“Top Physics studies at LHC in SM and BSM with the ATLAS detector”

DISCRETE '08

Symposium on Prospects in the Physics of Discrete Symmetries

11–16 December 2008, IFIC, Valencia, Spain

SUSANA CABRERA (IFIC)

On behalf of the ATLAS collaboration

OUTLINE

- ATLAS PROSPECTS ON (1) :
  - SM:
    - L=100 pb^{-1}: $\sigma(pp \rightarrow tt)$.
    - L=1 fb^{-1}: M_{TOP}, σ(single top).
  - BSM: L=1 fb^{-1}
    - W polarization and Wtb anomalous couplings.
    - Rare Top quark decays FCNC
    - Resonant tt-bar production $Z' \rightarrow tt$
- Brief current status from TEVATRON (2) and (3)

(1) ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear.

(*) All the information presented in this talk is **PRELIMINARY.**

(**) All results presented here evaluated at $\sqrt{s}$=14 TeV

(2) http://www-cdf.fnal.gov/physics/new/top/top.html (CDF Top quark Physics results)

(3) http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html (DØ Top quark Physics results)

σ_{tt} (SINGLE LEPTON CHANNEL) L=100 pb^{-1}

σ_{tt}(LHC) = 883.90 pb **(Phys. Rev. 2008, D78, 034003)**

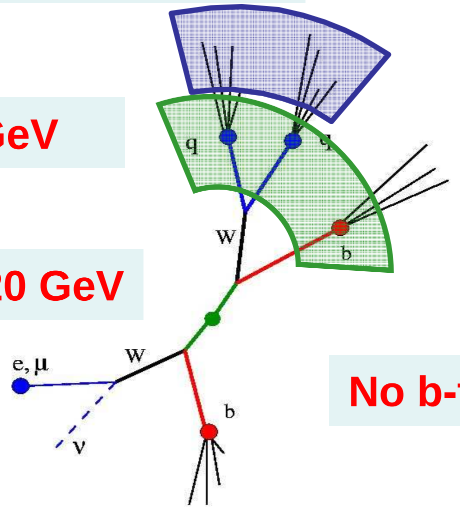
- Triggers: e/μ isolated & high p_T
- Dominant backgrounds: W+jets & Single top
- Excellent sample for:
  - Commissioning of b-tagging algorithms.
  - Determination of the light jet energy scale using the decay W→jj.

L= 100 pb^{-1}	e+jets	μ+jets
tt-bar (signal)	3274	2555
Eff(%)	18.2%	23.6%
Hadronic tt-bar	35	11
W+jets	1052	761
Single top	227	183
Z→ll+jets	78	107
Wbb-bar	25	17
Wcc-bar	26	19
WW	4	4
WZ	3	2
ZZ	0.4	0.3
Total Background	1446	1104
S/B	2.3	2.3

≥ 4 jets p_T >20 GeV
& ≥ 3 jets p_T> 40 GeV

P_T(lep) > 20 GeV

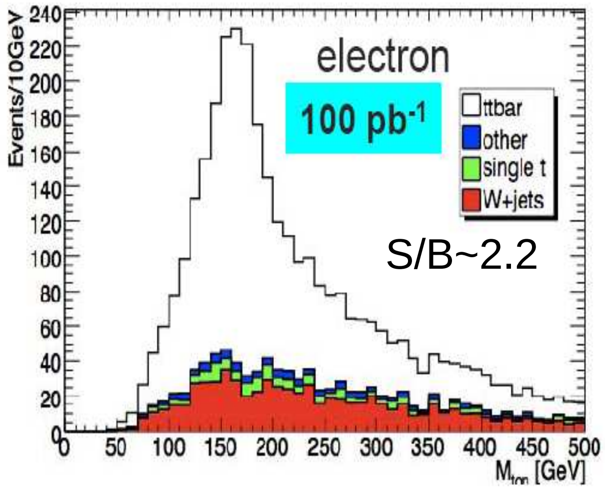
Missing E_T > 20 GeV



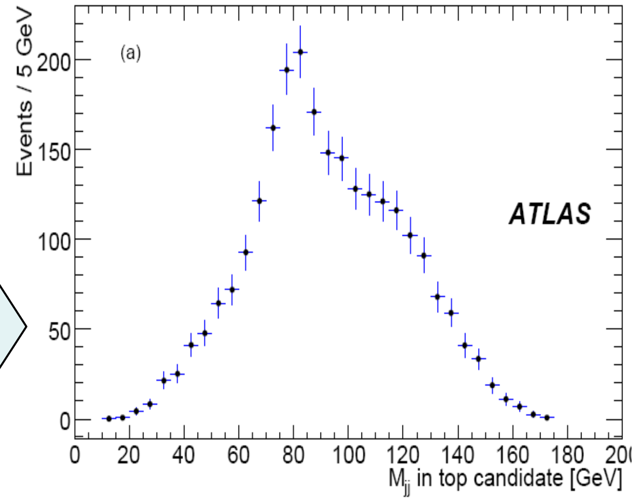
No b-tagging

σ_{tt} (SINGLE LEPTON CHANNEL) TT-BAR RECONSTRUCTION

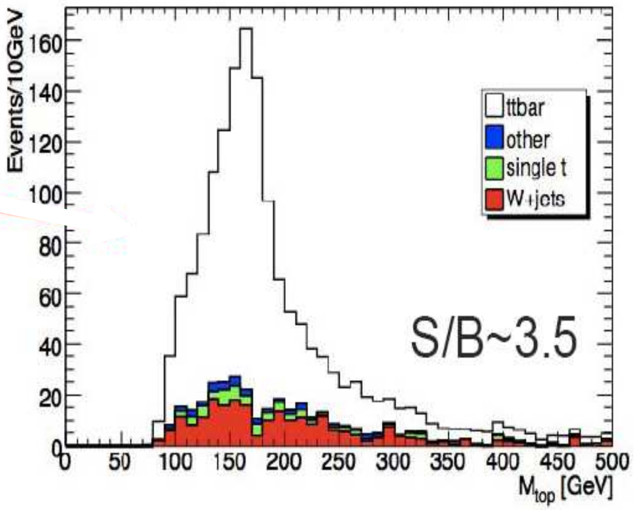
Hadronic Top Candidate:
j_1,j_2,j_3 / Σp_T^{max}



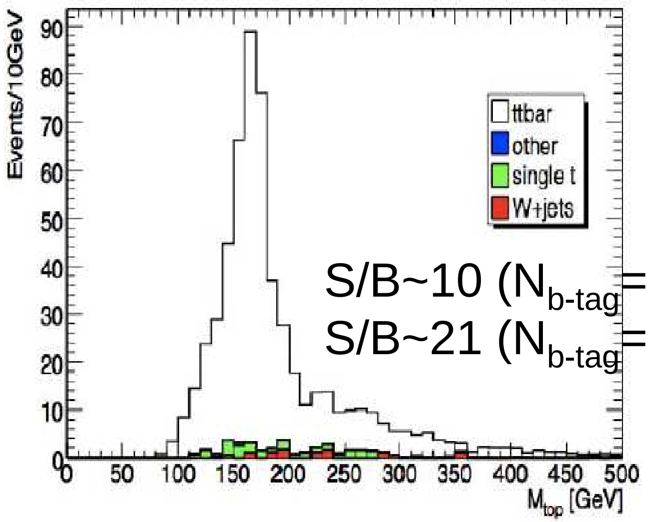
Hadronic W candidate:
j_1,j_2 / Σp_T^{max}



•$|m(jj)-m_W|<10$ GeV



N $_{b\text{-}tag}$ =1,2

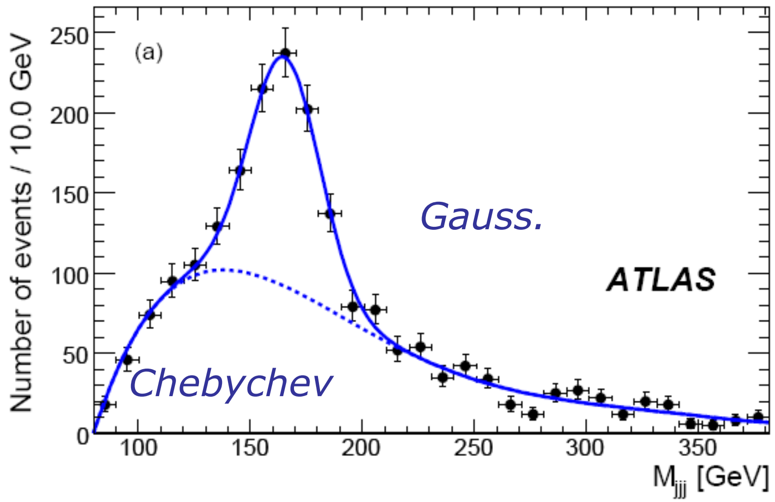


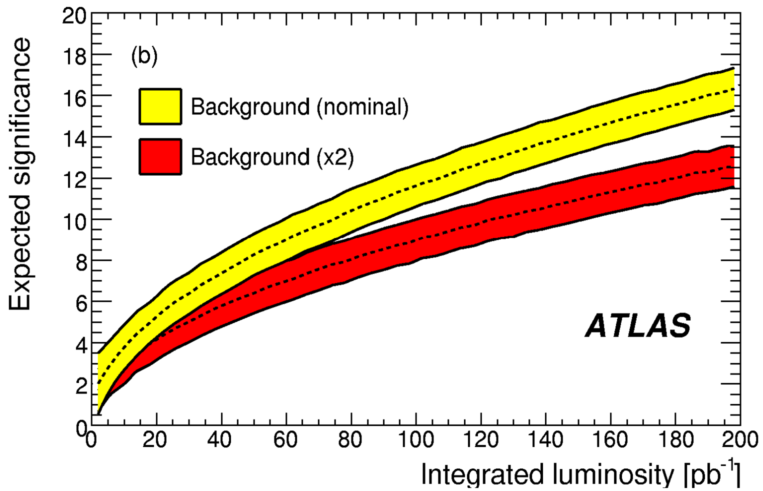
S/B~10 ($N_{b\text{-}tag}$=1)
S/B~21 ($N_{b\text{-}tag}$=2)

