Search for SUSY with Heavy Flavour at ATLAS

IoP Joint HEPP and APP Meeting

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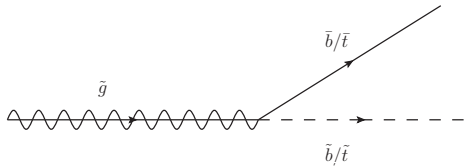
SUSY processes of interest

Why look for third generation SUSY?

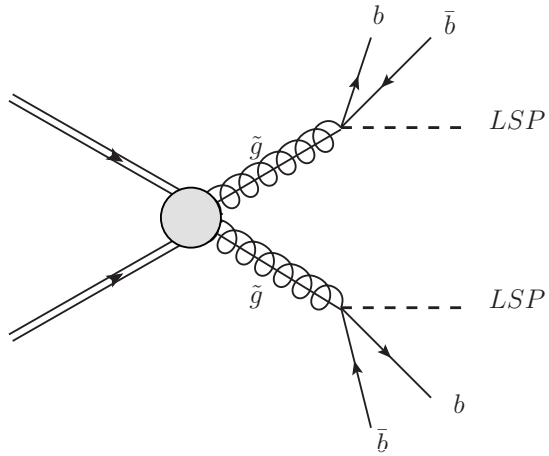
- Hierarchy problem solved naturally if the 3rd generation is light
- Large mixing in the third generation $\Rightarrow$ low $m(\tilde{t}_1)$ and $m(\tilde{b}_1)$

If $m(\tilde{g})$ accessible at 7 TeV then we search for Gluino mediated sbottom pair production.

If $m(\tilde{g}) > m(\tilde{b})$ consider:



If $m(\tilde{g}) < m(\tilde{b})$ consider:

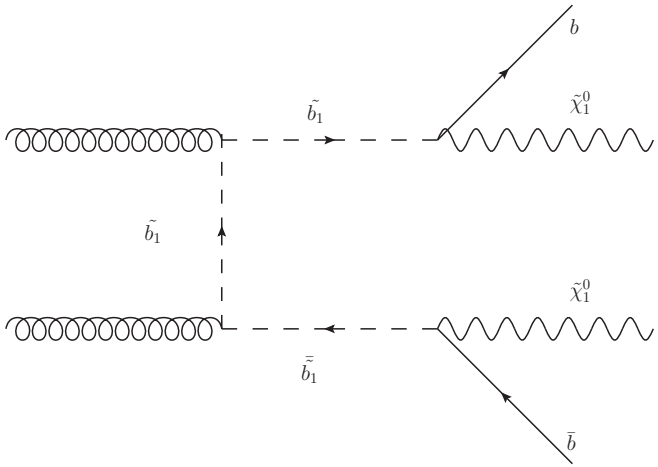


SUSY processes of interest

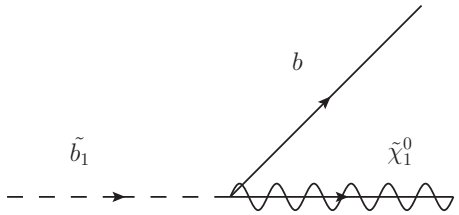
Why look for third generation SUSY?

- Hierarchy problem solved naturally if the 3rd generation is light
- Large mixing in the third generation $\Rightarrow$ low $m(\tilde{t}_1)$ and $m(\tilde{b}_1)$

If $m(\tilde{g})$ not accessible at 7 TeV then we search for direct sbottom pair production.



$\tilde{b} \rightarrow b + \tilde{\chi}^0$ always:



Search Strategies

- R-Parity conservation $\Rightarrow$ the Lightest Supersymmetric Particle (LSP) is stable.
  - Expect large Missing Transverse Energy (E_T^{miss})
- Squarks and gluinos decay to LSP:
  - High p_T jets (2 in $\tilde{b}\tilde{b}$ and 4 in $\tilde{g}$-mediated)
- Expect heavy flavour jets:
  - Require jets identified as b-jets (b-tag)

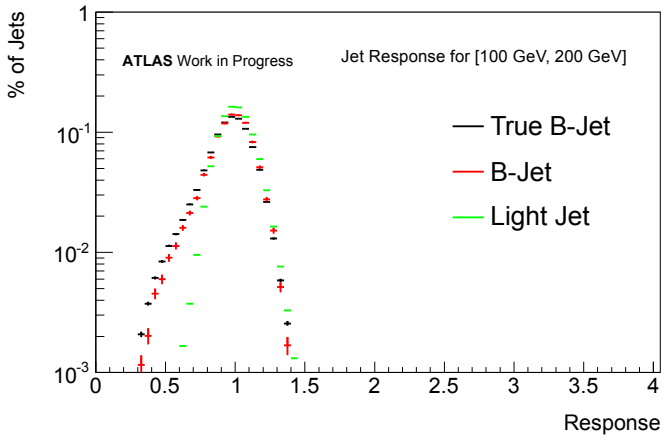
Analyses Philosophy

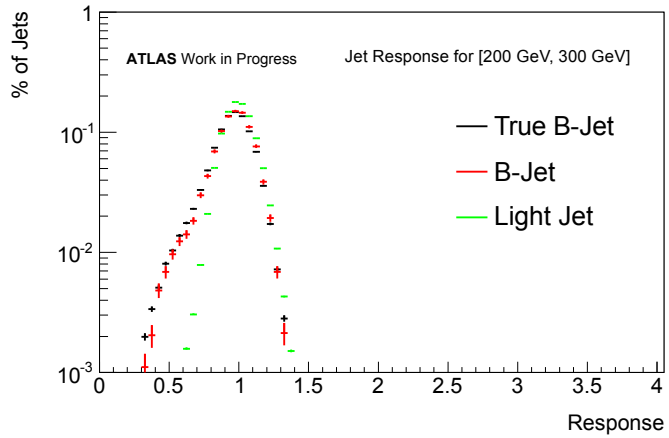
- Use cut and count analyses
- Try to minimize the dependence on Monte Carlo for Backgrounds
- In the absence of SUSY: set 95 % C.L. using CL_s

