ATLAS ELECTROWEAK RESULTS

II CPAN DAYS
VALENCIA 29 Nov – 1 Dec 2010

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Outline

- Motivation: Electroweak W, Z
- ATLAS
- Physics objects involved
- W cross-section measurement
- Z cross-section measurement
- W/Z + jets studies
- Electroweak studies at IFIC-Wisconsin group
- Conclusions

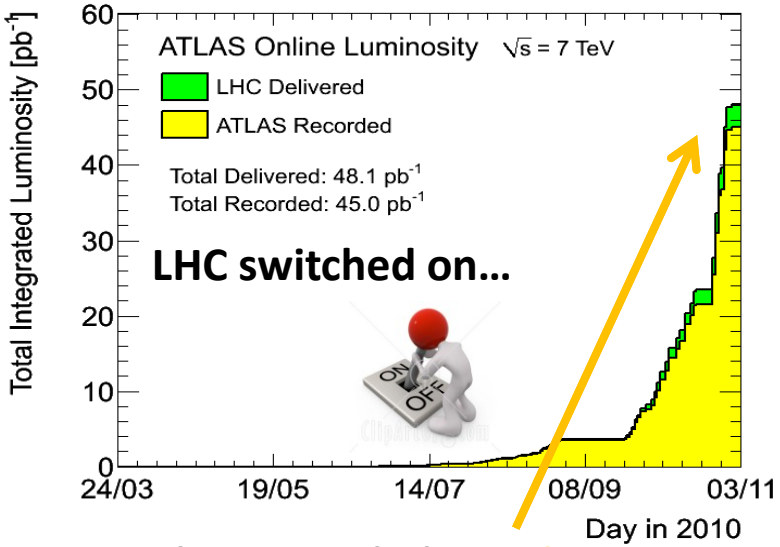
Motivation: Electroweak W, Z

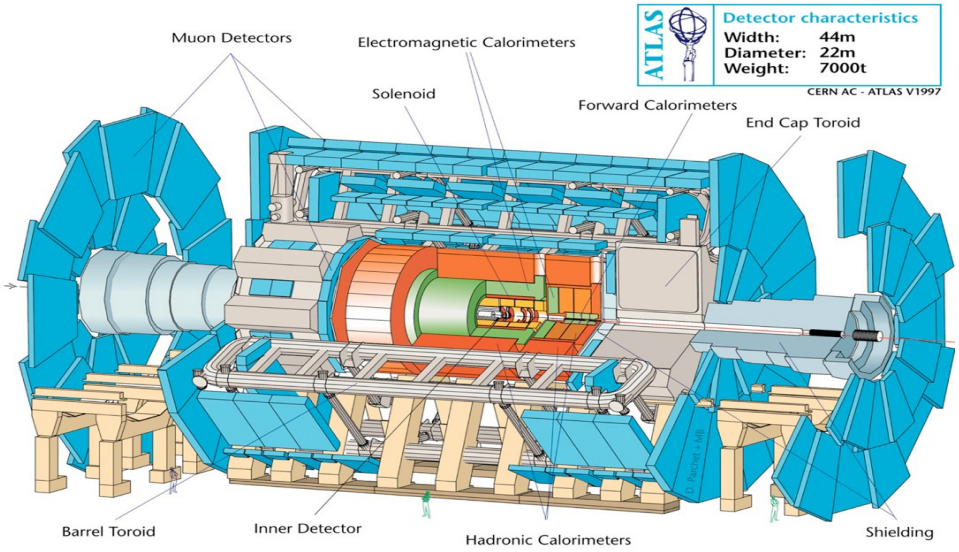
Two-fold interest:

- Comissioning of detector and perfomance of reconstruction (leptons, jets, Missing transverse energy…)

- Physics relevance per se:
  - test of QCD with higher order correction (W/Z production cross-section)
  - parton density functions in a new energy regime (W+/W- charge asymmetry)
  - background for most of high p_T analysis (including searches for New Physics)
  - first step to SM Higgs searches: H→WW (IFIC-Wisconsin group)

ATLAS





ATLAS has recorded: 45 pb-1

- For analysis data have to fulfill data-quality requirements: sub-detectors used for specific channels must be in nominal conditions.

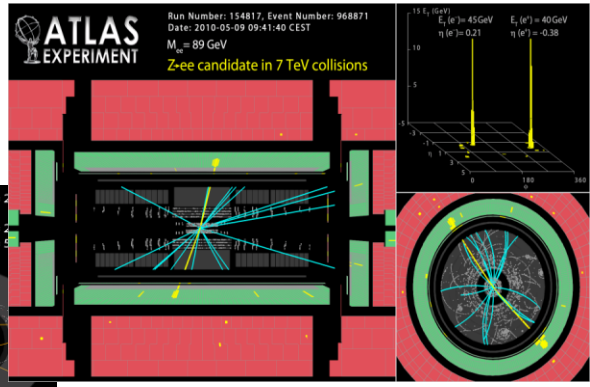
- Results presentd here are for different integrated luminosities (showing full results and on-going studies)

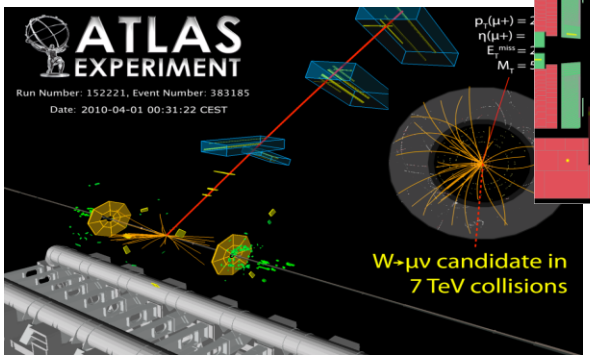
Monte Carlo

W/Z pythia signal samples generated with MRST LO* PDF.

Cross checks and acceptance calculations performed with MC@NLO.

All parts equally important for EW physics!





Objects for W/Z analysis

- Electron and Muon selection
- Missing transverse energy
- Leptons from QCD

Electron and muon selection

Electrons

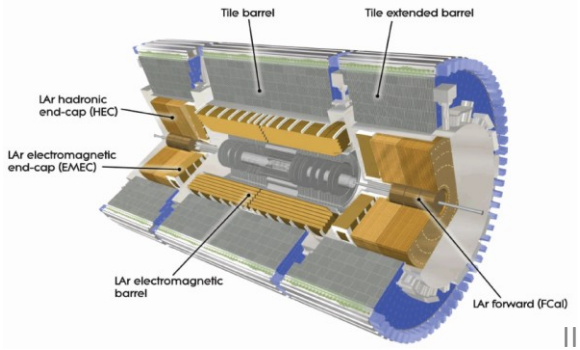
○ Trigger: Level 1 (hardware) requies coarse-granularity cluster with |η| < 2.5 and ET > 5GeV.

○ Offline: EM calorimeter cluster matched to Inner Detector (ID) track.

❑ **"Loose" selection**
- EM cluster + ID track

❑ **"Medium" selection**
- tighter requirements on EM cluster and cluster track match

❑ **"Tight" selection**
- stricter track quality, gamma conversion veto.
- 10^5 rejection against jets with p_T > 20 GeV for 72% reconstruction efficiency.



Muons

○ Trigger: Level 1 (hardware) requires 3-D coincidence in RPC or THC and pT > 6 GeV.

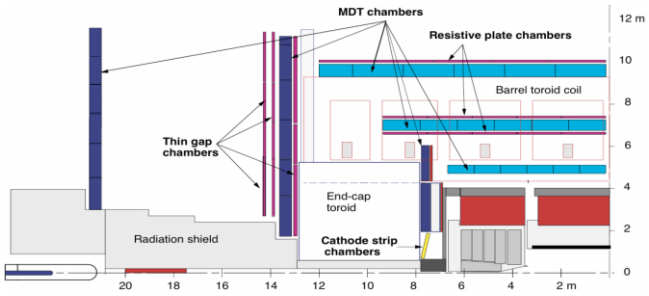
○ Offline: Combined muon in |η| < 2.4

❑ Combined tracks from Muon spectrometer and ID, using statistical combination (χ^2 test) of the two tracks.