σ_{tt} (SINGLE LEPTON CHANNEL) METHODS AND SYSTEMATICS

- Counting method:
  - Very sensitive to the uncertainty in the total background rate, specially W+jets background estimate.
  - Jet energy scale is a significant systematic.
- Likelihood fit method: m_{jjj} of hadronic top candidate
  - Sensitive to the uncertainty in the tt-bar reconstruction efficiency.
  - Dominant uncertainties are statistical and shape of fit function.

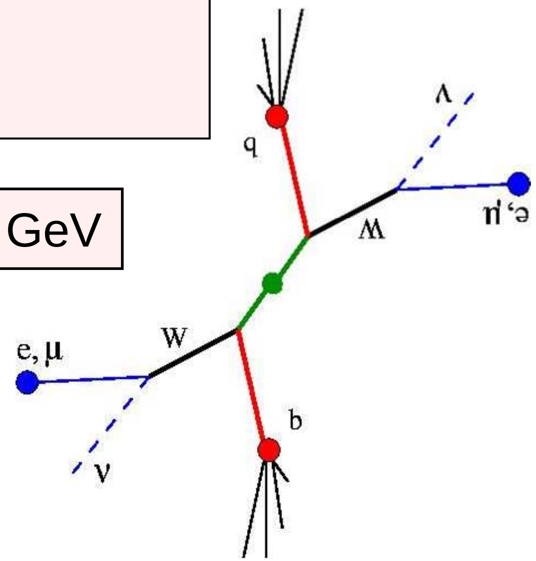
$$\sigma_{tt} = \frac{N_{DATA} - N_{BKG}}{Eff \times L}$$





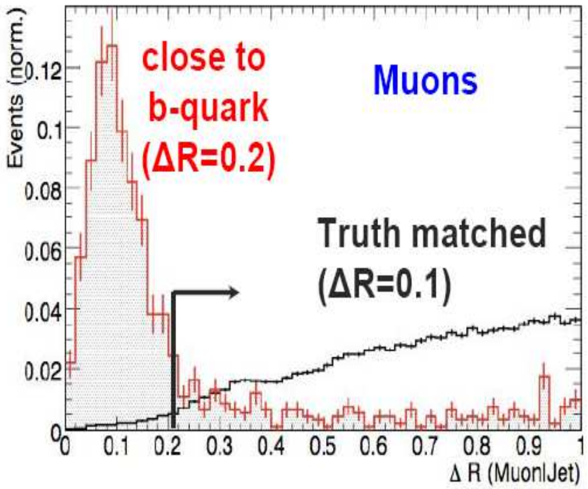
σ_{tt} (DI-LEPTON CHANNEL) L=100 pb^{-1} : 3 METHODS.

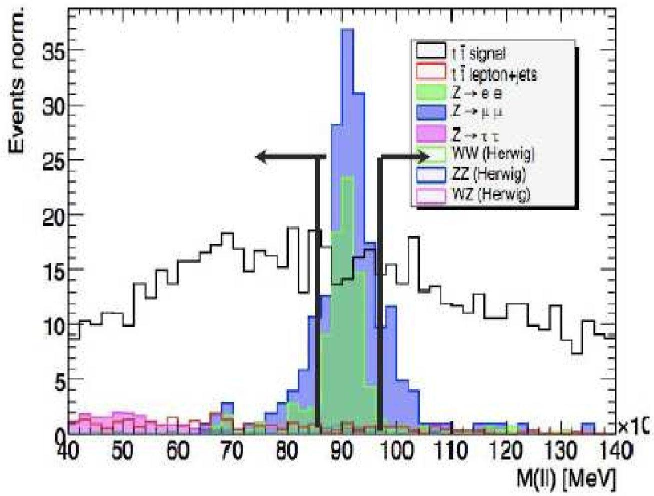
2 high p_T identified leptons (e/μ): opposite signed and isolated.
MAIN BACKGROUNDS:
Z→ee/μμ/ττ,(57%) ttbar(semileptonic)(17%)
W(→e/μ+ν)+jets, WW,WZ,ZZ,single top.



"CUT & COUNT" METHOD: E_t^{miss} > 30 GeV, 85 < M_{ll} <96 GeV

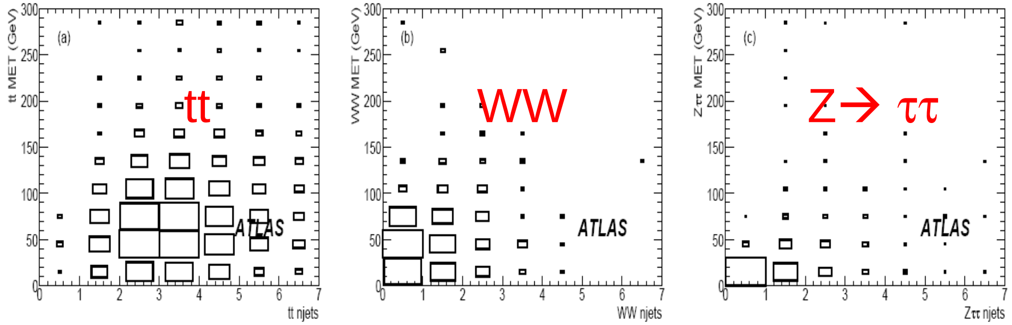
dataset	$e\mu$	ee	$\mu\mu$	all channels
$t\bar{t}$ (signal)	555	202	253	987
ε [%]	**20.2**	**14.7**	**18.3**	**17.9**
Total bkg.	86	36	73	228
S/B	6.3	5.6	3.4	4.3

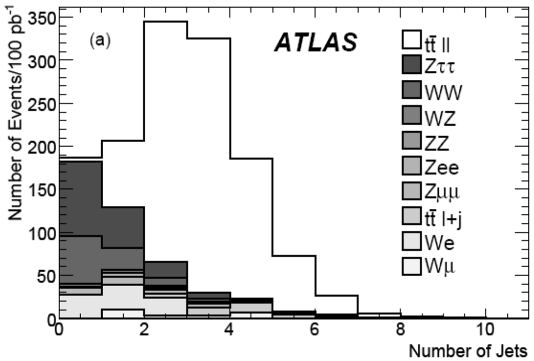




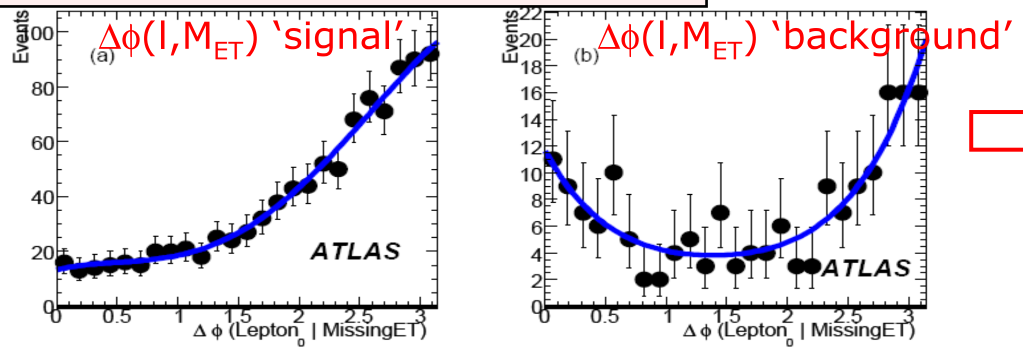
σ_{tt} (DI-LEPTON CHANNEL) L=100 pb^{-1} : SYSTEMATICS.

