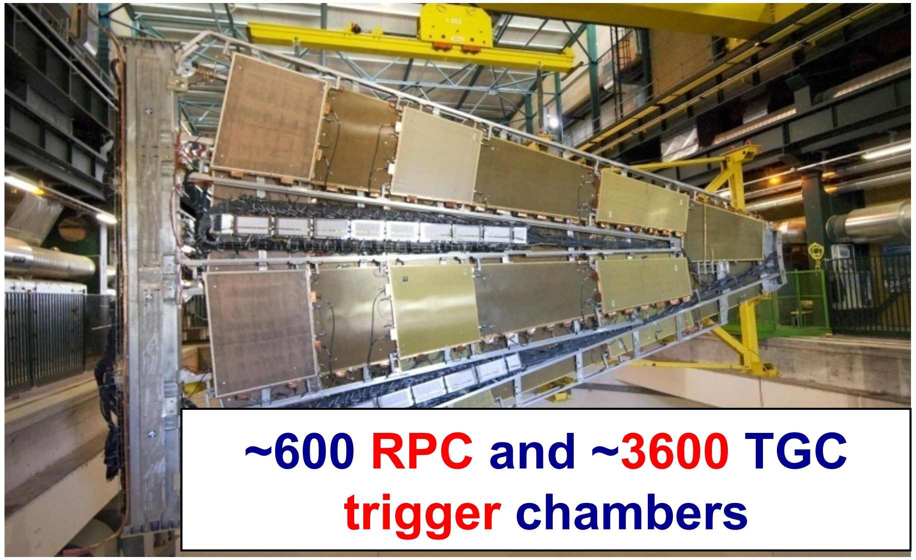
4 Superconducting magnets:
- Solenoid around ID (B=2T;7.6 kA)
- 3 Air core Toroids (with 8 coils each: 22.0 kA)
- B_{toroid} ~0.5-1T

Muon System

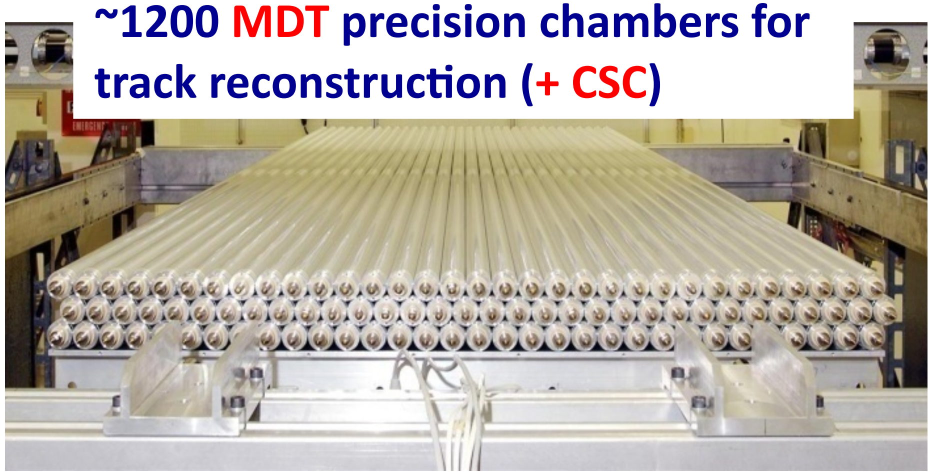
4 gas chamber technologies.







~600 RPC and ~3600 TGC trigger chambers



~1200 MDT precision chambers for track reconstruction (+ CSC)

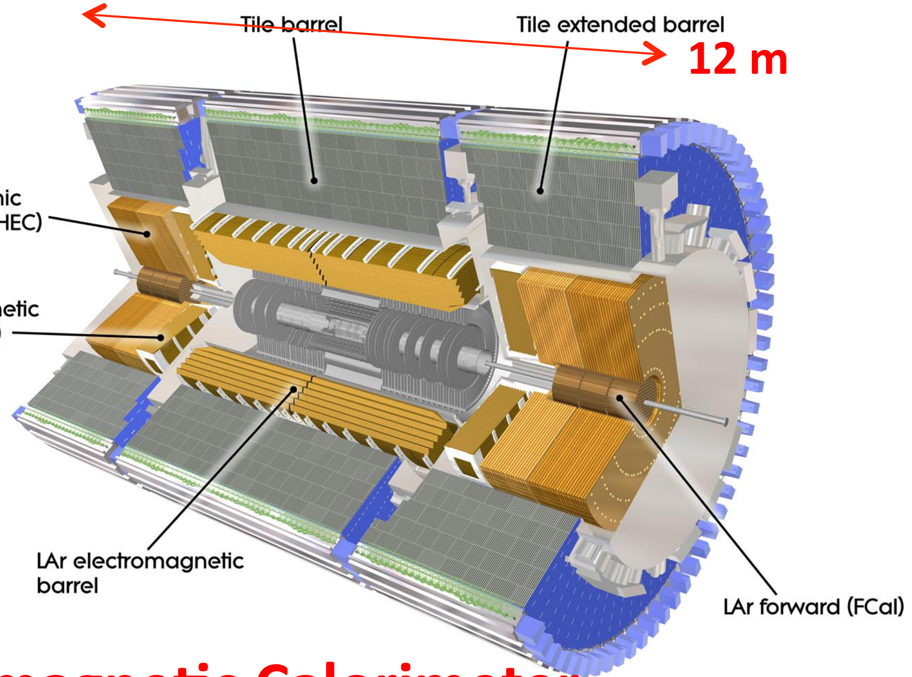
Muon System

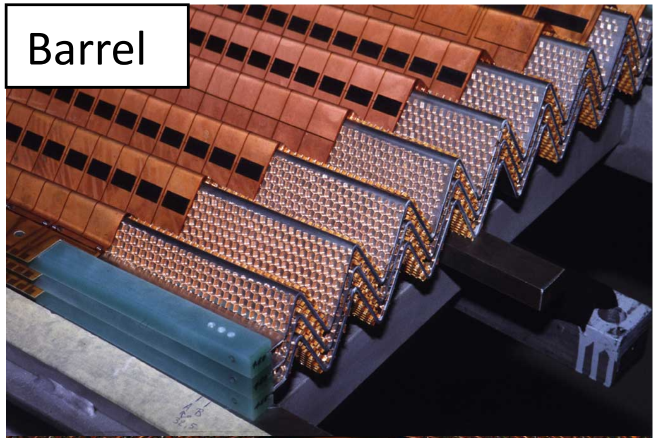
- Precision chambers : MDT ; CSC
  Trigger chambers : RPC ; TGC
- Coverage: $|\eta|<2.7$
- Total number of channels: 1.1×10^{6}
- Area: 12000 m^3
- Alignment accuracy: ~ 30-40 μm
- MDT resolution = 80 μm ($|\eta|<2$)
- CSC resolution =60 μm ($2<|\eta|<2.7$)
- Momentum resolution (ID+MS)
  $\sigma p_T/p_T$ ~**10%** (p_T ~ **1 TeV**)
  $\sigma p_T/p_T$ ~**2%** (p_T =**50 GeV**)

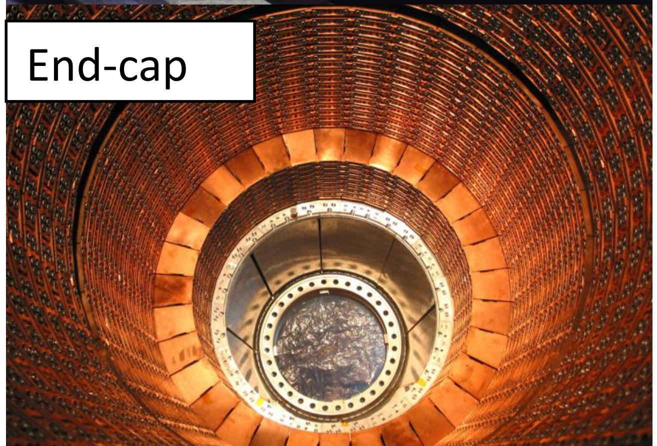
Calorimeters – 3 technologies

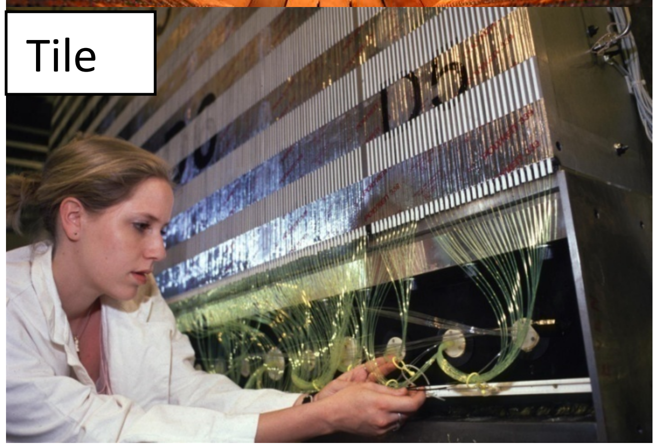
Precise energy measurements +
Trigger for e/γ , jets, missing E_T

Coverage **|η|<5**







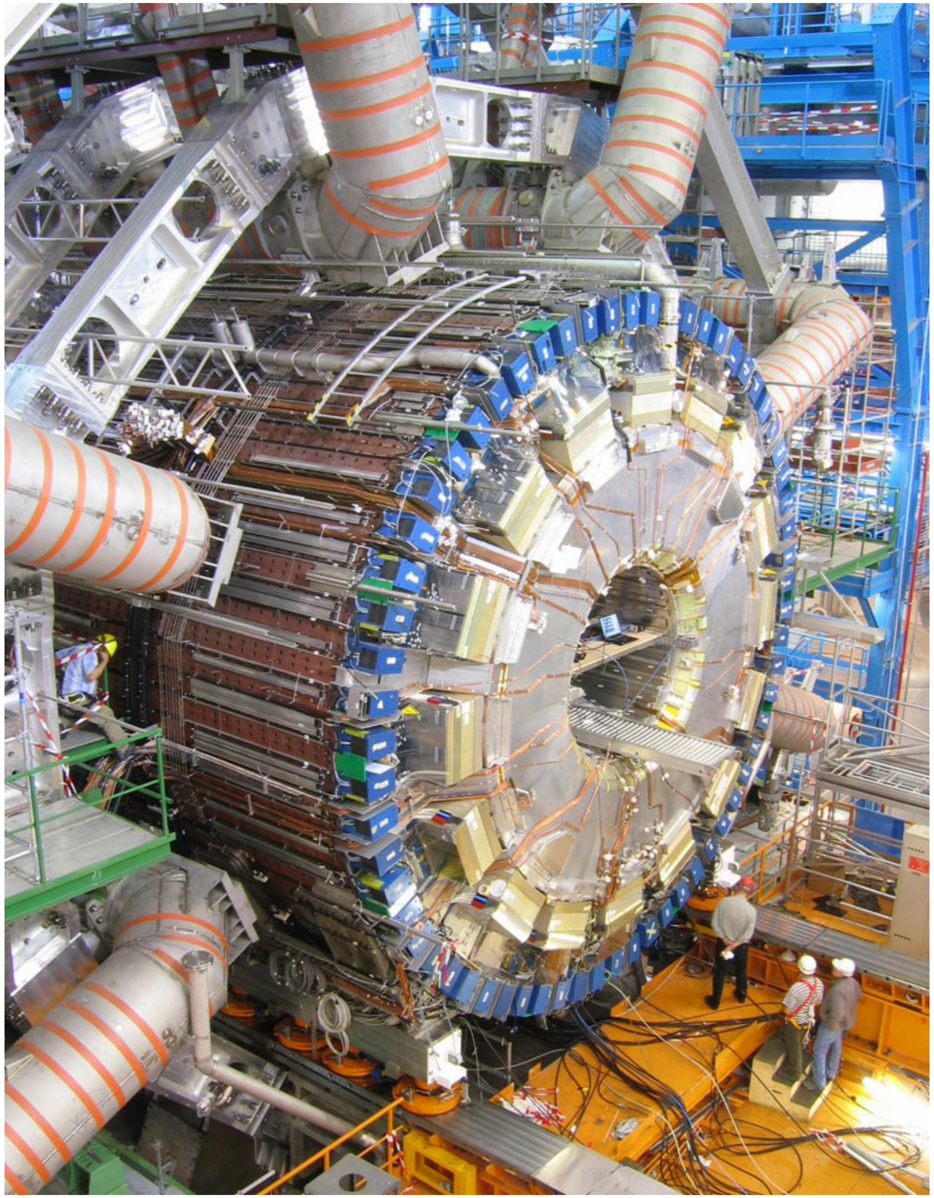


Electromagnetic Calorimeter

Barrel and End-cap: **Pb-LAr**
180’000 channels:

Hadron Calorimeter

Barrel **Iron-Tile**, End-Cap and Forward **Cu/W-LAr**
10 λ, ~20000 channels



May 2008

Lar-Pb EM calorimeter:

- 3 longitudinal layers with different granularity
- Extra presampler
- σ/E ~ 10%√E

•Barrel **|η|<1.475,**
•End-cap **1.375<|η|<3.2**

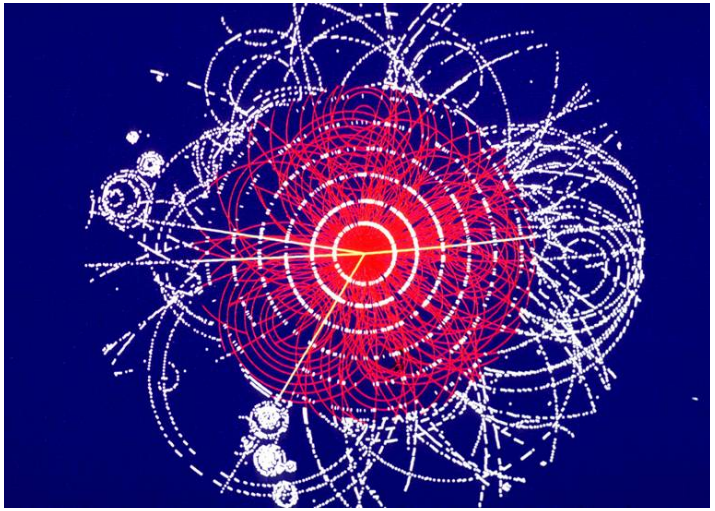
Hadron calorimeter

•σ/E ~ 50%√E⊕0.03
•|η|<1.7: Fe/scint. Tiles (Tilecal)
•3.2 <|η|<1.5: Cu-Lar (HEC)
•3.1<|η|<4.9: FCAL Cu/W-Lar
•|η|<4.9
•10l at |η|=0
•3-4 Longitudinal layers

ATLAS Inner detector

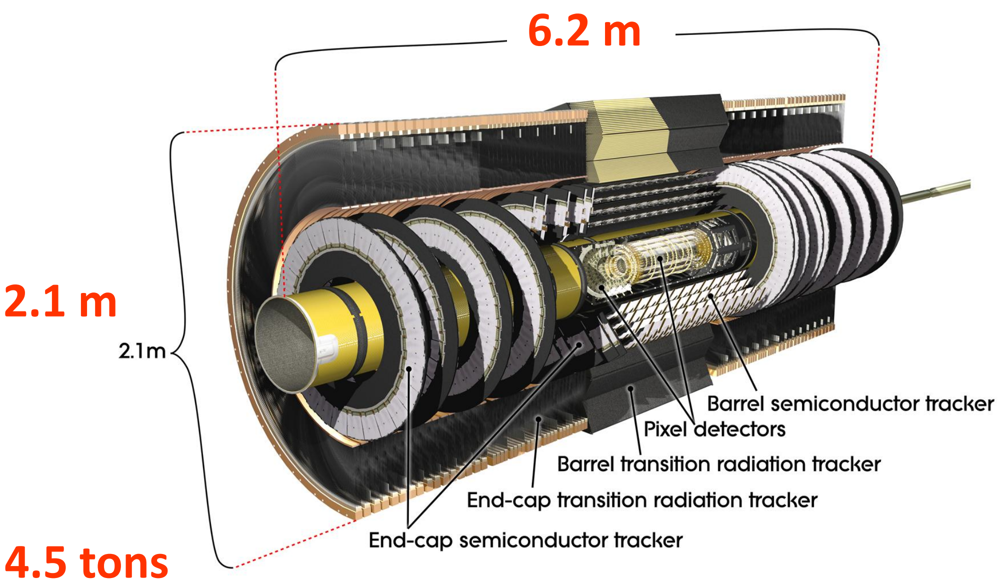
Tasks:

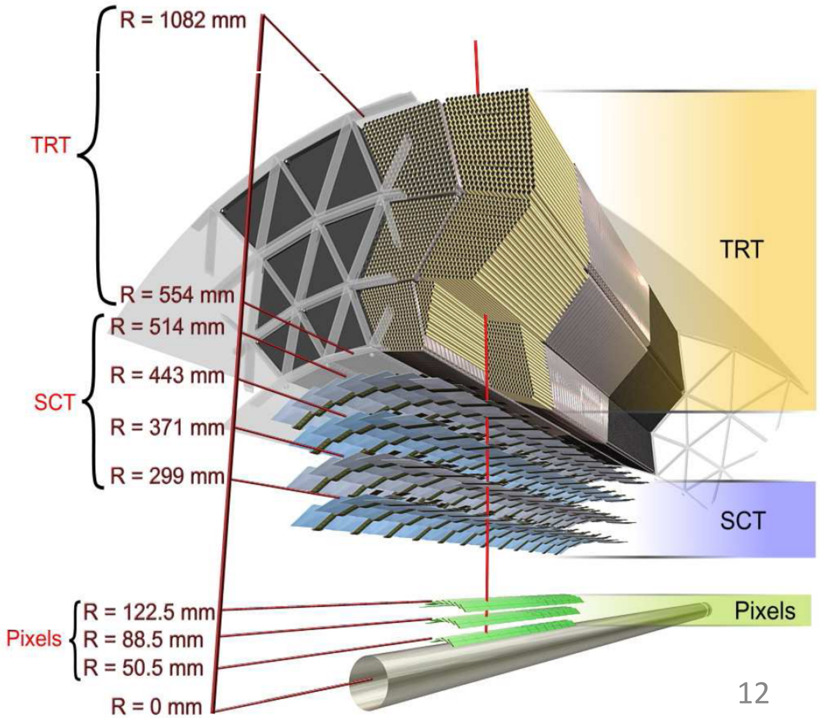
- Precise tracking and vertexing in $|\eta|<2.5$,
- B (solenoid) =2T
- <hits> in barrel ~ 3/8/30 pixel/SCT/TRT;
- $0.5X_0$ at $\eta=0$; $1.1\ X_0$ at $\eta=1.8$
- e/π separation; coverage: $|\eta|<2$



