MEASUREMENT OF PROPERTIES OF TOP QUARK DECAYS IN ATLAS

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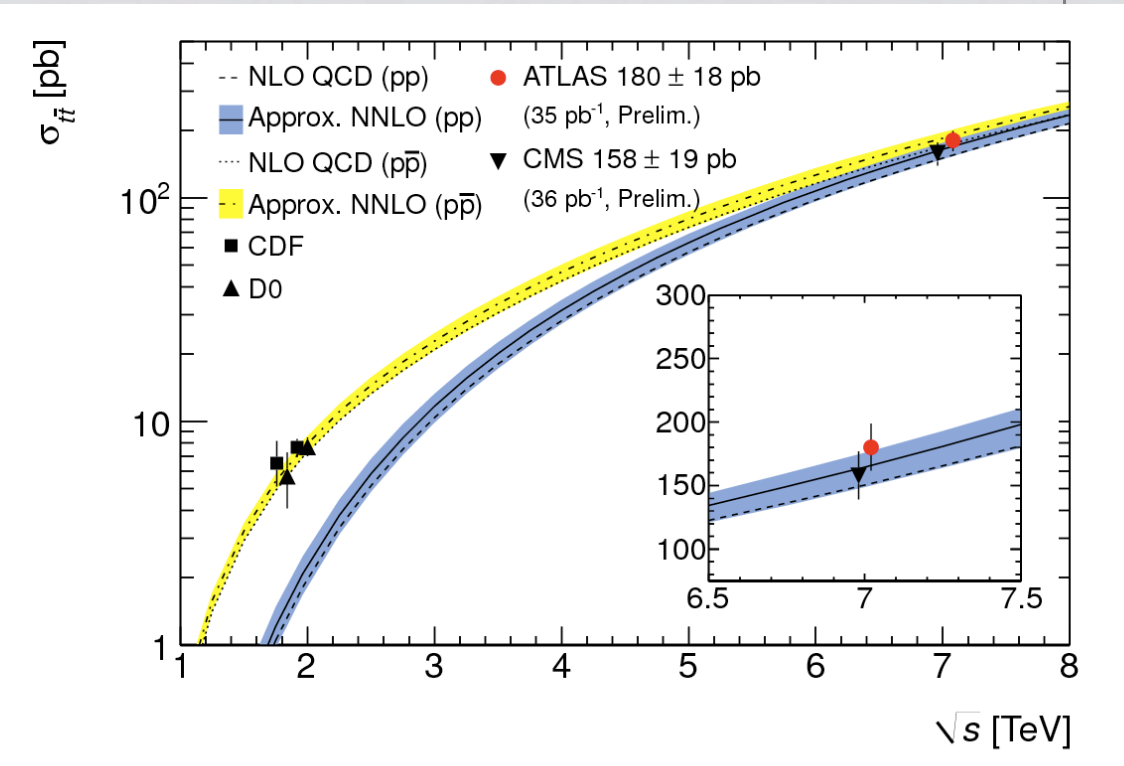
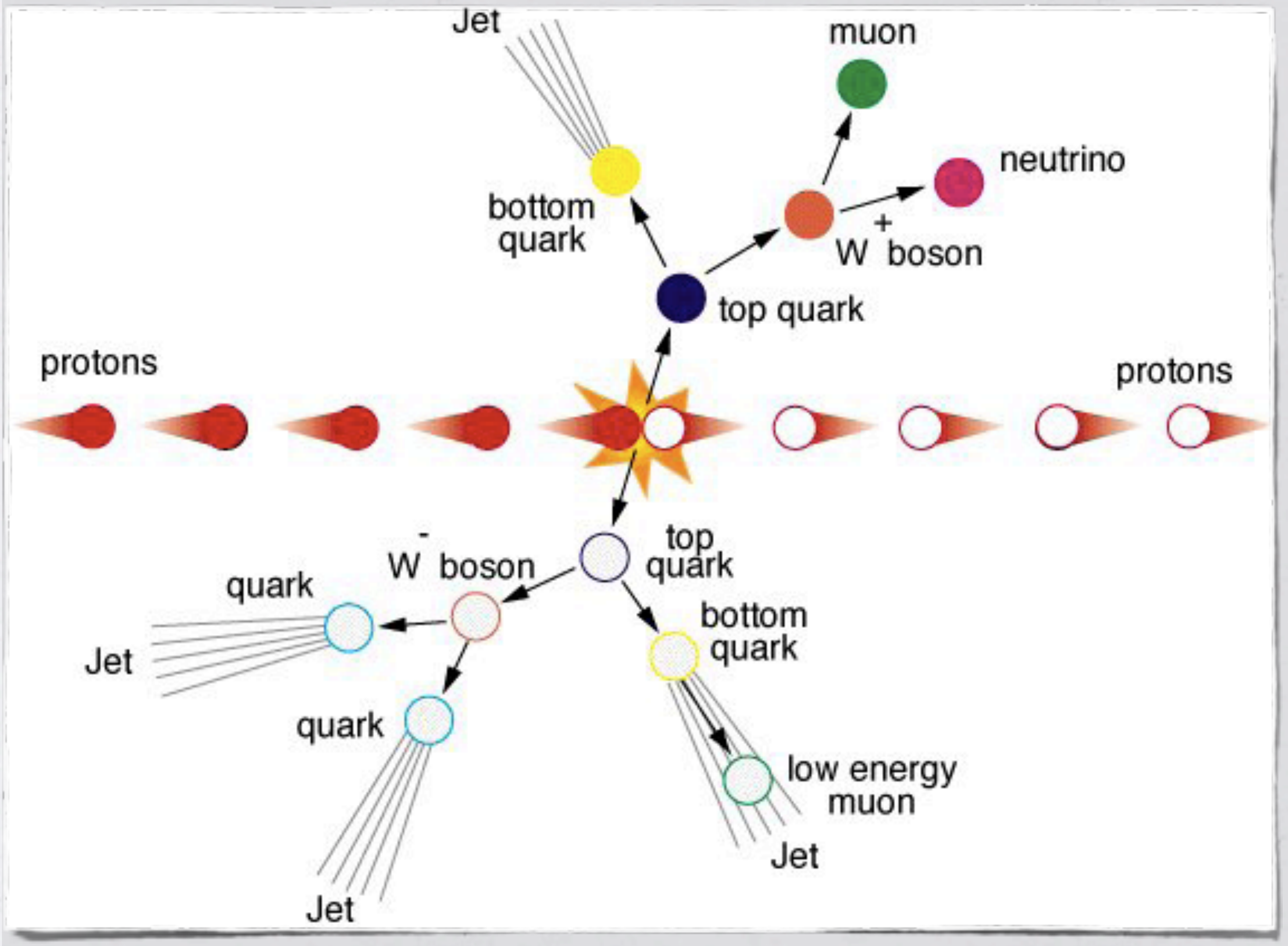
top quark properties at LHC

LHC is a top factory

- σ = 165 pb (7 TeV) : 20 times larger than TEVATRON
- 10 ttbar pairs per minute @ 10^{33} cm^{-2}s^{-1}





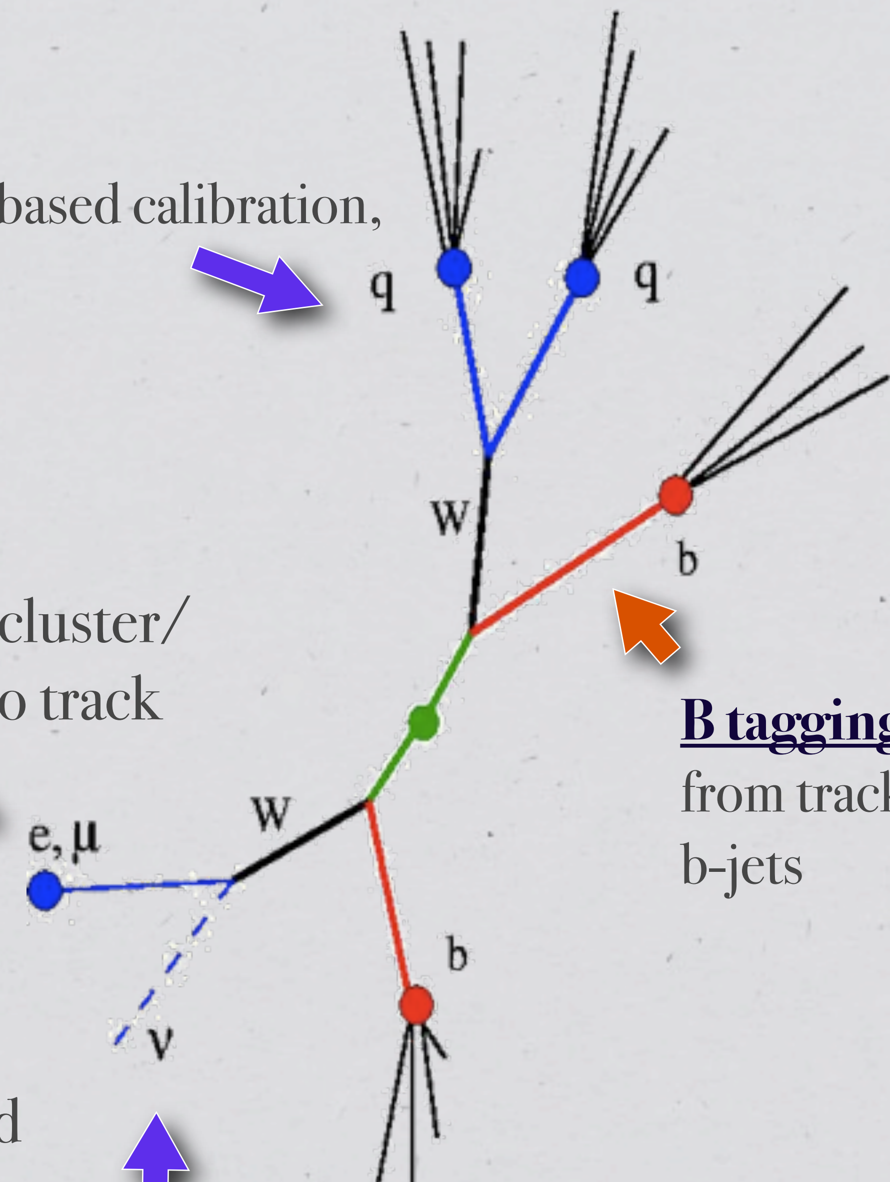
Top properties can be useful to:

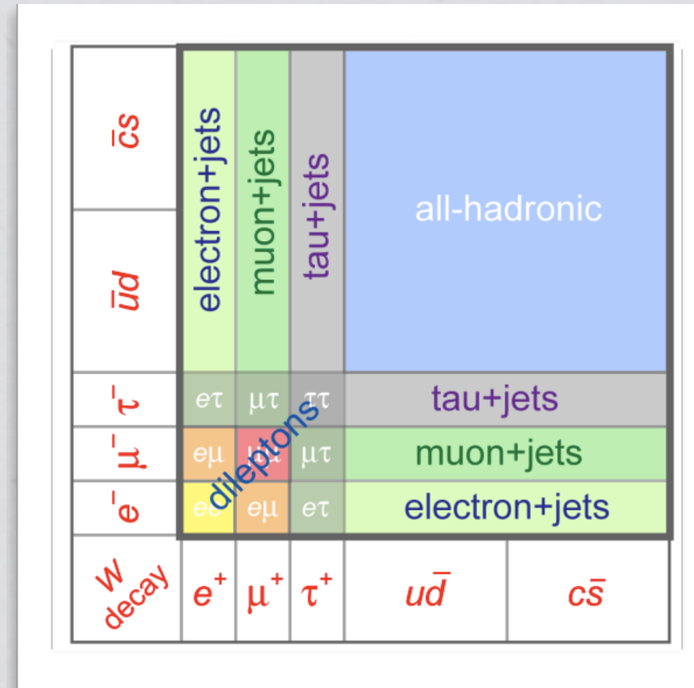
- precise test of SM predictions in terms of:
  charge, spin, tWb vertex
- look for new physics likely to show up in top sector:
  - rare decays
  - anomalous couplings
  - anomalous MET
  - ttbar charge asymmetry
  - new production/final states (FCNC,resonances)

Selection of top quarks

Single lepton events

jets: Anti-kt 0.4, MC based calibration,
|η|<2.5





electrons: good isolated EM cluster/ calorimetric object matched to track
|η|<2.47

muons: inner tracker+muon spectrometer object, track and calorimeter isolation
|η|<2.5

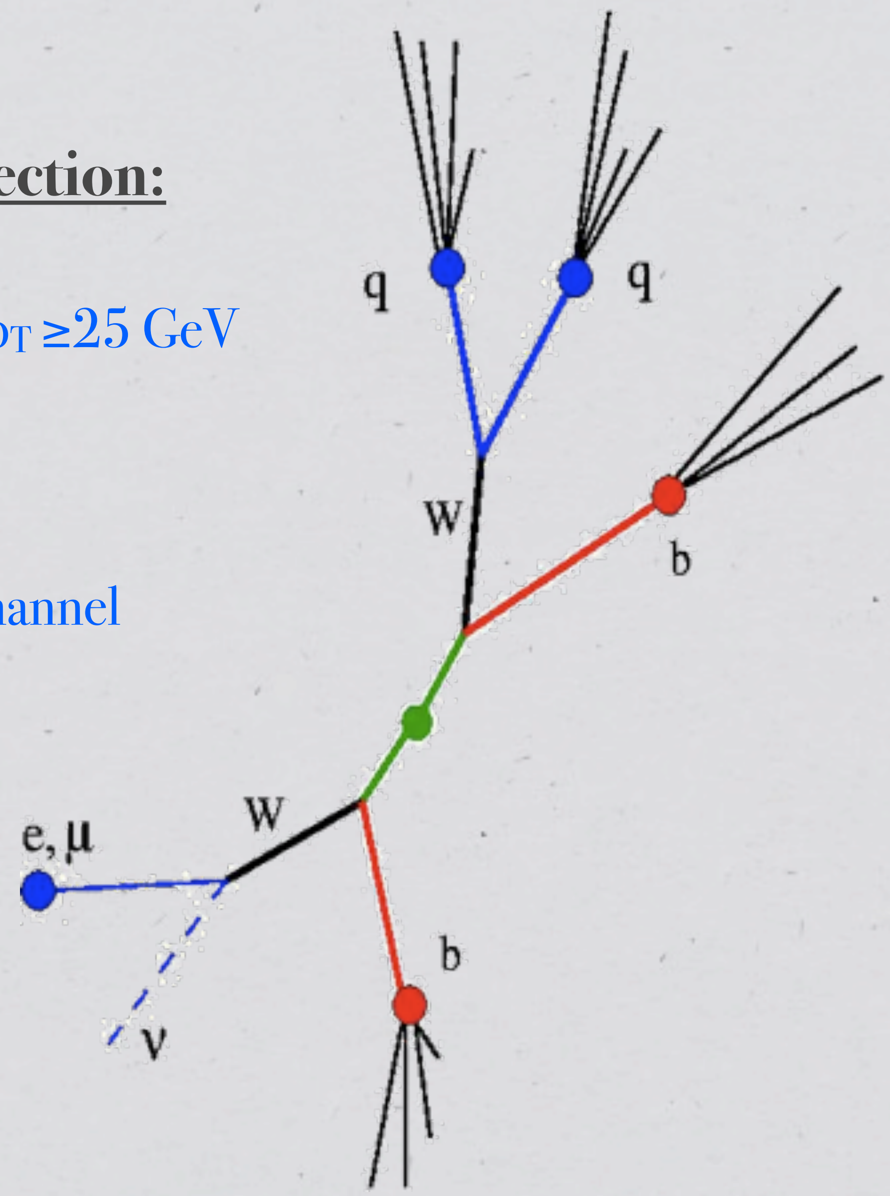
MET: Vector sum of calorimeter energy deposits corrected for identified objects + muons (muon calorimetric E subtracted)

B tagging algorithm SV0: secondary vertex from track in jets, **50% tagging efficiency** on b-jets

Selection of top quarks

Single lepton events selection:

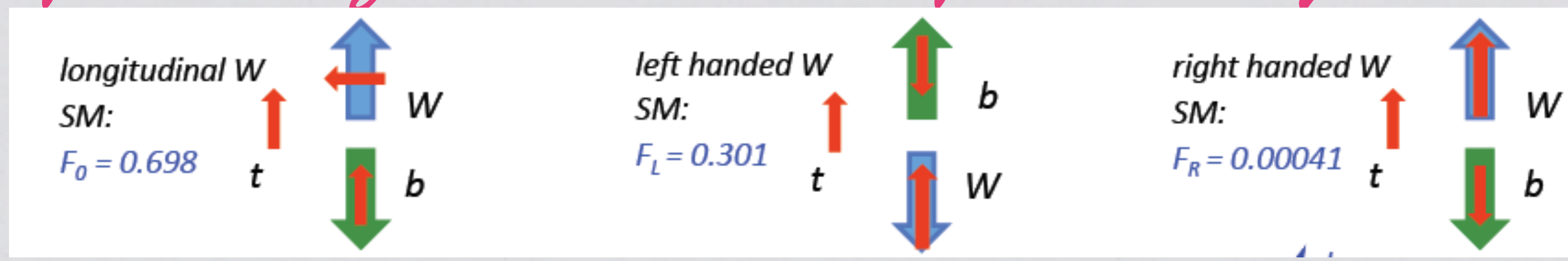
- 1 e/μ ($p_T \geq 20$GeV)
- 4 jets (at least 1 b-tagged) $p_T \geq 25$ GeV
- MET≥35GeV e channel,
  $MET_\mu \geq 20$GeV μ channel
- $m_T(W)>25$ GeV e channel,
  $MET+m_T(W)>60$ GeV μ channel



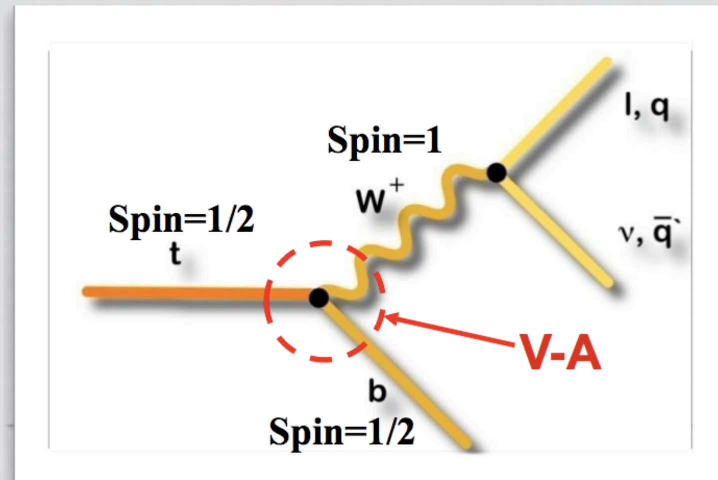
L_{int}=35 pb^{-1}

W polarization in top decays

W helicity fractions



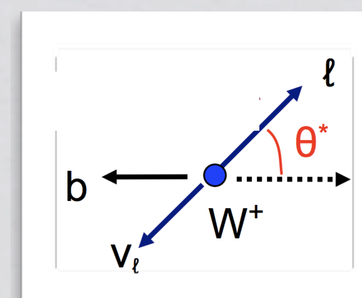
W polarization probes Wtb structure -> Extract limits on new physics:

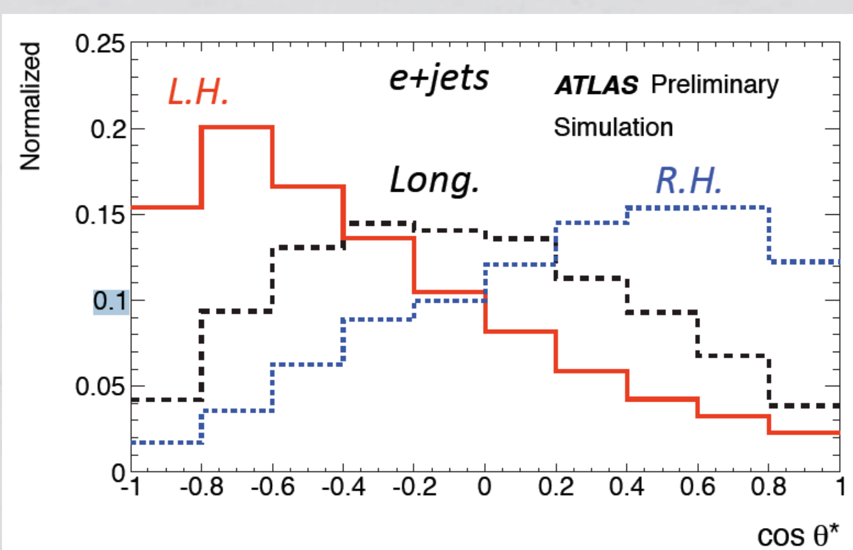


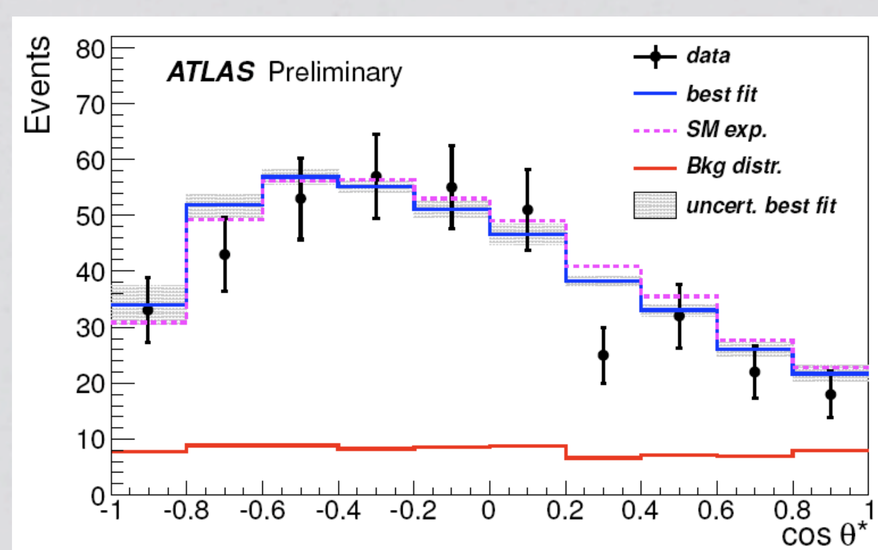
Single lepton ttbar final states are used:

- $p_z(\nu)$ obtained from kin. fit or from χ^2 minimization
- QCD multijet shape and normalisation from Data Driven methods: matrix method.

- **Method1:** helicity fractions from likelihood fit of $\cos\theta^*$ using MC templates corresponding to different pure helicity states.







W polarization in top decays

- **Method2:** angular asymmetries extracted counting events in 2 bins of $\cos\theta^*$ distribution.

$$A_z = \frac{N(\cos\theta^* > z) - N(\cos\theta^* < z)}{N(\cos\theta^* > z) + N(\cos\theta^* < z)}$$

3 different z values to extract the W helicity fractions F_0, F_L, F_R.
A detector correction function is used to recover undistorted parton level distributions.

	template method	Asymmetry method	V-A prediction
F_L	0.42±0.12	0.36±0.10	≈0.3
F_0	0.59±0.12	0.65±0.15	≈0.7
F_R	Fixed 0	-0.01±0.07	≈0

	Asymmetry method
A_+	0.50±0.07
A_{FB}	-0.29±0.08
A_-	-0.86±0.04

- statistically limited: (16%)
- main systematics: ISR/FSR (7%), JES (5%), background shape W/Z+jets (5%)

W polarization: limits on anomalous couplings

All the results are compatible with the SM therefore we extract limits on anomalous couplings.

The W_{tb} lagrangian up to operators of dimention 6 is given by: [arXiv0811.3842,arXiv:0904.2387]

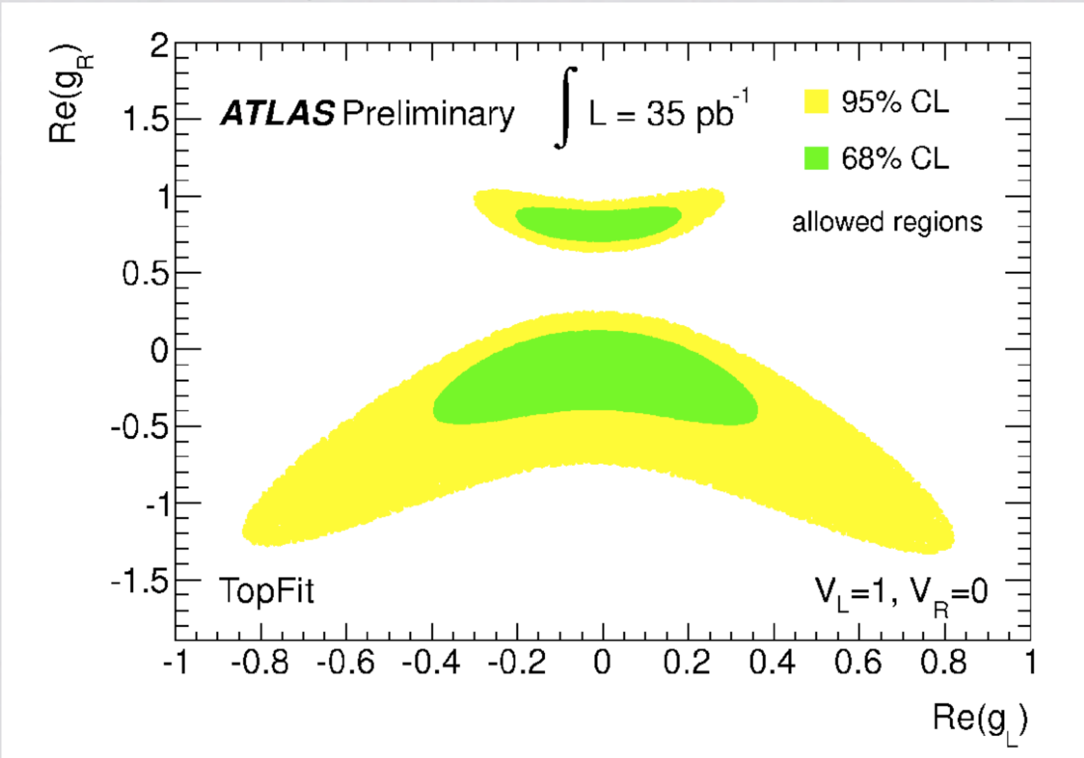
$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\,(V_L P_L + V_R P_R)\,t\,W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\,(g_L P_L + g_R P_R)\,t\,W_{\mu}^{-}$$

<u>limits compatible with 0 (e.g SM expectation):</u>

$\mathrm{Re}\,(V_R) \in [-0.44, 0.48]$

$\mathrm{Re}\,(g_L) \in [-2.83, 2.46]$

$\mathrm{Re}\,(g_R) \in [-5.59, 1.81]$



The anomalous couplings can be expressed in terms of the operator coefficients

$$V_R = \frac{1}{2}C_{\phi\phi}^{33*}\frac{v^2}{\Lambda^2} \quad g_L = \sqrt{2}C_{dW}^{33*}\frac{v^2}{\Lambda^2} \quad g_R = \sqrt{2}C_{uW}^{33}\frac{v^2}{\Lambda^2}$$

$$\frac{\mathrm{Re}\,(C_{\phi\phi}^{33})}{\Lambda^2} \in [-14.66, 15.78]\ \mathrm{TeV}^{-2},$$

$$\frac{\mathrm{Re}\,(C_{dW}^{33})}{\Lambda^2} \in [-2.83, 2.46]\ \mathrm{TeV}^{-2},$$

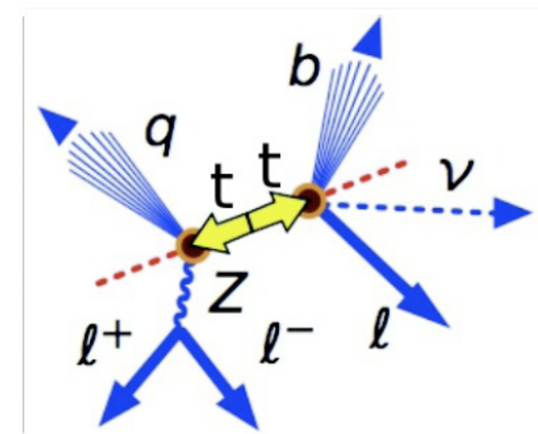
$$\frac{\mathrm{Re}\,(C_{uW}^{33})}{\Lambda^2} \in [-5.59, 1.81]\ \mathrm{TeV}^{-2}.$$

Λ new physics scale

L_{int}=35 pb^{-1}

FCNC in top decays

- FCNC forbidden at tree level in SM, and much smaller than t->Wb @1 loop
- Several SM extensions predict higher BRs (2HDM, MSSM, SUSY R-Parity violation..)
- Search for ttbar production with 1 top decaying via SM decay and 1 top decaying via FCNC into qZ

