The rise and fall of light stops in the LHC top quark sample

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10 June 2024
SUSY2024
`IFT Madrid`

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[Based on EB, G. Corcella, R. Franceschini and D. Sengupta [2312.09794]]

Introduction

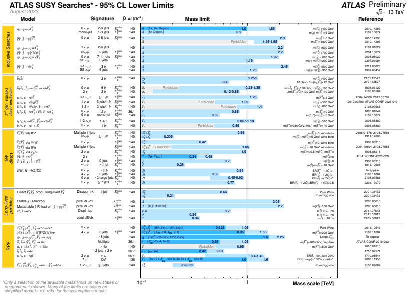
BSM physics at the LHC: status and prospects

Status

- No clear signs of new physics from searches, although some anomalies are present here and there in the data

Prospects

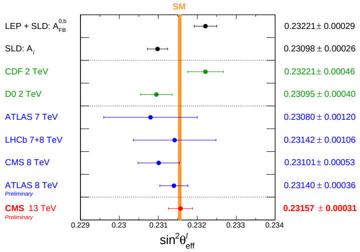
- Continue with direct searches, and move towards more complex final states target/more exclusive phase space (e.g. from long decay chains)



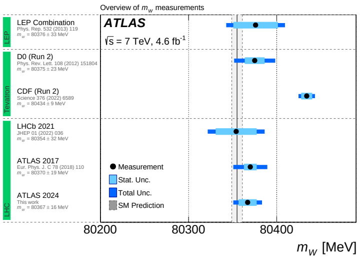
[ATL-PHYS-PUB-2023-025]

BSM physics at the LHC: status and prospects

[CMS-PAS-SMP-22-010]



[ATLAS, 2403.15085]



[See the talk of J. Ferrando this morning]

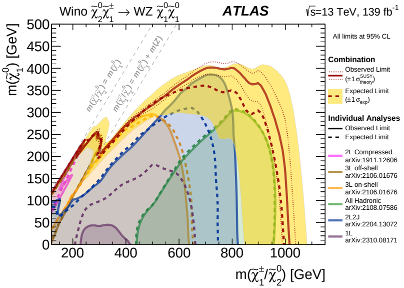
Status

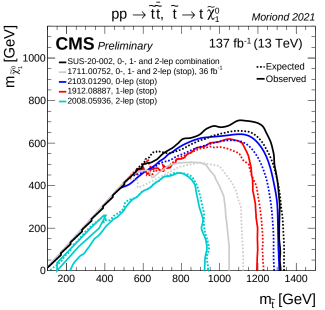
- Precision tests of observables with SM final states are as important as direct searches, however the general picture here is still of consistency with the SM as well

Prospects

- Continue with the SM physics program at the LHC (e.g. M_W, $\sin^2\theta^{\text{lep}}_{\text{eff}}$), identify new “precisely measured” observables as a target for BSM physics

Exp. searches for SUSY states





[ATLAS, 2403.02455]

[CMS, summary plots]

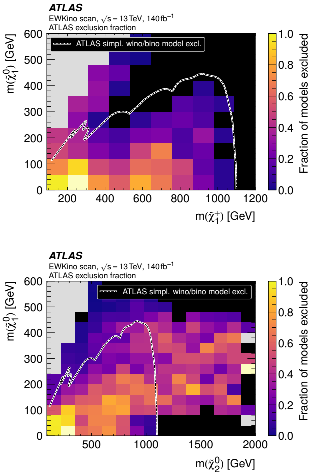
Experimental persp.

- Extensive research program, focusing (mostly) on SUSY simplified topologies
- Move towards non-minimal simplified models, new ideas etc.
- [See J. Hoya and M. Kazana talks this morning]

Simplified models vs pMSSM

Experimental persp.

- Well know in the theory community of the important differences between SSM results and realistic pMSSM scenarios
- For instance see the work of the global fitting collaborations (`MasterCode`, `Gambit`, ...) but also pheno papers
- Recent work from ATLAS in that direction, [2402.01392]
- Two similar studies from ATLAS and CMS for Run 1
- *Important effort to share exp. data in such a way that can be easily recasted*



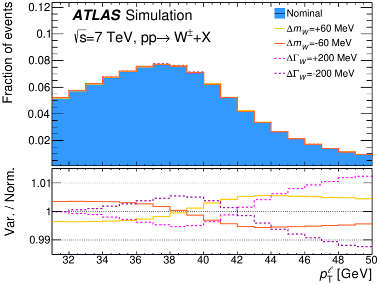
[ATLAS, 2402.01392]

