EXOTIC HIGGS DECAYS

Jessie Shelton

U. Illinois at Urbana-Champaign

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Why exotic Higgs decays?

- First thing you do with any new particle: does it do anything unexpected?
- Higgs decays are an especially interesting place to look for new, light particles:
  - $|H|^2$ one of leading places in SM where SM singlets can couple: especially easy for new particles to talk to the Higgs
  - 125 GeV Higgs has accidentally small SM width: even small couplings to new particles can give interesting branching ratios
- Higgs factories: phenomenal data set, ~10^6 Higgs bosons

Why exotic Higgs decays?

- Why should new physics be anywhere near the weak scale?
  - co-responsible for generating it
  - stabilize it
  - thermal dark matter
  - …why not?

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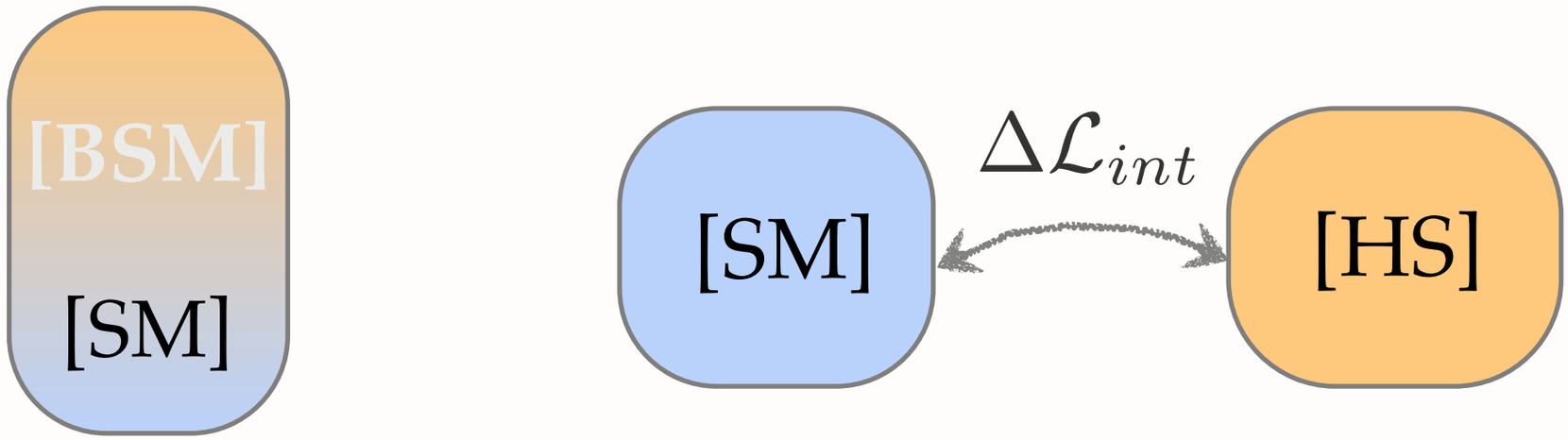
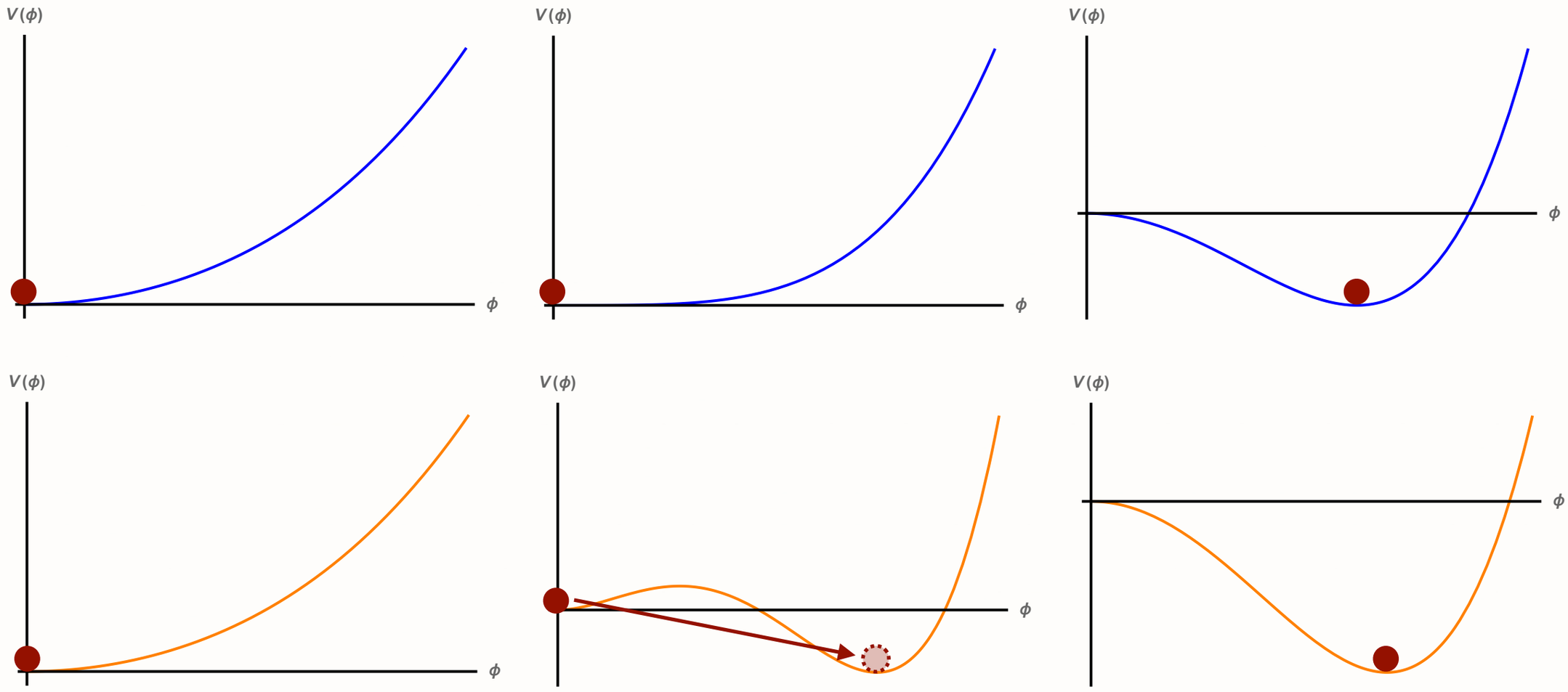
  - …why not?
- These motivations apply horizontally as well as vertically



