Early physics with top quarks at LHC

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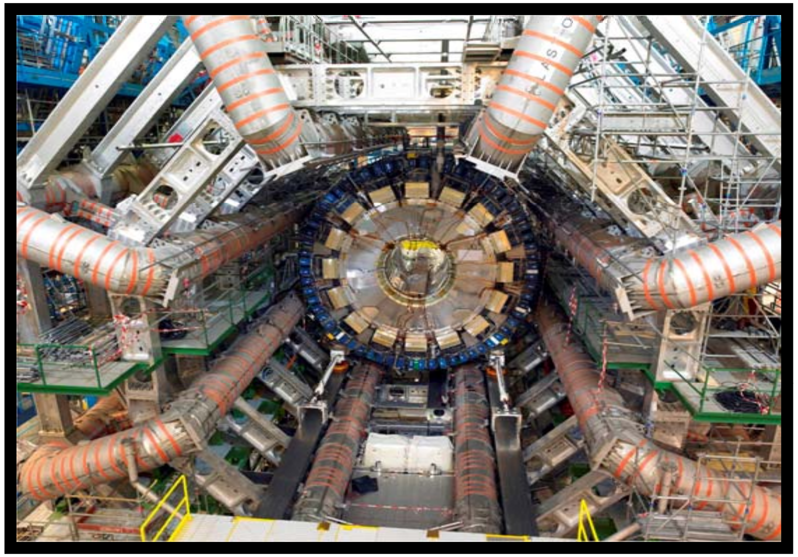
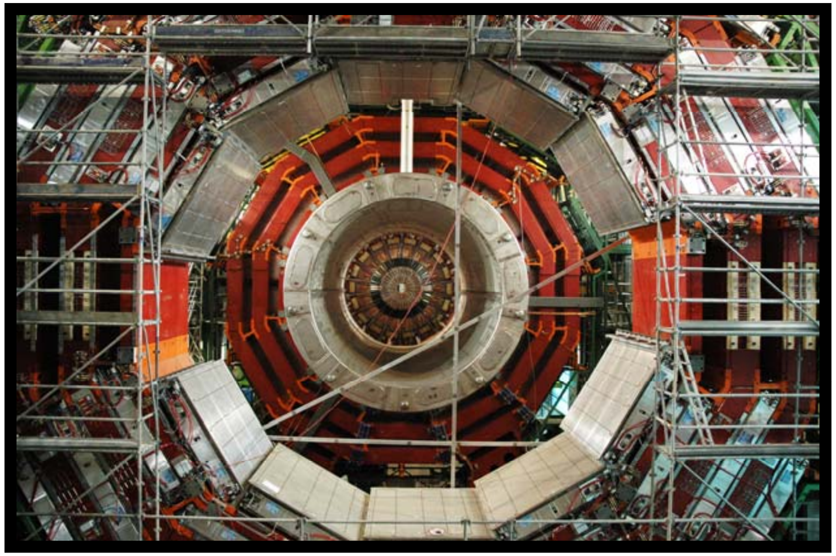
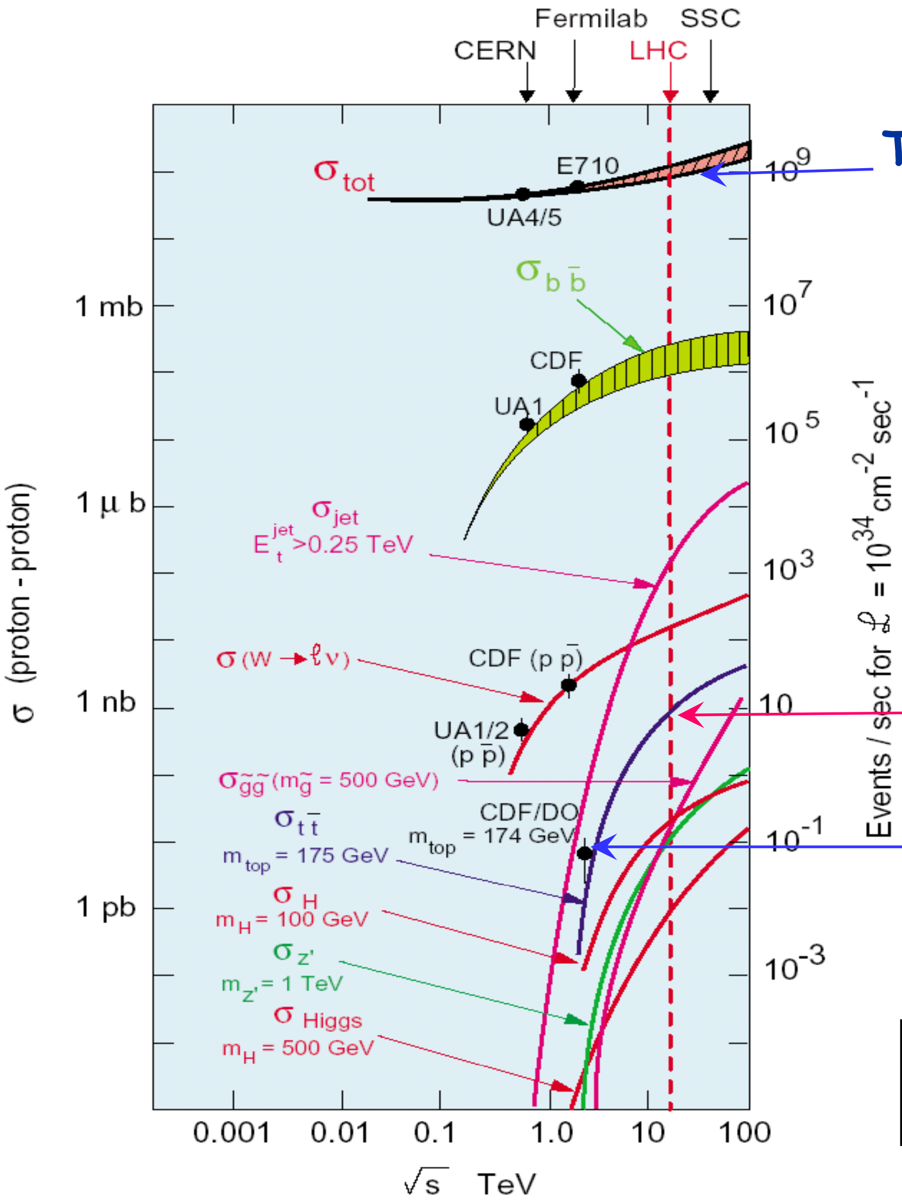
on behalf of the ATLAS and CMS collaborations

