ATLAS Electroweak Results

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On behalf of the ATLAS Collaboration

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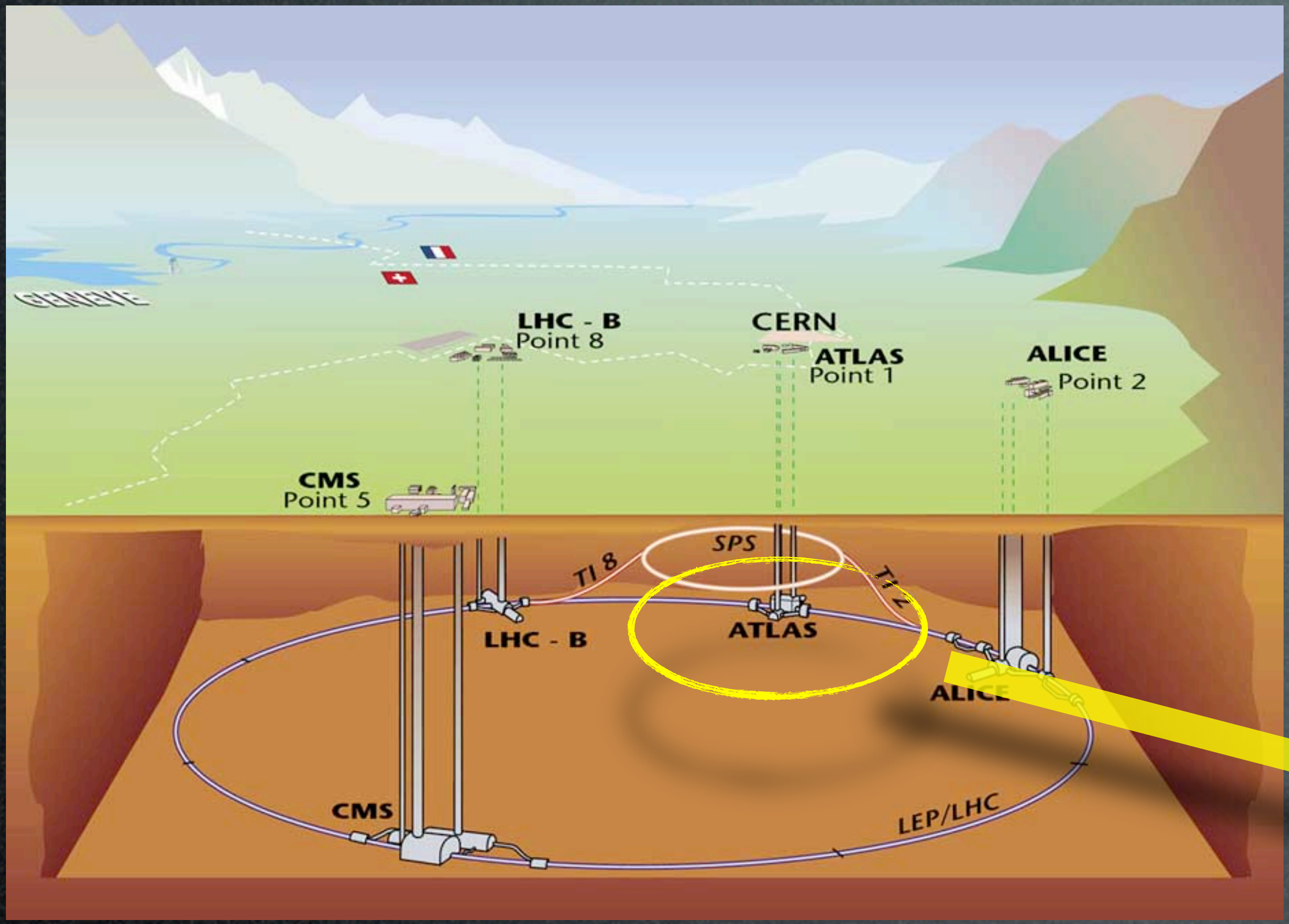
Outline

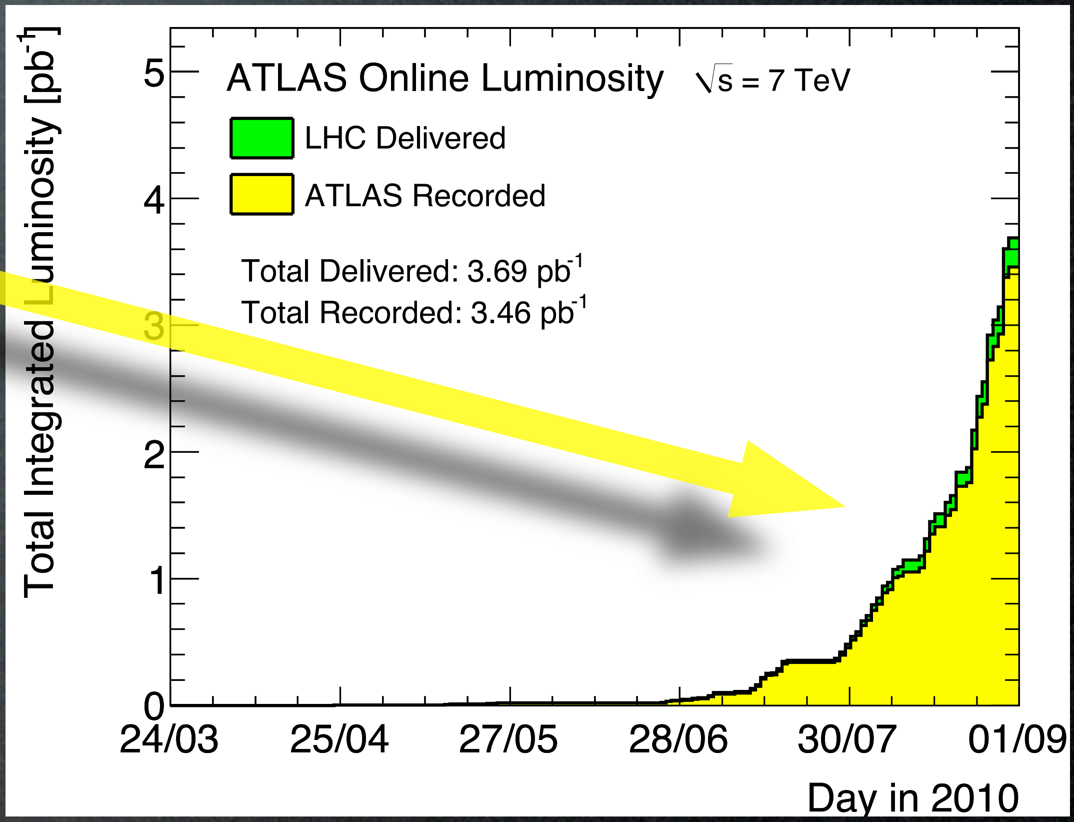
- Electroweak: W, Z and (a look at) Top physics
- ATLAS at LHC: detector and data
- Physics objects involved
- A first look at
  - W/Z+jets
  - Ttbar
- Conclusions

Electroweak: W and Z

- Two-fold interest:
  - commissioning of detector and performance 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)

LHC switched on...



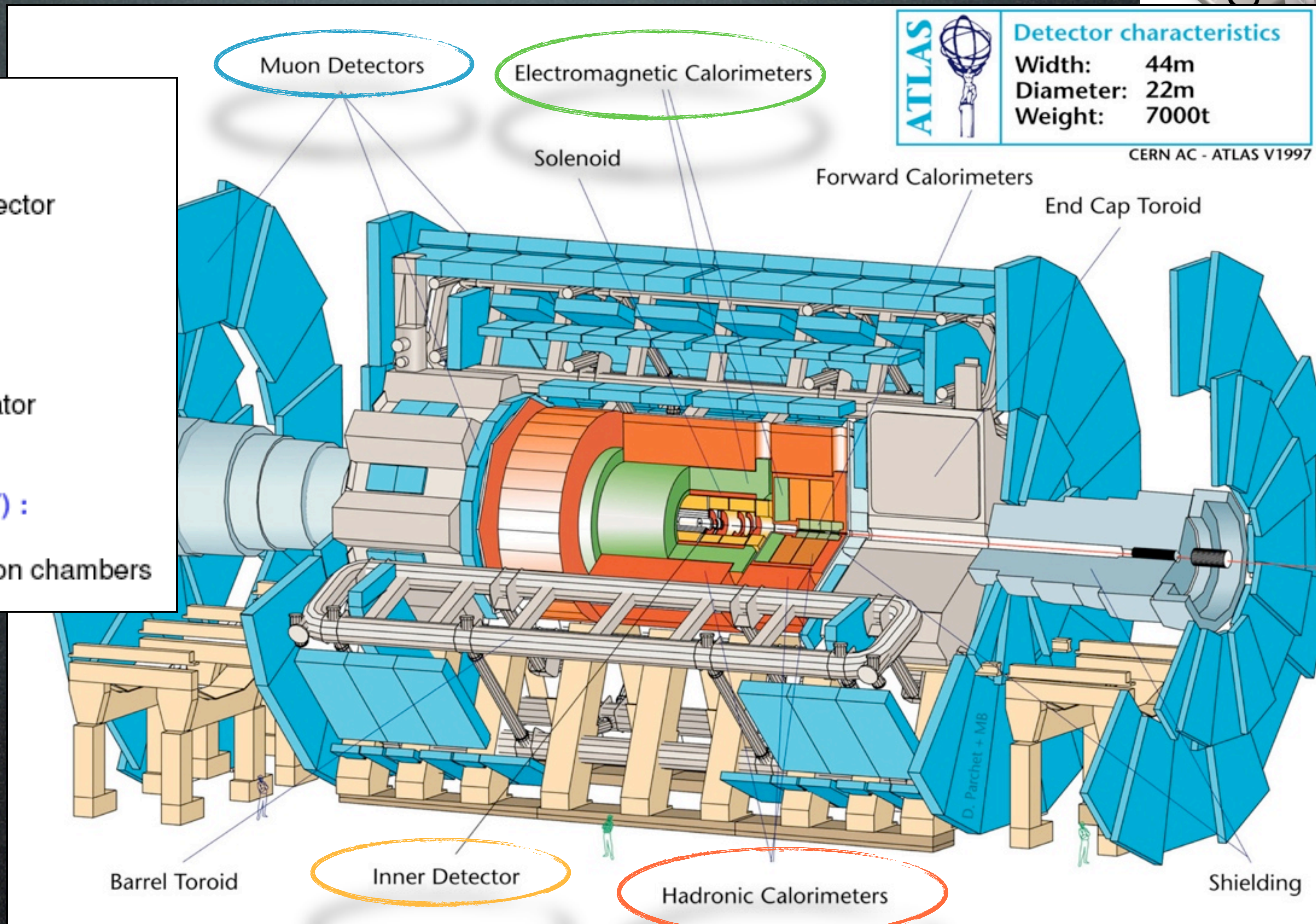


- Very smooth operations
- ATLAS recorded Integrated Luminosity = 3.5 pb^{-1}

- Measurements presented here have lower integrated luminosity: more coming soon!
- Results presented here are for different integrated luminosities (showing full results and on-going studies)

..and the ATLAS detector

- **Tracking ($|\eta|<2.5$, B=2T) :**
  - Silicon pixels and strips
  - Transition Radiation Detector (e/π separation)
- **Calorimetry ($|\eta|<5$) :**
  - EM : Pb-LAr
  - HAD: barrel: Fe/scintillator
    forward: Cu/W-LAr
- **Muon Spectrometer ($|\eta|<2.7$) :**
  - air-core toroids with muon chambers



- All parts equally important for EW physics!
- See L.Smirnova's talk for detector and performance

Objects for W/Z analysis

Distributions studied at different integrated luminosities

Electrons

- Trigger: Level 1 (hardware) requires coarse-granularity cluster with $|\eta| < 2.5$ and $E_T > 5$ GeV
- Offline: EM calorimeter cluster matched to Inner Detector (ID) track

★ "Loose" selection

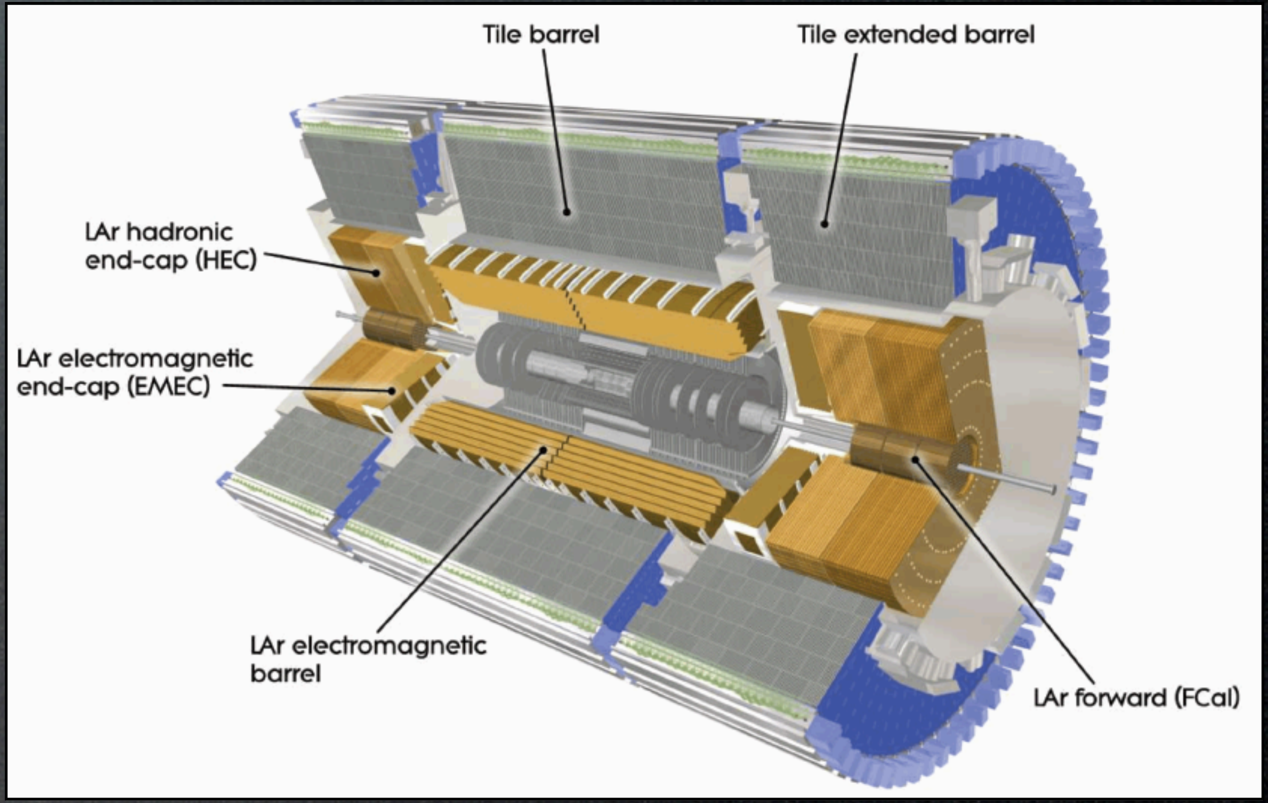
- EM cluster + ID track

★ "Medium" selection

- tighter requirements on EM cluster and on cluster-track match

★ "Tight" selection

- stricter track quality, γ conversion veto
- 10^5 rejection against jets with $p_T > 20$ GeV for 72% reconstruction efficiency

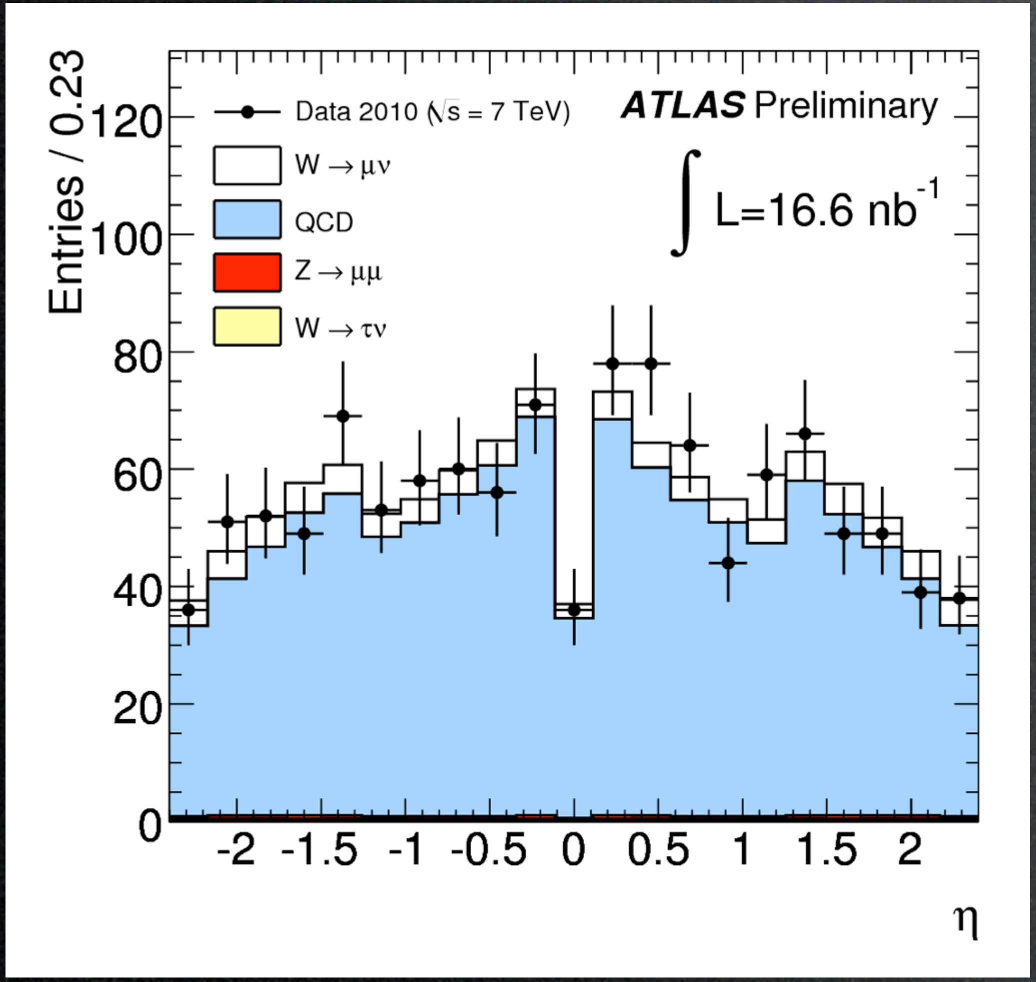


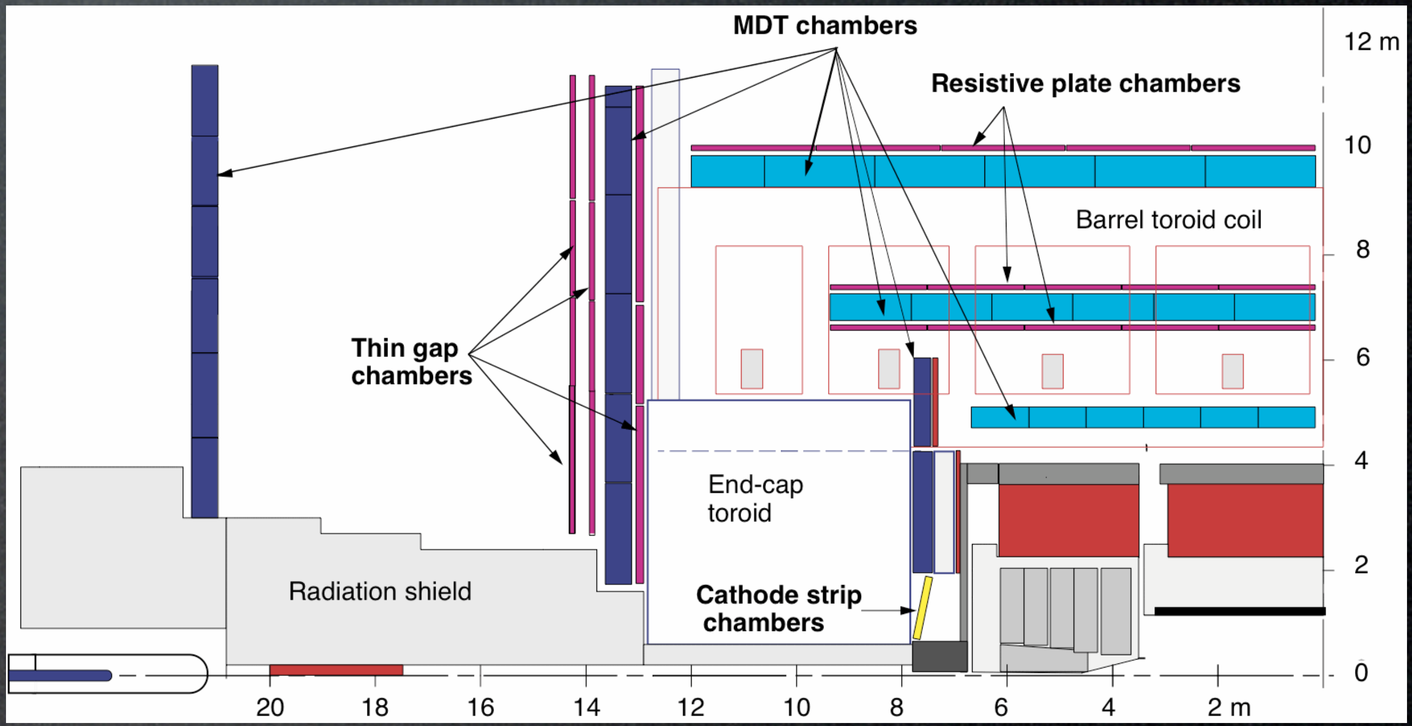
Muons

- Trigger: Level 1 (hardware) requires 3-D coincidence in RPC ($|\eta| < 1.05$) or TGC ($1.05 < |\eta| < 2.4$) and $p_T > 6$ GeV

