Status of the ATLAS experiment

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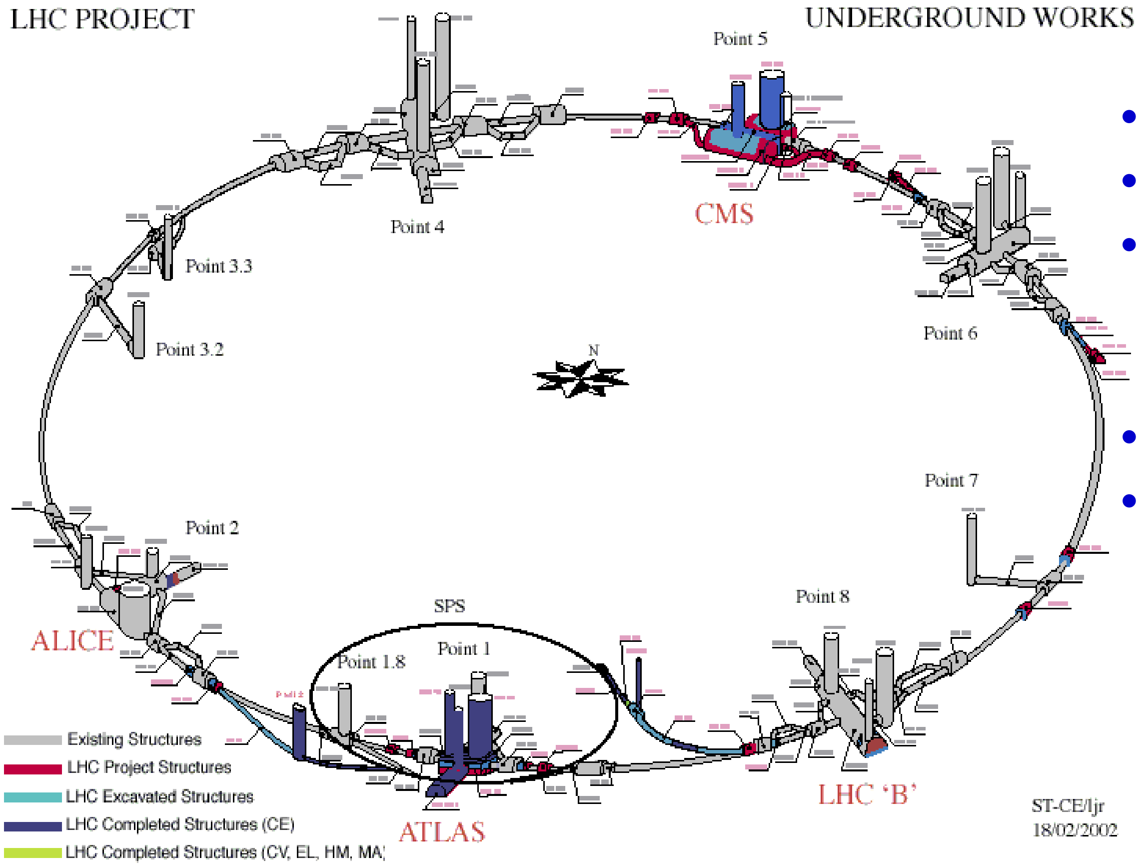
DESY seminar, LHC forum

Introduction

- LHC and ATLAS operation in 2009
  - LHC beam operation
  - ATLAS detector and trigger
  - Commissioning with single beam/beam splash
- Performance studies
  - Performance of each sub-detector
  - Combined reconstruction
- Charged particle multiplicities at $\sqrt{s}$=900 GeV
- Conclusion

LHC (Large Hadron Collider)



- Proton-proton collider
- 27 km circumference
- 4 interaction points
  - ATLAS, CMS
  - ALICE, LHCb
- CM energy : 14 TeV (design)
- High luminosity : 10^{34} $cm^{-2}s^{-1}$

ATLAS operation since Nov. 2009

LHC

- 20/11 : First beam circulating in the LHC
- 23/11 : First collision at $\sqrt{s}$=900 GeV
- 6/12 : Stable beams → Inner Detector fully on
- 8/12 : Collision at $\sqrt{s}$=2.36 TeV
- 16/12 : End of 2009 runs

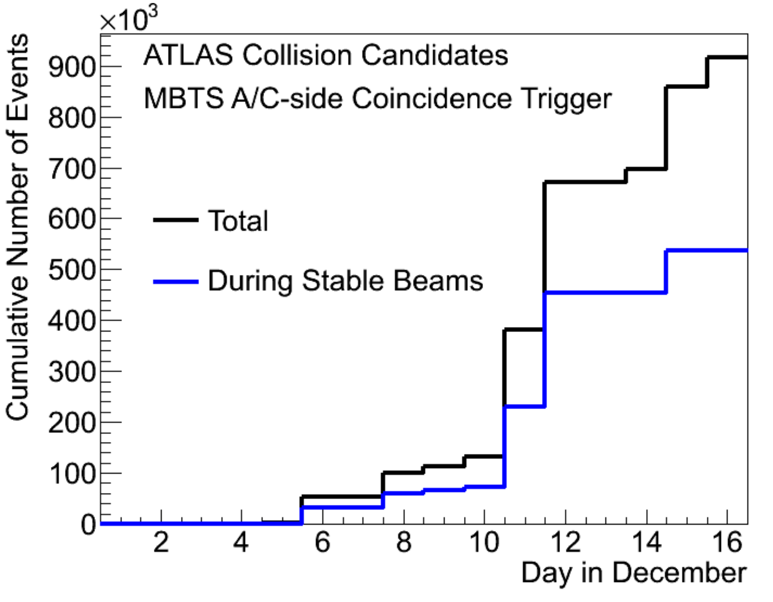
$\sqrt{s}$=900 GeV
L=7 × 10^{26} $cm^{-2}s^{-1}$

ATLAS

- Total collision candidates at 900 GeV
  - 920 k events, ~21 μb^{-1}
- In stable beam condition
  - 540 k events, ~12 μb^{-1}
- With ID and solenoid ON, good data quality
  - 380 k events, ~9 μb^{-1}

(cross section estimated from the observed rates at MBTS/LAr endcap, uncertainty ~ 30 %)

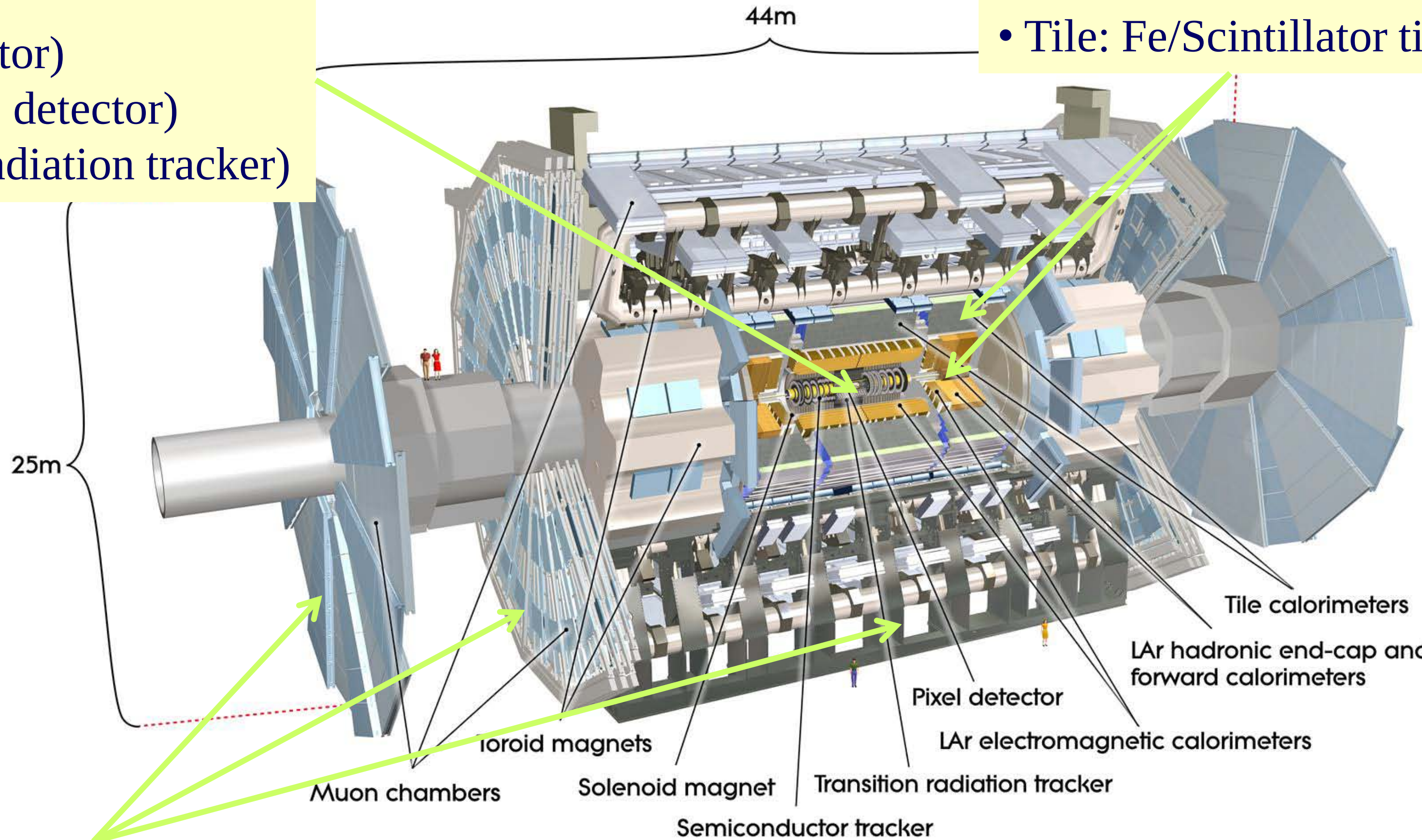
- Sample at 2.36 TeV
  - 34 k events
  - Without stable beam condition
  - ID not fully on



ATLAS detector

<u>Inner Detector</u>
- Pixel (pixel detector)
- SCT (silicon strip detector)
- TRT (transition radiation tracker)

<u>Calorimeter</u>
- LAr : EM calorimeter
- Tile: Fe/Scintillator tile



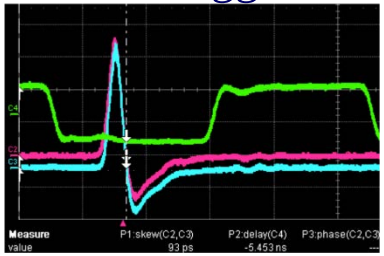
<u>Muon spectrometer</u>
- MDT, CSC : precise momentum measurement
- RPC, TGC : trigger chambers

<u>Magnet system</u>
- 2 T solenoid
- 0.5 T toroid

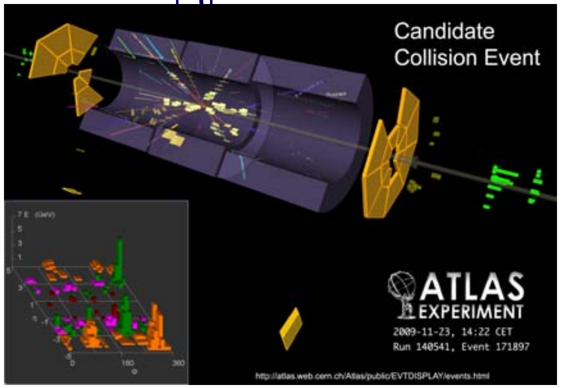
Trigger

- ATLAS trigger
  - 3 level trigger system
  - General strategy was to use L1 only selection
- L1 trigger (hardware)
  - Main triggers
    - BPTX (colliding bunch)
    - MBTS (detector activity)
- High Level Trigger (HLT, software trigger)
  - Event streaming
  - Online beam spot calculation
  - Space point (hit) counting algorithm at Level-2 and loose tracking at Event Filter
    - Runs on L1 BPTX trigger (prescaled)
    - Used for the MBTS trigger efficiency study
  - All others in pass-through mode

- Beam pick-up system (BPTX)
  - 4 sensors on each side, ~175 m upstream of the interaction point
  - Used to trigger on colliding bunches

