Top Physics at the LHC

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Outline

- Why Top Physics
- Top Physics: Tevatron vs. LHC
- Survey of expectations from Atlas and CMS, with emphasis on early (expected) results

Caveats

- As you heard yesterday, the LHC will start at 7 TeV. Then ~ 10 TeV, then ~ 14 TeV
- Unless otherwise stated, everything in this talk is at 10 TeV
  - To zeroth order, no dramatic differences, except in the most obvious way (lower cm energy → lower xsection → need more luminosity)
- I am on CMS so you may find a slight CMS bias – which I tried to eliminate but I may not have fully succeeded

Why top physics?

Some reasons familiar from Tevatron program:

- Tests of a not-so-well explored area of SM
  - σ, couplings, rare decays, production properties….
- M_{top}: crucial parameter that enters into consistency tests of rad. corrections, M_{Higgs}

Some reasons that are a bit new:

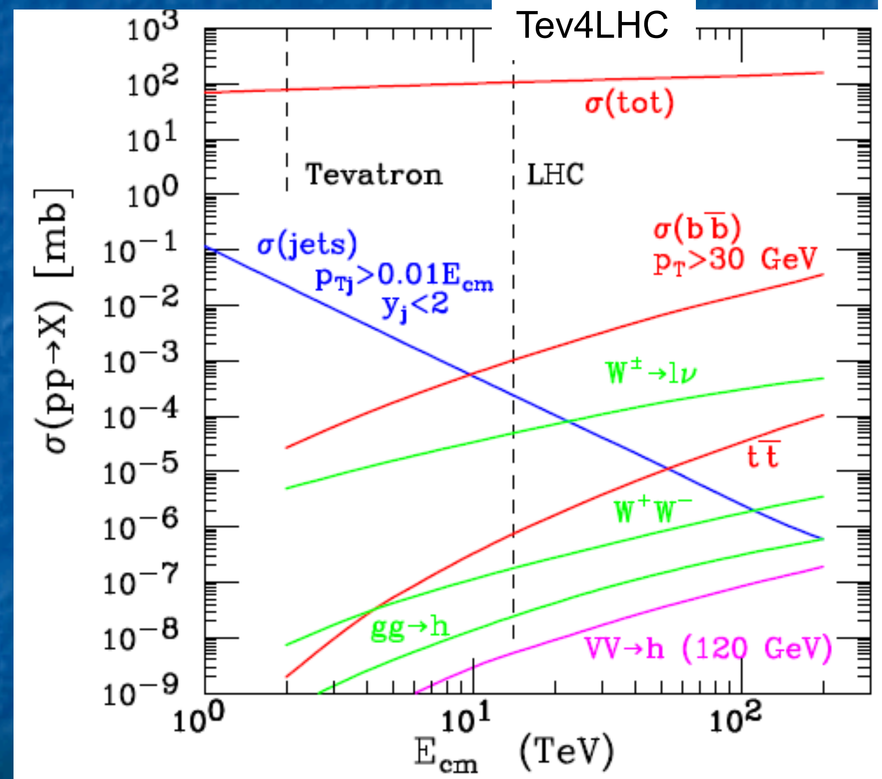
- Very high expected event rates:
  - Possibility to use top events as detector calibration
  - Top-pair production is often main background to searches for new physics → need to understand well

Top-pair production: LHC vs TeV

- The most significant difference is that σ(ttbar) is much larger at the LHC than at Tevatron
  (~ 450 pb vs. ~ 8 pb)
- The main backgrounds scale up in cross-section by about the same amount
  - Interesting aside on W BG, next page
- Thus any top pair physics that has been/can be/should be done at the Tevatron will be done at the LHC with similar techniques

  But (eventually) with very very high statistics

T. Han
Tev4LHC



Aside on W background

- W+jets main background to ttbar→lepton+jets

W+Multijet rates

σxB(W→eν)[pb]	N jet=1	N jet=2	N jet=3	N jet=4	N jet=5	N jet=6
LHC (14 TeV)	3400	1130	340	100	28	7
Tevatron	230	37	5.7	0.75	0.08	0.009

