Long-Lived Particle Searches

—

A Wish List

LHC Long-Lived Particle Mini-Workshop

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The Higgs as a source of new states

It is very 'easy' for any new BSM particles to couple to the Higgs via low-dimensional portals

$$\Delta\mathcal{L} = \frac{\mu}{\Lambda^2}|H|^2\bar{\psi}\psi \qquad \Delta\mathcal{L} = \frac{\zeta}{2}s^2|H|^2$$

The 125 GeV Higgs is very narrow (Γ_{SM} ~ 4.07 MeV), so any new decay mode only has to compete with the small SM bottom Yukawa ~ 0.02

The Higgs boson has a pretty big production cross section:
LHC makes 10^7, HL-LHC makes 10^8, 100TeV makes 10^{10}

Most importantly: The 125 GeV Higgs EXISTS for sure, so study it!

Exotic Higgs Decays have to be one of our primary search channels for new physics

Review/Survey: 1312.4992 DC, Essig, Gori, Jaiswal, Katz, T. Liu, Z. Liu, McKeen, Shelton, Strassler, Surujon, Tweedie, Zhong

Long Lived Particles (LLPs) are theoretically very motivated!

(see previous talks)

- SUSY (RPV, mini-split, GMSB, stealth, ..)
- baryogenesis
- Anything with dark photons
- Hidden Valleys
- Neutral Naturalness

Exotic Higgs Decays are an important possible source of LLPs

This occurs in many theory frameworks, e.g. Hidden Valleys, dark photons, …

… but there is also a very fundamental motivation from the Hierarchy Problem!

LLPs may be *required* for Naturalness!

(not just coming along for the ride)

Neutral Naturalness

In SUSY, and e.g. Little Higgs, top partners solve the (Little) Hierarchy Problem by canceling top contribution to Higgs mass.

The symmetry which relates
top ↔ top partner
also makes the top partner colored

Hence large production cross section, jet signatures, etc..

In light of current limits, alternatives obviously attractive…

Neutral Naturalness

Can make the top partner uncolored by slightly twisting the symmetry relating top ↔ top partner

This gives scalar or fermion top partners that are SM singlets or only carry EW charge!

e.g. Twin Higgs, Folded SUSY

hep-ph/0609152 Burdman, Chacko, Goh, Harnik
hep-ph/0506256 Chacko, Goh, Harnik

Normal colored top partner signatures completely absent!

→ evades current constraints

radically different phenomenology!

Neutral Naturalness

You 'lose' traditional top partner signatures, but you 'gain' something else…

The same twist in the symmetry which
makes the top partner uncolored under SM QCD
makes it colored under a mirror QCD'

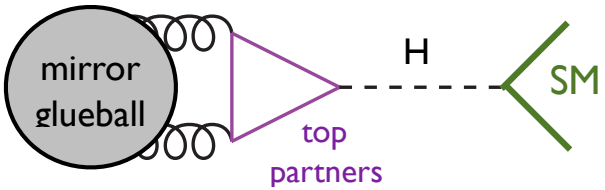
→ Naturalness motivation for Hidden Valleys!

A hidden sector with:

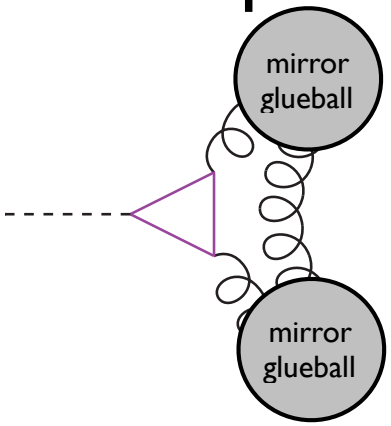
- couplings to the Higgs related to naturalness of theory
- its own confining gauge group
- some minimal matter content but many possibilities, so hadron spectrum could be glueballs, onia, pions..

