Commissioning of Particle ID with early LHC data

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on behalf of the ATLAS and CMS collaborations

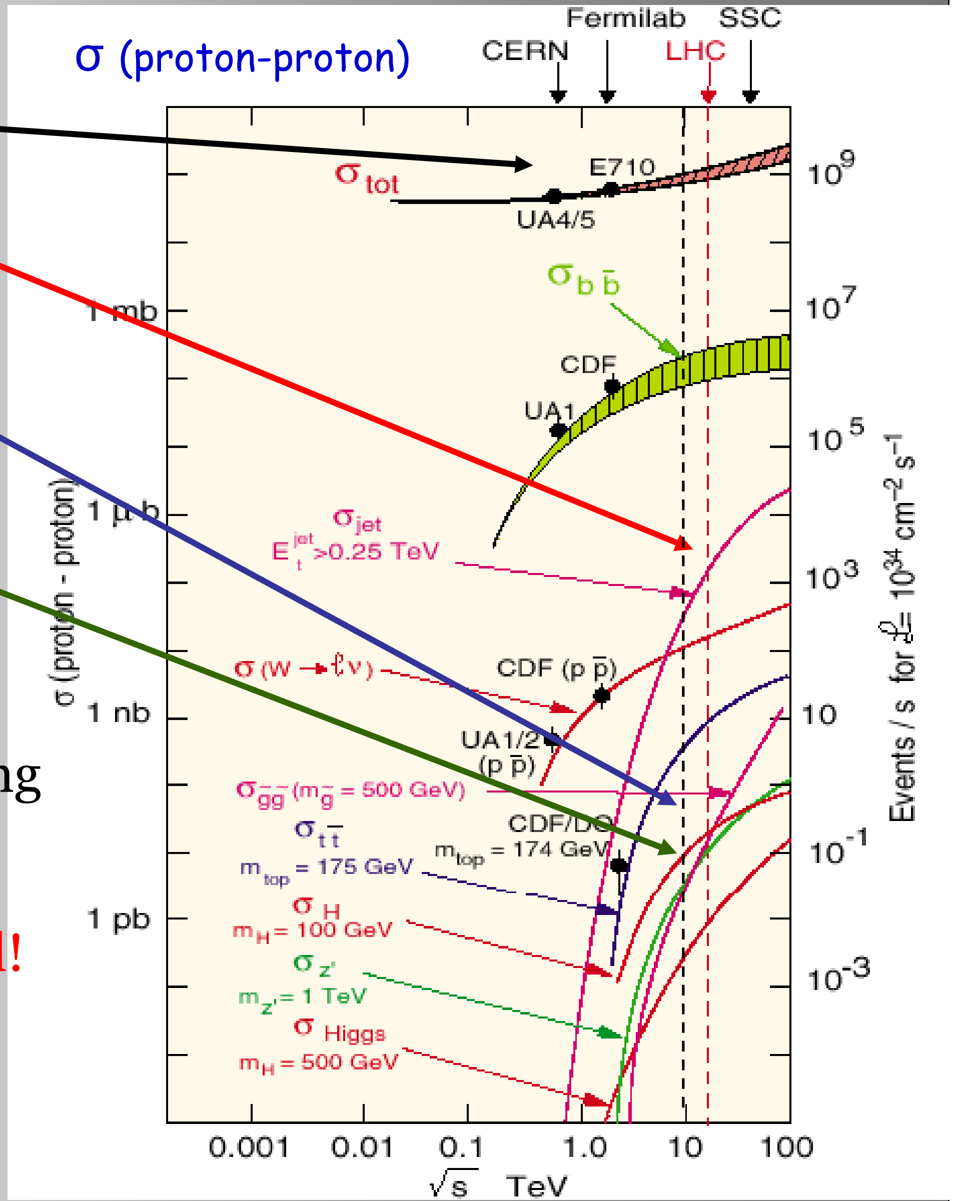
Disclaimer: This talk will only concentrate on lepton (e,μ, or τ) and photon particle identification

HCP 2008,
Galena, IL, USA

Particle ID: Motivation

Some Processes of Interest:

- Background
  - Total cross-section ~70mb
  - QCD di-jet ~ a few mb
- $W \to l\nu$ ($\sigma \times$b.f.=22nb for l=e,μ, or τ)
- $Z \to ll$ ($\sigma \times$b.f.=2nb for l=e,μ, or τ)
- $H_{120GeV} \to ZZ^{(*)} \to 4l$, $\sigma \times$b.f.~3fb (for l=e&μ)
- $H_{120GeV} \to \gamma\gamma$ σ~98fb
- New Physics: hard lepton, photon ($Z' \to ll$, etc.)



Need large luminosity and efficient background rejection to see interesting signal events:

Good Particle Identification is Crucial!

At start-up expect $\sqrt{s}$=10TeV: ~30% less signal events

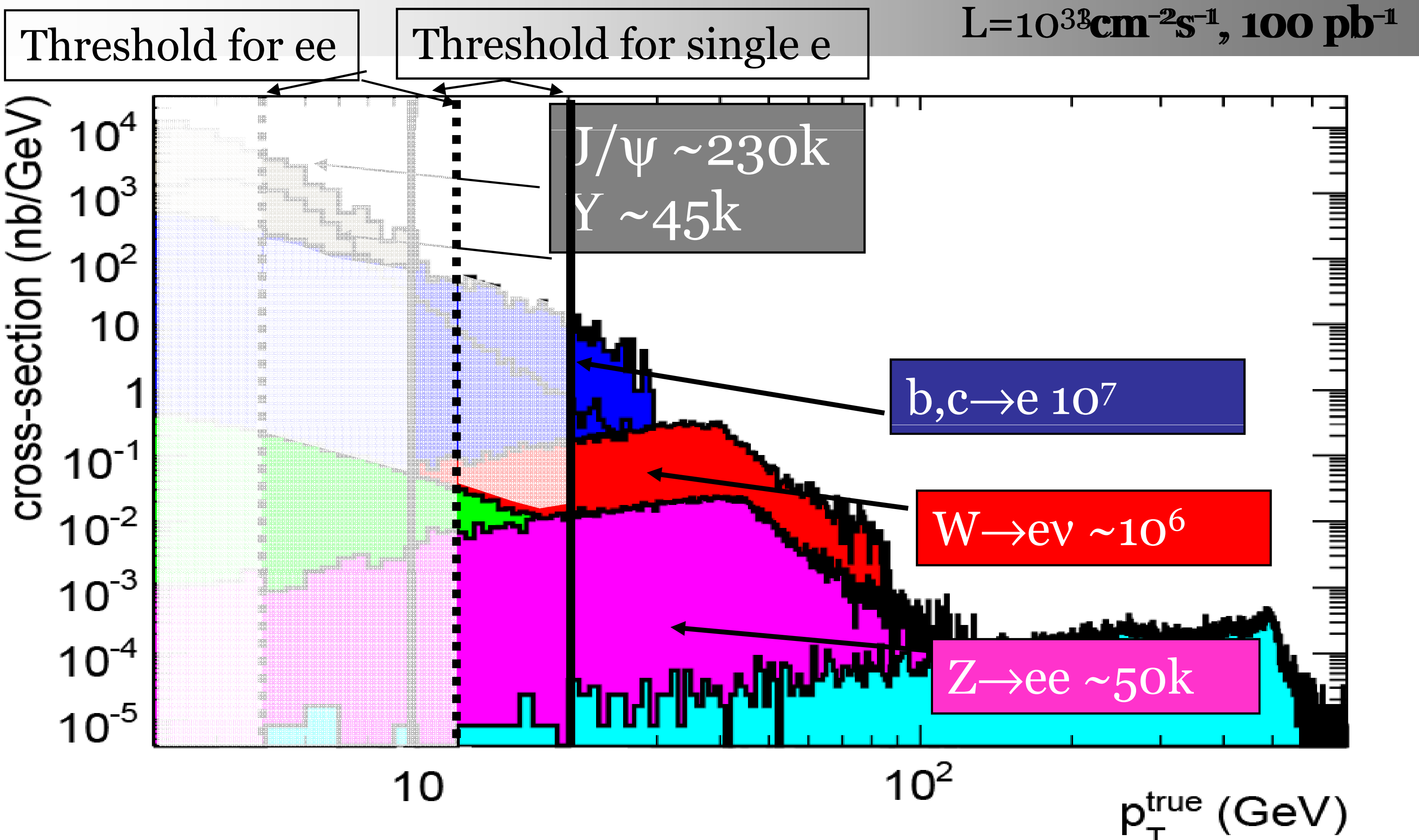
Early physics data samples

- Use early data for commissioning and calibration of the detector in situ with well-known physics samples
- Low luminosity (10^{31} vs 10^{33}cm^{-2}s^{-1})
  - Limit EW samples statistics (rate <1Hz vs ~50Hz): $Z \to ee/\mu\mu/\tau\tau$ and $W \to e/\mu\nu$
  - Give access to other lower p_T samples:
    - $J/\psi(\Upsilon) \to ee/\mu\mu$, $b,c \to e$
    - $W \to \tau\nu$
- Triggers are crucial for low p_T samples:
  - Events not selected by trigger are lost forever!
  - Need ~10^4 reduction for events to tape:

PID is going to be used in the triggers too!

Parameter	Phase A
k_b / no. bunches	43-156
Bunch spacing (ns)	2021-566
N (10^{11} protons)	0.4-0.9
Crossing angle (mrad)	0
$\sqrt{(\beta^*/\beta^*_{nom})}$	2
σ^* (mm, IR1&5)	32
$\mathcal{L}$ (cm^{-2}s^{-1})	$6\text{x}10^{30}$-10^{32}
Year ? (Oct schedule)	2008
$\int \mathcal{L}dt$? (my guess)	10-100 pb^{-1}

Example of low luminosity samples: electrons in ATLAS

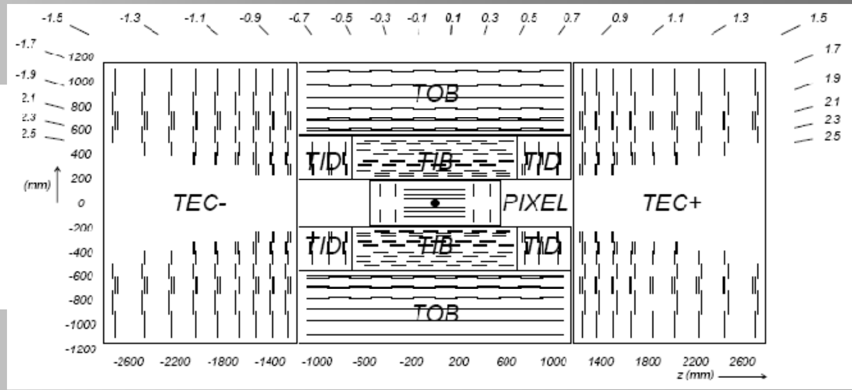


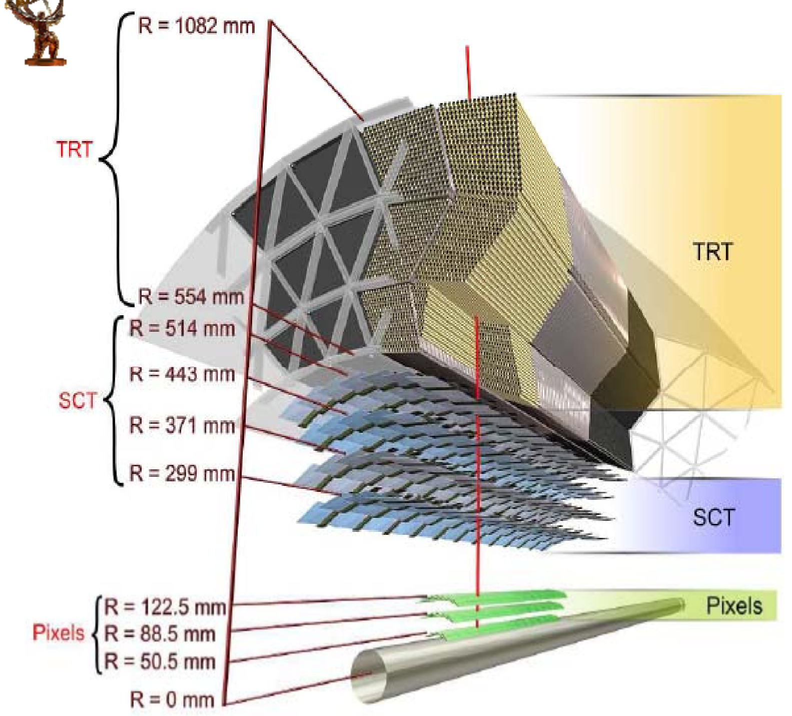
access to lower thresholds and higher statistics of electrons from the b,c→e and J/ψ,Υ →ee decays needed for understanding of the detector and trigger.

