Top Cross Section and Properties measurements at LHC

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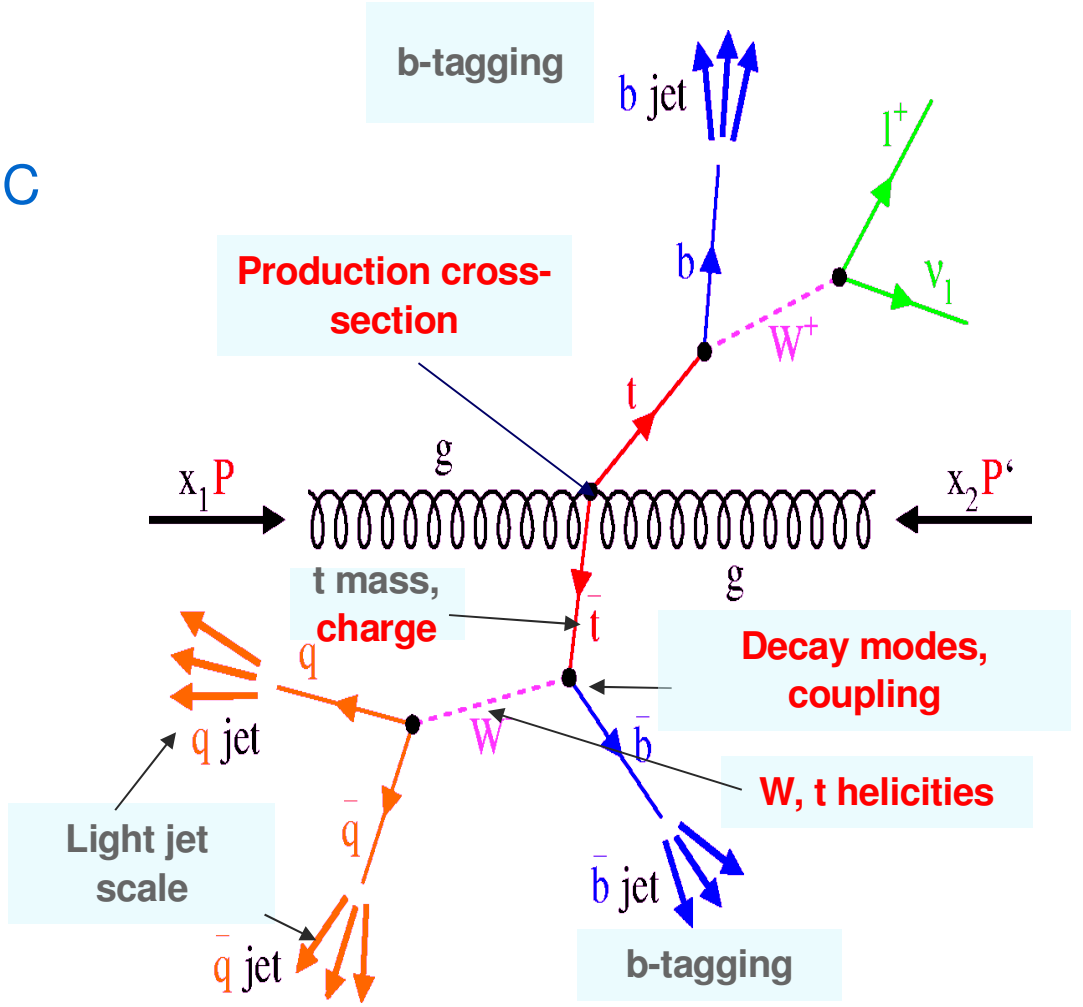
EPS – HEP Conference
Standard Model Electroweak Physics session
Krakow, 16th of July 2009

