Top Physics with the ATLAS detector

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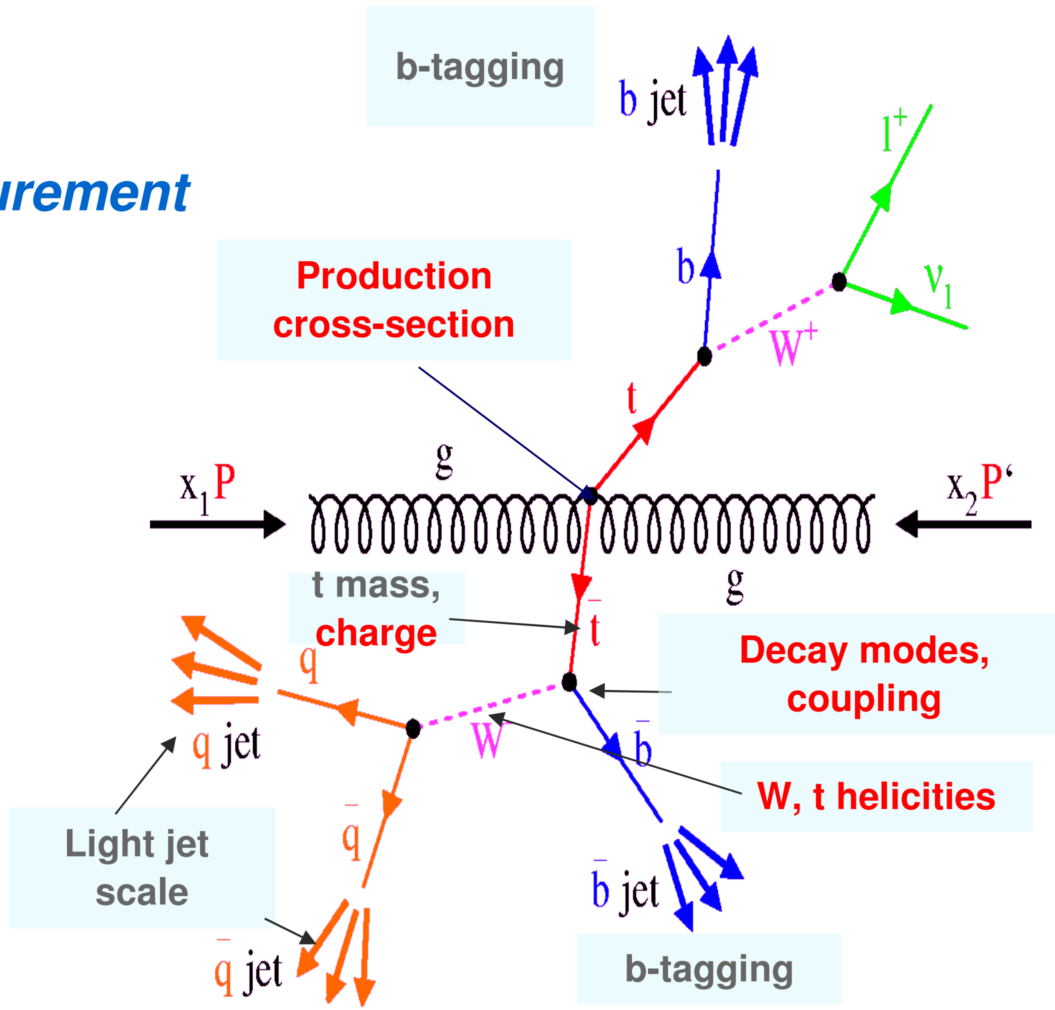
II CPAN DAYS

Valencia, 30th of November 2010

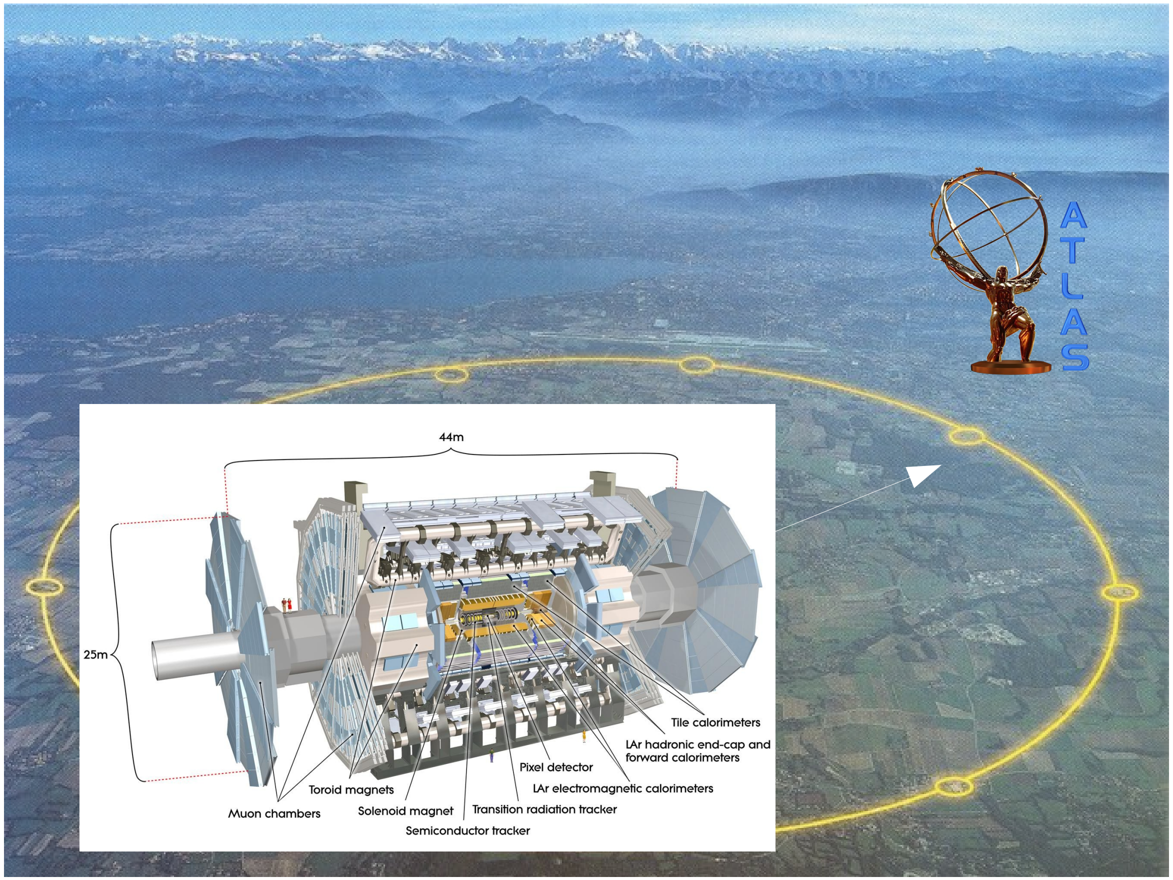
Outline

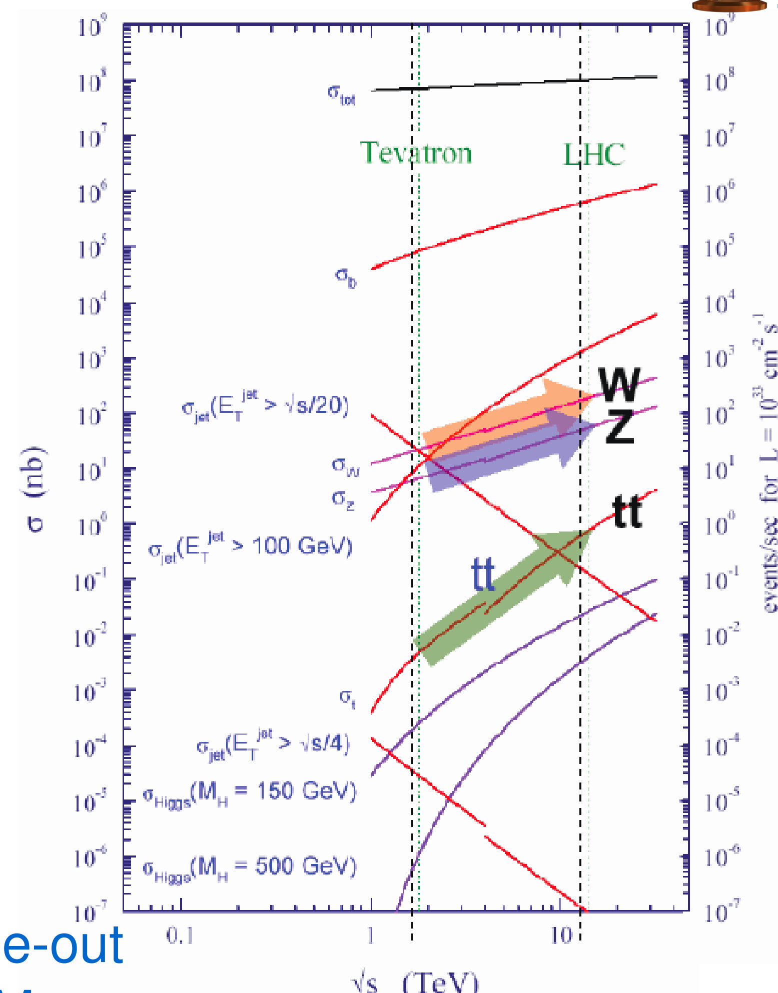
Top Physics in this talk:

- ***Preliminary cross-section measurement***
  - lepton+jets channel
  - Di-lepton channel
- ***Single top cross-section plans***
  - t-channel
  - Wt channel
- ***Top Mass***
  - 2010 data expectations
  - 2011 data expectations
- ***New physics in the top sector:***
  - tTbar resonances



LHC top quark physics



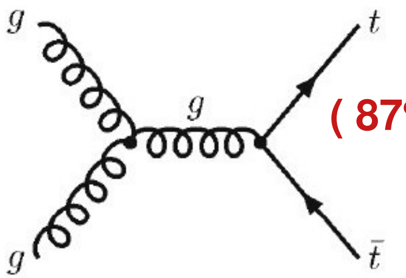


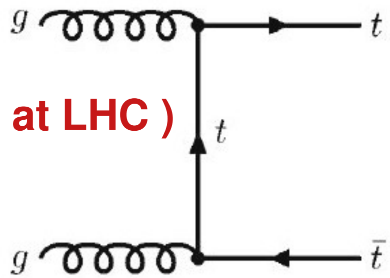
ATLAS is a general purpose detector, with inside-out design (Si detector, EM+HAD calorimeters, Muon chambers).

Top pair production is one of the dominant processes after other QCD processes and W/Z+jets

top quark production measurement

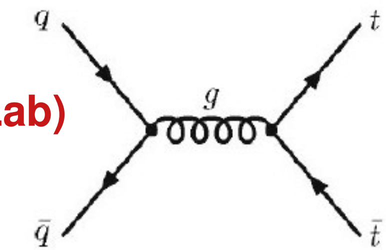
LHC: Gluonic production dominates





(87% at LHC)

(90% at FermiLab)



Ref: hep-ex 0804.1476

σ(tt 1.96 TeV)$^{\text{a pprox NNLO}}$= 7.5 ± 0.5 pb
Tevatron

σ(tt 14TeV)$^{\text{approx NNLO}}$ = 883 ± 45 pb

σ(tt 7 TeV)$^{\text{approx NNLO}}$ = 165 $^{+11}_{-16}$ pb

⇒ 1 tt/sec @ L=10^{33}

Cross section LHC = 100 x Tevatron

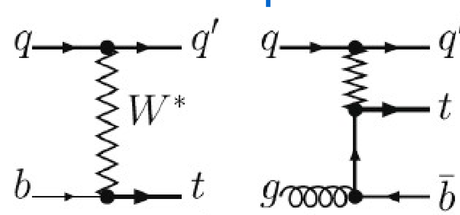
Background LHC = 10 x Tevatron

Use of b-tagging not essential to establish ttbar signal at LHC

LHC Single top production
σ(t, 14 TeV) ≅ 320 pb
dominated by t-channel

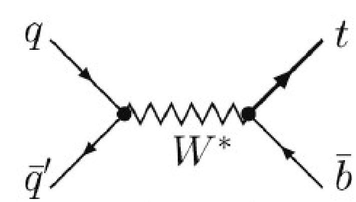
Tevatron: 5σ discovery in 2009:
D0 (arXiv:0903.0850)
CDF (arXiv:0903.0885)
σ(t, 1.96 TeV) = 3.9 ± 0.9 pb

~250 pb



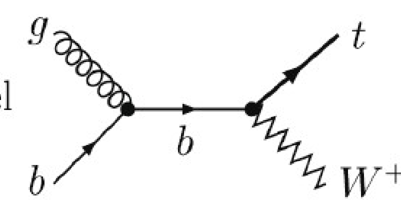
t-channel

~10 pb



s-channel

tW-channel



~60 pb

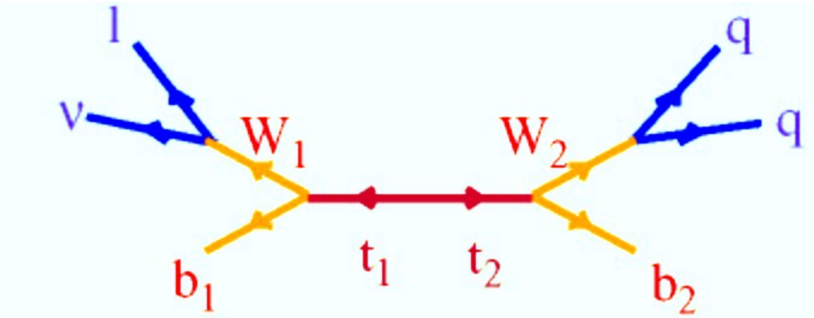
top quark production measurement

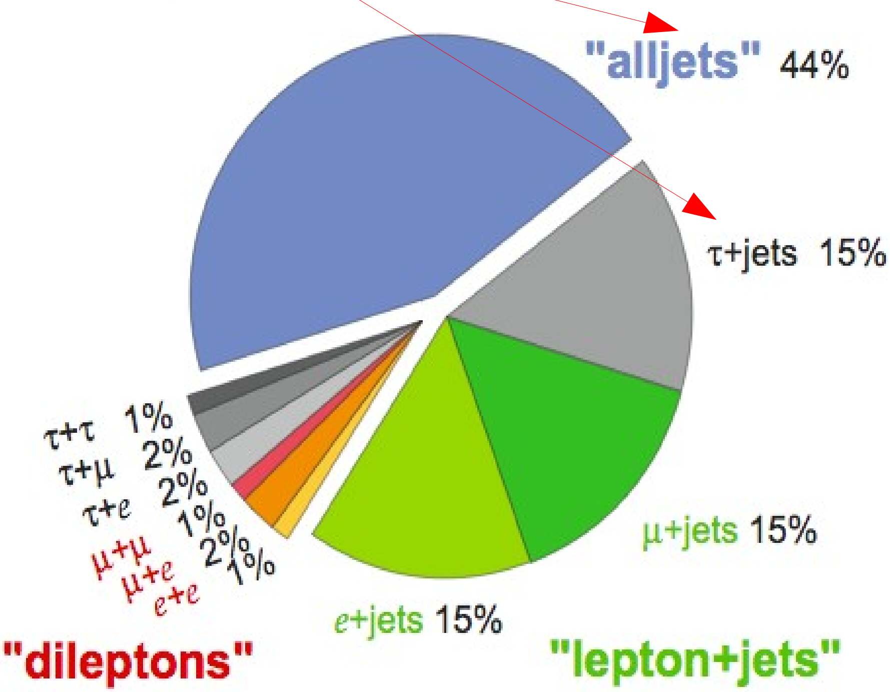
ttbar final states for the cross section measurement

tt final states not considered in the Top rediscovery at LHC in analyses up to O(100) pb^{-1}

