Search for direct pair production of stops and sbottoms with the ATLAS detector

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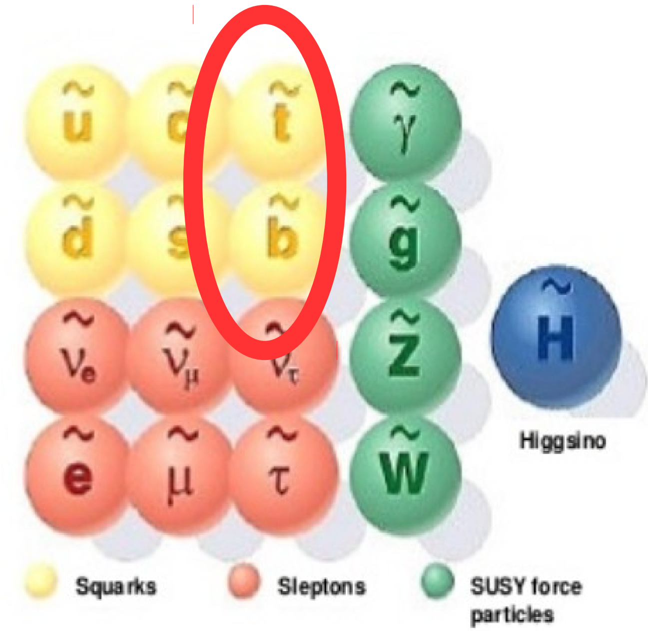
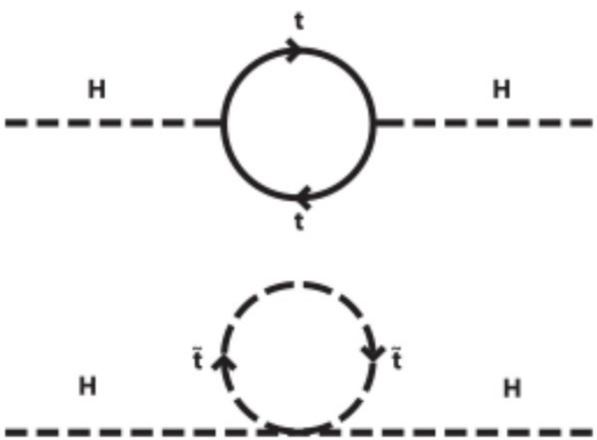
On behalf of the ATLAS Collaboration





Introduction and motivation

- Stop and sbottom key ingredient for solution of hierarchy problem
- Question ATLAS addressed, how much of the pMSSM parameter space for stop sbottoms with masses below ~TeV can we cover with early 13 TeV data?
- Two lines of development:
  - Address large parameter space
  - Address difficult final state kinematics
- Complete set of searches with first 36 fb^{-1} collected at 13 TeV now published. Today give broad view with emphasis on recent work

Parameter space for stop/sbottom searches

- Stop/sbottom sector:

  5 parameters:

  $m(t_L)=m(b_L),m(t_R),m(b_R)$

  mixing angles θ_t,θ_b

  Mass eigenstates t_1, t_2, b_1, b_2 from mixing of L-R states

  concentrate search on lighter states t_1, b_1

Chargino-neutralino sector:

4 parameters:

M1, M2, μ, $\tan\beta$

From mixing obtain 4 neutralinos and 2 charginos

From hierarchy of M1, M2, μ

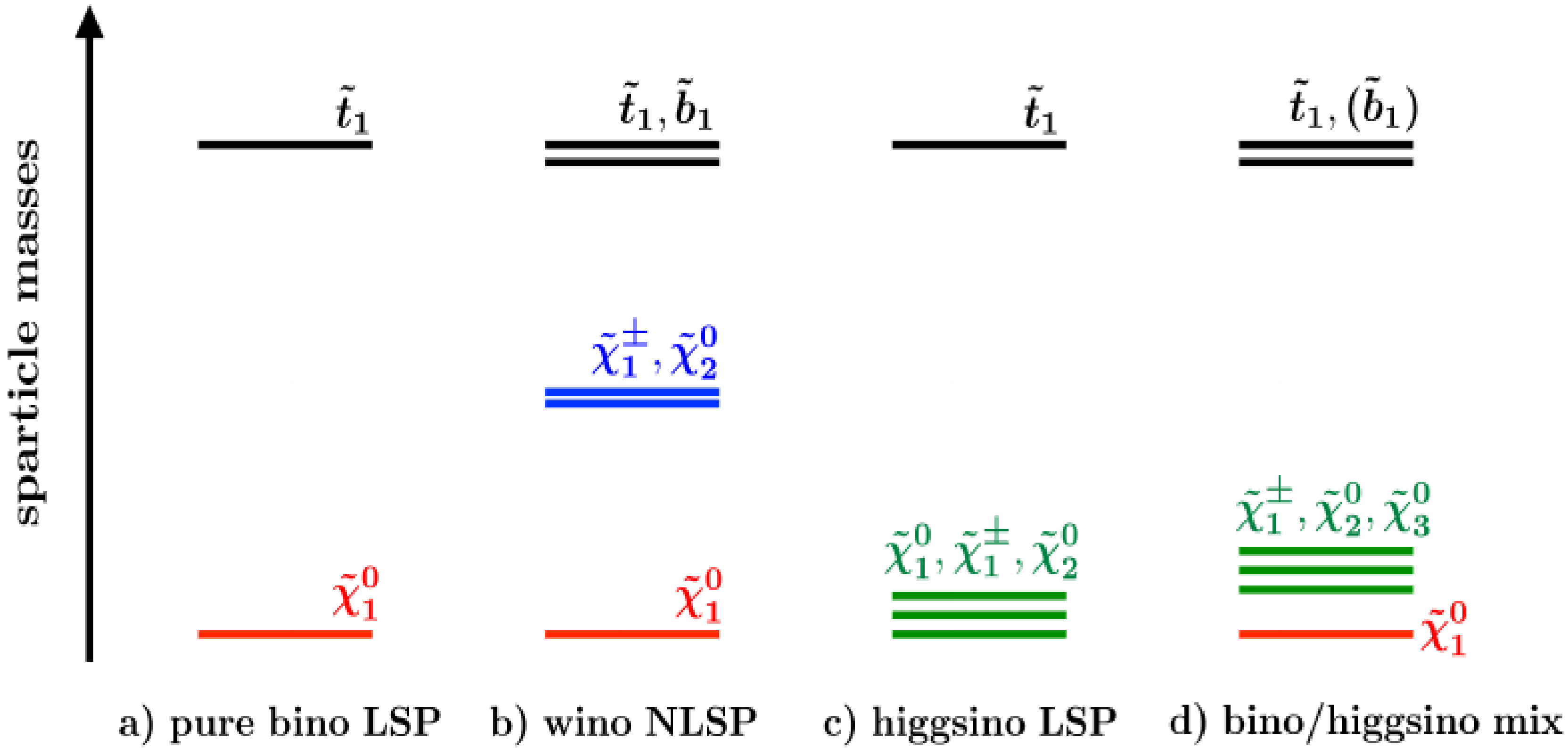
characteristic mass patterns for neutralinos/charginos

Take χ^0_1 as LSP

For searches parameter space collapsed to two dimensional space $m(t_1, \chi^0_1)$. Choose representative combinations of other parameters to cover the main phenomenologies

Searches for both stop and sbottom necessary

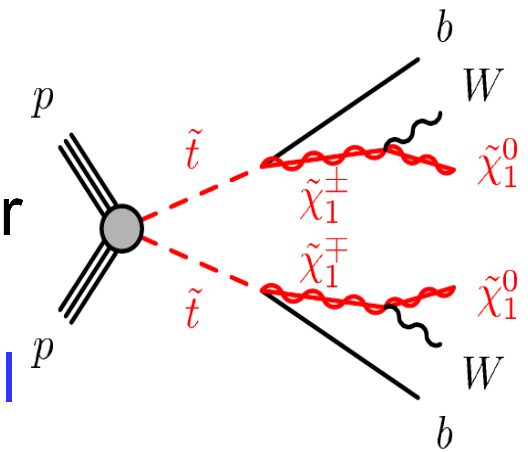
Benchmark parameter patterns

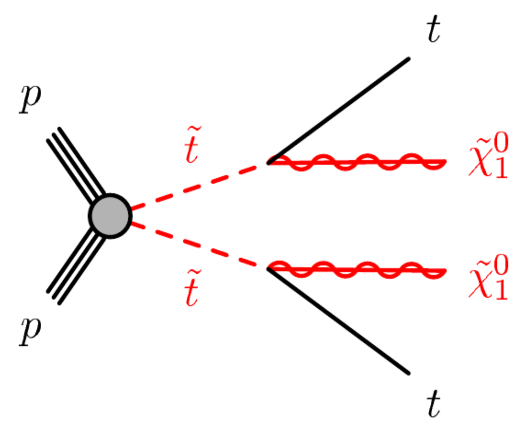


Each of these scenarios yields specific decay patterns/final state topologies
Optimise selections for each of these scenarios

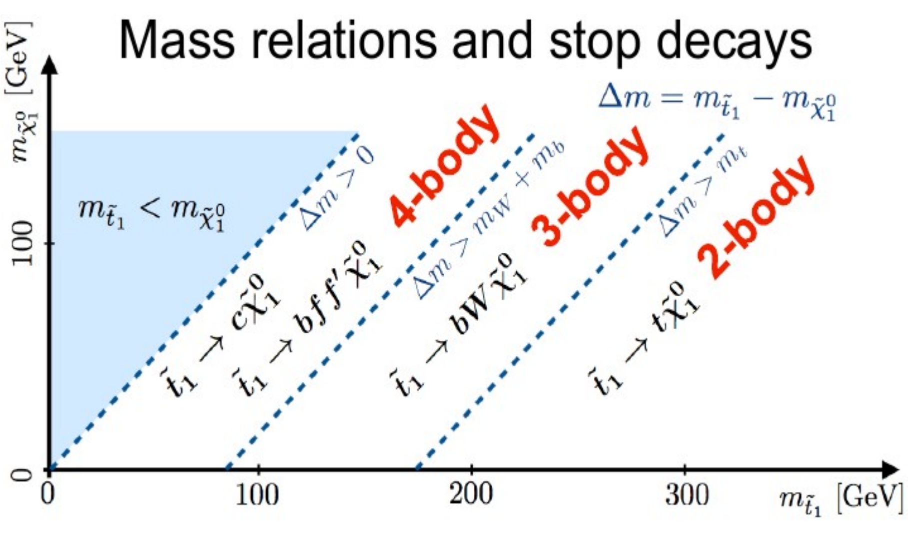
Stop final states

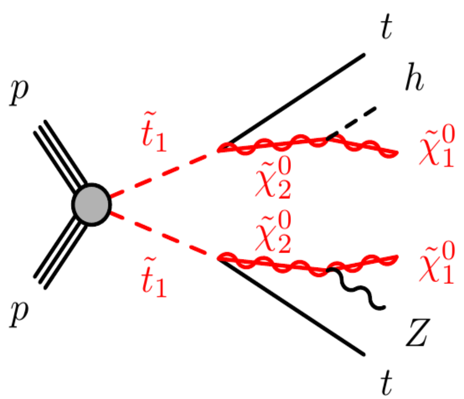
Final state bb $W^{(*)}W^{(*)}$
Classify in terms of number
Of leptonic decays of W:
0L, 1L, 2L : golden channel





