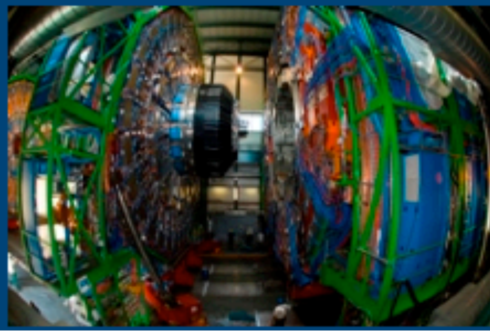
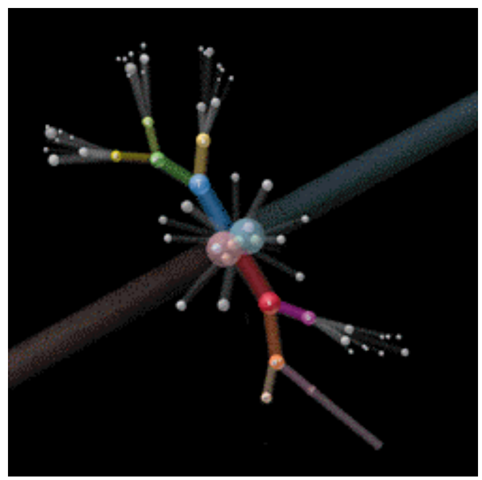
CTEQ Workshop

"Physics at the LHC: Early Challenges"



Top Physics at ATLAS

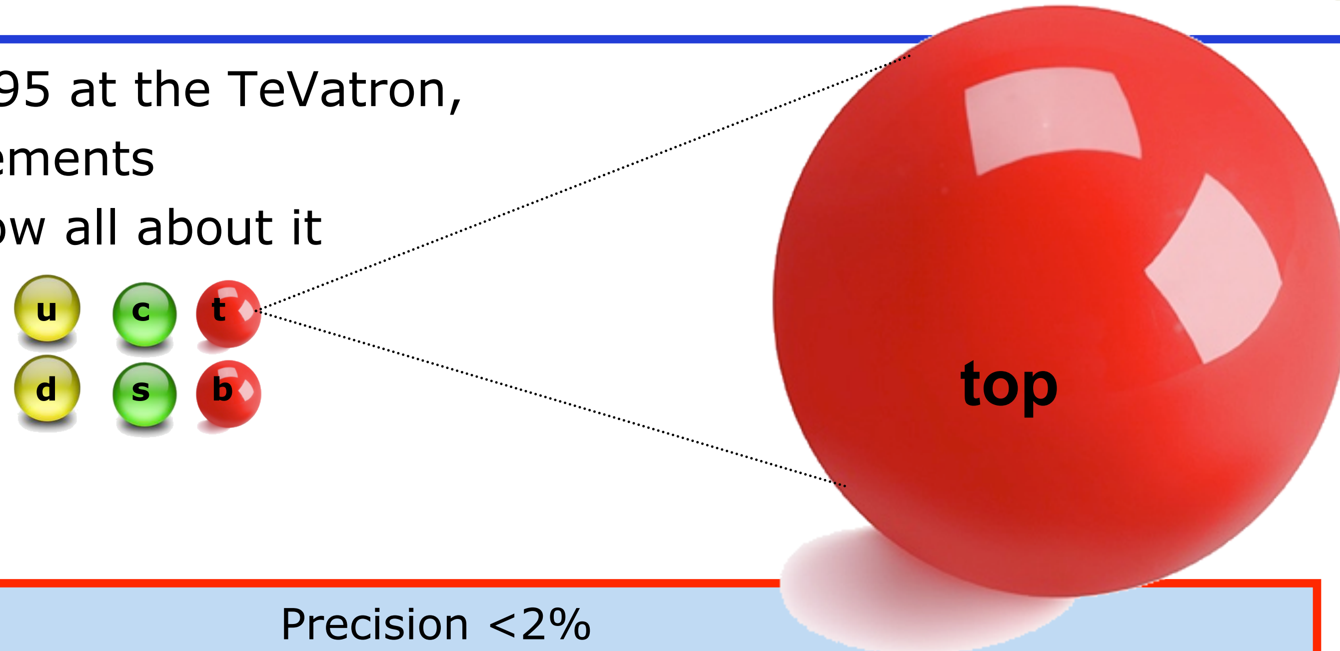


Simona Rolli

Tufts University

The Top Quark in the Standard Model

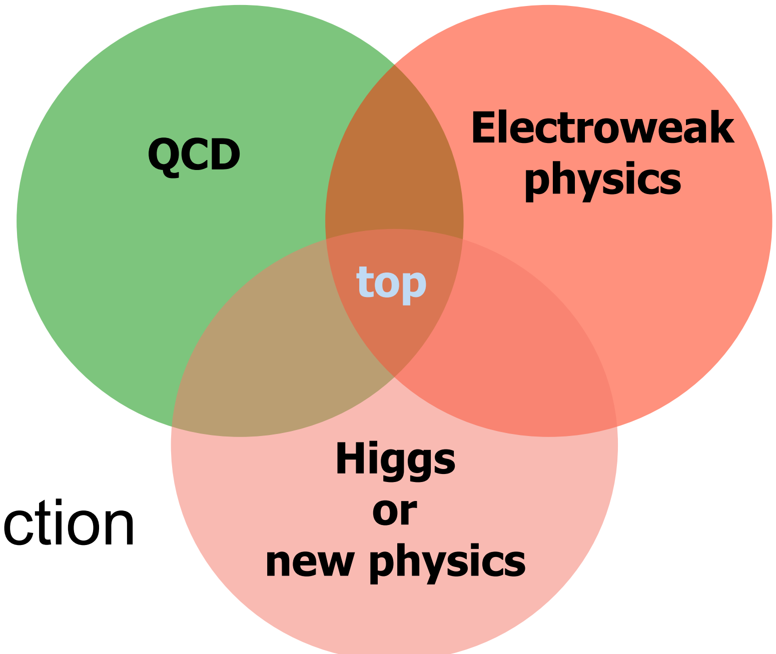
Discovered in 1995 at the TeVatron,
flurry of measurements
We still don’t know all about it



- Mass	Precision <2%
- Top width ~1.5 GeV	?
- Electric charge ⅔	-4/3 excluded @ 94% C.L. (preliminary)
- Spin ½	Not really tested – spin correlations
- BR(t→Wb) ~ 100%	At 20% level in 3 generations case
	FCNC: probed at the 10% level
- Production mechanisms	Single Top : just observed ad the TeVatron

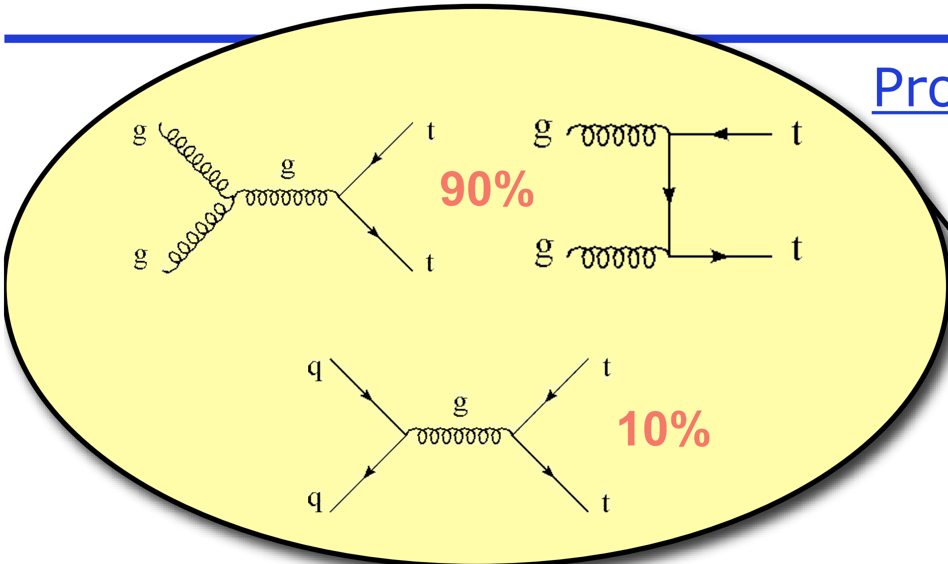
The LHC offers opportunity for further testing and **precision measurements**

Talk Outline



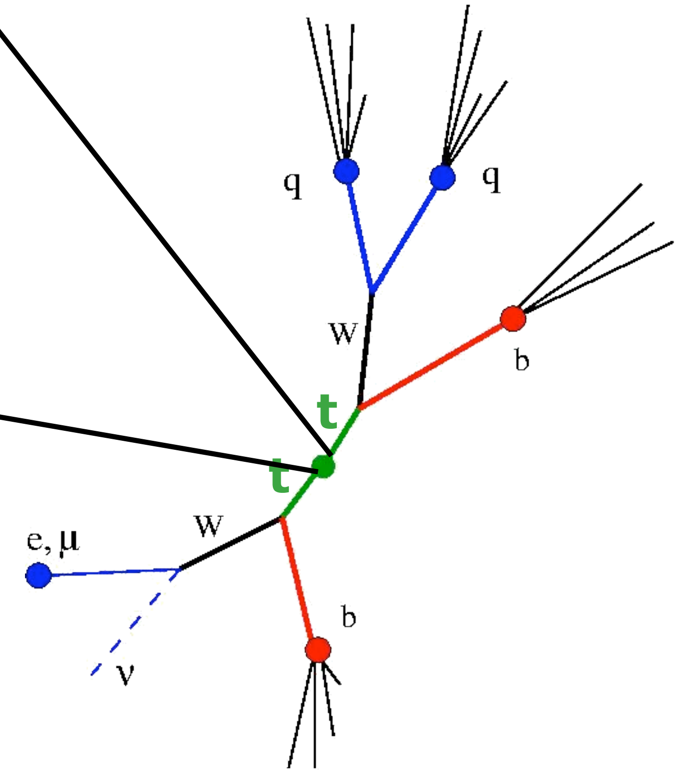
- Strong pair production
  - Standard top physics
  - Early top physics
- Top Properties
  - Mass,Charge,W polarization
- Electroweak single top production
  - Analysis strategies
  - Vtb measurements
- Using top for calibration purposes
  - Jet energy corrections, b-jets, missing energy
- A window to new physics
- Conclusions