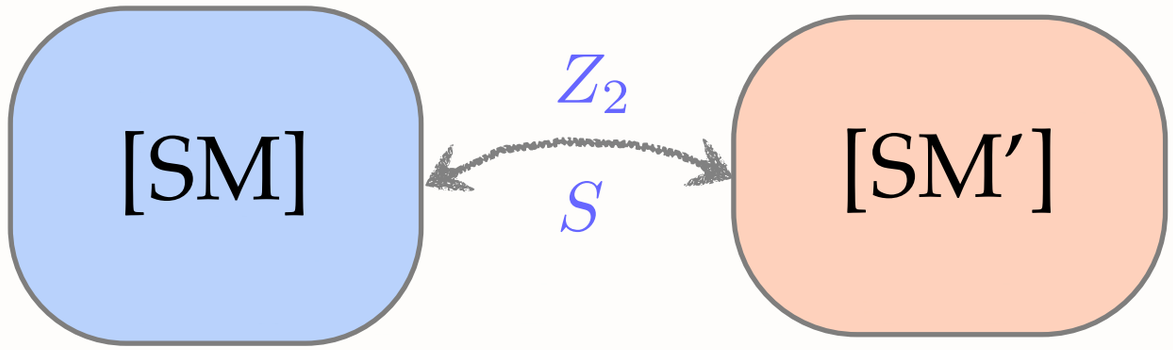
Why exotic Higgs decays?

- Extended Higgs sectors: (MS)SM + s, composite models, ...
  - electroweak phase transition: baryogenesis, cosmological history of the SM



Why exotic Higgs decays?