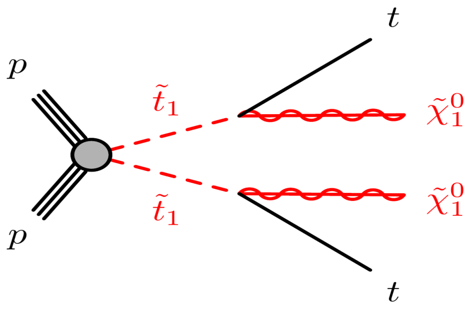
Mass hierarchy determines number of resonant top/W bosons, and analysis strategy





If decay through intermediate chi02: Z and h in final state

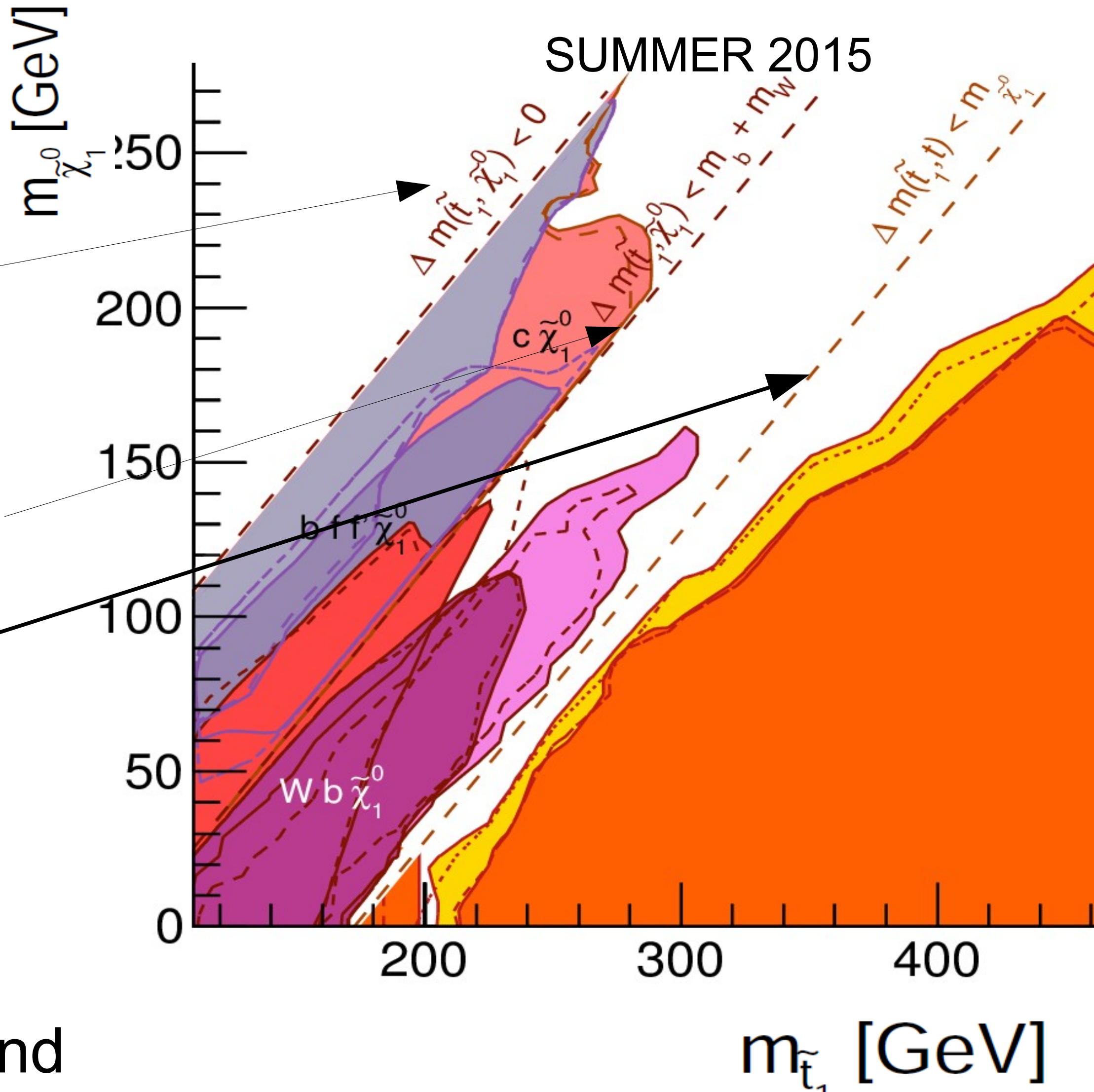
Difficult kinematics: Run1 coverage for bino LSP



m(stop)-m(chi01)~0

m(stop)-m(chi01)~m(W)

m(stop)-m(chi01)~m(t)



Compressed spectra:
final states invisible
or identical to SM background

Focus for Run 2 on covering holes in this plane

All of the decay modes searched for with full 2015-16 statistics (36 fb-1)

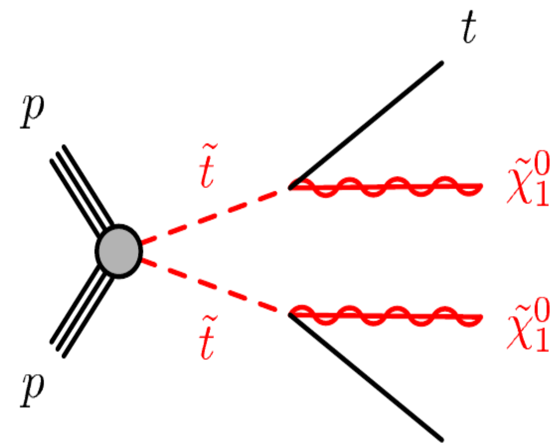
Channel	ATLAS
Stop 0L	JHEP 12 (2017) 085
Stop 1L	arXiv: 1711.11520, to JHEP (with DM interpretation)
Stop 2L	EPJC 77 (2017) 898
Stop with Z/h	JHEP 08 (2017) 006
Stop to stau	arXiv: 1803.10178, to PRD
Stop to charm	arXiv: 1805.01649, to JHEP NEW
Sbottom	JHEP 11 (2017) 195
RPV stop	Eur. Phys. J. C 78 (2018) 250 (4j paired resonance), Phys. Rev. D 97 (2018) 032003 (B-L), JHEP09 (2017) 088 (1L+multi-jets)
RPV re-interpretation	ATLAS-CONF-2018-003

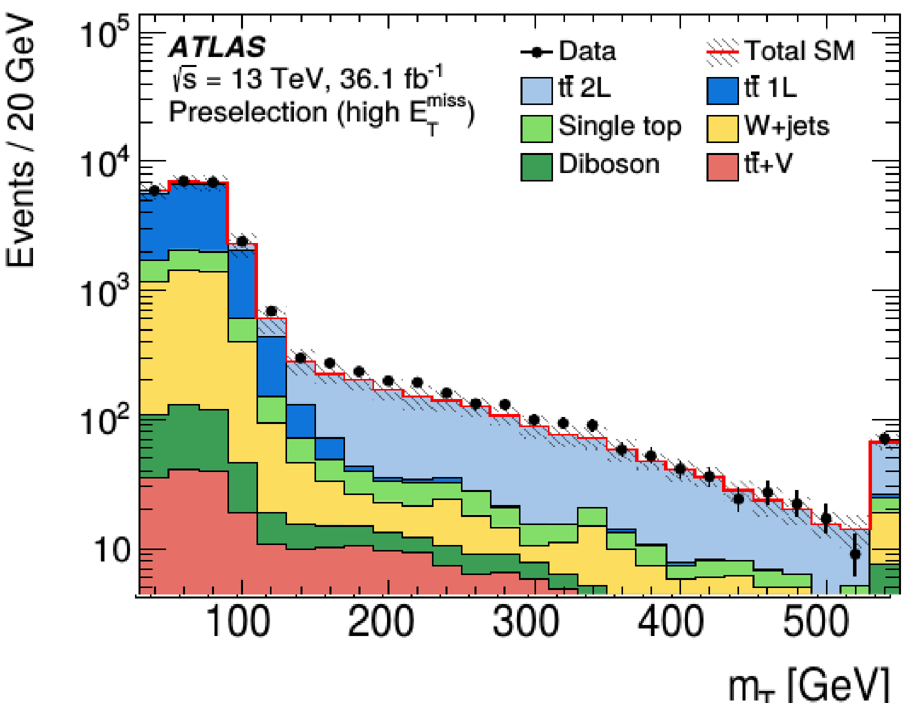
Stop 1L

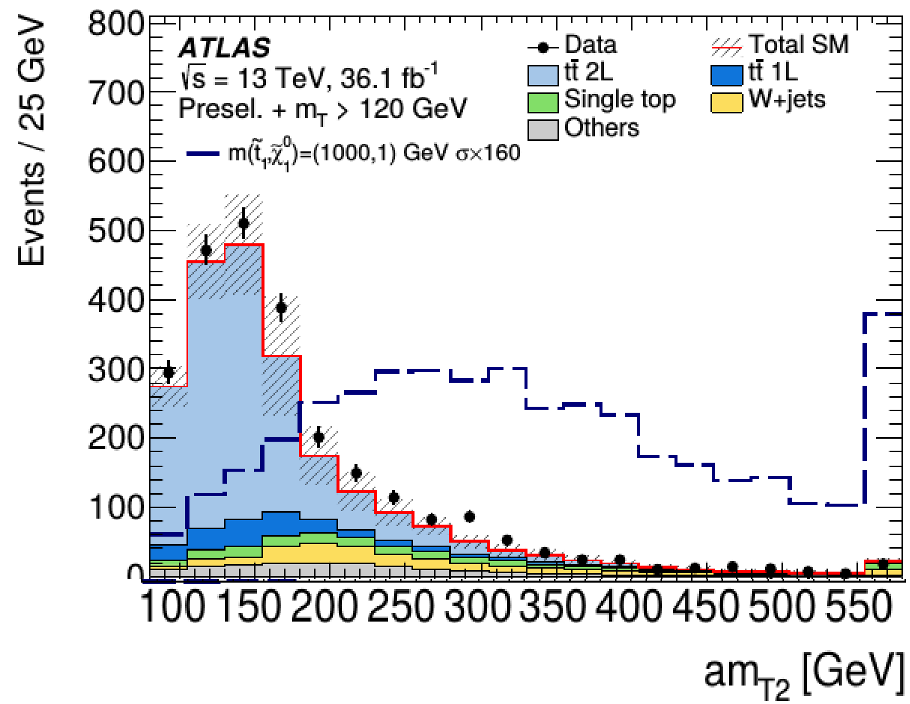
arXiv:1711.11520

Final state: 1 lepton (soft or hard)+b-jets+E_T^{miss}

- Exploit the presence of 1 leptonic (M_T) and one hadronic top decay (hadronic mass reco)
- Asymmetric stransverse mass to suppress dilepton background
- Angular correlations between jets to enhance signal discrimination