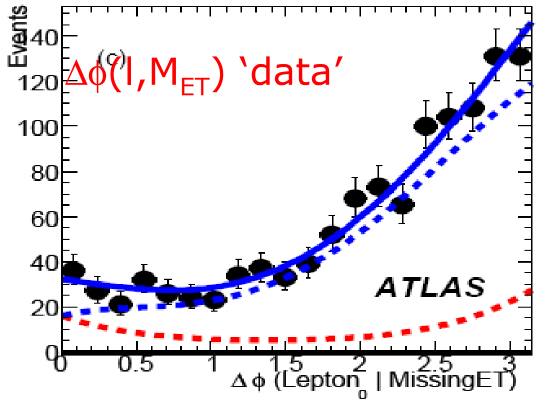
"INCLUSIVE TEMPLATE" METHOD: 2D binned likelihood: Et^{miss} vs N_{jets}





"LIKELIHOOD METHOD": $\Delta\phi(l,Et^{miss})$

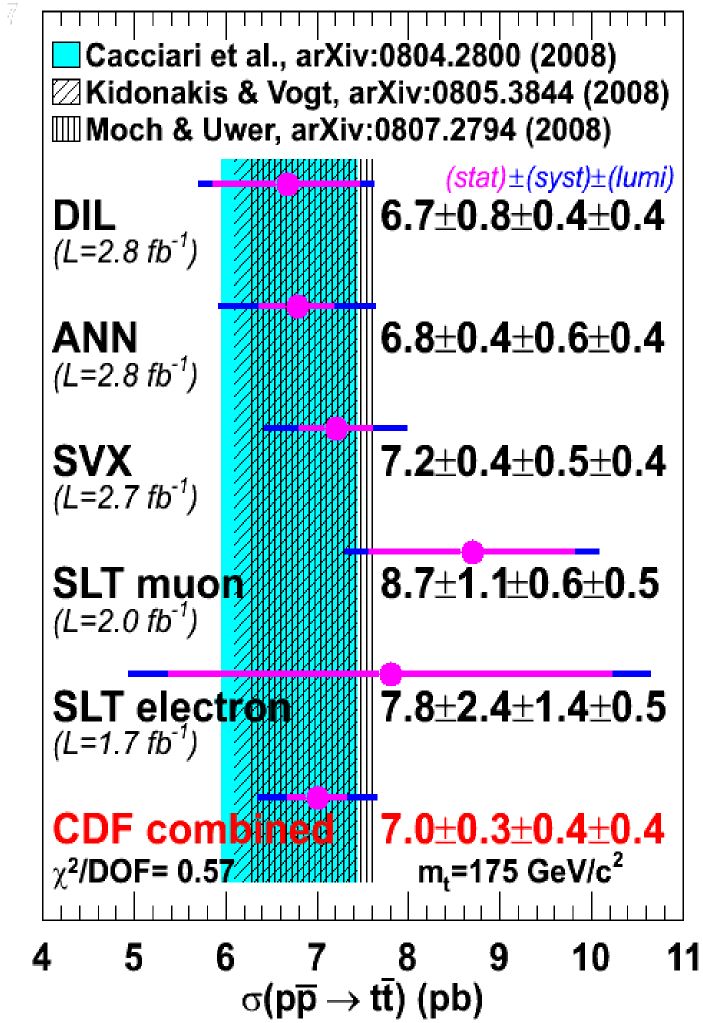




- Systematic uncertainties
  - Jet energy scale largest contributor
  - Others: PDF, ISR/FSR, shape of fit function.

σ_{tt} ATLAS PROSPECTS L=100 pb^{-1} VS CDF L=2.8 fb^{-1}

Δσ/σ(stat)	Δσ/σ(syst)	Δσ/σ(pdf)	Δσ/σ(lum)
Di-lepton "Cut & Count"			
4%	$^{+5}_{-2}$ %	2%	20-30%
Di-lepton Template			
4%	±4%	2%	20-30%
Di-lepton Likelihood			
5%	$^{+8}_{-5}$ %	0.2%	20-30%
Single lepton Likelihood			
7%	15%	3%	20-30%
Single lepton Counting			
3%	16%	3%	20-30%



CDF L=2.8 fb^{-1}

Δσ/σ(stat)=4% Δσ(syst)/σ=6% Δσ(lumi)/σ=6%

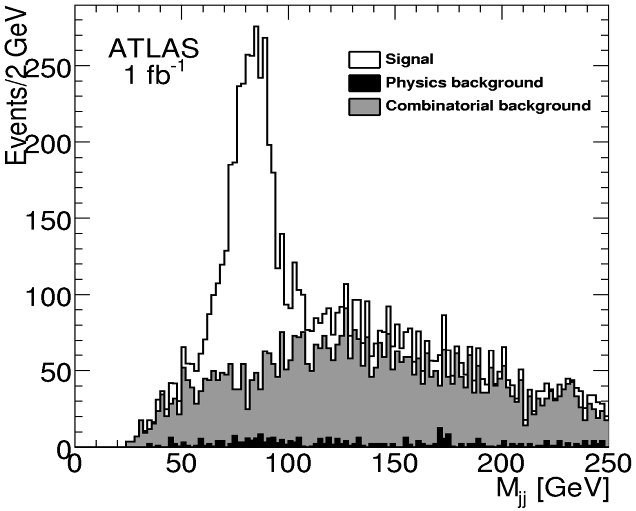
Δσ/σ=9%

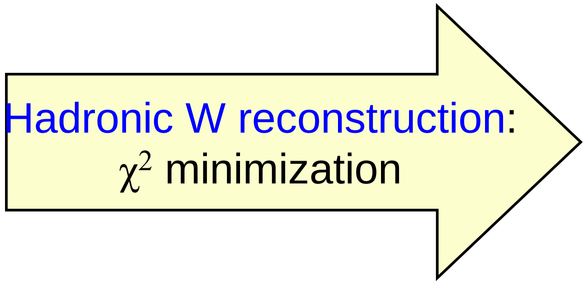
M_{TOP} ATLAS L=1fb^{-1} → χ^2 minimization method (I)

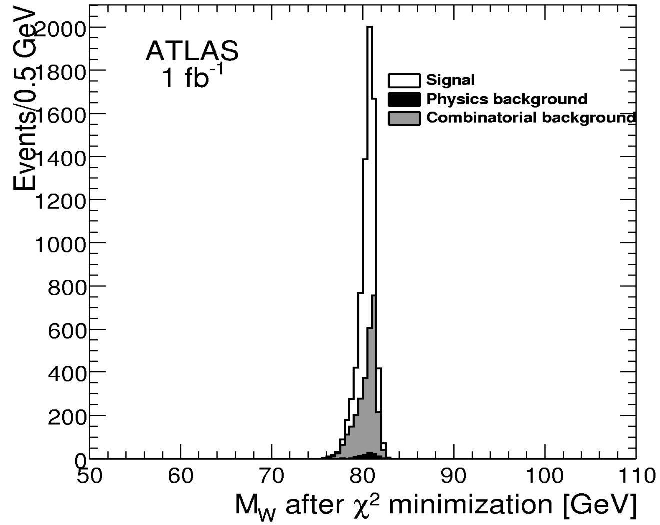
- Single lepton channel: at least 4 jets with p_T >40 GeV, 2 b-jets.
- Select the hadronic W candidate within a mass window of ±3 $\sigma(M_{jj})$ (30 GeV) around the peak value of the dijet mass distribution in events with only two light jets.
- For each preselected light jet pair in the event, perform a χ^2 minimization:

$$\chi^2 = \frac{(M_{jj}(\alpha_{E_{j1}}, \alpha_{E_{j2}}) - M_W^{PDG})^2}{(\Gamma_W^{PDG})^2} + \frac{(E_{j1}(1-\alpha_{E_{j1}}))^2}{\sigma_1^2} + \frac{(E_{j2}(1-\alpha_{Ej2}))^2}{\sigma_2^2} \qquad \sigma_E = E * \sqrt{(a^2/E) + b^2}$$

- For each event, the hadronic W boson candidate is taken as the pair of light jets with minimum χ^2 .