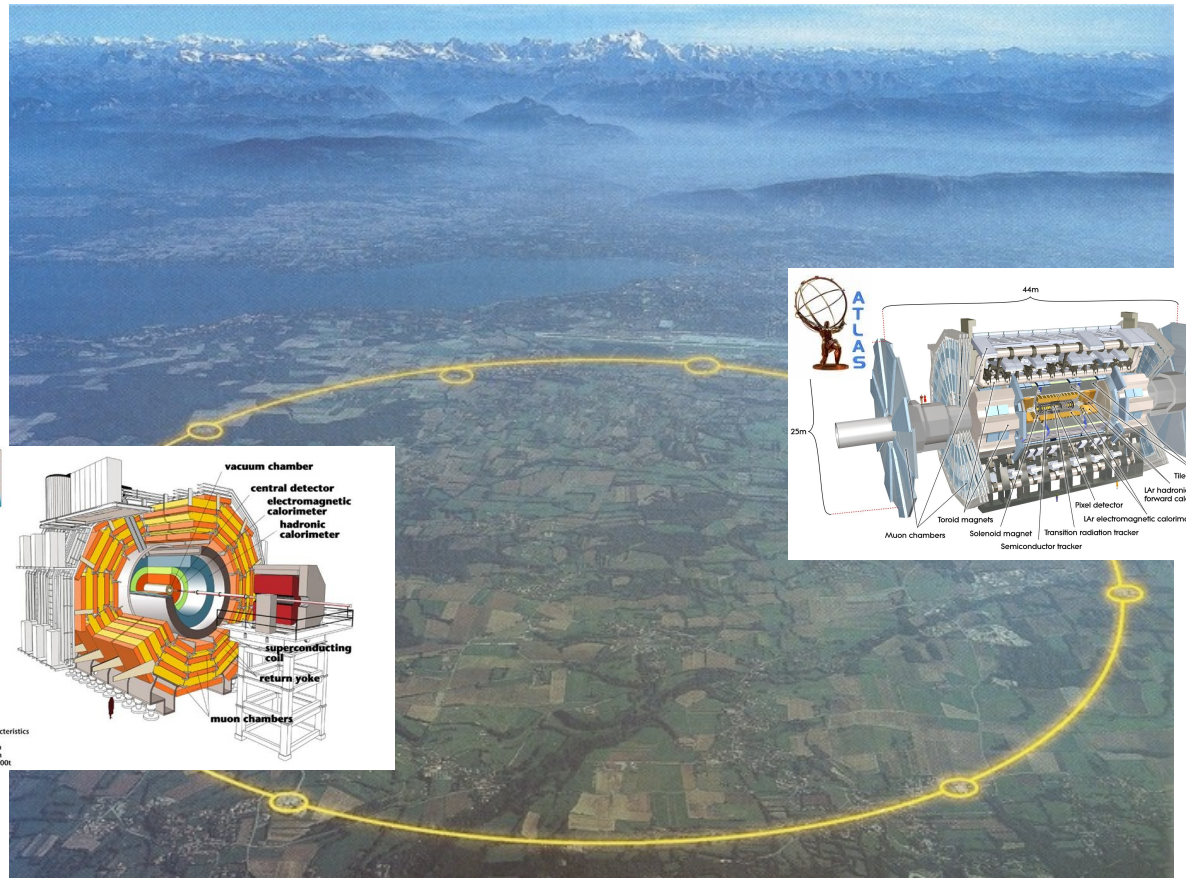
Outline

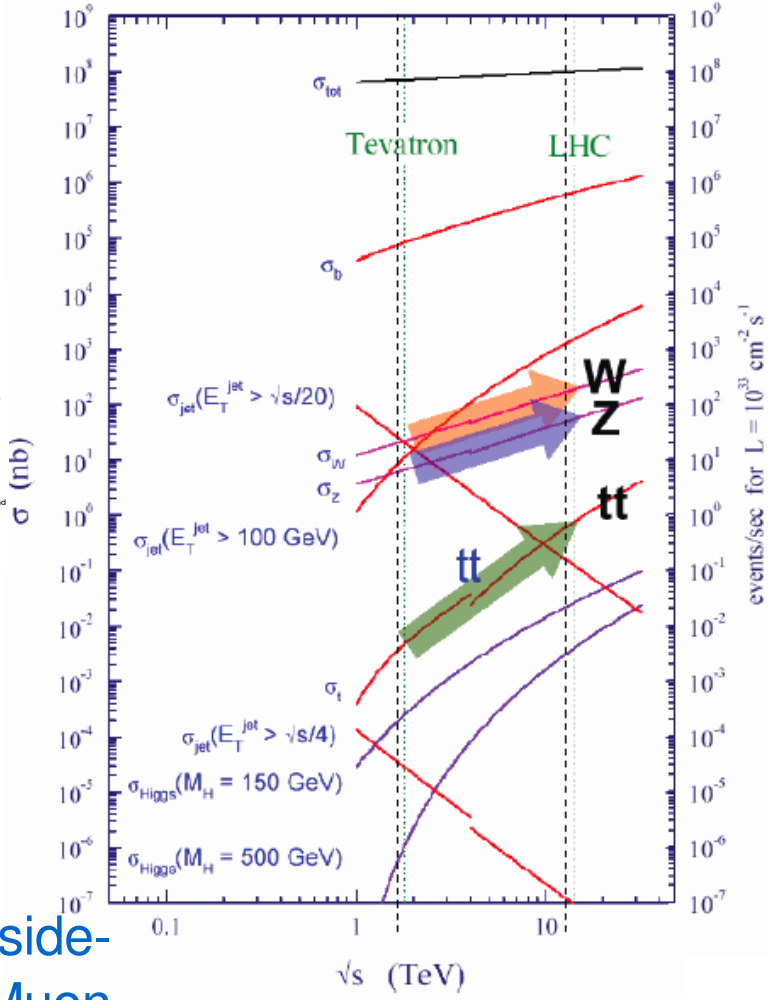
Top Physics in this talk:

- "Rediscovery of the top quark" at LHC
- Cross-section measurement
  - top pair production
  - single top production
- Top Quark Properties
- Charge discrimination
- Spin correlations
- New physics in the top sector:
  - Measurement of V_{tb} test of CKM , evidence of 4^{th} generation.
  - Anomalous Wtb coupling
  - FCNC search : t → qX (X=γ,Z,g)



LHC top quark physics





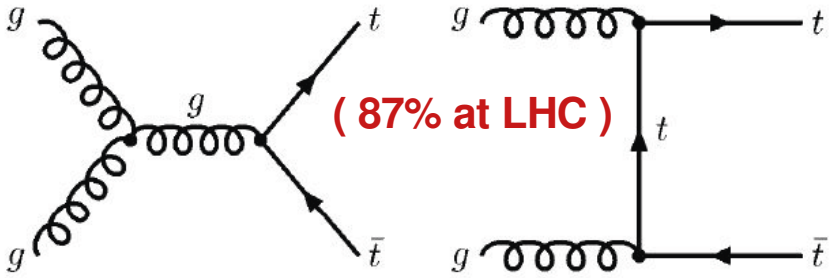
Both are general purpose detectors, with similar inside-out design (Si detector, EM+HAD calorimeters, Muon chambers), but with different points of strength.

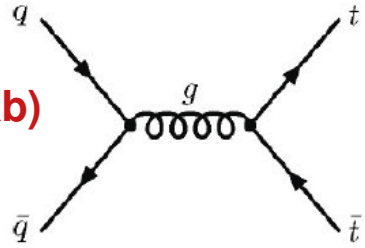
Top pair production is one of the dominant processes after other QCD processes and W/Z+jets

top quark production measurement

Ref: hep-ex 0804.1476

LHC: Gluonic production dominates





(90% at FermiLab)

$\sigma(tt\ 1.96\ TeV)^{approx\ NNLO} = 7.5 \pm 0.5$ pb Tevatron

$\sigma(tt\ 14TeV)^{approx\ NNLO} = 883 \pm 45$ pb

$\sigma(tt\ 10TeV)^{approx\ NNLO} = 401 \pm 25$ pb

$\Rightarrow$ ***1 tt/sec @ L=10^{33}***

Cross section LHC = 100 x Tevatron

Background LHC = 10 x Tevatron

Use of b-tagging not essential to establish ttbar signal at LHC

LHC Single top production

$\sigma(t, 14\ TeV) \cong 320$ pb

dominated by t-channel

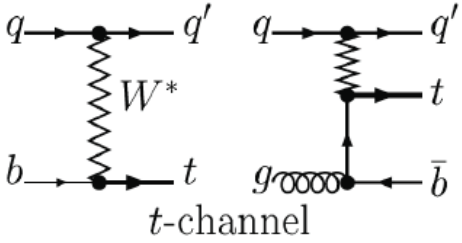
Tevatron: 5σ discovery this year:

D0 (arXiv:0903.0850)

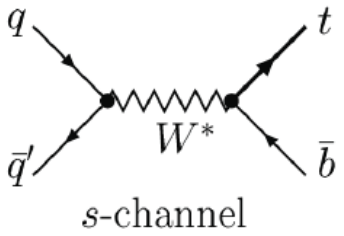
CDF (arXiv:0903.0885)