- Offline: Combined tracks from Muon spectrometer and ID, using statistical combination of the two tracks

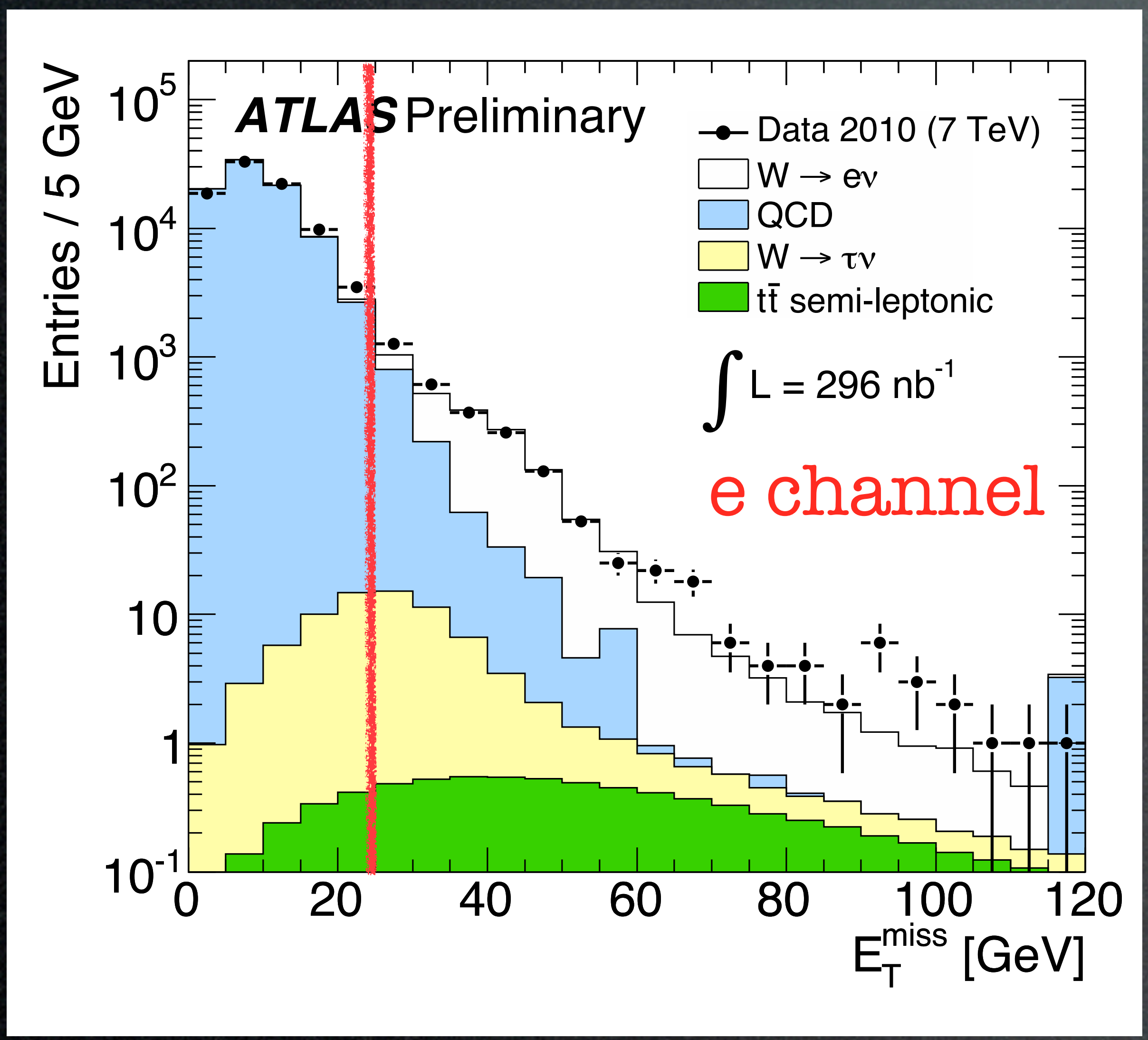
- > 94% reconstruction efficiency at $p_T > 20$ GeV

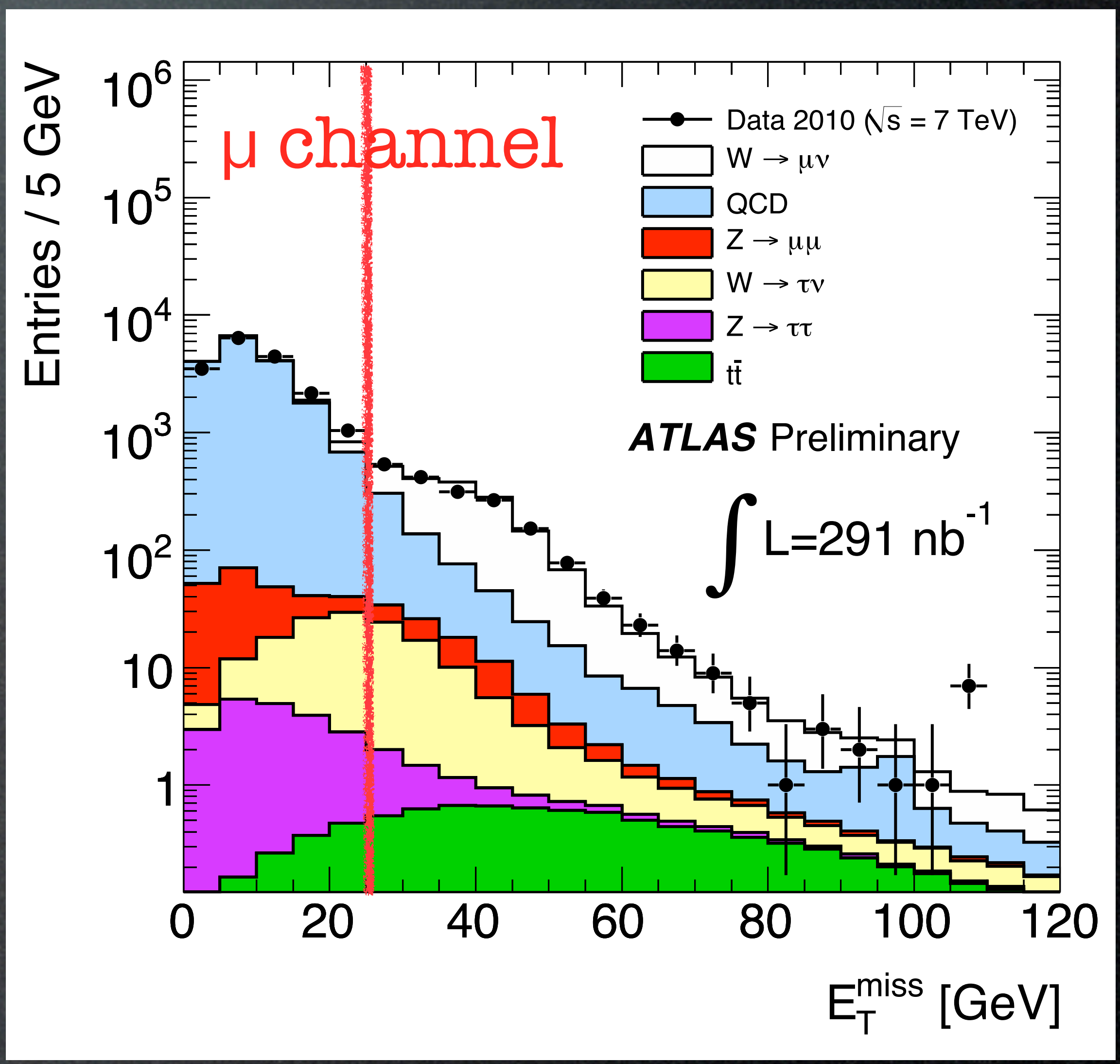




Missing E_T

- Missing transverse energy from calibrated 3-D topological clusters (hadron/$e^{\pm}$/γ, dead material energy loss)
- Quality requirements on jets to suppress fake ME_T
- Muon term added from its p_T





Leptons from QCD

- Decays of (especially) HF 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
- Similar to Tevatron techniques, also at 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

W cross-section measurement with 17 nb^{-1}

Some distributions studied with higher statistics (~1 pb^{-1})

Theoretical predictions

- W(ℓ ν) and Z(ℓ ℓ) in pp collisions (cross-section × B.R.)
  - from FEWZ (NNLO) calculations
  - MSTW2008 p.d.f. set
  - estimated theoretical uncertainty ~4%

$$\sigma^{NNLO}_{W\to\ell\nu} = 10.46\text{ nb} \quad (\sigma^{NNLO}_{W^+\to\ell^+\nu} = 6.16\text{ nb} \quad \text{and} \quad \sigma^{NNLO}_{W^-\to\ell^-\nu} = 4.30\text{ nb})$$

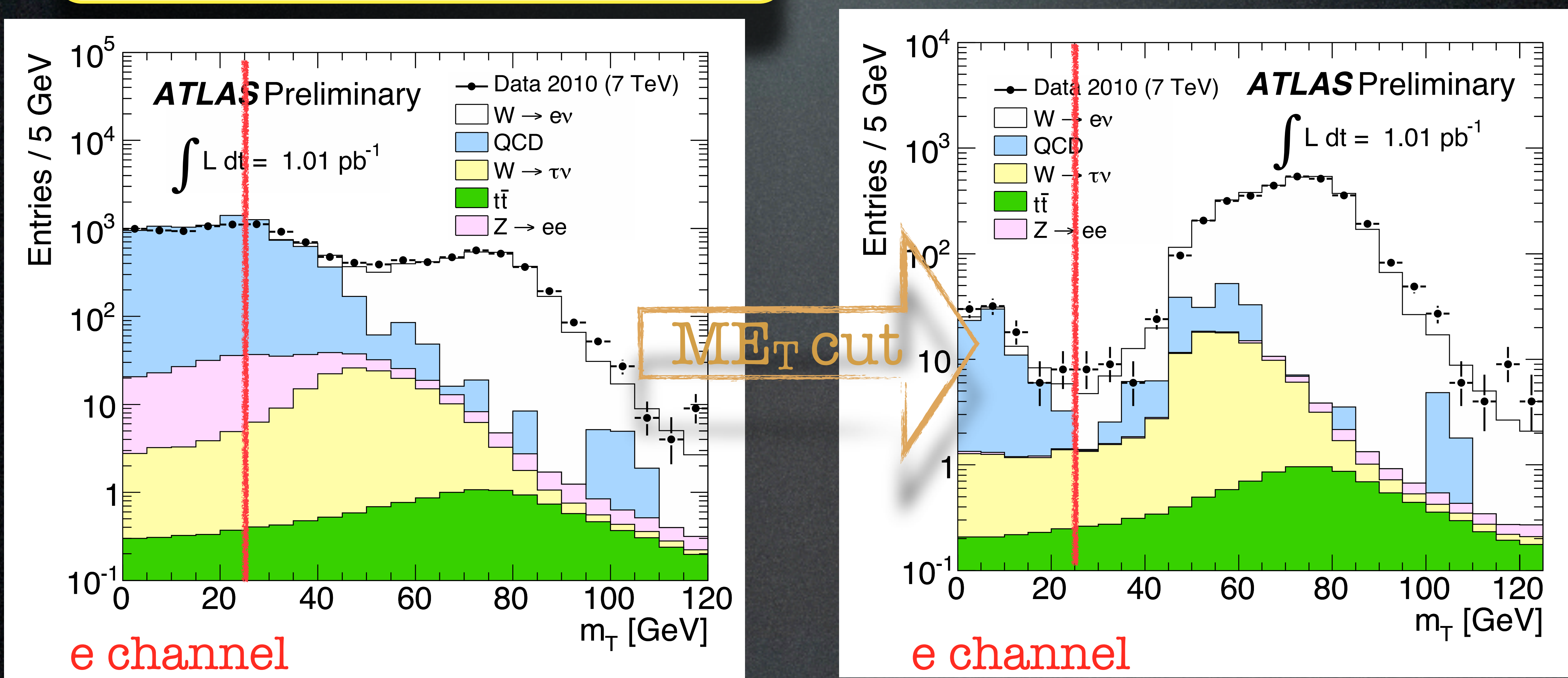
$$\sigma^{NNLO}_{Z/\gamma^*\to\ell\ell} = 0.99\text{ nb}$$ (66 GeV < M(ll) < 116 GeV)

Final signal selections

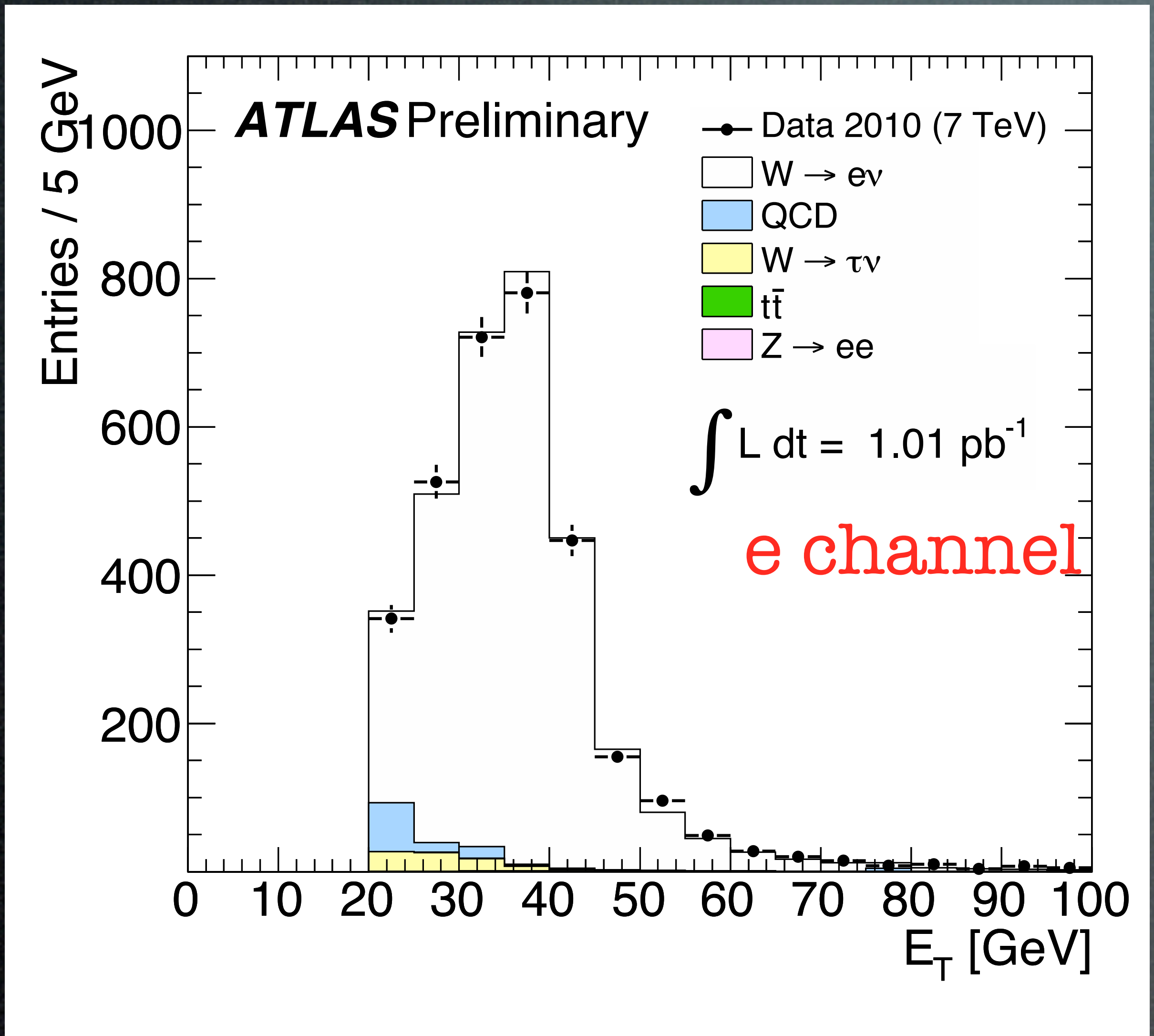
- 1 TIGHT electron
- $ME_T > 25$ GeV
- $M_T(W) > 40$ GeV

- 1 Combined muon
- $p_T > 20$ GeV
- Track isolated in ID
- $ME_T > 25$ GeV
- $M_T(W) > 40$ GeV

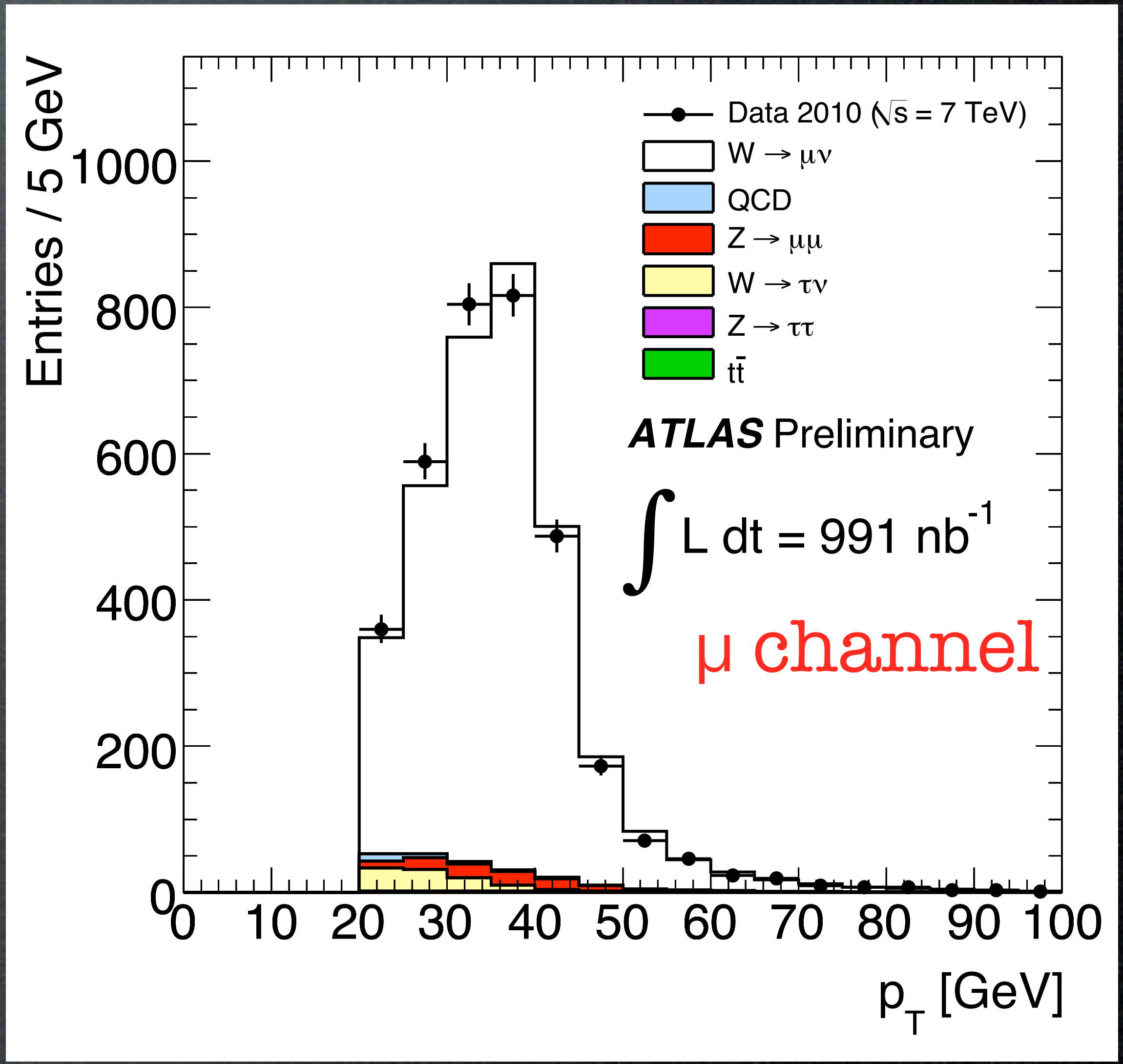
$$M_T = \sqrt{2(p_T^{\mu})(E_T^{\text{miss}})(1-\cos(\varphi^{\mu} - \varphi^{E_T^{\text{miss}}}))}$$



