Long-lived particles at the LHC

Simon Knapen
UC Berkeley & LBL

Triggering on Long-Lived Particles
04 / 18 / 17

Why long-lived particles?

Long lifetimes arise from a hierarchy of scales or a small coupling*

Three mechanisms:

- Off-shell decay
- Small splitting (phase space)
- Small coupling

* could either be a hierarchy or loop suppression

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small coupling

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

Set by symmetry structure,

typically n ≥ 4

$m \ll M$

hierarchy of scales

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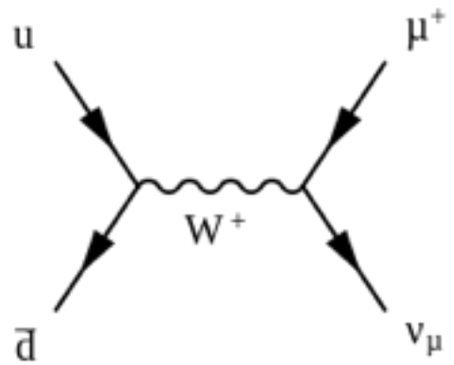
$\pi^+ \to \mu^+ \nu_\mu$



$$\Gamma \sim g_2^2 \left(\frac{m}{m_W}\right)^4 m$$

small coupling

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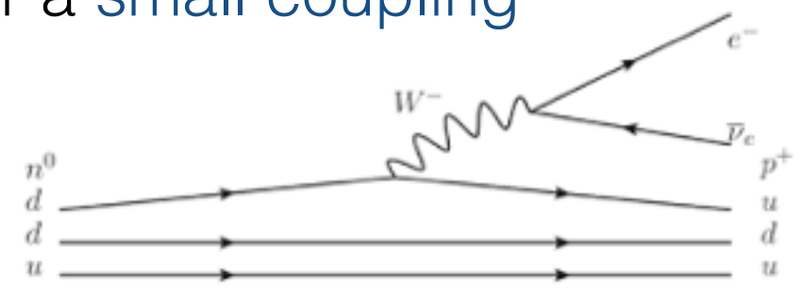
$$n^0 \to p^+ e^- \nu_e$$



- Off-shell decay
- Small splitting (phase space)
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$$\Gamma \sim g_2^2 \left(\frac{m_n - m_p}{m_W}\right)^4 (m_n - m_p)$$

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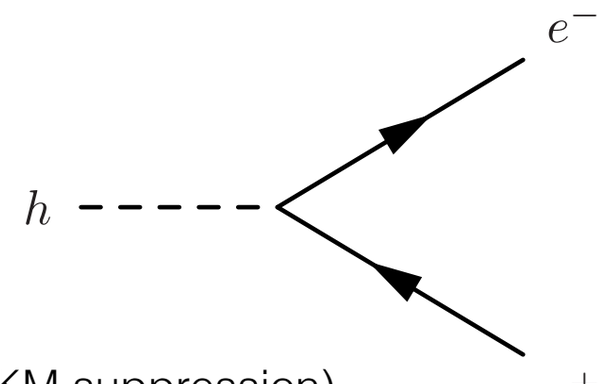
$c\tau \sim 40\ \mu\mathrm{m}$



(see also decays with CKM suppression)

small coupling

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

Set by symmetry structure,

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$m \ll M$

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Lessons from the SM:

- generic if there is more than one scale
- Often 3 body decays
- Weak theory prior on lifetime

(e.g. proton decay!)

small coupling

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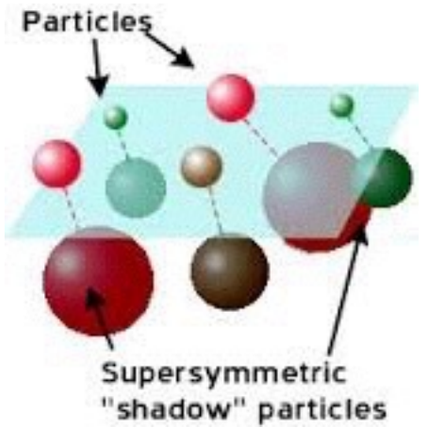
This talk

Central question:



Is SUSY a good benchmark generator of LLP's ?

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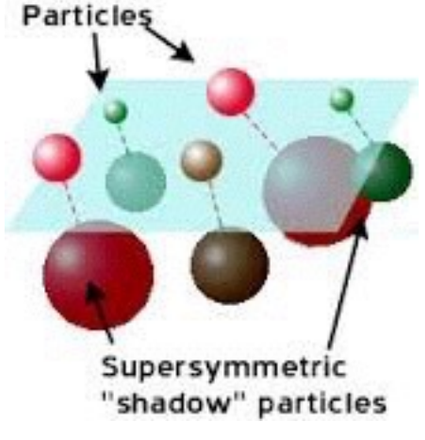


Is SUSY a good benchmark generator of LLP's ?

