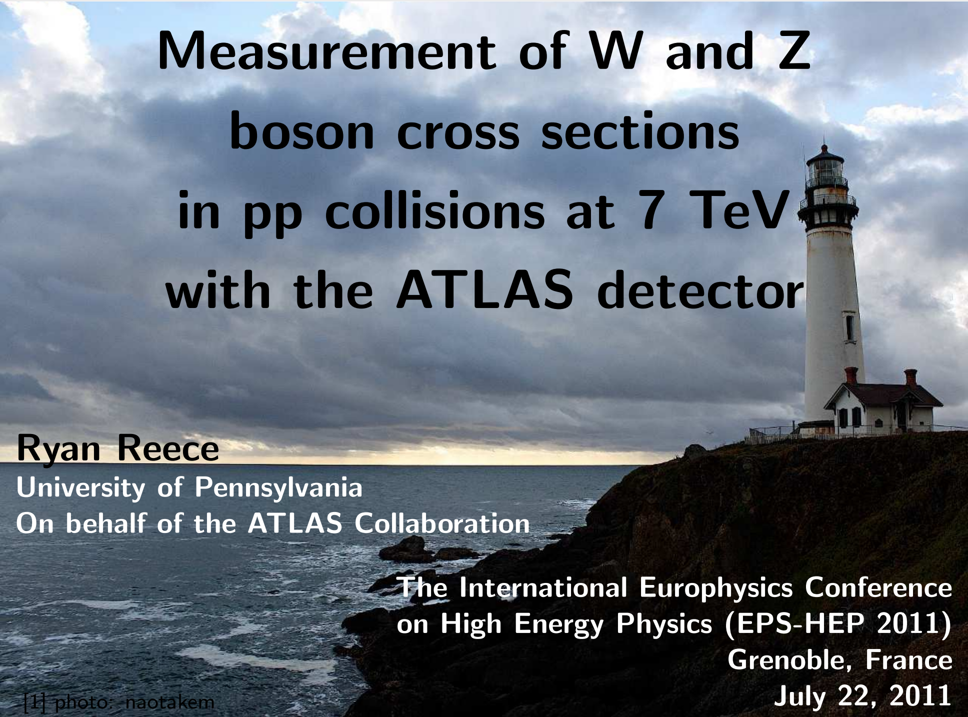


Measurement of W and Z boson cross sections in pp collisions at 7 TeV with the ATLAS detector

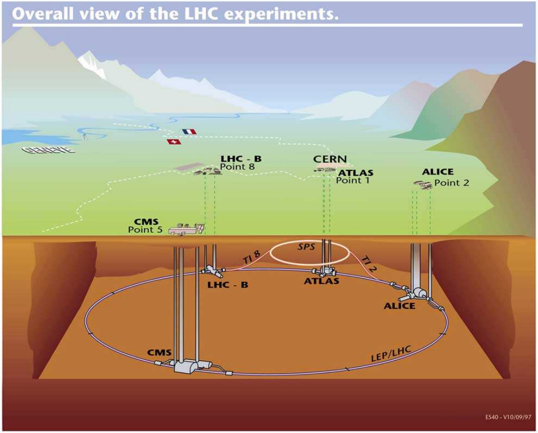
Ryan Reece
University of Pennsylvania
On behalf of the ATLAS Collaboration

The International Europhysics Conference on High Energy Physics (EPS-HEP 2011)
Grenoble, France
July 22, 2011

[1] photo: naotakem

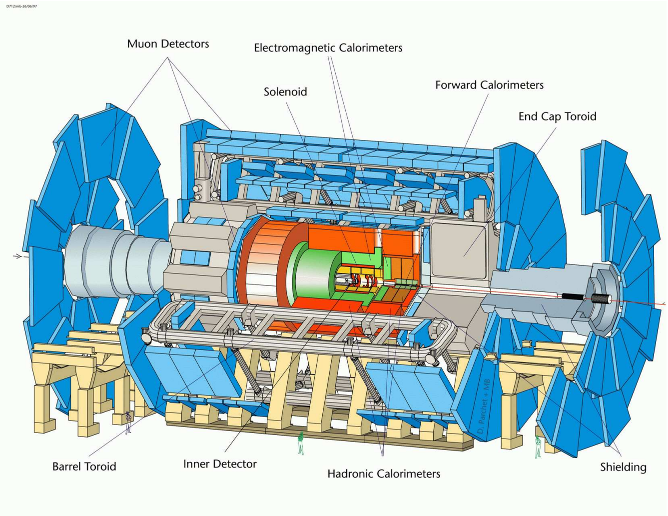
The Large Hadron Collider

- 27 km circumference
- pp collisions at $\sqrt{s} = 7$ TeV
- instantaneous luminosity 10^{30}–10^{33} cm^{-2} s^{-1}
- 50–150 ns bunch spacing



The ATLAS Experiment

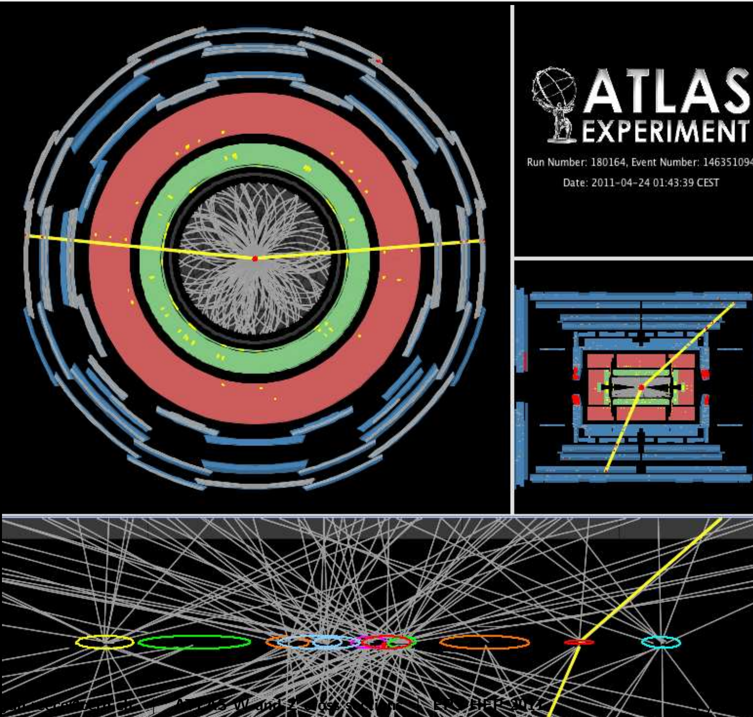
- 3000 scientists
- 38 countries
- 174 institutions
- 100 M readout channels
- tracking
- calorimetry
- muon spectrometry
- massive worldwide grid computing, $\sim$ 1 PB / year



$Z \to \mu\mu$ candidate with 10 additional soft “pile-up” interactions.

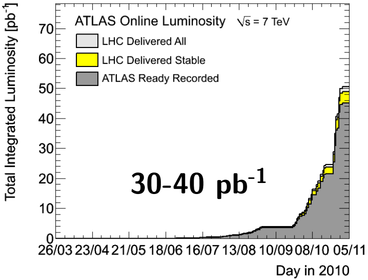
High p_{T} leptons allow us to select the interesting EW events.

Conversely, W/Z provide events for understanding high p_{T} lepton performance.

