European Strategy for Particle Physics

PARALLEL 7 / **BSM**

Symmetries for the Higgs

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On behalf of the PPG BSM WG

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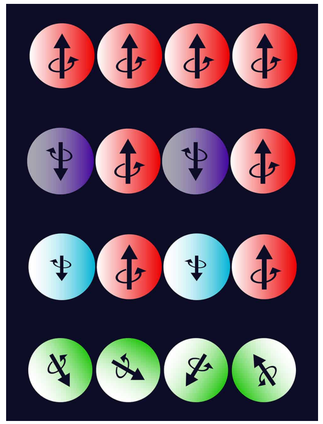
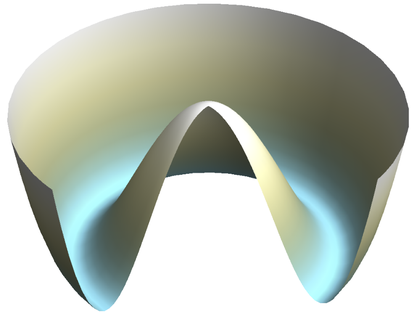
Symmetries for the Higgs

A superconducting analogy

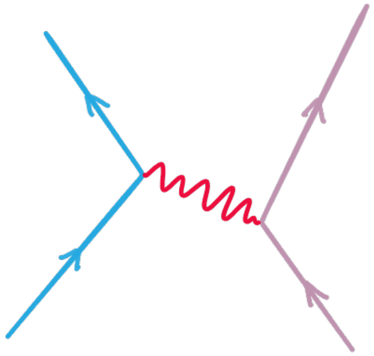
High-Tc Superconductors



Ginzburg-Landau Theory



Low-Tc Superconductors (BCS)



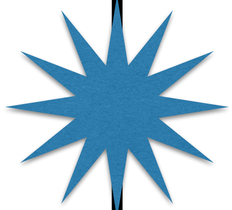
$$F = \alpha|\psi|^2 + \frac{\beta}{2}|\psi|^4 + \frac{1}{2m}|(-i\hbar\vec{\nabla} - g\vec{A})\psi|^2 + \dots$$

What is the BCS theory of electroweak symmetry breaking?

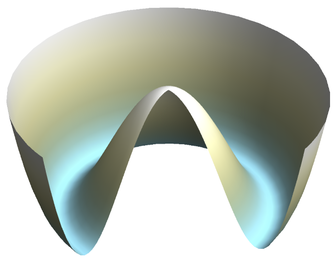
Higgs potential becomes ***calculable*** in symmetry extensions of the Standard Model
(supersymmetry, global symmetry, …)

Symmetries for the Higgs

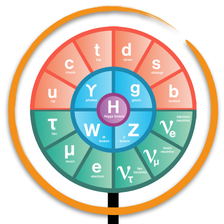
Supersymmetry



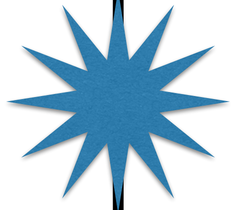
~~Supersymmetry~~
Sparticles m̃



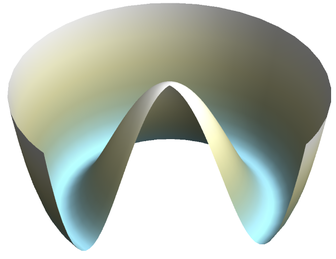
≲4π/G



Global symmetry



~~Global symmetry~~
Partner particles m̃



≲4π/G

Spanning BSM Signal Space

Symmetry extensions of SM are comprehensive signal generators

	γ	ℓ	τ	j	t	W	Z	h	E_T
γ	H,A						H		χ^0_1
ℓ		RPV	RPV	RPV	RPV				$\tilde{\ell}$
τ			H,A	RPV	RPV				$\tilde{\tau}$
j				H,A	RPV				$\tilde{q}$
t					H,A				$\tilde{t}$
W						H		$H^\pm$	$\chi^\pm$
Z							H	A	$\tilde{h}$
h								H	$\tilde{h}$
E_T									h