Electron/Photon PID

Inner Detector Tracking

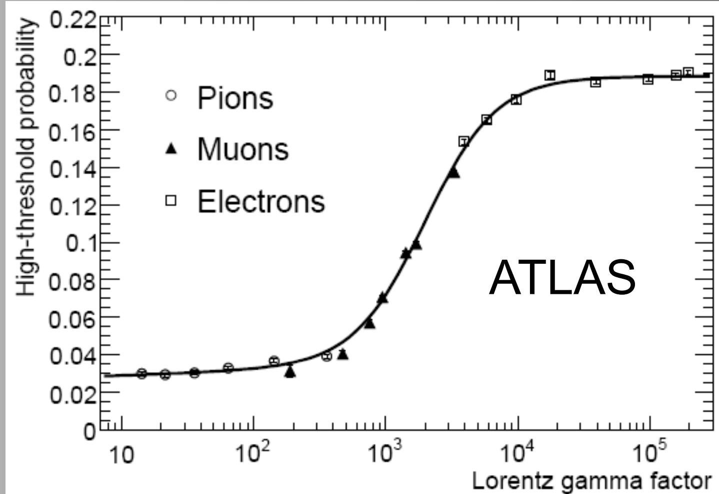
- 3 layers of Pixel Detector
- 4+6 layers of Silicon-Strip Tracker (SST)
- 4T Solenoidal magnetic field
- Material ~0.4-1.8 X_0





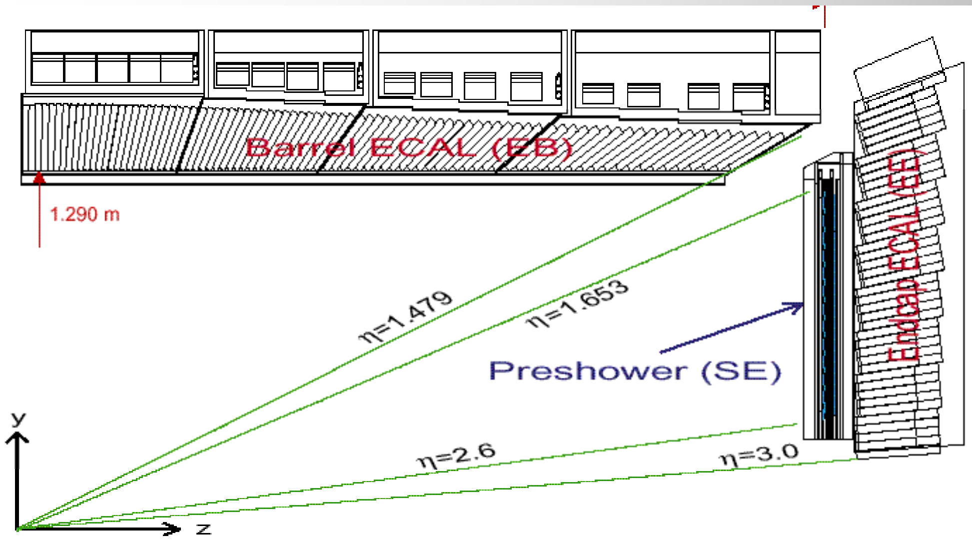
- 3 layers of Pixel Detector
- 4 layers of Semi-Conductor Tracker (SCT)
- 73-layer Transition Radiation Detector (TRT) [only within $|\eta|<2.0$, provides PID!]

  electrons cause large energy depositions due to the transition radiation
- 2T Solenoidal magnetic field
- Material ~0.5-2.4X_0



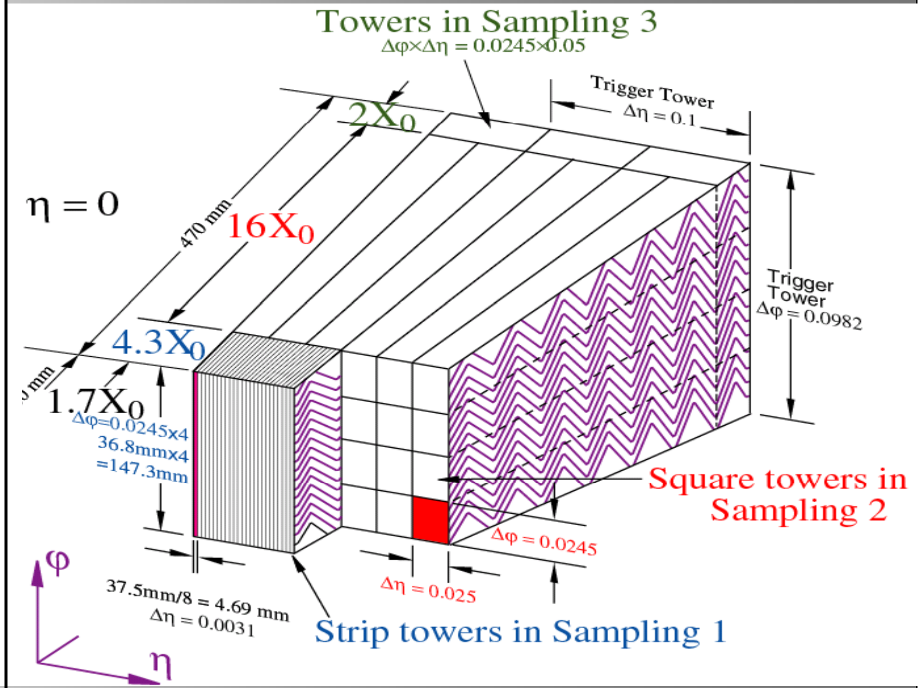
Electromagnetic Calorimeters

stand-alone performance



- crystal calorimeter 75848 $PbWO_4$
- size $\eta\times\phi\times$depth$\sim 0.0174\times0.0174\times25.8X_0$
- $\sigma_E/E = 2.8\%/\sqrt{E} \oplus 124MeV/E \oplus 0.26\%$
- linearity <0.5%
- coverage |η|<3.0

- Accordion-shaped Lead LAr
- 3 longitudinal layers at |η|<2.5
- $\sigma_E/E = 10\%/\sqrt{E} \oplus 24.5\%/E \oplus 0.7\%$
- shower direction $\sigma_\theta \sim 50mrad/\sqrt{E}$
- linearity < 0.5% up to 300GeV



Electron and Photon Reconstruction

- Calorimeter-based reconstruction
  - Used for photons and electrons
  - Photons do not match any track or match a conversion
- Electrons need to have a loose track match in (η,ϕ) and in energy vs momentum
  - Bremsstrahlung recovery is part of default electron reco in CMS; various algorithms exist in ATLAS
- Soft-electrons (low-p_T and electrons in jets): extrapolate Inner Detector tracks to the calorimeter

General requirements for e/γ ID:

✓ Trigger efficiency

✓ Understanding of detector (alignment, material)

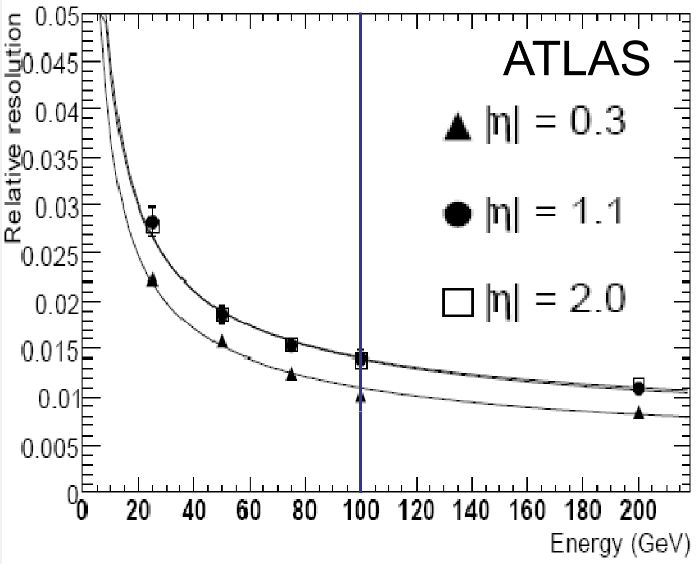
✓ ECAL calibration

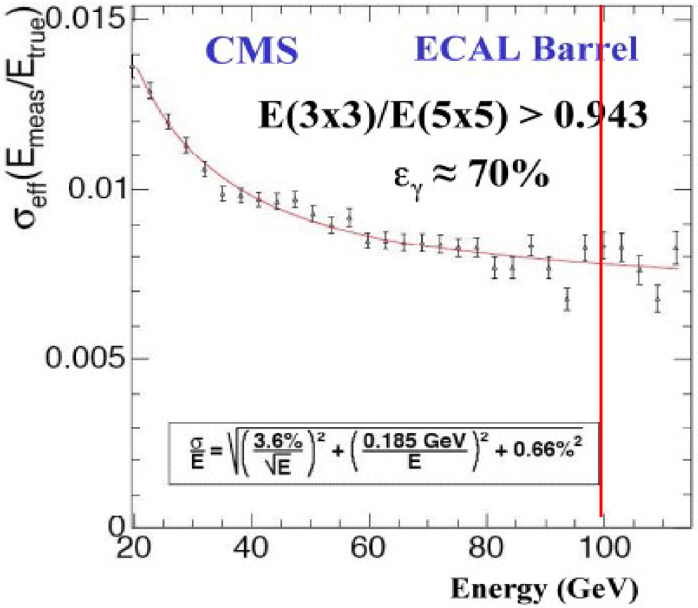
✓ Tracker momentum measurement

✓ Difficult PID: e/jet ~ 10^{-5} at 40GeV

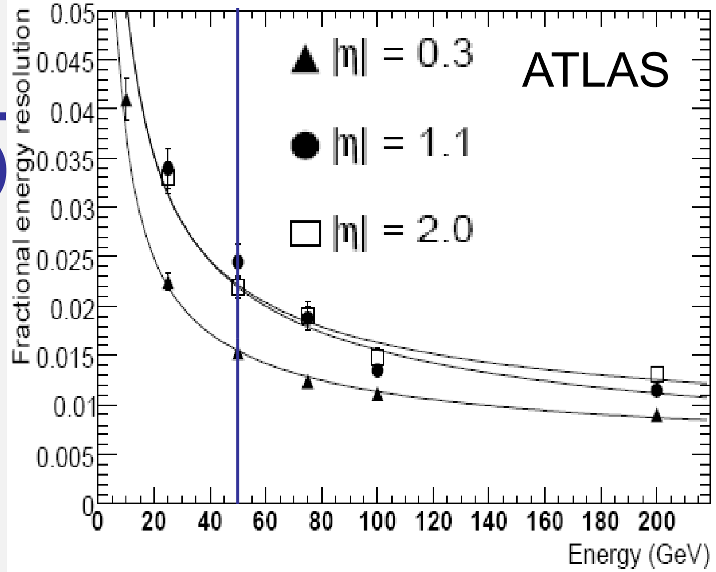
ATLAS/CMS: from design to reality

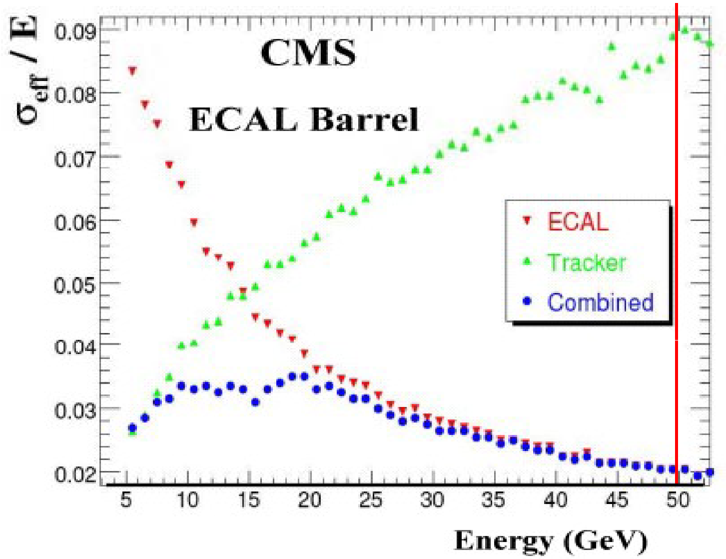
Photons at 100 GeV ATLAS: 1-1.5% energy resol. (all γ) CMS: 0.8% energy resol. ($\varepsilon_\gamma \sim 70\%$)





Electrons at 50 GeV ATLAS: 1.5-2.5% energy resol. (use EM calo only) CMS: ~ 2.0% energy resol. (combine EM calo and tracker)





Similar electron and photon performances in CMS and ATLAS!

