Motivation and Phenomenology of Long-Lived Particles

Nathaniel Craig
UC Santa Barbara

CLIC BSM Searches 02.21.18

Long-Lived Particles

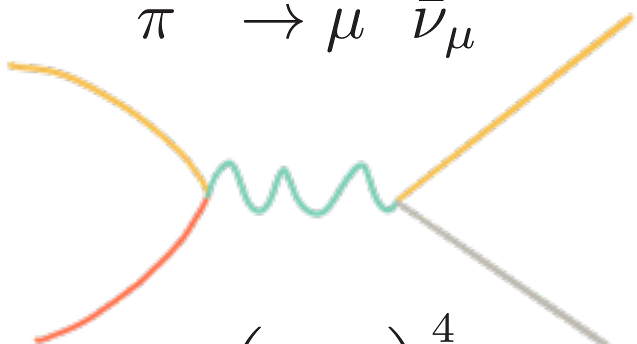
LLPs are generic in SM & BSM

$$\Gamma \sim g^2 \left(\frac{m}{M}\right)^n m$$

E.g. small couplings, hierarchy of scales

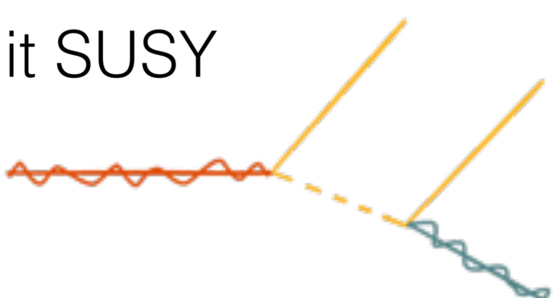
Off-shell decay

$\pi^- \to \mu^- \bar{\nu}_\mu$



$$\sim g^2 \left(\frac{m}{m_W}\right)^4 m$$

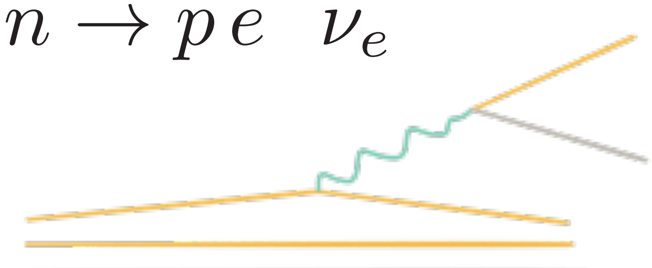
Split SUSY



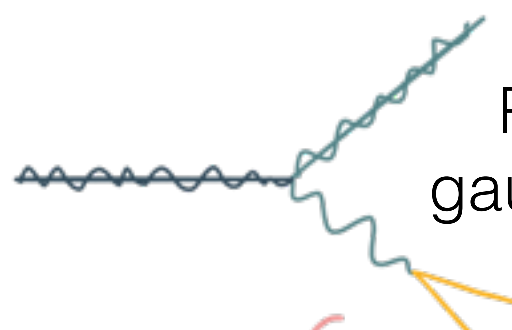
Hidden Valley

Small splitting

$n \to p\, e^- \nu_e$



$$\sim g^2 \left(\frac{m_n - m_p}{m_W}\right)^4 (m_n - m_p)$$

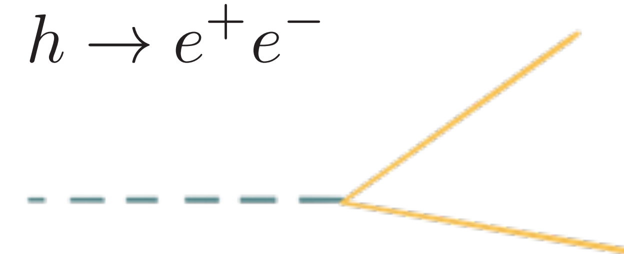


Pure gauginos

Stealth SUSY

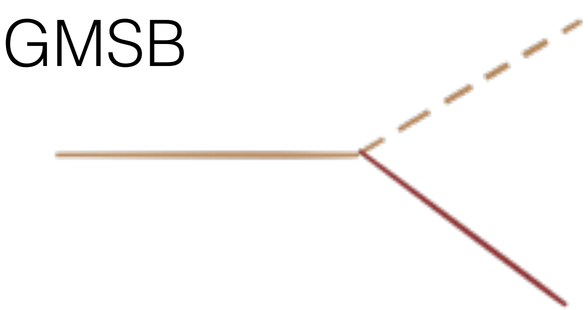
Small coupling

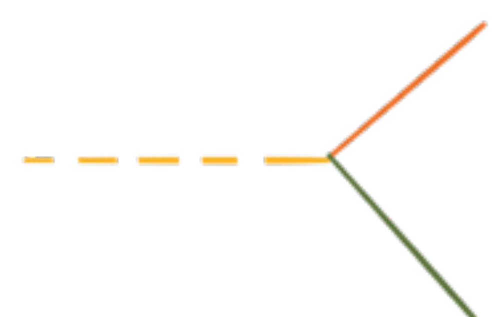
$h \to e^+ e^-$



$$\sim y_e^2 m$$

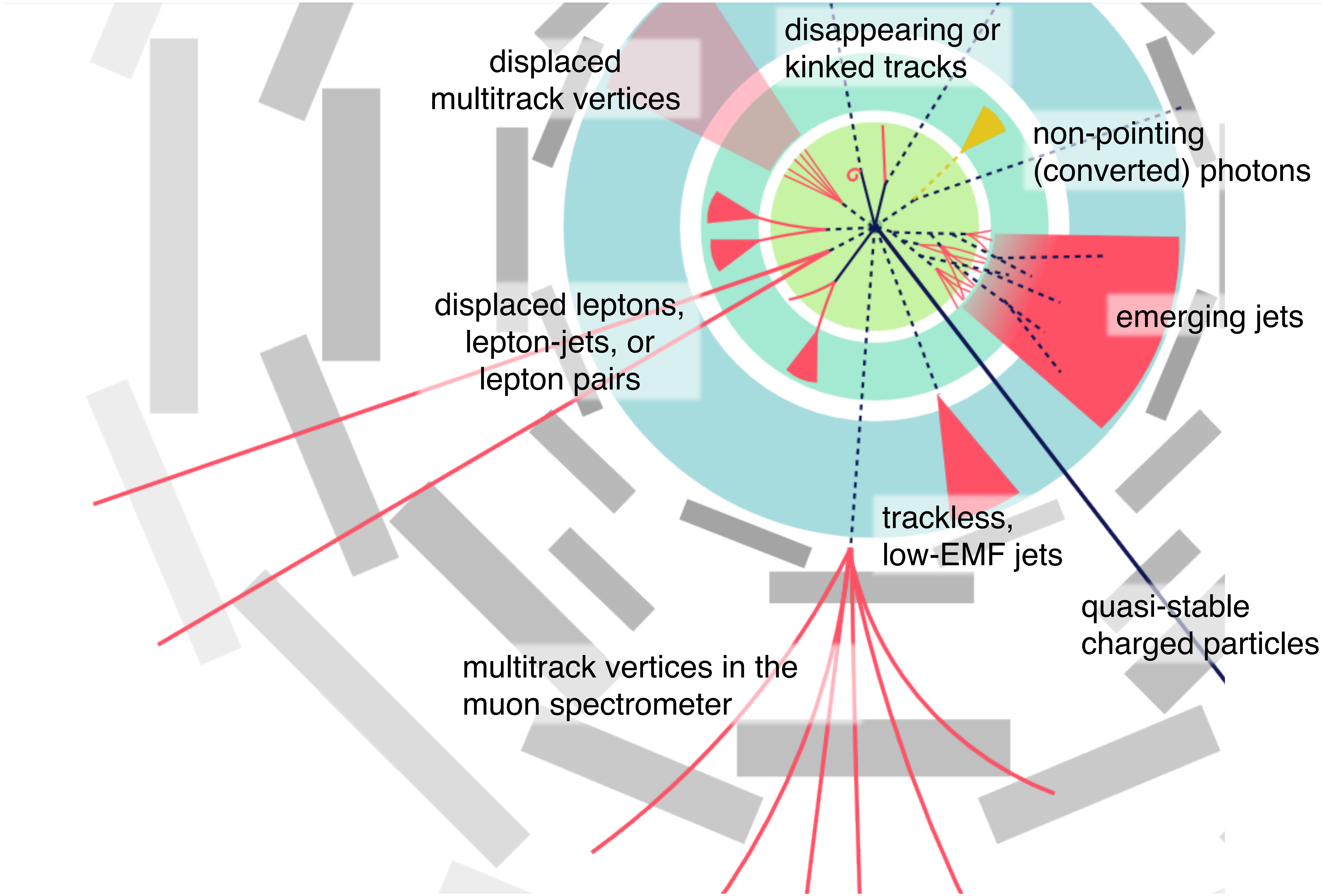
GMSB





RPV

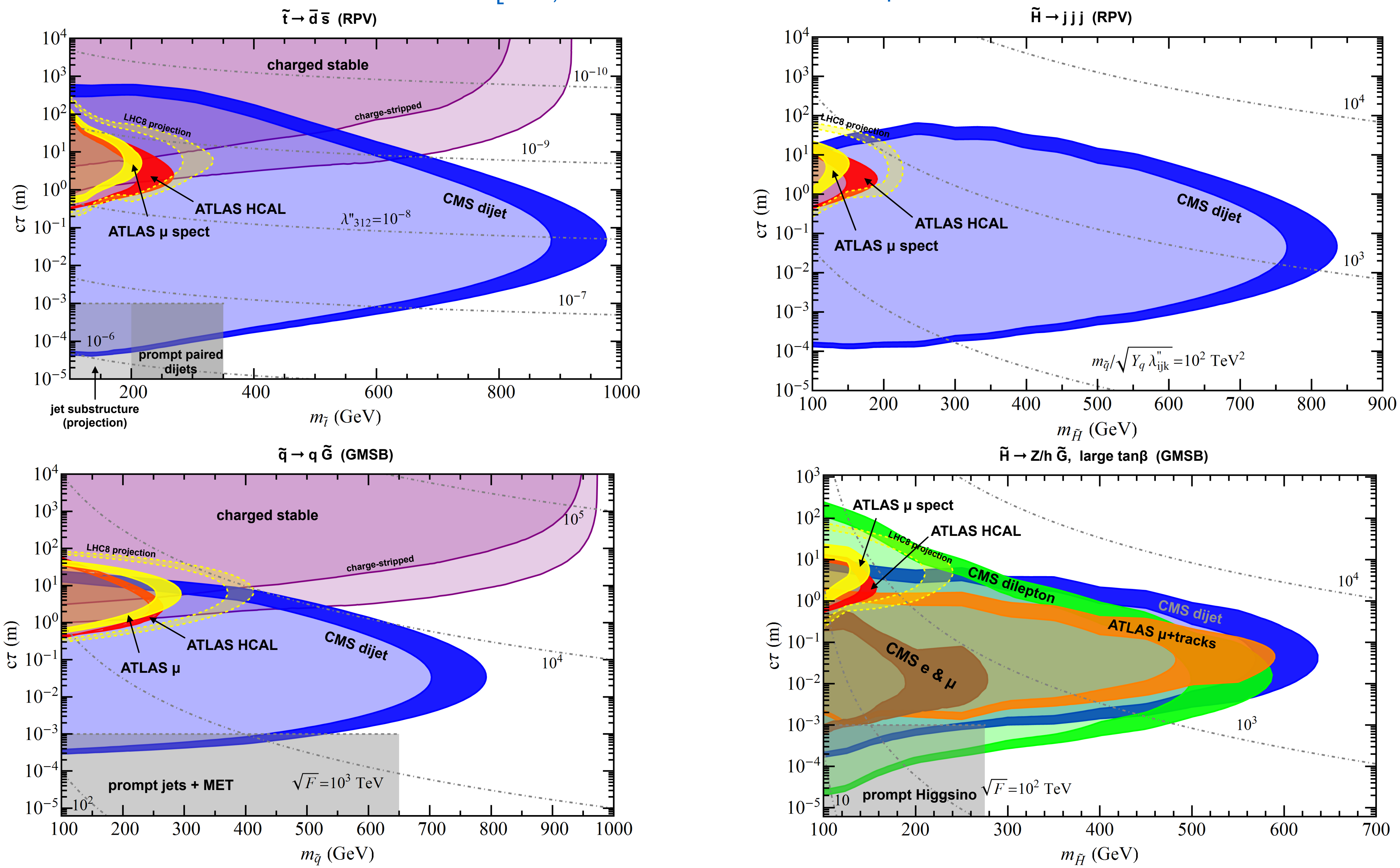
Long-Lived Signatures



