Search for new physics with top quarks in ATLAS

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Outline

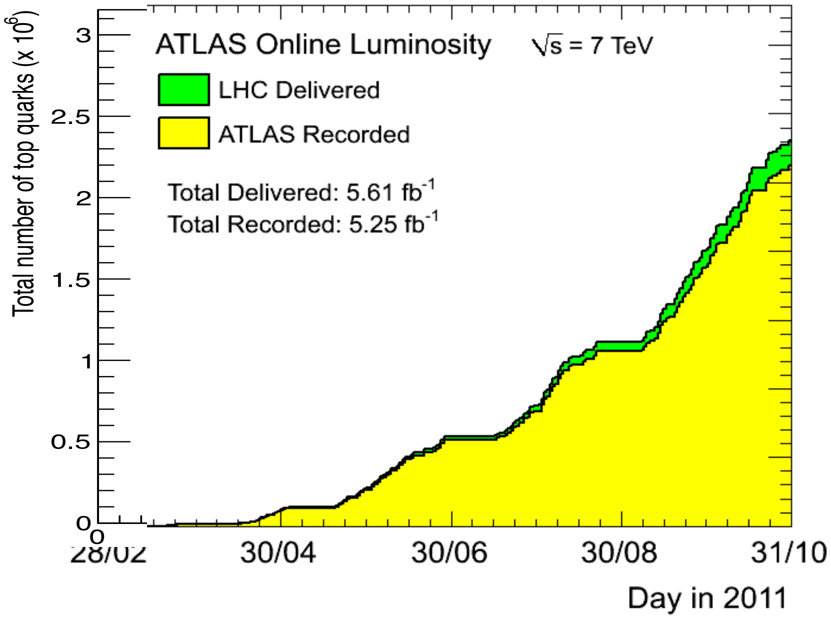
- Due to its large mass the top quark plays an important role in the decay of many BSM particles.
  - Direct searches for new physics with top quark final states
- Also, the LHC has already provided us high statistics of top quarks, we can aim for precision measurements
  - In 2012 LHC delivered 860,000 top quark pairs and 440,000 single tops to each experiment, more than ten times the Tevatron statistics

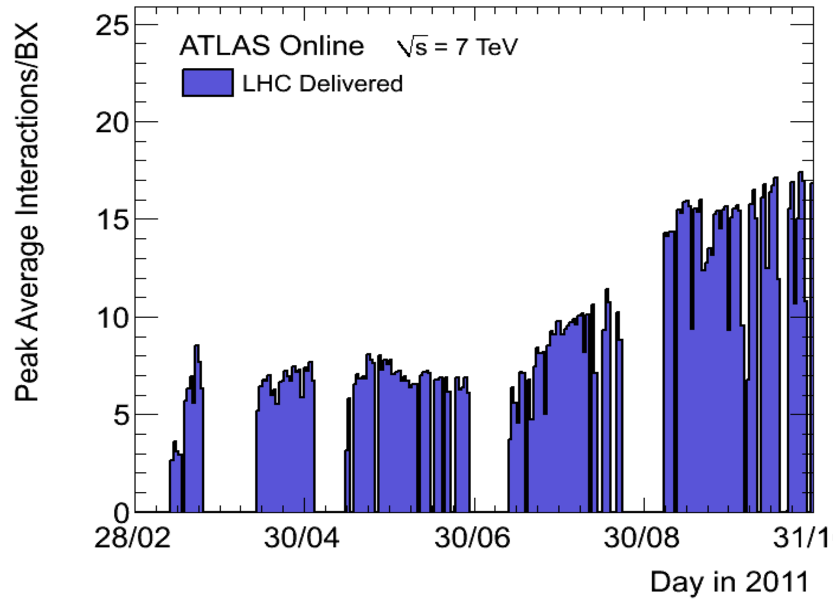
I will show some ATLAS results which are recent (most of them released in the last couple of weeks) and I am familiar with.

- Top quark charge asymmetry
- Single top FCNC production
- Scalar top searches

4th generation searches covered in the talk of Ehud on Saturday.

Which data ?

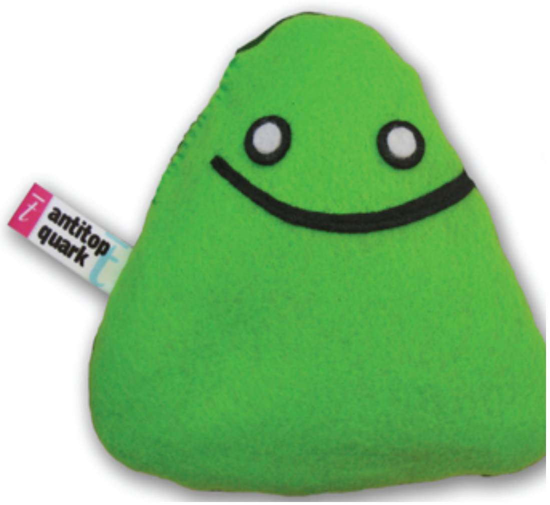




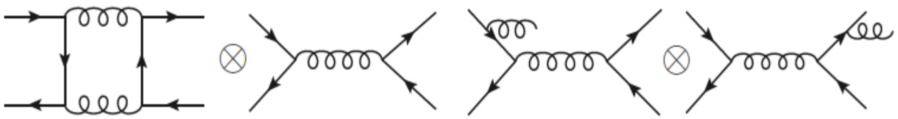
All results I will show have been obtained with the “ICHEP dataset” (1.0 fb^{-1}) or the “HCP dataset” (2.0 fb^{-1}).

Many 5 fb^{-1} results entering collaboration review, you’ll get them in next few weeks

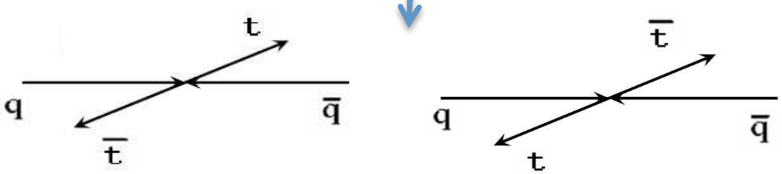
Top quark charge asymmetry



What it is



In SM, very small asymmetry from interference of NLO diagrams



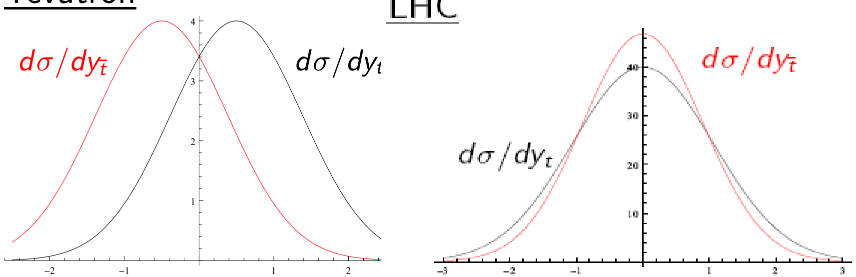
Preferred **Suppressed**

Asymmetry only in $q\bar{q}$ initial state: ~90% of collisions at Tevatron, but only ~20% at LHC

$$A(\cos\theta) = \frac{N_t(\cos\theta) - N_{\bar{t}}(\cos\theta)}{N_t(\cos\theta) + N_{\bar{t}}(\cos\theta)}$$

Parton level asymmetry. at Tevatron q direction Is mostly the p beam… but LHC is a pp collider

