

# EXTENDING COVERAGE FOR EXOTIC HIGGS DECAYS

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Triggering on New Physics at the HL-LHC  
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# Why exotic Higgs decays?

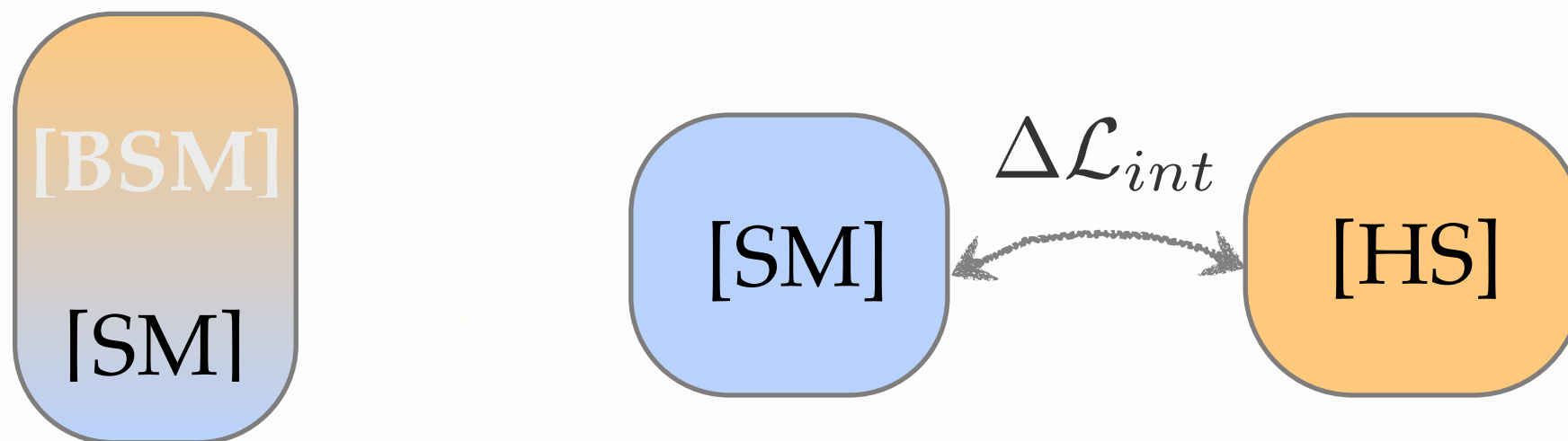
- First thing you do with any new particle: does it do anything unexpected?
- Higgs decays are an especially attractive place to look for *new, on-shell BSM states*:
  - $|H|^2$  one of leading places in SM where SM singlets can couple: easy for NP to talk to the Higgs
  - 125 GeV Higgs has accidentally small SM width: even *small couplings to NP* can substantially distort branching ratios
- HL-LHC: phenomenal data set,  $\sim 10^8$  Higgs bosons

# Why exotic Higgs decays?

- Motivations for new physics at the weak scale:
  - co-responsible for **generating it**
  - **stabilize it**
  - **thermal dark matter**
  - ...why not?

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- Motivations for new physics at the weak scale:
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  - **stabilize it**
  - **thermal dark matter**
  - ...why not?
- These motivations apply **horizontally** as well as **vertically**



# Why exotic Higgs decays?

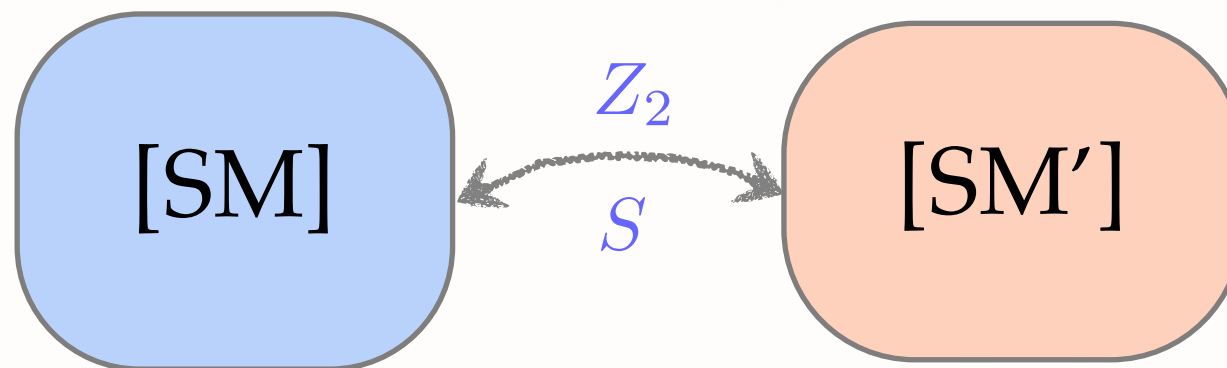
- **Extended Higgs sectors:** SM +  $s$ , MSSM +  $S$ , composite models, ...
  - simplest realization of Higgs portal coupling:  $|S|^2|H|^2$
  - **NMSSM:** dynamically generate  $\mu$ , relax phenomenological constraints on  $V(H)$ , neutralino dark matter
  - **electroweak phase transition:** baryogenesis, cosmological history of the SM



# Why exotic Higgs decays?

- **Naturalness**

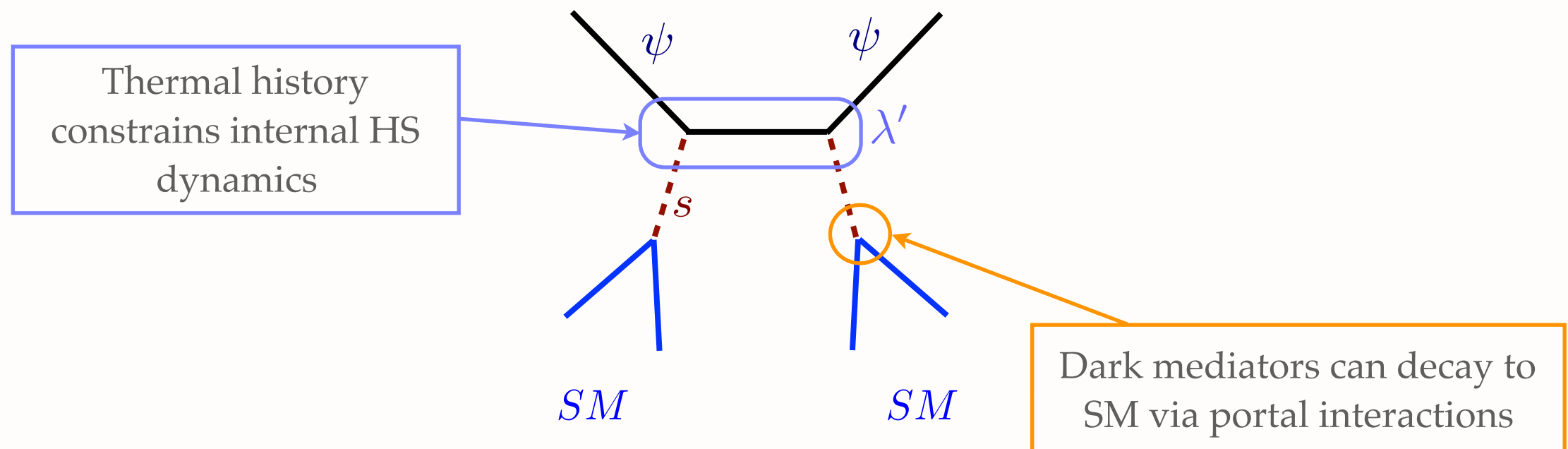
- Twin Higgs and related models:



- weak-scale states needed for naturalness can be **SM singlets**
- Higgs portal interactions by construction; also possibly hypercharge

# Why exotic Higgs decays?

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



# Why exotic Higgs decays?

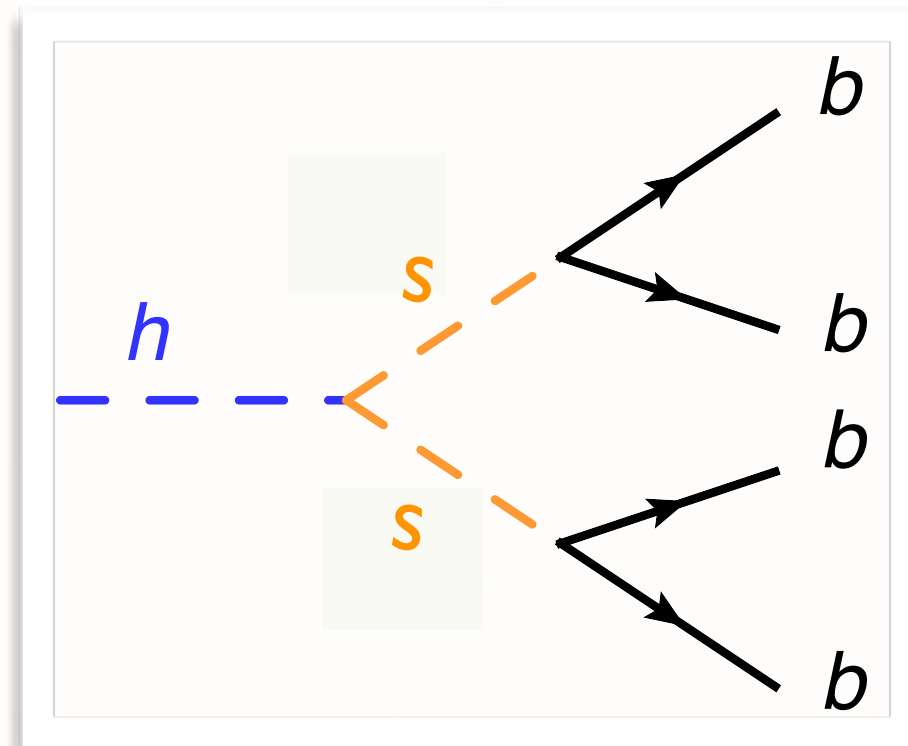
- **Why not?**
  - Hidden sectors are a **generic** ingredient in UV theories: e.g., SUSY-breaking
  - Generic signatures of new physics may be **light, weakly coupled states** just as well as **heavier, SM-charged states**
  - Characterize signatures by **leading operators** mediating SM-HS interactions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



