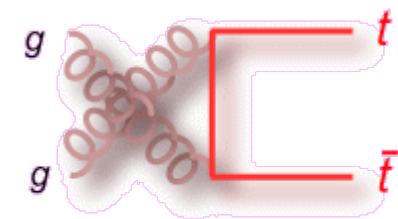
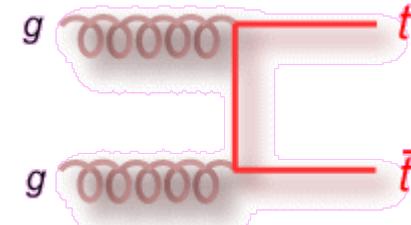
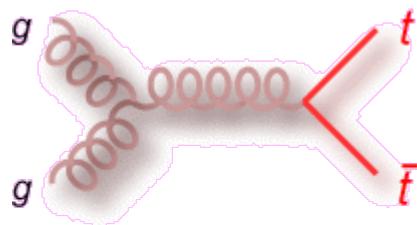


Top quark mass measurement with ATLAS

Pietro Cavalleri – LPNHE Paris
on behalf of the ATLAS Collaboration



Outline

- ★ Why the top quark mass at ATLAS?
- ★ Present status of top mass measurements
- ★ Focus on the lepton+jets channel (most promising analysis)
- ★ Overview on different ongoing analyses in ATLAS experiment

Why the top quark mass?

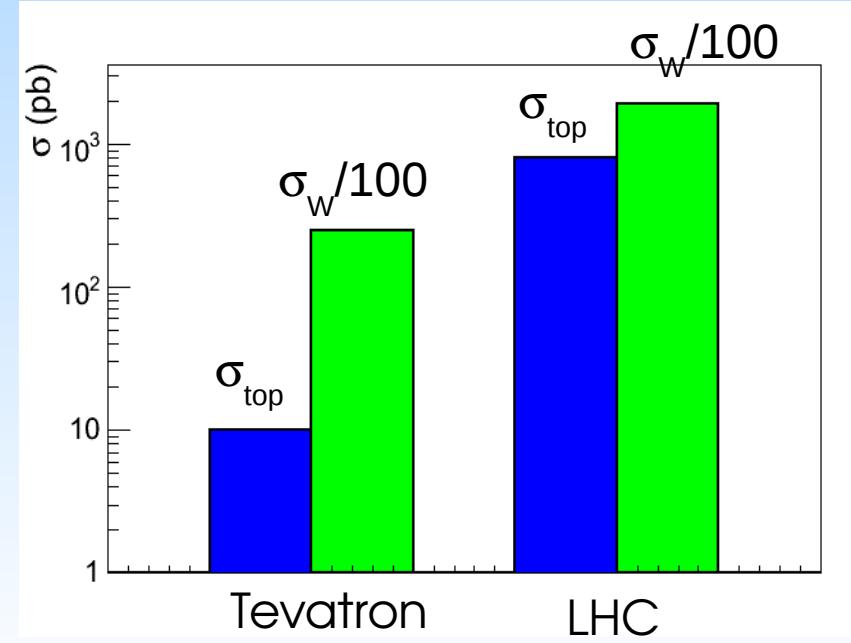
- ✓ High mass reference candle during the LHC start-up
- ✓ Its mass is a fundamental parameter of the Standard Model
- ✓ A precise measurement could constrain the Standard Model Higgs boson

$$M_w = 4 \sqrt{\frac{\pi^2 \alpha^2}{2G^2}} \frac{1}{\sin \theta_w (1 - \Delta R)}$$

$M_{top}^2, \log M_H$

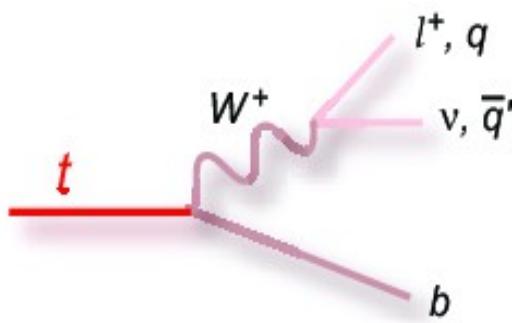
- ✓ SM Yukawa coupling ~ 1 --> Special role in Electro-Weak symmetry breaking???

- ✓ The LHC will be a top factory
 - >statistical error will be negligible
 - >the challenge will be the syst. error

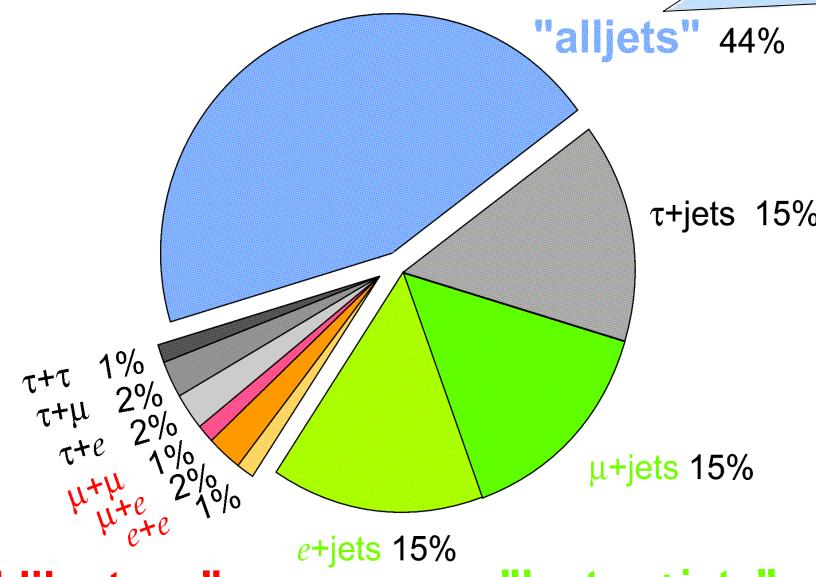


Analysis channels

The W decay determines the analysis channel



Top Pair Branching Fractions



- Huge background
- Huge combinatorics
- Branching Ratio=44% (~350000 evt)
- Possibility to reconstruct the whole event

