The SHIFT project

Solving the Higgs Fine-Tuning Problem with Top Partners

Partikeldagarna
23/11 2021, Chalmers, Gothenburg

Sara Strandberg (SU) on behalf of the SHIFT Collaboration

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  Gabriele Ferretti, Chalmers University (theory)
  David Milstead, Stockholm University (experiment)
  Jörgen Sjölin, Stockholm University (experiment)
  Sara Strandberg, Stockholm University (experiment)

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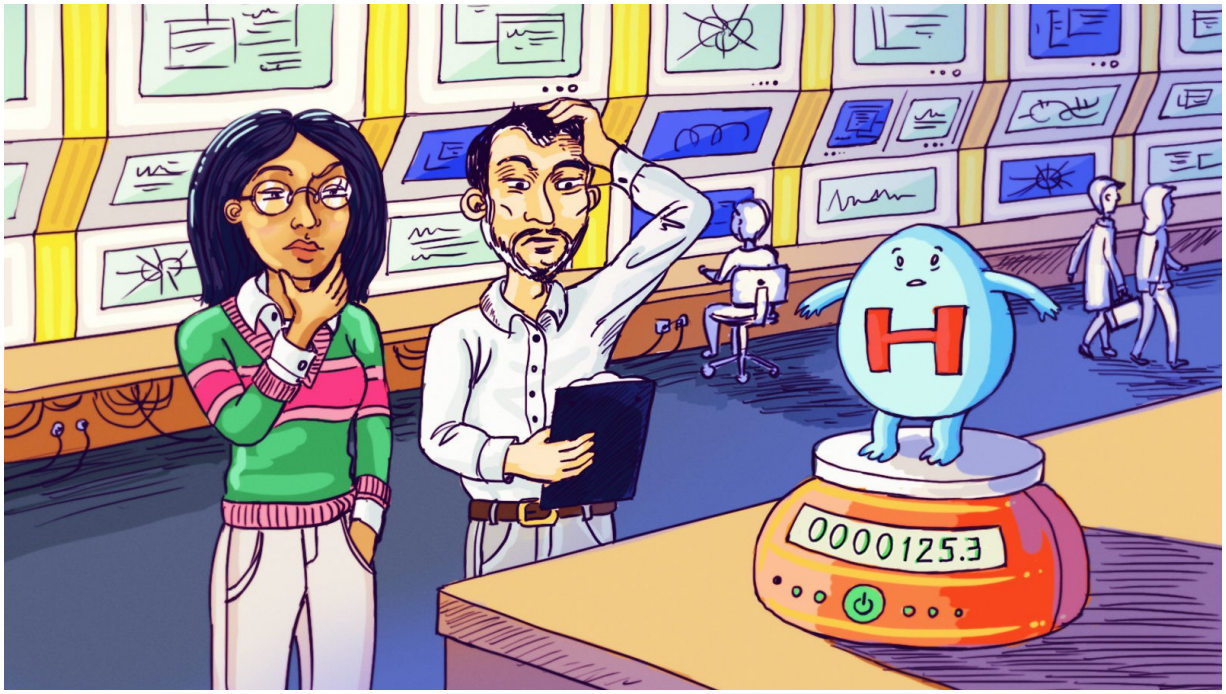
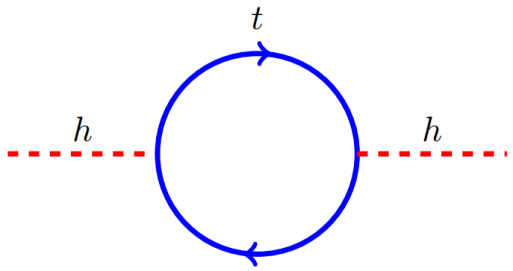
Scientific Motivation

- 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.



Scientific Motivation

- Largest correction to the Higgs boson mass comes from the top quark.



$$\delta m_h^2 \sim -\frac{y_t^2}{16\pi^2}(\Lambda_{\rm UV}^2 + \cdots) + \cdots$$

- This leading correction can be controlled if there exist new particles with properties similar to those of the top quark.

