Top physics at LHC

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VI IFAE, 11 – 13 April 2007

Napoli

Outline

- Introduction
  - The role of Top quark
  - Top quark Production
  - Top quark Decay
- Precise Measurements
  - Production cross section
  - Top quark Mass
- Commissioning
  - Mass measurement with first collisions

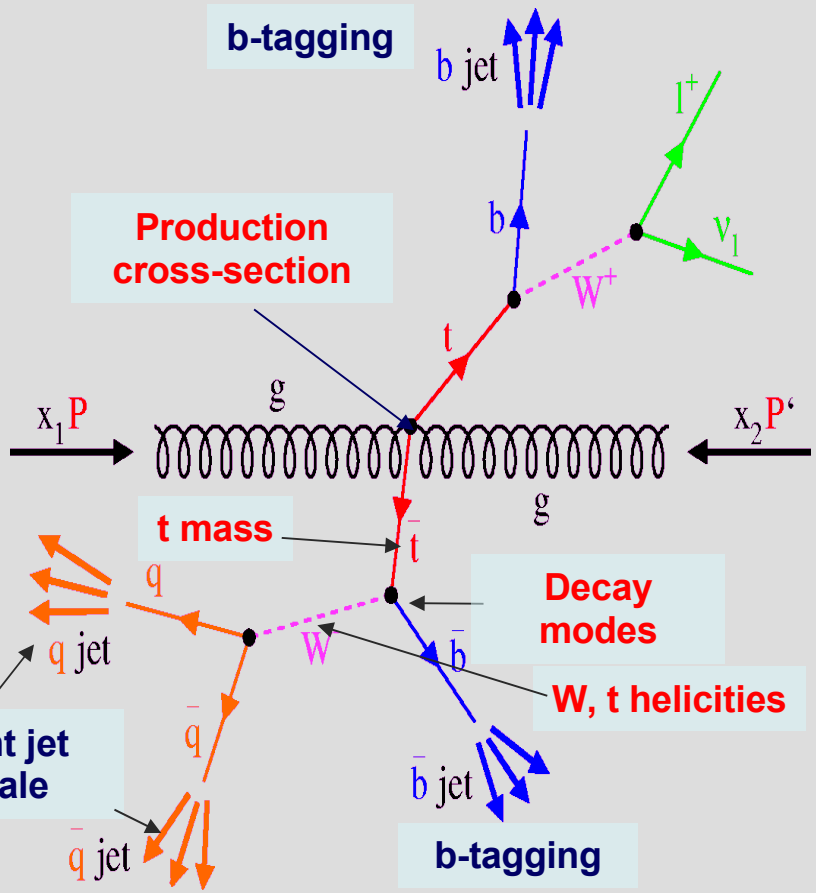
Top properties

- The top quark completes the three family structure of the SM
- It is massive **$\delta M/M < 2\%$**
- Spin=1/2, **Not directly**
- Charge=+2/3, **- 4/3 excluded @ 94%C.L.(D0)**
- Isospin=+1/2 **Not directly**
- $t \rightarrow bW$ **~100%, FCNC: probed at the 10% level**
- Large Γ=1.42GeV (m_b,M_W,a_s,EW corr.)
- Short lifetime **$c\tau$<52.5μm @95%C.L.(CDF)**

$\tau_{had} = \Lambda_{QCD}^{-1} >> \tau_{decay}$ → "t-quarks are produced and decay as free particles"

NO top hadrons

The Role of Top quark at LHC



1. Fundamental for **EW measurements**
   - m_t, σ_t, q_t, $|V_{tb}|$, σ_{tt}, BR_t, tt, pdfs
   - m_t can greatly help in the indirect constraint of the Standard Model (and new physics !) see next slide

2. Fundamental for **new physics search**
   - both production and decay: X→tt, t→X, ttX
   - larger couplings with Higgs –new physics?-
   - top is background to many search channels

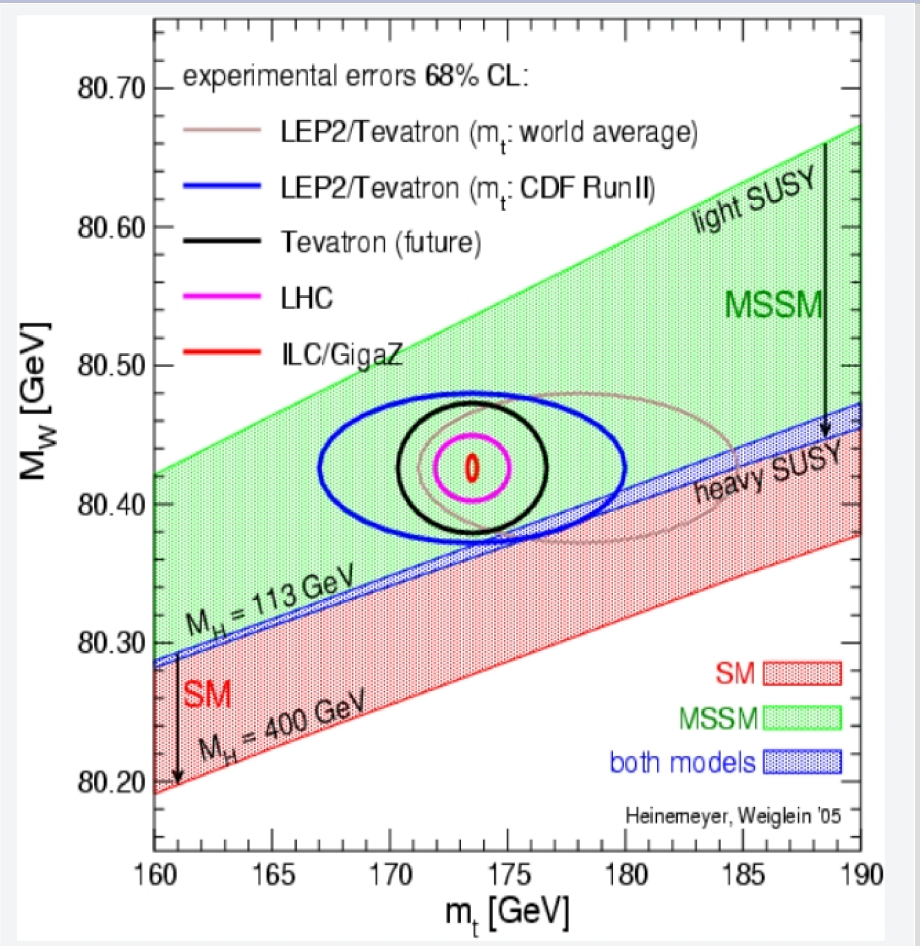
3. Essential for **commissioning** detector and tools: jet scale, b-tagging calibration

The Role of Top quark at LHC: an example

- Most recent result on top mass (CDF+D0):

M_{top}=170.9±1.5(syst)±1.1(stat)

