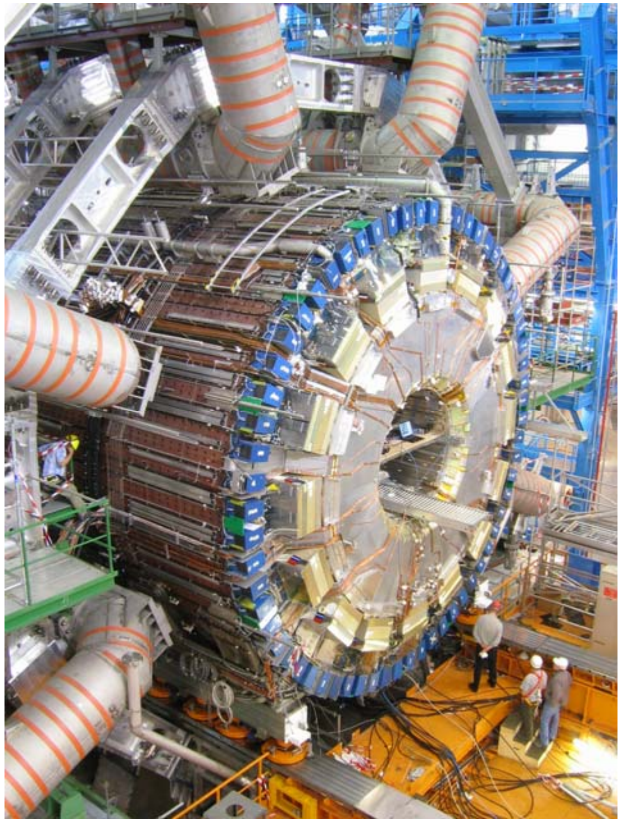
Top mass measurement at LHC

Anne-Isabelle ETIENVRE
CEA Saclay



ATLAS

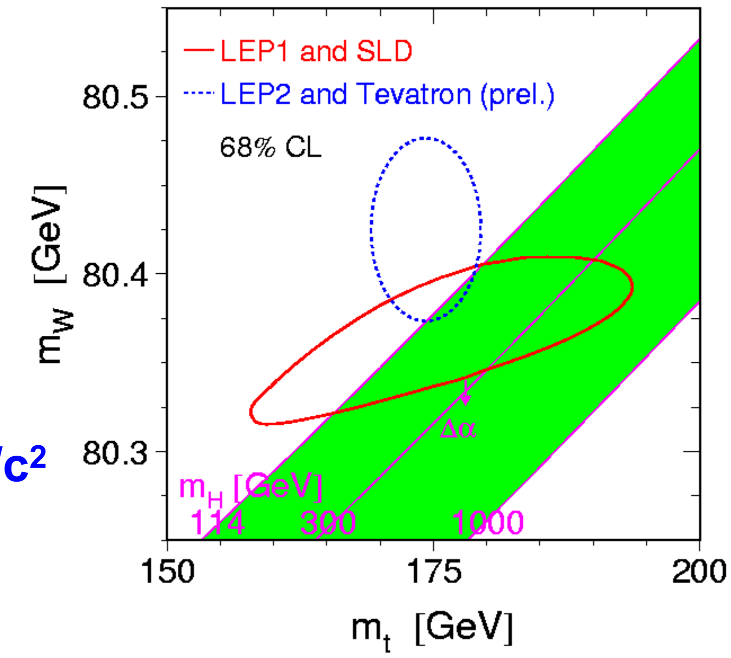
CMS

Motivations for an accurate top mass measurement

- **EW precision observables depend strongly on the value of the top mass**

→ ***a high accuracy in m_t measurement is needed for:***

- **consistency tests of the Standard Model**
- **constraints on the Higgs mass within the Standard Model**
- **high sensitivity to physics beyond the Standard Model**



- **What would bring $\Delta m_t \sim 1$ GeV/c² ?**

→ **Assuming δm_W = 15 MeV/c², m_{top} = 175 GeV/c² and current values on $\Delta\alpha$,**

$$\Rightarrow m_H = 63^{+22}_{-18}$$

($\delta m_H/m_H \approx 32\%$)

