Top quark physics: Standard Model and beyond

Venugopal Ellajosyula
On behalf of the ATLAS collaboration

October 2, 2019

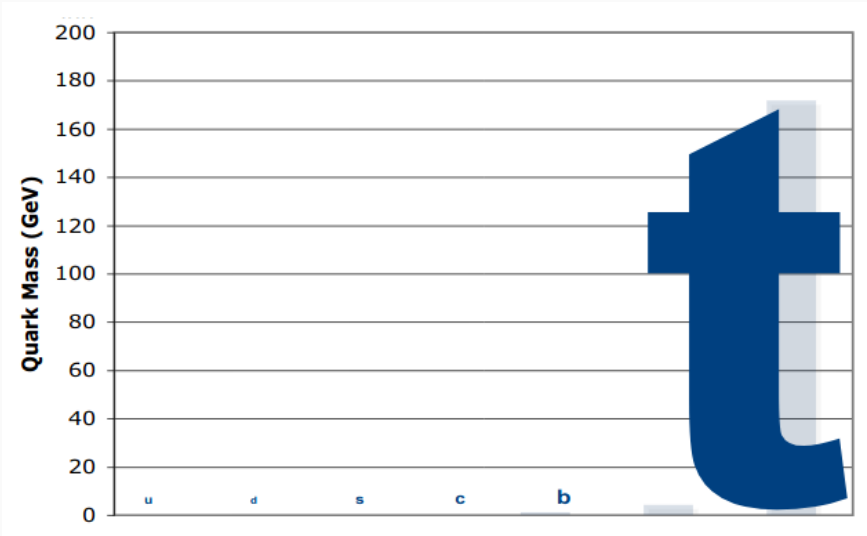
Uppsala University

Contents

- Motivation
- Standard Model (SM) measurements
- BSM searches with top quarks
  - Supersymmetry (SUSY)
  - Composite Higgs Models (CHM)
  - Dark Matter (DM)

The top quark

- Third generation of quarks predicted by Kobayashi and Maskawa in 1973
- b-quark discovered by E288 experiment in 1977 $\Rightarrow$ discovery of the sixth quark imminent
- 18 years later, on March 2 1995, the top-quark with a mass of 176$\pm$18 discovered by CDF and D0



- What are its properties? Why so heavy? More likely to couple to new physics because of mass?

Top quark and new physics

- SM predicts top kinematics
- Measurement of top quark properties gives a cross-check for SM
  - Deviations imply new physics
- New physics likely at high mass scales $\Rightarrow$ can couple to SM through the top quark.

Can measure:

- Mass
- Width
- Pair-production rate
- Single-production rate
- **Electroweak couplings**
- Polarization
- ...