❑ Track Isolation: sum of the transverse momenta of tracks with p_T > 1 GeV in the inner detector within a cone of ΔR < 0.4 around the muon track, divided by the total combined muon p_T .

Track Isolation: $$\sum \frac{p_T^{ID}}{P_T} < 0.2$$

○ > 94% reconstruction efficiency at p_T >20GeV.



MET and Leptons from QCD

Missing transverse energy (MET)

To achieve good MET reconstruction is crucial.

- Missing transverse energy from calibrated 3-D topological clusters (hadron/e±/γ, dead material energy loss).
- Quality requirements on jets to suppress fake MET.

$$E_{x,y}^{miss}\Big|_{e} = -\sum_{i} E_{x,y}^{i}$$

e channel: summing over all cluster cell energy components

$$E_{x,y}^{miss}\Big|_{\mu} = -\sum_{i} E_{x,y}^{i} - \sum_{k}^{isolated} p_{x,y}^{k} - \sum_{j}^{non-isolated} p_{x,y}^{j}$$

μ channel: Muon term added from its p_T.

Leptons from QCD

- Decays in Jets originated in QCD processes create “fake ” leptons to EW processes (leptons from W/Z)
  - these processes have x-sec up to 10^5 more than signal
- LHC use a lepton sample looser than the one to select signal
  - enriched in QCD fakes
  - can measure rate of QCD fakes in control region and extrapolate to signal region.
  - **IFIC-Wisconsin group contributions:**
    - **W+jets conf note:** http://cdsweb.cern.ch/record/1283753/files/conflIwj.pdf
    - **WW: note ongoing.**

W cross – section measurement with 330nb-1

Some distributions studied with higer statistics (35pb-1)

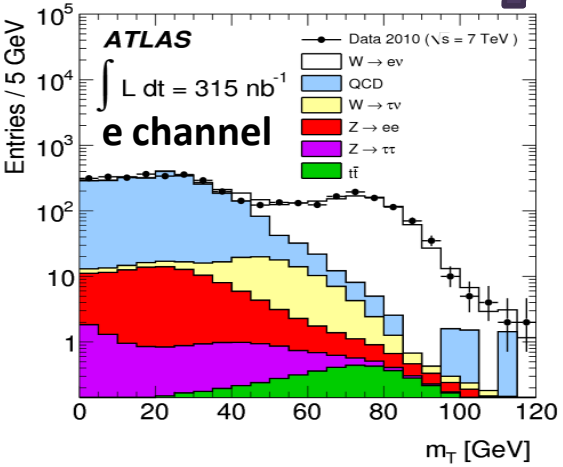
W signal selection

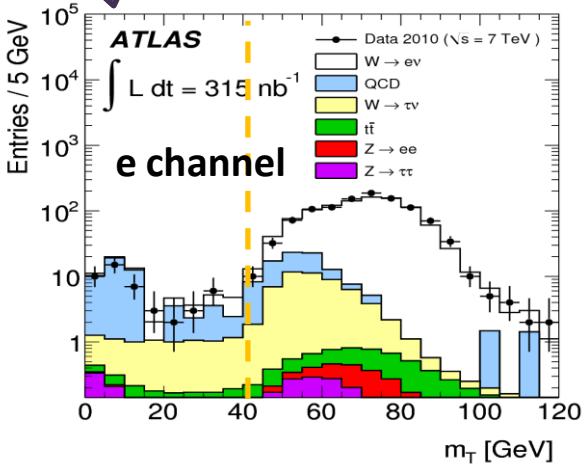
A) 1 tight electron, E_T > 20 GeV
B) MET > 25 GeV
C) Mt(W) > 40 GeV

$$m_T = \sqrt{2 p_T^l E_T^{miss} (1 - \cos \Delta\phi_{l, E_T^{miss}})}$$

Requirement e channel	Candidates with 35 pb-1
A	466.380
B	126.626
C	**118.898**

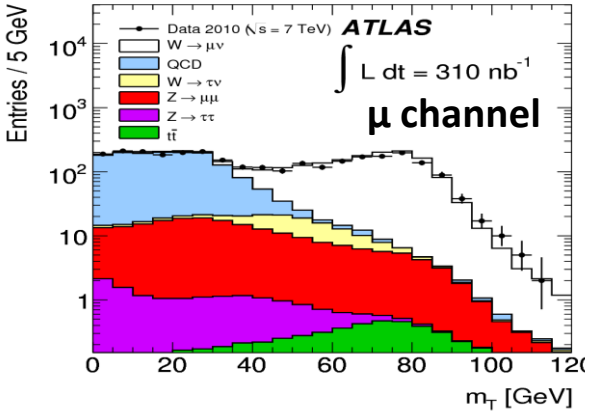
MET CUT

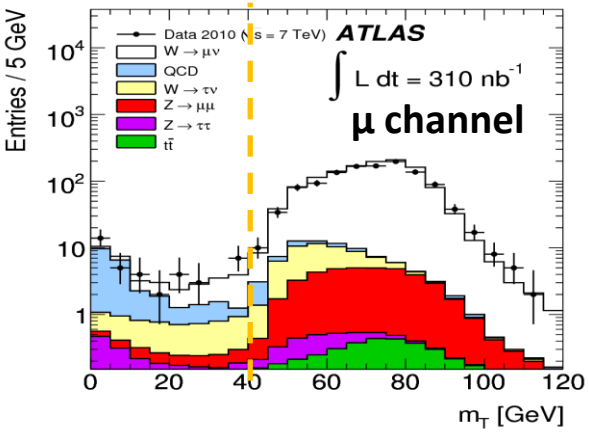




A) 1 combined muon, P_T > 20GeV
B) Track isolated in ID
C) MET > 25 GeV
D) Mt(W) > 40GeV

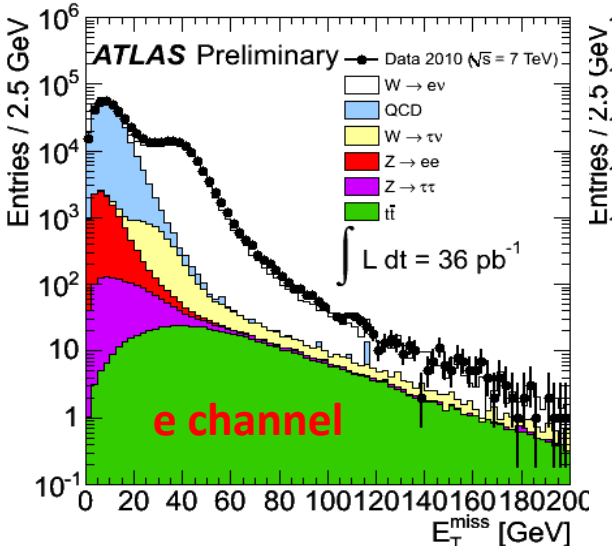
Requirement μ channel	Candidates with 35 pb-1
A	812.166
B	342.437
C	147.930
D	**142.081**