# Example: $h \rightarrow 4b$

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

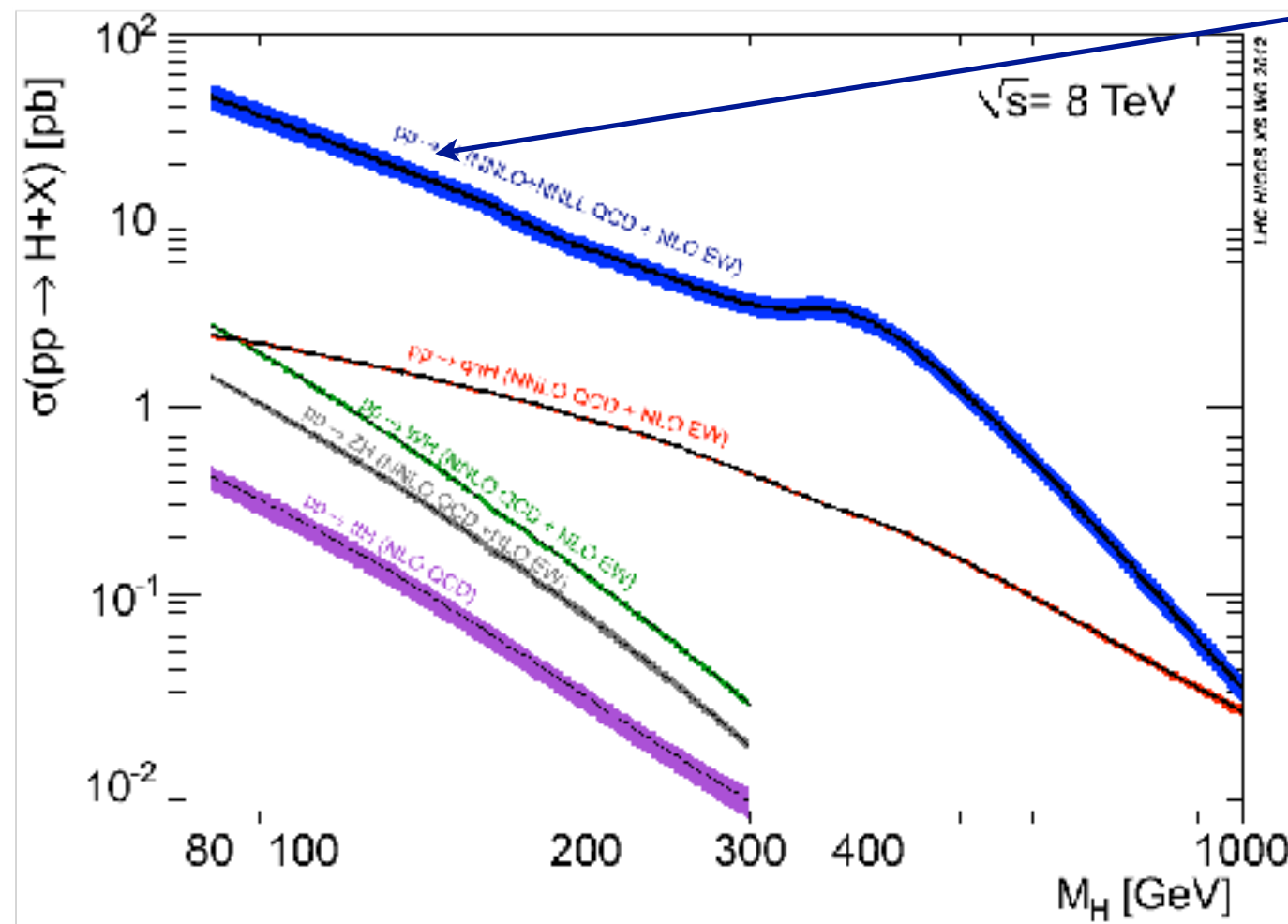
$$h \rightarrow ss(aa) \rightarrow 4b$$



- characterized by two quantities:  $m_s$ ,  $\text{Br}(h \rightarrow ss)$

# Higgs at the LHC

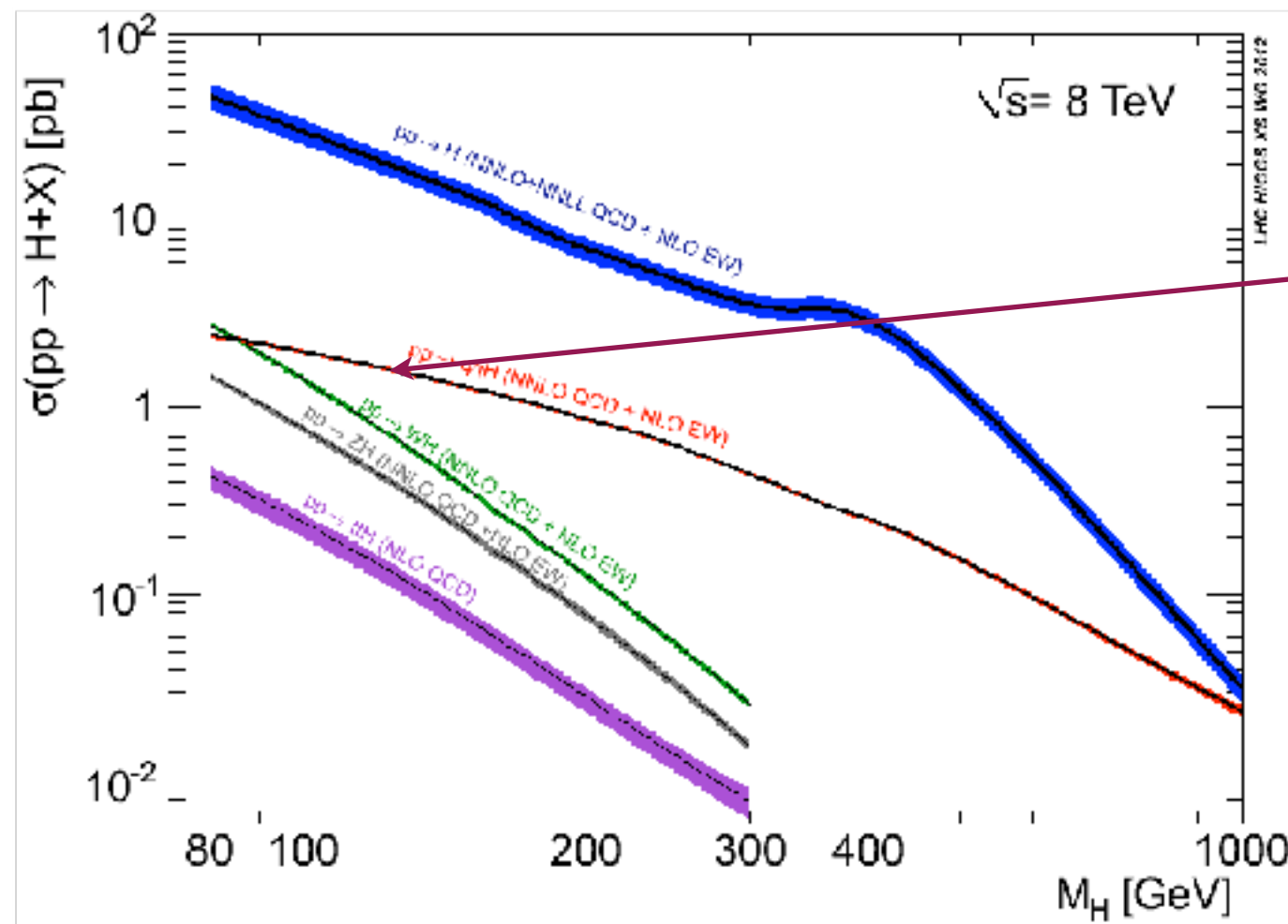
- Unique feature of Higgs as portal to new physics at LHC: interplay of associated production modes



gluon fusion: largest cross-section, fewest handles

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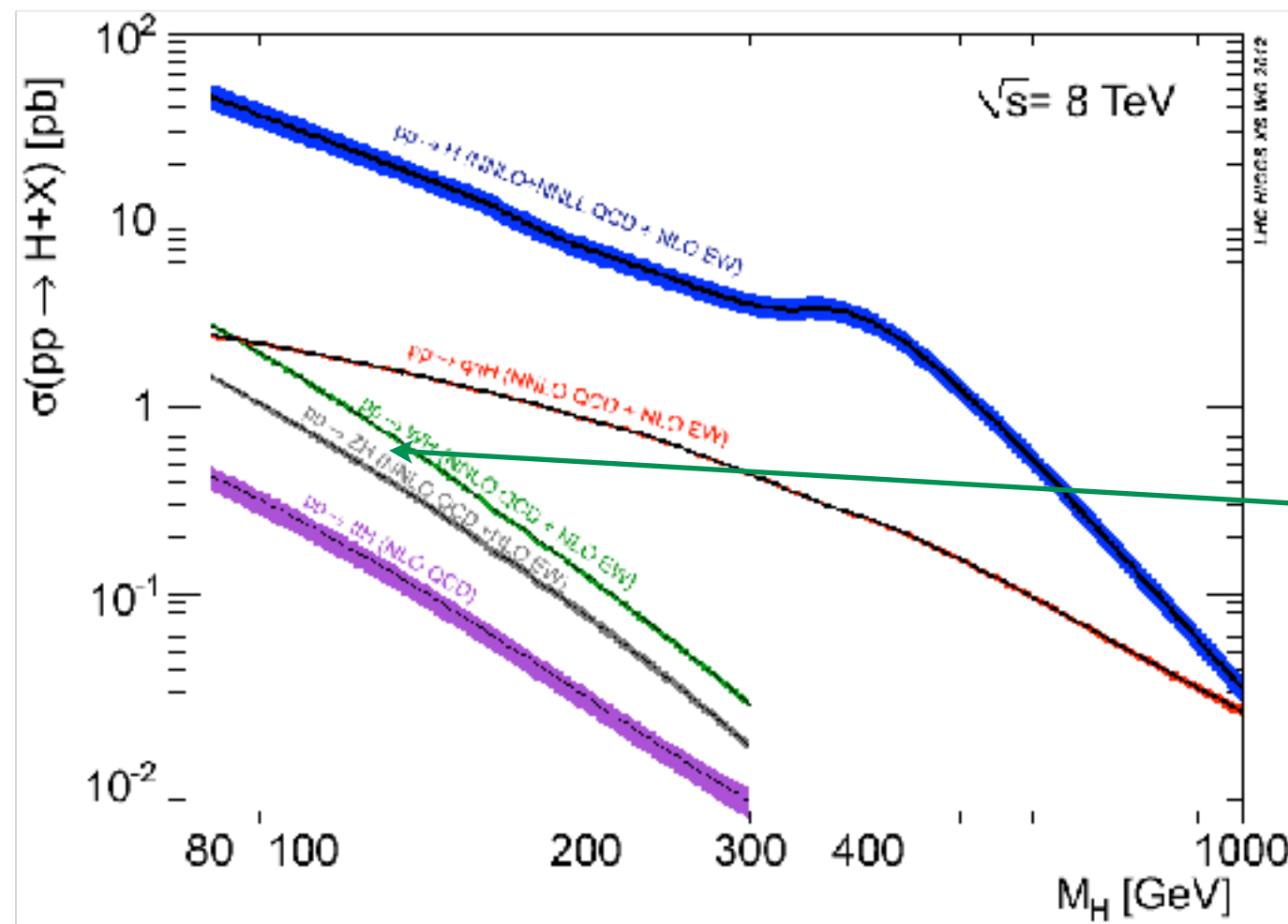
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VBF: associated tagging jets, higher Higgs  $p_T$



