The SHIFT project: status and prospects

Elin Bergeås Kuutmann
on behalf of the SHIFT project

SHIFT (Solving the Higgs Fine-tuning problem with Top partners)
Funded by the Knut & Alice Wallenberg foundation 2018 – June 2023

CHALMERS

UPPSALA UNIVERSITET

Stockholms universitet

People

Faculty:
Elin Bergeås Kuutmann, Uppsala University (experiment)
Rikard Enberg, Uppsala University (theory)
Gabriele Ferretti, Chalmers University (theory)
David Milstead, Stockholm University (experiment)
Jörgen Sjölin, Stockholm University (experiment)
Sara Strandberg, Stockholm University (experiment, **PI**)

Researchers/postdocs:
Avik Banerjee (Chalmers), Laura Barranco Navarro (SU), Diogo Buarque Franzosi (Chalmers, SU), Venugopal Ellajosyula (UU), Karl Gellerstedt (SU), Xuanhong Lou (SU), Luca Panizzi (UU), Stefan Richter (SU), Antonia Strübig (SU)

PhD students:
Yosse Andrean (SU), Filip Backman (SU), Dongwon Kim (SU), Thomas Mathisen (UU), Patrawan Pasuwan (SU), Laura Pereira Sanchez (SU), Ellen Riefel (SU)

International collaborators:
Juan Antonio Aguilar-Saavedra (U Granada, IFT Madrid), Andy Buckley (U Glasgow), Christoph Englert (U Glasgow), James Ferrando (DESY), Roberto Franceschini ("Roma Tre"), Fabio Maltoni (Louvain, CP3), David Shih (Rutgers U), Michael Spannowsky (Durham U), Riccardo Torre (INFN, Genova)

Other affiliated people:
Faculty / PIs
Rachid Benbrik (Cadi Ayyad University, Marrakech), Christophe Clément (SU), Stefano Moretti (Southampton University/UU), Christian Ohm (KTH),
Researchers / postdocs
Eliel Camargo-Molina (UU), Alexander Leopold (KTH), Harri Waltari (UU)
PhD students
Tom Ingebretsen Carlson (SU), Johan Löfgren (UU)
Master students
Simon Johansson Nyberg (UU)

Scientific motivation

The **Higgs mechanism** generates the masses of the elementary particles.
Manifest in the Higgs boson
==> *See Sara Strandberg's talk about the discovery, tomorrow afternoon*

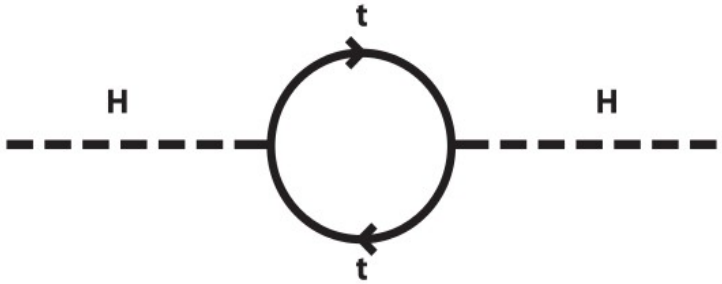
Higgs potential: $V = -\mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)$

μ is the only SM parameter with **dimension mass**.

$\mu^2 \ll M^2_{Planck}$ *hierarchy*

μ (and the Higgs boson mass) is sensitive to quantum loop corrections O(10^{19} GeV)

$\mu^2 = \frac{m_H^2}{2}$, $\Delta m_H^2 = \frac{-\lambda_f}{8\pi}\left[\Lambda_{UV}^2 + ...\right]$ especially from the top quark



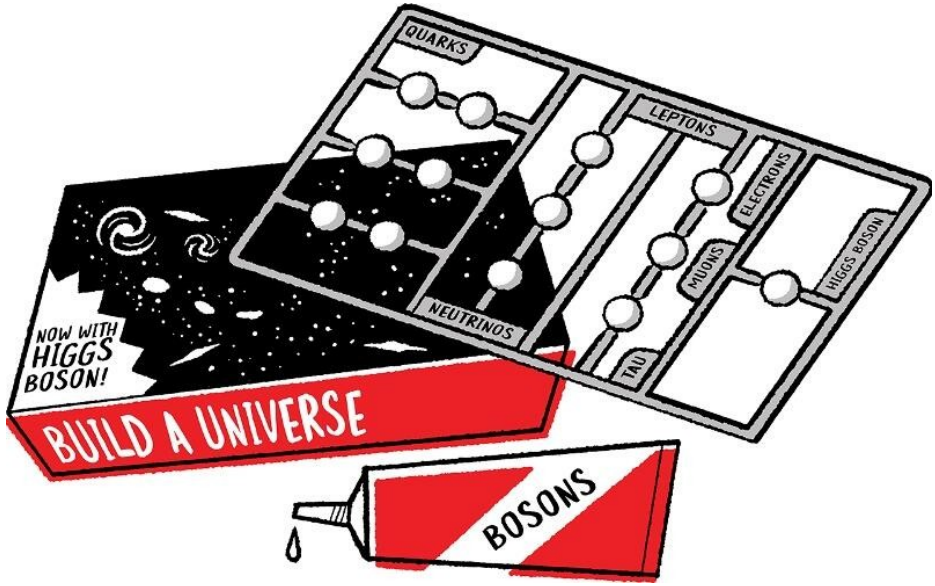


Image from iop.org

This needs **fine-tuning**

It is very very unlikely that μ has the value observed.

Is this a problem?

Scientific motivation (2)

Why is this a problem?

We like to understand why things are as they are.

Solving the Higgs fine-tuning problem:

- Declare it not to be a problem (not us...)
- Say that there must be more physics which can explain this

SHIFT: **Solving the Higgs Fine-turning problem with Top partners**

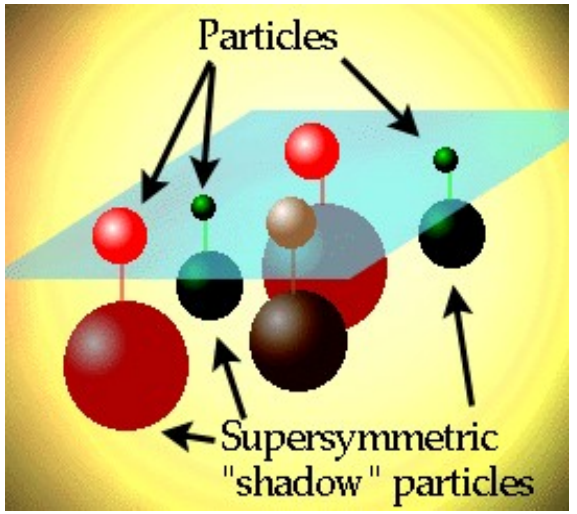
Our tracks:

- SUSY
- Compositeness
- Indirect searches

(T. Hudson Creative Commons BY-SA 3.0)

