Testable SUSY spectra from GUTs at the FCC-hh

Stefan Antusch

University of Basel
Department of Physics

UNI
BASEL

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

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We will discuss an example where a GUT scenario predicts a SUSY spectrum which may be fully testable at the FCC-hh

We will go through the general arguments behind this result and discuss how it may generalize to other GUT models

S. A., C. Sluka, (arXiv:1512.06727; arXiv:1604.00212)

Content

- ➢ Supersymmetry (SUSY): motivation; future discovery reach

- ➢ Predictive GUT models for quark-lepton mass ratios

- ➢ SUSY threshold corrections: the link between GUTs and the SUSY spectrum

- ➢ Results of a recent analysis; general arguments

SUSY

Attractive features include:

➢ Ameliorates/solves hierarchy problem

➢ SUSY changes RG running ➔ Simple schemes of gauge coupling unification (GUTs) ➔ GUTs compatible with proton decay
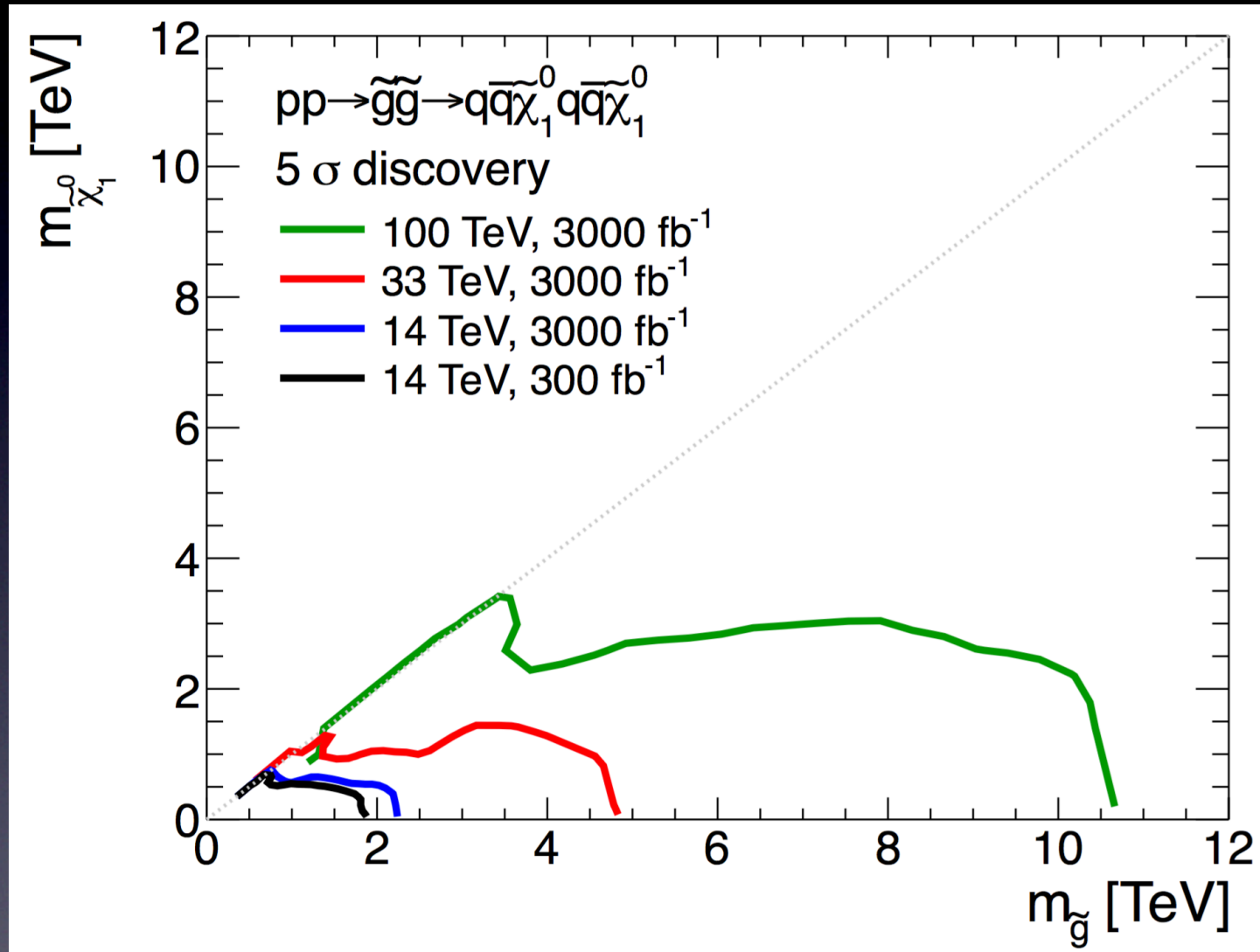
However:

➢ SUSY has to be broken (mass of SUSY particles free parameter)

➢ No signs of SUSY found so far ...