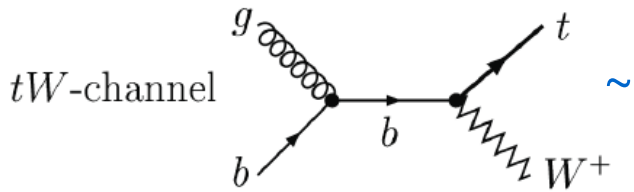
$\sigma(t, 1.96\ TeV) = 3.9 \pm 0.9$ pb

~250 pb



~10 pb





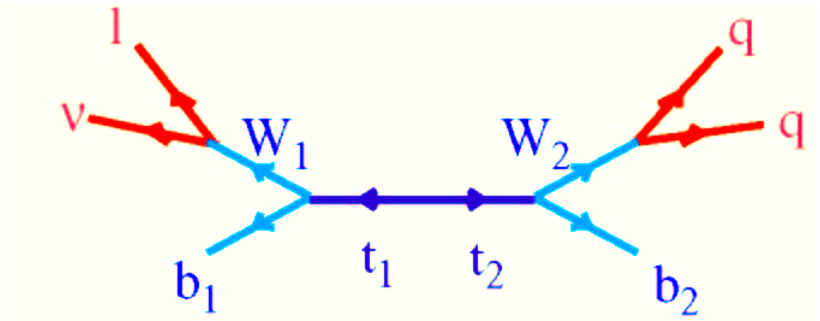
~60 pb

top quark production measurement

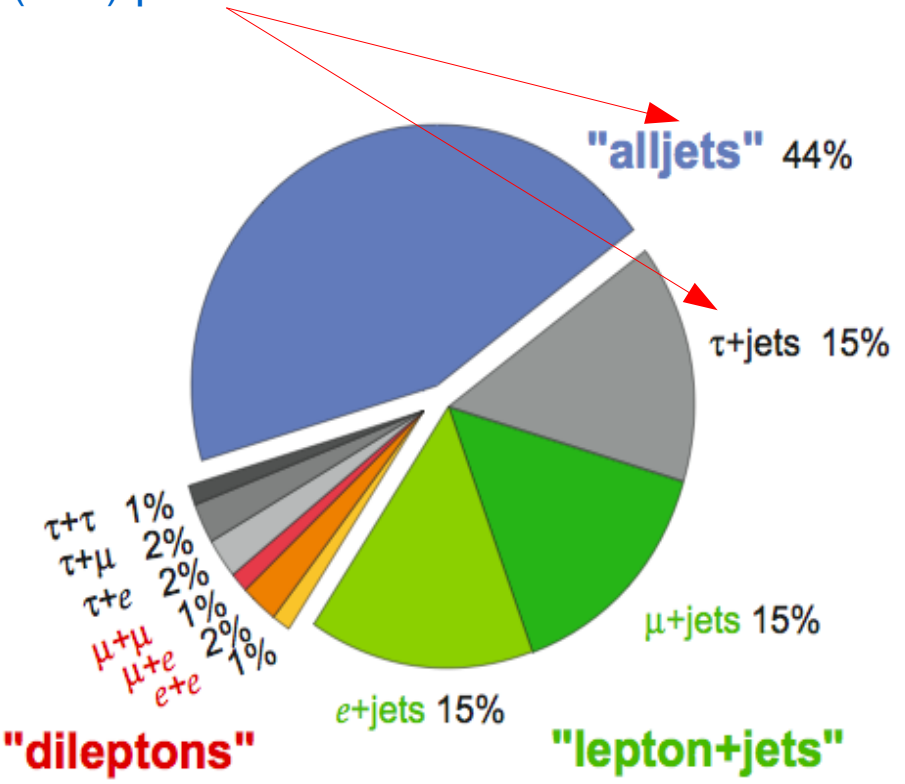
ttbar final states for the cross section measurement

tt final states (l=e,μ)

- Full hadronic **45%**: 6 jets
- Semileptonic **30%**: ℓ + MET + 4jets
- Dileptonic **11%**: 2ℓ +MET + 2jets



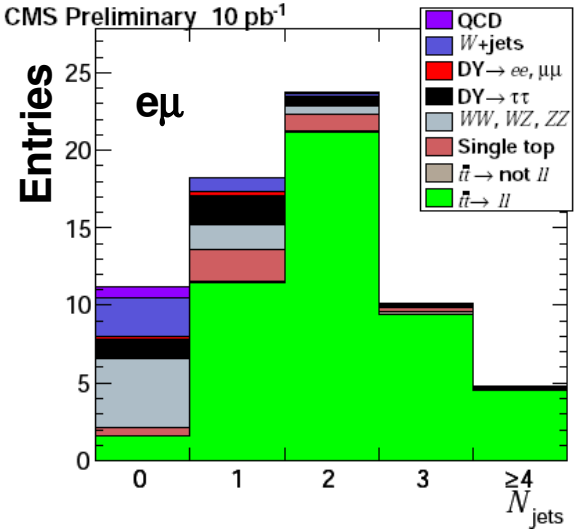
tt final states not considered in the Top rediscovery at LHC in analyses up to O(100) pb^{-1}



Top Rediscovery

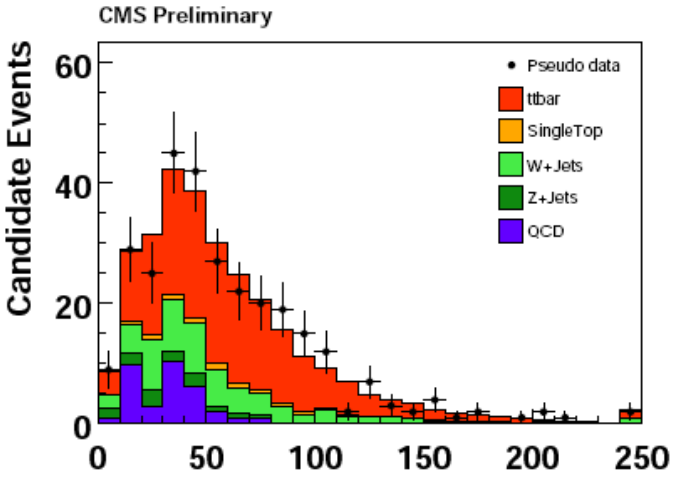
- ttbar production measurement

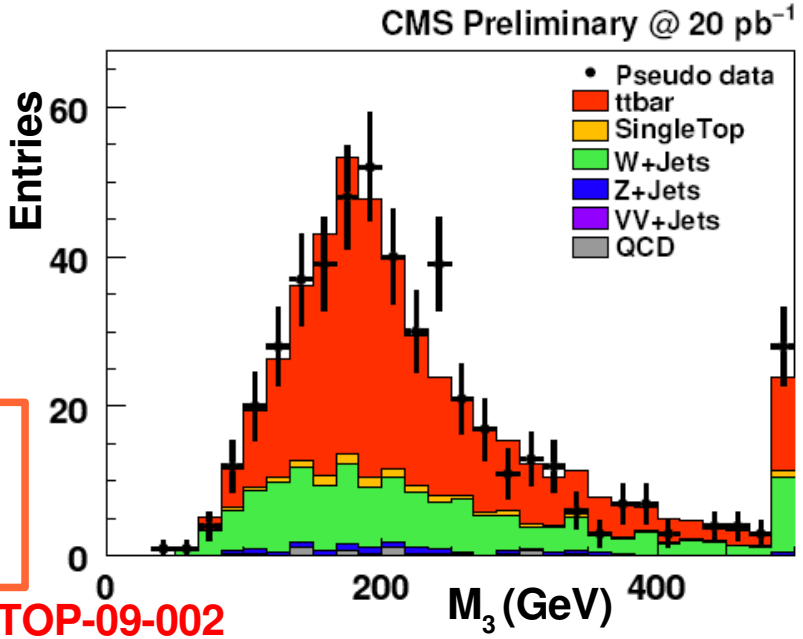
- **10 TeV, 10pb^{-1}** : Di-leptons (eμ): S/B= 9
  - combined uncertainty on xsec ee+eμ+μμ: $15\%_{(stat)} \pm 10\%_{(syst)} \pm 10\%_{(lumi)}$



ee, eμ, μμ:
2 isolated leptons of opposite charge, 2 jets, MET> 30 GeV

- **10 TeV, 20 pb^{-1}** e+jets: S/B= 1.6
  - $\Delta\sigma/\sigma = 23\%_{(stat)} \pm 20\%_{(syst)} \pm 10\%_{(lumi)}$





- **10 TeV, 20pb^{-1}** muon+jets: S: 320 events.

S/B = 1.8 **Template fit of M_3 or η(μ)**

$\Delta\sigma/\sigma = 12\%_{(stat)} \pm 19\%_{(syst)} \pm 10\%_{(lumi)}$

1 muon,
4 jets,
no b-tagging

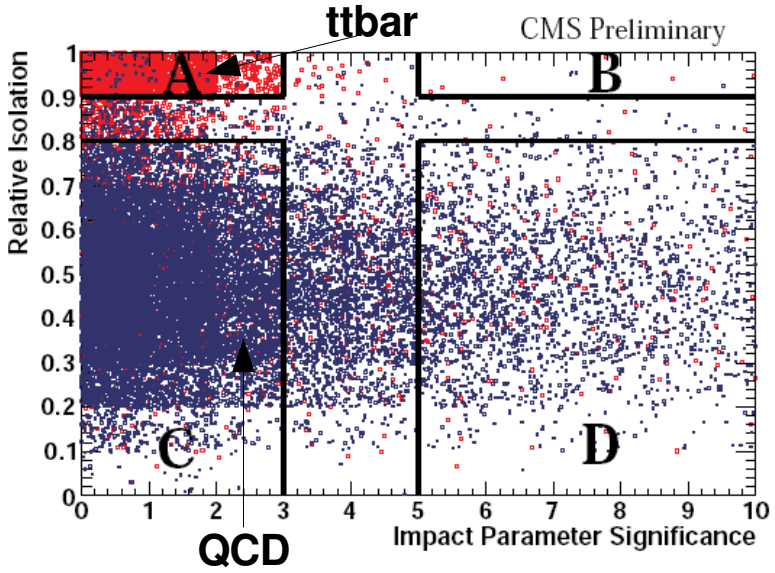
Ref: CMS-PAS-TOP-09-004, CMS-PAS-TOP-09-003, CMS-PAS-TOP-09-002

