# Electroweak results with the ATLAS Data

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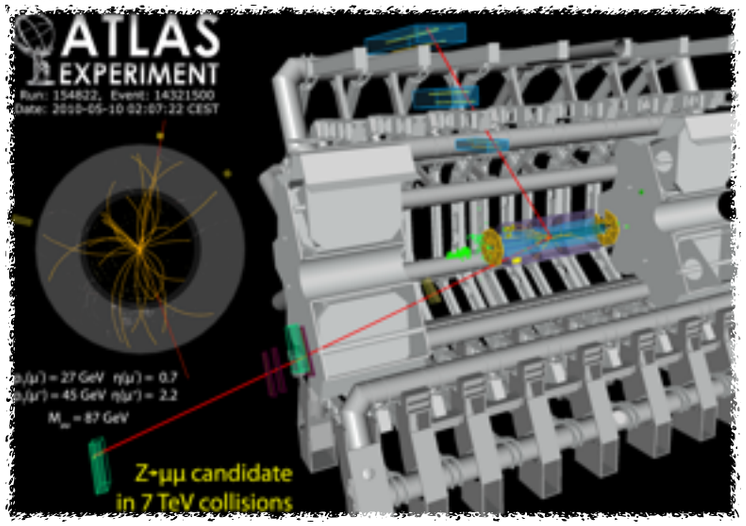
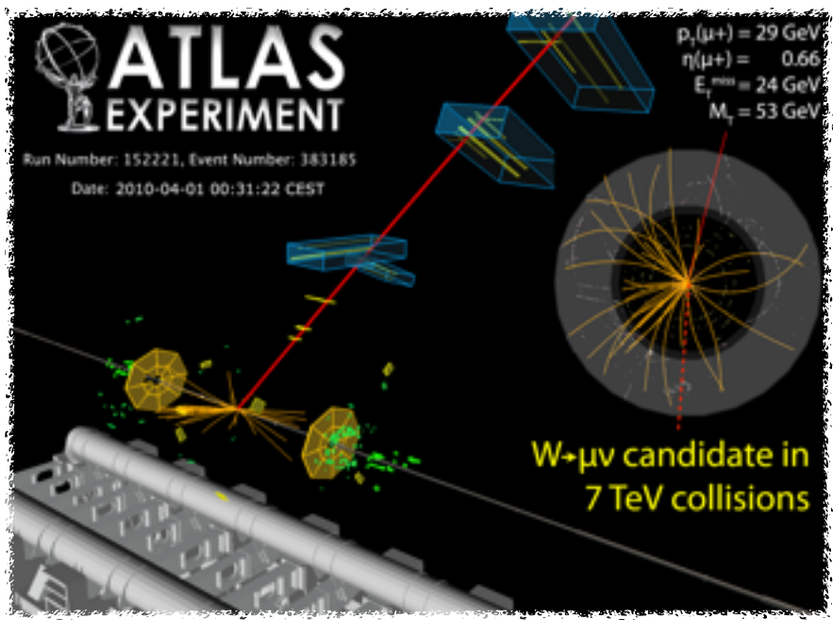
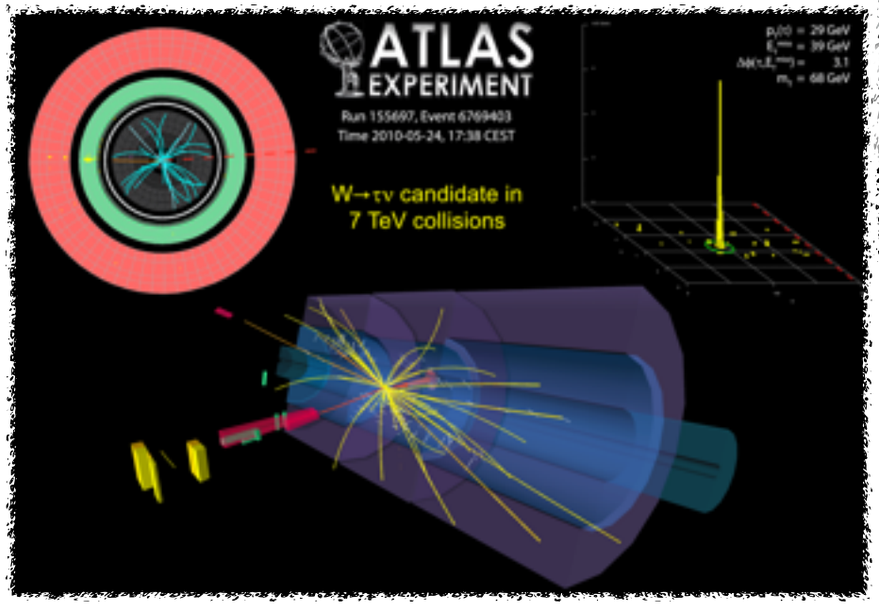
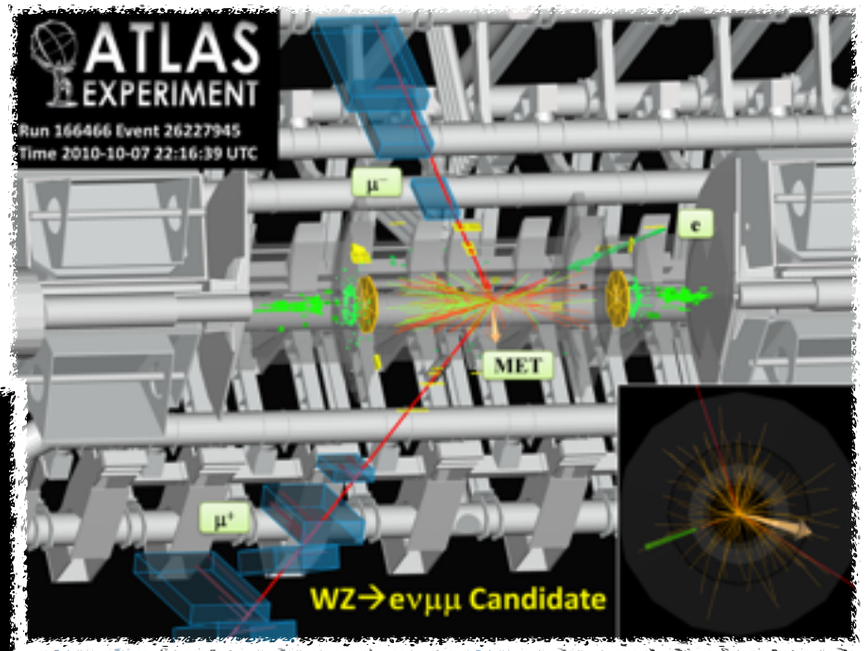
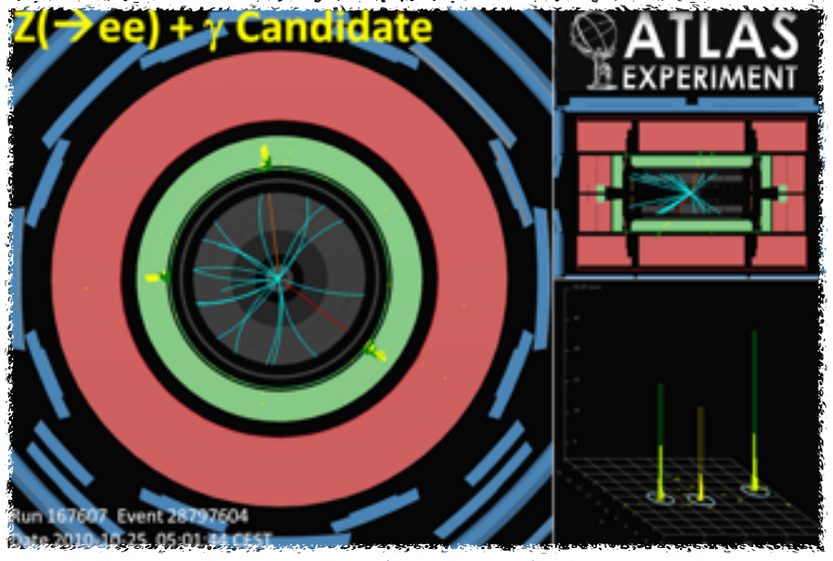
(INFN and Univ. Milano)
on behalf
of the ATLAS Collaboration




ATLAS EXPERIMENT

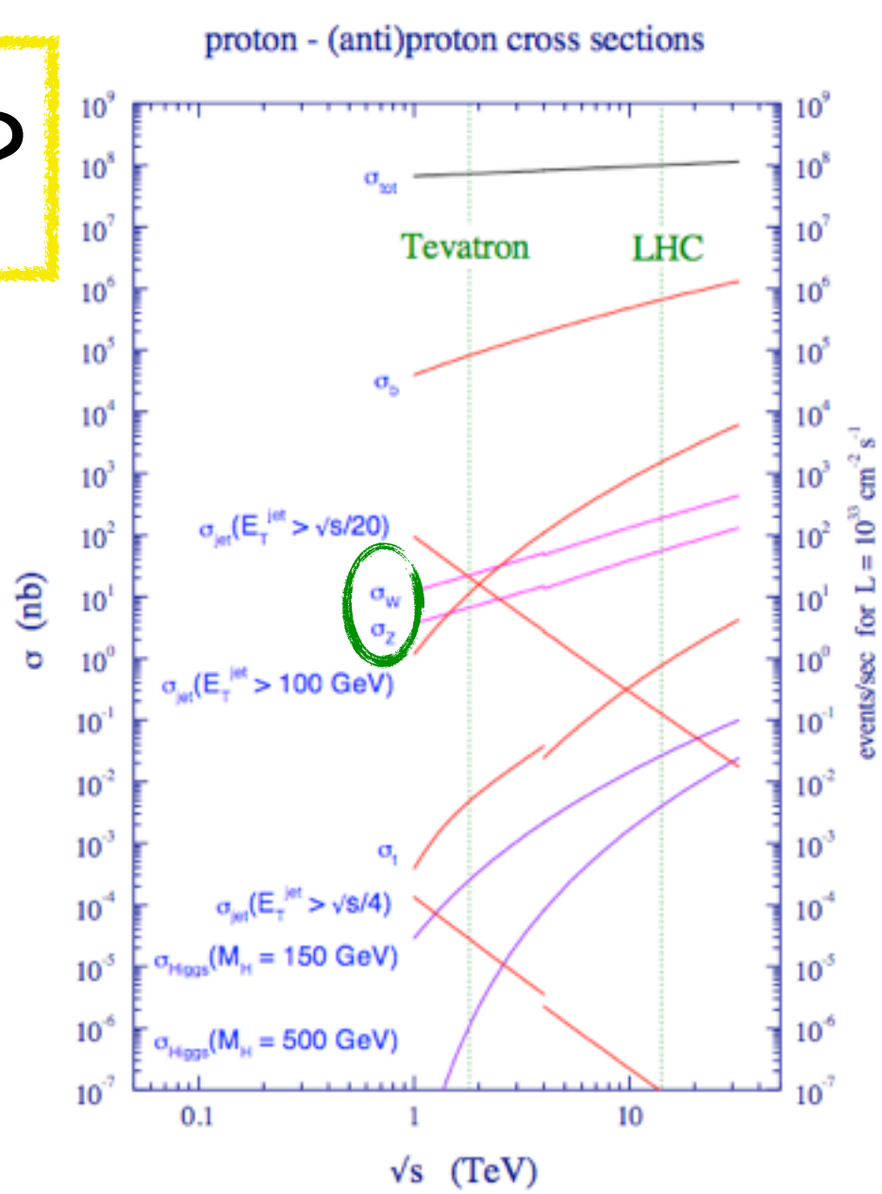
# Outline

- Introduction:
  - The ATLAS Detector
  - 2010 7 TeV proton-proton collision data
  - Cross section measurement
- W and Z bosons cross section measurements
  - inclusive cross sections
  - W and Z in association with jets
  - W charge asymmetry
- Di-bosons cross section measurements
- Summary of results

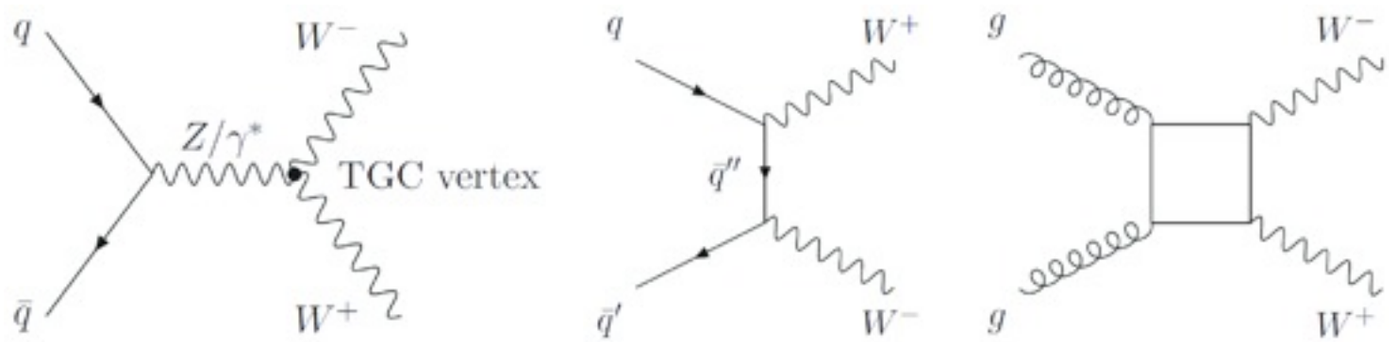
# Why Electroweak physics?

- W and Z final states are interesting:
  - they are the "standard candle" used to get to know our detector, i.e. **understand** and **calibrate** it (object identification and reconstruction, energy scale, trigger efficiency...),
  - they are **background** to searches for new particles.

- Di-bosons play an **important** role in electroweak physics:
  - production rate and kinematic distributions are sensitive to the **triple gauge couplings**,
  - important **background** to **Higgs** boson and new physics searches.

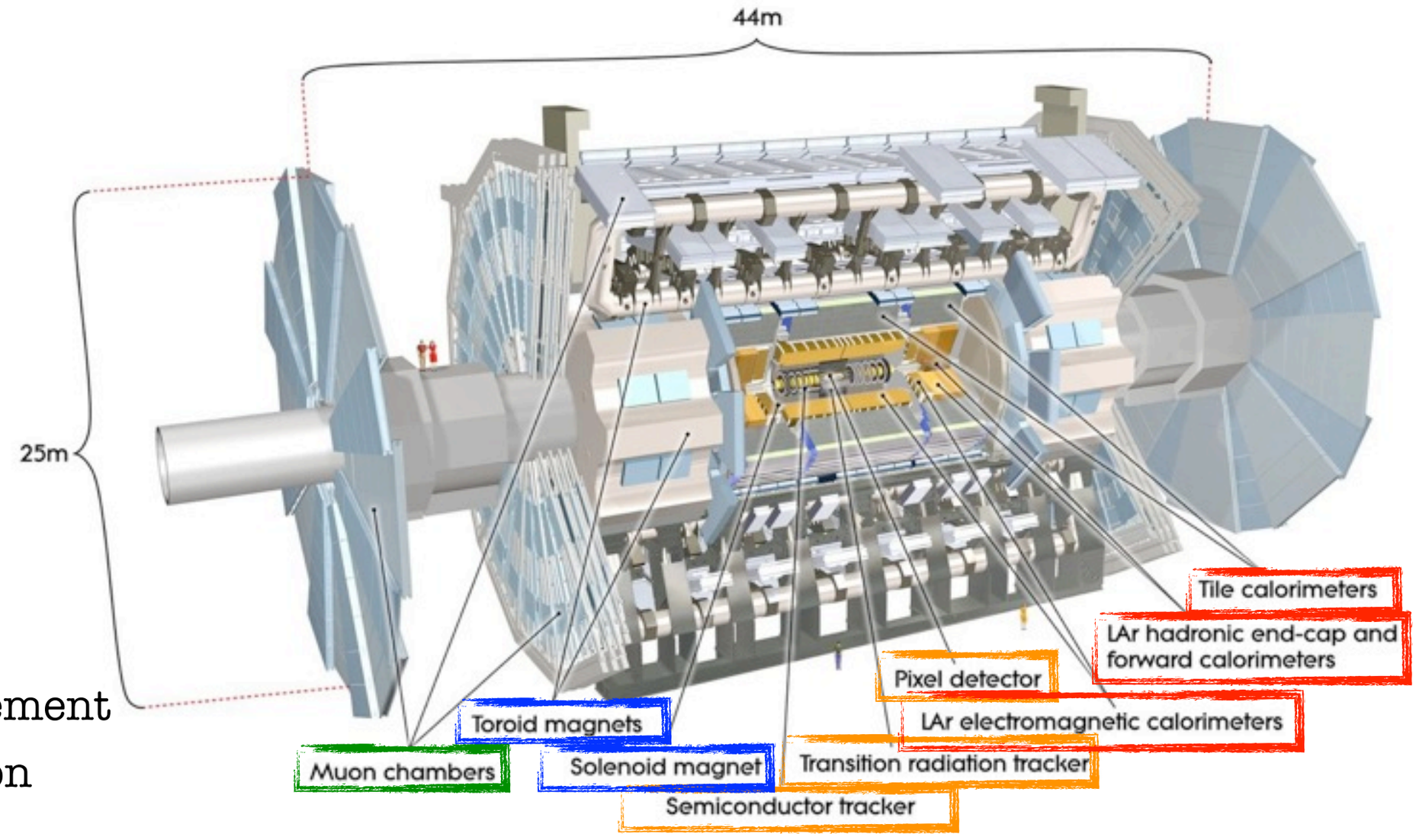



**Example: $W^+W^-$ production**



# The ATLAS Detector

- ATLAS (**A T**oroidal **L**HC **A**pparatu**S**) is one of the two multi-purpose experiments at the LHC.