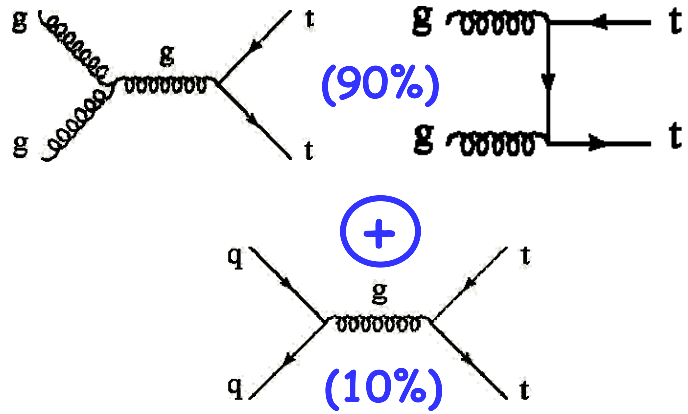




LHC is a $t\bar{t}$ factory



Total production cross section



$t\bar{t}$ production cross section at LHC:
~833 pb

$t\bar{t}$ production cross-section at Tevatron:
6.7 pb

2 $t\bar{t}$ events per second !
> 8 millions $t\bar{t}$ events expected per year

Top Physics day one

In 2008 ECM = 14 TeV few fb^{-1} ⇨ already negligible statistical err

1) Top properties and basic SM physics at $\sqrt{s}$ = 14 TeV :

- Estimate of σ_{top} ~ 20% accuracy
- Start to tune Monte Carlo
- Measure top mass ⇨ feedback on detector performance

2) Understand/calibrate detector and trigger: $t\bar{t} \rightarrow bl\nu\ bjj$

- Light jet energy scale selecting a pure sample of W →jj in tt events (< 1%)
- b-tag efficiency (~ 5%)
- Missing energy calibration

3) Prepare for new physics:

- Resonances, MSSM higgses, SUSY, FCNC
- Measure differential cross sections ($d\sigma/dp_T$, $d\sigma/dM_{tt}$) sensitive to new physics (provides also an accurate test of SM predictions)

Light jet energy calibration

Template histograms with different E scales α and relative E resolutions β:

$W \rightarrow qq$ in ~10^6 PYTHIA $t\bar{t}$ events

Simple $t\bar{t} \rightarrow l\nu b\ jjb$ selection with MC@NLO $t\bar{t}$ events :

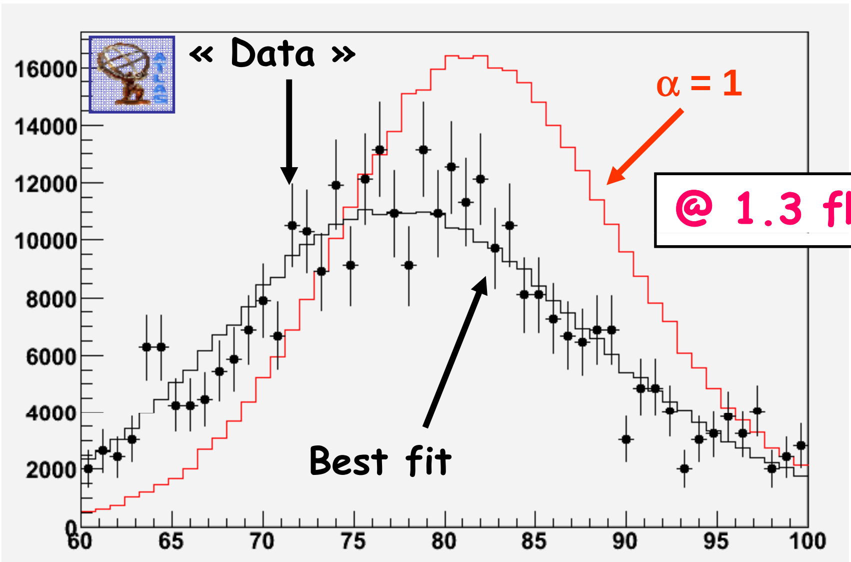
1(e/μ) p_T>20 GeV, E_{Tmiss}>20 GeV, = 4 jets p_T>40 GeV (2 b-tagged),