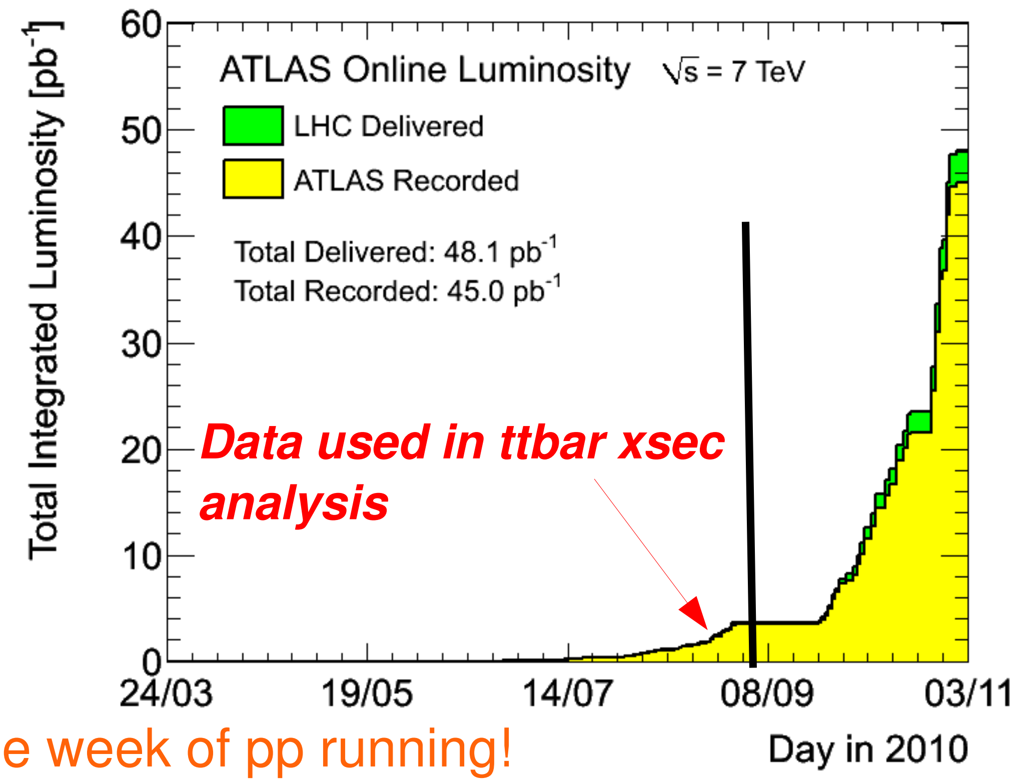
tt final states considered (l=e,μ)

- Full hadronic **44%**: 6 jets
- lepton+jets **30%**: ℓ + MET + 4jets
- Dileptonic **5%**: 2ℓ +MET + 2jets
- Others **21%**





Data and Integrated luminosity



- Half of 48 pb^{-1} delivered in one week of pp running!
- Peak L: 2.1×10^{32} cm^{-2}s^{-1}; Max for data used in xsec analysis 1×10^{31} cm^{-2}s^{-1}
- Max. average pile-up 4 interactions per bunch crossing
- Data Taking efficiency was 93.6% during p-p run, taking into account detector dead time and ramping-up of the HV.
  - Denominator is from stable beams declaration to beam dump hand-shake

Thanks to accelerator group for the LHC performance!

Ttbar cross section measurement

- ***Measurement done in 5 orthogonal final states*** (statistically easier to combine):
  - lepton+jets; e+jets, μ+jets
  - Di-leptons: ee+jets, μμ+jets, eμ+jets

- ***Measurement lepton+jets channel***
  - Data-driven methods to control QCD and W+jets backgrounds
  - 3 measurement methods:
    - Counting experiment
    - FitA template fits of the 3-jet mass distribution
    - FitB simultaneous fit of the yields of the b-tagged and pre-tagged samples
- ***Measurement Di-lepton Channel***
  - Counting experiment
  - Profile likelihood fit of the Signal and Background in the 3 channels

- ***Combined result***
  - Simultaneous likelihood fit to all channels to derive the combined cross section.

Pre-tag = before applying b-tagging selection criteria.

Ttbar xsec Selection

lepton+jets Selection:

- 1 electron or 1 muon trigger fired
- Exactly 1 lepton with $p_T > 20$ GeV matched to trigger
- $E_T^{Miss} > 20$ GeV and $E_T^{Miss} + m_T(W) > 60$ GeV
- ≥ 1 jet with $p_T > 25$ GeV and $|\eta|<2.5$

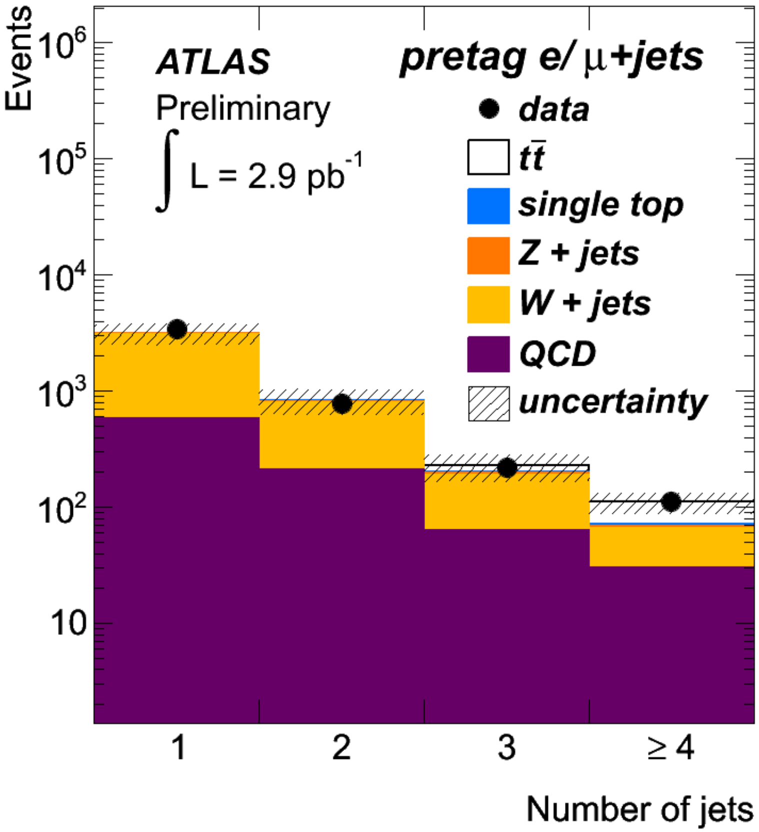
Di-lepton Selection:

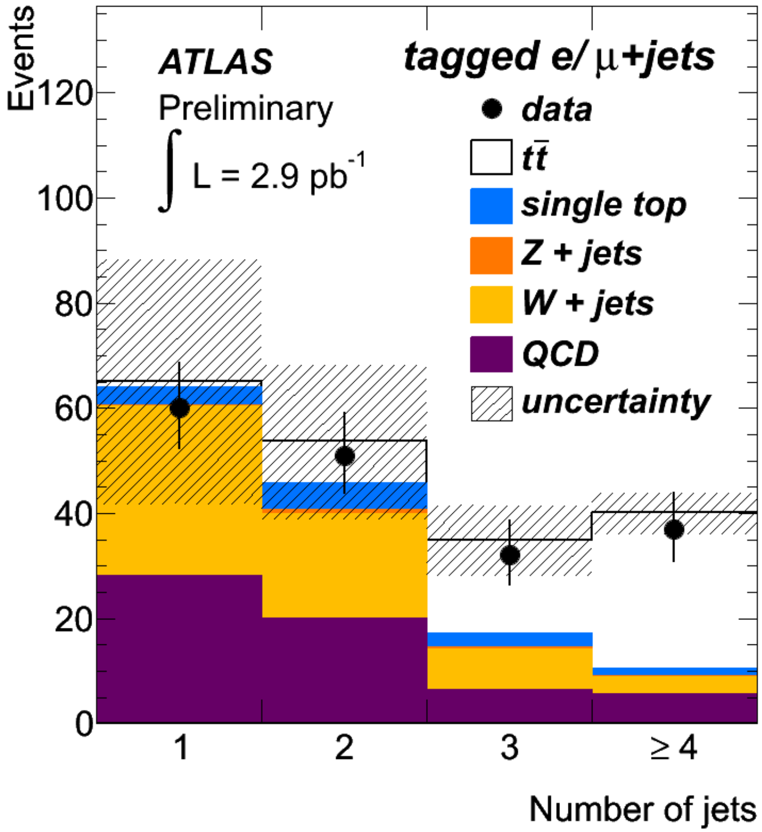
- 2 leptons of opposite charge (ee, $e\mu$, $\mu\mu$) with $p_T > 20$ GeV. At least 1 matched to trigger
- ≥ 2 jet with $p_T > 20$ GeV and $|\eta|<2.5$
- $E_T^{Miss} > 40$ GeV , $|m_{ee}-m_Z| < 5$ GeV (ee); $E_T^{Miss} > 30$ GeV , $|m_{\mu\mu}-m_Z| < 10$ GeV ($\mu\mu$) ; $H_T > 150$ GeV ($e\mu$)
- Vertex $d_0 < 500$ μm $\leftarrow$ to remove cosmic muons

H_T is defined here as the scalar sum of the p_T of the leptons and jets

QCD Background Lepton+jets

- Main backgrounds of the lepton+jets channels are W+jets and QCD.
- They are both determined in a *data-driven way* for tagged and pre-tag samples.
  - μ+jets QCD bkg is determined in the pre-tag sample with the *Matrix Method* and the tag rate is determined in a QCD enriched sample
  - e+jets QCD bkg is determined by a *likelihood fit* of the E_T^{Miss} distribution





W+jets Background Lepton+jets

- W+jets background is determined in a *data-driven* way for both pre-tag and tagged selections

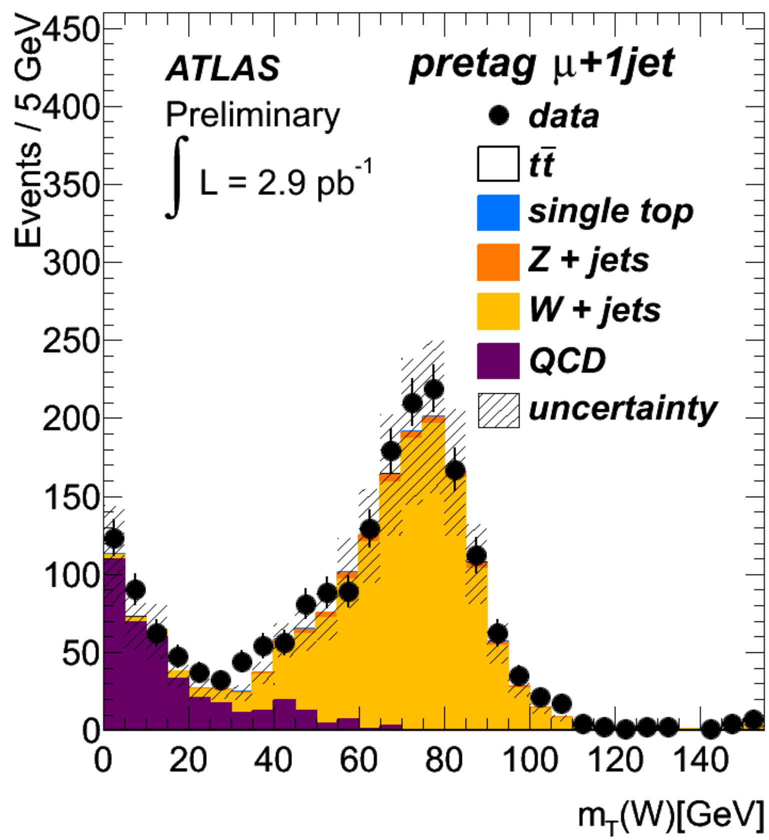
$$W^{\geq 4\text{-jet}}_{\text{tagged}} = W^{\geq 4\text{-jet}}_{\text{pre-tag}} \cdot f^{\geq 4\text{-jet}}_{\text{tagged}}.$$

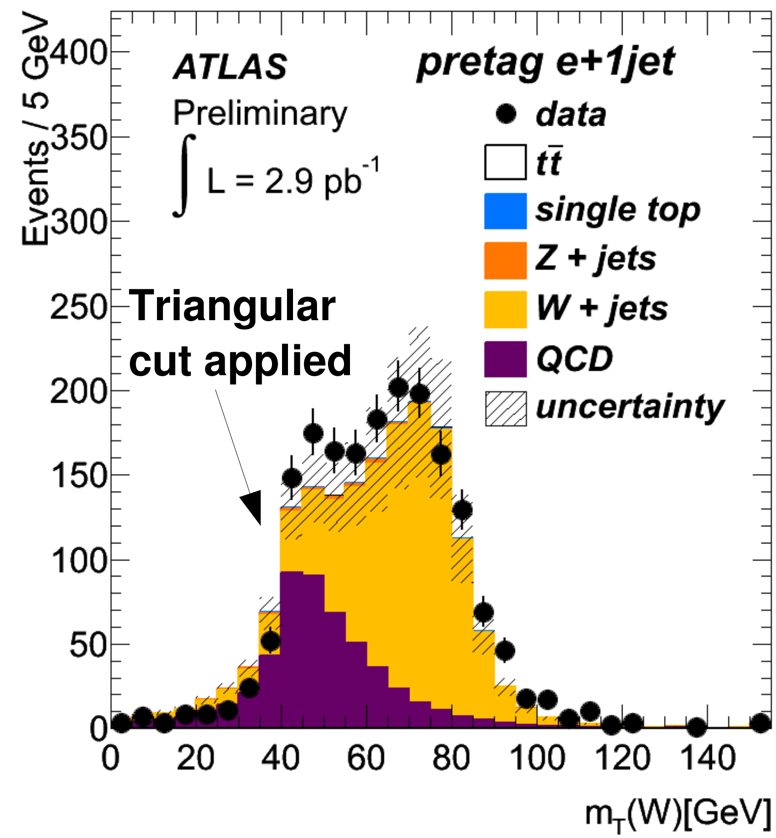
$$W^{\geq 4\text{-jet}}_{\text{pre-tag}} = W^{2\text{-jet}}_{\text{pre-tag}} \cdot \sum_{n=2}^{\infty} \left(W^{2\text{-jet}}_{\text{pre-tag}} / W^{1\text{-jet}}_{\text{pre-tag}}\right)^n$$