# Higgs at the LHC

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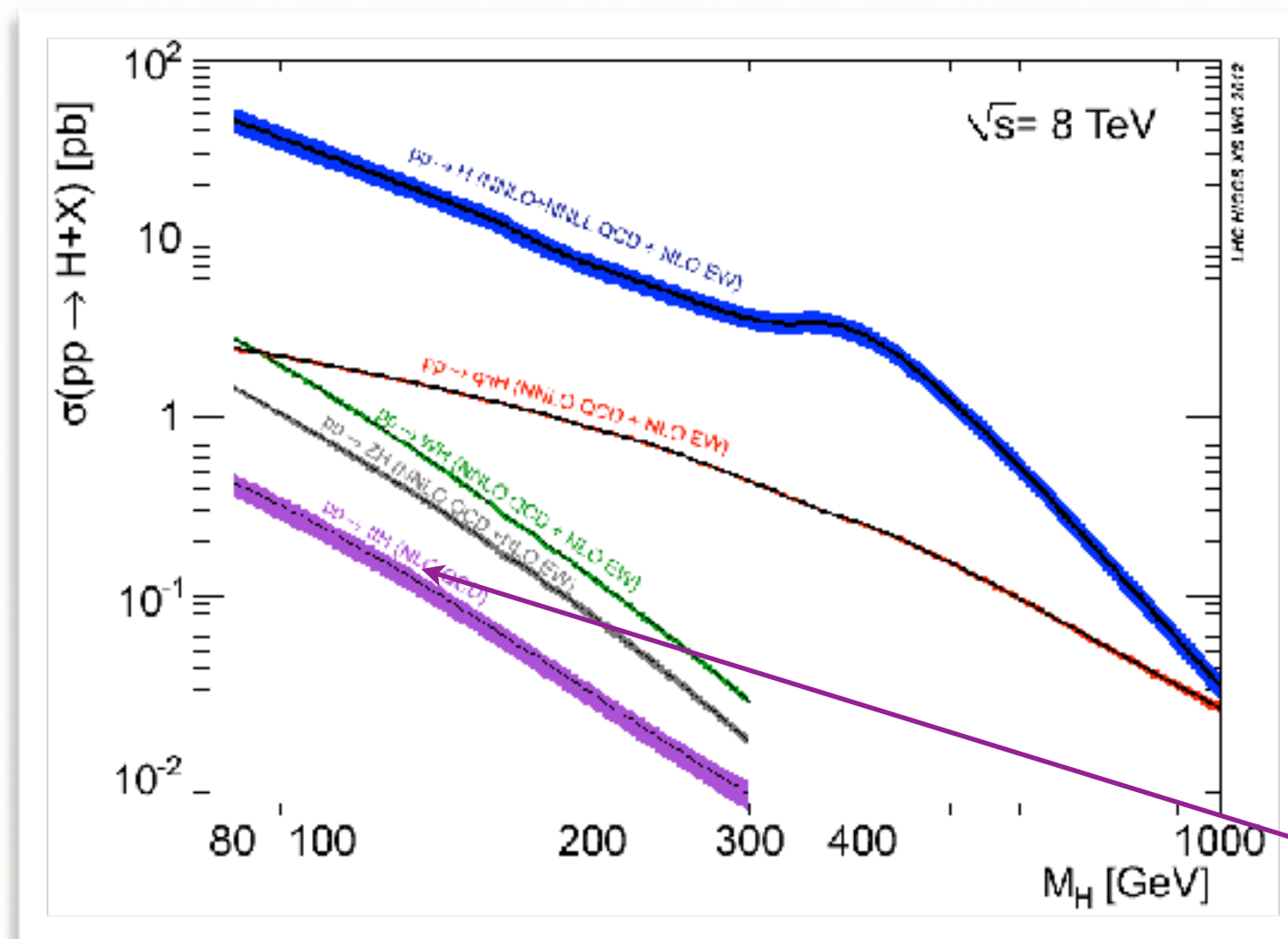
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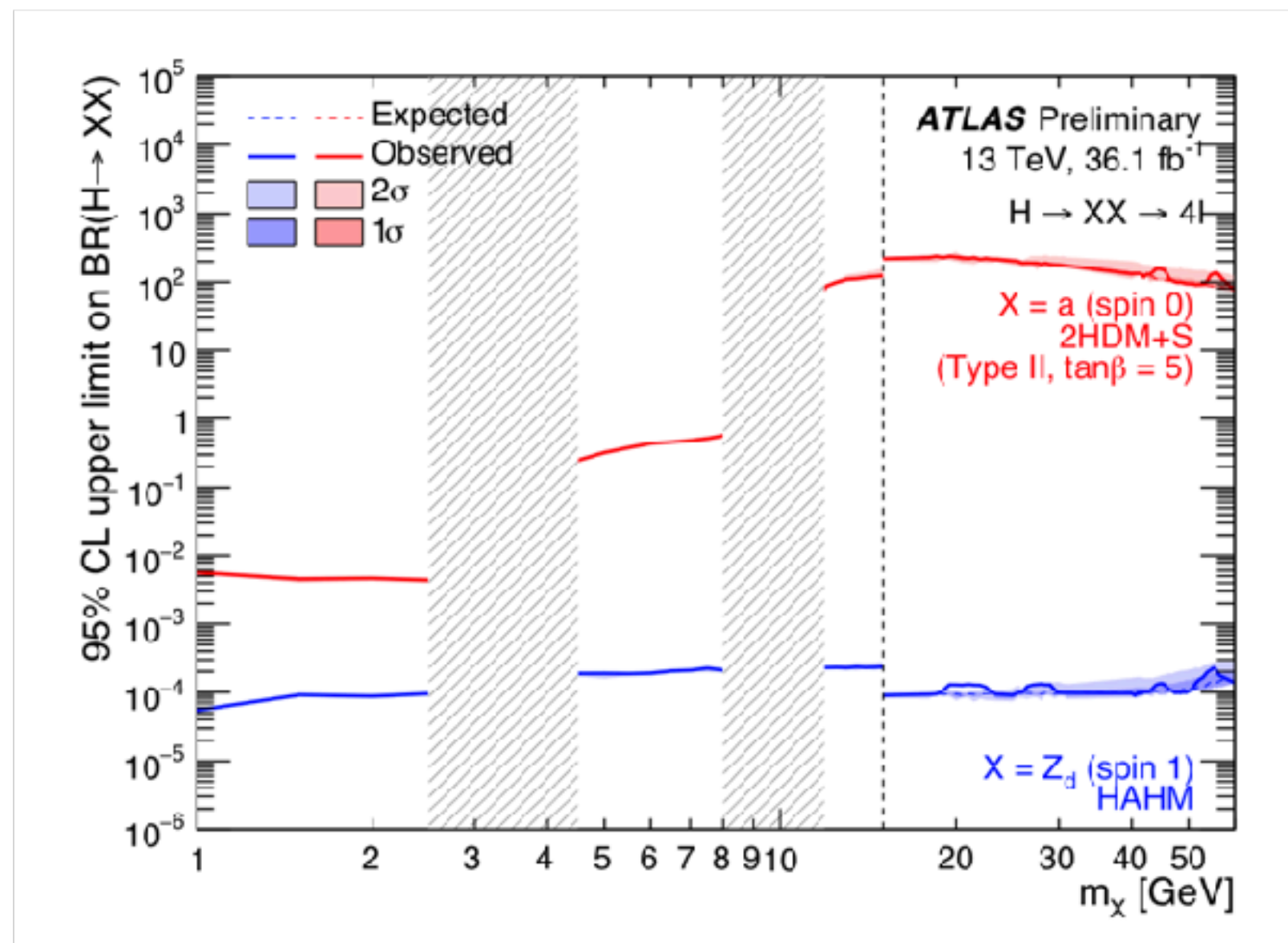
VH: associated isolated leptons, higher Higgs  $p_T$