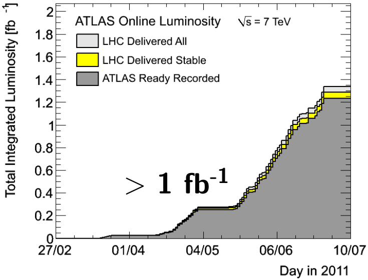


The dataset

2010



2011

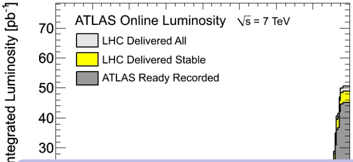


[3] ATLAS Data Summary

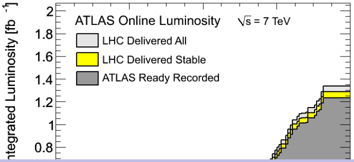
- June 2010: Observation of $W \to \ell\nu$ and $Z \to \ell\ell$
- Oct 2010: **Measurement of $W \to \ell\nu$ and $Z \to \ell\ell$ cross sections**
- Nov 2010: Observation of $W \to \tau_{\mathrm{h}}\nu$
- Feb 2011: Observation of $Z \to \tau\tau \to \ell\tau_{\mathrm{h}}$
- Mar 2011: Observation of $Z \to \tau\tau \to \ell\ell$
- July 2011: **Measurement of p_{T}^{Z}**
- July 2011: **Measurement of p_{T}^{W}**
- July 2010: Update: **Measurement of $W \to \ell\nu$ and $Z \to \ell\ell$ cross sections**
- July 2011: **Measurement of $Z \to \tau\tau$ cross section**
- July 2011: **Measurement of $W \to \tau\nu$ cross section**

The dataset

2010



2011



The results shown today use the 2010 dataset, where our detector related systematics have improved and the pile-up is less. At the end, I will show a hint of our $Z \to \tau\tau$ events in the 2011 data.

[3] ATLAS Data Summary

- June 2010: Observation of $W \to \ell\nu$ and $Z \to \ell\ell$
- Oct 2010: **Measurement of $W \to \ell\nu$ and $Z \to \ell\ell$ cross sections**
- Nov 2010: Observation of $W \to \tau_{\mathrm{h}}\nu$
- Feb 2011: Observation of $Z \to \tau\tau \to \ell\tau_{\mathrm{h}}$
- Mar 2011: Observation of $Z \to \tau\tau \to \ell\ell$
- July 2011: **Measurement of p_{T}^{Z}**
- July 2011: **Measurement of p_{T}^{W}**
- July 2010: Update: **Measurement of $W \to \ell\nu$ and $Z \to \ell\ell$ cross sections**
- July 2011: **Measurement of $Z \to \tau\tau$ cross section**
- July 2011: **Measurement of $W \to \tau\nu$ cross section**

Ingredients for a cross section

$$\sigma = \frac{N_{\rm obs} - N_{\rm bkg}}{A \cdot C \cdot \int dt\, \mathcal{L}}$$

$N_{\rm obs}$**:** number of observed events in the signal region

$N_{\rm bkg}$**:** estimated number of background events

- EW backgrounds are estimated with Monte Carlo, constrained to data with performance scale factors.
- QCD backgrounds are estimated with **data-driven** methods.

A**:** kinematic acceptance factor, estimated with generator-level Monte Carlo.

C**:** summarizes reconstruction efficiency, estimated with reconstructed Monte Carlo, corrected with **scale factors**.

$\int dt\, \mathcal{L}$**:** integrated luminosity.

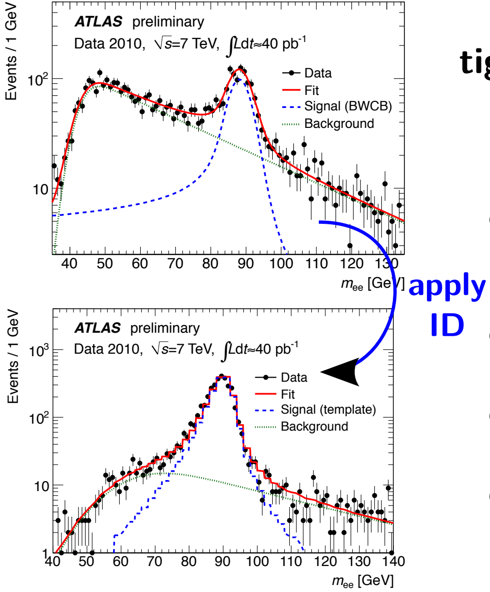
Progress in reducing systematics

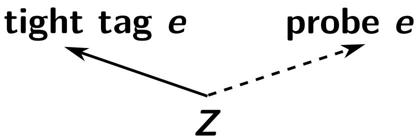
The main advancements in W and Z cross section measurements since last winter are due to the reduction of systematics.

Examples:

- **Tag and probe** studies lead to many improvements in electron and muon identification and **scale factors** correcting our simulation thereof.
- Reduced acceptance uncertanties by switching from using a LO Pythia generator to MC@NLO, p_{T}^{W} and p_{T}^{Z} reweighted to better agree with data (discussed later).

Tag and probe studies





- **"Tag"** events with sufficient purity, leaving an unbiased **"probe"** object.
- Measure probe ID efficiency *in situ*.
- Constrains the performance of our object identification.
- Derive **scale factors** for correcting our simulation.

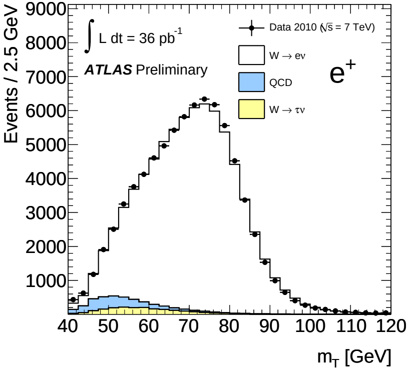
[4] ATLAS-PERF-2010-04-001

$W \to \ell\nu$ and $Z \to \ell\ell$

Event selection

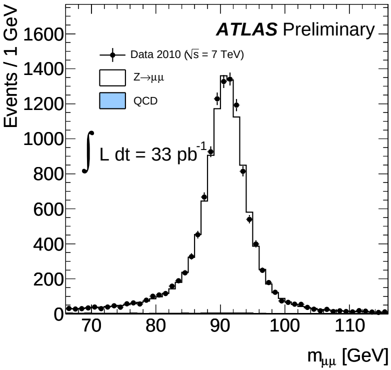
$W \to \ell\nu$

- One e/μ with $p_{\mathrm{T}} > 20$ GeV
- $E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV
- $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) > 40$ GeV



$Z \to \ell\ell$

- Two e/μ with $p_{\mathrm{T}} > 20$ GeV
- $m_{\ell\ell} = 66$–116 GeV



[6] STDM-2011-06

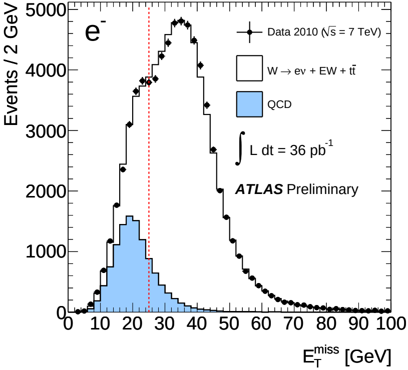
QCD background estimation

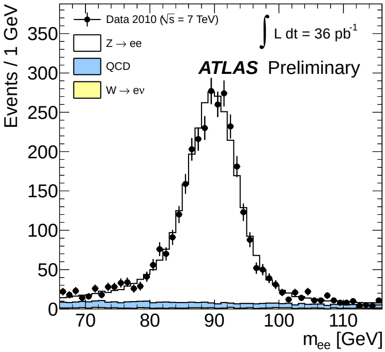
$W \to e\nu$: template fit to $E_{\mathrm{T}}^{\mathrm{miss}}$. Template derived from data with inverted electron ID and isolation.

$Z \to ee$: template fit to $m_{\ell\ell}$ to a sample with looser electron ID, extrapolated to the signal region.

$W \to \mu\nu$: matrix method using track isolation.

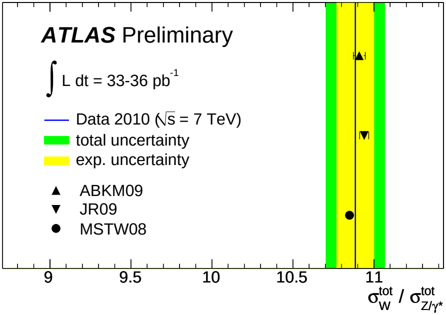
$Z \to \mu\mu$: ABCD method with track isolation in $m_{\mu\mu}$ side-band.