Neutral Naturalness

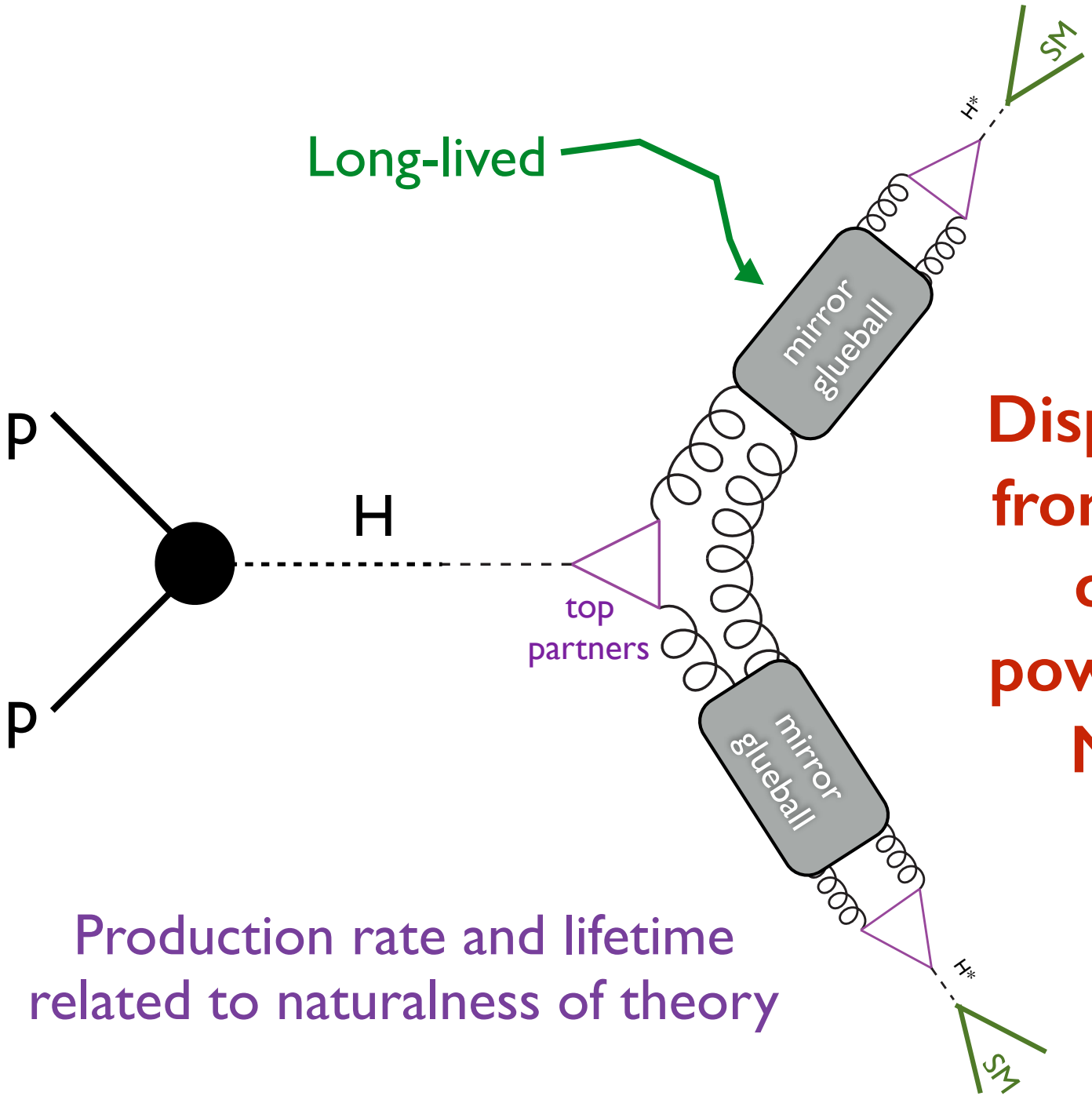
Mirror gluons talk to the Higgs via top partner loops.



Allows for production and (displaced!) decay of mirror hadrons!



1501.05310 Craig, Katz, Strassler, Sundrum DC, Verhaaren 1506.06141 Chacko, DC, Verhaaren 1512.05782



Displaced Vertices from exotic Higgs decays are a powerful probe of Naturalness!