Measurement of $t\bar{t}W$ cross-section

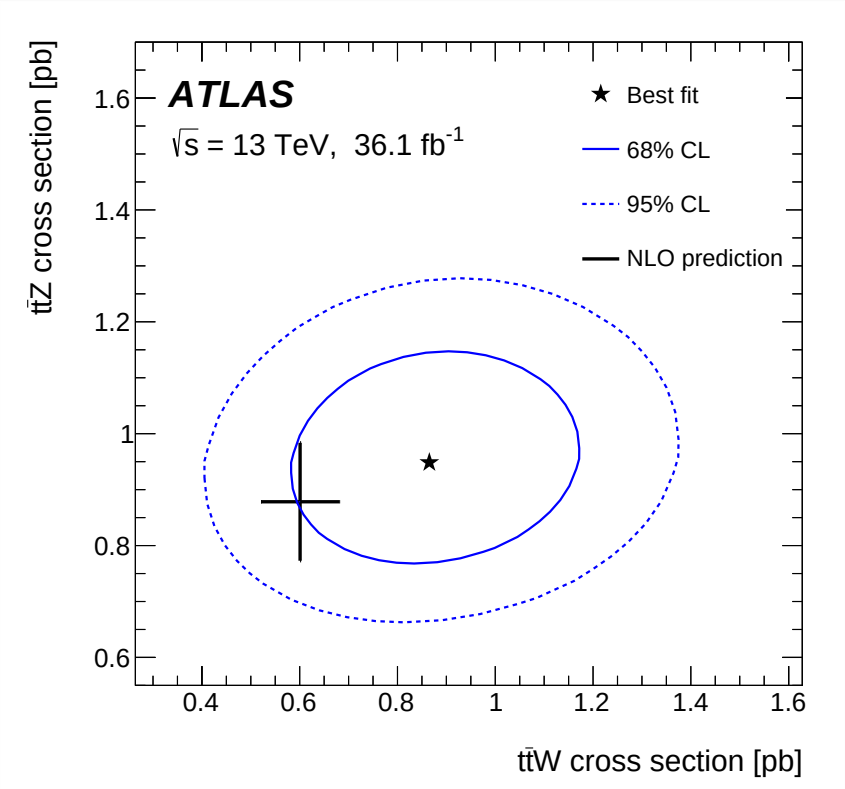
- Direct probe of the weak couplings of the top-quark
- Deviations from the SM can be parametrized in the framework of SM Effective Field Theory in a model independent way
- No deviations $\Rightarrow$ Set constraints on the weak couplings of the top quark in the SMEFT context.
- $t\bar{t}W$ important background for many SM processes like $t\bar{t}H$
- ATLAS measurement with 36.1 fb^{-1} of data collected during 2015 and 2016

$t\bar{t}$ decay	Boson decay	Channel
$(\ell^{\pm}\nu b)(q\bar{q}b)$	$\ell^{\pm}\nu$	SS dilepton
$(\ell^{\pm}\nu b)(\ell^{\mp}\nu b)$	$\ell^{\pm}\nu$	Trilepton

Results: Cross-sections

arxiv:1901.03584

- $\sigma_{t\bar{t}W} = 0.87 \pm 0.19$ pb $\Rightarrow$ No significant deviations from SM
- Further constraints on Wilson coefficients in the framework of SMEFT
- On-going analysis with full Run 2 data



Higgs fine-tuning problem

- Higgs mechanism responsible for generating masses of SM particles
- Mass of the Higgs boson itself destabilized by quantum effects $\rightarrow$ Higgs fine-tuning problem

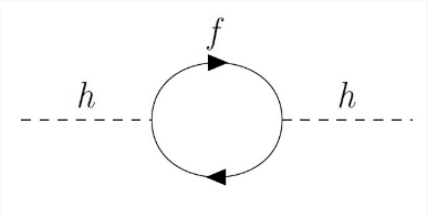
$$V(\phi) = \mu^2 |\phi|^2 + \lambda |\phi|^4$$

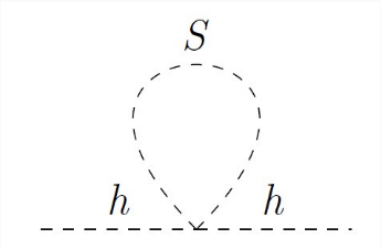
$$\mu^2 = m^2_{bare} - \frac{|\lambda_f|^2}{8\pi^2} (\Lambda^2_{UV} + ...) + ...$$

- Largest corrections from top quarks
- This leading correction can be controlled if there exist new particles with properties similar to those of the top quark
- Two main classes of solutions studied in the SHIFT project:
  - Supersymmetry
  - Composite Higgs Models (CHM)

Solving the Higgs Fine-Tuning problem (SHIFT)
Supersymmetry

- Every SM particle has a 'super'partner with similar properties but a spin that differs by half a unit