Cross section results

		σ [nb]	stat.	sys.	lumi.	acc.
$\sigma_W \cdot \mathrm{BR}(W \to e\nu)$	=	10.255	0.031	0.190	0.349	0.084
$\sigma_W \cdot \mathrm{BR}(W \to \mu\nu)$	=	10.210	0.030	0.179	0.373	0.153
$\sigma_{Z/\gamma*} \cdot \mathrm{BR}(Z/\gamma* \to ee)$	=	0.952	0.010	0.026	0.032	0.019
$\sigma_{Z/\gamma*} \cdot \mathrm{BR}(Z/\gamma* \to \mu\mu)$	=	0.935	0.009	0.009	0.032	0.019



- Dominant uncertainty is luminosity.
- Acceptance uncertainty remains significant due to the extrapolation from the fiducial volume.
- Detector related uncertainties partially cancel in the ratio.

Cross section results

		σ [nb]	stat.	sys.	lumi.	acc.
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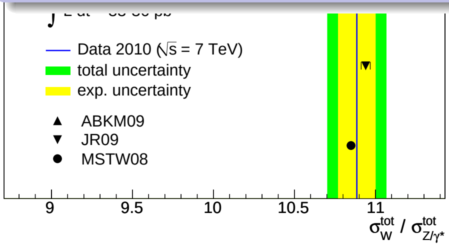
$\sigma_{Z/\gamma*} \cdot \mathrm{BR}(Z/\gamma* \to ee)$	=	0.952	0.010	0.026	0.032	0.019
[illegible]						019

Many more details on the $W \to \ell\nu$ and $Z/\gamma* \to \ell\ell$ cross section measurements, including differential measurements of $d\sigma/d\eta$ and their constraints on proton PDFs will be discussed in Massimiliano Bellomo's talk in the QCD session this afternoon.

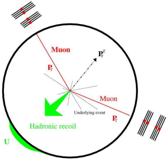


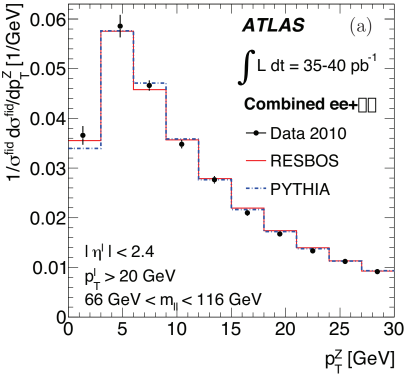
- Acceptance uncertainty remains significant due to the extrapolation from the fiducial volume.
- Detector related uncertainties partially cancel in the ratio.

p_{T}^{W} and p_{T}^{Z}

Z boson p_{T} measurement

- Important for modeling high-p_{T} lepton kinematics.
- At leading order, $p_{\mathrm{T}}^{W/Z} = 0$
- Non-zero $p_{\mathrm{T}}^{W/Z}$ is generated through the hadronic recoil of ISR, p_{T}^{R}.
- p_{T}^{Z} reconstructed directly from $p_{\mathrm{T}}(\mu_1) + p_{\mathrm{T}}(\mu_2)$, while p_{T}^{W} reconstructs p_{T}^{R}.
- Detector and FSR effects removed with a bin-by-bin unfolding.
- 3-4% precision per bin.

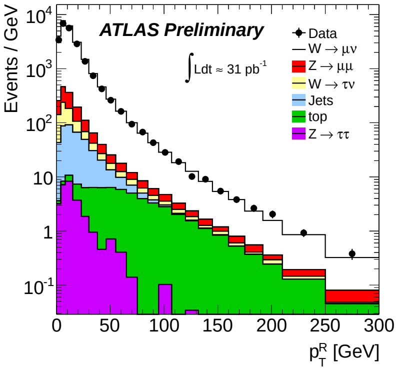


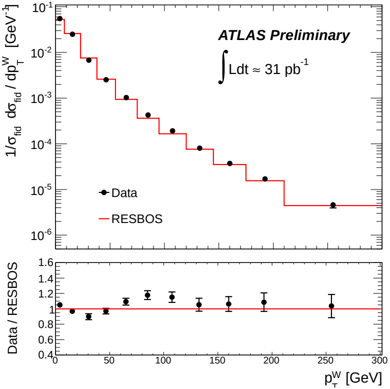


[7] arXiv:1107.2381v1

W boson p_T measurement

- Necessary for a future precision W mass measurement.
- Detector and FSR effects removed by inverting a response matrix parametrizing the probabilistic mapping of p_T^R to p_T^W.

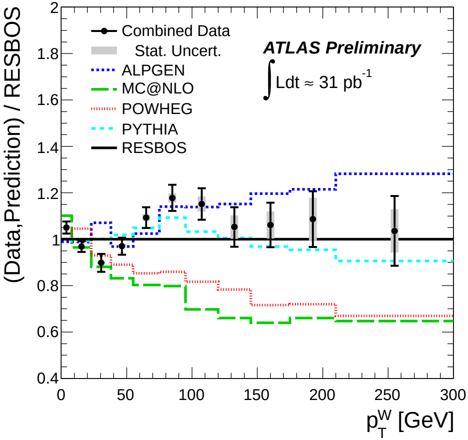




[8] STDM-2011-15

W, Z boson p_T reweighting

- The modeling of $d\sigma/dp_T^{W/Z}$ can have significant effects on the expected efficiency and acceptance.
- NLO generators MC@NLO and POWHEG have deficits at high $p_T^{W/Z}$.
- NLO effects are important at high $p_T^{W/Z}$ because the W/Z is polarized by higher order QCD.

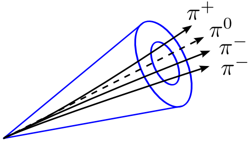


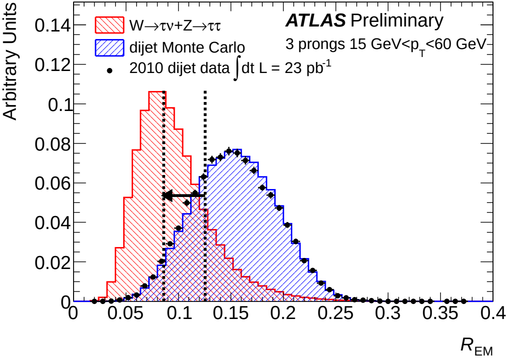
- $W \to \ell\nu$ and $Z \to \ell\ell$ cross section measurements use MC@NLO reweighted to match $p_T^{W/Z}$ for LO Pythia, which agrees with the data because it has been tuned well to the Tevatron data.

$Z \to \tau\tau$ and $W \to \tau\nu$

Taus in ATLAS

- Tracks are matched to jet seeds and discriminating variables are calculated from the combined tracking and calorimeter information.
- 1 or 3-prong signature
- Narrow clustering of tracks and calorimeter deposits.
- Three advanced discriminants: p_{T}-parametrized cuts, projective likelihoods, boosted decision trees.

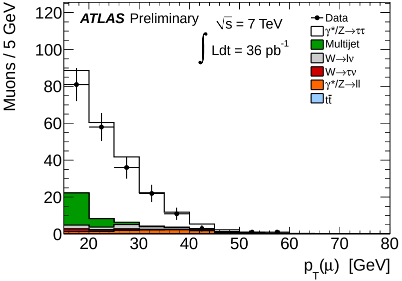


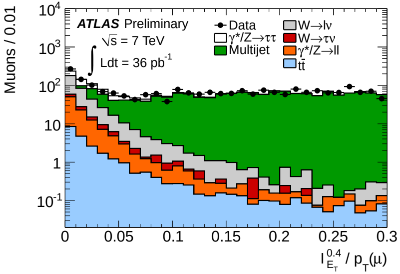


[9] ATLAS-CONF-2011-077

$Z \to \tau\tau \to \ell\tau_\mathrm{h}$ event selection

- single lepton trigger
- One tight e/μ with $p_\mathrm{T} > 16/15$ GeV
- One tight τ_h with $p_\mathrm{T} > 20$ GeV, 1 or 3 tracks, unit charge
- tight lepton isolation to reject QCD multijets
- opposite sign
- $\sum \cos\Delta\phi > -0.15$





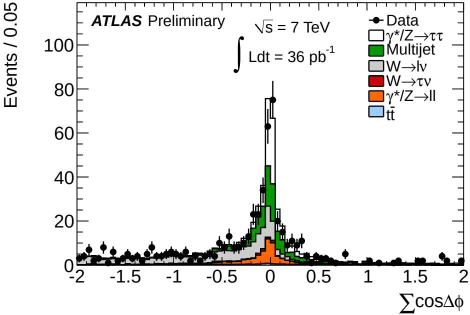
- Choose low p_T leptons to accept $Z \to \tau\tau$.
- Combat QCD with tight isolation.