Number of produced events for 1fb-1 at LHC

'dileptons'

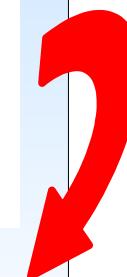
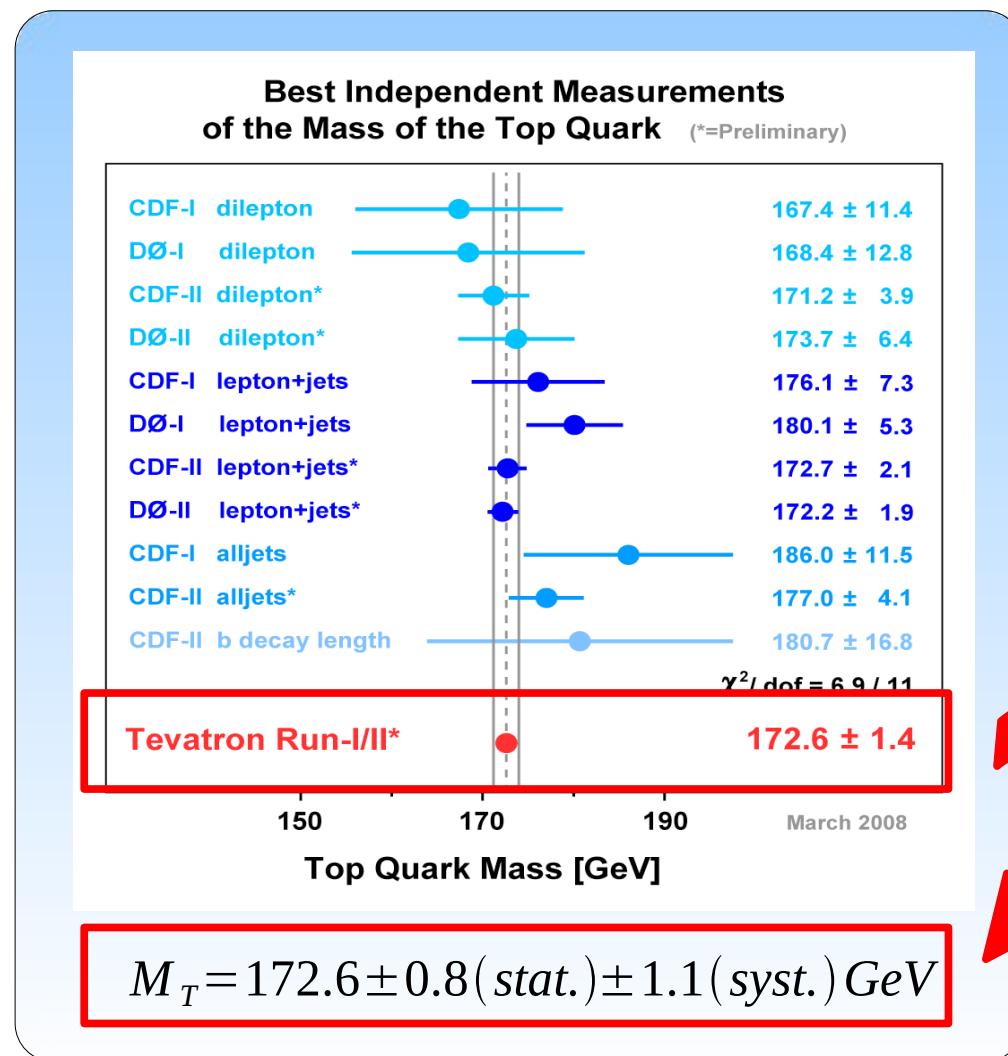
- Low bkg and BR (~50000 evts)
- No direct measurement of the invariant mass (2 neutrinos)
- Easy to detect: two high pT leptons and Missing Energy

"lepton+jets"

- Good compromise between BR and bkg
- ~250000 evts (without $\tau + \text{jets}$)
- "golden channel"