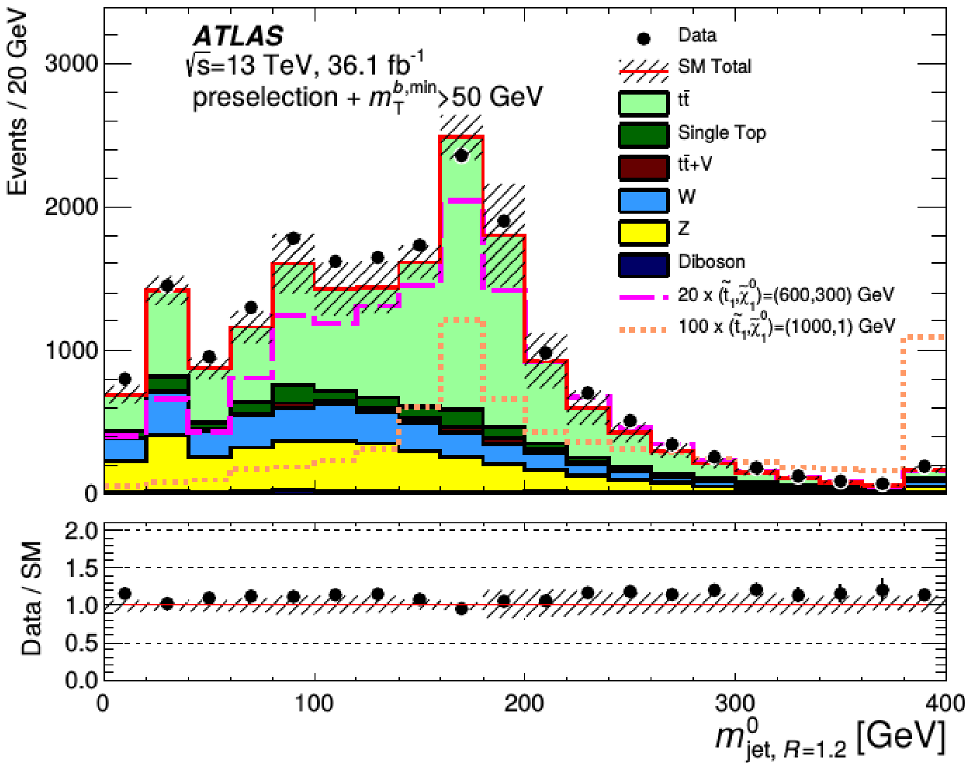


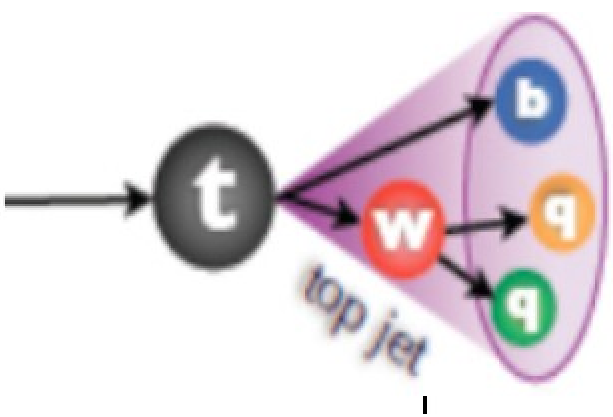


Stop 0L

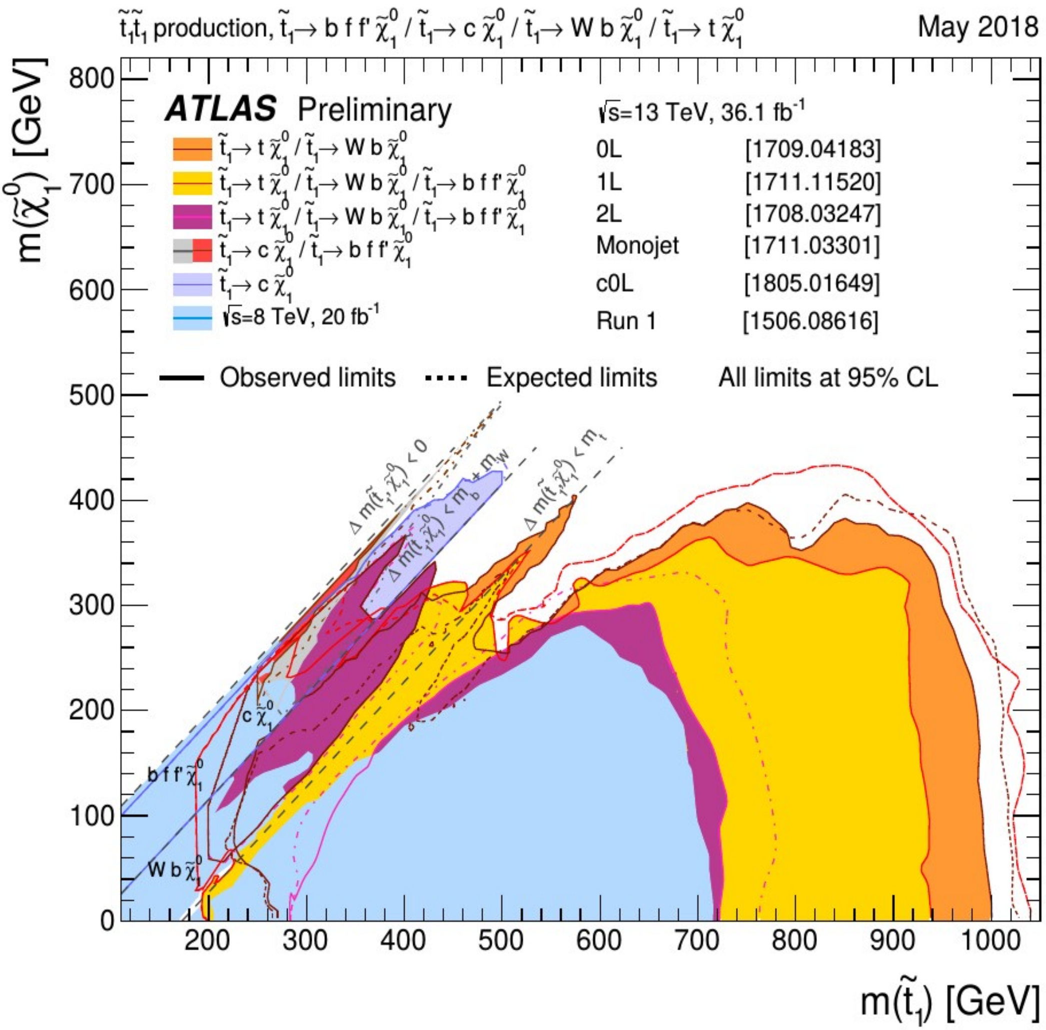
JHEP 12 (2017) 085

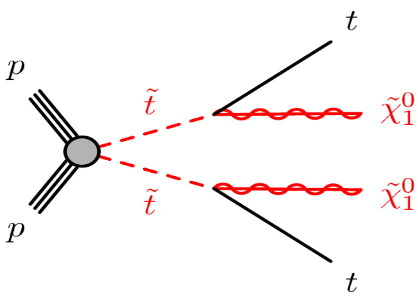
- Signature: 0L + E_T^{miss} + ≥4 jets with two b-tagged.
- For high mass stop, top reconstruction with large-radius jets (R=1.2) in boosted topology.
- For compressed mass spectra, exploit initial state radiation





Results: Scenario Bino-LSP





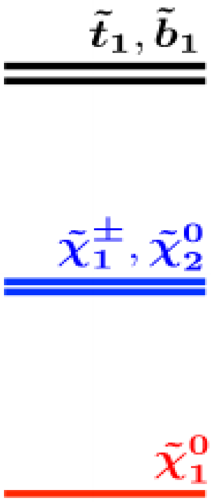
- Maximum coverage in stop mass for 0L analysis
- Dedicated searches cover difficult regions based on request of system recoiling against ISR jet

Benchmark scenario:
BR(stop1->top chi01)=100%

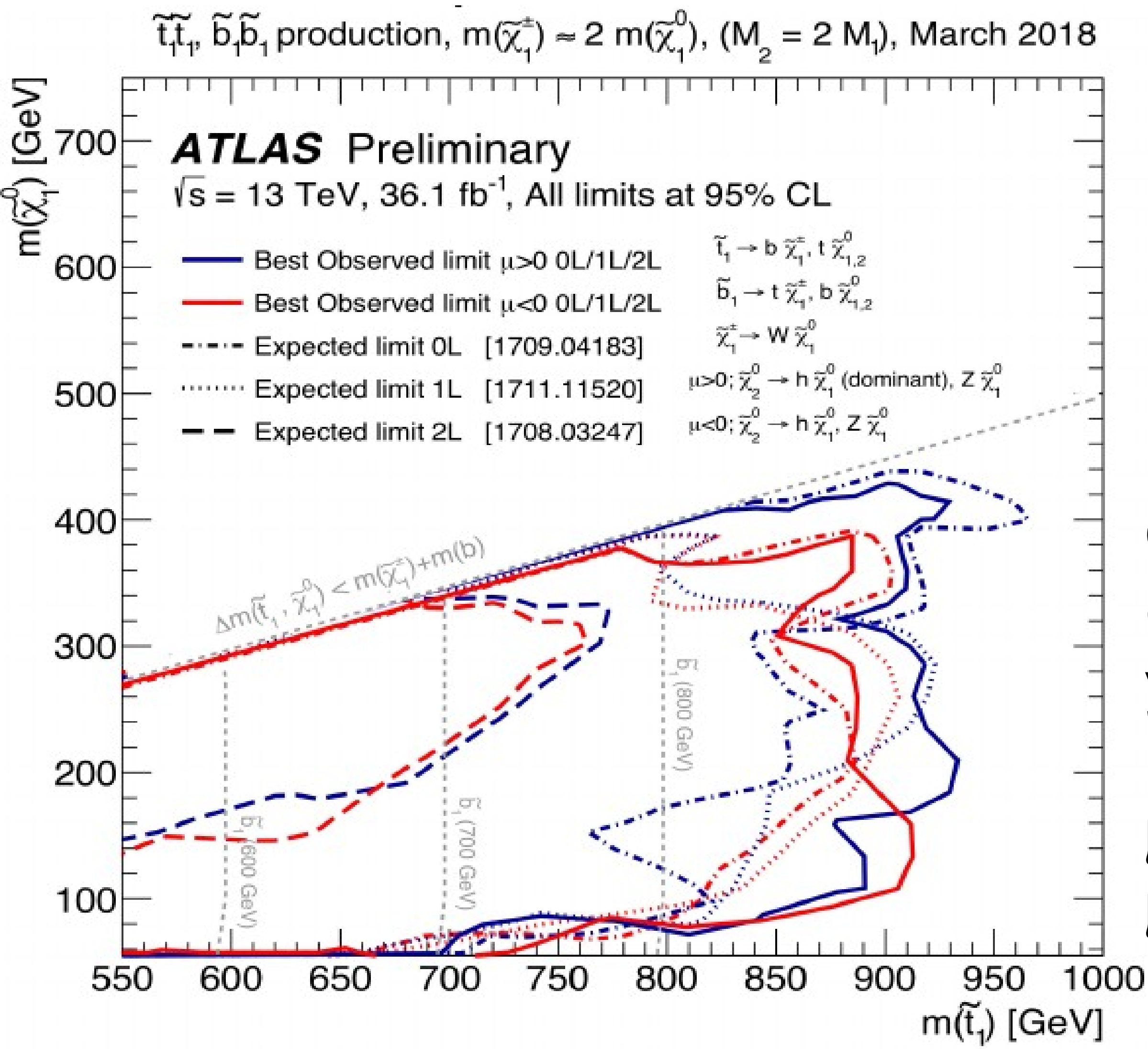
Achieve complete coverage for m(stop)<~1 TeV and m(chi01)<~300 GeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/

Results: scenario Wino NLSP



Assume m(chi02/chiplus)=2*m(chi01)