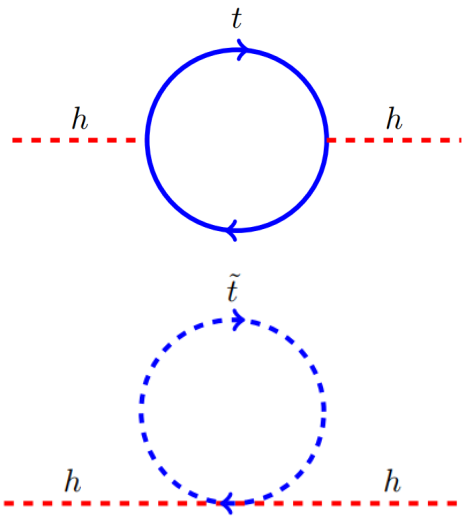
Solving the **HI**ggs **F**ine-Tuning Problem with **T**op Partners

- 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.

$$\delta m_h^2 \sim -\frac{y_t^2}{16\pi^2}(\Lambda_{\mathrm{UV}}^2 + \cdots) + \frac{\lambda_S}{16\pi^2}(\Lambda_{\mathrm{UV}}^2 + \cdots) + \cdots$$



- Cancellation if $\lambda_S = y_t^2$
- 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**.
- Mass difference between top and stop cannot be too large.

Compositeness solution

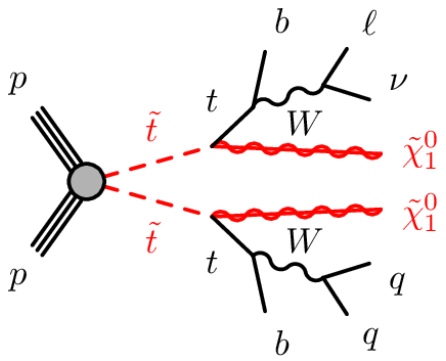
- The Higgs boson is a composite pseudo-Nambu-Goldstone boson (pNGB) from spontaneous breaking of a global symmetry in a new strongly coupled sector.

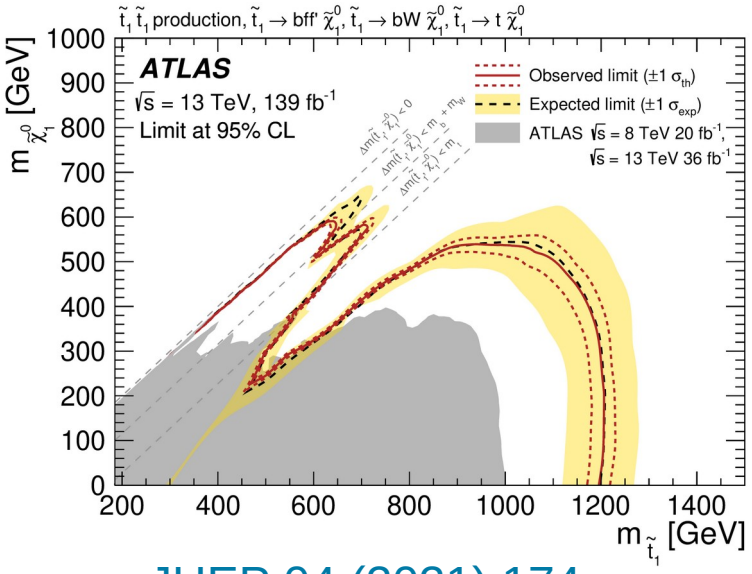
  → Higgs boson mass is protected by a Goldstone shift symmetry.

- The new particles that remove the dominant source of fine-tuning are **vector-like top quarks.**
  - spin 1/2,
  - carries colour charge,
  - its right and left components have the same quantum numbers (“vector-like”, i.e. not chiral).

Direct stop searches

- Stop searches in both RPC and RPV SUSY.





