Status of ATLAS

99th LHCC - Open Session
23 September 2009

C. Clement (Stockholm University)
on Behalf of the ATLAS Collaboration

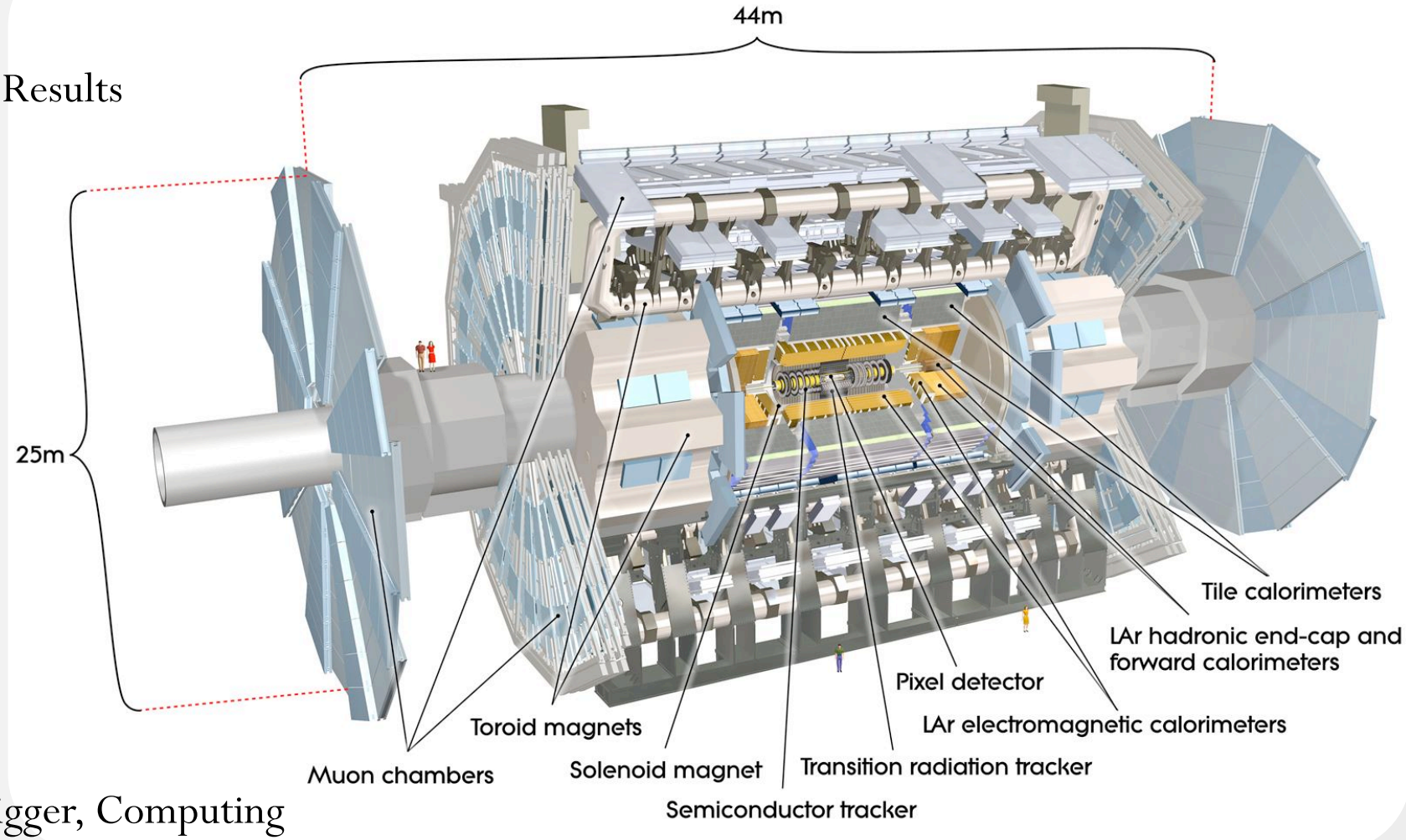
ATLAS Collaboration

37 Countries
169 Institutions
2800 Physicists (800 PhD students)

Albany, Alberta, NIKHEF Amsterdam, Ankara, LAPP Annecy, Argonne NL, Arizona, UT Arlington, Athens, NTU Athens, Baku, IFAE Barcelona, Belgrade, Bergen, Berkeley LBL and UC, HU Berlin, Bern, Birmingham, UAN Bogota, Bologna, Bonn, Boston, Brandeis, Brasil Cluster, Bratislava/SAS Kosice, Brookhaven NL, Buenos Aires, Bucharest, Cambridge, Carleton, CERN, Chinese Cluster, Chicago, Chile, Clermont-Ferrand, Columbia, NBI Copenhagen, Cosenza, AGH UST Cracow, IFJ PAN Cracow, UT Dallas, DESY, Dortmund, TU Dresden, JINR Dubna, Duke, Frascati, Freiburg, Geneva, Genoa, Giessen, Glasgow, Göttingen, LPSC Grenoble, Technion Haifa, Hampton, Harvard, Heidelberg, Hiroshima, Hiroshima IT, Indiana, Innsbruck, Iowa SU, Irvine UC, Istanbul Bogazici, KEK, Kobe, Kyoto, Kyoto UE, Lancaster, UN La Plata, Lecce, Lisbon LIP, Liverpool, Ljubljana, QMW London, RHBNC London, UC London, Lund, UA Madrid, Mainz, Manchester, CPPM Marseille, Massachusetts, MIT, Melbourne, Michigan, Michigan SU, Milano, Minsk NAS, Minsk NCPHEP, Montreal, McGill Montreal, RUPHE Morocco, FIAN Moscow, ITEP Moscow, MEPhI Moscow, MSU Moscow, Munich LMU, MPI Munich, Nagasaki IAS, Nagoya, Naples, New Mexico, New York, Nijmegen, BINP Novosibirsk, Ohio SU, Okayama, Oklahoma, Oklahoma SU, Olomouc, Oregon, LAL Orsay, Osaka, Oslo, Oxford, Paris VI and VII, Pavia, Pennsylvania, Pisa, Pittsburgh, CAS Prague, CU Prague, TU Prague, IHEP Protvino, Regina, Ritsumeikan, Rome I, Rome II, Rome III, Rutherford Appleton Laboratory, DAPNIA Saclay, Santa Cruz UC, Sheffield, Shinshu, Siegen, Simon Fraser Burnaby, SLAC, Southern Methodist Dallas, NPI Petersburg, Stockholm, KTH Stockholm, Stony Brook, Sydney, AS Taipei, Tbilisi, Tel Aviv, Thessaloniki, Tokyo ICEPP, Tokyo MU, Toronto, TRIUMF, Tsukuba, Tufts, Udine/ICTP, Uppsala, UI Urbana, Valencia, UBC Vancouver, Victoria, Washington, Weizmann Rehovot, FH Wiener Neustadt, Wisconsin, Wuppertal, Würzburg, Yale, Yerevan

The ATLAS Detector

- Detector status & Performance
- Cosmics Results
- DAQ, Trigger, Computing
- Physics



Current Detector Status

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	98.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.2%
LAr EM Calorimeter (ECal)	170 k	99.1%
Tile calorimeter (HCal)	9800	99.5%
Hadronic endcap LAr calorimeter	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	>97%
TGC Endcap Muon Trigger	320 k	99.8%

Work during Shutdown

Inner Detector

- Evaporative cooling for the ATLAS silicon detectors: system upgraded, all 6 old compressors modified+ 7th compressor for back up (still to be commissioned). New design validated. Refurbished distribution racks, more flexible control system, new reserve tank which can take *all* fluid.

- Replaced Optical Transmitters of the Pixel and Semi Conductor Tracker. These transmitters feed & encode clock and trigger commands to front end electronics.

- Upgrade of HV boards for the Semi Conductor Tracker

- Increased reliability of the Beam Condition Monitor. ATLAS Beam Loss Monitors installed.

- CO2 straw cooling for TRT: tests done, additional CO2 extraction lines being tested.

Work during Shutdown

Calorimeters

- All Liquid Argon power supplies were repaired and re-installed (all working today). A backup scheme is in development, available for 2010 shutdown.
- Front end boards optical transmitters, 12 out of 1600 dead
- Repairs carried out on 81/256 Tile HCal electronic drawers
- Completion of front end electronics, robotics and EM module for Zero Degree Calorimeter

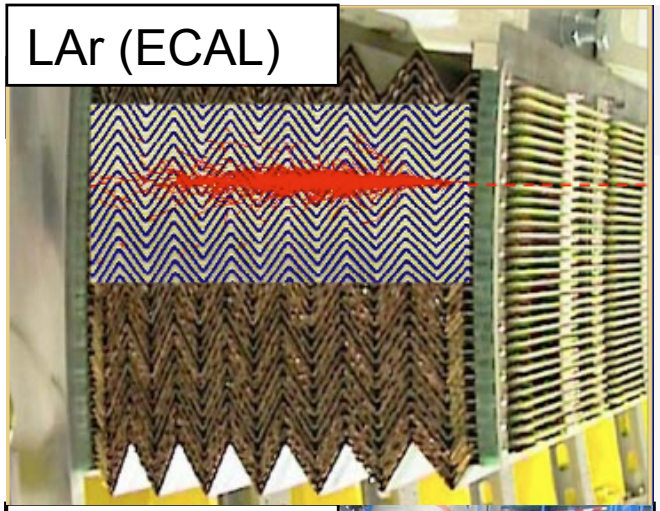
Muon Spectrometer

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

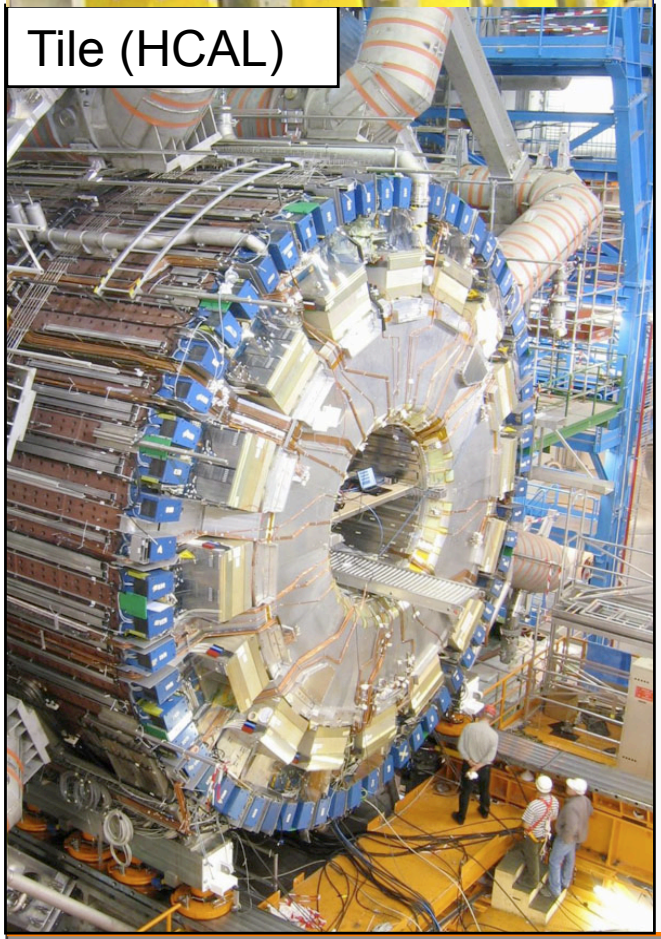
Shutdown was put to good use! Detector fully operational!

Items under watch: calorimeter power supplies, inner detector cooling, inner detector heater pads, LAr calorimeter readout link (backup solutions under preparation for next shutdown) and CSC chambers (readout rate issues).

LAr (ECAL)

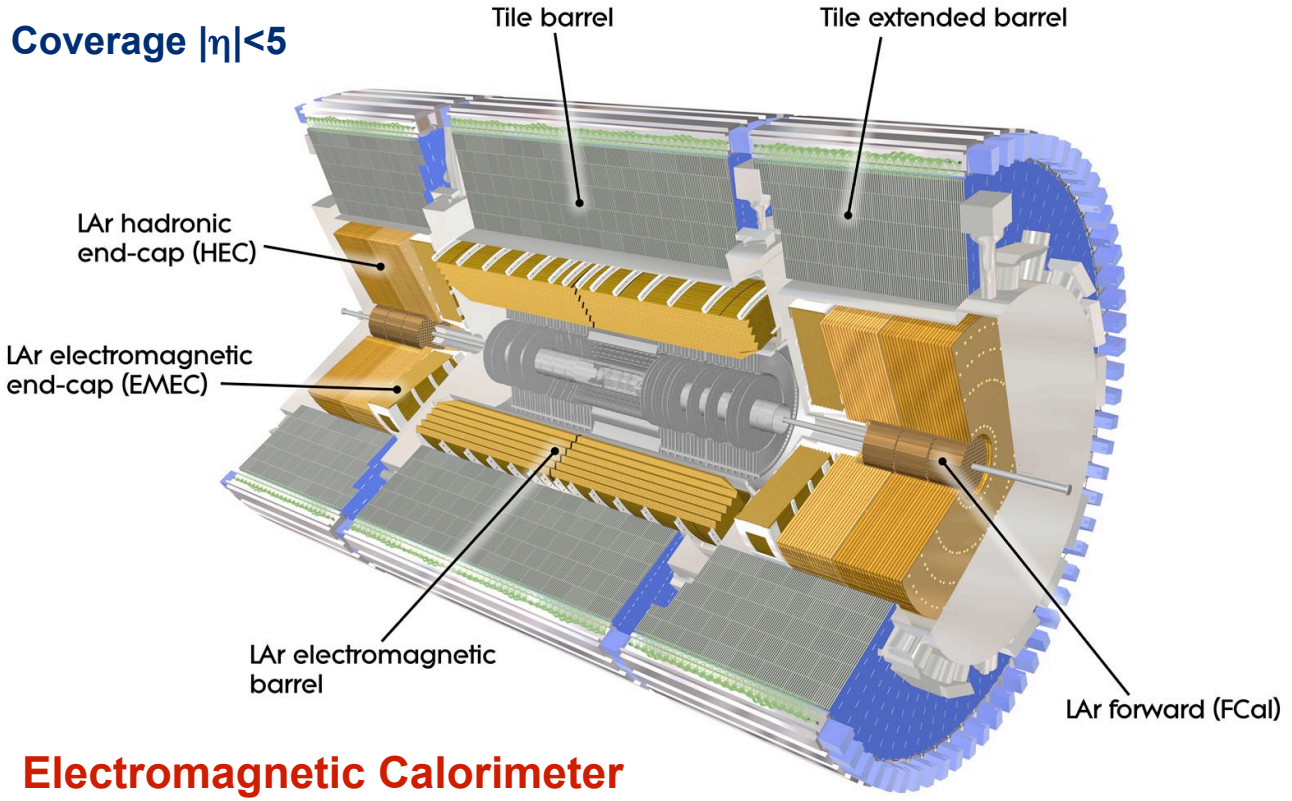


Tile (HCAL)



Calorimetry

Coverage $|\eta|<5$



Electromagnetic Calorimeter

barrel, end-cap: Pb-LAr

~10%/√E energy resolution e/γ

170'000 channels: longitudinal segmentation

Hadron Calorimeter

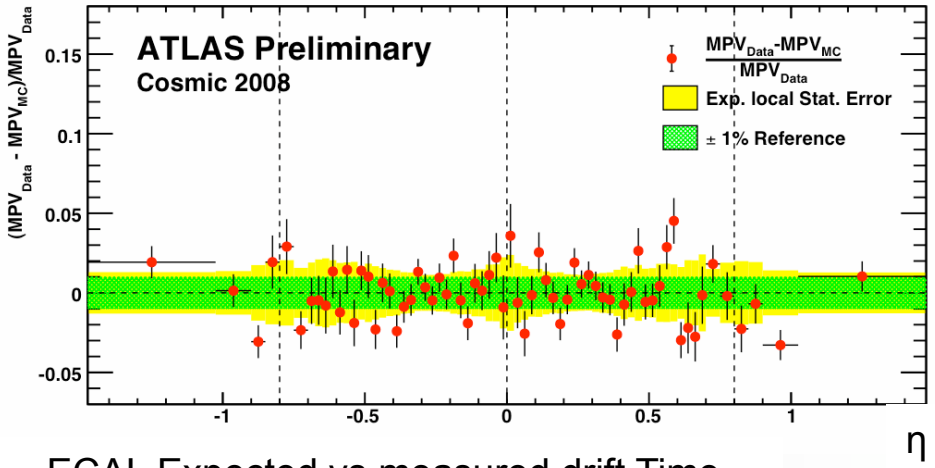
barrel Iron-Tile, EC/Fwd Cu/W-LAr (~20000 channels)

$\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$ pion (10 λ)

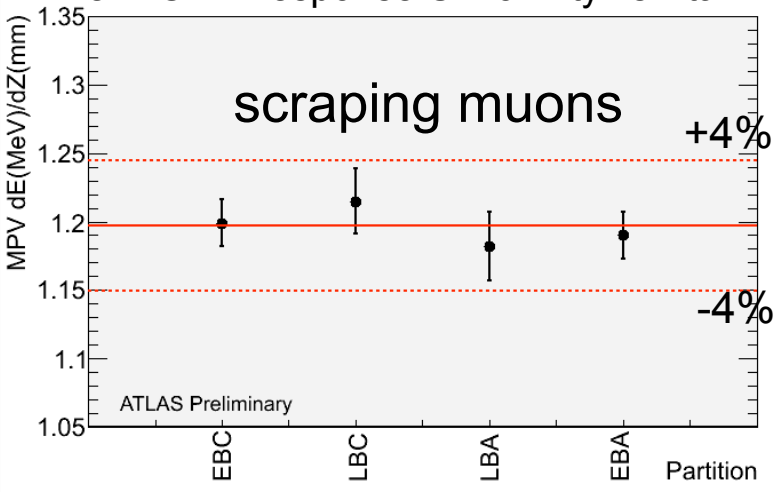
Trigger for e/γ , jets, missing E_T , γ/π^0 separation, ...

Calorimetry Performance with Cosmics and Single Beam

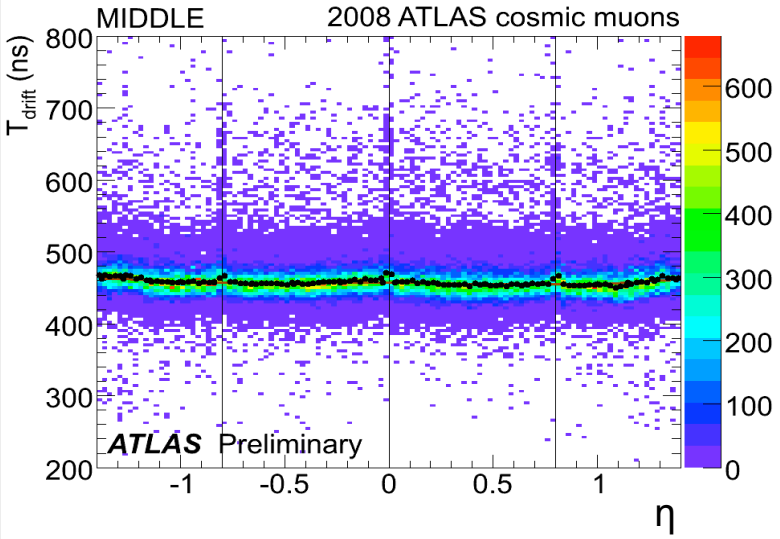
ECAL Middle Compartment Response Uniformity vs η

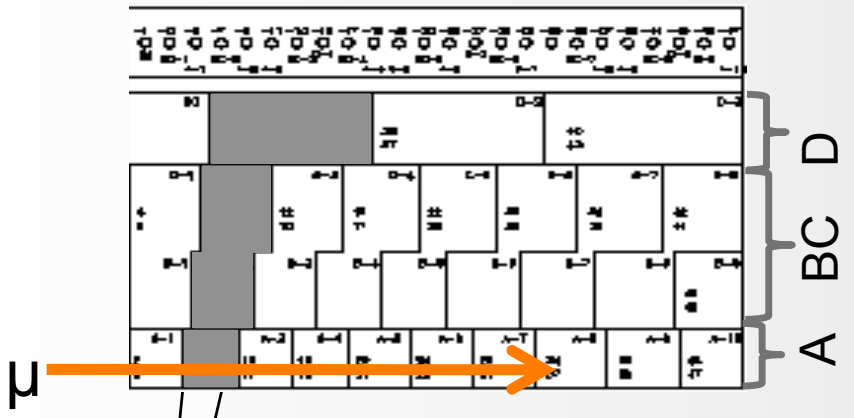


Tile HCAL Response Uniformity vs Eta

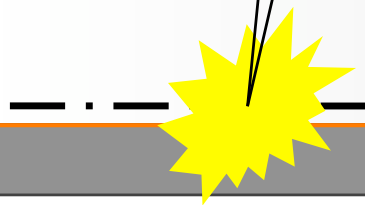


ECAL Expected vs measured drift Time





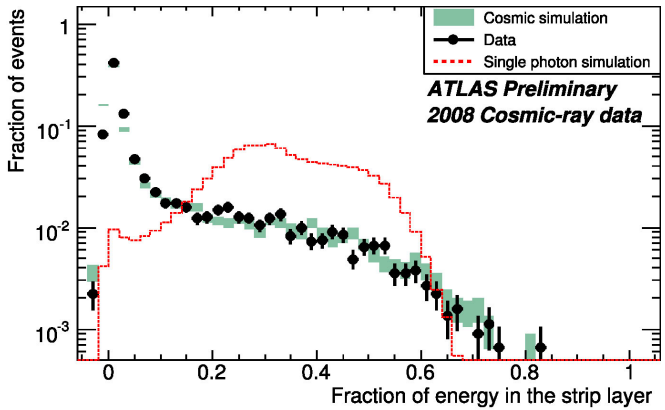
Cross check with scraping μ
the calibration with Cs source

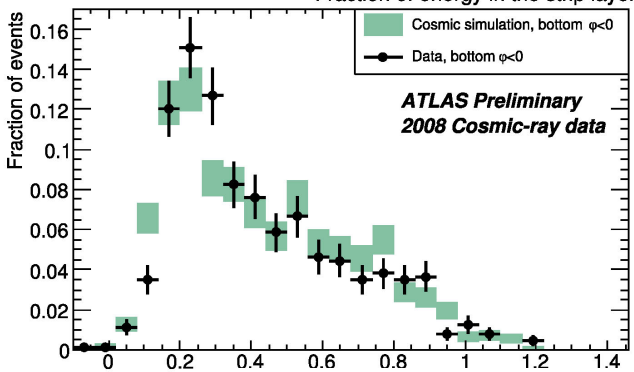


Cross check of the quality of calorimeter production
Contribution to constant term under control
Target uniformity Day 1: 2.5% or better
~0.7% with 100k Z➔ee