Berends scaling

$$f^{\geq 4\text{-jet}}_{\text{tagged}} = f^{2\text{-jet}}_{\text{tagged}} \cdot f^{\text{corr}}_{2\rightarrow\geq 4},$$

largest uncertainty

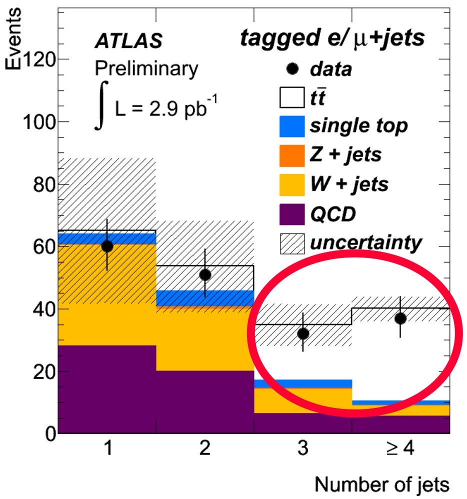


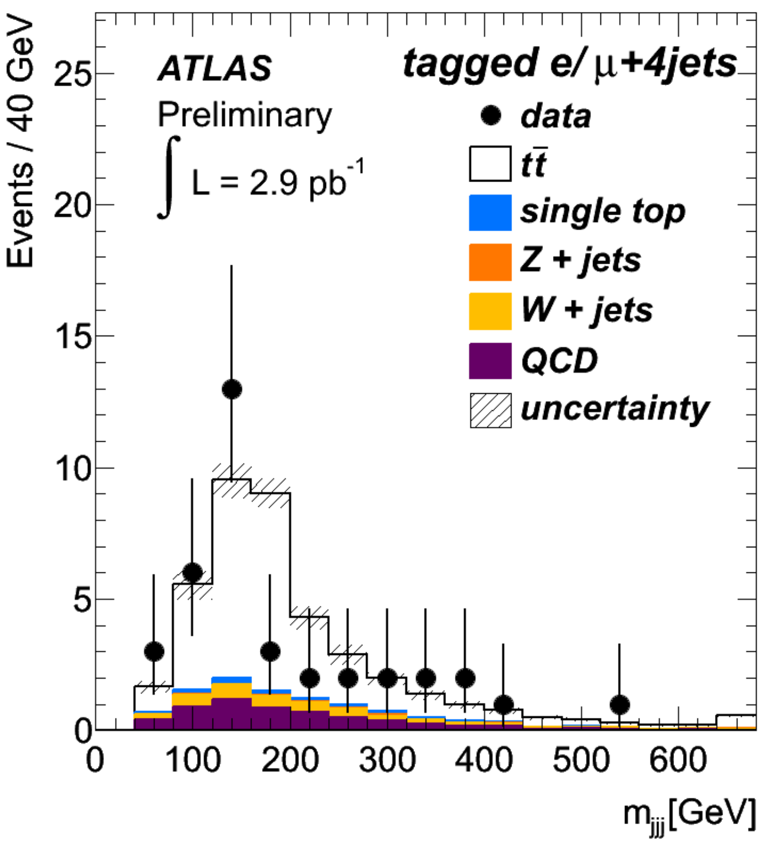


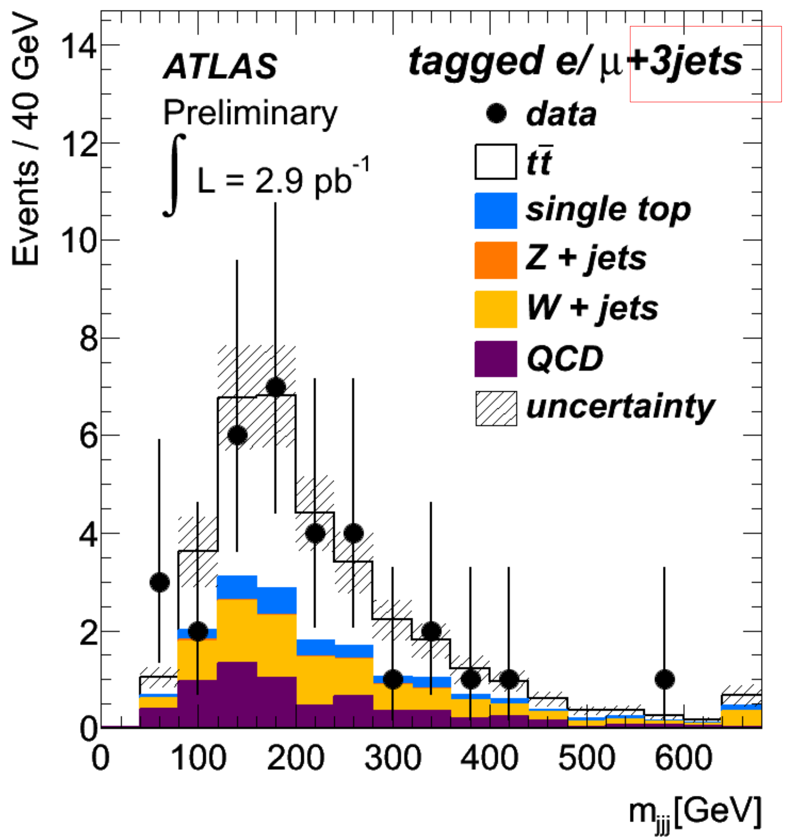
- Other backgrounds are determined with Monte Carlo

3-jets Mass Lepton+jets

- The mass 3-jet combination with the highest p_T would show a resonant component for the well reconstructed top-candidates.
- =3 jets sample is also providing information on the ttbar and background (1:1 ratio) → exploited in FitA method

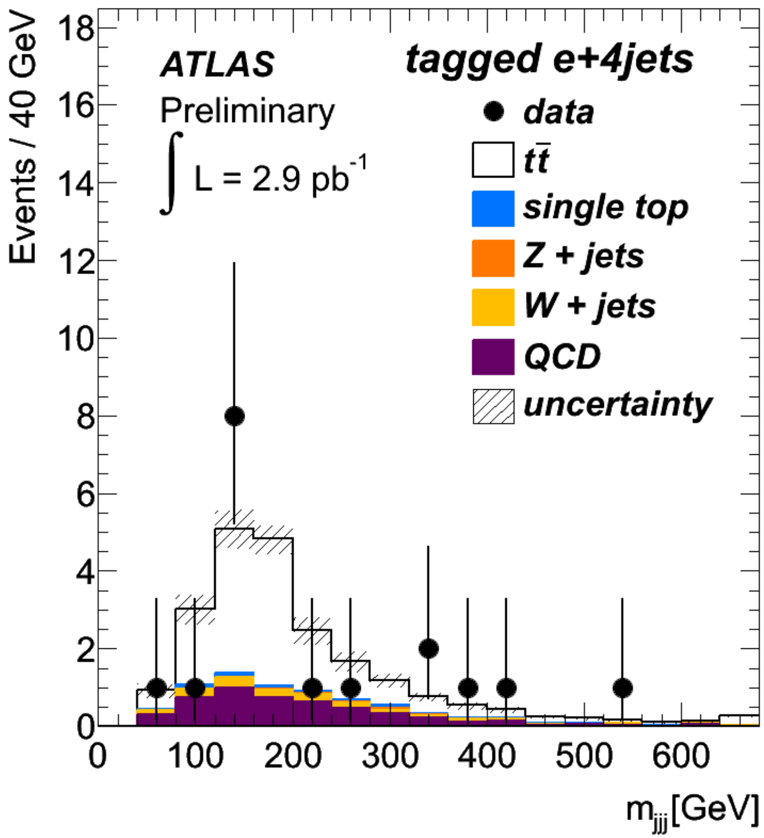


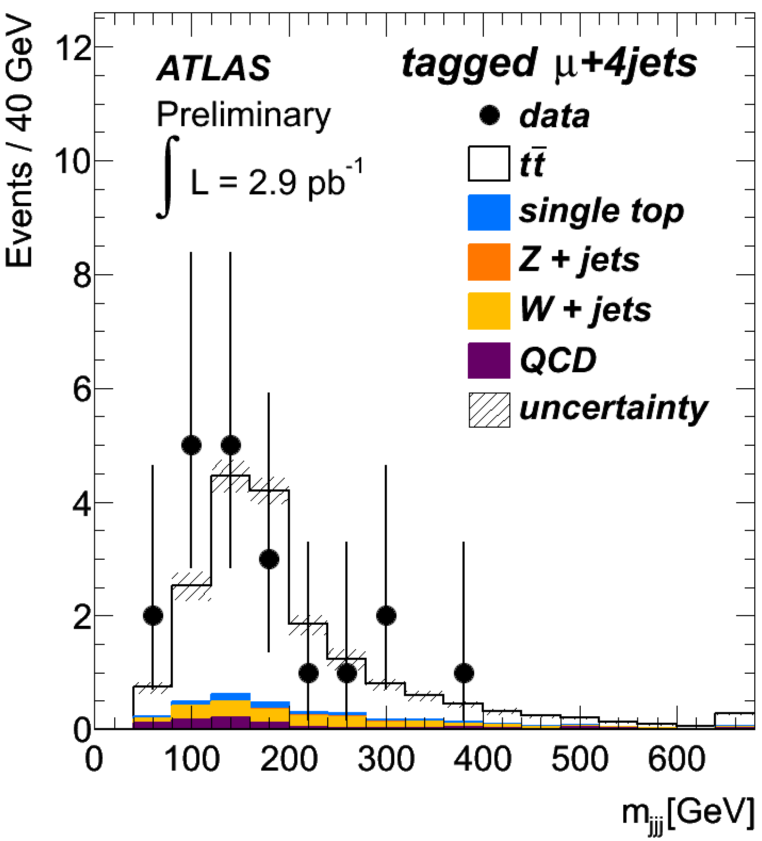




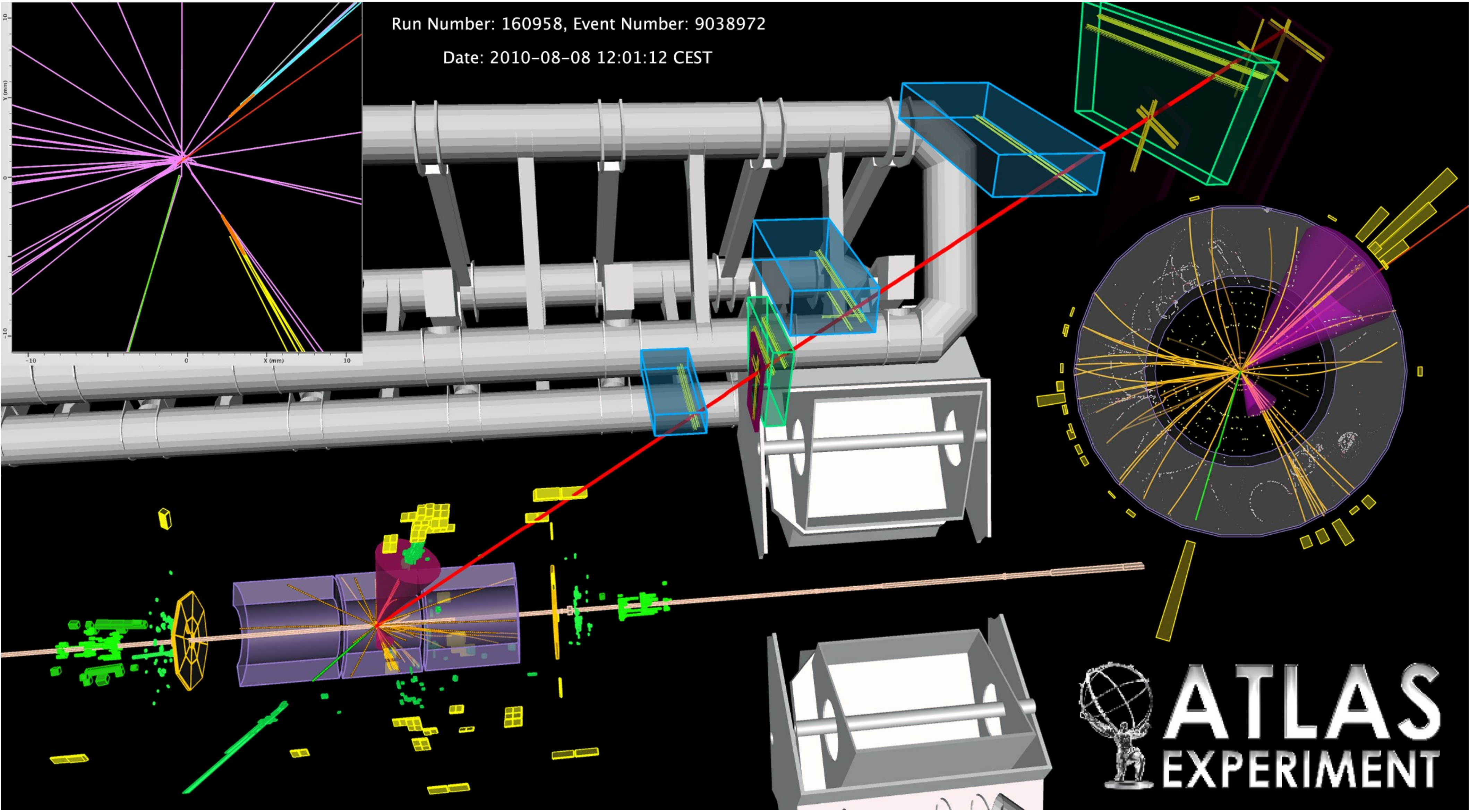
Systematics and Results

- l+jets xsec has been measured with 3 methods:
  - **Cut and Count** of the 4-jets tagged samples
  - **Fit A**: simultaneous fit of the 3 jets mass in the tagged samples of the 3-jets exclusive and 4 jets inclusive samples (only one using the mass shape information).
  - **Fit B**: simultaneous fit of the yields of the 4 jets pre-tag and tagged samples.
- For the C&C method, the main systematics are b-tagging, JES and background.





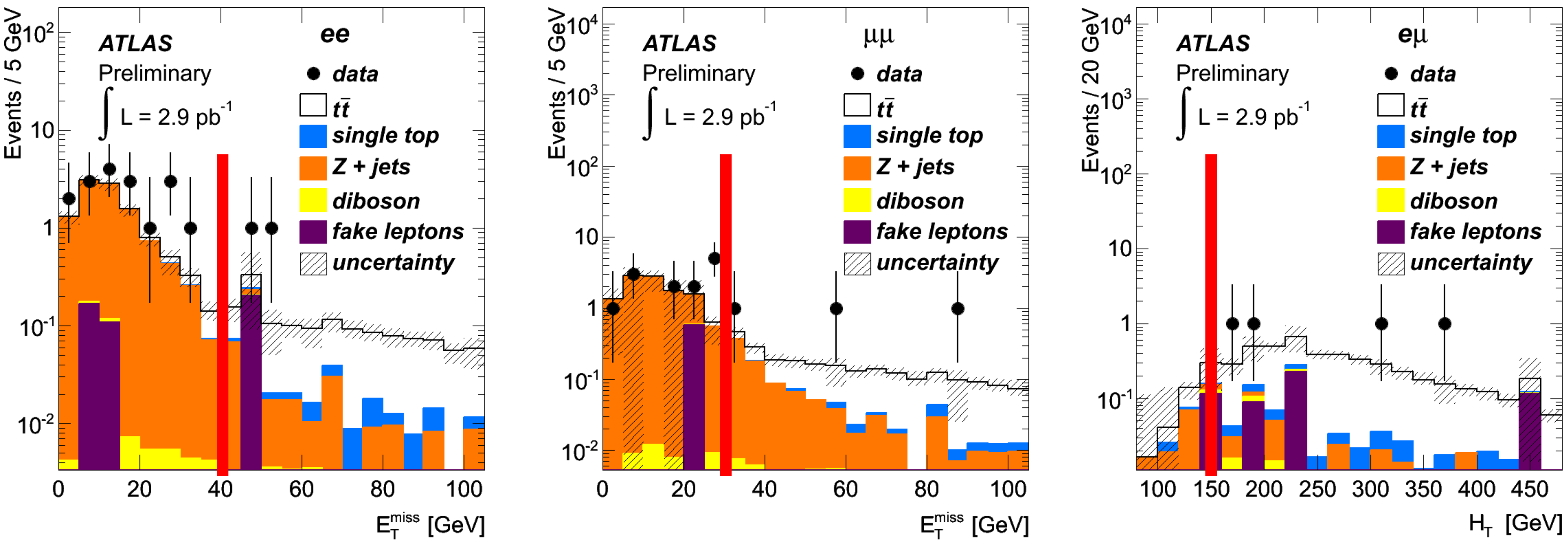
Top e-mu platinum event



Background Di-Lepton

Non-Z background:

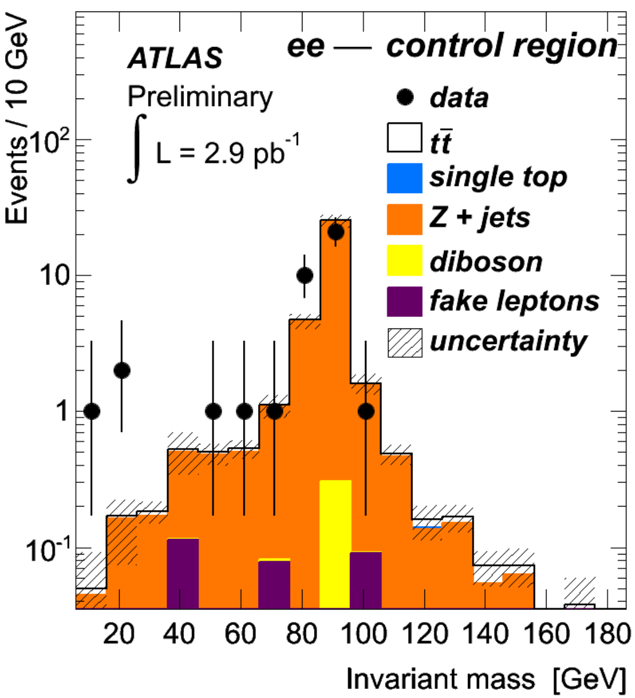
- Data Driven estimation of the non-Z background is performed with the matrix method.
- Main contribution is W+jets with a small contribution from QCD with 2 fake leptons.