👍

Huge infrastructure & intuition from prompt searches

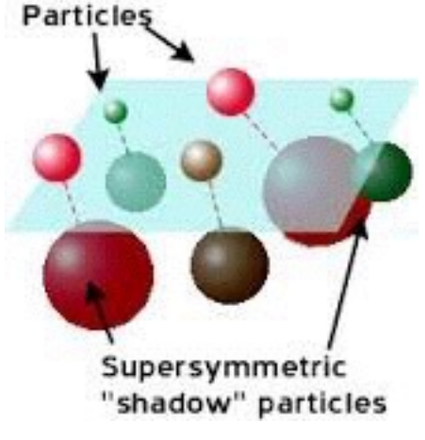
Some pretty compelling cases

👎

Theory bias could lead to blind spots

This talk

Central question:



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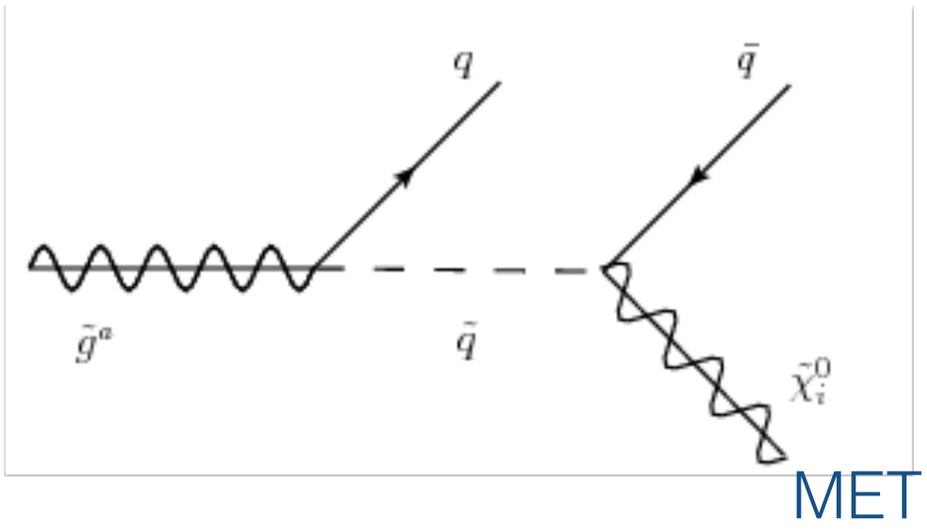
Theory bias could lead to blind spots

But first a quick reminder of some of the classics!

(SUSY & non-SUSY)

(Mini -) Split SUSY / GMSB

Split SUSY (3 body)



- Off-shell decay
- Small splitting (phase space)
- Small coupling

$$c\tau \approx 100\mu m \times \left(\frac{m_{\tilde{q}}}{10^3\,\mathrm{TeV}}\right)^4 \times \left(\frac{\mathrm{TeV}}{m_{\tilde{g}}}\right)^5$$

(Mini -) Split SUSY / GMSB

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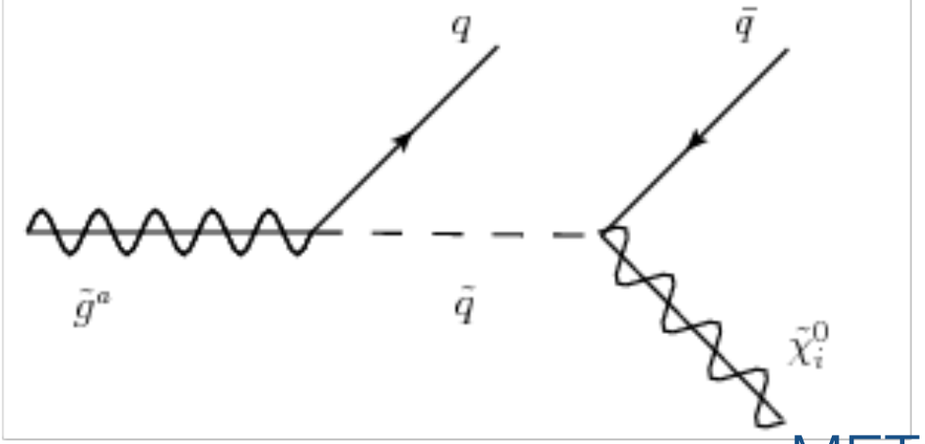
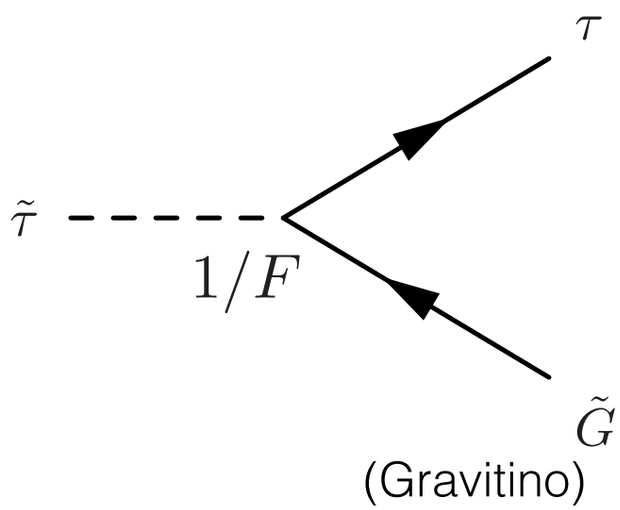


