LHC days in Split, October 5th , 2010

Top physics with ATLAS

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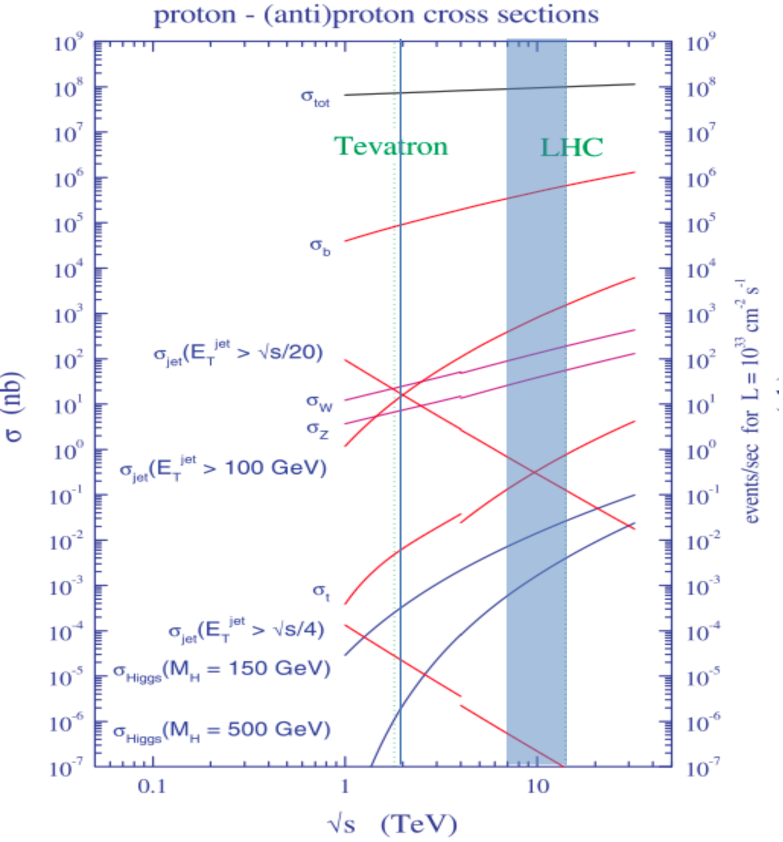
on behalf of the ATLAS collaboration

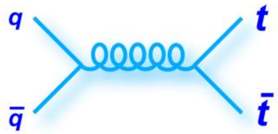
1. Introduction
2. Ingredients for top quark physics
3. First ttbar candidate events
4. Background estimation
5. Plans for first top measurements
6. Summary

Top production at the LHC

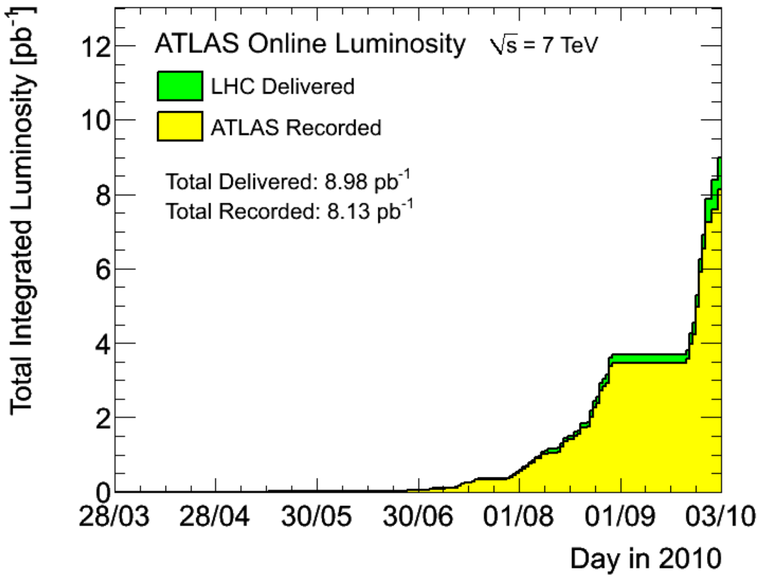


Top pair production :

- **Tevatron :** ≈ 85% quark-antiquark annihilation



- **LHC :** ≈ 85% gluon fusion



- **The LHC is a top factory**
  → σ_{tt} LHC (7 TeV) ≈ 20 σ_{tt} Tevatron
- **We expect 1 fb^{-1} by the end of 2011**
  → we might have double the statistics available at the Tevatron

Top physics at the LHC

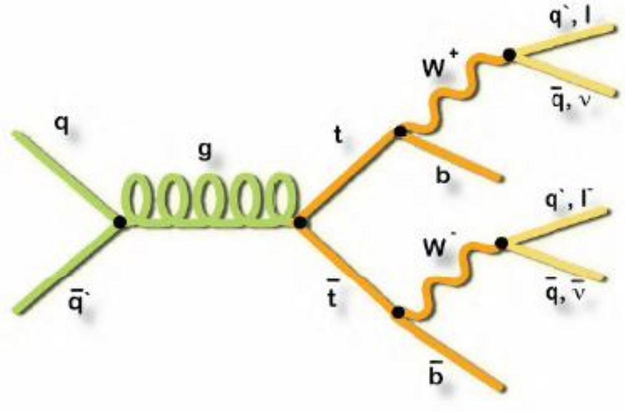
With early data :

- **Top rediscovery** (few pb^{-1})

→ First cross-section measurement

- **Detector calibration**

→ Jet energy scale, b-tagging efficiency



Next :

- **Precision tests of SM**

→ precise m_t measurement to constrain M_H

→ single top measurements

ttbar decay modes:

- all jets : 46%
- lepton plus jets : 44%
- dilepton : 10%

- **Top is a good probe to search for new phenomena**

→ **2 categories of searches :**

1. *Look at what top decays/couples to :*

→ charged Higgs decays in MSSM or NMSSM

→ decays to Zc, Zu (FCNC)

2. *Look at particles decaying to t-tbar or t-bbar :*

→ Many models predict heavy objects that decay into ttbar :
ex: Z', KK excitations, MSSM Higgs, topcolor

→ W' → t bbar search

→ 4th generation t'

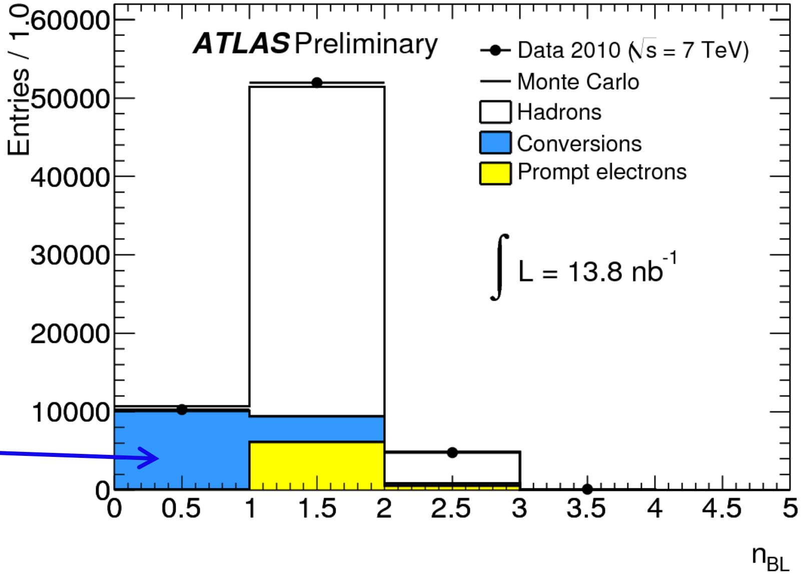
→ stop seach

SM top pair production is often the main background for new physics searches

Leptons

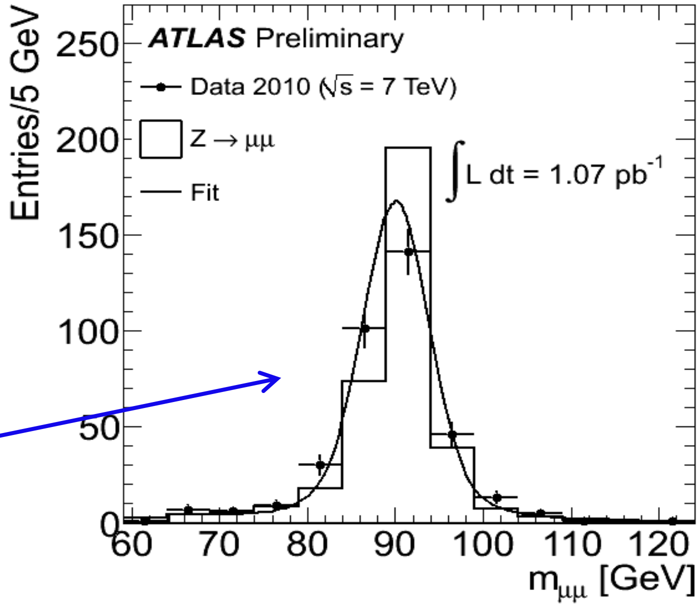
Electrons:

- **Main sources of fakes :**
  - γ conversion and fakes from hadron
- **Identification :**
  - Acceptance, E_T , and fiducial cuts
  - Lateral width of the shower
  - Fraction of energy in the strip layer (to reject π^0) :
  - Track quality : hits in pixel, pixel+SCT, d_0
  - Cluster-track matching ($\Delta\eta < 0.01$)
  - Hits in the B-layer n_{BL} (against γ conversion)



Muons :

- **Main sources of fakes :**
  - π,K decays and punch-through
- **Reconstruction :**
  - Statistical combination of ID & MS tracks
- **Relative momentum scale and resolution :**
  - $$\frac{\Delta p}{p} = \frac{p^{ID} - p^{MS}}{p^{ID}} \Rightarrow$$ Momentum scale < 2% (B & EC)
  - Good resolution observed with Z → μμ events



Jets

Reconstruction :

- Anti-k_t algorithm, R = 0.4
- Topoclusters as input

Calibration schemes :

Jets are calibrated at the truth-particle level to correct jet energy for calorimeter non-compensation, dead material, shower leakage, pile-up

- **EM + JES (default for top analyses) :**

  simple p_T and η dependent calibration (based on MC or from data using γ+jets and di-jets balance techniques)

commissioning

- **Global sequential (GS) :**

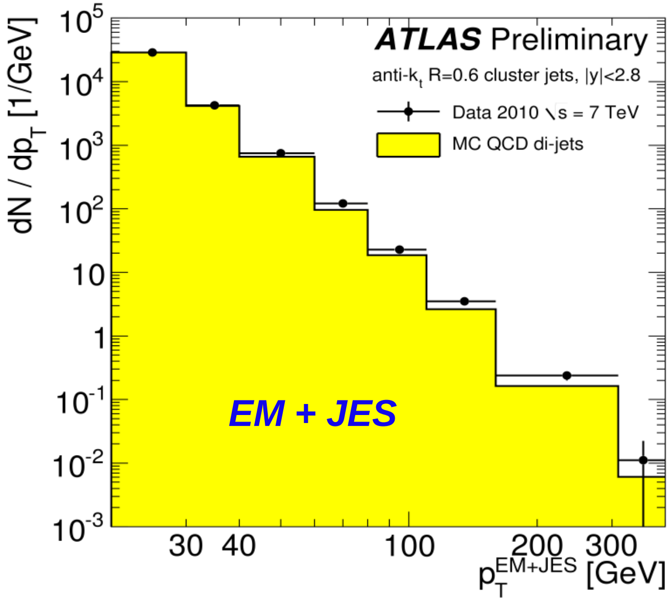
  start from EM+JES and add jet-by-jet information about the shower shape properties of the jet to improve the resolution
- **Global cell energy-density weighting (GCW) :**

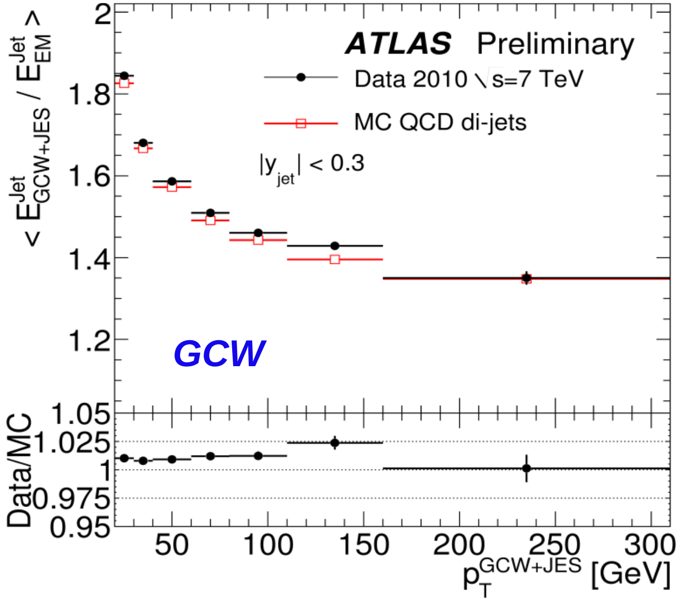
  cell weights based on cell energy densities to compensate for different calorimeter response to HAD/EM energy deposition (MC)
- **Local cluster weighting (LCW) :**

  uses properties of topoclusters to calibrate them individually (weights based on pions MC)