E_T(jets) > 20 GeV , $|\eta|<2.5$, $\Delta R>0.7$

From M. Mangano

3400/230=15

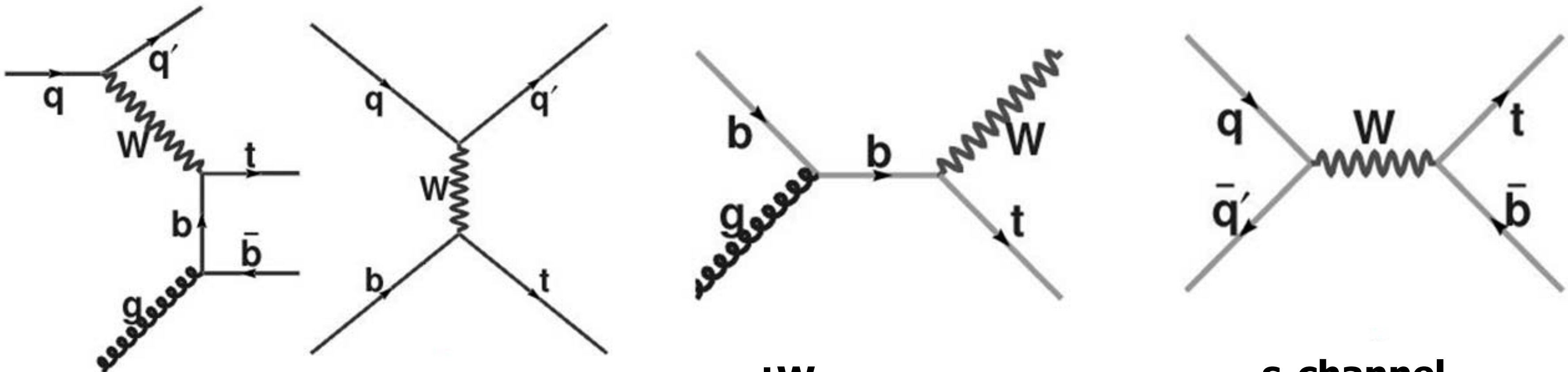
100/0.75=130

- σ(W) increases by ~ x10, but σ(W+4 jets) increases by ~ x100 -- just like σ(ttbar)

Consequence of high σ(ttbar)

- Can use ttbar events as "calibration" of energy scale and b-tagging
- Tail of ttbar events is major background to searches for new physics in events with lepton(s), jets, missing energy
  - σ(ttbar) ~ 450 pb
  - σ(SUSY)~ few pb (beyond Tevatron limits)
- Understanding ttbar tails, or even better, developing methods to estimate them with minimum (no?) theoretical (ie: Monte Carlo) input is a major theme at the LHC
  - Very interesting…..but I wont say anything about that
  - Beyond the scope of this talk

Single top physics: LHC vs TeV



t-channel
σ(LHC) ~ 130 pb
σ(TeV) ~ 1.1 pb

tW
σ(LHC) ~ 29 pb
σ(TeV) ~ 0.1 pb

s-channel
σ(LHC) ~ 5 pb
σ(TeV) ~ 0.6 pb

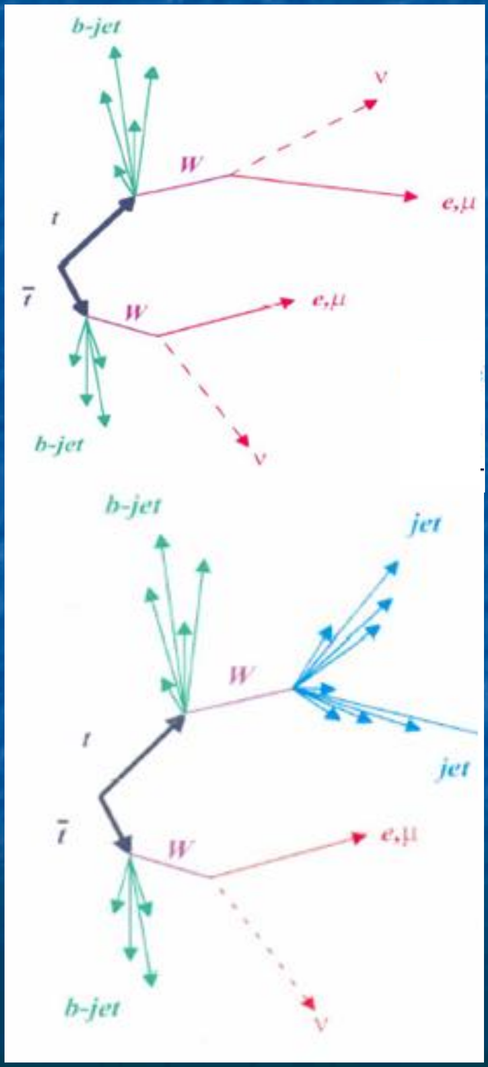
- High cross-section and good signal-to-noise wrt to W BG → t-channel signal can be extracted quite easily at the LHC
- Contrast with sophisticated multivariate analyses with poor signal-to-noise that are absolutely needed at the Tevatron

- Will now turn to a survey of Atlas/CMS analyses of MC data in preparation for the upcoming run
- Will emphasize the "early" analyses, with limited integrated luminosity
- Will not dwell on details. Rather try give a flavor for how these analyses will be done, and point out aspects that I find interesting
- Details of these analyses (and many more) are publicly available on the web:
  - http://cms.cern.ch/iCMS/ → Physics → Recent Physics Results → Top
  - https://twiki.cern.ch/twiki/bin/view/Atlas/TopPublicResults

