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ATLAS

Top Mass and Cross Section at ATLAS

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On behalf of the ATLAS Collaboration

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Outline

- Why the top quark?
- Top production & decays
- LHC & ATLAS detector
- Top pair production cross section measurements
- Single top cross section measurement
- Top mass measurements
- Summary

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults

Why the top quark?

- In the SM it's the only quark:

1. With a natural mass:

$$m_{top} = y_t v/\sqrt{2} \approx 173 \text{ GeV} \Rightarrow y_t \approx 1$$

   - Top quark interacts strongly with the Higgs sector - special role in EWSB?

2. That decays before hadronizing:

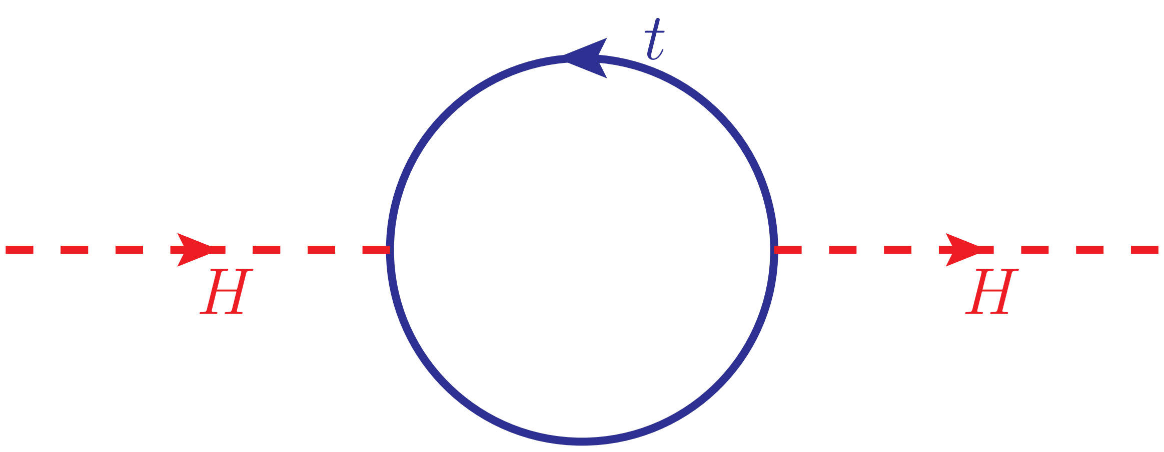
$$\tau_{had} \approx 2 \times 10^{-24} s$$

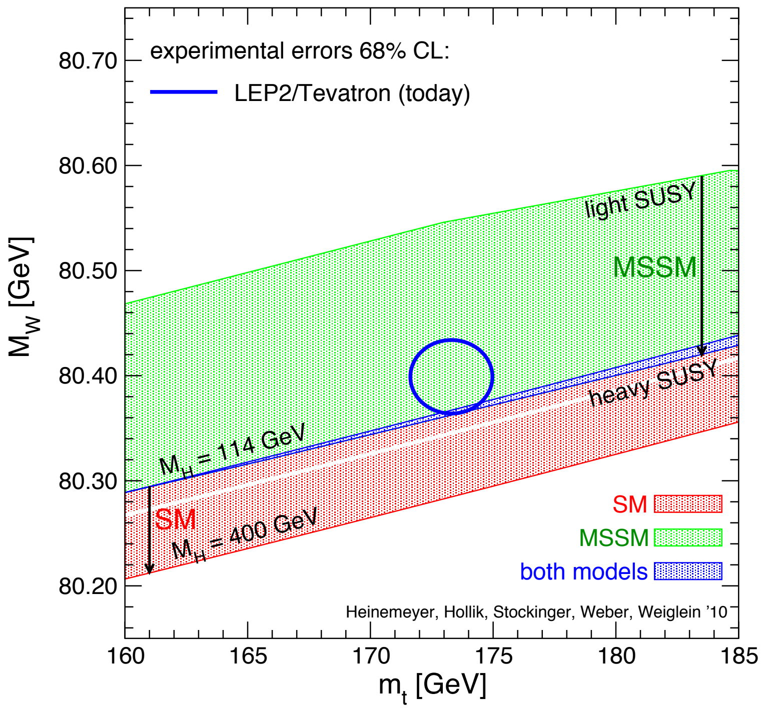
$$\tau_{top} \approx 5 \times 10^{-25} s$$

- Top is a unique window on QCD & EW physics.

Why the top quark?

- Higgs mass in the SM is sensitive to the top quark mass:

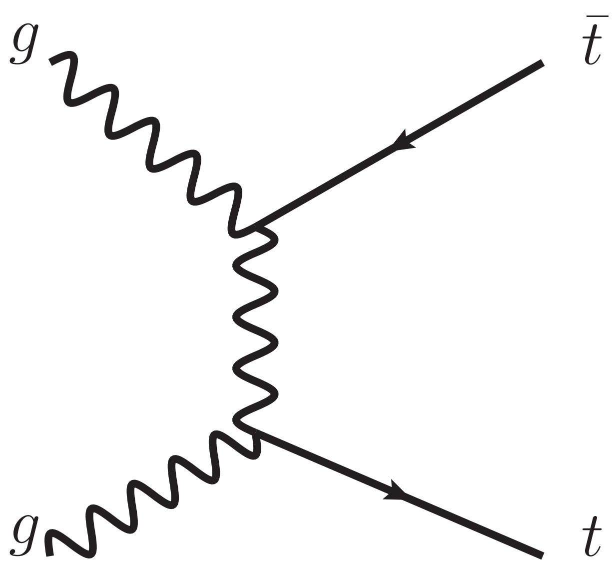


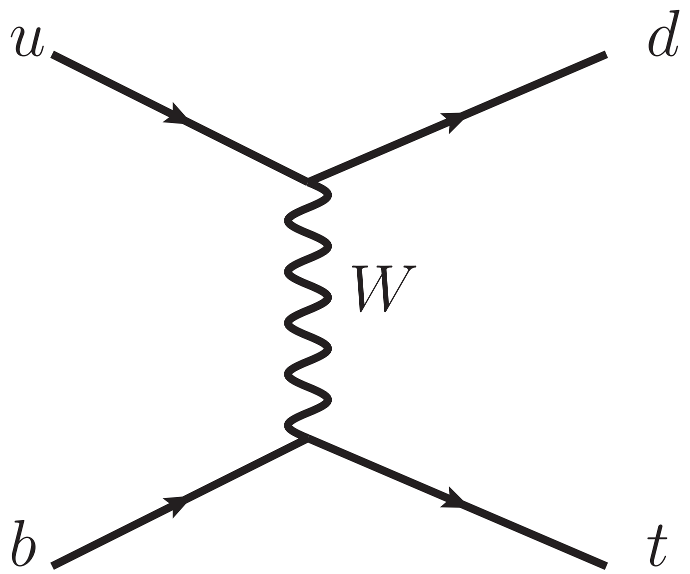


- In effective theory approach: $$\Delta m_H^t \sim -\frac{3}{8\pi^2} y_t \Lambda^2$$
- For less than 90% cancellation: $\Lambda < 3\ TeV$
- Top quark could be the place we see new physics.

Top Production

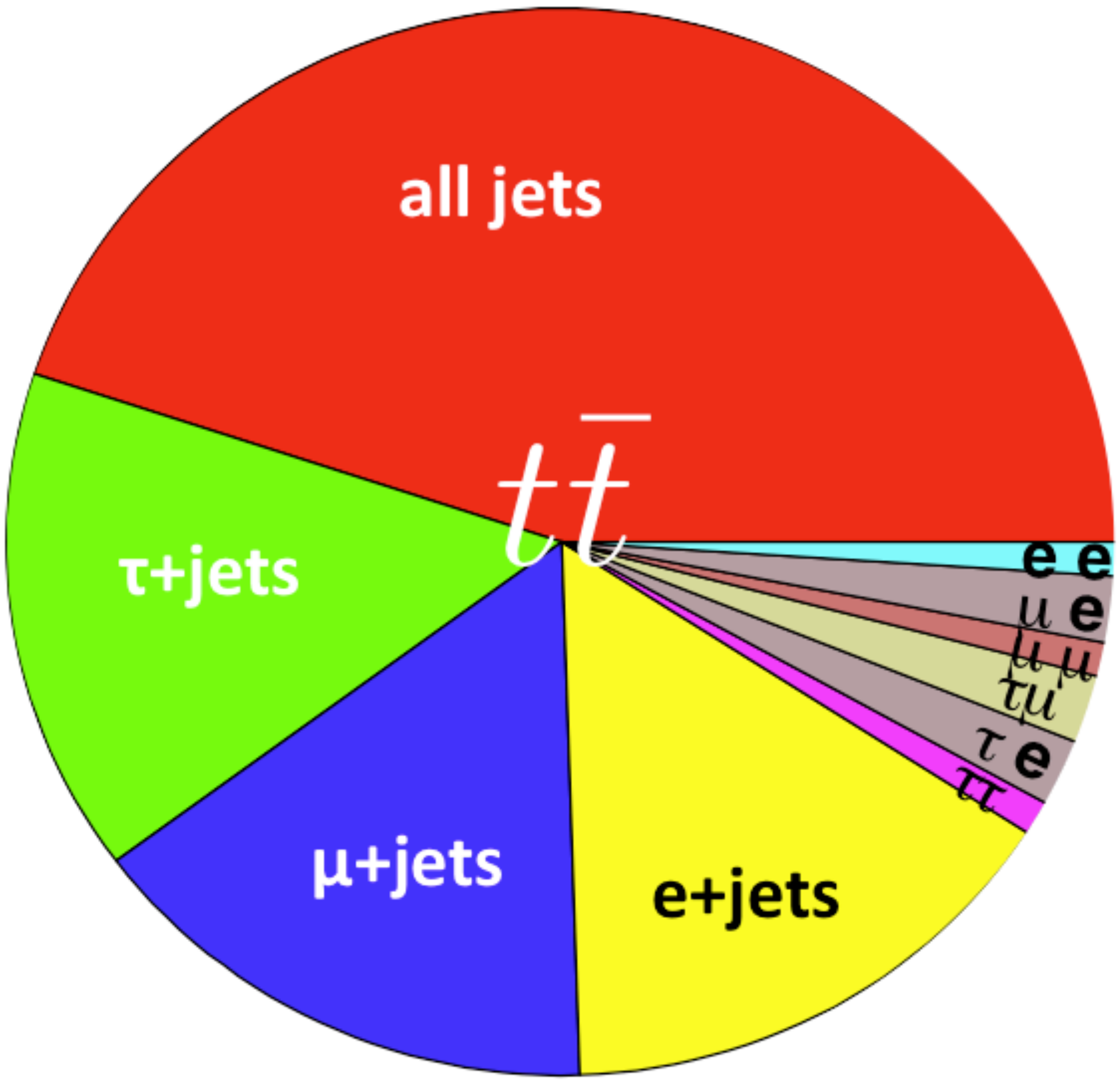
- Top pair production: QCD process, dominated by gg fusion.
  - Large cross section, σ = 165 pb
  - Test perturbative QCD, large sample for top properties studies.
- Single top production: EW process
  - Smaller cross section: $\sigma_{t\text{-}chan}$ = 66 pb
  - Probe EW interactions of the top quark.





Top Decays

- SM top decays ~100% to $W^{\pm}b$.
- Final states dictated by W boson decays.



Top pair final states:

All hadronic:

- 2 b-jets + 4 q-jets
- High Br
- Large multijet background

Lepton plus jets:

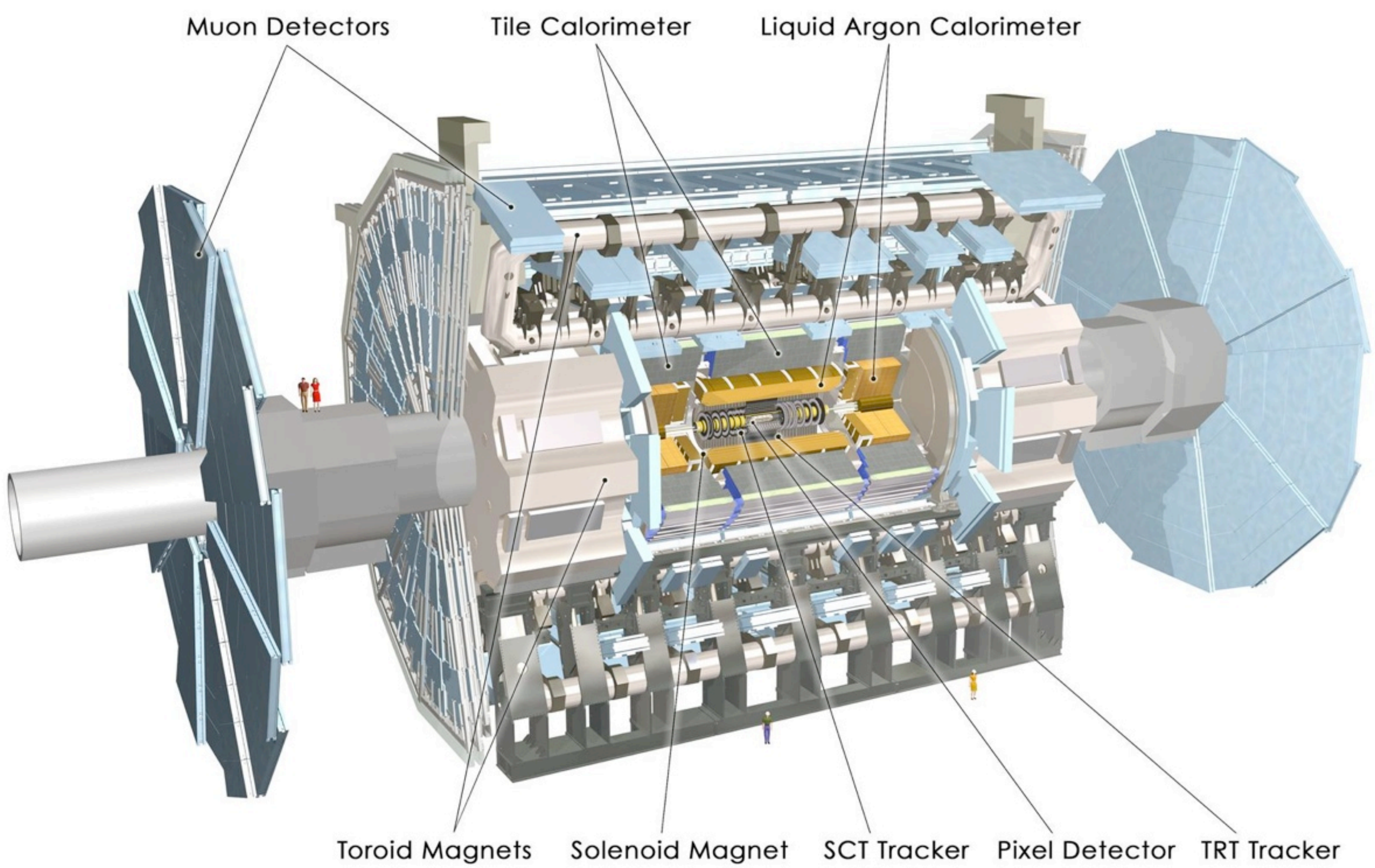
- e / μ + ν + 2 b-jets + 2 q-jets
- Good Br
- Manageable backgrounds