Performance with data :

➡ *Calibrated jets energies in data/MC agree at the level of 2%*





Missing transverse energy

- **Reconstruction :**

Include contributions from cells in topoclusters, muons and corrections for energy loss in the cryostat

- **Global calibration (independent of the object) :**
  - Global cell weighting calibration (GCW) :

    cell-level signal weight
  - Local cluster weighting calibration (LCW) :

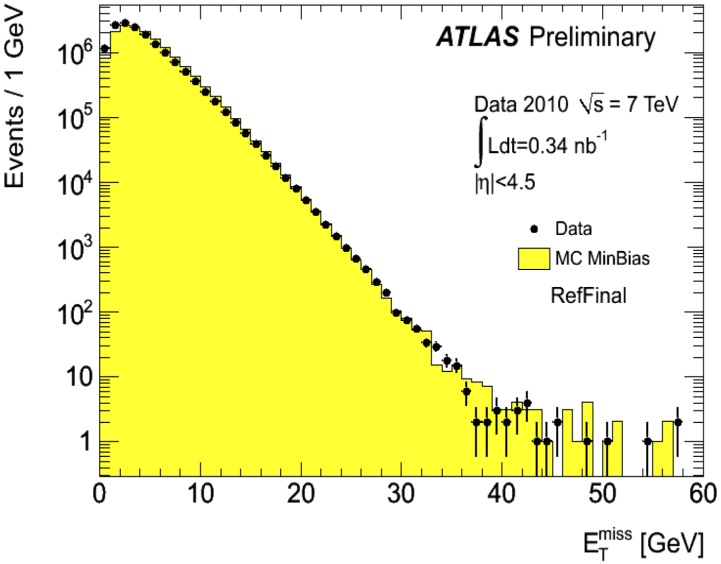
    cells weights according to the topocluster topology

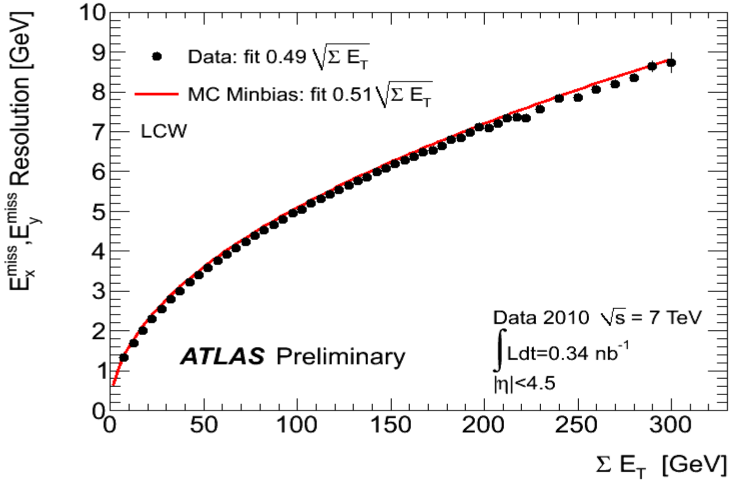
- **Refined calibration**

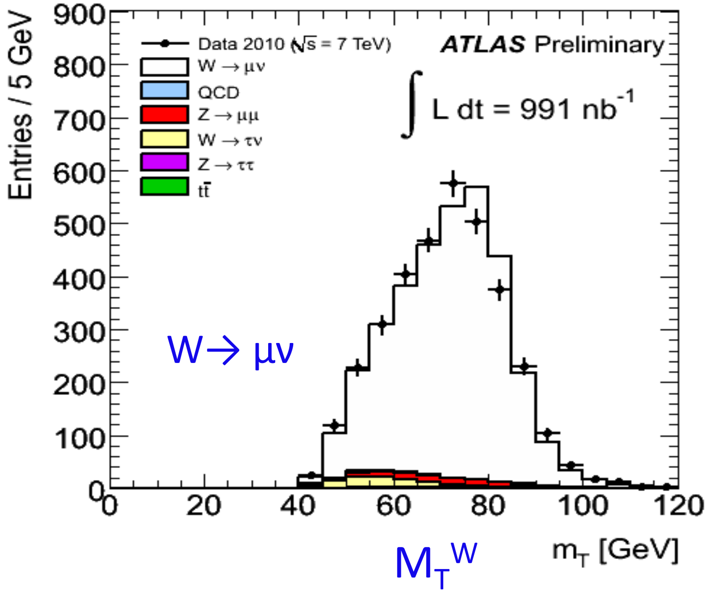
Refinement of the cells calibration from physics objects

- **Resolution :**

➡ *Good agreement between MC and data for min bias events*







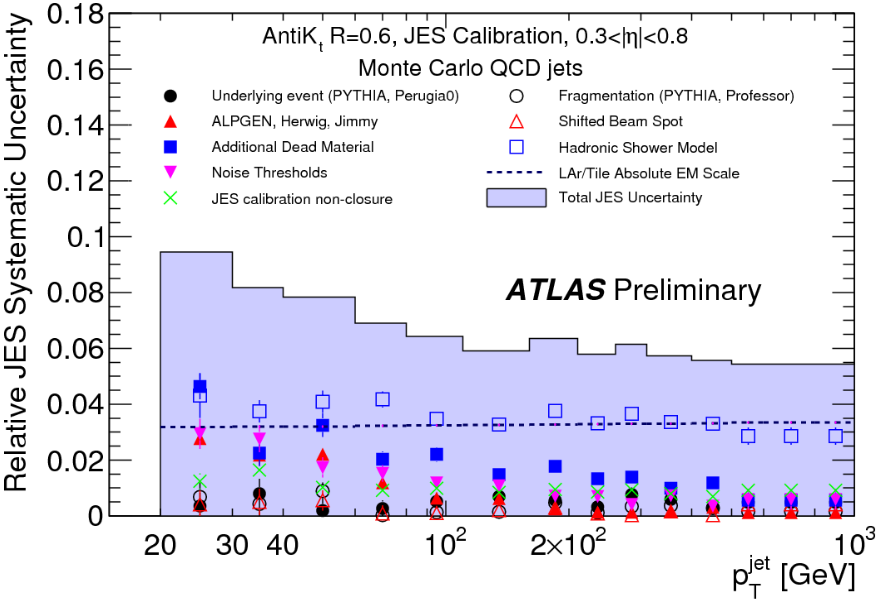
Jet energy scale and resolution

Jet energy scale uncertainty :

JES uncertainty estimated by comparing MC simulations using various detector configuration, hadronic shower and physics models

Main sources of systematic uncertainties :

- Dead material : 5%
- Noise description : 3%
- Hadronic shower model : 5%
- Lar/Tile absolute EM scale : 3%



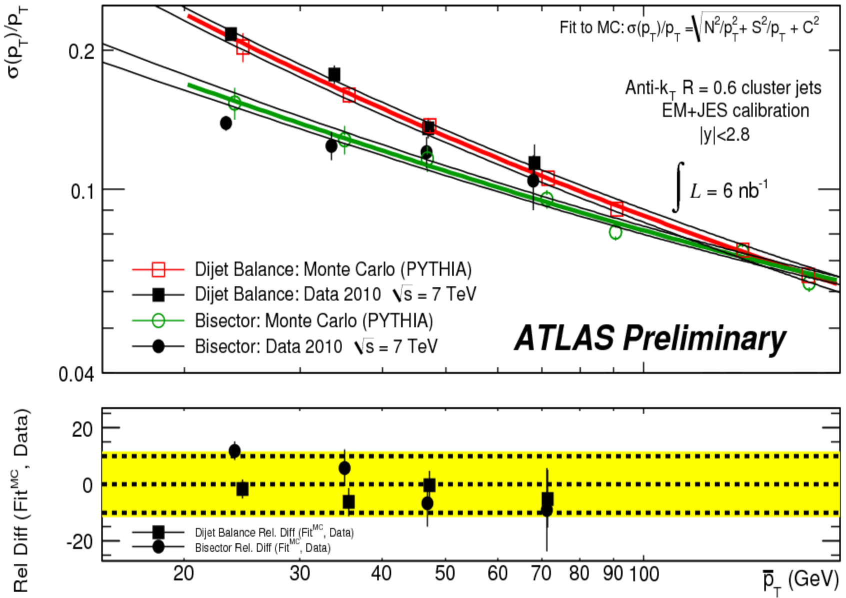
JES uncertainty , anti k_T , R = 0.4

	Barrel	End-caps
p_T < 60 GeV	8%	9%
p_T > 60 GeV	6%	7%

Jet energy resolution :

Jet energy resolution measured *in-situ* using di-jet balance and bi-sector techniques.

Measure $A = \dfrac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}} \longrightarrow \dfrac{\sigma_{p_T}}{p_T} = \sqrt{2}\sigma_A$



MC and data agree within 14% for 20 < p_T < 80 GeV

b-tagging

- **3 main identification algorithm categories :**
  1. Impact parameter based taggers : Trackcounting, JetProb

     → look for displaced tracks wrt PV
  2. Secondary vertex tagger : **SVO** (default for early top analyses)

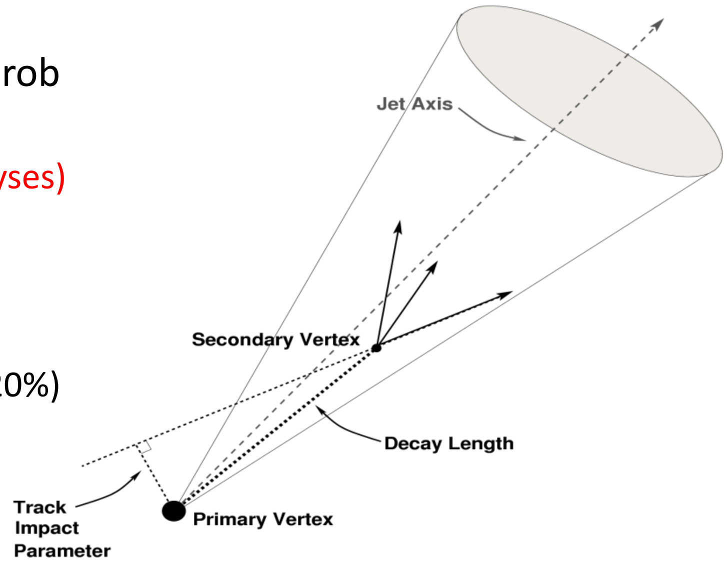
     → explicit reconstruction of the b-hadron decay vertex

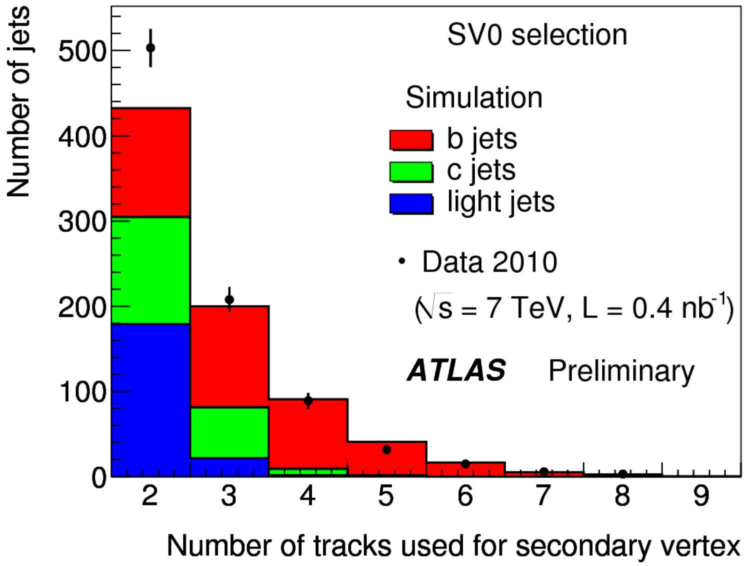
     → use 3D decay length significance L/σ(L) as discriminant variable
  3. Soft muon tagger :