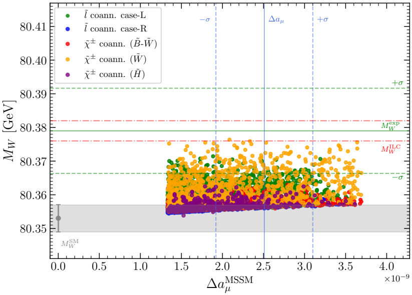
Indirect probe via precision measurements

Indirect probes

For example

- Higgs mass
- anomalous magnetic moment of the muon
- EWPOs (e.g. M_W)
- Flavor observables

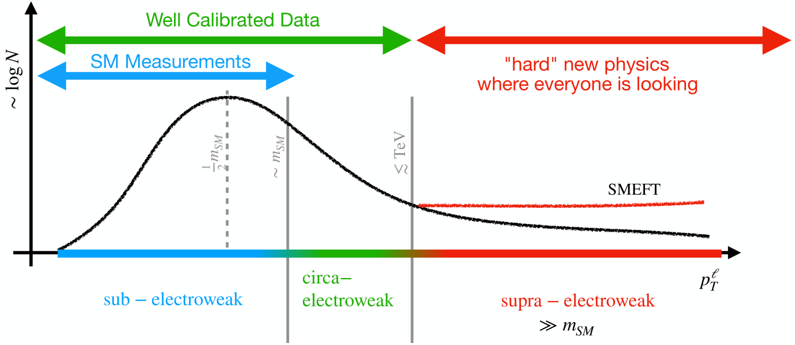




[EB et al., EPJC82 (2022)5,474, 2203.15710]

Are the two approaches so well disconnected?

- “SM” parameter measurements are characterized by an extremely good understanding of the experimental phase space



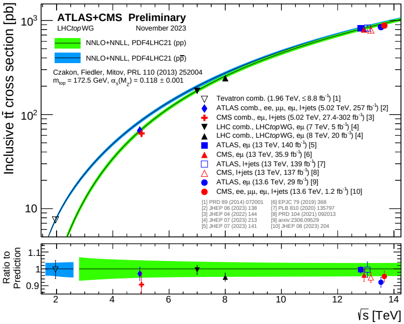
[R. Franceschini’s talk at LHCP2024]

Our study

Why the top?

Top@LHC

- Large production cross section at the LHC → LHC is a top factory
- Allow for a precise characterization of its properties (mass, BRs, etc.)
- Precise measurement of differential observables (e.g. spin correlations)
- Top is the heaviest quark → BSM physics portal



[LHCTopWG]

Our idea

The focus

- Try to understand if top quark observables currently measured with good precision (i.e. understanding of systematics, good statistics) and up to now only used for SM measurements can be used to probe new physics
- We focused ourselves on the invariant mass of the b-jet and the lepton, m_{bl} thas been to extract the top quark mass

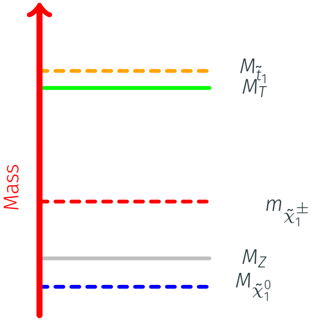
BSM in m_{bl}?

- Can we use this measurement to probe BSM physics?
- Note: here by BSM physics we mean the production and decay of BSM states
- Modification of the $t\bar{t}$ production process (i.e. loop corrections) is also a BSM effect that we have not considered

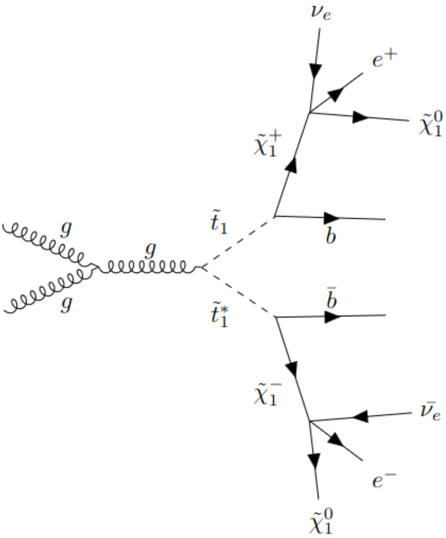
The scenario

The spectrum

- We consider a scenario with a light $\tilde{t}_1 \simeq \tilde{t}_R$
- Stop mass close to the top quark mass: $m_{\tilde{t}_1} \simeq M_T$
- Bino-like/Bino-higgsino $\tilde{\chi}_1^0$ and higgsino-like $\tilde{\chi}_1^\pm$.
- The MSSM parameters are adjusted to keep the stop mass roughly constant as we vary the chargino (μ parameter) and the bino masses