ttbar cross-section measurements

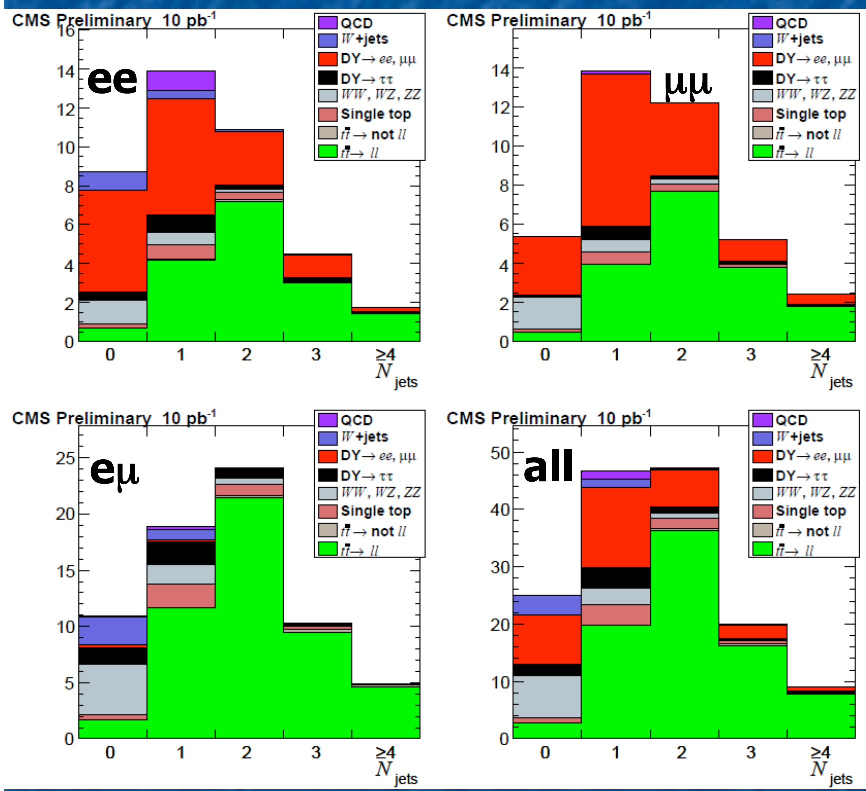
- Interesting per-se, but also very 1st step
  - Prove that can perform complex multi-object analyses
- Dilepton
  - ttbar → (l ν b) (l ν bbar)
  - BR ~ 4/81
  - Opposite sign isolated leptons (e or μ), ≥ 2 jets, missing transverse energy (MET)
- Lepton + jets
  - ttbar → (l ν b) (q qbar bbar)
  - BR ~ 12/81
  - Isolated lepton (e or μ), ≥ 4 jets, MET

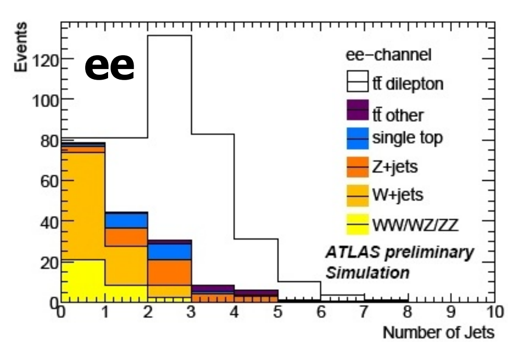
No b-tagging, at least initially

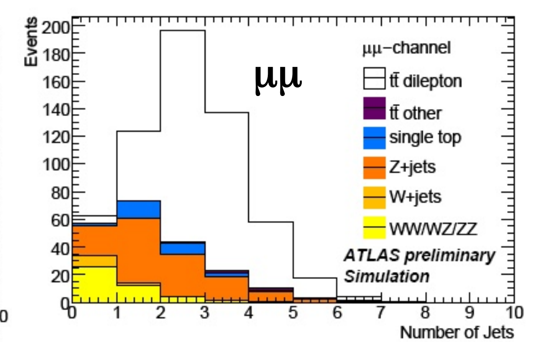


Dilepton cross-sections

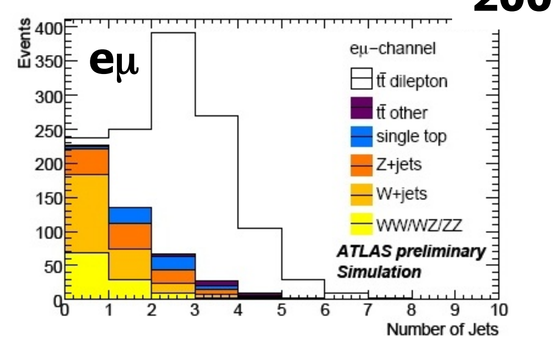
- Count events with two or more jets, subtract BG.
- BG for which MC cannot be trusted (fake leptons and Drell-Yan with fake MET) are determined in data driven way