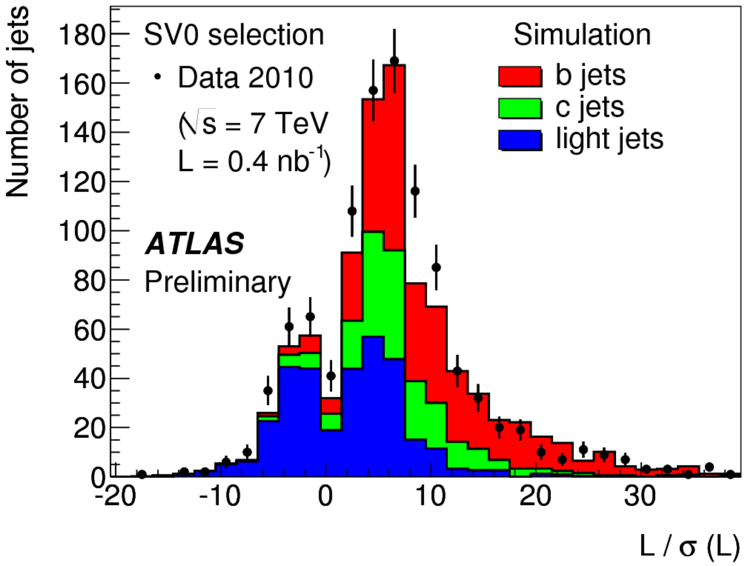
     → exploits semi-leptonic decay of b and c-hadrons to muons (BR=20%)

     → use p_T (μ) as discriminant variable

➡ *Can be used for calibration of lifetime tagging algorithm*







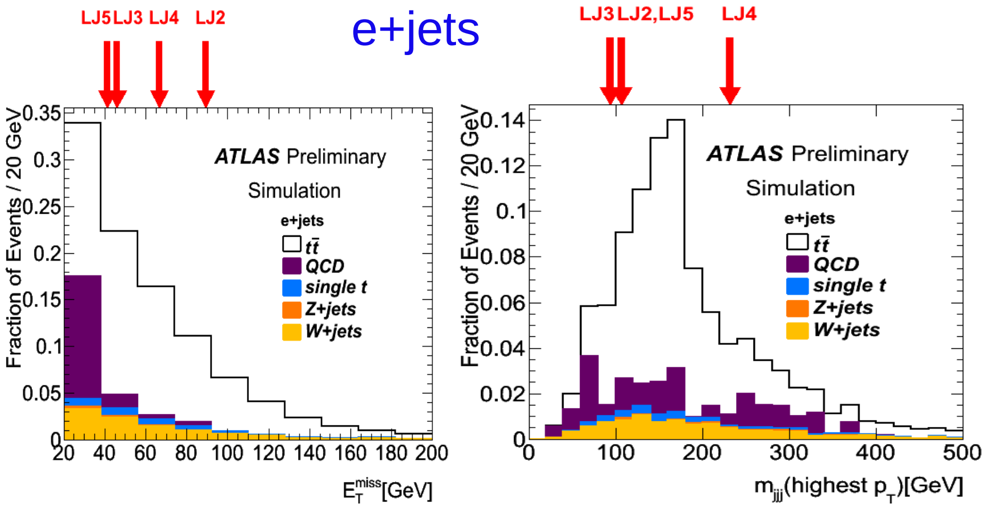
Top candidates : ℓ(e,μ)+jets channel

Event selection :

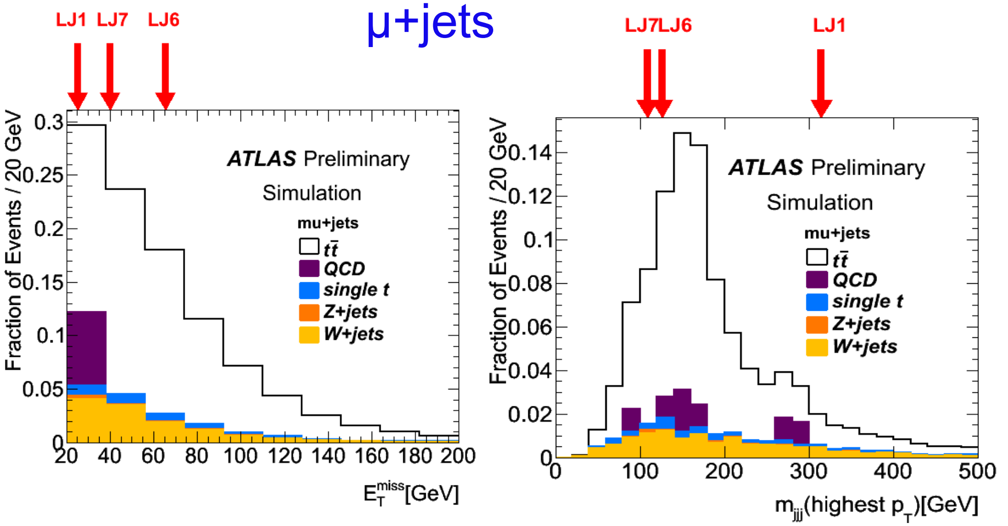
- Primary vertex with ≥ 5 tracks
- Exactly 1 isolated lepton (e,μ)
  - $p_T > 20$ GeV
  - trigger matching
- ≥ 4 jets (anti-kt R=0.4 at EM+JES scale)
  - $p_T > 20$ GeV
  - e/jet overlap removal
- ≥ 1 b-tagged (SV0 at 50% efficiency)
- $E_T^{miss} > 20$ GeV

→ *7 candidates in 295 nb^{-1}*

e+jets



μ+jets



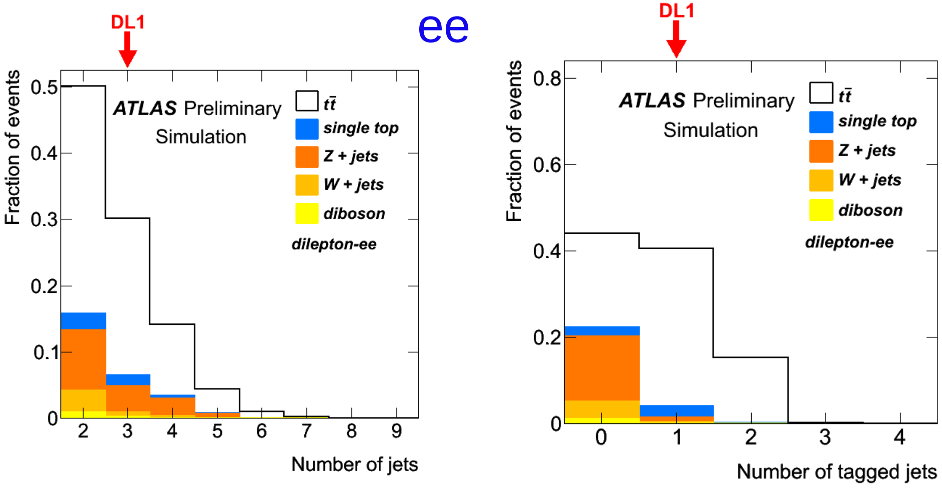
Top candidates : dilepton channel

Event selection :

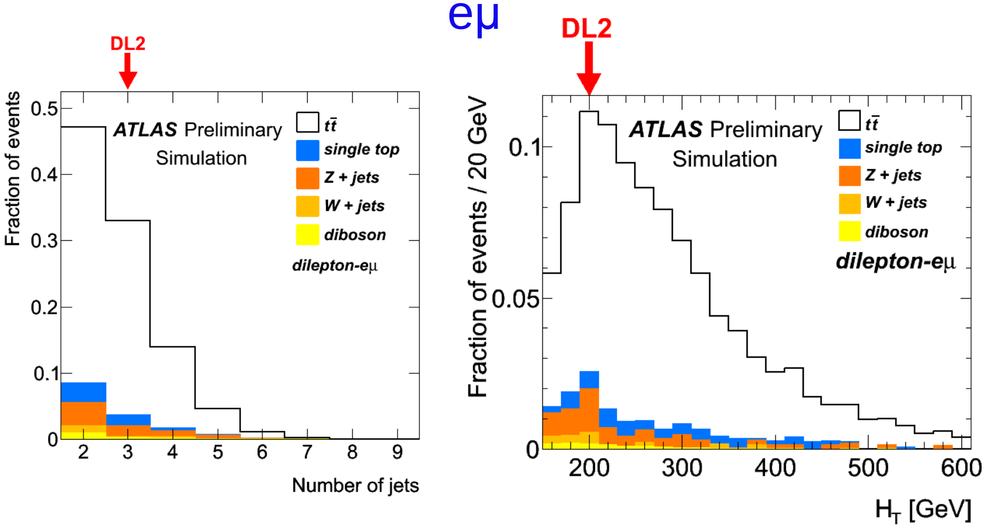
- primary vertex with ≥ 5 tracks
- Exactly 2 isolated leptons (e,μ)
  - p_T > 20 GeV
  - opposite charges
  - ≥ 1 with trigger matching
- ≥ 2 jets with p_T > 20 GeV
- **Specific selection for each channel :**
- **ee :** E_T^{miss} > 40 GeV, $|M_{ee} - M_Z|$ > 5 GeV
- **μμ :** E_T^{miss} > 30 GeV, $|M_{\mu\mu} - M_Z|$ > 10 GeV
- **eμ :** $H_T = \sum E_T$ (leptons+jets) > 150 GeV

➡ *2 candidates in 295 nb^{-1}*

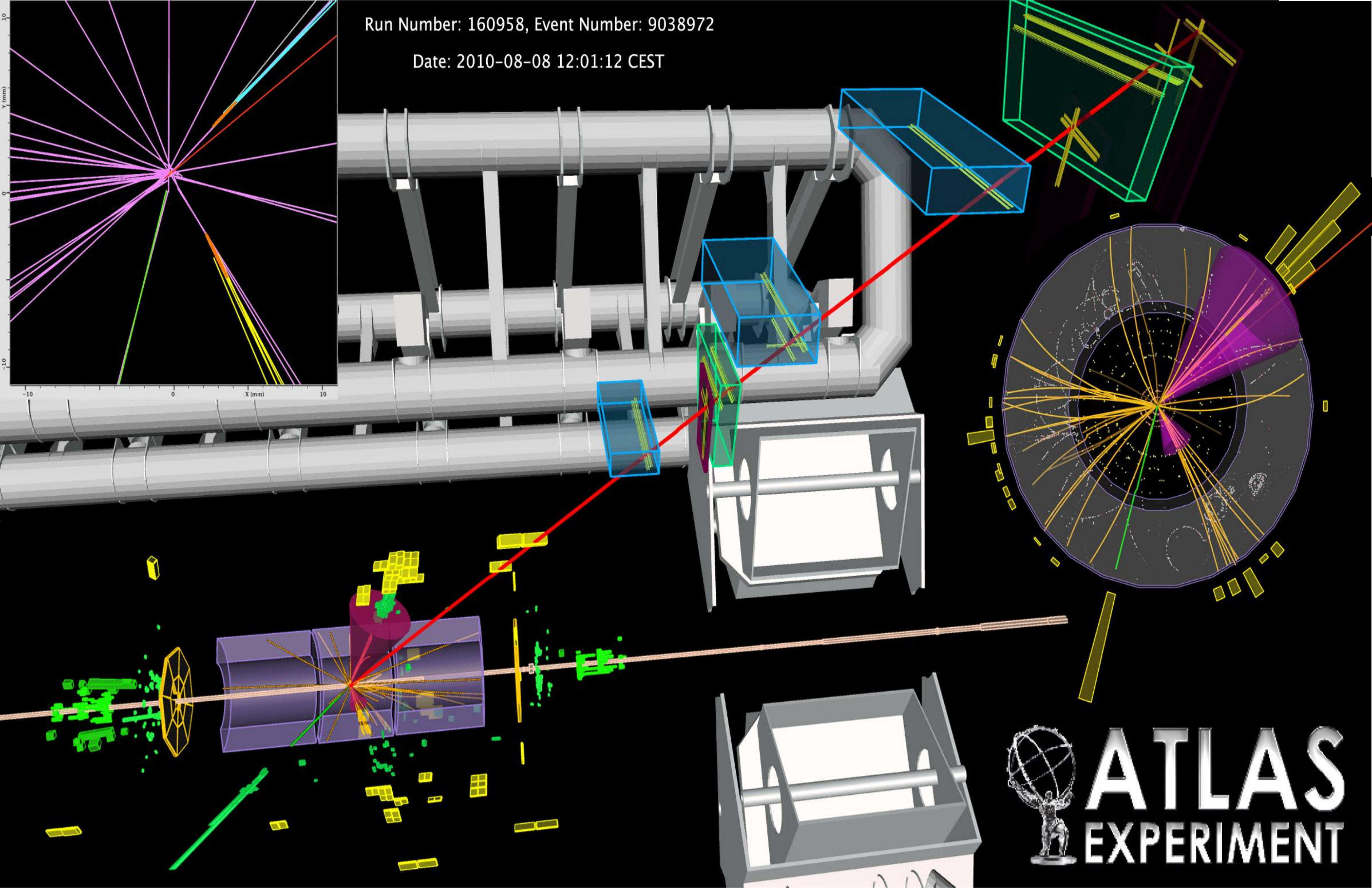
ee



eμ



Top eμ platinium candidate with 2 b-tagged jets



Run Number: 160958, Event Number: 9038972

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Data-driven background determination