Present status of the top mass measurement

Tevatron direct measurements in the different channels

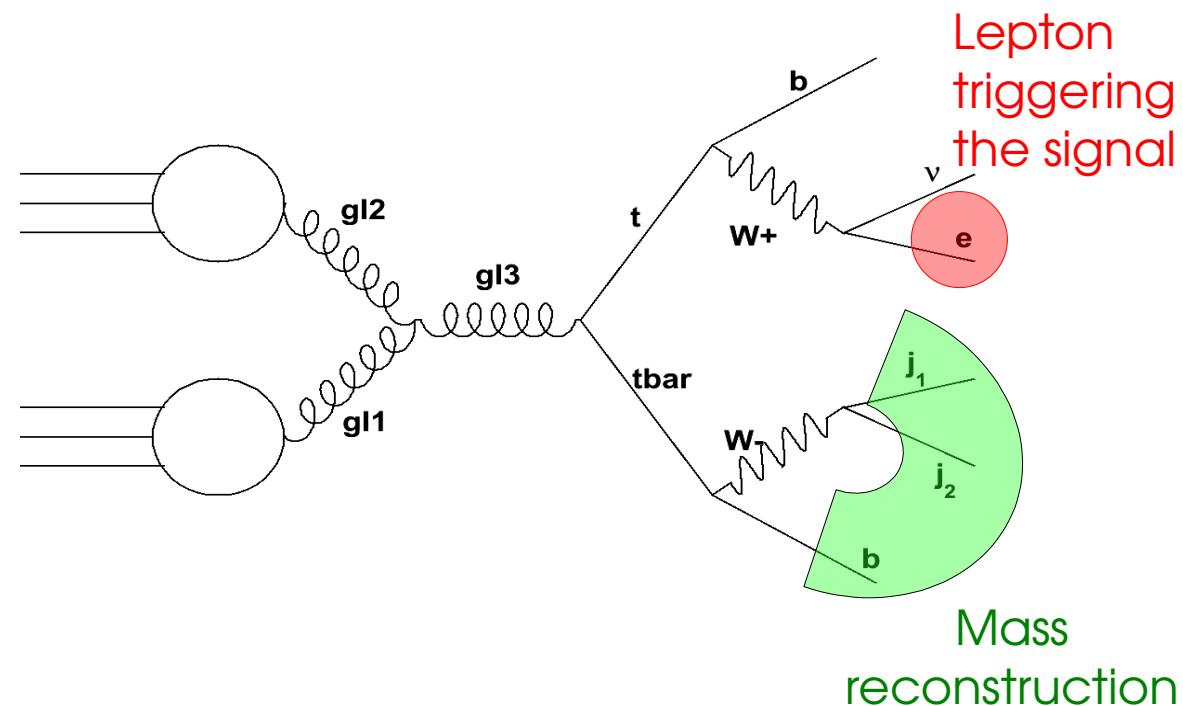


Tevatron
combined best
measurement

Lepton+Jets – Most promising analysis

Steps of the analysis

- Events selection
- Hadronic W mass reconstruction with chi2 minimization or geometric method
- Top mass reconstruction
- Top mass measurements: best value, statistical and systematic uncertainties



Analysis done with
2 b-tags, 1 b-tag and
no b-tag

Main backgrounds

- ✓ W boson production ($W \rightarrow l\nu$, $W + bb$ and $W + cc$)
- ✓ Z+jet with $Z \rightarrow ll$
- ✓ single top events
- ✓ fully leptonic and fully hadronic ttbar events

Event Selection

Standard cuts:

- ✓ 1 isolated lepton of $p_T > 20$ (25) GeV for muons (electrons)
 - ✓ isolation reject all the leptonic b-decays in all-jets channel
- ✓ Missing $E_T > 20$ GeV (reduces QCD bkg)
- ✓ At least 4 jets with $p_T > 40$ GeV

- ✓ Two jets must be b-tagged
- ✓ $| \eta | < 2.5$ for all these objects

Trigger efficiency:

71% of $e+jets$ events with $p_T > 25$ GeV
 74% of $\mu+jets$ events with $p_T > 20$ GeV

Cut flow for 1 fb⁻¹ data



Process	Number of events	1 isol. lep $p_T > 20$ GeV $E_T > 20$ GeV	≥ 4 jets $p_T > 40$ GeV	2 b-jets $p_T > 40$ GeV
Signal	313200	132380	43370	15780
W boson bkg.	9.5×10^5	154100	9450	200
Z+jets	1.2×10^6	180000	570	20
$t\bar{t} \rightarrow$ all-jets	466480	1020	560	160
$t\bar{t} \rightarrow$ di-lepton	52500	16470	2050	720
single top (t ch.)	81500	24400	1230	330

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The cut on the lepton reduces the $t\bar{t} \rightarrow$ alljets bkg

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The cut on jets reduces Z and di-lepton bkg

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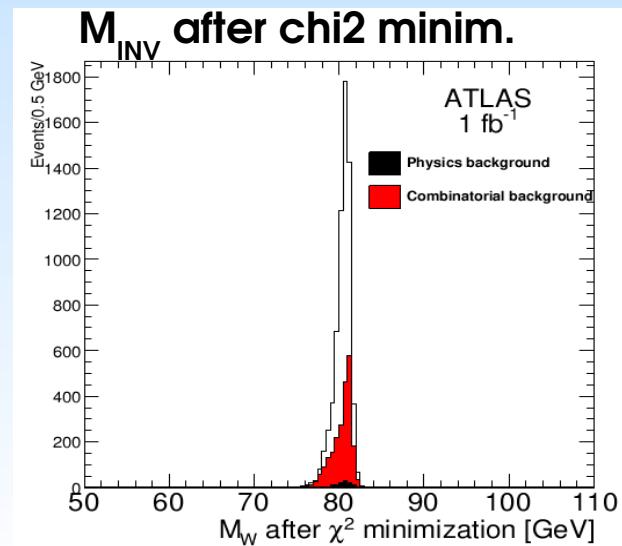
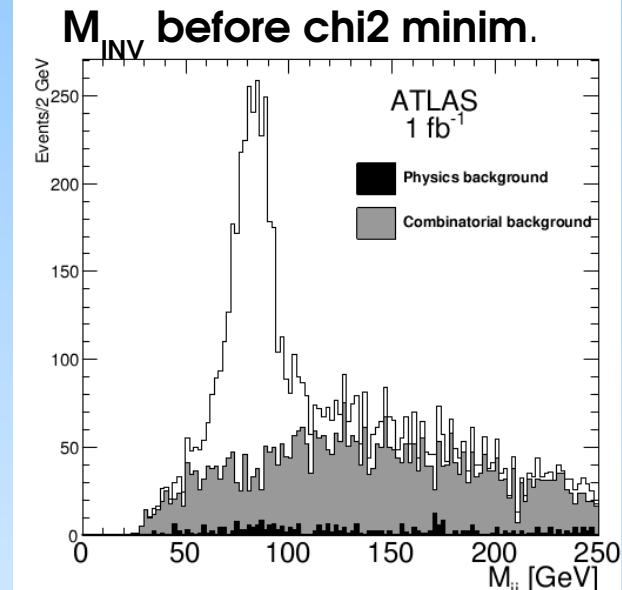
With this selection the S/B goes from 10^{-5} to ~ 10

