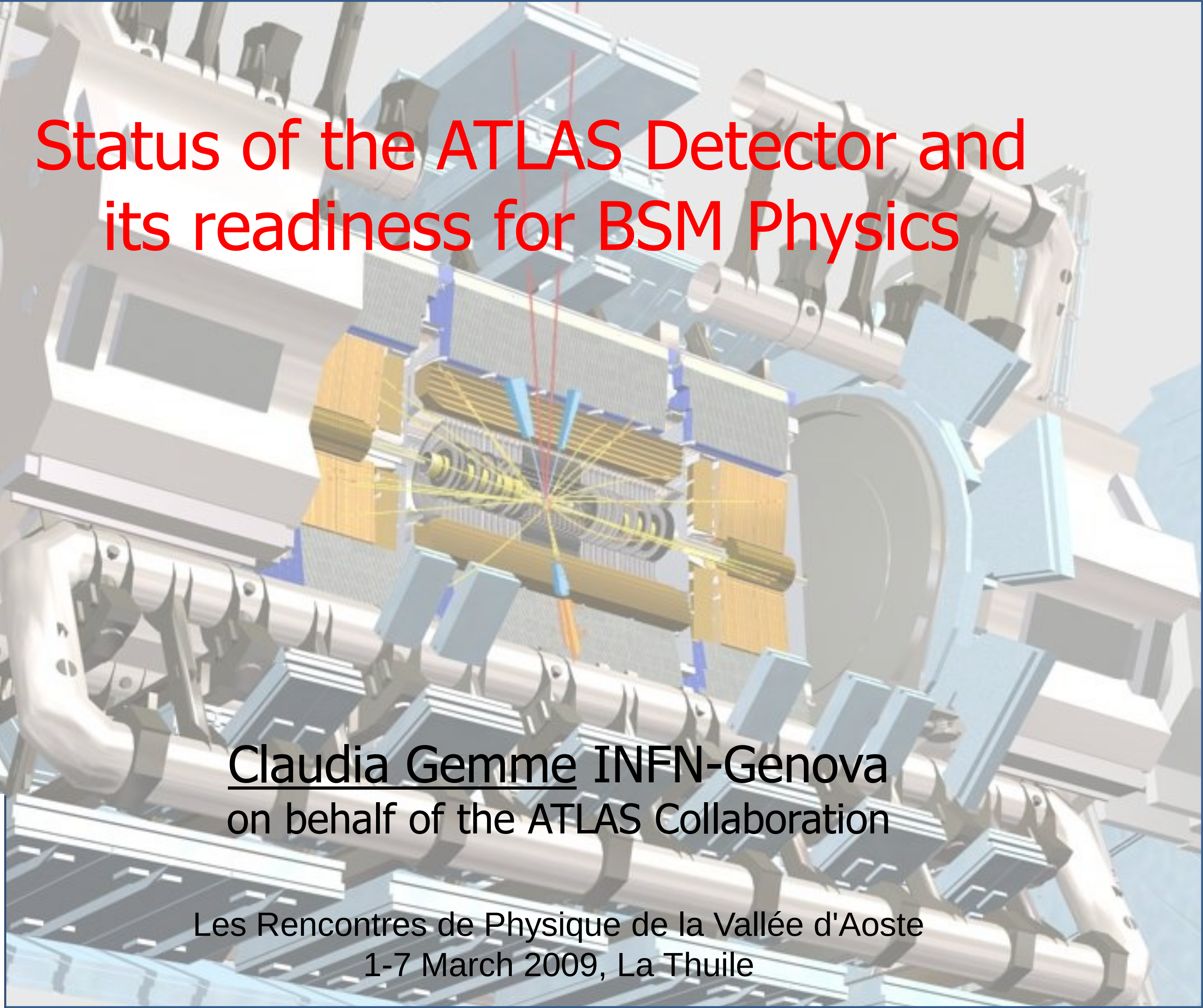


Status of the ATLAS Detector and its readiness for BSM Physics

Claudia Gemme INFN-Genova

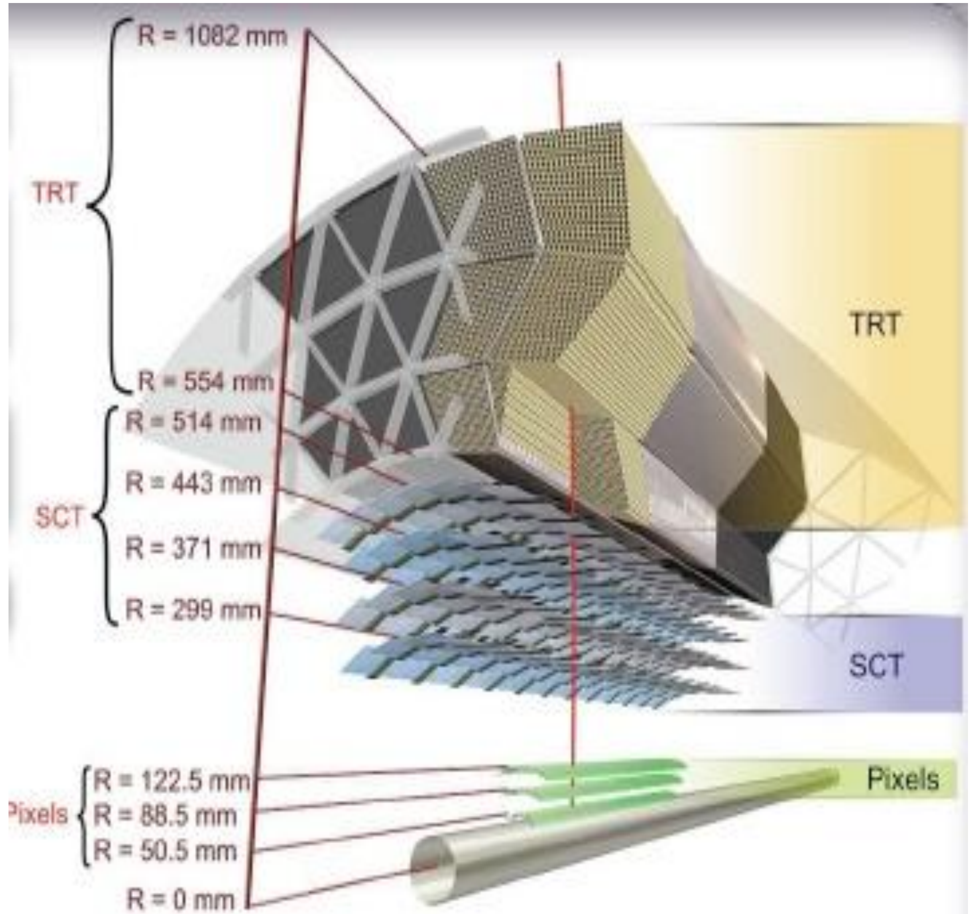
on behalf of the ATLAS Collaboration

Les Rencontres de Physique de la Vallée d'Aoste

1-7 March 2009, La Thuile

Tracking: Inner Detector

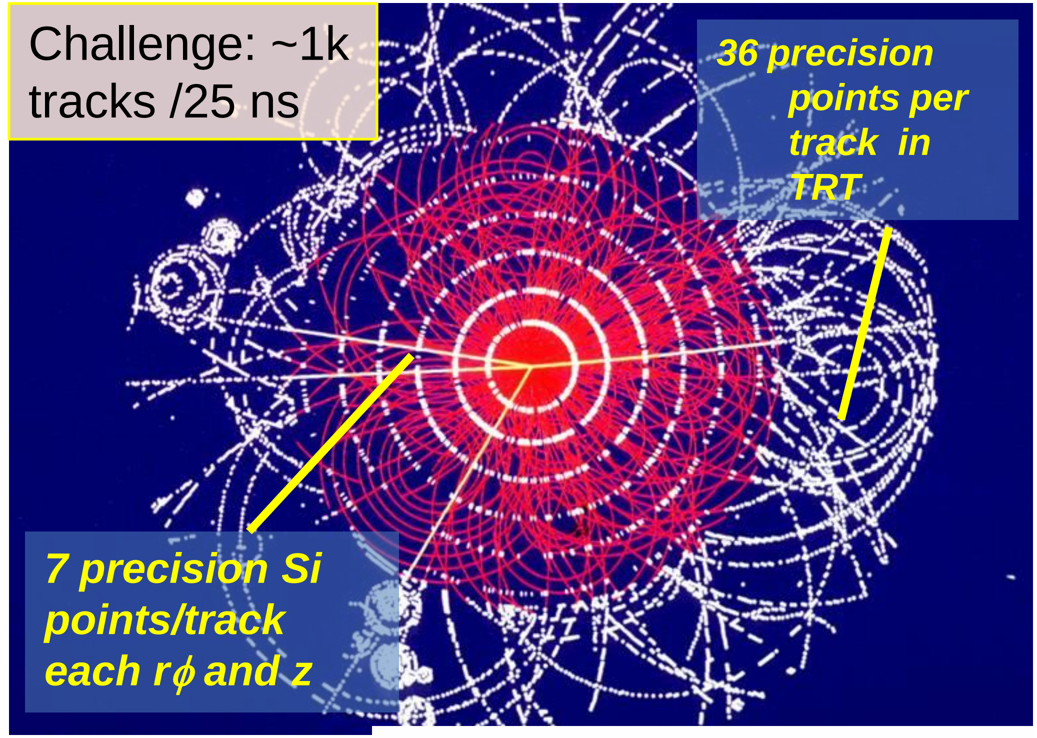
- ✓ Three different technologies detectors in a 2T Solenoid Magnet
- ✓ ~ 6m long, 1.1m radius
- ✓ Pixels: 50x400 μm^2 cell
- ✓ Silicon Strips (SCT): 80 µm pitch, 40 mrad stereo strips
- ✓ Transition Radiation Tracker (TRT): straw tubes providing up to 36 hits/track with e/π separation



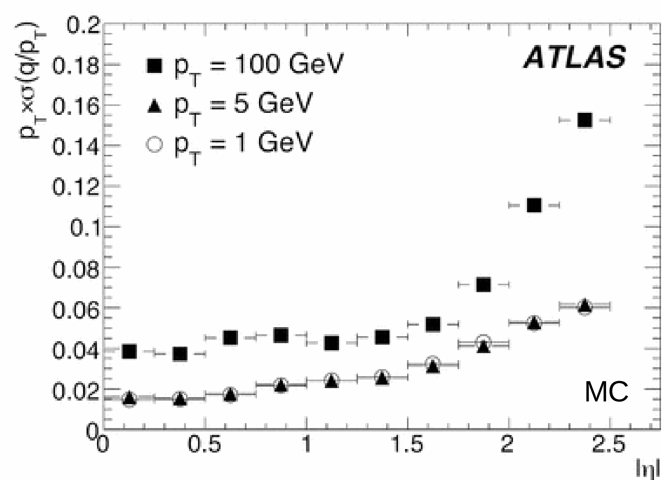
Required Resolution on momentum:
$\sigma_{pT}/pT = 0.05\%\ pT \oplus 1\%,\ |\eta| < 2.5$

Tracking: Inner Detector

- ✓ Three different technologies detectors in a 2T Solenoid Magnet
- ✓ ~ 6m long, 1.1m radius
- ✓ Pixels: 50x400 μm² cell
- ✓ Silicon Strips (SCT): 80 μm pitch, 40 mrad stereo strips
- ✓ Transition Radiation Tracker (TRT): straw tubes providing up to 36 hits/track with e/π separation



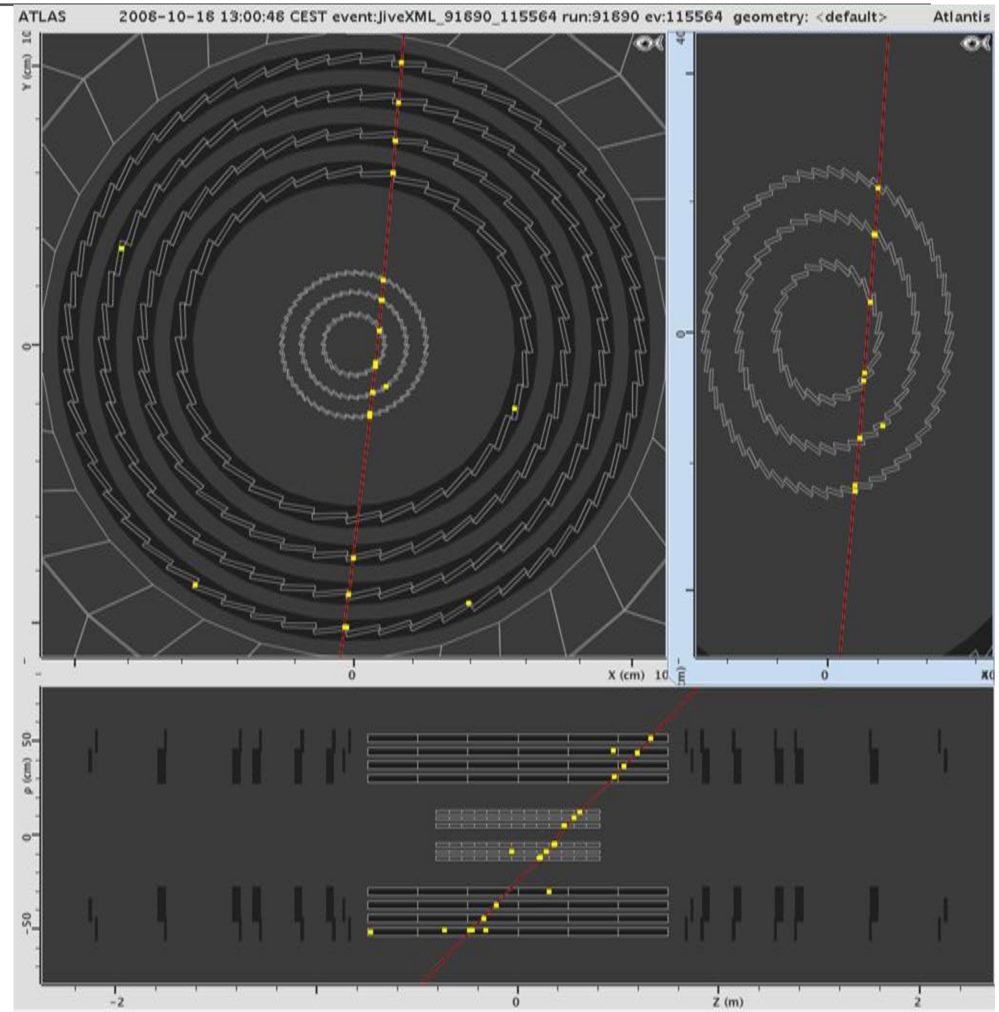
Required Resolution on momentum:
$\sigma_{pT}/pT = 0.05\%\, pT \oplus 1\%,\ |\eta| < 2.5$



Inner Detector: Status

- ✓ Commissioning of Pixel and SCT delayed up to August 2008 due to repair of the cooling plant. However in Sep ID was ready for beams.
- ✓ After LHC incident, very long commissioning period (calibration/cosmics).

- ✓ Pixel:
  - Active channels ~ 96 %
- ✓ SCT:
  - ~ 99% of barrel and ~ 97% of endcap operated
- ✓ TRT:
  - Active channels ~ 98%

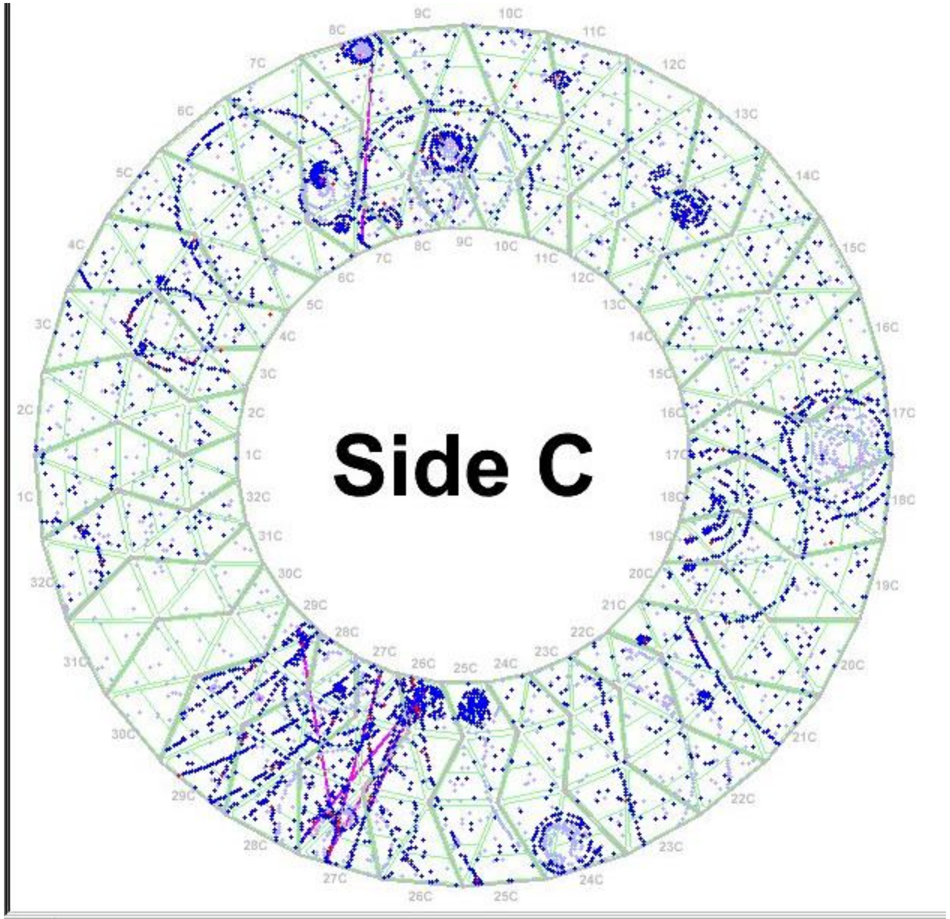


A cosmic muon crossing Pixel and SCT.
Very low noise in the detectors, ~1 hit/BC in the pixels!

Inner Detector: Status

- ✓ Commissioning of Pixel and SCT delayed up to August 2008 due to repair of the cooling plant. However in Sep ID was ready for beams.
- ✓ After LHC incident, very long commissioning period (calibration/cosmics).

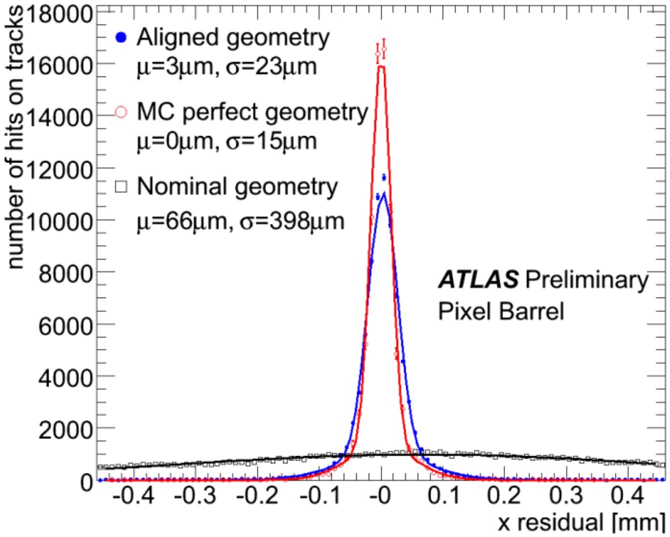
- ✓ Pixel:
  - Active channels ~ 96 %
- ✓ SCT:
  - ~ 99% of barrel and ~ 97% of endcap operated
- ✓ TRT:
  - Active channels ~ 98%

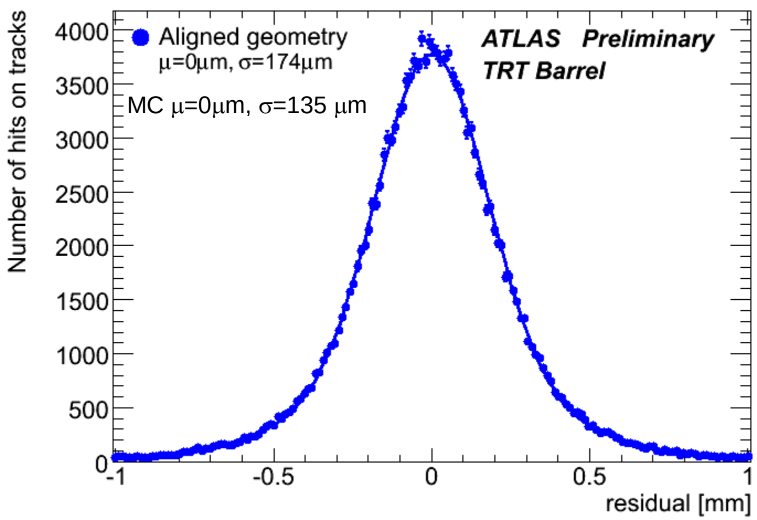


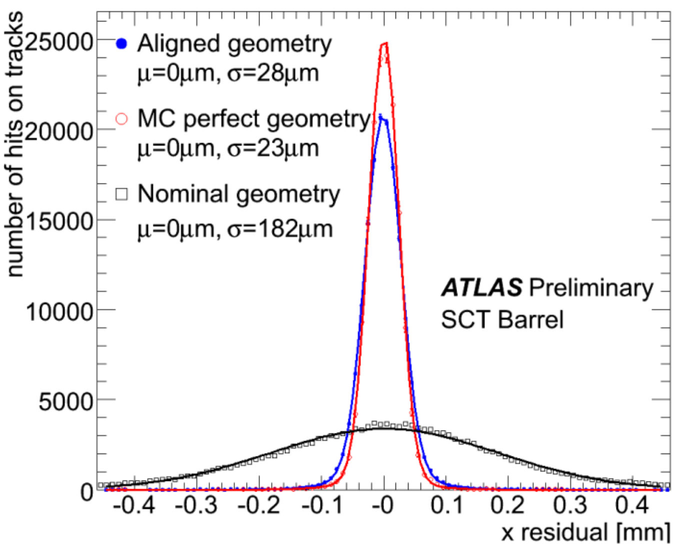
Cosmic muon crossing TRT barrel. Low momentum particles curl in the detector volume reminding of bubble chamber photos.