Tevatron LHC

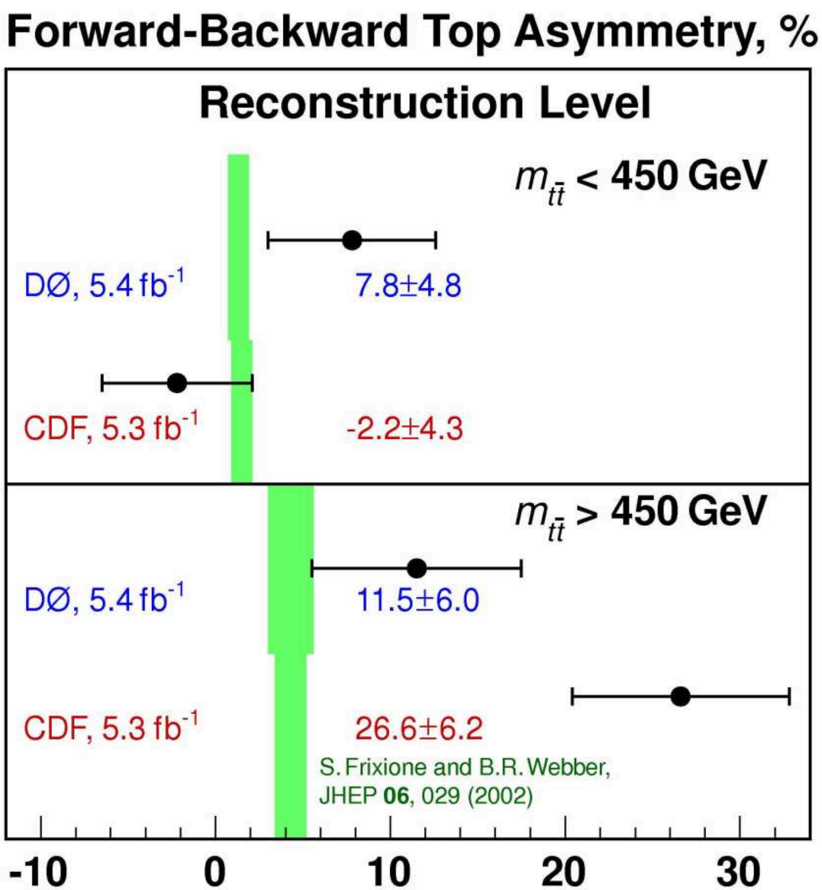


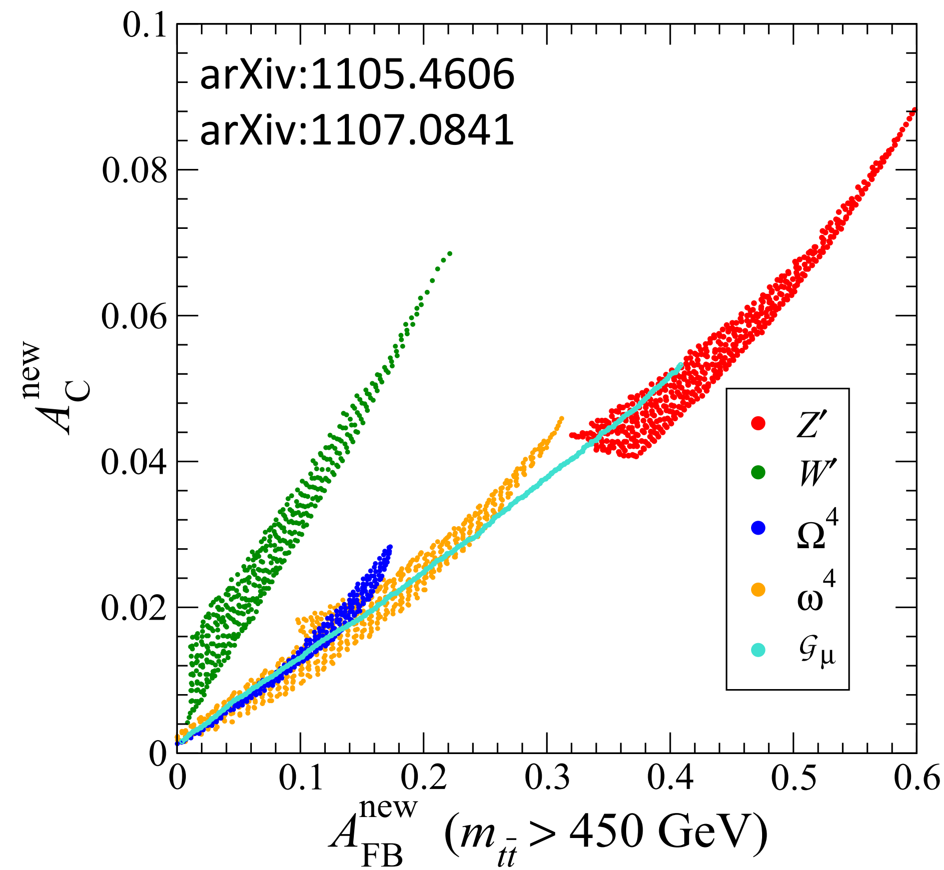
q is mostly from valence quark, more boosted than sea $\bar{q}$.. If top along q direction, it would tend to be less central than antitop

$$A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

Hence this is what we measure at LHC

Why it's interesting





New physics ?

Predictions show complementarity between Tevatron and LHC measurements

No reference yet, paper in preparation

- Preliminary results with 0.70 fb^{-1} shown at ICHEP. A paper with 1.04 fb^{-1} is in the final stages of collaboration review: I will show results which have been made available for conferences
- New: more data, measurement also as a function of $t\bar{t}$ invariant mass, improved treatment of systematics

Selection	Electron channel	Muon channel	
== 1 lepton with	p_T > 25 GeV	p_T > 20 GeV	
	E_T^{Miss} > 35 GeV	E_T^{Miss} > 20 GeV	Rejects multi-jet QCD
	M_T > 25 GeV	$E_T^{Miss}+M_T$ > 60 GeV	
>= 4 jets with	p_T> 25 GeV, $\|\eta\|$<2.5	p_T> 25 GeV, $\|\eta\|$<2.5	Rejects W
	>= 1 tagged jet	>= 1 tagged jet	

Definition: in this talk, M_T indicates the transverse mass between the leading lepton and the EtMiss vector.

Background determination

- Multi-jet from data (matrix method, next slide)
- W+jets: shape from MC. Normalization as follows

1. Rate before tagging: $N_{W^+} + N_{W^-} = \left(\frac{r_{MC}+1}{r_{MC}-1}\right)(D^+ - D^-),$

Number of observed events with positive or negative leptons

W^+/W^- ratio from MC

2. Rate after b-tagging: $W_{\geq 4,\text{tagged}} = W_{\geq 4,\text{pretag}} \cdot f_{2,\text{tagged}} \cdot k_{2\to\geq 4}.$

$k_{2\to\geq 4} \equiv f^{\text{MC}}_{\geq 4,\text{tagged}} / f^{\text{MC}}_{2,\text{tagged}}$

Extrapolation from 2-jet to 4-jet bin from MC

Fraction of W+2jet tagged events (from data)

- Z+jets, diboson, single top from MC

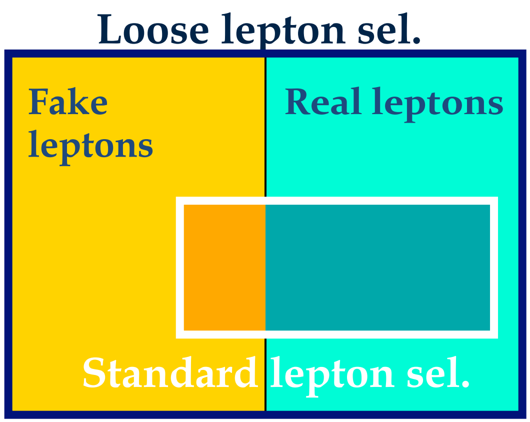
QCD background

- All analysis I will show estimated the multi-jet ("QCD") background from data with the so-called *matrix method*.
- a *tight* and a *loose* samples are defined
  - tight sample: standard lepton selection,
  - loose sample: looser lepton selection to enhance QCD (typically, drop cuts on isolation)
- the background is obtained solving this system:

$$N^{loose} = N^{loose}_{real} + N^{loose}_{fake},$$

$$N^{tight} = \varepsilon_{real} \cdot N^{loose}_{real} + \varepsilon_{fake} \cdot N^{loose}_{fake}$$

QCD background



✓ N^{loose} = events with a loose muon,

✓ N^{tight} = events with a tight muon,

✓ ε_{real} = / measured in Z(ll) events in data

✓ ε_{fake} = / measured with QCD selection (low E_T^{miss} and M_T).

Top direction reconstruction

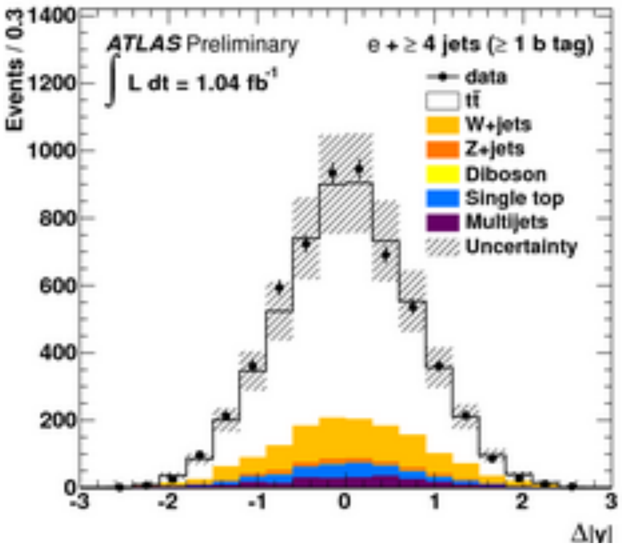
- Jets and leptons assigned to either top or antitop decay using a likelihood
  - Inputs are the 4-vectors of five highest p_T jets, E_T^{Miss}, and lepton, b-tagging information.
  - Constraints: W and top masses
  - Probability of each assignment computed (using experimental resolutions) and best combination chosen
- Then we unfold in 2 dimension ($t\bar{t}$ invariant mass, rapidity difference between top and antitop) from reconstructed to truth level (response matrix from mc@nlo, Bayesian iterative inversion)

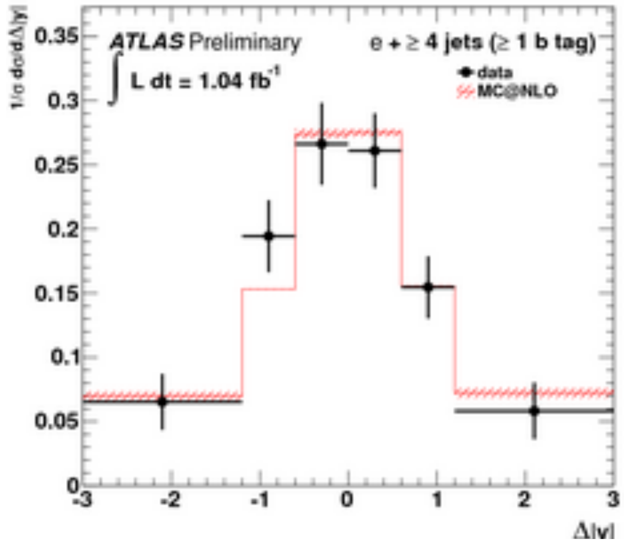
used as prior in next iteration

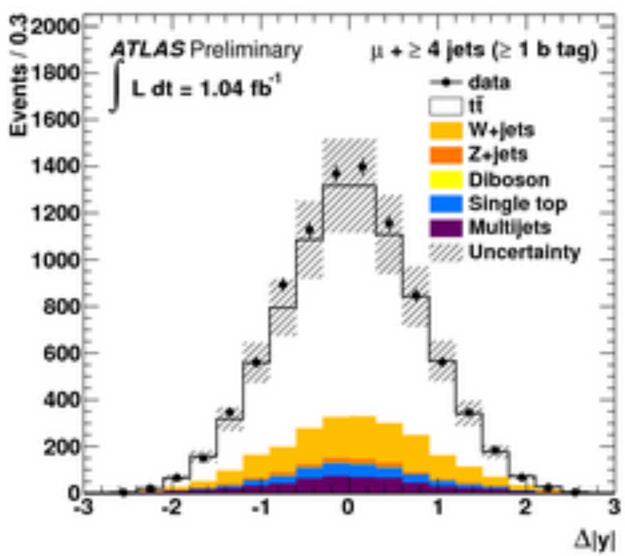
$$\boxed{P(T_j|S_i)} = \frac{\overbrace{P(S_i|T_j)}^{\text{response matrix}} P_0(T_j)}{\sum_j P(S_i|T_j) P_0(T_j)}$$

