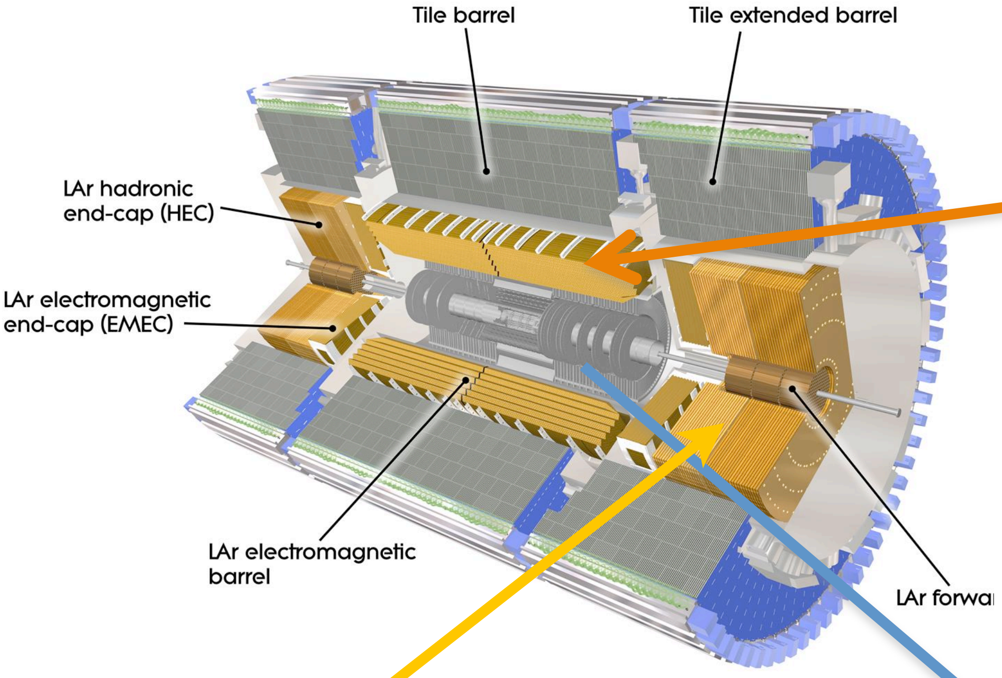
Calor 2010, Beijing, 10-14May 2010

Electron and photon reconstruction and identification with the ATLAS detector and performance with $\pi_0/\eta \rightarrow \gamma\gamma$ with $\sqrt{s} = 900$GeV data.

Danilo Banfi

On behalf of ATLAS collaboration

Calorimeters and Tracker

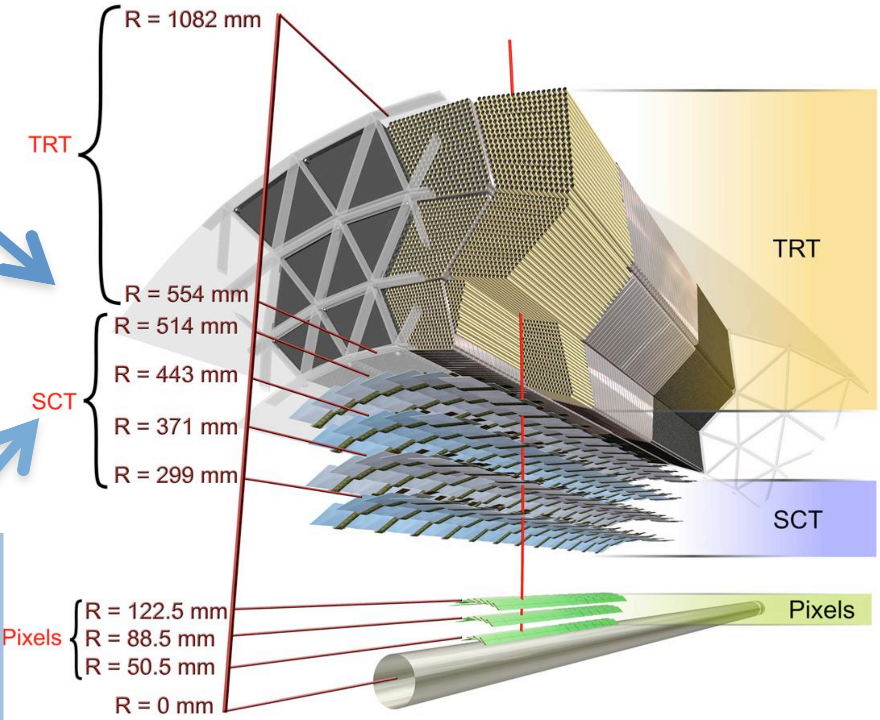


Calorimeter EM

- Pb-LAr (Lead - Liquid Argon) Sampling calorimeter (87°K)
- Accordion geometry for full Φ coverage
- Barrel (|η|<1.45) + 2 EndCaps (1.6<|η|<3.2)
- Depth 22-30X_0
- 3 longitudinal samplings (strip, middle, back) + PreSampler

Forward Calorimeter

- 3.1<|η|<4.9
- 3 module on each EndCap
  - first module (copper): optimized for EM showers
  - other 2 module (tungsten): optimized for Hadrons



Inner Detector constituted of 3 sub detector (|η|<2.5):

- Pixel (3 layers)
- SCT: SemiConductor Tracker (8 strips layers / 4 space points)
- TRT: Transition Radiation Tracker (straw tube, ~30 hits/track)

Electron/photon reconstruction strategy and Data Samples

Electrons and photons reconstruction pass through a series of steps:

1. Start from calorimeter cells calibrated to EM scale
2. Build a cluster using a fixed-size Δη × Δϕ = 3 × 5 (0.075 x 0.125) rectangular window of middle cells; position at local maxima in energy.
3. Match clusters against tracks and conversions to determine particle hypothesis:
   - Electron, photon, or converted photon
4. Rebuild clusters; sizes depend on particle hypothesis and calorimeter region.
5. Apply cluster position and energy calibrations.
6. If there's a matching track, take the candidate direction from tracker. Otherwise, infer direction from the calorimeter.
7. Calculate discriminating variables to reject backgrounds.

Events collected @ √s=900GeV (2009 runs):

- triggered during stable beam using Minimum-Bias-Trigger-Scintillator (MBTS $2.09<|\eta|<3.84$)
- required either time coincidence between the two EndCap or from MBTS
- good DQ flag for tracker, EM and HAD calorimeter, and solenoidal field to nominal value

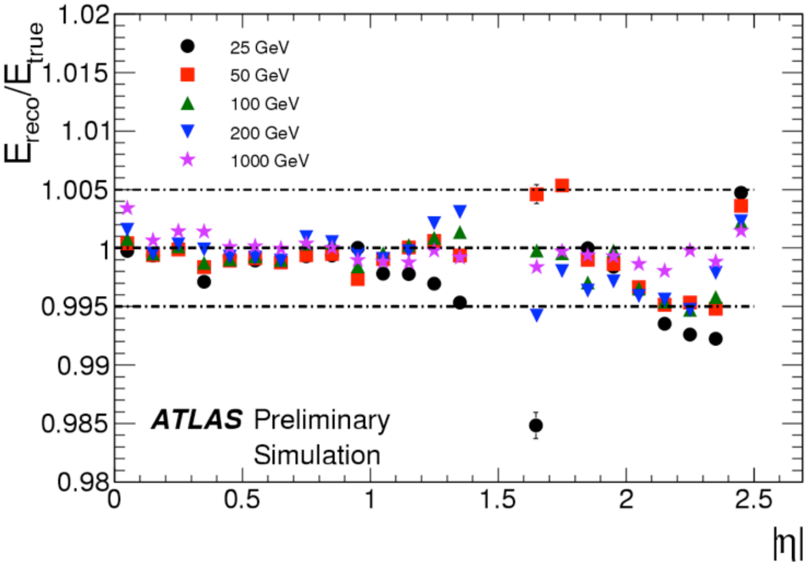
Full collected sample : 384186 collision candidates corresponding to $9\mu b^{-1}$

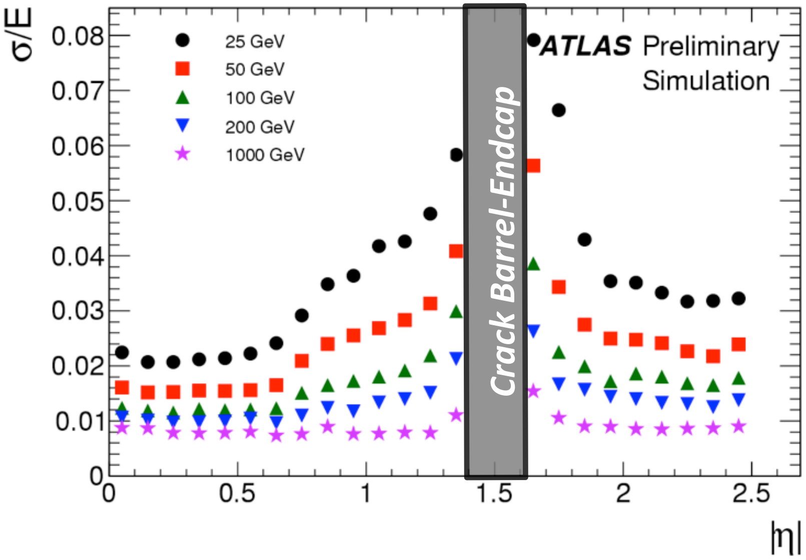
Selected only events with:

- cluster $E_T>2.5$GeV
- electron candidate cluster $|\eta|<2.47$ and photon candidates cluster $|\eta|<2.37$ (missing fine granularity strips used for photon's identification)

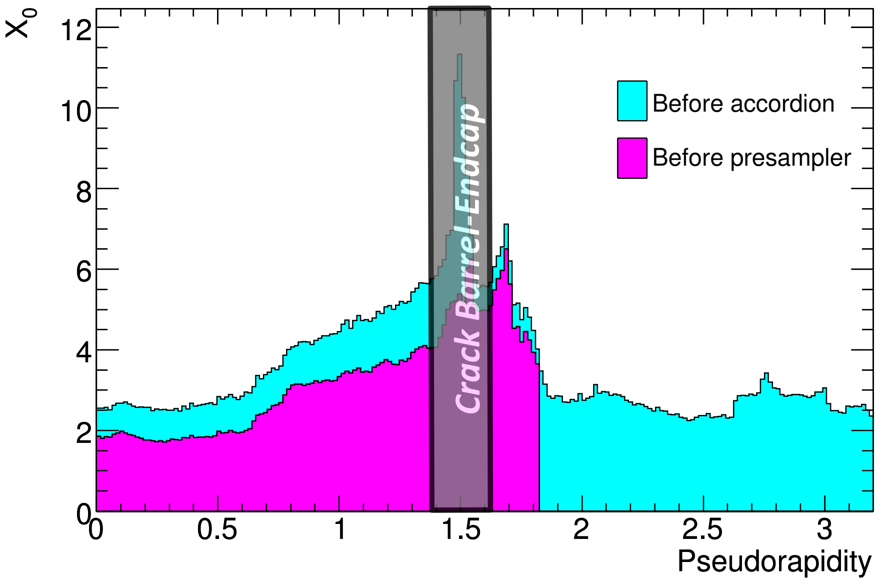
Final statistics : 1694 photon candidates and 879 electron candidates.

Cluster calibration: energy reconstruction performance for electrons (MC)





Calibration extracted from MC samples in the range from 25GeV to 1TeV, and extrapolated to lower energies.