$ttH$ : higher-mass events, b-jets and leptons; more useful for BSM Higgs than SM Higgs (combinatorics); big cross-section price



# Exotic Higgs decays at the LHC

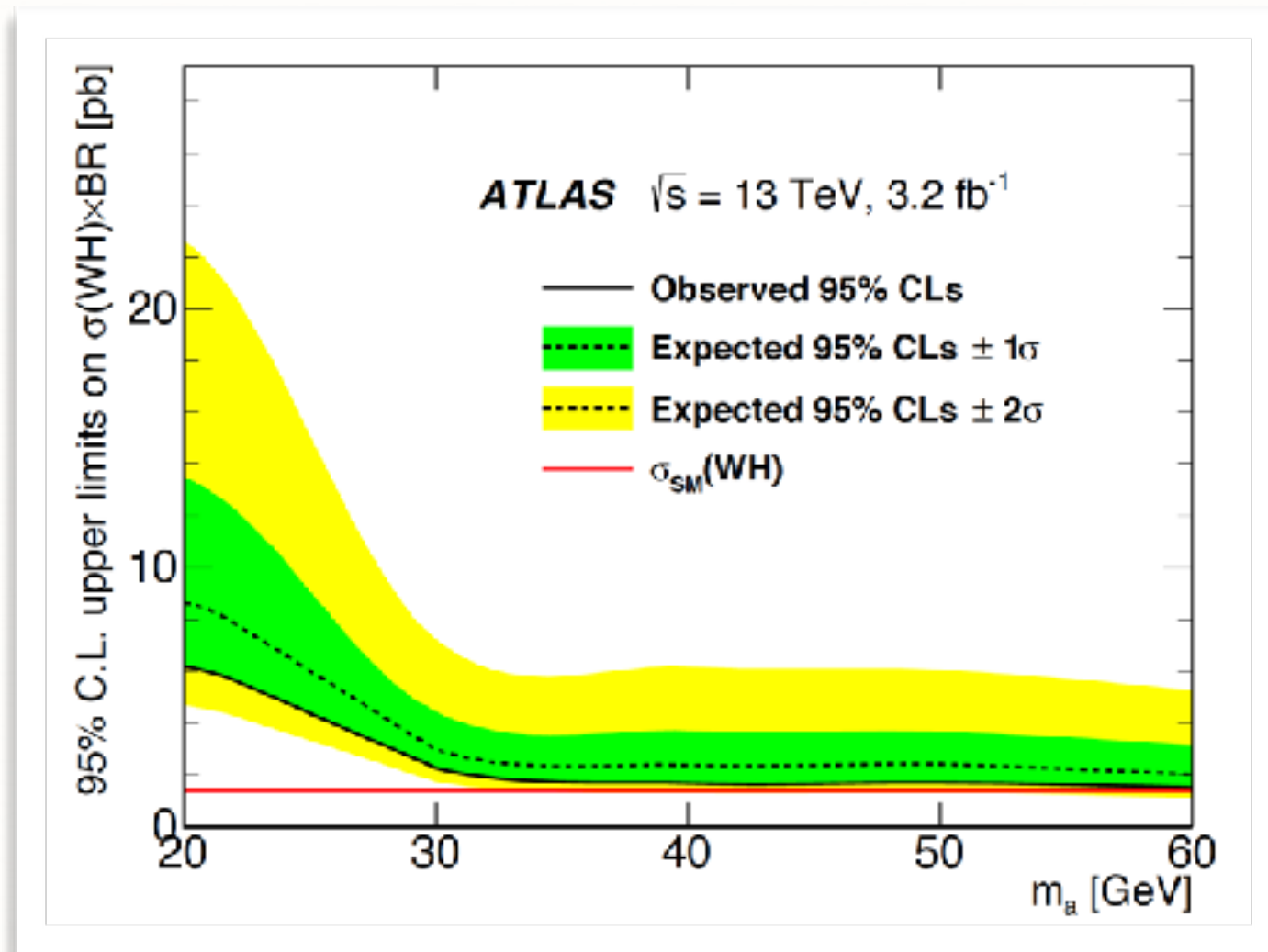
- Clean signals can access big ggF cross-section:





# Exotic Higgs decays at the LHC

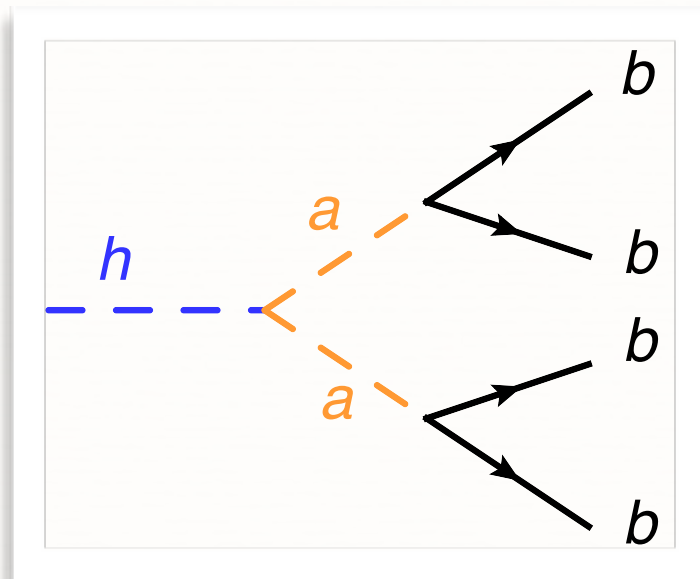
- Much less sensitivity to  $h \rightarrow 4b$  :