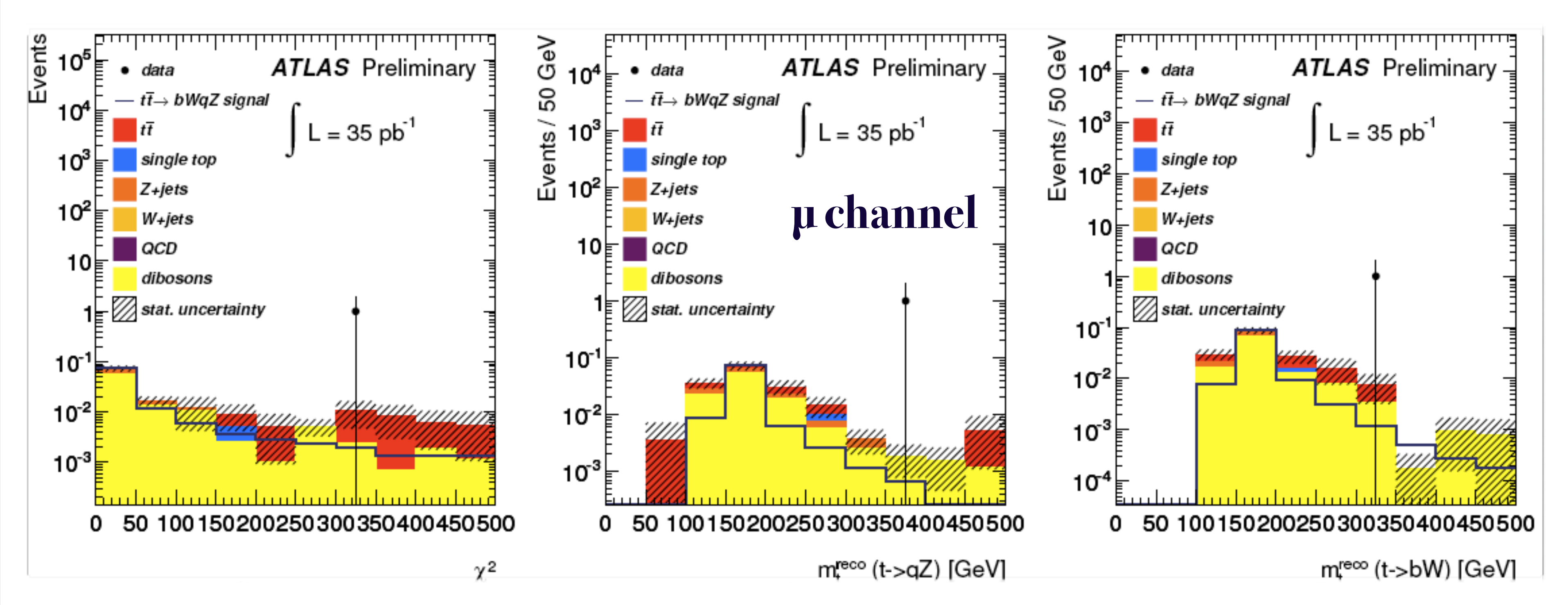


	SM prediction	New physics	Tevatron exclusion
BR(t→qZ)	10^{-12}%	10^{-2}-10^{-8}%	< 3.2%

Events with 3 leptons in the final state are selected:

- 3 leptons 2 out of which of same flavour (e/μ) and opposite charge (p_{T1}≥25GeV, p_{T2}≥20GeV, p_{T3}≥15GeV)
- =2 jets (p_{T1}≥30GeV, p_{T2}≥20GeV)
- MET ≥20GeV
- $p_z(\nu)$ obtained from χ^2 minimization

FCNC *in top decays*



- Z+jets 25% uncertainty. Major systematics: SM tt fragmentation (26%), ISR/FSR(34%), JES(13%)

Selection	Final selection	
Channel	e	μ
W+jets	0.00 ± 0.08	0.00 ± 0.08
Z+jets	0.10 ± 0.08	0.02 ± 0.01
Dibosons	0.08 ± 0.01	0.11 ± 0.01
$t\bar{t}$	0.05 ± 0.02	0.04 ± 0.02
Single-top	0.00 ± 0.00	0.00 ± 0.00
Expected background	0.23 ± 0.11	0.17 ± 0.08
Data	0	1
Signal Efficiency	$(8.53 \pm 0.09)\%$	$(11.96 \pm 0.11)\%$

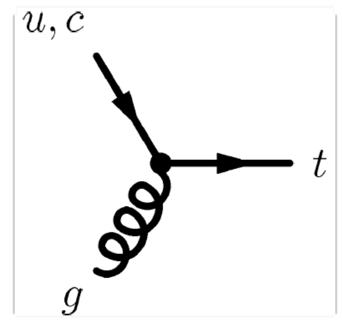
- No evidence for t→qZ decay.
- 95% CL upper limits on FCNC BR have been extracted using frequentist method (syst+stat errors)

	observed	(-1σ)	expected	$(+1\sigma)$
without systematics	16%	8%	11%	15%
with systematics	17%	9%	12%	16%

L_{int}=35 pb^{-1}

FCNC *in top production*

Production of a single top via FCNC:



Look for t→qg vertex (q=u,c)

Standard selection apart:

- exactly 1 b-tagged jet ($p_T \geq$25GeV)
- $p_z(\nu)$ obtained from m_W constraint

	SM prediction	New physics	Tevatron exclusion
BR(t→qg)%	$5 * 10^{-10}$	10^{-2}-10^{-6}	< 0.02/0.4 (u/c)

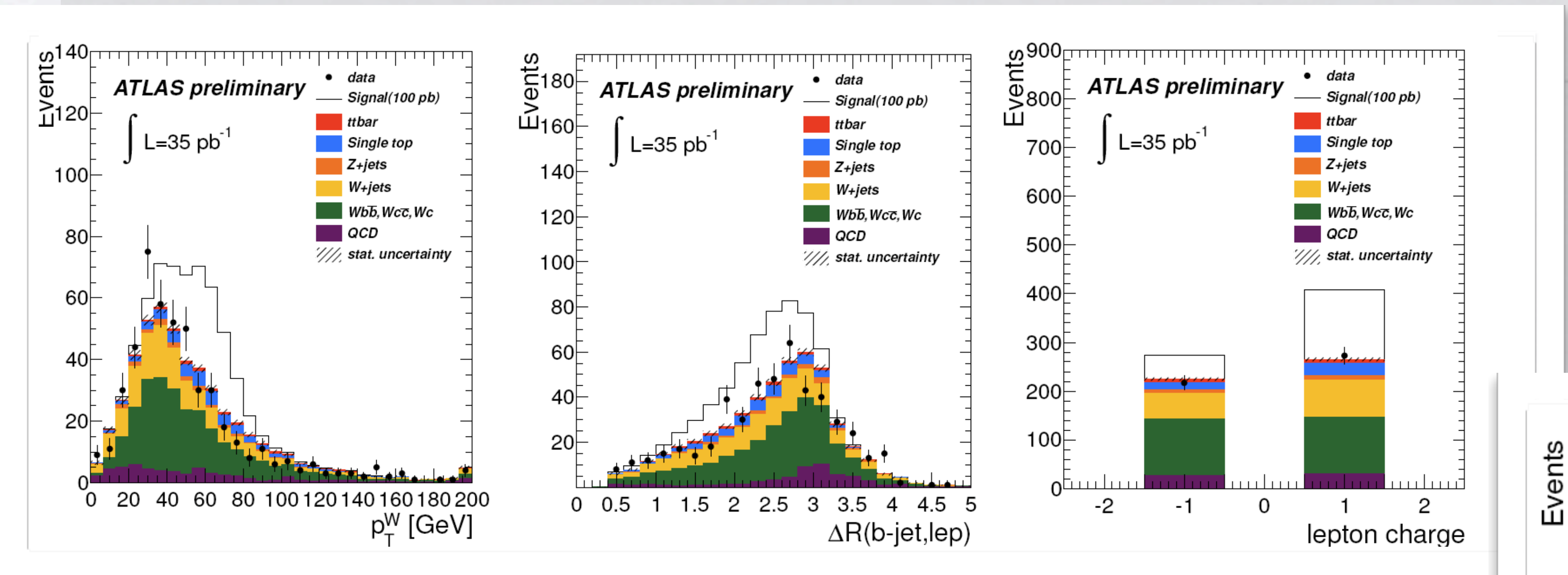
Cutflow after selection:

Channel	e			μ			combined		
Signal	0.8	±	0.0	1.2	±	0.0	1.9	±	0.0
Single top	12.9	±	1.3	20.9	±	2.1	33.9	±	2.5
$t\bar{t}$	5.1	±	0.5	6.8	±	0.7	12.0	±	0.9
W+light jets	37.7	±	7.8	71.4	±	14.5	109.1	±	16.5
$Wb\bar{b}/Wc\bar{c}$+jets	7.8	±	1.6	16.8	±	3.5	24.7	±	3.8
$W + c +$ jets	52.6	±	10.6	116.6	±	23.4	169.2	±	25.6
Z+jets + diboson	1.9	±	0.4	11.7	±	2.5	13.5	±	2.5
QCD	14.4	±	7.2	33.1	±	16.6	47.5	±	18.0
total background	132.4	±	15.1	277.5	±	32.5	409.9	±	35.8
data	150			340			490		

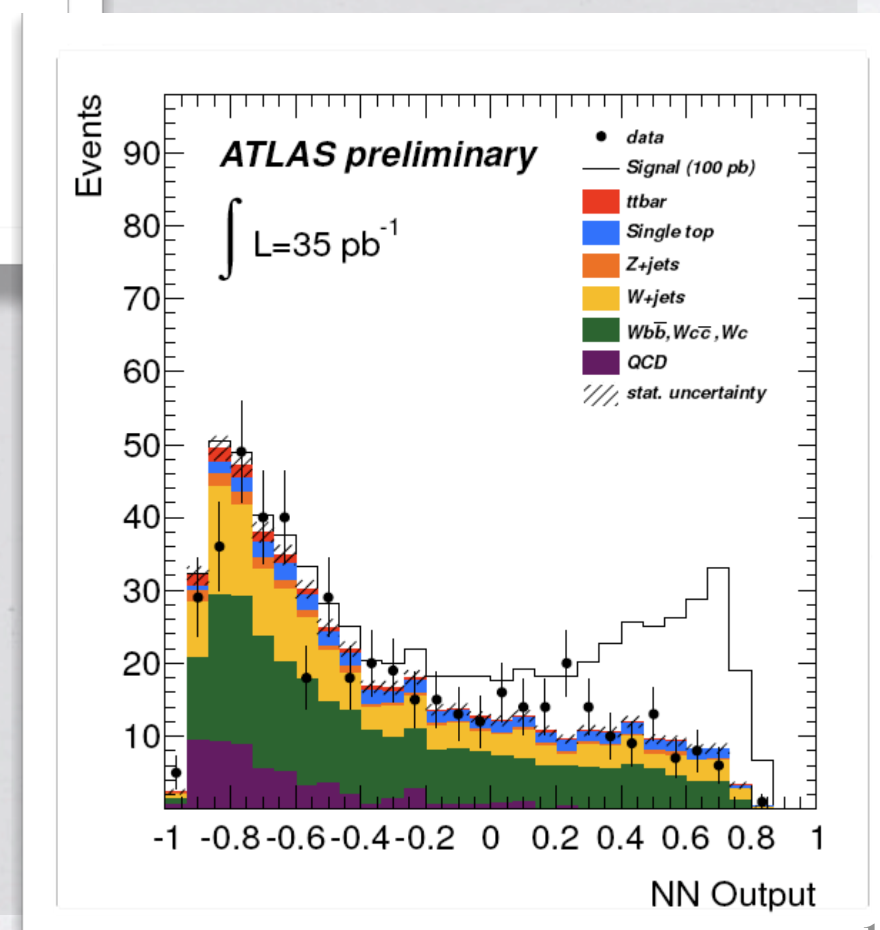
FCNC *in top production*

A neural network is used to separate background and signal: NeuroBayes©

- Most discriminating variables e/μ channels combined (13 input variables)