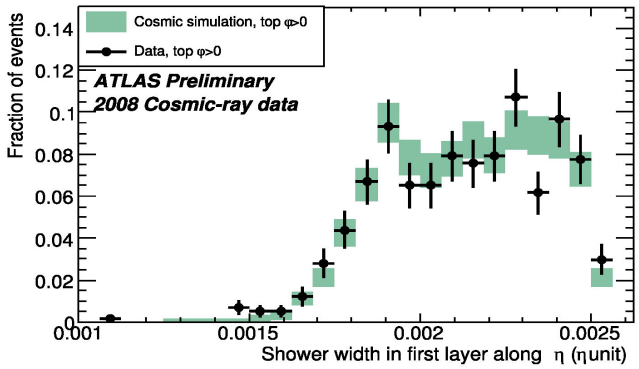
Calorimeter Based Measurements

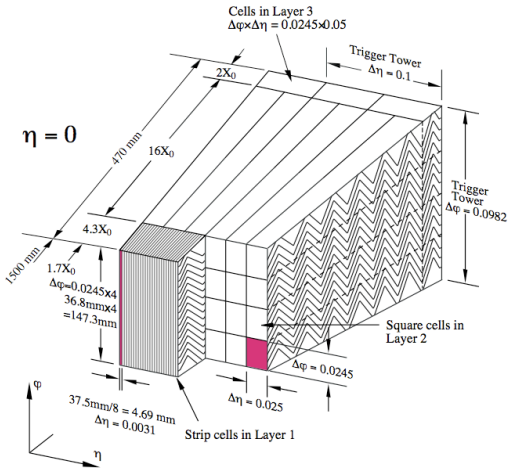
EM Showers in Cosmics





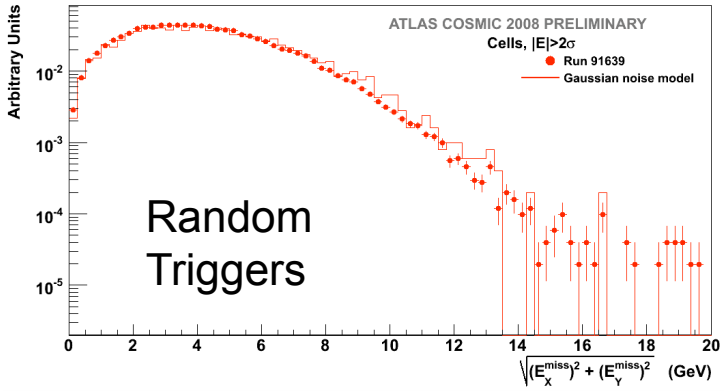
Fside =(E±3 -E±1)/E±1



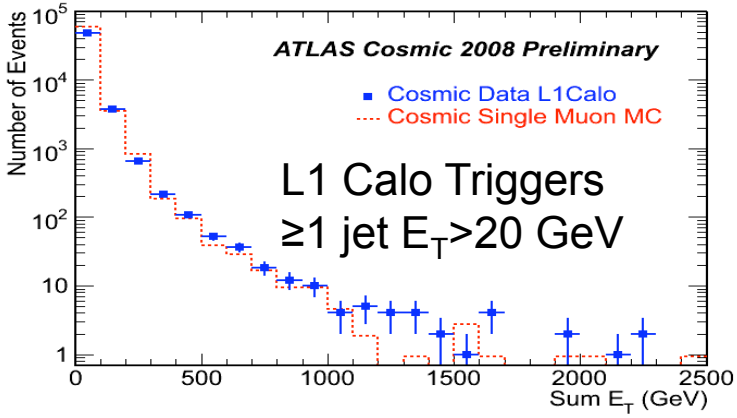


Jet / ETmiss

E_T^{miss} observed vs noise model

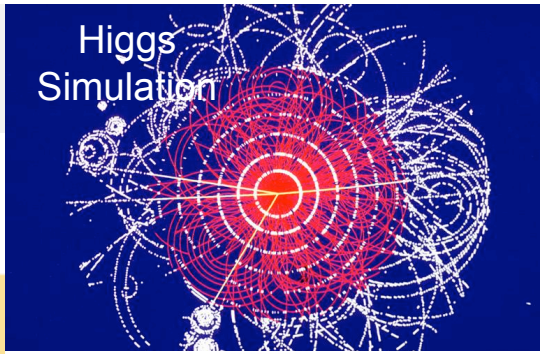


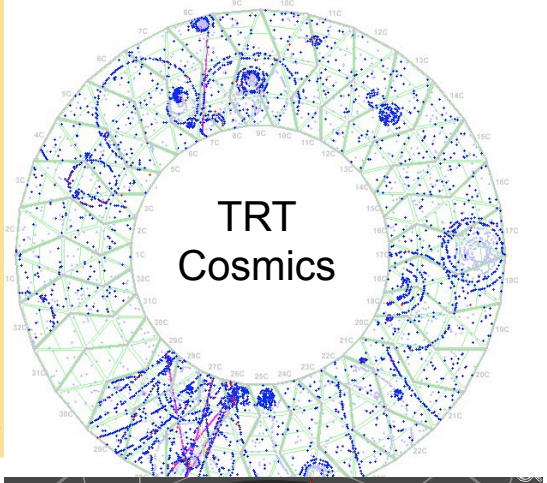
Sum E_T observed vs MC

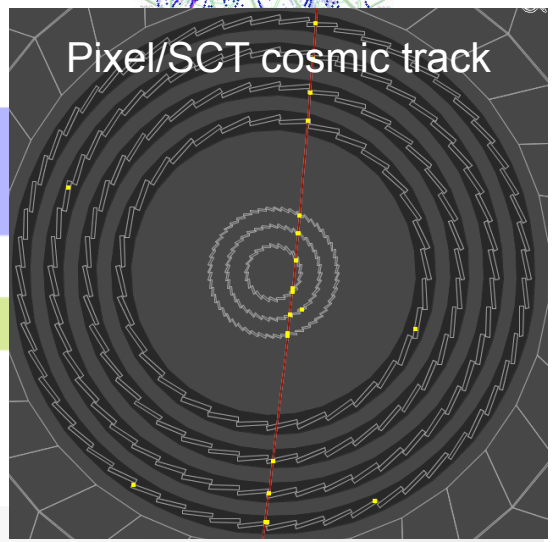


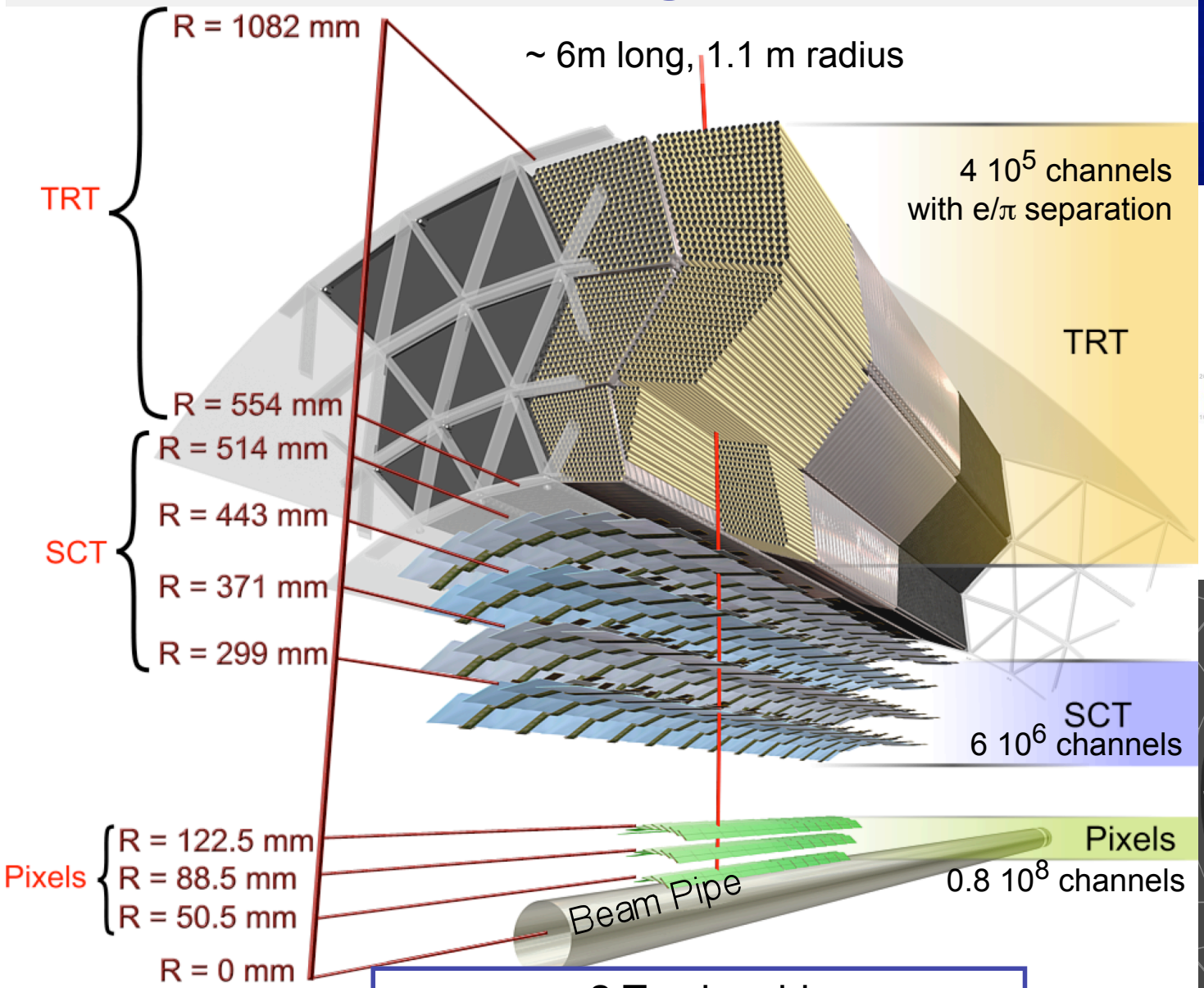
Reconstruction algorithms exercised on real data
EM shower properties well modelled by MC
Good understanding of per-event calorimeter variables

ATLAS Tracking Detectors





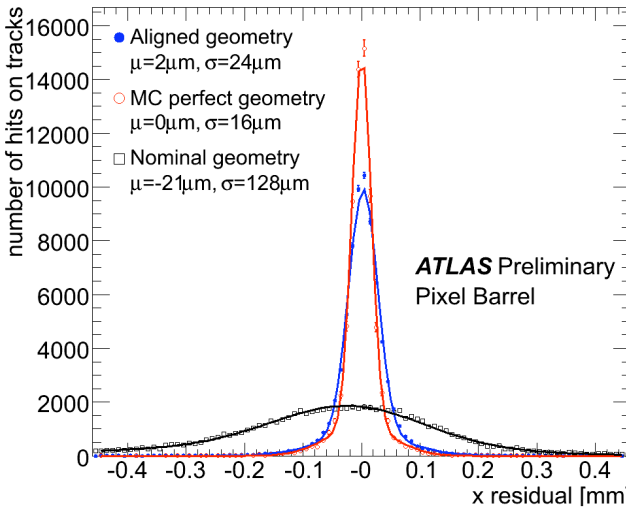


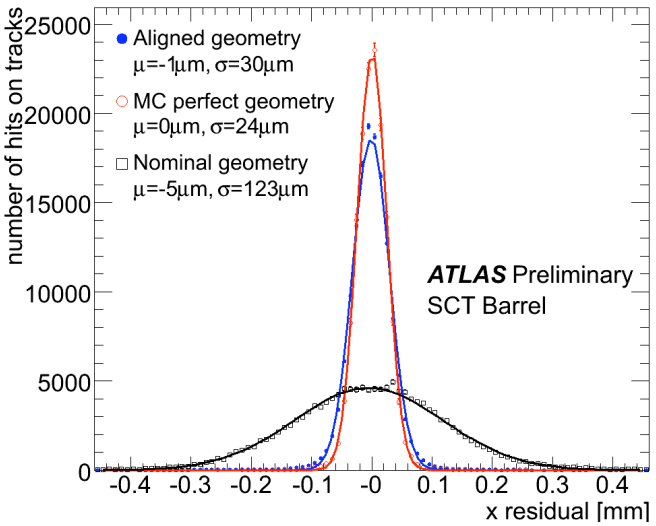


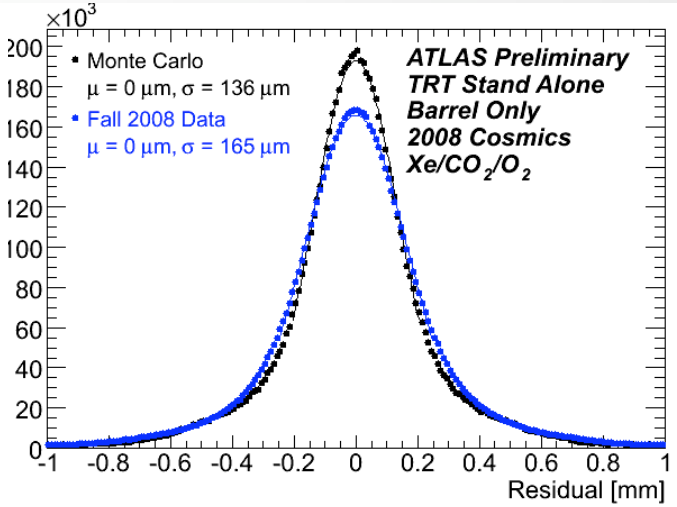
2 T solenoid

$\sigma/p_T \sim 3.8 \times 10^{-4}\ p_T\,(\mathrm{GeV}) \oplus 0.015$

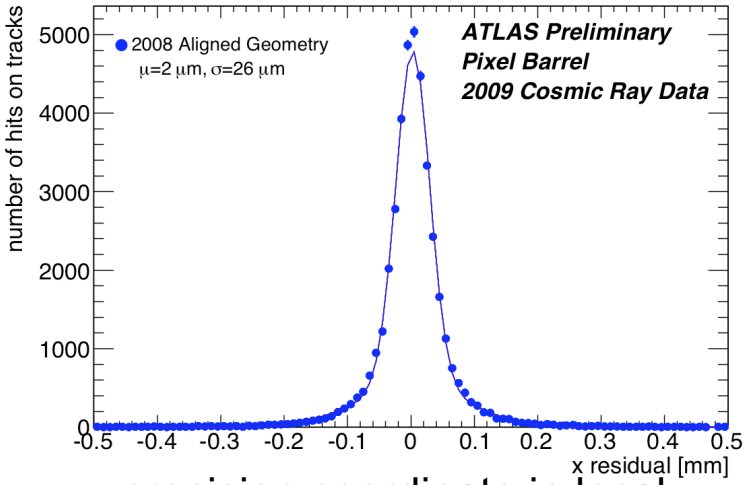
Inner Detector Performance



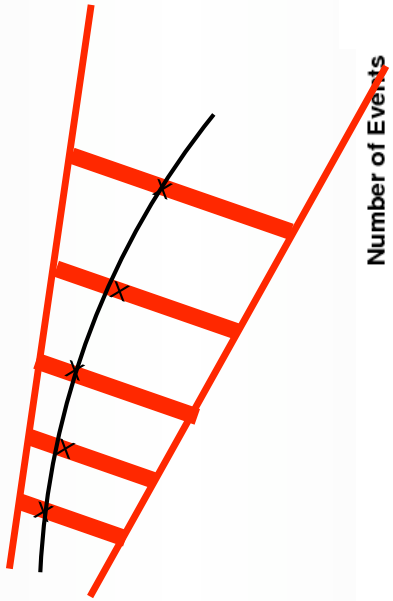




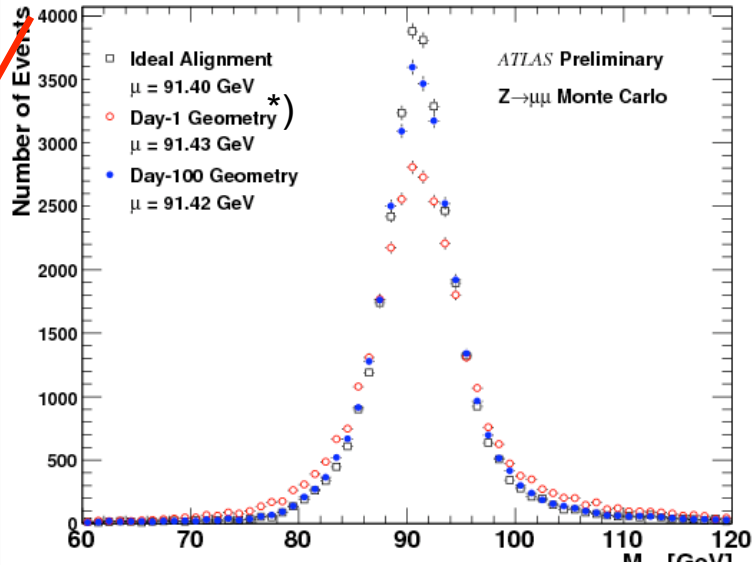
Residuals 2009 data, using 2008 alignment



x = precision coordinate in local module coordinates

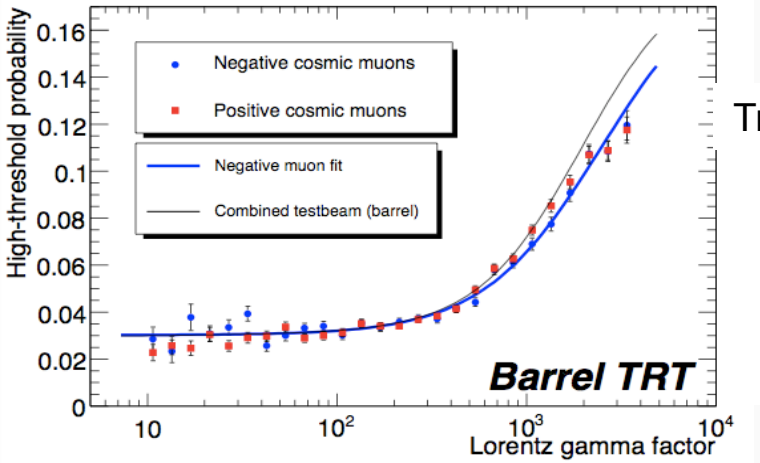


Z Mass expectations

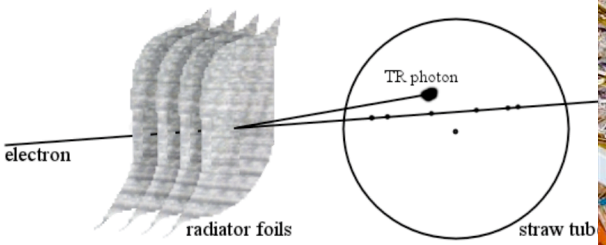


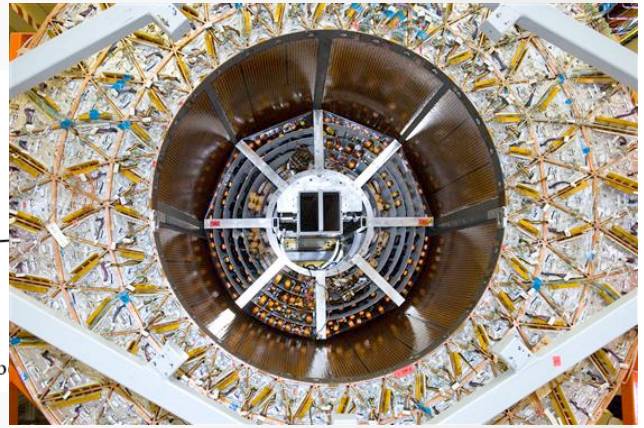
*) Day 1 assuming 20 μm smearing in silicon layer

