Start up and first physics results with the ATLAS Detector

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La Thuile, Aosta Valley, Italy

February 28 - March 6, 2010

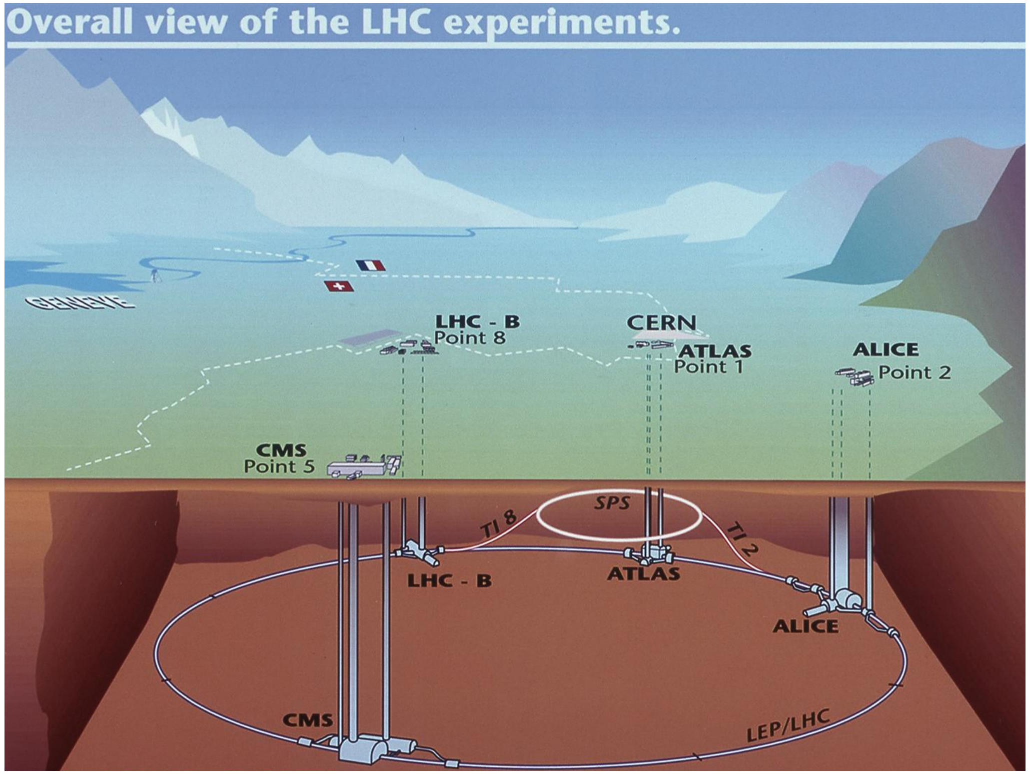
funded by CPAN

Outline

- The Large Hadron Collider
- The ATLAS Detector
- Detector performance plots of 2009 data taking
- Charged-particle multiplicities in p-p interactions at a center of mass energy of 900 GeV
- Outlook/Conclusion

The Large Hadron Collider

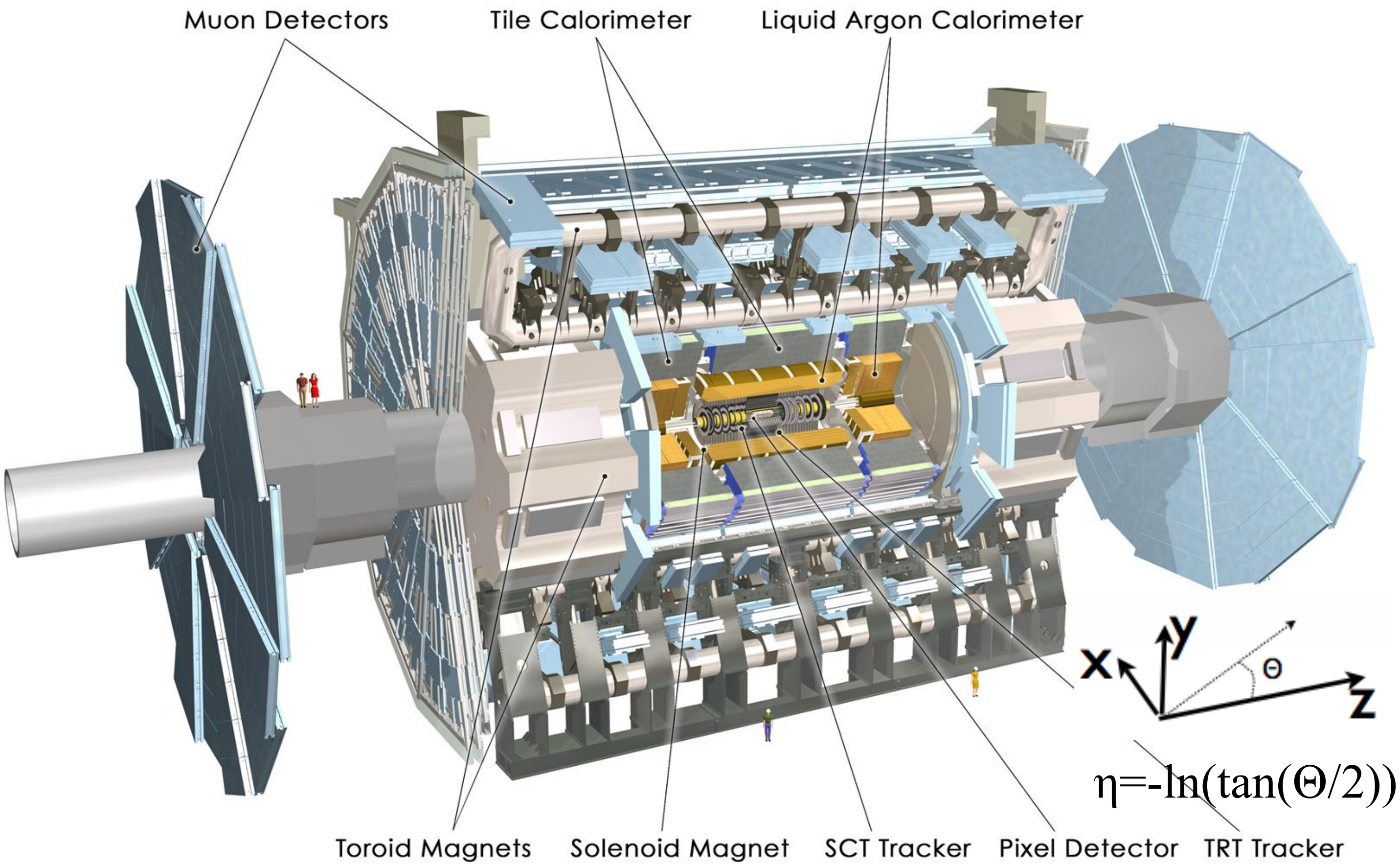
- Proton-proton collider
- 27 km circumference
- At 4 interaction points, detectors measure the outcome of the collisions:
  - ATLAS, CMS
  - Alice, LHCb



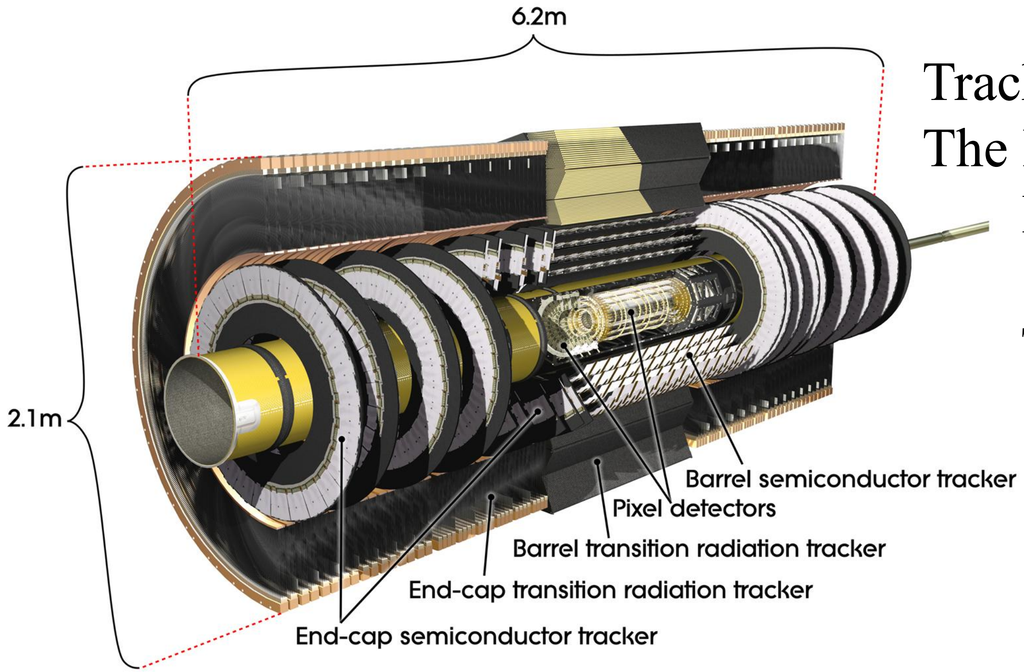
	Design	Start Up
Energy (c.m.)	14 TeV	900 GeV (2.36 TeV)
Luminosity	10^{34} cm^{-2}s^{-1}	~7 x 10^{26} cm^{-2} s^{-1}
Bunches/Beam	2808	4 (2 colliding in ATLAS)

The ATLAS Detector

- **A T**oroidal **L**HC **A**pparatur**S**: multi-purpose particle detector to cover large range of physics measurements
- mass ~ 7000 tons
- 25m high
- 46m long
- ~100 million electronic channels (most in the pixel and ID)



Inner Detector



Tracking detector with 2 Tesla solenoid field

The ID contains 3 sub-detectors: (resolution)

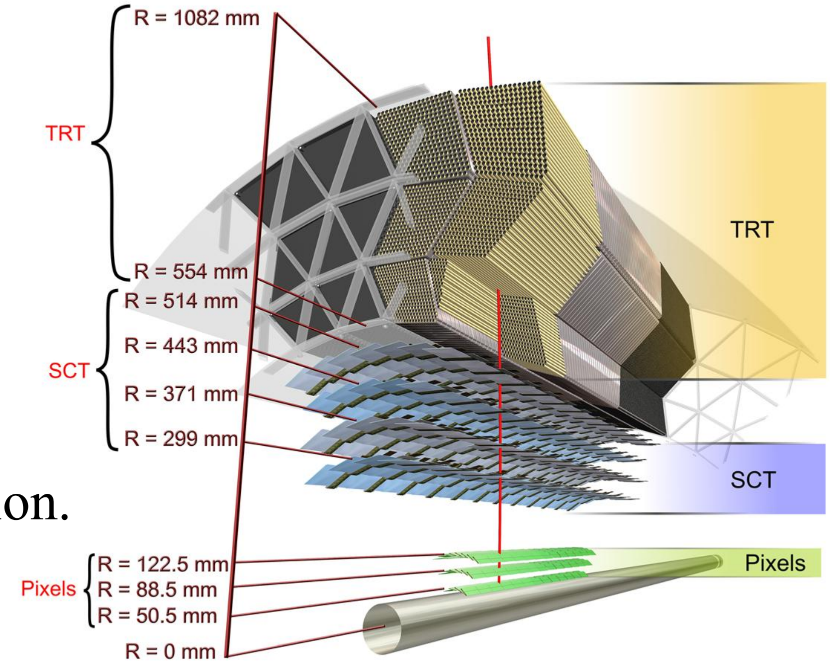
- Pixel detector: 10/115 μm in Rϕ/z
- Silicon strip detector (SCT): 17/580 μm
- Transition radiation tracker (TRT): 130μm in Rϕ

The ID provides around 3 pixel, 8 SCT and 30 TRT measurements per charged track at $\eta = 0$.

