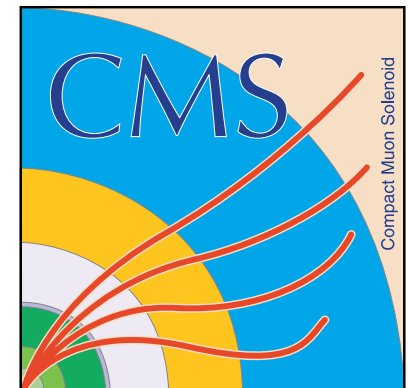


# SEARCH FOR THIRD GENERATION SQUARKS AT THE LHC

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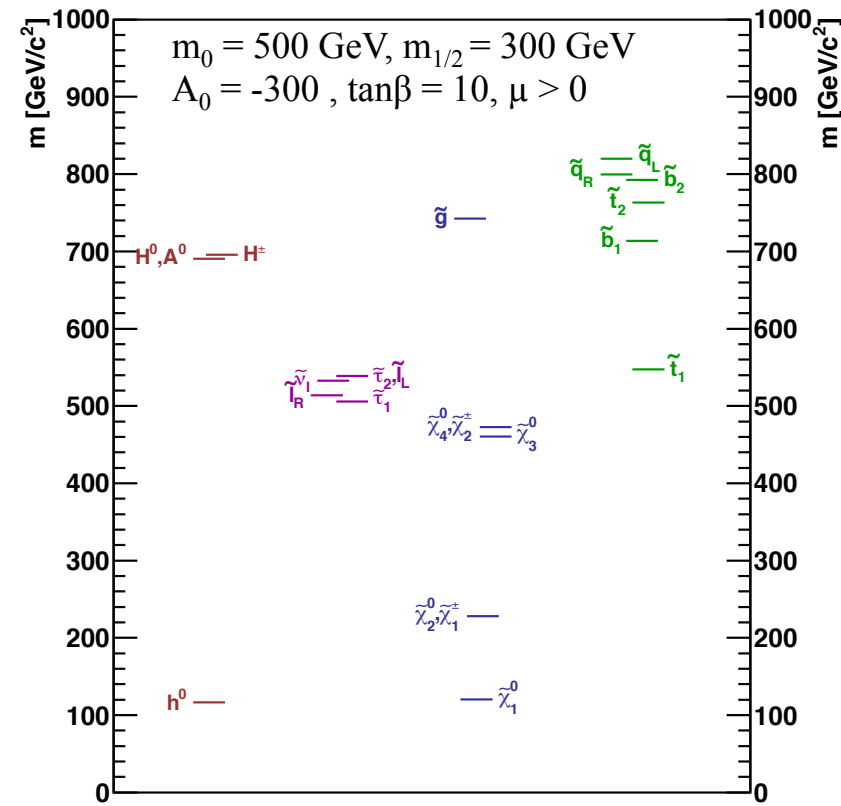
Hansjörg Weber (ETH Zürich)

on behalf of the ATLAS and CMS collaborations



# Search for 3<sup>rd</sup> generation squarks

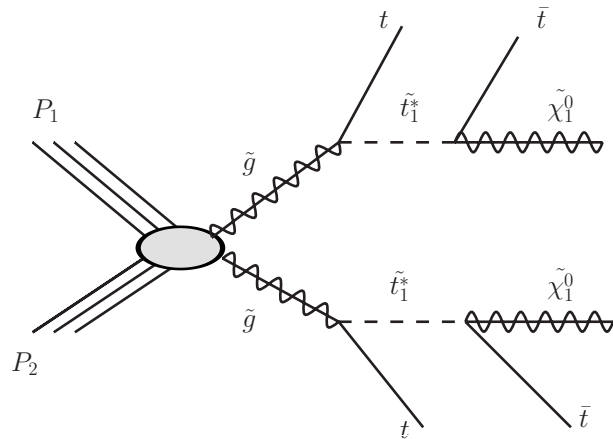
- There are many SUSY signatures and searches
  - See for general overview Sunil's talk
  - See for  $E_T^{\text{miss}}$  signature searches Michel's talk
- In many scenarios the superpartners of top and bottom quarks are the lightest squarks
  - These could be the first sparticles observed at the LHC
- ATLAS and CMS have a wide variety of searches very sensitive to 3<sup>rd</sup> generation squark signatures



# Squark signatures

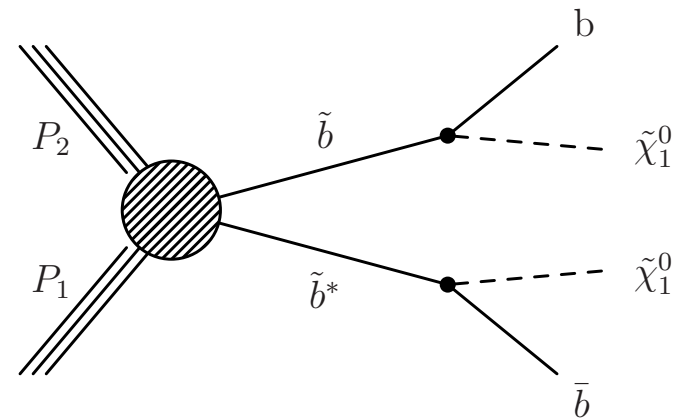
- There are **two** kind of squark production **mechanisms**

## Glauino-mediated squark production



- + relatively high production cross section
- + energetic events, high jet multiplicity

## Direct squark production



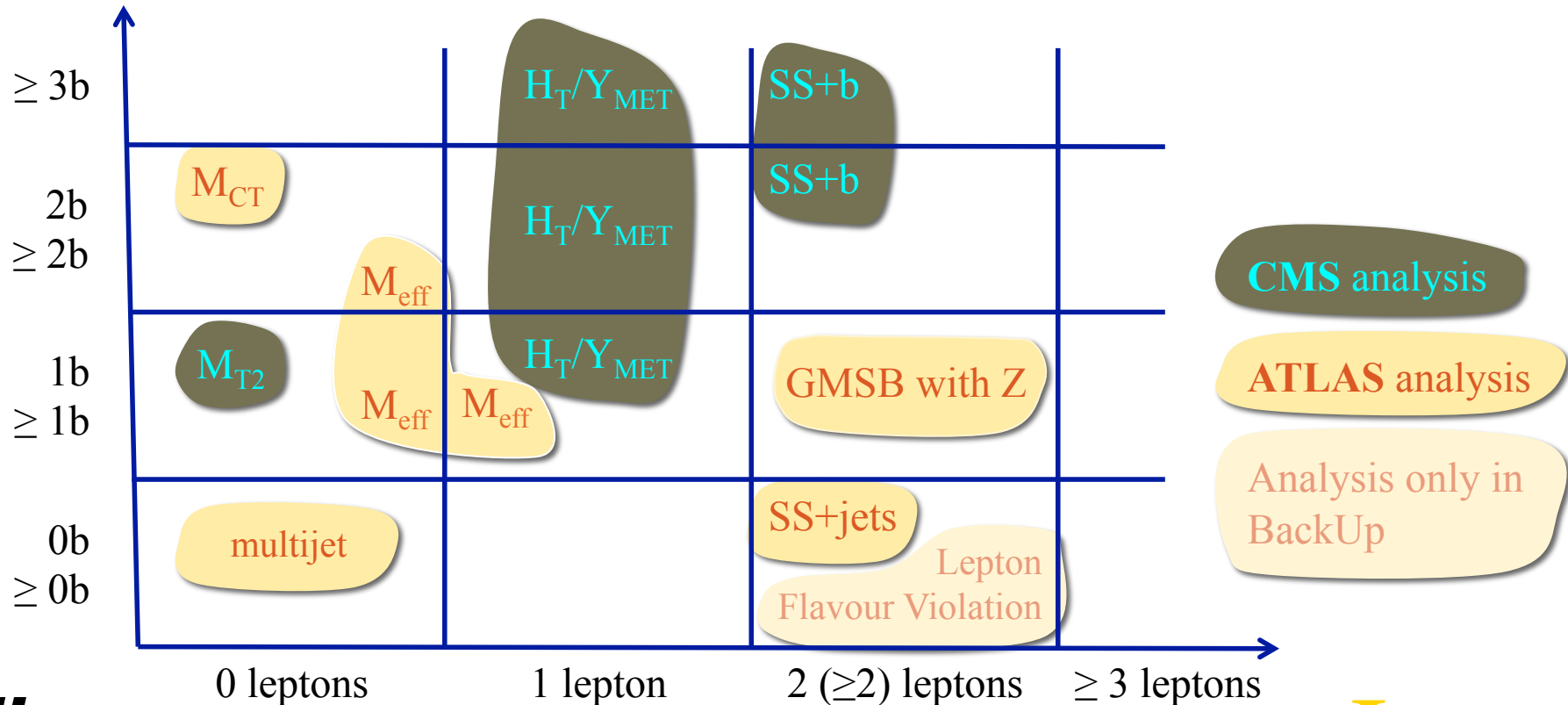
- difficult signature (larger background)
- small production cross section

# Simplified models

- To quantify the sensitivity to a given squark production/decay channel both **ATLAS** and **CMS** interpret their results in so-called **Simplified Models**.
  - These models are reduced to **exactly one decay mode** for the sparticle decay (100% branching ratio) and two or three parameters.
    - For SM particles often decays with respect to their SM branching ratios (e.g.  $Z \rightarrow qq$ ,  $Z \rightarrow ll$  both allowed)
  - For the simplified models of gluino mediated stop/sbottom production often the stop/sbottom is virtual
    - Only little difference in kinematics for most of the phase space if requiring a real stop/sbottom
- + Show the **kinematic sensitivity** for a topology.
- Are **no full models**  $\rightarrow$  might not show physical sensitivity:
- In a real model branching ratios are rarely 100%
  - Backgrounds from other SUSY decays not taken into account
    - In case of data-driven predictions, signal contamination of other SUSY decays can lead to background overprediction and reduce the discovery potential