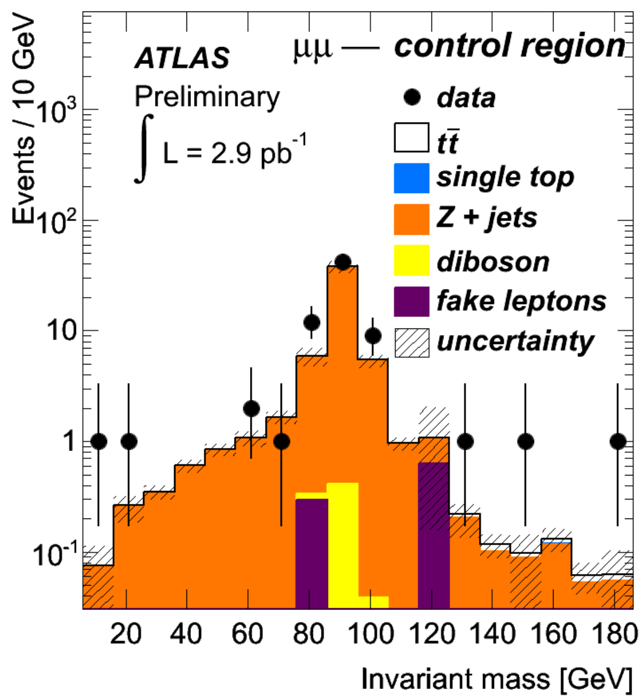


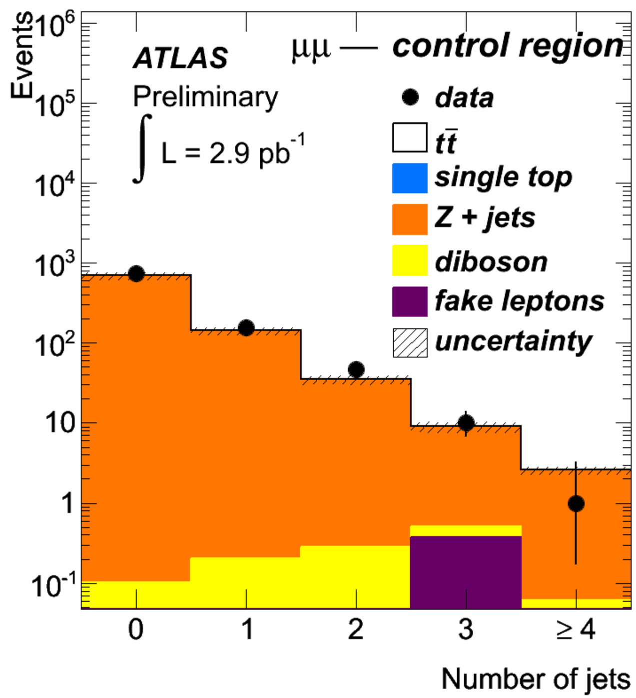
Z+jets background

Z background:

- Data Driven estimation of Z+jets background is done by using an orthogonal control region by inverting the Z mass veto cuts and lowering the E_T^{Miss} cut to > 20 GeV

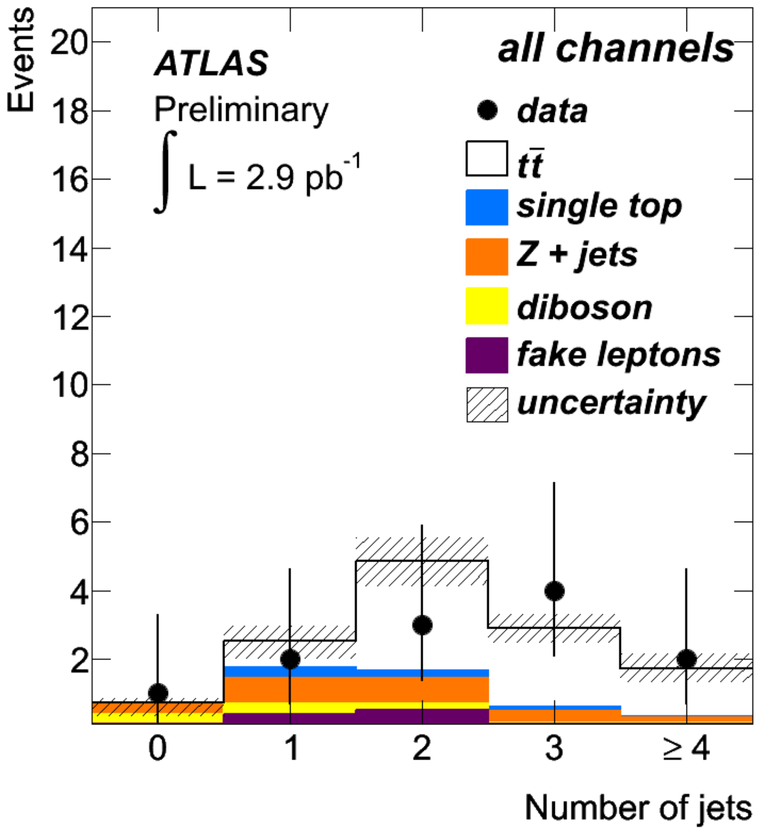


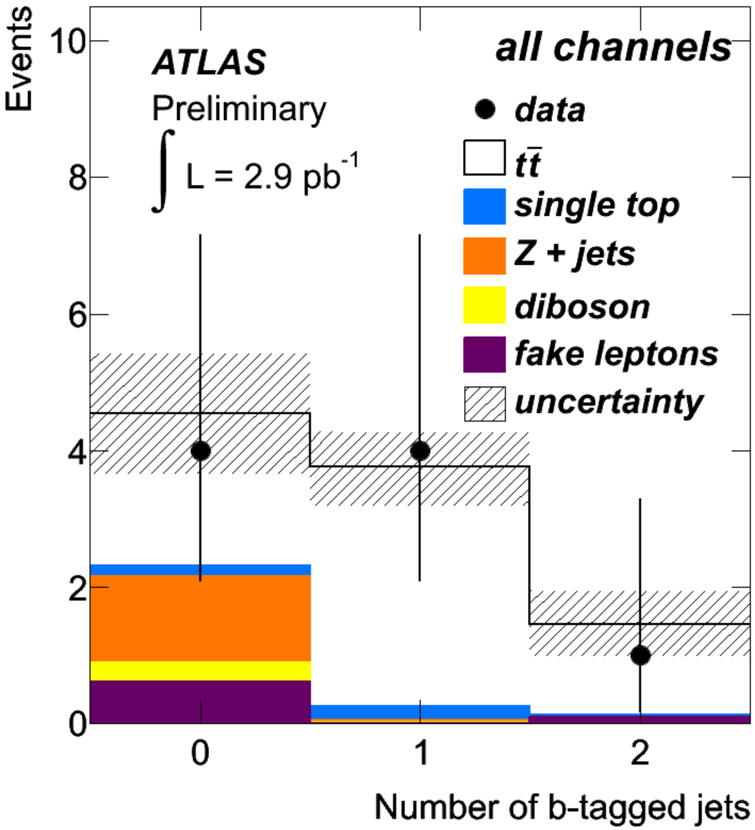




Signal and Background

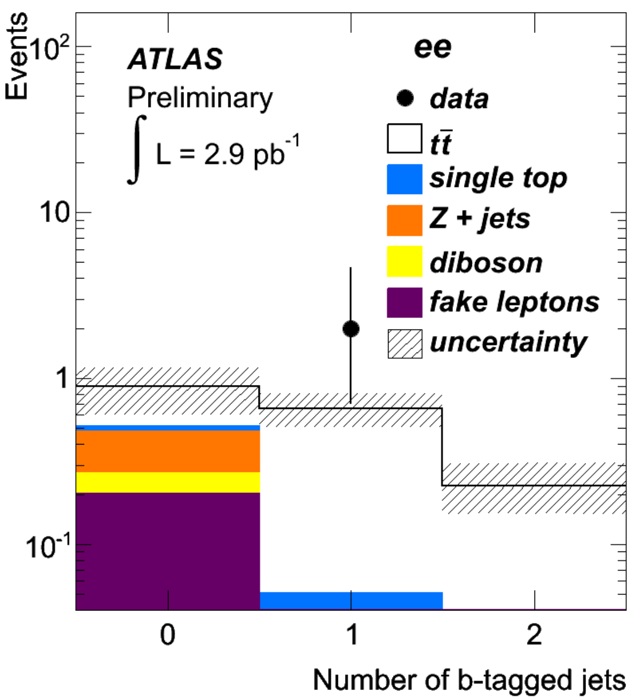
- Comparison of signal and background yields as a function of the number of jets and tagged jets.

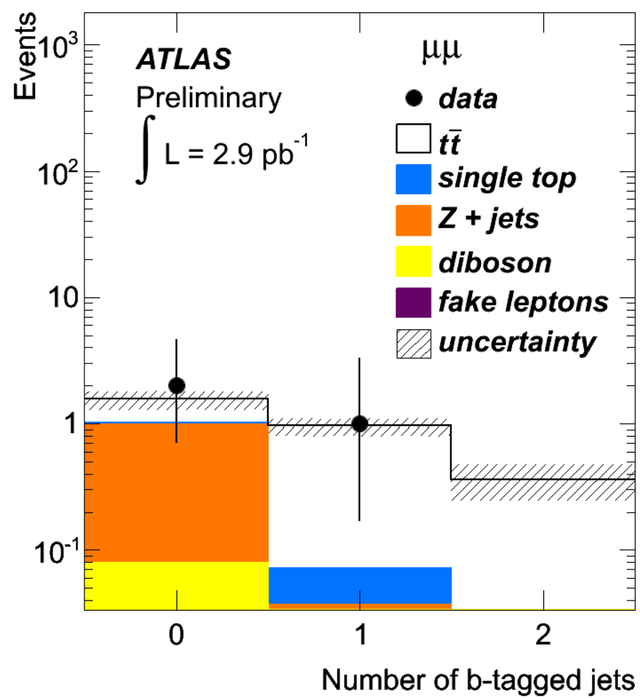


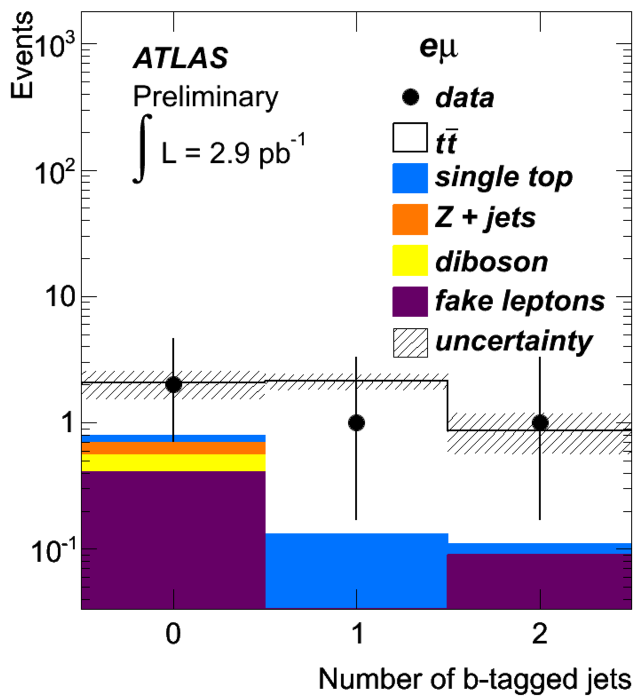


Systematics and Results

- Di-lepton channels cross-section is determined as Counting experiment where the backgrounds are determined from data.
- The cross section is inferred by a profile likelihood ratio
- Uncertainty is statistically dominated.
- Main systematics are background determination and JES





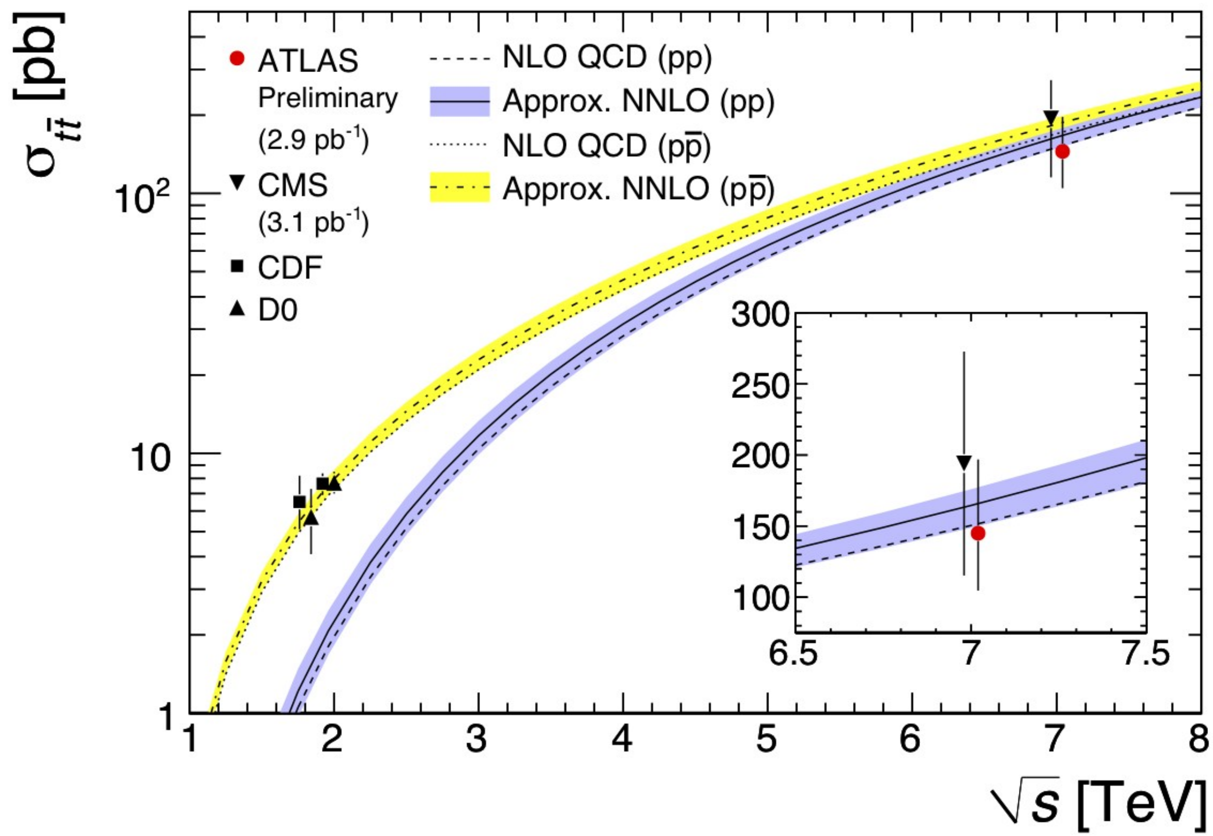


Combination of the channels

- The combination of the channel is done by using a binned profile likelihood and systematic uncertainties are modeled using a Γ function.