- Naturalness
  - Twin Higgs, related models, extend Higgs sector and add matter:

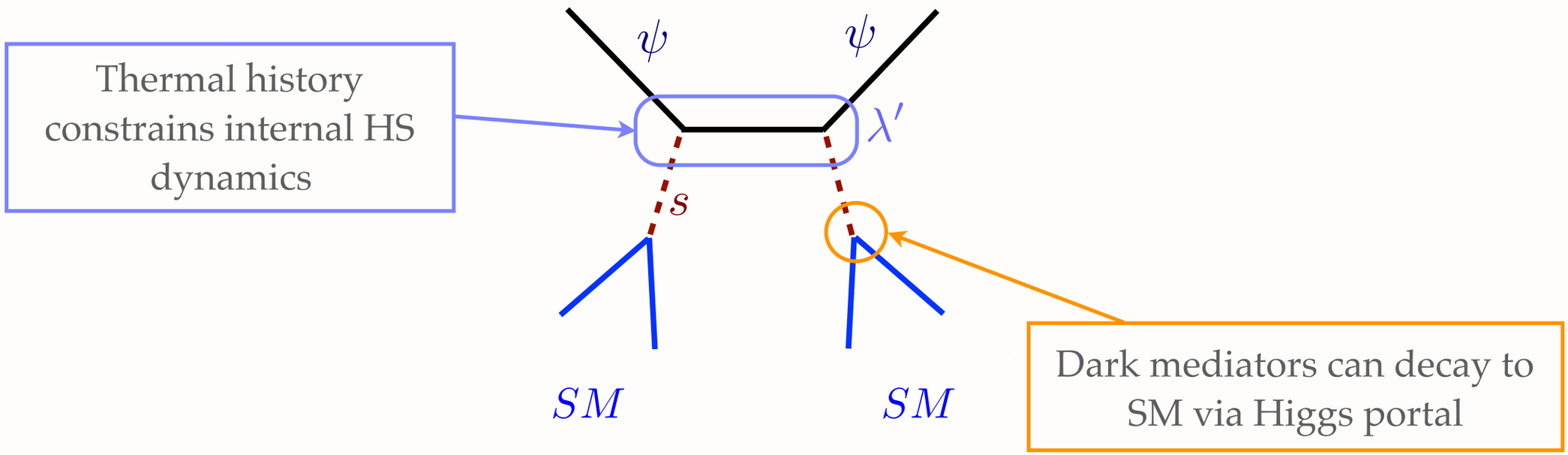


  - weak-scale states needed to solve hierarchy problem can be SM singlets
    - Higgs portal interactions by construction

[Chacko, Goh, Harnik; Craig, Howe; Craig, Knapen, Longhi; ...]

Why exotic Higgs decays?

- Dark matter:
  - First work on exotic Higgs decay: $h \longrightarrow$ dark matter
  - "WIMP miracle": a statement about cold dark matter freezing out via perturbative interactions
  - Hidden sector freezeout:



[Suzuki, Shrock; Pospelov, Ritz, Voloshin; Martin, JS, Unwin; Evans, Gori, JS]

Why exotic Higgs decays?

- Why not?
  - Hidden sectors are a generic ingredient in UV theories
  - Generic signatures of new physics may be light, weakly coupled states just as well as heavier, SM-charged states
  - Characterize signatures by leading operators mediating SM-HS interactions
    - Higgs portal: unique possibilities at Higgs factories: direct Higgs production, small SM width

[Chang, Dermisek, Gunion, Weiner; Curtin, JS, et al.; …]

Exotic Higgs decays at colliders

- lepton machines
  - FCC-ee: 240 GeV, 10 ab^{-1}: 10^6 Higgses
  - smaller data sets limit statistical reach
  - clean: benefits for (e.g.) all-hadronic modes
  - inclusive measurements are possible
- hadron machines
  - HL-LHC: 14 TeV, 3 ab^{-1}: 10^8 Higgses
  - enormous Higgs samples: fantastic statistical reach for clean decay modes
  - high backgrounds, trigger concerns