Coverage: $|\eta| < 2.5$ (2.0 for TRT)

Allows for accurate track and vertex reconstruction.

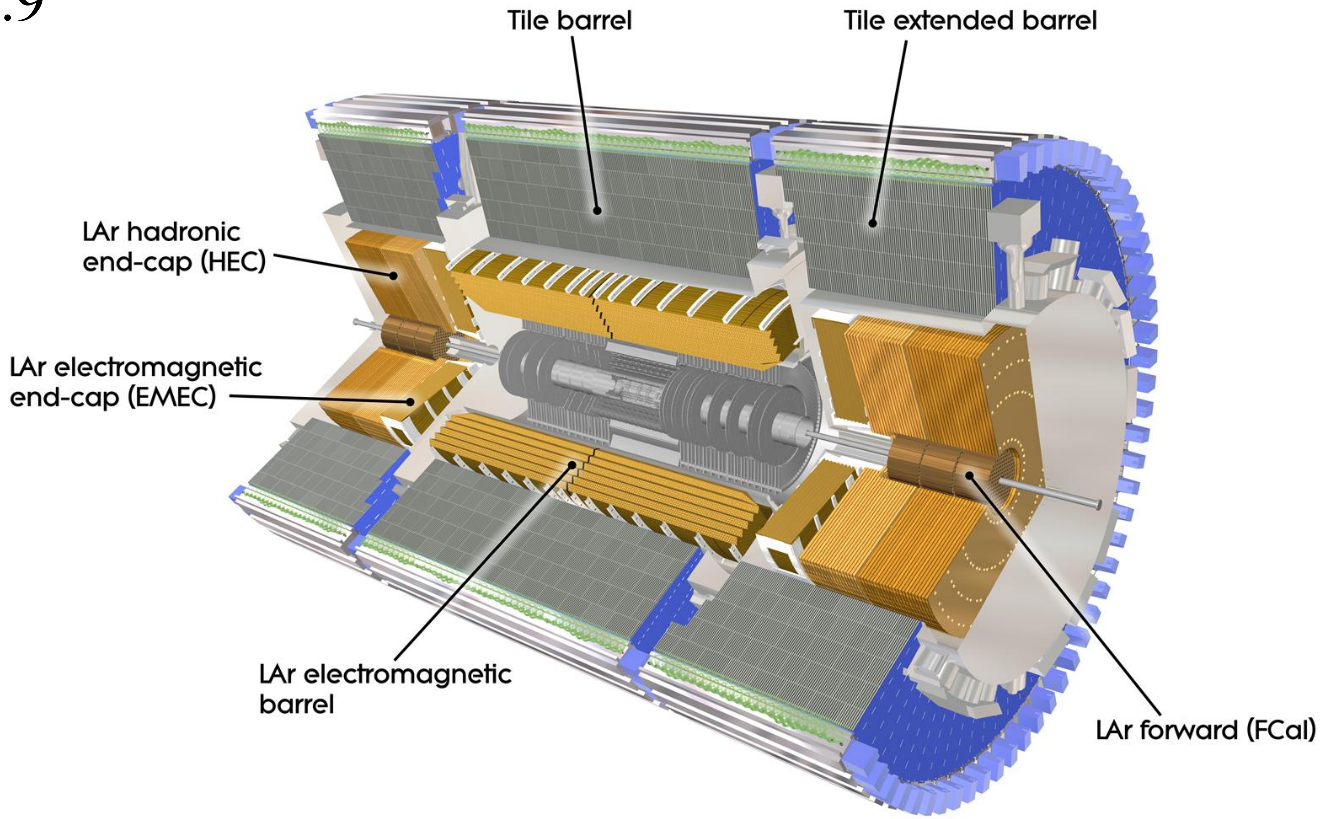
Resolution goal: $\sigma_{p_T} / p_T = 0.05\%\ p_T \oplus 1\%$



Calorimeters

- Measures energy deposit
  - very important to measure missing transverse energy
- Electromagnetic (LAr): $\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$
  - Precision measurements of photons and electrons
  - $|\eta|$ coverage up to 4.9
- Hadronic (Tile):
  - Measure energy deposit of hadrons
  - $|\eta|$ coverage up to 1.7

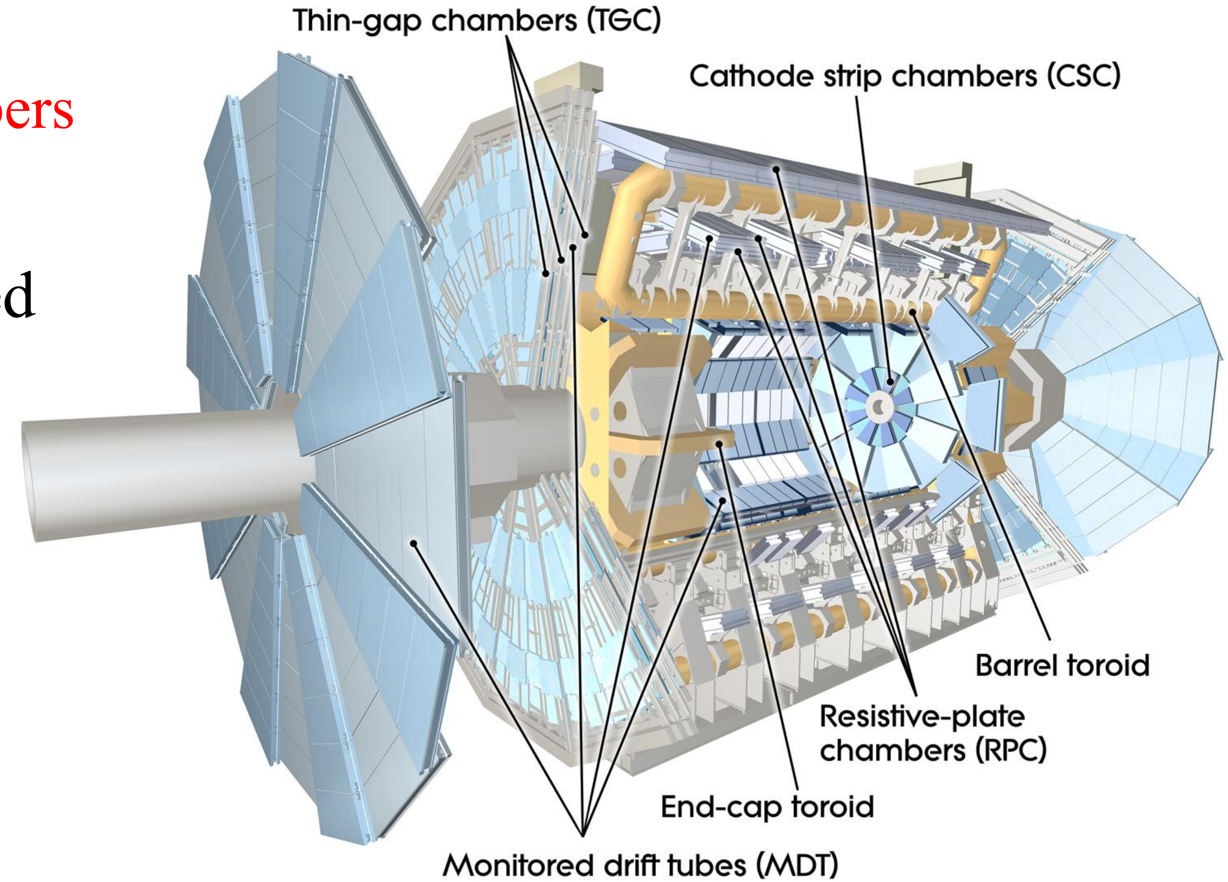
$$\sigma_E/E = 50\%/\sqrt{E} \oplus 3\%$$



Muon Spectrometer

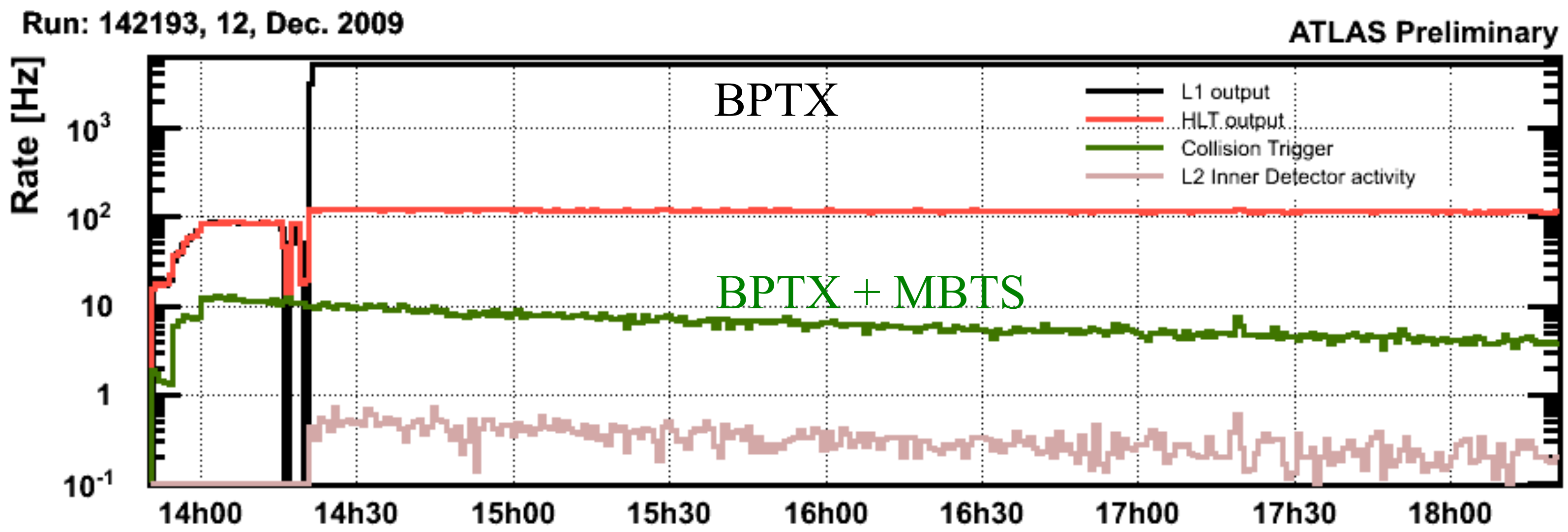
- Precision tracking chambers and trigger chambers
  - Monitored drift tubes
  - Cathode drift chambers
  - Thin-gap chambers
  - Resistive plate chambers
- |η| coverage up to 2.7
- Magnetic field produced by 3x8 air-core toroids
- magnetic field 0.5 T