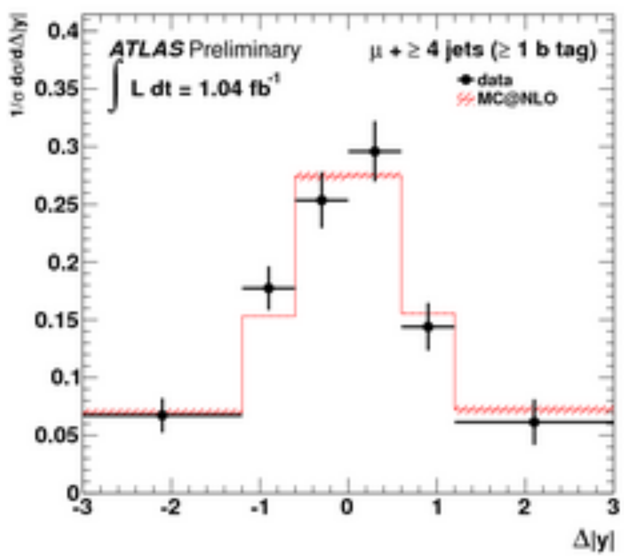
prior: MC truth from mc@nlo

Reconstructed and unfolded rapidities









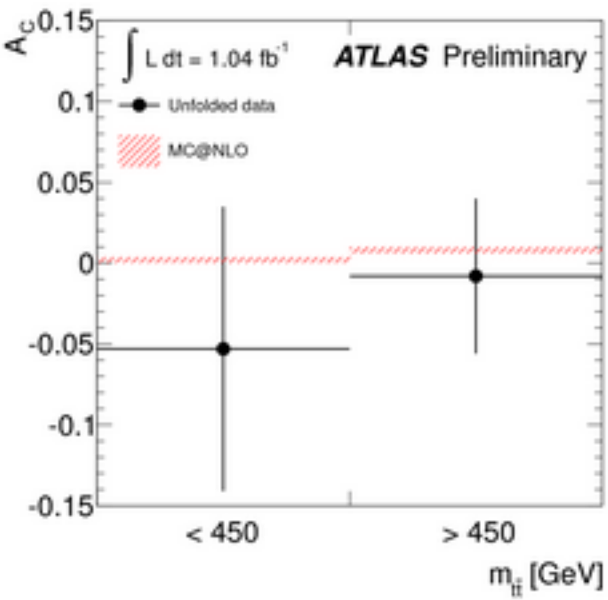
Results and interpretation

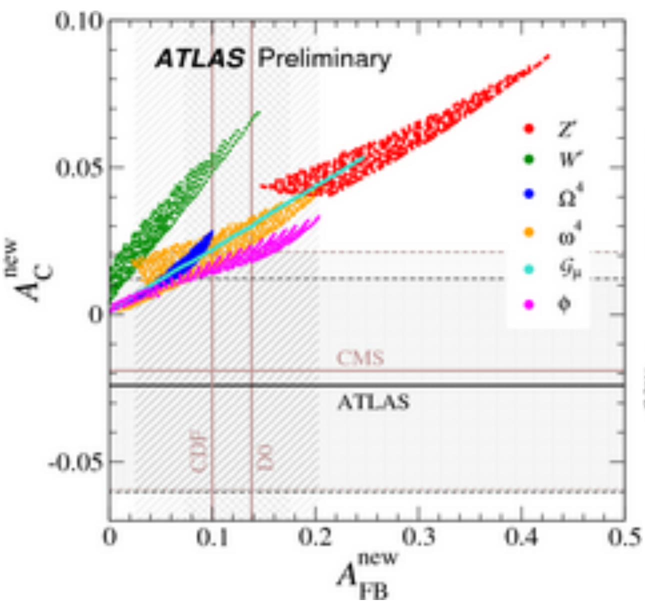
$$A_C = -0.018 \pm 0.028\,(\text{stat.}) \pm 0.023\,(\text{syst.})$$

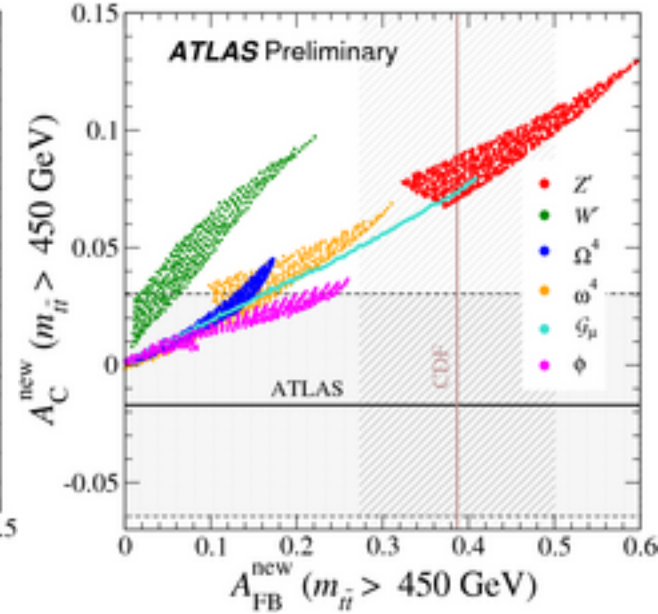
and

$$A_C = -0.053 \pm 0.070\,(\text{stat.}) \pm 0.054\,(\text{syst.}) \quad \text{for } m_{t\bar{t}} < 450 \text{ GeV},$$

$$A_C = -0.008 \pm 0.035\,(\text{stat.}) \pm 0.032\,(\text{syst.}) \quad \text{for } m_{t\bar{t}} > 450 \text{ GeV}.$$







Single top FCNC production

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No reference yet, paper in preparation

Motivations and strategy

- FCNC processes negligible in the SM, but enhanced to potentially observable rates in several new physics models
- ugt and cgt operators

$$\mathcal{L}_{eff} = g_s \sum_{q=u,c} \frac{\kappa_{qgt}}{\Lambda} \bar{t}\sigma^{\mu\nu} T^a (f_q^L P_L + f_q^R P_R) q G_{\mu\nu}^a + h.c.$$

can be probed with looking at either FCNC single top production (qg $\longrightarrow$ t) or decay (t $\longrightarrow$ gq). The former is actually more sensitive; I'll show results seeking

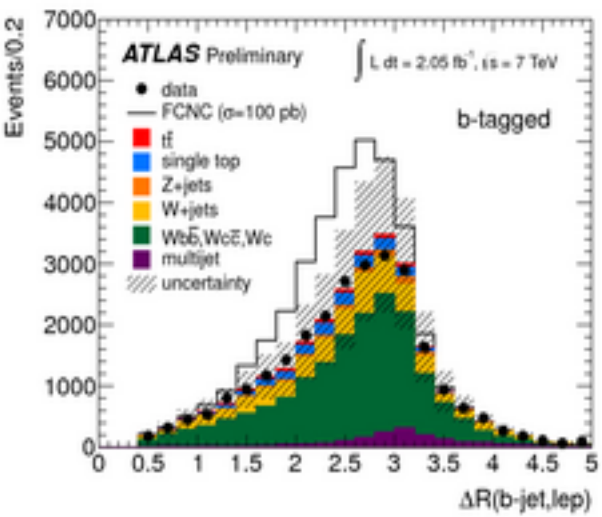
$$qg \rightarrow t \rightarrow Wb$$

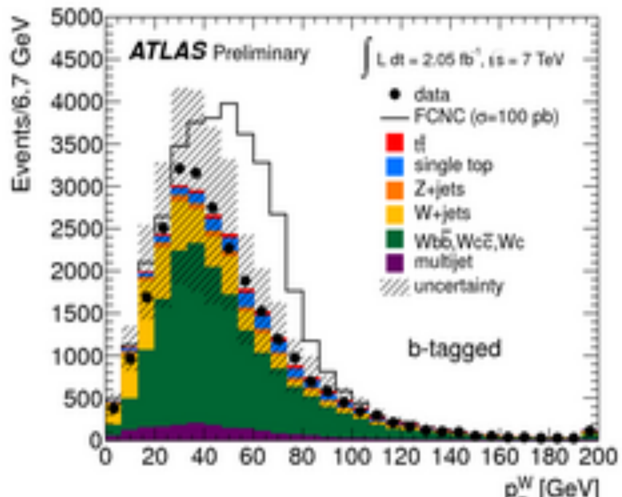
- Our preselection requires
  - Exactly one lepton with p_T > 25 GeV
  - E_T^{Miss} > 25 GeV and M_T+E_T^{Miss} > 60 GeV to supress QCD
  - Exactly one jet with p_T > 25 GeV, tagged as b.
- After this, 26223 events are observed in **2.05 fb^{-1}** of data, with a SM expectation of 24000 ± 7000. Only 113 signal events are expected for each pb of FCNC cross section. In order to have a good sensitivity, we use a **neutral network approach**

