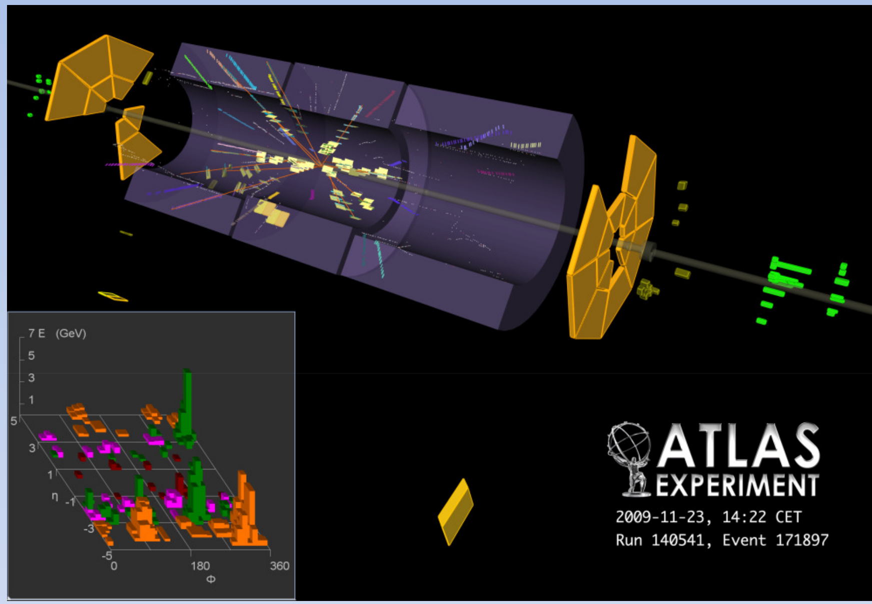
ATLAS: First Data



Stephen Haywood (RAL)

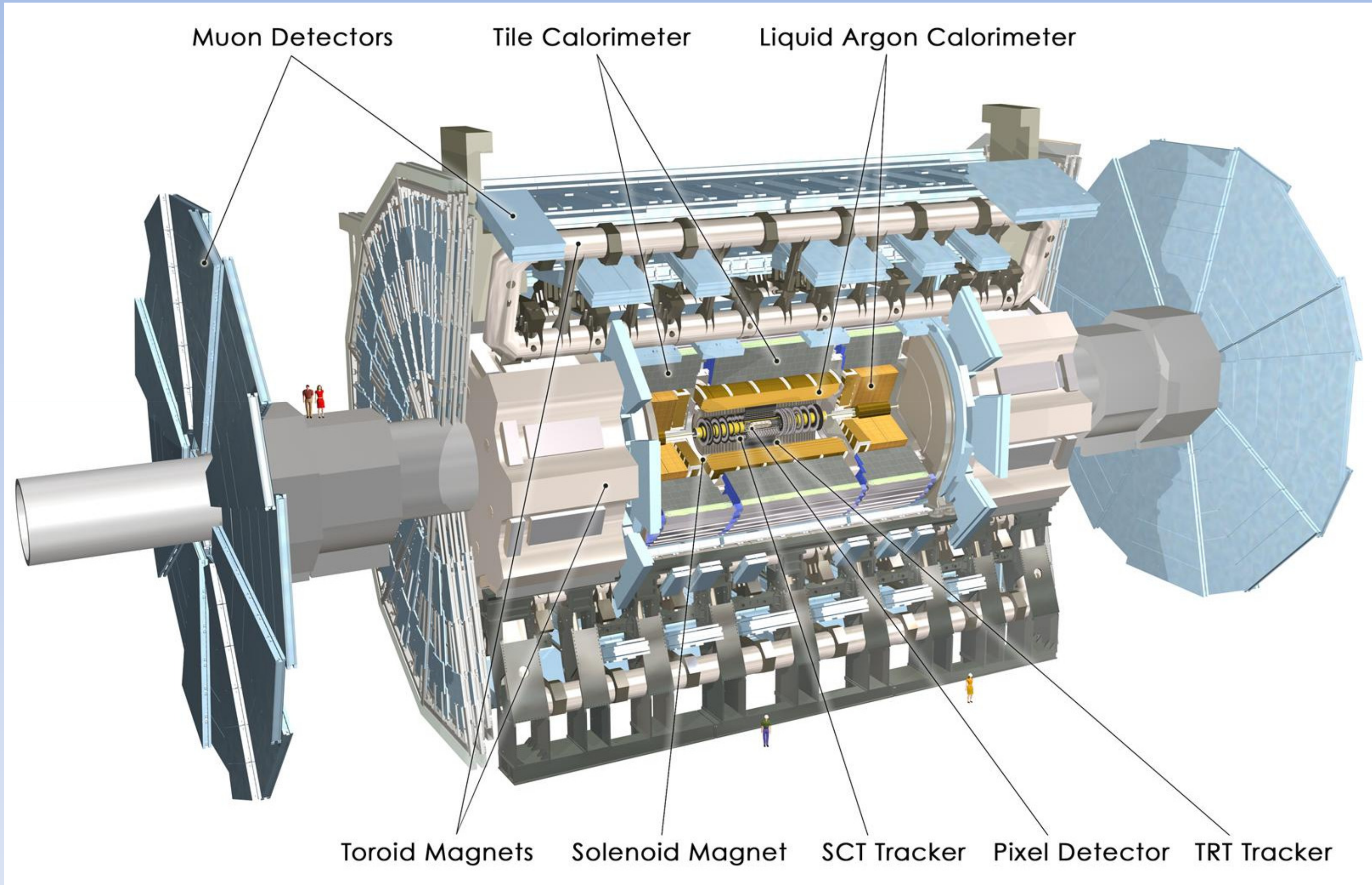
on behalf of the ATLAS Collaboration

Science & Technology Facilities Council

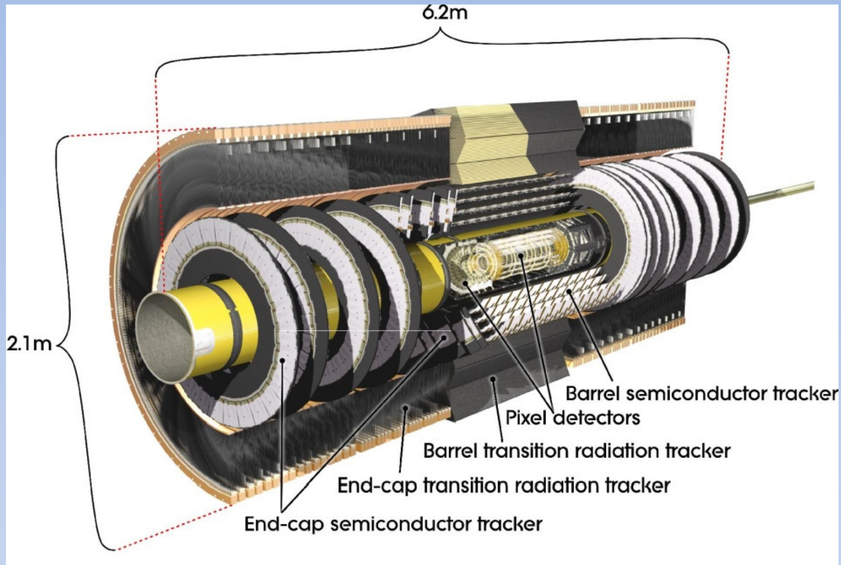
This Talk

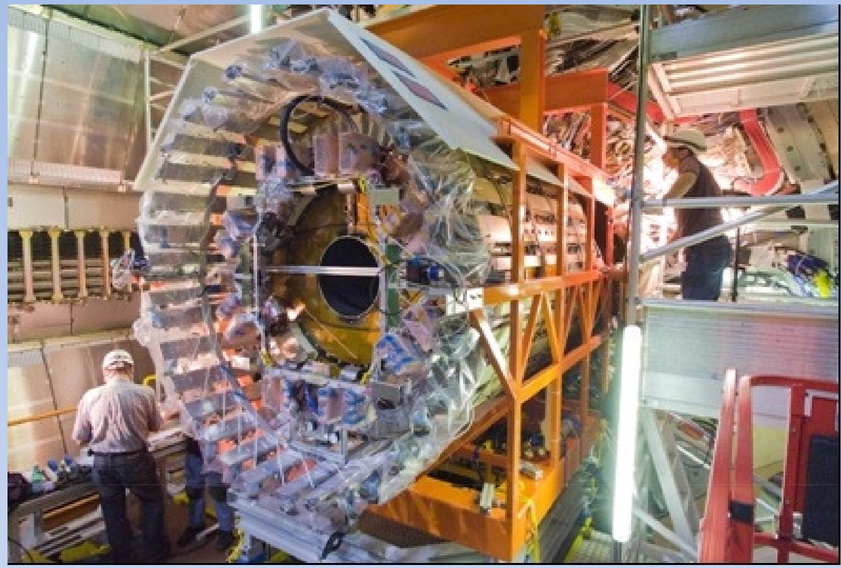
- The ATLAS Detector
- Preparing for Collisions: Cosmics, Splash Events
- Collision Data
- Sub-detector Performance
- Combined Performance
- Outlook
- Conclusions

The ATLAS Detector



Inner Detector (ID)





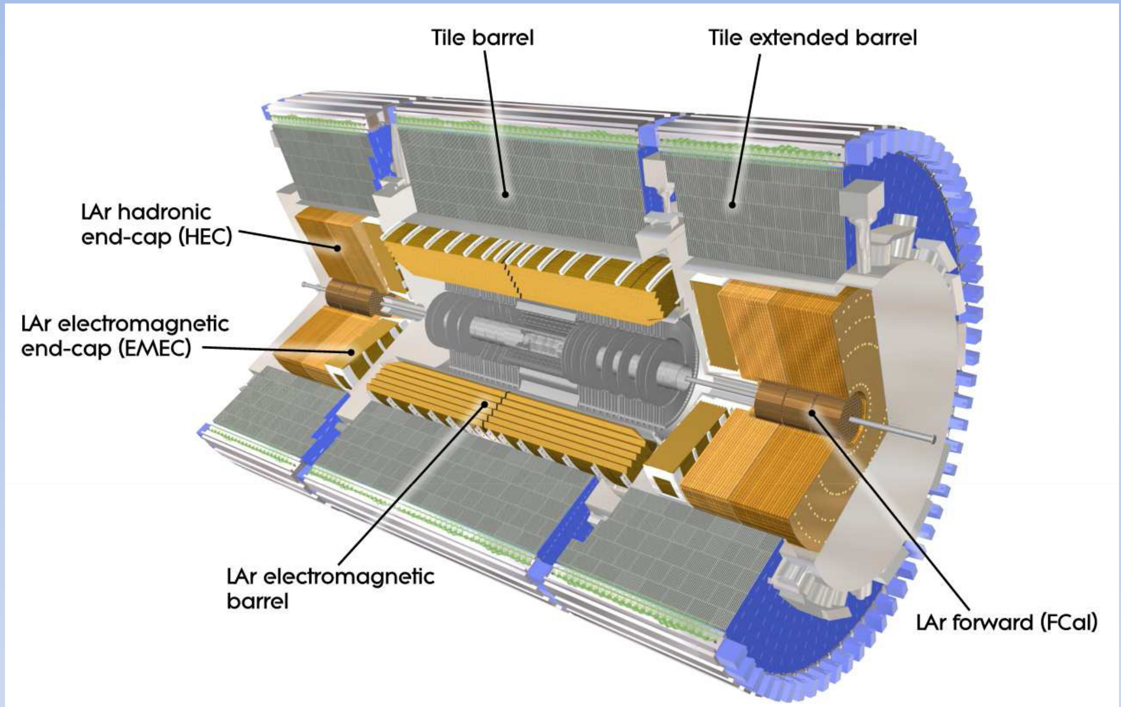
Inserting ID End-cap into ATLAS

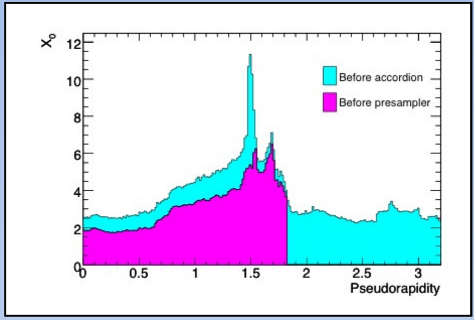
- B = 2T
- Expect $\sigma(1/p_T) = 0.34\ \text{TeV}^{-1} \times (1 \oplus 44\ \text{GeV}/p_T)$

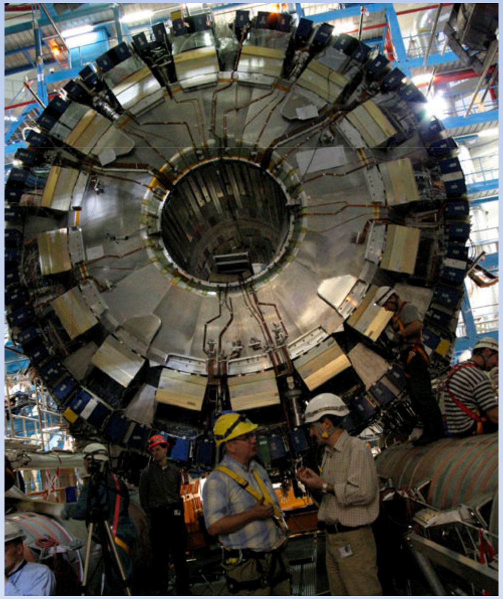
  $\sigma(d_0) = 10\ \mu\text{m} \times (1 \oplus 14\ \text{GeV}/p_T)$

Calorimetery

X_0 in front of EM Calo



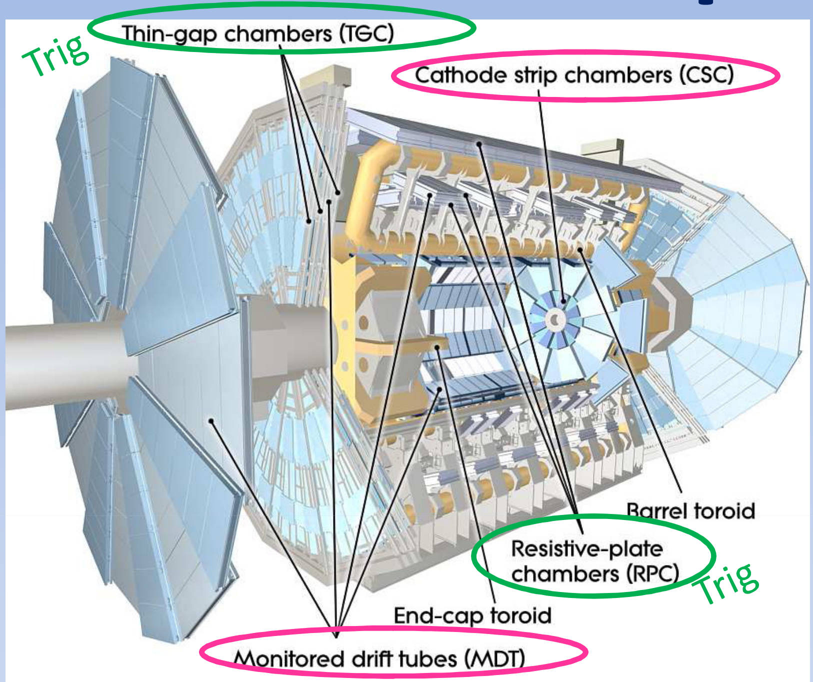


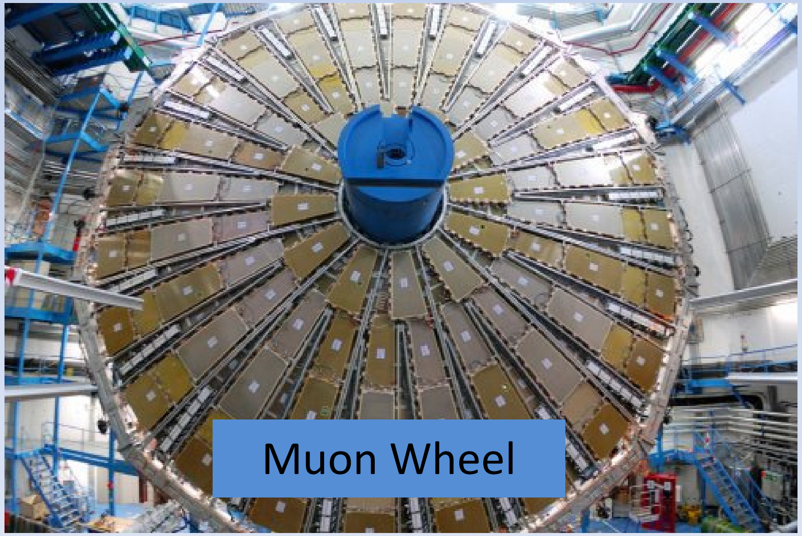


- EM Calo: LAr/Pb $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 0.7\%$
- Hadronic Calo: Scin/Fe and LAr/Cu
  $\sigma(E)/E \sim 50\%/\sqrt{E} \oplus 3\%$
- Forward Calo up to $|\eta| < 4.9$

Barrel LAr EM Calorimeter

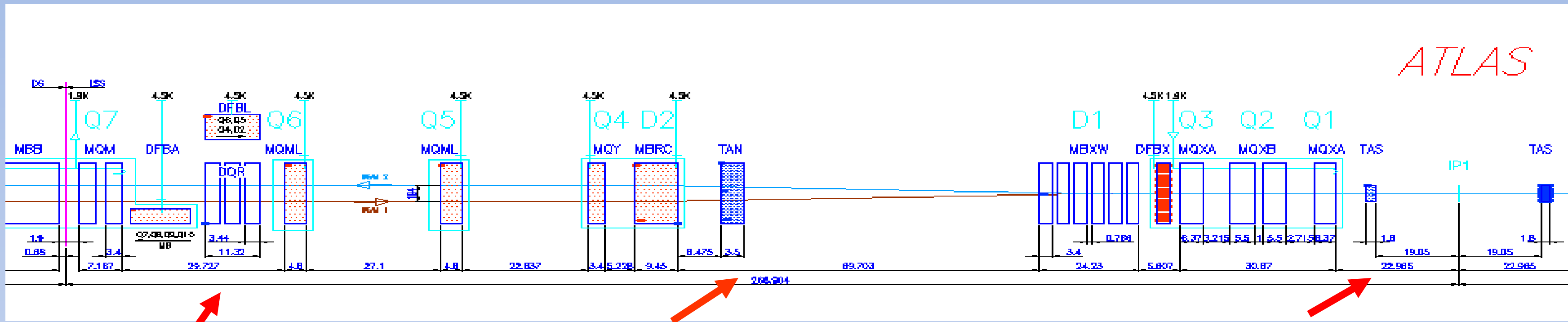
Muon Spectrometer





- B = 0.5 – 4 T
- Expect $\sigma(p_T)/p_T = 4\%$ at high p_T

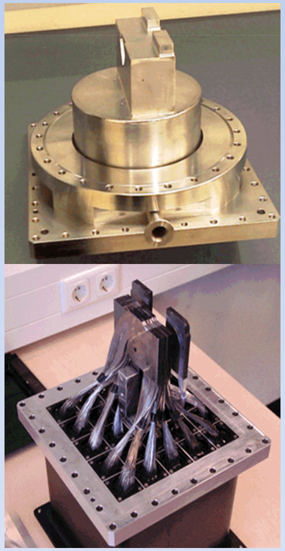
Very Forward Detectors

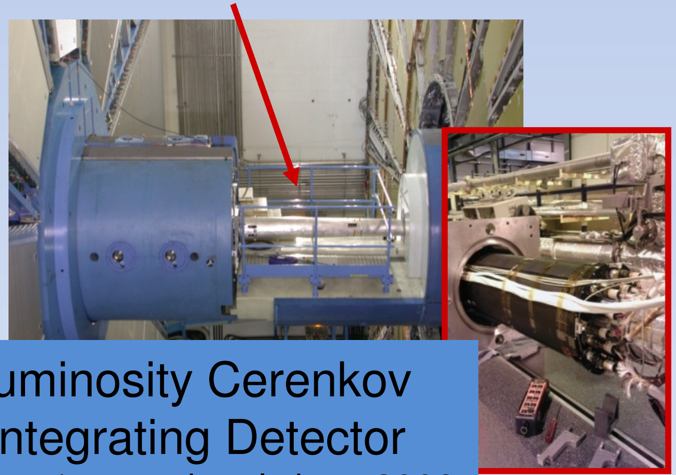


ALFA at 240 m

ZDC at 140 m

LUCID at 17 m





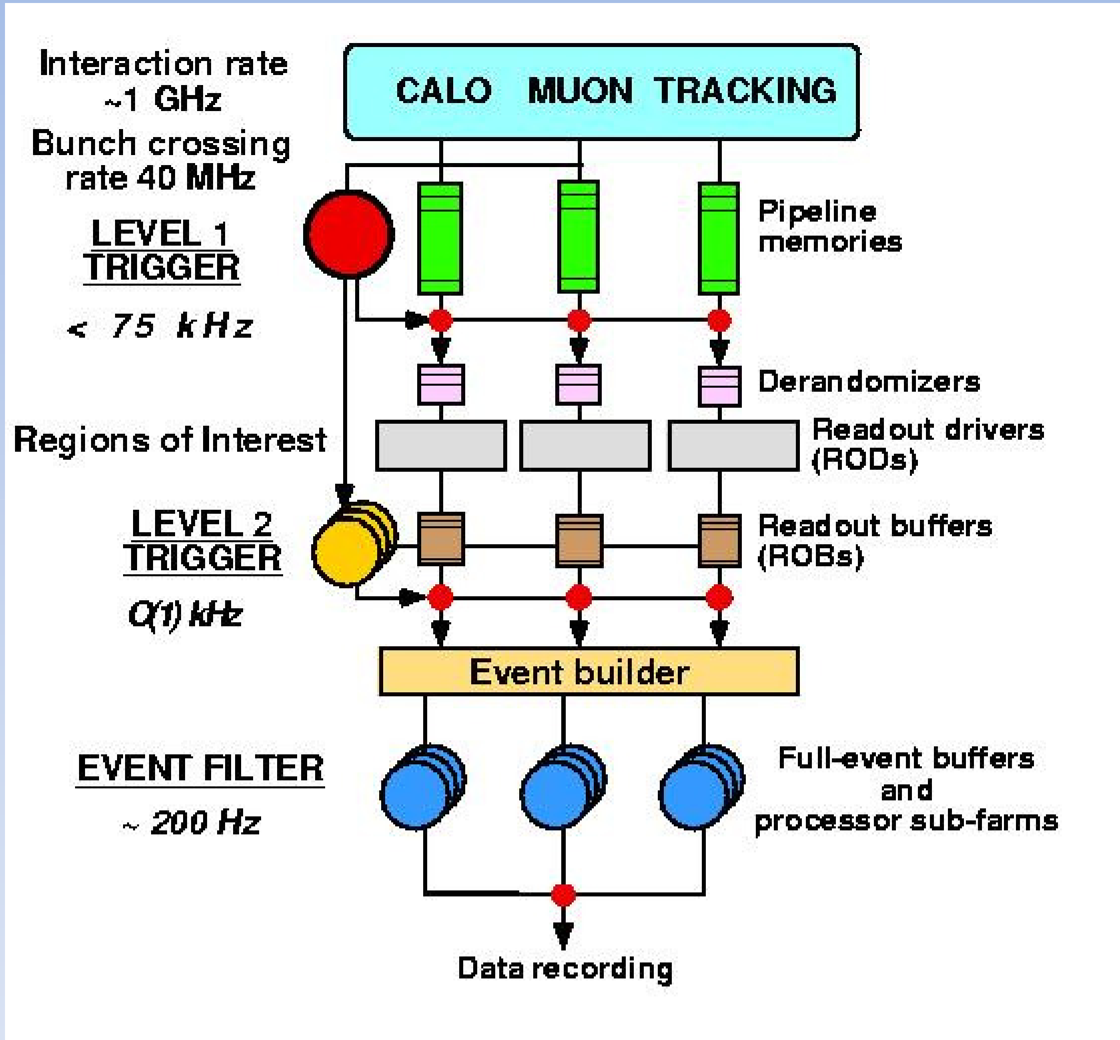
Zero Degree Calo
Data taking in 2009

Luminosity Cerenkov Integrating Detector
Phase 1 operational since 2008

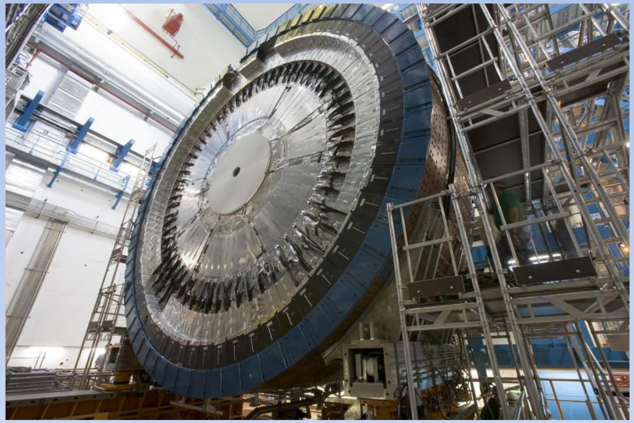
LoI for Forward Proton detectors at 220 and 420 m (AFP): ongoing ATLAS review