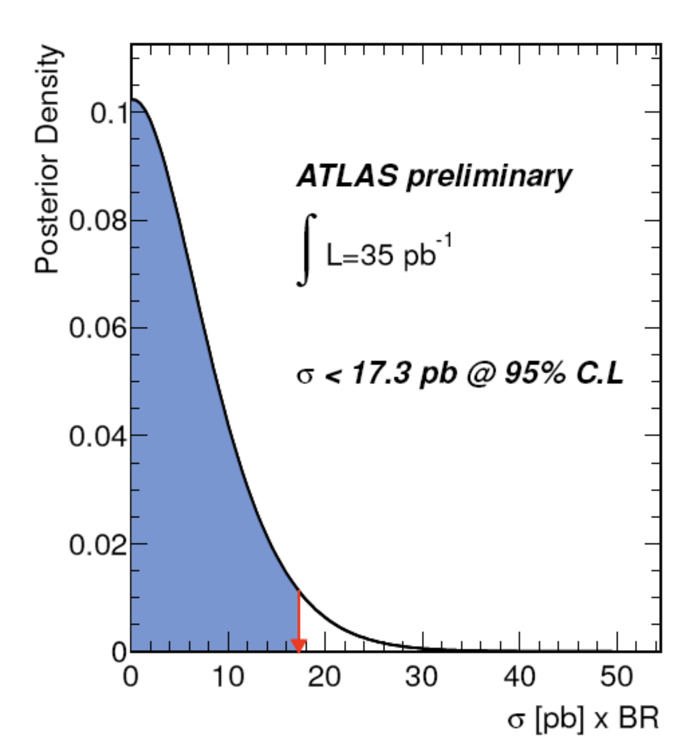


- NN Output



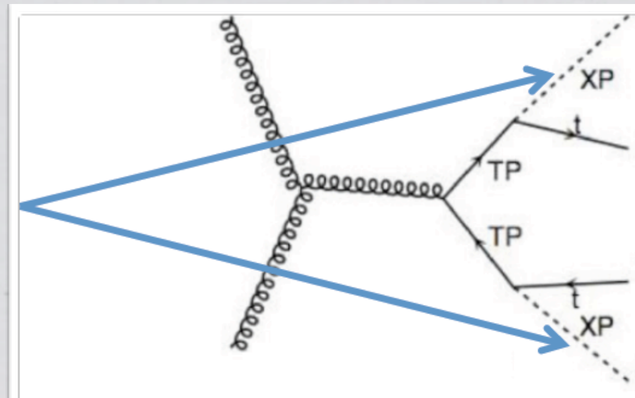
FCNC *in top production*

- Main systematics: JES, ISR/FSR, Heavy Flavour fraction in W+jets, b-tagging
- No excess observed:
  set limit on σ_{qg} * BR($t \rightarrow l\nu b$)
- systematic uncertainties are introduced as nuisance parameters with a Gaussian prior distribution for each parameter
- Upper limit from Bayesian posterior



	expected			observed
	(-1σ)	median	$(+1\sigma)$	
only normalization uncertainties	9.6 pb	13.7 pb	19.7 pb	15.6 pb
with all systematics	12.0 pb	17.4 pb	25.6 pb	17.3 pb

ttbar+ anomalous E_T^{Miss}



Alwall, Feng, Kumar *et al.* (2010)
Berger, Cao (2009)

- **Several models:** (e.g. little Higgs [1], stop quark SUSY, UED models with KK-parity[2]) predicting:
  - pair produced exotic top partner quark-like $T \to tA_0$
  - A_0 stable neutral scalar (DM candidate), escapes undetected.
- **Signature:** large E_T^{miss} (> 80 GeV) and m_T (>120 GeV)
- Current direct and indirect searches for 4th generation quarks which have similar signatures (lower Etmiss) lead to best present limits[3]:

  300≤m(T)≤ 600 GeV

Single lepton ttbar events selected:

- no b-tag requested
- $E_T^{miss} \geq 80$GeV
- m_T (lepton+ E_T^{miss})>120 GeV

Simple cut and count experiment!

[1]hep-ph/0105239,hep-ph/0308199 [2]hep-ph/0012100 [3]arXiv:1002.3366v2

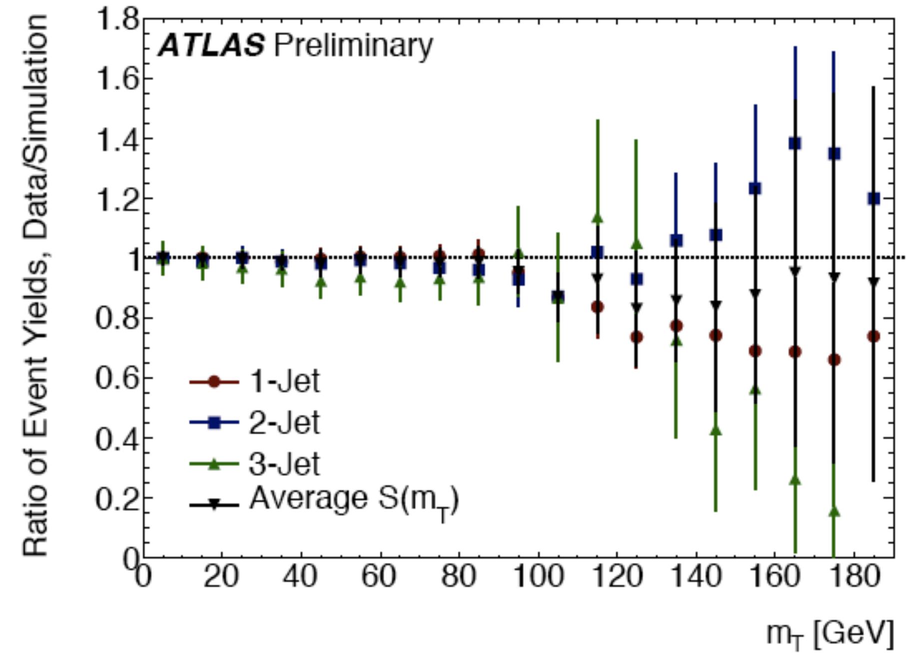
ttbar+ anomalous E_T^{Miss}

Analysed L_{int}=35 pb^{-1}

Background estimation from DD techniques:

- W+jets and single lepton ttbar treated together:
  - good agreement in tails of kinematic distributions.
  - lower jet multiplicities to study shape in high tail of m_T.
  - No evidence of Data/MC shape correction needed (~15% systematic uncertainty)
  - m_T distribution near m_W (60-90 GeV) to normalise MC.

W+jets and single lepton ttbar



- QCD shape and normalisation from Data:
  - invert electron ID criteria in e channel. Anti-electron templates are determined to be used for fitting.
    The region Etmiss<35 GeV is fit to determine fake eff., while the kinematics of anti-electron is used to determine the number of events passing in the signal region.
  - Matrix method (defining loose and tight sample) in μ channel.

Source	Yield
Single-Lepton $t\bar{t}/W$	8.4 ± 1.6
Dilepton $t\bar{t}$	7.6 ± 2.0
Z+jets	0.4 ± 0.1
Dibosons	$0.2 \pm <0.1$
Single Top	0.4 ± 0.1
QCD	0.2 ± 0.6
Total Background	17.2 ± 2.6
Data	17

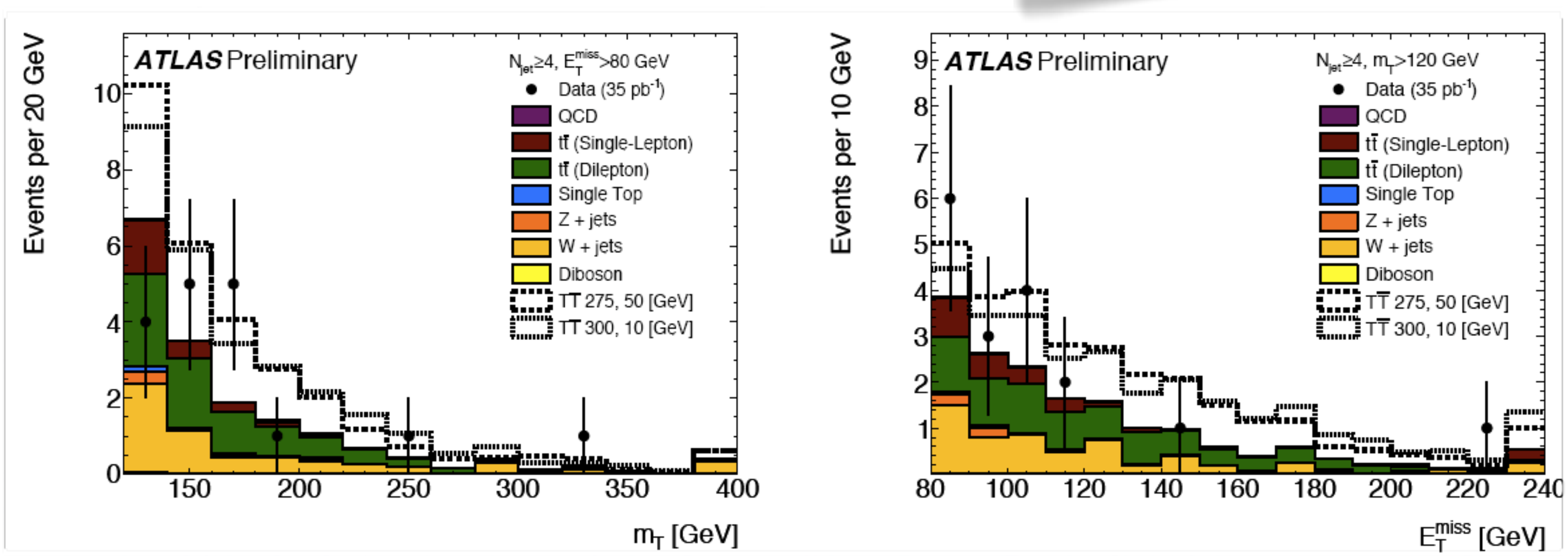
No disagreement with SM.

ttbar+ anomalous E_T^{Miss}

Exclusion limits at 95% C.L. have been extracted :

	m(T) 95% CL limit
for mA_0<50 GeV	< 275 GeV
for mA_0<10 GeV	< 300 GeV

Source	Relative Error
Dilepton $t\bar{t}$, Single Top, Dibosons, Z+jets	
Cross Section	15%
Dilepton Veto	15%
Jet Energy Scale & Resolution	11%
Luminosity	3.4%
Lepton ID	3%
Monte Carlo Statistics	1%
Total	25% (2.1 events)
Single Lepton Backgrounds	
Spread in $S(m_T)$	15%
Normalization	10%
b-Tag Veto	3%
QCD Shape	1%
Total	18% (1.6 events)
QCD	
Normalization in Control Regions	100%
Muon Statistics	0.6 events
Total	0.6 events



ttbar resonances

Search for resonances decaying to ttbar pairs in single lepton channel:

- Kaluza Klein gluon g_{KK} (coloured) in Randall Sundrum model (arXiv:0910.1350[hep-ph]) predicts wide ttbar resonance
- leptophobic Z' (colourless) in Topcolor model (arXiv:hep-ph/9411426): predicts narrow ttbar resonance
- **L_{int}=200 pb^{-1}**

Single lepton ttbar events selected

QCD background from Data Driven techniques:

- anti-electron method (for electron channel) and jet-electron method (for both channels) used

QCD shape: use multijet sample, use fake e/μ in data to model QCD distributions

QCD normalisation: Fit Etmiss spectrum before Etmiss cut for ttbar,W+jets,Z+jets+QCD to data.