- **Tracking system**:
  - charged particles momentum measurement
  - vertex reconstruction
- **Solenoid**
- **Calorimeter system**
- **Toroid**
- **Muon system**

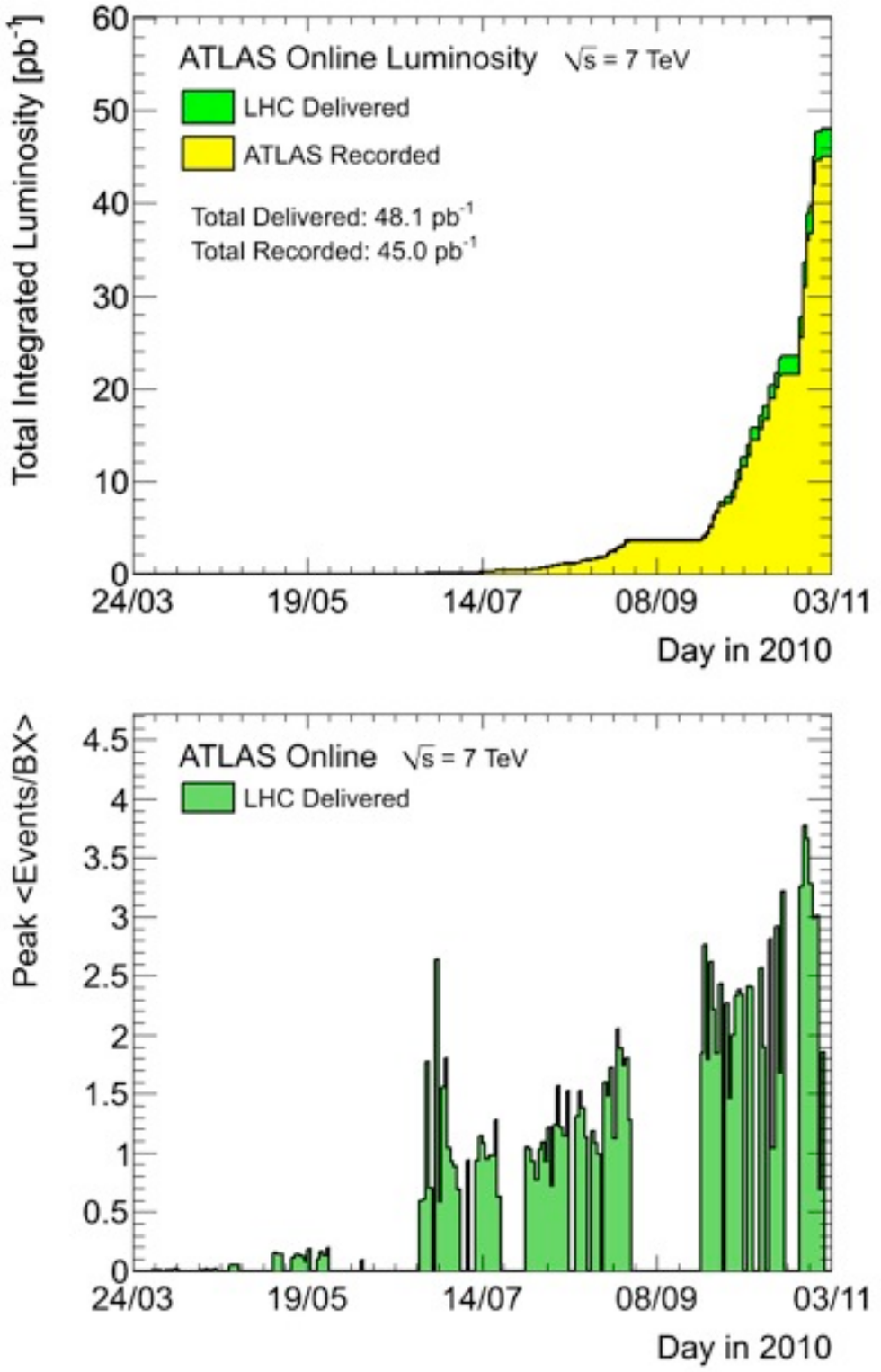
see N.Benekos' talk this morning

# ATLAS 2010 Data

- In the year 2010 the ATLAS Experiment has collected 45 $pb^{-1}$ of data, corresponding to 93.6% of the integrated luminosity delivered by the LHC.
  - Now, the integrated luminosity is higher than 1 $fb^{-1}$.
- Luminosity weighted relative fraction of good quality data:

| Inner Tracking Detectors | | | Calorimeters | | | | Muon Detectors | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pixel | SCT | TRT | LAr EM | LAr HAD | LAr FWD | Tile | MDT | RPC | CSC | TGC |
| 99.1 | 99.9 | 100 | 90.7 | 96.6 | 97.8 | 100 | 99.9 | 99.8 | 96.2 | 99.8 |

- During the running of the first year, the **luminosity** profile changed considerably, due to the machine commissioning.
  - Different **pile-up** conditions throughout the year.



# ATLAS Cross Section Measurement

- The cross section is measured using the following formula:

$$\sigma_W^{tot} \cdot BR(W \to l\nu) = \frac{N_{obs} - N_{bkg}}{A_W \cdot C_W \cdot \mathcal{L}}$$

[ Example for W analysis ]

- where:
  - $\mathbf{N_{obs}}$ is the number of events selected in data.
  - $\mathbf{N_{bkg}}$ is the number of background events expected (extracted from data or from Monte Carlo, depending on the analysis).
  - $\mathbf{L}$ is the integrated luminosity.
  - $\mathbf{A_W}$ denotes the kinematic and geometric acceptance for the signal process. It is determined from generator level Monte Carlo.
  - $\mathbf{C_W}$ is the ratio between the number of reconstructed events passing the selections of the analysis and the number of events within the fiducial acceptance.

- The cross section is also measured in the fiducial region:

$$\sigma_W^{fid} \cdot BR(W \to l\nu) = \frac{N_{obs} - N_{bkg}}{C_W \cdot \mathcal{L}}$$

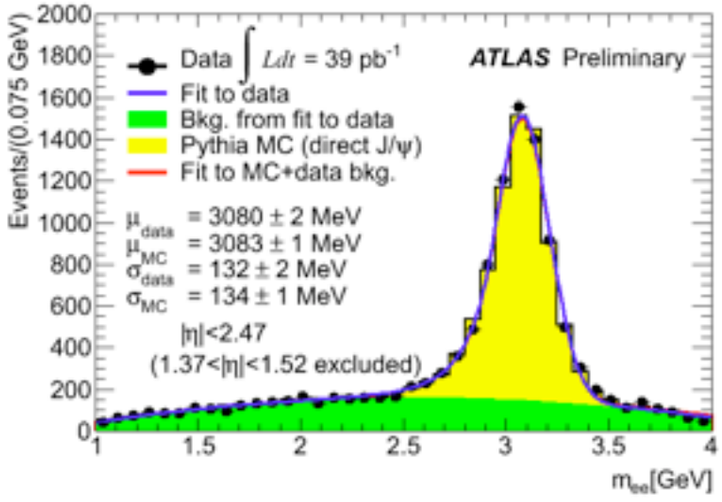
[not shown in the following]

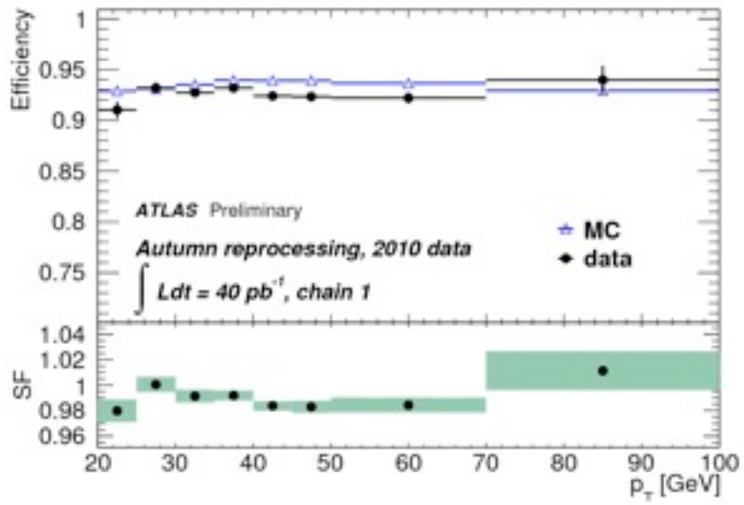
- This cross section is not affected by significant theoretical uncertainties.
- Future improvements on the prediction of the acceptance can be used to extract improved total cross section measurements.

  - Example for $\mathbf{W \to e\nu}$ :
    - $E_T^e > 20$GeV,
    - $|\eta| < 2.47$,
    - excluding $1.37 < |\eta| < 1.52$,
    - $p_T^\nu > 25$ GeV,
    - $m_T > 40$ GeV.
  - Example for $\mathbf{Z \to \mu\mu}$ :
    - $p_T^\mu > 20$ GeV,
    - $|\eta| < 2.4$,
    - $66 < m_{\mu\mu} < 116$ GeV.

# Remarks

- In the following, analyses including final states with W and Z bosons will be shown, mainly in **leptonic** channels.
  - Therefore, electron and muon reconstruction and identification are essential.
    - Electrons:
      - identification efficiency known at the 1% level,
      - energy scale uncertainty < 1%.
    - Muons:
      - reconstruction efficiency uncertainty <0.2/0.4%,
      - momentum scale uncertainty < 2%.



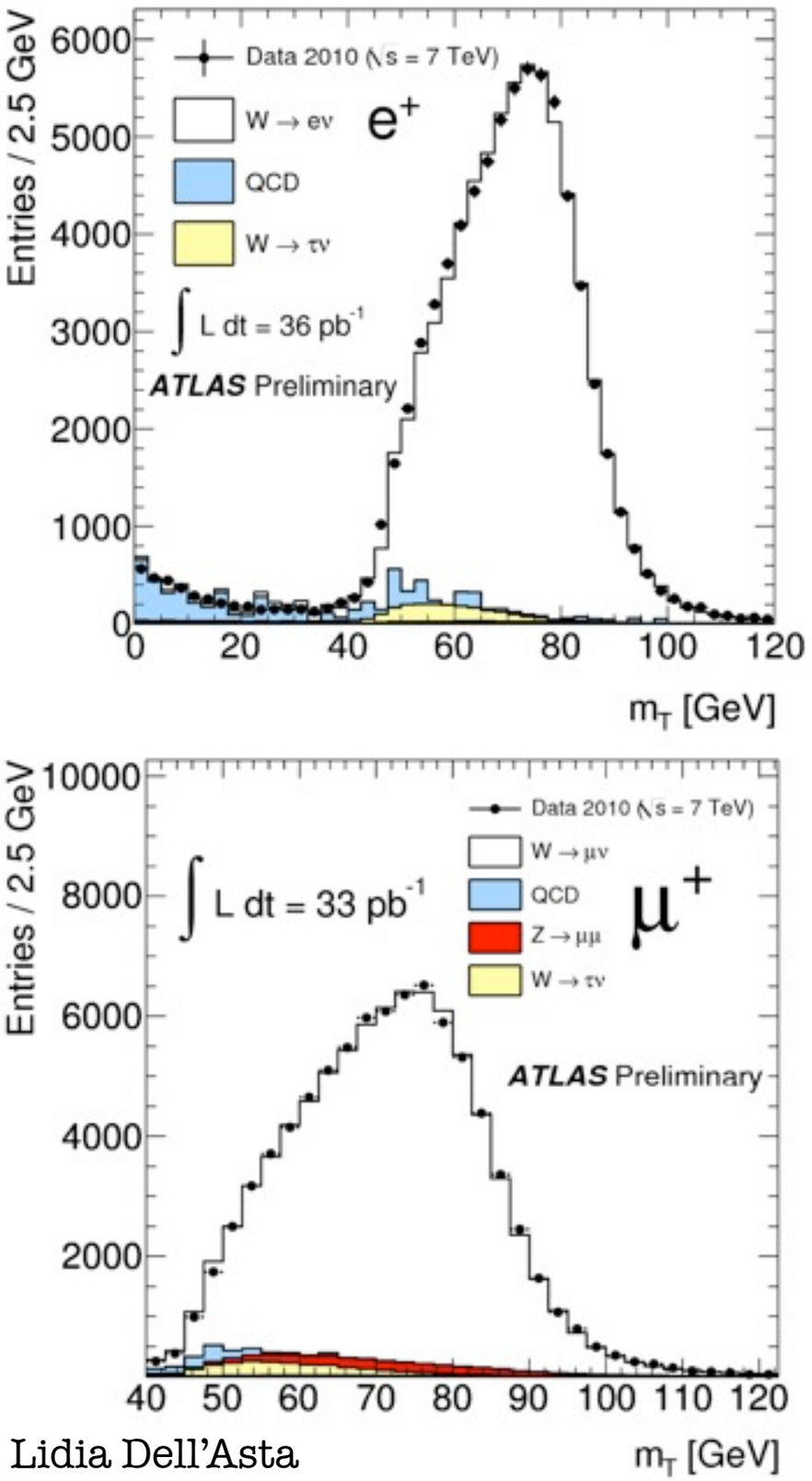




- Another key aspect of the analysis presented in the following is the **evaluation** of the **background**: data-driven techniques have been developed in different analysis.
  - 2D side-band methods (e.g. QCD background for $Z \rightarrow \tau\tau$ cross section),
  - fitting data with templates from either data or simulation (e.g. QCD background for W+jets analysis).

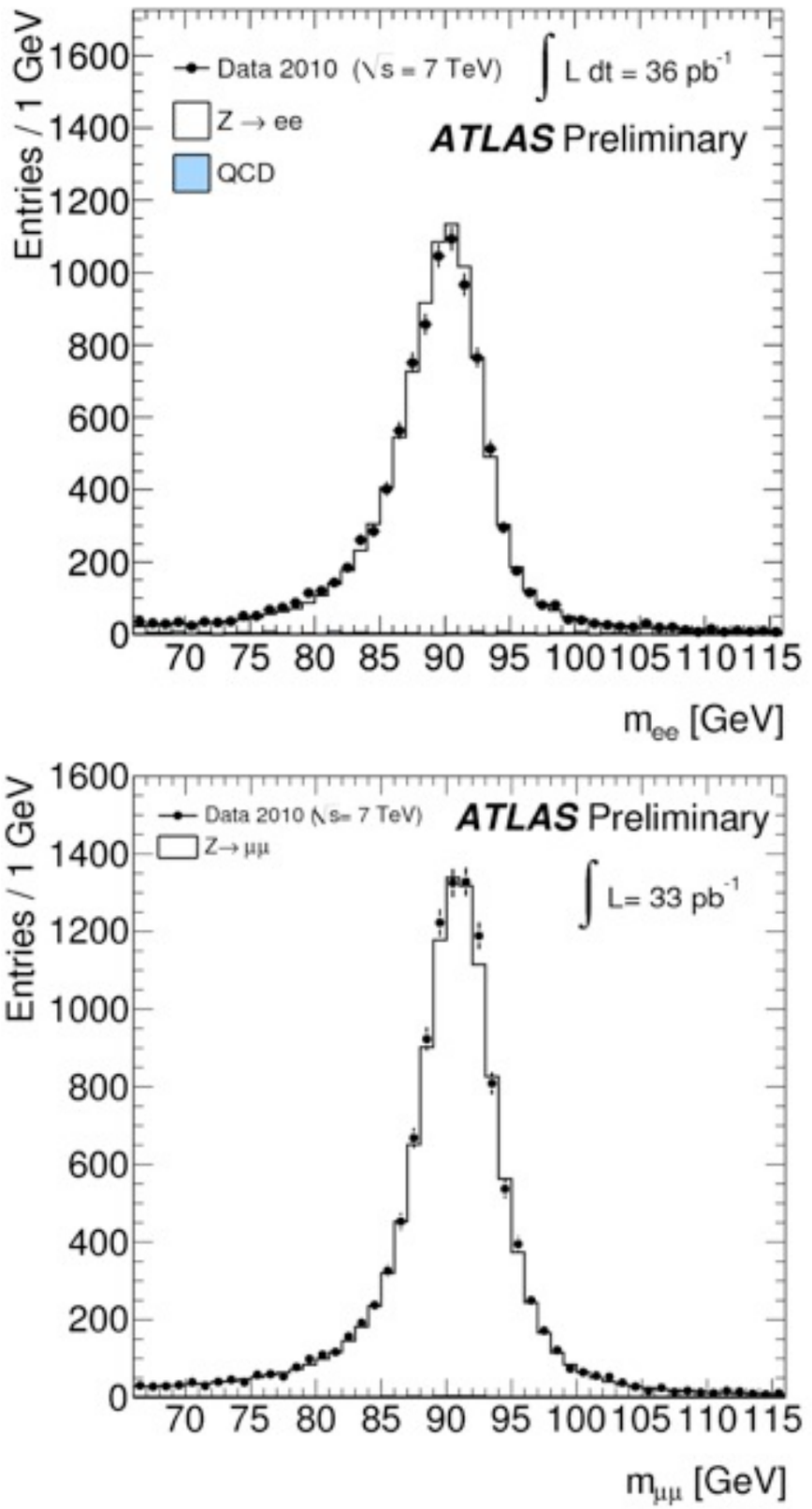
# W and Z bosons production

- In the following:
  - W and Z/$\gamma^*$ production cross section
  - $Z \rightarrow \tau\tau$ cross section
  - W+jets and Z+jets cross section
  - W charge asymmetry measurement

# W and Z/γ* cross section



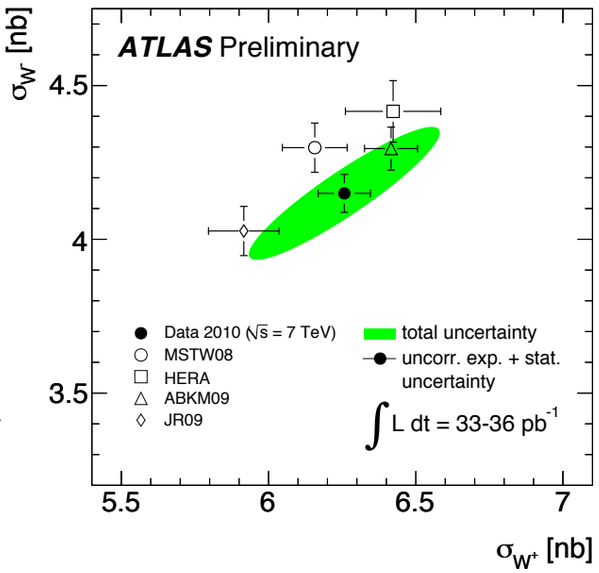

- **W → eν/μν analysis**:
  - the **signature** is one lepton and missing energy from the neutrino.
- **Z → ee/μμ analysis**:
  - the **signature** is two opposite charged leptons.
- **Background** estimate:
  - EW background from Monte Carlo,
  - QCD background extracted from data.

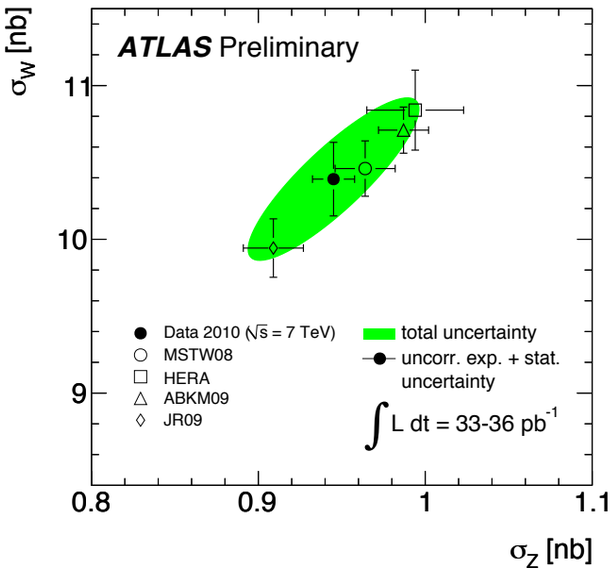


# W and Z/γ* cross section

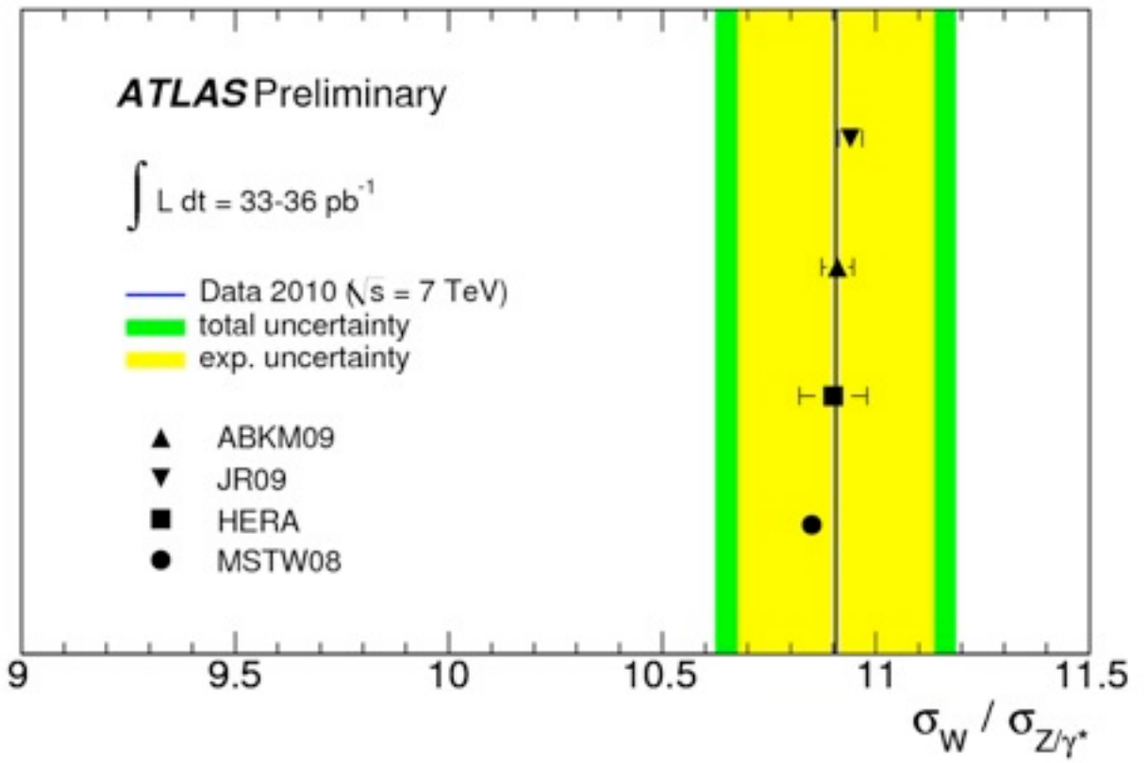
- Main **systematic** come from:
  - electron reconstruction and identification (~1.5/3%)
  - missing energy scale (2% for W channels)

  anyway, **smaller** than the systematic on **luminosity** (3.4%).
- The **systematic** on the **acceptance** (~3/4%) evaluated taking into account three contributions:
  - uncertainties within one PDF set were derived using the CTEQ 6.6 PDF,
  - uncertainties were found between different PDF sets (maximal difference between the MRST LO*, CTEQ 6.6 and HERAPDF 1.0 sets),
  - difference obtained between the PYTHIA and MC@NLO simulations, using the same PDF set, CTEQ 6.6.