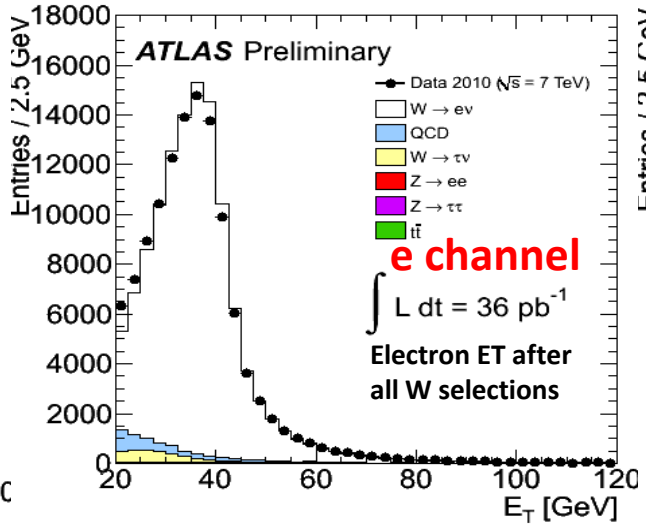




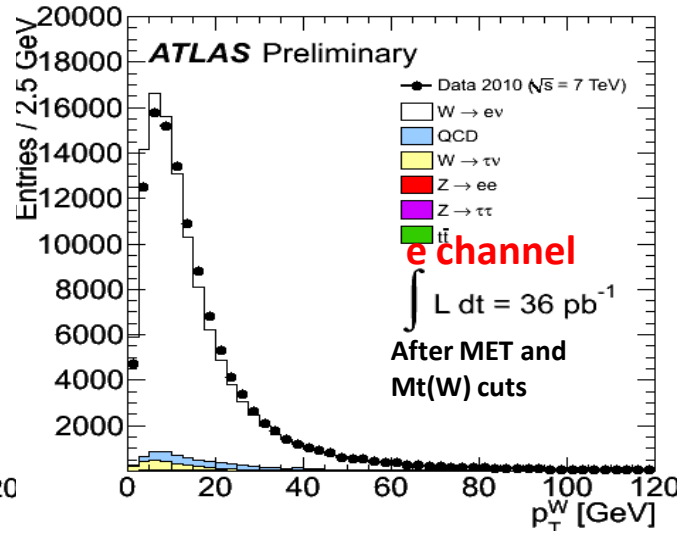
W signal selection

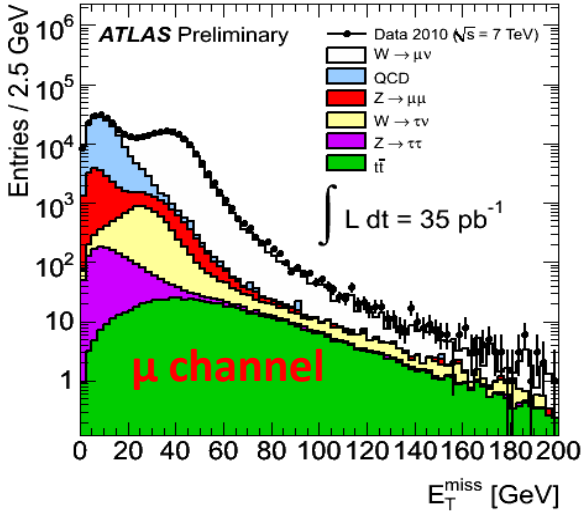
Selected lepton

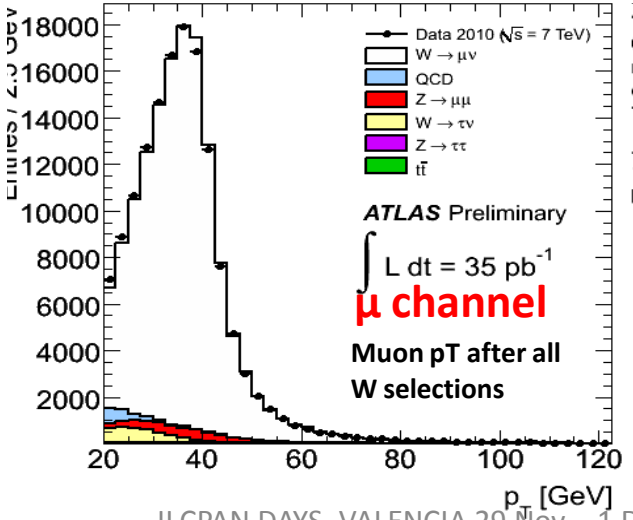


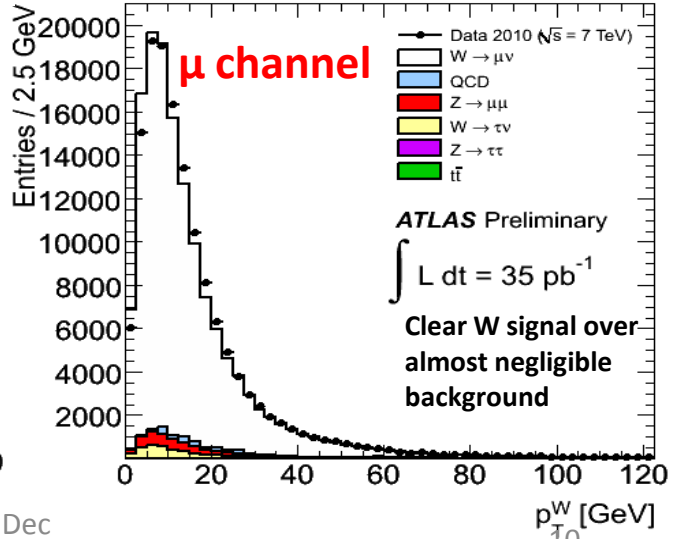


W Signal kinematics





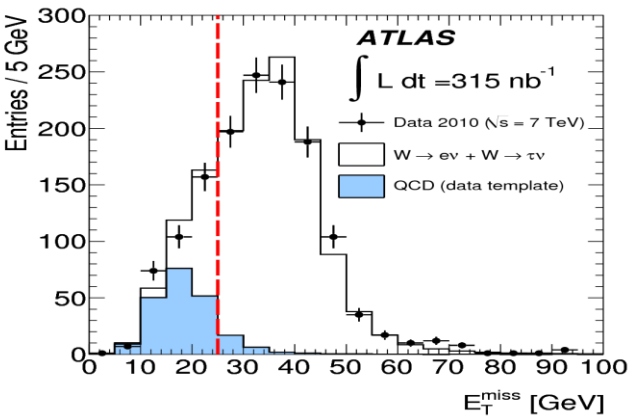




W background estimation

Electrons bkg: W→τν, Z →ee, Z →ττ and ttbar from MC

- **QCD background** was estimated using missing energy distribution.
- Systematic uncertanintly: shape of the background template was varied by applying different event selection criteria.



Muons bkg: W→τν, Z →μμ, Z →ττ and ttbar from MC

- QCD background estimated from comparison of events seen in data after the full W selection, to number of events observed if the isolation cut is not applied.

From MC **From DATA** $L = 315nb^{-1}$

ℓ	Observed candidates	Background (EW+$t\bar{t}$)	Background (QCD)	Background-subtracted signal N_W^{sig}
e^+	637	$18.8 \pm 0.2 \pm 1.7$	$14.0 \pm 2.1 \pm 7.1$	$604.2 \pm 25.2 \pm 7.6$
e^-	432	$14.7 \pm 0.2 \pm 1.3$	$14.0 \pm 2.1 \pm 7.1$	$403.2 \pm 20.8 \pm 7.5$
$e^\pm$	1069	$33.5 \pm 0.2 \pm 3.0$	$28.0 \pm 3.0 \pm 10.0$	$1007.5 \pm 32.7 \pm 10.8$
μ^+	710	$42.5 \pm 0.2 \pm 2.9$	$12.0 \pm 3.0 \pm 4.6$	$655.6 \pm 26.6 \pm 6.2$
μ^-	471	$35.1 \pm 0.2 \pm 2.4$	$10.9 \pm 2.4 \pm 4.1$	$425.0 \pm 21.7 \pm 5.4$
$\mu^\pm$	1181	$77.6 \pm 0.3 \pm 5.4$	$22.8 \pm 4.6 \pm 8.7$	$1080.6 \pm 34.4 \pm 11.2$

- **EW processes better known**: take from MC.
- **Larger muon than electron signal** due to different reconstruction **efficiency** (78%(e) vs 97%(mu)).
- **Larger EW bkg in muon** channel from large Z→μμ decays (with fake MET) and W→τν

W cross-section measurement

$$\sigma^{tot}_{W(Z)} \cdot BR(W(Z) \to \ell\nu\ (\ell\ell)) = \frac{N^{sig}_{W(Z)}}{A_{W(Z)}\, C_{W(Z)}\, L_{W(Z)}}$$

N^{sig}_{W} : number of background-subtracted signal events passing the selection criteria for W.

L_W : integrated luminosity.