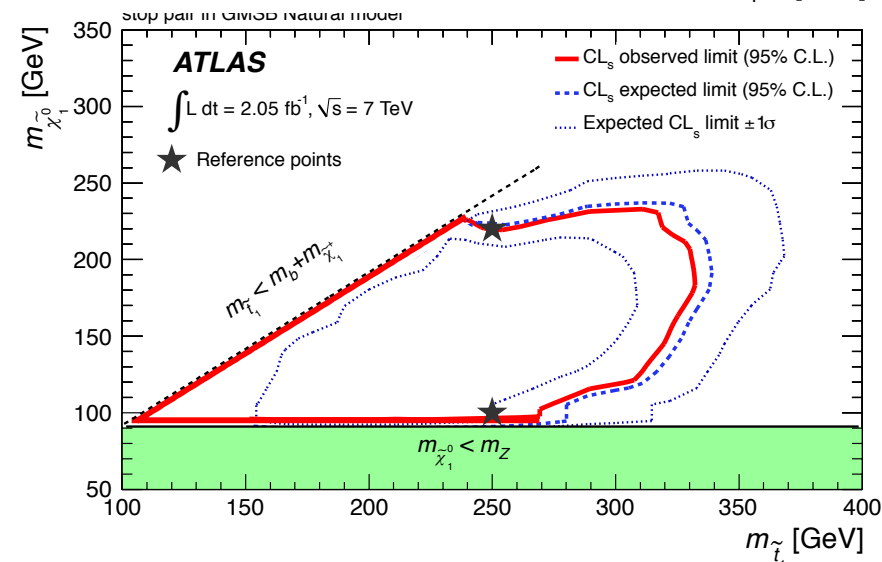
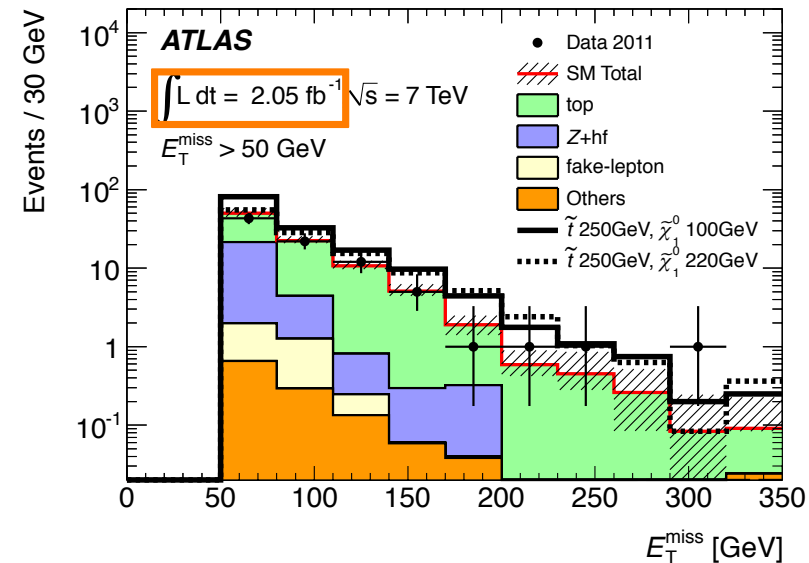
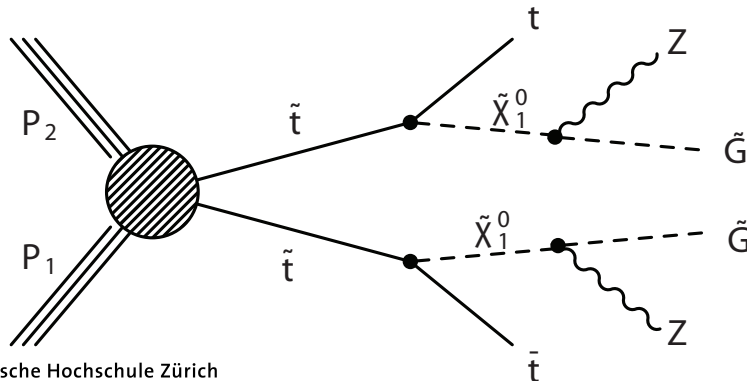
# Search channels

- Many different searches conducted by **CMS** and **ATLAS** which interpret their results in models of third generation squark production (most within mSugra breaking mechanism).
- I will show only one interpretation per analysis – the rest can be found in the back-up



# 3<sup>rd</sup> generation squark search in GMSB models

- In GMSB gravitino is LSP, NLSP can be the lightest neutralino.
- This ATLAS search looks for direct stop production with  
 $\text{stop} \rightarrow \text{top} + \text{neutralino} \rightarrow \text{top} + Z + \text{gravitino}$ 
  - Two OS leptons within  $86 \text{ GeV} < m_{ll} < 96 \text{ GeV}$
  - $\geq 2$  jets,  $\geq 1$  b-jets
  - Two search regions with  $E_T^{\text{miss}} > 80$  (50) GeV
- Exclude up to  $m_{\text{stop}} < 330 \text{ GeV}$  for  
 $m_Z < m_{\text{neutralino}}$  at 95% C.L.

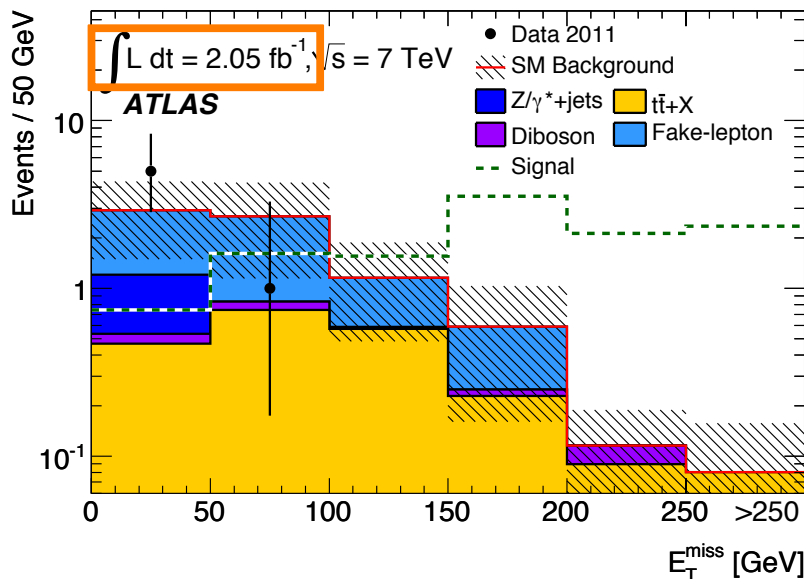


# SS dileptons + (b) jets

- The SM production cross section of two equally charged leptons is very small
- **SS dileptons** can be naturally produced in **gluino mediated stop decays**

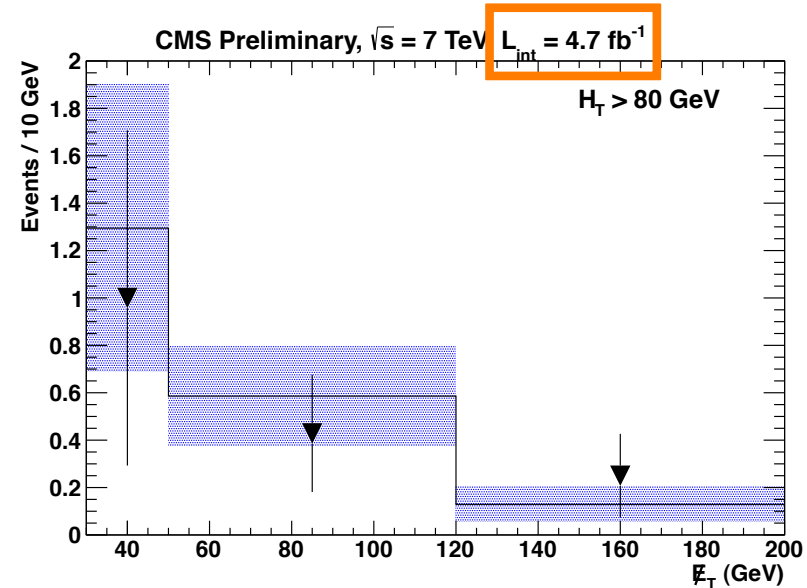
## ATLAS search: 2 search region

- Two SS leptons
- $\geq 4$  jets ( $p_T > 50$  GeV)
- $E_T^{\text{miss}} > 150$  GeV
- $m_T(\text{1st lepton}, E_T^{\text{miss}}) > 100$  GeV for SR2



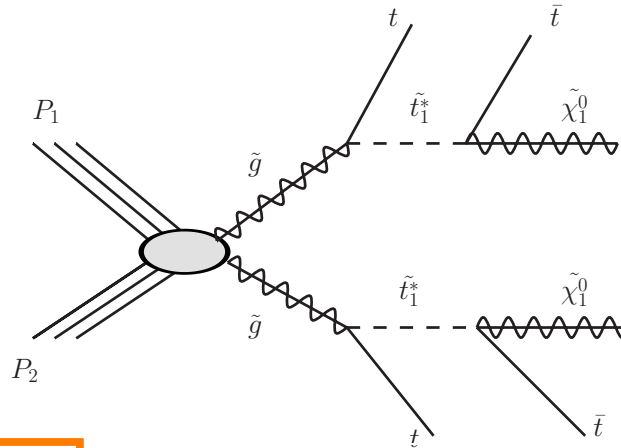
## CMS search: 7 search regions

- Two SS leptons
- $\geq 2$  jets;  $\geq 2,3$  b-tags
- $E_T^{\text{miss}} > 30 - 120$  GeV
- $H_T > 80 - 320$  GeV

