The Hidden Valley Scenario: A Generator of Models with Exotic Phenomenology

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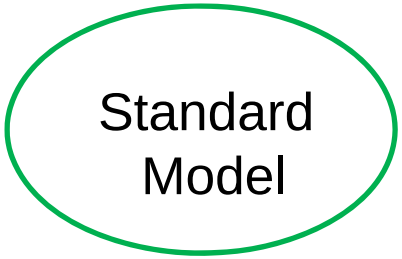
Plan

Mixed audience – Will focus on motivation and general implications

- What is a Hidden Valley?
- The HV FAQ
- General predictions of HV
- Strategies to look for HVs

Cartoon of Particle Theory of Recent Decades



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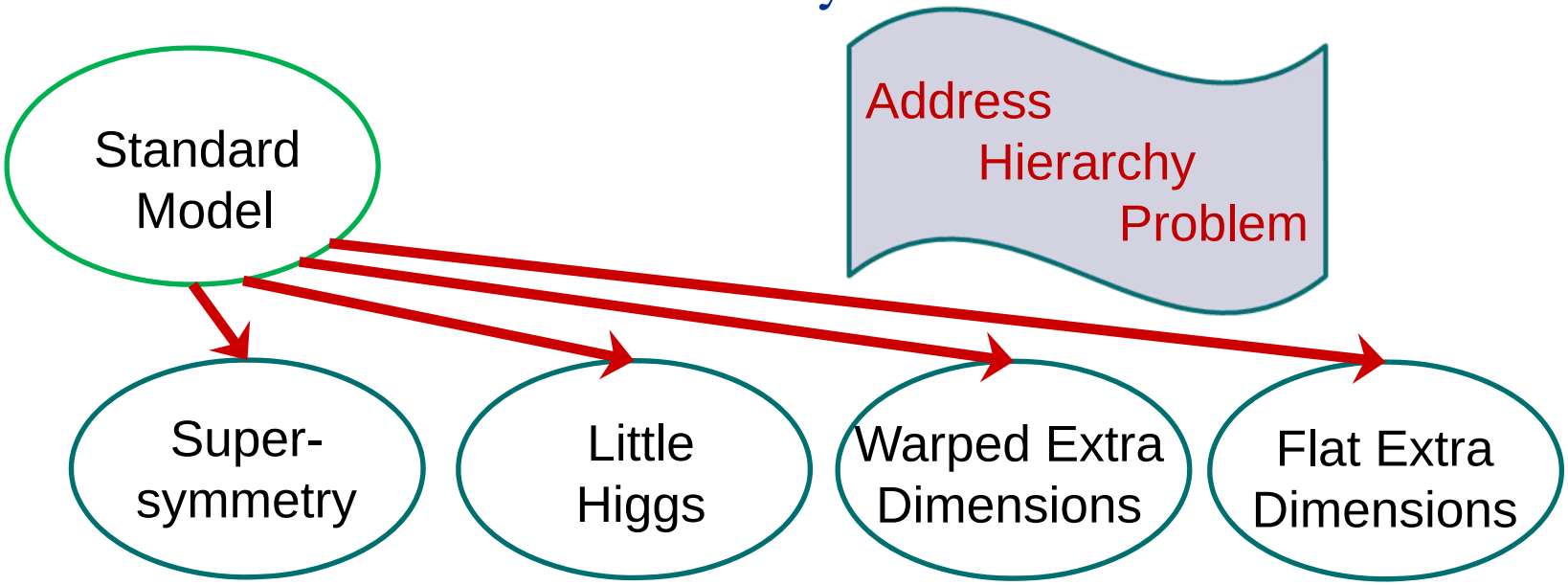

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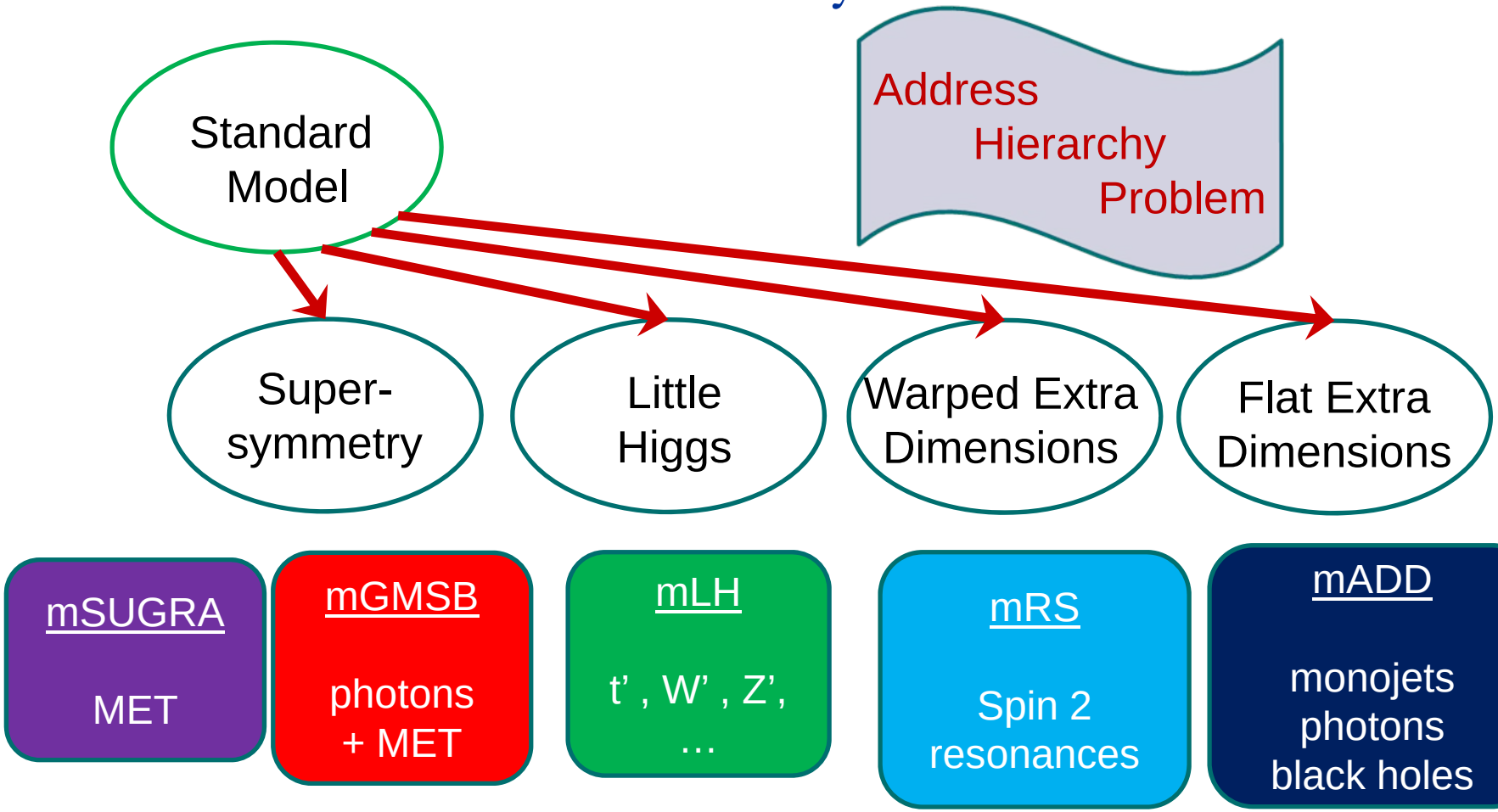