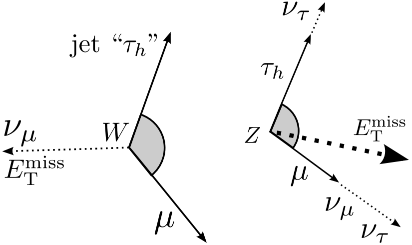
[10] STDM-2011-18

$Z \to \tau\tau$: W + jet suppression

$$\sum \cos \Delta\phi = \cos[\phi(\ell) - \phi(E_{\mathrm{T}}^{\mathrm{miss}})] + \cos[\phi(\tau_{\mathrm{h}}) - \phi(E_{\mathrm{T}}^{\mathrm{miss}})]$$

- Quantifies if the $E_{\mathrm{T}}^{\mathrm{miss}}$ is between the decay products
- Only dependent on the direction, not the magnitude of the $E_{\mathrm{T}}^{\mathrm{miss}}$.
- All channels except $\mu\mu$ require $\sum \cos \Delta\phi > -0.15$

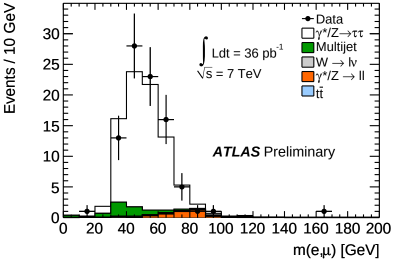




$Z \to \tau\tau \to \ell\ell$ event selection

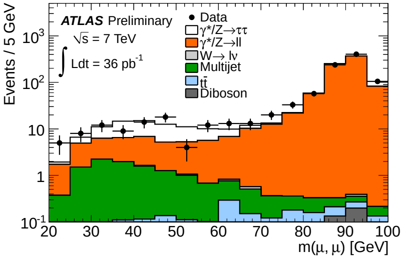
$e\mu$-channel

- one e with $p_{\mathrm{T}} > 15$ GeV
- one μ with $p_{\mathrm{T}} > 10$ GeV
- opposite sign, tight isolation
- $\sum \cos \Delta\phi > -0.15$
- $\sum E_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}} < 150$ GeV (rejects $t\bar{t}$)



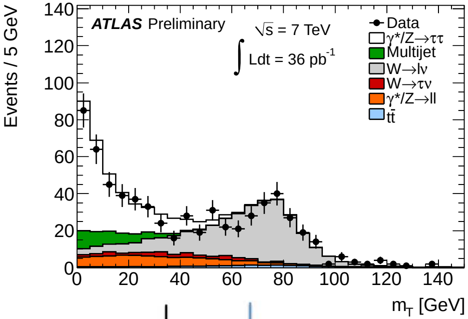
$\mu\mu$-channel

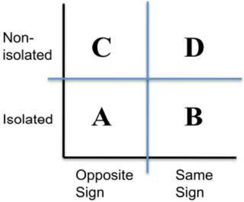
- two μ with $p_{\mathrm{T}} > 20$ GeV
- opposite sign, tight isolation
- BDT for rejecting $Z/\gamma* \to \ell\ell$
- $m_{\mu\mu} = 25$–65 GeV



$Z \to \tau\tau$ background estimation

- Jets are wider in data than in Monte Carlo ⇒ τ_{h} ID fake rate is underestimated in Monte Carlo.
- Normalize $W \to \ell\nu + \mathrm{jets}$ Monte Carlo using high m_{T} data.
- Other EW backgrounds estimated from Monte Carlo.
- QCD estimate is data-driven, scailing SS data by $R_{\mathrm{OS/SS}}$, measured in non-isolated (multijet rich) data sample, correcting for EW contamination with Monte Carlo.

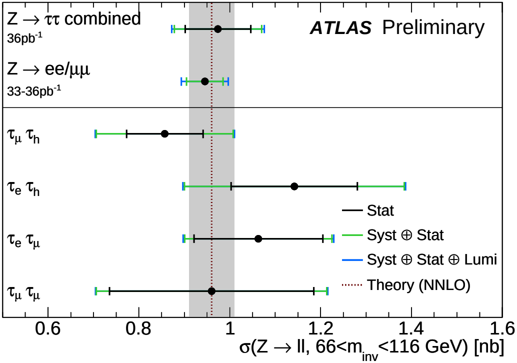




$$N^{\mathrm{A}} = N^{\mathrm{B}} \cdot \frac{N^{\mathrm{C}}}{N^{\mathrm{D}}} = N^{\mathrm{B}} \cdot R_{\mathrm{OS/SS}}$$

$$\sigma_{\text{combined}} = 0.97 \pm 0.07(\text{stat.}) \pm 0.07(\text{sys.}) \pm 0.03(\text{lumi.})\ \text{nb}$$

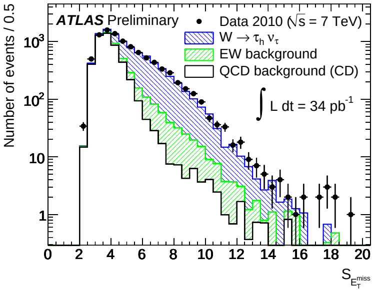
$$\sigma_{\text{theory}} = 0.96 \pm 0.05\ \text{nb at NNLO}$$

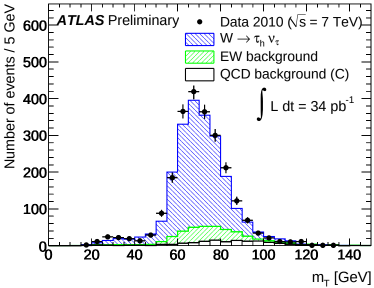


Dominant systematics

- τ_{h} energy scale 11%
- τ_{h} efficiency 8.6%
- μ efficiency 8.6%
- e efficiency 3-10%
- acceptance 3%
- luminosity 3.4%

$W \to \tau\nu$ event selection





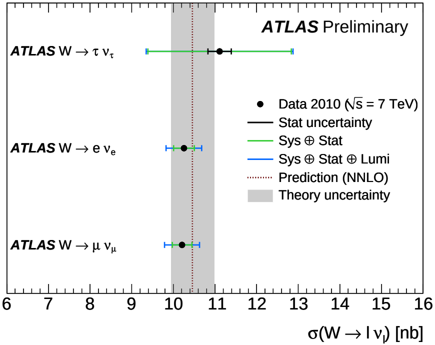
- $p_{\mathrm{T}}(\tau_{\mathrm{h}}) = 20 - 60$ GeV
- $E_{\mathrm{T}}^{\mathrm{miss}} > 30$ GeV
- $S_{E_{\mathrm{T}}^{\mathrm{miss}}} = \frac{E_{\mathrm{T}}^{\mathrm{miss}}}{(0.5\sqrt{\mathrm{GeV}})\sqrt{\sum E_{\mathrm{T}}}} > 6.0$
- veto events with leptons with $p_{\mathrm{T}} > 15$ GeV
- data-driven QCD estimate: scale events failing $S_{E_{\mathrm{T}}^{\mathrm{miss}}}$ by efficiency measured in inverted tau ID sample.