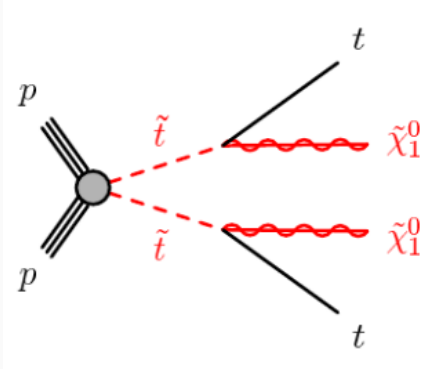


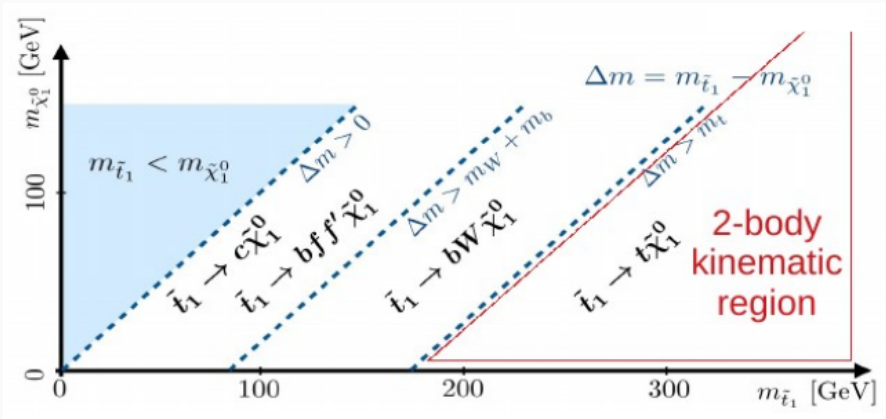
$$\mu^2 = m^2_{bare} - \frac{|\lambda_f|^2}{8\pi^2}\left(\Lambda^2_{UV} + ...\right) + \frac{\lambda_S}{16\pi^2}\left(\Lambda^2_{UV} + ...\right) + ...$$

- Cancellation if $\lambda_S = |\lambda_f|^2$
- Higgs boson mass protected by chiral symmetry
- Dominant sources of fine-tuning are removed by scalar top squarks or stops

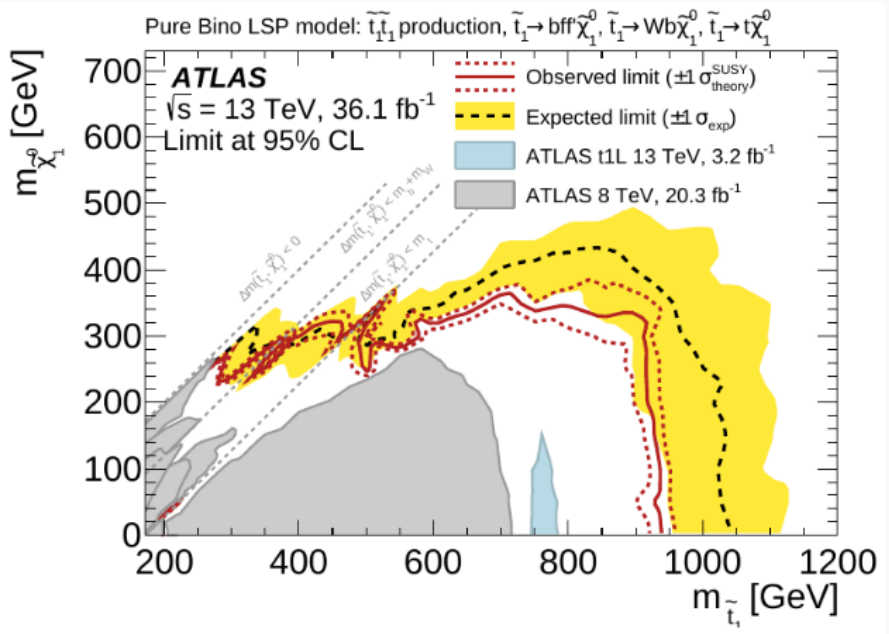
Direct search for stops

- Search in the 1-lepton channel, where one of the top decays leptonically and the other hadronically
- The lightest neutralino is assumed to be LSP, therefore present in the final state
- Focuses in the 2-body kinematic region where $\Delta m(\tilde{t}, \chi) > m_t$, $\tilde{t} \to t\chi$ becomes dominant
- On-going analysis with full Run 2 data