150 GeV< m_{jjb}< 200 GeV ⇨ W purity ~83%

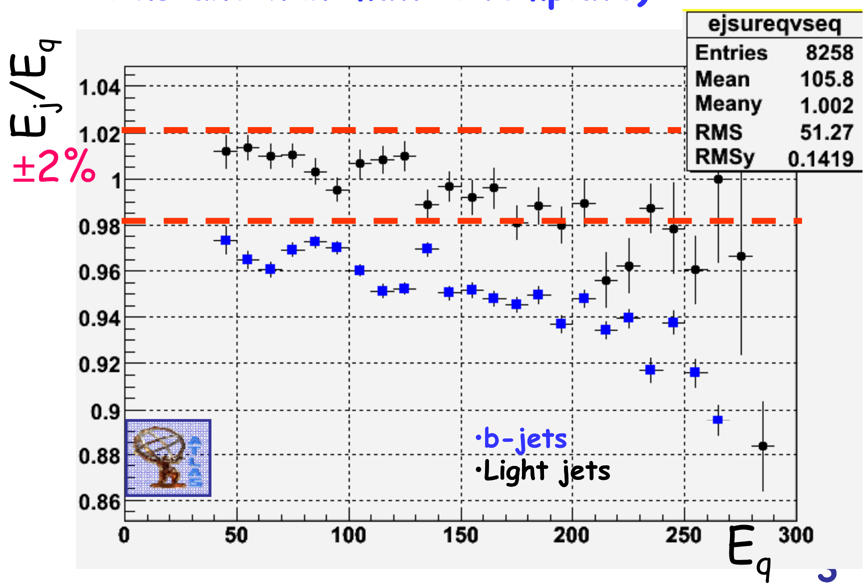
Fit each template histogram to m_{jj} in the « data », find best χ^2

α = 0.937 ± 0.004, β = 1.47 ± 0.05

Statistics limited. Unknown syst limit< 0.5% from combinatorial backg. and templates shape

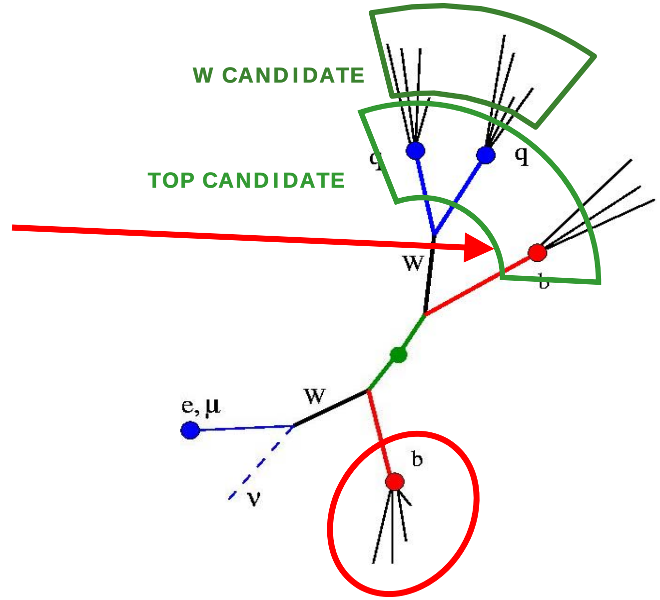


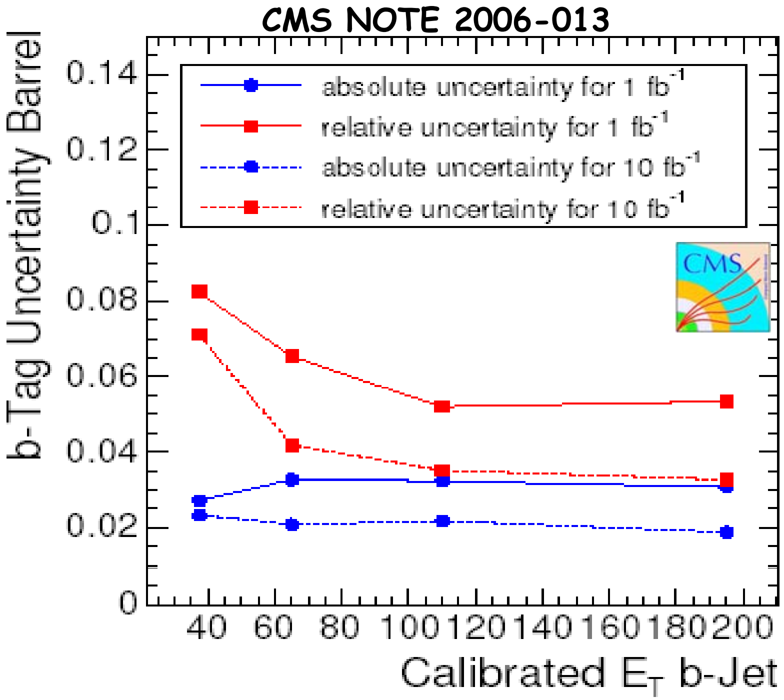
JES as a function of energy (n energy bins and nxn matrix template)



Calibrating b-tagging

- Using lepton+jets (and fully leptonic) $t\bar{t}$ events
- Optimize the jet pairing efficiency via mass constraints in kinematic fits and likelihoods.
- Only one jet is tagged as b-jet (on W_{had} side)





Isolate jet samples with a highly enriched b-jet content, on which the b-jet identification algorithms can be calibrated.