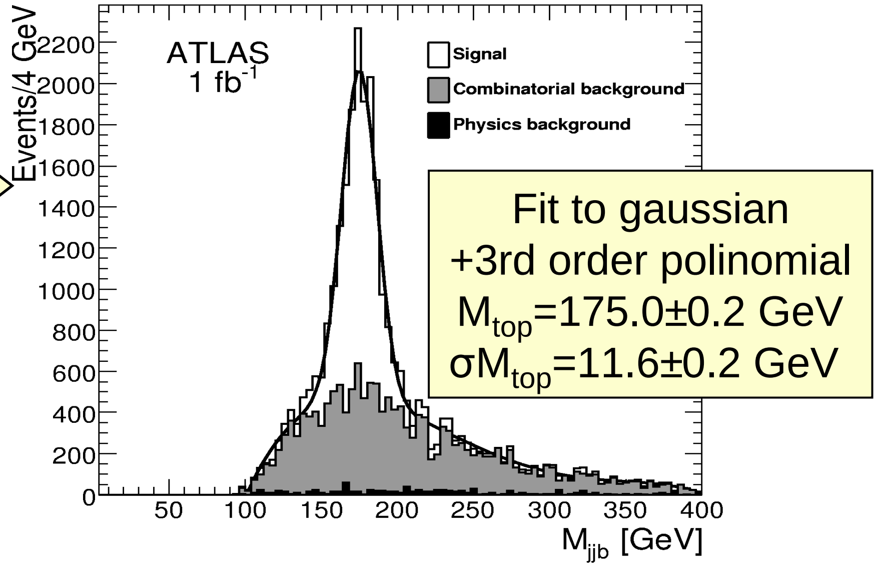






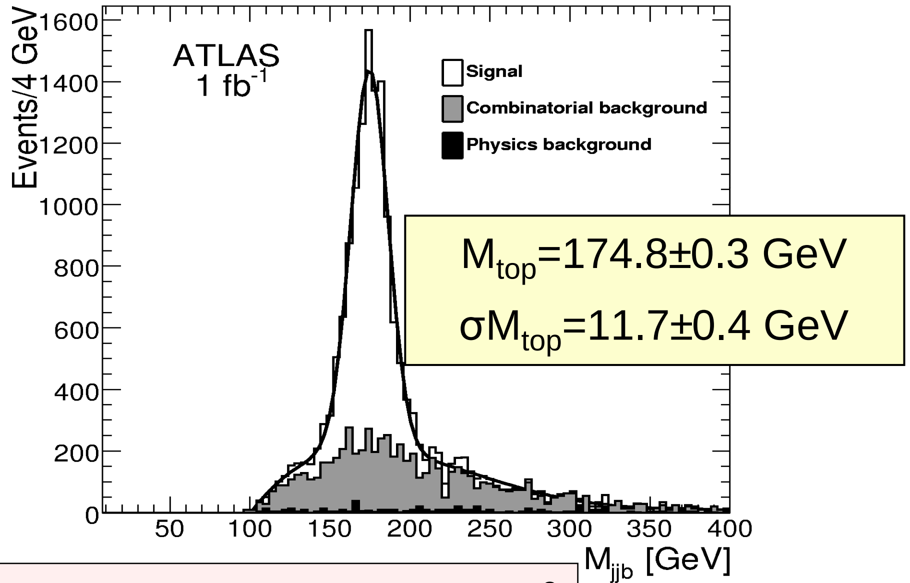
M_{TOP} ATLAS $L=1fb^{-1}$ → χ^2 minimization method (II)

Hadronic Top reconstruction:
b-jet closest to the hadronic W boson



- Combinatorial background rejection:
  - Increases the purity of M_{TOP} for high luminosity.
  - C1: $M(W_{had},b_{lep}) > 200$ GeV
  - C2: $M(\text{lepton},b_{lep}) < 160$ GeV

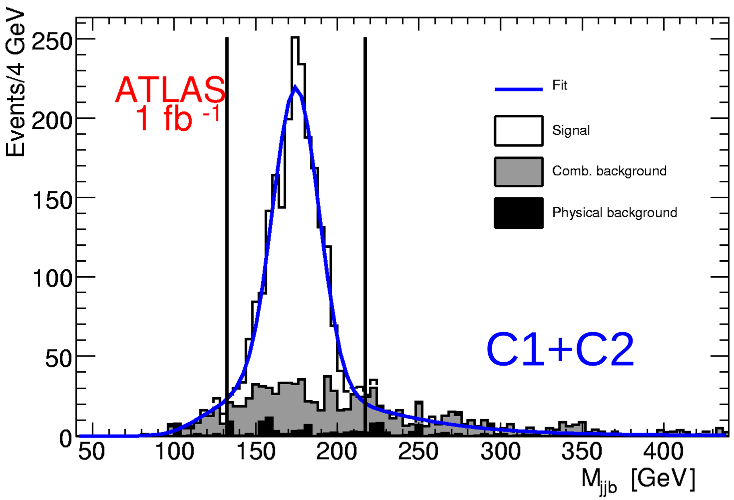
	Efficiency(%)	Top Purity
χ^2 Method.	2.22±0.03	40.2±0.8
+C1+C2	1.25±0.04	56.5±0.8



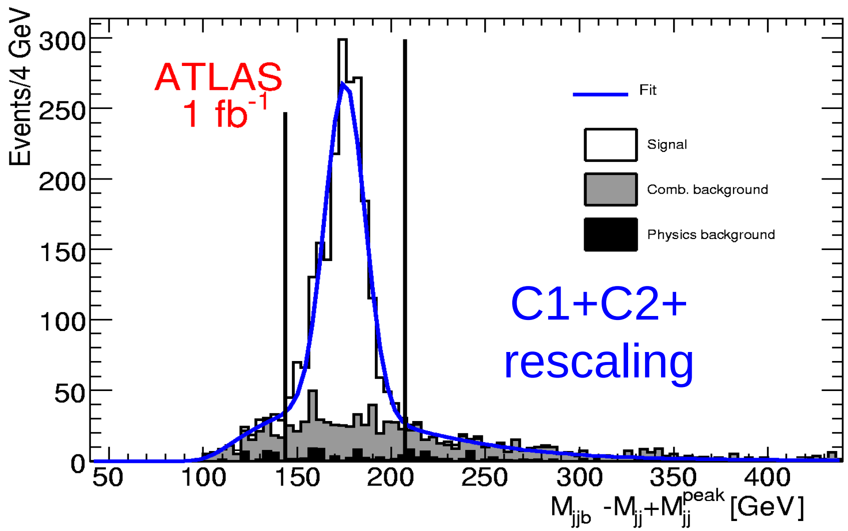
MC tt-bar with $M_{TOP}=175$ GeV/c^2

M_{TOP} ATLAS $L=1fb^{-1}$ → Geometric method

- Hadronic W boson reconstruction:
  - Choose the light jet pair with the smallest angular distance $\Delta R = \mathrm{sqrt}(\Delta\eta^2 + \Delta\varphi^2)$
  - Keep only events within a mass window of $\pm\sigma_{Mjj}$ (20 GeV) the peak value of the Mjj distribution.
- Rescaling: Mjjb –Mjj+Mjj^{peak} to remove at 1st order the contribution of light jets to the top mass resolution.



Fit to gaussian + threshold function
M_{top}=174.6±0.5 GeV σM_{top}=11.1±0.5 GeV

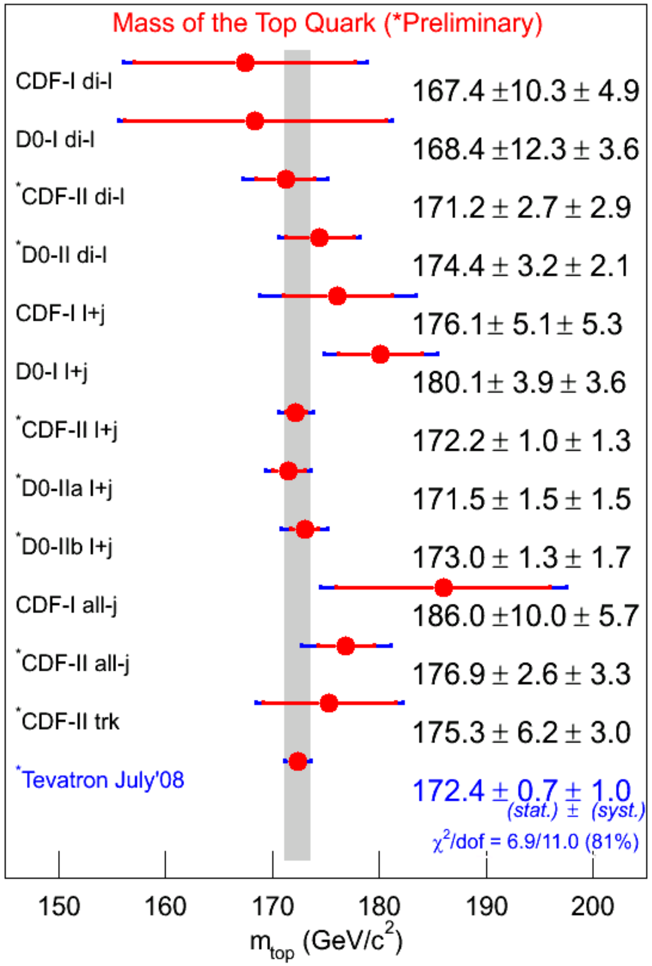


M_{top}=175.4±0.4 GeV σM_{top}=10.6±0.4 GeV

MC tt-bar with M_{TOP}=175 GeV/c^2

CONCLUSIONS M_{TOP} ATLAS L=1fb^{-1} vs TEVATRON

- Two methods developed:
  - The best estimator of M_{TOP} is the invariant mass of the hadronic top candidate in the single lepton channel.
- In-situ determination of the light jet energy scale using the sample of hadronic W candidate extracted from the tt-bar sample.
  - The systematic uncertainty will come from the b-jet energy scale, measured using data driven methods.
- In high luminosity scenario:
  - Stringent selection requirements to reduce combinatorial background and thus systematics.
- With L=1 fb^{-1} , if JES uncertainty is in the range 1-5% then a precision of 1-3.5 GeV should be achievable in M_{TOP} .
- RUN I & II TEVATRON (CDF+DØ) arXiv:0898.1089v1