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

4.8 σ wrt background-only hypothesis.
5.1 σ if using Gauss function for systematics

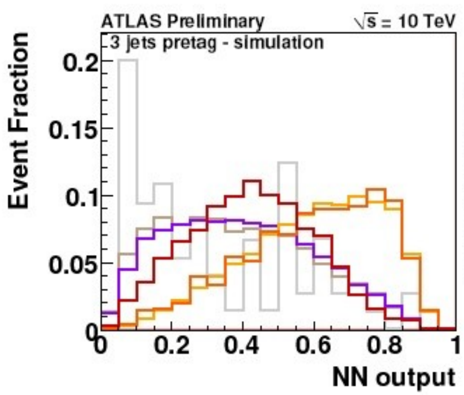


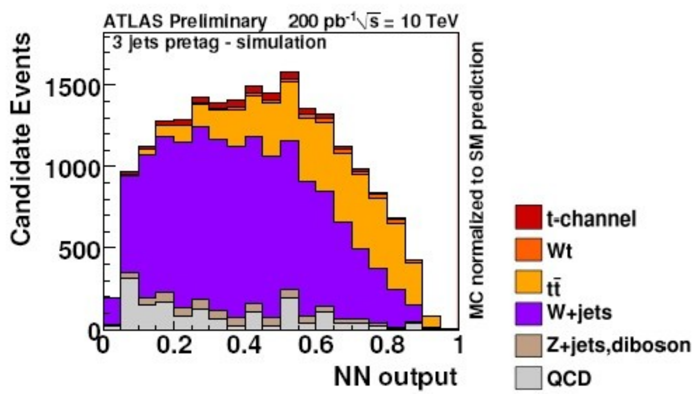
Single Top production measurement

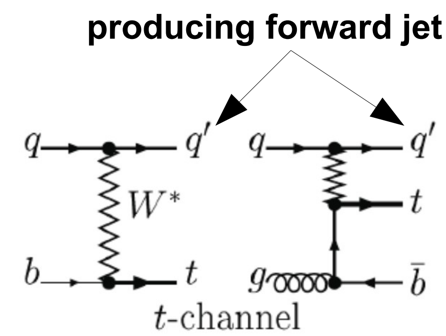
ATL-PHYS-PUB-2010-093

t-channel $\sigma_t \approx \sigma_{tt} / 3$

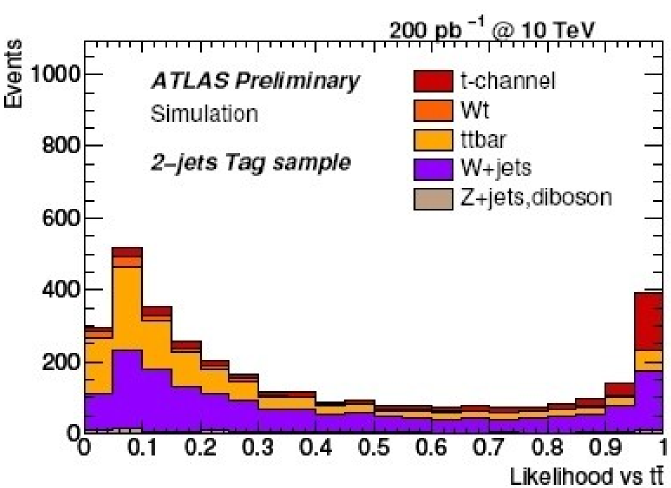
ATLAS: 2 methods for xsec measurement sequential cuts, and likelihood







Binned likelihood on the output of the NN on the 3-jets pre-tag sample to determine W+jets and ttbar rates



Method	$\Delta\sigma/\sigma$
Seq. cuts	$\pm 15(stat) \pm 35(syst) \pm 11(lumi)\%$
likelihood	$\pm 14(stat) \pm 32(syst) \pm 11(lumi)\%$

- **Sequential cuts analysis :**

Add kinematical cuts to reject tt and W+jets

- **Likelihood function analysis :**

Likelihood ratio with angular variables to discriminate tt & W+jets

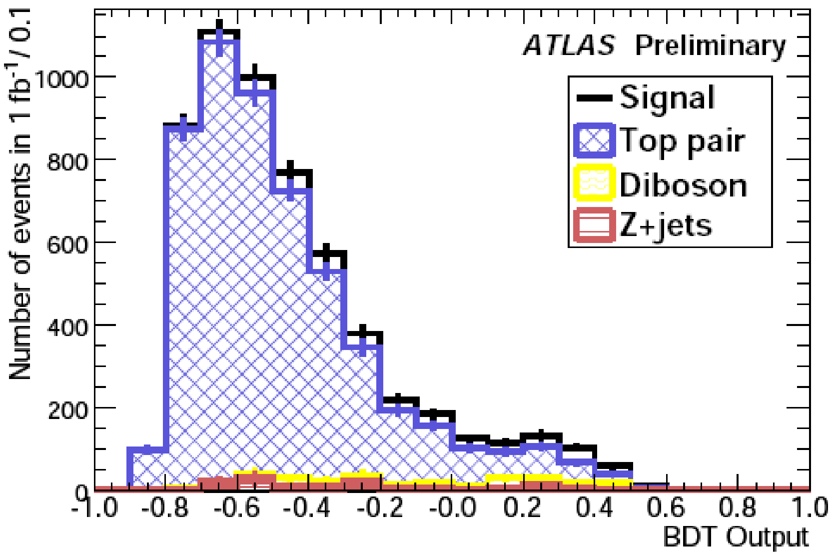
Main sources of systematics :

B-tagging, bkg normalisation, ISR/FSR, Generator

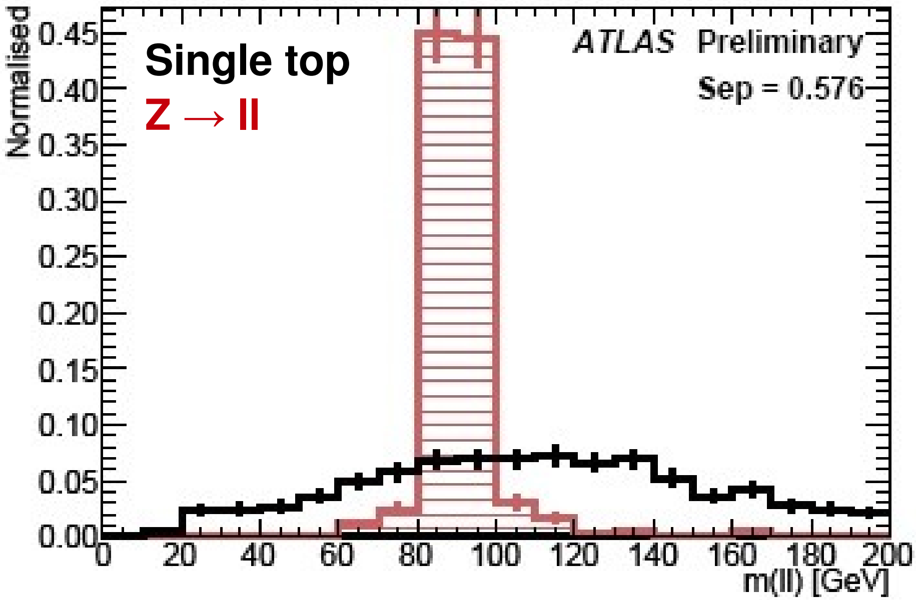
Significance with 200 pb^{-1} @10 TeV : 2.7 σ

Single Top production measurement

ATL-PHYS-PUB-2009-001



tt discriminant e-μ channel



BDT input variable distributions after kinematics cuts. Other inputs variables are E_T^{Miss} , H_T and angular distributions between leptons, jets and E_T^{Miss}

tW channel (associated W production)

Signature similar to tt, but with one less b-jet

ATLAS: cut-based analysis and boosted decision tree

Expected results for 1 fb^{-1} @10 TeV:

- **1 lepton+jets channel: 48% uncertainty (BDT analysis)**
- **di-leptons channel: 34% uncertainty (BDT analysis)**

- at 10 fb^{-1} , 1 lepton+jets chan cut method: 20% uncertainty

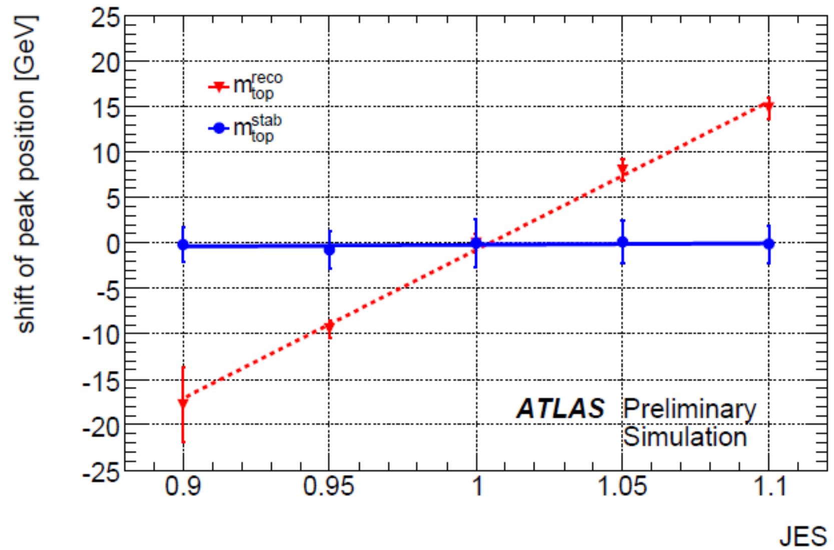
Top Mass prospects 2010 data

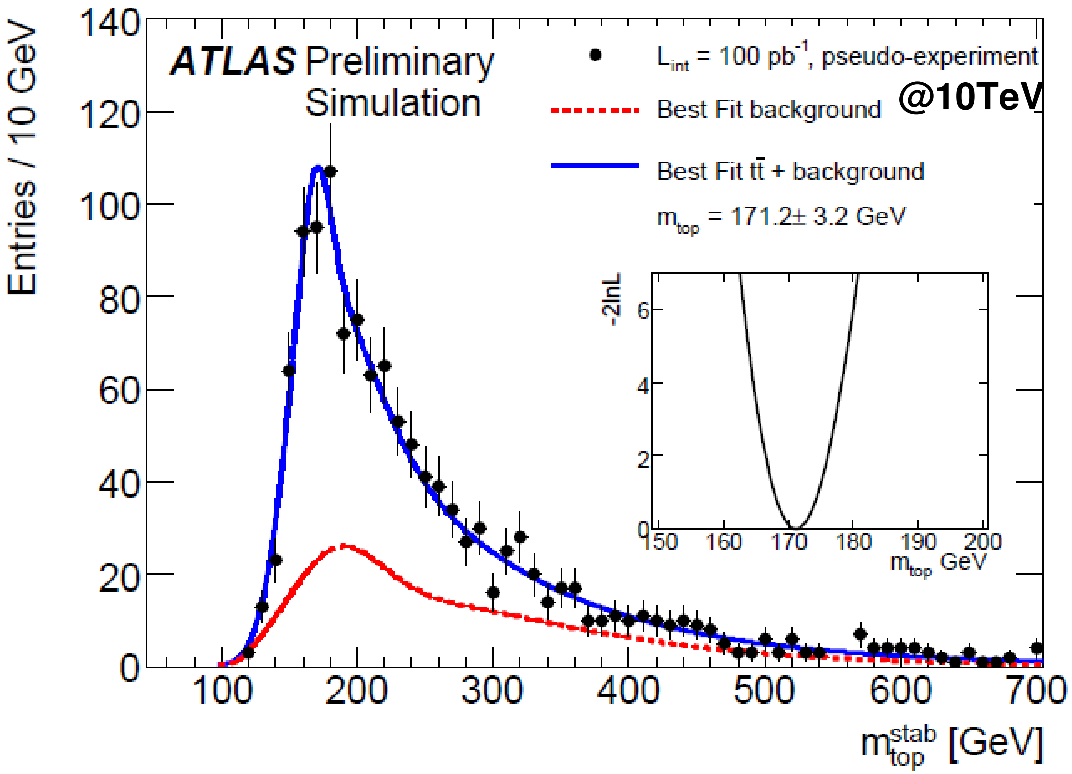
ATL-PHYS-PUB-2010-004

- 2010 Data sample:
  - ~45 pb^{-1} @ 7 TeV

$$m_{\rm top}^{\rm stab} \equiv \frac{m_{\rm top}^{\rm reco}}{m_W^{\rm reco}} \cdot m_W$$

- Employ stabilized mass, robust to against JES
- Loose selection without b-tagging: S/B ~ 1.4
- Input top mass 172.5 GeV

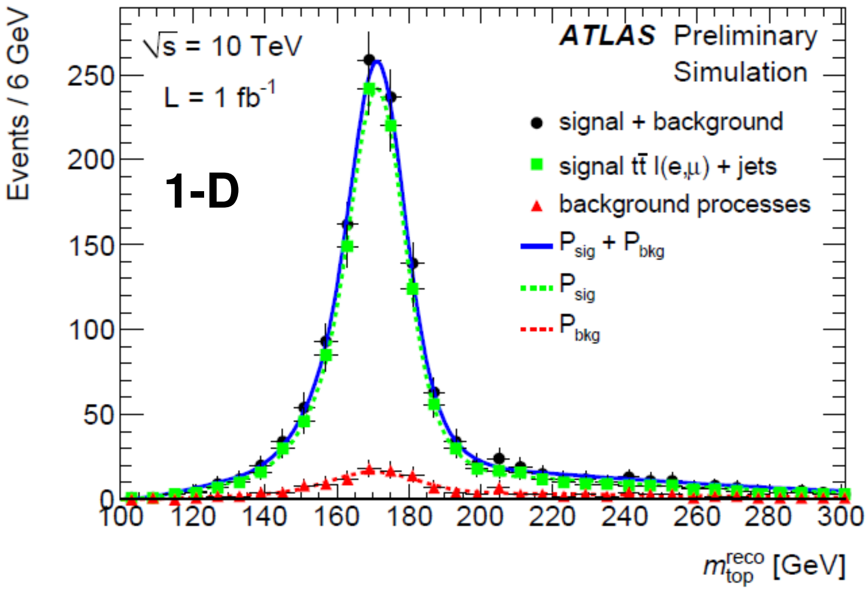




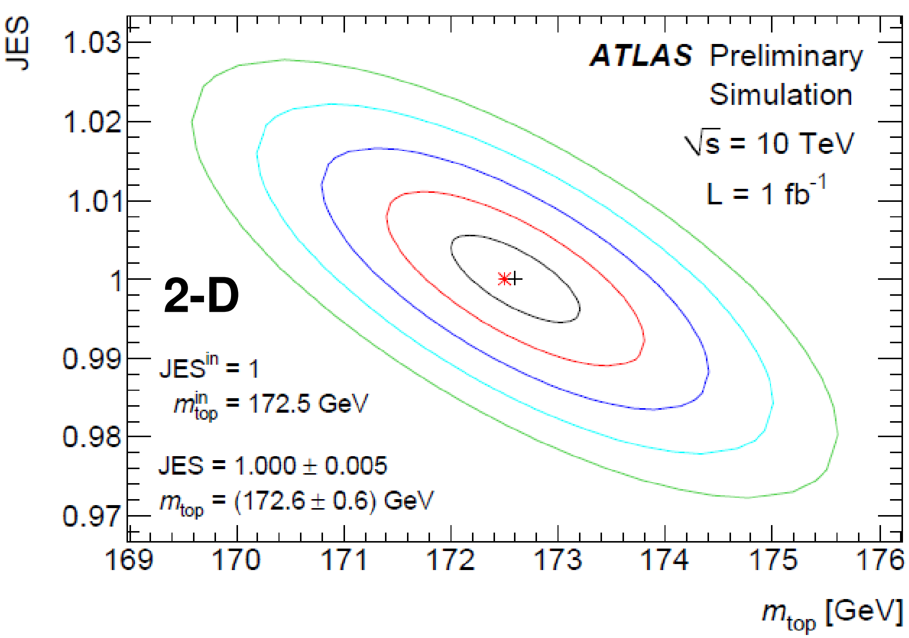
Statistical uncertainty [GeV] as a function of $\mathcal{L}_{\rm int}$			
@10TeV	10 pb^{-1}	30 pb^{-1}	100 pb^{-1}
Electron channel	10.8 ± 3.5	7.0 ± 2.1	2.7 ± 1.3
Muon channel	9.9 ± 3.9	5.8 ± 1.5	2.8 ± 0.8

~50% larger uncertainty @ 7 TeV

Top Mass prospects 2011 data



(a) The m_{top}^{reco} distribution



- 2-D method has a better S/B~8 by exploiting the b-tagging
- Kinematic fit of the decay products

→ it requires better understanding of the detector.