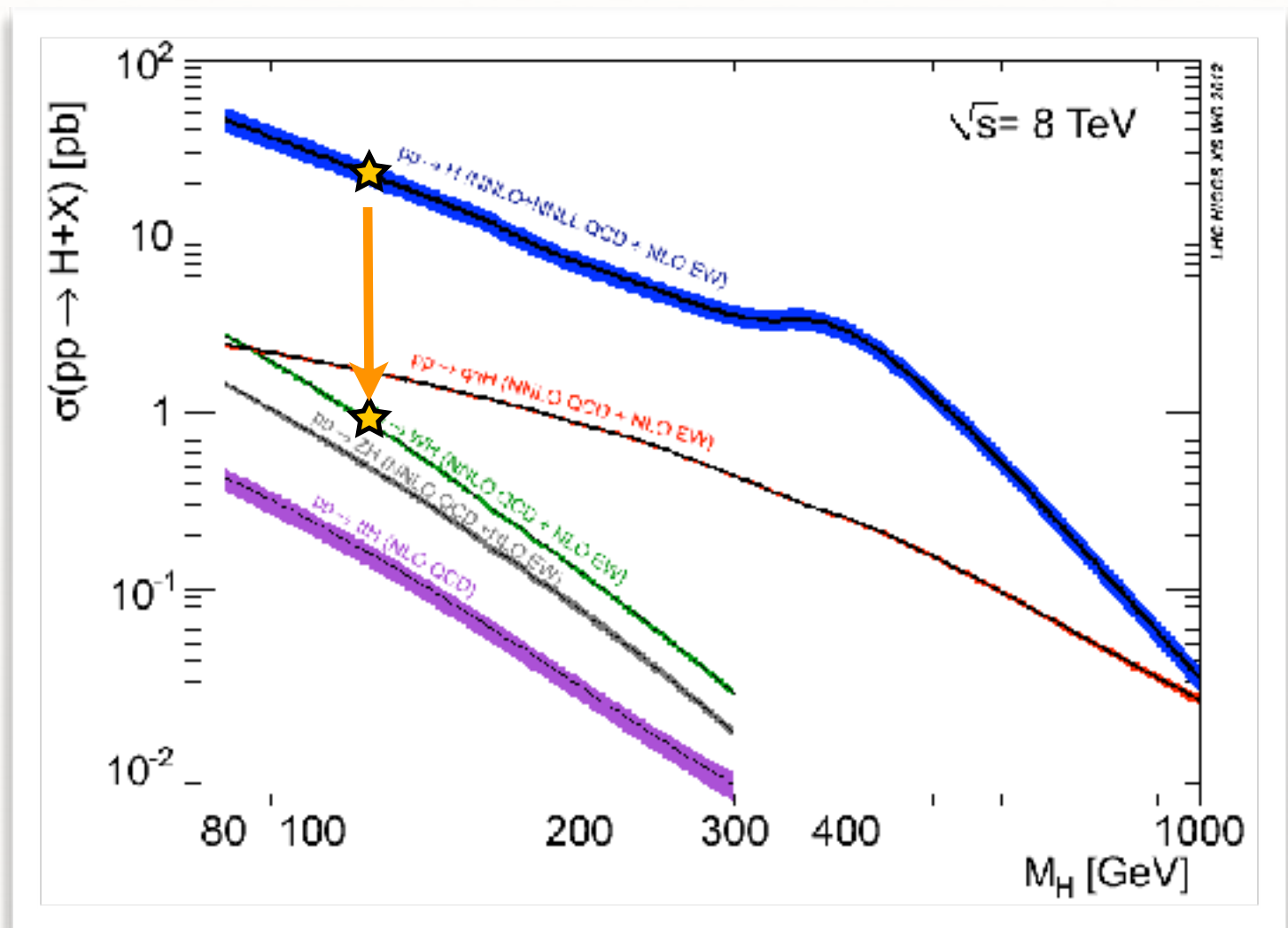
- and if some particles are invisible, even more challenges

# Exotic Higgs decays at the LHC

- Problem starts at the trigger

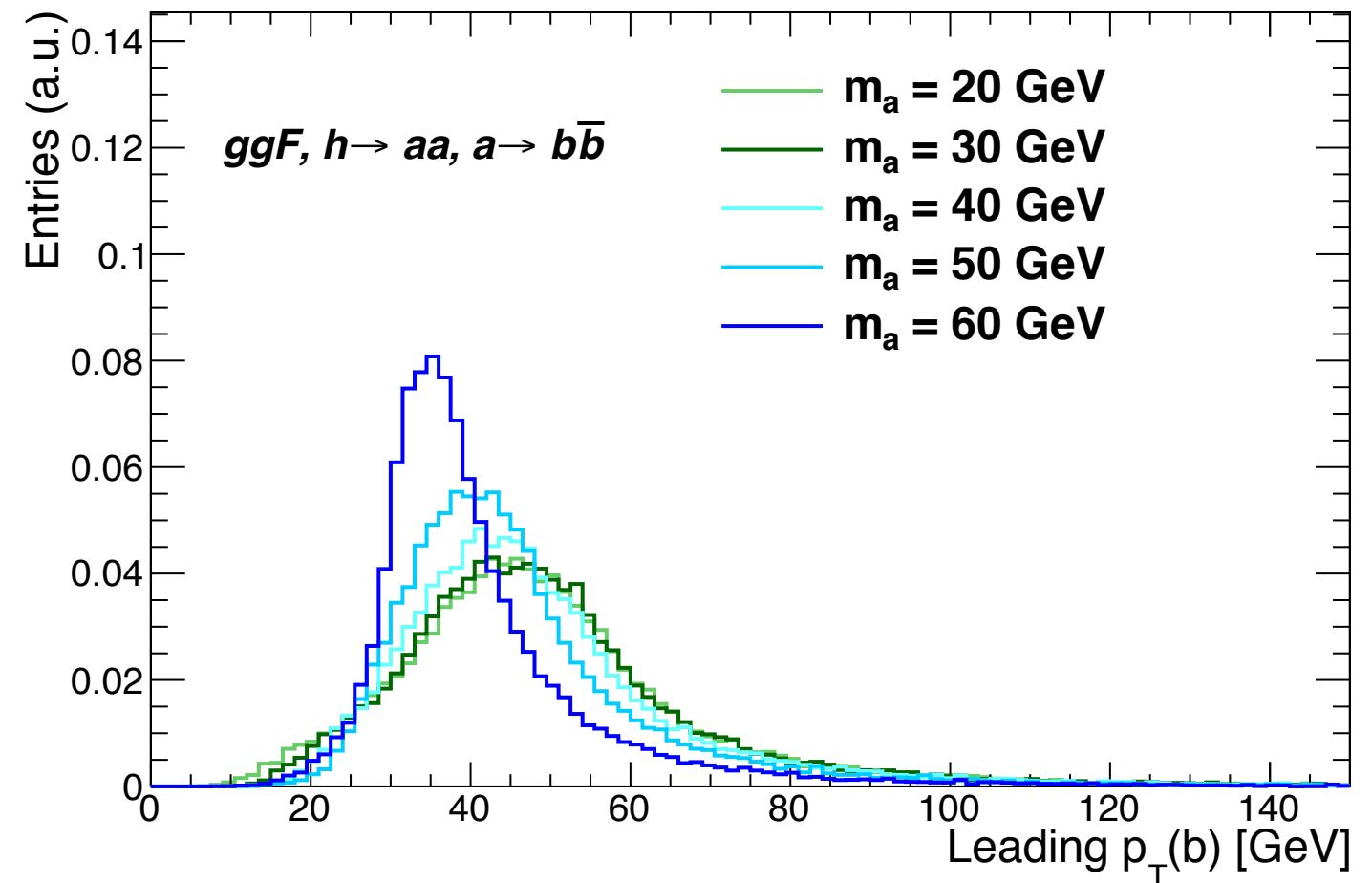
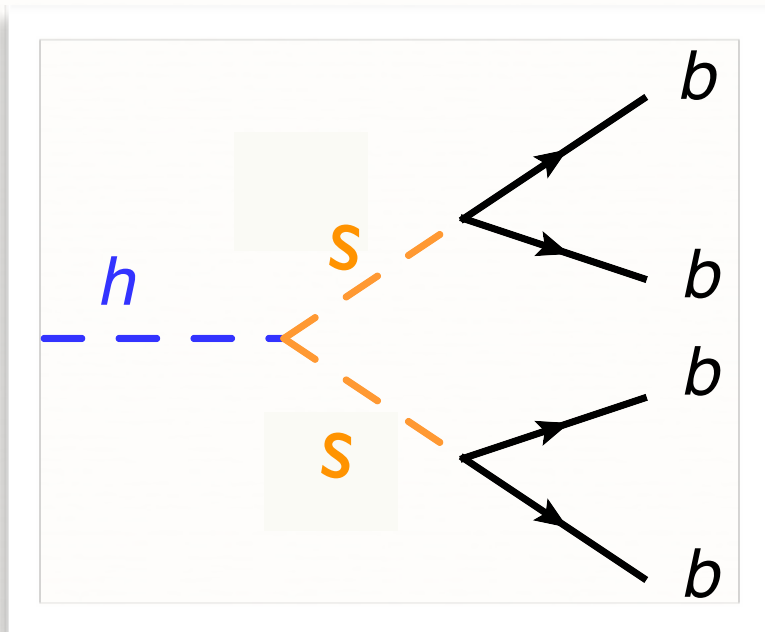