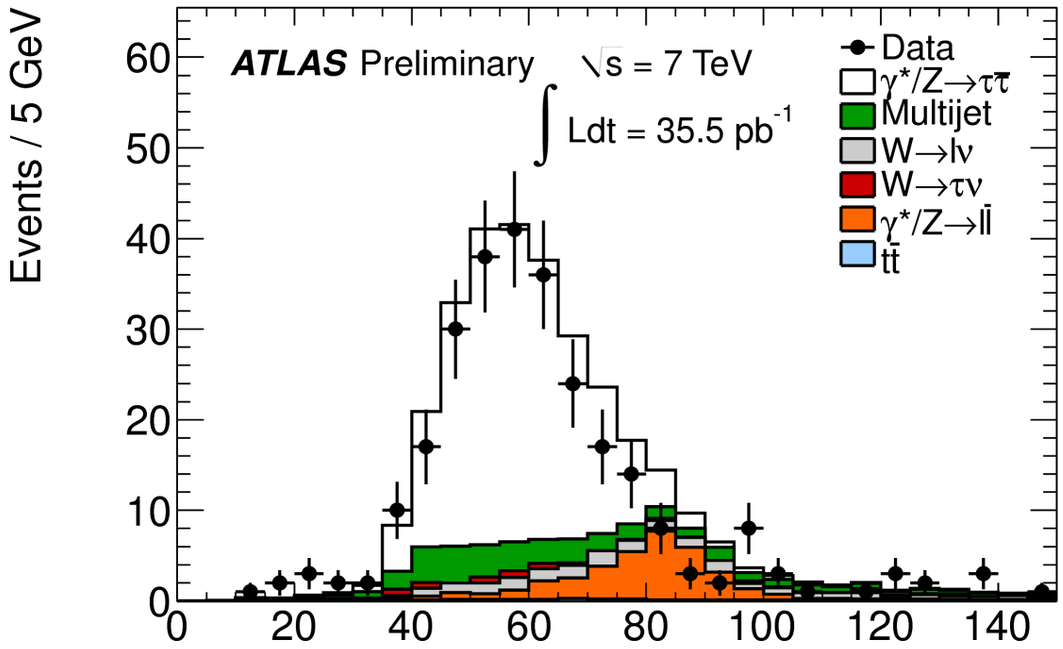

| | $\sigma^{\text{tot}}_{W^{(\pm)}} \cdot \text{BR}(W \to \ell\nu)$ [nb] |
|---|---|
| $W^+$ | $6.257 \pm 0.017(\text{sta}) \pm 0.152(\text{sys}) \pm 0.213(\text{lum}) \pm 0.188(\text{acc})$ |
| $W^-$ | $4.149 \pm 0.014(\text{sta}) \pm 0.102(\text{sys}) \pm 0.141(\text{lum}) \pm 0.124(\text{acc})$ |
| $W$ | $10.391 \pm 0.022(\text{sta}) \pm 0.238(\text{sys}) \pm 0.353(\text{lum}) \pm 0.312(\text{acc})$ |
| | $\sigma^{\text{tot}}_{Z/\gamma^*} \cdot \text{BR}(Z/\gamma^* \to \ell\ell)$ [nb], $66 < m_{ee} < 116$ GeV |
| $Z/\gamma^*$ | $0.945 \pm 0.006(\text{sta}) \pm 0.011(\text{sys}) \pm 0.032(\text{lum}) \pm 0.038(\text{acc})$ |



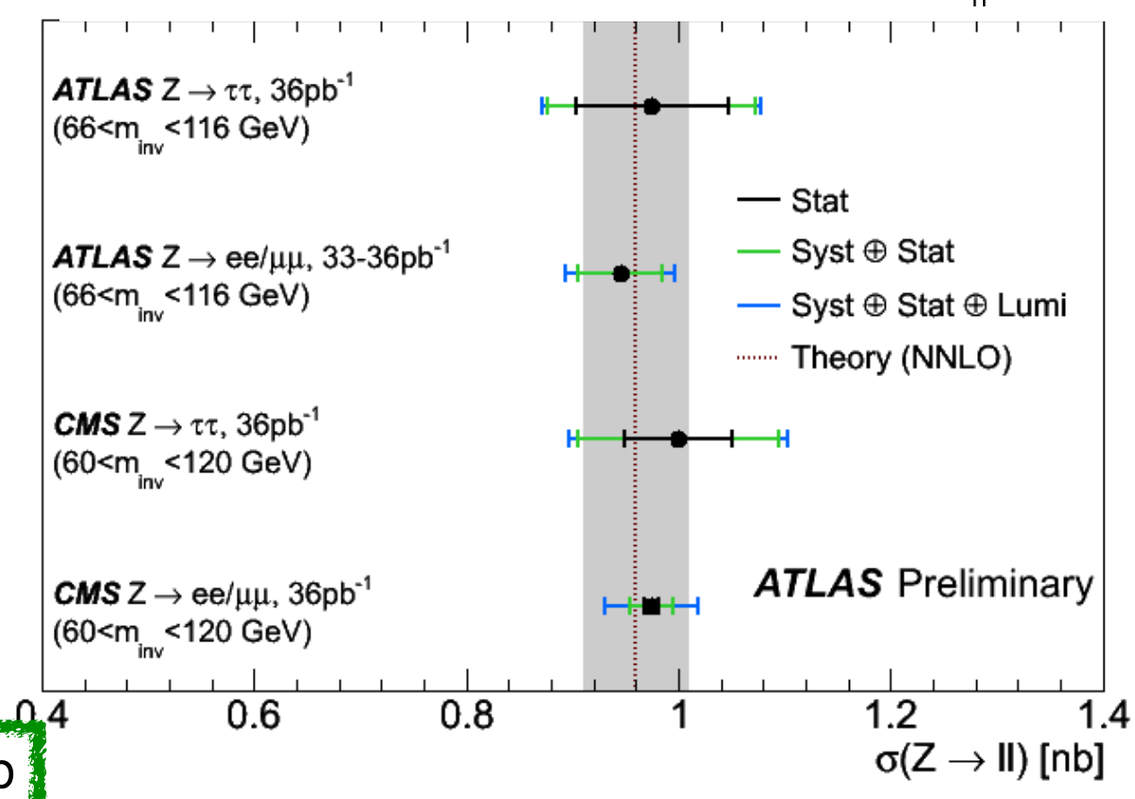

ATLAS-CONF-2011-041

# $Z \to \tau\tau$ cross section measurement

- Cross section measurement of $Z \to \tau\tau$ production, combining **di-lepton** and **lepton-hadron** channels.
- Event selection:
  - single lepton trigger
  - one electron with $p_T > 16$ GeV or muon with $p_T > 15$ GeV
  - one tight $\tau_h$ with $p_T > 20$ GeV, 1 or 3 tracks
  - tight lepton isolation
  - $M_T < 50$ GeV and $\Sigma\cos\Delta\phi(l, E_T^{miss}) > -0.15$
  - opposite charge of lepton and $\tau_h$
  - 35 GeV < $m_{visible}$ < 75 GeV
- Main sources of **systematics**:
  - energy scale: ~11%
  - tau identification: ~8.6%



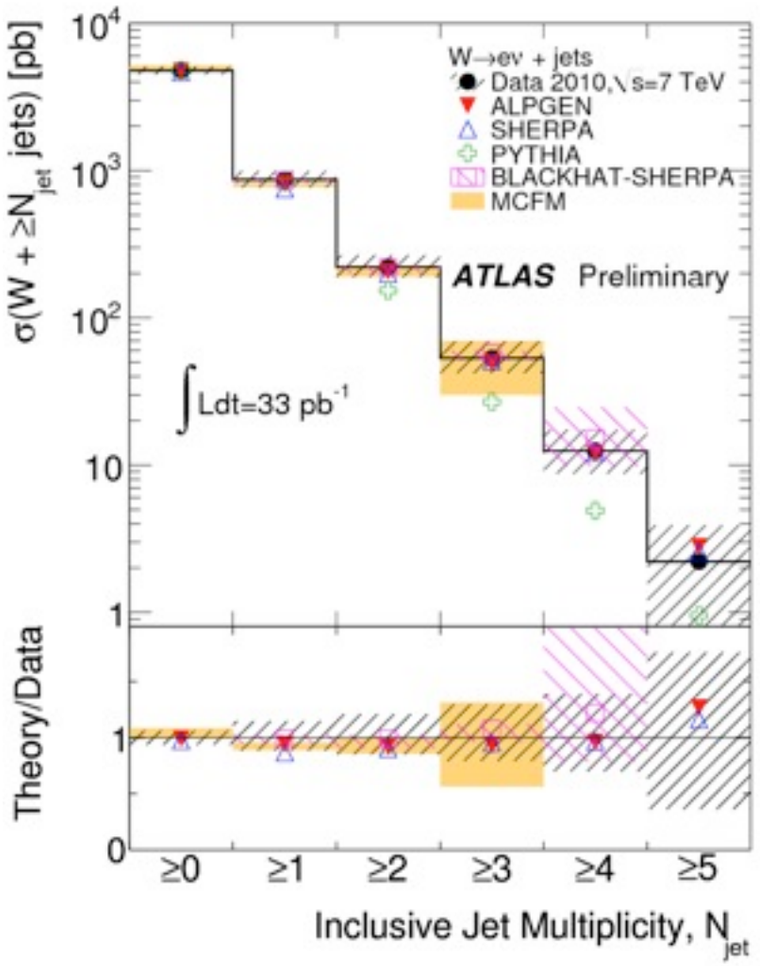

| Final State | Measured Total Cross-section ($66 < m_{inv} < 116$ GeV) |
|---|---|
| $\tau_\mu\tau_h$ | $0.86 \pm 0.08(\text{stat}) \pm 0.12(\text{syst}) \pm 0.03(\text{lumi}) \pm 0.003(\text{theo})$ nb |
| $\tau_e\tau_h$ | $1.14 \pm 0.14(\text{stat}) \pm 0.20(\text{syst}) \pm 0.04(\text{lumi}) \pm 0.004(\text{theo})$ nb |
| $\tau_e\tau_\mu$ | $1.06 \pm 0.14(\text{stat}) \pm 0.08(\text{syst}) \pm 0.04(\text{lumi}) \pm 0.004(\text{theo})$ nb |
| $\tau_\mu\tau_\mu$ | $0.96 \pm 0.22(\text{stat}) \pm 0.13(\text{syst}) \pm 0.03(\text{lumi}) \pm 0.002(\text{theo})$ nb |

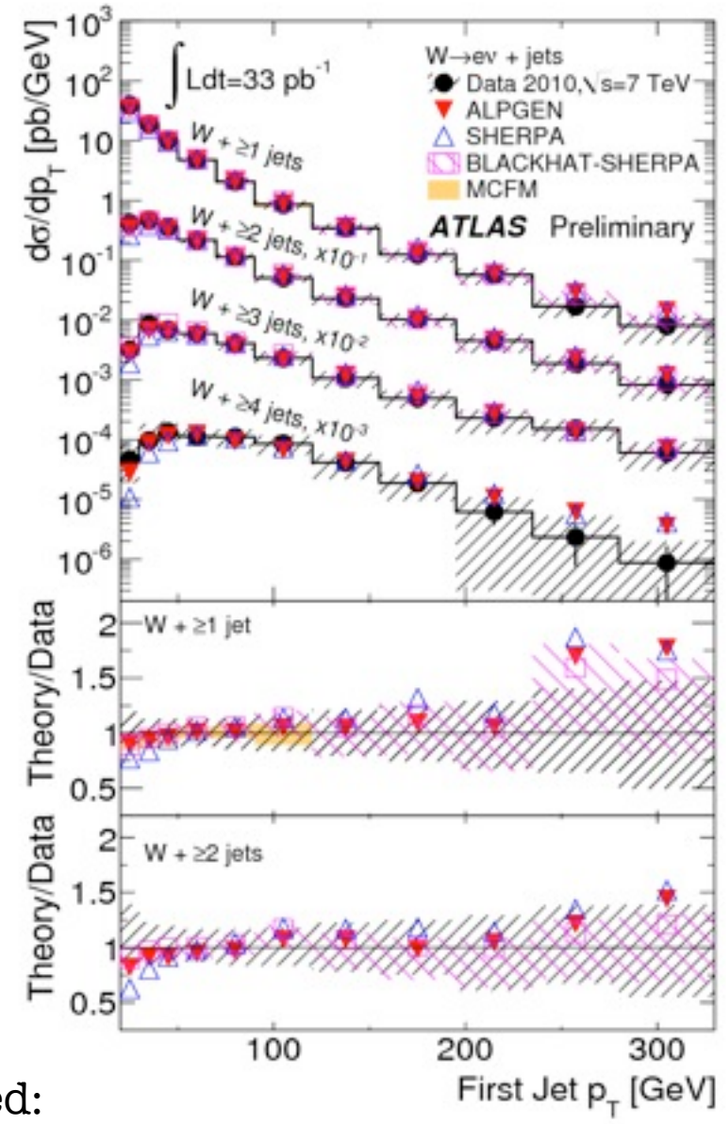



$\sigma_{combined} = 0.97 \pm 0.07$ (stat.) $\pm 0.07$ (syst.) $\pm 0.03$ (lumi.) nb

# W+jets production

- The study of massive vector bosons production in association with one or more jets is interesting as:
  - it is an important test of QCD,
  - these channels are background to SM processes (e.g. ttbar) and to Higgs boson searches.
- W+jets studied both in **electron** and **muon** channels.
- **Jets** are reconstructed with **anti-$k_t$** algorithm with radius parameter $\Delta R=0.4$.
  - $p_T > 20$ GeV
  - $|y| < 2.8$
  - lepton-jet overlap removal within $\Delta R < 0.5$.
- The **event selection** is based on:
  - single lepton trigger
  - one isolated lepton ($E_T > 20$ GeV)
  - no additional leptons
  - high missing transverse energy.



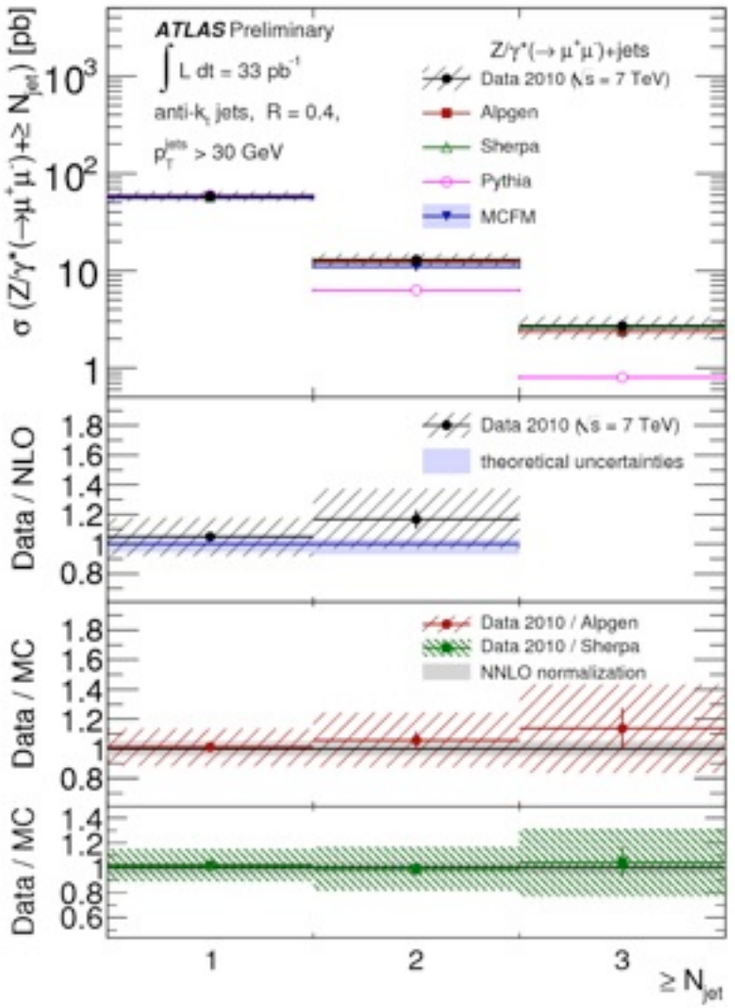

- Background was estimated:
  - QCD: through data fitting with templates
  - leptonic background: from Monte Carlo
- Main **systematics** from:
  - jet energy scale: ~9%
  - pile-up: ~7%

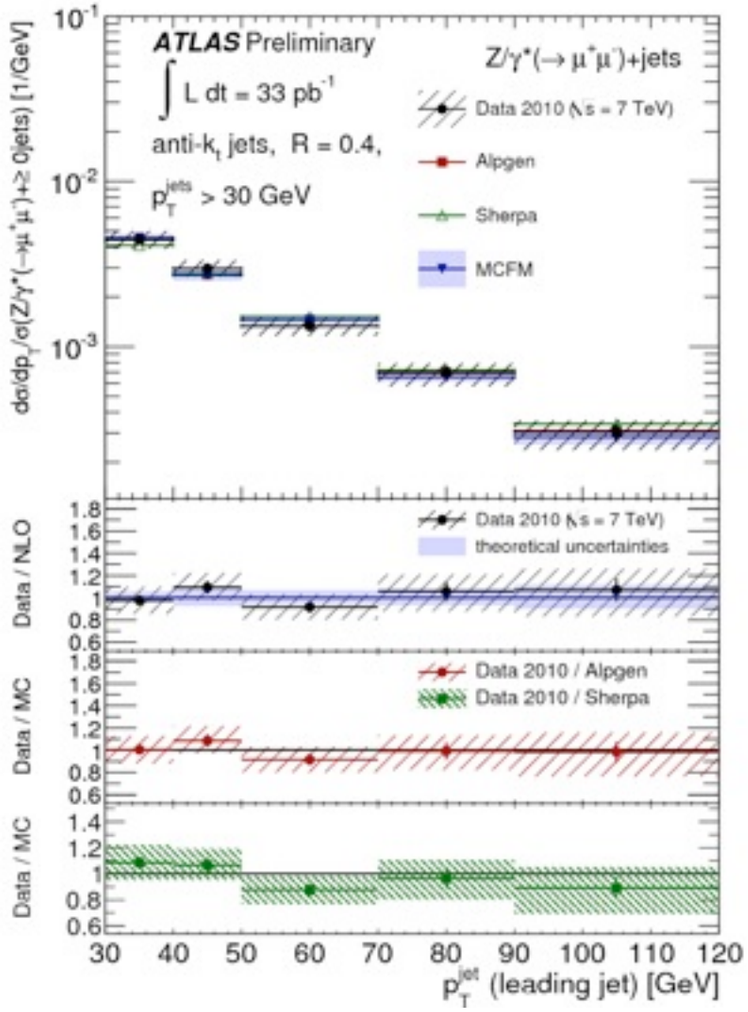
ATLAS-CONF-2011-060

# Z+jets production

- Z+jets studied both in **electron** and **muon** channels.
- **Jets** are reconstructed with **anti-$k_t$** algorithm with radius parameter $\Delta R=0.4$.
  - $p_T > 30$ GeV
  - $|\eta| < 2.8$
  - lepton-jet overlap removal within $\Delta R < 0.5$.
- The **event selection** is based on:
  - single lepton trigger
  - two opposite charge leptons ($E_T > 20$ GeV)
  - $66 < m_{ll} < 116$ GeV.