Top Rediscovery

- ttbar production measurement at 10 and 14 TeV

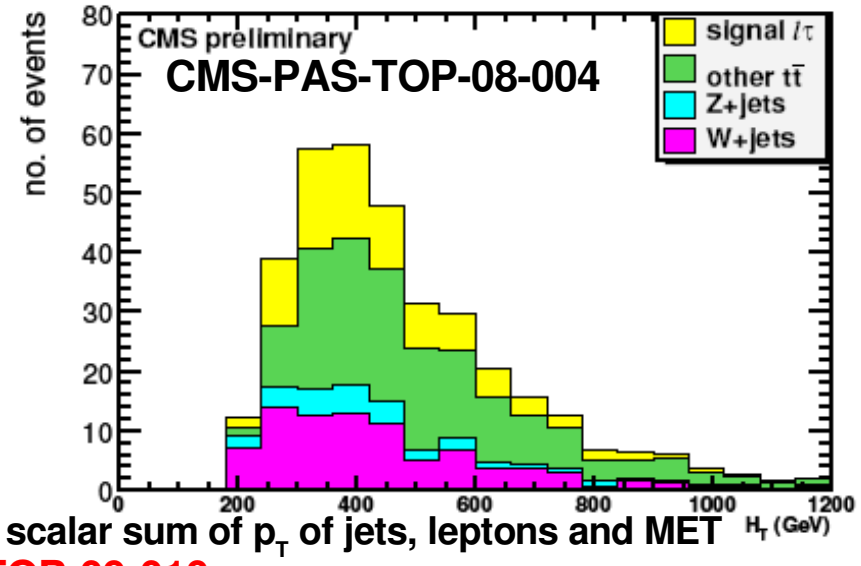
- **10 TeV, 20pb^{-1}** muon+jets: S: 390 events.
  S/B = 2.0 BDT analysis, data driven estimation of the QCD.
  $\Delta\sigma/\sigma = 9\%_{(stat)} \pm 22\%_{(syst)} \pm 10\%_{(lumi)}$

μ+jets:
TMVA BDT analysis
1 isolated muon from the IP, 4 jets.

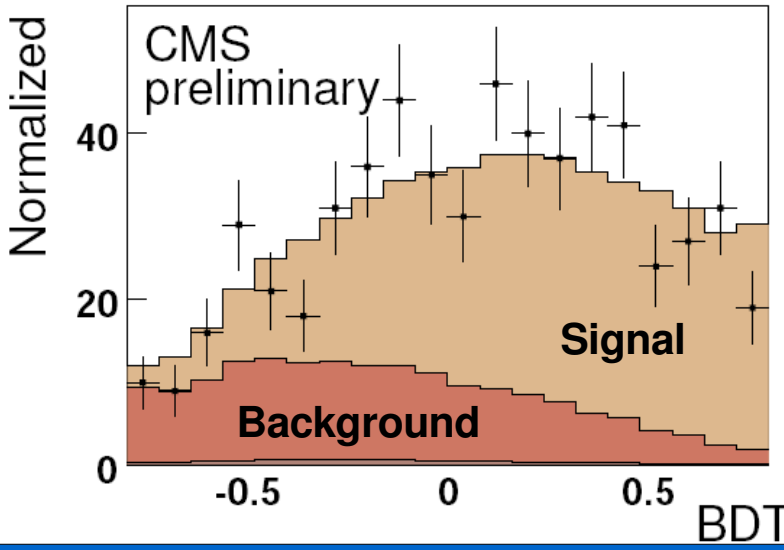


14 TeV, 100 pb^{-1} e,μ+τ: S/B= 0.4

- Stat Uncertainty on xsec: 11%



CMS-PAS-TOP-09-010



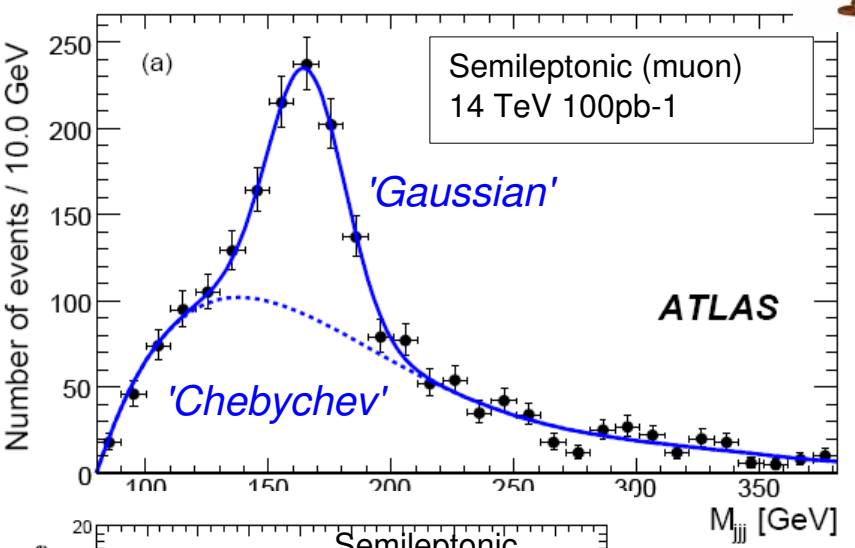
Top pair production measurement

Semileptonic (14 TeV 100 pb^{-1})

- Likelihood fit (and Counting Method)
  - Gaussian+Chebychev bkg
  - extract X-sec by scaling with efficiency
  - less sensitive to BKG normalisation, #jets, JES, more to shape

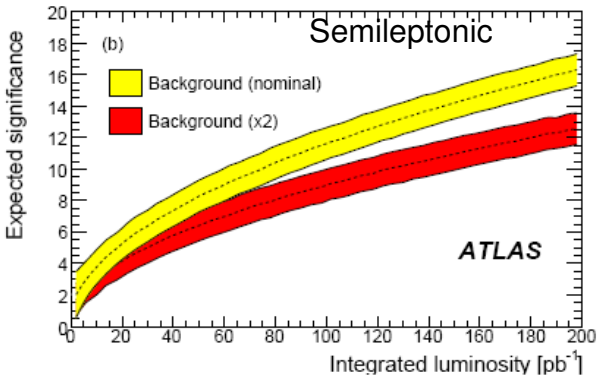
Likelihood method: $\Delta\sigma/\sigma = (7(\text{stat}) \pm 15(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$

Counting method: $\Delta\sigma/\sigma = (3(\text{stat}) \pm 16(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$



Dileptons (14 TeV 100 pb^{-1})

- Likelihood, Template and Counting Methods
  - 2(bjets) + 2 leptons (e,μ) + MET
  - Likelihood/Template of Njets vs MET distribution