Great reach at a 100 TeV pp collider:

➢ <u>SUSY spectra can be probed up to O(10 TeV)!</u>

See e.g.: arXiv:1311.6480, arXiv:1406.4512, arXiv:1506.02644

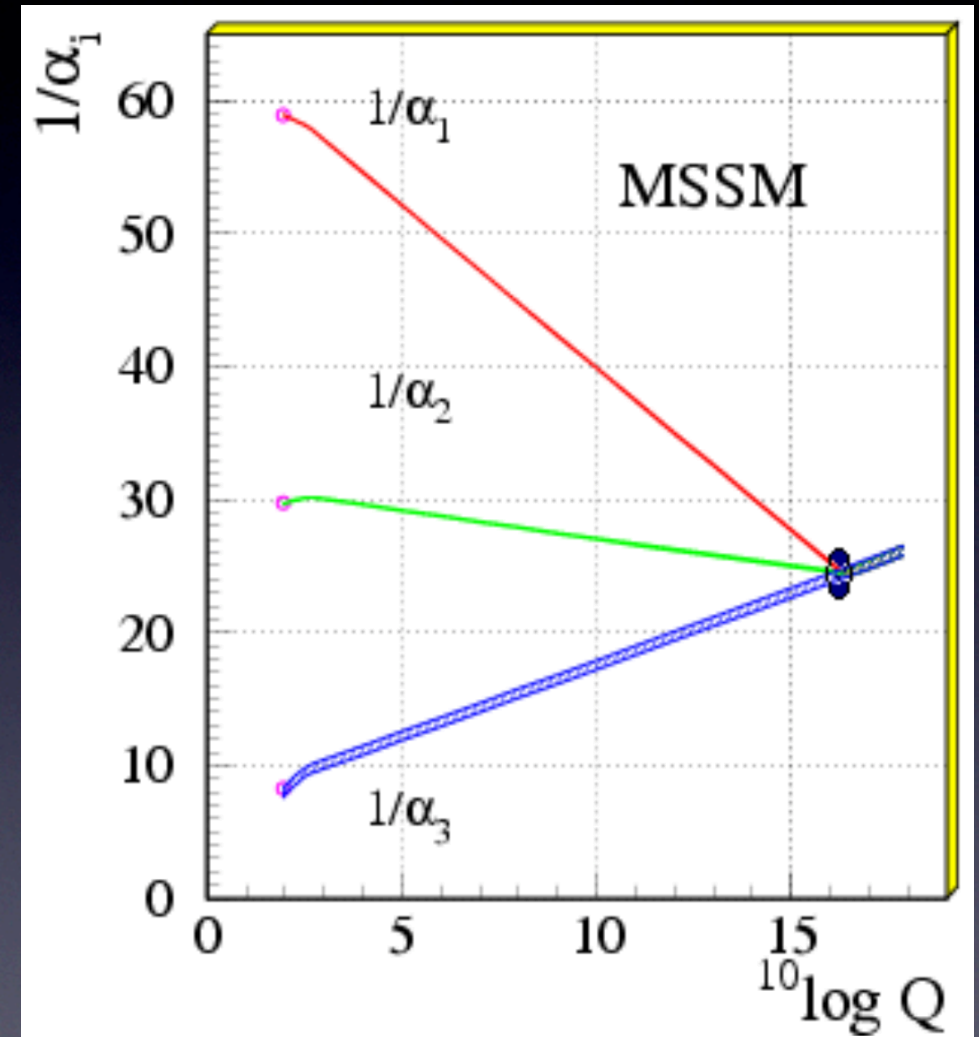Stefan Antusch   University of Basel & MPI for Physics (Munich)