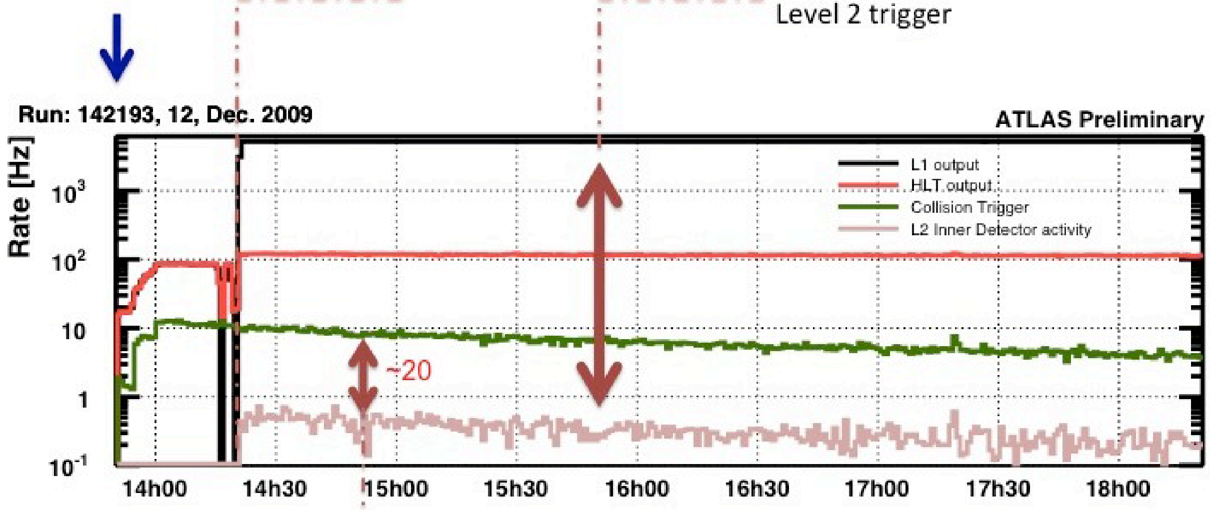


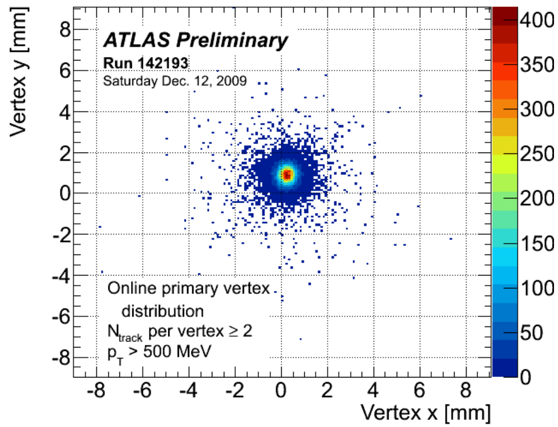
- Minimum Bias Trigger Scintillator (MBTS)
  - 16 scintillators on each side
  - $2.1<|\eta|<3.8$



Trigger rates and online beam-spot monitoring

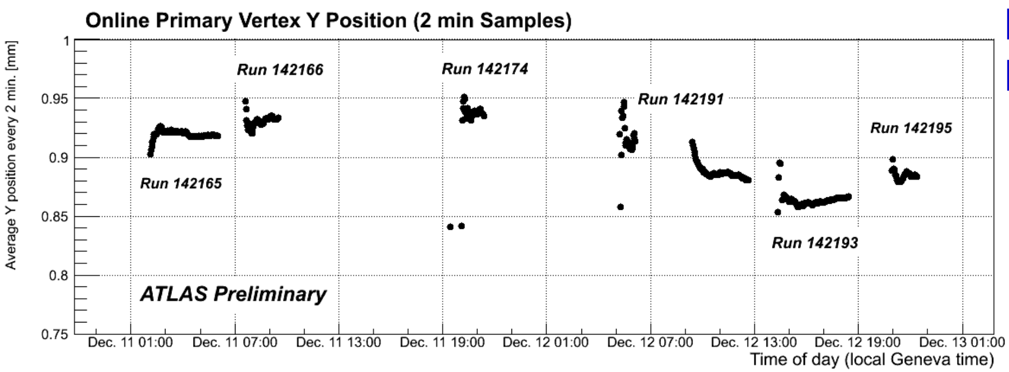
Trigger rate vs time for a typical LHC fill





L1 MBTS(x1) → HLT pass-through

L1 BPTX (prescale=20) → HLT selection

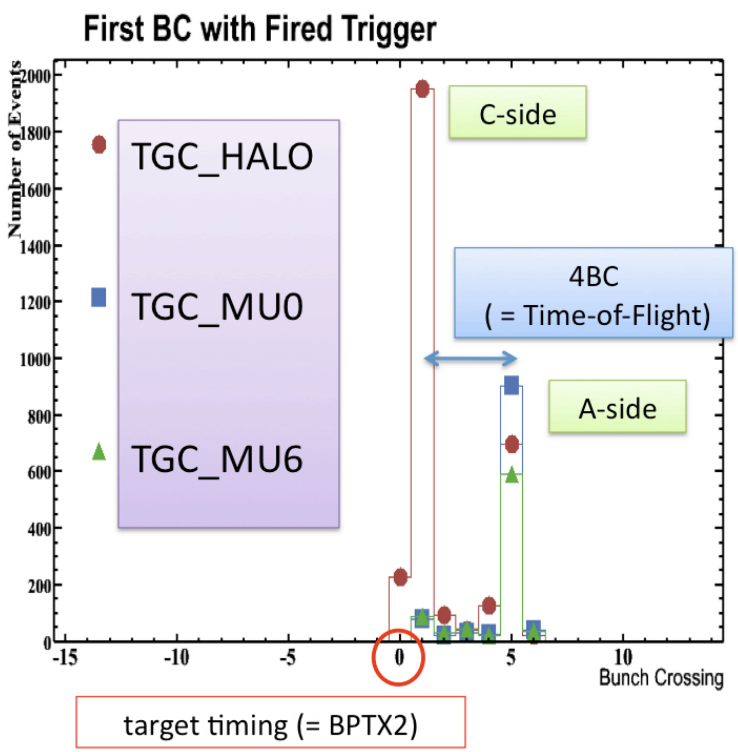


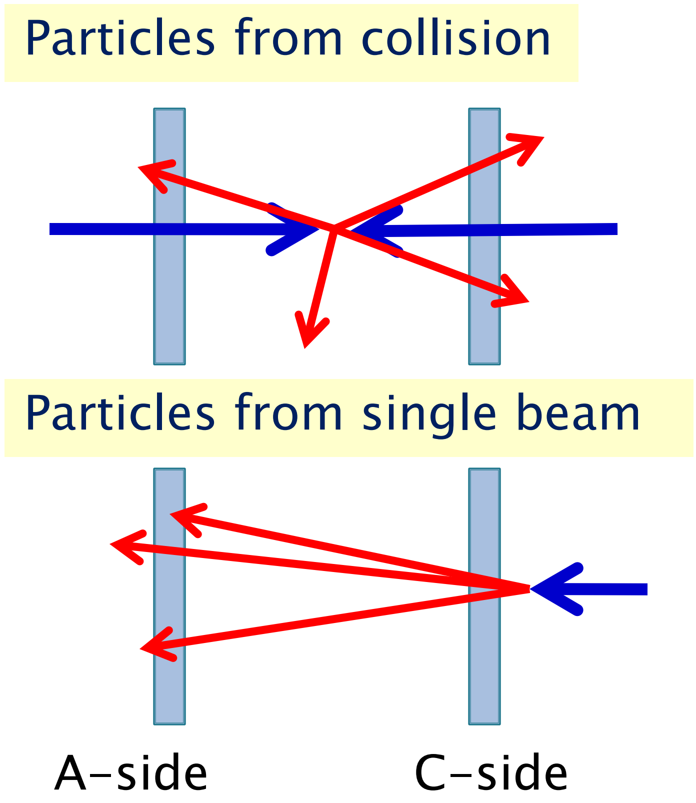
Online beam spot monitoring

→ feedback to LHC operation

Detector timing wrt. collision

- Most detectors were well timed-in within 25 ns during the combined cosmic running
- Overall adjustment to the collision timing was done with single beam data (splash events)



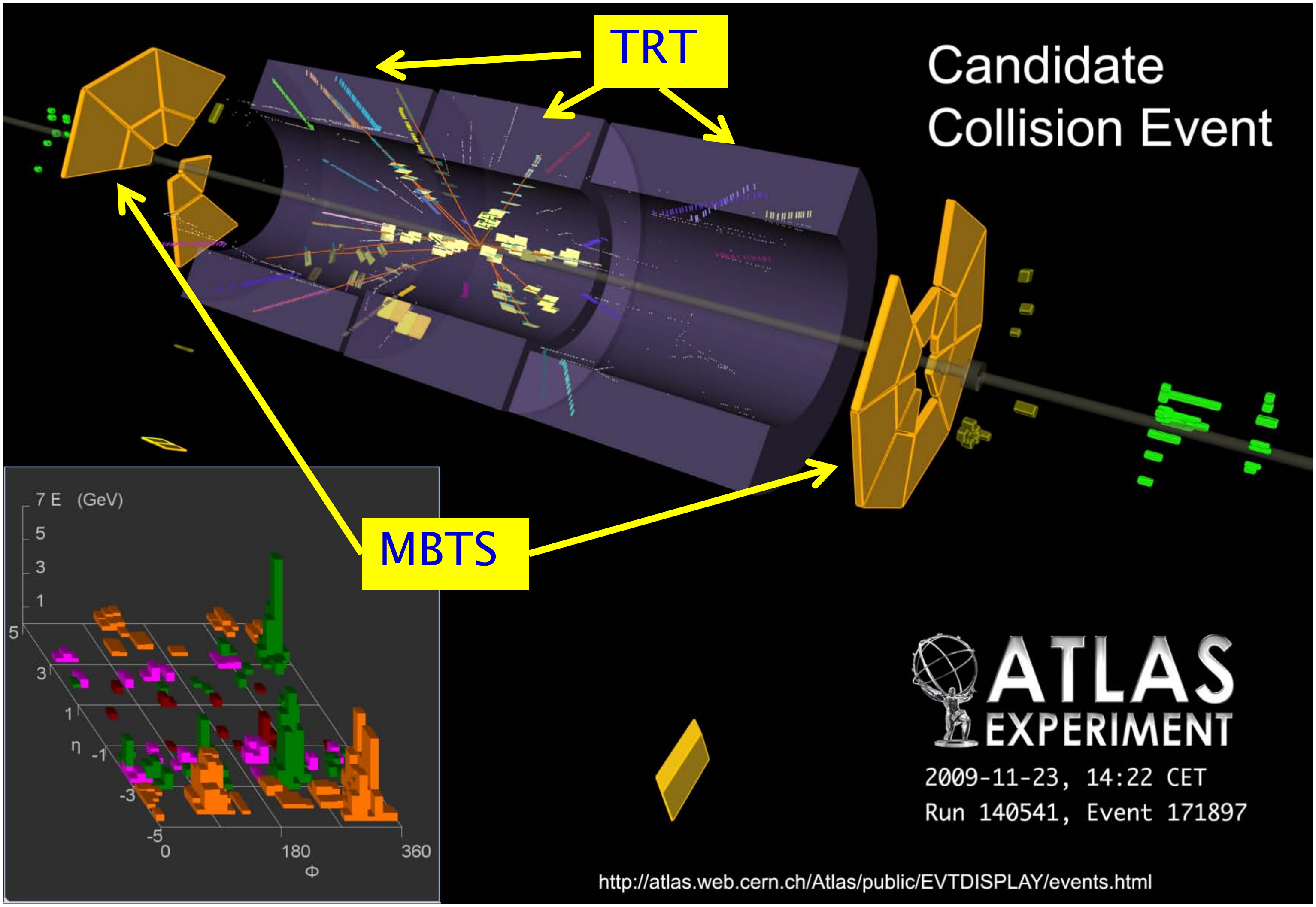


TGC timing with single beam run

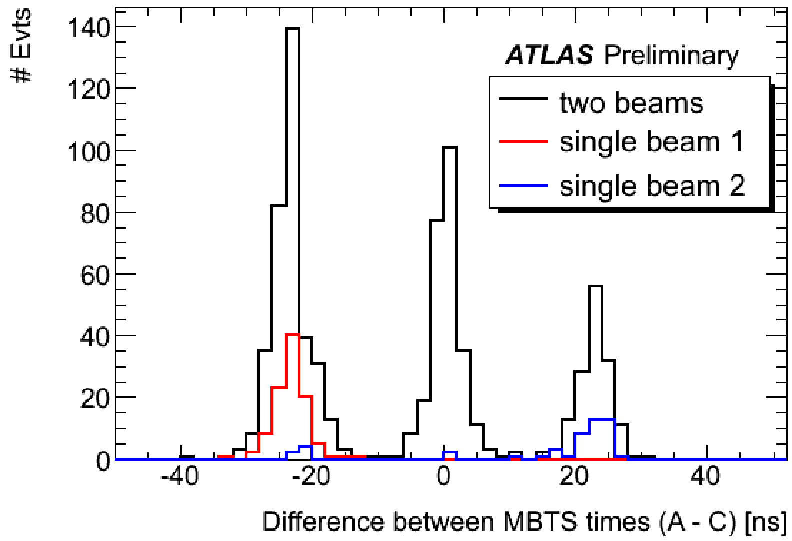
- Two peaks correspond to two sides
- Timing in each side within 1-2 bunch crossings (BC)

TGC: Thin Gap Chamber (Endcap muon trigger chambers)