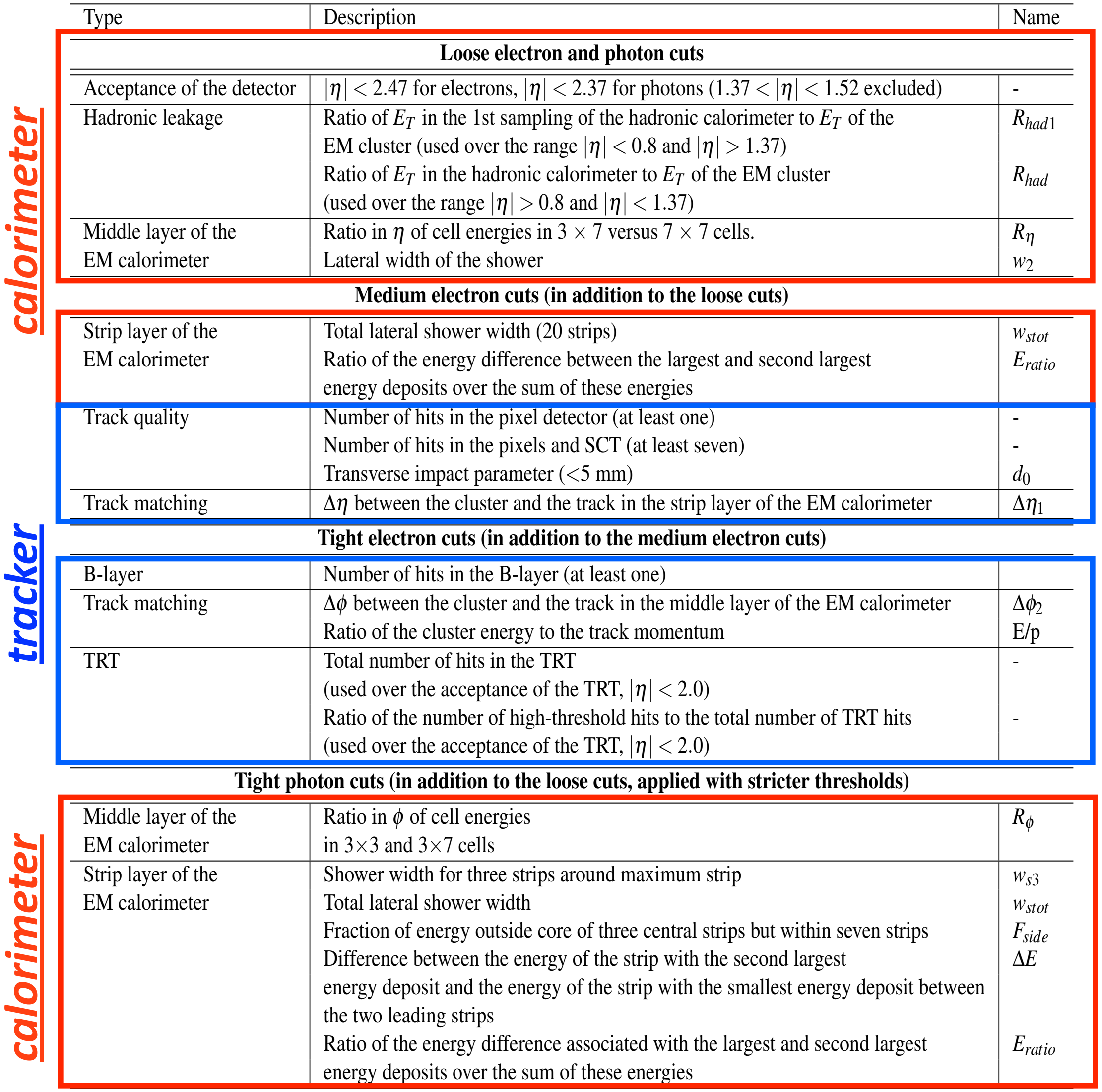


<u>Expected performance</u> tested on MC and beam test:

- Linearity (E_{reco}/E_{true}) better than 0.5% for both electrons and photons
- Energy resolution is strongly influenced by the amount of material in front of calorimeter

Identification variables (MC)

Lots of variables from ***calorimeter*** and ***tracker*** used for electron and photon identification and to reject background

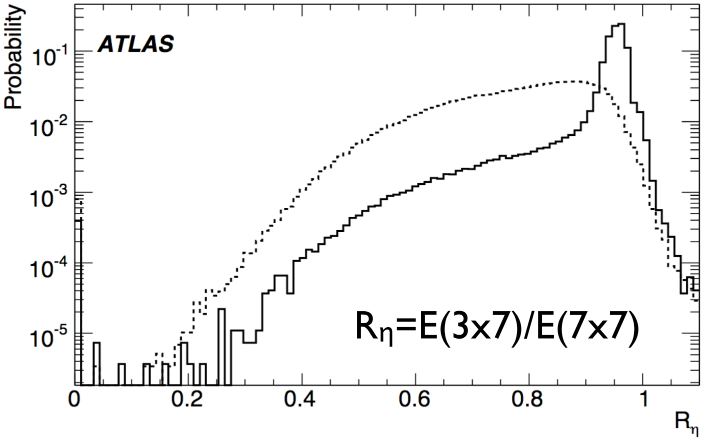


calorimeter

tracker

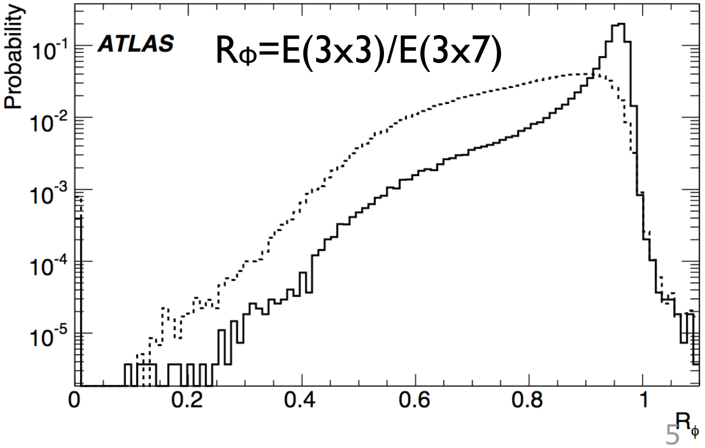
calorimeter

Type	Description	Name
	Loose electron and photon cuts	
Acceptance of the detector	$\|\eta\| < 2.47$ for electrons, $\|\eta\| < 2.37$ for photons ($1.37 < \|\eta\| < 1.52$ excluded)	-
Hadronic leakage	Ratio of E_T in the 1st sampling of the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| < 0.8$ and $\|\eta\| > 1.37$) Ratio of E_T in the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| > 0.8$ and $\|\eta\| < 1.37$)	R_{had1} R_{had}
Middle layer of the EM calorimeter	Ratio in η of cell energies in 3×7 versus 7×7 cells. Lateral width of the shower	R_η w_2
	Medium electron cuts (in addition to the loose cuts)	
Strip layer of the EM calorimeter	Total lateral shower width (20 strips) Ratio of the energy difference between the largest and second largest energy deposits over the sum of these energies	w_{stot} E_{ratio}
Track quality	Number of hits in the pixel detector (at least one) Number of hits in the pixels and SCT (at least seven) Transverse impact parameter (<5 mm)	- - d_0
Track matching	$\Delta\eta$ between the cluster and the track in the strip layer of the EM calorimeter	$\Delta\eta_1$
	Tight electron cuts (in addition to the medium electron cuts)	
B-layer	Number of hits in the B-layer (at least one)	
Track matching	$\Delta\phi$ between the cluster and the track in the middle layer of the EM calorimeter Ratio of the cluster energy to the track momentum	$\Delta\phi_2$ E/p
TRT	Total number of hits in the TRT (used over the acceptance of the TRT, $\|\eta\| < 2.0$) Ratio of the number of high-threshold hits to the total number of TRT hits (used over the acceptance of the TRT, $\|\eta\| < 2.0$)	- -
	Tight photon cuts (in addition to the loose cuts, applied with stricter thresholds)	
Middle layer of the EM calorimeter	Ratio in ϕ of cell energies in 3×3 and 3×7 cells	R_ϕ
Strip layer of the EM calorimeter	Shower width for three strips around maximum strip Total lateral shower width Fraction of energy outside core of three central strips but within seven strips Difference between the energy of the strip with the second largest energy deposit and the energy of the strip with the smallest energy deposit between the two leading strips Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies	w_{s3} w_{stot} F_{side} ΔE E_{ratio}



Example from MC:

- electrons from Z→ee (full line)
- di-jets (dashed line)



Cut based electrons and photon identification (MC)

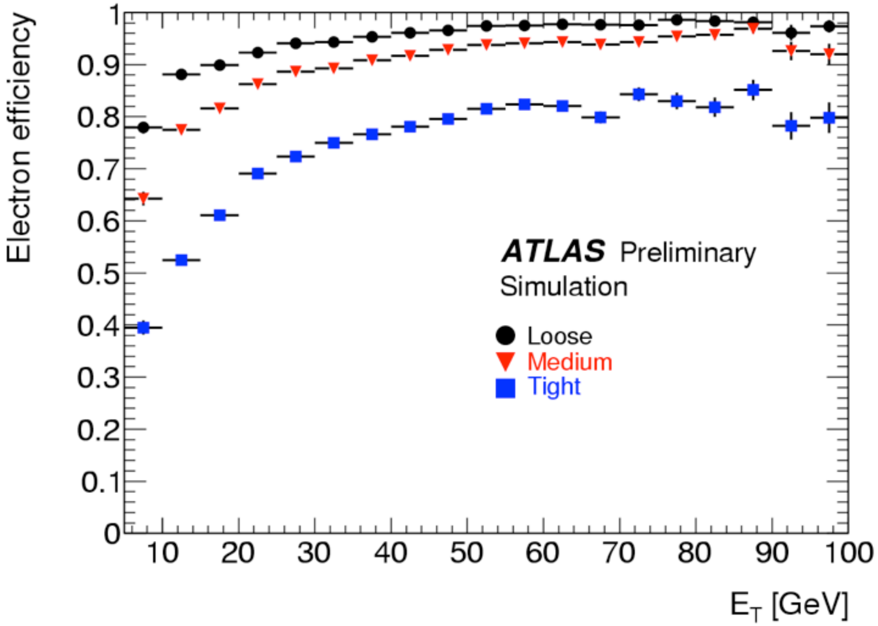
- Apply cut on each variable (η, energy and particle dependent)
- More than one definition of identification cuts are available

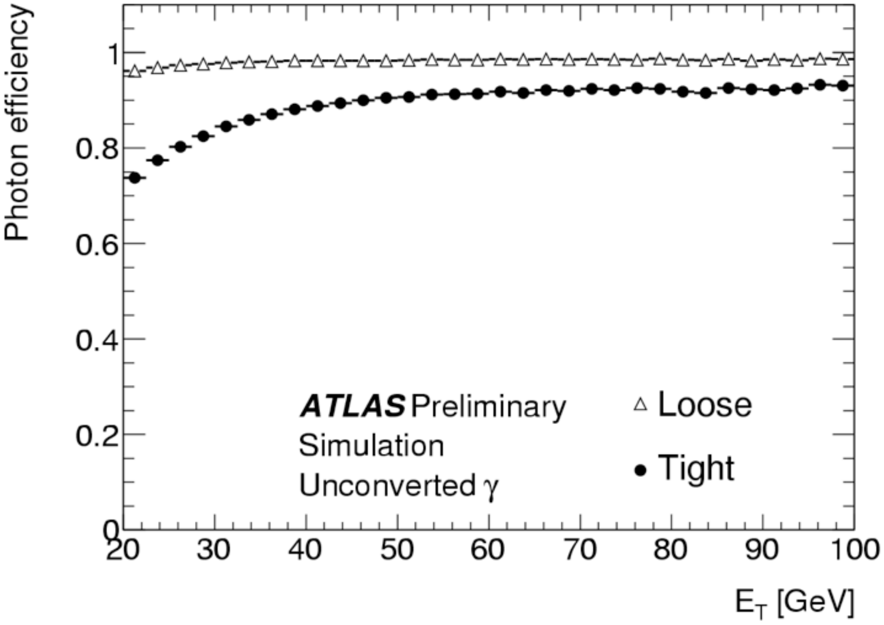
Electrons

Cut	Efficiency(%)		Jet Rejection
	Z→ee	b,c → e	
Loose	94.30±0.03	36.8±0.5	1066±4
Medium	89.97±0.03	31.5±0.5	6821±69
Tight	71.52±0.03	25.2±0.5	(1.38±0.06) x10^5