Background Estimation: QCD (i)

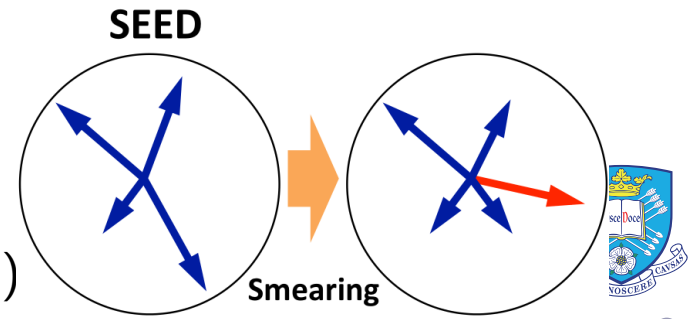
Use the Jet Smearing Method to estimate the E_T^{Miss} coming from detector jet energy mismeasurement or ν in b-jets.

1. Build response ($R = p_T^{reco}/p_T^{true}$) from the Monte Carlo



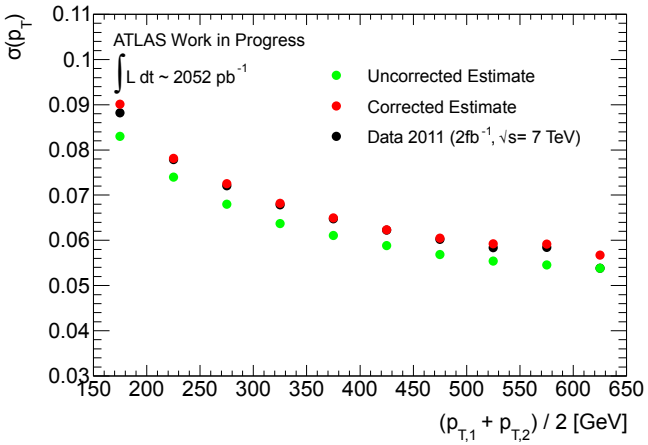


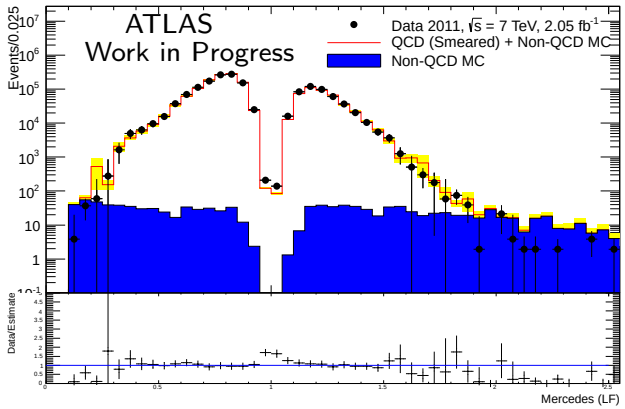
2. Modify and validate the Gaussian Core (in dijet balance) and tails (in Mercedes distribution)
3. Select clean, well-measured, seed events
4. Smear the jets in the seed events with R
5. Normalize in a QCD enriched control region (CR)



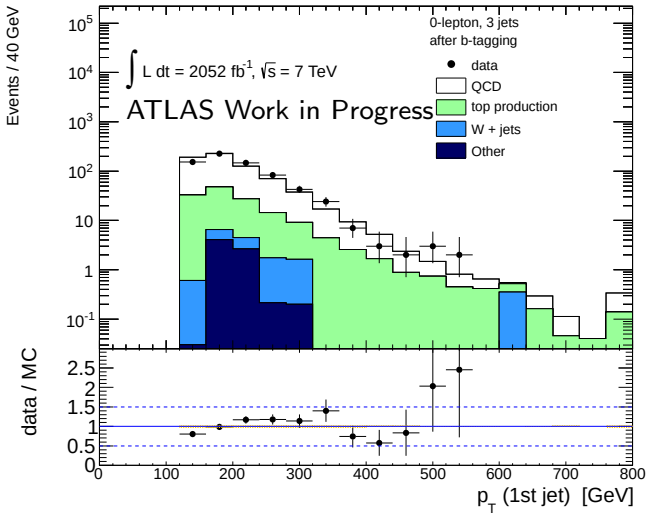
Background Estimation: QCD (ii)