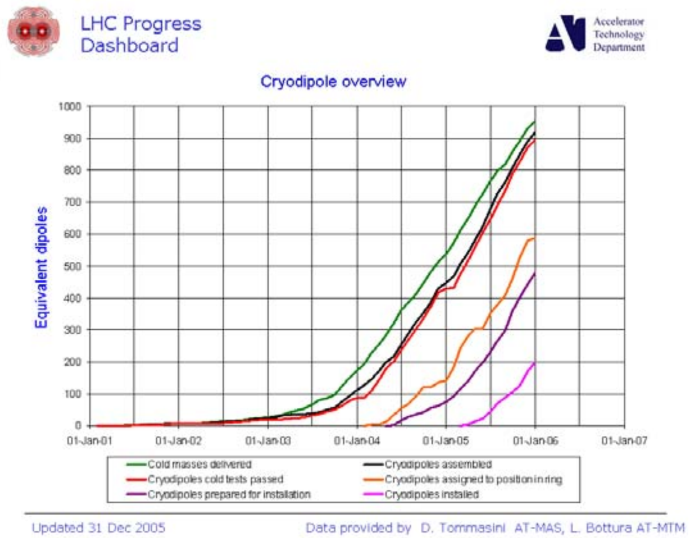
→ **Assuming δm_W = 15 MeV/c² and $\Delta\alpha = 0.00012$,**

$$\Rightarrow m_H = 73^{+20}_{-16}$$

($\delta m_H/m_H \approx 25\%$)

Expected statistics @ LHC

Data taking	Luminosity ($cm^{-2}s^{-1}$)	Integrated luminosity (fb^{-1})	Number of inclusive $\bar{t}t$ events
Very beginning (summer 2007)	10^{32}	10 days : 0.1	≈ 80 000
Low luminosity (2008)	10^{33}	100 days : 10	≈ 8 000 000
High luminosity (2010)	10^{34}	100 days : 100	≈ 80 000 000



Systematic errors on the top mass measurement

- **jet energy scale (light jets / b-jets)**
  - LHC aim : jet energy knowledge better than 1 %
  - light jet energy scale contribution can be strongly reduced using an in-situ calibration based on the W mass constraint

- **initial and final state radiations (ISR, FSR)**

  error calculated as 20% of $|m_t(ISR,FSR - on) - m_t(ISR,FSR - off)|$

- **b-quark fragmentation**

  error estimated changing the Peterson parameter (-0.006) within its theoretical uncertainty (0.0025)

- **combinatorial background**

  error estimated varying the background shape and size in the fitting procedure

Top mass measurement @ the LHC : references

In common to ATLAS/CMS:

- **summary report of the LHC Workshop on Standard Model Physics**
  → LHC Yellow Report on Standard Model Physics (1999 – 2000)

CMS : studies based on fast simulation

(studies with full simulation to be published soon)

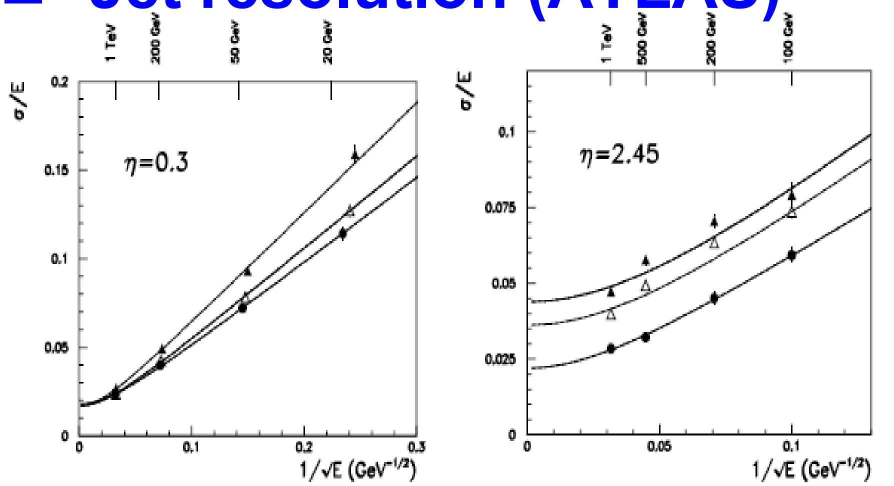
CMS-Notes : 1999-065, 2001-001

ATLAS : studies based on full or fast simulation

- **Physics Technical Design Report (P-TDR, 1999)**
- **Scientific note : hep-ex/0403021**
- **ATLAS-Notes : 2001-016, 2002-007, 2003-011, 2003-012, 2005-002**