See for example talks by C. Wagner, B. Grinstein

Slide from Carlos Wagner's talk

Important remarks

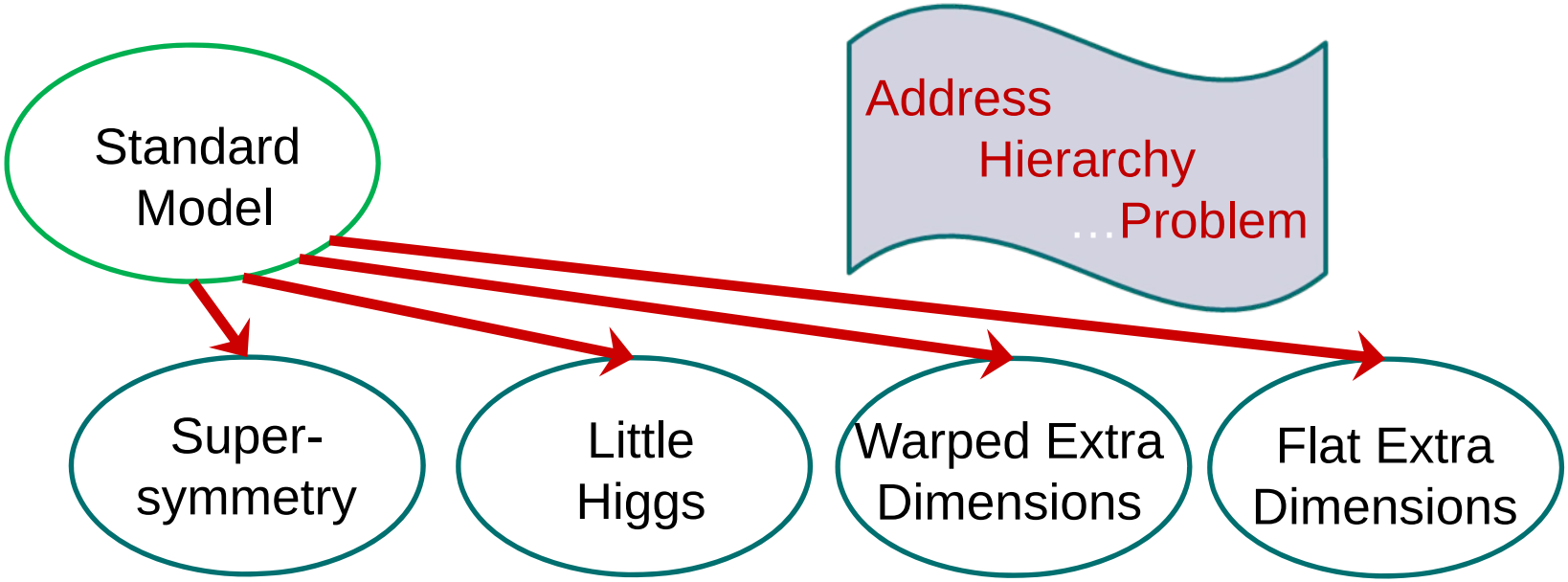
BUT HE SKIPPED IT !!

- I have presented only some simple, representative models. By no means should the particularly predictions of these models be considered general.

- For instance, the relation between the gaugino masses may be different from the one presented above, leading to different phenomenology. Anomaly mediation, in which the gaugino masses are proportional to the beta functions is an example.

- There may also be extended gauge symmetries that can affect the dynamics, particle content and RG evolution of parameters, as well as extra chiral fields, for instance singlets. An example will be presented below.

- The exact dynamics at the weak scale and the origin and nature of supersymmetry breaking is still unknown. We expect experiments to guide us in that direction. Marcela Carena will discuss some of these subjects. Collider signatures will be presented later.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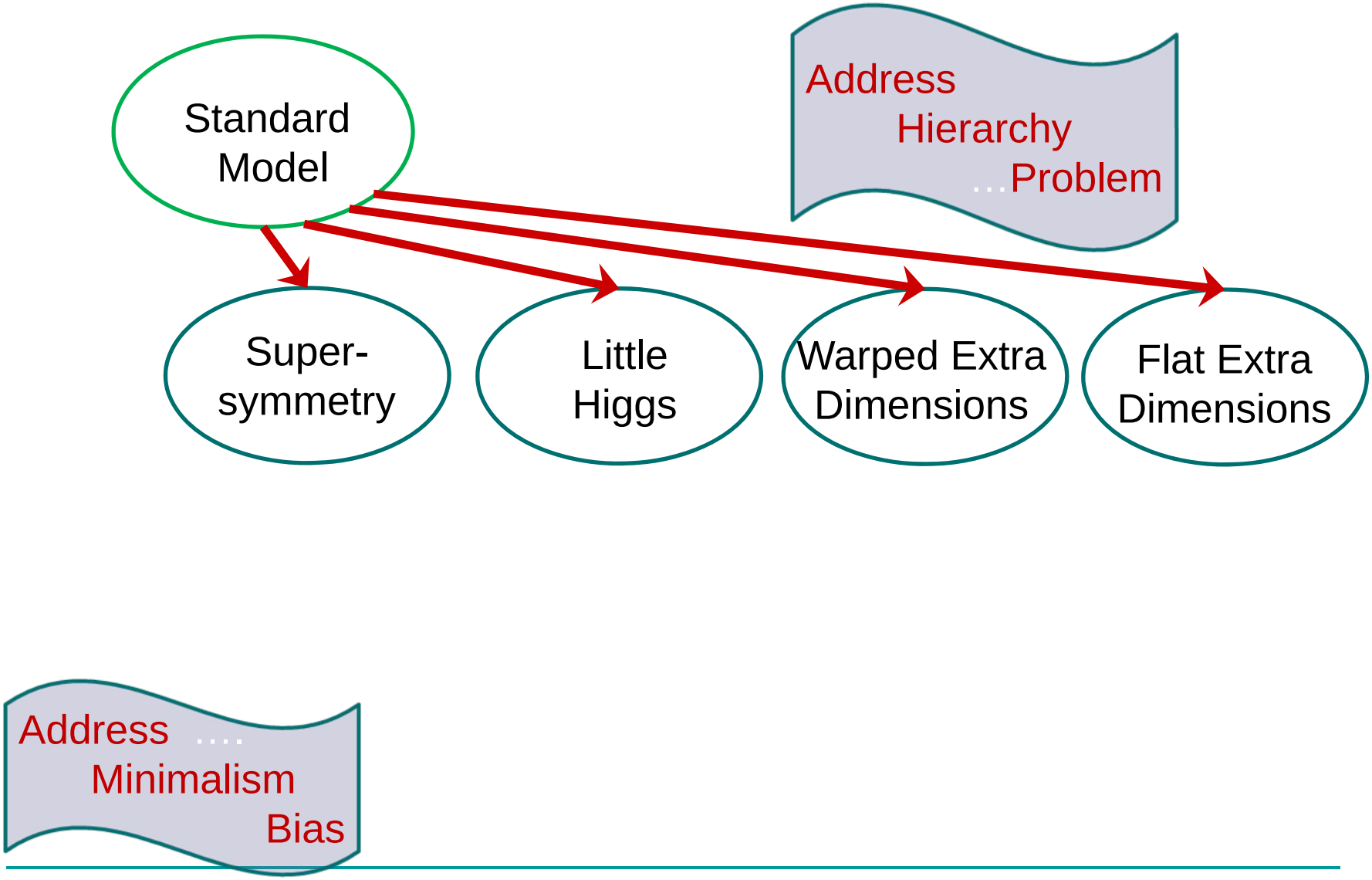
Address Hierarchy …Problem
Super-symmetry
Little Higgs
Warped Extra Dimensions
Flat Extra Dimensions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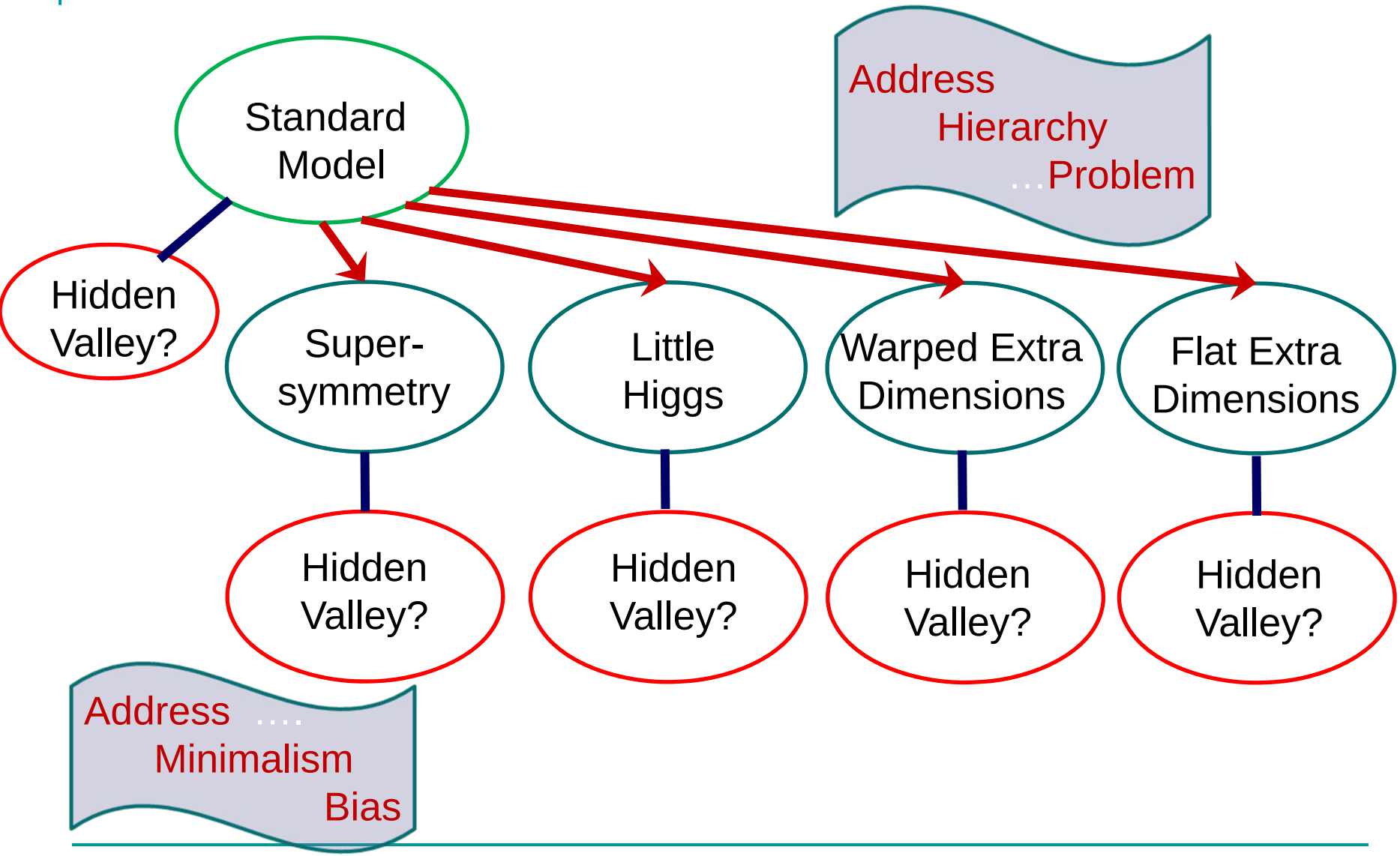
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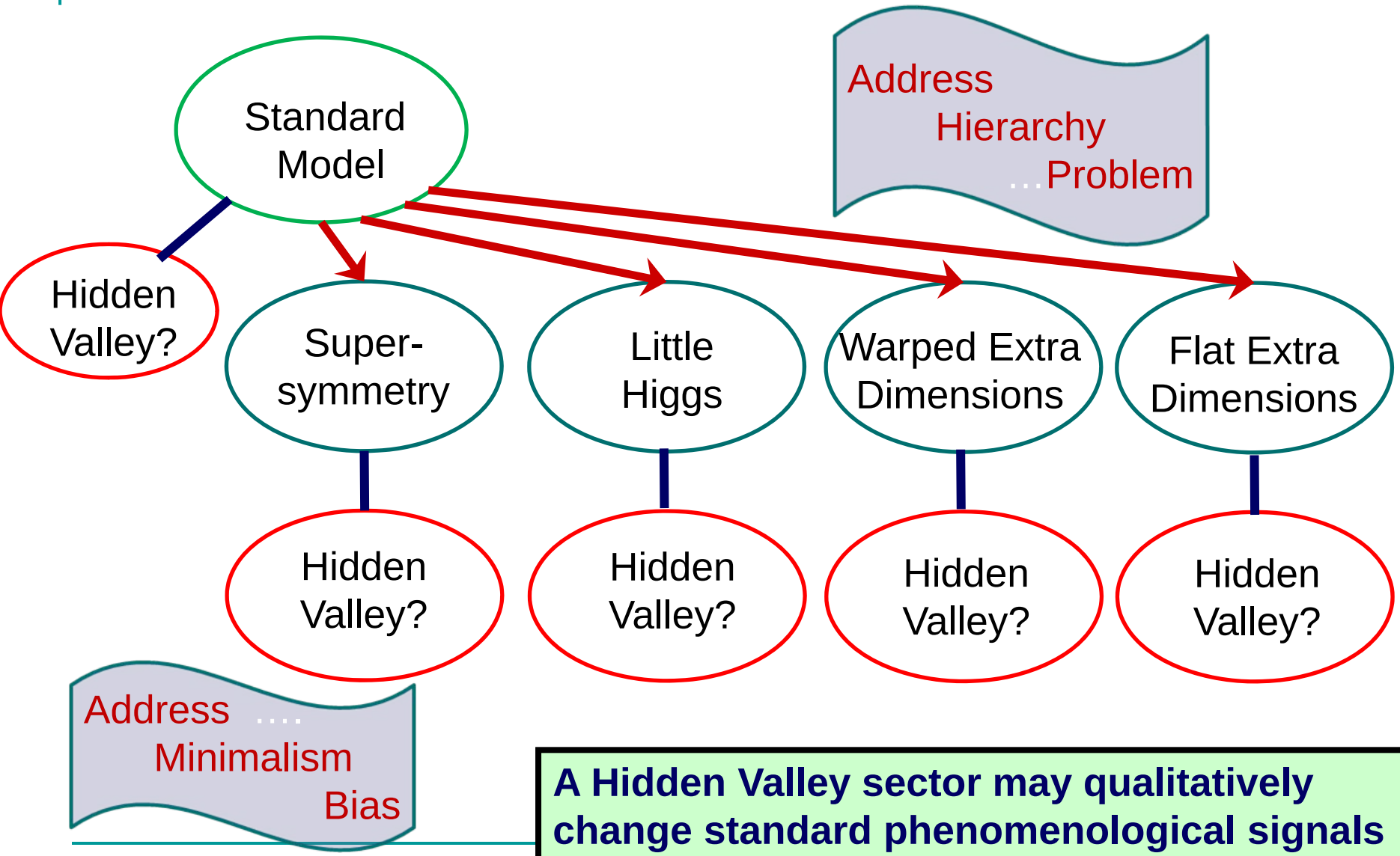