- The top quark mass is close to electroweak scale, it is a probe to constrain SM and BSM
- Example: M_{top} and M_W can be used to constrain Higgs boson mass
- Expected to reduce total error on top mass measurement down to 1 GeV at LHC experiments



Top, *W* and Higgs masses

$$\rho = \frac{M_W^2}{M_Z^2}(1 - \sin^2\theta_W) \equiv 1 + \Delta r, \quad (1)$$

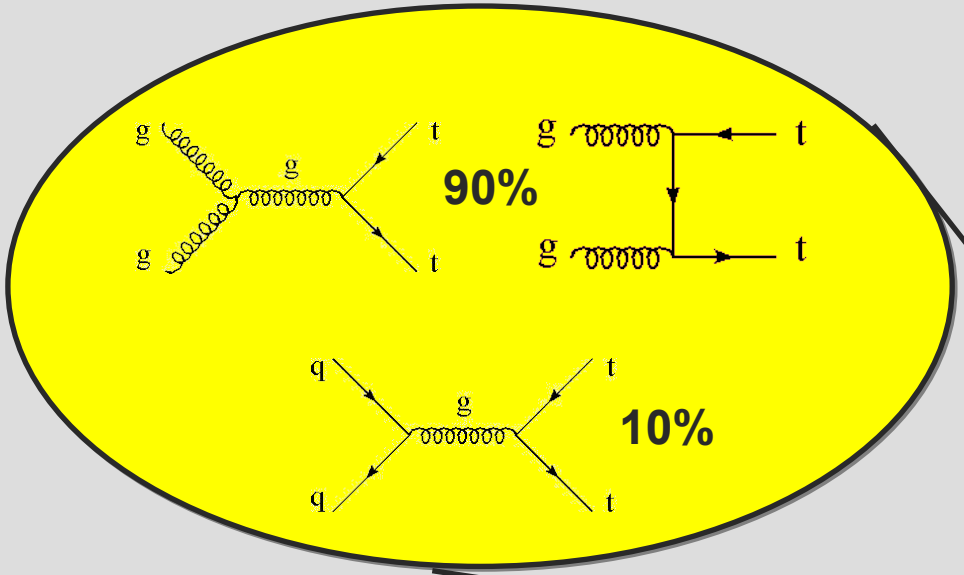
$$\Delta r = \frac{3G_F}{8\pi^2\sqrt{2}} M_{top}^2 + \frac{\sqrt{2}G_F}{16\pi^2} M_W^2 \left[\frac{11}{3}\ln\left(\frac{M_H^2}{M_W^2}\right) + \cdots\right] + \cdots \quad (2)$$

