The SHIFT project

Partikeldagarna 2018

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CHALMERS UNIVERSITY OF TECHNOLOGY

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Scientific Motivation

- The Higgs mechanism is responsible for generating the masses of the elementary particles in the SM.
- Mild changes induced by quantum corrections.
- Mass of the Higgs boson itself is greatly destabilised by quantum effects → Higgs fine-tuning problem.

$$V(\phi) = \mu^2|\phi|^2 + \lambda|\phi|^4 \qquad \mu^2 = m^2_{\text{bare}} - \frac{|\lambda_f|^2}{8\pi^2}(\Lambda^2_{\text{UV}} + \cdots) + \cdots$$

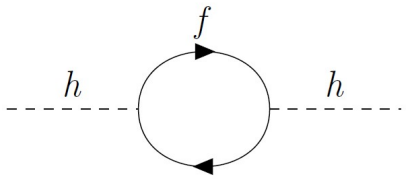
$$m_h^2 = 2|\mu|^2 \qquad -(92.9\,\text{GeV})^2 = m^2_{\text{bare}} + \mathcal{O}(10^{30})\,\text{GeV}^2 \;[\text{if } \Lambda_{\text{UV}} \sim M_P]$$

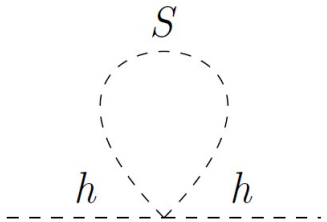
- Largest correction comes from the top quark.
- This leading correction can be controlled if there exist new particles with properties similar to those of the top quark.
- Two main classes of solutions to the Higgs fine-tuning problem are SUSY and compositeness.

SUSY solution

- Every SM particle has a hitherto unobserved superpartner with similar properties but with a spin that differs by half a unit.

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





- Cancellation if $\lambda_S = |\lambda_f|^2$
- Scalar Higgs boson related to fermion

  → Higgs boson mass protected by chiral symmetry.

- The new particles that remove the dominant source of fine-tuning are the superpartners of the top quark, the **scalar top squarks** or **stops**.

Compositeness solution

- The Higgs boson is a composite pseudo-Nambu-Goldstone boson (pNGB) from spontaneous breaking of a global symmetry in a new strongly coupled sector.

  → Higgs boson mass is protected by a Goldstone shift symmetry.

- The new particles that remove the dominant source of fine-tuning are **vector-like top quarks**.

Organization and Objectives

- So far, no signs of SUSY or compositeness at the LHC.
- Not too much room left for minimal models with a light top partner.
- Main objective of the SHIFT project:
  - **Widen the searches for physics beyond the SM that solves the Higgs fine-tuning problem.**
- Three different and complementary tracks:
  - Direct searches for the scalar top squarks in SUSY;
  - Direct searches for the vector-like top quarks in compositeness models;
  - Indirect searches for top partners which are not kinematically accessible at the LHC energies.
- **Strengthen collaboration between experimental and theoretical particle physicists in Sweden.**

Organization and Objectives

- Construct non-minimal simplified
  - SUSY models for direct searches for stops.
  - compositeness models for direct searches for vector-like quarks.
- Quantify ATLAS' current sensitivity to these models and, if still viable, search for them with Run 2 and early Run 3 data.
- Construct optimal observables for indirect searches of top partners and use them in analyses of Run 2 and early Run 3 data.