σ_{p_T}/p_T=10% at p_T = 1 TeV



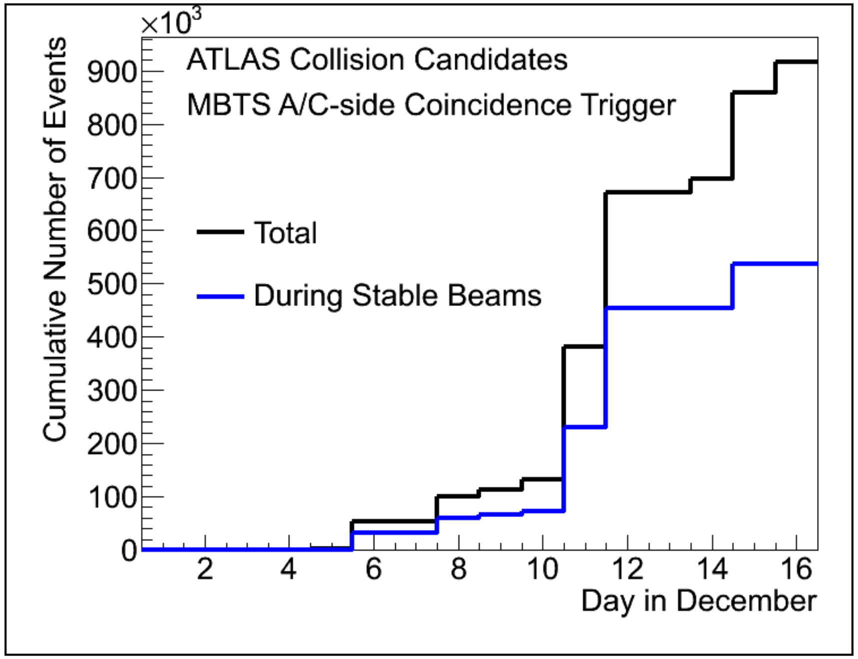
Trigger

- Primary physics trigger in 2009:
  - Beam pickup timing devices (BPTX)
    - Electrostatic beam pickup located at ± 175 m from interaction point
  - Minimum Bias Trigger Scintillators (MBTS)
    - located at ± 3.56m in z from the interaction point
    - 32 scintillating counters covering 2.09 < |η| < 3.84
- Average event rate of collision trigger (MBTS + BPTX): ~ 10 Hz



Data Taking in 2009

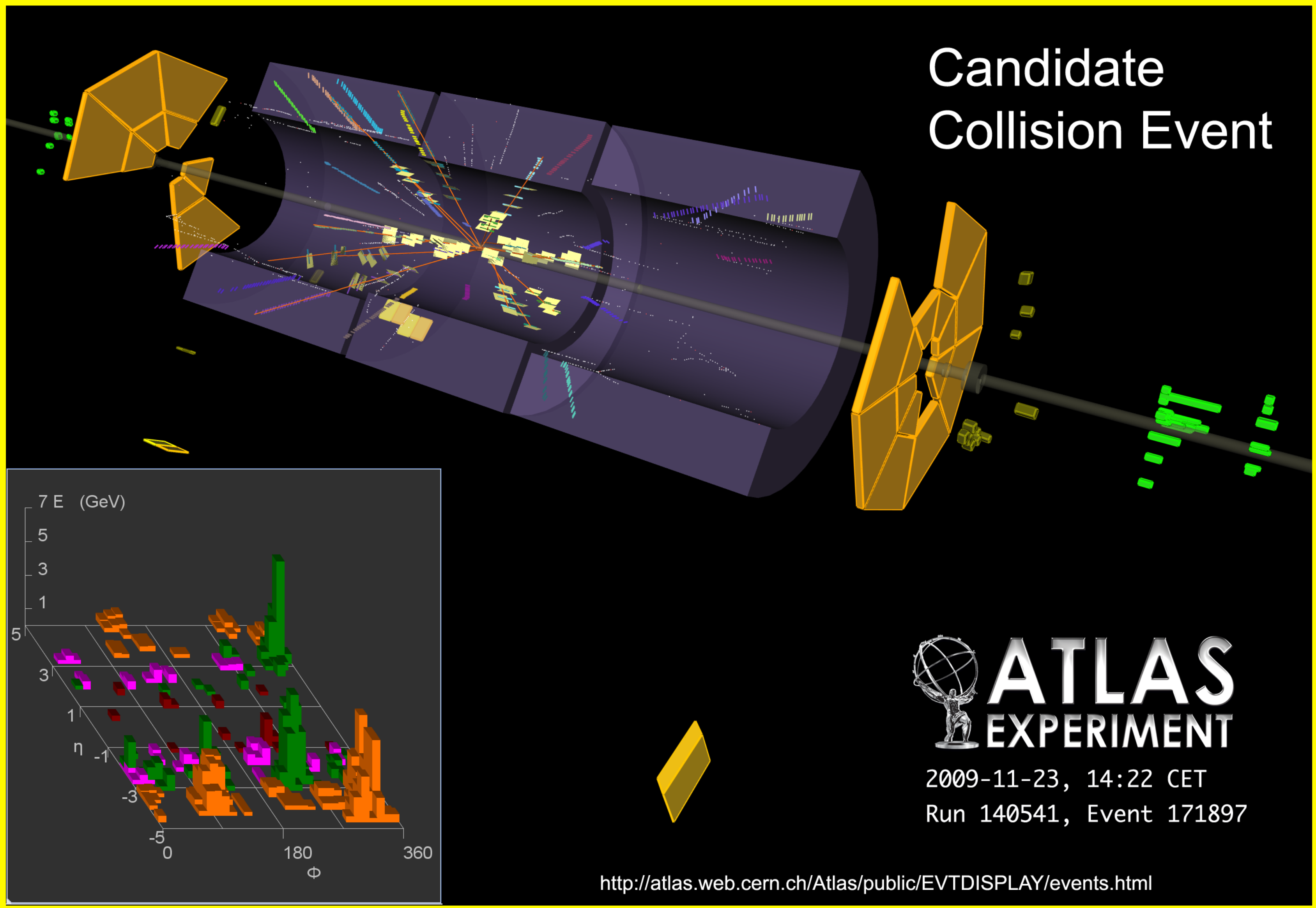
- 20 Nov 2009: single beam splash
- 23 Nov 2009: First collisions 900 GeV
- 6 Dec 2009: First collisions with stable beam. Full detector switched on!
- 8 Dec 2009: First collisions at 2.36 TeV
- 16 Dec 2009: end of 2009 data taking



Max peak luminosity seen by ATLAS : ~ 7 x 10^{26} cm^{-2} s^{-1}

Recorded data samples	# of events	Integrated Luminosity	
Total	917.000	20 μb^{-1}	(syst. uncertainty
900 GeV with Full Detector On	538.000	12 μb^{-1}	up to 30%)
2.36 TeV (world record)	34.000		

First Collision Candidate in ATLAS

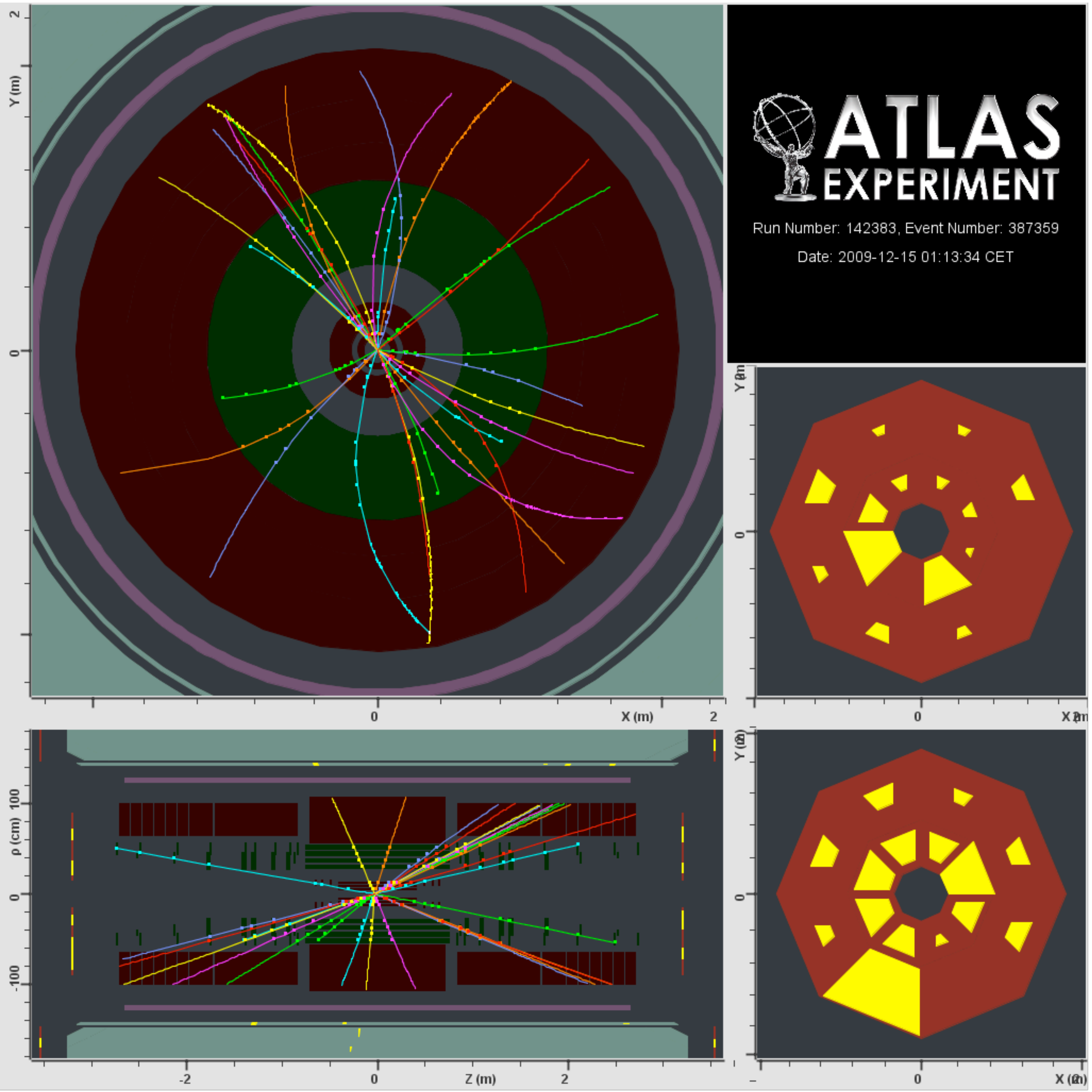


Detector Hardware Status in 2009

Subdetector	Number of Channels	Operational Fraction
Pixels	80 M	97.9%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.2%
LAr EM Calorimeter	170 k	98.8%
Tile calorimeter	9800	99.2%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Trigger	370 k	98.5%
TGC Endcap Muon Trigger	320 k	99.4%
LVL1 Calo trigger	7160	99.8%

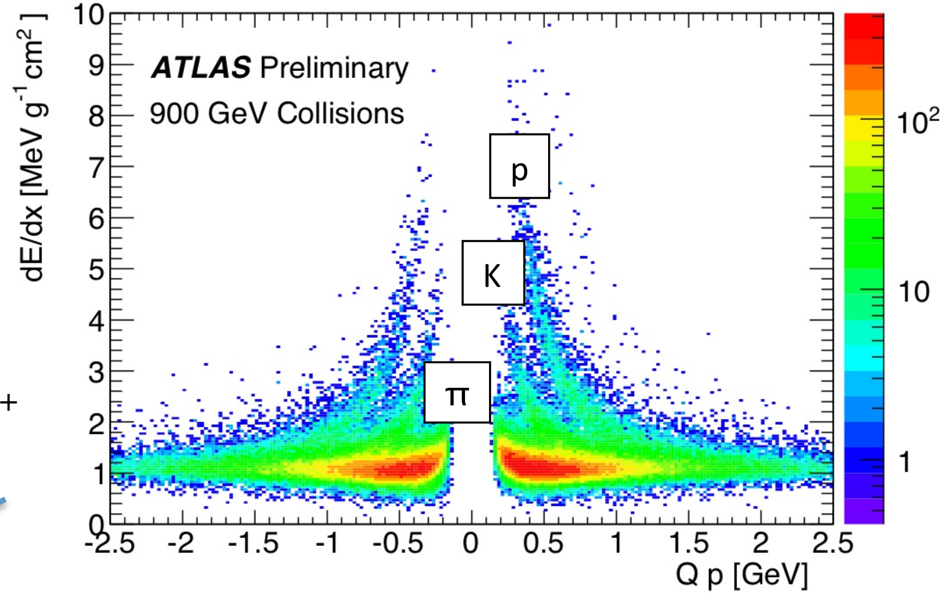
- High operational fractions of all detector systems!
- ATLAS is ready for 2010 data taking at higher energies!
- Pixels and Silicon strips (SCT) at nominal voltage only with stable beams
- Muon RPC and TGC operation fraction increased to 99.5% and 100% in 2010 (respectively)