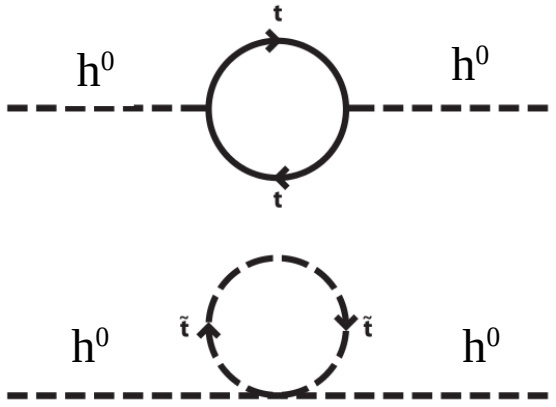
Solution 1: Supersymetry (SUSY)

Image: atlas.ch



Extend the SM with supersymmetry (SUSY)

- For each SM boson: a bosino
- For each SM fermion: a sfermion
  ==> for each top quark *t*: a *stop* $\tilde{t}$
- Top loop corrections and
  stop loop corrections cancel
  (almost).
- The stop particle must have a mass of
  ≤ 1.4 TeV
  ==> detectable at the LHC!



Solution 2: A composite Higgs boson?

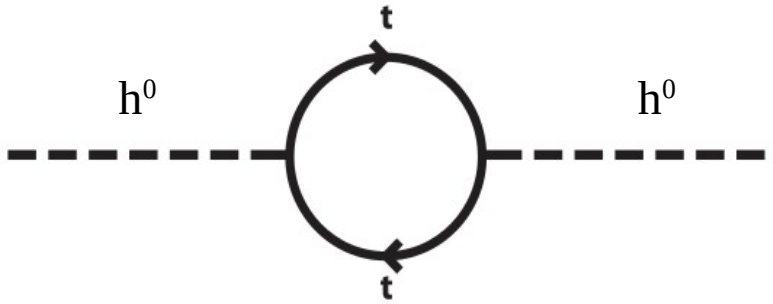
- Maybe h^0 is not elementary but a **pseudo-Nambu-Goldstone boson (pNGB)**.
- Higgs mass protected!

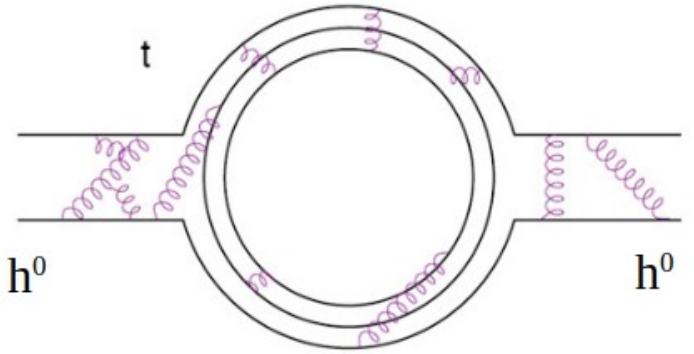
Can we detect this experimentally?

- Many scenarios with a composite Higgs also include vector-like quarks (VLQ), especially vector-like tops, *top partners*.
- What are VLQs?
  - carry colour charge
  - spin 1/2
  - their right and left components have the same quantum numbers (“vector-like”, i.e. not chiral).

Typical mass: ~ 1 TeV (LHC!)

These models typically also come with new scalars, *S*.

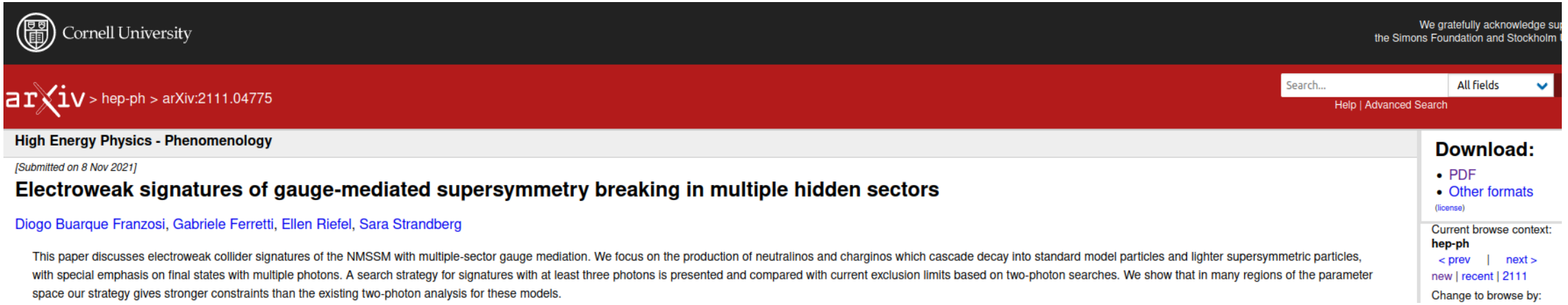




D. Kaplan, learner.org

SUSY: Phenomenological studies

arXiv: 2111.04775


Cornell University

We gratefully acknowledge su
the Simons Foundation and Stockholm

arXiv > hep-ph > arXiv:2111.04775

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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.

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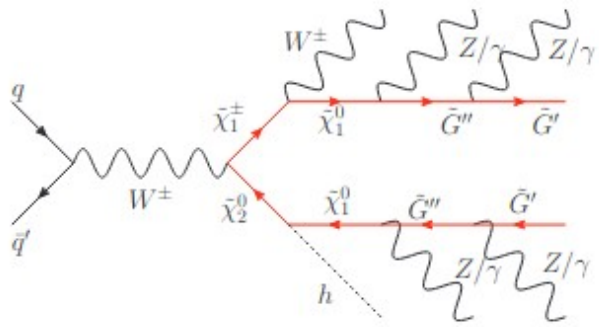
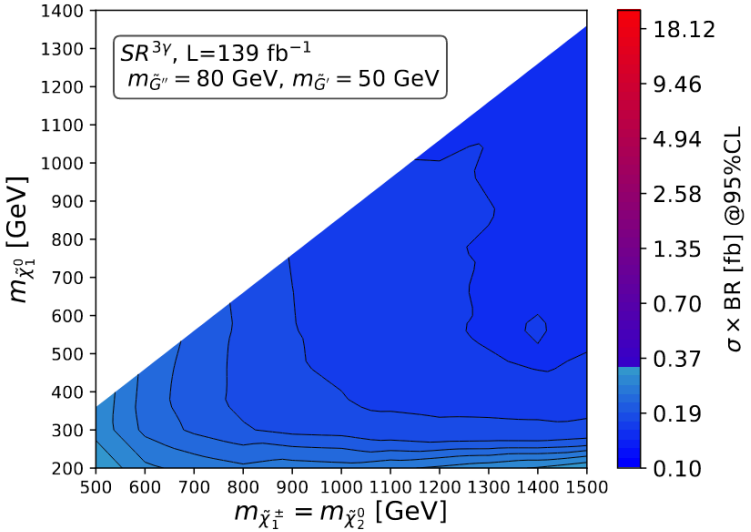
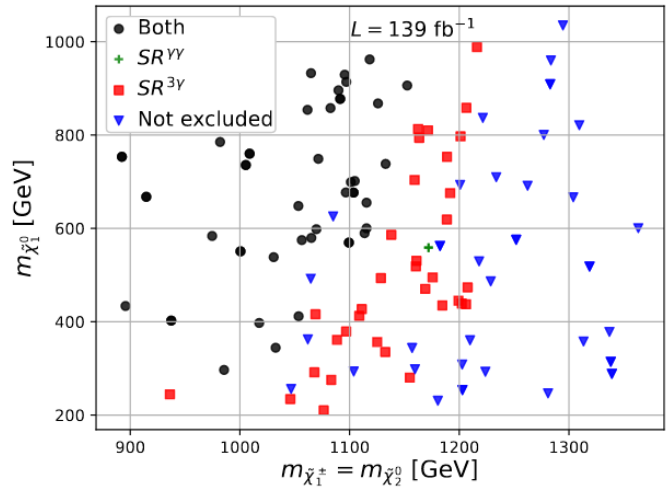
EW production of charginos and neutralinos cascading into SM particles and lighter SUSY particles
These models give unexplored experimental signatures with multiple gauge bosons
Search for events with **three photons** is proposed and found to perform better than existing two-photon searches.
Expected limits on σ_{prod}xBR are derived and
exclusion tests are carried out