Di-lepton:

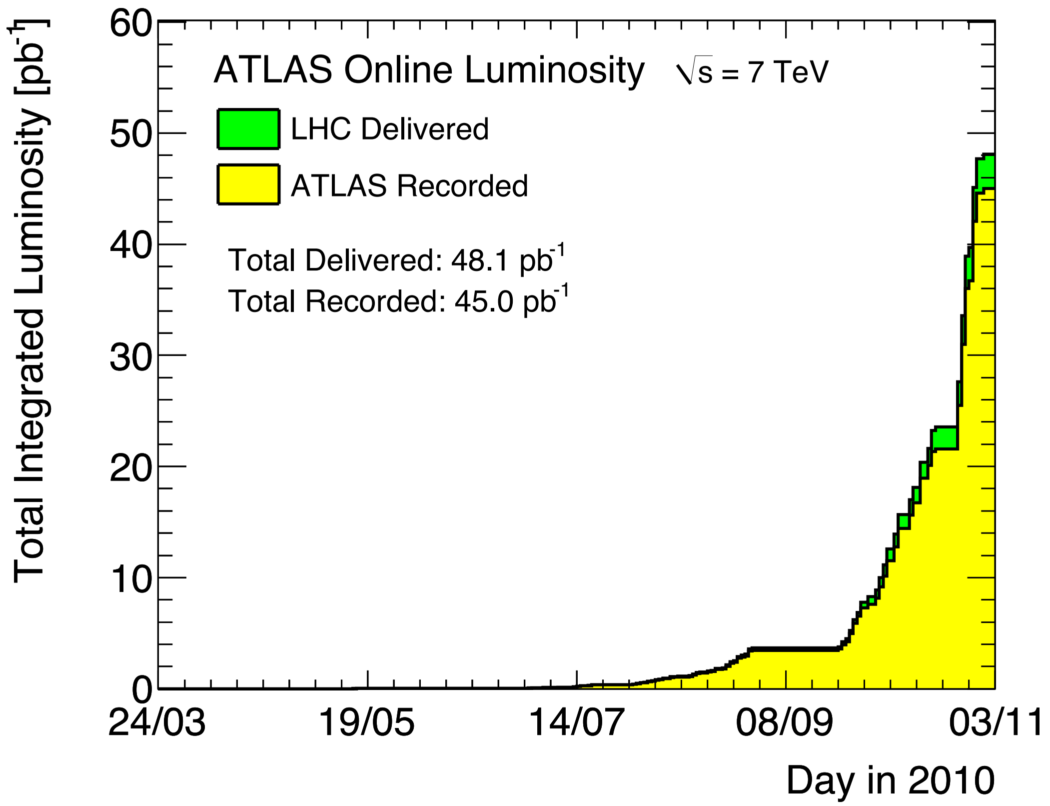
- ee / μμ / eμ + νν + 2 b-jets
- Small Br
- Small backgrounds

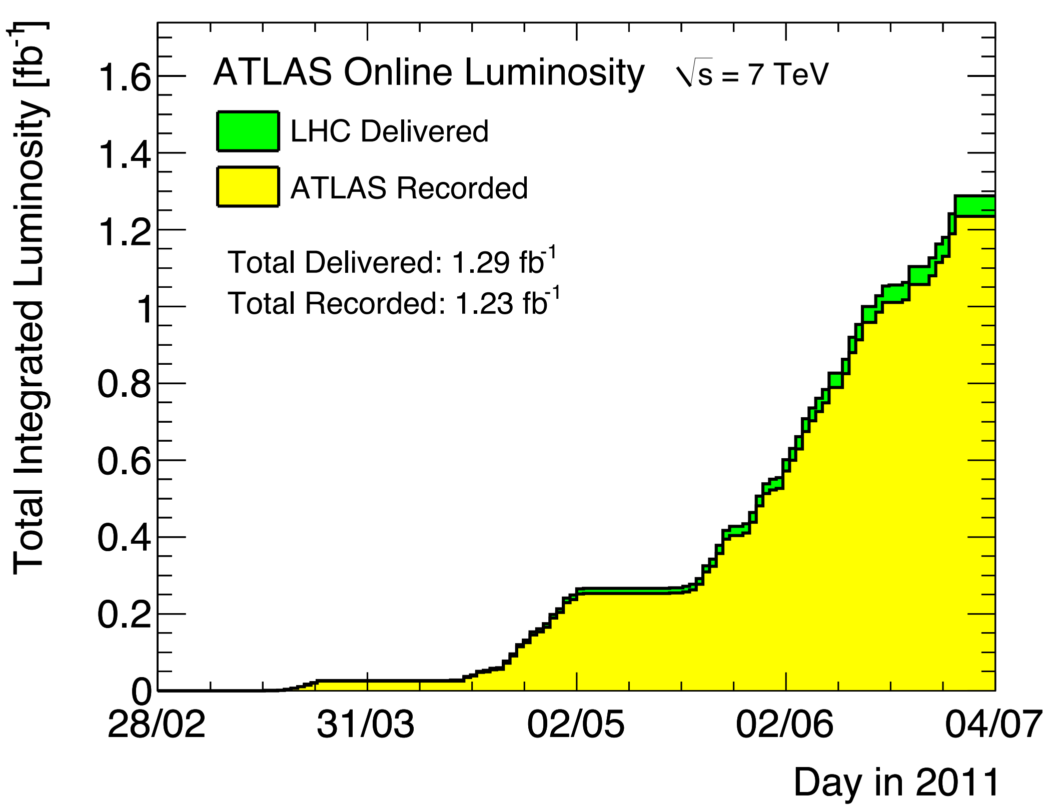
LHC & ATLAS

- Fantastic LHC performance:



- More tops on tape now than at a CDF or D0.
- Most results in this talk: 2010 data, L=35 pb^{-1}. Single top observation uses 2011 data (L=146 pb^{-1}).

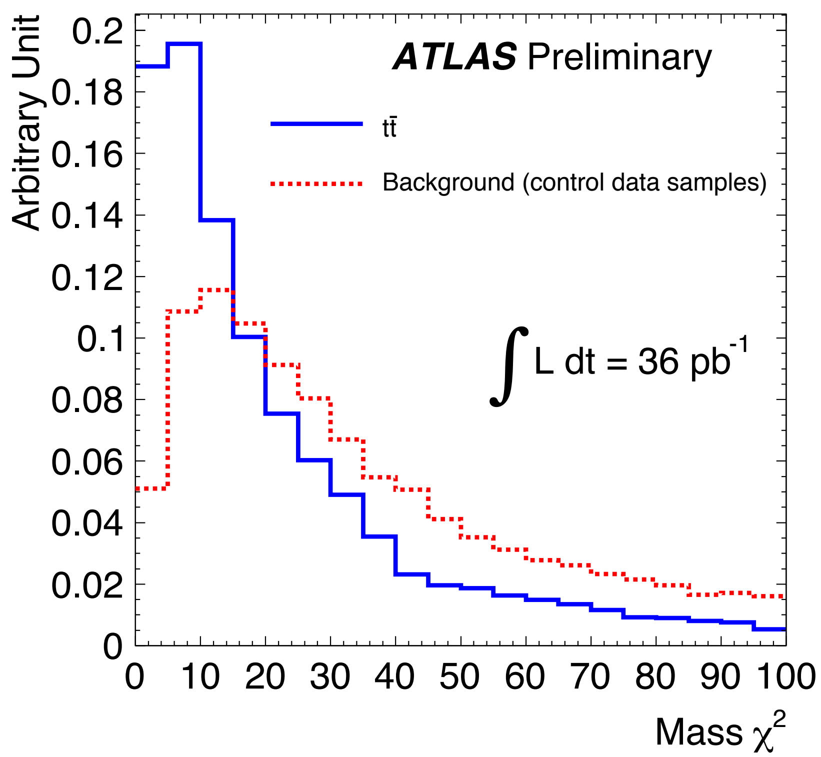


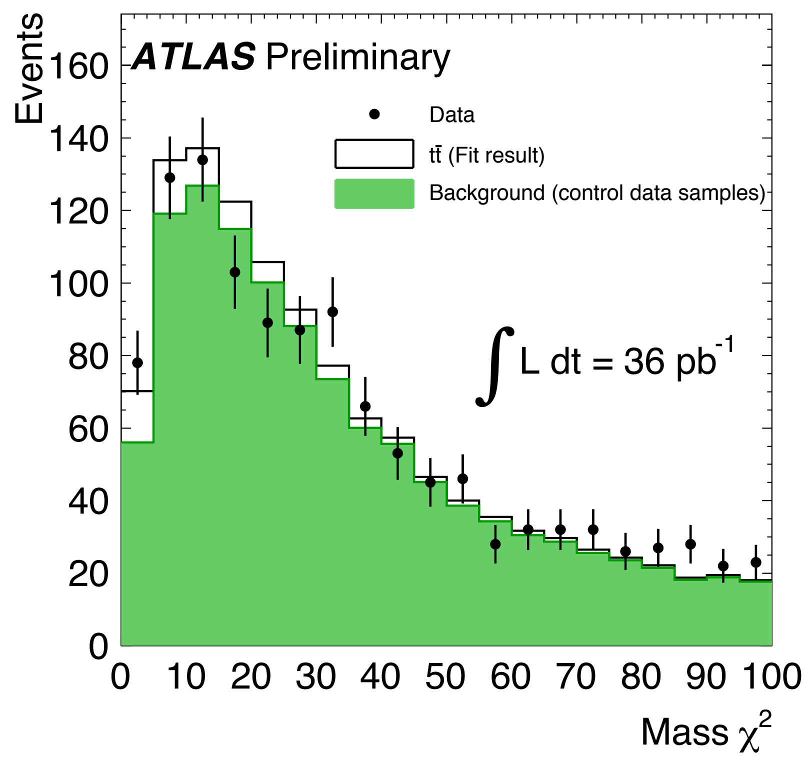


All Hadronic Search

- Select events with 6-jets, two of which must be identified as originating from b-decays using a secondary vertex tagger.
- Discriminate between signal & background with χ^2:

$$\chi^2 = \sum_{i=1}^{2} \left(\frac{m^i_{jjb} - m_t}{\sigma_t} \right)^2 + \left(\frac{m^i_{jj} - m_W}{\sigma_W} \right)^2$$





Challenging S:B ~ 1:15

Main systematics:

b-tagging, JES

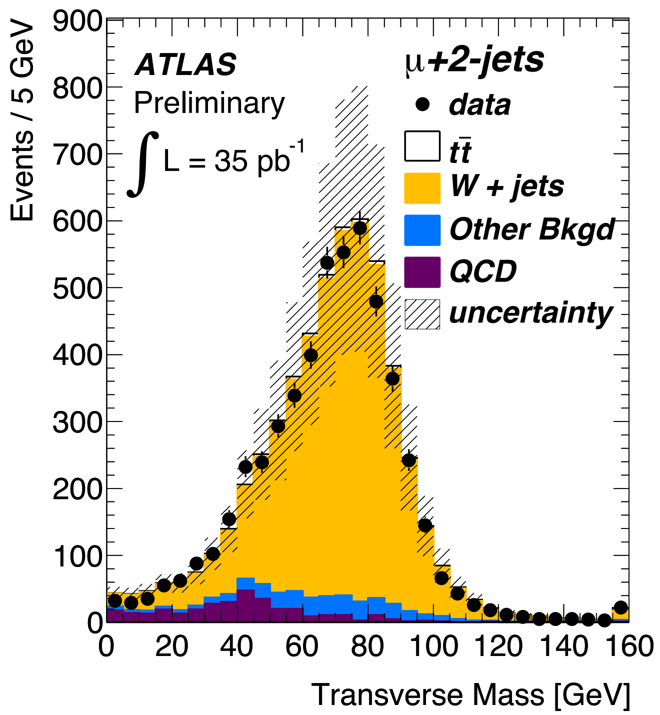
$\sigma(t\bar{t}) < 261$ pb @ 95%CL

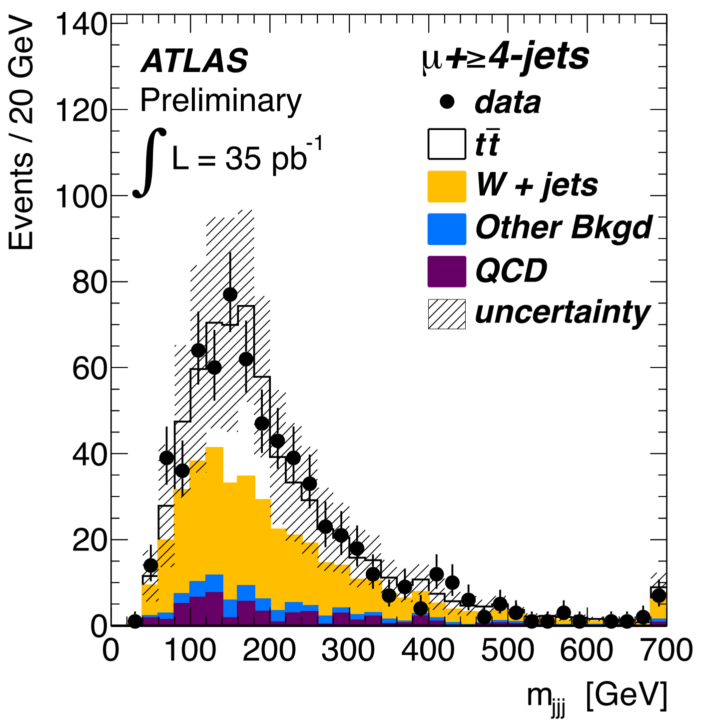
Lepton + Jets Cross Section

- Select events with high pT lepton, high transverse missing energy and multiple jets.