Hadronic W mass reco. with chi2 minimization

- ✓ Jet Energy Scale varies with jet energy.
To correctly reconstruct the hadronic W a rescaling is necessary
- ✓ The event by event *is situ* rescaling is performed by constraining the jet pair to known W mass (chi2 minimization)

$$\chi^2 = \frac{(M_{jj}(\alpha_{E_{j1}}, \alpha_{E_{j2}}) - M_W^{PDG})^2}{(\Gamma_W^{PDG})} + \frac{E_{j1}(1 - \alpha_{E_{j1}})^2}{\sigma_1^2} + \frac{E_{j2}(1 - \alpha_{E_{j2}})^2}{\sigma_2^2}$$

- ✓ The pair with the smallest chi2 is kept as the hadronic W candidate
- ✓ This chi2 allows also the jet energy to vary within resolution
- ✓ further on, only candidates within $\pm 2\Gamma_W$ are kept



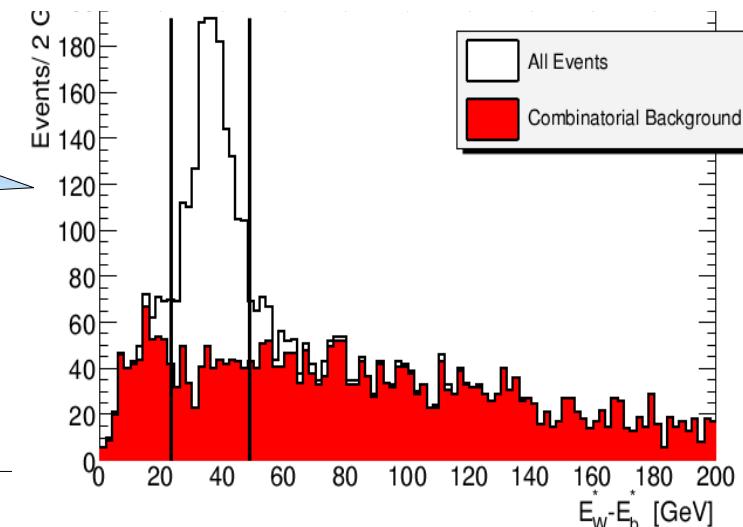
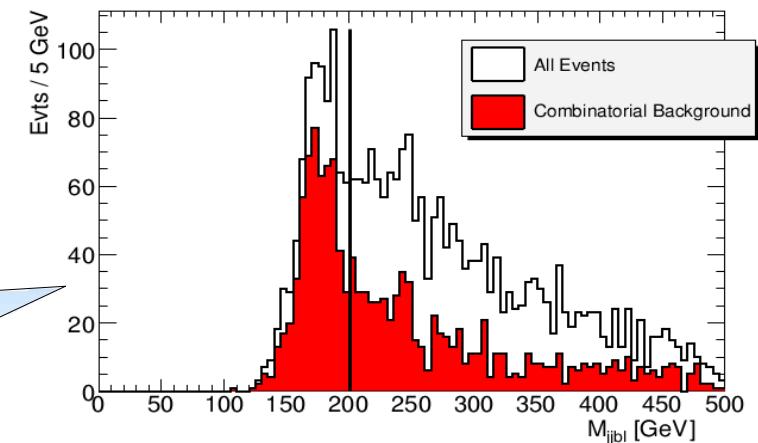
Top quark reconstruction

Need to choose from the two b-jets the one to associate to the had. W

- Method chosen: b-jet closest to the hadronic W

Additional cuts to improve the final top purity

- M_{INV} of had W and the *leptonic* b-jet > 200 GeV
- M_{INV} of the lepton and leptonic b-jet < 160 GeV
- $|\delta(E_W^* - E_b^*)| < 1.5 \sigma$ ($^* \equiv$ top rest frame)

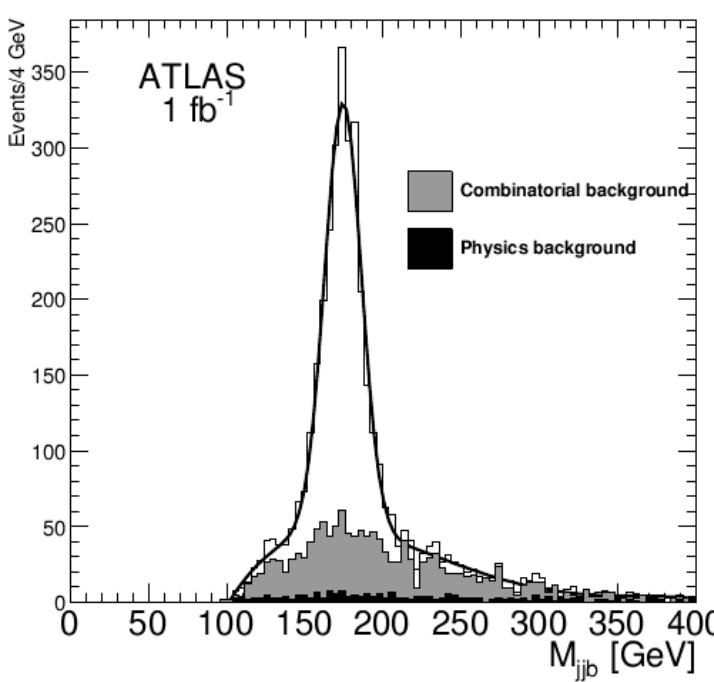


Top quark mass measurement

gauss+cubic fit

$$M_{top} = 174.8 \pm 0.3 \text{ GeV}$$

$$\Gamma_{top} = 11.6 \pm 0.2 \text{ GeV}$$



Systematic uncertainties	χ^2 minimization method
Light Jet Energy Scale	0.2 GeV/%
b Jet Energy Scale	0.7 GeV/%
ISR/FSR	$\simeq 0.3$ GeV
b quark fragmentation	≤ 0.1 GeV
Background	negligible
Method	0.1 to 0.2 GeV