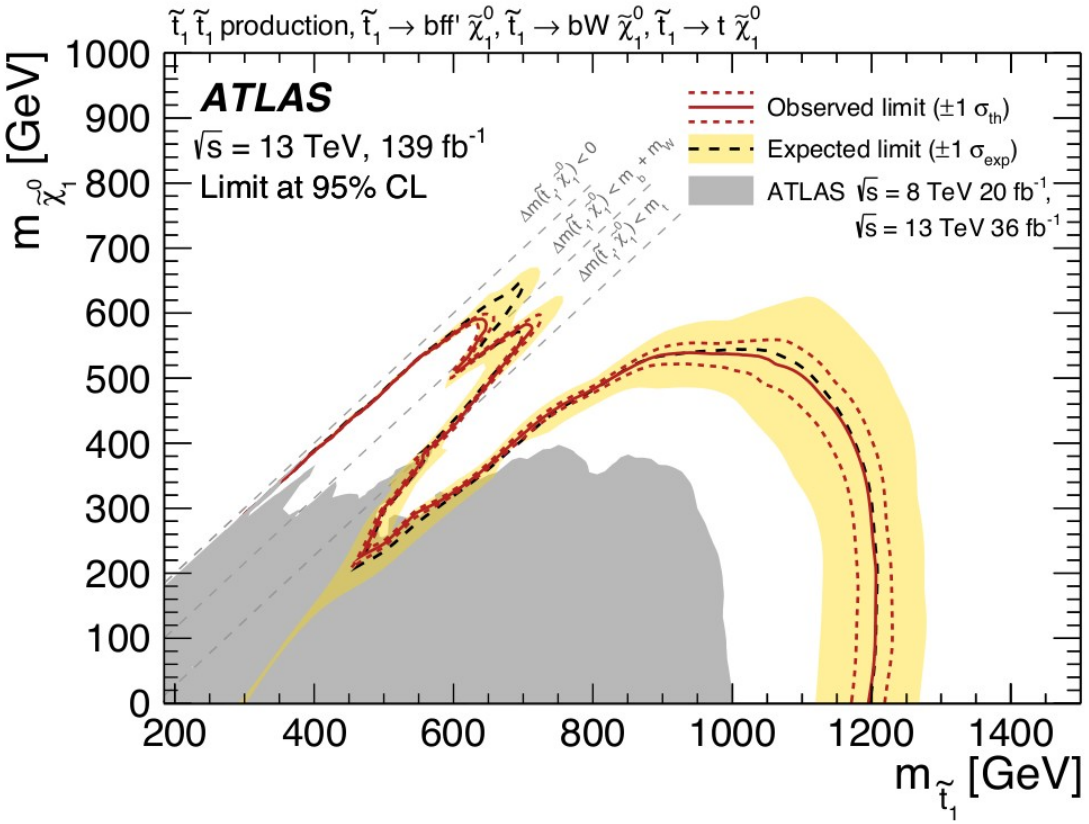


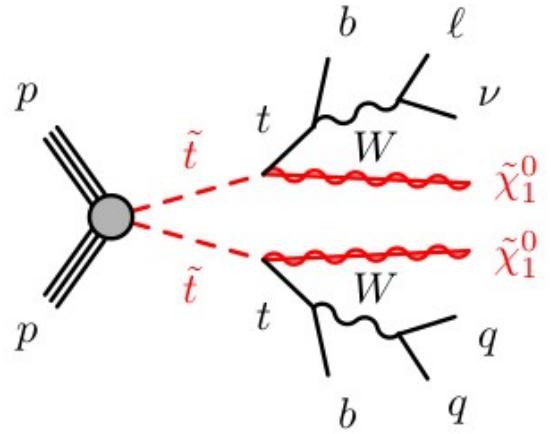
Elin Ber

SUSY: Experimental searches 1: direct stop pair production

Y. Andrean, L. Barranco Navarro, C. Clément, P. Pasuwan,
L. Pereira, S. Strandberg, A. Strübig

JHEP 04 (2021) 174





Next step: take the signal regions developed in the simplified model search into a grand pMSSM scan.

No public result at the moment. Similar study from Run 1: arXiv:1508.06608

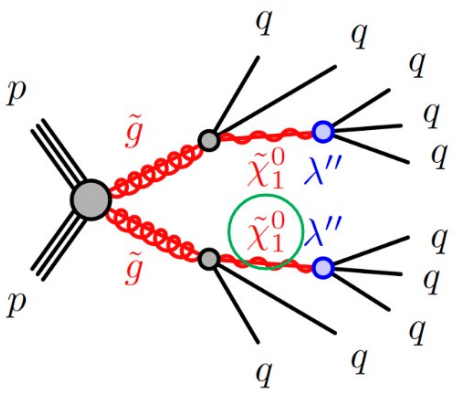
Experimental SUSY 2
R-parity violating SUSY: Displaced vertices in multijet events

F. Backman, S. Richter, D. Milstead (SU)
as part of KTH/SU effort with C. Ohm, A. Leopold, G. Ripellino (KTH)

- DV+ Jets
- Benchmark models: Strong RPV & EWK
- There are no SM interactions that can mimic the signature
- ATLAS paper in preparation

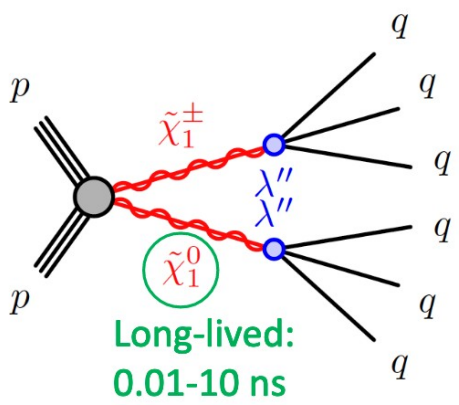
More details in
F. Backman's presentation earlier today,
C. Ohm's presentation earlier today,
G. Ripellino's PhD thesis.