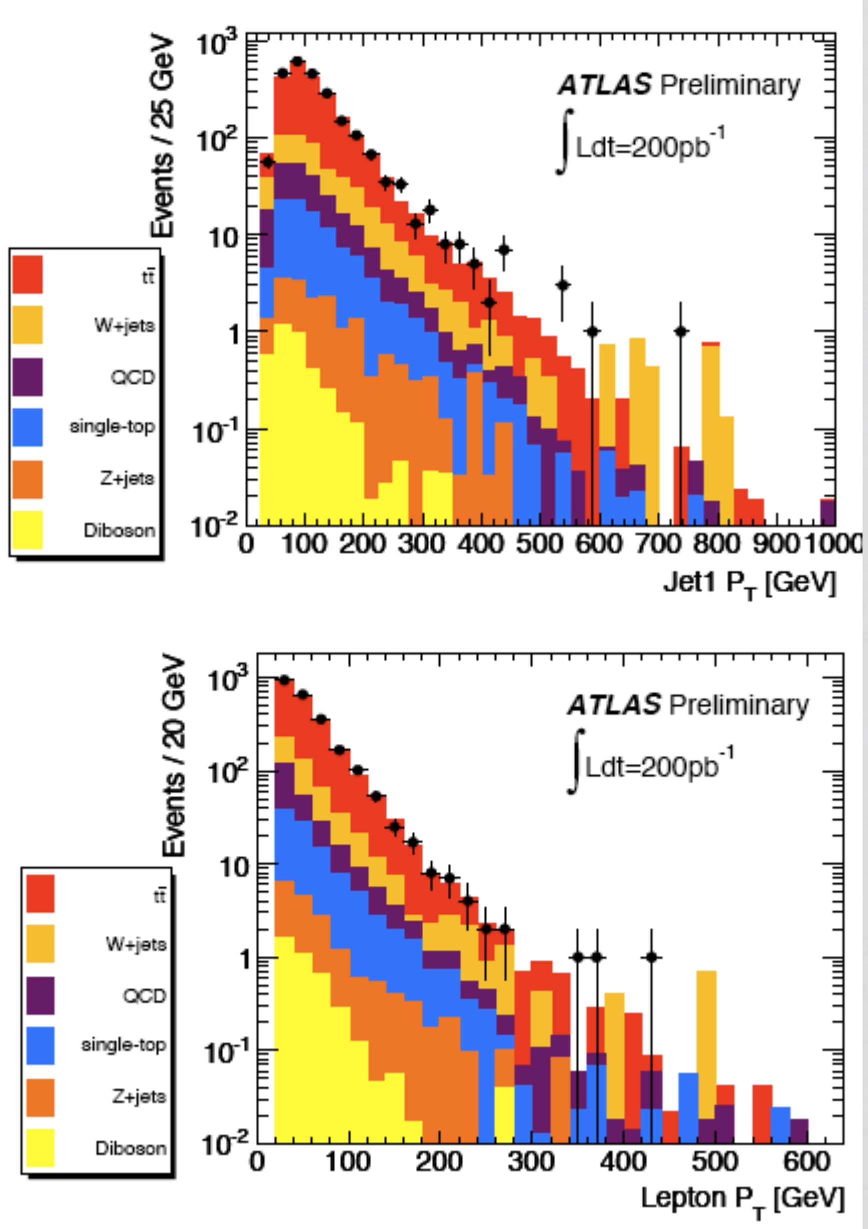
ttbar resonances: signal/background yields

W+jets:

- W+jets enriched data sample selected as: exactly 1 lepton (p_T>20 GeV), 30<E_T^{miss}<80 GeV, 40<M_T<80 GeV, no hard b-tag jet.
- Fit jet multiplicity distribution and extract scale factors in each jet bin.

	Electron channel	Muon channel
$t\bar{t}$	724	988
Single top	36	50
W+jets	93	172
Z+jets	6	8
Diboson	2	2
Total MC Background	861	1220
QCD Background	35	105
Total Expected	896	1325
Data observed	935	1396
Z', m = 500 GeV	15	21
g_{KK}, m = 700 GeV	68	93

good agreement in shapes of kinematic distributions



ttbar resonances: mass reconstruction

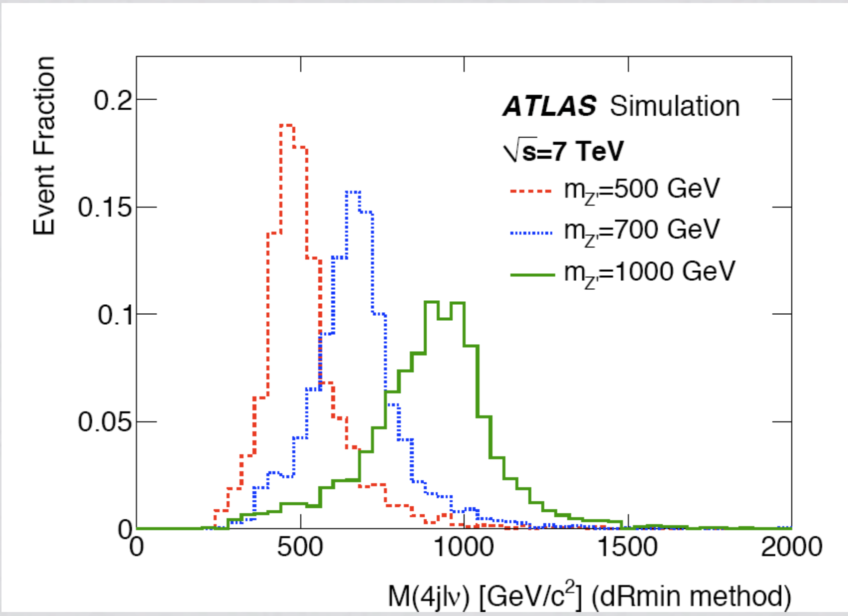
Main systematics:

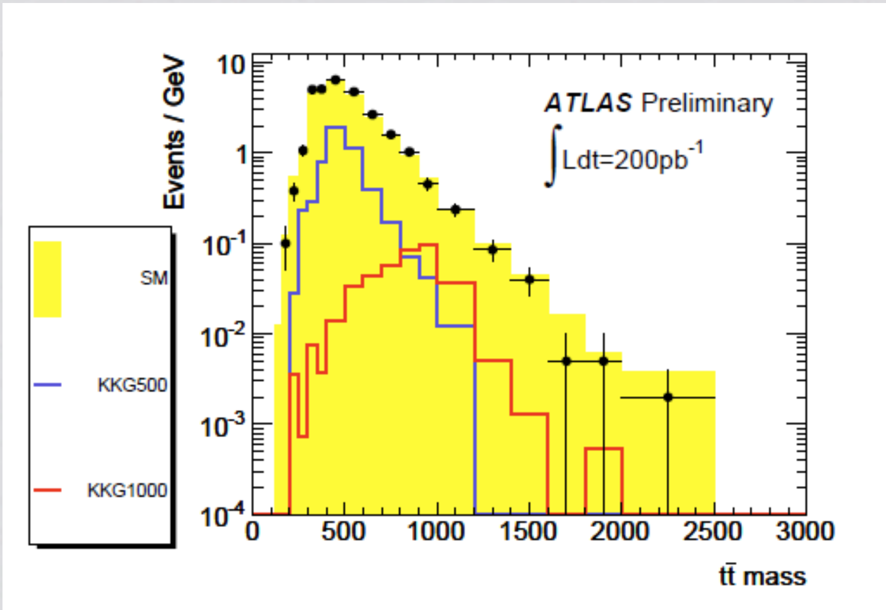
Main shape uncertainties arise from b-tagging efficiency (11%), jet energy scale (9%), modeling of ISR/FSR (7%).

		Systematic uncertainties
Luminosity		4.5%
Background normalization	SM $t\bar{t}$	(+7.0 -9.6)%
	Single top	10%
	W+jets	35%
	Dibosons	5%
	QCD	e : 30% μ : 50%
Lepton trigger and reconstruction efficiencies		≤ 1.5%

Mass reconstruction:

p_Z of neutrino obtained from m_W constraint. Jets far from the rest of the activity of the event are discarded $\Delta R_{min} > 2.5 - 0.015 \times m_j$ (m_j=jet mass). m_{ttbar} from E_T^{miss}+lepton+4 leading jets (3 if only 3 remain).