Inner Detector: Alignment

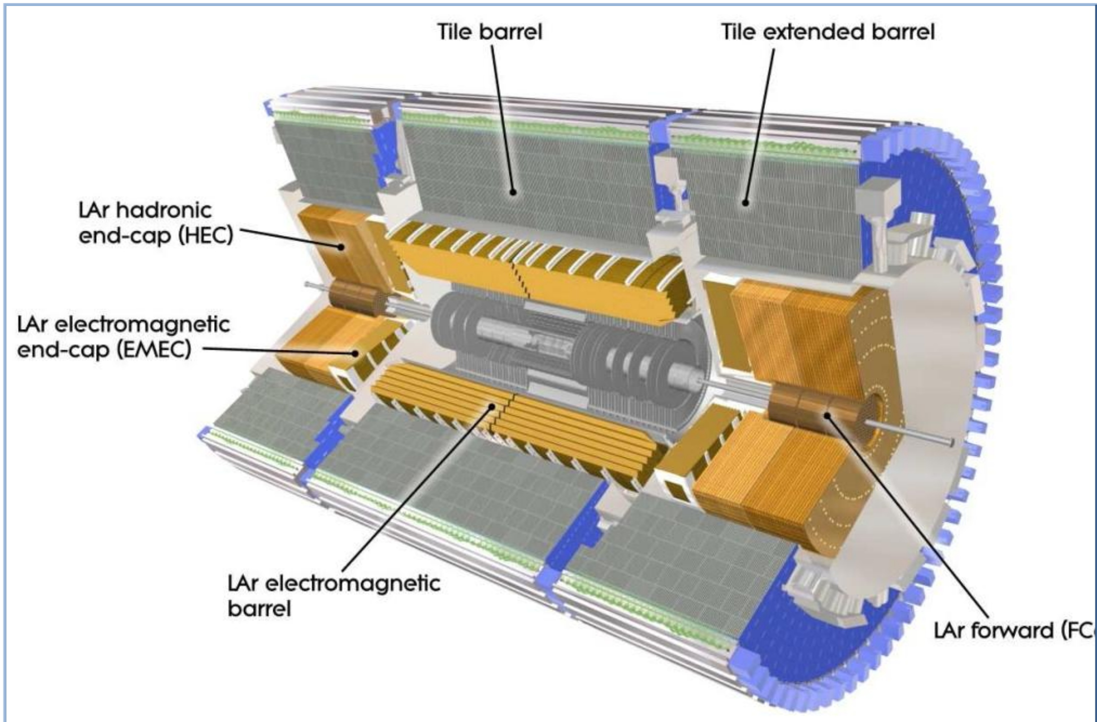
- ✓ Alignment is performed in steps of increasing number of DoF. With the present cosmics statistics, alignment possible almost at the *module level in Si barrel*. Limited statistics for *endcaps*, aligned as one rigid body.
- ✓ Mean and width of distributions is approaching the MC simulation for barrel region.
  - ✓ Residual resolutions indicate remaining misalignment of O(20 µm).







Calorimeters



Required Energy Resolution:
EM: $\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$, $|\eta| < 3.2$
Hadro: $\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$, $|\eta| < 3.2$

✓ Calorimeters cover the range $|\eta| < 4.9$, using different techniques.

Electromagnetic calo

- Accordion, Pb/LAr, $|\eta|<3.2$

Hadronic calo

- **Tile**: Fe/scintillator, $|\eta|<1.7$
- **LAr HEC**: Cu/LAr, two longitudinal wheels, $1.5<|\eta|<3.2$
- **LAr FCal**: Cu/W/LAr, $3.1<|\eta|<4.9$

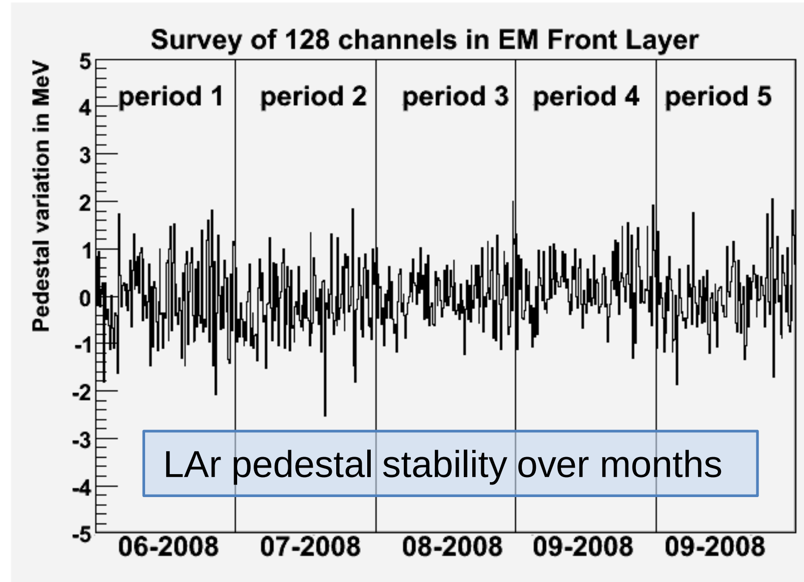
✓ Provide Trigger for e/γ, jets, missing E_T

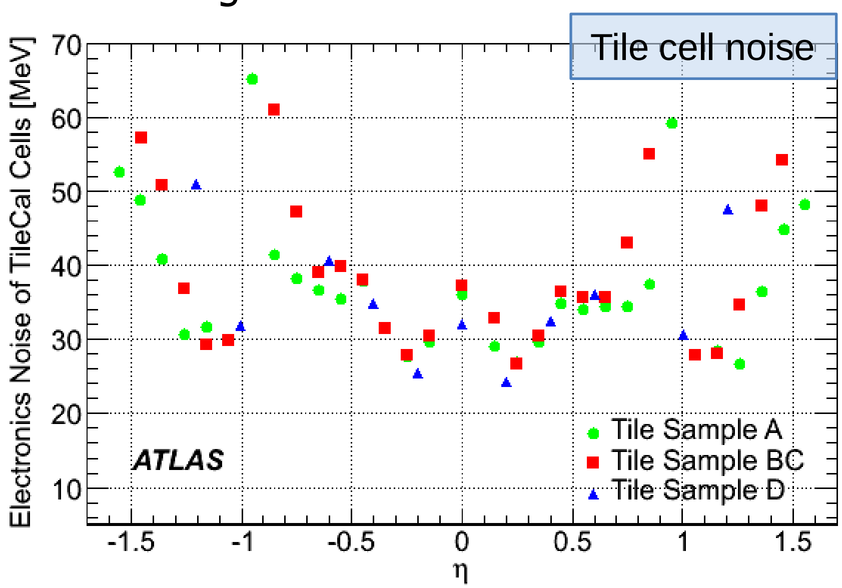
Calorimeter Status

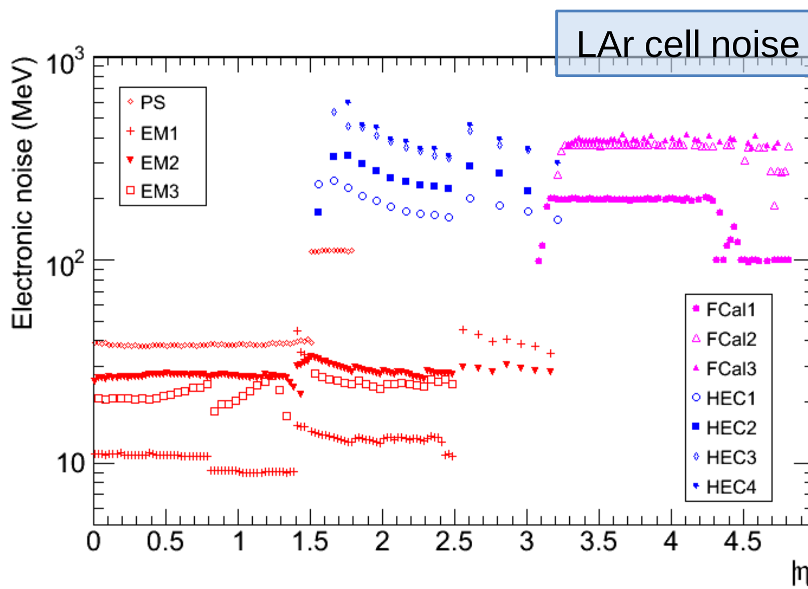
- ✓ LAr and Tile calorimeters had a very long commissioning in ATLAS (cosmics data taking since 2006).
- ✓ Both detectors are very stable in performances over months.
- ✓ Noise changes vs regions, sampling layers and η.
- ✓ Timing is already set to within a few ns for real collisions.

LAr: working channels=99.1%

Tile: working channels=98.6%





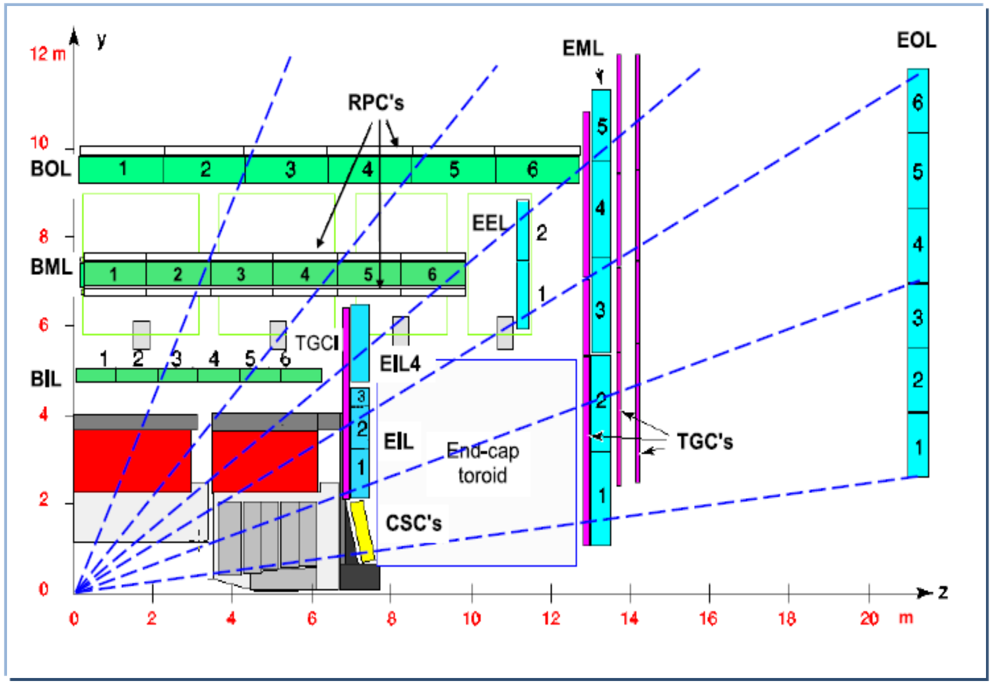


Muon spectrometer

- ✓ High momentum resolution with 3 layers of high precision tracking
  - MDT: Monitored Drift Tubes
  - CSC: Cathode Strip Chambers

- ✓ Trigger chambers make part of the LVL1 trigger in ATLAS
  - RPC :Resistive Plate Chambers
  - TGC: Thin Gap Chambers

- ✓ The air core system generates a strong bending power in a large volume (minimization of multiple-scattering effects).



Required Standalone Momentum resolution:

σ/p_T < 10% up to 1 TeV

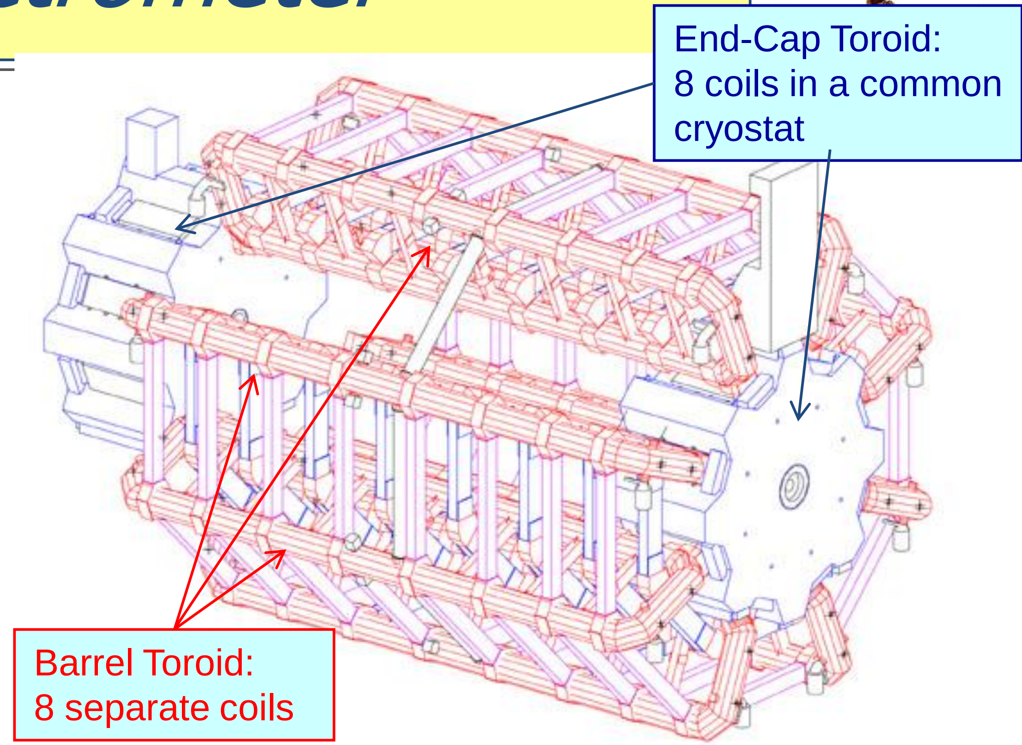
Acceptance: $|\eta|$ <2.7

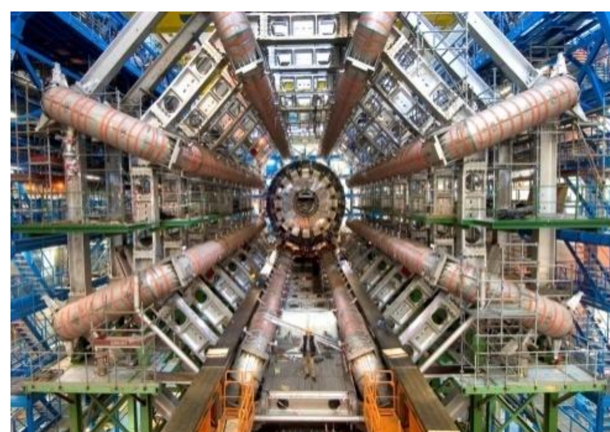
Muon spectrometer

- ✓ High momentum resolution with 3 layers of <u>high precision</u> tracking
  - MDT: Monitored Drift Tubes
  - CSC: Cathode Strip Chambers

- ✓ <u>Trigger chambers</u> make part of the LVL1 trigger in ATLAS
  - RPC :Resistive Plate Chambers
  - TGC: Thin Gap Chambers

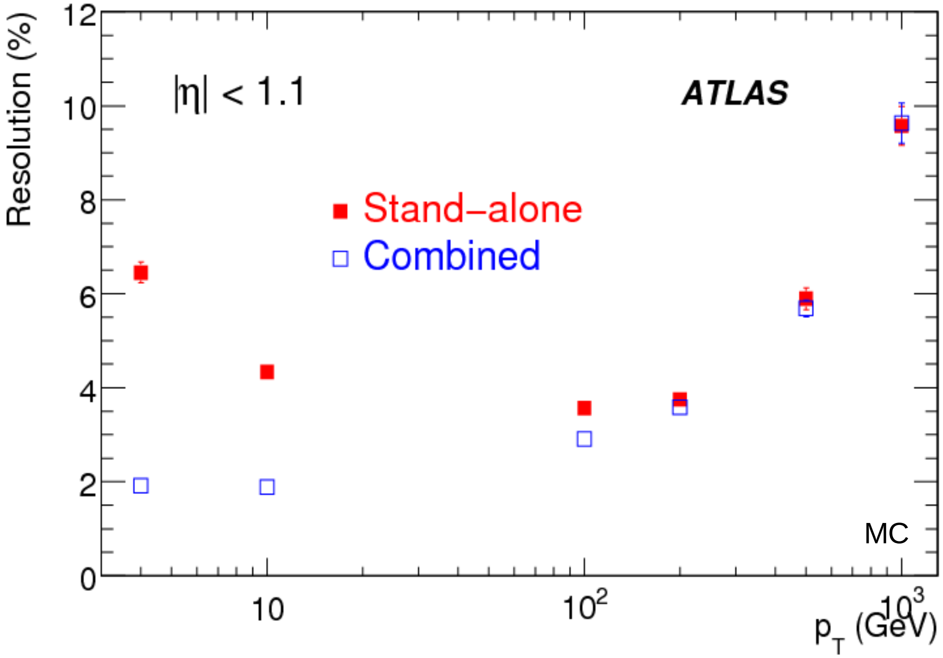
- ✓ The air core system generates a strong bending power in a large volume (minimization of multiple-scattering effects).





Muon spectrometer

- ✓ High momentum resolution with 3 layers of <u>high precision</u> tracking
  - MDT: Monitored Drift Tubes
  - CSC: Cathode Strip Chambers
- ✓ <u>Trigger chambers</u> make part of the LVL1 trigger in ATLAS
  - RPC :Resistive Plate Chambers
  - TGC: Thin Gap Chambers
- ✓ The air core system generates a strong bending power in a large volume (minimization of multiple-scattering effects).