200 pb^{-1}



In 10 pb^{-1}: Atlas 61 signal, 14 BG
CMS 60 signal, 16 BG

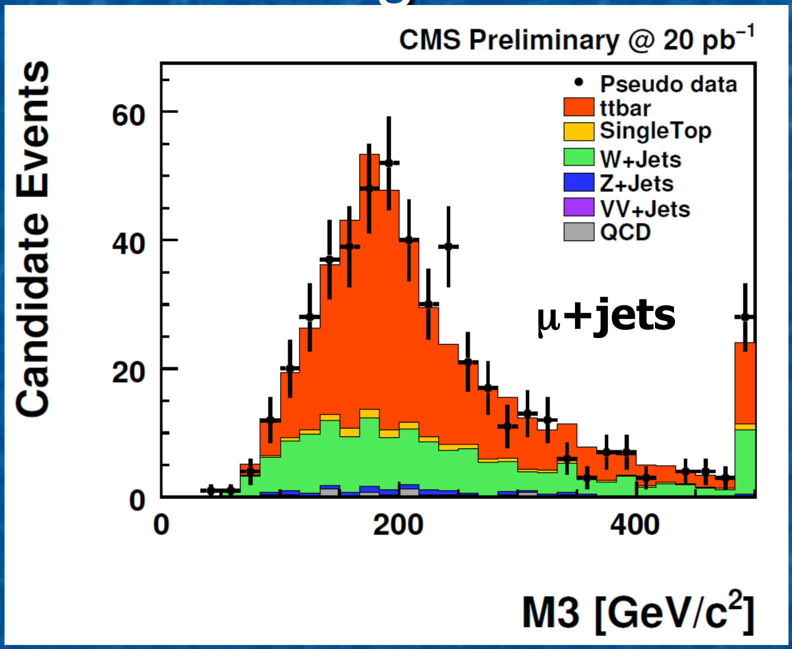
A clean measurement with systematic uncertainties of order 10% (excluding luminosity) for both experiments

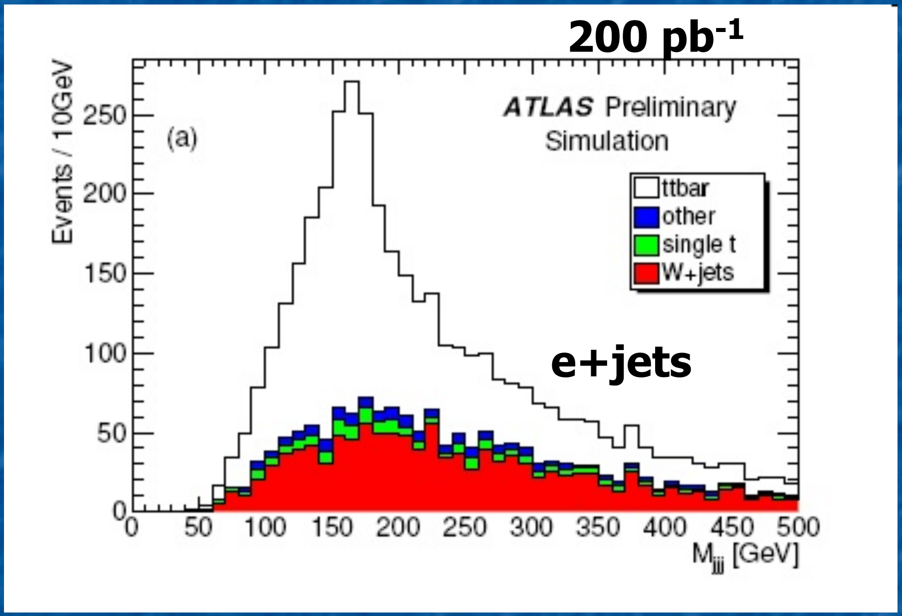
Lepton + jets cross-section

- The selection of l+4jets+MET is expected to give a sample which is roughy 2/3 ttbar and 1/3 W+jets (+ a few other smaller BGs)
- The W+jets BG must be estimated and subtracted
- Two methods used
  - Atlas only: “cut-and-count” where N(W+jets) = c * N(Z+jets) and c is measured in the low multiplicity bins and includes a (small) Monte Carlo correction
    - The uncertainty on N(W+jets) is then about 20% in 200 pb^{-1}.
  - Both CMS and Atlas: use kinematics to separate ttbar from W+jets.
    - There are many possibilities: single variable fits all the way to multivariates
    - Here I will only show single variables
    - Eventually, of course: b-tagging

The M3/M_{jjj} variable (1)

- Invariant mass of the 3 jets that have the highest vector-sum P_T.
- Provides good discrimination between top and W+jets





- Signal can then be extracted from templated fits
  - Both e+jets and μ+jets are used

The M3/M_{jjj} variable (2)

- Expected event yields are remarkably similar in the two experiments…..

