Electroweak and Top physics at ATLAS

LATHUILE WORKSHOP 2011

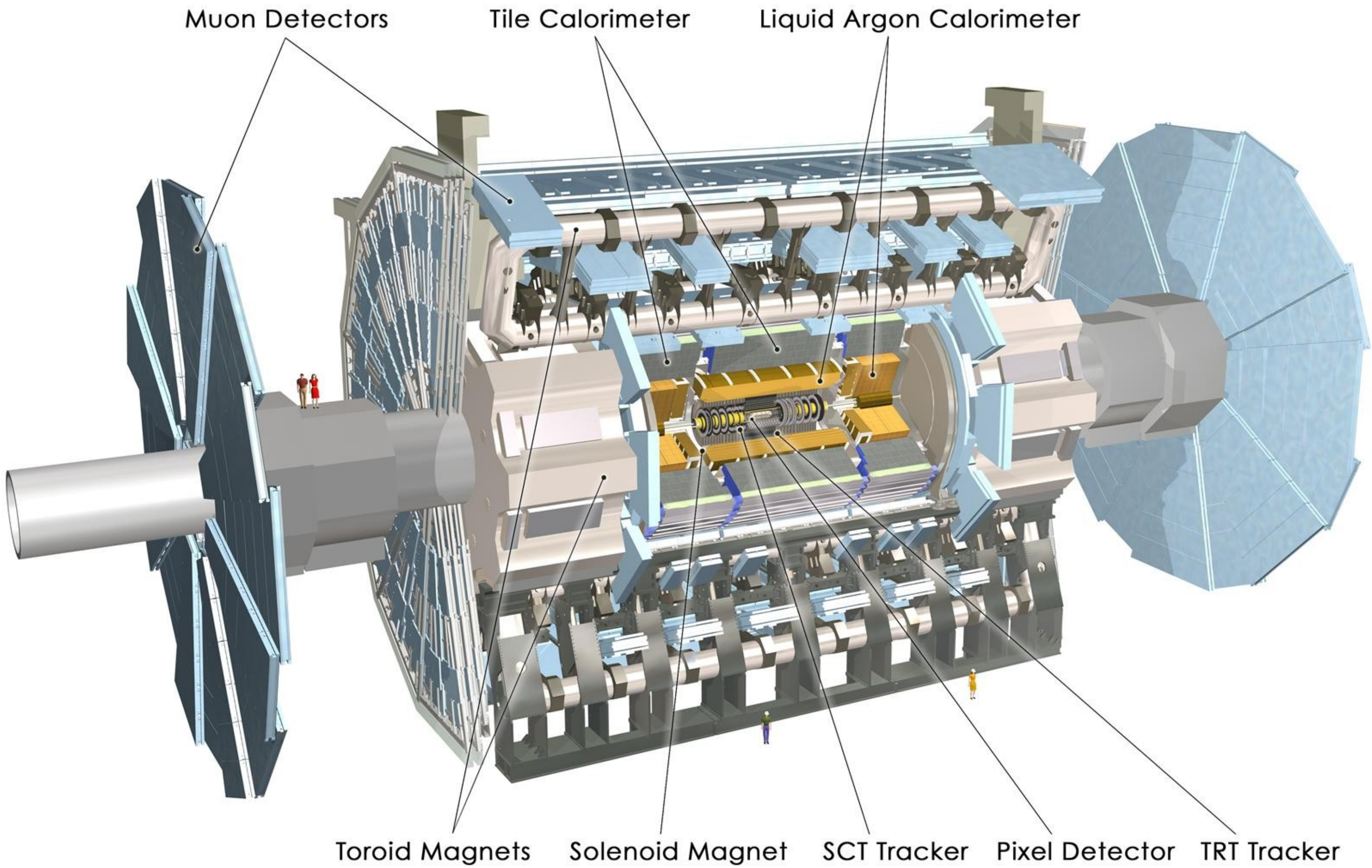
FEB 27-MARCH 5, AOSTA VALLEY

RIKARD SANDSTRÖM, NIKHEF

on behalf of

THE ATLAS COLLABORATION

The ATLAS detector

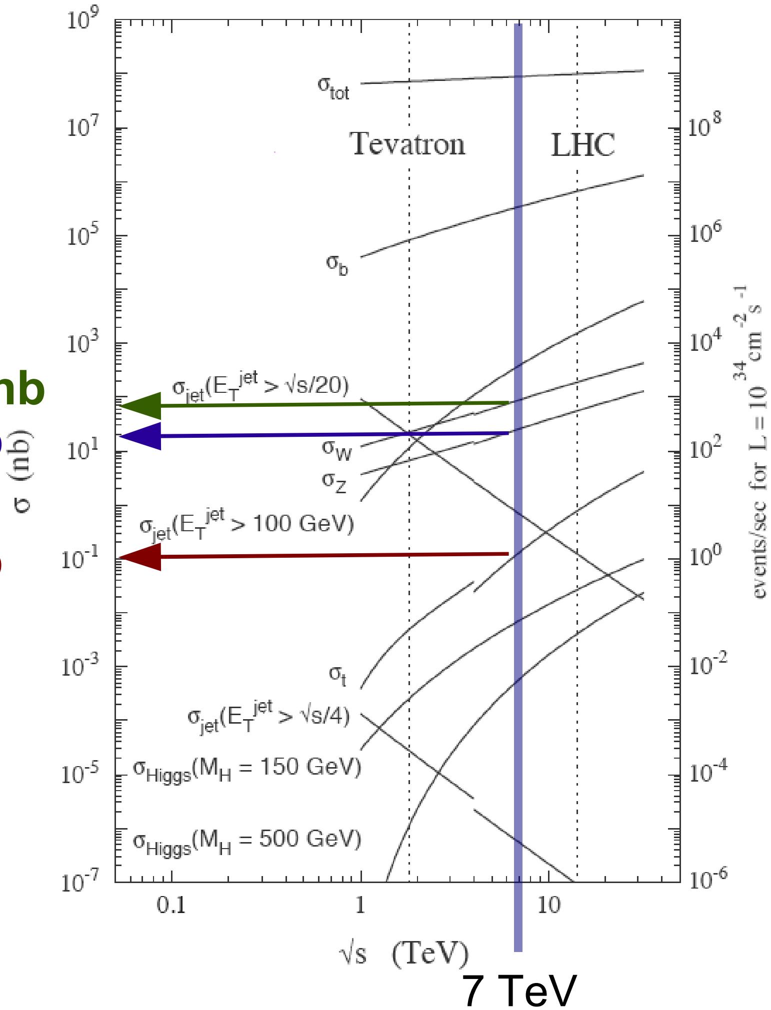


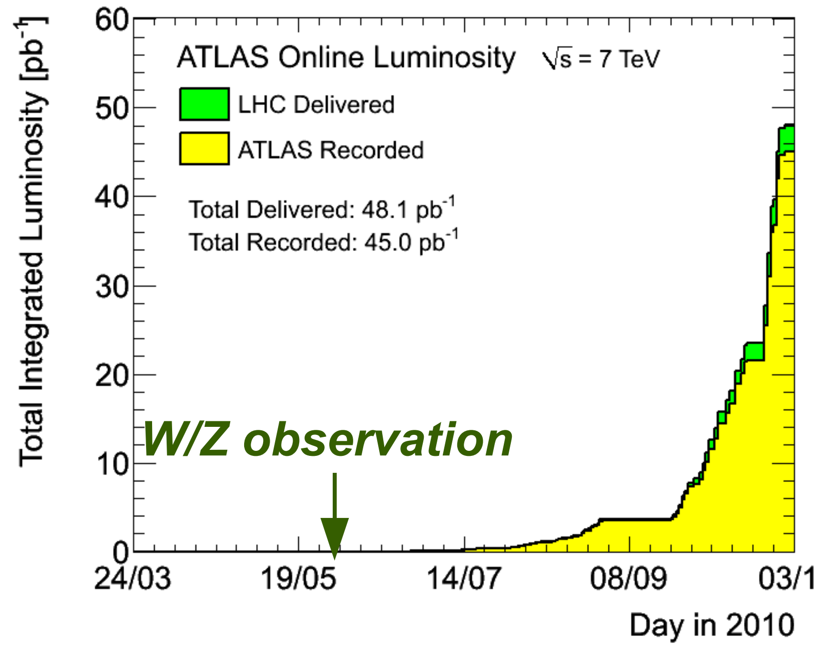
LHC collision data 2010

W: 10.5 nb

Z: 1.0 nb

t: 164 pb

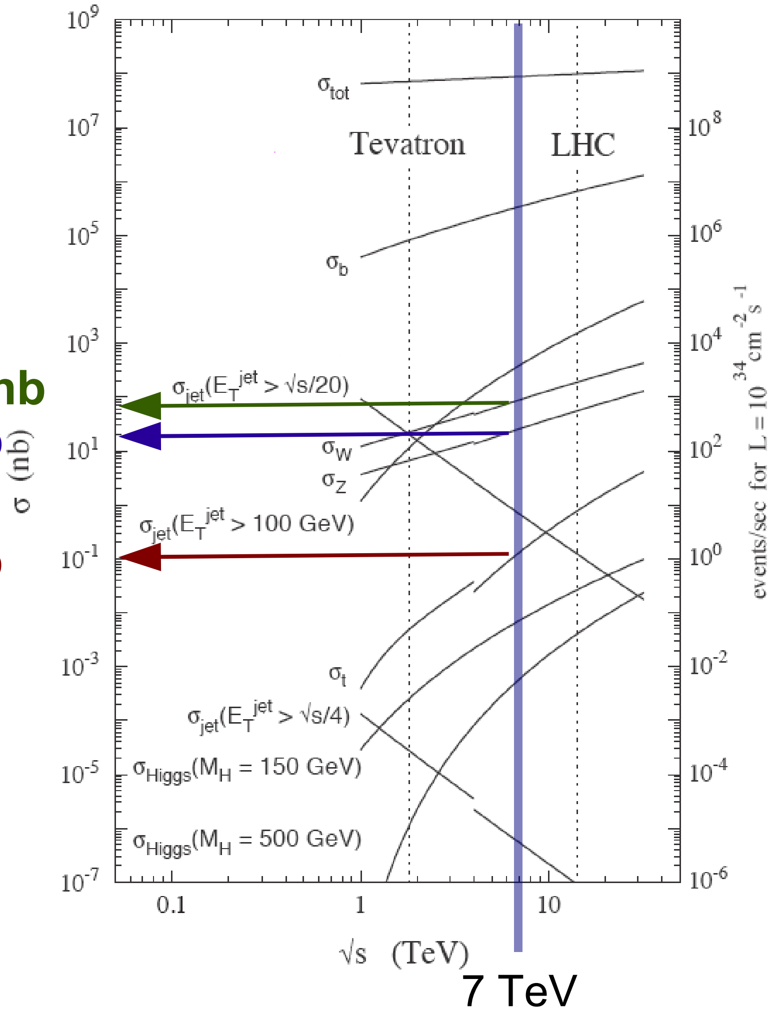


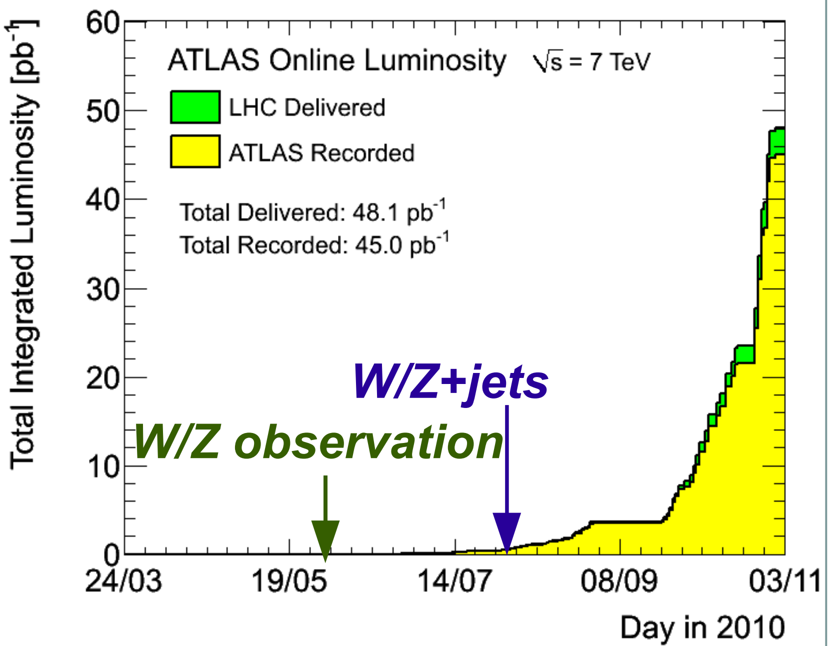


LHC collision data 2010