Geometrical acceptance (generator level)

Correction factor (detector level)

Aw : fraction of decays satisfying the geometrical and kinematical constraints. Determinated from MC.

$$A_W = \left(\frac{N^{acc}}{N^{all}}\right)_{gen}$$

MC	A_W $W \to e\nu$	A_W $W \to \mu\nu$
PYTHIA MRST LO*	0.462	0.480
PYTHIA CTEQ6.6	0.471	0.490
PYTHIA HERAPDF1.0	0.470	0.489
MC@NLO HERAPDF1.0	0.465	0.483
MC@NLO CTEQ6.6	0.465	0.483

$$L = 315 nb^{-1}$$

Cw : factor correcting for reconstruction, identification and trigger efficiencies of the leptons.

Electrons

Parameter	$\delta C_W/C_W$(%)
Trigger efficiency	<0.2
Material effects, reconstruction and identification	5.6
Energy scale and resolution	3.3
E_T^{miss} scale and resolution	2.0
Problematic regions in the calorimeter	1.4
Pile-up	0.5
Charge misidentification	0.5
FSR modelling	0.3
Theoretical uncertainty (PDFs)	0.3
Total uncertainty	7.0

Muons

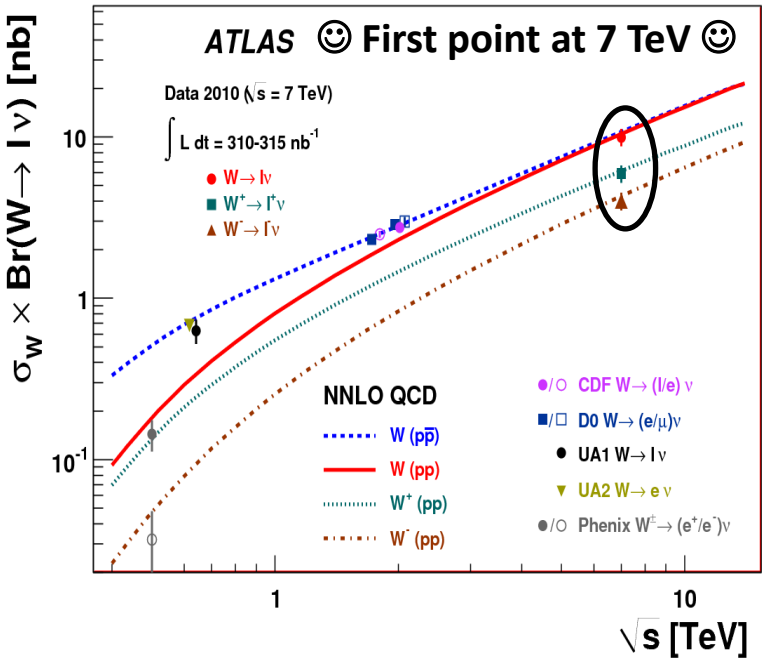
Parameter	$\delta C_W/C_W$(%)
Trigger efficiency	1.9
Reconstruction efficiency	2.5
Momentum scale	1.2
Momentum resolution	0.2
E_T^{miss} scale and resolution	2.0
Isolation efficiency	1.0
Theoretical uncertainty (PDFs)	0.3
Total uncertainty	4.0

W cross-section measurement

$$\sigma^{tot}_{W(Z)} \cdot BR(W(Z) \to \ell\nu\ (\ell\ell)) = \frac{N^{sig}_{W(Z)}}{A_{W(Z)} \cdot C_{W(Z)} \cdot L_{W(Z)}}$$

$$L = 315 nb^{-1}$$

	$\sigma^{tot}_{W^{(\pm)}} \cdot \mathrm{BR}(W \to e\nu)$ [nb]	$\sigma^{tot}_{W^{(\pm)}} \cdot \mathrm{BR}(W \to \mu\nu)$ [nb]
W^+	$6.27 \pm 0.26(\mathrm{stat}) \pm 0.48(\mathrm{syst}) \pm 0.69(\mathrm{lumi})$	$5.71 \pm 0.23(\mathrm{stat}) \pm 0.30(\mathrm{syst}) \pm 0.63(\mathrm{lumi})$
W^-	$4.23 \pm 0.22(\mathrm{stat}) \pm 0.33(\mathrm{syst}) \pm 0.47(\mathrm{lumi})$	$3.86 \pm 0.20(\mathrm{stat}) \pm 0.20(\mathrm{syst}) \pm 0.42(\mathrm{lumi})$
W	$10.51 \pm 0.34(\mathrm{stat}) \pm 0.81(\mathrm{syst}) \pm 1.16(\mathrm{lumi})$	$9.58 \pm 0.30(\mathrm{stat}) \pm 0.50(\mathrm{syst}) \pm 1.05(\mathrm{lumi})$



Theory prediction:

$$\sigma^{tot}_{W} \cdot \mathrm{BR}(W \to \ell\nu) = 9.96 \pm 0.23(\mathrm{stat}) \pm 0.50(\mathrm{syst}) \pm 1.10(\mathrm{lumi})\ \mathrm{nb}$$

$$\left(\sigma^{NNLO}_{W^+ \to l^+\nu} = 5.93 nb \quad and \quad \sigma^{NNLO}_{W^- \to l^-\nu} = 4.00 nb\right)$$

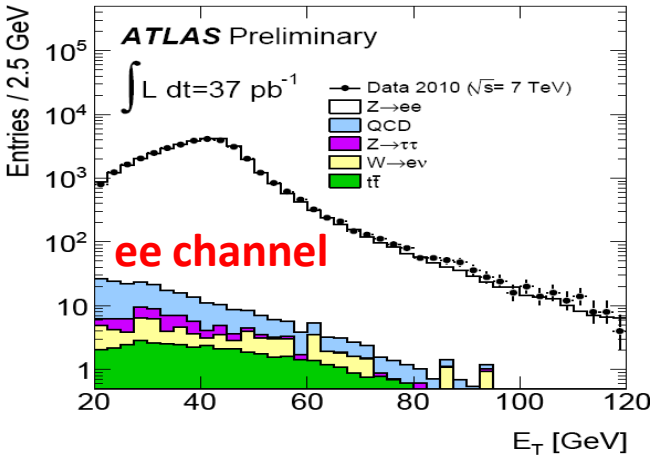
- Remarkable agreement with theory.
- $W^+/^-$ asymmetry due to parton composition in protons observed.

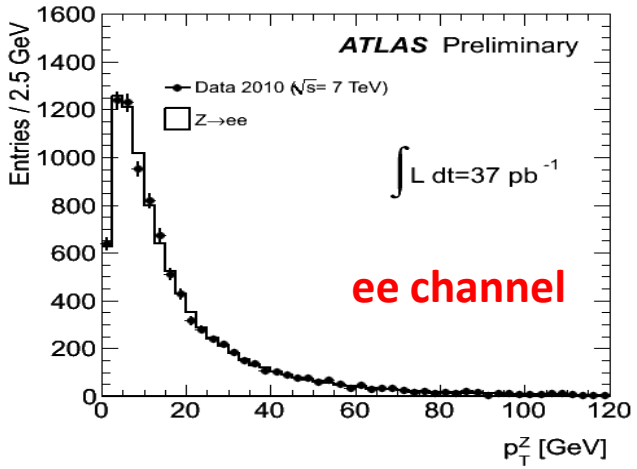
Z cross – section measurement with 330nb-1

Some distributions studied
with higer statistics (35pb-1)