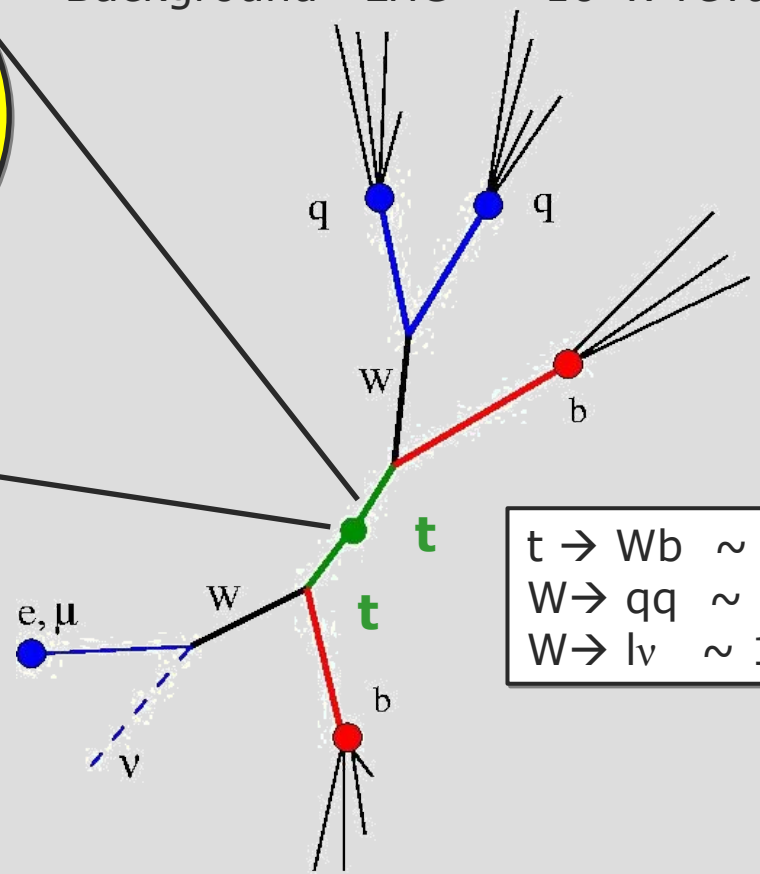
ttbar production at LHC

Production: σ_{tt}(LHC) ~ 830 ± 100 pb

→ ***1 tt/sec @ L=10^{33}***

Cross section LHC = 100 x Tevatron
Background LHC = 10 x Tevatron



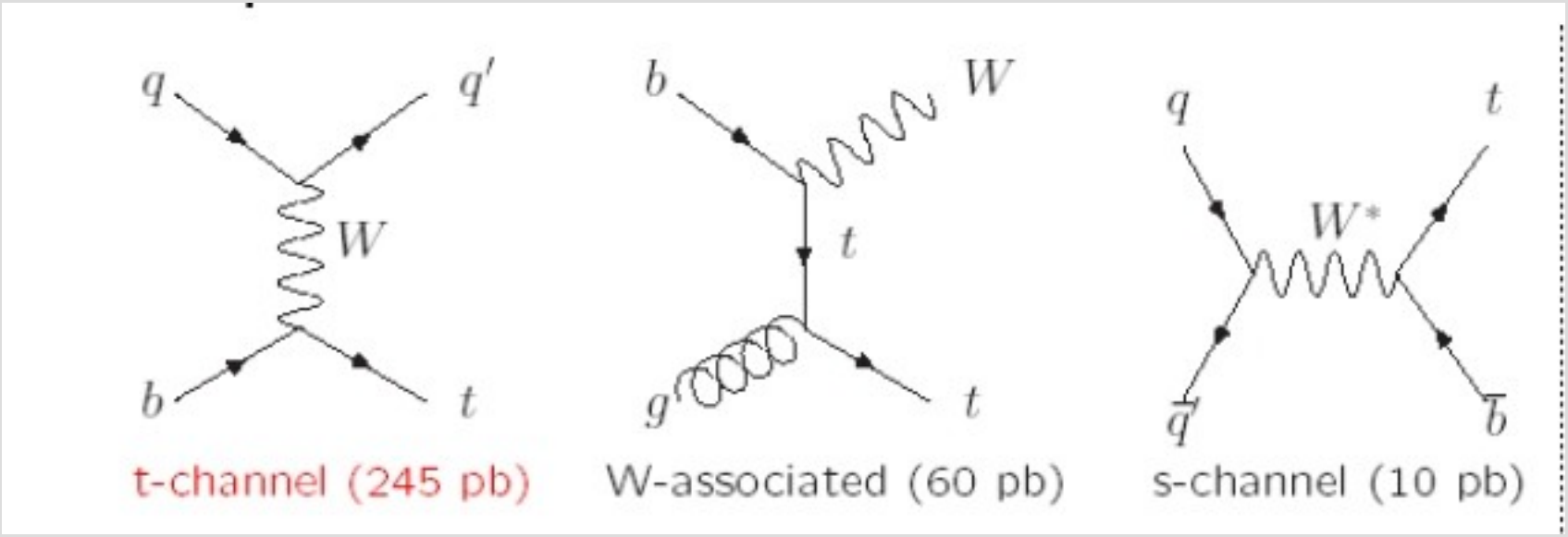


t → Wb	~ 1
W→ qq	~ 2/3
W→ lν	~ 1/3

Production mainly via
gluon-gluon fusion
(as opposed to Tevatron)
Statistics is not a problem at LHC
($\delta M<0.1$GeV already with 10fb^{-1})

Single Top Production

- Single top production never observed yet
- Direct measurement for $|V_{tb}|$
- Some properties can be studied in this channel with less ambiguity w.r.t ttbar (polarization, charge)
- New physics: new charged boson will modify SM cross section in s and t channels and their relative importance



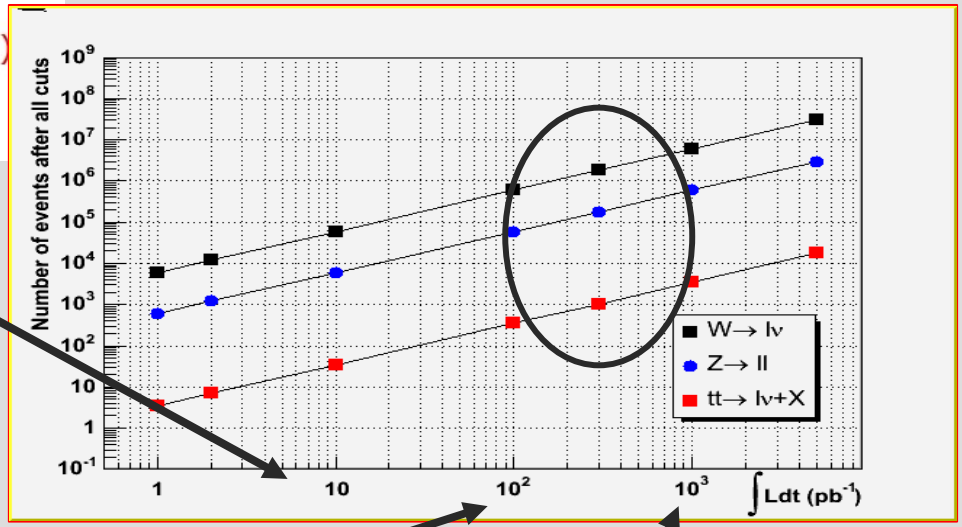
t-channel (245 pb) W-associated (60 pb) s-channel (10 pb)

The top production at LHC

	1.96 TeV	14 TeV	
ttbar pairs	$5.06^{+0.13}_{-0.36}$ pb	833^{+52}_{-39} pb	(x170)
Single top (s-channel)	0.88±0.12 pb	10±1 pb	**(x10)**
Single top (t-channel)	1.98±0.22 pb	245±17 pb	(x120)
Single top (Wt channel)	0.15±0.04 pb	60±10 pb (sara' scoperto a LHC)	(x400)
Wjj (*)	~1200 pb	~7500 pb	(x6)
bb+other jets (*)	~2.4x10^5 pb	~5x10^5 pb	(x2)

(*) with kinematic cuts in order to better mimic signal
Belyaev, Boos, and Dudko [hep-ph/9806332]

Statistics will not be a problem at LHC since the very first days, BUT needed detailed knowledge of detectors (MET, JES, b-Tagging, b-Jet Calib) and of Physics at LHC energies (PileUp, UE, Pdfs) for precise measurements: reduce systematics will be the real challange

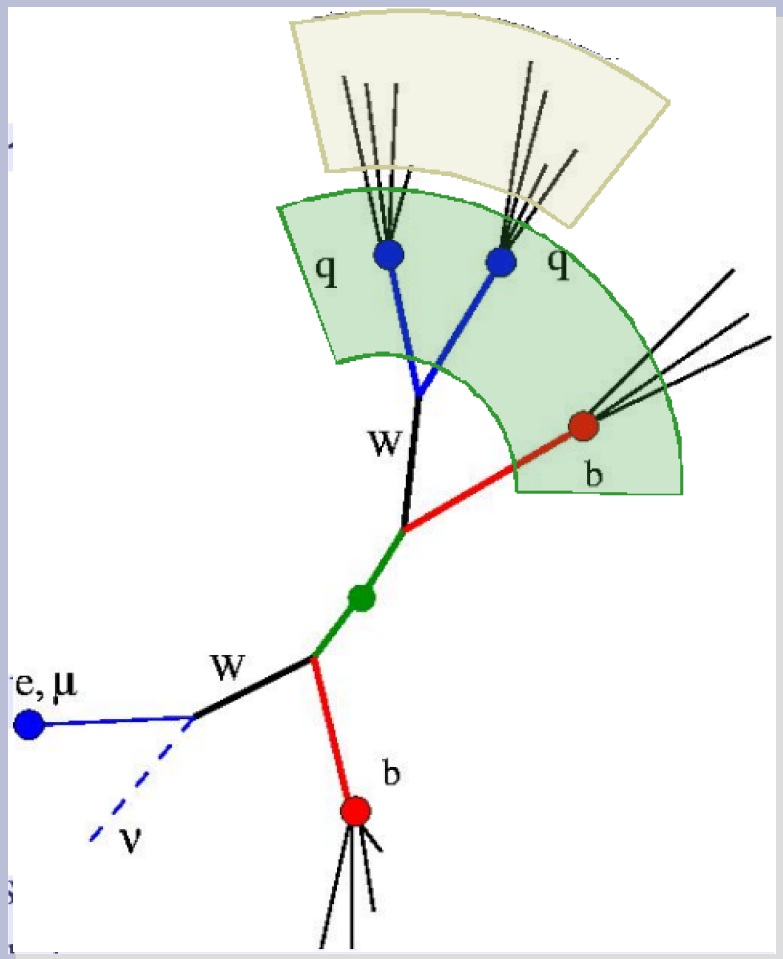


10 pb^{-1} ≡ 1 month at 10^{30} and < 2 weeks at 10^{31}, ε=50%

100 pb^{-1} ≡ few days at 10^{32}, ε=50%

1 fb^{-1}
Similar statistics to D0/CDF

Top decays



LHC “golden channel” is semileptonic decay (lepton=e,mu) BR~30%

- Semi-leptonic decay:
  - “Easy” to trigger
  - Complete reconstruction of the event
  - Selection: high Pt isolated lepton, High MET, 4 jets
- Di-leptonic decay:
  - Very high trigger efficiency
  - High Purity (main bkg is other top decays)
  - Only partial reconstruction of event
- Full hadronic decay:
  - Highest BR
  - Not many trigger possibilities at LHC: multi-jet trigger thresholds too high