Selected lepton kinematics

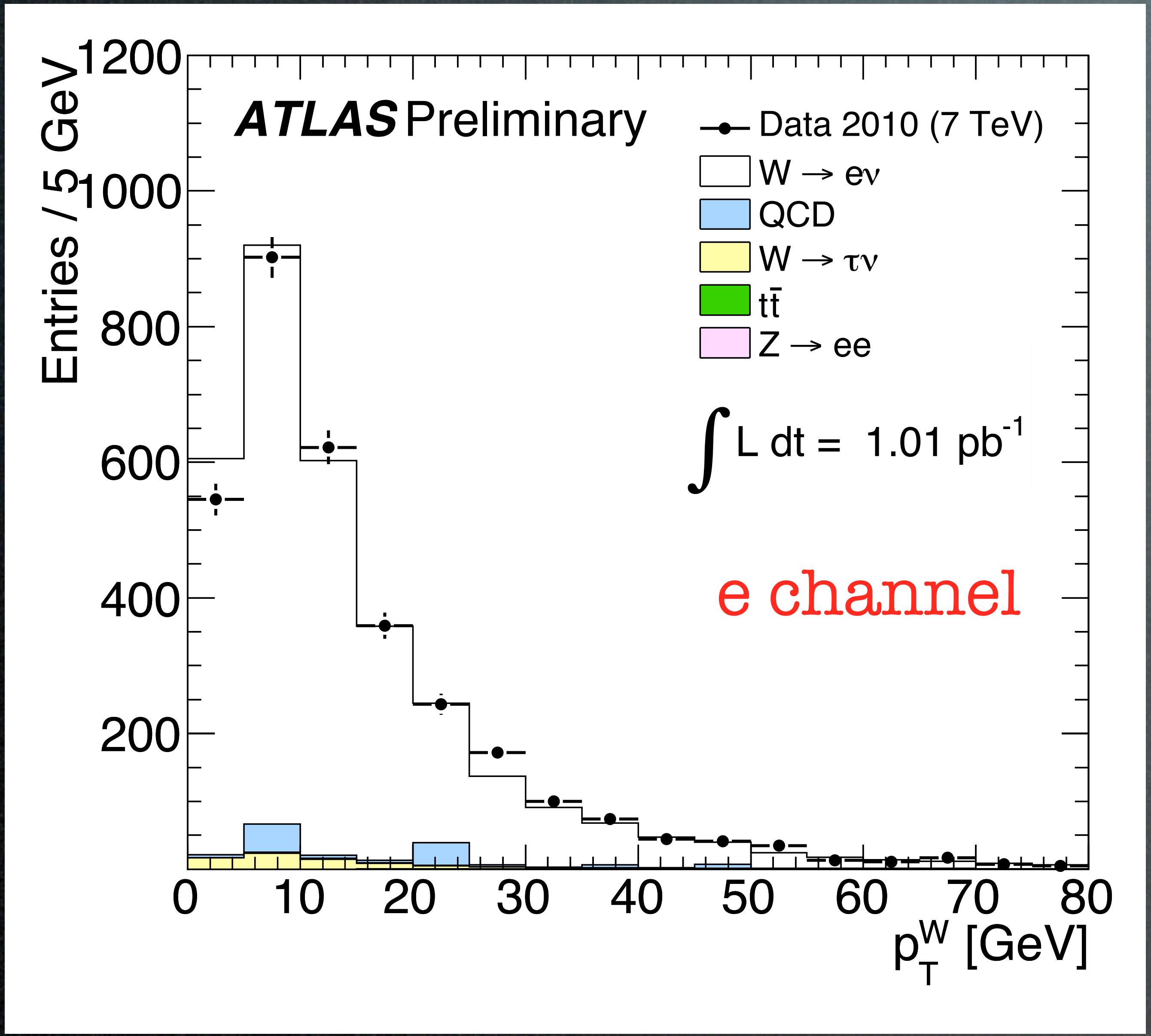


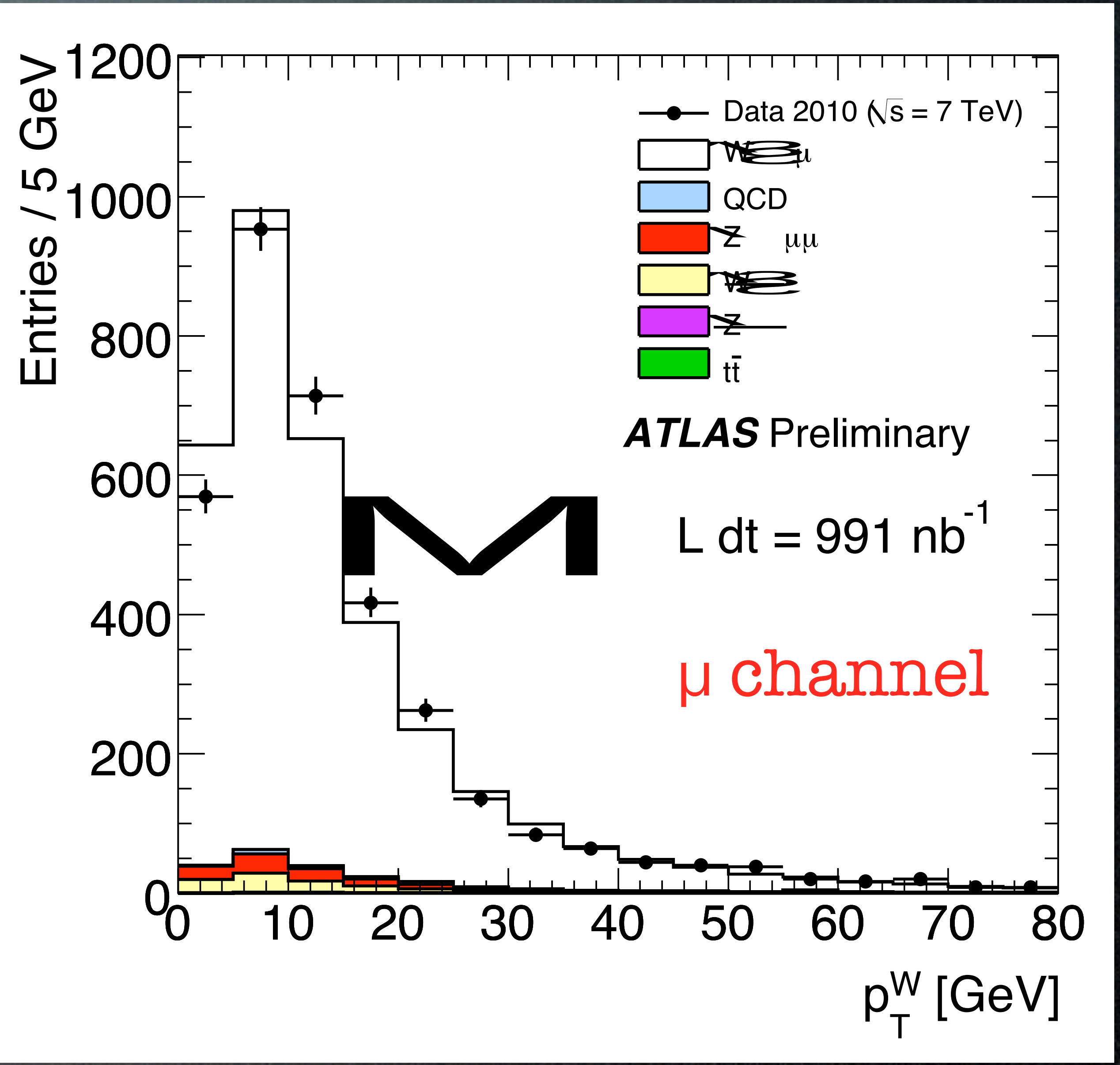
Electron E_T after all W selections



Muon p_T after all W selections

Selected Signal kinematics





- After ME_T and $M_T(W)$ cuts
- clear W signal over almost negligible background

Cut flow

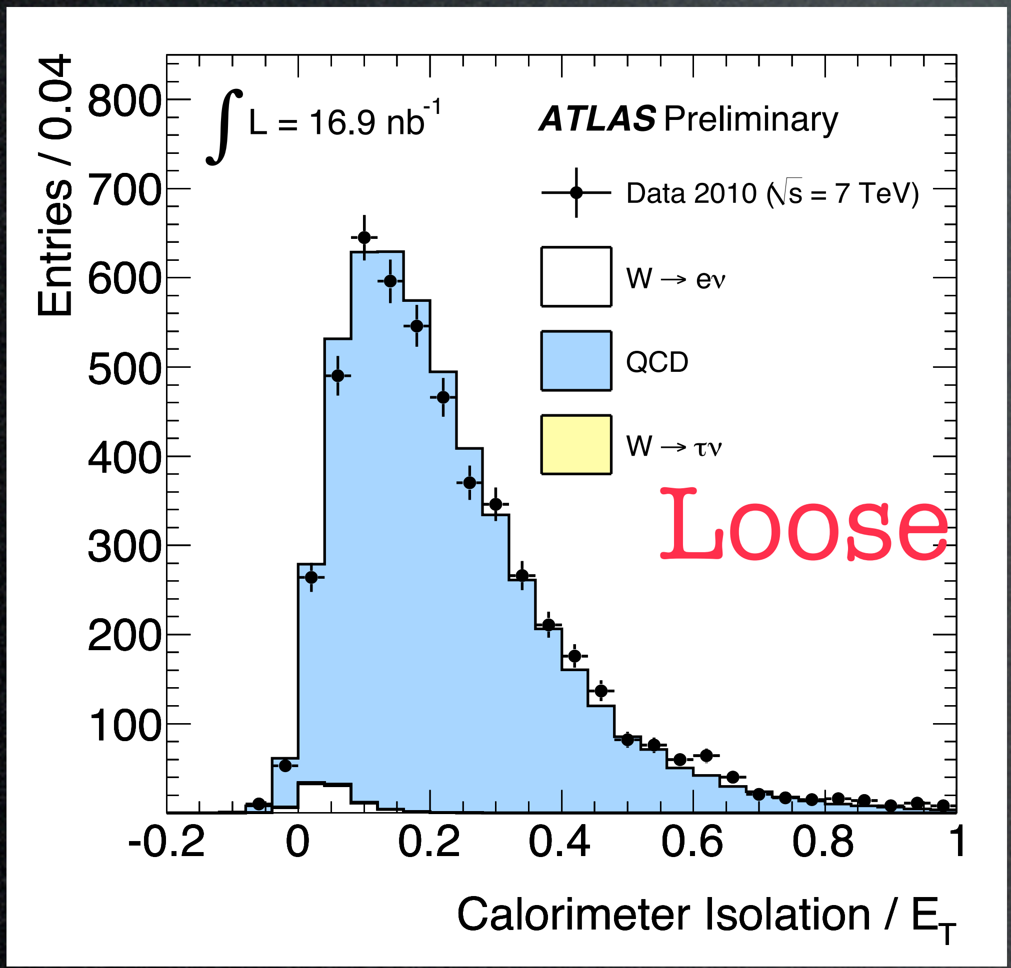
Integrated Lumi = 17 nb^{-1}

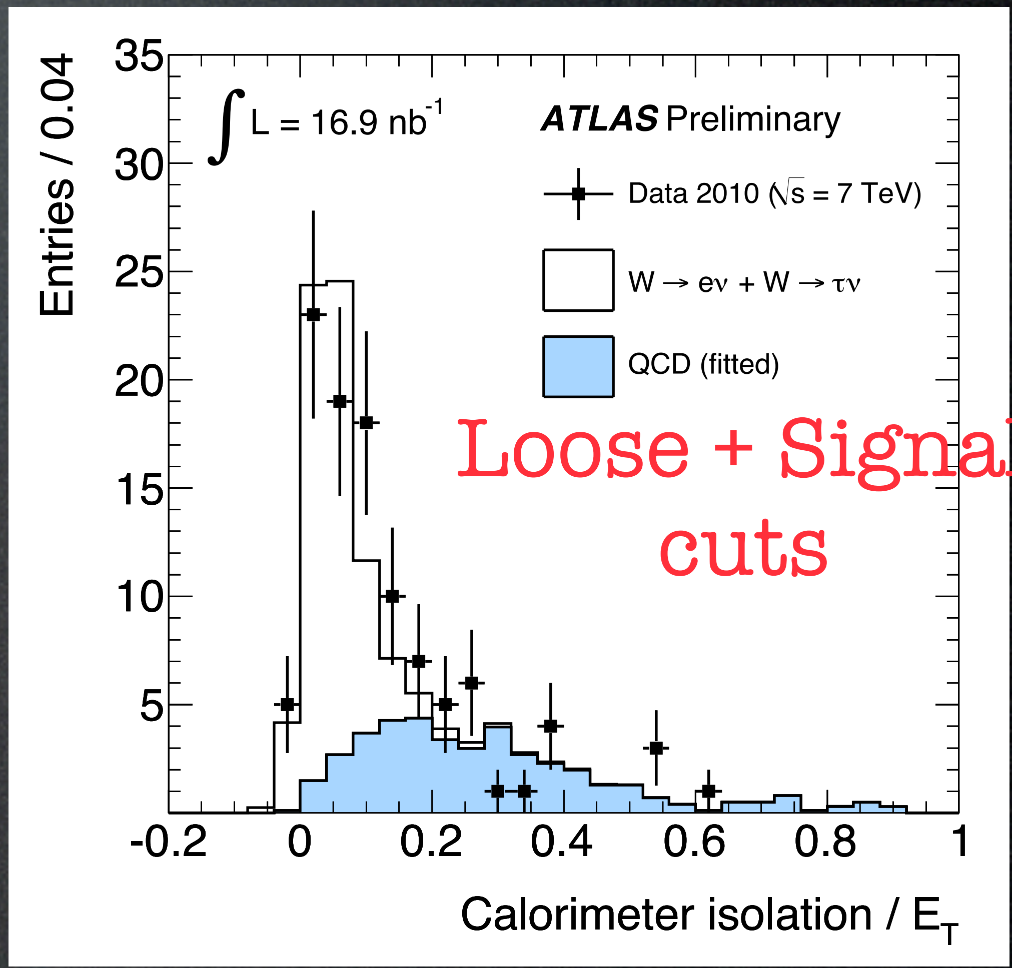
Requirement e channel	Number of candidates
Triggered (Section 5)	2.4×10^6
Preselection (Section 6)	5.1×10^3
Tight electron (Section 4.1)	177
$E_T^{miss} > 25$ GeV	49
$m_T > 40$ GeV	46

Requirement μ channel	Number of candidates
Triggered (Section 5)	2.0×10^6
Preselection (Section 6)	1155
$p_T > 20$ GeV	420
$\sum p_T^{ID} / p_T < 0.2$	186
$E_T^{miss} > 25$ GeV	77
$m_T > 40$ GeV	72

Background estimation: QCD, e

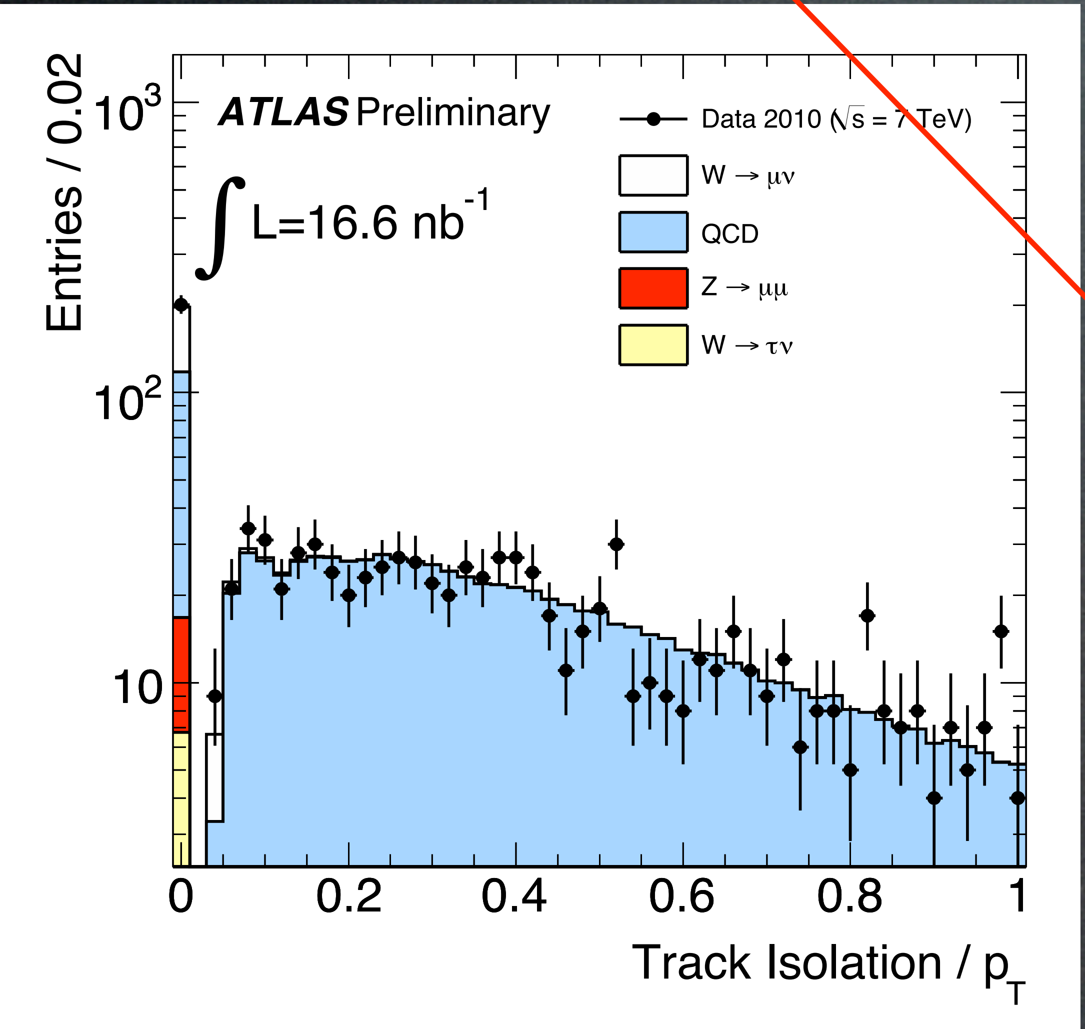
- in Electron channel: Heavy-Flavour decays, conversions, hadrons faking electrons
- Use calorimetry isolation E_T
  - fit Loose electrons in data with MC templates (higher statistics)
  - then extrapolated to signal region
  - QCD in signal region: 1.1 ± 0.2 (stat) ± 0.4 (syst)