Inner Detector Performance in Cosmics

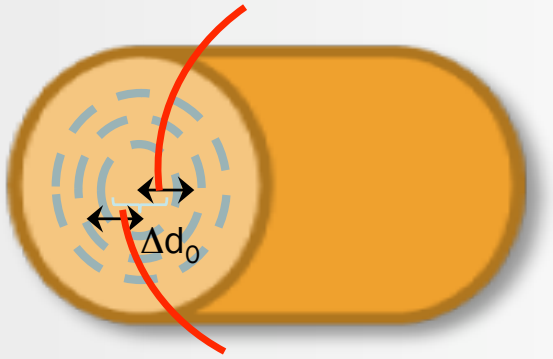


Transition radiation $\pi^{\pm}$/e separation

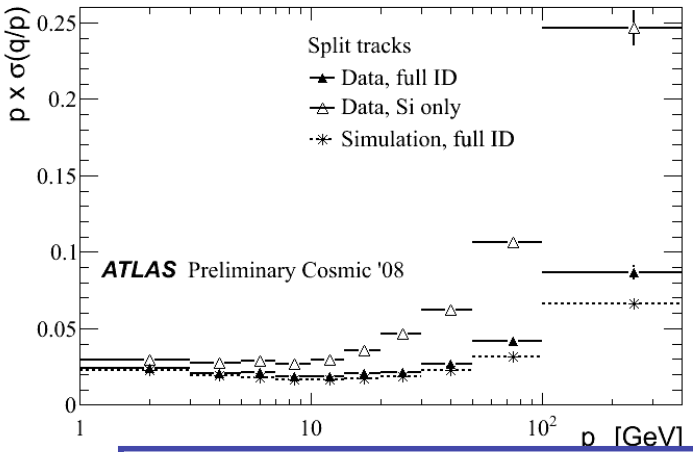




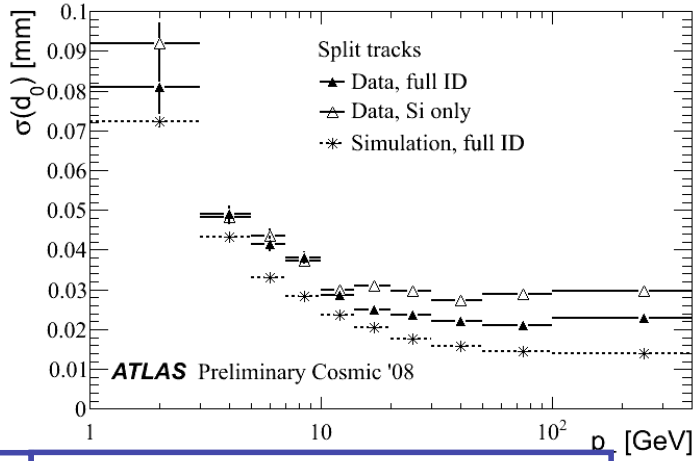
Split Tracks



Momentum resolution



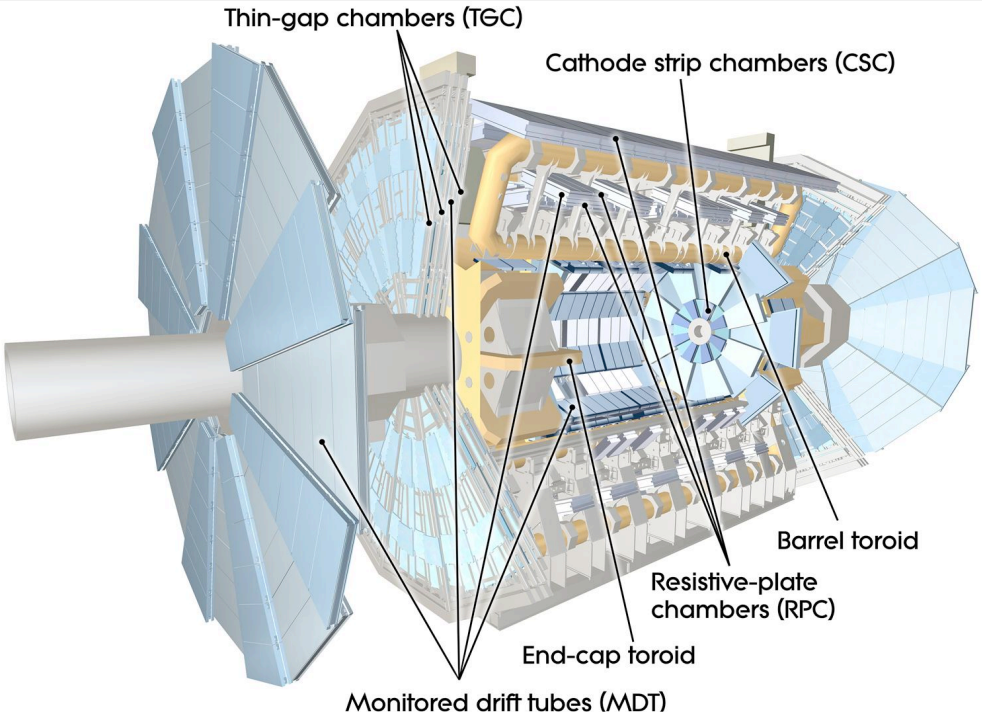
Impact Parameter Precision

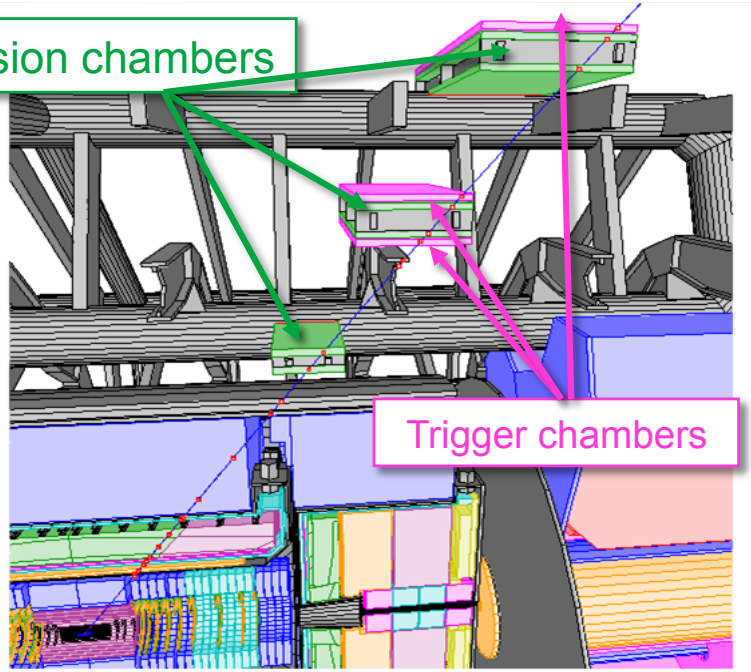


Expectations:

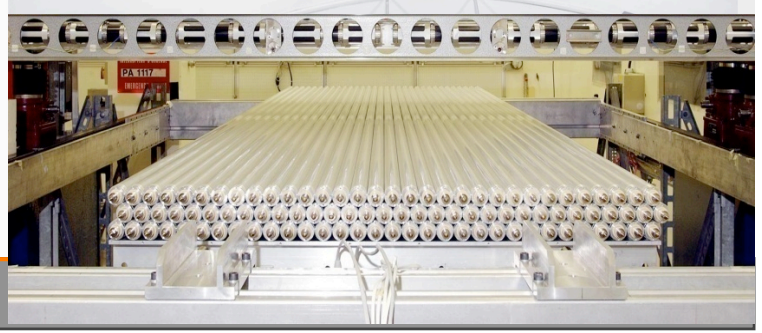
p_T $\sigma(1/p_T)$~	$\sigma(d_0)$ (μm)~
3.8×10^{-4} p_T (GeV) $\oplus$ 0.015	10 $\oplus$ 140/p_T (GeV) (at η <0.5)

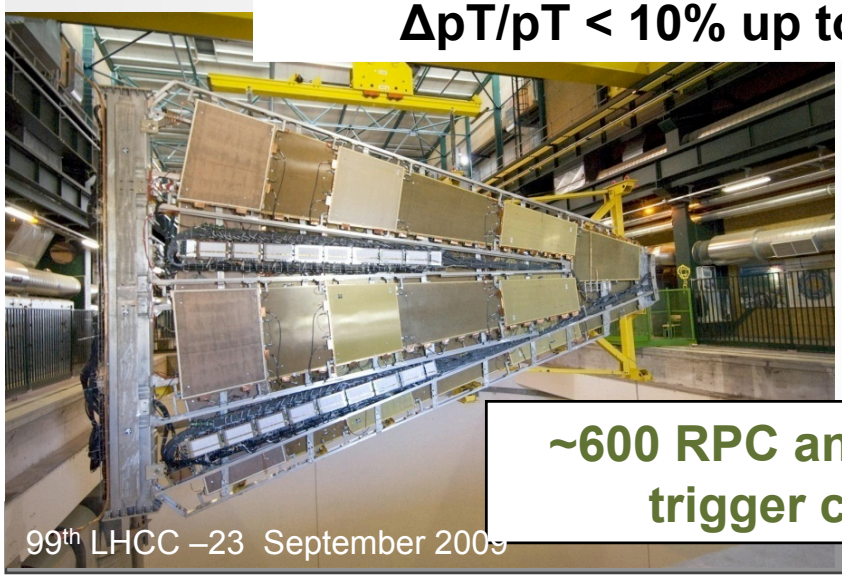
Muon System





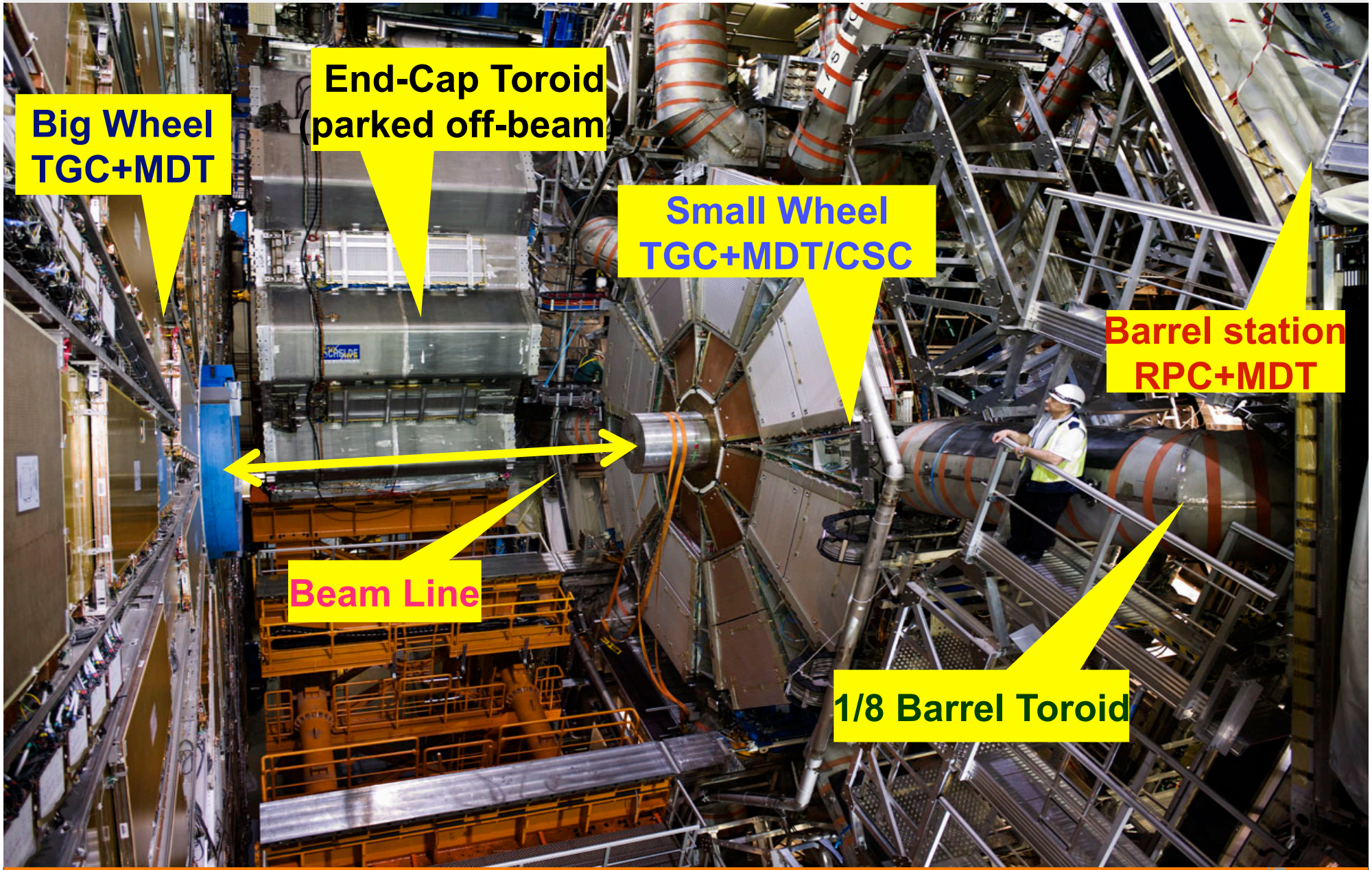
Stand-alone momentum resolution
ΔpT/pT < 10% up to 1 TeV





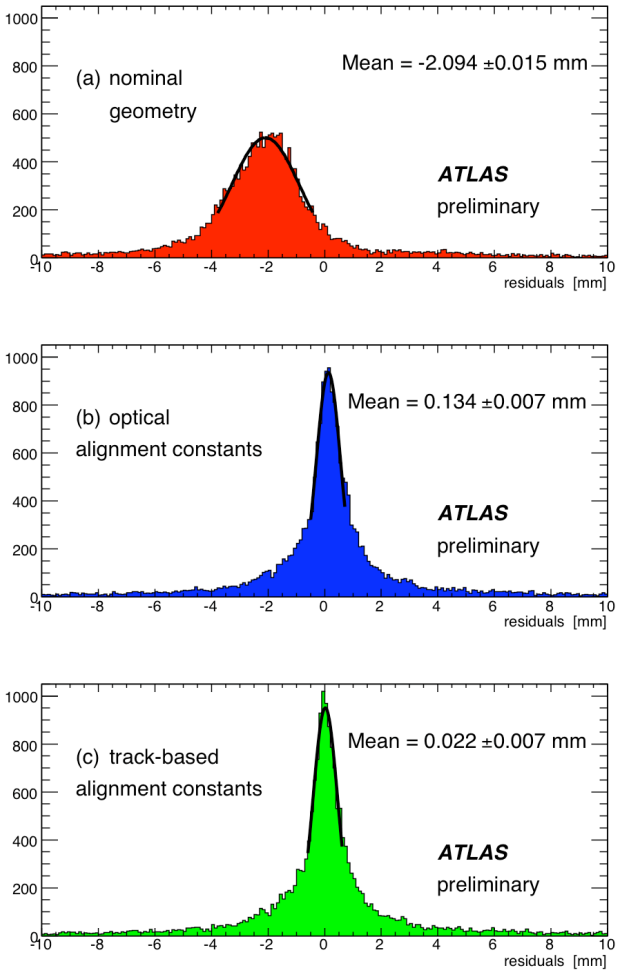
~600 RPC and ~3600 TGC trigger chambers

The Muon Endcap

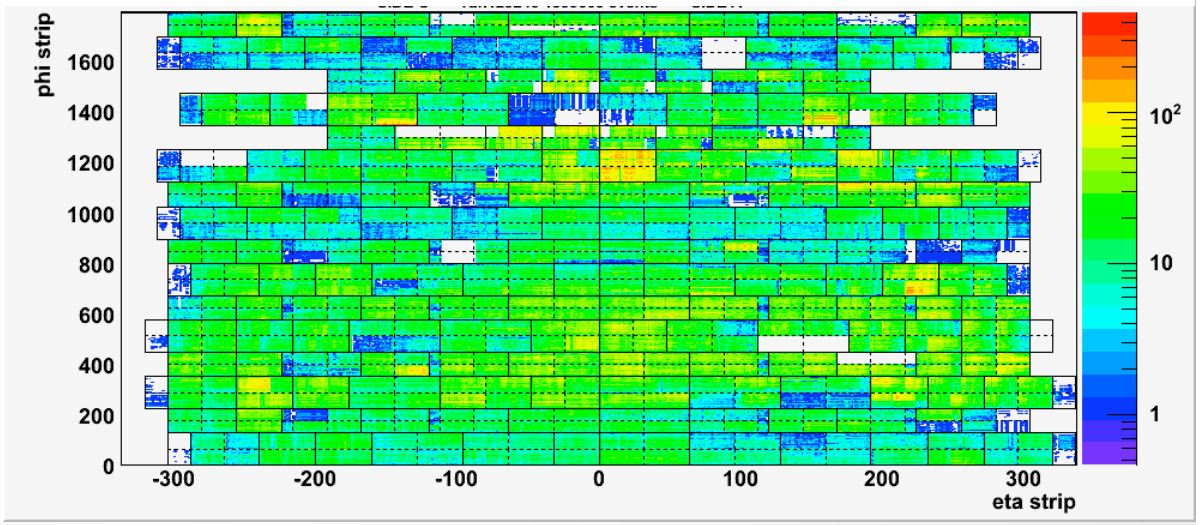


Muon Detector

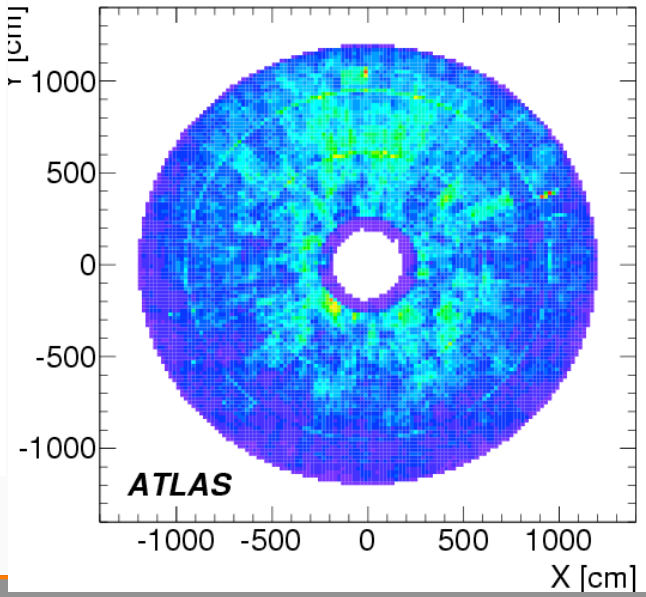
Goal ~10% δp/p for 1TeV muon
=> 50μm precision on 500μm sagitta



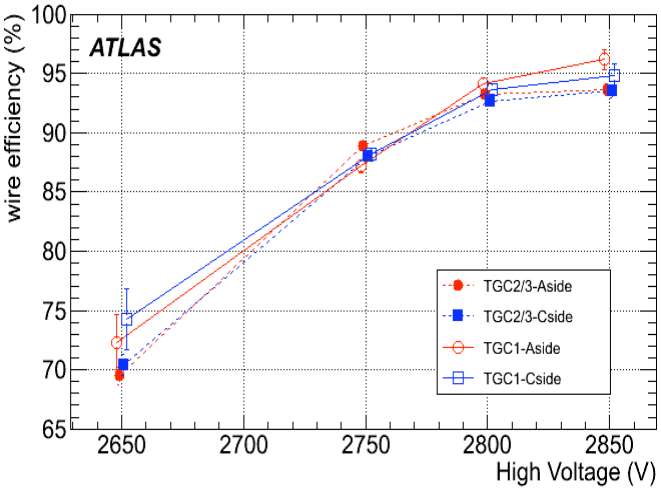
Barrel L1μ Trigger Hit Map



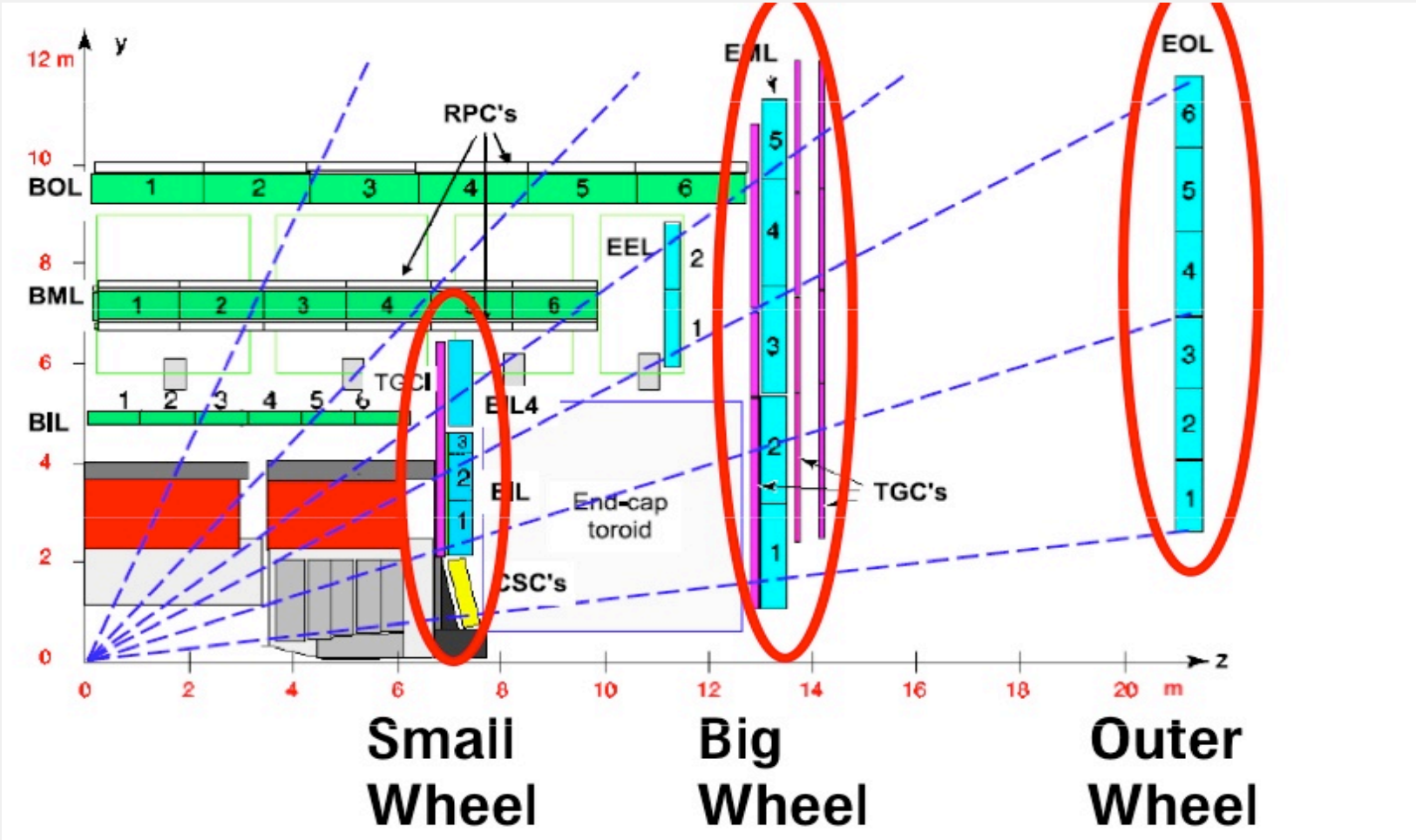
Endcap L1μ Trigger Hit Map



Endcap L1μ wire efficiency vs HV



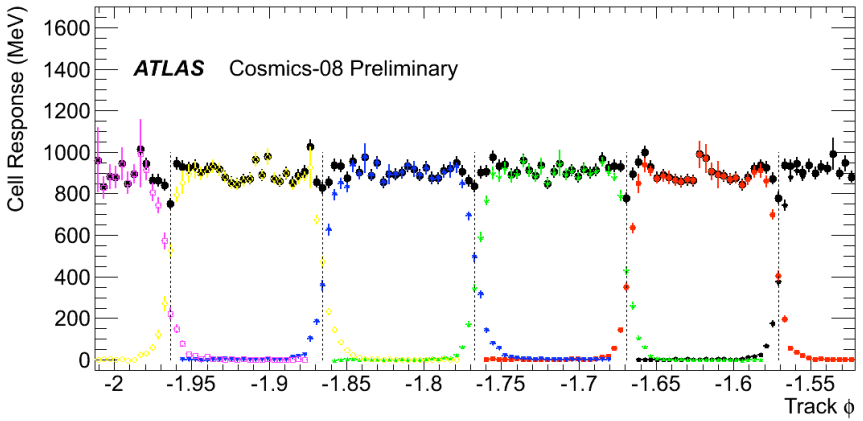
Muon EE Chambers



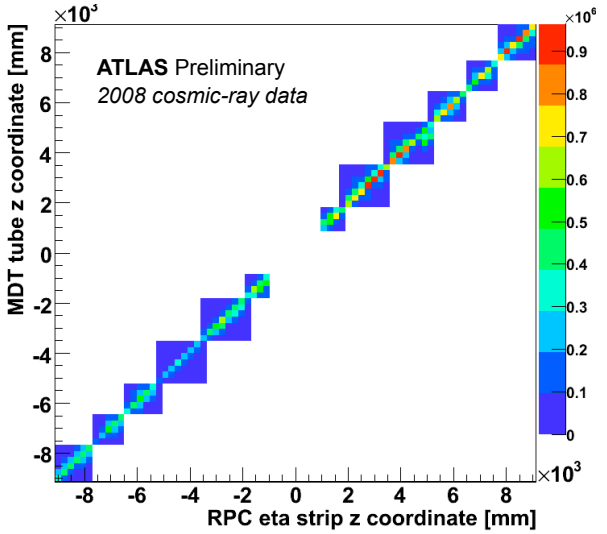
Used the shutdown to install precision chambers in the fwd region
EEL : 10 out of 30 chambers installed
Brought total number of MDT chambers to 1098!