Strong RPV



$m_{\tilde{g}} = 1.6$ - 2.6 TeV
$m_{\tilde{\chi}} = 50$ - 2450 GeV

EWK RPV



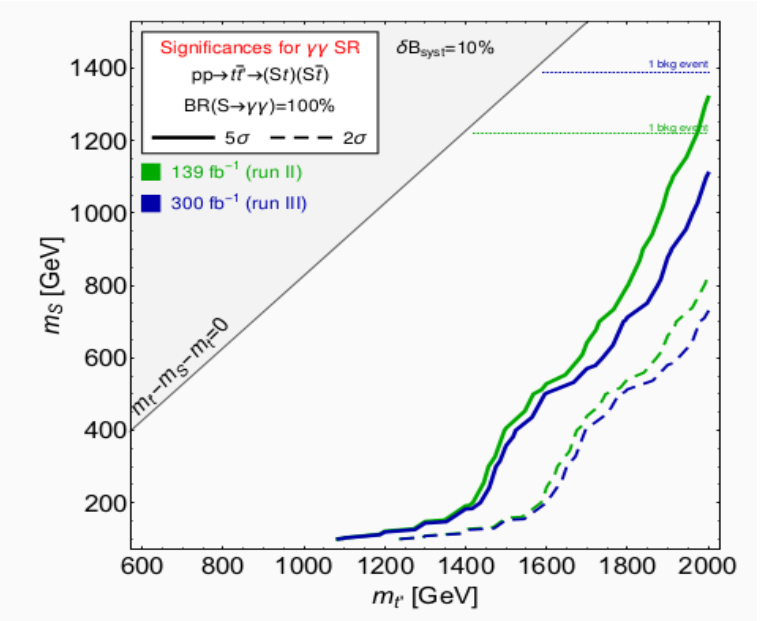
$m_{\tilde{\chi}} = 100$ - 1700 GeV

Composite Higgs: Experimental searches

SHIFT participants: E. Bergeås Kuutmann, V. Ellajosyula, T. Mathisen, L. Panizzi (STA)

ATLAS and CMS have searched for VLQs, but *only decaying into SM particles.*

- In compositeness (and other BSM theories), we get pNGBs as scalars *S*, which **can occur in the decay chain**
- If so, the stated limits could be *wrong*!
- Phenomenological study for prospects in Run 2 and Run 3 evaluated in **JHEP05(2020)028 (1907.05929),** a SHIFT phenomenology paper



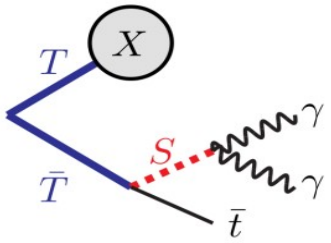
Plots from JHEP05(2020)028

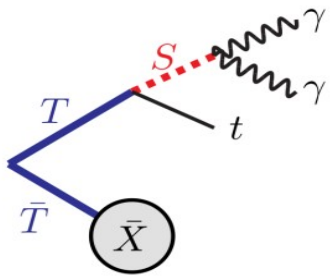
Search for pairs of top-like VLQ (T)

$T\bar{T} \rightarrow St + X\,, \quad S \rightarrow \gamma\gamma$

Decay signature: 2 photons, one *b*-jet + lots of energy.

The only VLQ -> BSM analysis in ATLAS!



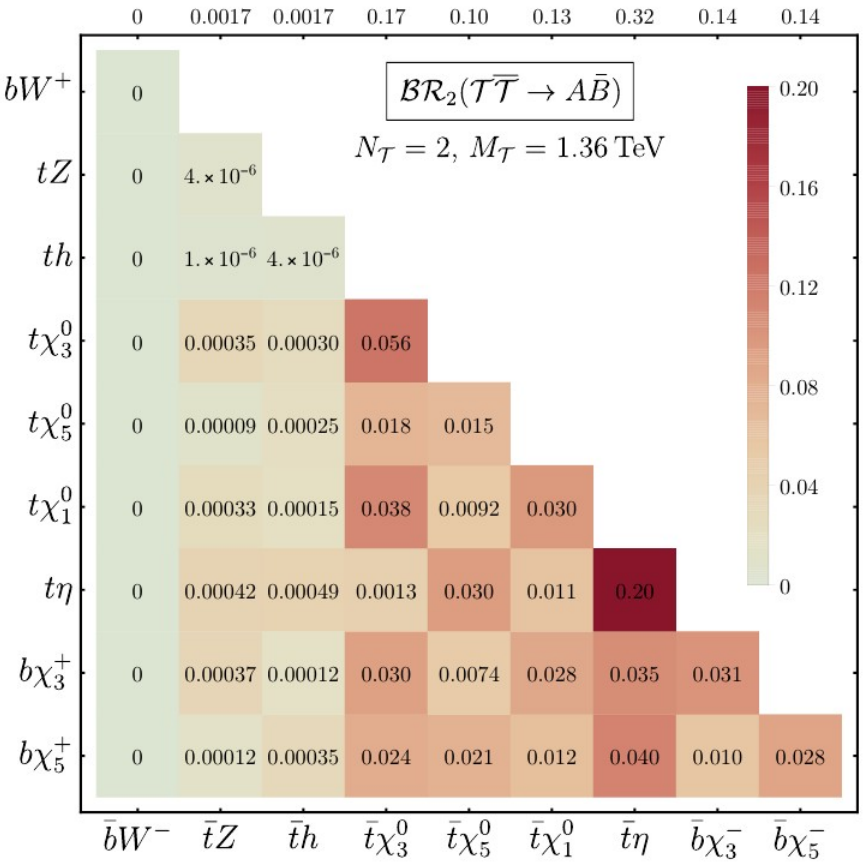


Vector-like quarks in composite Higgs models

arXiv: 2202.00037 A Banerjee, D B Franzosi, G Ferretti

VLQs in SU(5)/SO(5) model can have significant BRs to the new scalars and 3rd gen quark, compared to the SM channels.
Amongst the most promising signatures at the LHC are final states containing a diphoton resonance along with a top quark.