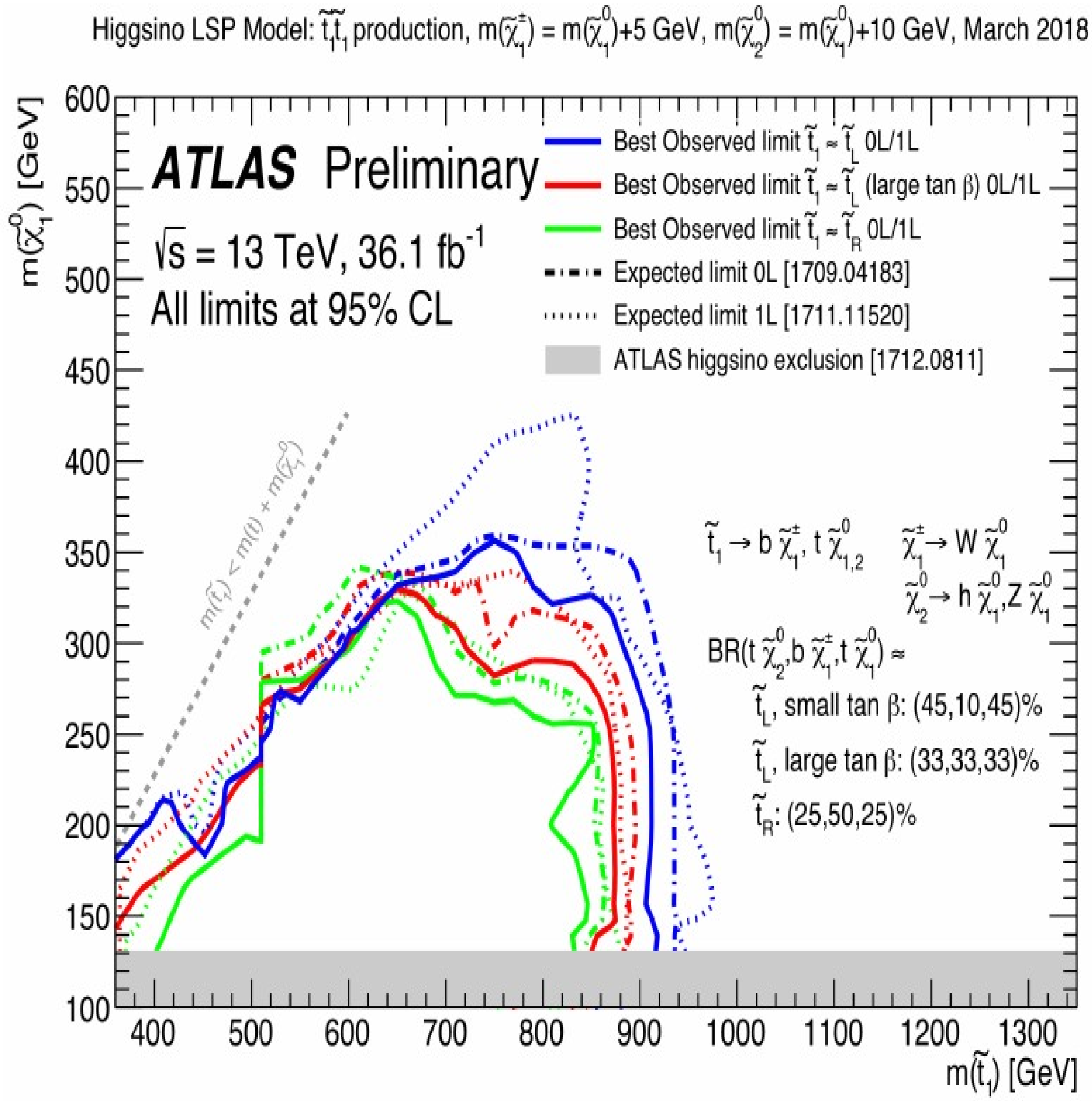
Choice of sign of μ (higgsino mass) yields different decay BRs for chi02

$\mu>0$ dominantly into h

$\mu<0$ significant Z contribution

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/

Results: scenario Higgsino LSP



Final states with additional Soft leptons from chargino/neutralino2 decay

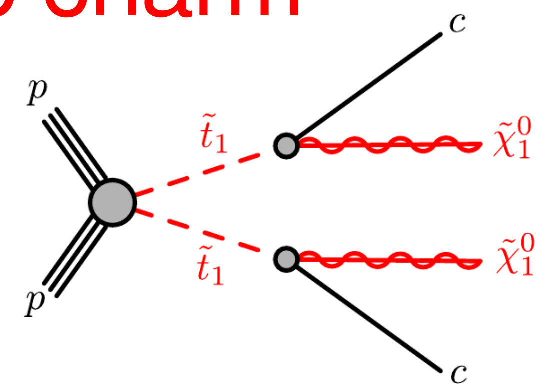
Assume three different scenarios for left/right composition of stop1 resulting In different BRs

Best limits for t_1=t_L

Dominated by neutral decays

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/SUSY/

A compressed search: stop to charm



Loop decay competing with tree level ones

Require:

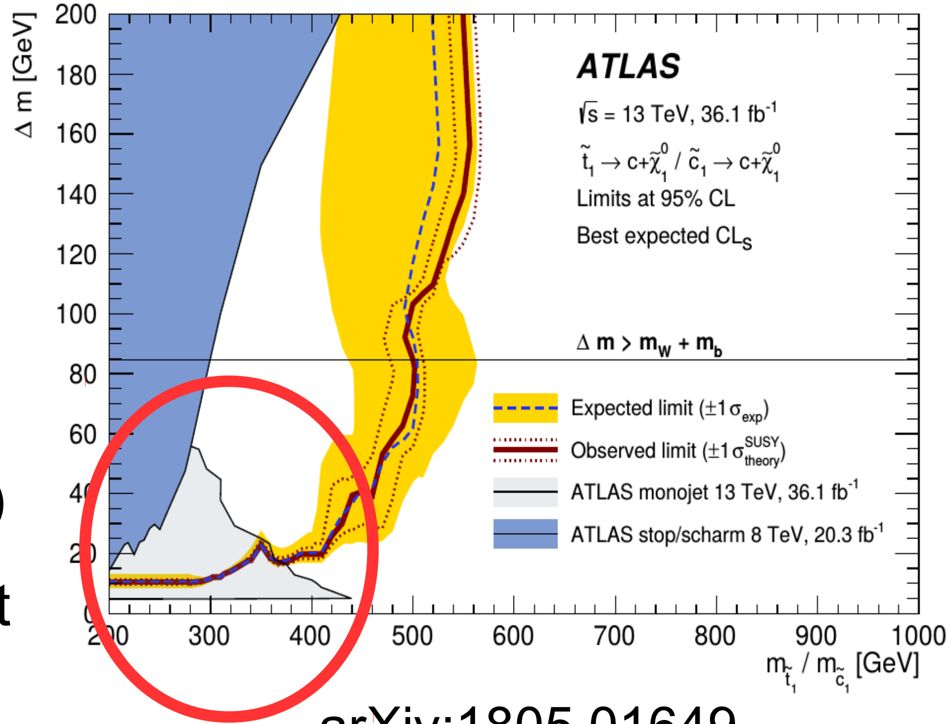
- At least 1 c-tagged jet
- 1 high pt non-c-tagged jet to boost the system
- high Etmiss

No excess found,

Set limits assuming BR(stop → charm)=100%

Show results in plane: DM=m(stop)-m(chi01) vs m(stop)

Complementary reach to monojet searches



arXiv:1805.01649

Sbottom searches: 0L

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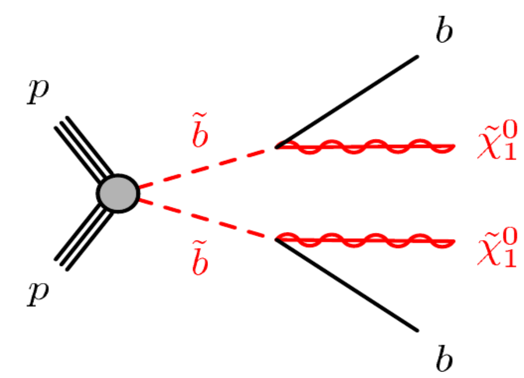
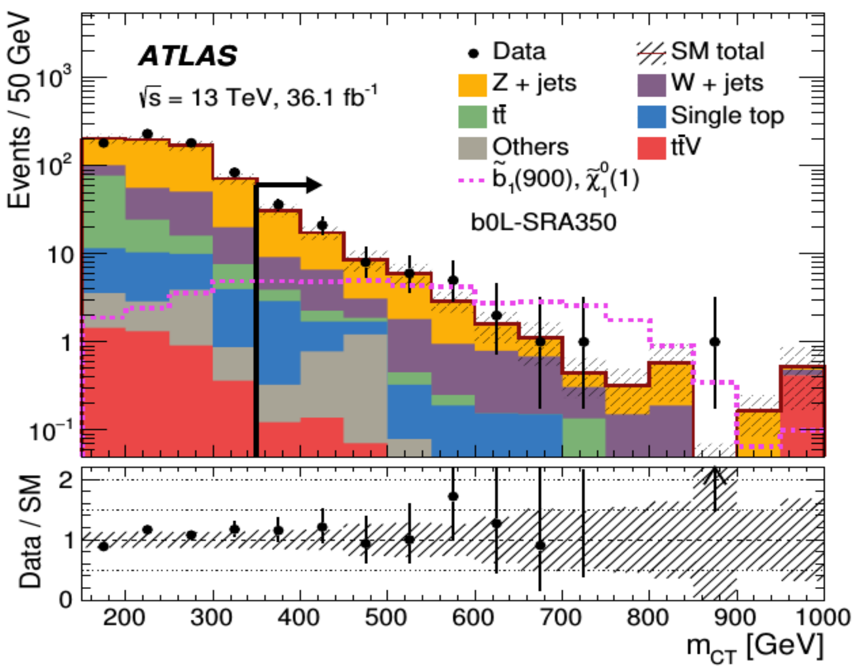
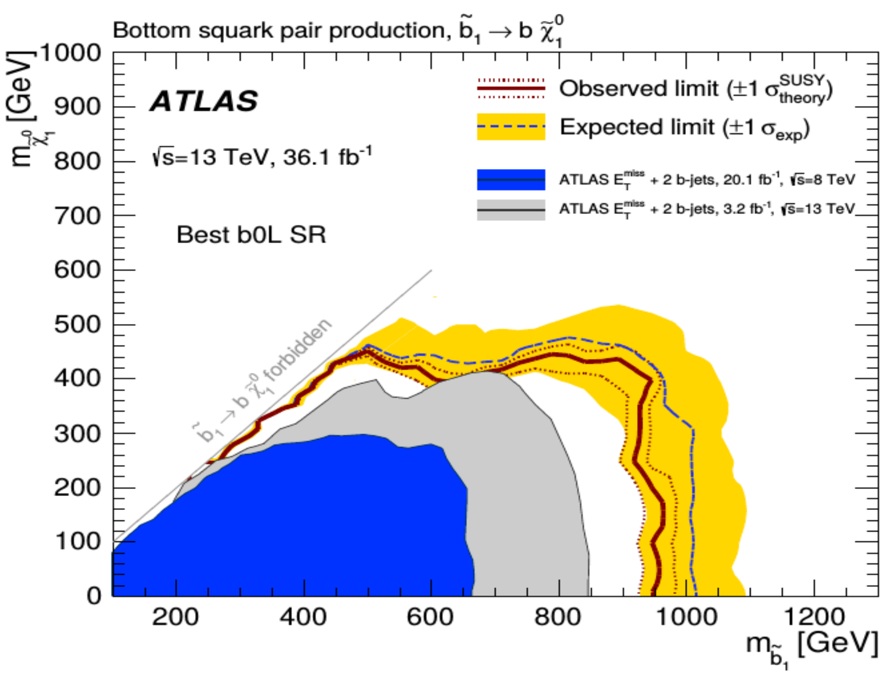
Require two b-tagged jets
Veto leptons