Expected uncertainties:

- **1D: $\Delta(m_{top})$ @10 TeV, 100 pb^{-1} = $\pm 2_{stat}$ $\pm 4_{syst}$ GeV**
- **2D: $\Delta(m_{top})$ @10 TeV, 1 fb^{-1} = $\pm 0.6_{stat}$ $\pm 2_{syst}$ GeV**

uncertainty comparable to Fermilab results.

Ttbar resonances

ATL-PHYS-PUB-2010-008

Basic event selection :

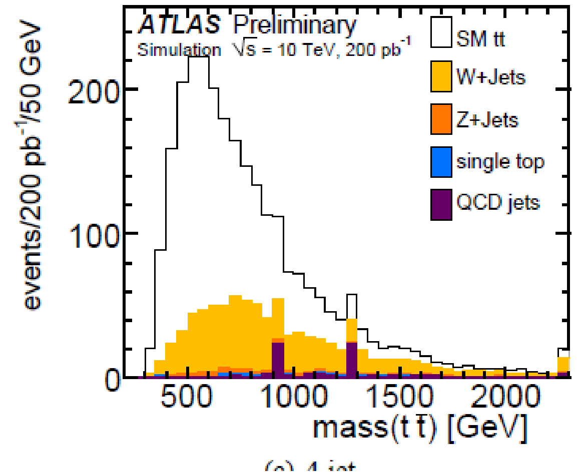
- ≥ 1 isolated lepton (e,μ) with pT > 20 GeV
- ≥ 2 jets with pT > 30 GeV, 1 b-tagged jet
- if MT (W) < 40 GeV : > 60 GeV (against QCD)

Mass spectrum reconstruction :

- Minimal reconstruction : mbjjbℓν (for early analyses)
- Full reconstruction : $m_{Z'} = m_{bjjbl\nu} - m_{bjj} - m_{bl\nu} + 2m_t^{PDG}$
- Monojet approach : jets anti-kT, R=1.0

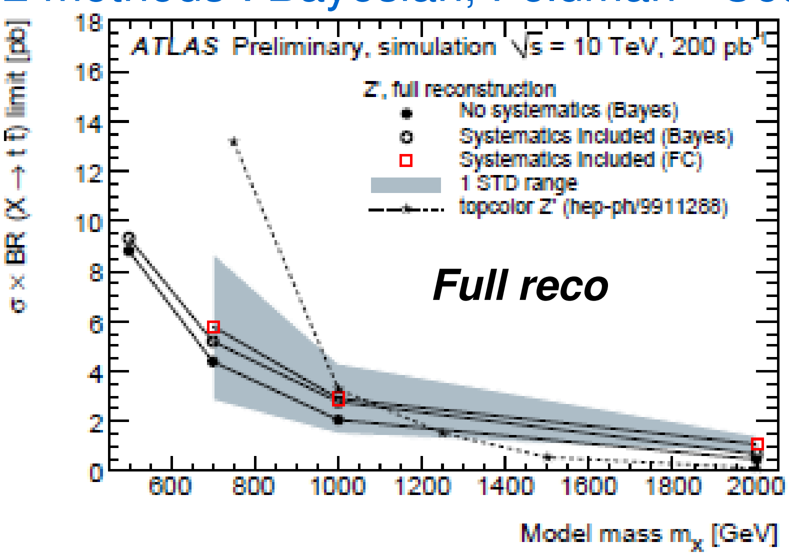
→ for highly boosted top quarks

Minimal

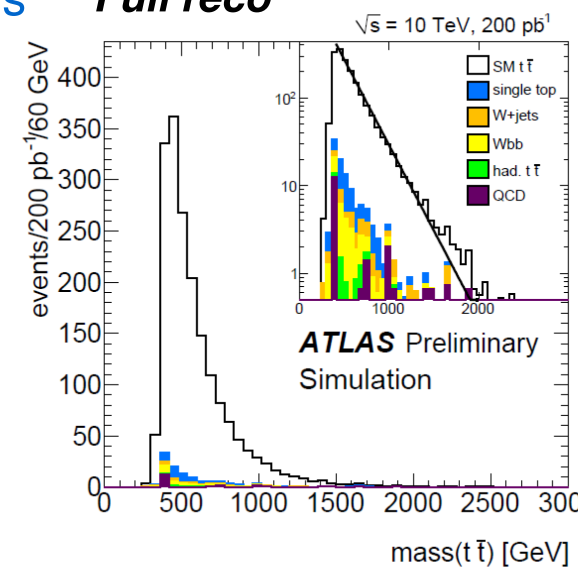


Sensitivity :

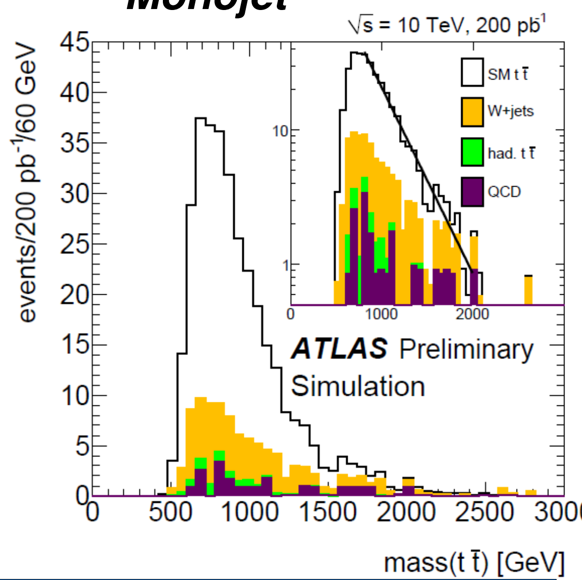
2 methods : Bayesian, Feldman - Cousins



Full reco



Monojet



Summary and Discussion

• Top Physics is among the ATLAS physical results of the first year of LHC data taking.

• **ATLAS performed the measurement of the Top pairs cross section measurement** for *both the lepton+jets and di-lepton channels.* Statistical and systematic errors are comparable in the final result.

• Measurement of the **cross-section in channels with τ** are expected in 2011.

• **Top Mass** measurement with good accuracy possible with 2010 data. Accuracy comparable with Fermilab results could be in 2011.

• **Single top** cross section measurement in the *t-channel and Wt channel* and **ttbar resonances** searches **can be delivered with O(0.1-1 fb^{-1}).**

Stay tuned for more results in 2011.

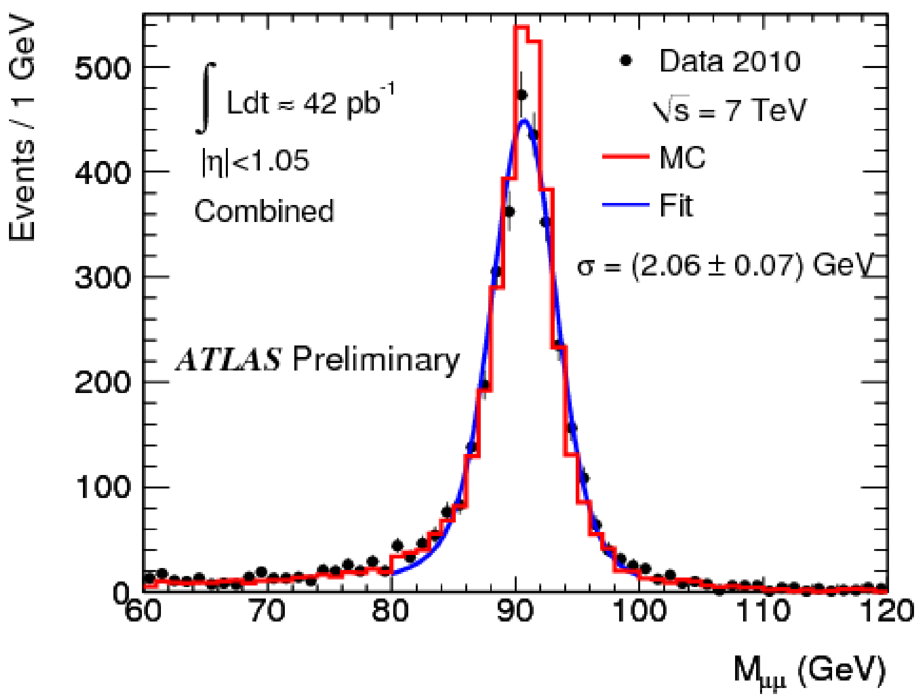
• **Top Physics measurements are a necessary step to show the sensitivity of ATLAS detector to new physics.**

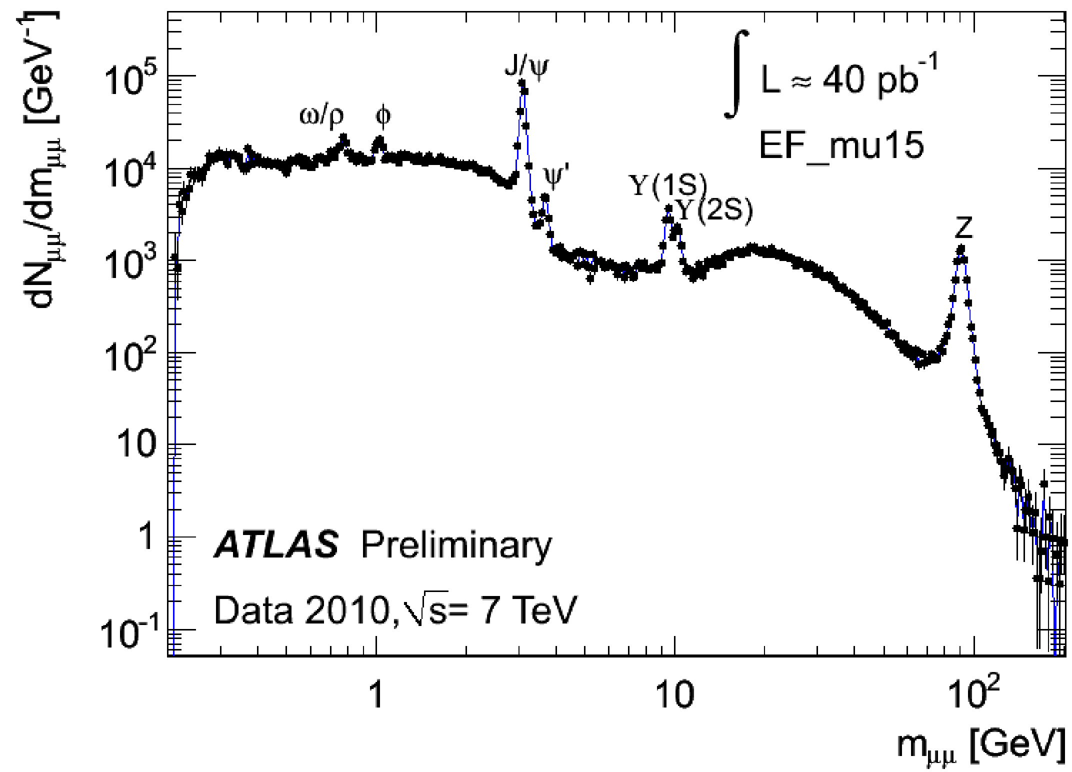
•More informations at:

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

Bonus Slides

Muons





Combined Muon pairs of opposite charge

p_T> 20 GeV

Track isolation in DR<0.4 ptcone<0.2 p_T muon

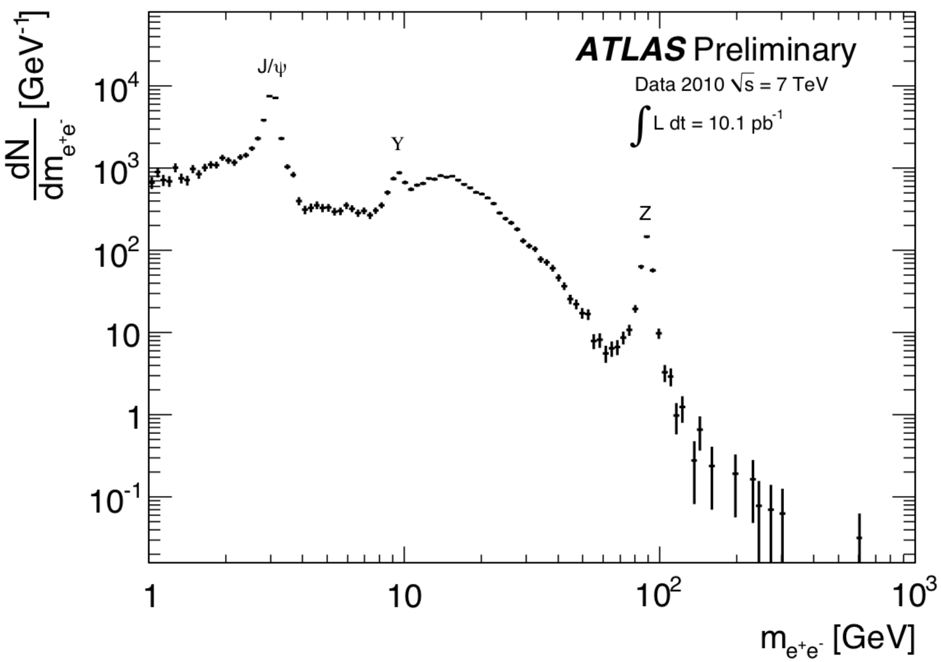
Leading muon, p_T>15 GeV, second muon, p_T>2.5 GeV

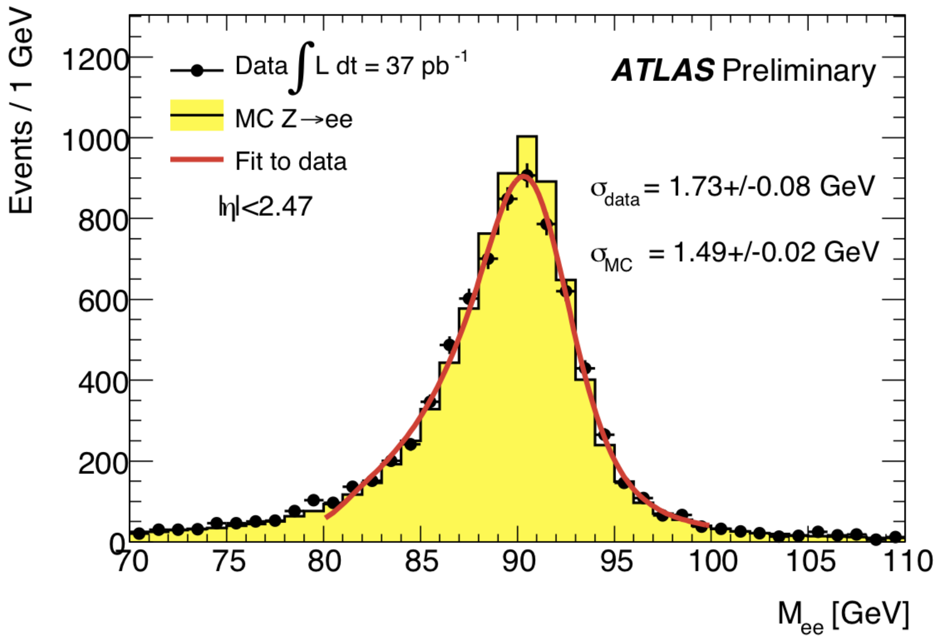
Electrons

- Calibrate EM scale with constrained fit to the Z line-shape in 28 calorimeter regions. Typical corrections 2%, consistent with precision of cryostat temperature measurement in test beam.