Compositeness / VLQ leg

Credit: Symmetry Magazine

People

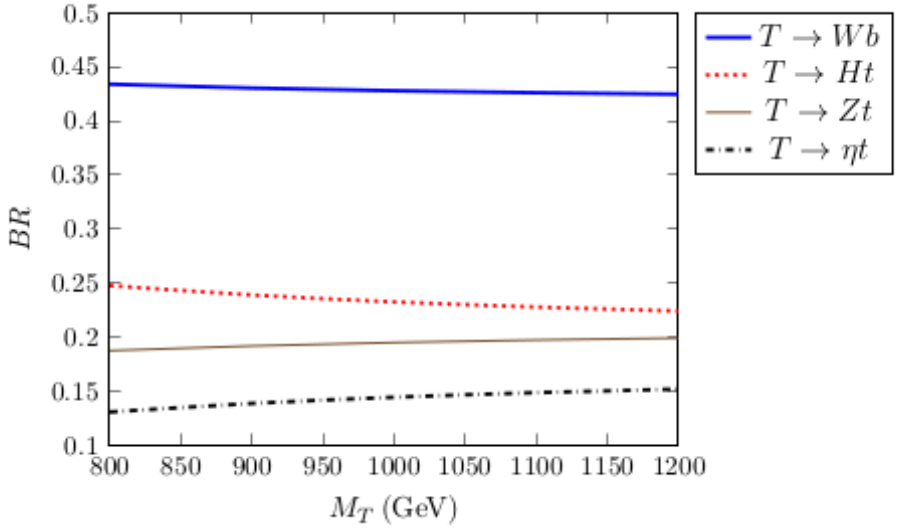
- Faculty:
  - **Elin Bergeås Kuutmann**, Uppsala University (experiment; coordinator)
  - **Rikard Enberg**, Uppsala University (theory)
  - **Gabriele Ferretti**, Chalmers University (theory)
- Researchers/postdocs:
  - Diogo Buarque Franzosi, Chalmers University (theory)
  - Venugopal Ellajosyula, Uppsala University (experiment)
  - Luca Panizzi, Uppsala University (theory)
- PhD students:
  - Thomas Mathisen, Uppsala University (experiment)
- Associated collaborators:
  - Rachid Benbrik, Cadi Ayyad University (theory)
  - Max Isacson, Uppsala University (experiment)
  - Yao-Bei Liu, Heinan IST / Southampton University (theory)
  - Tanumoy Mandal, Delhi University / Uppsala University (theory)
  - Stefano Moretti, Southampton University / Uppsala University (theory)

Activities and plans

- Current ATLAS and CMS searches have focused on VLQ → SM particles.
- Look at VLQ → non-SM scalars.
- Model building: which models are viable?
- Which models are detectable at the LHC?
- ATLAS searches for the most promising models.
- Short-term goals (by end of 2018 or early 2019):
  - Phenomenological paper on a first compositeness model with VLT → t/b + non-SM scalar, as a guideline for LHC searches.
  - Probe sensitivity of possible decays.
  - Experiment: Setting up searches in ATLAS for these final states

Master and bachelor theses

- Thomas Mathisen (master thesis, Uppsala University 2018):
  Studies of Hypothetical Vector-Like Quarks at the Large Hadron Collider



- Hesham El Faham (master thesis, Uppsala University 2018):
  Phenomenological Studies on Composite Higgs Models

SUSY leg

Credit: Symmetry Magazine

People

- Faculty:
  - **Gabriele Ferretti**, Chalmers University (theory)
  - **David Milstead**, Stockholm University (experiment)
  - **Sara Strandberg**, Stockholm University (experiment; coordinator)
- Researchers/postdocs:
  - Alex Kastanas, Stockholm University (experiment)
  - [recruitment ongoing], Stockholm University (experiment)
- PhD students:
  - Filip Backman, Stockholm University (experiment)
  - Patrawan Pasuwan, Stockholm University (experiment)
  - Laura Pereira Sanchez, Stockholm University (experiment)
- Associated collaborators:
  - Yosse Andrean, Stockholm University (experiment)
  - Christophe Clement, Stockholm University (experiment)