LLPs at LHC

Not that many places to hide once the searches catch up

[Liu, Tweedie 1503.05923]



LLP Opportunities

Two natural questions for CLIC:

1. If an LLP signature is seen at the LHC, what can we learn from CLIC?

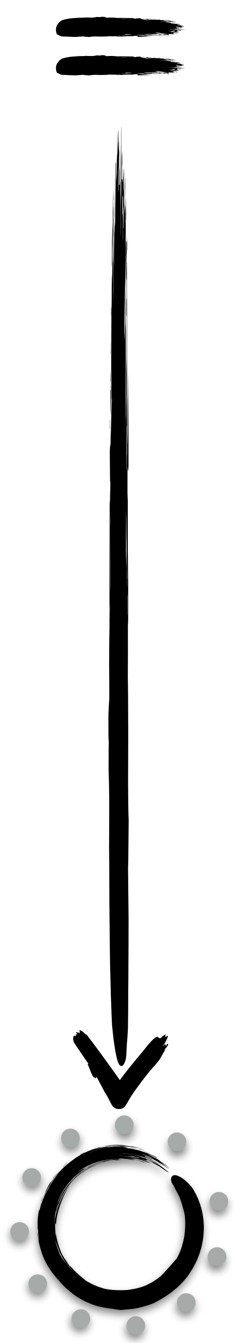
Not much to say about this today, though presumably improved mass, lifetime measurements are possible.

2. If we see nothing at the LHC, what are the prospects for CLIC?

LHC weak points are triggering, backgrounds, resolution near IP; significant opportunities for LLPs neutral under QCD or neutral under SM.
Many motivated examples…

Example 1: Twin Higgs

[Chacko, Goh, Harnik ‘05]



Standard Model $\xleftrightarrow{Z_2}$ **Standard Model**

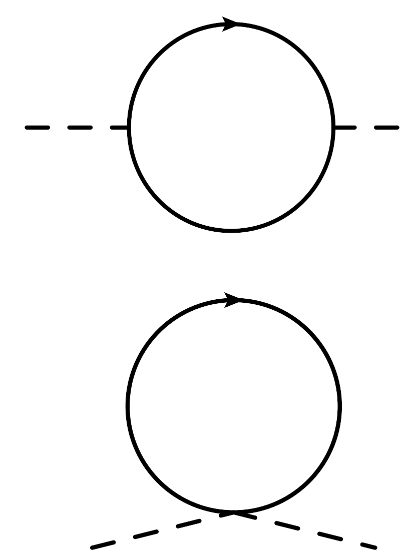
Radiative corrections to the Higgs mass are SU(4) symmetric thanks to Z_2:

$$V(H) \supset \frac{9}{64\pi^2} g^2 \Lambda^2 \left(|H_A|^2 + |H_B|^2 \right)$$

Higgs is a PNGB of ~SU(4), but partner states neutral under SM.