Strong Pair production at the LHC

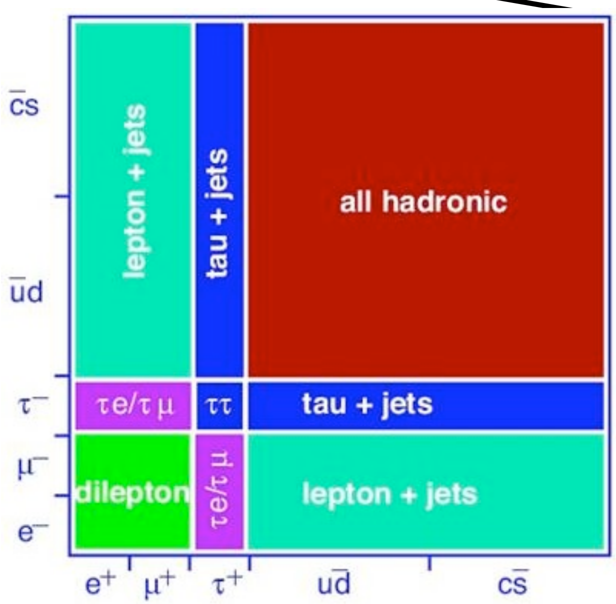


Production: σ_{tt}(LHC) ~ 830 ± 100 pb

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



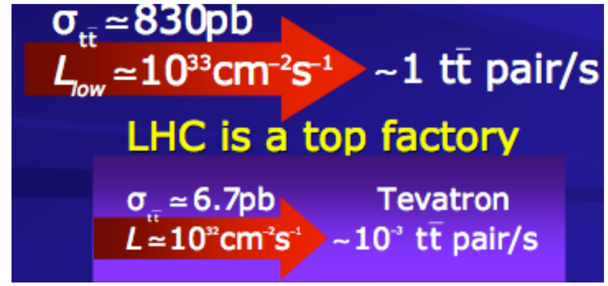
Decay



L+jets (l=e,μ) *is the Golden channel*
→ 2.5 million events/year

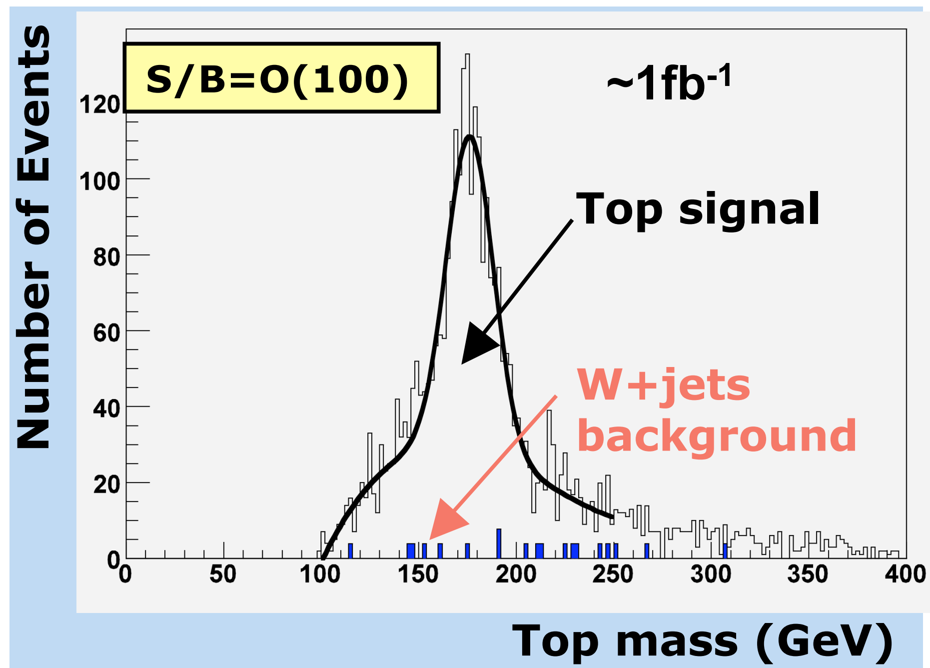
Top quark physics with b-tag

LHC is a top factory → Seeing top is easy



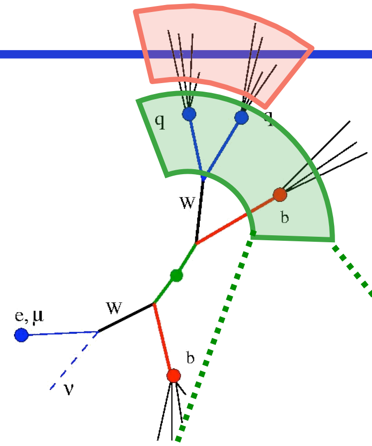
Selection: High P_T Lepton
Large Missing E_T
4 high-P_T jets (2 b-jets)

→ signal efficiency few %
→ *very* small SM background



- 'Standard' Top physics at the LHC:
  - b-tag is important in selection
  - Most measurements limited by systematic uncertainties
- 'Early' top physics at the LHC:
  - Cross-section measurement (~ 20%)
  - Decay properties

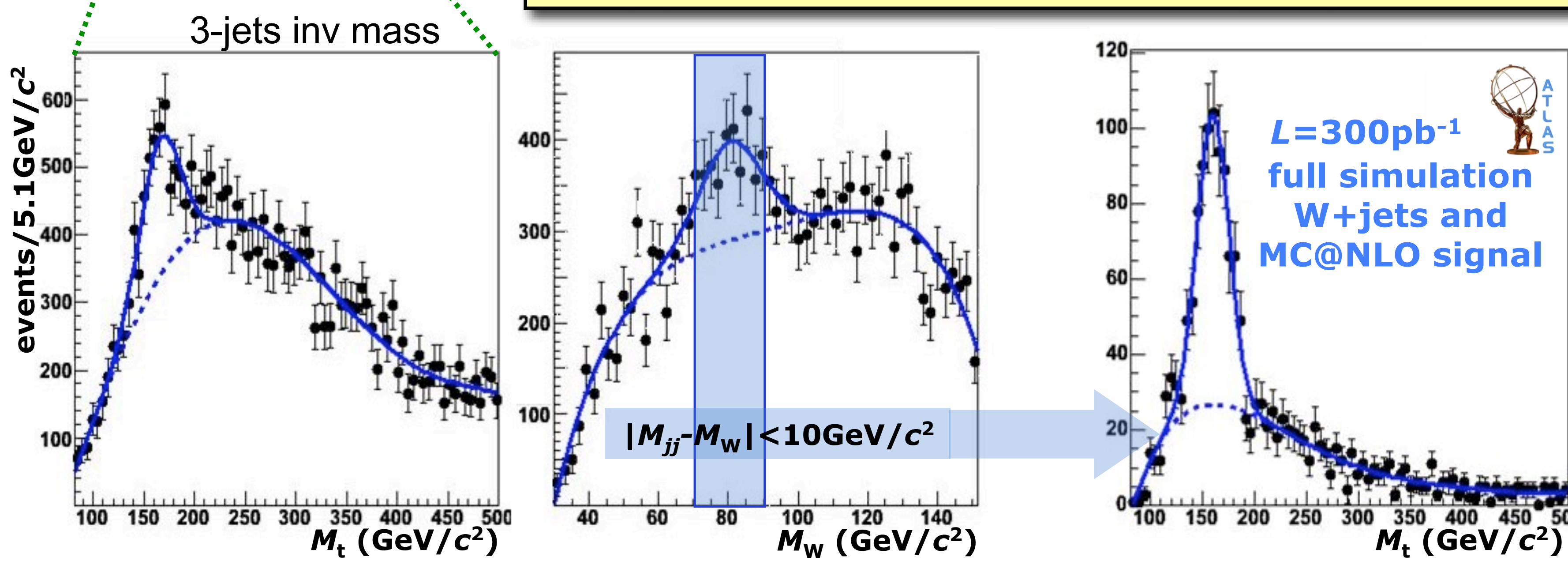
Top quark physics without b-tag (early phase)



Selection

- semileptonic top: p_T(lepton)>20GeV/c, missing E_T>20GeV
  - no b-tagging required
- hadronic top: N_{jet}>4, p_T(jet)>40GeV/c (0.4 cone algorithm)
- 3 jets with highest vector-sum p_T identified as top
  - of these, 2 leading jets in 3-jet rest frame identified as W

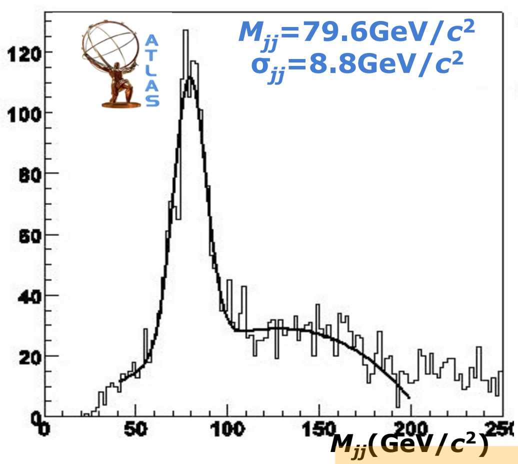
A top peak can be seen without b-tag requirement

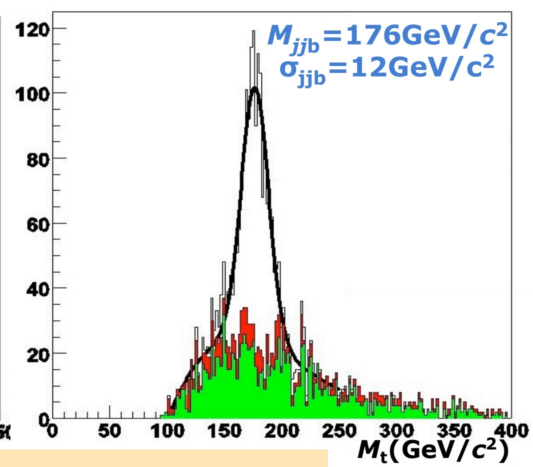


Top Properties: Mass

Lepton+jets

- isolated lepton (e,μ): p_T>20GeV/*c*, |η|<2.5
- missing E_T>20GeV
- at least 4 jets: p_T>20GeV/*c* (corrected), |η|<2.5
  - at least 2 light jets to reconstruct hadronic W
  - 2 b-tagged jets to select the bjj system with highest P_T
- very effective in background rejection ($S/B=10^{-4} \rightarrow 30$)
  - mainly from bb, W/Z+jets and Wbb