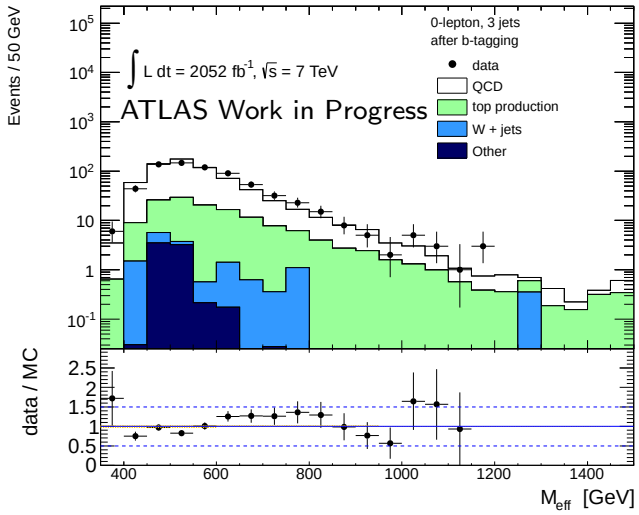
Dijet balance widths (left) and the Mercedes distribution (right) are both well modelled





⇒ good description of various kinematic variables in CR:





Background Estimation: Non-QCD

For the top and W/Z use a semi data-driven technique based on transfer factors from background enhanced control regions (CR) to signal regions (SR):

$$N_{SR}^{bkg,est} = \frac{N_{SR}^{bkg,MC}}{N_{CR}^{bkg,MC}}(N_{CR}^{data} - N_{CR}^{other,MC}) = TF(N_{CR}^{data} - N_{CR}^{other,MC}) \quad (1)$$

This allows for the cancellation of correlated uncertainties in the ratio

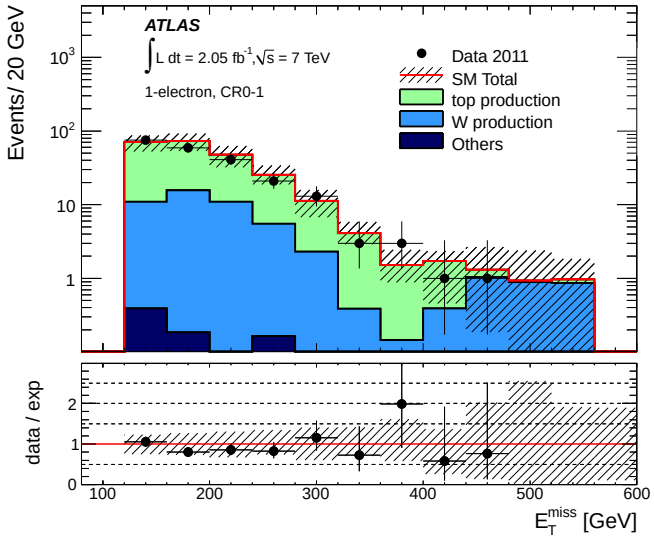


Figure: m_{Eff} in Control Region

arXiv:1203.6193

$\Longrightarrow$

TF(CR→SR)

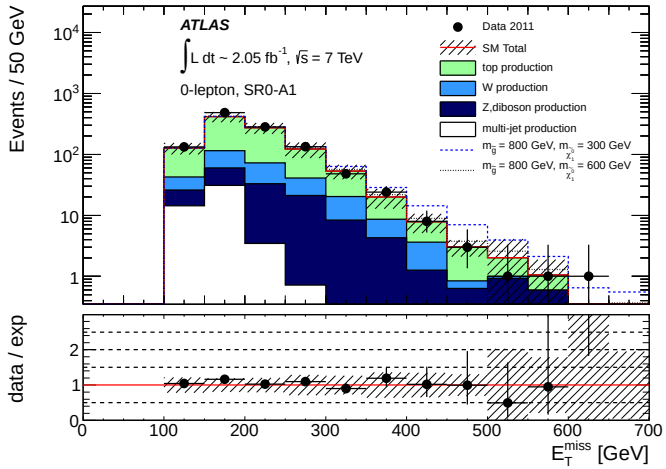


Figure: m_{Eff} in Signal Region

Search for gluino-mediated sbottom pair production

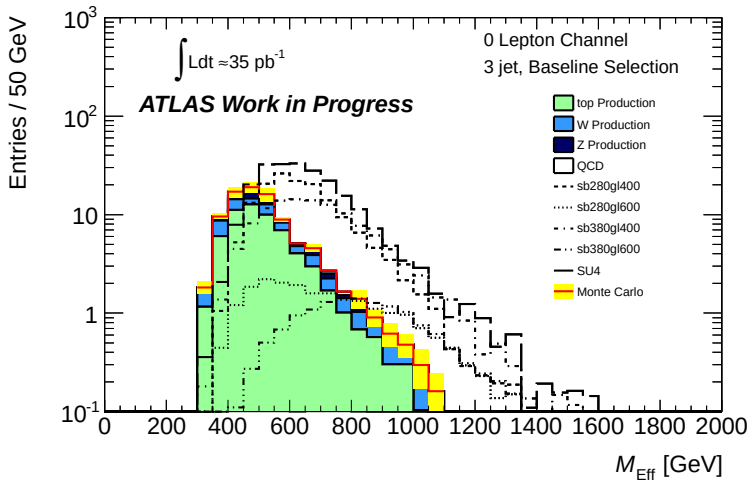
0-lep + b-jets + effective mass: arXiv:1203.6193, subm. to PRD