Combined performance

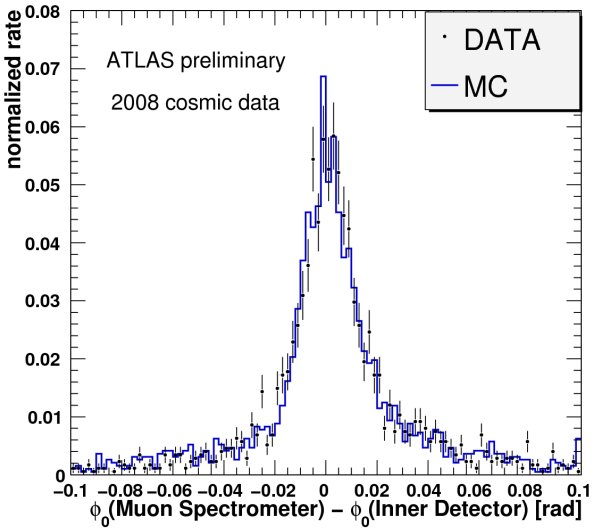
HCAL layer 1 response vs ID track position

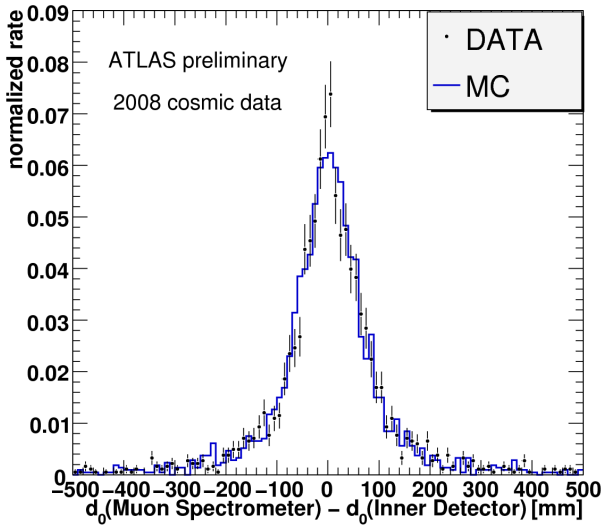


MDT tube vs RPC strip



Muon System vs Inner Detector Tracks

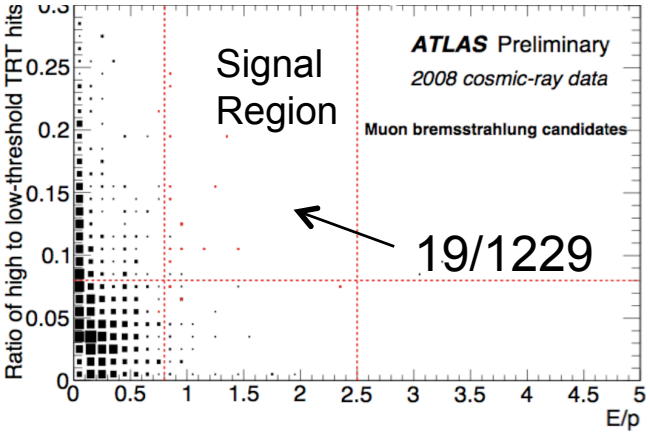




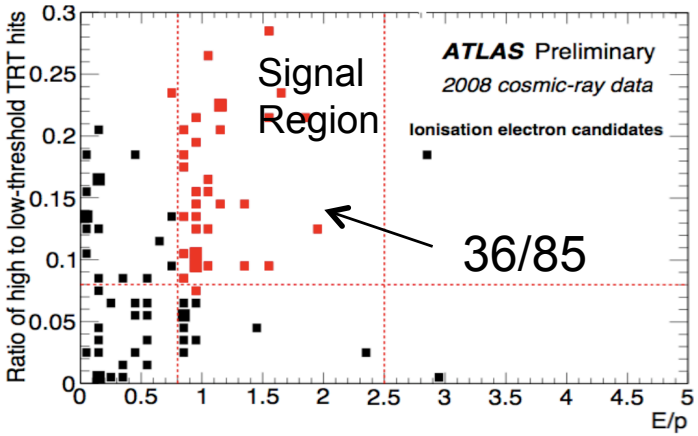
First Electrons in ATLAS

... or combining EM calorimeter and tracking ...

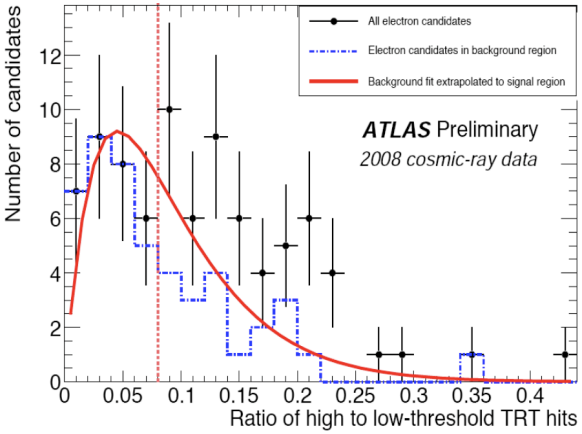
One track candidates
$\mu \rightarrow \mu\gamma$ background