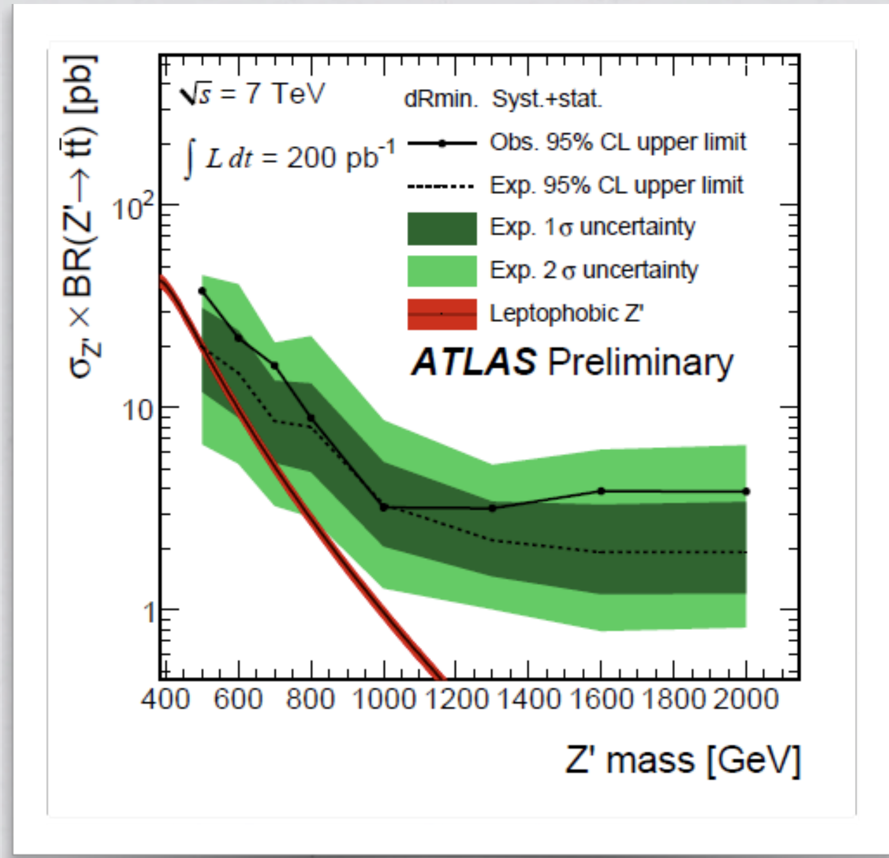


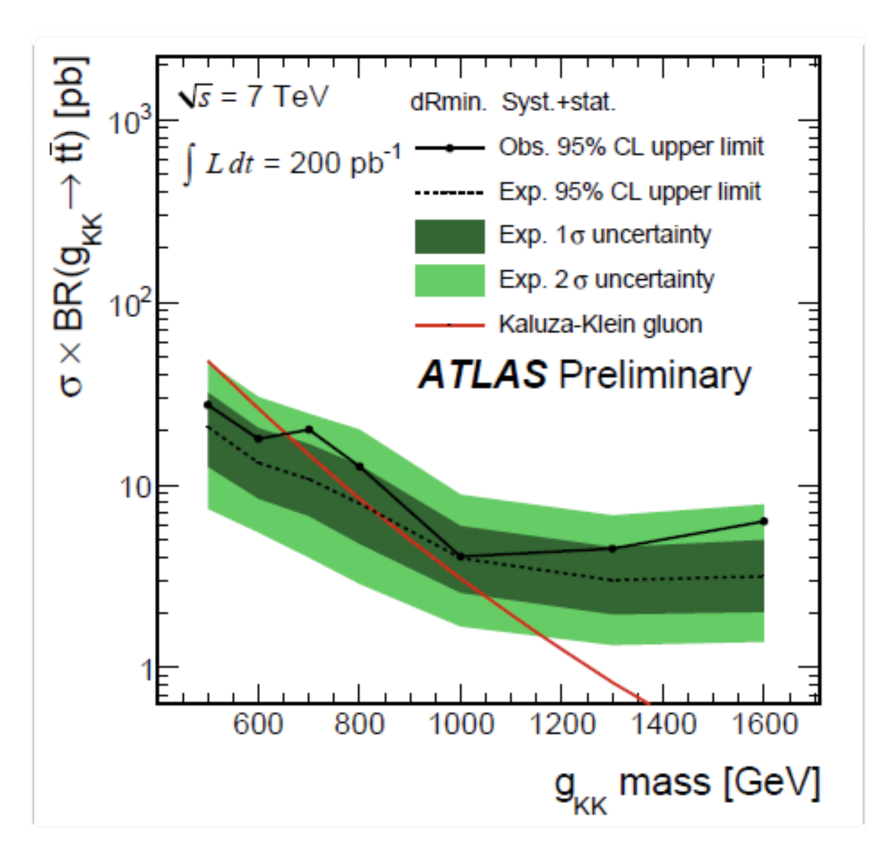


ttbar resonances: results

Z' in top color model narrow resonance:

- observation cannot exclude mass range until now
- Analysis probes already x-sections of few pb at $m_{Z'}$~1 TeV





g_{KK} in Randall Sundrum model (wide resonance):

- g_{KK}>650 GeV/c² @95%CL
- with more statistics will probe up to 1 TeV

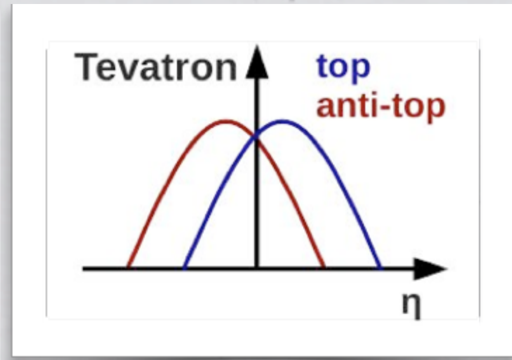
L_{int}=0.7 fb^{-1}

ttbar charge asymmetry

New! Results shown for the first time by ATLAS

At NLO, QCD predicts an asymmetry for ttbar produced via qqbar initial state

- mainly through interference of box/s-channel and ISR/FSR diagrams
- the top quark is predicted to be emitted preferably in the direction of the incoming quark (antitop in the direction of the antiquark)



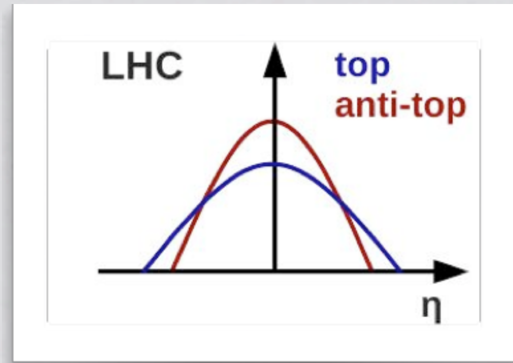
- **New physics models:**

  (e.g. axigluons, leptophobic Z') can alter this asymmetry

- **Measurements at Tevatron:**

  2 σ excess over the SM predictions. For m_{tt}>450 GeV, 3.4 σ excess.[1]

- **At LHC, ttbar mainly produced via gg fusion which is symmetric**
  - still a small asymmetry is predicted from qqbar initial state (~0.5 % MC@NLO)
  - in the lab frame, top preferentially emitted in forward/backward directions while antitop are more centrally produced



Asymmetry

$$A_C = \frac{N(\Delta|Y| > 0) - N(\Delta|Y| < 0)}{N(\Delta|Y| > 0) + N(\Delta|Y| < 0)}$$

Standard selection for single lepton ttbar final states is applied.

[1]Phys. Rev. D **83** (2011) 112003 , D0 6062-CONF (2010)

Friday, 22 July 2011

ttbar charge asymmetry: backgrounds

QCD: data driven estimate of the normalization

- use matrix method: define a loose and tight lepton selection. Loose sample without and with looser isolation requirements for the muon and electrons, respectively.

W+jets: data driven estimate of the normalization

- use the W charge asymmetry (more W_+ produced than W_- in pp collisions)
- $r_{MC} = W_+ / W_-$ well known theoretically can be used to extract the total number of W+jets before tagging

$$N_{W^+} + N_{W^-} = \left(\frac{r_{MC}+1}{r_{MC}-1}\right)(D^+ - D^-)$$

$D_{+/-}$: number of events in data after the ttbar selection,

- extract the number of W+jets after tagging:

$$W_{\text{tagged}} = W_{\text{pretag}} \cdot f_{\text{tagged}}$$

f_{tagged} MC ratio between 4jet pretag/tagged

uncertainties from r_{MC}, JES, PDF, generator and HF fraction.