The signal



Stop-top contamination

- The final state is similar to the top one
- $\tilde{\chi}_1^\pm \to W\tilde{\chi}_1^0 \to l + MET$
- W OS or not depending on the $\tilde{\chi}_1^\pm$, $\tilde{\chi}_1^0$ mass difference
- A similar signature could be obtained in the decay channel $\tilde{t}_1 \to t\tilde{\chi}_1^0$, which however is much strongly constrained

The scenario

The Higgs-stop connection

- In the MSSM, the stop sector closely connected to the Higgs sector because of the Higgs mass
- All the benchmark points are at ±2 GeV from the measured value of M_H
- However **SARAH-SPheno** does not include the best calculation for these spectra
- In any case, one can move to NMSSM or adjust a bit more the parameters

Input parameters

- $m_{\tilde{u}}(1,1)^2 = m_{\tilde{u}}(2,2)^2 = m_{\tilde{q}}(i,i)^2 = m_{\tilde{l}}(i,i)^2 = m_{\tilde{e}}(i,i)^2 = m_{\tilde{d}}(i,i)^2 = 1.2 \cdot 10^7\ \text{GeV}^2$ for $i = 1, 2, 3$
- All the off-diagonal squark and slepton mass terms are set to zero;
- $m_{\tilde{u}}(3,3)^2 = 1.7 \cdot 10^5\ \text{GeV}^2 \rightarrow \tilde{t}_1$ almost pure SU(2) singlet state;
- $M_1 \in [5{,}1000]$ GeV, $M_2 = 1$ TeV, $M_3 = 3.5$ TeV;
- $M_A^2 = 2 \cdot 10^6\ \text{GeV}^2$, $\tan\beta = 10$;
- $\mu \in [100\ \mathrm{GeV}, m_{\tilde{t}_1}]$;
- $A_t \in X_t + \mu \cdot \cot\beta + [-100, 100]$ GeV; the exact value is obtained by trial-and-error to get the desired $m_{\tilde{t}_1}$.
- All other trilinear couplings are set to zero.

Methodology

Methodology

Point generation

- Keeping the stop mass fixed, scan the parameter space
- Spectrum generation performed with `SARAH+SPheno`
- Check the Higgs mass constraint
- Check the collider constraints with `SModelS` (e,g.from searches for direct production of the electroweakinos)

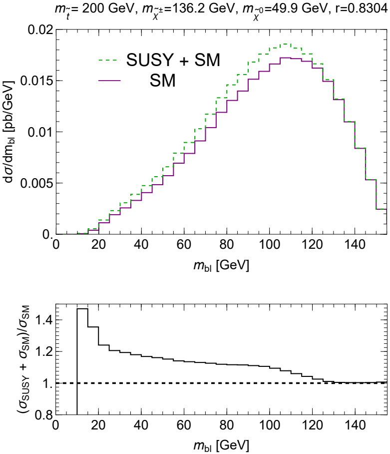
Collider simulation

- The parameter space points that pass the selection are simulated using `Pythia8`
- Cuts applied inspired by exp. analyses

$$\begin{aligned} p_T(l) \geq 25\ \mathrm{GeV}, \quad |\eta(l)| < 2.5 \\ p_T(j) \geq 25\ \mathrm{GeV}, \quad |\eta(j)| < 2.5 \\ \mathrm{anti-kT\ jets}, R = 0.4 \\ \Delta R(l,j) > 0.2, \quad \Delta R(j,j) > 0.5 \\ \Delta R(l,l) > 0.1 \end{aligned}$$

Results

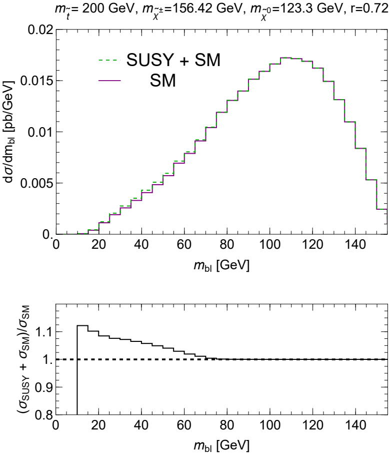
The m_{bl} distribution



Benchmark 1

- Point allowed by `SModelS`
- $m_{\tilde{t}_1} \simeq 200 GeV$,
  $m_{\tilde{\chi}_1^{\pm}} \simeq$ 136 GeV,
  $m_{\tilde{\chi}_1^0} \simeq$ 50 GeV
- Significant effect that grows monoticallt as m_{bl} decreases

The m_{bl} distribution



Benchmark 1

- Point allowed by `SModelS`
- $m_{\tilde{t}_1} \simeq 200 GeV$,
  $m_{\tilde{\chi}_1^{\pm}} \simeq$ 156 GeV,
  $m_{\tilde{\chi}_1^{0}} \simeq$ 132 GeV,
- Milder effect that grows monoticallt as m_{bl} decreases

Are we sensitive to these effects?