ATLAS Electron and Photon performance*

*** Updated results from CMS are expected this summer**

Photon Performance

- Selection efficiency with isolation ~85%
- Jet rejection factor ~5000 (before isolation) and ~9000 (after) for all jets

Selection cuts	$E_T > 25$ GeV		$E_T > 40$ GeV	
	Quark jets	Gluon jets	Quark jets	Gluon jets
Before isolation	1770±50	15000±700	1610±100	15000±1600
After isolation	2760±100	27500±2000	2900±240	28000±4000

Electron Performance

Cuts	$E_T > 17$ GeV		
	Efficiency (%)		Jet rejection
	$Z \to ee$	$b,c \to e$	
Loose	87.97 ± 0.05	50.8 ± 0.5	567 ± 1
Medium	77.29 ± 0.06	30.7 ± 0.5	2184 ± 7
Tight (TRT.)	61.66 ± 0.07	22.5 ± 0.4	$(8.9 \pm 0.2)10^4$

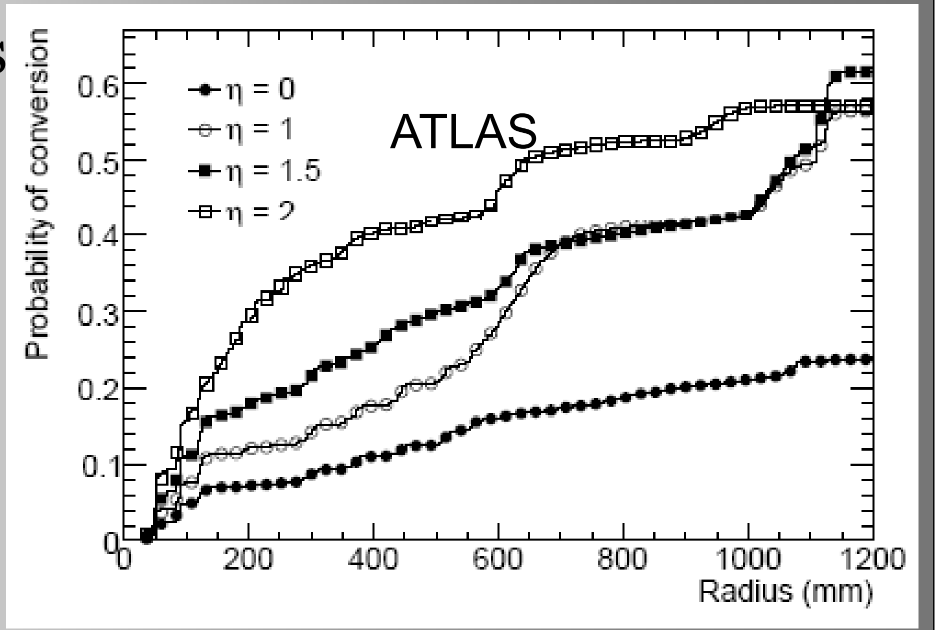
After Tight selection expect:
- Isolated Electrons 11%
- b,c→e 63%
- Background 26%

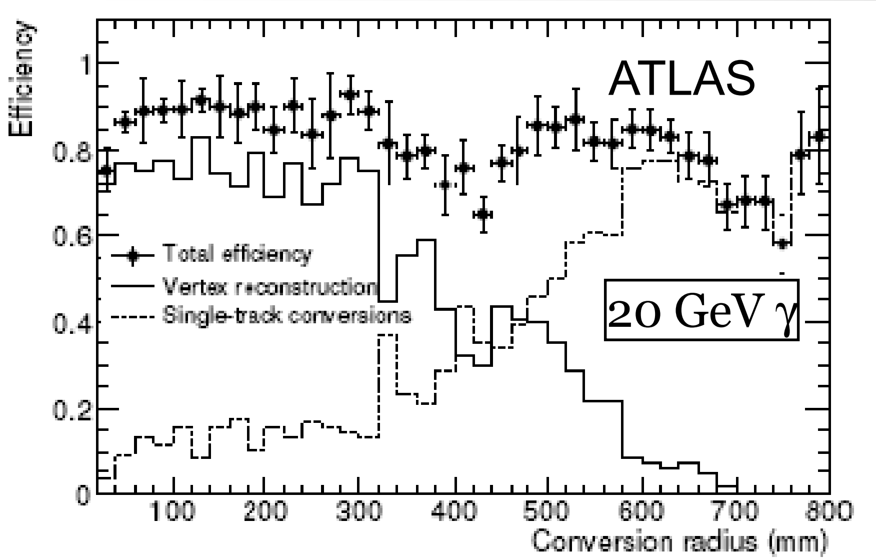
To go further

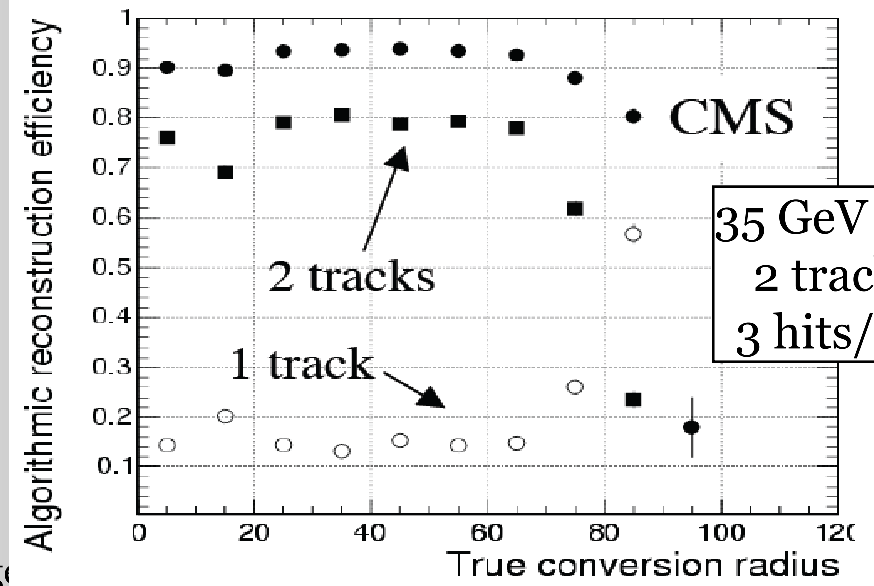
- Multivariate methods: improve rejection by 40-60% for a fixed efficiency, or gain of ~4-8% in efficiency for a fixed rejection

Photon Conversions

- Outward/Inward seed/track finding is crucial for conversions
  - New TRT stand-alone tracking implemented in ATLAS
- Conversion Types
  - Double: Pairs of opposite charge tracks fitted to common vertex
  - Single: asymmetric with soft electron lost or two tracks merged
- Determined photon direction helps to find primary vertex







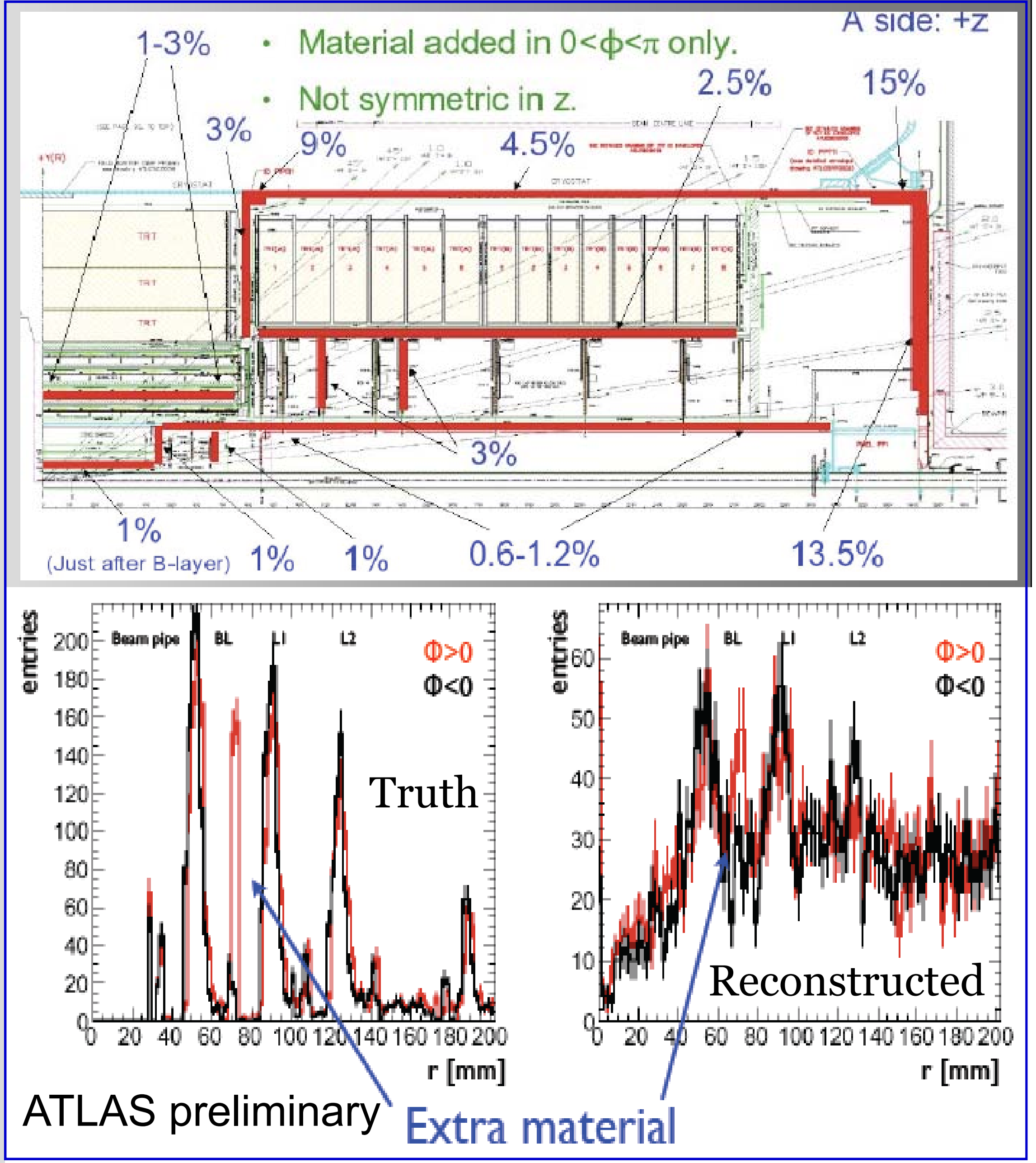
Understanding of the Material

Photon conversions used both in ATLAS and CMS

- use $\pi^0 \rightarrow \gamma\gamma$ from minbias events
- $\sim 10^9$ minbias events for 1% uncertainty

Results from ATLAS study with "distorted material" simulation

300k minbias events

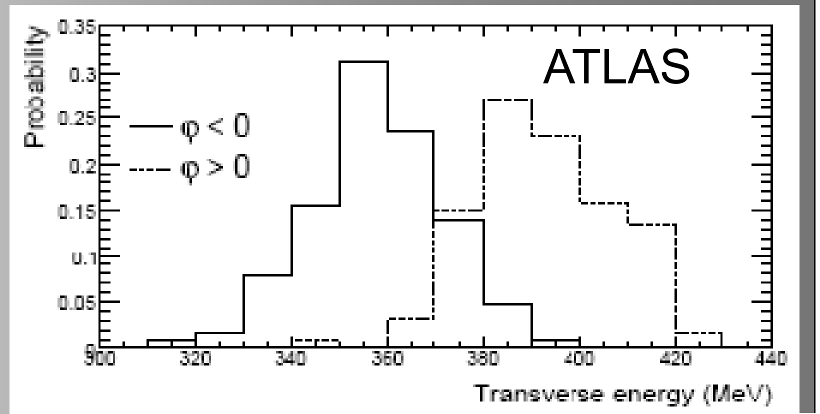


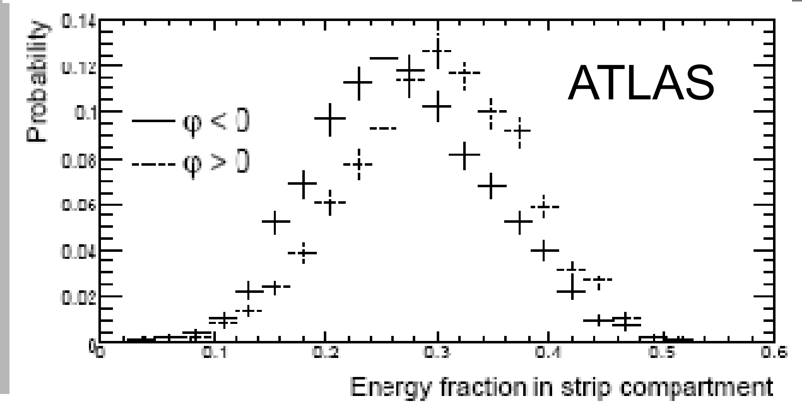
ATLAS:

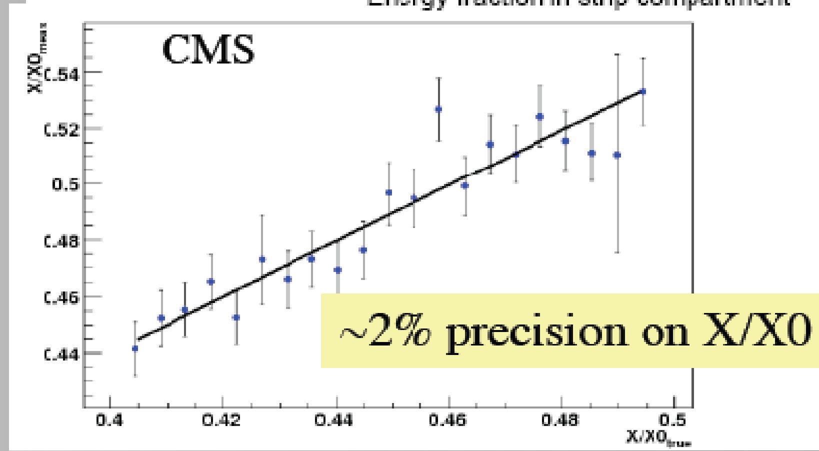
- 2^{nd} sampling E_T in minbias events
  - 2M events ~ 1 day of data-taking
  - sensitivity 20% extra material in 0.1x0.1 regions
- 1^{st} sampling energy deposit (W/Z)