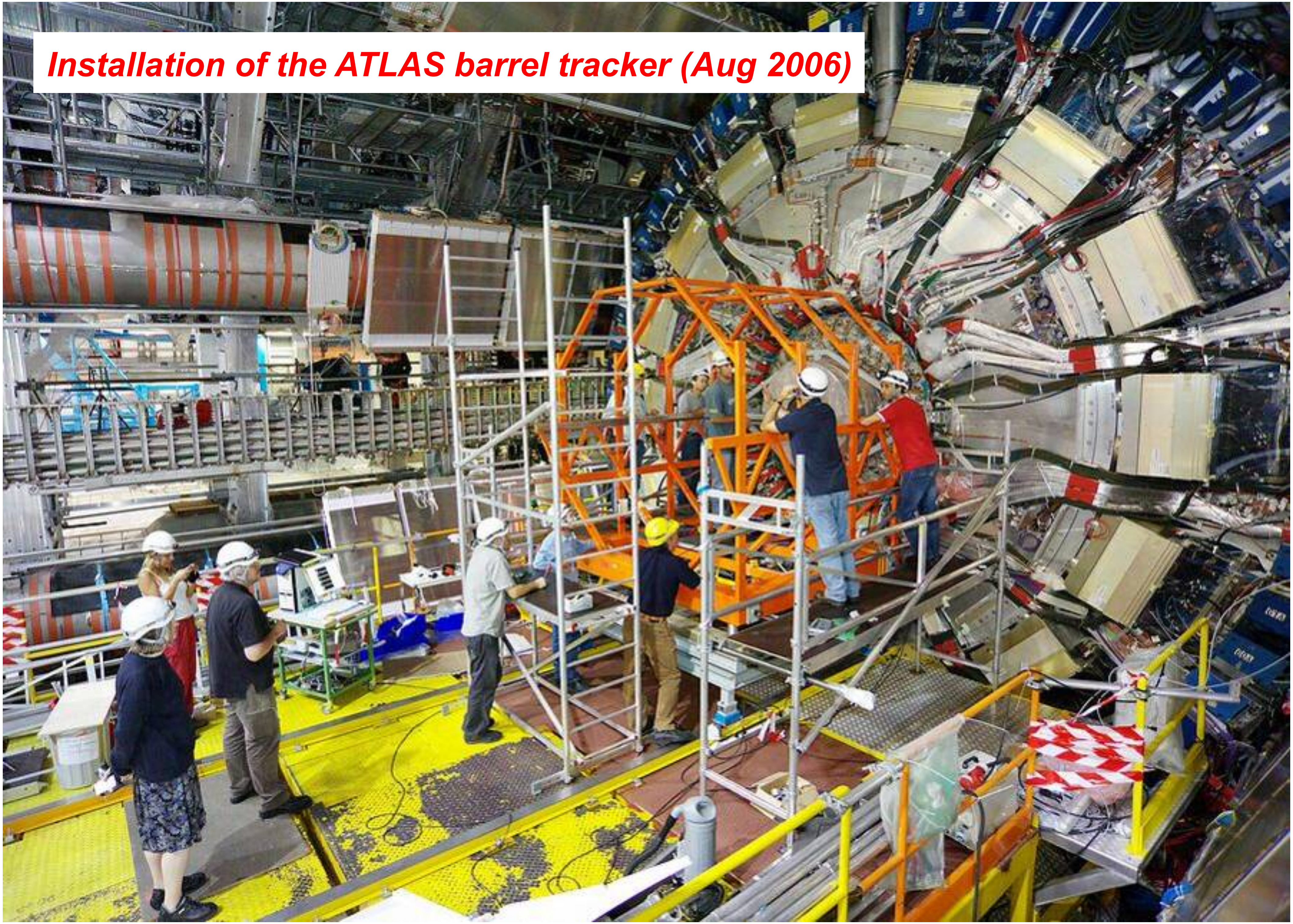
3 technologies

- **Si Pixels**: 80M channels ; 3 layers and 3 disks ; $|\eta|<2.5$
- **10^6 Si strips (SCT)**: 6M channels; 4 layers and 9 disks ;
- **Transition Radiation Tracker(TRT)** : 350k channels ; $|\eta|<2.0$
- 2 Tesla solenoid **$\sigma/p_T \sim 5\times10^{-4}\ p_T \oplus 0.01$**



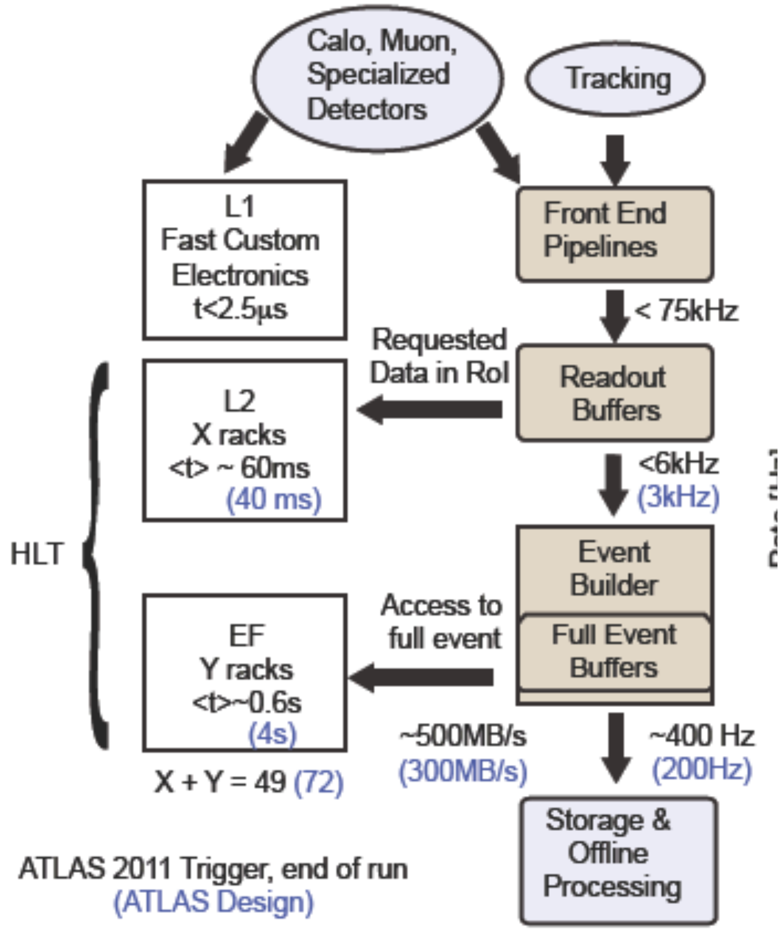


Installation of the ATLAS barrel tracker (Aug 2006)



Trigger

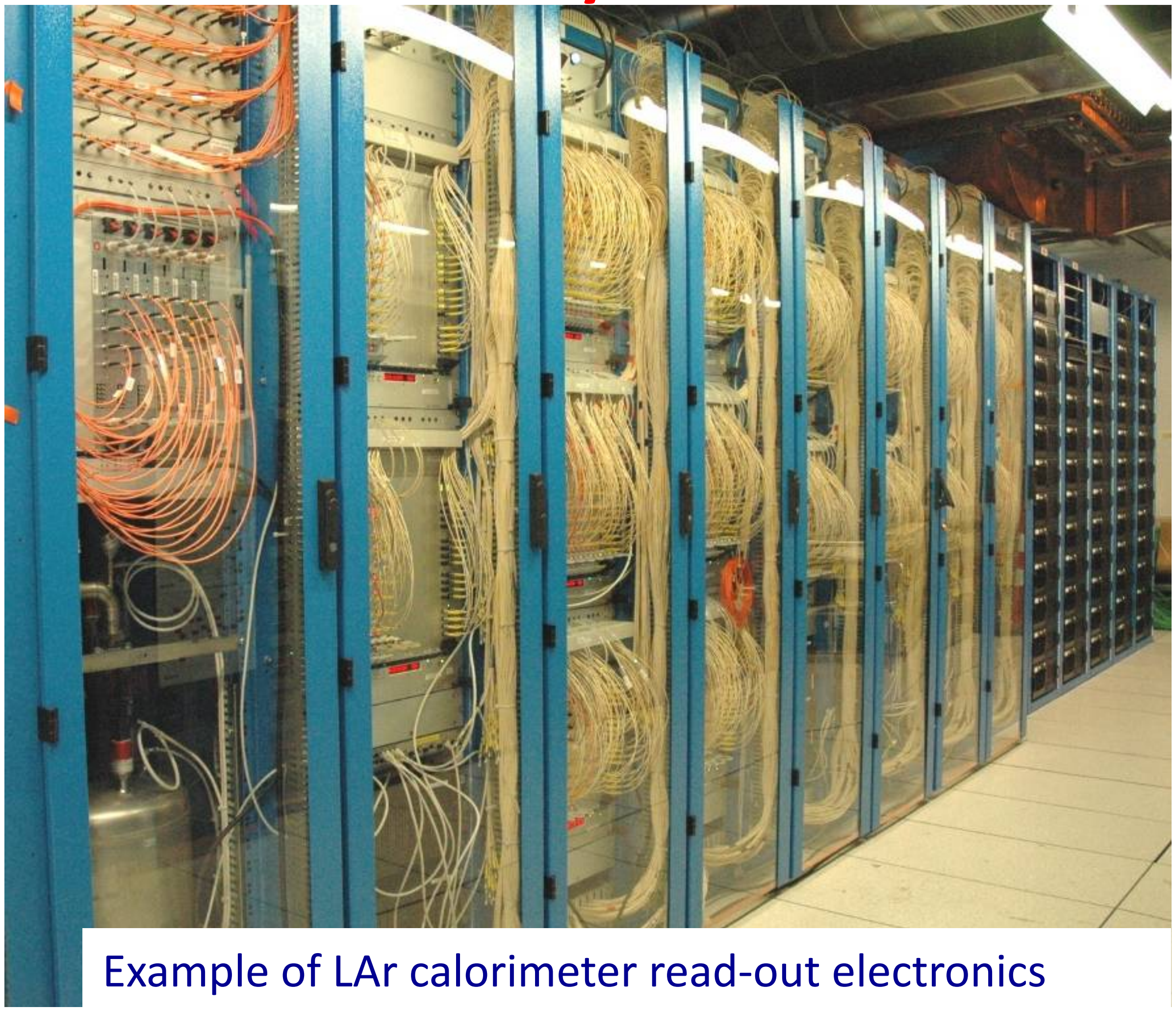
- Level-1
  - Implemented in hardware
  - Muon + Calo based
  - coarse granularity
  - e, μ, π, τ, jet candidate selection
  - Define regions of interest (ROIs)
- Level-2:
  - Implemented in software
  - Seeded by level-1 ROIs, full granularity
  - Inner Detector – Calo track matching
- Event Filter:
  - Implemented in software
  - Offline-like algorithms for physics signatures
  - Refine LV2 decision
  - Full event building



- Collision rate 40MHz
- LV1 accepts up to 75kHz
- recorded ~300 Hz

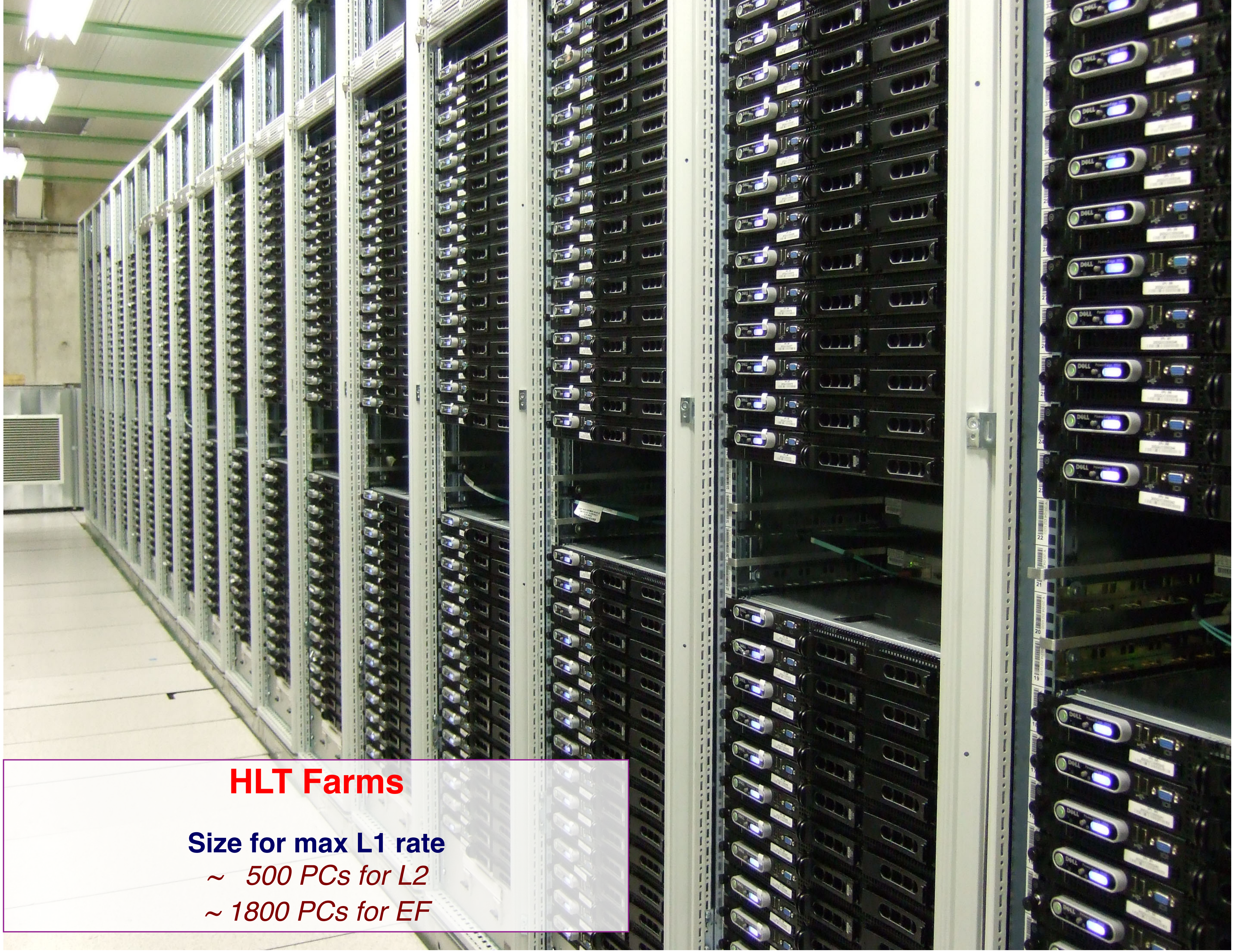
Example of Level-1 Trigger electronics

The read-out electronics, trigger, DAQ and detector control systems .



Example of LAr calorimeter read-out electronics

In total about 300 racks with electronics in the ATLAS underground counting rooms


HLT Farms
Size for max L1 rate
~ 500 PCs for L2
~ 1800 PCs for EF

10th September 2008, ~10:00 am
After almost 20 years of a hard work
the ATLAS Detector is ready to take the first LHC event on.

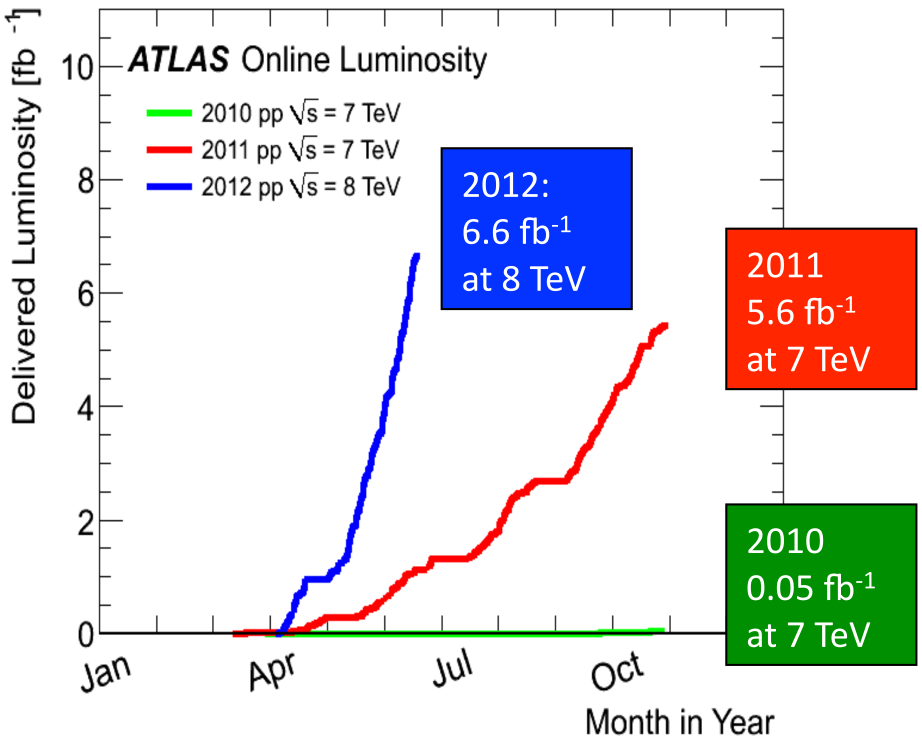
Data taking phase (2012)

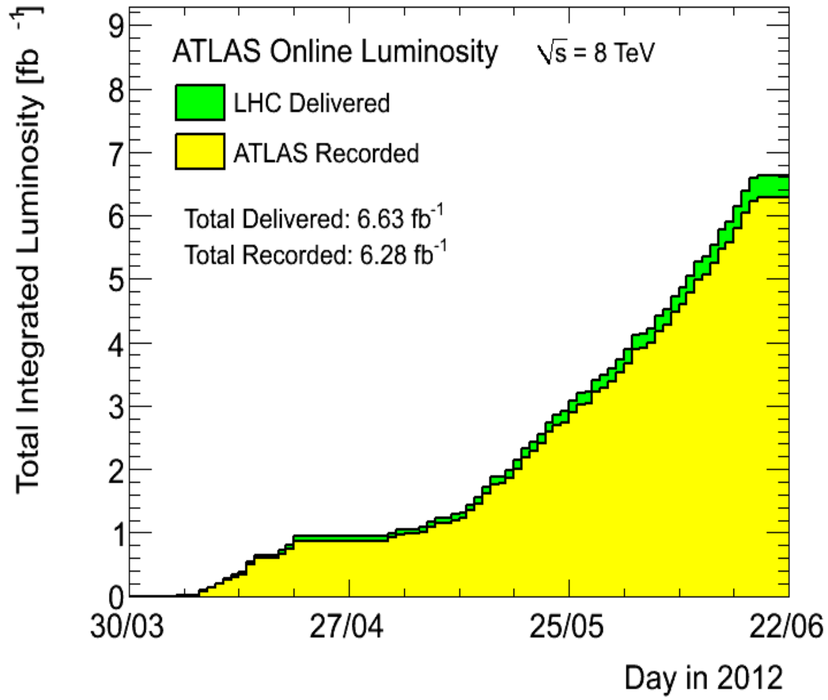
Subdetector	# of Channels	Approximate Operational %
Pixels	80 M	95.9%
SCT Silicon Strip	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile Calorimeter	9800	99.5%
Hadronic endca LAr Calorimeter	5600	99.6%
Forward LAr Calorimeter	3500	99.8%
LVL1 Calo Trigger	7160	100.0%
LVL1 Muon RPC Trigger	370 k	99.5%
LVL1 Muon TGC Trigger	320 k	100.0%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	97.7%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	99.7%