W: 10.5 nb
Z: 1.0 nb

t: 164 pb

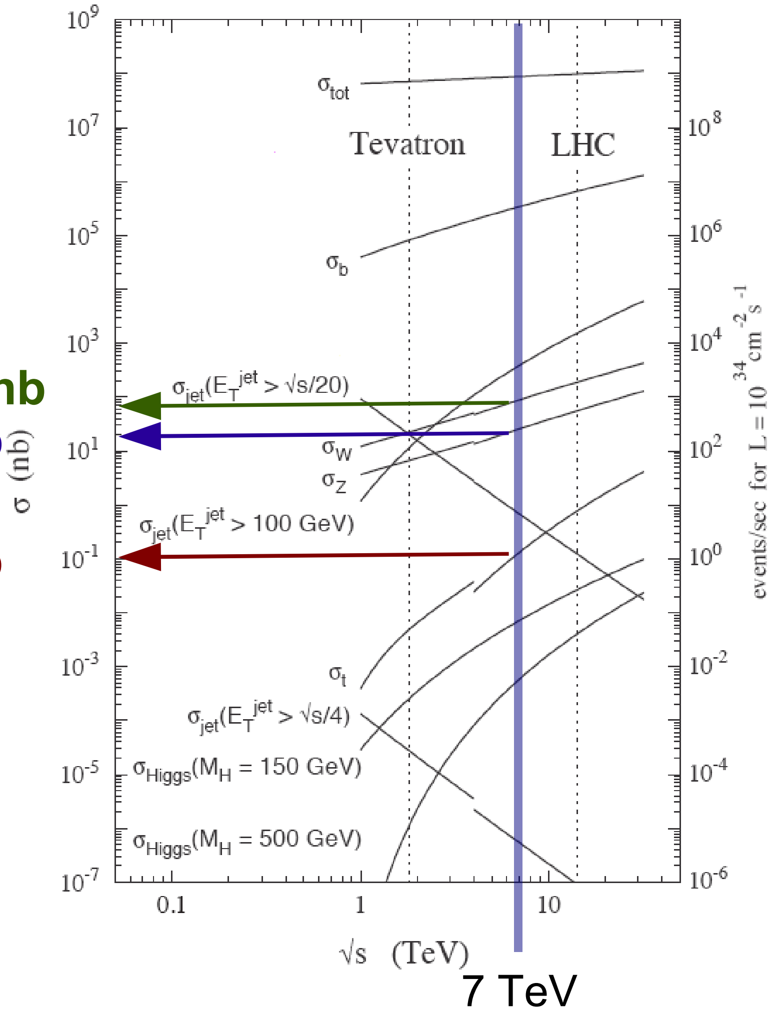


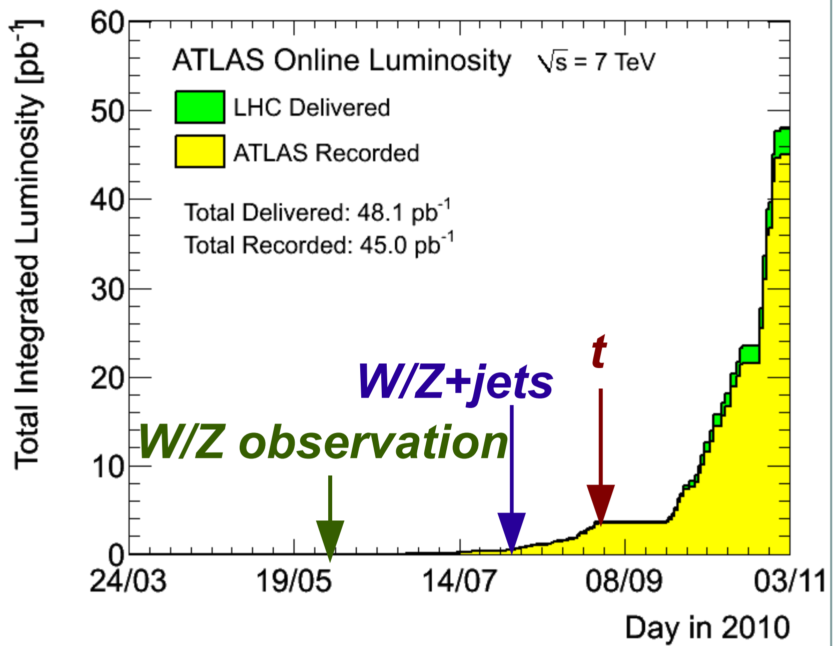


LHC collision data 2010

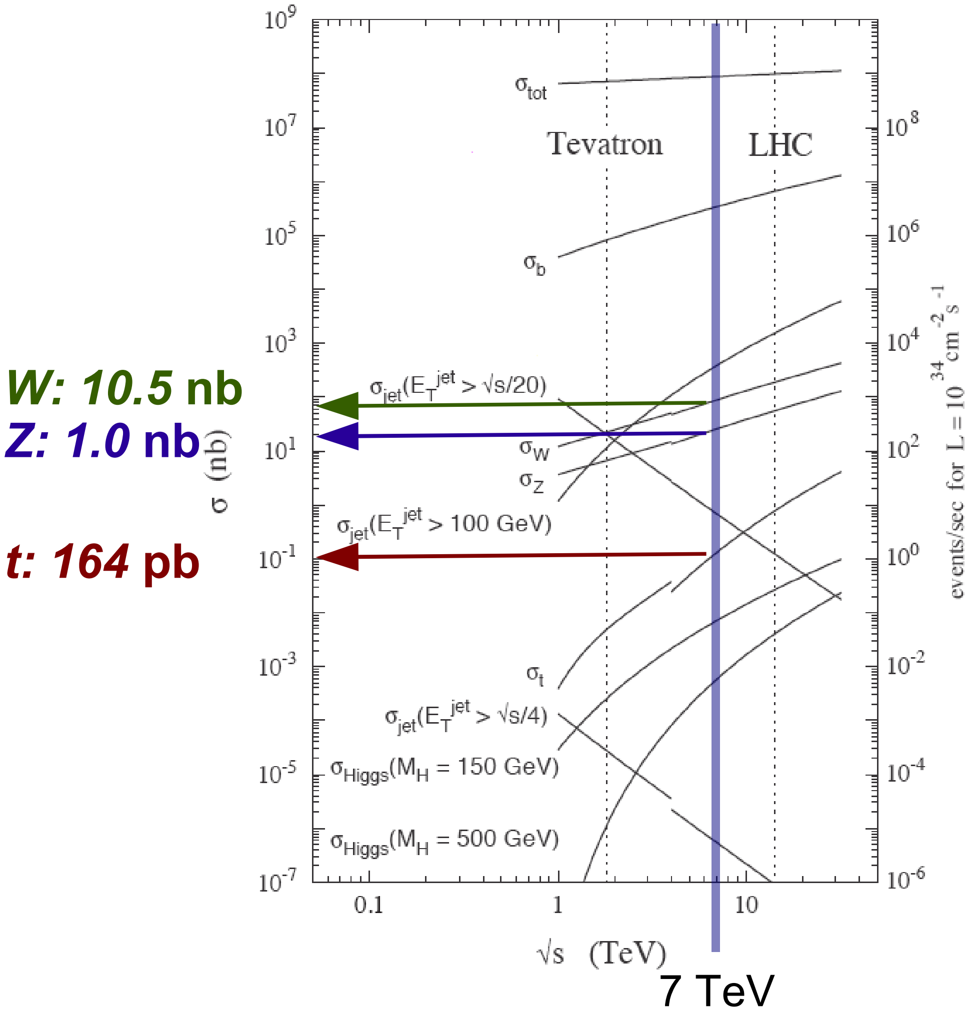
W: 10.5 nb
Z: 1.0 nb

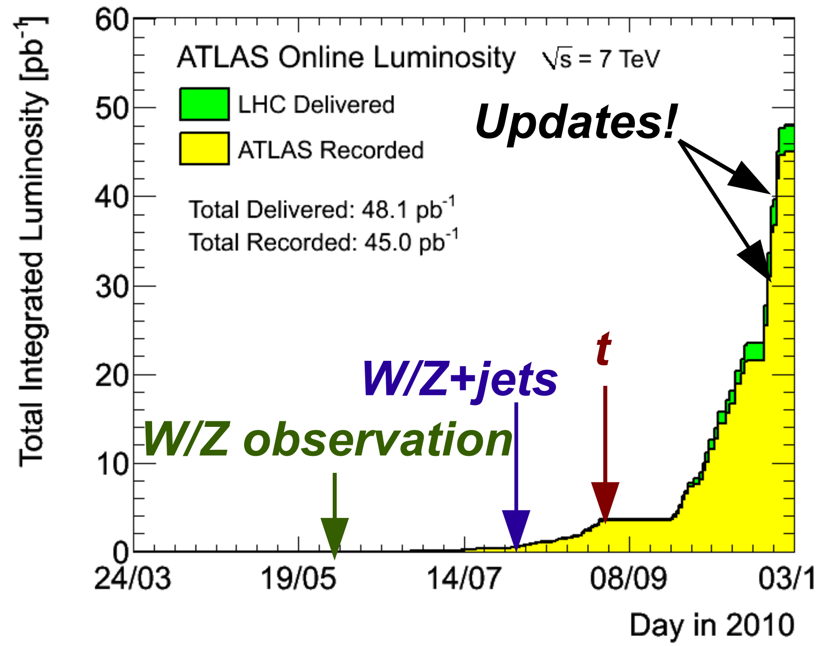
t: 164 pb





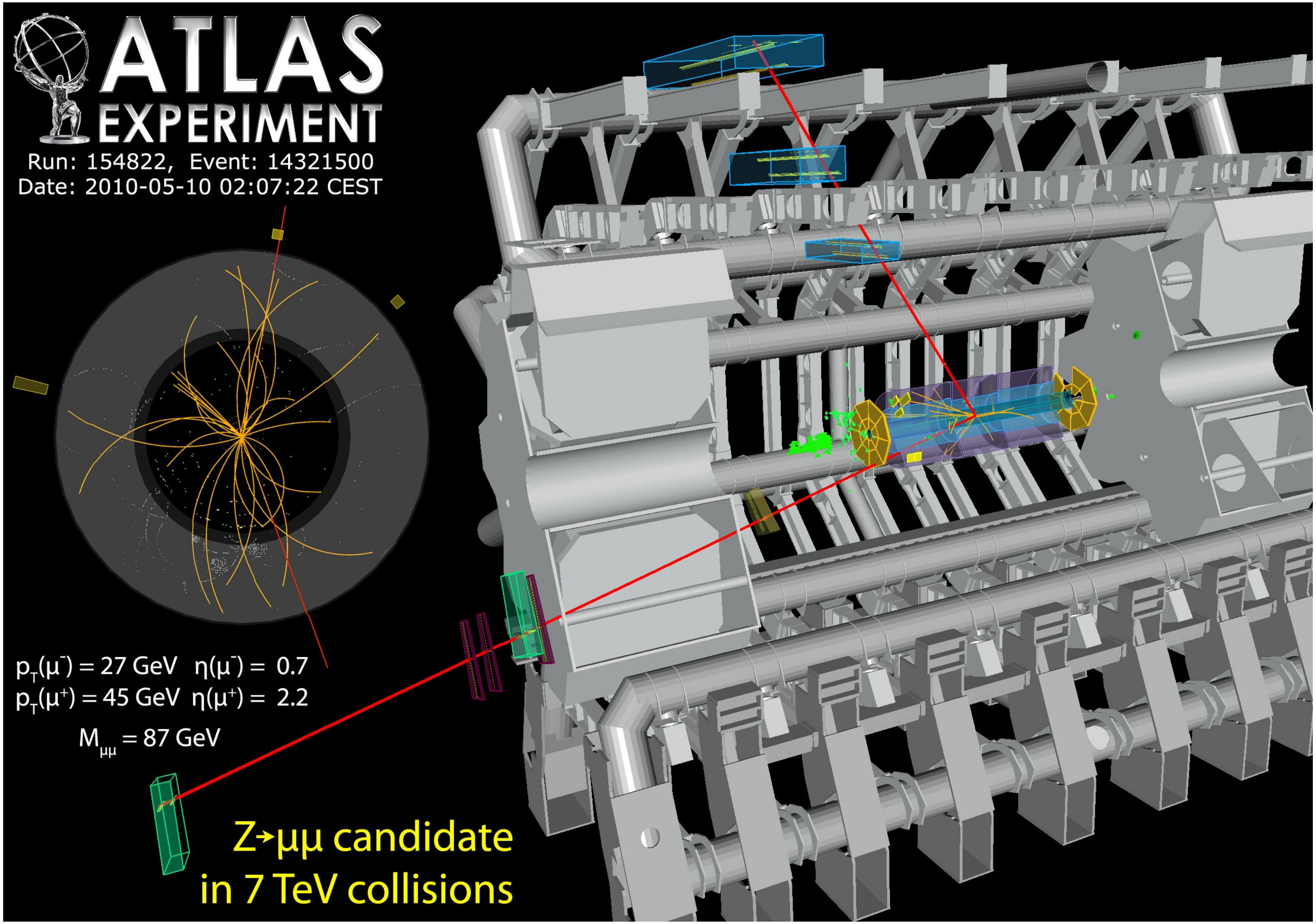
LHC collision data 2010





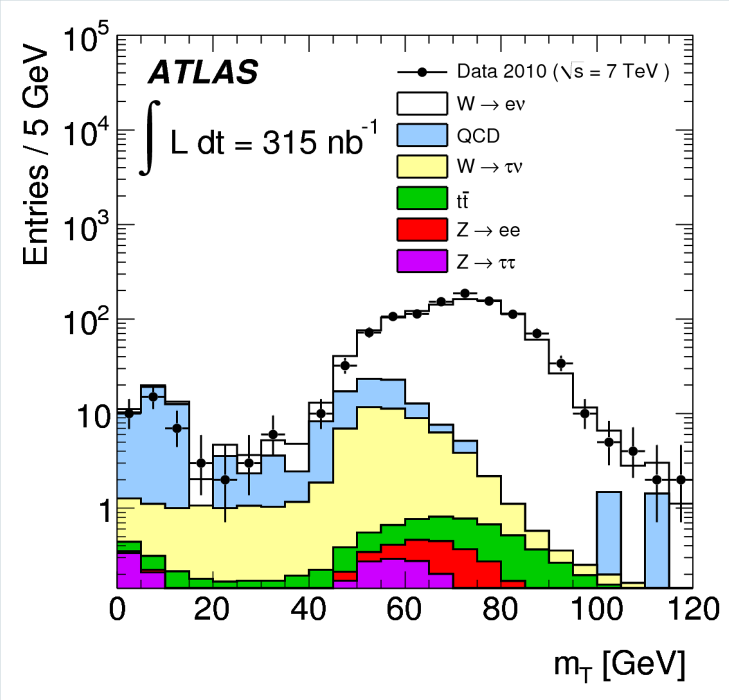
Many of the results shown today are being updated with the full 2010 data.