Remarks:

- ✓ Jet Energy Scale will be the main source of systematic uncertainty
- ✓ light JES is reduced thanks to *in situ* rescaling
- ✓ with a JES~1% (5%) the syst. error will be ~1(3.5) GeV

$$M_{top} = 174.8 \pm 0.3 \text{ GeV (stat.)} \pm 1 \text{ GeV (syst.)}$$

with JES=1%

Ongoing analysis - Dileptons

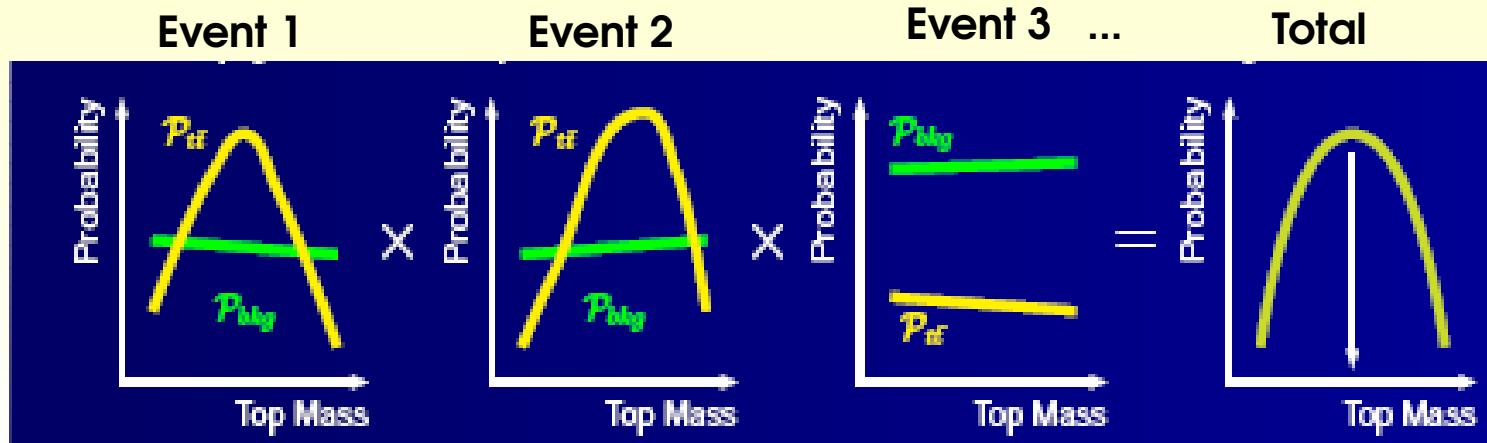
Matrix Element method (likelihood method)

Calculation of a probability density for signal and bkg as a function of the top mass

- ✓ convolution of the Matrix Element of the process with the detector resolution functions
- ✓ integration over the unmeasured quantities of the phases space

$$P_s(\mathbf{x}|M_t) = \frac{1}{\sigma(M_t)} \int d\Phi |M_{t\bar{t}}(q_i, p_i; M_t)|^2 W(p, x) f_{PDF}(gl_1) f_{PDF}(gl_2)$$

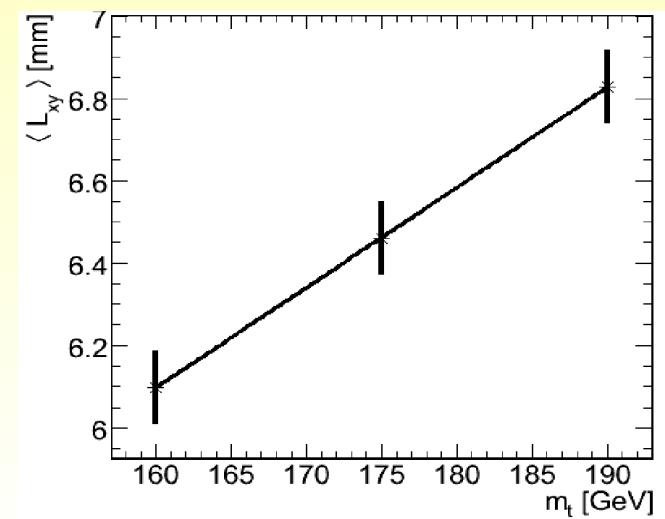
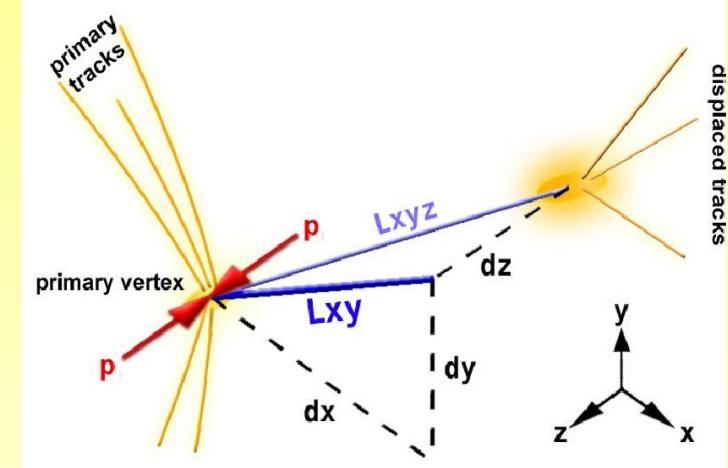
- ✓ Multiply each event prob. to extract the best mass