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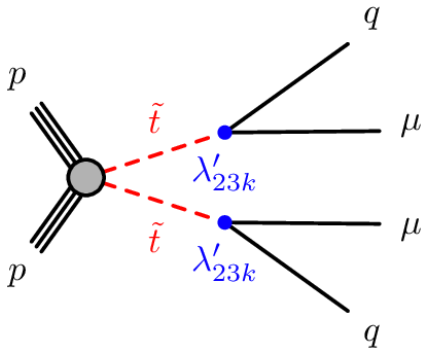
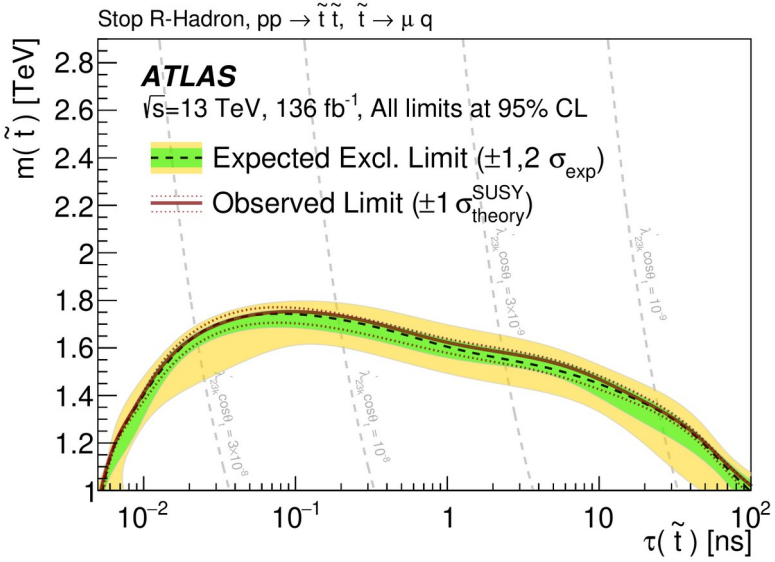




Phys. Rev. D 102 (2020) 032006

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.
- Look beyond minimal

  (the SM is not minimal...)
- 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.

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.

Non-minimal models CH

Springer Link

Regular Article - Theoretical Physics | Open Access | Published: 07 May 2020

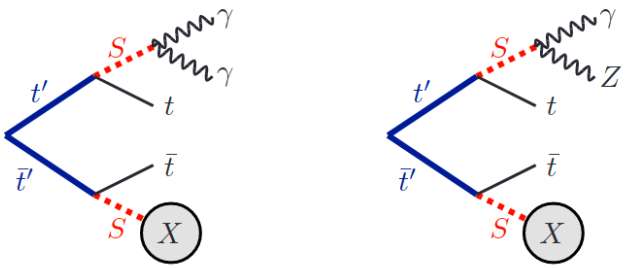
Signatures of vector-like top partners decaying into new neutral scalar or pseudoscalar bosons

R. Benbrik, E. Bergeaas Kuutmann, D. Buarque Franzosi, V. Ellajosyula, R. Enberg, G. Ferretti, M. Isacson, Y.-B. Liu, T. Mandal, T. Mathisen, S. Moretti & L. Panizzi

Journal of High Energy Physics **2020**, Article number: 28 (2020) | Cite this article

201 Accesses | **12** Citations | **1** Altmetric | Metrics

A preprint version of the article is available at arXiv.



- Current searches for vector-like top quarks (t') assume decays exclusively to SM particles: $t' \to Wb/Zt/ht$
- Introduce an additional (pseudo)scalar S: $t' \to St$
- Possible e.g. in 2HDM (Type-II) and Composite Higgs Models.
- See talks by A. Banjeree and D. Buarque Franzosi.
- Next step to search for such models with ATLAS data.
- L. Panizzi ATLAS short-term associate.

Non-minimal models SUSY

Cornell University

We gratefully acknowledge support from the Simons Foundation and member institutions.

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High Energy Physics - Phenomenology

[Submitted on 8 Nov 2021]

Electroweak signatures of gauge-mediated supersymmetry breaking in multiple hidden sectors

Diogo Buarque Franzosi, Gabriele Ferretti, Ellen Riefel, Sara Strandberg

This paper discusses electroweak collider signatures of the NMSSM with multiple-sector gauge mediation. We focus on the production of neutralinos and charginos which cascade decay into standard model particles and lighter supersymmetric particles, with special emphasis on final states with multiple photons. A search strategy for signatures with at least three photons is presented and compared with current exclusion limits based on two-photon searches. We show that in many regions of the parameter space our strategy gives stronger constraints than the existing two-photon analysis for these models.