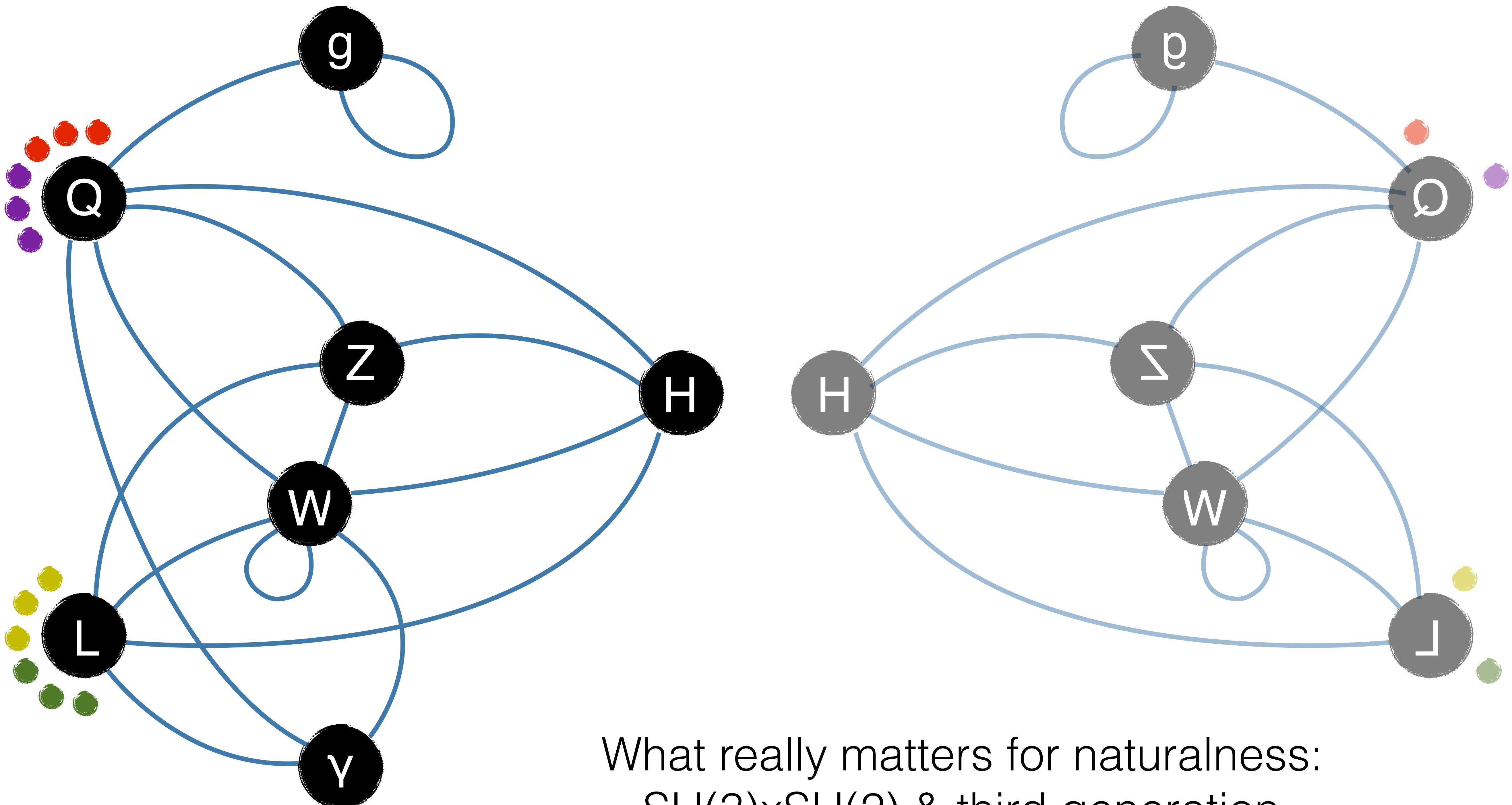
$$\mathcal{L} \supset -y_t H_A Q_3^A \bar{u}_3^A - y_t H_B Q_3^B \bar{u}_3^B$$

$$H_A \to h + \dots \qquad H_B \to f - \frac{h^2}{2f} + \dots$$



[NC, Katz, Strassler, Sundrum '15]

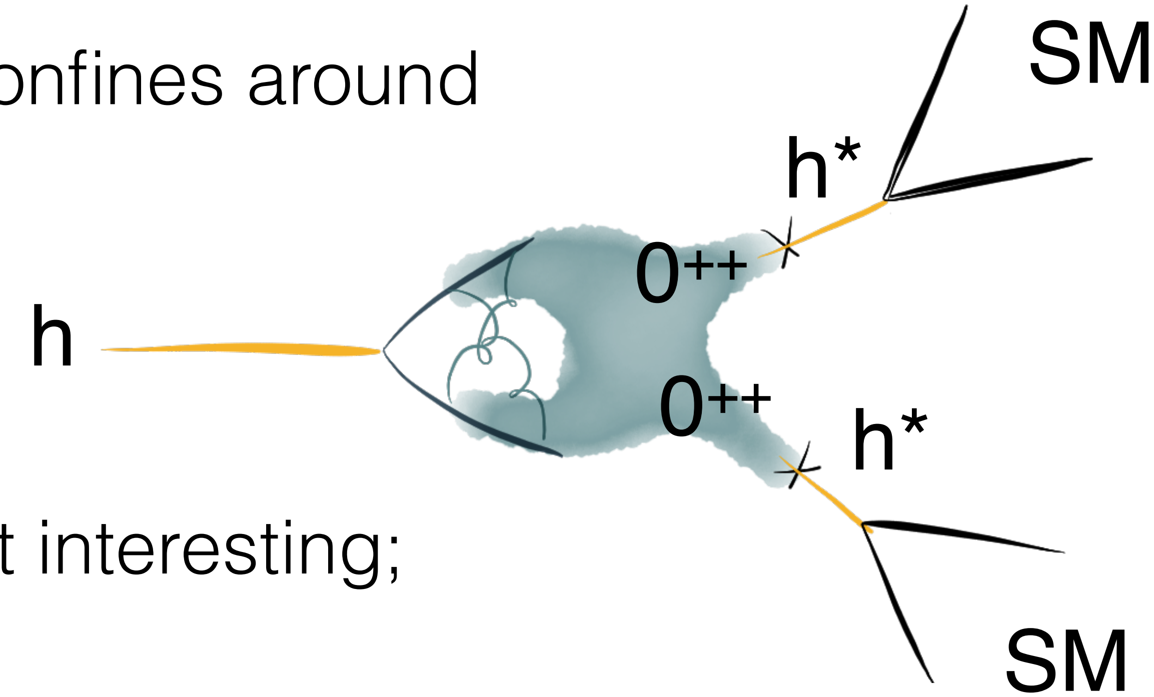
Fraternal twins

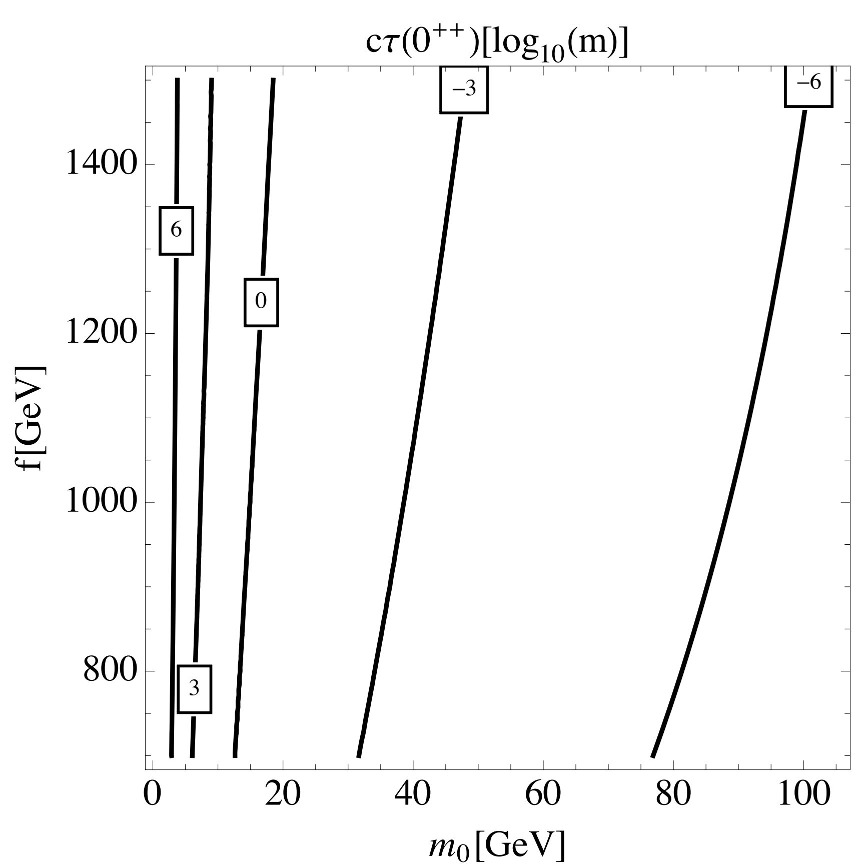


What really matters for naturalness:
SU(3)xSU(2) & third generation
⇒ Dark QCD

Exotic Higgs Decays

- Twin sector must have twin QCD, confines around QCD scale
- Higgs boson couples to bound states of twin QCD
- Various possibilities. Glueballs most interesting; have same quantum # as Higgs





$$\mathcal{L} \supset -\frac{\alpha_3'}{6\pi}\frac{v}{f}\frac{h}{f}G'^{a}_{\mu\nu}G'^{\mu\nu}_{a}$$