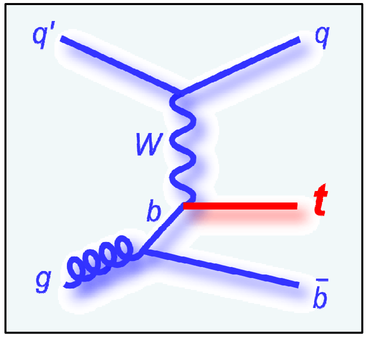


$$M_{TOP} = 172.4 \pm 1.2 \text{ GeV/c}^2$$

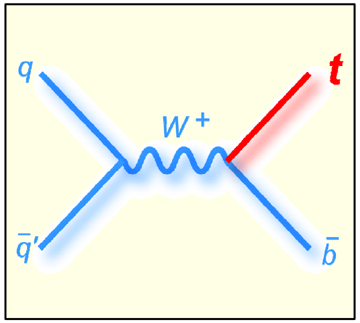
$$\Delta M_{TOP}\ /M_{TOP} \sim 0.7\%$$

SINGLE TOP PRODUCTION: FROM TEVATRON TO LHC

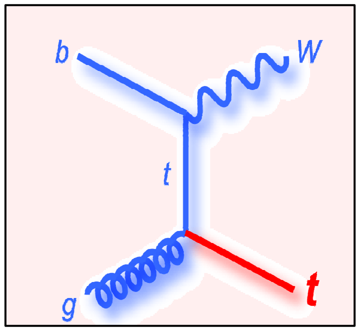
t-channel



s-channel



Wt

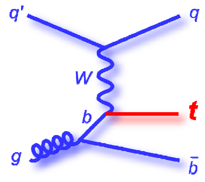
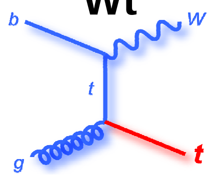


- Tevatron presented evidence for electroweak single top production:
  - DØ: L=0.9 fb^{-1} → 3.4σ (Phys.Rev.Lett.98:181802,2007.)
  - CDF: L=2.7 fb^{-1} → 3.8 σ (5 σ expected significance) (Neural Network, most sensitive analysis)
  - **(see John Parsons ´s contribution Parallel Session A. Parallel Session A. CP violation in the SM and beyond-I)**
  - 5σ observation by Tevatron is around the corner: but measurements statistically limited.
- LHC will have higher statistics to study top properties and to perform new physics searches: charged Higgs, W´etc.

	$\sigma_{TEVATRON}$	σ_{LHC}		
t-channel	1.98±0.25 pb	246±12 pb (1)	x 120	Similar S/B
s-channel	0.88±0.11 pb	11±1 pb (1)	x 11	S/B / 10
Wt	~0.1 pb (NOT USED)	66±2 pb (2)	x 660	S/B x 6
Top pairs	6.7±0.8 pb	833±100 pb (3)	x 120	
W+jets	~2 nb	~20 nb	x 10	

(1) Sullivan,Z.,PRD 70 (2004)114012, Campbell et al. PRD 70(2004)094012
(2) Campbell, Tramontano, Nucl. Phys. B726(2005) 109-130
(3) Moch and Uwer (Phys. Rev. 2008, D78, 034003 [arXiv : 0807.2794])

EVENT YIELD: Sequencial CUT versus MVA ($1fb^{-1}$)

	t-channel  1 high P_T b-jet 1 lepton, missing E_T 2 forward jets: b,j		**Wt**  1 high P_T b-jet 1 lepton, missing E_T 2 light jets	
	"Cut"	**BDT**	"Cut"	**BDT**
Signal ST	1460±56	**542**	639.0±19.5	**85.5 ±7.1**
Other ST	148 ±9	**18**	1417.6 ± 50.0	**13.3 ±4.5**
Top pairs	2816±65	**184**	3022.0 ± 58.2	**113.5 ±10.9**
W+jets +Wbb	942±37	**211**	3384.0 ± 80.9	**99.4 ± 9.0**
Total Bkg	3906±75	**413**	7823.6 ± 111.5	**226.2 ± 14.9**
S/B	37%	**1.31**	8.1%	**37%**
S/√B	23.4	**26.6**	7.2	**5.6**

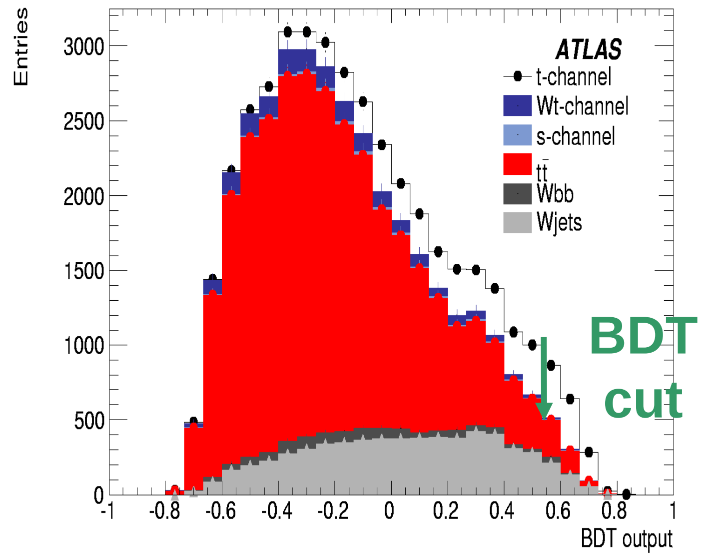
- t channel is the most promising one for single top observation at the LHC.
- Statistical significance is good for t-channel and Wt
- S/B is better than unity: t-channel and BDT.

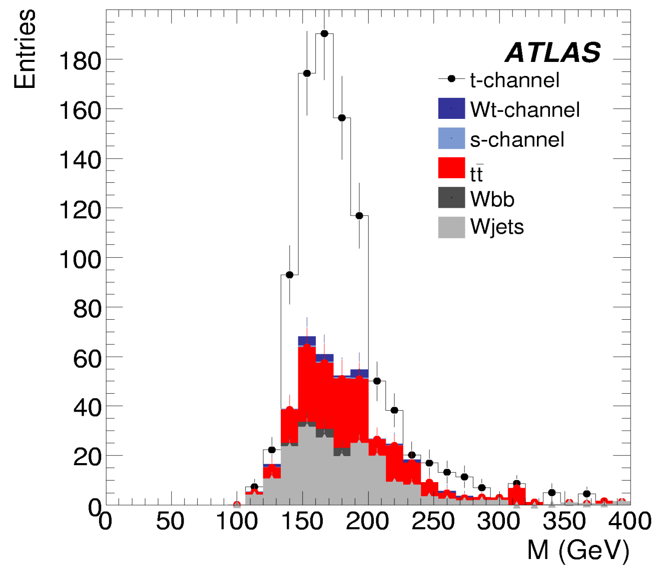
T-channel: MVA technique BDT

- M.V.A techniques to reduce W+jets background at low p_T and tt-bar background at high p_T
- Specific BDT against tt-bar with variables less sensitive to JES, for instance:
  - p_T and cos(θ*) of leading jet
  - ΔR(j1,j2),ΔR(j1,lep),ΔR(j1non-b,l)

Source	δσ/σ cut-based	δσ/σ BDT
Stat. error	**5.0%**	**5.7%**
MC stat.	**6.5%**	**7.9%**
Luminosity	18.3%	**8.8%**
B-tag efficiency	18.1%	**6.6%**
Jet energy scale	21.6%	9.9%
Lepton ID, trigger	**2.3%**	**1.8%**
Theory (xs, PDF, ISR/FSR…)	28.1%	13.5%
Total 1(10) fb^{-1}	**45% (22%)**	**22% (10%)**

→Δ|Vtb|/|Vtb|~12%

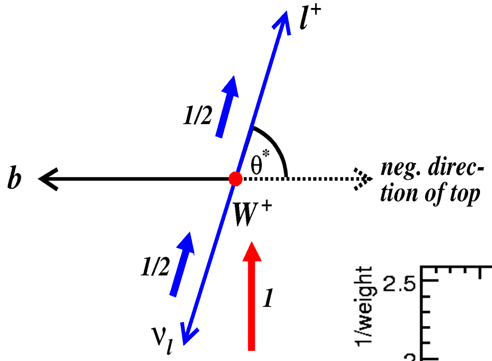




Leptonic Top mass M(lνb)

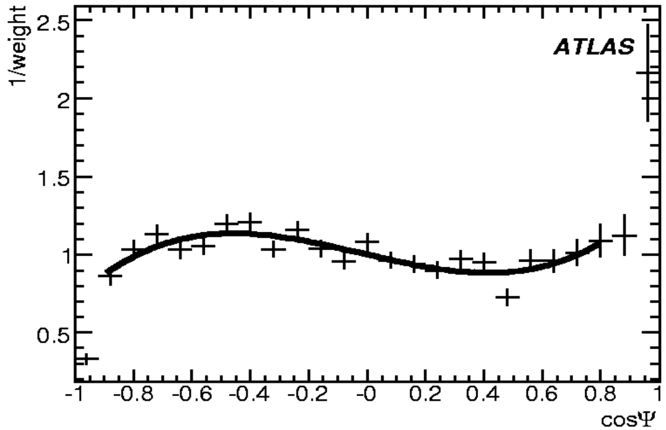
Top quark decay: W polarization measurements.