CMS:

- E/p distribution
- Use of the bremsstrahlung fraction for electron tracks:
  - $\langle X/X_0 \rangle \sim -\ln(1-f_{brem})$

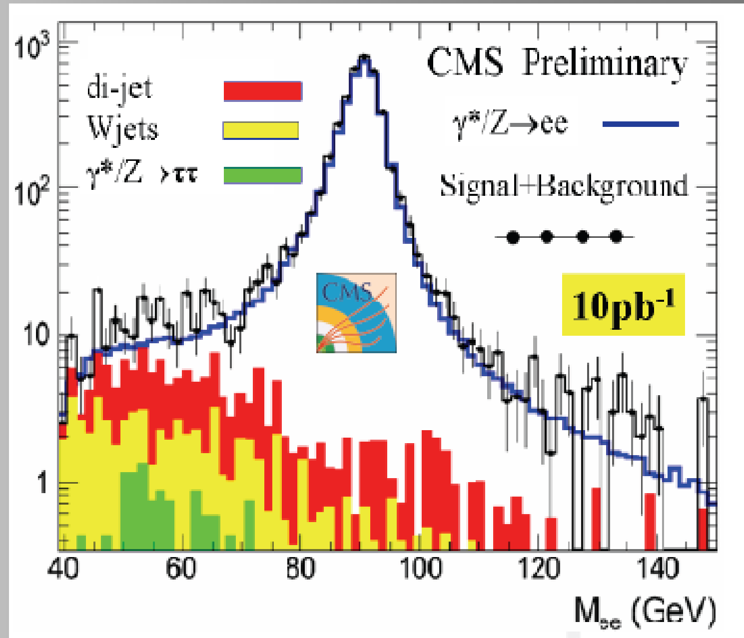




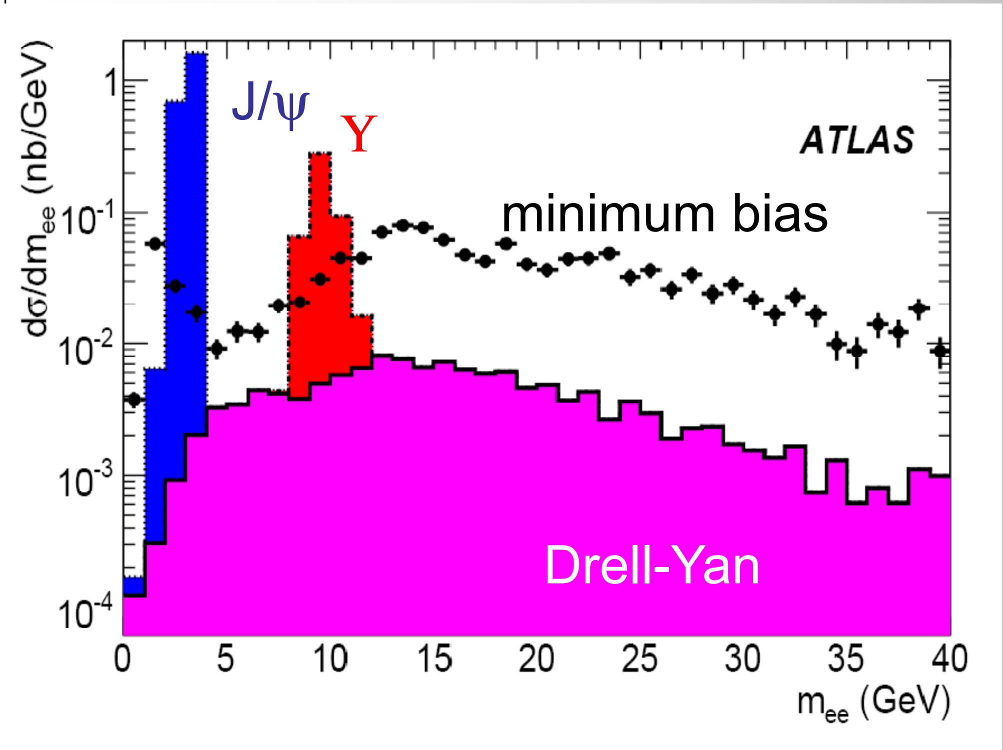


Main Calibration Samples

- These samples will be seen early
- Fairly simple selections
- For Z robust analysis is planned in the beginning (without tracker)



Z→ee ~40k events in 100pb^{-1}

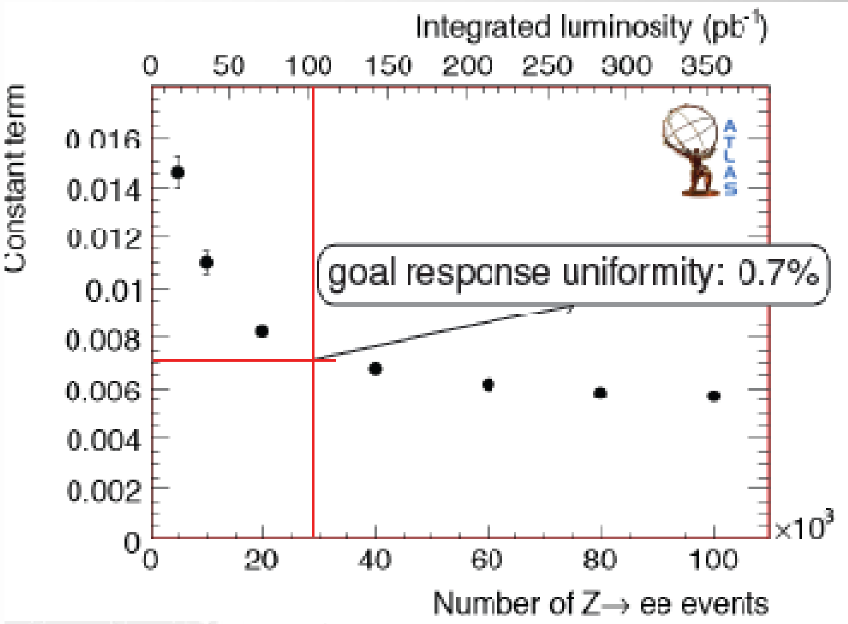


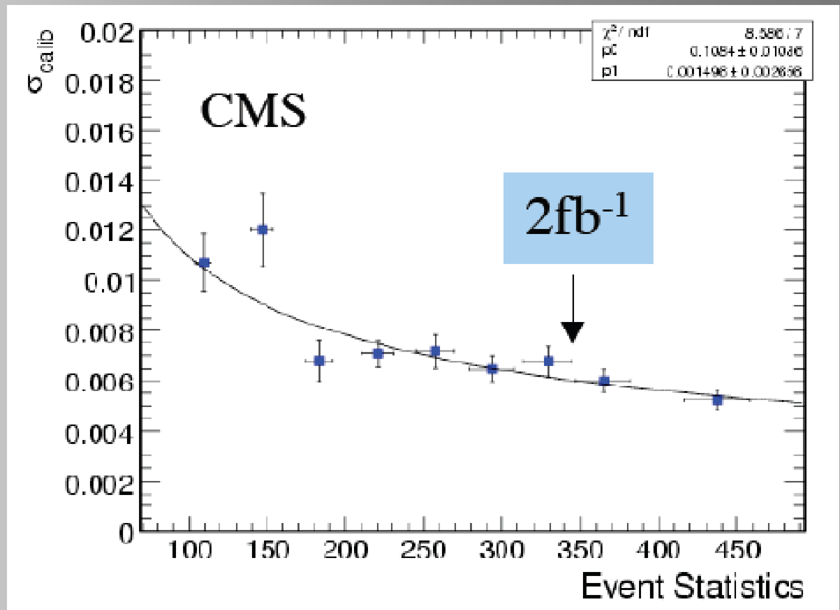
Expected number of signal events passing L1 and offline tight soft electron selection with E_T>5GeV (×10³) with 100 pb^{-1} at 10^{31} cm^{-2} s^{-1}

J/ψ	Υ(1S)	Drell-Yan
230k	45k	14k

$Z(J/\psi)\to ee$ calibration, energy scale

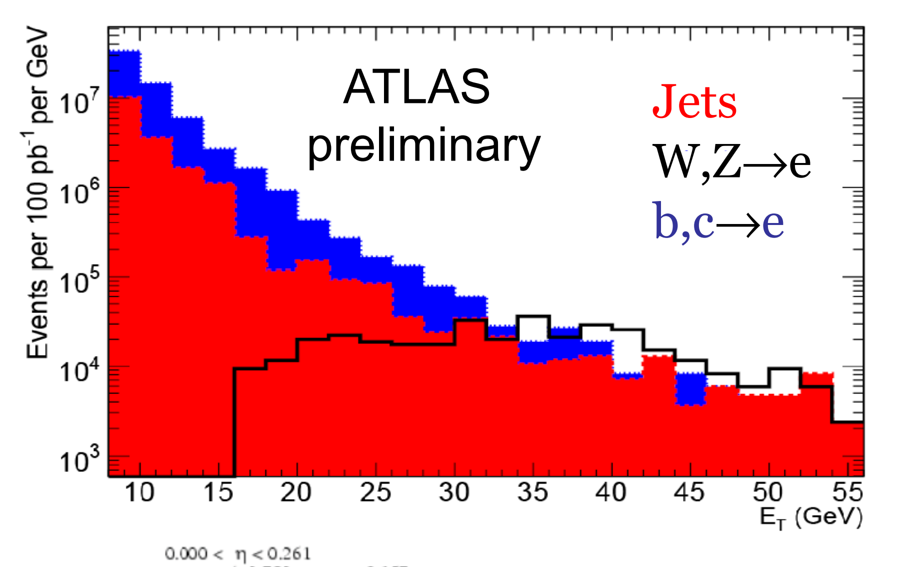
- Mass constraint to correct residual long-range non-uniformities
- In ATLAS, inter-calibrate large locally uniform regions
  - assuming ID material is known to a good accuracy
  - ~30k $Z\to ee$ events achieve uniformity of ~0.7% in 0.1x0.1 ($\eta \times \phi$)
  - ~200k $J/\psi\to ee$ events for 0.6%
  - two samples provide cross-check of calibration and check the linearity of calorimeter
- In CMS, local crystal to crystal response is non-uniform
  - Use single jet triggers to inter-calibrate ϕ rings (need ~11M events, e.g. a few hours of full trigger bandwidth to reach 2-3% precision)
  - Need $2fb^{-1}$ to reach 0.6% uniformity: this is required for $H\to\gamma\gamma$ searches





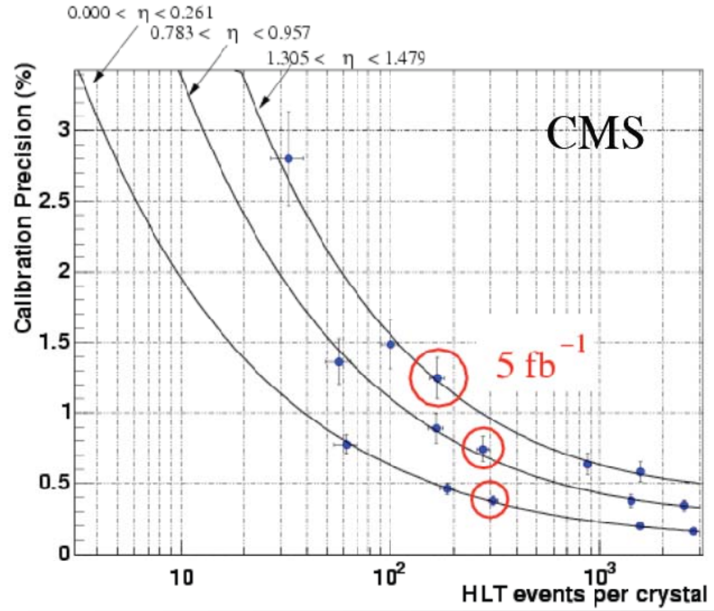
Calorimeter-ID inter-calibration

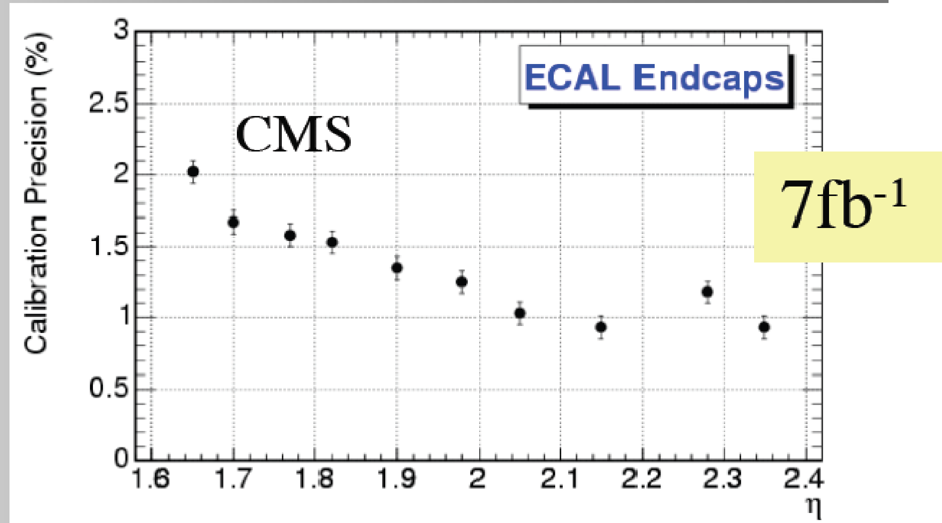
Inter-calibrate in small regions using E/p peak



Main Electron Samples:

- Isolated electrons of $W \to e\nu$
- Non-isolated electrons from $b,c \to e$ (10 times more statistics with E_T>10GeV, dominate up to p_T~35GeV)
  - Keeping single electron trigger threshold as low as possible is crucial!