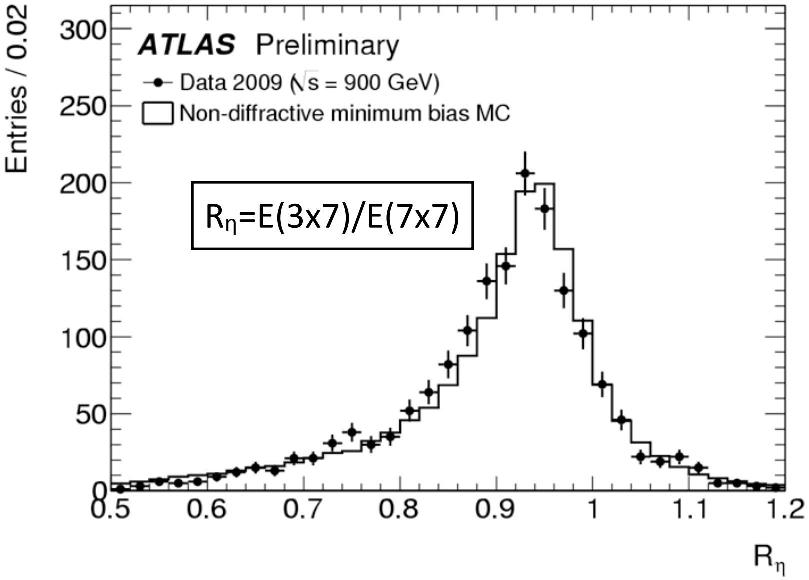
Photons

Cut	Efficiency (%)			Jet Rejection
	All	Unconverted	Converted	
Loose	94.45±0.01	97.80±0.01	91.73±0.01	908±4
Tight	82.88±0.02	85.04±0.03	79.94±0.04	4470±40

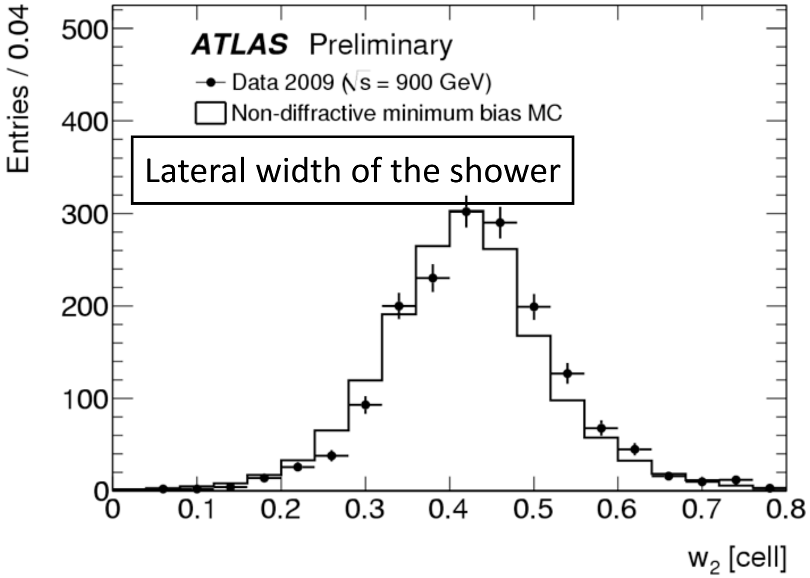




Photons Candidates @900GeV: some variables

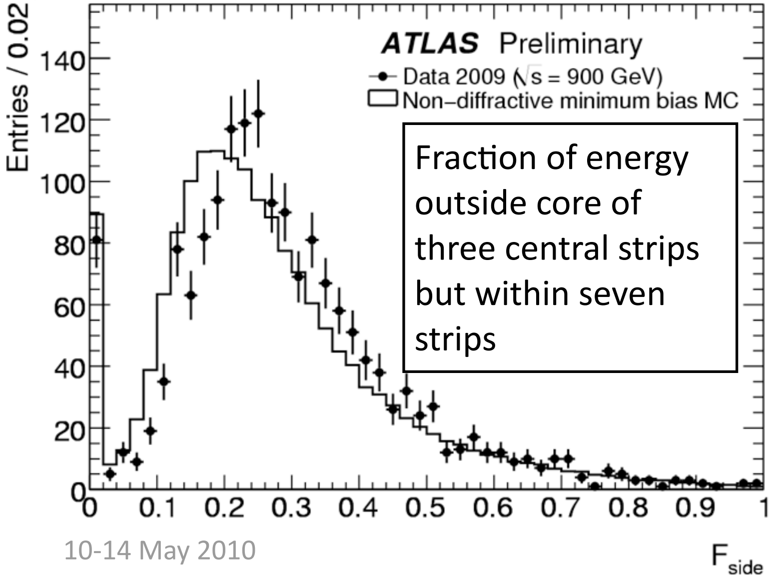


$R_\eta = E(3x7)/E(7x7)$

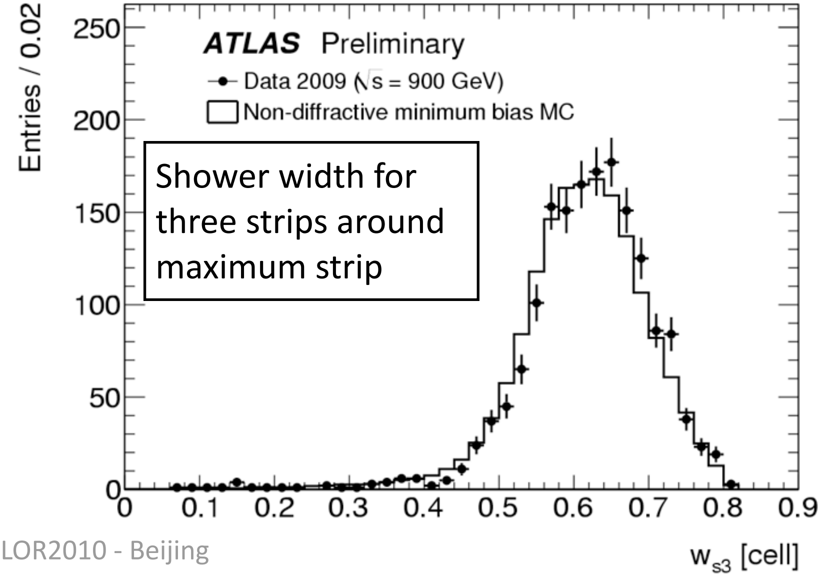


Lateral width of the shower

Despite the small disagreement, the MC description of the calorimeter is already pretty accurate: ongoing studies show that including a better description of the cross-talk and an improved material description in the simulation would explain part of the observed difference between data and MC



Fraction of energy outside core of three central strips but within seven strips



Shower width for three strips around maximum strip

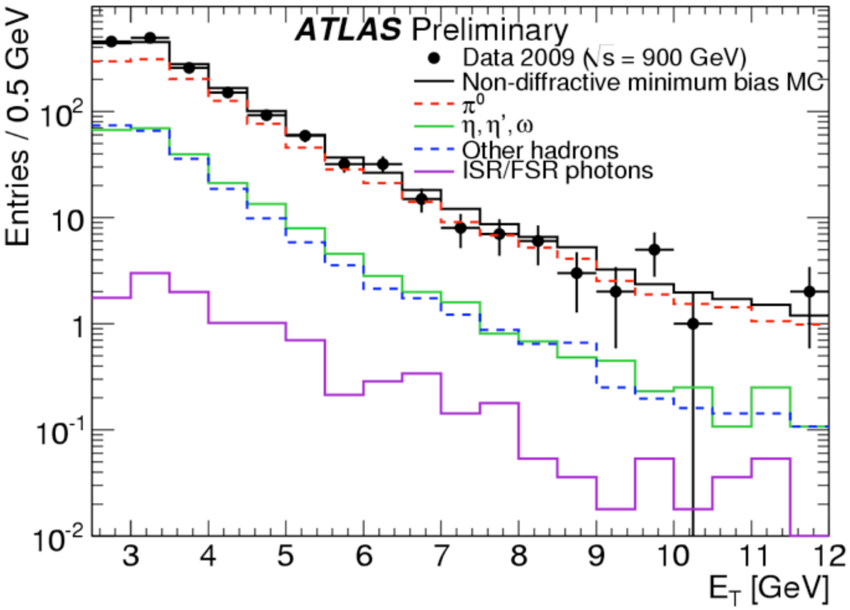
Identification of photons @ √s=900GeV

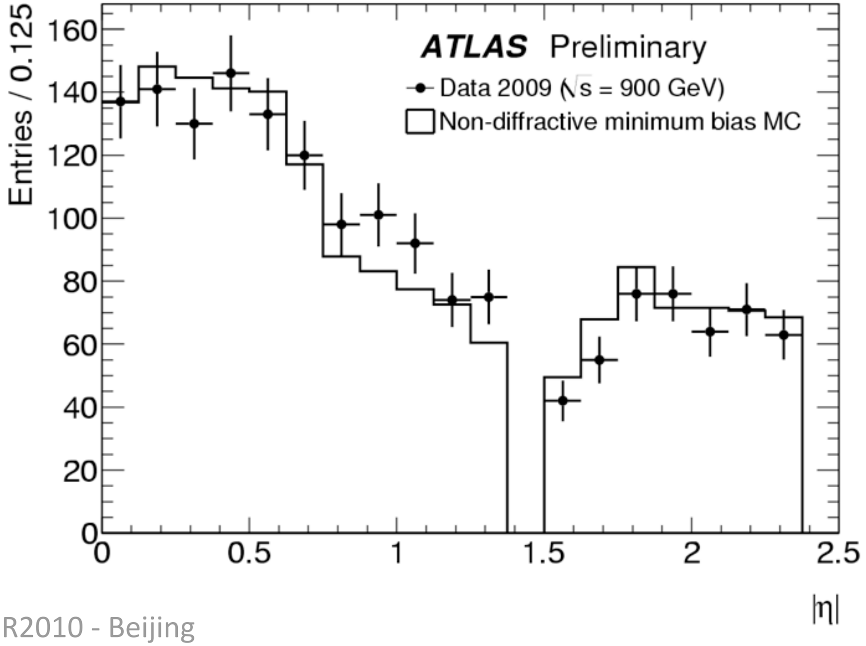
Only 14% of the photon candidates are reconstructed as converted (98% of them are ambiguous and reconstructed also as electrons).

Photon candidates from MC : 71% from π_0 decay, 14% from η,η'or ω decay to two photons, 14% from other complex hadron decays. Only 0.7% are prompt photons, from initial or final state radiation of quark.

Fractions of candidates that pass cuts are very low (compared to MC efficiency) because the cuts are NOT optimized in this range of energy.

