Search for SUSY in final states with jets and two same charge or three leptons with ATLAS detector

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Peter Tornambè

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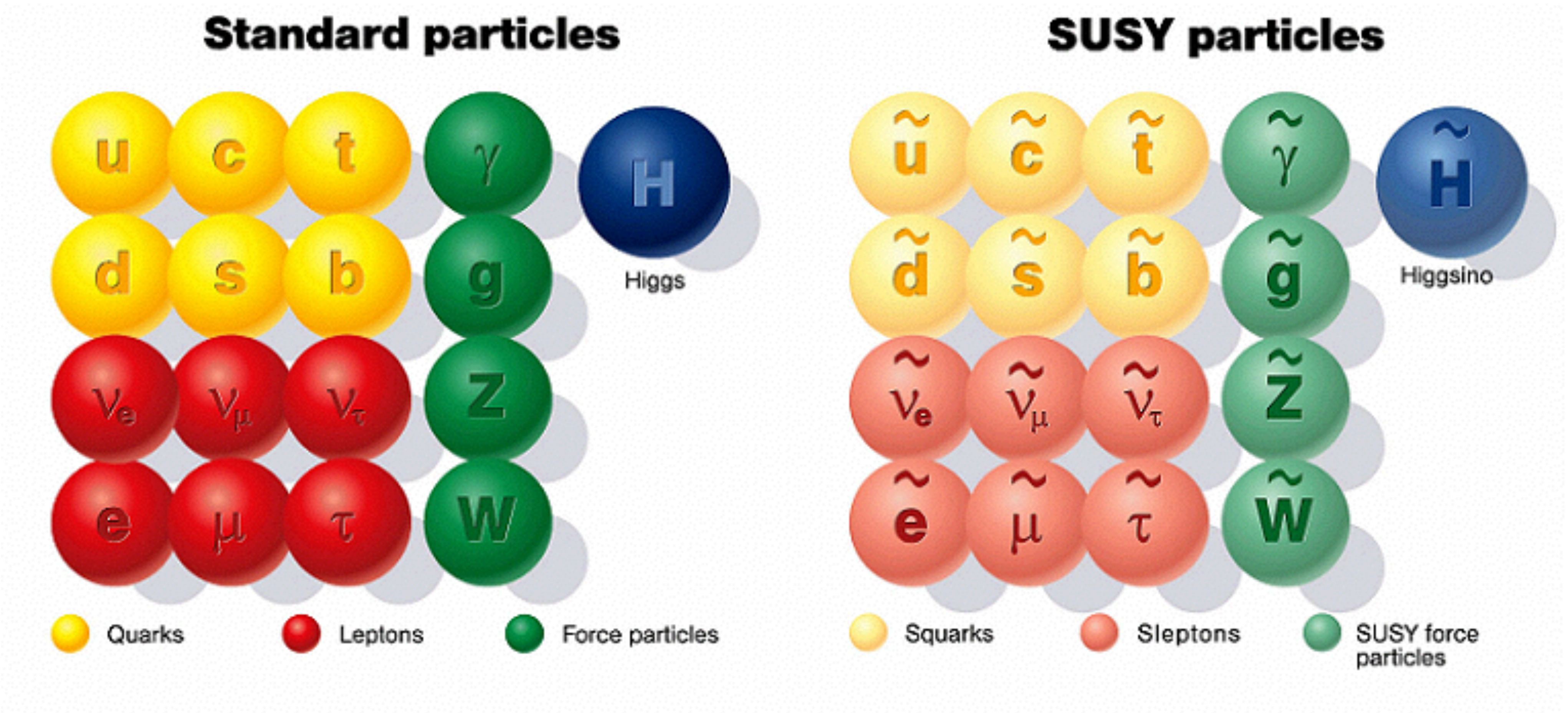
Motivation

- search for strongly produced SUSY particles in **multi-lepton signatures**;
- 2 same-sign or 3 leptons production rare in SM, very **low background**;
- powerful in **compressed SUSY scenario**;



will report here on results on LHC run1 data, as documented in **arXiv:1404.2500v1**

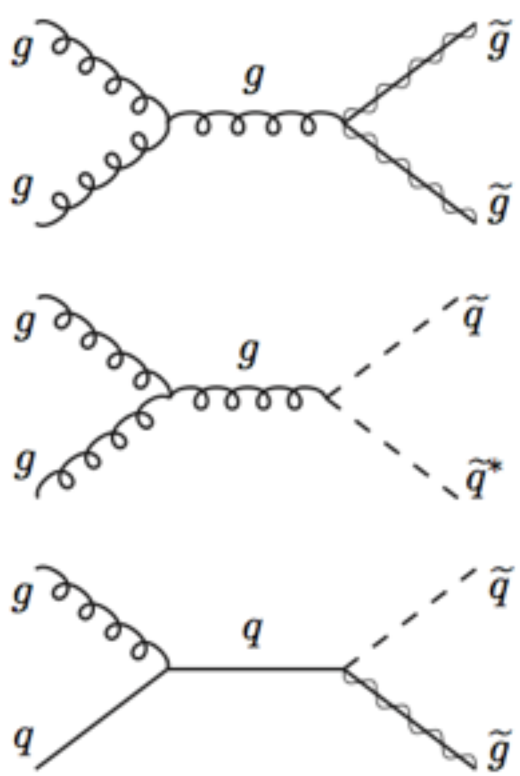
SUSY production and decays

SUSY predicts new bosonic partners for the fermions and new fermionic partners for the bosons of the Standard Model

If R-parity is conserved:

- SUSY particles are produced in pairs;
- lightest SUSY particles (LSP) are stable;

In many models neutralino is LSP (possible candidate for DM)



squarks and gluinos, could be produced in strong interaction processes at the LHC

they decay via cascades ending with a stable LSP

Final states characterized by E_T^{miss} with multiple jets and possible leptons (from sleptons decays)

$\tilde{g}$
$\hookrightarrow \tilde{q}_L \quad q$
$\hookrightarrow \tilde{\chi}_4^0 \quad q$
$\hookrightarrow \tilde{\ell}_L^{\pm} \quad \ell^{\mp}$
$\hookrightarrow \tilde{\chi}_2^0 \quad \ell^{\pm}$
$\hookrightarrow \tilde{\ell}_R^{\pm} \quad \ell^{\mp}$
$\hookrightarrow \tilde{\chi}_1^0 \quad \ell^{\pm}$

Signatures with strong production

GLUINO-MEDIATED STOP/SBOTTOM

$\tilde{g} \to b\,\tilde{b}_1$
$\tilde{g} \to t\,\tilde{t}_1$

- $\to t\,\tilde{\chi}_1^\pm$ — Gluino-stop ($b\tilde{\chi}_1^\pm$) degenerate ($m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_1^0}$)
- $\to b\,\tilde{\chi}_1^\pm$ — Gluino-stop ($b\tilde{\chi}_1^\pm$) on-shell