ALFA: Absolute Luminosity for ATLAS
Installation in 2010

Trigger



Min-Bias Trigger Scintillators (MBTS)



- 16 counters (2 rings) on each end
- $2.1 < |\eta| < 3.8$

Preparing for Collisions

1992 ATLAS LoI

1997 Construction starts

2003 Installation at Point 1 starts

2008 Installation completed; Cosmic data-taking starts

11 Sep 2008 First Beams circulated in LHC

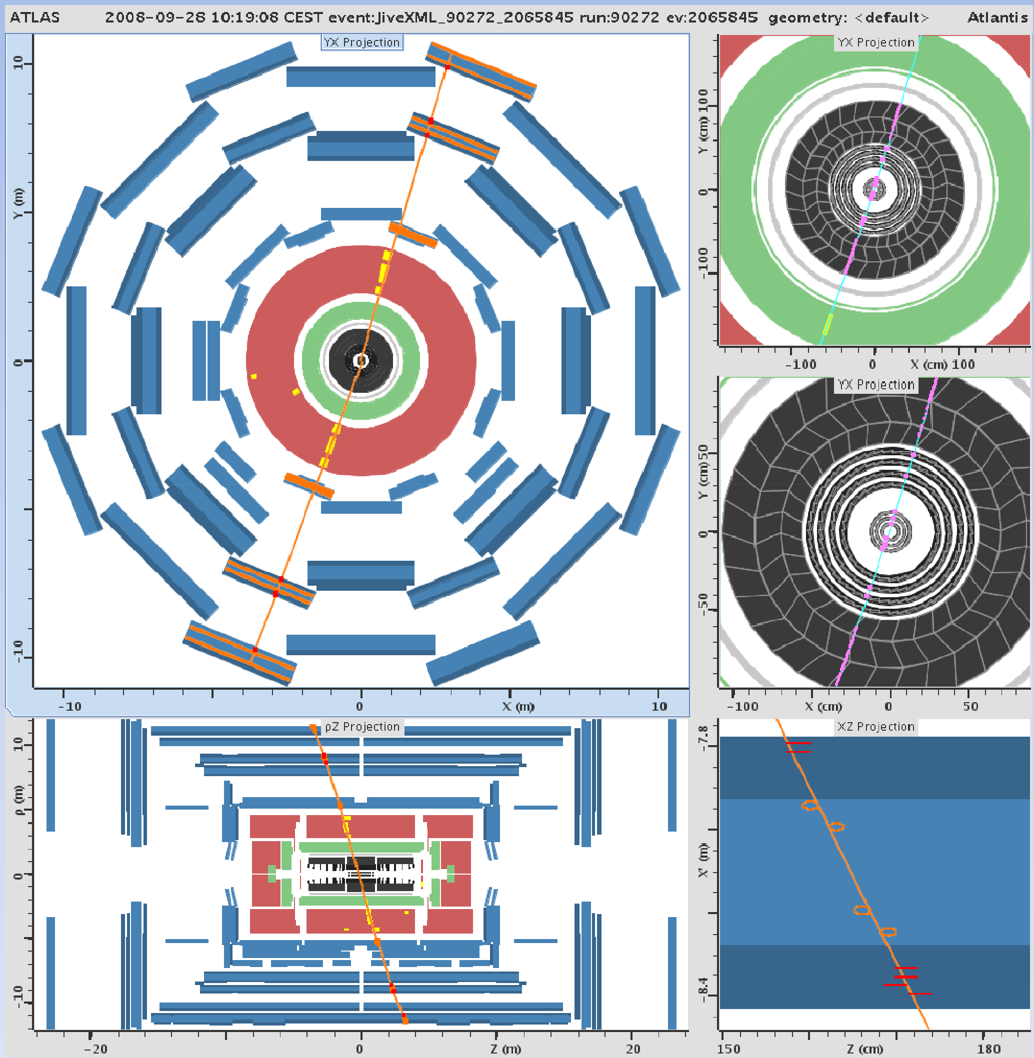
20 Sep 2008 LHC magnet failures

20 Nov 2009 Single Beam Splash in ATLAS

23 Nov 2009 First collisions at $\sqrt{s}$ = 900 GeV

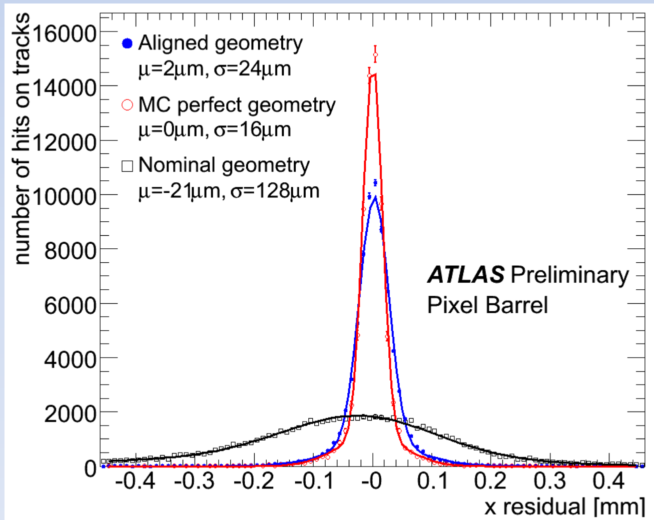
8 Dec 2009 First collisions at $\sqrt{s}$ = 2.36 TeV

Cosmics



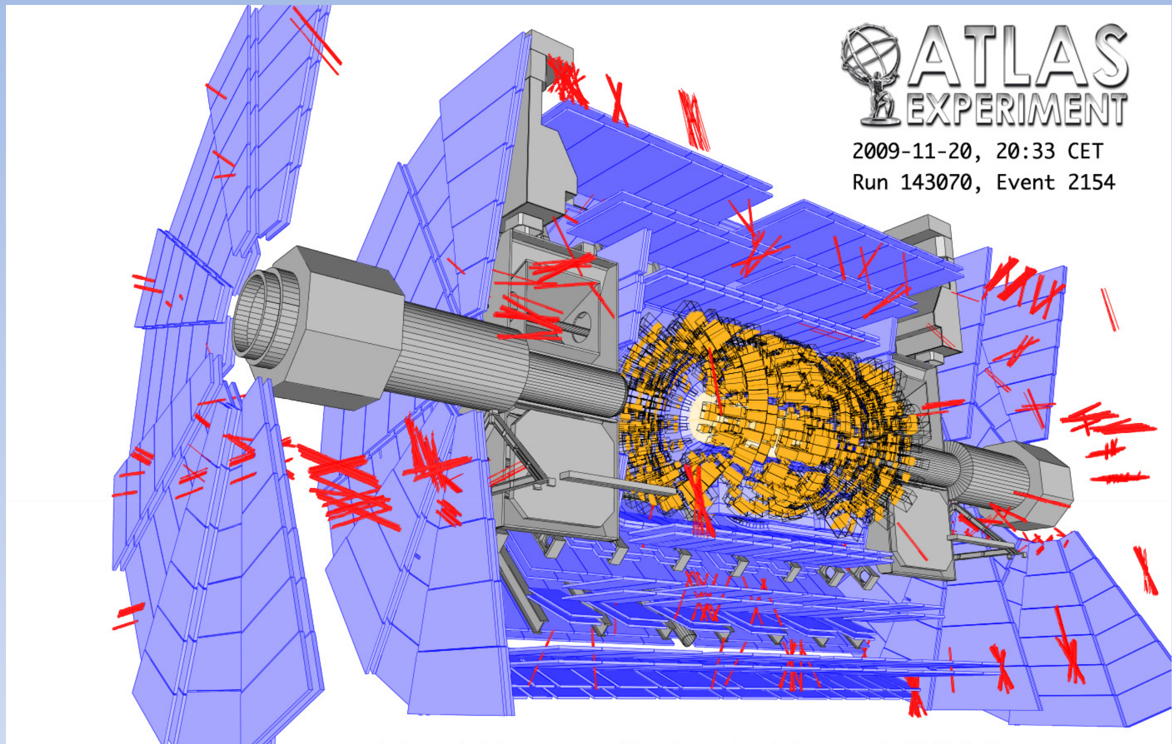
- Efficiencies
- Hit Resolutions
- Track parameter resolutions
- Alignment
- Calibrations

Pixel Alignment



Praying for Events

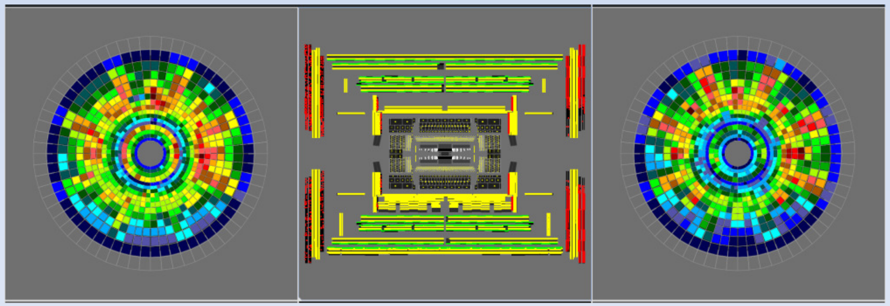
Beam Splash



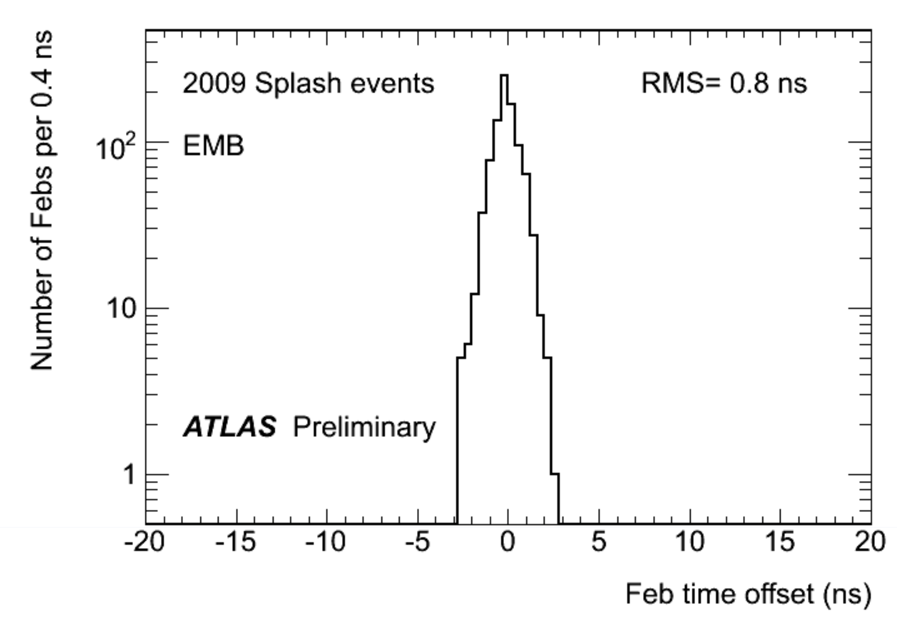
First Beam Splash Event 2009

Large numbers of channels fired simultaneously – great for timing-in detectors

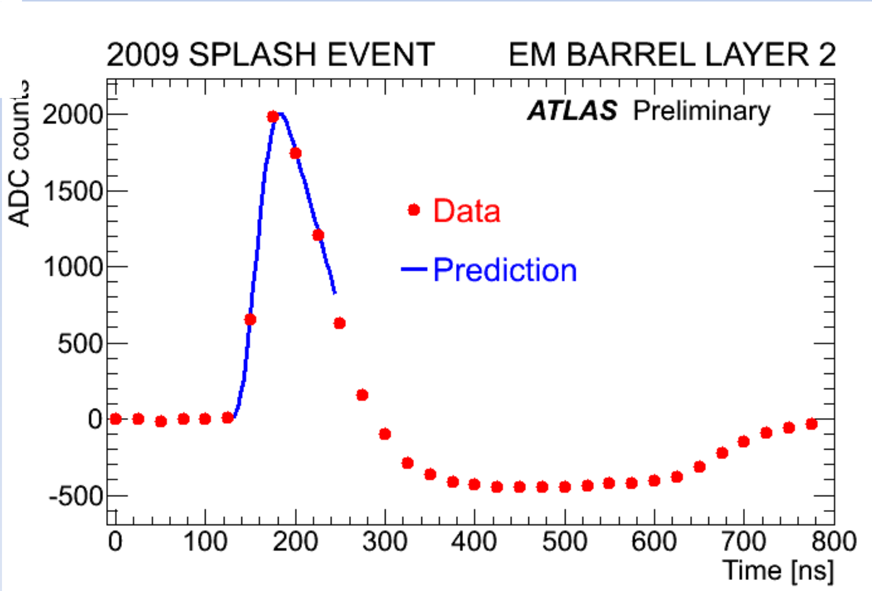
Hits in each event:
- 300,000 SCT
- 350,000 TRT
- 490,000 MDT
- 320,000 RPC
- 65,000 TGC
- 3,000 TeV in Calo



Hits in Calo End-caps

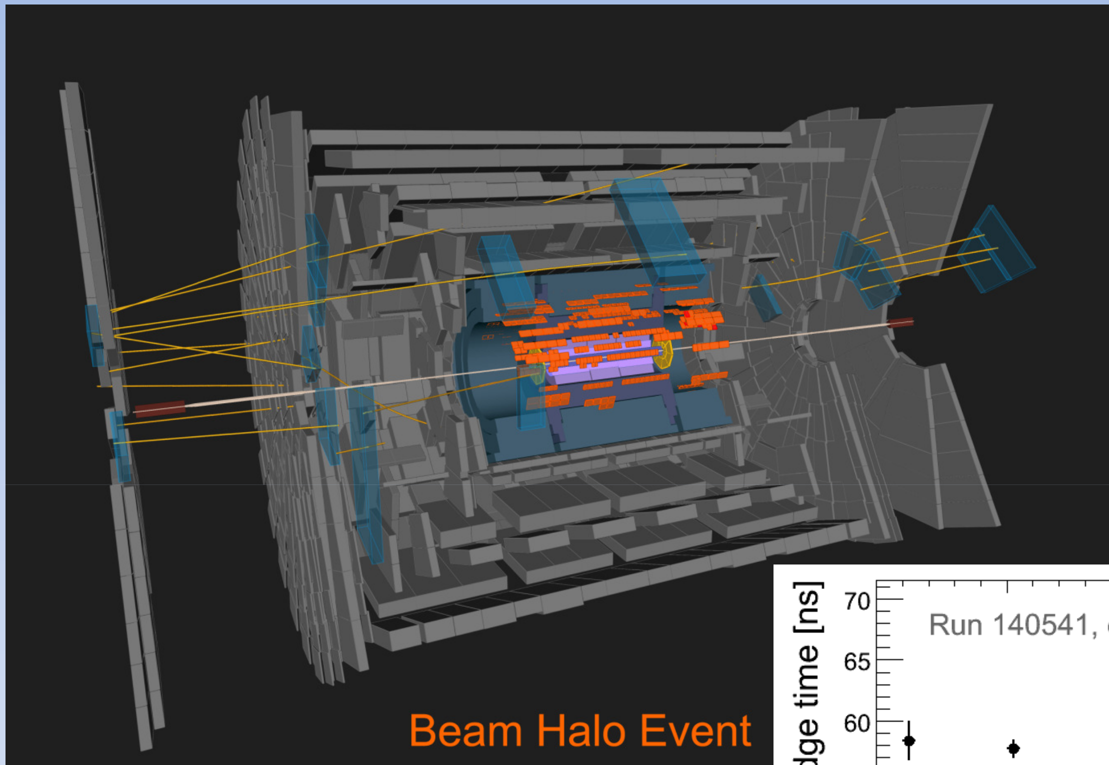


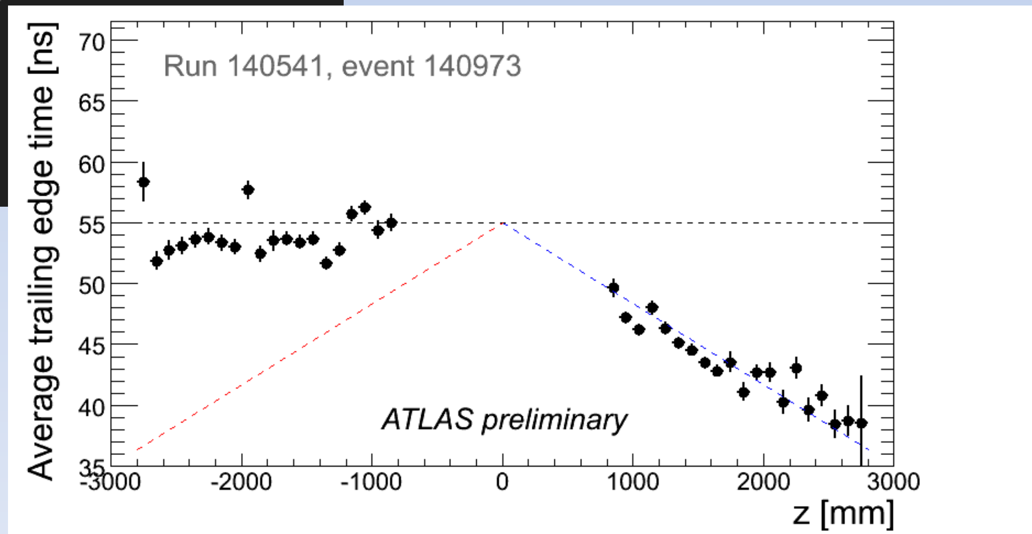
Relative timing in EM LAr Barrel Calo



Pulse shape in EM LAr Barrel Calo

Beam-Halo & Beam-Gas





TRT timing

Timing calibrated for collisions.
Deviation from constant offset indicates early hits from BG.

Collision Data

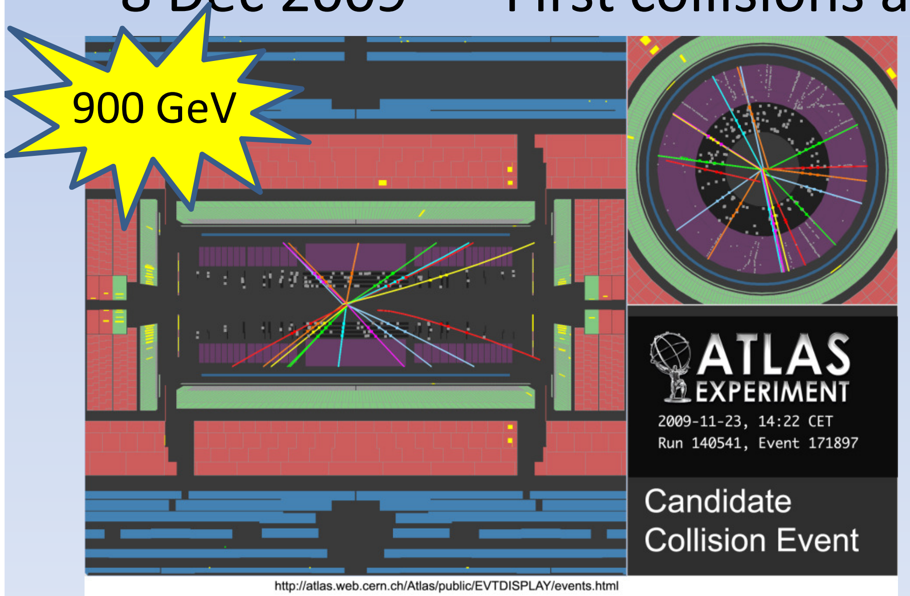
23 Nov 2009 First collisions at $\sqrt{s}$ = 900 GeV

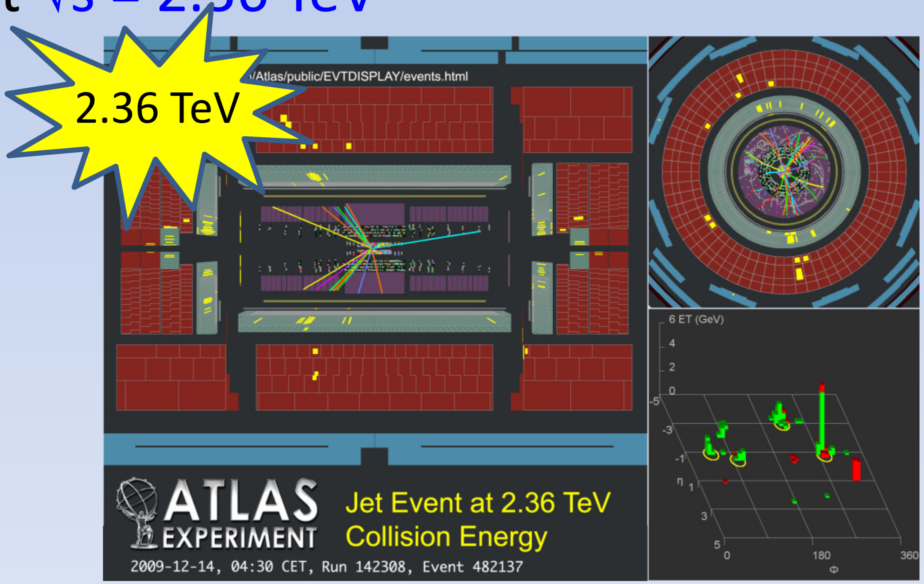
ATLAS records ~200 events; first at 14.22.