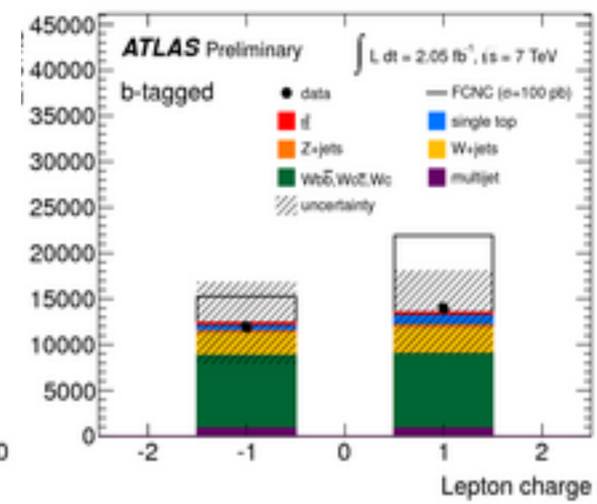
Neural network inputs

$p_{T,W}$
$\Delta R(\ell, b)$
Lepton charge
m_t
m_b
η_b
$\Delta\phi(W, b)$
$p_{T,\ell}$
$p_{T,b}$
$\cos\theta^*$
$\Delta R(W, b)$

- FCNC top quarks are produced almost at rest – p_T of top and decay products is softer, W and b have large relative angles.
- Also, FCNC produce some 4 times more positive than negative leptons (top/antitop), compared to a ratio between 1 and 2 of SM backgrounds.
- In total, 11 variables considered for the NN discriminant. The distribution for the more sensitive ones are shown.

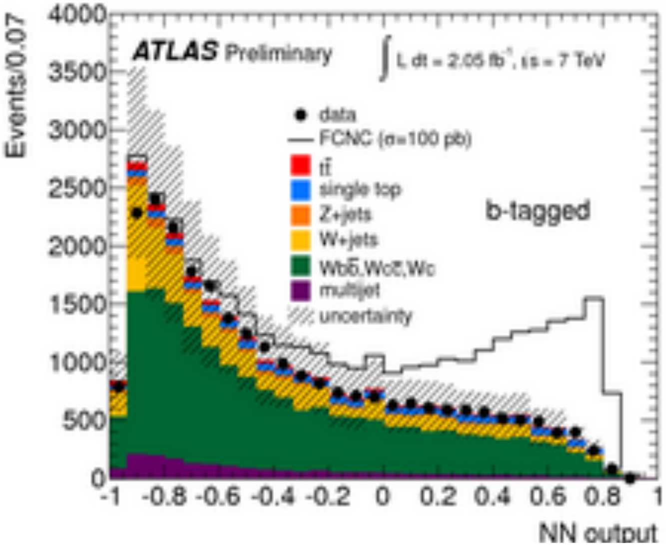






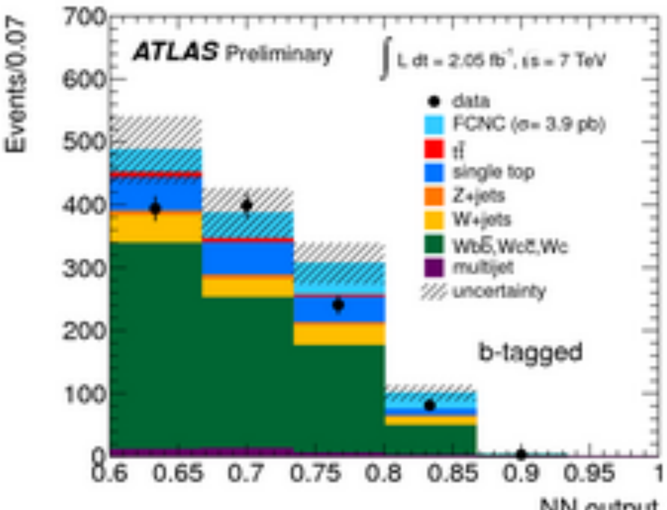
The agreement between data is quite good also before b-tagging, where any signal would be negligible.

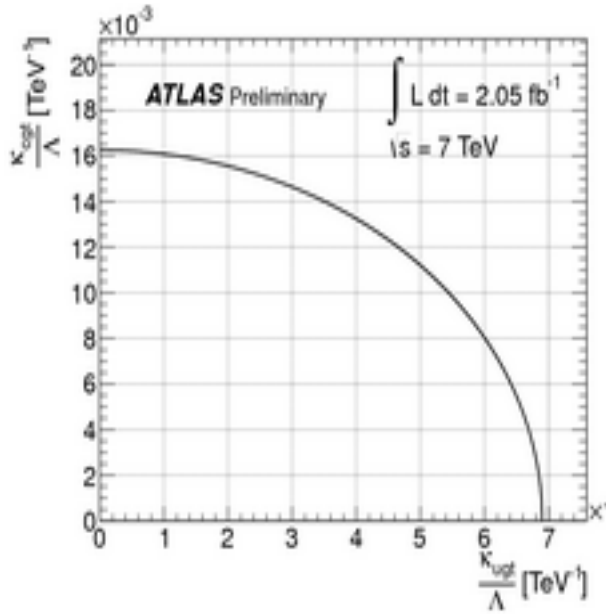
Results

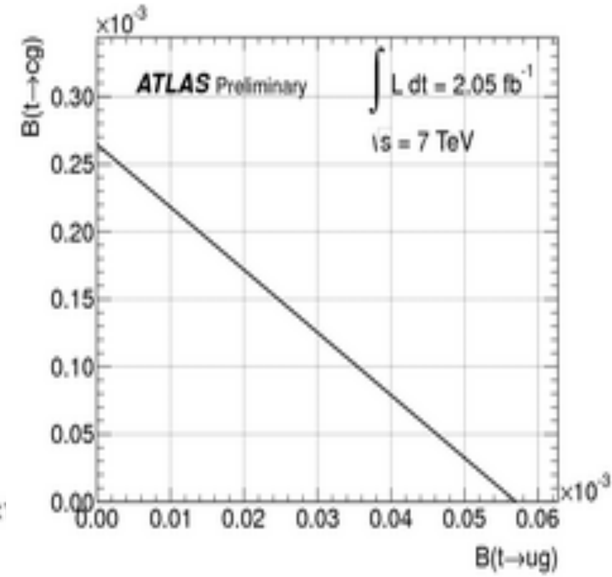


The observed (expected) limit is 3.9 pb (2.4 pb) at 95% C.L.

Resulting limits on couplings and branching ratios are better than previous best limits (from D0) by a factor of 4 and 15 for tug and tcg respectively.



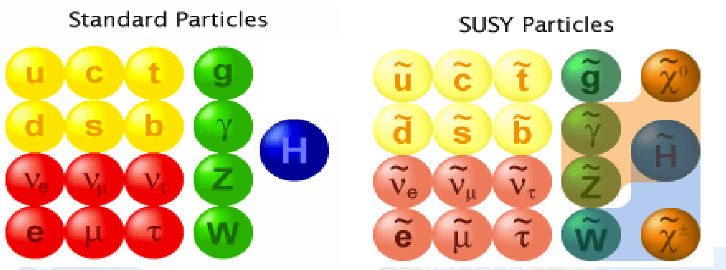


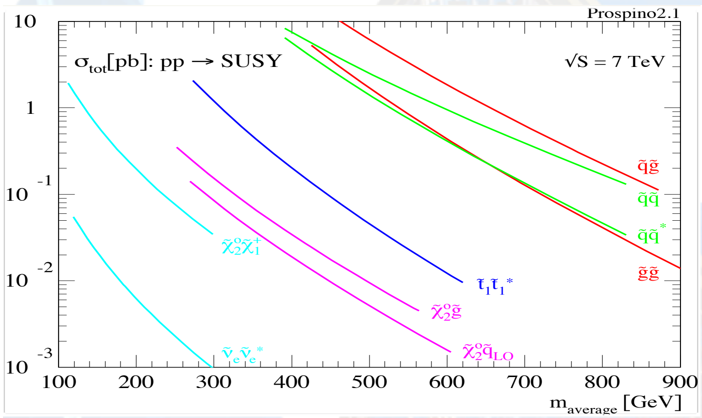


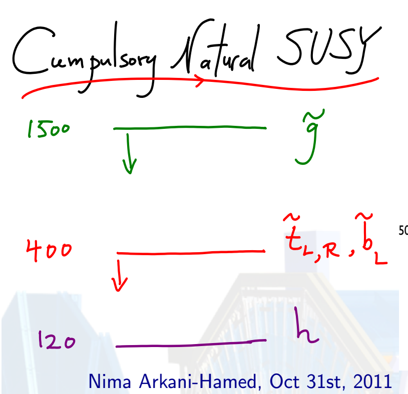
Zoom of high NN values. Signal here Is light blue, normalized to observed Limit; uncertainty band centered on SM+signal

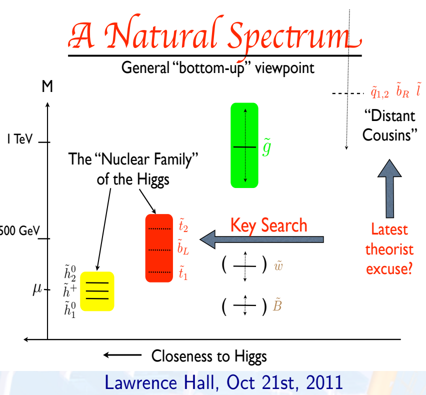
Scalar top searches

Motivation









Supersymmetry is a pretty promising extension of SM

- Provides a natural solution to hierarchy problem
- R-parity conservation gives a nice DM candidate

First searches at LHC tried to catch the easy preys: high-cross section squarks and gluinos.
No signal -> strong limits (between 600-1100 GeV)

A scalar top as light as 100 GeV is still allowed.