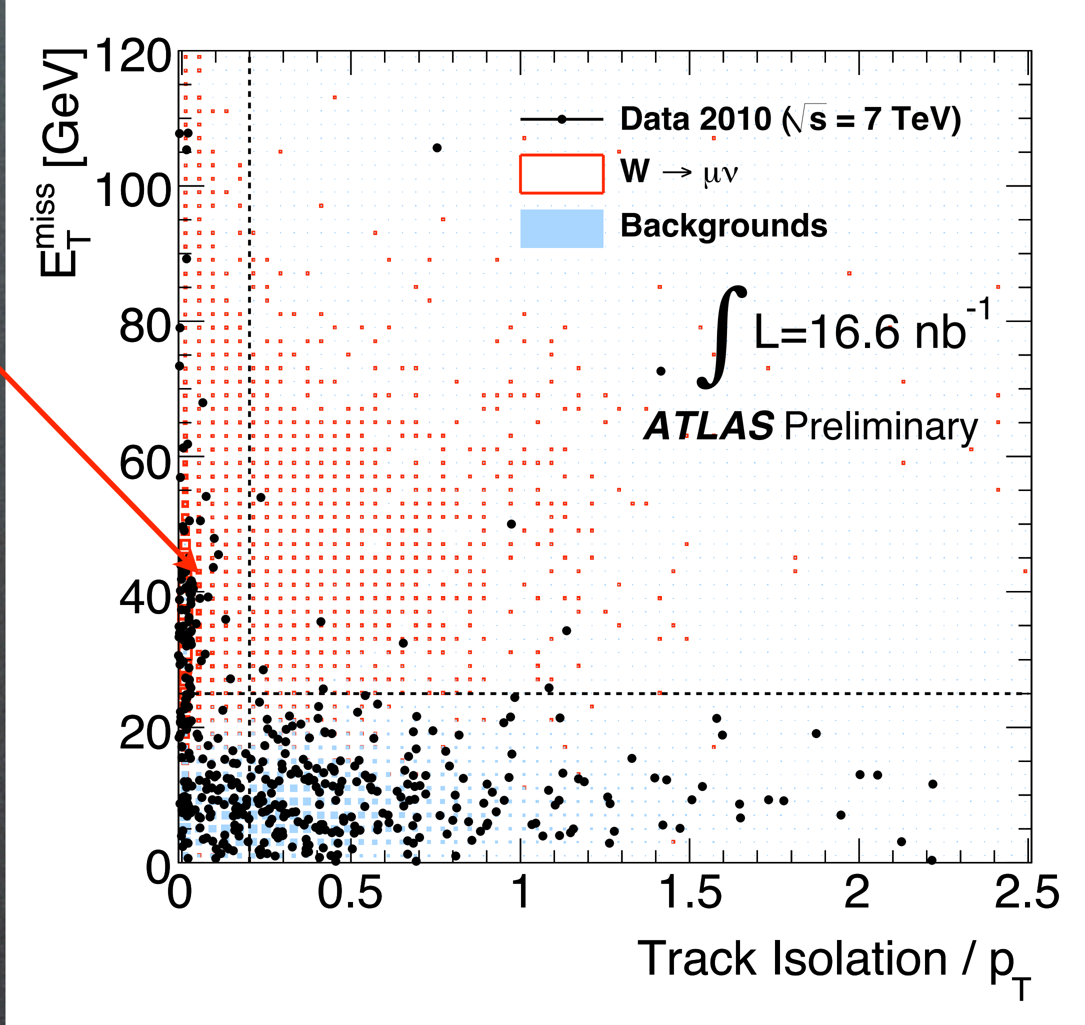




Background estimation: QCD, μ

- "ABCD" method to predict background in signal region from control regions dominated by bkg (jets, π/K decays)
- **Uncorrelated** variables: ME_T and track Isolation/p_T
- QCD in signal region: 0.9 ± 0.3 (stat) ± 0.6 (syst)





Background estimation: ALL

From MC | From DATA

ℓ	Observed candidates	Background (EW)	Background (QCD)	Background-subtracted signal N_W^{sig}
e^+	27	$0.9 \pm 0.0 \pm 0.1$	$0.6 \pm 0.1 \pm 0.3$	$25.6 \pm 5.2 \pm 0.3$
e^-	19	$0.6 \pm 0.0 \pm 0.1$	$0.6 \pm 0.1 \pm 0.3$	$17.8 \pm 4.4 \pm 0.3$
$e^\pm$	46	$1.5 \pm 0.0 \pm 0.1$	$1.1 \pm 0.2 \pm 0.4$	$43.4 \pm 6.8 \pm 0.4$
μ^+	47	$2.4 \pm 0.0 \pm 0.2$	$0.7 \pm 0.3 \pm 0.5$	$43.8 \pm 6.9 \pm 0.6$
μ^-	25	$2.0 \pm 0.0 \pm 0.2$	$0.2 \pm 0.1 \pm 0.2$	$22.8 \pm 5.0 \pm 0.3$
$\mu^\pm$	72	$4.4 \pm 0.0 \pm 0.3$	$0.9 \pm 0.3 \pm 0.6$	$66.7 \pm 8.5 \pm 0.7$

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

Towards the cross-section...

$$\sigma_{tot} = \sigma_W \times BR(W \to \ell\nu) = \frac{N_W^{sig}}{A_W C_W L_{int}},$$

Geometrical acceptance
(generator level)
at Born level

Correction factor
(detector level)

Electron channel	
Trigger efficiency	0.999 ± 0.001(tot)
Reconstruction/identification efficiency	0.78 ± 0.05(syst)

Final C_W

$C_W(e) = (65.6 \pm 5.3)\%$

$C_W(\mu) = (81.4 \pm 5.6)\%$

Muon channel	
Trigger efficiency	0.88 ± 0.01 ± 0.03
Reconstruction/identification efficiency	0.97 ± 0.01 ± 0.04
Trigger scale factor	0.97 ± 0.01 ± 0.04
Reconstruction scale factor	0.99 ± 0.01 ± 0.04

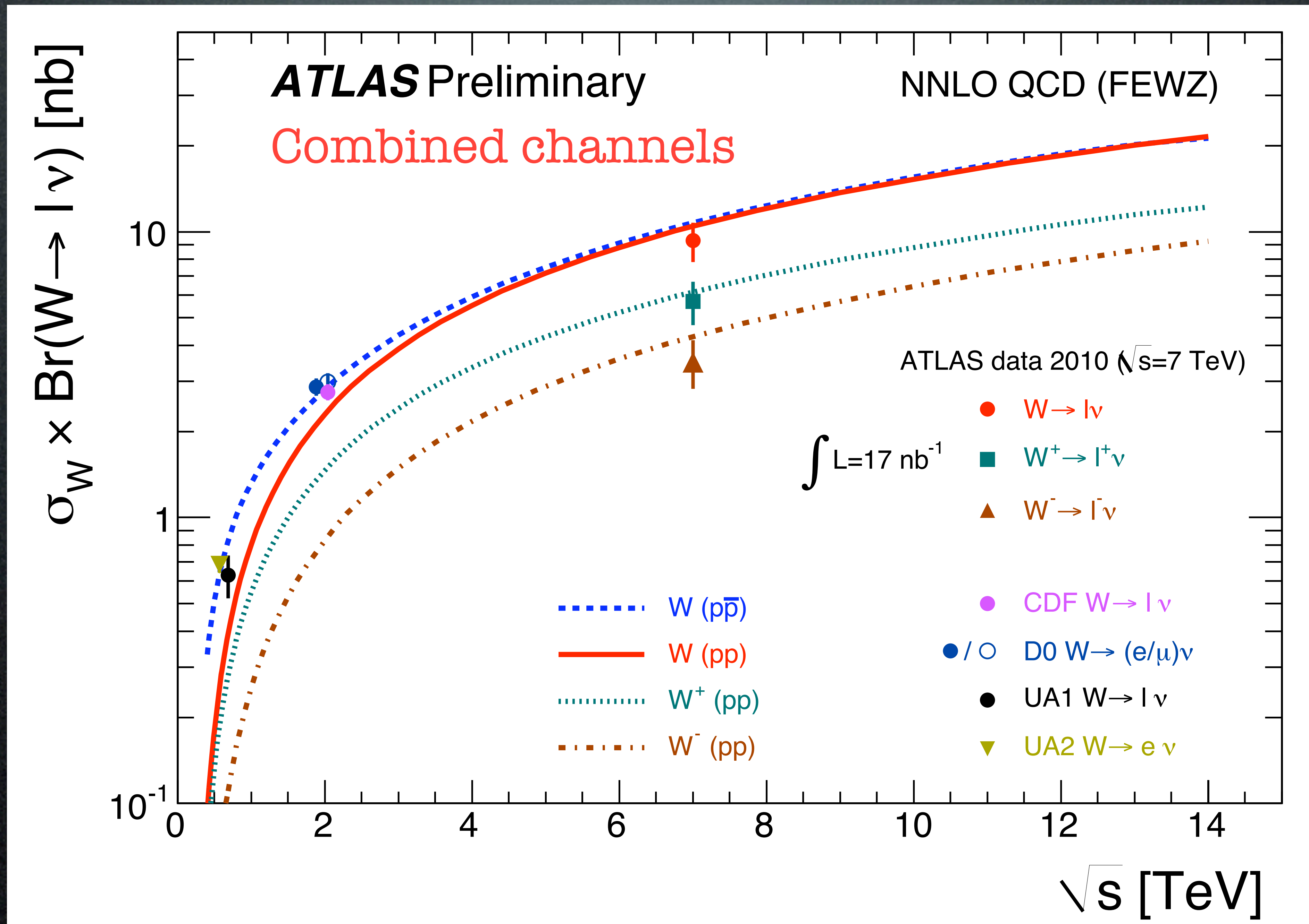
W cross-section

$L = 16.9\ nb^{-1}$	Estimated N(signal)	cross-section (nb)
W(eν)	46	8.5 ± 1.3 (stat) ± 0.7 (syst) ± 0.9 (lumi)
W(μν)	72	10.3 ± 1.3 (stat) ± 0.8 (syst) ± 1.1 (lumi)
Combined	118	9.3 ± 0.9 (stat) ± 0.6 (syst) ± 1.0 (lumi)

Theory:

$$\sigma^{NNLO}_{W\to\ell\nu} = 10.46\ \text{nb} \quad (\sigma^{NNLO}_{W^+\to\ell^+\nu} = 6.16\ \text{nb} \quad \text{and} \quad \sigma^{NNLO}_{W^-\to\ell^-\nu} = 4.30\ \text{nb})$$

First point at 7 TeV...



- Remarkable agreement with theory (4% theor. uncertainty not shown)
- $W^{+/-}$ asymmetry due to parton composition in protons observed

Z cross-section measurement with 225 nb^{-1}

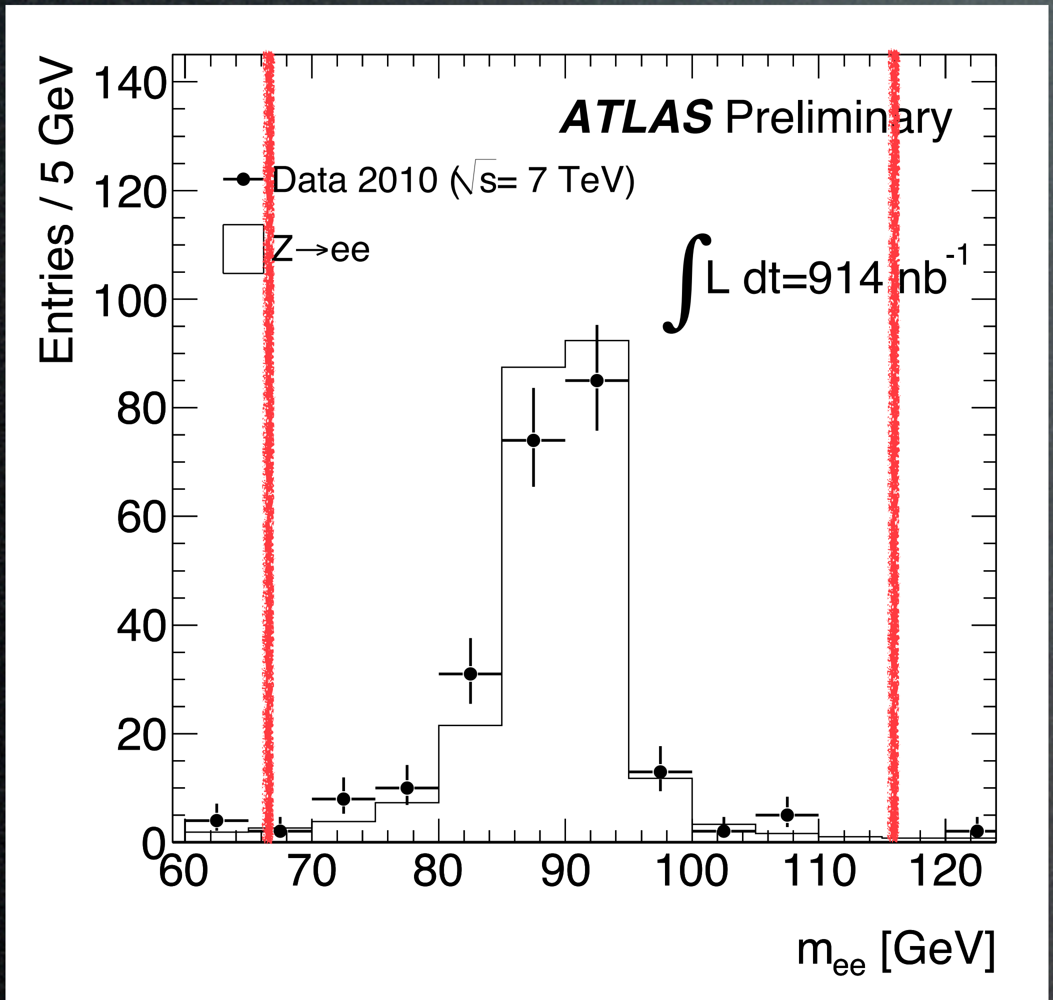
Some distributions studied with higher statistics (~1 pb^{-1})