A Hidden Valley sector may qualitatively change standard phenomenological signals

What is a "Hidden Valley"?

A unexpected place …

… of beauty and abundance …

… discovered only
after a long climb …

What is a "Hidden Valley"?

- Take any "Hidden Sector" of particles and forces
  - Matter not charged under the known gauge forces (EM, weak, strong)
  - May have very light particles (<< 100 GeV)

- **If** mass gap …
  - No massless particles (no unbroken scale invariance)
- …**and** coupled to SM at the 100 MeV – 100 TeV scale
  - Many different mechanisms to do this

- **Then** some new heavy particles (or even W/Z/t) may decay to hidden sector
- And (**if mass gap not too small**)

  some hidden particles may decay back to SM particles
  - On measurable time scales!!
  - ➔ **Remarkable range of diverse and unusual experimental signatures**

Very limited constraints from colliders, cosmology, precision tests

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Extremely General !!

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The HV FAQ

FAQ: Why is minimalism bias a problem at LHC?

A much bigger problem at a hadron collider than it would be elsewhere

- LHC produces 10^{13} – 10^{16} collisions per year
- Only (!) $10^{9\text{-}10}$ are stored
  - Trigger with as little as 10^{-6} overall efficiency – requires good strategies
- 10^9 is a huge number; perhaps few 1000 are signal of new physics
  - Event reconstruction must be automated
  - New physics search analysis selects events with typical 10^{-6} efficiency

Any failure of trigger, reconstruction or analysis strategy can eliminate a signal

If no one proposes a particular phenomenological signature,

- No one may ever look for it
- **No one may find it accidentally using standard methods!!!**

Plenty of examples at Tevatron and even LEP

FAQ: Isn't this an infinite problem?

- There are an infinite number of types of hidden valley models

This is a very large problem, but not infinite, and not entirely out of control

Many models give similar signatures

- And some signatures arise more easily than others
- And not all signatures are theoretically reasonable

Thus classification problem can be divided and organized

Also there are general characteristics that are

- Very common in HV models
- Much less common in the literature on minimal models

In this sense, models with an HV make a general set of predictions

MJS + Zurek 06

Typical of Hidden Valleys (and not minimal models)

New neutral particles – may be

- Many in Number
- Light
- Long-Lived
  - Possibly w/ displaced decays
- Lorentz-Boosted
- High in Multiplicity
- Oddly Clustered/Distributed

Produced most commonly in decays of

- Higgs(es)
- LSP/LKP/LTP (not necessarily neutral)
- Techni-resonances ; RS-gravitons
- Z'
- Quirk-onium
- Black Holes or Excited Strings
- Radiated off new particles
- Rare Z/W decays