- *disappearing tracks*
- *R-hadrons*
- *HSCPs*
- *displaced photons*
- *....*

Practicalities

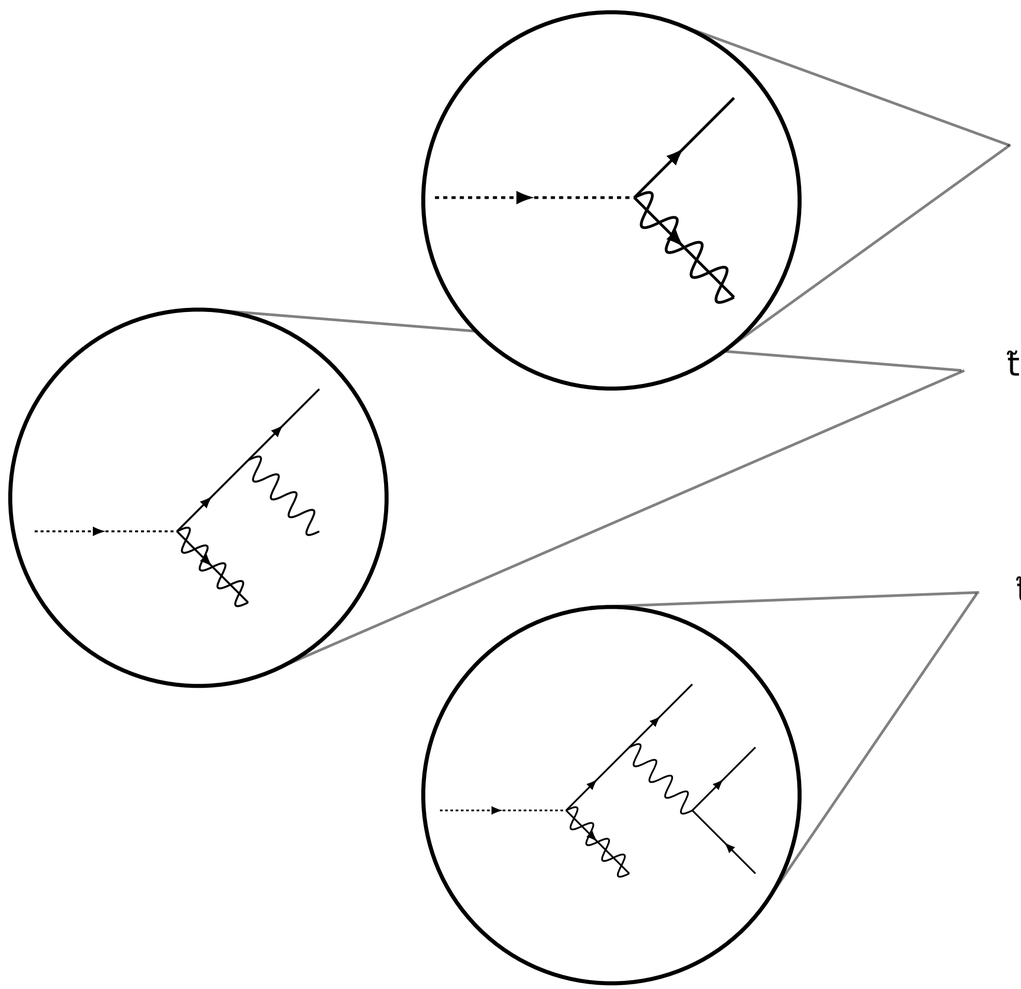
Reconcile vast landscape of possibilities with uniform treatment of experiments.