Data with 5 GeV E_T di-electron trigger (prescaled in later data)

Trigger selection produces shoulder around 15 GeV

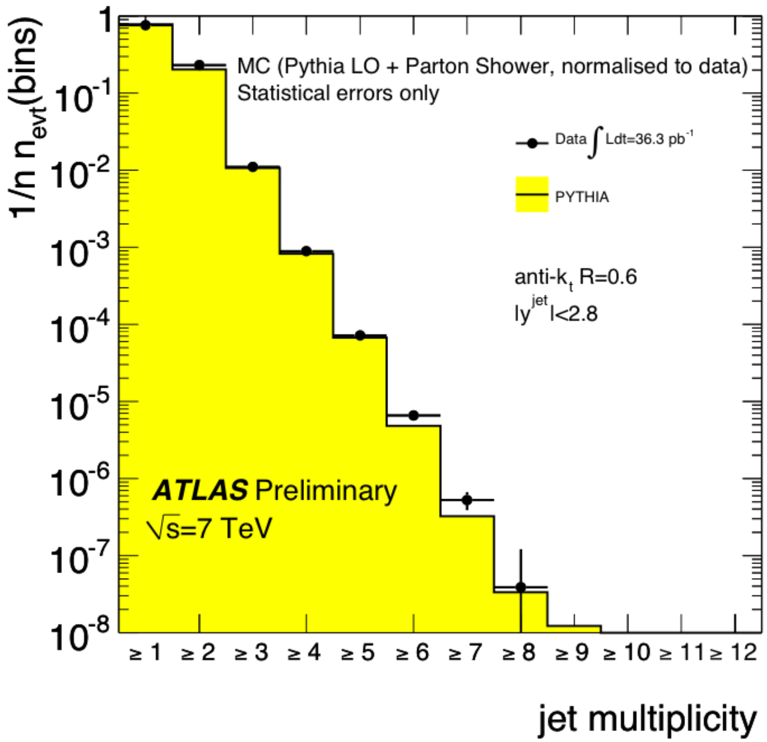


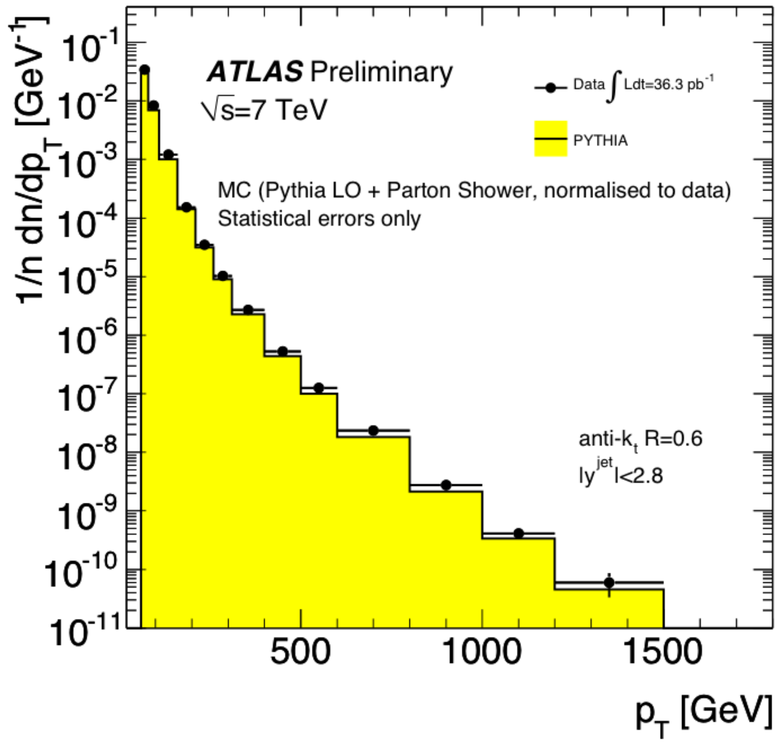


Fit to a Breit-Wigner convolved with crystal ball function.

Stat errors only.

Jets





Jets corrected to hadronic scale

(JES uncertainty ~7%)

- Jet p_T>60GeV
- Highest p_T jet 1.3 TeV

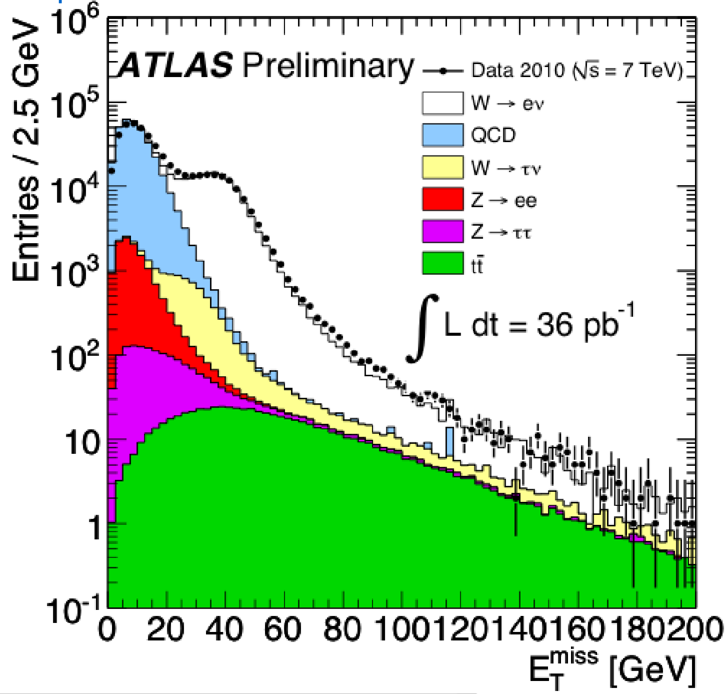
Count jets with p_T>60 GeV

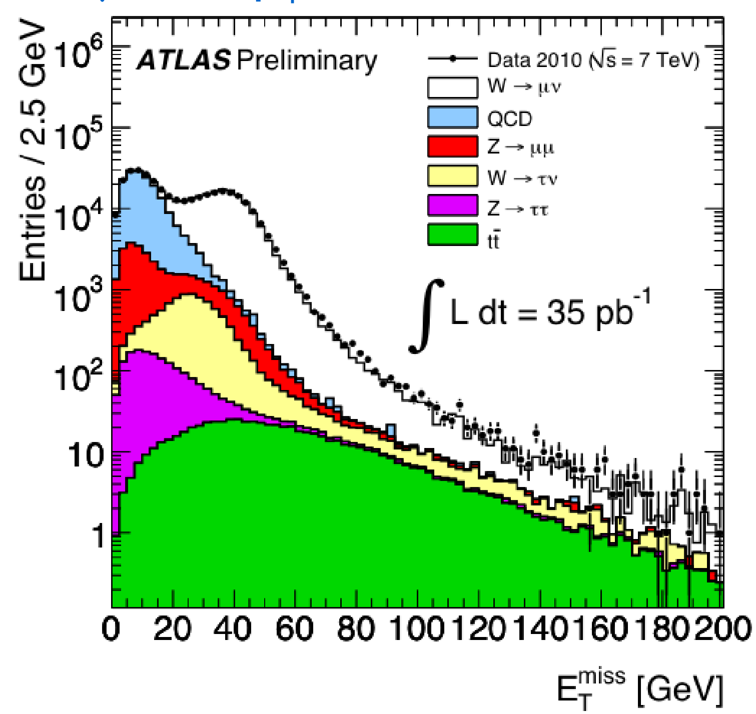
1 event with 8 jets

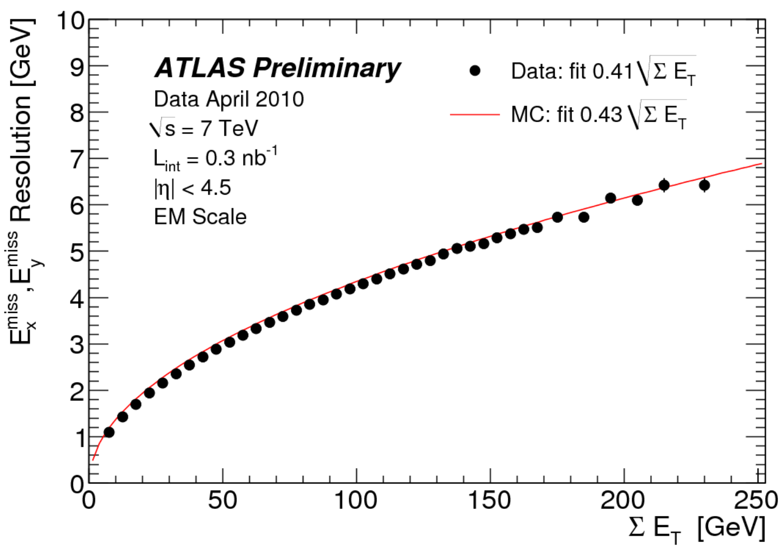
Shape comparison with MC PYTHIA (LO + parton shower)

Missing Transverse Energy

E_T^{miss} distribution for events with e or μ with p_T>20 GeV



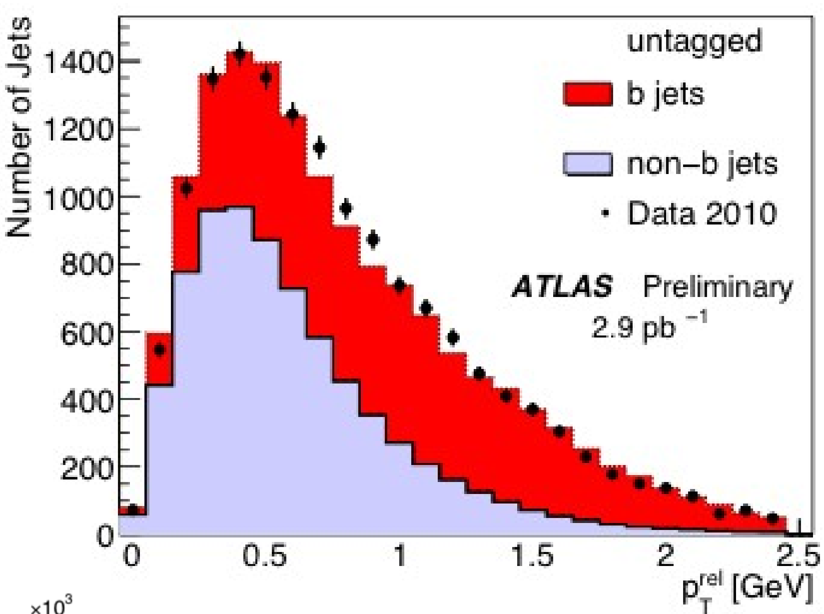


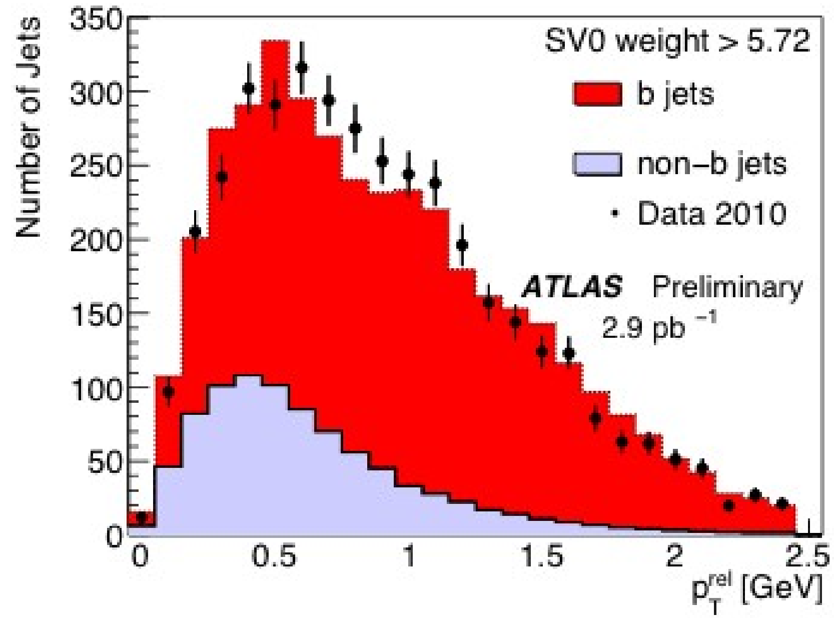


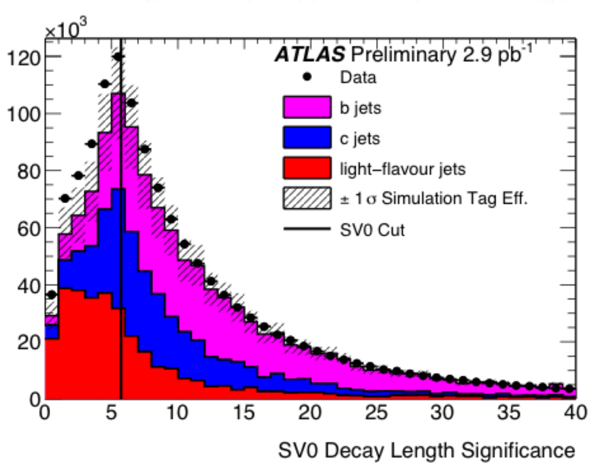
E_T^{miss} resolution as a function of the $SumE_T$

B-tagging

- Calibrate SV0 (secondary vertex) tagger $L/\sigma(L)>5.72$
  - 50% tag efficiency point in simulated ttbar events.
- Tag rates from template fit to p_T^{rel} of muons
  - Evaluate data/MC scale factors.