Of course, it depends on the precision on the measurement (stat+syst uncert.) We try to estimate the significance by:

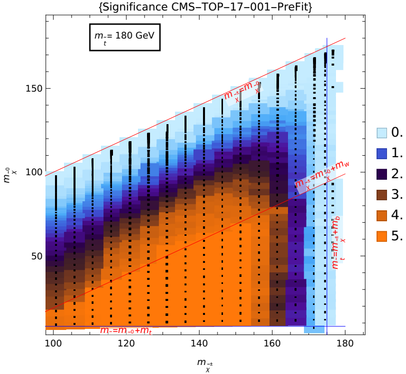
Significance

- We calculate the signal yield for a given luminosity from the value computed above with `Pythia8`: S_i, for the i-th bin
- We compute the background uncertainty from our estimation of the backround multiplied by relative uncertainty obtained from the exp. papers: $\delta B_i = B_i \times u_i$, where u_i is the relative exp. uncertainty for the i-th bin
- For a given point we defined the significance as

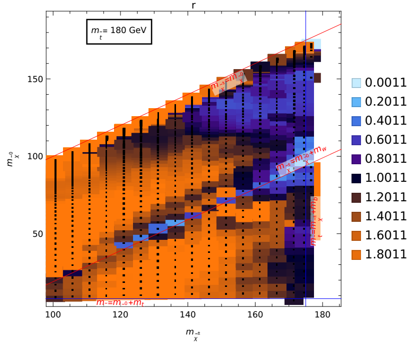
$$z = \sqrt{\sum_i \left(\frac{S_i}{\delta B_i} \right)^2}$$

- We decided to use the “pre-fit” value for the exp. uncertainties

Exclusion planes: $m_{\tilde{t}_1} = 180$ GeV

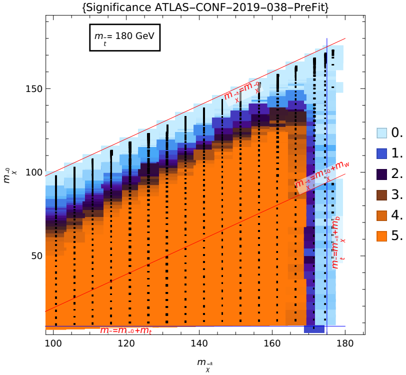


Uncertainties from [CMS, 1812.10505]

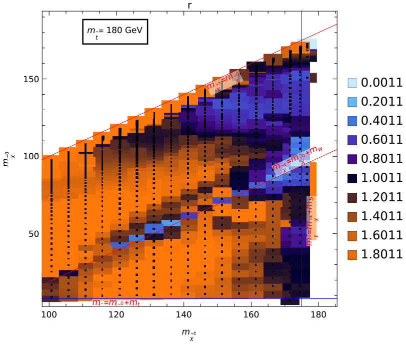


Exclusions from **SModels**, $r = \frac{\sigma(\text{signal})}{\sigma(UL)}$

Exclusion planes: $m_{\tilde{t}_1} = 180$ GeV

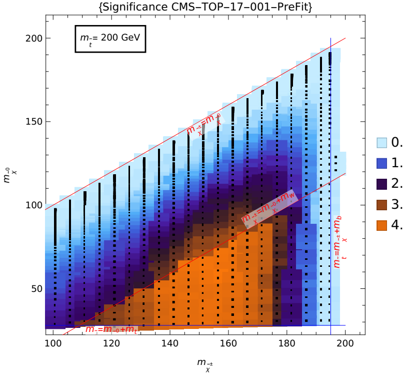


Uncertainties from [ATLAS-CONF-2019-03]