Main discriminant: m_{CT} built with the two b-tagged jets



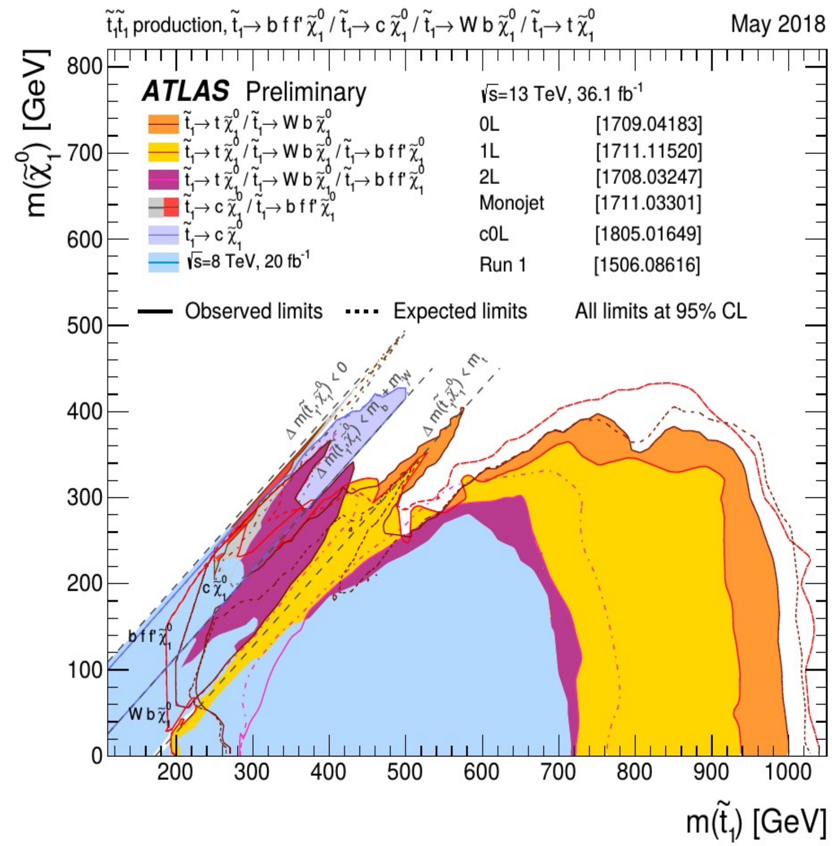
$$m_{\mathrm{CT}}^{2}(v_1,\ v_2) = [E_{\mathrm{T}}(v_1) + E_{\mathrm{T}}(v_2)]^2 - [\mathbf{p}_{\mathrm{T}}(v_1) - \mathbf{p}_{\mathrm{T}}(v_2)]^2,$$





Conclusions

- Comprehensive ATLAS research program for stop and sbottom carried on first 36 fb^{-1} of 13 TeV data
- Focus on
  - Covering a very broad parameter space in MSSM
  - Addressing difficult signatures, covering kinematic holes
- No excess found, stringent limits on pMSSM models set, yet part of parameter space still uncovered
- Searches go on targeting full LHC Run2 statistics (>120 fb^{-1})

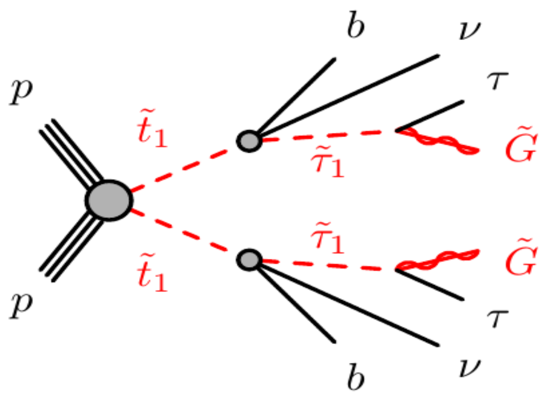


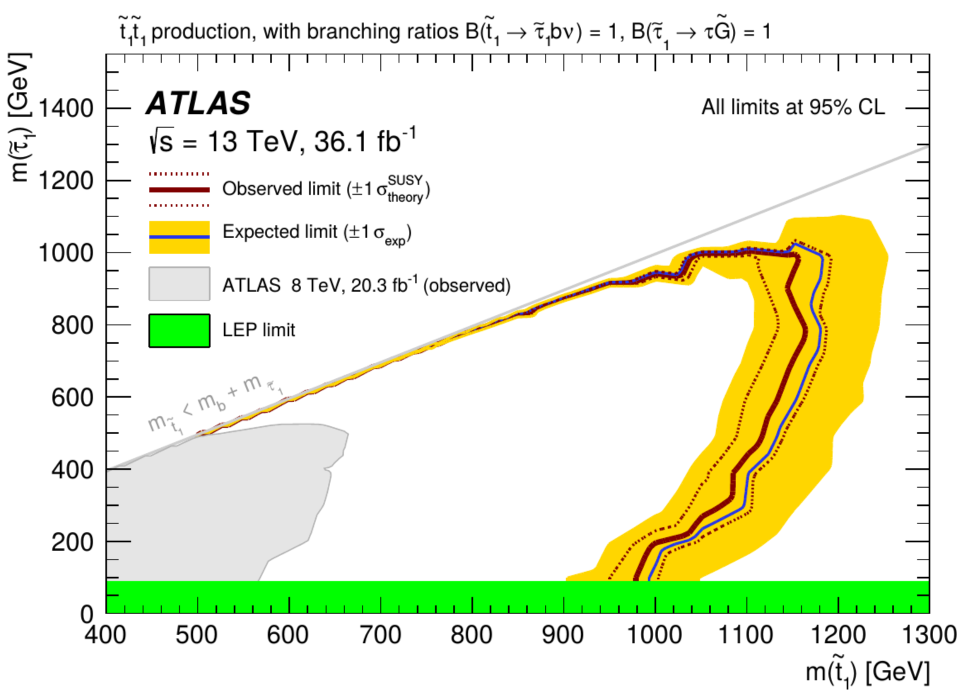
Backup

Stop to stau

arXiv:1803.10178

Motivated by tau-rich GGM/GMSB models
Two channels: $\tau_{lep}\tau_{had}$, $\tau_{had}\tau_{had}$ with large E_T^{miss} and M_{T2}



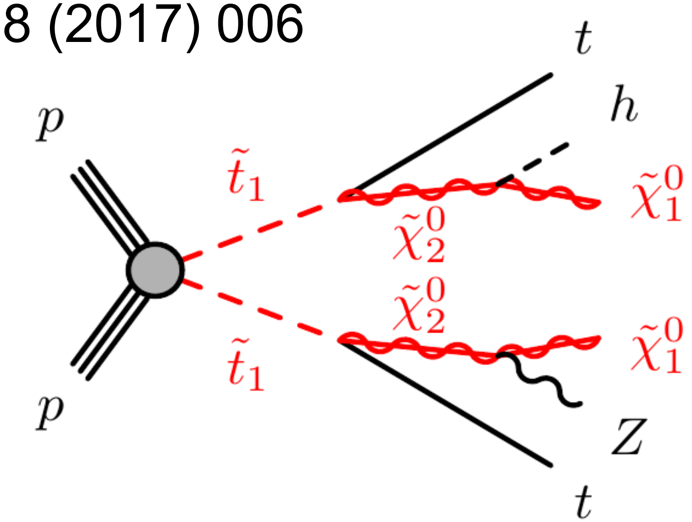


Interpreted as a combination of the two channels

Exclude up to 1.16 TeV stop

JHEP 08 (2017) 006

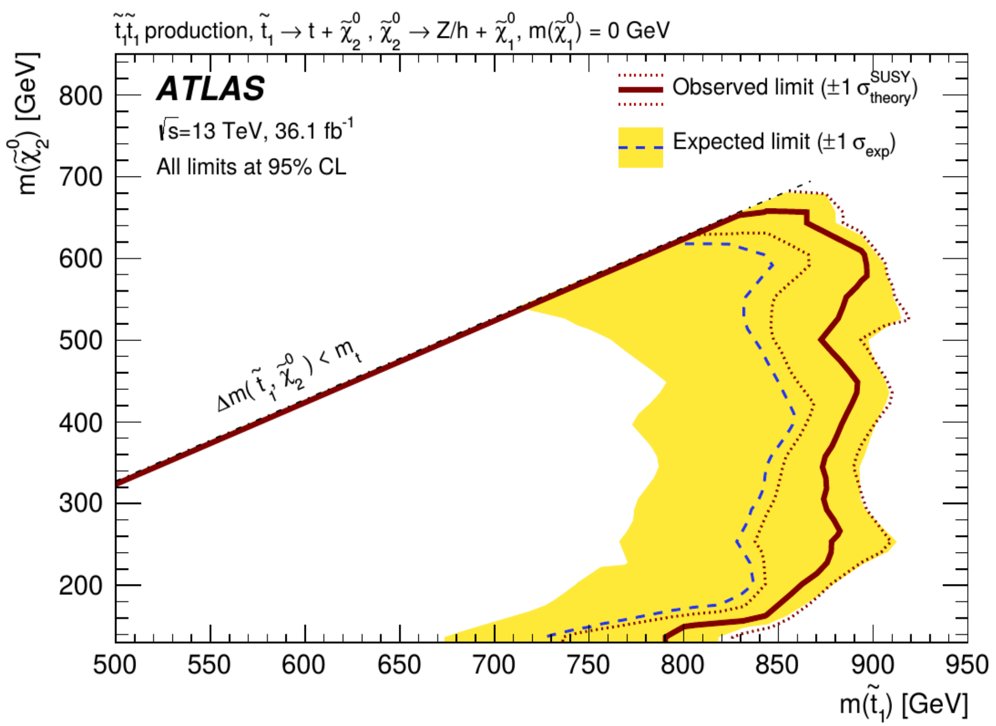
Stop to Z/h



Simplified model targeting χ^0_2 decaying via higgs or Z boson

Final states:

- 3l+1b (Z decay)
- 1l+4b (h decay)

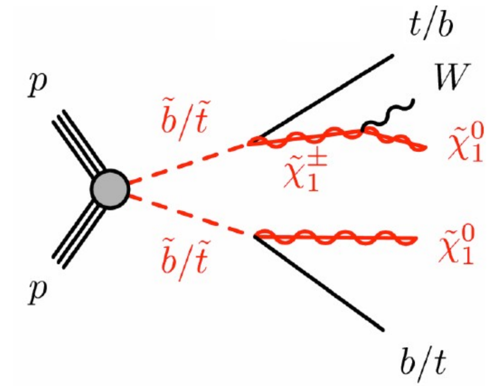


Backgrounds:

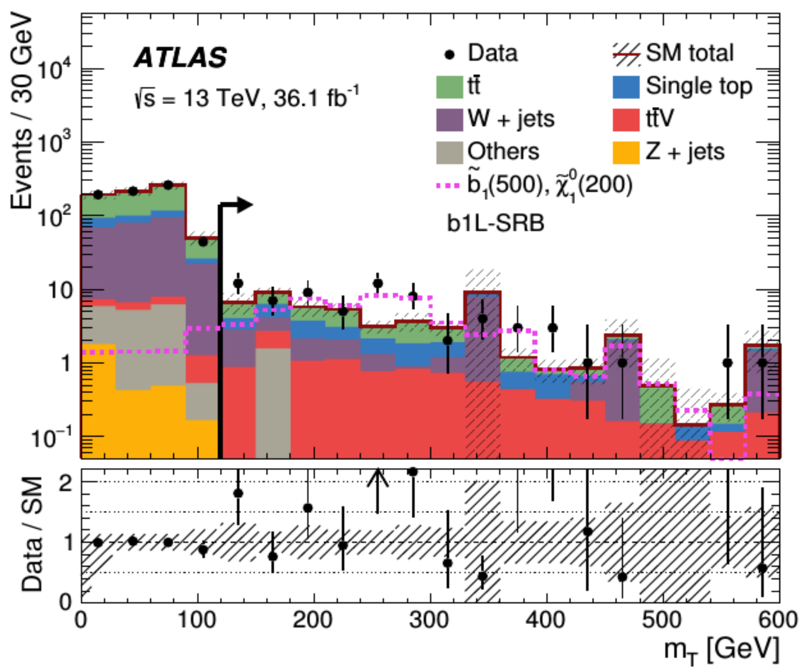
- ttZ in 3l+1b
- ttbar in 1l+4b

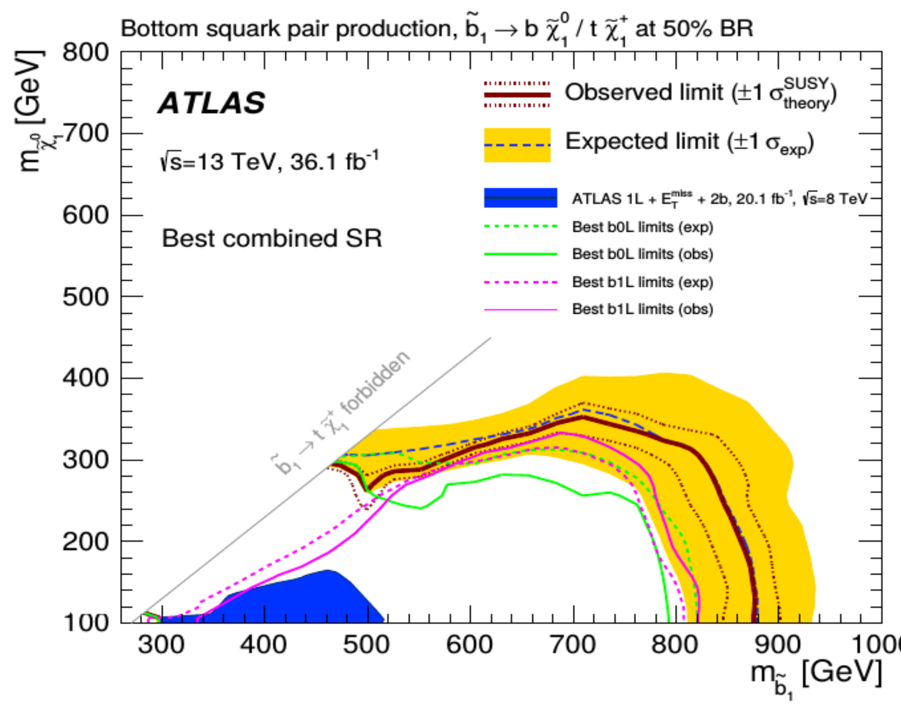
Sbottom searches: 1l

Require one isolated lepton
two b-tagged jets and ETmiss



Lepton transverse mass and asymmetric MT2
To reject ttbar and W+jets backgrounds





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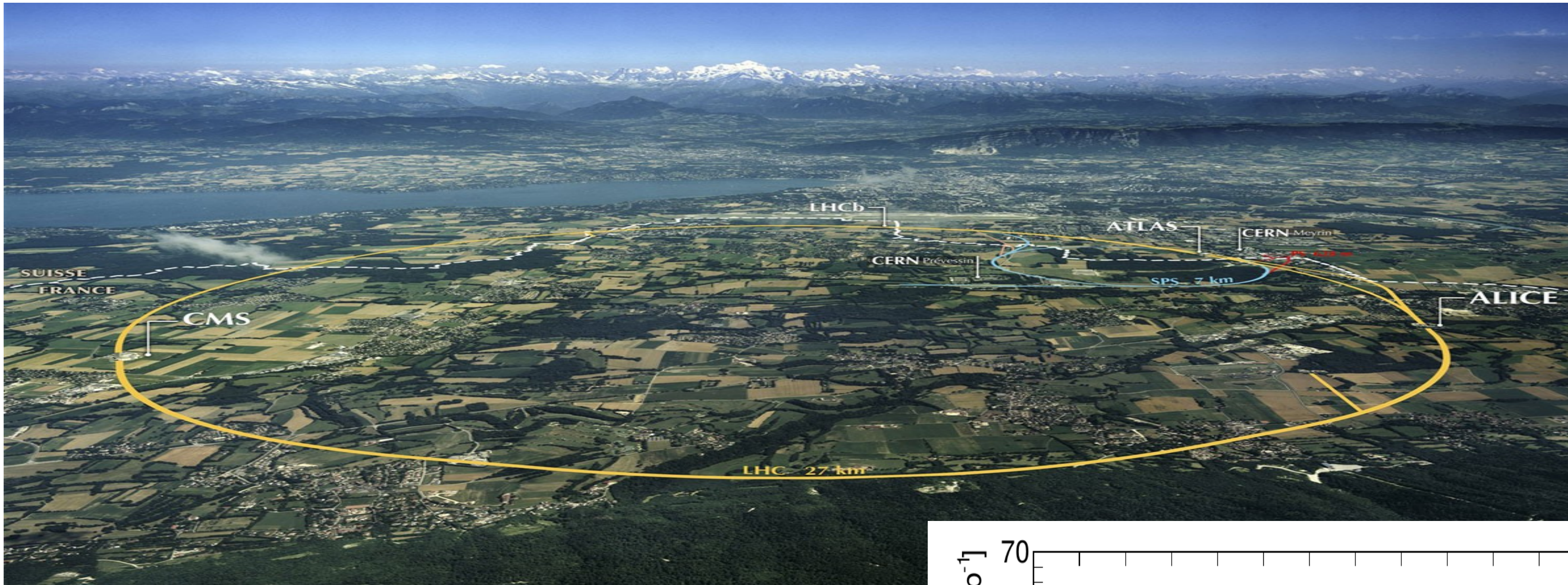
Dedicated selections for soft regions near the diagonal

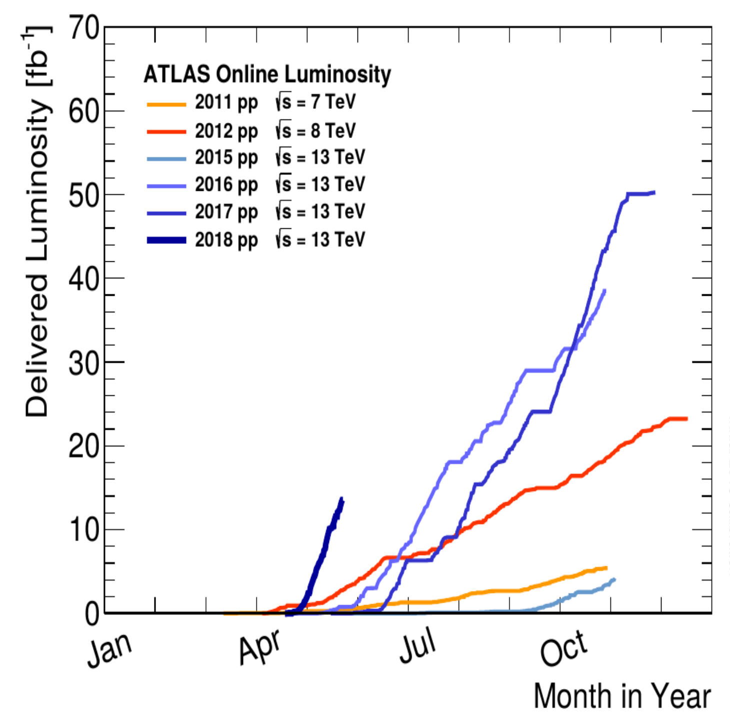
LHC



Proton-Proton collisions

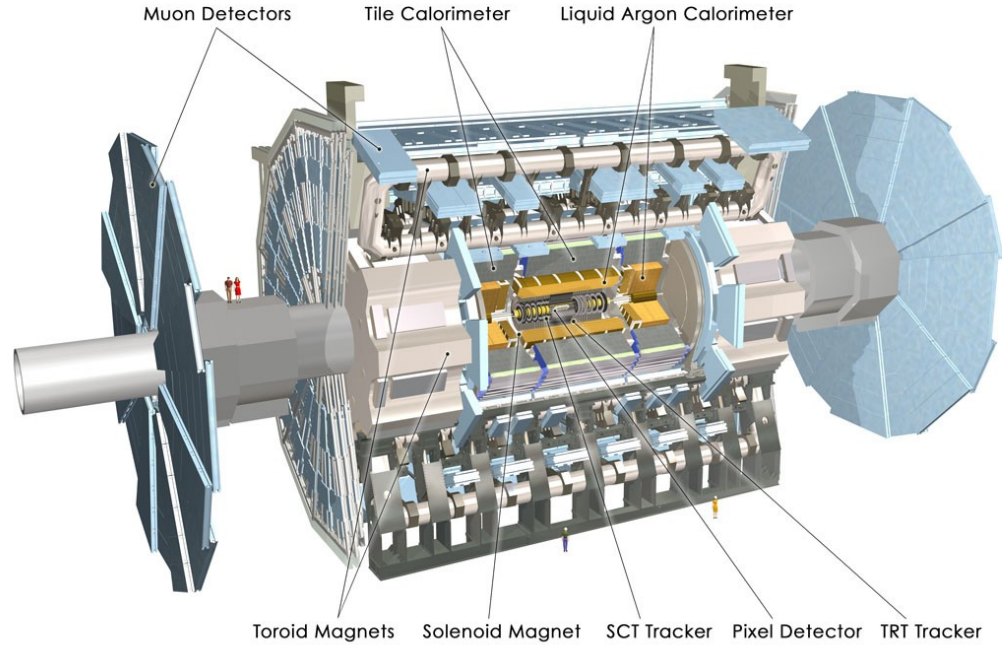
$\sqrt{s}$ = 7 TeV Int. Lumi ~5 fb^{-1} (2011)
$\sqrt{s}$ = 8 TeV Int. Lumi ~20 fb^{-1} (2012)
$\sqrt{s}$ = 13 TeV Int. LumI >40 fb^{-1}(2015+2016)
$\sqrt{s}$ = 13 TeV Int. LumI >120 fb^{-1} (by 2018)
$\sqrt{s}$ = 14 TeV Int. Lumi ~ 300 fb^{-1} (by 2022)