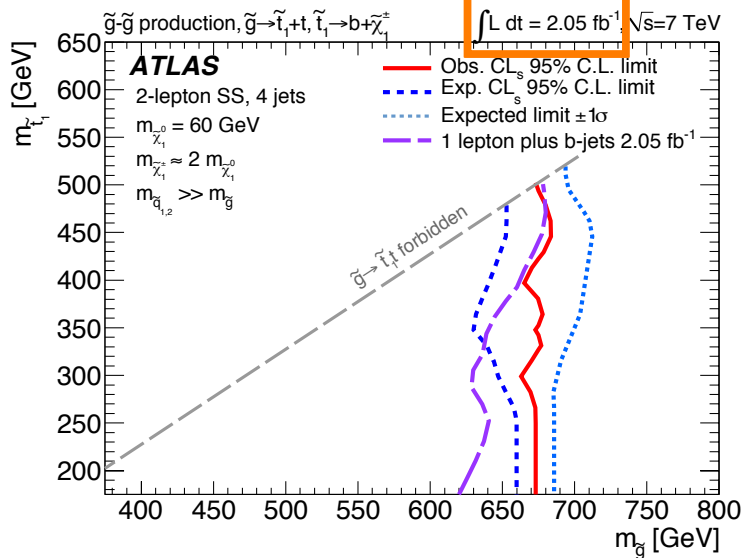


# SS dileptons + (b) jets

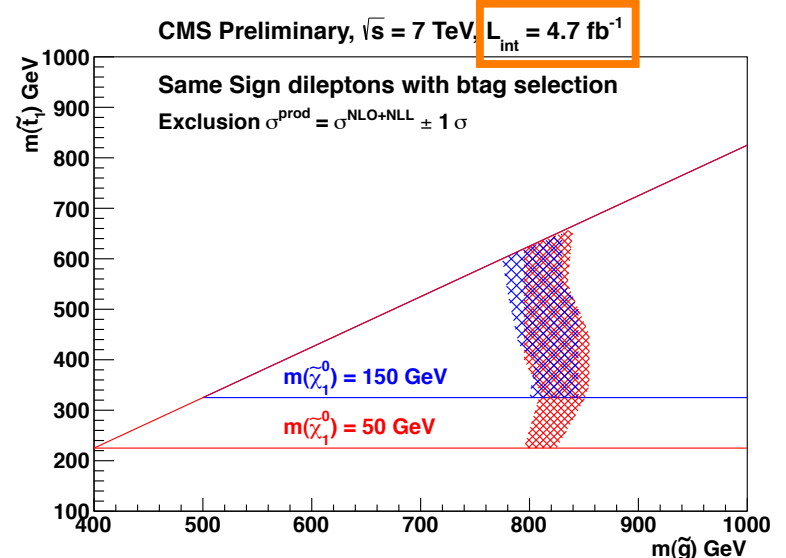
- Interpretation of result in gluino-mediated stop production with real stop



ATLAS search



CMS search



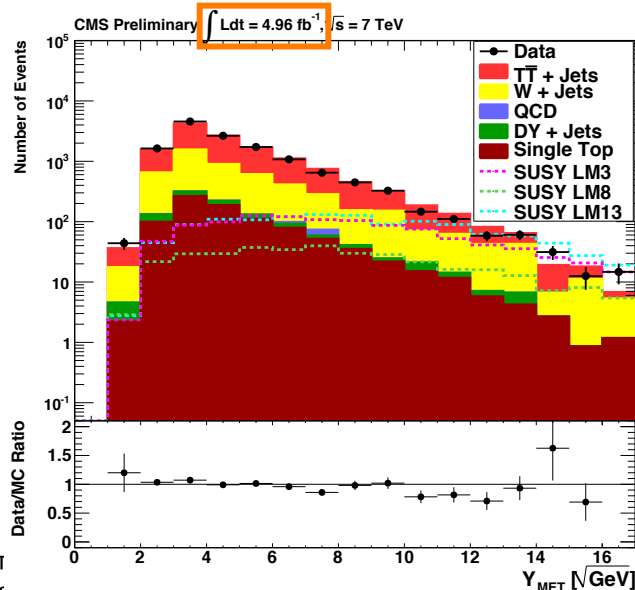


# Single lepton analyses

- Single lepton analyses are sensitive to stop decays with one leptonic W

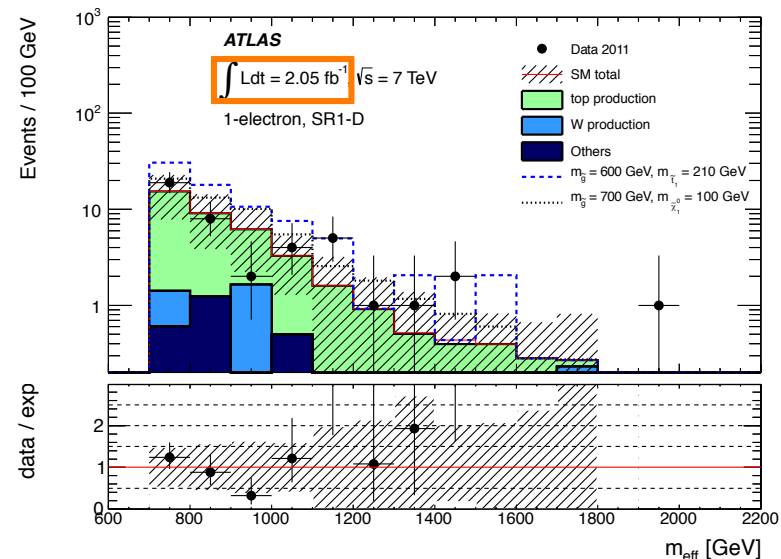
$$\text{CMS search: } Y_{\text{MET}} = E_T^{\text{miss}} / \sqrt{H_T}$$

- Exactly one lepton
- $E_T^{\text{miss}} > 60 \text{ GeV}$
- $\geq 1, 2, 3 \text{ b-tags}$
- $H_T > 650 \text{ GeV}$
- $Y_{\text{MET}} > 5.5 \text{ GeV}^{1/2}$



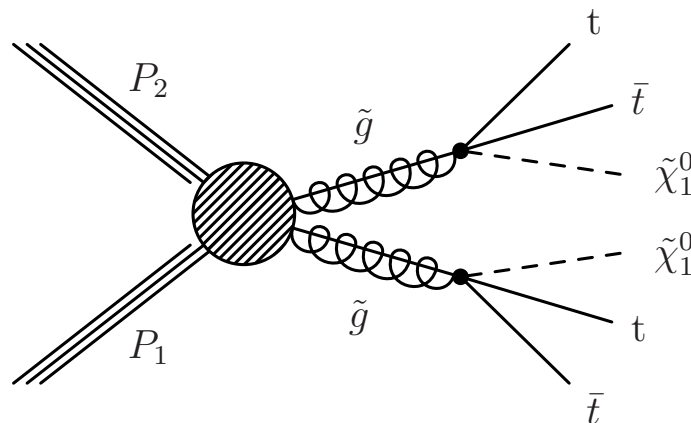
$$\text{ATLAS search: } m_{\text{eff}} = \sum_i (p_T^{\text{jet}})_i + E_T^{\text{miss}} + \sum_j (p_T^{\text{lep}})_j$$

- Exactly one lepton
- $m_T > 100 \text{ GeV}$
- $\geq 1 \text{ b-tags}$
- $E_T^{\text{miss}} > 80, 200 \text{ GeV}$
- $m_{\text{eff}} > 700 \text{ GeV}$



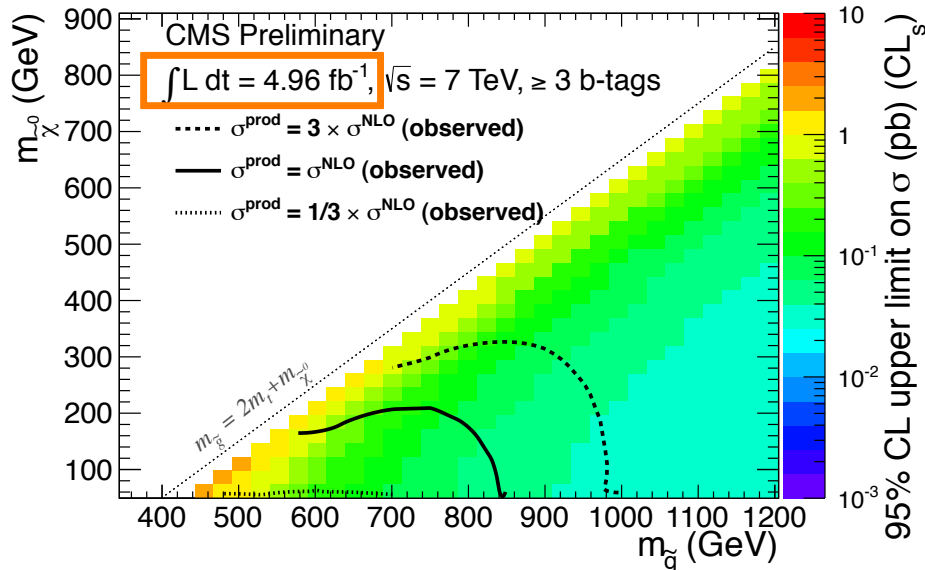
# Single lepton analyses

- Interpretation of results in gluino-mediated stop production

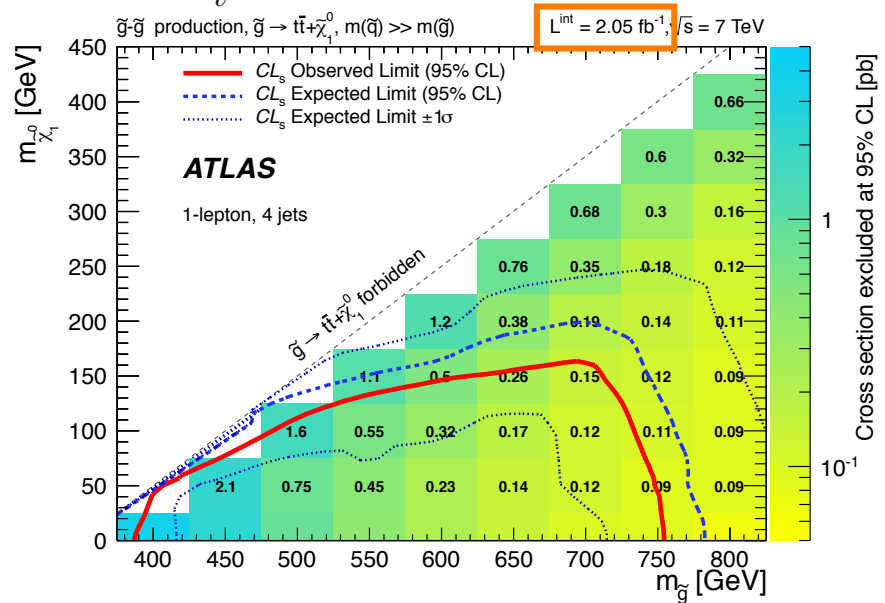


## CMS search

$pp \rightarrow \tilde{g}\tilde{g}, \tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0; m(\tilde{q}) \gg m(\tilde{g})$