ATLAS-CONF-2011-042



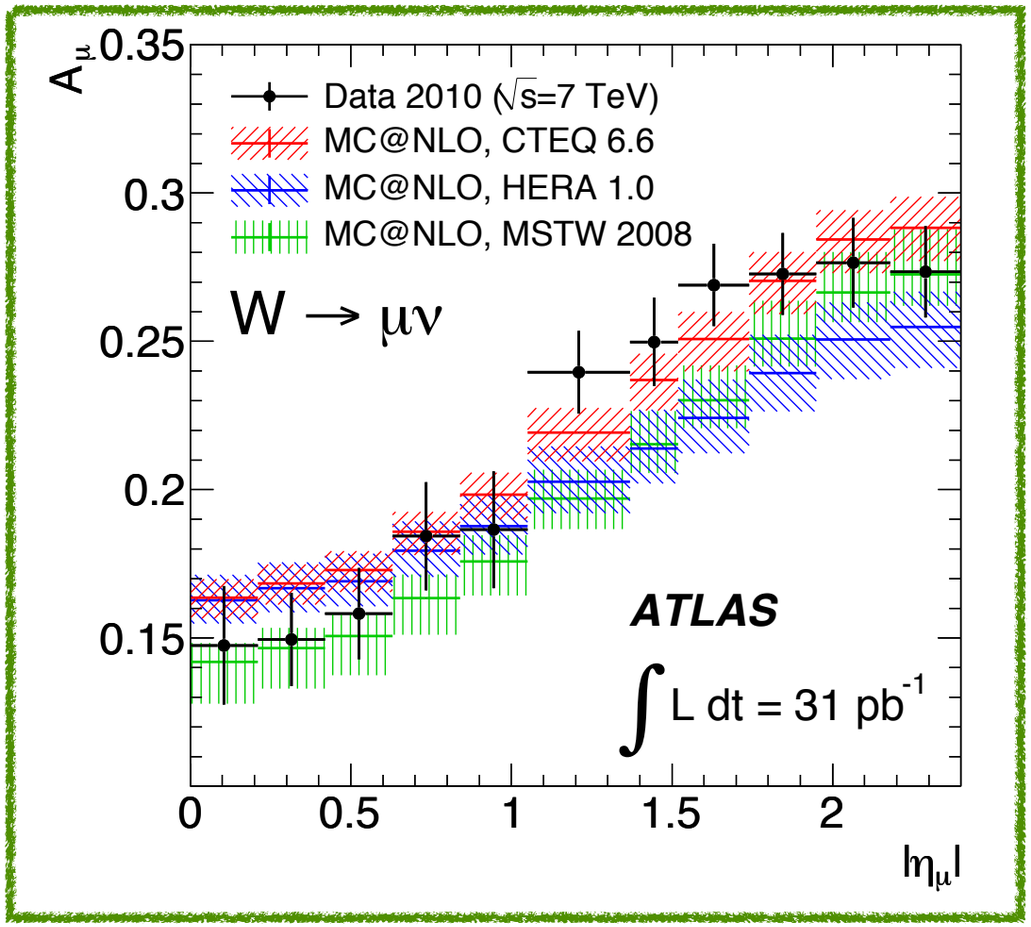

- Background was estimated:
  - QCD: from data in electron channel and from MC in the muon channel
  - others: from Monte Carlo
- Main **systematics** from:
  - jet energy scale: ~10/20%

# W charge asymmetry

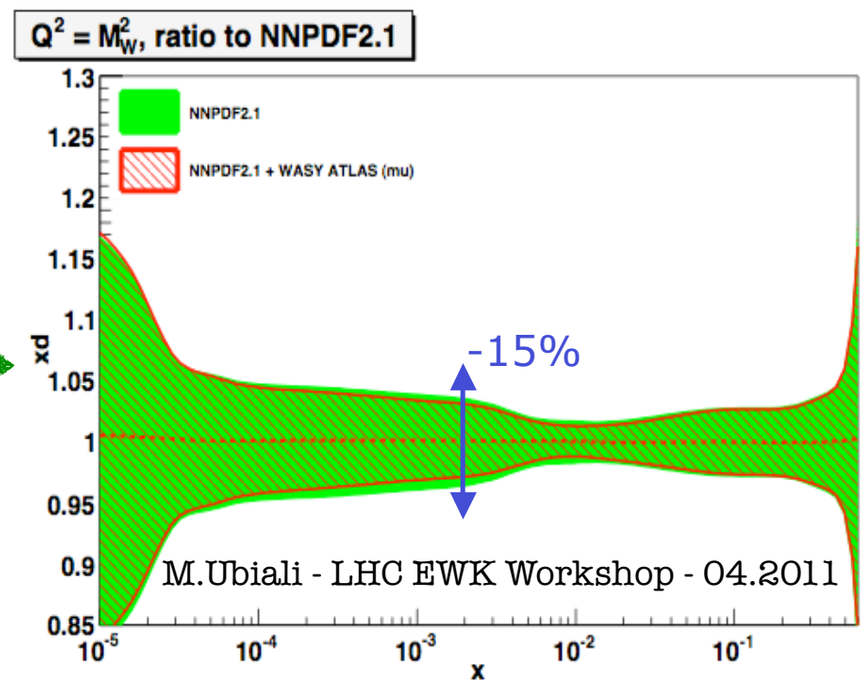
- The measurement of W charge asymmetry is important as it is sensitive to **valence quark distribution**.

$$A_\mu = \frac{d\sigma_{W\mu+}/d\eta_\mu - d\sigma_{W\mu-}/d\eta_\mu}{d\sigma_{W\mu+}/d\eta_\mu + d\sigma_{W\mu-}/d\eta_\mu}$$

  - The measurement at the LHC can contribute to the **understanding** of **PDFs** in the low x rage.
- The charge asymmetry has been studied in the **muon** channel.
  - Similar selection as the cross section measurement.
- Main **systematics** from:
  - Trigger and reconstruction: ~6-10%
  - Background: ~1-2%
  - $p_T$ scale and resolution: ~2-5%
- **$\chi$2 comparison** between measurement uncertainty and PDF predictions:
  - CTEQ: 9.16/11
  - HERA: 35.81/11
  - MSTW: 27.31/11




Measurement is input to PDF fits



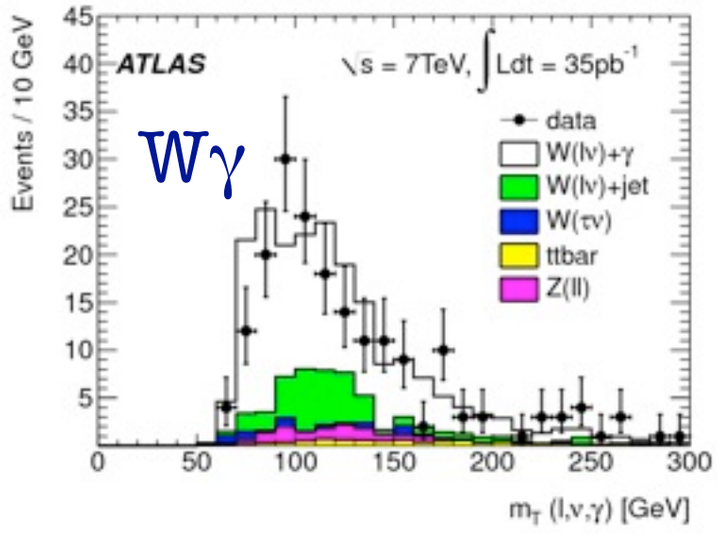

arXiv:1103.2929
Submitted to PLB

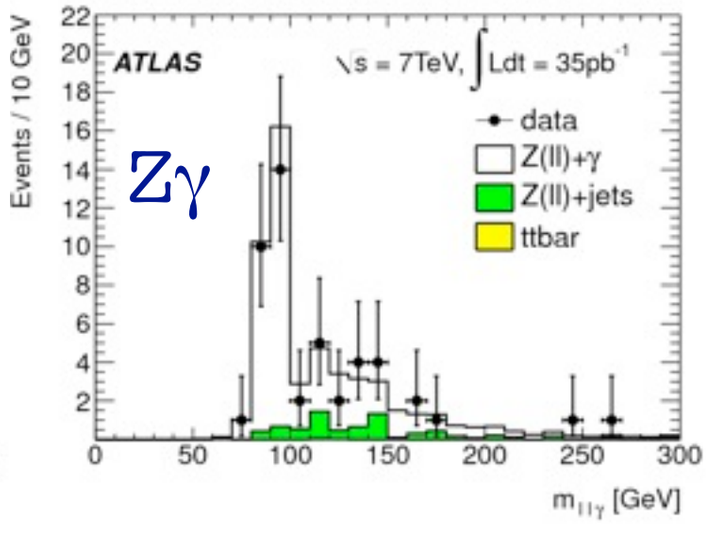
# Di-bosons productions

- In the following:
  - $W\gamma$ and $Z\gamma$ production
  - $W^+W^-$ production
  - $W^{\pm}Z$ production

# Wγ and Zγ production

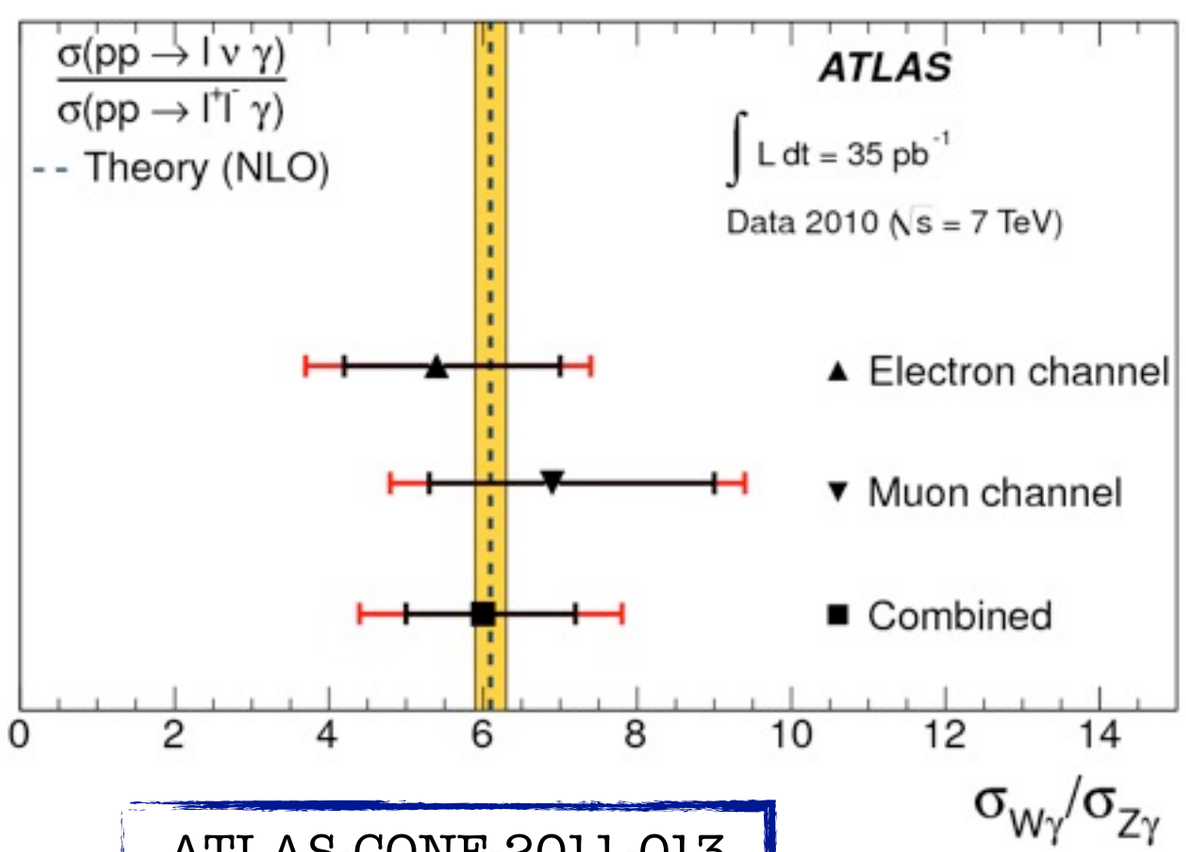
- The measurement of W and Z in association with high energy photons provide important tests of the Standard Model.
  - Physics beyond the SM would enhance those cross sections.
- **Leptonic** channels are considered.
- The **event selection** is based on the presence of one high $p_T$ lepton and one high $E_T$ photon and:
  - for Wγ: $E_T$miss > 25 GeV and $m_T(l,\nu)$ > 40 GeV
  - for Zγ: m(l,l) > 40 GeV
  - suppression of photons from FSR with isolation cut
- The main **systematic** uncertainties come from:
  - photon reconstruction and identification efficiency (~11%)




| | $\sigma$[pb] |
|---|---|
| $pp \to e^{\pm}\nu\gamma$ | $48.9 \pm 6.6 \pm 8.3 \pm 1.7$ |
| $pp \to \mu^{\pm}\nu\gamma$ | $38.7 \pm 5.3 \pm 6.4 \pm 1.3$ |
| $pp \to l^{\pm}\nu\gamma$ | $42.5 \pm 4.2 \pm 7.2 \pm 1.4$ |
| $pp \to e^{+}e^{-}\gamma$ | $9.0 \pm 2.5 \pm 2.1 \pm 0.3$ |
| $pp \to \mu^{+}\mu^{-}\gamma$ | $5.6 \pm 1.4 \pm 1.2 \pm 0.2$ |
| $pp \to l^{+}l^{-}\gamma$ | $6.4 \pm 1.2 \pm 1.6 \pm 0.2$ |

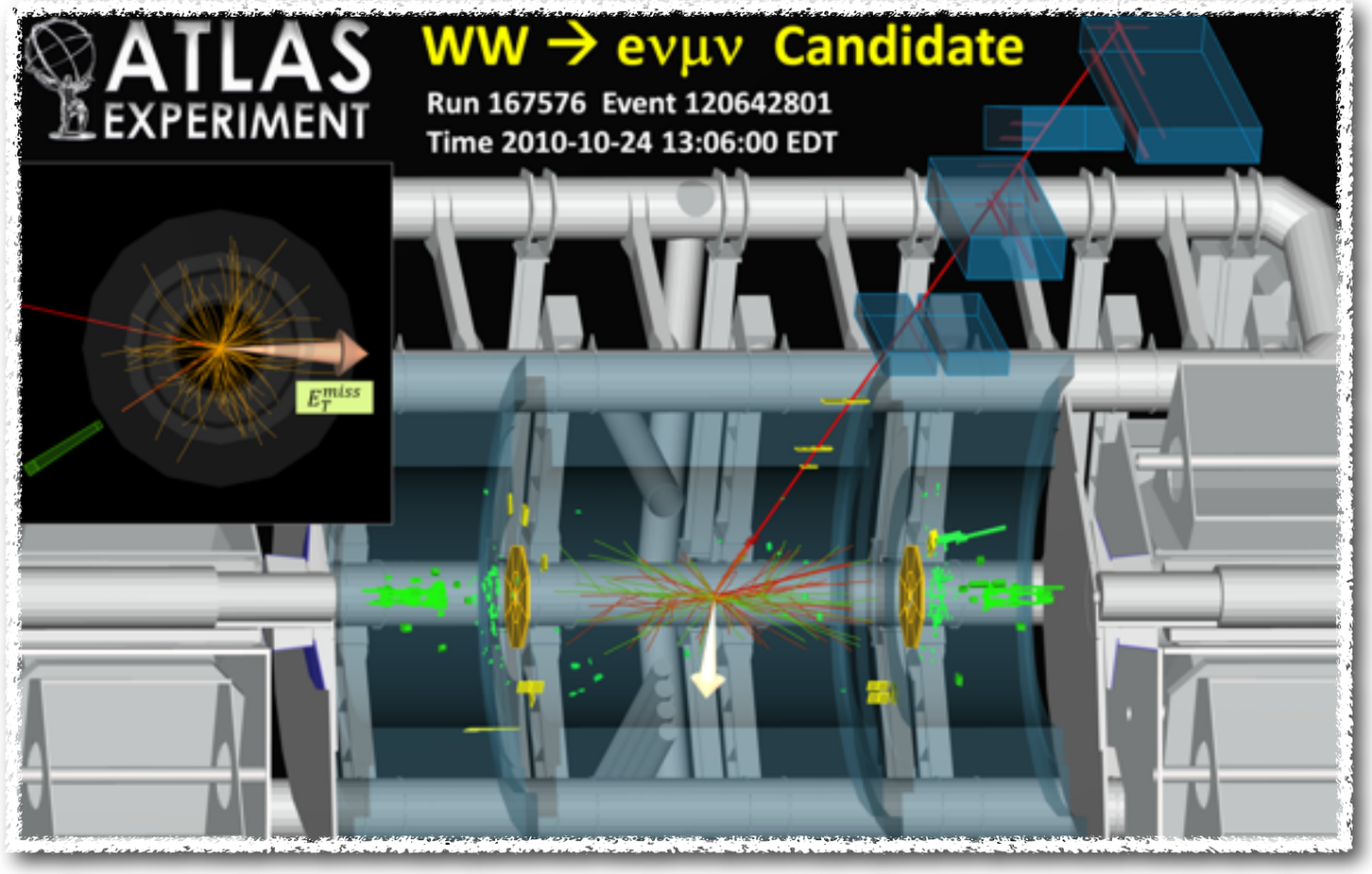
NNLO prediction:
Wγ: 42.1 ± 2.7 pb
Zγ: 6.9 ± 0.5 pb




ATLAS-CONF-2011-013
arXiv:1106.1592
Submitted to JHEP

# $W^+W^-$ production

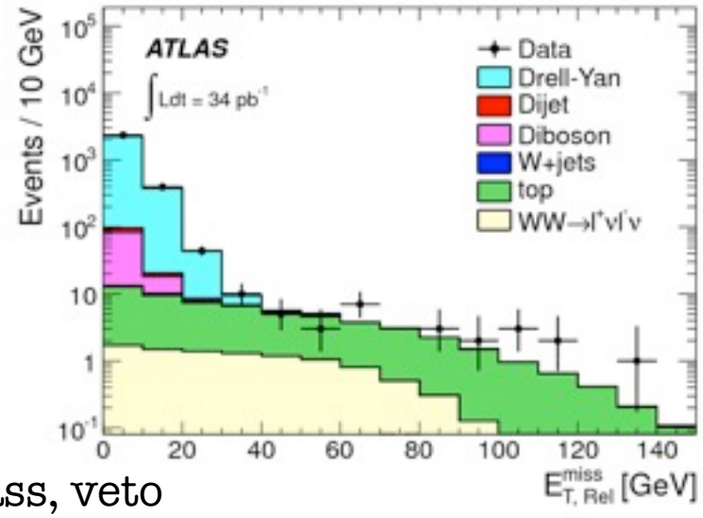
- Candidate $W^+W^-$ events are reconstructed in the **fully leptonic** decay channel (tau leptonic decays included):
  - looking for $l^+\nu_l l^-\nu_l$ events
  - better signal to background ratio than the semi-leptonic or hadronic channels,
  - main **backgrounds** are W+jets, Drell-Yan production, top production (ttbar and Wt) and other di-bosons processes.
- The main sources of **background** have been evaluated from Monte Carlo, except from the background from **W+jets**.