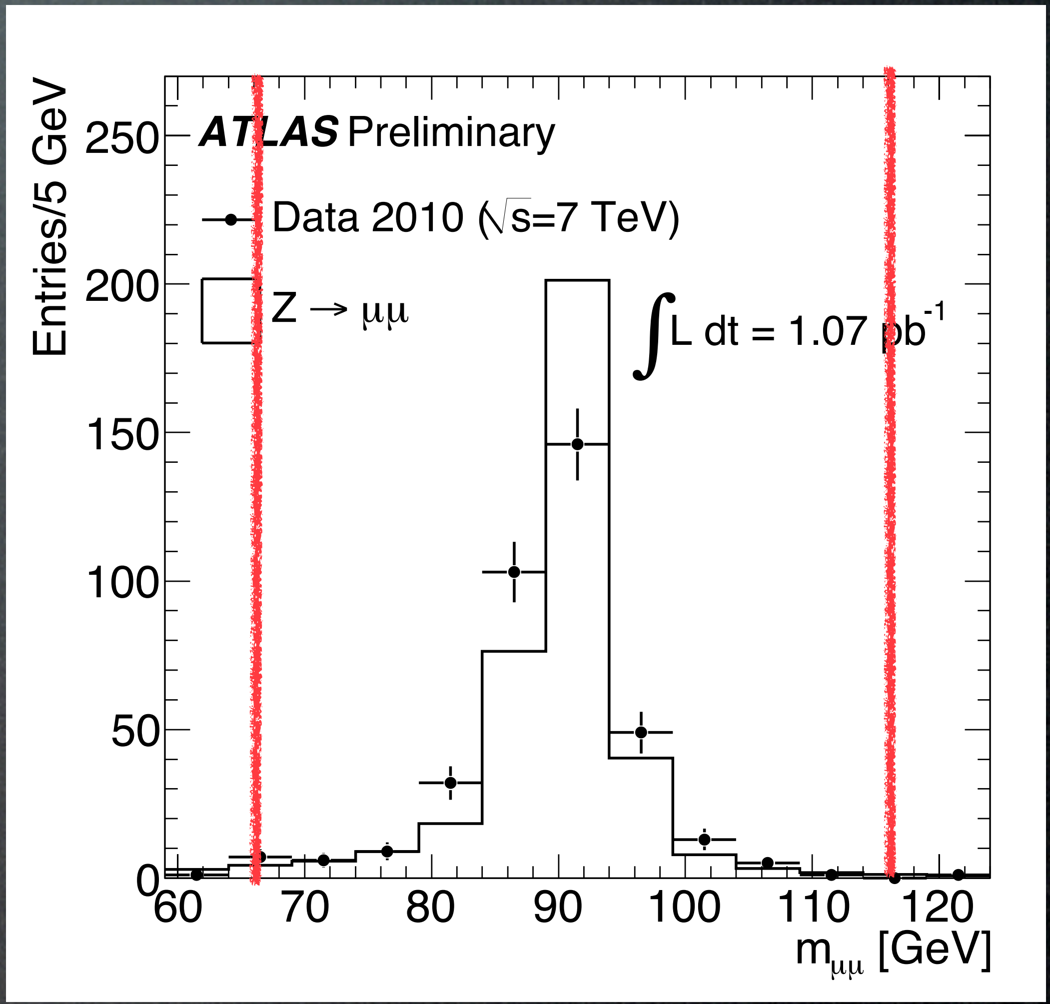
Final signal selections

- 2 MEDIUM electrons
- $E_T > 20$ GeV
- Opposite charge

- 2 Combined mu
- $p_T > 20$ GeV
- Opposite charge
- Track in ID isolated

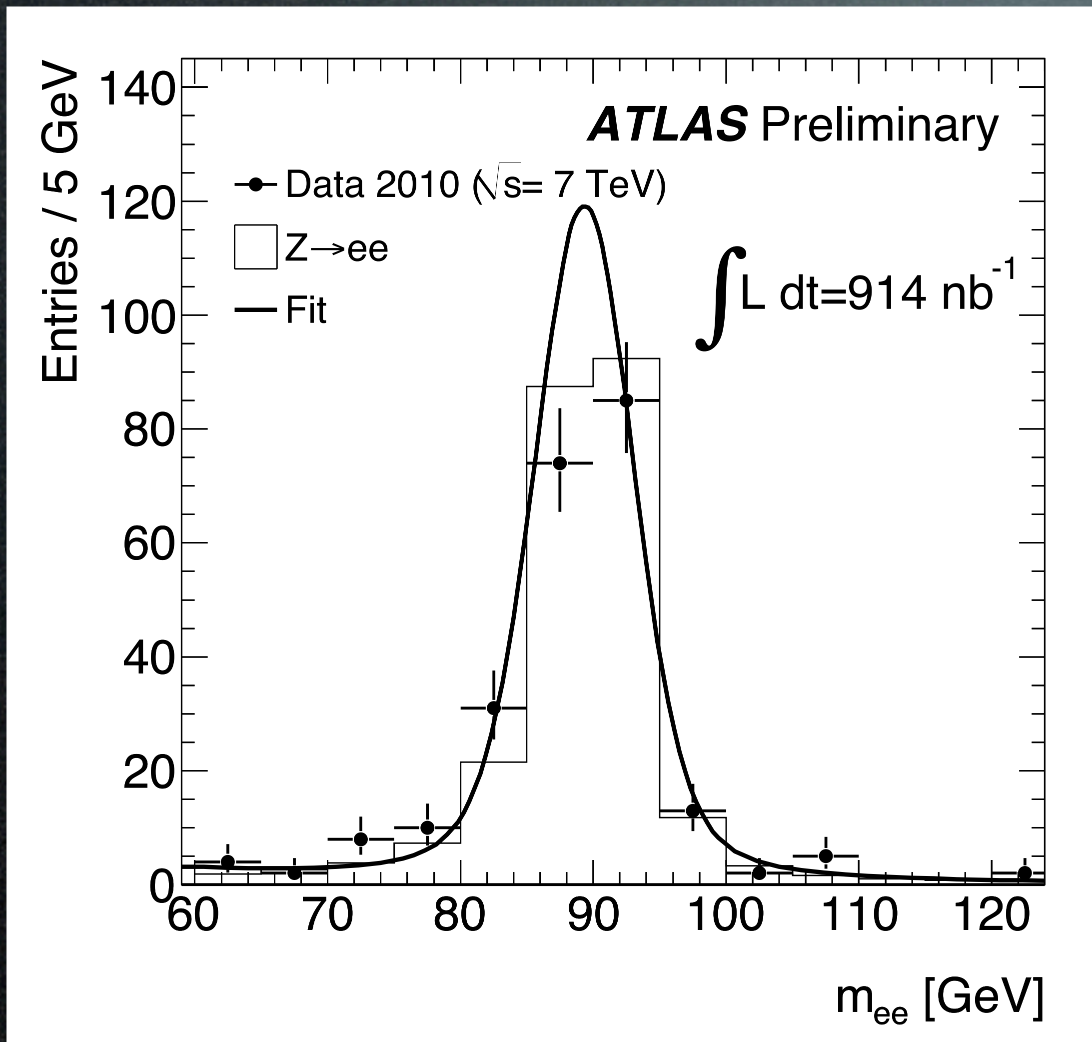
$66 < M(l^+ l^-) < 116$ GeV

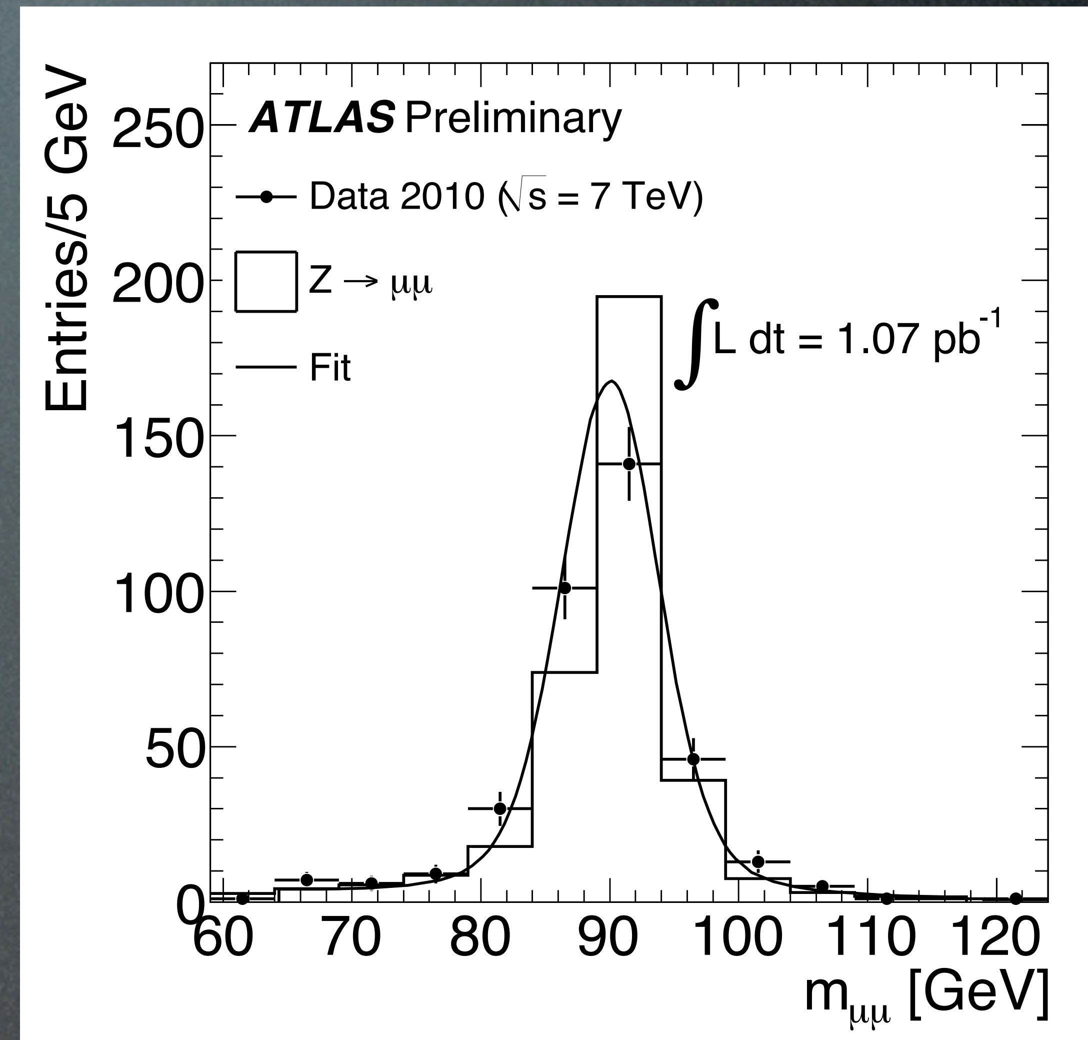




Backgrounds negligible!

Z Mass fit





- Fit using theoretical lineshape ⊗ Gaussian
- Electron: width = (3.2 ± 0.3) GeV
  - compatible with test beams and insitu $\pi^0 \to \gamma\gamma$
- Muon: width = (3.3 ± 0.3) GeV
  - slightly worse than expected due to misalignment of ID or MS

Cut flow

Integrated Lumi ~220 nb^{-1}

	Electron channel	Muon channel
Requirement	Number of candidates	Number of candidates
Triggered	4.4×10^6	3.8×10^6
$\ell^+\ell^-$ pairs	51	85
$66 < m_{\ell^+\ell^-} < 116$ GeV	46	79

Electron channel

- Calo trigger with $E_T > 10$ GeV (for ~90% data)
- L = 219 nb^{-1}

Muon channel

- Muon trigger with $P_T > 6$ GeV (for ~90% data)
- L = 229 nb^{-1}

Background estimation: QCD

- Electrons:
  - Predict Loose-Loose pairs from MC
  - then extrapolate to Medium electron (signal region)
  - Predicted QCD evts in signal region: 0.49 ± 0.07 (stat) ± 0.05 (syst)
  - Same-sign pair passing other cuts: 1

- Muons:
  - From simulation
  - Predicted QCD evts in signal region: 0.17 ± 0.01 (stat) ± 0.01 (syst)
  - Same-sign pair passing other cuts: 0

Towards the cross-section...

$$\sigma_{tot} = \sigma_{Z/\gamma^*} \times BR(Z/\gamma^* \to \ell\ell) = \frac{N_Z^{sig}}{A_Z C_Z L_{int}}$$

Geometrical acceptance (generator level) at Born level

Correction factor (detector level)

Final C_Z

$C_Z(e) = (64.5 \pm 9.0)\%$

$C_Z(\mu) = (79.7 \pm 5.5)\%$

Syst. uncertainty on A_Z = 3%

- LO-NLO differences and PDF dependence

Syst uncert. on C_Z = 14(7)% for e (mu)

- Trigger and reconstruction data/MC discrepancies

Z cross-section

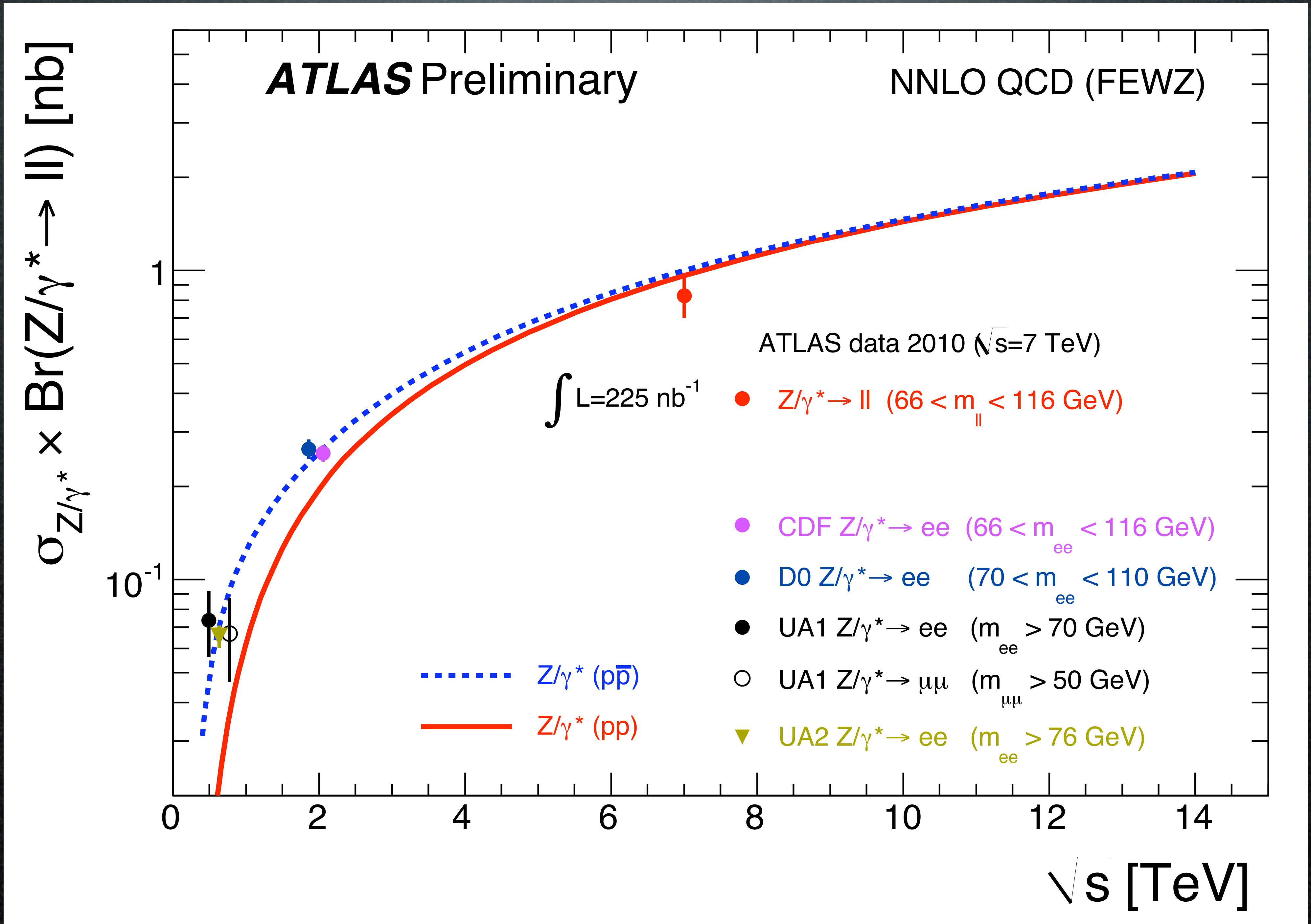
$L = \sim 225\ nb^{-1}$	Estimated N(signal)	cross-section (nb)
Z(eν)	46	0.72 ± 0.11 (stat) ± 0.10 (syst) ± 0.08 (lumi)
Z(μν)	79	0.89 ± 0.10 (stat) ± 0.07 (syst) ± 0.10 (lumi)
Combined	125	0.83 ± 0.07 (stat) ± 0.06 (syst) ± 0.09 (lumi)

Theory:

$$\sigma^{NNLO}_{Z/\gamma^* \to \ell\ell} = 0.99 \text{ nb}$$

(66 GeV < M(ll) < 116 GeV)

First point at 7 TeV...

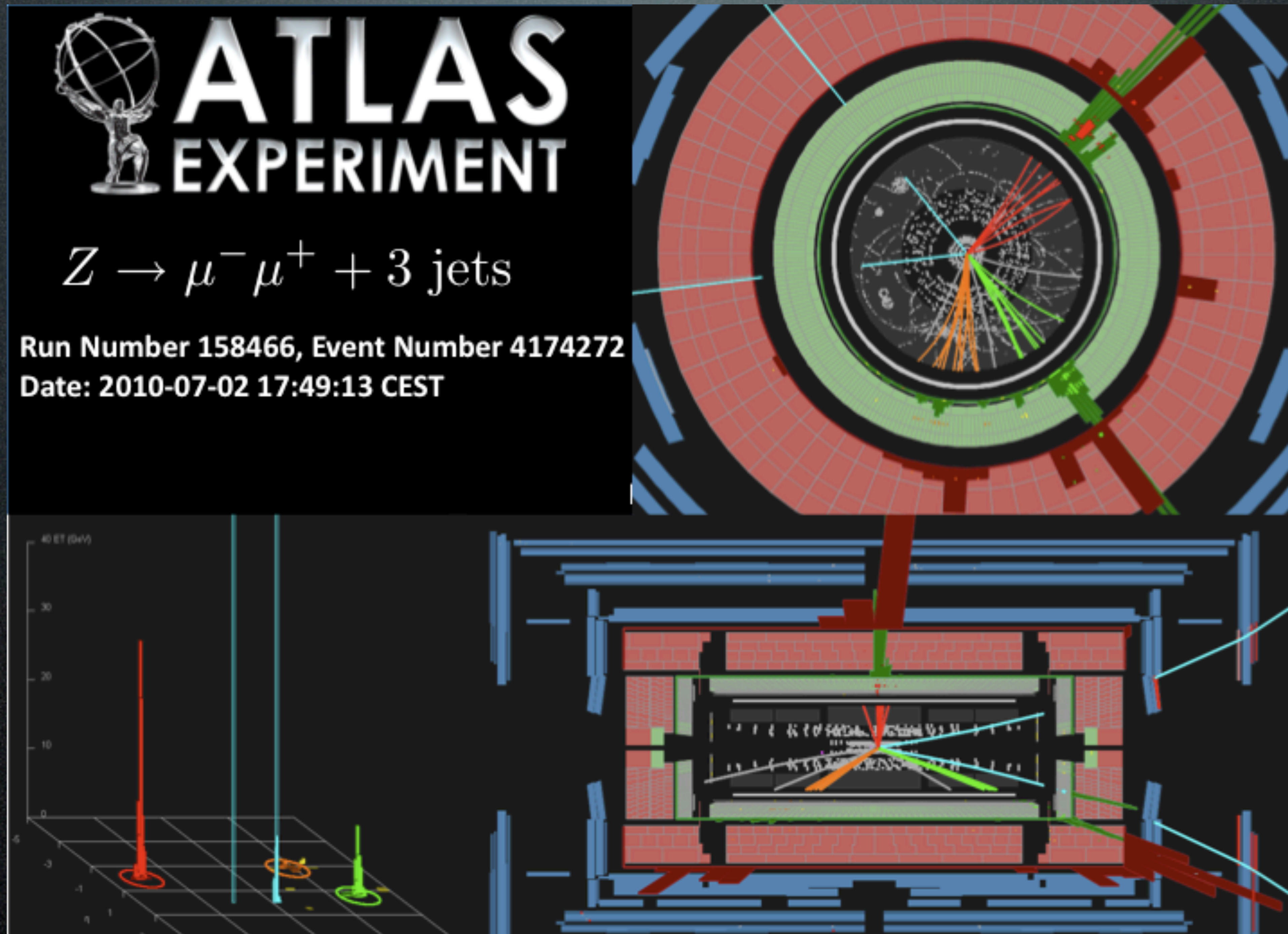


- Good agreement with theory
- 4% theoretical uncertainty not shown

W/Z + jets studies

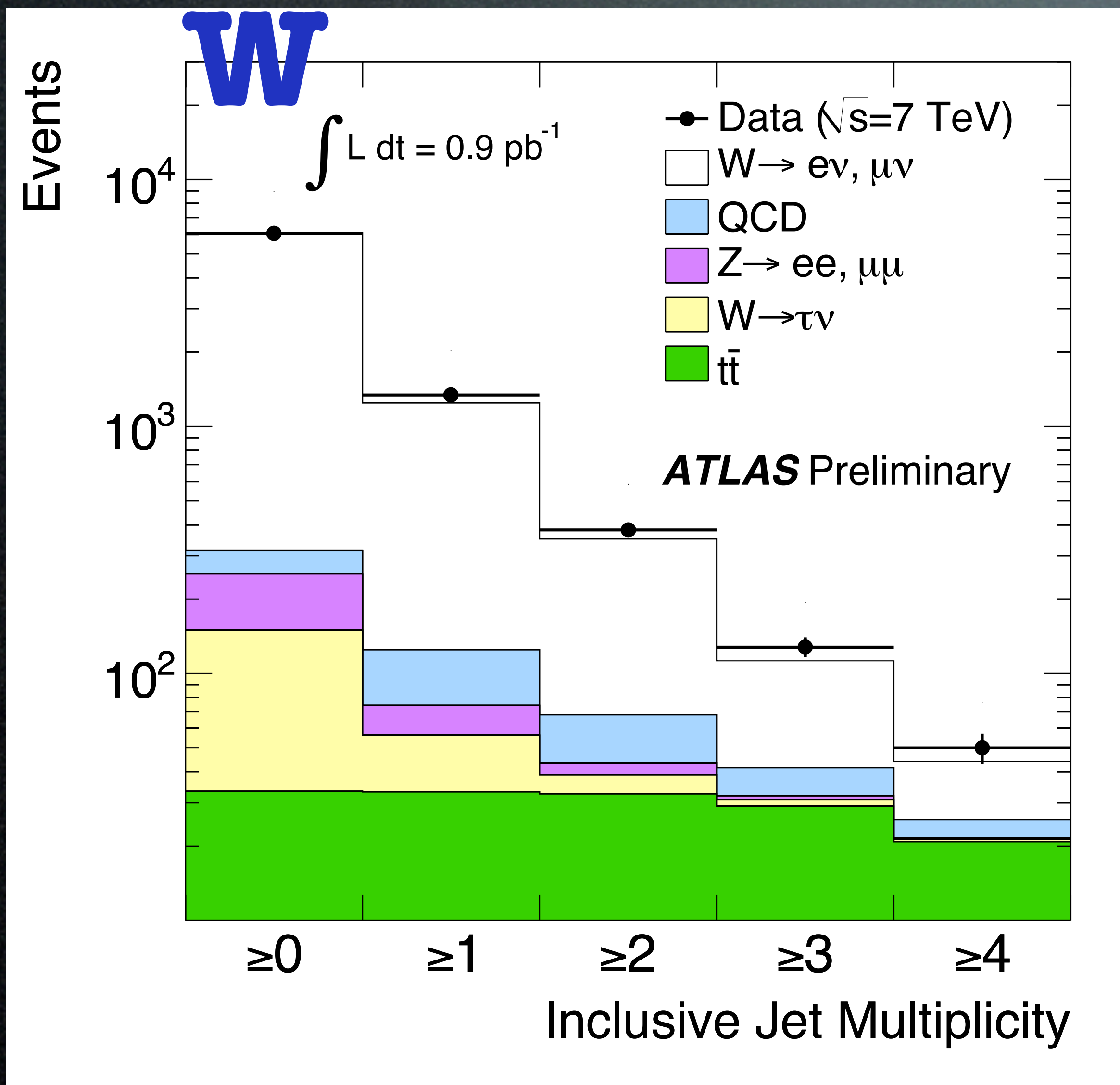
Preliminary data-MC agreement with 0.9 pb^{-1}

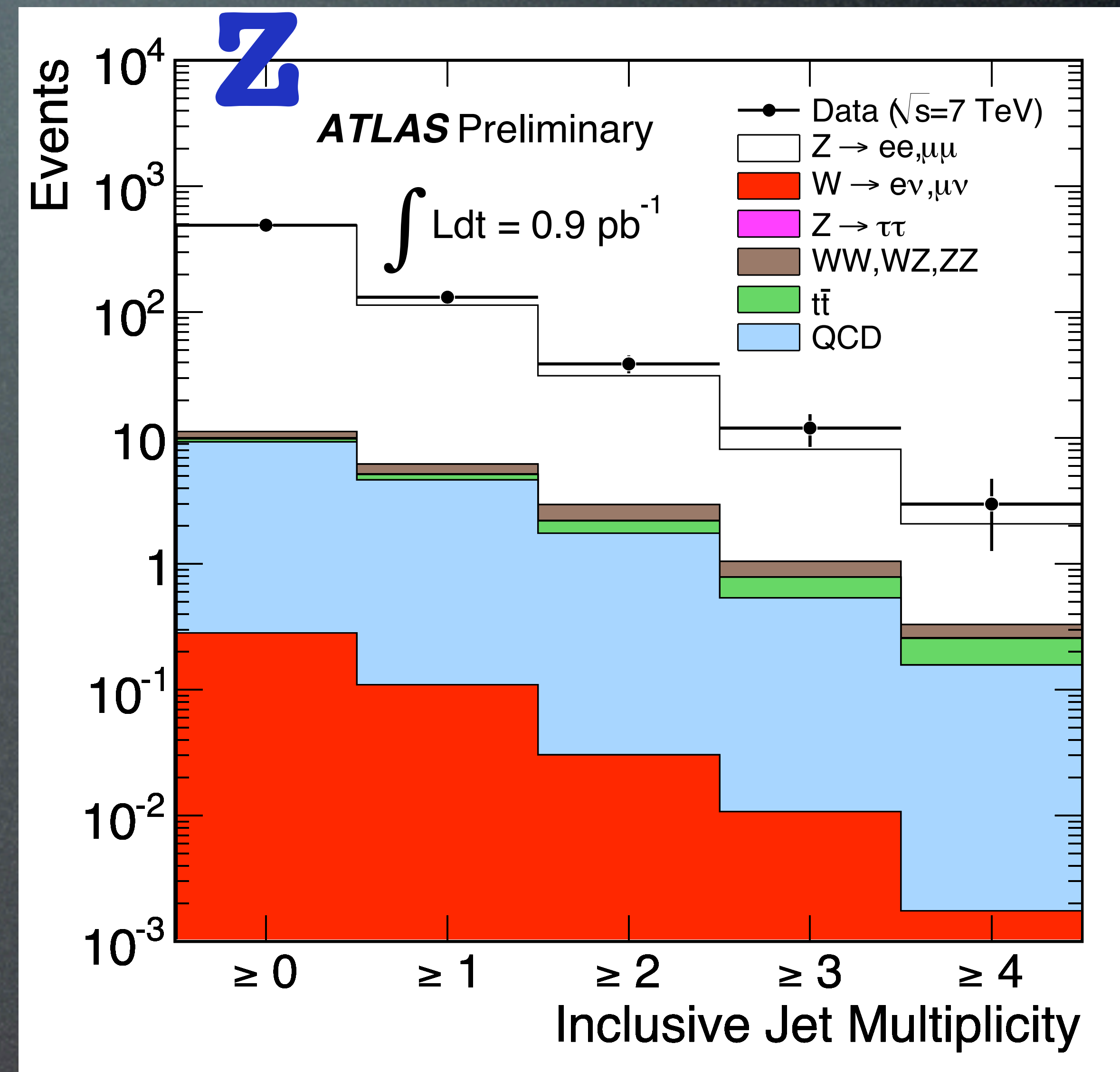
Z + 3 jets candidate!