- Cross section can be extracted with and without the use of b-tagging information - provides confirmation it really is the top quark.

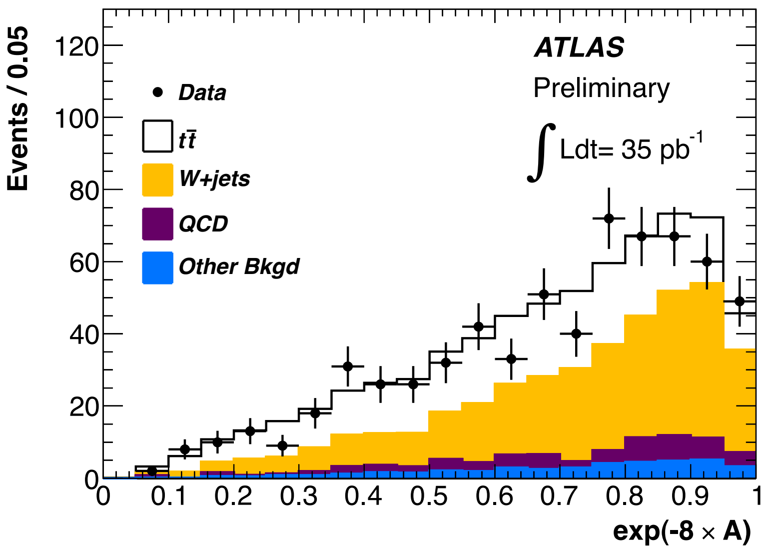
- Multijet backgrounds modelled using data, W+jets shape from simulation, but normalisation typically allowed to float.

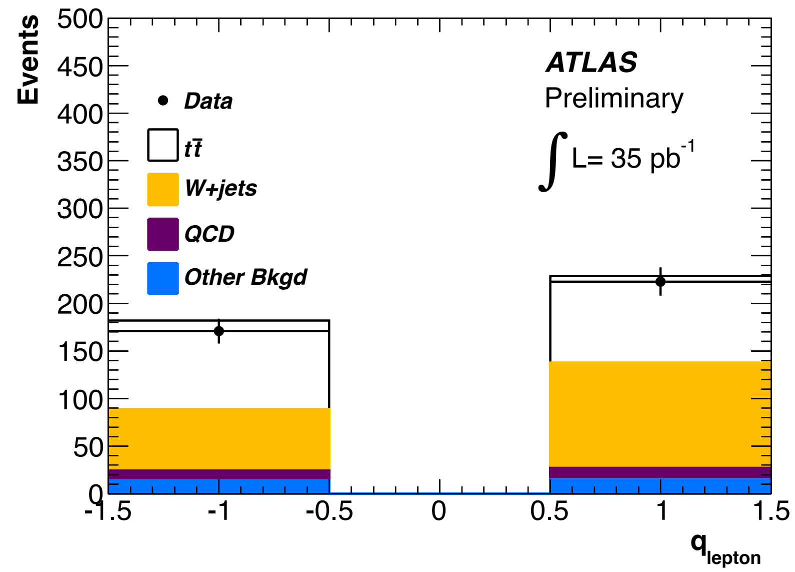


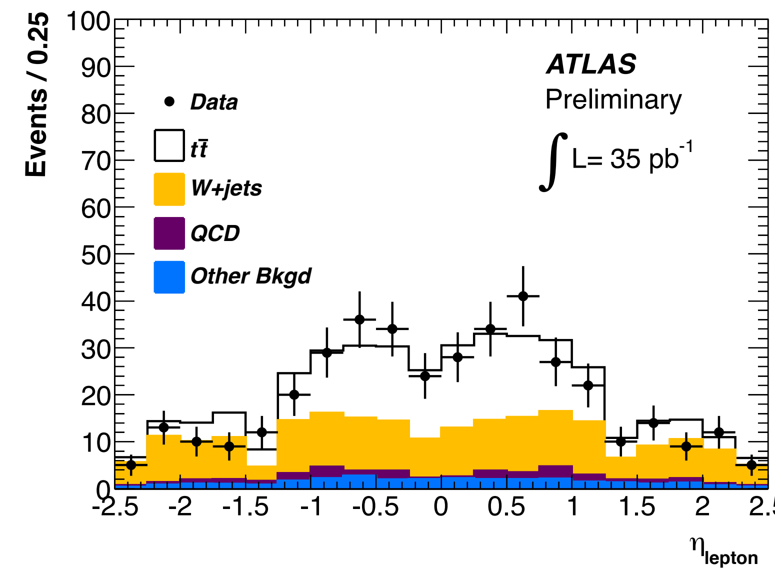


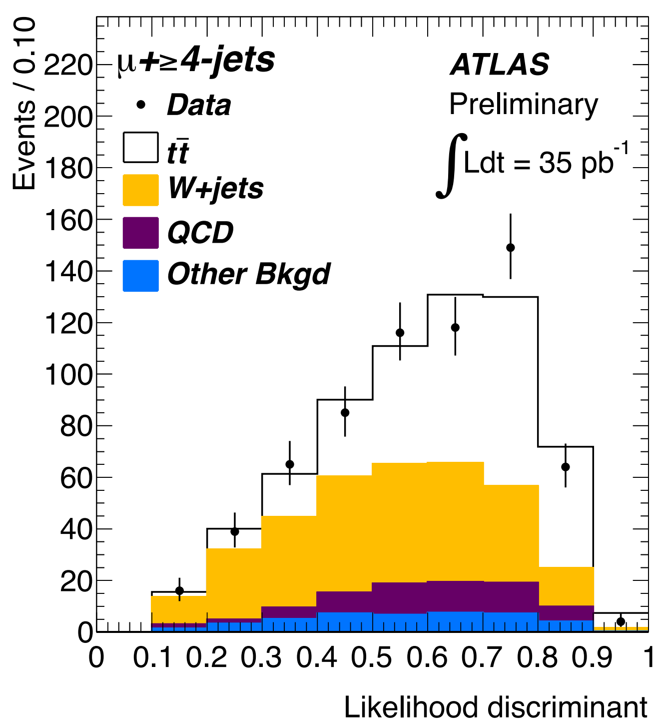
Lepton + Jets Cross Section

- Analysis without b-tagging combines 3 variables that separate top from W+jets in a likelihood discriminant:









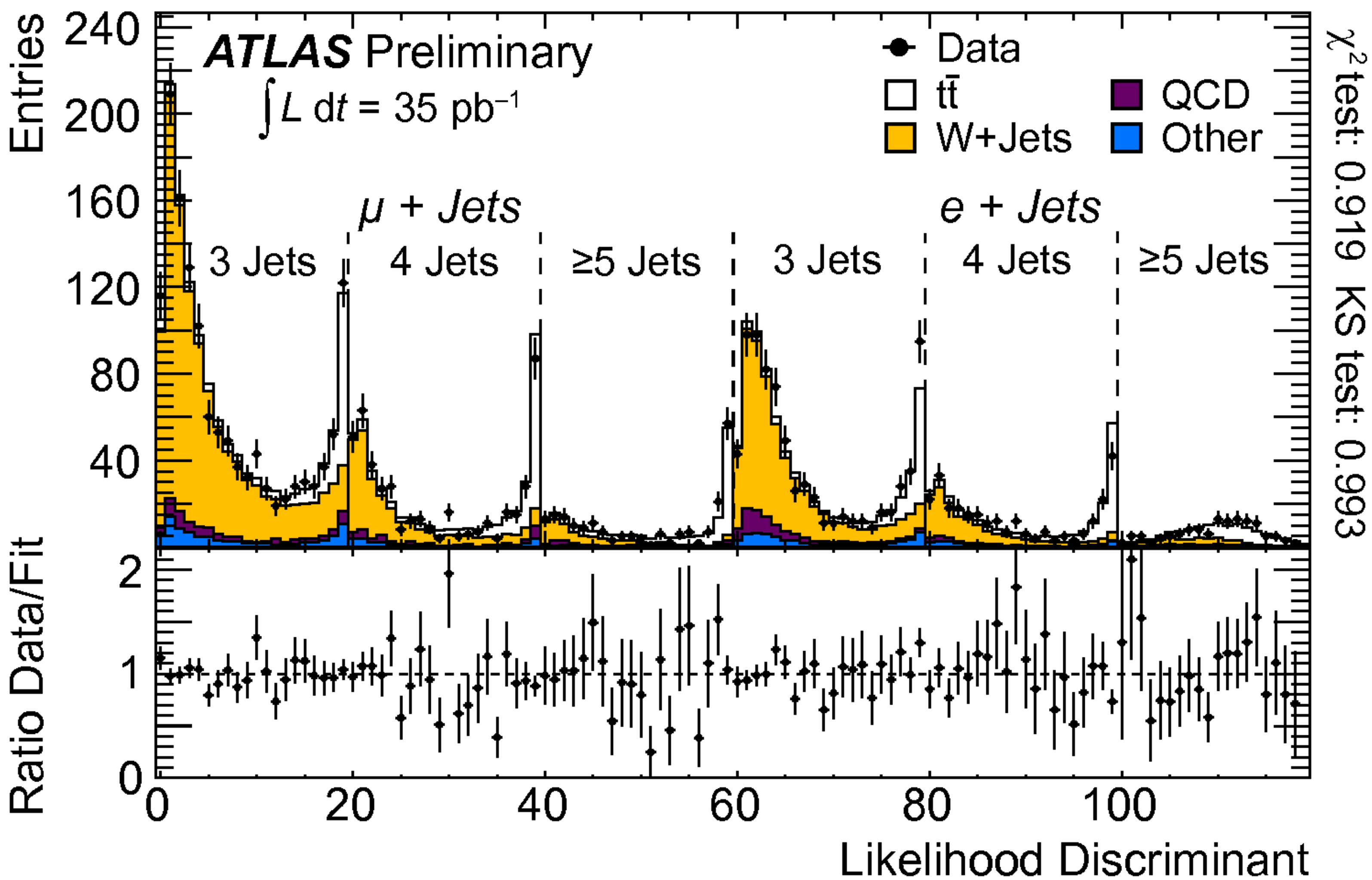
Fit templates to data - systematic uncertainties included in the fit and can be constrained by the data.

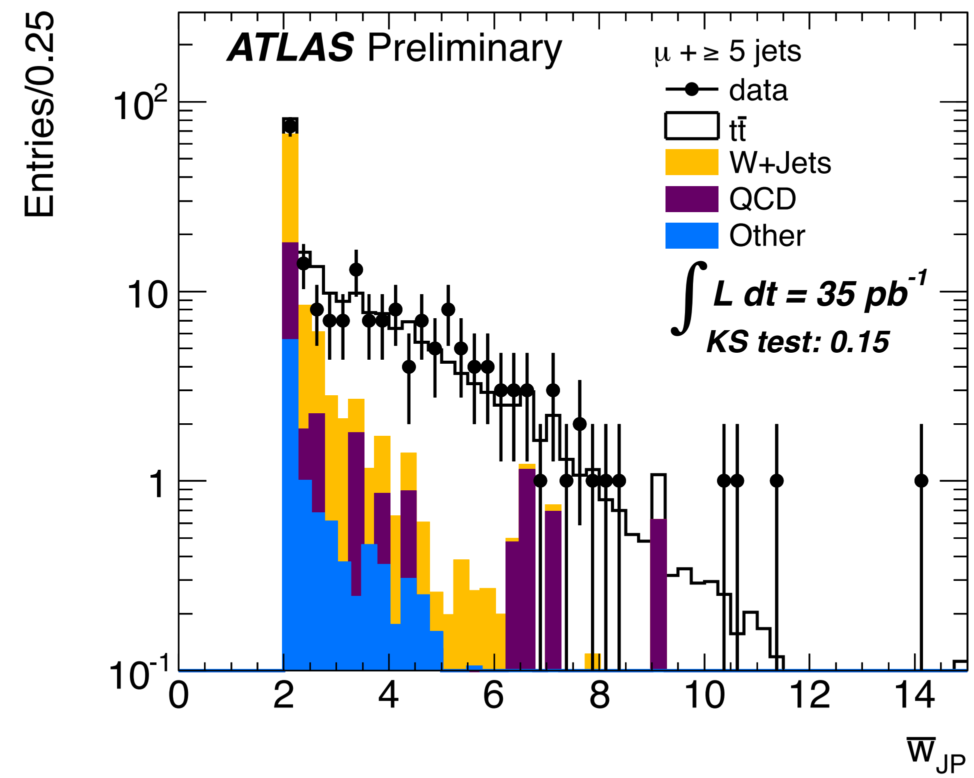
Largest systematic uncertainties from jet energy scale & reconstruction.

$$\sigma(t\bar{t}) = 171 \pm 17^{+20}_{-17}(syst.) \pm 6(lumi.)\ \text{pb}$$

Lepton + Jets Cross Section

- Analysis with b-tagging is similar, but adds continuous b-jet probability variable:



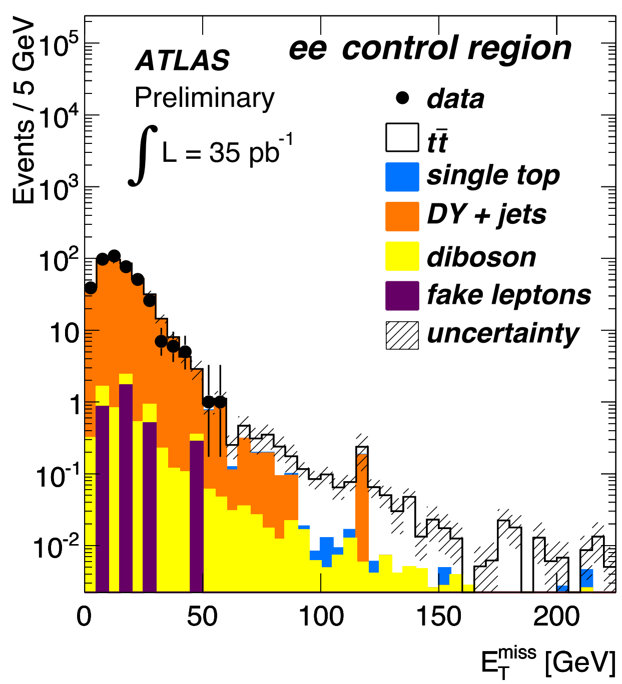


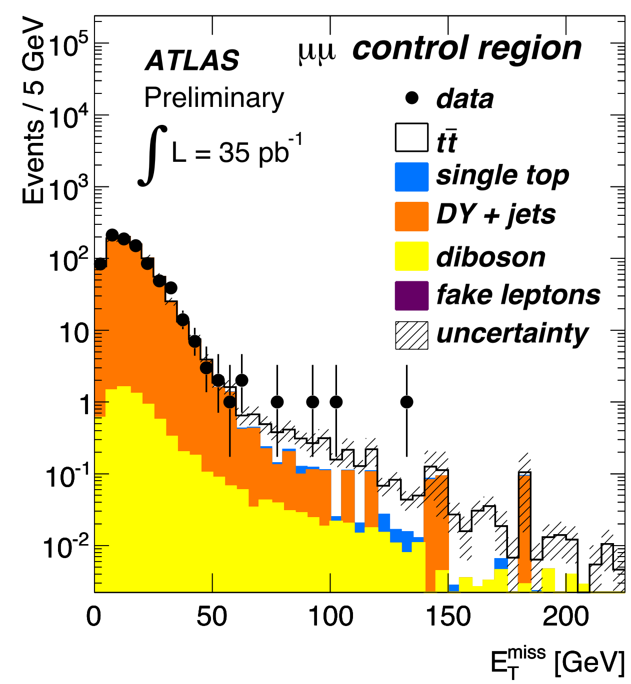
Largest systematic uncertainties from W + heavy flavour & b-tagging.

$$\sigma(t\bar{t}) = 186 \pm 10^{+21}_{-20}(syst.) \pm 6(lumi.)\ \mathrm{pb}$$

Dilepton Cross Section

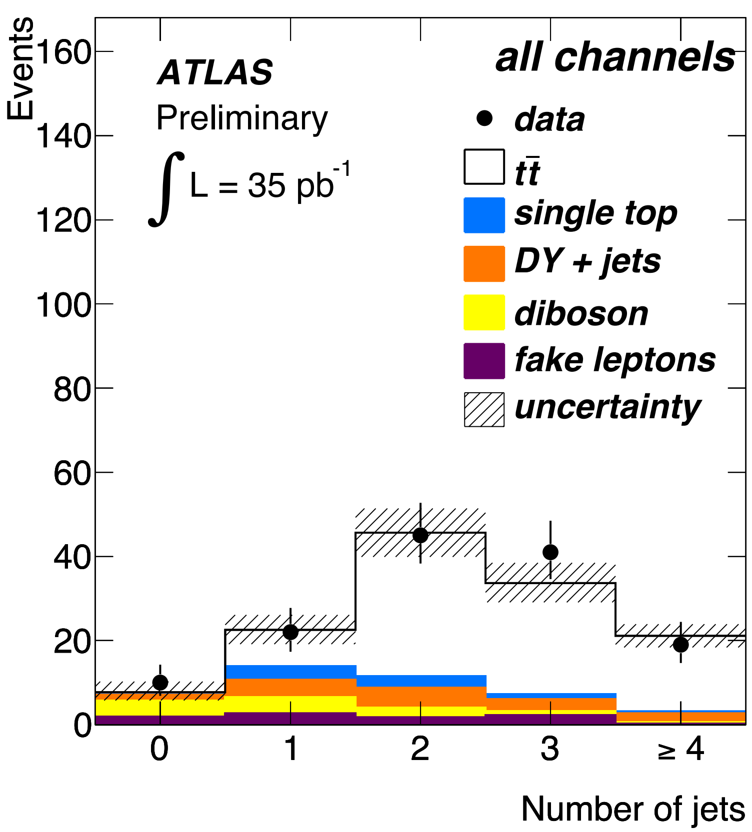
- Select events with two opposite sign leptons.
- For ee & μμ, reject Z events with MET and m_{ll} selections.
- Backgrounds:
  - Z + jets - for ee & μμ normalized in data control region
  - W + jets + QCD - extracted from the data.
  - Diboson / single top - from MC.

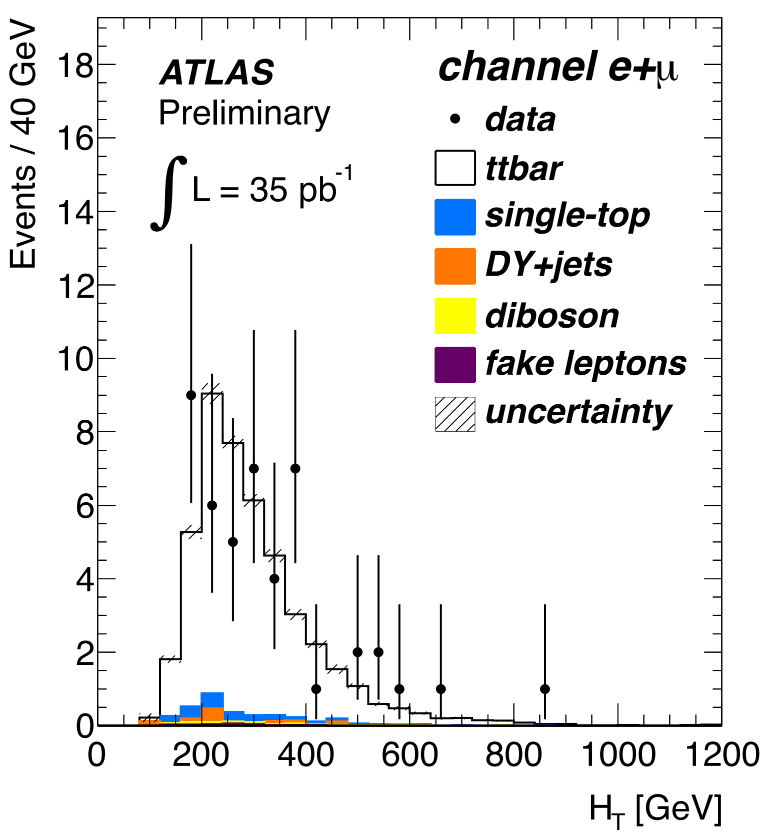




Dilepton Cross Section

- Clean final state - cross section extracted from counting events with at least two jets.
- Analysis with b-tagging uses looser kinematic selections.





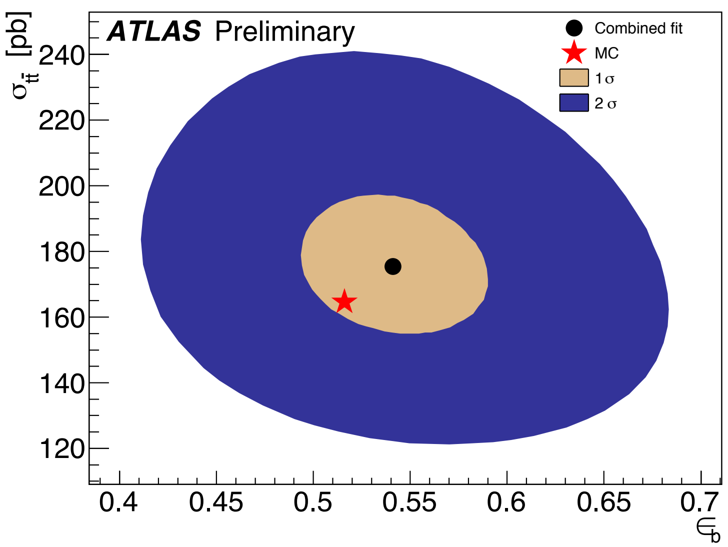
Largest systematic uncertainties from JES, lepton ID, MC modelling & b-tagging.

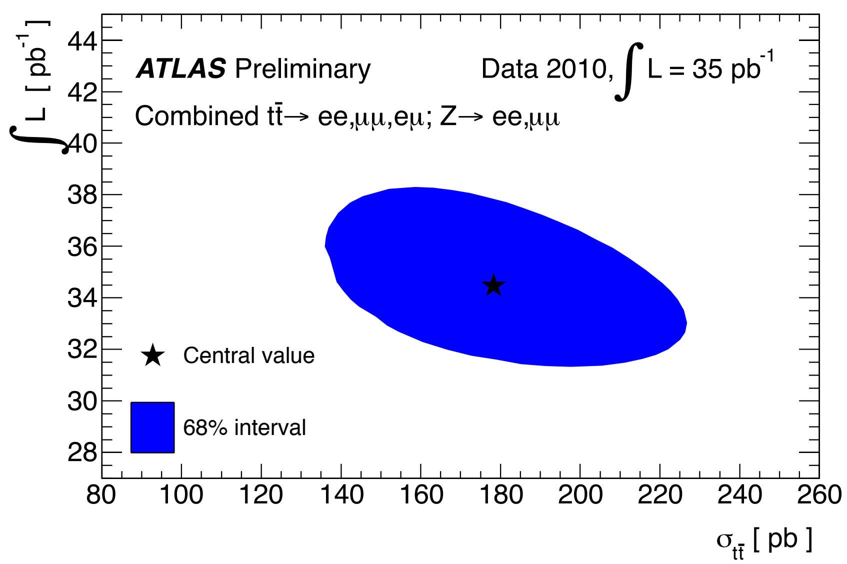
$$\sigma(t\bar{t}) = 173 \pm 22^{+18}_{-16}(syst.)^{+8}_{-7}(lumi.)\ \mathrm{pb}$$ (w/o b-tagging)

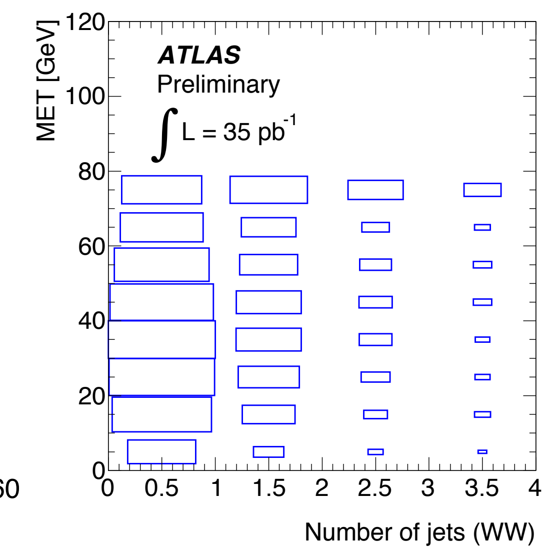
$$\sigma(t\bar{t}) = 171 \pm 22^{+21}_{-16}(syst.)^{+7}_{-6}(lumi.)\ \mathrm{pb}$$ (w/ b-tagging)

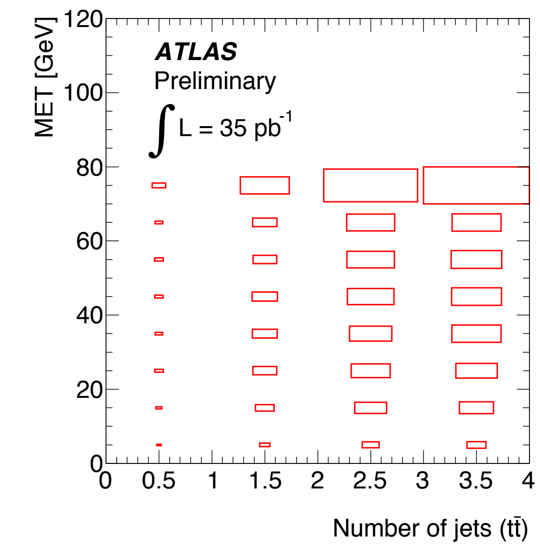
Dilepton Cross Section

- Alternate techniques possible to cross-check primary results:
  - Perform 2D fit for cross-section & b-tag efficiency.
  - Add Z sample & perform 2D fit for cross-section & luminosity.
  - Perform 'inclusive' dilepton analysis by fitting n(jets), MET.