- **Main backgrounds in the ℓ+jet channel :**
  - W+jet events
  - QCD multi-jets events with a fake lepton

- **W+jets : from MC** → data-driven methods underway (W/Z ratio, W asymetry)

- **QCD : matrix-method (+ other methods to cross-check) :**

⟶ define 2 event samples :

- **Tight :** standard event selection
- **Loose :** e(μ) wihout B-layer (isolation) cut

$$\left.\begin{array}{l} N^{loose} = N^{loose}_{real} + N^{loose}_{fake} \\ N^{tight} = \varepsilon_{real} N^{loose}_{real} + \boxed{\varepsilon_{fake} N^{loose}_{fake}} \end{array}\right.$$

Nb of fake leptons in selected data events

→ ε_{real} estimated from MC Z → ℓℓ (but it will be estimated from data with more statistics)

→ ε_{fake} estimated from a data control sample enriched in QCD multi-jets events :

- ≥ 1 jet with p_T > 20 GeV
- E_T^{miss} < 10 GeV

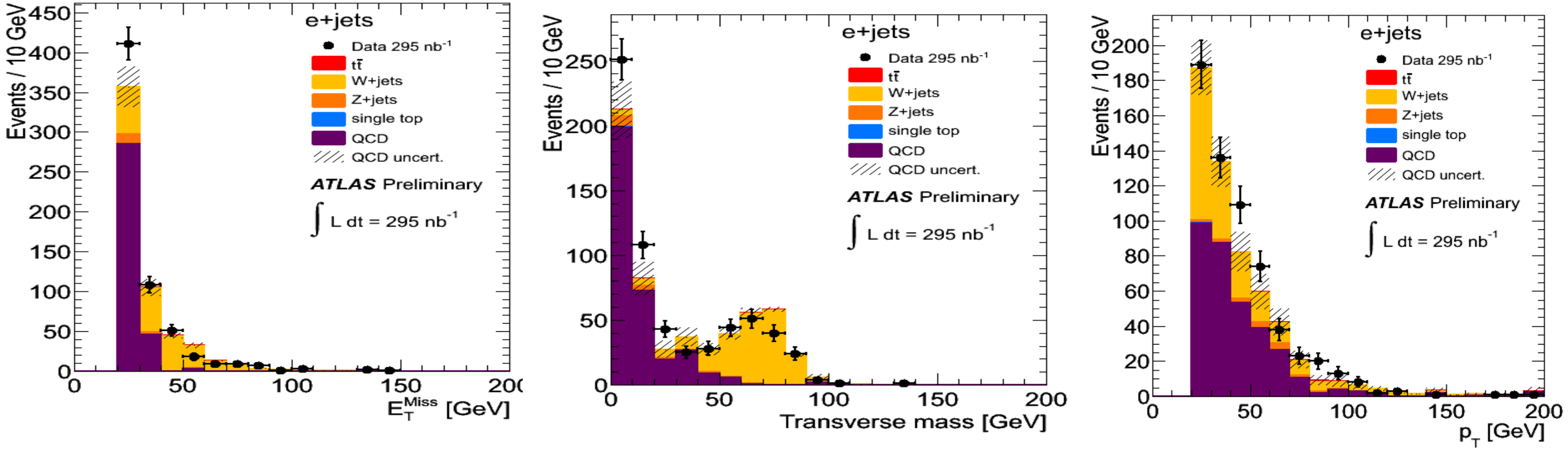
Iterative procedure required due to a small residual contamination of the control sample from W and Z events (typically converges after 2 iterations)

This procedure is applied in bins for estimates versus N_{jets} or kinematic variables

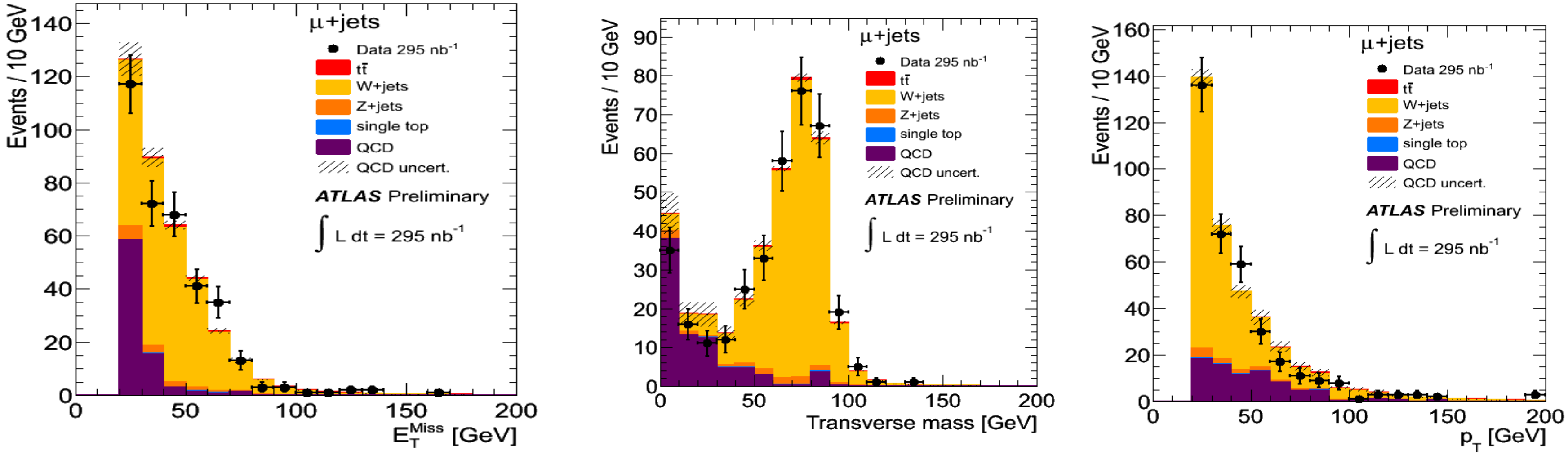
Event distributions

- **Modified l+jets selection :** 1 ℓ, ≥ 1 jet with p_T > 20 GeV and E_T^{miss} > 20 GeV (no b-tagging requirement)
- **QCD from matrix method** (with stat. unc.)
- **Other processes from MC** (no stat. unc.)

e+jets



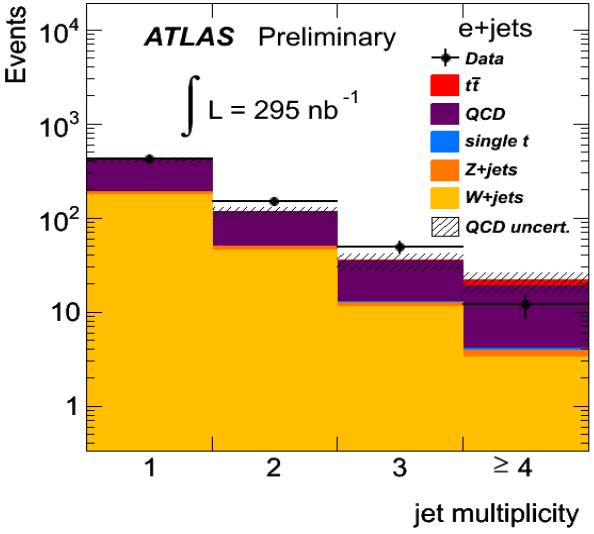
μ+jets

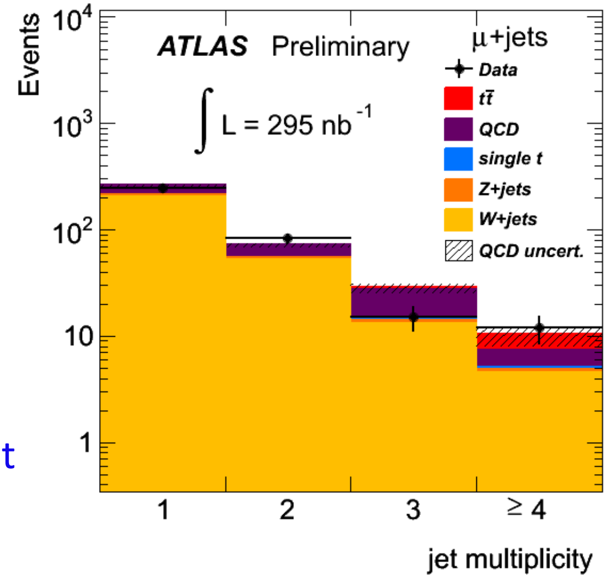


Impact of b-tagging

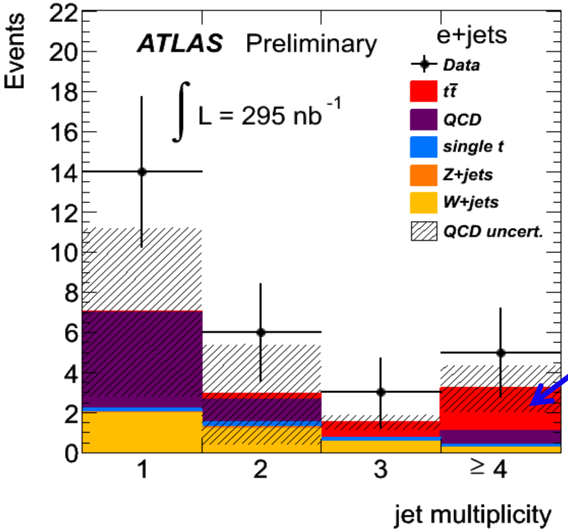
e+jets

μ+jets

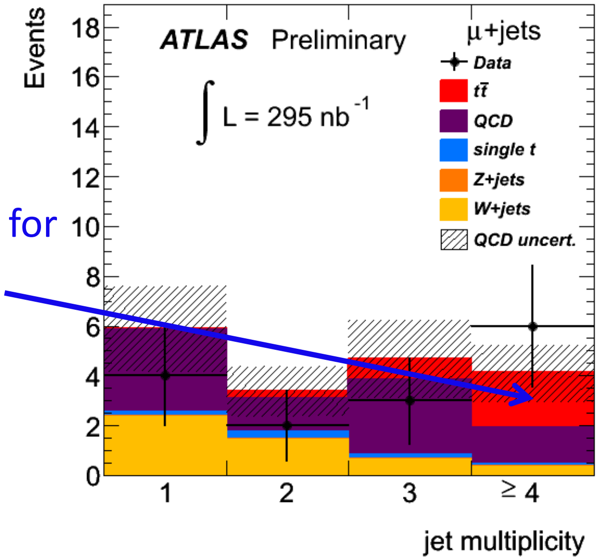




≥ 1 b-tagged jet



Event selection for top searches



plans for first top measurements

All these MC analyses are done at 10 TeV (σ_{tt} @10 TeV ≈ 2.5 x σ_{tt} @ 7 TeV)

- **Top anti-top cross-section :** (200 pb^{-1} at 10 TeV)
  - **Lepton + jets channel :**

1. Cut and Count method :

$$\boxed{\sigma = \frac{N_{sig}}{\varepsilon \times L} = \frac{N_{obs} - N_{bkg}}{\varepsilon \times L}}$$

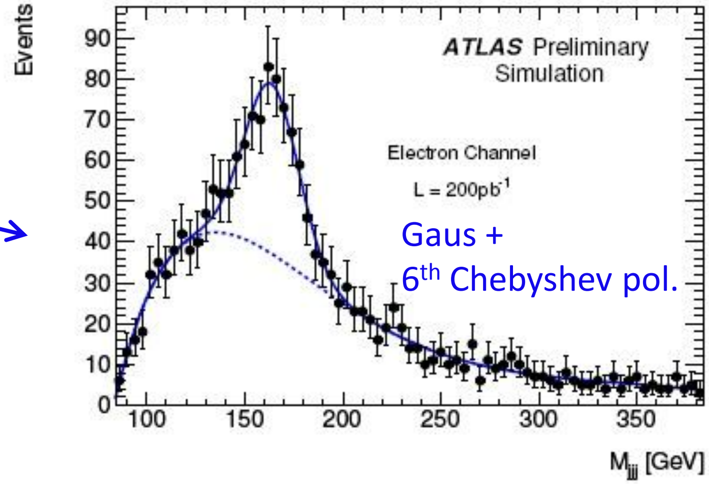
$$\frac{\Delta\sigma}{\sigma} = \pm 3(stat) \pm < 15(syst)\%$$

→ JES, ISR/FSR, W+jets

2. Hadronic top mass fit method:

$$\frac{\Delta\sigma}{\sigma} = \pm 15(stat) \pm < 15(syst)\%$$

→ JES, ISR/FSR



Gaus + 6th Chebyshev pol.

