ATLAS Detector and Early Physics

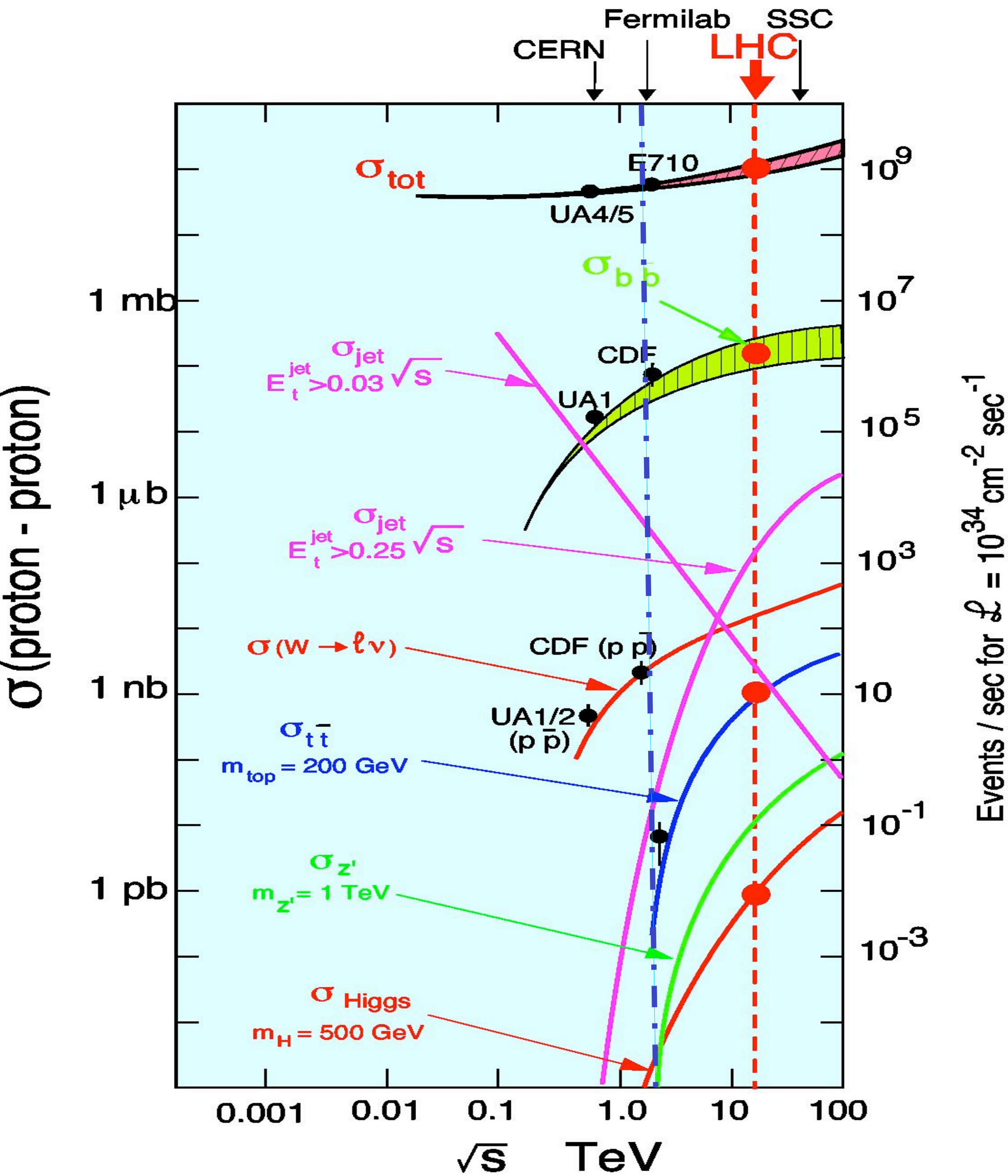
- ATLAS Detector
- Performance and Status
- Early Physics
- Summary

Zhengguo Zhao

University of Science and Technology of China

Experiments at Large Hadron Collider

LHC— Factory for b, t-quarks, W, Z



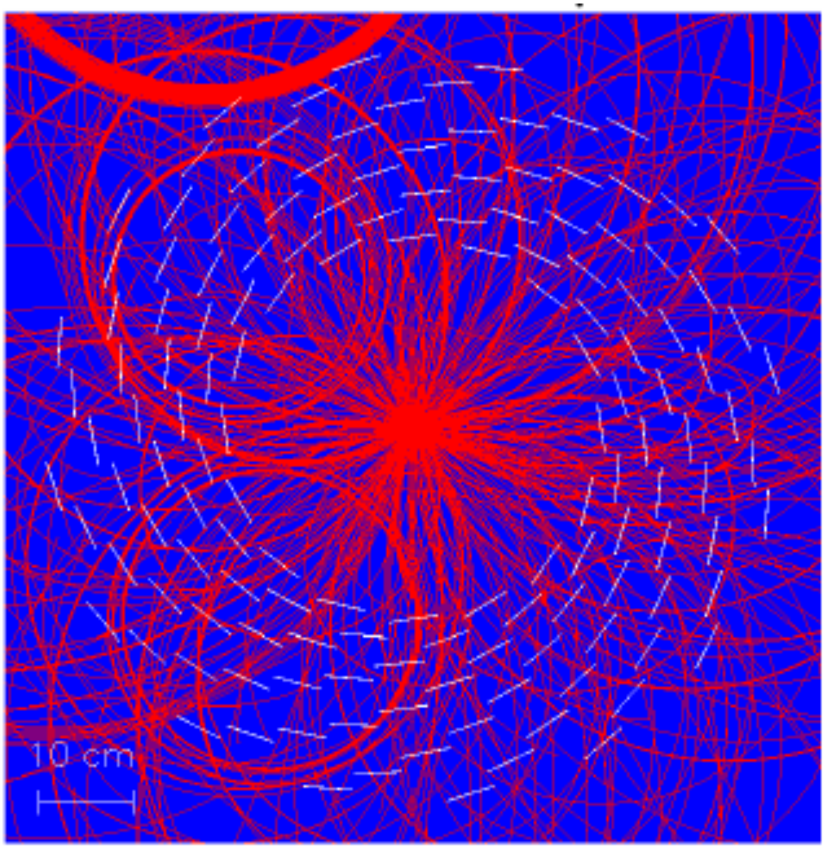
$N = L \times \sigma(pp \to x) = 10^9$ collision/s

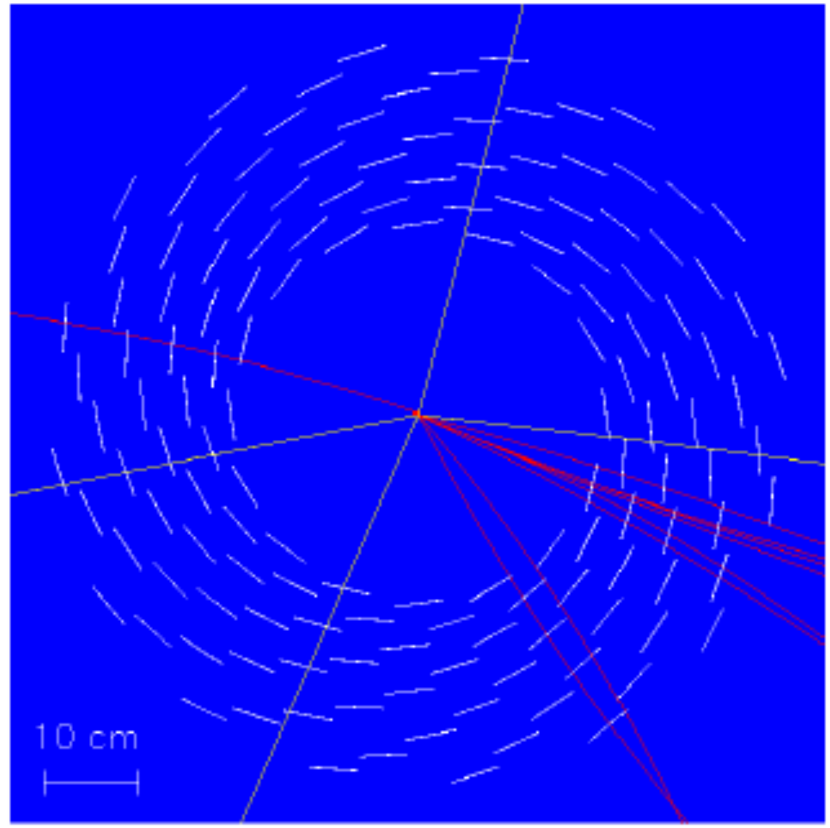
- Mostly low p_t events (soft) events. 20 inelastic (low-p_T) events ("minimum bias") produced simultaneously in the detectors at each bunch crossing → pile-up
- Interesting high p_t events are rare
- New physics rate ~ $10^{-(3-5)}$ Hz → event selection 1 in 10^{12-14}

Final object to be detected

- leptons (e, μ, τ)
- γ
- jets, light hadrons(π,p..)
- E_T^{miss}

Challenge For Tracking $H \rightarrow ZZ \rightarrow 4\mu$





Challenge To The Detector

- Fast response (20-50 ns), otherwise too large pile-up.
  - integrate over 1-2 bunch crossings
  - pile-up of 25-50 minimum bias events

  → very challenging readout electronics

- High granularity to minimize probability that pile-up particles be in the same detector element as interesting object

  → large number of electronic channels, high cost

- High radiation resistant

  e.g. in forward calorimeters, up to 10^{17} n / cm^2 in 10 years of LHC operation

- Good particle identification

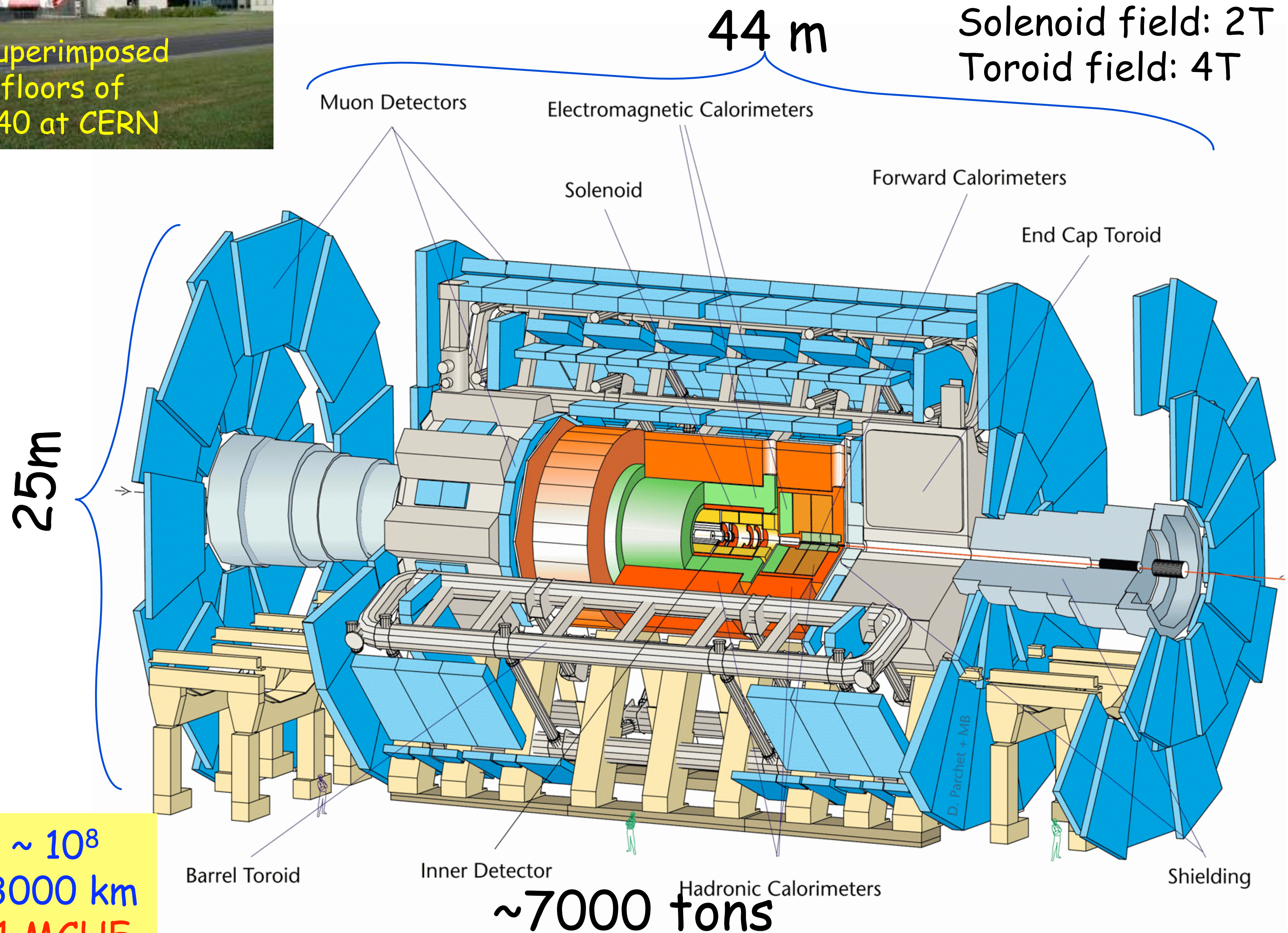
- Good E, P resolution

Main Design Choice

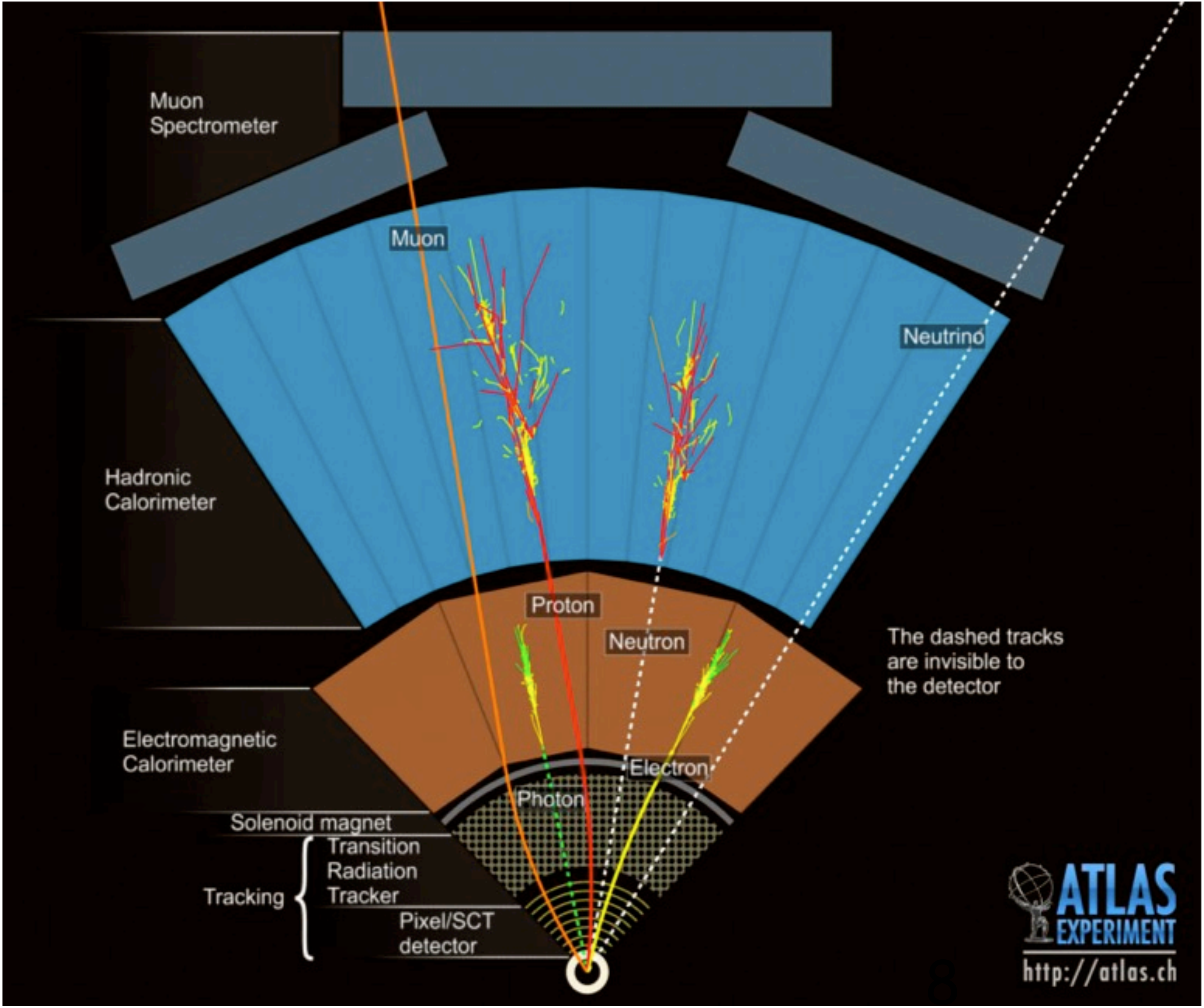
- Efficient tracking for lepton momentum measurement; enhance e/γ identification; excellent b tagging capability at low luminosity.
- Very good electromagnetic calorimeter for e/γ identification, complemented by thick and hermetic hadronic calorimeter for jet and missing transverse energy measurement.
- Stand-alone and precise muon measurement over a wide polar angle range.

The ATLAS Detector

Solenoid field: 2T
Toroid field: 4T



Channels: ~ 10^8
L_{cable}: ~ 3000 km
Cost: 541 MCHF


Muon Spectrometer
Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
The dashed tracks are invisible to the detector
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Transition Radiation Tracker
Tracking
Pixel/SCT detector
ATLAS EXPERIMENT
http://atlas.ch

Particle Detection at ATLAS

e	Track; energy deposit in ECAL
γ	No track, energy deposit in ECAL
μ	Track in both inner tracker and muon spectrometer
ν	No signal, only missing energy
$q/g/\tau$	Hadronic jet, signal in all subdetector
b	Secondary vertex, signal in all subdetector

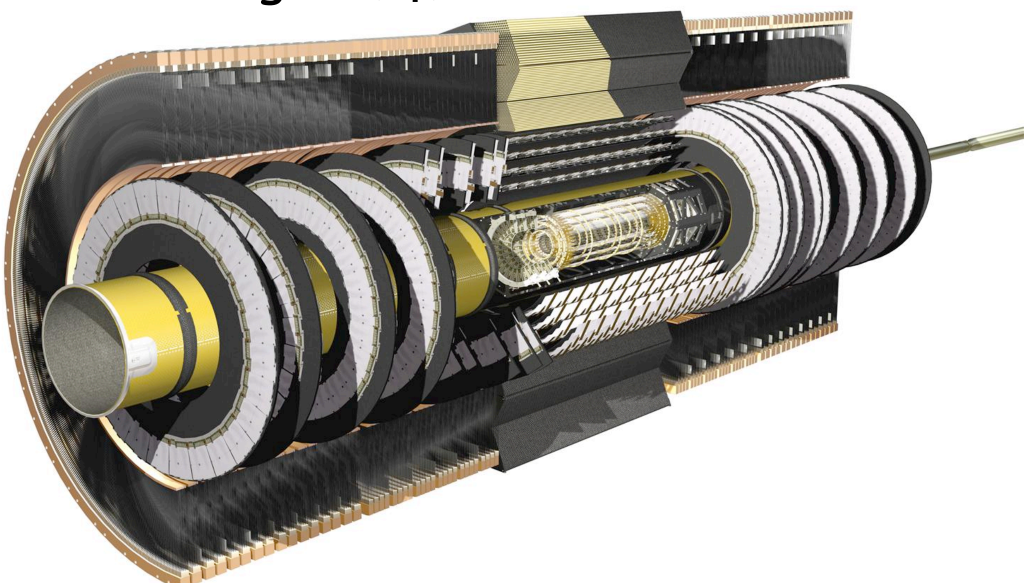
ATLAS Required Performance

Subdetector	Required resolution	eta coverage Measurement	eta coverage Trigger
Tracking	$p_T/p_T = 0.05\% p_T \oplus 1\%$	2.5	
EM calorimetry	$\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$	3.2	2.5
Hadronic calorimetry (jets)			
Barrel and Endcap:	$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$	3.2	3.2
Forward:	$\sigma_E/E = 100\%/\sqrt{E} \oplus 10\%$	3.1–4.9	3. 1–4.9
Muon spectrometer:	$\sigma_{p_T}/p_T = 10\%$ (p_T=1 TeV)	2.7	2.4

Calibration and reconstruction relies on MC, which needs to be valided by test beam and cosmic ray data -> improve the MC of the detector