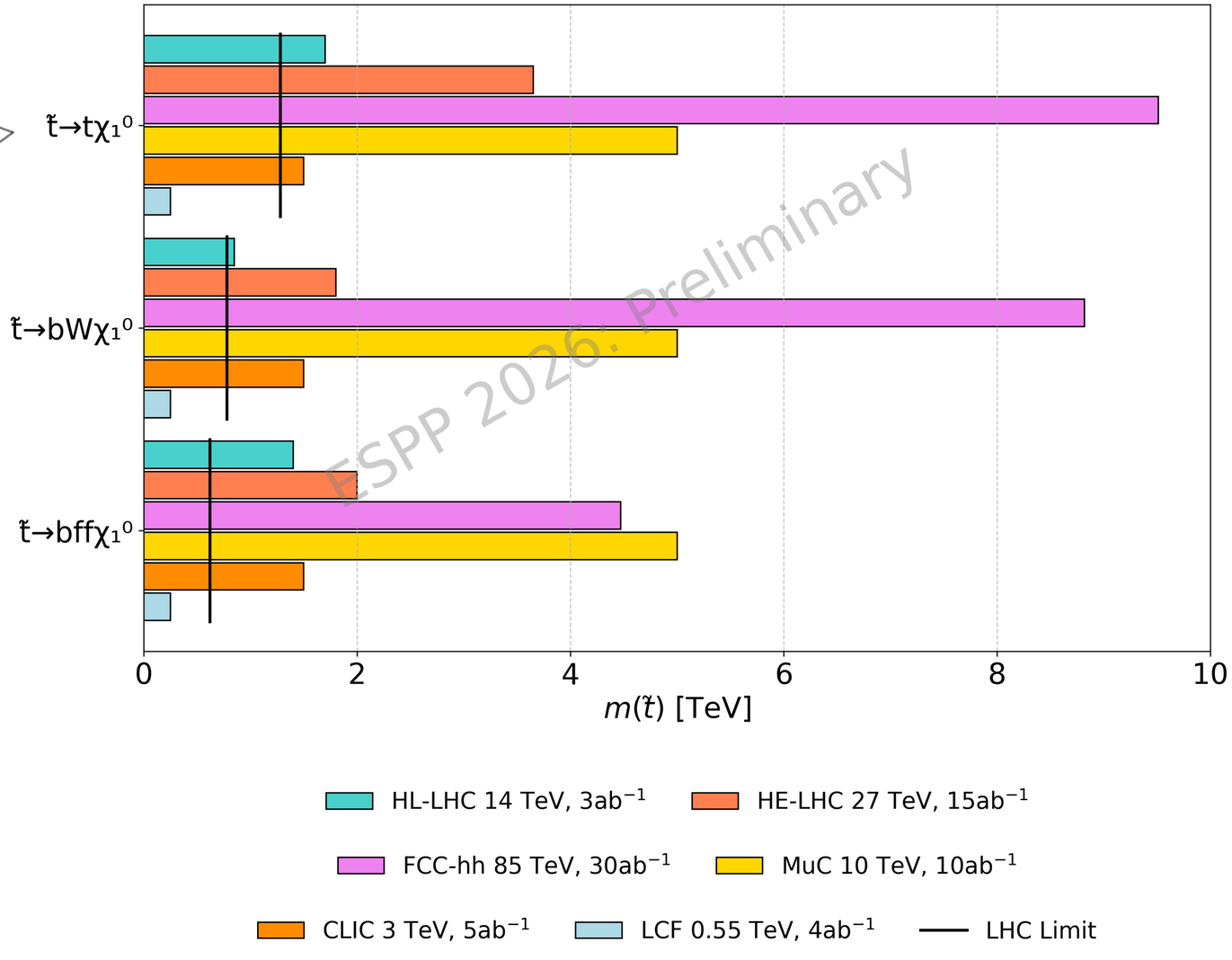
- Starting point: **Snowmass 2021 SUSY projections** [arXiv:2209.13128]
- Mass reach in simplified models for representative splittings
- Update FCC-hh sensitivity using **`collider-reach`**
- Populate missing benchmarks w/ **`collider-reach`** from 13 TeV

Additionally:

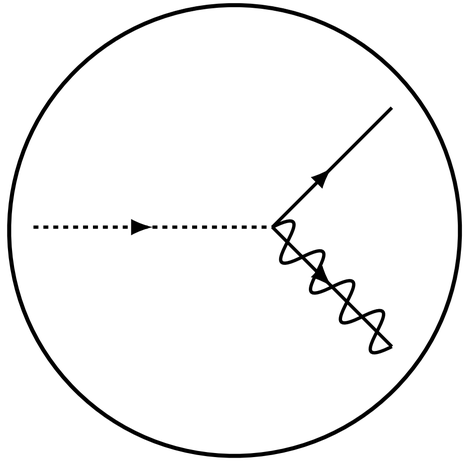
- Top partners in composite/little Higgs.
- Quantification of Higgs mass prediction.