Produce in rare Higgs decays (BR~10^{-3}-10^{-4})

$$gg \to h \to 0^{++} + 0^{++} + \ldots$$

Decay back to SM via Higgs

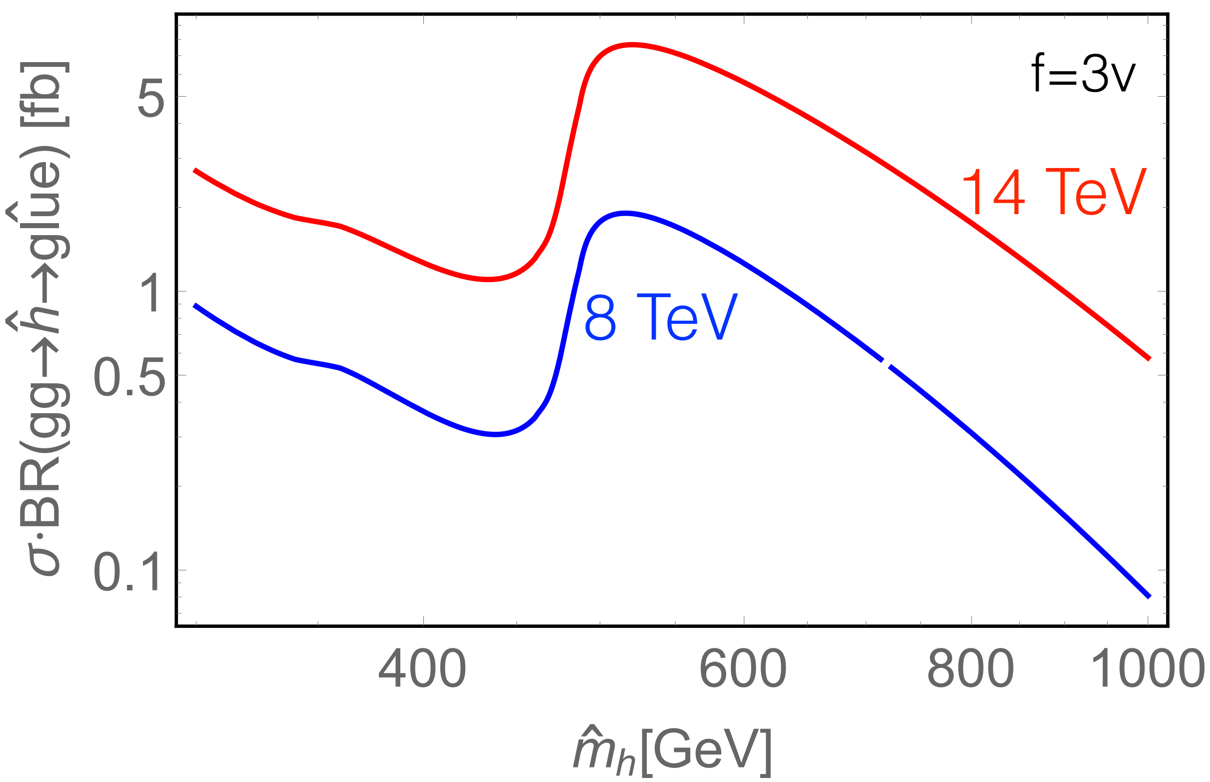
$$0^{++} \to h^* \to f\bar{f}$$

Long-lived, decay length is macroscopic; length scale ~ LHC detectors

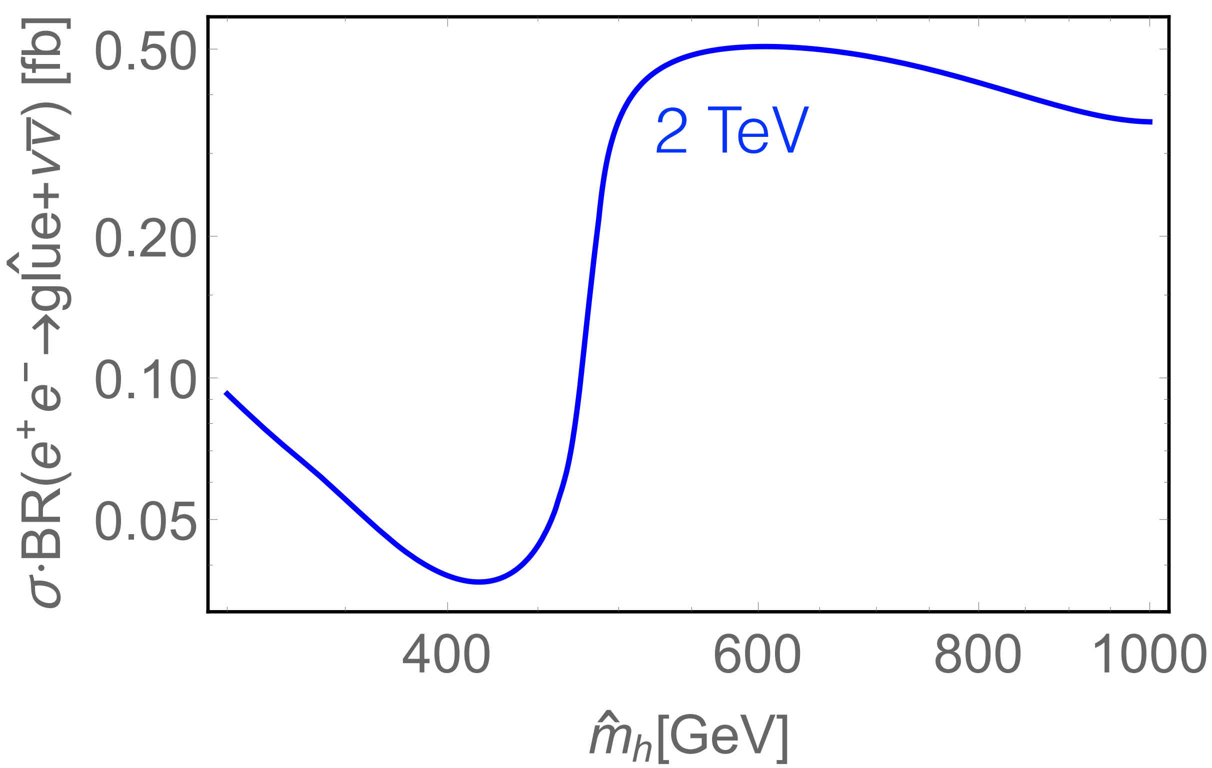
Exotic Heavy Higgs Decays

h(125) not the only production mode; glueballs also produced in decays of heavy twin Higgs:

LHC

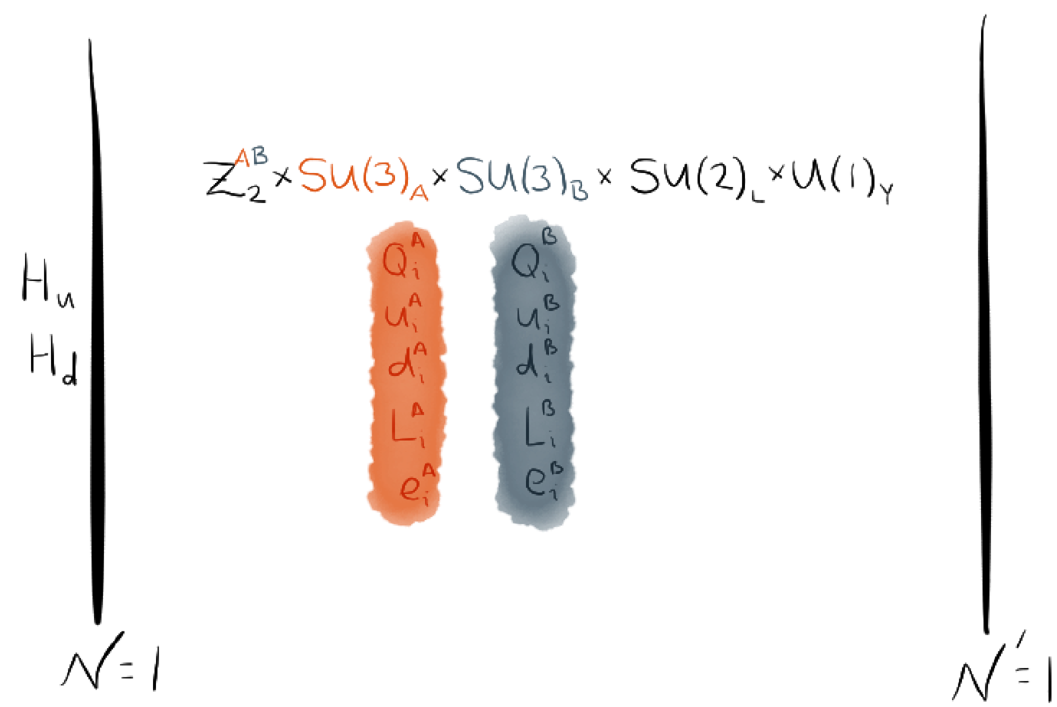


CLIC



Rate comparable to h(125), but more striking kinematics.
Also an open mode for higher glueball masses.

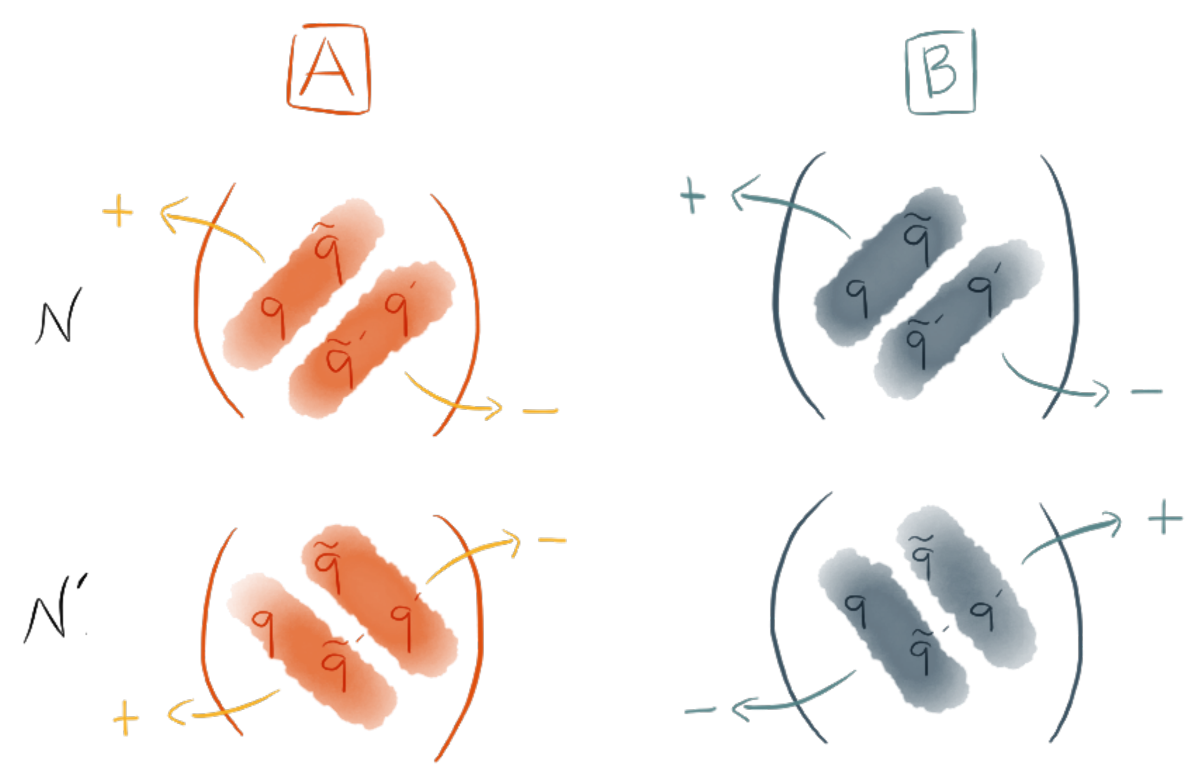
Example 2: Folded SUSY



[Burdman, Chacko, Goh, Harnik '06]

SUSY-like theory with uncolored sparticles. Start with a discrete symmetry + 5D SUSY.

Reduce symmetries & SUSY at the boundaries

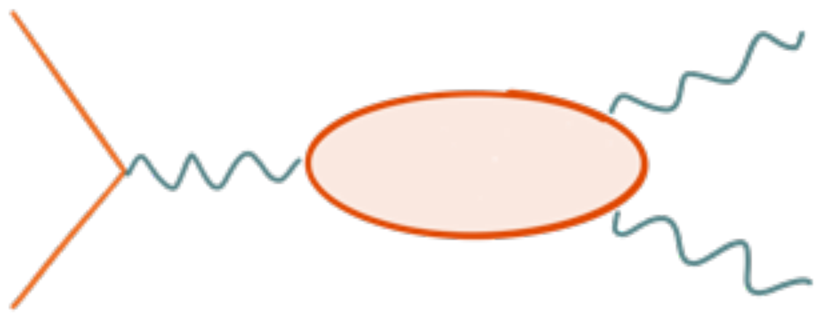


Sparticles carry standard EWK quantum #'s, but QCD charges replaced with QCD' charges

Once again…Dark QCD

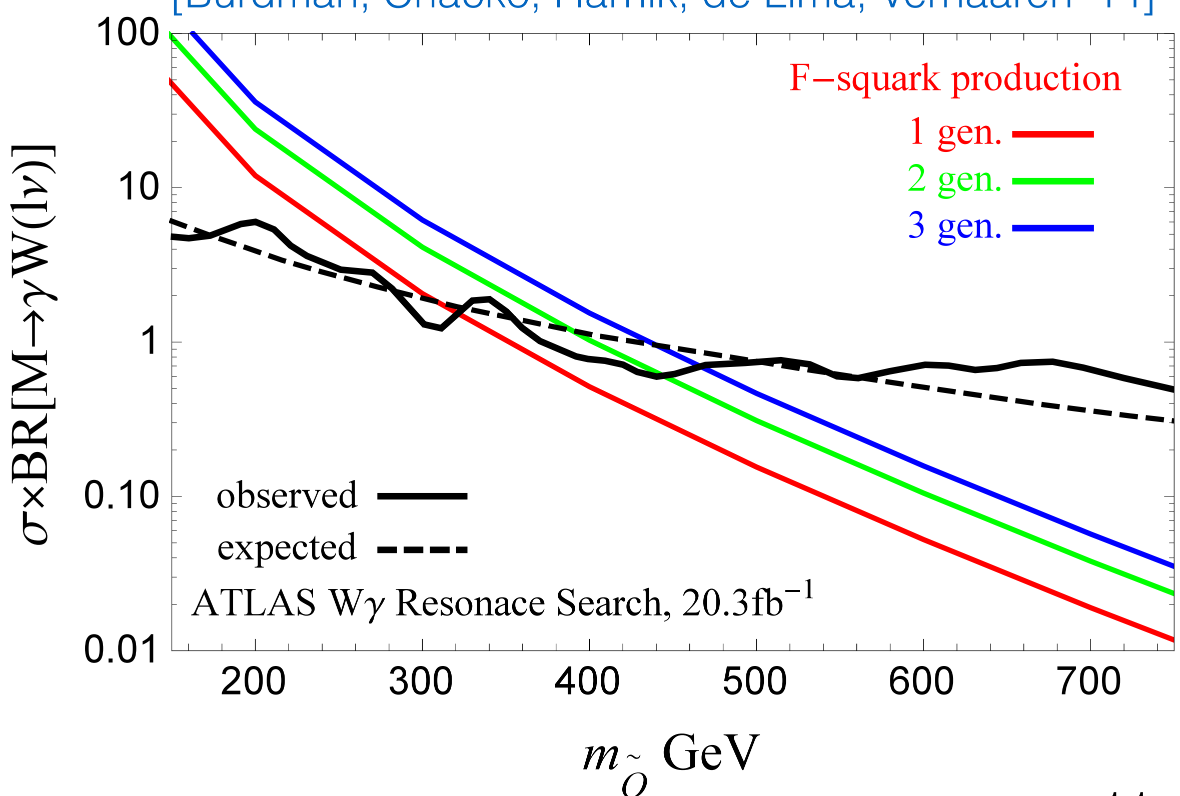
Colorless Signals

F-squarks carry electroweak quantum numbers.