Candidate collision event

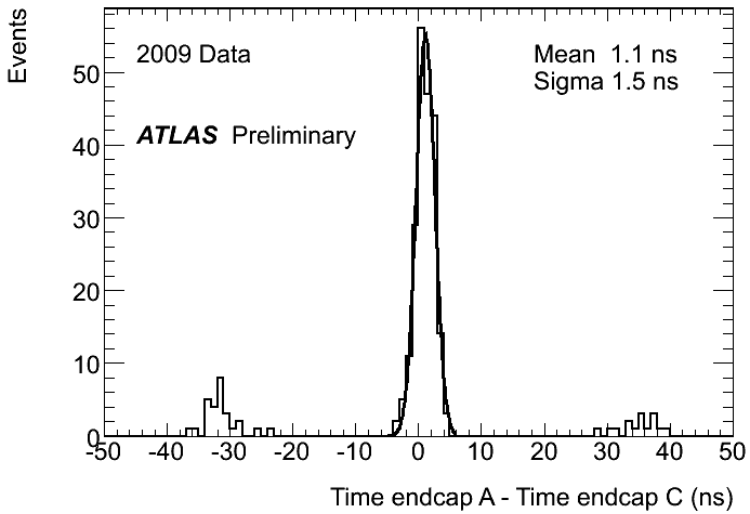


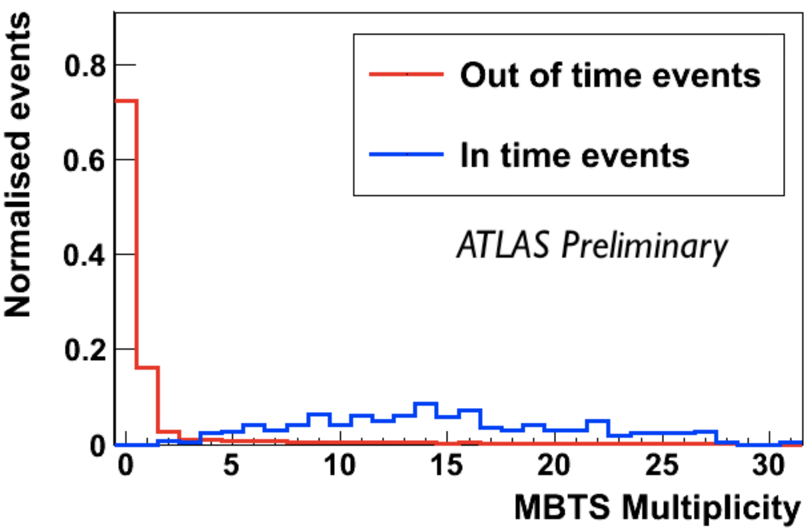
Selecting collision events with timing



- MBTS timing difference on two sides
  - Peak at ~±25 ns for single beam events
  - Peak at 0 ns seen with both beams

Timing difference on two sides with LAr



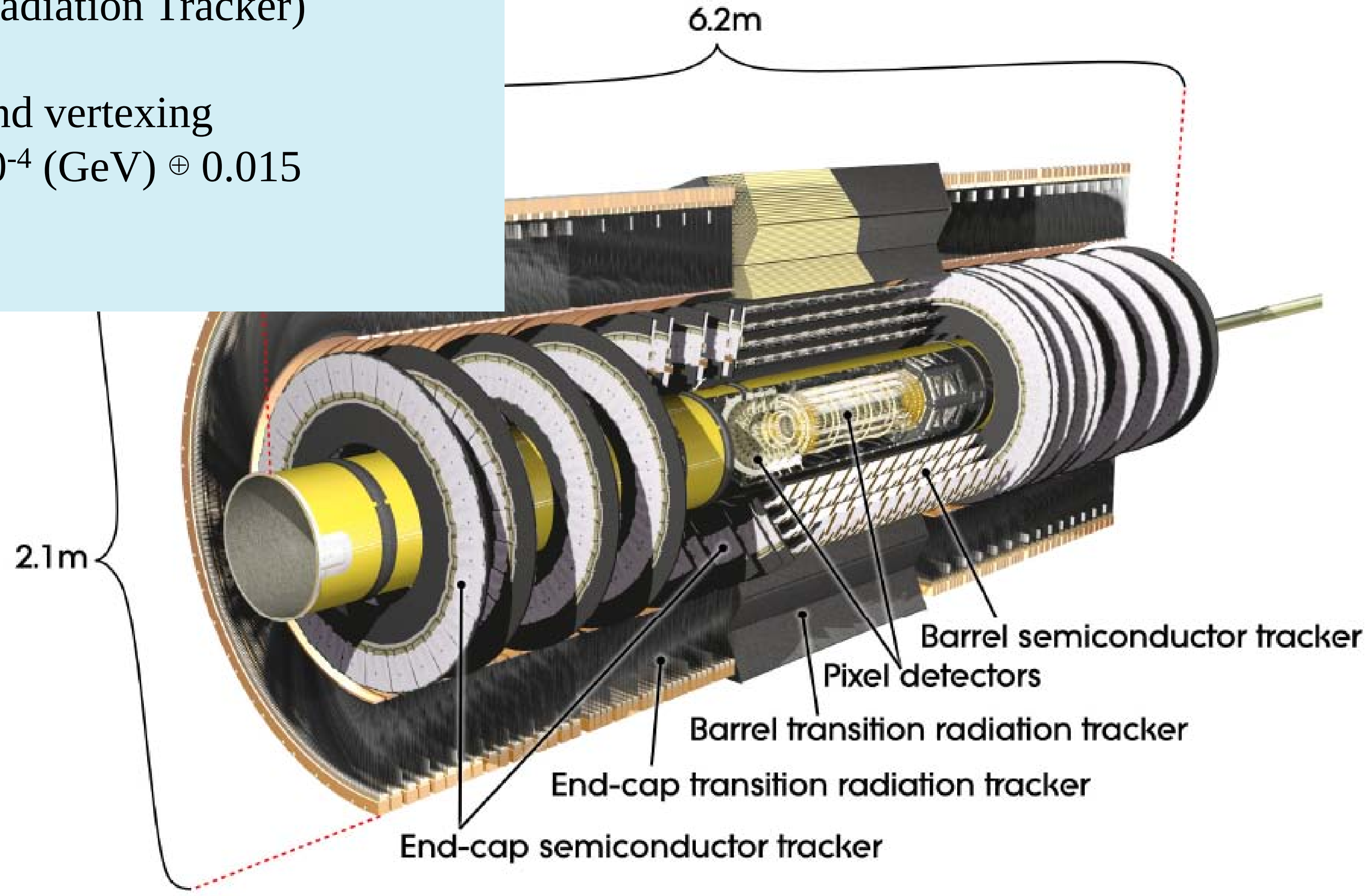


- These results came out just a few hours after the first collision
- DAQ → Reconstruction at Tier0 → Distribution to Tier2 sites takes typically ~4 hours

Performance studies

Inner Detector

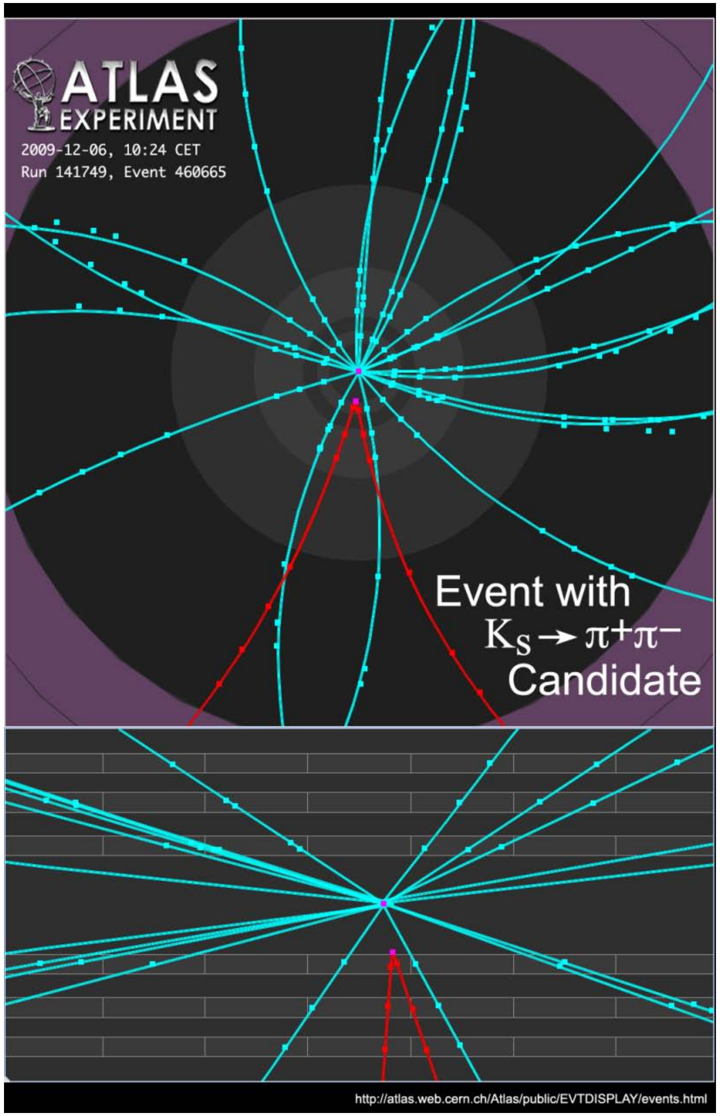
- Pixel
- SCT (Semi-Conductor Tracker, silicon strip)
- TRT (Transition Radiation Tracker)
    - e/π sepration
- Precise tracking and vertexing
    - $\sigma/p_T = 3.4 \times 10^{-4}$ (GeV) $\oplus$ 0.015
- 2 T solenoid field
- $|\eta|<2.5$

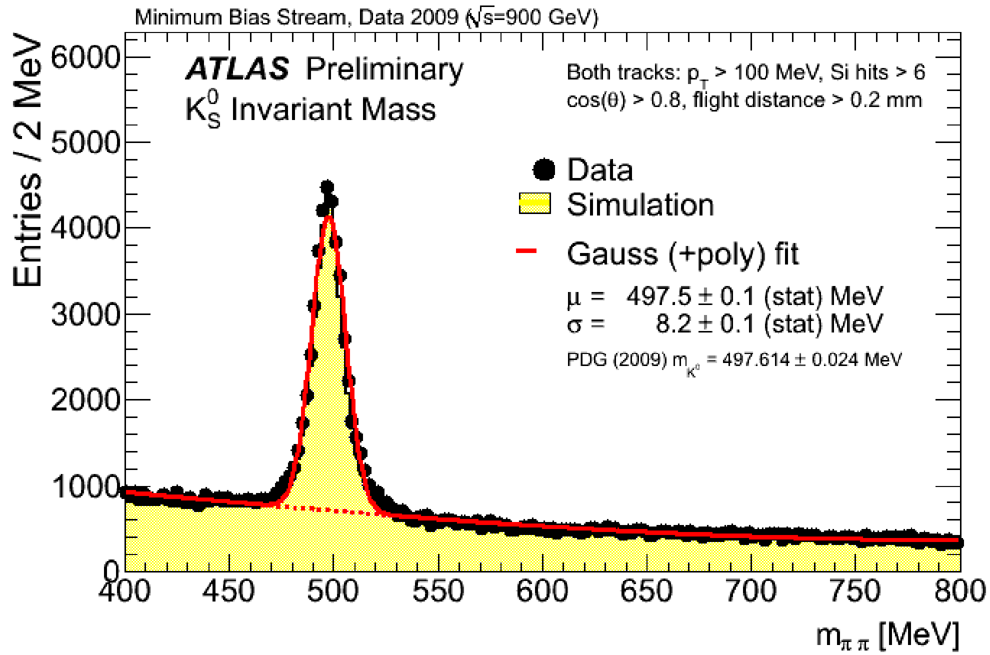


K_S^0

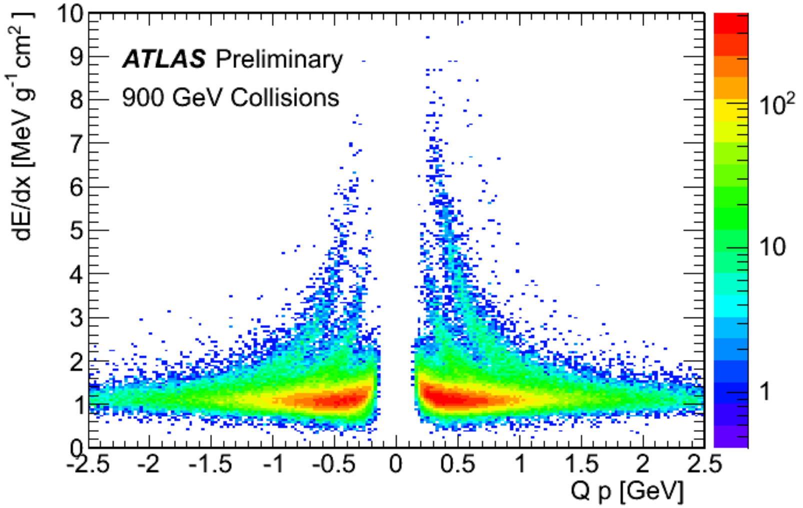
Invariant mass of two oppositely charged tracks with

- More than 6 Pixel+SCT hits
- p_T > 100 MeV
- Refit the vertex of the two tracks and require the direction of the two track momentum sum to be consistent with the primary to secondary vertex
- K_S^0 sample is used extensively for tracking studies