Comments: 20 pages, 24 figures
Subjects: **High Energy Physics - Phenomenology (hep-ph)**; High Energy Physics - Experiment (hep-ex)
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(or arXiv:2111.04775v1 **[hep-ph]** for this version)

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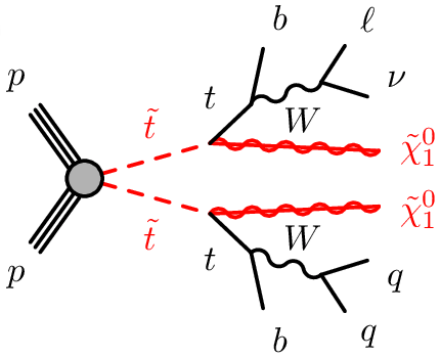
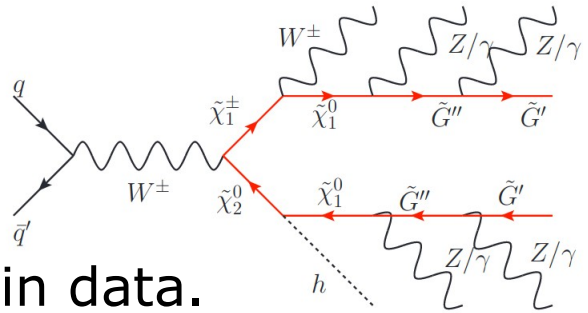


- Current searches for $\tilde{t}$ assume LSP is stable $\tilde{\chi}_1^0$ or massless gravitino ($\tilde{G}$).
- Phenomenology changes if GM with multiple hidden sectors ($\tilde{\chi}_1^0 \to \tilde{G}''\gamma \to \tilde{G}'\gamma\gamma$).
- Look at EW production of charginos and neutralinos.
- Next step is to search for such models in data.



Non-minimal models (2)