$\tilde{\chi}_1^\pm \to W^{\pm(*)}\tilde{\chi}_1^0$

- $\to t\,\tilde{\chi}_1^0$
  - Gluino-stop ($t\tilde{\chi}_1^0$) off-shell ($m_{\tilde{g}} < m_{\tilde{t}} + m_t$)
  - Gluino-stop ($t\tilde{\chi}_1^0$) on-shell ($m_{\tilde{g}} > m_{\tilde{t}} + m_t$)
- $\to$ b s — Gluino-stop (bs) RPV

GLUINO SQUARK

$\tilde{g} \to q\,\tilde{q}$

- $\to q'\,\tilde{\chi}_1^\pm$
  - $\to W^{\pm(*)}\tilde{\chi}_1^0$ — Gluino-squark (via W)
  - $\to \tilde{\ell}\nu, \ell\tilde{\nu}$
- $\to q\,\tilde{\chi}_2^0 \to \tilde{\ell}\ell, \tilde{\nu}\nu$

$\tilde{\ell}\nu, \ell\tilde{\nu}$ / $\tilde{\ell}\ell, \tilde{\nu}\nu$ — Gluino-squark (via slepton)

DIRECT SBOTTOM

$\tilde{b}_1 \to t\,\tilde{\chi}_1^\pm \to W^{\pm(*)}\tilde{\chi}_1^0$

- direct sbottom ($t\tilde{\chi}_1^\pm$) fixed $m_{\tilde{\chi}_1^0}$
- direct sbottom ($t\tilde{\chi}_1^\pm$) varied $m_{\tilde{\chi}_1^0}$

DIRECT SQUARK

$\tilde{q} \to q'\,\tilde{\chi}_1^\pm \to \tilde{\ell}\nu, \ell\tilde{\nu}$
$\tilde{q} \to q\,\tilde{\chi}_2^0 \to \tilde{\ell}\ell, \tilde{\nu}\nu$

- direct squark (via slepton)

Powerful signature for New Physics

Signal Regions

Data is divided into two mutually exclusive **SS** and **3L** samples:

- **SS**: the two leading isolated leptons must have same charge sign and p_T > [20,15] GeV, veto on 3rd signal lepton with p_T > 15 GeV;
- **3L**: the three highest-p_T leptons must have p_T > [20,15,15] GeV, no requirements on the electric charge;

5 SRs are defined to have a good sensitivity to all signal models, kinematic variables are used to select the events and have non-overlapping SRs:

1. E_T^{miss};
2. jet and b-jet multiplicity;
3. Effective mass computed from signal leptons and selected jets;
4. transverse mass computed from the highest-p_T lepton and MET;

$$\boxed{m_{eff} = E_T^{miss} + \sum p_T^l + \sum p_T^{jet}}$$

$$\boxed{m_T = \sqrt{2 p_T^{l_1} E_T^{miss} (1 - cos[\Delta\phi(l_1, p_T^{miss}])}}$$

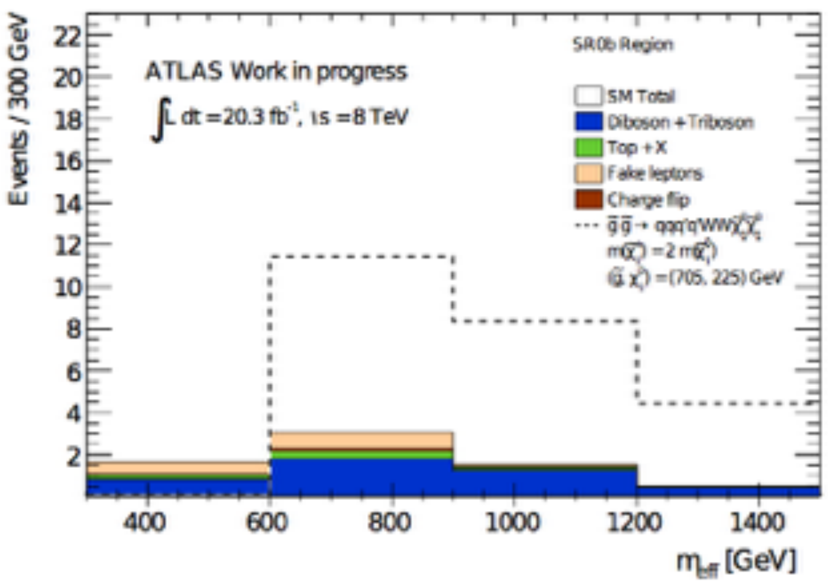
Signal Regions

SR	Leptons	$N_{b-\text{jets}}$	Other variables	Additional requirement on m_{eff}
SR3b	SS or 3L	≥ 3	$N_{\text{jets}} \geq 5$	m_{eff}>350 GeV
SR0b	SS	$= 0$	$N_{\text{jets}} \geq 3$, E_T^{miss}> 150 GeV, m_T> 100 GeV	m_{eff}>400 GeV
SR1b	SS	≥ 1	$N_{\text{jets}} \geq 3$, E_T^{miss}> 150 GeV, m_T>100 GeV, SR3b veto	m_{eff}>700 GeV
SR3Llow	3L	-	$N_{\text{jets}} \geq 4$, $50 < E_T^{\text{miss}} < 150$ GeV, Z boson veto, SR3b veto	m_{eff}>400 GeV
SR3Lhigh	3L	-	$N_{\text{jets}} \geq 4$, E_T^{miss}> 150 GeV, SR3b veto	m_{eff}>400 GeV

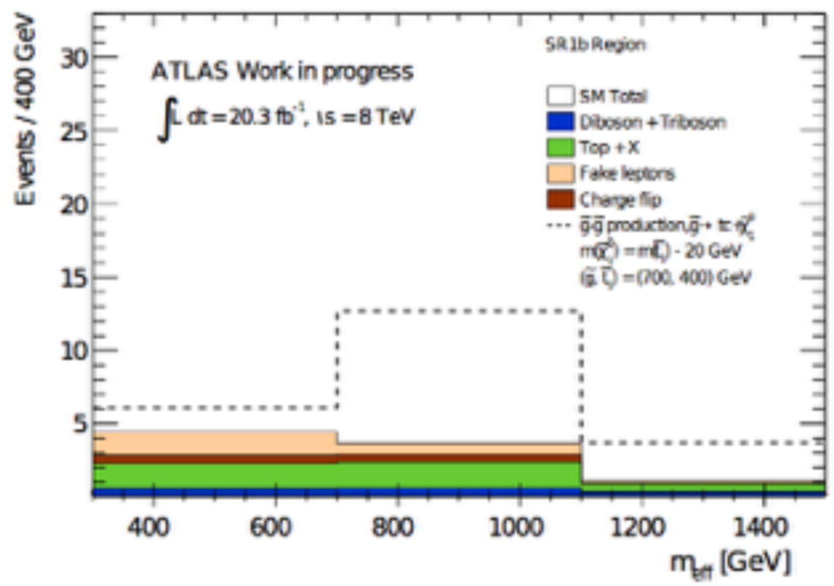
Each SR is motivated by different SUSY scenarios:

- **SR3b**: gluino-mediated stop -> signature with 4 b-jets, sensitive to compressed scenarios;
- **SR0b**: gluino-mediated and directly produced squarks (1st and 2nd generation);
- **SR1b**: direct bottom squark and gluino-mediated top squark;
- **SR3L**: scenarios where squarks decay in multi-step cascades, it can produce off-shell V bosons (low) or on-shell vector boson (high);

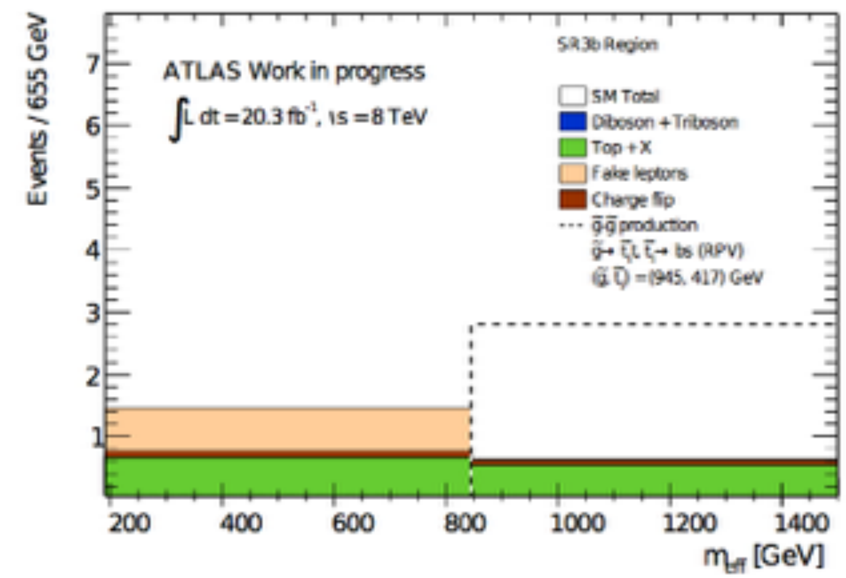
Signal Regions



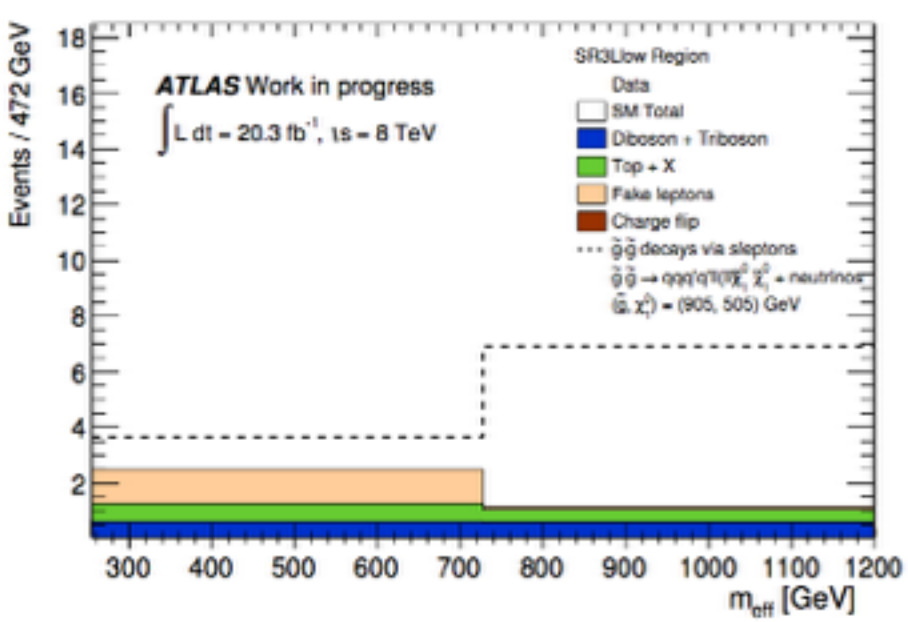
M_{eff} spectra SR0b: MC expectation



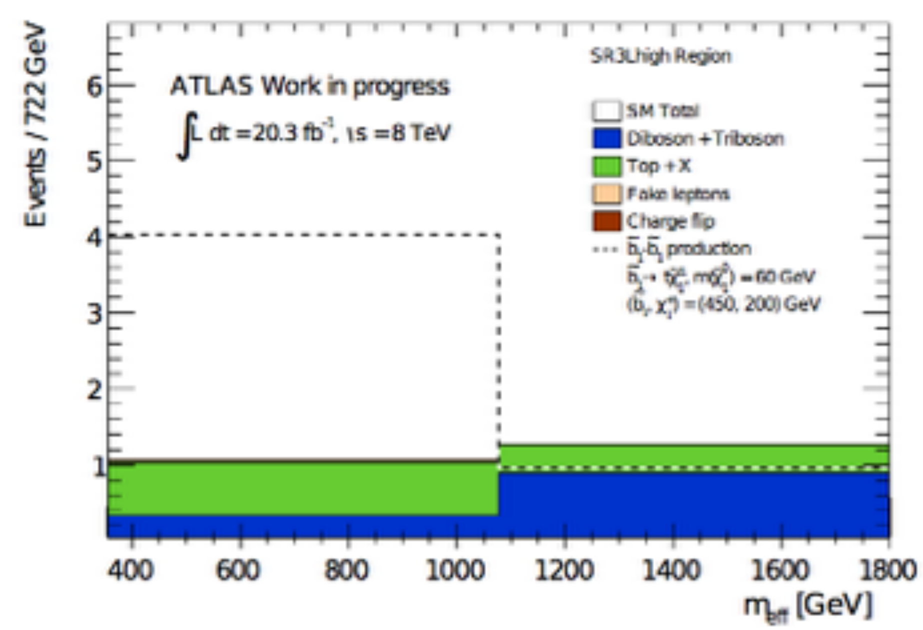
M_{eff} spectra SR1b: MC expectation



M_{eff} spectra SR3b: MC expectation



M_{eff} spectra SR3L low: MC expectation



M_{eff} spectra SR3L high: MC expectation

Background

Searches in SS and 3L are characterized by low SM background

There are three different types of backgrounds:

IRREDUCIBLE

1. **prompt multi-lepton background**: dominated by $t\bar{t}V$ and VV, estimated from MC samples;

2. **"fake" leptons background**: hadrons misidentified as leptons, with leptons originating from heavy-flavour decays and electrons from photon conversion;
3. **charge flip background**: leptons' charge mis-measured, dominated by $t\bar{t}$ events, negligible for muons;

