$W \to \ell\nu$ AND $Z/\gamma^\star \to \ell\ell$ CROSS-SECTION MEASUREMENTS IN p-p COLLISIONS AT $\sqrt{s} = 7$ TeV WITH THE ATLAS DETECTOR

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University of Göttingen and University of Glasgow

Hadron Collider School 2012 in Göttingen

24th July 2012

Outline

DATASET

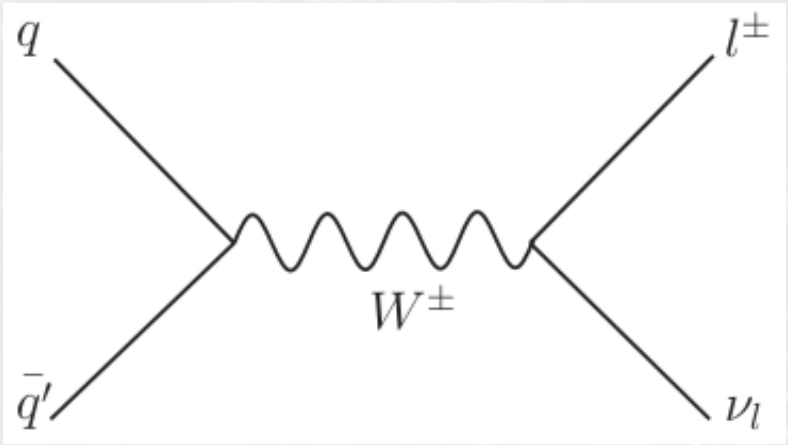
First W^+, W^- and $Z/\gamma^\star$ production cross section measurements with ATLAS at $\sqrt{s} = 7$ TeV

- data collected from March to July 2010

$$\int \mathcal{L} dt$$

  - $W \to e\nu_e$: $315\ \text{nb}^{-1}$
  - $W \to \mu\nu_\mu$: $310\ \text{nb}^{-1}$
  - $Z \to ee$: $316\ \text{nb}^{-1}$
  - $Z \to \mu\mu$: $331\ \text{nb}^{-1}$

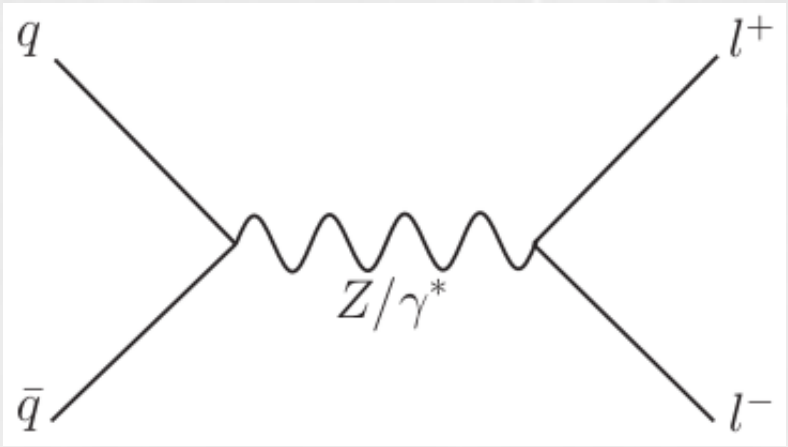
SIGNATURE: $W \to \ell\nu_\ell$ & $Z/\gamma^\star \to \ell\ell$



$W \to \ell\nu_\ell$ signature:

- one isolated lepton with high p_T
- $\not{E}_T$ from neutrino

$\Rightarrow$ peak in m_T distribution

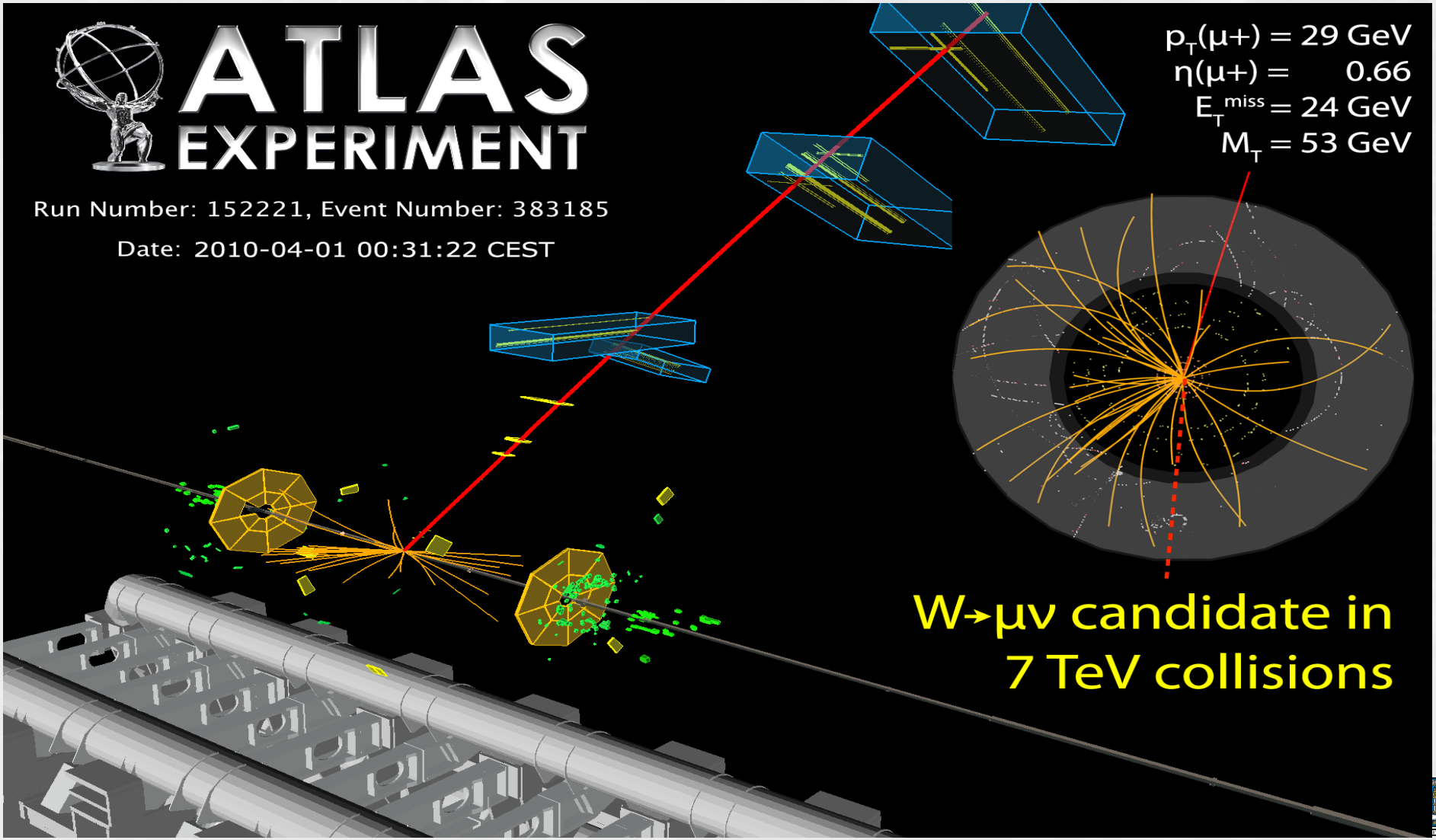


$Z/\gamma^\star \to \ell\ell$ signature:

- two opposite charged isolated leptons with high p_T

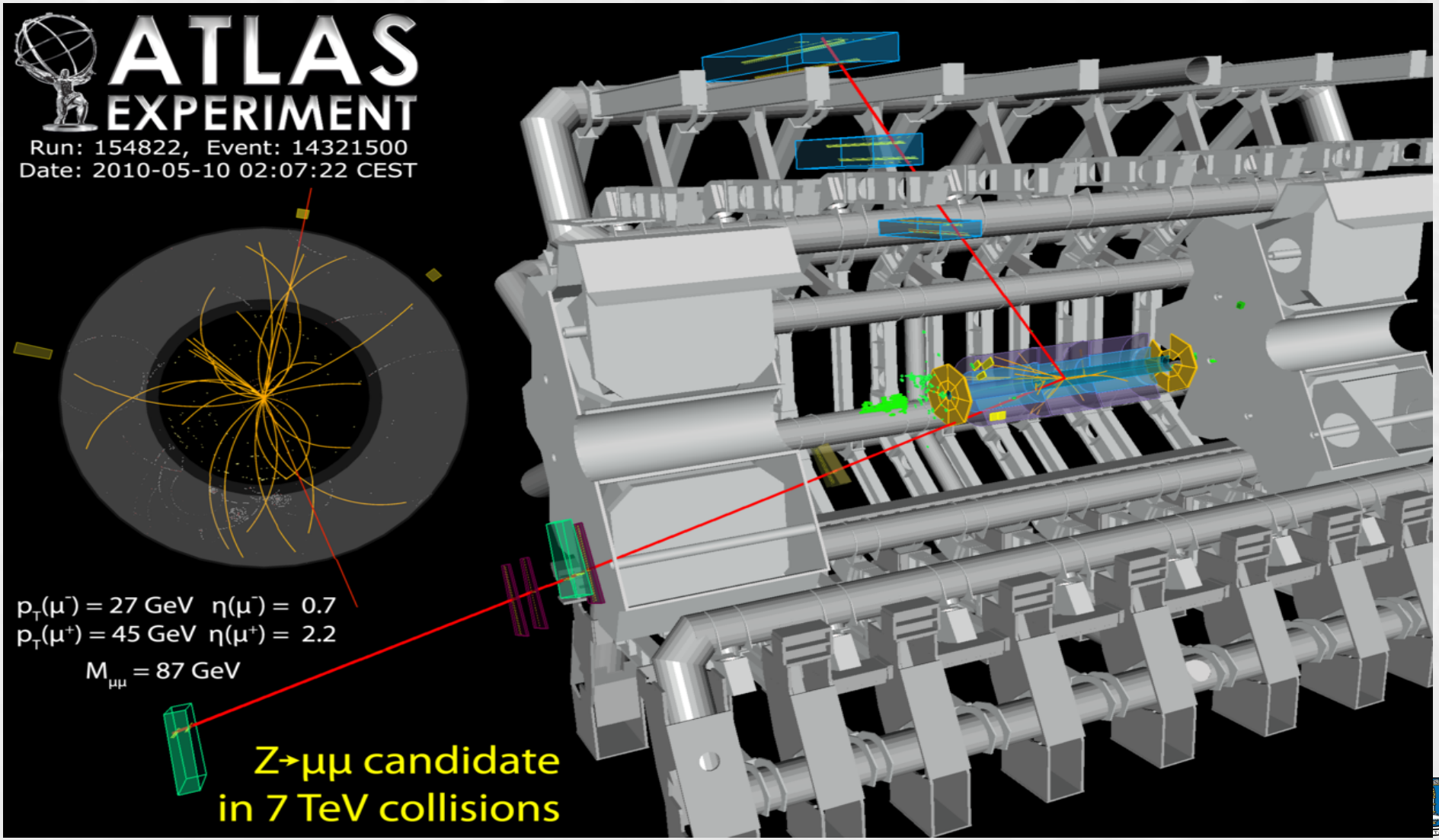
$\Rightarrow$ peak in $m_{\ell\ell}$ distribution

EVENT DISPLAY: $W \to \mu\nu$ @ $\sqrt{s} = 7$ TeV



animation: → http://www.atlas.ch/multimedia/#w-boson-event

EVENT DISPLAY: $Z \to \mu\mu$ @ $\sqrt{s} = 7$ TeV

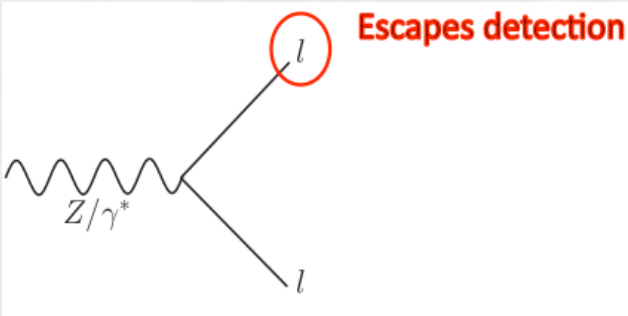


animation: → http://www.youtube.com/watch?v=5xcw7sU_jkg

BACKGROUND PROCESSES (I)

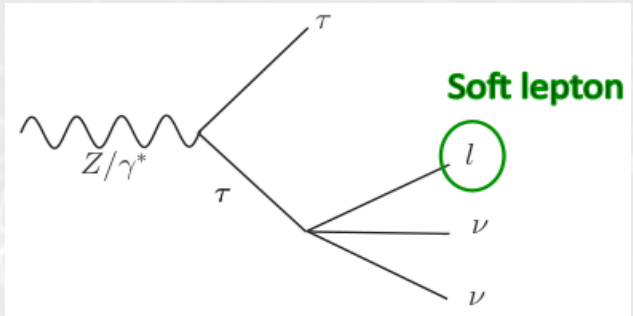
EW and top backgrounds are estimated from MC

- bgr for $W \to \mu\nu, e\nu_e$



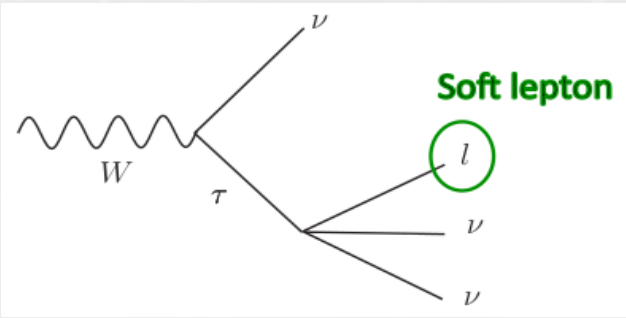
  - 1 muon outside muon-spec. acc. $\to \not{E}_T$
  - larger η for cal. in $W \to e\nu$

- bgr for W and Z



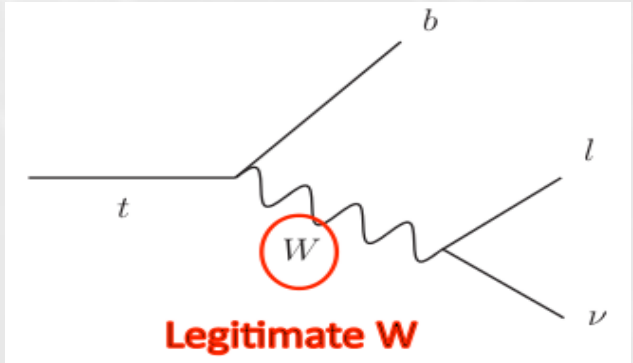
  - smaller bgr via single or double leptonic τ decays

- bgr for $W \to \mu\nu, e\nu_e$



  - in particluar via $\tau \to \ell\nu\nu$

- bgr for W and Z



BACKGROUND PROCESSES (II)

QCD background are estimated in data-driven approaches

- Semileptonic decays from heavy quarks
- Hadron fakes (hadrons misidentified as leptons)
- e-channel $\to$ electrons from conversions