The scalar top is the one particle you want light to cancel the top correction to the Higgs mass.

Stop production

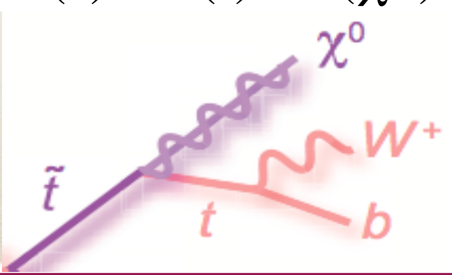
Gluino mediated production: $\tilde{g}\tilde{g} \longrightarrow \tilde{t}t\tilde{t}t$. If gluino not too heavy, best channel to find and study stop at LHC

- Cross section depends on gluino mass, final state relatively spectacular (= easy to separate from SM): 2 real tops plus the stop decay products.

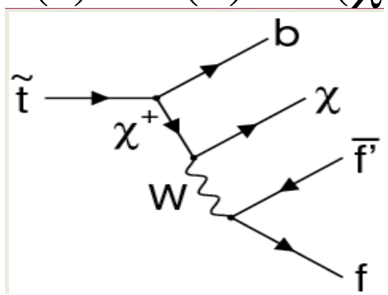
Direct production: depends only on the stop mass, but more difficult: small cross section if stop heavy, difficult to separate from SM if light

Stop decay

$m(\tilde{t}) > m(t) + m(\chi^0)$

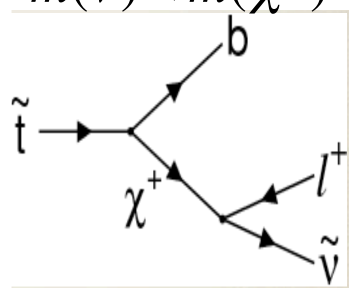


$m(\tilde{t}) > m(b) + m(\chi^\pm)$



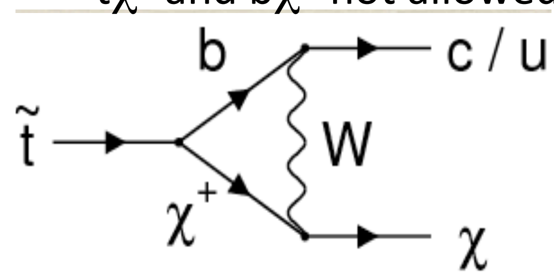
Same final state but different kinematics
Same visible final state as in top decay

$m(\tilde{t}) > m(b) + m(\chi^\pm)$
$m(\tilde{\nu}) < m(\chi^\pm)$



~100% blν blν final state

Significant only if $t\chi^0$ and $b\chi^\pm$ not allowed.



What follows in next slides

In practice, what I will be able to show to you is

- A search for events with 1 lepton, hard jets, missing energy with harsh cuts to suppress top pair production
  - Boosted direct stops contribute to signal, but requires gluino mediated contribution to be sensitive
  - This is a recent **2 fb^{-1}** update of a 35 pb^{-1} published analysis
- A new search channel, based on 2 same sign leptons, jets, missing energy
  - Targeting gluino pair production which can give two same sign tops in final state, this suppresses the SM background
- A published 1 fb^{-1} analysis (PRL 108, 041805) looking for anomalous E_T^{Miss} in a top-antitop selection
  - Good sensitivity to pair produced spin ½ top partner T, each decaying into a top and invisible particle (DM candidate). Very similar to $\tilde{t}\tilde{t} \longrightarrow tt\,\chi^0\chi^0$, but about 6 times cross section.

ATL-CONF-2012-003
Paper in preparation

b-jets+E_T^{Miss}+1 lepton analysis

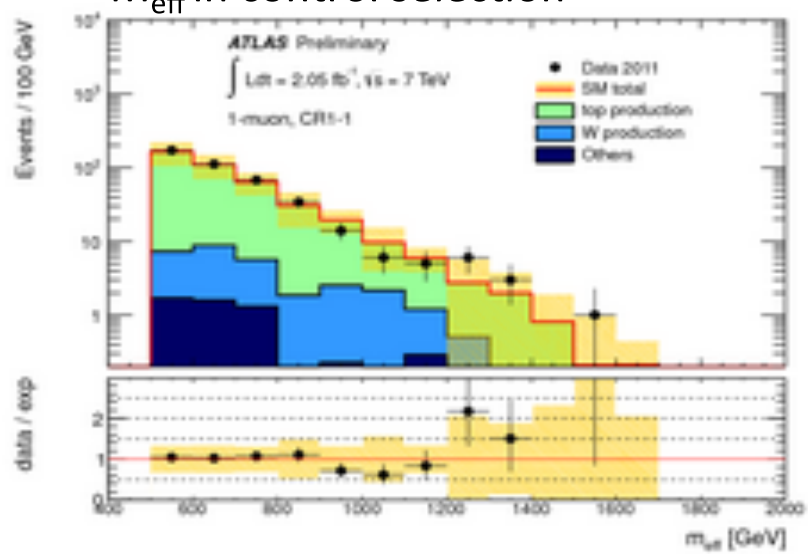
- Selection is:
  - Exactly one electron (p_T > 25 GeV) or muon (p_T> 20 GeV) used to trigger
  - ≥4 jets with p_T(jet1) > 60 GeV and p_T(jet2,3,4) > 50 GeV, one of the 4 leading jets must be b-tagged
  - E_T^{Miss} > 80 GeV and m_T > 100 GeV (relies on extra MET in signal from lightest susy particles)
  - m_{eff} > 700 GeV (selection SR1D) or m_{eff} > 700 GeV, E_T^{Miss} > 200 GeV (selection SR1E)
  - Effective mass definition: $\mathrm{m_{eff}} = \sum_{i\leq n}(p_{\mathrm{T}}^{\mathrm{jet}})_i + E_{\mathrm{T}}^{\mathrm{miss}} + \sum_j (p_{\mathrm{T}}^{\mathrm{lep}})_j$

Main background (SM top pairs) estimated using the selection:
Leptons, jets, b-jet selection as in signal region
40 < m_T < 100 GeV, m_{eff} > 500 GeV
and extrapolating to signal region with MonteCarlo:

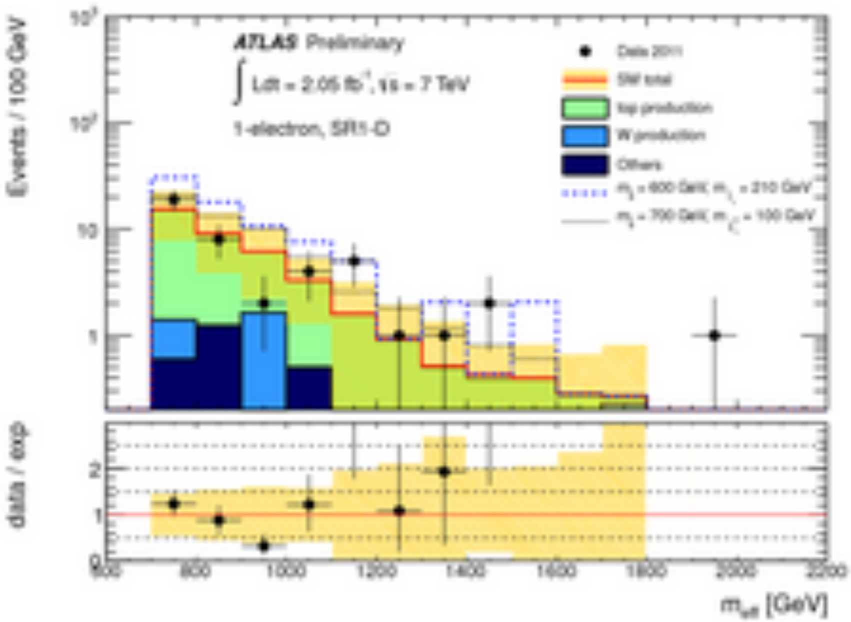
$$N_{SR}^{est,Bkg} = \frac{N_{SR}^{MC}}{N_{CR}^{MC}}(N_{CR}^{data} - N_{CR}^{MC,others})$$

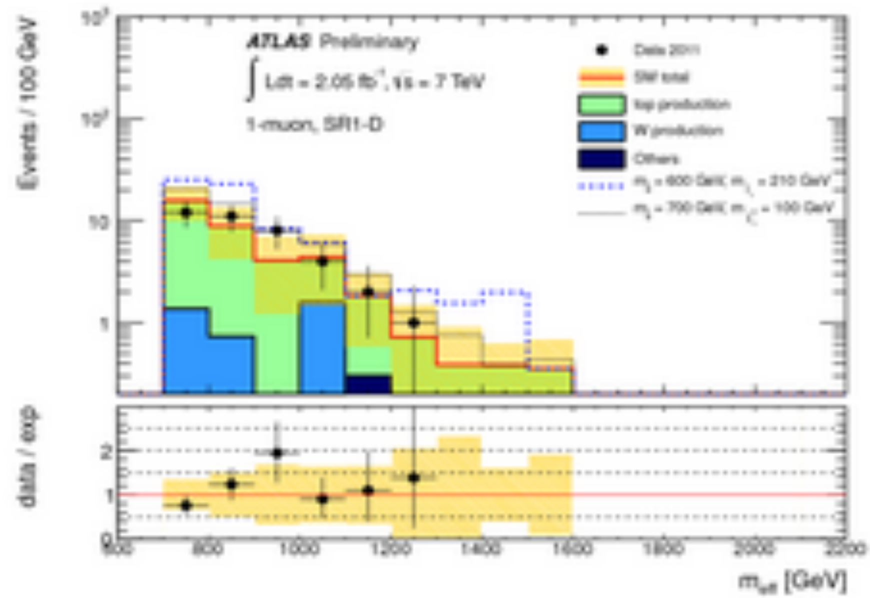
Standard SUSY searches technique, many uncertainties reduced in the ratio

M_{eff} in control selection



b-jets+E_T^{Miss}+1 lepton analysis





SR	SM background	Data
SR1-D (e)	39 ± 12 (39)	43
SR1-D (μ)	38 ± 14 (37)	38
SR1-E (e)	8.1 ± 3.4 (7.9)	11
SR1-E (μ)	6.3 ± 4.2 (6.1)	6

No evidence of a signal!