Z boson with p_T = 144 GeV
muon p_T = 96 GeV and 68 GeV
M(mumu) = 79 GeV: the harder muon has left a significant energy deposit, presumably through bremsstrahlung
The jet E_T are 168, 105, and 45 GeV

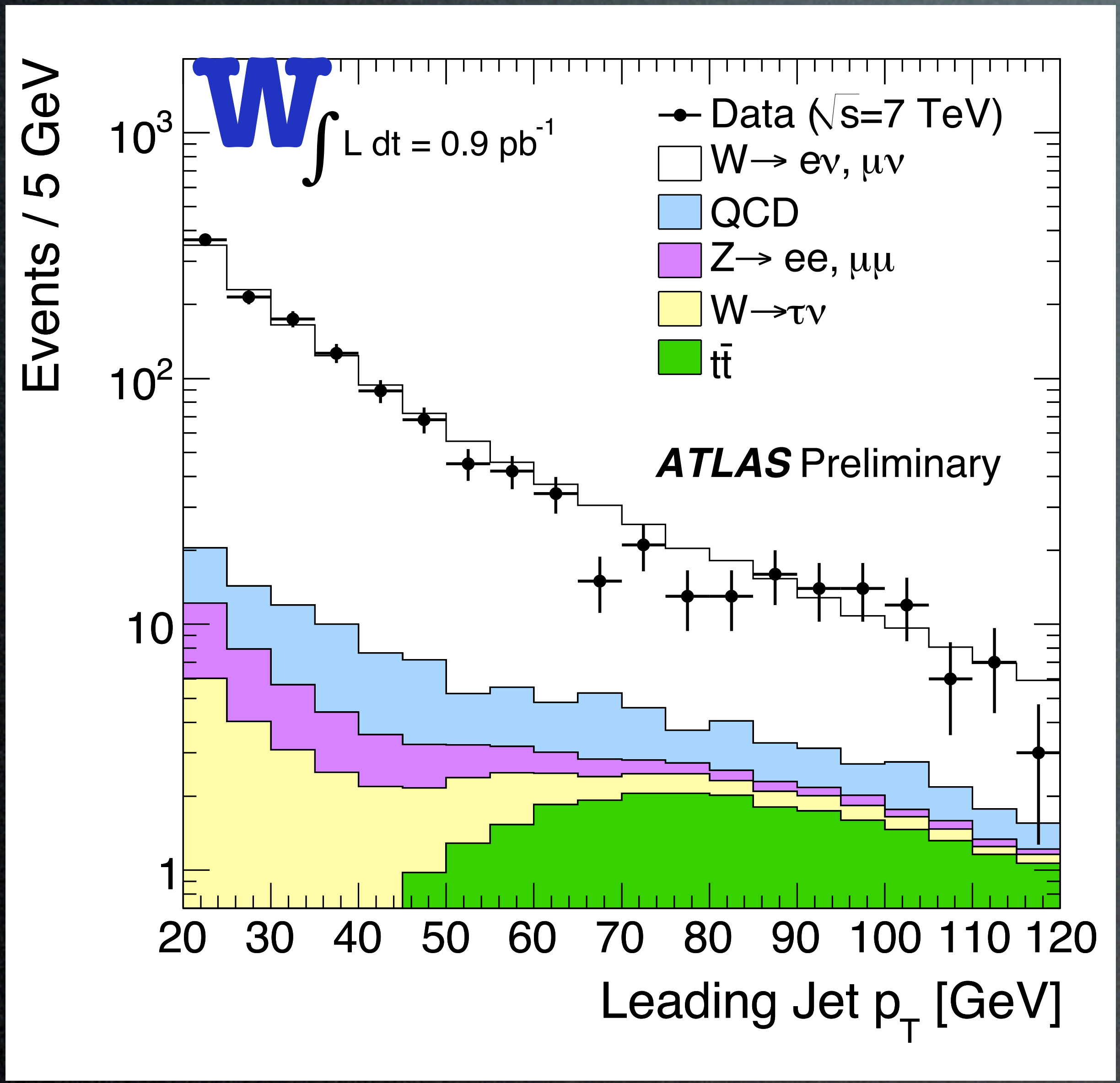
Jet multiplicity in W/Z evts

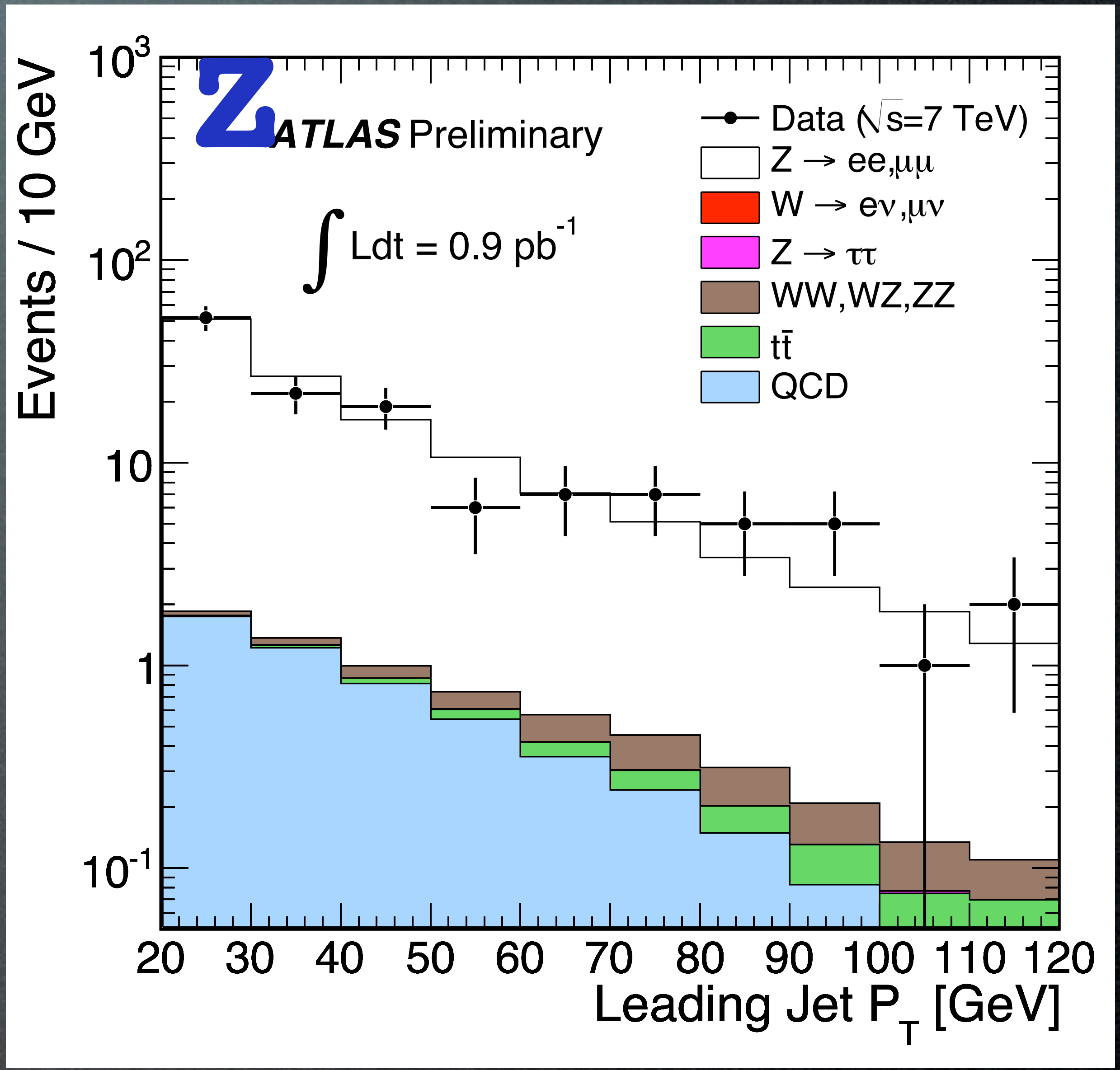




- W/Z (lν) + jets
- Anti-k_T jet algorithm with R=0.4, $|\eta| < 2.8$ and $p_T > 20$ GeV
- **MC normalized to inclusive data sample**

Leading Jet p_T





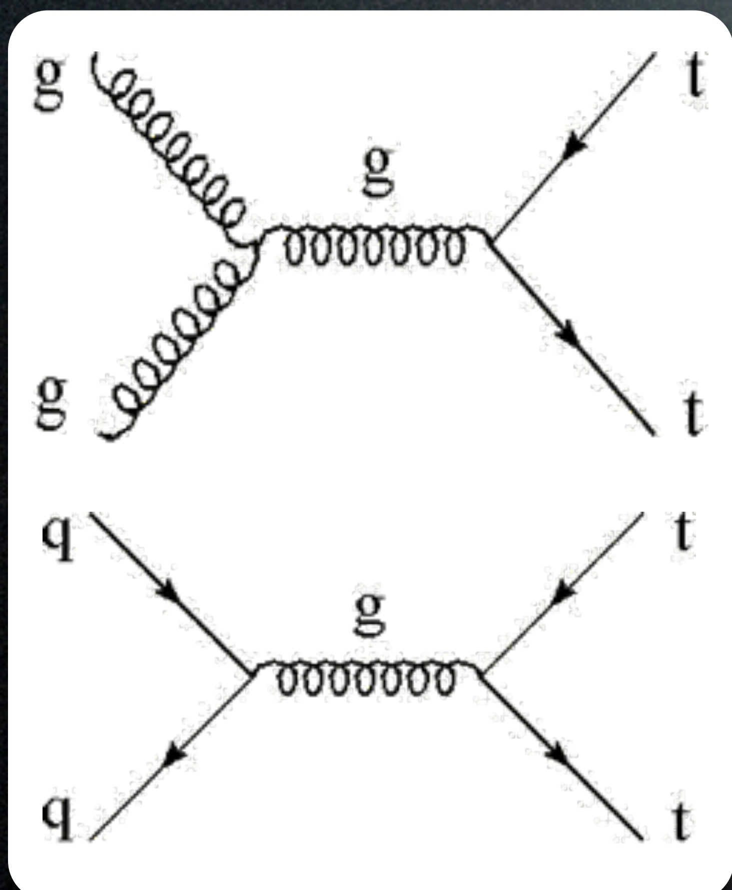
- Same W/Z selections as Inclusive cross-section
- Jets overlapping in space with the lepton are removed
- Background estimation entirely from simulation

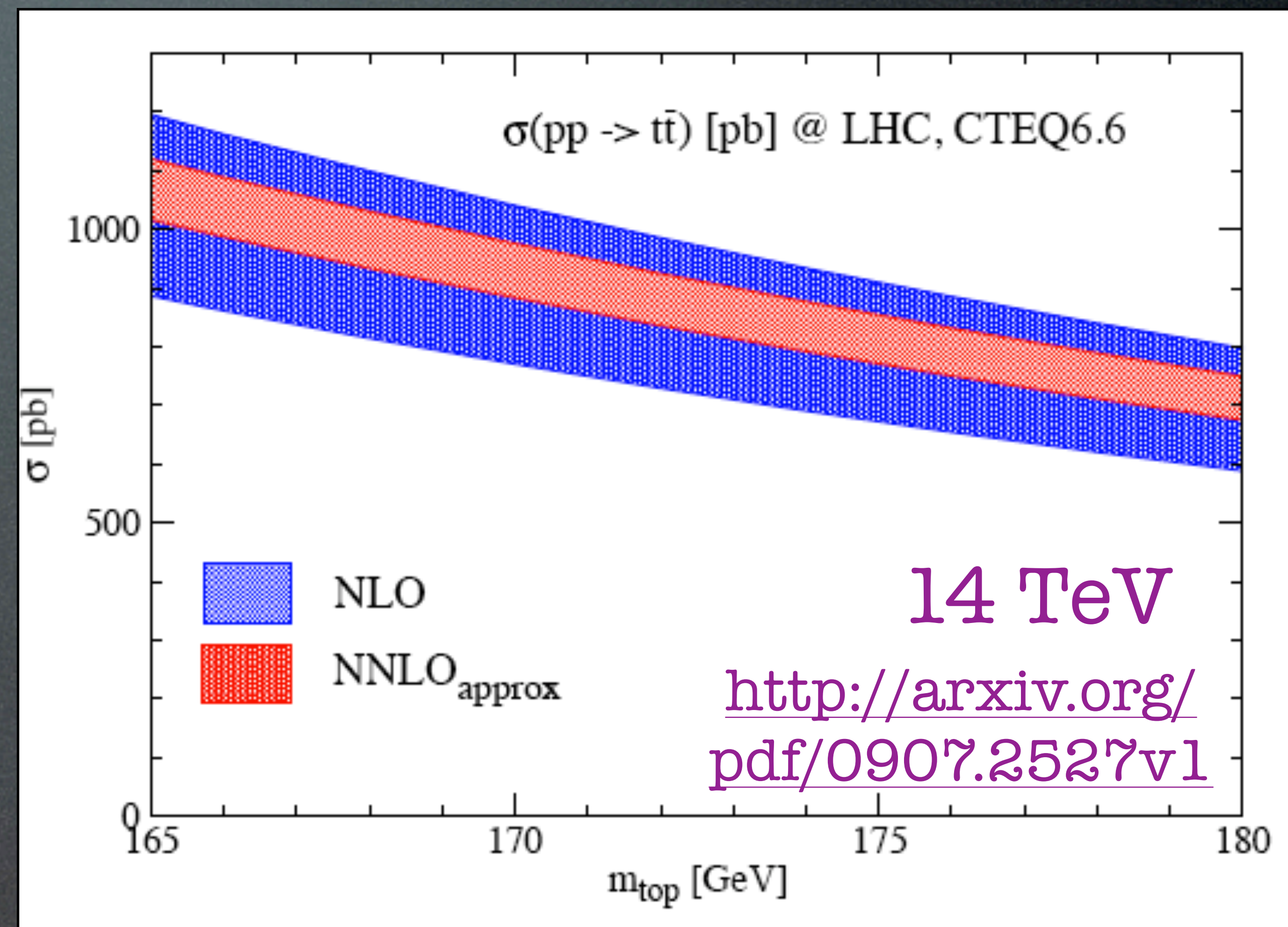
W/Z + jets (and others) as background for Top quark

L = 280 nb^{-1}

Ttbar cross-section

Cross-section measurement is **first** place where things can 'go wrong' w.r.t. SM in busy events



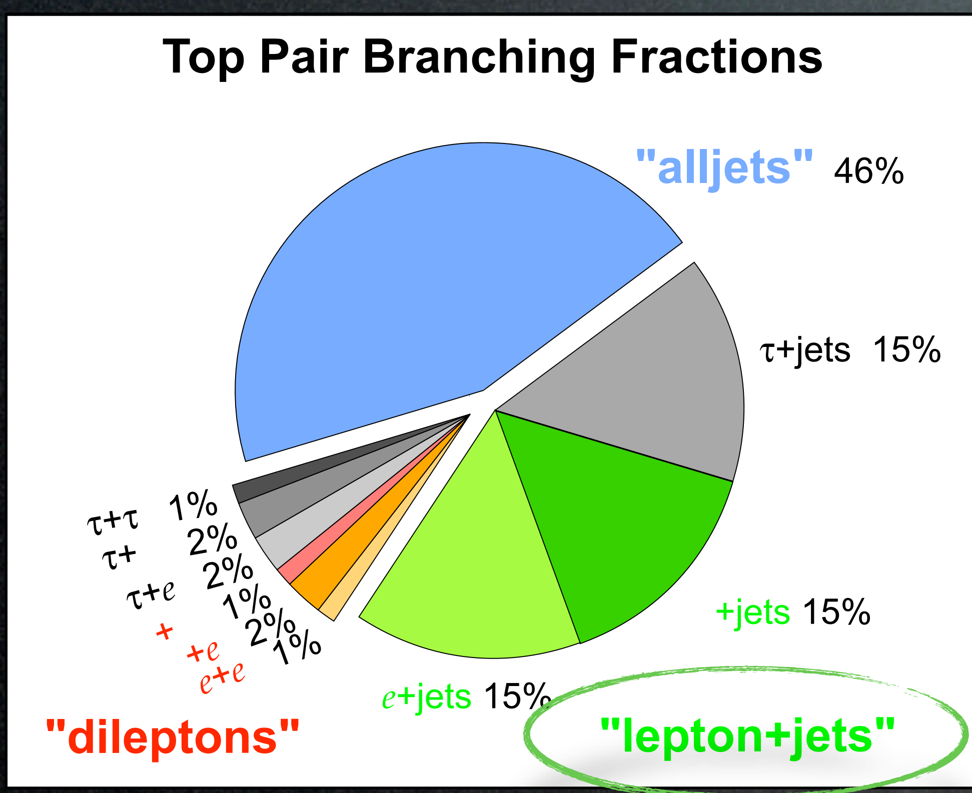


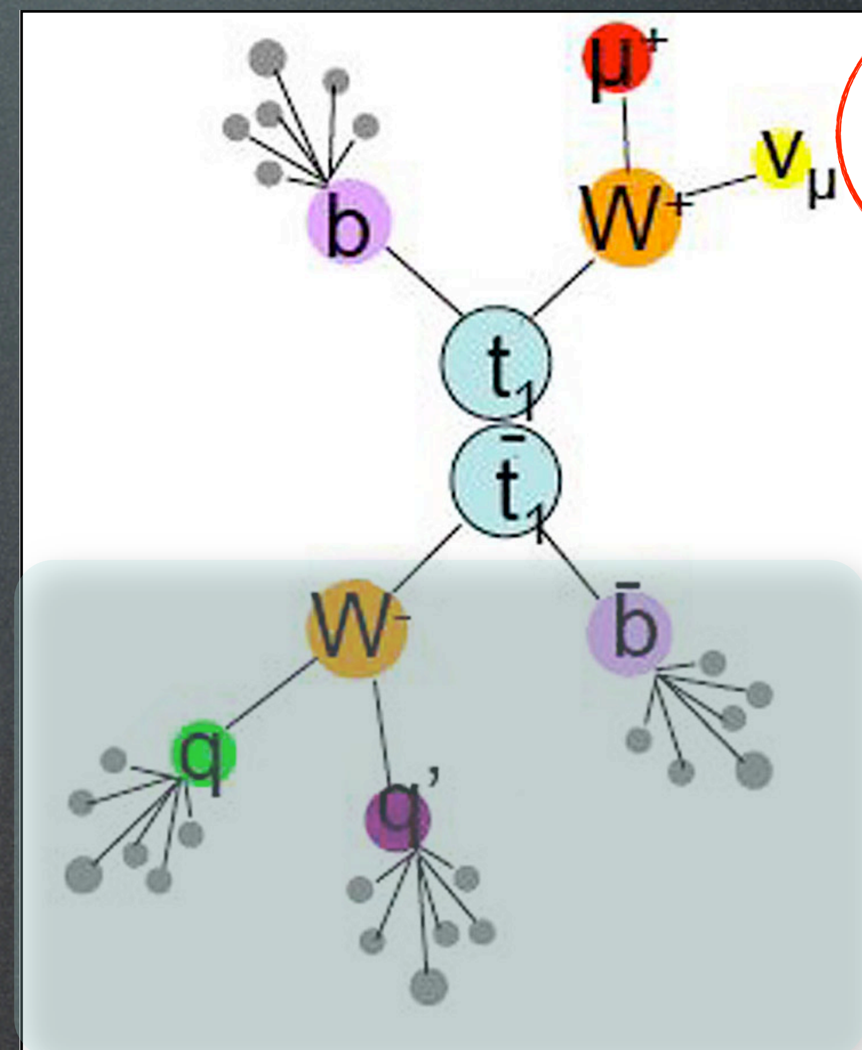
$$\sigma^{\rm NLO}(\sqrt{s} = 14\ {\rm TeV}, m_t = 171\ {\rm GeV}, {\rm CTEQ6.5}) = 875^{+11.6\%}_{-11.5\%}\ ({\rm scales})^{+3.4\%}_{-3.3\%}\ ({\rm pdf})\ {\rm pb}$$

$$\sigma^{\rm approxNNLO}(\sqrt{s} = 14\ {\rm TeV}, m_t = 172.5\ {\rm GeV}, {\rm CTEQ6.6}) = 883^{-1.0\%}_{-4.2\%}\ ({\rm scales})^{+3.3\%}_{-3.1\%}\ ({\rm pdf})\ {\rm pb}$$

Ttbar cross-section

- Consider 1 lepton + jets events: BR ~30% (e or μ)
- Also di-leptonic channel considered
- Wrap them all up: Top is next step in detector commissioning!