Cut	All photons candidates 1694	
	Fraction of candidates Data (%)	Fraction of candidates MC (%)
Loose	25.4±1.0	30.5±0.1
Tight	4.1±0.5	6.6±0.1

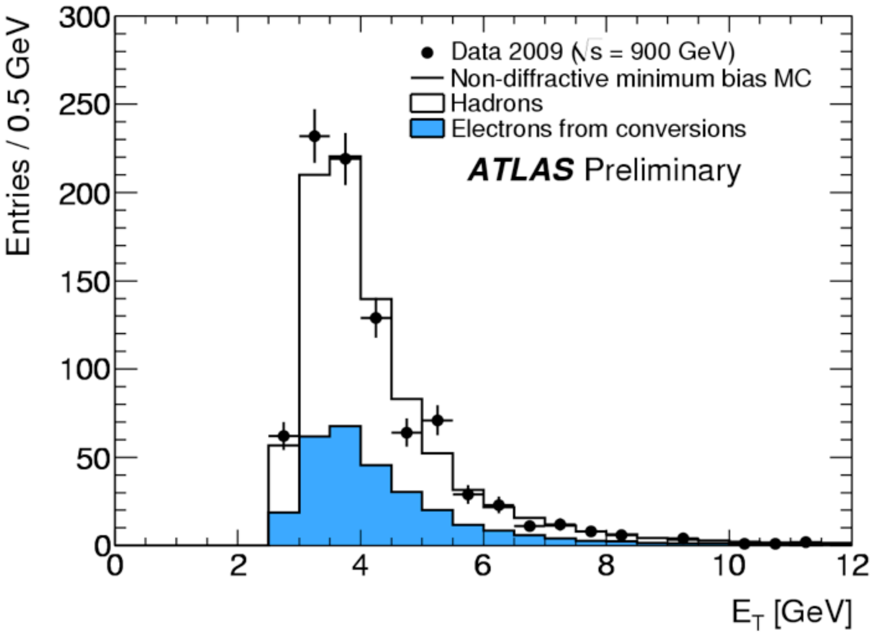


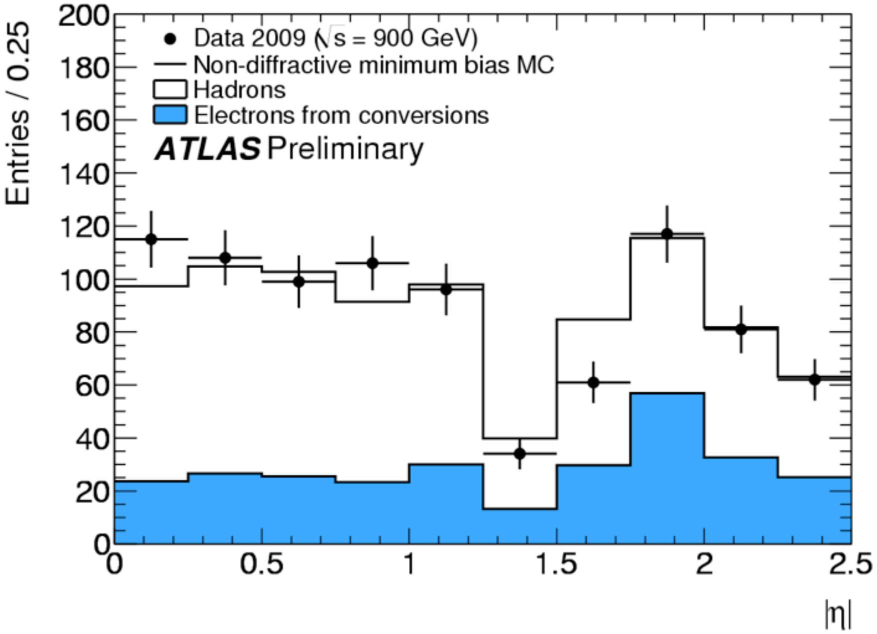


Identification of electrons @ $\sqrt{s}$=900GeV

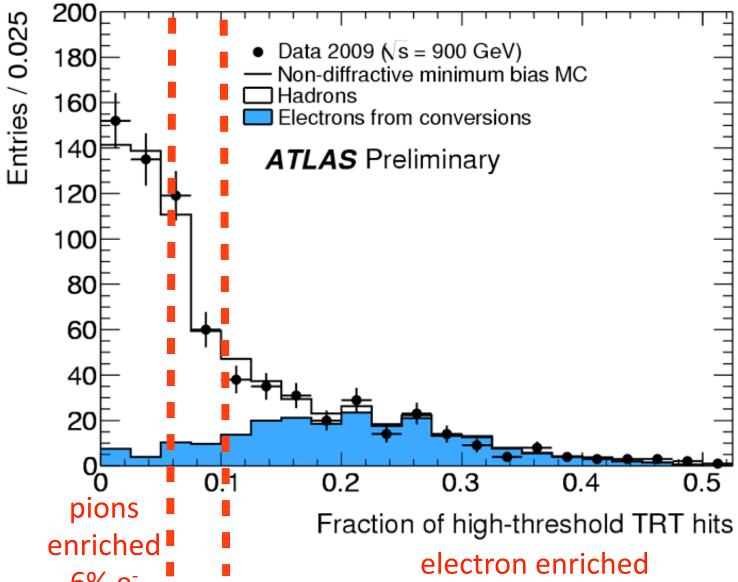
Loose electrons candidates from MC : only 33% are real electrons, mostly from photon conversion (3% background like Dalitz, <1% prompt electrons from b,c→e)
Fractions of candidates that pass cuts are very low (compared to MC efficiency) because the cuts are NOT optimized in this range of energy

Cut	All electron candidates 879	
	Fraction of candidates Data (%)	Fraction of candidates MC (%)
Loose	46.5±1.7	50.9±0.2
Medium	10.6±1.0	13.1±0.2
Tight	2.3±0.5	2.4±0.1





Data-driven background estimation for electrons



pions enriched
6% e^-
70% pions

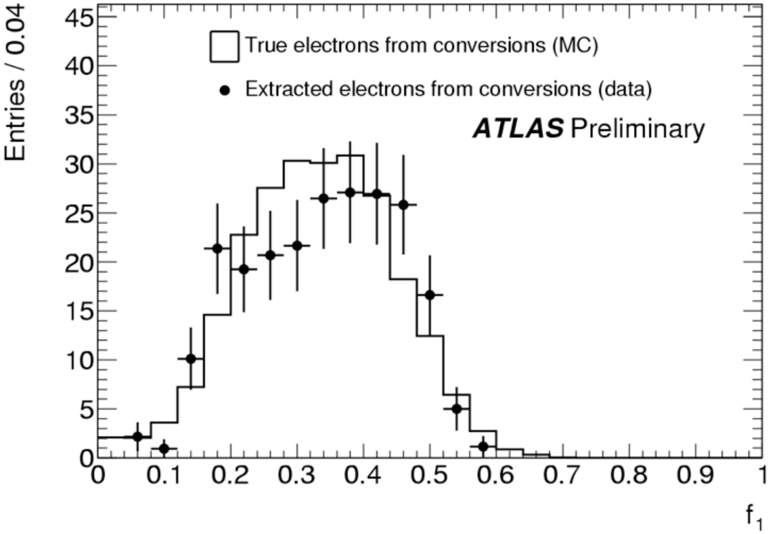
electron enriched
80% e^- & 10% pions

The electron candidate sample is expected to be constituted by:

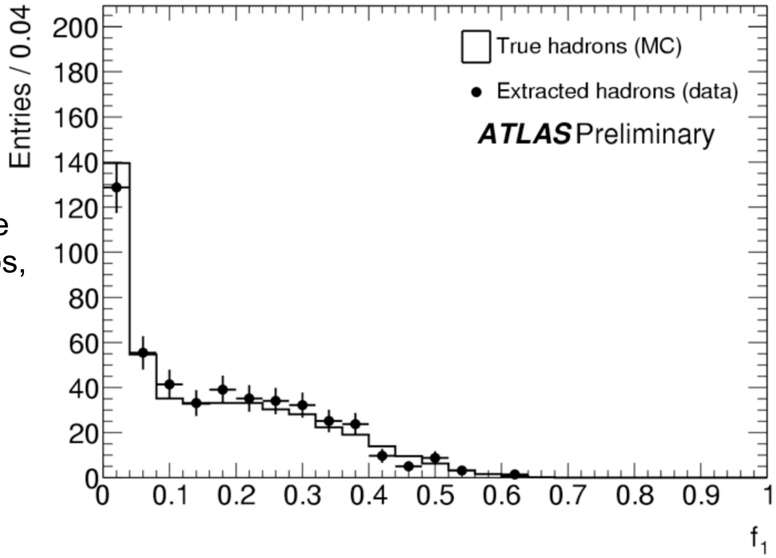
- charged hadrons faking electrons
- electrons from conversion

These 2 components can be separated based on the measured fraction of high-threshold TRT hits ($|\eta|<2.0$, at least 10 TRT hits). TRT response to electrons and pions tuned on the base of beam test. Other uncorrelated variable could be used to refine the selection.

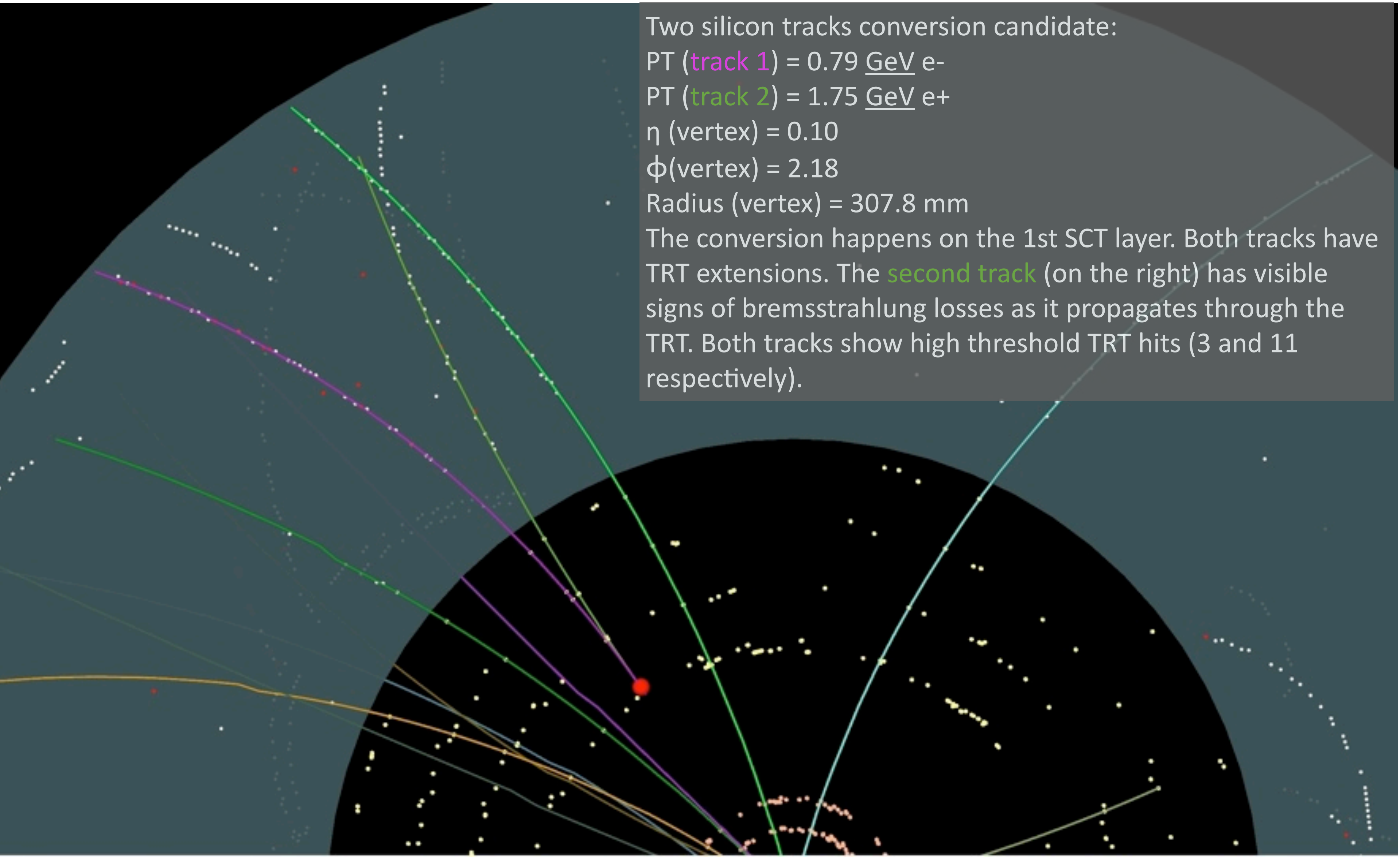
In our sample of 717 electrons candidates , 501 are from hadrons and 216 from conversions.



f_1 = Fraction of the energy in the strips, as extracted from data compared to the truth from MC



Conversion studies: event display @√s=900GeV



Two silicon tracks conversion candidate:
PT (track 1) = 0.79 GeV e-
PT (track 2) = 1.75 GeV e+
η (vertex) = 0.10
ϕ(vertex) = 2.18
Radius (vertex) = 307.8 mm