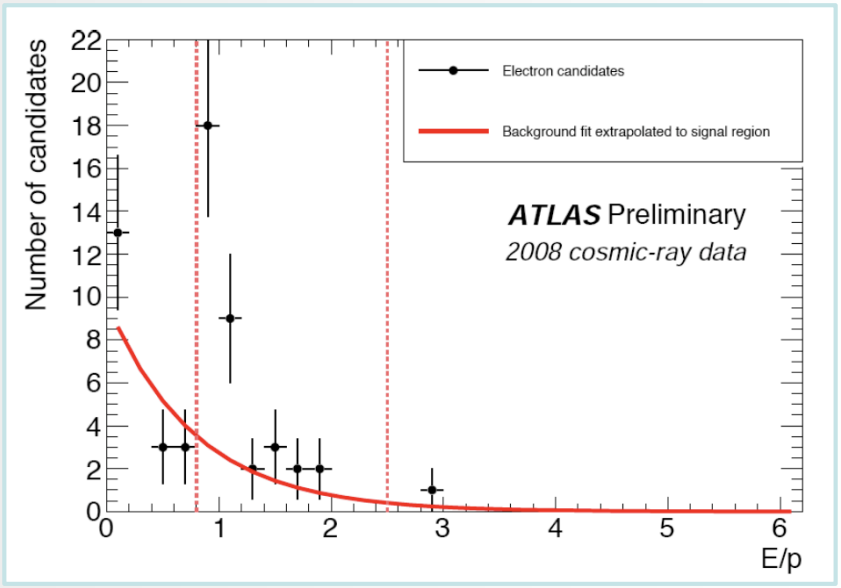


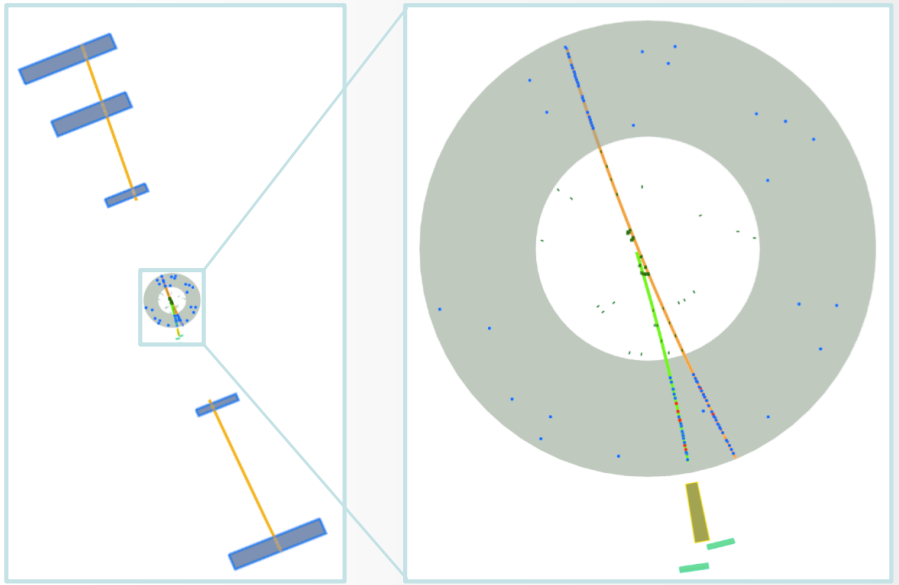
Two track candidates



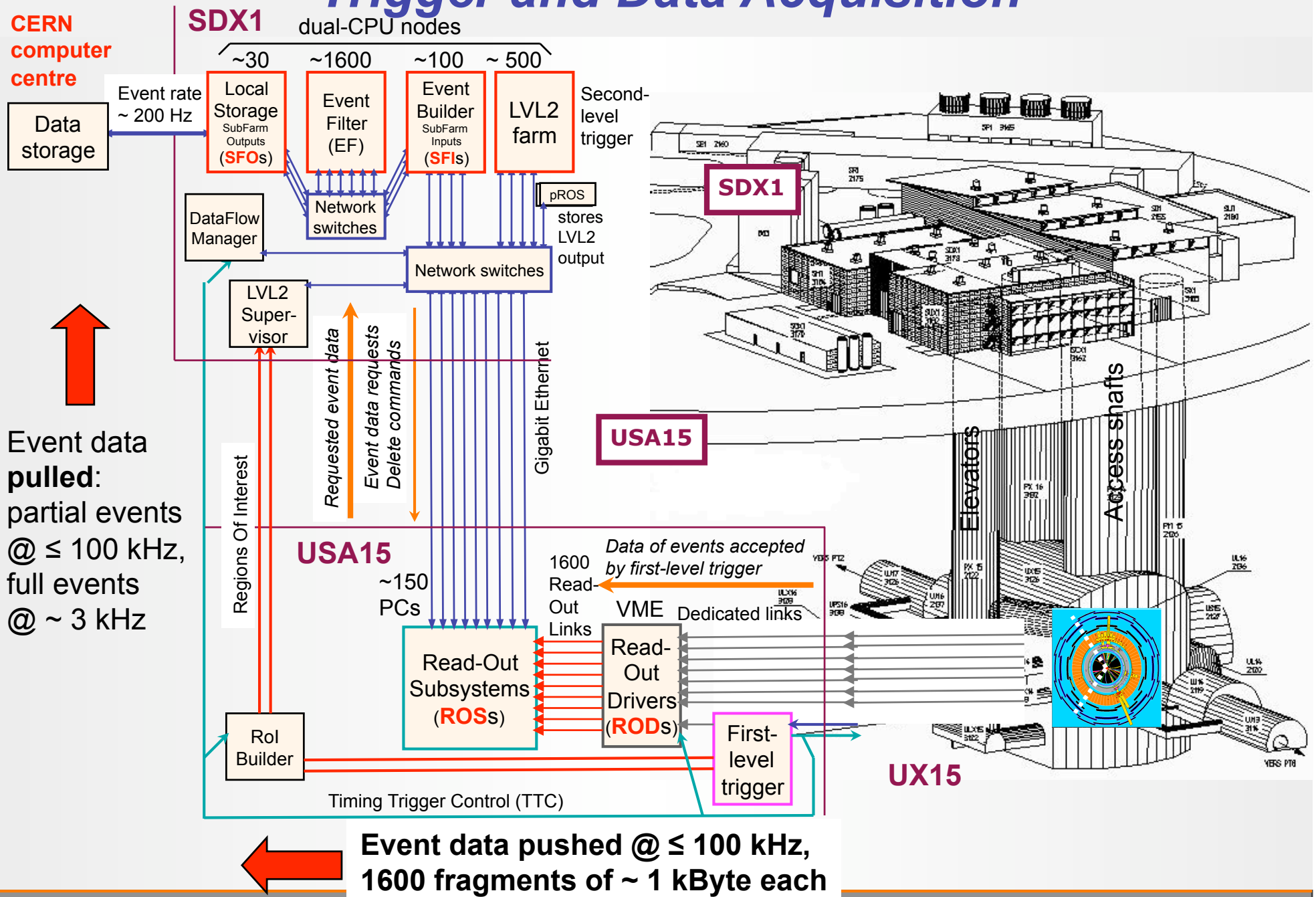
Background normalization



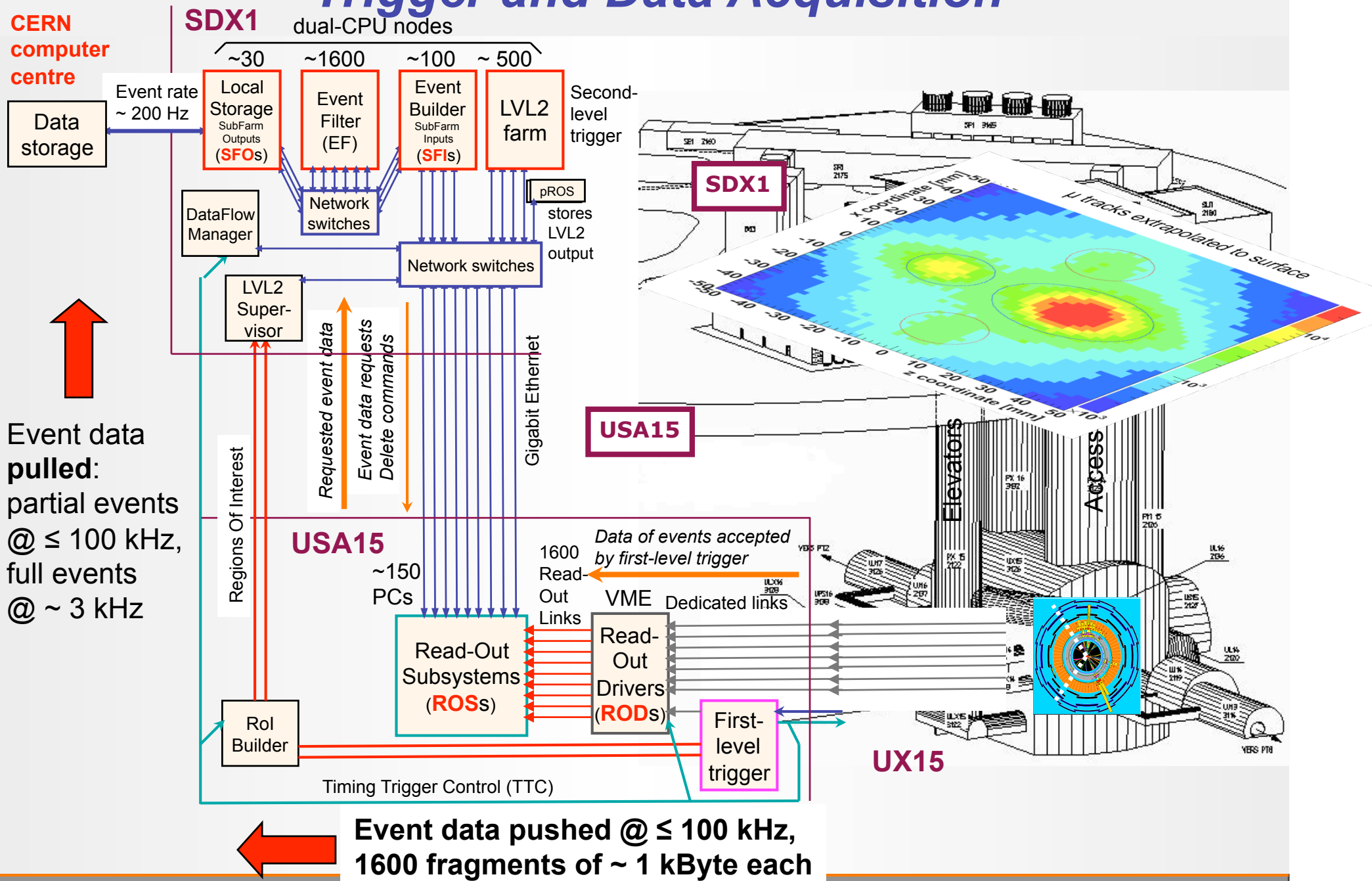




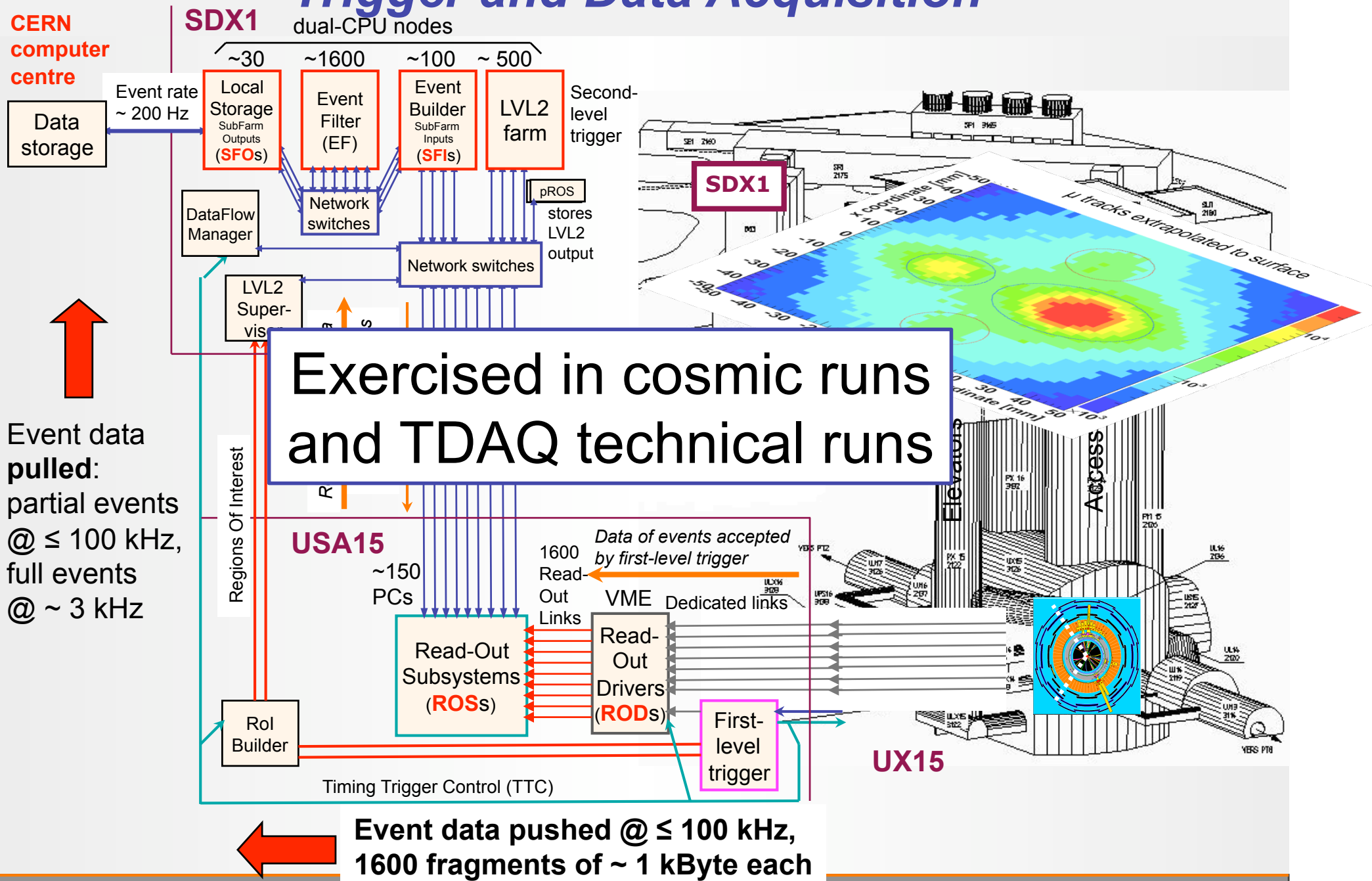
Trigger and Data Acquisition



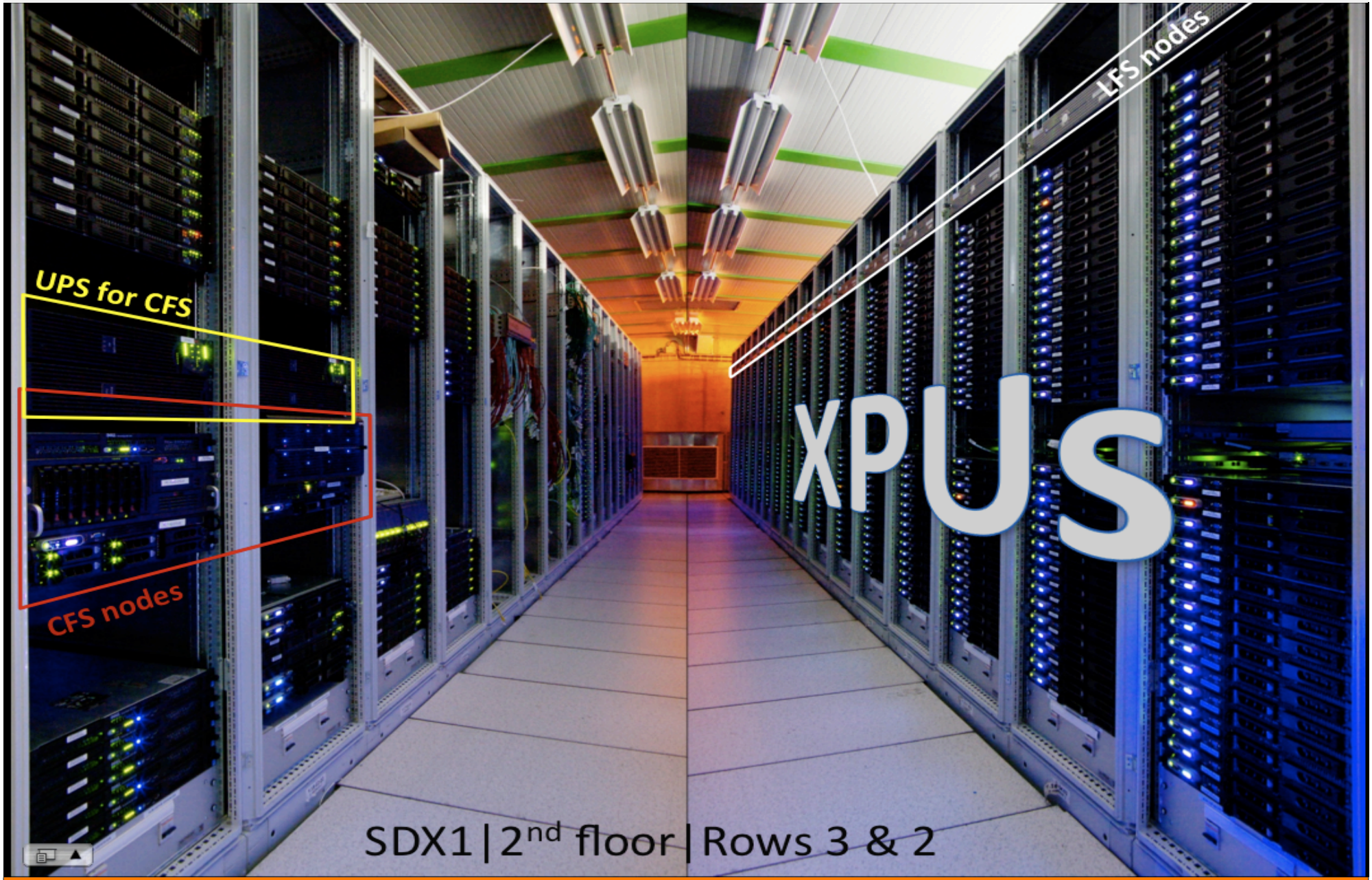
Trigger and Data Acquisition



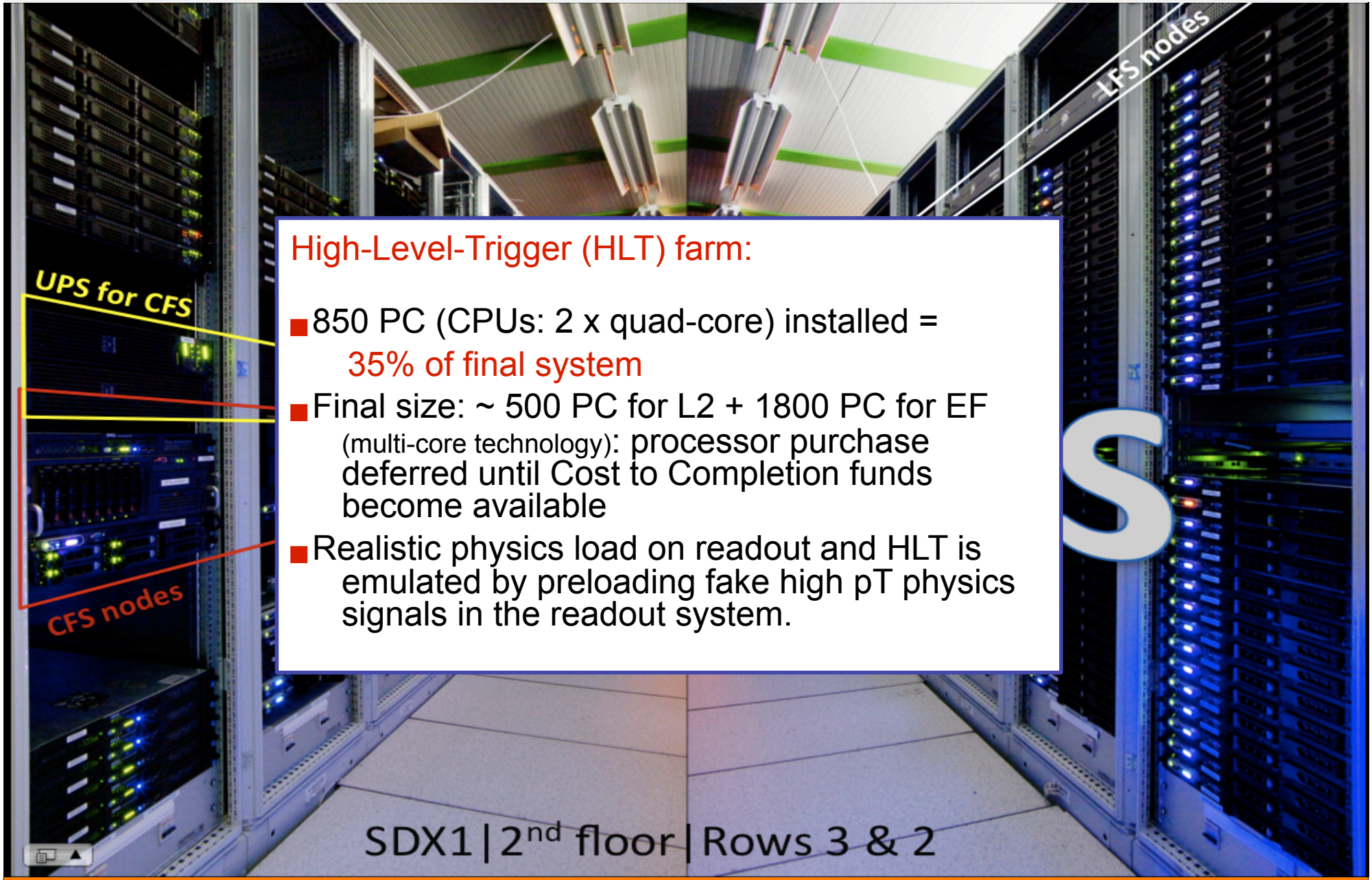
Trigger and Data Acquisition



High Level Trigger Farm



High Level Trigger Farm



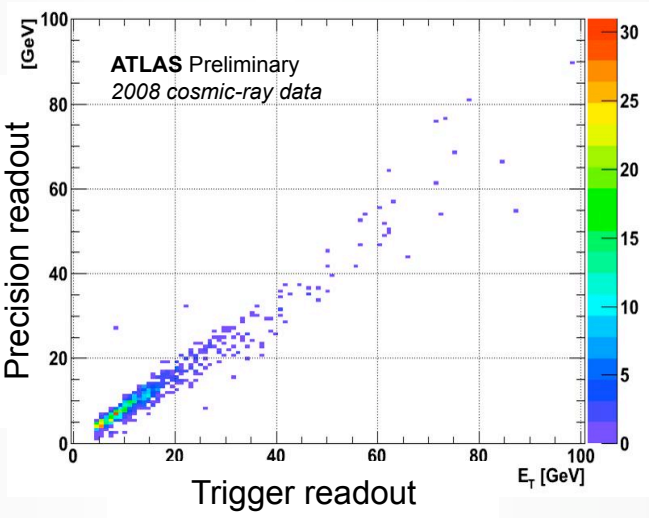
High-Level-Trigger (HLT) farm:

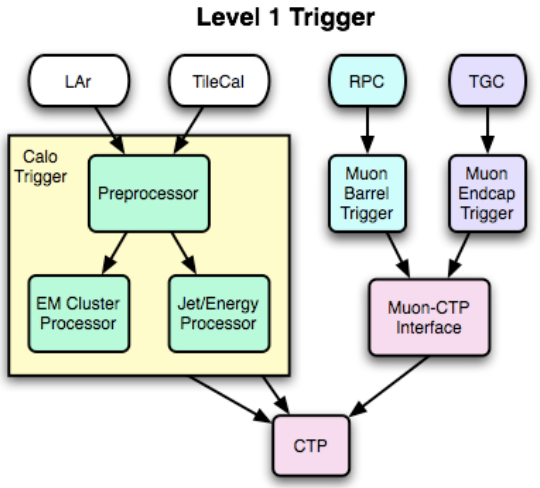
- 850 PC (CPUs: 2 x quad-core) installed = 35% of final system
- Final size: ~ 500 PC for L2 + 1800 PC for EF (multi-core technology): processor purchase deferred until Cost to Completion funds become available
- Realistic physics load on readout and HLT is emulated by preloading fake high pT physics signals in the readout system.

Trigger & Cosmics

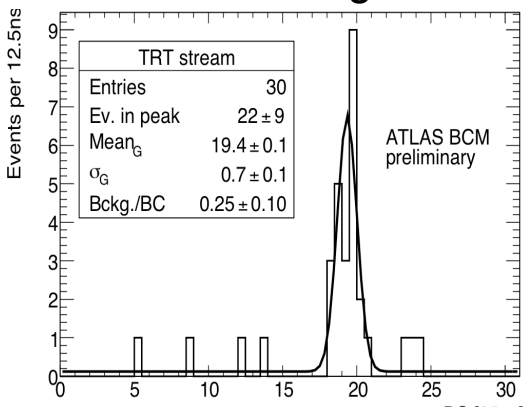
Sources of L1 triggers in cosmics data-taking

- ✧ EM and H Calorimeters
- ✧ Barrel and End cap muon chambers
- ✧ MinBias scintillators
- ✧ Zero Degree Calorimeter
- ✧ LUminosity Cerenkov Detector
- ✧ Beam Condition Monitors
- ✧ Transition radiation tracker
- ✧ Randoms **for high L1 rate > 50kHz**
- ✧ Calibration triggers





BCM timing



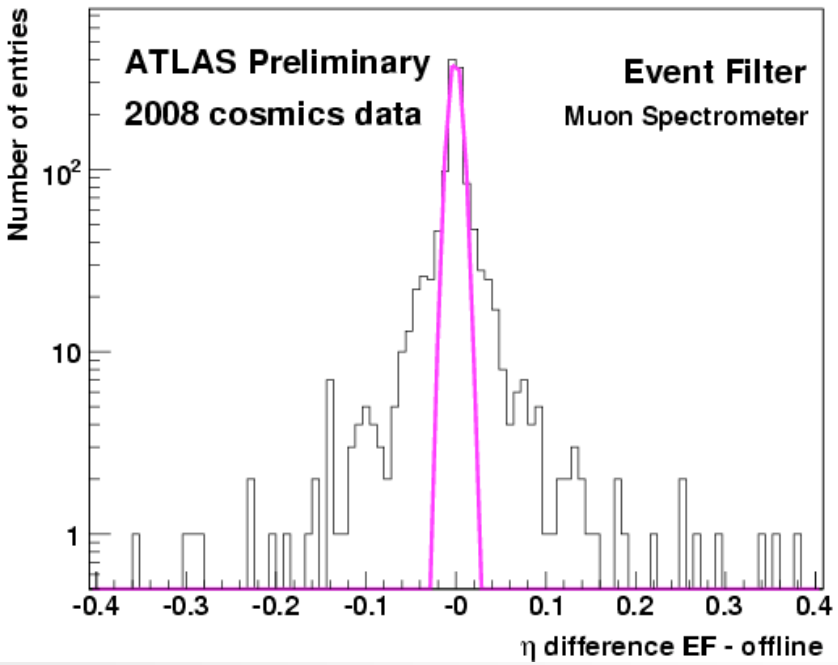
Timing in ATLAS smallest detector!
Beam Condition Monitor 12 x 1 cm^2

Example of High Level Trigger menu excercised in cosmic runs

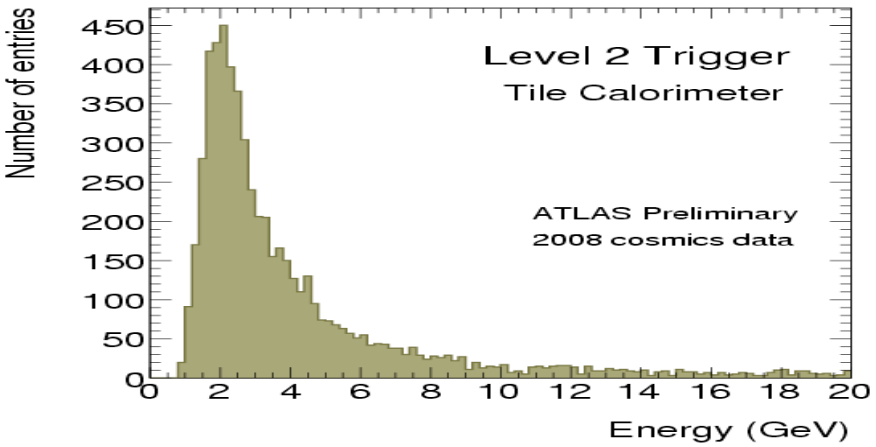
High Level Trigger chains

High Level Trigger

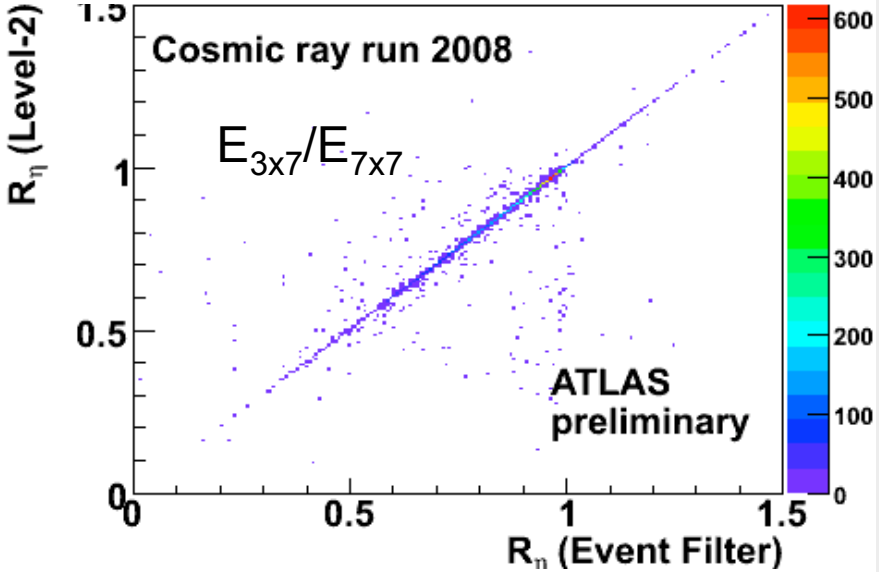
μ system track: η offline vs event filter



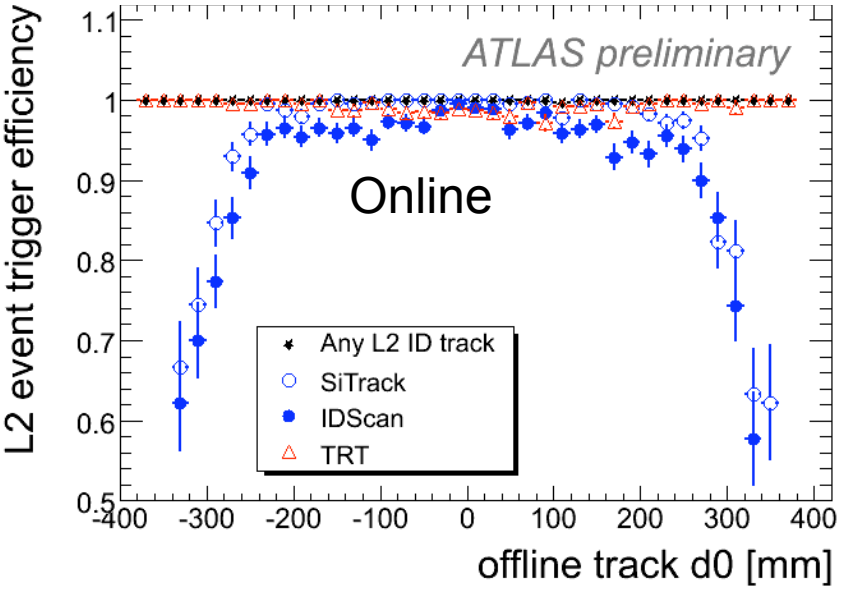
L2 MuonID with calorimeter



Shower shape at L2 trigger vs event filter



Tracking efficiency at L2 trigger



DAQ, Trigger and Operation

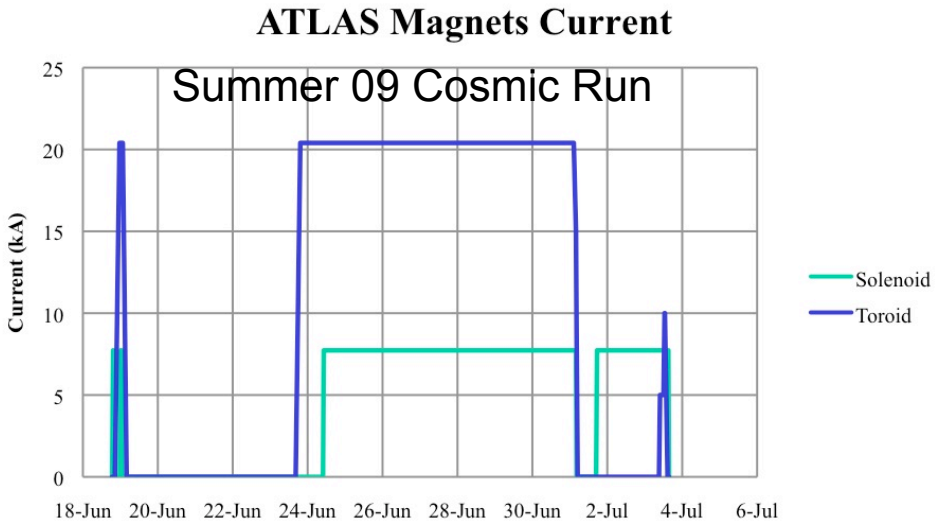
DAQ exercised with all systems on a regular basis, with event payloads up to 10x nominal.

Frequent runs with L1 trigger rates > 50kHz

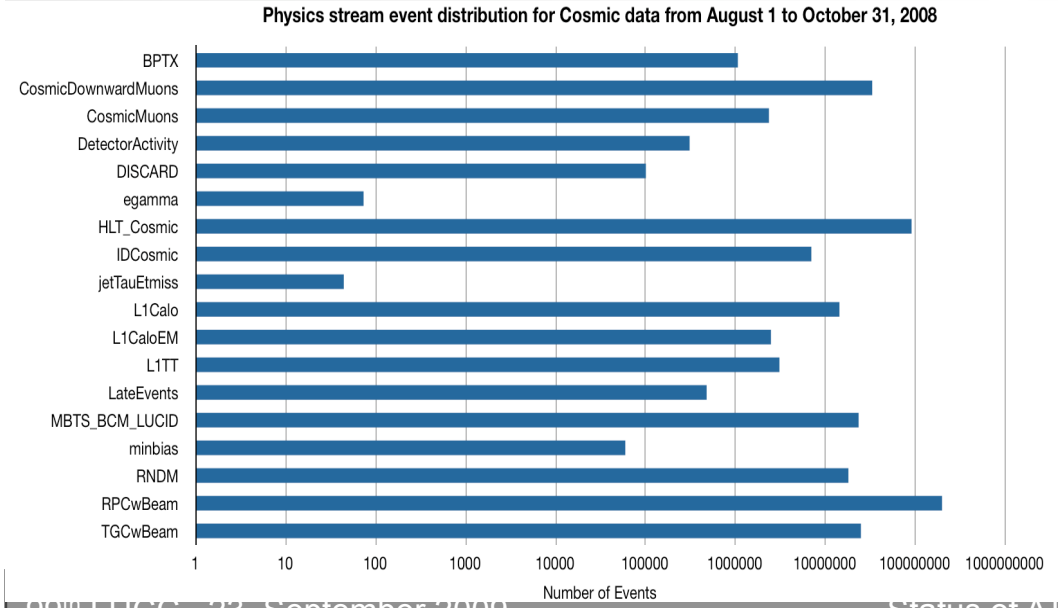
~100M cosmic muons recorded in June 2009 with full ATLAS (+ > 300 M in 2008)

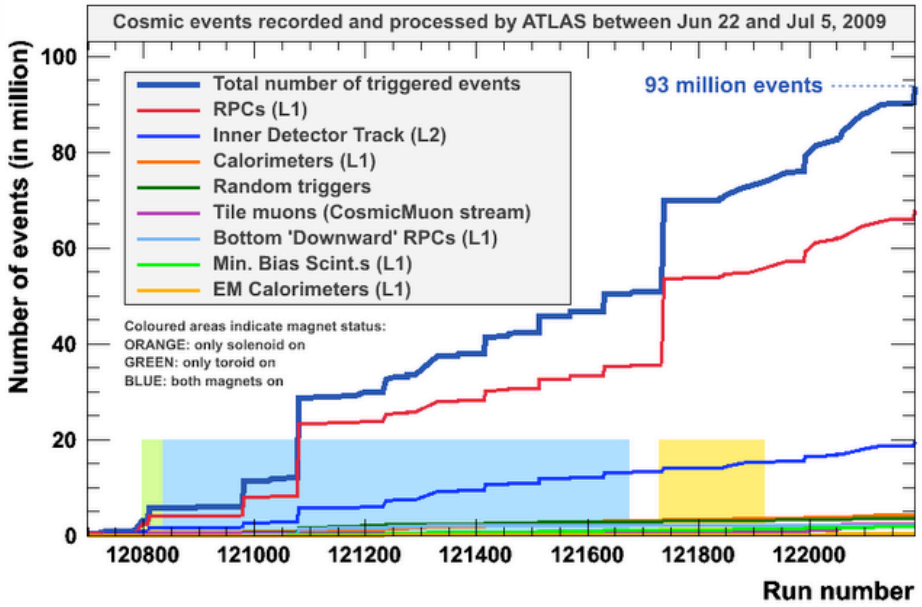
Emulate fake LHC fills, up to 80% data taking efficiency for 6/14hour LHC fill pattern.

Global cosmics restart on October 12th and run continuously through first beam.