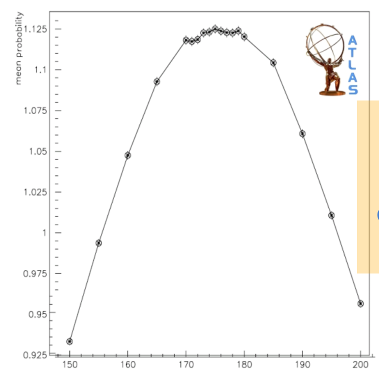




full simulation, L=10fb^{-1}
δM_t(stat)=0.05GeV/c^2
δM_t(sys)=1.3GeV/c^2
Alternative measurements give similar uncertainty

Dileptons:

- two opposite-signed leptons: p_T(lepton)>20GeV/*c*, |η|<2.5
- missing E_T>40GeV
- 2 b-jets: p_T>25GeV/*c* (corrected), |η|<2.5
- Final state reconstruction
- 6 unknowns (neutrinos' momenta), M_t hypothesis
  - conservation of transverse momentum
  - mass-constrain each l–ν pair to M_W
  - mass-constrain each l–ν–b-jet system to M_t
- weight assigned to each solution
  - based on comparison with MC
  - average weight over whole event sample
- M_t from solution with highest mean weight



fast simulation
L=10fb^{-1}
δM_t(stat)=0.04GeV/c^2
δM_t(sys)=1.7GeV/c^2

Other Mass Measurements

Kinematic fit to reconstruct entire tt final state:

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

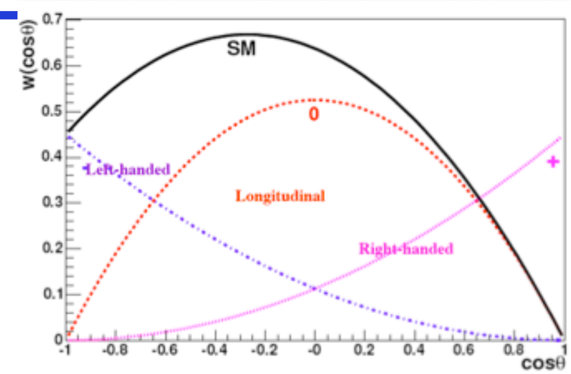
fast simulation: δM_t(sys)=0.9GeV/c^2 (smaller FSR effect)

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

- t and t tend to be back-to-back : used as constraint to reduce bkg
- Boosted top decay leads to three overlapping jets
  - Top identified as one large cluster ($0.8 < \Delta R < 1.8$)
    - 3 jets in 1 hemisphere tend to overlap: collect E in a cone around candidate top
  - Mass calculated as the sum of all the towers included in the cluster
    - less sensitive to jet calibration. Mass scale recalibration based on hadronic W,
    - Sensitive to underlying events

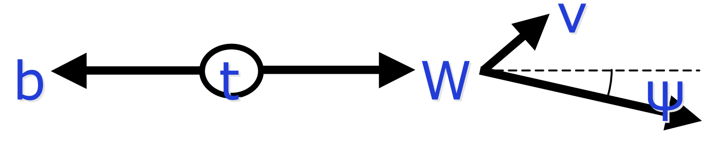
fast simulation: δM_t(sys)=1.6GeV/c^2

Top Properties: W Polarization



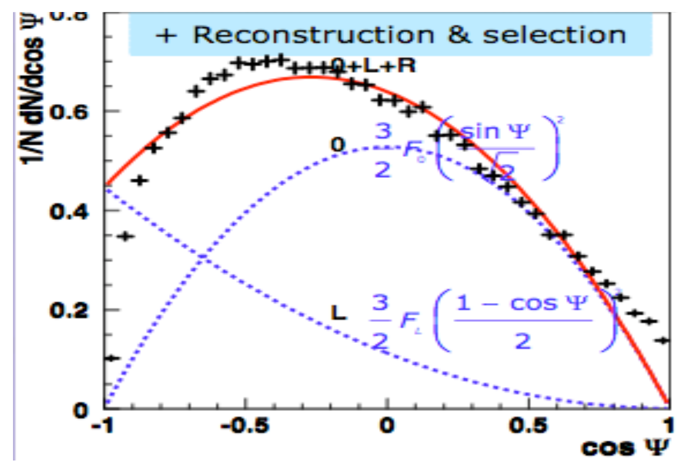
Top decays before hadronization

- spin information passed directly onto Wb
- SM predicts 70% longitudinal W and 30% left-handed W
  - depending on M_t and M_W only $f_0 = \frac{m_t^2}{2m_W^2 + m_t^2}$
- parametrize in terms of angle between
  - direction of W in top rest frame
  - direction of lepton in W rest frame



- Precision in measurements of the fractions F_0(longitudinal) and F_R
- Unfold selection and detector effects

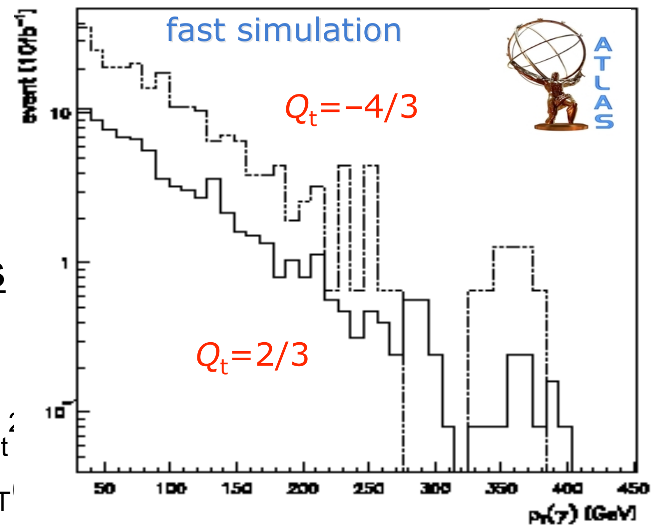
fast simulation L=10fb^{-1}		F_0	F_R
Stat	CMS (SL)	±0.023	±0.015
	ATLAS (SL+DL)	±0.004	±0.003
Sys	CMS (SL)	±0.022	±0.053
	ATLAS (SL+DL)	±0.016	±0.012



Top Properties: Charge

- Aimed at confirming $Q_t=2/3$ SM hypothesis
  - non standard value $Q_t=-4/3$ not yet excluded
    - can arise from wrong W-b association
- Two procedures for direct measurement
  - Top e.m. coupling through photon radiation in tt events

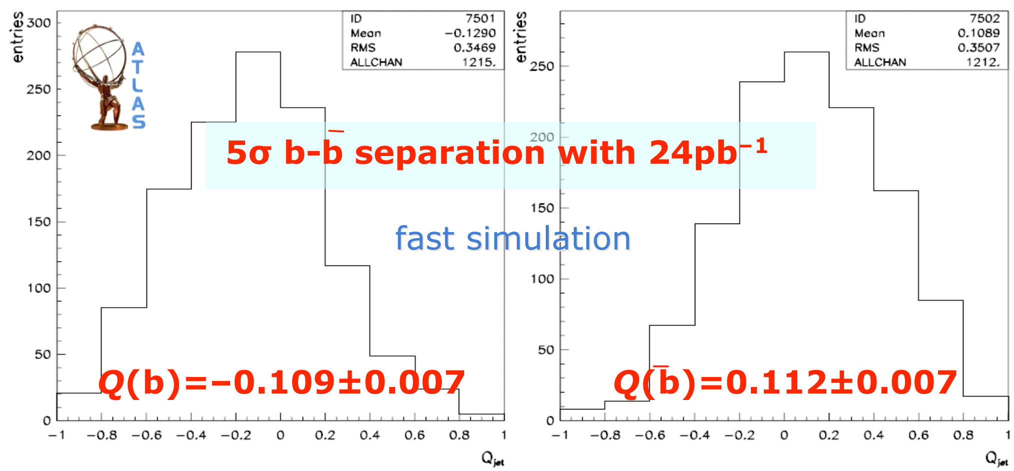
    Detection of the hard γ from top:
    - gg initial state dominance at LHC reduces ISR
    - radiative tt production & (interfering) decay: x-section $\propto Q_t^2$
    - radiative tt decay: reduced by requiring high M(bjjγ) or M_T



  - reconstruct charge of decay products (lepton/dilepton+jets)
    - easy for W boson (Q_l)
    - challenging for b-jets

$$Q_{jet} = \frac{\Sigma_i Q_i \left|\vec{p}_{jet} \cdot \vec{p}_i\right|^2}{\Sigma_i \left|\vec{p}_{jet} \cdot \vec{p}_i\right|^2}$$

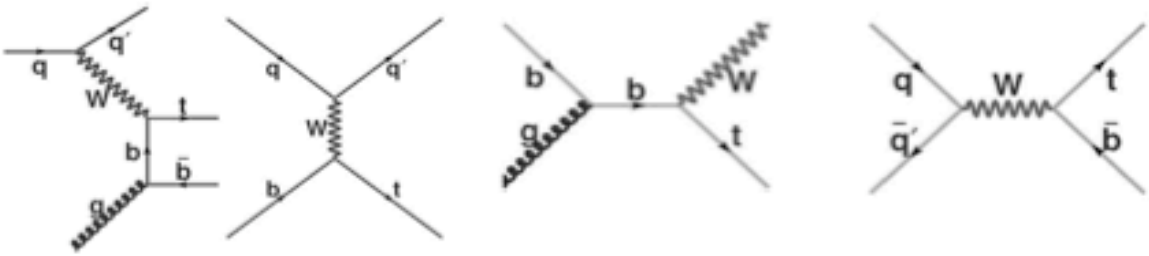
    - l-b association: $M_{lb} < M_t$
    - Systematics underway



Single Top at LHC

- All 3 contributing mechanisms in SM:

W-g (t-channel) | W+t | W* (s-channel)



- Computation at NLO available for W* and W-g :
  - Increase of σ(W*) by ~30 %
  - Affect p_T(jet) distribution, H_T etc…

Channel	σ x BR(pb)
W-g	54.2
W+t	17.8
W*	2.2
ttbar	246
Wbb	66.7
W+jets	3,850

Decay modes:

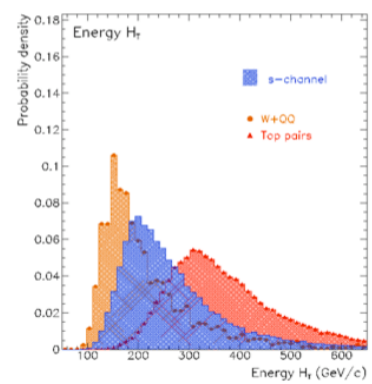
- W* : W* → t bbar → ($l^+\nu$b) bbar
- Wg: q'g → t q bbar → ($l^+\nu$b) q bbar
- W+t: bg → t W → ($l^+\nu$b) qq'

1 leptons + MET
+ ≥ 2 jets
+ 1(2) b-tags

Common selection for all 3 single-top samples :

- 1 High pT Lepton + mET
→ reduce non-W events
- At least two high-p_T jets
→ reduce W+jets events

- Single-top ~22-26%
- ttbar ~ 38%
- WQQ ~ 1.5% , W+njets < 1/1000



Why Single Top ?