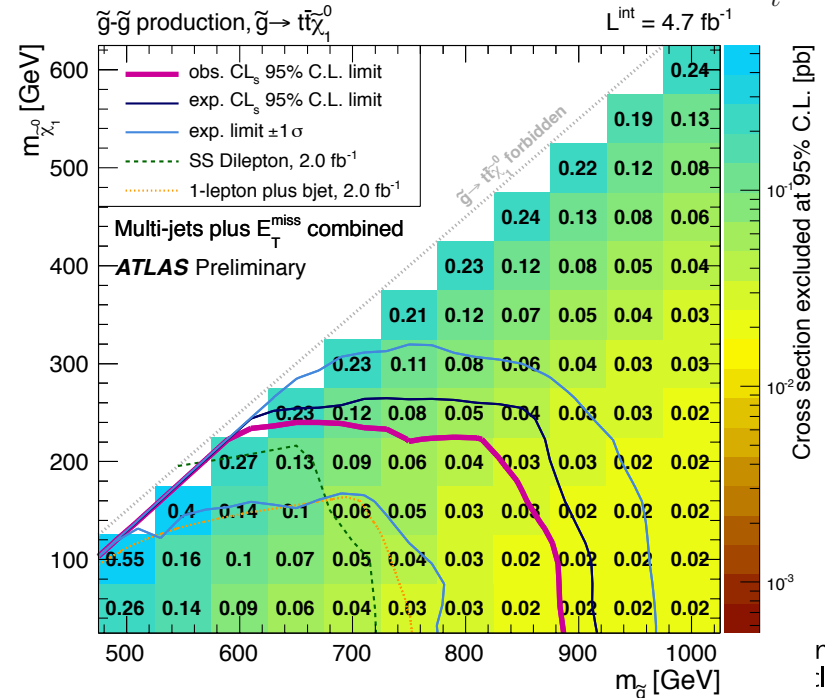
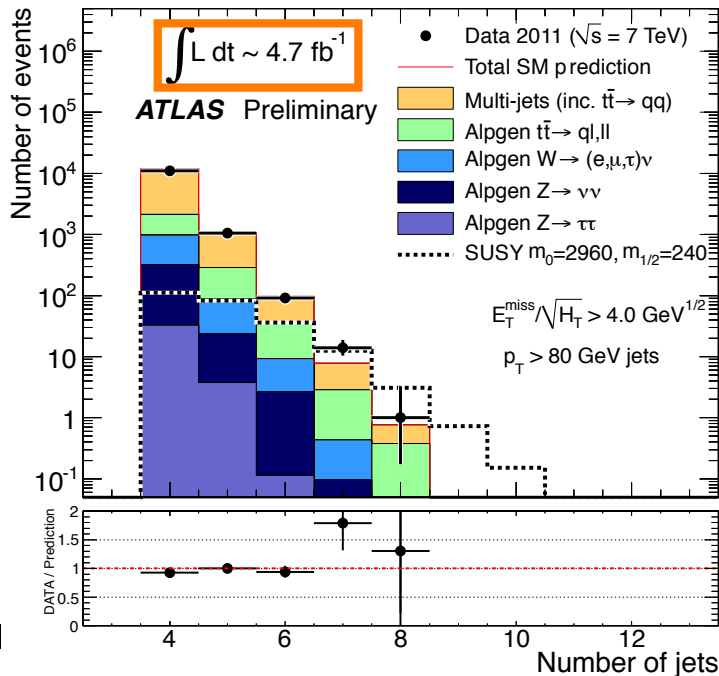
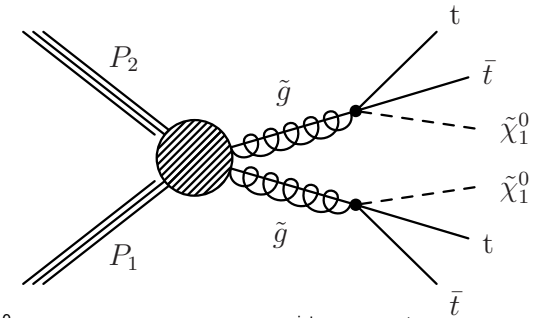


## ATLAS search



# multijet search

- In gluino-mediated stop production many jets are being produced
- There is a dedicated multijet search by **ATLAS** with 6 search regions
  - $\geq 6 - 9$  jets with either  $p_T > 55$  GeV or  $p_T > 80$  GeV
  - $E_T^{miss}/\sqrt{H_T} > 4$  GeV<sup>1/2</sup>

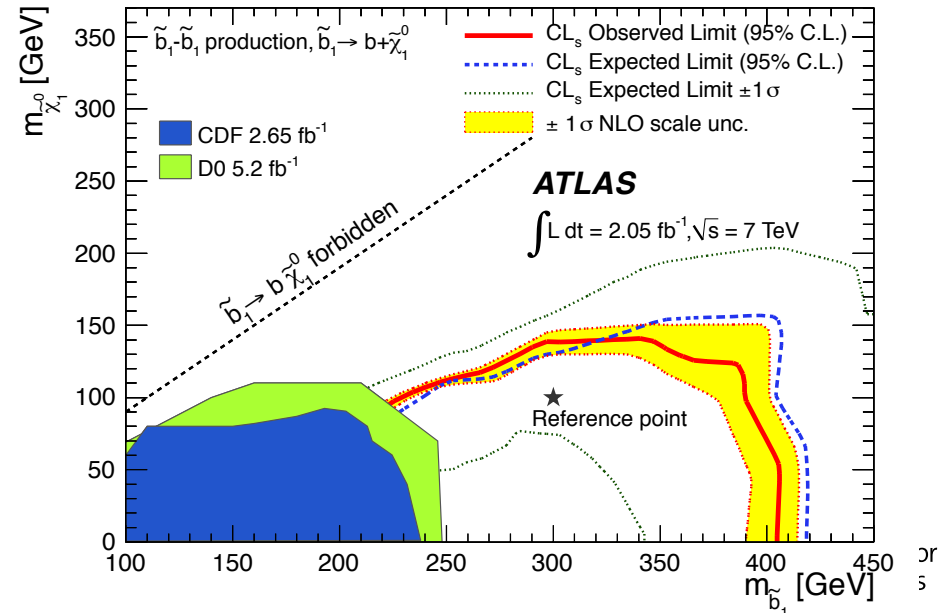
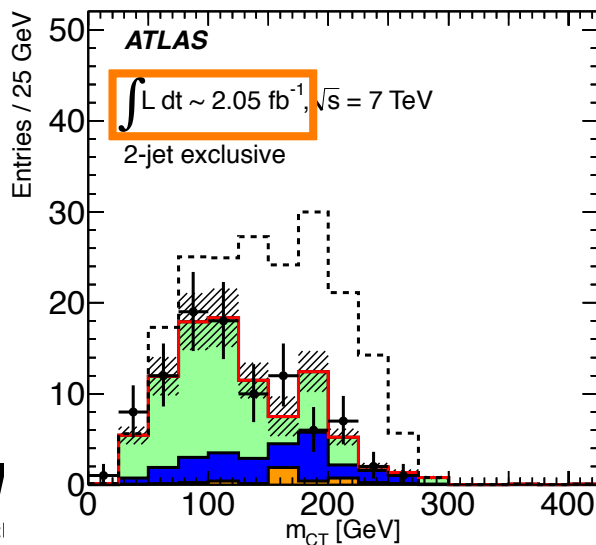
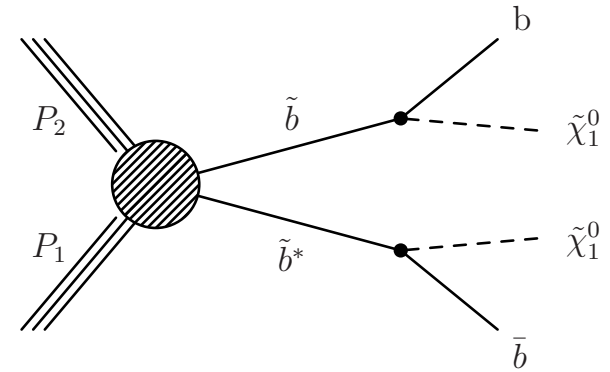


# Fully hadronic scalar b search

- Also **ATLAS** search for direct sbottom production in the **two b jet, 0 lepton channel**
- Uses boosted-corrected **contransverse mass**

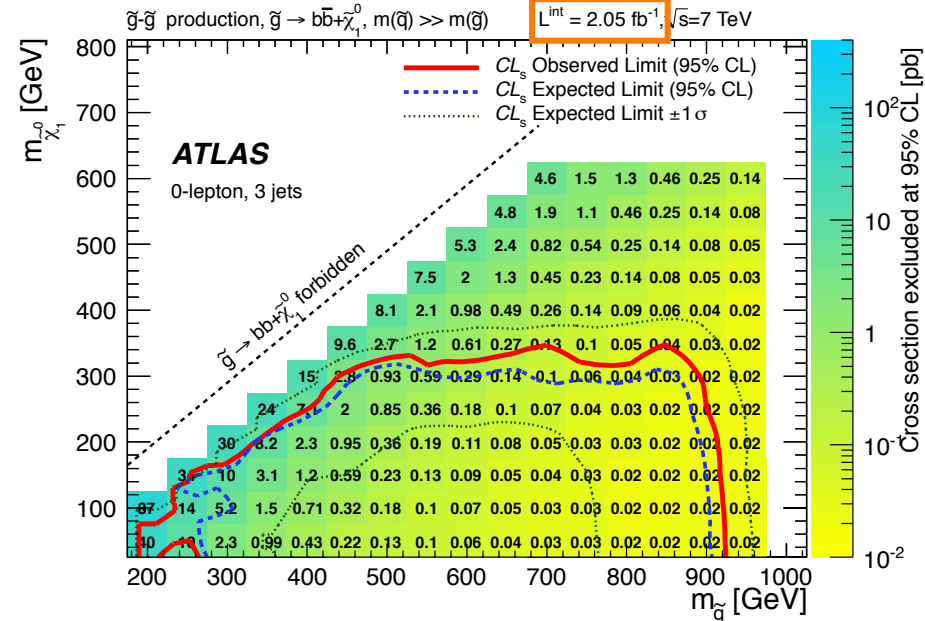
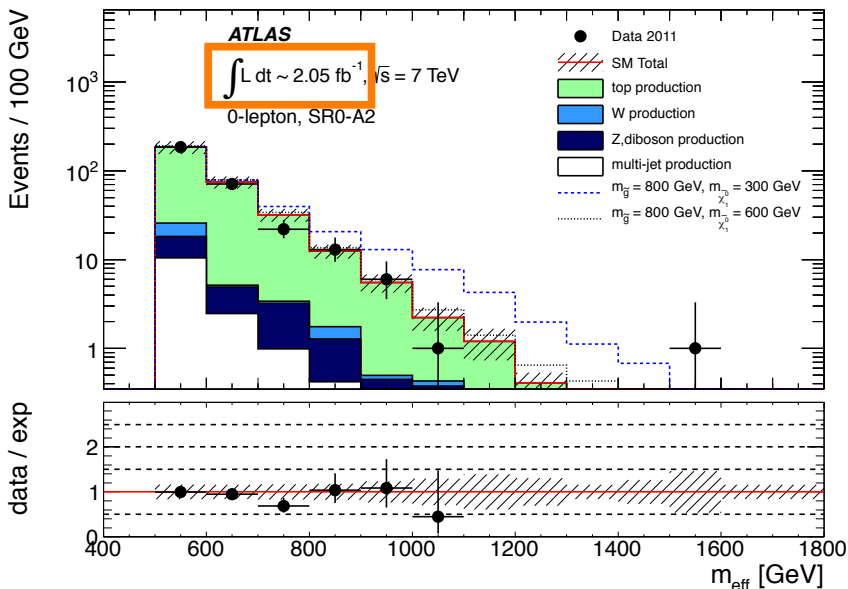
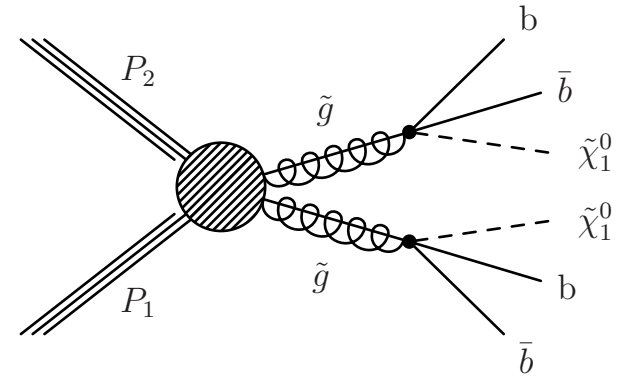
$$m_{\text{CT}} = \sqrt{[E_{\text{T}}(\mathbf{v}_1) + E_{\text{T}}(\mathbf{v}_2)]^2 - [\vec{p}(\mathbf{v}_1) - \vec{p}(\mathbf{v}_2)]^2}$$