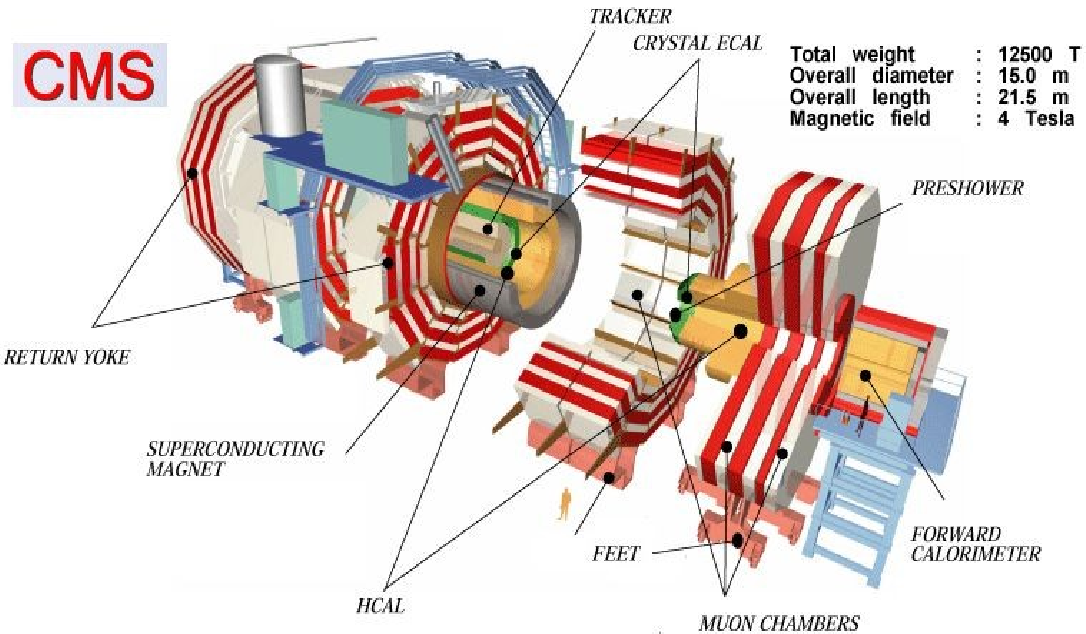
Consistently above the promised luminosity
This year is going extrememly well!



The experiments

ATLAS
Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
~ 3000 km of cables

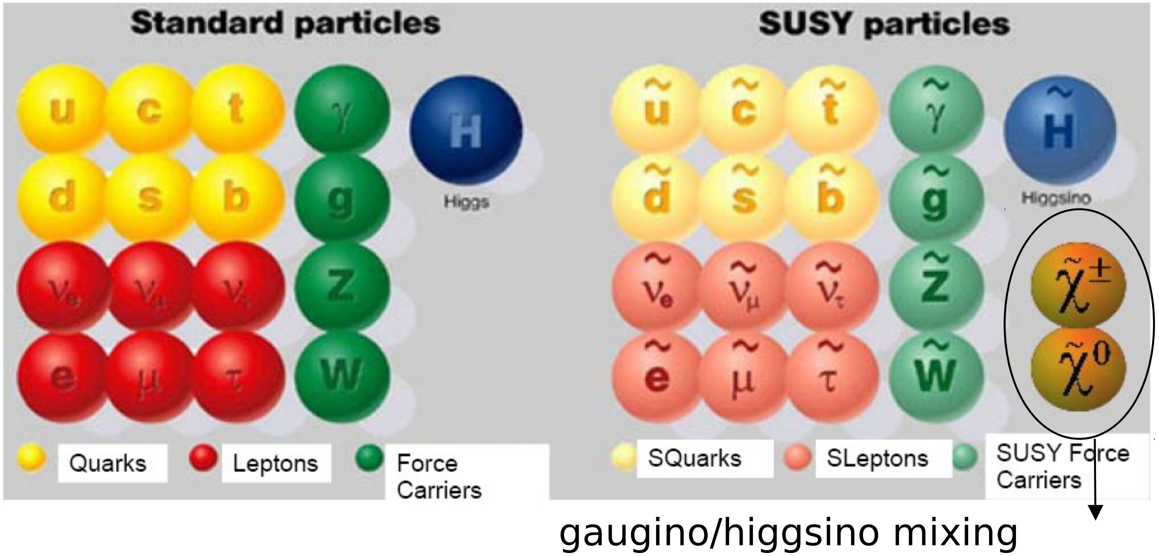




Varied signatures for SUSY: need excellent performance for

- electrons,
- photons,
- muons,
- jets,
- Etmiss,
- tau jets,
- b-jets

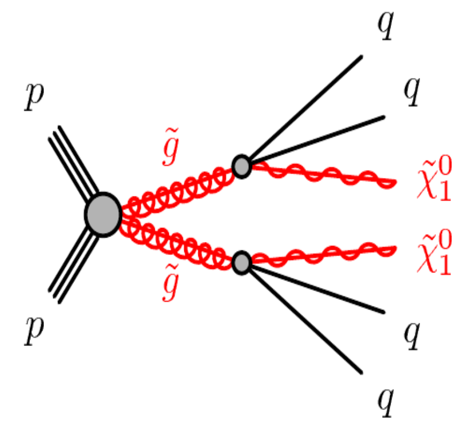
SUSY



(Still) our favourite template for a BSM theory:

- Theorists like it for a series of good reasons, and the good reasons tell us that some of the SUSY particles should be in the TeV region
- It does provide a great candidate for Dark Matter
- Experimentalists like it because of rich panoply of signatures, some of them abundantly produced at colliders, and easy to separate from backgrounds

"simplified models"



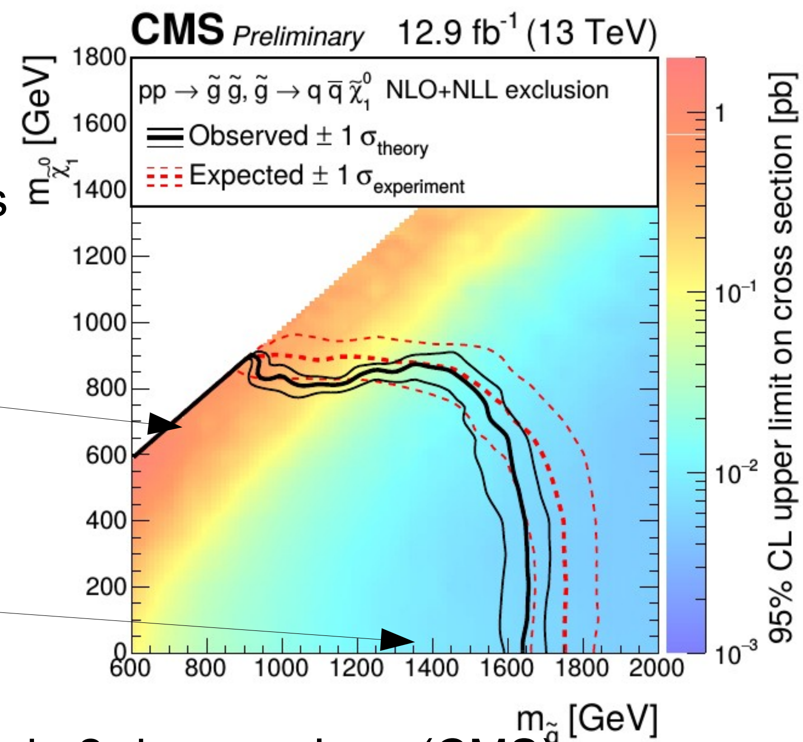
Simplified models as a tool for analysis optimisation and display:

- Generate pair of particles with a given decay on both legs
- Assume no other contribution to new physics
- 2-d space of masses of involved sparticles

- Optimise selection based on mass hierarchy in different areas of 2-d space: define different Signal Regions

m(gl)~m(lsp): soft topology:
Rely on hard jet recoiling against gluino-gluino system

m(gl)>>m(lsp): hard topology:
Cut hard on jets and Etmiss

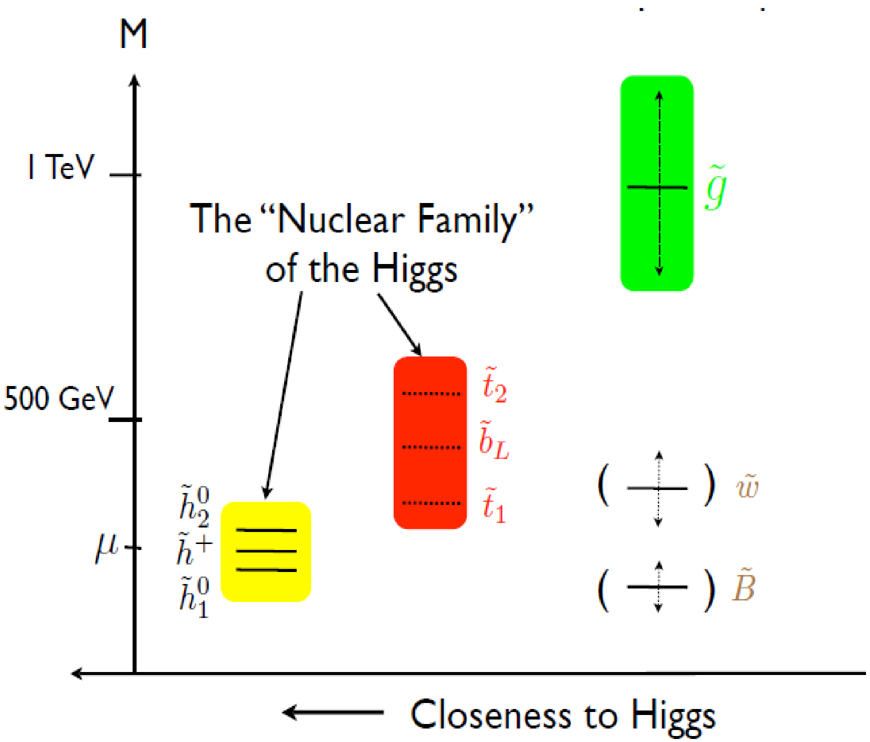


- Plot excluded cross-section as a color map in 2-d mass plane (CMS)
- Assume for initial particles SUSY production cross-section and 100% BR in studied channel and define excluded region in 2-d plane

Three case studies

LHC searches only up to ~3 TeV sparticle masses.

Approximate upper limit on some sparticle masses from the Requirement of "small" fine-tuning of the Higgs mass.



Plot by L. Hall

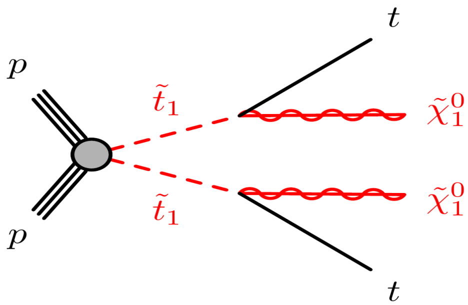
Gluino <~ a few TeV

Stop <~ 1 TeV

Higgsino <~2-300 GeV

To what extent we can explore this hierarchy?