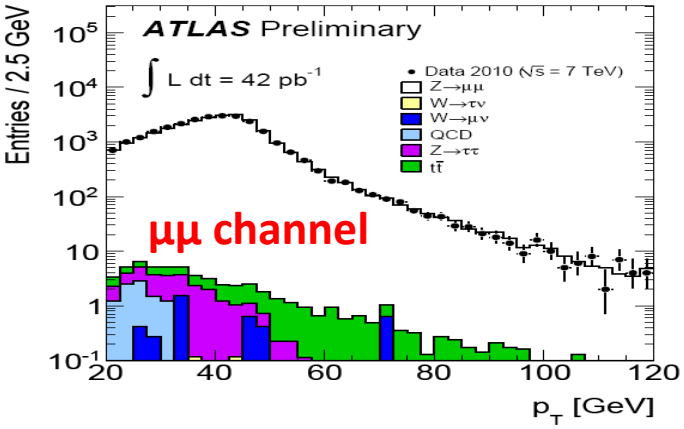
Z signal selection

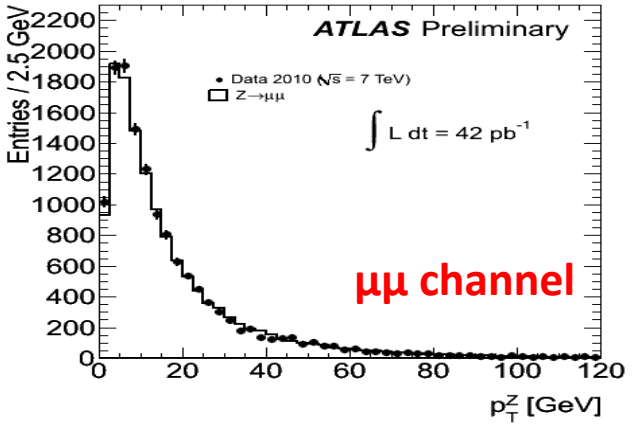
2 Electrons:
- E_T > 20GeV
- Opposite charge
- Medium ID
- 66 < m_{ee} < 116 GeV





2 Muons:
- P_T > 20GeV
- Track isolation
- Opposite charge
- 66 < $m_{\mu\mu}$ < 116 GeV





Requirement	Electron channel Number of candidates	Muon channel Number of candidates
$\ell^+\ell^-$ pairs	9,985	14,804
66 < $m_{\ell^+\ell^-}$ < 116 GeV	9,170	13,858

The background estimation was calculated in a similar way to W signal:

- EW + ttbar from Monte-Carlo simulation
- QCD bkg from data using the invariant-mass distribution as a template.

Z cross-section measurement

ℓ	Observed candidates	Background (EW+$t\bar{t}$)	Background (QCD)	Background-subtracted signal N_Z^{sig}
$e^{\pm}$	70	$0.27 \pm 0.00 \pm 0.03$	$0.91 \pm 0.11 \pm 0.41$	$68.8 \pm 8.4 \pm 0.4$
$\mu^{\pm}$	109	$0.21 \pm 0.01 \pm 0.01$	$0.04 \pm 0.01 \pm 0.04$	$108.8 \pm 10.4 \pm 0.0$

$$L = 330 nb^{-1}$$

$$\sigma^{\text{tot}}_{W(Z)} \cdot BR(W(Z) \to \ell\nu\ (\ell\ell)) = \frac{N^{\text{sig}}_{W(Z)}}{A_{W(Z)} \cdot C_{W(Z)} \cdot L_{W(Z)}}$$

N_Z^{sig} : number of background-subtracted signal events passing the selection criteria for Z.

L_Z : integrated luminosity.

Geometrical acceptance (generator level)

Correction factor (detector level)

Az: fraction of decays satisying the geometrical and kinematical constraints . Determinated from simulation.

$$A_W = \left(\frac{N^{acc}}{N^{all}} \right)_{gen}$$

MC	A_Z $Z \to e^+e^-$	A_Z $Z \to \mu^+\mu^-$
PYTHIA MRST LO*	0.446	0.486
PYTHIA CTEQ6.6	0.455	0.496
PYTHIA HERAPDF1.0	0.451	0.492
MC@NLO HERAPDF1.0	0.440	0.479
MC@NLO CTEQ6.6	0.445	0.485

Cz : factor correcting for reconstruction, identification and trigger efficiencies of the leptons.

Cz values

Electron: 65.1% ± 6.1%

Muon: 77.3% ± 4.3%

Z cross-section measurement

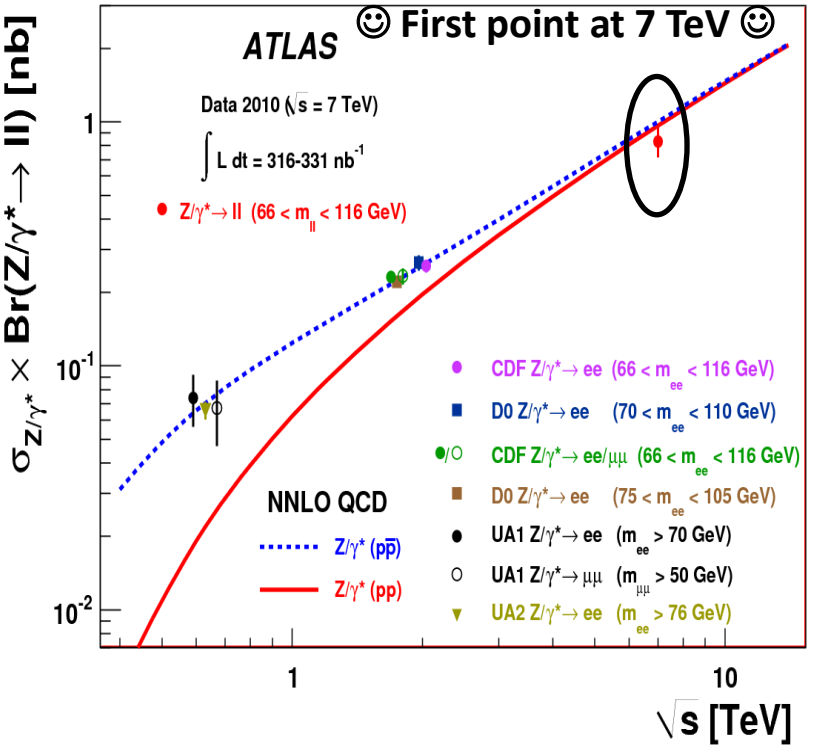
$$\sigma^{\text{tot}}_{W(Z)} \cdot BR(W(Z) \to \ell\nu\ (\ell\ell)) = \frac{N^{\text{sig}}_{W(Z)}}{A_{W(Z)} \cdot C_{W(Z)} \cdot L_{W(Z)}}$$

	$\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to ee)$ [nb], $66 < m_{ee} < 116$ GeV	$\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \mu\mu)$ [nb], $66 < m_{\mu\mu} < 116$ GeV
Z/γ^*	$0.75 \pm 0.09(\text{stat}) \pm 0.08(\text{syst}) \pm 0.08(\text{lumi})$	$0.87 \pm 0.08(\text{stat}) \pm 0.06(\text{syst}) \pm 0.10(\text{lumi})$

Theory prediction:

$$\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \ell\ell) = 0.82 \pm 0.06(\text{stat}) \pm 0.05(\text{syst}) \pm 0.09(\text{lumi})\ \text{nb}$$