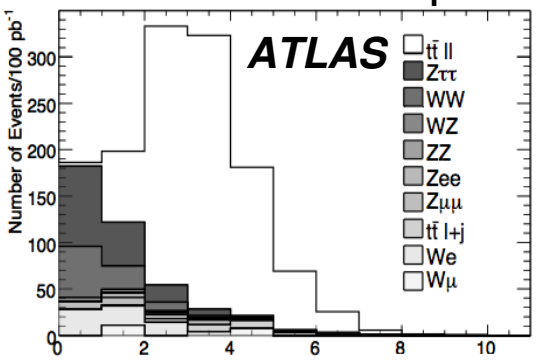


Fit statistical significance only

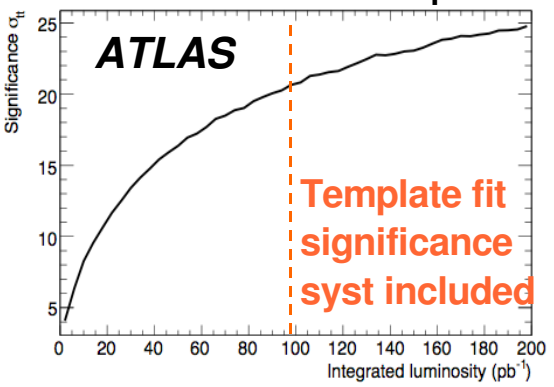
	ATLAS uncert. @ 100pb^{-1}		
Method	stat(%)	syst(%)	lumi(%)
count	3.6	3.6	5
template	3.8	4.2	5
likelihood	5.2	6.7	5

Ref: hep-ex 0901.0512

Dileptons



Dileptons



Template fit significance syst included

Single Top production measurement

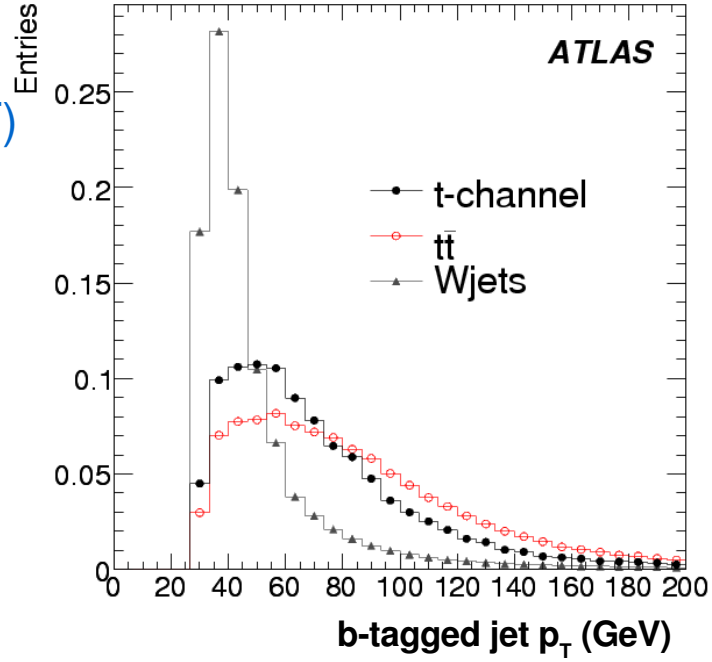
t-channel

ATLAS: cut-based analysis (baseline), and multivariate (BDT)

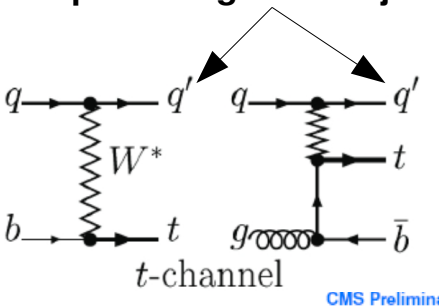
O(1k) events per fb^{-1}, similar size tt background ⇒ large systematics (jet E scale, b-tagging).

1 fb^{-1} : $\Delta\sigma/\sigma$ = 5.7% (stat) ± 22% (syst)

1 fb^{-1} : $\Delta V_{tb} / V_{tb}$ = ± 11% (stat+syst) ± 4% (theory))



producing forward jet



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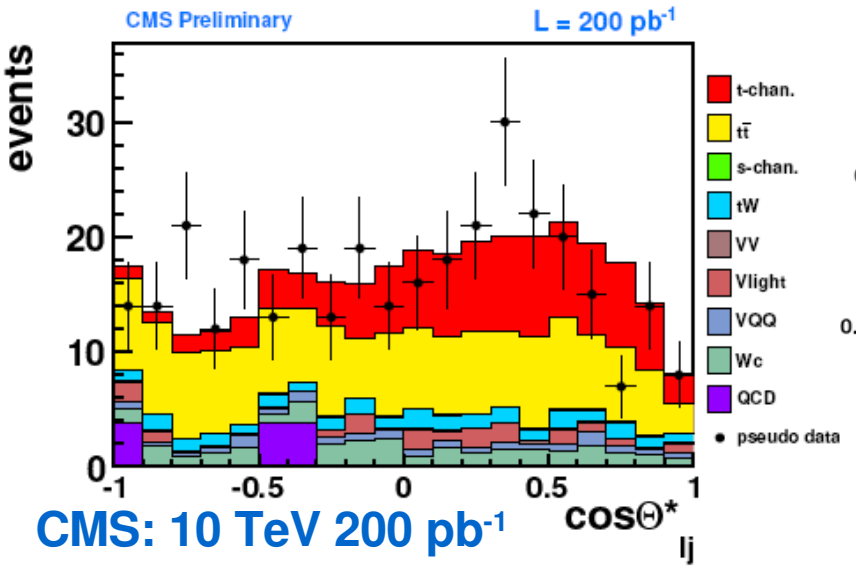
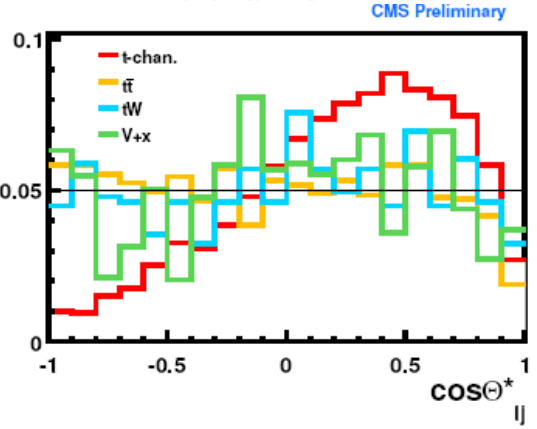
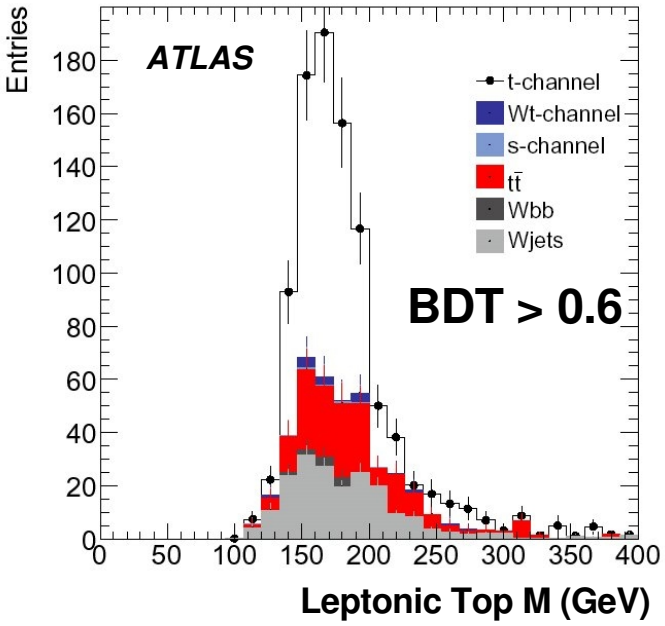