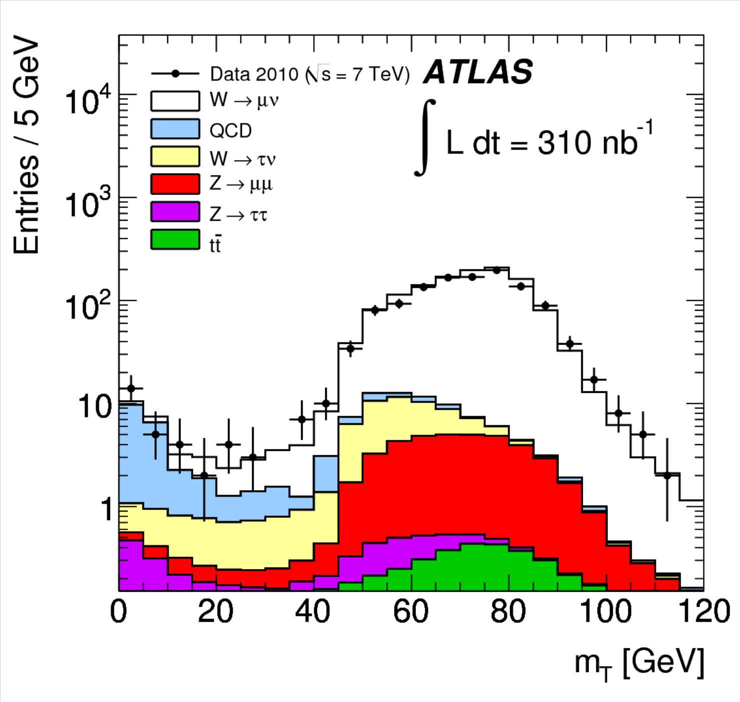
Z observation



W observation

$W \to e\nu$ $W \to \mu\nu$

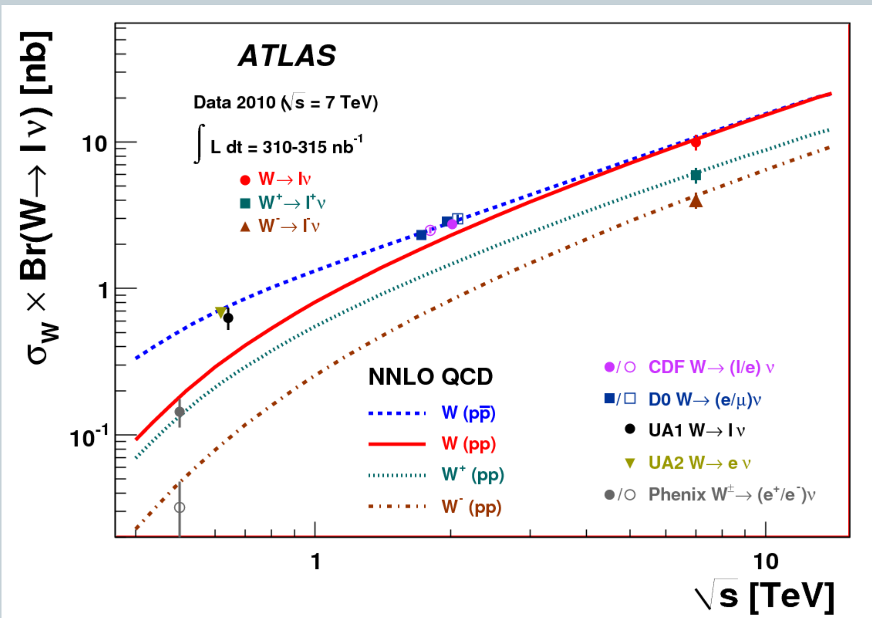


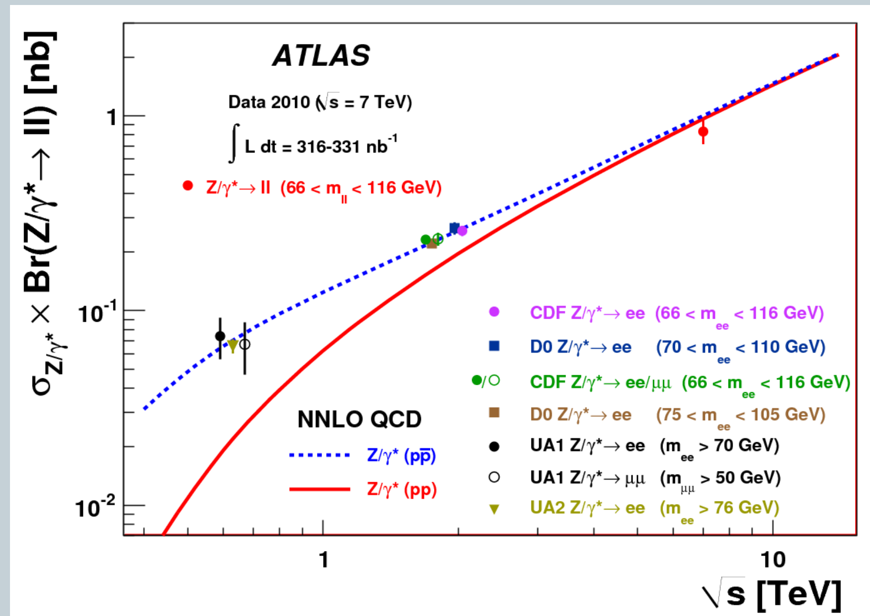


- With ~300 nb^{-1} we observed the first 1000 $W \to e\nu$ and $W \to \mu\nu$.
  - A clear signal over very small background in both electron and muon channel!

W & *Z* cross section

$W \to l\nu$ $\qquad$ $Z \to ll$



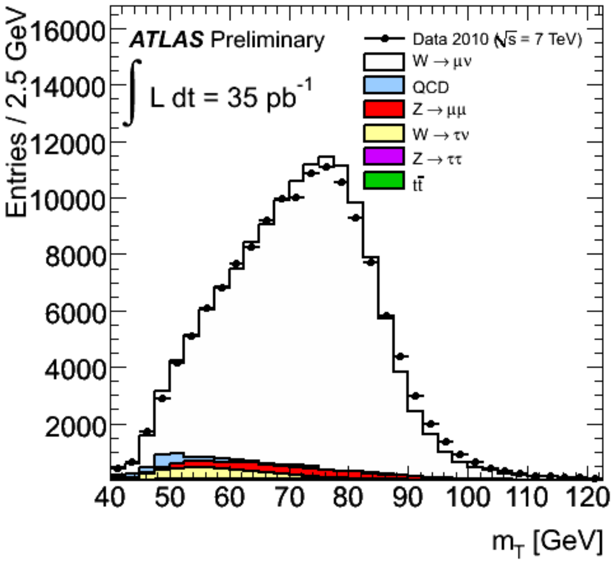


$\sigma_W^{tot} \cdot \mathrm{BR}(W \to \ell\nu) = 9.96 \pm 0.23(\mathrm{stat}) \pm 0.50(\mathrm{syst}) \pm 1.10(\mathrm{lumi})\ \mathrm{nb}$

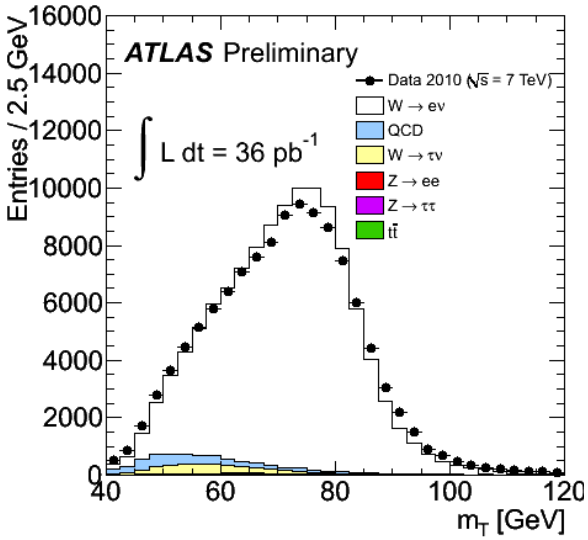
$\sigma_{Z/\gamma^*}^{tot} \cdot \mathrm{BR}(Z/\gamma^* \to \ell\ell) = 0.82 \pm 0.06(\mathrm{stat}) \pm 0.05(\mathrm{syst}) \pm 0.09(\mathrm{lumi})\ \mathrm{nb}$

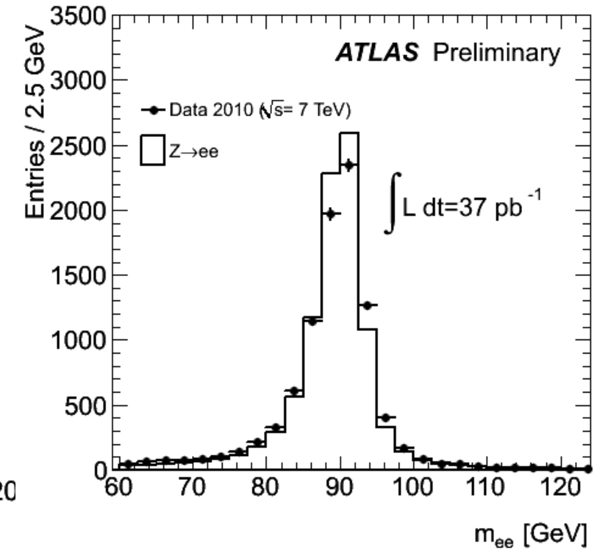
- LHC & ATLAS continue the tradition of electroweak boson measurements and extend the field to new energies.
  - Important tests of the Standard Model!

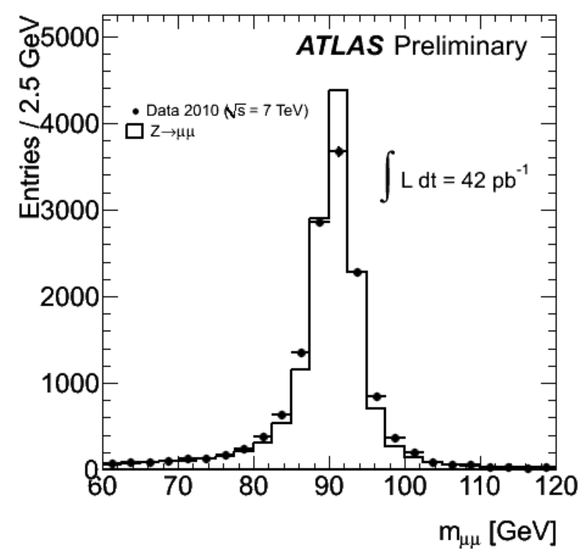
W & Z – updated results



- New cross sections very soon public, using full 2010 data.
  - We already have many public plots of the W & Z kinematic distributions.







Muon charge asymmetry from $W^{\pm}$

- In proton-proton collisions the production rate of W^{+} is significantly larger than W^{-}.
  - The proton contains two *u* and one *d* valence quarks.
  - The *W* asymmetry depends on the momentum fraction *x* of the partons, which we observe as a dependence on η.

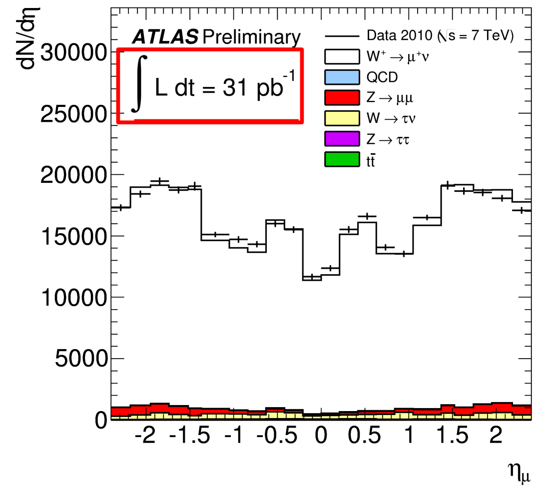
$$x_{1,2} = \frac{m_W}{\sqrt{s}} \cdot e^{\pm y}, y \simeq \eta$$

  - What we measure:

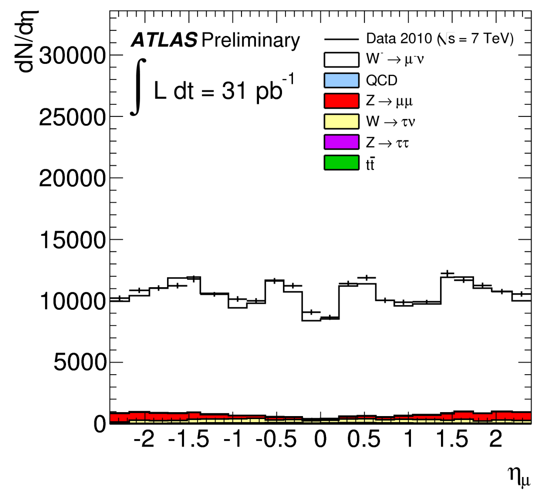
$$A_{\mu} = \frac{d\sigma_{W_{\mu^+}}/d\eta_{\mu} - d\sigma_{W_{\mu^-}}/d\eta_{\mu}}{d\sigma_{W_{\mu^+}}/d\eta_{\mu} + d\sigma_{W_{\mu^-}}/d\eta_{\mu}}$$

- This is the second analysis of this asymmetry from ATLAS.
  - The first analysis used 310 nb^{-1} and 2 η-bins.

W+



W-



Charge asymmetry from $W^{\pm}$ – uncertainties

Systematics:

- Trigger efficiency (2-7%)
  - Geometrical acceptance η dependent.
- Muon reconstruction efficiency (1-7%)
  - Geometrical acceptance η dependent.
- Muon momentum scale and resolution (1-2%)
- Luminosity (1%)

Main backgrounds:

- $Z \to \mu\mu$, with one μ missed. (3%)
- $W \to \tau\nu$, with $\tau \to \mu$. (2%)
- $Z \to \tau\tau$, with one $\tau \to \mu$. (1%)
- $t\bar{t} \to b\bar{b}q\bar{q}\nu\mu$. (1%)
- Multijet events with $b/c \to \mu$. (<1%)

➔ Total: 7% background
- Implies systematic uncertainty of 1-2%.

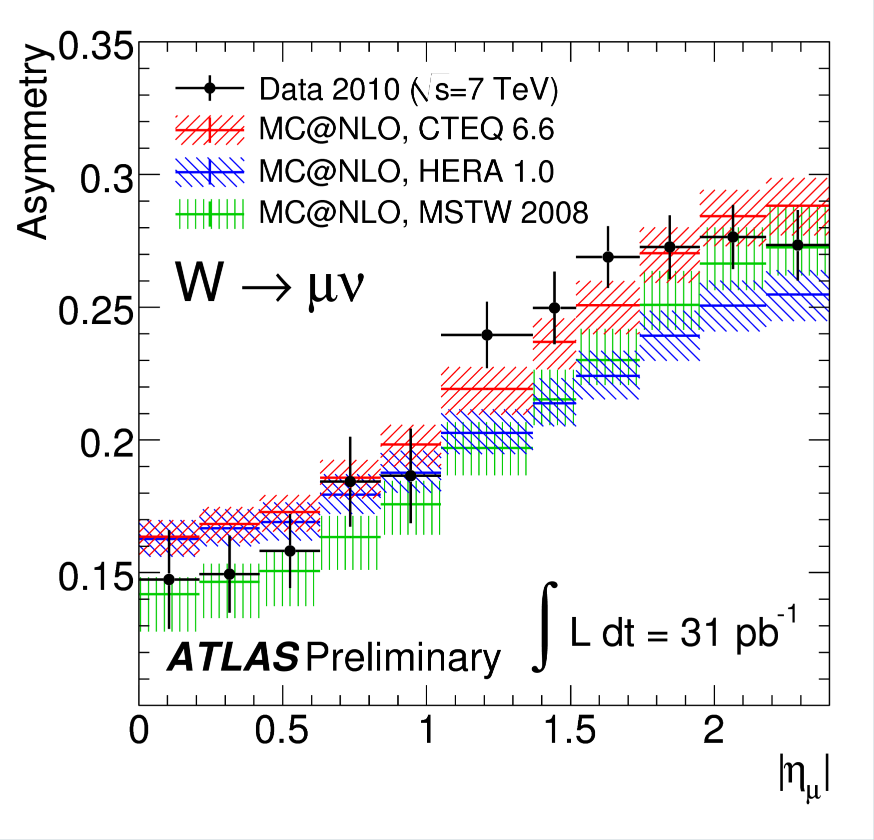
- **Statistical uncertainty:**
  - Statistical uncertainty is similar to systematic uncertainty per η bin. Typical values for both sources:

    ~4% in endcaps

    ~6% in barrel

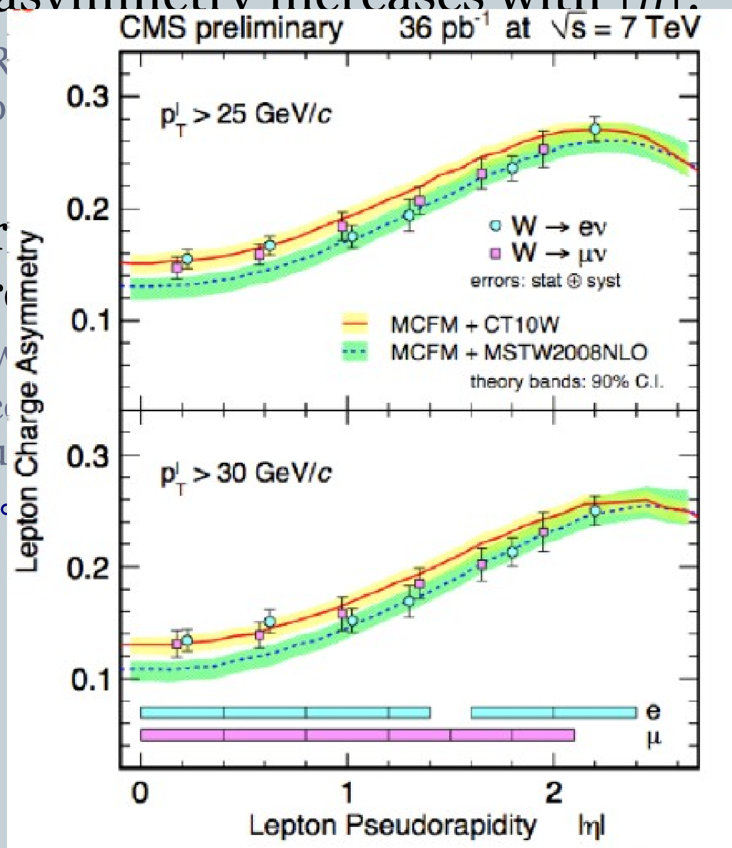
Charge asymmetry from $W^{\pm}$ – conclusions

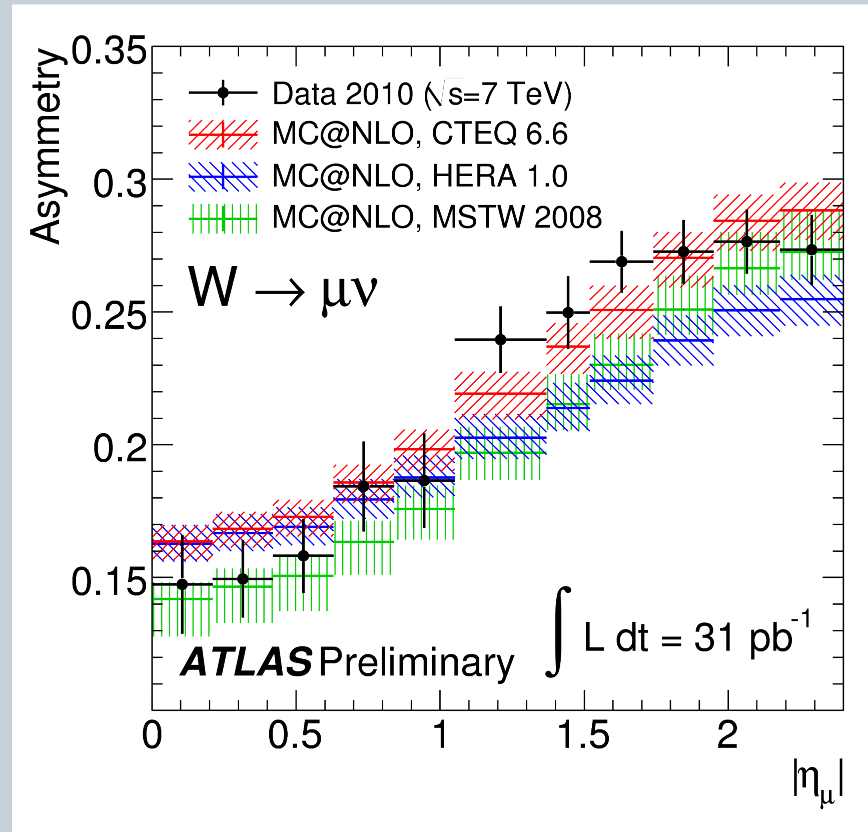
- *W* asymmetry increases with $|\eta|$.
  - Relates to parton distribution functions of valence quarks.
- Parton distribution functions agree the data.
  - We expect that these results will further constrain next generation PDF uncertainties.
    - Especially for low *x* valence quarks.



Charge asymmetry from $W^{\pm}$ – conclusions

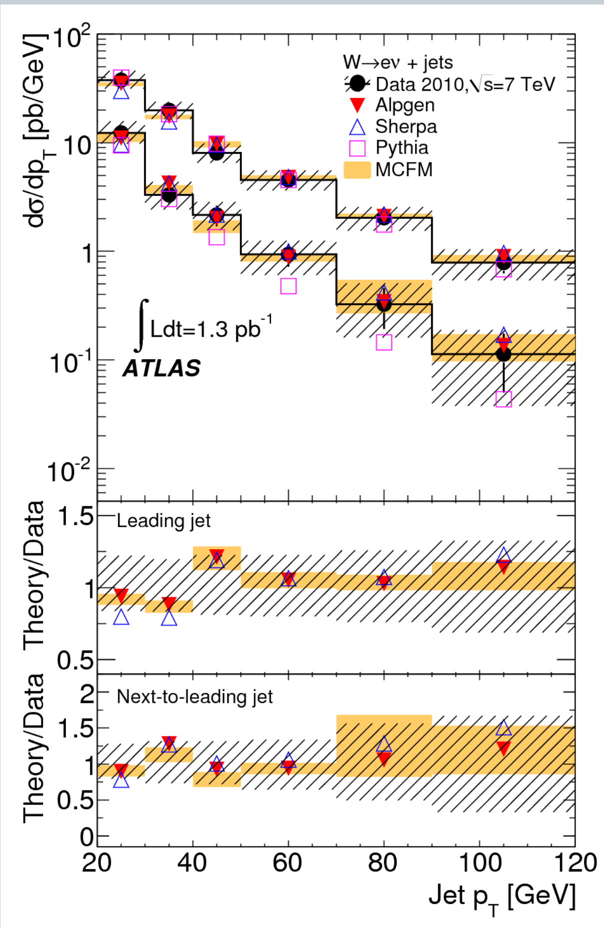
- *W* asymmetry increases with $|\eta|$.
  - R
    o
- Par
  agr
  - W
    c
    u





W+jets

$W \rightarrow e\nu$+jets



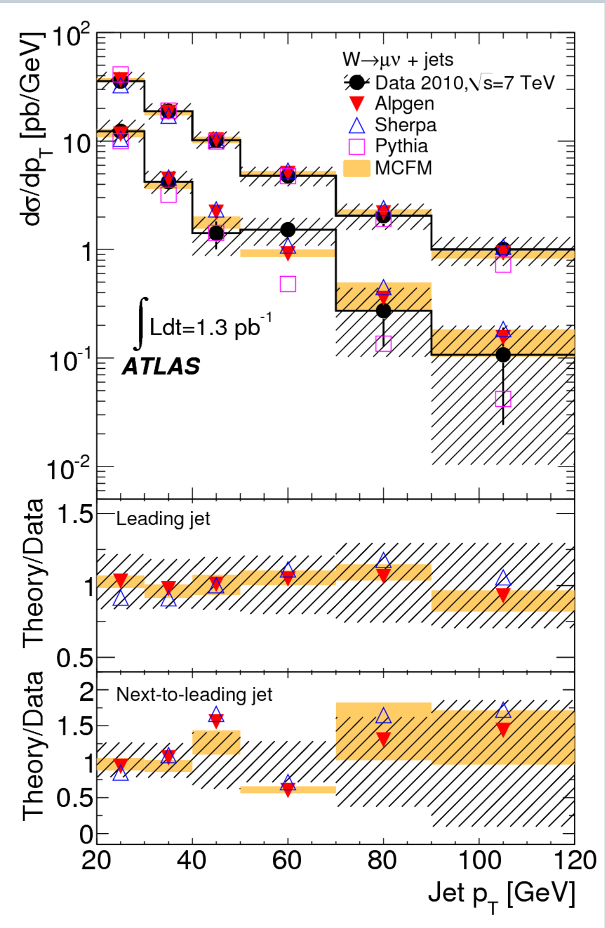
- With 1.3 pb^{-1}, we measured cross section also for *W/Z+jets*.
  - Important test of QCD
  - Input to many physics analysis
  - *See talk by E. Meoni Tuesday!*
- *Here:* $W \rightarrow l\nu$+jets cross section as function of pt of two leading jets.

Pythia: Leading-order generator

Alpgen, Sherpa: Match N+1 ME to a LL parton shower (rescaled to NNLO inclusive XS)