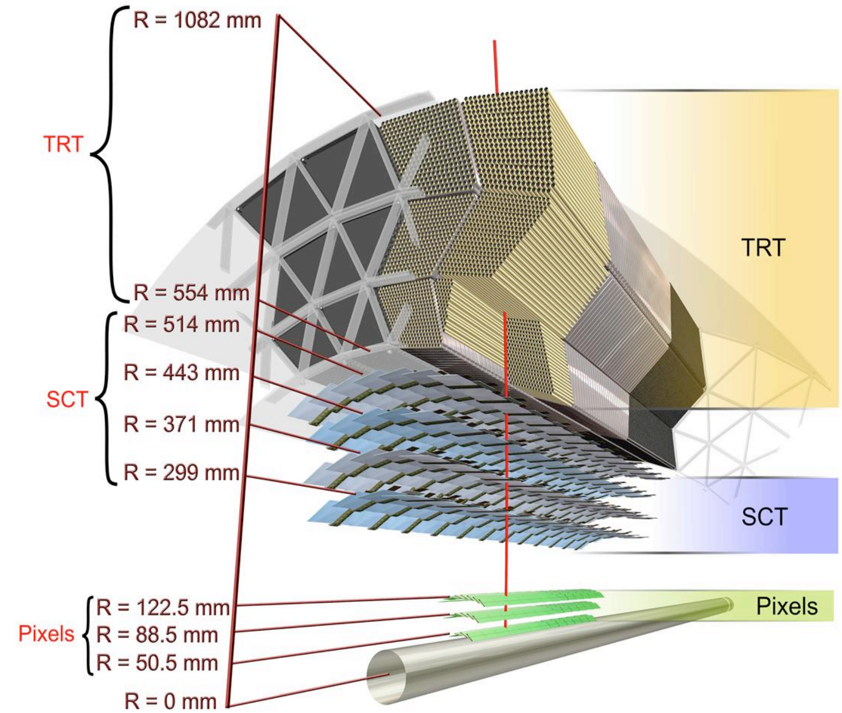
Inner Detector

Tracking $|\eta|<2.5$ B=2T



Momentum resolution:

$\sigma/p_T \sim 3.4\times10^{-4}\, p_T(\text{GeV}) \oplus 0.015$



- Transition Radiation Tracker
- 4mm diameter straws with 35 µm anode wire
- Layers: 73 in Barrel (axial) 2x160 in Endcap (radial)

- 4/9 double layers in Barrel/Endcap
- 4088 modules, 6M chan., strips 80 µm
- Resolution 17x580 µm

- 3 layers in Barrel and Endcap
- Pixel size 50 x 400 µm
- Resolution 10x110 µm
- 80 M channels

Inner Detector Requirement

- SUSY studies
  Control the charge misidentification <= 1%

- H->4l
  Good track efficiency (>=95%) with low track fake rate (<=1%)

- Good b tagging efficiency
  50% eff. with a rejection factor 100 (low luminosity)

- Enhance electron identification using the transoition radiation

- Resolution: σ_{p_T}/p_T=0.05%+1% cannot compete with ECAL nor muon spectrometer at high energies

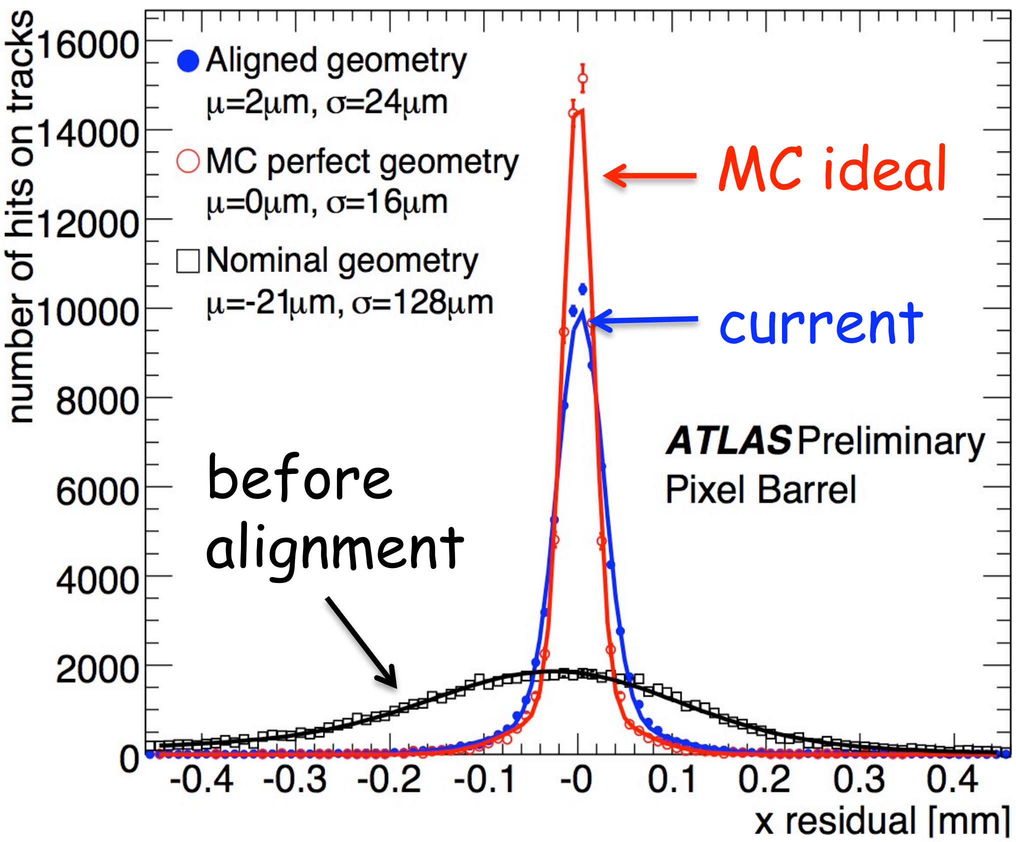
Inner Detector Status

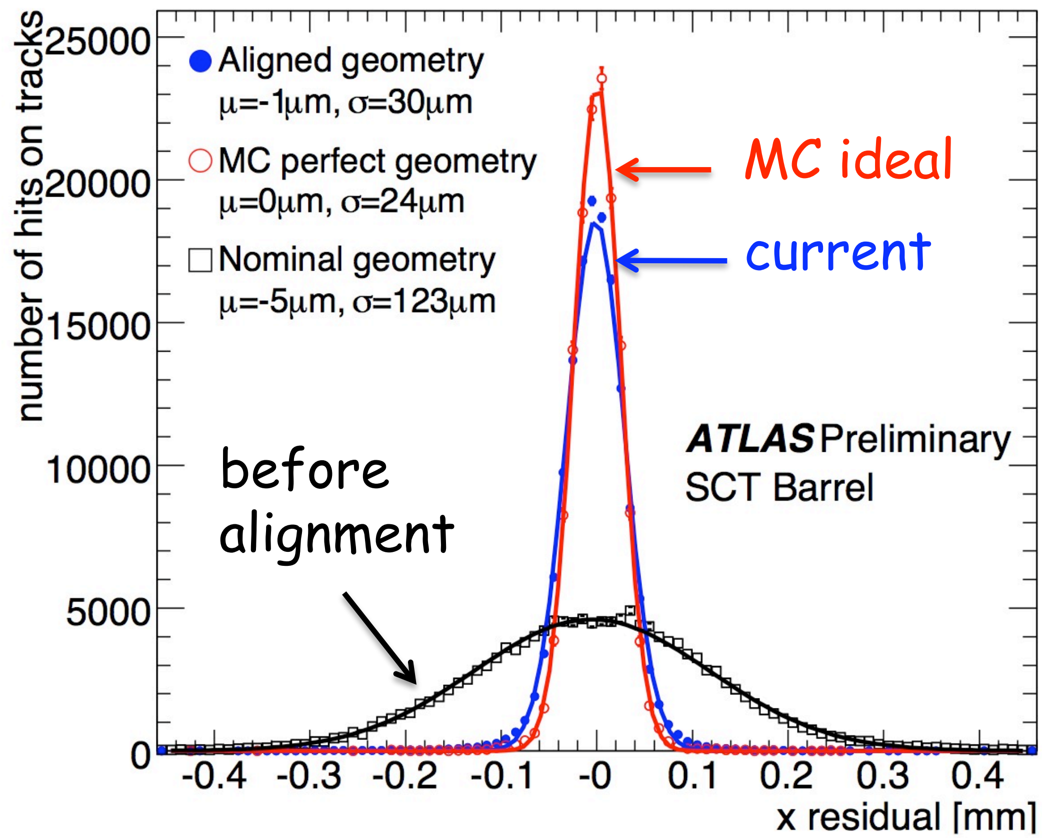
- Pixel
  - 80 M channels, 1.6% dead channel
  - Hit efficiency~ 99.8%
  - Noise occupancy ~10^{-10}

- SCT
  - 6 M channels, dead channel < 1%
  - Noise occupancy: Barrel: 4.4×10^{-5} ; Endcap: 5×10^{-5}
  - Hit efficiency > 99.5%

- TRT
  - e-π separation via TRT: $0.5 < E < 150$ GeV
  - 98% of the 52k channels operational

Pixel and SCT Cosmic Ray Results





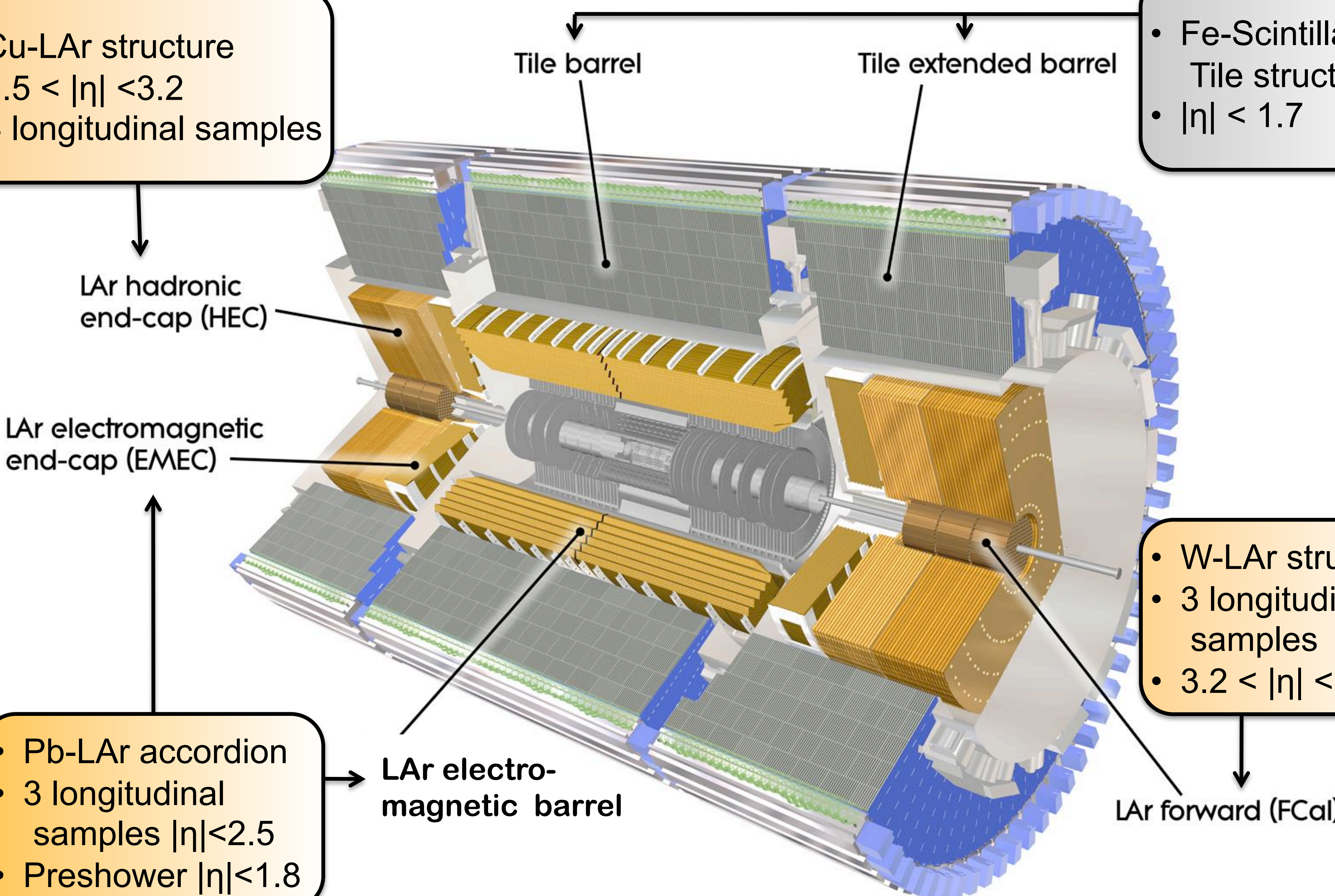
For 2009/2010 running

- Very high efficiency: 99.8 for Pixcel, 99.5% for SCT
- Good alignment available

Calorimeter System

- Cu-LAr structure
- 1.5 < |η| <3.2
- 4 longitudinal samples

- Fe-Scintillating Tile structure
- |η| < 1.7



- W-LAr structure
- 3 longitudinal samples
- 3.2 < |η| < 4.9

- Pb-LAr accordion
- 3 longitudinal samples |η|<2.5
- Preshower |η|<1.8

Requirement to the calorimeter

Electromagnetic calorimeter

- Reconstruct e/γ from H, Z'/W' and b taging
- H->$\gamma\gamma$ mass resolution 1%
- Jet rejection with inner detector: 10^5 and ε=70% for e; 10^3 and ε = 80% for γ (include converted γ)

Hadronic calorimeter

- Large coverage: good transverse missing energy(MET) resolution and tagging jets associated to the heavy Higgs production.
- Thickness: provide good MET resolution and limit punch through to the muon.

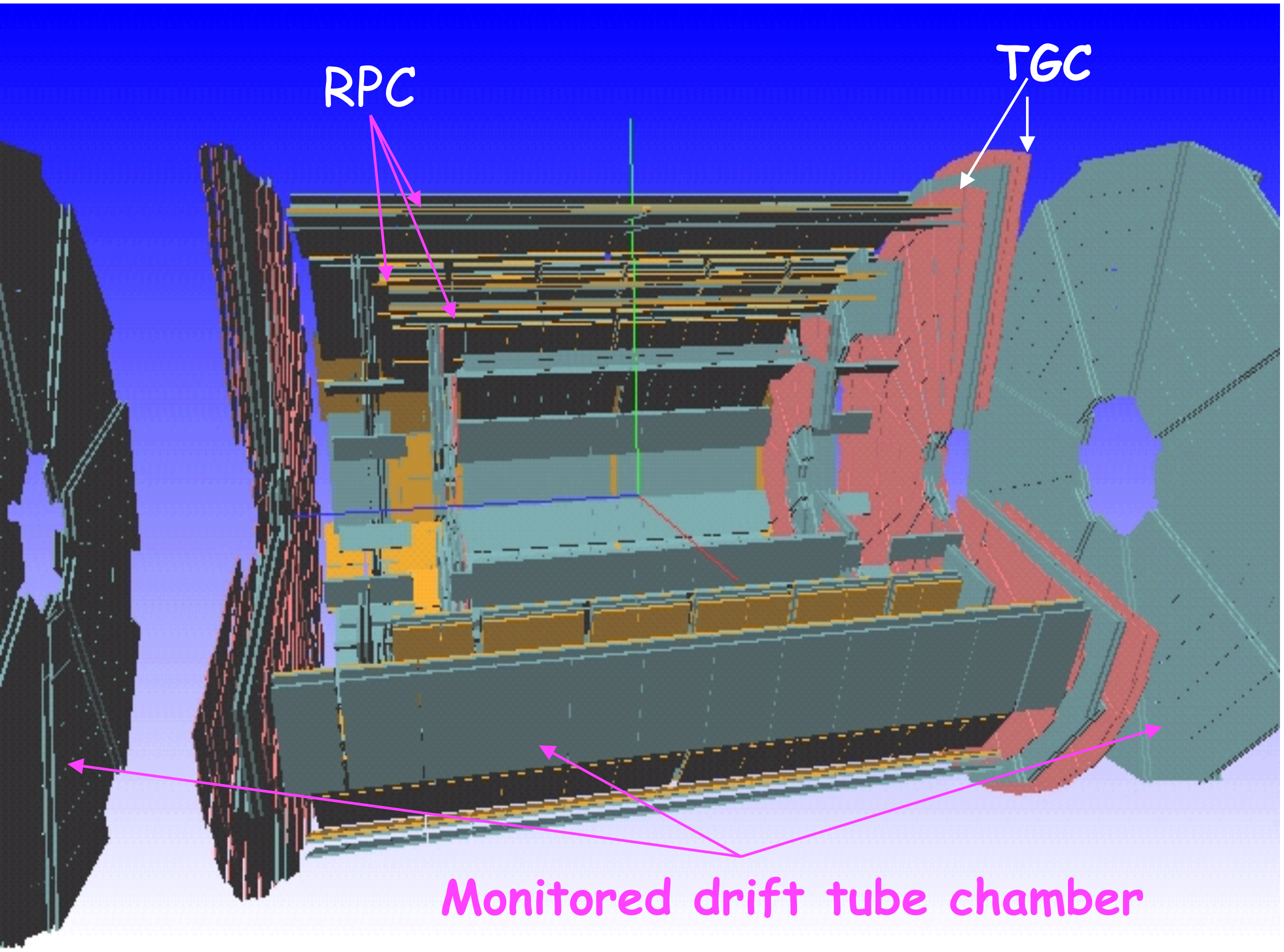
Calorimeter Status

- LAr calorimeter
  - Dead channels 0.02% (+0.9% from readout – being fixed)
  - Noisy channels 0.003%
  - Electronic calibration procedure is operational

- Tile calorimeter
  - Dead channels: < 1.4% (replaced during the shutdown)
  - Calibration system is operational (Cs source, laser, charge inj.)

- L1 calorimeter trigger
  - Dead channels: < 0.4% of 7200 analogue channels
  - Channels to channel noise suppression allows E_T=1GeV cut (aim: 0.5 GeV)

Muon Spectrometer



Precision chambers:
- MDTs in the barrel and end-caps
- CSCs at large rapidity for the innermost end-cap stations

Trigger chambers:
- RPCs in the barrel
- TGCs in the end-caps

Requirements:

Trigger Chambers:
P_t threshold 6 GeV

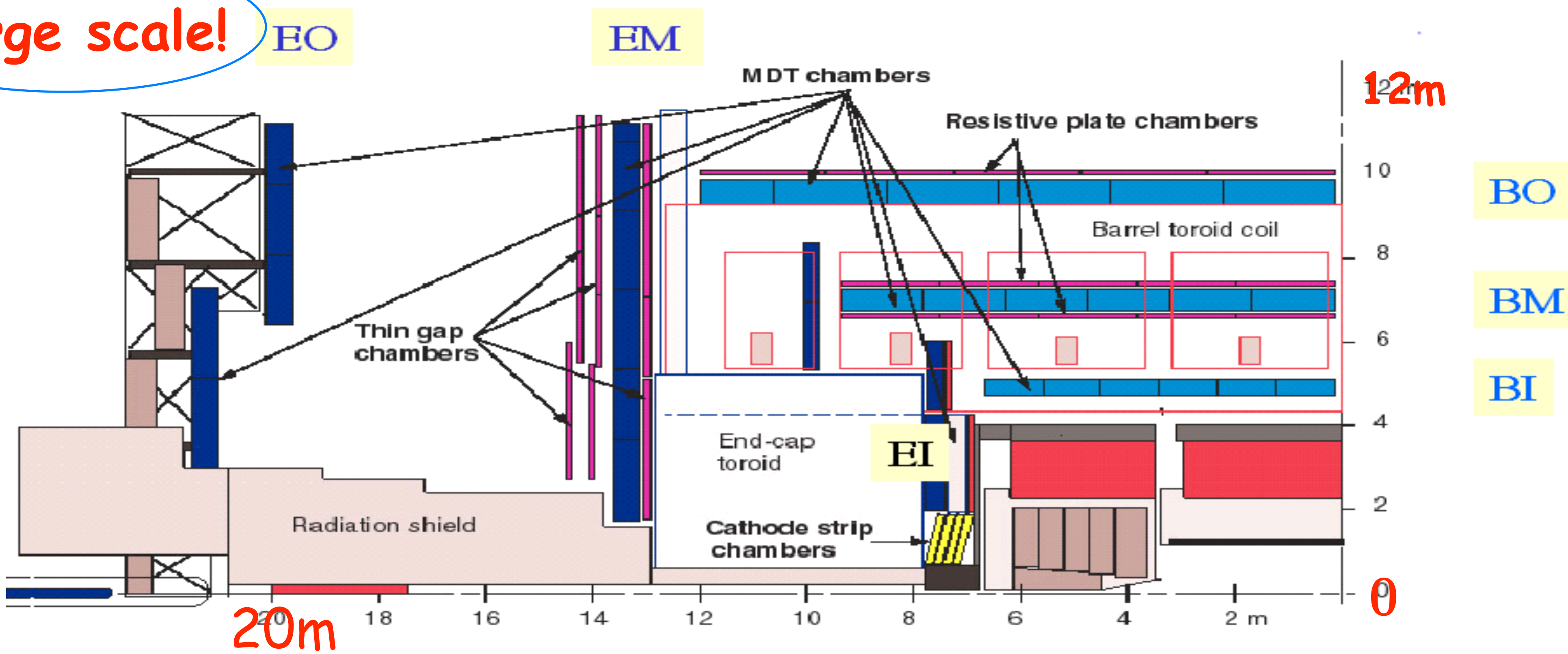
Rapidity range:
$|\eta|<=2.7$

Track and p measurement:
σ_{p_T}/p_T = 3% at 100 GeV
10% at 1TeV

A crucial component to reach the required accuracy is the sophisticated alignment measurement and monitoring system

Muon Spectrometer

Large scale!