Main systematics :ISR/FSR

For 1 fb^{-1} ($10fb^{-1}$) relative accuracy on the b-jet identification efficiency is ~ 6% (4%) in barrel region and about 10% (5%) in the endcaps.

Day one: can we see the top?

We will have a non perfect detector:
Let's apply a simple selection

- No b-tag
- relaxing cut on 4th jet: p_T>20 GeV:

W =2 jets maximising p_T W in jjj rest frame

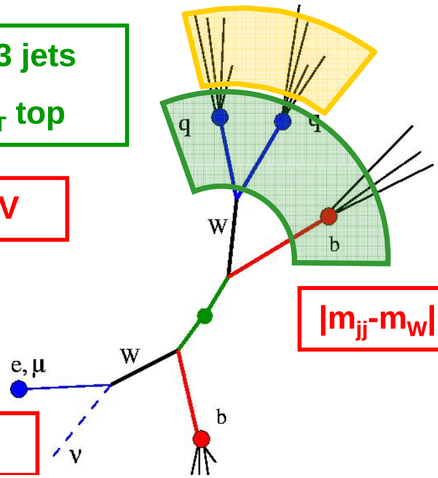
Hadronic top=3 jets maximising p_T top

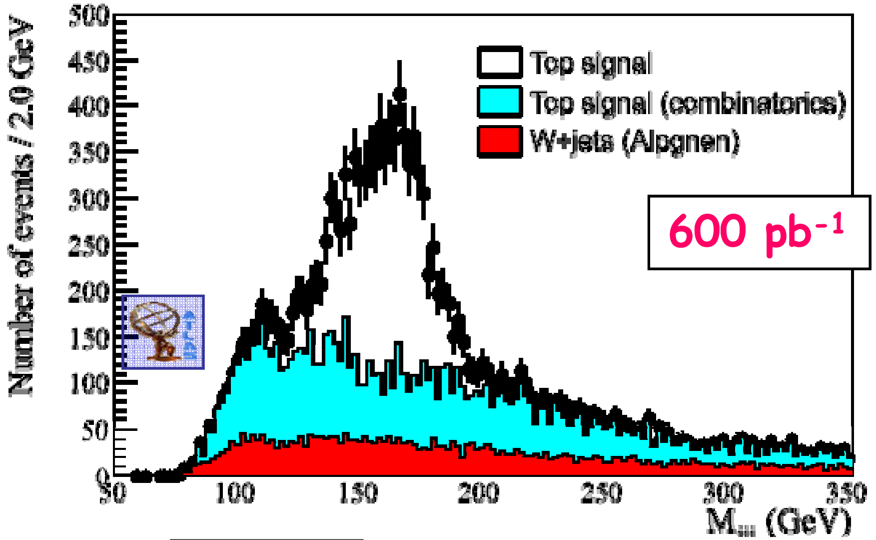
4 jets p_T> 40 GeV

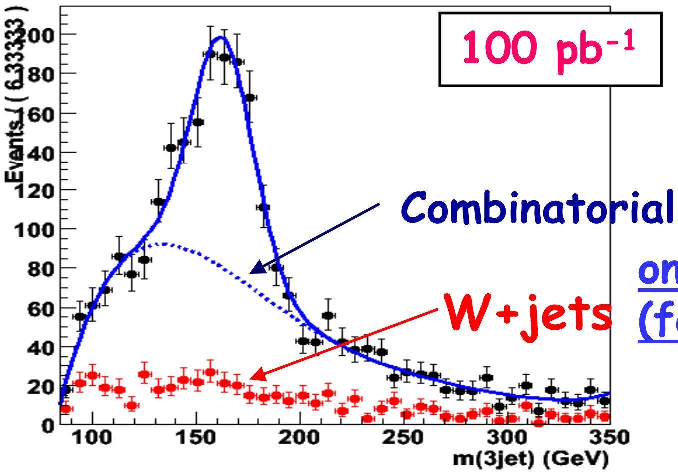
Isolated lepton p_T> 20 GeV

E_T^{miss} > 20 GeV

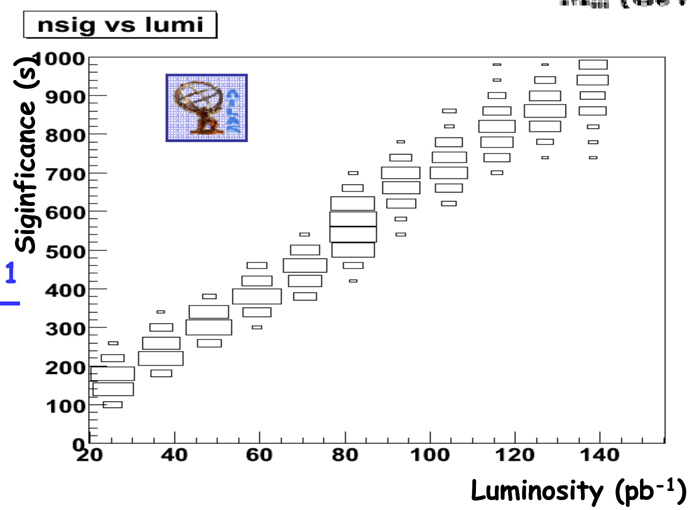
$|m_{jj}-m_W|$ < 20 GeV







only with 100 pb^{-1}
(few days)