Systematic construction of the general low energy Lagrangian to study the phenomenology of VLQs and pNGBs.
Emphasis on the **specific pattern in the VLQ spectrum** arising in this class of models, especially focusing on the **presence of nearly degenerate states.**



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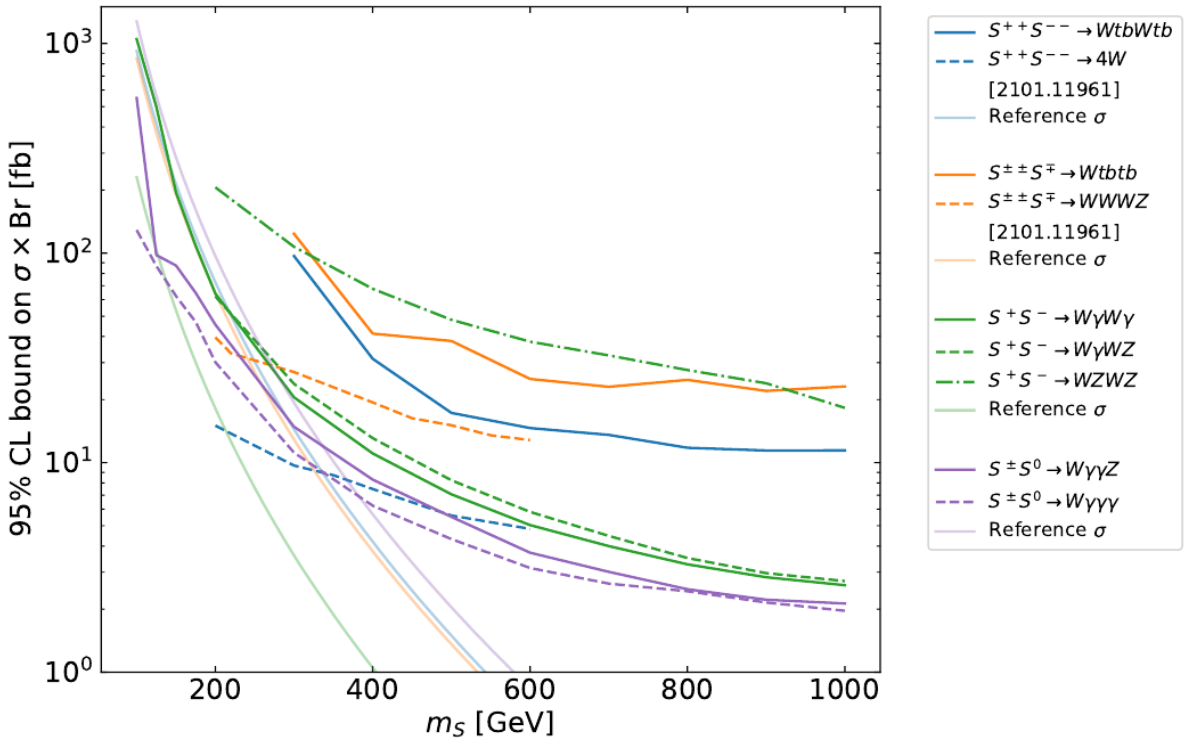
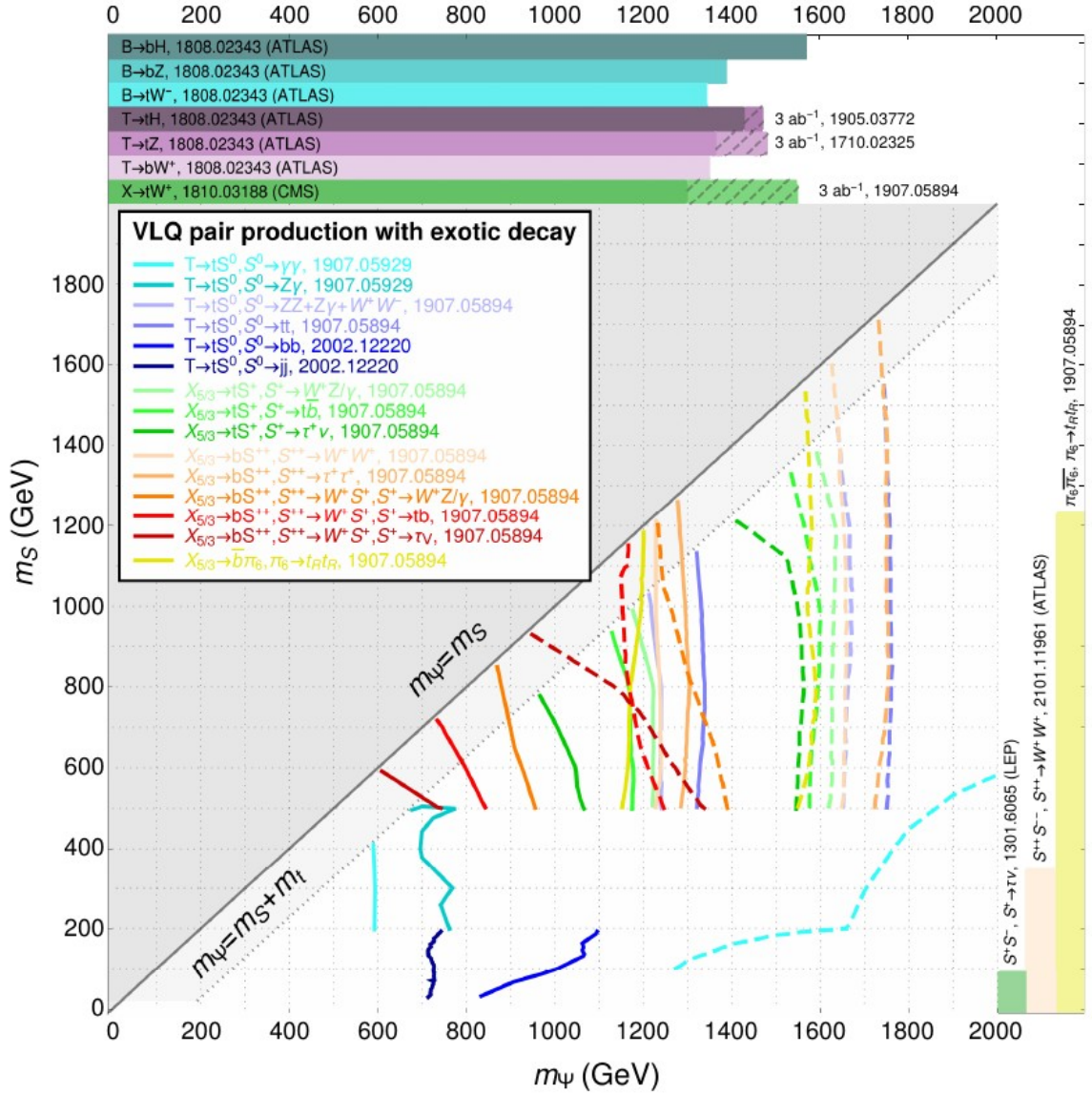
Compositeness phenomenology 2: Snowmass contribution

arXiv: 2203.07270 SHIFT contribution: A Banerjee, D B Franzosi, G Ferretti, L Panizzi

Summary plots of exclusion limits for pNGBs and VLQs using currently available information.