Activities and plans

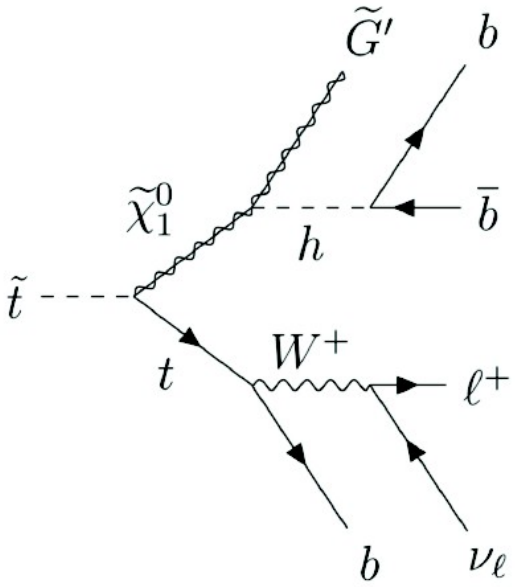
- Current activities:
  - RPC SUSY: Searches for scalar top squarks in single-lepton final state with full Run 2 dataset [see talk by Yosse Andrean].
  - RPV SUSY: Searches for long-lived particles in DV+jets and DV+MET final states.
  - First look at non-minimal models.
- Short- and long-term goals:
  - Complete ongoing searches.
  - Review stop coverage in RPV SUSY scenarios and let that steer future searches.
  - Look further into new RPC models e.g. GMSB-type models with massive LSPs and (extended) NMSSM models.

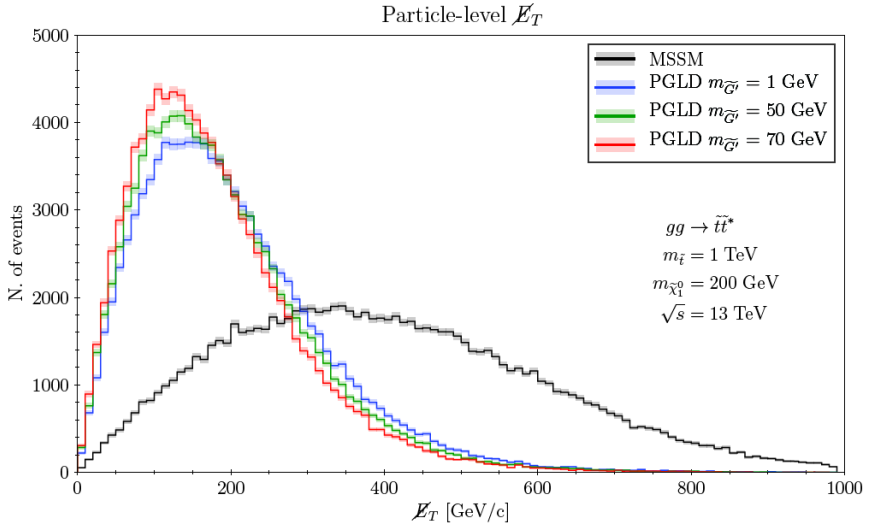
Master and bachelor theses

- Joakim Flinckman (bachelor thesis, Stockholm University 2018)