Refining the selections: lepton+jets case

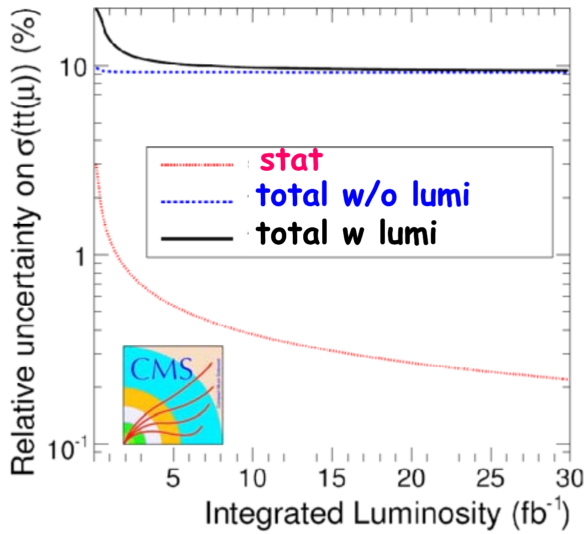
More refined selection studied with the aim of applying it to x-section, mass, polarization studies..

Example: CMS NOTE 2006/064

- 1 isolated lepton p_T>20 GeV
- ≥4 jets E_T>30 GeV $|\eta|$<2.4
- 2 b-tagged jets
- Coverging kin. fit to m_W

ε_{sel} ~ 6.3%

S/B~26.7

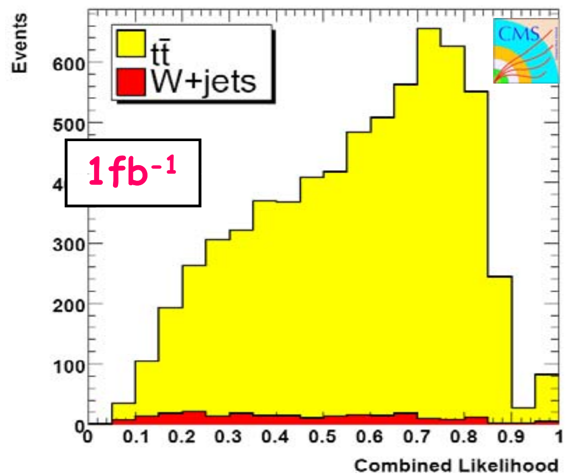


@5 fb^{-1} $\sigma_{tt(\mu)}$=0.6% (stat)± 9.2% (syst)±5.0%(lumi)

Exploiting new topological variables from D0?

- Sphericity S and Aplanarity A
- Centrality C
- $H_T = \sum_{jet=1}^{4} p_T$
- $\Delta\phi(lep,\nu)$
- K_{Tmin}=min $\Delta(\eta,\phi)$ between 2 jets

Not very useful to separate from W+jets after selection



Summary of cross-section

- The cross-section has also been extracted from in the di-leptonic and fully hadronic channels here examples from:

  CMS NOTES 2006-064/ 2006-077

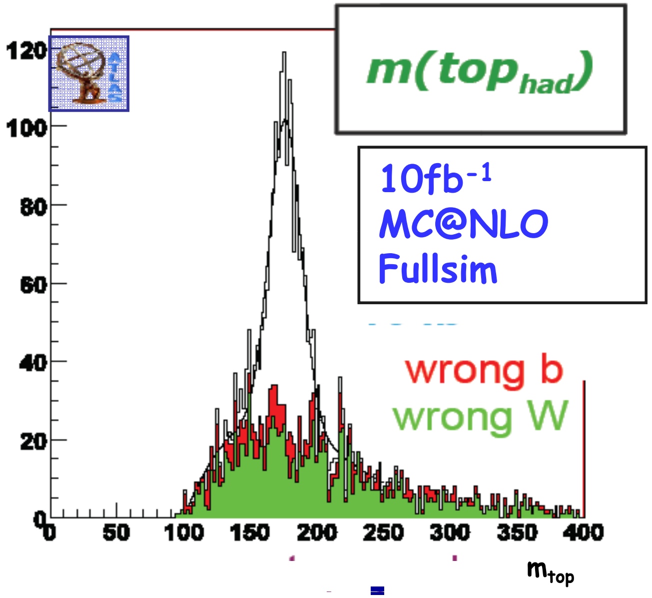
	$\Delta\sigma_{tt}/\sigma_{tt}$ syst (%)	$\Delta\sigma_{tt}/\sigma_{tt}$ stat (%)	$\Delta\sigma_{tt}/\sigma_{tt}$ lumi (%)	Main syst (%)		Main bkg	Eff (%)	S/B
$10fb^{-1}$ Lepton+jets	9.7	0.4	3	Btag PDF PileUp	7 3.4 3.2	tt W+j	6.3	26.7
$10fb^{-1}$ Dilepton	11	0.9	3	PDF Btag JES	5 4 4	tt_{ll} with ($W\rightarrow\tau\nu_\tau$, $\tau\rightarrow l$)	5	5.5
$1fb^{-1}$ hadronic	20	3	5	JES PileUp	11 10	QCD	1.6	1/9