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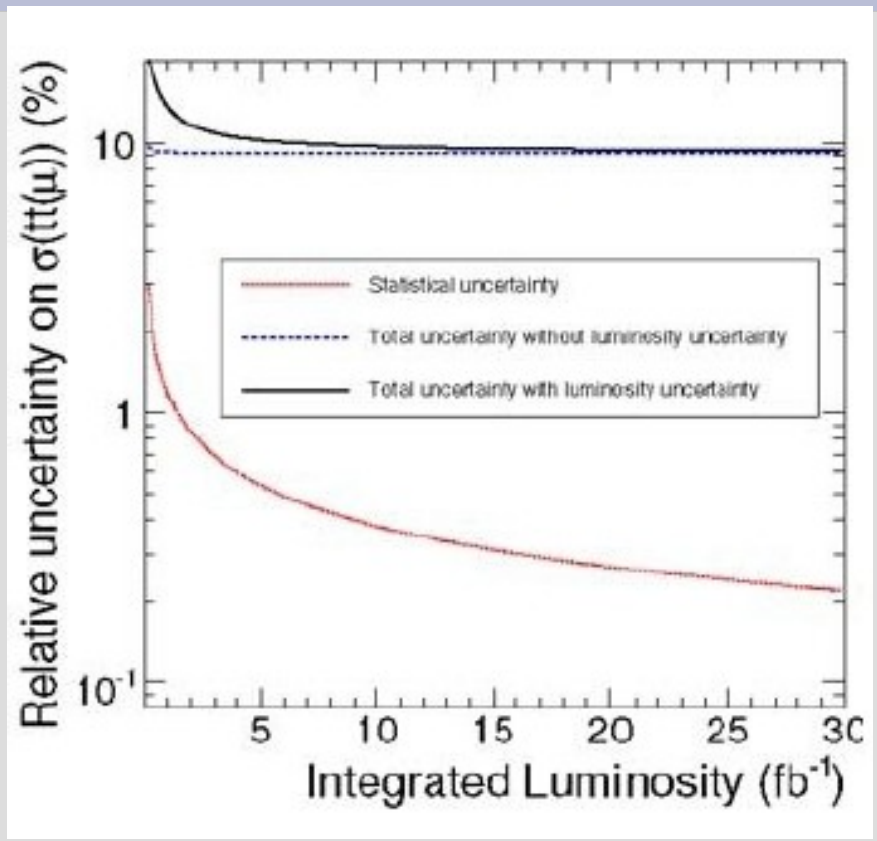
Cross section Measurement

Measurement from semi-leptonic decay with muon in final state

- Trigger Eff (isolated muon) ~70%
- Request of 4 jets , with 2 b-tags
- Complete reconstruction of the event
- High Purity: S/B>5 (bkg comes mostly from other top decays (non-top <4%)

Main Systematics:
JES, pile-up, b-tagging



CMS

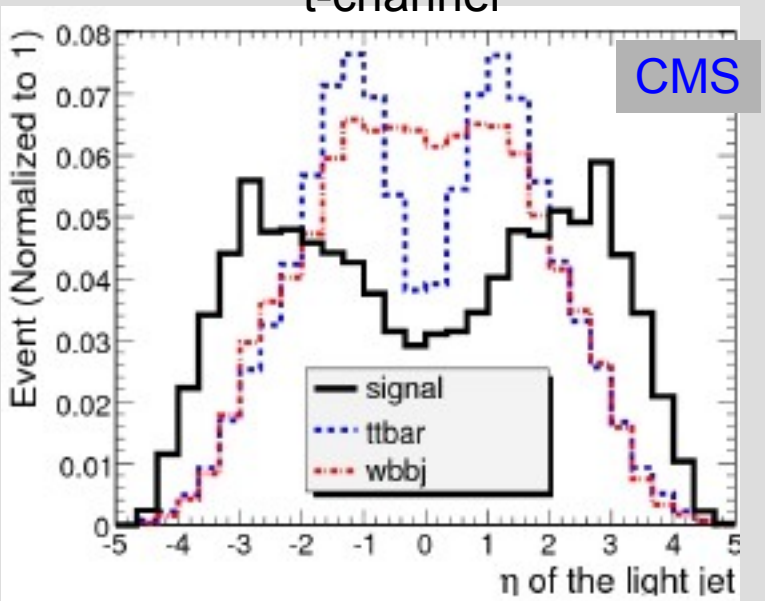
$\Delta\sigma/\sigma$ (1 fb^{-1})= 1.2%(stat)+14%(syst)+10%(lumi)
$\Delta\sigma/\sigma$ (10 fb^{-1})= 0.4%(stat)+10%(syst)+5%(lumi)

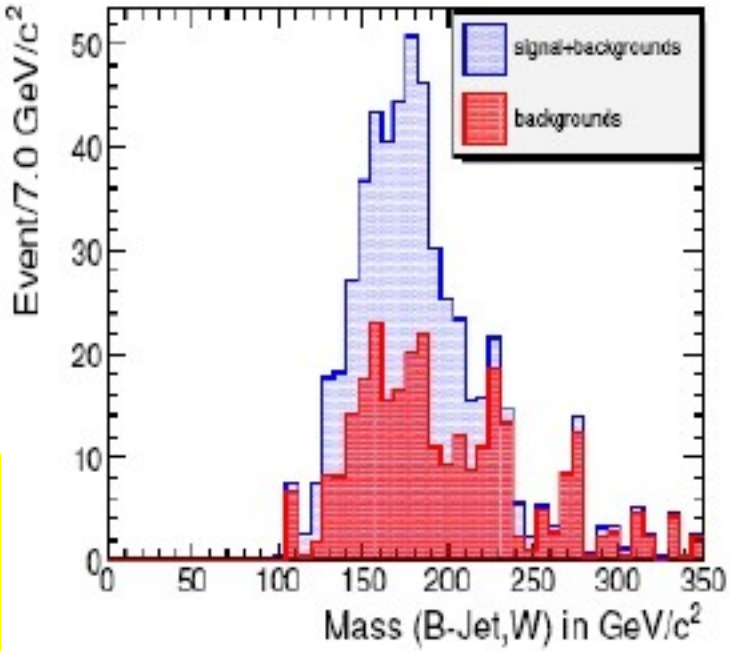
Cross section Measurement: single-top

- Performed independently for the three channels
- Main backgrounds: ttbar, W+jets
- Event jet multiplicity (b and light jets) and event topology are used to select events and distinguish between channels
- S/B=1.3 (t-channel), ranging from 1/7 to 1/3 for other channels
- For 10fb^{-1}:

$\Delta\sigma/\sigma$ = 10% (t-channel)
$\Delta\sigma/\sigma$ = 36% (s-channel)
$\Delta\sigma/\sigma$ = 19-26% (Wt, 1-2 leptoni)

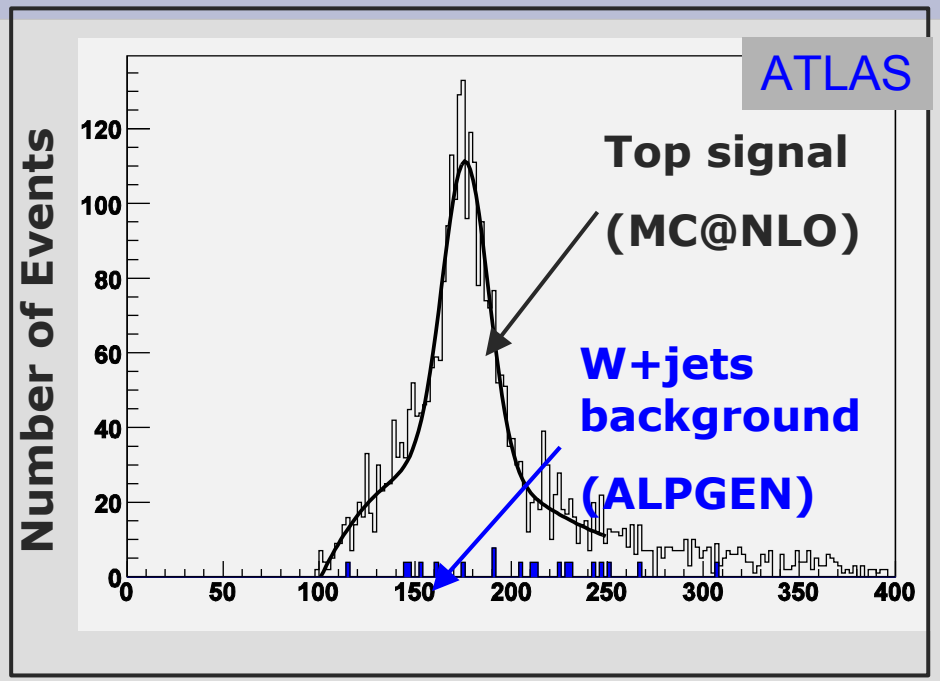
t-channel

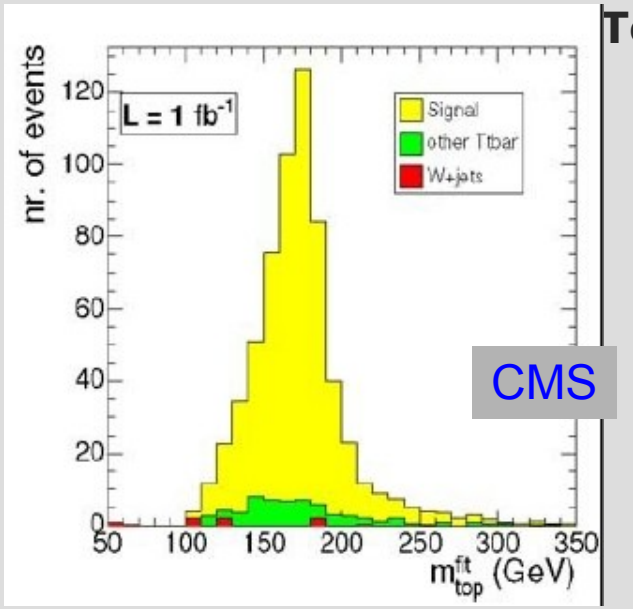




Top quark Mass measurement

- Top mass measured in semi-leptonic channel
- Leptonic branch used to trigger event (isolated high Pt lepton, MET)
- Hadronic top reconstructed from three jet invariant mass
- b-tagging fundamental to remove background (combinatorial and W+jets)
- "In-situ" light jet calibration: constraining jj invariant mass at M_W^{PDG}

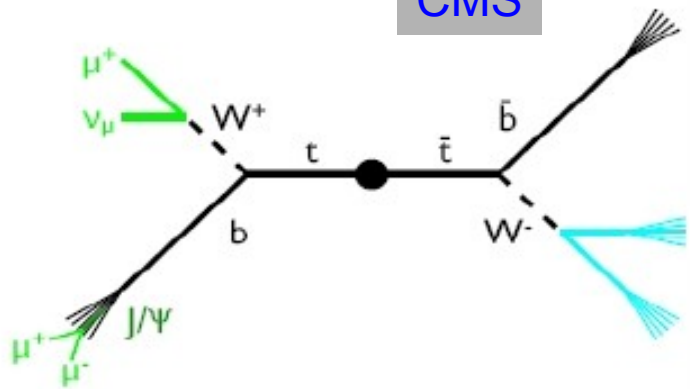


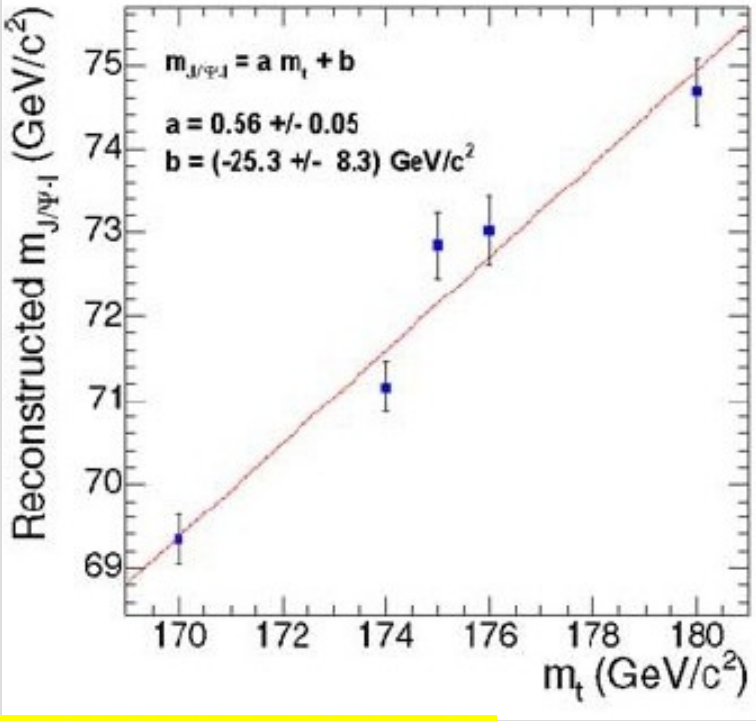


Mass measurement: alternative methods

- Example from CMS: measurement from J/Ψ
- Top mass extracted from m(l,J/Ψ)
- BR(t->lnJ/ΨX)=5.5x10^{-4} ("only" 4500 events with 10fb^{-1}) but completely different systematics from traditional channel (no use of b-tabbing, no JES influence)