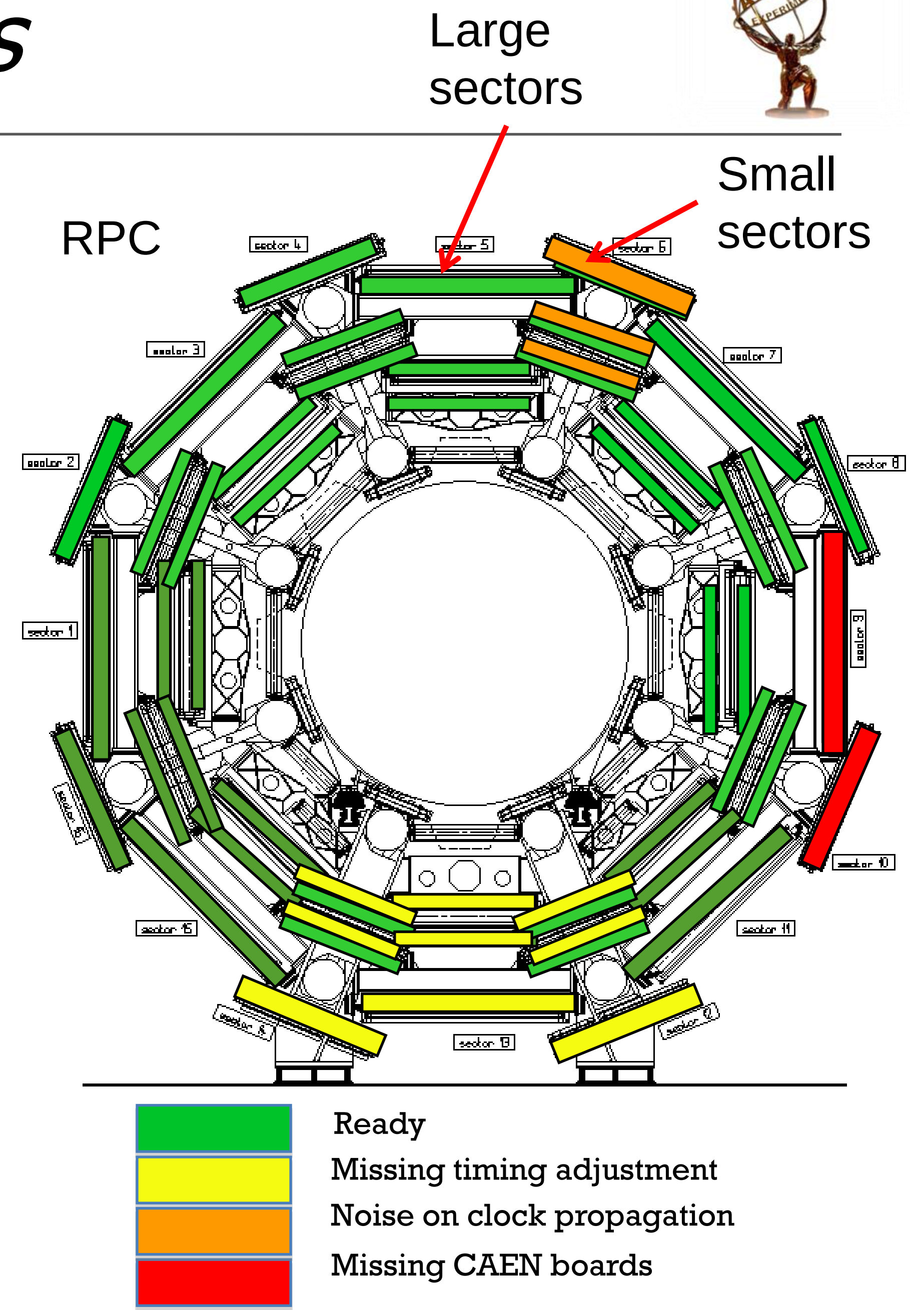
Required Standalone Momentum resolution:

σ/p_T < 10% up to 1 TeV

Acceptance: $|\eta| < 2.7$

Muon System: status

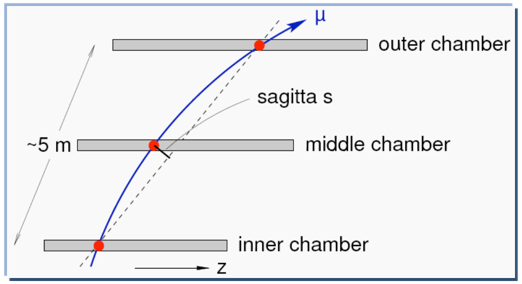
- ✓ Installation was completed in June 2008. But few problems were limiting the active channels number in 2008.
- ✓ MDT: 98.5% active channels. Remaining HV and gas problems to be fixed during the 2009 shutdown.
- ✓ CSC: 99.5% active chambers but rate limitation in read-out to be solved
- ✓ RPC: 92% cabled. Commissioning still on-going.
- ✓ TGC: 99.8% ready. 3 Chambers damaged by over-pressure exchanged. Excellent timing (all events in the same BCO)



Muon spectrometer: results

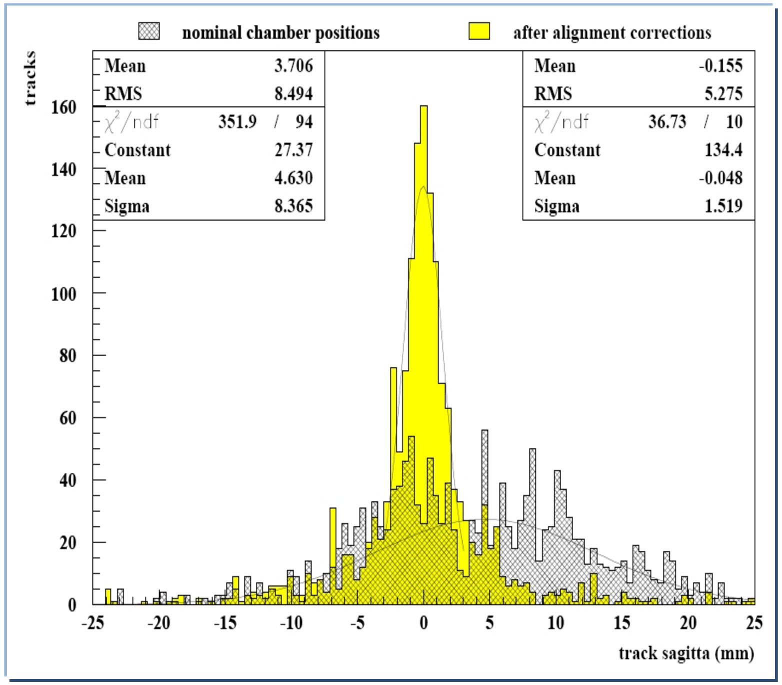
✓ To achieve a 10% momentum resolution at 1 TeV: sagitta of 500μm measured with 50μm accuracy.

✓ As the Single chamber resolution is ~ 40 μm: muon chambers must be aligned to 30 μm accuracy.



✓ An optical alignment system of 12k sensors follows displacement with great precision and provides an initial absolute precision

- ~ 200 μm in large barrel sectors
- ~ 1 mm in small barrel sectors
- ~ 40 μm in the endcap (survey done during commissioning)



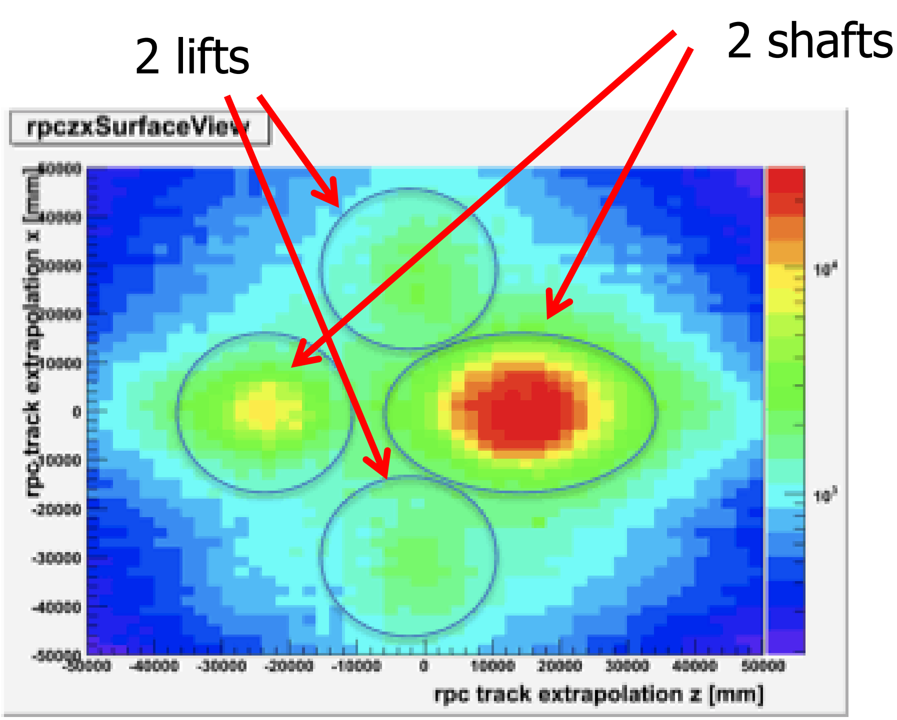
Whole Endcap: Mean compatible with 0 within 50 μm accuracy of the optical alignment; width of 1.5mm, compatible with the expected multiple-scattering width .

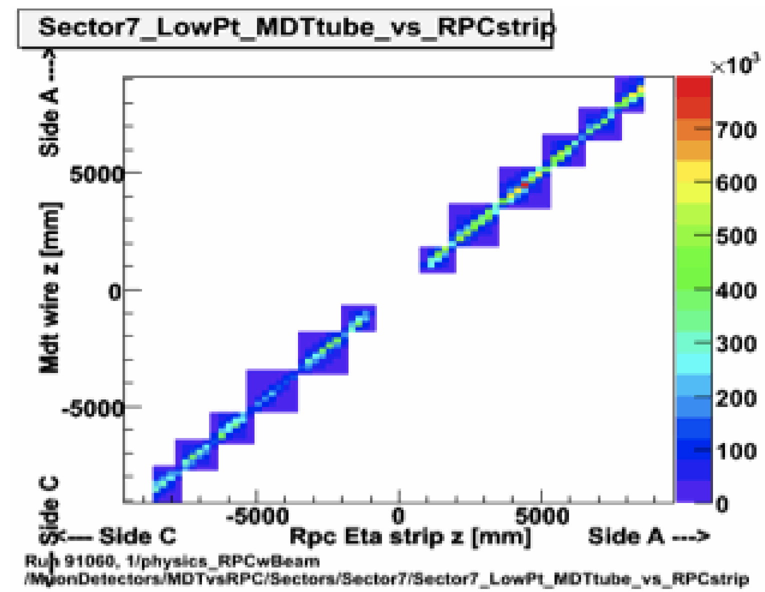
✓ Track alignment will be needed to get more precise initial alignment constants.

- MC indicates that 100k projective tracks/sector B-field off are needed to get the required 30 μm accuracy
- Confirmed that it is doable with cosmics on large sectors.

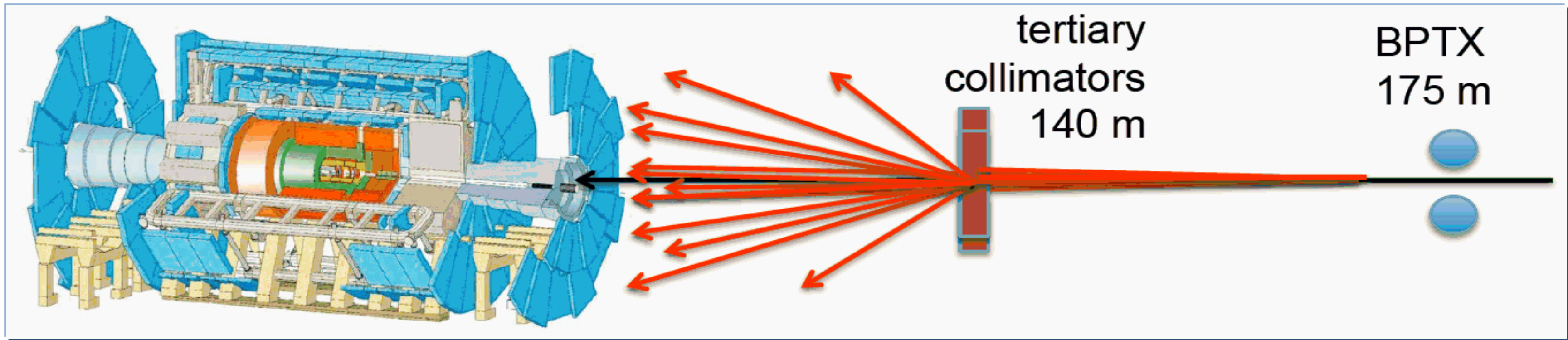
Muon spectrometer: results

- ✓ Extrapolation at ground level (100 mt) of RPC tracks.
- ✓ Recorded muons mainly arrive from the big shafts.
- ✓ Very good correlation between the RPC eta strip and the MDT tube coordinate.

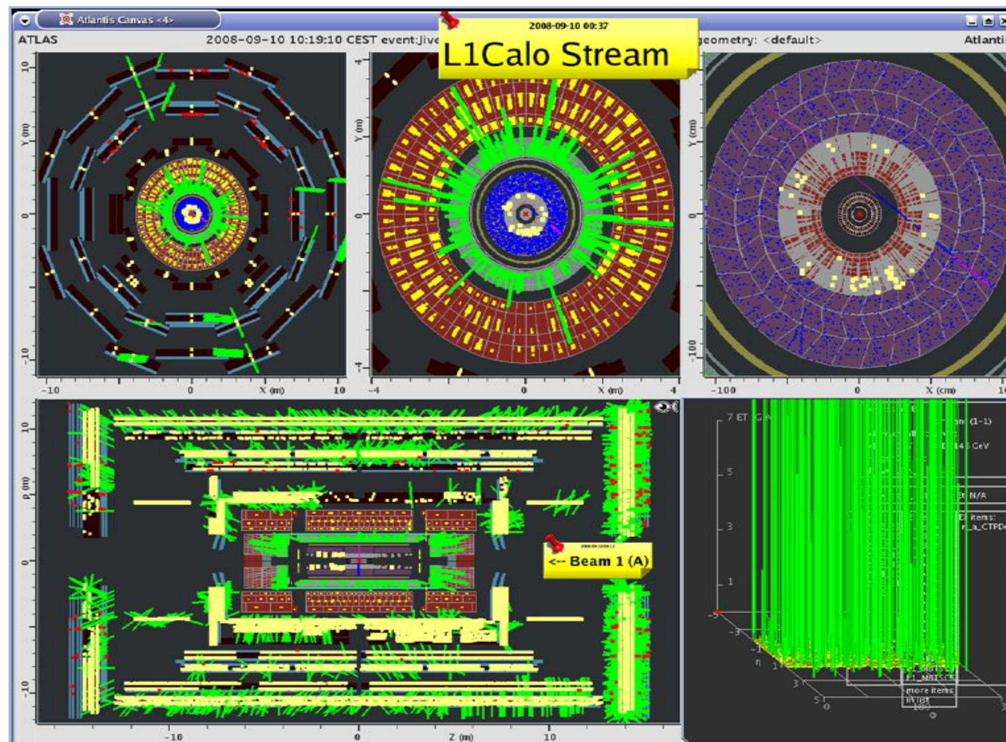




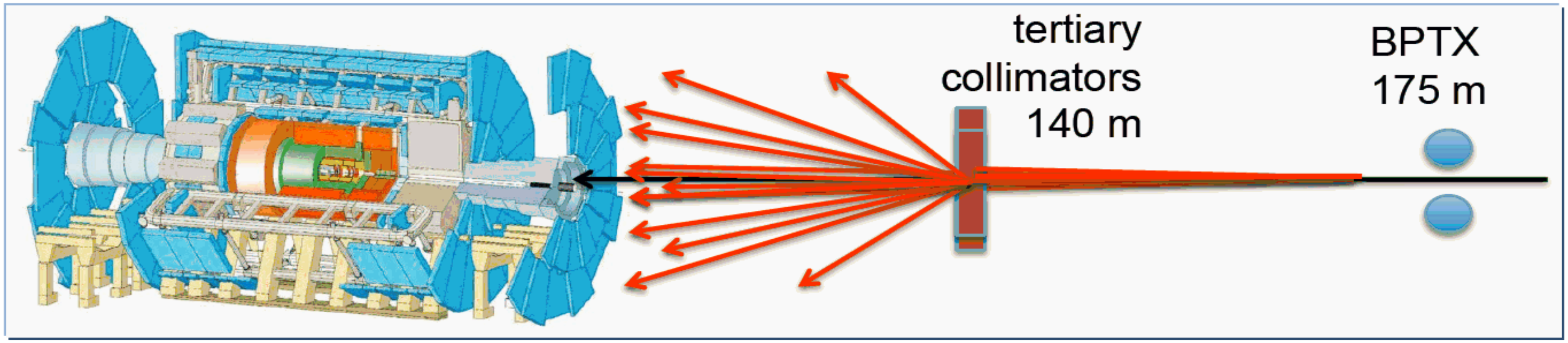
LHC beam in ATLAS



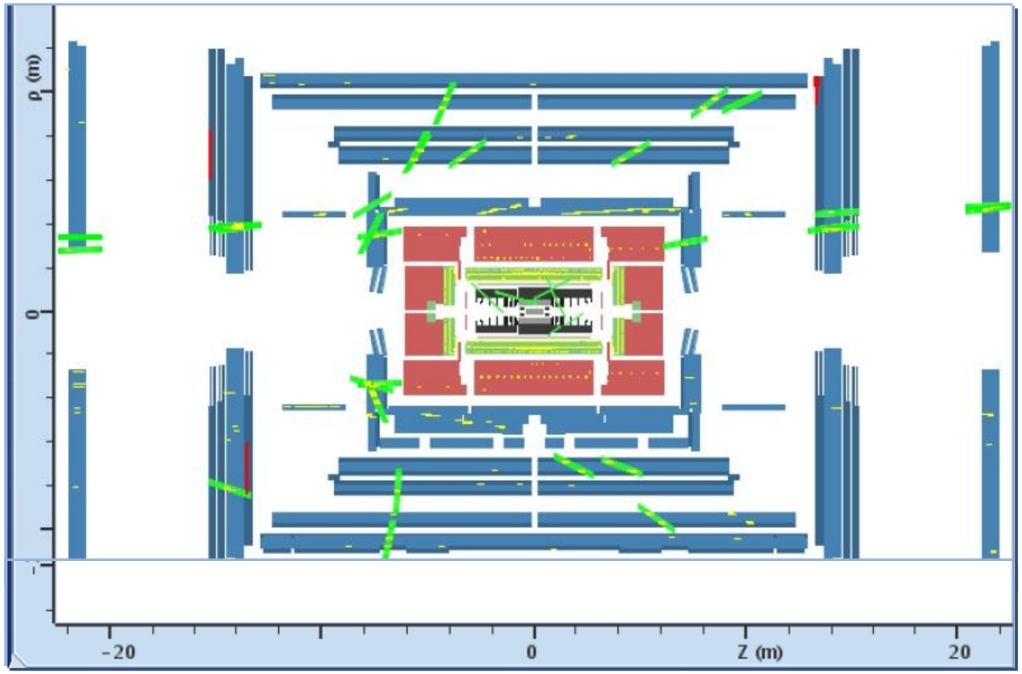
- ✓ The first beam was injected in ATLAS on Sep10th.
- ✓ ATLAS was running with
  - Pixel and SCT barrel off;
  - SCT Endcaps, forward calorimeters and muon chambers at reduced HV.
- ✓ Beam "splash" events with closed collimators (on relevant side): each shot resulted in proton collisions with the collimators.
- ✓ Circulating beams: typically lower energy deposits, depending on beam conditions.



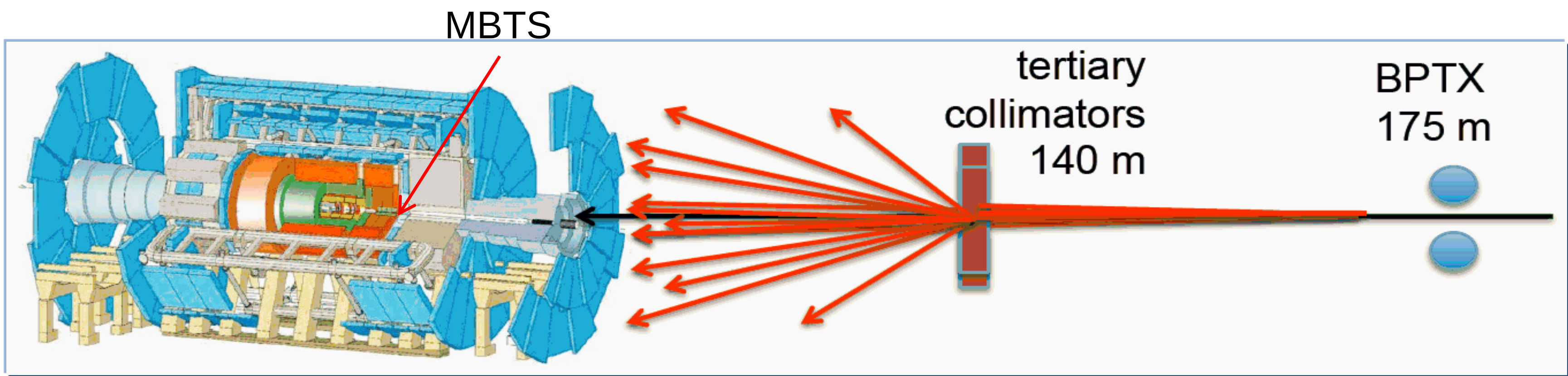
LHC beam in ATLAS



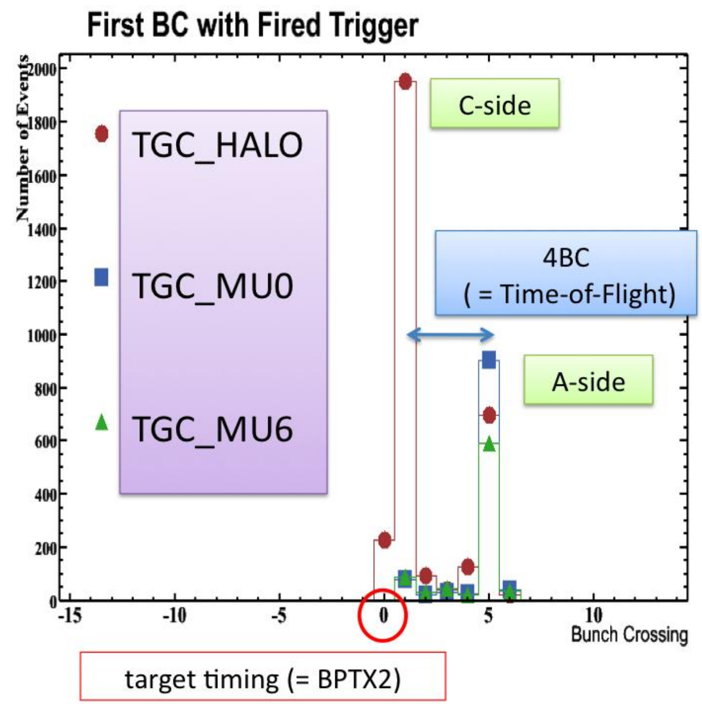
- The first beam was injected in ATLAS on Sep10th.
- ATLAS was running with
  - Pixel and SCT barrel off;
  - SCT Endcaps, forward calorimeters and muon chambers at reduced HV.
- Beam "splash" events with closed collimators (on relevant side): each shot resulted in proton collisions with the collimators.
- Circulating beams: typically lower energy deposits, depending on beam conditions.