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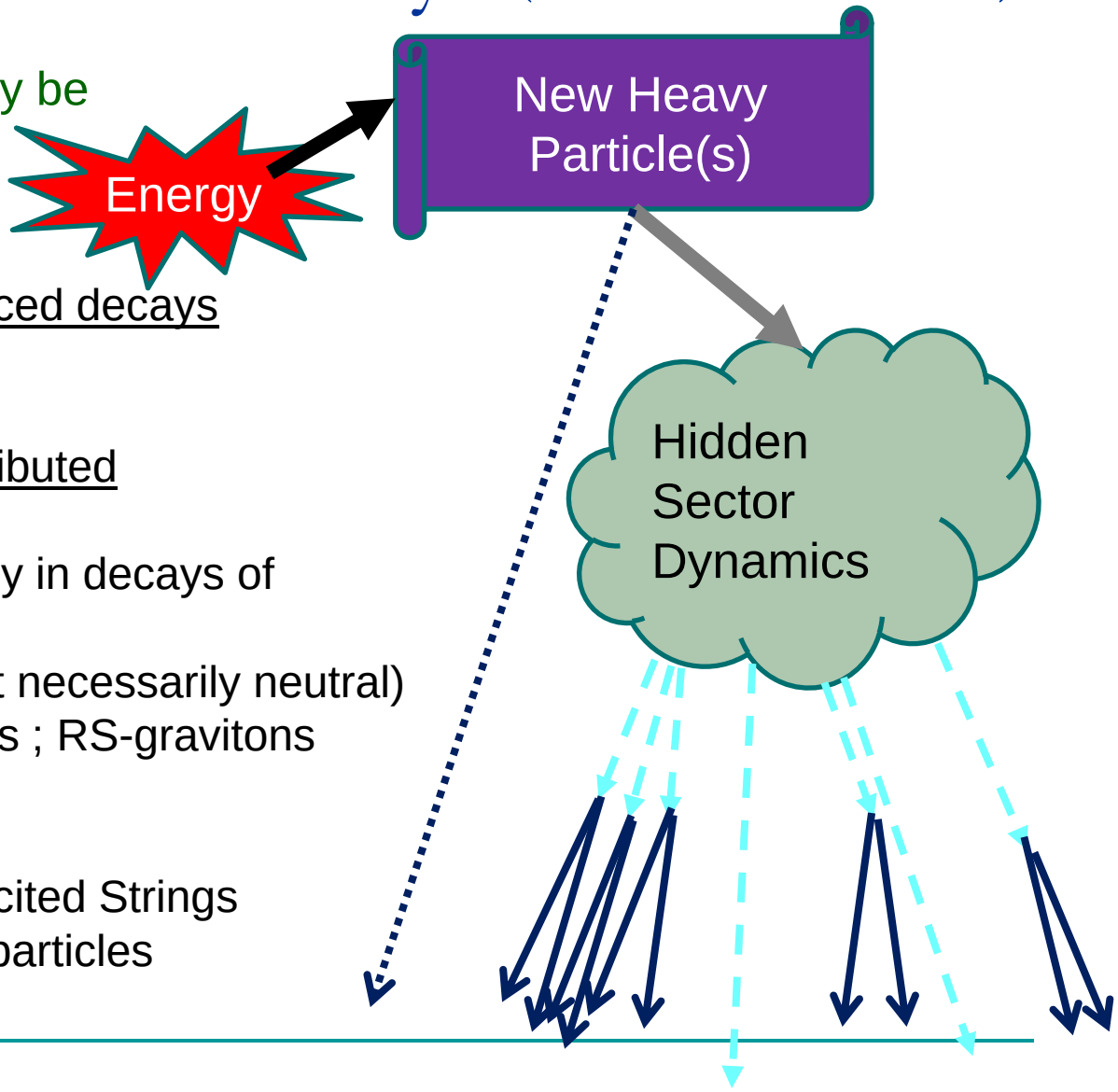

Typical of Hi

New decay channels and signatures absent in minimal version of favorite model

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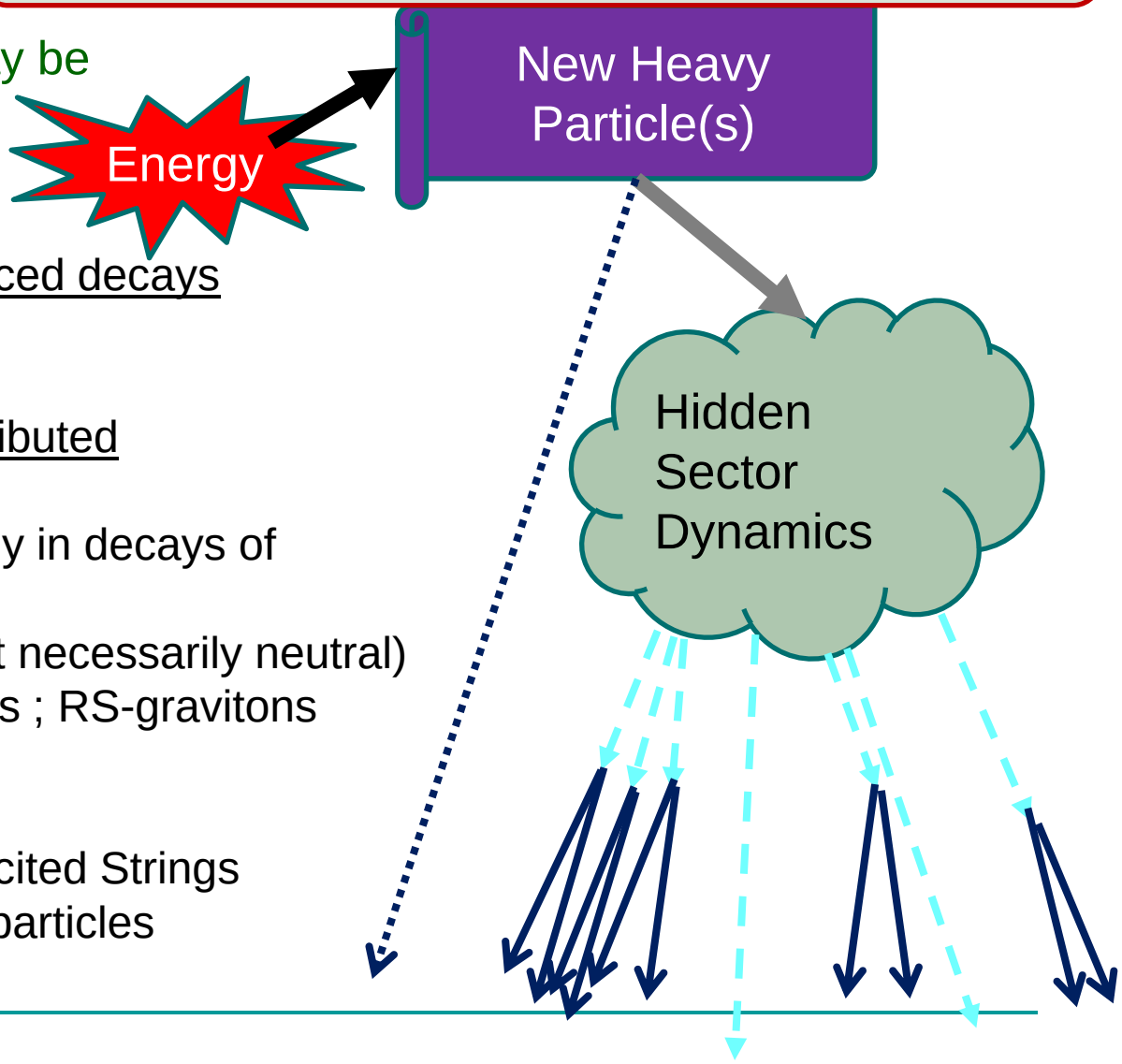
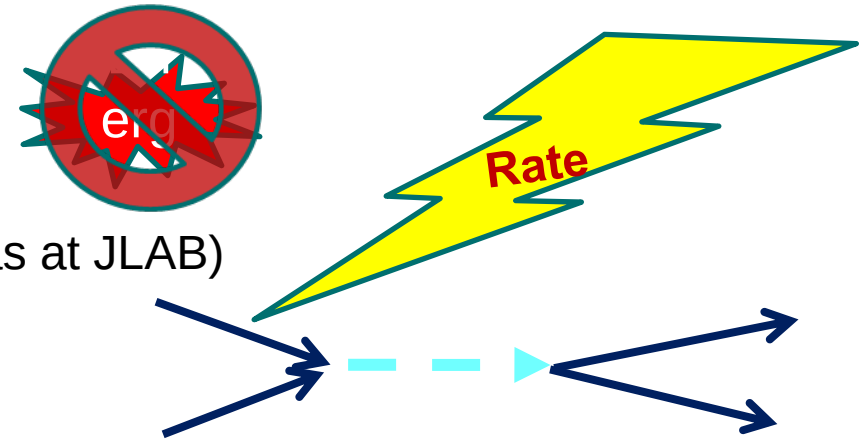


Interesting for other communities?



- **Motivation for Luminosity Frontier**
  - Super B factories, GigaZ
  - Extreme-intensity low-energy e+e- (as at JLAB)
  - Beam dumps
- Could give new cosmic ray signals
  - probably out of reach now but not forever
- Possible Source of Sterile Neutrinos
- Possible Home of Dark Matter
  - with cosmological and astrophysical implications
- Probably not connected with flavor … but…

However,

FAQ: Isn't HV unmotivated?

- 2006: MJS and Zurek:

  one **general** motivation for hidden valleys is dark matter.

- 2008: Arkani-Hamed, et al.; [Pospelov et al.]
  - PAMELA/ATIC results motivate **specific** subclass of hidden valleys ("dark sectors") with a dark vector boson mixing with photon.

LESSONS:

- Caution: Motivation is time-dependent.

- Nature has handed us apparently unmotivated phenomena before.
  - Who ordered the muon?
  - Why expect neutral currents?