Motivations

- Properties of the Wtb vertex :
  - Determination of $\sigma(pp \rightarrow tX)$, $\Gamma(t \rightarrow Wb)$
  - Direct determination of $|V_{tb}|$
  - Top polarization
- Precision measurements → probe to new physics
  - Anomalous couplings
  - FCNC

  } t-channel,Wt
  - Extra gauge-bosons W' (GUT, KK)
  - Extra Higgs boson (2HDM)

  } s-channel
- Single-top is one of the main background to …

  … Higgs physics…

M(top) = 175 GeV/c^2	s-channel	t-channel	Associated tW	Combined (s+t)
TeVatron σ_{NLO}	0.88 ± 0.11 pb	1.98 ± 0.25 pb	0.1 pb	
LHC σ_{NLO}	10.6 ± 1.1 pb	247 ± 25 pb	62^{+17}_{-4} pb	
Run II 95% CL CDF	<3.2 pb	< 3.1pb	NA	< 3.5
Run II 95% CL D0	4.6-5.0 ±1.4-1.9 pb		NA	4.6-5.0 ±1.4-1.9 pb

σ_{t+s} = 2.9 pb for m(top) = 175 GeV/c^2

B.W. Harris et al.:Phys.Rev.D66,054024 T.Tait: Phys.Rev.D61,034001
Z.Sullivan Phys.Rev.D70:114012 A.Belyaev,E.Boos: Phys.Rev.D63,034012

ATLAS analysis strategies

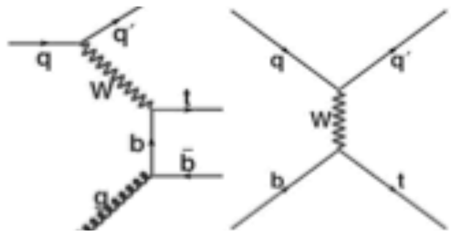
In the late '90 several studies were conducted to produce a physics TDR. Current studies are meant to devise analysis strategies for early data taking and the full statistics, using the latest software tools.

Description of cuts	Cumulative Selection Efficiency (%)			
	W-g fusion	$t\bar{t}$	$Wb\bar{b}$	Wjj
Pre-selection cuts	20.0	44.4	2.49	0.667
Njets = 2; p_T>30GeV	13.2	0.95	0.99	0.37
Forward jet; p_T>50, $\|\eta\|$>2.5	4.3	0.046	0.072	0.06
m_{tot}>300 GeV	3.58	0.025	0.043	0.048
H_T > 200 GeV	2.08	0.019	0.036	0.027
150 < m_t < 200 veto	1.64	0.01	0.0052	0.0066
Events/30 fb^{-1}	26 800 ± 1000	720 ± 160	104 ± 60	7900 ± 1600

Description of cuts	Cumulative Selection Efficiency (%)					
	W^*	*W-g* fusion	Wt	$t\bar{t}$	$Wb\bar{b}$	Wjj
Pre-selection cuts	27.0	20.0	25.5	44.4	2.49	0.667
njets = 2; p_T > 30 GeV	15.7	6.8	3.79	0.93	1.35	0.201
nb-jet = 2; p_T > 75 GeV	2.10	0.05	0.018	0.023	0.038	0.0005
scalar sum of p_T >175 GeV	1.92	0.036	0.016	0.021	0.030	0.0004
m_{tot}>200GeV	1.92	0.036	0.014	0.021	0.025	0.0003
150<$m_{l\nu b}$<200 GeV	1.67	0.031	0.008	0.017	0.016	0.0002
Events/30 fb^{-1}	1106 ± 40	510 ± 148	42 ± 21	1290 ± 228	328 ± 61	226 ± 113

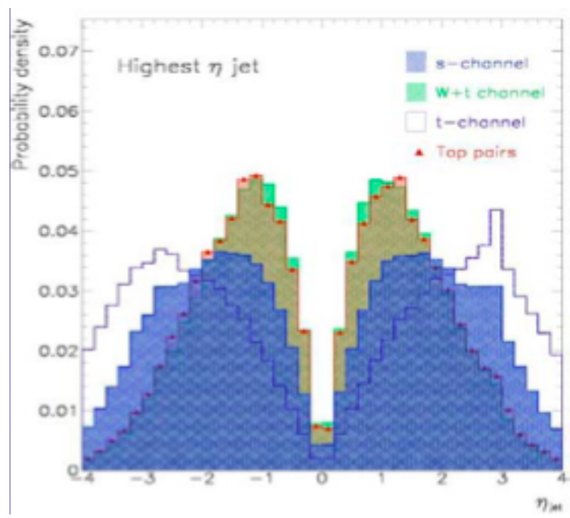
Description of cuts	Cumulative Selection Efficiency (%)		
	Wt	$t\bar{t}$	$Wb\bar{b}$
Pre-selection cuts	25.5	44.4	2.49
njets = 3; p_T > 50 GeV	3.41	4.40	0.05
nb-jet = 1	3.32	3.24	0.037
m_{tot} < 300 GeV	1.43	0.71	0.008
65 < m_{jj} < 95 GeV	1.27	0.41	0.003
Events/30 fb^{-1}	6828 ± 269	30408 ± 742	58 ± 19

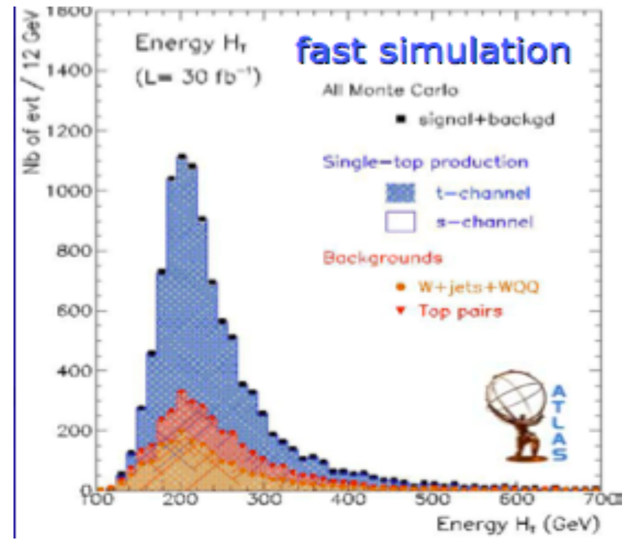
Wg channel



Selection criteria

- Number of jets : N(jet) = 2
- Presence of a high-p_T b-tagged jets (p_T>40GeV/c)
  Wg evts have 1 b-jet escaping the acceptance
  → requires **only** 1 b-tagged jet
- Presence of a high-p_T forward jet
  → 1 jet with $|\eta|$>2.5 and $p_T \geq$ 50GeV/c
- Reconstruct $M_{l\nu b}$ within ±25 GeV/c^2
- Window in H_T

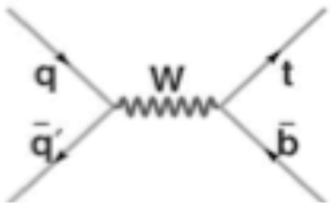


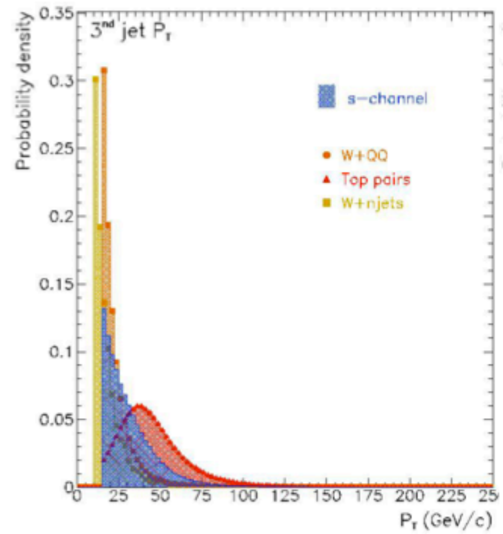


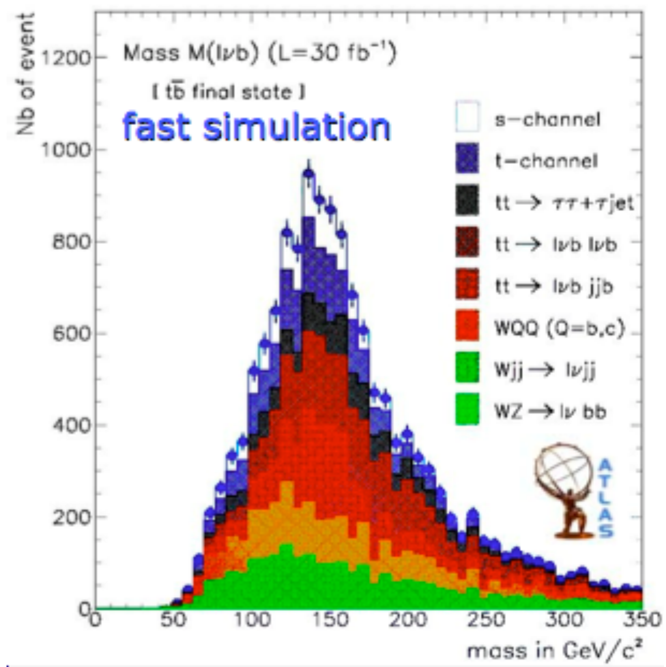
	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection (%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	0.22	0.44	0.023	0.007	0.006	0.0013
N^{event}(30 fb^{-1}) ± MC stat.	150 ± 6	7,080 ± 160	125 ± 13	500 ± 150	130 ±40	1,500 ± 750

- N(jet) = 2 → reduces tt by ~6 vs Wg
- 1 high-p_T fwd jet → reduce tt (by ~5), Wt(~10), Wjj(~2)
- Great uncertainty on WQQ / W+jets backgrounds

s-channel







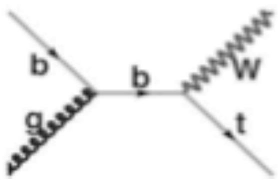
Selection criteria

- Number of jets : N(jet) = 2
- Presence of two high p_T jets
- Presence of two central, high-p_T b-tagged jets
  → Wg usually have 1 b-jet escaping the acceptance
- Reconstruct $M_{l\nu b}$ within m_{top} ± 25 GeV/c²
- Window in H_T