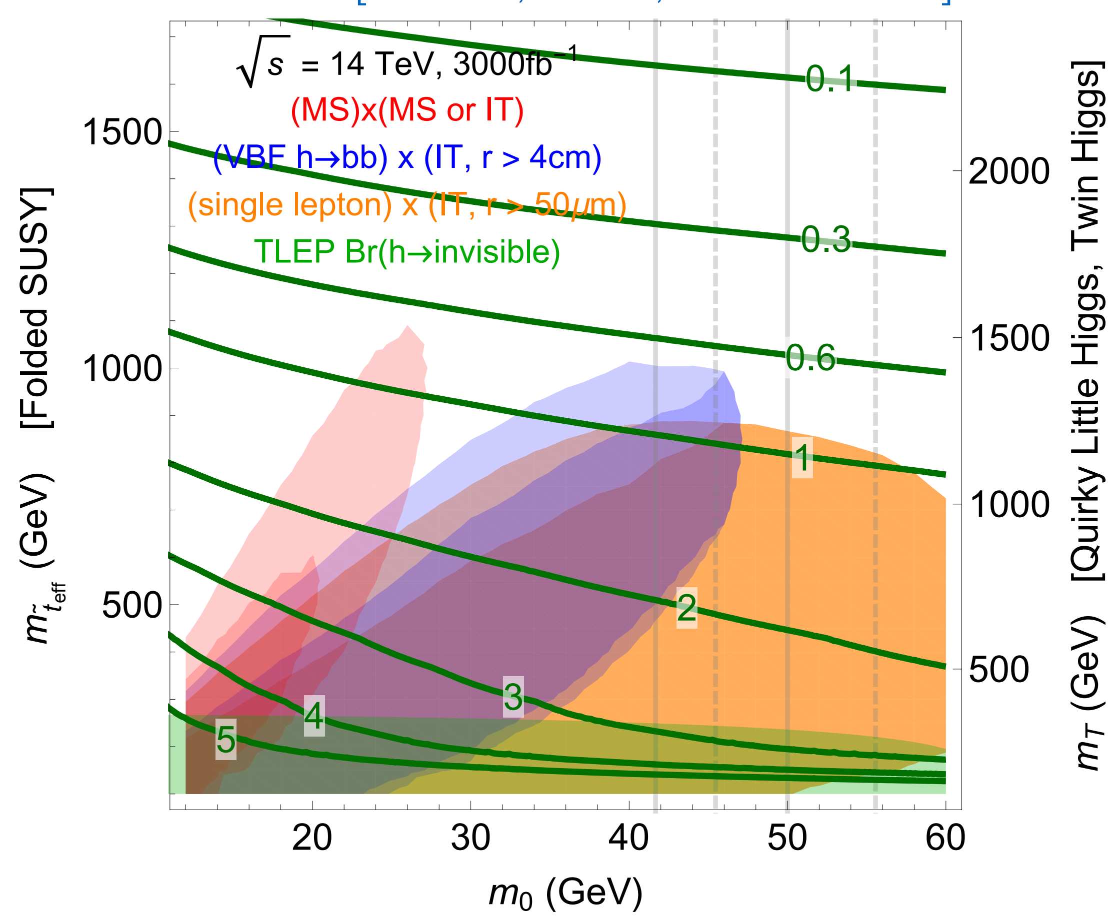


- Produced via a *Z*, annihilate into hidden glueballs, which decay back to SM via Higgs; displaced decays @ LHC length scales. [Curtin, Verhaaren '15]
- Produced via a *W*, annihilate back into the SM to shed their charge.
- (Also leave their mark indirectly, correcting Higgs decays to photons.)

[Burdman, Chacko, Harnik, de Lima, Verhaaren '14]

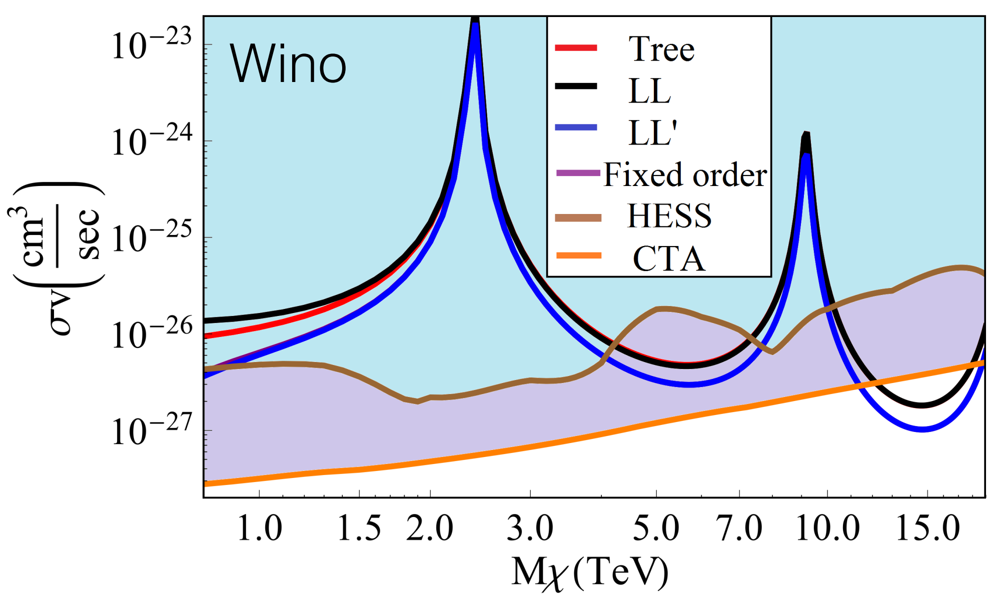


[Chacko, Curtin, Verhaaren '15]

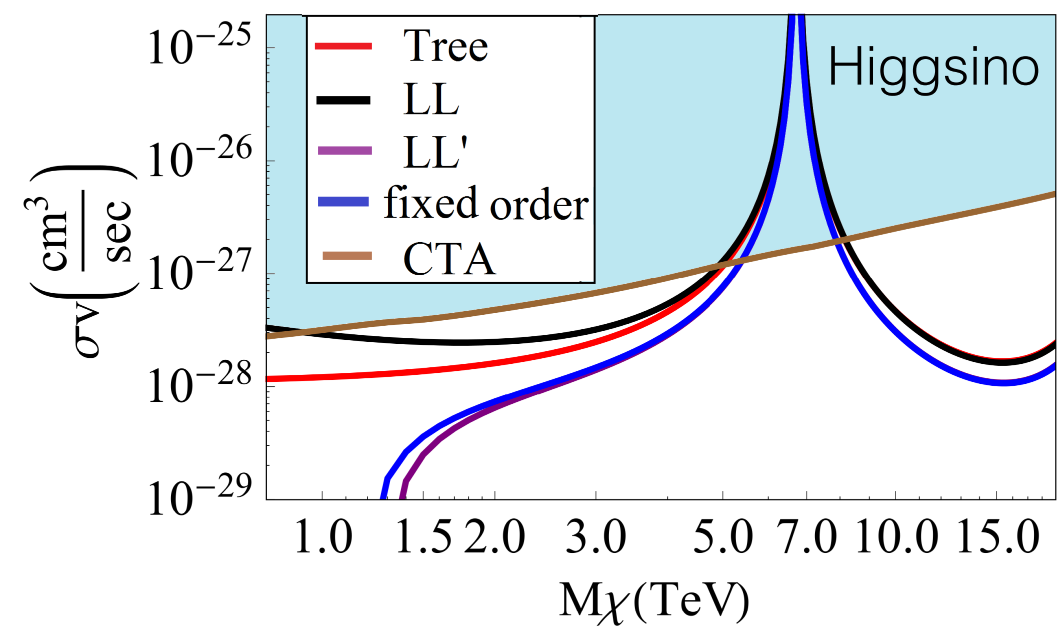


Example 3: Pure Higgsinos

E.g. SUSY does not make the weak scale fully natural, but explains DM. Natural candidates are pure wino (~3 TeV) or pure higgsino (~1 TeV).