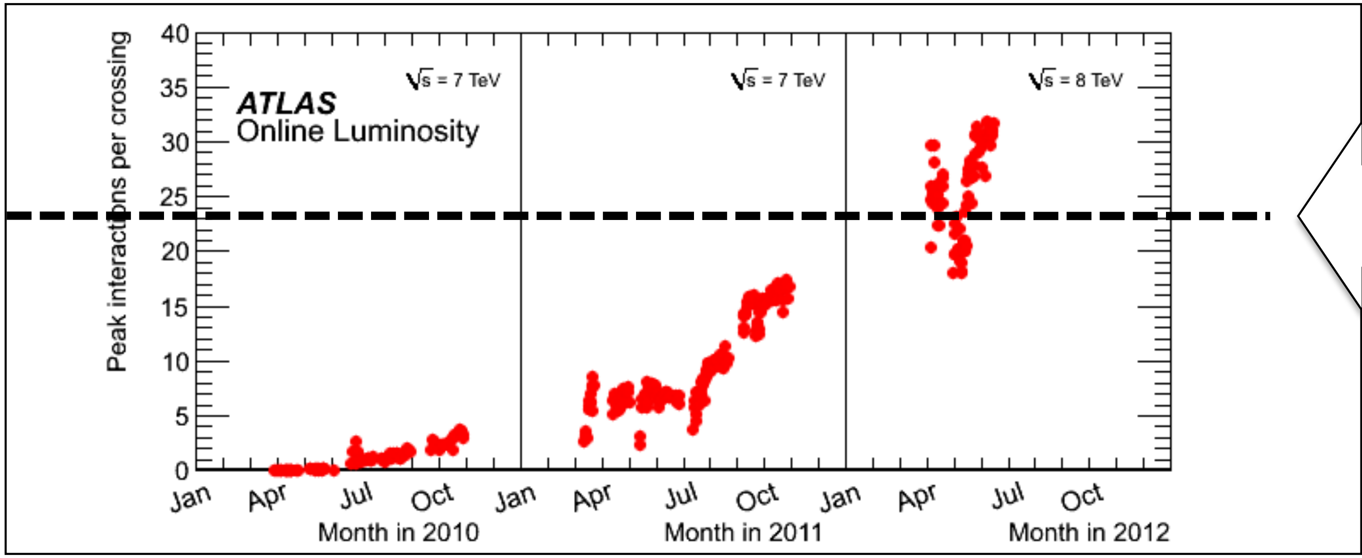
ATLAS 2012 p-p run										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.6	100	96.2	99.1	100	99.6	100	100	99.4	100

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and June 18th (in %) – corresponding to 6.3 fb^{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future.

Data taking phase

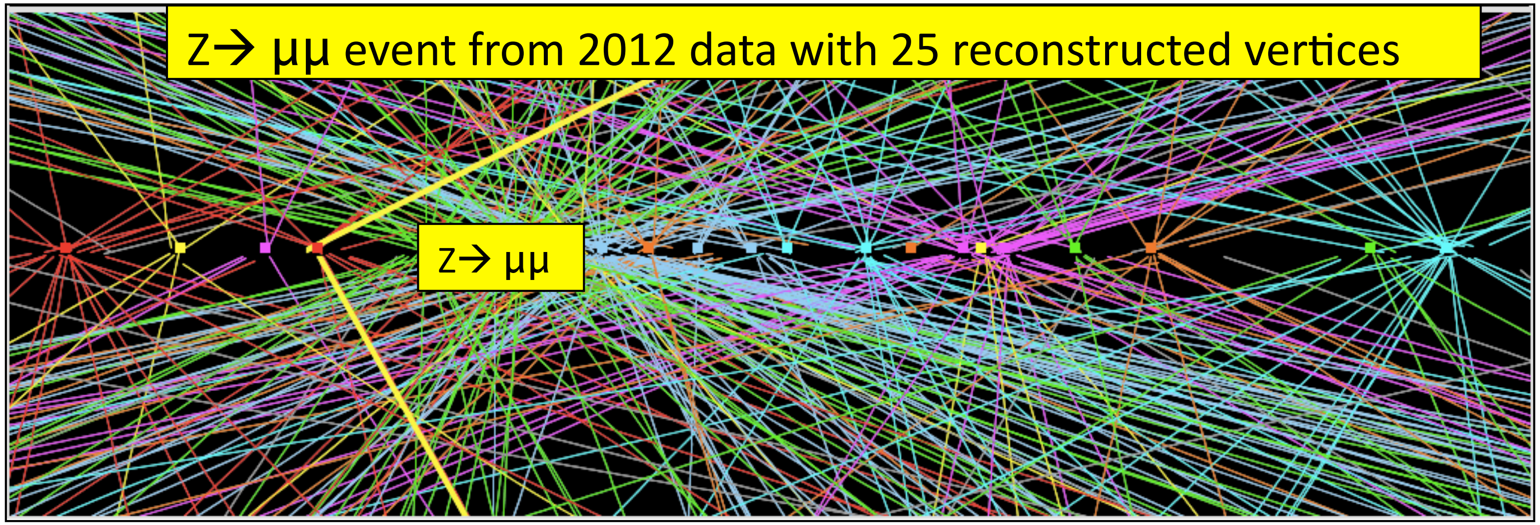


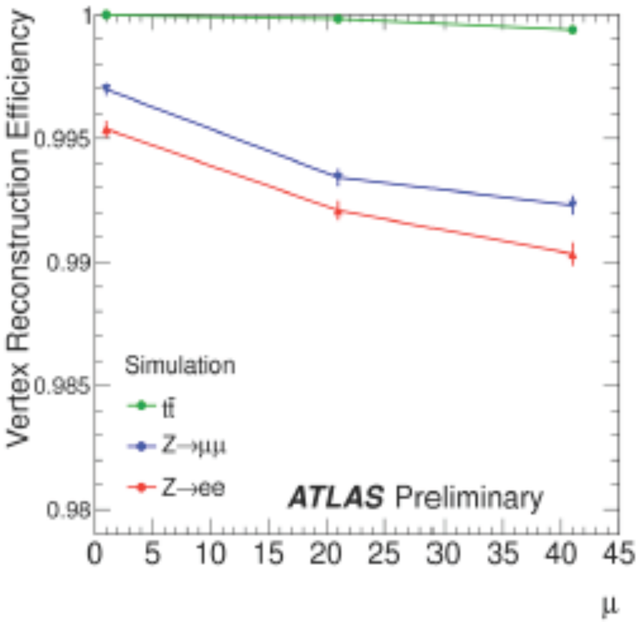




NOTE:
Design value expected to be reached at $L=10^{34}$!

A real challenge in 2012: PILE-UP



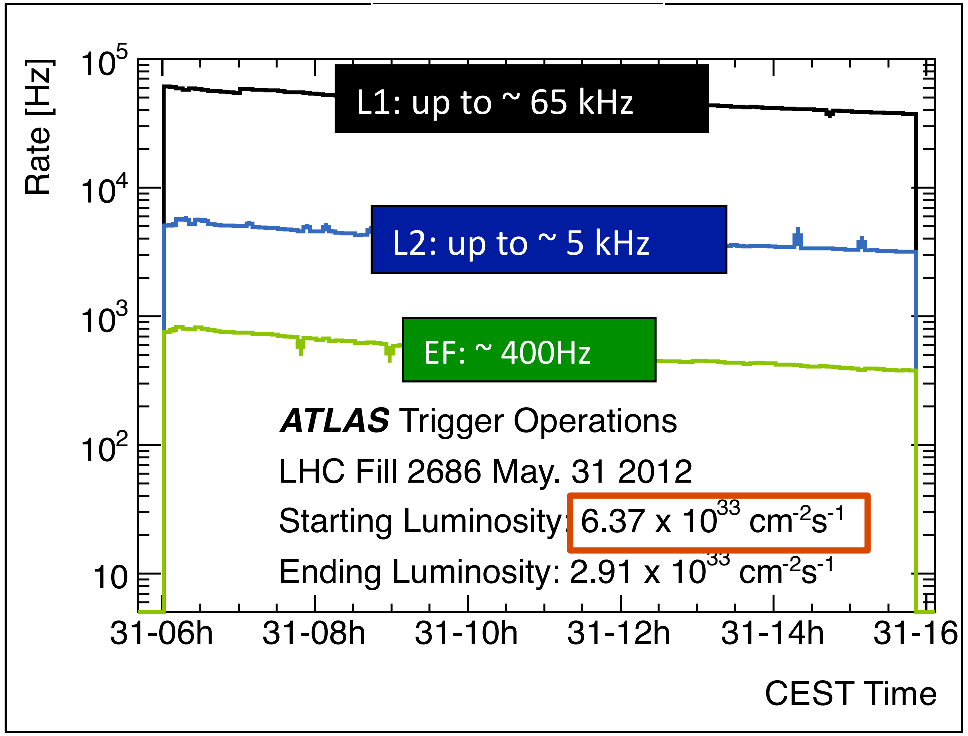


- Vertex reconstruction in the high track density environments is a challenging task
- Current reconstruction is performing well
    - Our vertex reconstruction efficiency remains very high
- The challenge is to:
    - Cleanly reconstruct each vertex
    - Select the correct vertex for your each analysis

Trigger in 2012

Optimization of selections (e.g. object isolation) to maintain low un-prescaled thresholds (e.g. for inclusive leptons) in spite of projected x2 higher L and pile-up than in 2011

Trigger rates



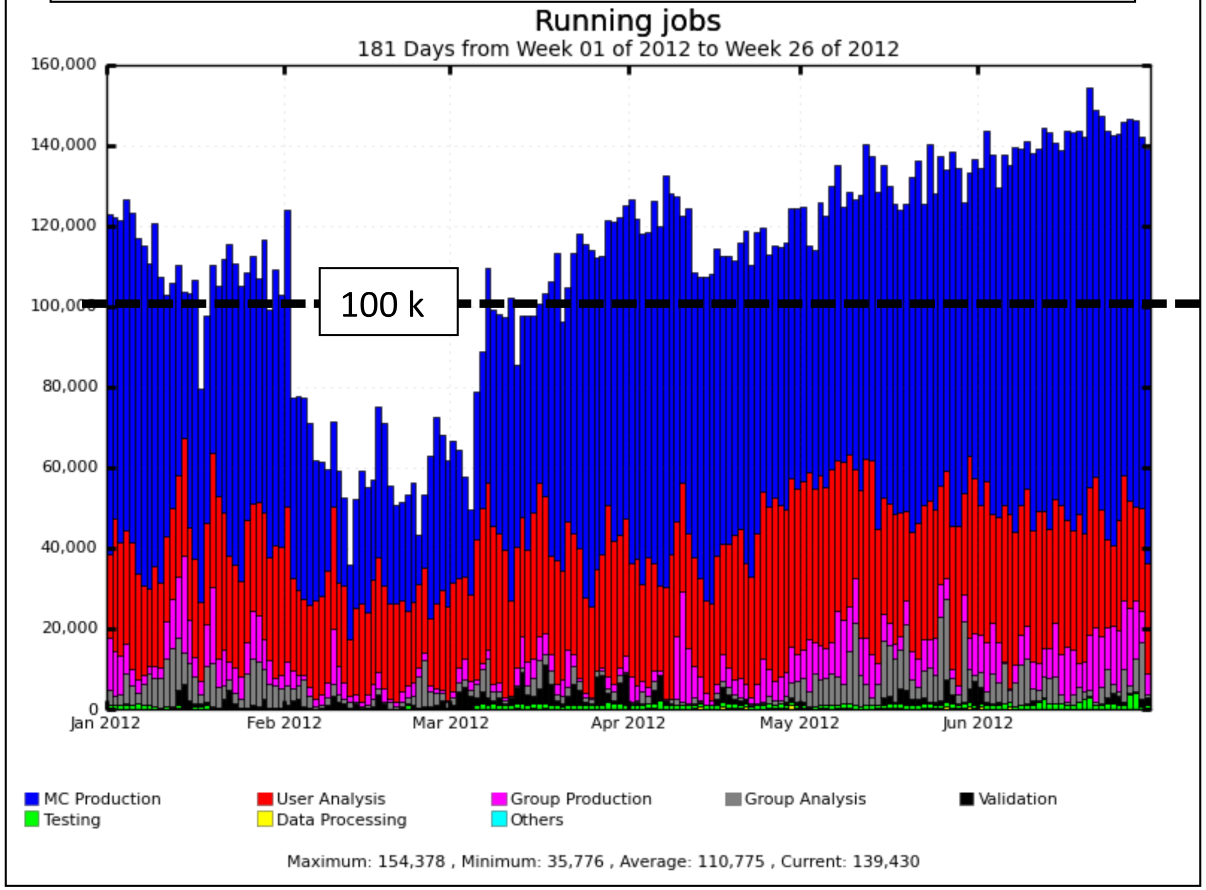
Lowest un-prescaled thresholds (examples)

Item	p_T threshold (GeV)	Rate (Hz) 5×10^{33}
Incl. e	24	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: ~ 500 items in trigger menu !

It would have been impossible to release physics results so quickly without the outstanding performance of the Grid (including the CERN Tier-0)

Number of concurrent ATLAS jobs Jan-July 2012



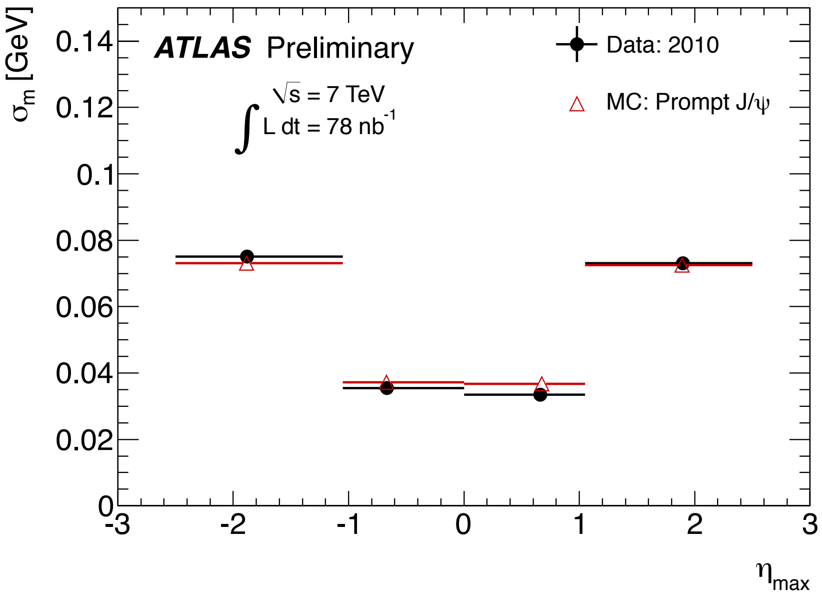
Includes MC production, user and group analysis at CERN, 10 Tier1-s, ~ 70 Tier-2 federations → > 80 sites

> 1500 distinct ATLAS users do analysis on the GRID

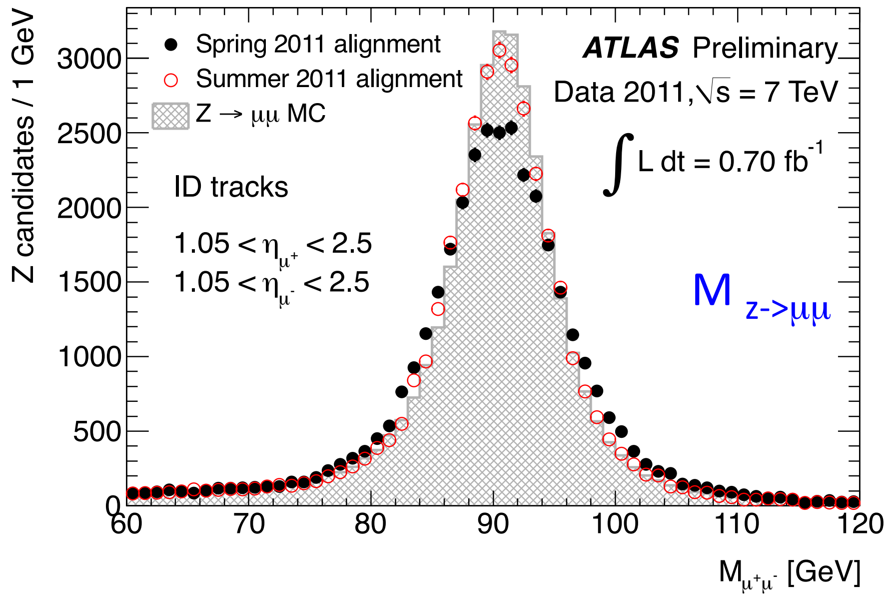
Inner detector performance

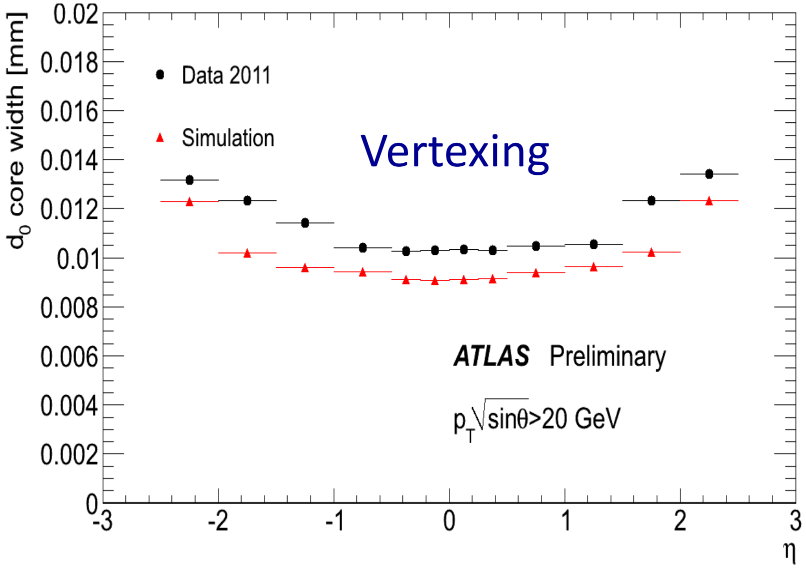
Tracking: combined Pixel, SCT and TRT (low level threshold)