	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection ε(%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	1.73	0.105	0.002	0.035	0.059	0.0001
N^{event}(30 fb⁻¹) ± MC stat.	1,141 ± 7	1,680 ± 48	10 ± 3	2,580 ± 150	1,148 ± 38	170 ± 85

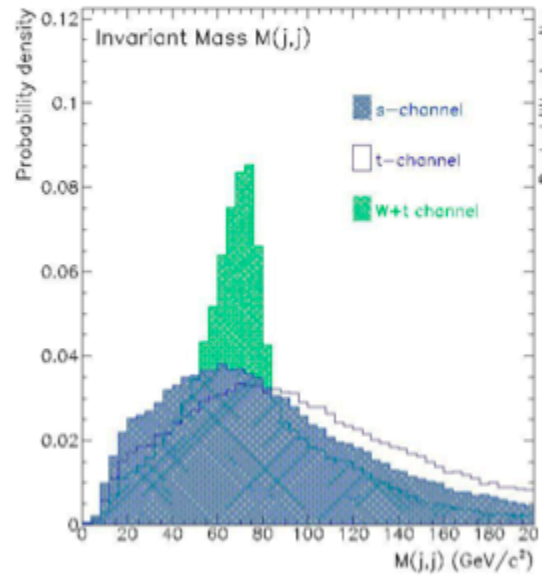
- N(jet) = 2 → reduces tt by a factor ~ 20 vs W*
- 2 high-p_T b-jets → reduces WQQ by ~2 and Wg by ~8
- $M_{l\nu b}$ and H_T → reduce non-top by ~2

Wt channel



Selection of a specific topology

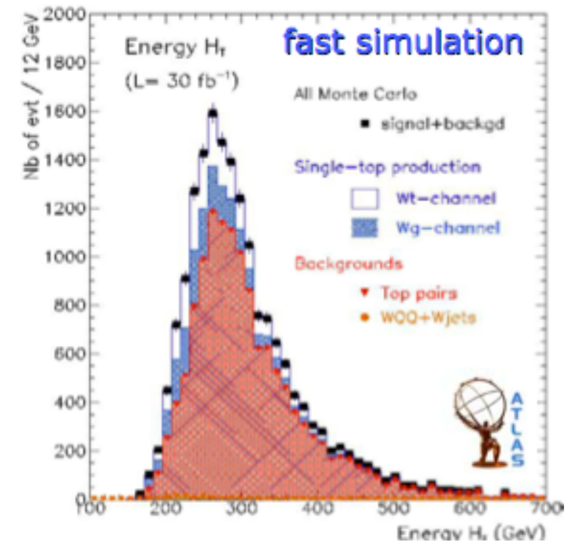
- Number of high-p_T jets Njet) = 3
- Presence of a high-p_T b-tagged jets
  → Only **one** b-jet in W+t events
- Presence of a W-boson mass peak
  → requires 60 < M(j,j) < 90 GeV/c²
- Reconstruct $M_{l\nu b}$ within ±25 GeV/c²
- Window in H_T or Invariant Mass



	W*	Wg	W+t	tt	WQQ	W+jets
Pre-Selection ε(%)	26.2	23.7	22.4	38.3	1.46	0.05
Selection ε(%)	0.16	0.25	0.88	0.35	0.004	0.0003
N^{event}(30 fb⁻¹) ± MC stat.	105 ± 5	4,050 ± 80	4,720 ± 80	26,300 ± 400	90 ± 20	xxx ± 85

- N(jet) = 3 → reduces Wjj & WQQ ~3.5 wrt W+t
- M(jj) ~ M_W → reduces WQQ/jets by ~3 wrt W+t

→ Good knowledge of tt background is mandatory



V_{tb} Measurement

- Indirect measurement
  - based on CKM unitarity constraint (3 generations)

$$\frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2} = \frac{BR(t \to Wb)}{BR(t \to Wq)}$$

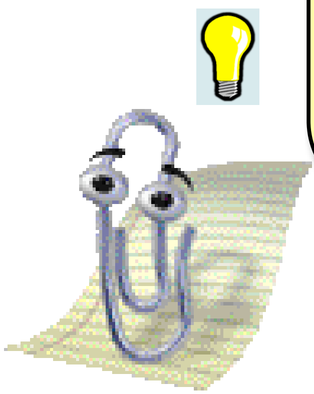
- Direct measurement
  - based on electroweak single top production ($\sigma \propto |V_{tb}|^2$)
    - measure yield of single top production
    - combine with $BR(t \to Wb)$ and M_t (from tt channel)
  - unbiased test of 3-generation structure of SM
  - penalized by poor knowledge of W+jets, WQQ background
  - no systematic effects taken into account

channel	*S/B*	uncertainties on σ		$\Delta V_{tb}/V_{tb}$
		stat ($30fb^{-1}$)	theoretical	
s-channel	0.55	5.6%	7.5%	4.7%
t-channel	2.3	0.54%	11%	5.5%

Top quark pair production as calibration tool

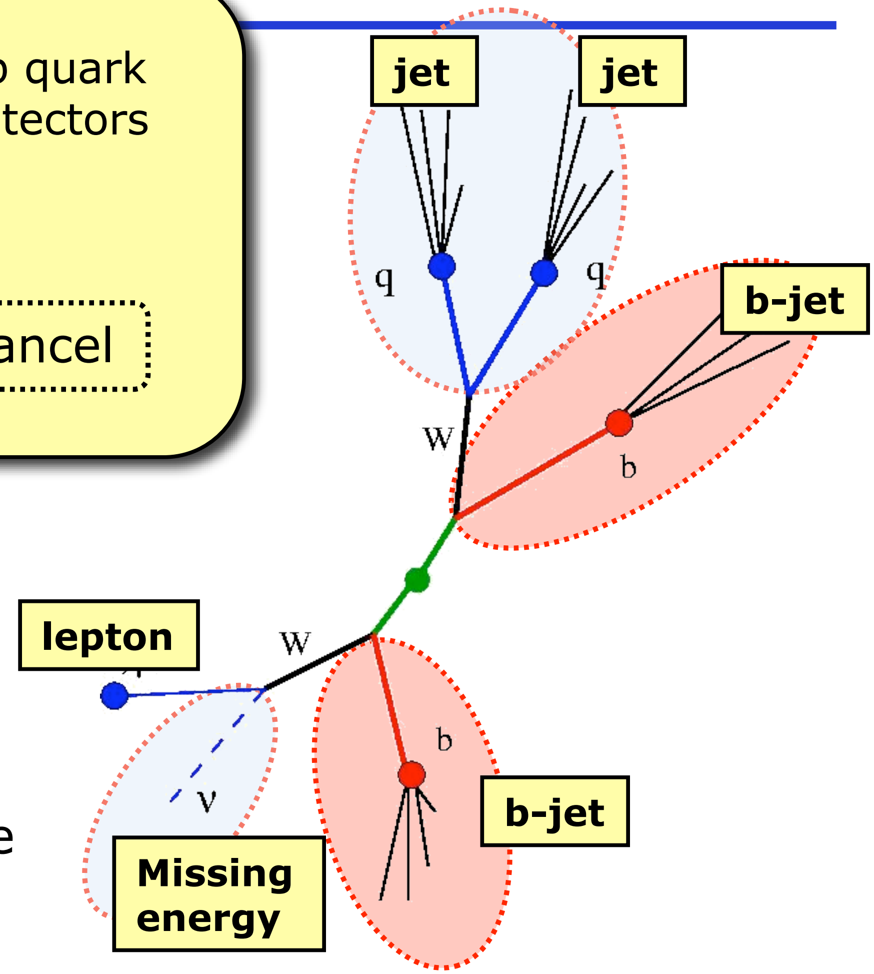
You can use production of top quark pairs to help calibrate LHC detectors in complex event-topologies

Yes ✓ | No | Cancel



→ <u>A candle for complex topologies</u>:

- Calibrate light jet energy scale
- Calibrate missing E_T
- Obtain enriched b-jet sample
- Leptons and trigger

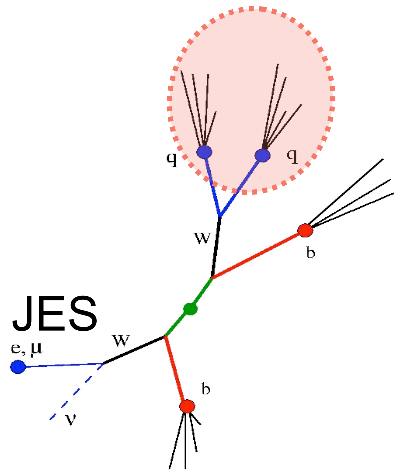


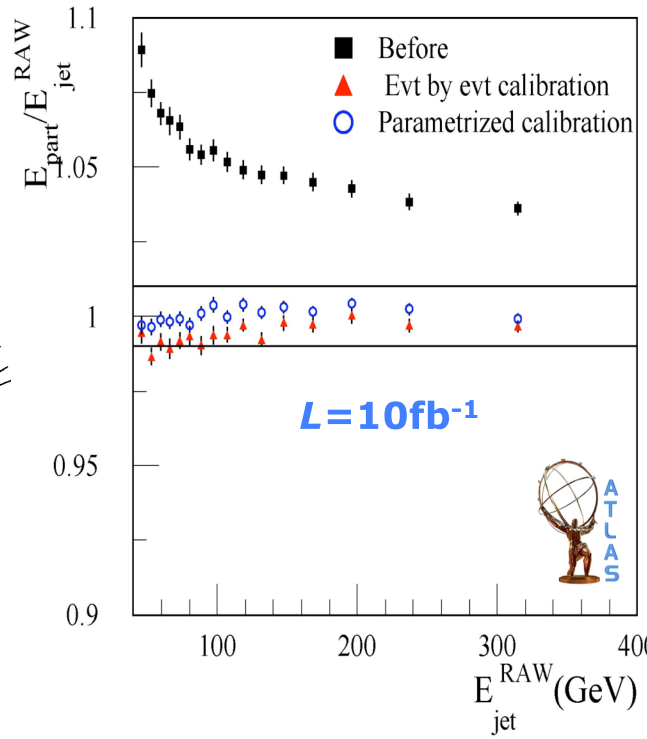
Note candles: 2 W-bosons
2 top quarks

Calibrating jet energy scale

One of the most relevant systematic effects on M_t

- jet energy: measurement of parton energy
- 1% uncertainty on absolute JES induces δM_t~1GeV/c^2
- sizeable effects also from
  - b-jet energy scale
  - QCD radiation, underlying event, cone algorithm
- at start-up, 5÷10% uncertainty
  - test-beam data
- <u>in-situ correction with Z/γ+jet</u>
  - p_T(jet) correction
  - residual mass shift (2% on M_t)
- $M_{jj}=M_W$ additional constraint on JES
- clean W→jj sample needed
  - 80% purity within tt→lν+jets