Total MDT chambers: 1155 (371,232 tubes)

Total CSC chambers: 32 (67,000 channels) Large quantity !

Alignment sensor, ~10,000 channels

Tracking Sagitta resolution: 50 μm

Single wire resolution: 85 μm

Alignment precision: 40 μm

High precision !

Requirements to the Ms

- Excellent stand-alone performance at high luminosity
  σ_{p_T}/p_T = 3% at 100 GeV , 10% at 1TeV
- Low momentum trigger capability at low luminosity
  P_t threshold 6 GeV
- Larger rapidity range
  2-6 Tm for $|\eta|<1.3$, 4-8 Tm $1.6<|\eta|<2.7$

Muon System Status

Precision chambers

spatial resolution 35-40 μm

MDT (barrel/endcap)

- 99.8% of chambers operational
- Dead channels 0.2% (+0.5% recoverable)

CSC (small wheel)

- All chambers operational
- Dead channels 1.5%

Optical alignment system (12232 sensors)

- 99.7% (barrel), 99% (endcap) operational

Trigger chambers

spatial resolution 5-10 mm
time resolution < 1 BC

RPC (trigger chambers, barrel)

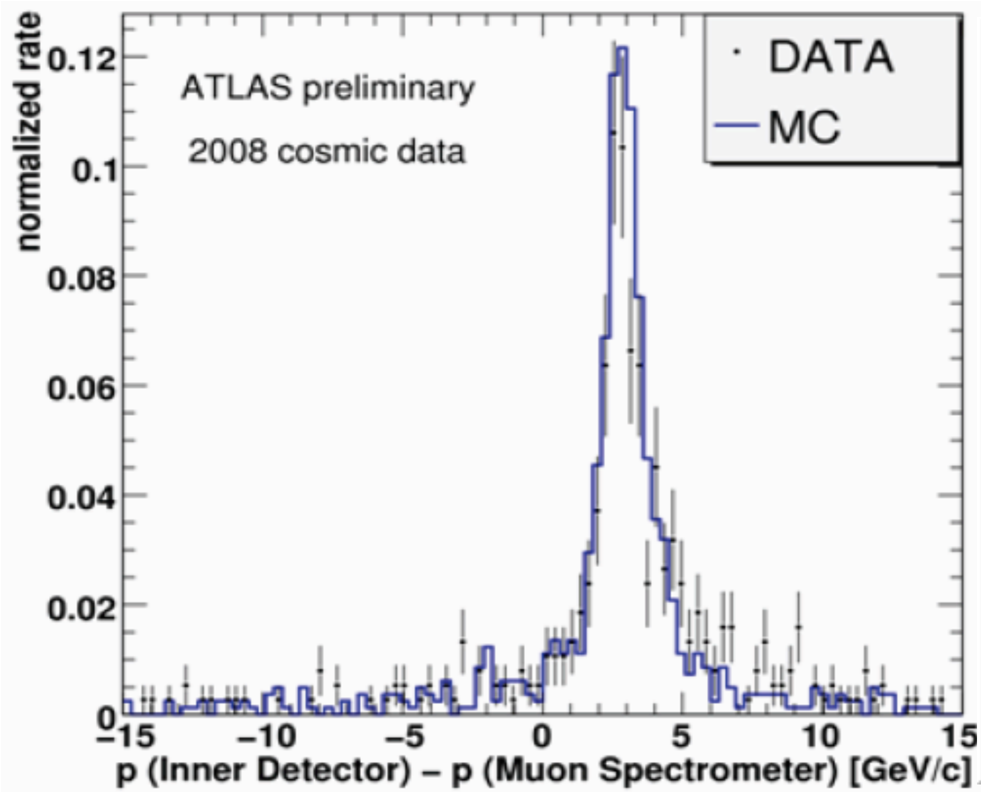
- 95.5% operational (goal 2009: 98%)
- Dead strips < 2%, hot strips < 1%

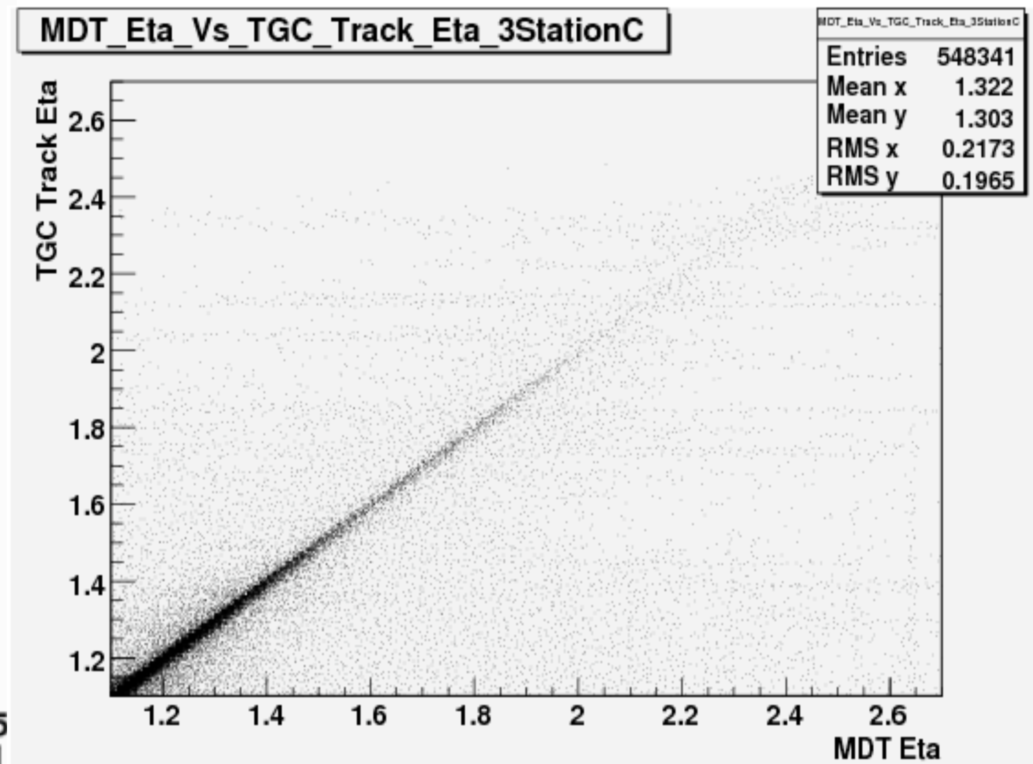
TGC (trigger chambers, endcap)

- 99.8% of chambers operational
- Noisy channels < 0.02%

Muon system standalone resolution
$\Delta p_T/p_T < 10\%$ up to 1 TeV

Muon Spectrometer



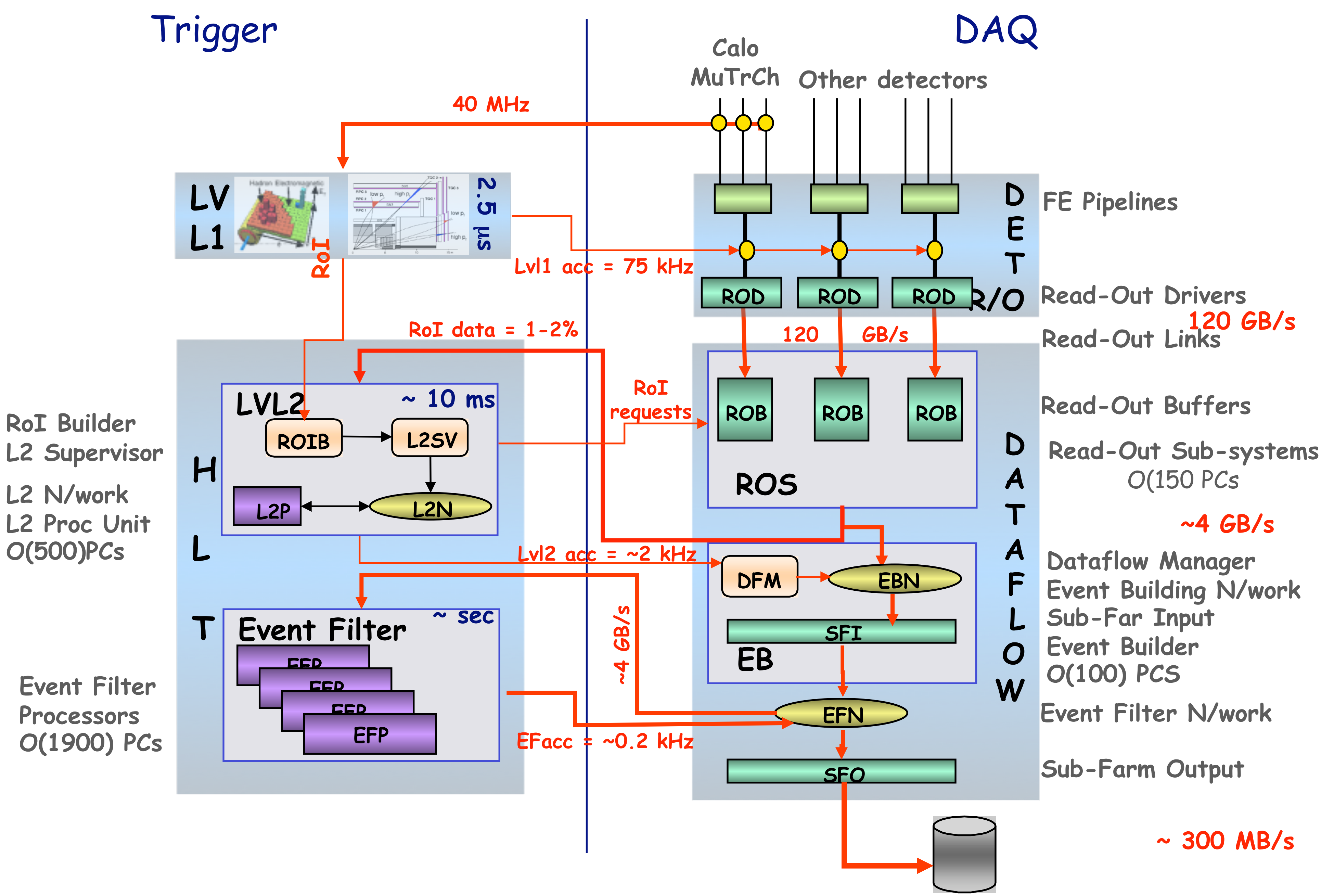


Momentum difference between ID and muon spectrometer (due to momentum loss in calorimeters)

Correlation endcap trigger (TGC) and precision (MDT) chambers

Muon tracking is working well standalone

Trigger, DAQ and Detector Control



Present Detector Status

Sub-detector	Number of channels	Operational fraction (%)
Pixels	80 M	98.5
SCT Silicon Strips	6 M	99.5
TRT Transition Radiation Tracker	350 k	98.2
LAr EM Calorimeter	170 k	99.1
Tile Calorimeter	9800	99.5
Hadronic endcap LAr calo	5600	99.9
Forward LAr calorimeter	3500	100
MDT Muon Drift Tubes	350 k	99.3
CSC Cathode Strip Chambers	31 k	98.4
RPC Barrel Muon Trigger	370 k	~95.5 (aim >98.5)
TGC Endcap Muon Trigger	320 k	99.8

Concerns

- Long-term reliability of some components
  - LV power supplies of LAr and Tile calorimeters;
  - Liquid-Argon readout optical links;

- Inner detector cooling.

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

Expected number of events

Channels	Number of events after selection ($\sqrt{s}$ = 10 TeV, 100 pb^{-1})
J/ψ -> $\mu\mu$	10^6 (7×10^4 at 7 TeV)
Υ -> $\mu\mu$	5×10^4 (5×10^3 at 7 TeV)
W -> $\mu\nu$	3×10^5
Z -> $\mu\mu$	3×10^4
ttbar->WbWb->$\mu\nu$+X	800
QCD jets (p_T > 1 TeV)	500
WW/WZ	50/10

ATLAS Physics Road Map

10 pb^{-1}

- Initial detector & trigger synchronisation, commissioning, calibration & alignment, material.
- Rediscover SM processes: jet, lepton rate, Z, W.

100 pb^{-1}

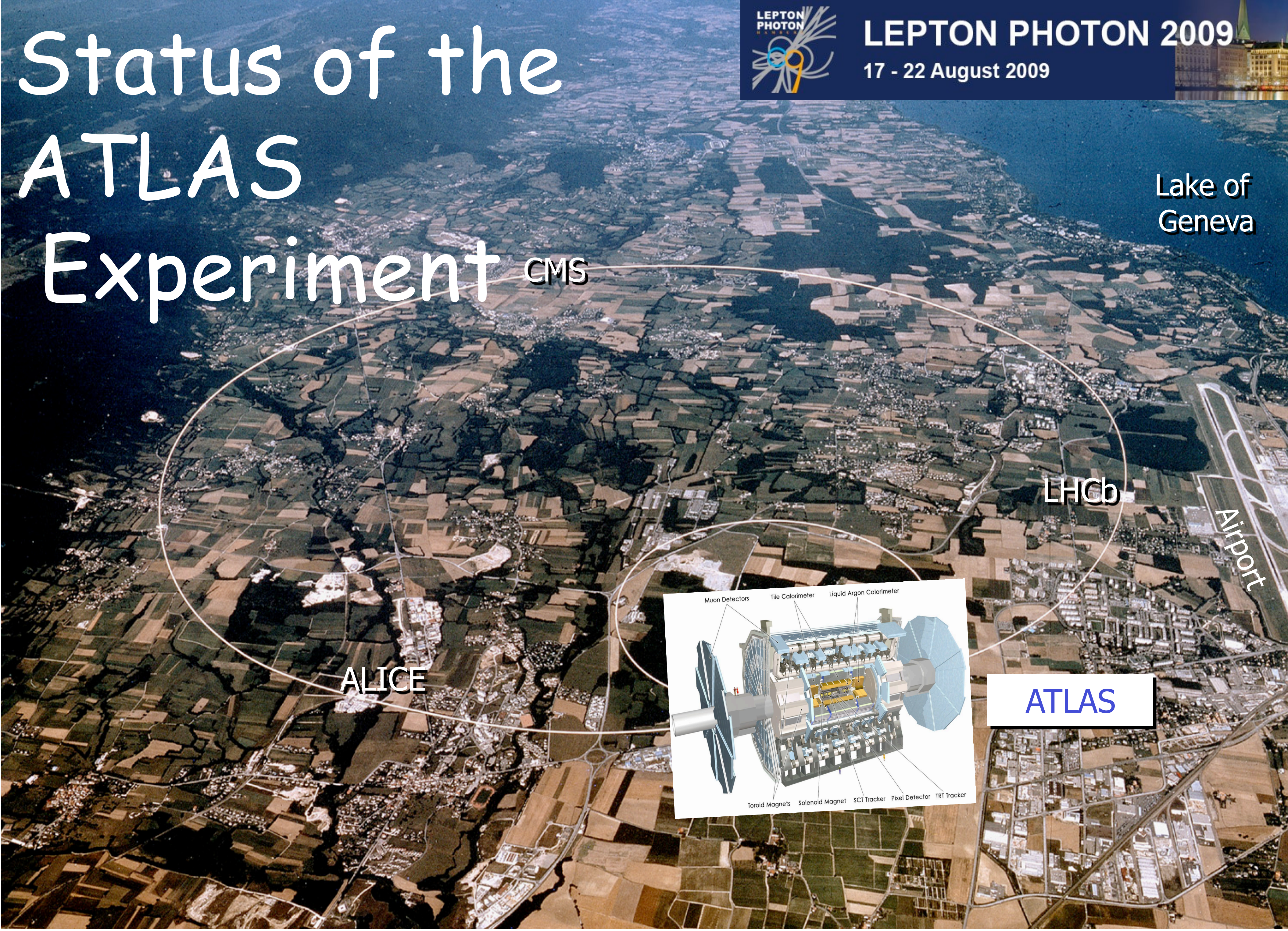
- Understand SUSY and Higgs background from SM.
- More accurate alignment & EM/Jet/ETmiss calibration.
- Early discoveries.

1 fb^{-1}

- Higgs discovery sensitivity (MH=130~500 GeV).
- Explore SUSY to m ~ TeV.
- SM precision measurements.