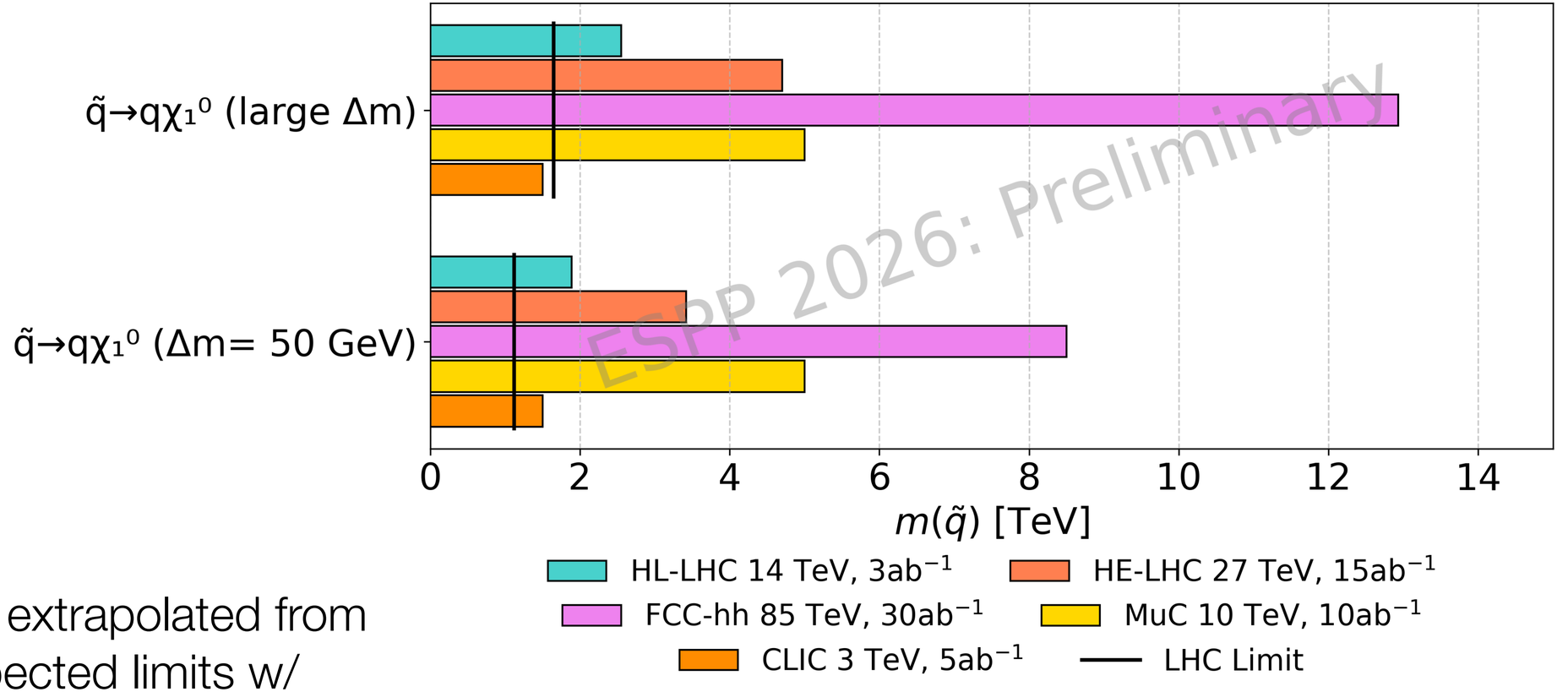
Stop Squarks





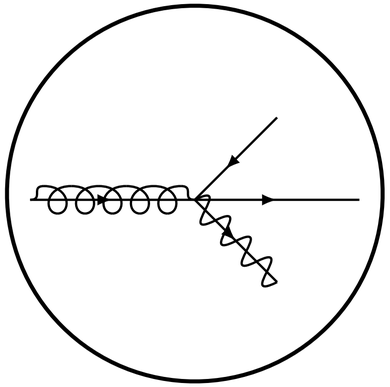
Light-flavor Squarks

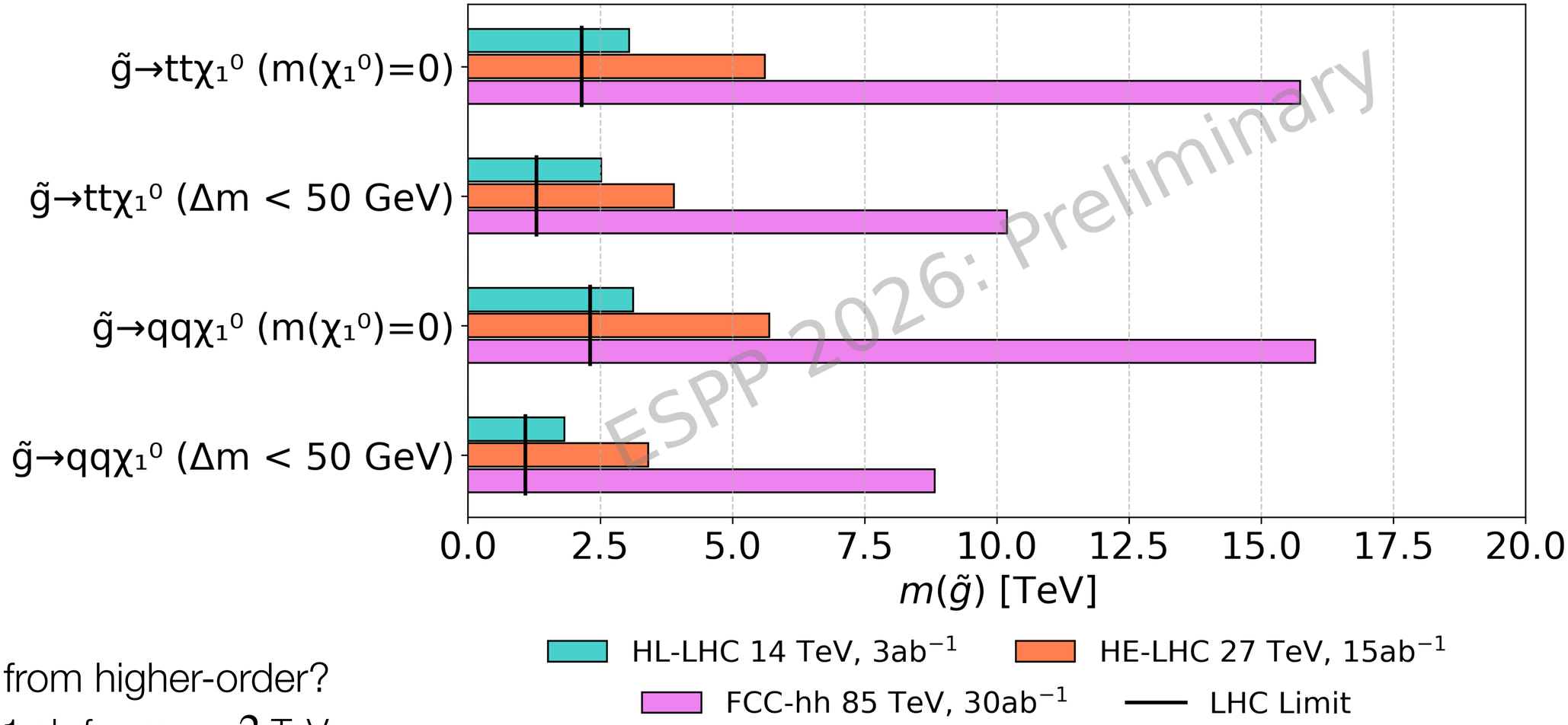




Compressed squarks extrapolated from ATLAS 13 TeV expected limits w/ **`collider-reach`**

Gluinos





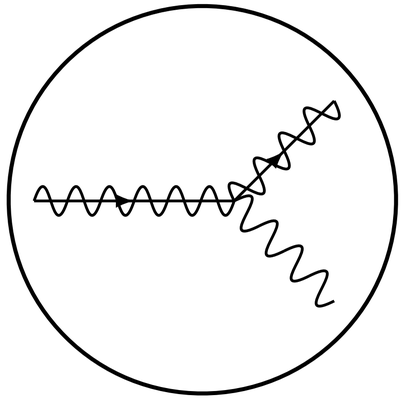
MuC-10 reach from higher-order?
[2502.20443]: 0.1 ab for $m_{\tilde{g}} = 2$ TeV