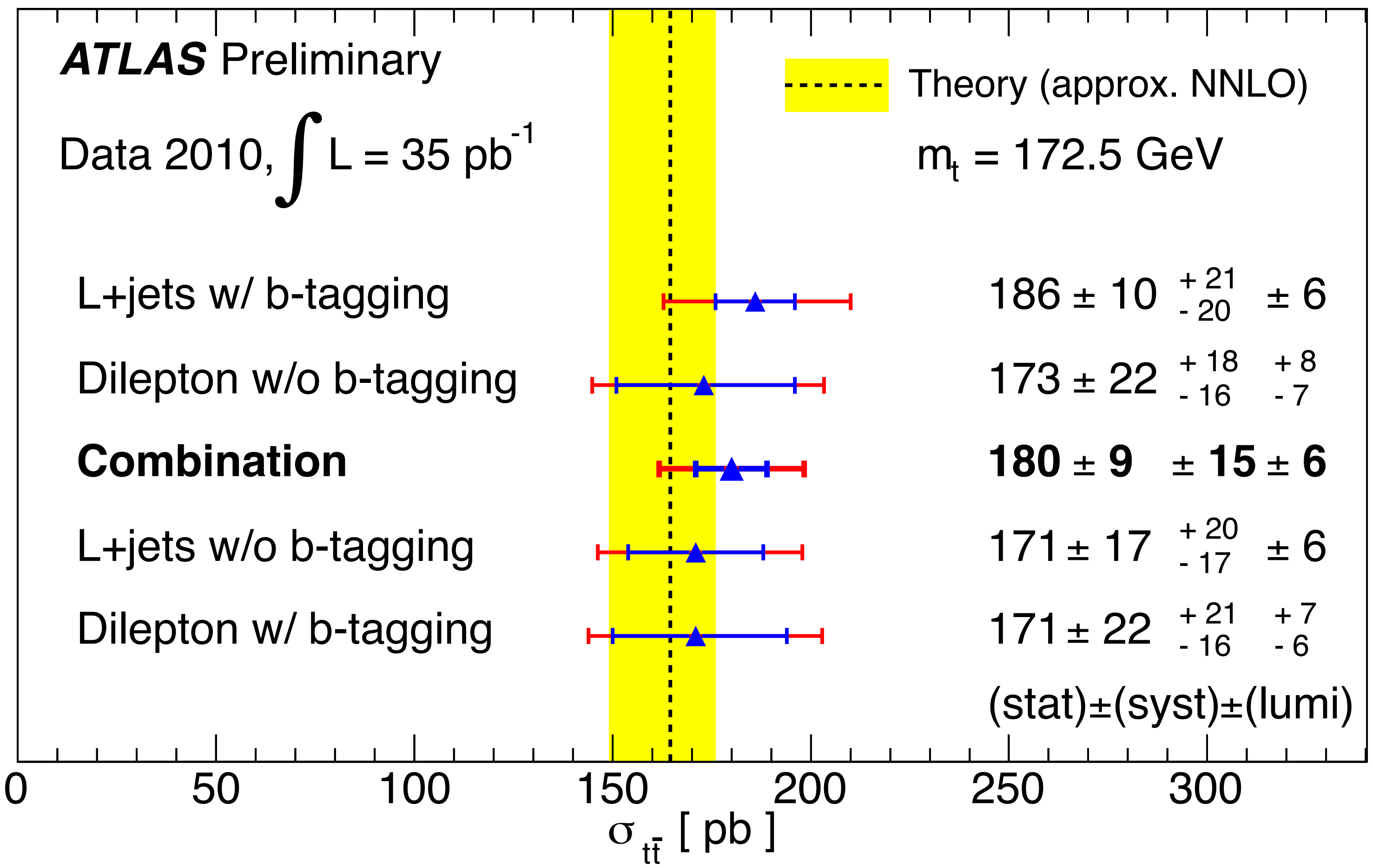


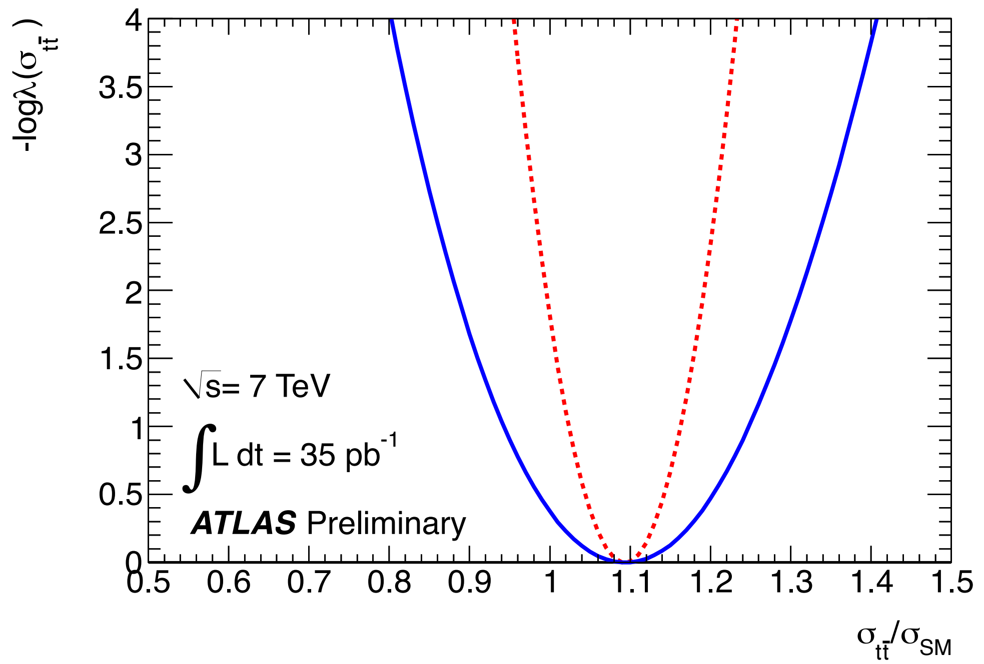
	$\sigma_{t\bar{t}}$ [pb]	σ_{WW} [pb]	$\sigma_{Z\to\tau\tau}$ [pb]
$e\mu$	163±28±14±6	46±26±9±2	1400±290±160±40
All channels	171±22±14±5	59±21±12±2	1400±290±160±40
Theory	165^{+11}_{-16}	$46.2^{+2.3}_{-2.3}$	1076^{+54}_{-54}

All results consistent - top quark production well established at LHC.

Combination

- Combine untagged dilepton analysis with tagged lepton + jets analysis in a profile likelihood fit.

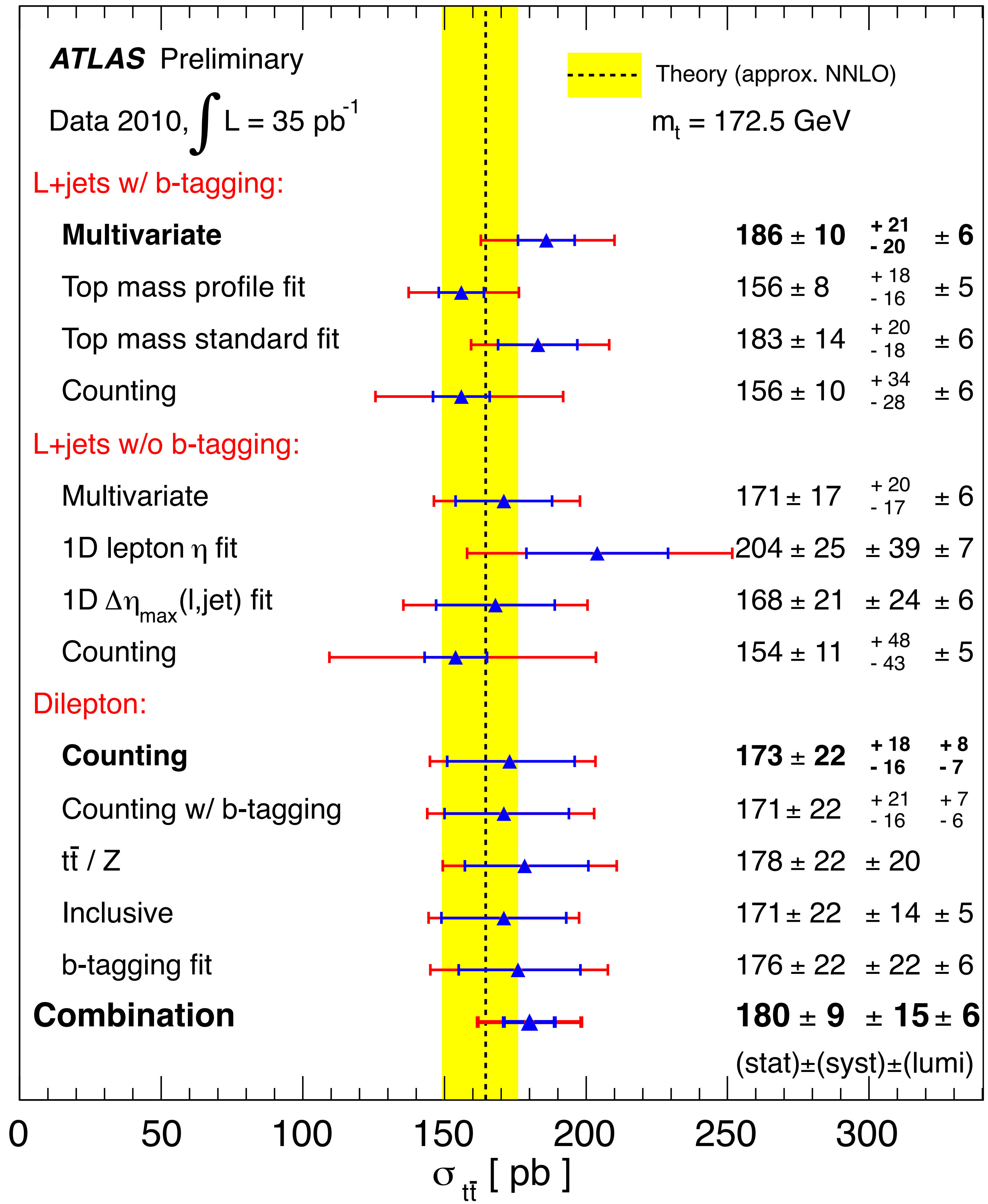




$$\sigma_{t\bar{t}} = 180 \pm 18(comb.)\mathrm{pb}$$

- Achieve 10% precision on top pair production cross section with 2010 data.

Cross Section Summary

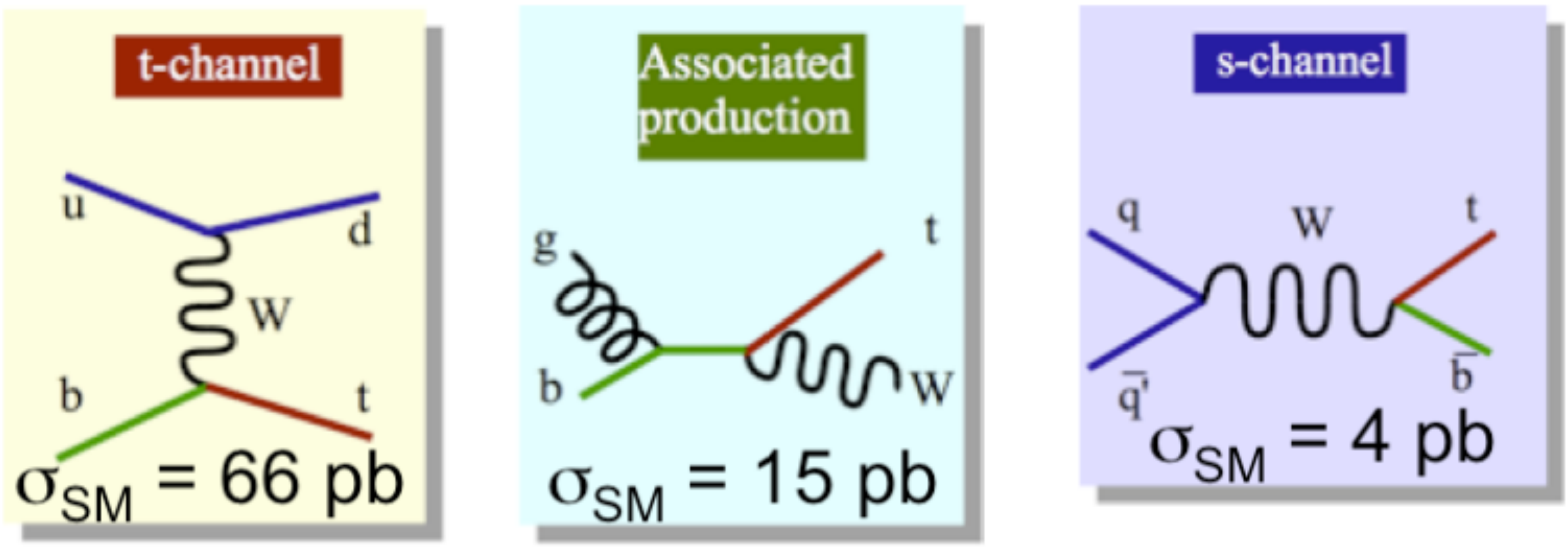


Results cross-checked with different methods.

All results consistent with each other & the SM prediction.

Further improvements expected with 2011 data.

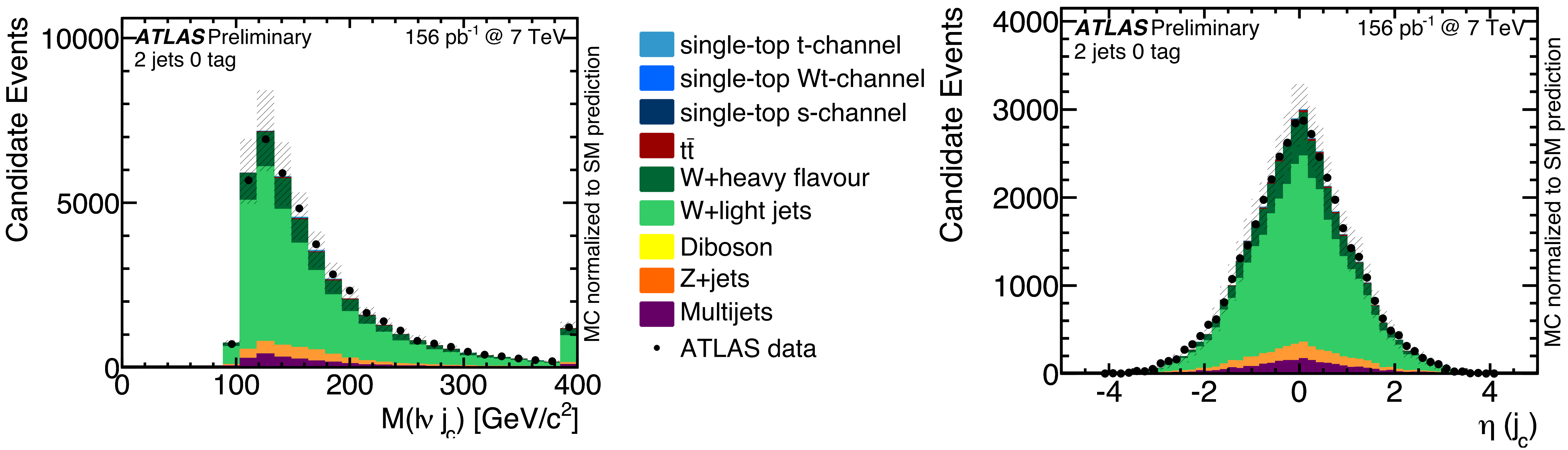
Single Top



- Searches with 2010 data for t-channel & Wt production.
- New 2011 result - observation of t-channel single top production.