6 Dec 2009 Machine protection system commissioned

Stable beams; Inner Detector at nominal voltage

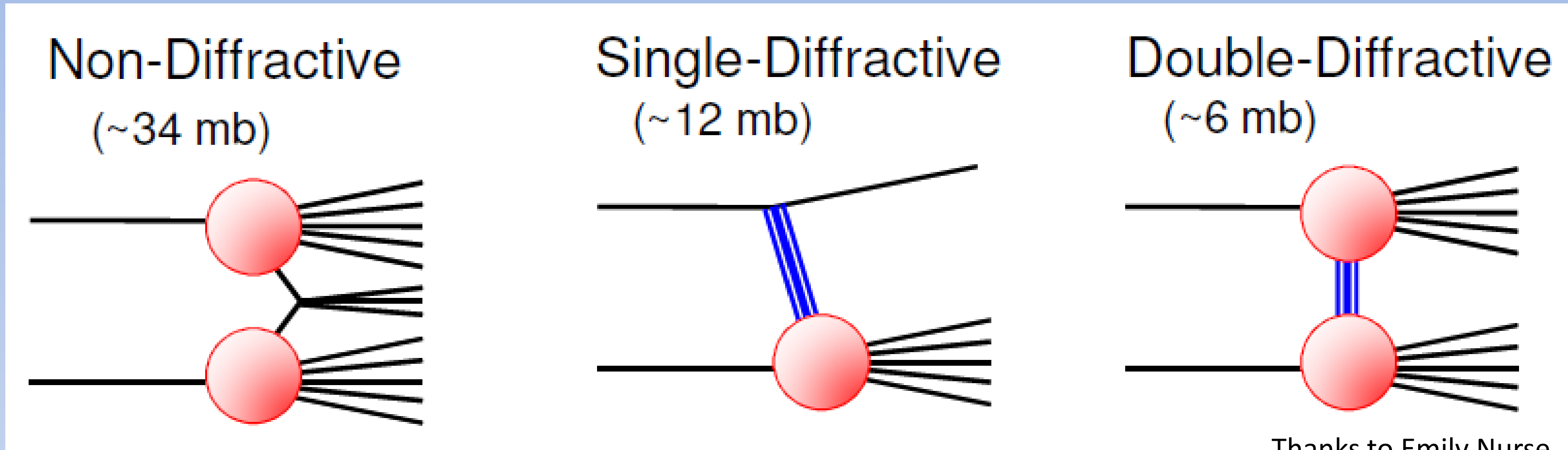
8 Dec 2009 First collisions at $\sqrt{s}$ = 2.36 TeV





B=0
ID HV at standby

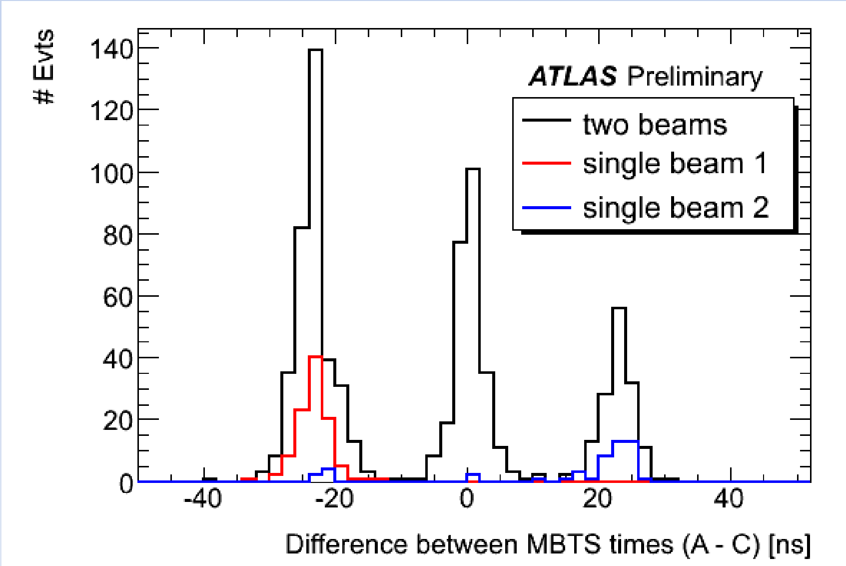
Minimum Bias Events



Thanks to Emily Nurse

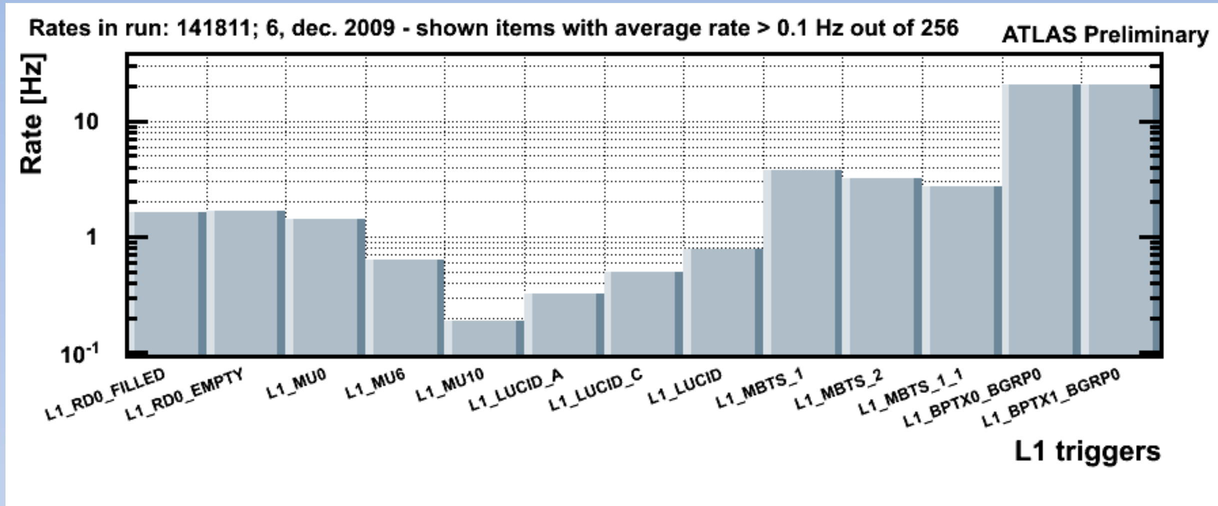
Timing difference between two sides of MBTS.

Peak at zero corresponds to collisions.



Triggering

Trigger Rates
Dominated by Beam Pickup
& MBTS

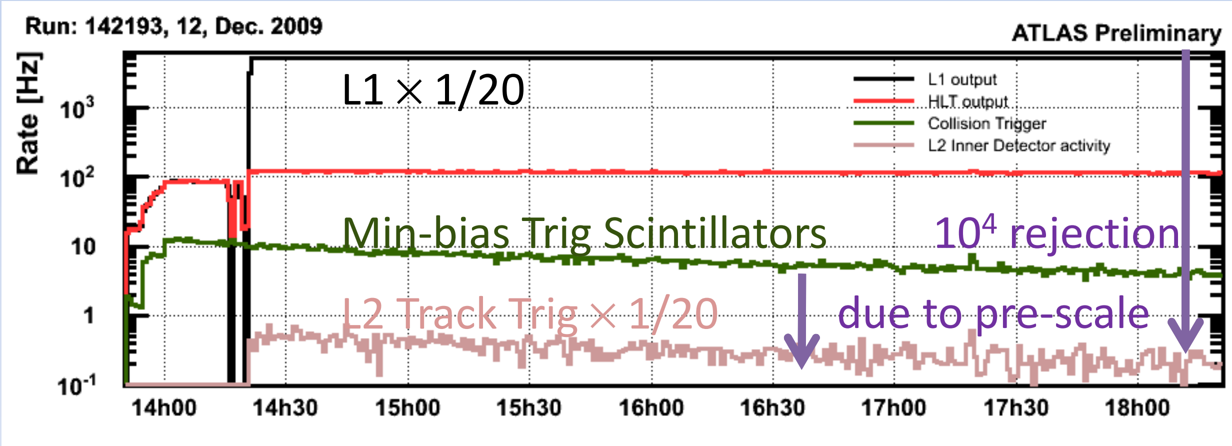


<u>Beam injection</u>

- Record collisions
- ID HV off
- HLT not engaged

<u>Beams stable</u>

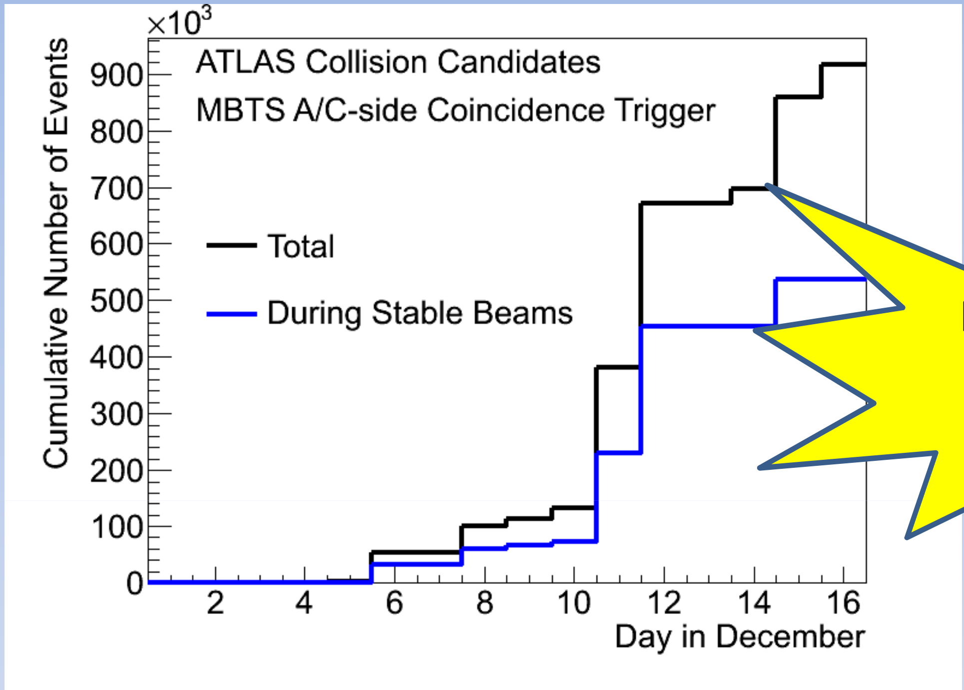
- ID HV on
- HLT engaged
- L1 unconstrained



Rates vs Time

Luminosity

Num Events in December



Max Peak Lumi at ATLAS $7\times10^{26}\ cm^{-2}s^{-1}$

Data Samples	# Events	Integrated Lumi (<30% uncertainty)
Total	920k	$20\ \mu b^{-1}$
With Stable Beams	540k	$12\ \mu b^{-1}$
$\sqrt{s}$ = 2.36 TeV	34k	$1\ \mu b^{-1}$

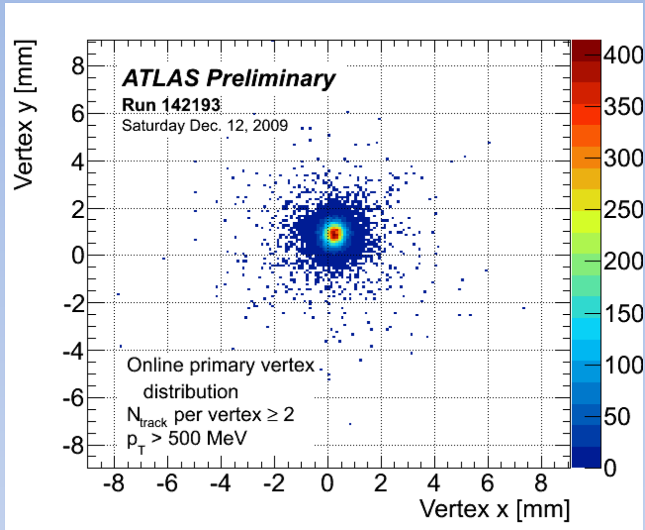
Av Data-taking Eff ~90%

Sub-detector Performance

	Sub-detector	# Channels	Op Fraction (%)
Inner Detector	Pixels	80M	97.9
	SCT – Si strips	6.3M	99.3
	TRT – TR Tracker	350k	98.2
Calorimetry	EM LAr Calo	170k	98.8
	Hadronic Tile Calo	9.8k	99.2
	Hadronic LAr End-cap Calo	5.6k	99.9
	LAr Forward Calo	3.5k	100
Muon Spectrometer	MDT – central Muon det	350k	99.7
	CSC – forward Muon det	31k	98.4
Trigger	RPC – Barrel Muon Trig	370k	98.5
	TGC – End-cap Muon Trig	320k	99.4
	Level-1 Calo Trig	7.2k	99.9