Ongoing analysis - Dileptons

Decay length method:

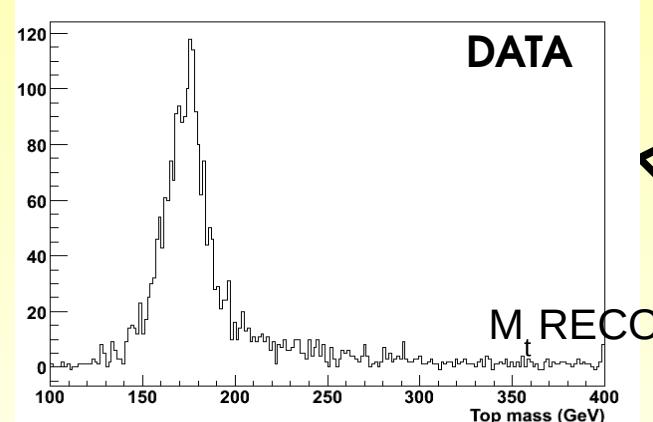
- ✓ use the sensitivity of the B decays length on the top mass
 - Correlate the mean transverse decay $\langle L_{xy} \rangle$ to M_{top}
- ✓ independent of Jet Energy Scale
--> allows cross check to conventional methods
- ✓ reconstruction of the event topology is not necessary



Ongoing analysis - Lepton+Jets

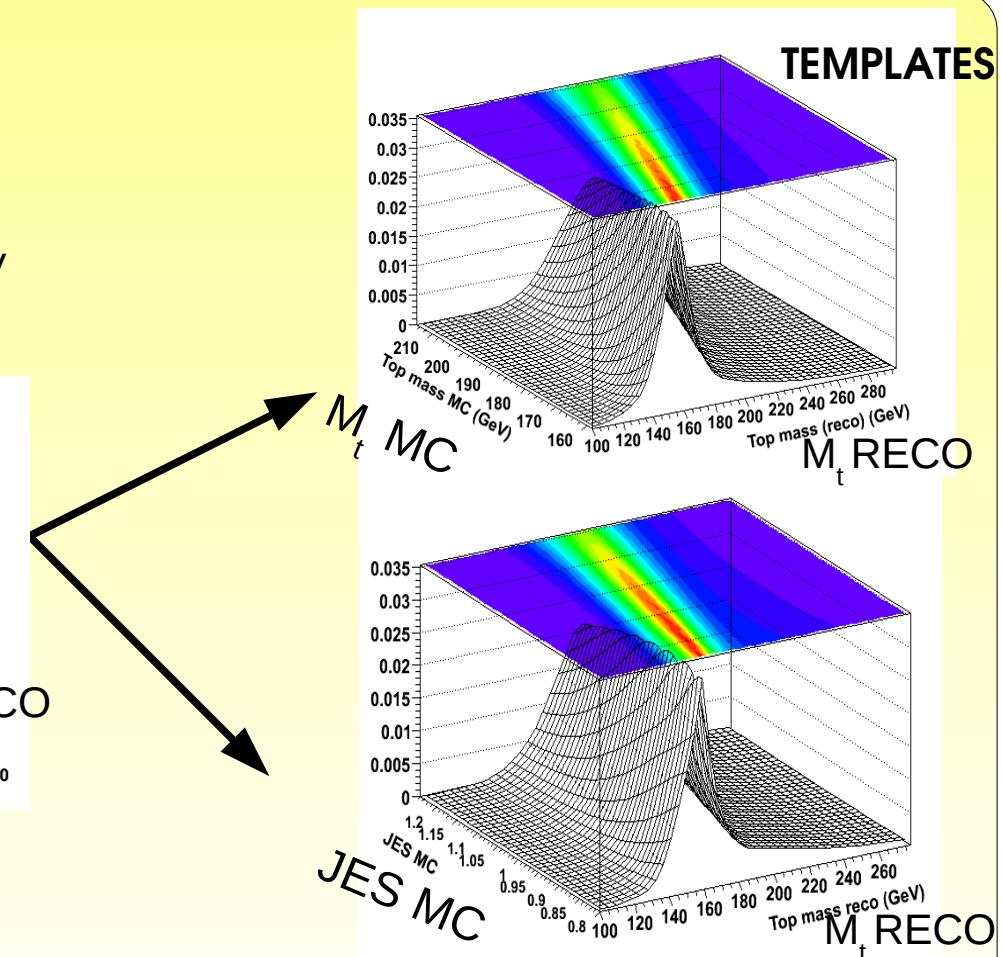
Template method

The method consist in comparing the data with Monte Carlo distributions (*Templates*) to determine simultaneously M_{top} and Jet Energy Scale



Advantages:

- ✓ Reduce syst. uncertainty due to jet calibration
- ✓ Take in account bias like pT cuts on jets



Find the pair (M_{top} , JES) for which templates correspond to data

Conclusions and outlook

- ★ The most promising channel is the lepton+jets one: good statistics, high pT lepton to trigger the signal.
- ★ The mass measurement is expected to have an uncertainty of ~ 1 (3.5) GeV with a Jet Energy Scale of 1(5)% with 1fb-1
- ★ Ongoing analysis on dilepton, all hadronic and pure leptonic ($t \rightarrow W b \rightarrow l\nu J/\psi(l^+l^-)$) that will give independent measurements.