Example: Gluino discovery reach

From: Cohen, Golling, Hance, Henrichs, Howe, Loyal, Padhi, Wacker (arXiv:1311.6480)

Grand Unified Theories (GUTs)

➢ Unification of the three forces of the Standard Model
(➜ Gauge coupling unification)

➢ Unification of quarks and leptons in joint multiplets at high energy

... two consequences

→ 1) Predictions for the quark-lepton Yukawa coupling ratios

Examples (in SU(5) GUTs):

$$y_{33} \; \bar{\mathbf{5}}_3 \, \mathbf{10}_3 \, \langle \bar{H}_5 \rangle \;\; \Rightarrow \;\; \boxed{\left. \frac{m_\tau}{m_b} \right|_{M_{GUT}} = 1}$$

"b-τ unification",
Georgi, Glashow ('74)

$$y_{22} \; \bar{\mathbf{5}}_2 \, \mathbf{10}_2 \, \langle \bar{H}_{45} \rangle \;\; \Rightarrow \;\; \boxed{\left. \frac{m_\mu}{m_s} \right|_{M_{GUT}} = 3}$$

Georgi, Jarlskog ('79)

$$y_{33} \; \bar{\mathbf{5}}_3 \, \frac{\langle H_{24} \rangle}{\Lambda} \, \mathbf{10}_3 \, \langle \bar{H}_5 \rangle \;\; \Rightarrow \;\; \boxed{\left. \frac{m_\tau}{m_b} \right|_{M_{GUT}} = \frac{3}{2}}$$

S. A., Spinrath (arXiv:0902.4644)

Other examples: e.g. $m_\mu / m_s = 9/2$ or 6, $m_e/m_d = \frac{1}{2}$ or $\frac{1}{3}$, ...

cf.: S. A., Spinrath (arXiv:0902.4644); S. A., King, Spinrath (arXiv:1311.0877)

... two consequences

➜ 2) Constraints on the boundary conditions for the soft breaking parameters at M_{GUT}: e.g. only one m^2_{16} in SO(10), m^2_5 and m^2_{10} in SU(5); flavour symmetries often imply (partial) flavour universality!

... two consequences

➜ 2) <u>Constraints on the boundary conditions for the soft breaking parameters at M_{GUT}</u>: e.g. only one m^2_{16} in SO(10), m^2_5 and m^2_{10} in SU(5); flavour symmetries often imply (partial) flavour universality!

In our discussion, we will assume that the GUT scenario predicts quark lepton mass ratios at M_{GUT} for all three generations.

We will also assume that the soft SUSY parameters at M_{GUT} are CMSSM(-like).

RG running and SUSY loop threshold corrections: Link to the SUSY spectrum

➢ Procedure: RG running from high to low energies

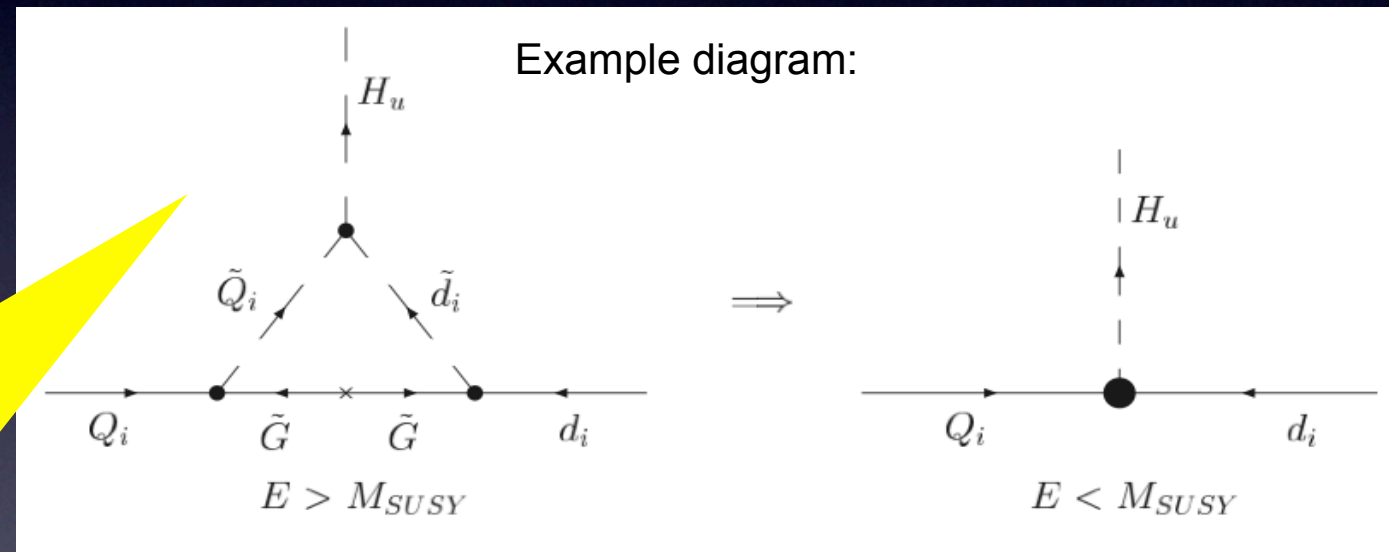| GUT scale $(M_{GUT} \sim 10^{16}$ GeV)	➤	SUSY scale (sparticle masses)	➤	Exp. Data $(E \sim O(v_{EW}))$