Exclusions from **SModels**, $r = \frac{\sigma(\text{signal})}{\sigma(UL)}$

Exclusion planes: $m_{\tilde{t}_1} = 200$ GeV



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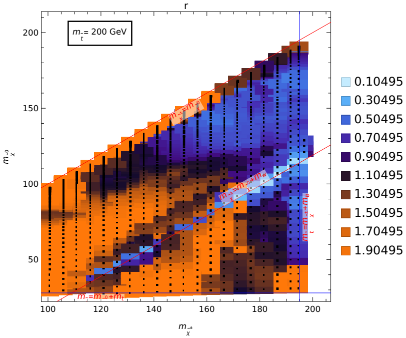
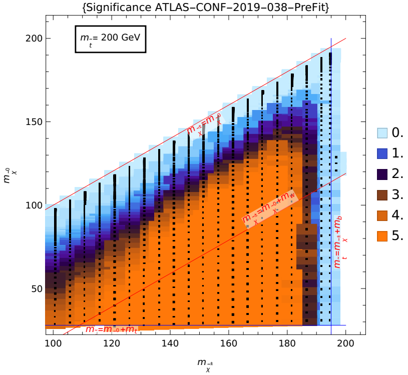
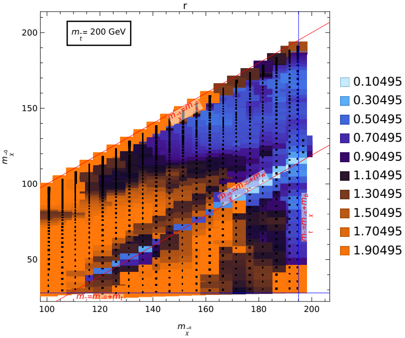


Exclusions from `SModels`, $r = \dfrac{\sigma(\text{signal})}{\sigma(UL)}$

Exclusion planes: $m_{\tilde{t}_1} = 200$ GeV

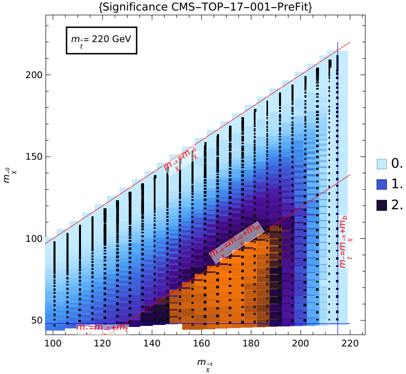


Uncertainties from [ATLAS-CONF-2019-03]

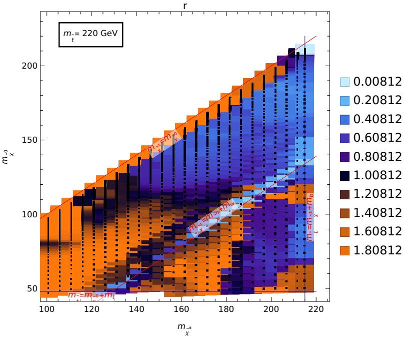


Exclusions from **`SModels`**, $r = \frac{\sigma(\text{signal})}{\sigma(UL)}$

Exclusion planes: $m_{\tilde{t}_1} = 220$ GeV

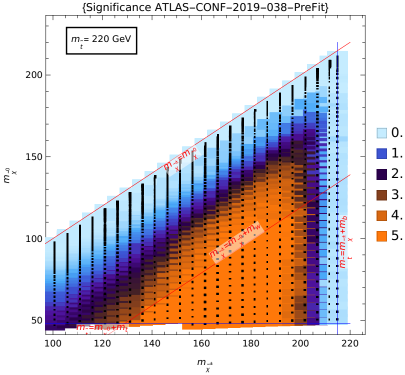


Uncertainties from [CMS, 1812.10505]

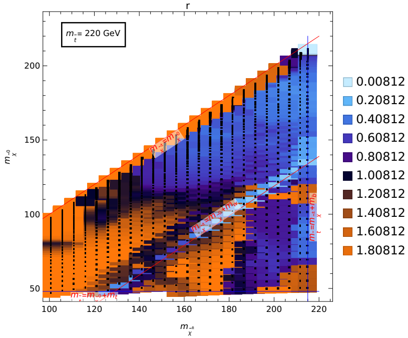


Exclusions from **`SModels`**, $r = \frac{\sigma(\text{signal})}{\sigma(UL)}$

Exclusion planes: $m_{\tilde{t}_1} = 220$ GeV



Uncertainties from [ATLAS-CONF-2019-03]



Exclusions from `SModels`, $r = \frac{\sigma(\text{signal})}{\sigma(UL)}$

Conclusions

Conclusions

- Realizations of low-scale SUSY are difficult to probe → new strategies are needed
- Looking at observables that up to now where used only for SM measurement is a new avenue to pursue
- We have shown that the m_{bl} distribution seems to be sensitive to stop production, and it is therefore a new possible target for such a searches.
- Similar approach taken by [Agashe et al. in 2310.13687 and 2404.17574] for the $l + MET$ final state (connection to M_W extraction)

Future developments

- Improve analysis with `SModelS` (SR combination enabled)
- Implement the signal and test it in `Contur`
- Release the SLHA files on `Zenodo`
- Develop a more “complete” MSSM scenario