Wino/Bino

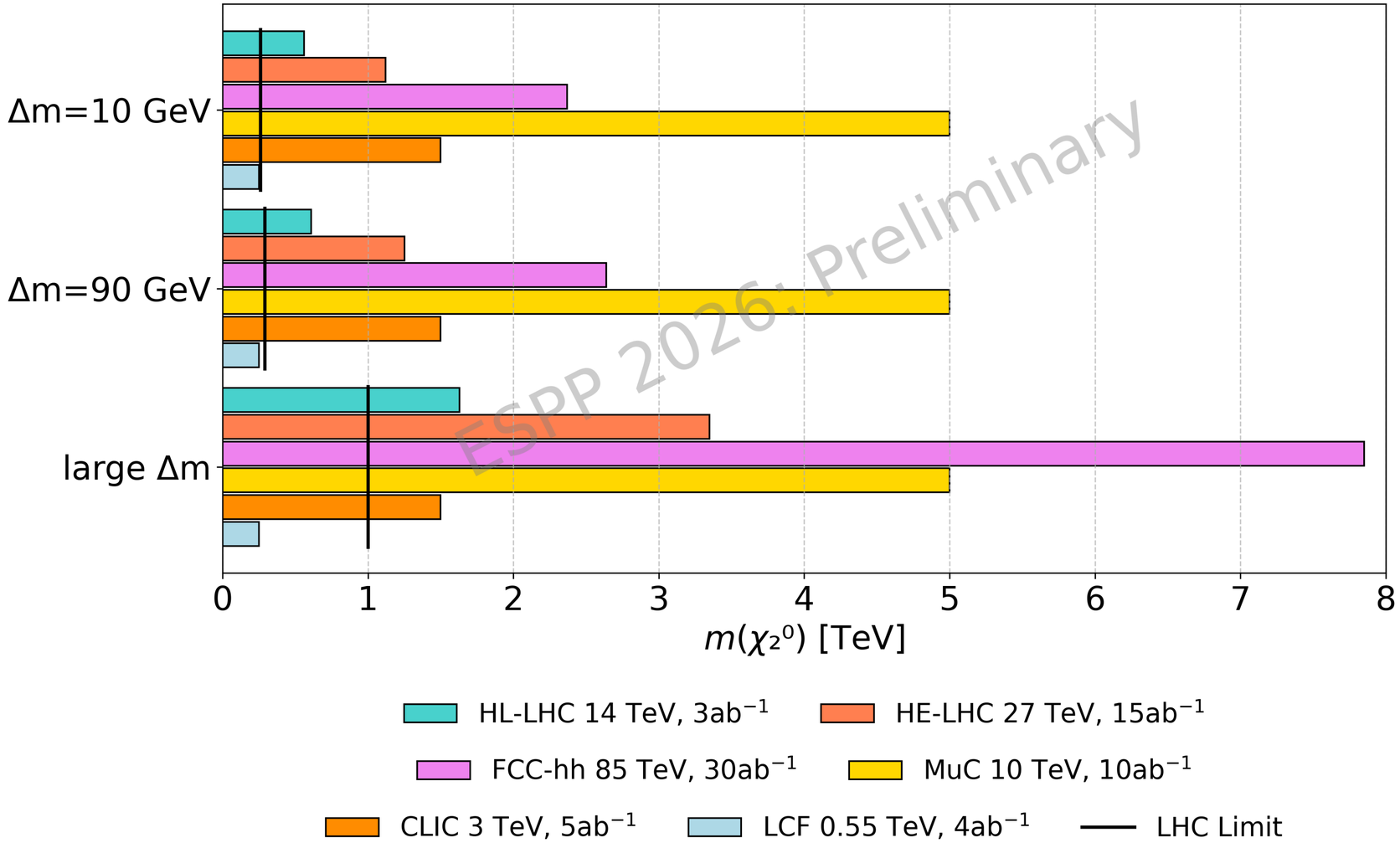
Wino decays to bino LSP

$$\chi_1^{\pm} \to W^{\pm(*)} + \chi_1^0$$

$$\chi_2^0 \to Z^{(*)}/h^{(*)} + \chi_1^0$$



(Pure wino w/ SM splittings DM benchmarks)