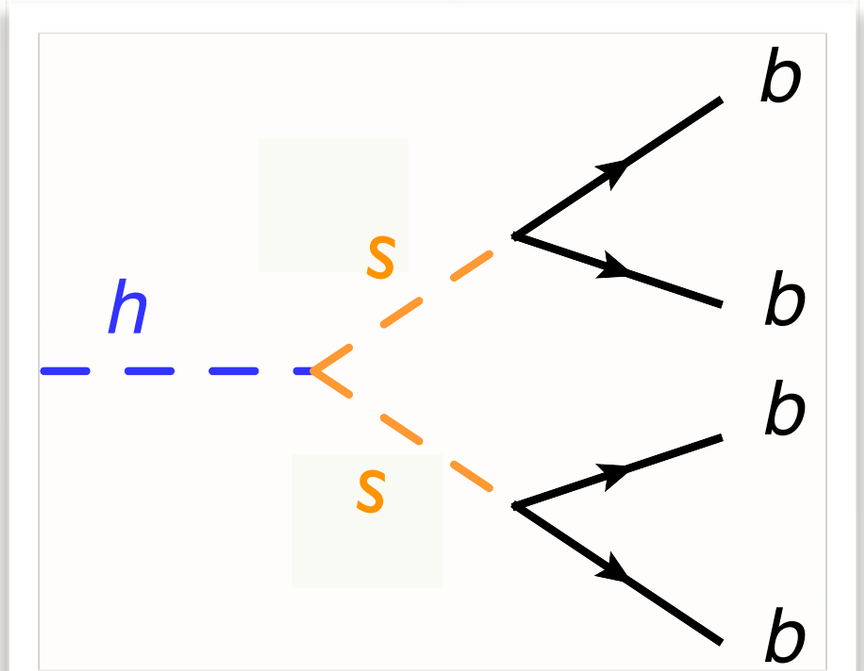
Exotic decays at lepton machines

- Great advantages of lepton colliders:
  - hadronic final states
  - with poor mass resolution (e.g., with *MET*)
  - high multiplicity / low p_T
- Extremely well-motivated decay modes are in this class: Higgs portal couplings to (pseudo-)scalars, $h \to aa,\ ss$
  - Yukawa-weighted - heavy flavor rich
  - gauge-weighted (axion-like) - gluon rich

Example: $h \longrightarrow 4\ b$

- Generic prediction of Higgs-portal (pseudo-)scalars:

$$h \to ss(aa) \to 4b$$

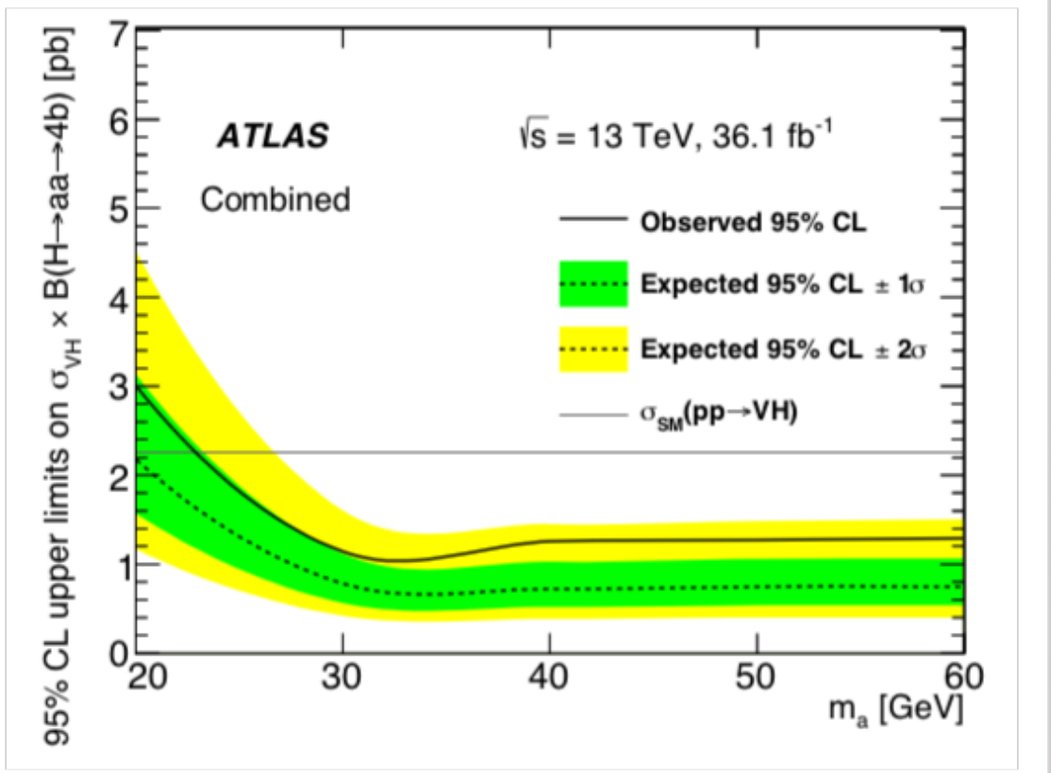


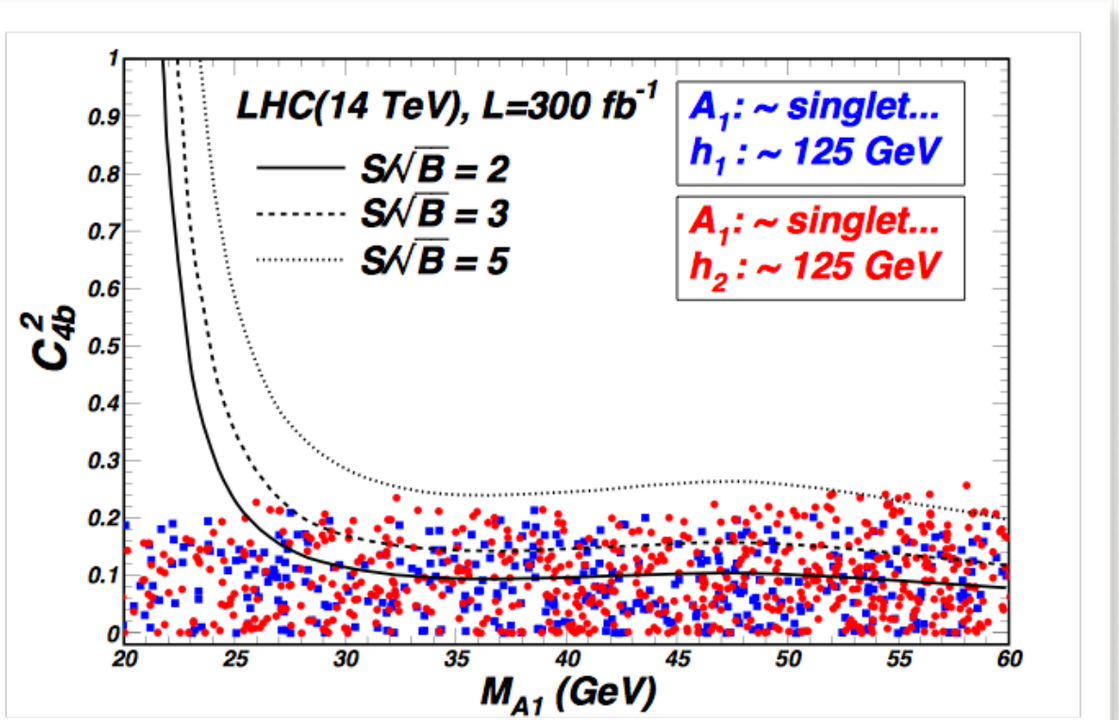
- characterized by two quantities: m_s, Br $(h \to ss)$