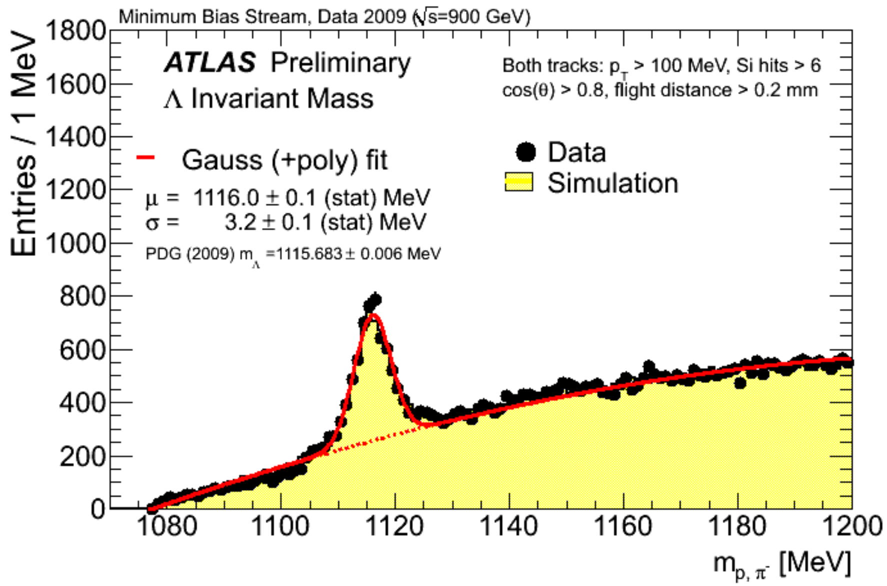
Detector/Combined Performance Plots

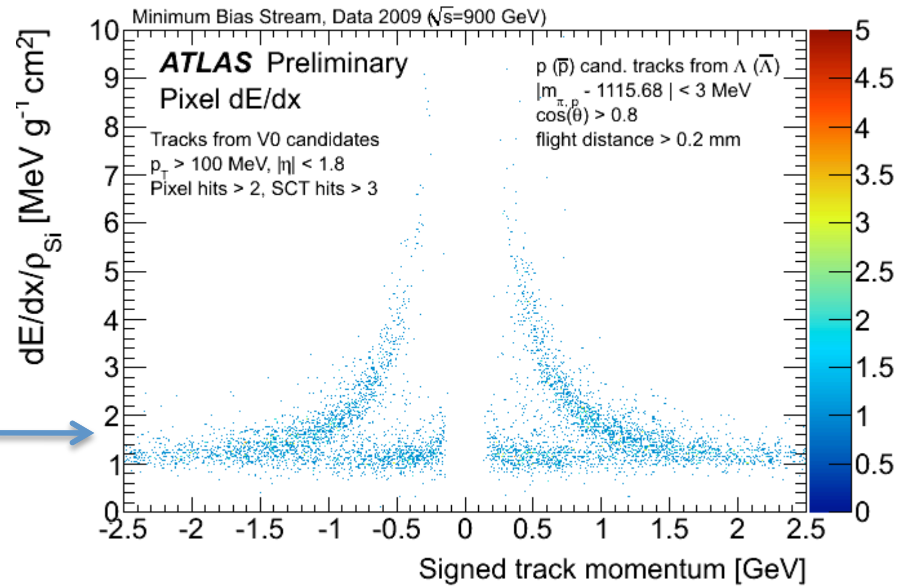


Pixel Detector: Energy Deposit

- Analogue readout of pixel detector allows measurement of energy deposit dE/dx
- Band for p, K, pions can be seen
- Cross-check with $\Lambda \rightarrow p\pi^-$, $\overline{\Lambda} \rightarrow \overline{p}\pi^+$ to identify particles confirms bands!

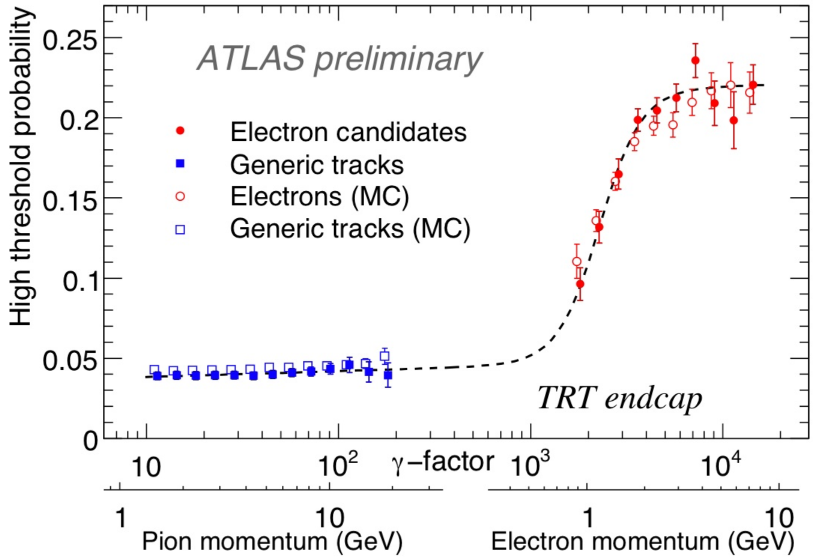


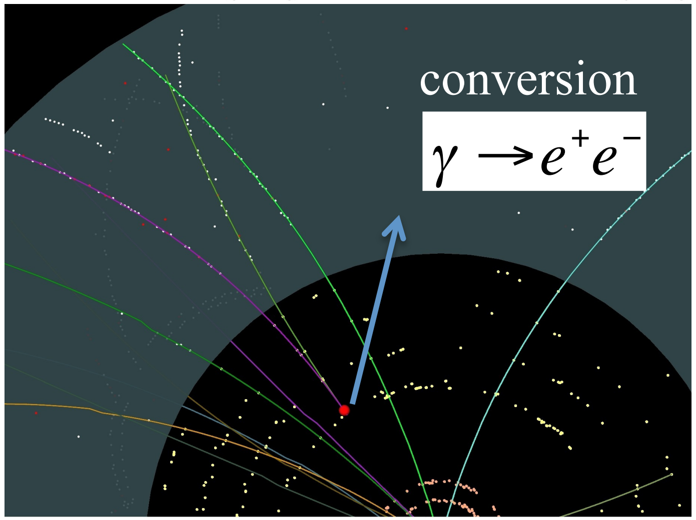


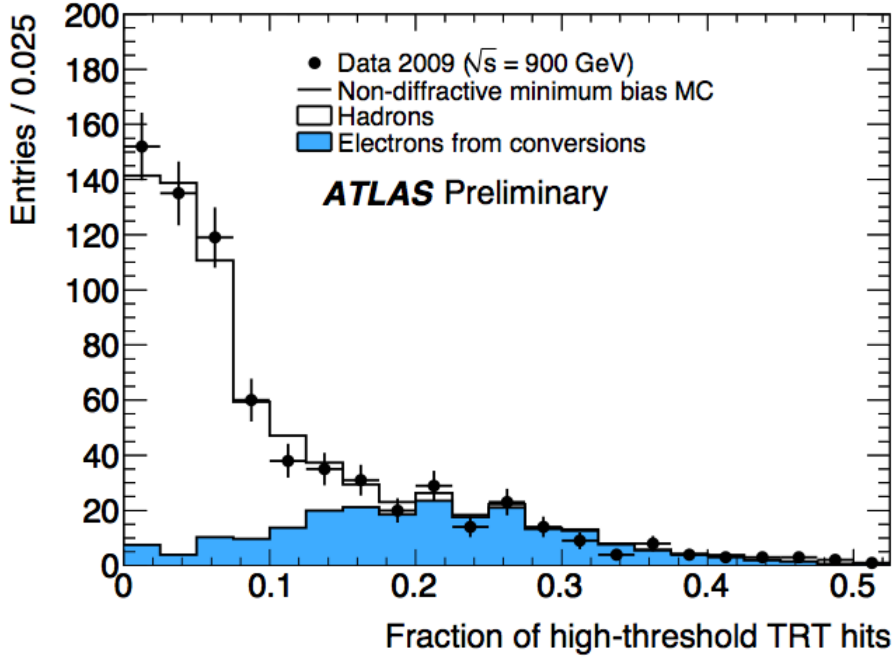


TRT and electron identification

The intensity of the transition (=photon) radiation in the TRT is proportional to the Lorentz Factor $\gamma = E/m_0c^2$ of the traversing particle.
Use number of high threshold hits to separate electrons and pions!