[11] STDM-2011-23

$W \to \tau\nu$ cross section results

$$\sigma(W \to \tau\nu) = 11.1 \pm 0.3(\text{stat.}) \pm 1.7(\text{sys.}) \pm 0.4(\text{lumi.})\ \text{nb}$$

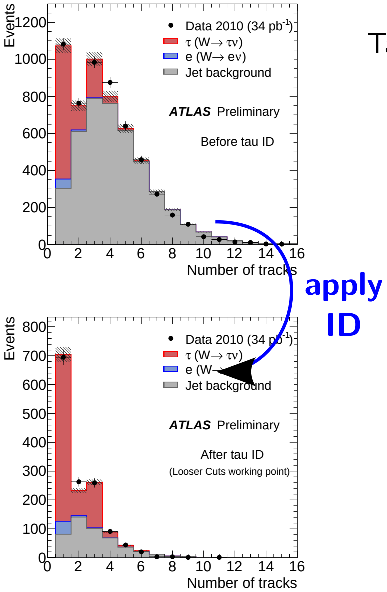
$$\sigma_{\text{theory}} = 10.46 \pm 0.52\ \text{nb at NNLO}$$



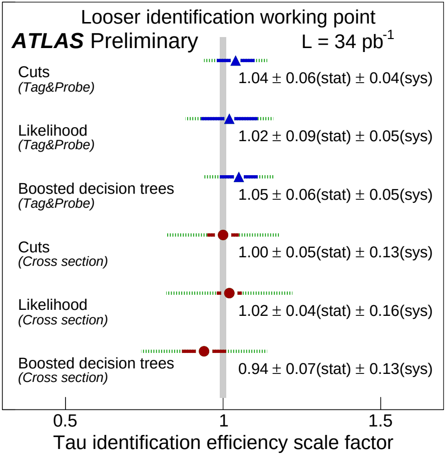
Dominant systematics

- τ_{h} efficiency 10.3%
- τ_{h} energy scale 8.0%
- τ_{h} + MET trigger efficiency 7.0%
- luminosity 3.4%
- acceptance 2.3%

$W \rightarrow \tau_h \nu$ tau ID measurement

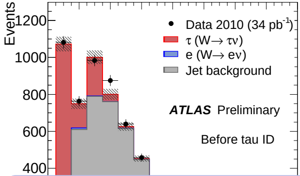


Tag jet + MET events, probe for tau.

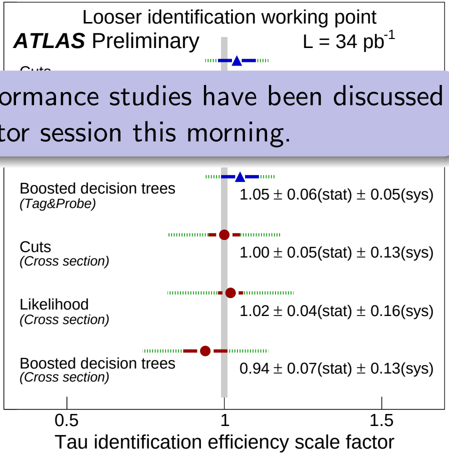


[12] ATLAS-CONF-2011-093

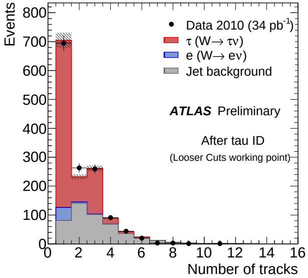
$W \rightarrow \tau_h \nu$ tau ID measurement



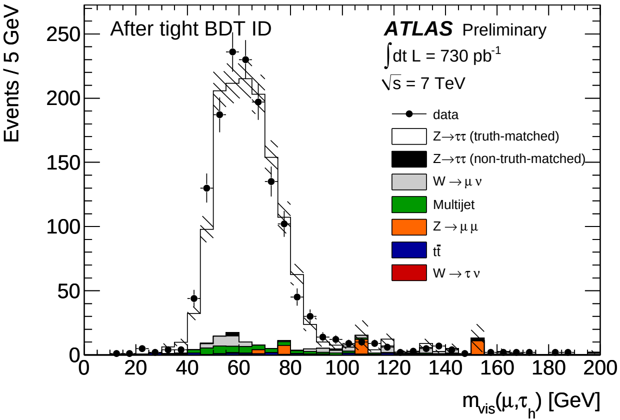
Tag jet + MET events, probe for tau.



Many more details on tau performance studies have been discussed in Stan Lai's talk in the Detector session this morning.



$Z \to \tau\tau \to \ell\tau_{\rm h}$ with 730 pb^{-1}



- We now have a substantial control sample of hadronic tau decays.
- More data-driven efforts in taus to come.

[13] ATL-COM-PHYS-2011-842

Conclusions

- ATLAS has published (or will soon publish this month) W and Z cross section measurements with the 2010 dataset for all lepton flavors:
  - $W \to e\nu$
  - $W \to \mu\nu$
  - $W \to \tau\nu$
  - $Z \to ee$
  - $Z \to \mu\mu$
  - $Z \to \tau\tau$
- We have also published precision measurements of the p_{T}^{W} and p_{T}^{Z} line-shapes.
- W and Z performance studies have improved our knowledge of our object identification for e, μ, and τ.
- The 2010 ATLAS Standard Model analyses have set an impressive standard for measurements with the 2011 data.

Backup Slides

References I

[1] Photo credit:
http://www.flickr.com/photos/naotakem/3239696763/sizes/l/in/photostream/

[2] ATLAS public event displays.
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayPublicResults

[3] The ATLAS Data Summary.
https://atlas.web.cern.ch/Atlas/GROUPS/DATAPREPARATION/DataSummary/2011/

[4] The ATLAS Collaboration. *Electron performance measurements with the ATLAS detector using the 2010 LHC proton-proton collision data.*
ATLAS-PERF-2010-04-001 (publiication draft pending internal review). July 2011.
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/EGAMMA/egamma-2010/

[5] The ATLAS Collaboration. *Measurement of the* $W \rightarrow \ell\nu$ *and* $Z/\gamma* \rightarrow \ell\ell$ *production cross sections in pp collisions at* $\sqrt{s} = 7$ *TeV with the ATLAS detector.* arXiv:1010.2130v1 [hep-ex]. Oct 2010.

[6] The ATLAS Collaboration. *Measurement of the* $W \rightarrow \ell\nu$ *and* $Z/\gamma* \rightarrow \ell\ell$ *production cross sections in pp collisions at* $\sqrt{s} = 7$ *TeV with the ATLAS detector.* STDM-2011-06 (publiication draft pending internal review). July 2011.

References II

[7] The ATLAS Collaboration. *Measurement of the transverse momentum distribution of $Z/\gamma*$ bosons in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector.* arXiv:1107.2381v1 [hep-ex]. July 2011.

[8] The ATLAS Collaboration. *Measurement of the transverse momentum distribution of W bosons in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector.* STDM-2011-15 (publiication draft pending internal review). July 2011.

[9] The ATLAS Collaboration. *Reconstruction, Energy Calibration, and Identification of Hadronically Decaying Tau Leptons.* ATLAS-CONF-2011-077. May 2011.

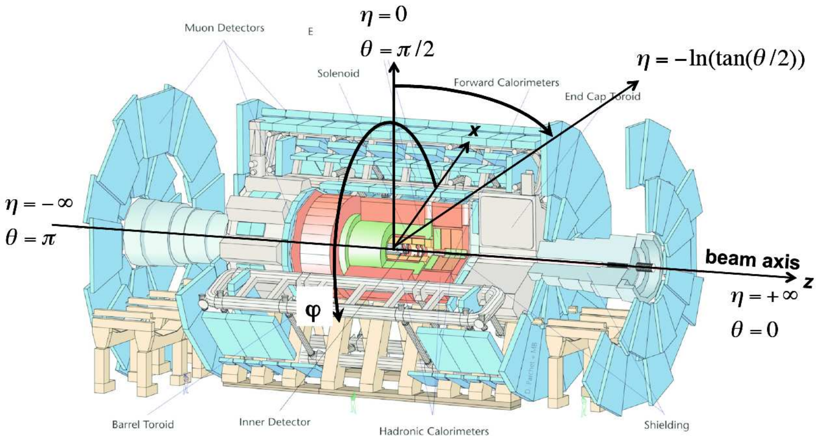
[10] The ATLAS Collaboration. *Measurement of $Z \to \tau\tau$ production cross section in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector.* STDM-2011-18 (publiication draft pending internal review). July 2011.