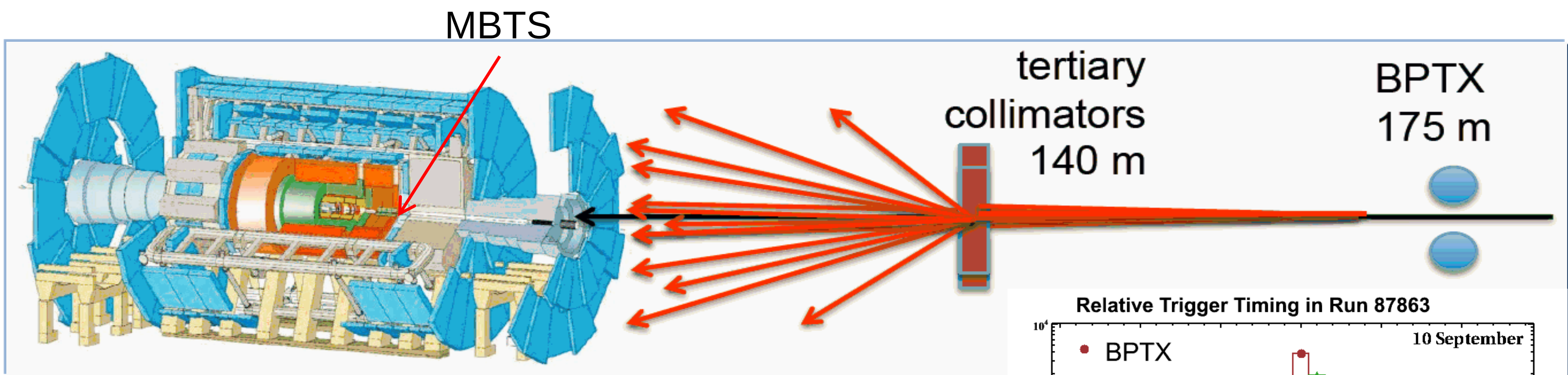
Triggering splash events

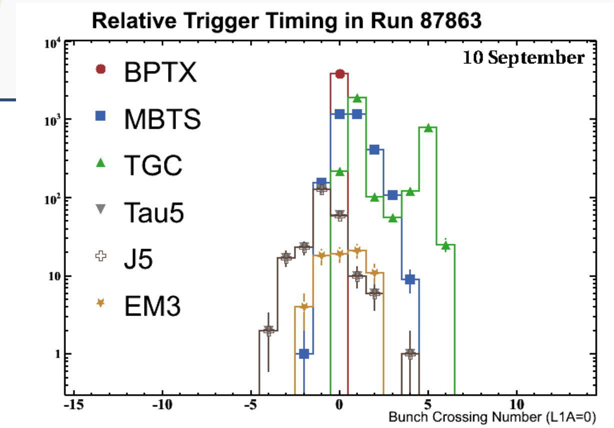


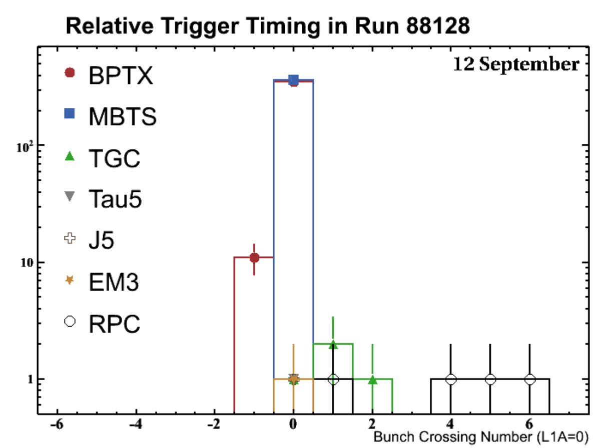
- Trigger was provided by the Minimum Bias Trigger Scintillators (MBTS), placed on the front face of the end-cap calorimeter cryostats and Beam Pick-up (BPTX).
- Other L1 components (RPC, TGC, L1CALO) were active but not used to select events.
- TGC: The spread of each timing peak is about 1BC, it means the timing alignment is perfectly done at this level.
  Time of flight C->A side ~4BC
- Improvements in timing in few days for all L1 triggers.



Triggering splash events





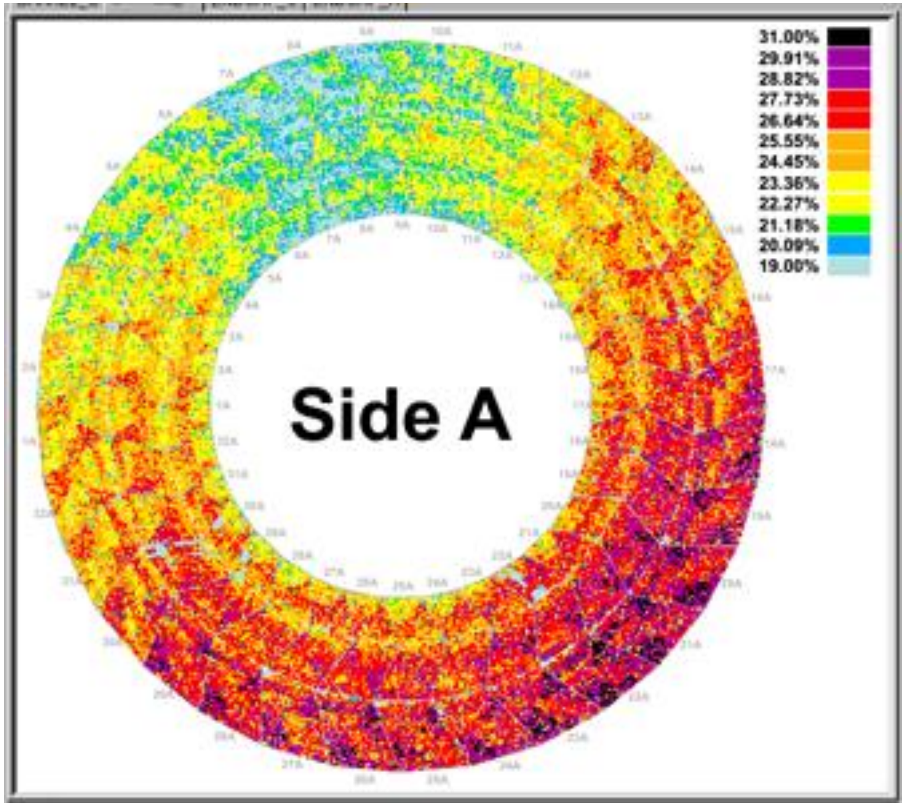


- ✓ Trigger was provided by the Minimum Bias Trigger Scintillators (MBTS), placed on the front face of the end-cap calorimeter cryostats and Beam Pick-up (BPTX).
- ✓ Other L1 components (RPC, TGC, L1CALO) were active but not used to select events.
- ✓ TGC: The spread of each timing peak is about 1BC, it means the timing alignment is perfectly done at this level.
  Time of flight C->A side ~4BC
- ✓ Improvements in timing in few days for all L1 triggers.

Splash events: TRT

- In beam splash events many particles hit the entire detector at the same time. Therefore it is possible to check and eventually correct the time calibration in the full detector at once.

- In TRT the systematic pattern from top to bottom is due to calibration constant coming from cosmic data without correcting for the time of flight. Apart from that, pattern is very uniform, confirming good accuracy of timing settings.

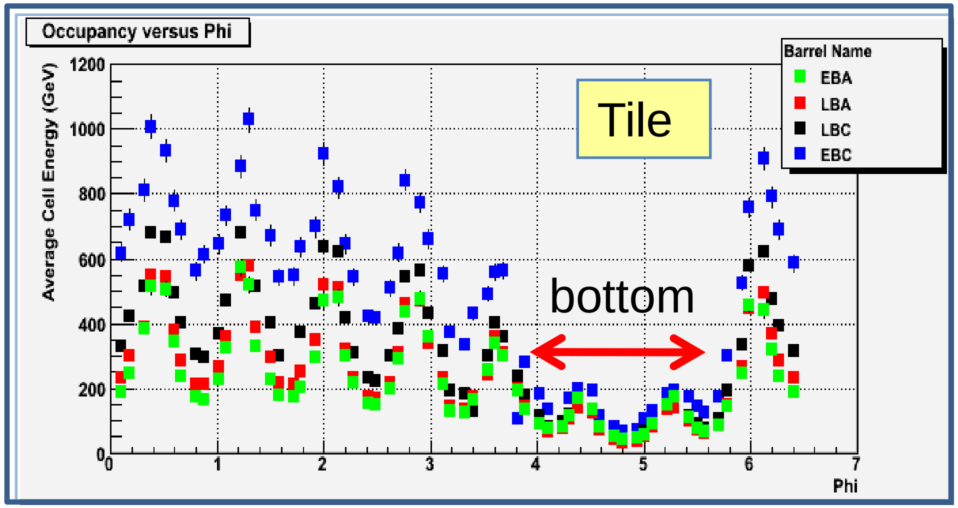


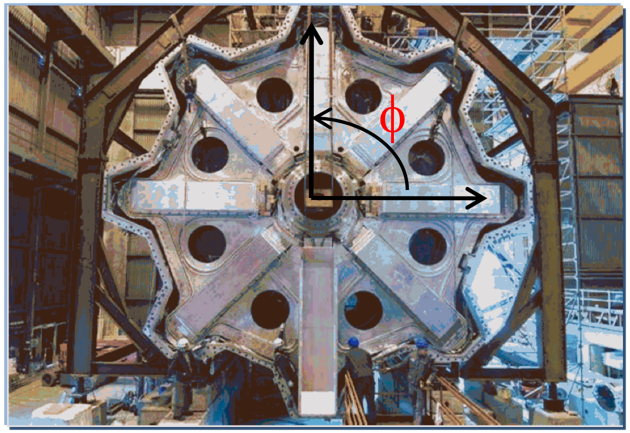
TRT barrel side A: time distribution in a single splash event.

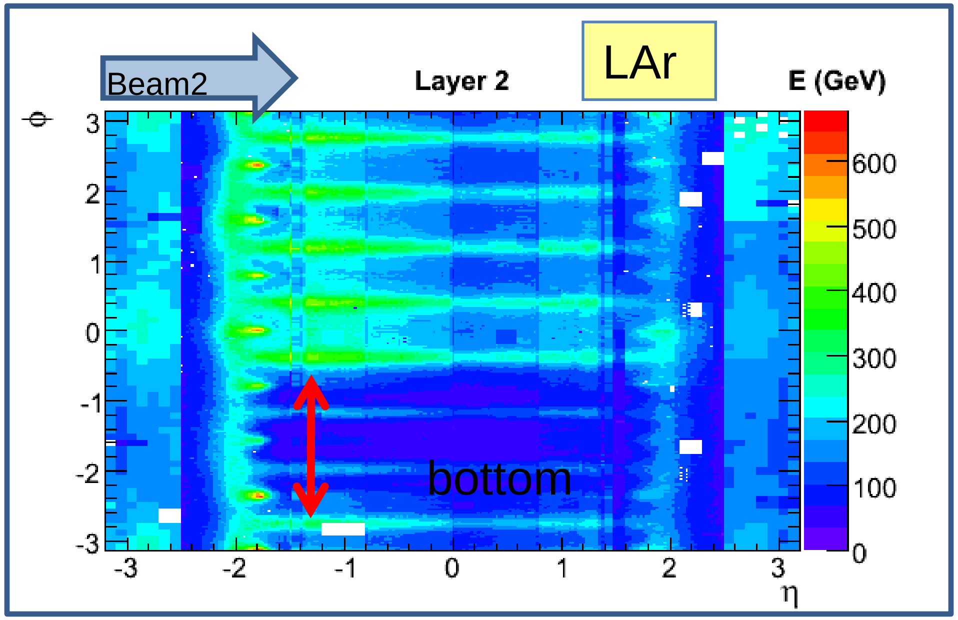
Splash events: Calorimeters

Energy deposition in calorimeters in beam splash events recorded Sep 10th

- ✓ Well visible is the 8-fold structure in ϕ due to the End Cap toroid material in front of calorimeters for particles coming from the C-side.
- ✓Both detectors have lower response on the bottom due to additional material (mainly detector support structure)
- ✓Reduced flux from C to A side visible in LAr plot.





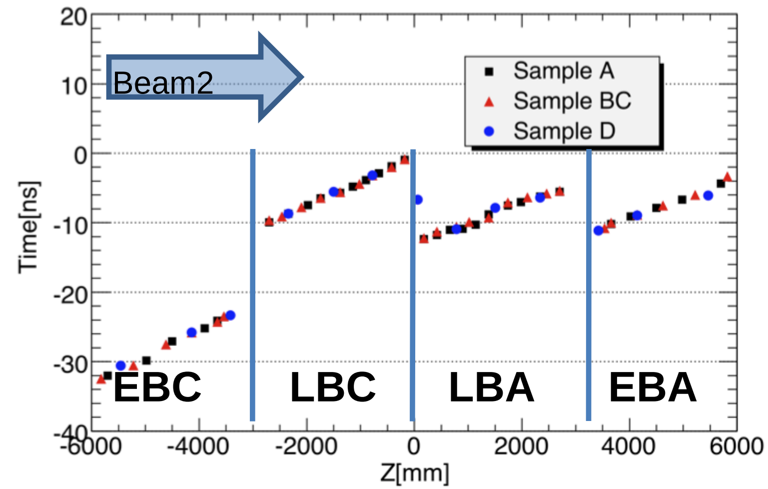


First beam: results

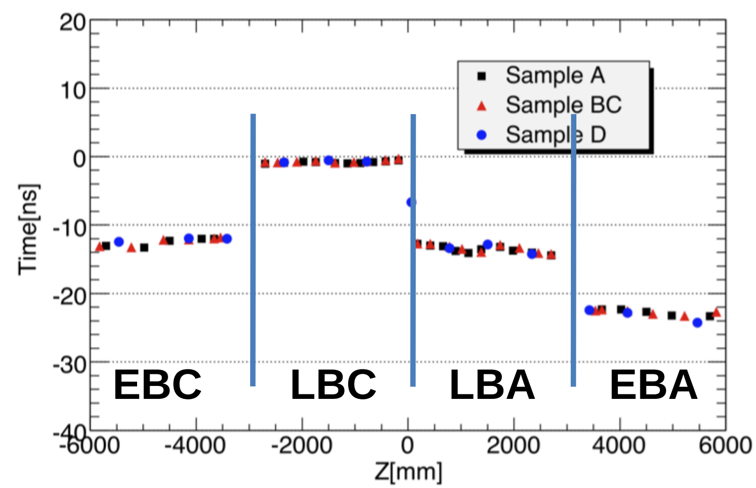
Muon energy deposition from halo events in Tile Hadronic calo.

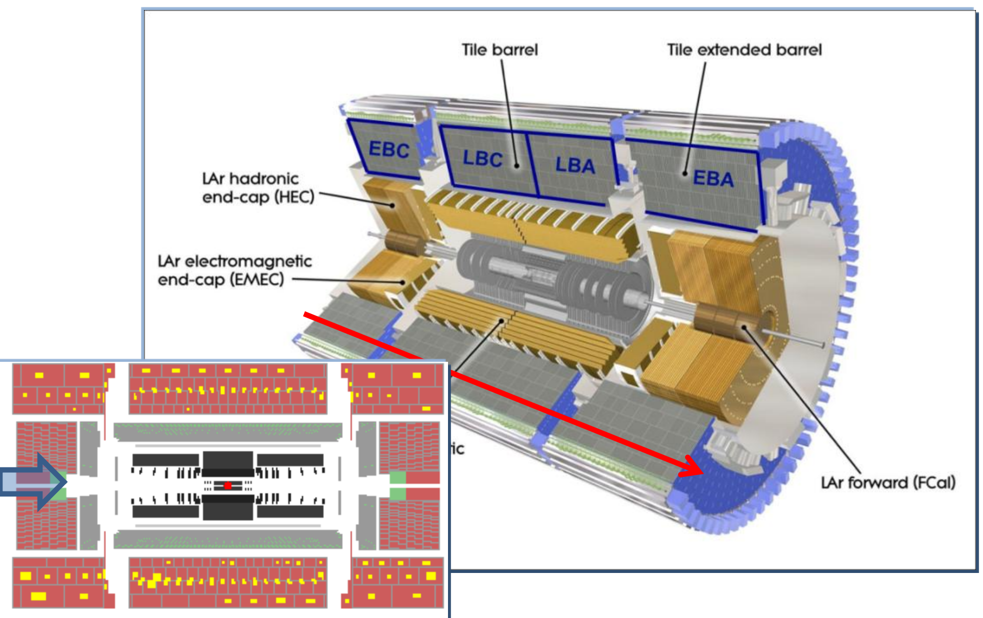
- ✓ Observed slopes match the time the muons take to cross the calorimeter along the beam direction.
- ✓ Once the ToF corrections are applied,
  - time dispersion in each partition is ~2ns,
  - Offsets between partitions within 1 BC.
- ✓ Very good time equalization performed with laser calibration data.

Timing uniformity



Time of flight correction applied



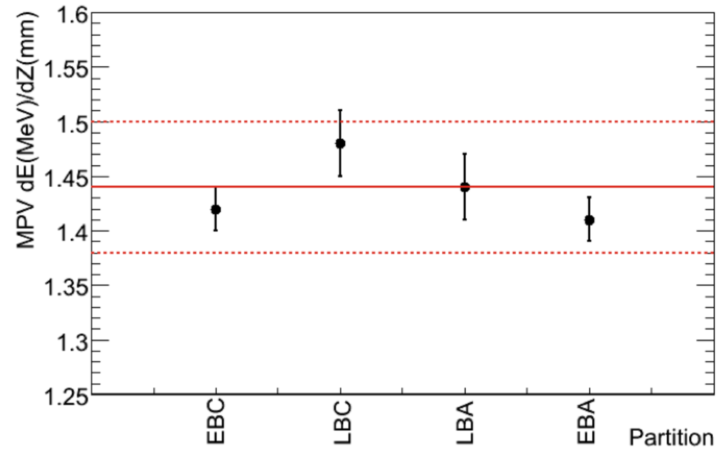


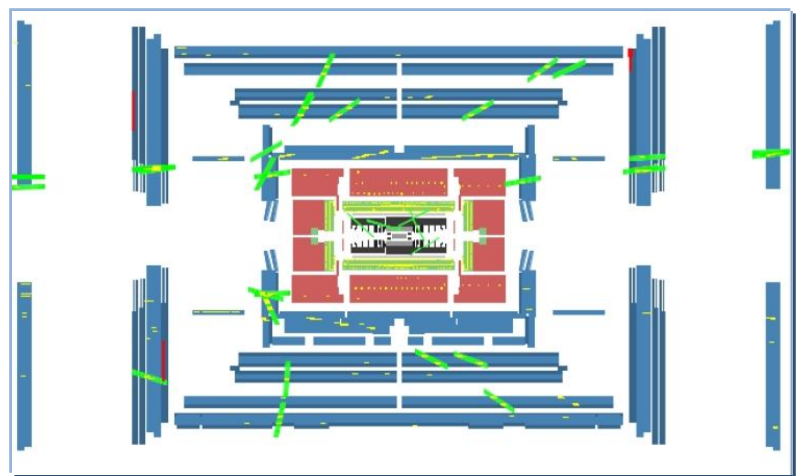
First beam: results

Muon energy deposition from halo events in Tile Hadronic calo.