REDUCIBLE

Prompt lepton background

Source: few SM processes produce events with two same-charge or 3 real leptons

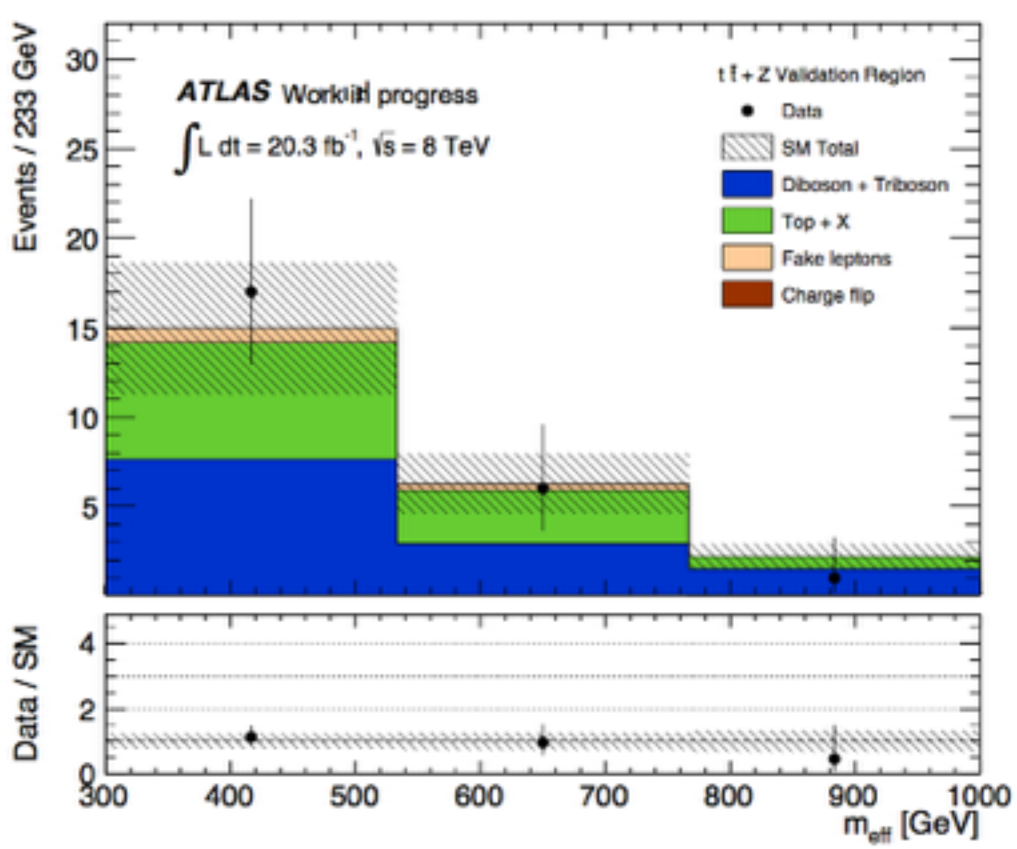
- **Diboson**: WZ,ZZ,W±W±,WWW*,WZW*,ZZZ*;

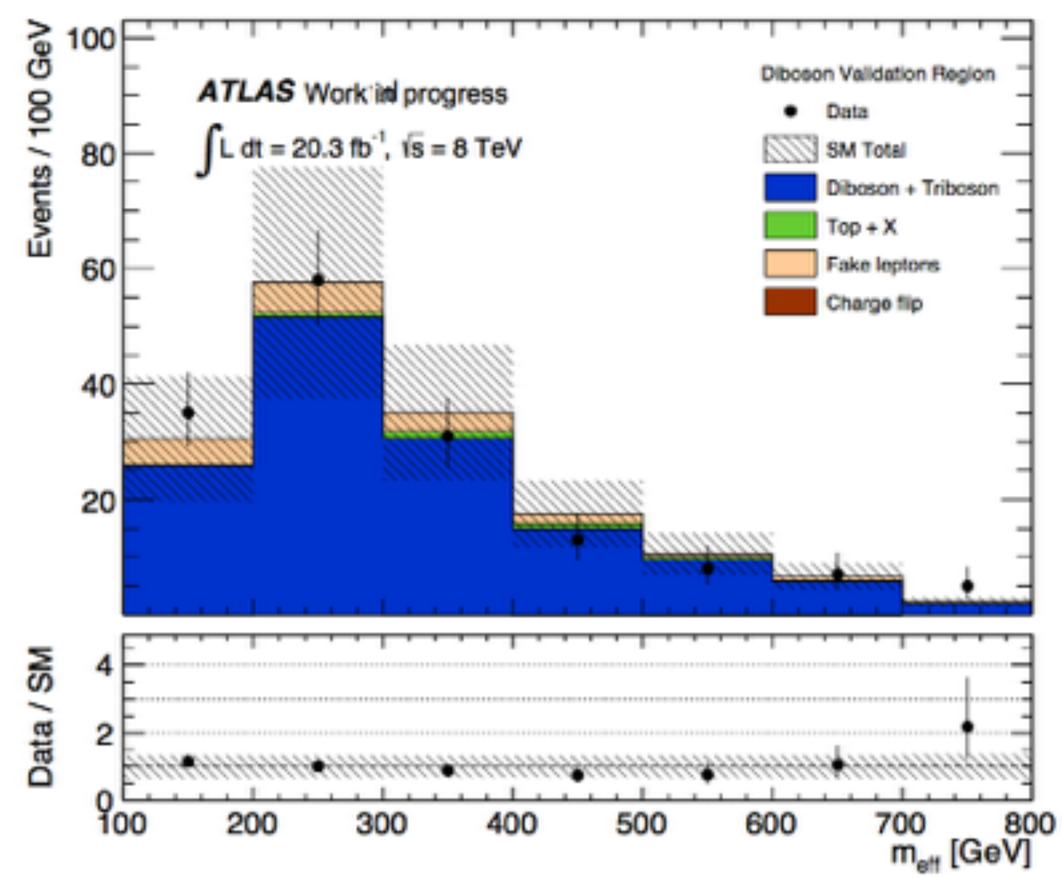
Main bkg in SR0b

- **ttbar+boson**: ttW,ttZ,ttWW;
- **Associate Higgs production**: ttH,WH,ZH;

Main bkg in SR1,3b

- low cross section processes;
- estimated from MC samples;