[11] The ATLAS Collaboration. *Measurement of the $W \to \tau\nu$ production cross section in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS Experiment.* STDM-2011-23 (publiication draft pending internal review). July 2011.

[12] The ATLAS Collaboration. *Measurement of hadronic tau decay identification efficiency using $W \to \tau\nu$ events.* ATLAS-CONF-2011-093. July 2011.

[13] The ATLAS Collaboration. *Approved preliminary plots of m_{vis} for $Z \to \tau\tau \to \ell\tau_{\mathrm{h}}$ events with 730 pb^{-1}*. ATL-COM-PHYS-2011-842 July 2011.

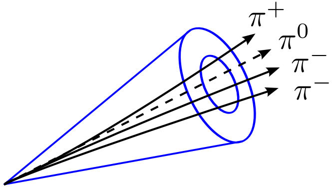
Collider kinematics



$\vec{p}_T = (p_x, p_y)$ $\quad$ $p_T = p\sin\theta, \quad E_T = E\sin\theta$ $\quad$ $\vec{E}_T^{miss} = -\sum_{\text{clusters}\, i} E_i \hat{n}_i$

Phenomenology of tau decays

$\tau^- \to$	$e^- \, \bar{\nu}_e \, \nu_\tau$	17.8%	leptonic 35.2%
	$\mu^- \, \bar{\nu}_\mu \, \nu_\tau$	17.4%	
	$\pi^- \, \pi^0 \, \nu_\tau$	25.5%	1 prong 49.5%
	$\pi^- \, \nu_\tau$	10.9%	
	$\pi^- \, 2\pi^0 \, \nu_\tau$	9.3%	
	$K^- \, (N\pi^0) \, (NK^0) \, \nu_\tau$	1.5%	
	$\pi^- \, 3\pi^0 \, \nu_\tau$	1.0%	
	$\pi^- \, \pi^- \, \pi^+ \, \nu_\tau$	9.0%	3 prong 15.2%
	$\pi^- \, \pi^- \, \pi^+ \, \pi^0 \, \nu_\tau$	4.6%	



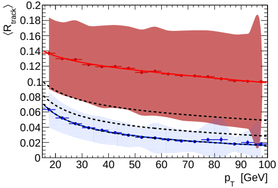
Tau identification variables

- Electrmagnetic radius: $R_{\mathrm{EM}} = \frac{\sum_{i \in \{\mathrm{EM}\ 0-2\}}^{\Delta R_i < 0.4} E_{\mathrm{T},i}^{\mathrm{EM}} \Delta R_i}{\sum_{i \in \{\mathrm{EM}\ 0-2\}}^{\Delta R_i < 0.4} E_{\mathrm{T},i}^{\mathrm{EM}}}$
- Track radius: $R_{\mathrm{track}} = \frac{\sum_{i}^{\Delta R_i < 0.4} p_{\mathrm{T},i} \Delta R_i}{\sum_{i}^{\Delta R_i < 0.4} p_{\mathrm{T},i}}$
- Leading track momentum fraction: $f_{\mathrm{track}} = \frac{p_{\mathrm{T},1}^{\mathrm{track}}}{p_{\mathrm{T}}^{\tau}}$
- Core energy fraction: $f_{\mathrm{core}} = \frac{\sum_{i \in \{\mathrm{all}\}}^{\Delta R_i < 0.1} E_{\mathrm{T},i}^{\mathrm{EM}}}{\sum_{i \in \{\mathrm{all}\}}^{\Delta R_i < 0.4} E_{\mathrm{T},i}^{\mathrm{EM}}}$
- Electromagnetic fraction: $f_{\mathrm{EM}} = \frac{\sum_{i \in \{\mathrm{EM}\ 0-2\}}^{\Delta R_i < 0.4} E_{\mathrm{T},i}^{\mathrm{EM}}}{\sum_{j \in \{\mathrm{all}\}}^{\Delta R_j < 0.4} E_{\mathrm{T},j}^{\mathrm{EM}}}$
- Cluster mass: m_{clusters}, invariant mass clusters at the EM energy scale.
- Track mass: m_{tracks}, invariant mass of the track system.
- Transverse flight path significance: $S_{\mathrm{T}}^{\mathrm{flight}}$

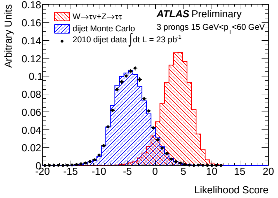
Motivation: taus tend to be collimated more than jets, have a leading track, and often significant neutral pion deposits in the EM calorimeter.

Tau discriminants

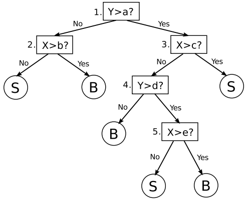
- **Cuts**
  p_{T}-parametrized cuts on R_{EM} and R_{track}, and a cut on f_{track}.

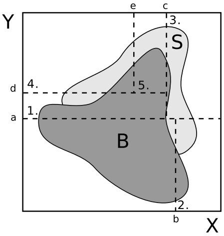


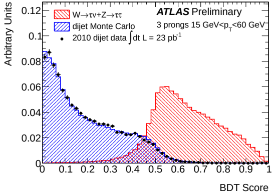
- **Projective likelihood**
  $$d = \ln\left(\frac{L_S}{L_B}\right) = \sum_{i=1}^{N} \ln\left(\frac{p_i^S(x_i)}{p_i^B(x_i)}\right)$$



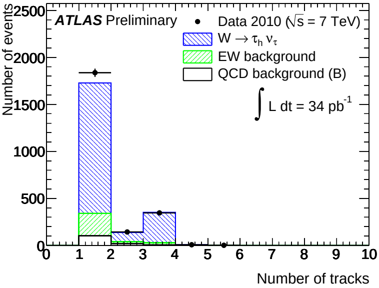
- **Boosted decision trees (BDT)**

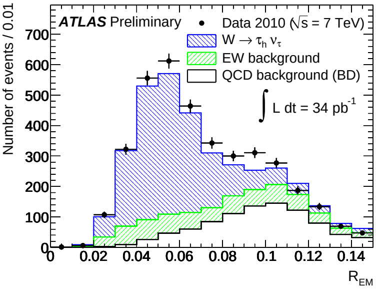




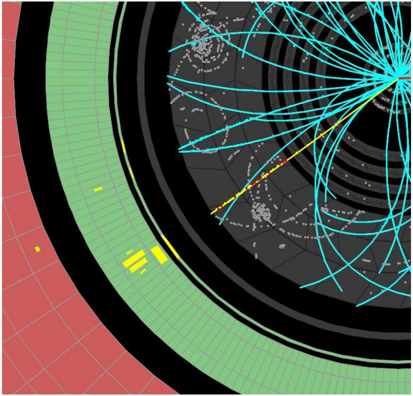


Seeing hadronic taus



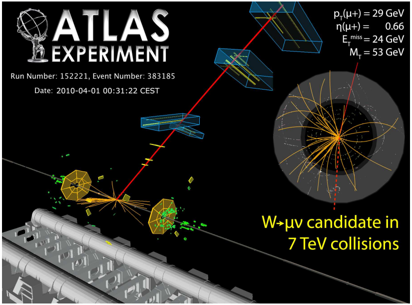


Electrons in ATLAS



- Seeded by matching calorimeter clusters from a sliding-window algorithm to inner detector tracks.
- Candidates are selected by:
    - track quality
    - track-cluster matching
    - narrow calorimeter cluster
    - high electromagnetic fraction
- Tight candidates have cuts on E/p and high thesholds hits from the transistion radiation in the TRT.