Production rate and lifetime related to naturalness of theory

Neutral Naturalness

This motivates LLP searches with Higgs-portal signal models

Most importantly

$h \rightarrow XX$

where X is long-lived and decays via a small Higgs mixing

(i.e. to bb, $\tau\tau$ and light jets)

These searches are CHALLENGING

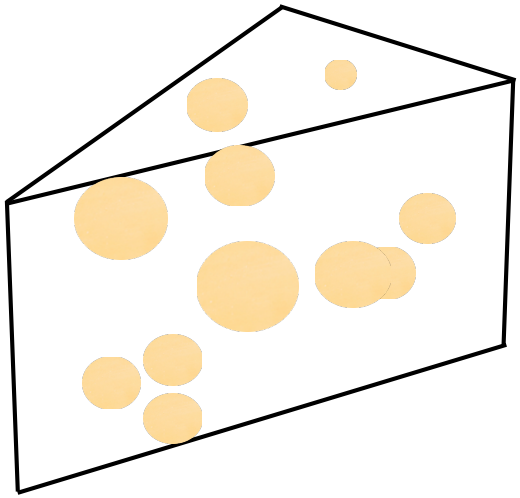
- difficult to trigger on LLP decay (few e or μ)
- soft decay products (125 GeV Higgs)

Current Neutral LLP Searches

Exp	Search	run	signal	LLP Daughters	LLP Scale	Parent Scale	Associated Objects	# LLP Decays	decay Location	decay Detector	L1 trigger
CMS	EXO-12-035-pas	8 TeV	GMSB neutralino → ɣ + G	ɣ + MET	100-300 GeV	x2 + ~ 50	jets, MET	1	tracker	ECAL (timing)	one photon
	EXO-14-017-pas	8 TeV	GMSB neutralino → ɣ + G	ɣ + MET	200-300 GeV	x2 + ~ 50	MET	2	tracker	tracker (convers	diphoton
	1211.2472	7 TeV	H->XX	2 leptons	20+ GeV	100+ GeV	none	2	tracker	same	dilepton
	1411.6530v2	8 TeV	H->XX, RPV SUSY	2 jets	50+ GeV	200+ GeV	none or jets	1	tracker	same	HT > 300 GeV
	1411.6977	8 TeV	H->XX, RPV SUSY	2 leptons	20+ GeV	100+ GeV	none	1	tracker	same	dilepton
	1409.4789	8 TeV	RPV SUSY	e and mu	0.5 – 1 TeV	x2	none	2	tracker	tracker, MS	one muon
ATLAS	1504.03634	8 TeV	H->XX, HV Z', Stealth SUSY	2x ~ anything	10+ GeV	100+ GeV	none	2	Muon System	same	Muon RoI
	1501.04020	8 TeV	H->XX	2x ~ anything	10+ GeV	100+ GeV	none	2	HCAL	same	CalRatio
	1409.0746	8 TeV	H → HV .. → X X	2 leptons	0.4 – 2 GeV	~ 100 GeV	none	2	tracker	same	standard lepton(s)
	1504.05162	8 TeV	SUSY (split, rpv, gmsb)	2 leptons or 5+ charges	10+ GeV	600+ GeV	various		tracker	same	HARD MET, Jet, lepton
LHCb	1412.3021	7tev 0.62/fb	H->XX	2 quarks	25 – 50 GeV	100 GeV	none	1	0.4-4.8mm From beam	tracker	single track > 1.5 – 3.5 GeV

not yet

more like



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Several searches for LLPs from SUSY-type theories (blue)

Easier to trigger on due to **high mass scales**

Probably much more to do there…

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Some searches with sensitivity to Higgs portal LLP **production** (green)

Many of those assume **LLP → leptons**, i.e. NOT Higgs portal decay.

Easier to trigger (lepton), and very motivated e.g. dark photon!

LLP mass gap: few - 20 GeV (complicated onium region)

See Josh's Talk!

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Some searches with sensitivity to Higgs portal LLP **production** (green)

Higgs portal decay of LLP: only at large lifetimes (or LHCb)

→ allows use of dedicated triggers for LLP decay

→ at large lifetimes, requiring just one LLP decay would help a lot!