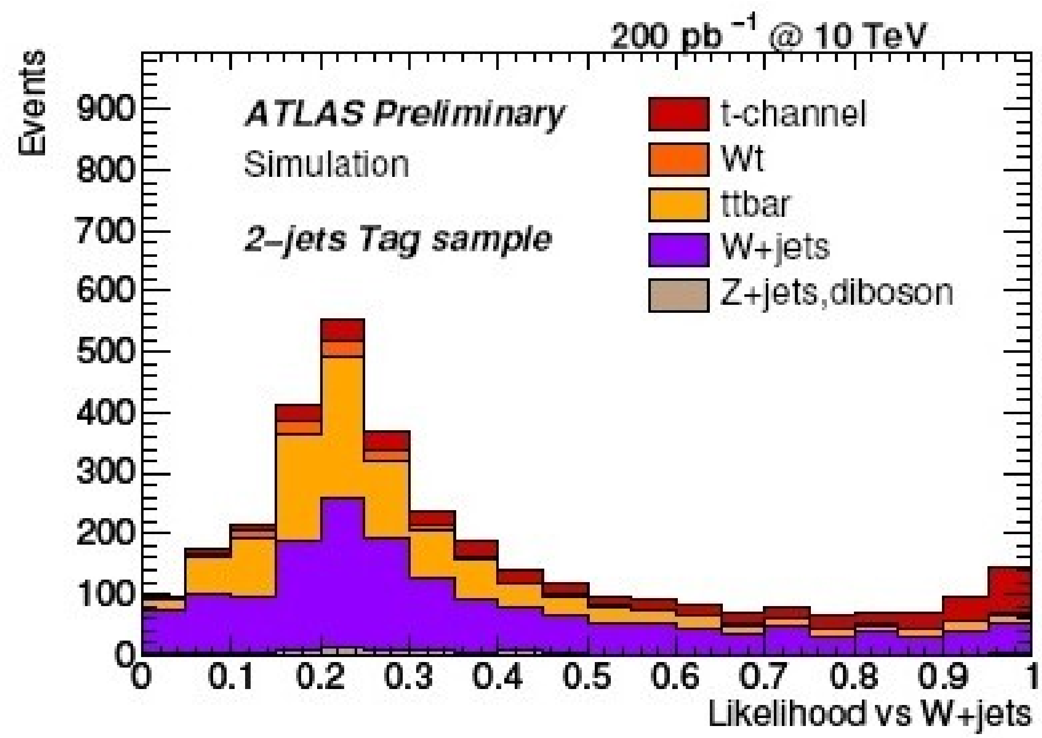
After all corrections

- Mis-tag rate from vertex mass fit or rate of $L/\sigma(L)<-5.72$
  - Mis-tag rate ranges from 0.2 to 1%, as p_T increases

Single top

Event selection :

- = 1 isolated lepton (e,μ) with pT > 20 GeV
- = 2 jetswith pT > 30 GeV, 1 b-tagged jet
- > 20 GeV, MT (W) > 30 GeV (against QCD)



Top Spin Correlation

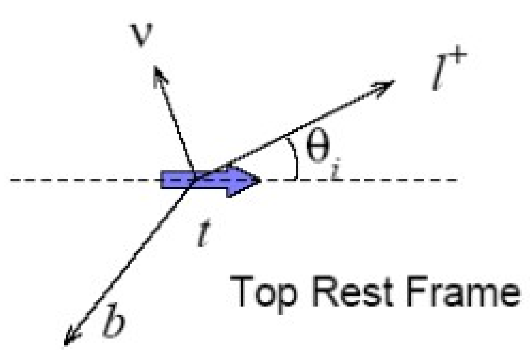
The top anti-top are produced unpolarized, but their spins are correlated

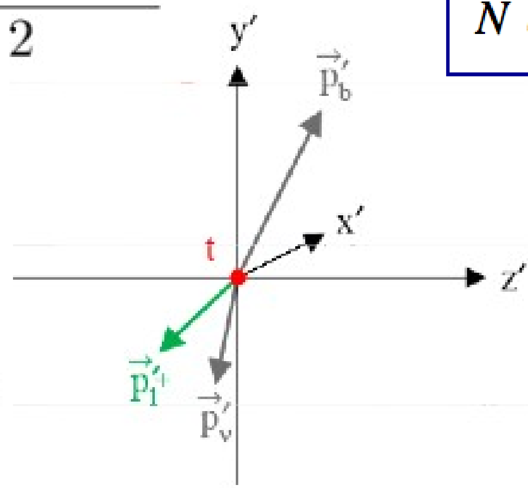
$\Gamma(t) \approx$ 1.4 GeV » Λ^2_{QCD}/m_{top} The top quark decays before hadronizing: the decay products keep information of the angular correlations

SM prediction of the ttbar correlations can be tested by measuring the angular distribution of the decay products (it has never been observed).

in t (tbar) rest frame

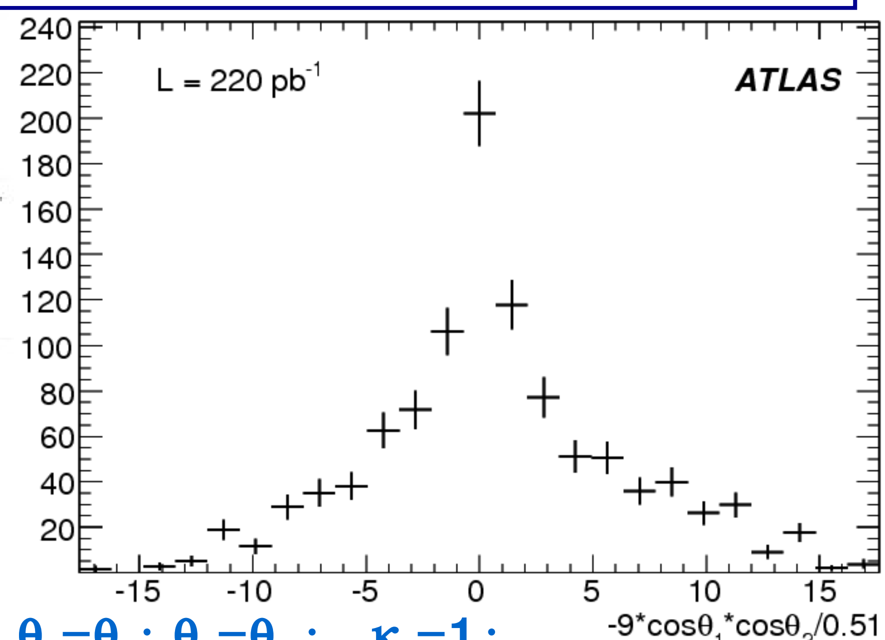
$$\frac{1}{\Gamma}\cdot\frac{d\Gamma}{d\cos\theta_i}=\frac{1+\alpha_i\cos\theta_i}{2}$$





in tt rest frame

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_l\,d\cos\theta_q}=\frac{1}{4}(1-A\kappa_l\kappa_q\cos\theta_l\cos\theta_q)$$



$\theta_1=\theta_l$; $\theta_2=\theta_q$; $\kappa_1=1$;

Results for 220 pb^{-1}: SM prediction

A =0.67±0.17$_{(stat)}$±0.18$_{(syst)}$±0.25$_{(MC)}$ 0.422

A =-0.40±0.11 ±0.09 -0.290

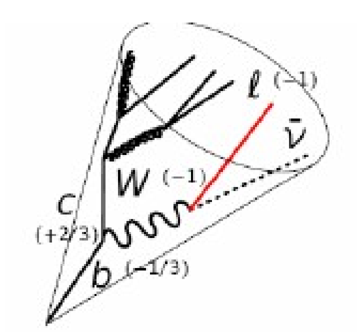
Top quark Charge discrimination

– Goal is to discriminate between SM q_{top}=2/3 and exotic models with q_{top}=-4/3

Determinate sign of the lepton charge, determine the b-quark – lepton matching, determinate sign of b quark in the B-jet

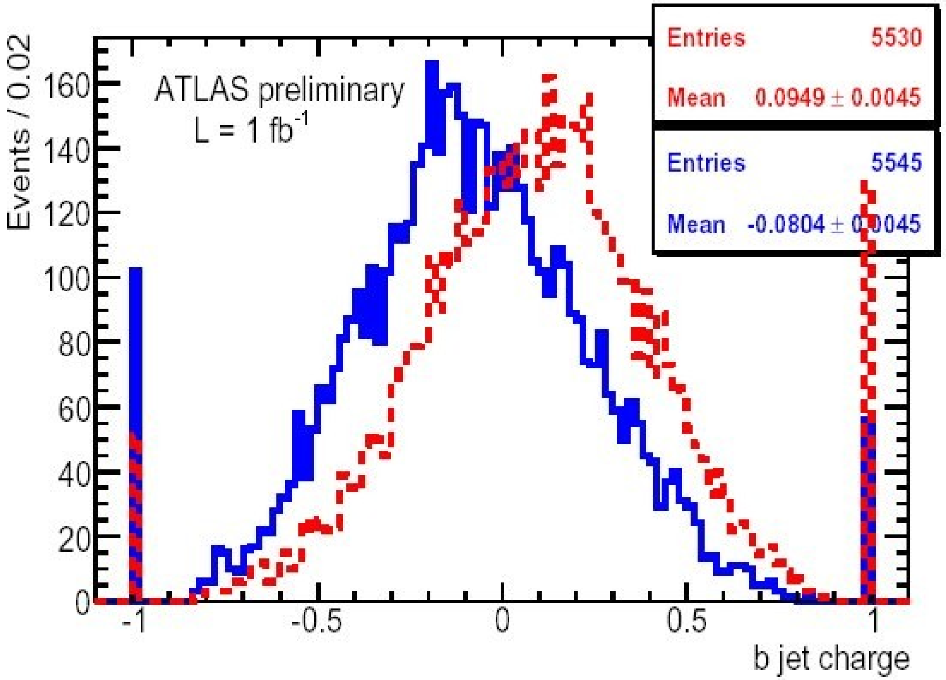
– Technique:

- Charge weighting $$Q_{\mathrm{bjet}} = \frac{\sum_i q_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}$$ k=0.51 optimizes the discrimination
- Semileptonic B decays approach - -



$b \rightarrow q\, l^- \bar{\nu}$

$\bar{b} \rightarrow \bar{q}\, l^+ \nu$



Separation at 5σ with ~100 pb^{-1} (**ATLAS**)

Systematics: ISR/FSR, MC model, b-jet scal

Wtb Anomalous Coupling

In general, the t→bW vertex can be written as:

$$\mathscr{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)\,t\,W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)\,t\,W_{\mu}^{-} + \mathrm{h.c.}$$

W helicity fractions F_0 , F_L , and F_R depend on these couplings

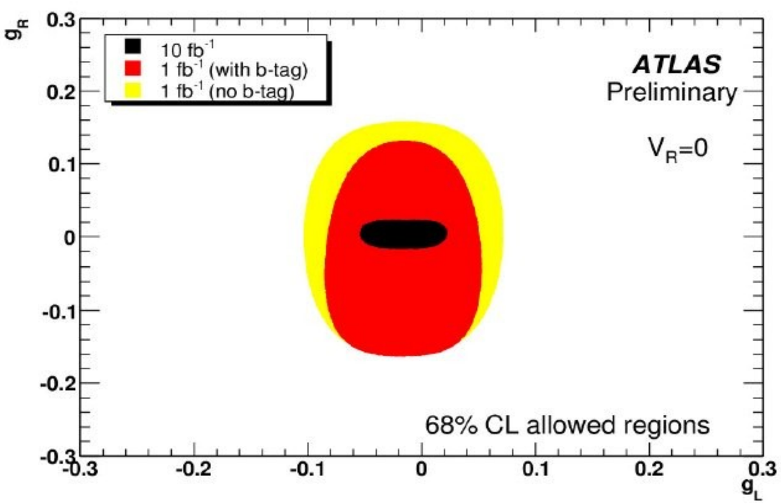
($P_{R/L} = (1 \pm \gamma^5)/2$)

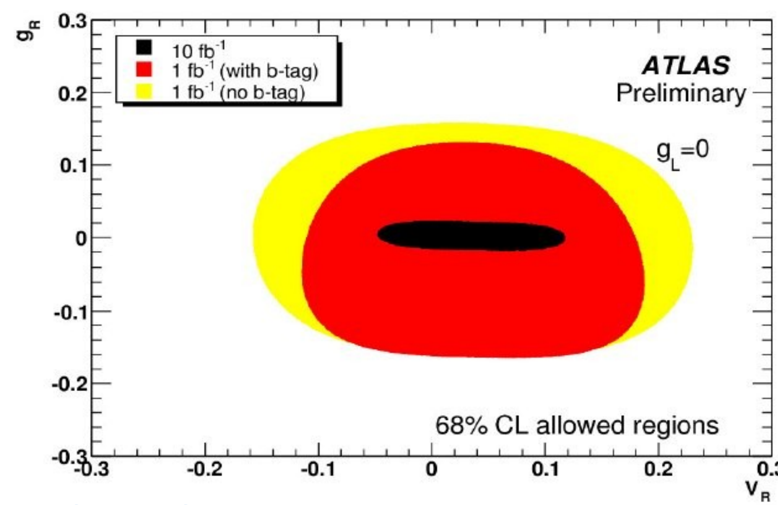
anomalous coupling terms

ATLAS: measure $\rho_L = F_L / F_0$, $\rho_R = F_R / F_0$ and angular (forward/backward) asymmetries

Results can be delivered for 1 fb^{-1}

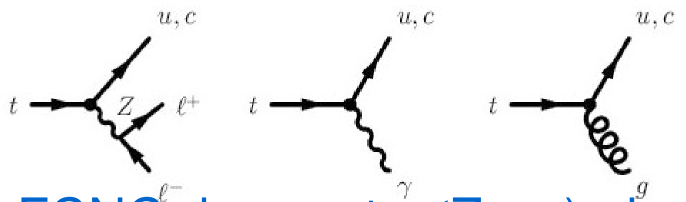
SM prediction: $\rho_L = 0.423$, $\rho_R = 5.1 \cdot 10^{-4}$





Dominating systematics: ISR/FSR, pile-up

FCNC Searches



FCNC decays $t \rightarrow (Z,\gamma,g)q$ is suppressed in SM (10^{-10}

NP could manifest itself with BR 10^{-3} - 10^{-6}

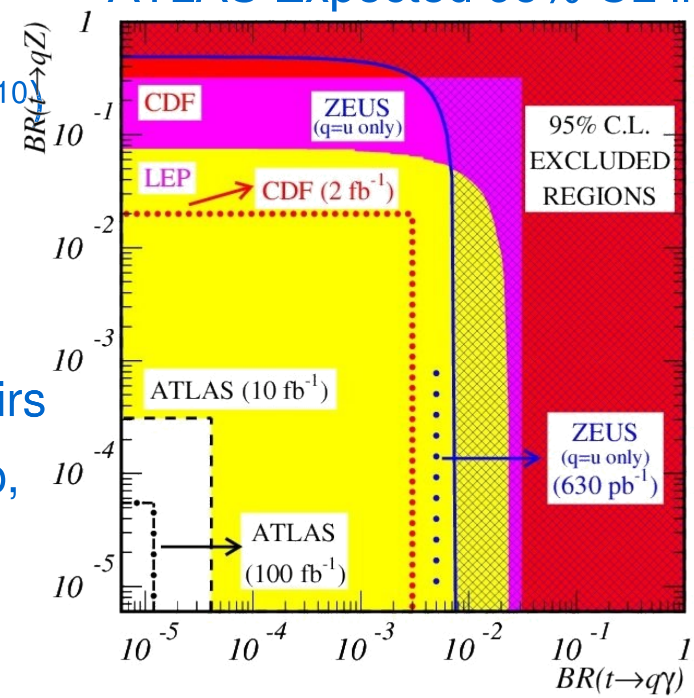
Signature in top-pair production:

- 1 top decays $t \rightarrow Wb$ with leptonic W
- Look for high E_T gluon jet or photon or lepton pairs

Main systematics: ISR/FSR, MC generator, pile-up, bkg. uncertainties.

ATLAS: Some contributions can be removed using likelihood selection with event shape and top mass reconstruction.

ATLAS Expected 95% CL limits:



Channel	Exp		BR 5σ sens.
$t \rightarrow Zq$	ATLAS	@ 1 fb^{-1}	10^{-2} (lklhd)
$t \rightarrow g\ q$	ATLAS	@ 1 fb^{-1}	10^{-2} (lklhd)
$t \rightarrow gq$	ATLAS	@ 1 fb^{-1}	10^{-2} (lklhd)