arXiv:1711.11520v1



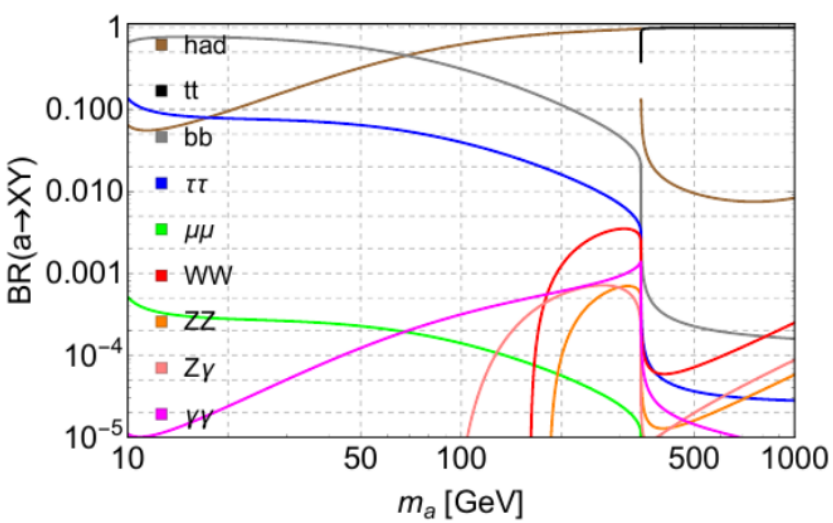
Solving the Higgs Fine-Tuning problem (SHIFT)
Composite Higgs models

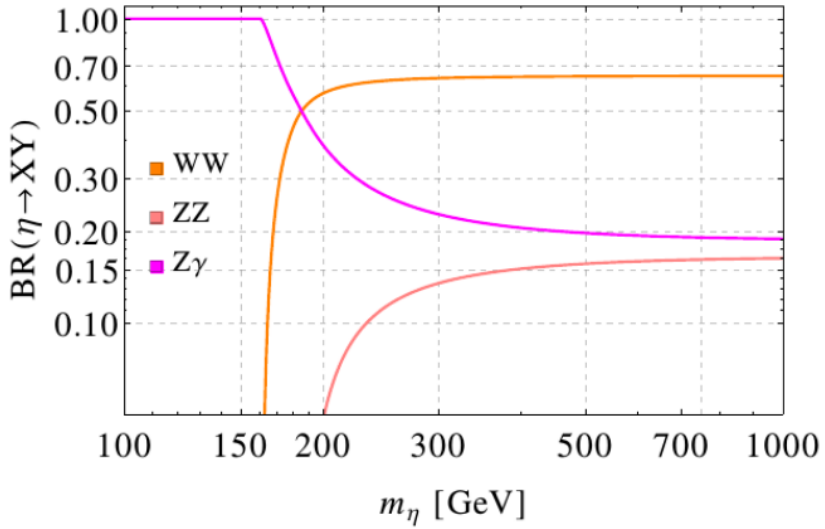
- The Higgs boson is a composite pseudo-Nambu-Goldstone boson (pNGB) from spontaneous breaking of a global symmetry in a new strongly coupled sector $\rightarrow$ This protects the Higgs mass
- Such models predict new vector-like top (VLT) partners.
- ATLAS and CMS have searched for such top-partners decaying to SM particles ($T \rightarrow Ht, Zt, Wb$) $\Rightarrow$ Bounds around 1.3 TeV
- These searches assume 100% branching to SM particles $\rightarrow$ Constraints relax if this is not true

Collaboration between theorists and experimentalists at Uppsala University and Chalmers University to study BSM decays of VLT.