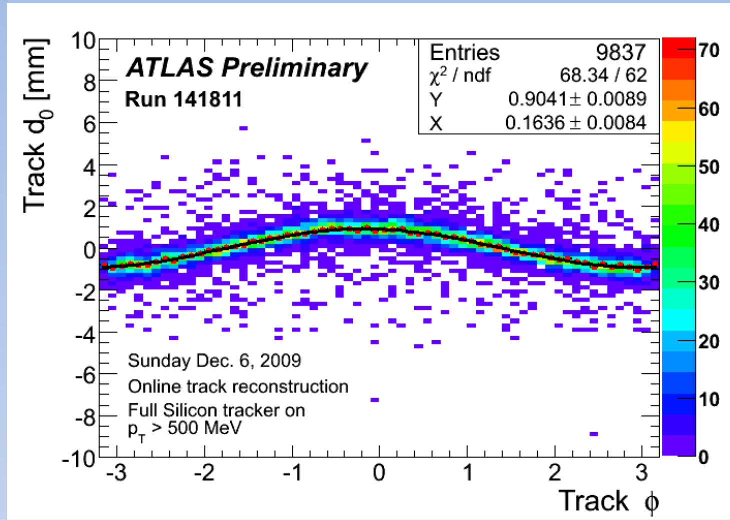
Trigger

Beam–spot in x-y

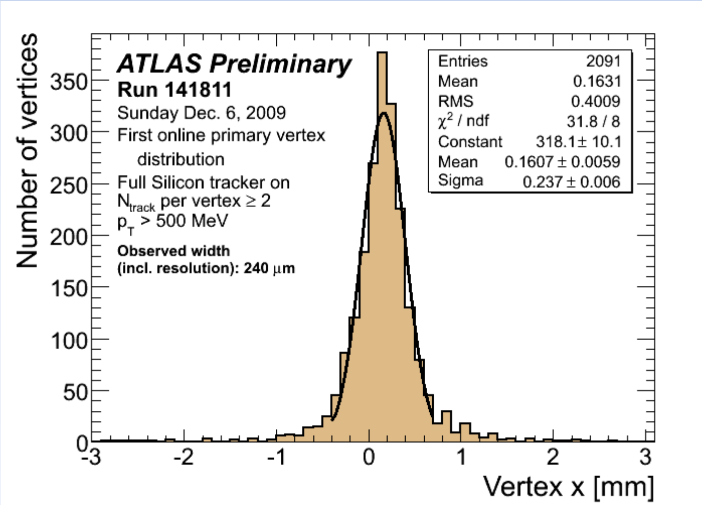


Impact param vs ϕ

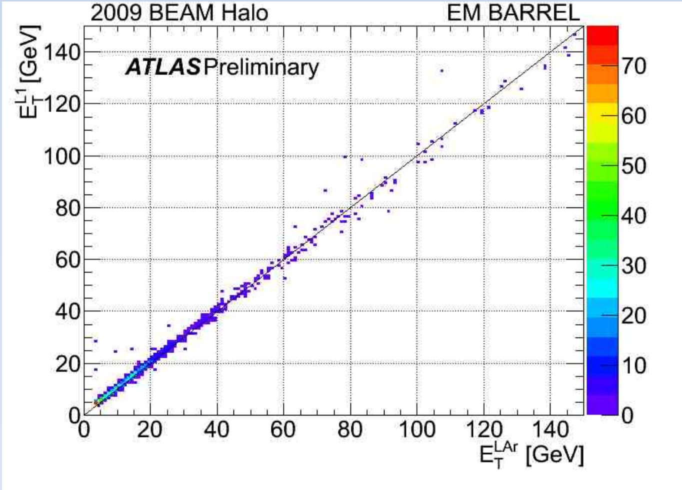
Sine wave indicates offset ~1 mm



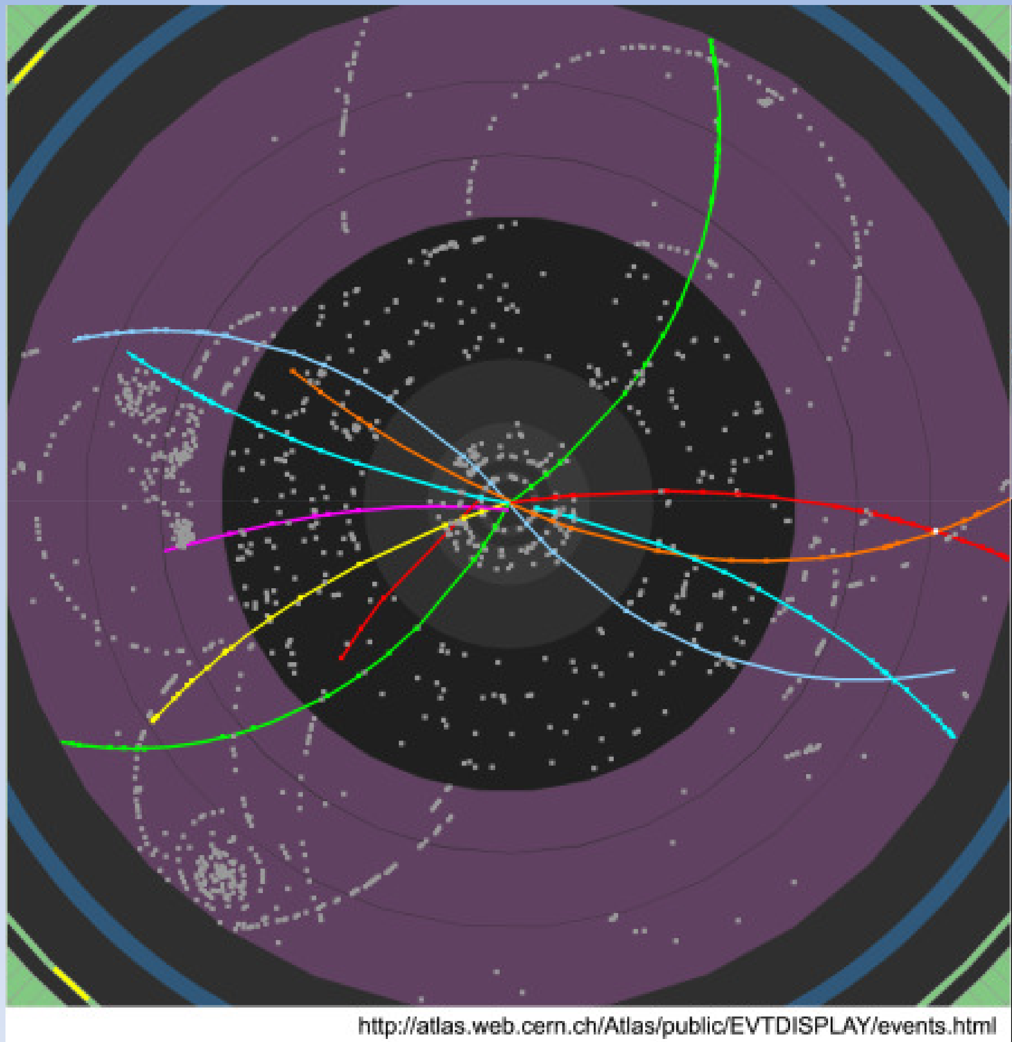
Transverse Width of Beam-spot

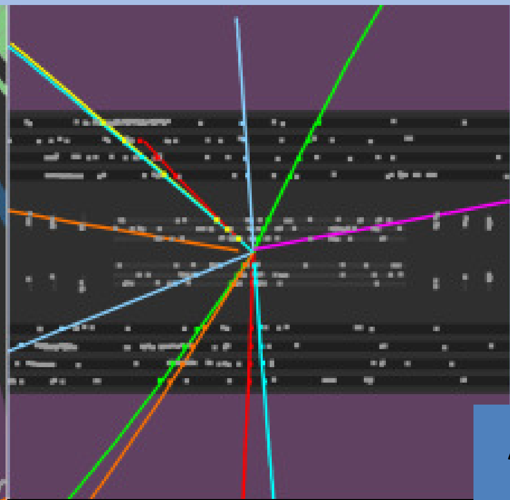


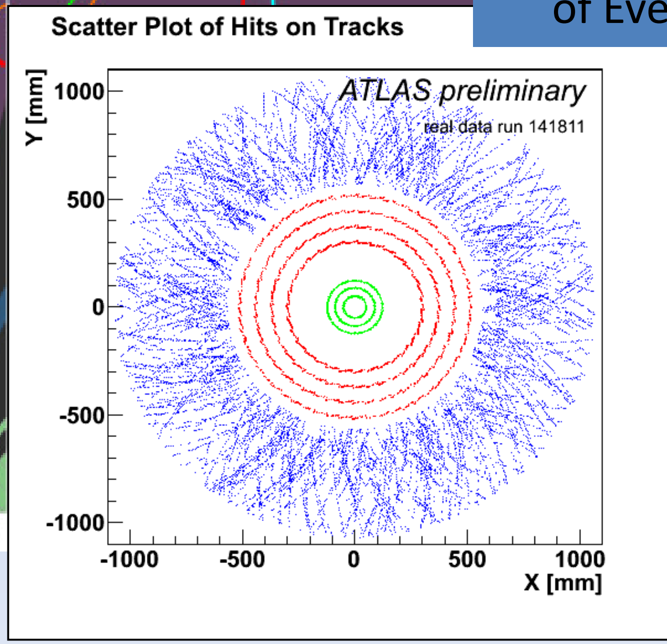
L1Calo energy vs Offline



Inner Detector





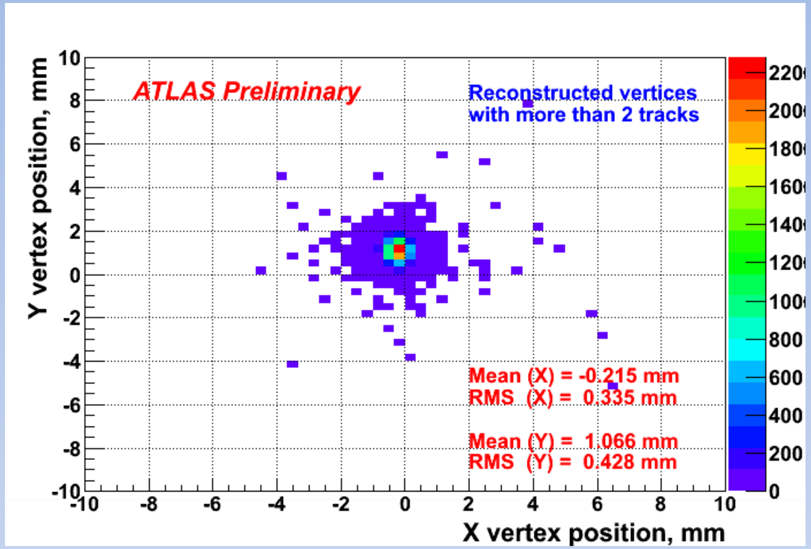


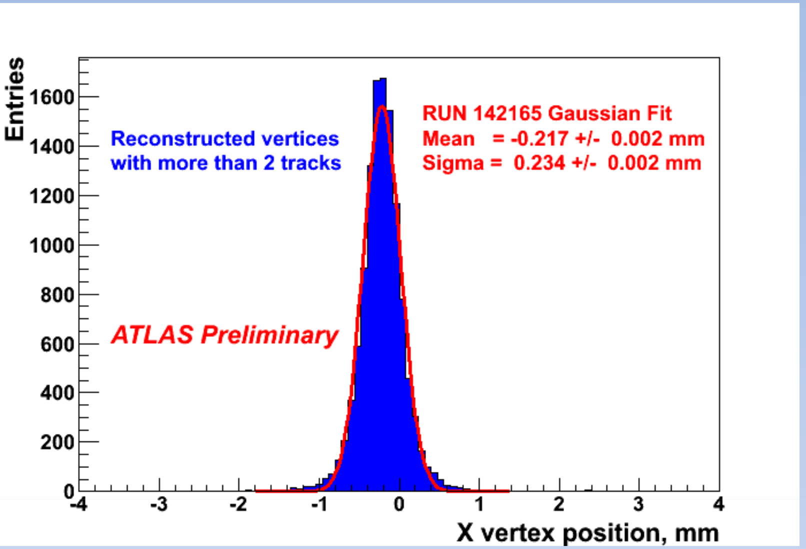
Accumulation of Events

Beam–spot in x-y

Transverse Width of Beam-spot

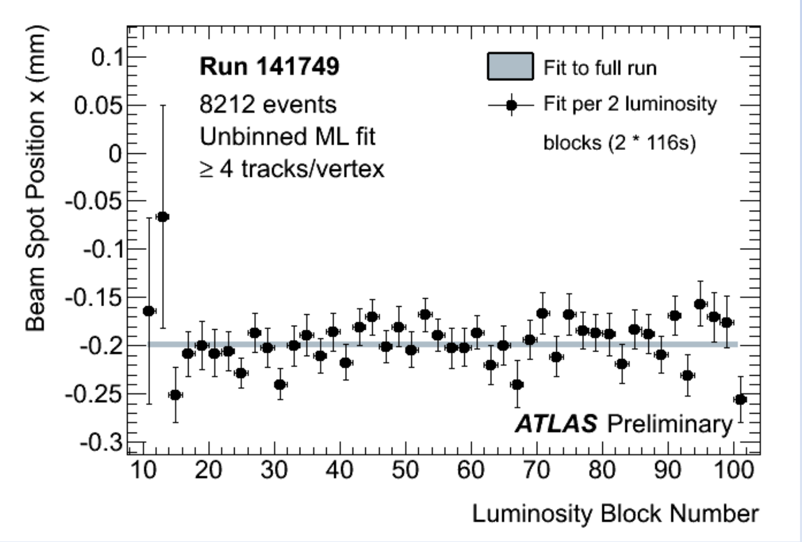
σ = 234 μm

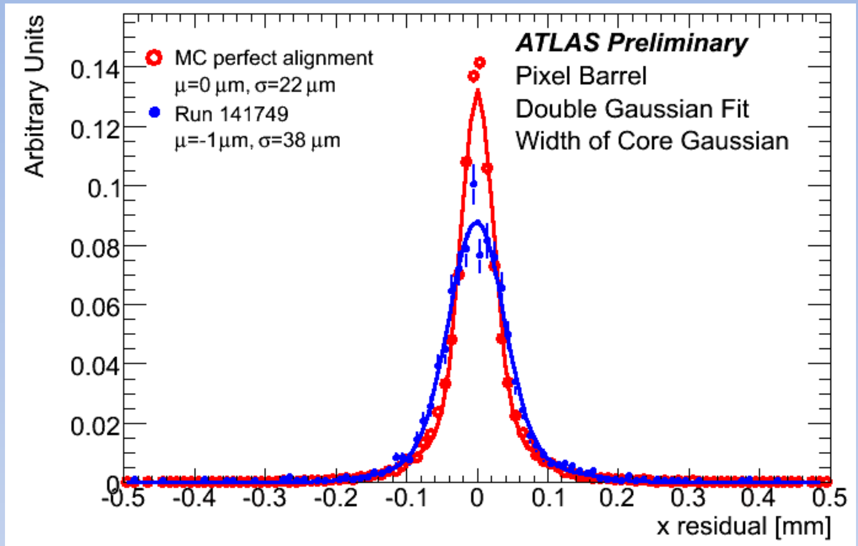


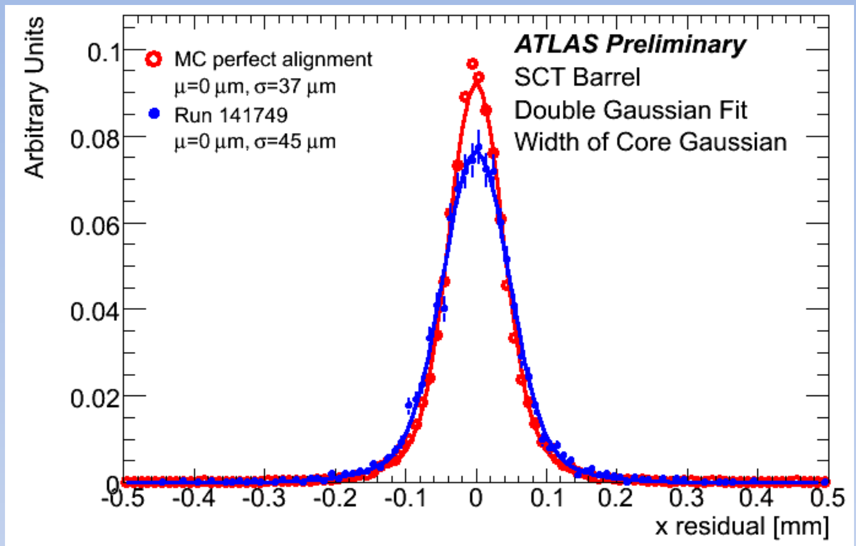


Stability of Beam-spot vs Time

Lumi Block ≈ 2 mins







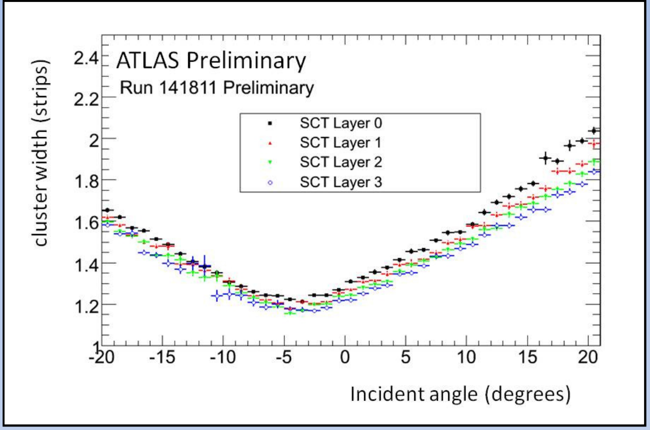
Residuals (unbiased) in x in Pixel Barrel
σ(observed) = 38 μm σ(expected) = 22 μm
p_T > 2 GeV; use Cosmic Alignment

Residuals (unbiased) in x in SCT Barrel
σ(observed) = 45 μm σ(expected) =37 μm
p_T > 2 GeV; use Cosmic Alignment

- Alignment deduced from Cosmics is not bad
- Cosmics illuminated “vertical” modules
- Also “global” distortions ?
- Improvements are needed

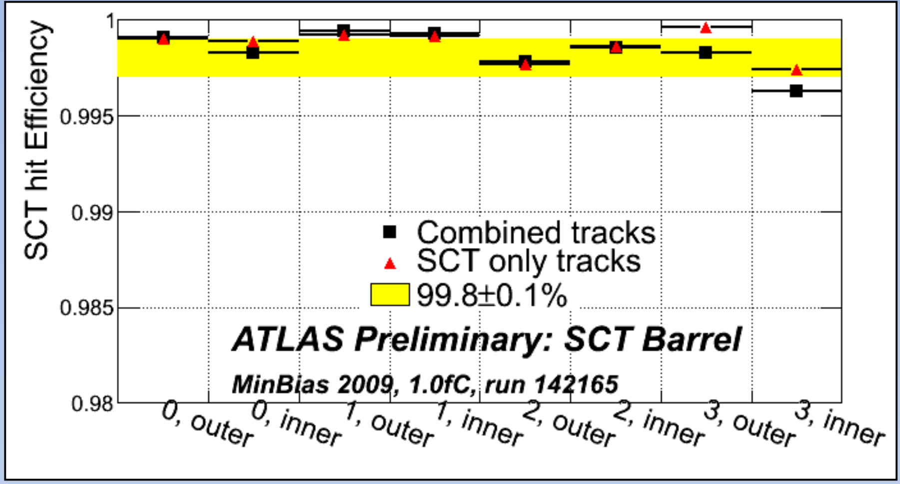
SCT Cluster Width (in strips) vs Incident Angle

Measures Lorentz Angle

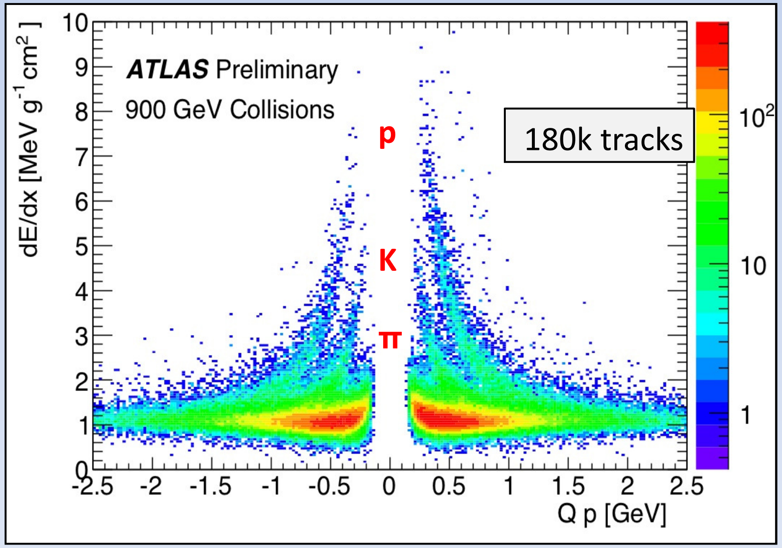


SCT Hit Efficiency, by Layer

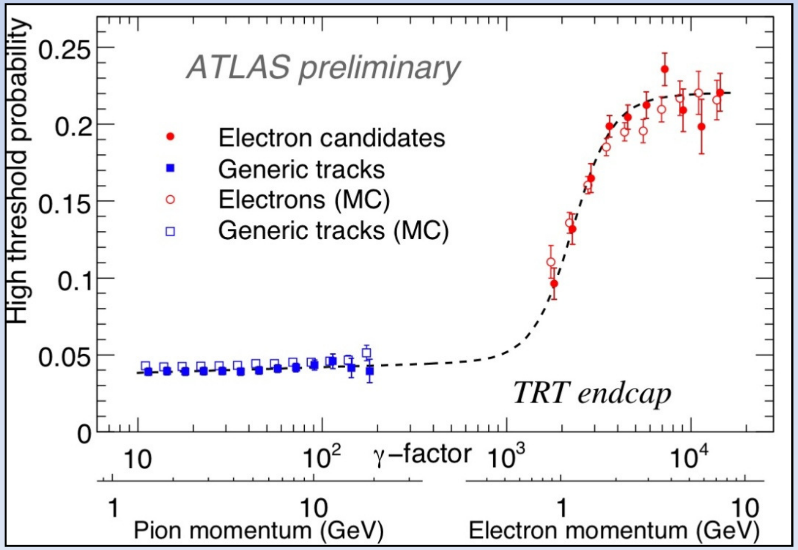
Dead Modules & Chips are excluded



dE/dx in Pixels vs Qp

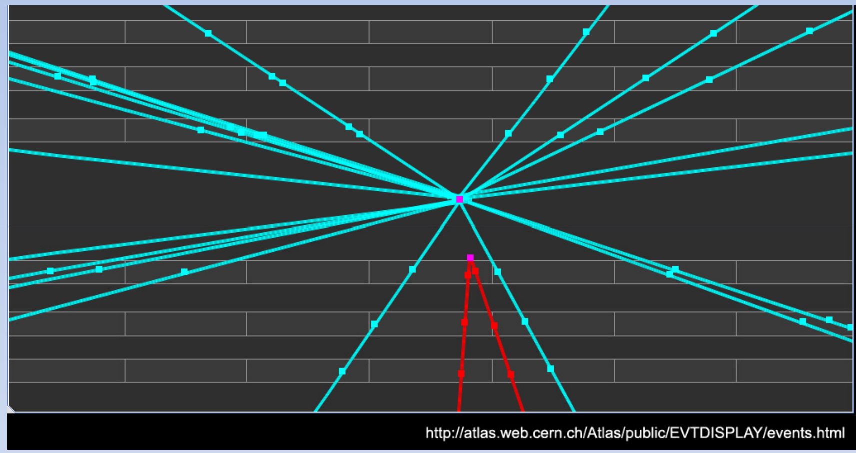


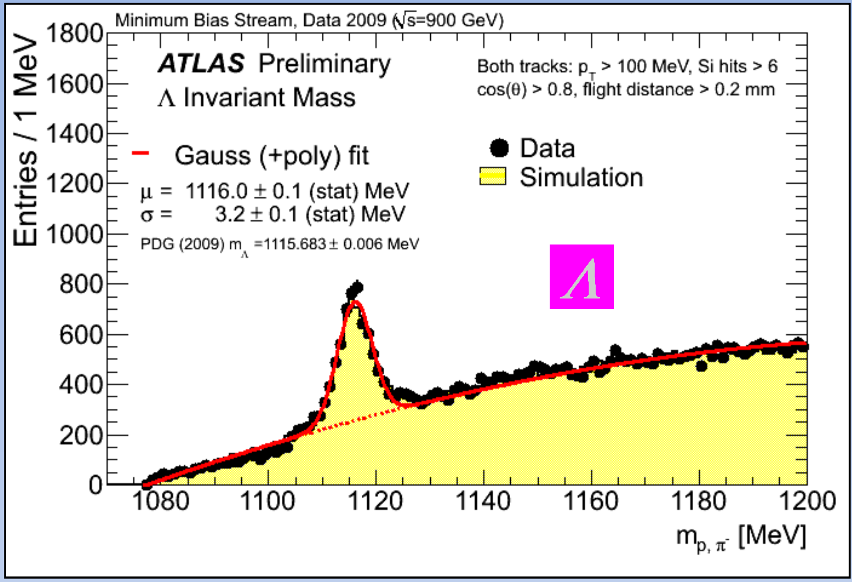
Transition Radiation in TRT vs Lorentz Boost

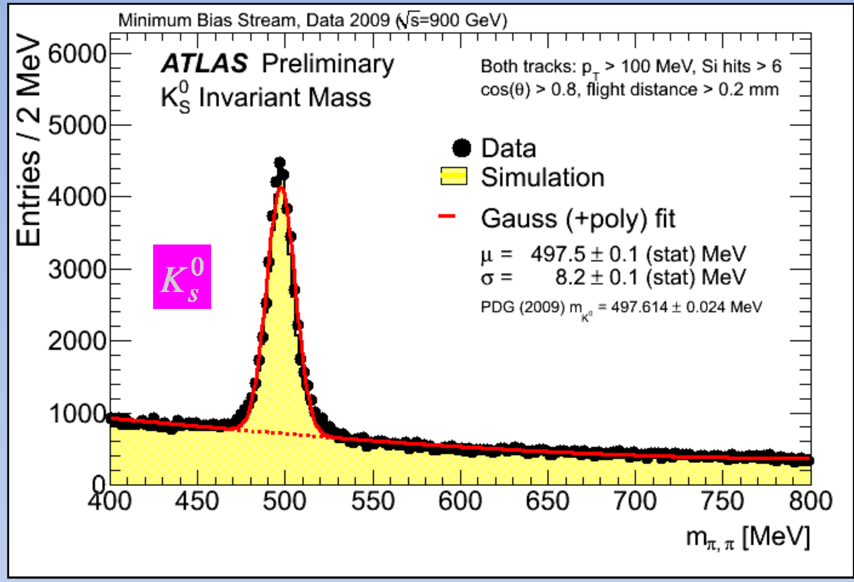


V⁰'s

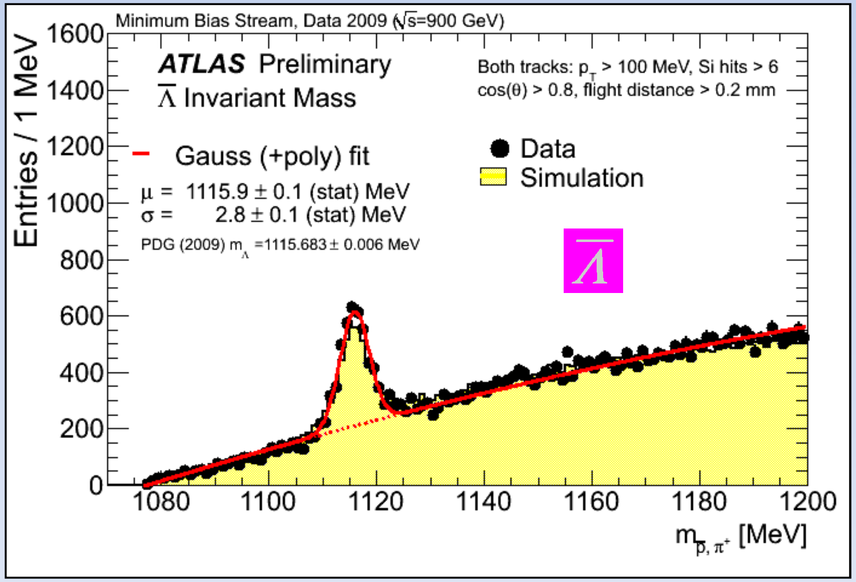

ATLAS
EXPERIMENT
2009-12-06, 10:24 CET
Run 141749, Event 460665
Event with
$K_S \rightarrow \pi^+\pi^-$
Candidate