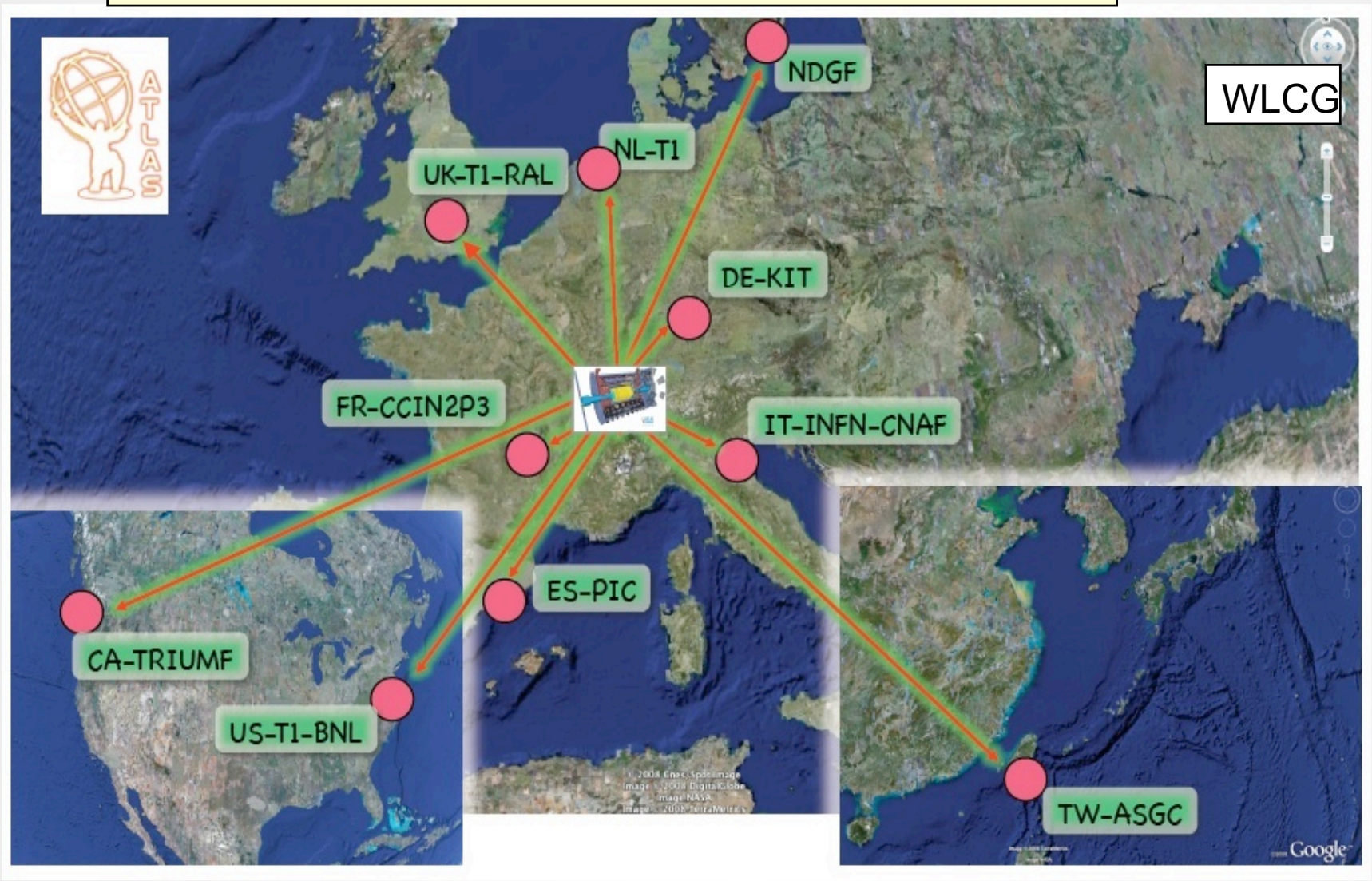
Follow predefined data-taking program for commissioning, alignment, timing...





Computing Infrastructure and Operation

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



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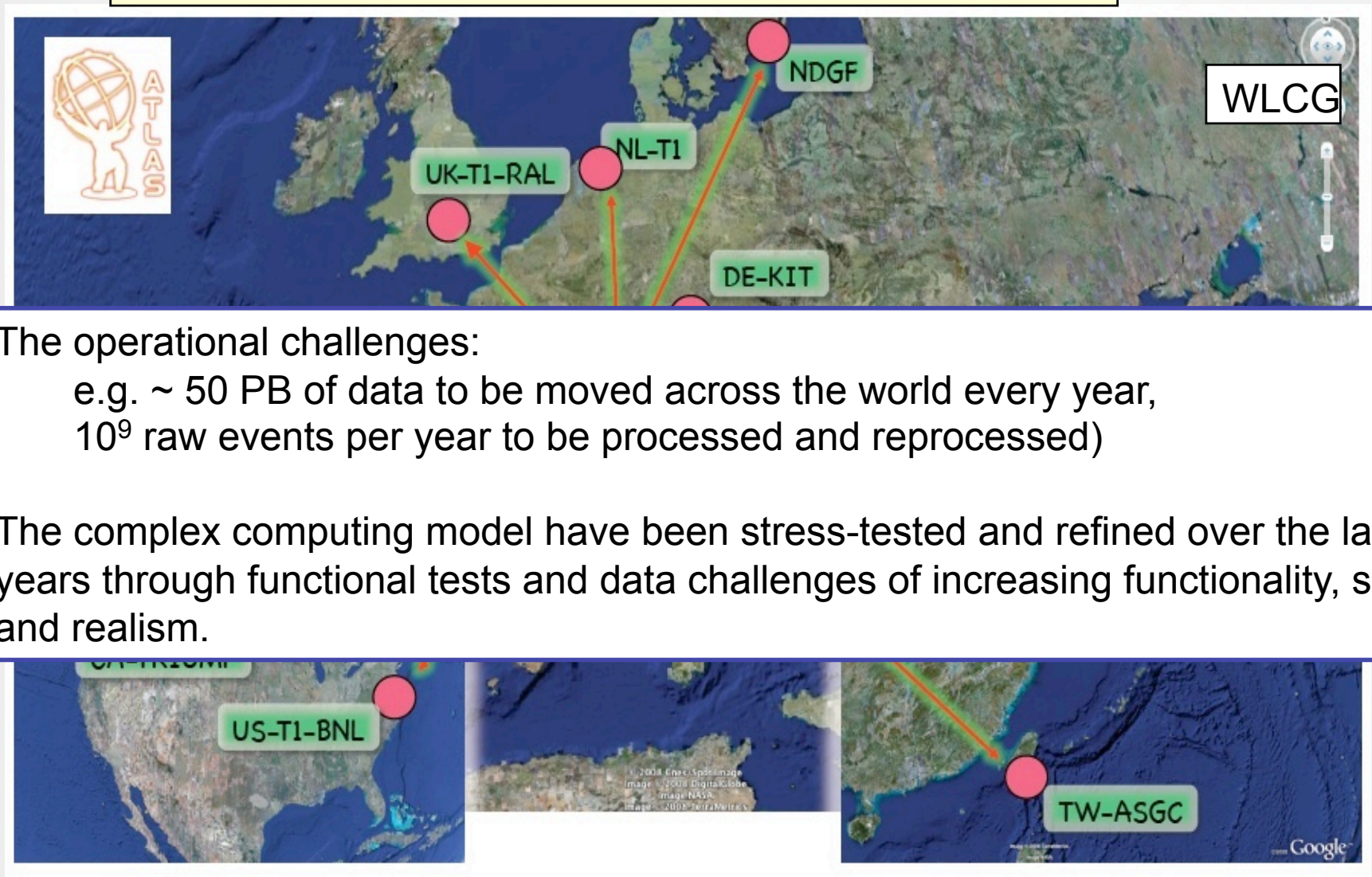


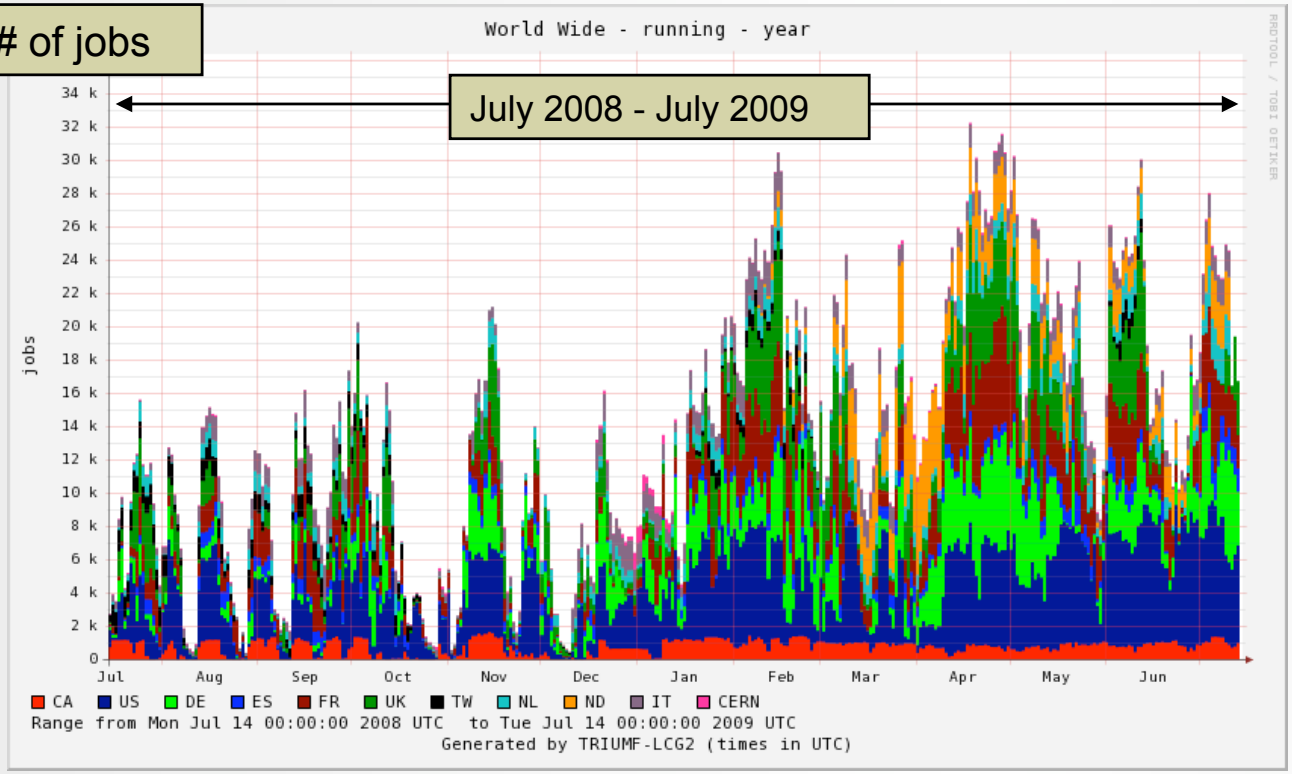
The operational challenges:

e.g. ~ 50 PB of data to be moved across the world every year,
10^9 raw events per year to be processed and reprocessed)

The complex computing model have been stress-tested and refined over the last years through functional tests and data challenges of increasing functionality, size and realism.

ATLAS

# of jobs

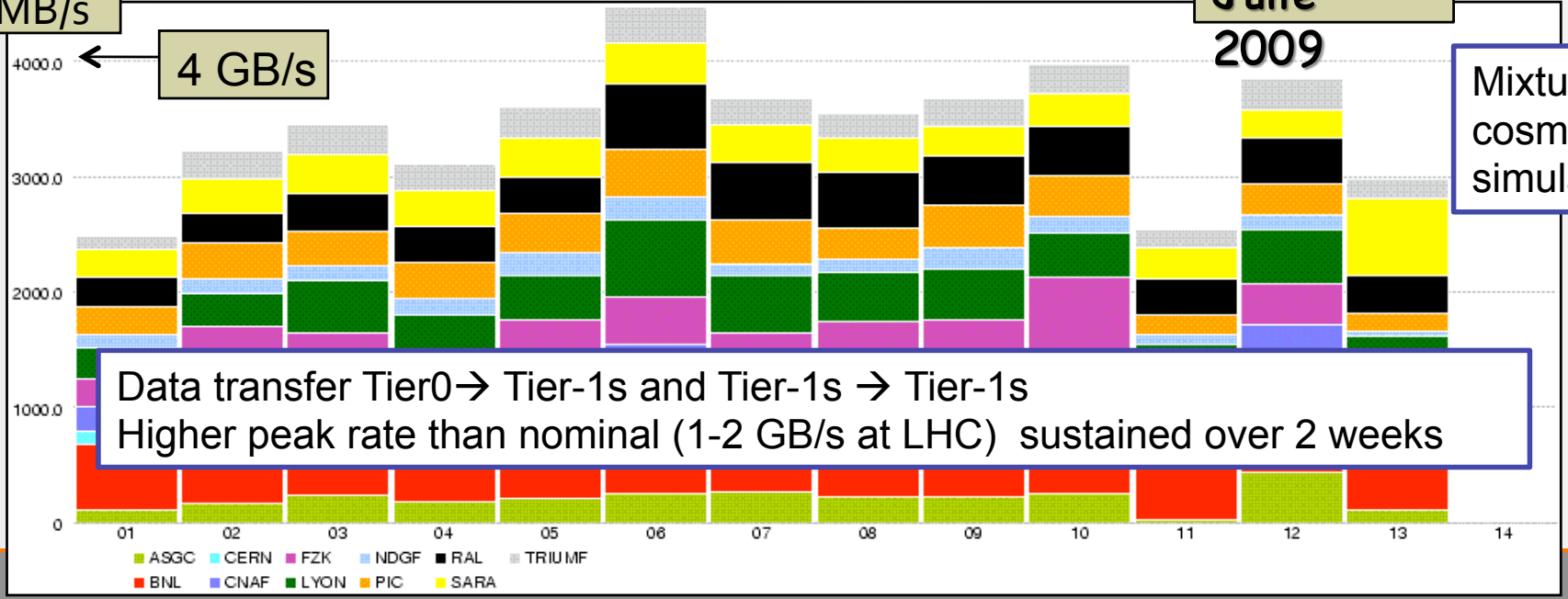


Production of MC samples for simulation studies.
>30 kjobs/day achieved

MB/s

4 GB/s

June 2009



Mixture of cosmics and simulated data

Data transfer Tier0→ Tier-1s and Tier-1s → Tier-1s
Higher peak rate than nominal (1-2 GB/s at LHC) sustained over 2 weeks

Looking towards first physics

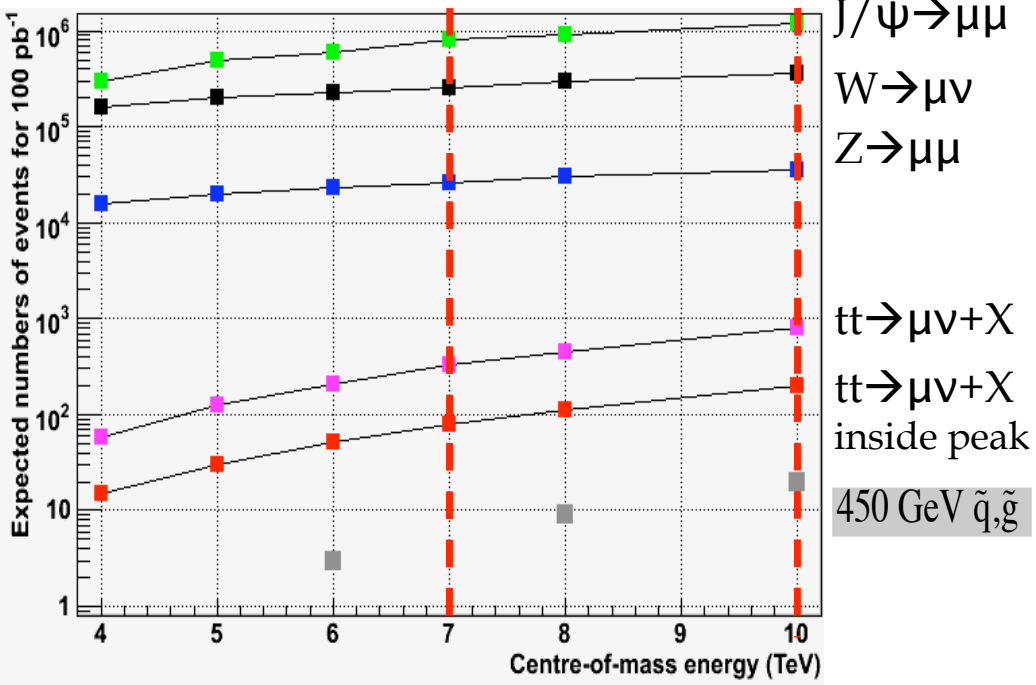
Channels (examples …)	Expected events in ATLAS after cuts $\sqrt{s}$= 10 TeV, 100 pb^{-1}
$J/\psi \rightarrow \mu\mu$	~ 10^6
$\Upsilon \rightarrow \mu\mu$	~ $5\ 10^4$
$W \rightarrow \mu\nu$	~ $3\ 10^5$
$Z \rightarrow \mu\mu$	~ $3\ 10^4$
$t\bar{t} \rightarrow W\,b\,W\,b \rightarrow \mu\nu + X$	~ 350
QCD jets $p_T > 1$ TeV	~ 500
$\tilde{g},\tilde{q}$ m ~ 1 TeV	~ 5

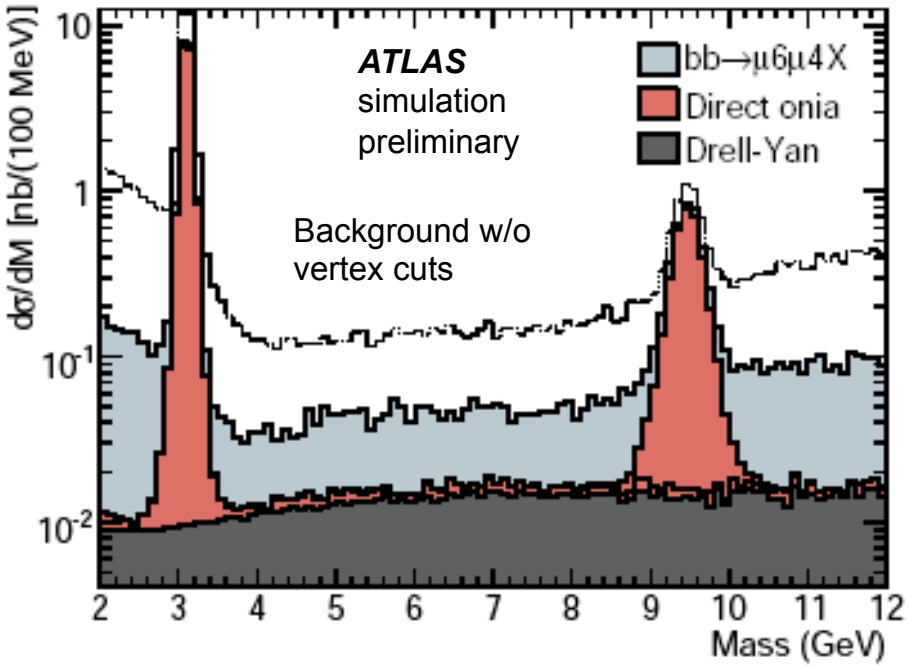
1) Calibration with well-known processes
e.g. - Z → ee, μμ tracker, ECAL, system, etc.
- tt → blν bjj jet scale from W → jj, b-tag,...

2) Rediscover & measure Standard Model
W, Z, tt, QCD jets …

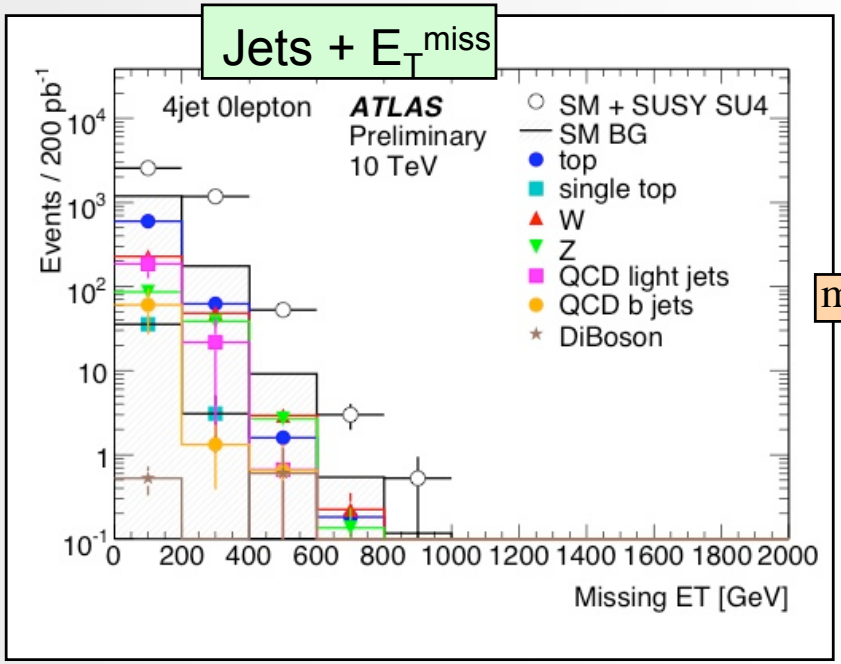
3) Early discoveries ?
Potentially accessible: SUSY, Z', …. surprises ?