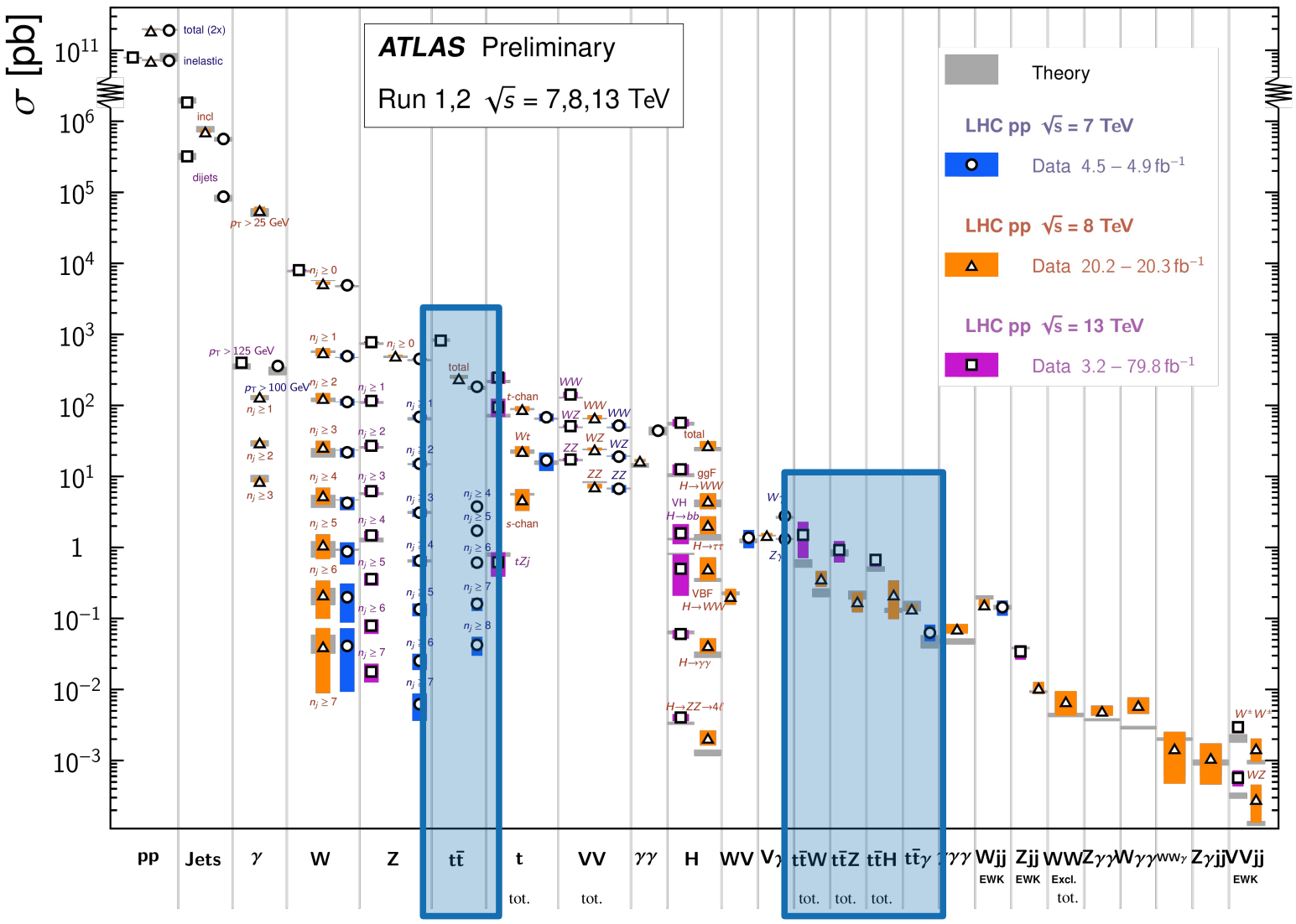
  A comparison of GMSB and MSSM with light top quark partners

  - First look at GMSB model with two hidden sectors (neutralino decays to heavy pseudo-goldstino (PGLD)).