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- Google Scholar
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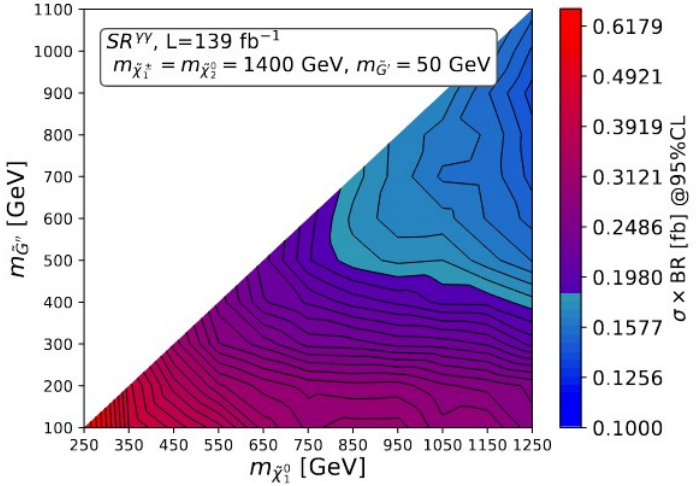
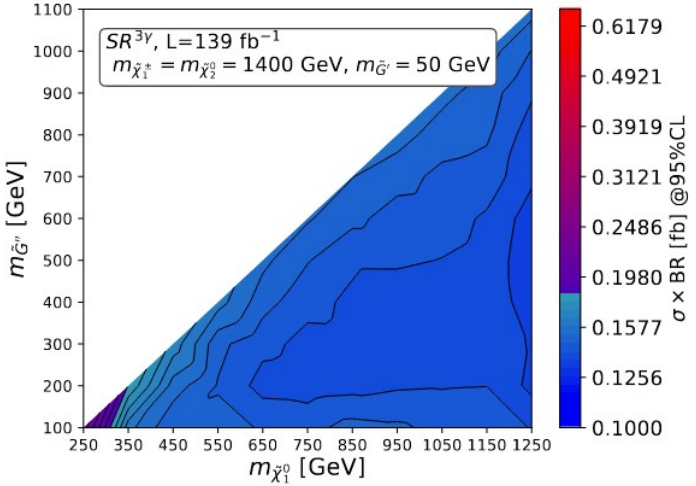
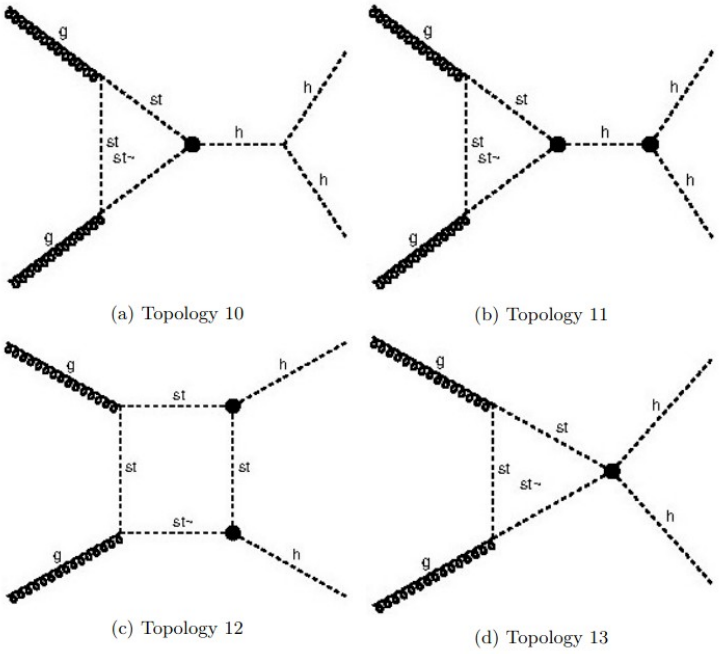
- Proposed multiphoton + $E_{\mathrm{T}}^{\mathrm{miss}}$ search more sensitive than existing diphoton + $E_{\mathrm{T}}^{\mathrm{miss}}$ search.



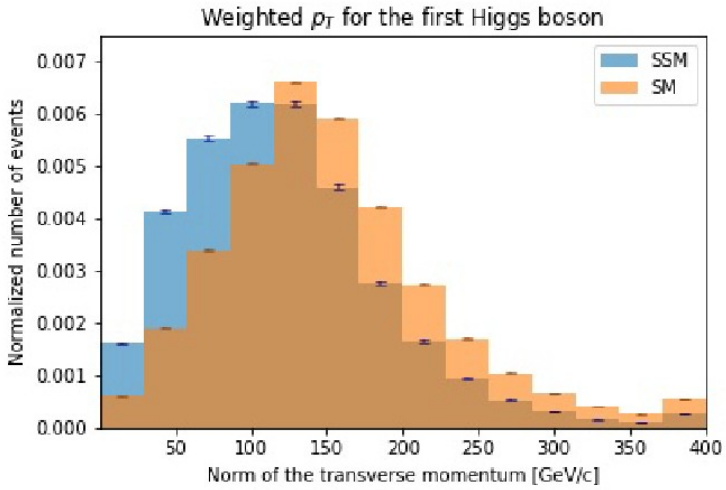


Indirect searches

- Even if top partners are too heavy to be directly produced at the LHC they can enter loops and alter various observables e.g. in top and Higgs sector.
- Extract constraints on EFT operators. See talk by X. Lou.
- Study how kinematics of HH events change by BSM particles in loops, using simplified model by L. Panizzi.



H. Brännström master thesis



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Is there still room for naturalness?

from 14 April 2020 to 01 May 2020 — Nordita, Stockholm

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Scope

In the Standard Model, the mass of the Higgs boson is greatly destabilised by quantum corrections, and free parameters of the model need to be extremely fine-tuned in order to arrive at the measured Higgs mass. A fundamental aim of this program is to quantify the extent to which current measurements and searches can constrain models which attempt to restore naturalness by extending the SM. The expected sensitivity from future high precision running at the LHC and of planned non-collider experiments will also be studied. This program deviates from related work in this field by maintaining a sharp focus on the naturalness question and how well a top quark partner can resolve it in different theoretical scenarios using a range of measured observables.