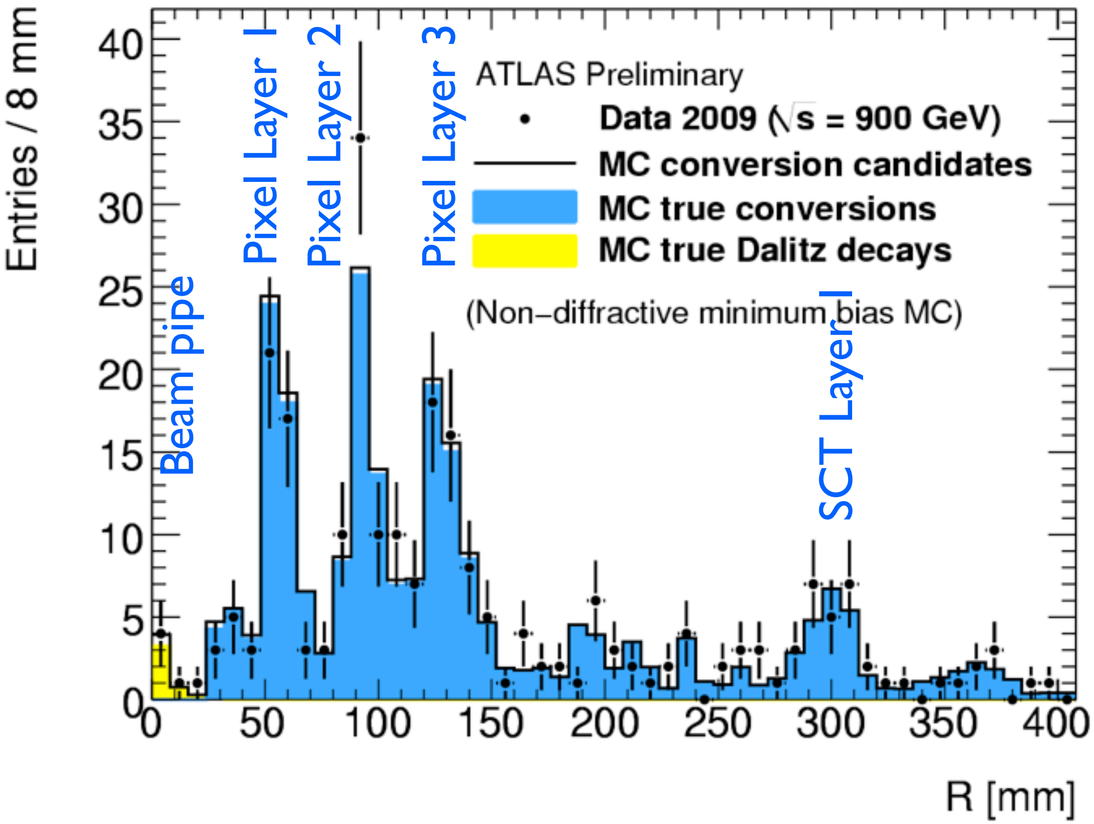
The conversion happens on the 1st SCT layer. Both tracks have TRT extensions. The second track (on the right) has visible signs of bremsstrahlung losses as it propagates through the TRT. Both tracks show high threshold TRT hits (3 and 11 respectively).

Conversion studies: material mapping @ $\sqrt{s}$=900GeV

Different tracking algorithms are available:

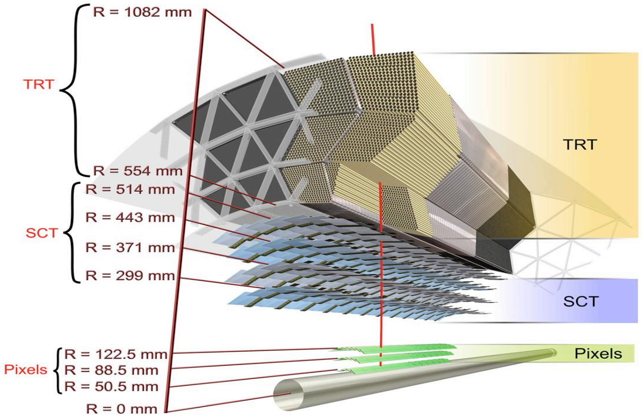
- Inside-out (seed with Pixel/SCT, extrapolate to TRT)
- Outside-in (seed with TRT, extrapolate to Pixel/SCT)
- TRT standalone (not used for mapping material so close to beam pipe)

The algorithm begins by selecting single track with p_T>500MeV and a significant fraction of high-energy hits in the TRT. Photon conversion candidates are then created pairing oppositely-charged tracks. Many selecting criteria are applied to reduce combinatorial background.



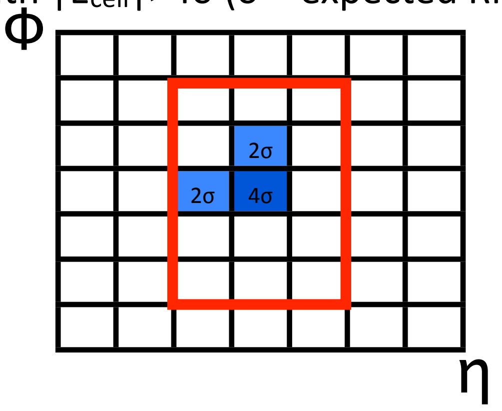
Good agreement allow for detailed material studies in the region for r<400mm.

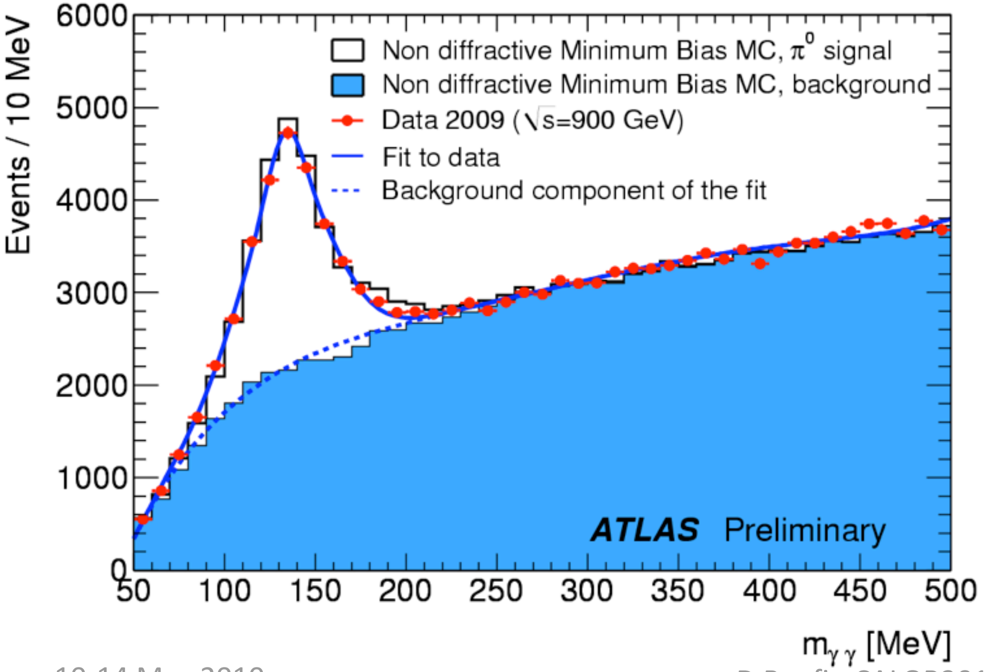
The ratio of photon conversion in a given volume to the number of Dalitz decay allows the setting of a very stringent constrain on the amount of material in it, in particular in the BP region.



π_0 studies @ $\sqrt{s}=900$GeV

- Standard fixed size clustering is inefficient for very low energy γ (cluster p_T must be at least 2.5GeV) : a fixed size 3x5 cluster is built around a topological cluster seeded by a cell with $|E_{cell}|>4\sigma$ (σ = expected RMS of the electronic noise in the cell)
- reject overlapping clusters
- required cluster $E_T>400$MeV
- $E_1/(E_1+E_2+E_3)>0.1$ for reducing background from charged hadrons
- $|\eta|<2.37$
- $p_T^{pair}>900$MeV
- A calibration optimized for very low energy γ has been used to reconstruct the energy of the γγ pairs





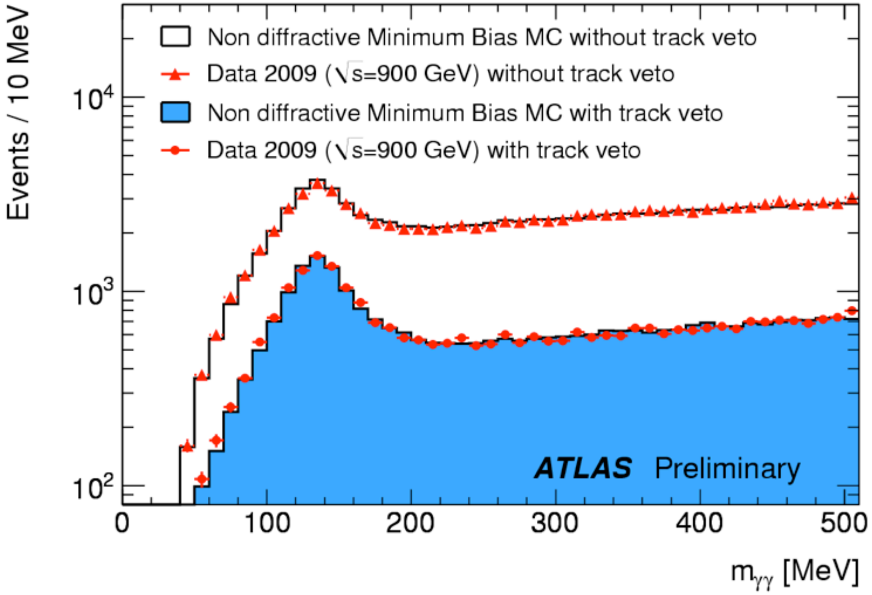
$m(\pi_0)=134.0\pm0.8$ MeV (Data)
$m(\pi_0)=132.9\pm0.2$ MeV (MC)
$m(\pi_0)=134.9766\pm0.0006$ (PDG)
σ = 24MeV (Data)
σ = 25.2MeV (MC)

The 1% agreement between Data and MC is well within the 2-3% expected uncertainty on the energy scale.

The 1.5% discrepancy between the MC and the PDG nominal π0 mass is consistent with the expected accuracy of the specific cluster calibration procedure for low-energy photons.

π_0 studies @ √s=900GeV: track veto and conversion

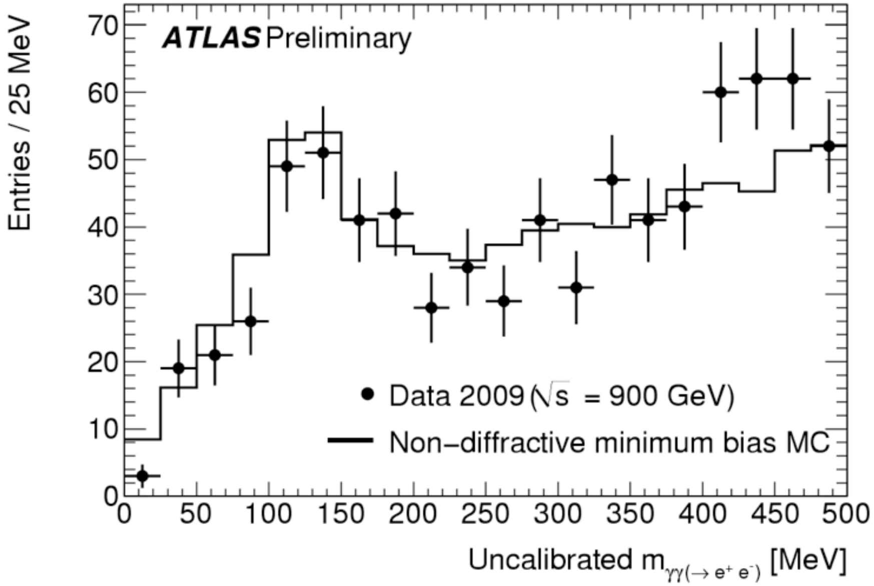
Track Veto : reject all the photons candidates with an associated matching track. The S/B is improved by almost a factor of two.