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EXAMPLE:

Dark Sector with **Dark Photon** and **Lepton-Jets**

Pospelov et al.
Arkani-Hamed et al
Arkani-Hamed & Weiner

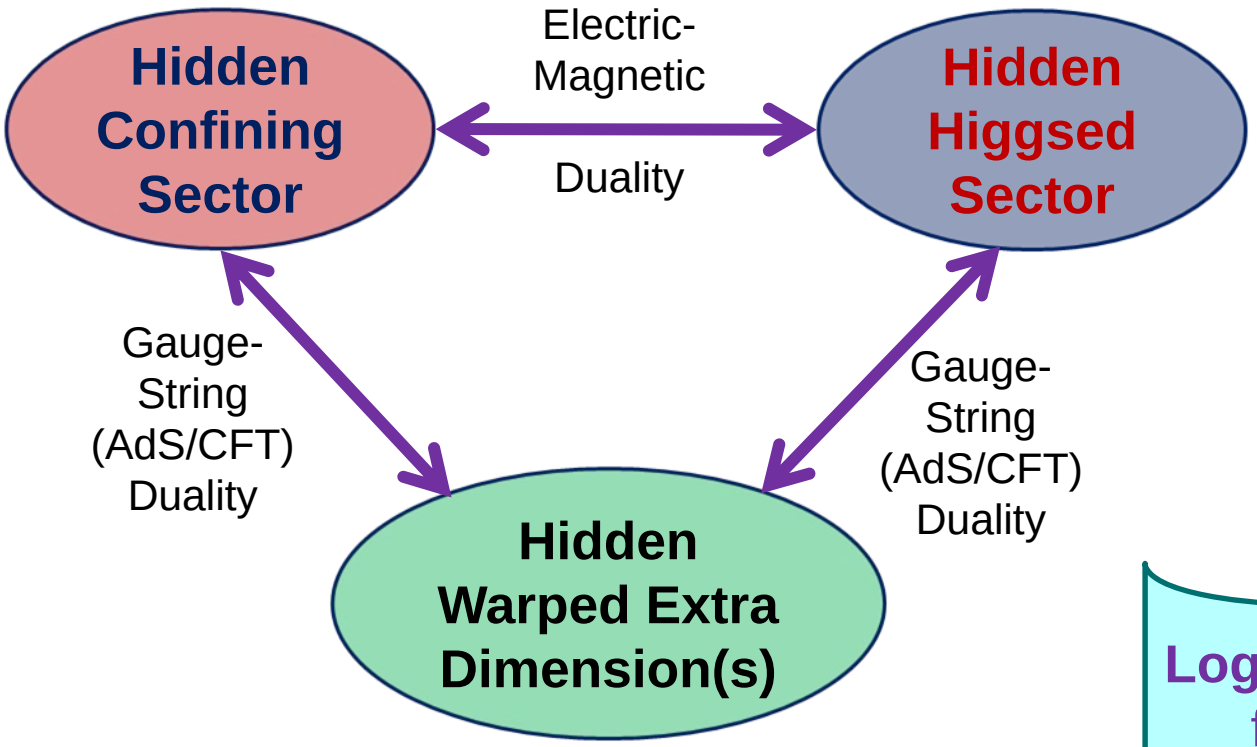
FAQ: Isn't HV unmotivated?

Beyond dark matter, two other important motivations

- String theory **NEVER** generates the simplest version of any model
  - If string theory predicts anything, it is that the world will not be minimal
- GMSB SUSY breaking can leave low energy remnants

But the experimental motivation described above is perhaps the most important

FAQ: Is a HV a confining hidden sector?



Logically Impossible
for one to be a HV
but not the others

FAQ: Do HVs predict highly displaced vertices (from new long-lived particles) ?

Not all Hidden Valley models will give this signature – BUT

- HV sectors make long-lived particles with displaced vertices **much more likely**
  - Many new metastable particles [just like QCD hadrons]
  - Widely varying lifetimes [just like QCD hadrons]
  - Compare with GMSB: only one new metastable particle (NLSP)

Note that if these arise in low-energy processes, triggering can be issue

Reconstruction can be an issue if lifetimes are sufficiently long

New Decays: Higgs

MJS + Zurek 06

- Easy to give H exotic decays using new particles (including HV sectors)
  - H → aa → 4 b's, 4 taus
  - H → ss → aaaa→ 8 b's
  - H → vv → 4 leptons
  - H → (vvvv) (vvvv) [lepton-jets]
  - … … …

e.g. Dermisek Gunion 04

Cheng, Fox, Weiner 05

MJS 08; Gopalakrishna et al 08

Arkani-Hamed Weiner 05

Dobrescu , Landsberg, Matchev 01

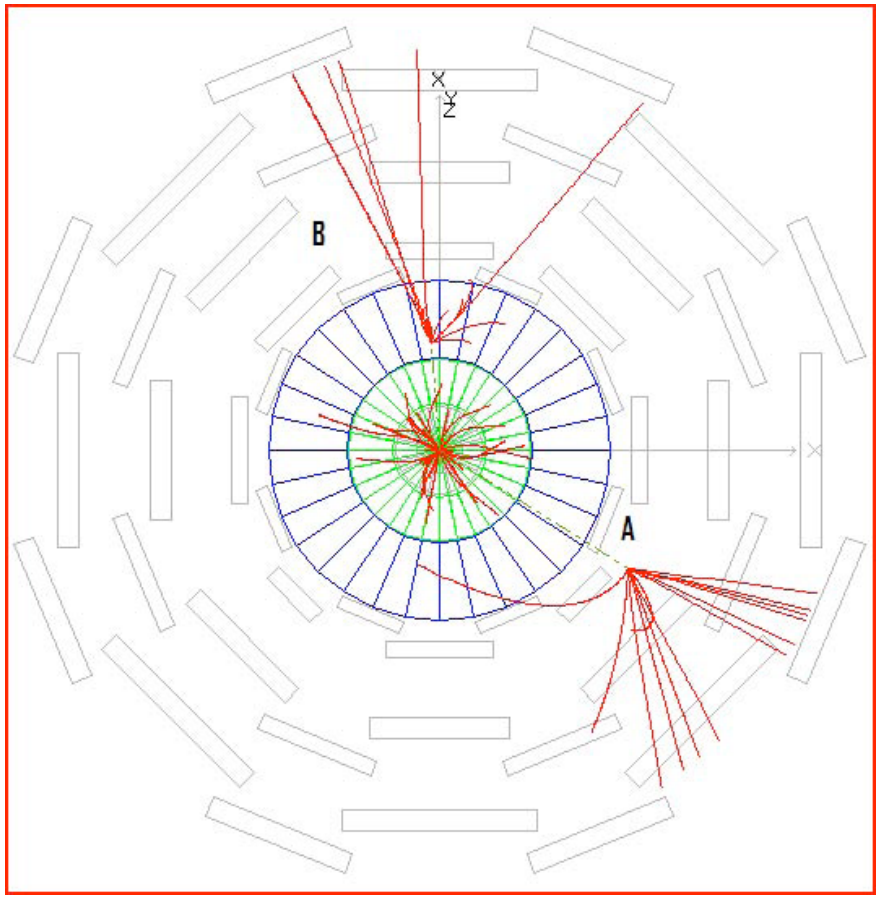
If no Higgs by 2014-15 in standard channels, need open minds !

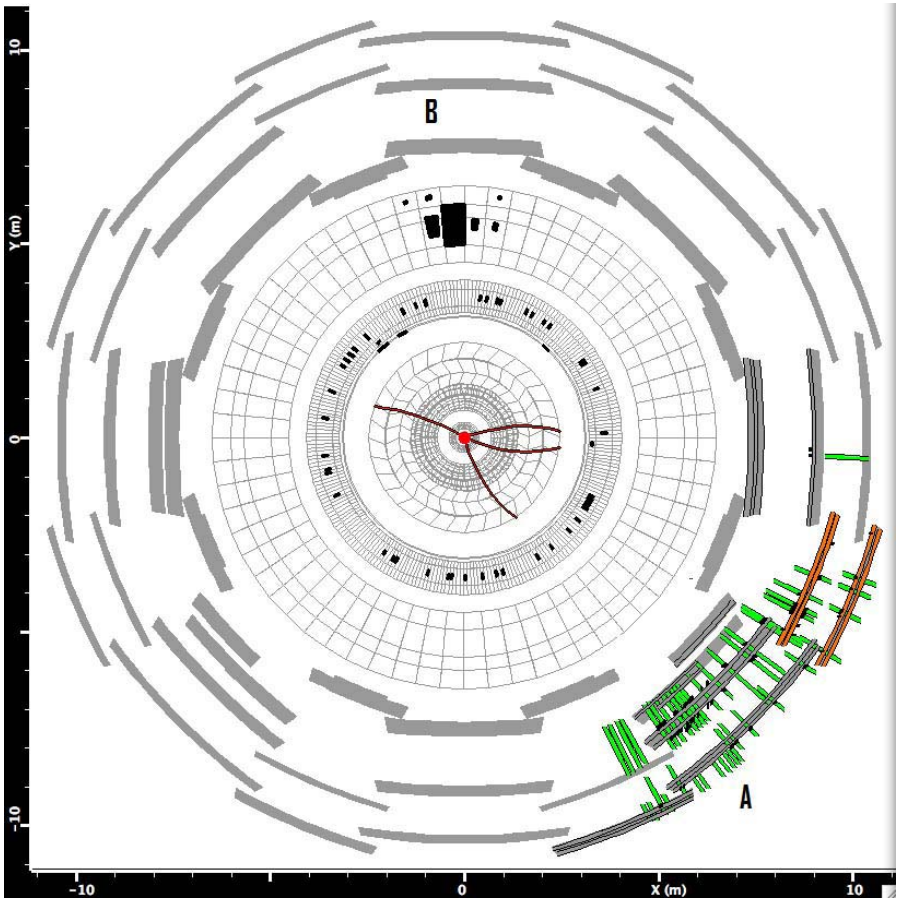
- Some of the new particles can be long-lived