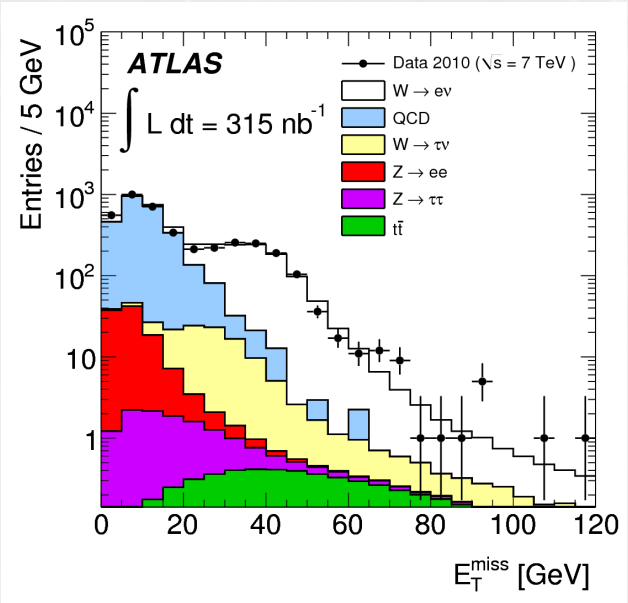
EVENT SELECTION (I)

$$W \to \ell\nu_\ell$$

EVENT SELECTION (I)

$W \to e\nu_e$ selection:

- one high E_T electron with E_T>20 GeV in $|\eta| < 2.47$
- no isolation
- additional electrons are vetoed
- $\not{E}_T$>25 GeV
- m_T>40 GeV



$W \to \mu\nu_\mu$ selection:

- one high p_T muon with p_T>20 GeV in $|\eta|$<2.4
- Isolation cut: $\Sigma p_T^{ID}/p_T$<0.2
- $\not{E}_T$>25 GeV
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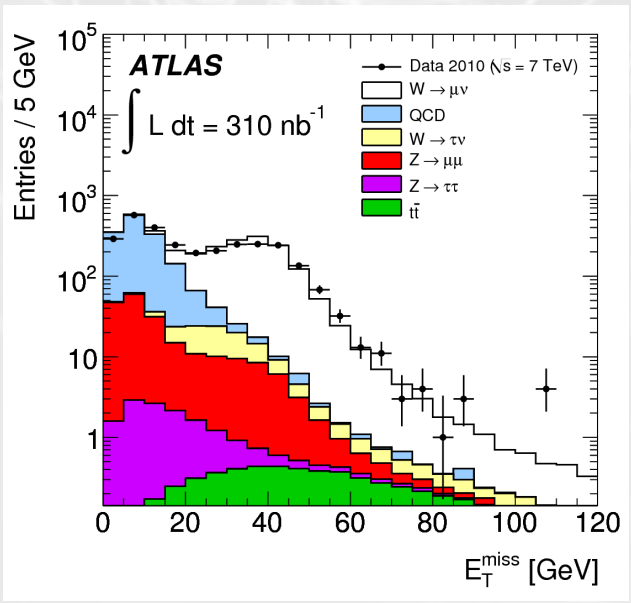

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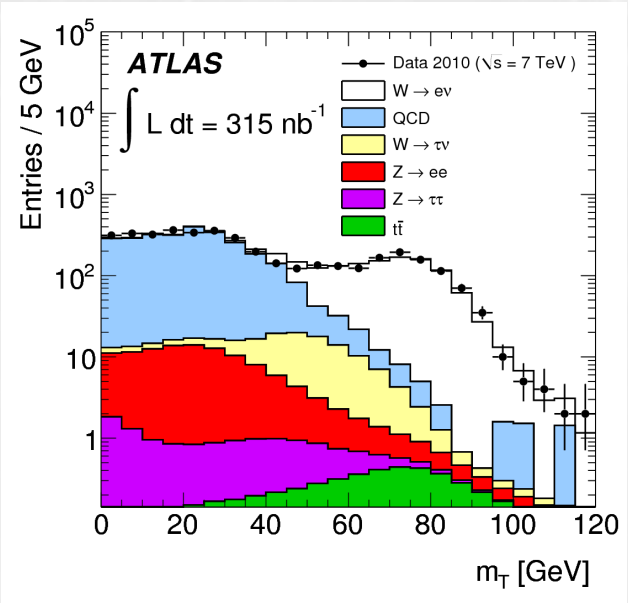

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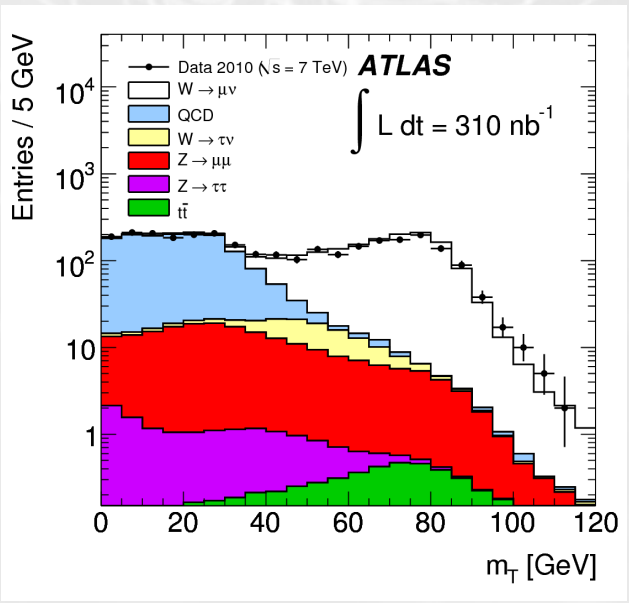

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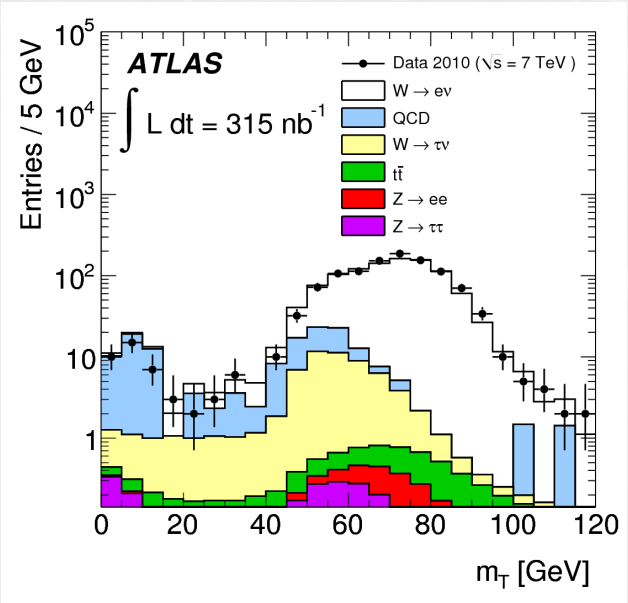

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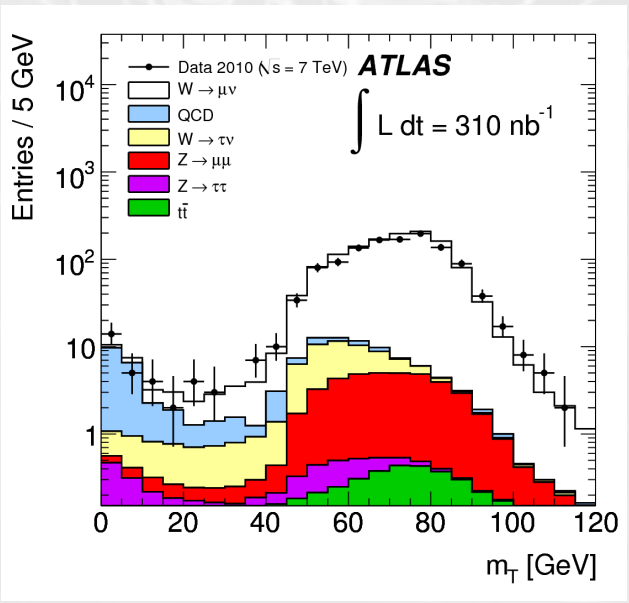