Exotic decays of vector-like top partners

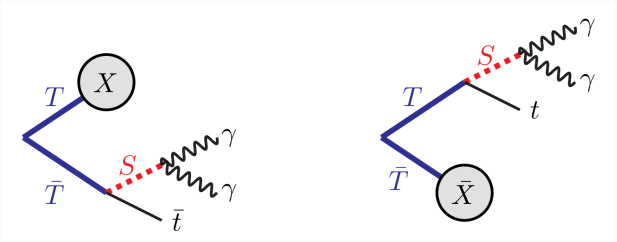
- Many models predict non-standard decays of VLT
- Example: $T \to St$, where S can be a scalar or a pseudo-scalar
- Branching ratios of these exotic states depend on their properties



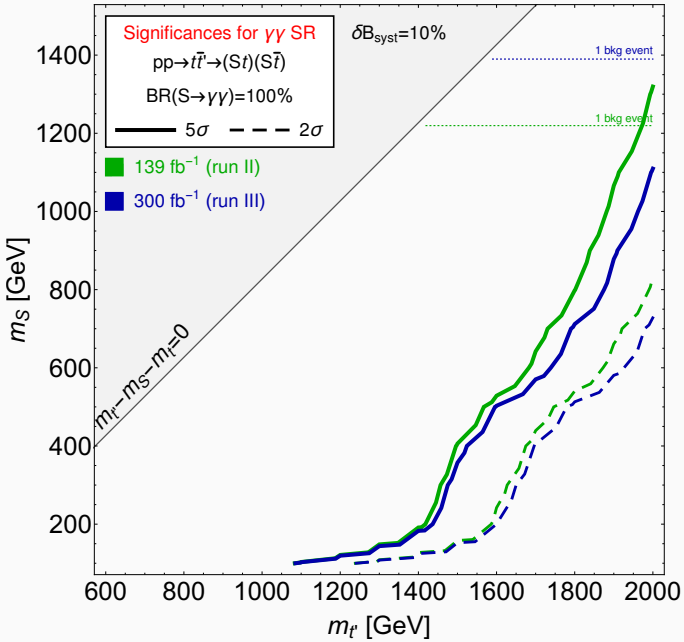


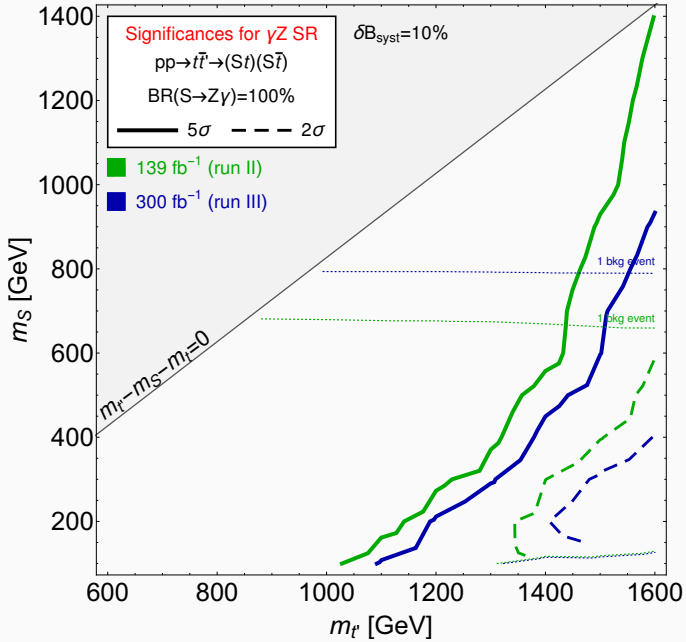
Bizot, Cacciapaglia, Flacke 18

Possible final states of interest



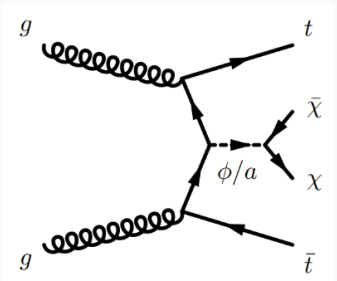
- Model independent search for VLT with decays to non-SM particles decays to exotic scalar + t/b
- Signal: $pp \to T\bar{T} \to tS(\to Z\gamma/\gamma\gamma) + X$
- Optimistic reach in Run 2 and Run 3 evaluated in 1907.05929