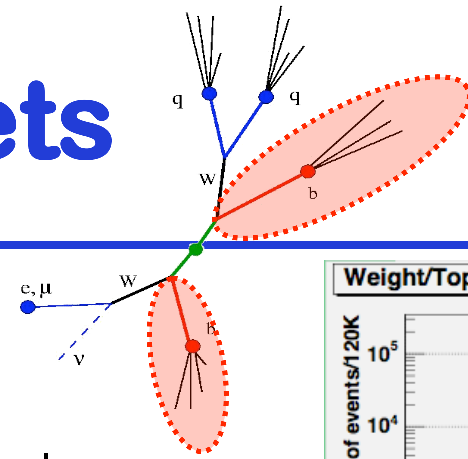




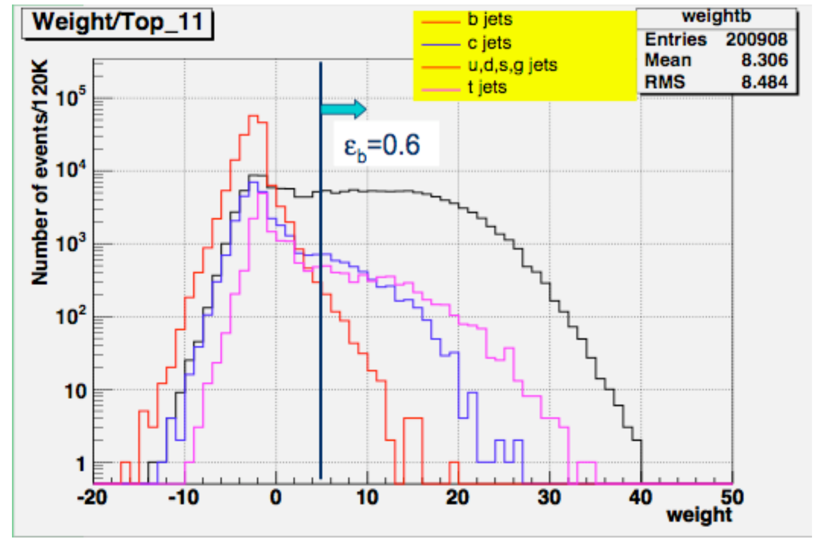
- goal: 2÷3% uncertainty in 1 year (target 1%)
- Alternative method: P_T balance in Z/γ + jet events

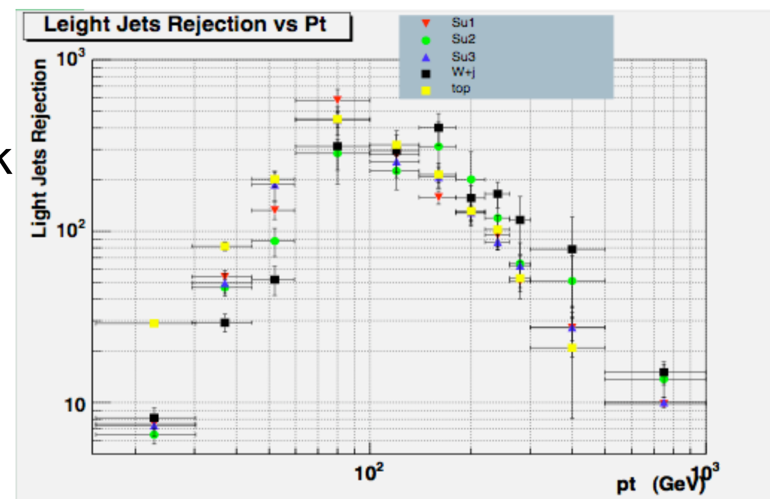
full simulation
tt MC@NLO

Calibrating b-jets



- b-tagging techniques rely on
  - impact parameter of decay tracks
  - primary/secondary vertex separation
  - soft leptons
    - targeting b and c semileptonic decays
- Typical performances
  - efficiency ~60% on p_T>40GeV/c jets
  - light flavour rejection $1/\varepsilon_u$~200
- Jets from b-quarks need specific corrections
  - semileptonic decays of heavy-flavoured quark
    - neutrino induces a large shift on the jet energy
    - effect enhanced if lepton is muon (MIP)
    - jet direction affected as well as jet energy



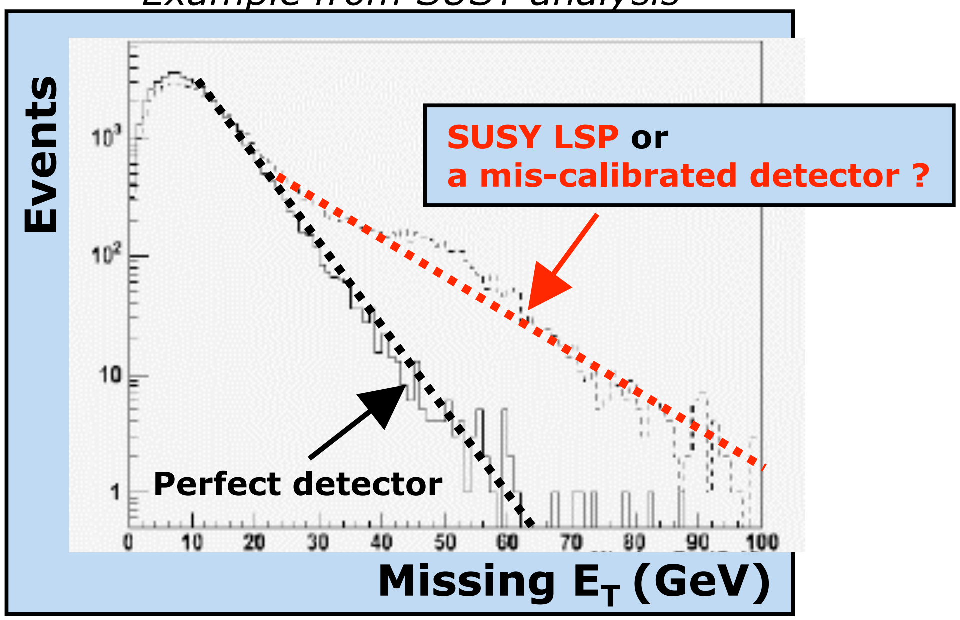


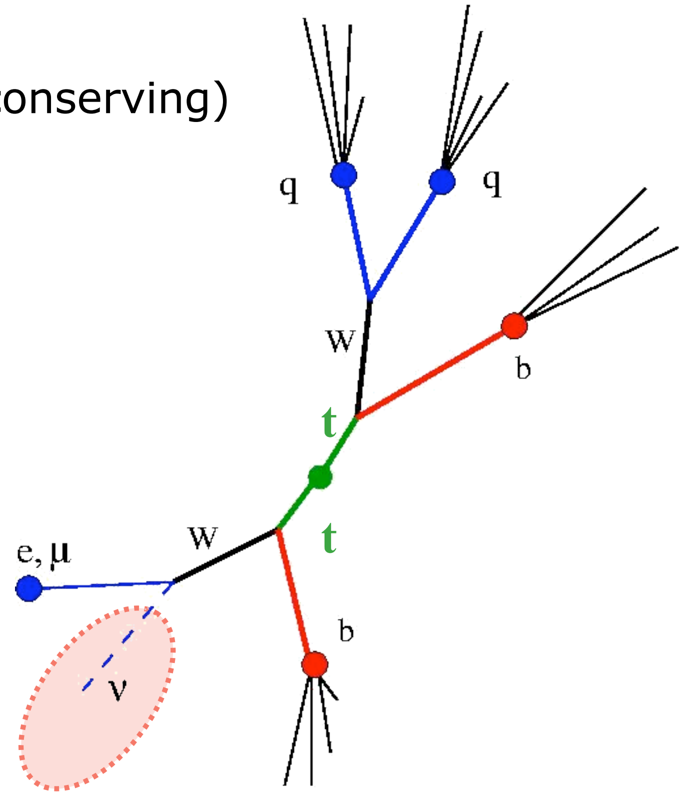
Calibrating the missing energy

- The neutrino momentum is constrained from kinematics: M_W
  → known amount of missing energy per event

- Calibration of missing energy **vital** for **all** (R-parity conserving) SUSY and most exotics!

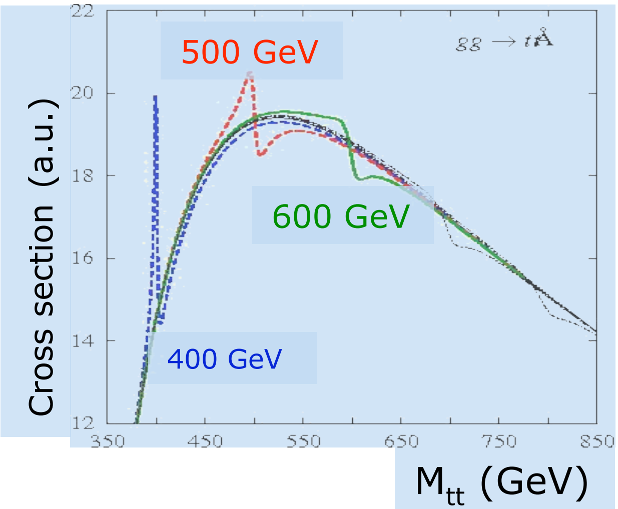
Example from SUSY analysis





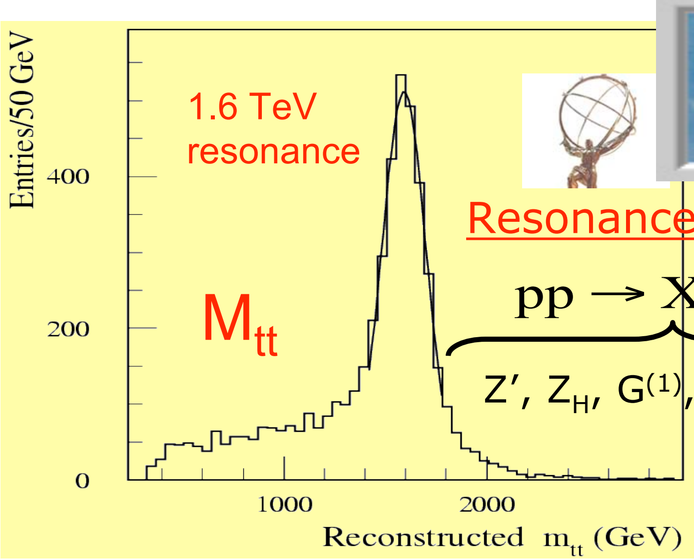
Range: $50 < P_T < 200$ GeV

A window to new physics ?