RG running and SUSY loop threshold corrections: Link to the SUSY spectrum

At the SUSY scale:

Hall, Rattazzi, Sarid ('93),
Carena et al ('94), Blazek et al ('95),
S.A., Spinrath ('08); S.A., Sluka, ('15)

SUSY threshold effects at M_{SUSY} <u>depend on the SUSY parameters</u>, i.e. on the spectrum, tan β, …. and can strongly affect the low scale results for the quark and lepton masses!

Example diagram:

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Example GUT scenario

➢ We consider GUT models which feature the following quark-lepton mass relations at M_{GUT}, m_τ/m_b,$= 3/2$, $m_\mu/m_s = 6$, $m_e/m_d = \frac{1}{2}$,

as well as CMSSM boundary conditions for the soft SUSY breaking parameters (i.e. parameters are then m_0, $m_{1/2}$, A_0 and tan β).

Model examples: see Refs given in arXiv:1512.06727

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Analysis

➢ RG running and SUSY loop threshold corrections with *REAP* extension *SusyTC*

REAP: S. A., Kersten, Lindner, Ratz, Schmidt (hep-ph/0501272)
SusyTC: S.A., C. Sluka (1512.06727)

➢ Calculation of m_h at 2-loop performed with *FeynHiggs 2.11.2*

FeynHiggs: Heinemeyer, Hahn, Rzehak, Weiglein, Hollik

➢ Vacua metastable, lifetime constraints checked

➢ ...

For more details: S. A., C. Sluka, (arXiv:1512.06727)

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Results of MC Monte Carlo analysis: CMSSM parameters