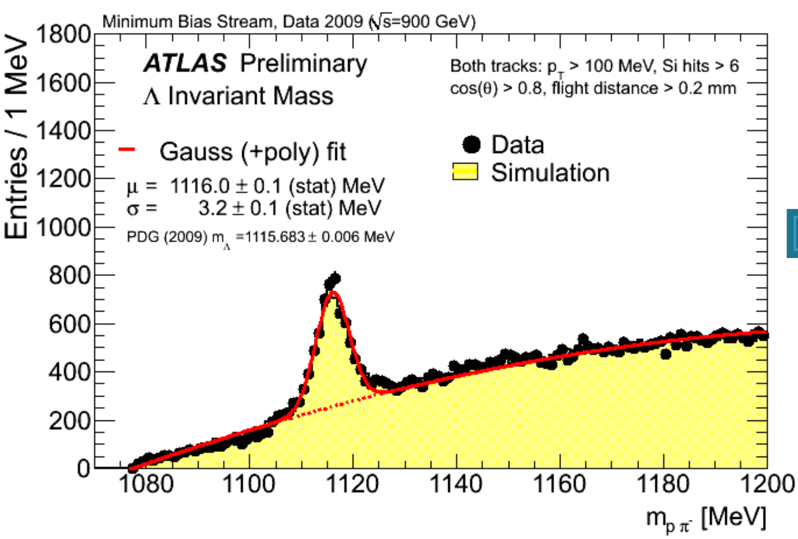
Pixel dE/dX and Λ→pπ



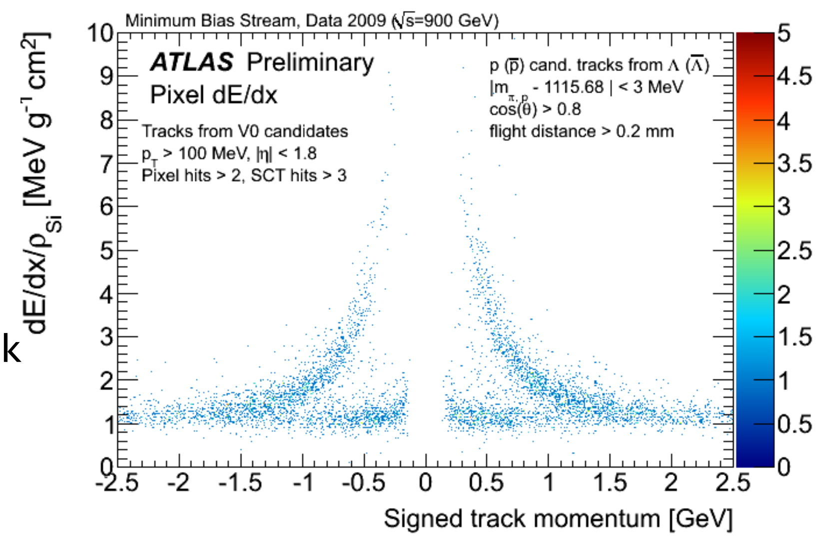
dE/dX from the Pixel detector

- Bands from π, K, proton

- dE/dX of proton candidates selected using $\Lambda/\bar{\Lambda}$ mass constraint
- Proton band is dominant
- Pion band from the BG is also seen

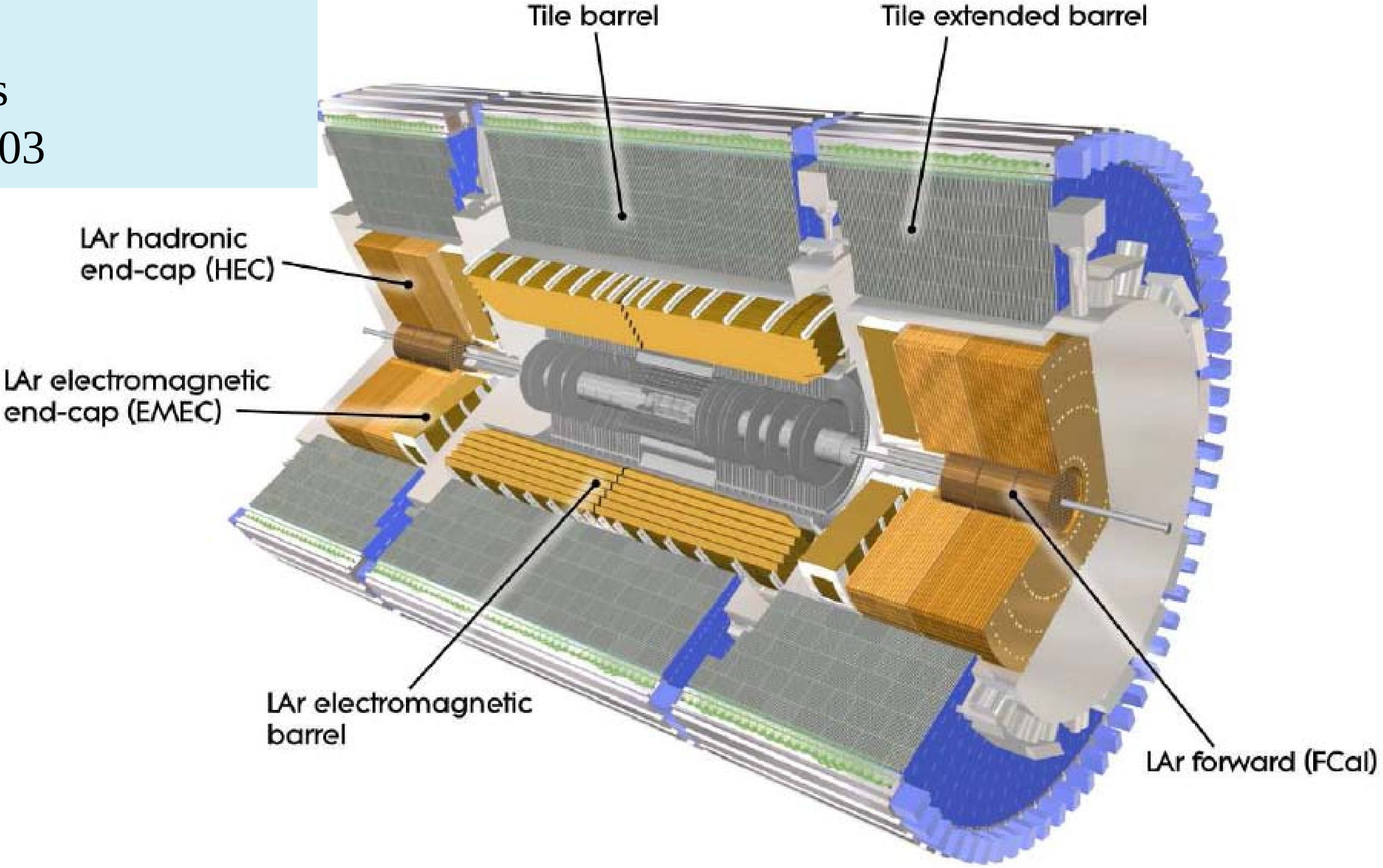


±3 MeV
around the peak

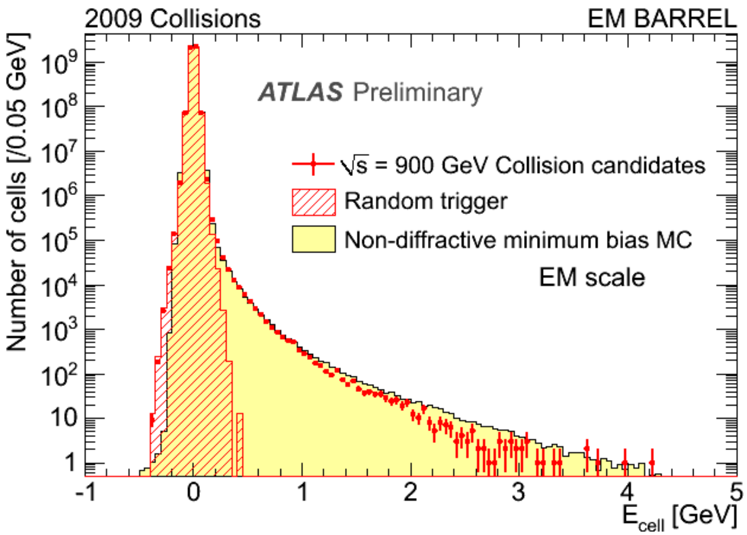


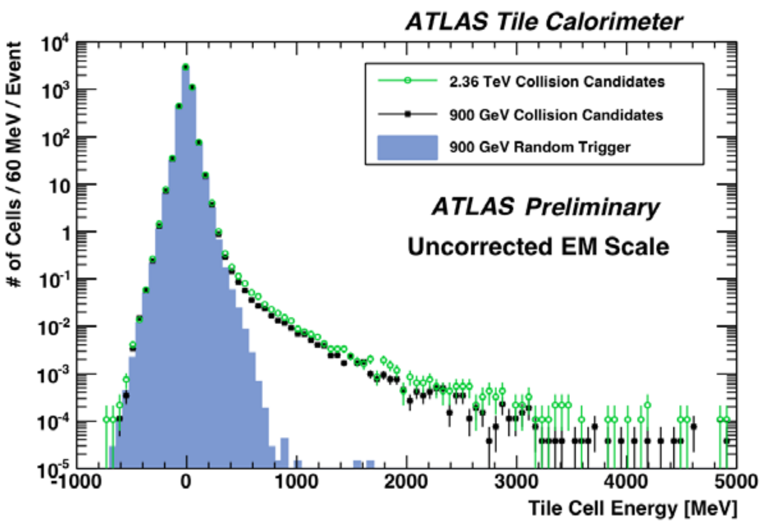
Calorimetry

- EM calorimeter
  - LAr, accordion structure
  - e/γ identification
  - σ/E ~ 1% at 100 GeV
- Hadronic calorimeter
  - Fe/scintillator tiles
  - σ/E ~ 50 %/√E⊕0.03



Raw cell energies



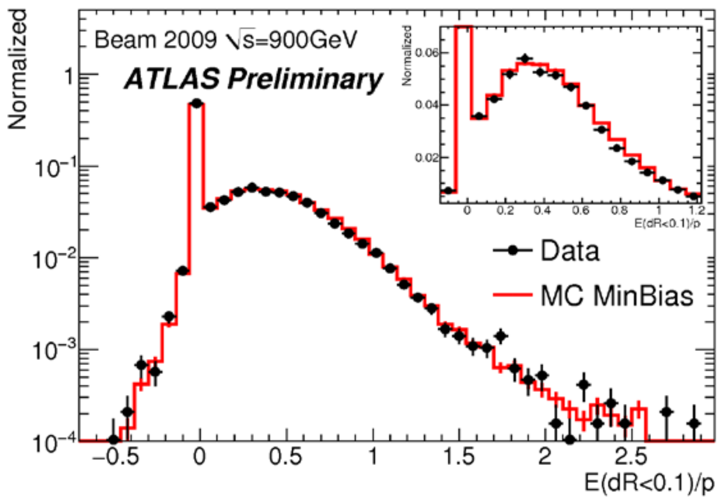


Raw cell energy distributions

- Random trigger → noise
- Collision candidates
- Reasonable agreement between data and minimum bias MC
- Data points taken at √s=2.38 TeV is also shown for the Tile calorimeter measurement

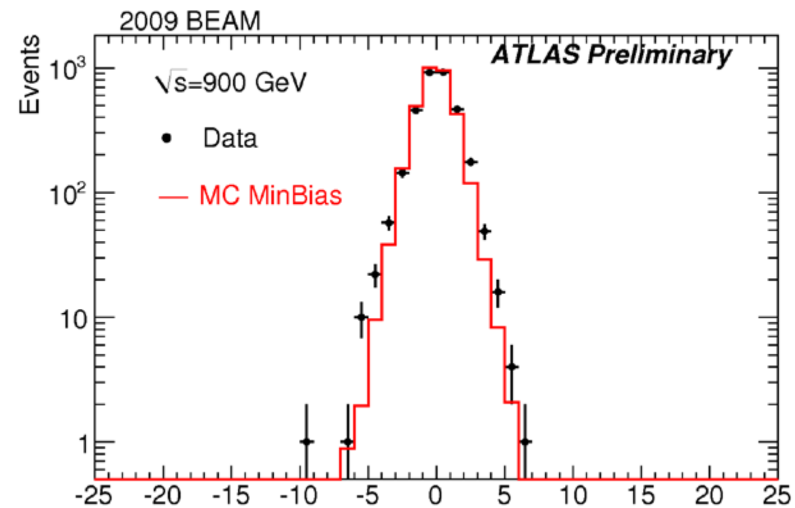
Response to hadrons

Calorimeter response to single hadron
→ Will be used for hadronic calibration



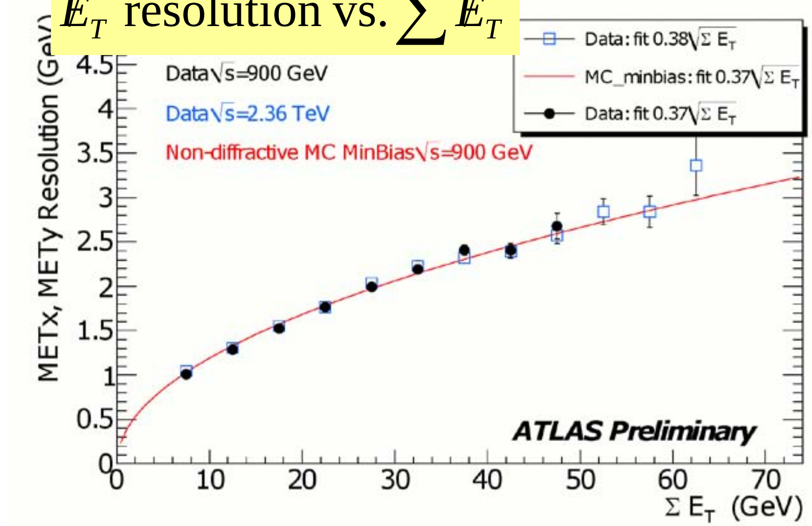
<u>E/p</u>

- Isolated track: no track in a cone of 0.4
  - 0.5<pt<10 GeV
  - |η|<0.8
- Energy sum of cells in a cone of R=0.1 around the isolated track