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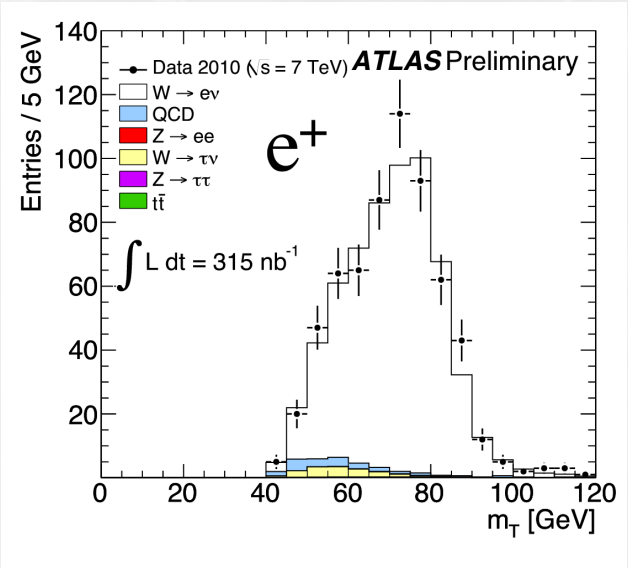

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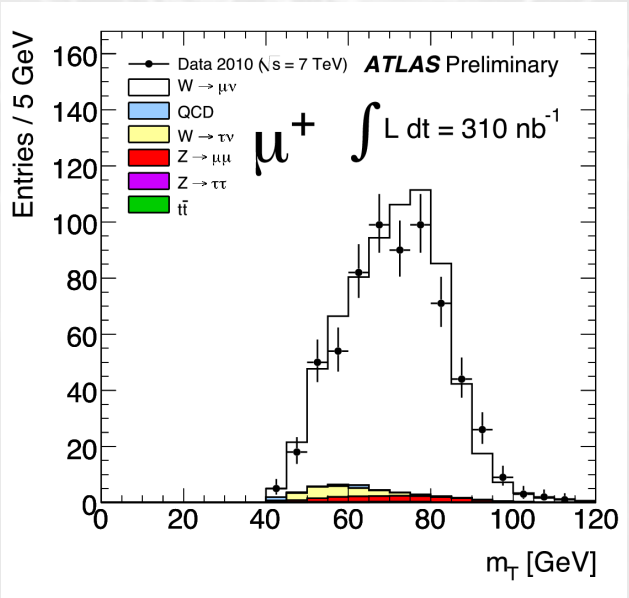


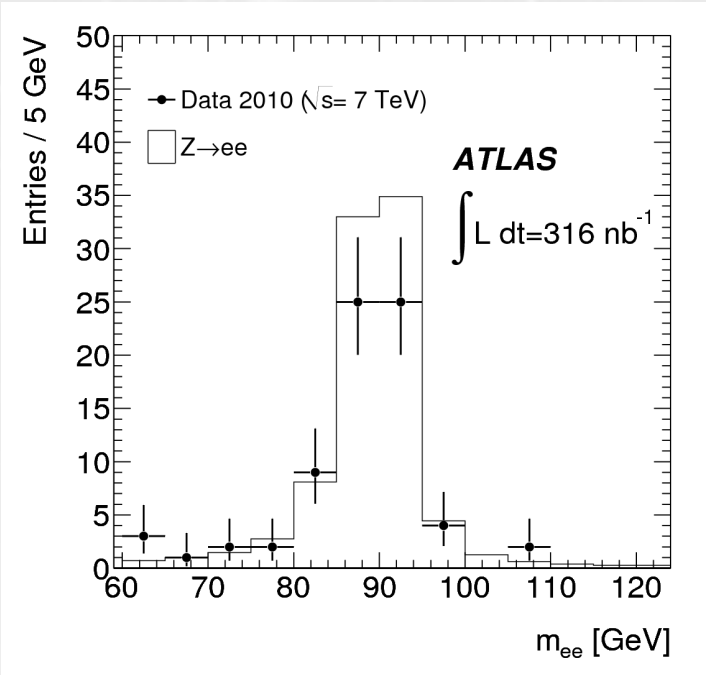
EVENT SELECTION (II)

$$Z/\gamma^\star \to \ell\ell$$

EVENT SELECTION (II)

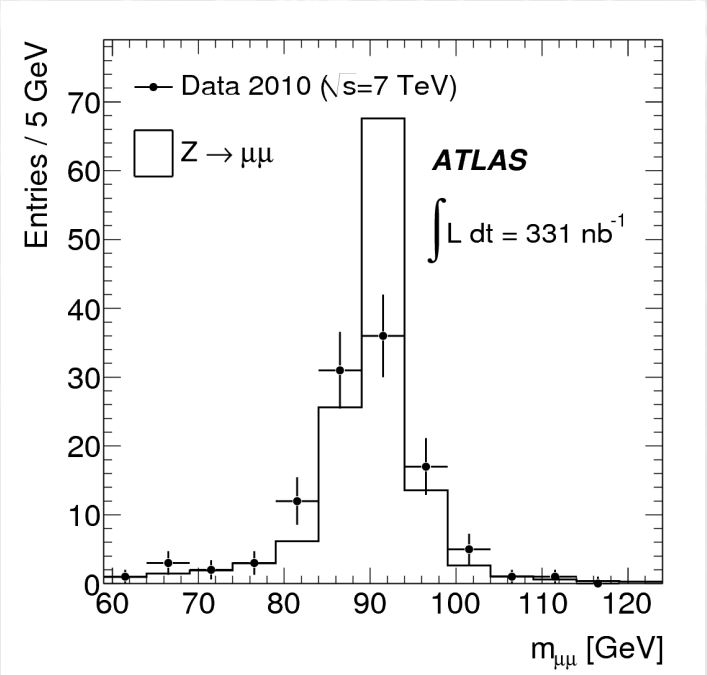
$Z/\gamma^\star \rightarrow$ ee selection:

- two high E_T electrons with E_T>20 GeV in $|\eta| < 2.47$
- opposite charg and same flavour
- veto on three or more electrons
- $66 < m_{ee} < 116$



$Z/\gamma^\star \rightarrow \mu\mu$ selection:

- two high p_T leptons with p_T>20 GeV
- opposite charge and same flavour
- $66 < m_{\mu\mu} < 116$



NUMBER OF OBSERVED CANDIDATE EVENTS N_{obs}

W $\to \ell\nu_\ell$ channel:

1069

1181

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	$77.6 \pm 0.3 \pm 5.4$	$22.8 \pm 4.6 \pm 8.7$	$1080.6 \pm 34.4 \pm 11.2$

Z $\to \ell\ell$ channel:

70

109

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	$0.21 \pm 0.01 \pm 0.01$	$0.04 \pm 0.01 \pm 0.04$	$108.8 \pm 10.4 \pm 0.0$

From number candidates to cross section

Pocket equation:

$$\sigma = \frac{N_{processed\ldots events}}{Luminosity}$$

As we measure only on the leptonic channel:

$$\sigma_{W(Z)} \rightarrow \sigma_{W(Z)} \cdot BR\left(W \rightarrow l\nu(Z \rightarrow ll)\right)$$