Gluino-Mediated: Analysis

- Signal is busy: 4 b-jets and 2 $\tilde{\chi}^0 \Rightarrow$ b-jets + E^T_{Miss}
- Measure of event activity: $M_{Eff} = E^T_{Miss} + \sum_{i=1}^{4} p_T(\text{jet}_i)$

Selection cuts: 0 lepton

- MET + jet trigger fully efficient:
  - 3 jets $p_T > 130, 50, 50$ GeV
  - $E^T_{Miss} > 130$ GeV
- QCD Rejection:
  - $E^T_{Miss}/M_{Eff} > 0.25$
  - $\Delta\phi_{\text{min}}(E^T_{Miss}, \text{jets}_{1-3}) > 0.4$ rad
- Enhance SUSY signal:
  - ≥ 1 b-jet and ≥ 2 b-jets
  - $M_{Eff} > 500/700/900$ GeV



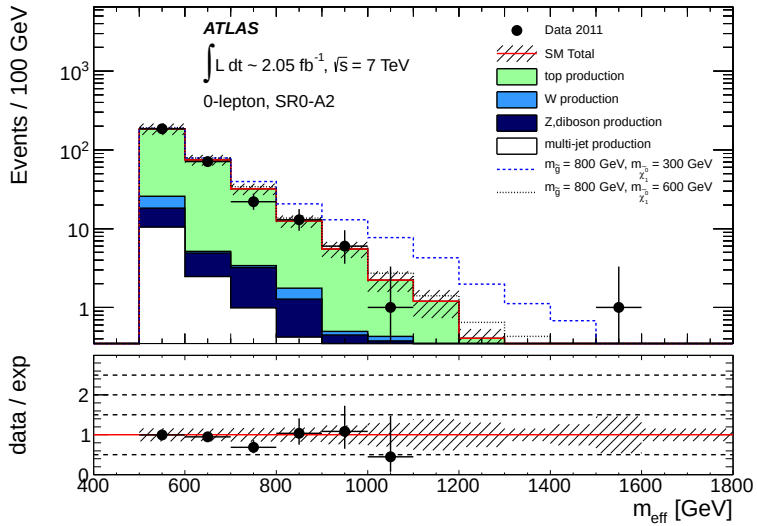
M_{Eff} provides a simple yet powerful discrimination variable

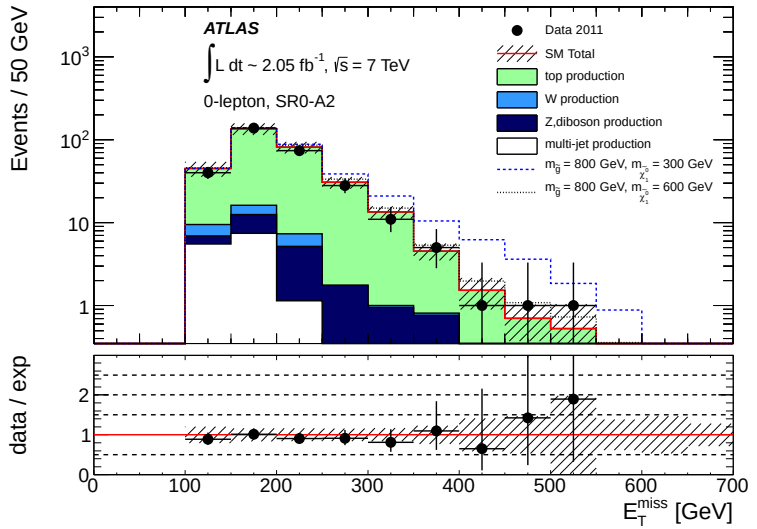
We expect $t\bar{t}$ to be the dominant background

Gluino-mediated: Results

Theory uncertainties in the transfer factor dominate background systematics.

# b	m_{Eff} >	Top	W/Z	Other	Total	Data
≥ 1	500 GeV	705	248	53	1000 ± 180	1112
≥ 1	700 GeV	119	67	7.3	190 ± 50	197
≥ 1	900 GeV	22	16	1.5	39 ± 14	34
≥ 2	500 GeV	272	22.5	21	316 ± 72	299
≥ 2	700 GeV	47	4.5	2.8	54 ± 11	43
≥ 2	900 GeV	8.5	0.8	0.5	9.8 ± 3.2	8