MJS+Zurek 06
See also Carpenter et al 06

Because Higgs is light, in some cases this creates an urgent issue: trigger

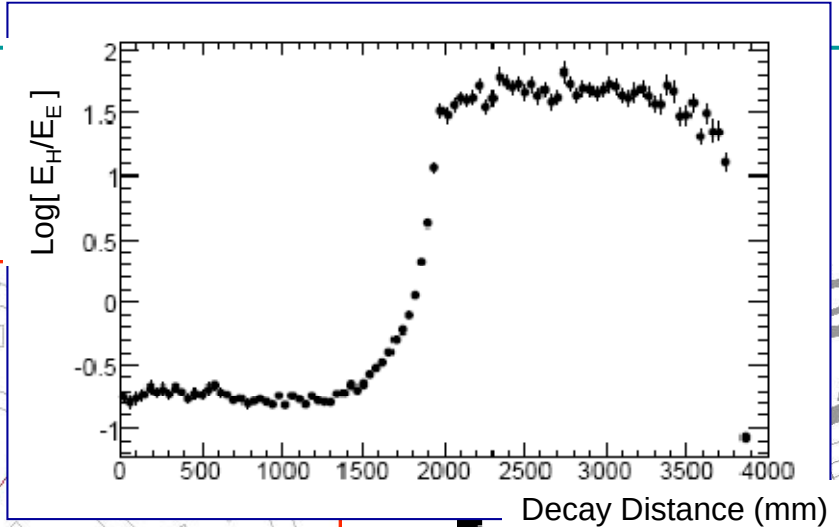
ATLAS
Public note

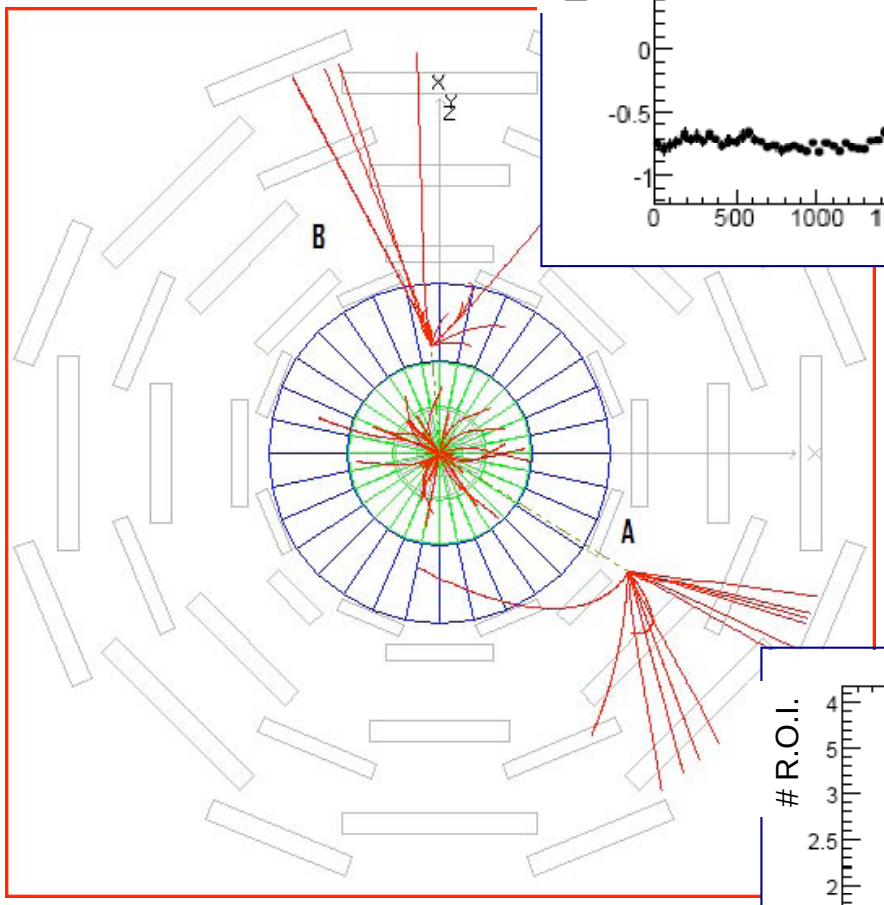


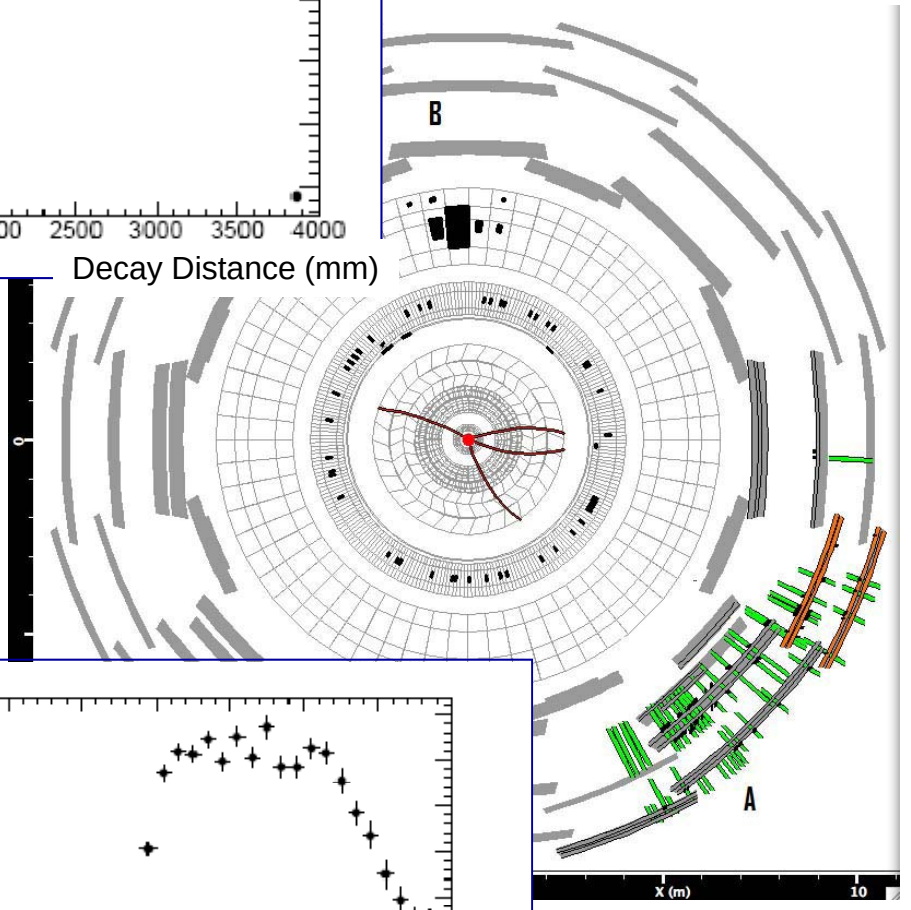


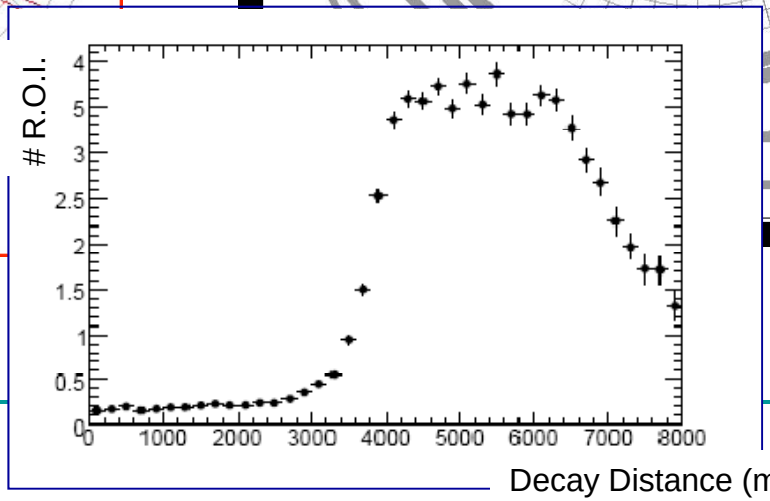
Decay Distance (mm)