As a result of the geometrical features of the detector and the object selection:

$$N_{events} = \frac{N^{signal}_{W(Z)}}{A_{W(Z)} \cdot C_{W(Z)}}$$

From number candidates to cross section

Pocket equation:

$$\sigma = \frac{N_{processed\ldots events}}{Luminosity}$$

Number of candidates

$$N_{events} = \frac{N_{W(Z)}^{signal}}{A_{W(Z)} \cdot C_{W(Z)}}$$

From number candidates to cross section

Pocket equation: $$\sigma = \frac{N_{processed\ldots events}}{Luminosity}$$

$$N_{events} = \frac{N^{signal}_{W(Z)}}{\underbrace{A_{W(Z)}} \cdot C_{W(Z)}}$$

Factor due to the geometry of the detector and kinematic constrains

From number candidates to cross section

Pocket equation: $$\sigma = \frac{N_{processed\ldots events}}{Luminosity}$$

$$N_{events} = \frac{N^{signal}_{W(Z)}}{A_{W(Z)} \cdot C_{W(Z)}}$$

Factor due to the candidate selection

$$C_{W(Z)} = f\left(\varepsilon_{event\_select.}, \varepsilon_{reconstruction}, \varepsilon_{lepton\_select.}, \varepsilon_{trigger}\right)$$

From number candidates to cross section

Pocket equation: $$\sigma = \frac{N_{processed\ldots events}}{Luminosity}$$

$$\sigma^{total}_{W(Z)} = \frac{N^{signal}_{W(Z)}}{A_{W(Z)} \cdot C_{W(Z)} \cdot L_{W(Z)}}$$

Requires theoretical extrapolation

$$\sigma^{fiducial}_{W(Z)} = \frac{N^{signal}_{W(Z)}}{C_{W(Z)} \cdot L_{W(Z)}}$$

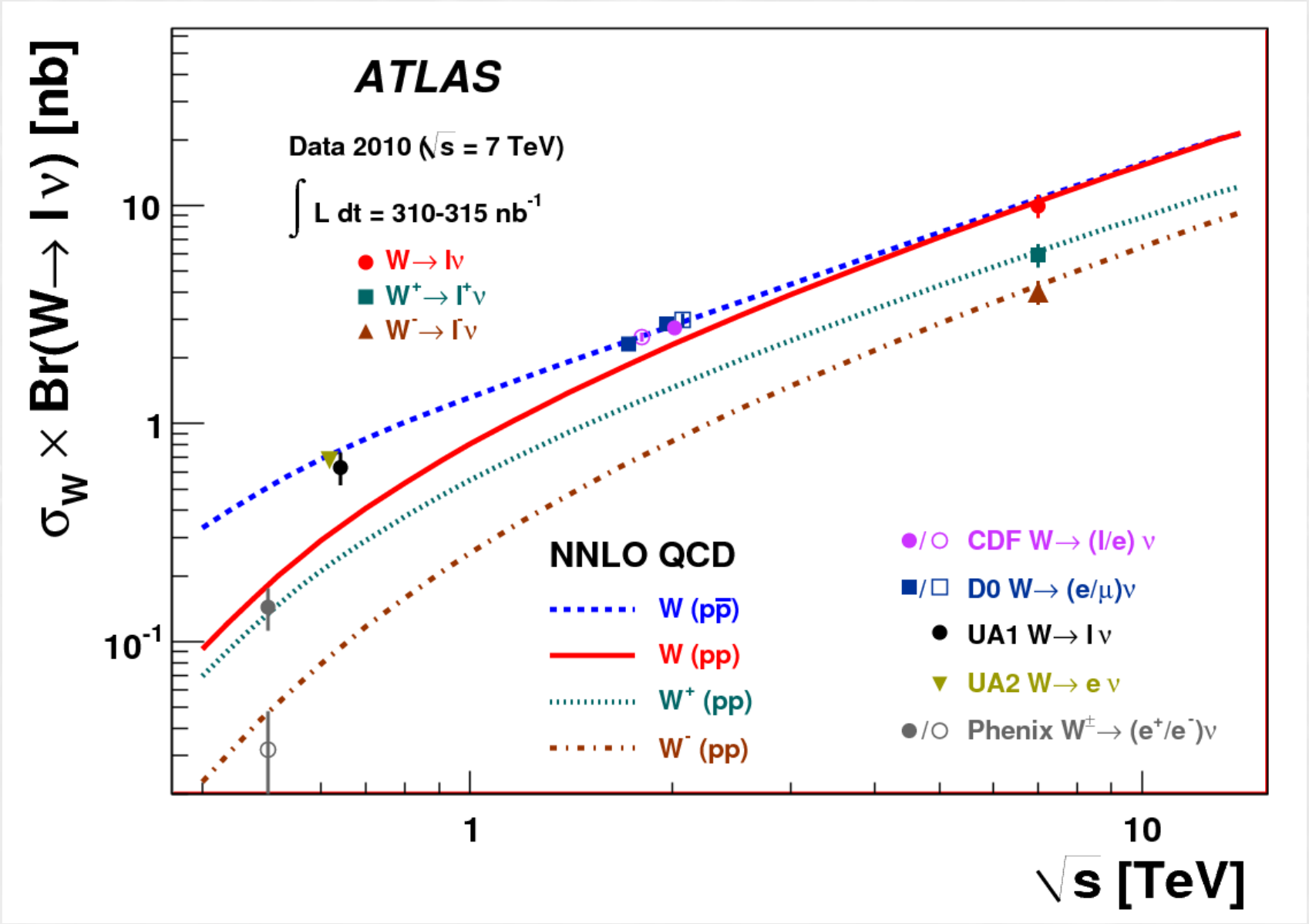
Direct measurement

From number candidates to cross section

	$\sigma_W^{fiducial} \cdot BR(W \to ev)$ [nb]	$\sigma_W^{fiducial} \cdot BR(W \to \mu\nu)$ [nb]
W^+	$2.92 \pm 0.12(stat) \pm 0.21(syst) \pm 0.32(lumi)$	$2.71 \pm 0.11(stat) \pm 0.12(syst) \pm 0.30(lumi)$
W^-	$1.93 \pm 0.10(stat) \pm 0.14(syst) \pm 0.21(lumi)$	$1.83 \pm 0.10(stat) \pm 0.08(syst) \pm 0.20(lumi)$
W	$4.85 \pm 0.10(stat) \pm 0.34(syst) \pm 0.53(lumi)$	$4.60 \pm 0.10(stat) \pm 0.20(syst) \pm 0.51(lumi)$

	$\sigma_{Z/\gamma^*}^{fiducial} \cdot BR(Z/\gamma^* \to ee)$ [nb] $66 < m_{ee} < 116 GeV$	$\sigma_{Z/\gamma^*}^{fiducial} \cdot BR(Z/\gamma^* \to \mu\mu)$ [nb] $66 < m_{\mu\mu} < 116 GeV$
Z/γ^*	$0.33 \pm 0.04(stat) \pm 0.03(syst) \pm 0.04(lumi)$	$0.43 \pm 0.04(stat) \pm 0.02(syst) \pm 0.05(lumi)$