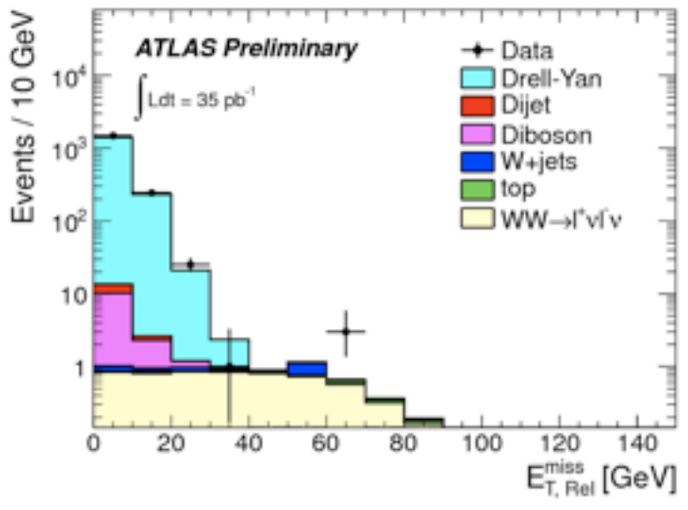



- The **W+jets** background was **estimated** directly from **data** (the rate at which hadronic jets are mis-identified as leptons may not be accurately described in the MC).
  - The W+jets background is defined by defining a control region, similar to $W^+W^-$ signal selection, that is enriched in W+jets events.
    - The control region is defined using an alternative lepton definition.
  - The selected events are then required to pass the full $W^+W^-$ event selection.
    - The jet is treated as if it were a fully identified lepton.
  - The W+jets background is then estimated by scaling this control sample by a measured fake factor.

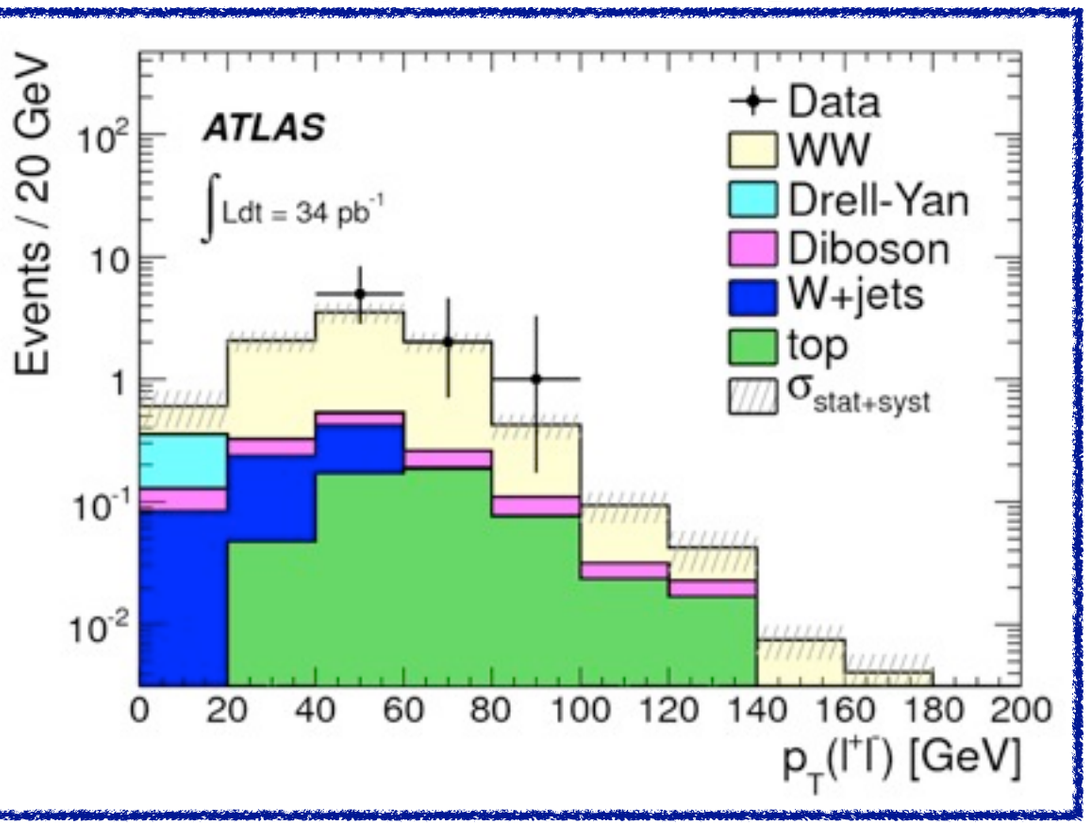
# $W^+W^-$ production

- The **event selection** is based on:
  - single lepton trigger
  - **Signal** selection:
    - two opposite-sign leptons ($p_T$ > 20 GeV)
    - missing energy
  - **Background** rejection:
    - requirements on the leptons invariant mass, veto events with $|m_{ll} - m_Z| < 10$ GeV and $m_{ll} < 15$ GeV (Z bkg)
    - high missing transverse energy, $E_T^{miss,rel} > 40$ GeV (20 GeV for eμ channel)
    - veto events with jets (ttbar bkg)
- Main **systematics** coming from:
  - modelling of jet production in association with $W^+W^-$
  - jet energy scale
- **Candidates** selected in data: 8
  - expected signal: 6.85 ± 0.07 (stat.) ± 0.66 (syst.)
  - expected background: 1.68 ± 0.37 (stat.) ± 0.42 (syst.)




Good background description




$$\sigma_{W^+W^-} = 41^{+20}_{-16}(\text{stat.}) \pm 5(\text{syst.}) \pm 1(\text{lumi.})\ \text{pb}$$

Systematic error smaller than statistical!

NNLO prediction: 44 ± 3 pb

ATLAS-CONF-2011-015
arXiv:1104.5225 - Submitted to PRL

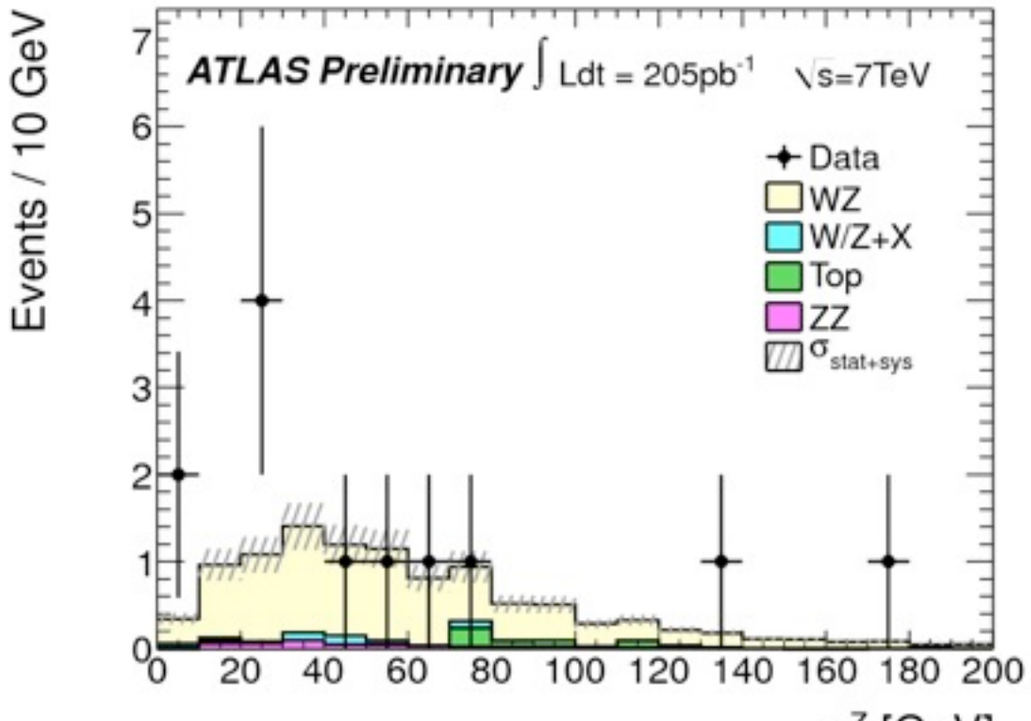
# $W^{\pm}Z$ production

- New results using **205 pb$^{-1}$** 2011 data.
- $W^{\pm}Z$ searched in the **fully leptonic** channel: both the W and the Z decay leptonically (tau leptonic decays taken into account).
  - The **signature** is three leptons and missing energy.
  - The backgrounds come from other di-bosons production (ZZ and Zγ), Z+jets and top events.
- Event selection based on:
  - two same flavour opposite sign leptons with mll within 10 GeV from Z mass,
  - additional third lepton,
  - transverse missing energy, $E_T^{miss}$ > 25 GeV
  - $m_T$(third lep, $E_T^{miss}$) > 20 GeV
- The dominant **systematic** contribution is from the description of the pile-up condition description for $E_T^{miss}$.
- **Candidates** selected in data: 12
  - expected signal: 9.1 ± 0.2 (stat) ± 1.3 (sys)
  - expected background: 2.0 ± 0.3 (stat) ± 0.7 (sys)

NNLO prediction: 16.9 pb

$$\sigma^{tot}_{WZ} = 18^{+7}_{-6}(stat)\ ^{+3}_{-3}(syst)\ ^{+1}_{-1}(lumi)\ pb$$

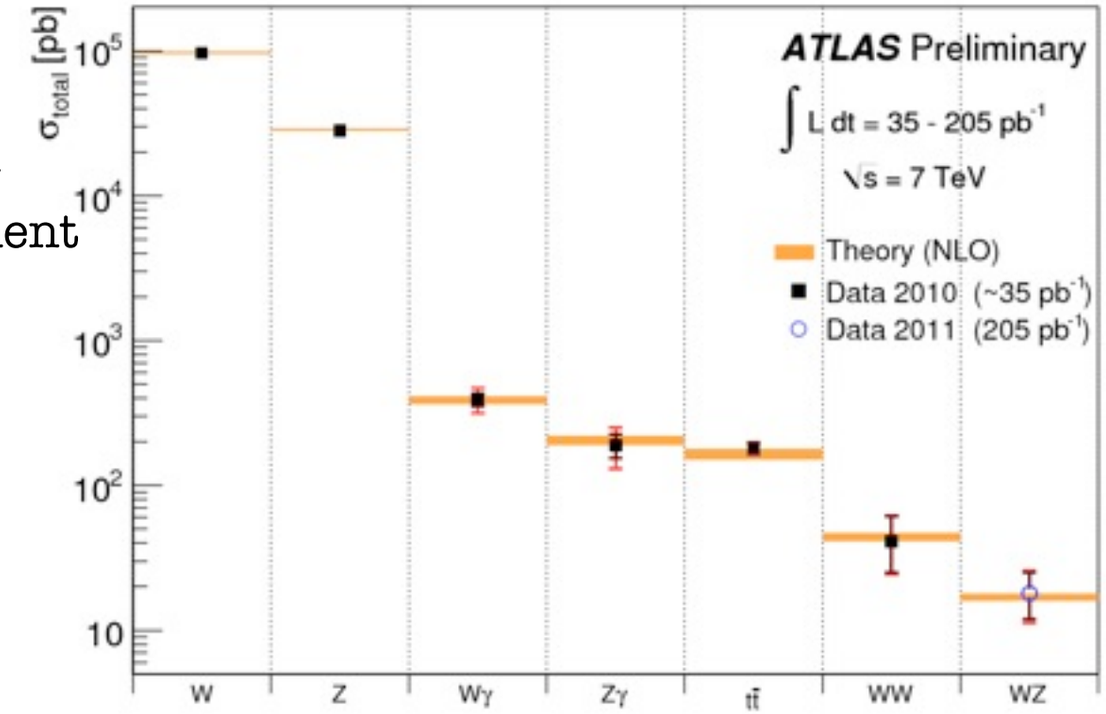
Systematic error smaller than statistical!

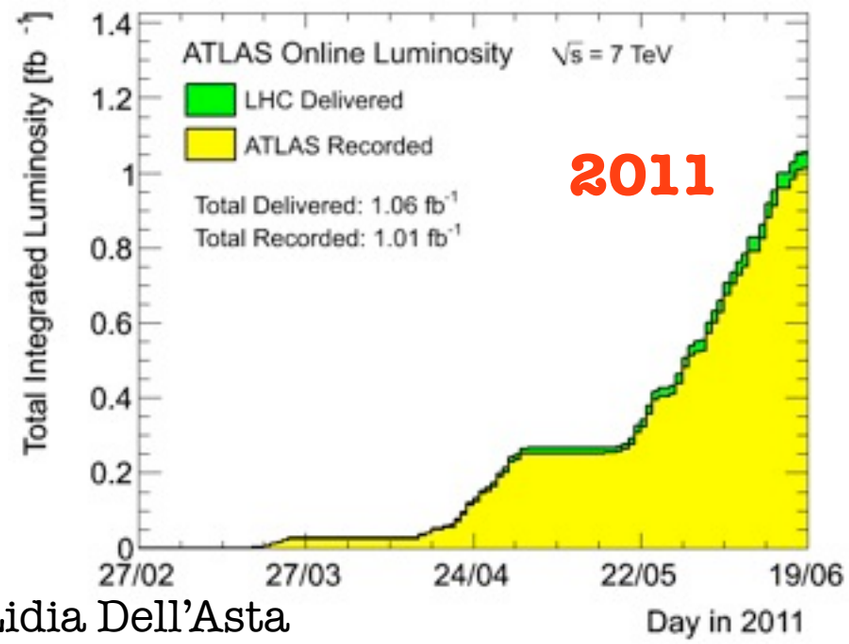



ATLAS-CONF-2011-084

# Conclusions

- In the year 2010, ATLAS has collected 45 $pb^{-1}$ of proton-proton interactions at a centre-of-mass energy of 7 TeV.
- Such amount of data has allowed to **commission** the full detector and the online and offline object reconstruction.
- **Main electroweak results** with ~35 $pb^{-1}$ of data:
  - Cross section measurement of W and Z/$\gamma^*$ production
  - W+jets and Z+jets production cross section measurement
  - W charge asymmetry
  - Di-bosons production cross section:
    - W$\gamma$ and Z$\gamma$
    - WW
- **New results** with 2011 data (~205 $pb^{-1}$):
  - WZ production cross section



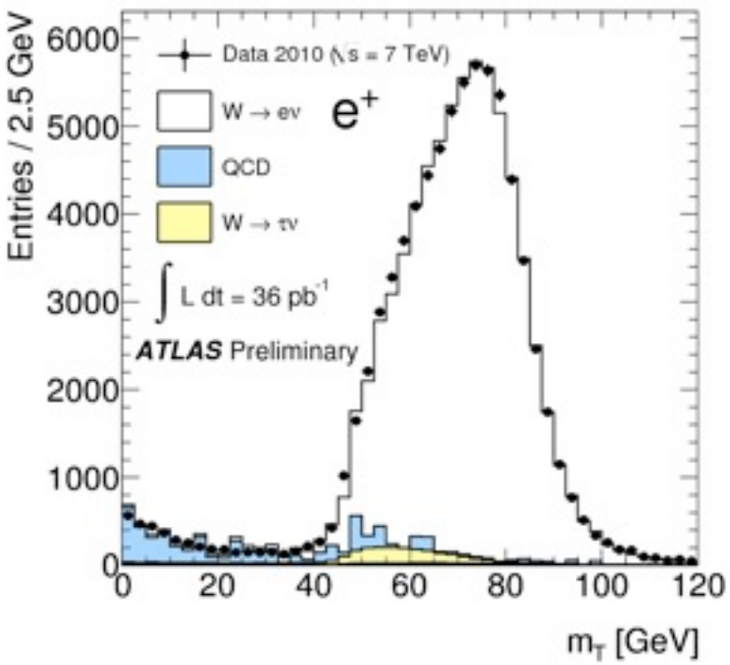



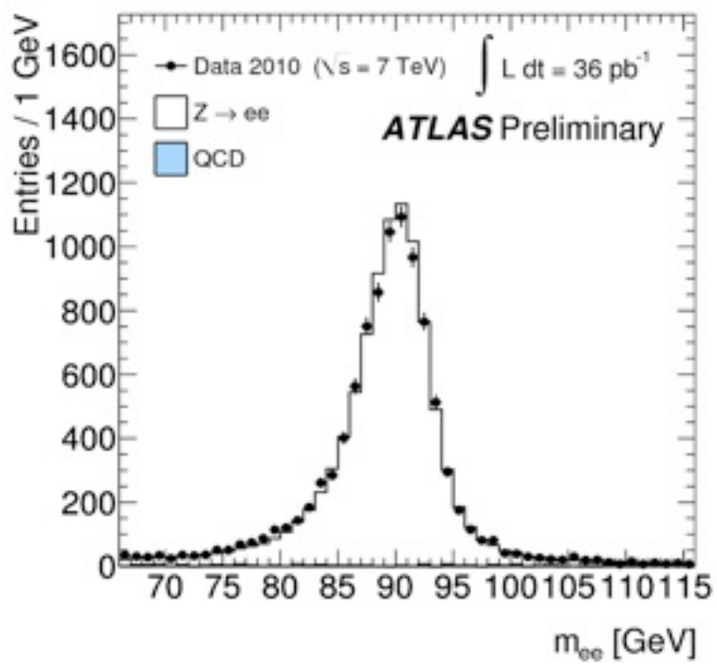

- **More data** is coming.
  - Analysis for which the statistical error is the dominating one (e.g. di-bosons production) will profit from the increased statistic.
  - New analyses will be possible ($W\rightarrow\tau\nu$ cross section, $p_T(W)$, $p_T(Z)$, W/Z+b in W/Z+jets events, ZZ production, WW/WZ also in hadronic channels...)