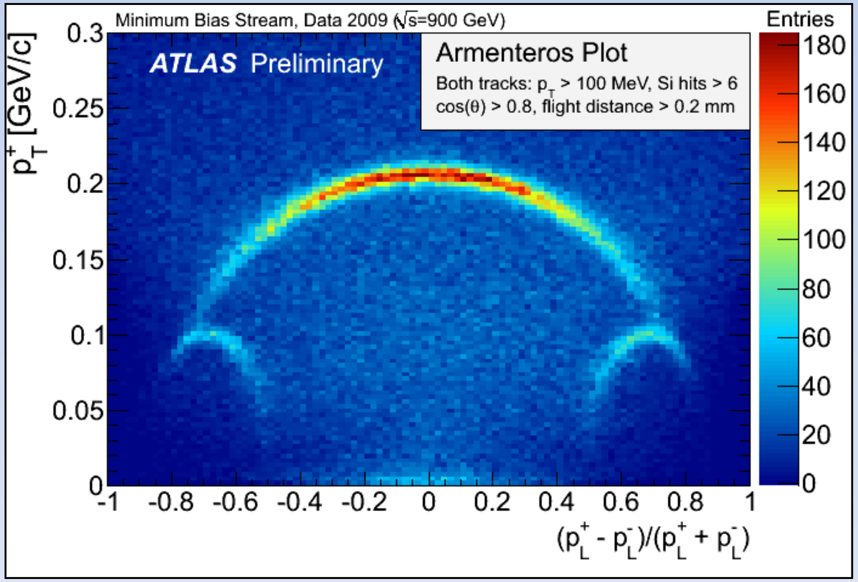

http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html



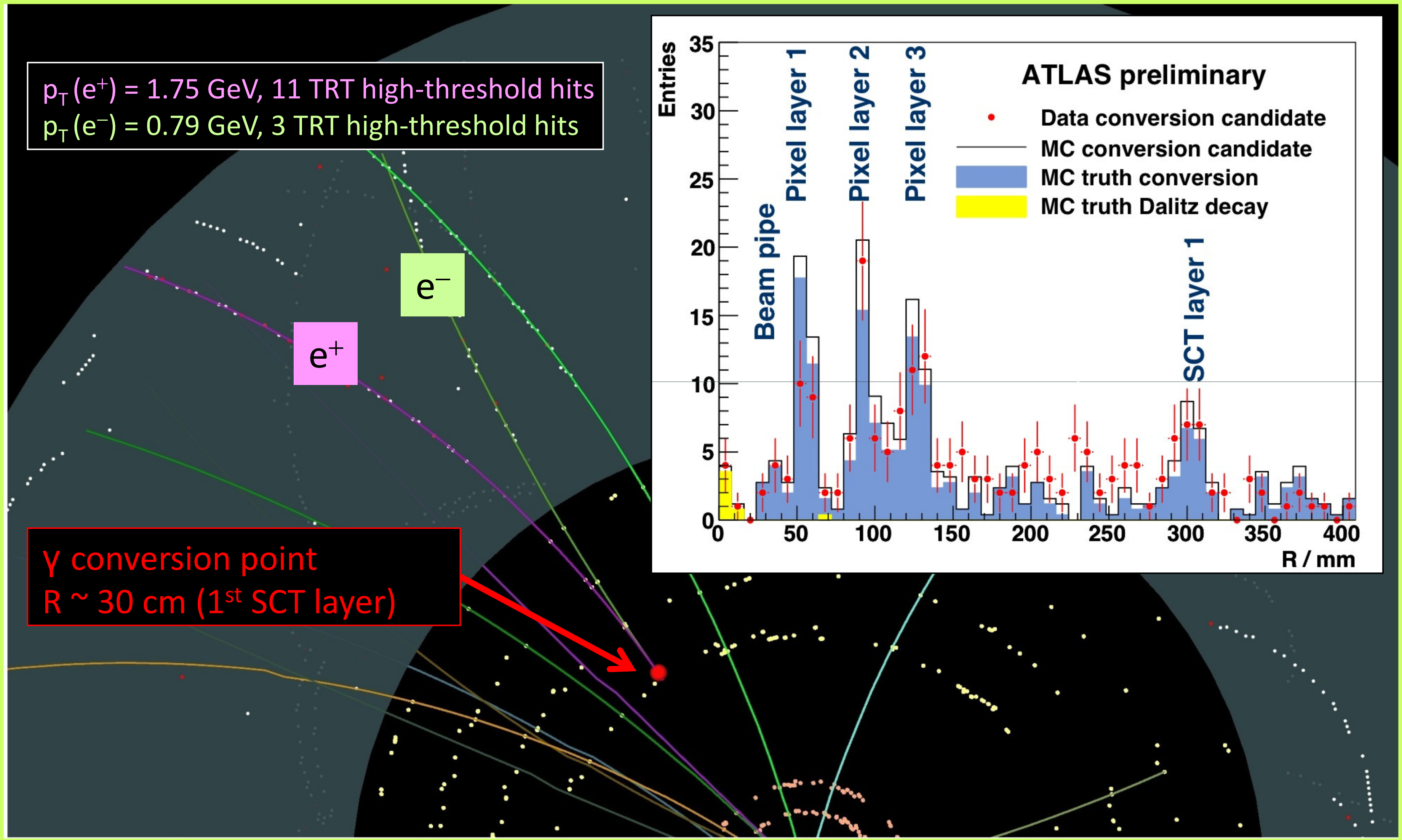


Armenteros Plot: p_T vs $(p_L^+ - p_L^-)/(p_L^+ + p_L^-)$

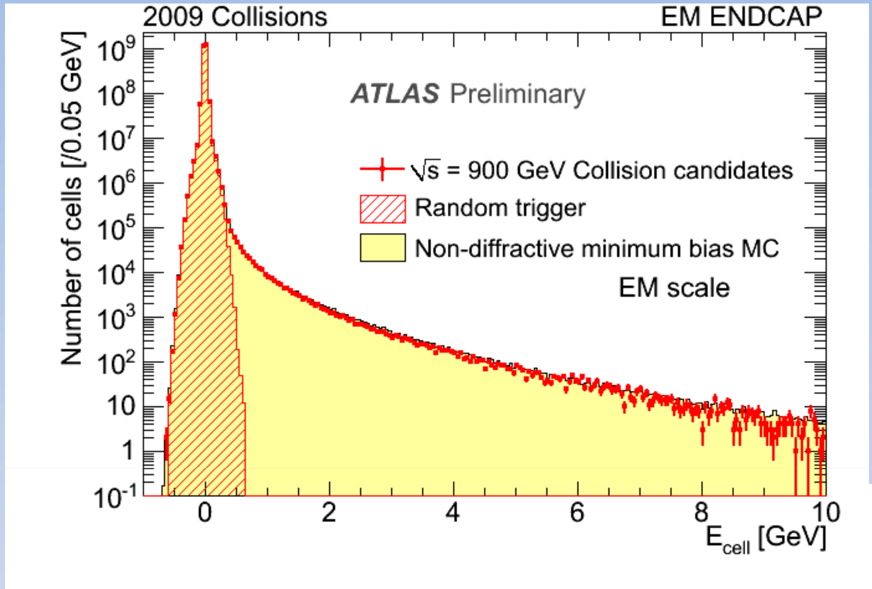




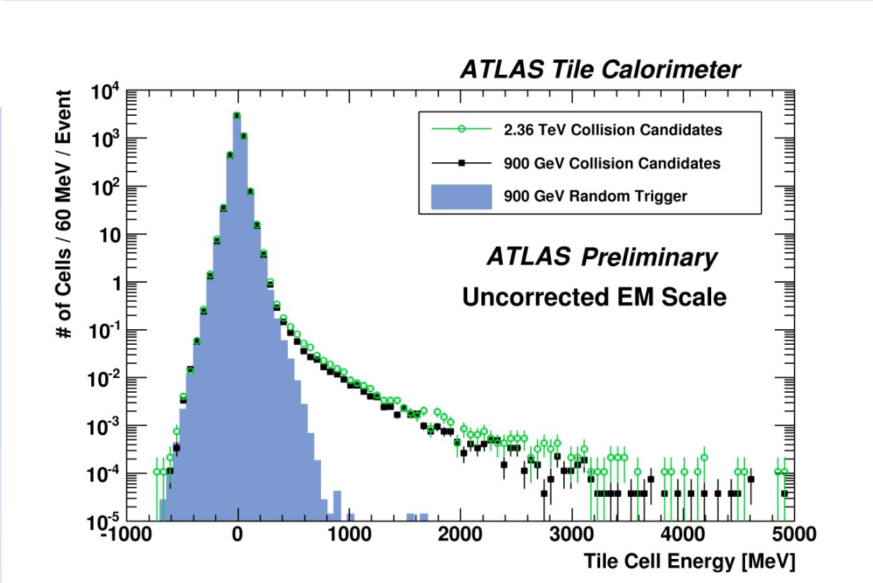
Conversions



Calorimetry

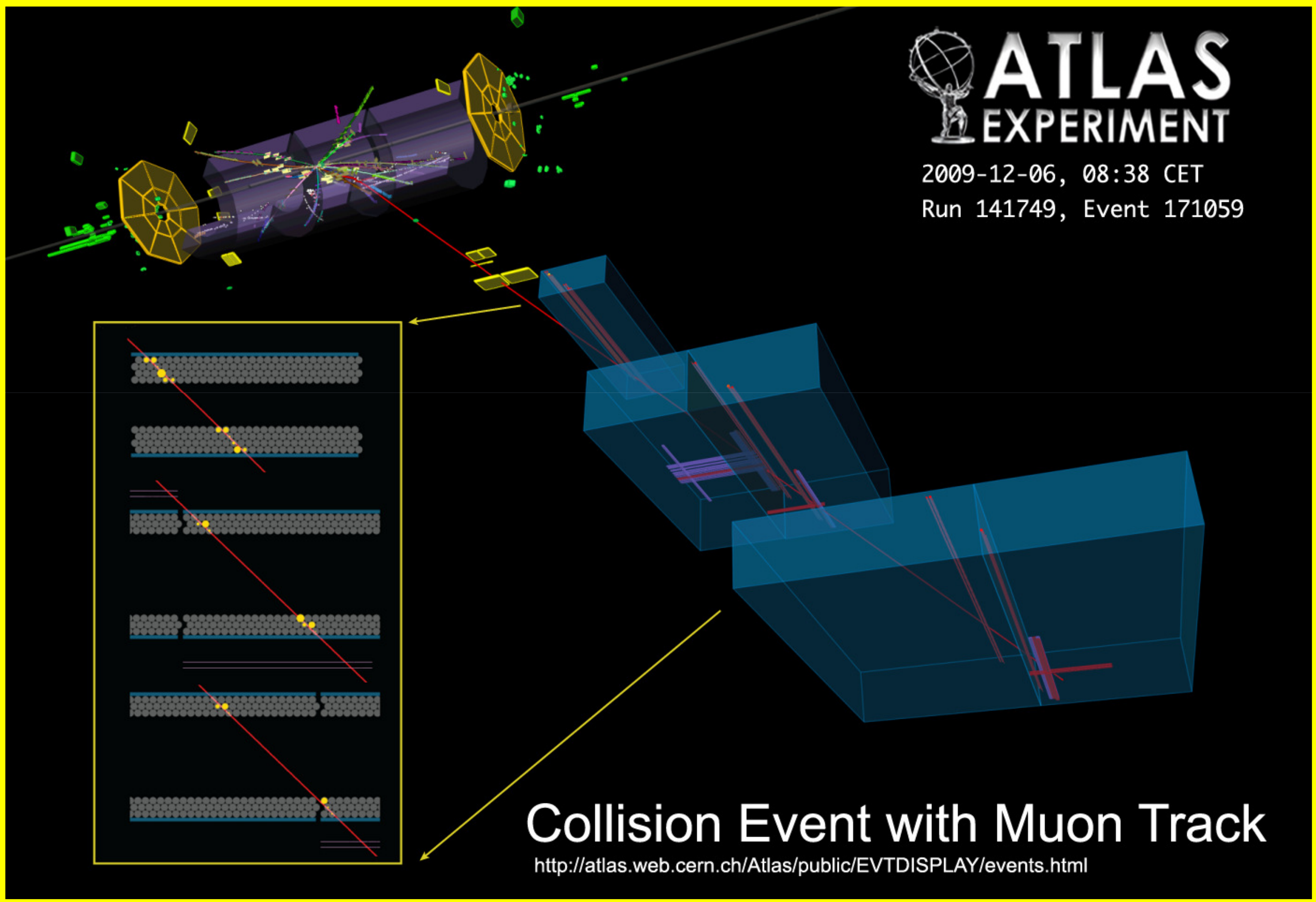


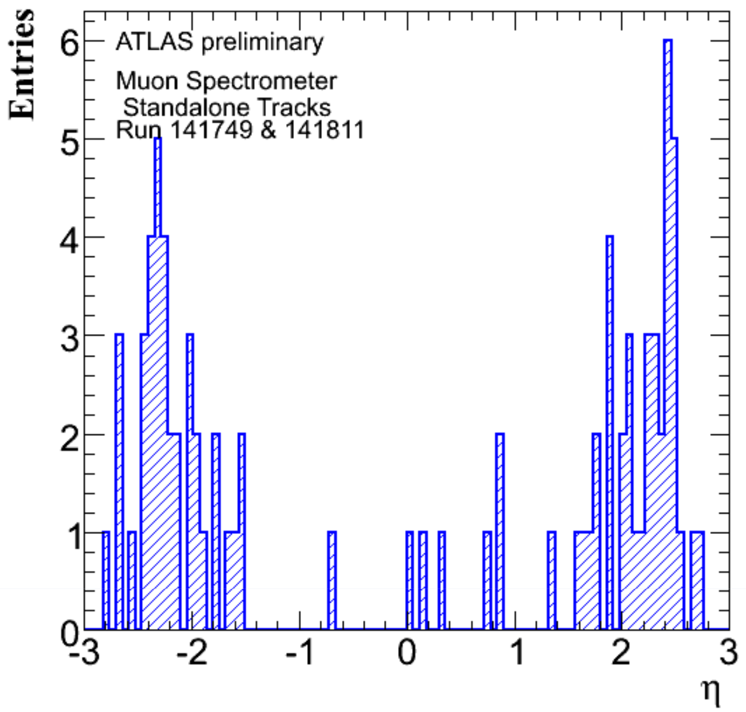
Energy of Cells in EM LAr End-cap Calo



Energy of Cells in Hadronic Tile Calo

Muon Spectrometer

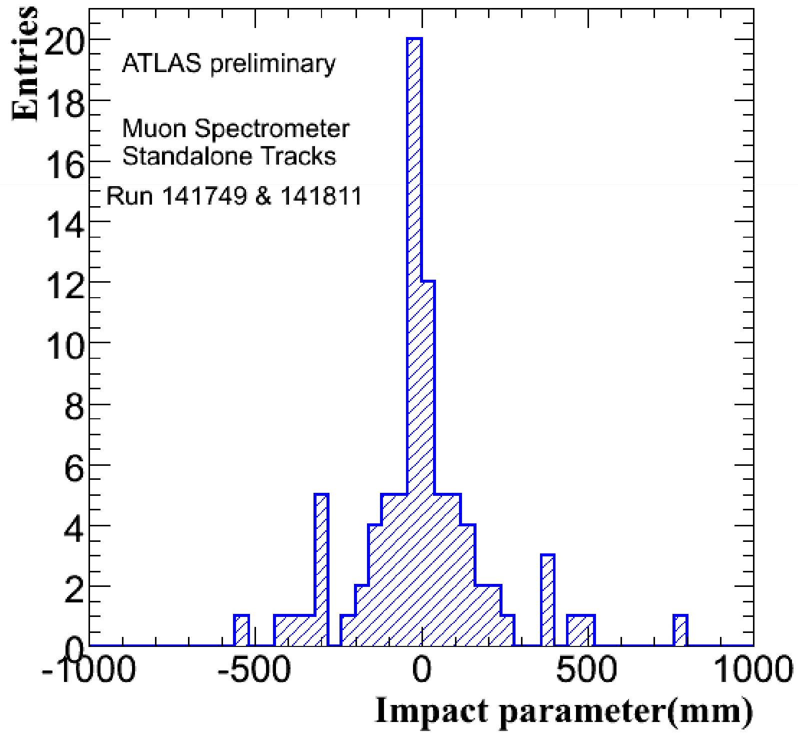




|η| of Muon Tracks

Peaked at high values for Min-Bias

(At low p_T, only forward tracks have enough p to traverse calorimeters)



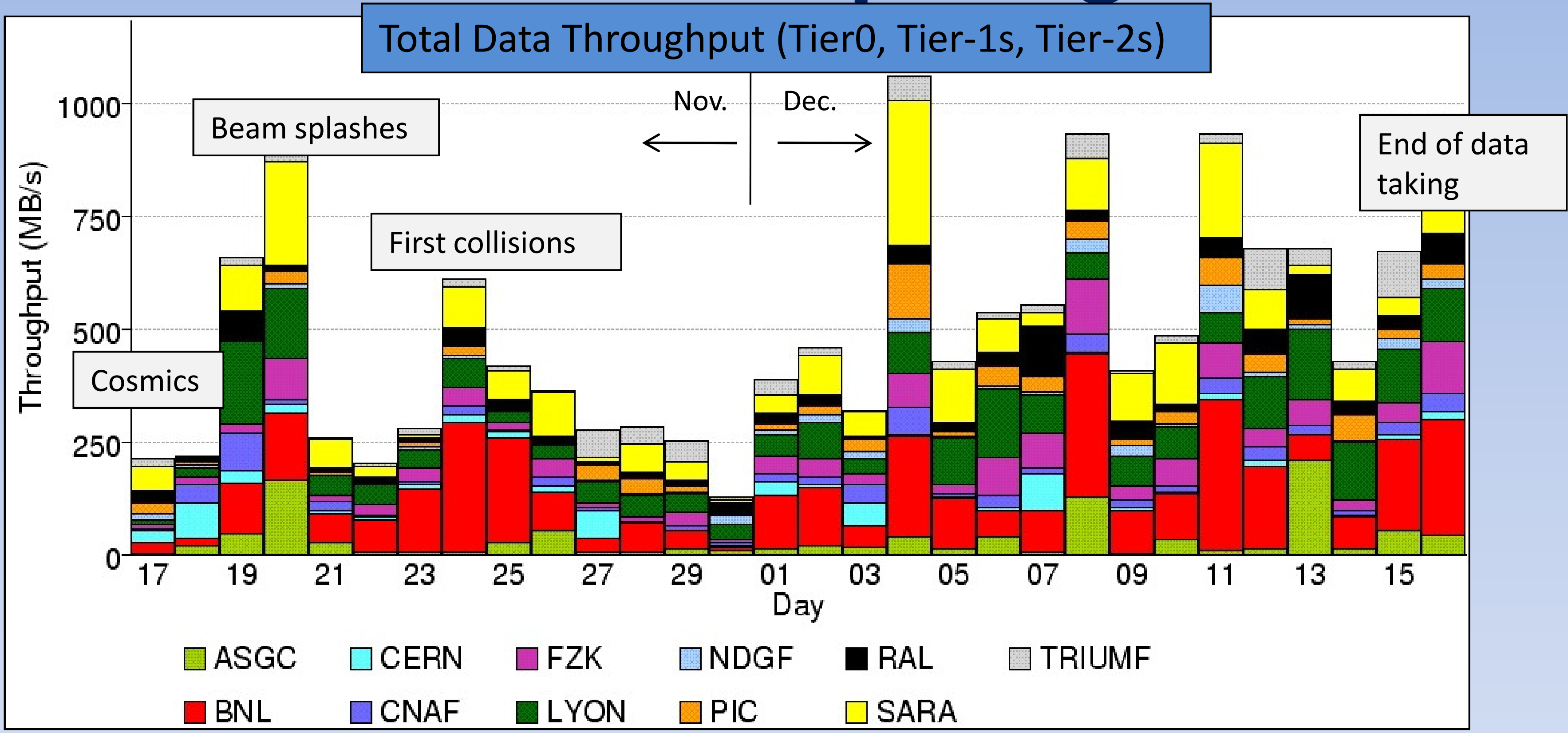
According to MC (low p_T threshold):

- 78% π/K decays
- 22% c/b decays

Impact Parameter of Muon Tracks

Expect width due to multiple-scattering of 200 mm for 3 GeV muons

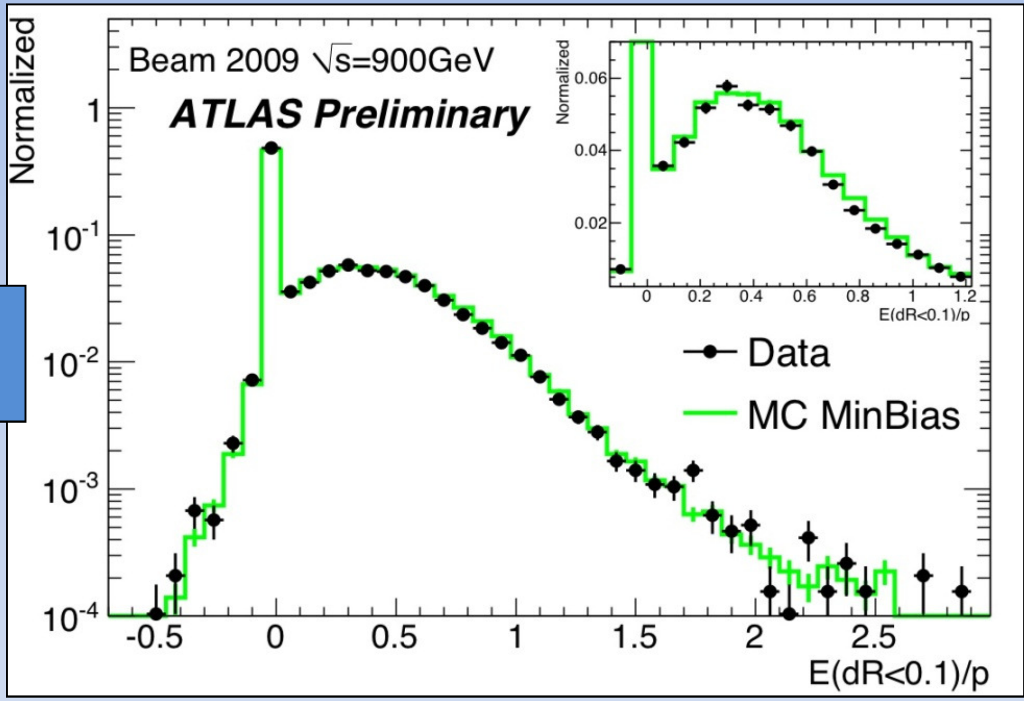
Grid Computing



- 0.2 Pbytes of data stored since 20 Nov 2009
- 8 hours between collisions in ATLAS and data arriving at Tier-2
- Reprocessing (align, calib) done at Tier-1s over Xmas

Combined Performance

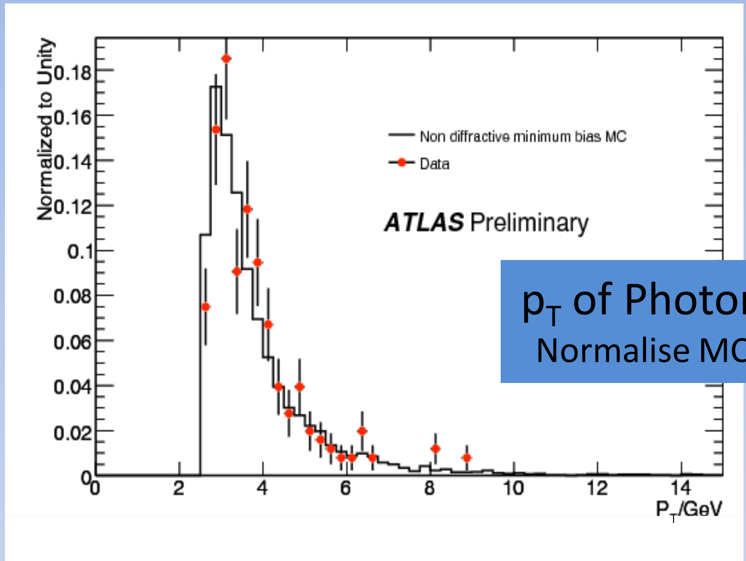
E(Calo)/p(ID)
for Isolated Hadrons



$|\eta| < 0.8$
$0.5 < p_T < 10$ GeV
Cluster energy at EM scale

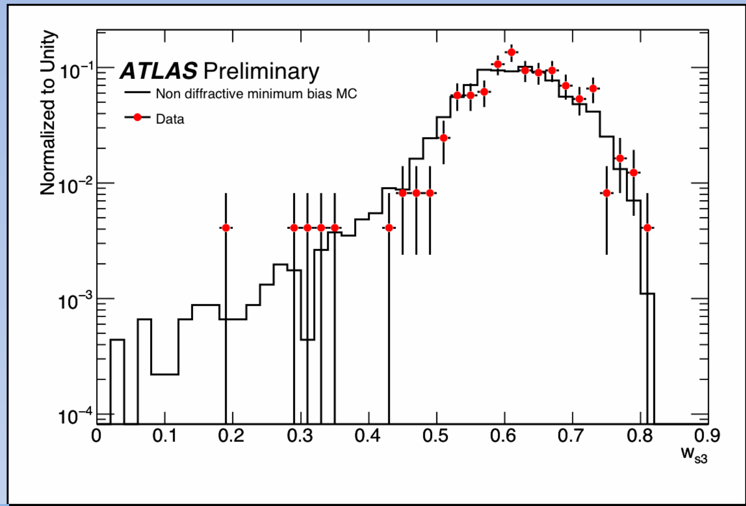
Good agreement in the (challenging) low-E region indicates good description of material and shower physics in G4 simulation (thanks also to years of test-beam)