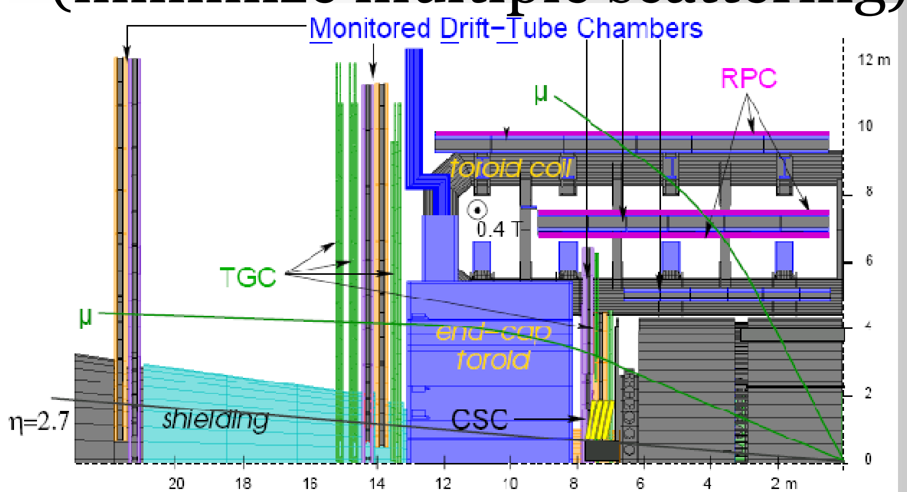


Muon PID

Muon System Design

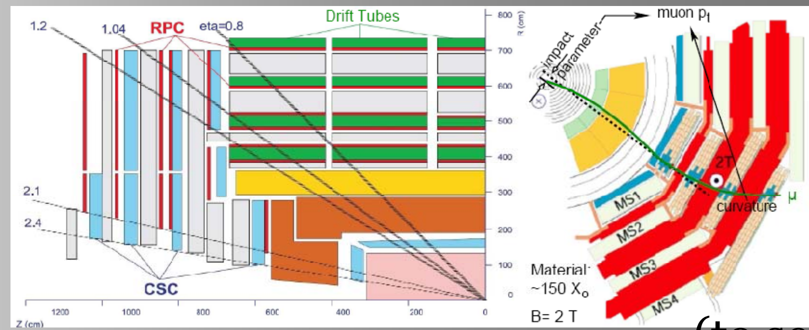
Standalone muon spectrometer in air-core toroid

(minimize multiple scattering)



- Resolution
  - Not limited by multiple scattering
  - Uniform in η
- Accurate measurement of very non-uniform B field required

Instrumented return yoke of inner detector solenoid ⇒ high bending power and momentum resolution in ID



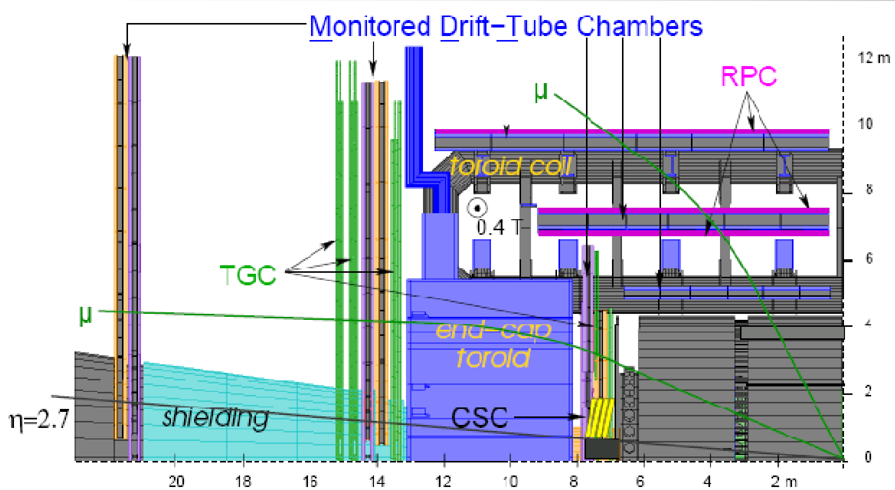
(to scale)

- Resolution
  - Limited by multiple scattering
  - η-dependent
- Uniform B field in the barrel

Muon System Design

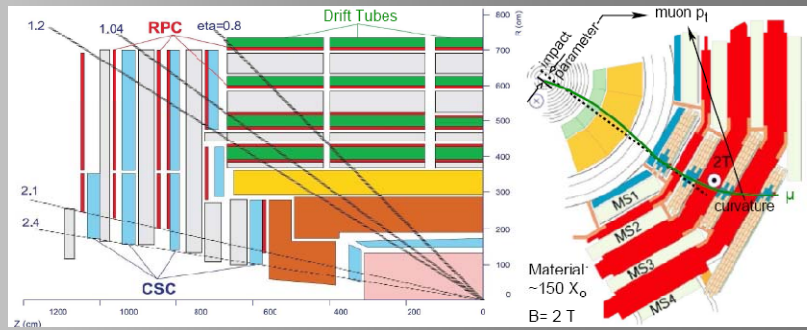
Optical Alignment System (<35μm resolution)

Pseudorapidity coverage <2.7



Laser alignment of muon and ID with 200μm precision

Pseudorapidity coverage <2.4



(to scale)

Fast Trigger Chambers (<10ns time resolution):

- Thin Gap Chambers (TGC)
- Resistive Plate Chambers (RPC)

- Resistive Plate Chambers (RPC)

High Resolution Tracking Detectors:

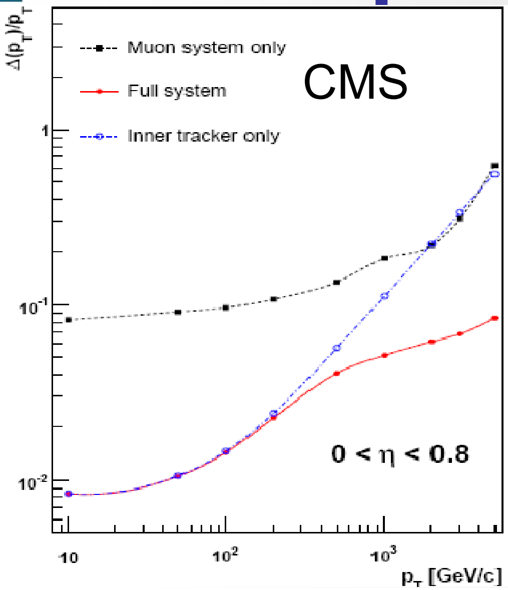
- Cathode-Strip Chambers (CSC)
- Monitored Drift Tube (MDT)

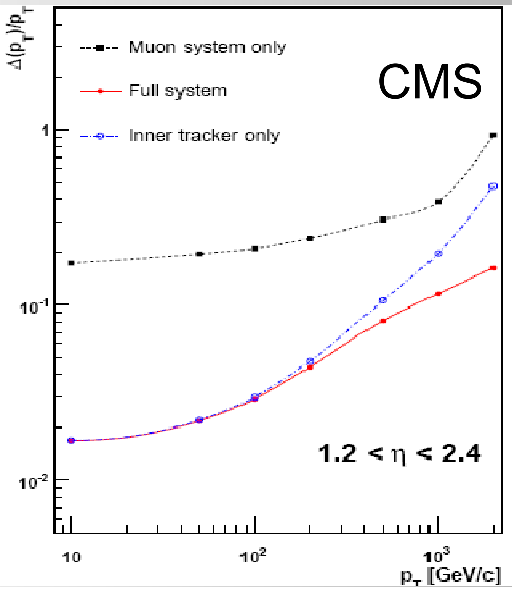
Spatial Resolution 80μm/MDT tube

- Cathode-Strip Chambers (CSC)
- Drift Tube Chambers (DT)

Spatial Resolution <=100μm

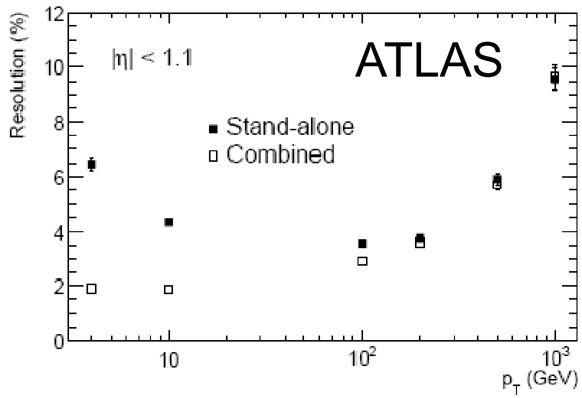
Expected Momentum Resolutions

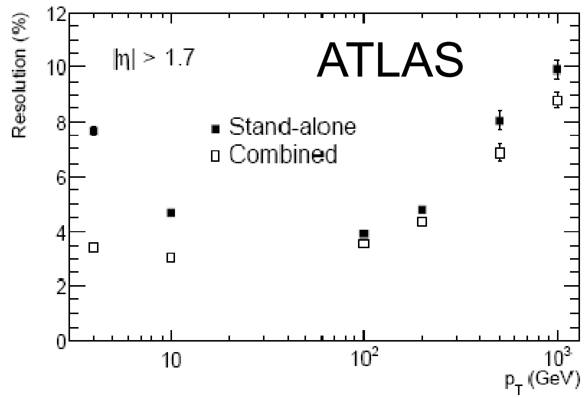




Main Contributions to standalone resolution: (CMS/ATLAS)

- Multiple Scattering in Muon System (low p_T)
- Chamber resolution (high p_T) (ATLAS only)
- Energy loss fluctuations
- Chamber Alignment





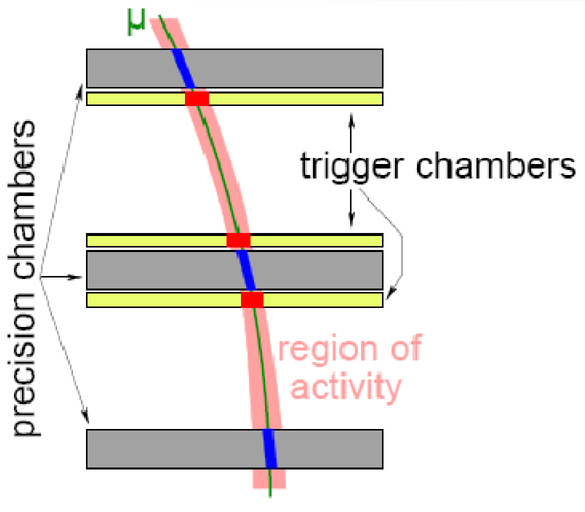
Combined ID/Muon reconstruction needed for optimal resolution in CMS

Combined (standalone) resolutions:
[numbers are old, but show the main trends]

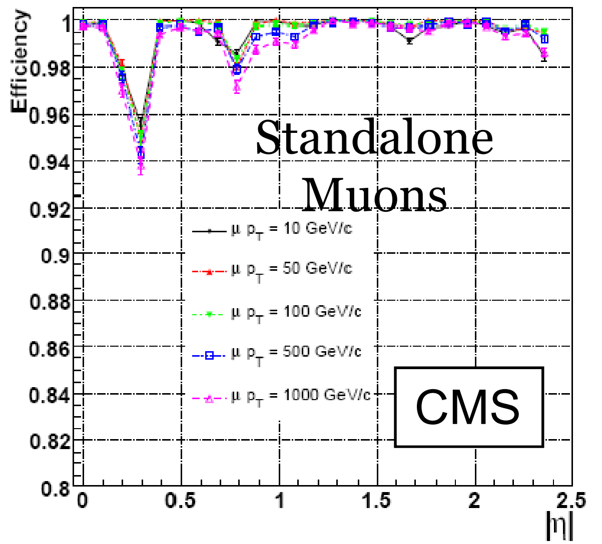
$-p = 10$ GeV and $\eta \approx 0$	1.4% (3.9%)	0.8% (8%)
$-p = 10$ GeV and $\eta \approx 2$	2.4% (6.4%)	2.0% (11%)
$-p = 100$ GeV and $\eta \approx 0$	2.6% (3.1%)	1.2% (9%)
$-p = 100$ GeV and $\eta \approx 2$	2.1% (3.1%)	1.7% (18%)
$-p = 1000$ GeV and $\eta \approx 0$	10.4% (10.5%)	4.5% (13%)
$-p = 1000$ GeV and $\eta \approx 2$	4.4% (4.6%)	7.0% (35%)