CMS

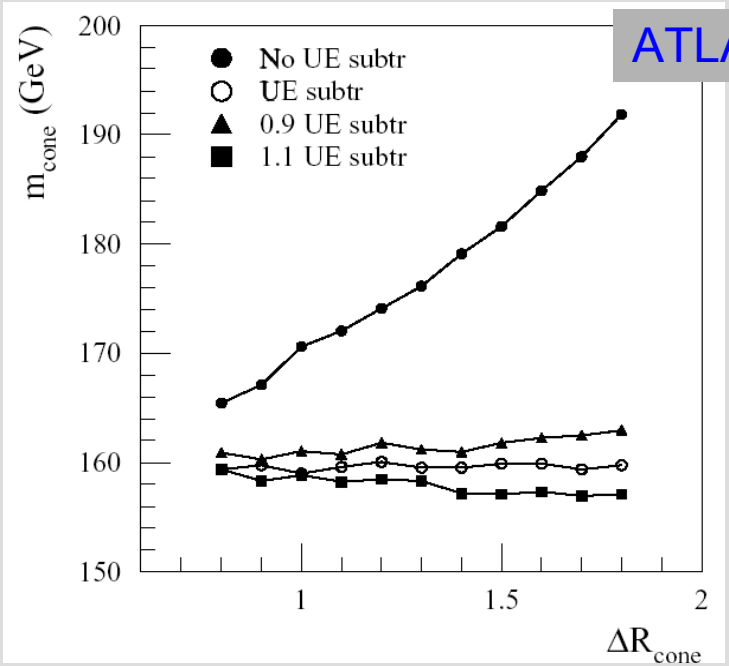




$\Delta M = 1.2(stat)+1.5(syst)$ GeV $(L=20\ fb^{-1})$

Mass measurement: alternative methods

- Example from ATLAS: high Pt sample
- Standard semi-leptonic selection plus Pt(jjb)>200GeV
- collect all energy around candidate top in a wide cone
- Less sensitive to JES
- Need to subtract UE (measuring it far away from jet activity)



	δm_t (GeV/c²)
Initial state radiation	0.1
Final state radiation	0.1
b-quark fragmentation	0.3
UE estimate (±10%)	1.3
mass scale calibration	0.9

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Expected performances at day-1

- Can we do top physics with very first data?
- We will have to cope with reduced performance detector
  - Investigate possibility to perform preliminary top mass measurement w/o b-tagging (pessimistic scenario)

Based on detector construction quality, test-beam results, cosmics, simulations

	Expected performance day 1	Physics samples to improve
ECAL uniformity	~ 1%	Minimum-bias, $Z \rightarrow ee$
e/γ scale	~ 2 %	$Z \rightarrow ee$
HCAL uniformity	~ 3 %	Single pions, QCD jets
Jet scale	< 10%	$Z (\rightarrow ll)$ +1j, $W \rightarrow jj$ in tt
events		
Tracking alignment	20(100)-200 μm in Rϕ?	Generic tracks, isolated μ , $Z \rightarrow \mu\mu$

ATLAS

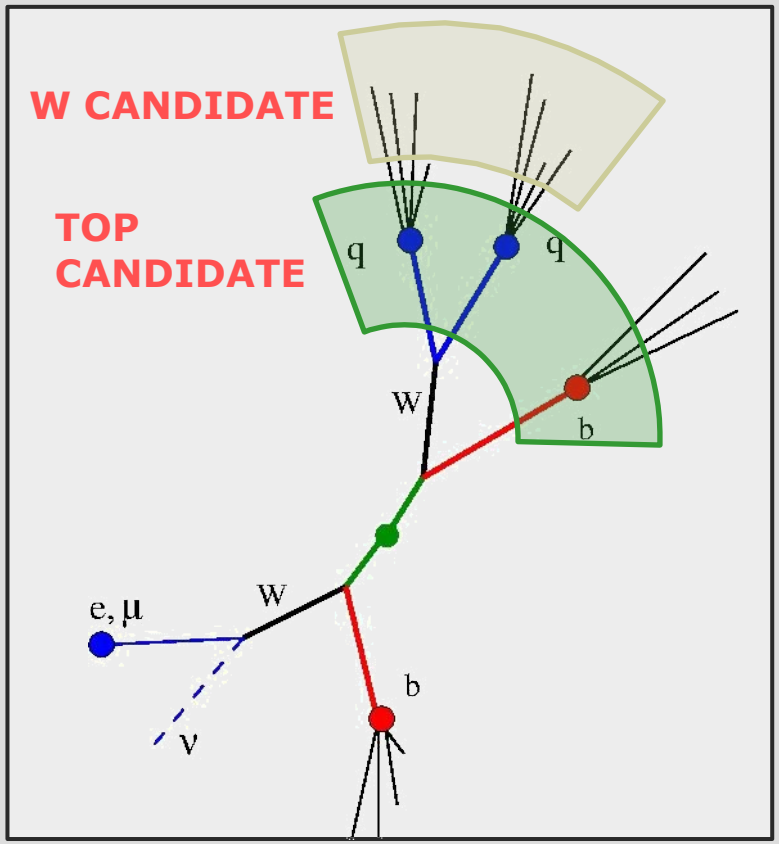
Ultimate statistical precision achievable after few weeks of operation. Then face systematics...
Example: tracker alignment : 100 μm (1 month) $\rightarrow$ 20μm (4 months) $\rightarrow$ 5 μm (1 year) ?

Commissioning: top mass measurement

- In most pessimistic scenario b-tagging is absent at start
- Can we then observe the top with few robust selection cuts?

MET	P_T > 20 GeV
1 lepton	P_T > 20 GeV
3 jets(R=0.4)	P_T > 40 GeV
4th jet	P_T > 20 GeV

$\varepsilon = 11\%$



• Assign jets to W-boson and top-quark:

1) Hadronic top:

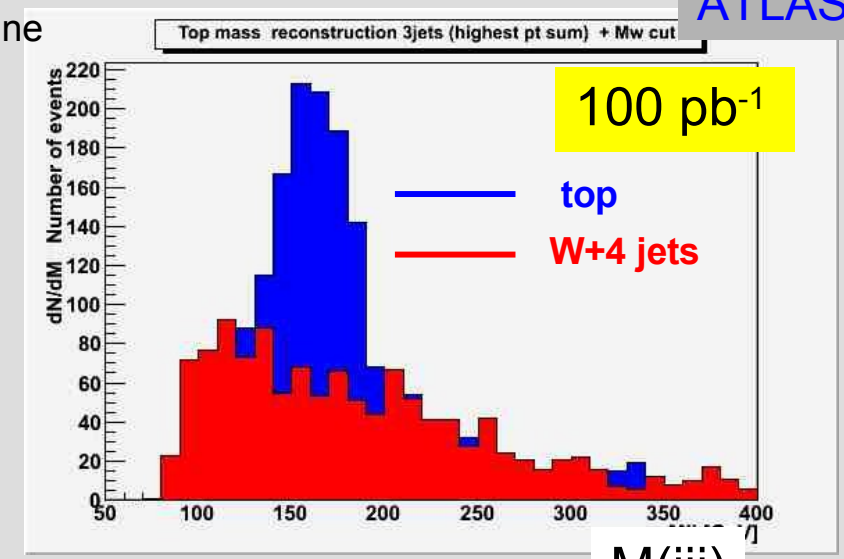
Three jets with highest vector-sum p_T as the decay products of the top