# Back Up

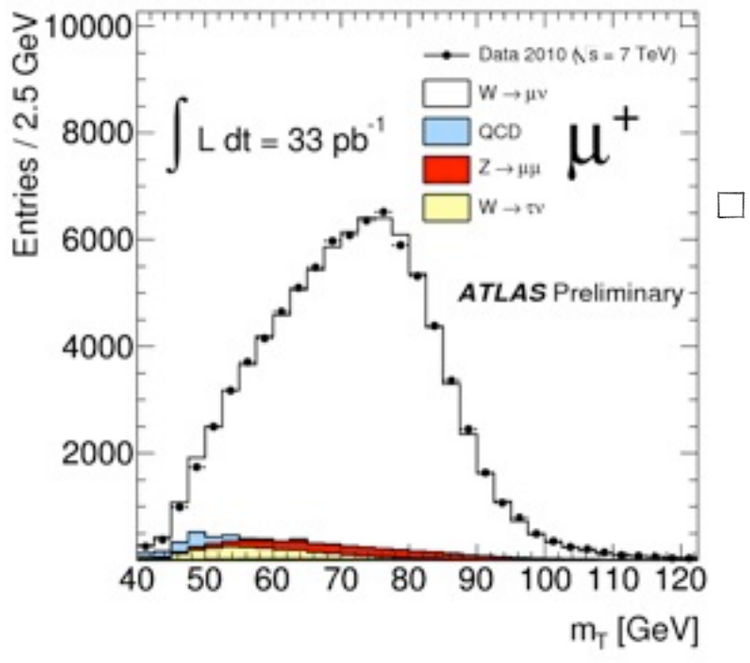
# W and Z/γ* cross section

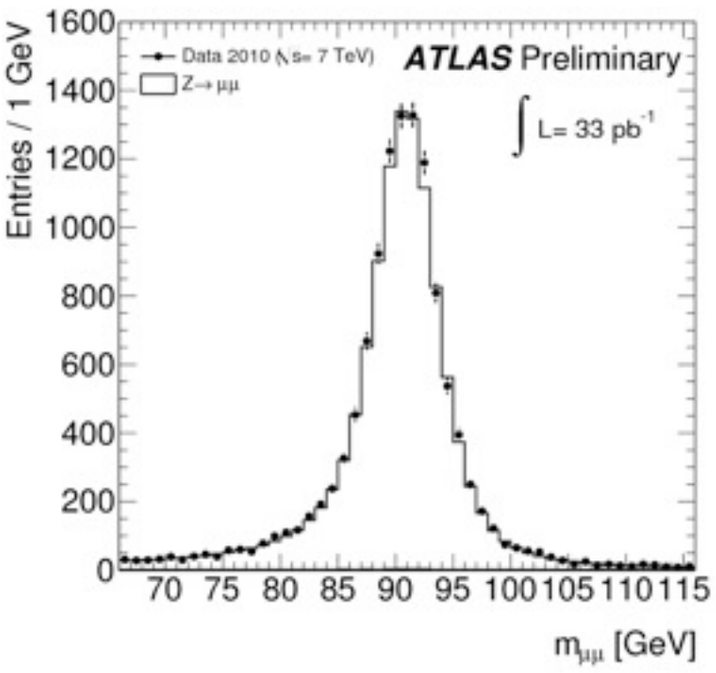
- **W → eν/μν selection**:
  - one well reconstructed lepton with $p_T$ > 20 GeV
    - Electron
      - passing tight ID requirements
      - $|\eta| < 2.47$, excluding also the transition region, $1.37 < |\eta| < 1.52$
    - Muon
      - combined (Inner Detector and Muon system) and isolated
      - $|\eta| < 2.47$
  - missing transverse energy, $E_T$miss > 25 GeV
  - $m_T$ > 40 GeV



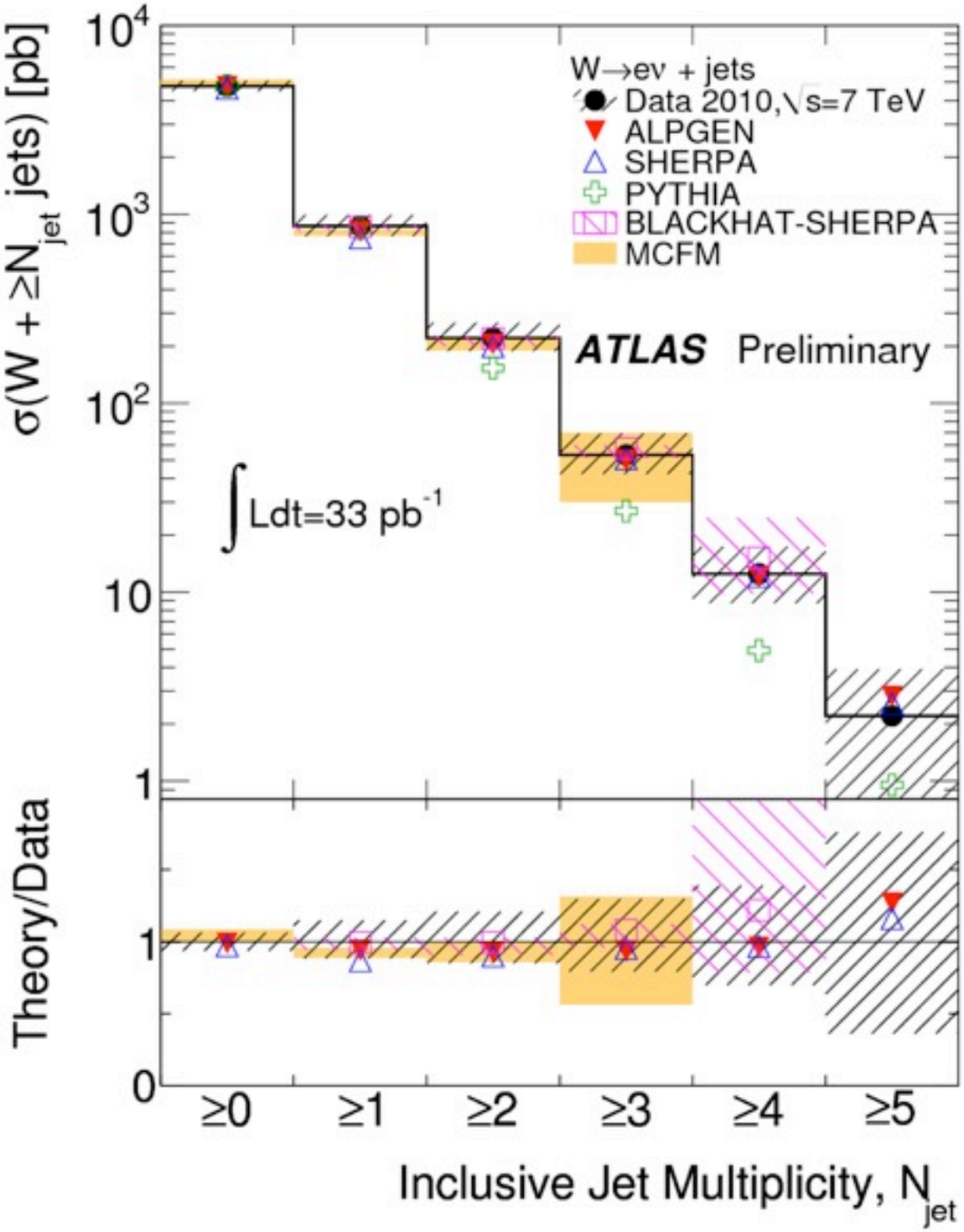



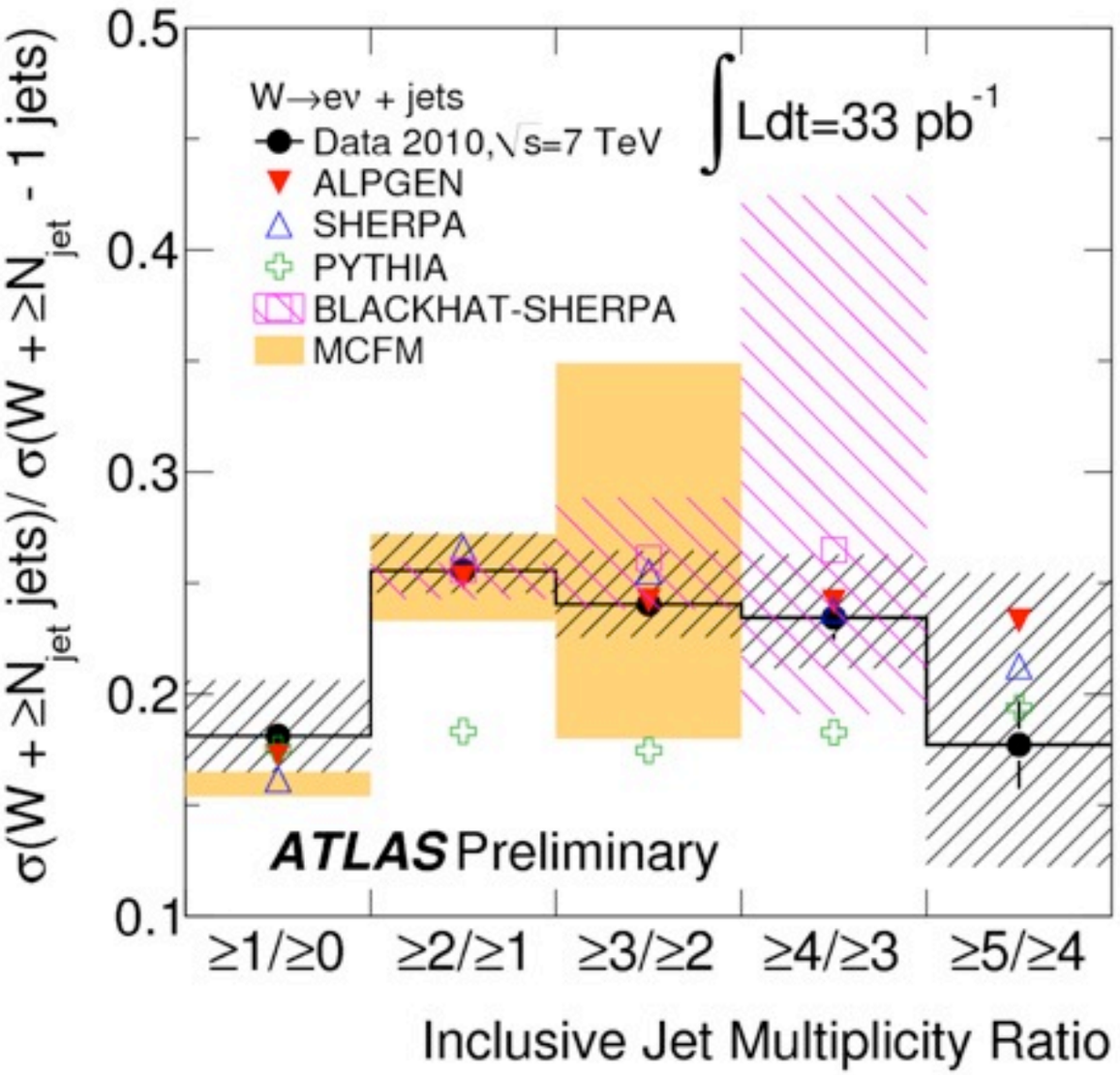

- **Z → ee/μμ selection**:
  - two reconstructed leptons with opposite charge
    - Electron
      - passing medium ID
      - forward region included
  - $66 < m_{ll} < 116$ GeV