Plus luminosity uncertainty (we have already achieved 11% with data)

plans for first top measurements

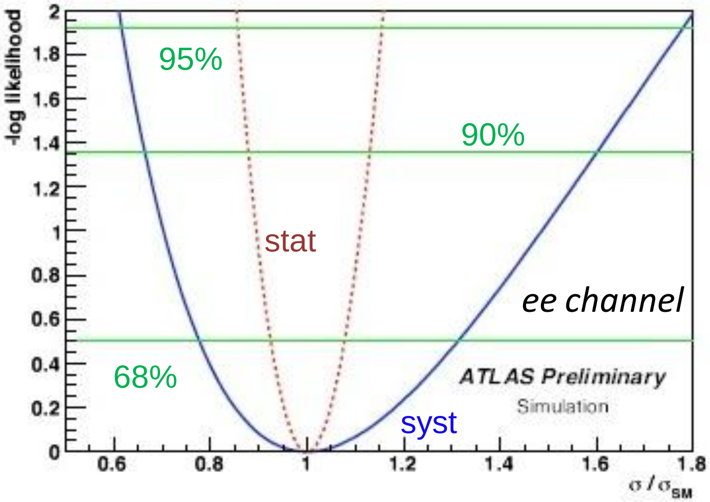
All these MC analyses are done at 10 TeV (σ_{tt} @10 TeV ≈ 2.5 x σ_{tt} @ 7 TeV)

- **Top anti-top cross-section :** (200 pb^{-1} at 10 TeV)
  - **Lepton + jets channel**
  - **Dilepton channel :**

Simple Cut and Count method + profile likelihood ratio

$$\frac{\Delta\sigma}{\sigma} = \pm 3(stat) \pm 10(syst)\%$$

⟶ signal model, fake rate, ISR/FSR



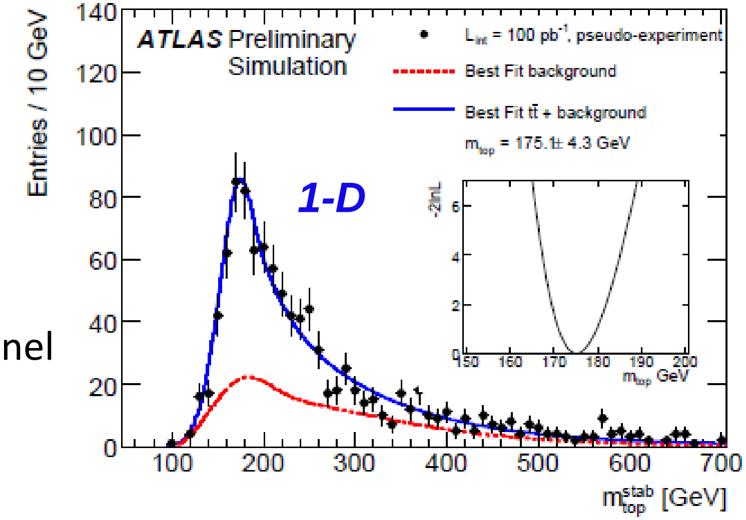
Plus luminosity uncertainty (we have already achieved 11% with data)

plans for first top measurements

All these MC analyses are done at 10 TeV (σ_{tt} @10 TeV ≈ 2.5 x σ_{tt} @ 7 TeV)

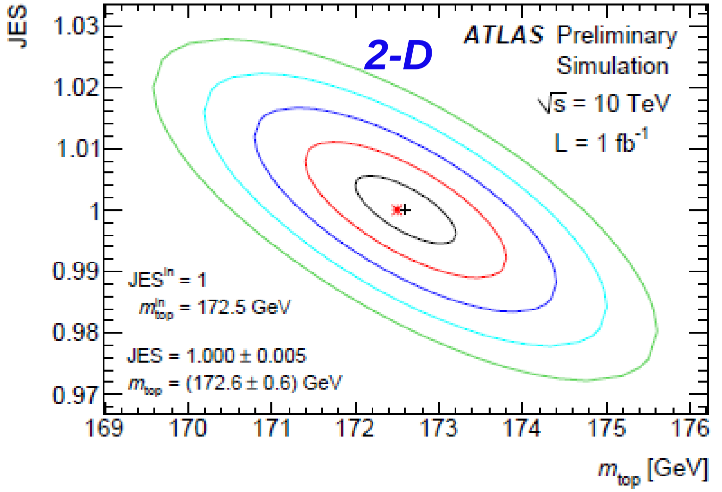
- **Top anti-top cross-section :**
  - **Lepton + jets channel**
  - **Dilepton channel**
- **Top quark mass :** template method in the lepton + jets channel
  - **1-D analysis :** *m_t measurement only*
  - **2-D analysis :** *simultaneous measurement of m_t and JES*

➡ *Need a better understanding of the detector*



	Expected uncertainties		
Method	stat	syst	total
1-D (100 pb^{-1})	2 GeV	4 GeV	4.5 GeV
2-D (1 fb^{-1})	0.6 GeV	2 GeV	2.1 GeV

└→ JES, ISR/FSR



plans for first top measurements

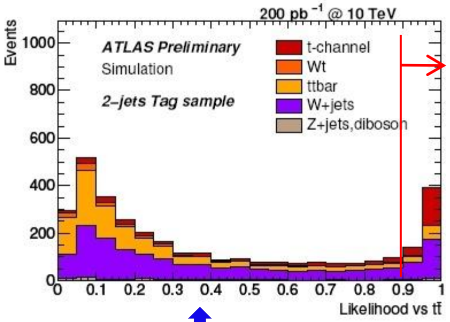
All these MC analyses are done at 10 TeV (σ_{tt} @10 TeV ≈ 2.5 x σ_{tt} @ 7 TeV)

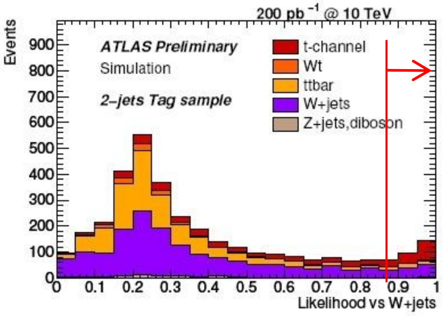
- **Top anti-top cross-section :**
  - **Lepton + jets channel**
  - **Dilepton channel**
- **Top quark mass**
- **Single top (t-channel) :** (200 pb^{-1} at 10 TeV)
  - **Sequential cuts analysis :**

→ Add kinematical cuts to reject tt and W+jets

  - **Likelihood function analysis :**

→ Likelihood ratio with angular variables to discriminate tt and W+jets





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

→ b-tagging, bkg normalisation, ISR/FSR, Generator

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

plans for first top measurements

All these MC analyses are done at 10 TeV (σ_{tt} @10 TeV ≈ 2.5 x σ_{tt} @ 7 TeV)

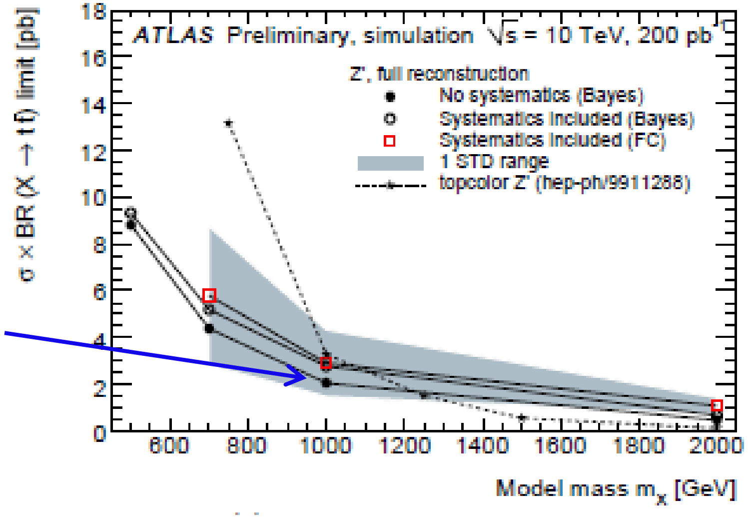
- **Top anti-top cross-section :**
  - **Lepton + jets channel**
  - **Dilepton channel**
- **Top quark mass**
- **Single top (t-channel)**
- **Early tt resonance searches :** (200 pb^{-1} at 10 TeV)

- **Main sources of systematics :**

Jet energy scale and resolution, luminosity

- A 95% C.L. limit of $\sigma \times BR(X \rightarrow tt) = 3$ pb is expected

for a narrow ($\Gamma/m << 7\%$) spin 1 resonance mass of 1 TeV



Early analyses with ATLAS are expected to extend significantly the mass reach of existing searches

Summary

- **Top quark physics requires a good understanding of all the detector**
  - Leptons identification, reconstruction and resolution
  - Jets reconstruction, calibration and resolution
  - Missing transverse energy calibration and resolution
  - B-tagging algorithms

→ *In advanced commissioning stage with a good overall data/MC agreement*

- **First top candidates have been observed with 295 nb^{-1}**

- **QCD background data-driven estimates already done with the matrix method**

9 pb^{-1} of data are now available and we expect 1 fb^{-1} by the end of 2011

- Data-driven estimates of Drell-Yan and W+jet backgrounds underway
  - → can them be used to establish the top quark signal in ATLAS and the first x-section measurement
- Start on top mass fitting and background studies for single top measurement
- Top quark is a window to physics beyond the Standard Model

→ *A very promising Top quark era has begun now*

Backup slides

Electrons

- **Electrons sources :**
  - W/Z decays : W(Z) → e(e)
  - Heavy flavour decay b,c → eX
  - γ conversion : γ → ee
  - Fakes from charged hadrons : h → eX

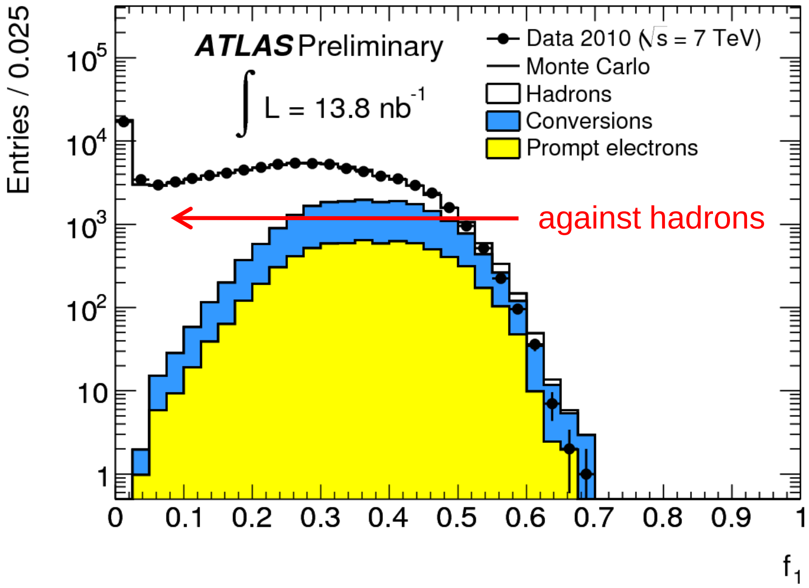
- **Different identification definitions :**
  - ***Loose :***
    - Acceptance, E_T , fiducial and tracking cuts
    - Lateral width of the shower
  - ***Medium :***
    - Strip layer of the EM calorimeter (to reject π^0) :

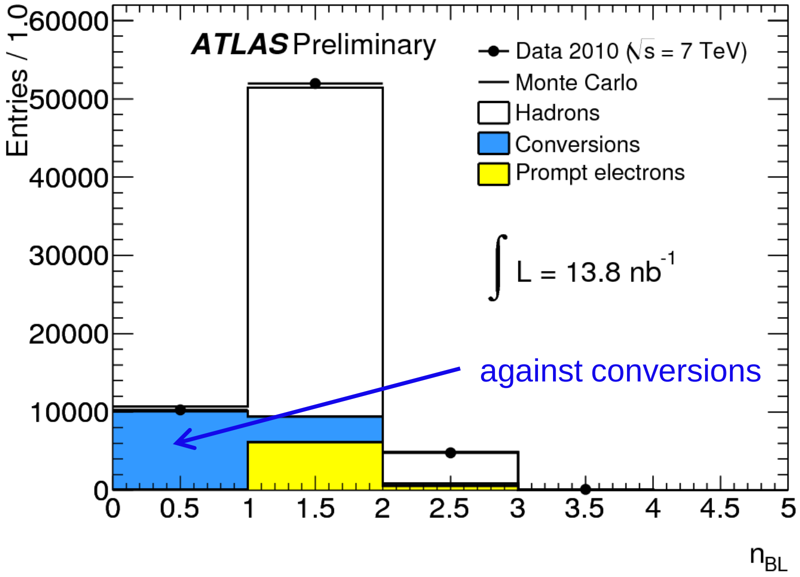
      fraction of energy f_1, additional shower shapes
    - Track quality :

      hits in pixel, pixel+SCT, d_0 , fiducial B-layer
    - Cluster-track matching ($\Delta\eta < 0.01$)
  - ***Tight :***
    - Hadronic leakage :

      ratio E_T^{HAD} / E_T^{EM} for first and all Had sampling
    - Additional shower shape in the Middle layer
    - Hits in the B-layer n_{BL} (against γ conversion)
    - Cluster-track matching : ratio E/P (against hadrons)
    - Transition Radiation Tracker cuts :

      number of hits and ratio High/Low thresholds





Muons

Muons sources :