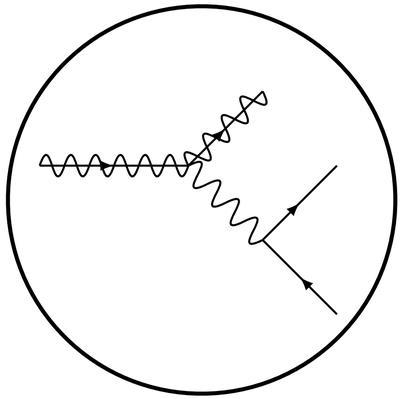


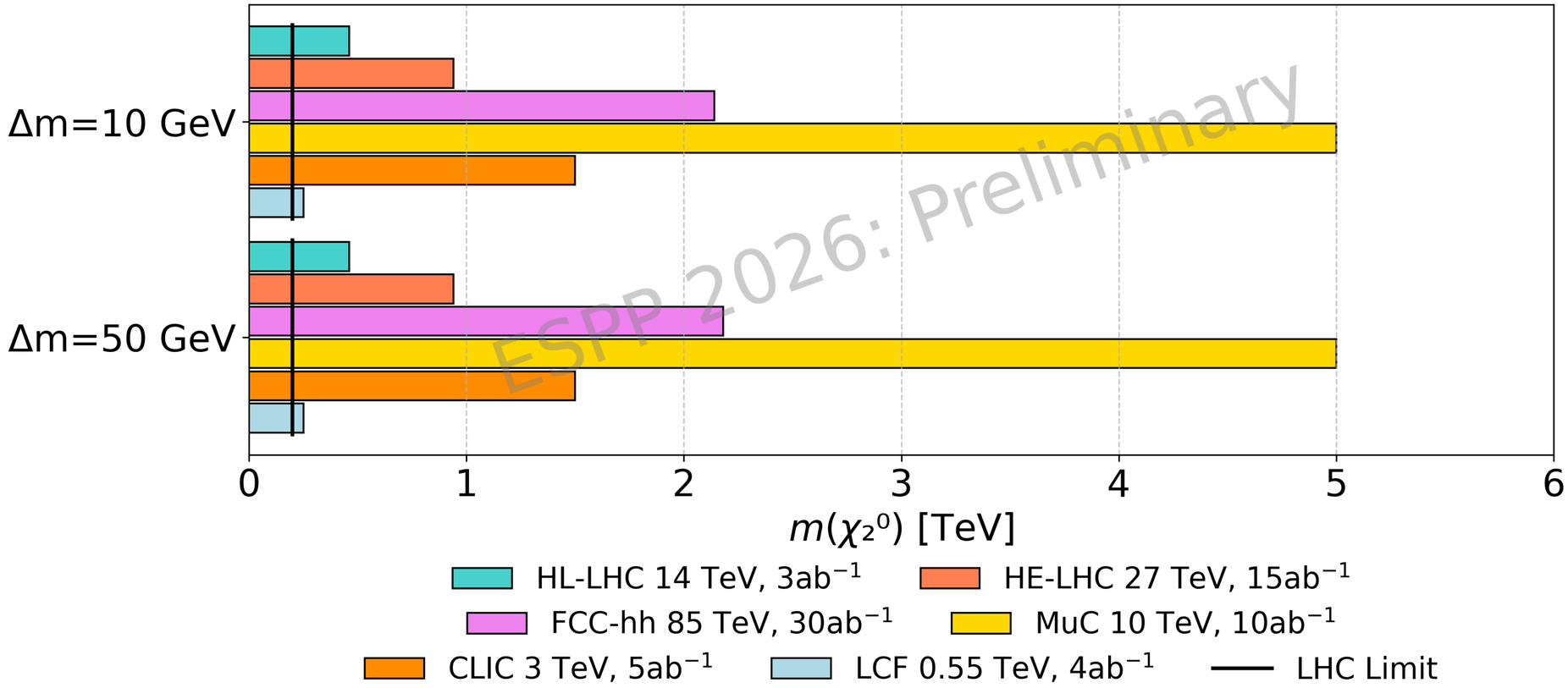
Higgsino

Decays within higgsino multiplet

$$\chi_1^{\pm} \to W^{\pm *} + \chi_1^0$$

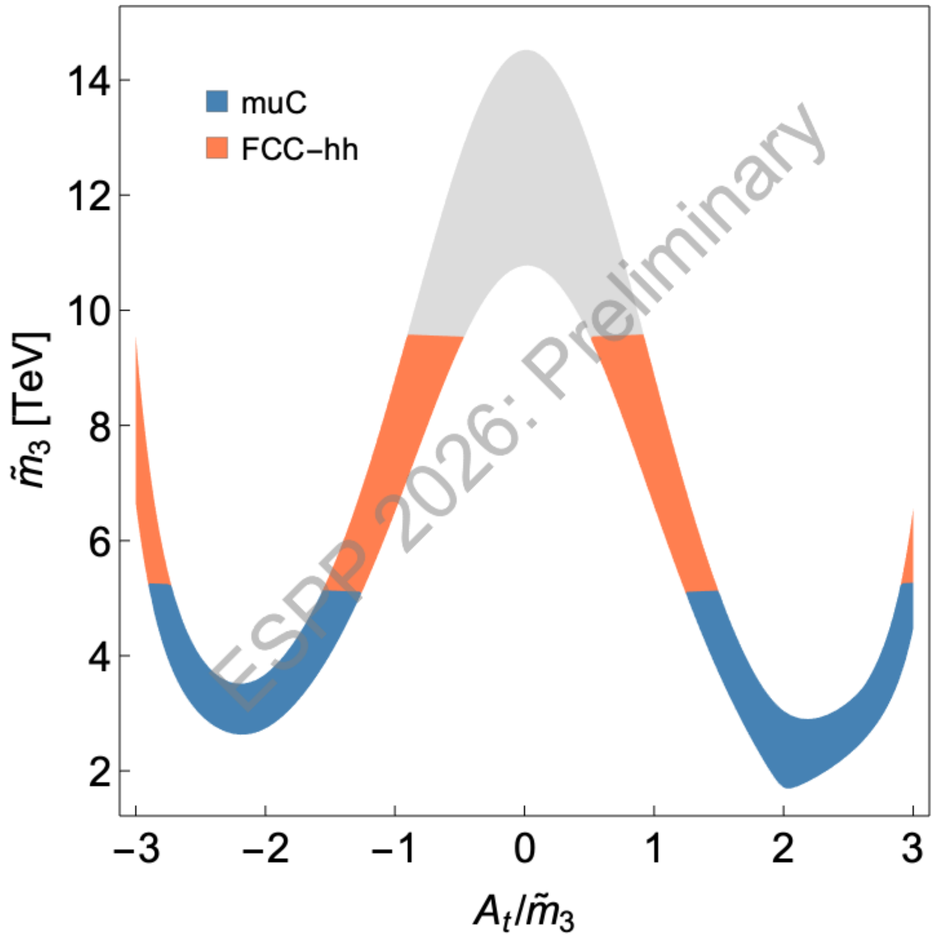
$$\chi_2^0 \to Z^*/h^* + \chi_1^0$$





(Pure higgsino w/ SM splittings in DM benchmarks)

Predicting the Higgs Mass



Measured Higgs mass provides a sharp target for supersymmetry.