Photon Candidates



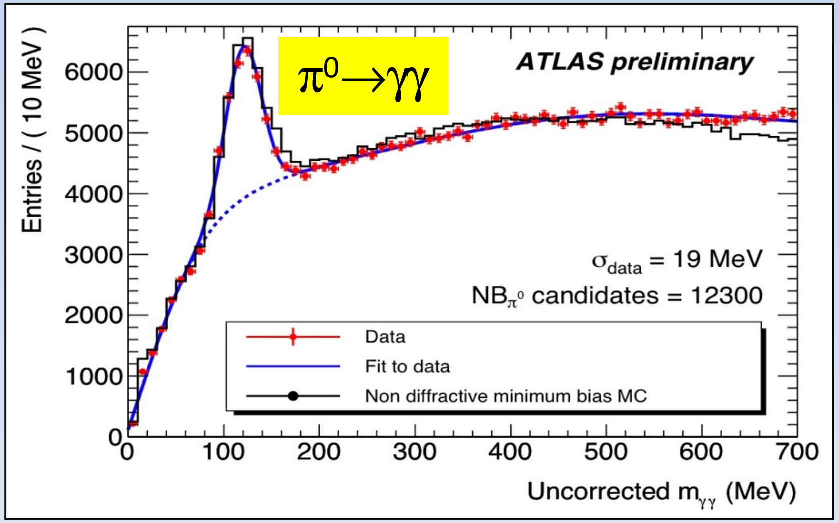
p_T of Photon Candidates
Normalise MC to Data events

p_T > 2.5 GeV



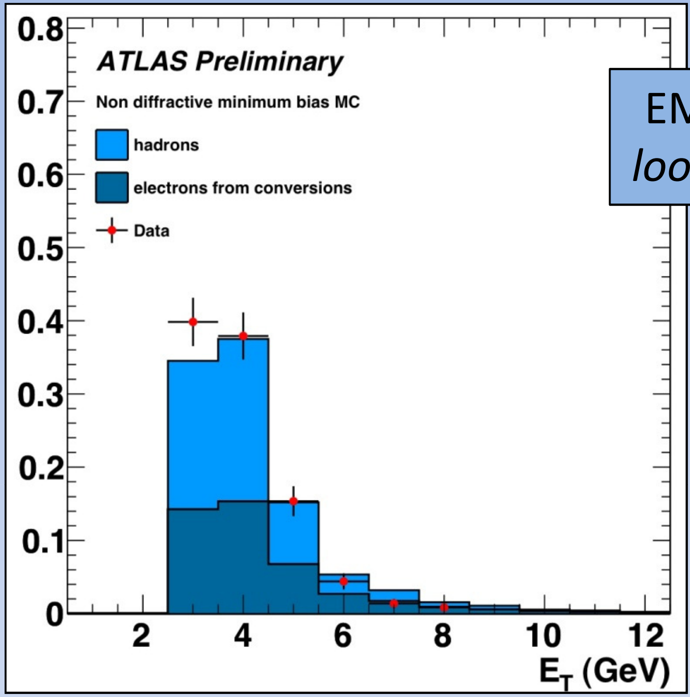
Width in η of Photon Candidates
Normalise MC to Data events

$$w_{s3} = \sqrt{\sum E_i (i - i_{max})^2 / \sum E_i}$$



Mass of γγ pairs
Shower shapes compatible with photons
$E_T(\gamma)$ > 300 MeV; $E_T(\gamma\gamma)$ > 900 MeV
No corrections for upstream material

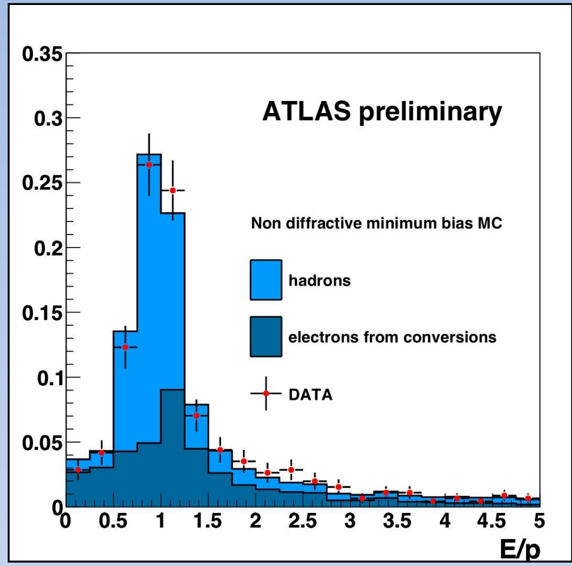
Electron Candidates



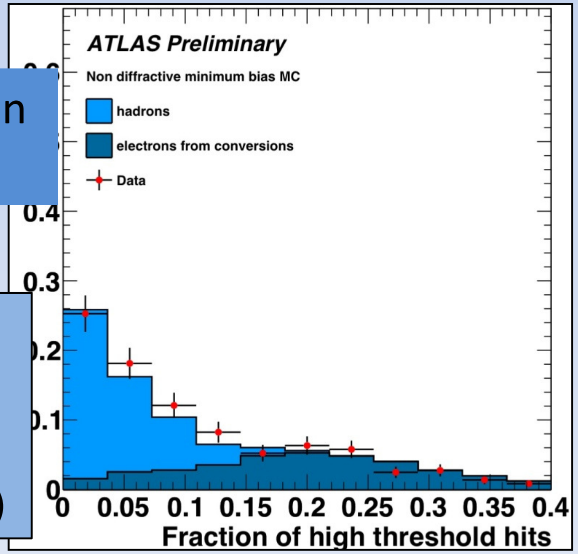
p_T of Photon Candidates
Normalise MC to Data events

EM clusters E_T > 2.5 GeV
loosely matched to a track

E(Calo)/p(ID)



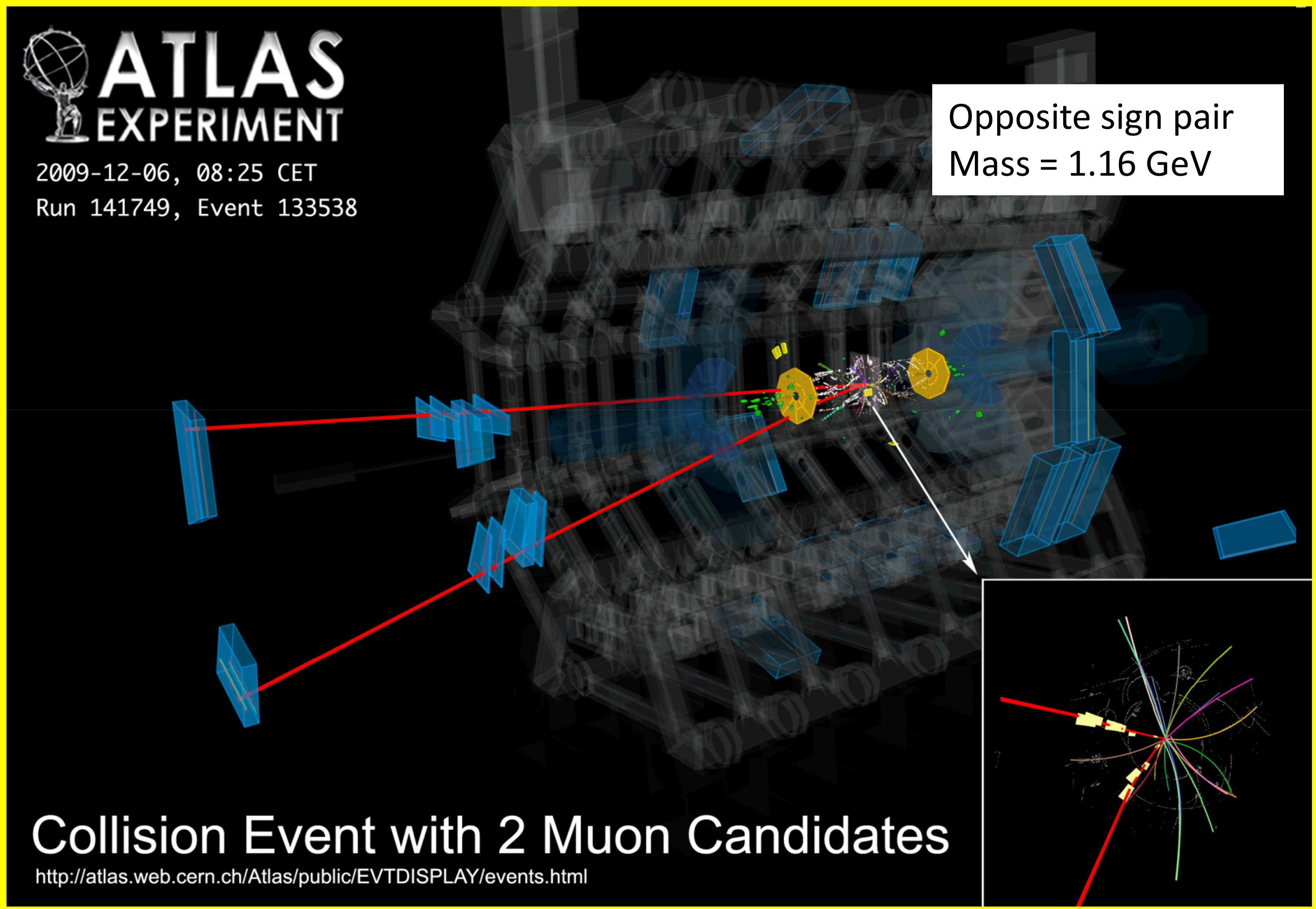
Transition Radiation in TRT



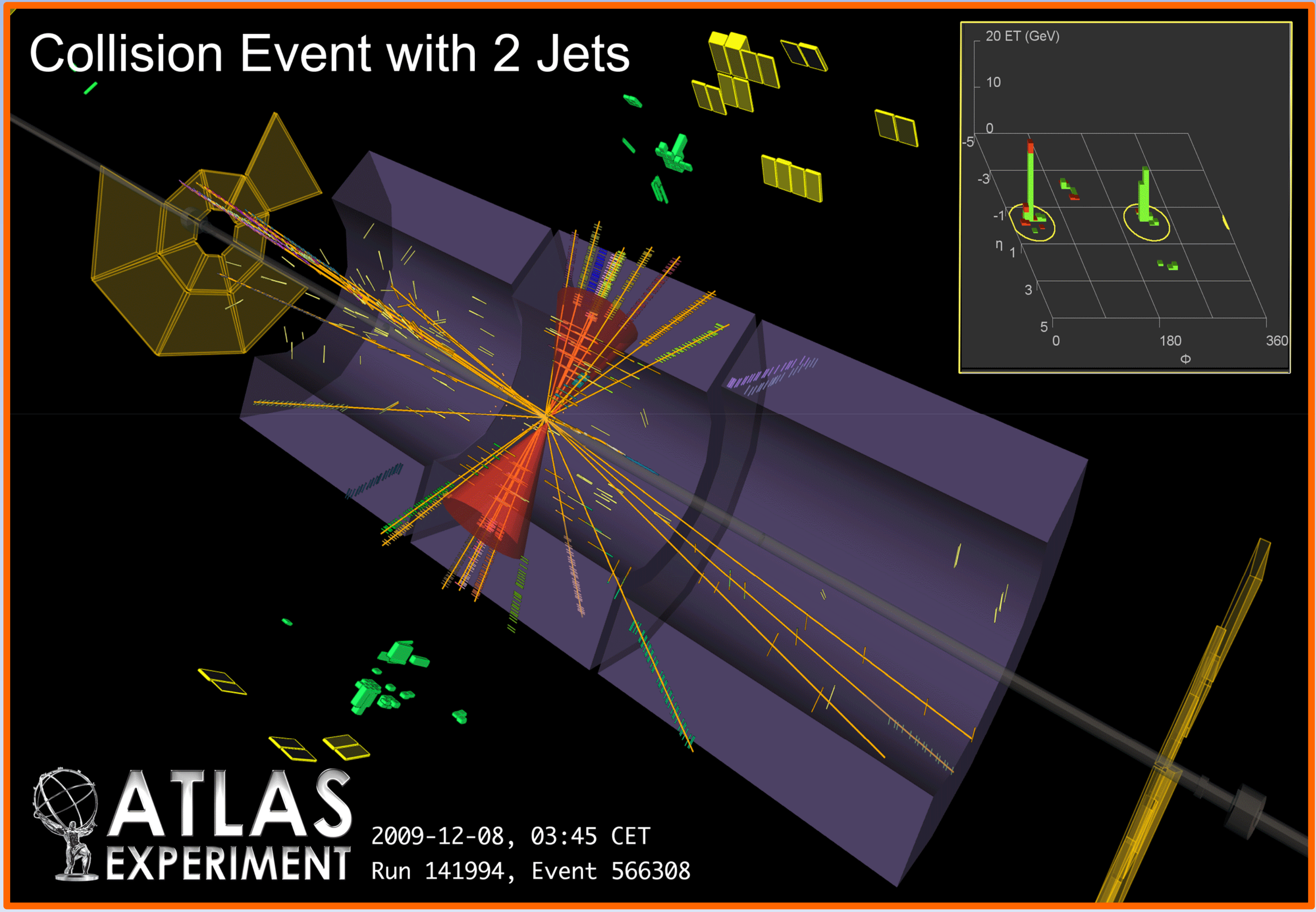
According to MC:
- 70% hadron fakes
- 30% electrons from conversions

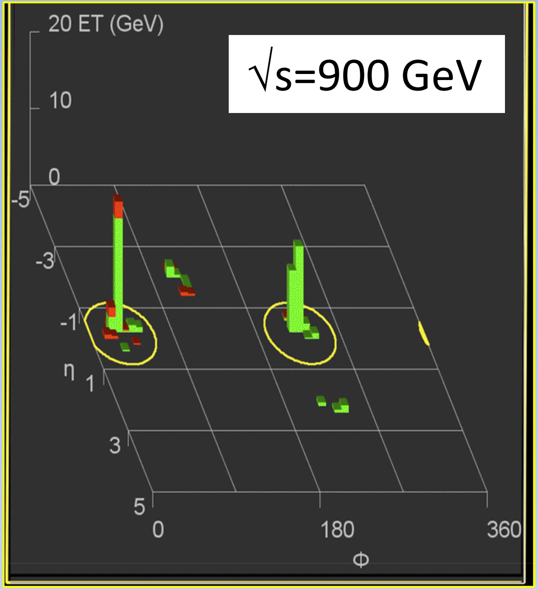
In 330k MB events:
- 783 candidates
- 364 loose criteria (Layer2 shape)
- 87 med criteria (+ Strips shape)
- 19 tight criteria (+ track match, E/p, TR)

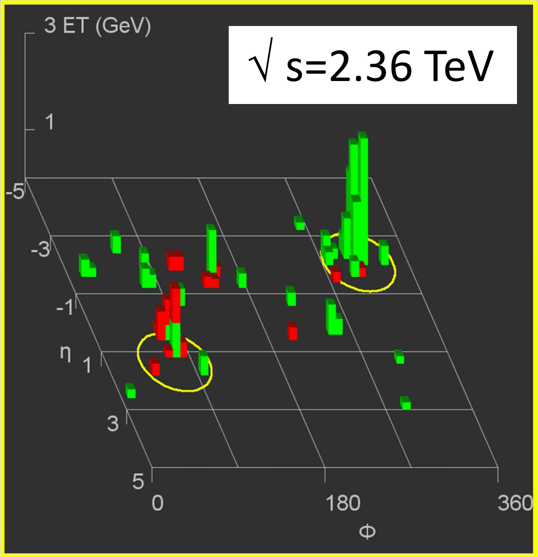
Muons


ATLAS EXPERIMENT
2009-12-06, 08:25 CET
Run 141749, Event 133538
Opposite sign pair
Mass = 1.16 GeV
Collision Event with 2 Muon Candidates
http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

Jets


Collision Event with 2 Jets
20 ET (GeV)
10
0
-5
-3
-1
η
1
3
5
0
180
360
Φ
ATLAS EXPERIMENT
2009-12-08, 03:45 CET
Run 141994, Event 566308

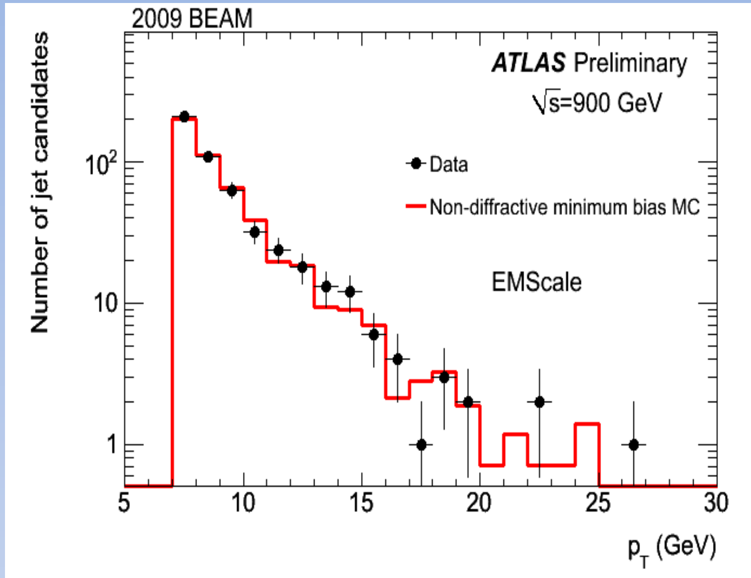


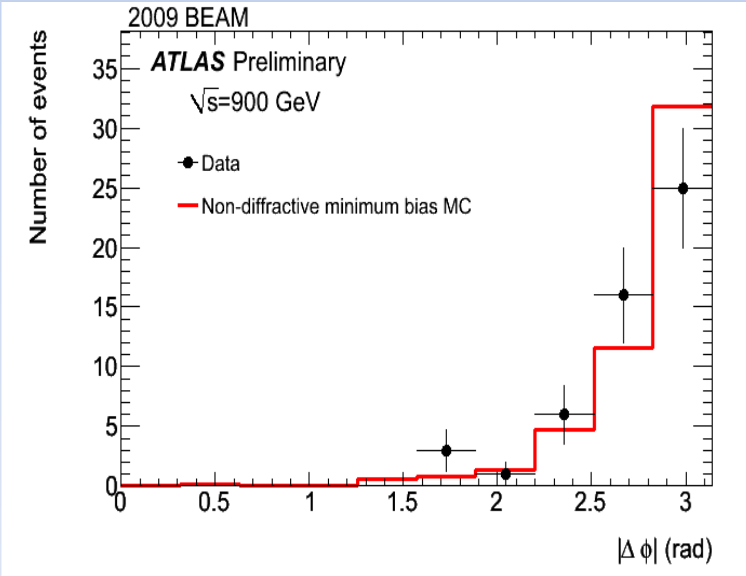


p_T

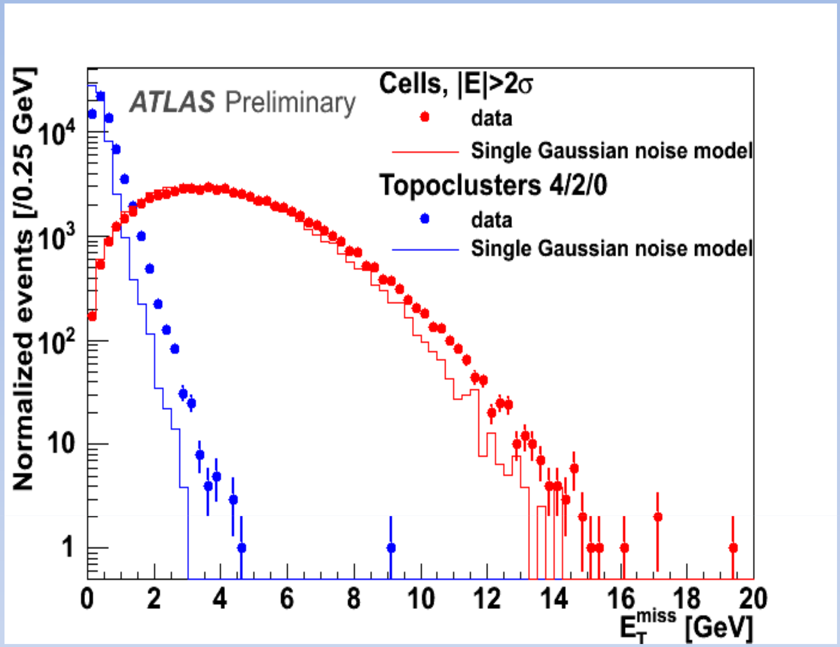
Use anti-k_T jet algorithm with D=0.4

$\Delta\phi$ between two highest-E_T jets





Missing Energy

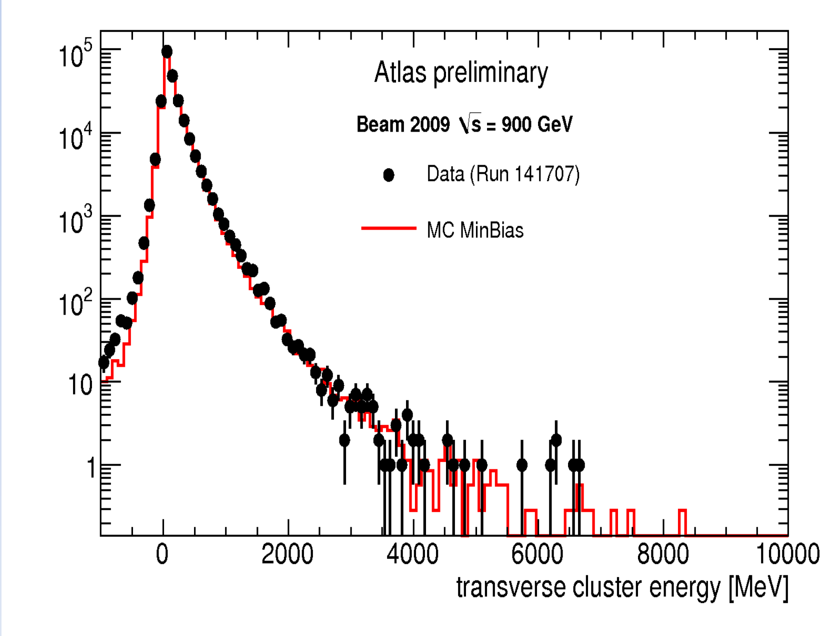


E_T(miss) calculated from Calo Clusters and "Topological" Calo Clusters in Random Trigger (empty) Events

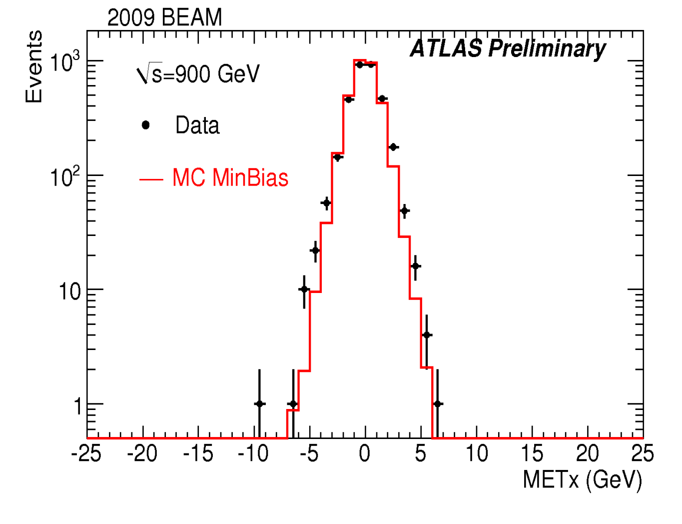
Simple model for noise – reasonable, but not yet perfect

"Topological" Clusters are formed by clustering Calo cells with E>0 in 3D so as to reduce effects of noise

Topological Calo Clusters provide an estimate of E_T(miss) which is more robust against noise compared to using all Calo Clusters