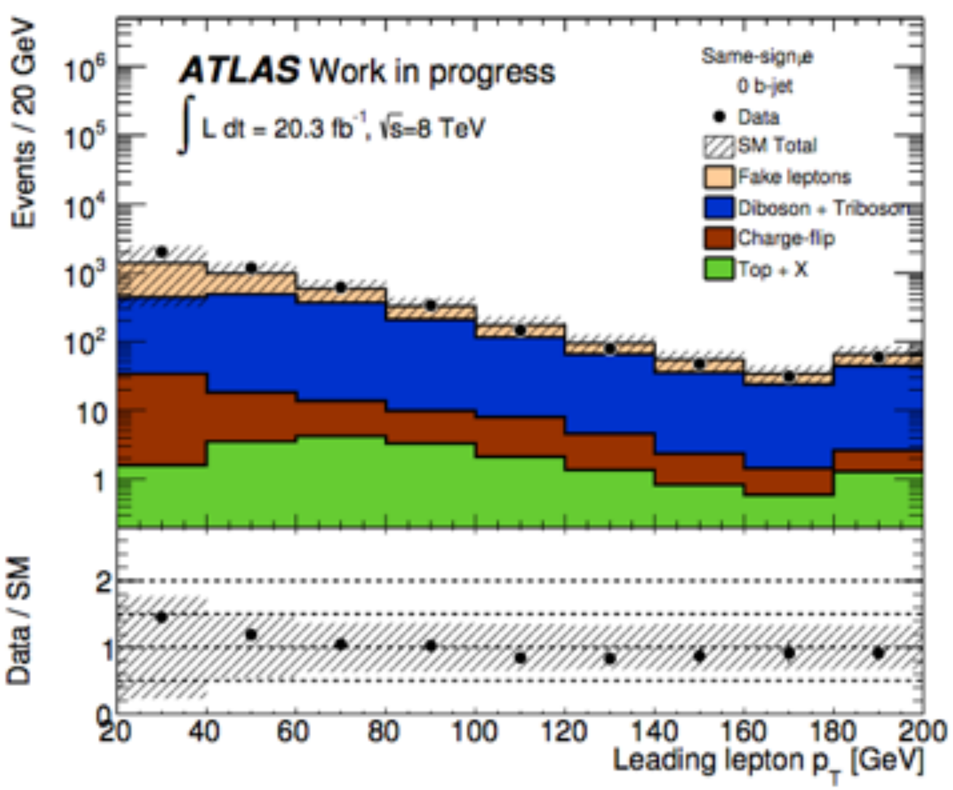


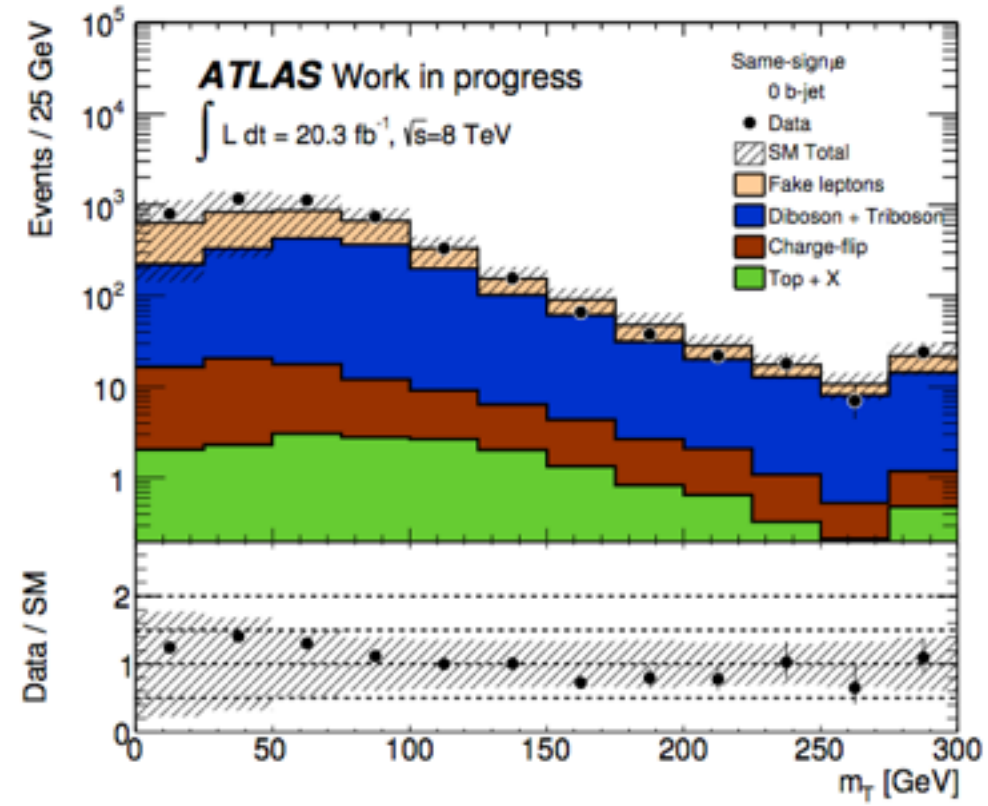


Fake lepton background

Source: events with fake lepton originating from heavy-flavor meson decay

- **Several sources of lepton fakes**: light hadrons faking electrons, non-isolated leptons in bottomed/charmed hadrons decays, etc;
- **Dominant source in SR1b**;
- estimated with **data-driven matrix method**;