ATL-CONF-2012-004
Paper in preparation

Same sign lepton analysis

- Selection:
  - $\geq$ 2 leptons (e or mu) with p_T > 20 GeV, leading pair with same charge and invariant mass > 12 GeV.
  - $\geq$ 4 jets with p_T > 50 GeV
  - Two signal candidate selections: E_T^{Miss} > 150 GeV (SR1), E_T^{Miss} > 150 GeV and M_T > 100 GeV (SR2)
- Backgrounds:
  - Fake and non isolated leptons: estimated with matrix method
  - Electron charge misidentification, in particular in top pair production.

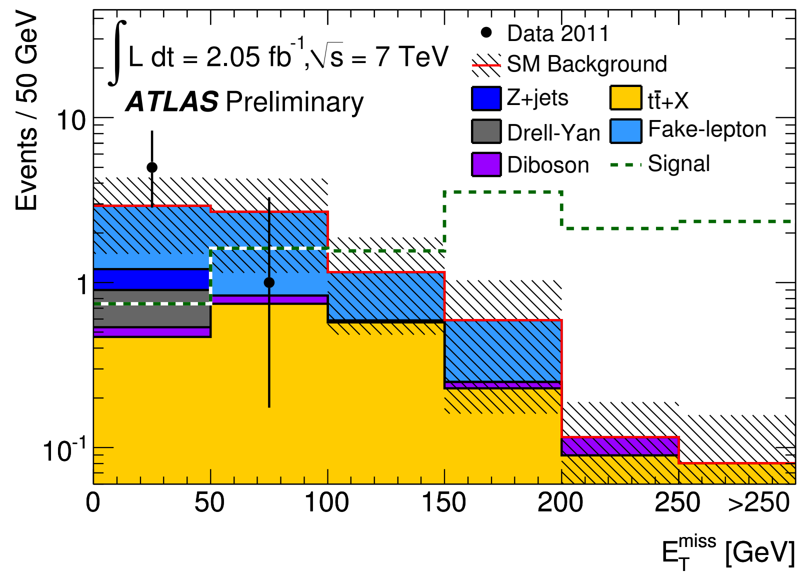
$$e^{\mp}_{\mathrm{hard}} \rightarrow \gamma_{\mathrm{hard}} e^{\mp}_{\mathrm{soft}} \rightarrow e^{\mp}_{\mathrm{soft}} e^{\mp}_{\mathrm{soft}} e^{\pm}_{\mathrm{hard}}$$

MonteCarlo corrected charge misidentification probability from measuremtns of same sign electrons with mass in Z peak

  - Diboson and $t\bar{t}W, t\bar{t}WW, t\bar{t}Z$ from MonteCarlo

Same sign search results

	SR1	SR2
$t\bar{t}$ +X	0.37 ± 0.26	0.21 ± 0.16
Diboson	0.05 ± 0.02	0.02 ± 0.01
Fake-lepton	0.34 ± 0.20	< 0.17
Charge mis-ID	0.08 ± 0.01	0.039 ± 0.007
Total SM	0.84 ± 0.33	0.27 ± 0.24
Observed	0	0
σ_{vis}	<1.6 fb	<1.5 fb



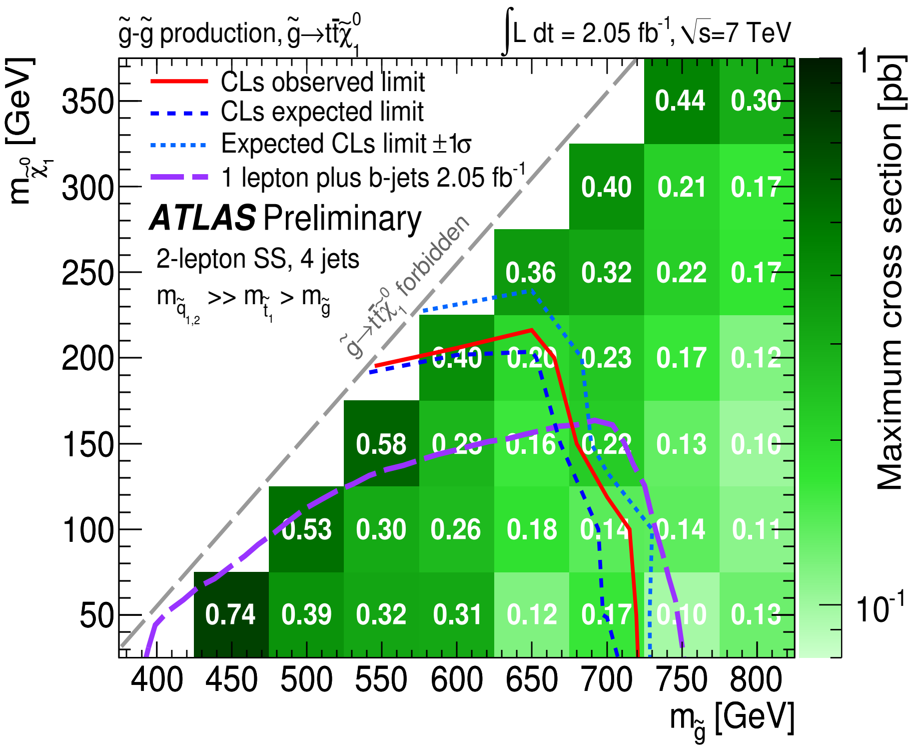
No signal candidates are observed in either signal region.
Limits on the signal cross section times cuts acceptance times efficiency (σAε) reported.

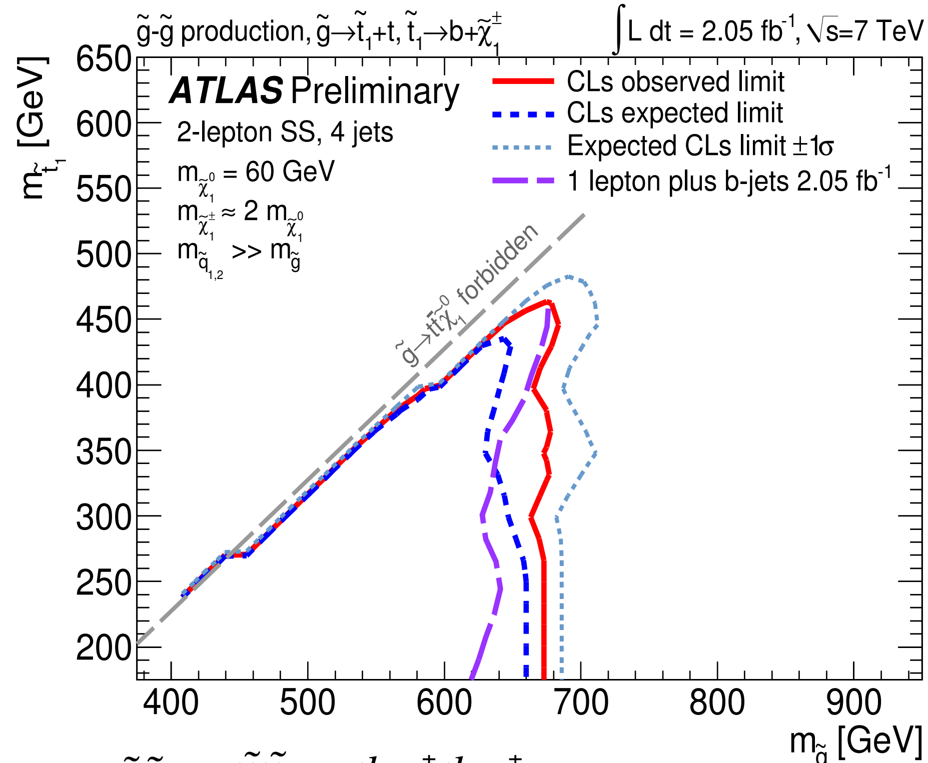
Events with 2 SS leptons and 4 jets with p_T > 50 GeV. SR1 are the events with E_T^{Miss} > 150 GeV on this plot.

These are quoted in all SUSY papers. We also try to provide (as HEPdata files, after submission of the paper) Aε for signal benchmarks. You can

- Validate your simplified detector simulation setup with these values
- Use the σAε limits to constrain your favorite model.