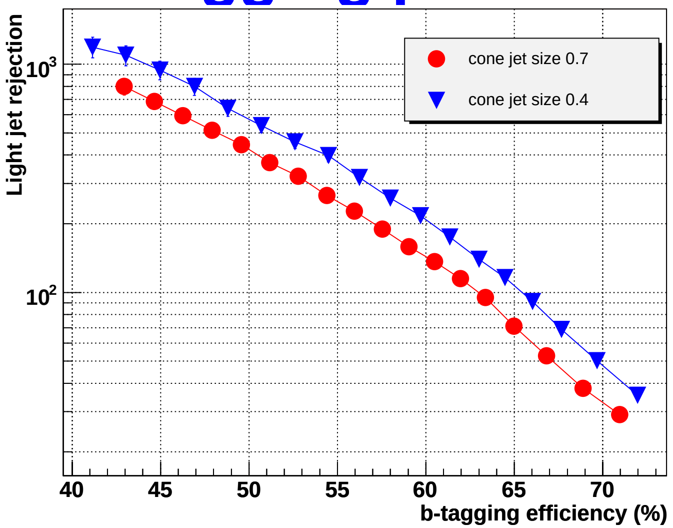
A few words on jet performances

Jet resolution (ATLAS)



σ_E /E = 60-80% / √E + 6-8 %
(σ_E ≈ 9 GeV @ 100 GeV)

b-tagging performances (ATLAS)



Typical b-tagging efficiency = 60 %
→ Light jet rejection ~ 200

Outline

- **Top mass measurement in the lepton + jets channel**
  - **using the hadronic top decay**
  - **using a kinematic fit**
  - **using large p_T(top) events**
- **Top mass measurement in leptonic final states with J/ψ**
- **Top mass measurement in the dilepton channel**
- **Top mass measurement in the all hadronic channel**

Top mass measurement in the lepton + jets channel (1/8)

Main backgrounds

Process	σ (pb)
Signal	250
bb → lν + jets	$2.2\ 10^6$
W + jets → lν + jets	$7.8\ 10^3$
Z + jets → l^+l^- + jets	$1.2\ 10^3$
WW → lν + jets	17.1
WZ → lν + jets	3.4
ZZ → l^+l^- + jets	9.2

Before any cuts,
S/B ≈ 10^{-4}

Event selection

- **Lepton selection**
  1 reconstructed lepton (e, μ) isolated, P_T (lepton) > 20 GeV/c , |η| < 2.5
  E_T^{miss} > 20 GeV
- **Jet energy precalibration**
- **Jets selection**
  → 2 b-jets , P_T > 40 GeV/c, |η| < 2.5
  → ≥ 2 light-jets, P_T > 40 GeV/c, |η| < 2.5

After this selection,
S/B ≈ 30

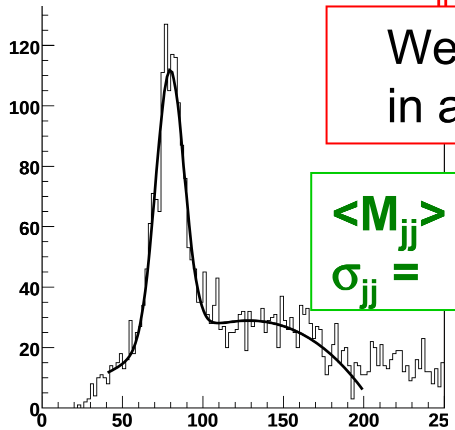
Top mass measurement in the lepton + jets channel (2/8)

Principle

Reconstruction of the hadronic W

- Invariant mass m_{jj} for events with only 2 light jets:

ATLAS (full sim.)



We select the hadronic W candidates in a mass window of $\pm$ 5 σ_{jj} around $\langle m_{jj} \rangle$

$\langle M_{jj} \rangle$ = 79.6 ± 0.4 GeV/c²
σ_{jj} = 8.8 ± 0.5 GeV/c²

- Choice of the light jet pair and rescaling:

χ^2 based on M(W) :

$$\chi^2 = \frac{\left(M_{jj}(\alpha_1,\alpha 2) - M_W\right)^2}{\Gamma_W^2} + \left(\frac{E_{j1}(1-\alpha_1)}{\sigma_{j1}}\right)^2 + \left(\frac{E_{j2}(1-\alpha_2)}{\sigma_{j2}}\right)^2$$

χ^2 minimisation → choice of the light jet pair (j_1, j_2) and determination of the rescaling factors (α_1, α_2)