Top mass measurement in lepton + jets channel

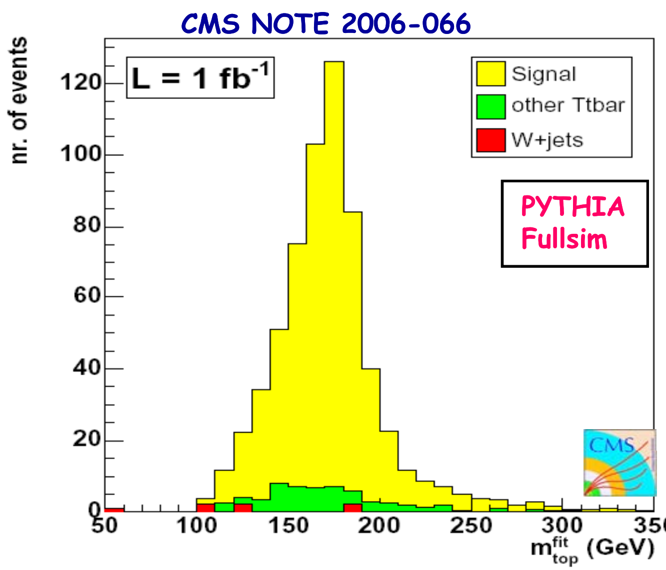
1) minimization of χ^2 ⇨ reconstruct m_W hadronic & jet E rescaling (α_1,α_2)

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

- keep W's if $|m_W - 80.4\ \mathrm{GeV}| < 2\Gamma_{mW}$
- chose b-jet that maximises top p_T
- W purity 56.5%, top purity 45%, ε=1.1%



2) Kinematic fit:



Kinematic fit to reconstruct entire $t\bar{t}$ final state:

- χ^2 based on kinematic constraints ($E_{l,j}$ & directions vary within resolution) χ^2 minimisation, event by event
- M_{top} fitted in slices of χ^2
- Estrapolation from linear fit: $m_{top} = m_{top}(\chi^2 = 0)$

Gaussian/Full Scan Ideogram estimator for m_t:

- Event by event likelihood method convoluting the event resolution function with expected theoretical template. m_{top} obtained from maximum likelihood method

Top mass measurement (lepton+jets channel)

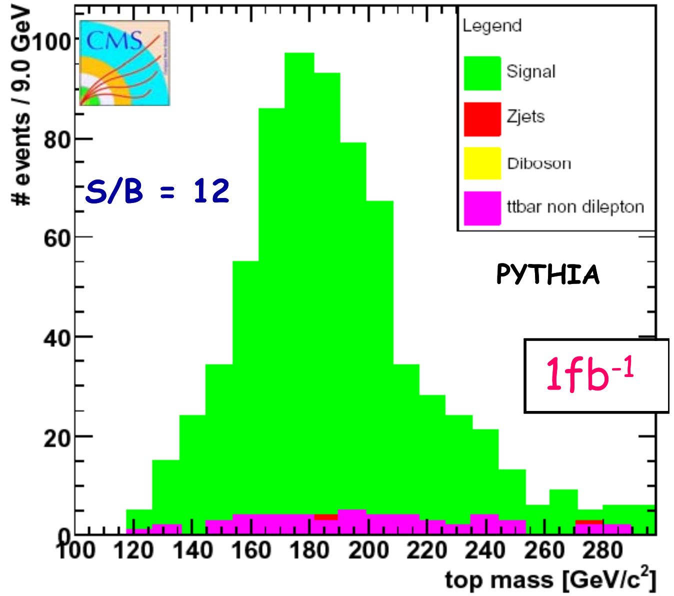
c) Selection of high p_T top quarks p_T(top) > 200 GeV/c:

- t and $\bar{t}$ tend to be back-to-back ⇨ used as constraint to reduce bkg
- 3 jets in 1 hemisphere tend to overlap: collect E in a cone around candidate top
- less sensitive to jet calibration. Mass scale recalibration based on hadronic W,
- independent systematic errors ⇨ gain in combination

Comparing the 3 methods

Source of uncertainty	Had. top δM_{top} (GeV/c²)	Kinematic fit δM_{top} (GeV/c²)	High P_T sample δM_{top} (GeV/c²)
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 @10fb-1	0.05	0.1	0.2

Di-lepton channel and Hadronic channels



Dilepton channel: clean channel but need to reconstruct 2 ν's. Reconstruction via 0C fit assuming m_W and 2 equal masses for top $m_{t1}=m_{t2}$ (6 eq. ,6 unknowns)

- The different ν solutions are weighted using the SM prediction for the ν and $\bar{\nu}$ E spectra
- The neutrino solution with the highest weight is chosen ⇨ m_{top}

Hadronic channel: full kinematic reconstruction of both sides but huge QCD multijet background:

- 6-8 jets, ET>30 GeV
- Centrality>0.68,aplanarity>0.024
- E_{Ttot}- E_T of 2 leading j>148 GeV
- 2 b-tagged jets
- Best jet pairing obtained from likelihood based mainly on angular distrubution of jets.