- Two jets ( $p_{\text{T}} > 130$  GeV, 50 GeV), **both b-tagged**
- $E_{\text{T}}^{\text{miss}} > 130$  GeV,  $\Delta\phi(E_{\text{T}}^{\text{miss}}, \text{jets}) > 0.4$
- $m_{\text{CT}} > 100, 150$  or  $200$  GeV



# Hadronic search with $m_{\text{eff}}$

- The **ATLAS**  $m_{\text{eff}}$  search in the zero lepton channel interprets its result in gluino-mediated and direct sbottom production (back-up)
  - $\geq 3$  jets;  $\geq 1, 2$  b-tags
  - $\Delta\phi(E_T^{\text{miss}}, \text{jets}) > 0.4$
  - $E_T^{\text{miss}} > 130$  GeV,  $E_T^{\text{miss}}/m_{\text{eff}} > 0.25$
  - $m_{\text{eff}} > 500 - 900$  GeV (6 search regions)



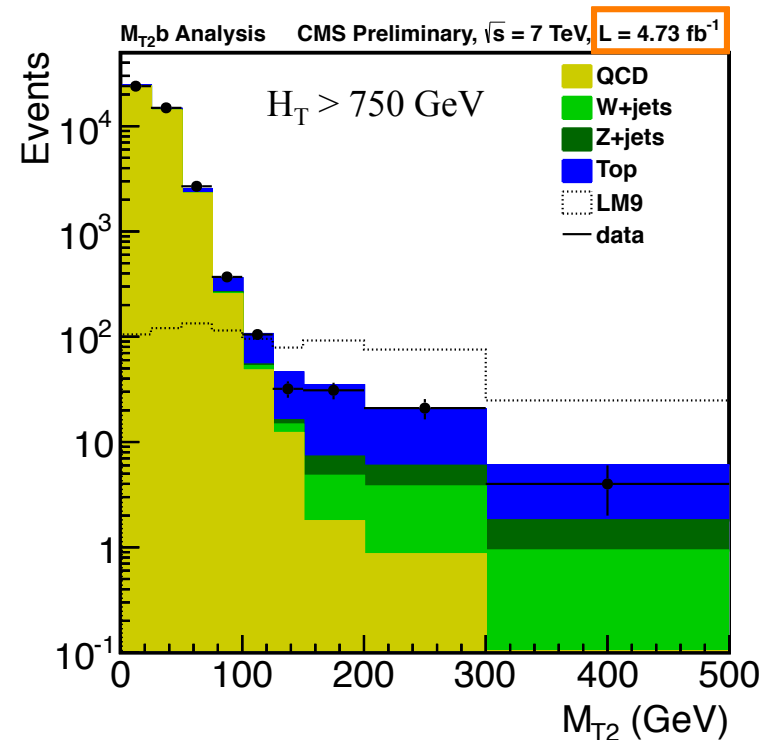
# Hadronic search with $M_{T2}$

- The **CMS**  $M_{T2}$  analysis uses the **shape information** in the search variables by using a **multi-binned approach** in  $M_{T2}$  and  $H_T$  and combining these exclusive bins in a likelihood and using a test statistic as defined by the LHC Higgs Combination group

$$M_{T2}(m_c) = \min_{\vec{p}_T^{c(1)} + \vec{p}_T^{c(2)} = \vec{p}_T^{miss}} \left[ \max(m_T^{(1)}, m_T^{(2)}) \right]$$

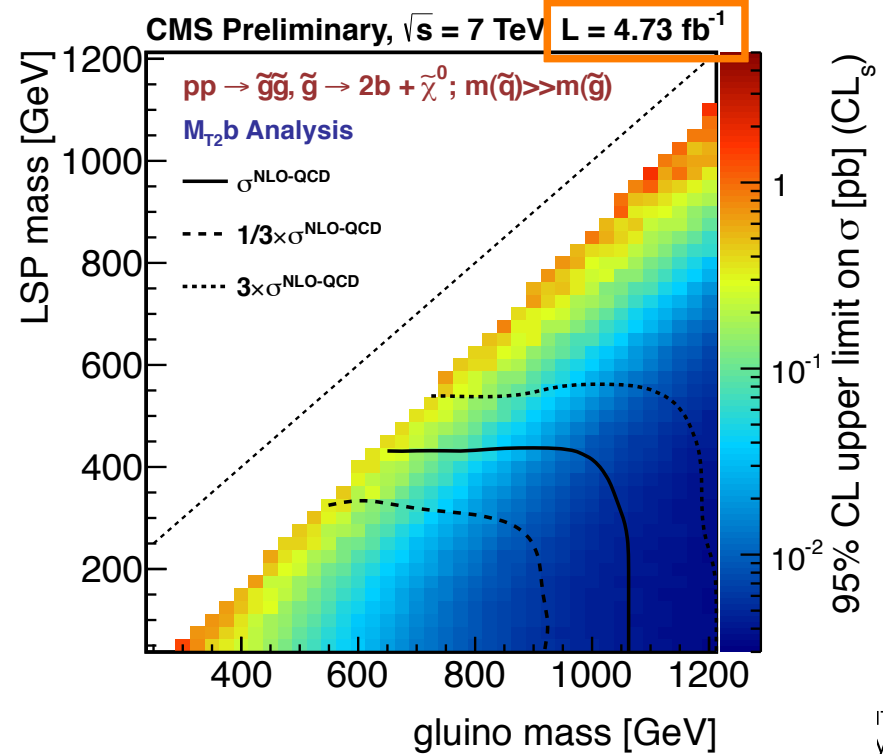
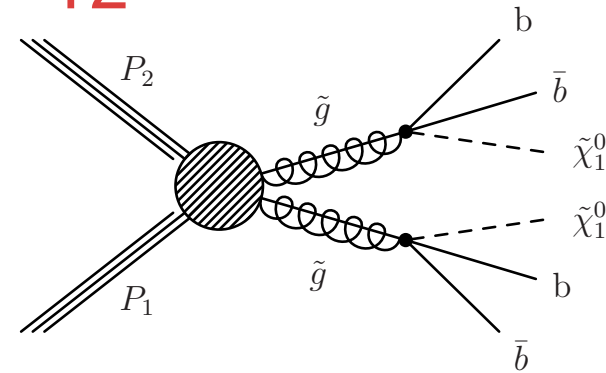
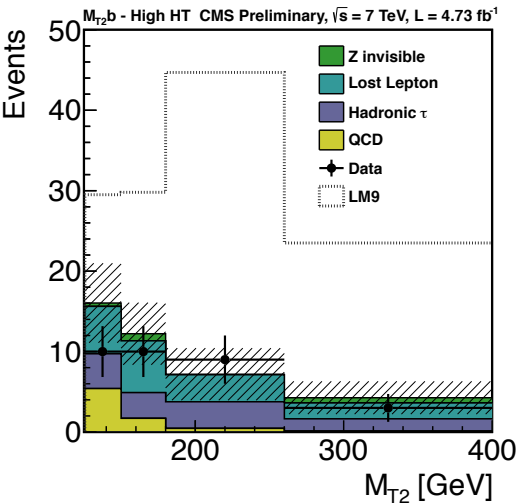
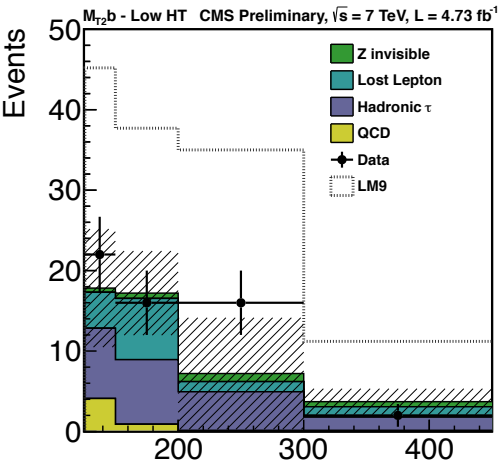
For this analysis:  $m_c = 0$ ,  $m_{\text{pseudojet}} = 0$ ,  
where all jets are combined into  
two pseudojets

- $\geq 4$  jets
- $\geq 1$  b-tag
- $\Delta\phi(E_T^{\text{miss}}, \text{jet}) > 0.3$  for leading four jets
- $750 \text{ GeV} \leq H_T < 950 \text{ GeV}$ ,  $H_T > 950 \text{ GeV}$
- Four bins in  $M_{T2}$**  starting with  $M_{T2} > 125 \text{ GeV}$