MET

- Off-shell decay
- Small splitting (phase space)
- Small coupling

$$c\tau \approx 100\mu m \times \left(\frac{m_{\tilde{q}}}{10^3\,\mathrm{TeV}}\right)^4 \times \left(\frac{\mathrm{TeV}}{m_{\tilde{g}}}\right)^5$$

Gauge Mediation* (2 body)



MET

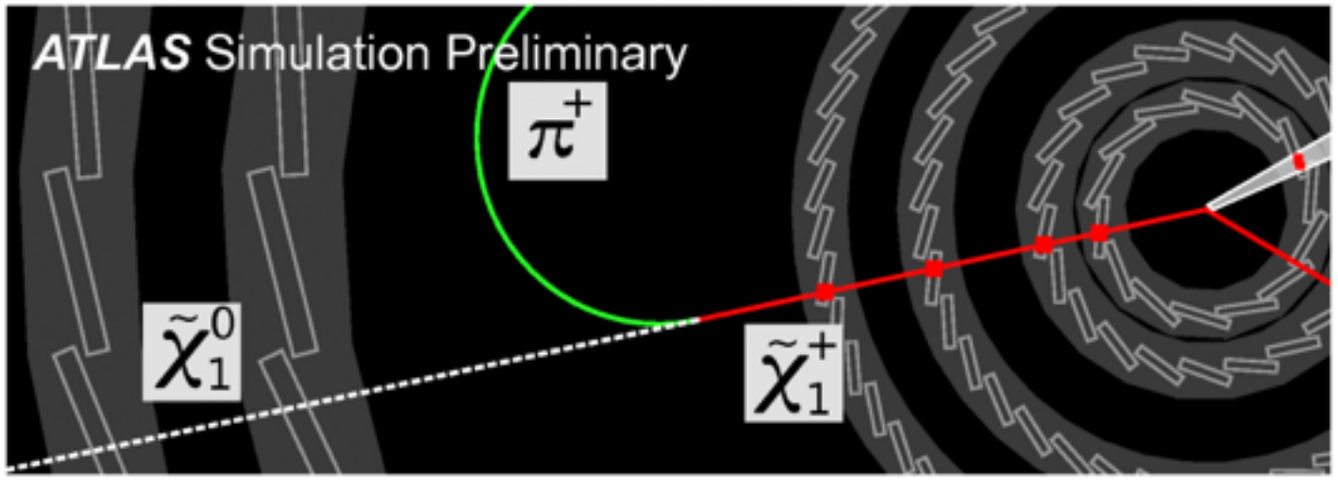
$$c\tau \approx 100\mu m \times \left(\frac{\sqrt{F}}{100\,\mathrm{TeV}}\right)^4 \times \left(\frac{100\,\mathrm{GeV}}{m_{\tilde{\tau}}}\right)^5$$

* Common misconception: decay NOT gravity suppressed!

Nearly degenerate EW-ino's

aka "anomaly mediation"

- Off-shell decay
- Small splitting (phase space)
- Small coupling



$$c\tau \approx 0.7\,\mathrm{cm} \times \left(\frac{\Delta m}{340\,\mathrm{MeV}}\right)^3$$

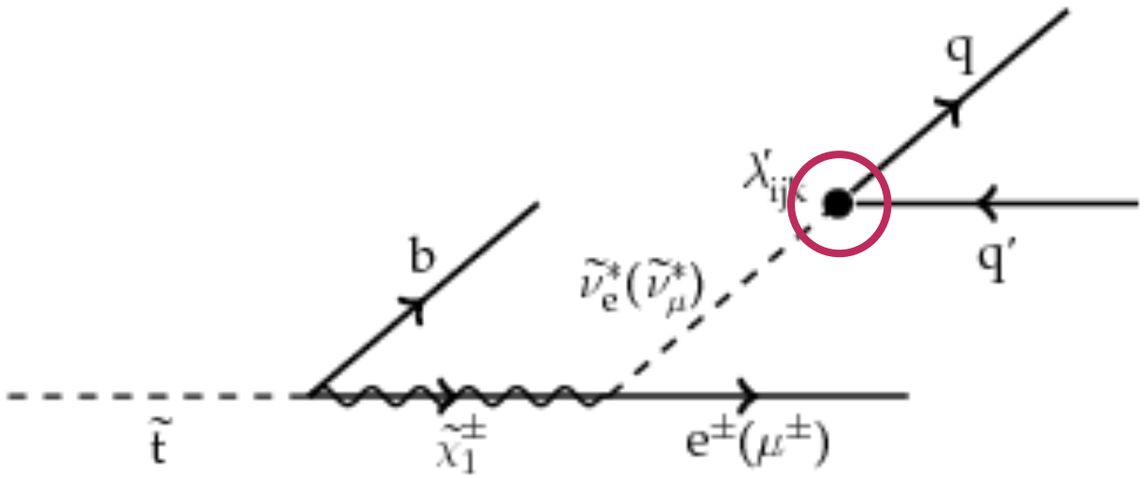
Disappearing track search

R-Parity Violating SUSY

Two or three-body decay

(many different options)