Indirect leg

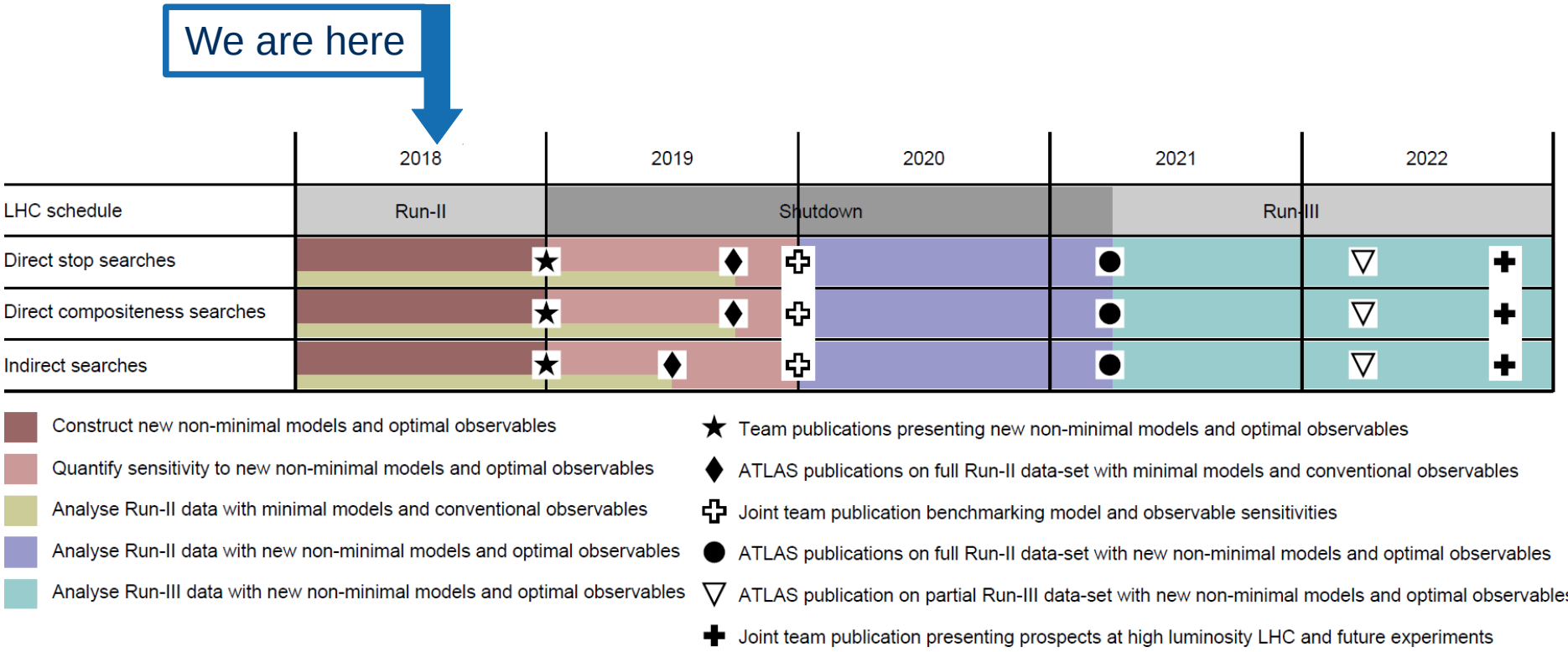


People

- Faculty:
  - **Jörgen Sjölin**, Stockholm University (experiment; coordinator)
- Researchers/postdocs:
  - Diogo Buarque Franzosi, Chalmers University (theory)
  - [recruitment ongoing], Stockholm University (experiment)
- PhD students:
  - Nabila Shaik, Stockholm University University (experiment)

Activities and plans

- Current activity:
  - Analysis of the ttW(j) process in the same-sign final state [see talk by Nabila Shaik].
- Short term goals:
  - Background estimation of electron charge-flips and fake leptons from heavy flavour jets.
  - Reweighting of the SM Monte Carlo using EFT matrix elements.
  - Consistent baseline MVA fitting framework for EFT operators.
- Long term goals:
  - Optimal fitting framework of EFT operators.
  - Include more final states such that the complete top EFT basis is covered.


We are here
2018
2019
2020
2021
2022
LHC schedule
Run-II
Shutdown
Run-III
Direct stop searches
Direct compositeness searches
Indirect searches
Construct new non-minimal models and optimal observables
Quantify sensitivity to new non-minimal models and optimal observables
Analyse Run-II data with minimal models and conventional observables
Analyse Run-II data with new non-minimal models and optimal observables
Analyse Run-III data with new non-minimal models and optimal observables
Team publications presenting new non-minimal models and optimal observables
ATLAS publications on full Run-II data-set with minimal models and conventional observables
Joint team publication benchmarking model and observable sensitivities
ATLAS publications on full Run-II data-set with new non-minimal models and optimal observables
ATLAS publication on partial Run-III data-set with new non-minimal models and optimal observables
Joint team publication presenting prospects at high luminosity LHC and future experiments