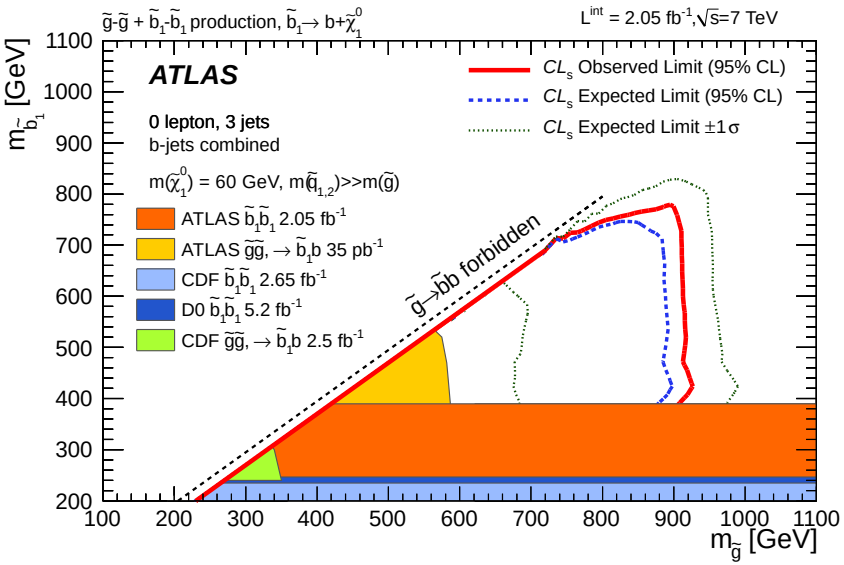
Gluino-mediated: Interpretation

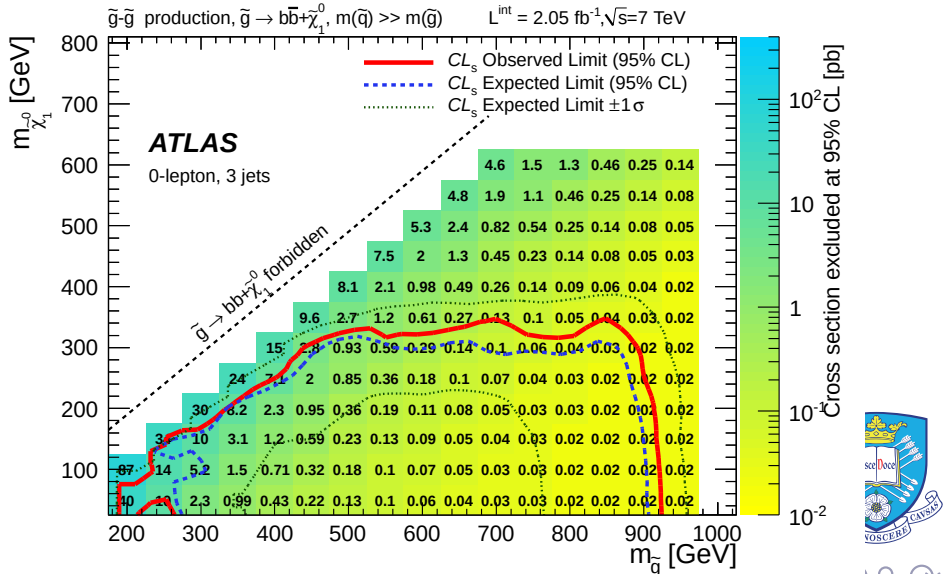
No excess so we set 95 % C.L. Upper Limits

Interpretation dependent on mass spectrum

- $m(\chi) < m(\tilde{b}) < m(\tilde{g})$
- $\tilde{g} \rightarrow \tilde{b}b$ and $\tilde{b} \rightarrow b\tilde{\chi}^0$
- Exclude: $m(\tilde{g}) < 920$ GeV for $m(\tilde{b}_1) < 750$ GeV

- $m(\chi) < m(\tilde{g}) < m(\tilde{b})$
- $\tilde{g} \rightarrow b\bar{b}\tilde{\chi}^0$ via virtual $\tilde{b}$
- Exclude: $m(\tilde{g}) < 900$ GeV for $m(\tilde{\chi}^0) < 300$ GeV





Search for direct sbottom pair production

0-lep + 2 b-jets + m_{CT}: arXiv :1112.3832, accepted by PRL

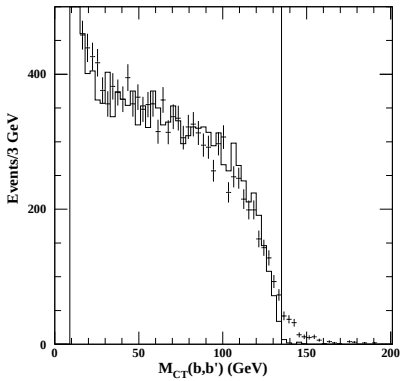
Sbottom-Pair: Analysis

Contransverse Mass

$$m_{CT}^2 = [E_T(b_1) + E_T(b_2)]^2 - [\vec{p_T}(b_1) - \vec{p_T}(b_2)]$$

- $\tilde{b}_1\tilde{b}_1$ events: Endpoint at $\frac{m(\tilde{b}_1)^2 - m(\tilde{\chi}_1^0)^2}{m(\tilde{b}_1)}$
- $t\bar{t}$ events: Endpoint at ≈ 135 GeV

$t\bar{t}$ $m_{CT}(b, b)$ from JHEP 1003:030,2010:

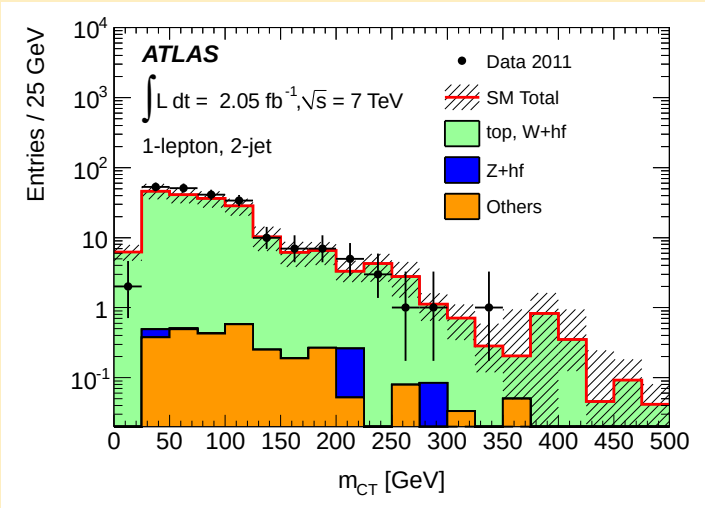


Selection cuts: 0 lepton ($p_T > 20$ GeV)