CMS: 10 TeV 200 pb^{-1}

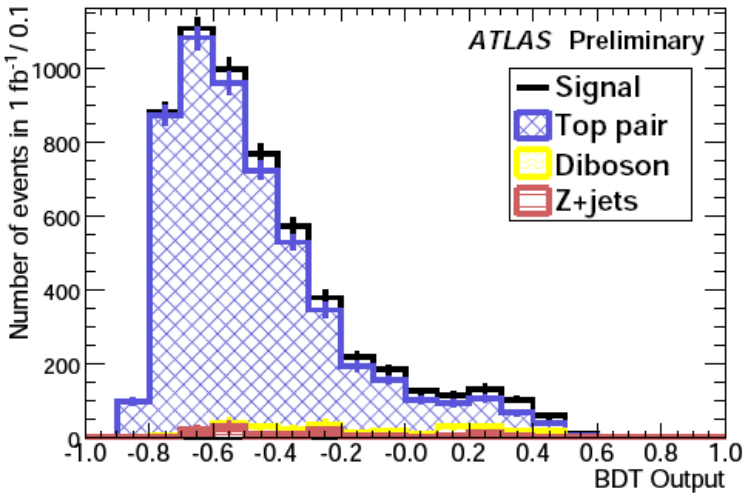
likelihood fit of the cosθ*$_{lj}$ distribution in the top rest frame

200 pb^{-1} : $\Delta\sigma/\sigma$ = 35% (stat) ± 14% (syst) ± 10% (lumi)



Single Top production measurement

ATL-PHYS-PUB-2009-001



tt discriminant e-μ channel

tW channel (associated W production)

Signature similar to tt, but with one less b-jet

ATLAS: cut-based analysis and boosted decision tree

Expected results for 1 fb^{-1}:

- **1 lepton+jets channel: 48% uncertainty (BDT analysis)**

  UPDATED:
- **di-leptons channel: 34% uncertainty (BDT analysis)**
- at 10 fb^{-1} , 1 lepton+jets chan cut method: 20% uncertainty

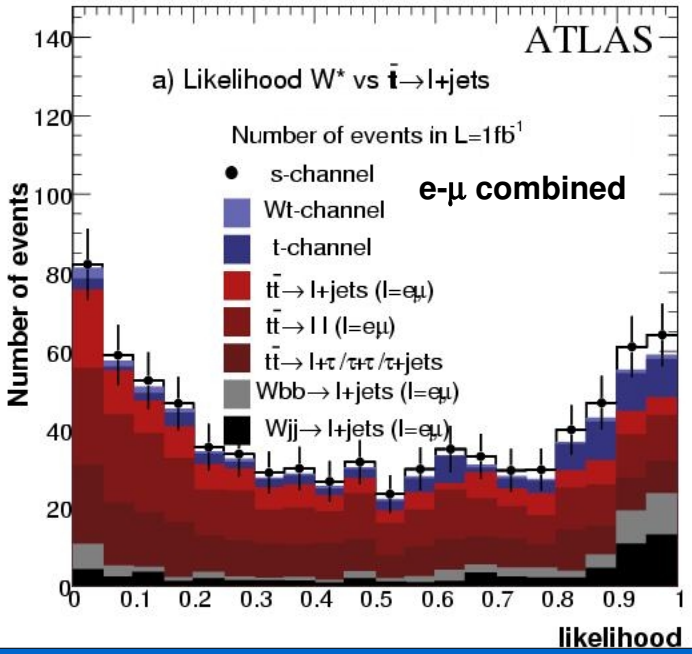
s-channel: very low cross section.

Could be mediated by new physics ($H^{\pm}$)

ATLAS: Likelihood analysis

50% uncertainty at 10 fb^{-1}

3σ evidence at 30 fb^{-1}



Top Branching Ratio

Measure the ratio (R) of the top branching ratio in top quark decay

$$R = \frac{B(t \to Wb)}{B(t \to Wq)} \qquad [q=b,s,d]$$

SM predicts:

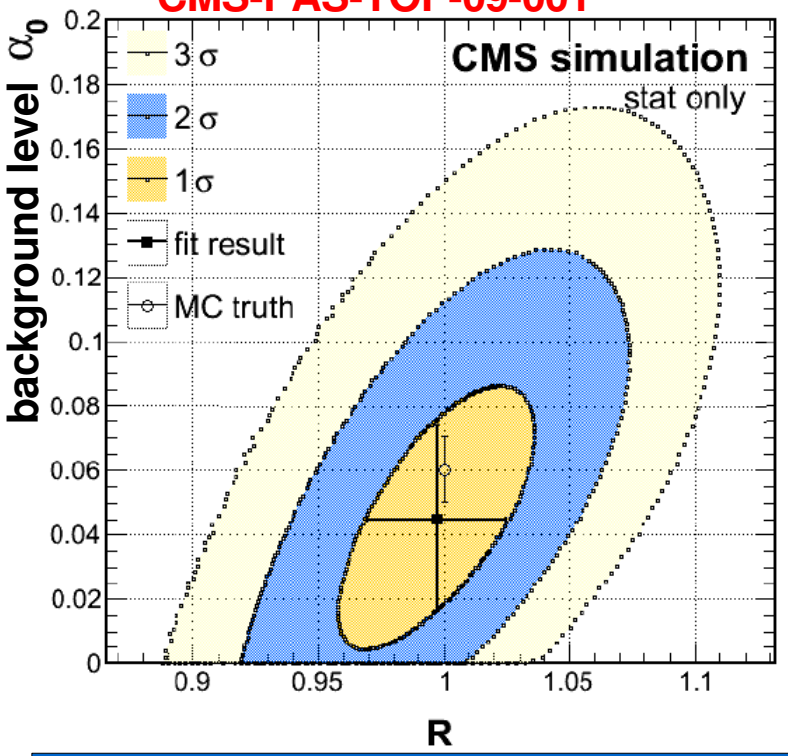
$$R = \frac{|V_{tb}|^2}{|V_{tb}|^2 + |V_{td}|^2 + |V_{ts}|^2}$$

$$R = |V_{tb}|^2 \sim 1$$ SM: R = 0.9980 to 0.9982 @ 95% CL

$$P_k = R^2\, P_k(bb) + 2R(1-R)\, P_k(bq) + (1-R)^2\, P_k(qq)$$

P_K: Prob. of k b-tagging; **$P_k(bb)$, $P_k(bq)$, $P_k(qq)$**: contribution of tt events with 2,1,0 b-quarks.

CMS-PAS-TOP-09-001



The Top branching ratio measurement allows a direct access to the V_{tb} CKM matrix element

The physics observable is the relative number of tt_{bar} events with 0, 1, 2 b-tagged-jets.
A result of (1-R)~O(10^{-1}) will represent an evidence of fourth quark generation.

CMS Results expected for **250 pb^{-1} at 10 TeV**:

$\Delta R/R = 2\%_{(stat)} \pm 10\%_{(syst)}$

Main systematics are b-tagging eff. and background model uncertainties. Sensitivity similar to current Tevatron one.

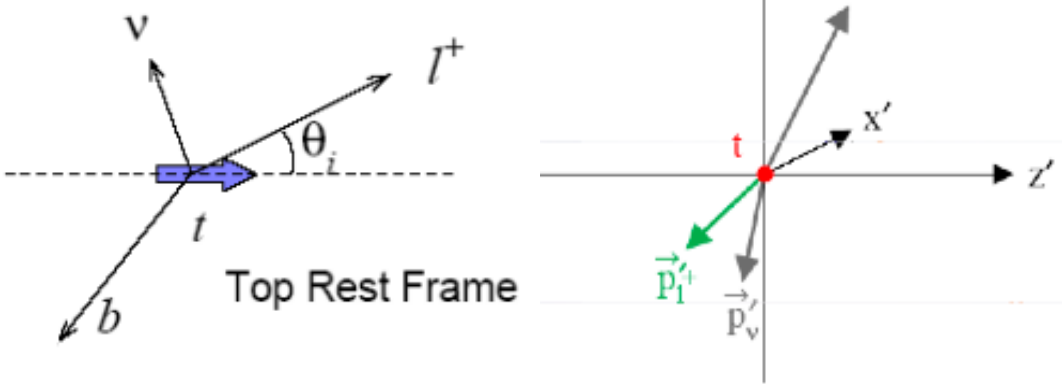
Top Spin Correlation

The top anti-top are produced unpolarized, but their spins are correlated
$\Gamma(t) \approx 1.4\ \text{GeV} \gg \Lambda^2_{QCD}/m_{top}$ The top quark decays before hadronizing: the decay products keep information of the angular correlations

SM prediction of the ttbar correlations can be tested by measuring the angular distribution of the decay products (it has never been observed).