- Off-shell decay
- Small splitting (phase space)
- Small coupling



Need $|\lambda| \lesssim 10^{-8}$

No MET, unless neutrino in decay chain

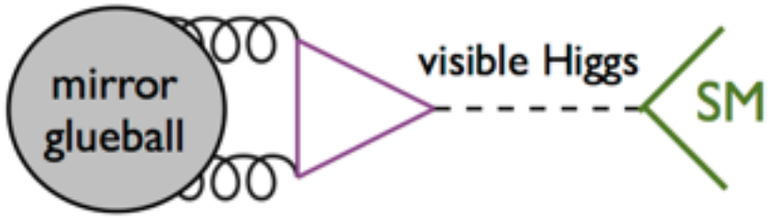
dark glueballs / pions

Generic ingredient of hidden valley

& neutral naturalness models

- Off-shell decay
- Small splitting (phase space)
- Small coupling

For instance, Higgs portal:



$$c\tau \sim 18\ \mathrm{m} \times \left(\frac{10\ \mathrm{GeV}}{m_0}\right)^{7}$$

(For hidden pions, see enormous diphoton literature!)

dark glueballs / pions

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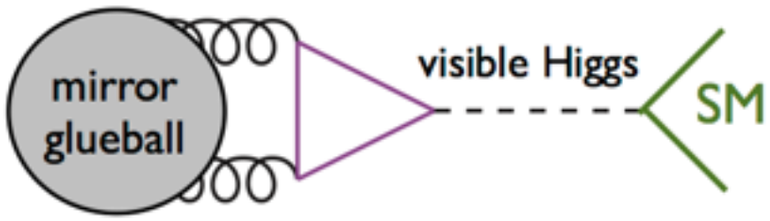
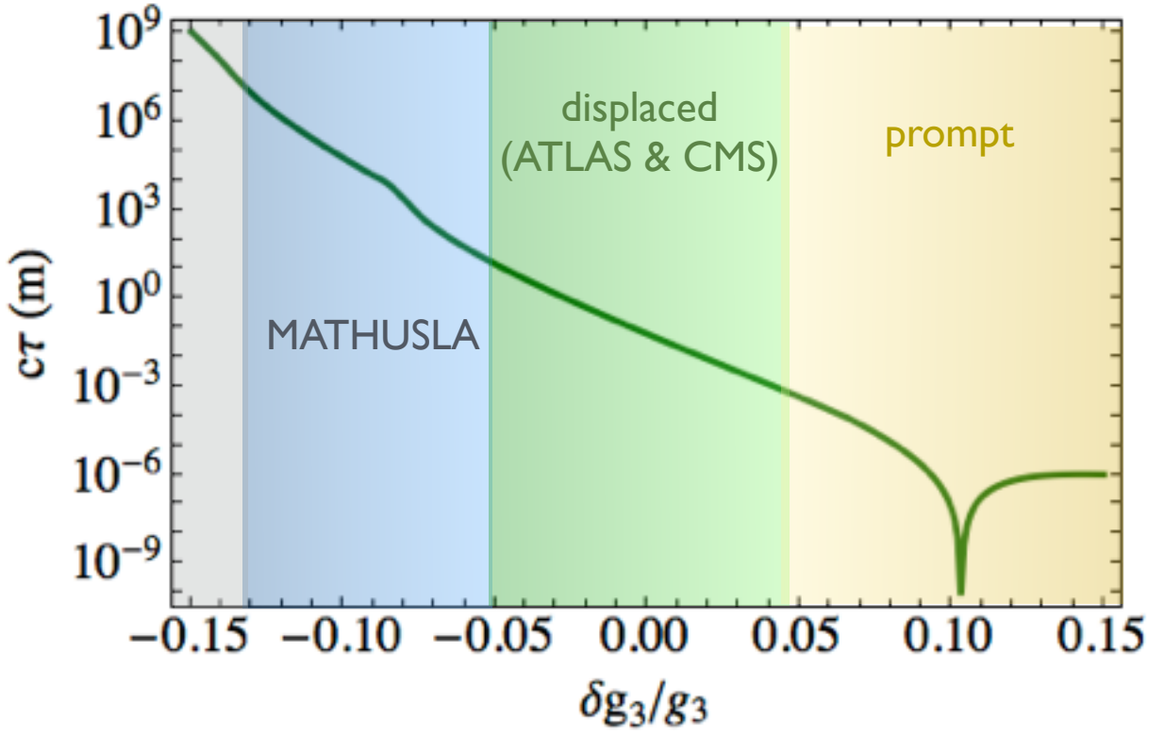


$$c\tau \sim 18\ \mathrm{m} \times \left(\frac{10\ \mathrm{GeV}}{m_0}\right)^{7}$$

(For hidden pions, see enormous diphoton literature!)