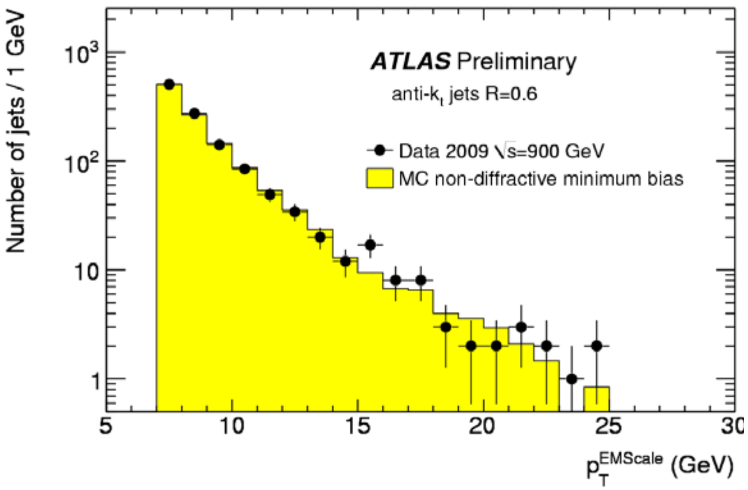


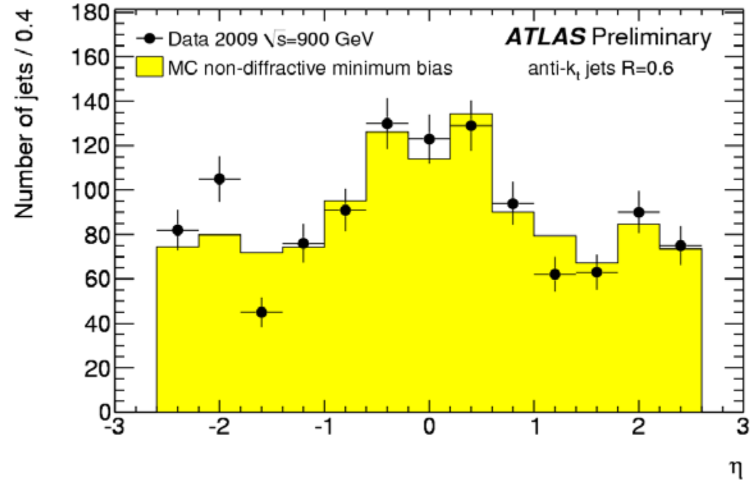
X - component of $\not{E}_T$ (GeV)

$\not{E}_T$ resolution vs. $\sum E_T$

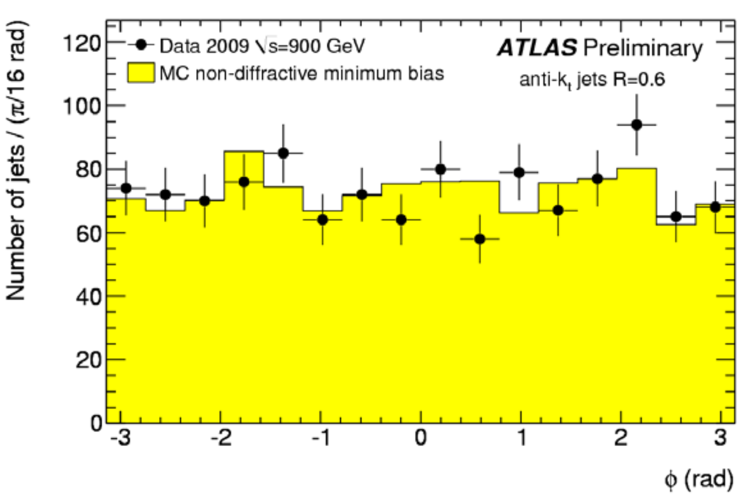


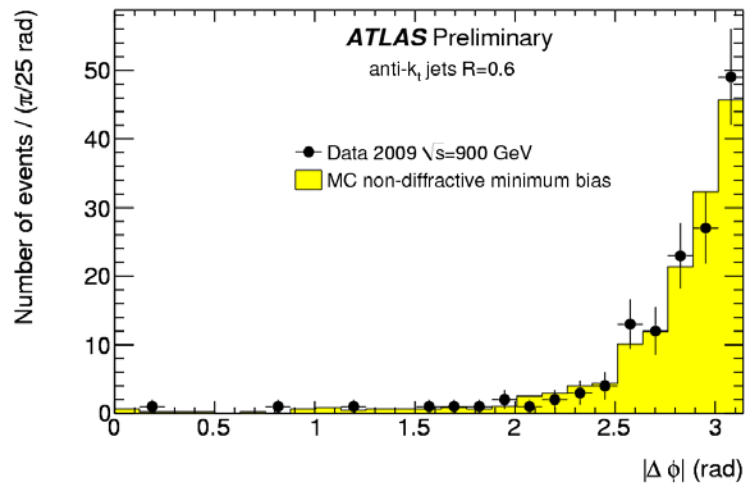
Jets





Anti-kt algorithm with D=0.4 ET>7 GeV



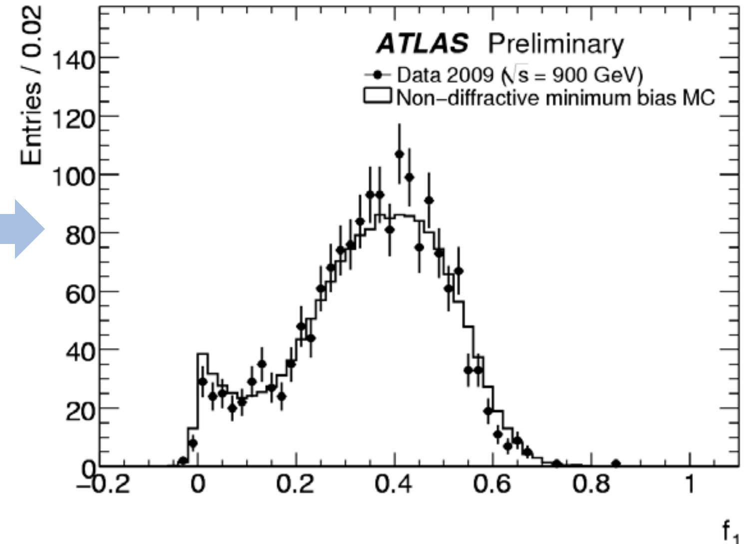


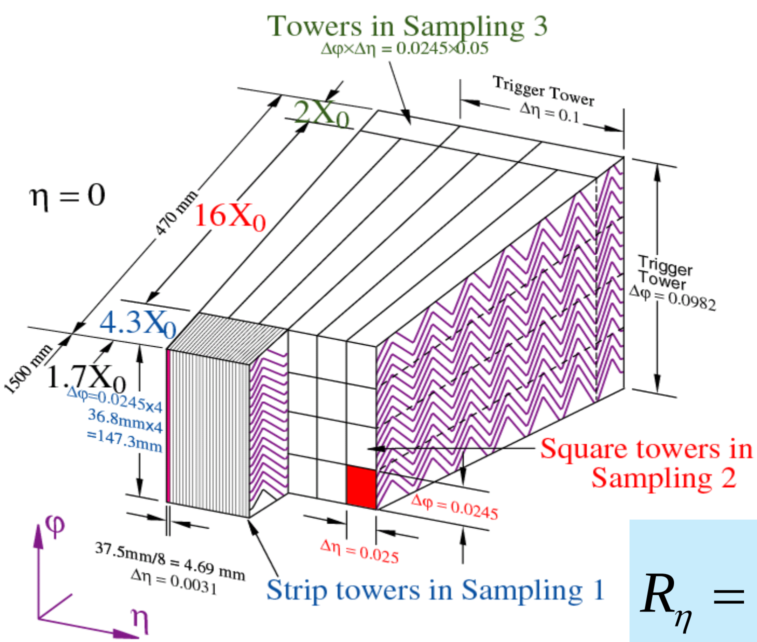
ΔR between the two jets (back-to-back)

EM shower shapes

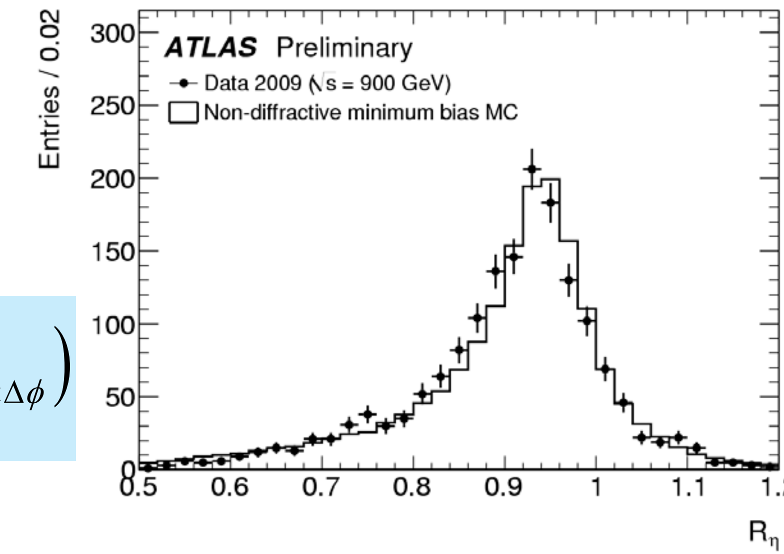
Distributions of longitudinal and lateral EM shower shape variables.

Fraction of energy in the first sampling layer

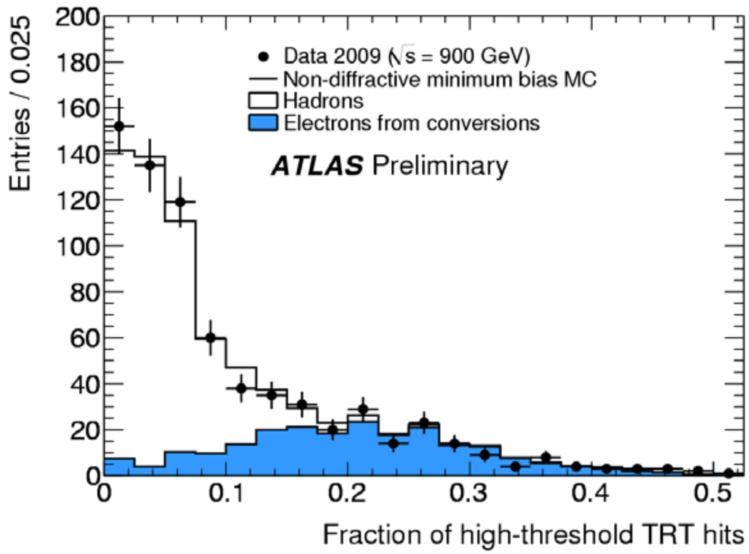




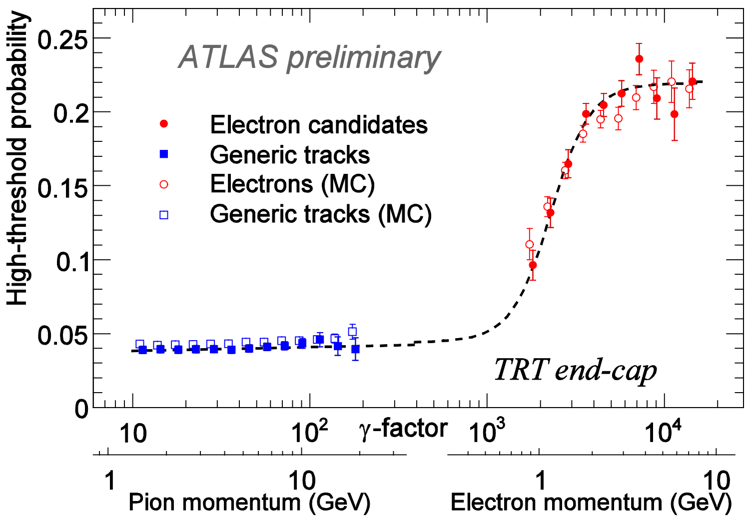
$$R_\eta = \frac{E_{3\times7}}{E_{7\times7}}, \left(E_{\Delta\eta\times\Delta\phi}\right)$$



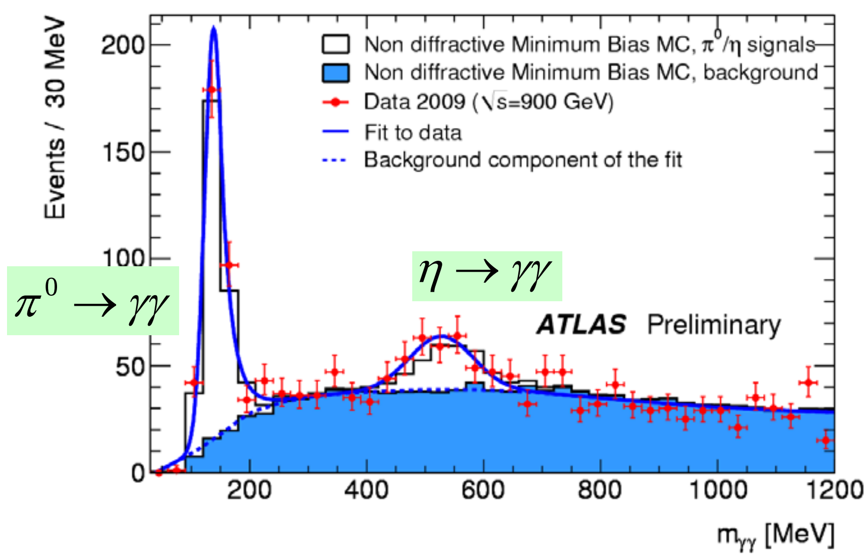
Electron ID with TRT, Di-photon mass



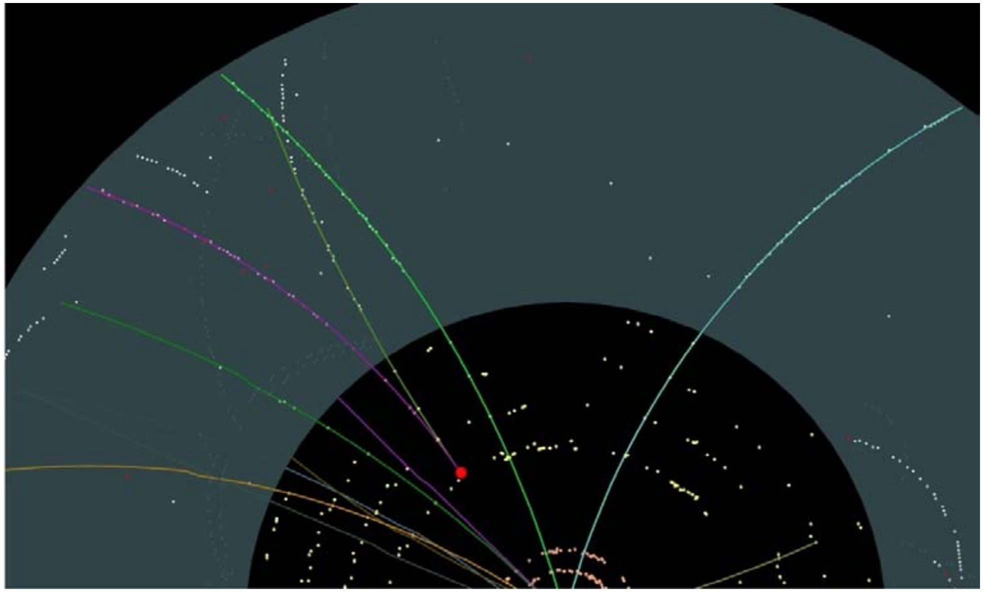
- Fraction of high threshold TRT hits compared to minimum bias MC
- Conversion candidates provide a sample enriched with real electrons