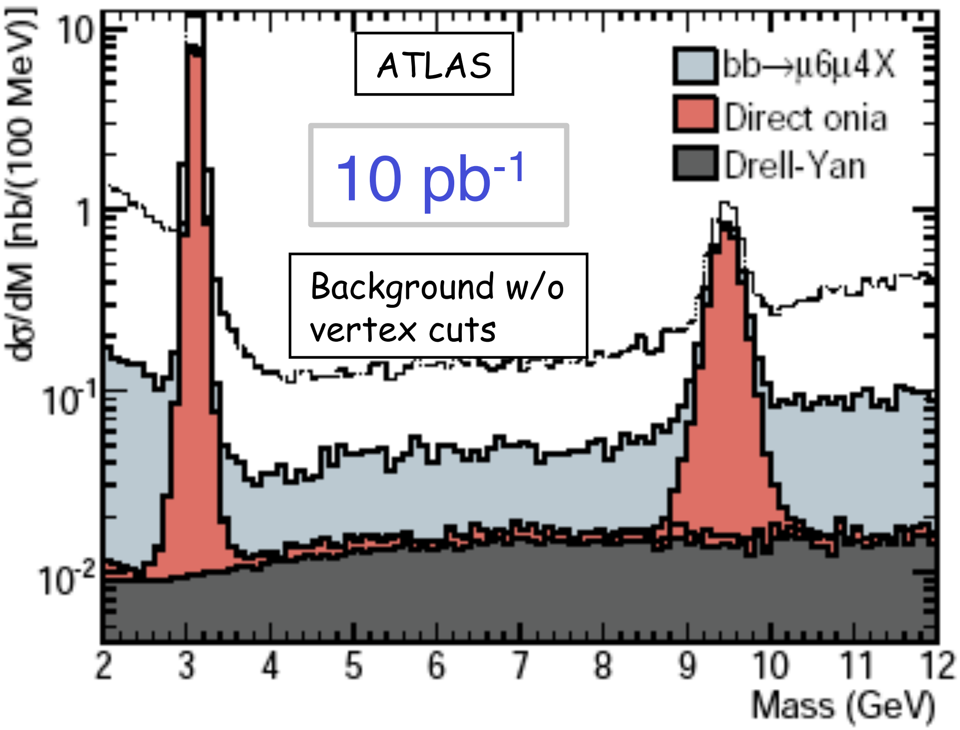
Status of the ATLAS Experiment

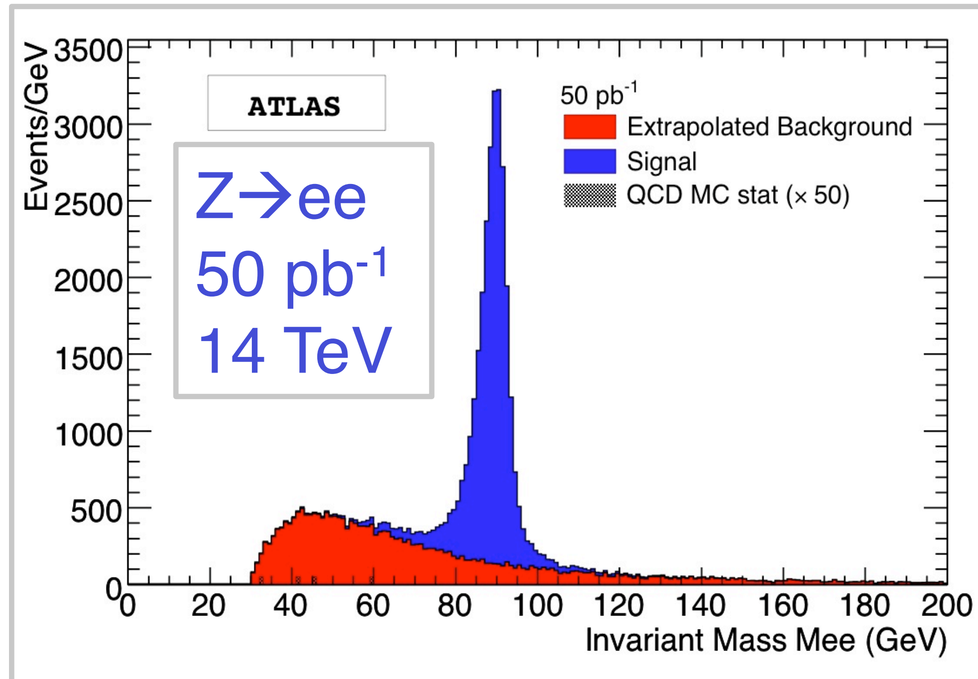
LEPTON PHOTON 2009
17 - 22 August 2009



Kerstin Jon-And, Stockholm University, on behalf of the ATLAS

The SM Early Signals: J/ψ, Υ, W, Z



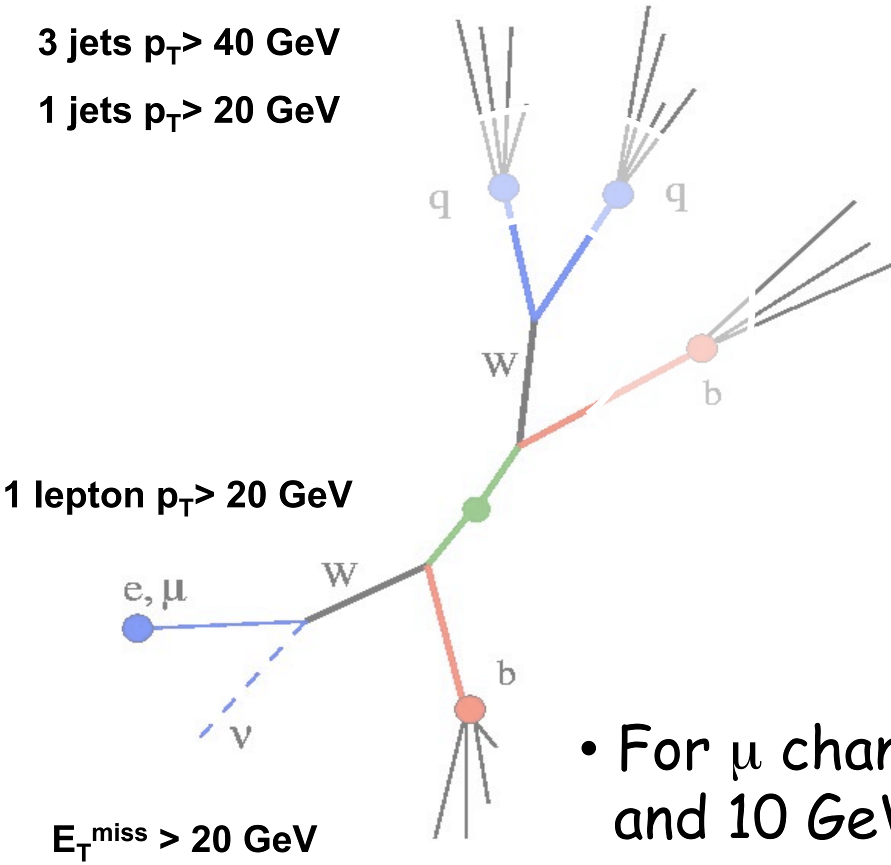


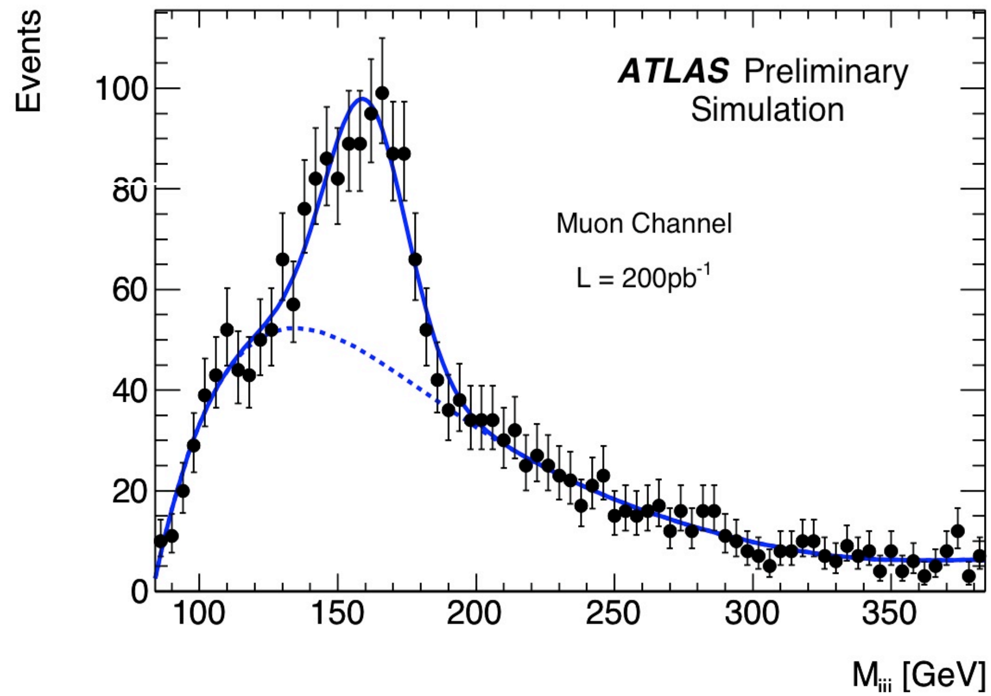
- Muon Spectrometer and ID alignment
- ECAL calibration, E and p scale of full detector
- Lepton trigger and reconstruction efficiency

The first Top Quarks from ATLAS

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

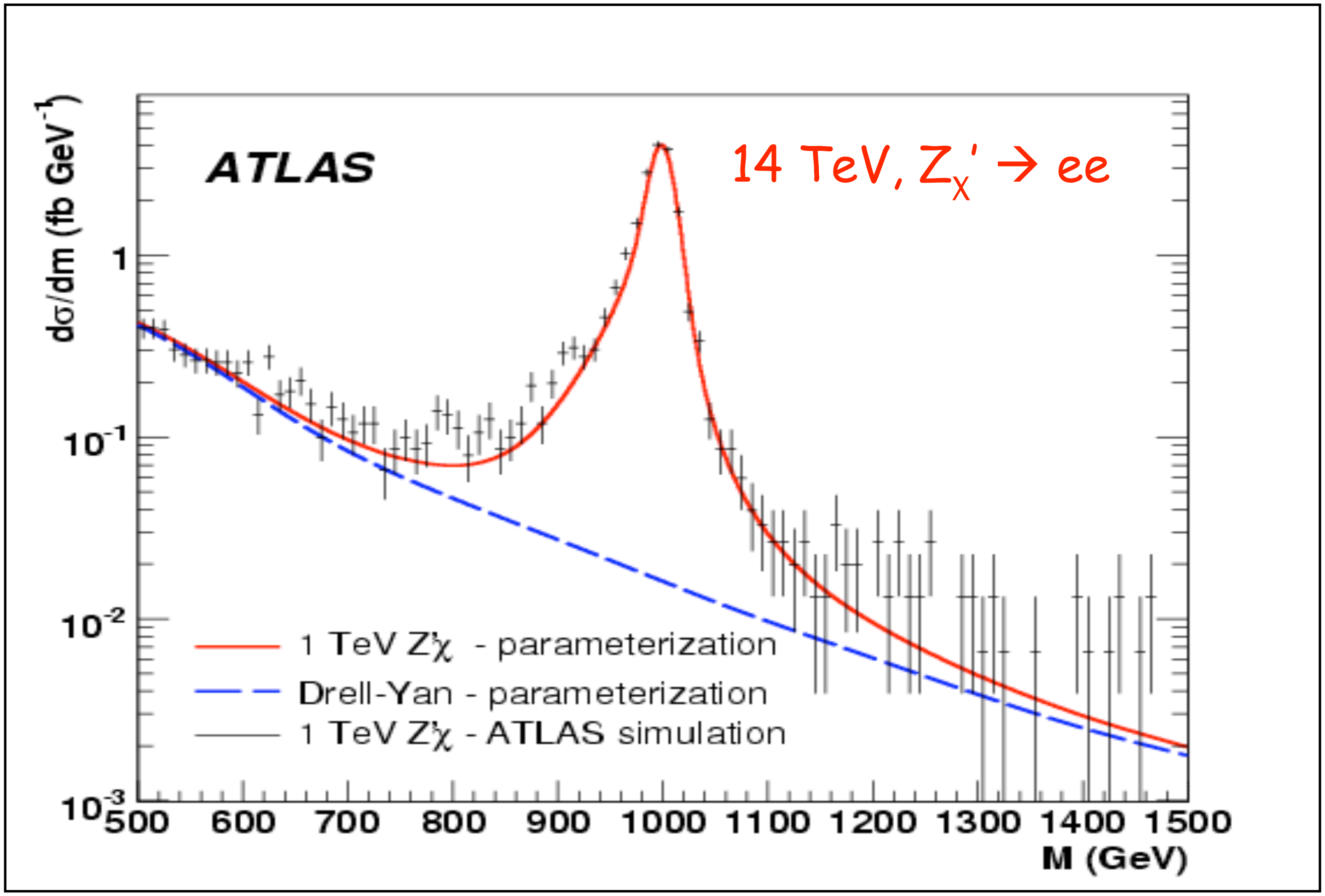
10 TeV, 200 pb^{-1}, μ-channel
no b-tagging





- For μ channel, expect 600 and 1600 events at 7 and 10 GeV
- Expected uncertainty of cross section < 20% (+luminosity uncertainty)
- Contain lepton, jets, b-jets and E_T^{miss}, background to all searches

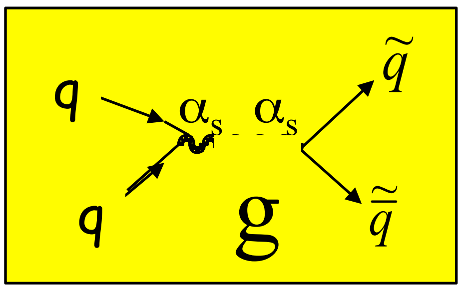
$Z' \rightarrow ll$ with mass ~ 1 TeV

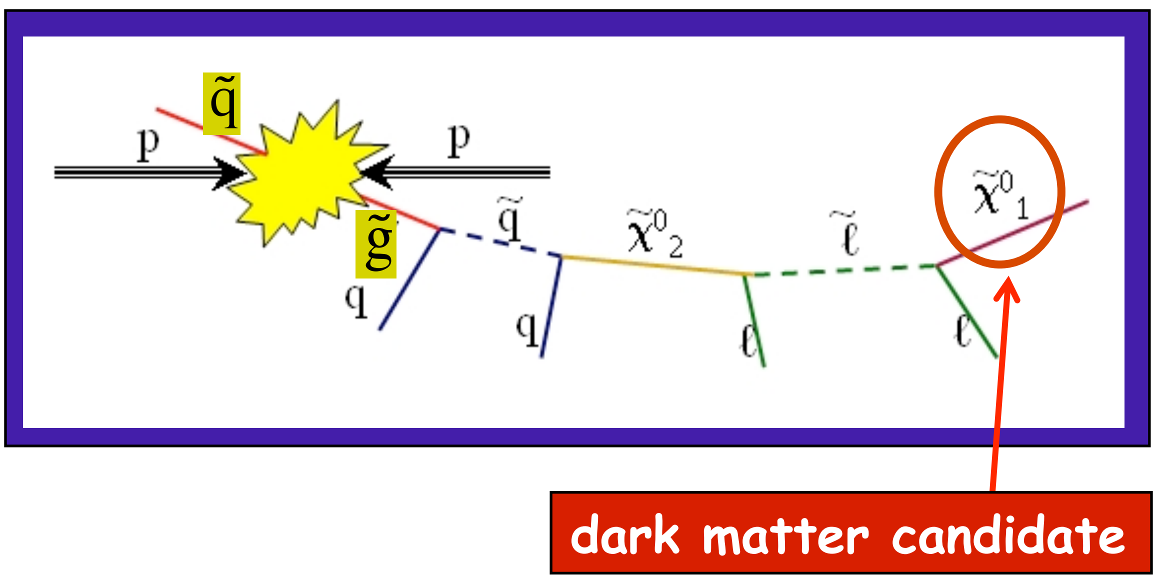


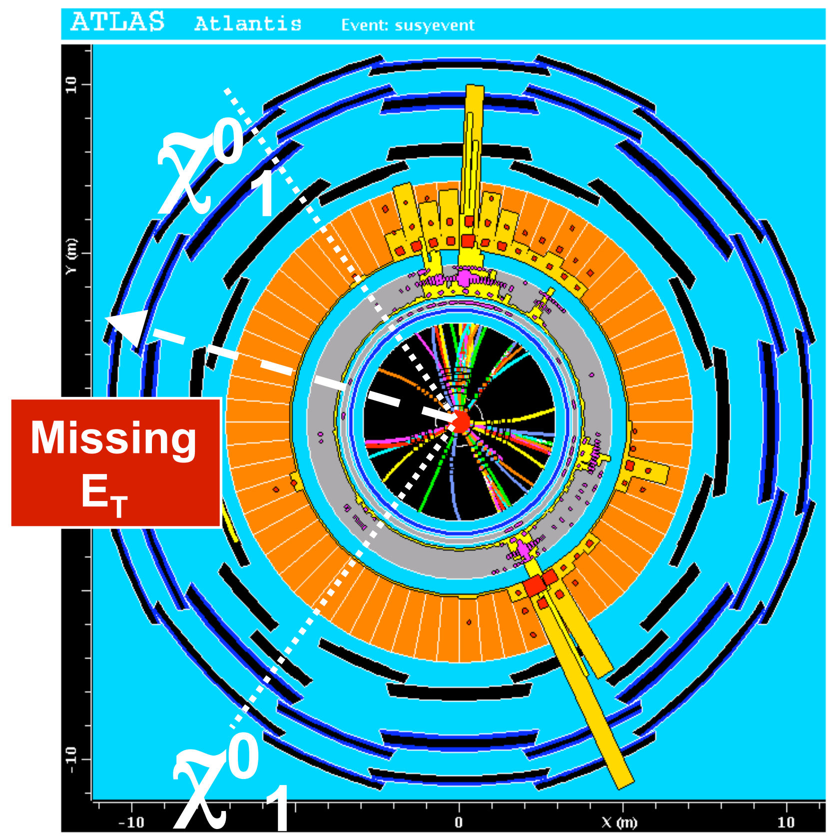
Sensitivity beyond Tevatron limits with 200 pb^{-1} and $\sqrt{s} \geq 7$ TeV (100 pb^{-1} at 10 TeV)

SUSY Particles

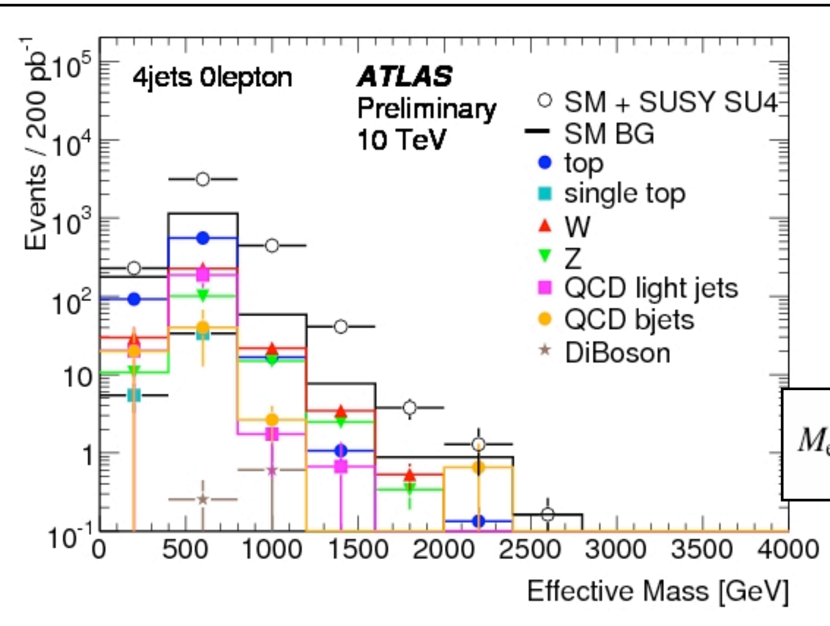
- Huge production cross-section for the production of $\boxed{\tilde{q}\tilde{q}, \tilde{g}\tilde{q}, \tilde{g}\tilde{g}}$ for M_{susy}~1 TeV
- Expect 1 event/5 days at $L=10^{31}\ cm^{-2}\ s^{-1}$
- Final states: lepton+multi-jet+missing E_T





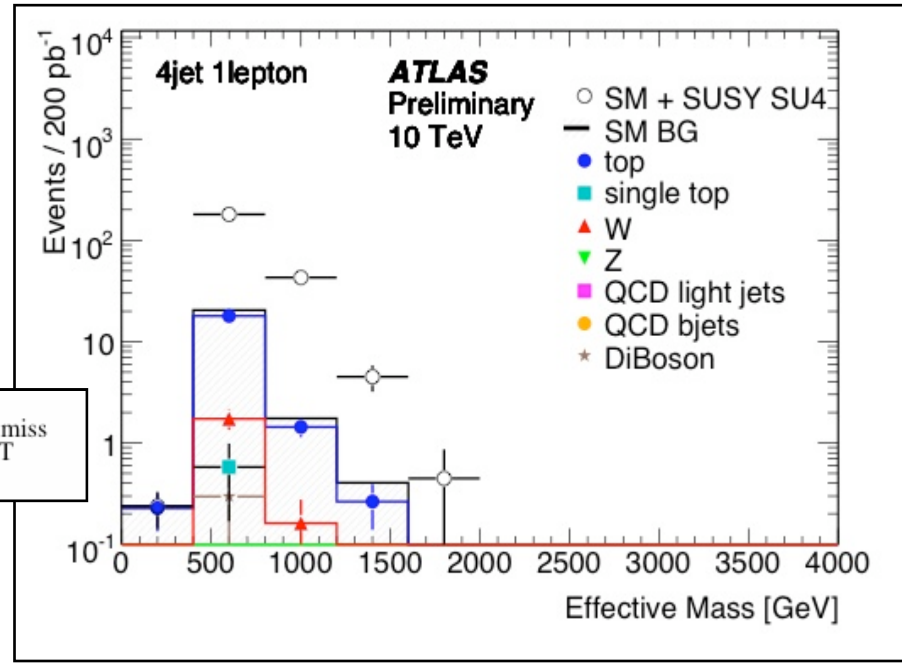


m_{SUSY} ~ 750 GeV with 200 pb^{-1} at $\sqrt{s}$ =10 TeV



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

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



Jets + E_t^{miss}: highest reach

Jets + E_t^{miss}+lepton: robust against background uncertainty

- ATLAS discovery reach beyond Tevatron expected exclusion (~400 GeV) with 200 pb^{-1} for $\sqrt{s} \geq 7$ TeV
- Crucial to understand backgrounds, fake missing transverse energy and jet energy
- LHC reach: m($\tilde{q}$,$\tilde{g}$) ~ 3 TeV

Conclusion

- The ATLAS detector is in good shape and ready to take colliding data for exciting physics.
- Dead channels is on the level of 1-2%.
- Cosmics ray and single beam data shows good detector performance.
- Computing and software have proven to be able to handle the massive data for world wide distribution.
- ATLAS upgrade activity has been going on for 3-4 years: pixcel, forward muon, low voltage power supplies….. (RD51 has done three years test beam).

Let’s cross our finger and hope that

- LHC could ramp up its energy and luminosity smoothly
- Detectors could commission with long term stability, good performance and a reasonable age.
- LHC experiments will then be the frontier of high energy physics in the next 10 year and beyond.

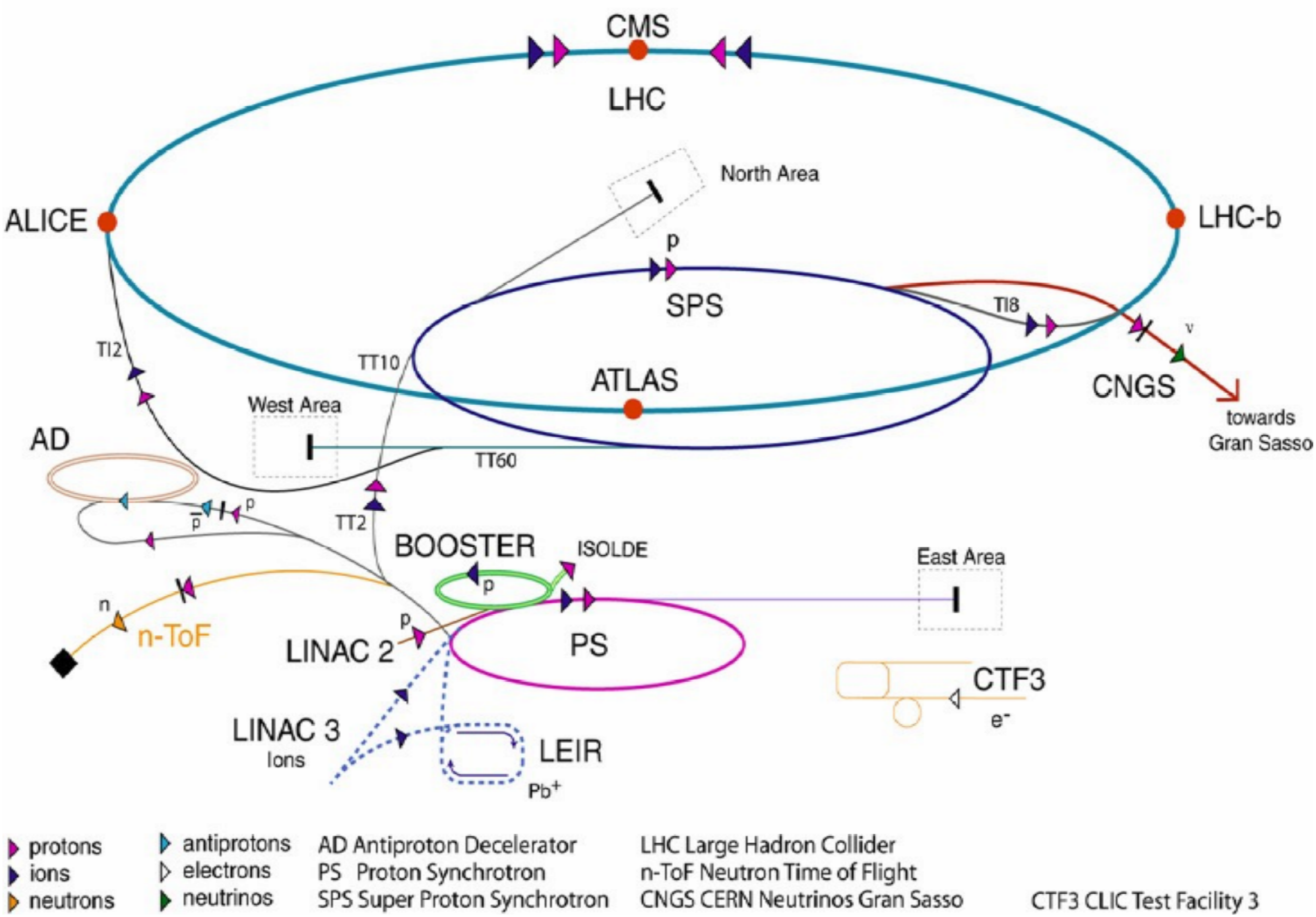
Early Physics (~100 pb^{-1})

- Without understanding the detector performance and data quality, hardly one can go for publication with convincing results. Needs time to understand stand such a complicated giant.
- First tuning of MC (minimum-bias, underlying event, tt, W/Z+jets, jets,…)
- Measure particle multiplicity in minimum bias (a few hours of data taking …)
- Measure QCD jet cross-section to ~ 30%? (~103 events with ET (j) > 1 TeV)
- Z, W are standard candles to reply on. Xsec(10%), mass, width.
- Establish diboson (WW, WZ…) events and measure Xsec
- Observe top signal with ~ 30 pb^{-1}
- Measure tt xsec. to 20% and m(top) to 10 GeV?
- Improve knowledge of PDF (low-x gluons !) with W/Z?