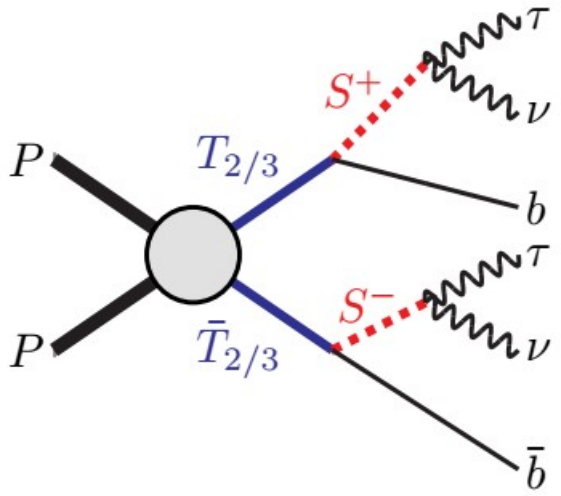
Also describes a general parametrisation implemented in a software for Monte Carlo simulations and study the **SU(5) / SO(5) scenario** as a concrete example.





Compositeness phenomenology 3: Vector-like tops decaying to S^+b

R. Benbrik, EBK, V. Ellajosyula, S. Moretti, L. Panizzi, S. Johansson Nyberg

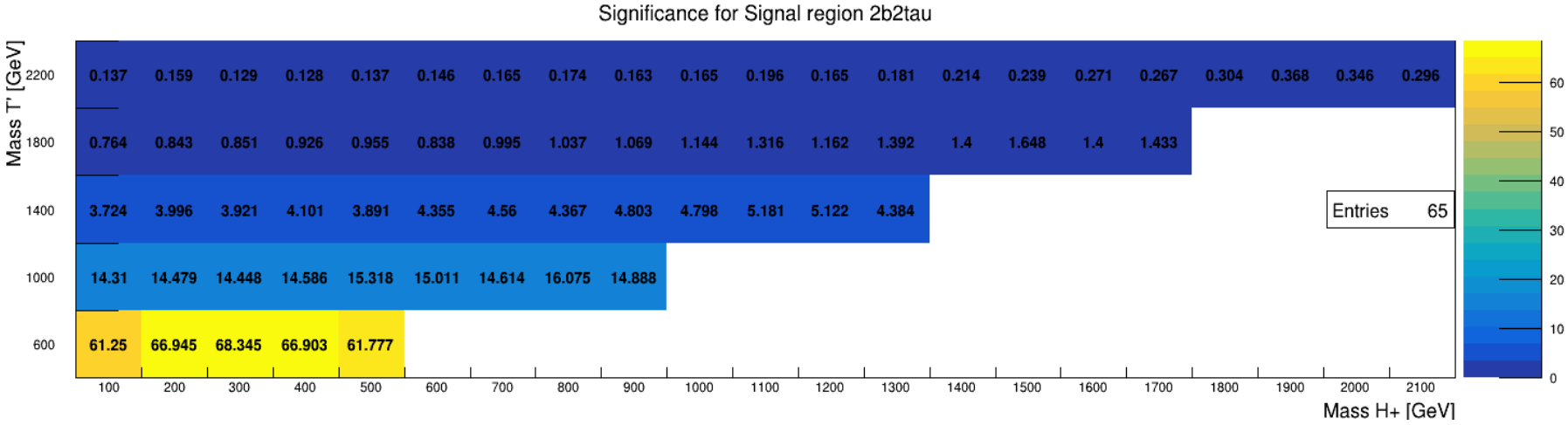


Previous pheno study to estimate sensitivity for $T \rightarrow S^0t$ (**JHEP05(2020)028 (1907.05929),** the SHIFT phenomenology paper)

Newer possibilities include $T \rightarrow S^+b$

T as a part of a doublet (T B) in models such as 2HDM+VLQ gives significant branching into S^+b, and S^+ can further decay into $\tau\nu$

Pheno analysis performed by MSc student, Simon Johansson Nyberg



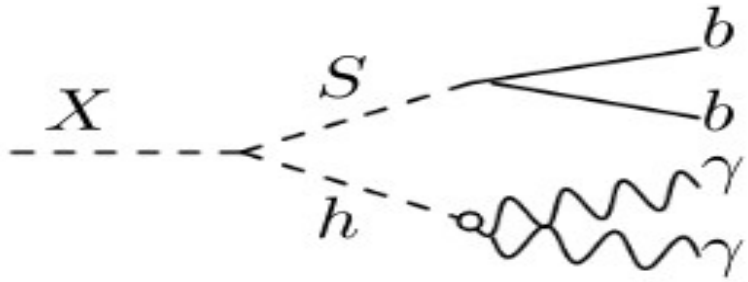
Search for signature of an extended Higgs sector

Y. Andrean, C. Clement, L. Pereira, S. Strandberg

The extension gives out multiple extra scalar particles.
Here focus on asymmetric decay of X->SH
where X (S) is a heavier (lighter) scalar.

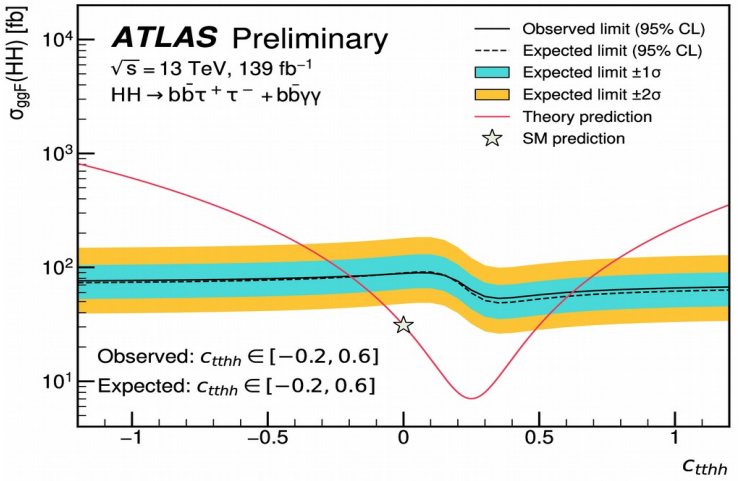
First in ATLAS for search of this model.

See talk by Y. Andrean earlier today, link.



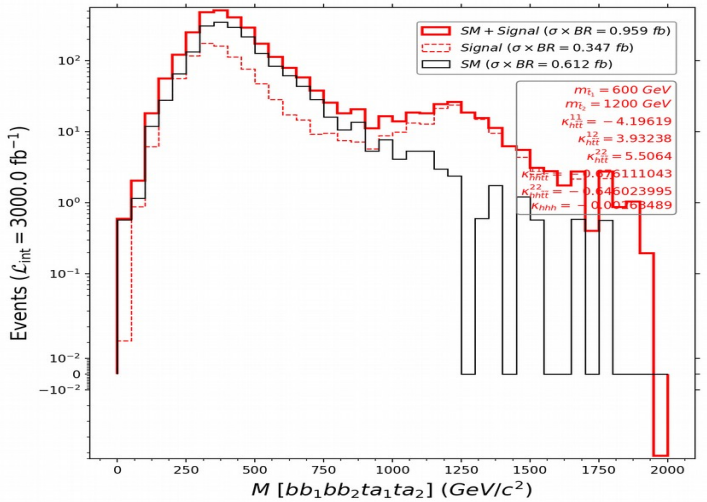
Di-Higgs EFT & top partner models

T. Carlson, L. Pereira, J. Sjölin, S. Strandberg:
Effective field theory interpretations of HH events in the ATLAS detector using event reweighting.
Includes combination of decay channels.
For examples of public results see e.g. ATL-PHYS-PUB-2022-019
(also C. Dimitriadi, A. Ferrari, S. Ördek (UU))
See C. Dimitriadi's presentation earlier today.