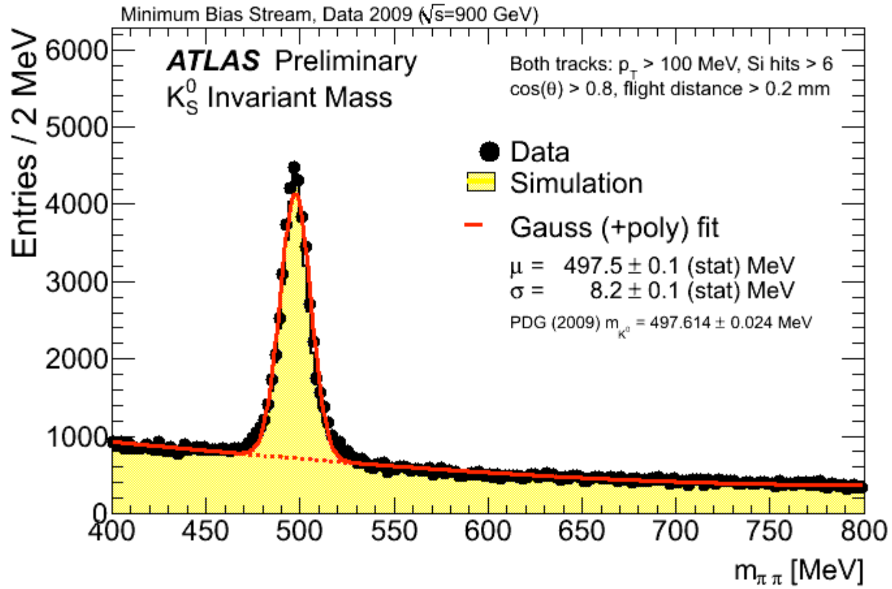


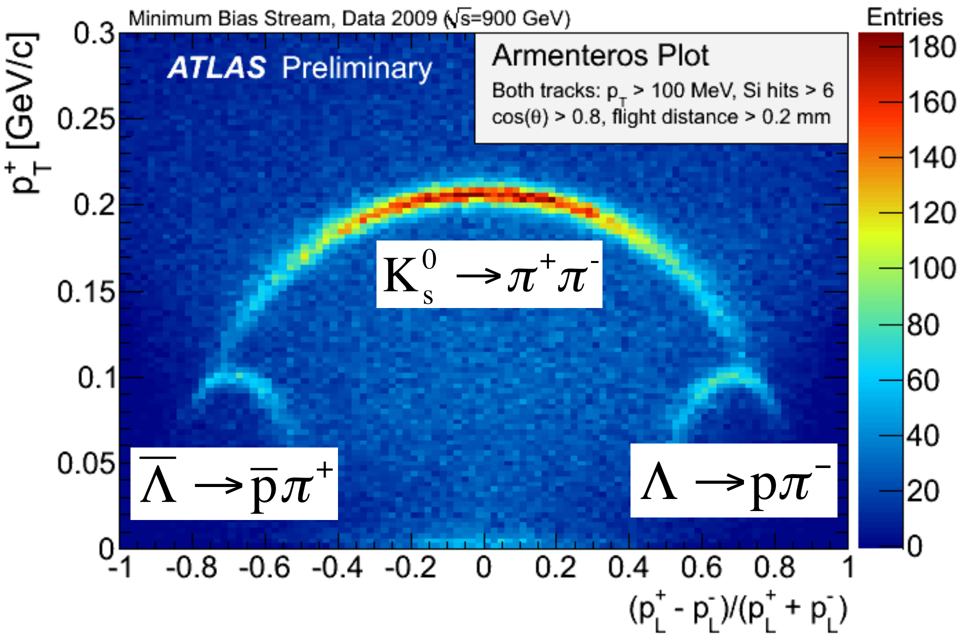


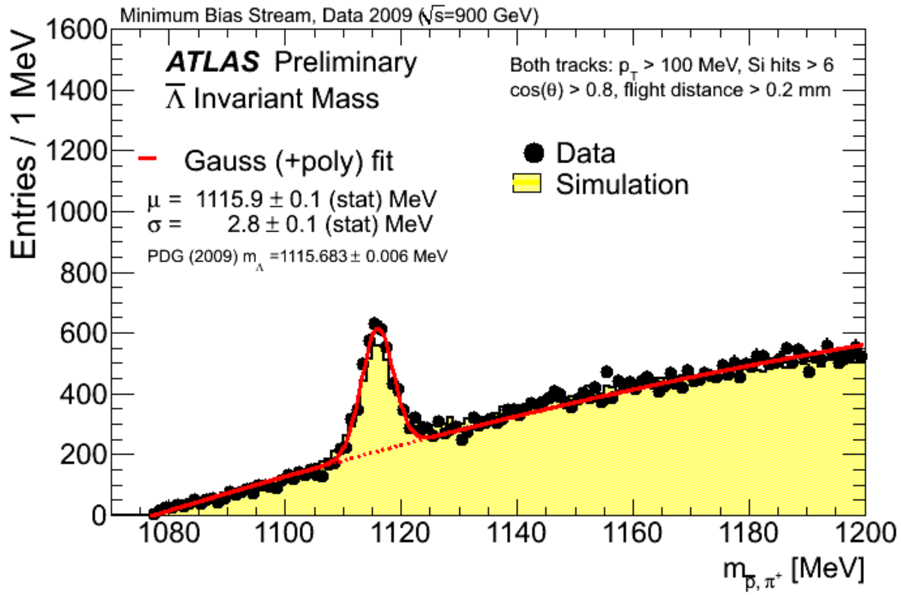
Cross-check: the "tail" towards high-threshold hits is due to electrons from conversion candidates!

Particle Decays

- Use well known particle decays to understand and validate detector performance
- Can be used to measure the track momentum resolution/scale and tracking efficiency

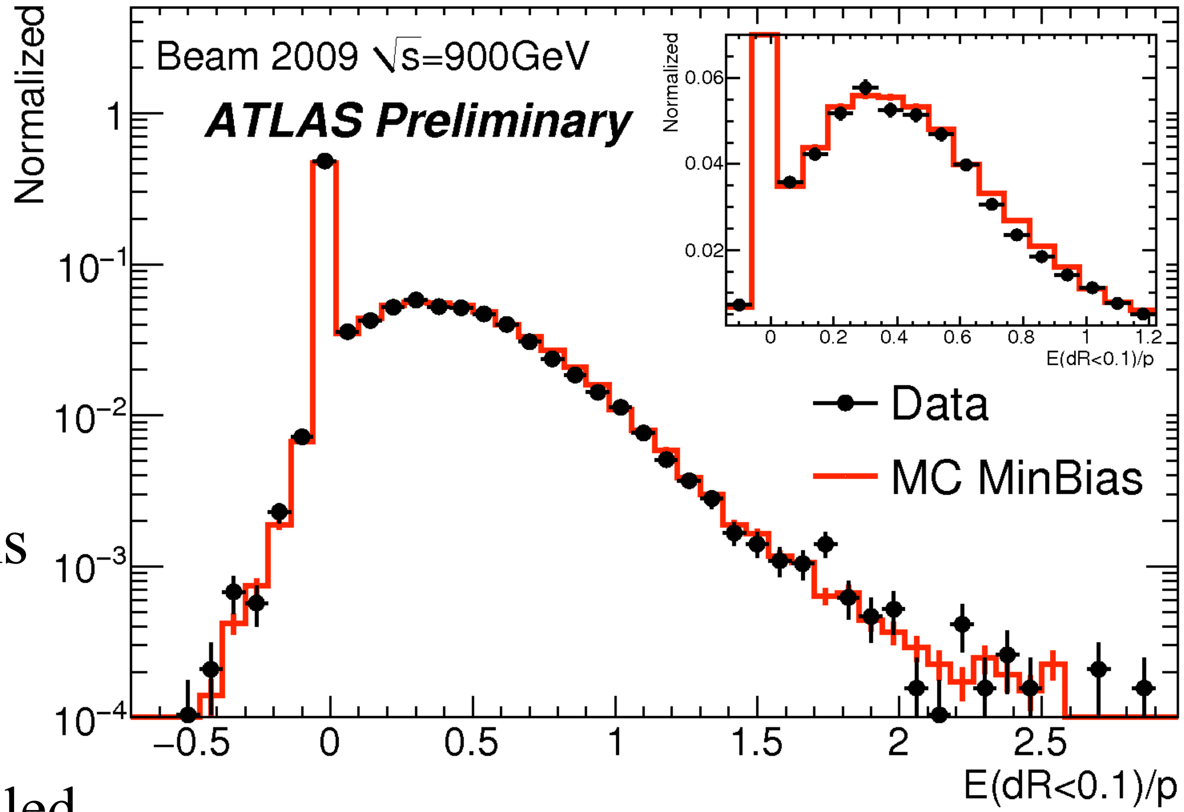






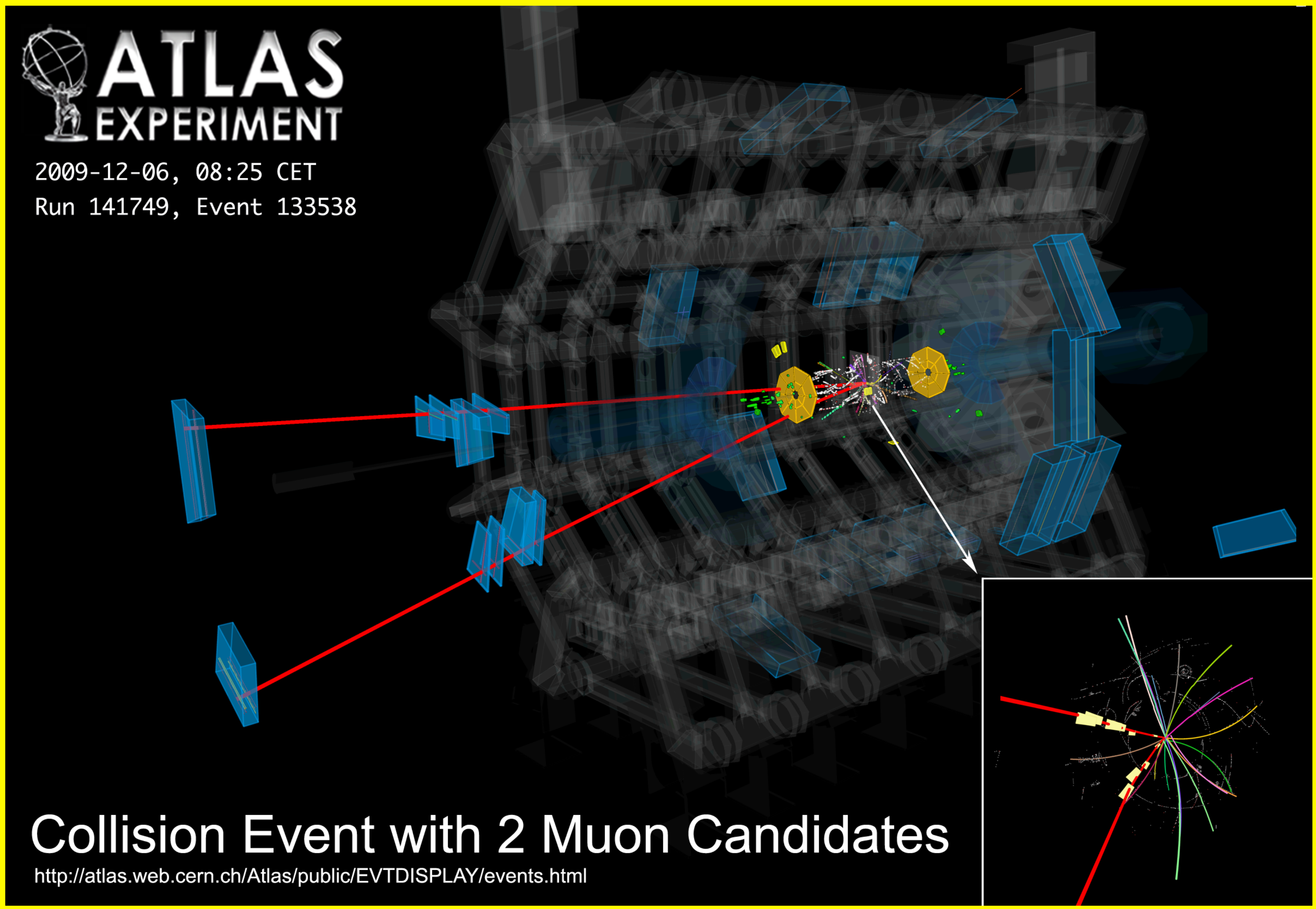
Calorimeter Response to Isolated Tracks

- Sample of isolated hadrons
  - $0.5<p_T<10$ GeV, $|\eta|<0.8$
  - No other track within $\Delta R=0.4$
- Plot: $E(\Delta R<0.1)/p$
- a powerful tool to test simulation of calorimeter response to single hadrons
- Remarkable quality of simulation:
  - very promising for detailed understanding of jet energy calibration