And if nature is favoring us:

- Discover SUSY up to gluino masses of ~ 1.3 TeV ?
- Discover a Z' up to masses of ~ 1.3 TeV ?
- Prepared for surprises

Accelerator chain of CERN (operating or approved projects)



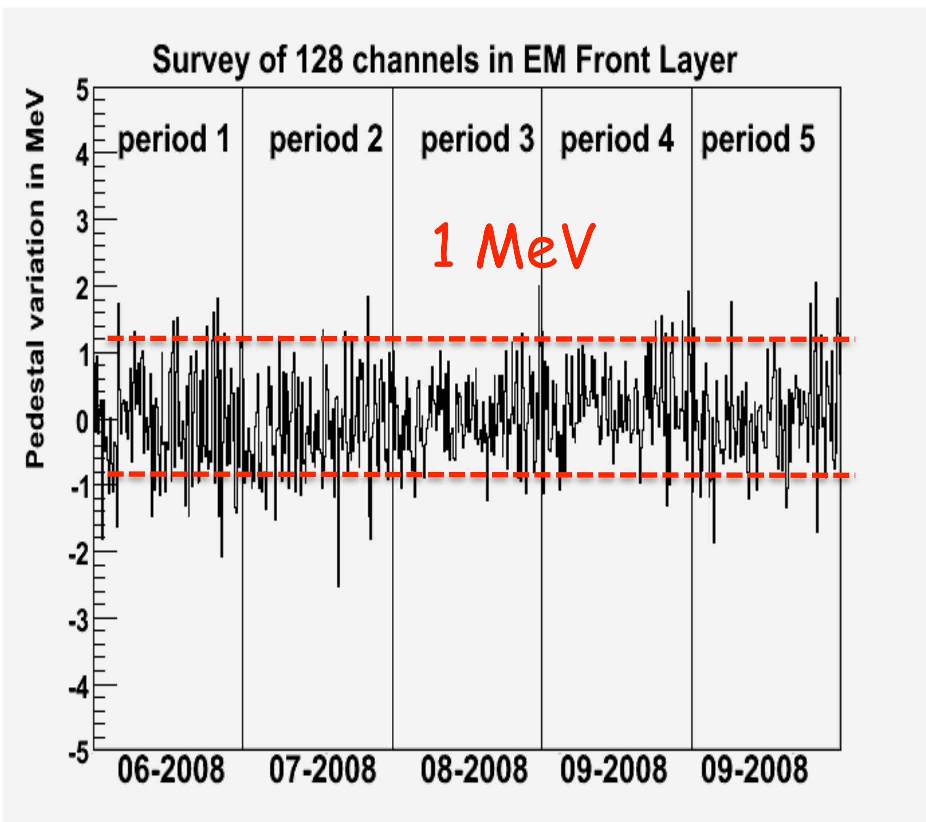
Main Components of the LHC Accelerator

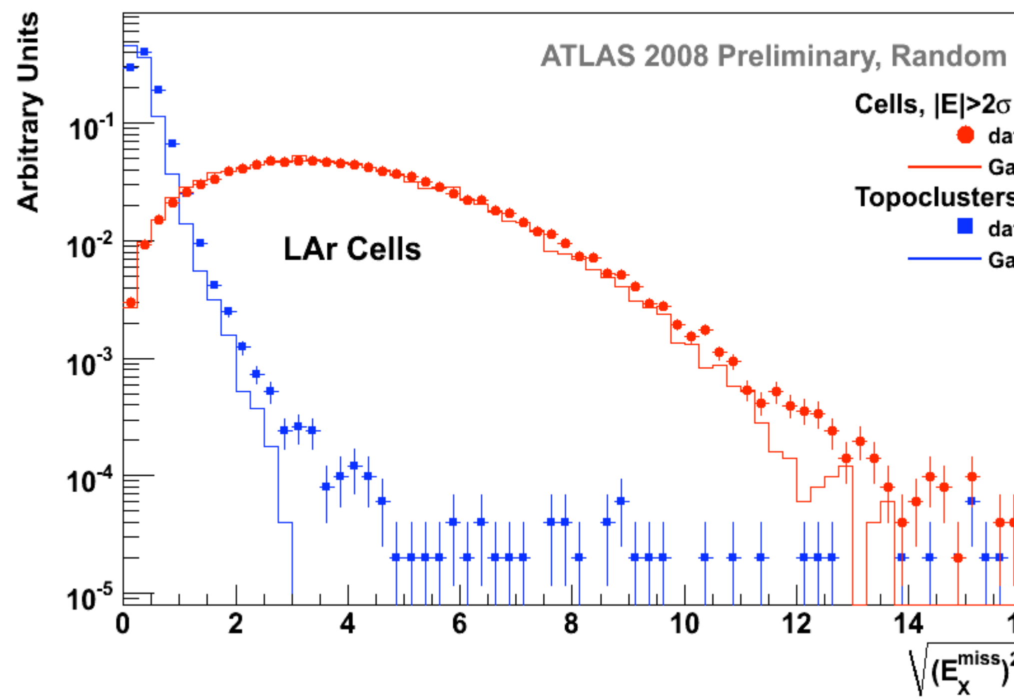
- Power converts: power the magnets?
- Beam dump: get rid of the beam, in an emergency, or at the end of a fill
- Magnets: bending, focusing, steering...
- Radio frequency cavity (RF)
- Cryogenics: keep the magnets cold
- Vacuum: the beam has to travel in a very good vacuum
- Collimators: catching particles before they catch the magnets
- Current leads: feeding the current from warm into the cold mass of the magnets

LAr Results

Pedestal stability for 128 channels of barrel EM strip (or front) layer over a 5 months period

$E_{T,miss}$ reconstruction on randomly triggered events using cells or topological clusters



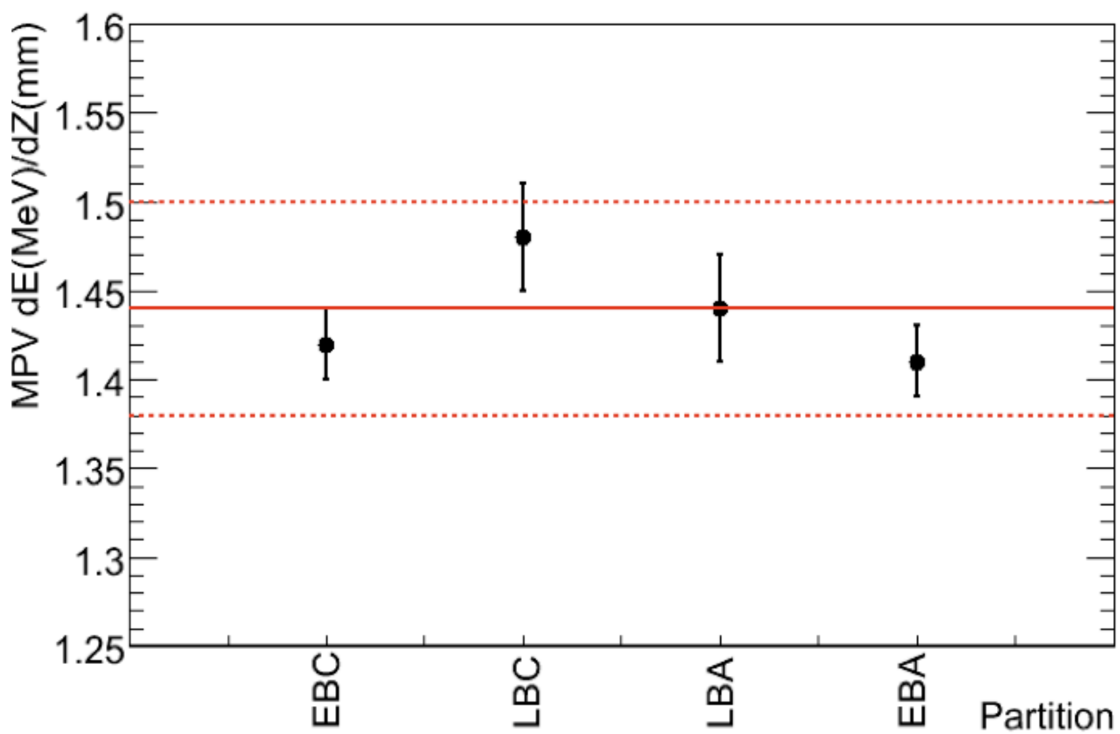


Very good stability and understanding of reconstruction and noise behaviour

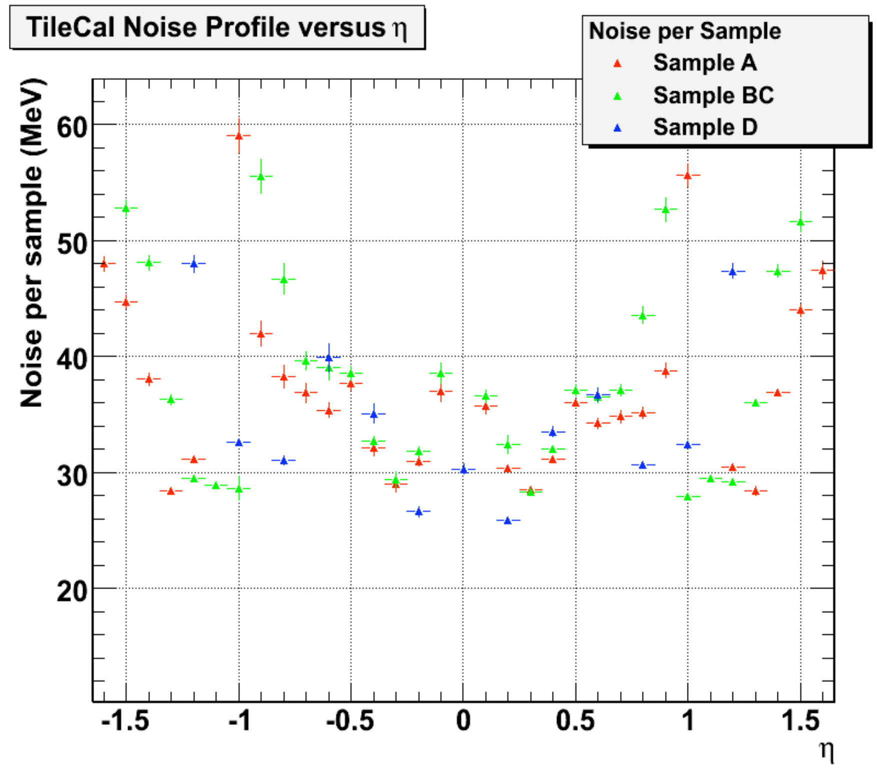
Luminosity Ramp Up

Luminosity 1 mon run	Int. Lumi. (1/fb)	Interest proc. (with e, μ, γ)	X-section	Events for calibration and measurements
10^{29}	0.0001 (100 nb^{-1})	$W \to \mu\nu$, $e\nu$(DY) J/ψ, $y \to \mu\mu$, ee	$\sigma_{\mu\nu}$ ~20nb	Detecte 1000 μ ($W \to \mu\nu$) ~800 J/ψ, ~100 y
10^{30}	0.001 (1 pb^{-1})	$Z \to$ $\mu\mu$, ee ttbar	$\sigma_{\mu\mu}$ ~ 2nb σ_{tt} ~ 750pb	Detect 1500 $\mu\mu$ from Z Detect 800 tt
10^{31}	0.01 (10 pb^{-1})	Z+jet $\gamma\gamma$, $W\gamma$, $Z\gamma$	$\sigma_{q\mu\mu}$ ~ 40 pb $\sigma_{\gamma\gamma}$ ~ 24 pb	400 Zjet events, JE cali. 250 $\gamma\gamma$ with M>60 GeV
10^{32}	0.1 (100 pb^{-1})	WZ, WW, Z+ n jets	$\sigma_{e\mu}$ ~2.4pb	~50 $e\mu$ from WW selection ~10 trilepton events (WZ)
10^{33}	1.0 (10M $W \to l\nu$) (1M $Z \to ll$) Understand detect ~2%	$ZZ \to 4l$, $ll\nu\nu$ $H \to WW$? $W' \to e/\mu\ \nu$? $Z' \to ee$, $\mu\mu$? SUSY?	σ_{4l} ~ 0.08pb	~ 11 $ZZ \to 4l$, 10 $ZZ \to ll\nu\nu$ Searches: Single μ M_T > 1 TeV dileptom mass > 1 TeV Higgs $\to$WW (~165 GeV) SUSY $\to$ multi-leptons

Tile results



Muon dE/dz from horizontal muons during single beam running



Tile calorimeter noise measured during first beam period

Low noise, uniform response, well understood calibration

W, Z Cross Section Measurement

Theoretical predictions on the single W and Z production cross-sections, calculated at NNLO with a precision of 1%.

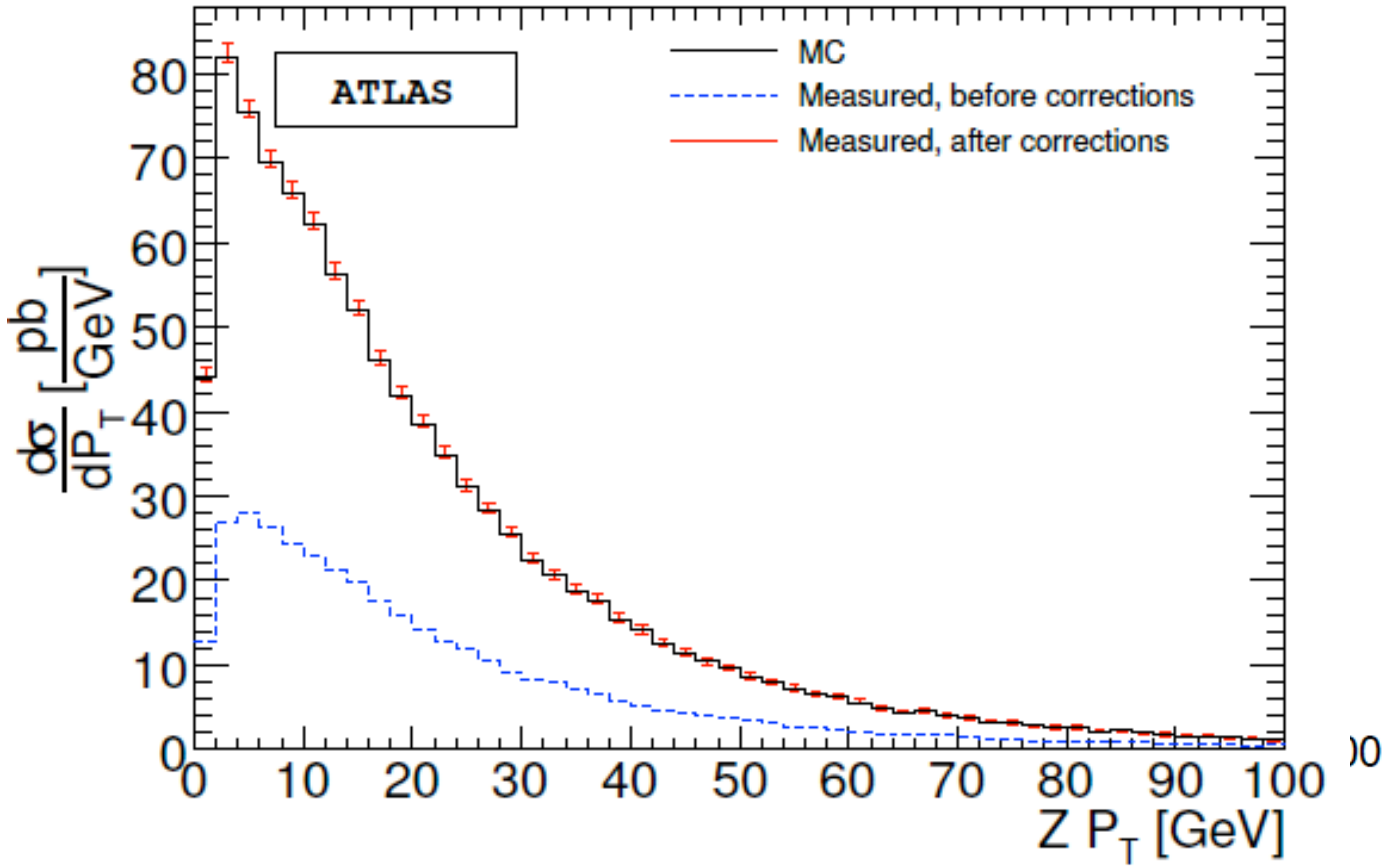
With 50 pb^{-1} of data, ATLAS allows to measure the cross section to a precision of 5%(luminosity is not included)

W, Z cross section ratio

$$BR(W \to \mu\nu_\mu) = \mathbf{R}\left(\frac{\sigma(pp \to WX)}{\sigma(pp \to ZX)}\right)_{teoria} BR(Z \to \mu^+\mu^-)_{LEP}$$

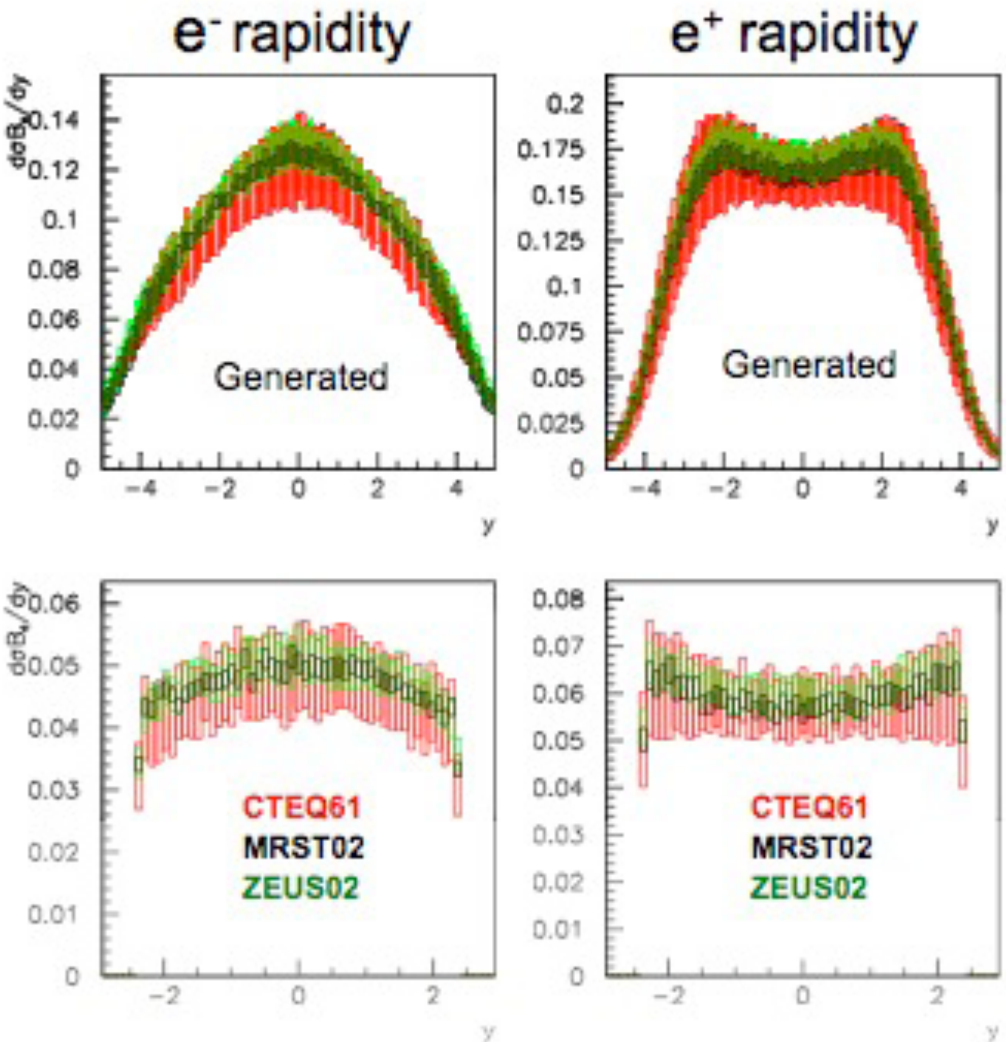
$$\Gamma_W = \left(\frac{\mathbf{1}}{\mathbf{R}}\right)\left(\frac{\sigma(pp \to WX)}{\sigma(pp \to ZX)}\right)_{teoria} BR(Z \to l^+l^-)_{LEP}\Gamma(W \to l\nu_l)_{teoria}$$

Z differential cross section measurement



Studying the spectrum in the lowmass region can help to improve the PDF precision.