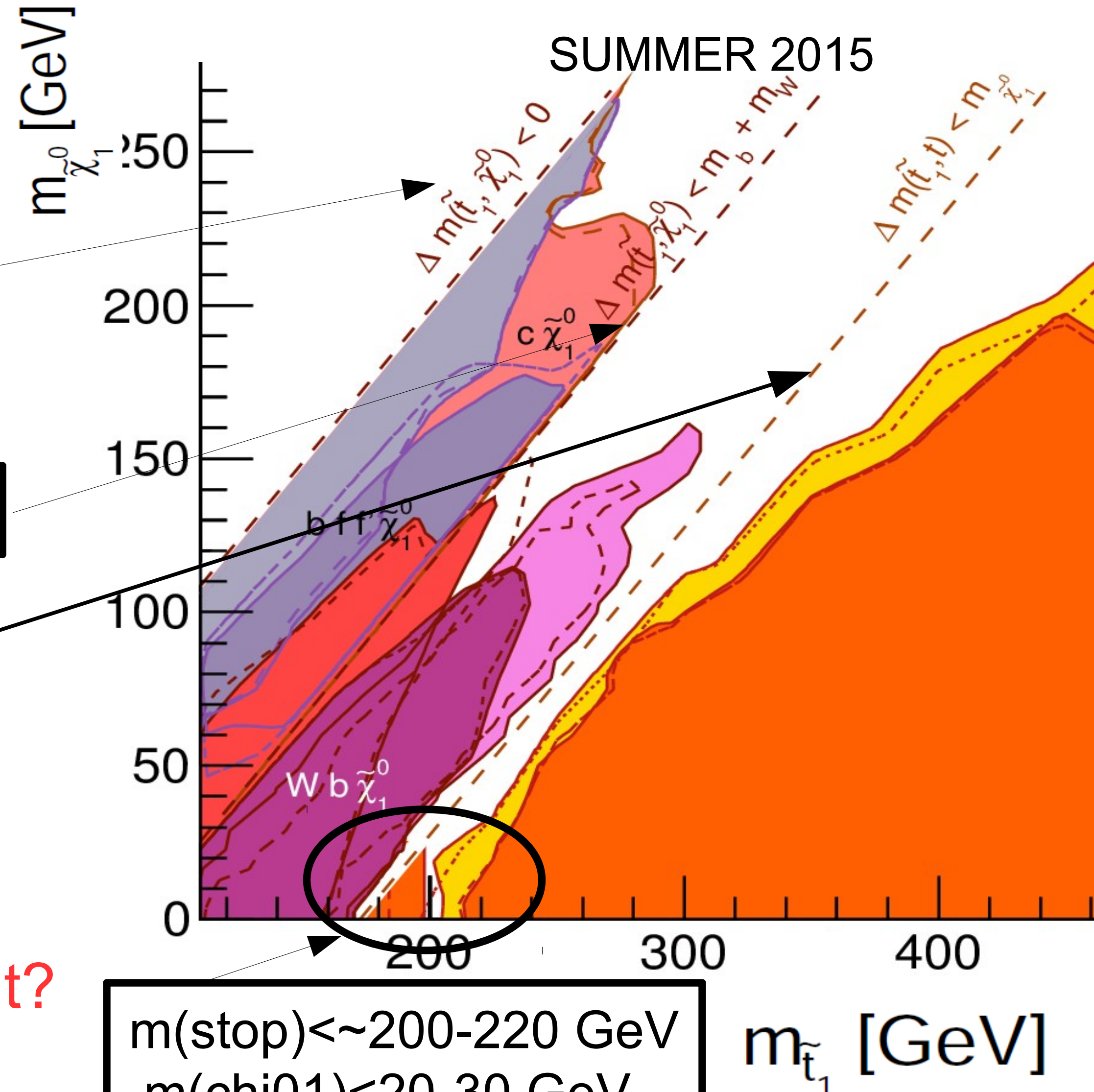
stop → top NLSP: Run 1 coverage (ATLAS)



m(stop)-m(chi01)~0

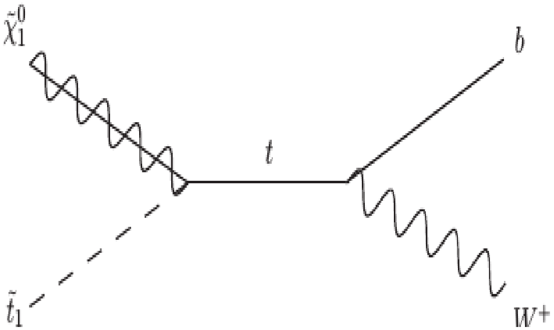
m(stop)-m(chi01)~m(W)

m(stop)>~200 GeV,
m(stop)-m(chi01)~m(t)

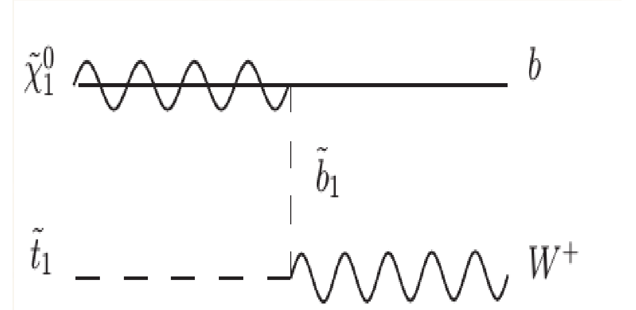


Why are these areas difficult?

m(stop)<~200-220 GeV
m(chi01)<20-30 GeV



DM relevance of stop

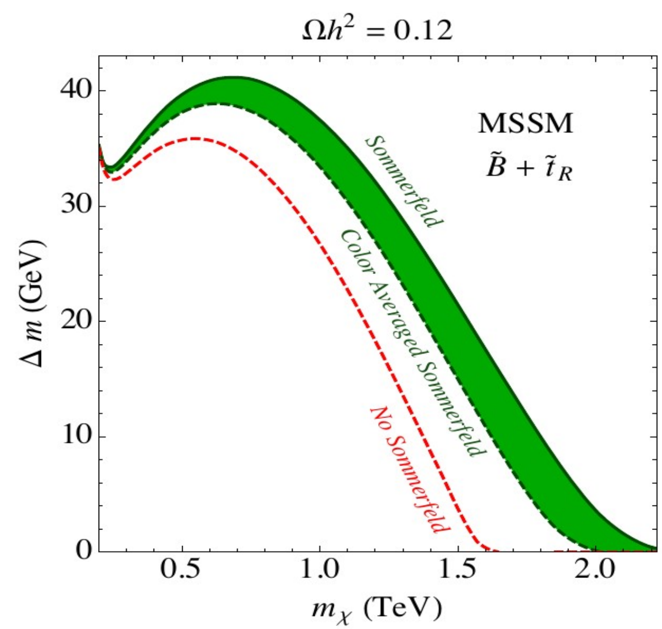


Bino LSP can boost its σ_{ann} through coannihilation with stop

For enhancement to be relevant: $\Delta m = m_{top} - m_{LSP}$ small

$$\Gamma(\tilde{t}_1 \to cN) = \frac{2g^2 \tan^2\theta_W \, \theta_{tc}^2 \, \Delta M^2}{9\pi \, m_{\tilde{t}_1}} = 100 \text{ cm}^{-1} \left(\frac{\theta_{tc}}{10^{-5}}\right)^2 \left(\frac{\Delta M}{30 \text{ GeV}}\right)^2 \left(\frac{400 \text{ GeV}}{m_{\tilde{t}_1}}\right)$$

$$\Gamma(\tilde{t}_1 \to Nb\ell^+\nu_\ell) = \frac{3\, g^6 \tan^2\theta_W \, \Delta M^8}{70(6\pi)^5 M_W^4 \, m_t^2 \, m_{\tilde{t}_1}} = 28 \text{ cm}^{-1} \left(\frac{\Delta M}{30 \text{ GeV}}\right)^8 \left(\frac{400 \text{ GeV}}{m_{\tilde{t}_1}}\right) ,$$



Region below Δm=30 GeV relevant

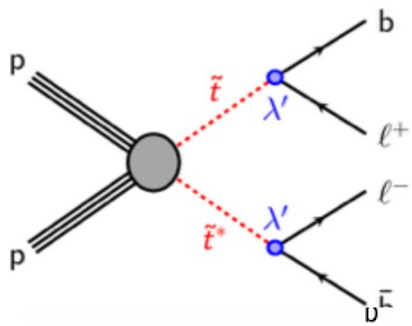
Stop RPV (examples)

Lepton number (L) Violation | Baryon number (B) Violation

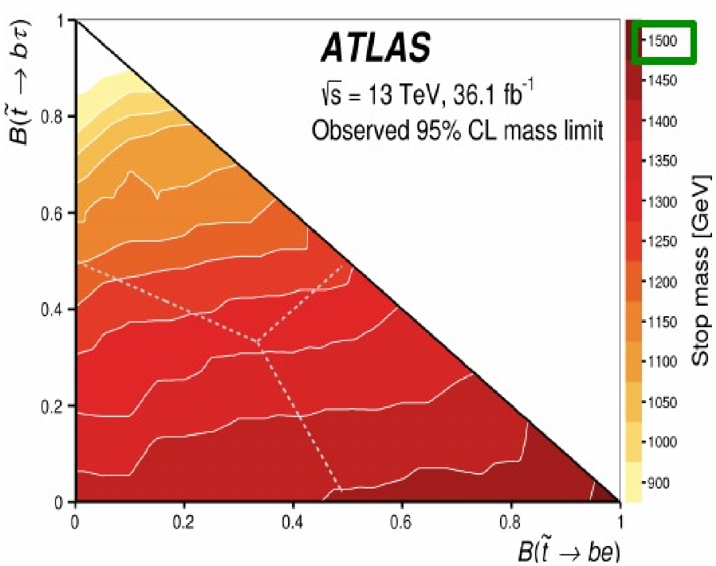
$$\mathcal{W}_{\mathrm{RPV}} = \frac{\lambda_{ijk}}{2} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{\lambda''_{ijk}}{2} \bar{U}_i \bar{D}_j \bar{D}_k + \kappa_i L_i H_u$$

$R = (-1)^{3B+L+2S}$

LQD - λ’



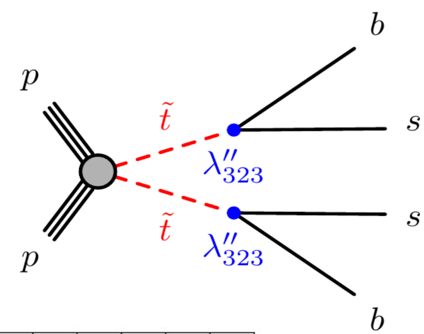
2L+2 jets
>=1 b-tagged jet

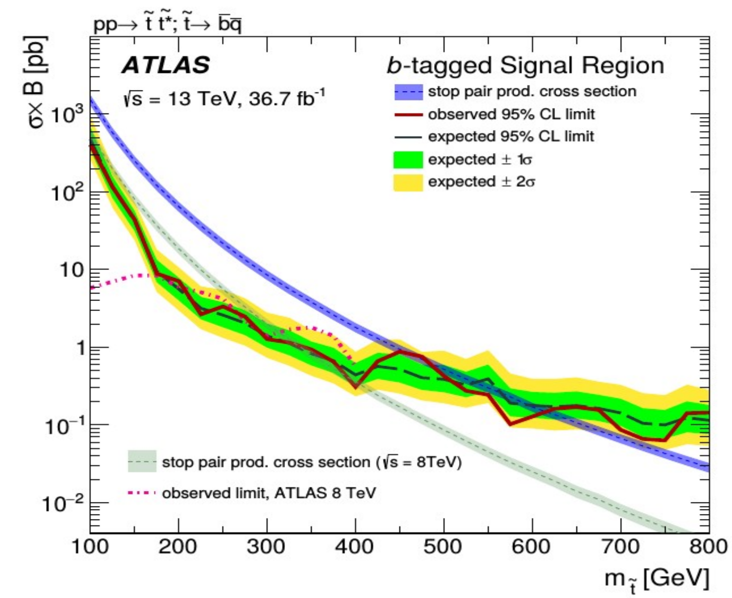


Eur. Phys. J. C 78 (2018) 250

UDD - λ”

4-jet final state
Inclusive or with b-tagging





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