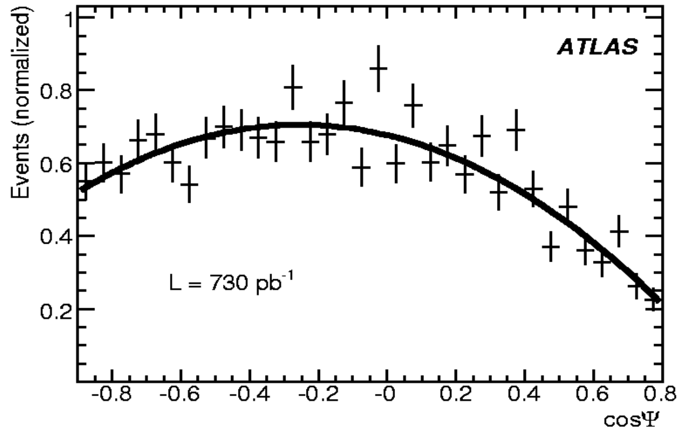
- F_0,F_- and F_+ := fractions of W-bosons produced from Top decays with the 3 helicity states: “longitudinal”, “right-handed” and “left-handed” ($F_0+F_-+F_+=1$)



$$\boxed{\frac{1}{N}\frac{dN}{d\cos\psi}=\frac{3}{2}\left[F_0\left(\frac{\sin\Psi}{\sqrt{2}}\right)^2+F_L\left(\frac{1-\cos\Psi}{2}\right)^2+F_R\left(\frac{1+\cos\Psi}{2}\right)^2\right]}$$

SM: F_0=0.7 F_L=0.3 F_R=0



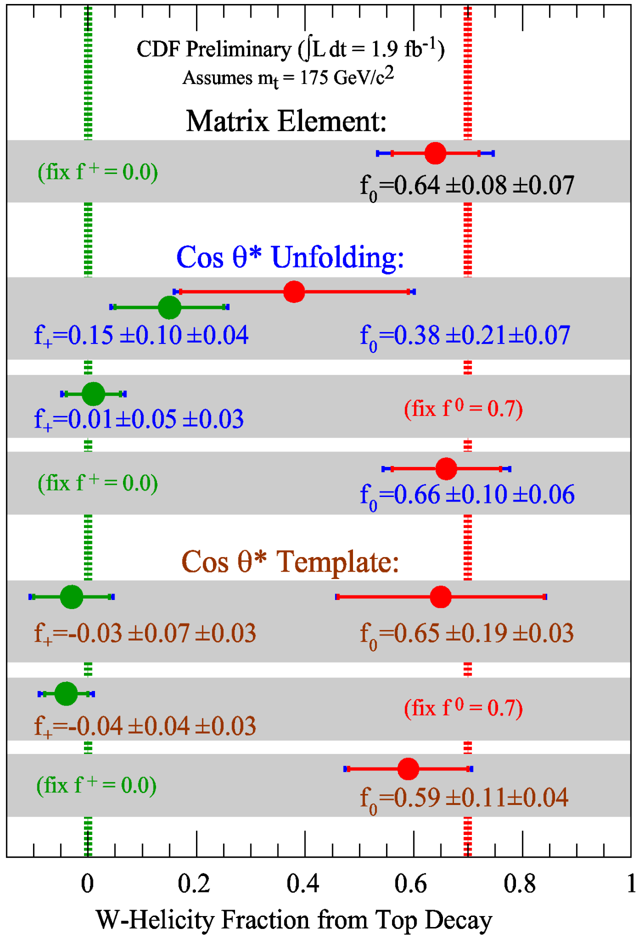


Fit 3rd pol. -0.9<cosΨ<0.9 → derive event-by-event correcting weight

- Correction to recover parton level after background substraction is necessary.
- Particle radiation, quark fragmentation and hadronization, and final event reconstruction dominate the resolution of the reconstructed objects in the decay t→W(→lν)b

W polarization: ATLAS prospects vs TEVATRON status.

ATLAS prospects L= 1 fb^{-1}			
Source of uncertainty	F_L	F_0	F_+
Factorisation	0.000	0.001	0.001
Structure function	0.003	0.003	0.004
ISR	0.001	0.002	0.001
FSR	0.009	0.007	0.002
b-fragmentation	0.001	0.002	0.001
Hadronization scheme	0.010	0.016	0.006
Pile-up (2.3 evt)	0.005	0.002	0.006
M_{top} (2 GeV)	0.015	0.011	0.004
b-tagging efficiency (5%)	0.007	0.002	0.005
b-jet energy scale (5%)	0.02	0.002	0.002
S/B scale (20%)	0.004	0.002	0.001
Total systematic	0.03	0.02	0.02
Total statistical	0.02	0.04	0.02
Expected precision	12%	5%	0.03



CDF Combination L=2 fb^{-1}

$F_0 = 0.66 \pm 0.16 \rightarrow \Delta F_0/F_0 \sim 24\%$

$F_+ = -0.03 \pm 0.07$

W polarization and anomalous Wtb couplings.

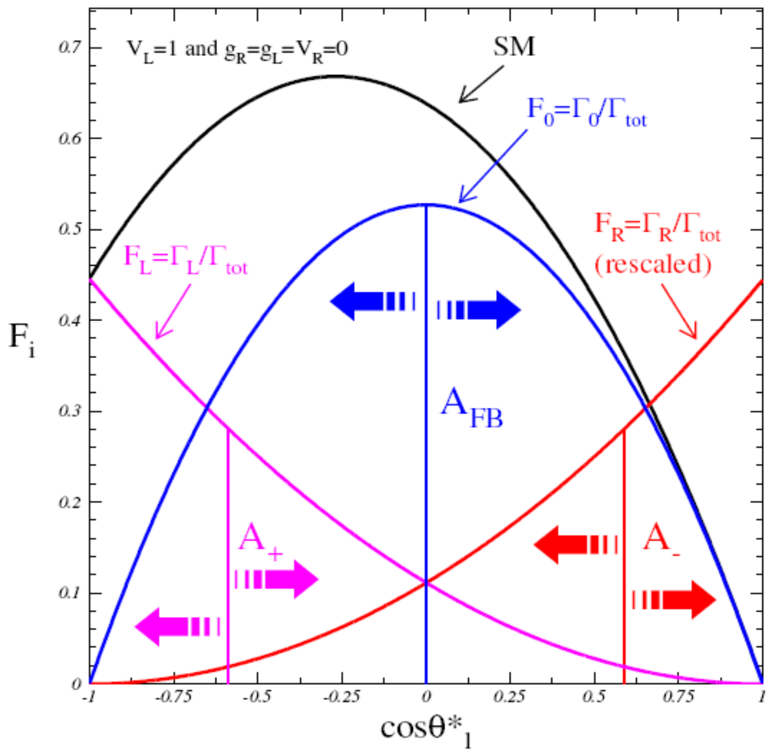
$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}(V_L P_L + V_R P_R)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}(g_L P_L + g_R P_R)tW_{\mu}^{-} + h.c.$$

Phys. Rev. D67 (2003) 014009; Eur. Phys. J. C50 (2007) 519

- W polarisation sensitive to new anomalous couplings (V_L, V_R, g_L, g_R)
  - (taken real if CP is conserved)
- In SM: $V_L \equiv V_{tb} \approx 0.999$ and (V_R, g_L, g_R) vanish
- Variables more sensitive to anomalous couplin
  - $\rho_{R,L} \equiv F_{+,-} / F_0$
- Simpler variables:

$$A_t = \frac{N(x>t) - N(x<t)}{N(x>t) + N(x<t)}$$

$$\begin{aligned} A_{\mathrm{FB}} &= \frac{3}{4}\left[F_R - F_L\right], \\ A_+ &= 3\beta\left[F_0 + (1+\beta)F_R\right], \\ A_- &= -3\beta\left[F_0 + (1+\beta)F_L\right], \end{aligned}$$



Z

A_{FB} [z=0] $A_{\pm}$ [$z=\mp(2^{2/3}-1)$]

ATLAS PROSPECTS FOR ANOMALOUS Wtb COUPLINGS

- L= 1 fb^{-1} → Systematic uncertainties dominate all measurements:
  - Jet Energy Scale, M_{TOP}, background method, ISR+FSR, MC generator, Pile-up…

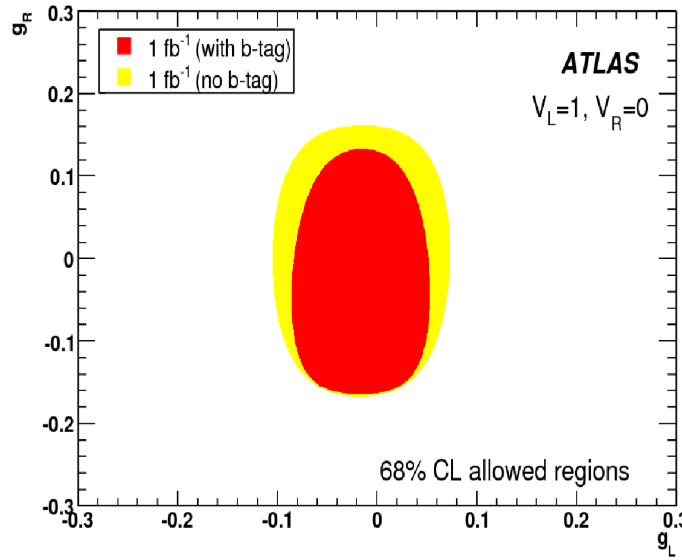
Source	ρ_L	ρ_R	A_{FB}	A_+	A_-
Expected value	0.453	0.004	0.229	0.542	0.830
Total systematic	0.163	0.012	0.033	0.052	0.027
Statistical error	0.048	0.007	0.026	0.028	0.014
			19%	11%	4%