ATLAS
Public note









New Decays: SUSY

MJS 06

mSUGRA: jets (leptons) + MET

GMSB

more complicated

(often easier)

- If Gravitino LSP ➔
- Lightest SM sparticle is NLSP
  - NLSP decays to partner + MET (Gravitino)
  - so not necessarily neutral
  - and may be long-lived

With HV

much more complicated

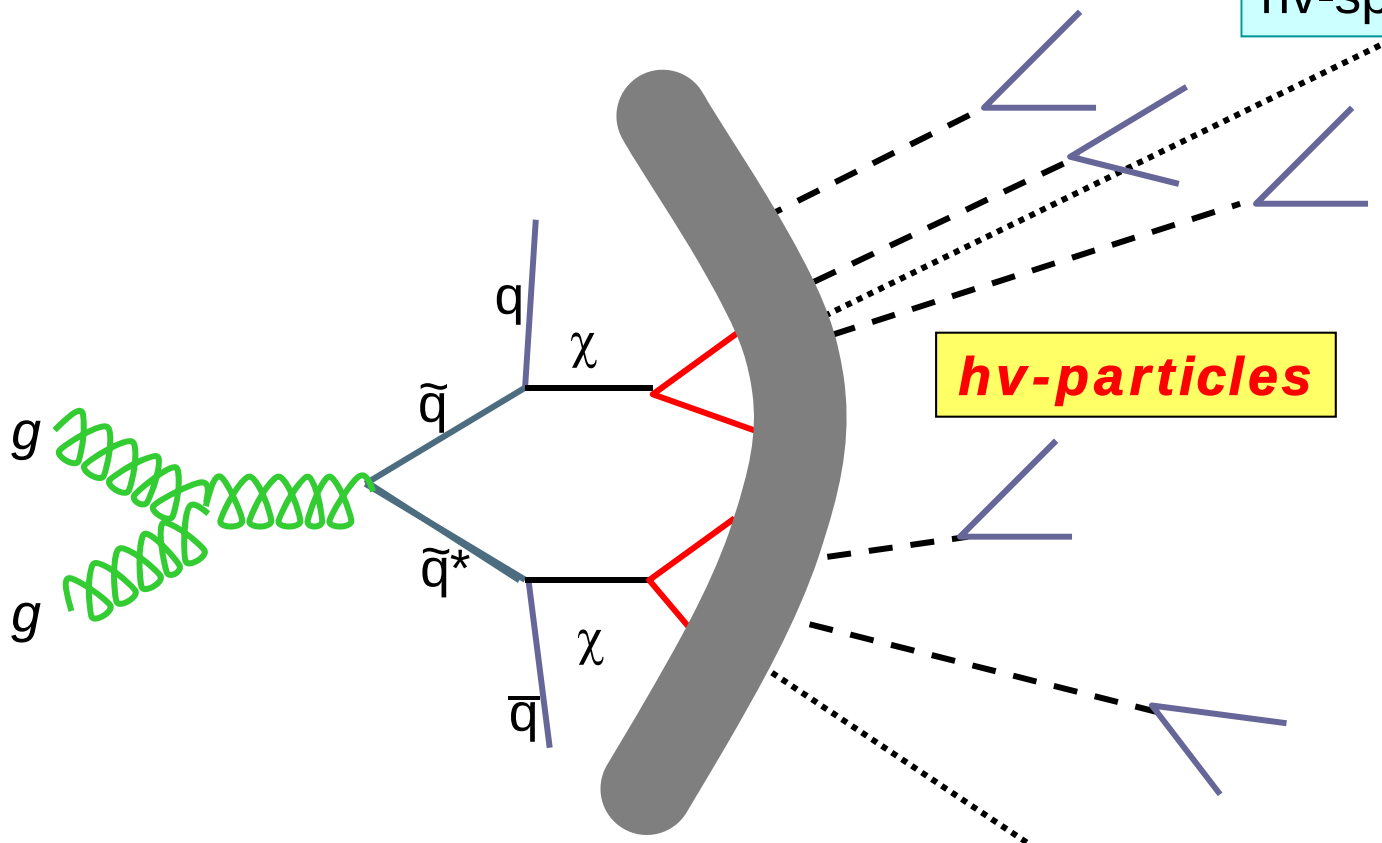
(may be easier or harder)

- If LSP is in HV ➔
- Lightest SM sparticle not LSP
  - SM LSP decays to partner + HV particle(s)
  - so not necessarily neutral
  - and may be long-lived
- Then HV particles might decay
  - and may be long-lived

SUSY decays to a hidden valley

MJS July 06

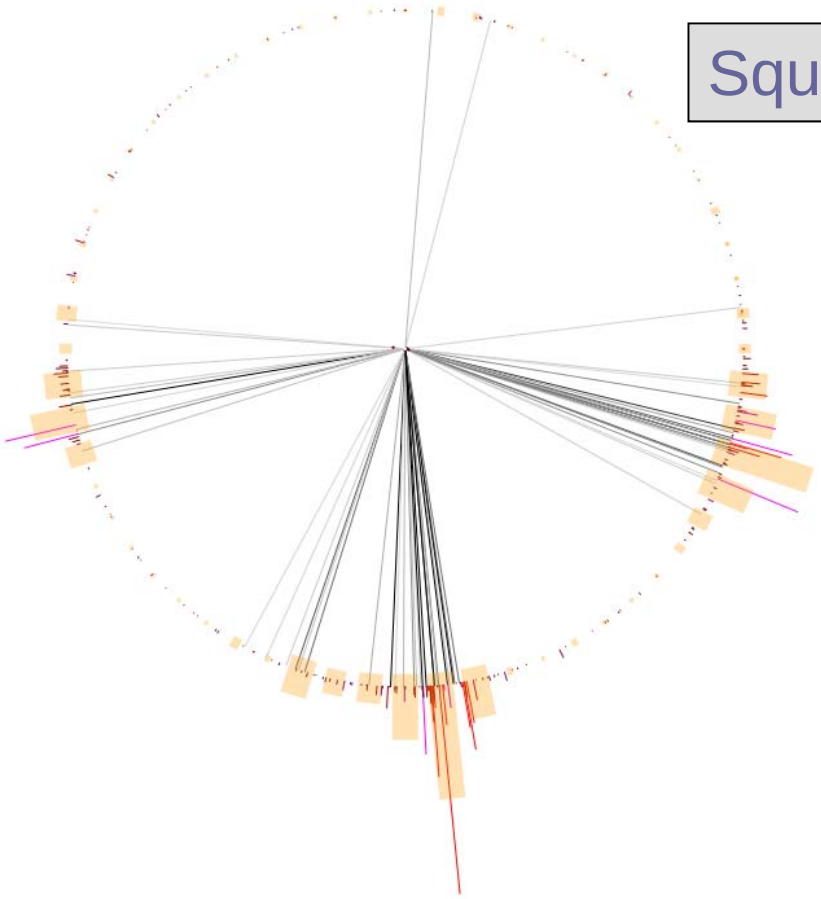
The lightest hv-sparticle (LSP)



The traditional missing energy signal is replaced with multiple soft jets/leptons, reduced missing energy, and possibly multiple displaced vertices

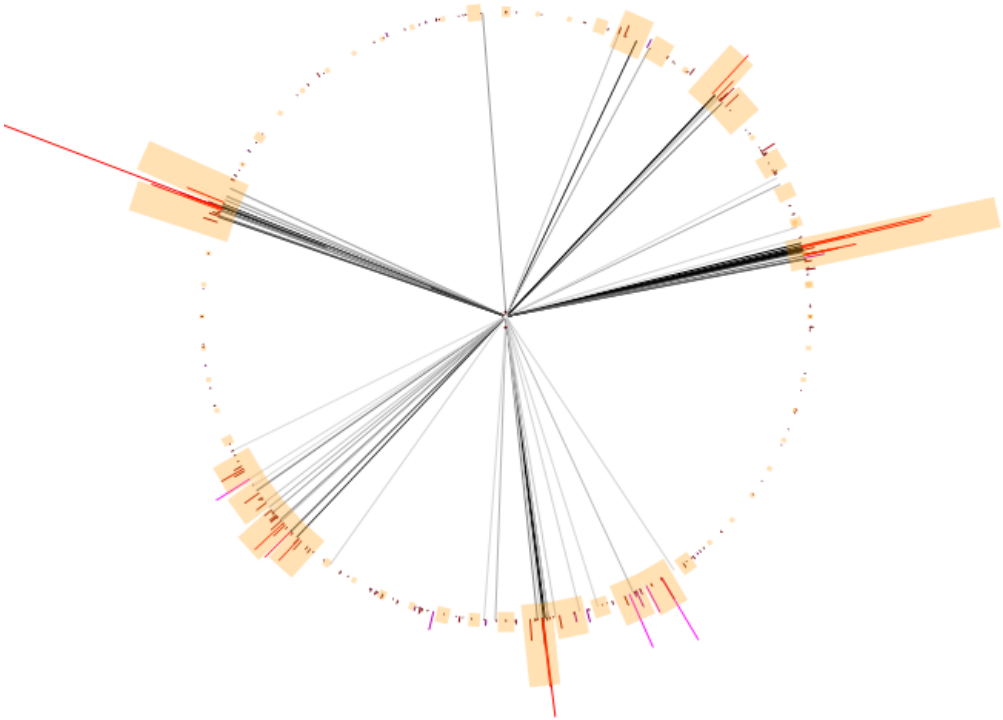
The lightest hv-sparticle (LSP)