Tracking



Alignment





P_t scale well determined

- at < % level at low P_t
- at % level at P_t~100 GeV

Vertex accuracy:

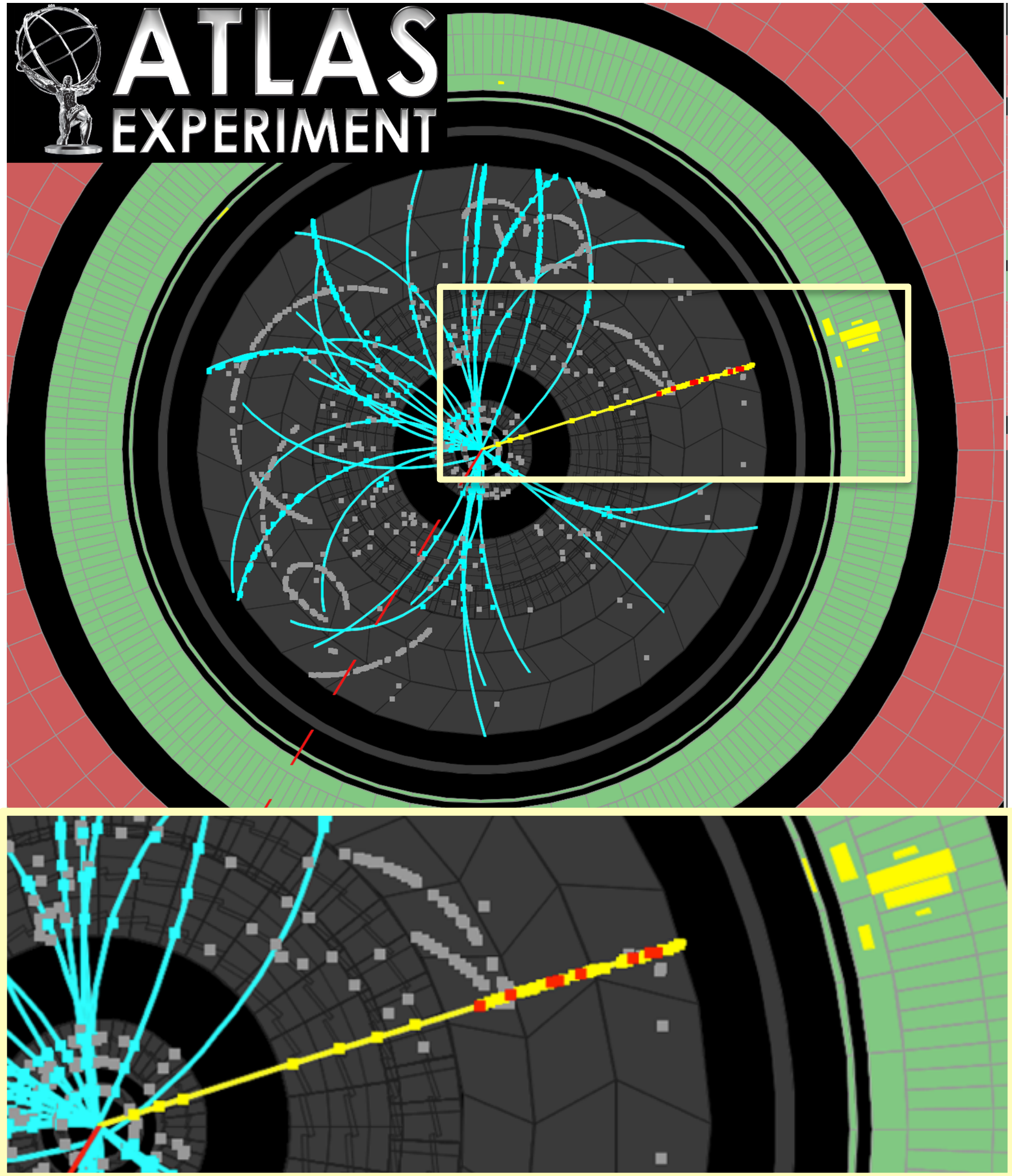
- ~ 10 μm

Data close to MC and close to design

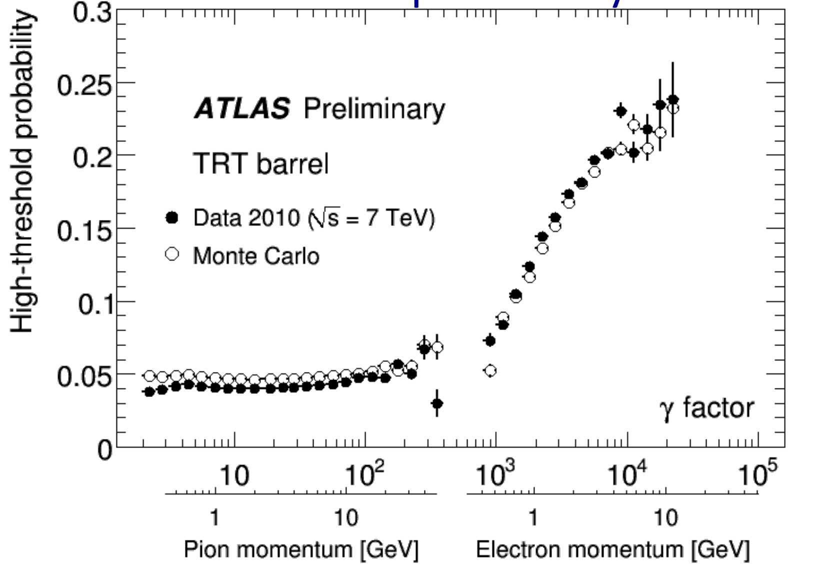
Inner detector performance

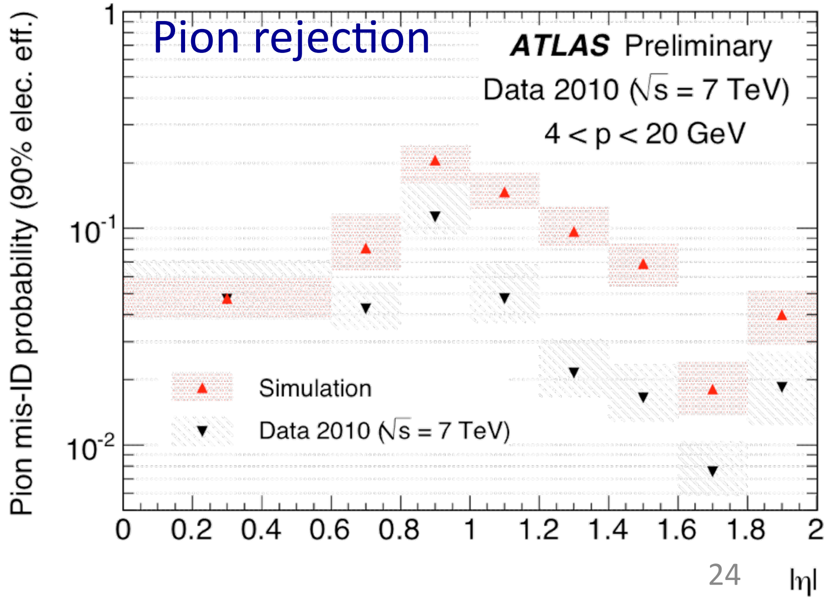
Particle identification with TRT (High level threshold)

W-> eν event display



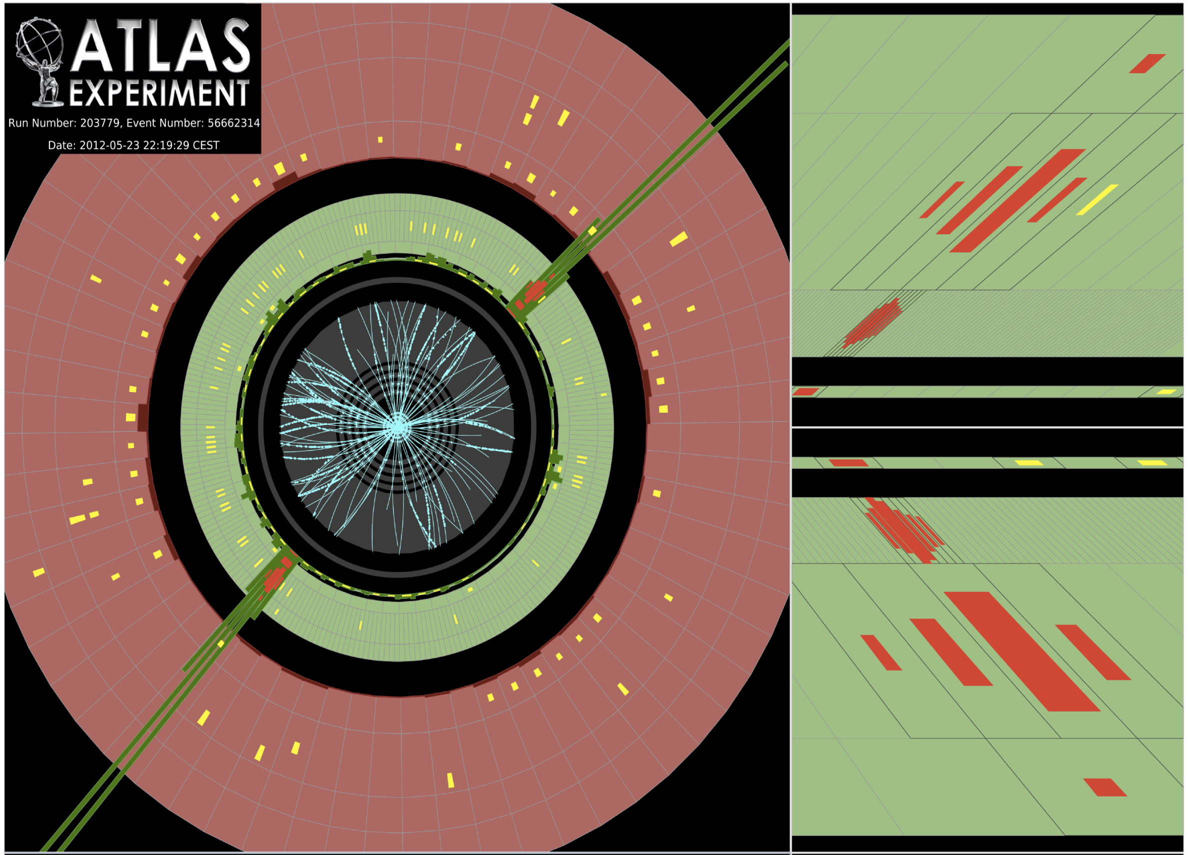
TR hit probability

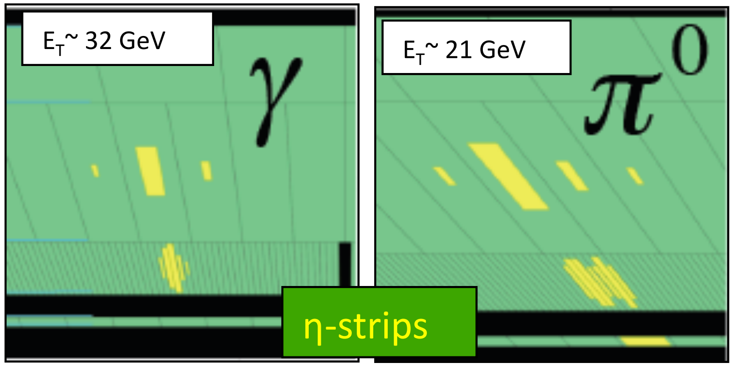




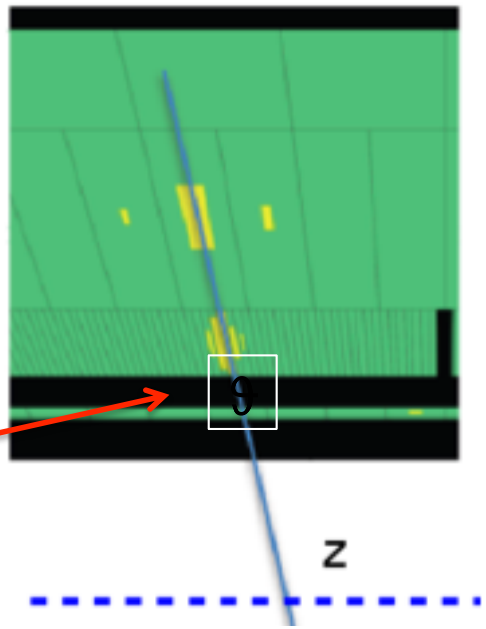
EM-Calo Performance

Fine granularity makes it a powerful identification instrument to suppress jet – background including **jet → π^0 → fake γ** (cross sections are **10^4-10^7** larger than γγ background)





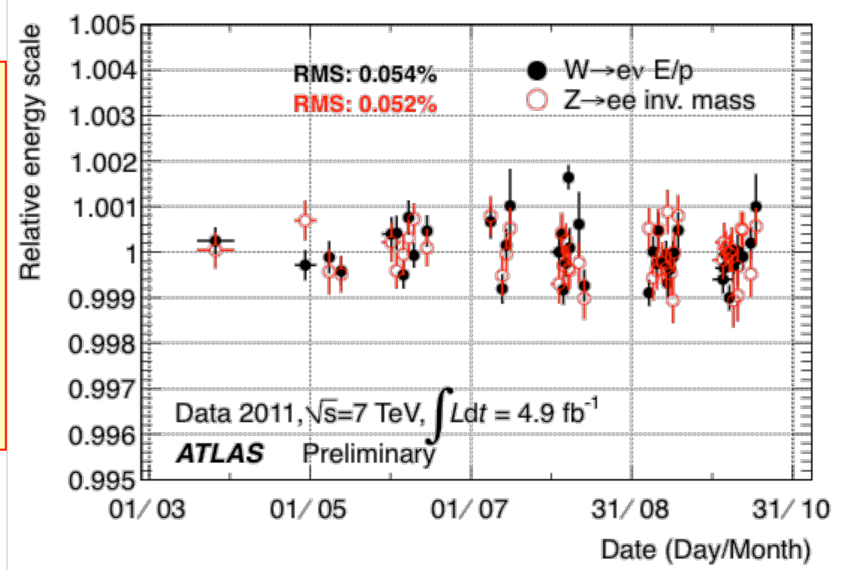
Measurement of the photon direction with calorimeter allows to define Z of primary vertex with accuracy of ~ 1.5 cm

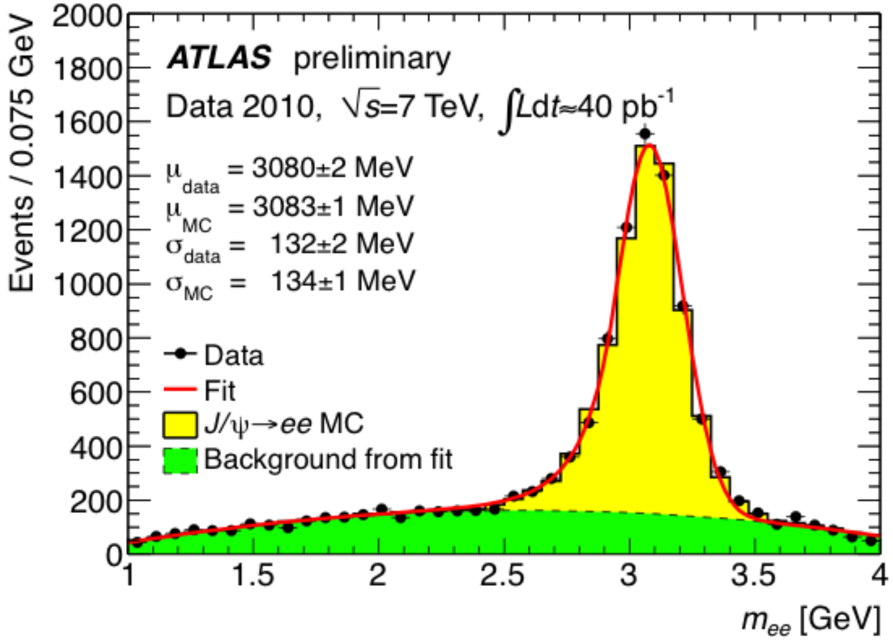


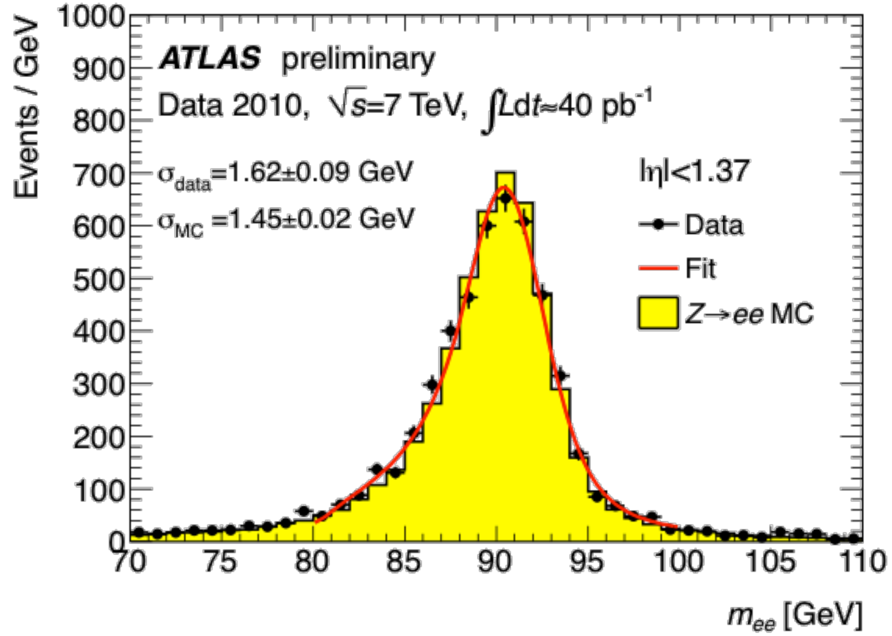
EM-Calo Performance

Present understanding of calorimeter:

- E-scale at m_Z known to ~ 0.3%
- Linearity better than 1% (few-100 GeV)
- "Uniformity" (constant term of resolution): ~ 1% (2.5% for 1.37<|η|<1.8)
- Very well described by MC model