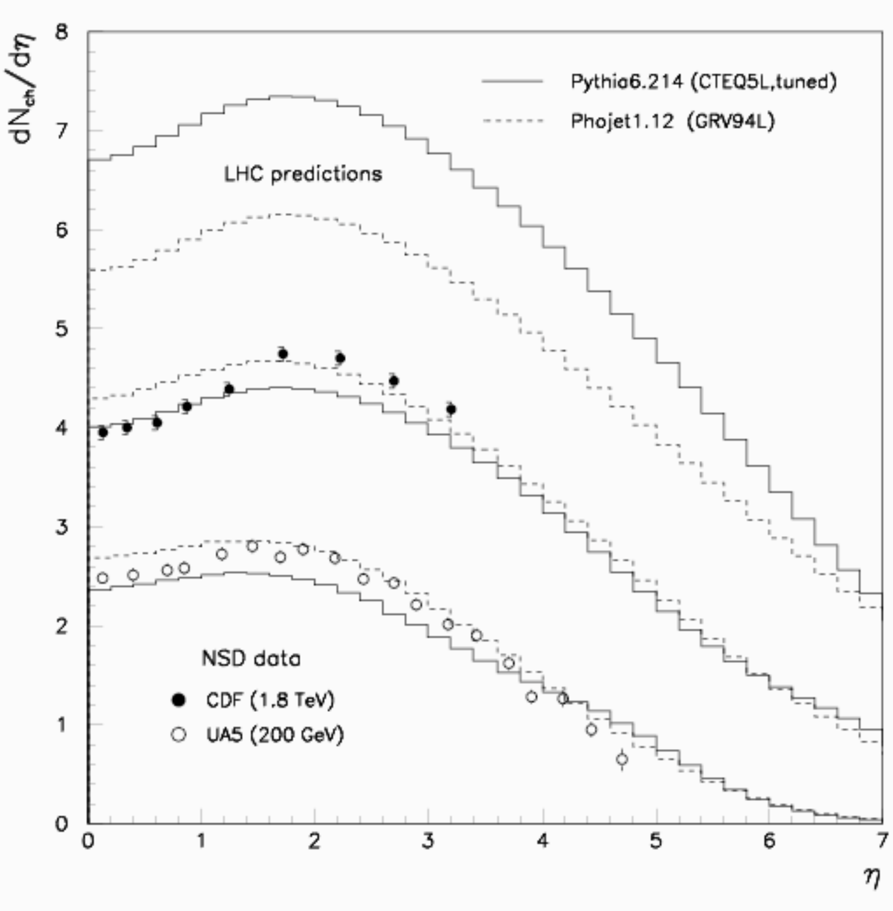
W leptonic decay and the PDF's

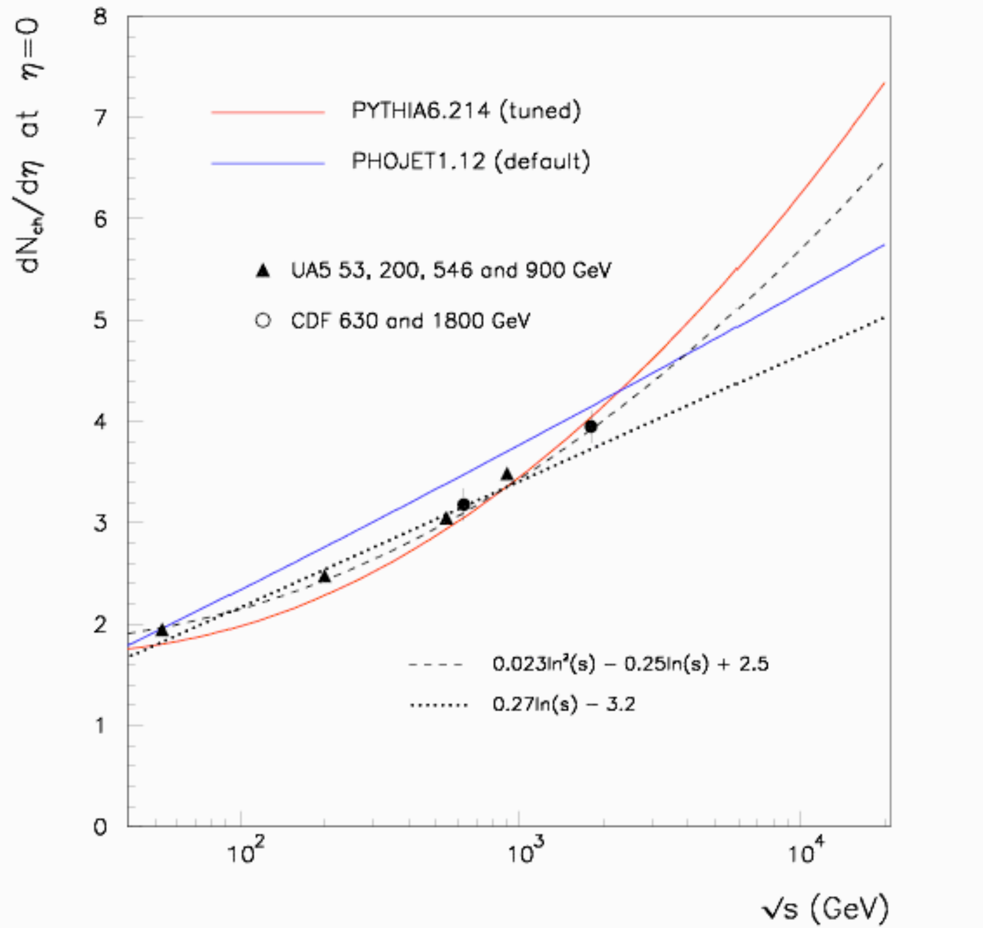


Observing the lepton asymmetry instead of the lepton distribution one can reduce the uncertainty inside each PDF set (less than 4%) and maintain the spread between thedifferent sets

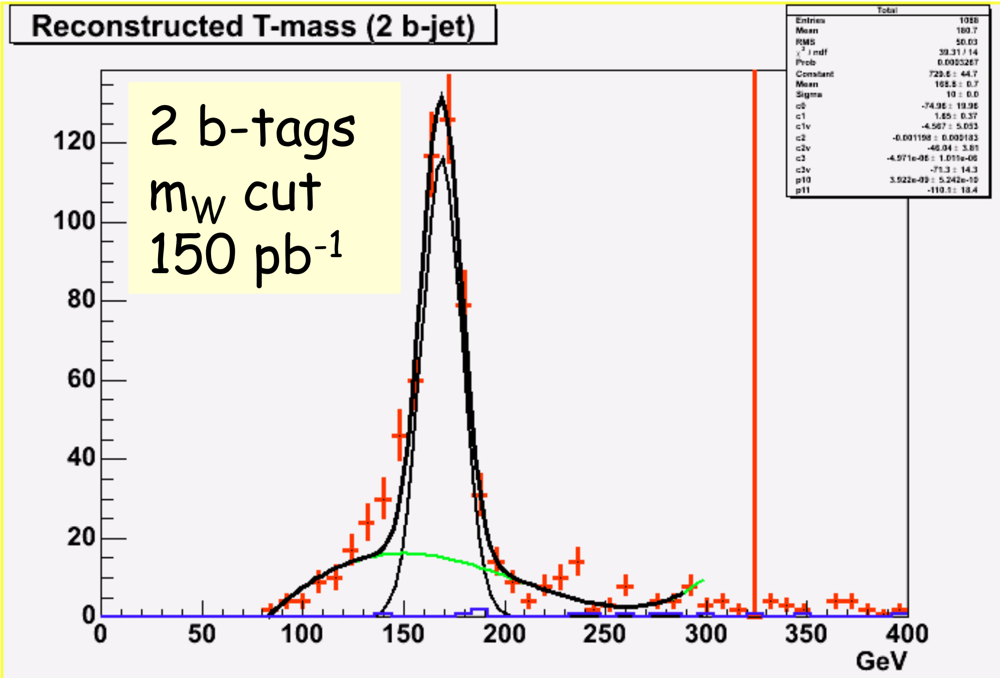
Minimum Bias Events

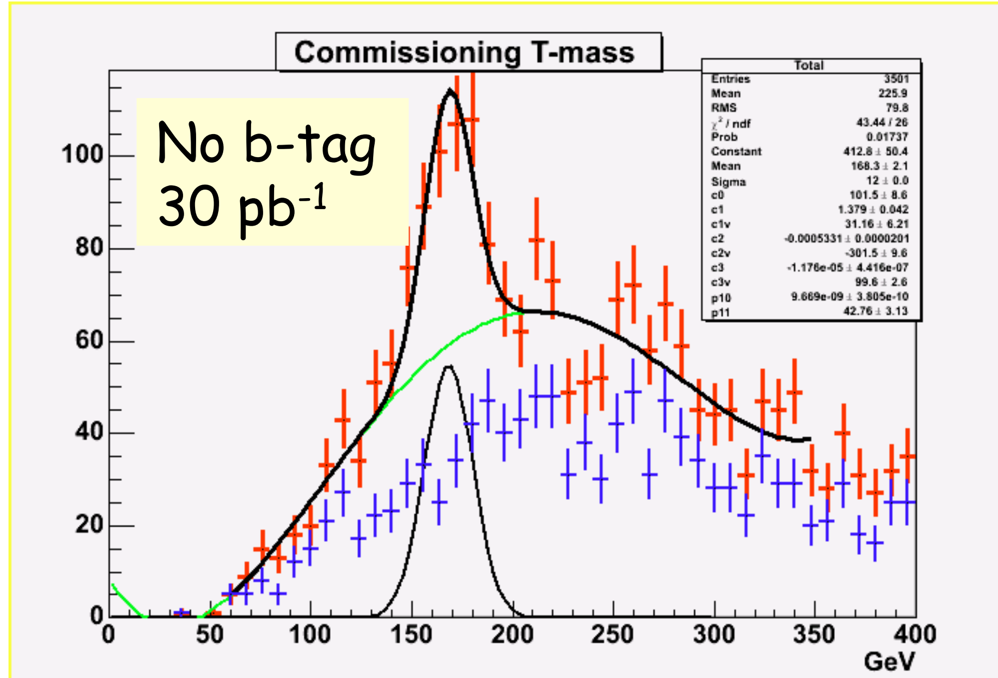
- Minimum bias particle density drives detector global occupancy even at « low » $L=10^{33}cm^{-2}s^{-1}$
- Uncertainties up to 30% from extrapolation from lower energies
- Can be measured in a few days, but should always be kept in mind when defining startup scenarios (occupancies, rates….)





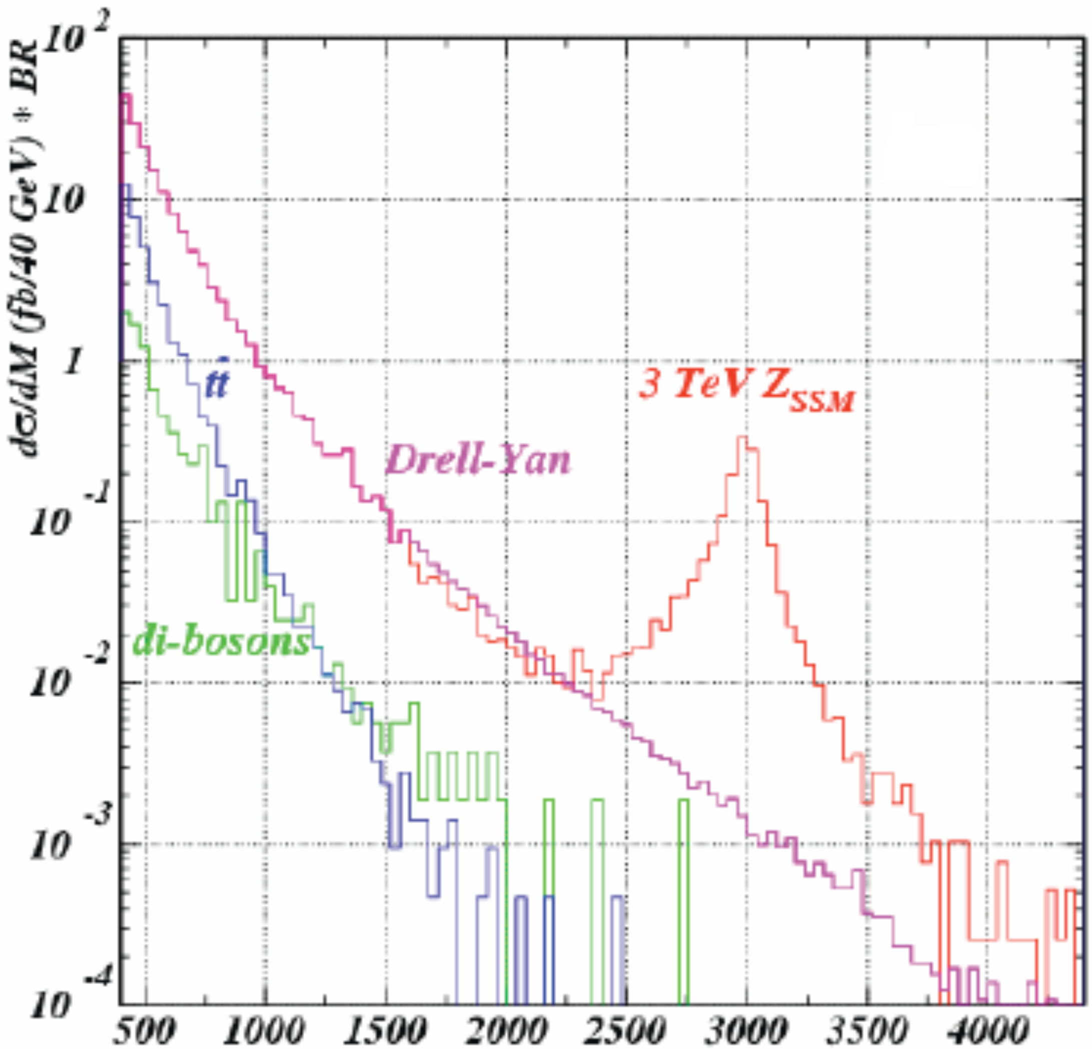
Top Quark Mass





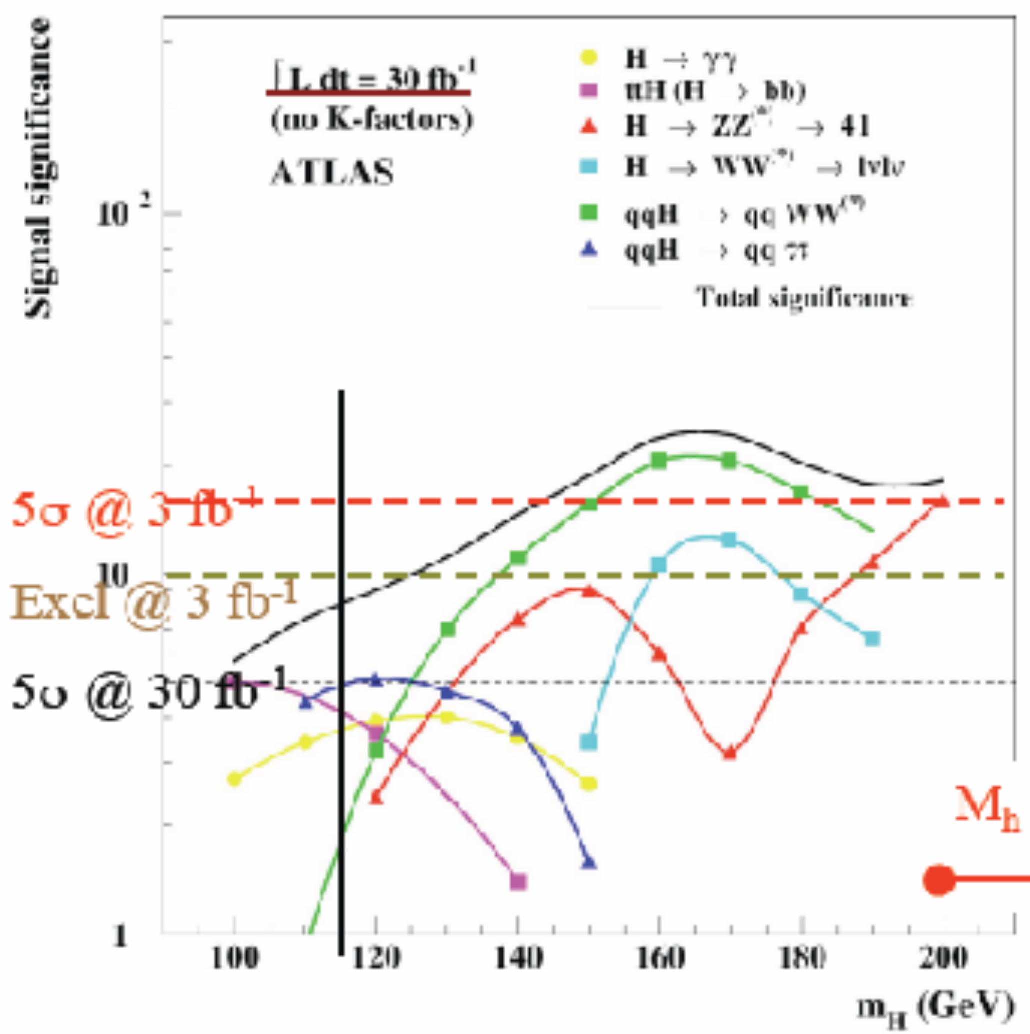
- Reconstructed in $tt \rightarrow W(l\nu)bW(qq)b$
  - Most important background : W+4 jets
- Selection without b tag at the beginning
- Isolated lepton with P_T>20 GeV
- Exactly 4 jets (ΔR=0.4) with P_T>40 GeV
- W and top peaks visible with 30 pb^{-1}
- With b tag : σ(Mtop)~0.8 GeV with 150 pb^{-1}

Search for High Mass Dilepton Resonance



Search for $Z' \rightarrow e^+e^- / \mu^+\mu^-$

Higgs Search



- m_H>150 GeV could be visible in 2008
- Lower masses 5σ @ 30 fb^{-1} need more luminosity