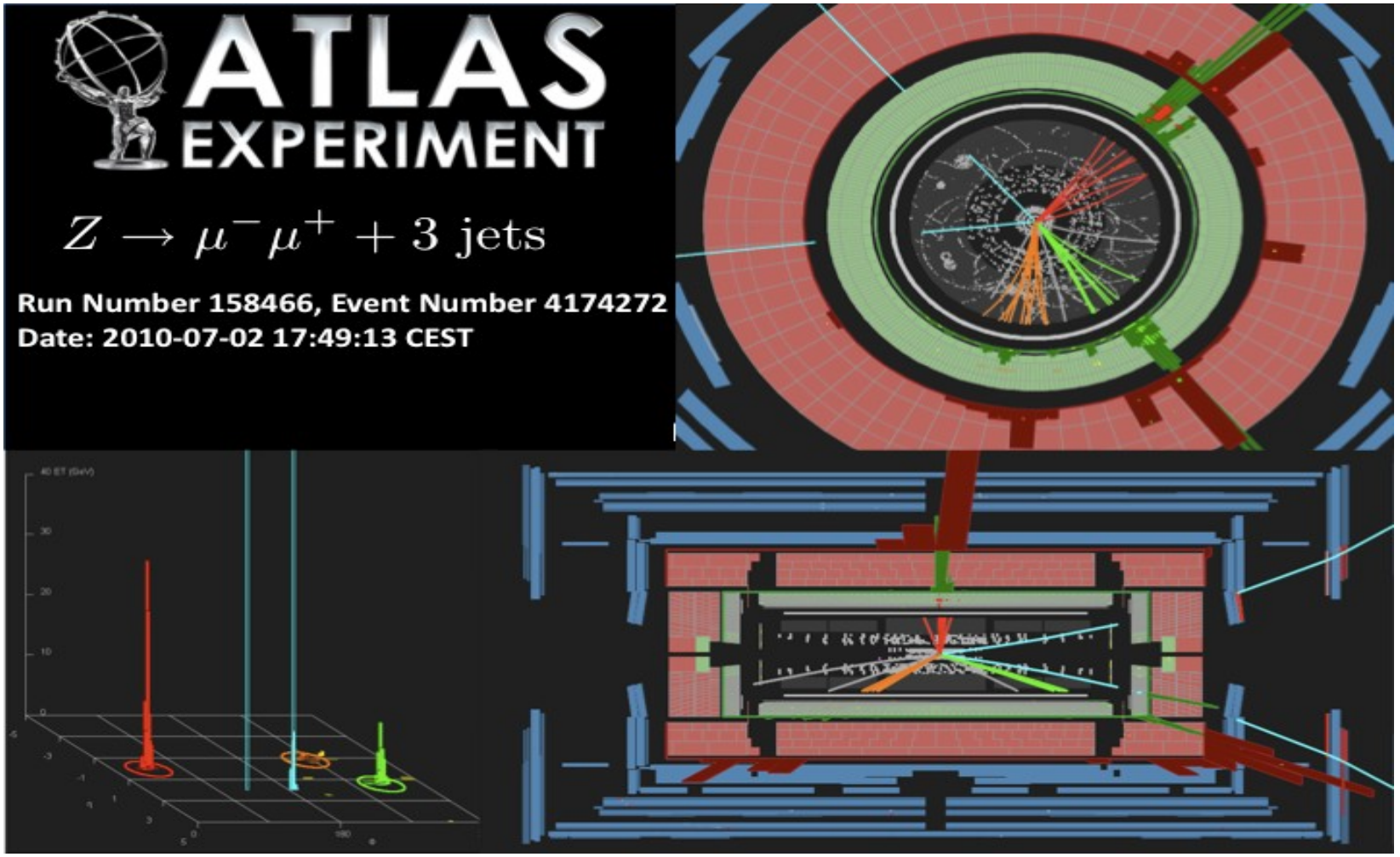
for range $66 < m_{ll} < 116 GeV$



W/Z + jets studies with 330nb-1

Some distributions studied
with higer statistics (35pb-1)

Z + 3 jets



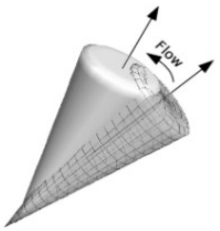
- Z boson with pT = 144 GeV
- Muons pT = 96 GeV and 68 GeV

•M(μμ) = 79 GeV: the harder muon has left a significant energy deposition presumable through bremss.

- The jets ET are 168, 105 and 45 GeV

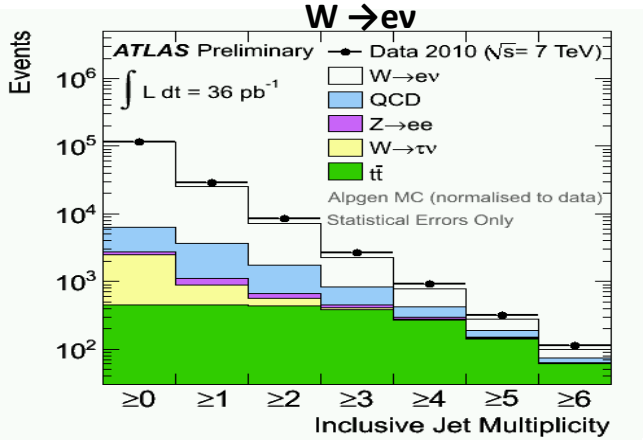
W/Z + jets

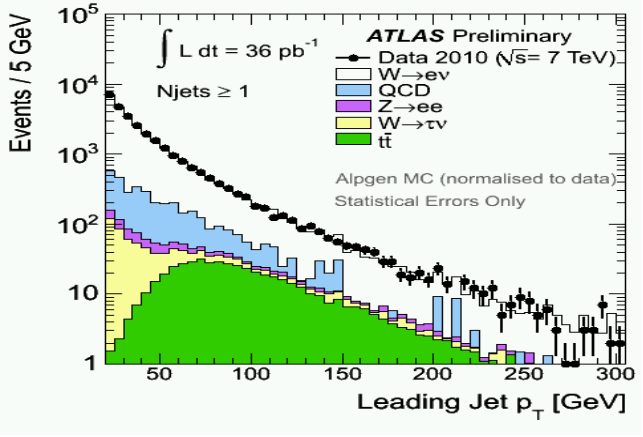
- W+jets is background for many physics searches (see next section).
- W selection as described previously.
- Jets overlapping in space with the lepton are removed.
- Background estimation entirely from simulation.



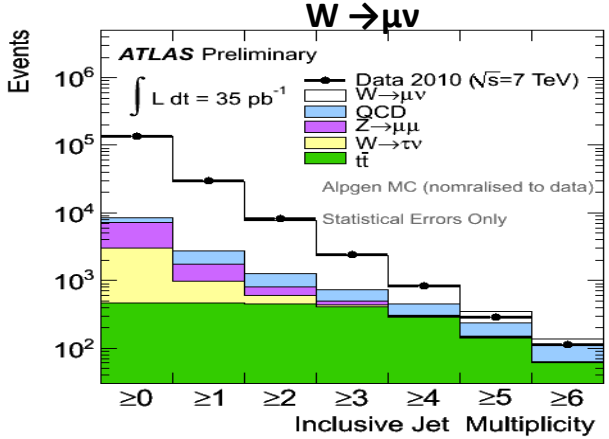
The jet algorithm used is Anti-kT with R = 0.4 and the jets are selected with $|\eta| < 2.8$ and $p_T > 20$ GeV.

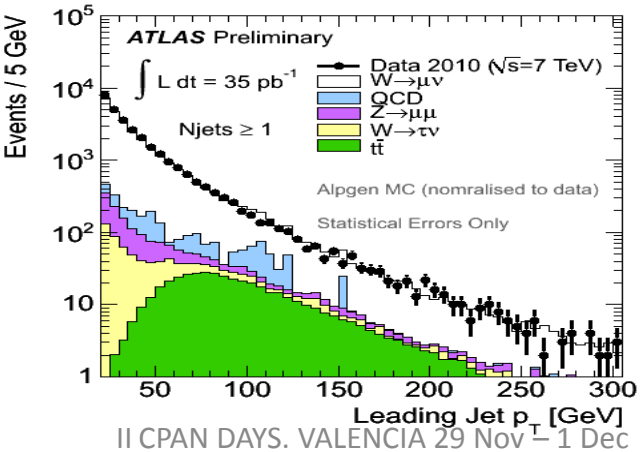
W →eν



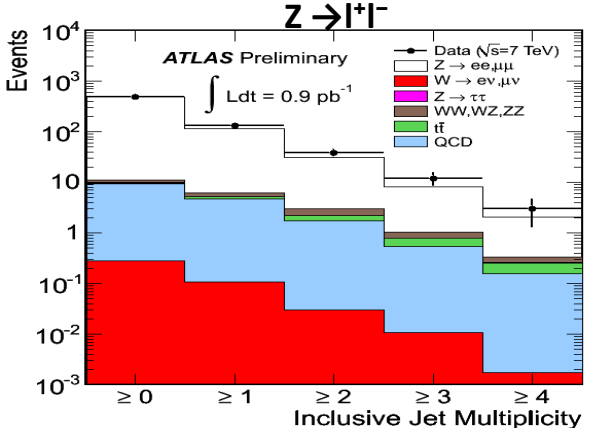


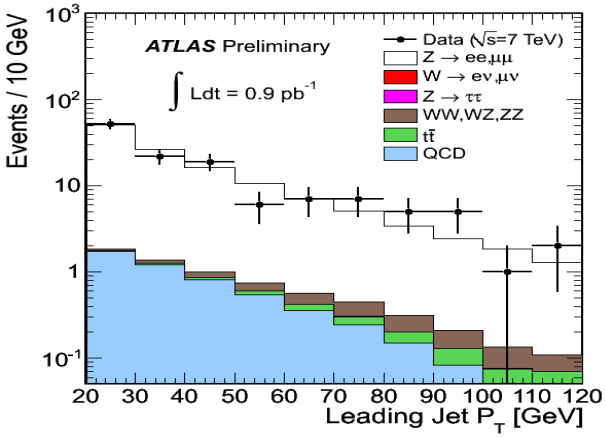
W →μν





Z →l⁺l⁻





Electroweak studies at IFIC-Wisconsin group

IFIC-Wisconsin group

IFIC-Wisconsin group

- Xin Chen (PostDoc)
- Amanda Kruse (PhD student)
- Yesenia Hernández (PhD student)
- Bruce Mellado García (IP)
- Yibin Pan (PostDoc)
- Carlos Solans (PostDoc)
- Guillermo Torralba (Master student)
- Juan Antonio Valls Ferrer (IP)
- Yingchun Zhu (PostDoc)
- Luca Fiorini (researcher)