Registration for this program has not yet been opened.

More information will be available here later.

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from 14 April ~~2020~~ May 2020 April 2021

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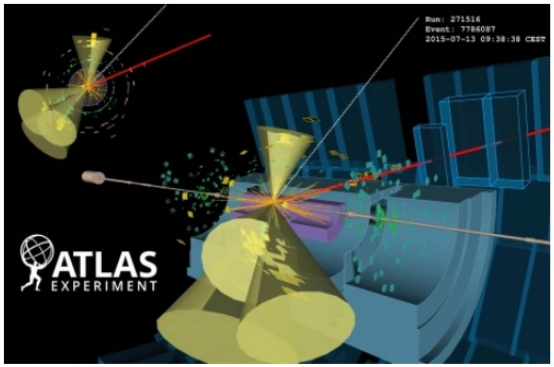
Solving the HIggs Fine-Tuning Problem with Top Partners

In the Standard Model, the mass of the Higgs boson is greatly destabilised by quantum corrections, and free parameters of the model need to be extremely fine-tuned in order to arrive at the measured Higgs mass.

In the SHIFT project we aim to find the underlying mechanism protecting the mass of the Higgs boson from large quantum corrections. The leading correction, which arises from the top quark, can be cancelled by introducing top-quark partners to the theory. Therefore we study possible signatures of such top partners and search for them using data from the ATLAS experiment at CERN's Large Hadron Collider.



ATLAS EXPERIMENT Photo Credits ©CERN

The project which is funded by the Knut and Alice Wallenberg Foundation, involves theorists and experimentalists from Chalmers University of Technology, Stockholm University and Uppsala University and runs over five years (2018-2022). It covers direct searches for top partners in supersymmetry and compositeness models and indirect searches via precision measurements of processes involving top quarks.

Project P.I.

Sara Strandberg

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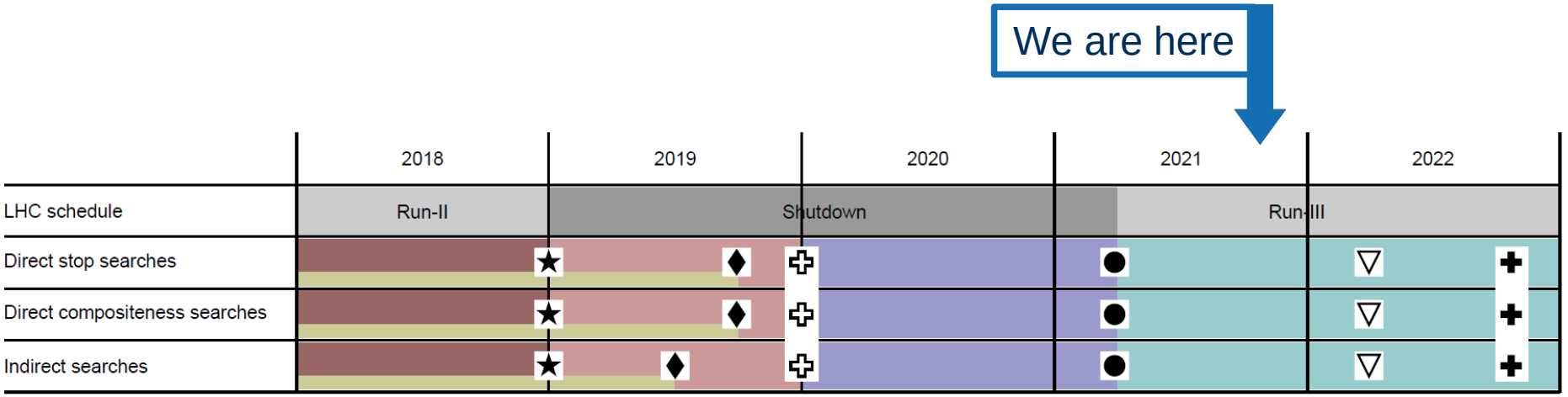
Backup Material

The Grand Plan



- 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

Indirect leg