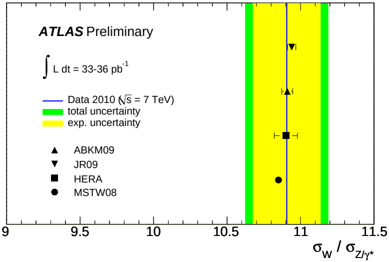
Muons in ATLAS



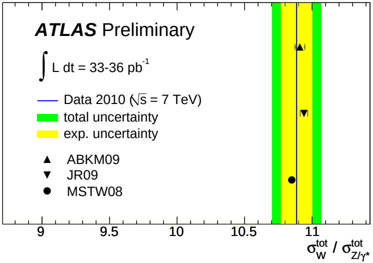
- Combination of muon spectrometer segments with inner detector tracks.
- Track combination matching to reject decays in flight.
- Impact parameter constraints to reject cosmic muons.

$W \to \ell\nu$ and $Z \to \ell\ell$ systematics reduction

Moriond result March 2011

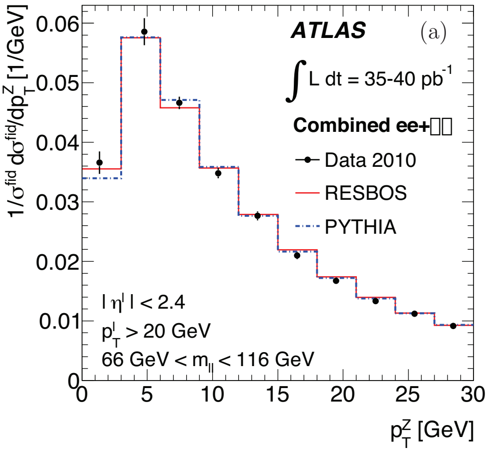


July 2011 update



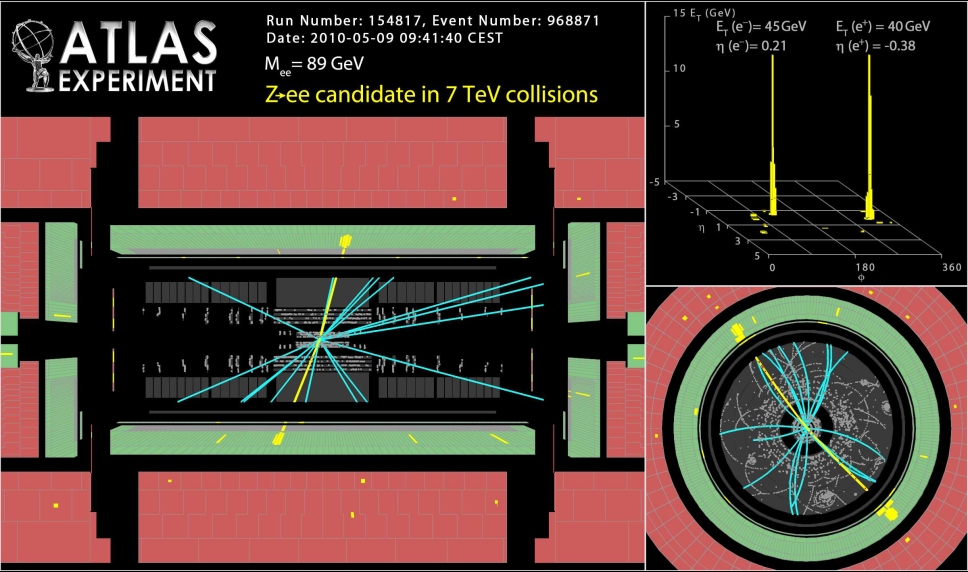
Z boson p_T measurement

- Important for modeling high-p_T lepton kinematics.
- At leading order, $p_\mathrm{T}^{W/Z} = 0$
- Non-zero $p_\mathrm{T}^{W/Z}$ is generated through the hadronic recoil of ISR, p_T^{R}.
- Detector and FSR effects removed with a bin-by-bin unfolding.

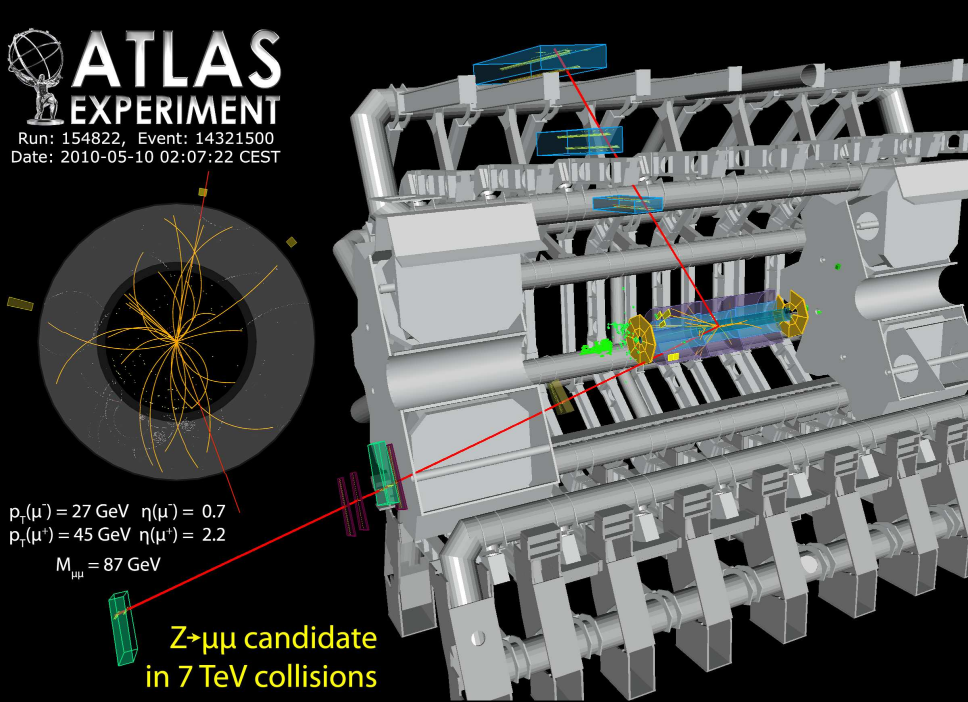


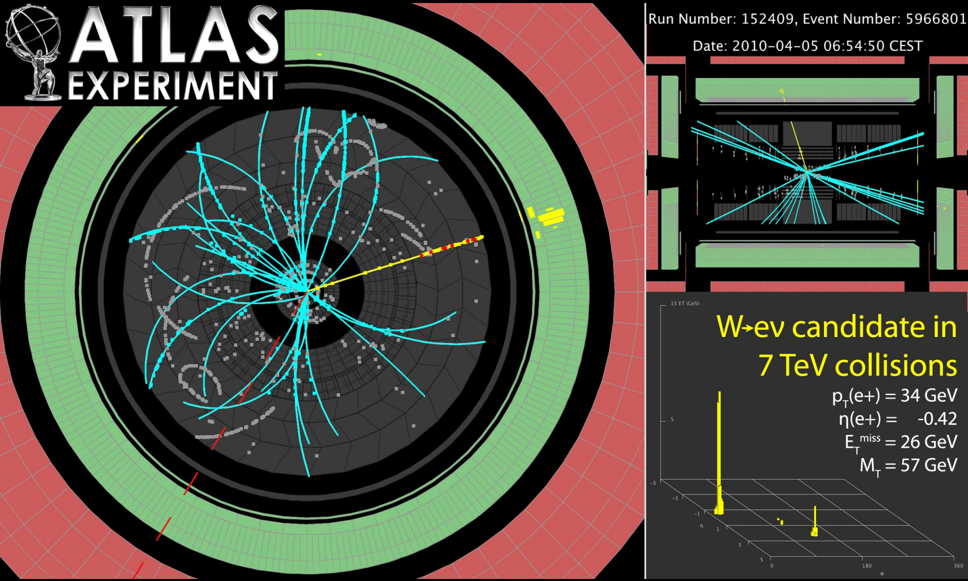
$$\frac{\Delta\sigma_Z^i}{\Delta {p_\mathrm{T}}^i} = \frac{1}{\Delta p_\mathrm{T}} \cdot \frac{N_\mathrm{obs}^i - N_\mathrm{bkg}^i}{A^i \cdot C^i \cdot \int dt\mathcal{L}},$$