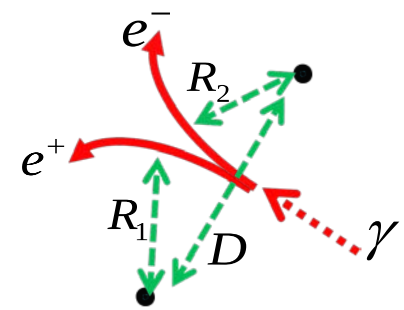


- Invariant mass of 2 photon candidates
  - EM topological clusters (seed>4σ)
- E_T (cluster) > 800 MeV
- E_T (γ γ) > 2200 MeV
- Track veto

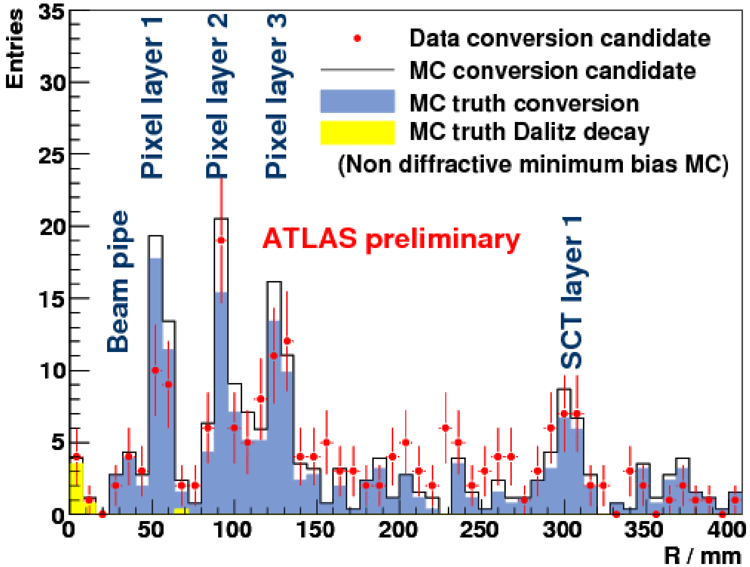


Photon conversion





- Use multi tracking algorithms
  - Inside-out, Outside-in
  - TRT only
- Small $\Delta\varphi$ and $\Delta\cot\theta$
- $D-R_1-R_2 \sim 0$
- Common vertex

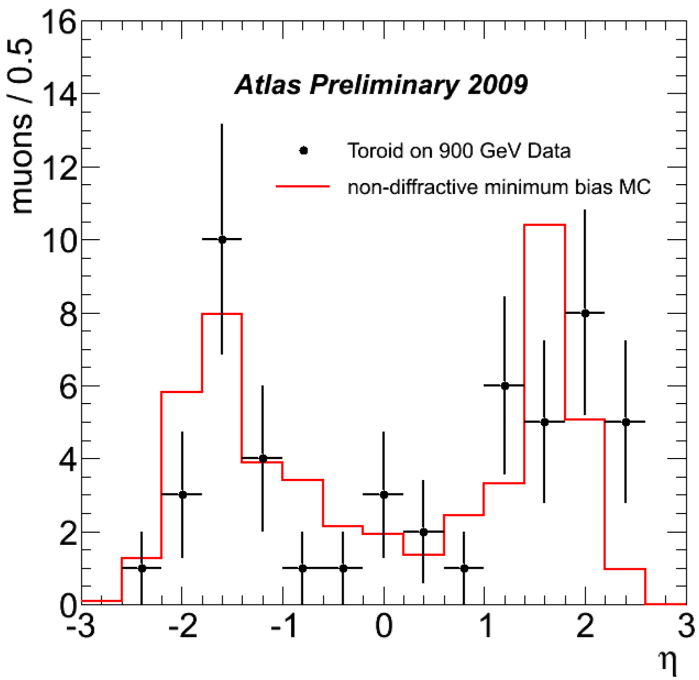


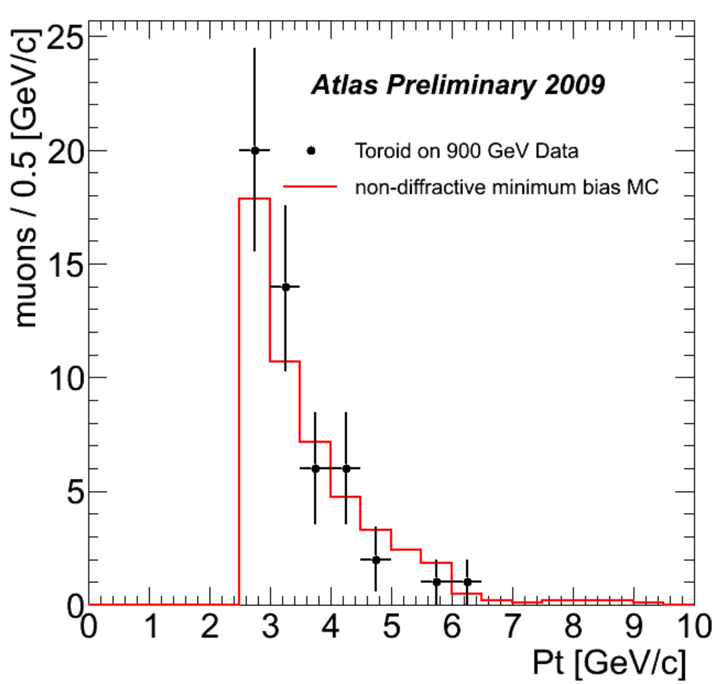
Conversion radius distribution

<u>Conversion at the 1st layer of SCT</u>
pt (track1) = 0.79 GeV (e-)
pt (track2) = 1.75 (GeV) (e+)
Both track extends to TRT with high threshold hits (3 and 11, respectively)

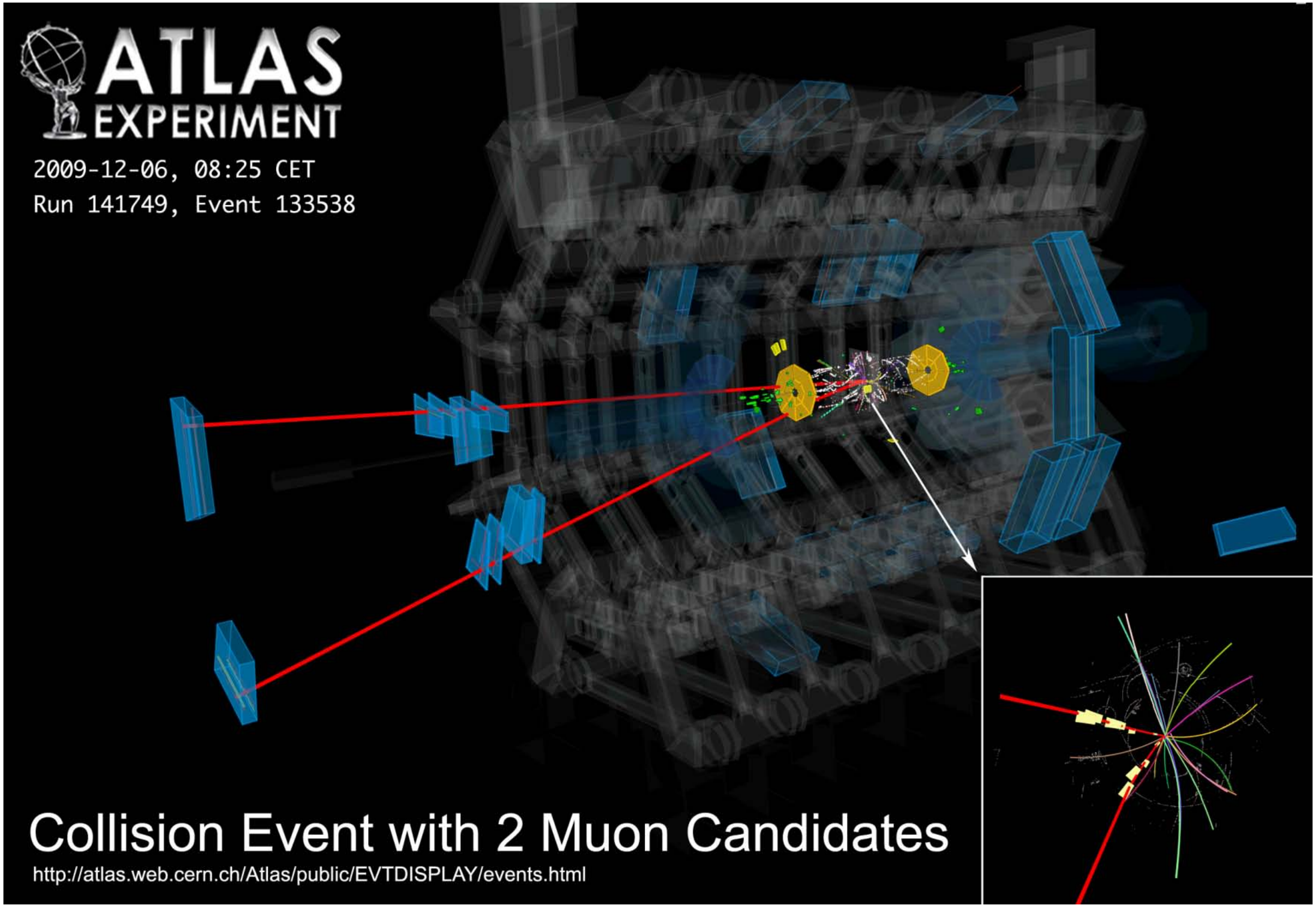
Muon distributions

- Muons reconstructed using Muon spectrometer and ID
  - p_T>2.5 GeV and |η|<2.5 in runs with toroid magnet on
- Muon candidates have very low transverse momentum at 900 GeV
  - ~50 candidates mostly in the endcap
- Good agreement between data/MC ithin the statistical uncertainty





Muon


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

Detector status

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.5%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.2%
LAr EM Calorimeter	170 k	98.6%
Tile calorimeter	9800	98.0%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.5%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Trigger	370 k	99.5%
TGC Endcap Muon Trigger	320 k	100%

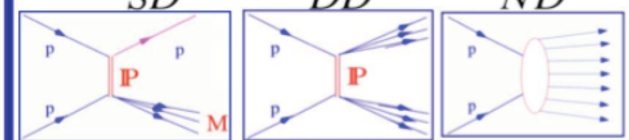
Detectors status is excellent with >99 channels operational

Analysis

Charged particle multiplicities at $\sqrt{s}$=900 GeV

- The measurement of charged particles in inclusive proton-proton collision constrains phenomenological models of soft QCD
- Important ingredient for future studies of high p_T physics at the LHC

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



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

Distributions of primary charged particles in inelastic events

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

Phase space

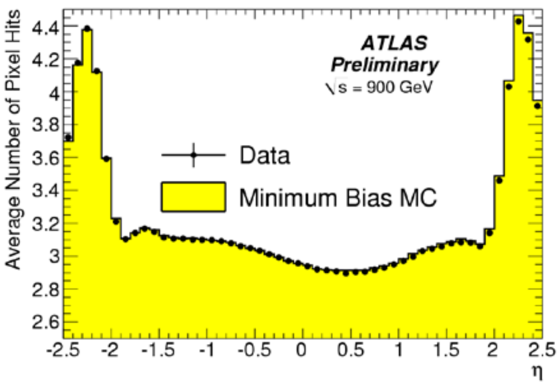
$$p_T^{\text{track}} > 0.5\,\text{GeV}$$
$$|\eta| < 2.5$$
$$N_{\text{ch}} \geq 1$$