HH decay to bb$\tau\tau$

S. Moretti, L. Panizzi, J. Sjölin, H. Waltari: **Simplified top partner models in HH** events at LHC.
The simplified models are matched to UV model benchmark points.
MSSM. Right-handed stop at 600 GeV, nearly degenerate with the LSP.
Left-handed stop beyond the reach of current experiments - large stop mixing.



Indirect searches

Maybe the top partners exist but are beyond the reach of the LHC

Electroweak phase transition in the SMEFT

E. Camargo-Molina, R. Enberg, J. Löfgren

See separate talk by R. Enberg earlier today.

The aim is to connect electroweak symmetry breaking and the Higgs sector to early-universe cosmology and ultimately to Higgs pair production and gravitational waves.

J. High Energ. Phys. 2021, 127 (2021)

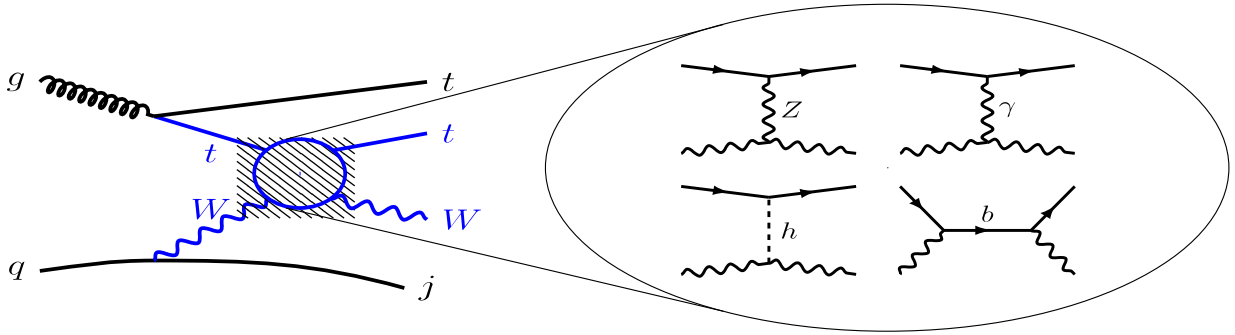
A new perspective on the electroweak phase transition in the Standard Model Effective Field Theory

José Eliel Camargo-Molina ✉, Rikard Enberg & Johan Löfgren

Journal of High Energy Physics **2021**, Article number: 127 (2021) | Cite this article

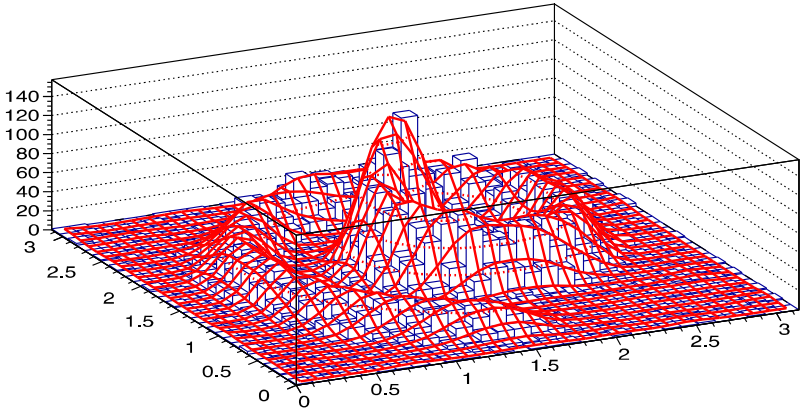
Indirect searches (cont.)

L. Barranco Navarro, D. Kim, J. Sjölin:
Constraining top-Z couplings in ttWj events.
The ttWj channel provides constraints to break degeneracies among top-Z related EFT operators derived from direct ttZ measurements.
Blinded data analysis Nabila Ahlgren's PhD thesis (2020), unblinding of the data on-going.
Analysis inspired by arXiv:1511.03674.



K. Gellerstedt, J. Sjölin:
Use of **Fourier methods** for **estimating continiuous probability densities** to analyze **events in higher dimensions**.

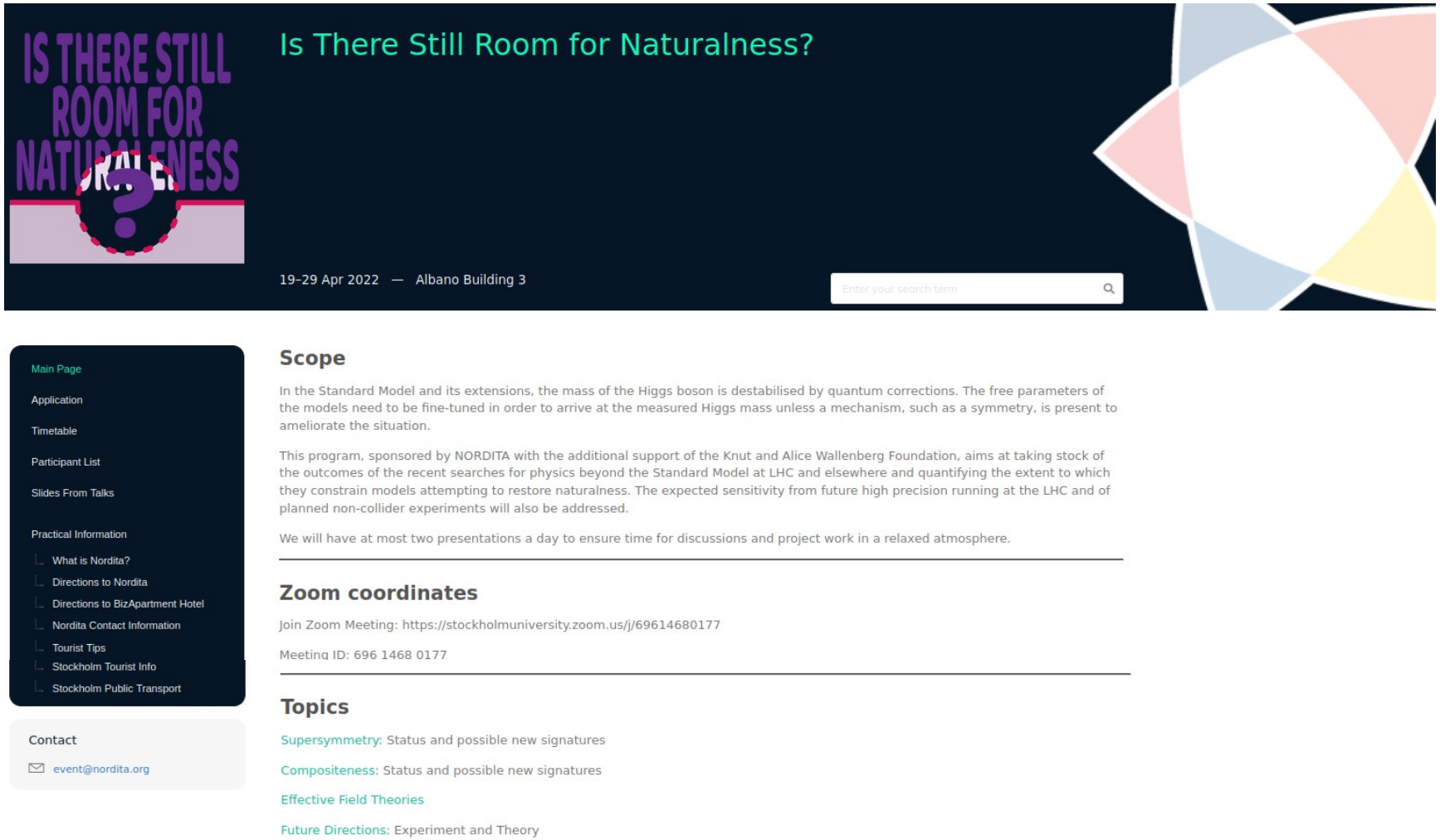
See arXiv:2202.13801 for more information.