# Hadronic search with $M_{T2}$

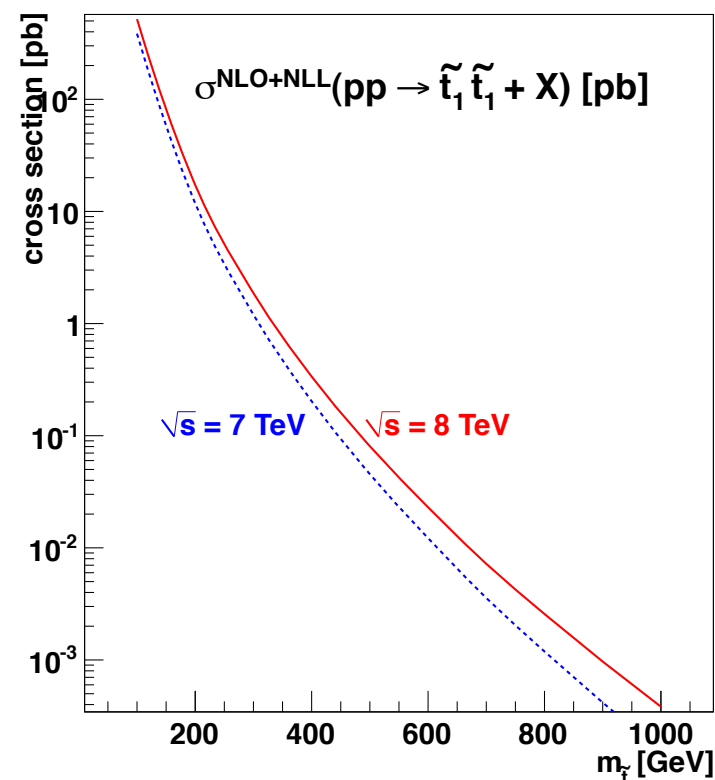
- Results and interpretation



# Summary

- Both **ATLAS** and **CMS** have a variety of SUSY searches, many of them **sensitive to 3<sup>rd</sup> generation squarks production**.
- Also signatures beyond mSugra have been looked at.
- **Impressive limits** set in squark production, especially for gluino-mediated production.
- **No sign of SUSY so far...but still a lot of space:**  
E.g. direct squark production still limited by low cross section.
- Stay tuned for **ATLAS** and **CMS** 2012 analyses

Note:  $\sigma^{\text{NLO}}(\text{pp} \rightarrow \text{t}\bar{\text{t}}+\text{X}) = 225 \text{ pb}$

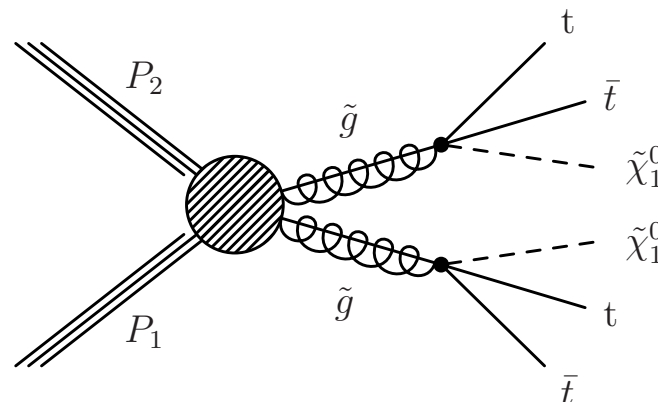




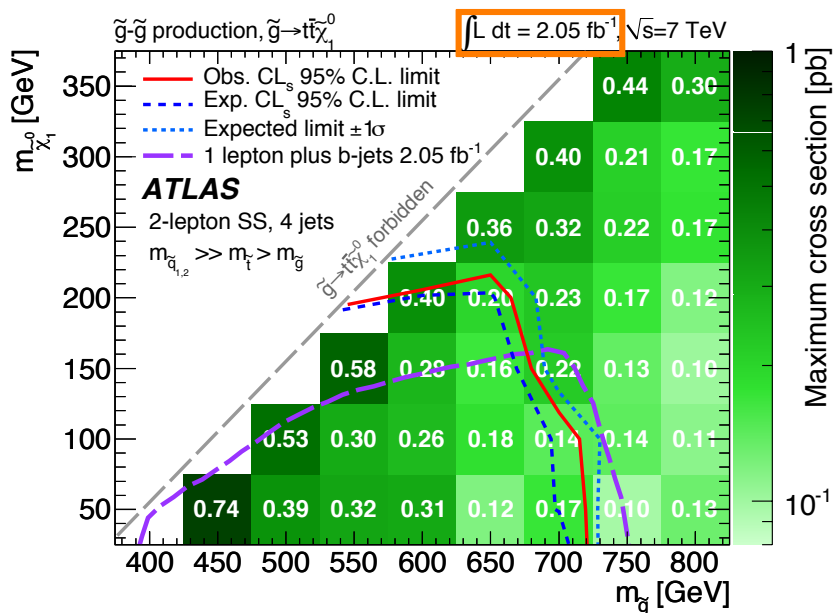
# Backup

# SS dileptons + (b) jets

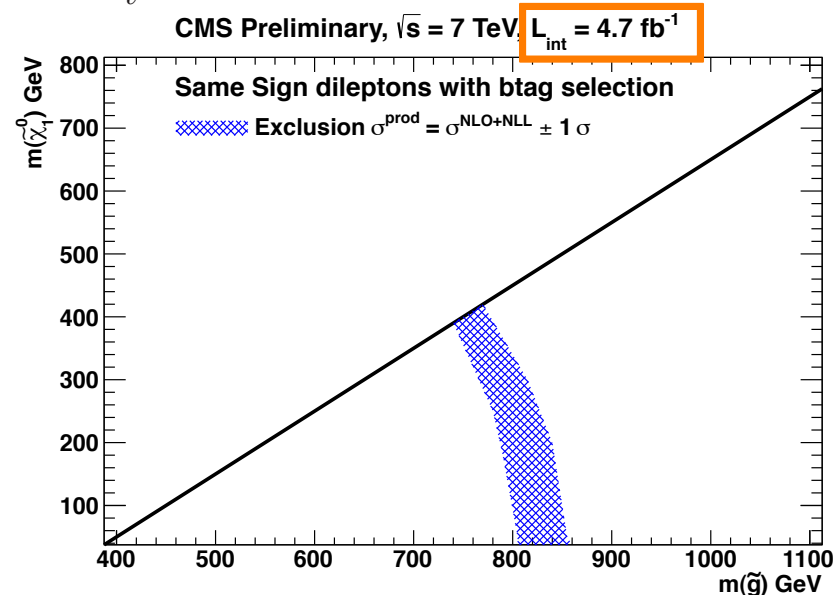
- Interpretation of results in model of gluino-mediated stop production (virtual stop)



ATLAS search

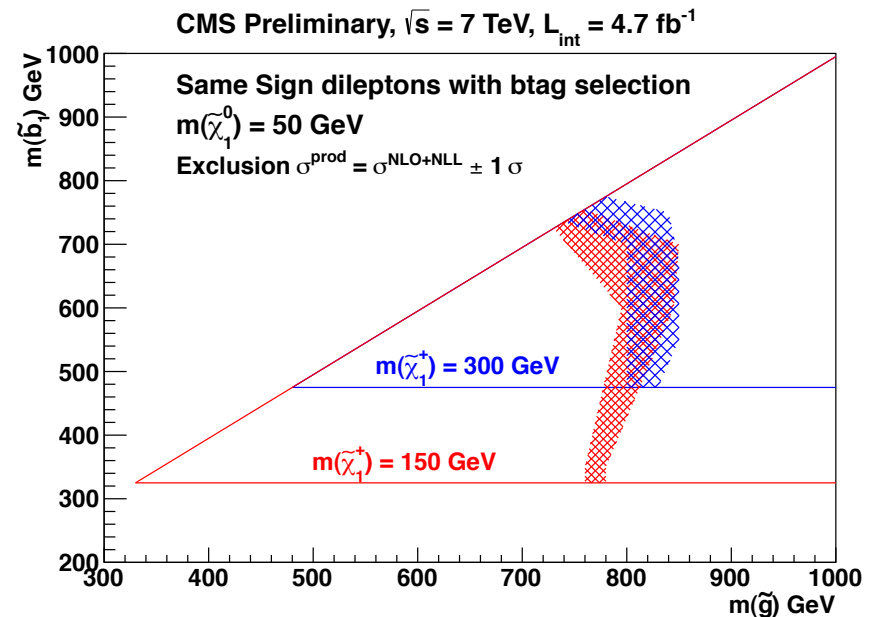
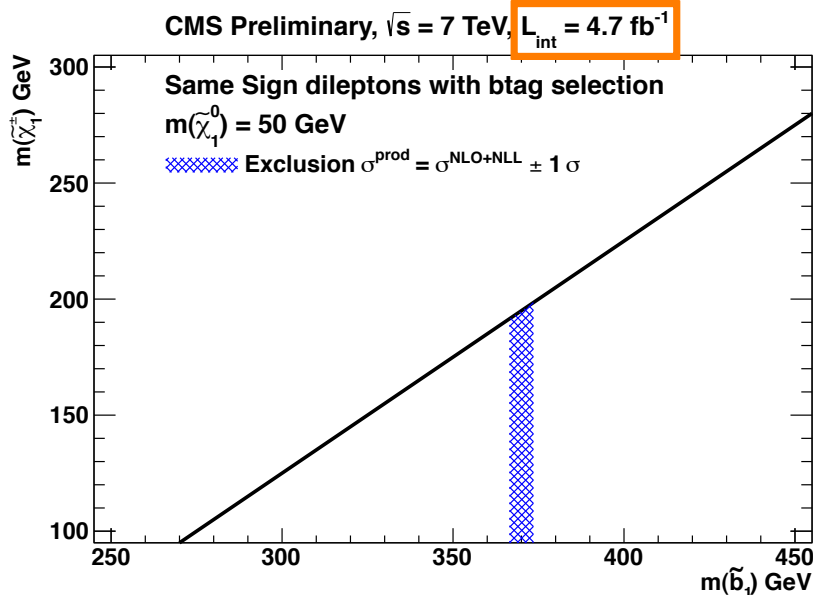
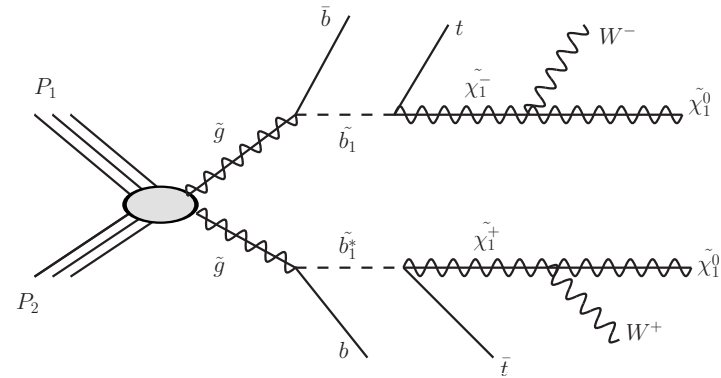
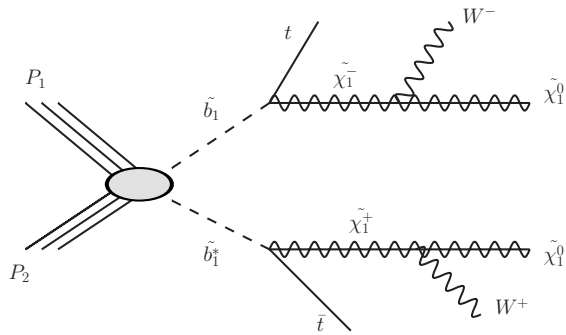