Missing Search: hadronic LLP decay in tracker.
Would have to use different trigger (e.g. lepton or vbf)

Search Wish List for Higgs Portal LLP Production

Mass gaps in current searches:

- X→ leptons: 2 - 20 GeV
- X→ hadrons: < 10 GeV

Tough!
(reconstruction, SM background)
.. but motivated!

Searches for single LLP decay in tracker using prompt triggers (lepton, VBF)

For Higgs portal with non-conspicuous final states (e.g. LLP decay through same Higgs portal)

Search for single LLP decay in outer detectors (long lifetime)

Backgrounds!?

Shorter lifetimes: identify DV for < ~ mm displacements

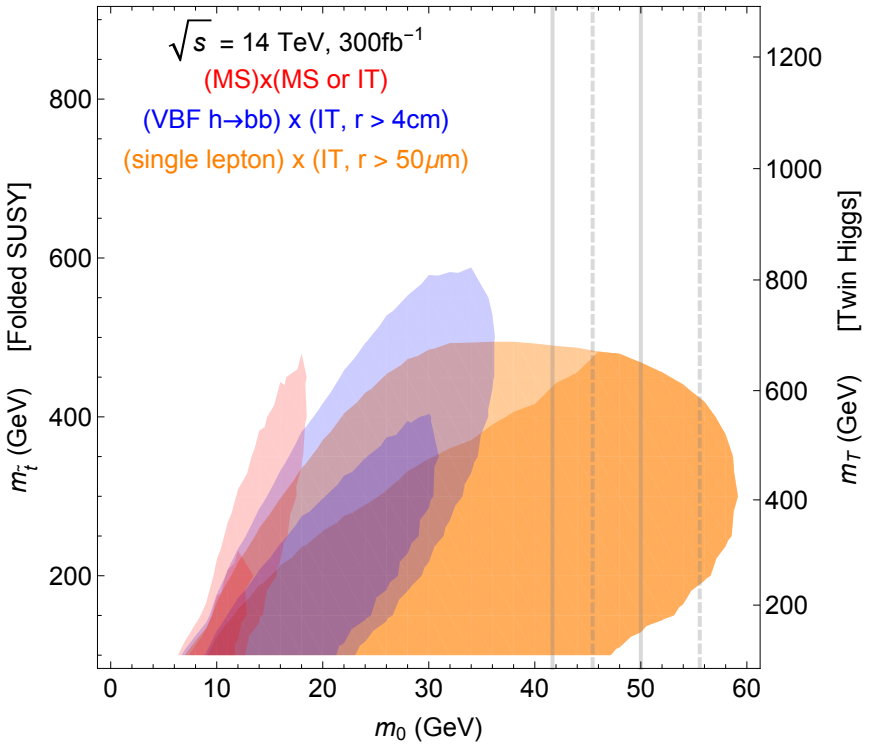
More backgrounds from b's.
LHCb might be amazing??
(Don't know best way to do this yet, needs study!)

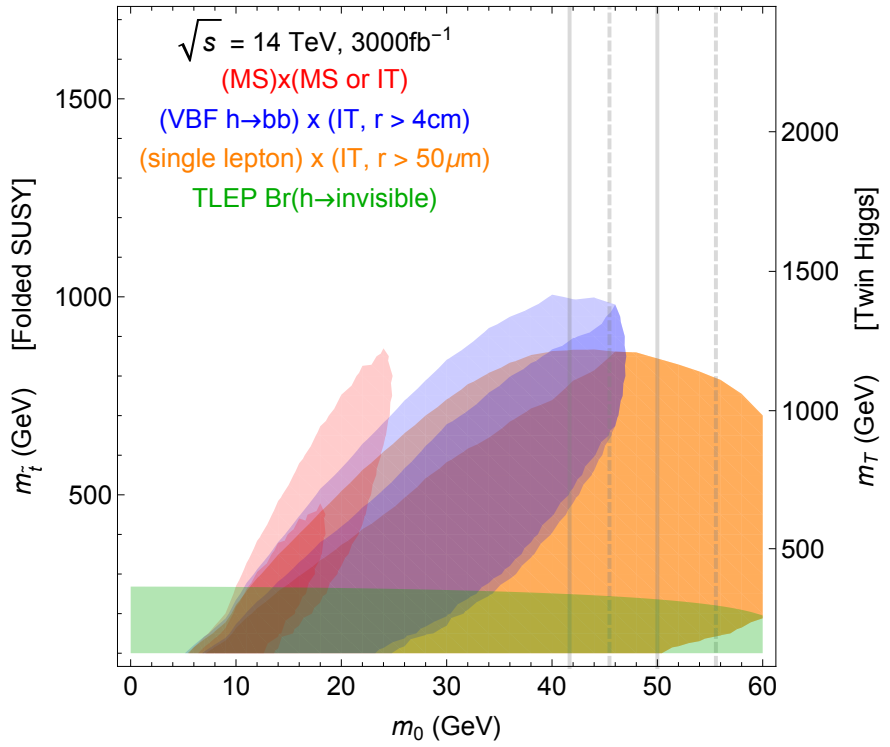
Resulting Neutral Naturalness Sensitivity