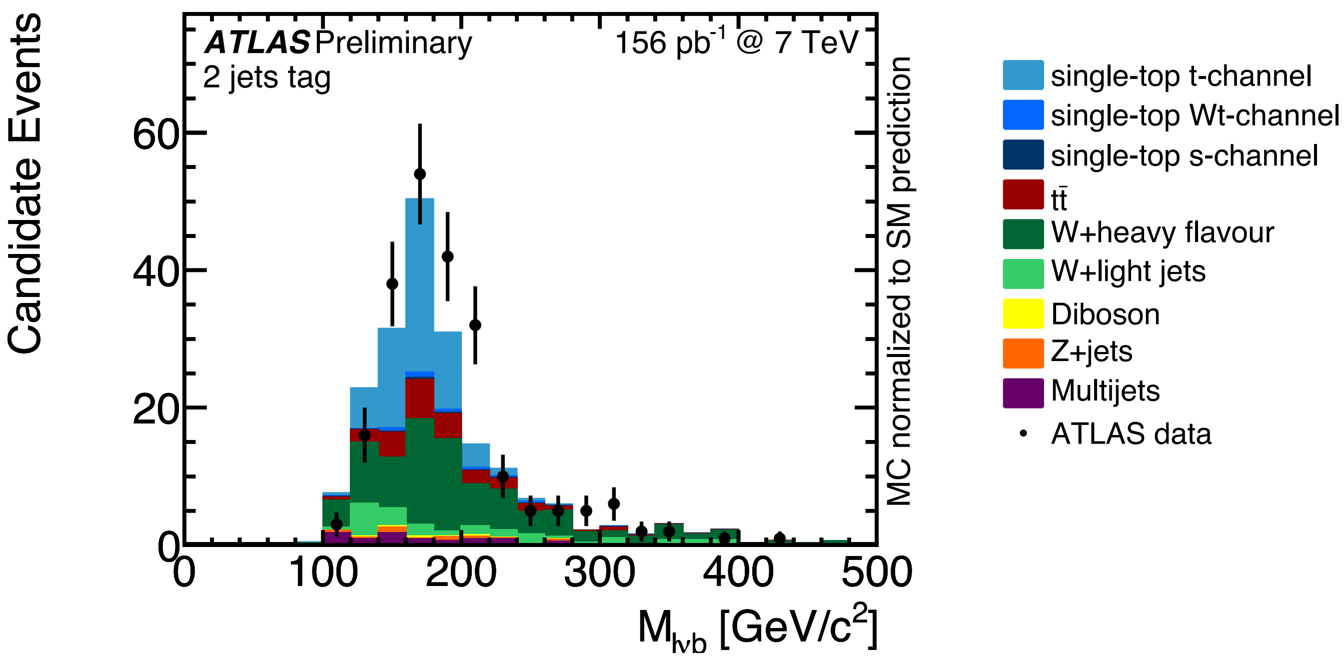
Single Top t-channel

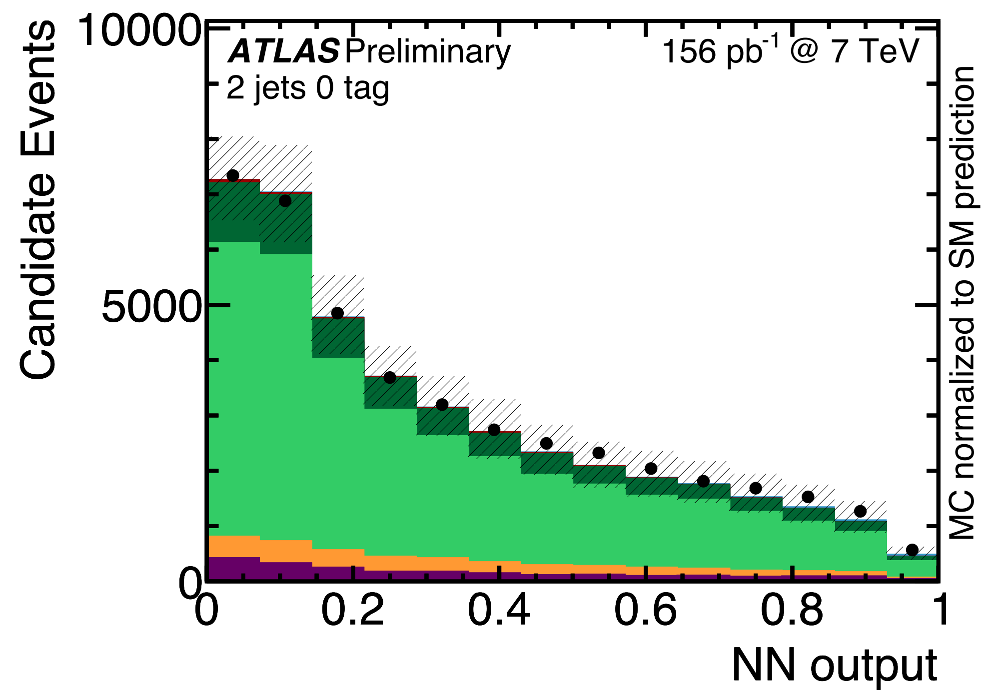
- Select events with high p_T lepton, ==2 jets, one of which must be b-tagged.
- Backgrounds higher than top-pair production (W+jets events), plus must remove top-pair events.
- Use MET & M_T requirements to remove multijet events.
- Background modelling checked in 0 tag data:



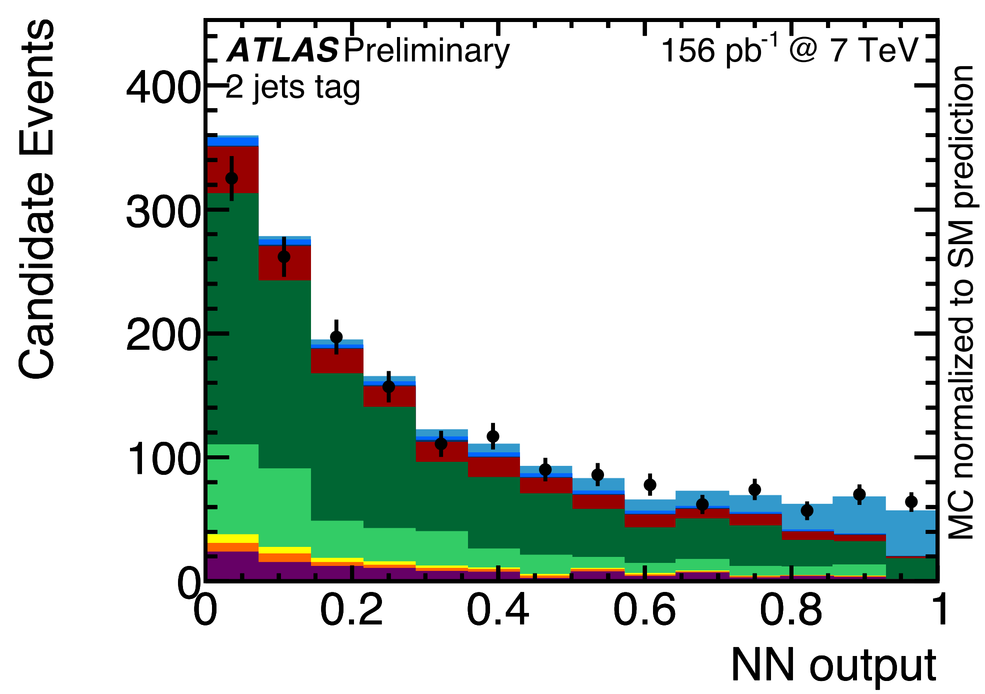
Single Top t-channel

- Two analyses: one using cuts on kinematic variables, the other a Neural Network discriminant:



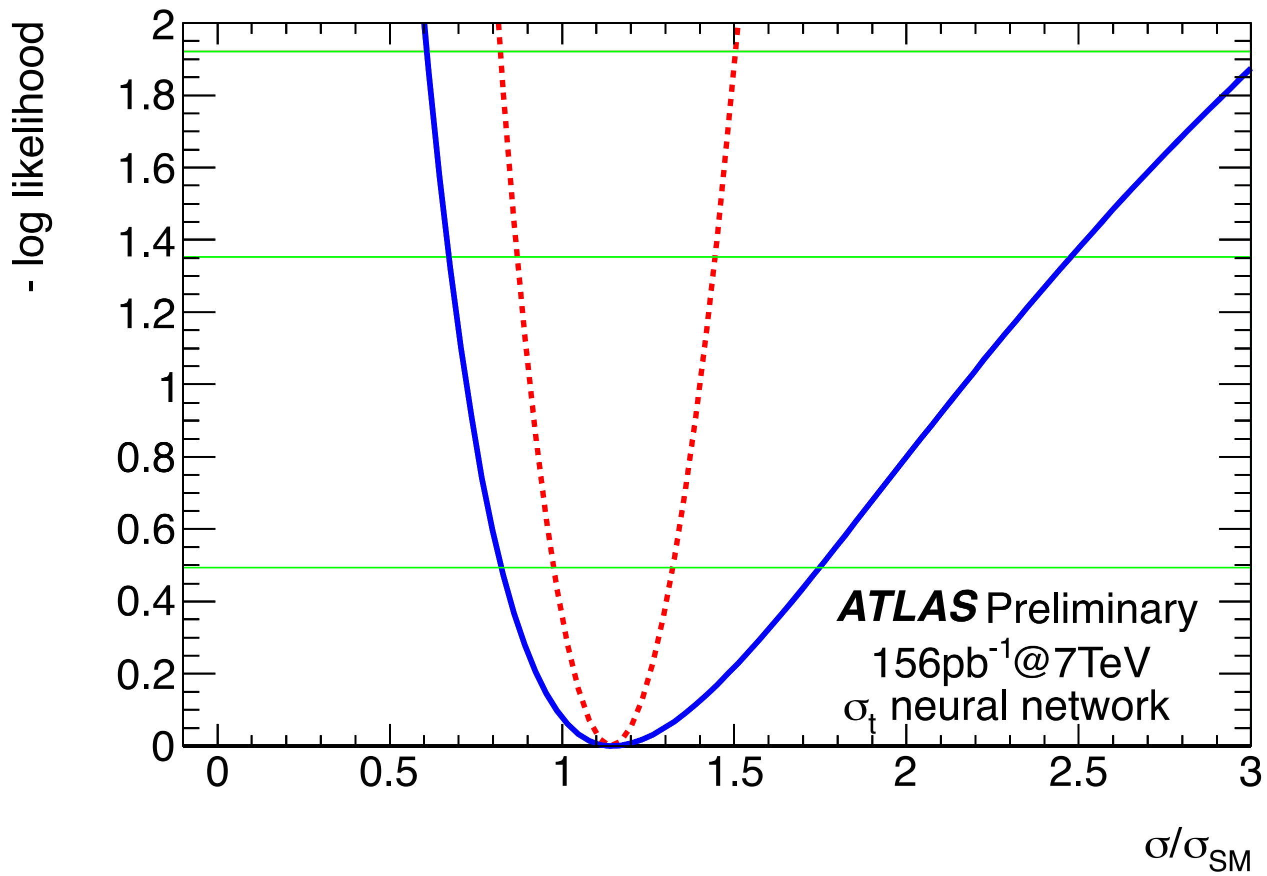


	Cut-based		Neural
	Lepton +	Lepton -	network
single-top *t*-channel	32.2 ± 11.7	13.3 ± 3.6	66.4 ± 19.6
single-top *s*-channel	0.3 ± 0.1	0.2 ± 0.1	0.9 ± 0.2
single-top *Wt*-channel	0.6 ± 0.2	0.6 ± 0.3	1.0 ± 0.2
$t\bar{t}$	3.6 ± 1.8	3.2 ± 1.6	6.3 ± 3.0
W+light jets	2.6 ± 1.4	2.1 ± 2.6	9.0 ± 1.9
W+heavy flavour	14.9 ± 5.3	15.9 ± 5.4	35.8 ± 12.7
Diboson	0.3 ± 0.2	0.3 ± 0.1	0.4 ± 0.1
Z+jets	0.6 ± 0.5	0.5 ± 0.4	1.0 ± 0.8
Multijets	1.6 ± 1.2	0.7 ± 0.9	3.6 ± 2.8
TOTAL Exp	56.9 ± 13.0	36.8 ± 7.2	124.4 ± 23.7
S/B	1.31	0.57	1.14
DATA	72	43	134



Single Top t-channel

- Cross section extracted from profile-likelihood ratio fit.



$$\sigma_t = 76^{+41}_{-21}\ \mathrm{pb\ (NN)}$$

$$\sigma_t = 97^{+54}_{-30}\ \mathrm{pb\ (cuts)}$$

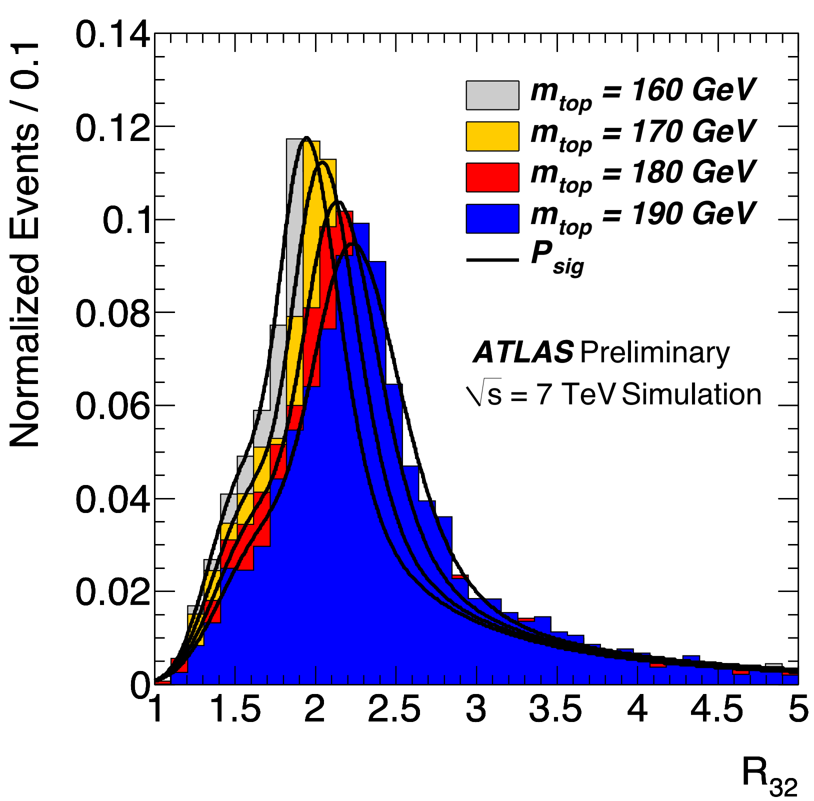
- Significance of result compared to background-only model is 6.2σ (5.7σ expected) for NN, 6.1σ (4.4σ expected) for cut based.