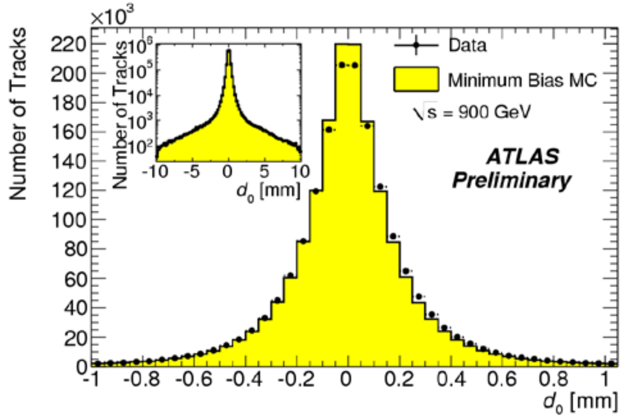
- Final results should reflect what was measured directly with little model dependence as possible
- Do not extrapolate to unmeasured phase space

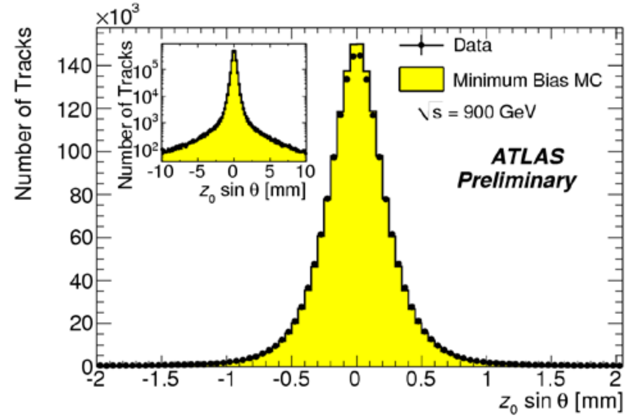
Analysis method

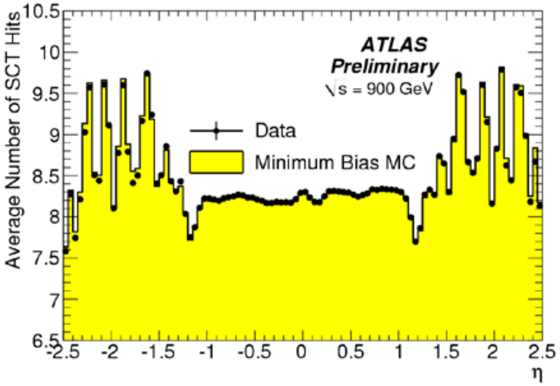
- Trigger
  - L1_MBTS_1, require at least 1 out of the 32 MBTS scintillators fires
    - Single-arm trigger overlapping with the acceptance of the tracker
    - Efficiency ~ 100 % (estimated from data)
- Tracking (Inside-out pattern recognition)
  - p_T>0.5 GeV, $|\eta|<2.5$
  - Number of hits on the track (>1 Pixel, >6 SCT hits)
  - $|d_0^{PV}|<1.5$ mm, $|z_0^{PV}\sin\theta|<1.5$ mm
    - Remove secondary charged particles
- Require primary vertex
  - Vertexing requires >3 tracks with p_T>150 MeV, $|d_0^{BS}|<4$ mm
- Apply correction for trigger, tracking and vertexing efficiencies
  - Tracking efficiency from MC with many cross checks with data
  - Trigger and vertexing efficiency from data
- ~330 k events after selection
  - Contribution of beam background estimated from unpaired bunches is < 10^{-4}

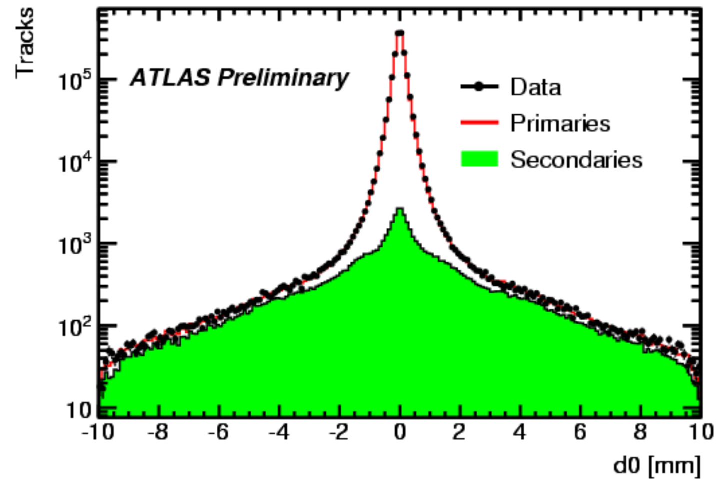
Tracking distributions





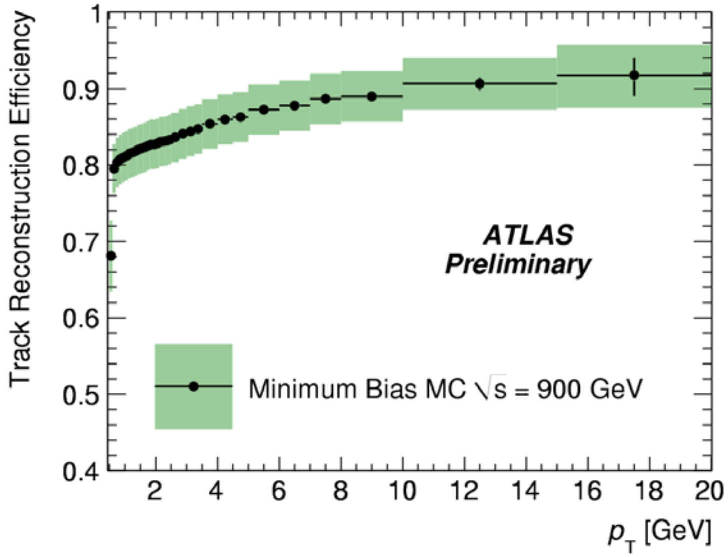




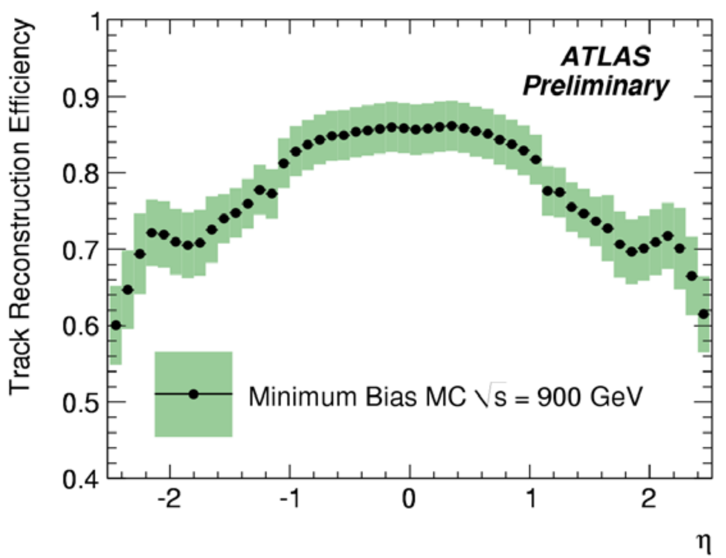


- Very good agreement between data/MC
- Secondary particles in $|d_0^{PV}|<1.5$ mm, $|z_0^{PV}\sin\theta|<1.5$ mm are subtracted by normalizing MC using the side-band

Efficiencies

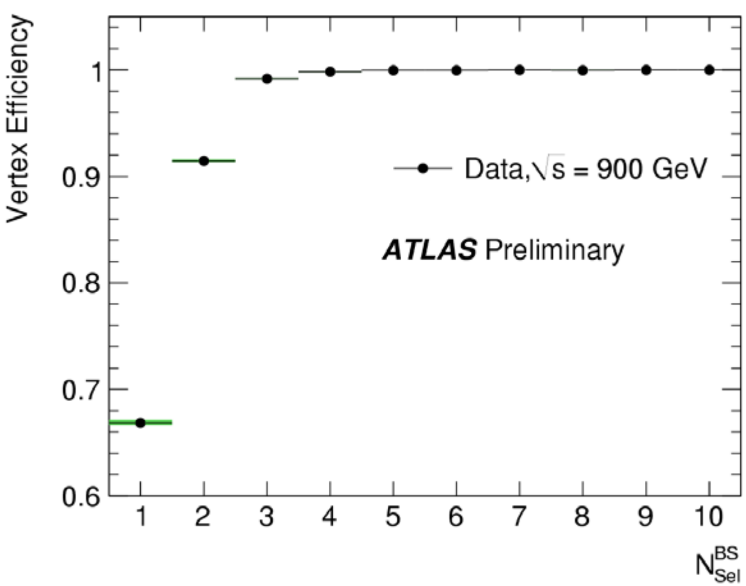


Tracking efficiencies as functions of p_T and η
Estimated from MC

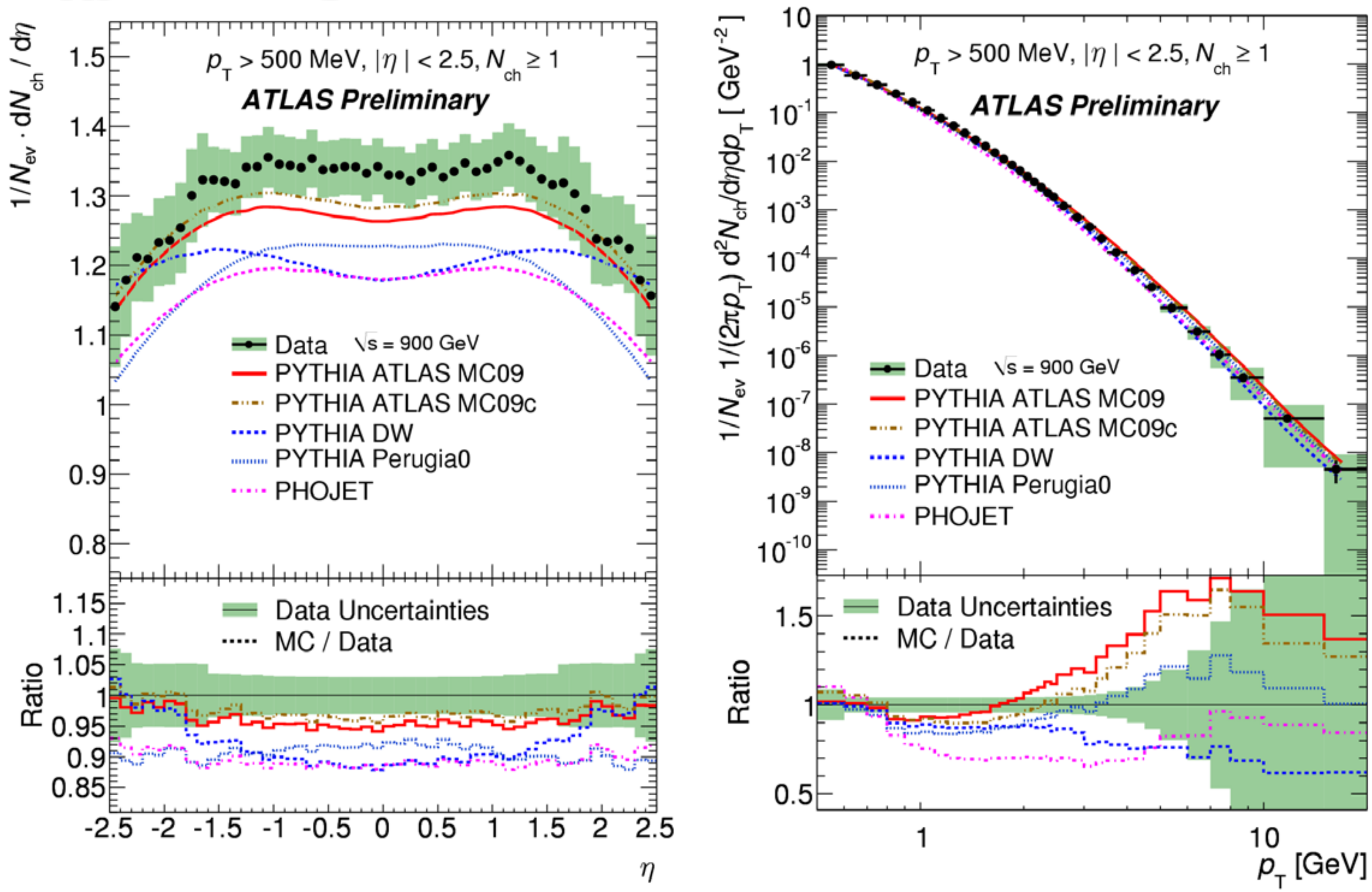


Vertex reconstruction efficiency parameterized as a function of the number of tracks without the d_0 and z_0 cuts

$$\varepsilon = \frac{\#\,\text{triggered}\,\&\,\text{vertex}}{\#\,\text{triggered}}$$