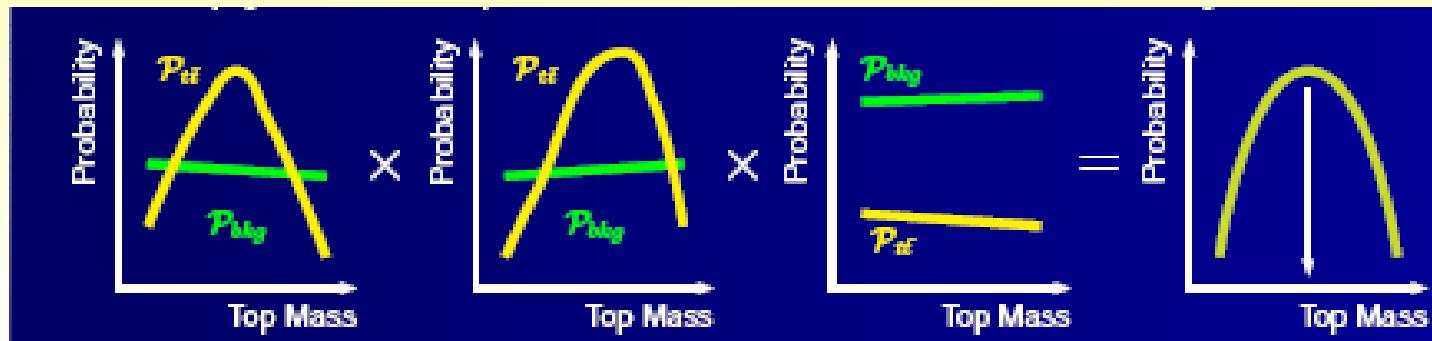
Back-up slides

Ongoing analysis: dileptons channel

Mass measurement using a likelihood: **Matrix Element method (ME)**

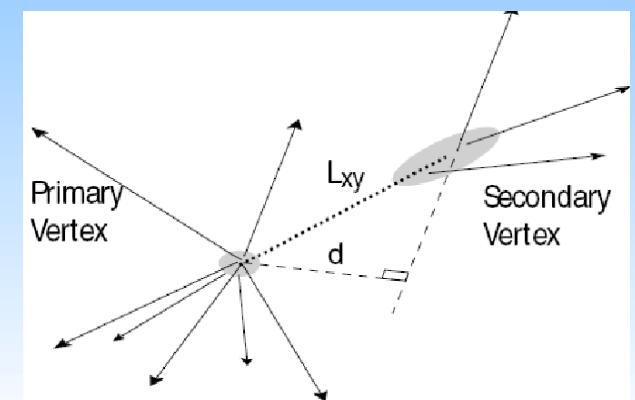
Calculation of a probability density for signal and bkg as a function of the top mass

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Lepton + Jet with no B-tag

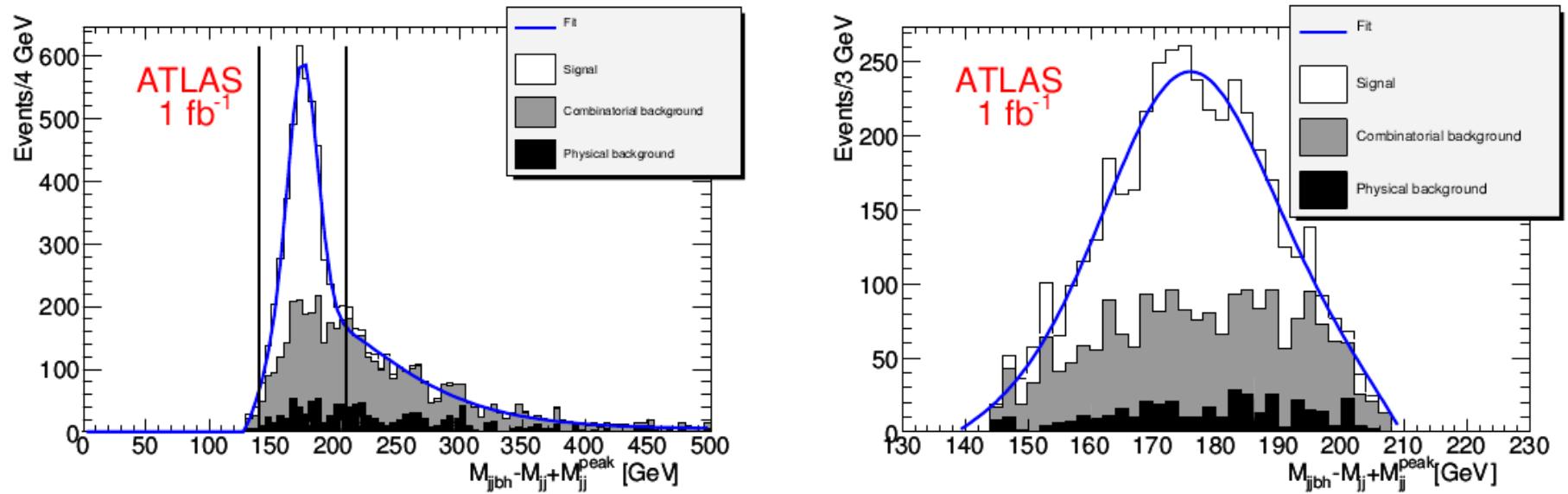


Figure 23: Events without b -tagging: $m_{\text{top}} = M_{\text{jjb}} - M_{\text{jj}} + M_W^{\text{peak}}$ with the geometric method, after purification cuts (left, **C1** and **C3** cuts: $m_{\text{top}} = 175.0 \pm 0.4$ GeV, with a width equal to 11.7 ± 0.5 GeV; right, **C3**, **C4** and **C5** cuts: $m_{\text{top}} = 175.2 \pm 0.5$ GeV, with a width equal to 12.4 ± 0.8 GeV).