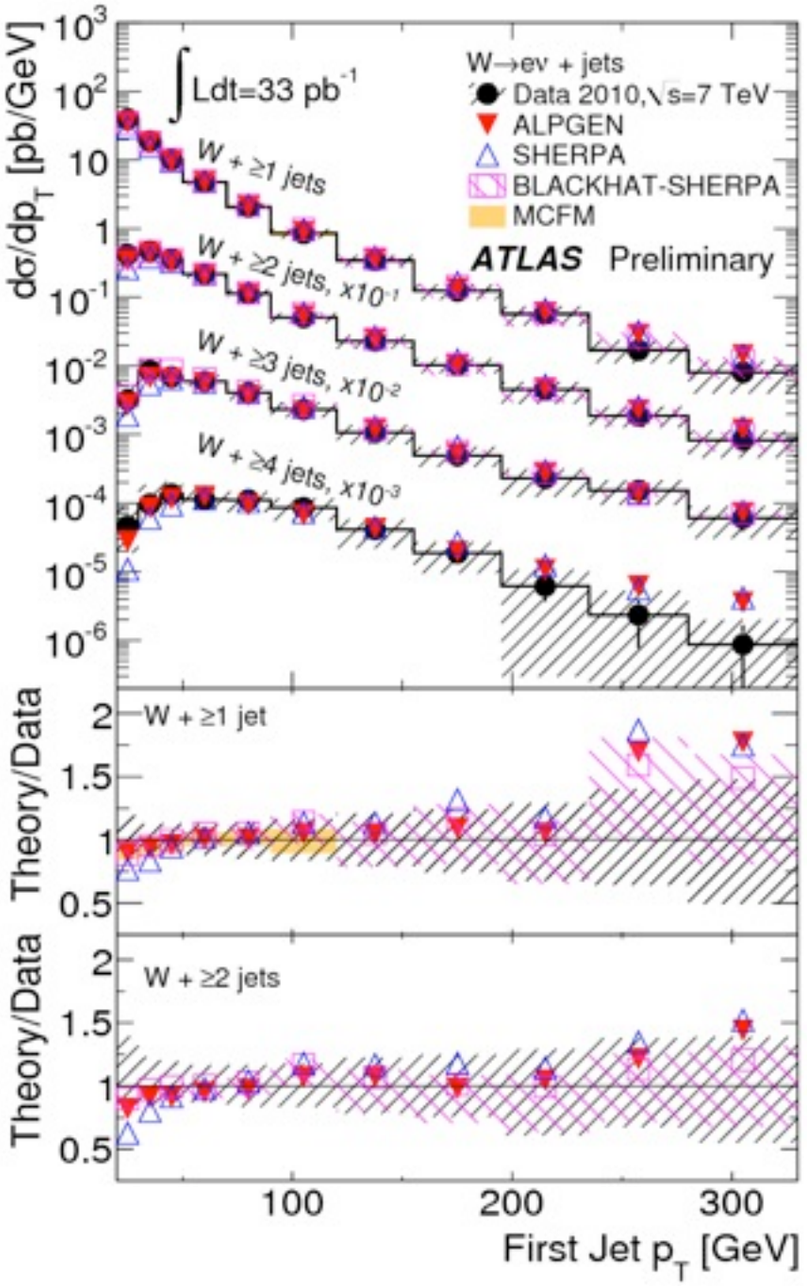



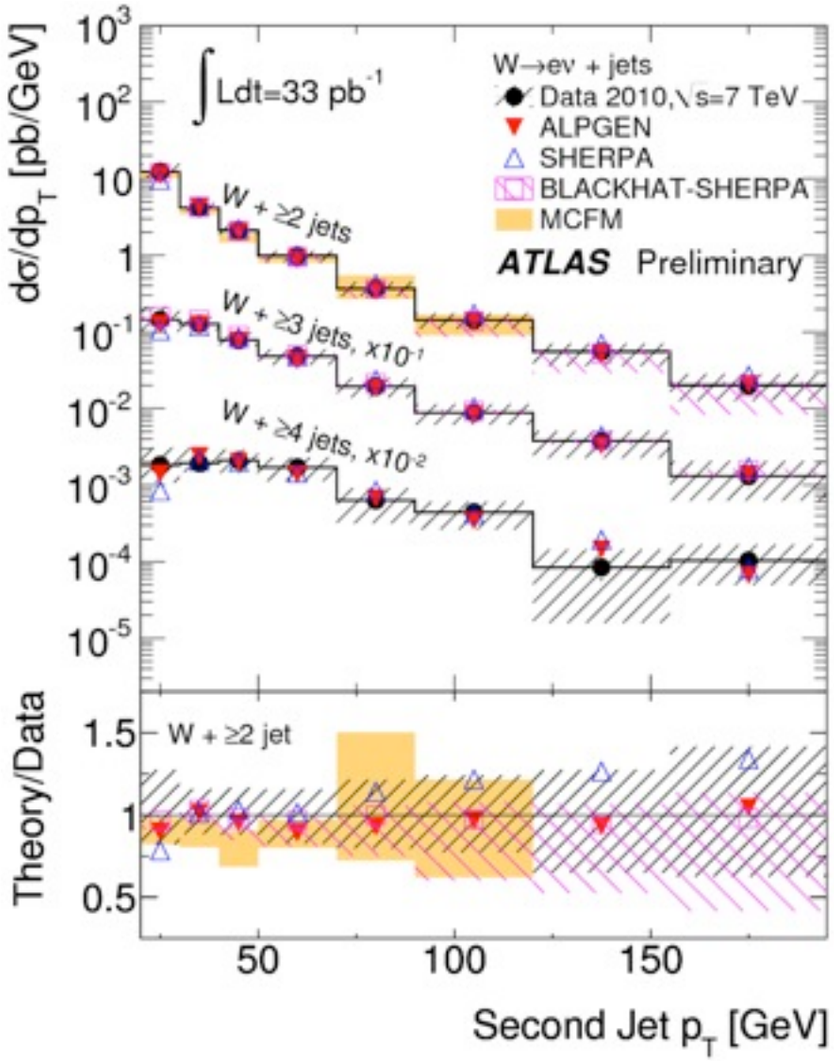
# W+jets production - electron channel

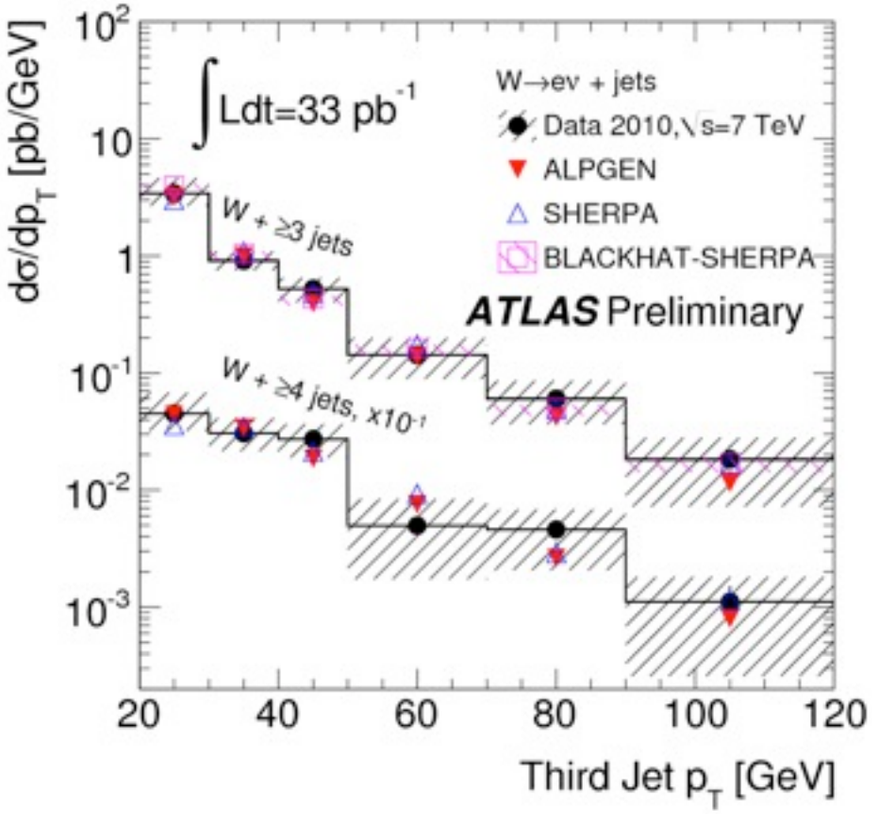


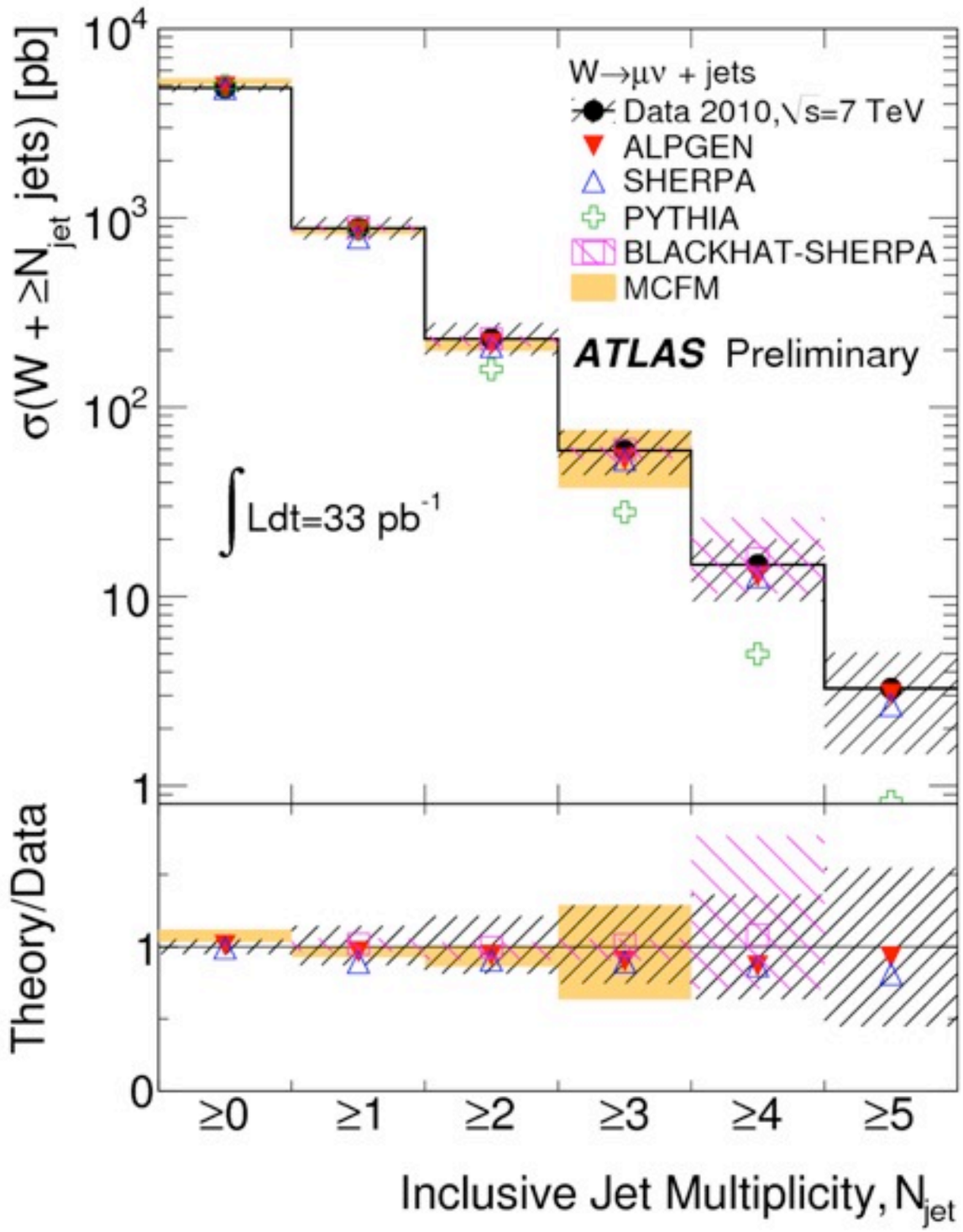
# W+jets production - electron channel

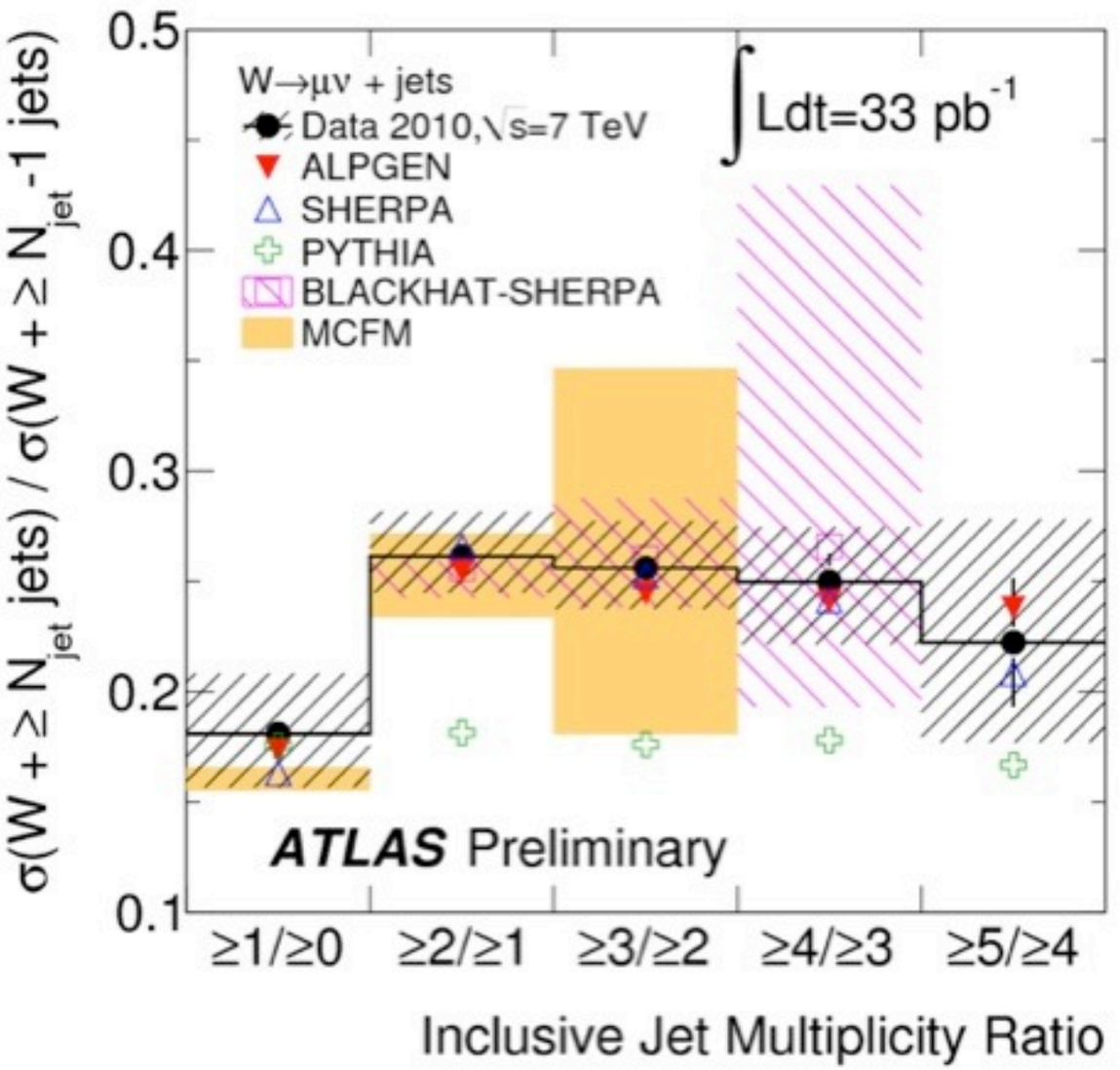


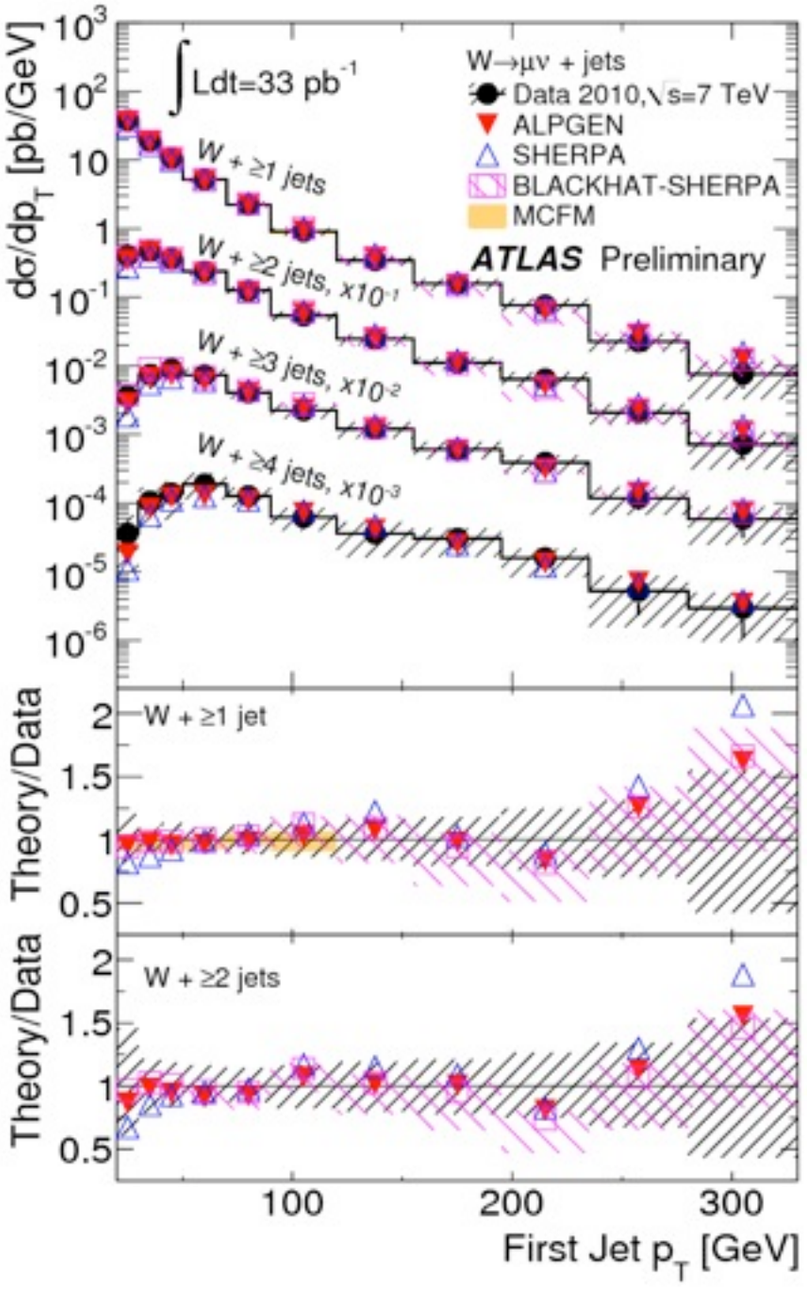



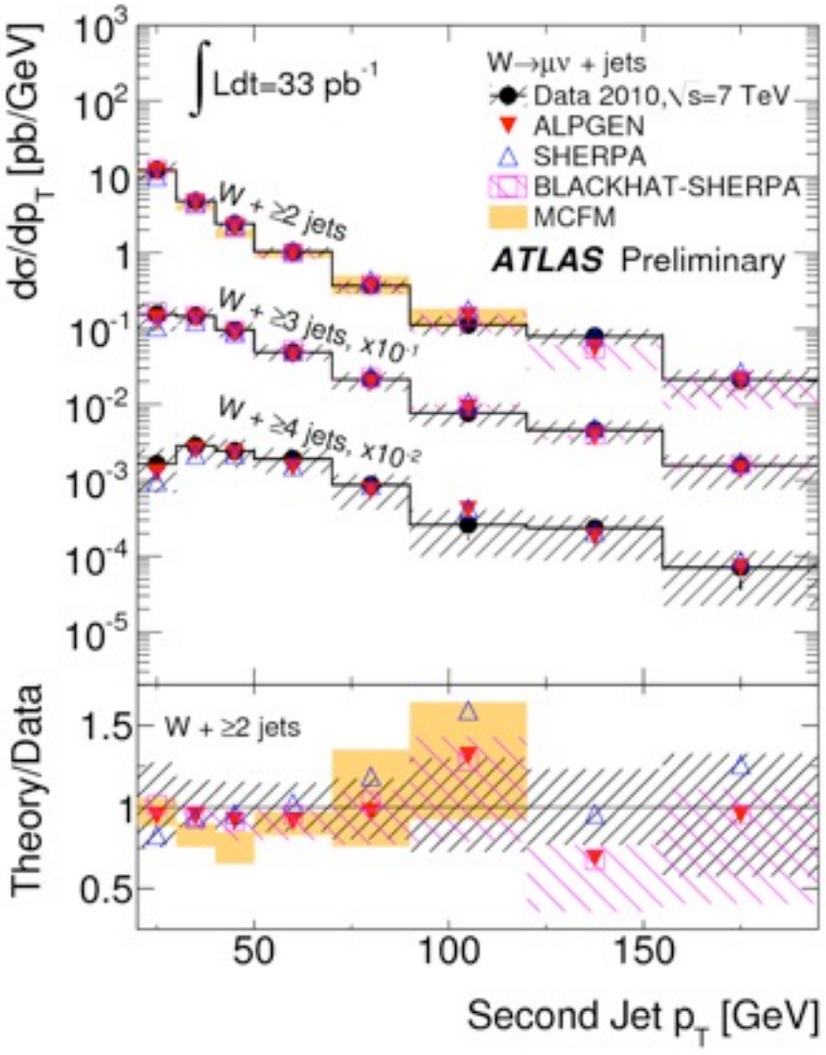
# W+jets production - muon channel

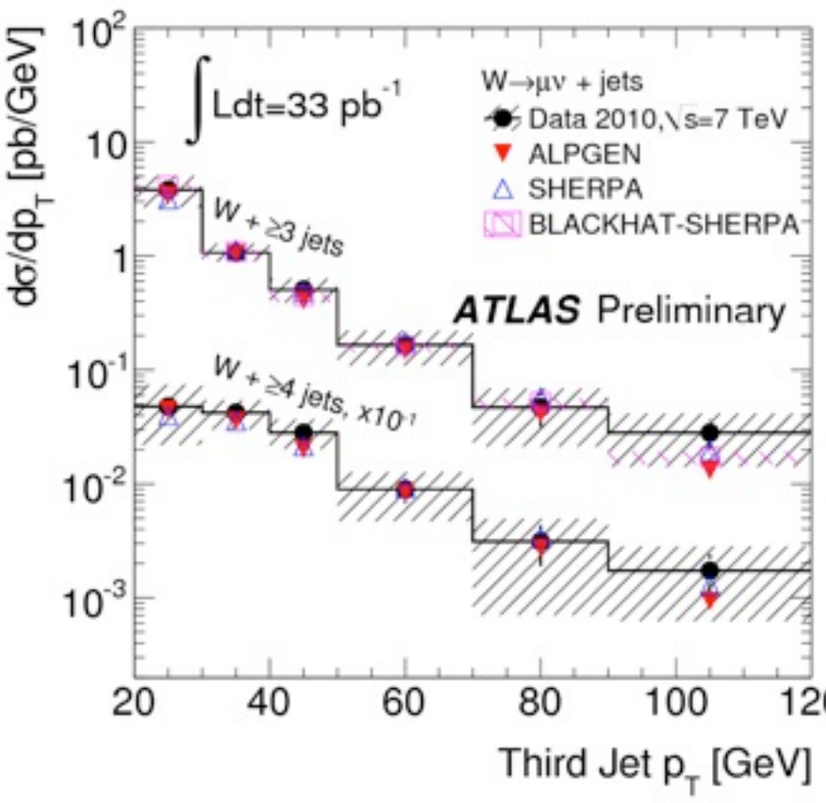


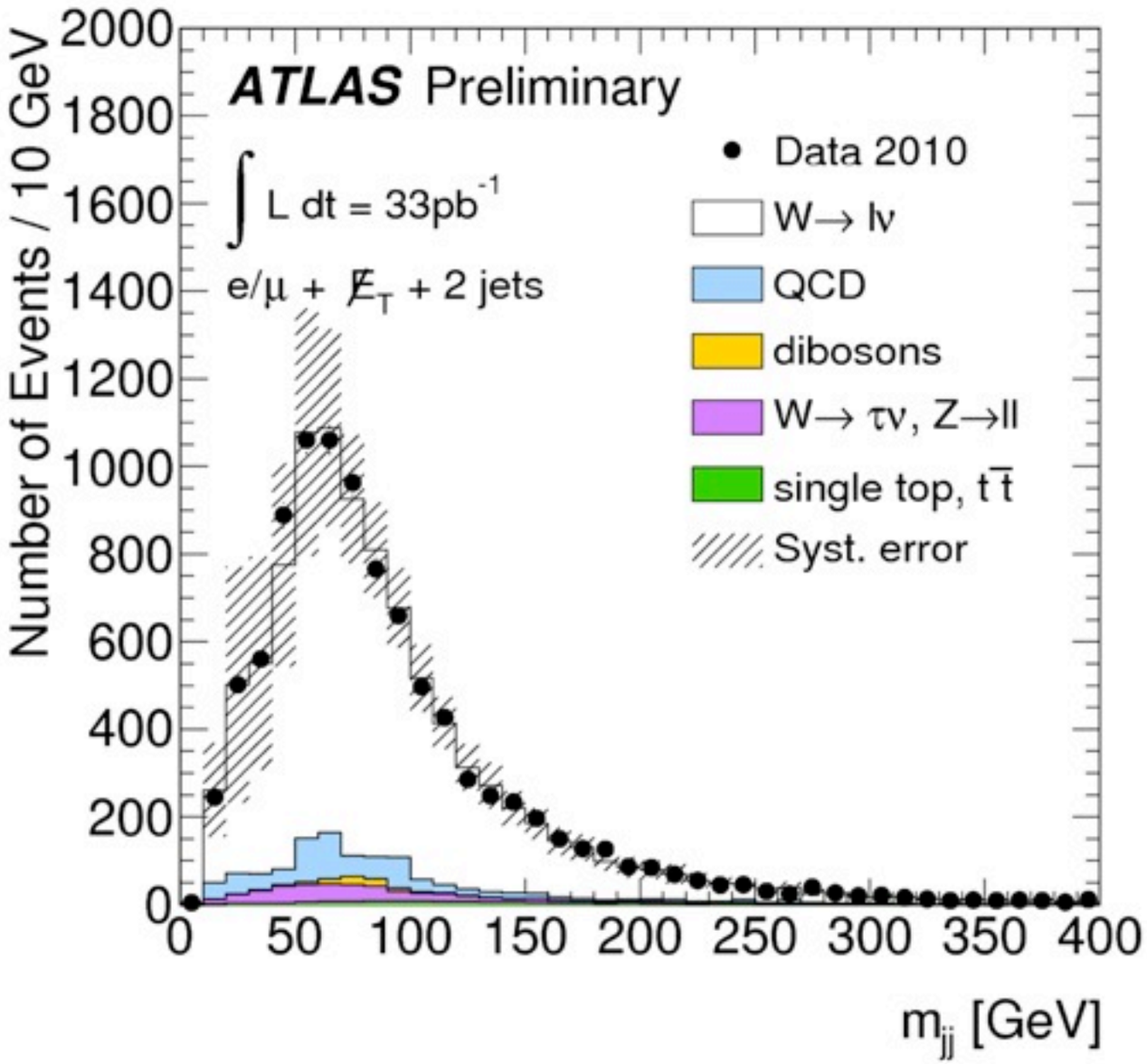
# W+jets production - muon channel



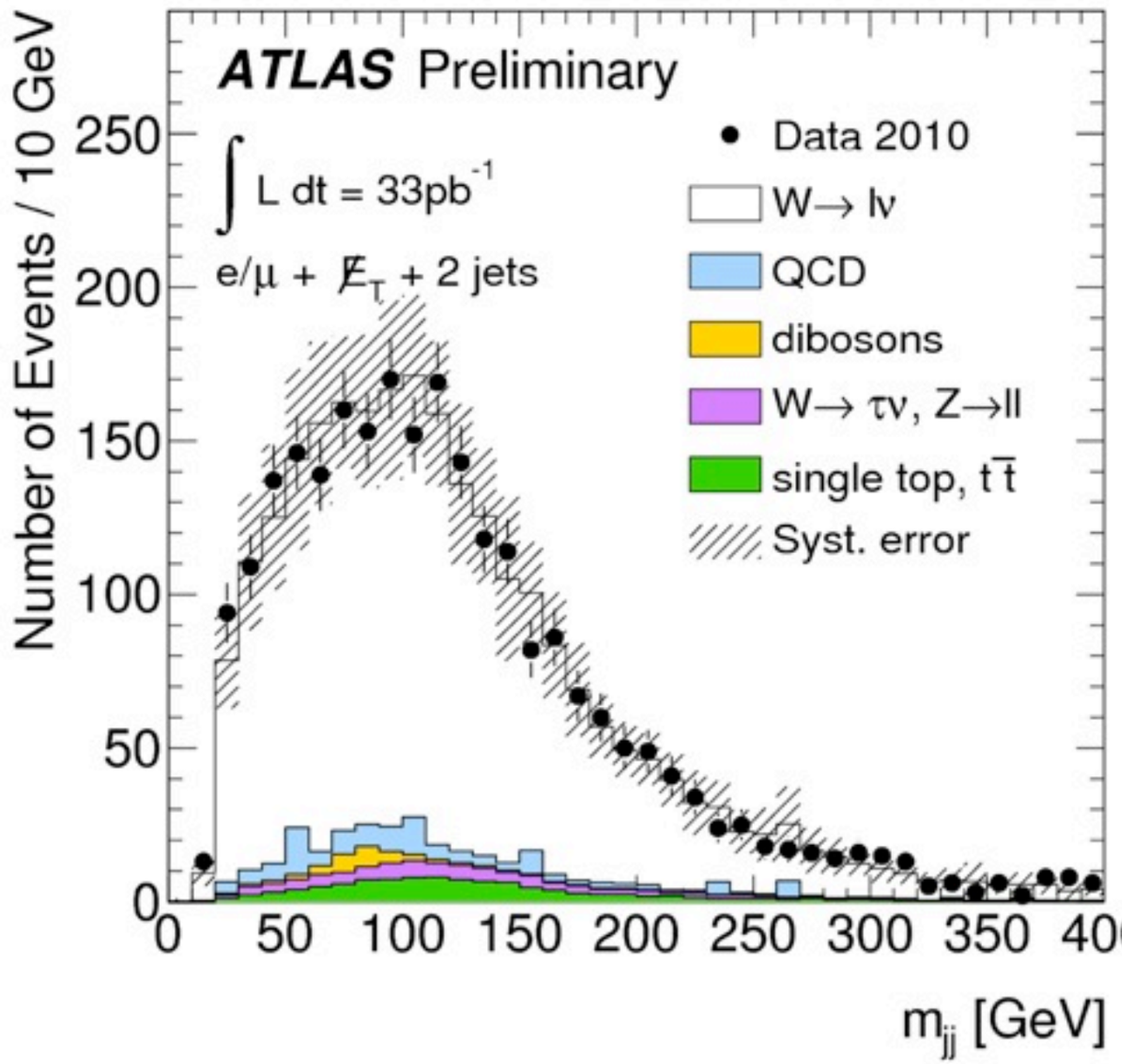



# e/μ + $E_T$miss + 2 jets

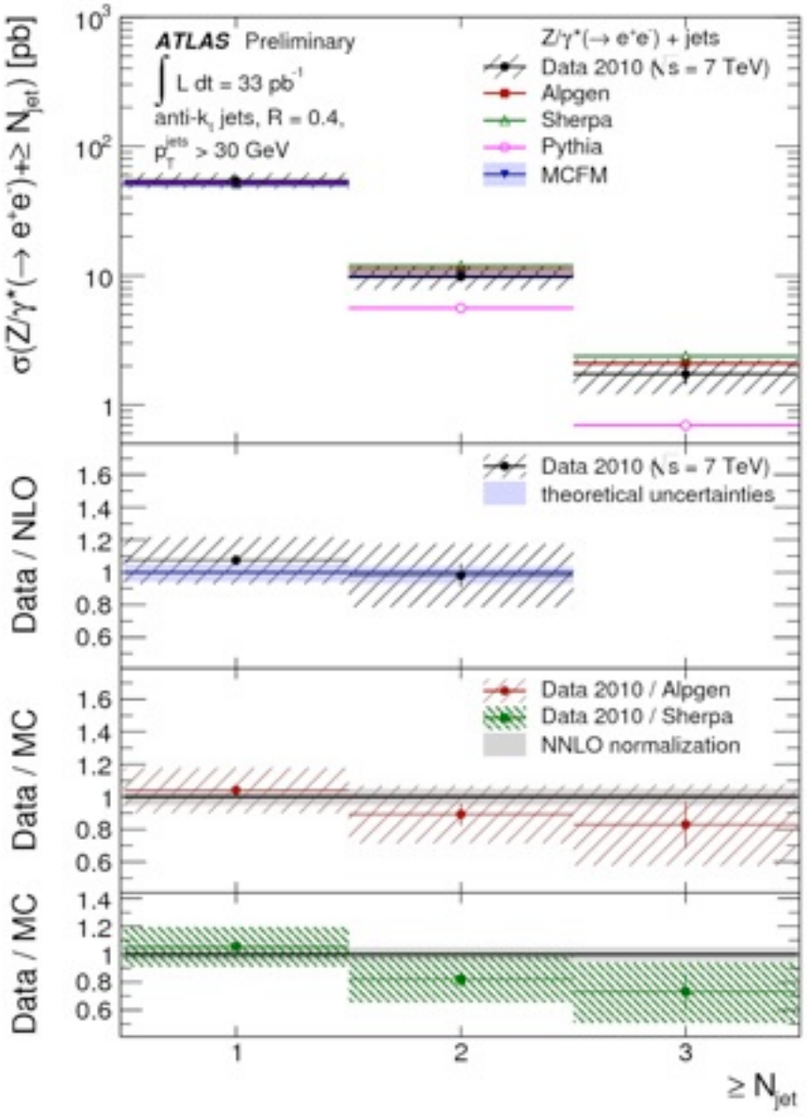


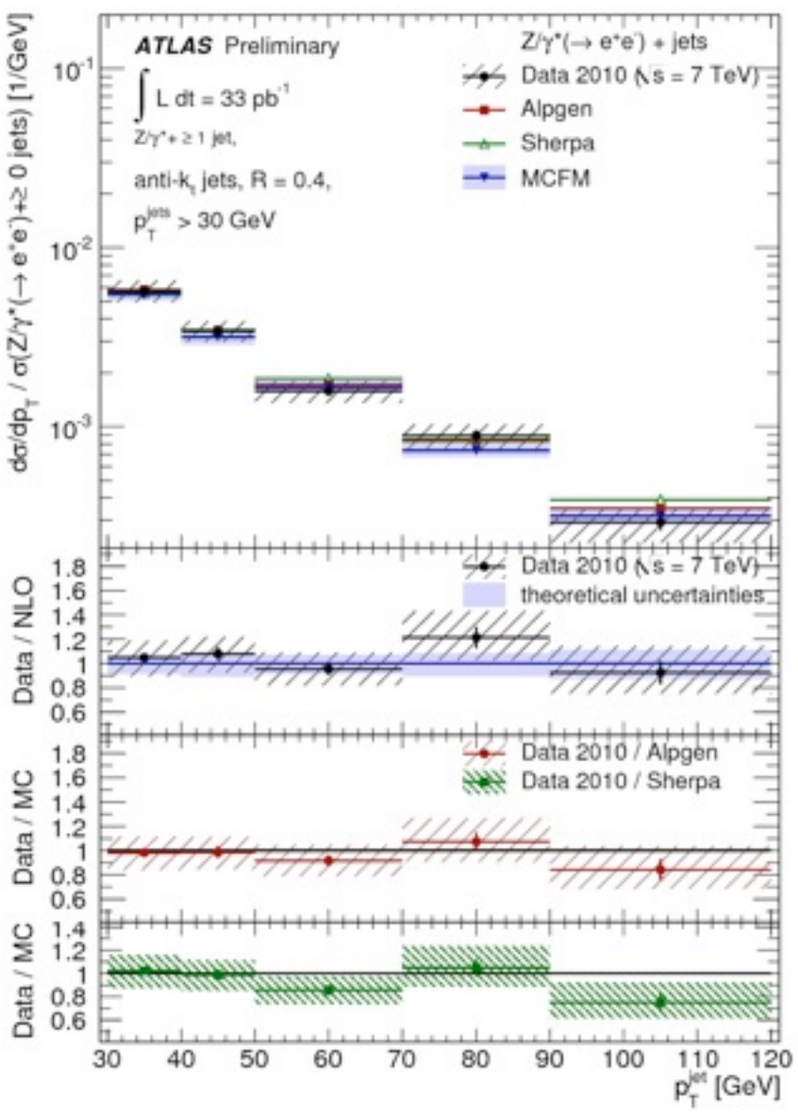

Using the standard ATLAS W+jets selection.

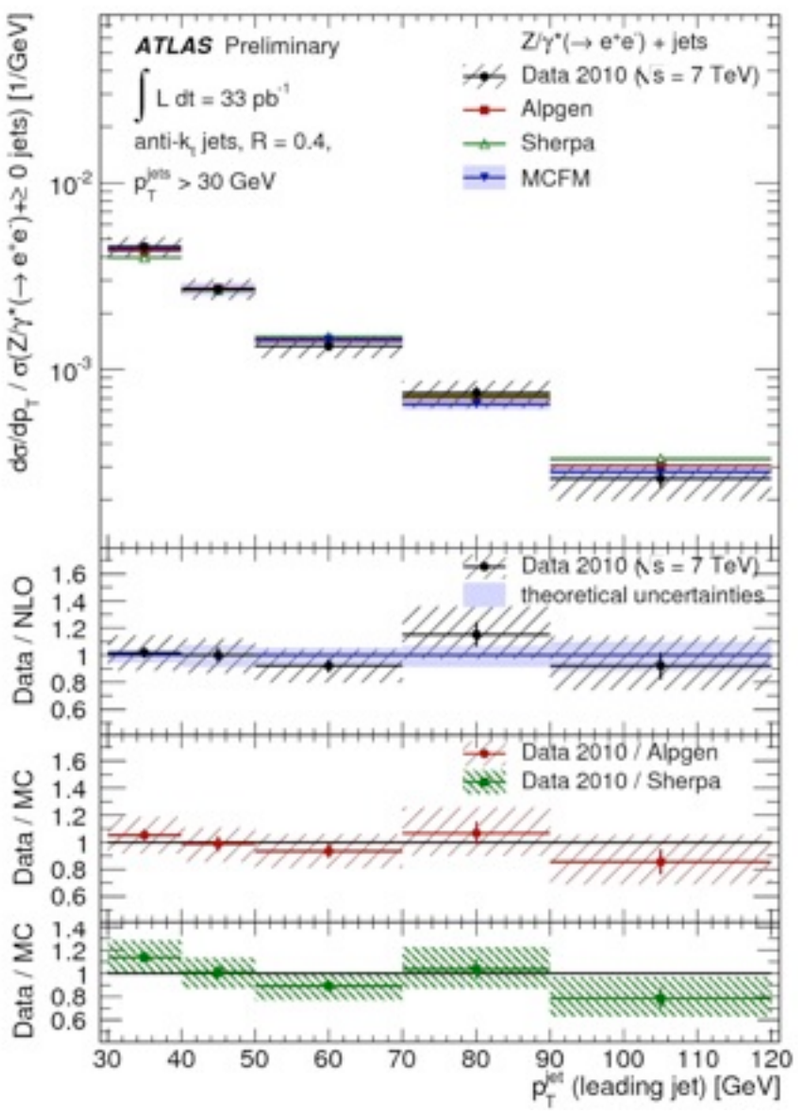



Using a selection similar to the one of CDF.