Hadronic Higgs decays at the LHC

- Challenging for LHC: high backgrounds, starting at trigger

$$h \to 4b$$

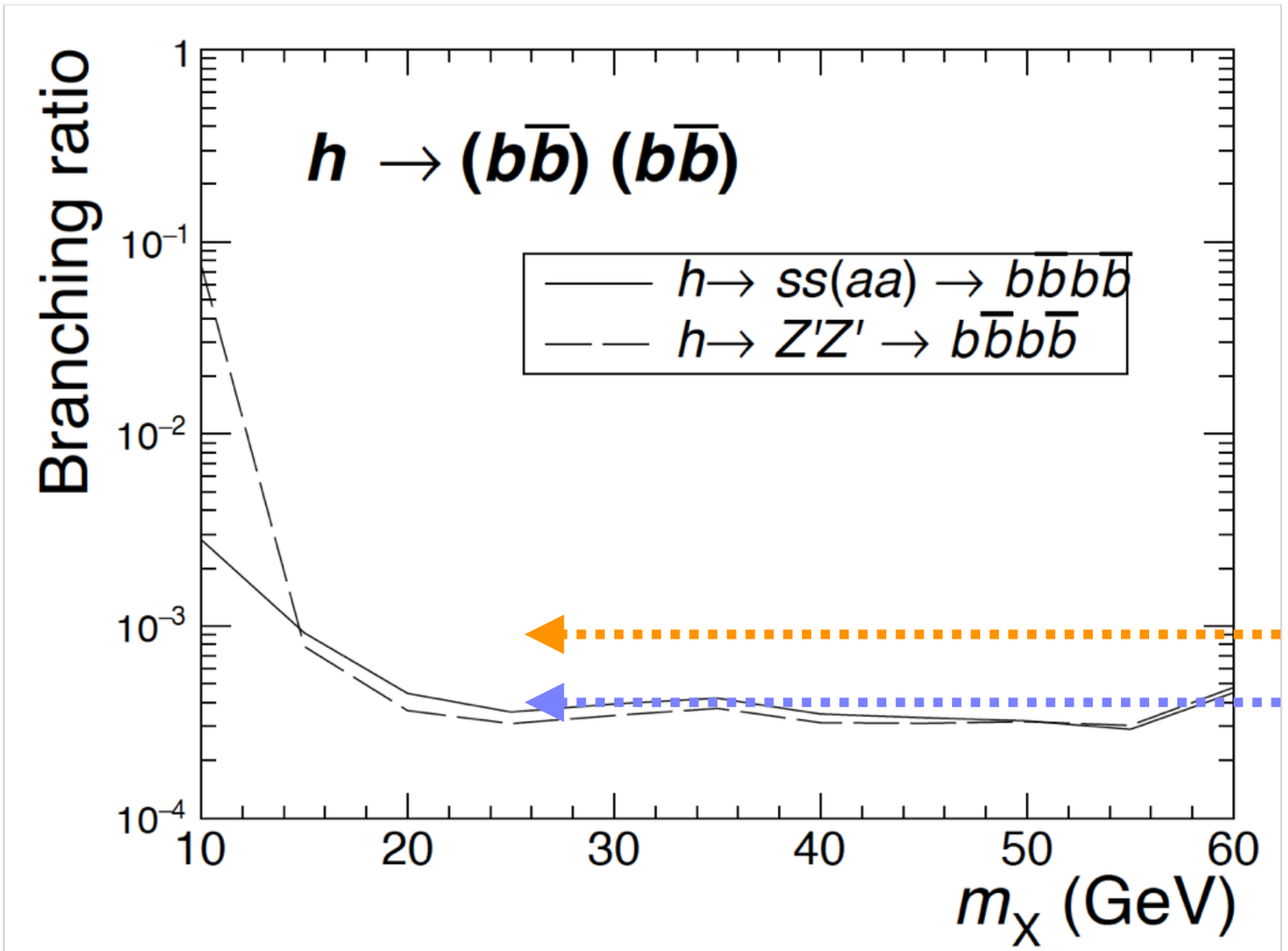




[ATLAS; Cao, Ding, Han, Yang, Zhu]

Hadronic Higgs decays at the ILC

- Better prospects at e^+e^- machines where backgrounds are much smaller



ILC: 9 x 10^{-4}

CEPC: 4 x 10^{-4}

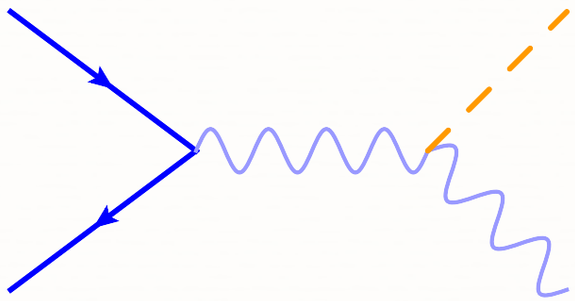
[Liu, Wang, Zhang (2016)]