Expected number of events after cuts 100 pb^{-1}





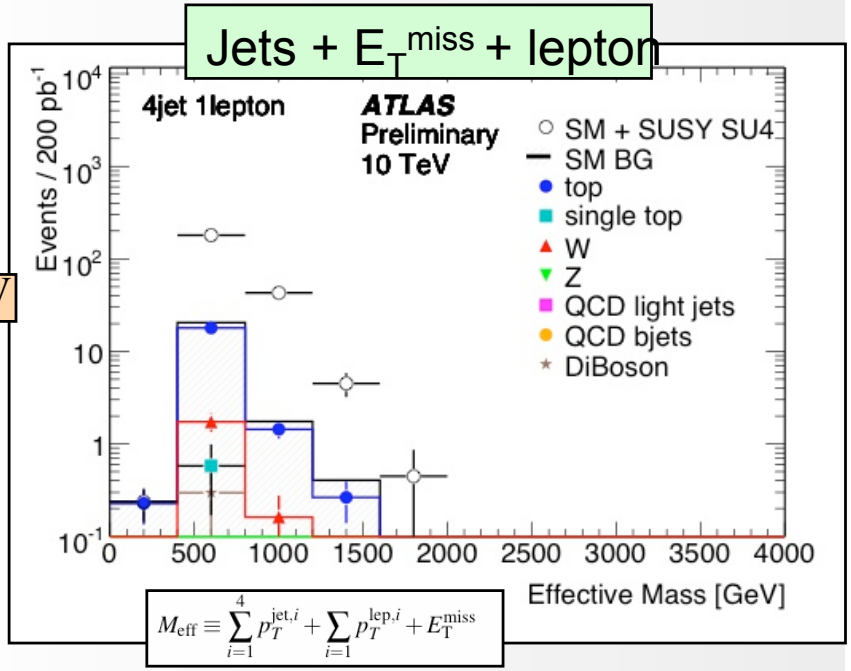
Jets + E_T^{miss}

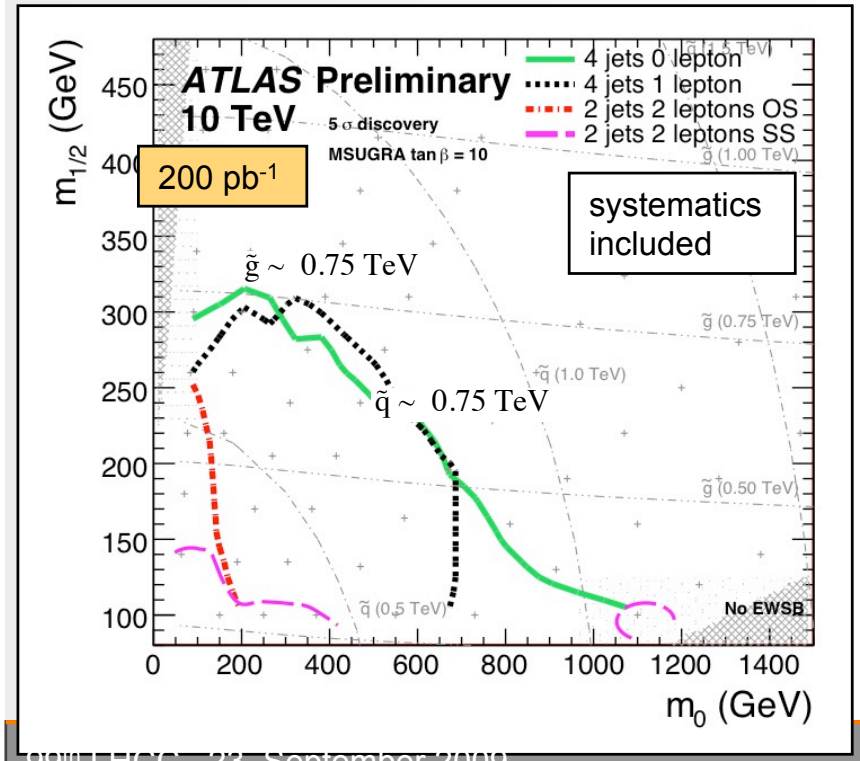


$\sqrt{s}$ = 10 TeV
200 pb^{-1}

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

Jets + E_T^{miss} + lepton

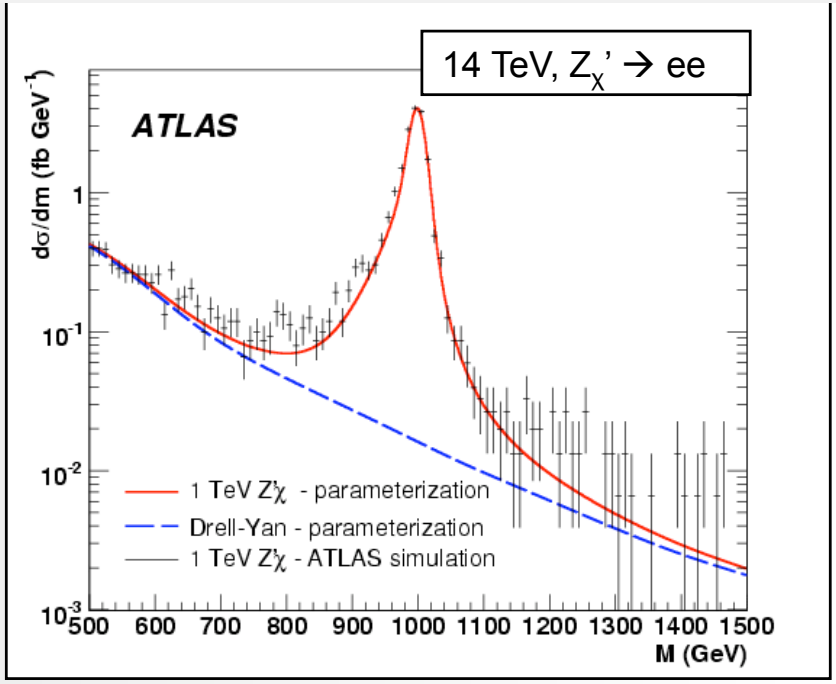




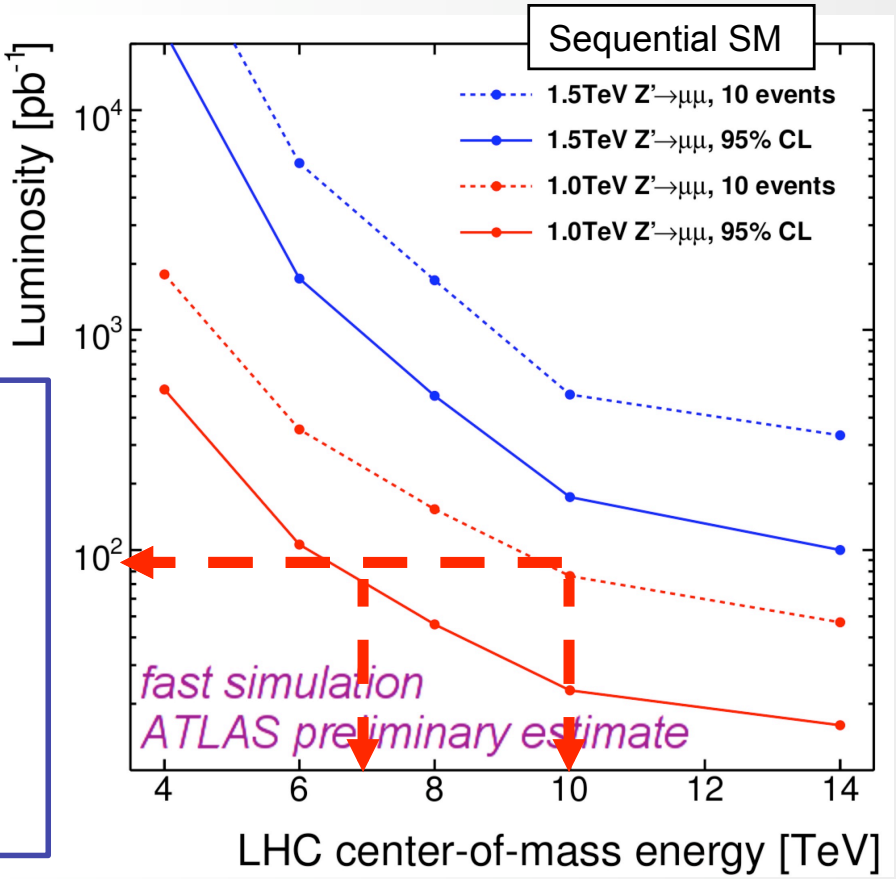
Jets + E_T^{miss} channel: highest reach
1-lepton channel: more robust against bkg uncertainties

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

Z' → ll, Mass ~ 1 TeV



Is this a manifestation of new forces or new dimensions ?
From angular distribution of leptons can disentangle Z' (spin=1) from G (spin=2).
Requires more data …



- Signal is (narrow) mass peak above small and smooth SM background
- Does not require ultimate EM calorimeter performance
- Discovery beyond Tevatron exclusion reach (m ~ 1 TeV) possible with 200 pb^{-1} and √s ≥ 7 TeV (100 pb^{-1} at 10 TeV)
  → perhaps sometime in 2010 ?

Conclusions

- ATLAS experiment in very good shape, fraction of problematic channels at the few permil level in most cases.
- All components of the experiment, detector, trigger, data acquisition, timing, calibration, alignment, data quality, software, have been heavily exercised with cosmics data and/or simulations, and are ready to go.
- Substanstial operational experience gained with the ATLAS detector, trigger and DAQ, using cosmics.
- Large cosmic datasets allowed to extensively test ATLAS software, computing model, and data distribution scheme to the grid.
- Analysis of cosmic data has been extremely useful to bring ATLAS performance to a level where it is already good enough for first physics.

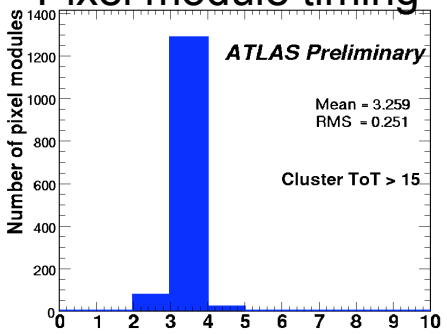
Backup Slides

Detector Timing

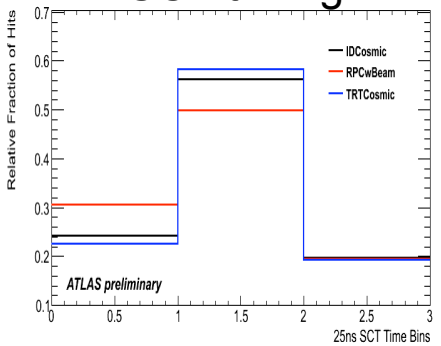
ATLAS takes 40 million 'pictures per second'

Upon a positive trigger decision, need to select & send out the right 'picture'

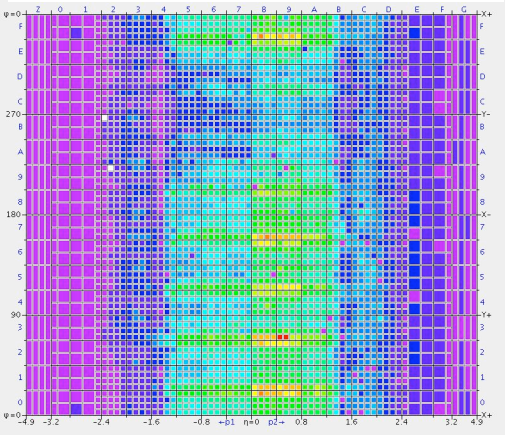
Pixel module timing



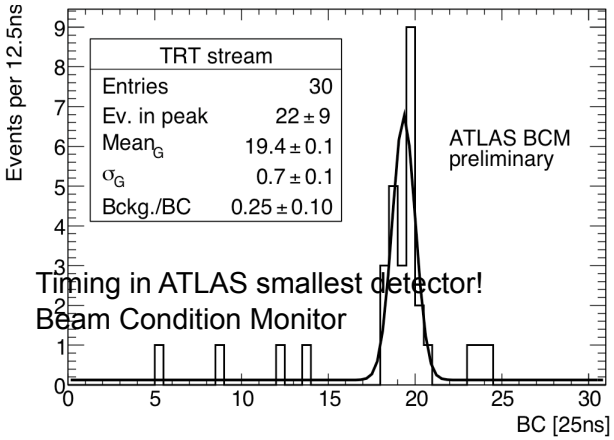
SCT timing



L1Calo timing / beam on collimators

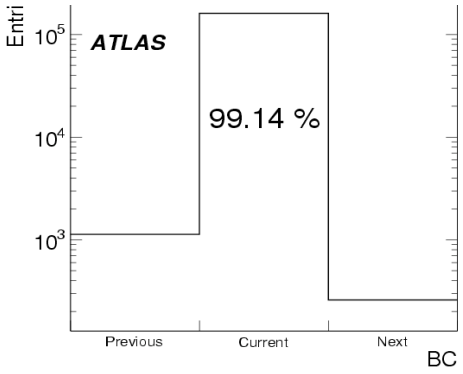


BCM timing

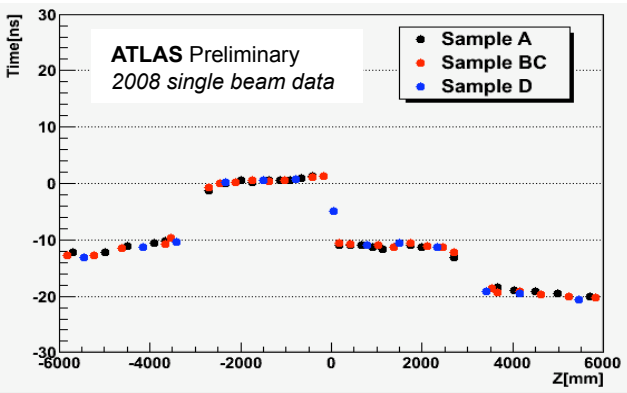


Timing in ATLAS smallest detector!
Beam Condition Monitor

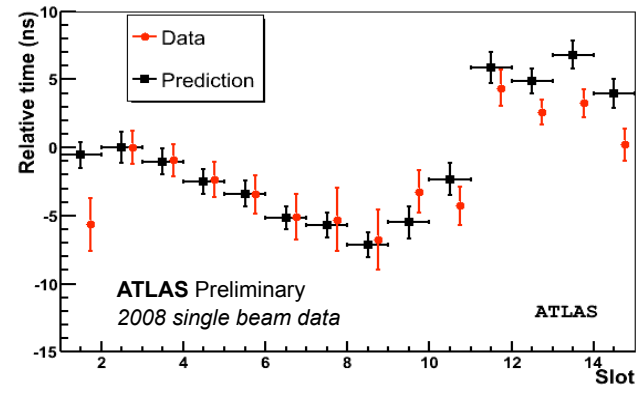
Timing in TGC, TGC trigger

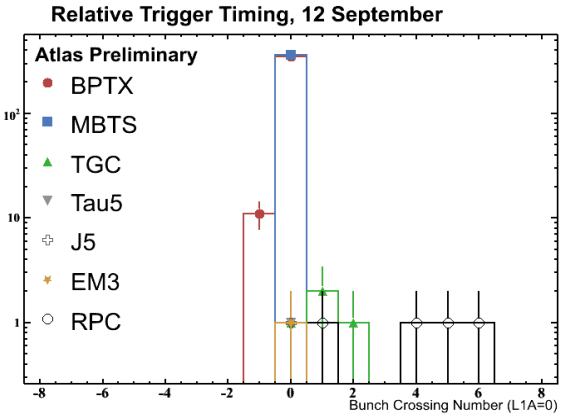


Tile (HCAL) timing / single beam

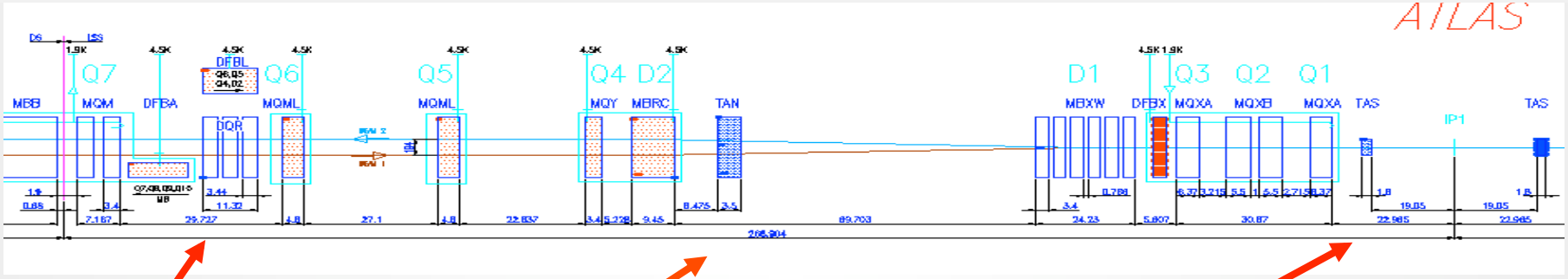


ECAL timing / single beam

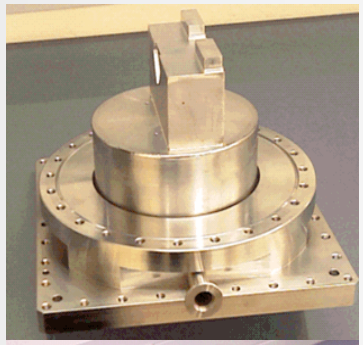


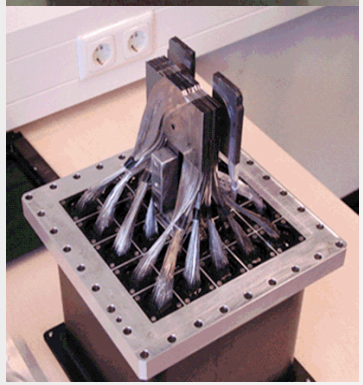


Forward Detectors



ALFA at 240 m

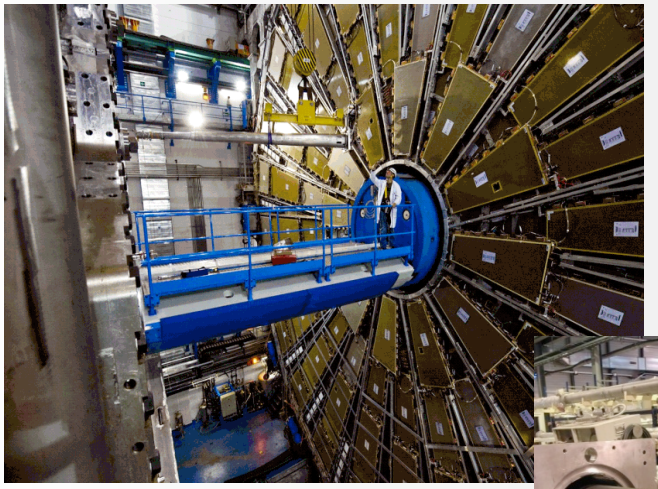


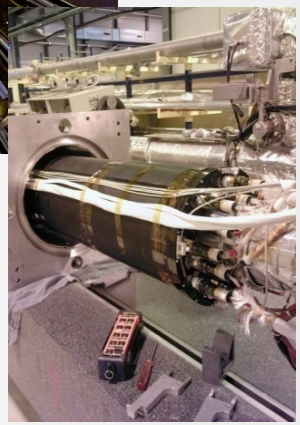


ZDC at 140 m

Zero Degree Calorimeter

LUCID at 17 m



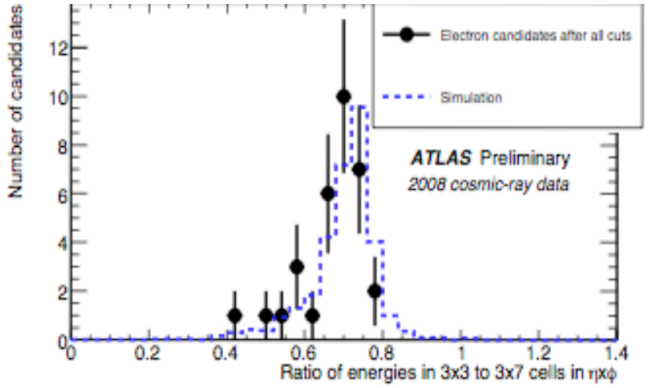


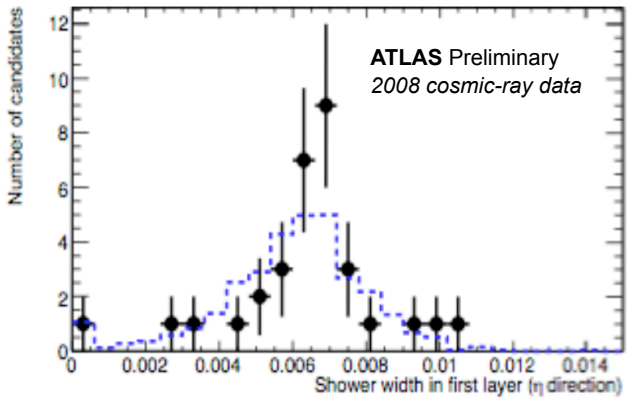
Luminosity Cerenkov Integrating Detector

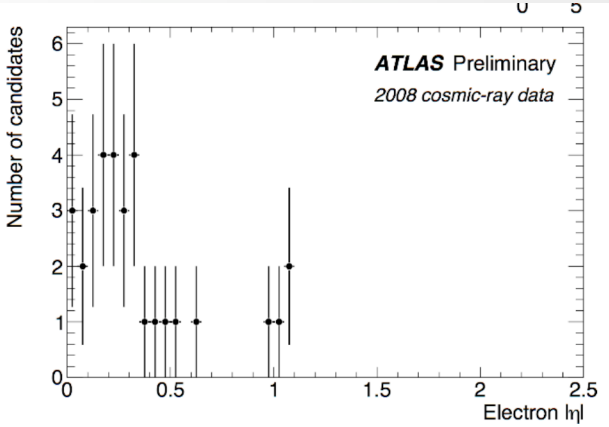
Absolute Luminosity for ATLAS

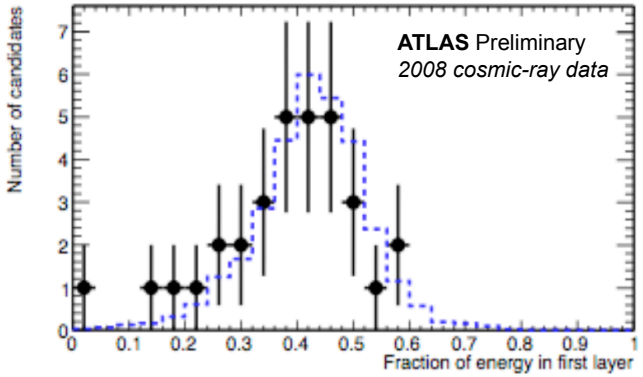
Operated reliably in ATLAS both in readout and as source of L1 triggers