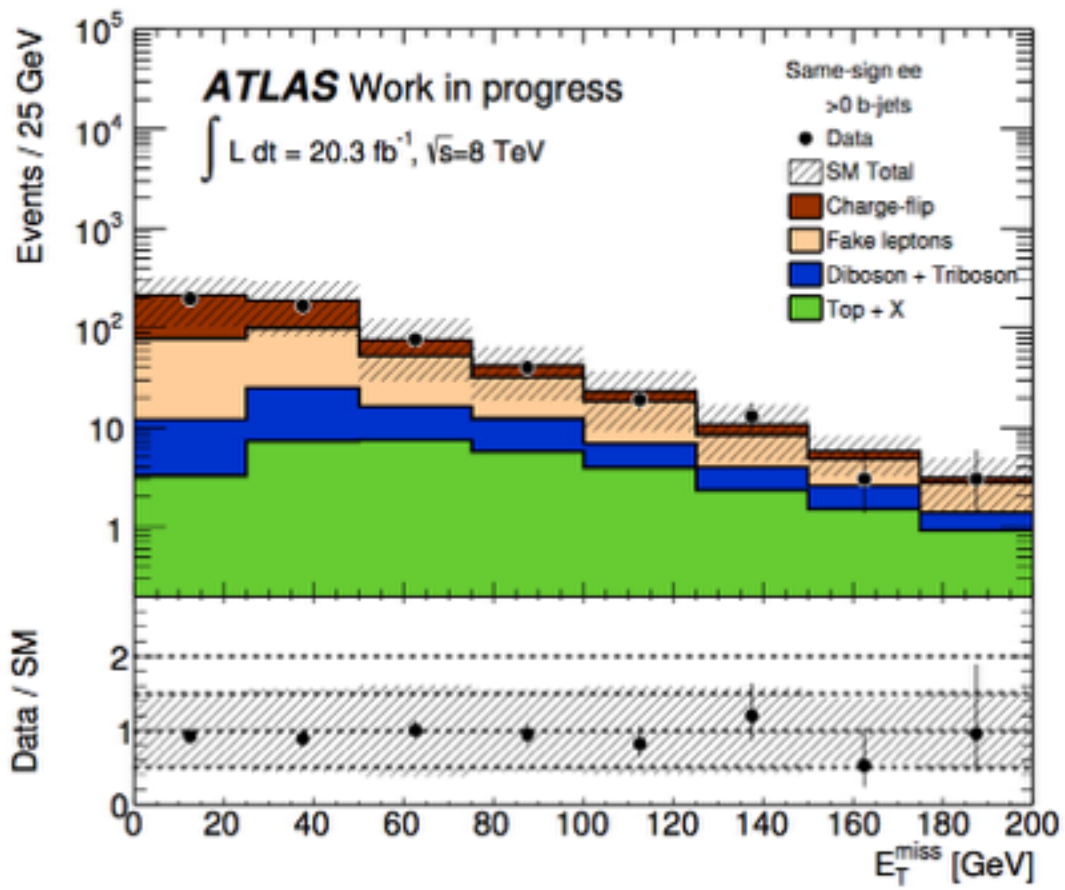


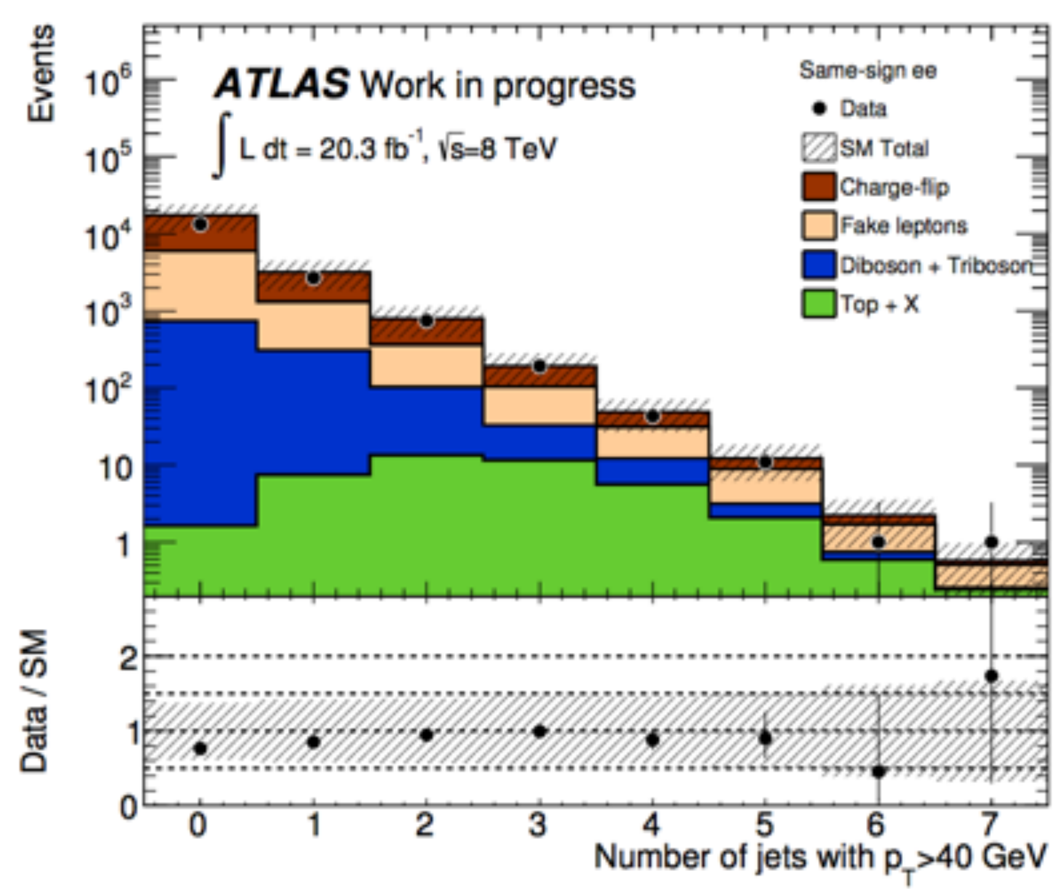
Charge flip background

Source: two opposite-sign leptons for which charge of one lepton is **mis-measured**

Mostly brehmstrahlung photons that convert in e^+e^- pair in material

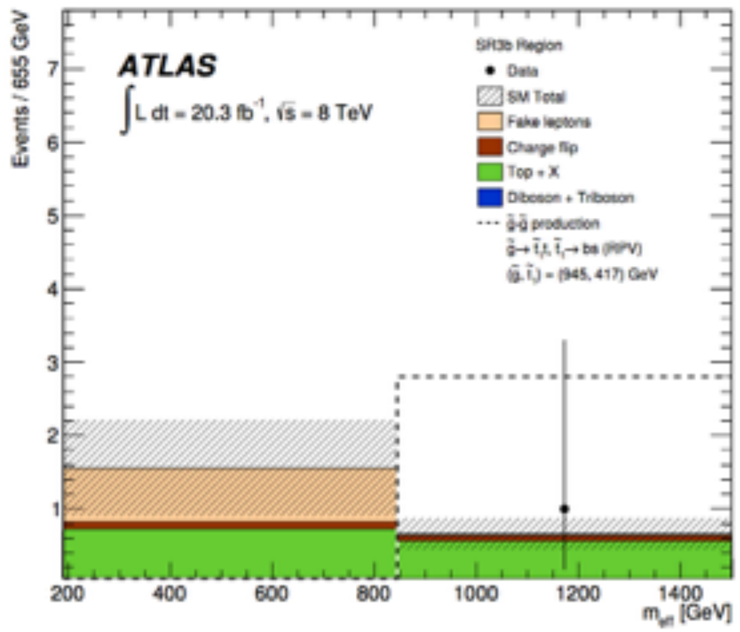
- relevant for the **SS lepton** pair signature;
- **significant for electrons** (trident events), while negligible for muons;
- dominated by dilepton **ttbar** events;
- estimated using **data-driven likelihood methods**;



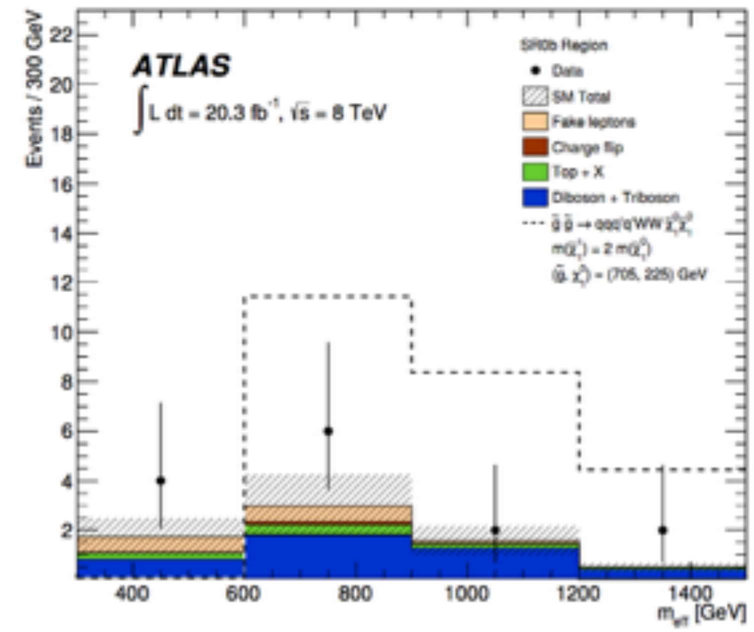


Results

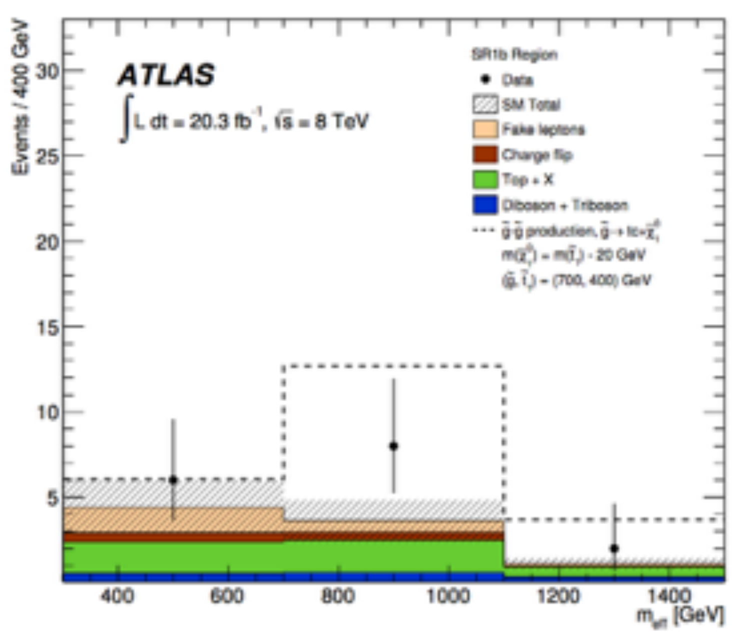
Effective mass distribution of the observed data events and SM predictions for the five signal regions