S. A., C. Sluka,
arXiv:1512.06727
arXiv:1604.00212

1σ HPD intervals

Fixed tan β = 30
(optimal value), μ>0

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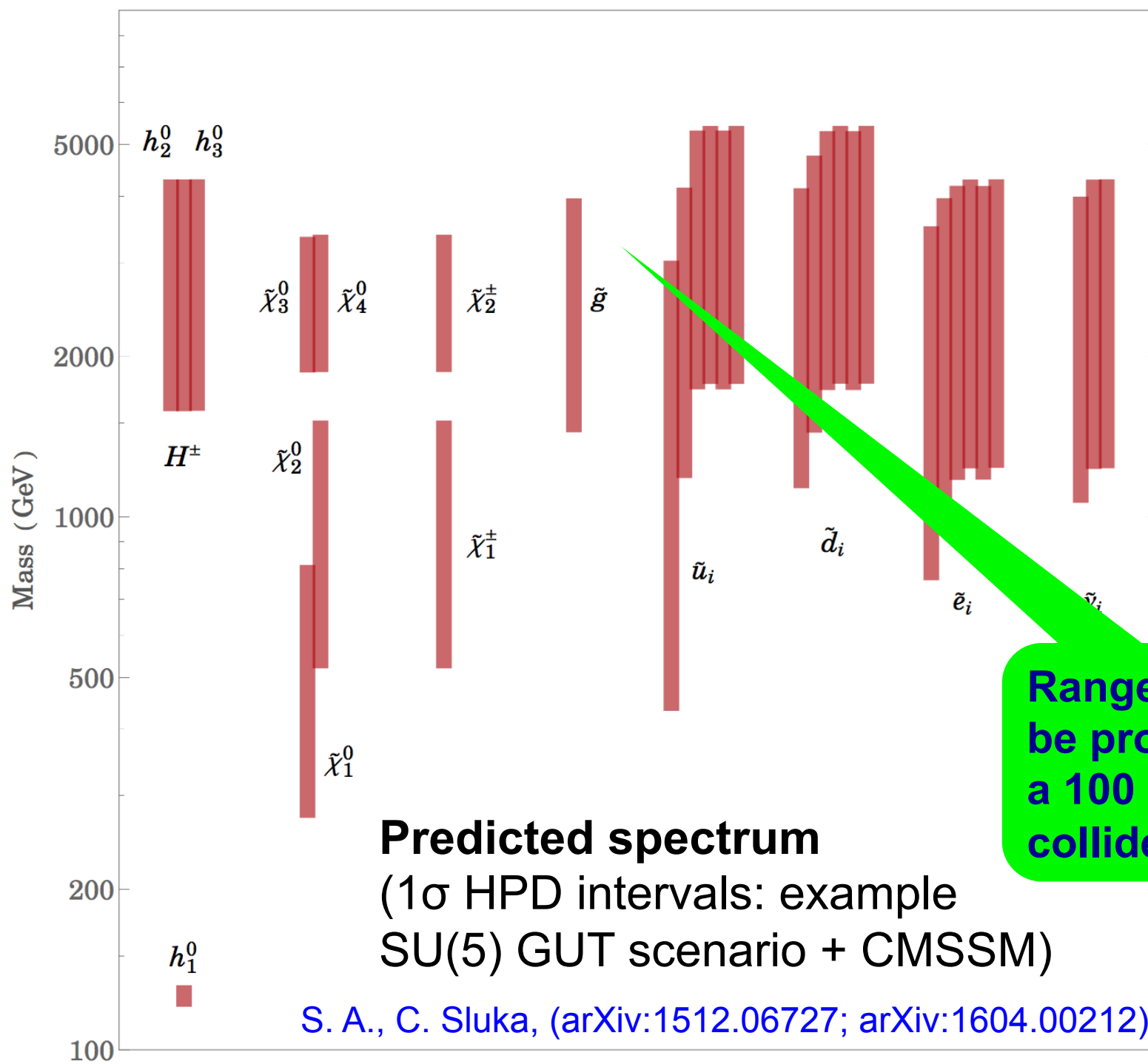
Note: No contraints from present SUSY searches applied. Sparticles out of LHC run 1 reach is a result!

Range can be probed at a 100 TeV pp collider

Predicted spectrum
(1σ HPD intervals: example SU(5) GUT scenario + CMSSM)

S. A., C. Sluka, (arXiv:1512.06727; arXiv:1604.00212)

General argument: SUSY spectra from predictive GUTs

➢ GUT predictions for quark-lepton mass ratios require some amount of SUSY loop threshold corrections for each generation.

This implies that SUSY spectrum cannot be "too split". More specifically, the <u>ratios</u> of trilinear couplings, gaugino masses, μ and sfermion masses get constrained. Also tan β cannot be too small.

In a CMSSM-like scenario ➜ ratios between m_0, $m_{1/2}$ and A_0 are constrained

➢ With the above-described constraints, obtaining the measured value of the mass m_h of the SM-like Higgs fixes the overall SUSY scale!

The combination of the two effects can result in a predicted sparticle spectrum from GUT models!

S. A., C. Sluka, (arXiv:1512.06727; 1604.00212)

Summary

➢ We discussed how certain classes of predictive GUT models are capable of predicting a SUSY spectrum fully testable at a 100 TeV pp collider, like the FCC-hh.

➢ The predictions for the sparticle spectrum can be understood as follows:

- Predictive GUTs fix the quark lepton mass ratios at high energy (M_{GUT})

- They require SUSY threshold corrections, which imply constraints on the SUSY spectrum

- Adding constraints from m_h, the combined constraints can be powerful enough to predict the sparticle spectrum!

➢ Ongoing: Investigation of other example GUT scenarios

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Thanks for your attention!