Example: twin Higgs



adapted from N. Craig, SK, P. Longhi, M. Strassler: 1601.07181

Dark photons

Decay through mixing with SM photon

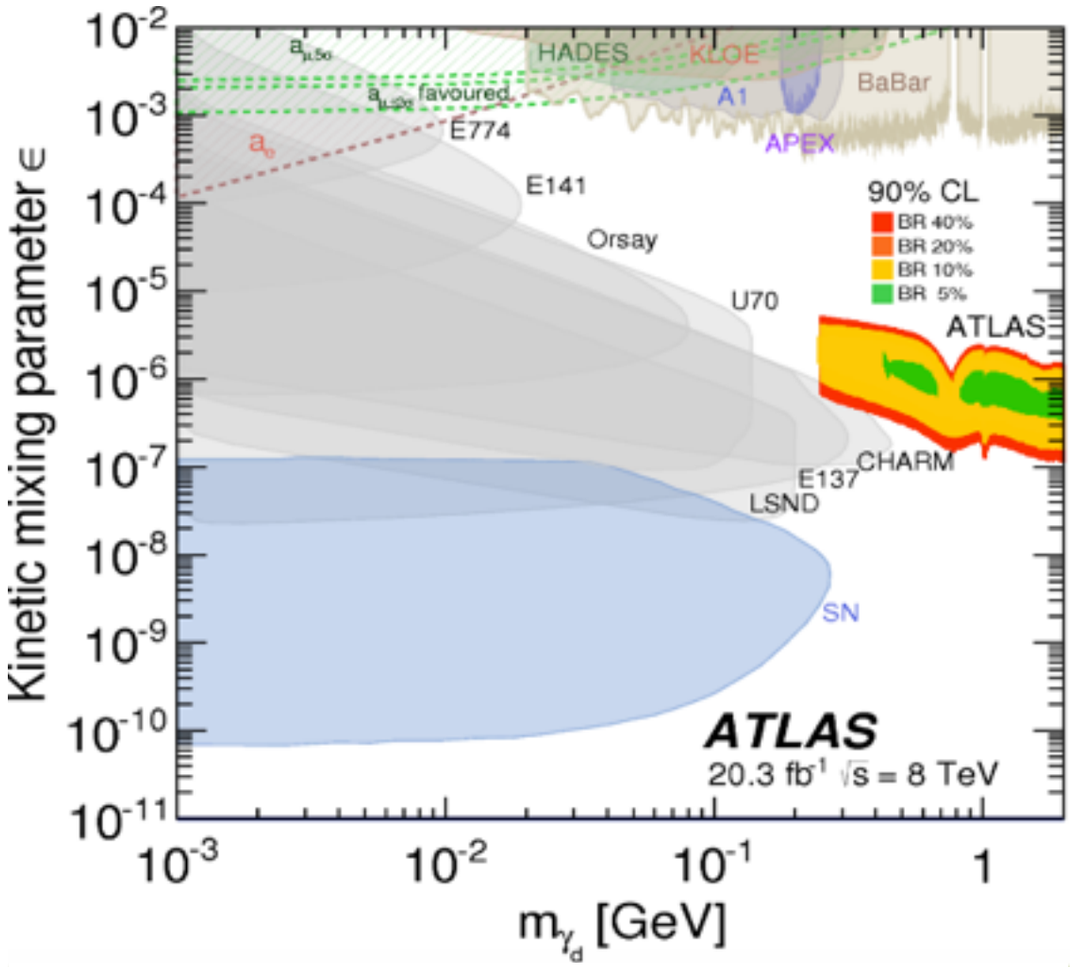
↓

To same flavor, charged states only

Strong complementarity with intensity frontier

- Off-shell decay
- Small splitting (phase space)
- Small coupling

$$h \to \gamma_d \gamma_d$$



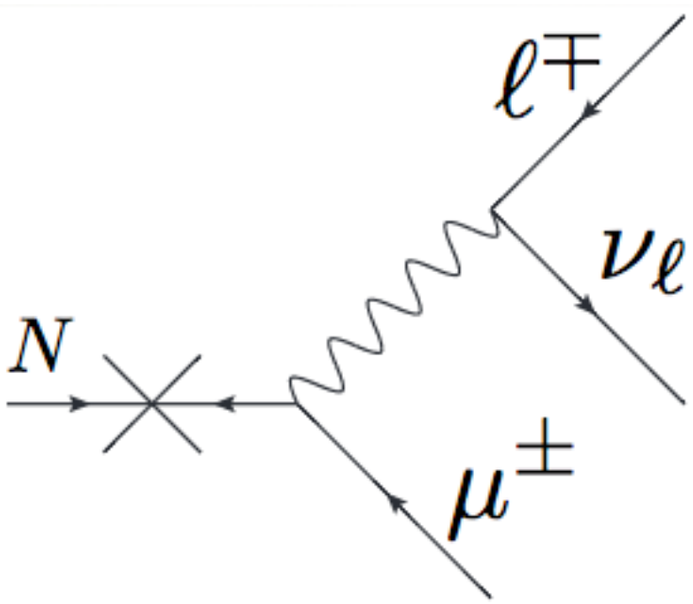
Sterile Neutrino's

Three-body decay

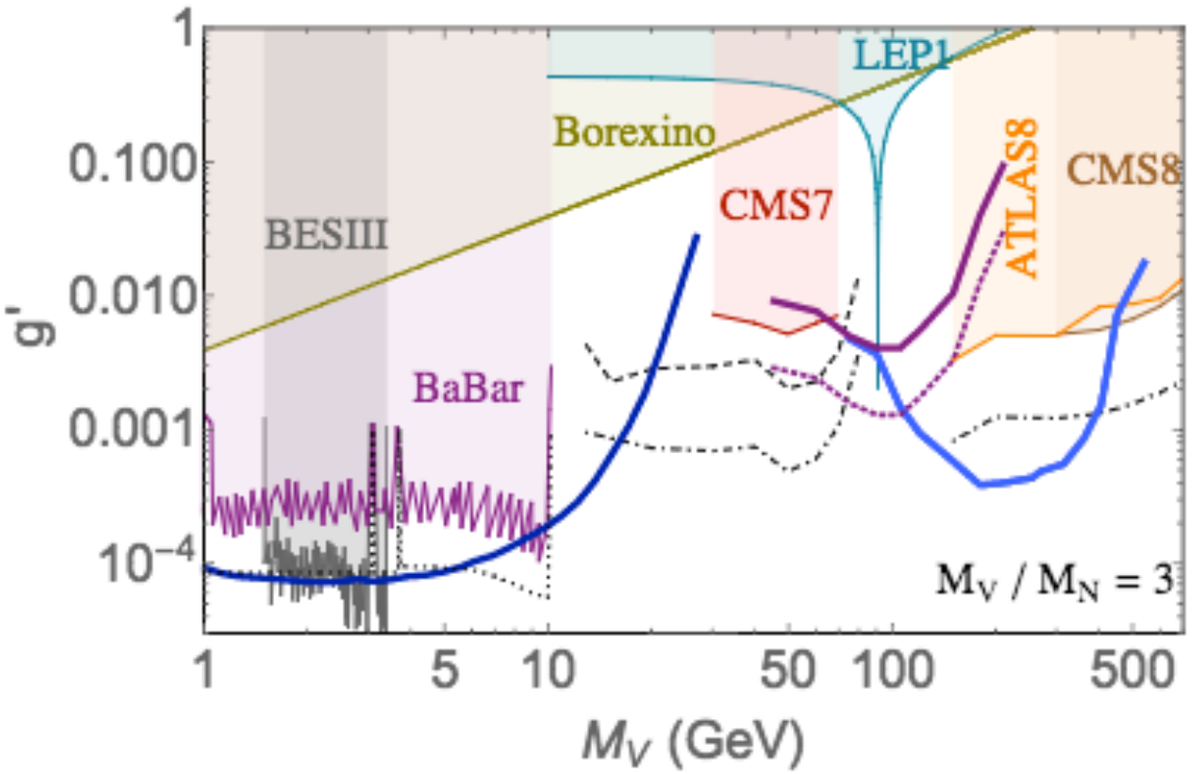
At least one lepton/neutrino

- Off-shell decay
- Small splitting (phase space)
- Small coupling

example:



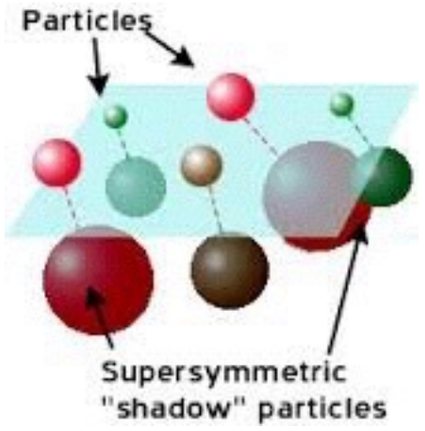
with vector portal



B. Batel, M. Pospelov, B. Shuve: 1604.06099

Back to our question

Central question:



Is SUSY a good benchmark generator of LLP's ?

Three categories:

1. Tracks (to primary vertex)
2. Displaced vertex with MET
3. Displaced vertex without MET

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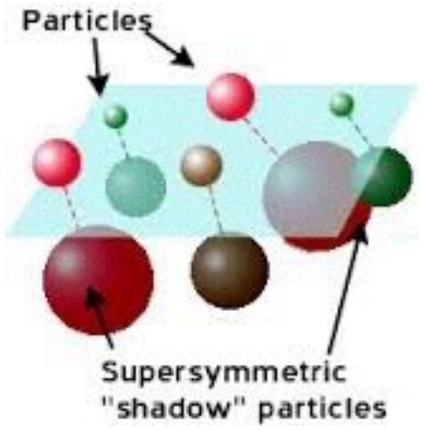

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Two crucial pitfalls!

(See later)

Tracks (to primary vertex)

Signature	Simplified Model	Covered?
Heavy Stable Charged Particles (HSCP)	Mini-Split / GMSB	✔
Disappearing tracks*	Squeezed chargino's	✔
Kinks	GMSB / RPV	Challenging, but decent coverage by other searches**
non-helix tracks	Quirks, Monopoles, …	(Poorly) covered by monojet search (See Tim's talk)

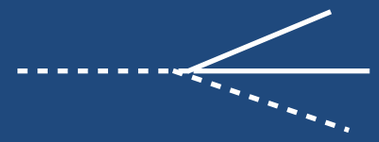
* very powerful, IF as inclusive as possible!