- MET + jet trigger fully efficient:
  - Exactly 2 jets with $p_T > 130$ GeV and $p_T > 50$ GeV
  - $E_{Miss}^T > 130$ GeV
- QCD Rejection: $E_{Miss}^T / M_{Eff} > 0.25$ and $\Delta\phi_{\min}(E_{Miss}^T, \text{jets})$
- Enhance S/B: 2 b-jets and $m_{CT} > 100/150/200$ GeV

Top + Wbb CR

CR: 1 lepton + E_T^{Miss} + 2 b-jets

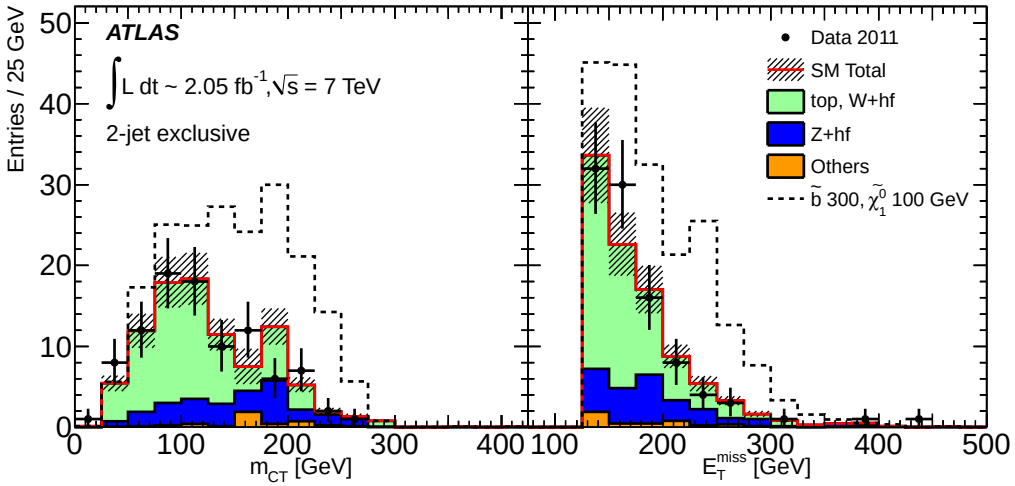


Sbottom-Pair: Results

The dominant systematics on background estimates are driven by control region statistics and theoretical uncertainties on the modelling of the top.

m_{CT} (GeV)	top, Wbb	Zbb	Others	Total SM	Data
0	67 $\pm$ 10	23 $\pm$ 8	3.6 $\pm$ 1.5	94 $\pm$ 16	96
100	36 $\pm$ 10	23 $\pm$ 9	3.1 $\pm$ 1.6	62 $\pm$ 13	56
150	12 $\pm$ 5	12 $\pm$ 6	2.7 $\pm$ 0.9	27 $\pm$ 8	28
200	3.2$\pm$ 1.6	3.9$\pm$ 3.2	1.0 $\pm$ 0.9	8.1$\pm$ 3.5	10

Good agreement between data and SM expectation.



Sbottom-Pair: Interpretation

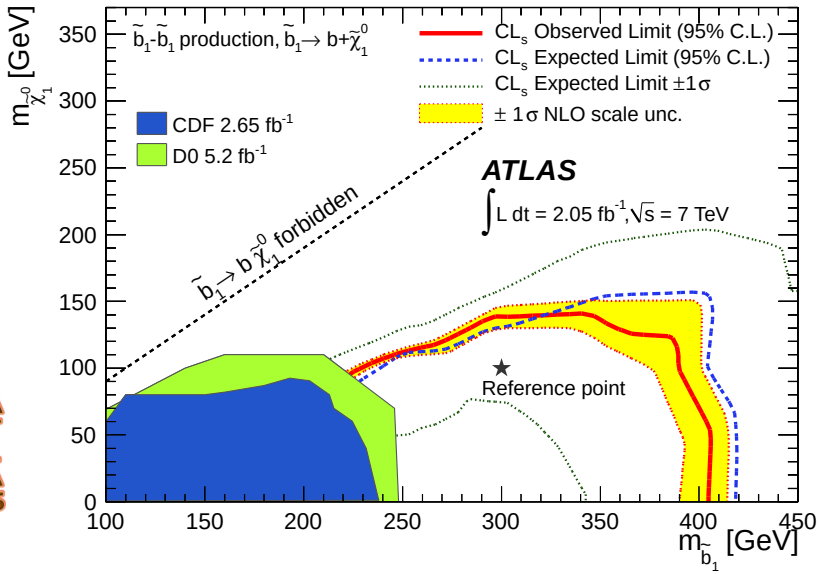
95 % C.L. UL on Cross Section × Acceptance × Efficiency