	Events/pb^{-1} (CMS)	Events/pb^{-1} (Atlas)
μ+jets	16	16
e+jets	11	13

- Statistical uncertainties:

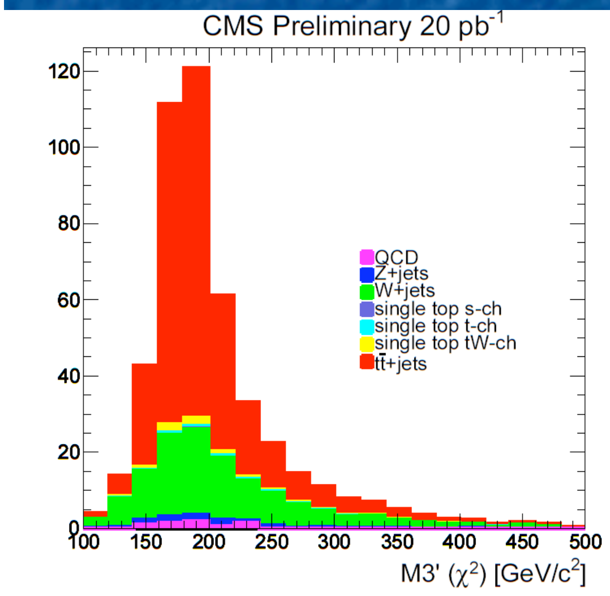
	Stat error in **20** pb^{-1} (CMS)	Stat error in **200** pb^{-1} (Atlas)
μ+jets	16%	15%
e+jets	23%	14%

(the apparent difference in statistical power comes from the fact that here CMS takes the shapes of ttbar and BG from MC, while Atlas fits to Gaussian + 6^{th} order Chebychev polynomial, with fully floating parameters)

- Systematics are dominated by jet energy scale (order 15% for 10% jet energy scale uncertainty)

A comment about M3/M_{jjj}

- The plot looks great. Mass peak! -- But it is a bit deceiving
- In CMS MC for only ~ 30% of the events are the 3 jets in the M3 reconstruction from the t→q qbar b decay
  - Even wrong combinations show a broad peak around M_{top}
- Refined selections can reduce the combinatorics:
  - Requiring that two jets are consistent with the W mass (Atlas)
  - Selecting 3 jets based on a mass-χ^2-sorting technique (CMS)



- CMS example:
  - Get sharper peak, improvement in statistical power….
    - 16% → 12% (μ+jets in 20 pb^{-1})
  - … at the price of worse systematics from jet energy scale
    - 15% → 19% (for 10% jet energy scale syst)

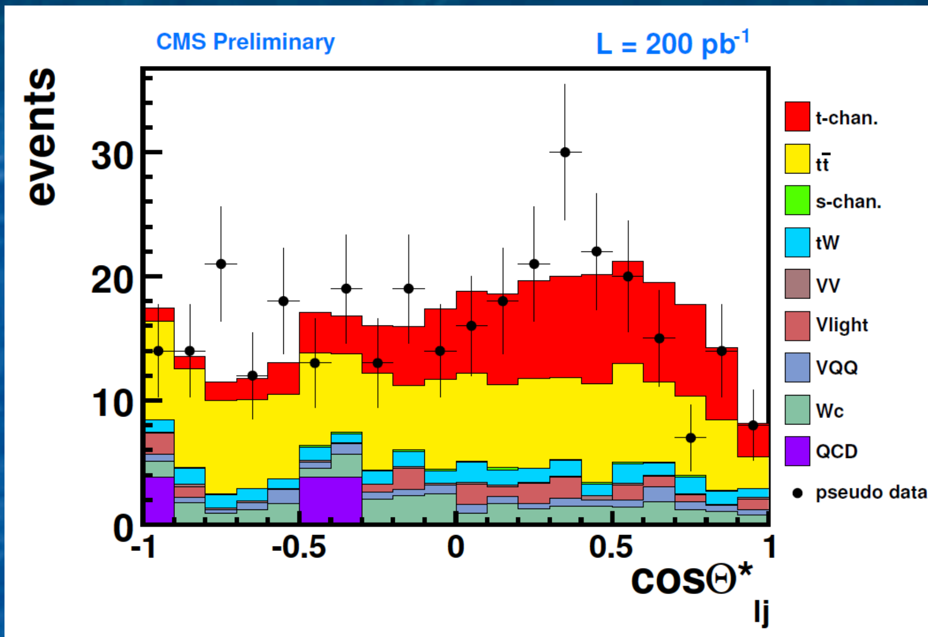
Conclusions about σ(ttbar)

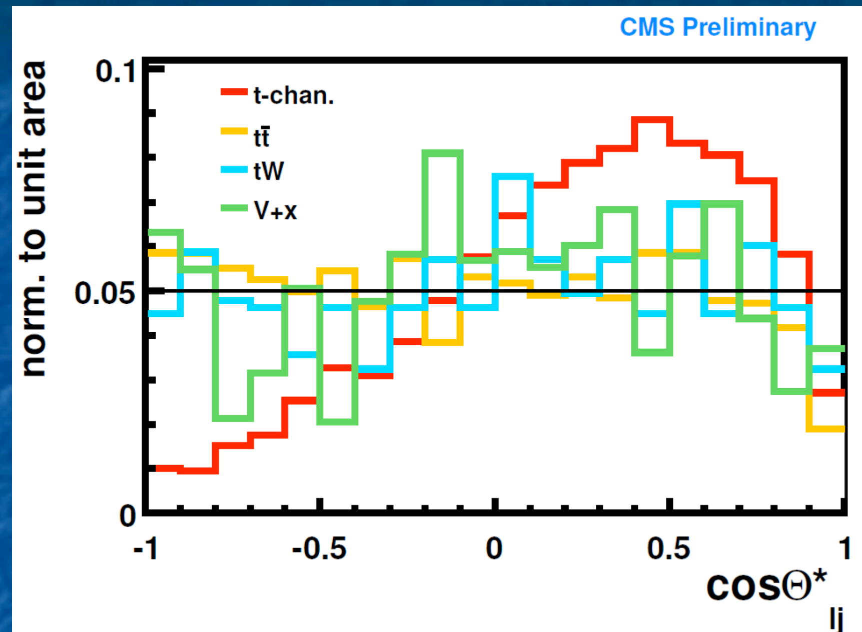
- Both experiments are well prepared to measure σ(ttbar) with as little as few tens of pb^{-1}.
- Several analysis strategies have been layed out and are well understood