- W/Z decays : W(Z) → μ(μ)
- Heavy flavour decay b,c → μX
- π,K decays in flight
- punch-through and cosmic muons

Muon reconstruction :

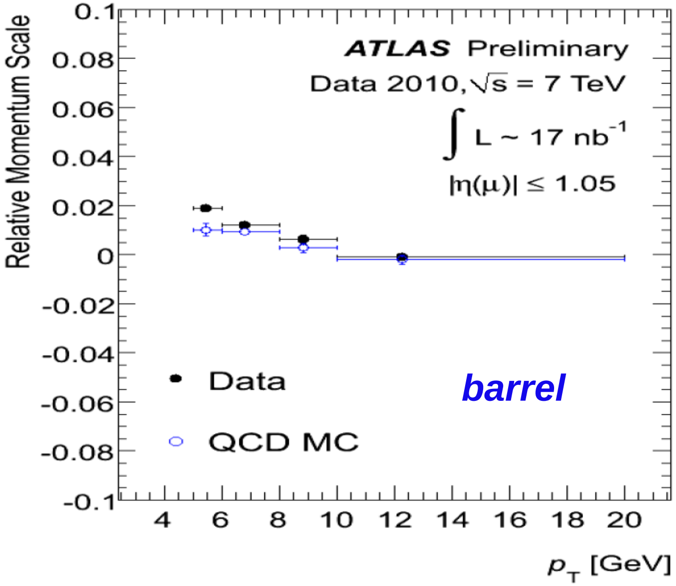
- ***2 main sub-systems :***
  - Inner Detector : pixel, SCT, TRT
  - Muon Spectrometer
- ***Different strategies :***
  - Stand-alone muon : MS only
  - Combined muon : ID + MS
  - Segment tagged muon : ID + track segments in MS
  - Calorimeter tagged muon : ID + MIP in the calorimeter

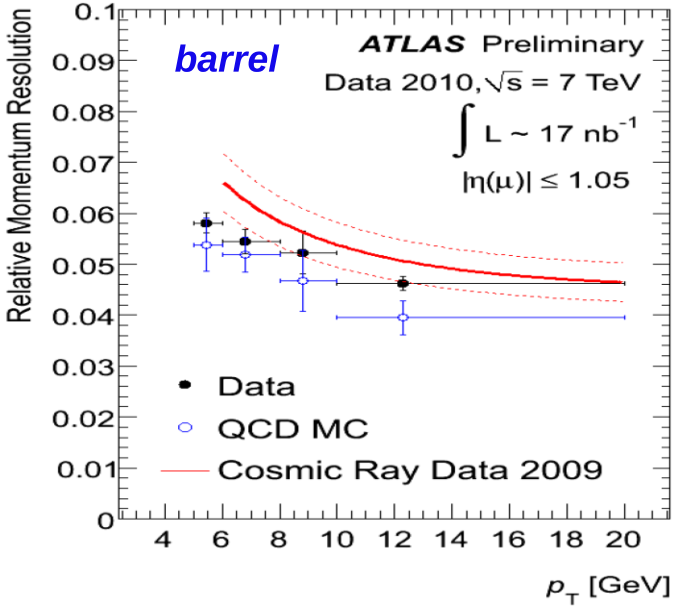
MC validated with first data :

- **Relative efficiencies** measured using the complementarities of the different strategies

  ➡ *agreement within 3%*
- **Relative momentum scale and resolution :**
  - Momentum scale < 2% (B & EC)
  - Resolution (10 < p_T < 20 GeV)
    - 5% in the barrel
    - 8% in the end caps

$$\frac{\Delta p}{p} = \frac{p^{ID} - p^{MS}}{p^{ID}}$$





b-tagging

- **Main identification algorithm categories :**

1. Impact parameter based taggers :

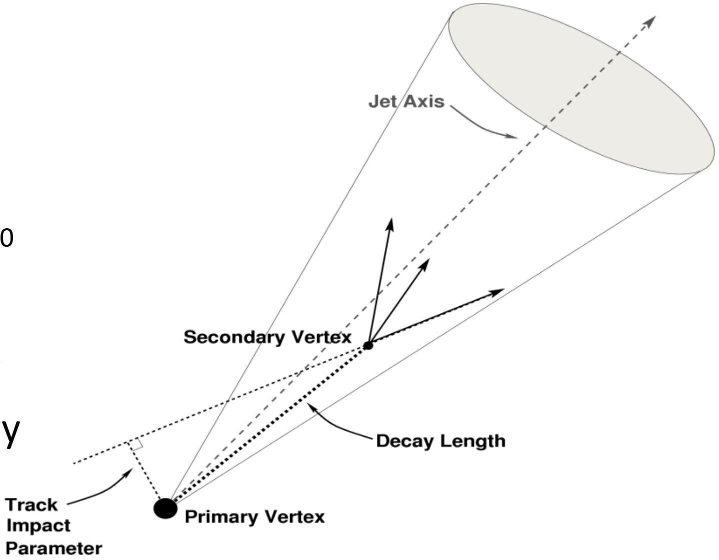
- TrackCounting :

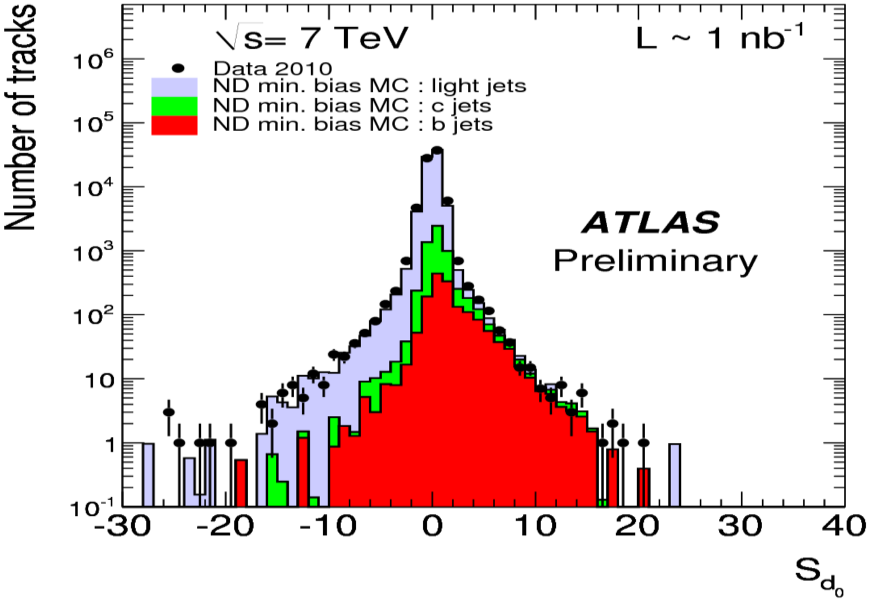
. requires at least 2 good tracks with $S_{d0} = d_0 / \sigma_{d0}$ above a threshold

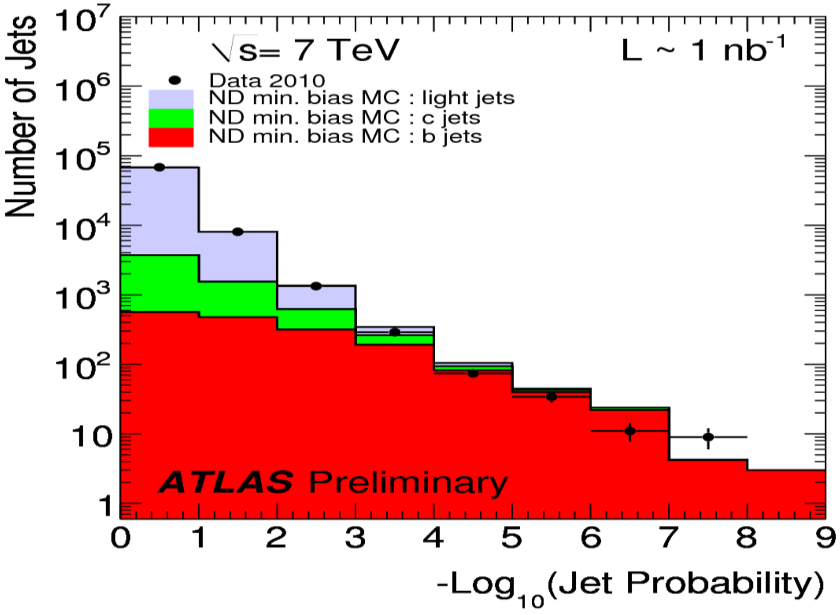
- JetProb (ALEPH) :

. calculate probability for a track to come from PV

. combine all tracks in jet to derive a jet probability to originate from PV







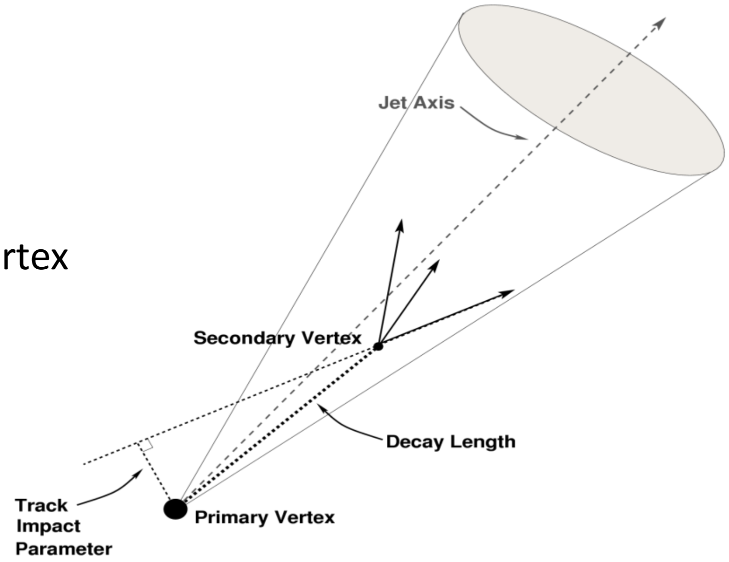
b-tagging

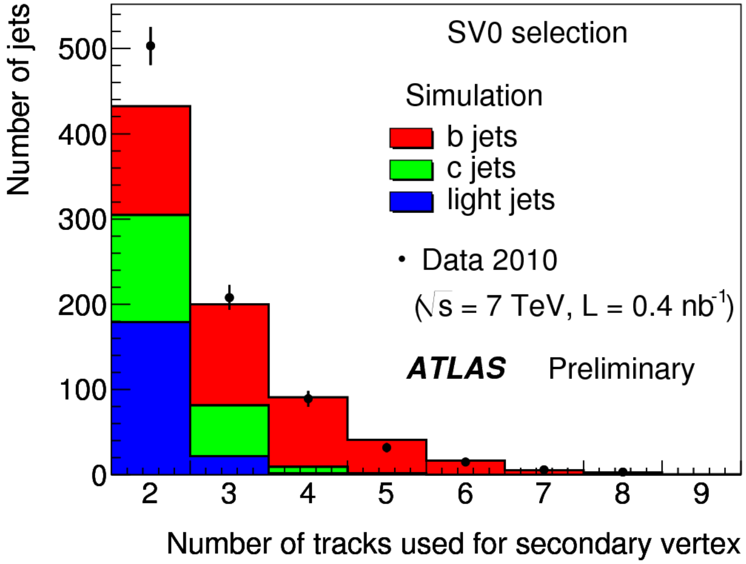
- **Main identification algorithm categories :**
  1. Impact parameter based taggers
  2. Secondary vertex tagger :