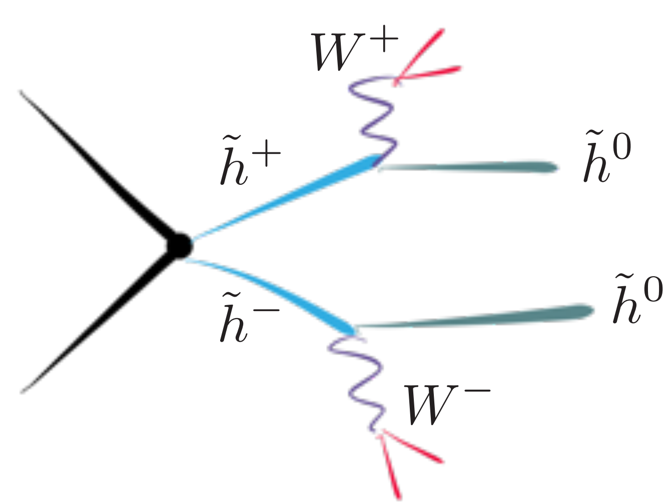


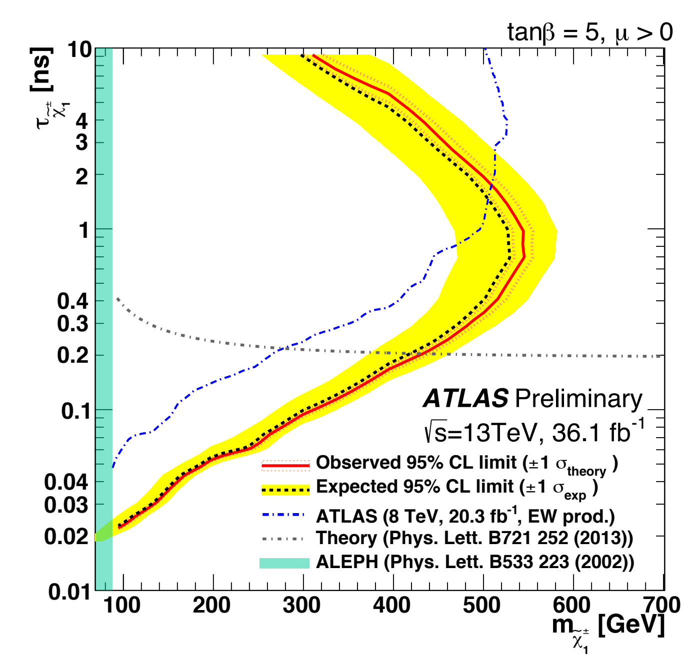
Thermal wino effectively excluded by indirect detection; thermal higgsino still in play



"Pure Higgsino" challenging at colliders: ~350 MeV splitting means short O(cm) charged stub.

Essentially impossible at LHC for any mass above LEP bound.





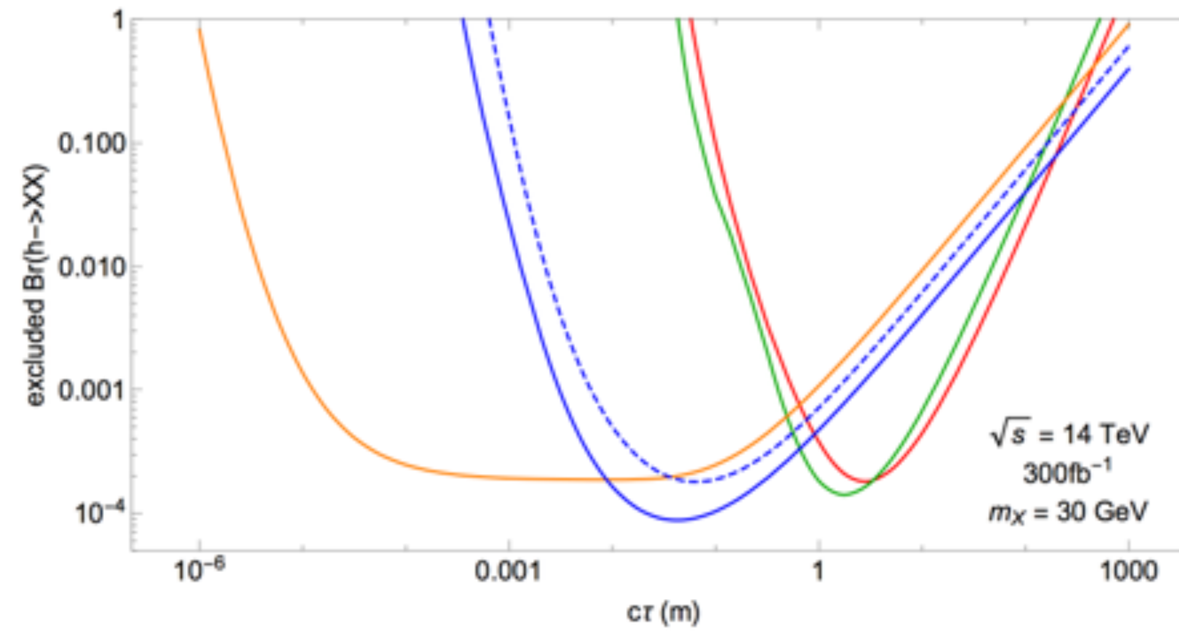
Displaced Decays @ CLIC

LLPs from h(125)

LHC advantage: $3\text{x}10^7$ Higgses at ATLAS+CMS with 300/fb @ 14 TeV

LHC disadvantage: Triggering (e.g. no vertex-based displaced search sensitive to Higgs @ 8 TeV)

[Curtin & Verhaaren '15]



CLIC in principle: $1.5\text{x}10^6$ Higgses from 0.35/1.4/3 TeV (w/out polarization). Improved triggering & environment

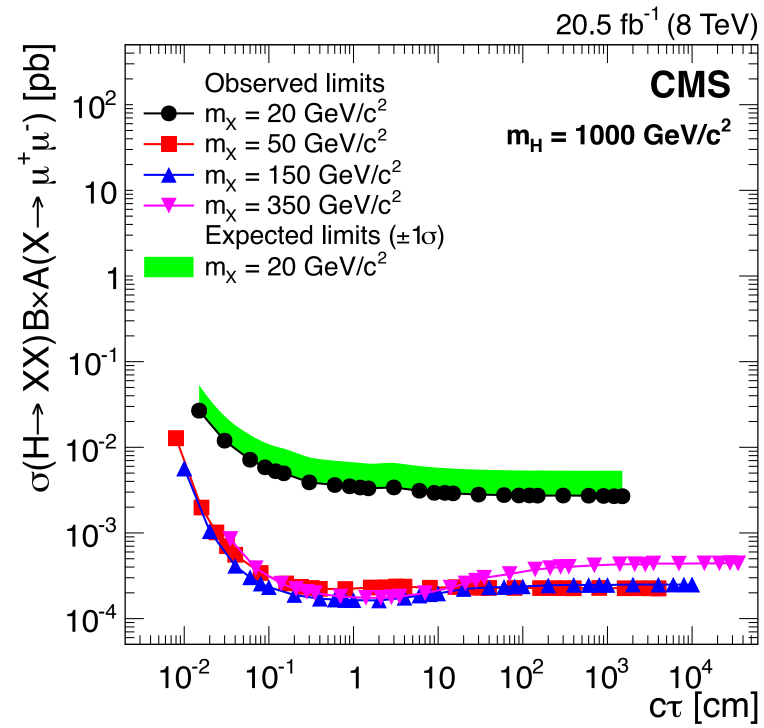
Maximal CLIC sensitivity: BR ~ $3\text{x}10^{-6}$ (4 evts, no bkg, perfect acceptance), c.f. BR ~10^{-4} at LHC. *Key questions: backgrounds, tracker resolution.*

Displaced Decays @ CLIC

LLPs from heavy Higgses

LHC advantage: ≤ 600 1 TeV twin Higgses decaying into LLPs at ATLAS+CMS with 300/fb @ 14 TeV

LHC disadvantage: Backgrounds (CMS vertex search not background-free at 8 TeV)



CLIC in principle: ≤ 700 1 TeV twin Higgses decaying into LLPs with 2/ab @ 2 TeV, lower backgrounds?