MCFM: NLO prediction at parton level for Njet≤2, LO for Njet=3

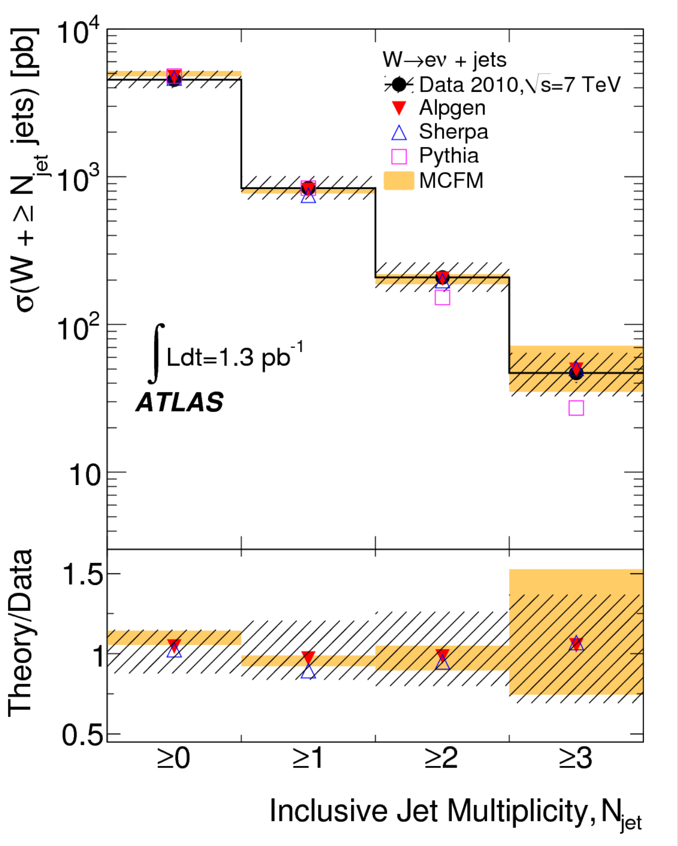
$W \rightarrow \mu\nu$+jets



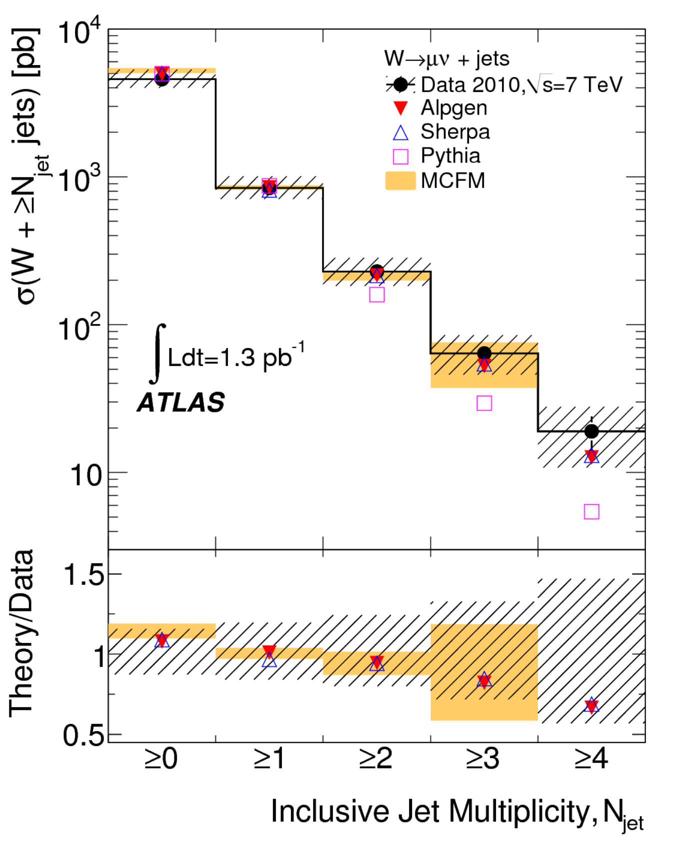
W+jets – jet multiplicity

$W \rightarrow e\nu$+jets

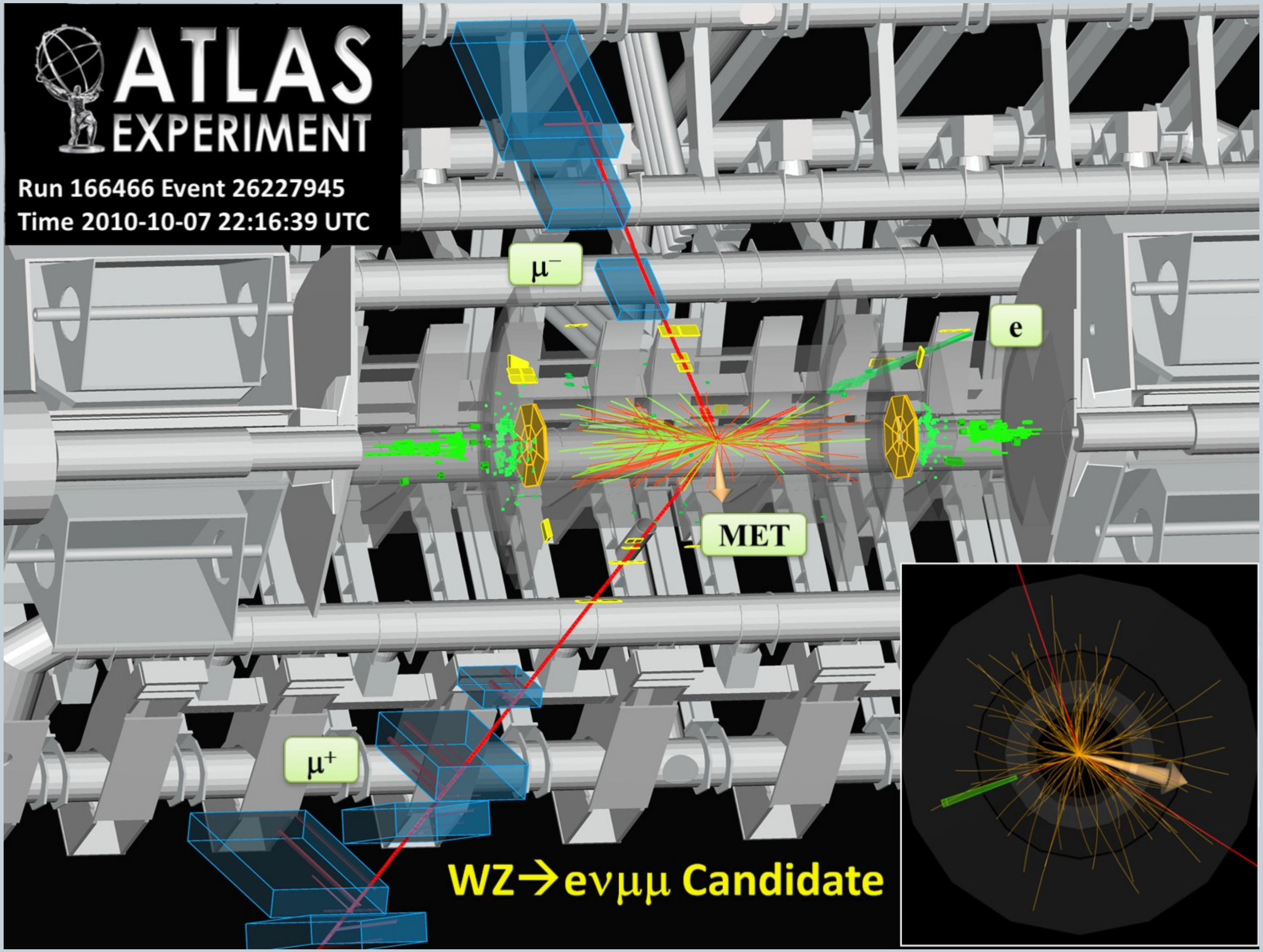
$W \rightarrow \mu\nu$+jets



- Also the observed jet multiplicity agrees with simulation.
  - The theoretical uncertainty is only shown for MCFM.
  - Pythia does not reproduce the data at high jet multiplicity.
    - $2 \rightarrow 2$ at matrix element level + additional jets from parton shower is insufficient.
  - The uncertainties between bins are correlated.



Di-bosons

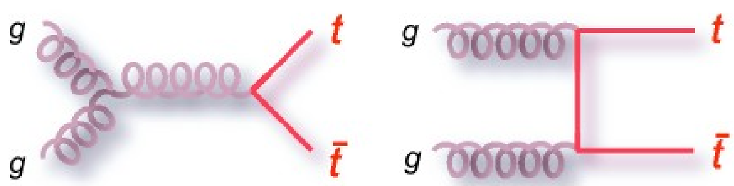


- Searches for di-boson events ongoing!
  - Full analysis not finalized yet.

- WZ candidate on the left:
  - $M(\mu\mu)$ = 96 GeV
    - Muon p_T = 65 GeV & 40 GeV
  - $M_{T(}(e\nu)$ = 57 GeV
    - Electron E_T = 65
    - Neutrino E_T = 21 GeV

The top quark

Main LHC production modes (~80-85%) are gluon fusion:

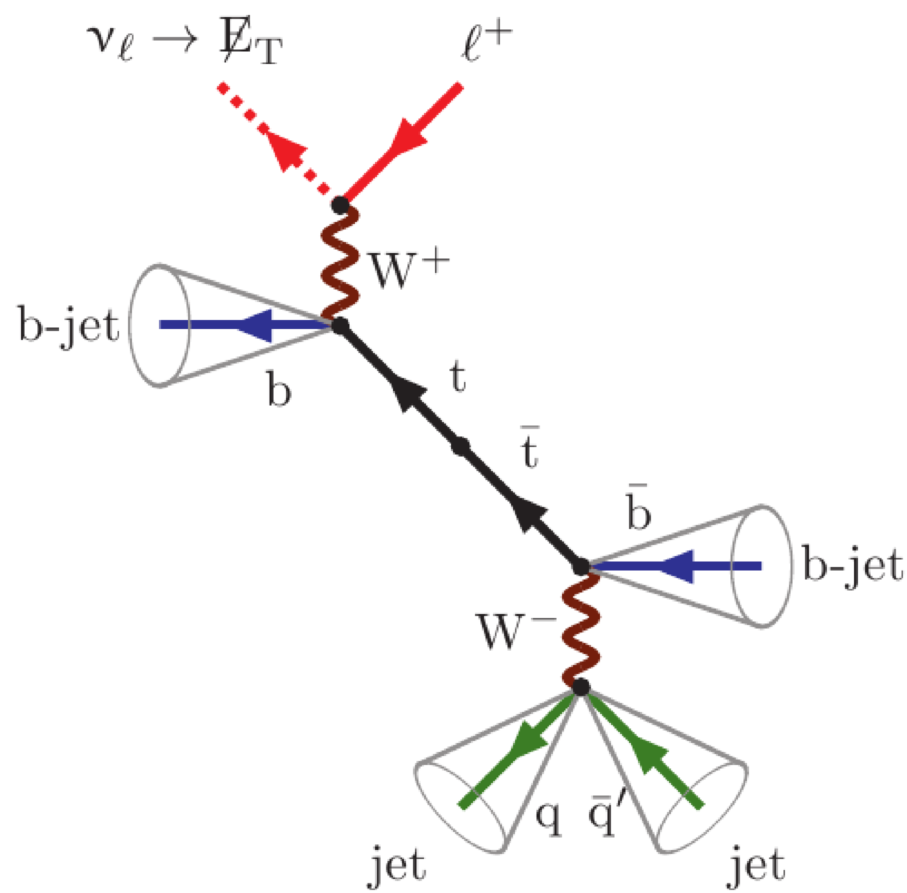


(remaining 15-20% is $q\bar{q}$-annihilation)

Decay modes:

- dileptonic: $t\bar{t} \to b\bar{b}\ell^+\ell^-\nu_\ell\bar{\nu}_\ell$
  2 jets, 2 leptons, E_T^{miss} 6.5%
- semi-leptonic: $t\bar{t} \to b\bar{b}q\bar{q}'\ell\nu_\ell$
  4 jets, 1 lepton, E_T^{miss} 37.9%
- fully hadronic: $t\bar{t} \to b\bar{b}q\bar{q}'q''\bar{q}'''$
  6 jets 55.6%

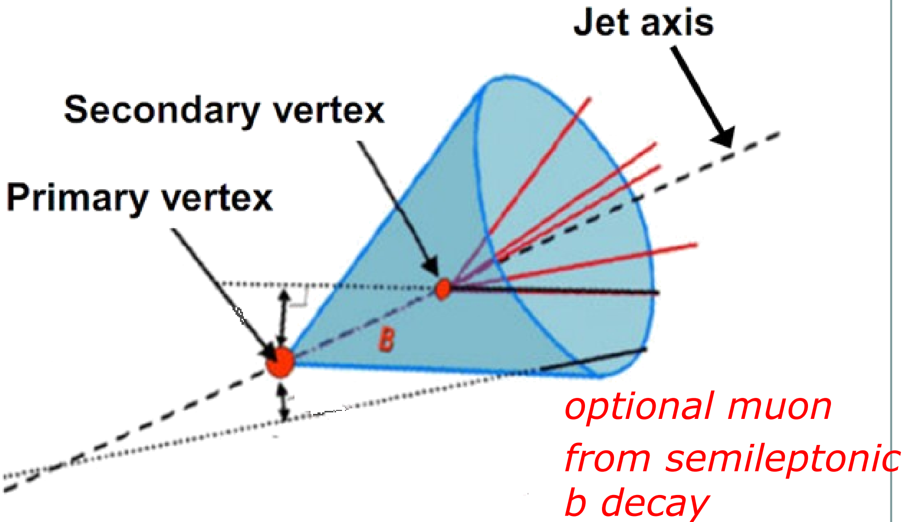
NB: $\tau \to e, \mu$, or hadrons

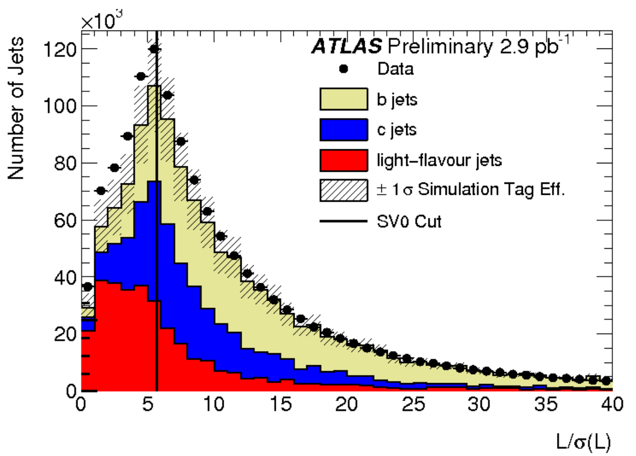


Additional jets come from ISR/FSR.

B-tagging

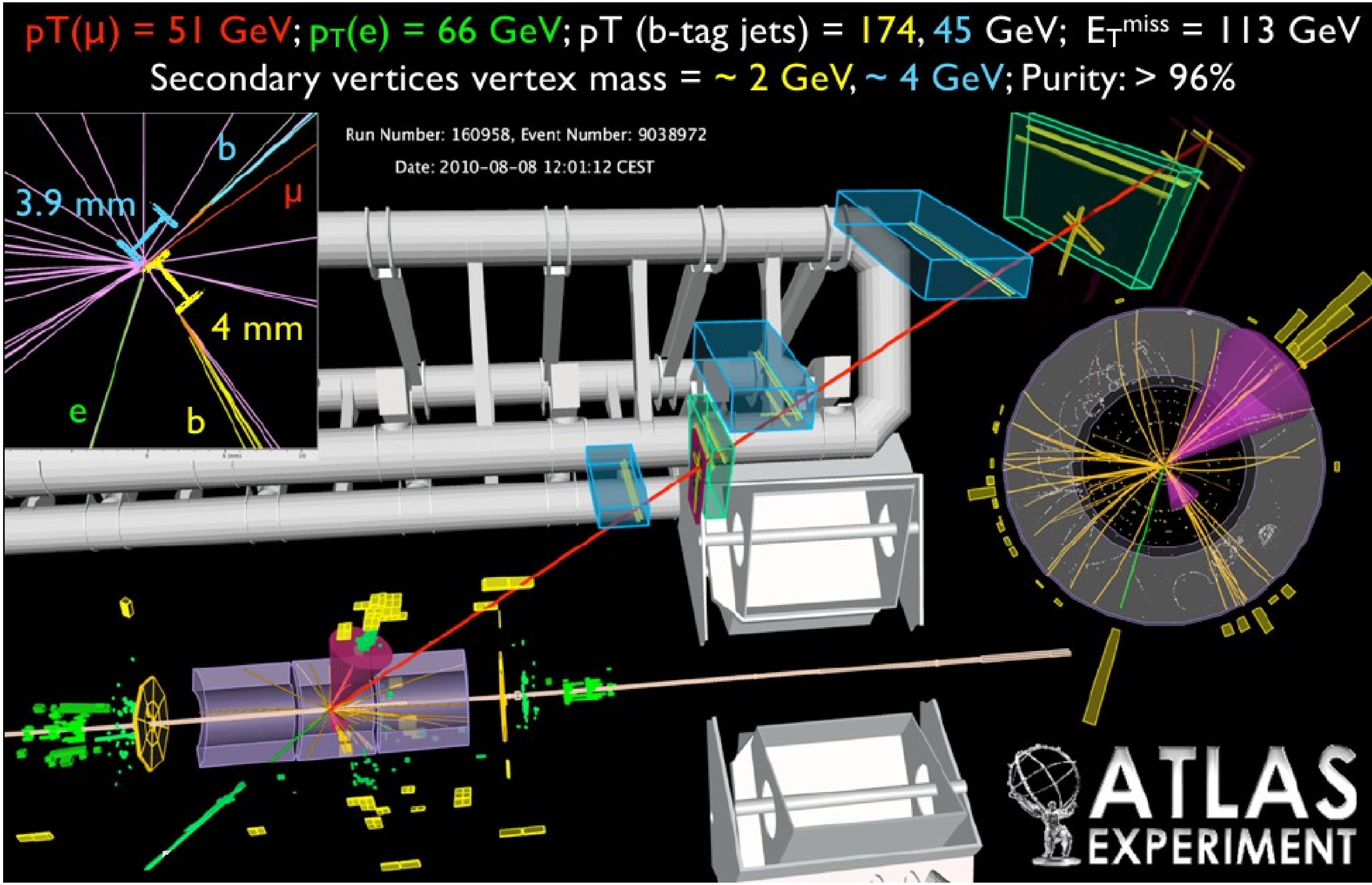
- Identification of jets originating from *b*-quarks very important in top physics.
- General concept: Exploit relatively long lifetime of *B*-hadrons resulting in flight times of *O*(few) mm.
  - Identifiable secondary decay vertex.





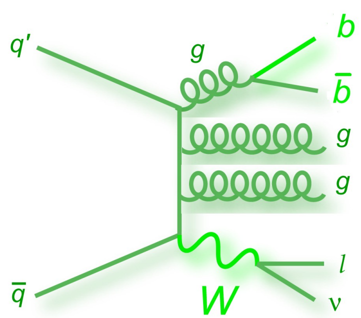
- Multiple techniques possible
  - here comparatively simple and robust method exploited:
    selection based on decay length significance $L / \sigma(L)$
  - Working point gives 50% efficiency for identifying *b* in $t\bar{t}$, at mistag rate < 1%.

$e + \mu + 2\ b$-tagged jets

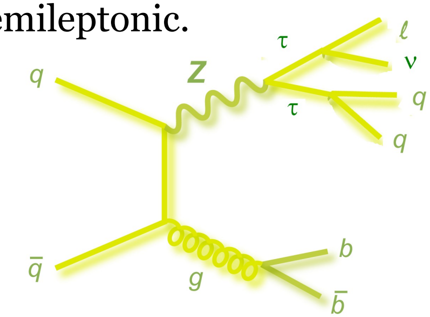


Backgrounds – single lepton channel

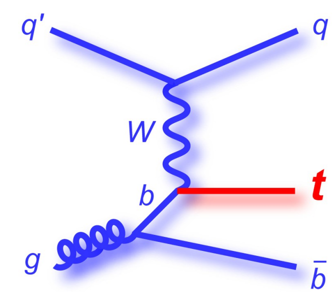
- Multi-jet events.
  - One lepton from a jet instead of the *W*.
  - Reduced by:
    - isolation criteria on the lepton
    - B-tagging at least one of the jets
- *W*+jets.
  - Reduced by:
    - B-tagging at least one of the jets
  - Irreducible:
    - $W{+}b\bar{b}$+jets.