CMS search



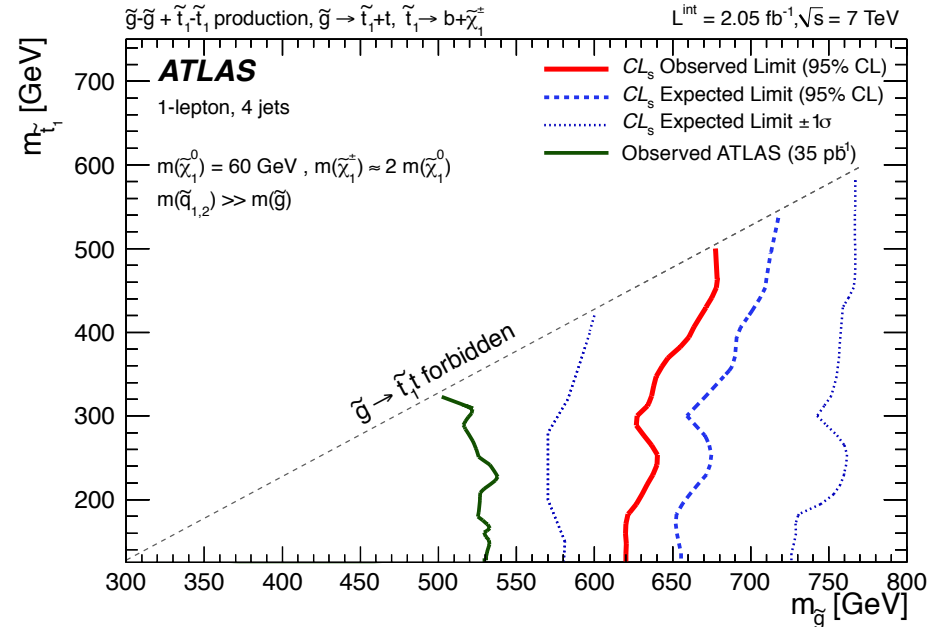
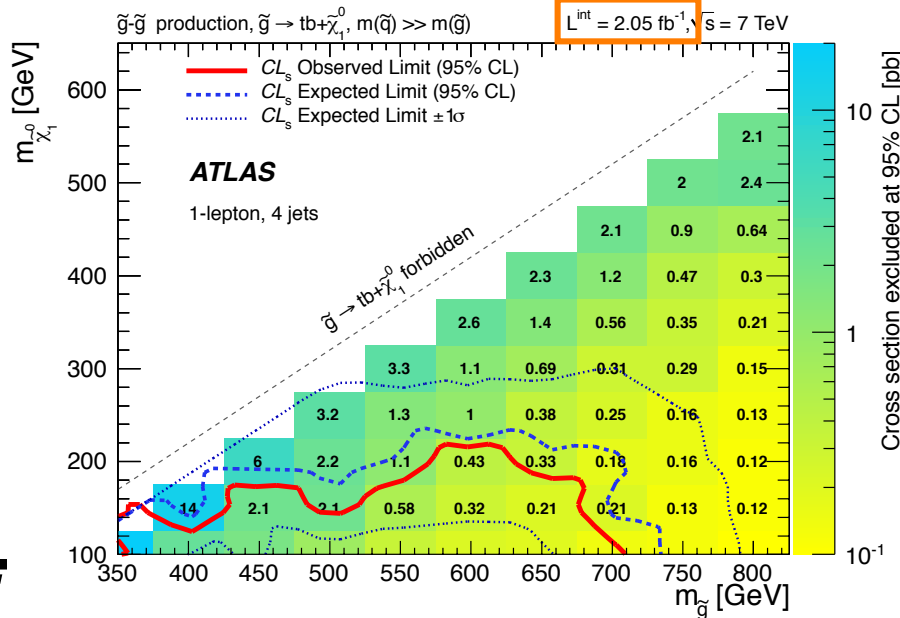
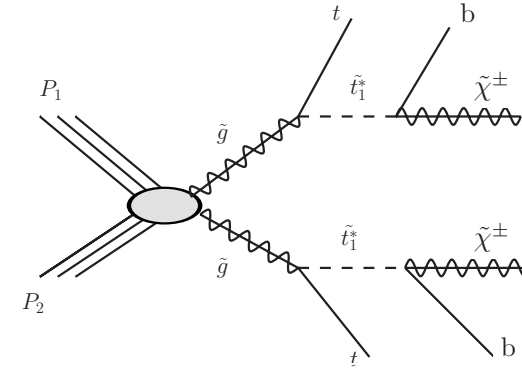
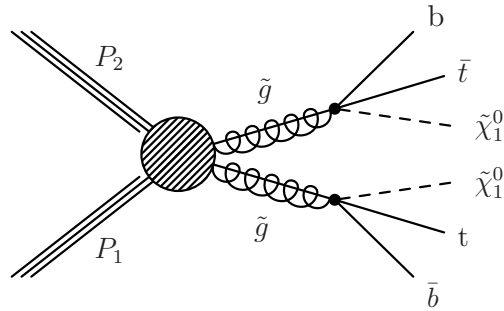
# SS dileptons + (b) jets

- **CMS SS+b search sets also limits in direct sbottom production and gluino-mediated sbottom production**



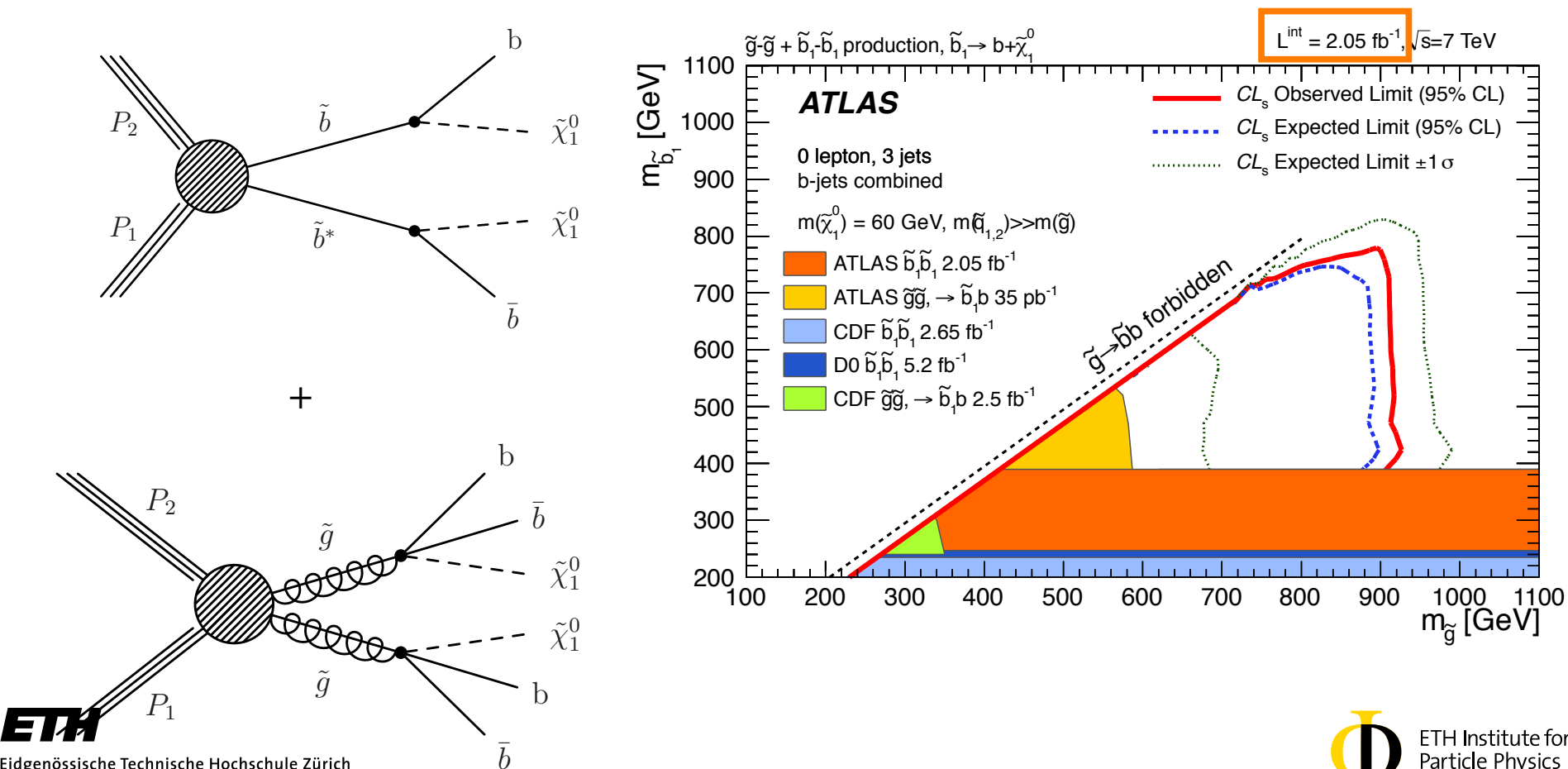
# Single lepton analyses

- **ATLAS** analysis sets also limits in several variants of in gluino-mediated stop production