** see Z. Liu, B. Tweedie:1503.05923

SUSY

non-SUSY

Displaced vertex with MET



Signature	Simplified Model	Covered?
Z/γ + MET	GMSB	✔
h + MET	GMSB	covered by dijet
ℓ ℓ + MET	mini-split, RPV, sterile neutrino	✔
τ τ + MET	mini-split, RPV	probably covered
j j + MET	mini-split, RPV	✔
t t + MET	mini-split	probably covered
diboson (W,Z,γ) + MET	hidden valley ?	probably covered

SUSY

non-SUSY

Displaced vertex without MET

Signature	Simplified Model	Covered?
j j	RPV, dark photon	✔
ℓ ℓ	RPV, dark photon	✔
τ τ	RPV, dark photon	probably covered
γ γ	dark pion	depends on lifetime
t t	scalar mixed with Higgs	probably covered
diboson (W,Z,γ)	dark pion ?	probably covered

(For non-trivial flavor, use RPV)

SUSY

non-SUSY

Pittfals

Sources of theory bias:

1. Production mode: SUSY comes with a specific set of production topologies

   → Try to be as inclusive as possible

   (see Yuhsin's talk)

Pittfals

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   (see Yuhsin's talk)

2. Multiplicity: SUSY tends to emphasize pair production

   → Obvious fix: when possible, also look at case with single displaced object

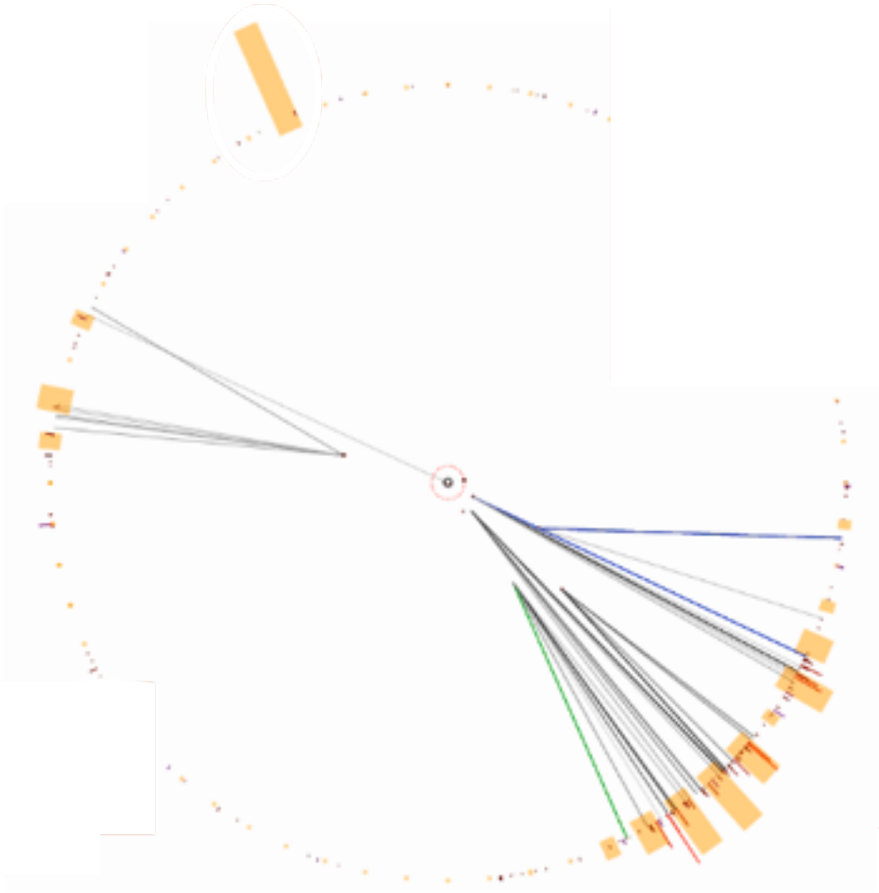
   But for hidden valleys, this may not be enough!