The total Higgs width

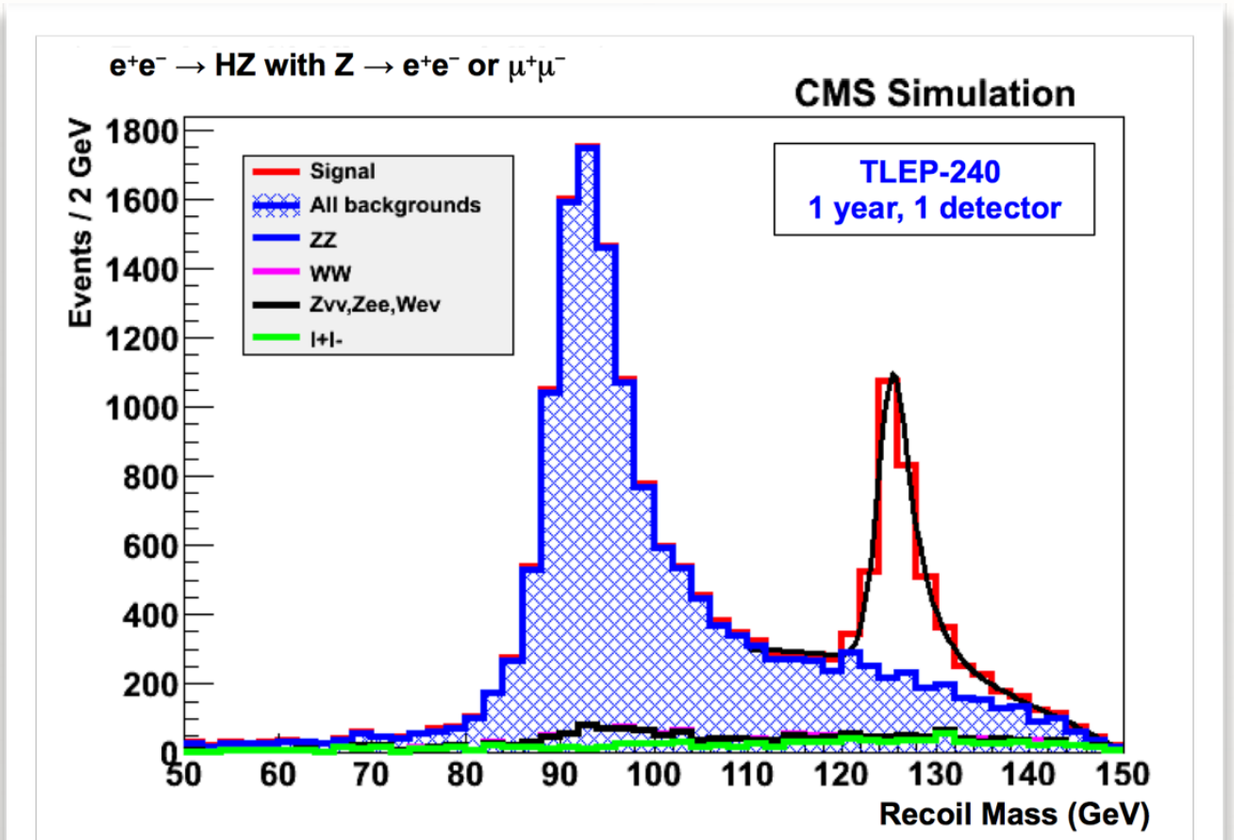
- Total Higgs width: needed to understand possible BSM decays in a model-independent way.
  - Tiny! extremely challenging to measure
- at the LHC:
  - interference between Higgs, other SM contributions in diboson spectra
  - from global fit
  - requires assumptions about form/nature of BSM physics to interpret as bound on Higgs width