Squark-Antisquark Production at LHC



Stable Neutralino

Unstable Neutralino
Decaying to hv-Sector



Hacked simulation using
Hidden Valley Monte Carlo 1.0
Mrenna, Skands and MJS

Average MET can drop significantly

New Decays: Gravity Effects

MJS unpub

- Take RS: If couplings of a KK graviton are universal [not guaranteed]
- And the HV has more degrees of freedom than the SM [easily could]

Then the dominant decays of a KK graviton will be to HV particles, not SM

  - Resonance could be much wider than expected
  - Much lower peak cross-section for photon pairs, electron/muon pairs

- Could be largely invisible
- Or dominant decays to two jets containing multiple dark photons
- Or dominant decays to spherical distribution of dozens of b pairs
- Or … etc … etc … etc …????

Same discussion applies for Black Holes, ADD graviton exchange

Lessons:

- Conventional wisdom about what a model predicts assumes minimalilty
- Even slightly nonminimal models can look very different
  - (mSUGRA → mGMSB, MSSM→NMSSM)
- A hidden sector can be vastly non-minimal
  - Many new degrees of freedom, wide range of decay channels
  - Complicated dynamics that theorists may not even be able to predict

Thus: any given solution to hierarchy problem can give vast array of signatures

So what should we do?

- There are too many possible models for model-based searches.

- Return to the HV predictions, pursue quasi-model-independent approaches.
- Focus especially on non-standard event selection and analysis techniques

Early Search Strategies

Non-Standard Selection

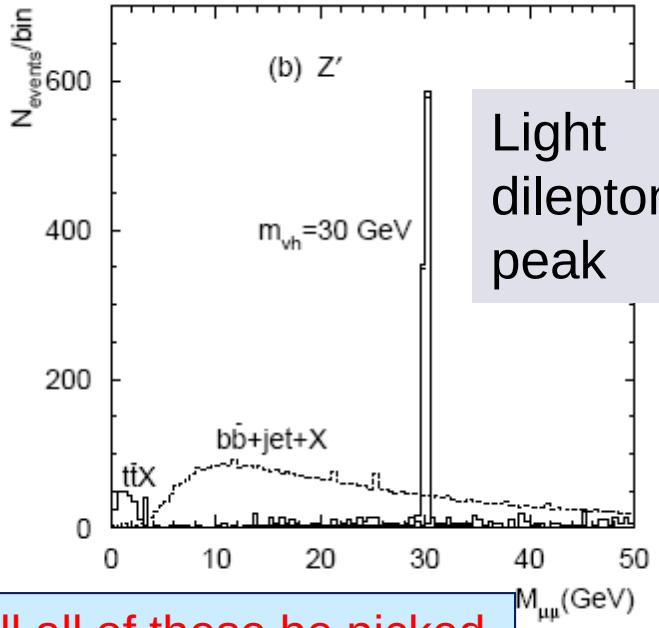
- [Light] dilepton resonance

  possibly boosted and/or non-isolated

  e.g. lepton(ic)-jets

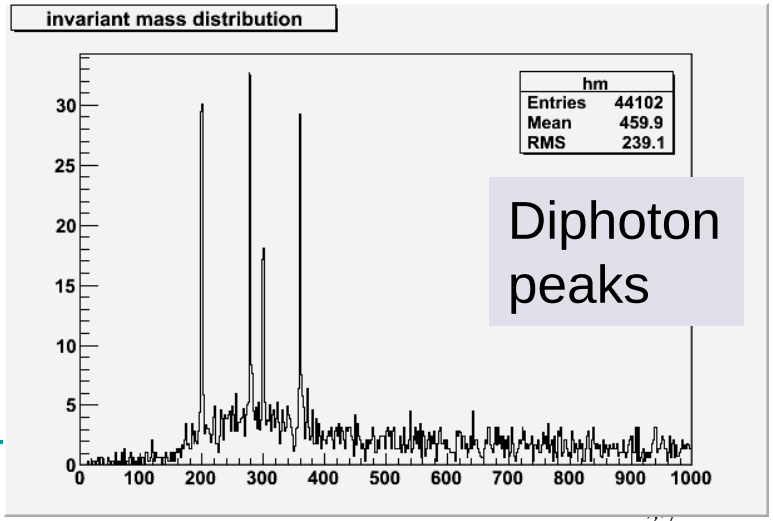
  - Inclusive sample? Swamped!
  - Refined samples with less background
    - requiring jets (perhaps many)?
    - requiring large HT?
    - requiring unusual event shape?
    - Etc.
  - Loosen isolation for one or both leptons?
    - Sample with 3 or more leptons?

- [Light]diphoton resonance
- [Light] dilepton/diphoton edge/endpoint



Light dilepton peak

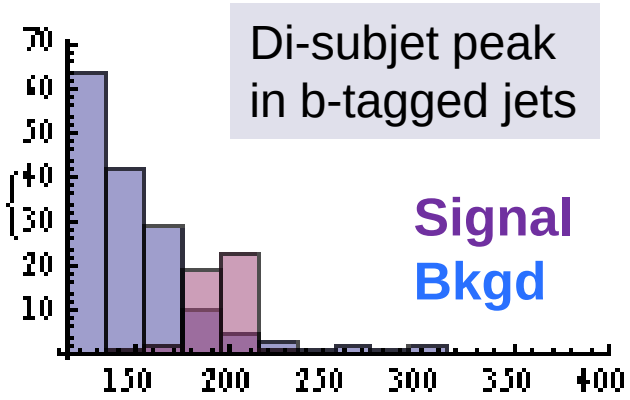
Will all of these be picked up efficiently by global search strategies?



Diphoton peaks

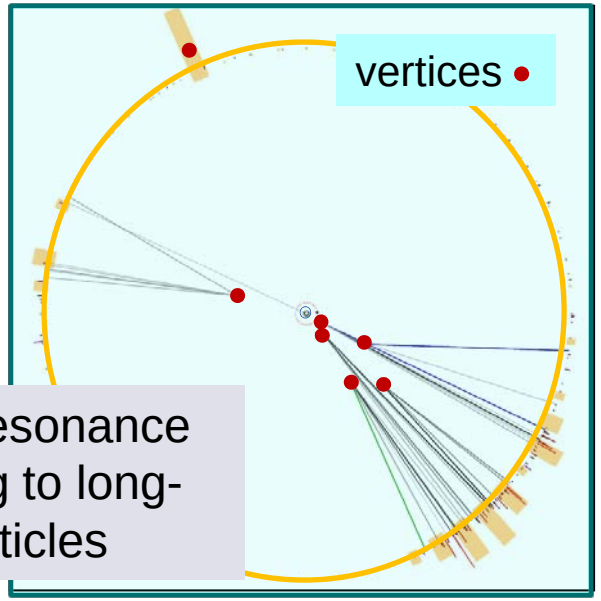
Early Search Strategies

Non-Standard Analysis



- Heavy-flavor resonances
  - Events with many b-tagged jets or many displaced tracks
  - High-pT jet(s) may be b-pair -- so use jet sub-structure

- Long-lived particles
  - Displaced jet pairs/triplets/quartets
  - Displaced lepton pairs (or lepton and jets)
  - Displaced photons
  - Careful – not necessarily isolated



Heavy resonance decaying to long-lived particles

- Plenty of others but this should keep us busy for a couple of years

Summary

- **VERY easy to overturn conventional wisdom; should raise concern**
- Adding a hidden valley (hidden sector with mass gap) to SM or BSM theory can drastically and qualitatively change its phenomenological signatures
- Some of the novel signals are not likely to be picked up using the hadron collider searches appropriate to minimal BSM models
- Even if nature does not have a hidden valley, it should be clear that a few new triggers, smarter and more flexible reconstruction codes, and a wider variety of analysis strategies are all needed for robust searches at the LHC
- LHC theorists and experimentalists must work closely together to make sure gaps through which new physics could slip are firmly closed
- Luminosity frontier, cosmic rays, astro/cosmo need further development