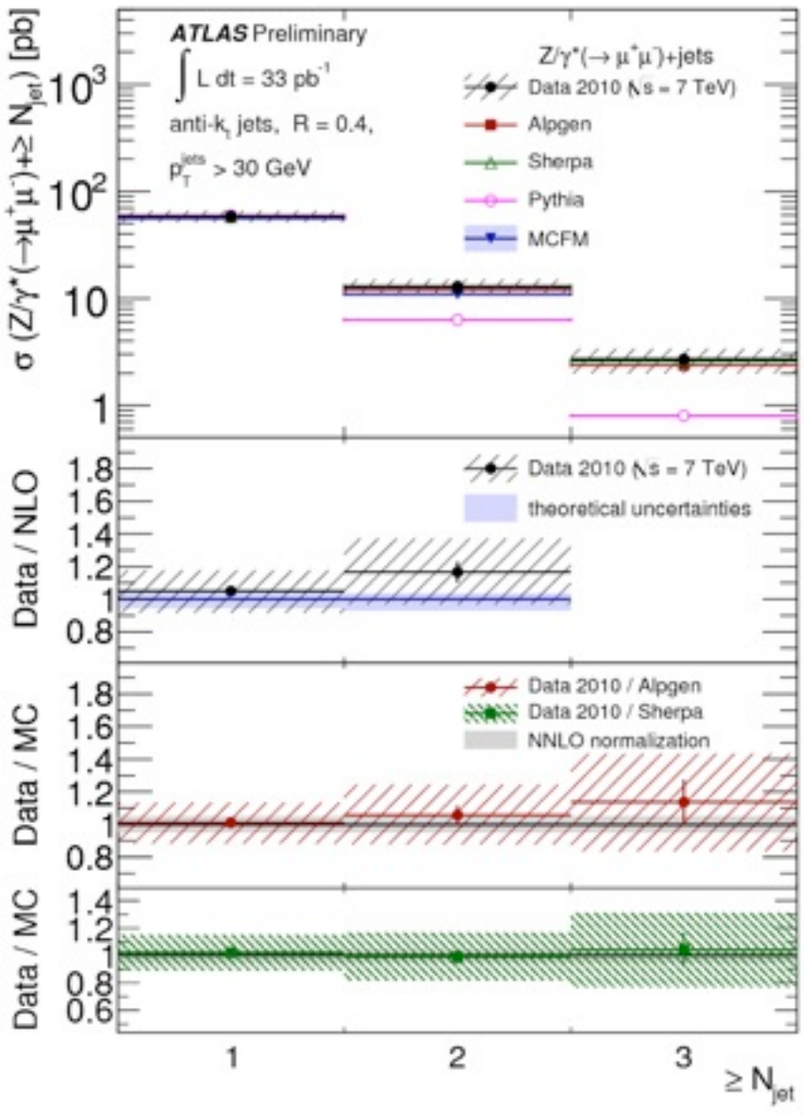
# Z+jets production - electron channel

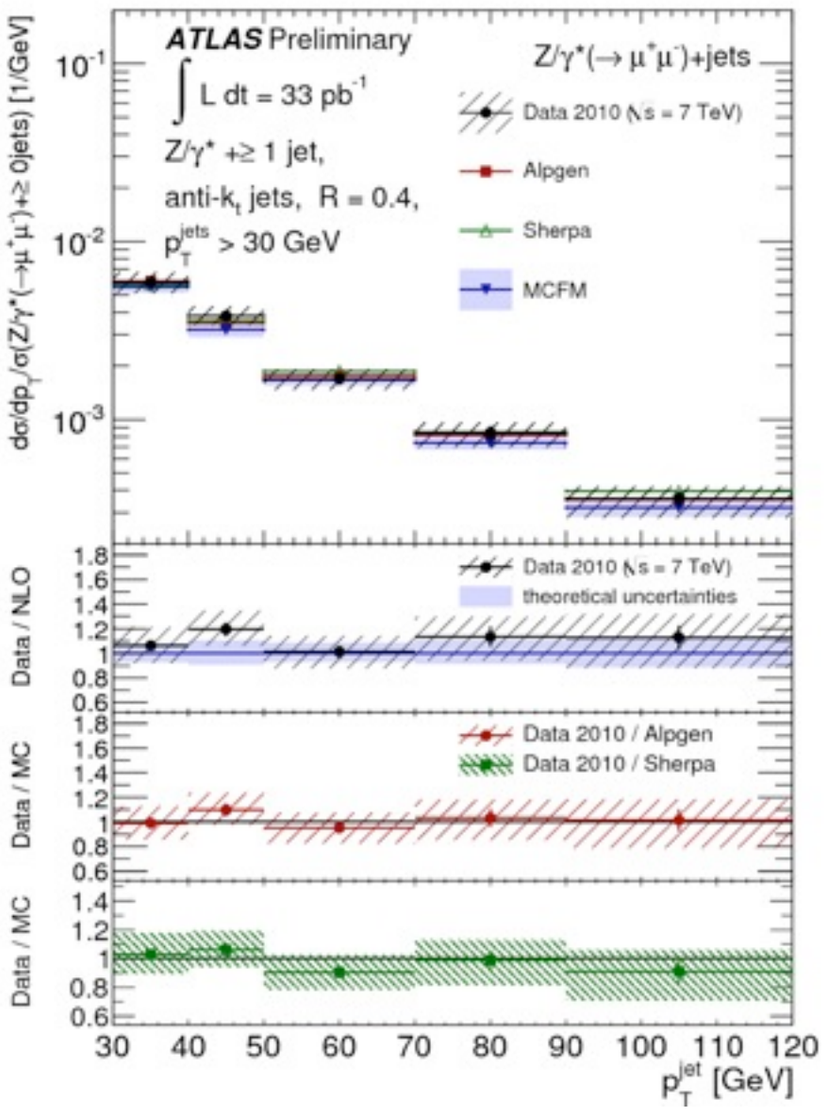


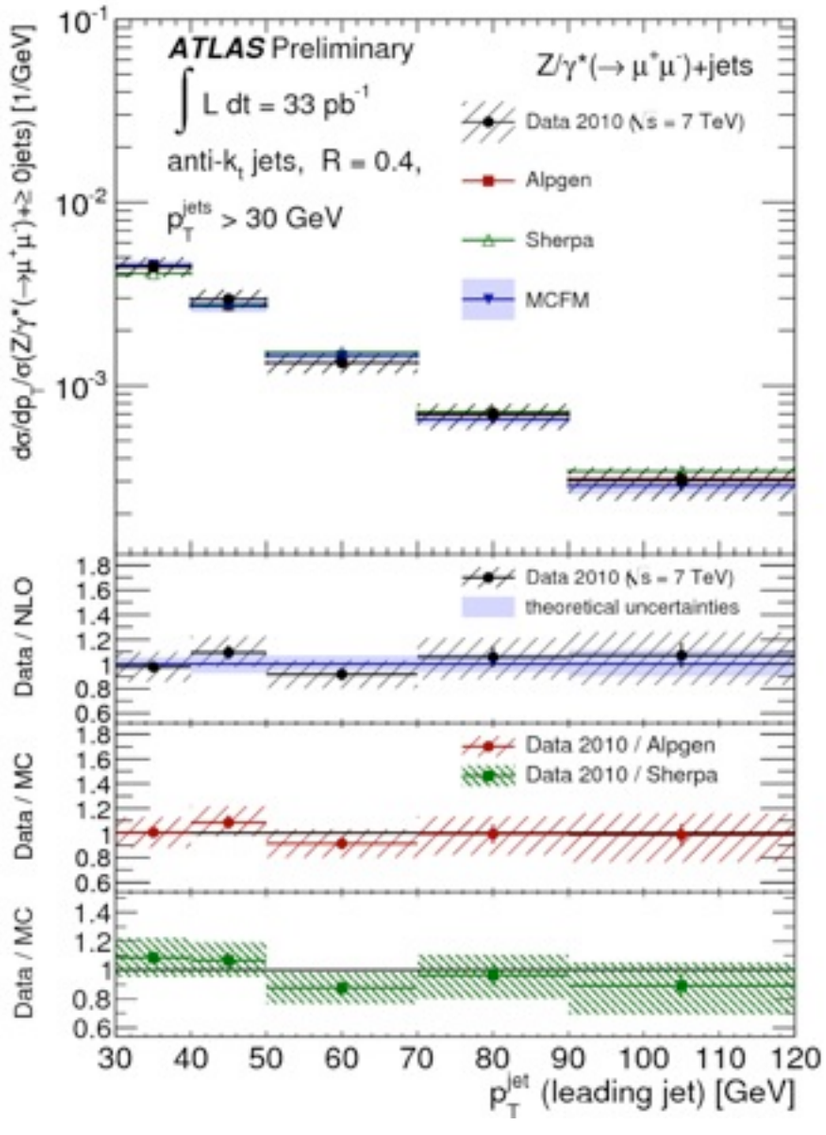



# Z+jets production - muon channel

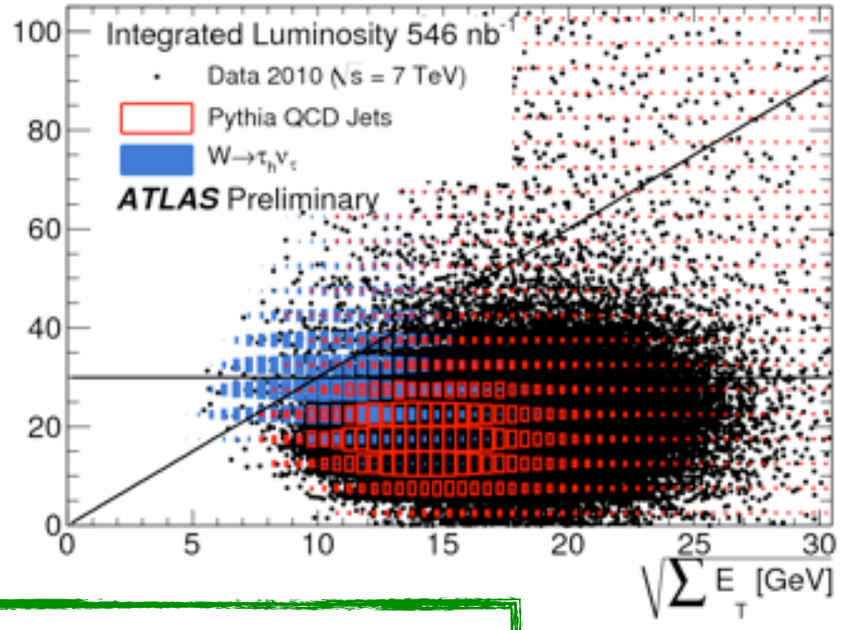


# W→τν observation

- W→τν decay observation with only ~0.5 $pb^{-1}$.
- Very **challenging** analysis due to overwhelming QCD background.
  - High background rejection by means of a cut on the significance of missing transverse energy.
- Events selected in data: 78
  - expected QCD background (from data): 11.1 ± 2.3 (stat.) ± 3.2 (syst.)
  - expected EW background (from MC): 11.8 ± 0.4 (stat.) ± 3.7(syst.)
  - observed signal: 55.1 ± 10.5 (stat.) ± 5.2 (syst.)
    - expected from MC: 55.3 ± 1.4 (stat.) ± 16.1 (syst.)

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