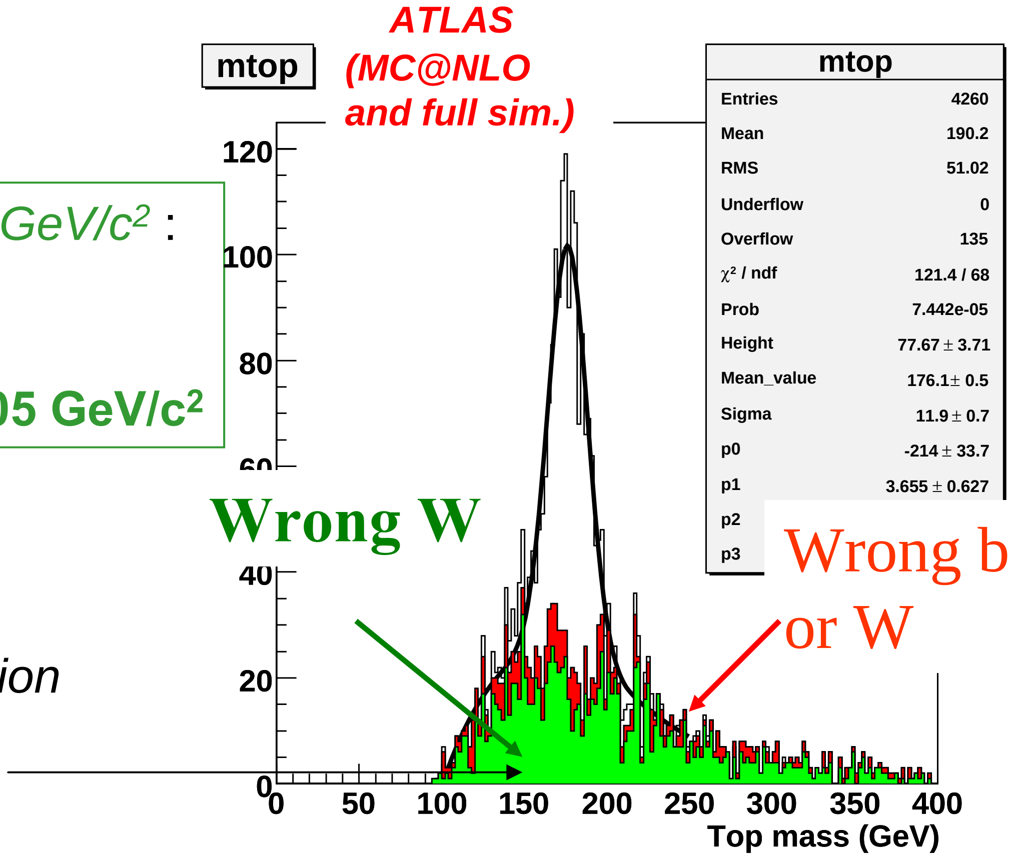
reconstruction of the hadronic scaled W,
kept as candidate if | M(W) – 80.4 | ≤ 2 σ_W

Top mass measurement in the lepton + jets channel (3/8)

Principle (cont.)

- **Choice of the b-jet :** *b-jet giving the top of maximum P_T*
- **Reconstruction of the resulting top mass**

for a generated top mass = 175 GeV/c² :
M(top) = 176.1 ± 0.6 GeV/c²
σ(top) = 11.9 ± 0.7 GeV/c²
Statistical error for 10 fb⁻¹ : 0.05 GeV/c²



Warning: expect a contamination due to tt → jjb jjb events

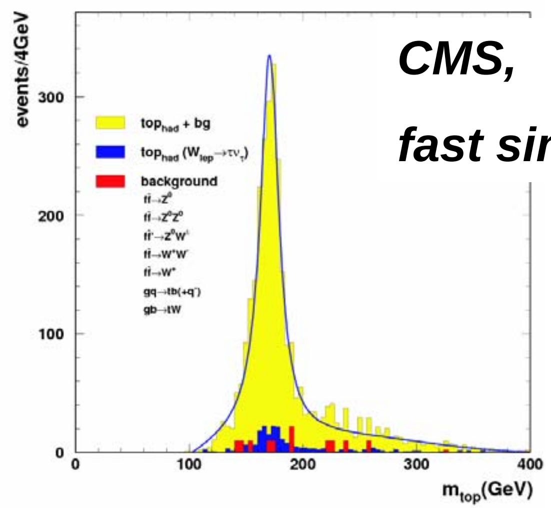
Top mass measurement in the lepton + jets channel (4/8)