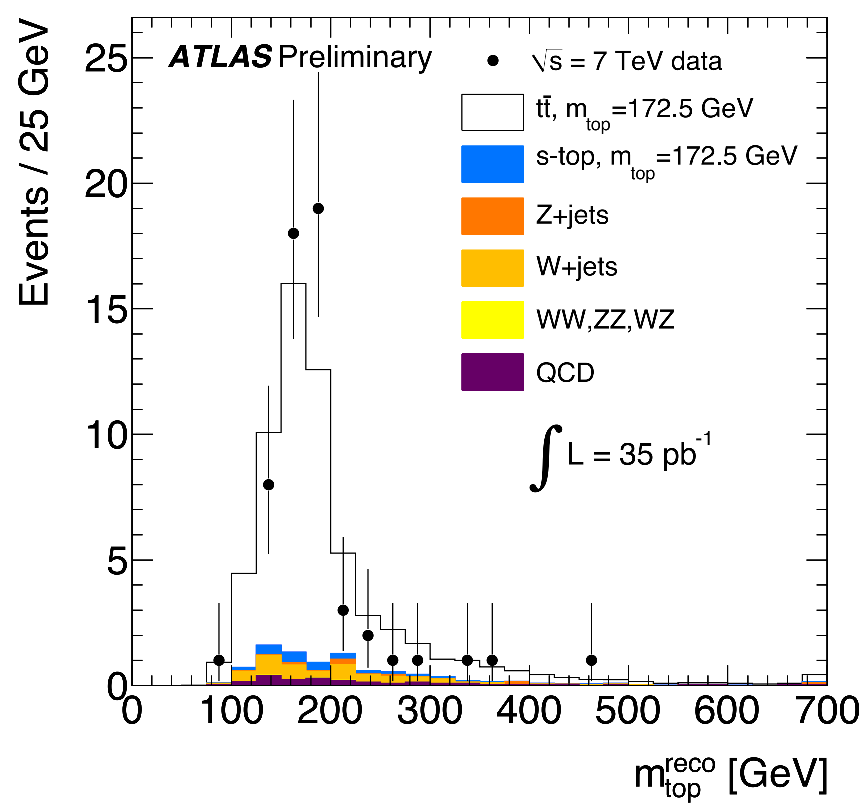
- Dominant systematics: Signal modelling, b-tagging.

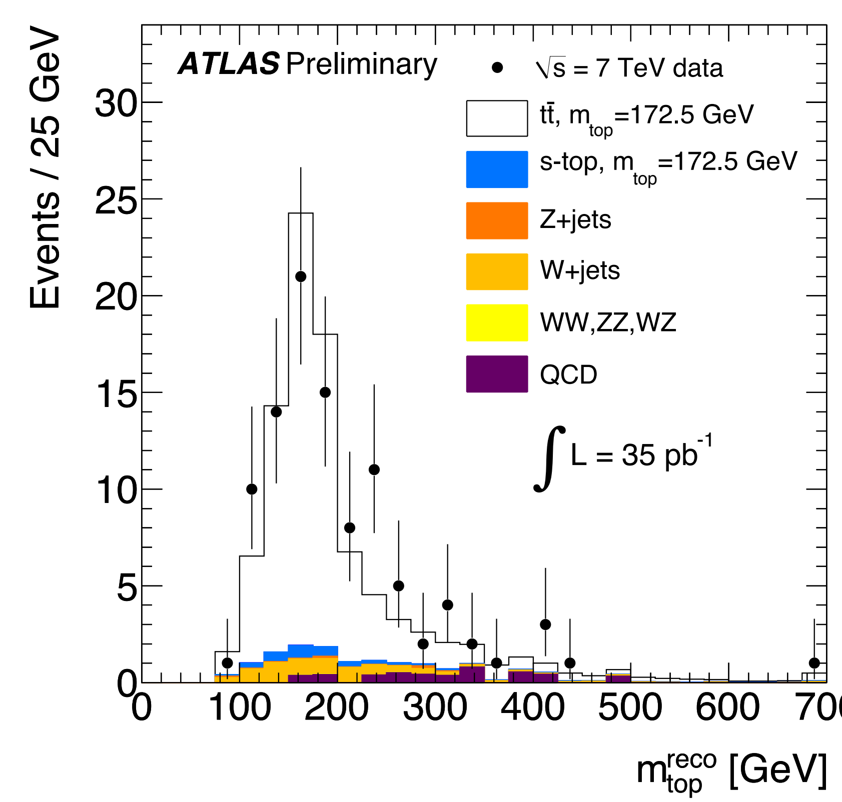
Top Mass

- Lepton plus jets channel allows direct reconstruction of the top quarks from the decay products.
- Can reconstruct the top mass from the 3 jet (bjj) mass.
- To reduce sensitivity to JES use:

$$R_{32} = \frac{m_t^{reco}}{m_W^{reco}} = \frac{m_{bjj}}{m_{jj}}$$

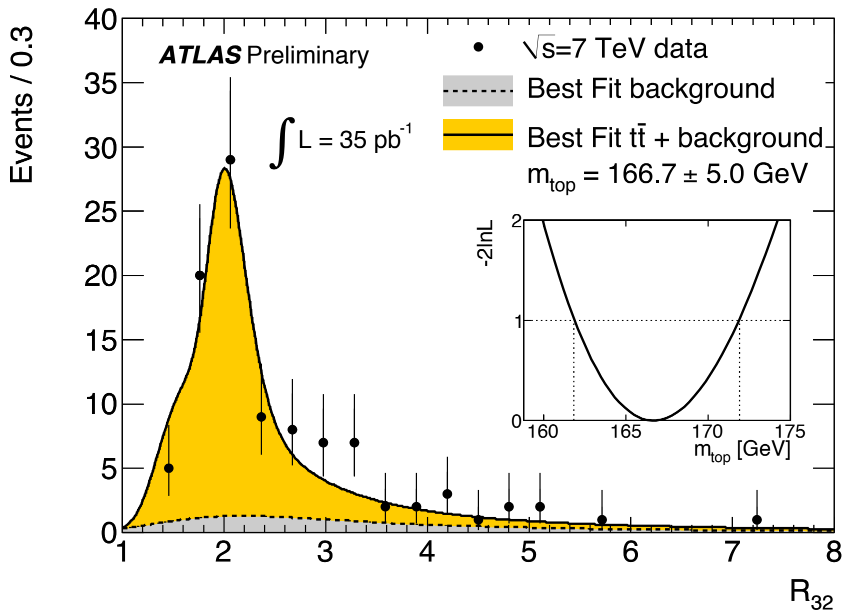


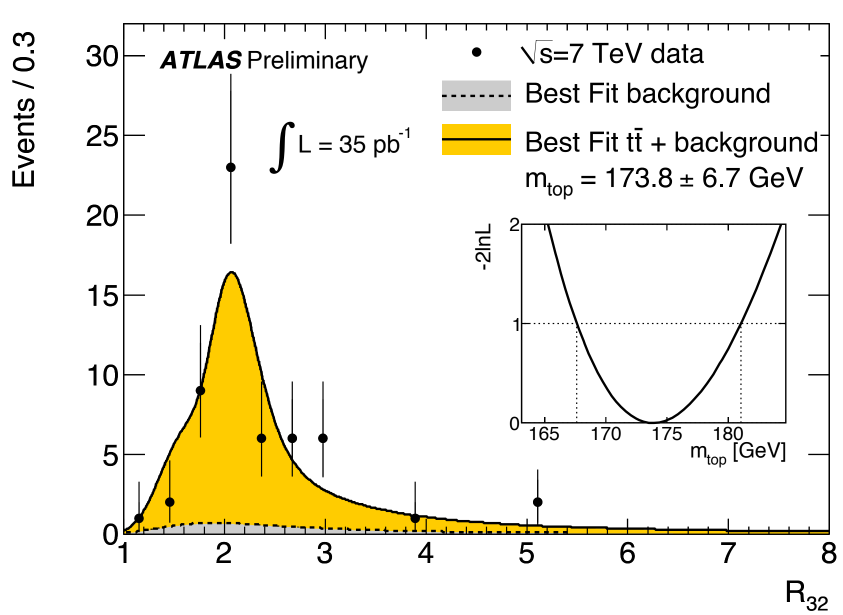




Top Mass

- Use 1D template fit to extract the mass.
- Signal templates parameterized as a function of m_t, background template independent of m_t.





Mass extracted from binned likelihood fit:

$$m_t = 169.3 \pm 4.0(stat.) \pm 4.9(syst.)\ \text{GeV}$$

Tevatron July 2010 combination:

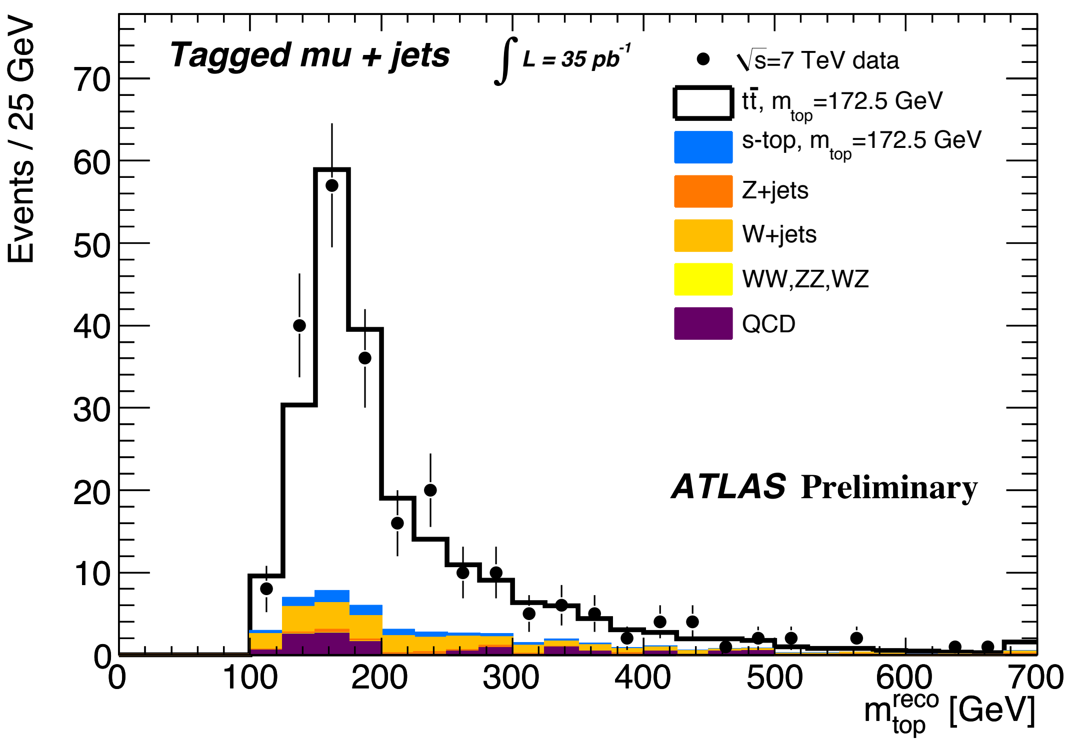
$$m_t = 173.3 \pm 0.6 \pm 0.9\ \text{GeV}$$

Dominant systematics	e-channel	μ-channel
ISR and FSR (sig. only)	2.2 GeV	2.6 GeV
Jet energy scale	2.3 GeV	1.9 GeV
b-jet energy scale (±2.5%)	2.5 GeV	2.5 GeV
Total systematic uncertainty	**4.8 GeV**	**5.0 GeV**

Top Mass

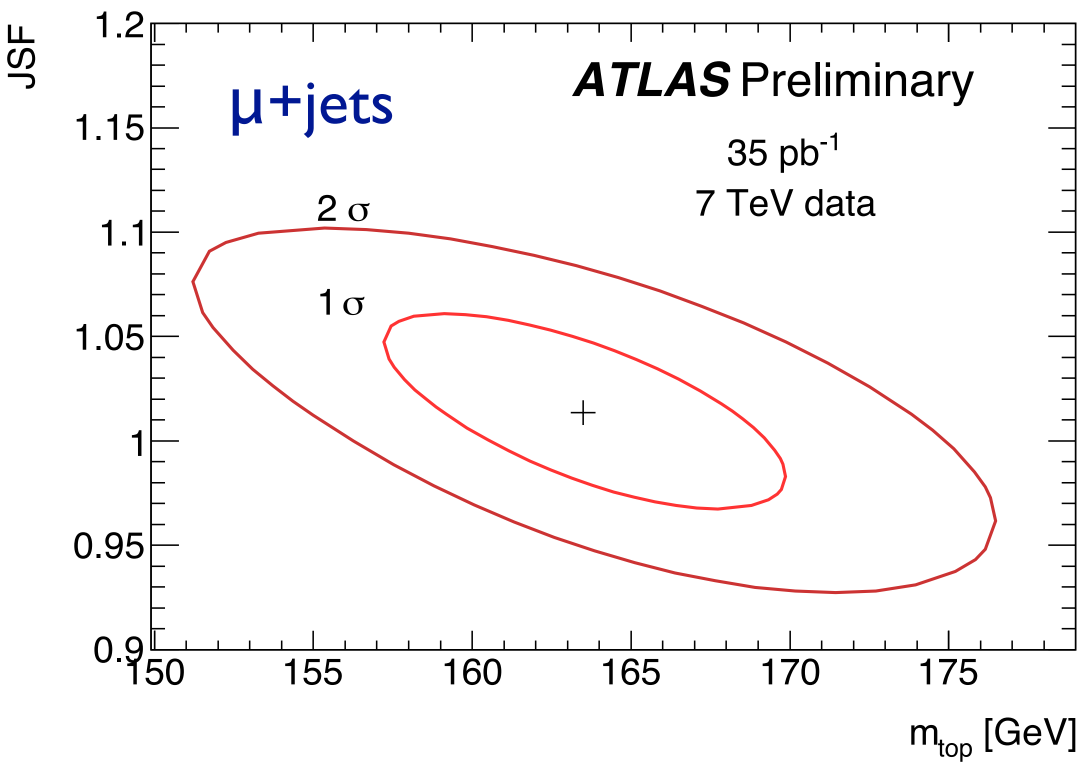
- Primary result is cross checked with two other methods:

Full kinematic fit to reconstruct entire event, then use template fit:



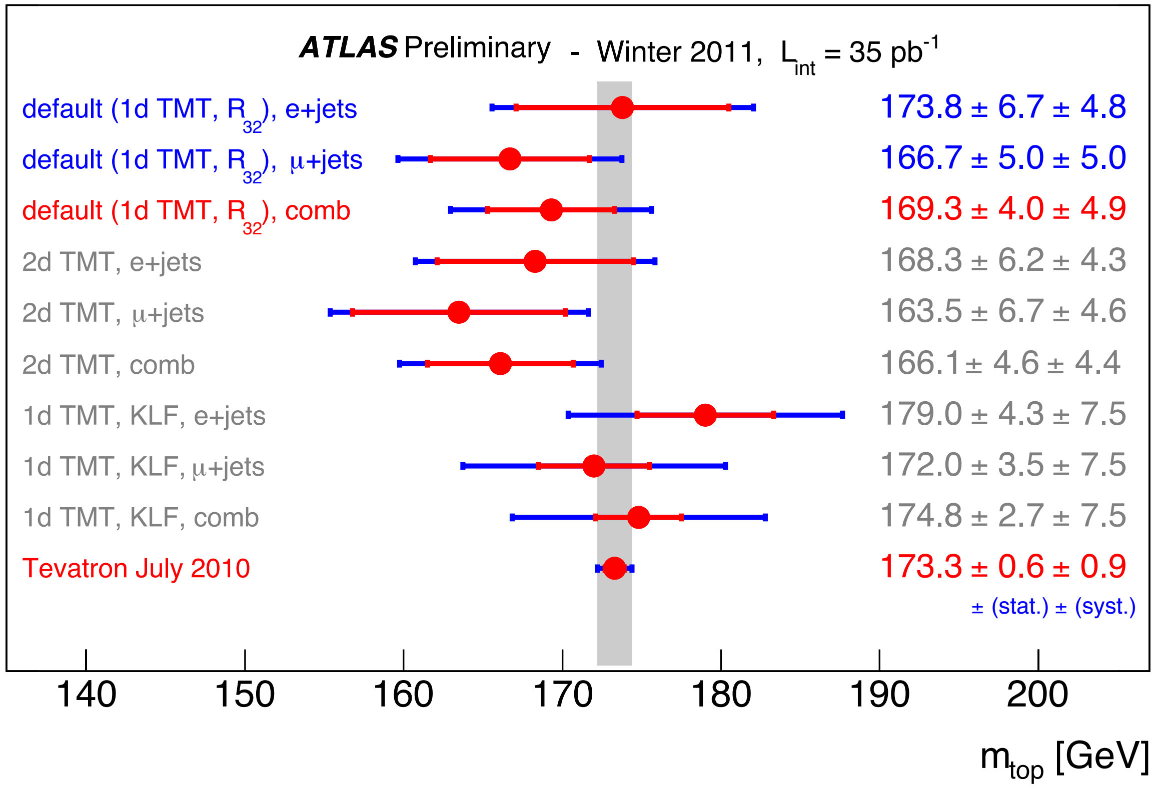
$$m_t = 174.8 \pm 2.7(stat.) \pm 7.5(syst.)\ \text{GeV}$$

Simultaneous fit to m_t & overall JES factor:



$$m_t = 166.1 \pm 4.6(stat.) \pm 4.4(syst.)\ \text{GeV}$$

Top Mass



- All three methods give consistent results.
- Main analysis has 3.7% precision.
- Looking ahead:
  - Improvements in JES.
  - Exploit new data.

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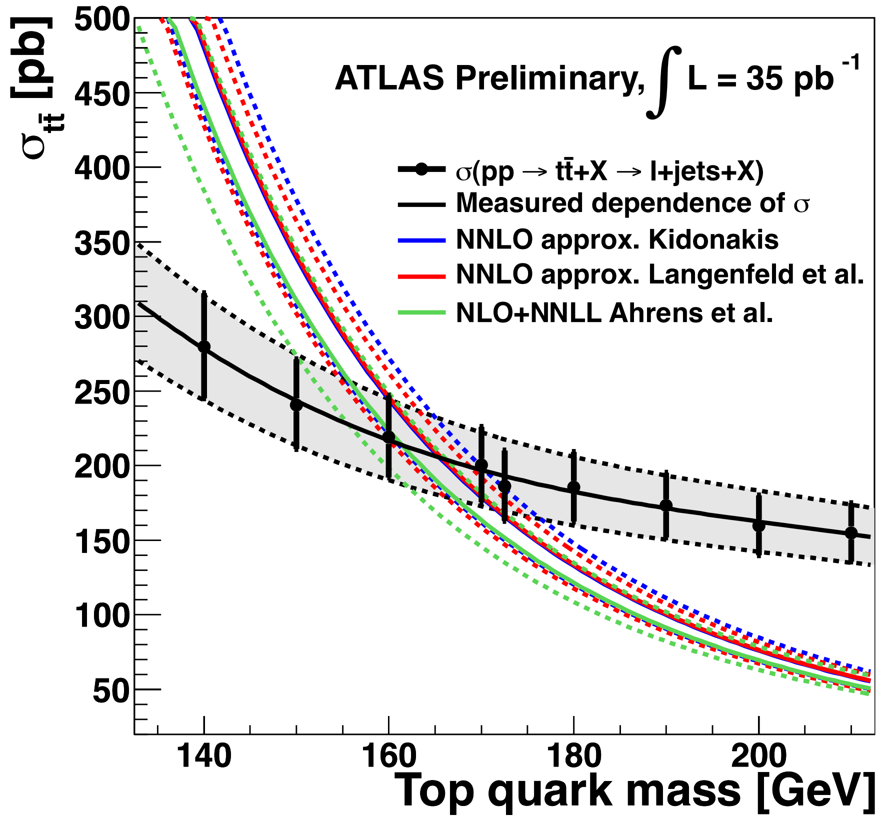
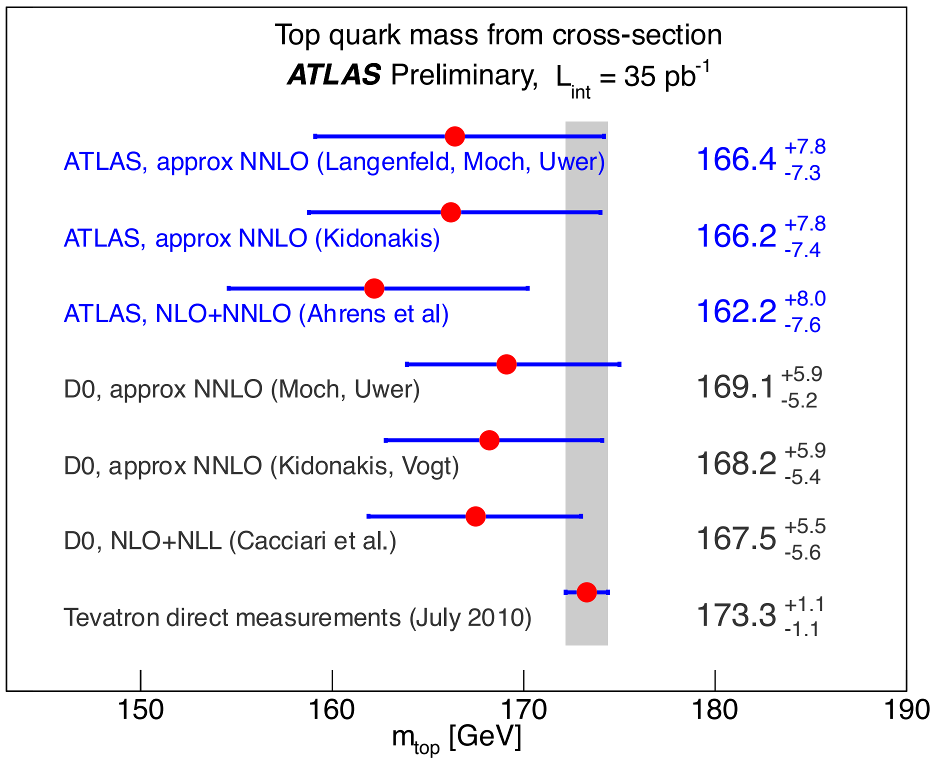
Top Mass from Cross Section

- Standard top mass extract relies on the top mass parameter in the MC.
- Not clear theoretically which renormalization scheme this mass corresponds to.
- Independent approach: Extract the mass by comparing measured top pair production cross section with theory.
  - Mass is well defined in the theoretical calculation.

Top Mass from Cross Section

- Extraction obtained using lepton + jets cross section measurement:





$$m_t^{pole} = 166.4^{+7.8}_{-7.3}\ \text{GeV}$$

- Consistent with direct measurements and equivalent D0 analysis.

Summary

- First year of LHC data has already led to precision measurements of the top pair production cross section.

- First 2011 data has allowed observation of single top production at ATLAS.

- First top mass measurements performed.

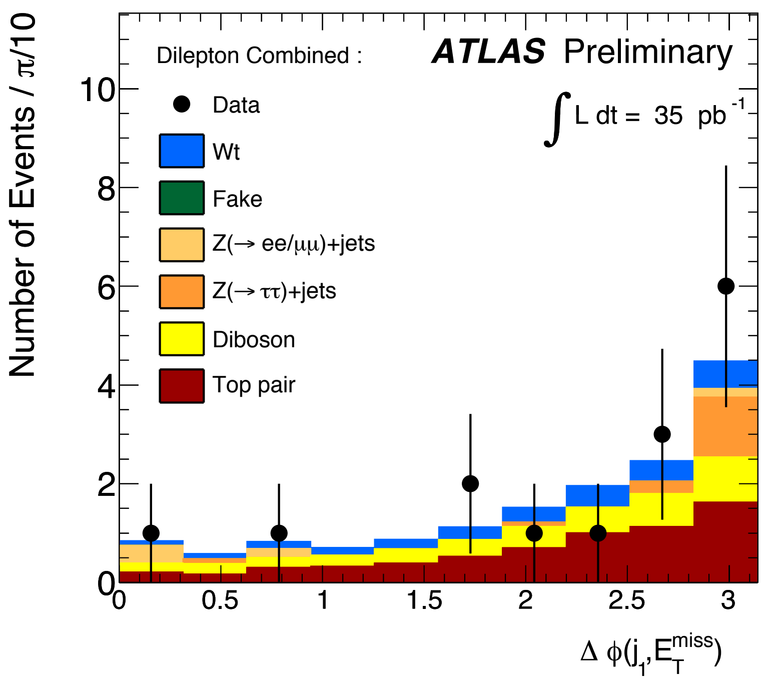
- Stay tuned for more results with 2011 data later in the Summer.

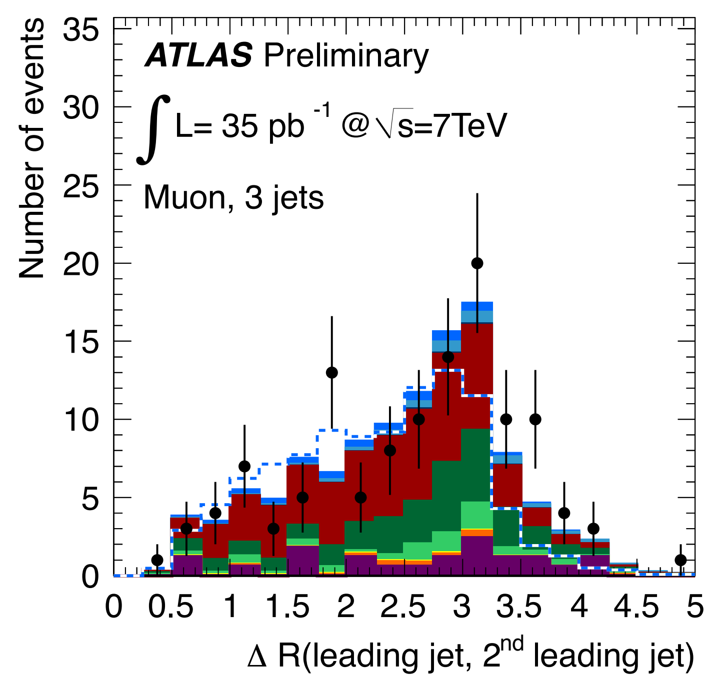
The University of Manchester

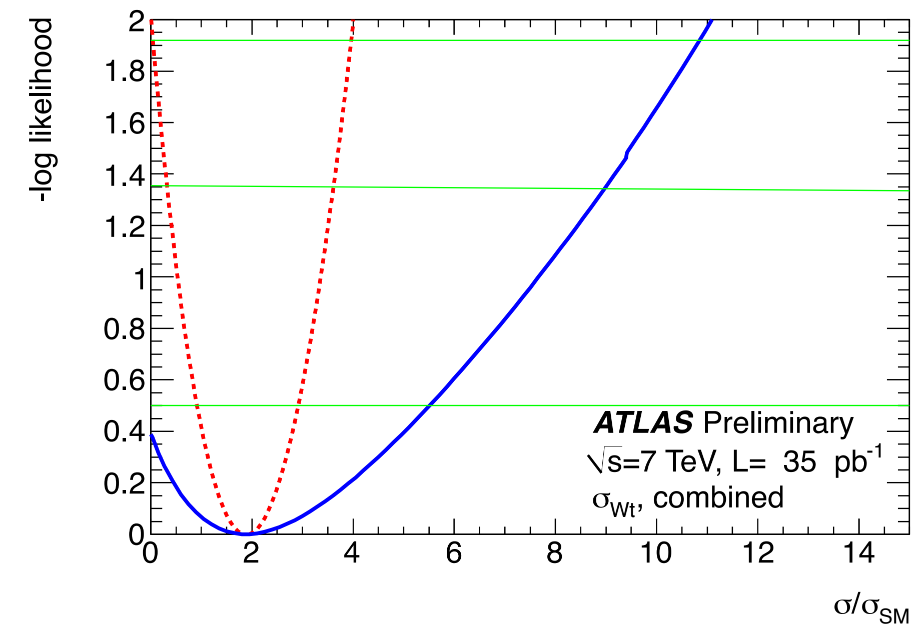
Backup

Wt Search Result

- Use lepton + jet events like for t-channel, but optimise the cuts.
- In addition include the di-lepton channel.







$$\sigma_t < 158\ pb \text{ observed}$$

$$\sigma_t < 94\ pb \text{ expected}$$