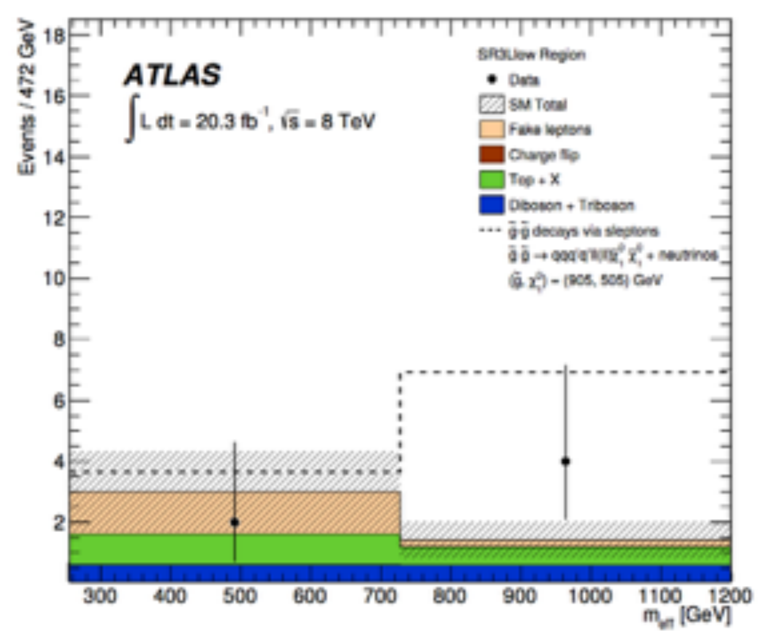
(a) SR3b



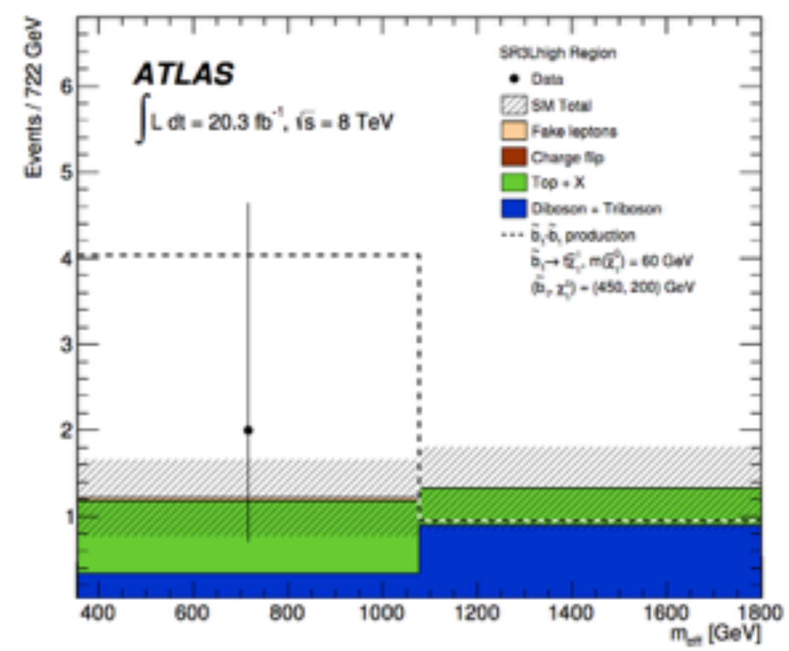
(b) SR0b



(c) SR1b



(d) SR3Llow



(e) SR3Lhigh

Model independent limits

No significant excess of events over the SM expectations is observed in any signal region

Upper limits at 95% CL on the number of BSM events for each signal region are derived using the CL_S prescription

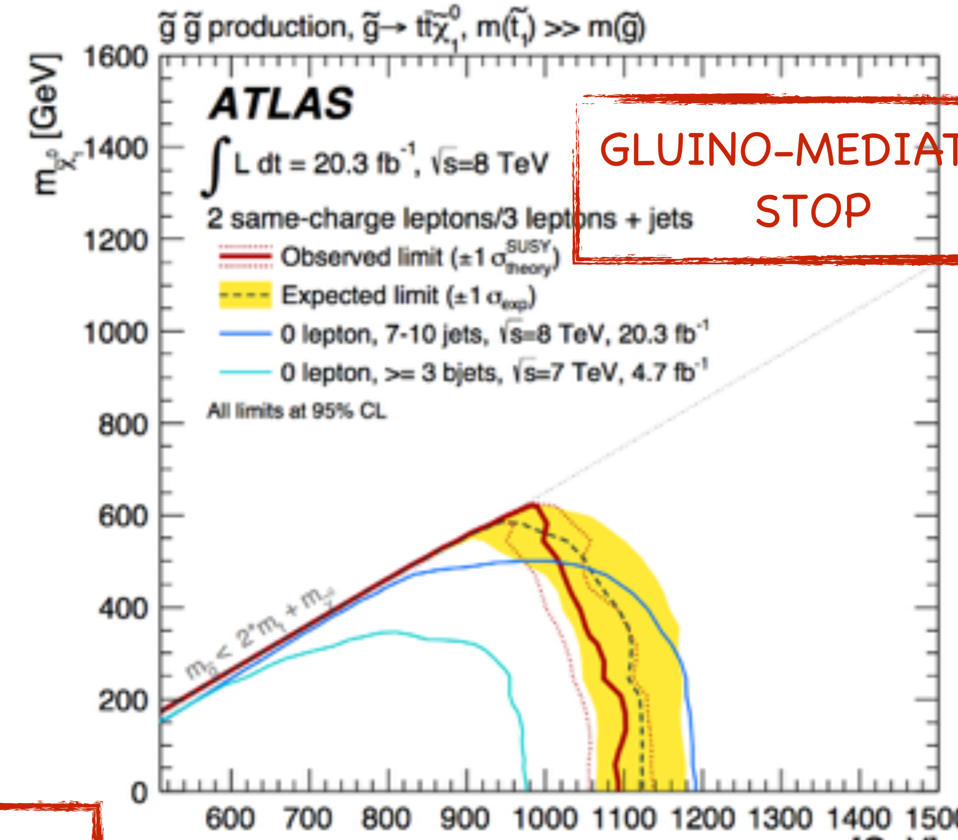
Signal channel	$\langle\sigma_{\mathrm{vis}}\rangle^{95}_{\mathrm{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}
SR3b	0.19	3.9	$4.4^{+1.7}_{-0.6}$
SR0b	0.80	16.3	$8.9^{+3.6}_{-2.0}$
SR1b	0.65	13.3	$8.0^{+3.3}_{-2.0}$
SR3Llow	0.42	8.6	$7.2^{+2.9}_{-1.3}$
SR3Lhigh	0.23	4.6	$5.0^{+1.6}_{-1.1}$

Limit on number of events in SR originating from any BSM process
Any model predicting more can be excluded, we would have seen it!