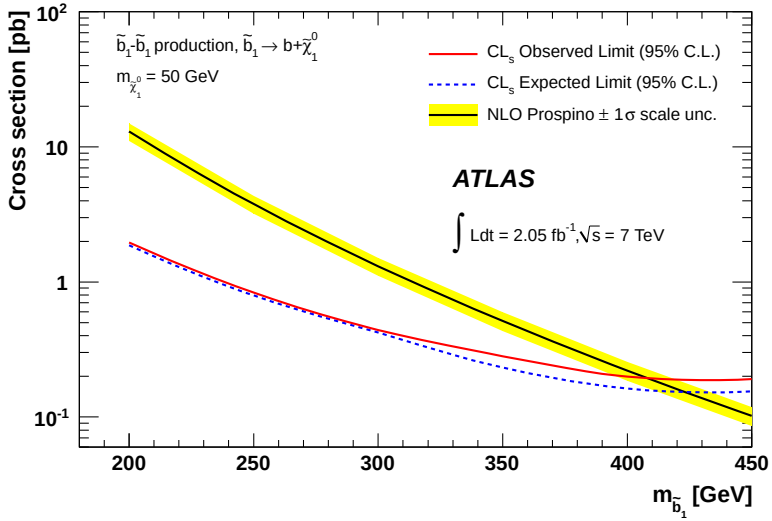
In tightest signal region exclude: N(events) > 11.4 and $\sigma \times$ Acc $\times$ Eff > 5.6 fb

In phenomenological MSSM:

- $\tilde{g}$ mass set very high
- $\tilde{b} \rightarrow b\tilde{\chi}^0$ with 100%

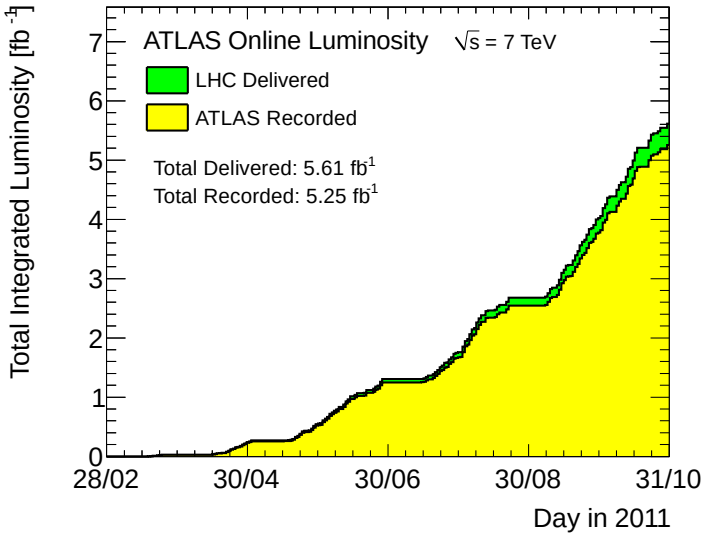
$m(\tilde{g}) < 390$ GeV excluded for $m(\tilde{\chi}^0)$ below ≈ 100 GeV





Conclusions and outlook

These searches are documented in ArXiV:1112.3832 (accepted by PRL) and arXiv:1203.6193



- Took a good bite out of the SUSY parameter space ☹
- Current analyses with 5 fb^{-1}: allow for 3 b-jet requirement
- Looking forward to 8 TeV data, where ATLAS will aim to push closer to the diagonals

BACKUP SLIDES

Backup: Jet Smearing Dijet Balance

The dijet balance $A(p_{T,1}, p_{T,2})$, is defined for 2 jets with $p_{T,1}, p_{T,2}$ as:

$$A(p_{T,1}, p_{T,2}) = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}} \tag{2}$$

The width of $A(p_{T1,}, p_{T2,})$ (σ_A) is related to σ_R via:

$$\sqrt{2}\sigma_A = \frac{\sigma_{P_T}}{P_T} = \sigma_R \tag{3}$$

$\Rightarrow$ allows derivation of correction. Below we show the balance for a p_T bin (200 GeV-240 GeV).