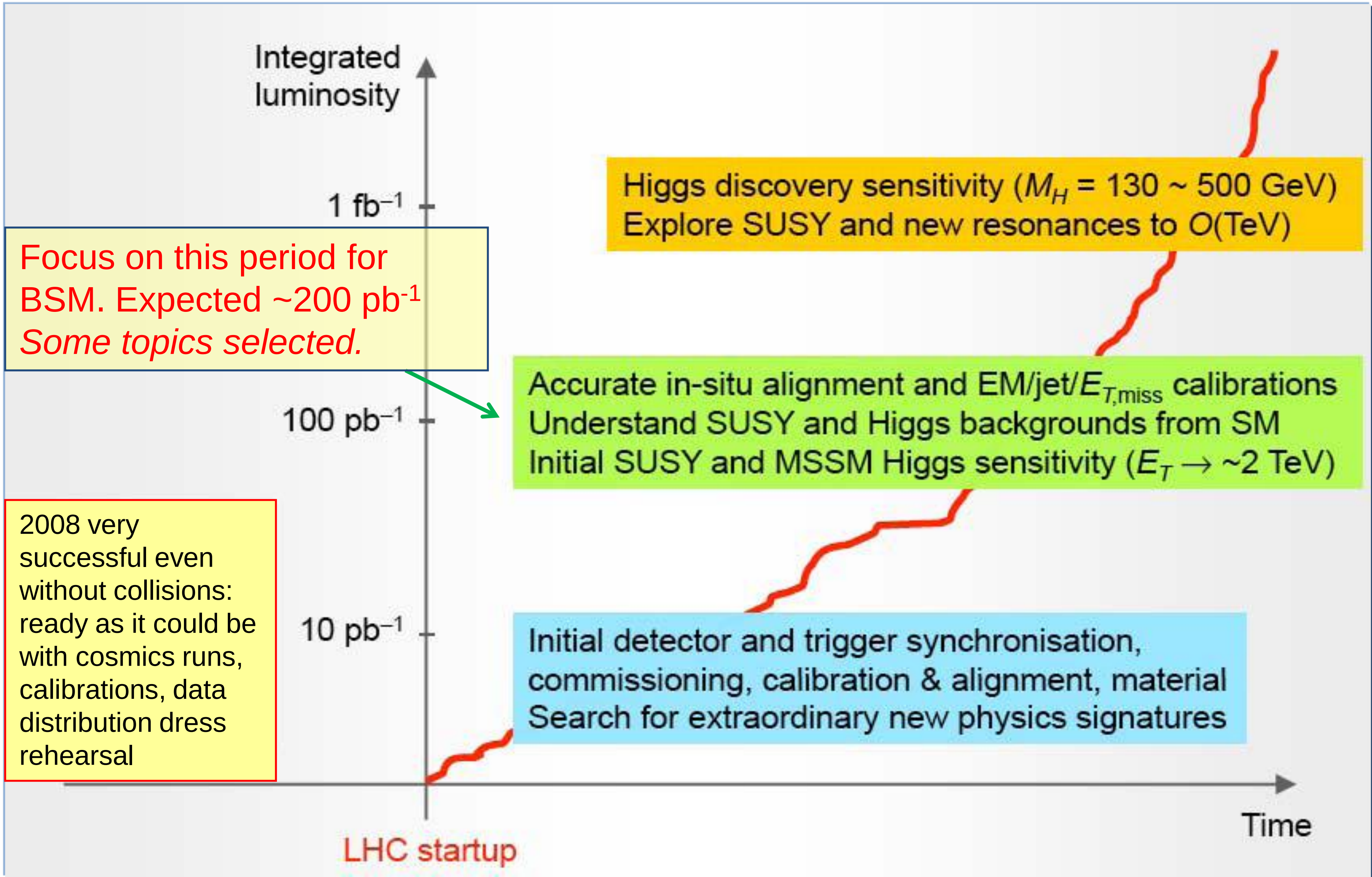
- ✓ Verify the intercalibration of Tile calorimeter cylinders, already calibrated with radioactive gamma sources, down to the 4% precision level. The red lines represent the average MPV value of the 4 barrels and its 4% uncertainty
- ✓ Good agreement with cosmics results.

Energy response uniformity



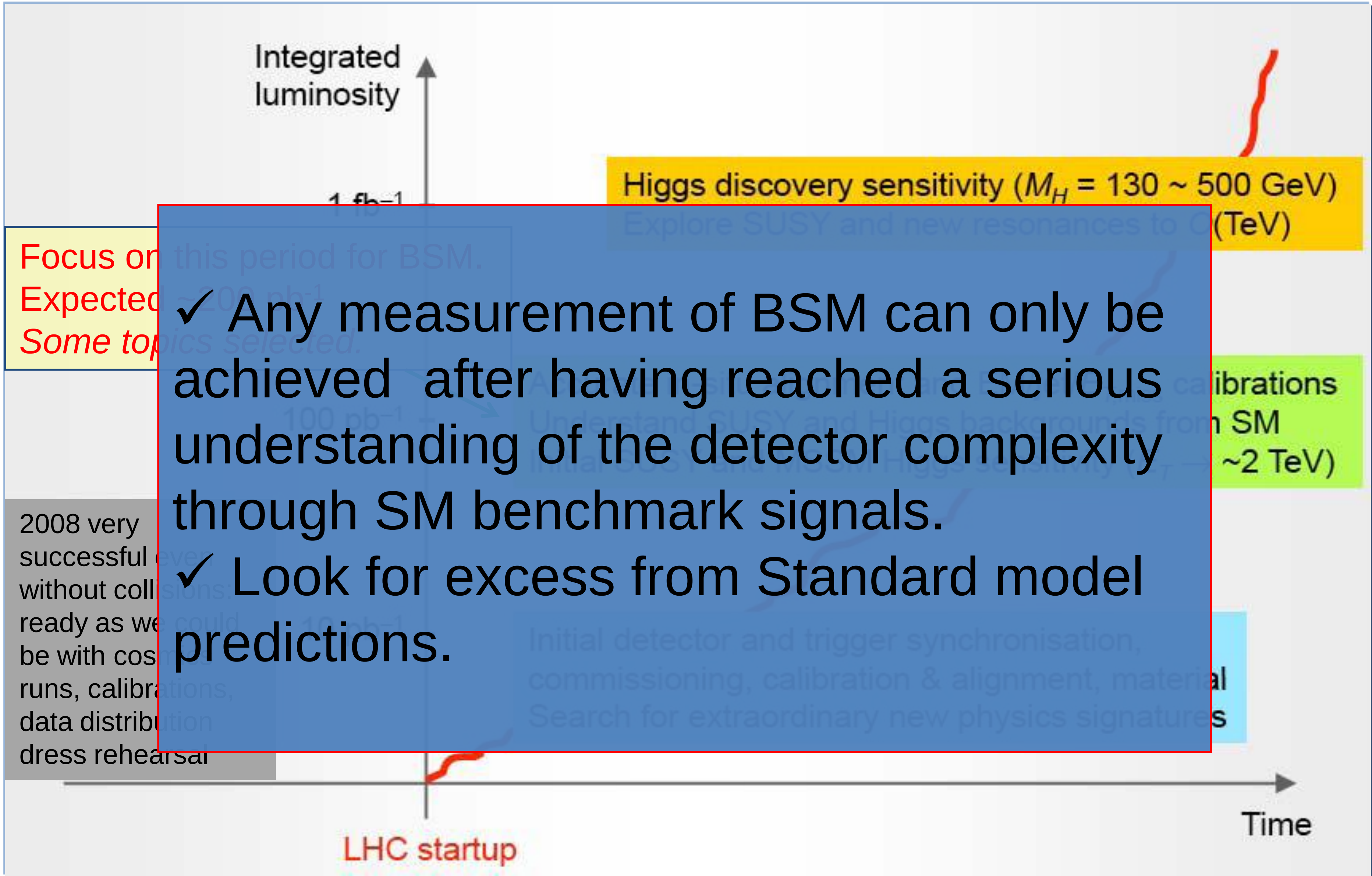


LHC startup



Integrated luminosity
1 fb^{-1}
100 pb^{-1}
10 pb^{-1}
Time
LHC startup
Higgs discovery sensitivity (M_H = 130 ~ 500 GeV)
Explore SUSY and new resonances to O(TeV)
Accurate in-situ alignment and EM/jet/$E_{T,miss}$ calibrations
Understand SUSY and Higgs backgrounds from SM
Initial SUSY and MSSM Higgs sensitivity ($E_T \rightarrow$ ~2 TeV)
Initial detector and trigger synchronisation,
commissioning, calibration & alignment, material
Search for extraordinary new physics signatures
Focus on this period for BSM. Expected ~200 pb^{-1}
Some topics selected.
2008 very successful even without collisions: ready as it could be with cosmics runs, calibrations, data distribution dress rehearsal

LHC startup

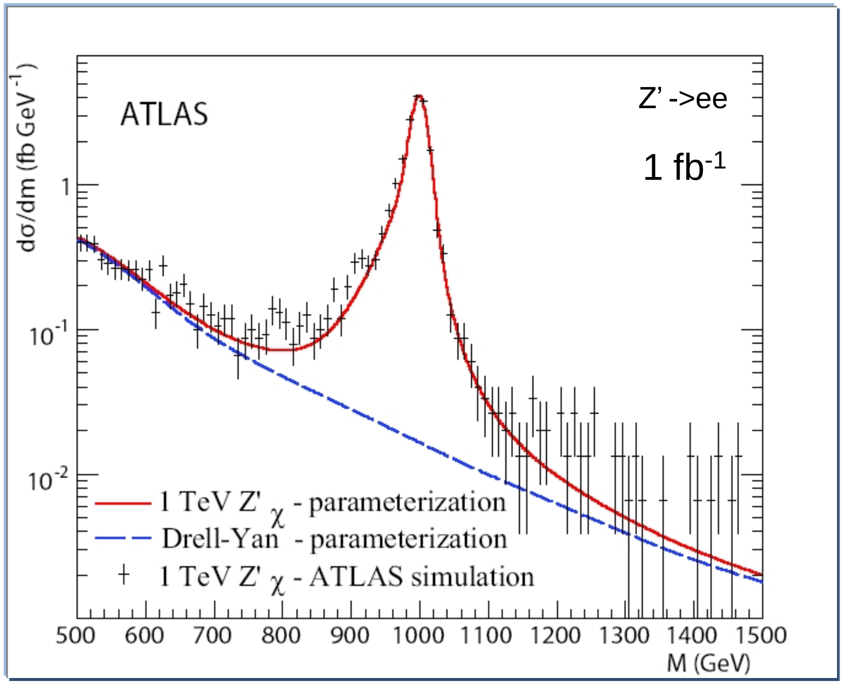


✓ Any measurement of BSM can only be achieved after having reached a serious understanding of the detector complexity through SM benchmark signals.

✓ Look for excess from Standard model predictions.

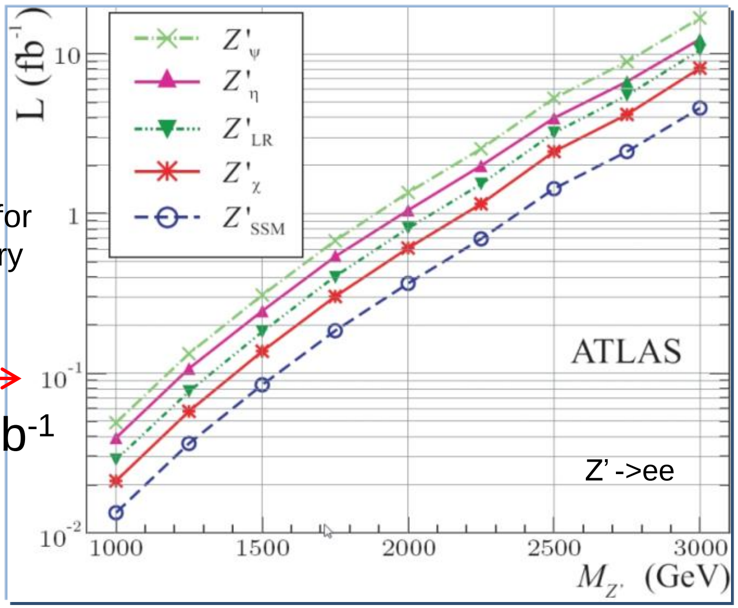
Early discoveries: Z′

- ✓ A narrow Z′ resonance decaying in two leptons is predicted by several extensions of the Standard Model.
- ✓ Tevatron:95% CL limit at M~1TeV
- ✓ Signal creates clear peak
  - Easier for electrons than muons though
  - Muons suffer from worsening resolution at high momentum



Luminosity for 5σ discovery

100 pb^{-1}

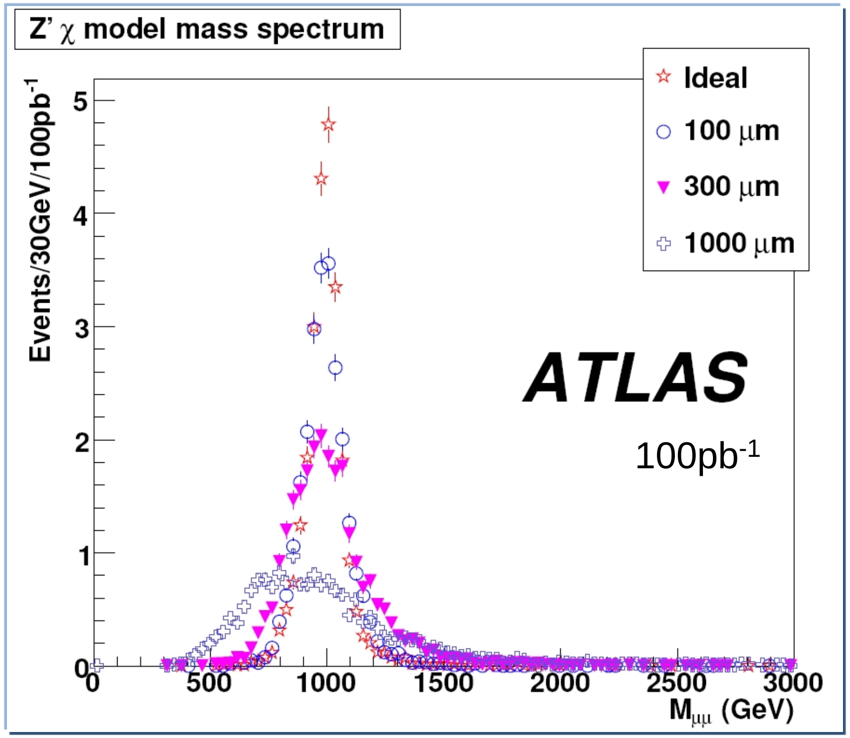


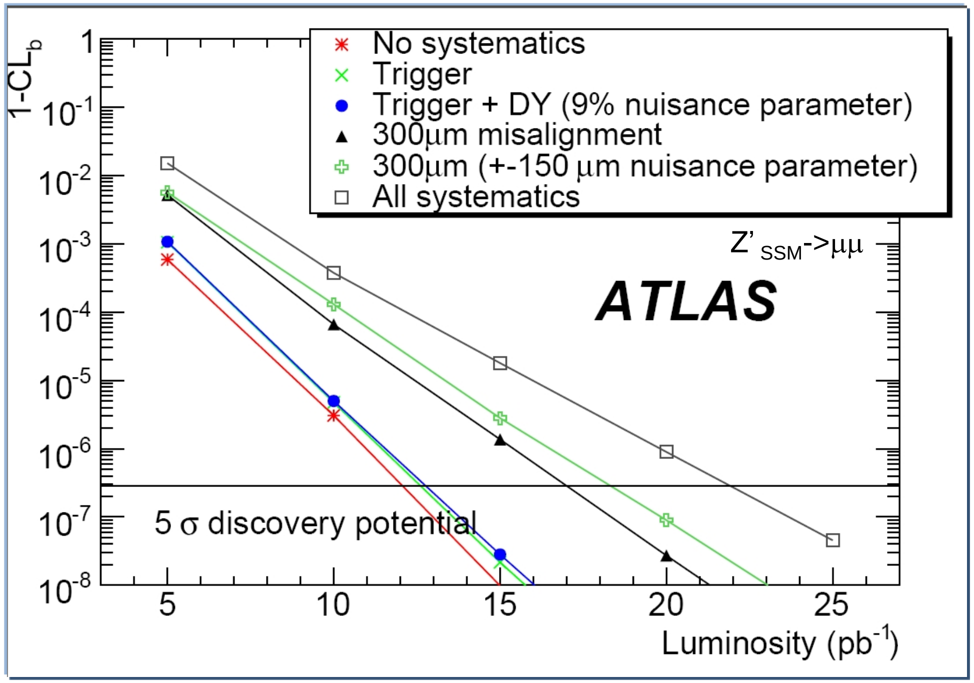
- ✓ For $M_{Z'}$ ~ 1TeV an early discovery would be possible – considering many possible scenarios.
- ✓ Also at Ecm = 10TeV, 5σ discovery of Z′~1TeV should be possible with ~100 pb^{-1}.

Z': detector misalignment

'One' Detector effect:

- ✓ A detailed study was carried out in order to determine the effect of possible larger uncertainties in the position of the muon chambers to the Z' search.
- ✓ Visible in the broadening of the peak and in the discovery potential.





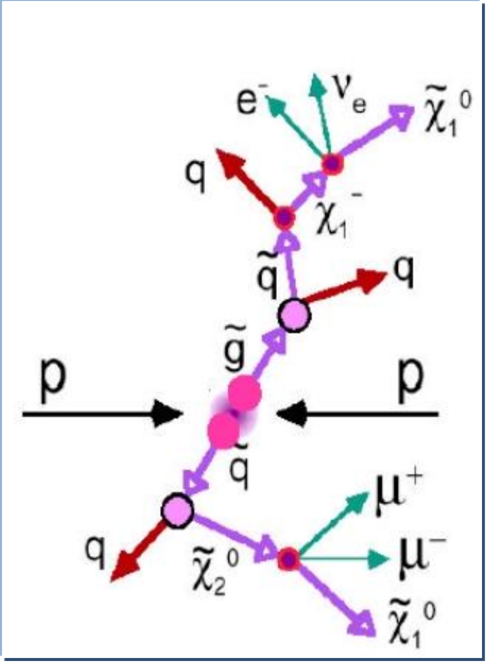
Early Discoveries: Super Symmetry

General characteristics of R-parity conserving SUSY:

- Sparticles produced in pairs and lightest SUSY particle (LSP) stable
  - → Large amount of missing transverse energy
- Coloured sparticles are copiously produced and cascade down to LSP
  - → Emission of many hard jets and sometimes leptons

Generic SUSY signatures:

- Large missing ET missing from LSP
  - → ET missing challenging to control at startup
- > 3 hard jets from cascade decays
- N leptons (according to the topology)
  - → growing N: reduces QCD background
- Angular or event shape variables for background rejection



Even at reduced Ecm = 10TeV, for SUSY particles with mass ~400 GeV, 5σ discovery should be possible with ~few tens of pb^{-1} *good data*.

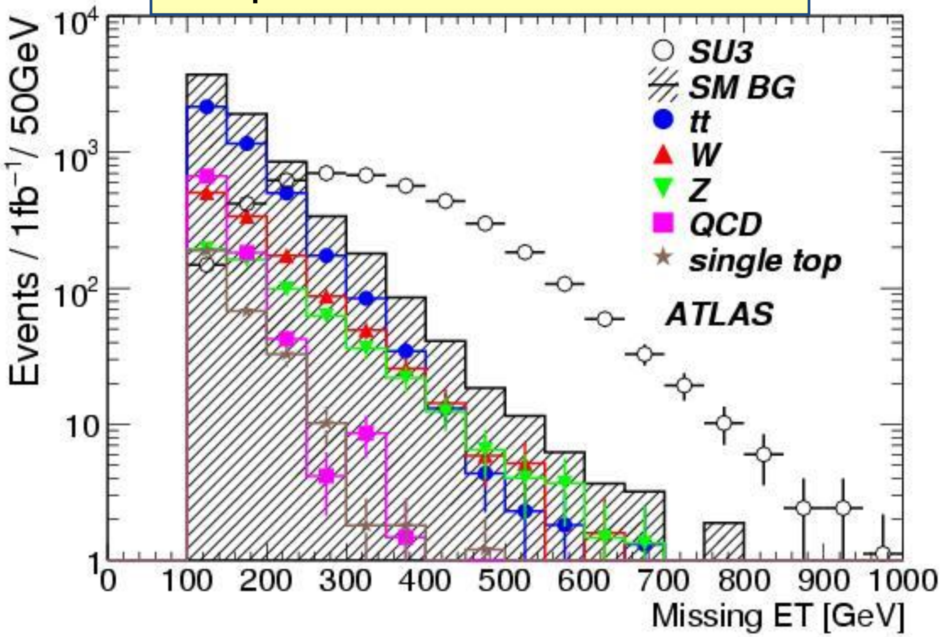
Below Ecm≈8 TeV, the sensitivity collapses.

Main backgrounds:
tt+jets, W+jets, Z+jets, QCD (multijet)

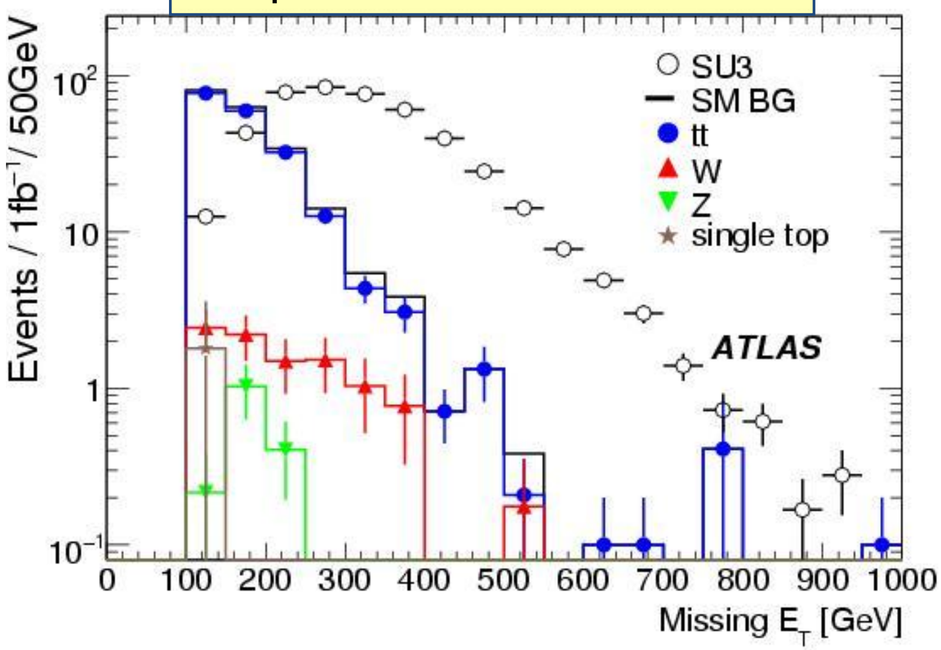
SUSY: Golden search modes

- Look at excess in the SM predictions of Missing ET, Effective mass, etc $\rightarrow$ Understanding of Standard model background is crucial!
- Systematic to be understood: Detector effects, jet resolution and scale uncertainty and Missing ET tails, trigger effects, etc…
- The 0-lepton mode has the best estimated 5σ reach but the 1-lepton mode has better rejection against QCD.