- *Z*+jets
  - Where one lepton is not found → fake missing E_T
  - Irreducible:
    - $Z{+}b\bar{b}{+}\tau\bar{\tau}$ semileptonic.



- Single top + jets.
  - Irreducible



Estimating multi-jet background – single lepton channel

μ+jets contrib. from heavy flavour decays

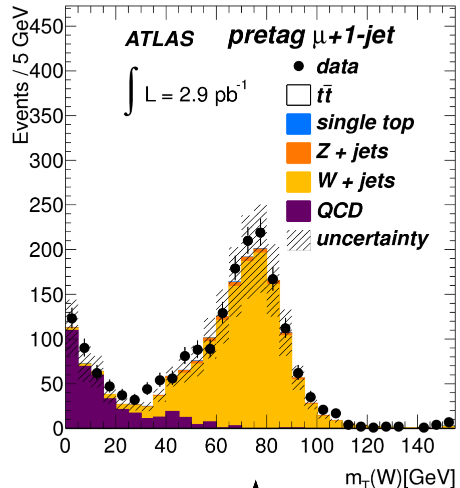
- Use Matrix method: Define a loose selection in addition to the one used in the main event selection:

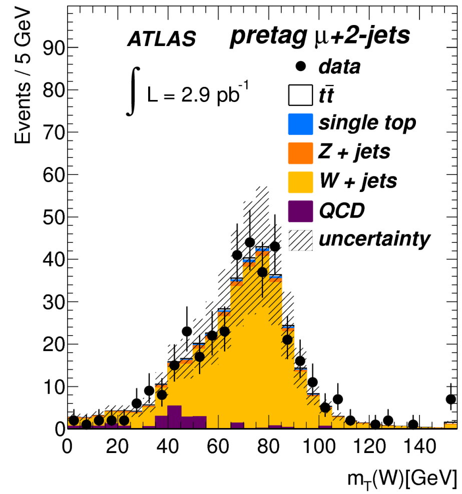
$$N^{\text{loose}} = N^{\text{loose}}_{\text{real}} + N^{\text{loose}}_{\text{fake}},$$
$$N^{\text{std}} = rN^{\text{loose}}_{\text{real}} + fN^{\text{loose}}_{\text{fake}}$$

  - r measured in $Z \rightarrow \mu\mu$ events
  - f measured in 2 separate QCD enriched control regions

***e* + jets** contribution from heavy flavour, $\gamma \rightarrow ee$, $\pi^{\pm}$

- Use E_T^{miss} template fitting method where QCD templates are obtained from 2 separate control regions.
  - Jets with high EM fraction.
  - Events with bad track quality.

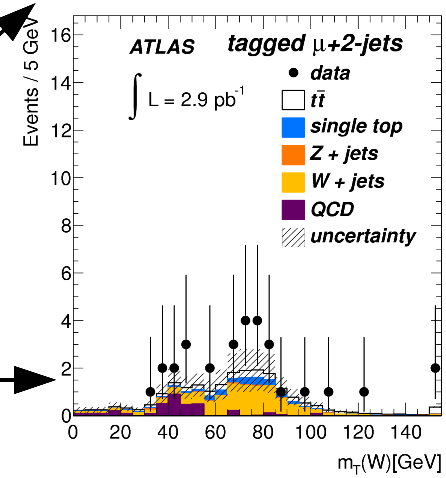




No E_T^{miss}+$m_T(W)$, 1 jet, no b-tag

2 jets, no b-tag

2jets, all cuts included



Estimating W+jet background – single lepton channel

Fraction which are b-tagged

Number of W+4jets events

$$\mathrm{W}^{\mathrm{tagged}-\geq 4\mathrm{jet}} = \mathrm{W}^{\mathrm{pretag}-\geq 4\mathrm{jet}} \cdot f_{\mathrm{tagged}}^{\geq 4-\mathrm{jet}}$$

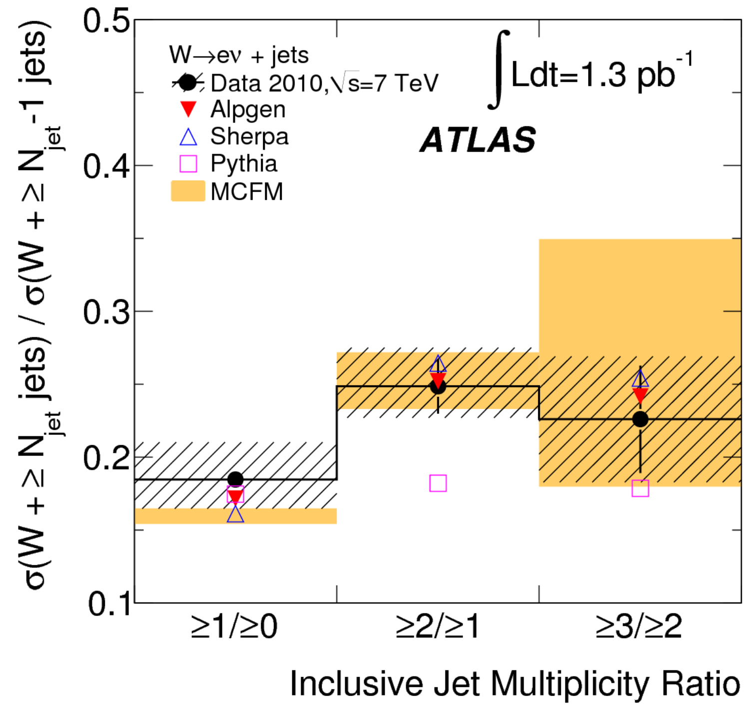
Number of W+4jets was extrapolated from low-jet multiplicity control sample using Berends-Giele scaling

$$\frac{W + (\mathrm{n}+1)\ \mathrm{jets}}{W + \mathrm{n\ jets}} \sim \mathrm{const}$$

$$f_{\mathrm{tagged}}^{\geq 4-\mathrm{jet}} = f_{\mathrm{tagged}}^{2-\mathrm{jet}} \cdot f_{2\rightarrow\geq 4}^{\mathrm{corr}}$$

Tag fraction in 2-jet sample

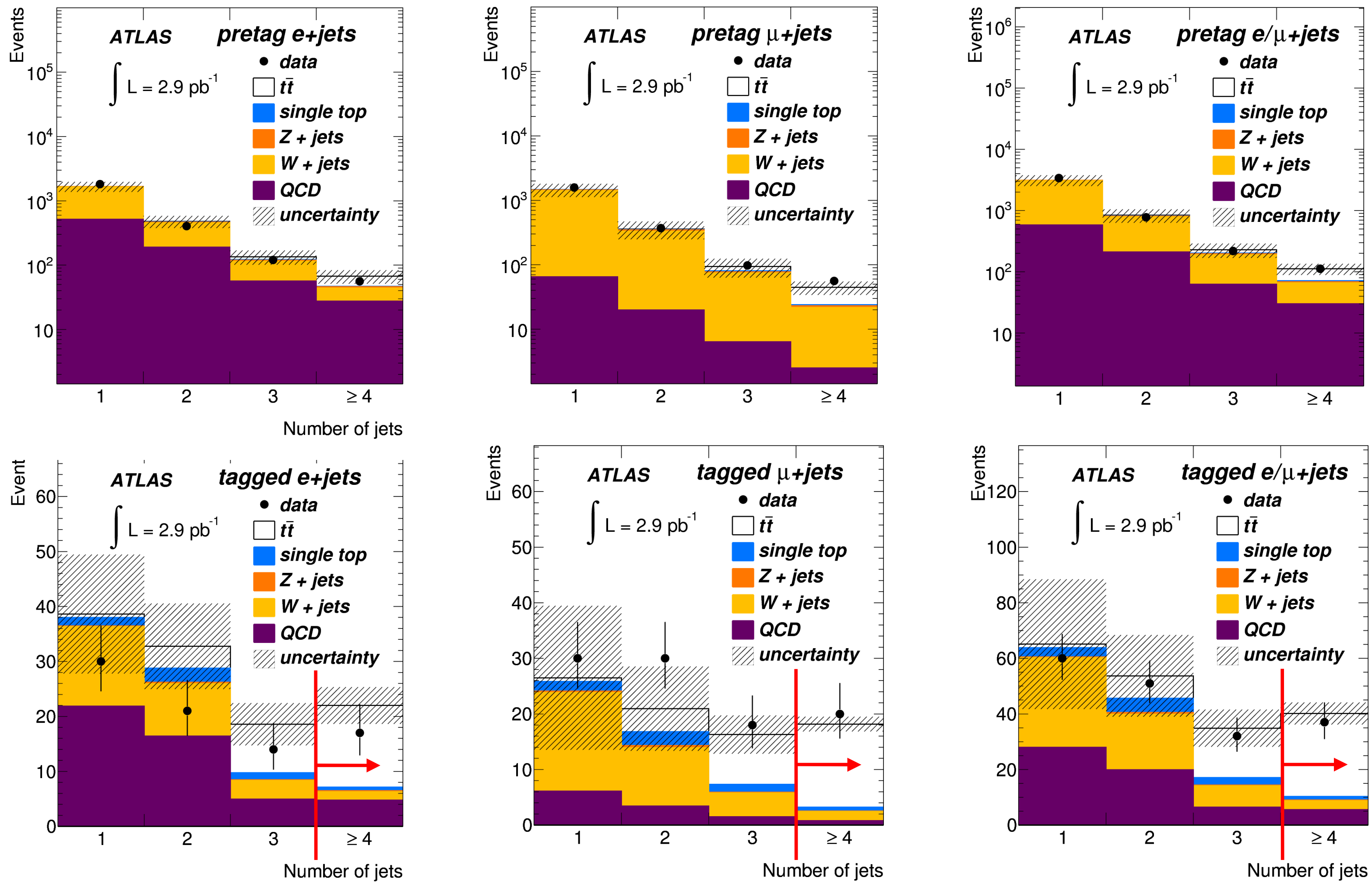
Accounts for different flavor composition for 2-jet and 4-jet events. Estimated with ALPGEN.



Jet multiplicities – single lepton channel

Before b-tagging

After b-tagging



Cross section determination – single lepton channel

Number of events passing all cuts:

	e+jets	μ+jets	combined
Observed	17	20	37
Total est. bkg	7.5 ± 3.1	4.7 ± 1.7	12.2 ± 3.9
$t\bar{t}$	$9.5 \pm 4.1 \pm 3.1$	$15.3 \pm 4.4 \pm 1.7$	$24.8 \pm 6.1 \pm 3.9$

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{\int \mathcal{L}dt \cdot \epsilon_{t\bar{t}} \cdot Br(t\bar{t} \to \ell + jets)}$$

$$\epsilon_{t\bar{t}} \cdot Br(t\bar{t} \to \ell + jets) = \begin{cases} 3.1 \pm 0.7\% & (e + jets) \\ 3.2 \pm 0.7\% & (\mu + jets) \end{cases}$$

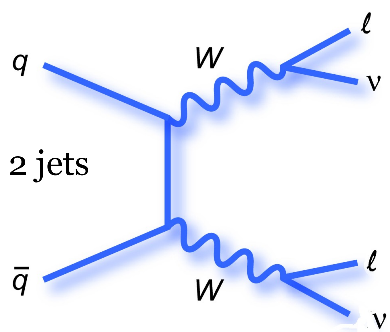
Cross section after subtracting estimated background:

	e+jets	μ+jets	e/μ +jets combined
Counting σ [pb]	$105 \pm 46 \ ^{+45}_{-40}$	$168 \pm 49 \ ^{+46}_{-38}$	$142 \pm 34 \ ^{+50}_{-31}$

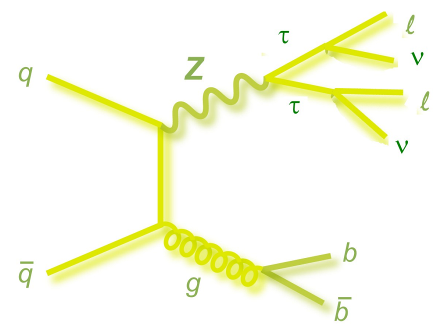
The result is confirmed by two fit based methods!

Backgrounds – di-lepton channel

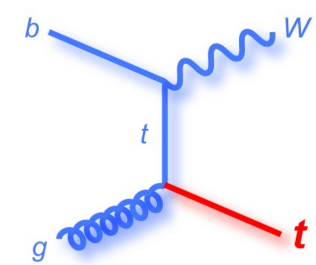
- Multi-jet events.
  - Both leptons from a jet.
  - Reduced by:
    - isolation criteria on the lepton
    - B-tagging at least one of the jets
- *W*+jets.
  - One lepton from a jet.
- Di-boson events.
  - E.g., *WW*
  - Reduced by
    - requiring at least 2 jets



- *Z*+jets / Drell-Yan+jets
  - Reduce by
    - $E_T$miss > 40 GeV (*ee*), 30 GeV (μμ)
    - *Z* mass veto
    - Scalar sum of E_T > 150 GeV for *e*μ channel
  - Irreducible:
    - $Z+\tau\bar{\tau}$ semileptonic.