The total Higgs width

- Inclusive measurements of Higgs production allows clean determination of total width:



$$\delta\Gamma_h \lesssim 1\%$$

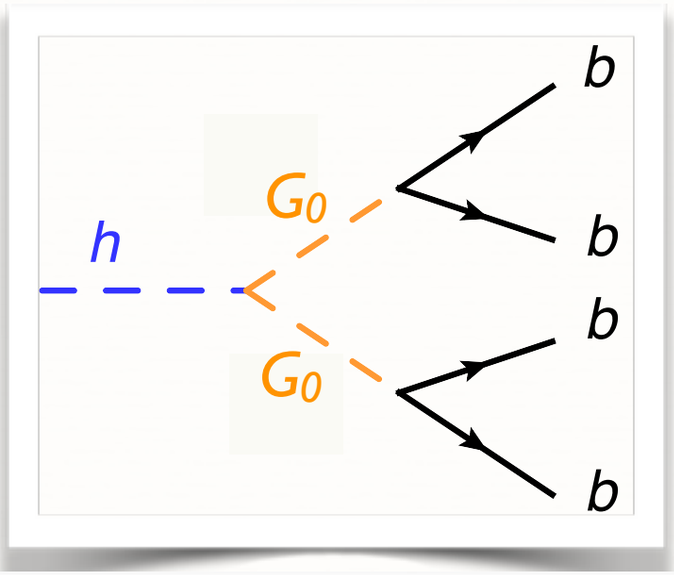


$$(p_{ee} - p_Z)^2 = s + m_Z^2 - 2\sqrt{s}E_Z$$

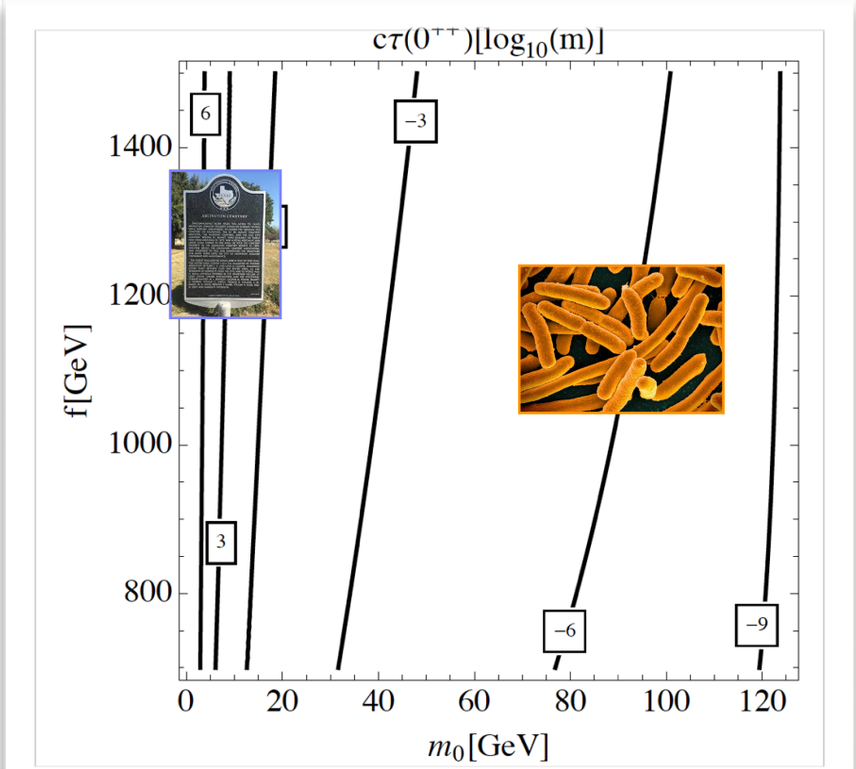
[TLEP physics case, 1308.6176; ILC physics case, 1506.05992]

Displaced decays

- New physics may easily be long-lived!
  - If Higgs is decaying into a multi-state hidden sector, generic possibility



- Major advantage: inherently low-background, striking signals
- Major challenge: reconstruction
  - trigger limitations at LHC: a lot of scope for lepton colliders



[Curtin, Essig, Gori, JS; Craig, Katz, Strassler, Sundrum; …]

Conclusions

- The observed 125 GeV Higgs boson is highly sensitive to the potential existence of new light degrees of freedom
- Higgs portal couplings + BSM at weak scale are vital ingredients of many theories of cosmology, naturalness
- HL-LHC has powerful statistical reach, but only for specific low-background decay modes
- e^+e^- Higgs factory: powerful discovery machine for best-motivated and generic decays, inclusive measurements