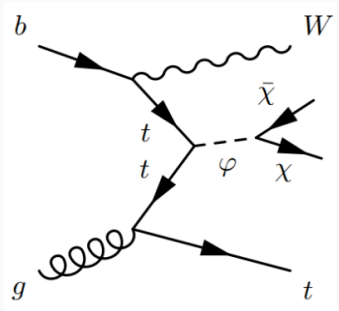




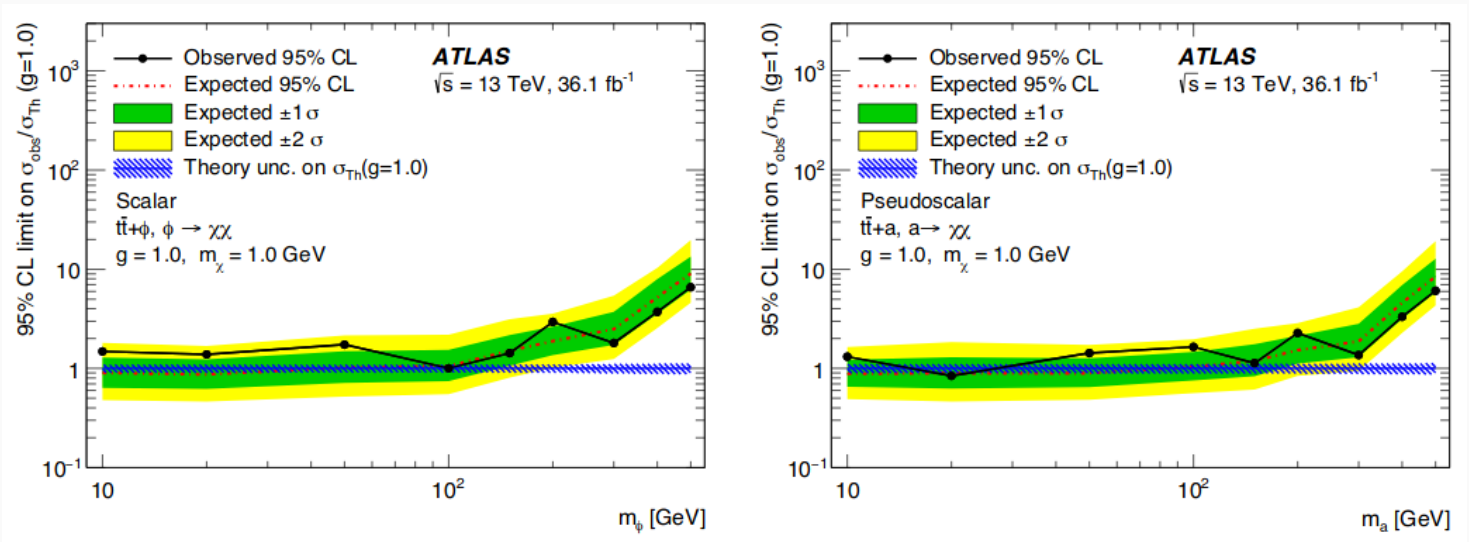
Dark matter and tops

- Dark Matter (DM) candidates possible in several models, like SUSY, 2HDM+a
- Final states involving tops: $tW + E_T^{miss}$, $t\bar{t} + E_T^{miss}$ 1711.11520





- Overlap possible between the $t\bar{t} + E_T^{miss}$ and $tW + E_T^{miss}$ @NLO (See Olga's talk)
- $t\bar{t}$ + DM analysis: 1ℓ, jets, and E_T^{miss} with the (m_{med},m_χ) benchmarks of (20,1) and (300,1) GeV
  - On-going analysis with full Run 2 data



Summary

- Top portal is a good place to look for new physics either via measurements of SM processes or through direct searches. Plenty of work on-going to that end in Sweden.
- Measurements of $t\bar{t}W$ cross-sections
  - No significant deviations from SM.
  - Constraints on Wilson coefficients using SMEFT.
- Searches for stops in single lepton final states on-going with full Run 2 data.
- New searches for vector-like top partners possible in final states with $\gamma\gamma$ and $Z\gamma$.
- DM+top searches to constrain masses of dark matter candidates in two channels: $t\bar{t}$+DM, and tW+DM.
  - Overlap between channels may need to be treated separately.