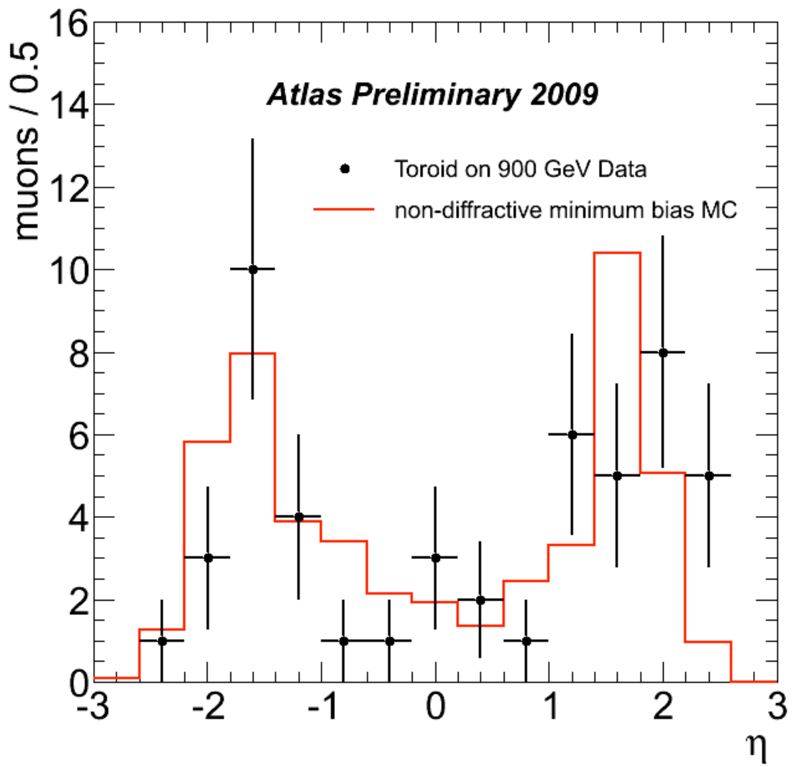


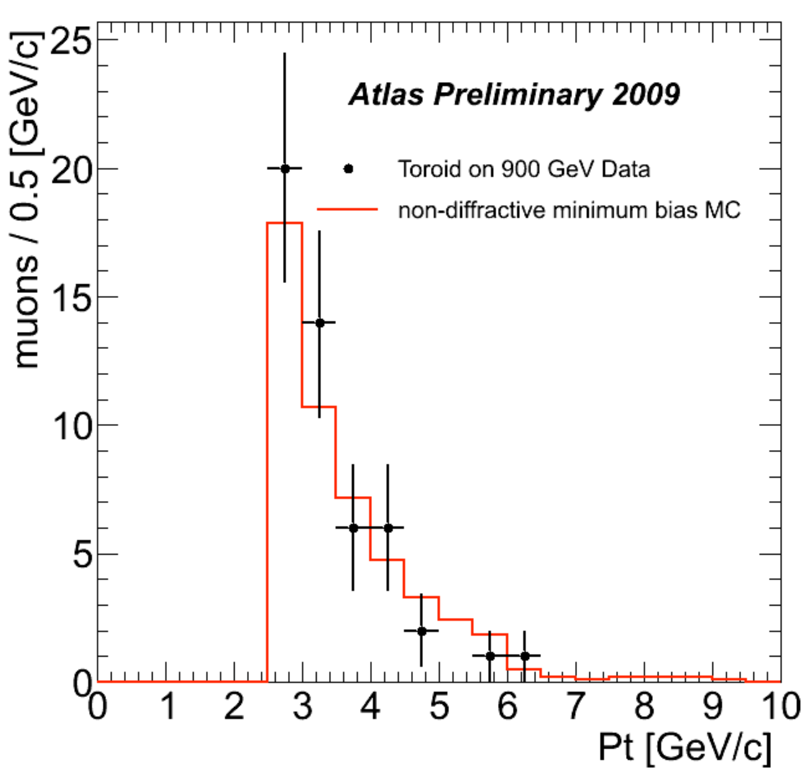
- A pay-off from the many years of test-beam studies and detailed comparisons to G4 simulation (models, material, etc)

Muon Spectrometer



Muon Spectrometer



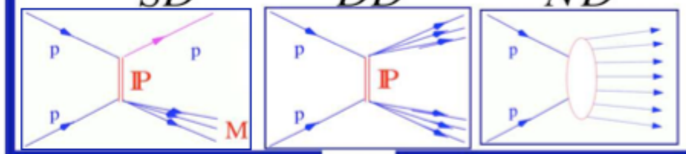


- Muon candidates reconstructed using ID and Muon Spectrometer
  - $p_T > 2.5$ GeV and $|\eta| < 2.5$, only for runs with muon toroid magnet on
- Muon candidates are very forward and low momentum at 900 GeV
- Nice agreement between MC and data within the limited statistics (50 muon candidates, MC normalized to data)

Charged Particle Multiplicities

- The measurement of charged particles in inclusive proton-proton reactions constrains phenomenological models of soft QCD and therefore is an important ingredient for future studies of high transverse momentum phenomena at the LHC.

$$\sigma_{Tot} = \sigma_{el} + \sigma_{SD} + \sigma_{DD} + \sigma_{ND}$$



Single **D**iffractive
Double **D**iffractive
Non **D**iffractive

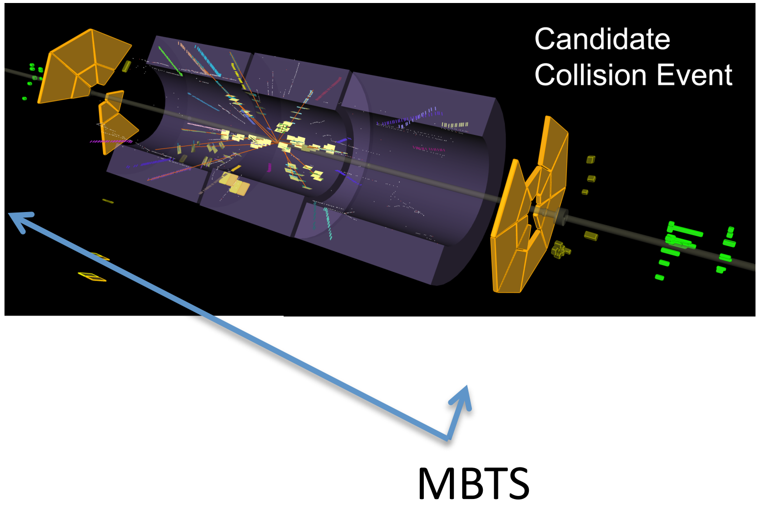
- Use minimum bias trigger to study inelastic collisions
- Look at distributions of primary charged particles

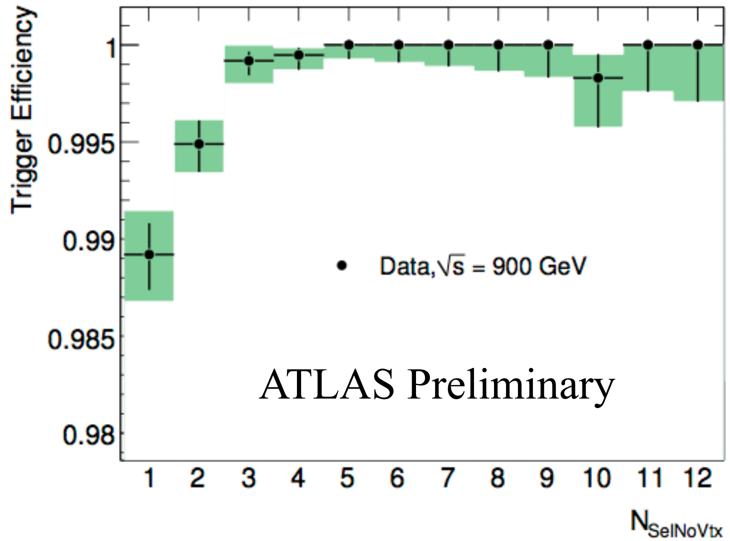
$$\frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta}, \quad \frac{1}{N_{ev}} \cdot \frac{1}{p_T} \cdot \frac{dN_{ch}}{dp_T}, \quad \frac{1}{N_{ev}} \cdot \frac{dN_{ev}}{dN_{ch}}, \quad \langle p_T \rangle \; vs. N_{ch}$$

- in the phase space $p_t > 500$ MeV and $|\eta| < 2.5$

Minimum Bias Trigger

- Min. Bias Trigger Scintillators
  - Require at least 1 hit on either side
    - “single arm” trigger
- Measure trigger efficiency from data
  - with orthogonal trigger which requires
    - colliding proton bunches in ATLAS
    - require > 6 hits in Pixel/SCT and a “loose” track with $p_T > 200$ MeV
- Trigger Efficiency wrt. the analysis selection is extremely high
  - d_0 cut wrt. beam spot (not PV), no z_0 cut
- No biases from track η, p_T observed
- Very low systematic uncertainty <0.03%



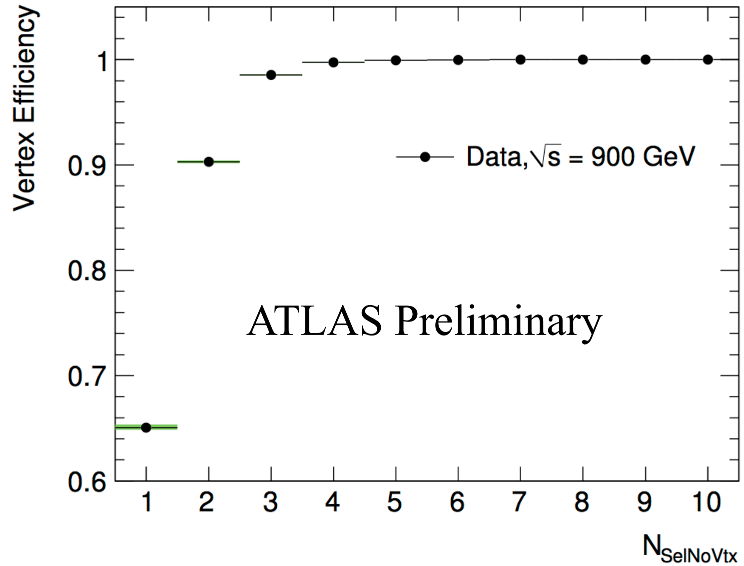


Analysis Overview

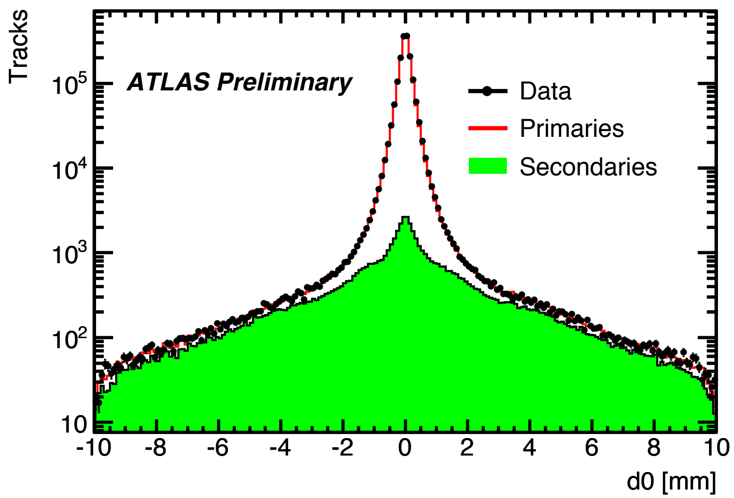
- Use all data taken at 900 GeV with stable beams and where trigger, tracking detectors, and solenoid were operational
- Measure fully inclusive inelastic distributions to avoid any model dependence
  - Makes it easy for theorists to compare ATLAS results with their model
- Study events with
  - a reconstructed primary vertex and ≥ 1 reconstructed track with
    - $p_T > 500$ MeV, $|\eta| < 2.5$
    - ≥ 1 hit in pixel, ≥ 6 hits in SCT
    - $|d_0^{PV}| < 1.5$ mm, $|z_0^{PV}|\sin(\theta) < 1.5$ mm
- Correct for trigger, vertex & track (in)efficiency to hadron level
  - But do not extrapolate outside our phase space
- This leaves **~326k events** for analysis
  - Beam background estimated from unpaired bunches is $< 10^{-4}$

Primary Vertex Reco & Secondaries

- The reconstructed primary vertex must
  - contain ≥ 3 tracks with
    - $p_T > 150$ MeV, $|d_0^{BS}| < 4$ mm
  - Vertex reconstruction efficiency is derived entirely from data
    - ~100% for events with 4 or more tracks
    - Systematic uncertainty < 0.1%