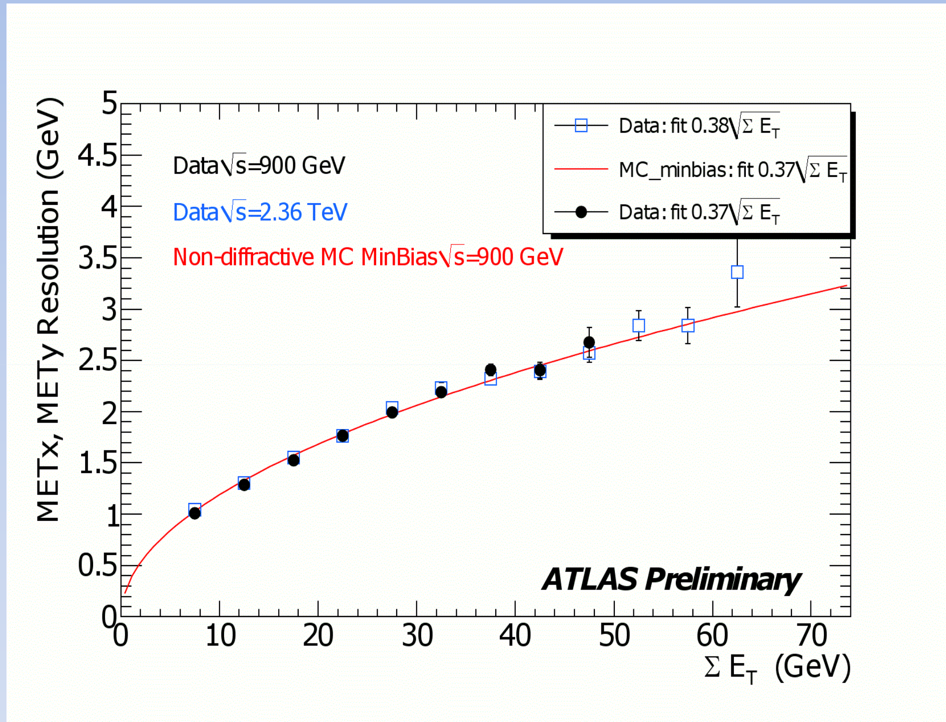


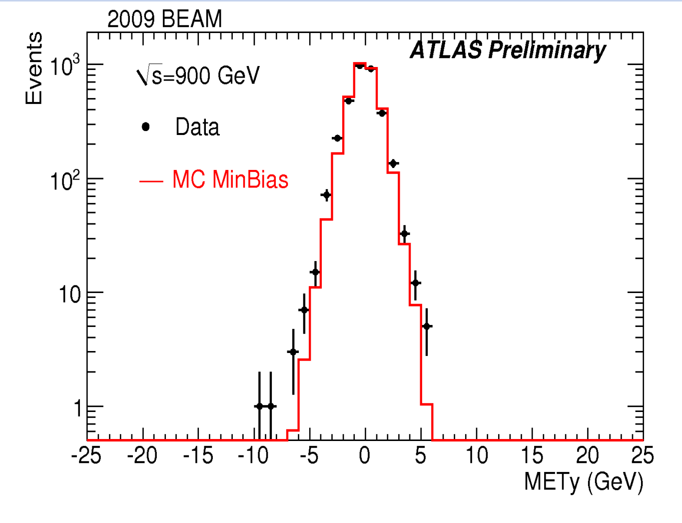
E_T "Topological" Calo Clusters in Minimum Bias Events



Use "Topological" Clusters

x & y components of E_T(miss)





Resolution of x & y components of E_T(miss)

Outlook

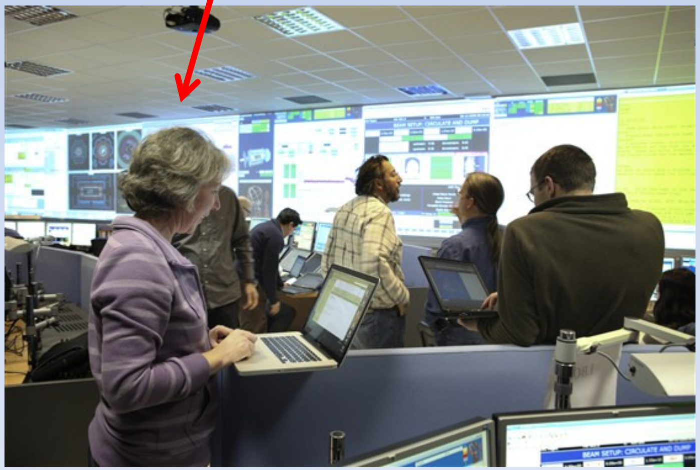
Need to

- Improve Alignment of Inner Detector – goal O(10) μm
  Use Hardware (FSI),Tracks, Resonances
  Likewise for Muon Spectrometer
- Confirm X_0 – goal O(1)%
  Use Conversions, Brem, K^0 decays, J/ψ
- Commission vertexing for B-decays, b-tagging, τ's
- Check Energy-scales in Calorimeters
  Use J/ψ & $Z \rightarrow ee$, E/p, $j\gamma$ events
- Calibrate b-tagging and commission more sophisticated algo's
- Etc etc etc etc

Problems

We need a bigger control room !

The Inner Detector Project Leader needs a chair !



- No disasters, no big problems
- Recall operating fractions between 98 and 100%
- Replace Inner Detector Evaporative Cooling Plant with more robust system
- Some Heater Pads in ID have died
- A few inoperative Cooling Circuits in SCT & Pixels
- LAr Calo Optical Transmitters (1%) have died; back-up being developed
- Follow evolution of: ID Optical Transmitters, Calo LV Power Supplies, Muon Spectrometer Power Supplies, RPC Gas Inlets
- Rate limitations in CSC Muon Trigger Chambers

Early Physics

This year, hoping for 200-500 pb^{-1} at $\sqrt{s}$ = 7-10 TeV

Channel (electrons)	Primary Trigger (L1Calo)	Events per pb^{-1} (7 TeV)
$b/c \rightarrow eX$	e10	100,000
$J/\psi \rightarrow ee$	2e5	1,500
$W \rightarrow e\nu$	e20	2,000
$Z \rightarrow ee$	e20	200

- Minimum Bias: $d^2N/d\eta dp_T$ .... not easy !
- B-Physics: Onia x-sections
- QCD: $d\sigma_{jet}/dp_T$
- W/Z: x-sections
- Start searches for Higgs, SUSY, $X \rightarrow ee, \mu\mu, \gamma\gamma$

Conclusions

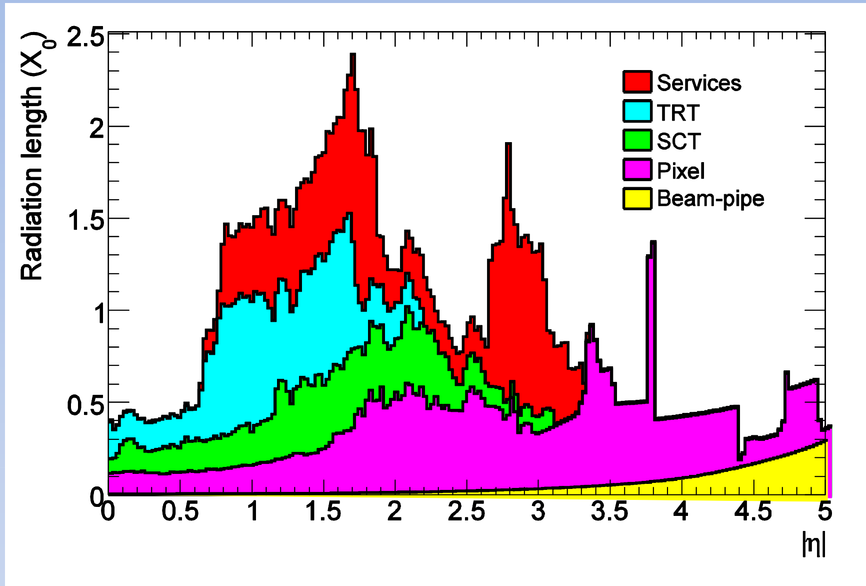
- ATLAS was very excited with the rapid start-up of the LHC in Nov & Dec 2009 – more successful than we dared to hope for
- ATLAS was ready on Day-1 and again has performed better than we dared hope
- Our Software is working well, as is the whole Computing Infrastructure (Grid)
- Initial results look very good: excellent agreement with expectations – the result of much effort in Test-beams and tuning MC's
- There is <u>lots to do</u>
- ATLAS is eagerly awaiting lots of data, at the highest energies

Thanks to ...

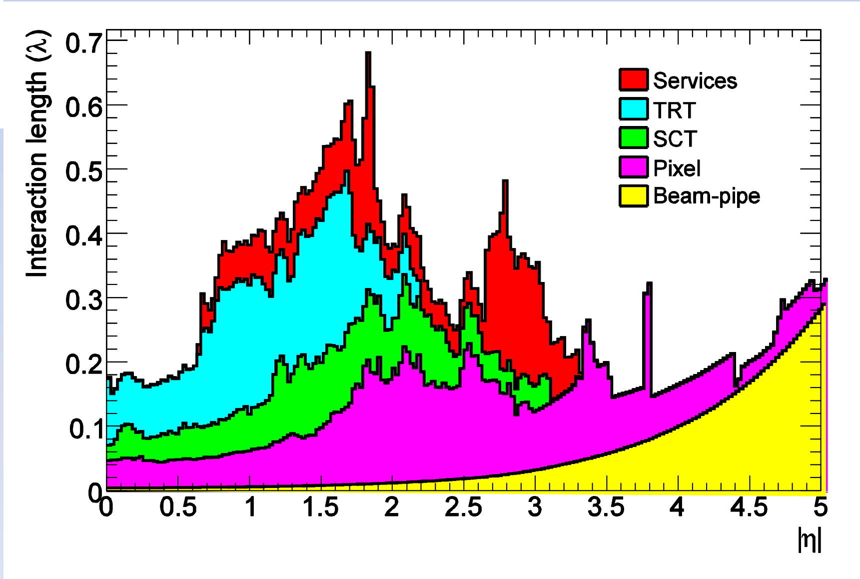
- **CERN Accelerator Team** for making it possible
- Our Engineers & Technicians for constructing & operating a beautiful detector

Back-up

ID Material

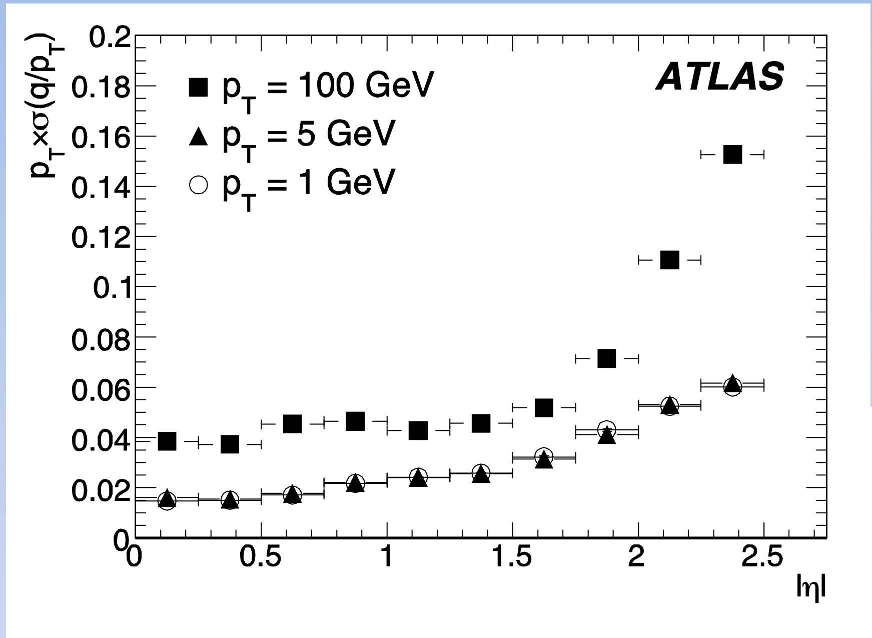


Radiation Lengths

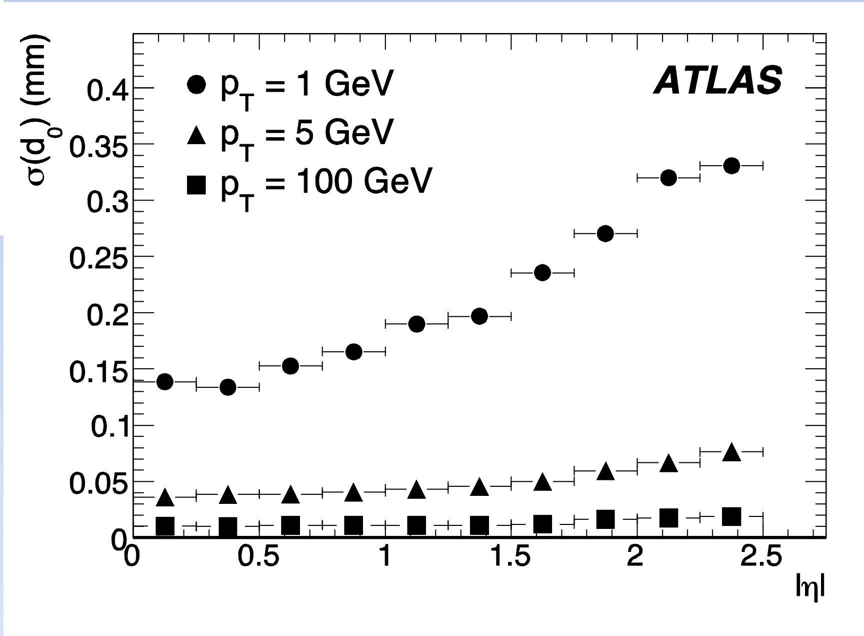


Interaction Lengths

Expected ID Resolutions



Relative p_T Resolution

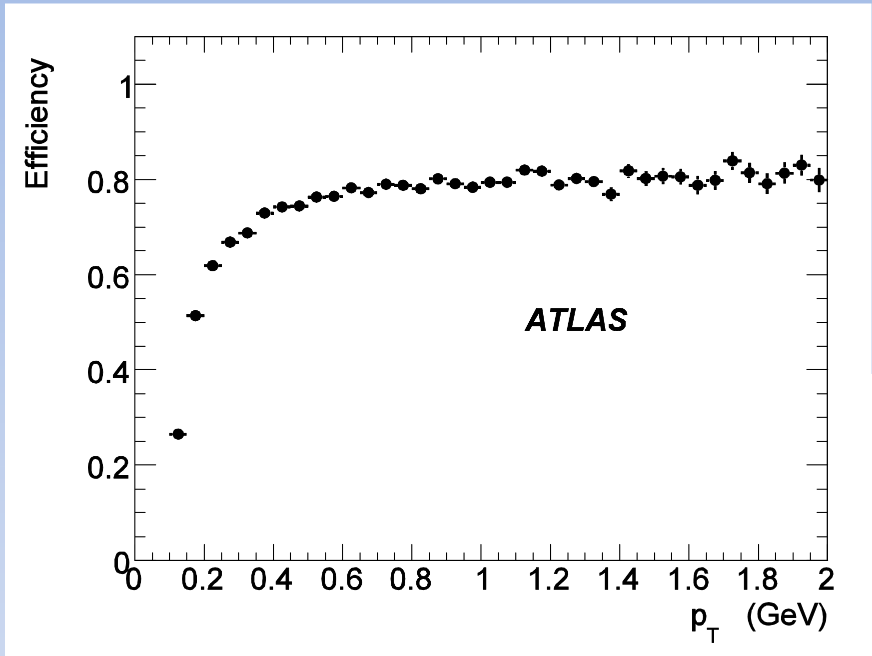


Impact Parameter Resolution

Expected ID Resolutions

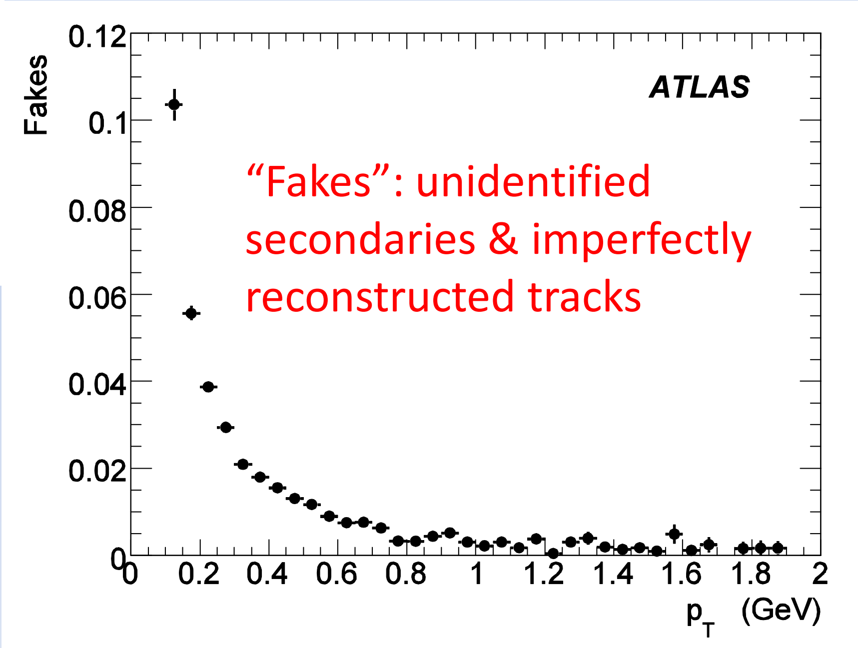
Parameter	$0.25 < \|\eta\| < 0.50$		$1.50 < \|\eta\| < 1.75$	
	$\sigma(p_T=\infty)$	Π (GeV)	$\sigma(p_T=\infty)$	Π (GeV)
Q/p_T	0.34 TeV^{-1}	44	0.41 TeV^{-1}	80
ϕ	70 μrad	39	92 μrad	49
$\cot\theta$	0.7×10^{-3}	5	1.2×10^{-3}	10
d_0	10 μm	14	12 μm	20
$z_0 \times \sin\theta$	91 μm	2	71 μm	4

Minimum Bias in ID



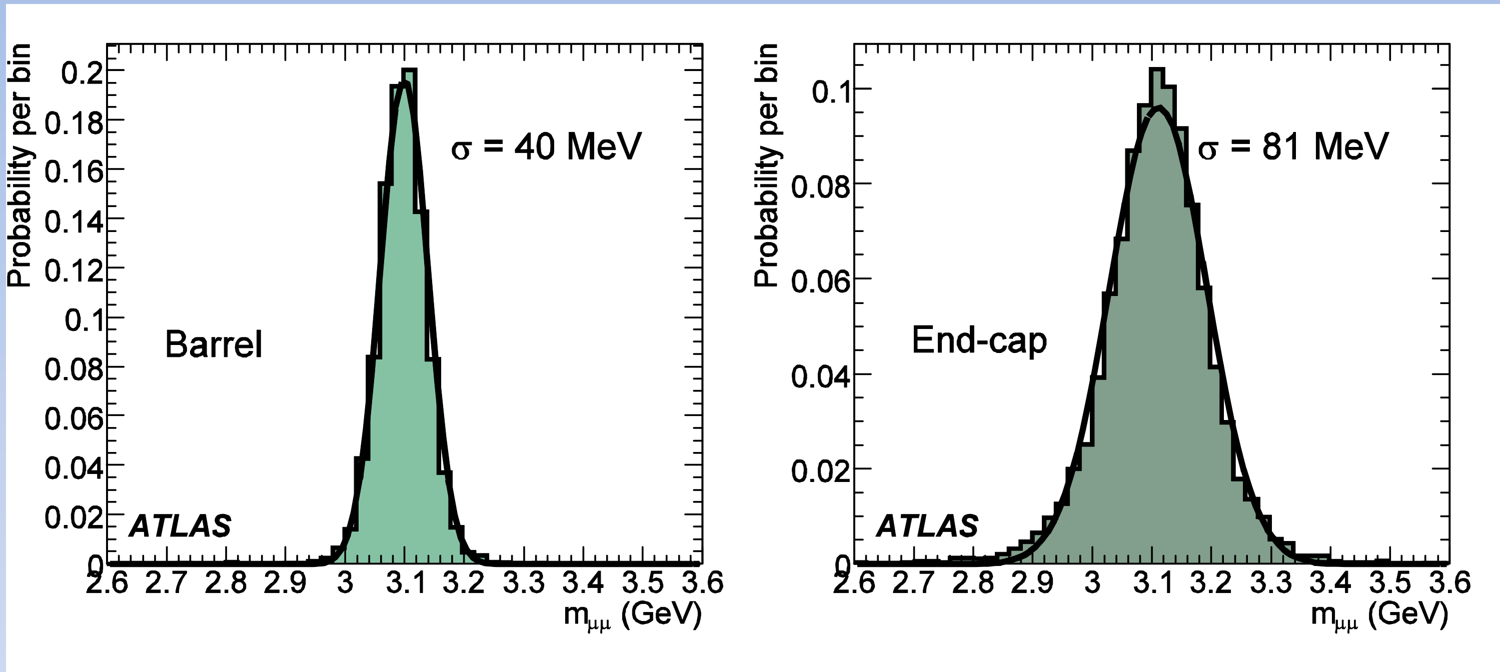
Efficiency

Default tracking for $p_T > 0.5$ GeV
Special algorithms to go down to ~ 0.15 GeV



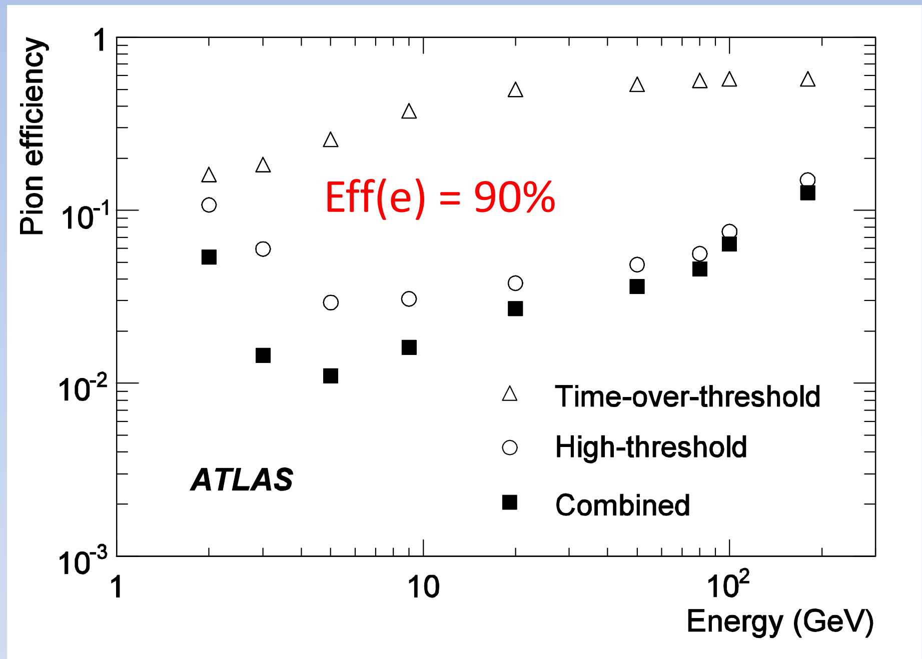
Fake Rate

J/ψ in ID

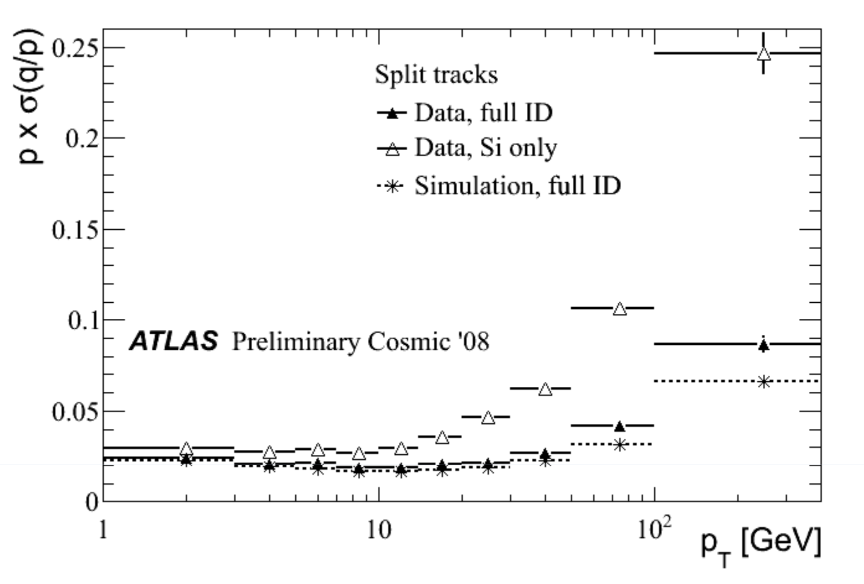


Probability per bin
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
σ = 40 MeV
Barrel
ATLAS
2.6 2.7 2.8 2.9 3 3.1 3.2 3.3 3.4 3.5 3.6
$m_{\mu\mu}$ (GeV)
Probability per bin
0.1
0.08
0.06
0.04
0.02
0
σ = 81 MeV
End-cap
ATLAS
2.6 2.7 2.8 2.9 3 3.1 3.2 3.3 3.4 3.5 3.6
$m_{\mu\mu}$ (GeV)