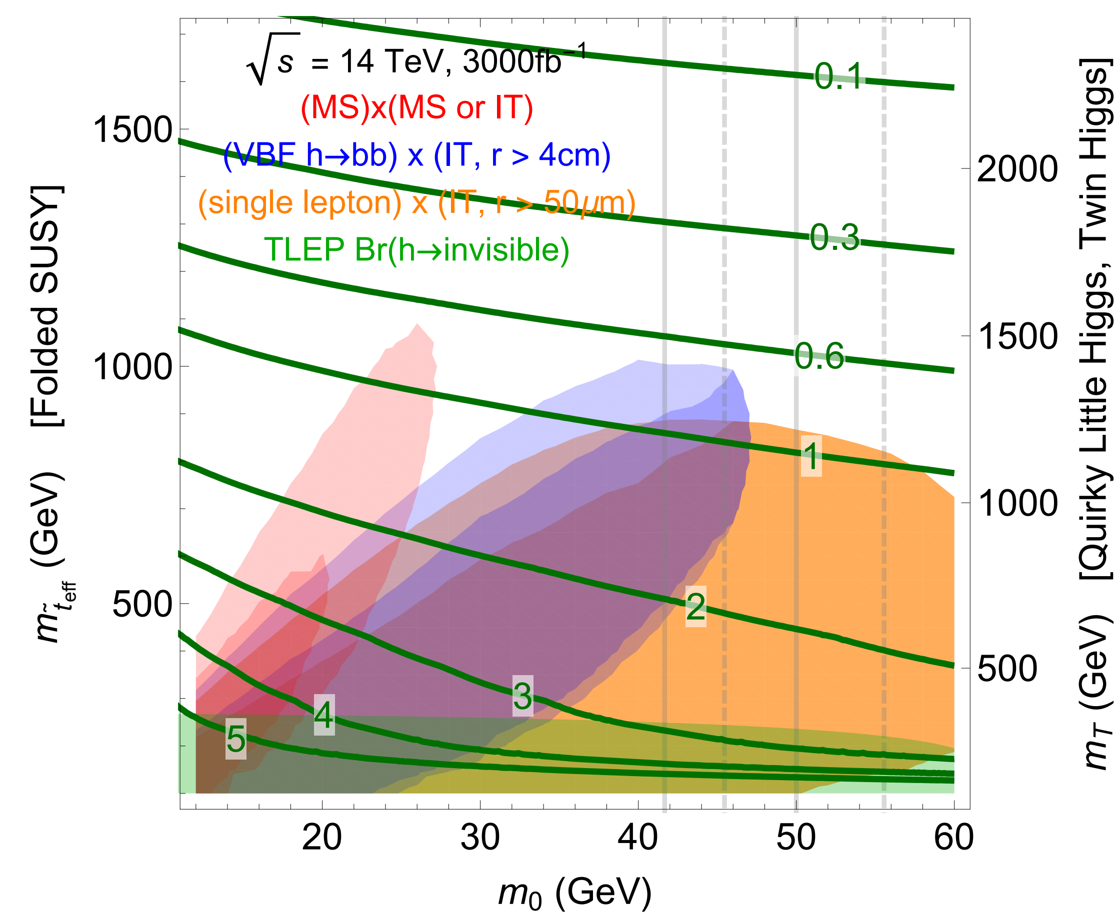
Maximal CLIC sensitivity: Discovery reach up to kinematic limit?
Key questions: rates, backgrounds, tracker resolution

Displaced Decays @ CLIC

LLPs from (s)quirkonia (e.g. folded SUSY)

LHC advantage: Large electroweak cross sections

LHC disadvantage: Backgrounds (CMS vertex search not background-free at 8 TeV)



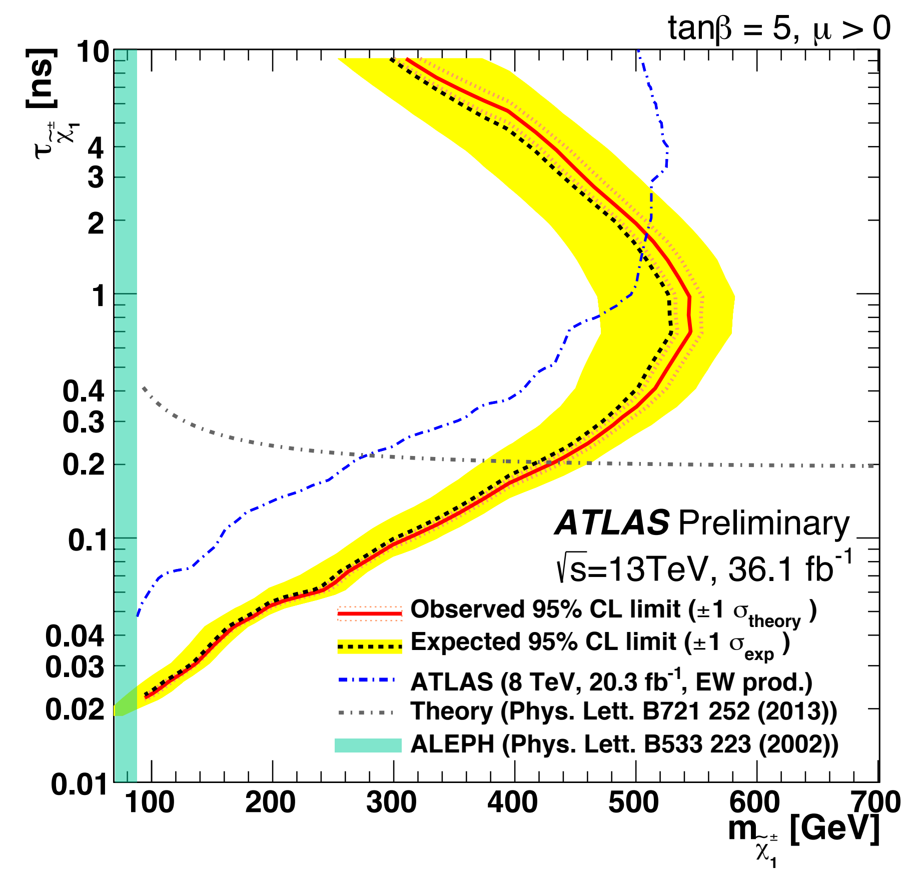
Maximal CLIC sensitivity: Discovery reach up to kinematic limit? *Key questions: rates, backgrounds, tracker resolution*

Displaced Decays @ CLIC

Pure Higgsinos / Pure Higgsino DM

LHC advantage: Large electroweak cross sections.

LHC disadvantage: Triggering (1cm charged stub essentially impossible, decay products too soft).



Maximal CLIC sensitivity: Discovery reach up to kinematic limit? *Key questions: rates, backgrounds, tracker resolution*

Conclusions

- LLPs are generic and arise in many motivated extensions of the Standard Model (especially those consistent with current LHC null results).
- LHC coverage sub-optimal for LLPs neutral under QCD or neutral under the SM. E.g. arising from exotic h(125) decays, heavy Higgs decays, electroweak production.
- CLIC potential strengths in backgrounds, triggering, tracker resolution provide potentially significant reach beyond LHC, covering a variety of motivated targets.
- A clear target for further study…

Thank you!