Model dependent limits

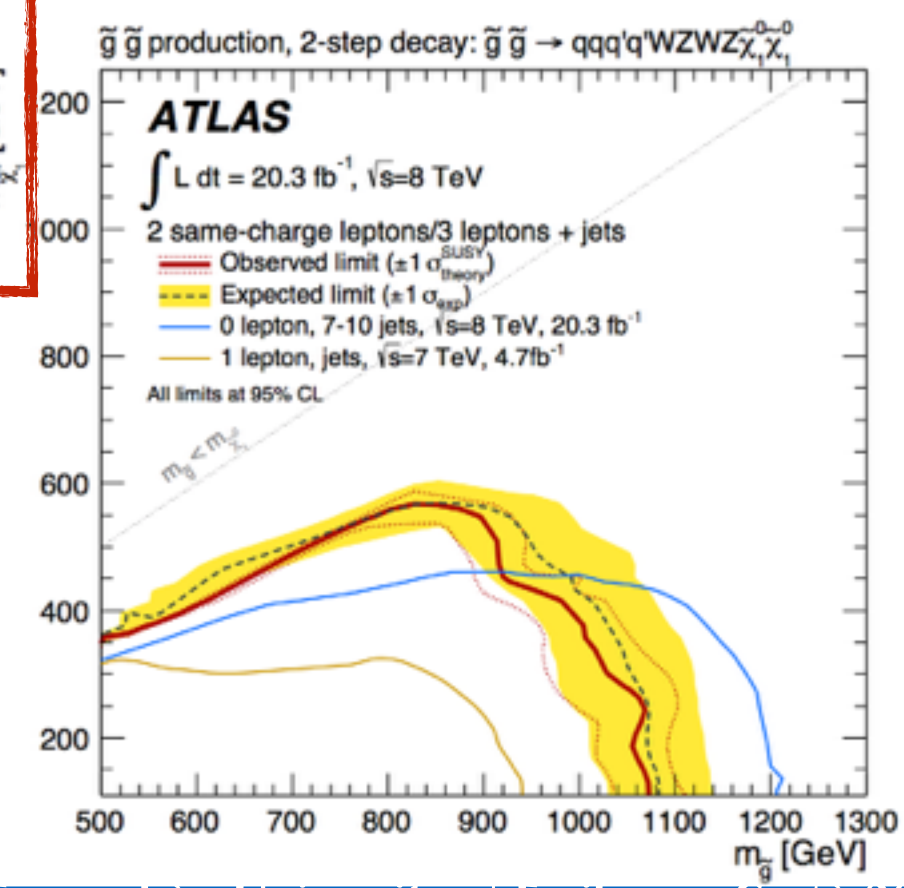
Exclusion limits also set on the signal models listed at the beginning:

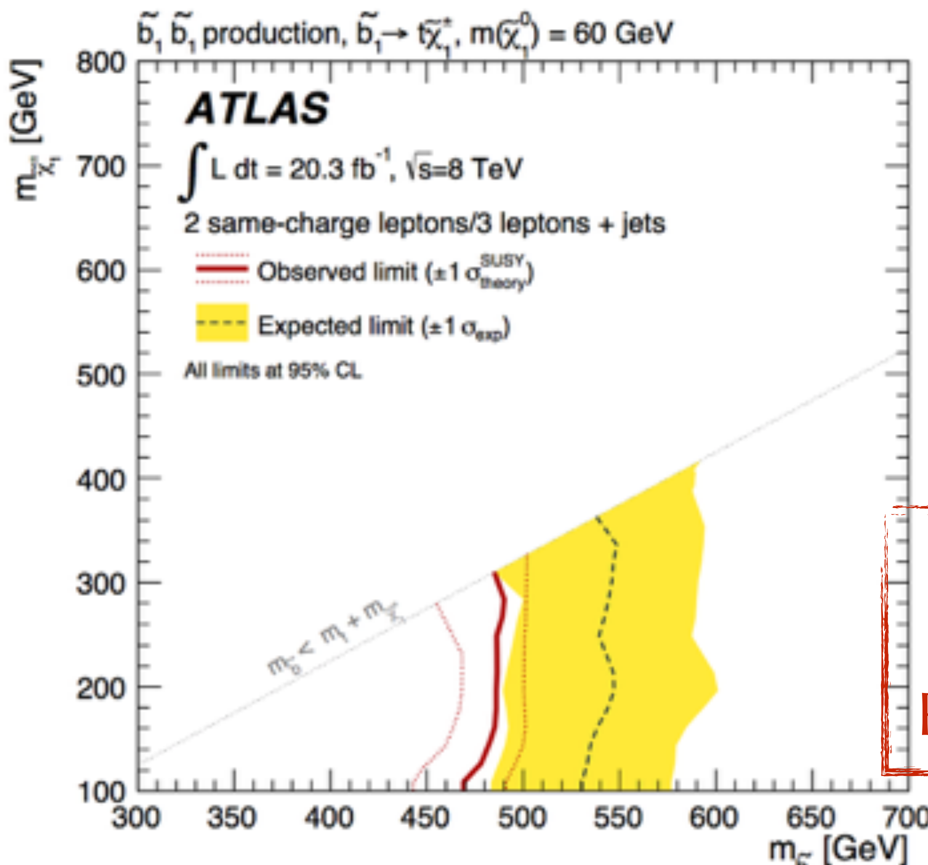
- final m_{eff} requirements are relaxed in each signal region and the fit inputs are the binned m_{eff} distributions;
- Three categories of simplified models are used to design the signal regions and interpret the results: gluino-mediated top squark, gluino-mediated (or direct) first- and second- generation squark, and direct bottom squark production;



GLUINO-MEDIATED STOP

GLUINO-MEDIATED 1st-2nd GEN. SQUARK





DIRECT SBOTTOM PRODUCTION

Conclusions

- **Search** for SUSY in final states with same-sign leptons, L = 20.3 fb^{-1}
  → interesting signature with low SM background, great sensitivity to new physics!
- **No evidence** of BSM processes, it should come from SUSY or anything else;
- **Exclusion limits** set on various natural SUSY scenarios;

Run 2: possibility to access higher masses and improve sensitivity to all SUSY and BSM models

data taking started in May and analysis is already ongoing…

Sensitivity to gluino masses up to 1 TeV, sbottom up to 500 GeV