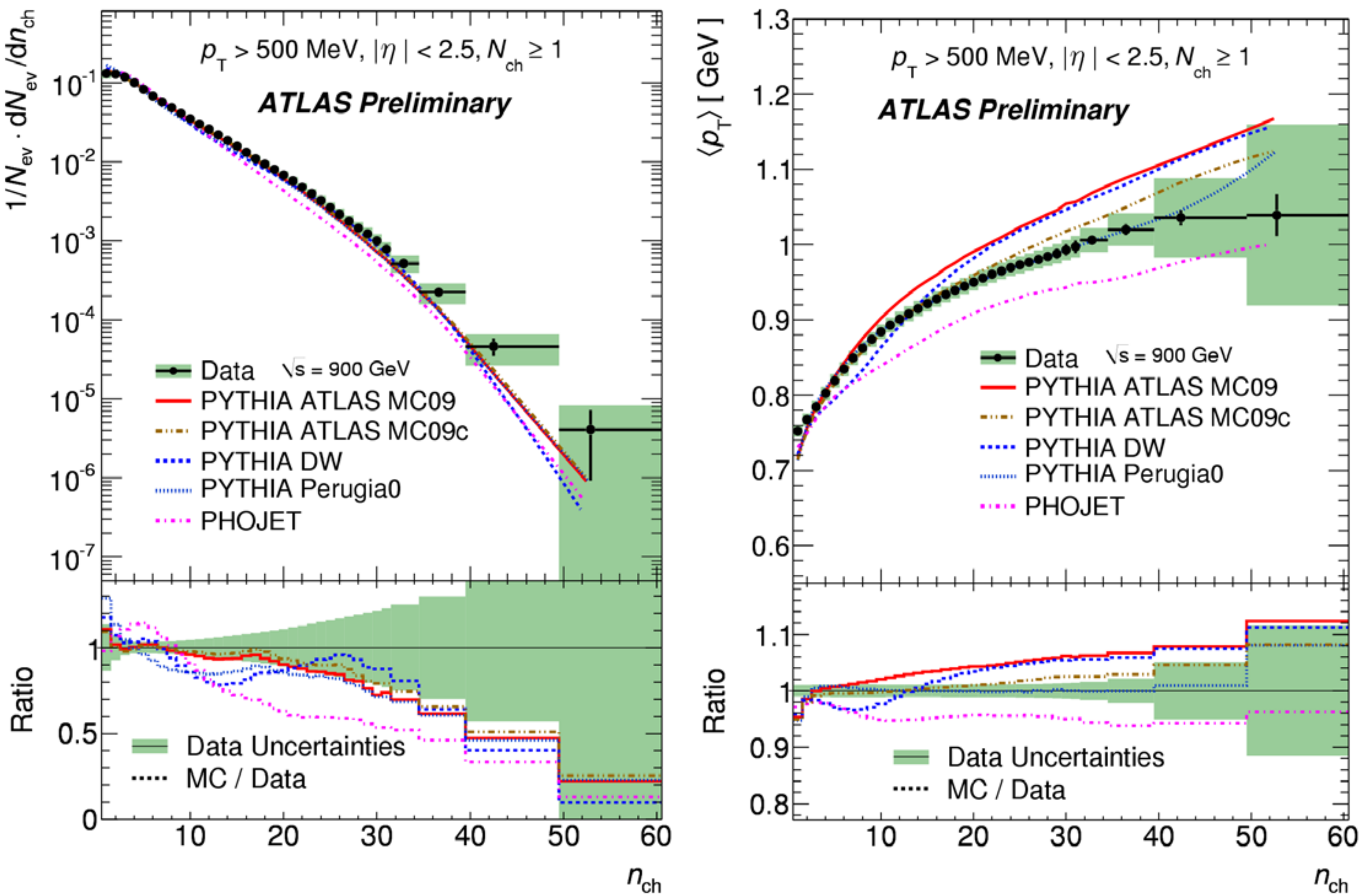


N_{ch} vs. p_T and η



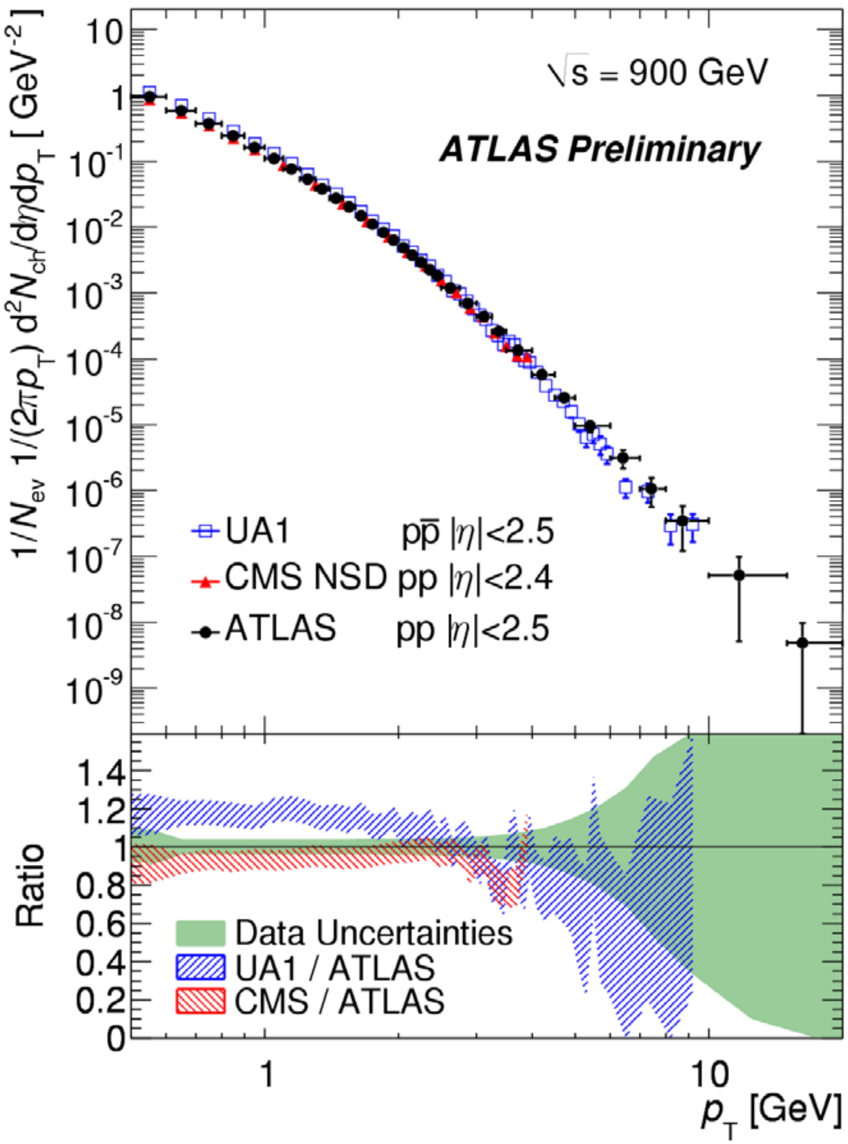
- Distributions are normalized to the number of events
- All MC tunes underestimate ATLAS data
- data/MC agree well only for p_T<0.7

N_{ch} distribution and $<p_T>$ vs. N_{ch}



- All MC underestimate data at N_{ch}>10
- Increase of $<p_T>$ as a function of N_{ch}. Change of slope at N_{ch}~10 (also seen at CDF)

Comparison with other experiments



Comparison to UA1

- N_{ch} higher than ATLAS data by ~ 20 %
- Consistent with the double-arm trigger requirement used by UA1 which rejects events with low charged particle multiplicities

Comparison to CMS

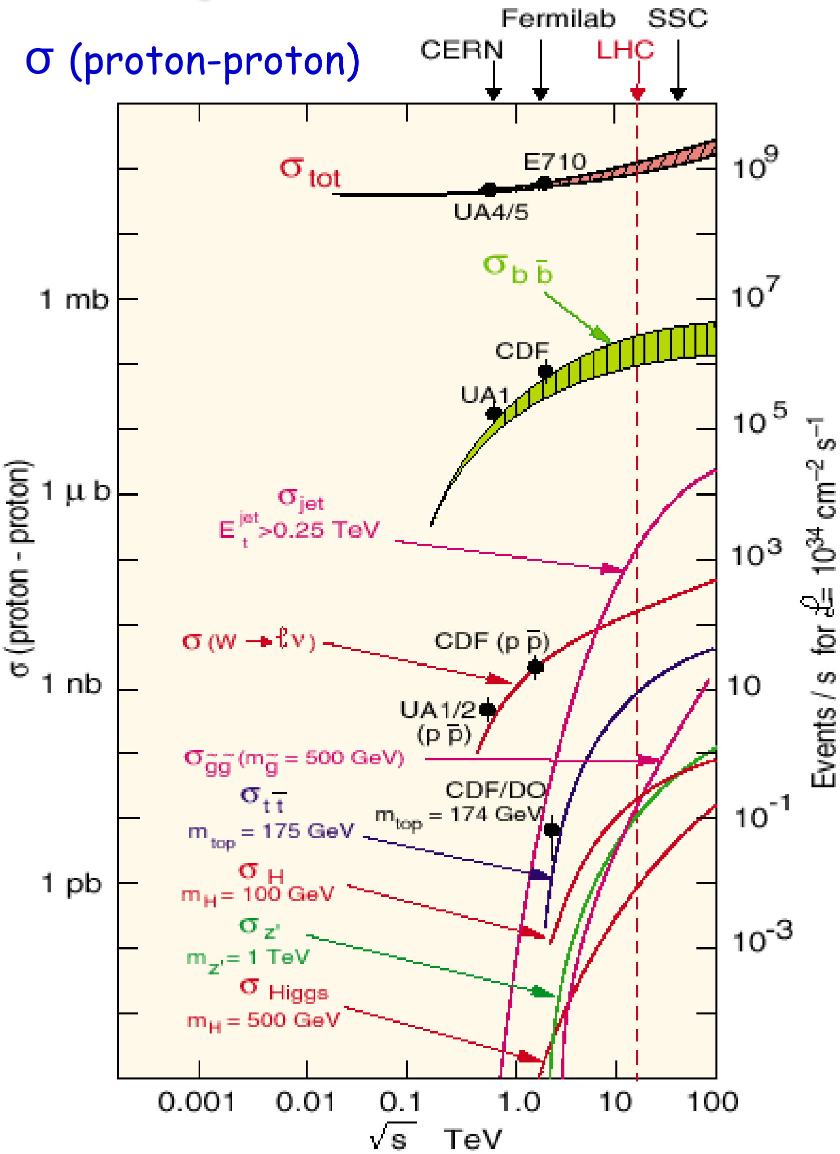
- N_{ch} consistently lower than ATLAS data
- Different treatment of diffractive components

Conclusion

- ATLAS data-taking with 900 GeV collision was very successful
  - 380 k collision events with ID fully on and good data quality
  - Detector operational status is excellent
- Performance studies with collision events
  - Tracking (alignment, resonances, vertexing)
  - Response to hadrons (single hadron, jets, missing E_T)
  - Electron & photon isolation (shower shapes, di-photon mass, γ conversion)
  - Muon reconstruction (limited statistics but reasonable distributions)
  - In general data show good agreement with minimum bias MC
- Charged particle multiplicity measurement
  - Measurement done in p_T>0.5 GeV, $|\eta|$<2.5 ($N_{ch}\geq 1$)
  - All MC tunes underestimate ATLAS data
- Expecting higher CM energy and luminosity from LHC and more physics to come in 2010

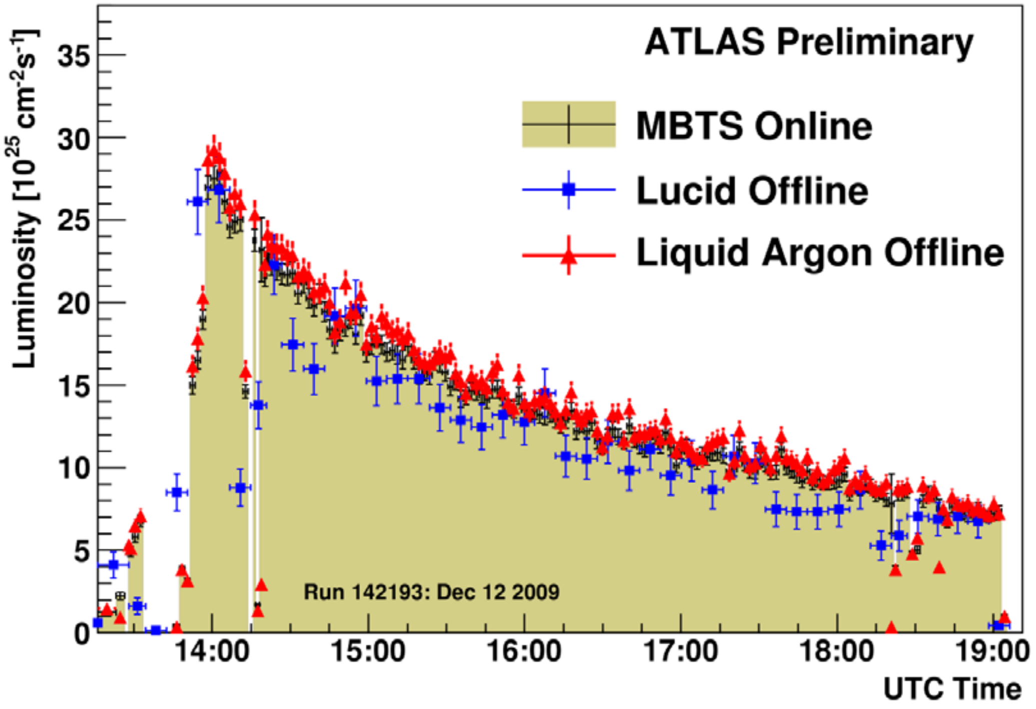
Backup slides

Physics at the LHC



- Main physics goals
  - Discovery of Higgs particle
  - Search for physics beyond the Standard Model
- Large cross section for QCD dijet

Luminosity



ATLAS Preliminary
MBTS Online
Lucid Offline
Liquid Argon Offline
Run 142193: Dec 12 2009
Luminosity [10^25 cm^-2 s^-1]
0
5
10
15
20
25
30
35
14:00
15:00
16:00
17:00
18:00
19:00
UTC Time

Timing with TRT

Average drift timing edge from TRT