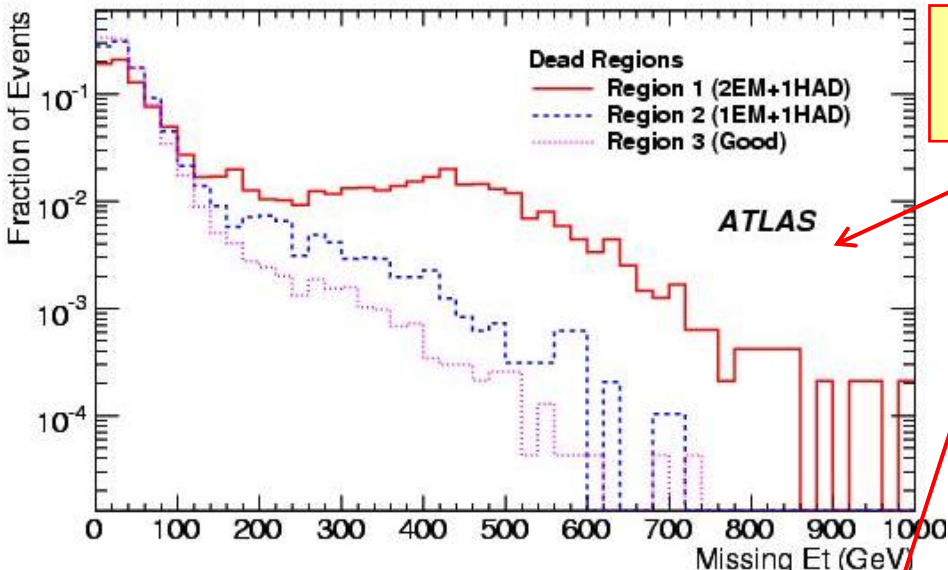
0-lepton search mode, 1 fb^{-1}



1-lepton search mode, 1 fb^{-1}

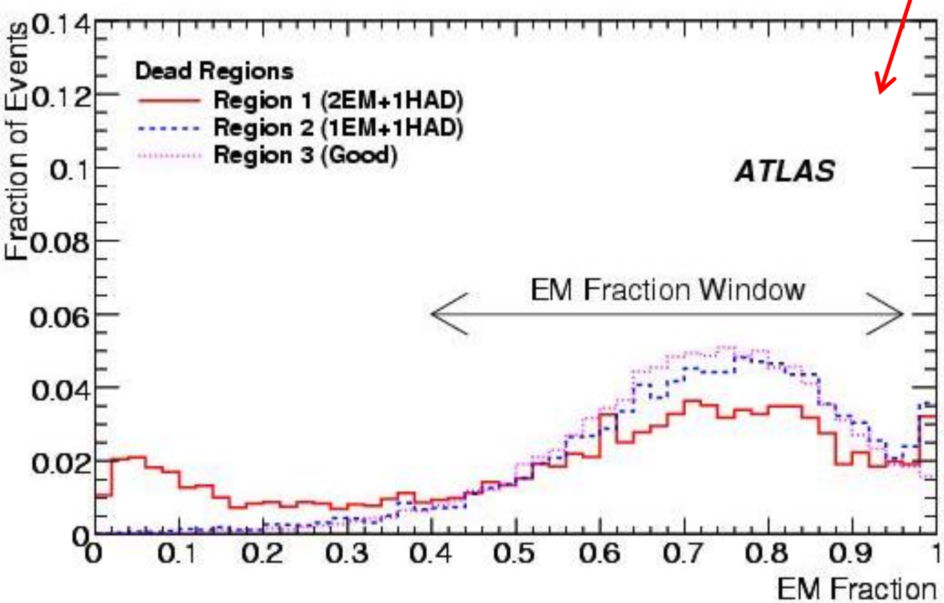


Dead channels effect



Region1 : EM and hadronic Endcap problems
Region2 : EM Barrel problem
Region3 : no problem

- Simulation studies on the effect of dead channels on missing ET
  - Large increase of the tails is observed.
- MC samples used to develop cuts able to reduce the fake missing ET maintaining high efficiency on signal
- For example fakes are reduced applying a cut on EM fraction as shown in the plot.



$$Jet\ EMF = \frac{(Jet\ E\ in\ EMB, EMEC, FCAL0)}{(Total\ Jet\ E)}$$

Conclusions

2008 achievements

- ✓ ATLAS was fully installed and ready for beam. Few percents of the subdetectors were not operational and when possible they are being repaired.
- ✓ Cosmics/beam have been very useful to verify and improve alignment and timing, thus validating the intense calibration program that many subdetectors had in previous period and exercize the data-taking system.

2009 plans

- ✓ Exploit the long shutdown:
  - Fix various electronics/LV problems on the calorimeters.
  - Consolidation work on the ID cooling and environment gas systems
  - Complete barrel hardware commissioning for RPCs
  - Change to radhard the optical fibers in the MDT wheels. Start installing un-staged muon Endcap EE chambers.
- ✓ Prepare for an extremely long run when maintenance will be reduced.
- ✓ Restart global commissioning two months before injected beam to be ready for collisions and "old" and "new" physics.

Back-up

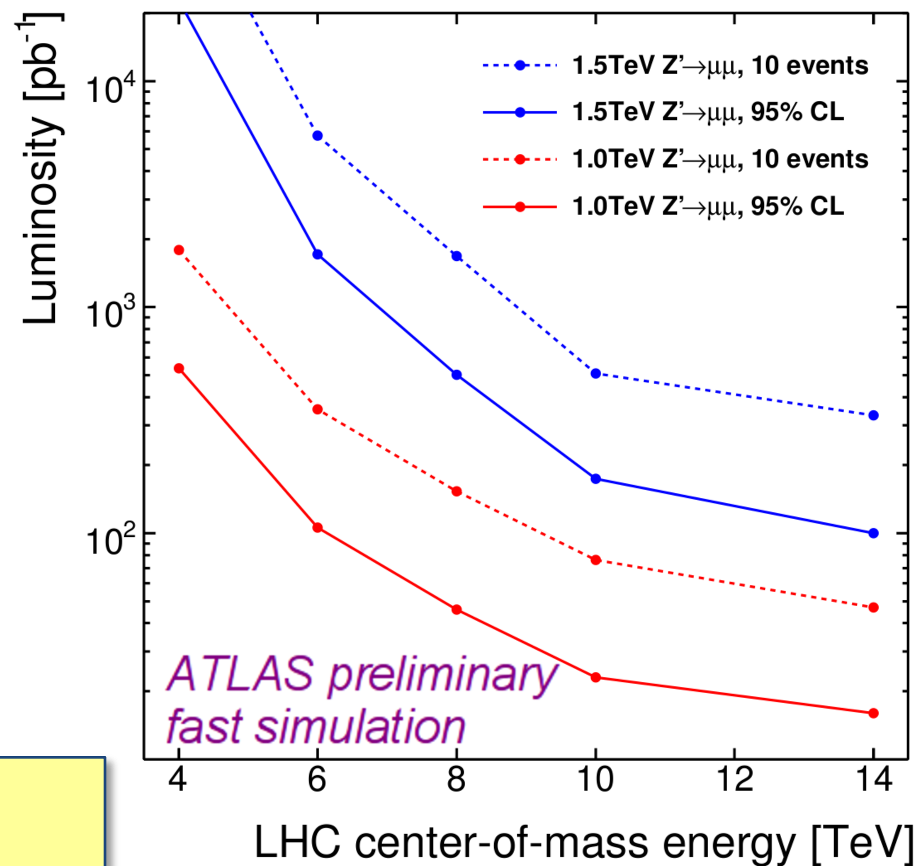
LHC startup (spare)

Year	2009											2010														
Month	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
Base '	SH	SH	SH	SH	SH	SH	SH	SH	SU	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	PH	SH	SH	SH	SH	SH	SH
	44 weeks physics possible																									

- ✓ LHC current plan foresees to run up to 44 weeks.
- ✓ Conclusion 5TeV/beam for Physics
- ✓ 4 TeV "on the way" to 5TeV (limited in 2010)
- ✓ Estimated integrated luminosity
  - during first 100 days of operation.. ≈100pb-1
    - » Peak L of 5.10^{31} η (overall) = 10% gives 0.5pb-1/day
    - » Peak L of 2.10^{32} η (overall) = 10% gives 2.0pb-1/day
  - During next 100 days of operation.. ≈ 200pb-1?

Z′: discovery potential vs Ecm

- ✓ As the first run will not be at 14 TeV, interesting to see how the discovery potential scale with energy.
- ✓ Study carried out with fast simulation and scaled according to cross-section in the fiducial acceptance for lower $\sqrt{s}$.
- ✓ The discovery potential shown corresponds >=10 events (i.e. about 5σ)



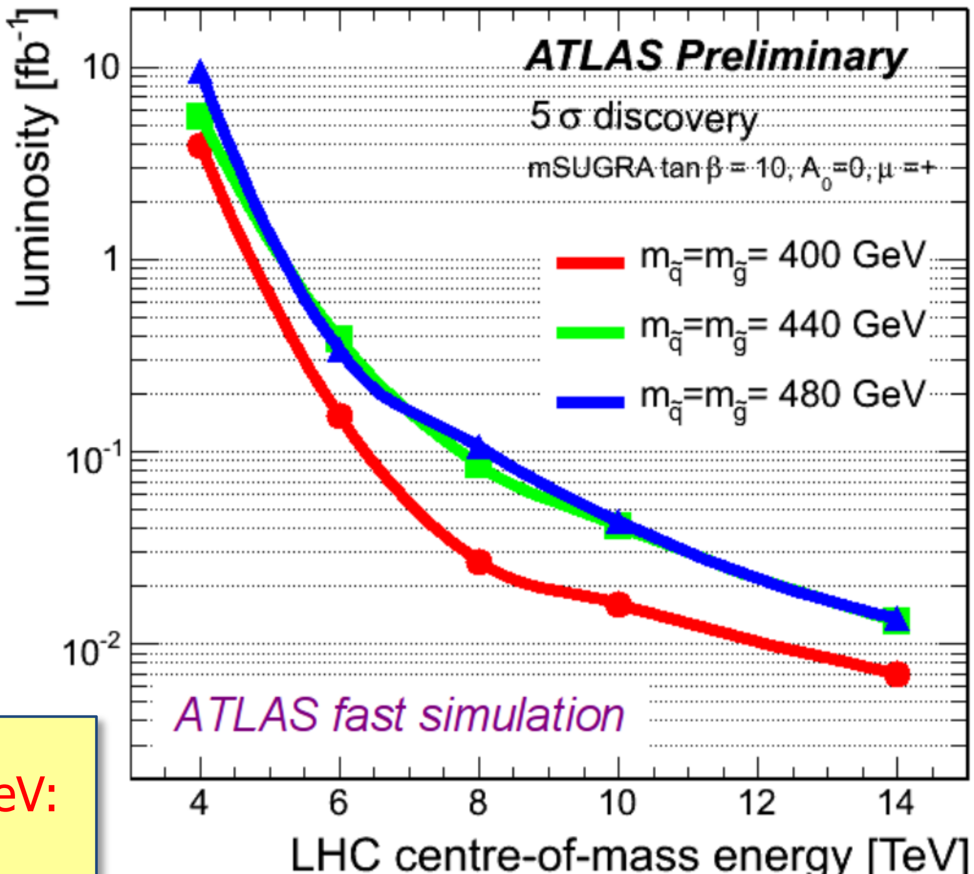
For $M_{Z'}$ ~1TeV, with Ecm = 10 TeV

95% CL limit with ~30 pb^{-1}

5σ discovery possible with ~100 pb^{-1}

SUSY: Discovery potential vs Ecm

- ✓ 1-lepton search mode is used as this channel should be understood more rapidly then the statistically more powerful inclusive 0-lepton search mode.
- ✓ Tevatron current limit is ~400 GeV in this model (equal mass squarks and gluinos)
- ✓ Below Ecm≈8 TeV, the sensitivity collapses.



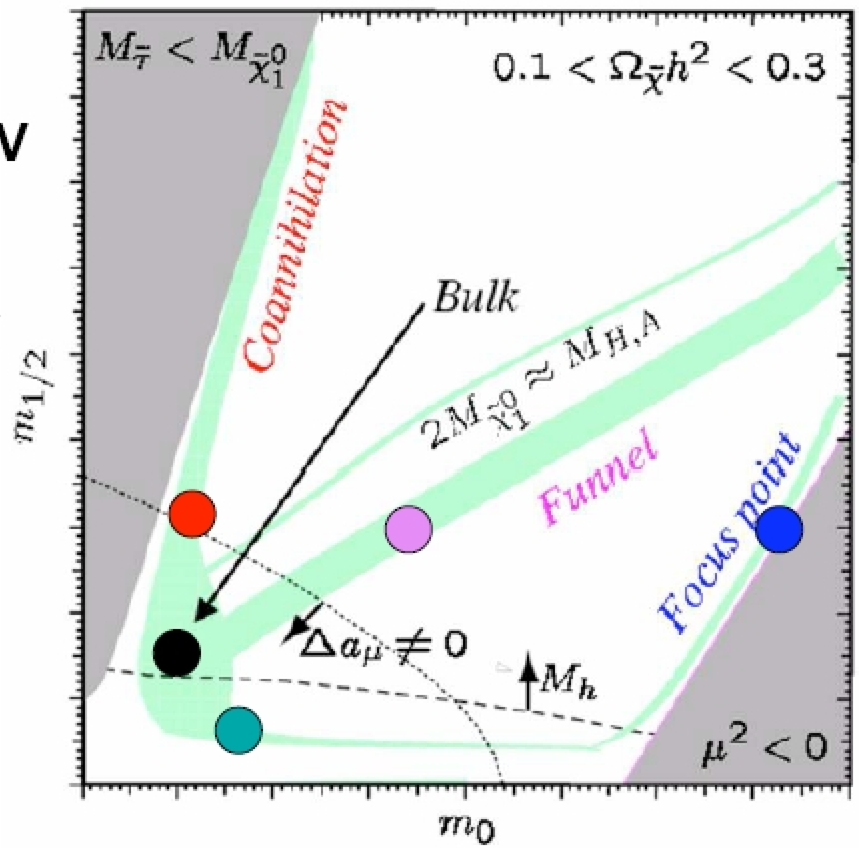
For SUSY particles with mass >400 GeV:

with Ecm = 8-10 TeV

5σ discovery possible with ~30-15 pb^{-1}

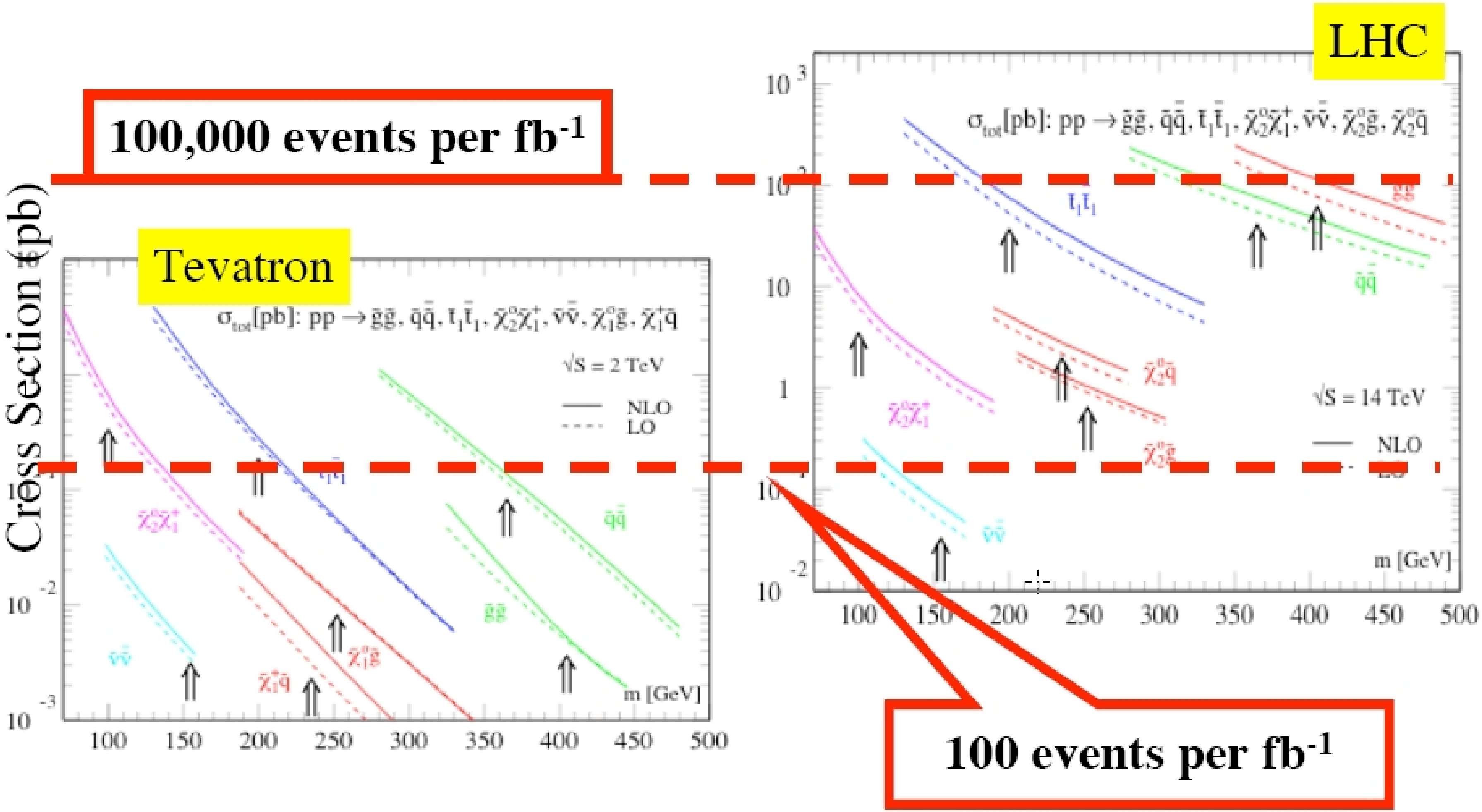
Benchmarks in SUSY Parameter space

- **SU1:** m($\tilde{g}$)≈830 GeV,m($\tilde{q}$)≈750 GeV
  - Coannihilation region
- **SU2:** m($\tilde{g}$)≈860 GeV,m($\tilde{q}$)≈3500 GeV
  - Focus point
- **SU3:** m($\tilde{g}$)≈720 GeV,m($\tilde{q}$)≈620 GeV
  - Bulk point
- **SU4:** m($\tilde{g}$)≈420 GeV,m($\tilde{q}$)≈420 GeV
  - Just beyond Tevatron reach
- **SU6:** m($\tilde{g}$)≈900 GeV,m($\tilde{q}$)≈870 GeV
  - Funnel regions



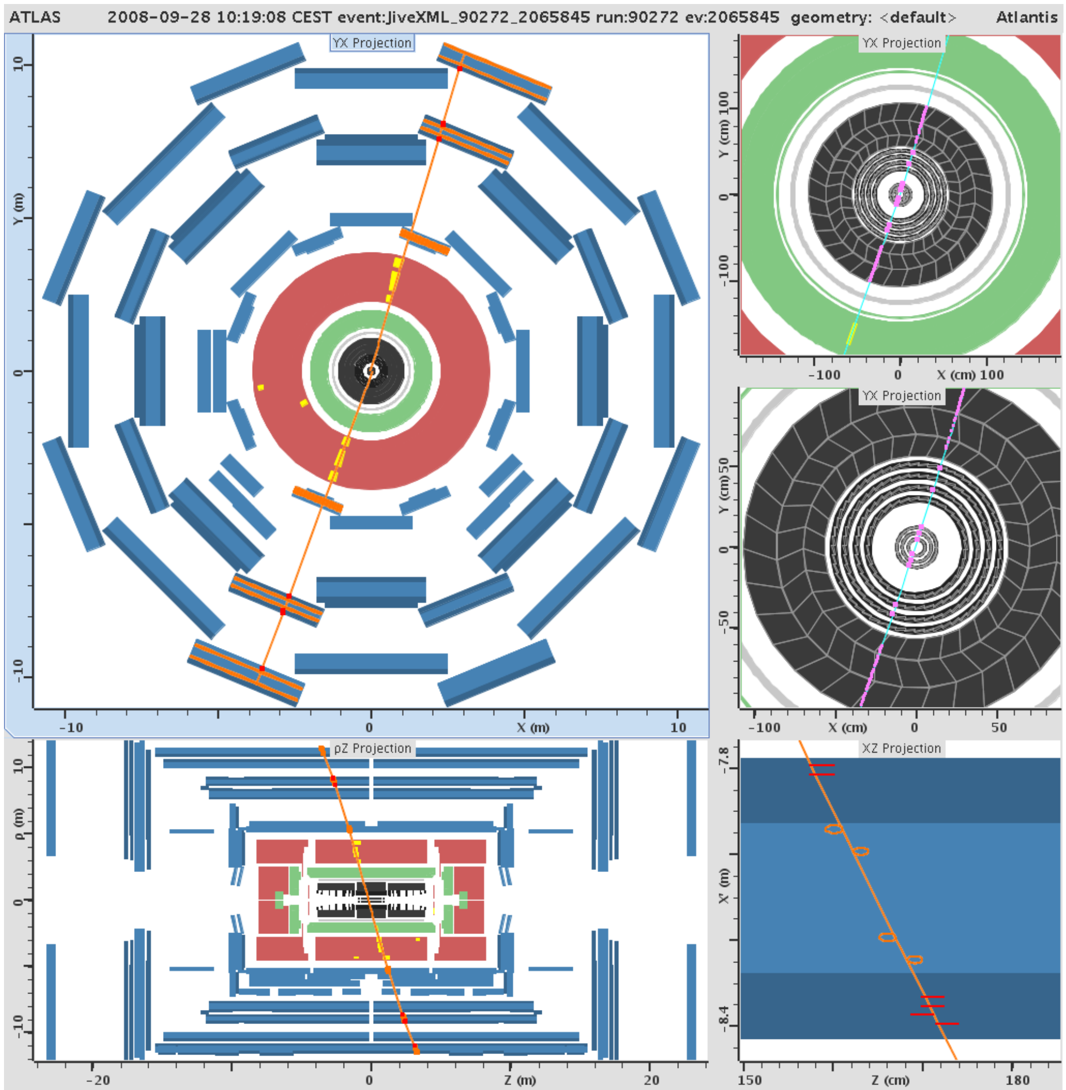
Attempt to span broad parameter space to understand model dependence