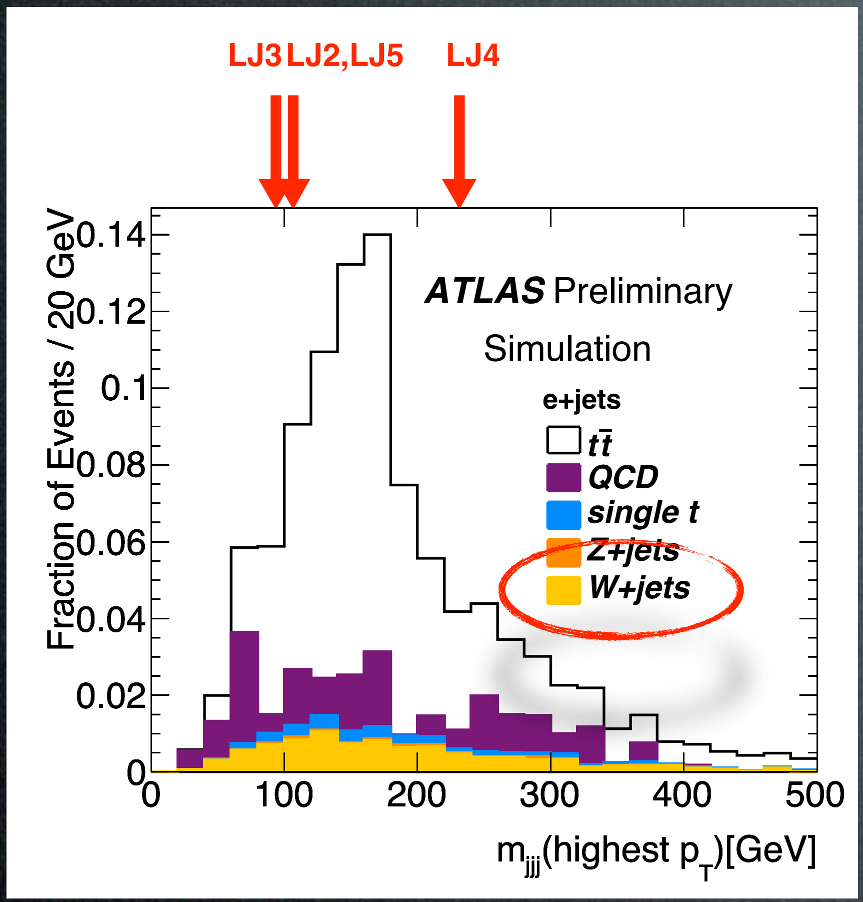


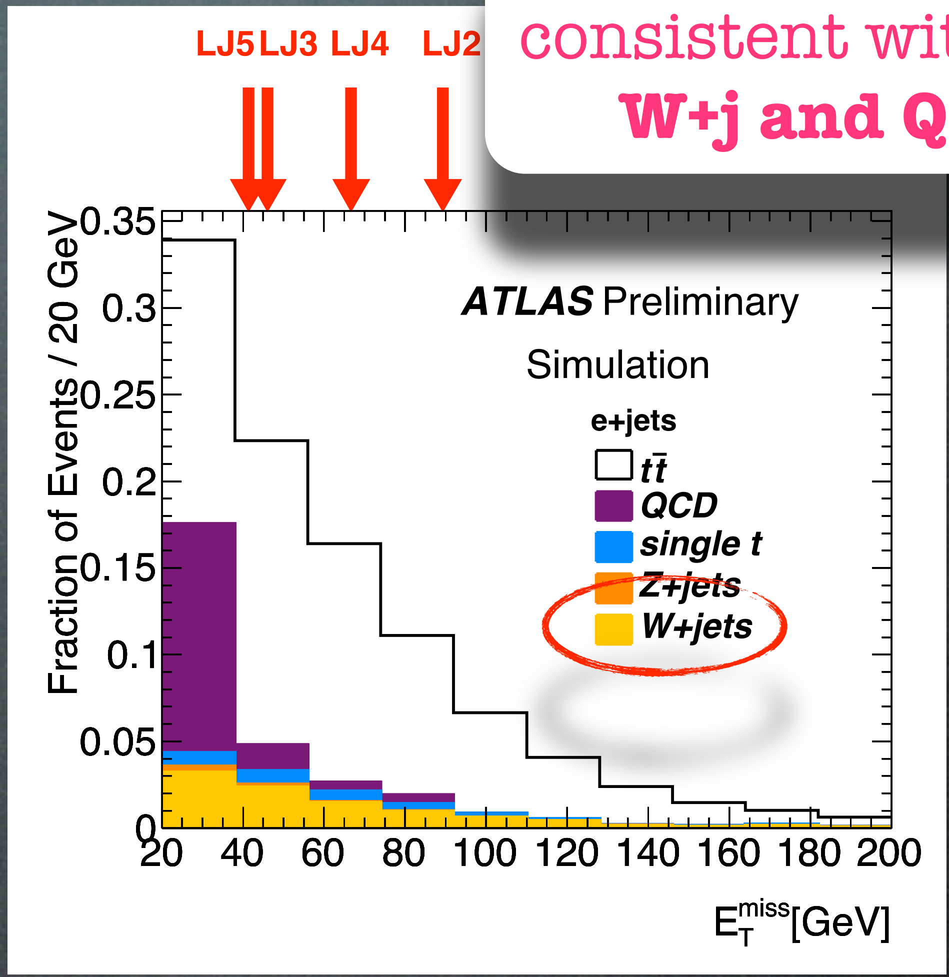


1. High-momentum, isolated lepton
2. Large missing transverse Energy (Neutrino)
3. ≥ 4 Jets
4. b-jet ID

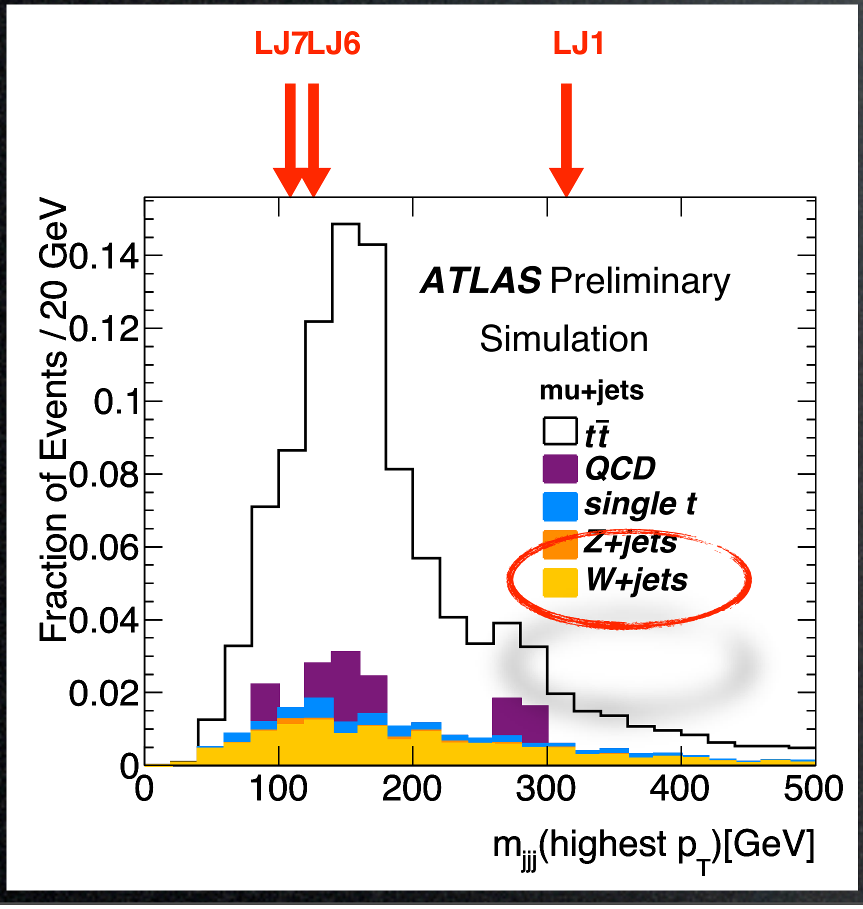
- Complementary to W/Z + jets analysis
- Focuses on higher jet multiplicities

Lepton+jets channel





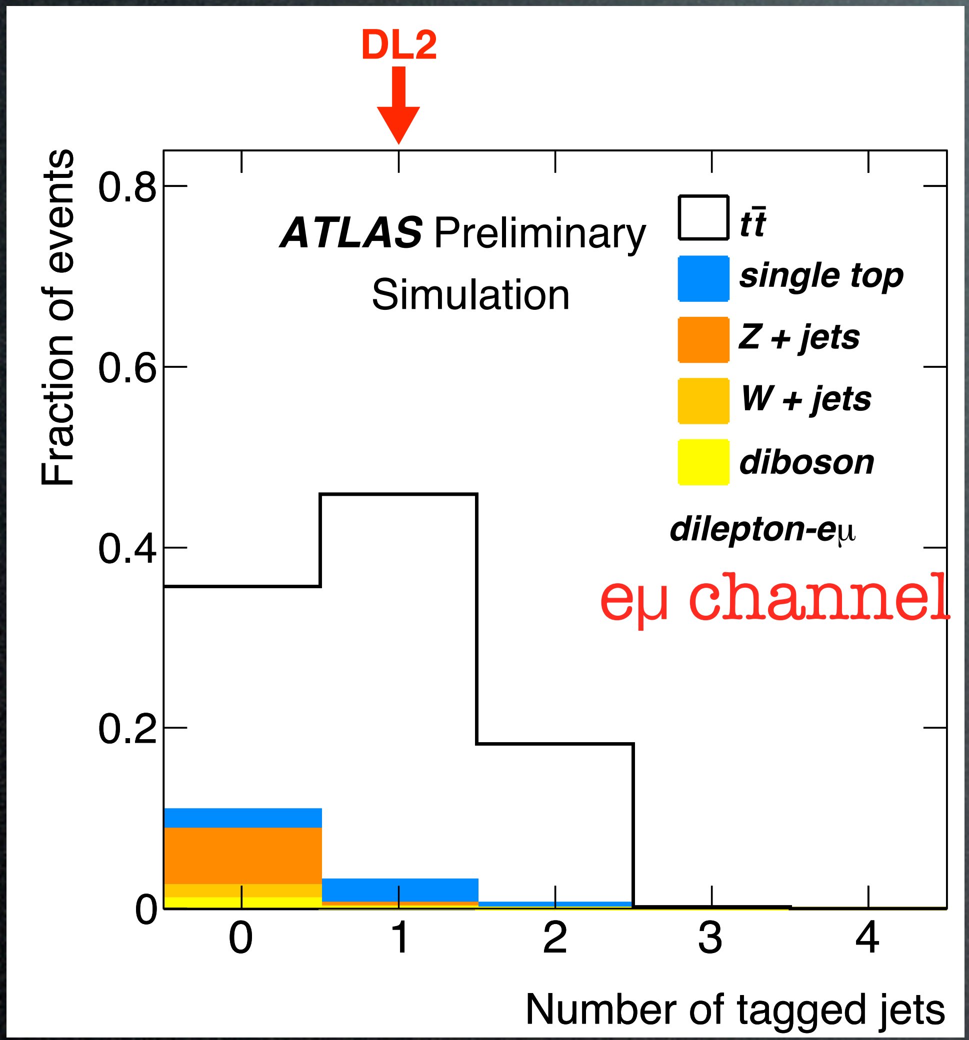
7 candidates (LJ) in 280 nb^{-1}
consistent with MC expectations
W+j and QCD: biggest bkg

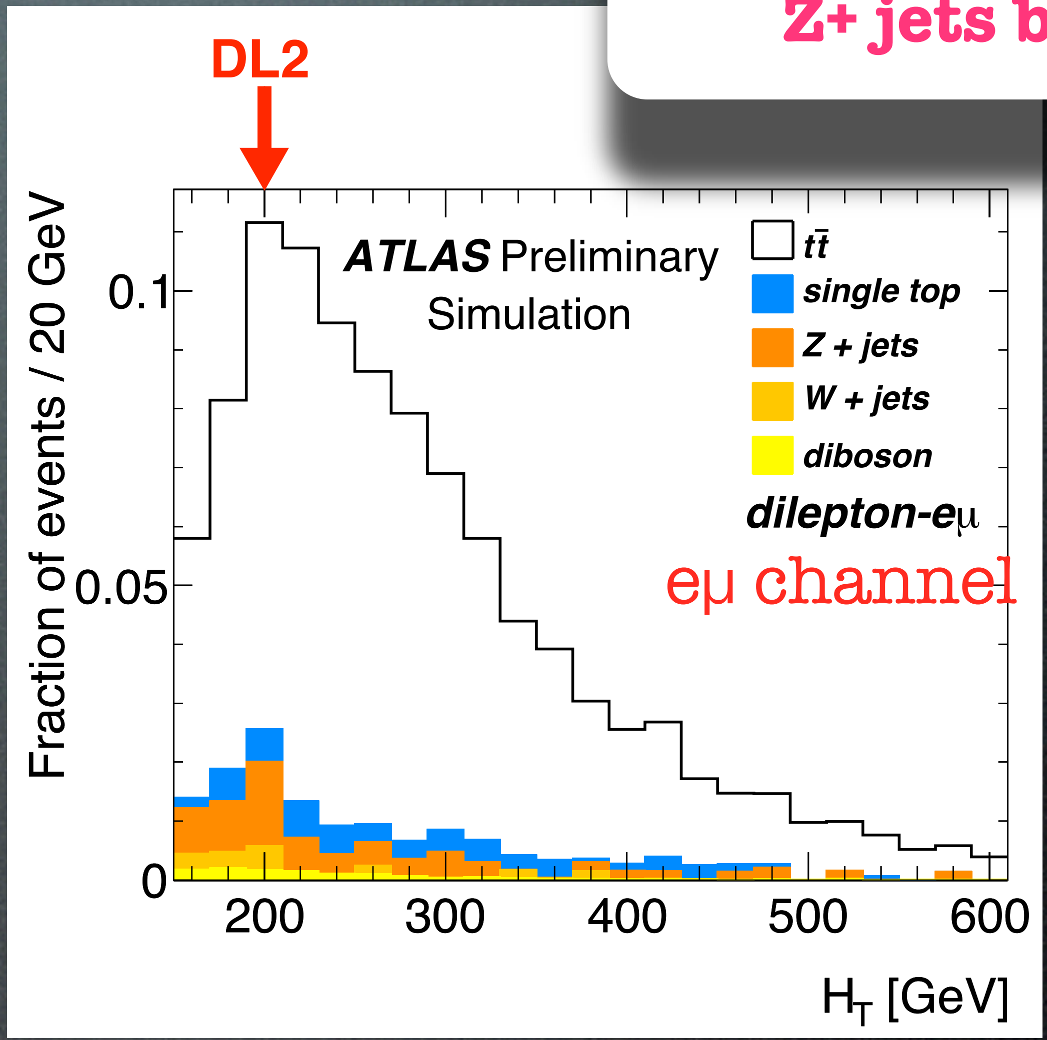


- 10 GeV lepton trigger
- = 1 isolated lepton (medium e or combined μ), $p_T > 20$ GeV, $|\eta| < 2.5$
- ≥ 4 Anti-k_T 0.4 Jets ($p_T > 20$ GeV)
- ≥ 1 b-tag using SV0 tagger with cut corresponds to 50% b-jet eff.
- $ME_T > 20$ GeV

Di-Lepton channel

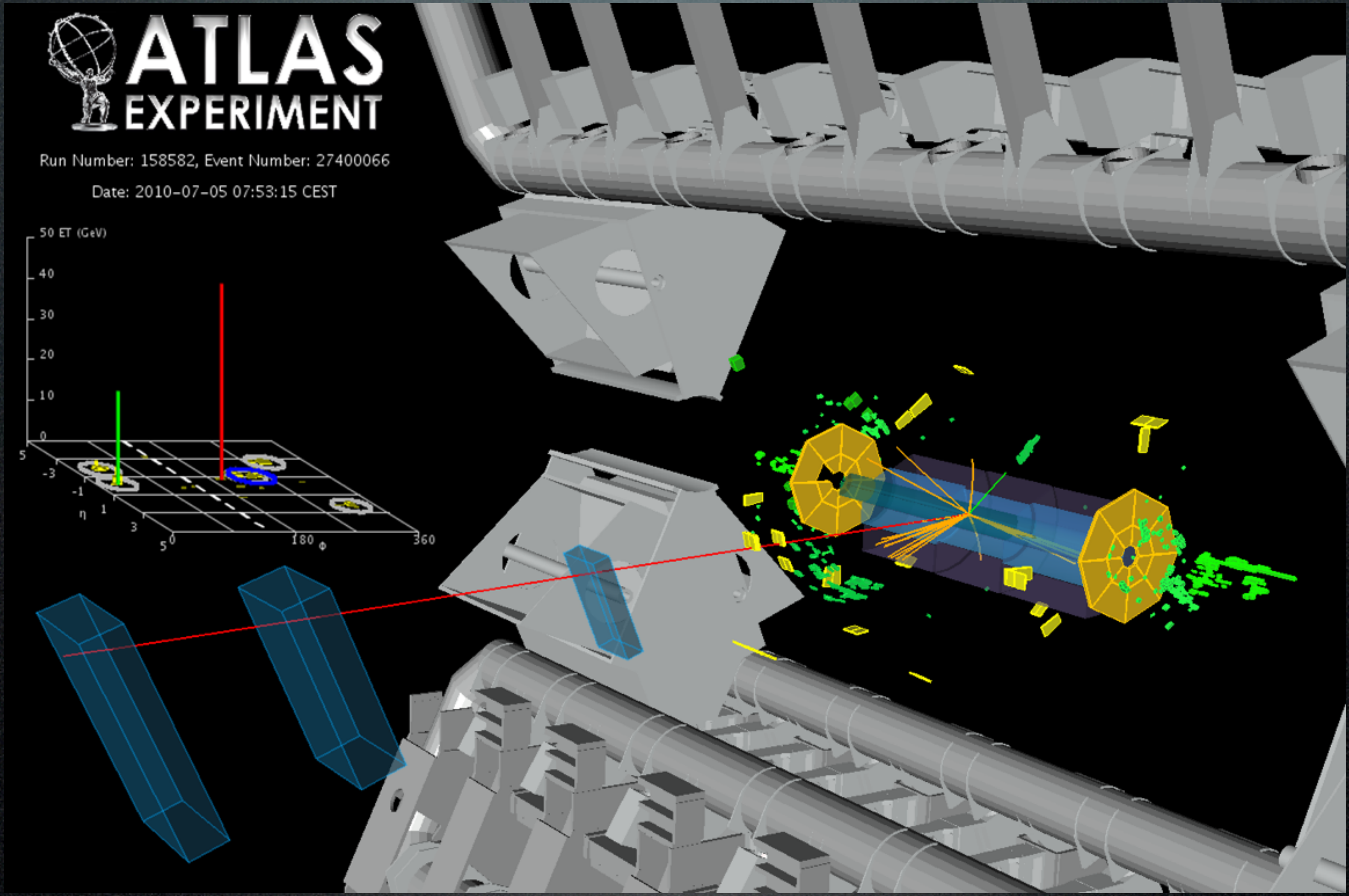
2 candidates in 280 nb^{-1}
Z+ jets biggest bkg





- 10 GeV lepton trigger
- = 2 isolated lepton (medium e or combined μ), $p_T > 20$ GeV, $|\eta| < 2.5$, Opposite charge, M(Z) veto
- ≥ 2 Anti-k_T 0.4 Jets ($p_T > 20$ GeV)
- Σp_T (lep, jet) >150 GeV (e+ μ)
- $ME_T > 40$(ee)/30(μ μ) GeV

e + μ candidate!