Pion "Efficiency" in TRT

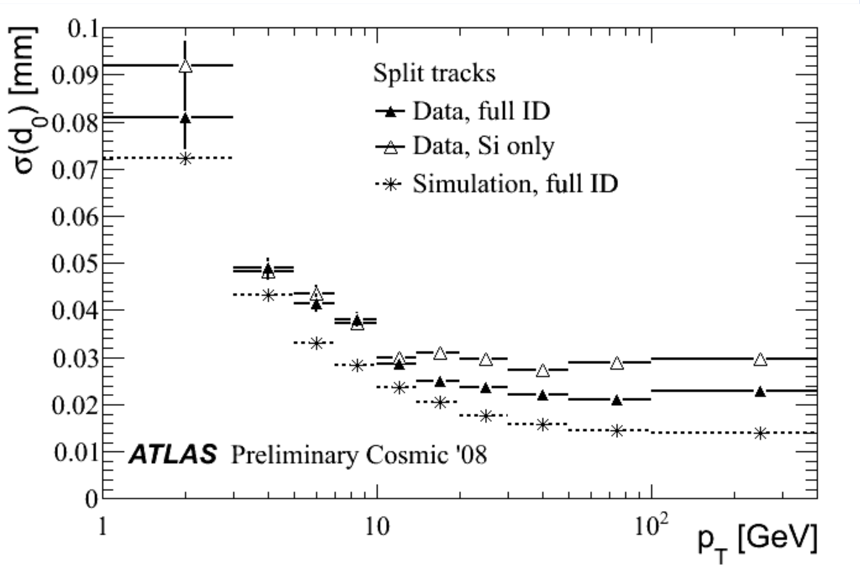


Cosmics in ID



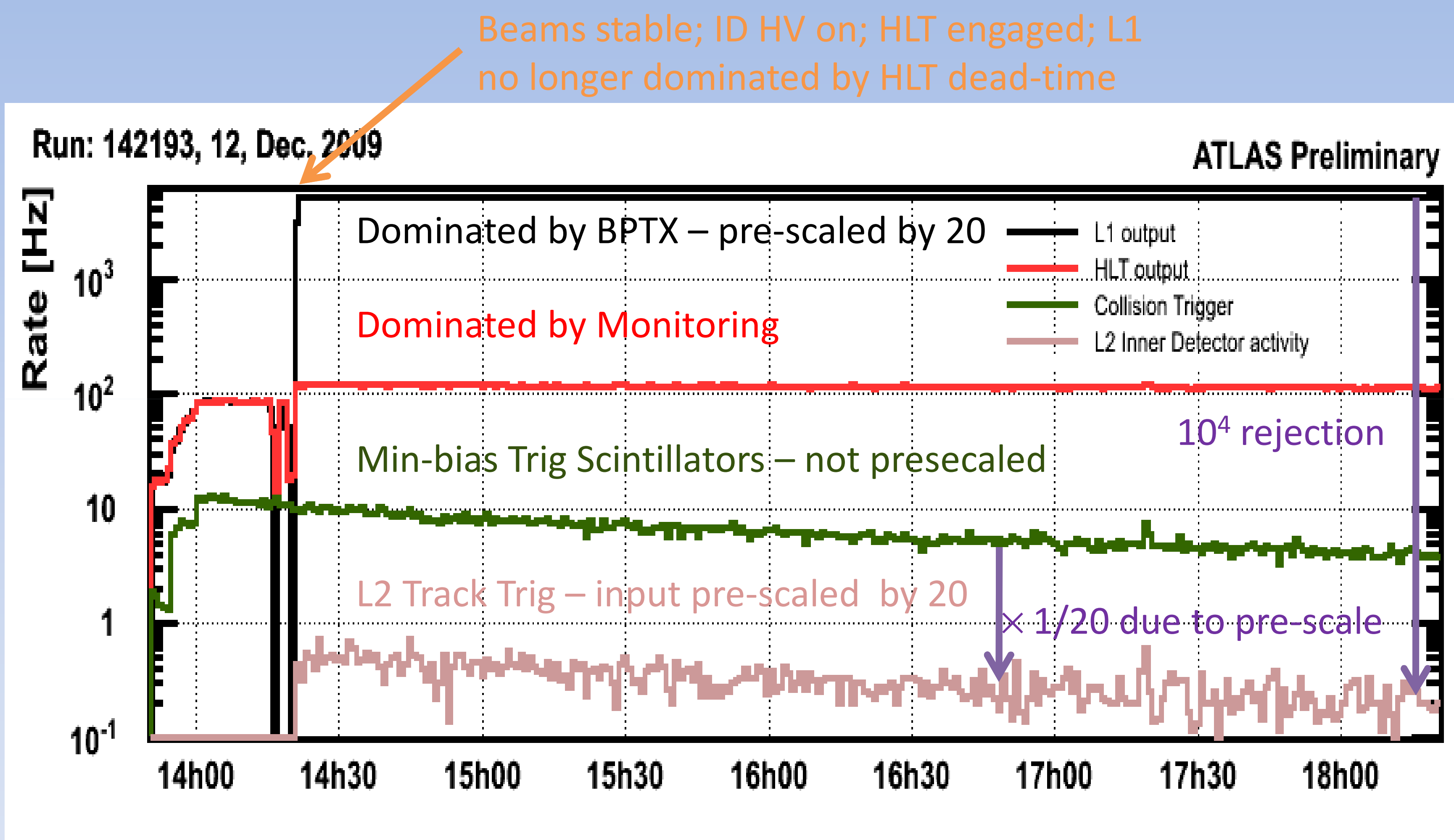
Relative p_T Resolution

Split tracks into two halves and compare parameters



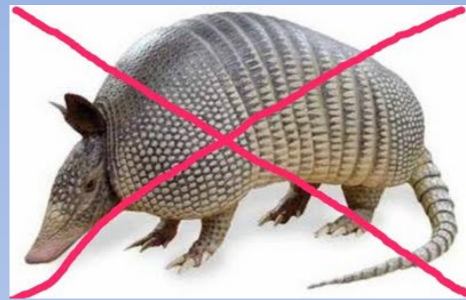
Impact Parameter Resolution

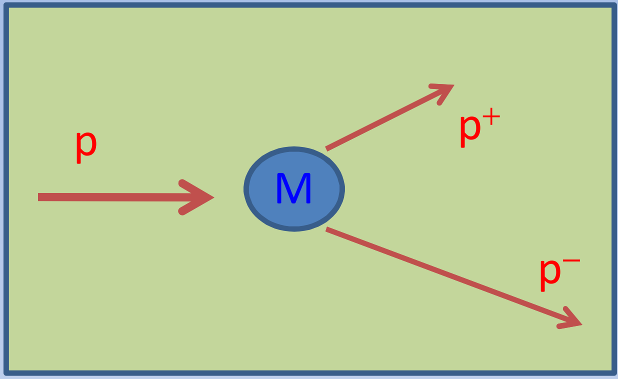
Trigger Rates



MBTS and L2 Track Trigger have similar rates – both selecting "central" events

Armenteros Plot





$$p_L^+ = \gamma(+p^*\cos\theta^* + \beta E^{*+})$$

$$p_L^- = \gamma(-p^*\cos\theta^* + \beta E^{*-})$$

$$p_T = p^*\sin\theta^*$$

$$R \equiv \frac{p_L^+ - p_L^-}{p_L^+ + p_L^-} = \frac{\beta(E^{*+} - E^{*+}) + 2p^*\cos\theta^*}{\beta(E^{*+} + E^{*+})} = \frac{(E^{*+} - E^{*+})}{M} + \frac{2p^*}{\beta M}\cos\theta^*$$

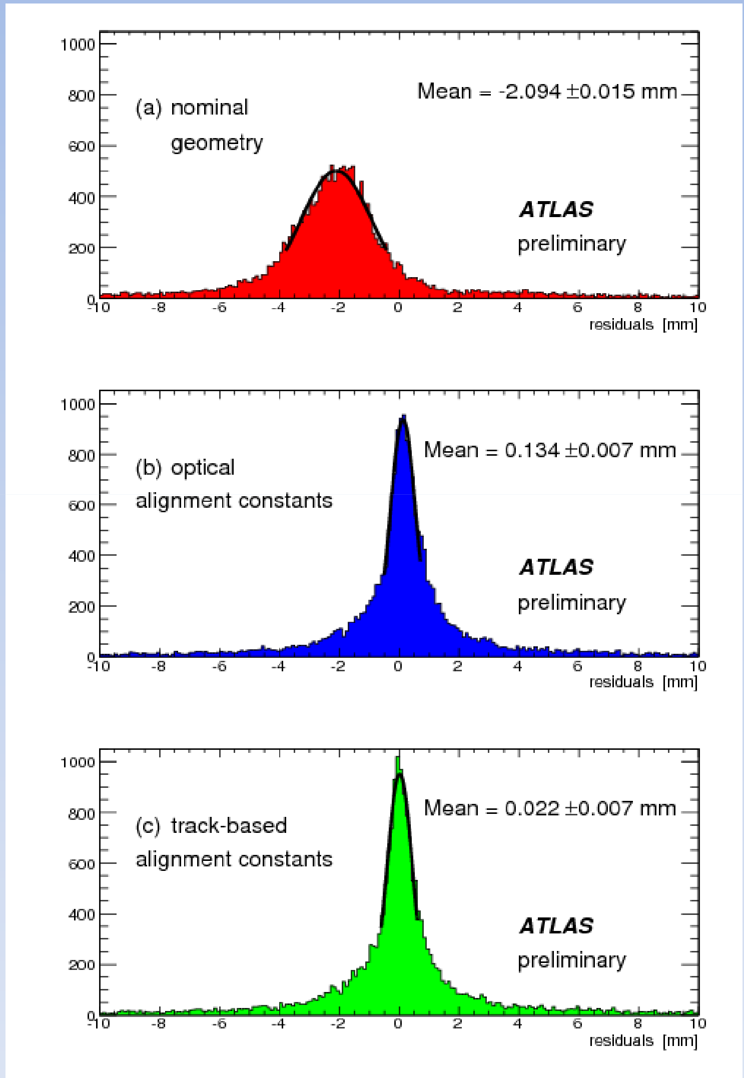
$$= f(M, m^+, m^-) + \tfrac{2}{\beta} g(M, m^+, m^-)\cos\theta^*$$

$$p_T = Mg(M, m^+, m^-)\sin\theta^*$$

$$\left(\frac{R - f(M, m^+, m^-)}{\frac{2}{\beta} g(M, m^+, m^-)}\right)^2 + \left(\frac{p_T}{Mg(M, m^+, m^-)}\right)^2 = 1$$

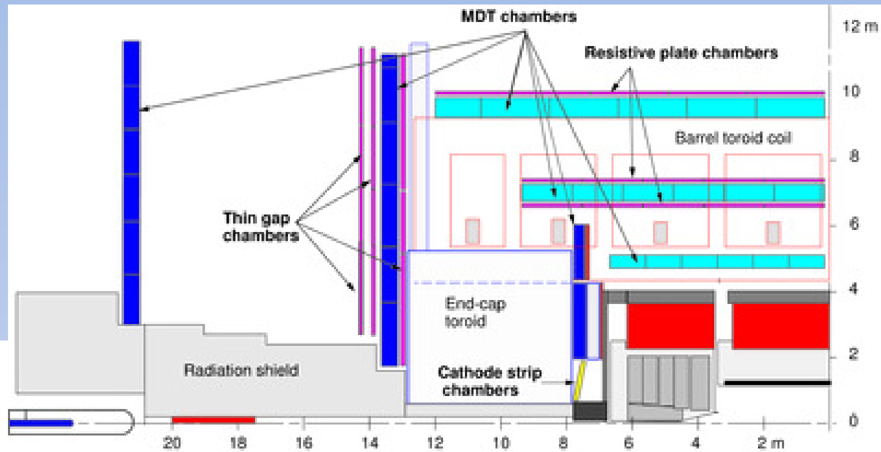
An ellipse, provided $\beta \approx 1$

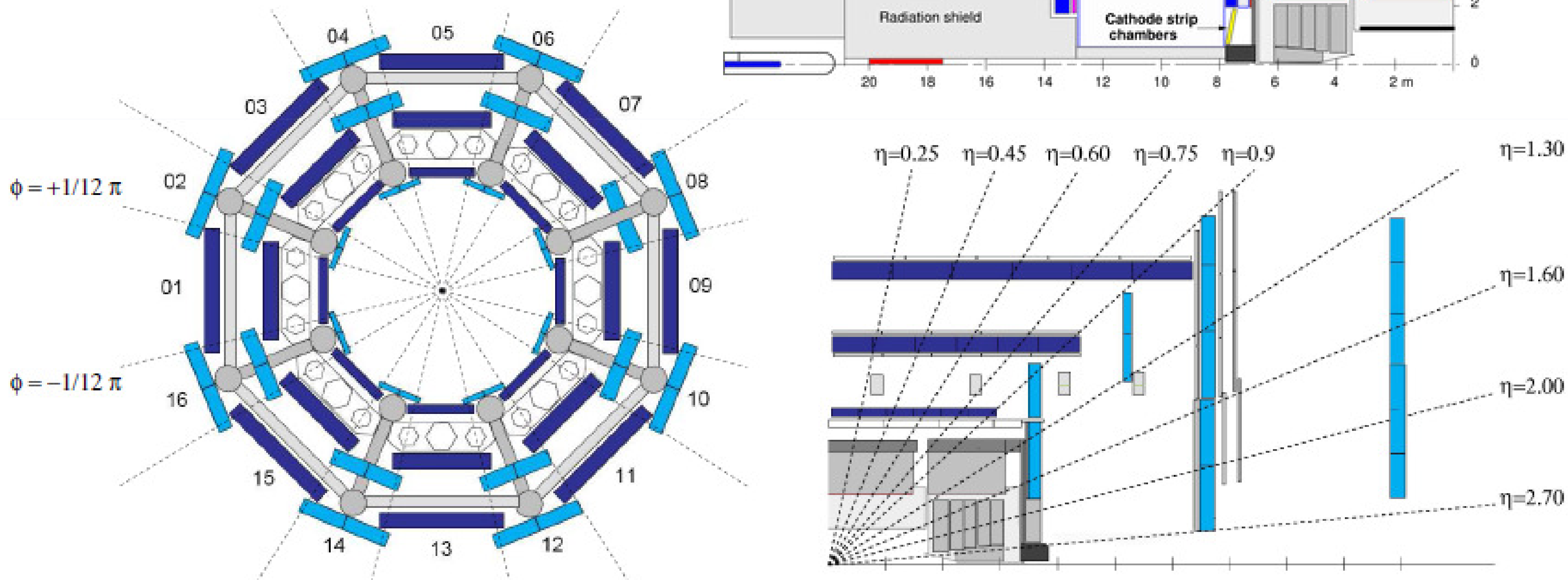
Muon Alignment



Target: 30 μm

Muon Spectrometer

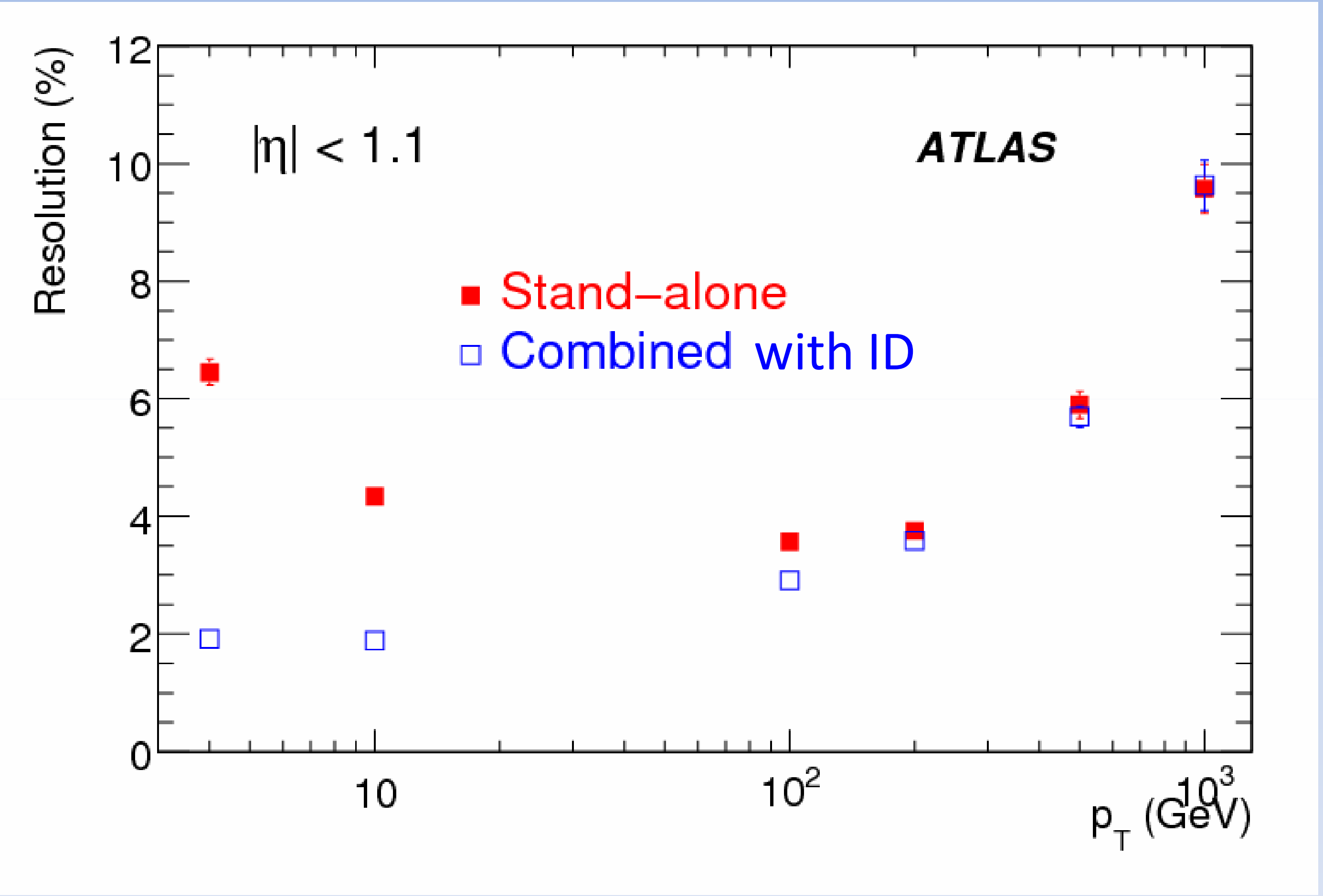




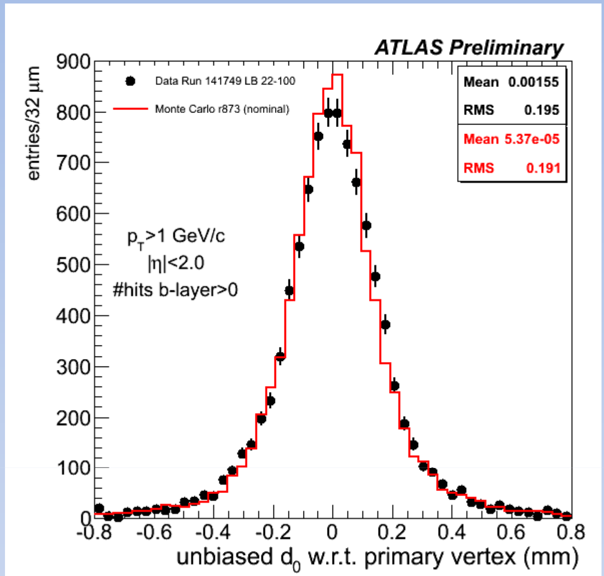
(a) ϕ-binning

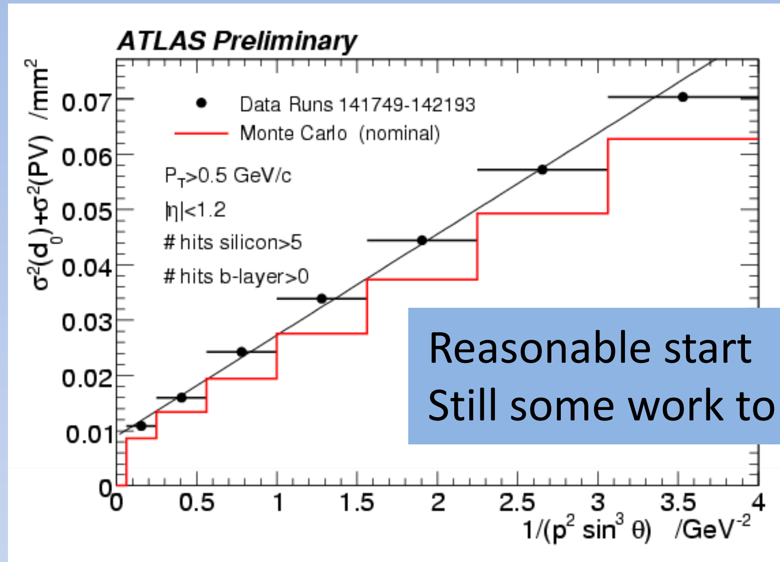
(b) η-binning

Muon Spectrometer Resolution



B-tagging





Reasonable start
Still some work to do

Impact Parameter

Impact Parameter Resolution

When	What	Light-jet Rejection	B-jet Efficiency
Early Data	IP & Secondary Vertices	~100	50%
Later	High-perf Algos	~300	60%