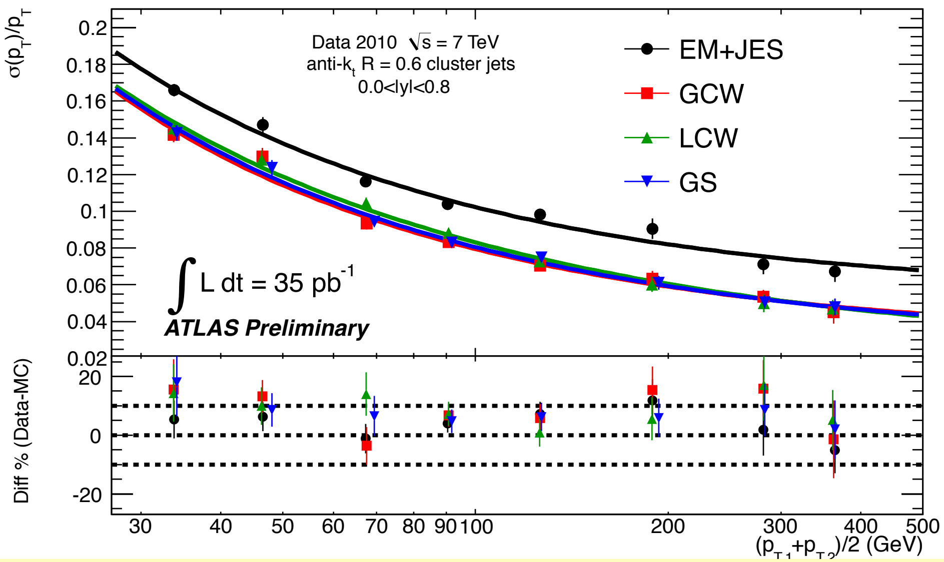




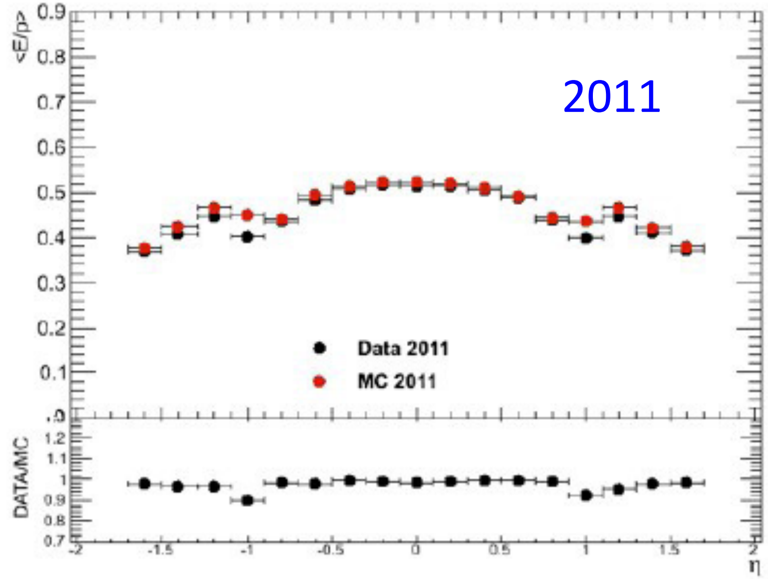


Hadron calorimeter performance

Jet resolution (Lar+Tilecal (|η|<0.8)



E/p response in Tile had. calorimeter



Resolution close to design:

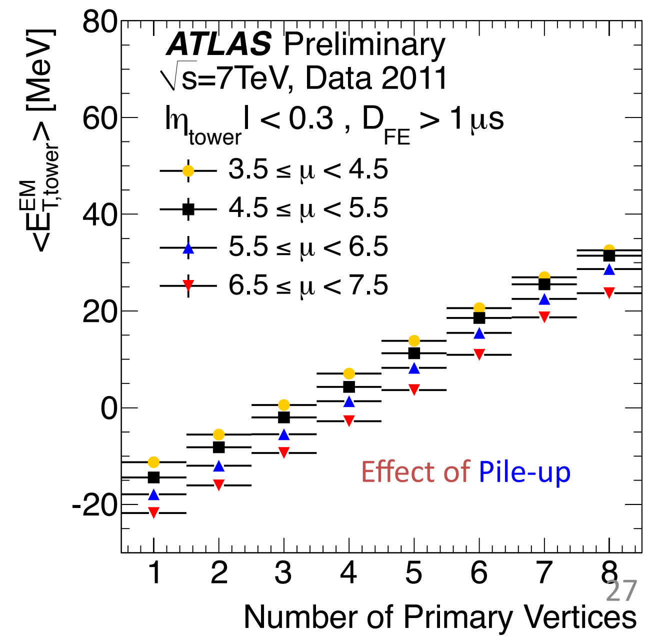
- constant term ~3% at ~2TeV (GCW/LCW/GS calibrations)

Pile-up effect:

- worsens low pt resolution by ~20%.
- Improvements expected after pile-up corrections for in-time/out-time bunches/noise threshold tuning

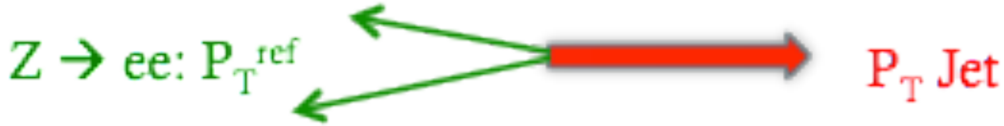
Good performance, agreement with MC

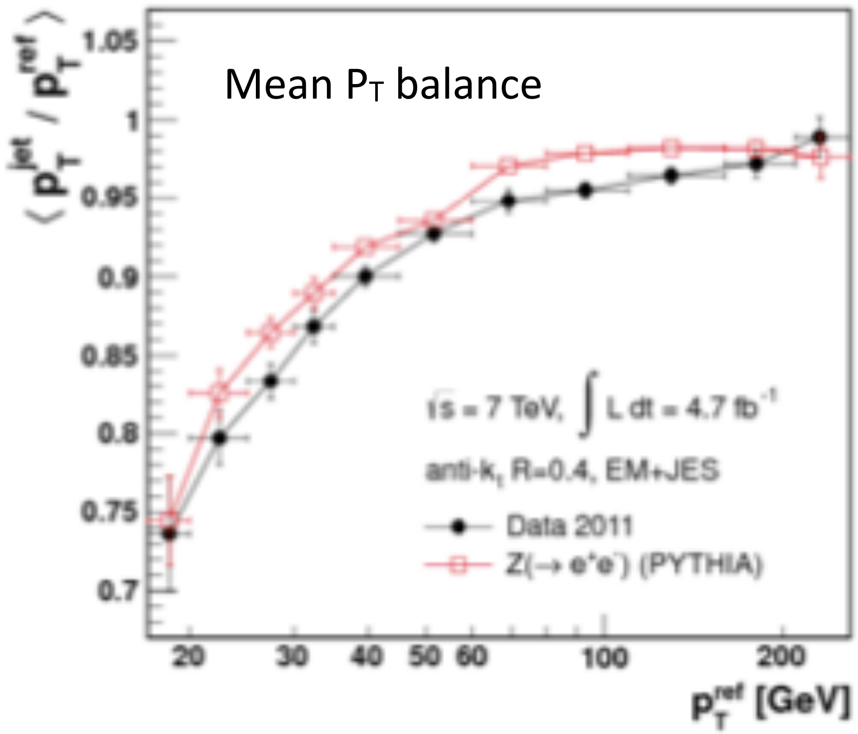
- thanks to >10 years test-beam, cosmics.

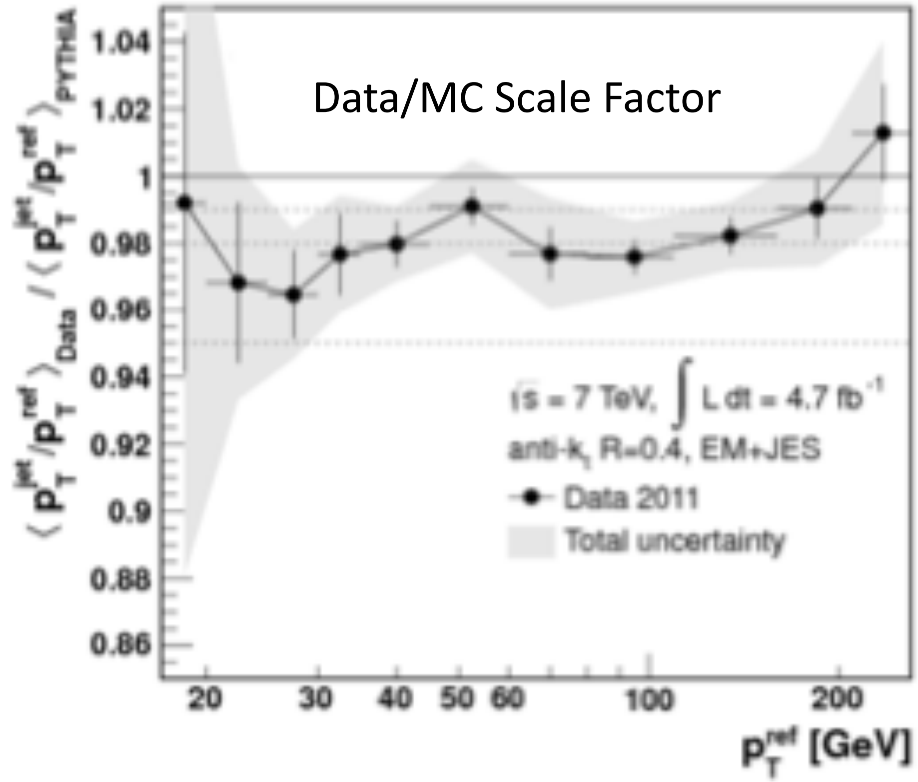


Hadron calorimeter performance

Understanding detector performance basic ingredient of all physics analyses,
Jet Energy Scale is one of the main systematics of precision measurements and searches

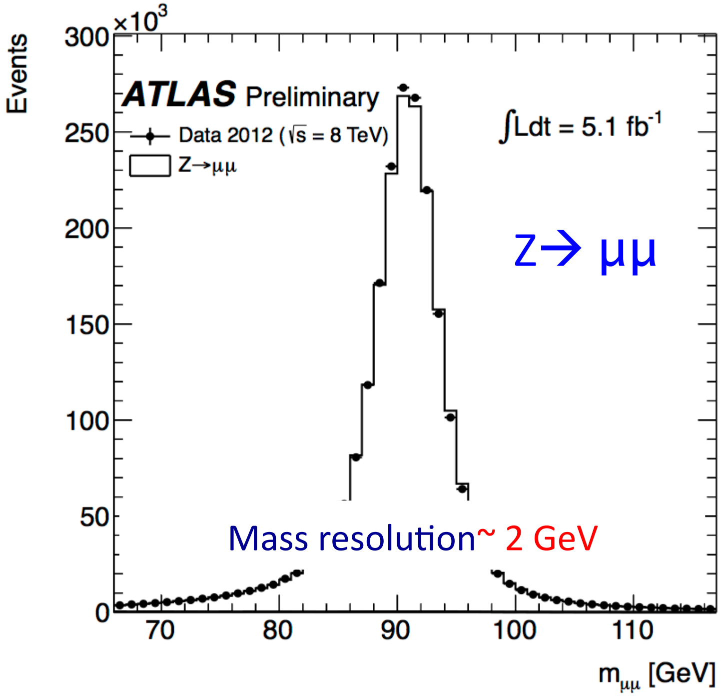


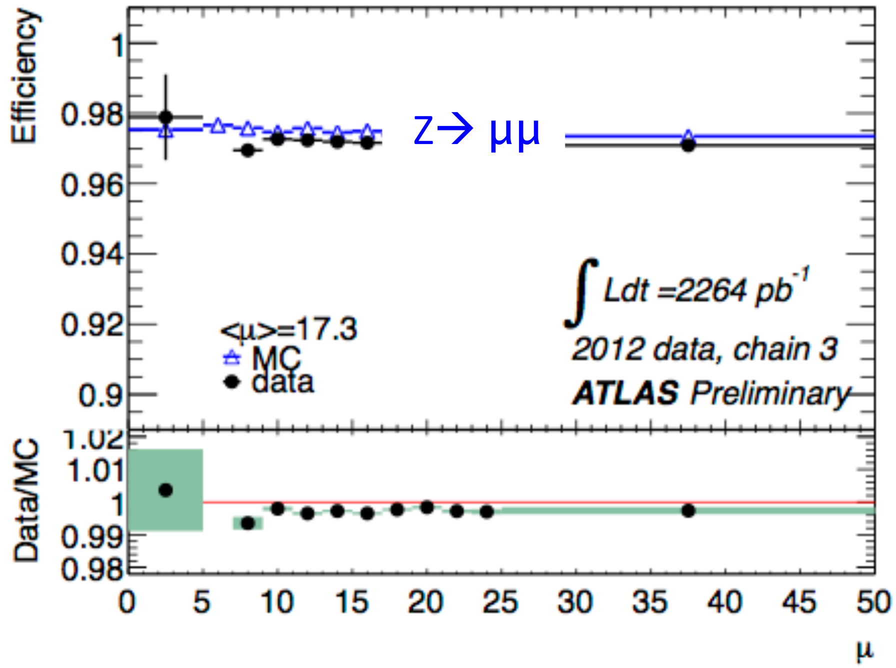




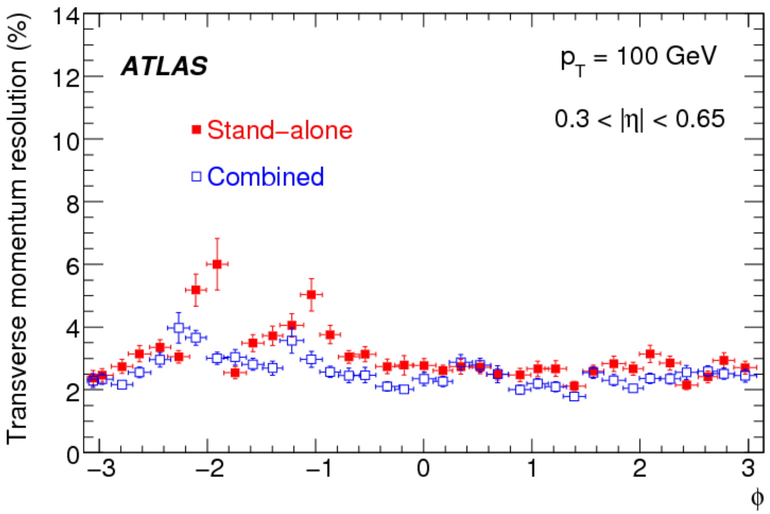
Data/MC *in situ* Jet Energy Scale determined with **2% accuracy above 25 GeV** and constrains JES uncertainty down to 15 GeV

Muon Spectrometer performance





~99%



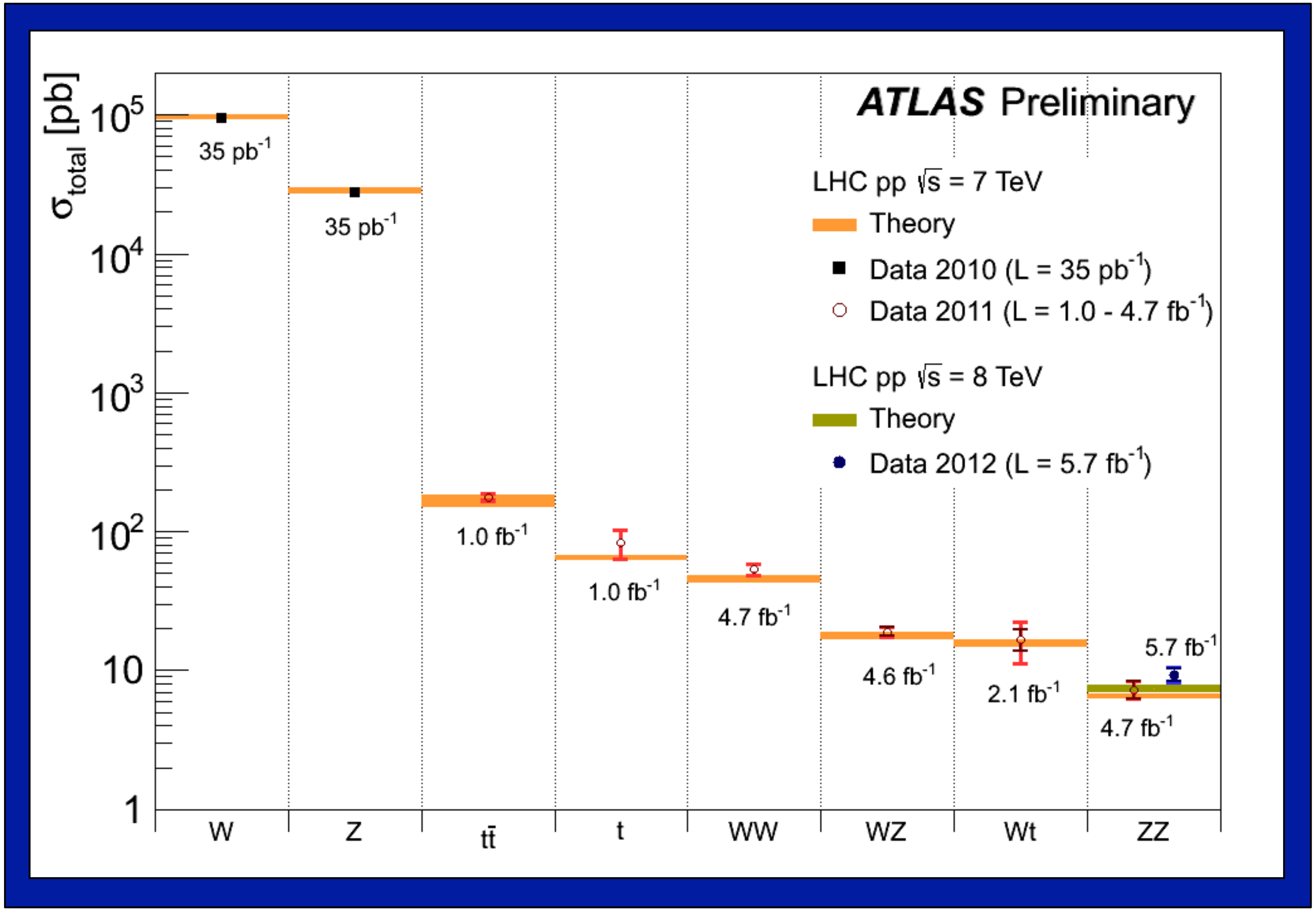
Muons reconstruction:

- reconstruction efficiency ~ 97%, ~ flat down to p_T ~ 6 GeV and over |η|~2.7

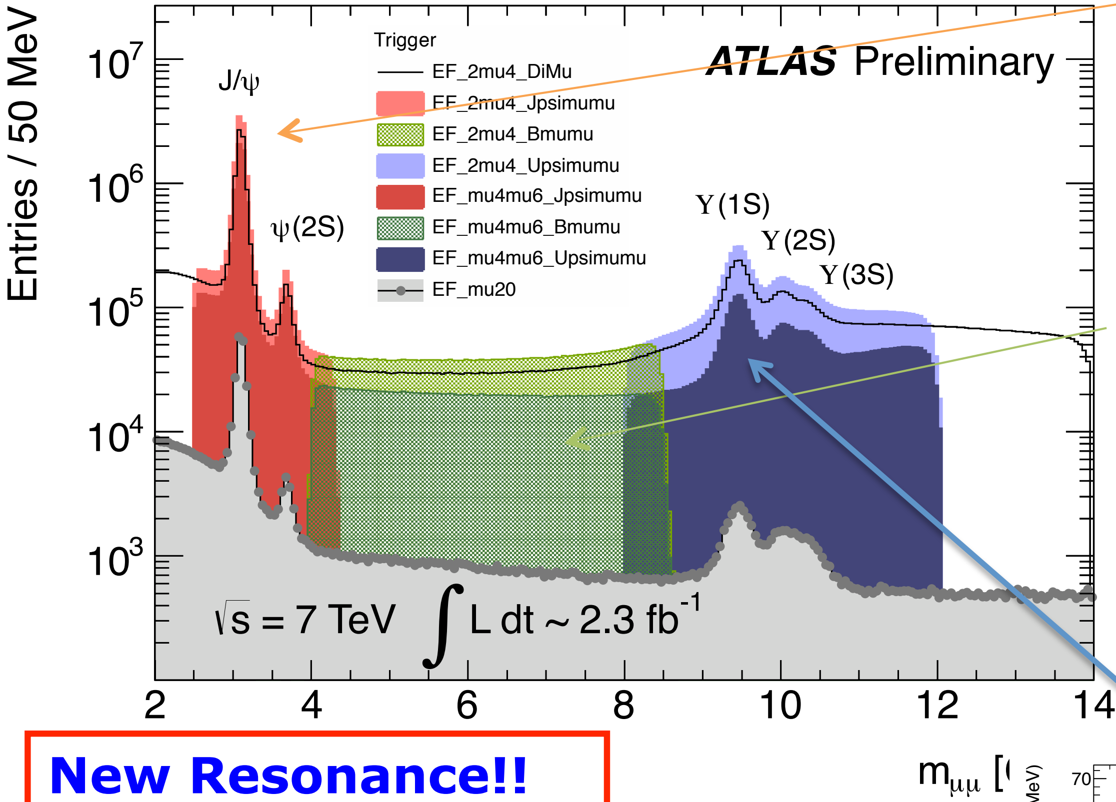
•$\sigma p_T/p_T$ close to design up to ~100GeV:
- At low P_t mult. scattering in ID dominate (~2%)
- TeV region improvement after better alignment

•Good agreement data-MC

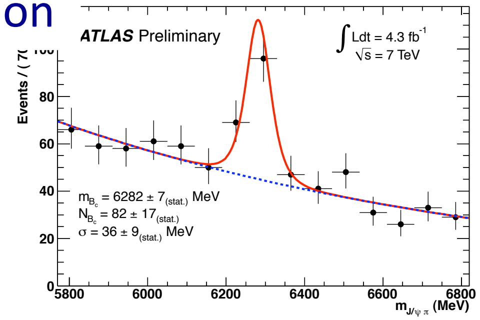
Some physics results: Standard Model cross sections



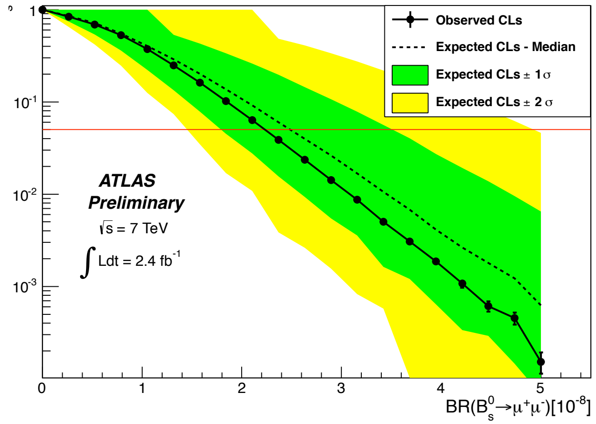
Some results: Muon Resonances



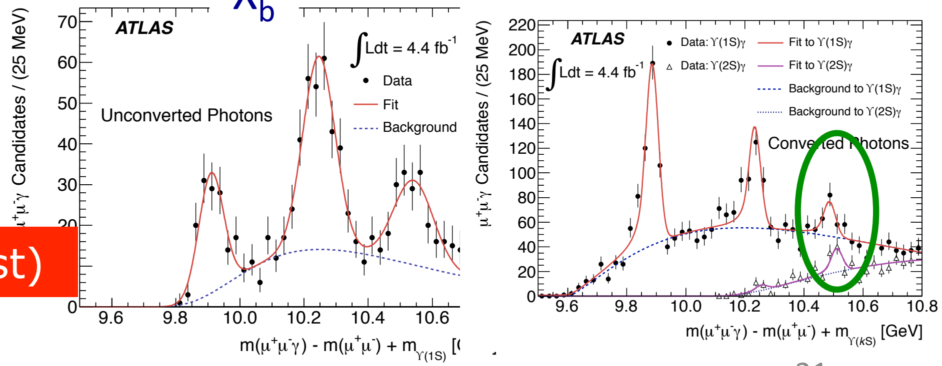
B_c observation



B->μμ



X_b



New Resonance!!

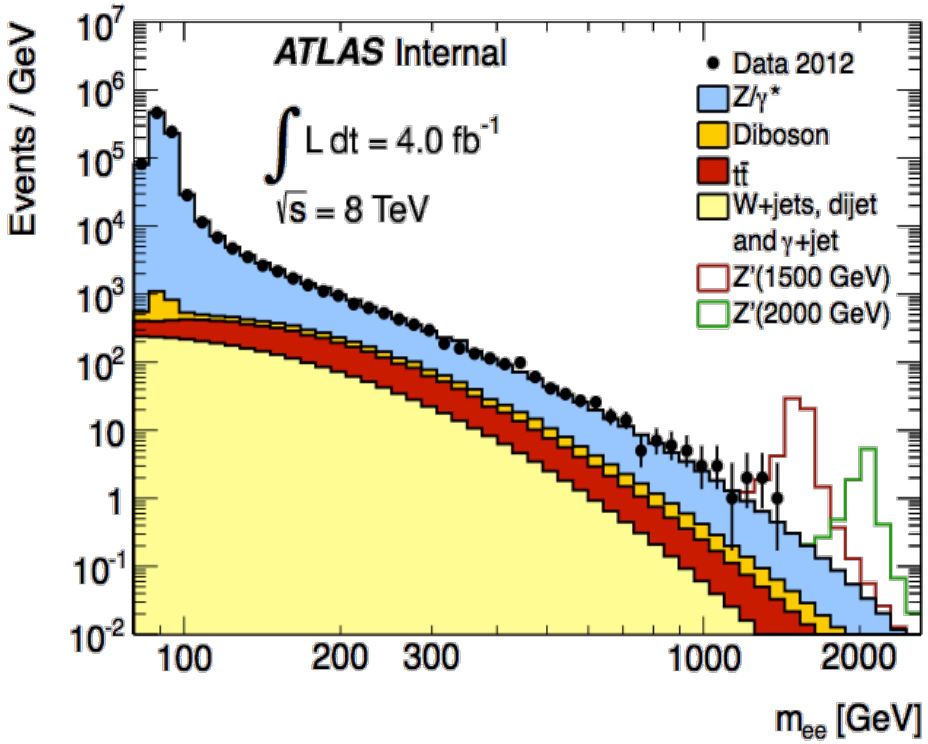
$X_b(3P) \to Y(1s, 2s)\ \gamma$

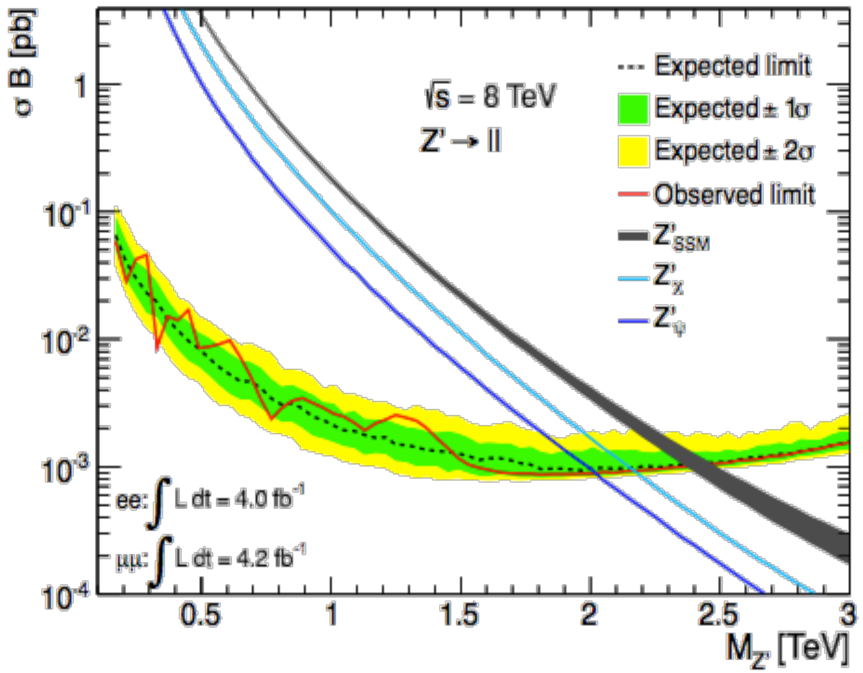
$M[X_b(3P)] = 10.539 \pm 0.004\ (stat) \pm\ 0.008\ (syst)$

Some results: Searches with leptons

Heavy gauge boson: Z', W':

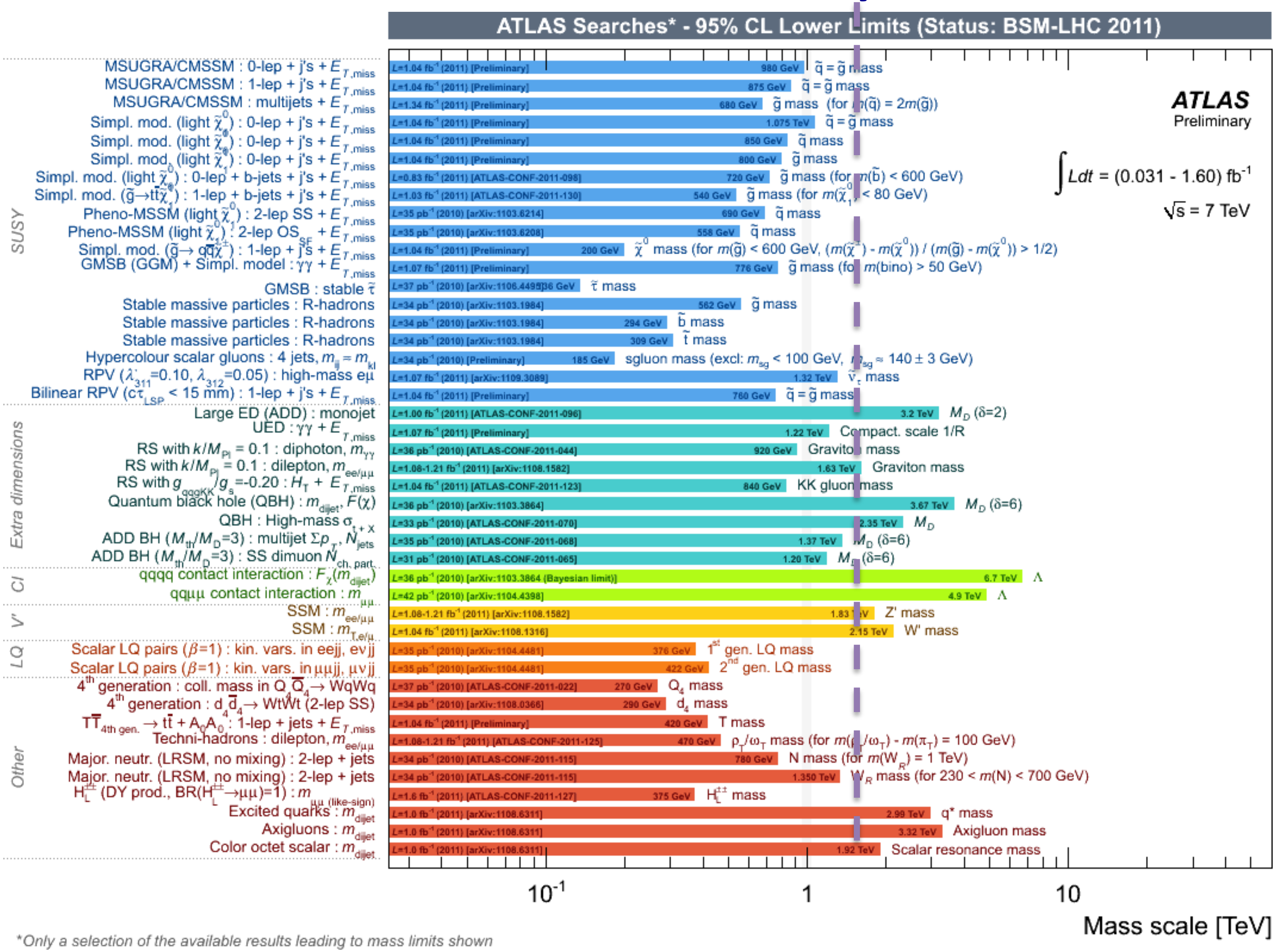
SSM limits	E_{cm}	Observed	Expected
Z'→ee,μμ	8 TeV	2.42 TeV	2.41 TeV
Z'→ee,μμ	7 TeV	2.21 TeV	2.26 TeV
W'→eν,μν	7 TeV	2.55 TeV	2.55 TeV
Z'→ττ	7 TeV	1.3 TeV	1.4 TeV





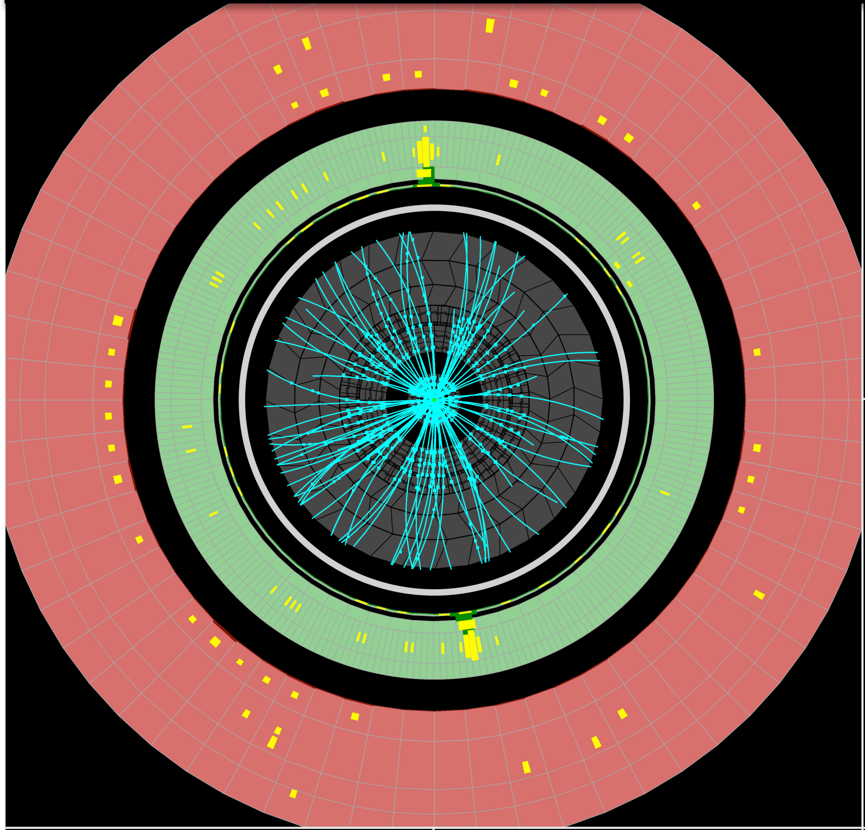
Summary of Beyond Standard Model searches:

TeV limit reached in many cases!



A new state with M~126 GeV

compatible with SM Higgs Boson

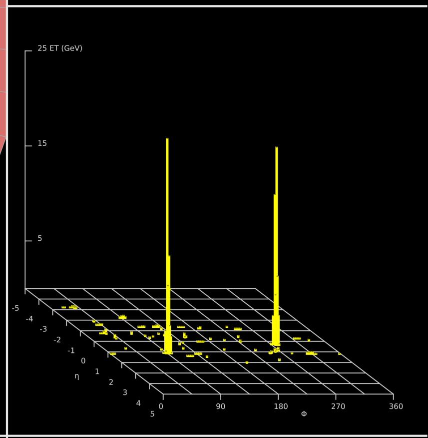


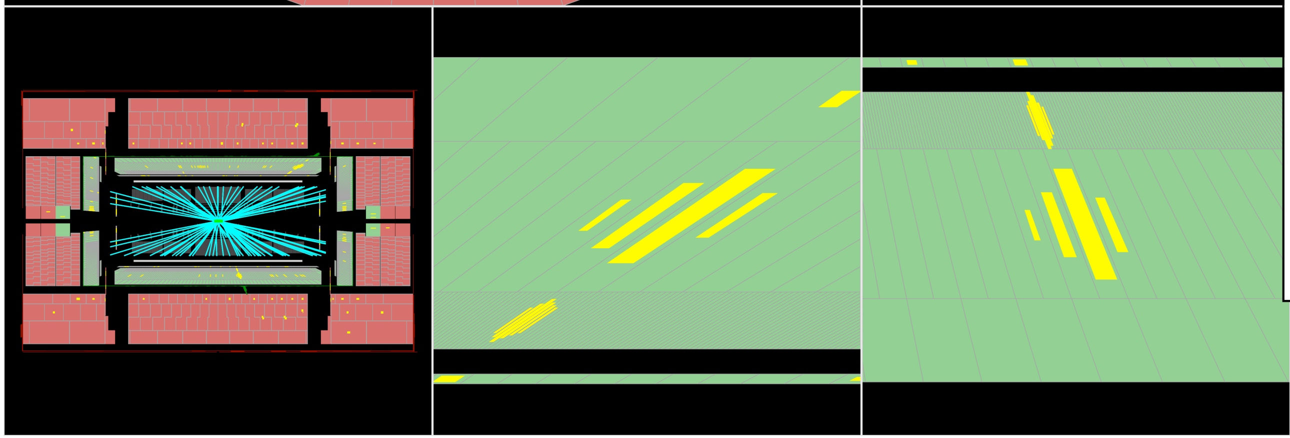
ATLAS EXPERIMENT

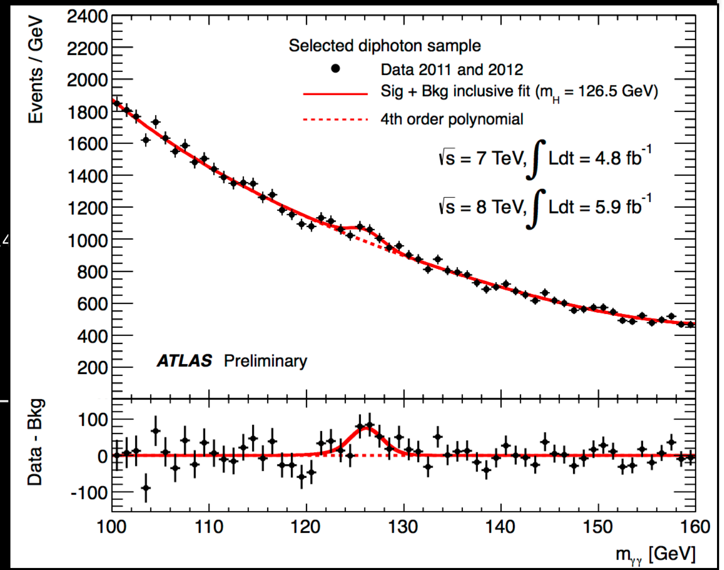
Run Number: 203779, Event Number: 56662314