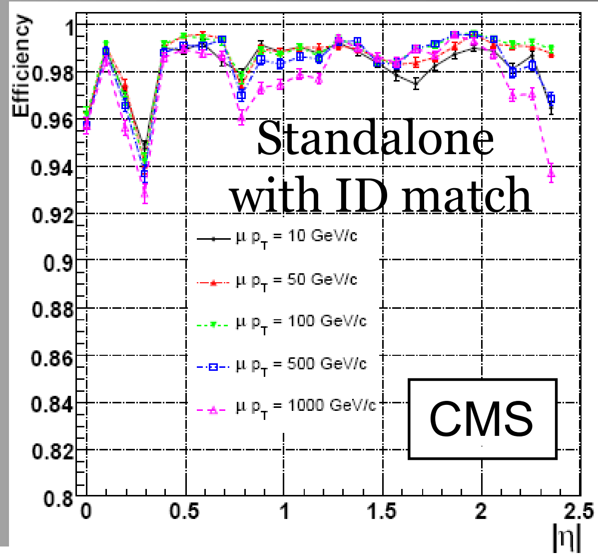
Annu. Rev. Nucl. Part. Sci. 2006.56:375-440

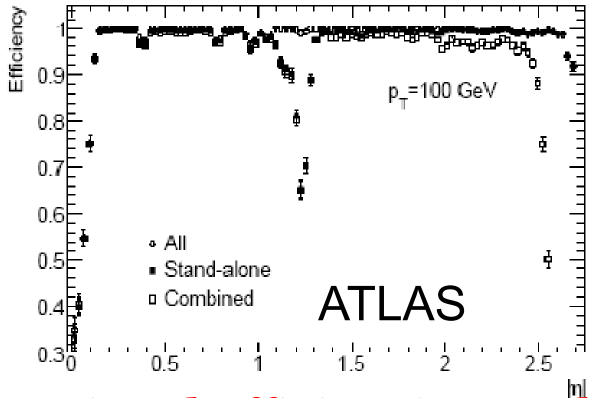
Muon Reconstruction Efficiencies

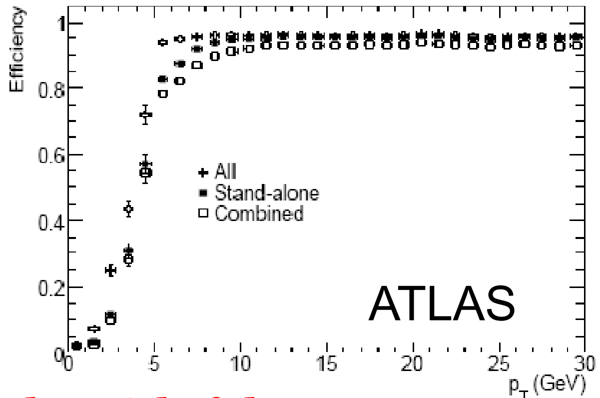


- Define Region of Activity (RoA)
- Reconstruct local straight segment in RoA
- Combine local segments
- Perform global fit in muon system
- Add Inner Detector Information





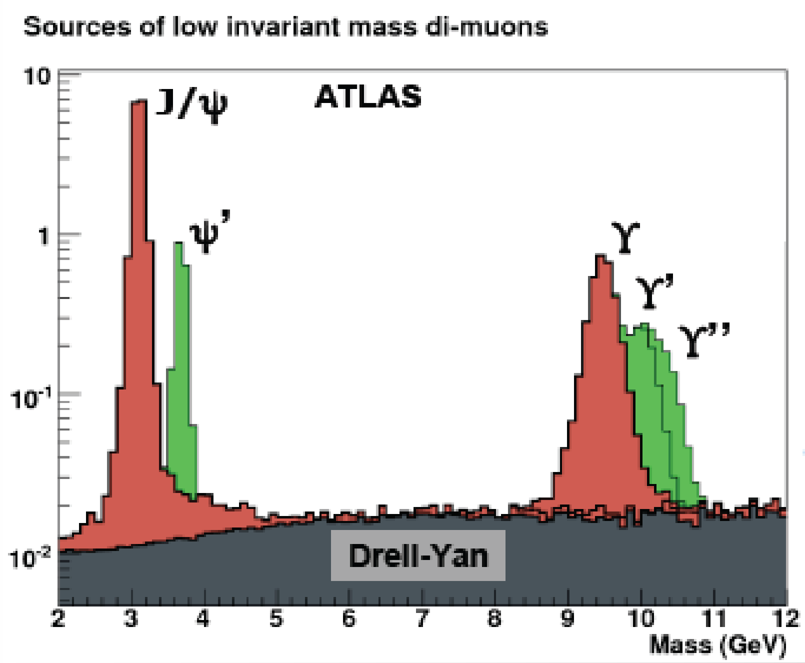




Signal efficiencies are high, with fake rate <0.5%. CMS muon system provides more uniform performance.

Combined ID/Muon reconstruction important for efficiency improvement in ATLAS

Main Calibration Samples



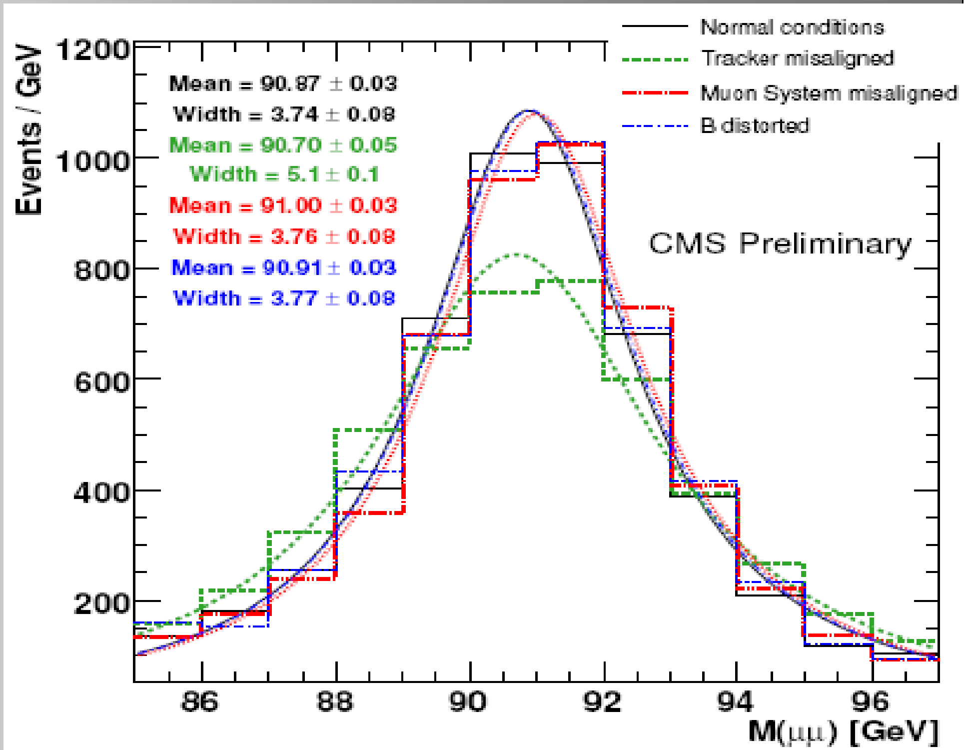
These will be the first peaks in data

Events in 100pb^{-1}:
J/ψ→μμ ~1600k (+~10% ψ')
ϒ→μμ ~300k (+~40% ϒ'/ϒ'')
Z→μμ ~60k

Dilepton resonances (mostly Z) sensitive to:

- Tracker-spectrometer misalignment
- Uncertainties on Magnetic field
- Detector momentum scale
- Width is sensitive to muon momentum resolution

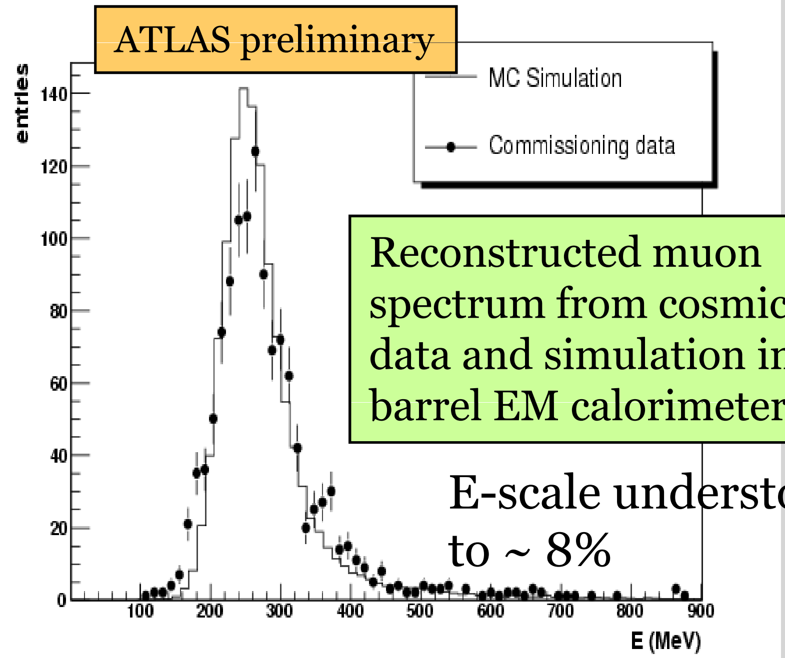
J/ψ and Z Cross-checks between samples



First Cosmics Results

~ 170k good cosmic muons collected with EM calorimeter used for this study (rate in ATLAS cavern is O[10 Hz]) → can record ~ 10^6 events before collisions start

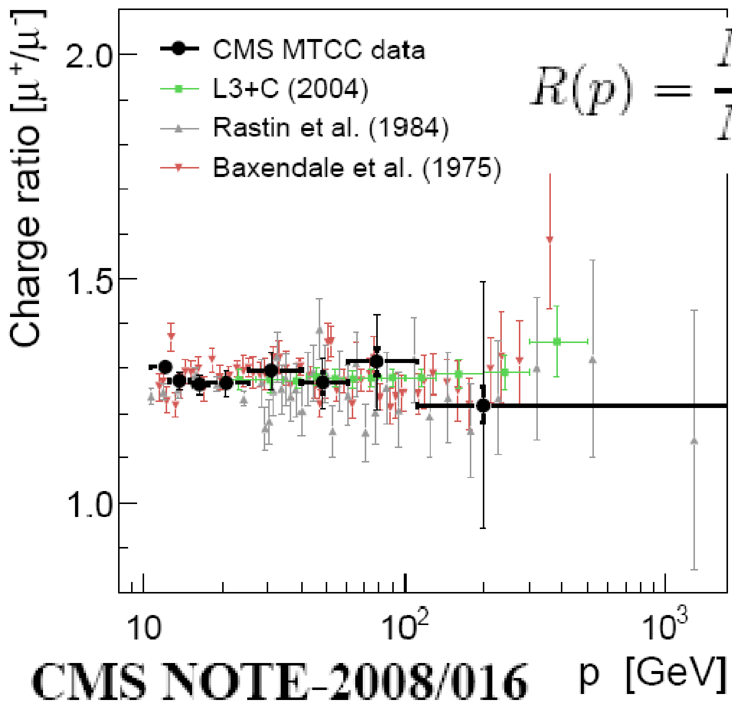
■ enough to check part of calibration vs η to 0.5% in best exposed modules



Reconstructed muon spectrum from cosmics data and simulation in barrel EM calorimeter

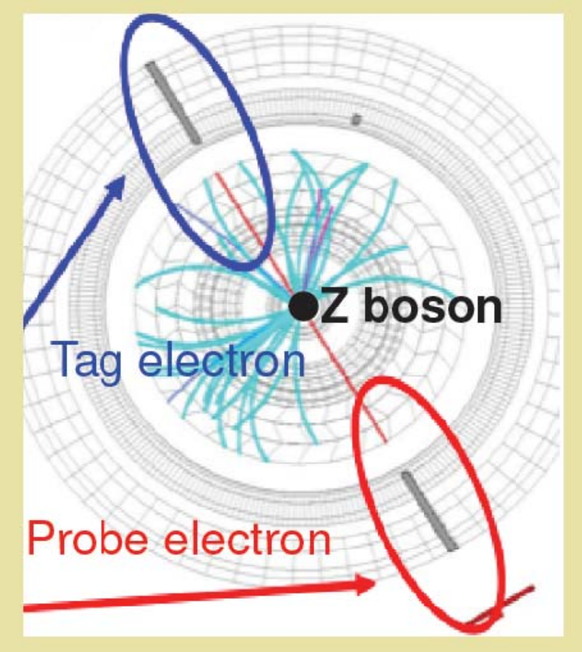
E-scale understood to ~ 8%

- Use 25M of events (of 200M) from Magnet Test and Cosmic Data Challenge (2006)
  - 15M with B-field ≥3.8T
- A section of all subdetectors included
- Standalone muon reconstruction
- Full trigger + offline chain tested
- Test part of the alignment procedure