e.g. Folded SUSY:

DC, Verhaaren 1506.06141

top partner mass





glueball mass

LHC can probe TeV-scale uncolored top partners!

Some recent progress

(th-exp collaboration)

1605.02742 Andrea Coccaro, DC, Henry Lubatti, Heather Russell, Jessie Shelton

LLP searches have to be able to probe regimes with non-zero backgrounds.

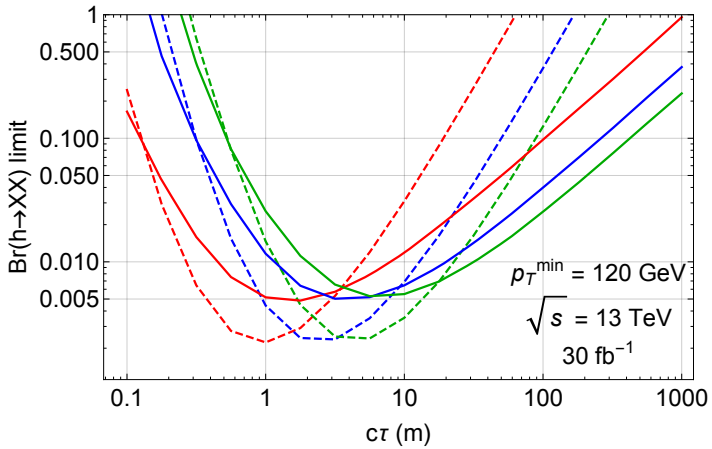
Can't simulate. We formulate ***general*** framework for ***fully differential*** data-driven background predictions for LLP searches.

→ ABCD method using
(DV reconstruction/isolation variable) vs (kinematic variable **Y** of rest of event)

Application: search for *single* LLP from h→XX in ATLAS Muon System
(existing triggers for signal and orthogonal sample!)

Projected limits of 1DV in MS search far superior at long lifetimes compared to existing 2DV search.

Hopefully will be implemented at run 2!



1DV with BG - - - - - 2 DV no BG

Some recent progress

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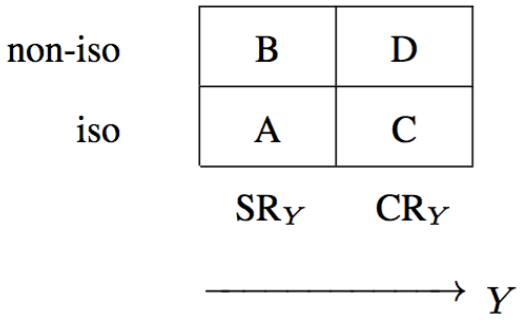
Our method readily generalizes to other production modes and other detector systems! (e.g. short displaced decays in tracker??)

Possible framework for model-independent LLP search program?



Y is determined by LLP production mode (e.g. # leptons, etc)

Build model-independent ratios that are functions of kinematic variables

$$\mathcal{R}_Y(H'_T, \ldots) = \frac{C/D}{A/B}$$

Deviations from unity ↔ hint of BSM

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Progress!

Backgrounds!?

Thank you!

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