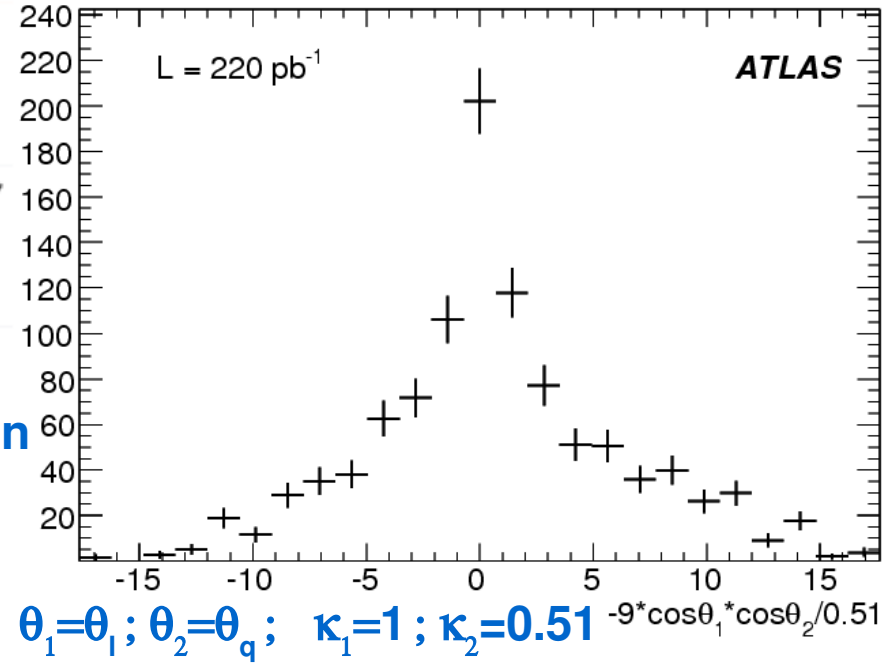
in t (tbar) rest frame

$$\frac{1}{\Gamma}\cdot\frac{d\Gamma}{d\cos\theta_i} = \frac{1+\alpha_i\cos\theta_i}{2}$$



in tt rest frame

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_l\, d\cos\theta_q} = \frac{1}{4}(1 - A\kappa_l\kappa_q\cos\theta_l\cos\theta_q)$$



Results for 220 pb^{-1}: **SM prediction**

$A = 0.67 \pm 0.17_{(stat)} \pm 0.18_{(syst)} \pm 0.25_{(MC)}$ 0.422

$A_D = -0.40 \pm 0.11_{(stat)} \pm 0.09_{(syst)}$ -0.290

$\theta_1=\theta_l$; $\theta_2=\theta_q$; $\kappa_1=1$; $\kappa_2=0.51$

Top quark Charge discrimination

- Goal is to discriminate between SM q_{top}=2/3 and exotic models with q_{top}=-4/3

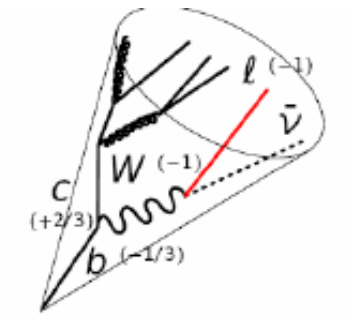
Determinate sign of the lepton charge, determine the b-quark – lepton matching, determinate sign of b quark in the B-jet

- Technique:
  - Charge weighting

$$Q_{\text{bjet}} = \frac{\sum_i q_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}$$

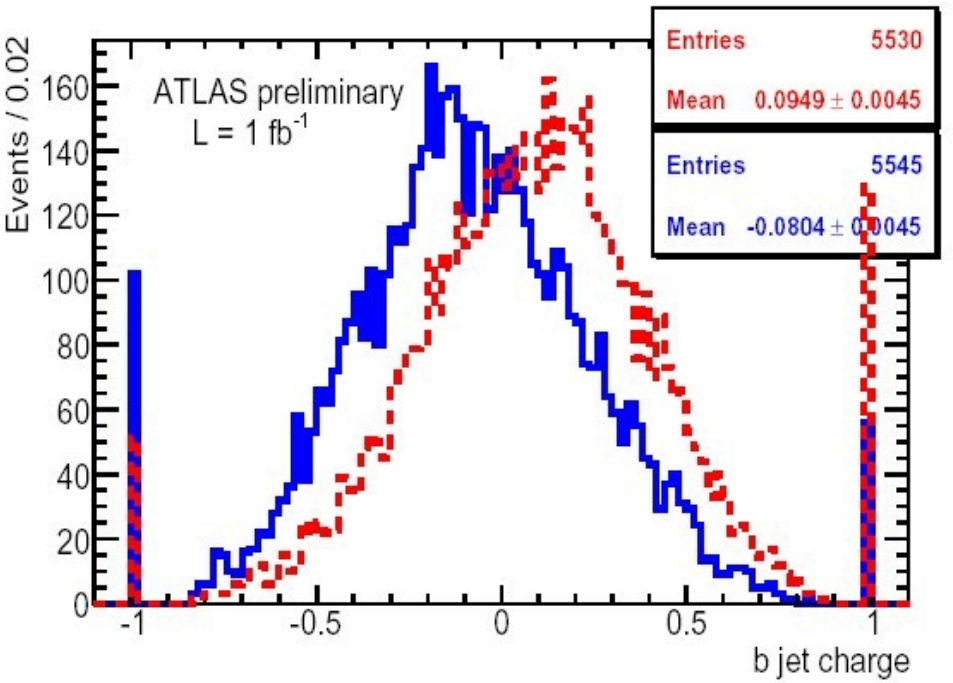
k=0.51 optimizes the discrimination

  - Semileptonic B decays approach



$b \rightarrow q\, l^- \bar{\nu}$

$\bar{b} \rightarrow \bar{q}\, l^+ \nu$



Separation at 5σ with ~100 pb^{-1} (**ATLAS**)

Systematics: ISR/FSR, MC model, b-jet scale

Wtb Anomalous Coupling

In general, the t→bW vertex can be written as:

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

W helicity fractions F_0 , F_L , and F_R depend on these couplings

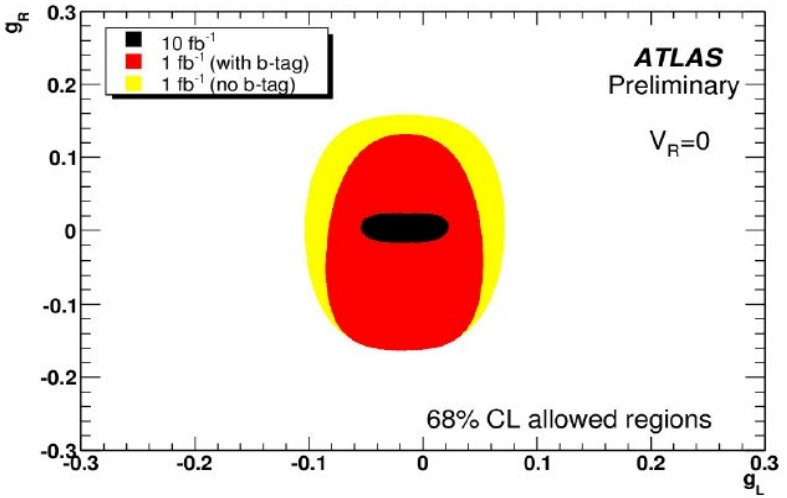
($P_{R/L} = (1 \pm \gamma^5)/2$)