Gluino-mediated stop limits





$\tilde{g}\tilde{g} \rightarrow t\bar{t}\,\chi^0 t\bar{t}\,\chi^0$ via off-shell stop.

Limits as a function of gluino and neutralino masses; SS (in red) and b-jet (in blue) limits cover complementary regions of parameter space.

$\tilde{g}\tilde{g} \rightarrow t\tilde{t}t\tilde{t} \rightarrow tb\chi^{\pm}tb\chi^{\pm}$

Limit as a function of gluino and stop masses, for fixed neutralino (60 GeV) and chargino (120 GeV) masses.

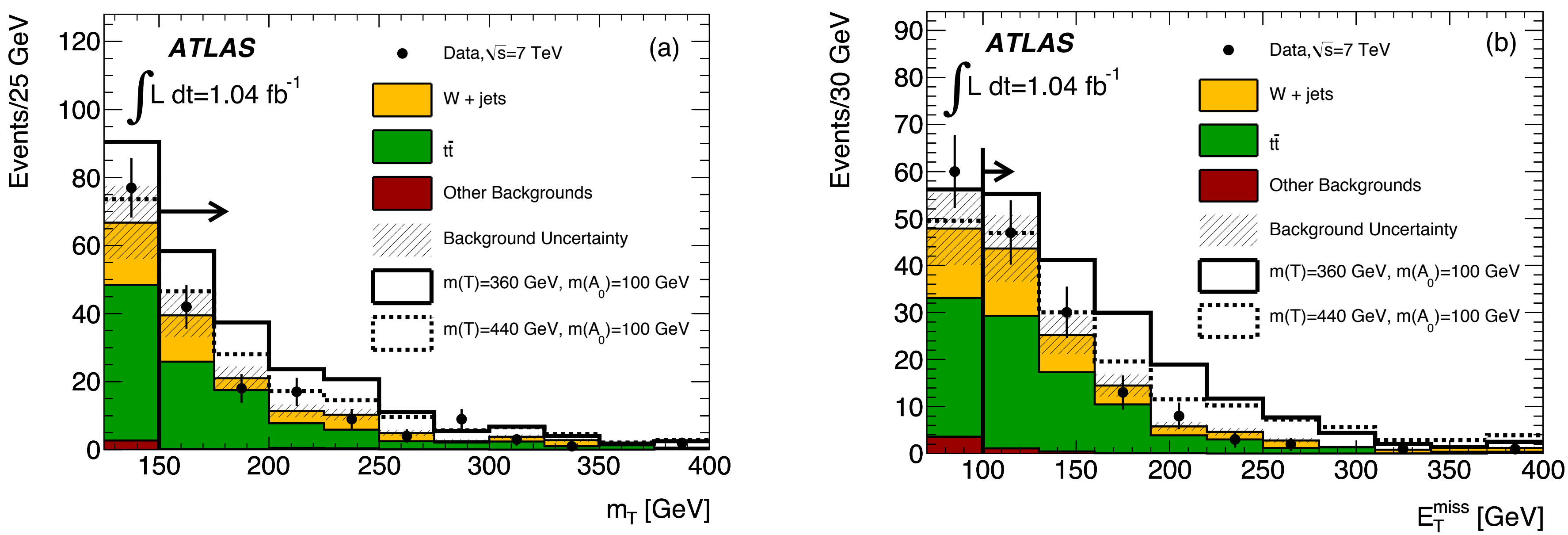
Extra E_T^{Miss} in $t\bar{t}$ events

Last year we published a search for anomalous missing energy in tt events.
The selection is

Exactly one electron (p_T > 25 GeV) or muon (p_T > 20 GeV)

≥ 4 jets with p_T > 25 GeV

M_T > 150 GeV, and E_T^{Miss} > 100 GeV to reject semileptonic tt and W+jets. The main background surviving the cuts is actually dileptonic ttbar with one undetected lepton (or tau)



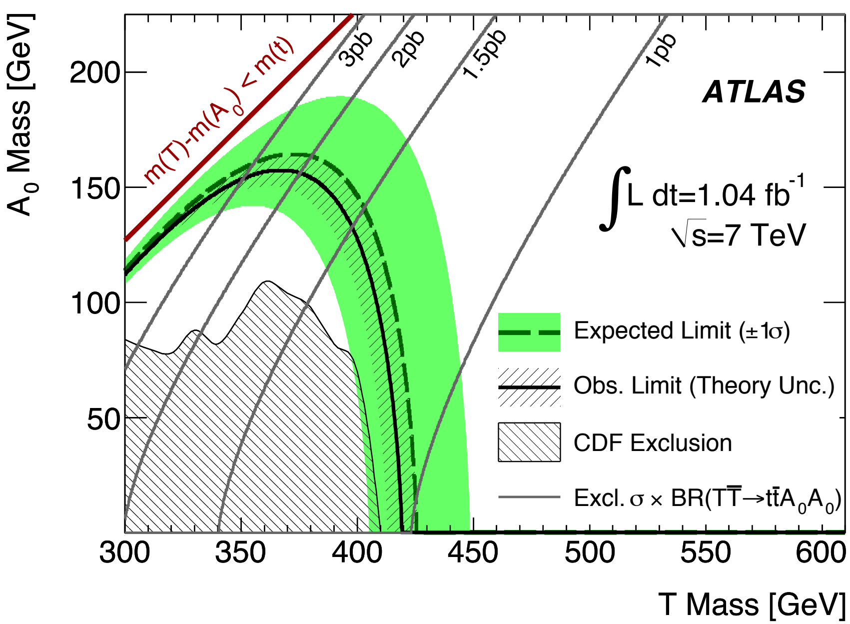
Anomalous E_T^{Miss} in $t\bar{t}$ events

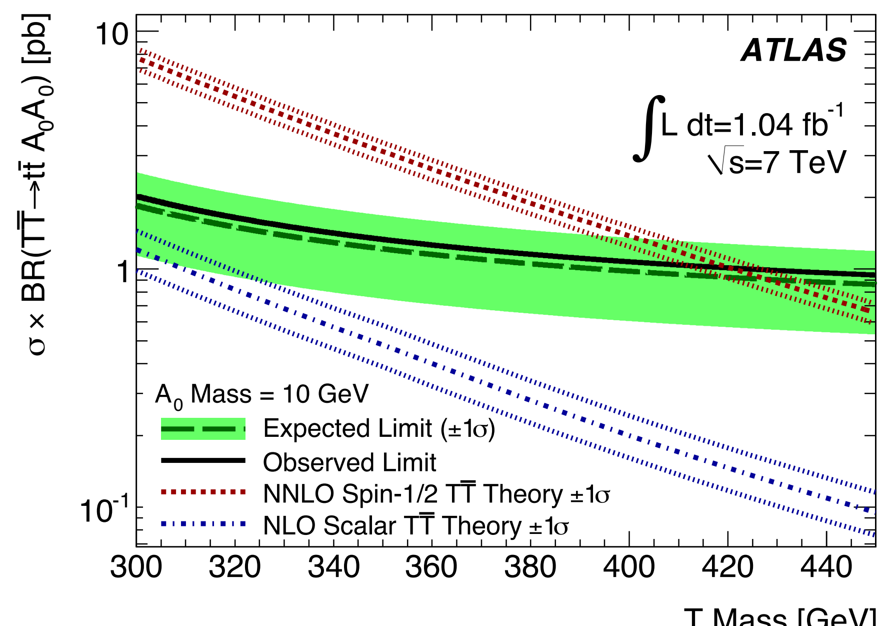
Source	Number of events
Dilepton $t\bar{t}$	62 ± 15
Single-lepton $t\bar{t}/W$+jets	33.1 ± 3.8
Multi-jet	1.2 ± 1.2
Single top	3.5 ± 0.8
Z+jets	0.9 ± 0.3
Dibosons	0.9 ± 0.2
Total	101 ± 16
Data	105

In 1.04 fb^{-1} of data, results are consistent with Standard Model expectations.

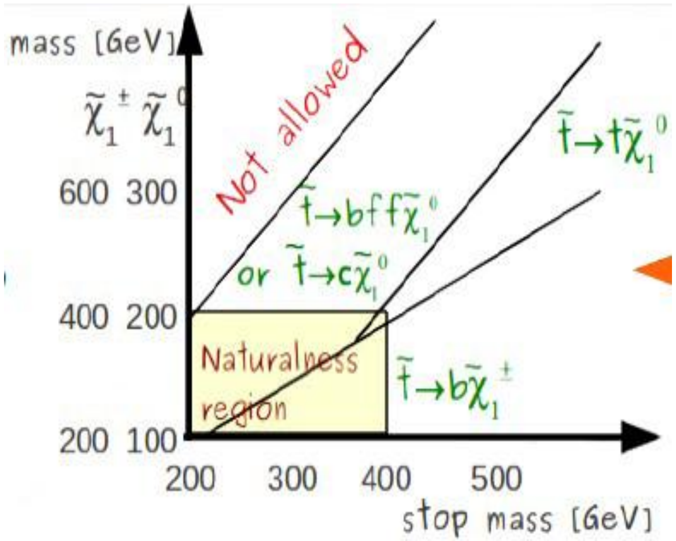
We place a limit on pair produced spin ½ top partner T decaying to an invisible particle

Pair produced scalar top decaying into top neutralino have the same acceptance, but are not excluded yet as the cross section is 6 times lower.