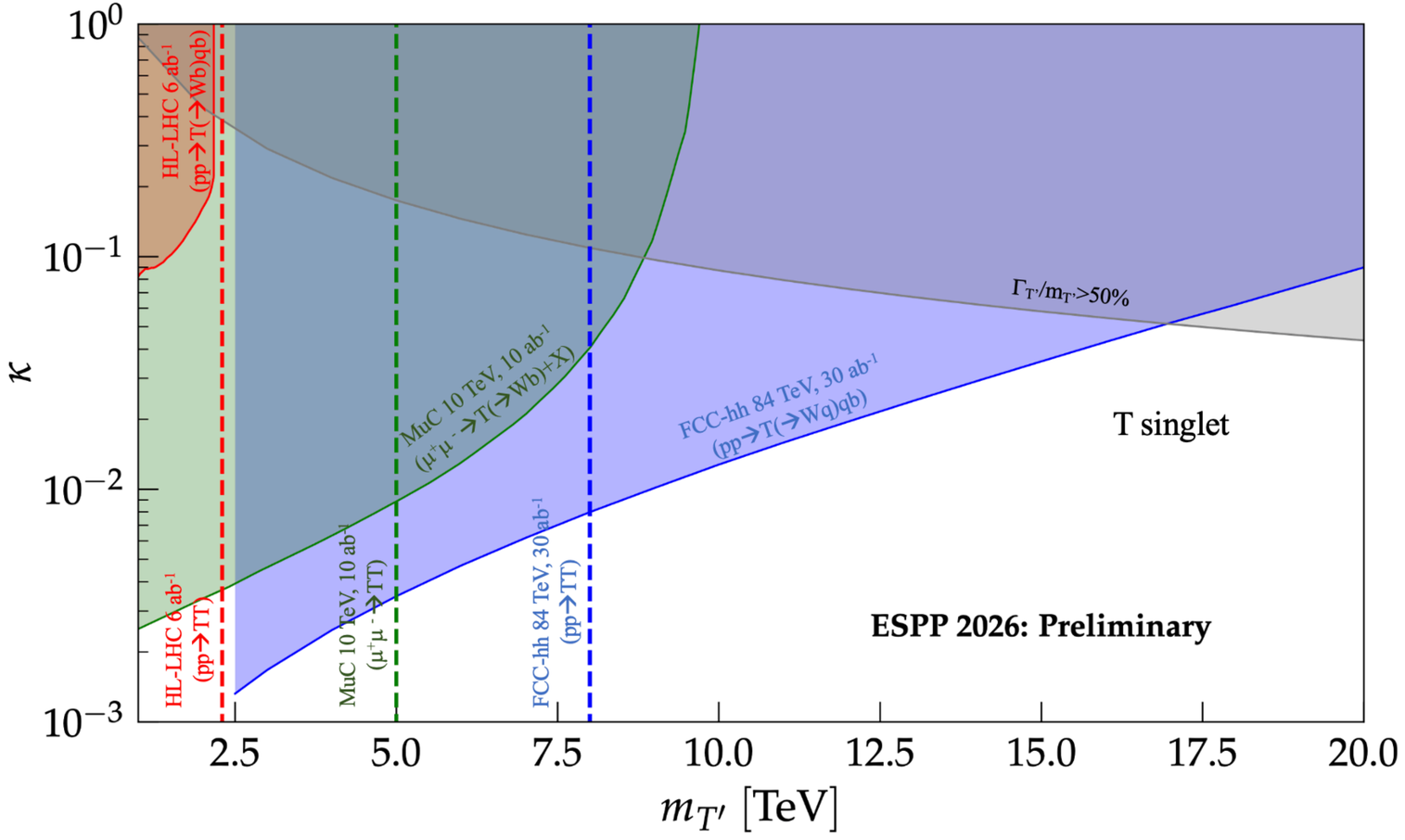
In some tension with natural expectations (i.e. quartic changes logarithmically with stop mass while vev changes quadratically).

Clear target independent of naturalness.

This plot: SUSYHD

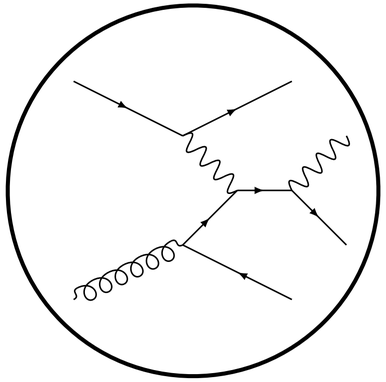
$$m_h = 125\,\text{GeV} \pm \text{SM errors}$$
$$\mu = 1\,\text{TeV}, \tilde{m}_{\text{other}} = 5\,\text{TeV}, \tan\beta = 20$$

Fermionic Top Partners



Light Higgs also favors light top partners in composite models (e.g. [arXiv:1204.6333])

$$m_h \simeq 125\,\mathrm{GeV} \times \left(\frac{m_{T'}}{1.4f}\right)$$



Study SU(2) singlet T' in single & pair production

HL-LHC: single & pair: ATLAS extrapolation

MuC 10: single: [2502.20443]; pair: kinematic threshold

FCC-hh: single: LO MG5 + ATLAS extrapolation; pair: rescale 100 TeV FCC-hh (c.f. 10 TeV from ATLAS extrap).

Width: [2502.20443]

Takeaways & Next Steps

- Dramatic improvement in sensitivity relative to LHC, with expected complementarity of strengths between high-energy hadron and lepton colliders.
- Significant coverage of natural parameter space for EWSB, and meaningful coverage of target provided by by $m_h = 125$ GeV.
- As signal generators for BSM, SUSY coverage indicates a factor of ~10 improvement in mass reach for broad classes of new physics.
- Next steps: Further improvement of fermionic top partner study (esp. FCC-hh), potential coverage of more exotic SUSY scenarios (disappearing tracks, R-hadrons, HSCPs, …) depending on resources.

Grazie mille!