Sparticle Cross Sections: LHC vs Tevatron

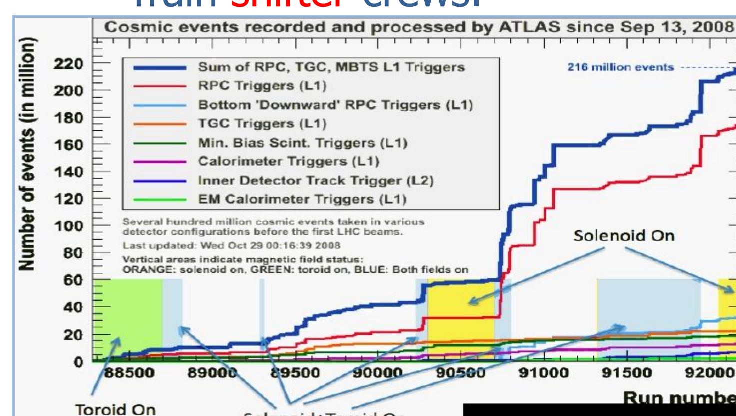


T. Plehn, PROSPINO

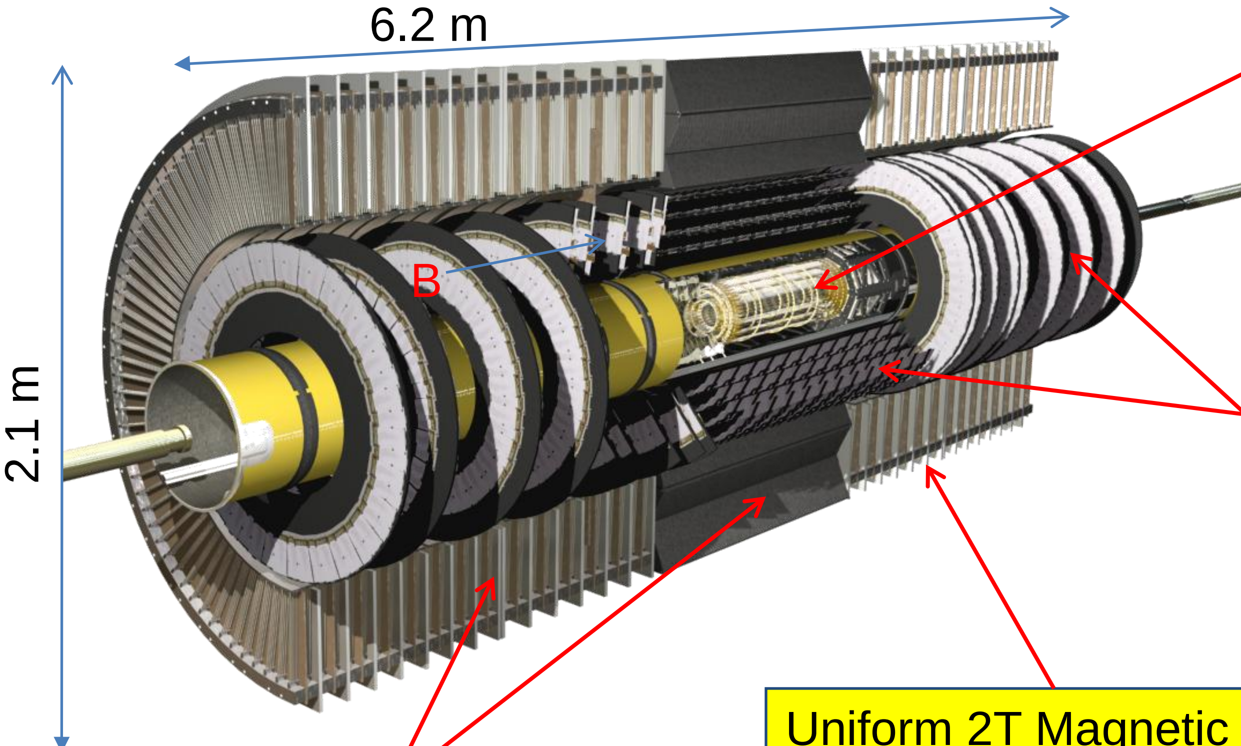
Combined results in cosmics



- ✓ Cosmics Data-taking has been very useful before and after the LHC accident (220 millions processed).
- ✓ Obviously cosmics cannot replace collisions for the detectors commissioning, however:
  - Alignment and timing
  - Combined data taking to exercise Trigger, DAQ, DCS and Data Quality
  - Train shifter crews.



Tracker: Inner detector



Pixel
- 5 cm from beam
- 50 μm x 400 μm
- Resolution: 12 x 100 μm

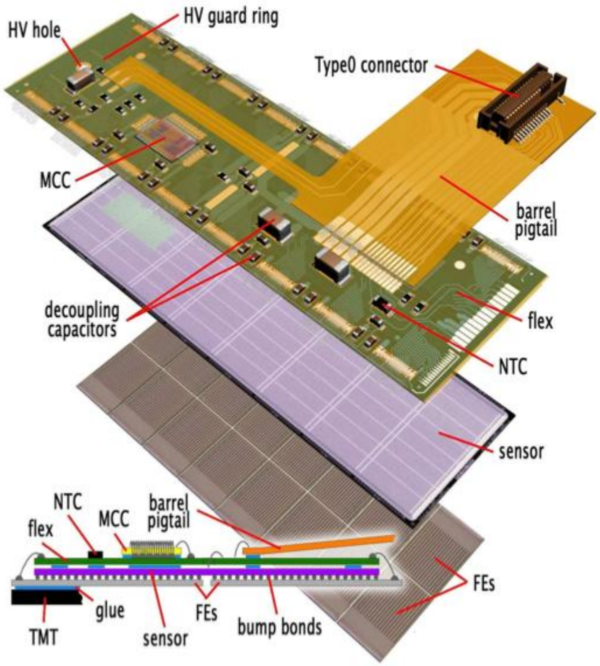
SCT (microstrips)
- 80 μm pitch
- 40 mrad stereo angle
- Resolution:16 x 580 μm

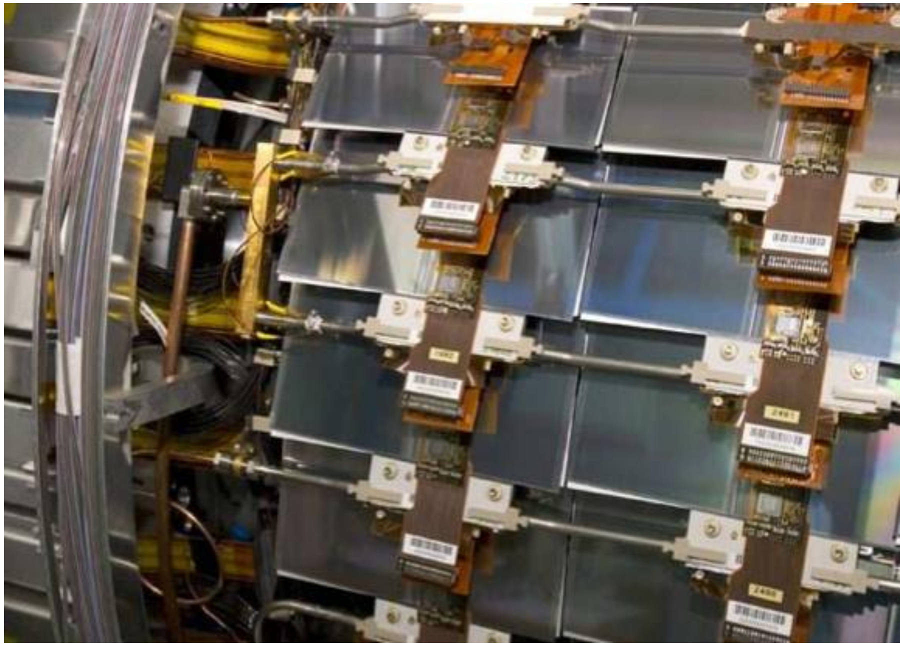
Uniform 2T Magnetic field provided by a solenoid.

TRT (straw tracker)
- 96 barrel modules
- 28 endcap disks
- Resolution: 170 μm

	Barrel		End-Cap	
Detector	Pixel	SCT	Pixel	SCT
#layers/disks	3	4	2 x 3	2 x 9
#modules	1456	2112	288	1976

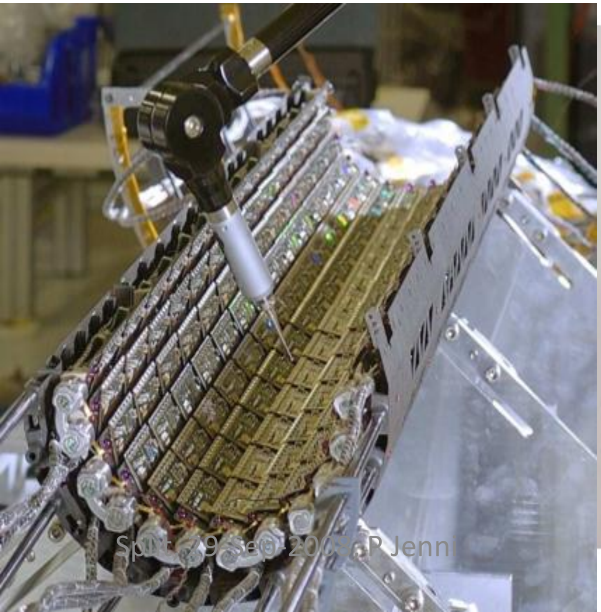
Inner Detector Silicon-sensors Spare

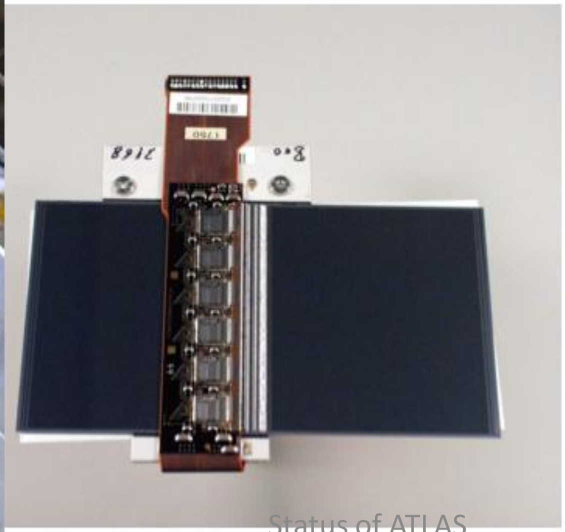


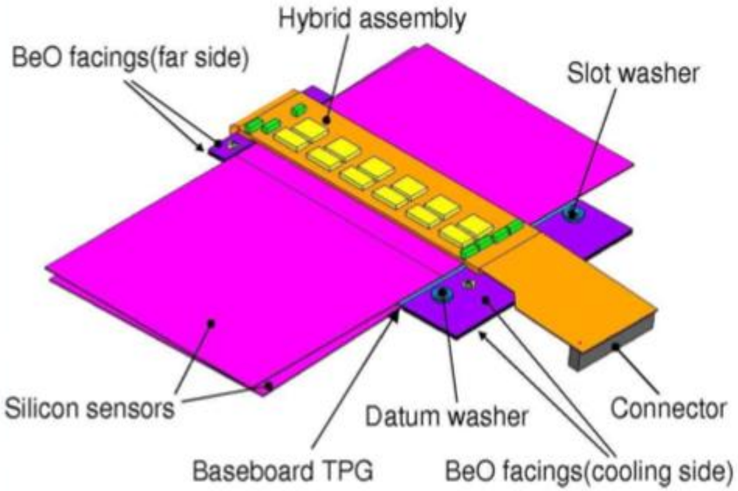


1744 Pixel modules, pixels 50x400 μm^2

4088 SCT modules, 80 μm micro-strips

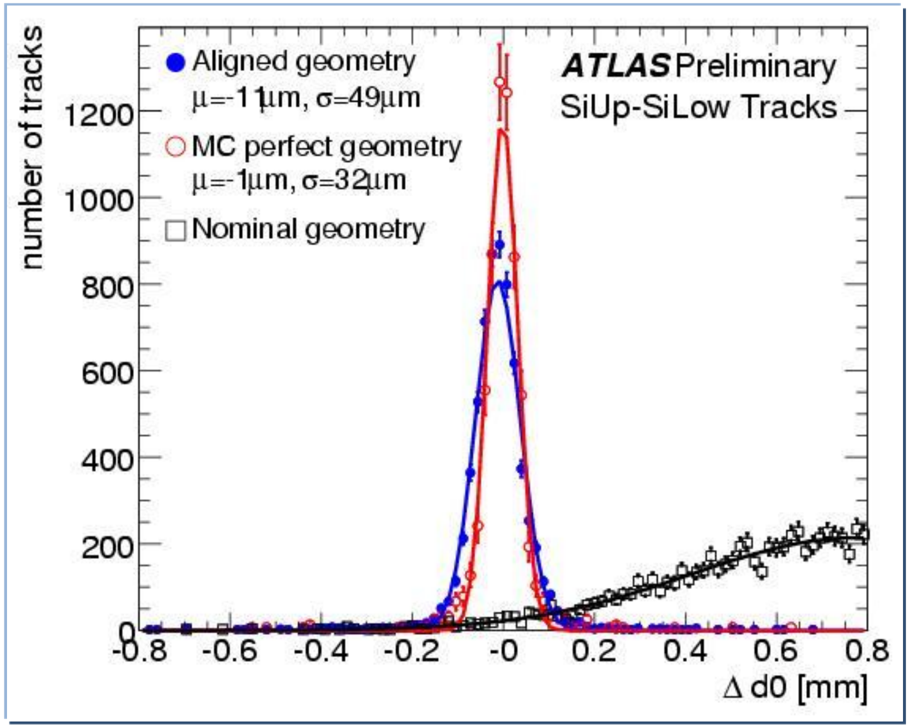






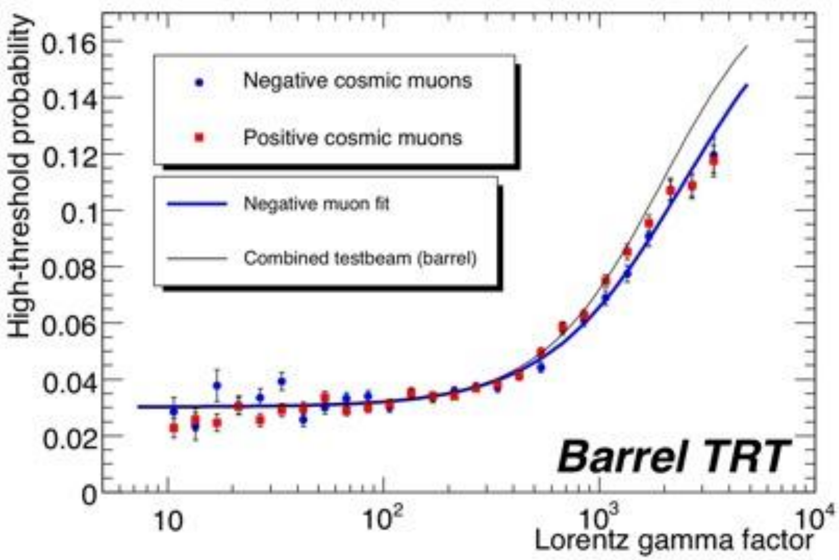
ID: track performances

- Tracking performance variables like impact parameter resolution, momemtun, etc can be studied by splitting the track in different part of the detector and comparing the track parameters value: Si vs TRT, ID vs muon, etc…
- Cosmics have the big advantage of crossing the top and bottom part of the detector; tracking performance variables can also be studied splitting up in upper and lower half tracks.
- Systematic 11 um offset in d0 distribution to be understood.

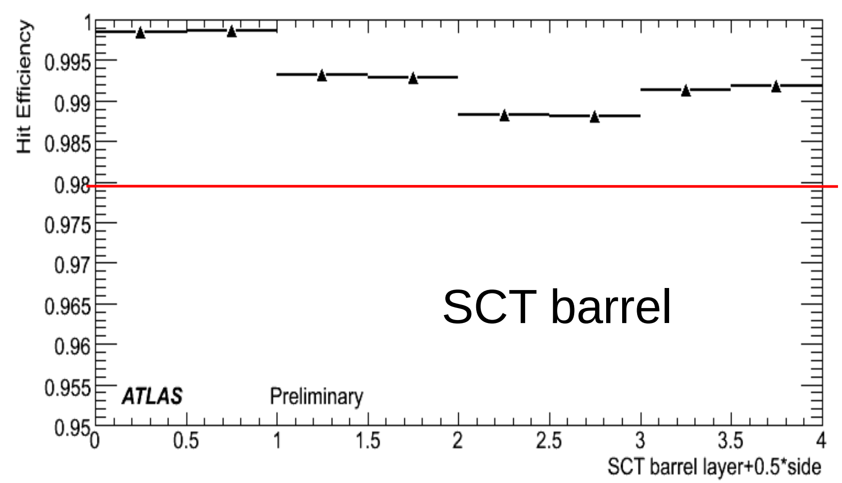


Inner Detector: Results

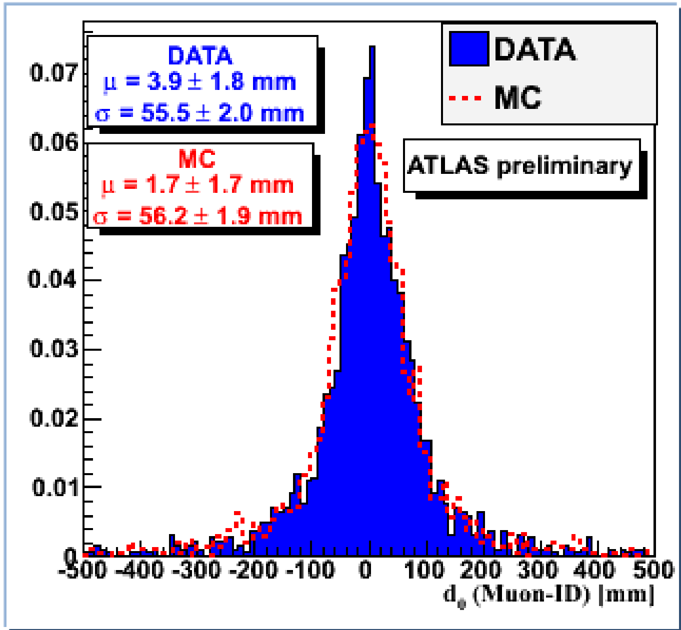
- ✓ For muons with $\gamma > 1000$ Transition radiation observed as energy deposits crossing a high energy threshold in the TRT. It will be used to identify electrons in the Tracker.

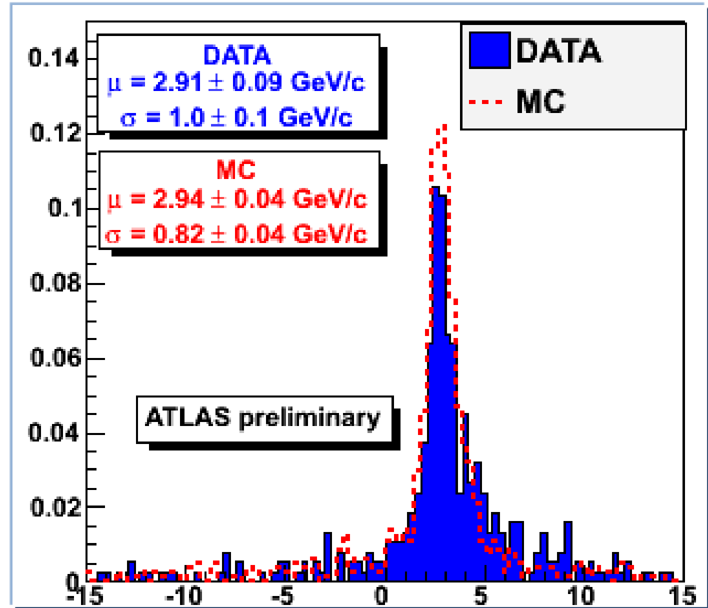


- ✓ Hit efficiency for SCT is well above 98% (similar for Pixel). Need careful correction of several effects like dead channels, calibrations, alignment.