π_0 peak could be reconstructed using one unconverted photon and one converted photon. Conversion matching in Δη<0.1 and ΔΦ<0.3, with a cluster E>300MeV and at least 4 silicon hits per tracks are used in this analysis.

No energy calibration applied, and this accounts for most of the shift of the peak.

Good agreement between data and MC is achieved.

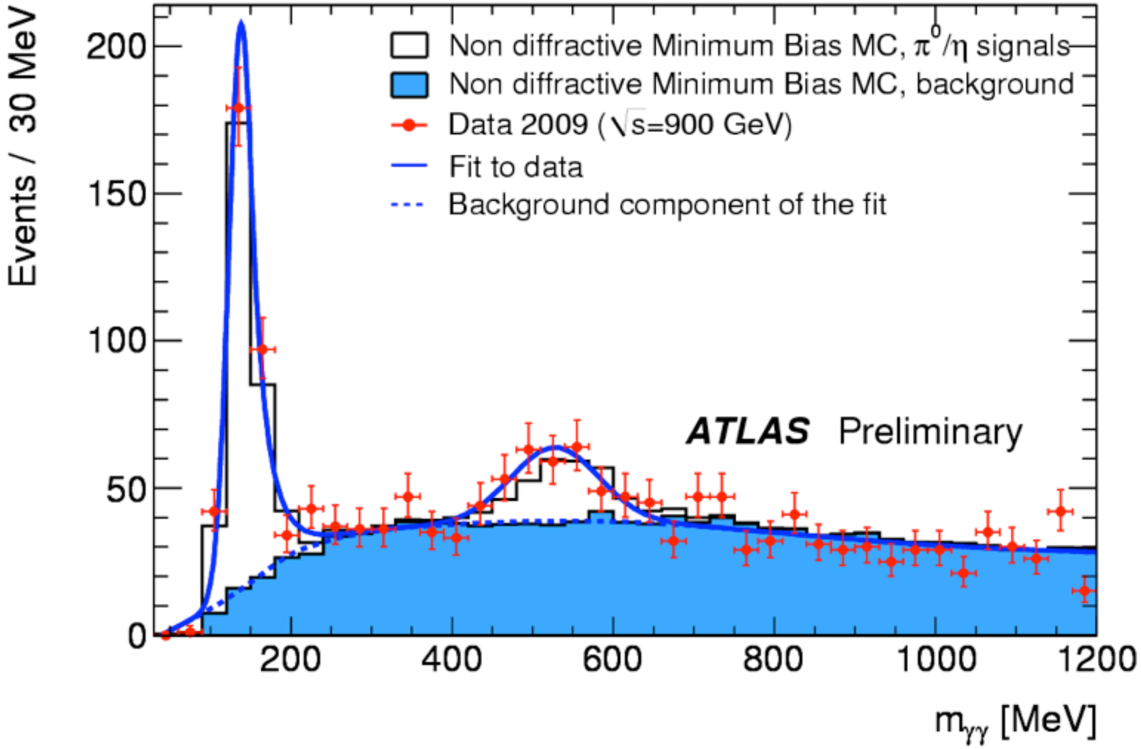


η studies @ √s=900GeV

The number of $\eta \rightarrow \gamma\gamma$ is expected one order of magnitude smaller than $\pi_0 \rightarrow \gamma\gamma$ in the minimum bias sample. To reduce combinatorial background we introduced:

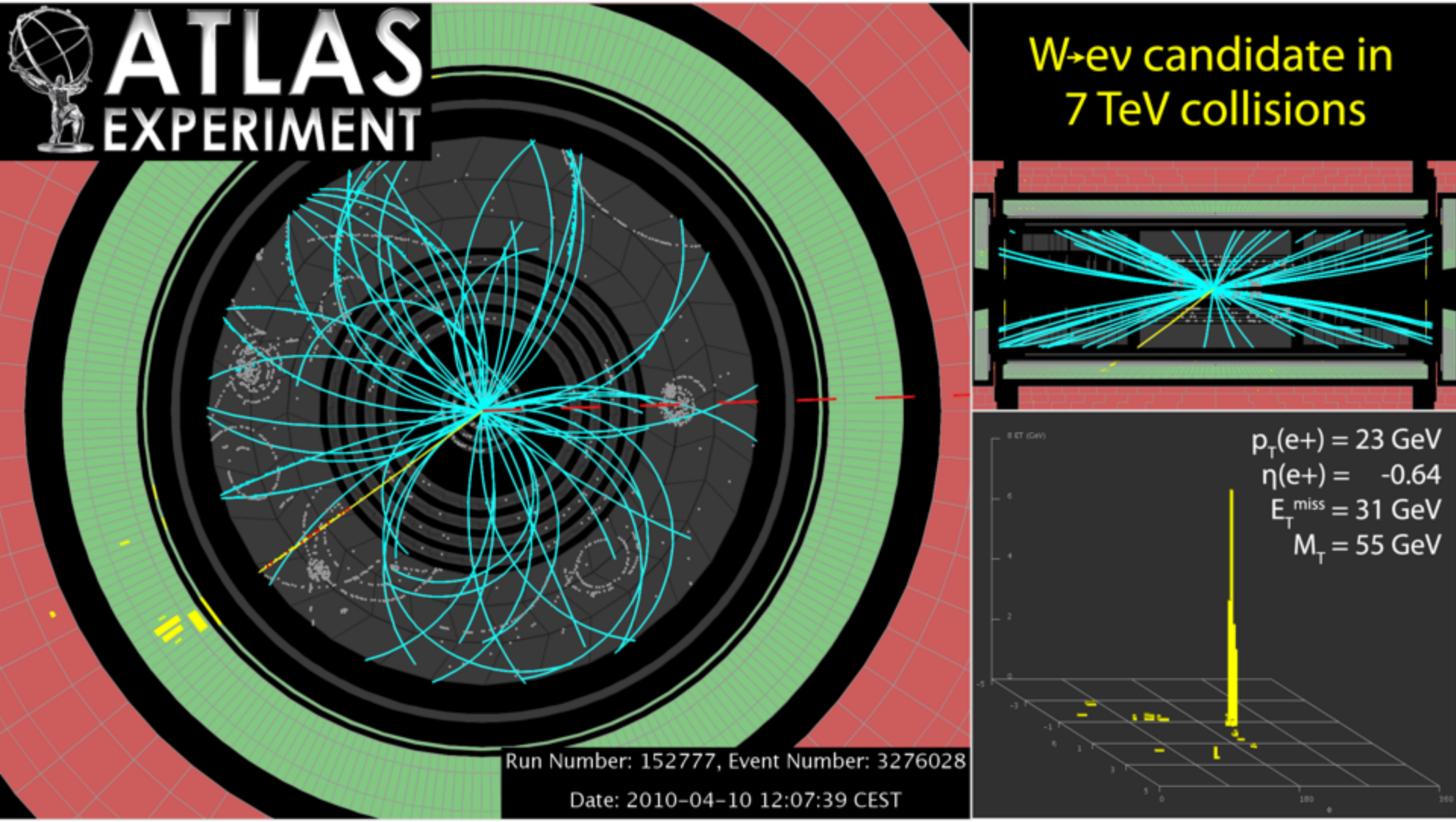
- tighter kinematic cuts:
  - $E_T > 800$MeV
  - $p_T^{pair} > 2200$MeV
- track veto (rejected all clusters that have any associated tracks)

Reconstructed mass agrees with MC and PDG value, within the statistical and energy scale (2-3%) uncertainties.



m(η)=527±11 MeV (DATA)
m(η)=544±3 MeV (MC)
m(η)=547.51±0.18 (PDG)

W→eν candidates: event display @√s=7TeV



W→eν candidate in 7 TeV collisions

$p_T(e+) = 23$ GeV
$\eta(e+) = -0.64$
$E_T^{miss} = 31$ GeV
$M_T = 55$ GeV

Run Number: 152777, Event Number: 3276028

Date: 2010-04-10 12:07:39 CEST

Calorimeter and ID are performing very well!

Conclusions

- The data sample collected by ATLAS @ √s = 900 GeV at the end of 2009 has yielded samples of 879 electron and 1694 photon candidates reconstructed with $E_T > 2.5$ GeV before identification cuts.

- Most of the features of the candidates are in remarkable agreement between data and MC, including the background composition for electrons.

- Despite its limitations due to low statistics and the very low energies shown, this first experimental validation of the ATLAS electron and photon reconstruction and identification performance supports the expectation that the ATLAS inner detector and calorimeters will provide excellent data for electron and photon early physics at the LHC.

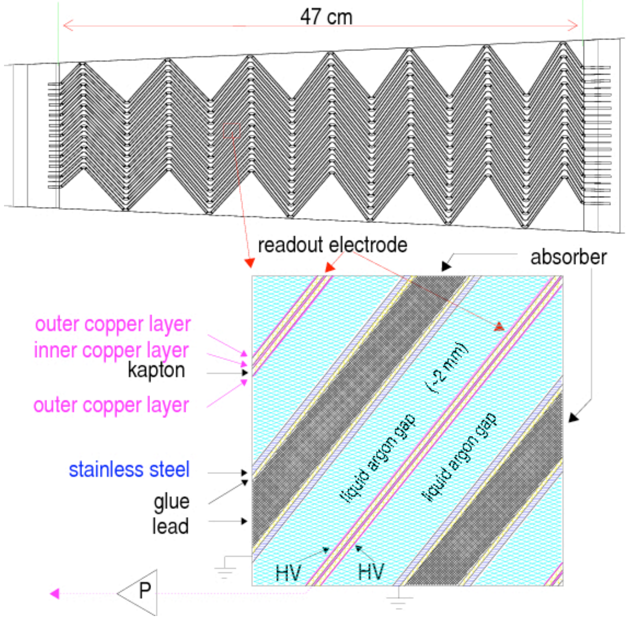
- After dedicated corrections for low-energy photons, the measured π0 mass is within 1% of the nominal PDG value for both data and Monte Carlo. This result is compatible with the uncertainty on the energy scale extracted from the test-beam.

- The extracted number of η candidates and the fitted mass agree with the Monte Carlo expectation.

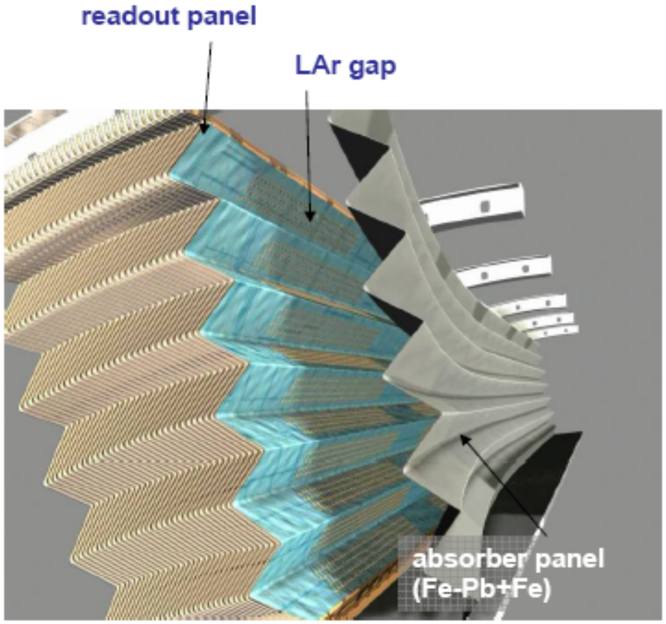
- The spatial distributions of the photon conversion vertices show, albeit with low statistics, that the Monte Carlo model of the tracker represents the installed detector well.