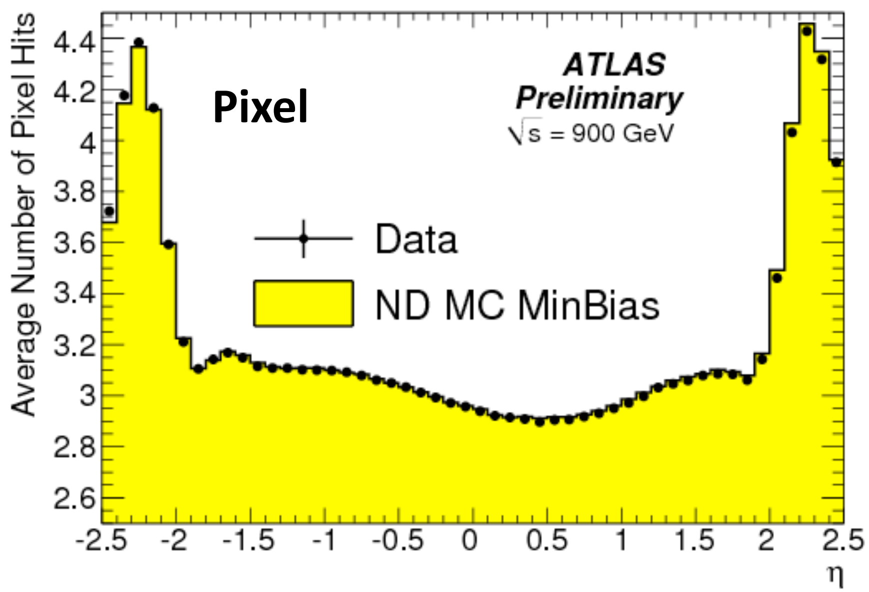


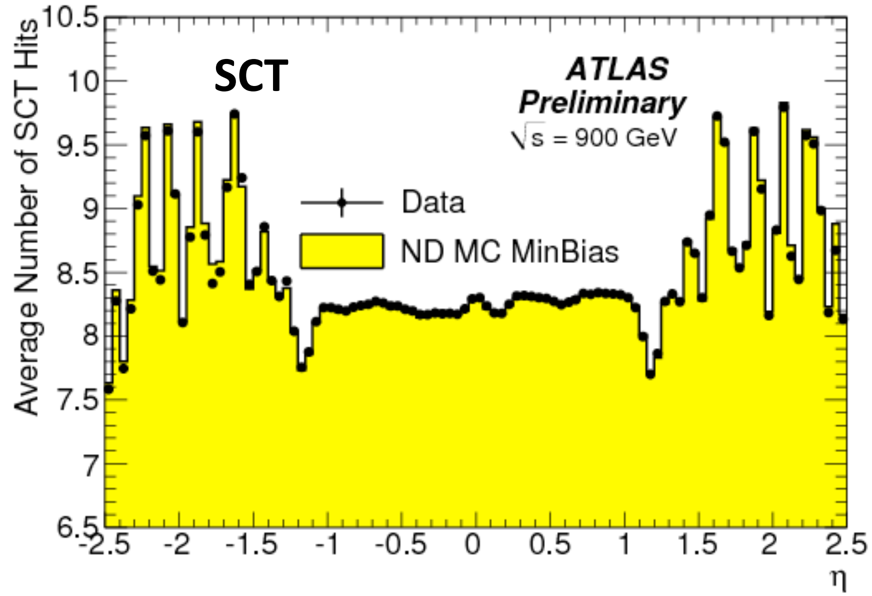
- Cut on d_0 and z_0 removes secondaries
  - Estimate remaining secondaries from the impact parameter distribution
    - 2.20% ± 0.05 (stat) ± 0.11 (syst) of selected tracks



Tracking Efficiency

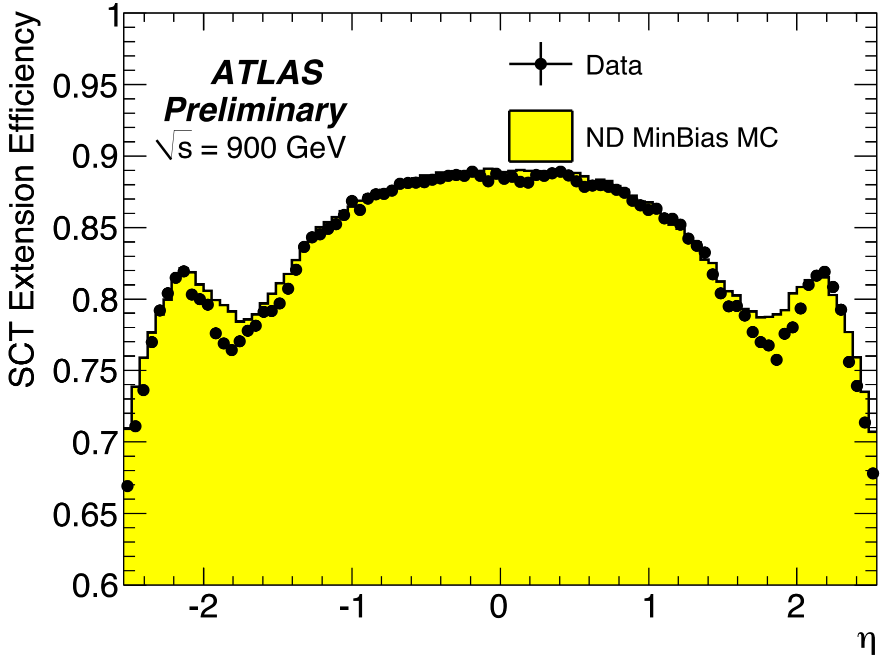
- The absolute tracking efficiency is derived from Monte Carlo
  - Careful checks needed that the data is well described by MC!
  - Any discrepancies between data and MC have to be accounted for (in terms of systematic uncertainties)
- Compare track hit multiplicities between data and Monte Carlo:
  - Average number of hits on tracks agree very well!

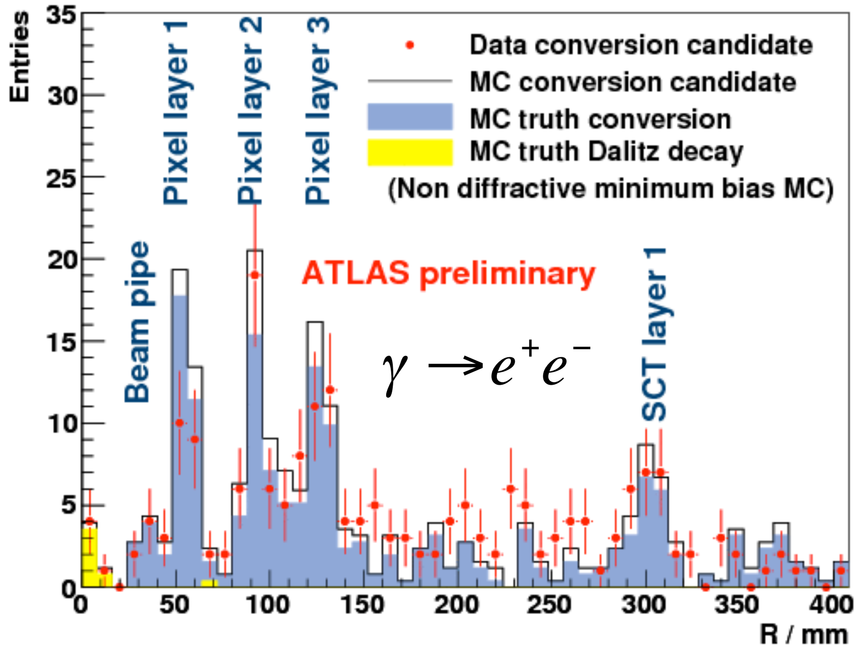




Material in the Inner Detector

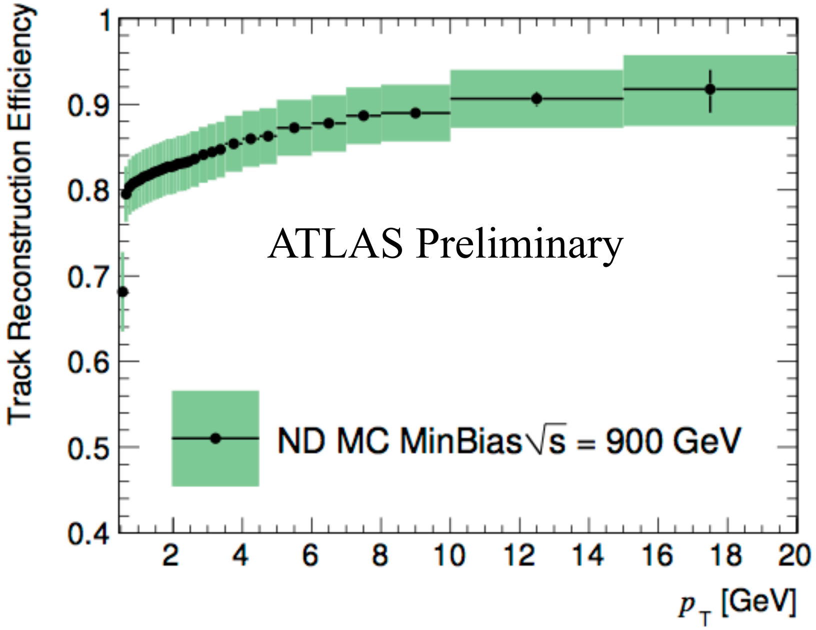
- Tracking inefficiency comes mostly from material interactions
  - largest contribution to systematic uncertainty!
- Material in ID is quite well understood (for this early stage)
  - Discrepancies are observed when e.g. looking at the efficiency to extend a pixel only track into the SCT
  - With more statistics conversions will be used to map the material

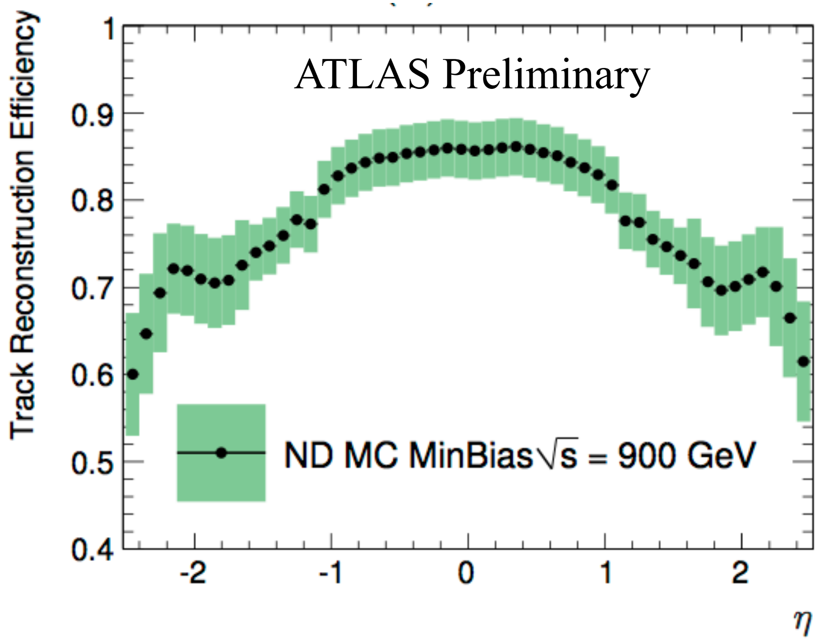




Tracking Efficiency

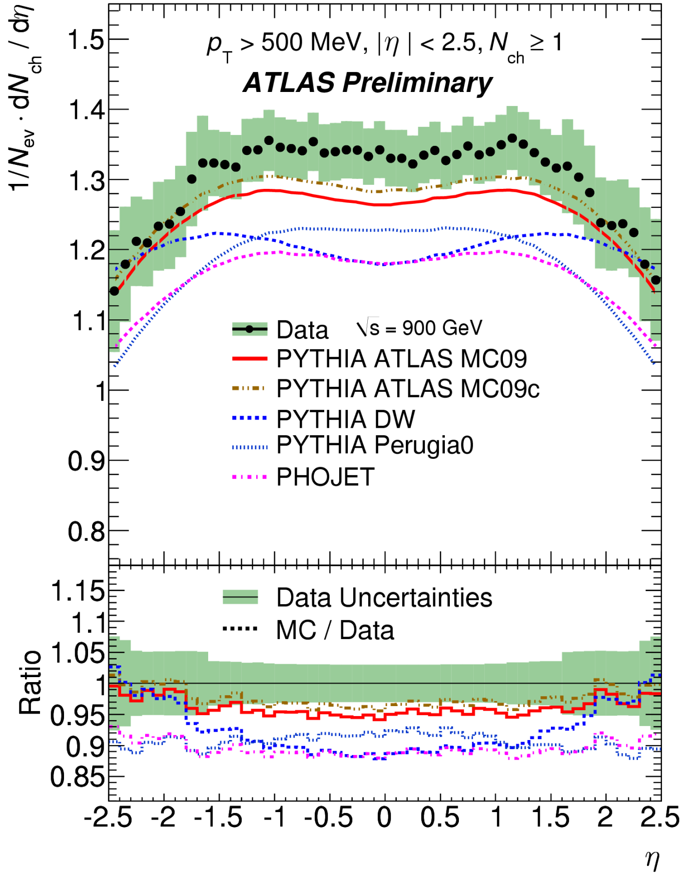
- Final tracking efficiencies vs. η and p_T are:

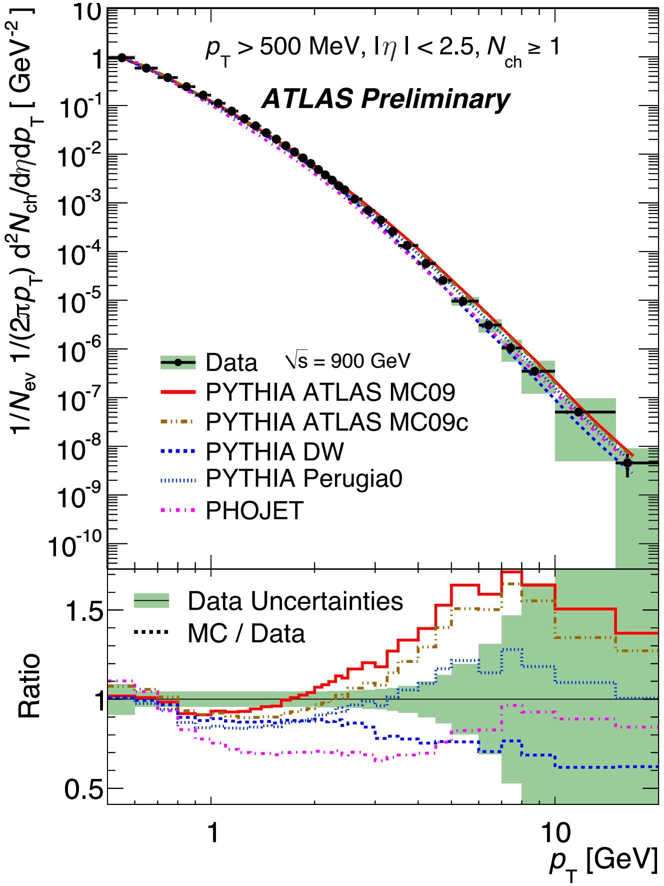




- An overall systematic uncertainty of 3.9% for η=0 was assigned
  - Green bands include both statistical and systematic uncertainties
  - Largest contribution comes from description of the material in the ID

Charged particle density versus η and p_T





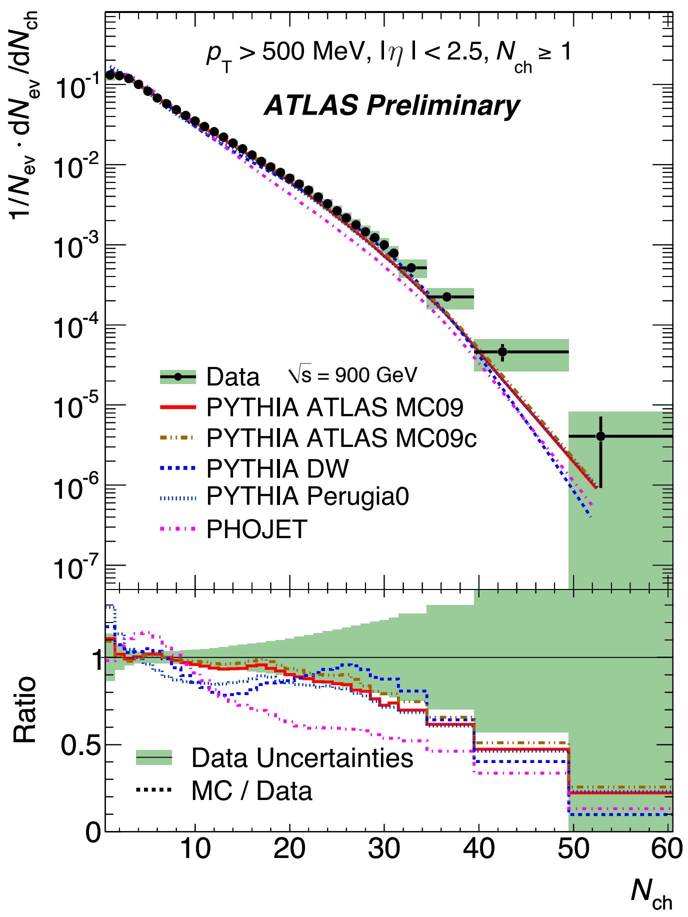
N_{ch}: number of primary charged particles corr. to hadron level

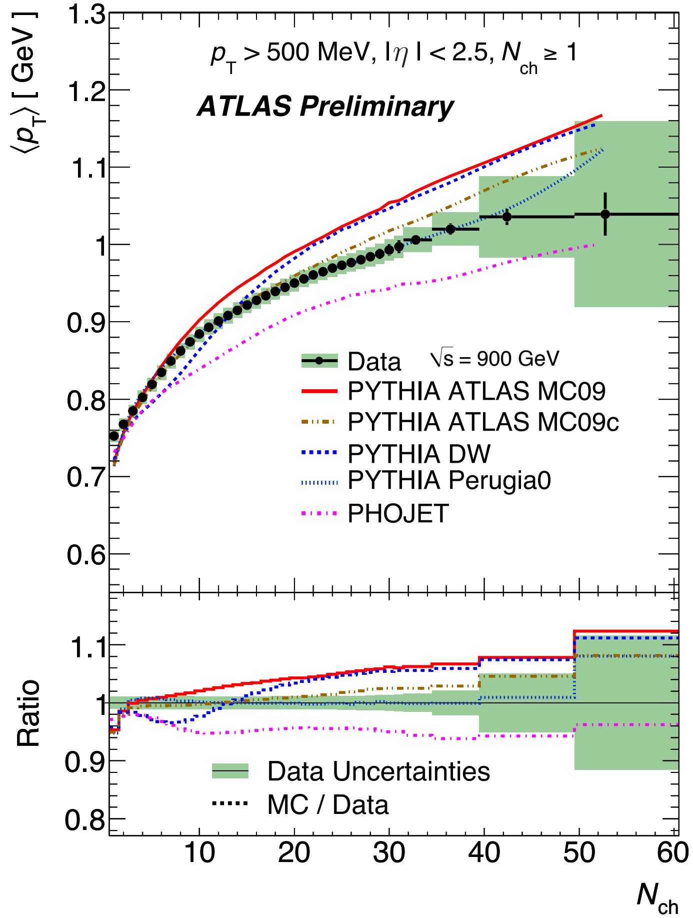
Normalized to # of selected events **N_{ev}**

p_T > 500 MeV
|η| < 2.5
N_{ch} ≥ 1

- (left) ATLAS data shows higher values than all MC tunes
  - But: MCs are tuned in different region of phase space
- (right) data/MC agrees well only for p_t < 0.7 GeV

Results II





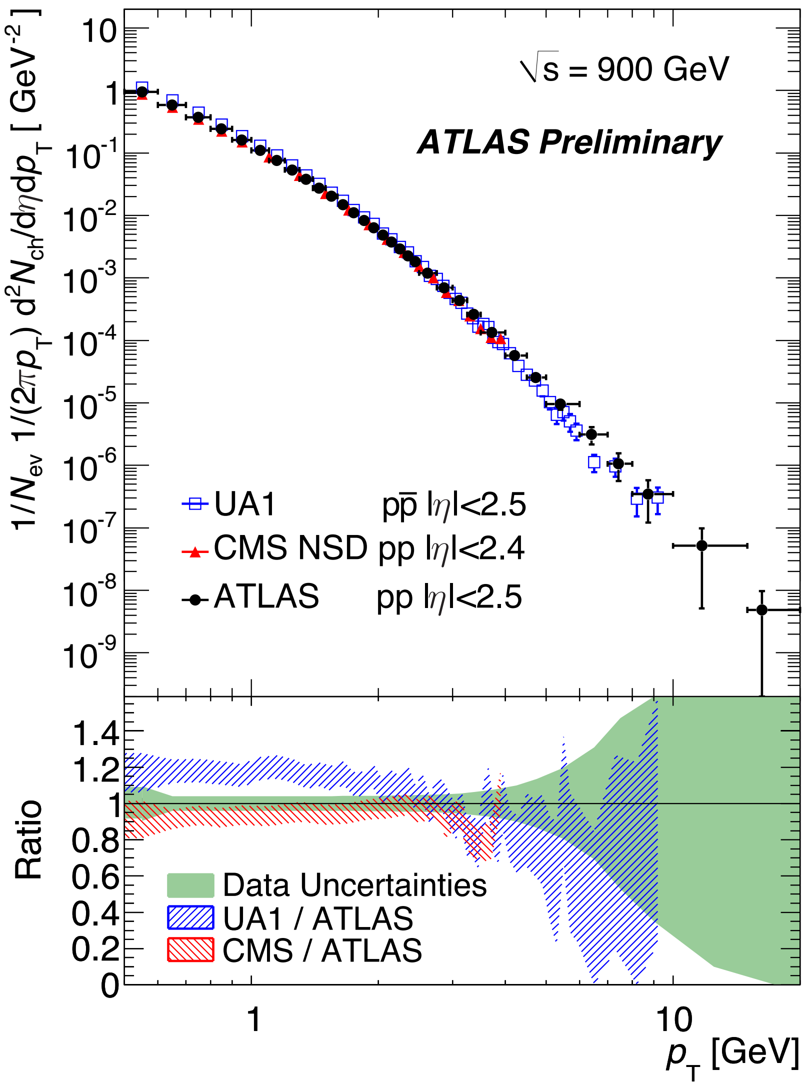
$\mathbf{N_{ch}}$: number of primary charged particles corr. to hadron level

Normalized to # of selected events $\mathbf{N_{ev}}$

p_T > 500 MeV
|η| < 2.5
$N_{ch} \geq 1$

- (left) MC excess of events at $N_{ch} = 1$ but always lower for $N_{ch} \geq 10$
- (right) increase of $<p_T>$ with higher N_{ch}
  - Change in slope around $N_{ch} = 10$ as seen by CDF

Comparison of Results



Compared to CMS:

N_{ch} consistently lower than measured by ATLAS. This is because of the correction CMS applies for the selection efficiency of the double diffractive component.

Compared to UA1:

UA1 data has been normalized by their associated cross-section measurement

N_{ch} ≈20% higher than ATLAS

UA1 used a “double arm” trigger which rejects events with low charged particle multiplicities

ATLAS Preliminary <N_{ch}>	
|η| < 2.5	1.333 ± 0.003(stat.) ± 0.040(syst.)
NSD |η| < 2.4	1.241 ± 0.040
➔ NSD obtained using the Pythia DW tune (Tevatron)	

CMS NSD (p_t > 0.5 GeV)	1.202 ± 0.043

Conclusion

- Data taking in 2009 was very successful
  - Understanding of the detector based on cosmic data taking in 2008/2009 has been improved further
  - The detector performance is very satisfactory at this early stage
  - Computing infrastructure to process data worked very well
- Many, many interesting studies have been produced within the ATLAS collaboration on a very short time scale
- The first physics analysis has been approved by the collaboration
  - The paper will follow very soon!

ATLAS is ready for data taking at higher energies!

- Thanks to the LHC team for the excellent performance in 2009
  - Expectations are high for 2010 ;-)
  - And proton beams have been circulated again (28.2.2010)!