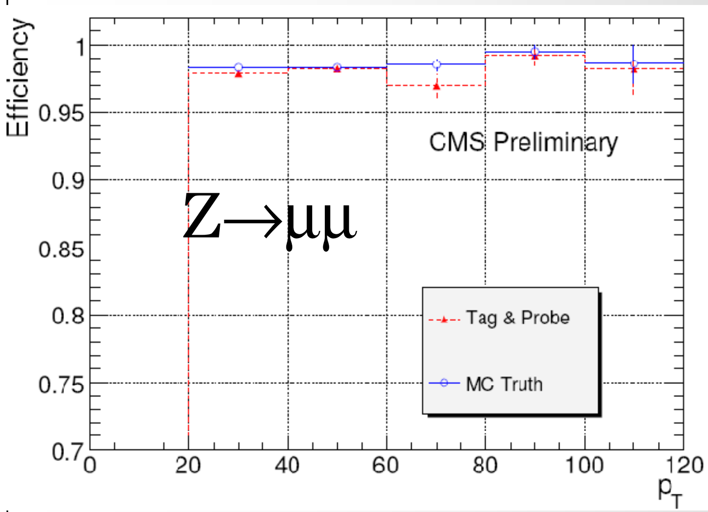


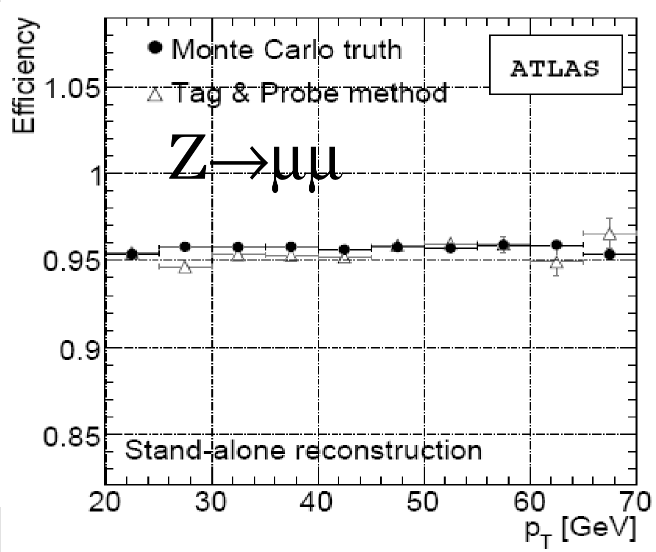
$$R(p) = \frac{N_{\mu^+}(p)}{N_{\mu^-}(p)}$$

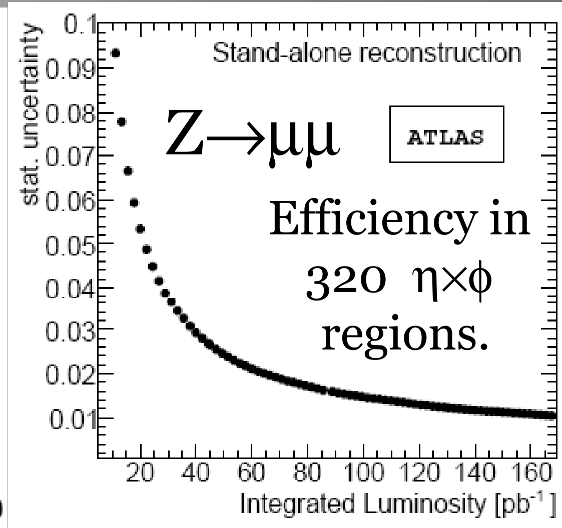
Efficiency extraction from Data (e/μ/γ)



- Tag& probe Method to determine electron/muon efficiencies:
  - Single trigger for unbiased sample (tag)
  - Simple object on the other side (probe)
  - Determine the efficiency with the number of events in Z mass window
- Agrees well with truth-matching (<~1%)
  - Electron trigger efficiency 0.2%(stat)/100pb^{-1} ATLAS
  - Muon efficiency see plot
- MC to go from e→γ in early data
  - Z→μμγ photon efficiency to 0.1%(stat) with 1fb^{-1} (CMS)





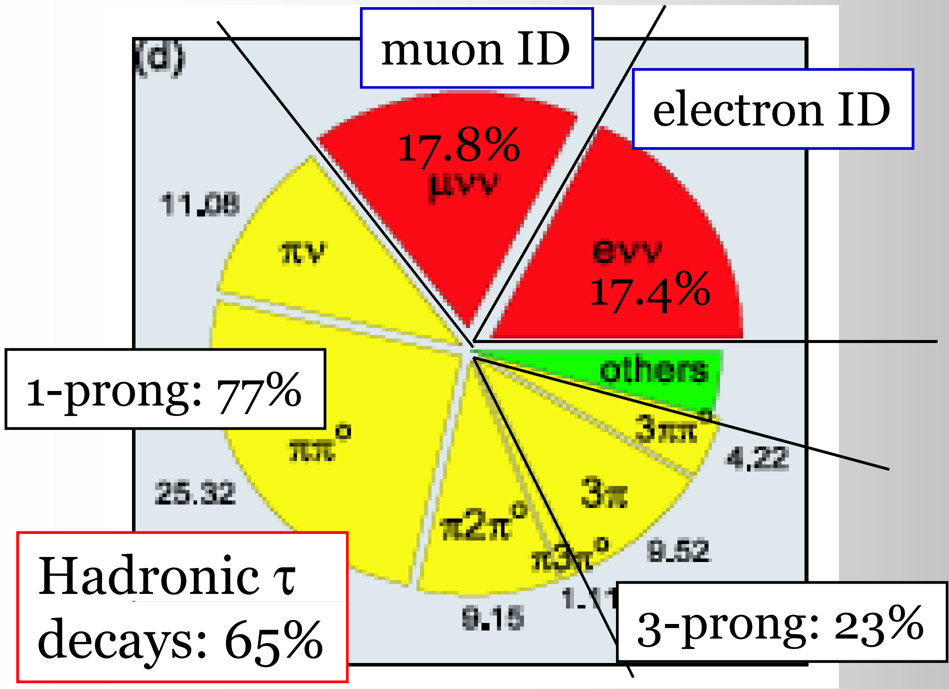


Tau PID

...will show only ATLAS results...

Tau characteristics

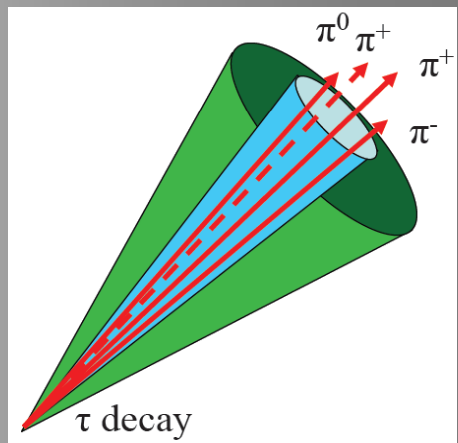
- Heavy Lepton: m_τ=1.78GeV
  - Decay Length: ct ~= 87mm
  - Decays into leptons and hadrons



  - Produces **t-jet**
- Main backgrounds for taus
  - QCD jets
  - Electron that shower late or with strong bremstrahlung
  - Muons interacting in the calorimeter

Tau-jets at LHC:

- Very collimated
  - 90% of the energy is contained in a 'cone' of radius R=0.2 around the jet direction for E_T>50 GeV
- Low multiplicity
  - One, three prongs
- Hadronic, EM energy deposition
  - Charged pions
  - Photons from p^o



ATLAS tau reconstruction/performance

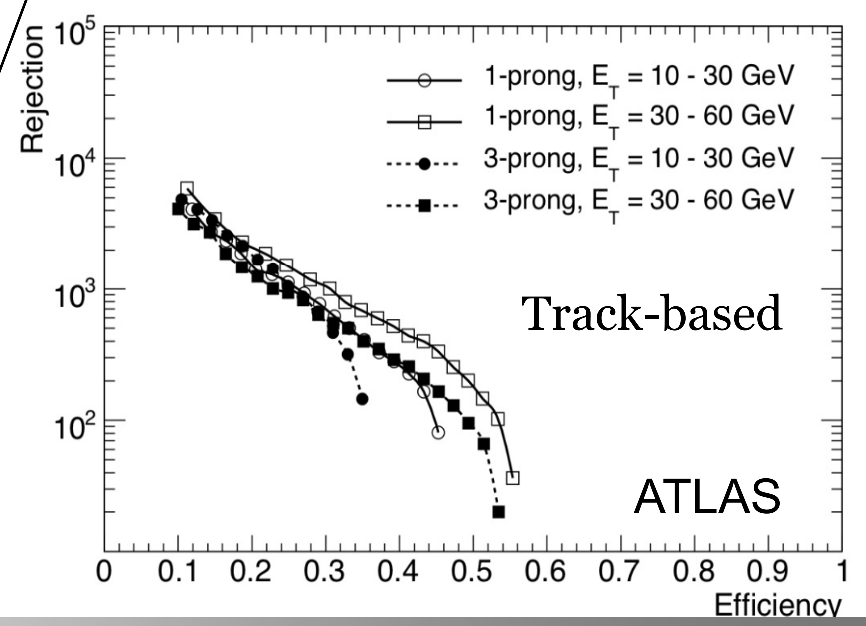
Calo-based (tauRec)

- Start from Clusters/Jets with E_T>10 GeV or Isolated Track >0.5GeV
- Associates tracks to candidate in ΔR<0.3
- Calibrate candidate energy using information from calorimeters

Track-based (tau1p3p)

- Seeds: good quality tracks (p_T > 6 GeV)
- Associates tracks to candidate in ΔR<0.2
- E_T determined using energy flow method
- Reconstructs π^0 subclusters with dedicated topological clustering

...merged for optimal tau reconstruction...
Tau identification (MVA) performed



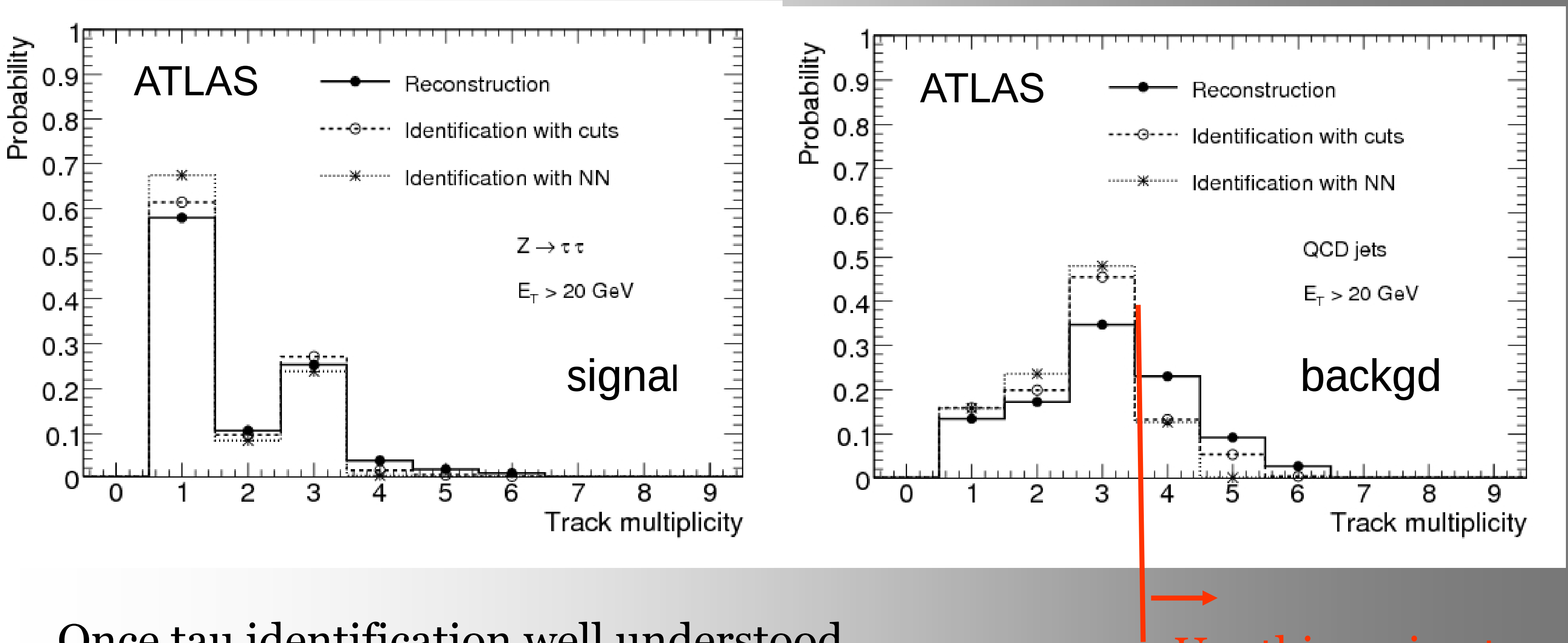
Typical jet rejections at 30% efficiency for the two algorithms:

Algorithm	E_T = 10-30 GeV	E_T = 30-60 GeV	E_T = 60-100 GeV	E_T > 100 GeV
Track-based (neural network)	1p: 740 ± 70 3p: 590 ± 50	1p: 1030 ± 160 3p: 590 ± 70		
Calo-based (likelihood)		1p: 1130 ± 50 3p: 187 ± 3	1p: 2240 ± 140 3p: 310 ± 7	1p: 4370 ± 280 3p: 423 ± 8

Track multiplicity spectra

- A handle to control QCD background
- Evidence for τ observability.