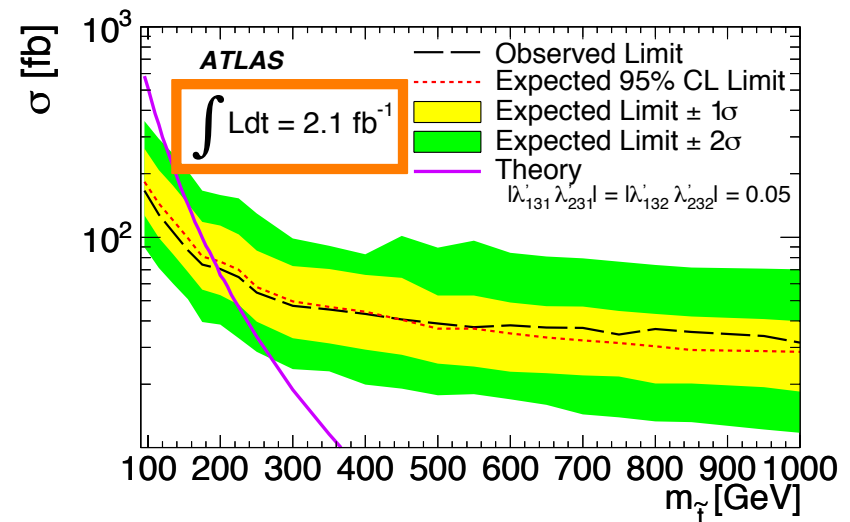
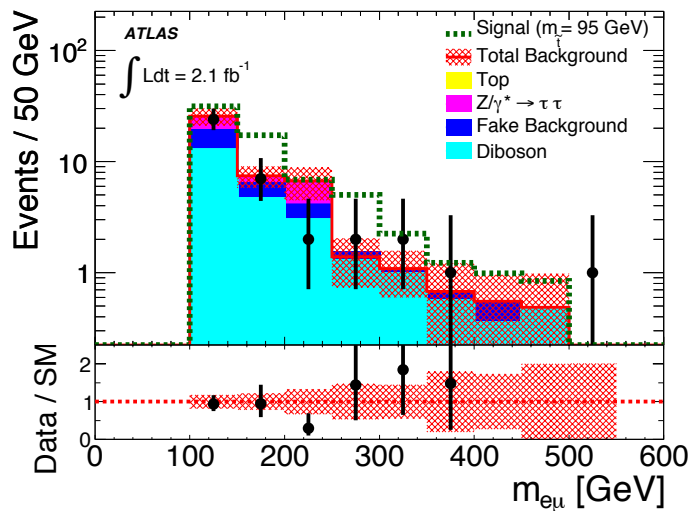
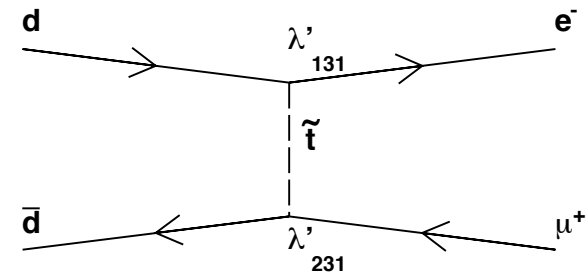
# Hadronic search with $m_{\text{eff}}$

- The **ATLAS**  $m_{\text{eff}}$  search in the zero lepton channel interprets its result in a model of gluino-mediated and direct sbottom production



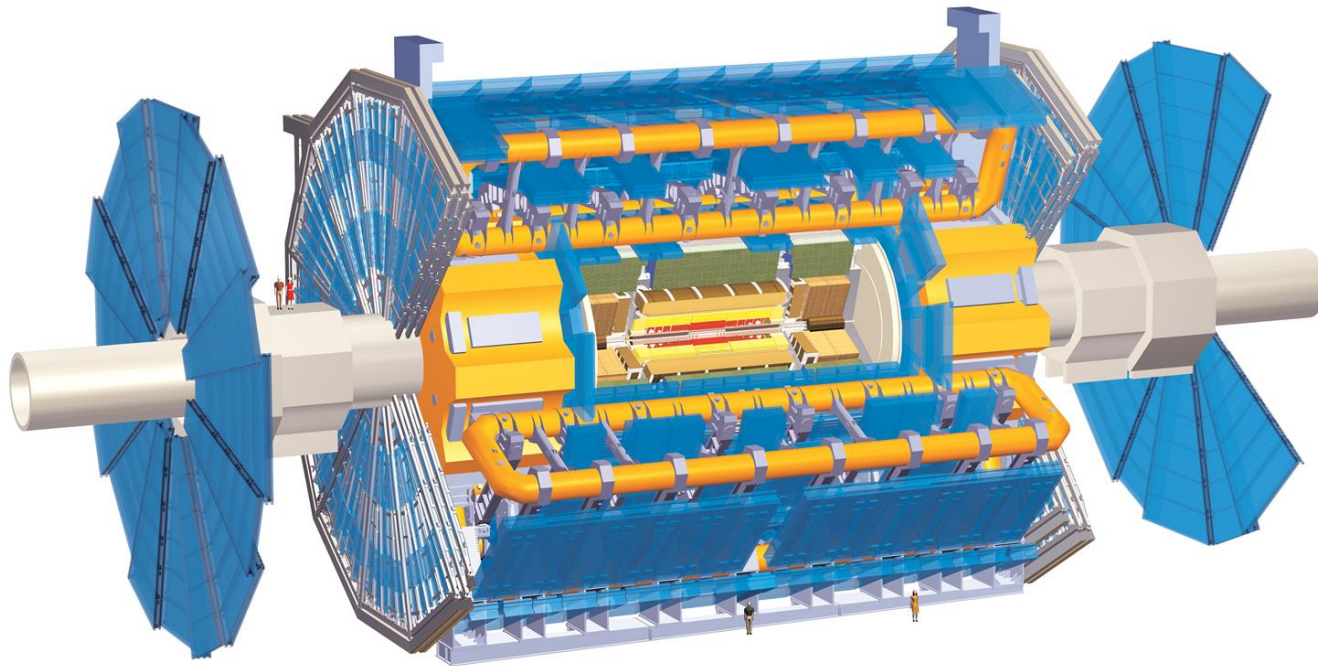
# 3<sup>rd</sup> generation squarks in R-parity violating SUSY

- In R-parity violating SUSY also **lepton flavour** conservation can be **violated** by an **exchange of a virtual squark**
- ATLAS** search in  $e^\pm\mu^\mp$ 
  - Muon  $p_T > 25$  GeV,  $|\eta| < 2.4$
  - Electron  $E_T > 25$  GeV,  $|\eta| < 1.37$  or  $1.52 < |\eta| < 2.47$
  - $m_{e\mu} > 100$  GeV,  $\Delta\phi_{e\mu} > 3.0$ ,  $E_T^{\text{miss}} > 25$  GeV



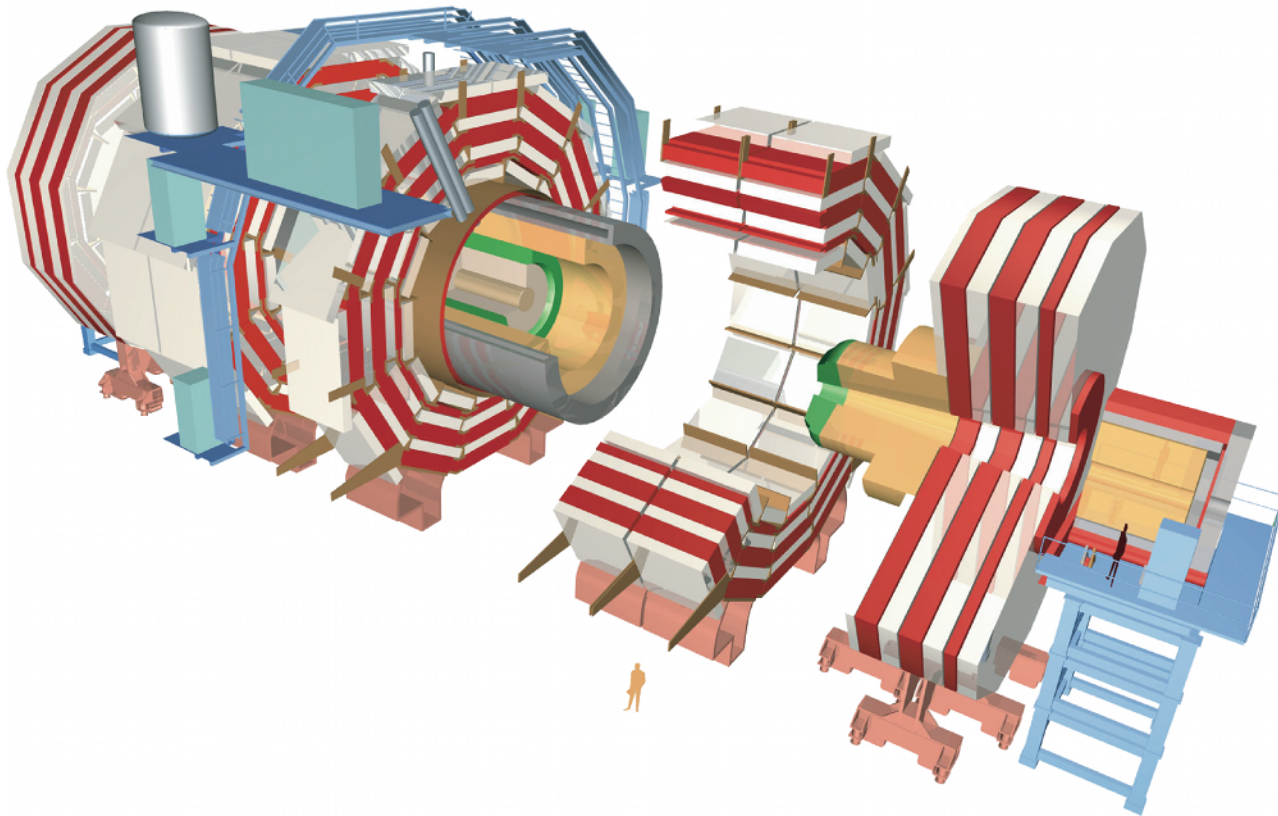


# The ATLAS detector





# The CMS detector



# Btagging in ATLAS and CMS

- **B-tagging** uses mainly **secondary vertex** and **impact parameter** information to distinguish jets from b hadrons from other jets
- Typical efficiency: 70 % for b jets at 1% (10%) fake rate for light (c) jets
- Various working points depending on wanted b jet efficiency / light jet rejection.