Activities

- WW analysis group convener: B. Mellado
- W+jets conf note:
  http://cdsweb.cern.ch/record/1283753/files/conflwj.pdf
- WW: note ongoing
- SUSY studies (X. Chen, C. Solans, G. Torralba)

Collaboration

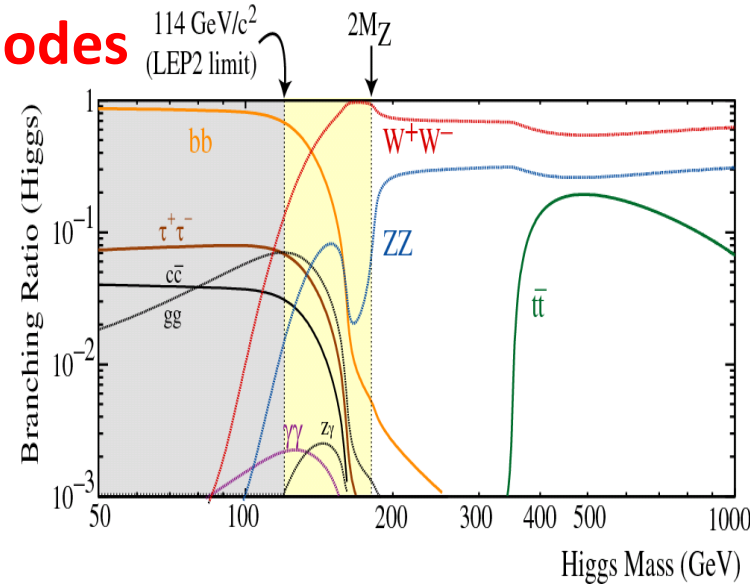
- Laboratoire de l'accelérateur linéaire (LAL):
  - Zhiqing Zhang (IP)
  - Xifeng Ruan (PhD student)

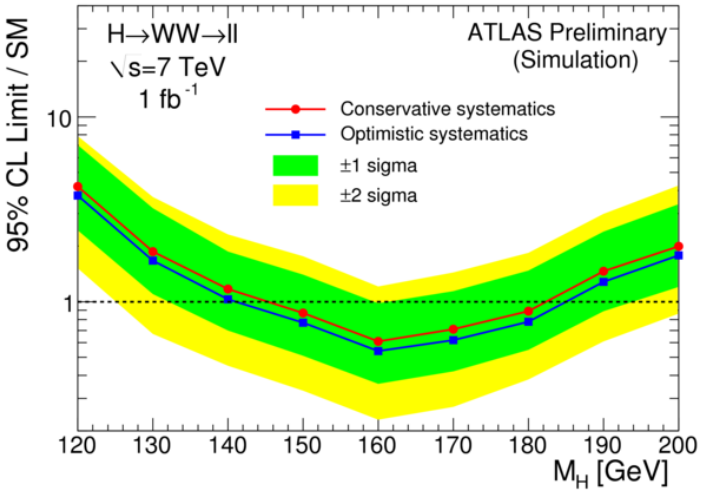
SM Higgs searches at IFIC

Main Decay Modes

Low Mass Higgs:
Close to LEP limit:
H→γγ, ττ, bb

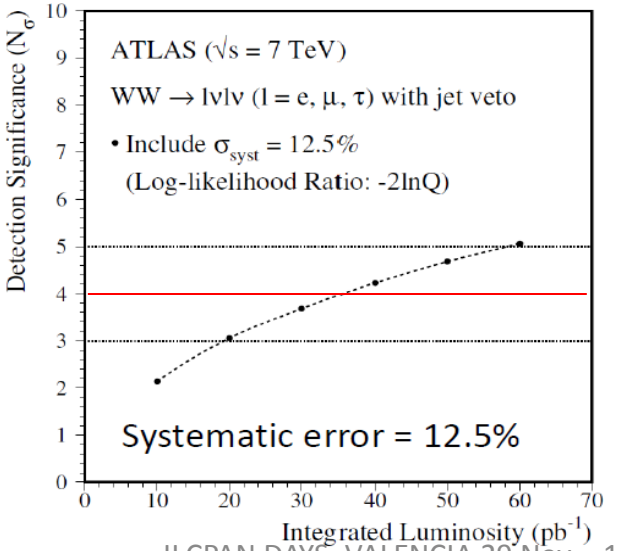
For **M_H > 140 GeV**:
H→WW(*), ZZ(*)

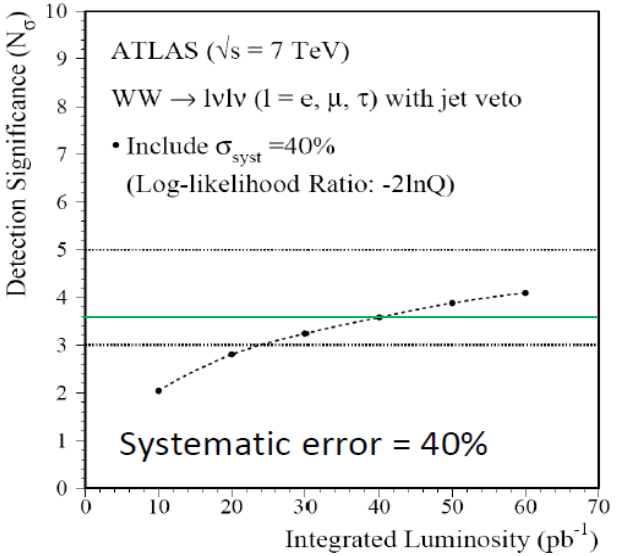




MC expected (35 pb-1):
3.90 for 12.5% systematic uncertainty
3.35 for 40% systematic uncertainty

Unfortunately, WW results are not public yet…





Conclusions

- Studies on EW processes gave chance to:
  - commission ATLAS
  - test SM expectations on W/Z production cross-section

- W/Z cross-sections have been extracted with 310-330 nb-1 with the ATLAS detector.

- Atlas has recovered 45 pb-1. Candidates with 35pb-1:
  - **W boson**: **118.898 $W \rightarrow e\nu$** and **142.081 $W \rightarrow \mu\nu$**
  - **Z boson**: **9.170 $Z \rightarrow e^+e^-$** and **13.858 $Z \rightarrow \mu^+\mu^-$**

- The W asymmetry and the W/Z ratio have been computed.

- Results agree well with SM predictions.

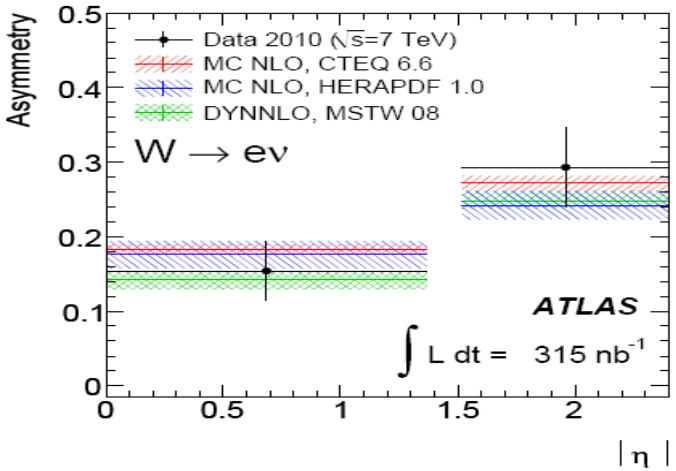
- IFIC-Wisconsin group is working in WW.