Total cross section measurement



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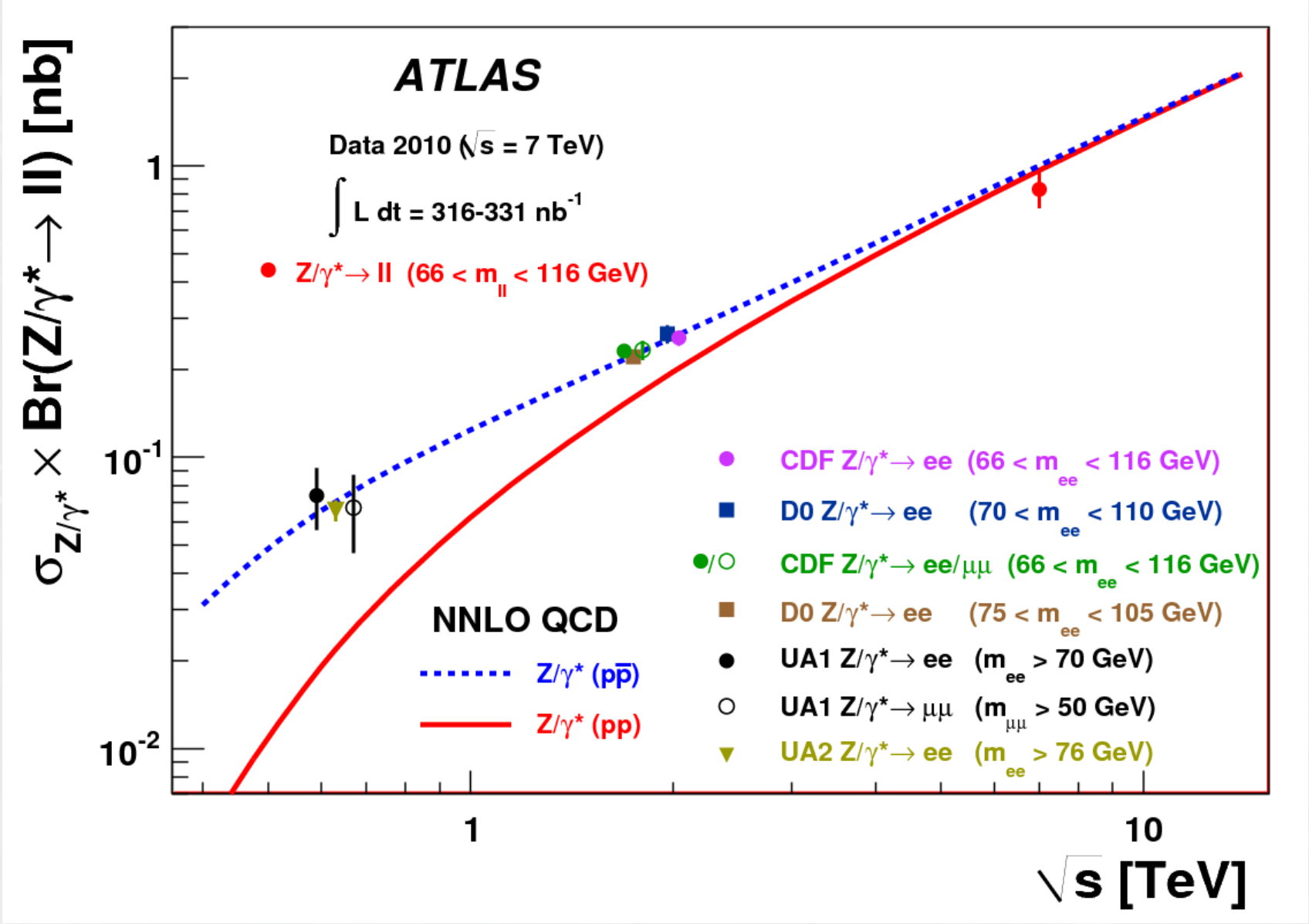
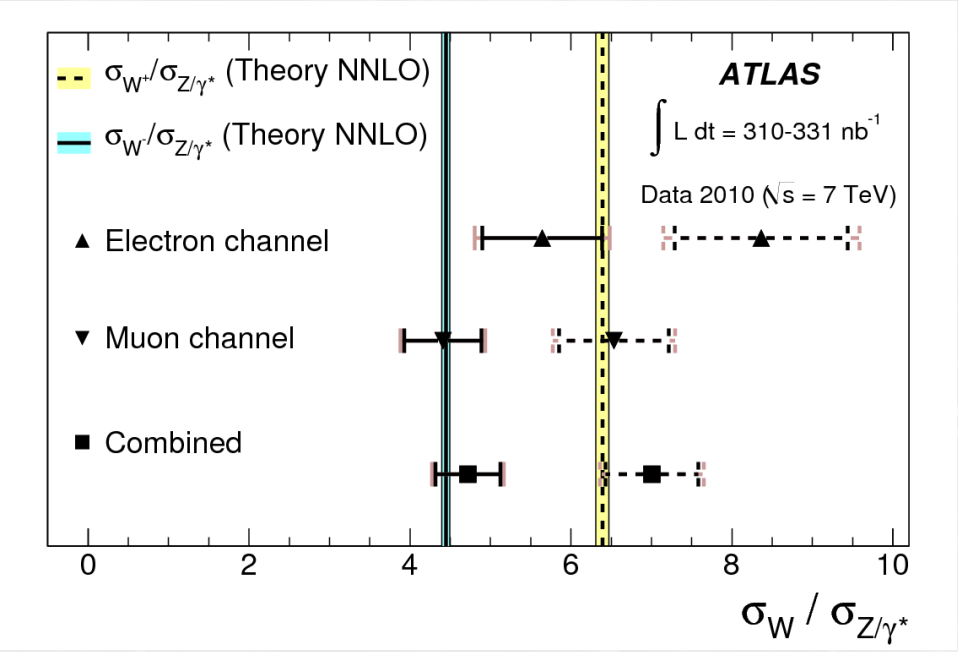
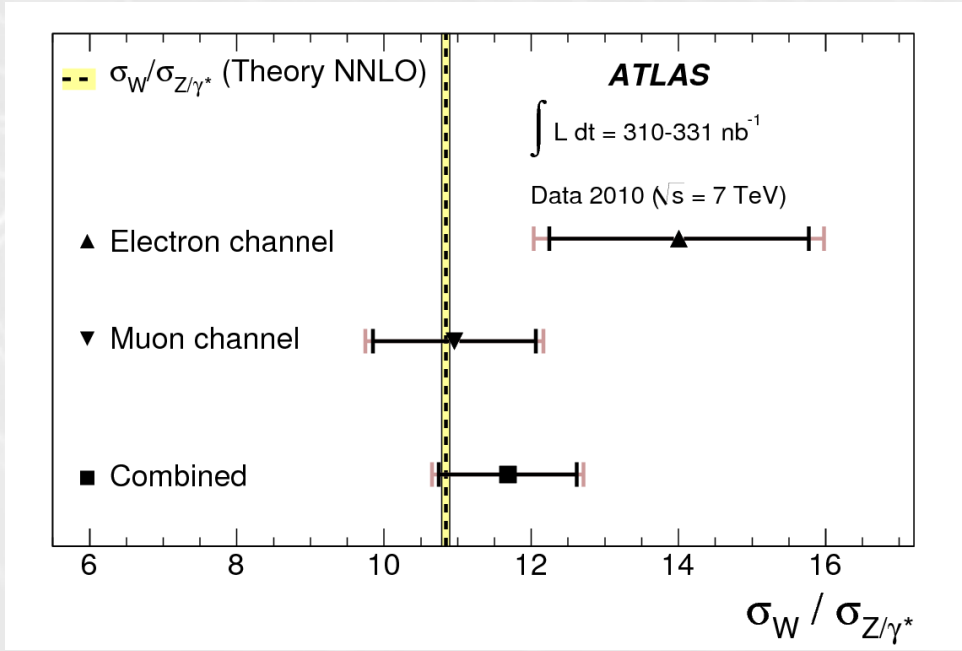