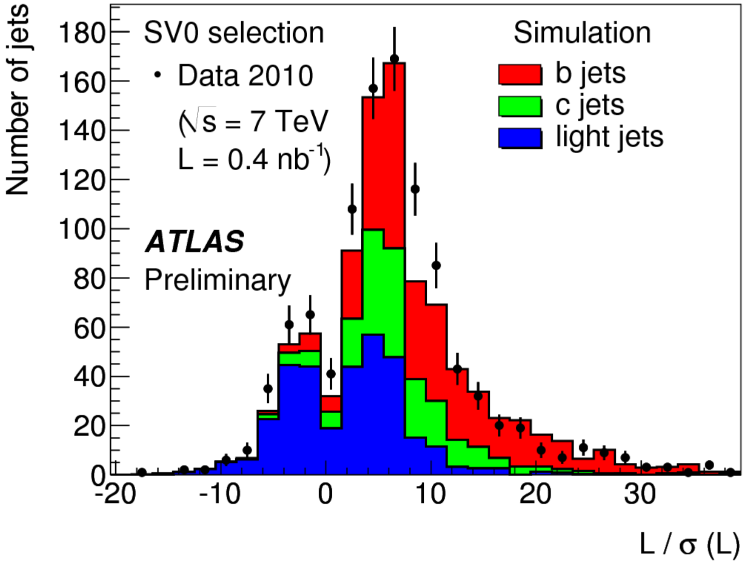
     - SVO (default for top analyses) **:**

     . explicit reconstruction of the b-hadron decay vertex

     . use 3D decay length significance L/σ(L) as discriminating variable



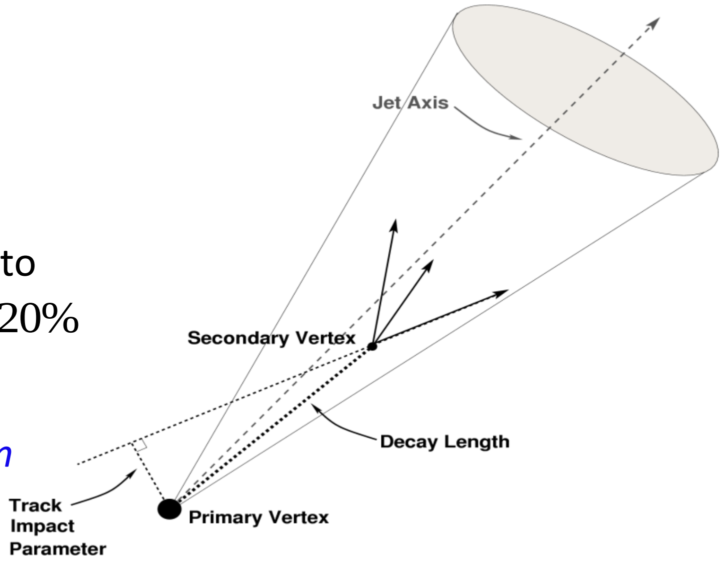


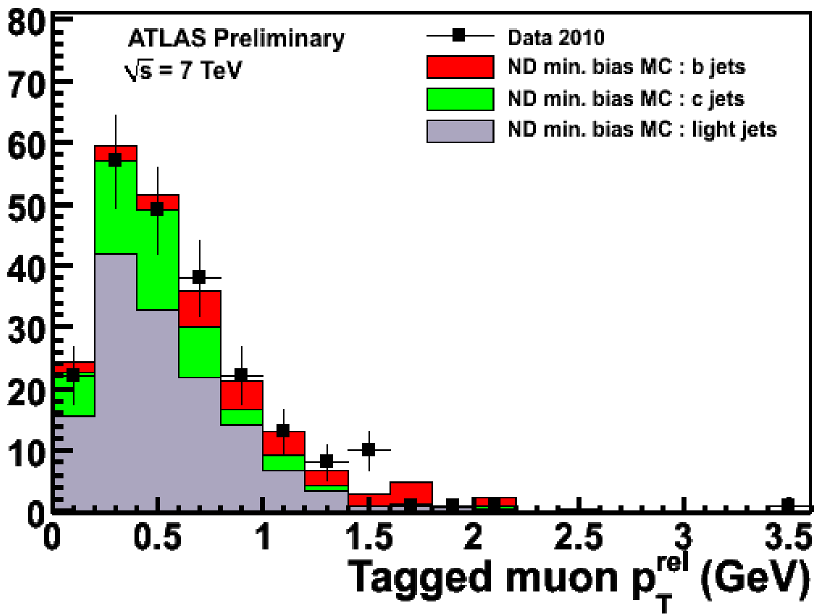


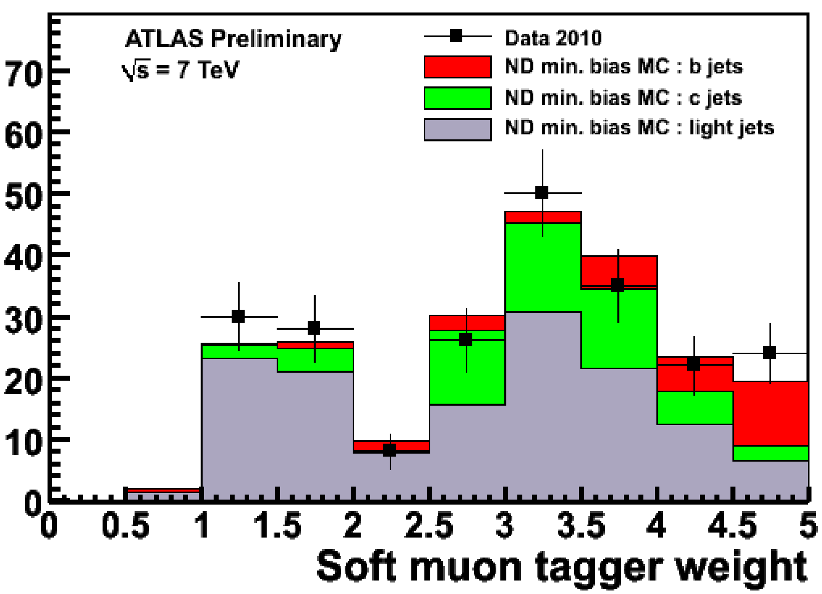
b-tagging

- **Main identification algorithm categories :**
  1. Impact parameter based taggers
  2. Secondary vertex tagger
  3. Soft muon tagger :
     - exploits semi-leptonic decay of b and c-hadrons to muons : $BR(b \to \mu \nu X) + BR(b \to c \to \mu \nu X) \approx 20\%$
     - use p_T (μ) as discriminant variable

➡ *Can be used for calibration of lifetime tagging algorithm*







Cross-section measurement : ℓ+jet channel

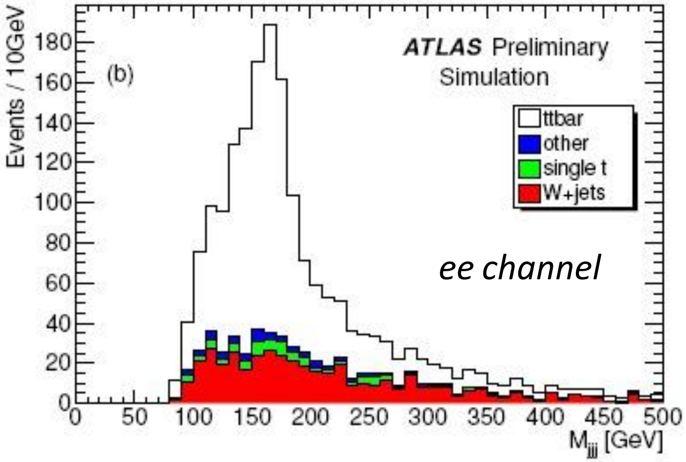
Event selection :

- = 1 isolated lepton (e,μ) with $p_T > 20$ GeV
- ≥ 4 jets with $p_T > 20$ GeV, ≥ 3 with $p_T > 40$ GeV
- $E_T^{miss} > 20$ GeV

200 pb^{-1} at 10 TeV		
	e+jets	μ+jets
signal	1286	1584
background	598	799

Hadronic top reconstruction :

- select the 3 jets with the hightest p_T^{top}
- 2 jets satisfy $|M_{jj} - M_W| < 10$ GeV



Cross section measurement : 2 methods :

1. Cut and count :

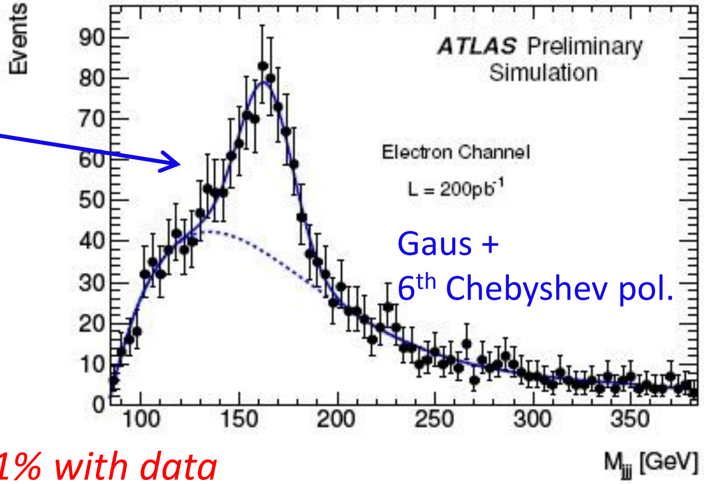
$$\sigma = \frac{N_{sig}}{\varepsilon \times L} = \frac{N_{obs} - \boxed{N_{bkg}}}{\boxed{\varepsilon} \times L}$$

from data

from MC

2. Hadronic top mass fit :

⟶ σ extracted from the integral of the Gaussian



Method	Δσ/σ	Main sys.
C & C	$\pm 3(stat) \pm < 15(syst) + 22(lumi)\%$	JES, ISR/FSR, W+jets
Fit	$\pm 15(stat) \pm < 15(syst) \pm 20(lumi)\%$	JES, ISR/FSR

Results assuming a 20% lumi. unc. but we have already achieved 11% with data

Cross-section measurement : dilepton channel

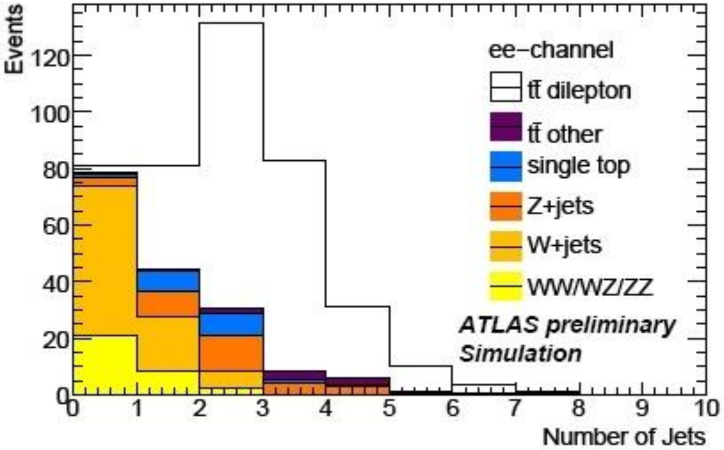
Event selection :

- = 2 isolated leptons (e,μ) with $p_T > 20$ GeV
- ≥ 2 jets with $p_T > 20$ GeV
- $E_T^{miss} > 20$ GeV

Additional cuts for ee or μμ events (against Drell-Yan) :

- $E_T^{miss} > 35$ GeV
- $|M_Z - M_{\ell\ell}| > 5$ GeV

200 pb^{-1} at 10 TeV			
	ee	μμ	eμ
signal	214	332	698
background	49	84	108

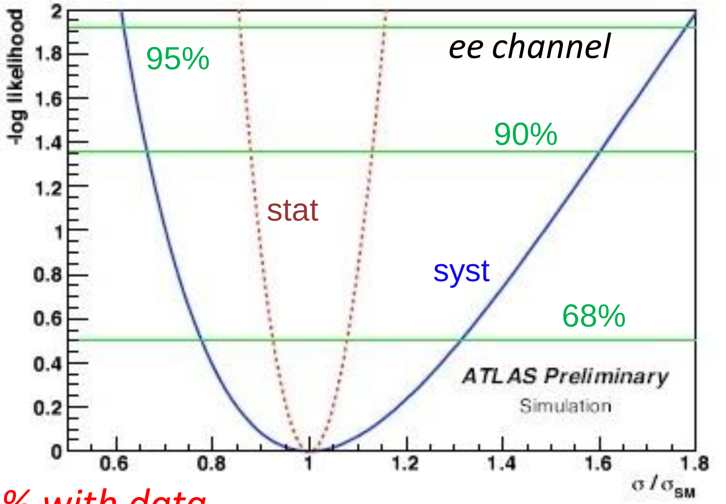


Backround determination :

- **Data-driven methods :**
  Drell-Yan and fake lepton rates (QCD, W+jets)
- **MC :** di-bosons, single top

Cross-section measurement :

Simple Cut and Count method + profile likelihood ratio



Uncertainties :