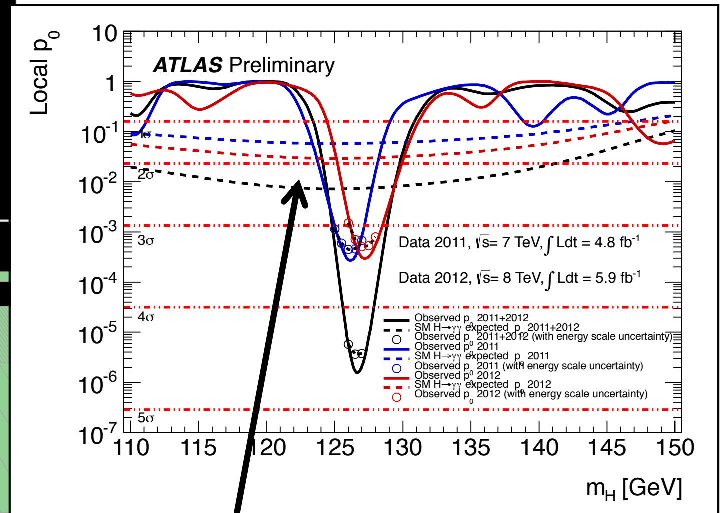
Date: 2012-05-23 22:19:29 CEST

γγ – channel





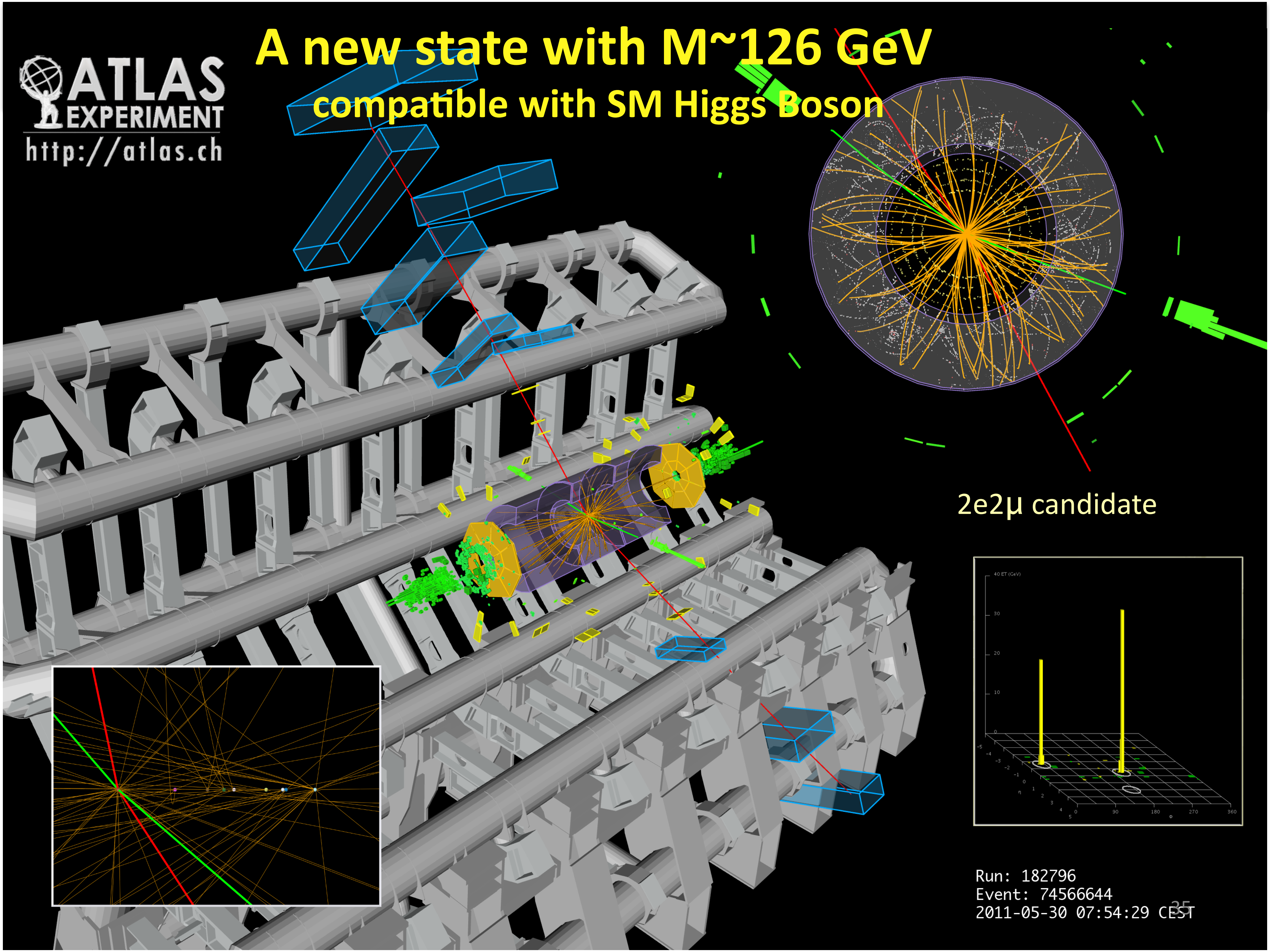




Expected from SM Higgs at given m_H

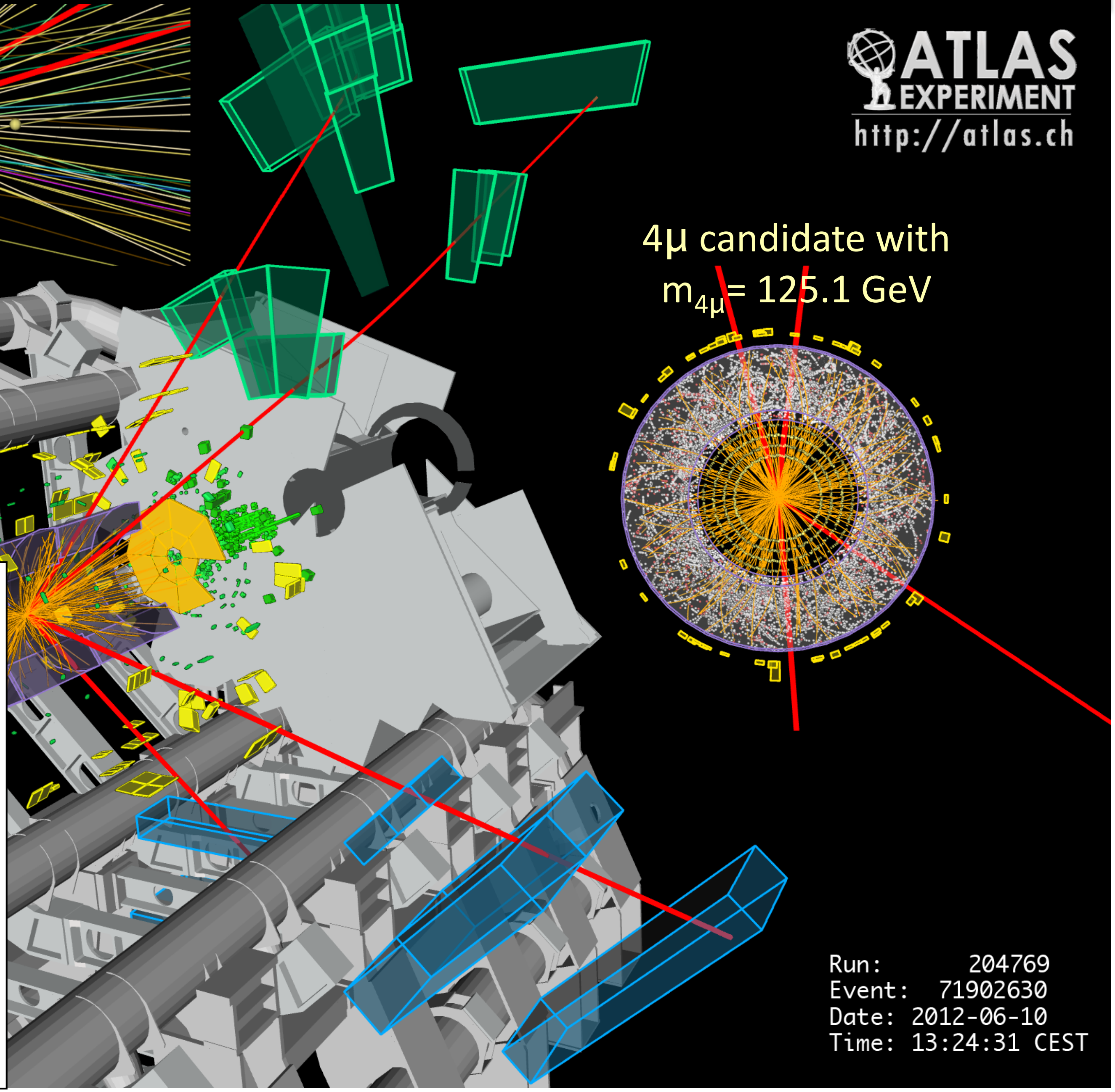
A new state with M~126 GeV

compatible with SM Higgs Boson

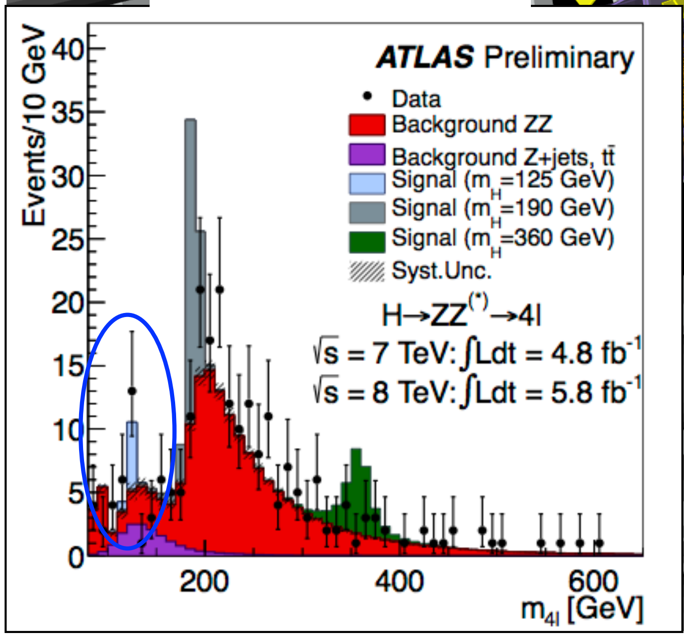


A new state with M~126 GeV

compatible with SM Higgs Boson



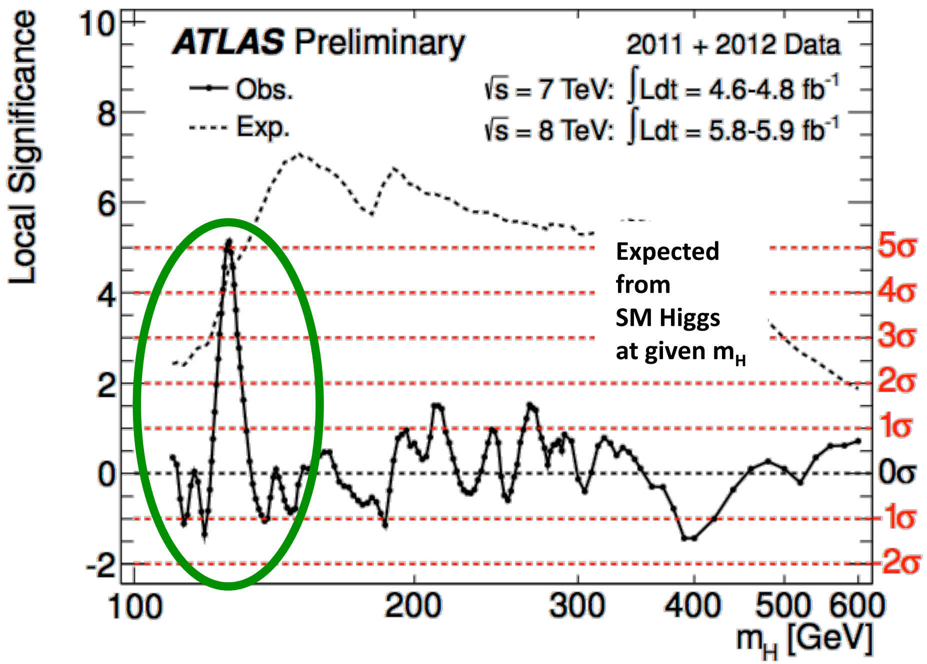
4 lepton channel

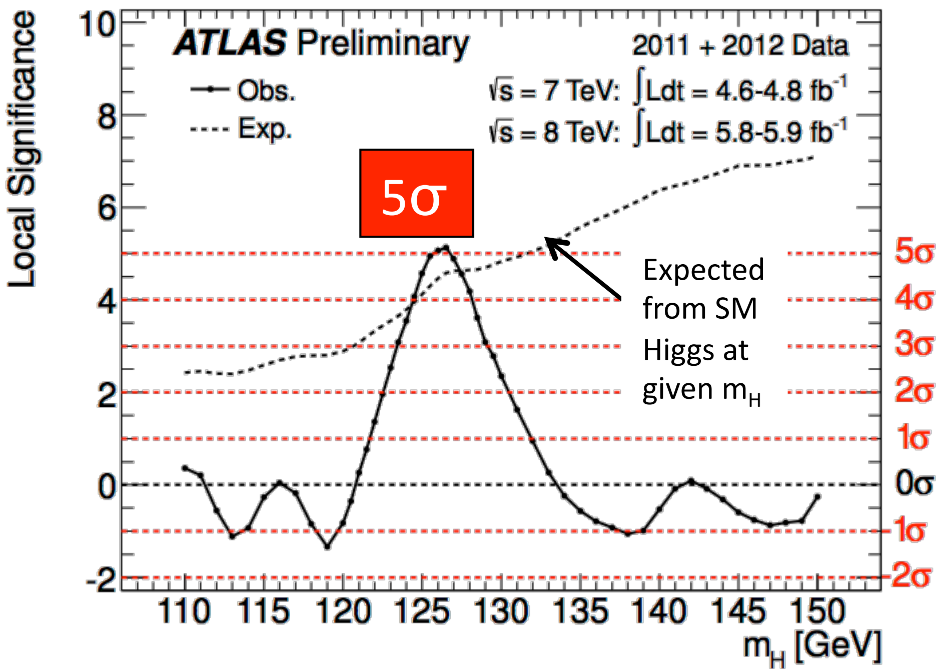


Combined results: The Excess!!!

Excellent consistency (better than 2σ !) of the data with the background-only hypothesis over full mass spectrum

except one region!