Structure in M_{tt}

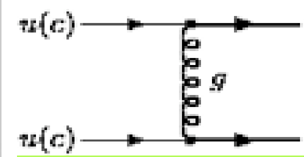
Interference from MSSM Higgses H,A → tt (can be up to 6-7% effect)



Resonances in M_{tt}

$$pp \to X \to t\bar{t}$$

Z′, Z_H, $G^{(1)}$, SUSY, ?



Like-sign tt ?

FCNC decays: GIM suppressed in SM, can be enhanced in SM extensions

q=u,c	t→Zq	t→γq	t→gq
BR(*L*=10fb^{-1})	$3.4\cdot10^{-4}$	$6.6\cdot10^{-5}$	$1.4\cdot10^{-3}$
BR(*L*=100fb^{-1})	$6.5\cdot10^{-5}$	$1.8\cdot10^{-5}$	$4.3\cdot10^{-4}$

Conclusions

1) Top quarks are produced by the millions at the LHC:
   → Almost no background:
   to measure top quark properties will be easy

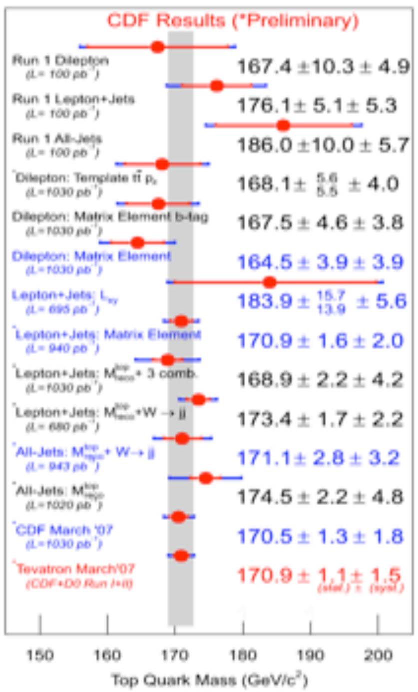
2) Top quarks are THE calibration signal for complex topologies:
   → Most complex SM candle at the LHC
   → Vital input for detector commissioning/calibration

3) Top quarks pair-like and singly produced……
   as a window to new physics:
   → FCNC, SUSY, MSSM Higgs,
   Resonances, anomalous couplings
   Also important SUSY background

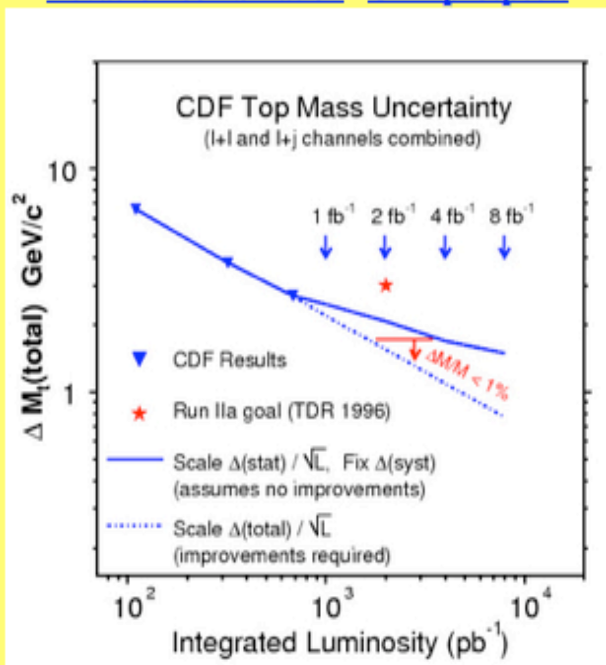
Backup Slides

Top Mass Now

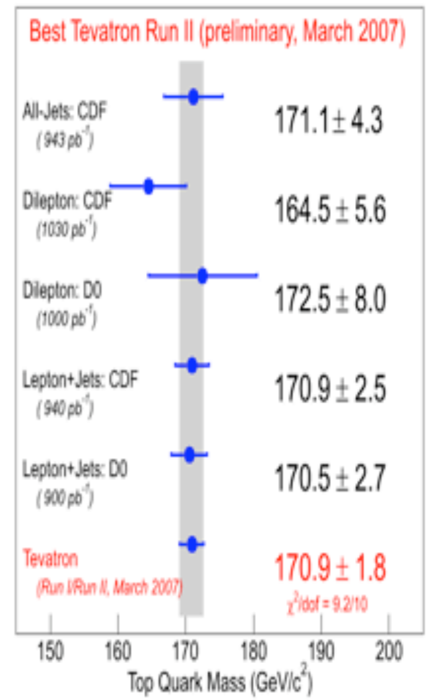
CDF measurements
(Updated 03/15/2007)



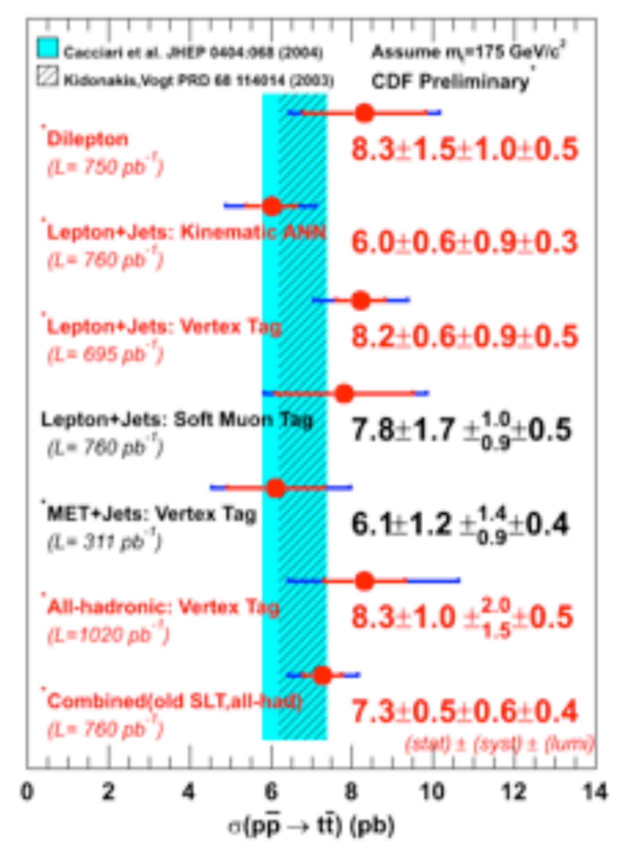
Top quark mass
[Tevatron combination](#) [CDF prospects](#)

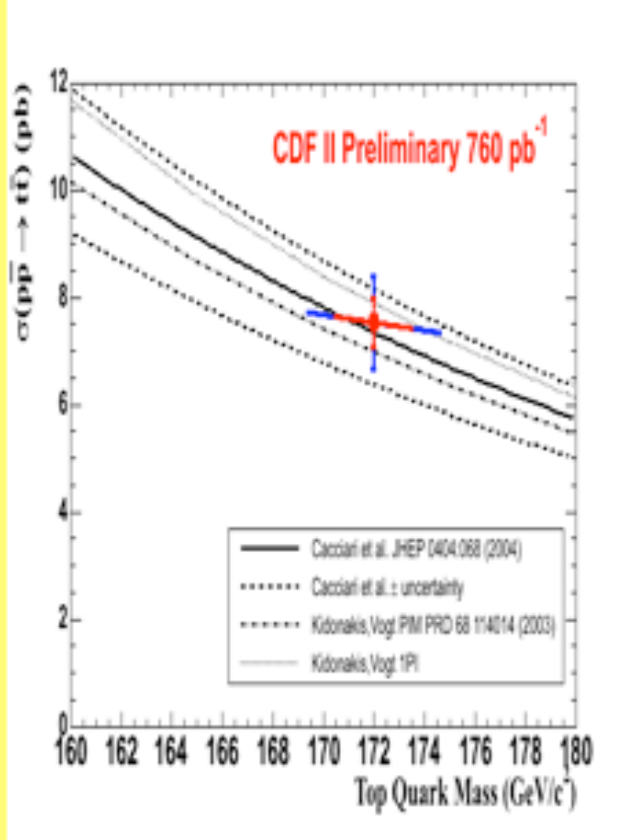


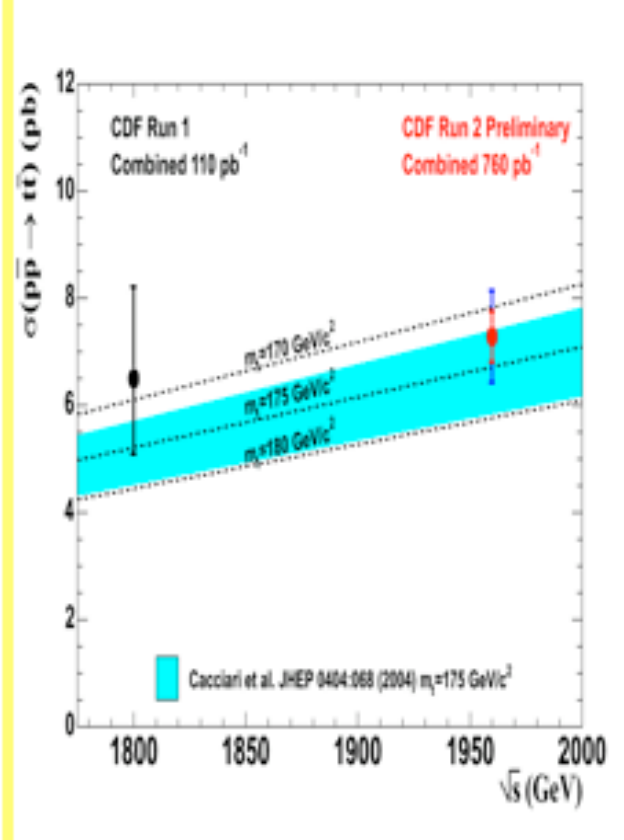
CDF and D0 best
(Updated 03/15/2007)