Single top cross-section

- Because of the high cross-section in the t-channel, this measurement is a lot easier at the LHC than at the Tevatron.
- CMS plans a 1st measurement of the t-channel based on a fit to a single variable
  - Due to V-A, events are distributed as ~ 1+ $\cos\theta^*_{ij}$, where θ^*_{ij} is the angle between the lepton and the light quark jet in the reconstructed top rest frame
  - All backgrounds are flat in $\cos\theta^*_{ij}$,
  - Then, since the simple event selection* already has a good signal-to-noise (~ ½), a simple 1D templated fit works

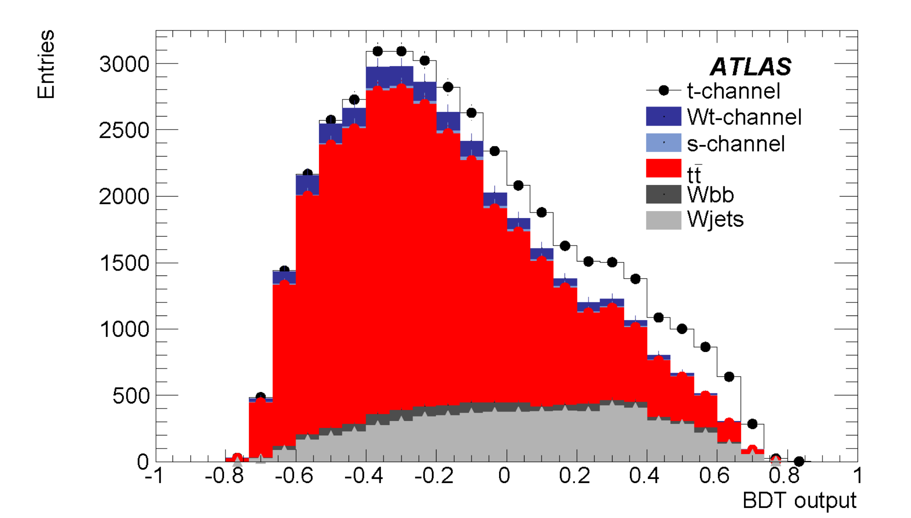
*** 1 isolated muon, MET, 1 b-tagged jet, 1 non-b jet**



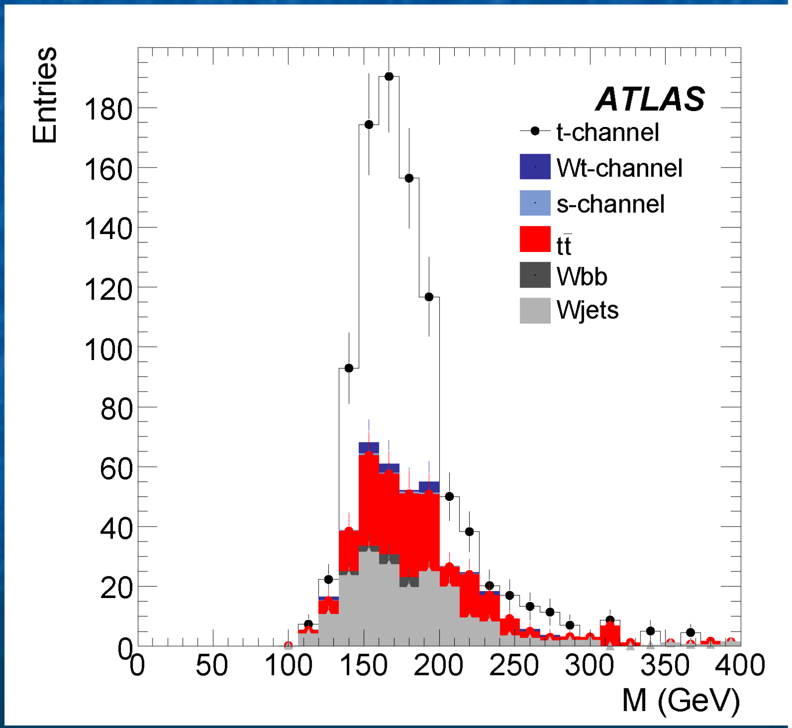


± 35% stat ± 15% syst in 200 pb^{-1} (2.7 σ)

t-channel (Atlas) (14 TeV)