Cross section ratio

W+ W- to Z/γ* ratio compared with NNLO theory predictions

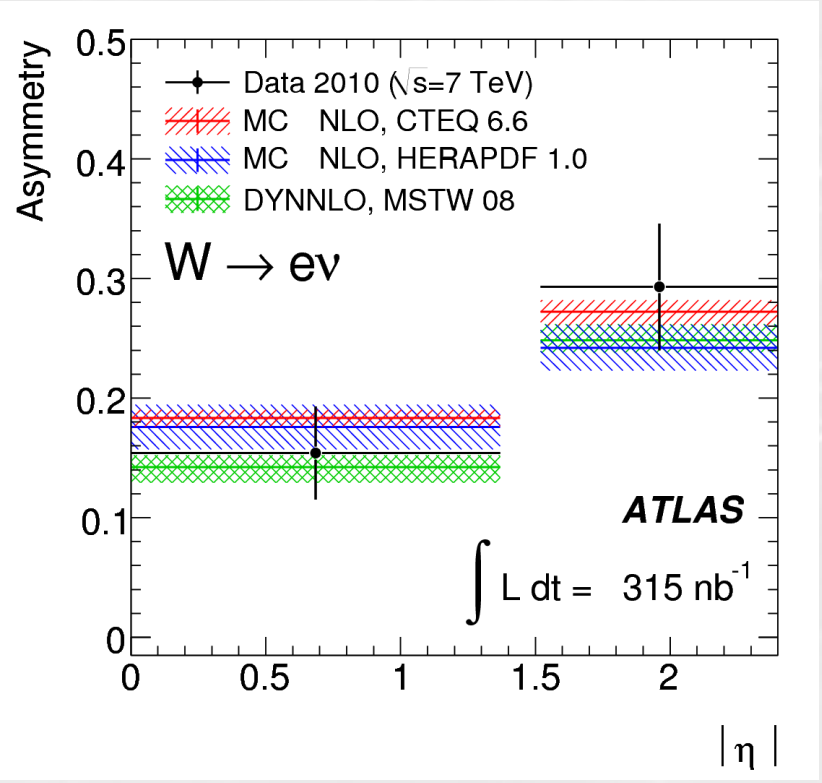


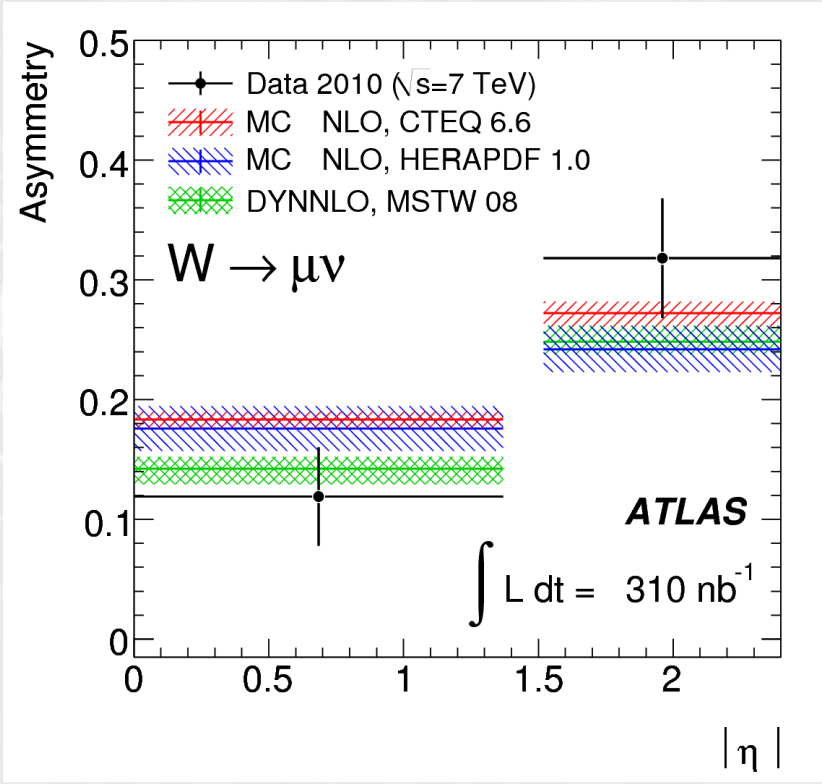


Combined W to Z/γ* ratio compared with NNLO theory predictions

W charge asymmetry

W charge asymmetry in the electron channel





$$A_l = \frac{\sigma^{fiducial}_{W^+} - \sigma^{fiducial}_{W^-}}{\sigma^{fiducial}_{W^+} + \sigma^{fiducial}_{W^-}}$$

W charge asymmetry in the muon channel

So, what was all of this for ..

ATLAS

Measurement of the W→lν and Z/γ* in proton proton collisions at sqrt(7) TeV with the ATLAS detector

Theory

Other experiments

So, what was all of this for ..

Other experiments (cited by similar measurements)

arXiv:1012.2466

Measurements of Inclusive W and Z Cross Sections in pp Collisions at sqrt(s)=7 TeV.

arXiv:1102.5435

Study of Z boson production in PbPb collisions at nucleon-nucleon centre of mass energy = 2.76 TeV.

arXiv:1204.1620

Inclusive W and Z production in the forward region at sqrt(s)=7 TeV.

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Other experiments (cited by similar measurements)

CMS

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CMS

arXiv:1102.5435

Study of Z boson production in PbPb collisions at nucleon-nucleon

So, what was all of this for ..

Other experiments (cited by similar measurements)

LHCb

arXiv:1204.1620

Inclusive W and Z production in the forward region at sqrt(s)=7 TeV.

So, what was all of this for ..

Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in sqrt(s) = 7 TeV proton-proton collisions.

arXiv:1012.1792

Measurement of the top quark-pair production cross section with ATLAS in pp collisions at s ,àö=7 TeV.

arXiv:1110.2299

Search for new phenomena in final states with large jet multiplicities and missing transverse momentum using sqrt(s)=7 TeV pp collisions with the ATLAS detector.

arXiv:1012.5419

Measurement of the centrality dependence of J/{\psi} yields and observation of Z production in lead-lead collisions with the ATLAS detector at the LHC.

arXiv:1103.4344

Search for supersymmetry in pp collisions at sqrt{s} = 7TeV in final states with missing transverse momentum and b-jets.

arXiv:1108.5602

Performance of Missing Transverse Momentum Reconstruction in Proton-Proton Collisions at 7 TeV with ATLAS.

arXiv:1109.5141

Measurement of the inclusive W+- and Z/gamma cross sections in the electron and muon decay channels in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector.

ATLAS

So, what was all of this for ..

arXiv:1109.6572

Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in sqrt(s) = 7 TeV proton-proton collisions.

Understanding the objects performance in a SM process, is the necessary to explore new physics scenarios.

ATLAS

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Measurement of the inclusive W+- and Z/gamma cross sections in the electron and muon decay channels in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector. Updated measurement.

Understanding the objects performance in a SM process,
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ATLAS

So, what was all of this for ..

Theory

arXiv:1101.1300

Impact of Heavy Quark Masses on Parton Distributions and LHC Phenomenology.

-> Comparison with predicted cross sections from theoretical PDF.

arXiv:1011.3540

FEWZ 2.0: A code for hadronic Z production at next-to-next-to-leading order.

-> Comparison with predicted cross section from NNLO MC generator.

arXiv:1101.5057

TMD Parton Distribution and Fragmentation Functions with QCD Evolution.

-> Comparison with predicted cross section from Transverse Mom. Dependent PDF

arXiv:1011.6259

NNLO Benchmarks for Gauge and Higgs Boson Production at TeV Hadron Colliders.

-> Comparison with NNLO predictions

arXiv:1106.5788

Parton distribution function dependence of benchmark Standard Model total cross sections at the 7 TeV LHC.

-> Complementary information for PDF discussions.

arXiv:1204.6038

Displaced Supersymmetry.

-> Complementary information for Electron and Muon selection in an exotic search.

arXiv:1206.7024

Physics at the LHC -- From Standard Model measurements to Searches for New Physics.