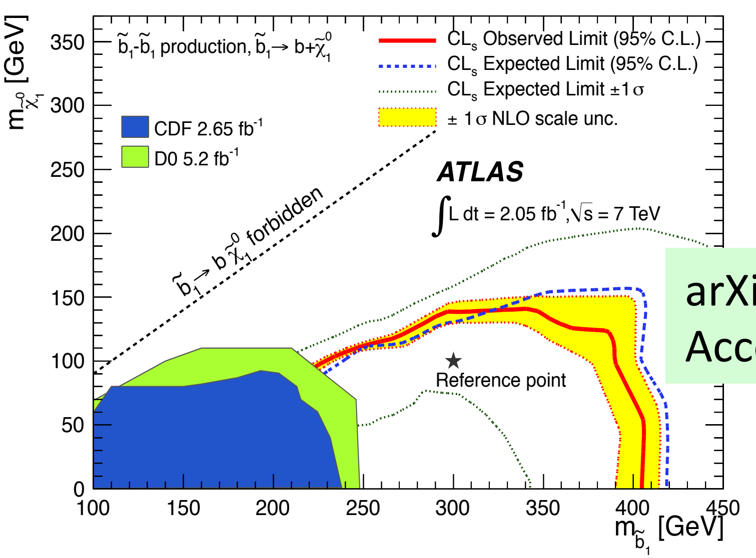




Direct stop searches



..*or* $\tilde{t}_1 \to bl\tilde{\nu}$ *if sneutrino LSP*



arXiv:1112.3832
Accepted by PRL

Many analysis are being performed with 5 fb^{-1}:

- $\tilde{t}\tilde{t} \to c\chi^0 c\chi^0$

This might sound prohibitive (two jets and missing energy have large backgrounds) but the Tevatron existing limit shows you can do it

Also notice we have already extended the Tevatron limit on direct sbottom production with $\tilde{b}\tilde{b} \to b\chi^0 b\chi^0$

- $\tilde{t}\tilde{t} \to b\chi^{\pm} b\chi^{\pm} \to ff'b\chi^0 ff'b\chi^0$ or $\tilde{t}\tilde{t} \to t\chi^0 t\chi^0$

We are doing it for many scenarios (0, 1, 2 lepton channels; stop lighter than or heavier than top).

Stay tuned!

Conclusions

- I've presented the last results in searches for new physics in top final states with ATLAS
  - Nothing exciting seen with 1-2 fb^{-1}
  - We will keep looking
  - 5 fb^{-1} analysis ongoing, also looking forward to the next 15-20 fb^{-1} (at 8 TeV)
- Many top measurements limited by systematics
  - We can get smarter, and trade statistics for systematics too
  - Also: look at more differential distributions, for example in charge asymmetry
- Constraints to scalar top direct production will come
  - Constrain a critical particle for SUSY models, without relying on gluino being within reach


Auxiliary Material

Analysis ingredients

Trigger

- All analysis shown based on single lepton selection, constant efficiency for $p_T > 20$ (25) muon (electron)

Jets

- AntiKt 0.4 algorithm
- b-tagging based on multivariate algorithm using tracks secondary vertices and impact parameter. 60% or 70% efficiency working points.

Transverse missing energy

Computed from calorimeter cells calibrated to the energy scale of the object (jet, electron, etc.) they belong to (if any), and muons.

Electrons

- $|\eta|<2.47$, top charge asymmetry and FCNC analysis discard electrons with $1.37 < |\eta| < 1.52$ (poorer resolution)
- Isolation: cuts on calorimeter ΣE_T in $\Delta R<0.3$ cone and/or track ΣP_T in $\Delta R<0.3$ cone.

Muons

- $|\eta| < 2.5$
- Isolation: cuts on calorimeter ΣE_T in $\Delta R<0.3$ cone and/or track ΣP_T in $\Delta R<0.3$ cone.

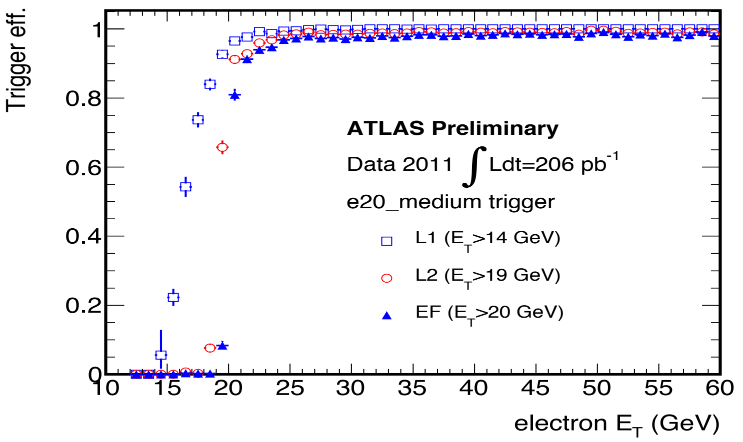
Details can be found in the specific analysis documentation

SM Monte Carlo samples

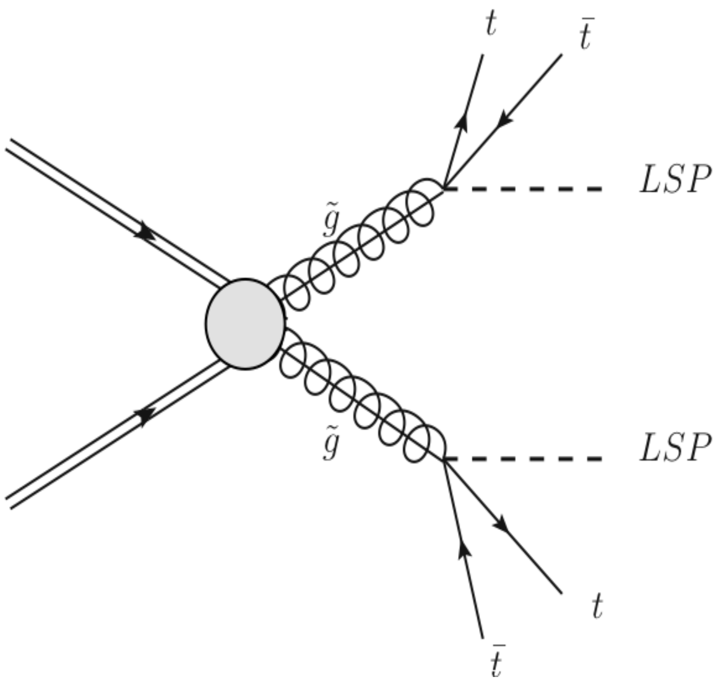
Baseline samples are quite uniform across the analysis I will show

- t-channel and Wt single top: AcerMC or MC@NLO
- s-channel single top: MC@NLO
- W+jets, Z+jets: Alpgen+Herwig
- WW,WZ,ZZ: Herwig
- tt: MC@NLO
- ttW, ttZ: MadGraph
- Minimum bias: Pythia
- PDF: CTEQ6

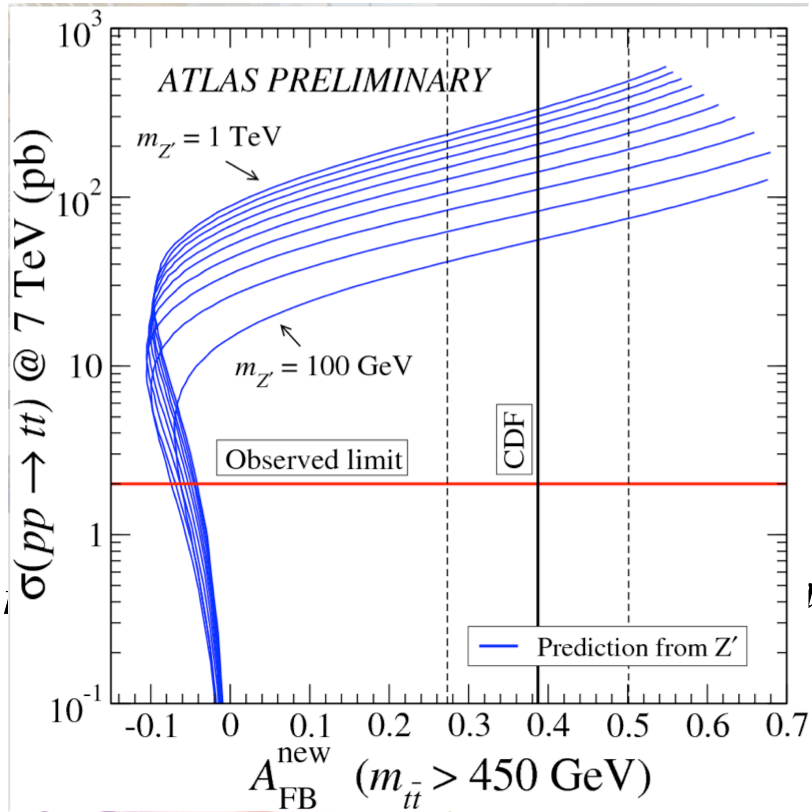
Comparison with other generators included in the systematics evaluation



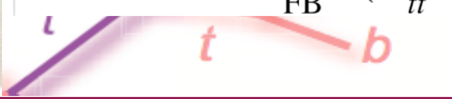
Trigger eff.
1
0.8
0.6
0.4
0.2
0
10
15
20
25
30
35
40
45
50
55
60
electron E_T (GeV)
ATLAS Preliminary
Data 2011 $\int Ldt=206\ pb^{-1}$
e20_medium trigger
L1 (E_T>14 GeV)
L2 (E_T>19 GeV)
EF (E_T>20 GeV)


t
$\bar{t}$
LSP
$\tilde{g}$
$\tilde{g}$
LSP
t
$\bar{t}$

Some other results



$\iota(\chi^{\pm})$



Significant only if
$t\chi^0$ and $b\chi^{\pm}$ not allowed.