Combined results: ID-muon





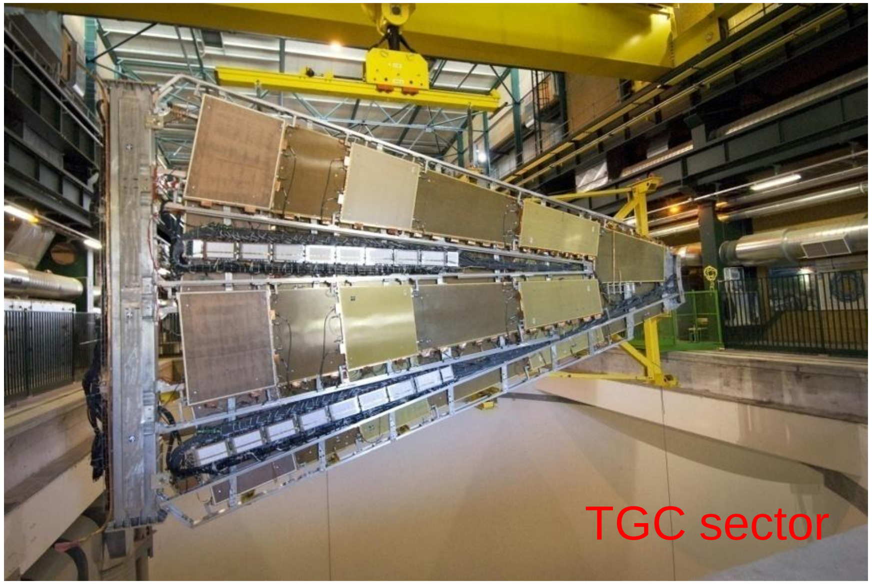
Momentum(ID-MS) [GeV/c]

Correlation between ID and muon tracks

- ✓ The data/MC agreement for all track parameter differences is fairly good.
- ✓ However, the measured deposited energy in the Tile calorimeter does not justify completely the ID-MS momentum difference (under investigation).

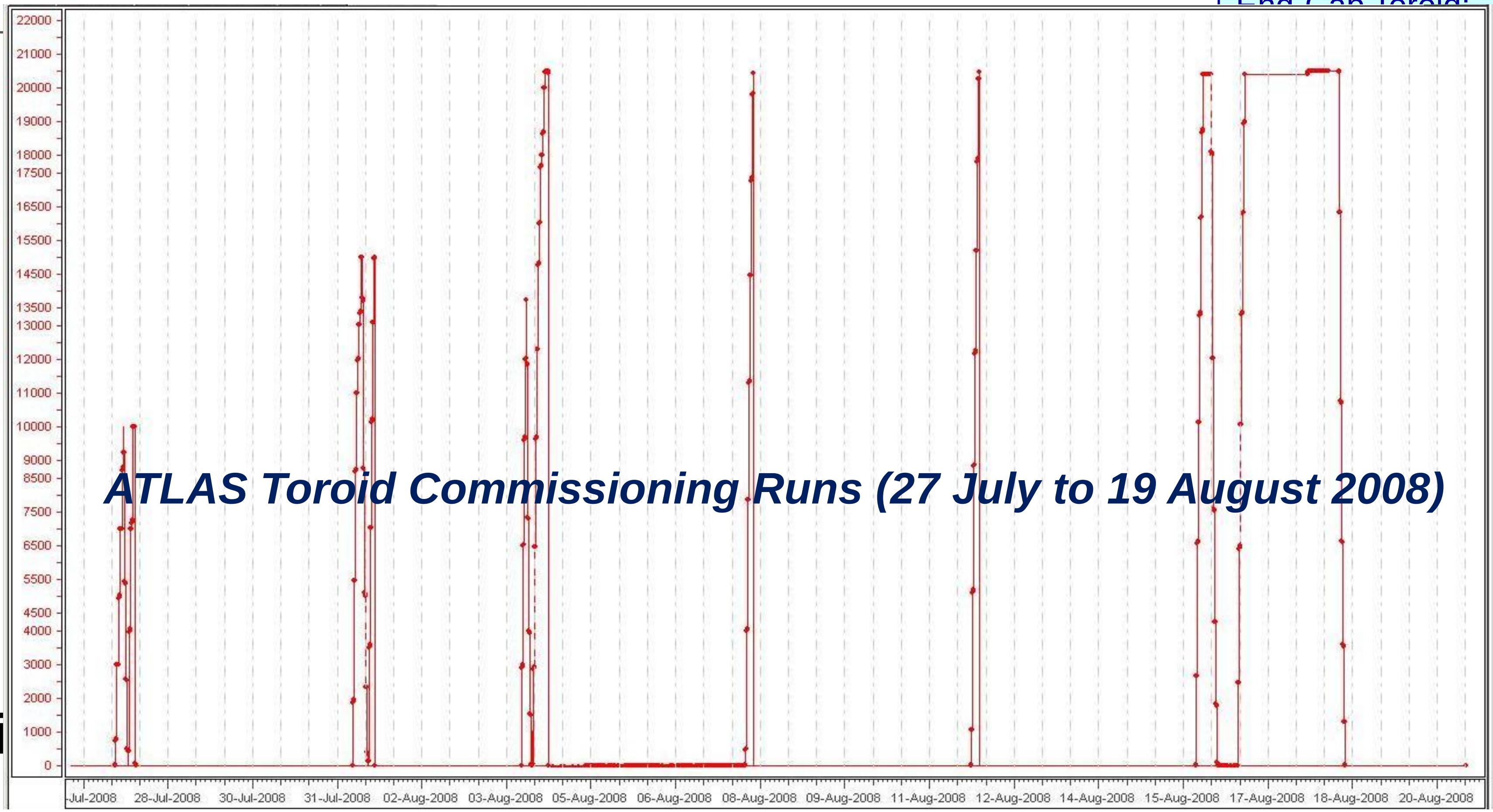
Muon spectrometer

	Function	Resolution (RMS)			Chambers	Channel	Coverage
MDT	Tracking	35 μm (z)	-		1108	339k	$\|\eta\| < 2.7$
CSC	Tracking	40 μm (R)	5 mm	7 ns	32	31K	$2.0 < \|\eta\| < 2.7$
RPC	Trigger	10 mm (z)	10 mm	1.5 ns	544	359k	$\|\eta\| < 1.05$
TGC	Trigger	2-6 mm (R)	3-7 mm	4 ns	3588	318k	$1.05 < \|\eta\| < 2.7$



Toroidal magnetic field-> Spare

End-Cap Toroid:
on



joi

Ramp-up of the current in 3 h10 min, slow dump in 2 h 40 min, fast dump in 2 min
Recovery time after a fast dump (quench) is typically 100 hrs

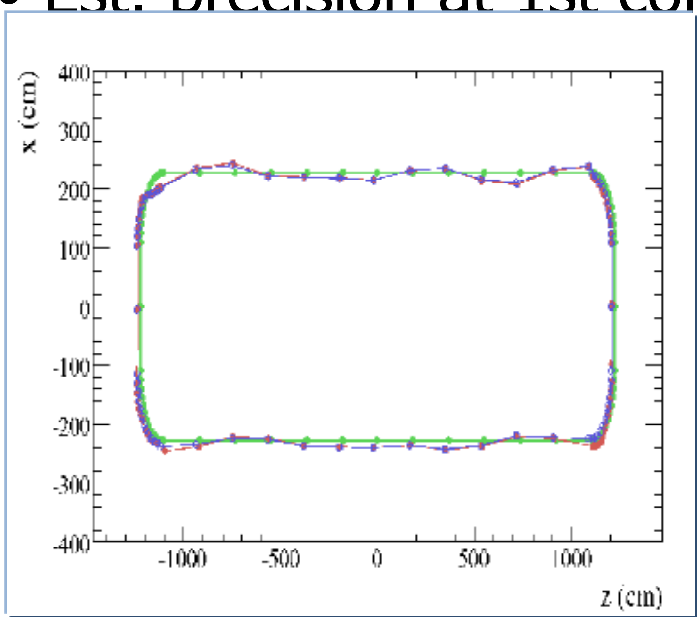
Since then the full magnet system has been operated for days (including the central solenoid), one more training quench occurred in ECT-A

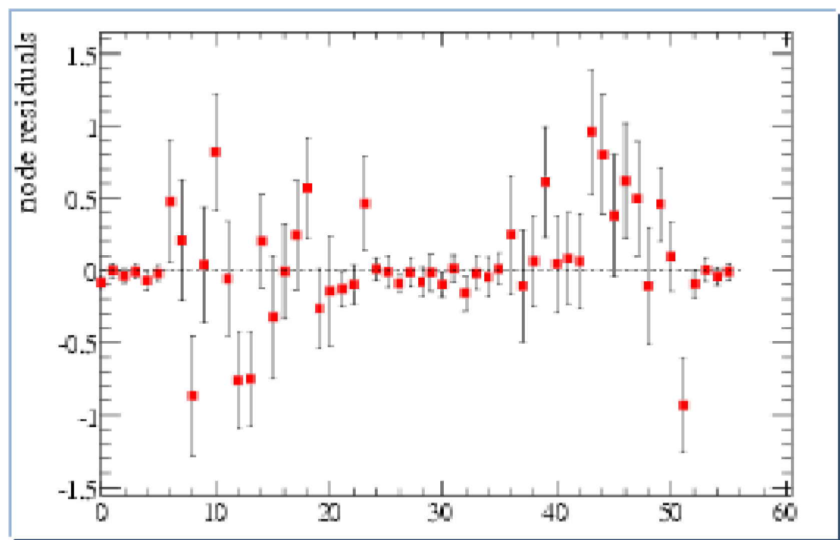
Muon spectrometer: B field -> spare

- ✓ Field measurement (1840 B-field sensors) -> 1-2mT
- ✓ 99% of 1650 field probes working
- Reconstruction of coil positions and deformation at 1 mm level
- Modeling of perturbations (TileCal, feet,

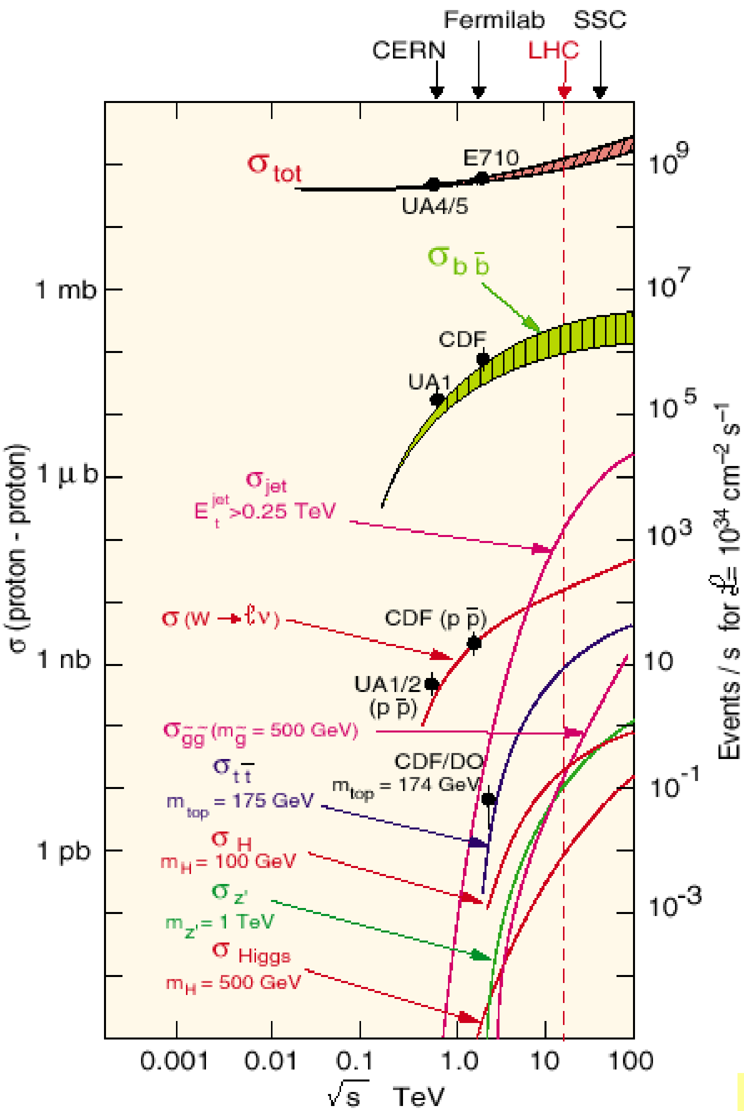
access struture, shielding) progressing well

- Est. precision at 1st collisions: sigmaB/B = 1.5%

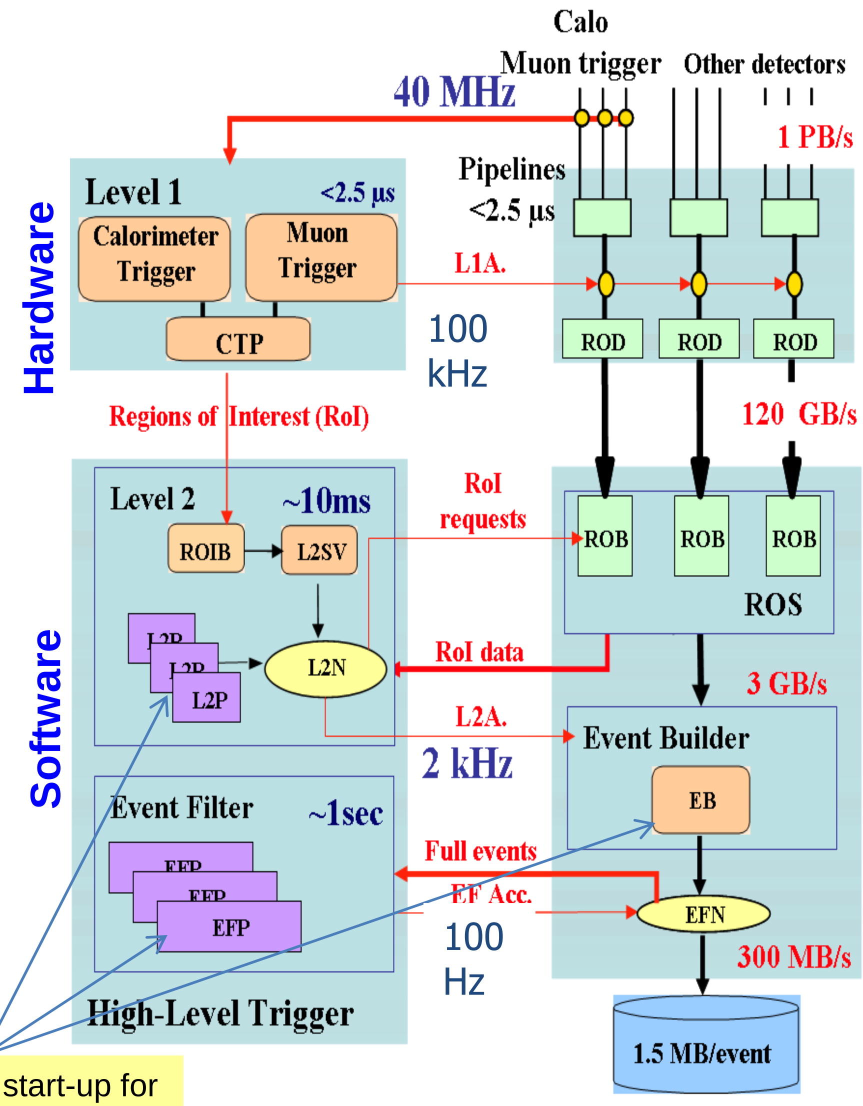




Trigger and Data Flow: battle of the Titans

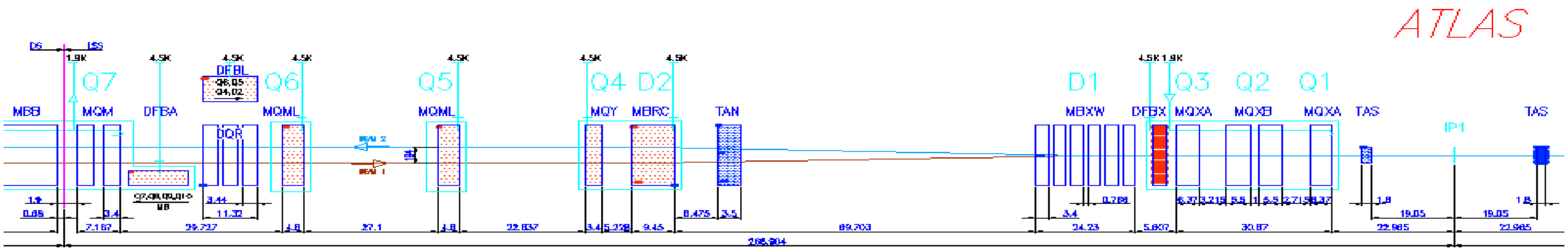


VS

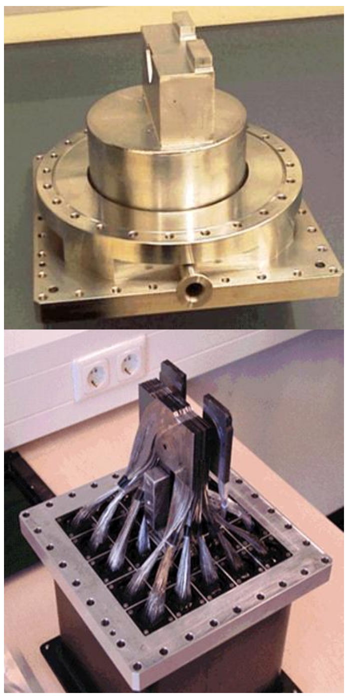


50% viable at start-up for resource reason

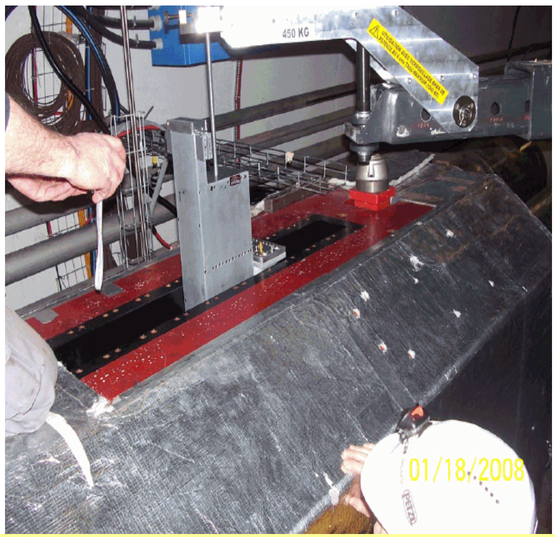
Forward Detectors



ALFA at 240 m

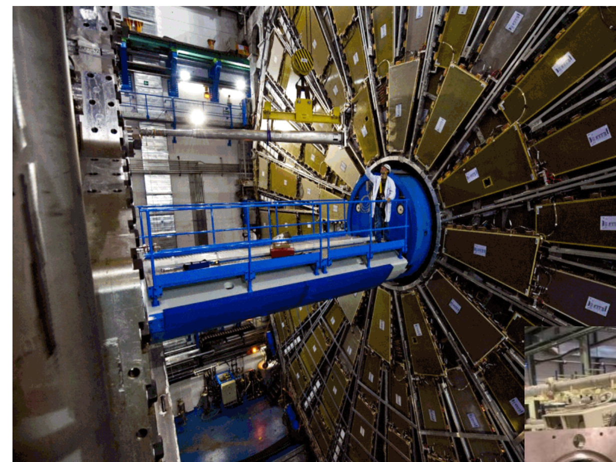


ZDC at 140 m



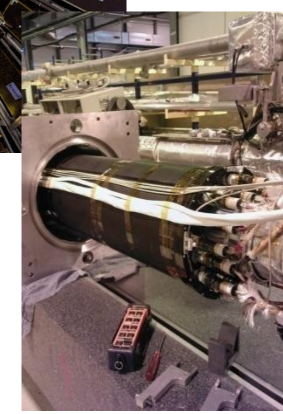
Zero Degree Calorimeter

LUCID at 17 m



Luminosity Cerenkov Integrating Detector

(Phase I detector is operational)



Absolute Luminosity for ATLAS

(Plus an internal LoI for future Forward Proton detectors at 220 and 420 m)

p-p cross-sections and Production rate

- SM might be seen as "background" for BSM physics.
- Understand detector performance in situ in the LHC environment
- • Perform first physics measurements
- • understanding minimum bias events
- • measure QCD jet cross-section
- • measure W, Z cross-section
- • observe a top signal
- • improve knowledge of particle density functions with W/Z
- and maybe
- • discover low mass SUSY up to ~1 TeV
- • discover a Z′ up to masses of ~1 TeV