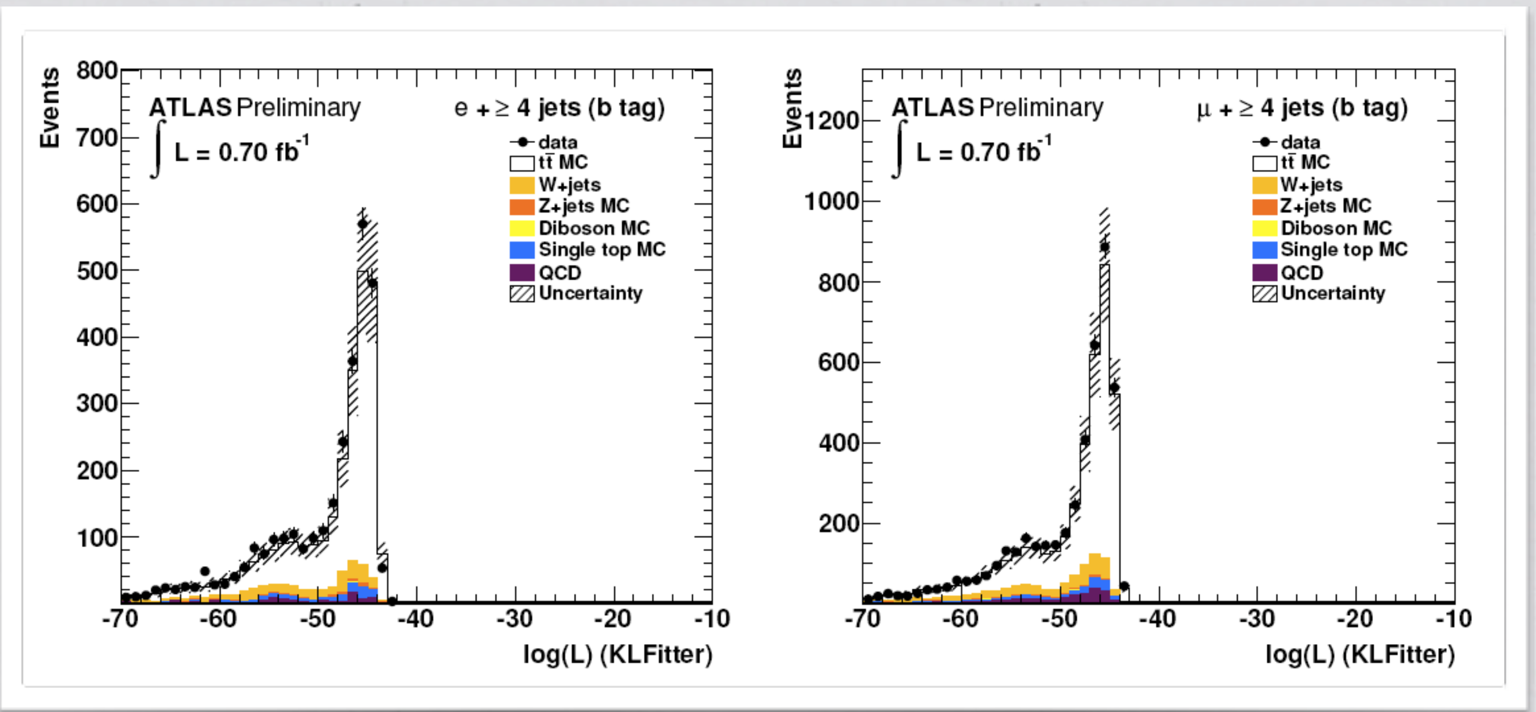
overall Data/MC agreement good

Channel	μ + jets pretag	μ + jets tagged	e + jets pretag	e + jets tagged
$t\bar{t}$	4784 ± 5	3247 ± 4	3293 ± 4	2218 ± 4
Single top	306 ± 2	171 ± 2	219 ± 2	124 ± 2
W+jets	5741 ± 915	494 ± 234	3436 ± 628	309 ± 144
Z+jets	632 ± 7	43 ± 2	535 ± 7	35 ± 1
Diboson	90 ± 2	8 ± 1	56 ± 1	5 ± 0
QCD	1103 ± 552	227 ± 227	665 ± 332	84 ± 84
Total background	7871 ± 1068	943 ± 326	4910 ± 711	557 ± 167
Signal + background	12655 ± 1068	4189 ± 326	8203 ± 711	2775 ± 167
Observed	12705	4392	8193	2997

ttbar charge asymmetry: reco & unfolding

ttbar system reconstructed using kinematic likelihood method:

- assigns a probability for the kinematics of an observed event to be compatible with a top quark pair decay.
- correct event topology on ttbar MC: w/o b-tag: 62 %, w/ b-tag: 74%



Unfolding to move from reconstructed asymmetry to truth asymmetry

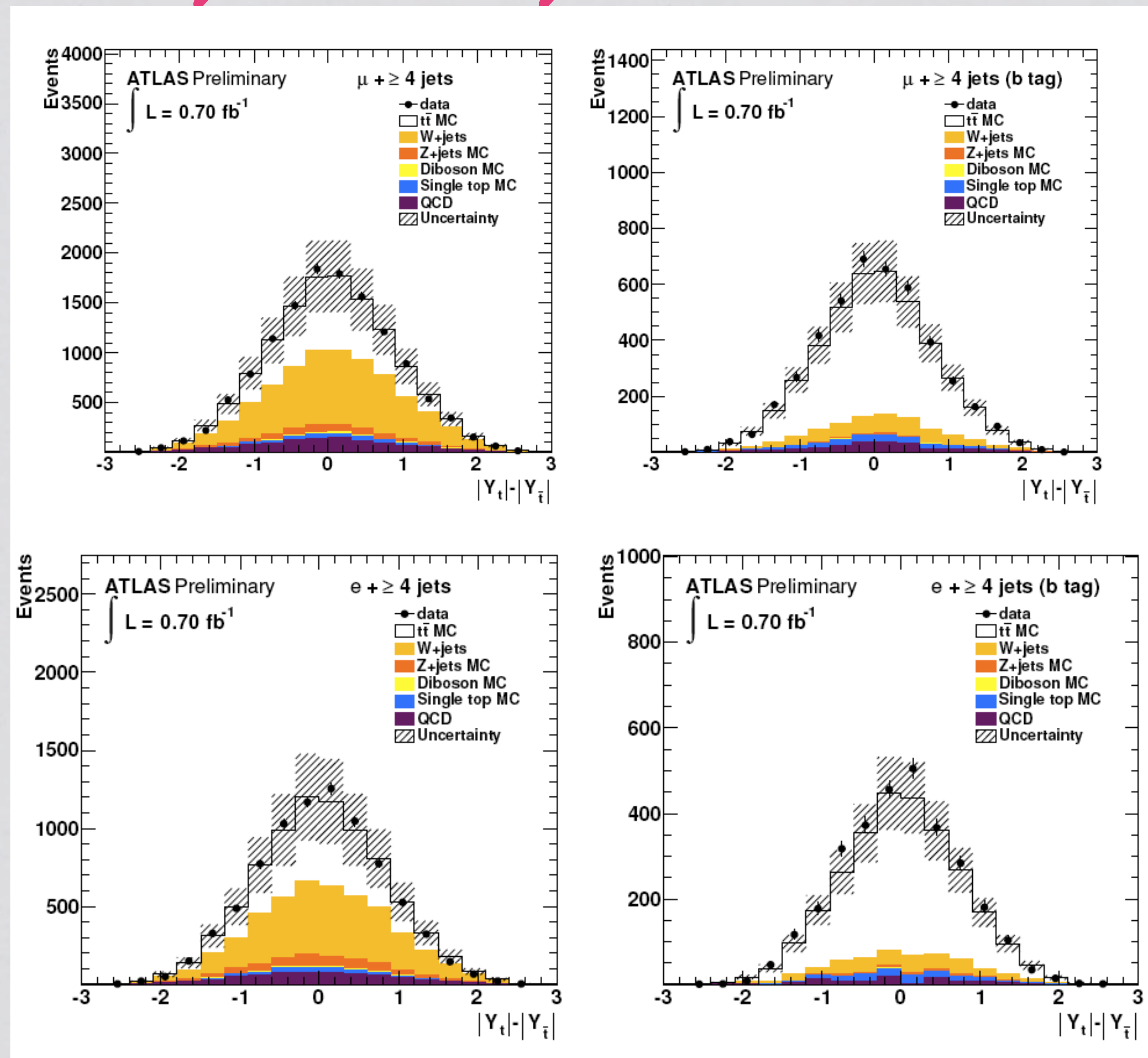
- Subtract background before unfolding
- should correct both from reconstruction/selection and acceptance effects:

$$S_i = \sum_j R_{ij} T_j.$$

- T_j: true distribution, S_i: reco distribution, R_{ij}: response matrix (expected bin j, reco bin i).
- Need to invert R_{ij} to get T_j

Bayes' theorem applied iteratively to invert R_{ij}

ttbar charge asymmetry: results



- Main systematics: JES, JER, ttbar modelling, top mass

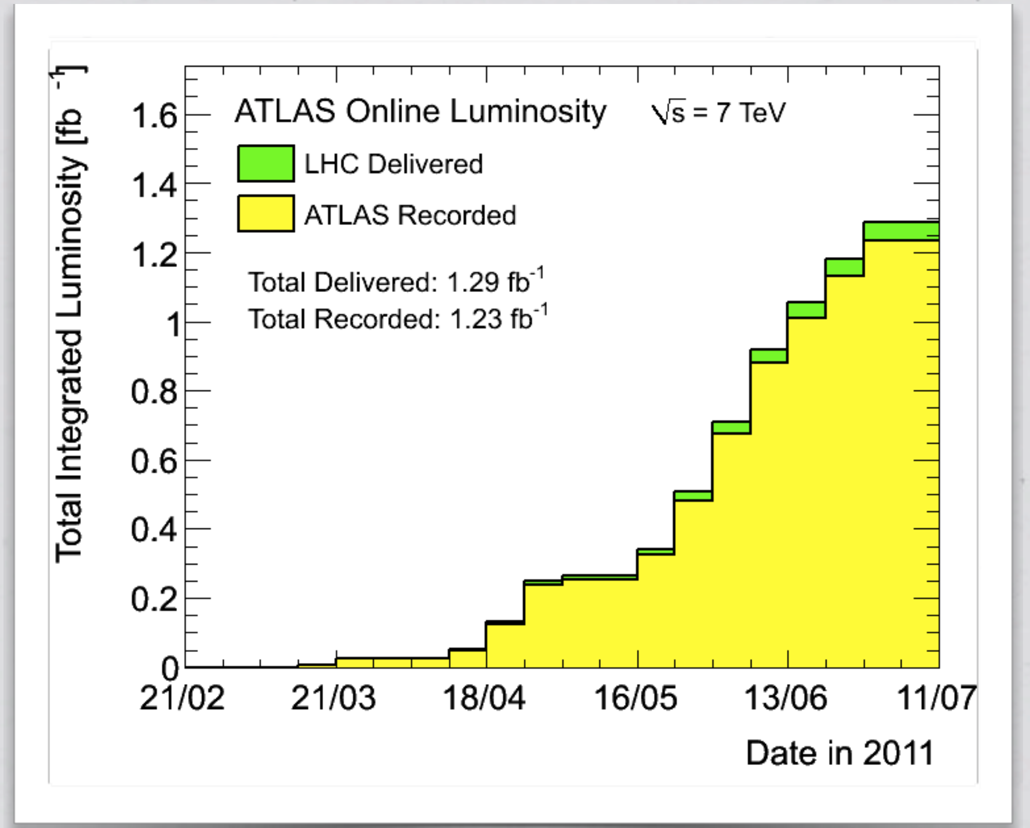
results after detector+acceptance unfolding: no significant hint of BSM asymmetry

	μ channel	e channel	combined	MC@NLO
A_C	-0.028±0.019(stat) ±0.022(syst)	-0.009±0.023(stat)±0.032(syst)	-0.023±0.015(stat)±0.021(syst)	0.005±0.001(stat)

Conclusions

Top properties have been exploited with 2010 L_{int}=35 pb^{-1} data, but also with higher statistics of data taken in 2011.

- Many interesting results that constrain several models.
- In many cases with very little data, already able to push the reach to the TeV scale, to reach Tevatron or to set world's best limits
- Statistically limited analyses will become very interesting now, we have already 1 fb^{-1} of data!



Our main goal now is to reduce the systematics

and … 2011 will be the year of top properties!