Backup Slides

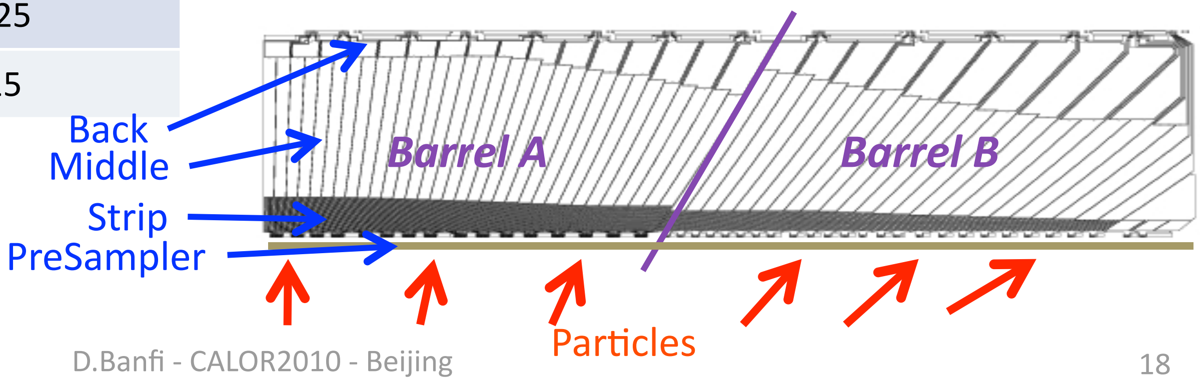
EM Calorimeter



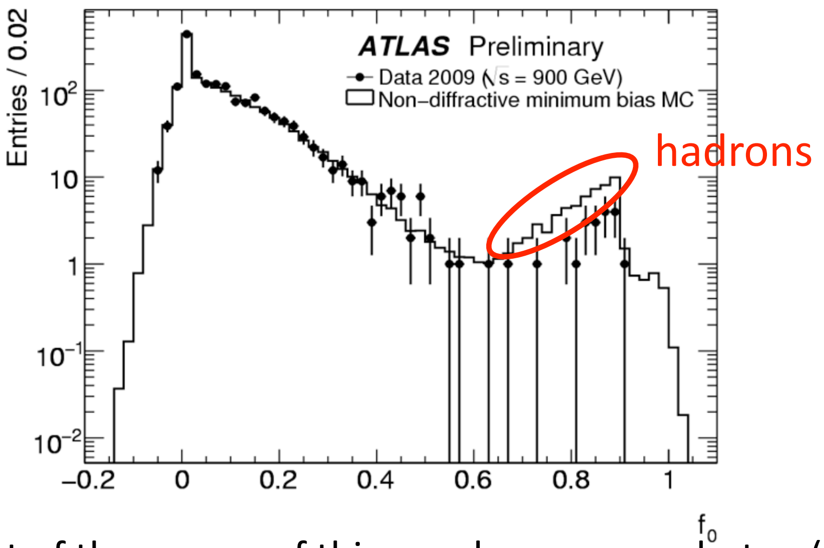
- Accordion geometry allow for a full Φ coverage
- 3 longitudinal compartments, plus the PreSampler
- ~170k channel
- Each channel calibrated to the EM scale with the electronic calibration system

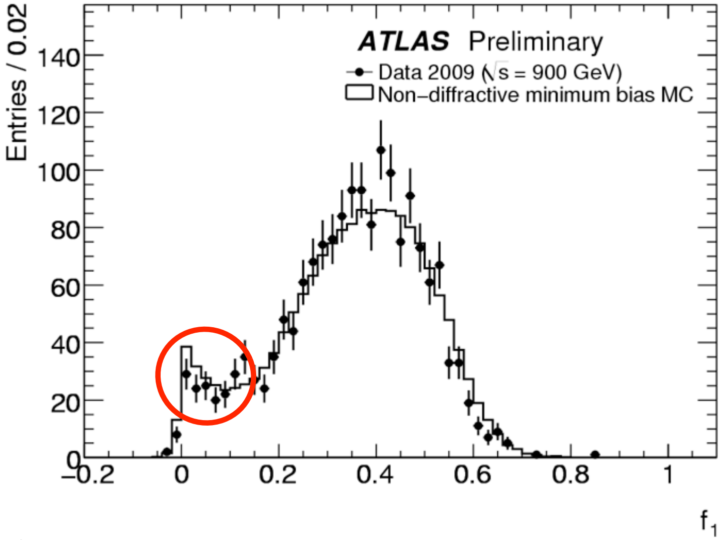


Compartment	η x ϕ barrel granularity
PreSampler	0.025 x 0.1
Layer 1 (Strip)	0.003 x 0.1 (up to 0.025 x 0.1 in EndCap)
Layer 2 (Middle)	0.025 x 0.025
Layer 3 (Back)	0.05 x 0.025

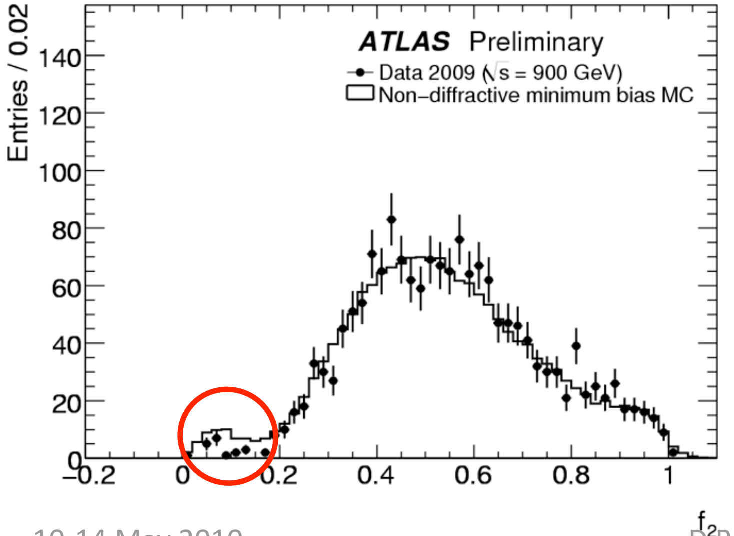


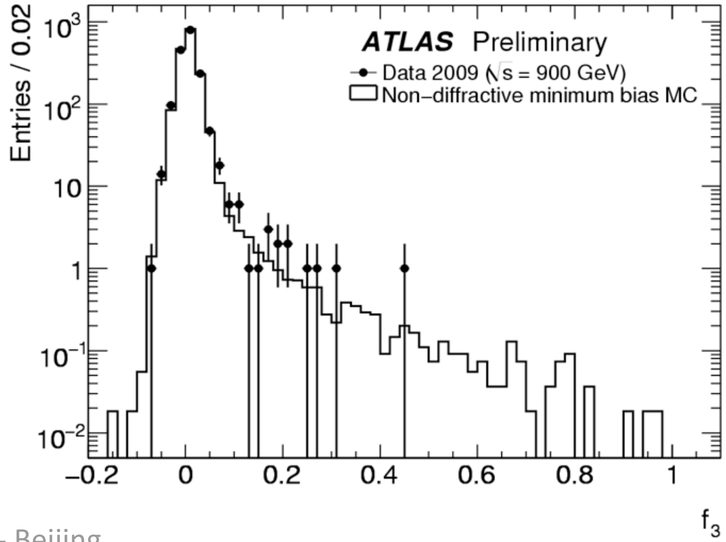
Photons @ √s=900GeV: fraction of energy in layers



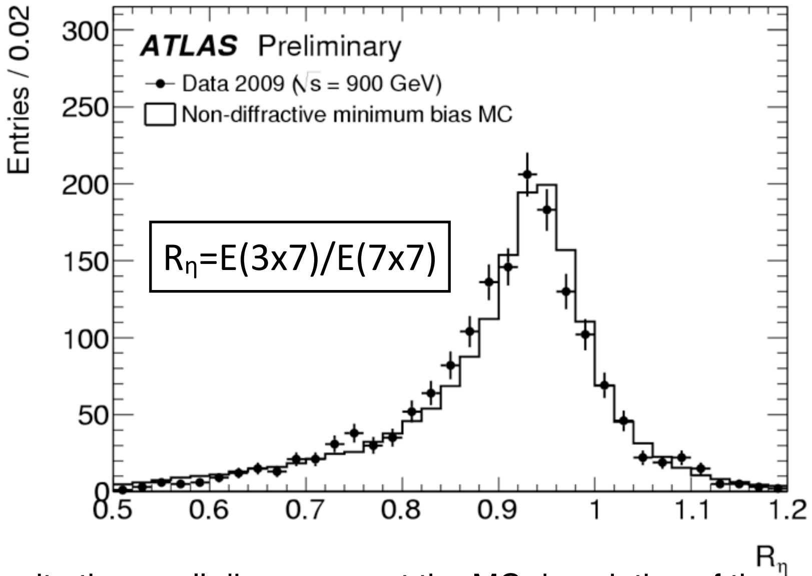


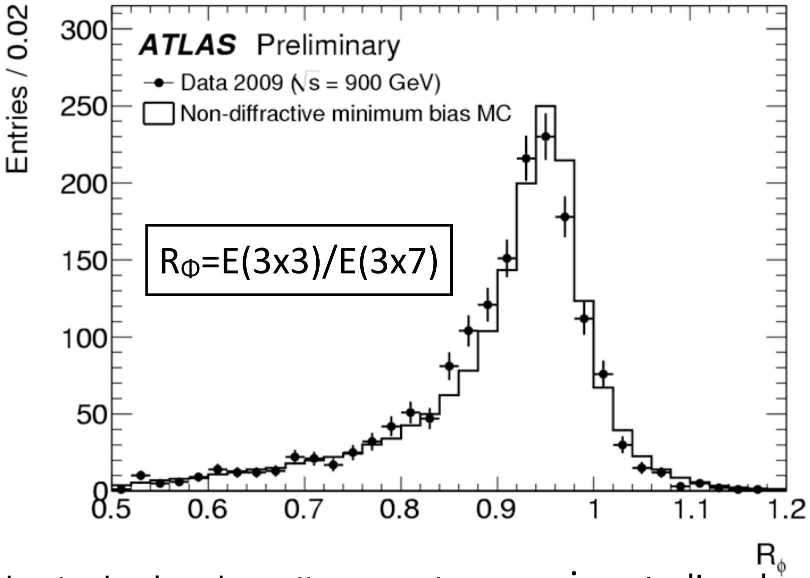
Most of the energy of this very low energy photon (E_T<10GeV) is deposited inside strips and middle layers, back is dominated by electronic noise. The small discrepancy is due to a not accurate simulation of energy deposited by hadrons in first sample of calorimeter (PS)



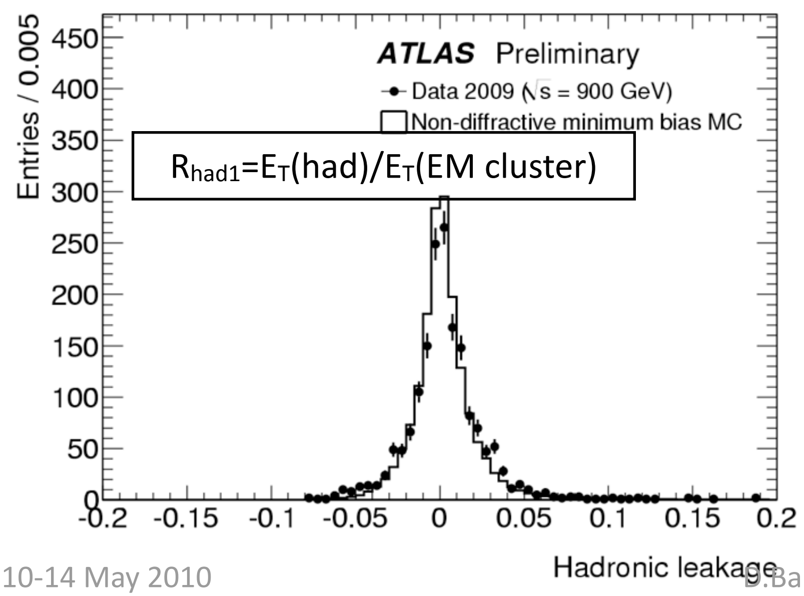


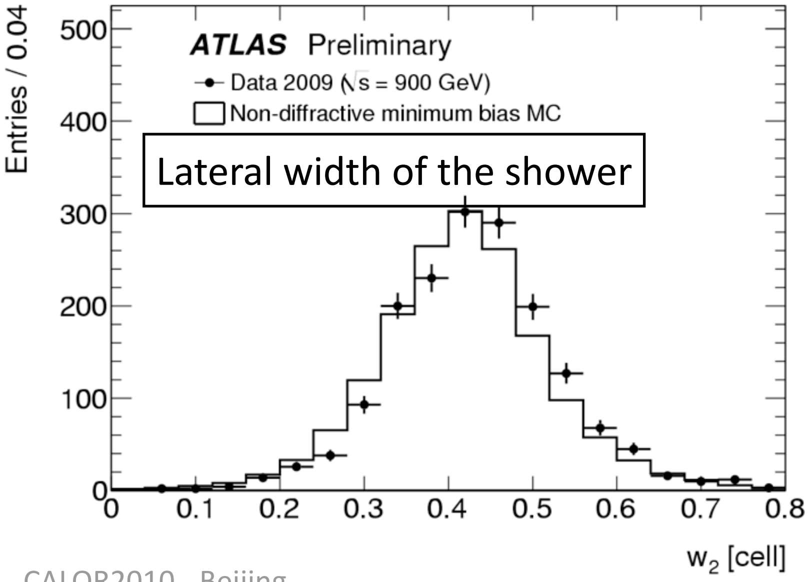
Photons Candidates @900GeV: medium cut variables