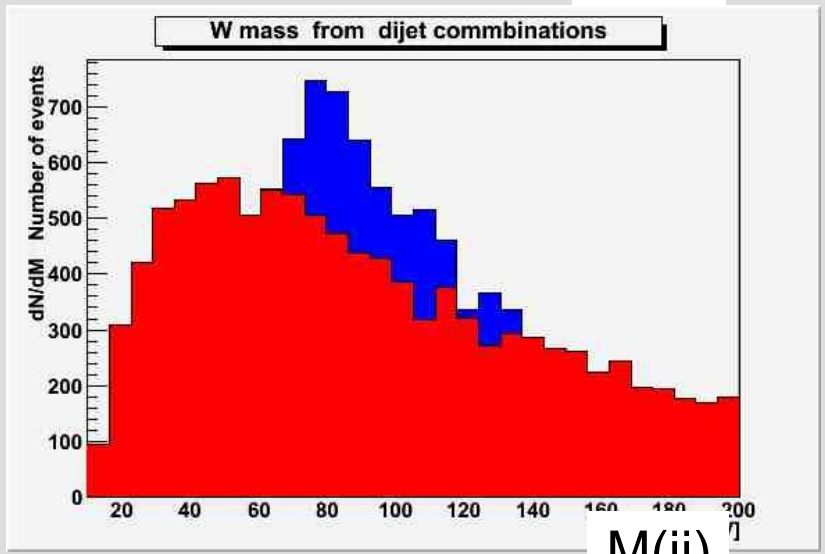
2) W boson:

Two jets in hadronic top with highest momentum in reconstructed jjj C.M. frame.

Commissioning: top mass measurement

- Data sets:
  - Signal: MC@NLO
  - Background W+4 incl. jets: ALPGEN
- M_{top} reconstructed
  - Events selected with M_{jj} close to nominal M_W, (within ± 10 GeV)



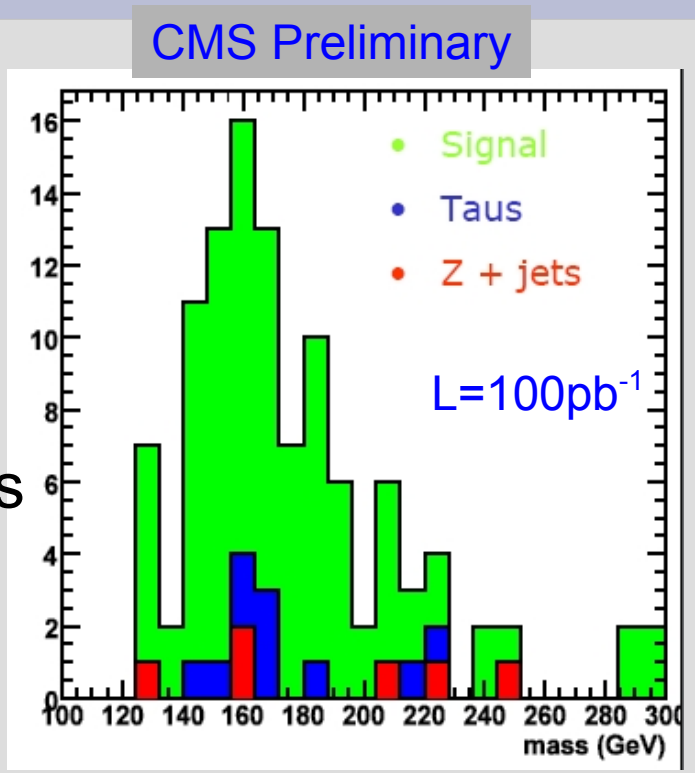


100 pb^{-1} is a few days of nominal low-luminosity LHC operation

We can easily see top peak without b-tag requirement

Commissioning: di-lepton channel

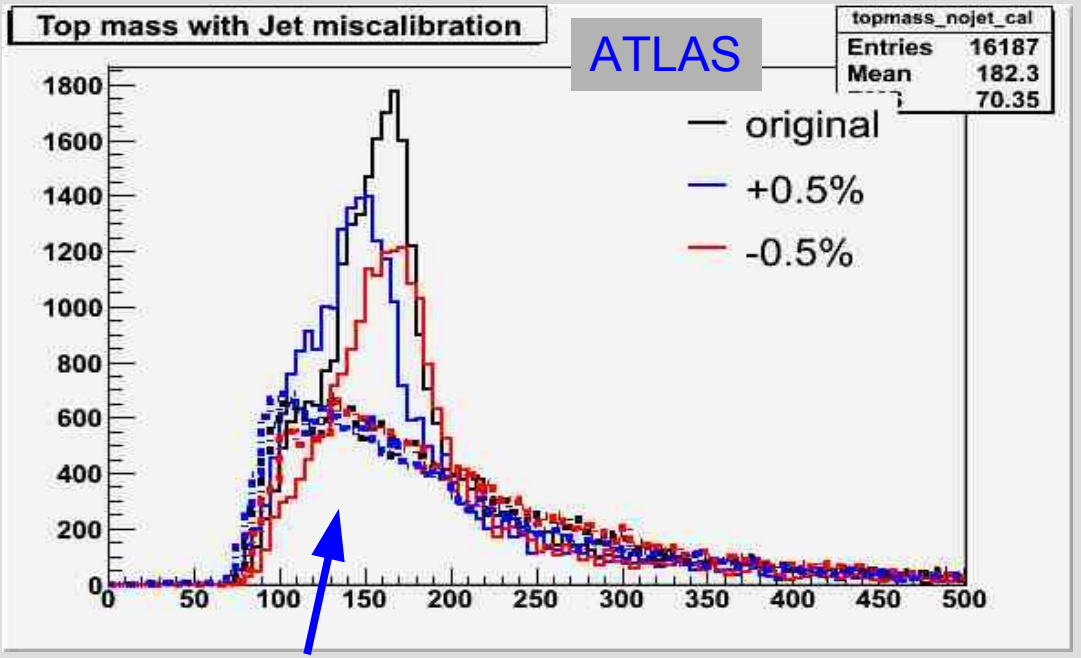
- Top reconstructed assuming:
  - no use of b-tagging
  - reduced ECAL acceptance
    - ($|\eta|$<1.47 instead of 2.5): 25% less ee, 12% less em
- Events selection:
  - 2 isolated high Pt leptons
  - different sign (same sign allowed but with Z veto)
  - 2 jets