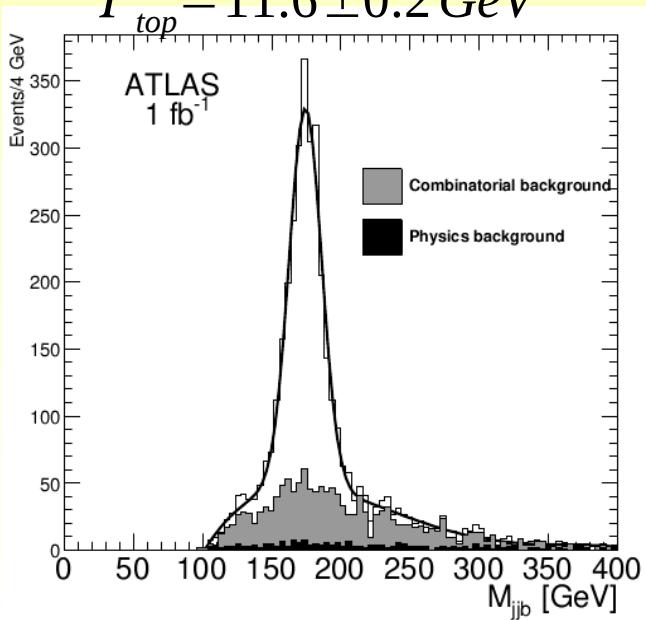
Lepton+Jets channel (4)

Top quark measurement

gauss+cubic fit after C2+C3 cuts (C4 and C5 improve purity without changing the final value)

$$M_{top} = 174.8 \pm 0.3 \text{ GeV}$$

$$\Gamma_{top} = 11.6 \pm 0.2 \text{ GeV}$$



Systematic uncertainty	χ^2 minimization method	geometric method
Light jet energy scale	0.2 GeV/%	0.2 GeV/%
b jet energy scale	0.7 GeV/%	0.7 GeV/%
ISR/FSR	$\simeq 0.3 \text{ GeV}$	$\simeq 0.4 \text{ GeV}$
b quark fragmentation	$\leq 0.1 \text{ GeV}$	$\leq 0.1 \text{ GeV}$
Background	negligible	negligible
Method	0.1 to 0.2 GeV	0.1 to 0.2 GeV

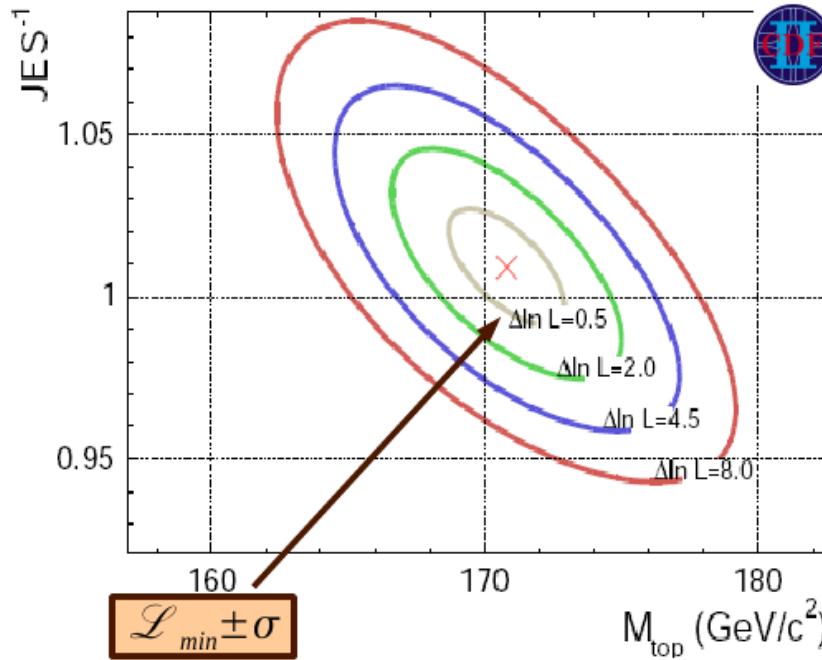
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- ✓ with a JES~1% (5%) the syst. error will be ~1(3.5) GeV

$$M_{top} = 174.8 \pm 0.3 \text{ GeV} \text{ (stat.)} \pm 1 \text{ GeV (syst.)} \\ \text{with } JES = 1\%$$

Top Mass $t + \text{jets}$ with \mathcal{ME} method

CDF Preliminary 940 pb⁻¹



$$\mathcal{L} = -\ln \left(\prod_{i \leq N} P_i \right),$$

N is a total number of event

Dominant Systematics



ISR/FSR Radiation	± 1.05 GeV
b JES	± 0.60 GeV
JES Residual	± 0.42 GeV
b tagging	± 0.31 GeV

Dominant Systematics



Relative b /light JES	± 0.57 GeV
b fragmentation	± 0.54 GeV
Signal Fraction	$+0.53$ GeV -0.24 GeV
Signal Modeling	± 0.45 GeV



$$m_t = 170.9 \pm 2.2 \text{ (stat. + JES)} \pm 1.4 \text{ (sys.) GeV}$$



$$m_t = 170.5 \pm 2.4 \text{ (stat. + JES)} \pm 1.2 \text{ (sys.) GeV}$$