R_η=E(3x7)/E(7x7)

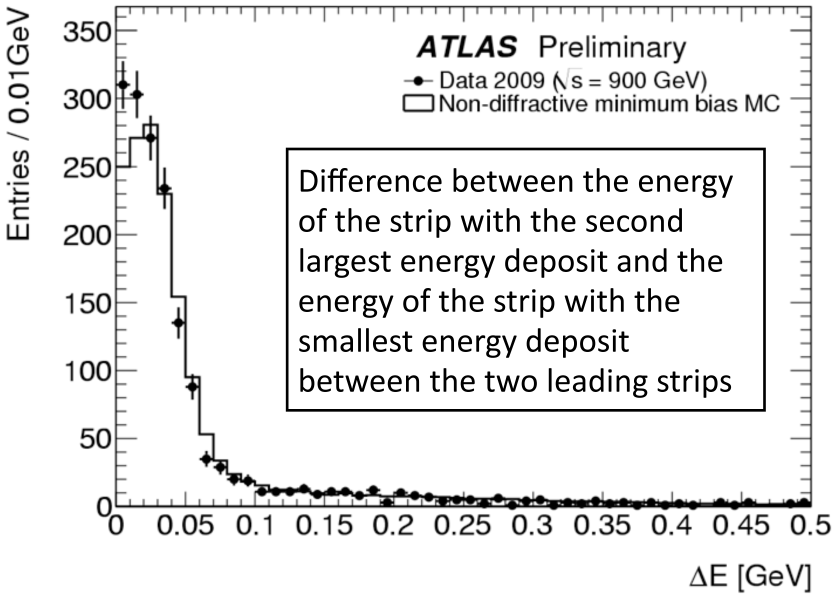

R_Φ=E(3x3)/E(3x7)

despite the small disagreement the MC description of the calorimeter is already pretty accurate: ongoing studies show that including the cross-talk between neighboring middle layer cells in the simulation would explain part of the observed difference between data and MC

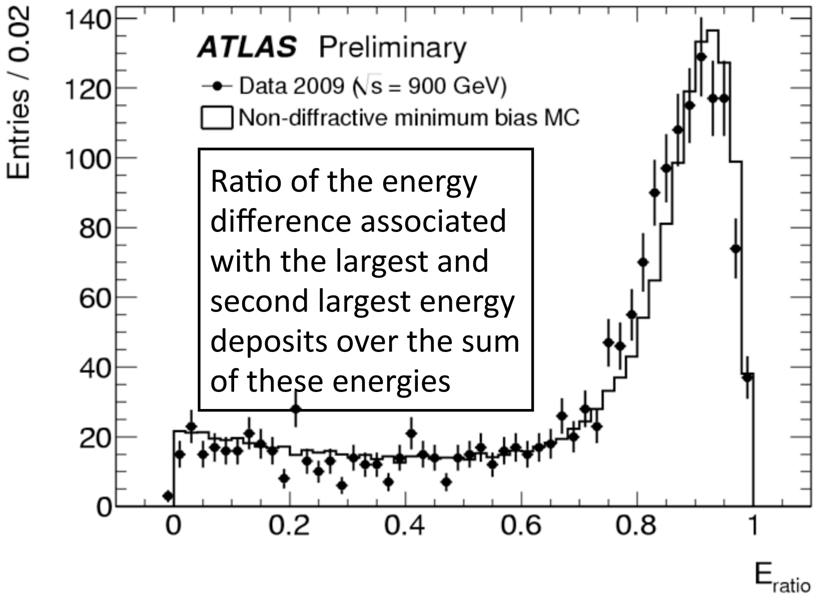

R_{had1}=E_T(had)/E_T(EM cluster)


Lateral width of the shower

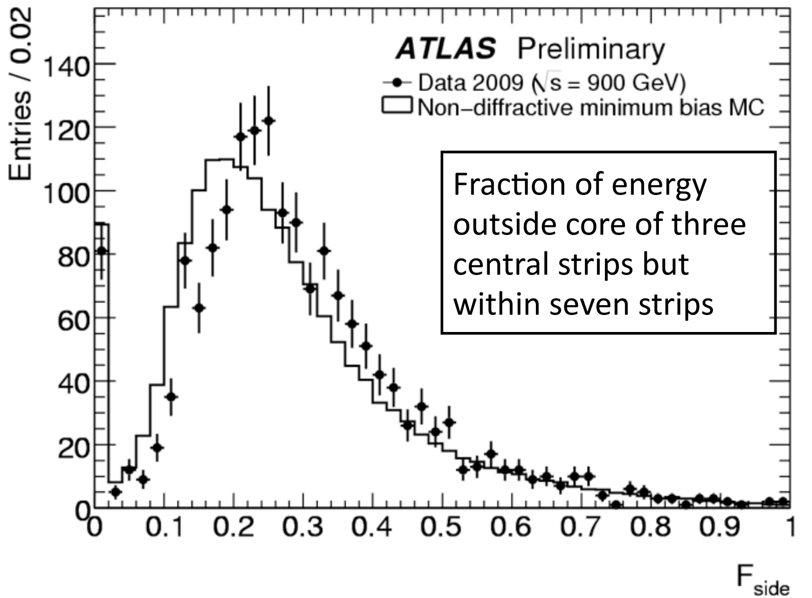
Photons Candidates @900GeV: tight cut variables



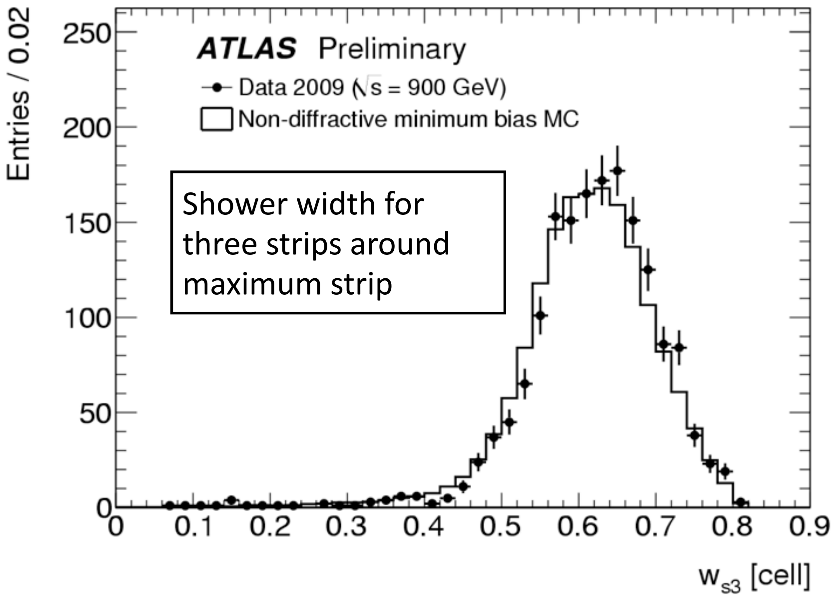
Difference between the energy of the strip with the second largest energy deposit and the energy of the strip with the smallest energy deposit between the two leading strips



Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies



Fraction of energy outside core of three central strips but within seven strips

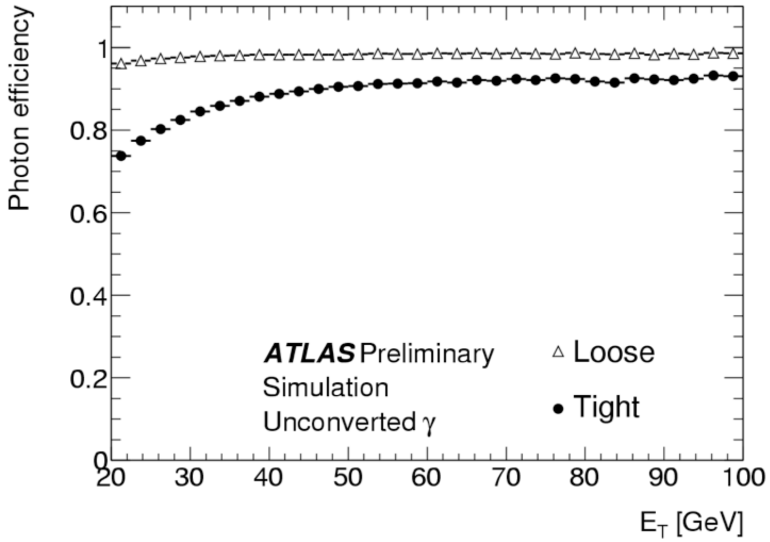


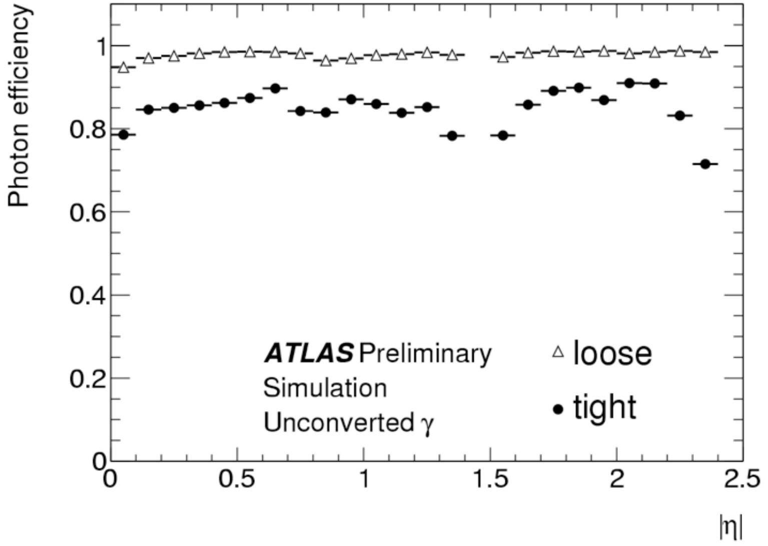
Shower width for three strips around maximum strip

Cut based photon identification (MC)

- Apply cut on each variable (η and energy dependent)
- More than one definition of identification cuts are available

Cut	**Efficiency (%)**			**Jet Rejection**
	All	**Unconverted**	**Converted**	
Loose (had + middle layer cuts)	94.45±0.01	97.80±0.01	91.73±0.01	908±4
Tight (Loose + strips and middle layer cuts)	82.88±0.02	85.04±0.03	79.94±0.04	4470±40





Cut based electron identification (MC)

- Apply cut on each variable (η and energy dependent)
- More than one definition of identification cuts are available

Cut	Efficiency (%)		Jet Rejection
	Z→ee	b,c → e	
Loose (had + middle)	94.30±0.03	36.8±0.5	1066±4
Medium (Loose + strips + trk qual + Δη trk match)	89.97±0.03	31.5±0.5	6821±69
Tight (Medium + ΔΦ trk match + TRT)	71.52±0.03	25.2±0.5	$(1.38\pm0.06)\times10^5$