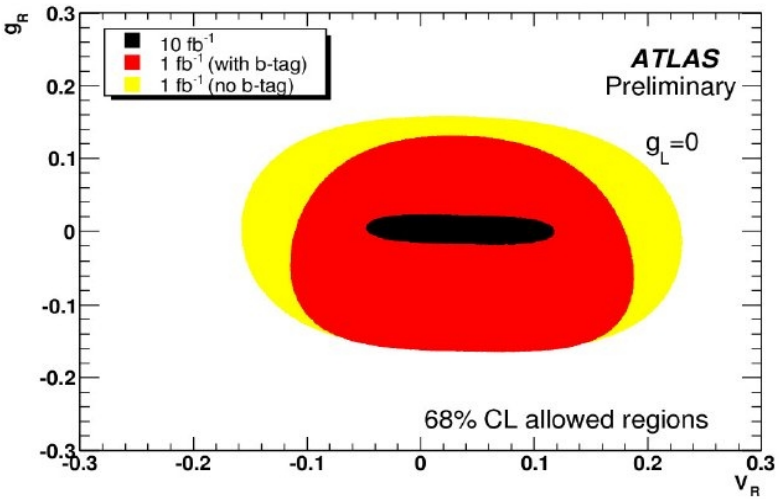
anomalous coupling terms

ATLAS: measure $\rho_L = F_L / F_0$, $\rho_R = F_R / F_0$ and angular (forward/backward) asymmetries

Results can be delivered for 1 fb^{-1}

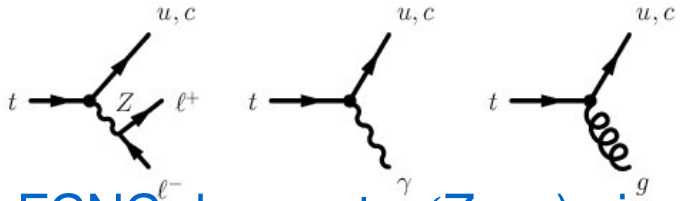
SM prediction: $\rho_L = 0.423$, $\rho_R = 5.1 \cdot 10^{-4}$





Dominating systematics: ISR/FSR, pile-up

FCNC Searches



FCNC decays $t \to (Z,\gamma,g)q$ is suppressed in SM (10^{-10})

NP could manifest itself with BR 10^{-3} -10^{-6}

Signature in top-pair production:

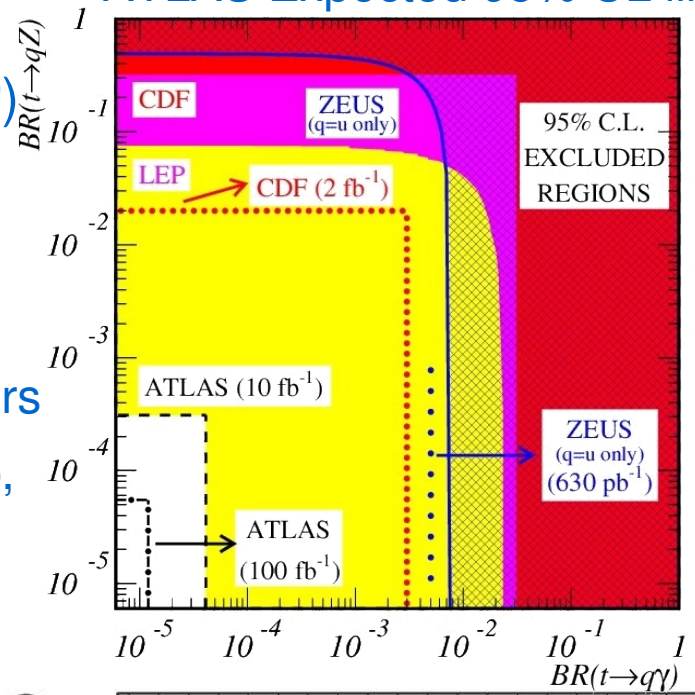
- 1 top decays $t \to Wb$ with leptonic W
- Look for high E_T gluon jet or photon or lepton pairs

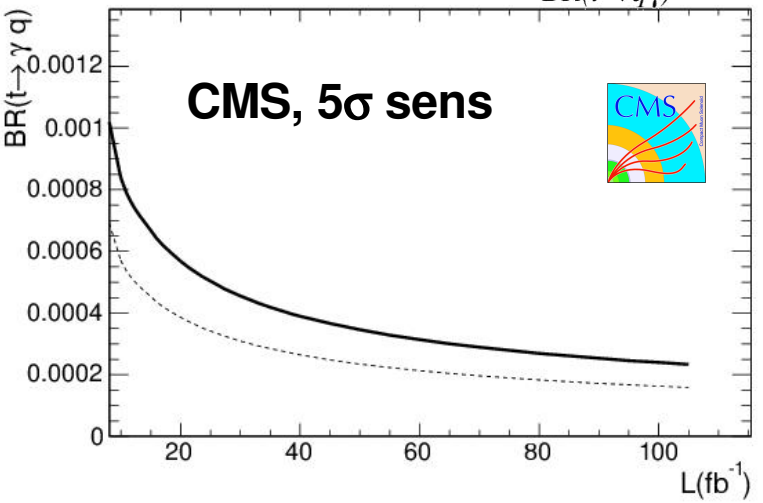
Main systematics: ISR/FSR, MC generator, pile-up, bkg. uncertainties.

ATLAS: Some contributions can be removed using likelihood selection with event shape and top mass reconstruction.

Channel	Exp	BR 5σ sens.
t→ Zq	CMS	@10 fb^{-1} 14.9•10^{-4} (cut)
	ATLAS	@ 1 fb^{-1} 10^{-2} (lklhd)
t→ γ q	CMS	@10 fb^{-1} 8.4•10^{-4} (cut)
	ATLAS	@ 1 fb^{-1} 10^{-2} (lklhd)
t→ gq	ATLAS	@ 1 fb^{-1} 10^{-2} (lklhd)

ATLAS Expected 95% CL limits:





Summary and Discussion

• Top Physics will not be among the first physical results of LHC, but **results will be possible with the first 10-100 pb^{-1} data. Expected already during the first year of LHC collisions**.

• **Top pairs cross section measurement** will be one of the first deliverables, requiring **O(10-100 pb^{-1}) for first results**. Statistics is not an issue, error is dominated by systematics (like JES, background and luminosity that will be reduced in the following years). 10 TeV scenario implies a factor 2 reduction of the signal and roughly the same amount of background events w.r.t. 14 TeV.

• Single top cross section measurement in the **t-channel and Wt channel can be delivered with O(1 fb^{-1}).** Multivariate (BDT) analyses show higher sensitivity reach in these final states. 30 fb^{-1} of data will be needed to yield a 3σ evidence of the s-channel.

• **1 fb^{-1}** of integrated data is also the benchmark for several Top quark properties analyses: charge discrimination, heavy flavour content, top quark spin correlation, Wtb anomalous coupling and FCNC.

• **Top Physics measurements are a necessary step to show the sensitivity of ATLAS and CMS detectors to new physics.**