Top Cross Section Now







Top Properties Now

Top quark production and decay properties			
lepton+jets	Search for resonances in ttbar mass spectrum	95% C.L. on σ ×BR(X->ttbar)	680
lepton+jets	Search for a Massive Fourth Generation t' Quark	t' mass > 258 GeV at 95% CL	760
lepton+jets	Top Quark Lifetime	$c\tau_{top} < 52.5\ \mu m$ @ 95% C.L.	318
dilepton	Search for Anomalous Kinematics	1.0-4.5%	194
lepton+tau	t->τ νq	5 obs vs 2.7+-0.4 bkg p-value 15%, or 1sigma excess	350
dilepton, lepton+jets, single and double Vertex b-tags	BR(t->Wb)/BR(t->Wq)	1.12 + 0.21 - 0.19 (stat) + 0.17 -0.13 (syst) > 0.61 @ 95% C.L.	162
dilepton, lepton+tau, lepton+jets single and double Vertex b-tags	Search for Charged Higgs in top decays	Limits on BR(t->H^+b)	194,162
lepton+jets	Top Production Mechanism	0.25+-0.24(stat)+-0.10(syst) for xs(gg->ttbar)/xs(ppbar->ttbar)	330

W helicity Now

W Helicity Plain English explanation			
lepton+jets	cosθ *	F_0= 0.61 +-0.12(stat) +-0.04 (syst) $F_+ < 0.11$ @ 95% C.L.	955
dilepton, lepton+jets (Run II)	M_{lb}^2	$F_+ < 0.09$ @ 95% C.L.	750
lepton+jets	cosθ *	F_0= 0.59 +-0.12(stat) +0.07-0.06(syst) $F_+ < 0.10$ @ 95% C.L.	955
lepton+jets	Combined cosθ * and Lepton Pt spectrum	F_0= 0.74 +0.22 -0.34 (stat+syst) $F_+ < 0.27$ @ 95% C.L.	162
dilepton, lepton+jets Run I	M_{lb}^2	$F_+ < 0.18$ @ 95% C.L.	109

Lifetime Efficiency from top data

It is necessary to evaluate the b-taggers performance from data

At the Tevatron this was done in two ways:

- rejection from jet samples
- b-tag efficiency from semileptonic decay and cross calibration with soft lepton/lifetime taggers

At LHC the high statistics ttbar sample can be used

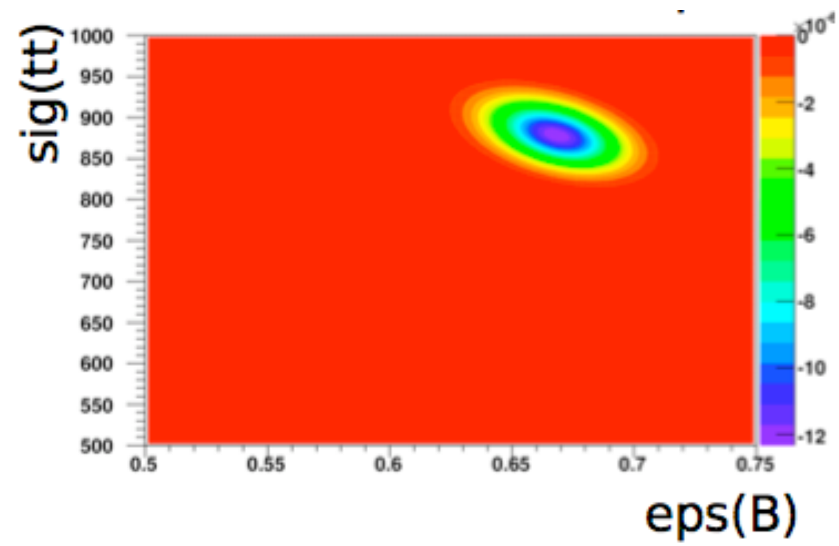
- relatively pure b-jet sample
- inclusive b-decay (not semileptonic only)
- high E_T sample
- large heavy flavor content:
  - -2 b-jets/events
  - -1 c-jet/2 events from W->jj
- it assumes Br(top->Wb) = 100%

Method: count the number of events with 1,2,3 tagged jets and extract ε(b),ε(c),σ(tt) using a likelihood fit

Lifetime Efficiency from top data

Several pseudo-experiments (~15 pb^{-1} each)

	'True'	Measured
ϵ_B (%)	67.9±0.2	66.8±2.3
ϵ_C (%)	20.3±0.4	28.5±5.3
ϵ_L (%)	0.93±0.03	-
$\sigma_{t\bar{t}}$ (pb)	857	878±28



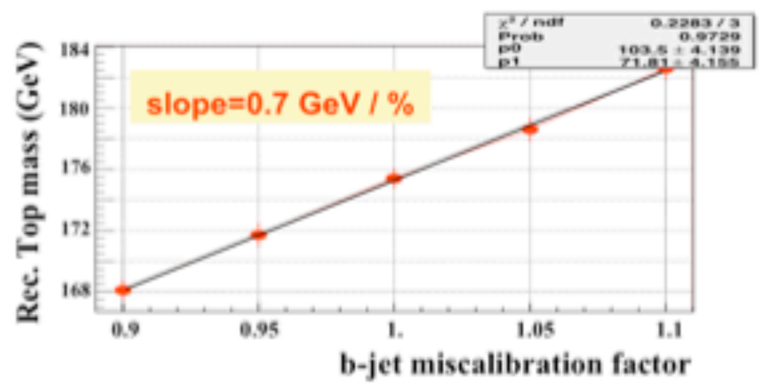
Working on systematics and improving event selection
Background evaluation needs more refinement (W+jets ok, QCD?)
- topological likelihood discriminant ?

Dilepton channel can be also used (no c-jet component)

Top Mass uncertainty in l+jets

Source of uncertainty	Systematic on m(top) ATLAS 10 fb^{-1} kinematic fit	/ hadronic top
b-jet scale (±1%)	0.7	0.7
light-jet scale (±1%)	0.2	0.2
Final state radiation	0.5	1.
b-quark fragmentation	0.1	0.1
Initial state radiation	0.1	0.1
Combinatorial bkg	0.1	0.1
Total syst	0.9	1.3
Statistical error	0.1	0.05

← Main systematics : b-jet scale



→ Δm(top) ~1 GeV achievable with 10 fb^{-1}

Other channels :

- Full leptonic channel : clean channel but 2 neutrinos (6 equations) : Δm(top) ~ 2 GeV (10 fb^{-1})
- Full hadronic channel : significant QCD background : Δm(top) ~ 3 GeV (10 fb^{-1})
- Semileptonic with b →J/ ψ→$\mu\mu$: 1 K evts / 100 fb^{-1} (high lumi) : Δm(top) ~ 1 GeV (small impact of b-jet scale but small statistics)

Cross Section Measurements

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

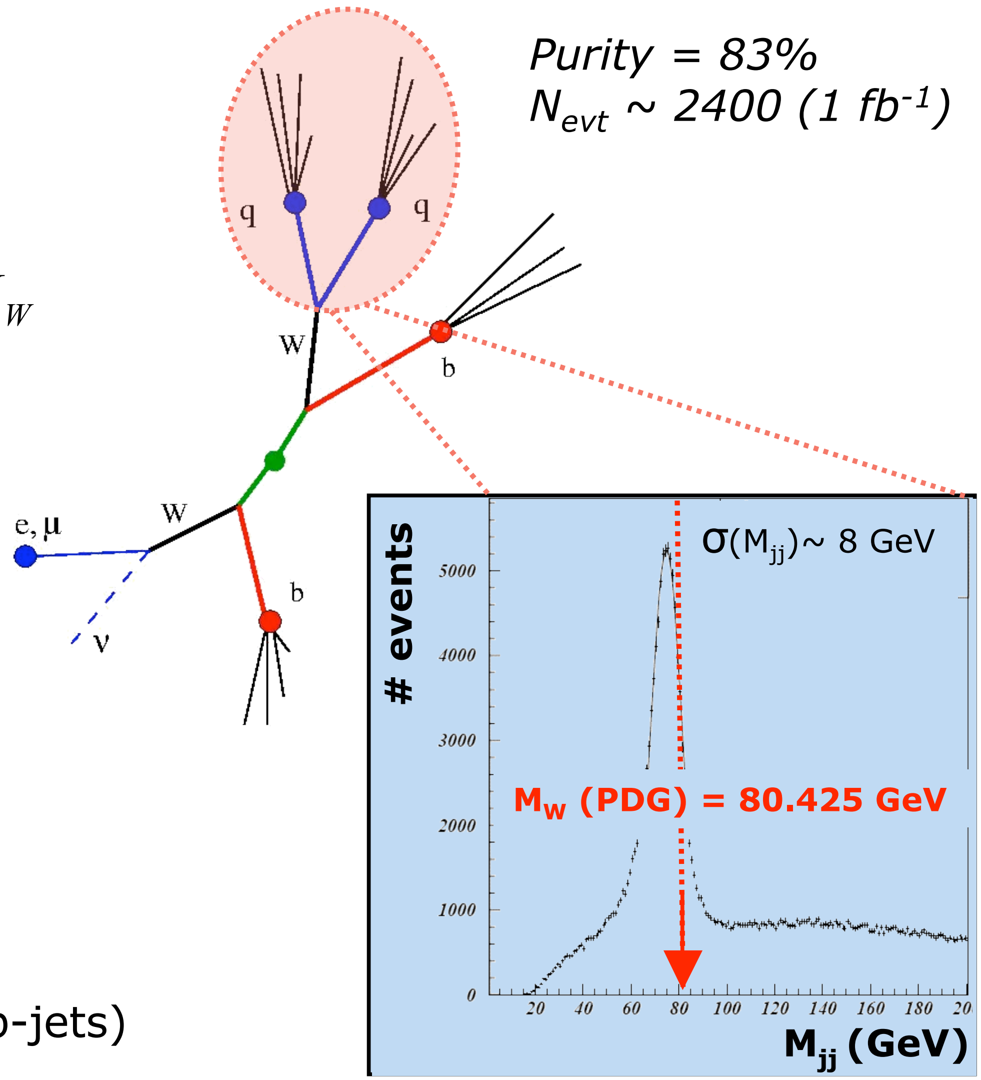
Calibrating the light jet energy scale

- Target uncertainty ~1%

Invariant mass of jets should add up to well known W mass (80.4 GeV)

$$M_{jj} = \sqrt{2E_{j1}E_{j2}(1-\cos\theta_{j1j2})} = M_W$$

Rescale jet energies:
$E_{parton} = (1+\alpha)\, E_{jet}$, with $\alpha = \alpha(P_T, \eta)$



Pro:
- Complex topology, hadronic W
- Large statistics

Con:
- Only light quark jets
- Limited P_T-range (50-200 GeV)

Precision: < 1% for 0.5 fb^{-1}
Alternative: P_T-balance in Z/γ+jet (6% b-jets)