CMS NOTE 2006-077

	(stat) δm_t (GeV/c^2)	(syst) δm_t (GeV/c^2)
@1fb^{-1} dilepton	~1.5	~4.2
@1fb^{-1} hadronic	~0.6	~4.2

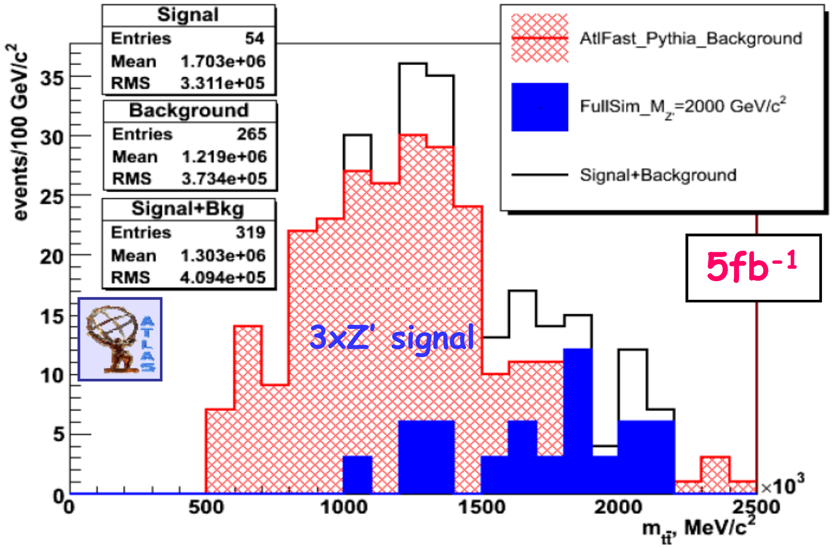
Resonances in M_{tt}

$pp \rightarrow X \rightarrow tt$ in lepton+jets channel

Technicolor, Strong EW symmetry breaking models, Z', SUSY:

- usual lepton+jets events preselection
- use W and top mass constraint:
  - neutrino p_Z from m_W constraint, solution giving best top mass is retained
  - $|m_{jj}-m_W| \leq 20$ GeV
  - b-jet associated with hadronic top is the one maximising p_{Ttop}
  - $|m_{bjj}-m_T| \leq 40$ GeV
- Since p_T of top from resonance decay is larger than in direct production

Add lower cut on top p_T 370,390,500 GeV/c for $m_{Z'}$ =1,1.5,2 GeV/c² to increase purity (s/B~0.06-0.08)

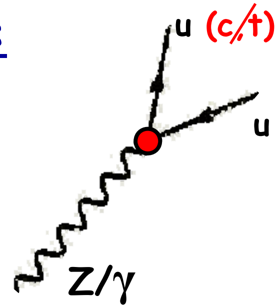


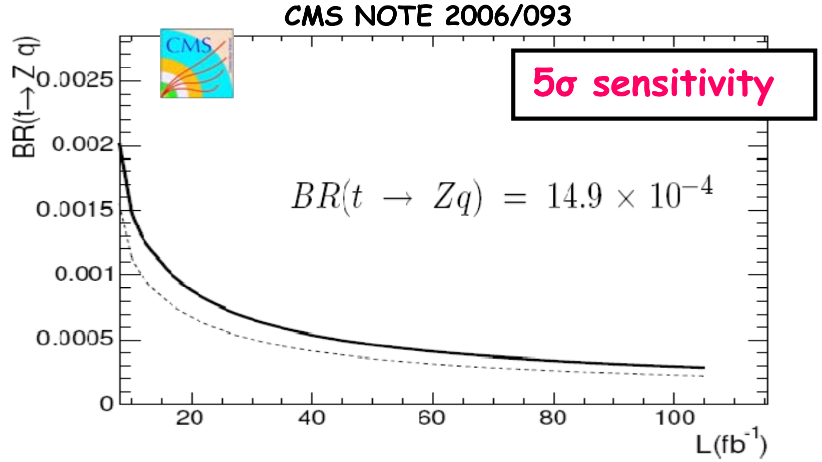
@5 fb^{-1}	$M_{Z'}$= 1 TeV	$M_{Z'}$= 1.5 TeV	$M_{Z'}$= 2 TeV
CL	~2.75σ	~2.96σ	~3.3σ
x-sec (pb)	~4	~3	~3

Flavour Changing Neutral Currents

No FCNC at tree level in SM:

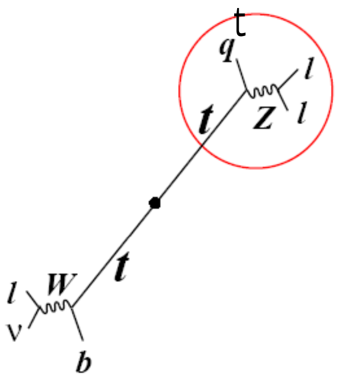
SM	10^{-14}-10^{-12}
2HDM	10^{-7}-10^{-4}
MSSM	10^{-6}-10^{-5}



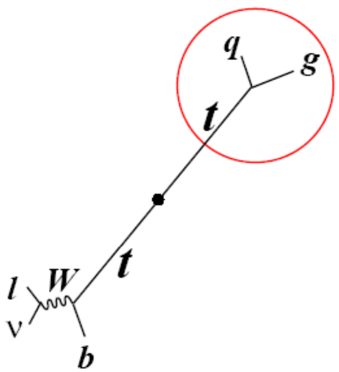


Look for FCNC in top decays:

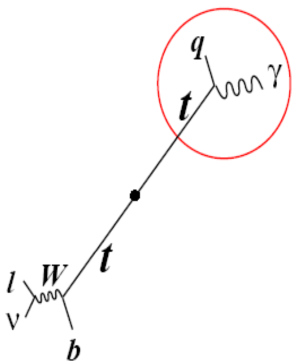
t→qZ
(2jets+3l+missing)

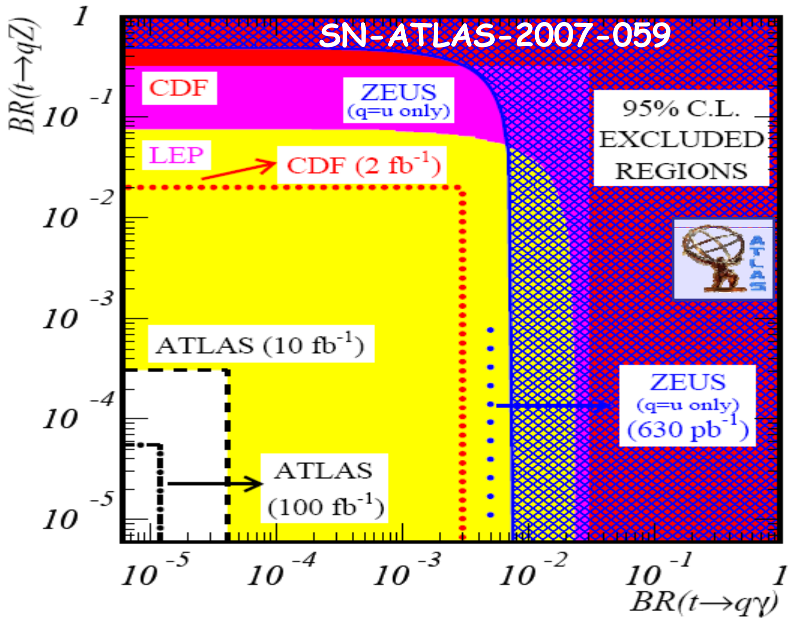


t→qg
(+1l+missing)



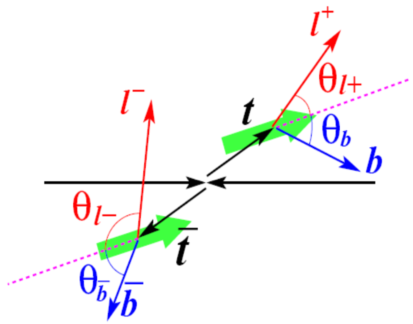
t→qγ
(+1l+1γ+missing)





@ 10 fb^{-1} 2 orders of magnitude better than Tevatron/LEP/HERA

Top spin correlations



t and $\bar{t}$ are produced unpolarized, but spins are correlated

anomalous coupling (technicolor),
$t \rightarrow H + b$, spin 0/2 heavy resonance
H/KK gravitons $\rightarrow t\bar{t}$, would move
A away from SM expectation

$$\rightarrow \boxed{A} = \frac{\sigma(t_L\bar{t}_L) + \sigma(t_R\bar{t}_R) - \sigma(t_L\bar{t}_R) - \sigma(t_R\bar{t}_L)}{\sigma(t_L\bar{t}_L) + \sigma(t_R\bar{t}_R) + \sigma(t_L\bar{t}_R) + \sigma(t_R\bar{t}_L)}$$

Fit to double differential distribution $\longrightarrow$

$$\frac{d^2N}{N\, d\cos\vartheta_1\, d\cos\vartheta_2} = \frac{1}{4}\left(1 - \boxed{A}\,\kappa_1\kappa_2\cos\vartheta_1\cos\vartheta_2\right)$$

Eur.Phys.J.C44S2 2005 13-33
Lepton+jets. + dilep. (10 fb^{-1})

Fitting to distribution of

- angles bewteen top spin analyser in top rest frame versus angle of t spin analyser in antitop rest frame
- Syst. dominated by b-JES, top mass and FSR

A=0.41 ±0.014(stat) ±0.023(syst)

CMS NOTE 2006/111
Lepton+jets (10 fb^{-1})

Fitting to distribution of

- lepton angle vs b-quark angle in the $t\bar{t}$ rest frame
- lepton angle vs lower energy quark angle from the W-decay in the $t\bar{t}$ rest frame

$A_{bt,lt} = 0.375 \pm 0.014(\text{stat})\ ^{+0.055}_{-0.096}(\text{syst})$

$A_{qt,lt} = 0.346 \pm 0.021(\text{stat})\ ^{+0.026}_{-0.055}(\text{syst})$

Conclusions

- **LHC startup will require a long period of development and understanding**

- **LHC is a top factory, but before performing precision measurements, a huge effort is needed in order to**
  - Understand the detectors and control systematics
  - Complete study using full simulations and NLO generators

- **Early top signal will help**
  - We could get top signal with ~ 100 pb^{-1}
  - $\sigma(tt)$ to ~13% and M_{top} to 1% with 1fb^{-1}

- **In addition our aim is, as soon as we get a large statistics (few fb^{-1}), to be ready for early discovery of new physics!**