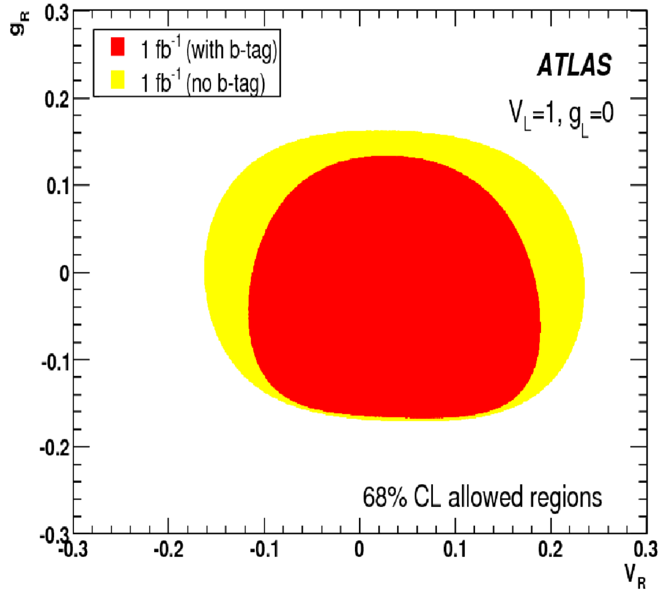
•ρ_L, ρ_R A_{FB} A_+ A_- set bounds to (V_L,V_R,g_L,g_R) using TopFit program

•J.A. Aguilar-Saavedra et al. Eur.Phys. J. C50: 519-533,2007.

•Expected precisión in anomalous couplings:

- $\Delta V_R/V_R \approx 0.15$, $\Delta g_L/g_L \approx 0.07$, $\Delta g_R/g_R \approx 0.15$



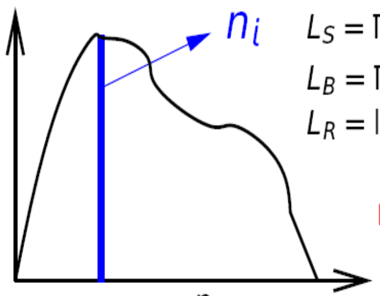


TOP QUARK FCNC DECAYS

- SM: Top quark FCNC decays highly suppressed O(10^{-14})
- BSM: SUSY models and Two Higgs doublet models: BR(t→FCNC)~O(10^{-4})

L=1 fb^{-1}	t t→bW(→lν) qγ (=1l,≥2j,=1γ,E_T^{miss})	t t→ bW(→lν)qg (=1l,=3j,E_T^{miss})	t t→ bW(→lν) qZ(→ll) (=3l, ≥2j,E_T^{miss})
N_{evt} (Bkgr) tt-bar,W+jets,Z+jets	650±66	19253±359	125±56
Signal Eff (%)	7.6±0.2	7.6±0.2	2.9±0.1
Discriminating variables	M_t^{FCNC} p^{γ}_T, $M_{b\gamma}$	M_t^{FCNC}, M_{qb},$M_{l\nu j}$,	M_t^{FCNC} M_{ll}^{min}, M_{bZ},

probabilistic analysis:



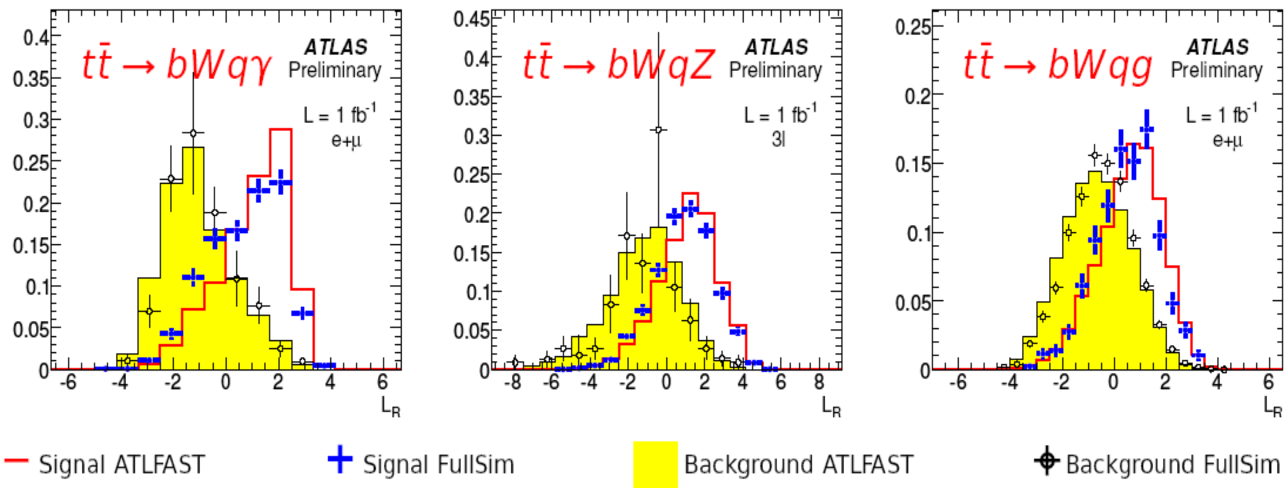
$L_S = \Pi_{i=1}^{N} P_i^{signal}$

$L_B = \Pi_{i=1}^{N} P_i^{back.}$

$L_R = \ln(L_S/L_B)$

$P_i = \frac{n_i}{n_{total}}$

no cut on L_R

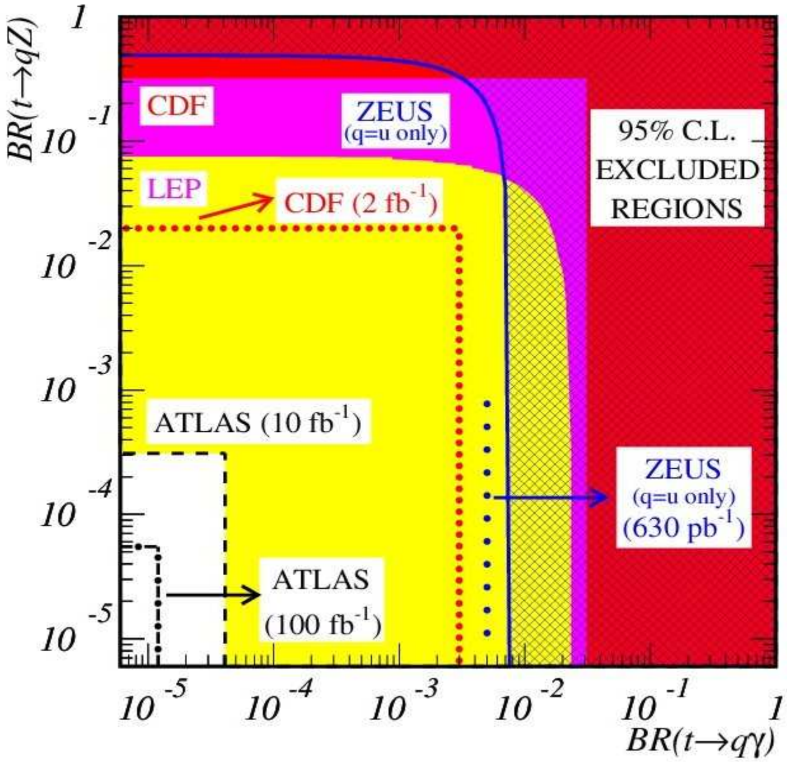


ATLAS prospects for Top quark FCNC decays (L=1 fb^{-1})

- Expected 95% CL limits

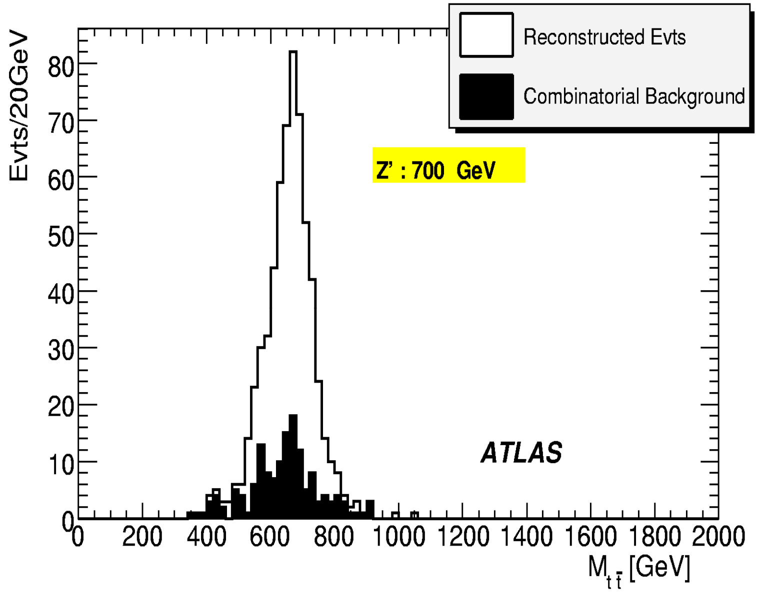
	ATLAS 1 fb^{-1}
BR($t \rightarrow q\gamma$)	10^{-3}
BR($t \rightarrow Zq$)	10^{-3}
BR($t \rightarrow qg$)	10^{-2}