Performances

64000 events @ 10 fb^{-1}

	Efficiency (%) (wrt semil. events)	W purity (%)	b purity (%)	top purity (%)
Full window	2.70 ± 0.05	56.0 ± 0.9	63.2 ± 0.9	40.5 ± 0.9
$\pm 3\,\sigma(M_{top})$	1.82 ± 0.04	69.1 ± 0.8	75.8 ± 0.8	58.6 ± 0.8

Comparison with CMS (very similar analysis)

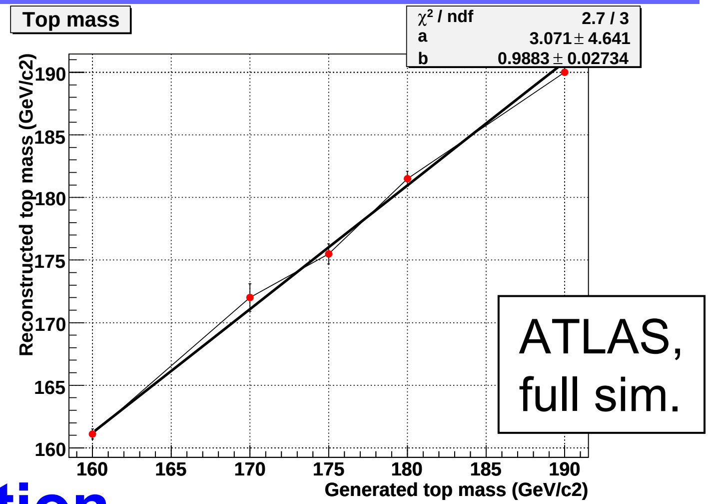


CMS,

fast sim.

$\sigma(top) \approx 10$ GeV/c^2
Statistical error for 10 fb^{-1} : 0.25 GeV/c^2

Top mass measurement in the lepton + jets channel (5/8)



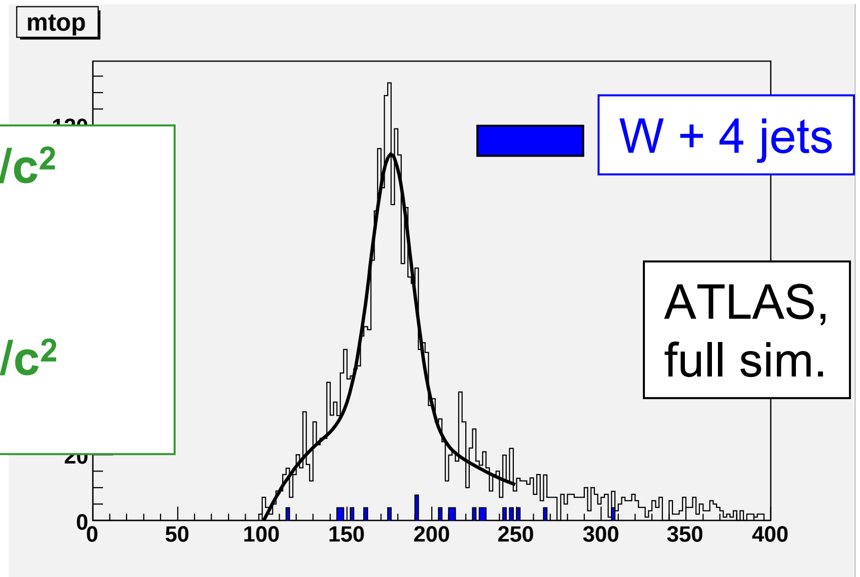
- **Good linearity of the method**

- **Remaining background contribution**

(W + 4 jets, generated with AlpGen)

Signal only : M(top) = 176.1 ± 0.6 GeV/c²
σ = 11.9 ± 0.7 GeV/c²

Signal + bkg: M(top) = 176.2 ± 0.6 GeV/c²
σ = 12.1 ± 0.7 GeV/c²



→ *Negligible contribution to the top mass measurement*

Top mass measurement in the lepton + jets channel (6/8)