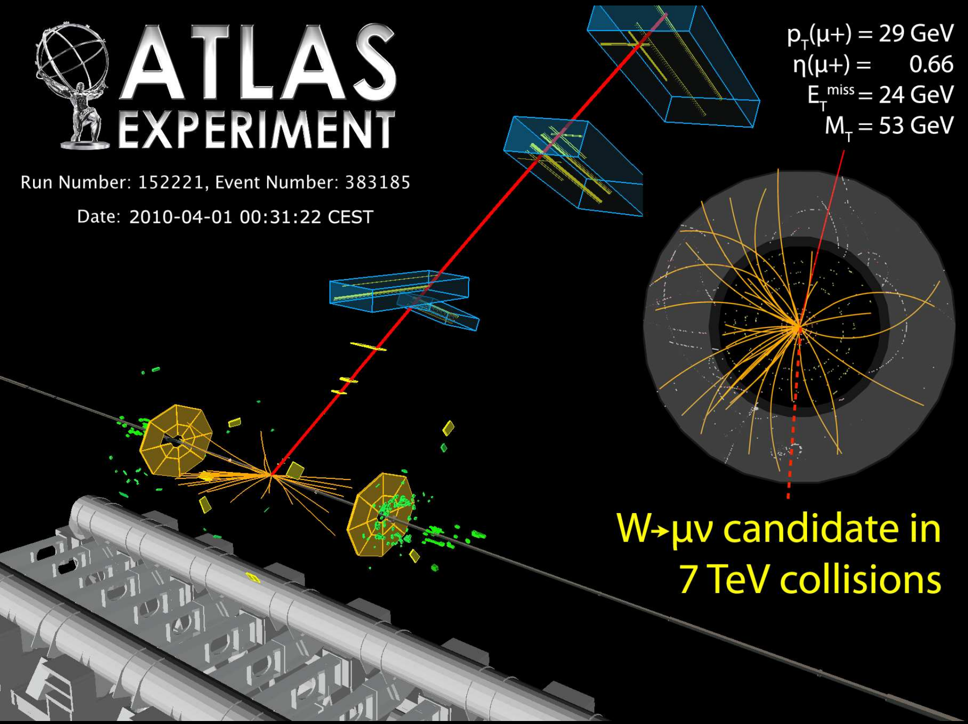
$$C^i = C_\mathrm{MC}^i \cdot \frac{\varepsilon_\mathrm{data}^{\mathrm{ID},i}}{\varepsilon_\mathrm{MC}^{\mathrm{ID},i}} \cdot \frac{\varepsilon_\mathrm{data}^{\mathrm{trig},i}}{\varepsilon_\mathrm{MC}^{\mathrm{trig},i}}$$



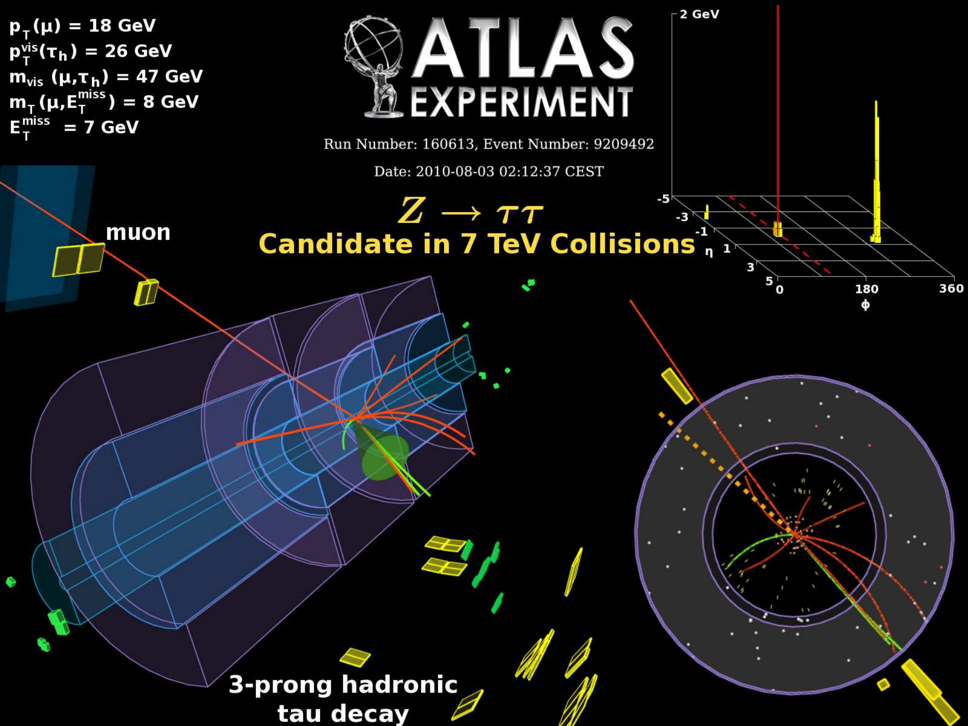
ATLAS EXPERIMENT
Run Number: 154817, Event Number: 968871
Date: 2010-05-09 09:41:40 CEST
M_{ee} = 89 GeV
Z→ee candidate in 7 TeV collisions
15 E_T (GeV)
E_T (e^-)= 45GeV
η (e^-)= 0.21
E_T (e^+) = 40GeV
η (e^+) = -0.38
10
5
-5
-3
-1
η
1
3
5
0
180
360
ϕ


ATLAS EXPERIMENT
Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST
$p_T(\mu^-) = 27$ GeV $\eta(\mu^-) = 0.7$
$p_T(\mu^+) = 45$ GeV $\eta(\mu^+) = 2.2$
$M_{\mu\mu} = 87$ GeV
Z→μμ candidate
in 7 TeV collisions


ATLAS
EXPERIMENT
Run Number: 152409, Event Number: 5966801
Date: 2010-04-05 06:54:50 CEST
W→eν candidate in
7 TeV collisions
$p_T(e+) = 34$ GeV
$\eta(e+) = -0.42$
$E_T^{miss} = 26$ GeV
$M_T = 57$ GeV



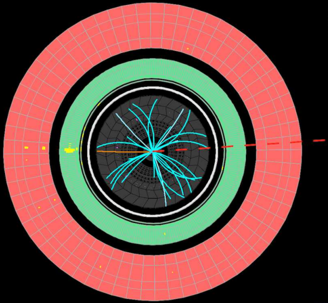
ATLAS EXPERIMENT
Run Number: 152221, Event Number: 383185
Date: 2010-04-01 00:31:22 CEST
$p_T(\mu+)$ = 29 GeV
$\eta(\mu+)$ = 0.66
E_T^{miss} = 24 GeV
M_T = 53 GeV
W→μν candidate in
7 TeV collisions


$p_T(\mu)$ = 18 GeV
$p_T^{vis}(\tau_h)$ = 26 GeV
m_{vis} (μ,τ_h) = 47 GeV
$m_T(\mu,E_T^{miss})$ = 8 GeV
E_T^{miss} = 7 GeV
ATLAS EXPERIMENT
Run Number: 160613, Event Number: 9209492
Date: 2010-08-03 02:12:37 CEST
$Z \rightarrow \tau\tau$
Candidate in 7 TeV Collisions
2 GeV
-5
-3
-1
1
3
5
η
0
180
360
φ
muon
3-prong hadronic tau decay

ATLAS EXPERIMENT

Run 155697, Event 6769403

Time 2010-05-24, 17:38 CEST



$W \to \tau\nu$ candidate in 7 TeV collisions

$p_T(\tau)$ = 29 GeV

E_T^{miss} = 39 GeV

$\Delta\phi(\tau, E_T^{miss})$ = 3.1

m_T = 68 GeV