-> Listed as one of the 2010-2011 major ATLAS results. Its implication on NNLO cross section was discussed.

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-> Listed as one of the 2010-2011 major ATLAS results. Its implication on NNLO cross section was discussed.

Summary

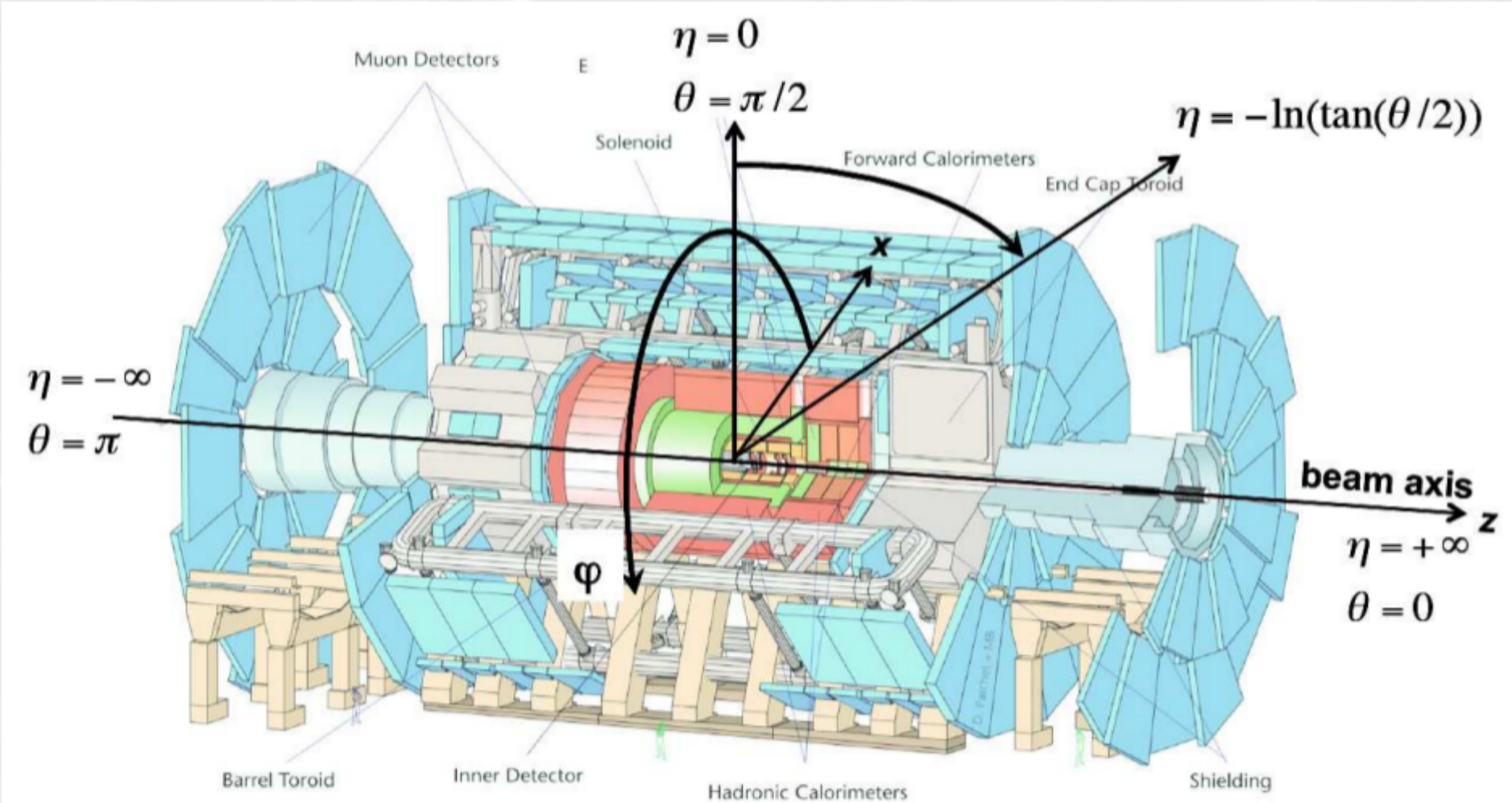
- Understanding the performance of the leptons in the ATLAS detector by using an SM process, is a necessary benchmark in order to explore new physics scenarios.
- The cross section measurement constrains NNLO cross section calculations.
- The observed W charge asymmetry provides important information about the PDF of the protons.

Thanks to Elzbieta for her valuable feedback and suggestions !!

REFERENCES

The ATLAS Collaboration, *Measurement of the* W $\to \ell\nu$ *and* $Z/\gamma^\star \to \ell\ell$ *production cross sections in proton-proton collisions at* $\sqrt{s} = 7$ *TeV with the ATLAS detector*, JHEP 1012 (2010) 060, arXiv:1010.2130.

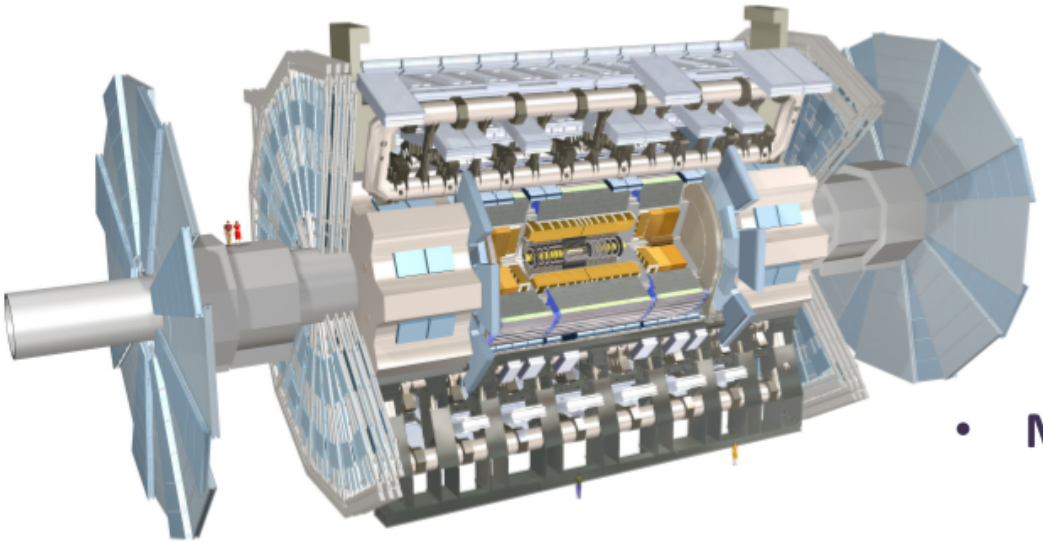
COLLIDER KINEMATICS



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

OBJECT DEFINITION

- **MUON**
  - $p_T > 20$ GeV
  - $|\eta| < 2.4$
  - **Combined muons**: Track in Inner Detector and Muon System
  - Vertex cuts
  - Relative track **isolation**



- **ELECTRON**
  - $E_T > 20$ GeV
  - **Central: $|\eta| < 2.47$**
    - **Excluding** calorimeter transition region **$1.37 < |\eta| < 1.52$**
  - **Forward: $2.5 < |\eta| < 4.9$**
  - **Identification cuts**
    - Shower shapes (central, forward)
    - Track quality and cluster-track matching, E/p (central)
    - Transition Radiation ($|\eta| < 2$)

- **MISSING TRANSVERSE ENERGY**

$$\vec{E}_T^{miss} = -\sum_{\text{clusters } i} E_i \hat{n}_i - \vec{p}_T^{\,\mu} + E_{loss}^{\mu} \hat{p}_T^{\mu}$$

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.