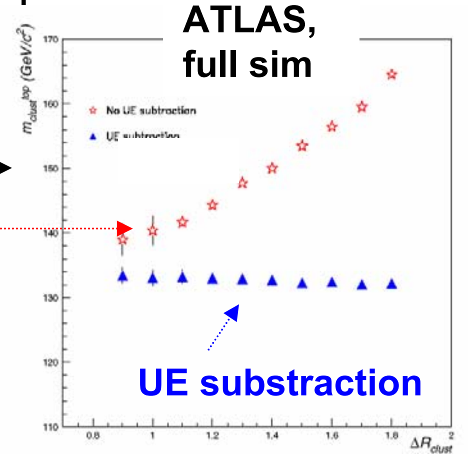
- **Alternative method : kinematic fit**
  - **Idea = reconstruct the entire tt final state → reduce the systematic uncertainty**
  - **Hadronic side : same method as previous slides**
  - **Leptonic side : reconstruction of the neutrino**
    - **$p_T(\nu) = E_T^{miss}$ and $p_z(\nu)$ from $M_W^{PDG} = M(l,\nu)$**
    - **quadratic ambiguity for $p_z(\nu)$**
  - **Top mass measurement :**
    - **→ χ^2 based on kinematic constraints (energy and direction of leptons and jets can vary within their resolutions)**
    - **→ χ^2 minimisation, event by event, for the two $p_z(\nu)$ solutions (the one giving the lower χ^2 is kept)**
    - **→ extrapolation : $m_{top} = m_{top}(\chi^2 = 0)$**
  - **Performances *(fast simulation, to be checked with full simulation)*:**
    - **efficiency = 1.1% → 26 000 events @ 10 fb^{-1} → $\delta m_{stat} = 0.1$ GeV/c^2**
    - **good linearity of the method**
    - **important reduction of the FSR systematic error**

Top mass measurement in the lepton + jets channel (7/8)

Method based on an high p_T top sample (p_T(top) > 200 GeV/c)

Principle

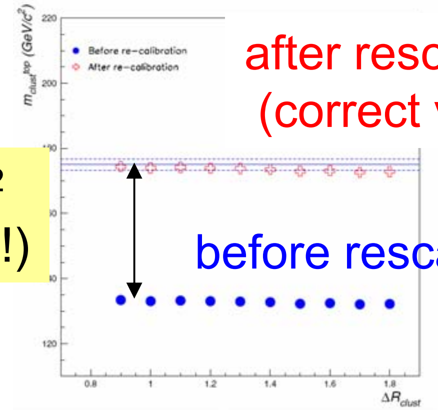
- the two tops are back-to-back: should reduce the bkg contribution
- but the three jets in one hemisphere tend to overlap : top is reconstructed with a large calorimeter cluster $0.8 < \Delta R_{top} < 1.8$ (summing up all calorimeter towers)
- UE have to be substracted
- Mass scale recalibration based on hadronic W



Performances :

- efficiency = 2 % w.r.t. to sample with p_T > 200 GeV/c → 3600 events @ 10 fb^{-1}
- δm_{stat} = 0.2 GeV/c^2

$\Delta m_{top} \approx 30$ GeV/c^2 (old jet calibration!)



Top mass measurement in the lepton + jets channel (8/8)

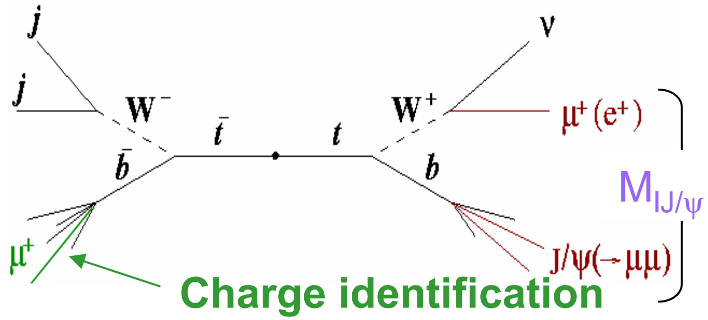
Systematic errors in the lepton + jets channel

Source of uncertainty	Hadronic top δM_{top} (GeV/c^2)	Kinematic fit δM_{top} (GeV/c^2)	High P_T sample δM_{top} (GeV/c^2)
Light jet energy scale (1 %)	0.2	0.2	
b-jet energy scale (1 %)	0.7	0.7	
b-quark fragmentation	0.1	0.1	0.3
ISR	0.1	0.1	0.1
FSR	1.	0.5	0.1
Combinatorial background	0.1	0.1	
Mass rescaling			0.9
UE estimate (± 10 %)			1.3
Total	1.3	0.9	1.6
Statistical error	0.05	0.1	0.2