Red: Isolated muon track (p_T = 48 GeV) ; Green: isolated electron track pointing to a green Calo cluster (E_T = 23 GeV)
blue circle in lego plot: b-tagged jet. Dashed line in lego plot: direction of the missing transverse energy (77 GeV)

QCD bkg: first results

- Use Matrix Method
- sample of **Loose** leptons (more QCD)
  - standard lepton cuts w/o quality/isolation cuts

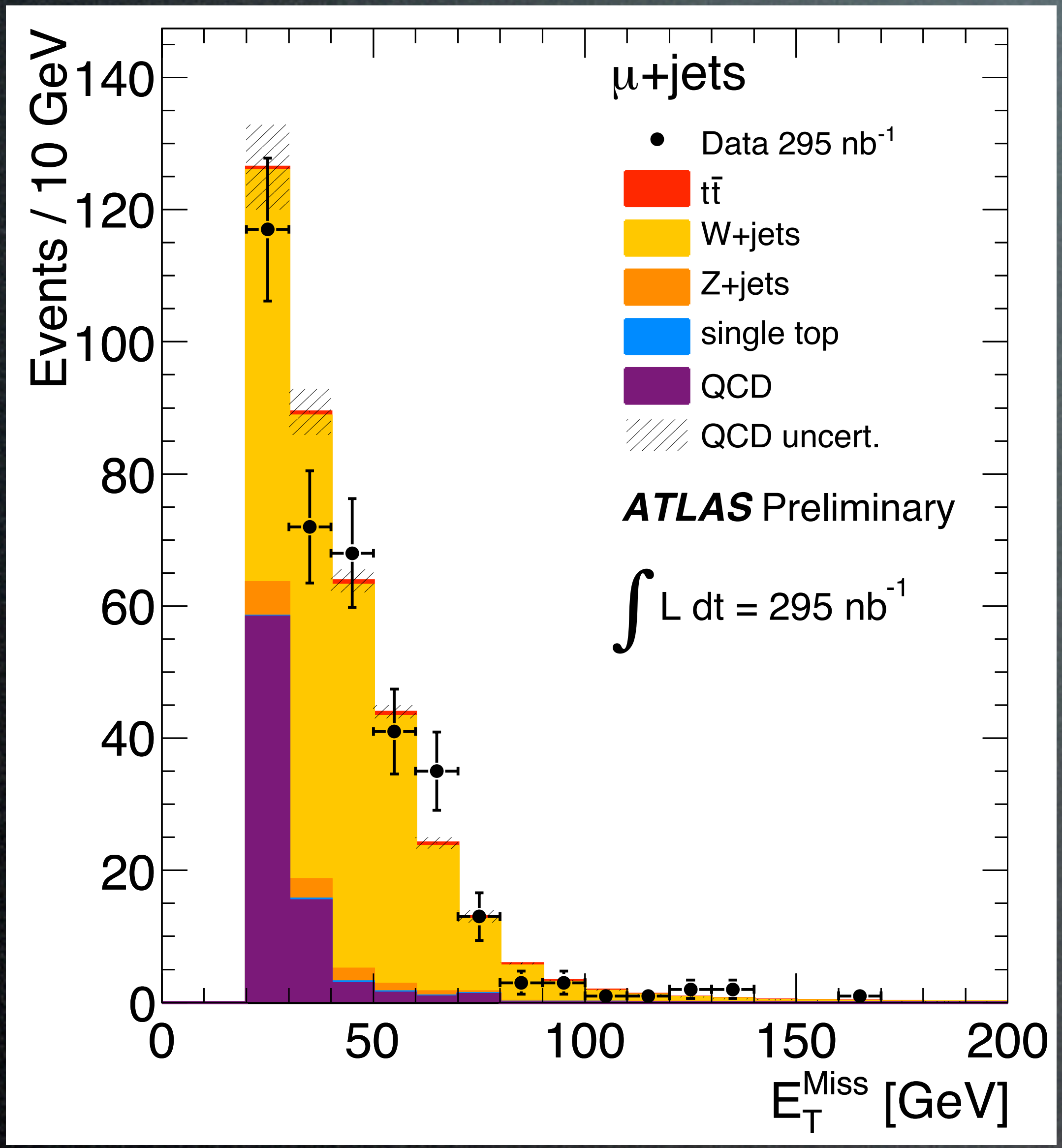
$$N^{\text{loose}} = N^{\text{loose}}_{\text{real}} + N^{\text{loose}}_{\text{fake}}$$
$$N^{\text{tight}} = \epsilon_{\text{real}} N^{\text{loose}}_{\text{real}} + \epsilon_{\text{fake}} N^{\text{loose}}_{\text{fake}}$$

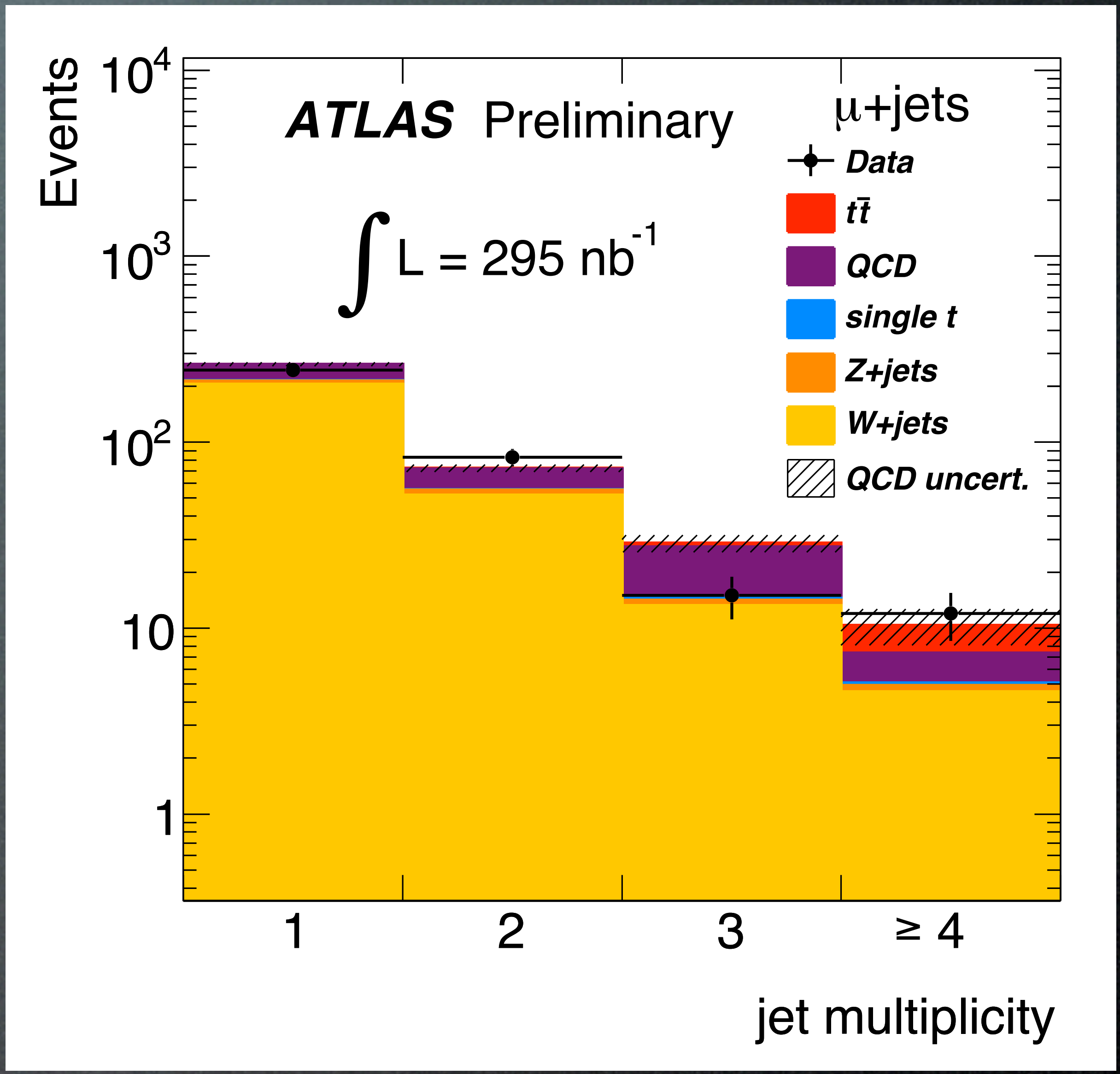
from Z(ll) MC
(later from data)

from control sample
(MEt > 10 GeV, ≥ 1 jet)

- Obtain: N_{fake}^{tight} = estimated number of leptons from QCD in signal region
- Cross-check with ABCD: agreement to within 30%

Ttbar + QCD from data





- With looser signal selections
- QCD normalization from estimation on data ($\pm 1\sigma_{stat}$)
- **others (W+jets) from MC**
- Good agreement with expectations

Conclusions

- Initial studies on EW processes gave chance to:
  - commission ATLAS
  - test SM expectations on W/Z production cross-sections
- W/Z inclusive x-sec agree with theory
- With more data:
  - refined W asymmetry
  - W/Z + jets exclusive measurements
  - Ttbar x-sec relying on data for EW (and QCD) bkg estimations

W: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-051/
Z: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-076/
Top:https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-063/
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-087/

Back-up

Sign/bkg MC expectations

Example: Sig = W; Bkg = Z + ttbar + QCD

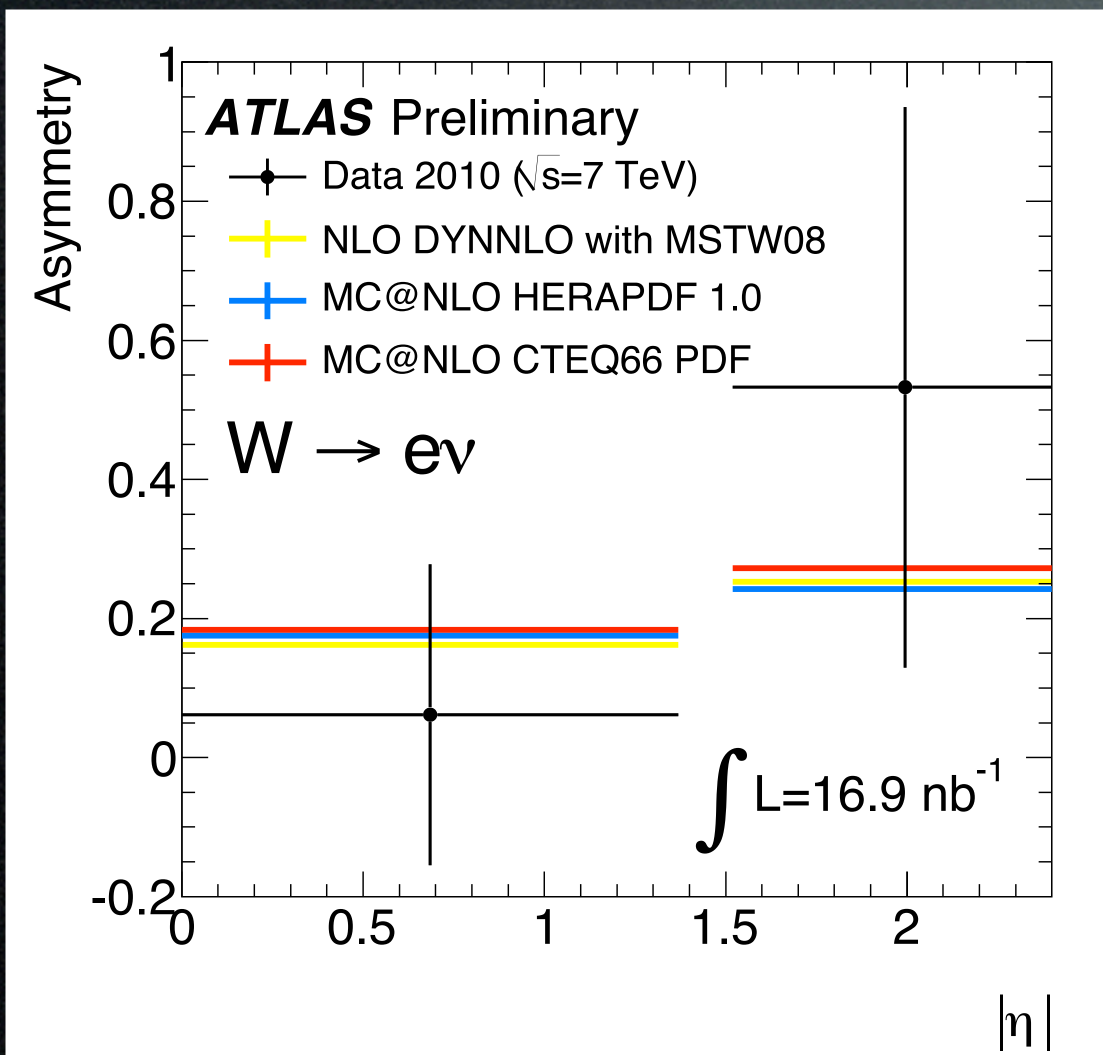
Physics process	Cross section (nb) [× BR]
$W \rightarrow e\nu$	10.46
$W \rightarrow \mu\nu$	10.46
$W \rightarrow \tau\nu$ (electron channel analysis)	10.46
$W \rightarrow \tau\nu \rightarrow \mu\nu\nu$	3.68
$Z \rightarrow ee$ ($m_{\ell\ell} > 60$ GeV)	0.99
$Z \rightarrow \mu\mu$ ($m_{\ell\ell} > 60$ GeV)	0.99
$Z \rightarrow \tau\tau$ ($m_{\ell\ell} > 60$ GeV)	0.99
$t\bar{t}$	0.16
Dijet (electron channel, $\hat{p}_T > 15$ GeV)	1.15×10^6
Dijet (muon channel, $8 < \hat{p}_T < 17$ GeV)	9.86×10^6
Dijet (muon channel, $17 < \hat{p}_T < 35$ GeV)	6.78×10^5
Dijet (muon channel, $35 < \hat{p}_T < 70$ GeV)	4.10×10^4
Dijet (muon channel, $70 < \hat{p}_T < 140$ GeV)	2.20×10^3
Dijet (muon channel, $140 < \hat{p}_T < 280$ GeV)	0.88×10^2
Dijet (muon channel, $280 < \hat{p}_T < 1120$ GeV)	2.35
$b\bar{b}$ (muon channel, $\hat{p}_T > 15$ GeV)	7.39×10^4
$c\bar{c}$ (muon channel, $\hat{p}_T > 15$ GeV)	2.84×10^4

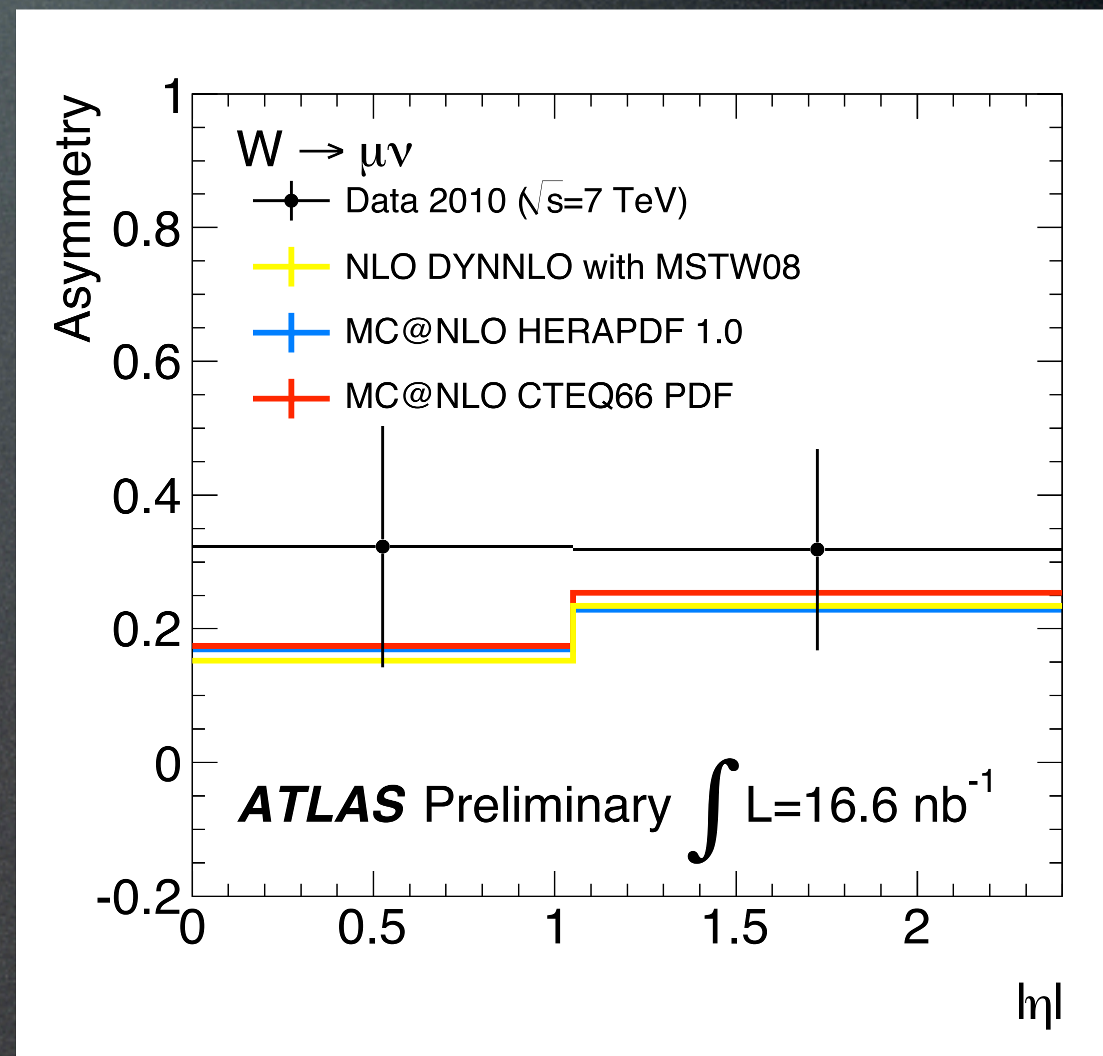
QCD can be estimated directly from data

W asymmetry

$$A = \frac{\sigma^{\ell^+} - \sigma^{\ell^-}}{\sigma^{\ell^+} + \sigma^{\ell^-}}$$

- Asymmetry predicted to be different from zero at p-p colliders (valence quarks): ~**0.2 (from theo)**
- varies as a function of lepton η (correlation with kinematic phase space of incoming partons)





A = 0.21 ± 0.12 ± 0.01 **A = 0.33 ± 0.12 ± 0.01**

Selected Signal kinematics