- **Main systematics :**
  signal model, fake rate, ISR/FSR
- **Final combined uncertainty** (200 pb^{-1} at 10 TeV) :

$$\frac{\Delta\sigma}{\sigma} = \pm 3(stat) + 10(syst) + 22(lumi)\%$$

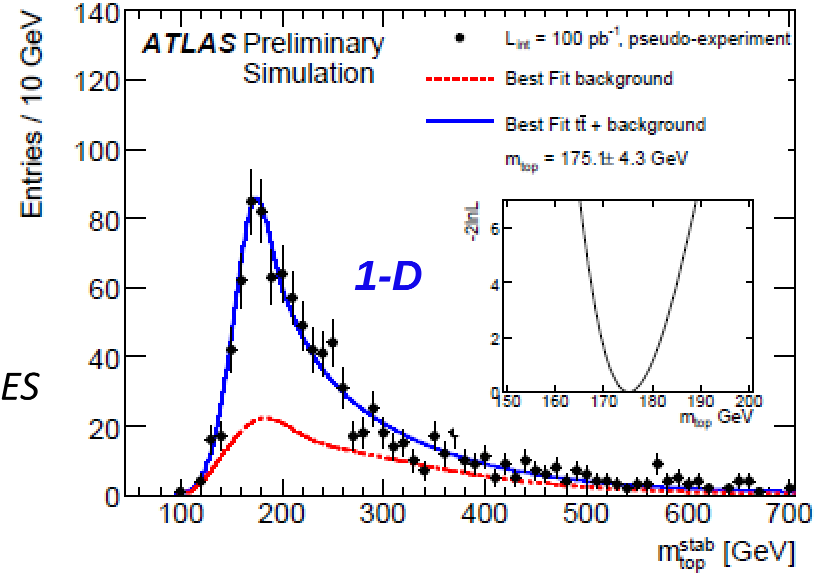
Result assuming a 20% lumi. unc. but we have already achieved 11% with data

Top quark mass (ℓ+jets channel)

- **2 analyses with the template method :**
  - **1-D analysis :** *m_t measurement only*

→ loose selection without b-tagging : S/B ≈ 1.3

→ Use stabilized mass $m_t^{stab} \equiv \frac{m_t^{reco}}{M_W^{reco}} M_W$ to minimize the impact of JES unc.



  - **2-D analysis :** *simultaneous measurement of m_t and JES*

→ Use b-tagging and and a kinematic fit to reconstruct the ttbar final state : S/B ≈ 8

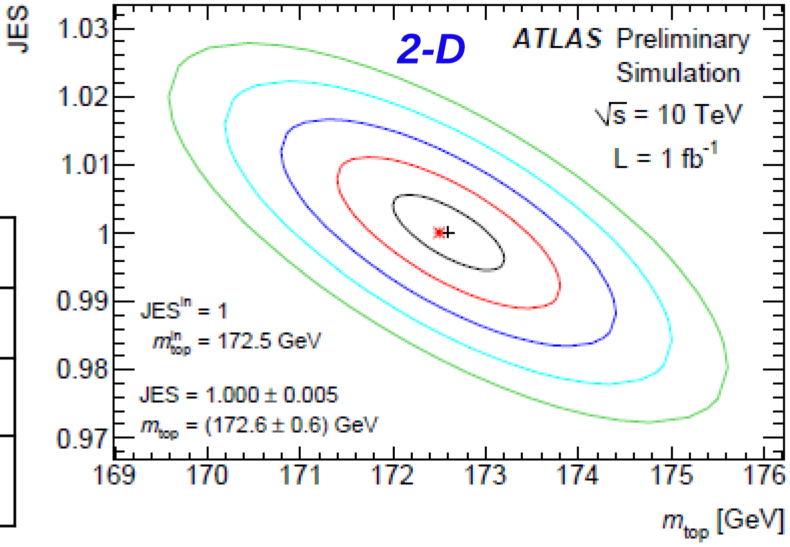
→ Explicit correction for the difference between b and light JES

➡ *Need a better understanding of the detector*

- **Uncertainties :**

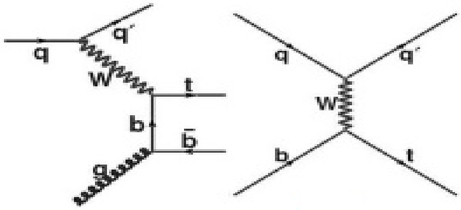
Main sources of systematics are b-JES and ISR/FSR

	Expected uncertainties		
Method	stat	syst	total
1-D (100 pb^{-1})	2 GeV	4 GeV	4.5 GeV
2-D (1 fb^{-1})	0.6 GeV	2 GeV	2.1 GeV



Single top (t-channel)

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



200 pb^{-1} at 10 TeV		
	Sequential cuts	liqeligoo
Signal t-chan	118	112
background	185	127

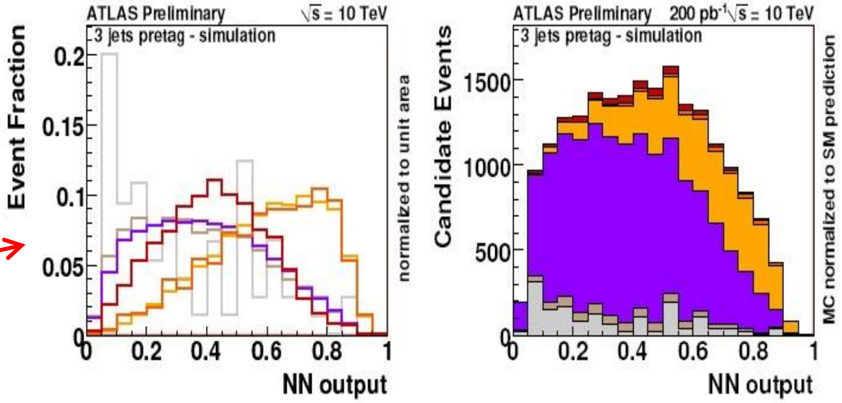
Event selection :

- = 1 isolated lepton (e,μ) with $p_T > 20$ GeV
- = 2 jets with $p_T > 30$ GeV, 1 b-tagged jet
- $E_T^{miss} > 20$ GeV, M_T (W) > 30 GeV (against QCD)

ttbar and W+jets normalization :

Use a binned likelihood fit to the output of a neural network in a control sample (3 jets)

➡ *Uncertainty of 14% for W+jets and 7% for ttbar*



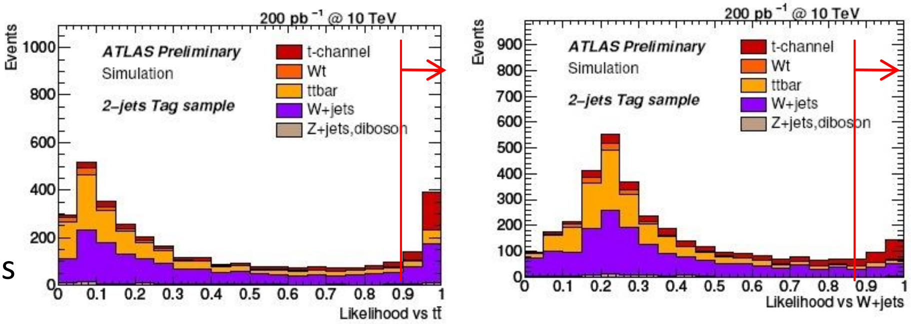
2 methods for X-section measurement :

- **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

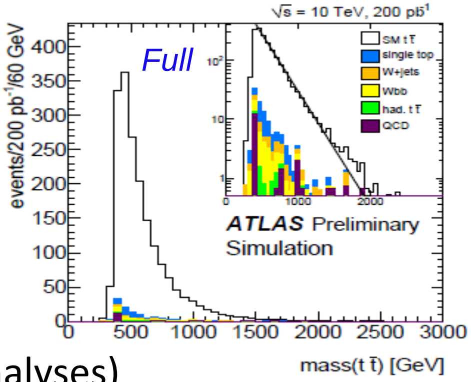
Significance with 200 pb^{-1} at 10 TeV : 2.7 σ

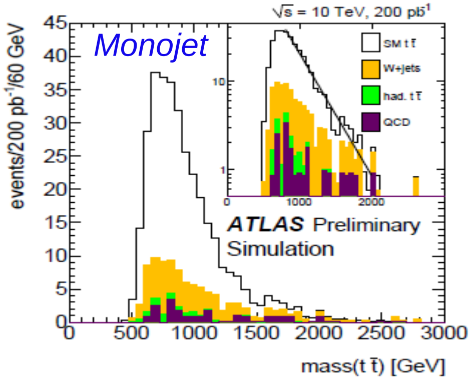
Method	$\Delta\sigma/\sigma$
Seq. cuts	$\pm 15(stat) \pm 35(syst) \pm 11(lumi)\%$
likelihood	$\pm 14(stat) \pm 32(syst) \pm 11(lumi)\%$

Early tt resonance searches

Basic event selection :

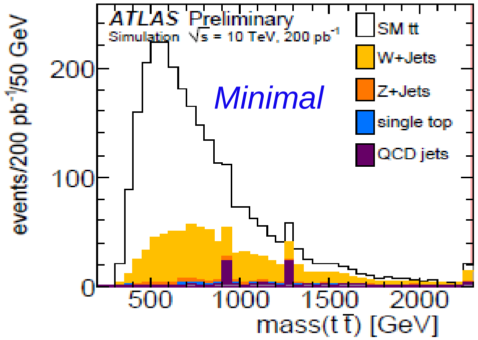
- ≥ 1 isolated lepton (e,μ) with p_T > 20 GeV
- ≥ 2 jets with p_T > 30 GeV, 1 b-tagged jet
- if M_T (W) < 40 GeV : E_T^{miss} > 60 GeV (against QCD)





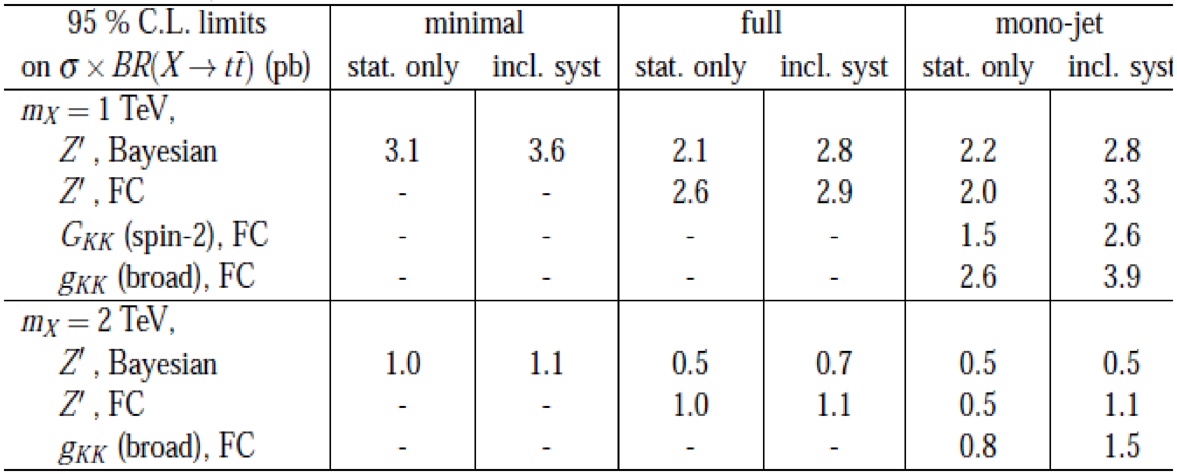
Mass spectrum reconstruction :

- **Minimal reconstruction :** $m_{bjjb\ell\nu}$ (for early analyses)
- **Full reconstruction :** $m_{Z'} = m_{bjjb\ell\nu} - m_{bjj} - m_{b\ell\nu} + 2m_t^{PDG}$
- **Monojet approach :** jets anti-k_T, topo, R=1.0
  → for highly boosted top quarks



Sensitivity :

- **2 methods :** Bayesian and Feldman - Cousins



95 % C.L. limits on $\sigma \times BR(X \to t\bar{t})$ (pb)	minimal		full		mono-jet	
	stat. only	incl. syst	stat. only	incl. syst	stat. only	incl. syst
$m_X = 1$ TeV,						
Z' , Bayesian	3.1	3.6	2.1	2.8	2.2	2.8
Z' , FC	-	-	2.6	2.9	2.0	3.3
G_{KK} (spin-2), FC	-	-	-	-	1.5	2.6
g_{KK} (broad), FC	-	-	-	-	2.6	3.9
$m_X = 2$ TeV,						
Z' , Bayesian	1.0	1.1	0.5	0.7	0.5	0.5
Z' , FC	-	-	1.0	1.1	0.5	1.1
g_{KK} (broad), FC	-	-	-	-	0.8	1.5