Hidden valleys

M. Strassler, K. Zurek : 0604261, …

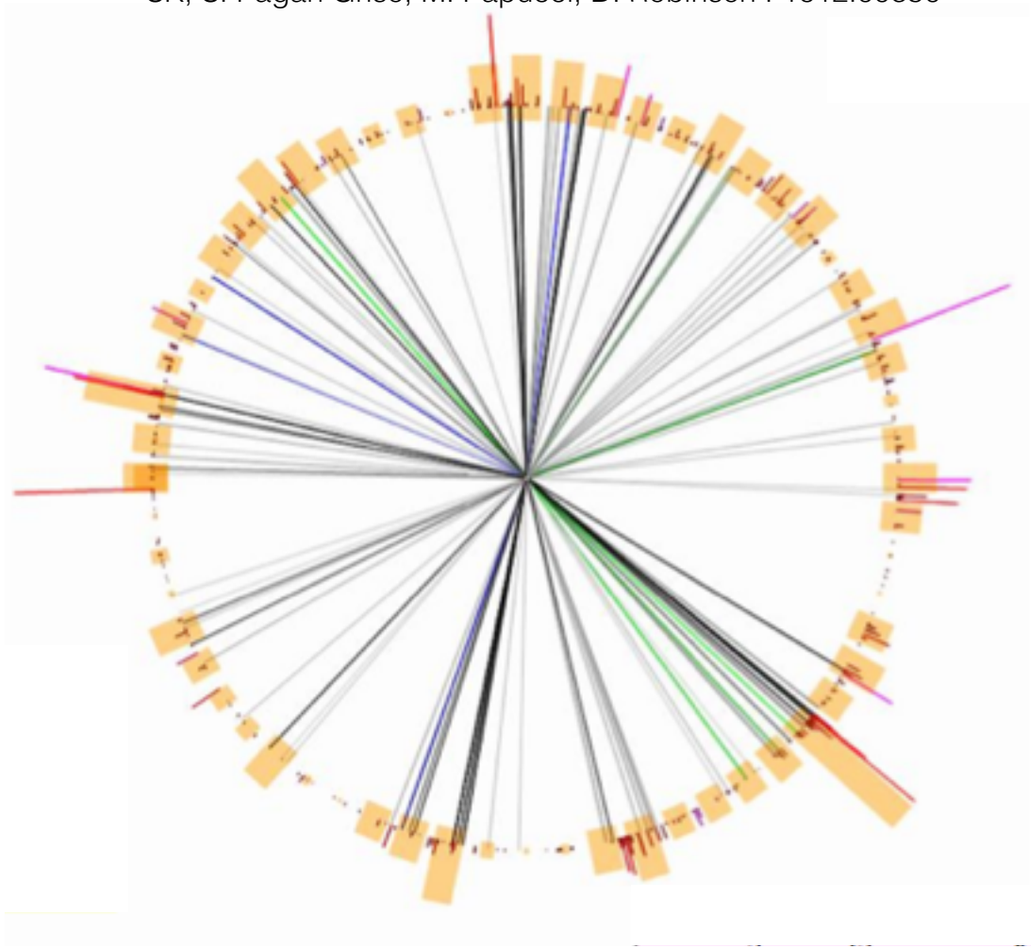
“Emerging jets”

P. Schwaller, D. Stolarski, A. Weiler: 1502.05409



“Soft Bombs”

SK, S. Pagan Griso, M. Papucci, D. Robinson : 1612.00850



- Larger multiplicity of softer vertices
- Generically comes with MET (some HV particles are likely stable / very long-lived *

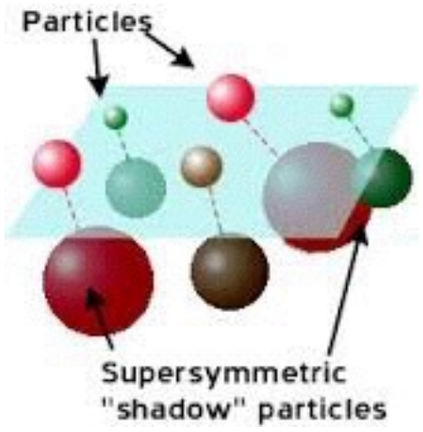
* leads to “semi-visible” jets: T. Cohen, M. Lisanti, T. Lou: 1503.00009

Event displays by Matt Strassler

(My) conclusion

Central question:

Is SUSY a good benchmark generator of LLP's ?



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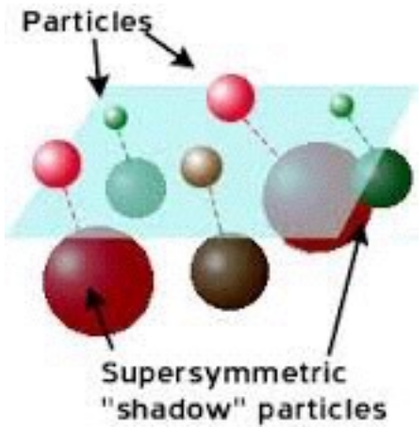

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SUSY is a good place to start, but a bad place to stop (e.g. hidden valleys!)

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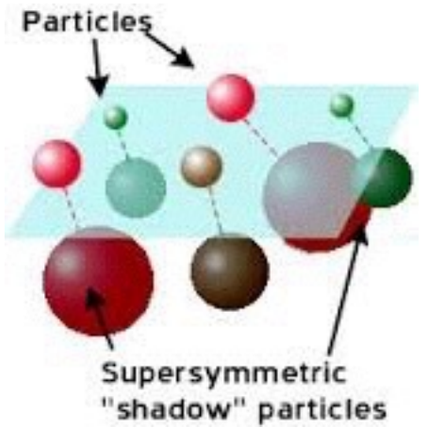

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To keep in mind when using SUSY:

1. There are decay topologies NOT covered by SUSY
2. Beware of hidden assumptions on production modes
3. Beware of hidden assumptions on multiplicity