The NORDITA workshop nordita.org/events/naturalness2022

Orignially planned for April 2020
.... but Covid
then April 2021 ... but Covid
then October 2021 ... but Covid
then April 2022 ... and we could meet!

2 weeks, 2 talks per day, rest of the time was discussion time.
Theorists and experimentalists met.
Is There Still Room for Naturalness?
Yes



The NORDITA workshop

Scientific talks:

E. Camargo-Molina: The EWPT and musings about the scale of new physics

J. Wells: Unnatural theories and their untenable conspiracies of numbers

C. Hays: The CDF W mass measurement

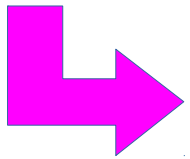
A. Juste: Probing the composite nature of the Higgs boson at the LHC

B. Liu: Non-natural signatures in the pursuit of naturalness

S. Cooperstein: Rare Higgs Boson Decays and Searches for BSM Signatures within the Higgs Sector

S. Moretti: A Composite 2HDM

N. Craig: 22 Solutions to the Hierarchy Problem



Only 19 left

C. Vázquez Sierra: Looking forward to Naturalness: results and prospects for low-mass searches in the forward region at the LHC

S. Bruggisser: An Answer from the SMEFT

W. Porod: LHC bounds on composite Higgs models, implications for naturalness

G. Dvali: Naturalness and new physics

R. Torre: The legacy of HL-LHC for the high energy precision program

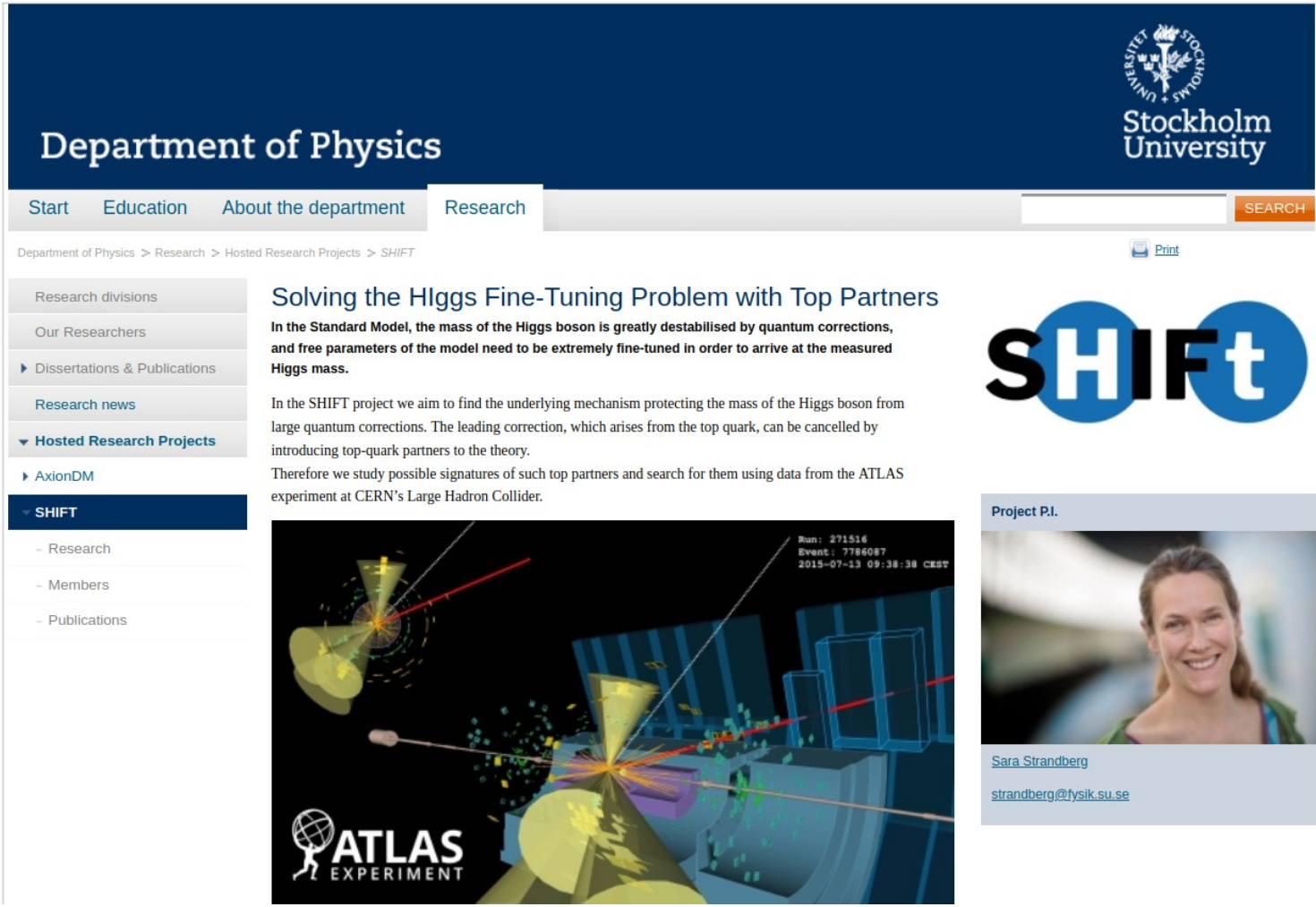
K. Agashe: Collider Physics Opportunities of Extended Warped Extra-dimensional Models

A. Banerjee: Chasing the Higgs shape at LHC

A. Wulzer: Muon colliders

Summary and prospects

Project ends 30 June 2023 (prolonged 6 months b/c Covid)
Many articles in the pipeline, lots of new results and insights
Even after this project, we are not done with compositeness, SUSY and indirect searches at the LHC
Di-Higgs studies another path



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