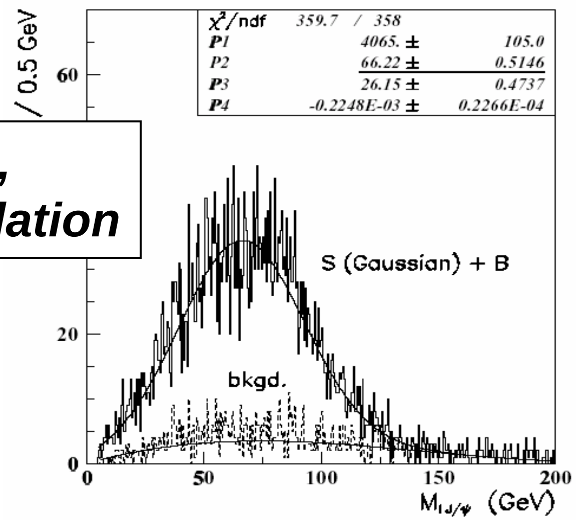
Top mass measurement in leptonic final states with J/ψ (1/2)

Principle

- **B.R. = $5.3\ 10^{-5}$**
  → to be performed @ high luminosity
- **Event selection :**
  - 1 isolated lepton (p_T > 15 GeV/c, $|\eta|$ < 2.4)
  - 3 non isolated muons (p_T > 4 GeV/c, $|\eta|$ < 2.4)
  - → **Efficiency = 30 % → 1000 events/y @ 10^{34} $cm^{-2}s^{-1}$**



- **Background :**
  - (W/Z +jets, WW,WZ, Wbb): negligible with these cuts
  - combinatorial : wrong J/ψ assignment to the isolated lepton
- **Reconstruction of the lJ/ψ invariant mass**

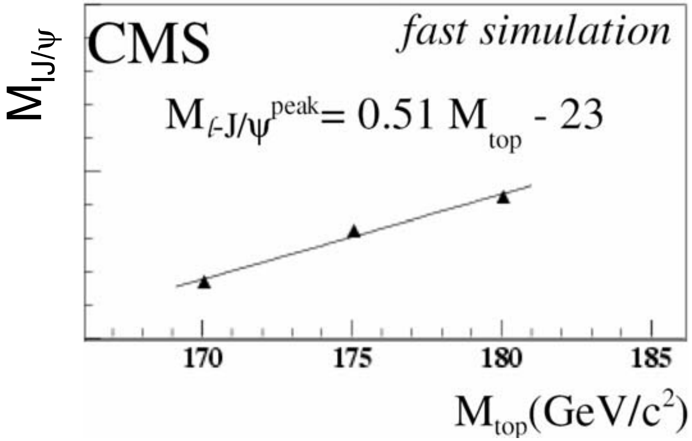


$M(lJ/\psi)$ = 66.2 ± 0.5 GeV/c²
$\sigma(M(lJ/\psi))$ = 26.1 ± 0.5 GeV/c²
Statistical error (4 y @ 10^{34}) : 0.5 GeV/c²

Top mass measurement in leptonic final states with J/ψ (2/2)

Top mass measurement

- Linear correlation between M(lJ/ψ) and M(top)



statistical error (4 y @ 10^{34}) : 1 GeV/c^2

- Systematic errors on this measurement

Source of uncertainty	$\delta M_{lJ/\psi}$ (GeV/c^2)
FSR	0.15
PDF	0.1
b-quark fragmentation	0.3
Background	0.1

systematic error of the order of 0.5 GeV/c^2 on the top mass

Top mass measurement in the di-leptons channel (1/2)

Principle

- **Very clean channel (background negligible)**

- **Indirect mass measurement (2 neutrinos)**

- **Event selection :**
  - 2 leptons of opposite charge ($p_T > 20$ GeV/c, $|\eta| < 2.5$)
  - $E_T^{miss} > 40$ GeV
  - 2 b-jets ($p_T > 25$ GeV/c, $|\eta| < 2.5$)

- **Final state reconstruction:**
  - Set of 6 equations based on kinematic conservation laws, plus assumption of the top mass value
  - More than one solution → compute weights based on kinematic MC distributions (cos θ^*_t, E_ν, $E_{\nu bar}$)
    → keep the solution with highest weight

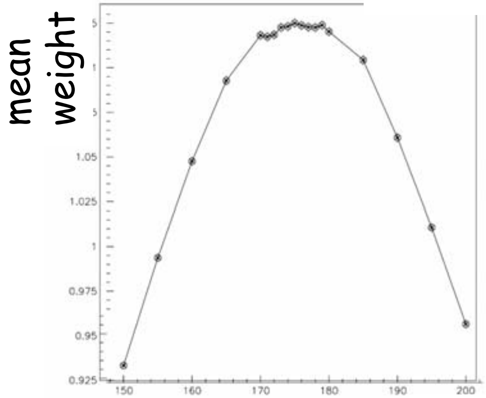
Top mass measurement in the di-leptons channel (2/2)

Top mass measurement

- Compute this optimal weight for several input top masses
  → mean weight for all events, for a given m_{top}

ATLAS, fast sim.