Top mass from cinematic fit

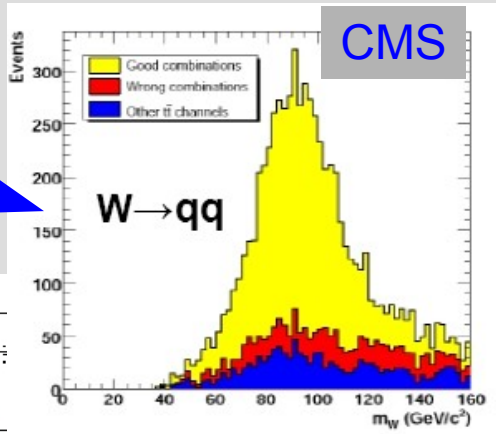
Commissioning and JES

- At Day-1 JES is set by:
  - Calorimeters calibrated at e.m. scale (test-beams)
  - Hadronic scale set by MC studies (example: jet weighting techniques), corrections for "detector effects" (cracks, e/h, leakage); need events (W->jj) for final calibration ("in-situ")

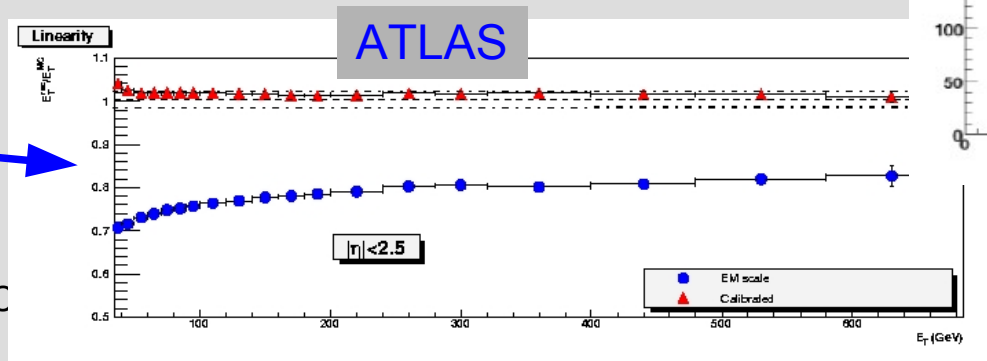


Effect of miscalibrated Jets

"in-situ" calibration: set JES to M_W



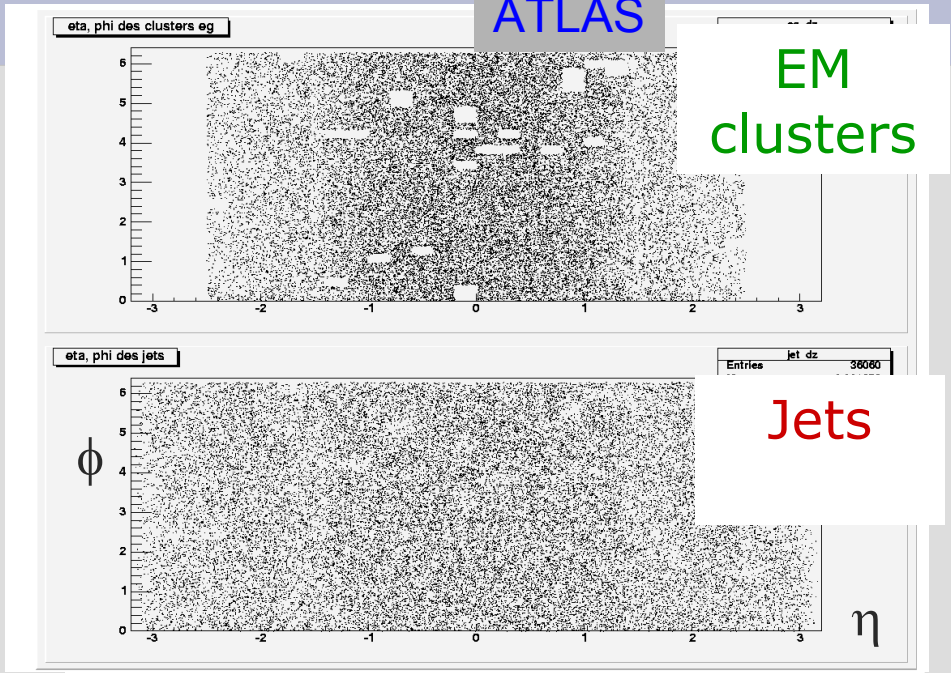
JES after correcting only for detector effects

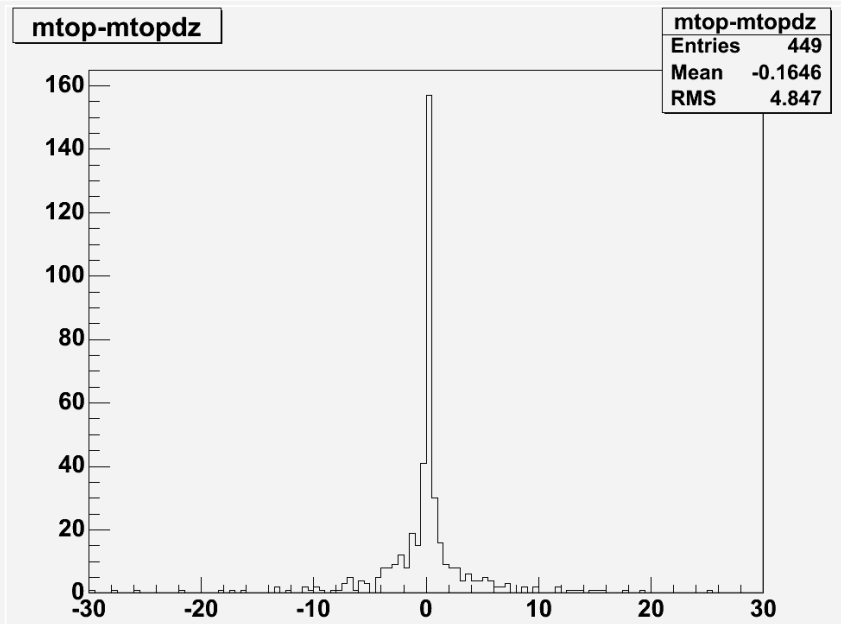


Commissioning and Dead Regions

- 10^5 tt events (~ 1.5 days @ $L=10^{33}$)
- Preselection of events:
  - At least one recontructed e or μ with P_T>20 GeV and |η|<2.5
  - MET>20 GeV
  - At least 4 jets with P_T>40 GeV and |η|<2.5, 2 b-tagged

- If the 33 weak HV sectors in EMB die (very pessimistic!), study effects on M_{top} after a crude recalibration:
  - Displacement of the peak of the mass distribution: -0.2 GeV





M_{top}(no dead regions) – M_{top}(dead regions)

Conclusions

- At LHC it is possible to study top properties with high precision (systematics and detector knowledge are dominant uncertainties)
- It will be possible to start top physics (with reduced performances) with the very first data: in this phase top will be (mainly) a tool to understand the detector
- Top quark is the calibration signal for complex topologies (it provides tools to understand: JES, b-tagging, MET, lepton ID and trigger performances)