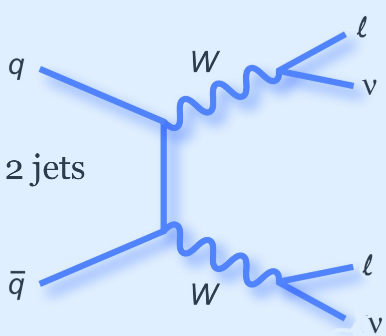


- Single top + jets.
  - Irreducible

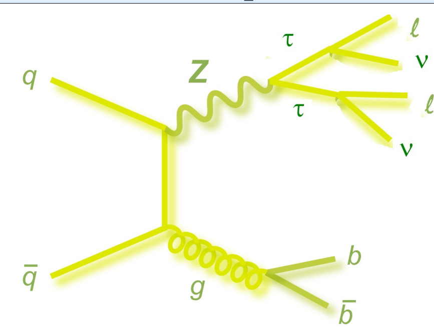


Backgrounds – di-lepton channel

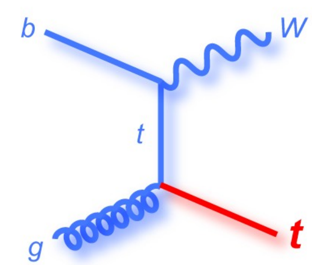
- Multi-jet events.
  - Both leptons from a jet.
  - Reduced by:
    - isolation criteria on the lepton
    - B-tagging at least one of the jets
- *W*+jets.
  - One lepton from a jet.
- Di-boson events.
  - E.g., *WW*
  - Reduced by
    - requiring at least 2 jets



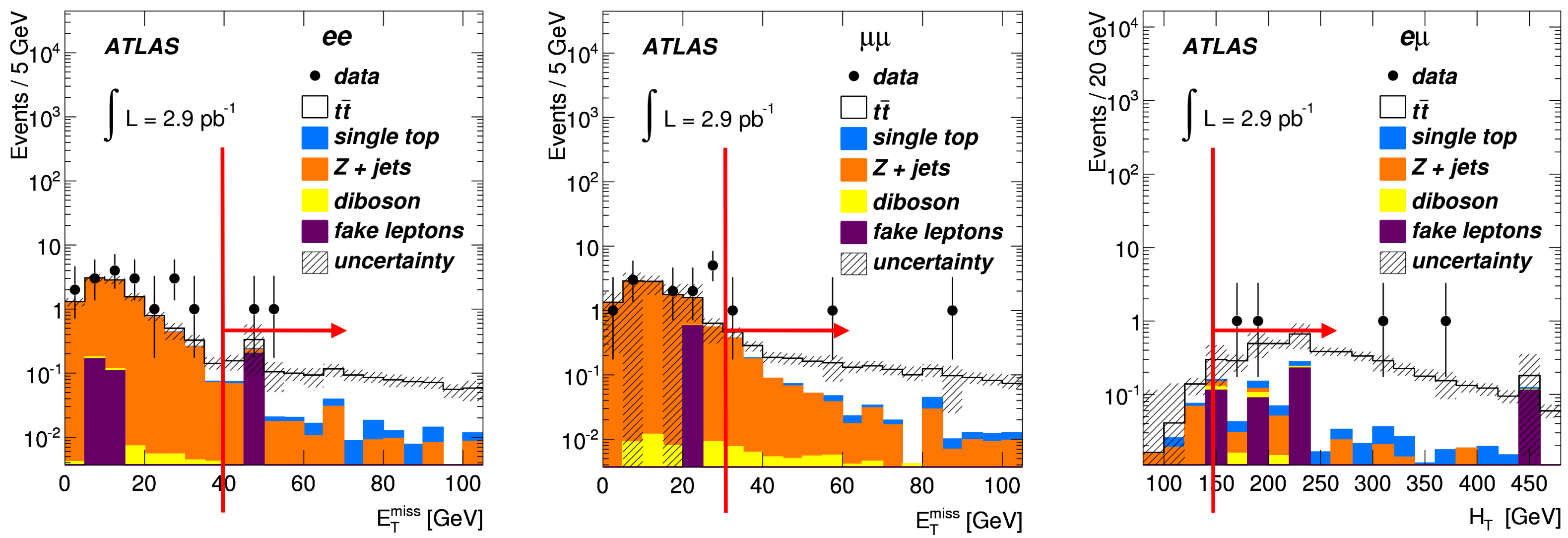
- *Z*+jets / Drell-Yan+jets
  - Reduce by
    - $E_T$miss > 40 GeV (*ee*), 30 GeV (μμ)
    - *Z* mass veto
    - Scalar sum of E_T > 150 GeV for *e*μ channel
  - Irreducible:
    - $Z+\tau\bar{\tau}$ semileptonic.



- Single top + jets.
  - Irreducible

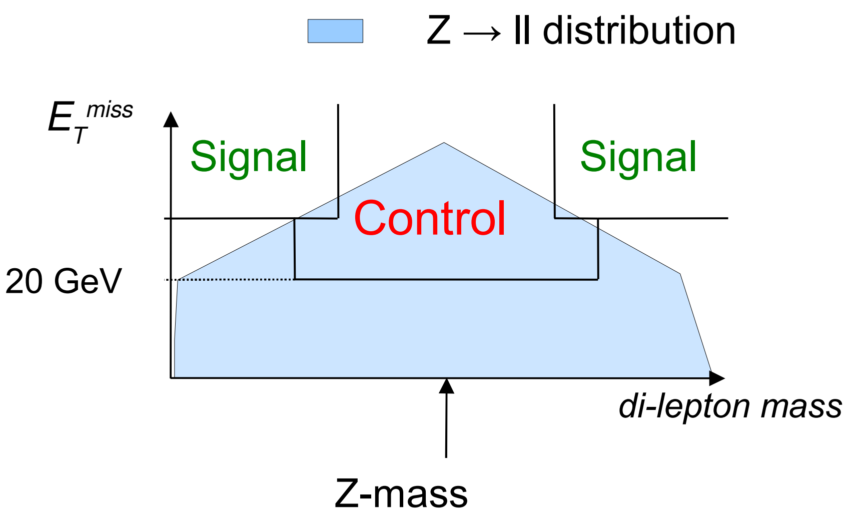


Missing energy & HT – di-lepton channel



- The large *Z*/DY+jets background can be reduced by requiring missing transverse energy (neutrinos).
- Since *e*μ channel does not contain as many *Z*, a scalar sum of the transverse energy of all jets and leptons was used instead.

Estimating Z/Drell-Yan background – di-lepton channel

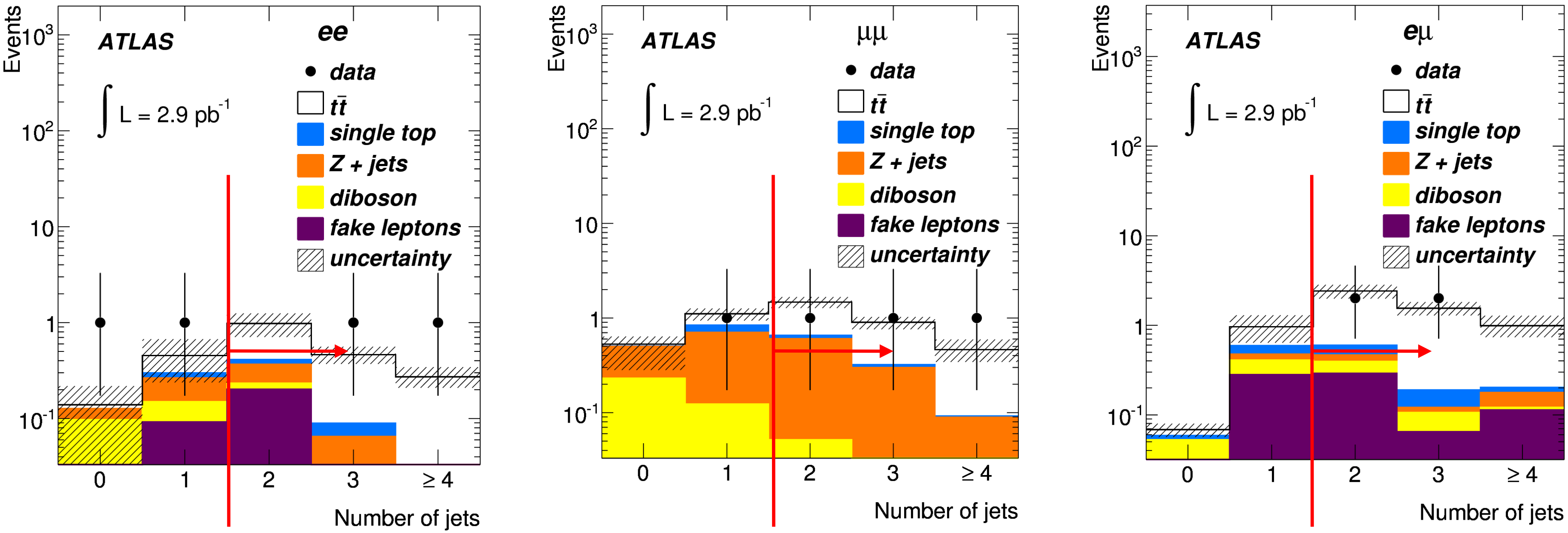


Process	ee	$\mu\mu$	$e\mu$
Z+jets (DD)	0.25 ± 0.18	0.67 ± 0.38	-
$Z(\to \tau\tau)$+jets (MC)	0.07 ± 0.04	0.14 ± 0.07	0.13 ± 0.06
Non-Z leptons (DD)	0.16 ± 0.18	-0.08 ± 0.07	0.47 ± 0.28
single top (MC)	0.08 ± 0.02	0.07 ± 0.03	0.22 ± 0.04
dibosons (MC)	0.04 ± 0.02	0.07 ± 0.03	0.15 ± 0.05
Total predicted (non $t\bar{t}$)	0.60 ± 0.27	0.88 ± 0.40	0.97 ± 0.30
$t\bar{t}$	1.19 ± 0.19	1.87 ± 0.26	3.85 ± 0.51
Total predicted	1.79 ± 0.38	2.75 ± 0.55	4.82 ± 0.65
Observed	2	3	4

- Define control region in Z-window and below the E_t^{miss}-cut.
  - Control region = Z candidates
- Determine the ratio of events in control region and signal region from simulation.
- Estimate Z/DY contamination by counting number of events in control region, and multiply by the above ratio.

$$N_{signal,data} = N_{control,data} \times \frac{N_{signal,MC}}{N_{control,MC}}$$

Jet multiplicities – di-lepton channel



- Di-leptons left after selection:
  - 2 *ee* (2 pass *b*-tagging)
  - 3 μμ (1 pass *b*-tagging)
  - 4 *e*μ (2 pass *b*-tagging)

(Uncertainty on *b*-tagging efficiency implies that a better cross section estimate is obtained with untagged jets.)

Cross section determination – di-lepton channel

Cross section after subtracting estimated background:

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{\int \mathcal{L}dt \cdot \epsilon_{t\bar{t}} \cdot Br(t\bar{t} \to \ell\ell)}$$

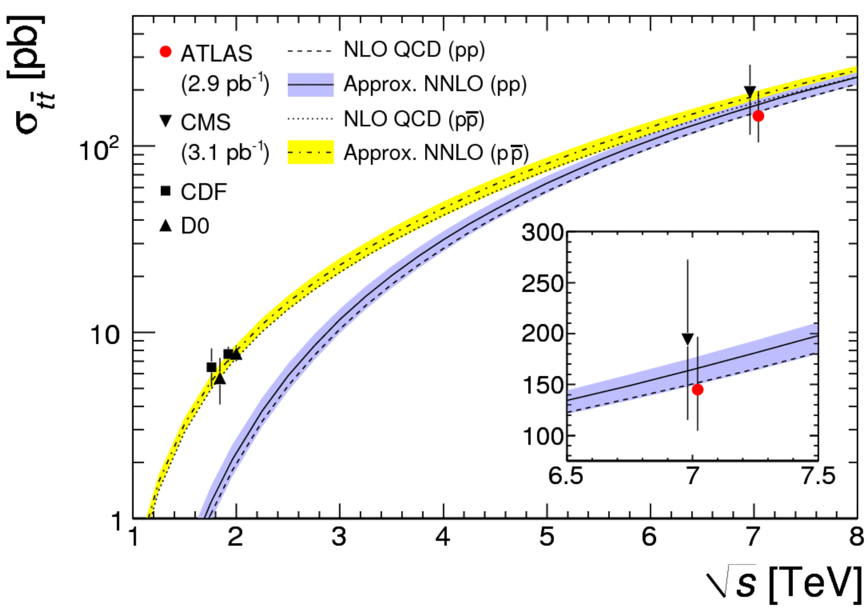
From MC: $\epsilon_{t\bar{t}} \cdot Br(t\bar{t} \to \ell\ell) = \begin{cases} 0.24\% & (ee) \\ 0.38\% & (\mu\mu) \\ 0.81\% & (e\mu) \end{cases}$

Channel	$\sigma_{t\bar{t}}$ [pb]
ee	$193 \, ^{+243}_{-152} \, ^{+84}_{-48}$
$\mu\mu$	$185 \, ^{+184}_{-124} \, ^{+56}_{-47}$
$e\mu$	$129 \, ^{+100}_{-72} \, ^{+32}_{-18}$
Combined	$151 \, ^{+78}_{-62} \, ^{+37}_{-24}$

Combining all channels

	Cross-section [pb]	Signal significance [σ]
Single lepton channels	$142 \pm 34\ ^{+50}_{-31}$	4.0
Dilepton channels	$151\ ^{+78}_{-62}\ ^{+37}_{-24}$	2.8
All channels	$\mathbf{145 \pm 31\ ^{+42}_{-27}}$	**4.8**

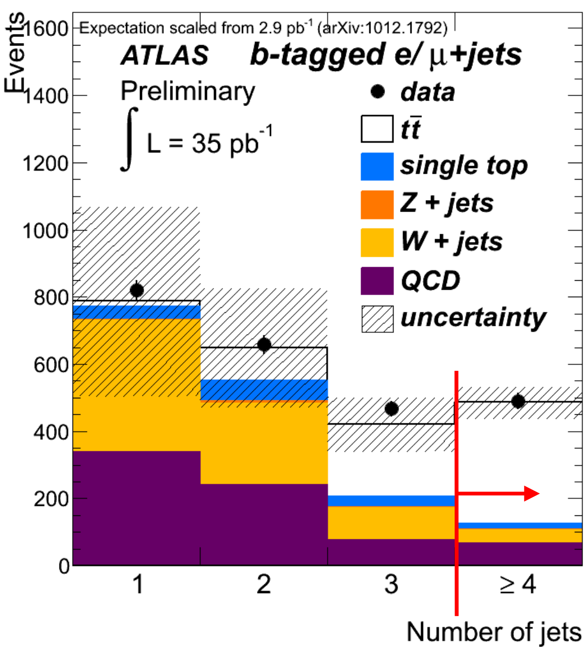
- Combining all single lepton and di-lepton channels in a joint likelihood fit.
  - Accounts for all systematics and correlations.
- The results agrees with theoretical prediction.
  - Agreement between ATLAS & CMS results.

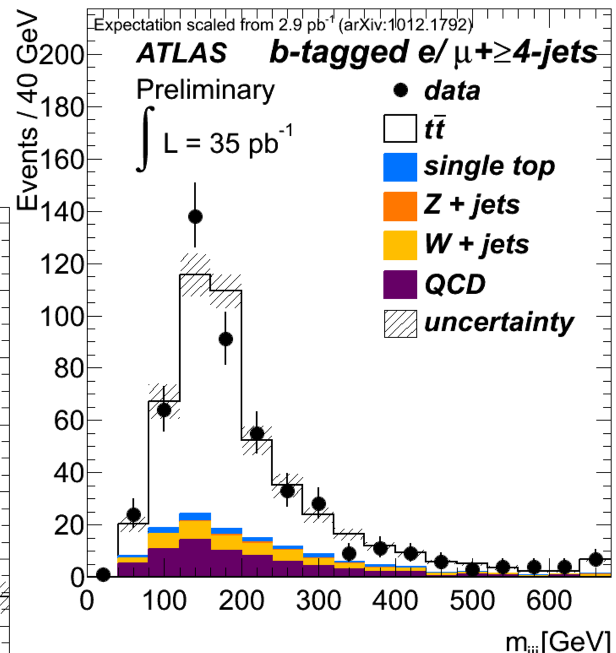


Updating the $t\bar{t}$ results

- The whole analysis is being updated with full 2010 data.
  - >1 order of magnitude more events.