BDT variable. Cut at 0.6, plot the mass

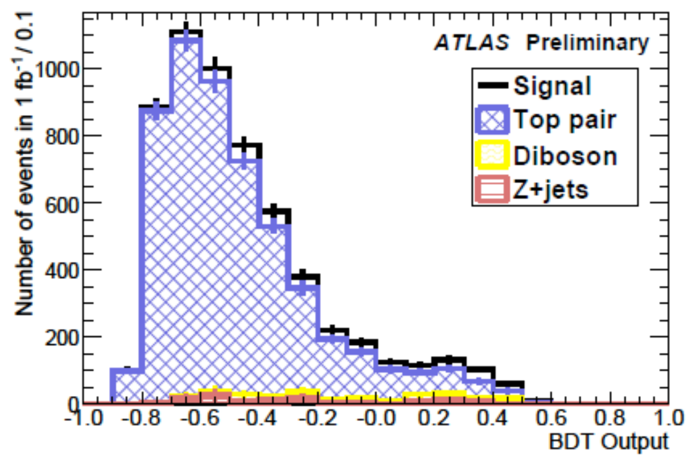


Atlas uses a multi-variate
Very clear signal in 1 fb^{-1}

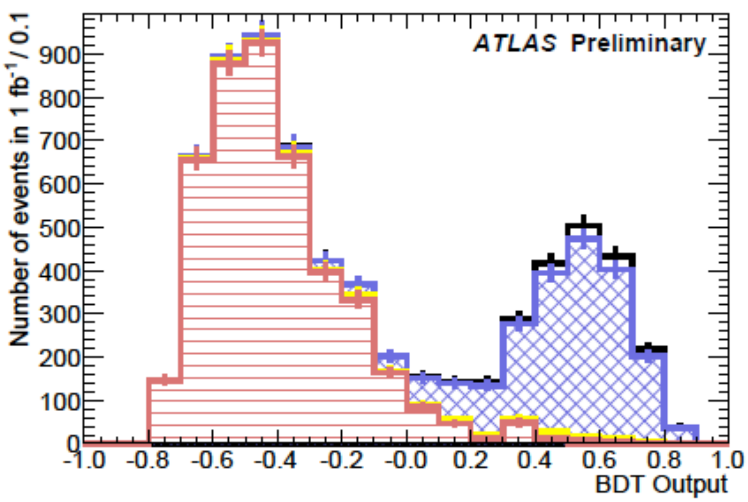
Expect cross-section measurement to
± 5.7% (stat) ± 22% (syst)

tW channel (Atlas)

- Select events with opposite sign dileptons + MET + 1 jet
- In 1 fb^{-1} get 220 signal events and 974 Bg events (mostly ttbar and Drell Yan)
- A straight BG subtraction then gives a σ(tW) uncertainty of 50%
- To improve on that, use boosted decision tree. Expect 34% σ(tW) uncertainty



(a) $t\bar{t}$ discriminant, $e\mu$ channel



(b) Z discriminant, ee channel

R = BR($t \rightarrow Wb$) / BR($t \rightarrow Wq$) (CMS)

- Take the dilepton $e\mu$ + 2 jets sample which is a very clean ttbar sample (see pg 11)
- Knowing the btag efficiency, from the number of btag jets can extract R
- Alternatively: assume R=1 (SM value) and measure the btag efficiency (ie: use as calibration)