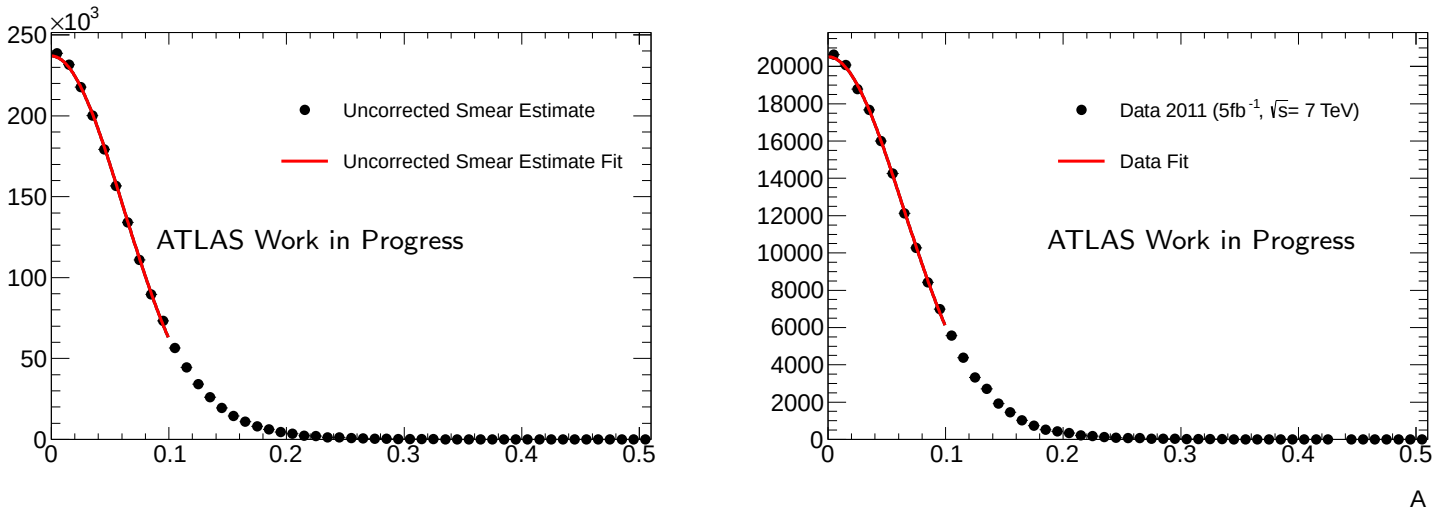


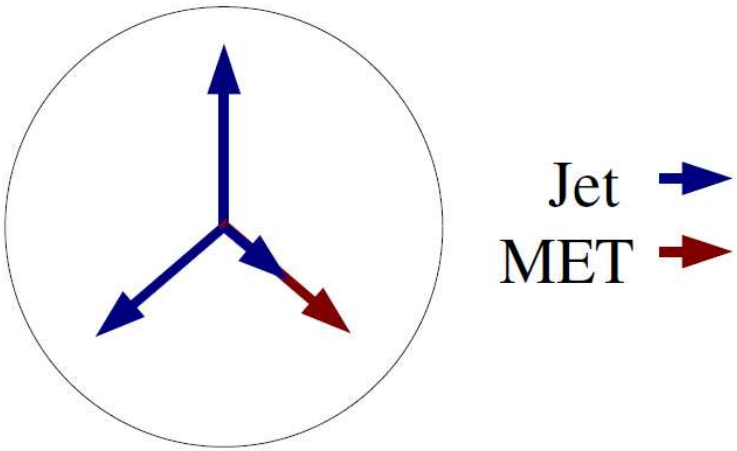
Figure: Smeared events (left) and Data events (right)

Backup: Mercedes Control Region

We use the Mercedes analysis to validate the non-Gaussian response

$$R_2 \simeq \frac{\vec{p}_{\mathrm{T}}^{J} \cdot (\vec{p}_{\mathrm{T}}^{J} + \vec{E}_T^{Miss})}{|\vec{p}_{\mathrm{T}}^{J} + \vec{E}_T^{Miss}|^2}, \tag{4}$$

And select events of the form:



with estimated true pt $= |\vec{p}_{\mathrm{T}}^{J} + \vec{E}_T^{Miss}|$ GeV

Backup: Exclusion Technique

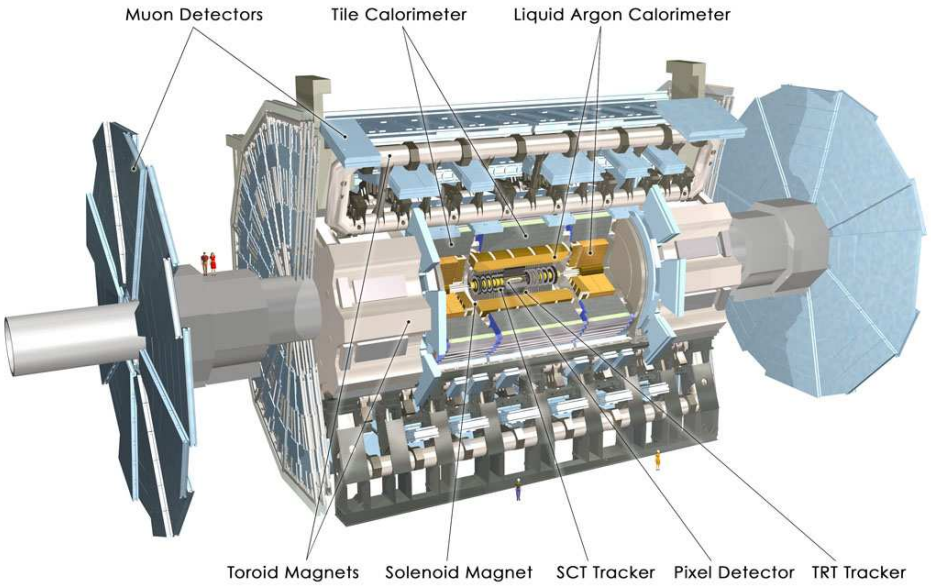
- The tool used to calculate the limits uses a profile-likelihood technique.

$$L(\mathbf{n}|\mu, \mathbf{b}, \boldsymbol{\theta}) = P(n_S|\lambda_S(\mu, \mathbf{b}, \boldsymbol{\theta})) \times P_{Syst}(\boldsymbol{\theta^0}, \boldsymbol{\theta})$$

where, for the second term:

  - JES (Signal and Background correlated)
  - b-tagging (Signal and Background correlated)
  - Luminosity (Signal and Background correlated)
  - Theoretical Signal uncertainties (PDF, Scale)
  - Other Background uncertainties

Backup: The ATLAS Experiment



- Inner detector: charged particle tracks and vertices, 2T solenoidal magnetic field
- Liquid argon and Tile calorimeters: electromagnetic and hadronic showers
- Muon spectrometer: muon tracks, toroidal magnetic field