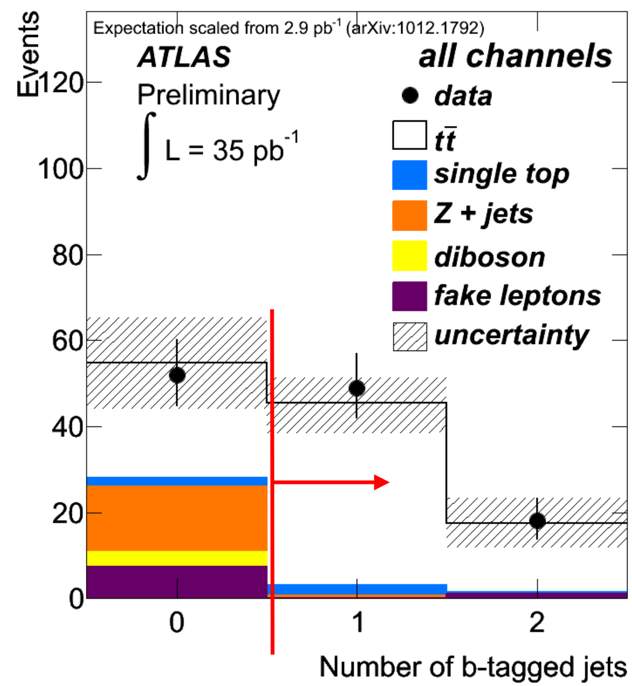
- Jet multiplicity in single lepton channel.





- Invariant mass of 3-jet combinations in single lepton channel.

- Number of *b*-tagged jets in di-lepton channel.



Summary

- Many Standard Model measurements were made.
- *W* & *Z* cross section
  - The measurements agree with theory.

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

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

- $W \to \mu\nu$ asymmetry
  - New analysis using 31 pb^{-1}.
  - Will provide useful information for low *x*.
- *W*/*Z* + jets cross section
  - Measured cross section as function of jet multiplicity agrees with NLO simulation.

- ATLAS has measured the top pair production cross-section at the LHC in the first 2.9 pb-1 of data.
- The cross-section is measured to be

$$\sigma_{t\bar{t}} = 145 \pm 31^{+42}_{-27}\ pb$$

- Agreement was found:
  - between the 5 subchannels ($e^{\pm}$, $\mu^{\pm}$, e^+e^- , $\mu^+\mu^-$, $e^{\pm}\mu^{\mp}$)
  - in kinematic properties of selected events with SM $t\bar{t}$ production
  - with (NLO/NNLO) QCD predictions

$$\sigma_{t\bar{t}} = 164^{+11.4}_{-15.7}\ pb$$

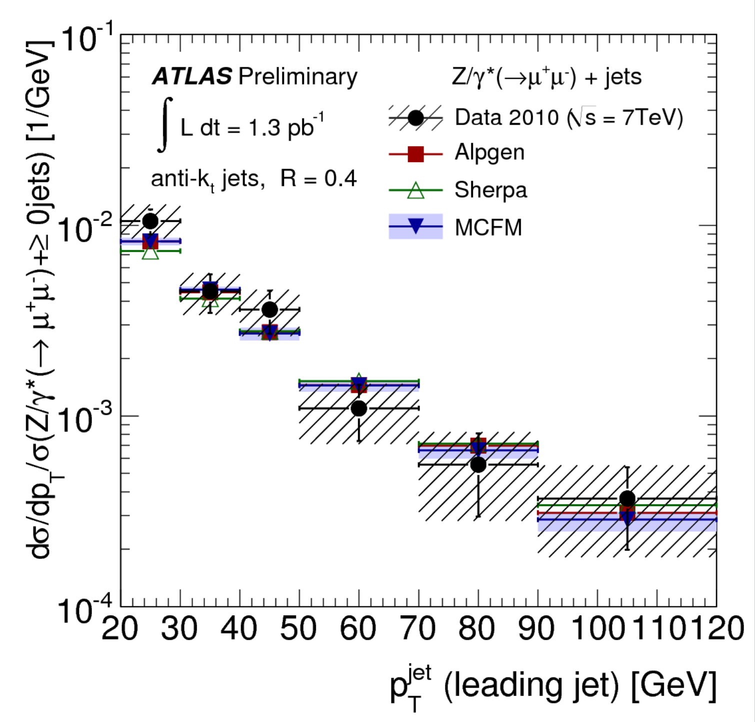
  - with CMS

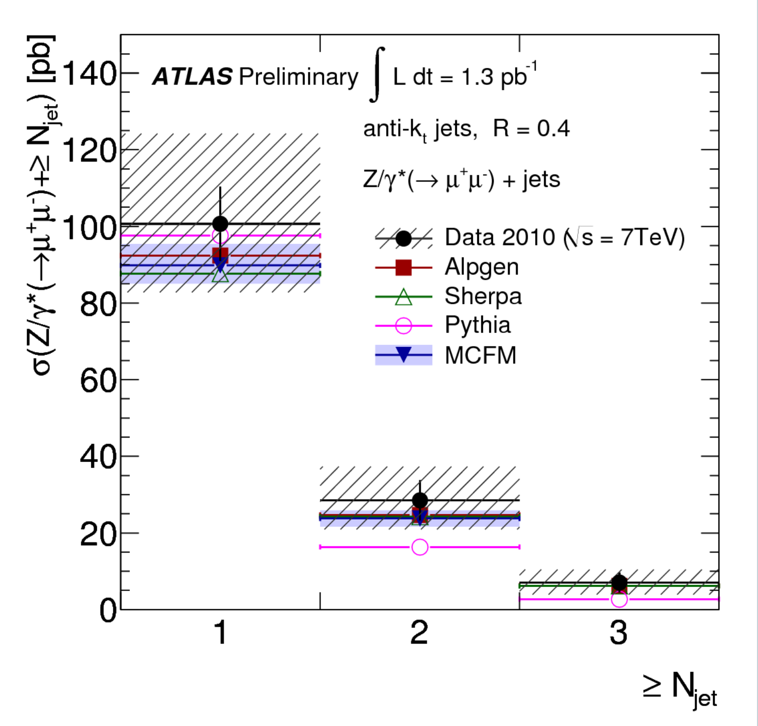
$$\sigma_{t\bar{t}} = 194 \pm 72\ (stat.) \pm 24\ (syst.) \pm 21\ (lumi.)\ pb$$

Backup slides

www.atlas.ch

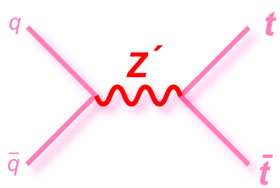
Z+jets


ATLAS Preliminary
∫ L dt = 1.3 pb-1
anti-kt jets, R = 0.4
Z/γ*(→μ+μ-) + jets
Data 2010 (√s = 7TeV)
Alpgen
Sherpa
MCFM
dσ/dpT/σ(Z/γ*(→ μ+μ-)+≥ 0jets) [1/GeV]
pT jet (leading jet) [GeV]

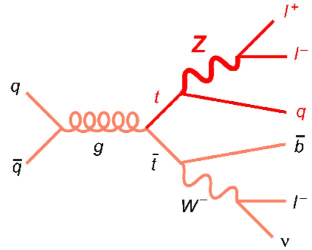

ATLAS Preliminary ∫ L dt = 1.3 pb-1
anti-kt jets, R = 0.4
Z/γ*(→ μ+μ-) + jets
Data 2010 (√s = 7TeV)
Alpgen
Sherpa
Pythia
MCFM
σ(Z/γ*(→μ+μ-)+≥ Njet) [pb]
≥ Njet

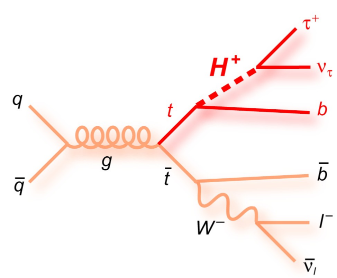
Motivation to study top quarks

- Precision EW+Higgs physics very sensitive to top mass.
- Top appears in many extensions to the Standard Model:
  - Heavy resonances pp → Z' → $t\bar{t}$



  - FCNC (highly suppressed in SM)





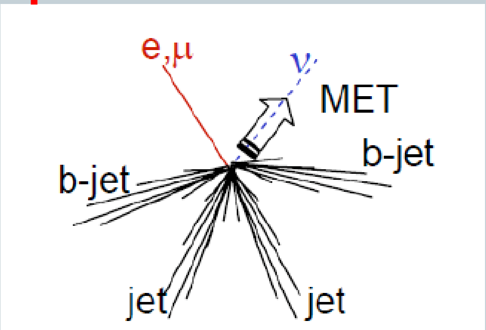
  - Charged Higgs

- Top as background:
  - Di-boson: WW,WZ,ZZ
  - Higgs: H→ZZ, …
  - Susy: stops
  - …
- To do list for 2011:
  - Top mass
  - Single top production cross-section
  - Top properties
    - Wtb vertex structure
    - top quark charge
    - spin correlations
  - FCNC
  - Heavy resonances

Event selection

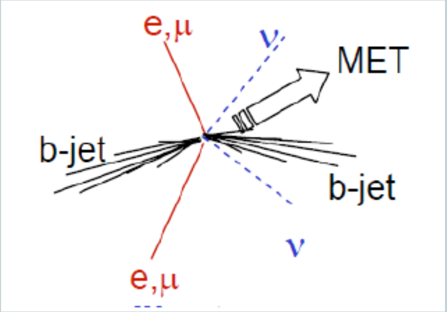
Cosmics,pile-up rejection: ⩾5 tracks from primary vertex
Trigger: Single lepton trigger, pT>10 GeV (fully efficient at 20 GeV)
Leptons: electron or muon, pT>20 GeV, isolated (to suppress leptons from hadrons decaying in-flight and semi-leptonic production in heavy flavor jets), |η|<2.5
Jets: anti-kt, R=0.4, |η|<2.5

Single lepton channel



Exactly 1 lepton (e or μ)
⩾4 jets with pT>25 GeV
⩾1 with b-tag (50% efficiency working point)
ETmiss >20 GeV (reject QCD BG)
ETmiss + mT(W) > 60 GeV ("triangular cut")

Dilepton channel



Exactly 2 leptons(ee, μμ, eμ) with opposite charge
⩾2 jets with pT>20 GeV, no b-tag
ee: |Mee -MZ| > 5 GeV , ETmiss >40 GeV
μμ: |Mμμ -MZ| > 10 GeV, ETmiss>30 GeV
eμ: HT>150 GeV (HT is scalar sum of pT of leptons and selected jets)

Cross section determination

- A binned likelihood fit was used to extract the cross-section.
  - Expected number of events:

$$N^{exp}(\sigma_{t\bar{t}}, \alpha_j) = L \cdot \epsilon_{t\bar{t}}(\alpha_j) \cdot \sigma_{t\bar{t}} + \sum_{bkg} L \cdot \epsilon_{bkg}(\alpha_j) \cdot \sigma_{bkg}(\alpha_j) + N_{DD}(\alpha_j)$$

  - L = luminosity, ε = efficiency * acceptance , α = variation of acceptance and background due to systematic uncertainties.

  - For each channel, define likelihood:

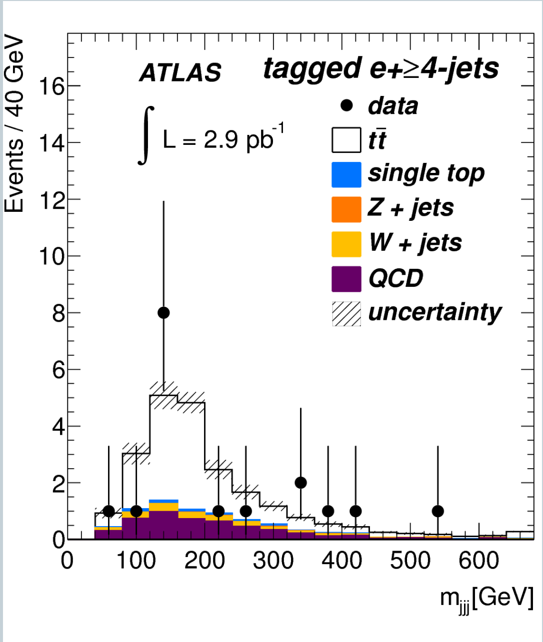
$$\mathcal{L}(\sigma_{t\bar{t}}, L, \alpha_j) = \text{Poisson}\left(N^{obs} \,|\, N^{exp}(\sigma_{t\bar{t}}, \alpha_j)\right) \times \text{Gauss}(L_0|L, \delta_L) \times \prod_{j \in syst} \Gamma_j(\alpha_j)$$

Counting experiment → Use Poisson to model N^{obs} given N^{exp} (contains cross-section as fit parameter)

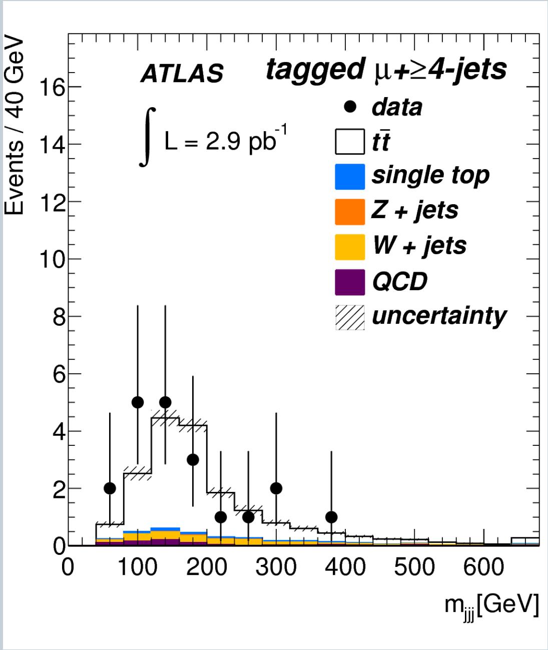
Luminosity uncertainty is a nuisance parameter, modelled by a Gaussian. L_0=2.9 pb^{-1}, δ_L=11%

Systematic uncertainties (JES, lepton efficiencies, uncertainties on data-driven measurements, etc) are modelled by Gamma functions (→ Gaussian at limit of small uncertainty)

Cross section uncertainties – single lepton channel



Control plots:
Invariant mass of jets



Uncertainty	Single electron	Single muon
Statistical	43%	29%
Jet energy scale	13%	11%
B-tagging efficiency	-10% / +15%	-10% / +14%
Multi-jet background	30%	2%
W+jet background	11%	11%