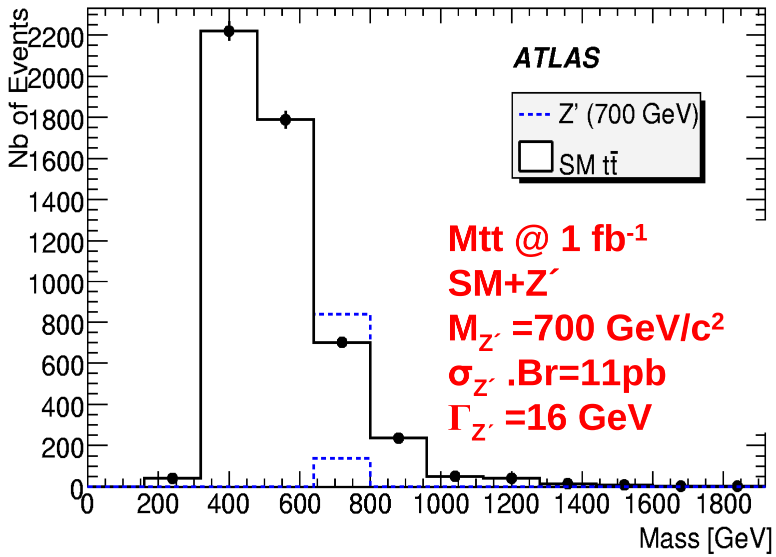
Source	$t \rightarrow q\gamma$	$t \rightarrow qZ$	$t \rightarrow qg$
Jet energy calibration	2%	5%	4%
Luminosity	10%	6%	10%
Top mass	6%	12%	5%
Background σ	7%	12%	15%
ISR/FSR	17%	7%	9%
Pile-up	22%	0%	13%
Generator	4%	14%	4%
χ^2	4%	7%	9%
Total systematic.	32%	25%	27%



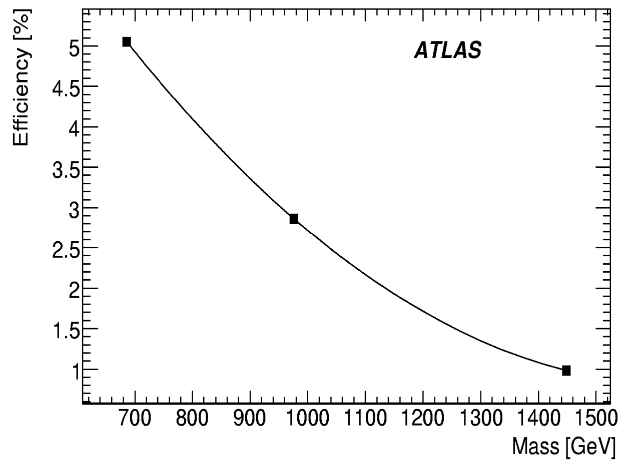
SEARCH FOR tt-bar RESONANCES in ATLAS

- Search for deviations in dσ/dMtt-bar using a counting method with sliding window:
  - Window width is twice the detector resolution.



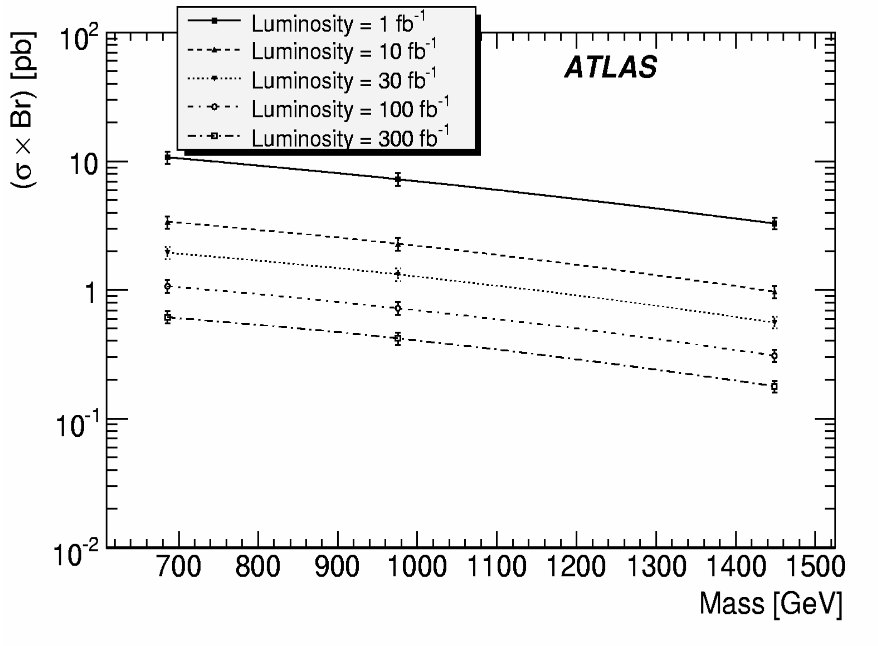


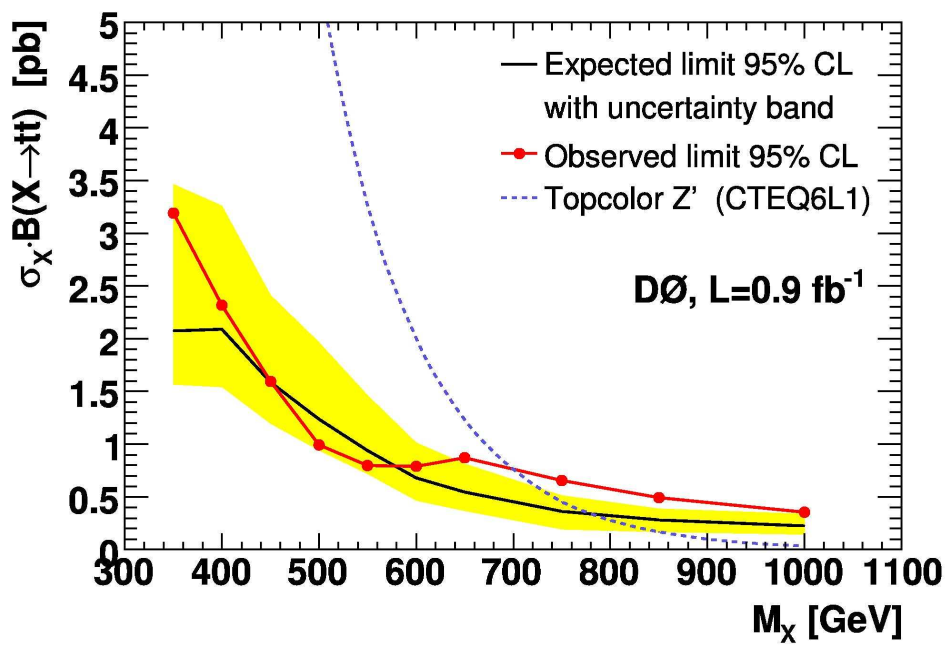
- Standard reconstruction tt-bar efficiency decreases with $M_{Z'}$.
  - At $M_{Z'}$ > 1 TeV, boosted top quarks decaying hadronically produce collimated jets
- New reconstruction techniques for hadronic top “monojets” in development.
  - Access to jet sub-structure with K_T algorithm.
  - Adequate b-tagging performance for high p_T jets.



ATLAS SENSITIVITY TO RESONANT TOP PAIR PRODUCTION.

- 5σ (stat+syst) sensitivity:
  - Limit on $\sigma_{Z'}$ vs $M_{Z'}$
    - $\sigma_{Z'}.Br > 11$ pb for $M_{Z'} = 700$ GeV/c^2 @ L= 1 fb^{-1}
- Main systematic on the discovery potential:
  - The reconstruction efficiency of Z´and tt-bar background.
- Application to a specific model:
  - DØ (CDF): In a top-color-assisted technicolor model, a leptophobic Z´ with $M_{Z'}$ < 760 GeV is excluded @ 95% CL





CONCLUSIONS

- Top Quark physics will play an important role in the early days of data taking of the ATLAS experiment at the LHC.
- With $L=100\ pb^{-1}$
  - σ(tt-bar) can be measured with an uncertainty (5-10)% dominated by systematics, apart from the luminosity uncertainty.
  - ATLAS will get this early data probably at $\sqrt{s}=10$ TeV, or perhaps even lower: prospects are being reevaluated.
  - Moch and Uwer (Phys. Rev. 2008, D78, 034003 [arXiv : 0807.2794])

M_{TOP}(GeV)	σtt (10 TeV) pb	σtt (14 TeV) pb
172.5	401.6	883.90

  - W+jets: roughly, 30% lower cross section.
- With $L=1\ fb^{-1}$:
  - t channel is the most promising one for single top observation at the LHC. Observation with 5σ may be possible.
  - If JES uncertainty is in the range 1-5% then a precision of 1-3.5 GeV should be achievable in M_{TOP} measurement.
  - The study of top properties (W polarization, dσ/dMtt-bar..) may provide a hint of new physics.