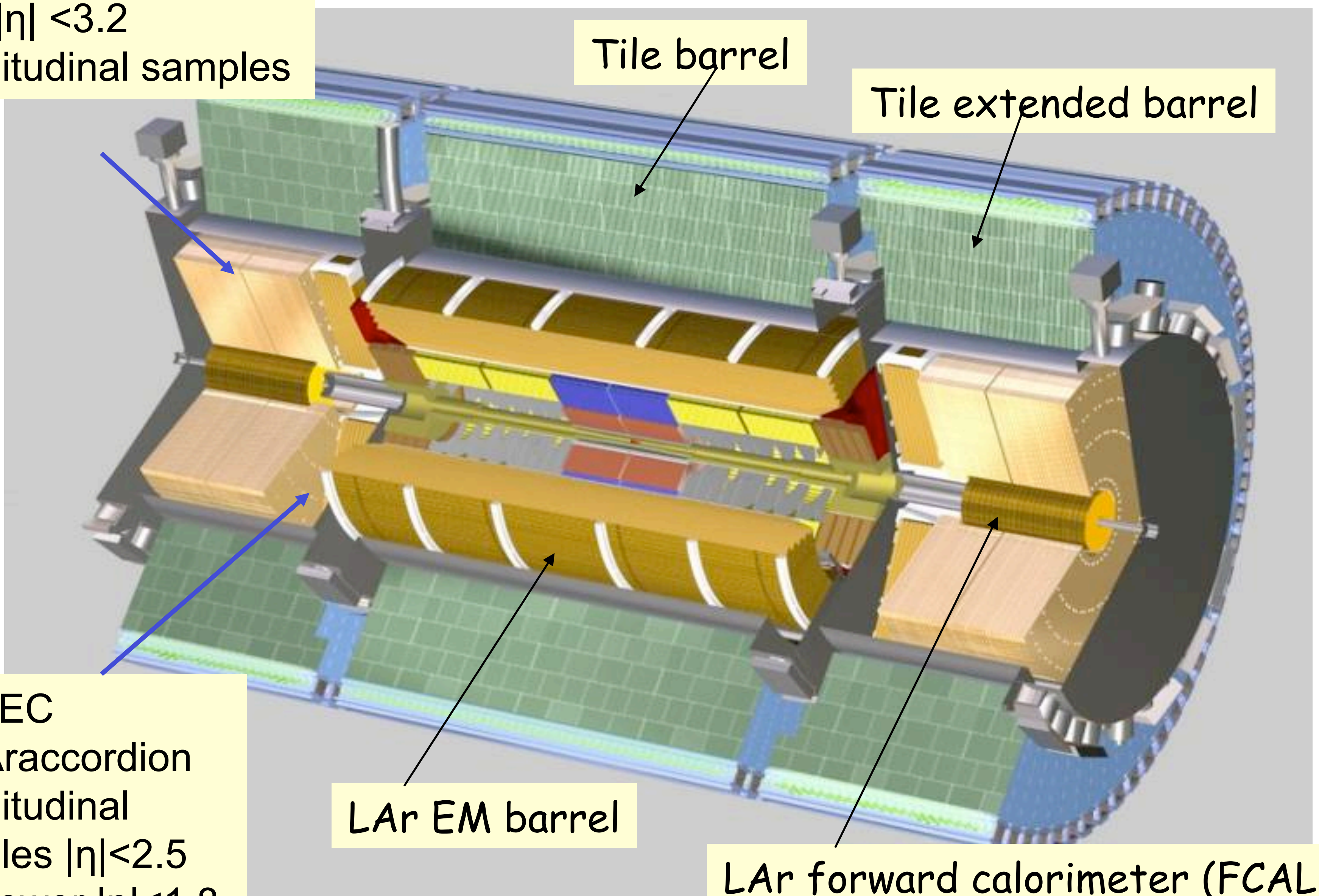
M_h up to 1 TeV also covered

ATLAS and CMS Resolution Performance

	ATLAS	CMS
Tracker	Si pixels, strips + TRT (pid) $\sigma/p_T \approx 5\text{x}10^{-4} p_T \oplus 0.01$	Si pixels, strips $\sigma/p_T \approx 1.5\text{x}10^{-4} p_T \oplus 0.005$
EM calorimeter	Pb + LAr $\sigma/E \approx 10\%/\sqrt{E} \oplus 0.007$	$PbWO_4$ crystals $\sigma/E \approx 2\text{-}5\%/\sqrt{E} \oplus 0.005$
Hadronic calorimeter	Fe+scintillator / Cu + Lar $\sigma/E \approx 50\%/\sqrt{E} \oplus 0.03$	Cu+scintillator $\sigma/E \approx 100\%/\sqrt{E} \oplus 0.05$
Combined Muons (ID+MS)	2%@50GeV to 10%@1TeV	1%@50GeV to 5%@1TeV

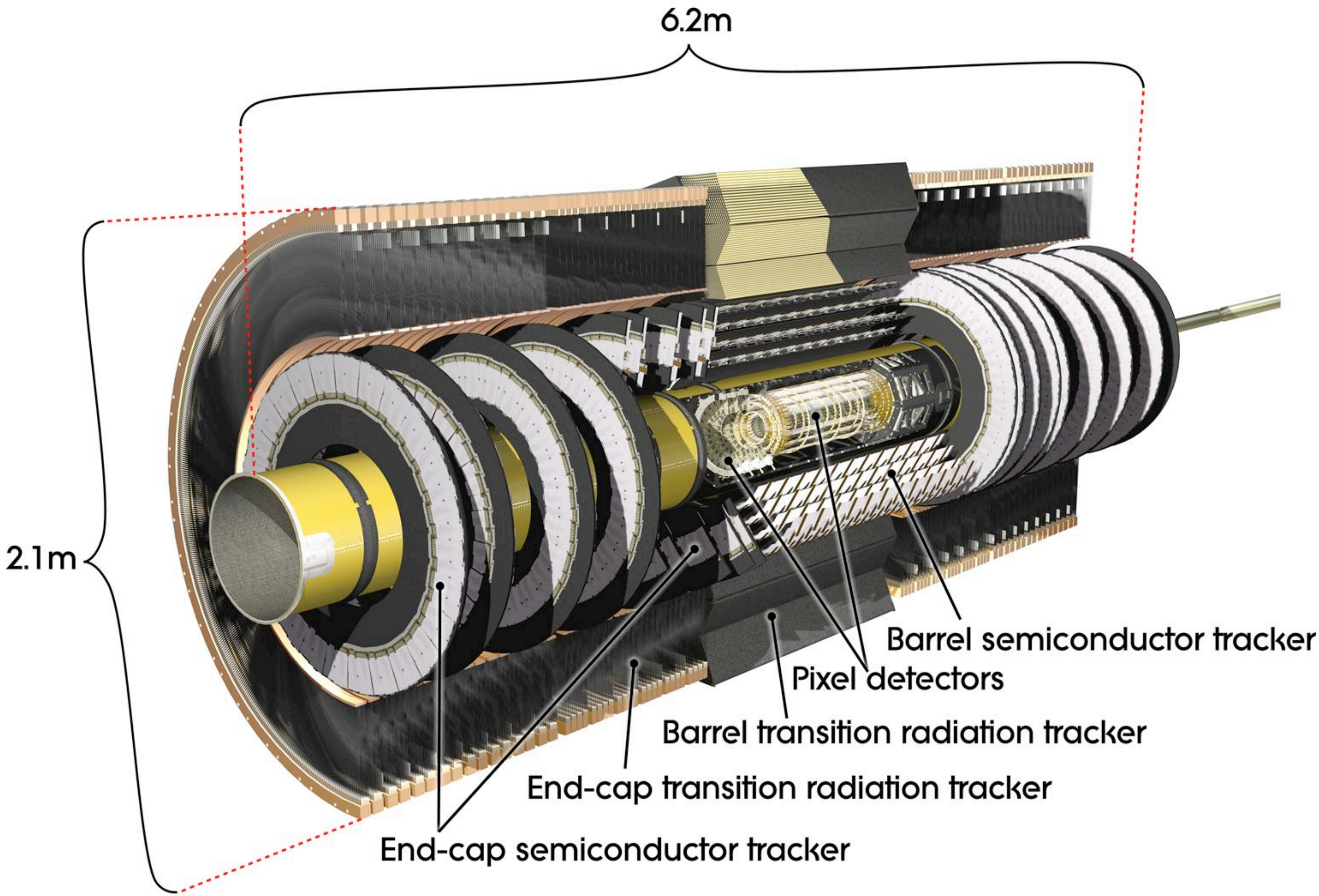
LAr and Tile Calorimeters

Hadronic end-cap(HEC)
- Cu-Lar structure
- 1.5 < |η| <3.2
- 4 longitudinal samples



LAr EMEC
- Pb-LAraccordion
- 3 longitudinal samples |η|<2.5
- Preshower |η|<1.8

Inner Detector

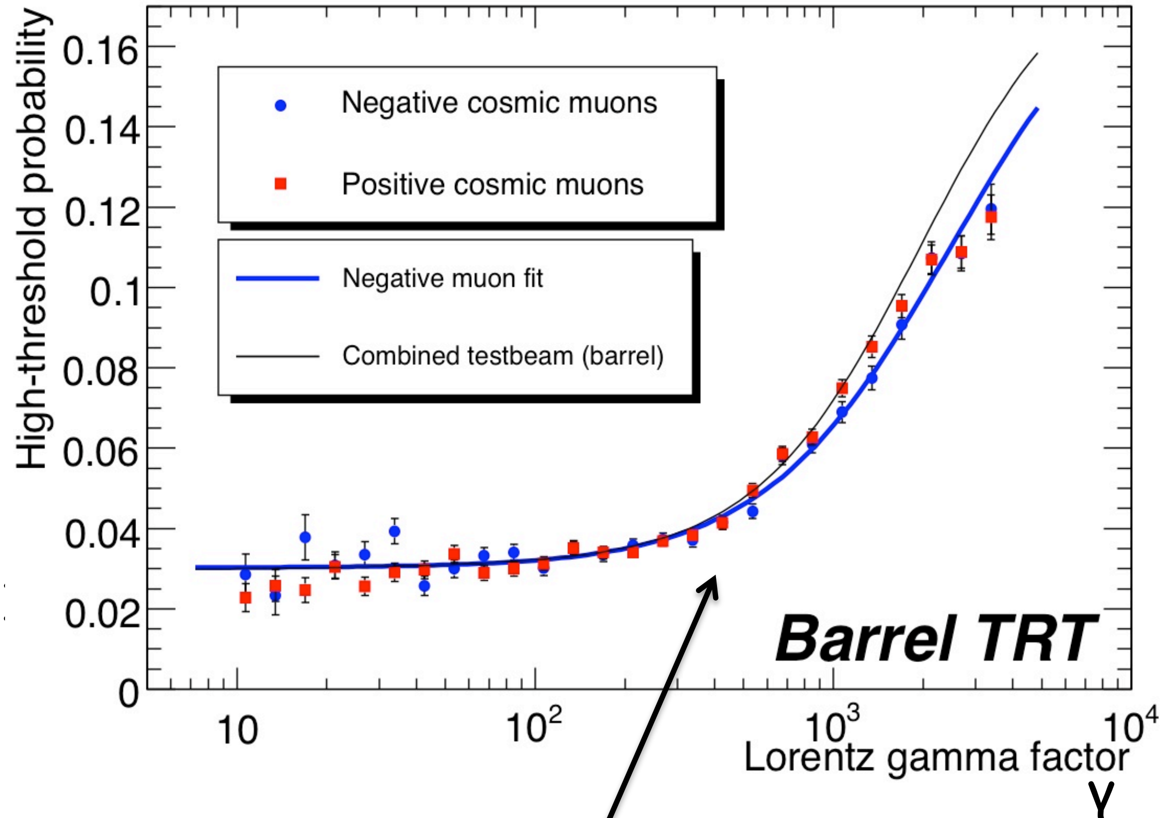


Transition radiation in the TRT

Transition radiation (TR) photons generated by radiator foils (boundary of 2 materials with different dielectric constants)

Effect starts at γ = (E/m) ≈

→ mostly for electron ID



In the TRT, photons are absorbed in chamber gas

→ large pulse

→ passes high threshold

Turn-on of TR from cosmics at about $\gamma=10^3$ as expected

Forward Muon Spectrometer

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

Small wheels: 32 **CSC** (Cathode
Strip Chambers) precision
chambers

February 2008

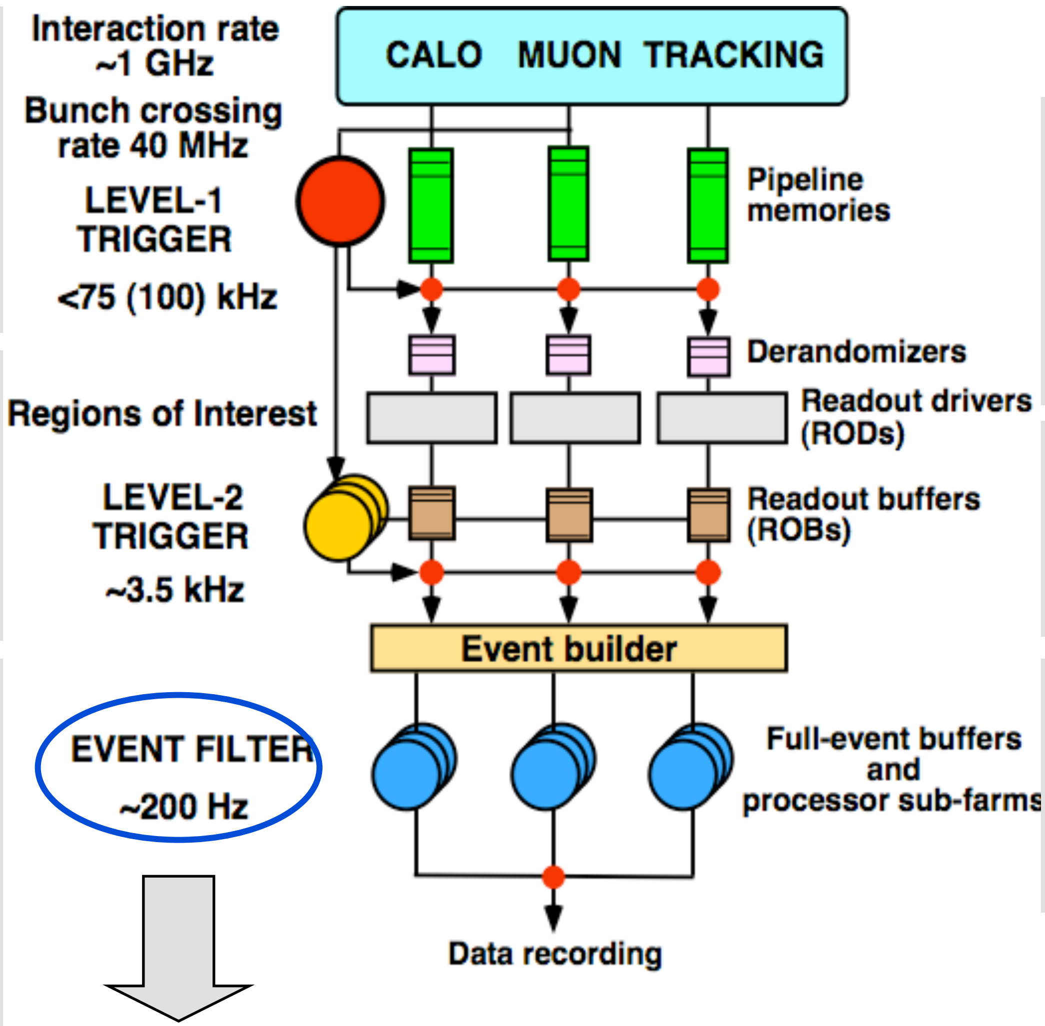
September 2007

Level-1 Trigger
Calorimeter
Muon System
Hardware based
Coarse granularity

High Level Trigger (HLT)

Level-2 Trigger
RoI
e/γ, μ, jet, ..
Full granularity in RoI

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



Front End
Electronics

Readout Drivers

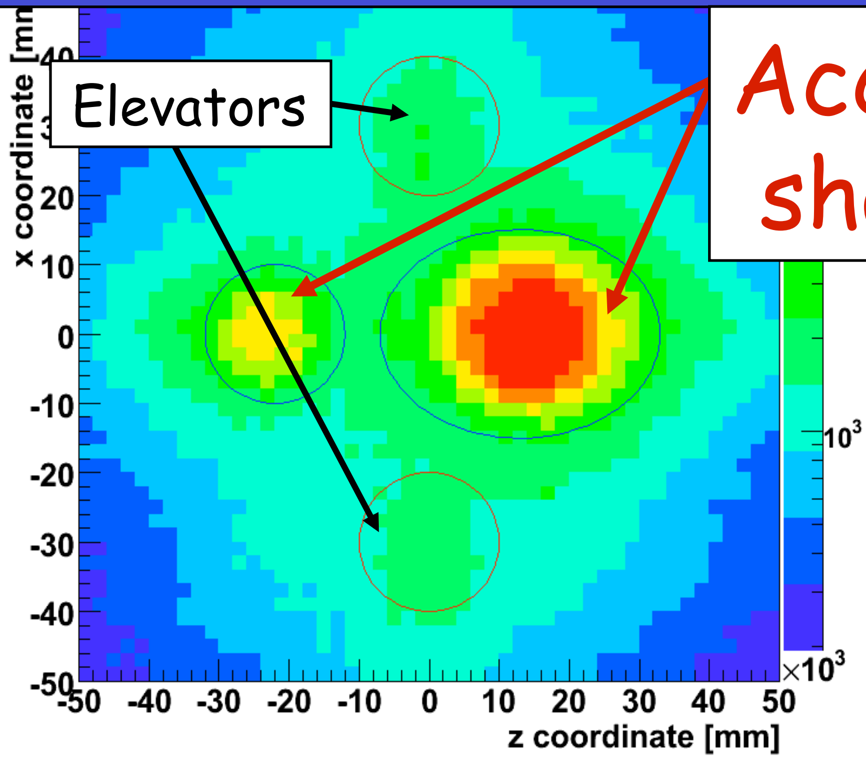
Readout System
Custom built
buffers in PC
farm

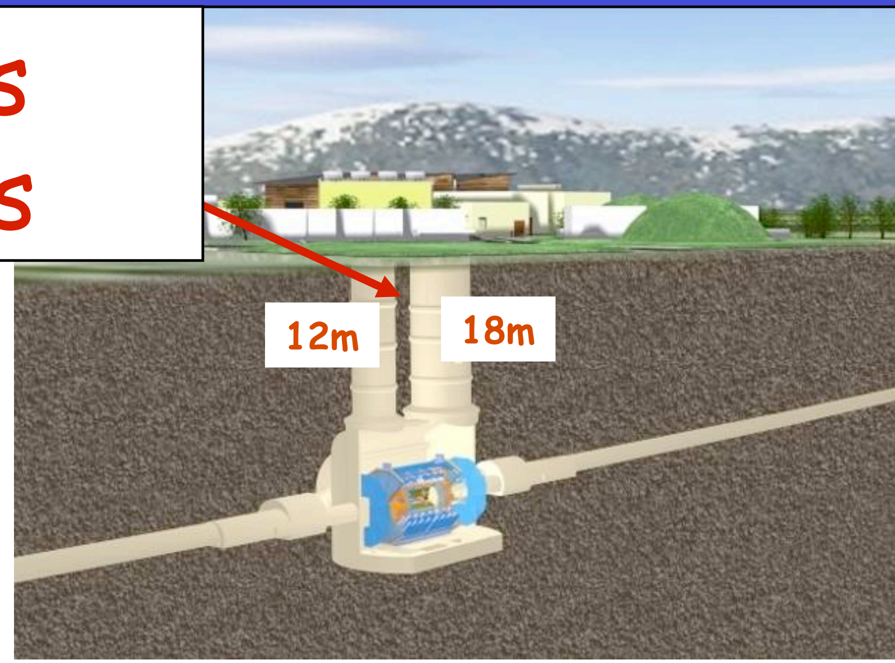
Event Building
More PC farms
on Data Network

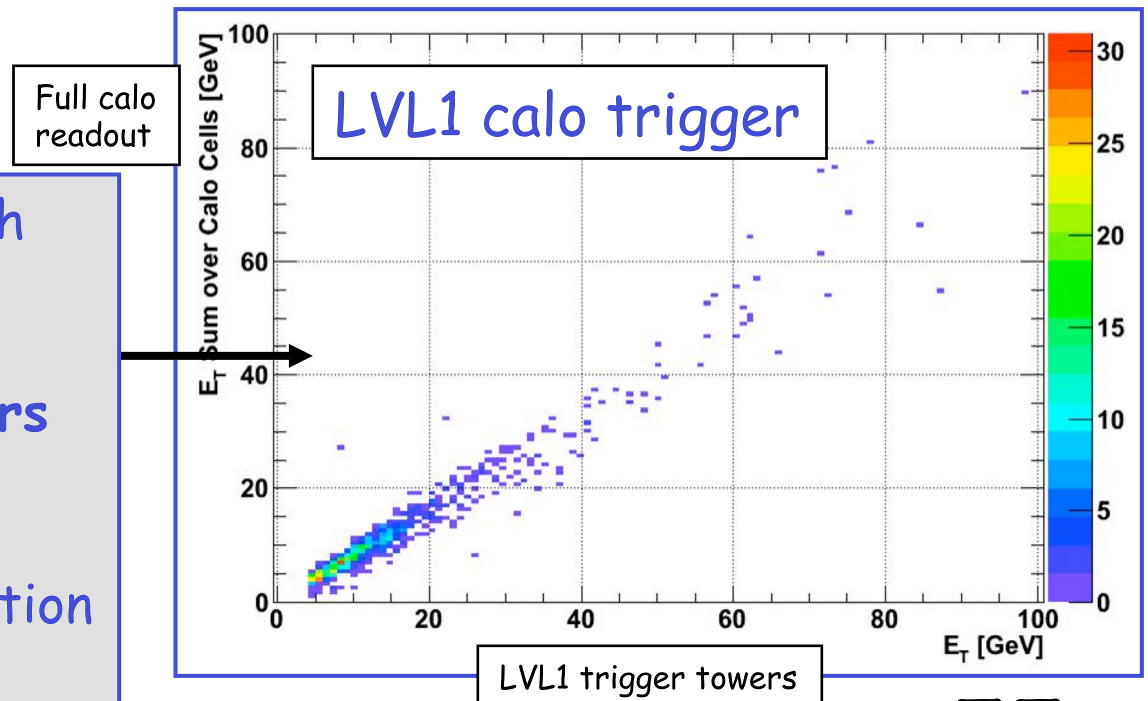
300 MByte/s
to Computer Center
~3 Pbytes stored
year