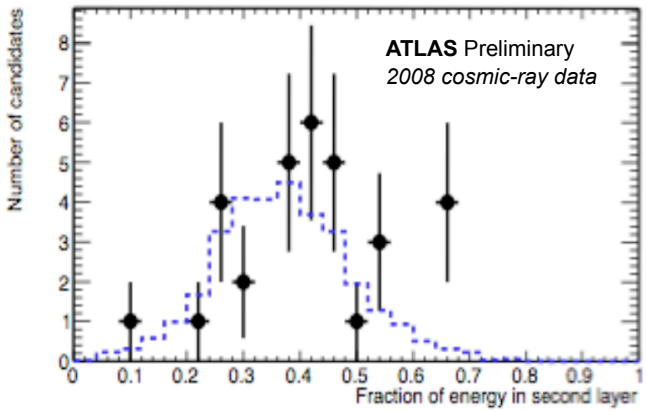
First Electrons in ATLAS

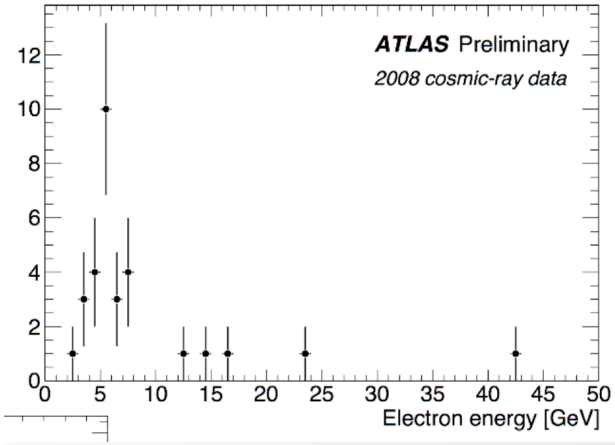




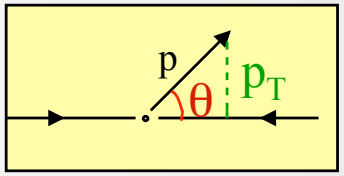


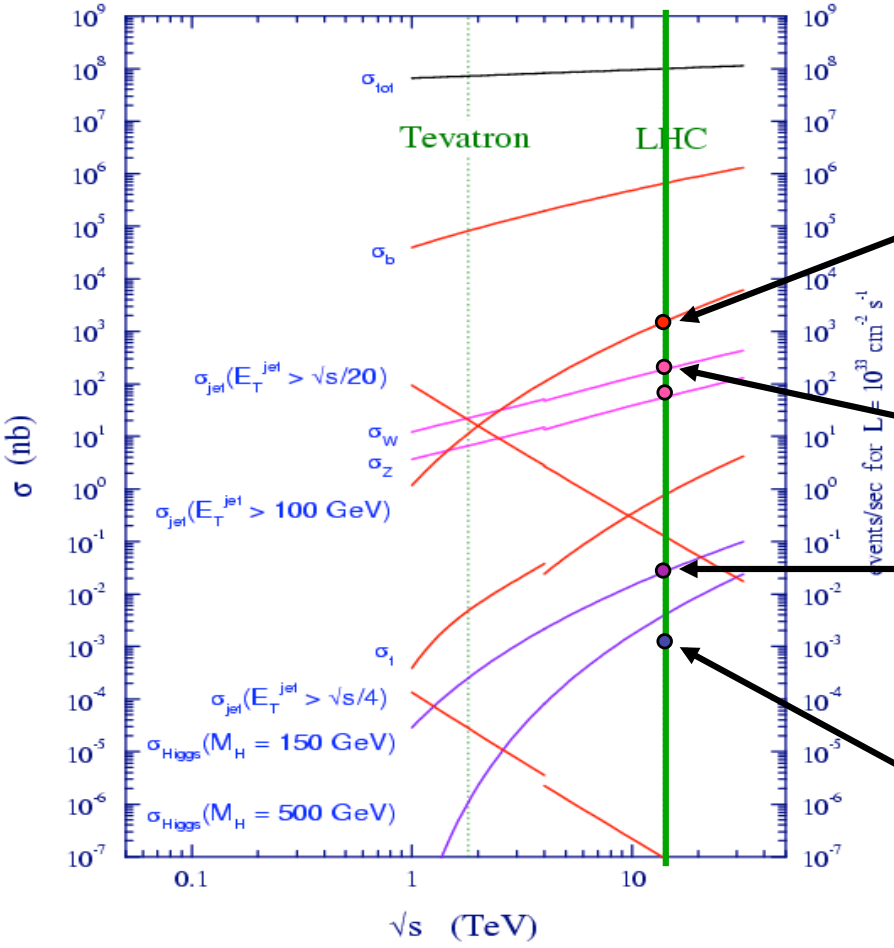




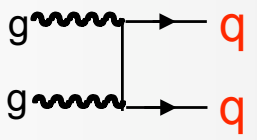


❶ Huge (QCD) backgrounds (consequence of high energy …)

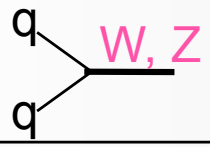




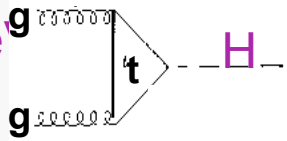
High-p_T QCD jets



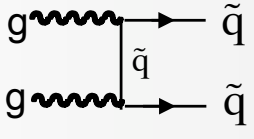
W, Z



Higgs m_H=150 GeV



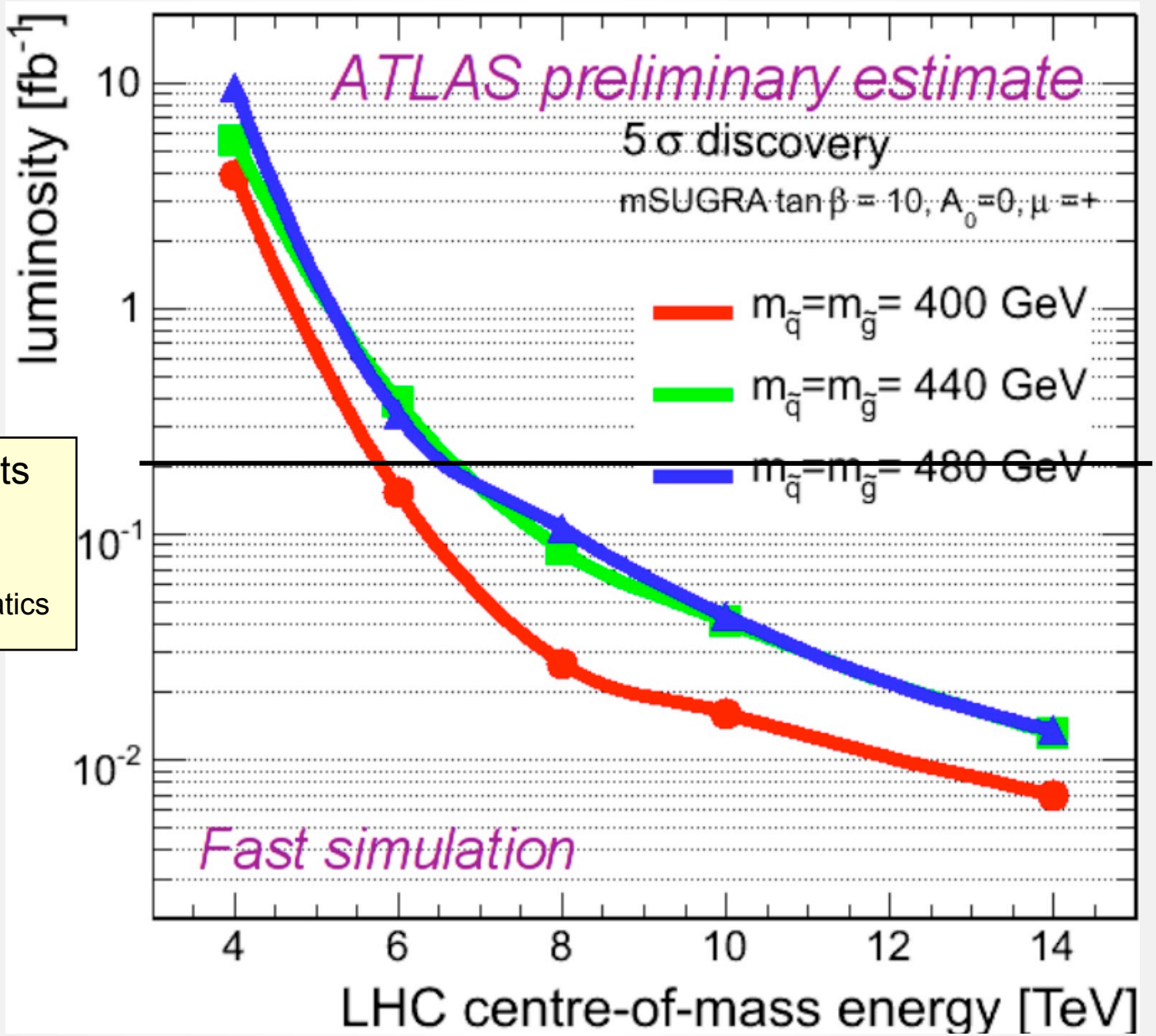
$\tilde{q}$,$\tilde{g}$ pairs, m ~ 1 TeV



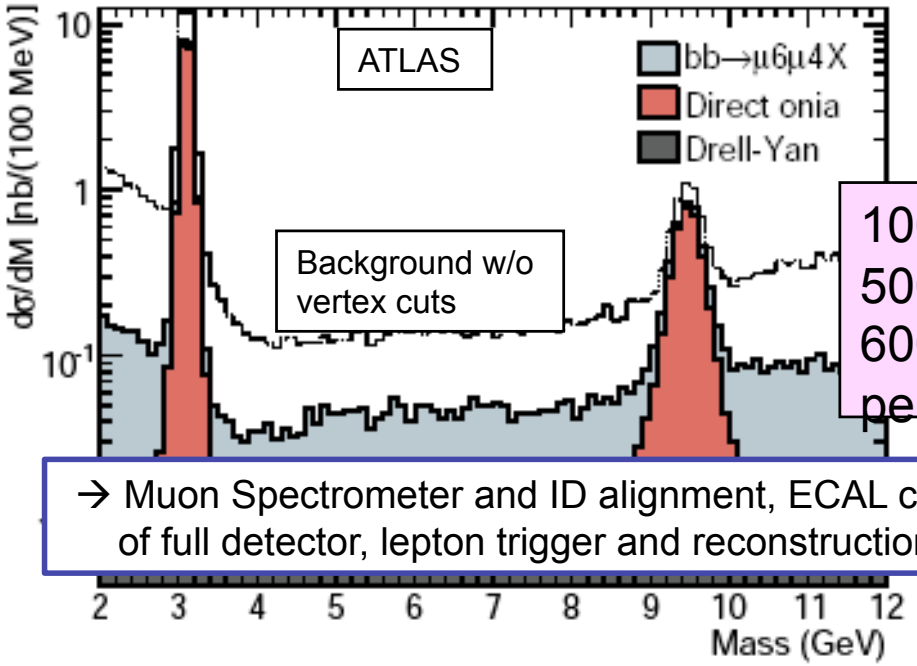
- No hope to observe light objects (W, Z, H ?) in fully-hadronic final states → rely on l, γ
- Mass resolutions of ~ 1% (10%) needed for l, γ (jets) to extract tiny signals from backgrounds, and excellent particle identification (e.g. e/jet separation)
- Signal (EW) /Background (QCD) for "light" objects larger at Tevatron than at LHC

Lepton + jets channel

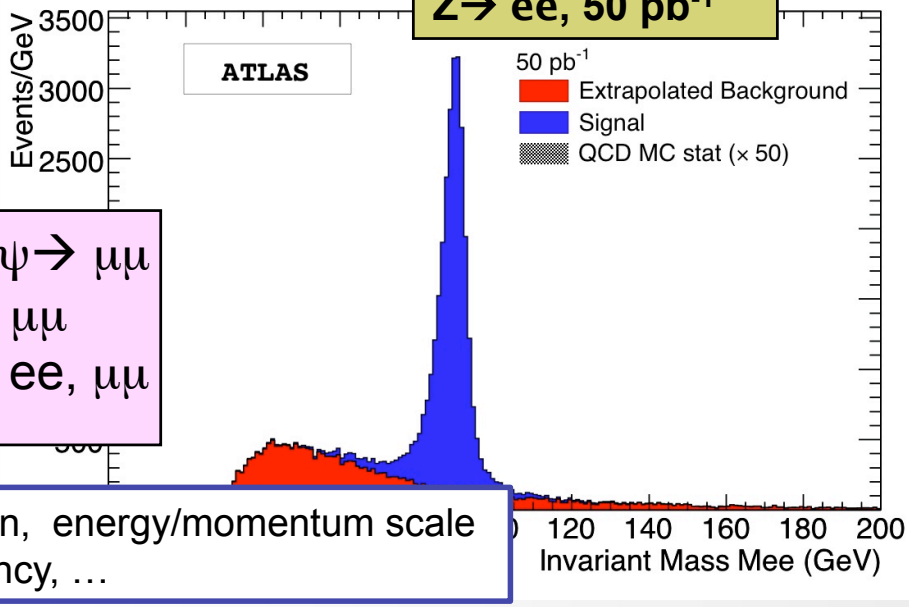
100% systematics included



SM "candles": J/ψ, Y, W, Z, top



10000 J/ψ→ μμ
500 Υ → μμ
600 Z → ee, μμ
per pb^{-1}



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

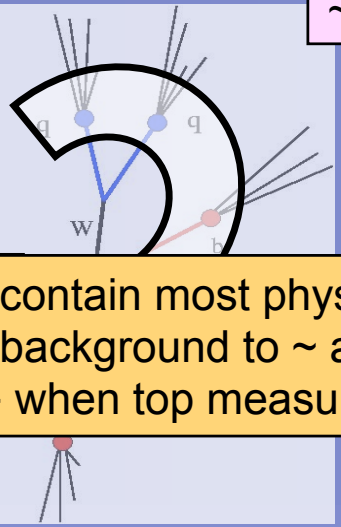
tt → bW bW → blν bjj

3 jets p_T> 40 GeV

1 jets p_T> 20 GeV

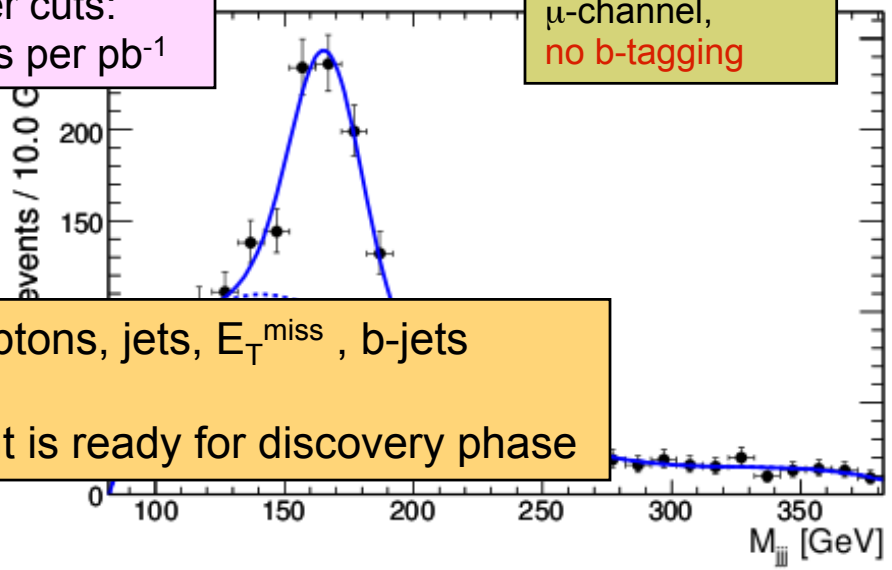
1 lepton p_T> 20 Ge

E_T^{miss} > 20 GeV



√s = 10 TeV, after cuts:
~ 15 l=e,μ events per pb^{-1}

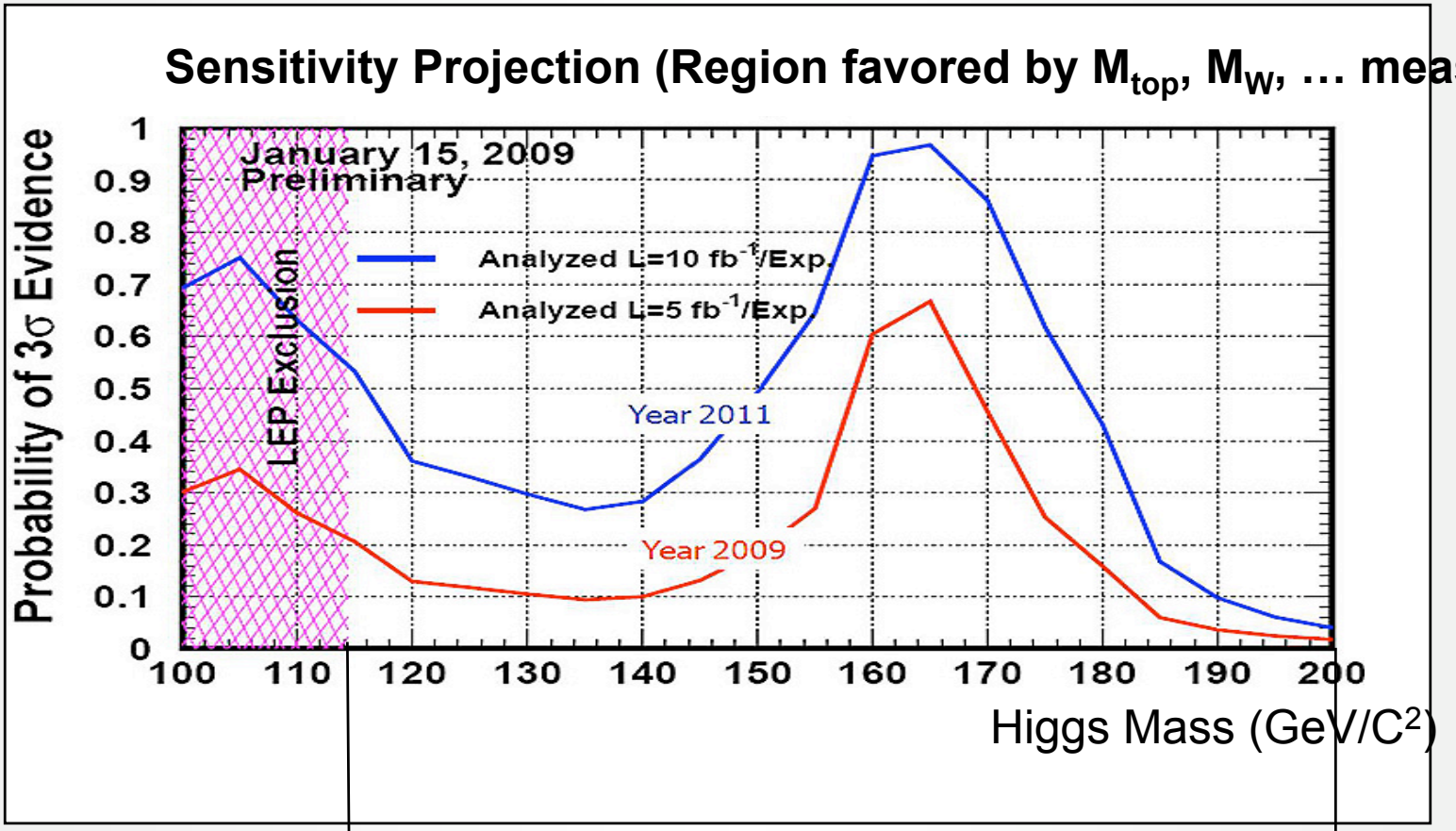
14 TeV, 100 pb^{-1}
μ-channel,
no b-tagging

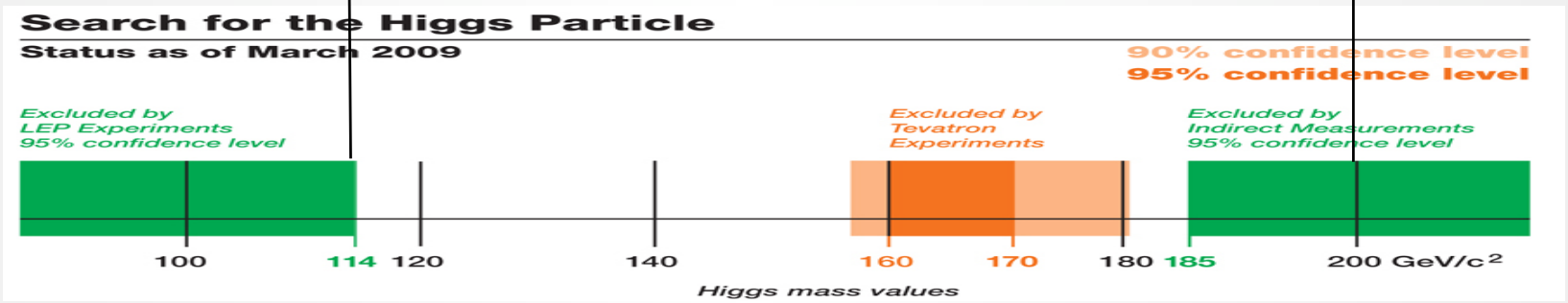


- contain most physics objects: leptons, jets, E_T^{miss} , b-jets
- background to ~ all searches

→ when top measured, experiment is ready for discovery phase

Sensitivity Projection (Region favored by M_{top}, M_W, … meas.s)



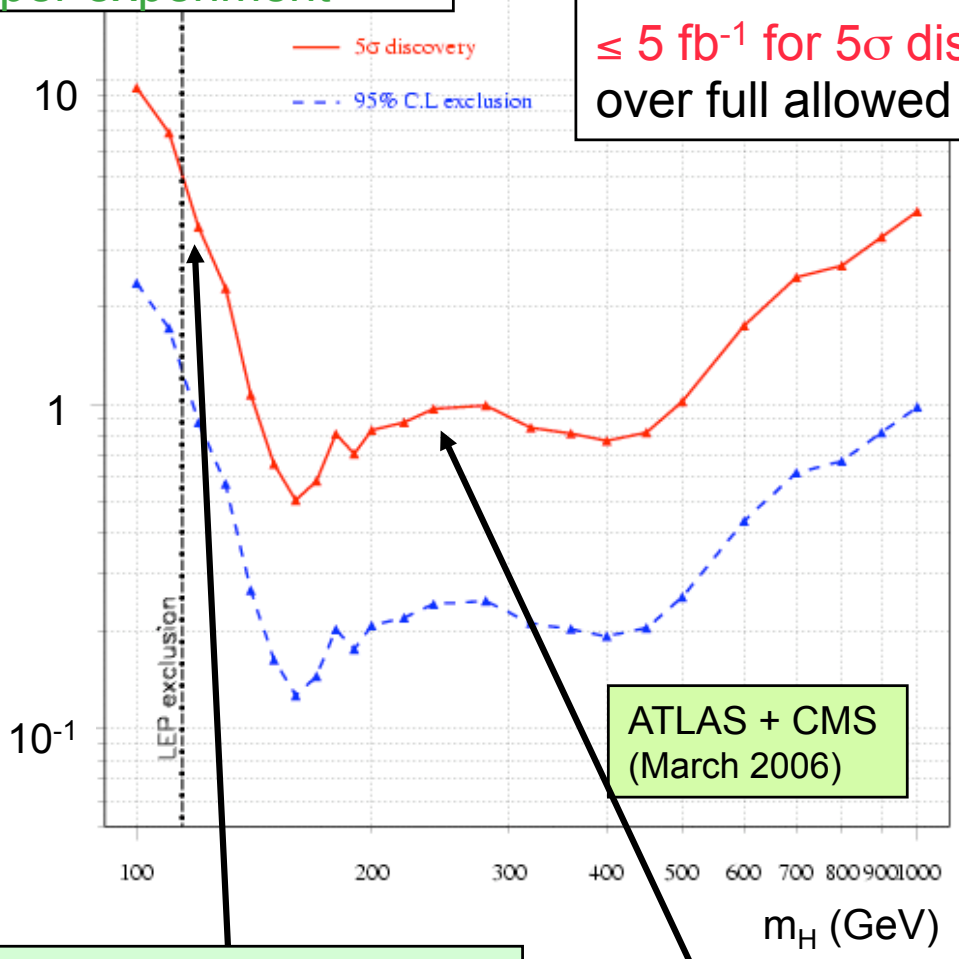


2010: 7 fb^{-1}/expt: exclude all masses

Summary of Higgs discovery potential at the LHC

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

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



ATLAS + CMS
(March 2006)

Most difficult region:
need to combine several channels (e.g. $H \rightarrow \gamma\gamma$, $qqH \rightarrow qq\tau\tau$) with small S/B or S

Easier region:
$H \rightarrow 4l$