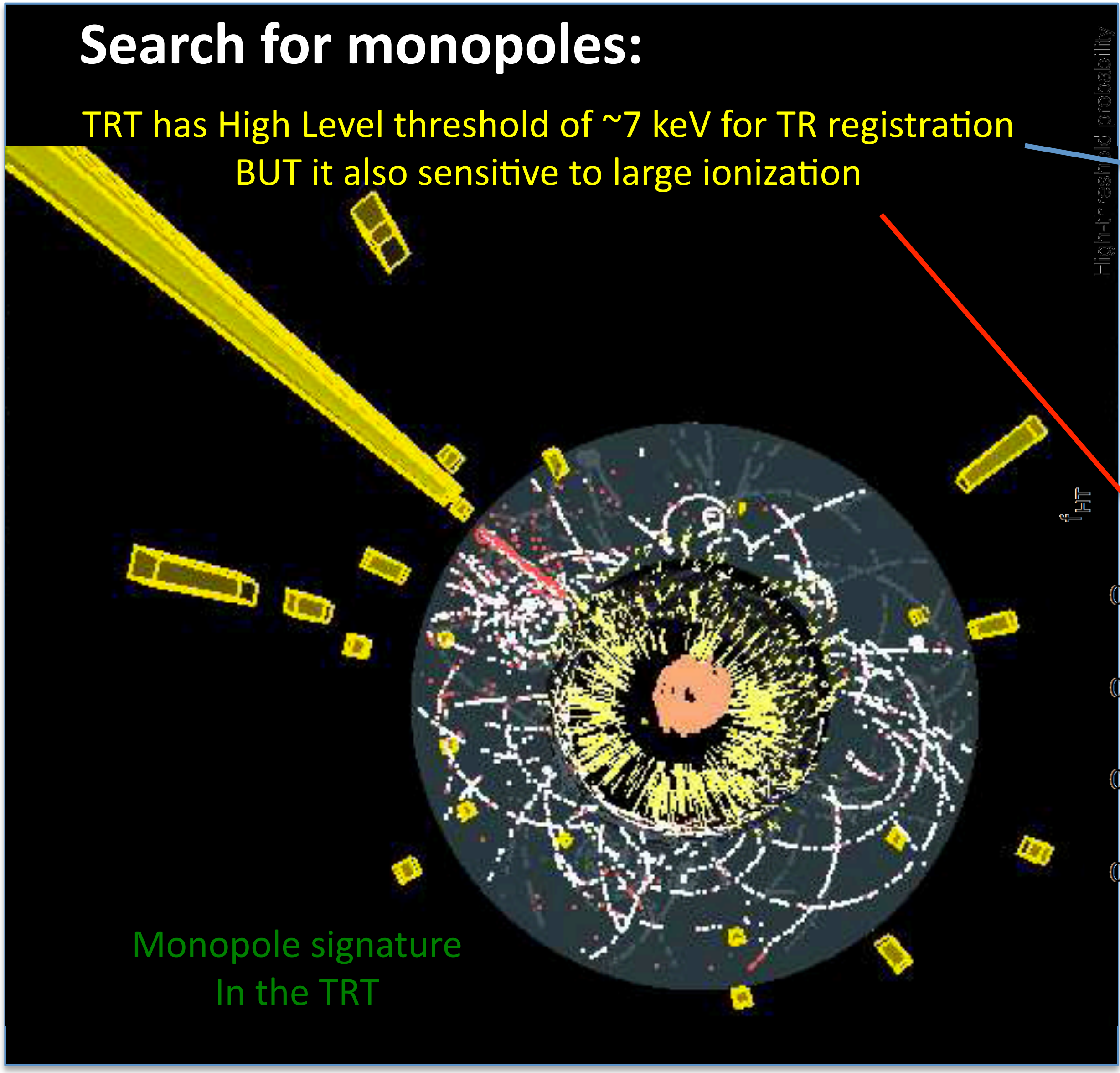


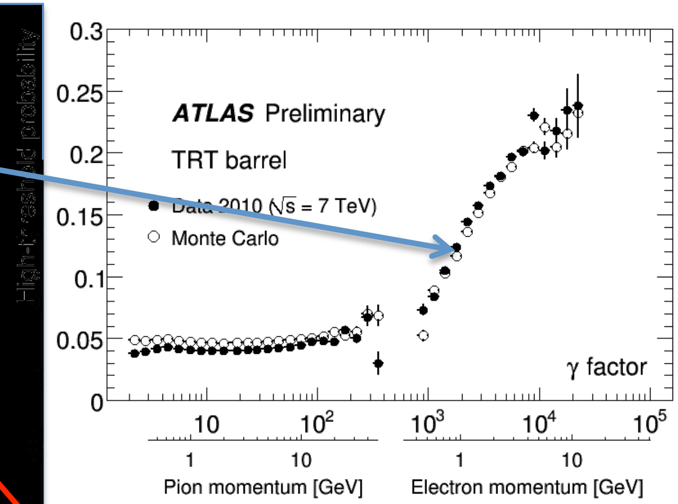


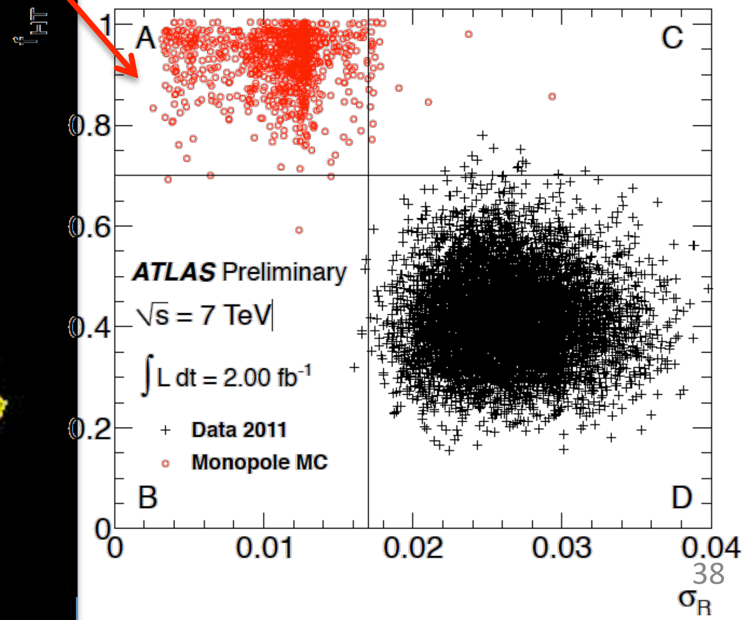
A new state with M~126 GeV!

What ATLAS can do for the physics with non-standard particles in a final state?

A few examples:







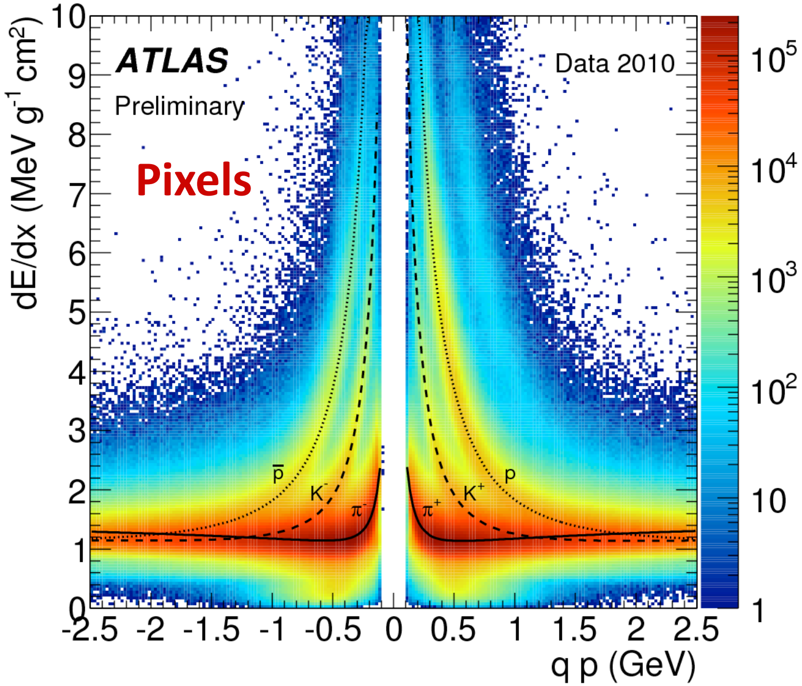
What ATLAS can do for the physics with non-standard particles in a final state?

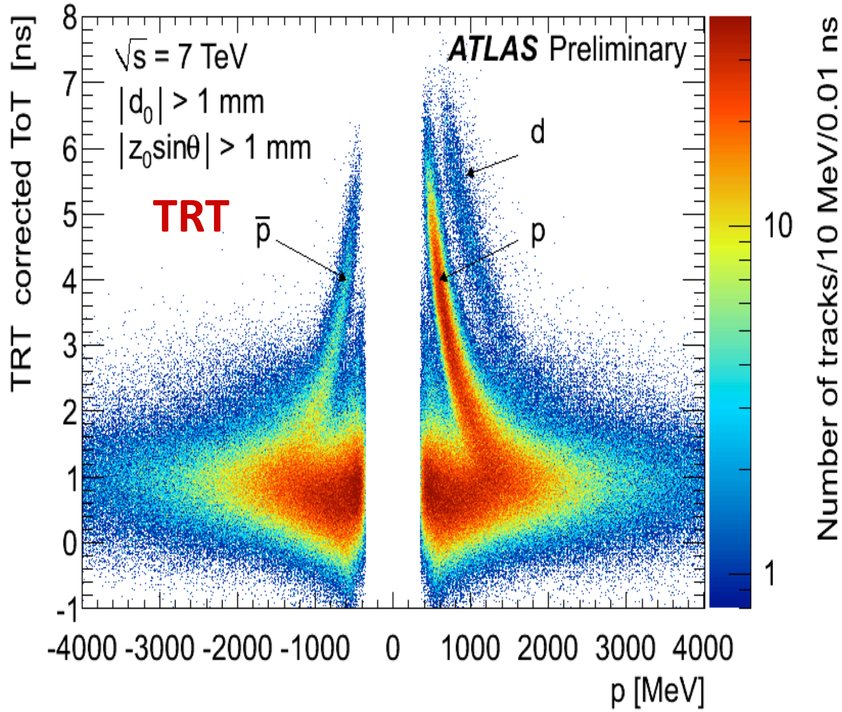
A few examples:

Search for particles with anomalous ionization:

Many subsystems provide dE/dx information on the particle track

Pixels, TRT, LAr-cal, Tile Cal, MDT – A powerful tool discovery instrument!





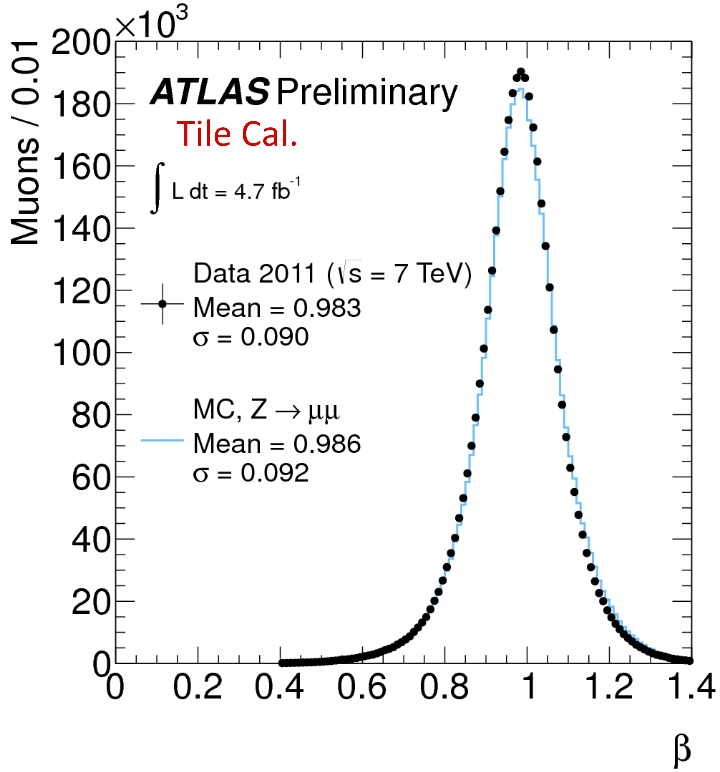
What ATLAS can do for the physics with non-standard particles in a final state?

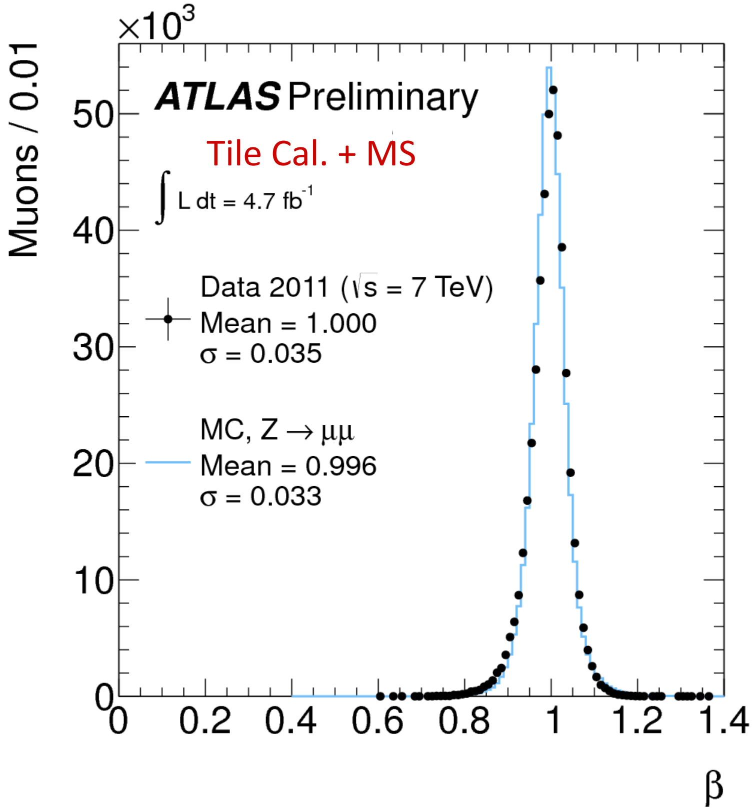
A few examples:

Search for slow particles.

β is measured in 3 systems Tile Cal, RPC and MDT.

A combination all detectors allow to measure β with accuracy ~3.5%





LHC plans (LS1, LS2, LS3)

LS = Long Shutdown

2009		LHC start up, $\sqrt{s}$ = 900 GeV	
2010–2012		$\sqrt{s}$ = 7-8 TeV , L = 6 to 8•10^{33} $cm^{-2}s^{-1}$, bunch spacing **50 ns**	~25 fb^{-1}
2013–2014	LS1	Go to design energy, nominal luminosity	
2015–2017		$\sqrt{s}$ = 13-14 TeV, L = 1•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•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•10^{34} $cm^{-2}s^{-1}$, bunch spacing **25 ns** **Plan for 50% more**	~3000 fb^{-1}

A real challenge!

SLHC

Conditions

- sLHC beyond ATLAS design specification (10^{34} $cm^{-2}s^{-1}$).
- Interactions per crossing: design **23** ->**80** Phase-I -> **200** Phase-II.
- High radiation, harsh environment.
- Higher occupancy in the detectors.

What for it is needed?

Higgs studies:

– 300 fb-1 : observe all H decay modes

– 3000 fb-1 : precision measurements of Higgs properties

- Mass 0.1%, width and rates < 10%
- Couplings (WWH, ZZH, ttH) 10-20% -> 5-10%

With 3000 fb-1, we can increase the mass range for:

– Boson-boson scattering

– SUSY (exclude or extend the kinematic range)

– New gauge bosons: Z', W'

– Compositeness

– Extra-dimensions

– SM physics (TGC)

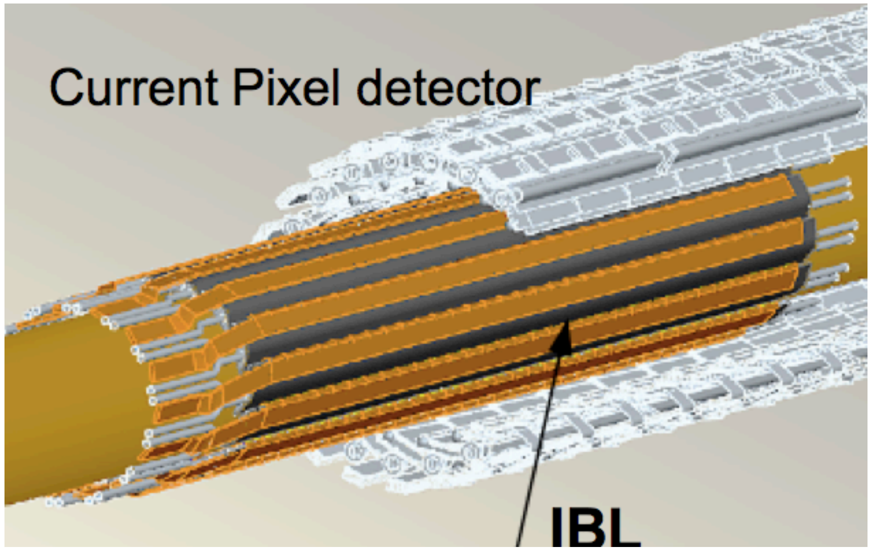
ATLAS is already preparing to run at a much higher luminosity in the forthcoming years, a new challenge to overcome the present limits

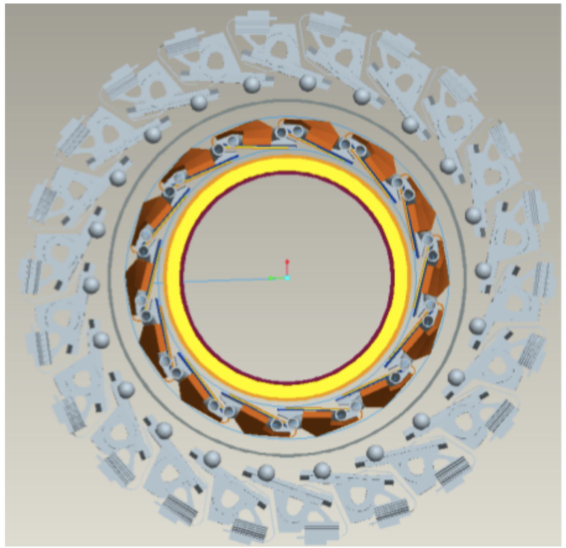
Phase-0 (installation 2013-14)

Main Improvements to Physics Capabilities

1. New small Be pipe
2. New insertable pixel b-layer (IBL) (drives shutdown schedule)
3. Finish the installation of the EE muon chambers staged in 2003.
4. Add topological processing in level 1 of trigger
5. Improve L1 trigger readout rate to 100kHz

Important!
IBL preserves current physics performance at high pileup



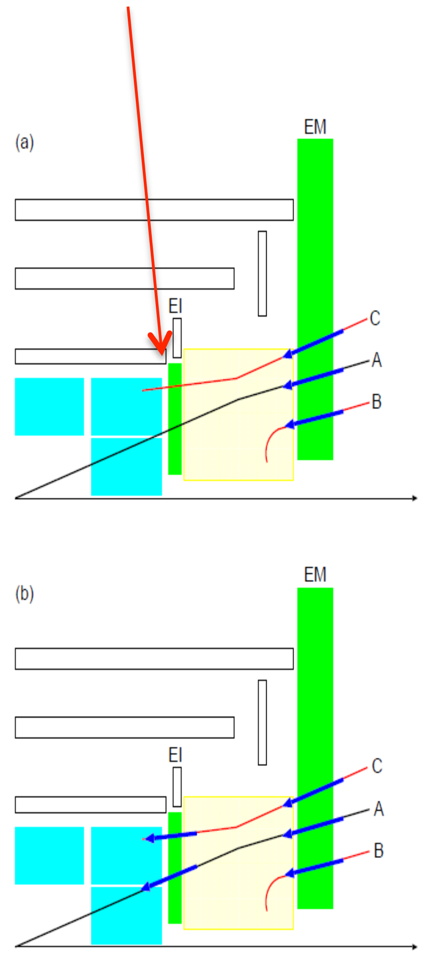


Phase-I (installation ~ 2018)

Major Projects

1. New muon small wheels with more trigger granularity and trigger track vector information.
2. Higher-granularity calorimeter LVL1 trigger and associated front-end electronic.
3. Fast track processor (FTK) using SCT and pixel hits (input to LVL2) expected installation before 2018.
4. Forward physics detection station at 220m for new diffractive physics (full 3D edgeless and timing detectors, target 2017).
5. Topological trigger processors combining LVL1 information from different regions of interest (improvements starting well before 2018).

New muon small wheel



B and C - background

Phase-II (installation 2022-23)

Upgrades:

1. New Inner Detector (strips and pixels)
2. New LAr front-end and back-end electronics
3. New Tiles front-end and back-end electronics
4. TDAQ upgrade (add level 0 to the trigger?)

Under study:

1. LAr new FCAL
2. LAr HEC cold electronics consolidation
3. Muon Barrel and Large Wheel system upgrade
4. L1 track trigger
5. LUCID upgrade

Conclusions

- An excellent detector with a great discovery potential built and successfully operates exceeding designed limits.
- Many SM results and exiting discovery already now.
- No sign of a new physics up to 1 TeV mass region (will be extended in many cases up to 2 TeV and more by the end of 2012).
- New break through may happen after long shutdown (2013-2014) when energy will rise up to 13-14 TeV in CM.
- Years 2018-2022 luminosity production up to 300 fb^{-1}.
- Significant extension of the rate capabilities after detector modifications in 2022.
- Years > 2022 detailed studies of known by that time particles and search for rare events.


We managed to catch one!
衆瞽探象之圖
What next?