DAQ software
Control, configuration,
Monitoring on Control
Network

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

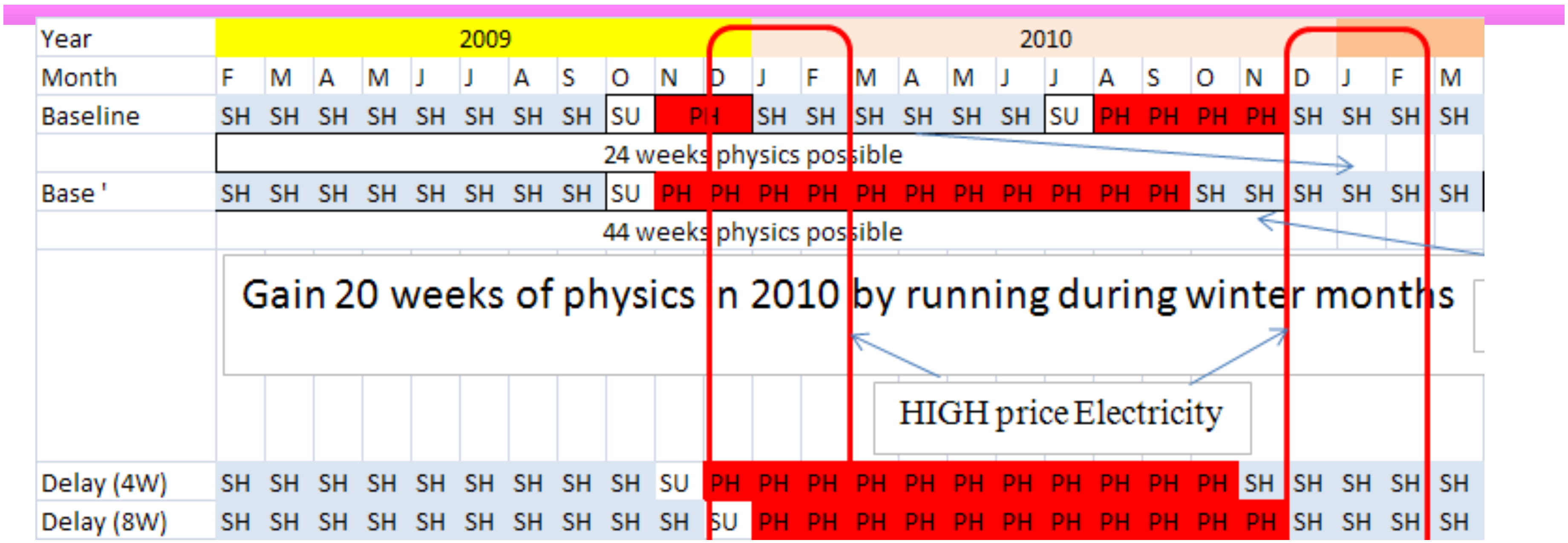






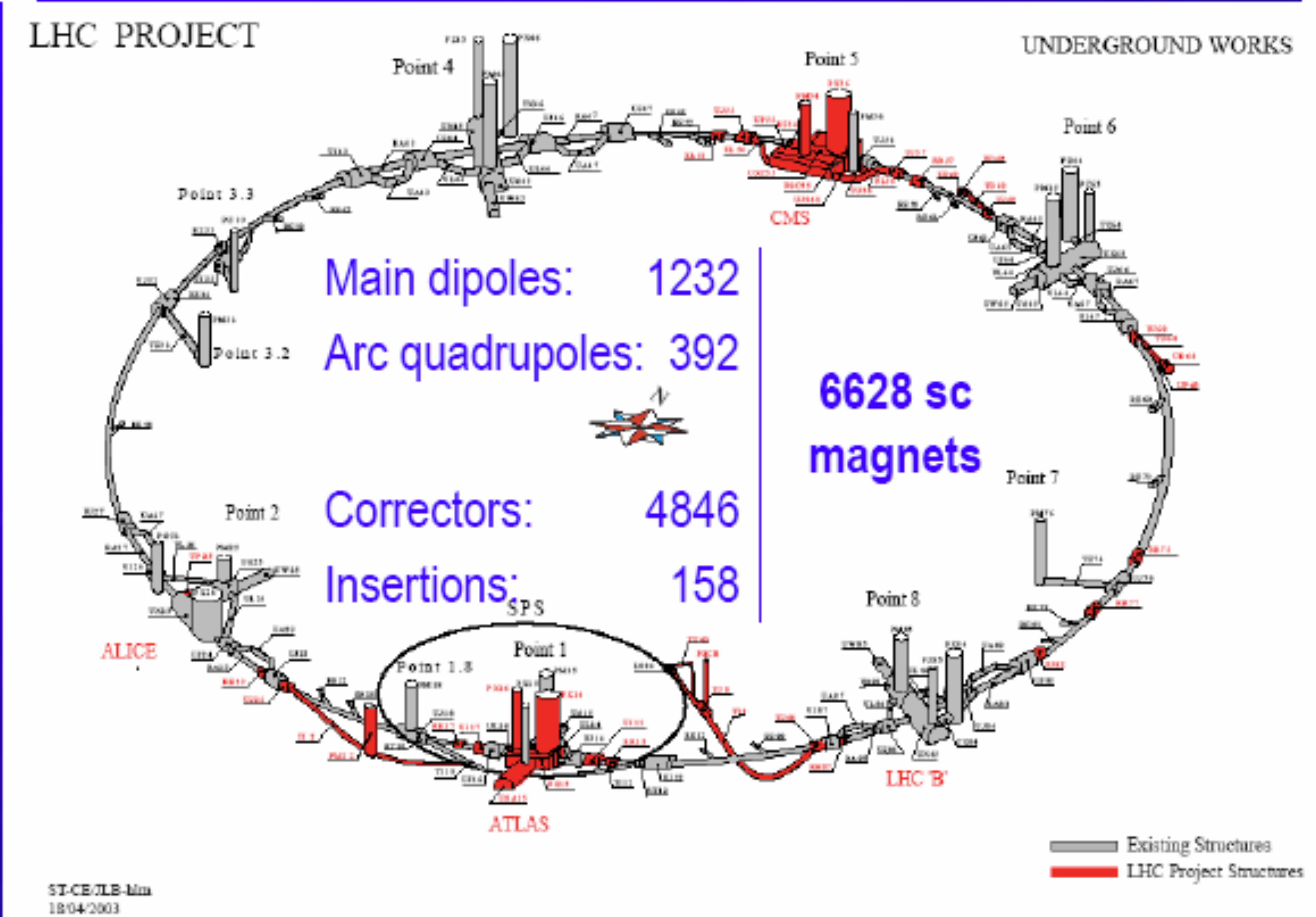
Muon (shower) energy measured with
full calorimeter readout
vs
energy measured in trigger towers
($\eta\times\phi$=0.1x0.1)
by level-one calorimeter trigger.
With initial calibration (final calibration will reduce the spread)

The 2009/10 LHC Run



- Decisions taken
  - Top energy is 5 TeV (had been reached for all other sectors)
  - No winter shutdown 2009/10
- Consequences
  - Enough data to compete with Tevatron in many areas by end of 2009/10 run

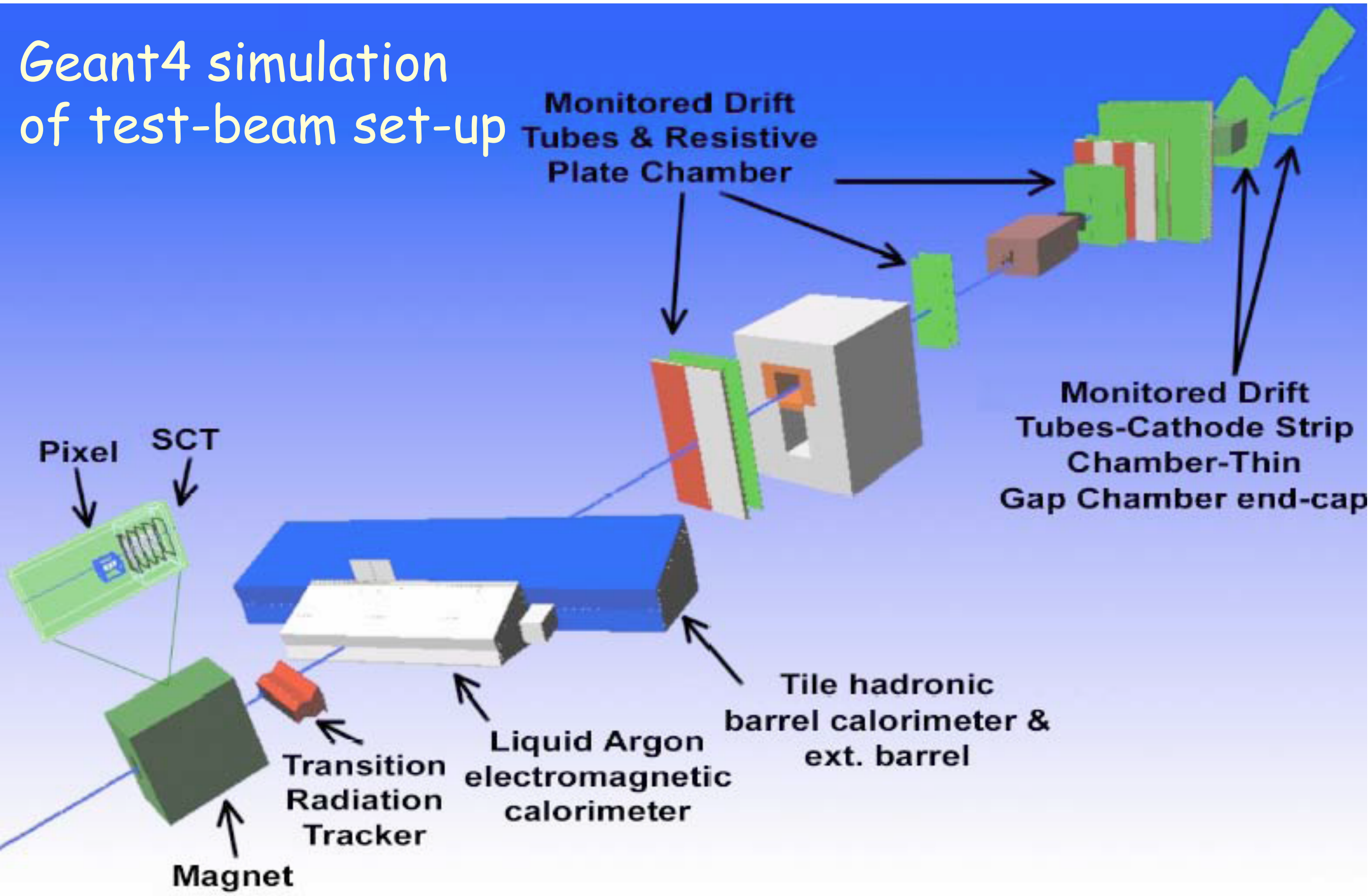
Machine layout



Main dipoles:	1232
Arc quadrupoles:	392
Correctors:	4846
Insertions:	158

6628 sc magnets

Combined Test Beam (~O(1%) Coverage)

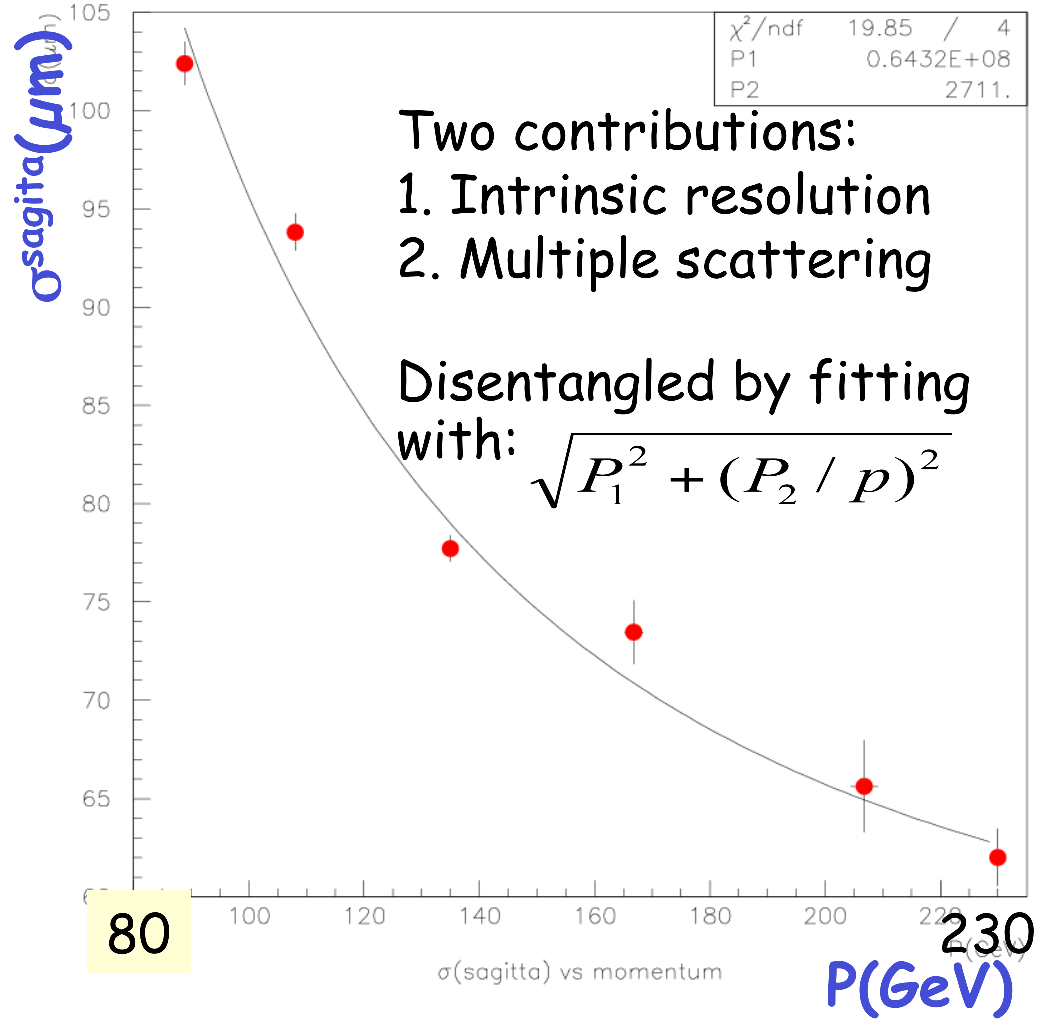


- B field: 0-.4 T
- $e^{\pm}$, $\pi^{\pm}$: 1- 250 GeV
- $\mu^{\pm}$, $\pi^{\pm}$, p up to 350 GeV
- γ: 20-100 GeV
- ~ 9×10^{7} events collected

- All ATLAS sub-detectors (and LVL1 trigger) integrated and run together with common DAQ and monitoring, "final" electronics, slow-control, etc.
- Data analyzed with common ATLAS software.
- Gained lot of global operation experience during ~ 6 month run.

MDT Resolution Measurement in H8

Sagitta resolution vs momentum

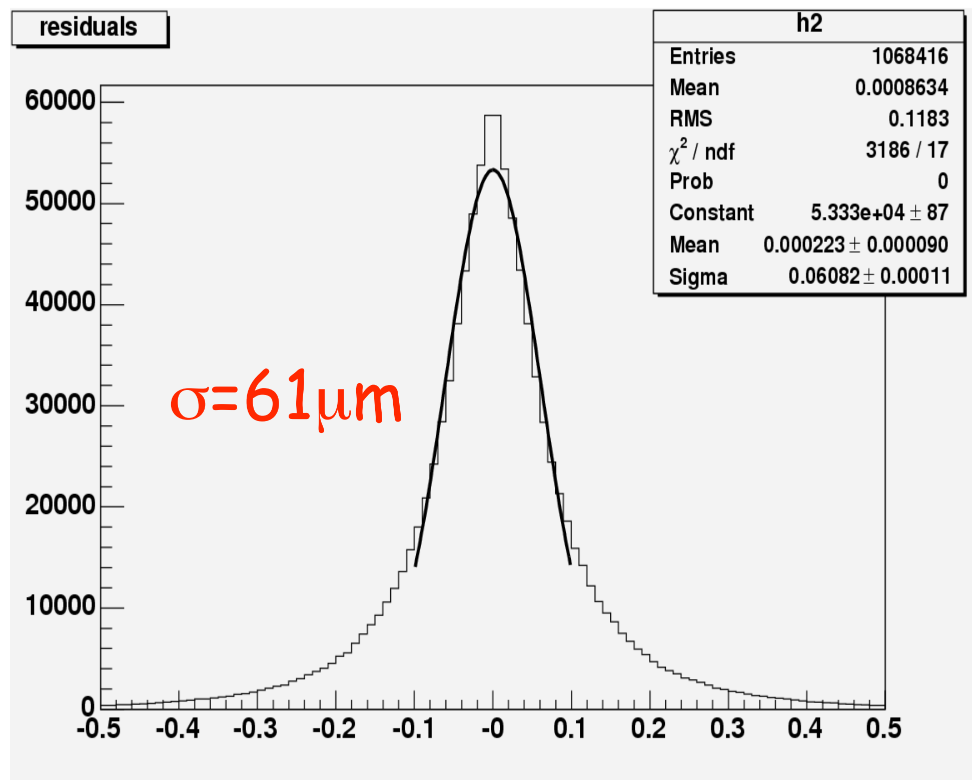


Two contributions:
1. Intrinsic resolution
2. Multiple scattering

Disentangled by fitting with: $\sqrt{P_1^2 + (P_2 / p)^2}$

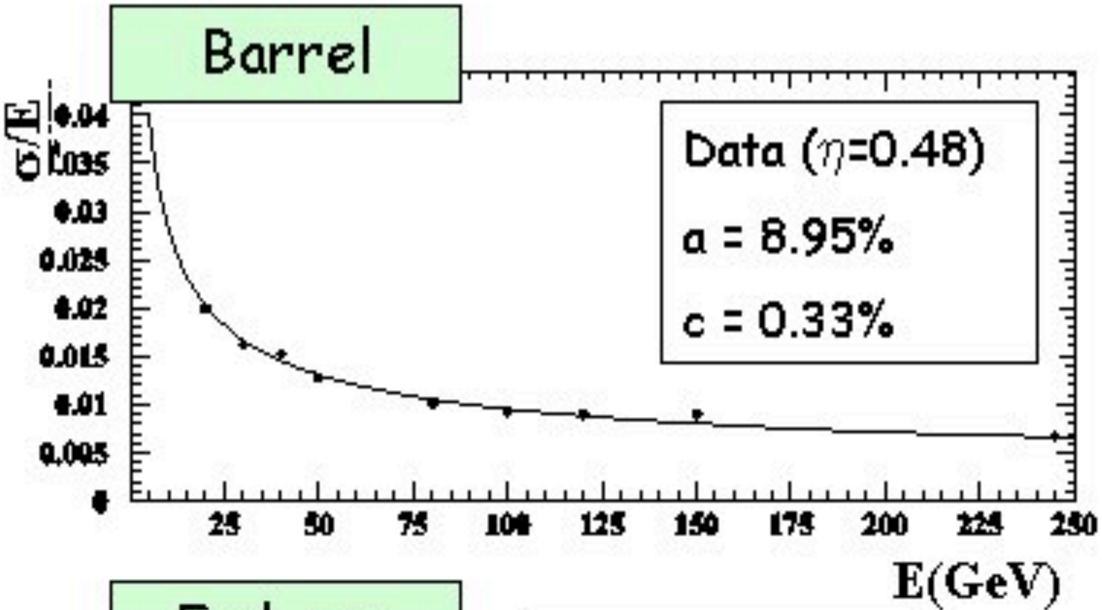
Intrinsic resolution ~50 μm

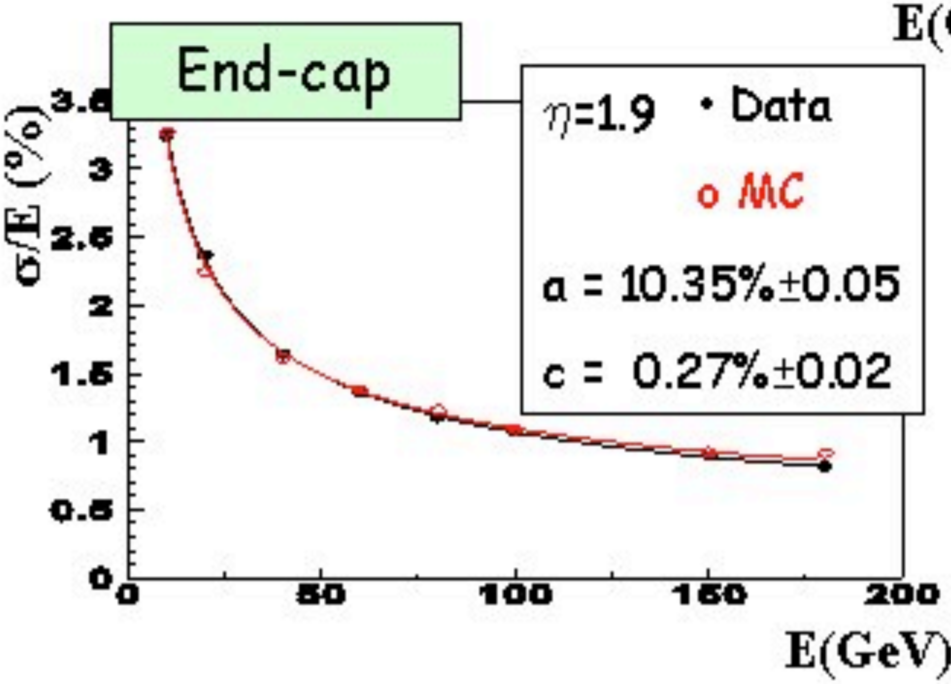
MDT fit residuals to data



Preliminary

Energy Resolution from EM Test Beam





$$\sigma_E/E = a/\sqrt{E} \oplus c \oplus n/E$$

For every tested points:

Barrel	End-cap
a < 10%	a < 12.5%
c < 0.4%	c < 0.5%

- Within specifications
- Good agreement with MC