Need to balance efficiency between single- and three-prong candidates



Once tau identification well understood, Optimisation for discoveries may become more inclusive i.e. optimise S/B (favour single-prong)

Use this region to control QCD normalisation

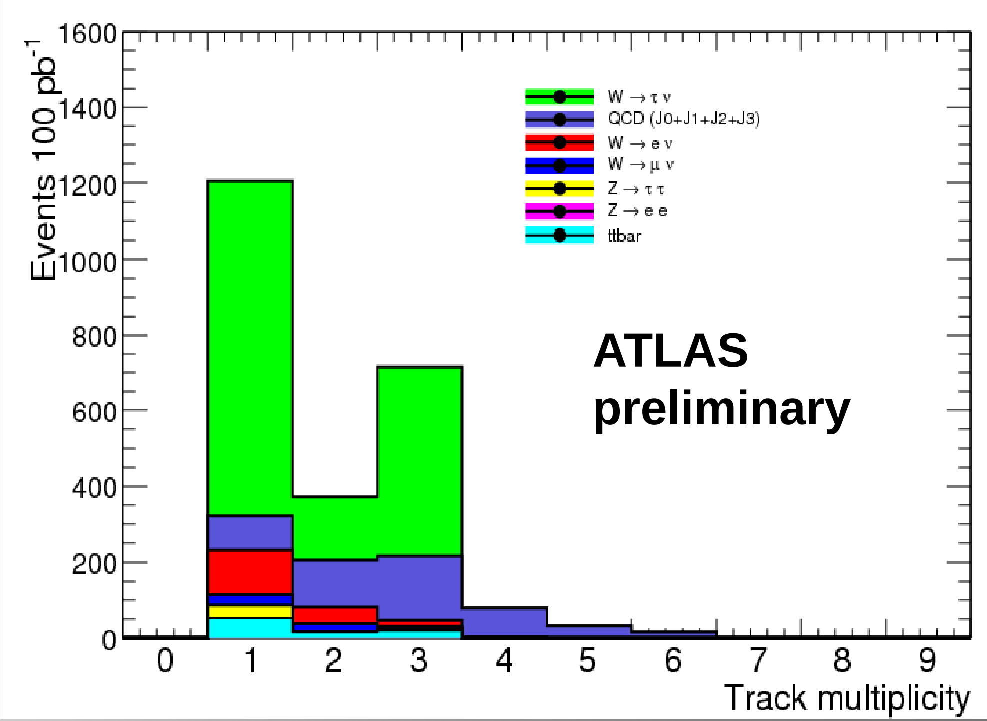
Tau Trigger Slice

- ✓ Tau physics can be done without tau triggers
  - ✓ Leptonic tau decays are triggered with lepton triggers
- ✓ Triggering on hadronic tau decays is difficult
  - ✓ huge QCD background, high occupancy in the events
  - ✓ Difficult not to bias track multiplicity spectra
  - ✓ Intensive effort in ATLAS to develop algorithms and optimise performance
- ✓ Tau Trigger configuration
  - ✓ high thresholds alone (E^{τ}_{T}>60GeV),
  - ✓ lower thresholds in combination with other signature (E_T^{miss}, lepton, jet)
- ✓ Increases dicovery potential for many physics channels, in few cases the only trigger
  - ✓ $W \rightarrow \tau\nu$ trigger (single tau + E_T^{miss}) only accessible at $L=10^{31}cm^{-2}s^{-1}$
  - ✓ Higgs in fully hadronic tau decays

ATLAS Trigger System	Tau Trigger Slice
L1: (hardware) 40MHz->75kHz (2.5ms)	Calorimetry
L2: (software) 75kHz->2kHz (40ms)	Calorimetry + tracking
EF: (software) 2kHz -> 100 Hz (4s)	Same algorithms as off-line

$W \to \tau\nu$ events with $100 pb^{-1}$

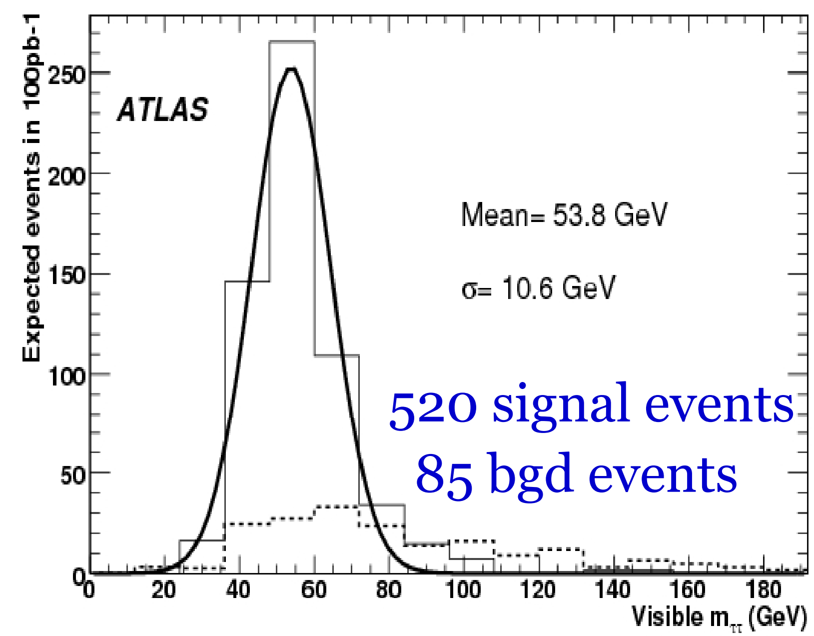
- The most abundant source of taus in SM processes.
- Triggered on single tau + E_T^{MISS}: only accessible at 10^{31}!
- Dominant bgd from QCD jets
  - S/B is 10 times worse at LHC than at TeVatron
- $W \to e\nu$ important background, but also excellent control channel.
- Main tau signature: Observe excess of events in the track multiplicity spectrum of identified taus.



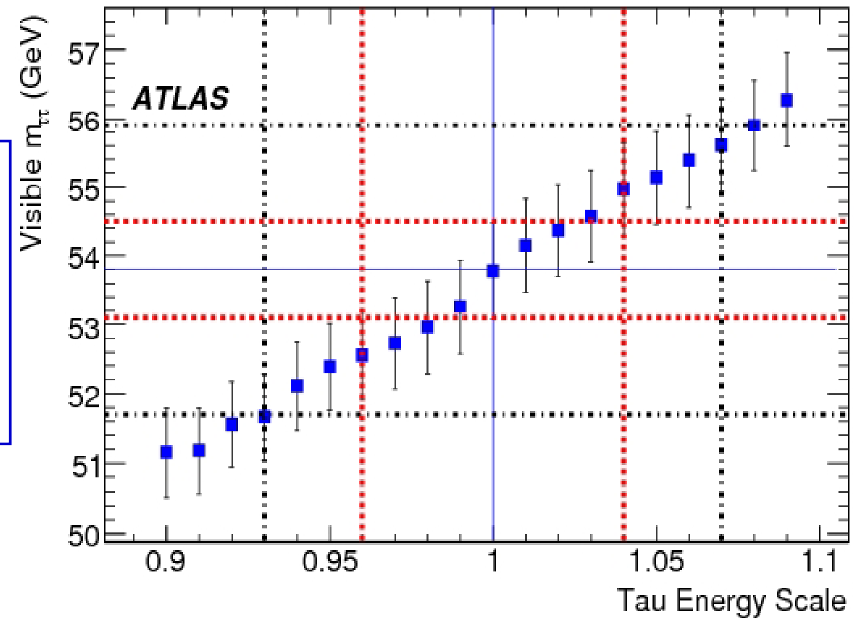
Events for $100pb^{-1}$	$W \to \tau\nu$	QCD
In pp collisions	$1.7\ 10^6$	$1.9\ 10^{12}$
Trigger	$8.8\ 10^4$	$8.6\ 10^7$
Offline selection	1550	510

$Z \rightarrow \tau\tau$ events (lep-had) with $100 pb^{-1}$

- 10 times smaller cross-section than $W \rightarrow \tau\nu$ but more interesting topology
- Triggered on single lepton.
- same-sign events (almost signal free) used to control bgd in opposite sign events (signal enriched).
- Observe excess of events in invariant mass of visible decay products, then reconstruct complete invariant mass (collinear approximation).

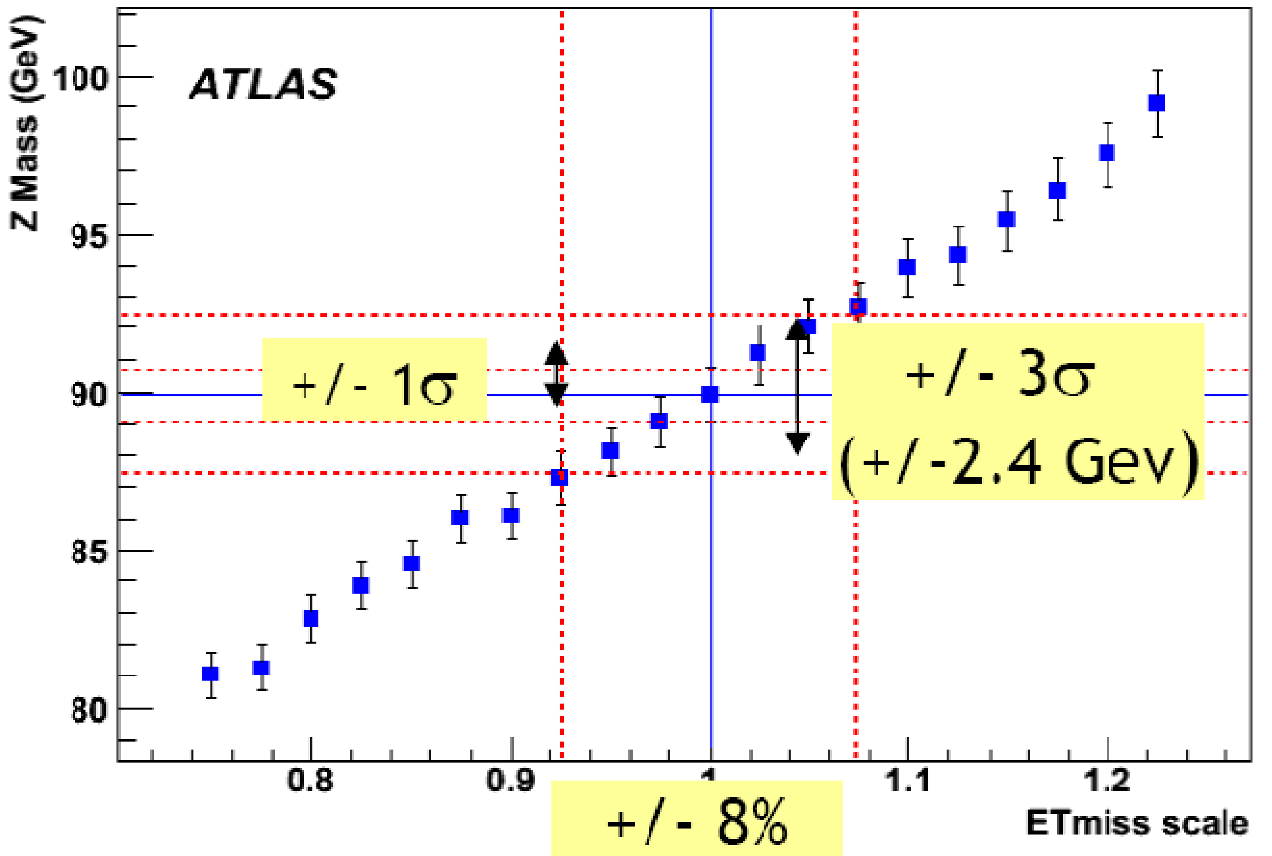


With statistical uncertainty only
from visible mass determine precision
- τ energy scale: ± 3% (visible τ energy)
- cross-section: ± 6%



$Z \rightarrow \tau\tau$ events (lep-had) with 100pb^{-1} (cont)

Taking into account only statistical uncertainty and assuming taus are well calibrated. From Z invariant mass determine E_T^{miss} scale (additional selection, collinear approximation)



In 100 pb^{-1}

in the mass bin (66-116 GeV)

209 signal evts

16 backgds evts OS ($B \approx 8\% S$)

26 backgds evts SS

$S/\sqrt{B}=50$

ETMiss scale precision:

3% with only stat errors

8% taking into account systematics, fit stability, ...

Note: E_T^{Miss} scale more easily understood with $W \rightarrow e/\mu\nu$ events

Conclusions

- Particle Identification is crucial for ATLAS/CMS discovery program
- Lower expected luminosities of the early data-taking allow access to abundant physics samples which are investigated by PID communities
- Both ATLAS & CMS have various methods in place to commission particle ID using early data
- Both experiments are ready to face the challenge of seeing new and interesting physics events expected at LHC