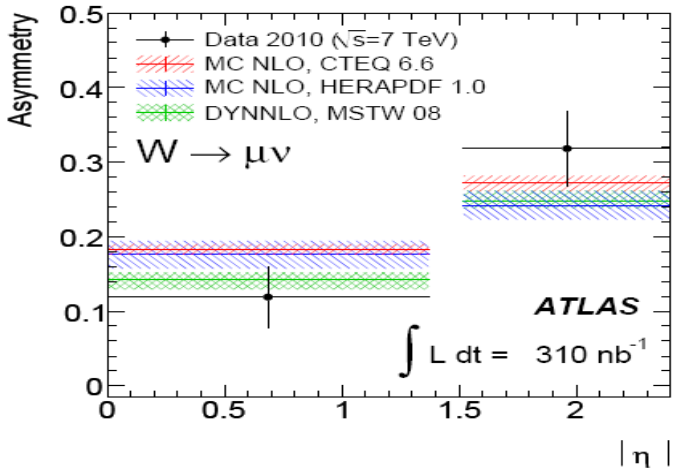
Back-up

W charge asymmetry and W/Z ratio

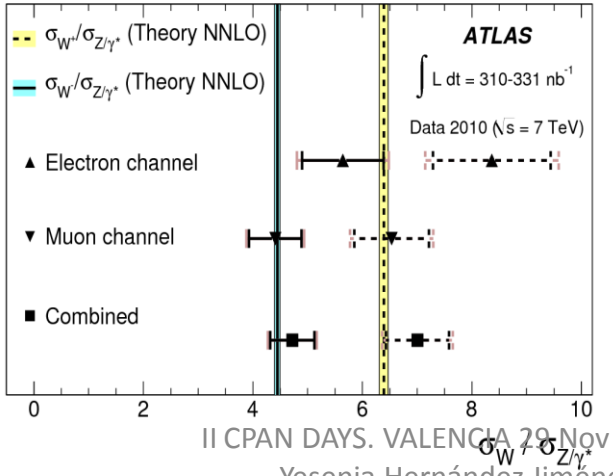
- W^+ and W^- are produced at different rates, which can be measured via the letpon charge asymmetry. This measurement is important to constraint PDFs.
- Many uncertaintis cancel fully or partially.

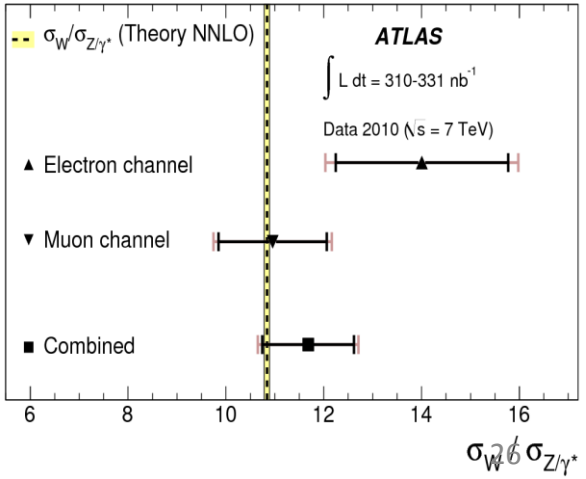
$$A_l = \frac{\sigma_{W^+} - \sigma_{W^-}}{\sigma_{W^+} + \sigma_{W^-}}$$





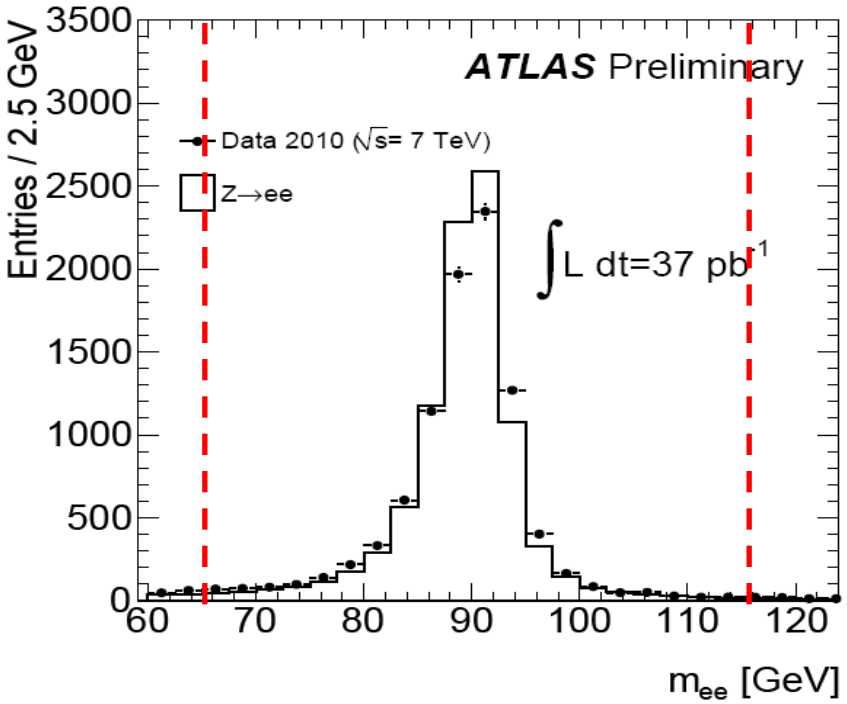
- The measured ratios between the W^+ and W^- and the Z cross section in the electron and muon decay channels compared to the theoretical predictions based on NNLO QCD calculations.

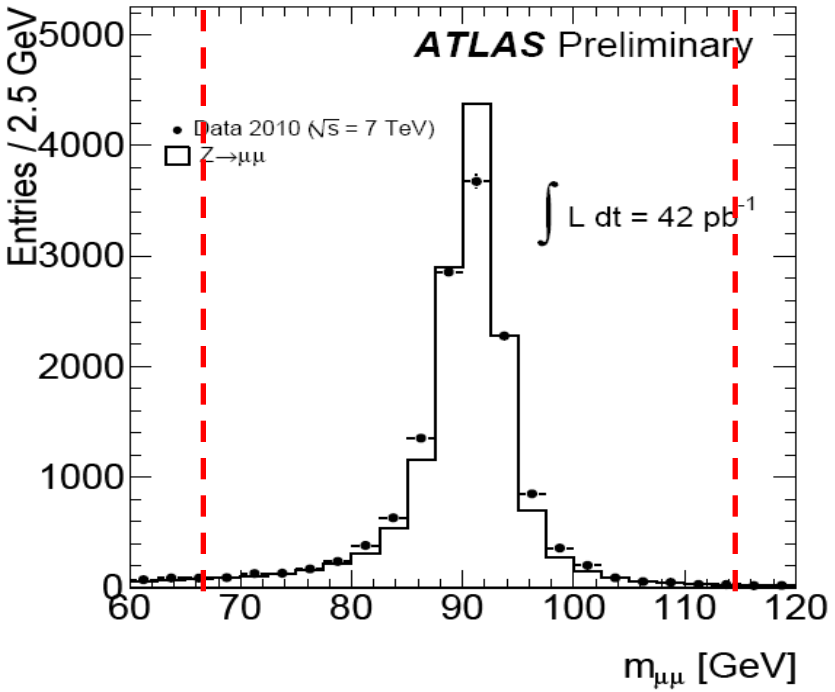




Z background estimation: QCD

66 < m(l^+l^-) < 116 GeV → **Backgrounds negligible!**





Electrons:

- Predict loose-loose pairs from MC
- then extrapolate to Medium electron (signal region)
- Predicted QCD events in signal region:

$$N_{QCD} = 0.91 \pm 0.11(stat) \pm 0.41(syst)$$

Muons:

- From simulation
- Predicted QCD events in signal region:

$$N_{QCD} = 0.04 \pm 0.01(stat) \pm 0.04(syst)$$