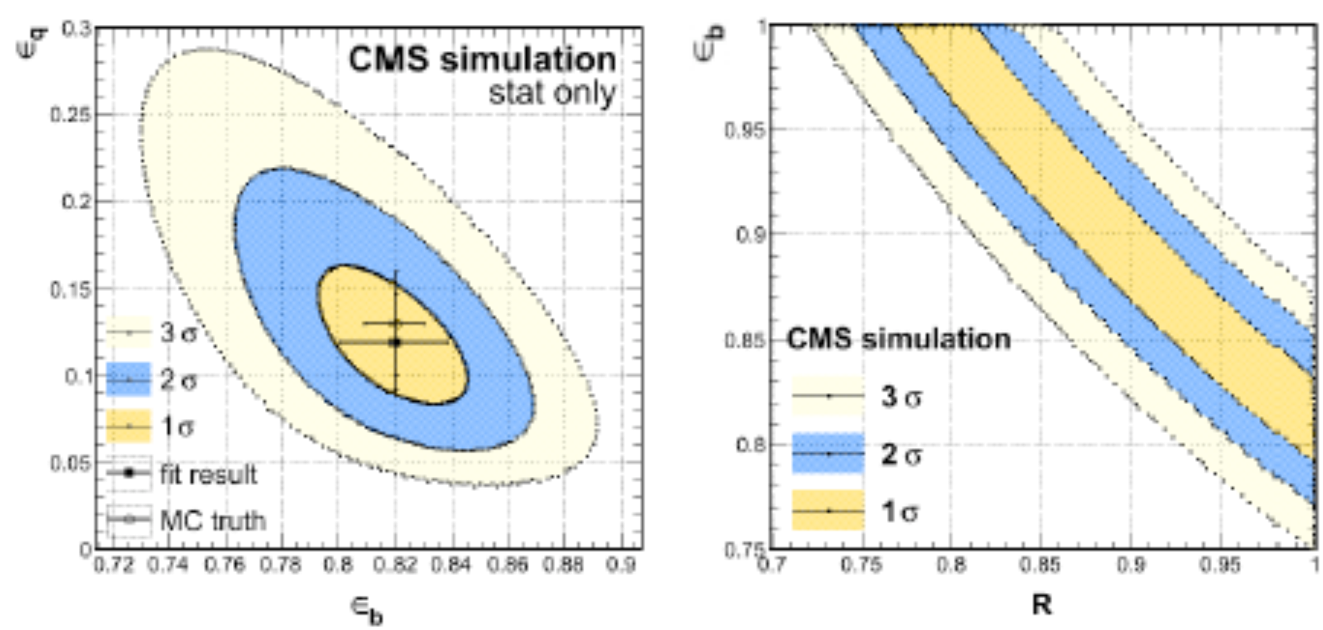


Figure 5: (*Left*) Jet Probability algorithm with the loose working point is used to fit both b-tagging (ε_b) and mistagging (ε_q) efficiencies, assuming $R = 1$. The contour plot for the simultaneous fit is shown with MC truth superimposed. (*Right*) Contour plots (1σ, 2σ and 3σ) for the likelihood obtained by floating R and ε_b.

In 250 pb^{-1}: gives R within 2% (stat) ± 9% (syst ε_b) ± 3% (other syst)

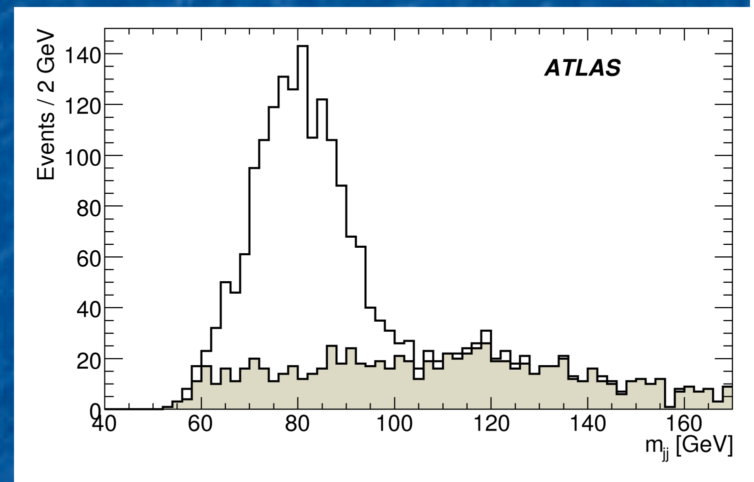
OR

taking R=1, gives ε_b within 2% (stat) ± 4% (syst)

Jet energy scale (JES) (14 TeV) using ttbar→ lepton + 4 jet events

Atlas:

- Look at W-mass peak for events with 2 btags
- JES to ± 2% with 50 pb^{-1}.

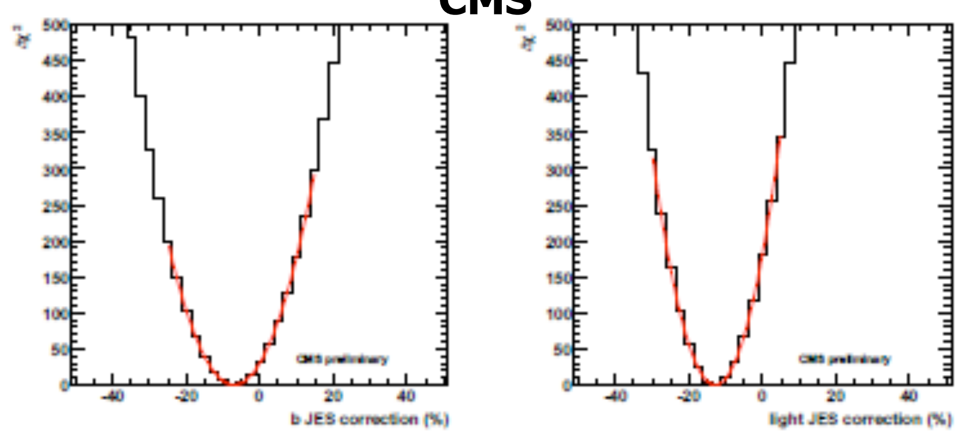


CMS:

- kinematical fits with top and W mass constraint with JES floating
- JES to ± 1% with 100 pb

NB: These are overall scale uncertainties
For PT and η dependence, need more stat

CMS



Conclusions

- Both Atlas and CMS have been preparing for a rich program of top physics
- We are just waiting for data