- m_{top} estimator corresponds to the maximum mean weight
- efficiency = 6.5 % → 20 000 events @ 10 fb^{-1}
- δm(stat.) = 0.04 GeV/c^2



m_{top}

Systematic errors

Source of uncertainty	δM_{Top} *(GeV)*
Statistic & reconstruction method	0.3
b-jet energy scale	0.6
b-quark frag.	0.7
ISR	0.1
FSR	0.6
Parton distribution function	1.2
Total	1.7

Top mass measurement in the all hadronic channel (1/2)

Principle

- **Advantage** : full kinematic reconstruction of both sides
  Disadvantage: huge QCD multijet background (*S/B = 10^{-8}*)

- **Event selection:**
  - $\geq$ 6 jets with $p_T(j) > 40$ GeV, $|\eta| < 3$
  - $\geq$ 2 jets with b-tag, $|\eta| < 2.5$

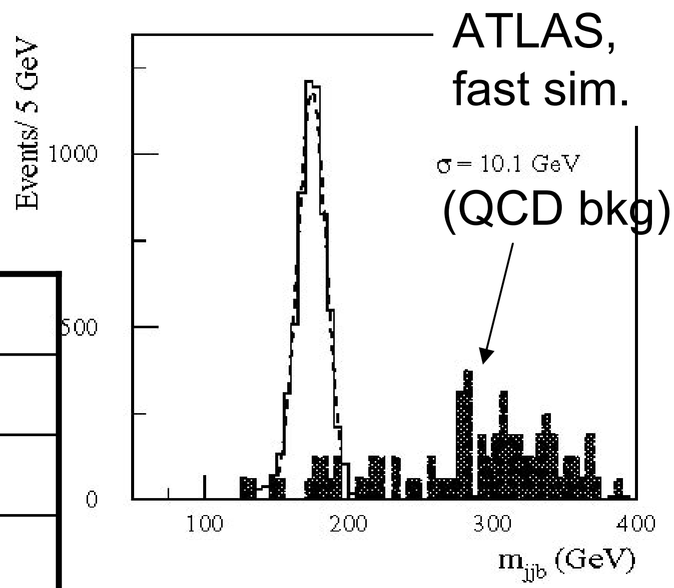
  $\Rightarrow$ *S/B = 1/19*

- **Final state reconstruction (kinematic fit):**
  - 2 W reconstruction : choice of two light-jet pairs
    (χ^2 , based on M_W^{PDG} constraint) $\Rightarrow$ *S/B = 1/3*
  - Association of both W candidates to the right b-jet:
    (χ^2 , based on m_t constraint: $m_{t1} = m_{t2}$)
  - Top mass window (130-200 GeV/c^2) $\Rightarrow$ *S/B = 6*
  - Improvement : sample of events with p_T(2 tops) > 200 GeV/c
    $\Rightarrow$ *S/B = 18*

Top mass measurement in the all hadronic channel (2/2)

Performances

- efficiency = 0.08 % → 3300 events @ 10 fb^{-1}
- δm_{stat} = 0.18 GeV/c^2
- systematic errors:



Source of uncertainty	δm_{top} (GeV/c^2)
Light jet energy scale	0.8
b-jet energy scale	0.7
b-quark fragmentation	0.3
ISR	0.4
FSR	2.8
TOTAL	3

the total systematic error is the order of 3 GeV/c^2 (FSR)

Conclusion

- **Various top mass measurement methods have been investigated**
  - **Some studies have still to be done with full simulation**
  - **statistical error negligible for 10 fb^{-1} (except J/ψ)**
  - **different sensitivity to the various sources of systematic errors**

    → reliable cross-checks of these methods

- **Possible to measure m_{top} with a precision ≈ 1 GeV/c^2 for 10 fb^{-1} (l + jets)**

- **Lot of work to do in order to reduce systematic errors**