Lepton trigger: lose two orders of magnitude right out of the gate



# Soft signals

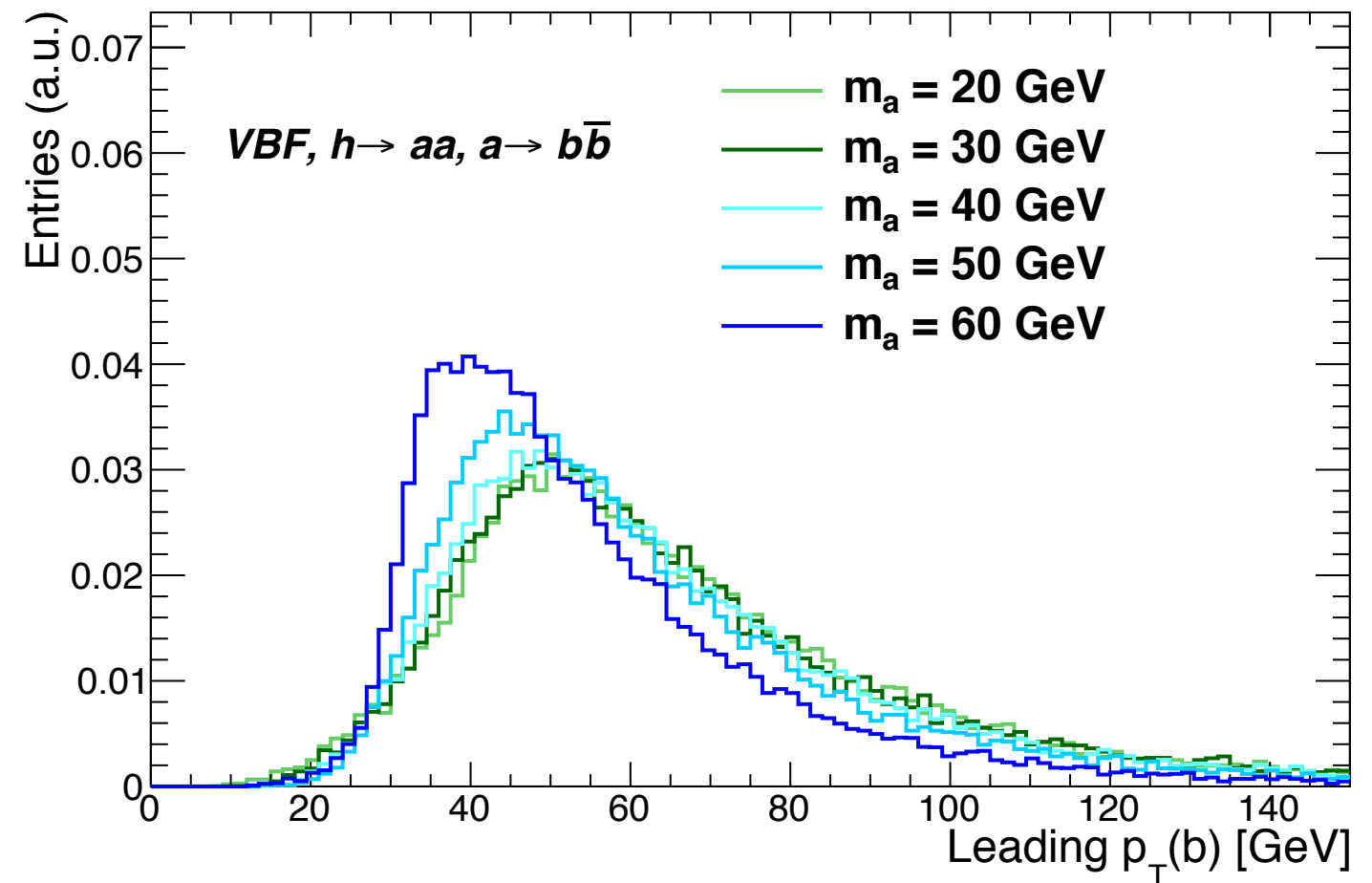
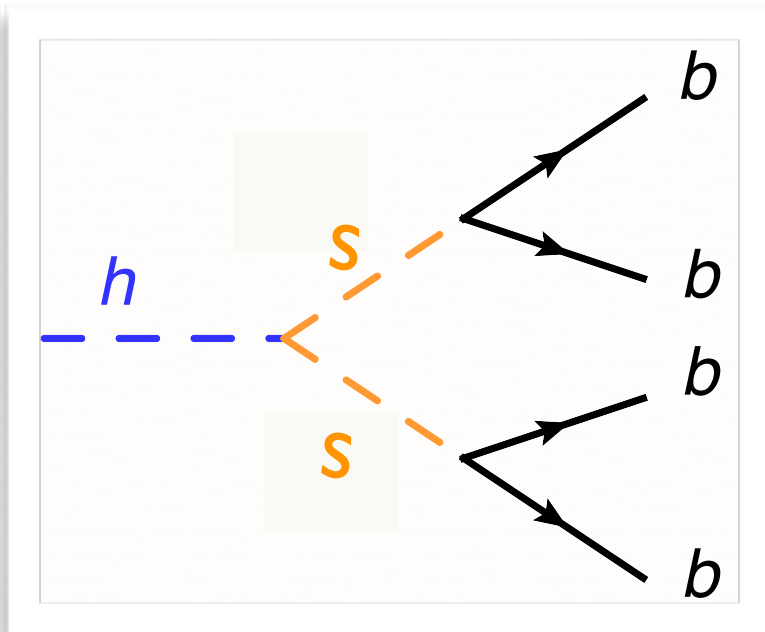
- Multi-body decay modes make kinematic challenge harder:





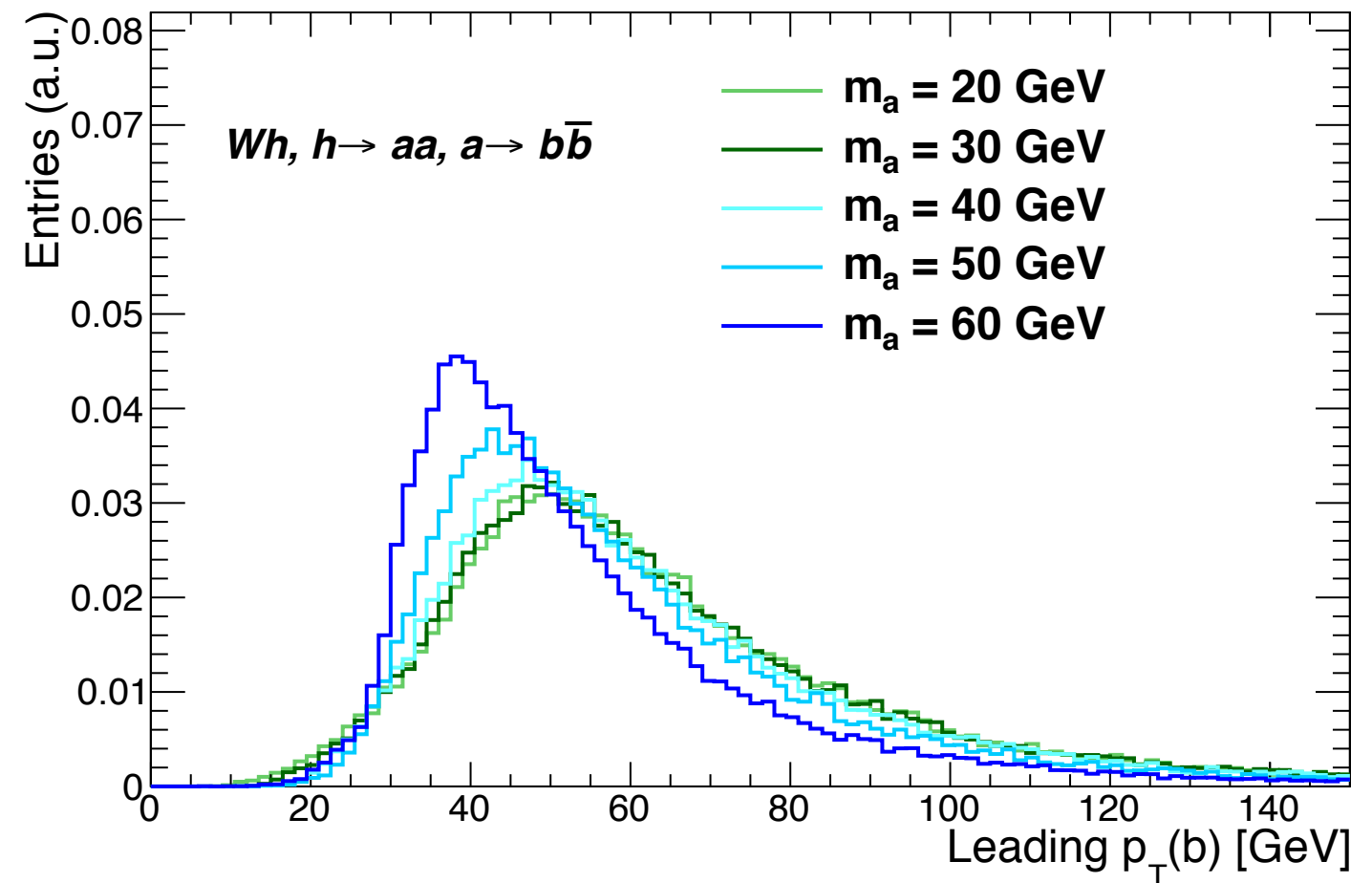
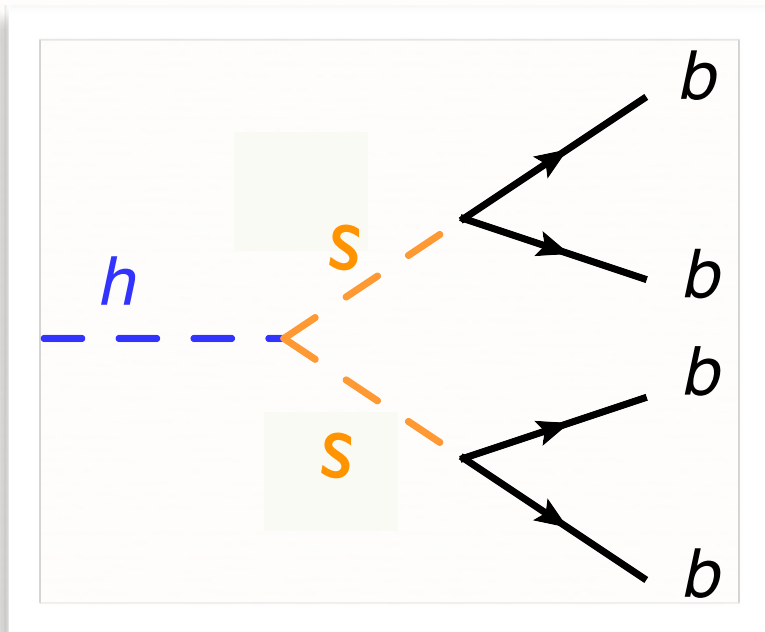
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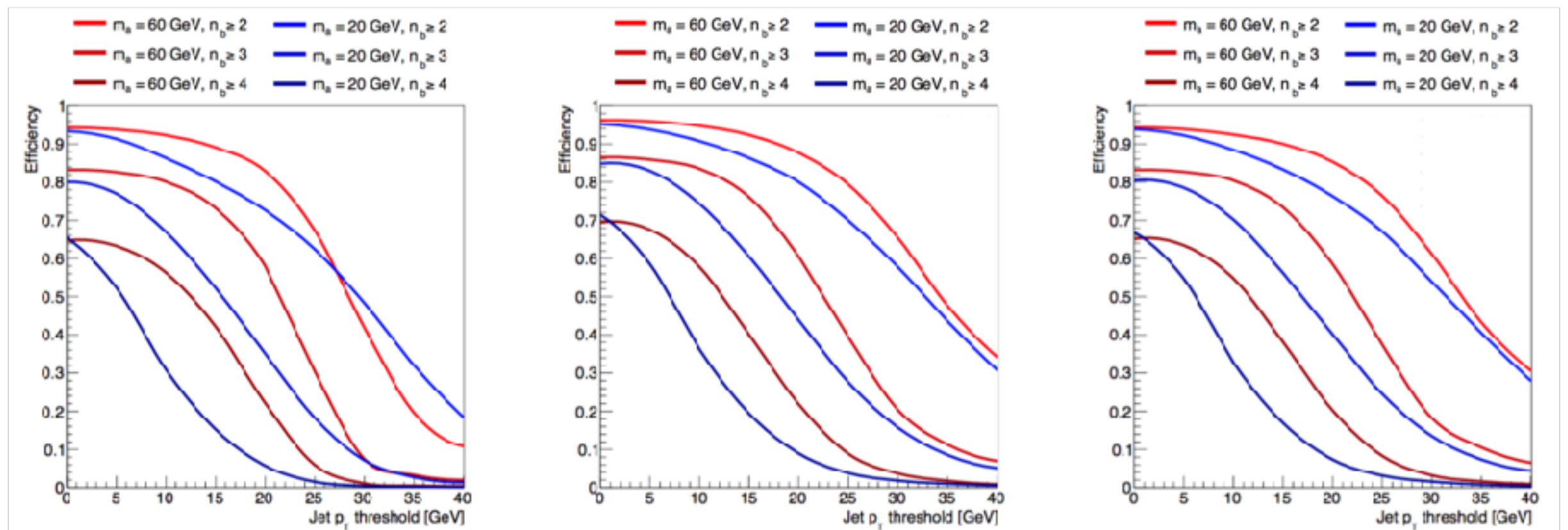
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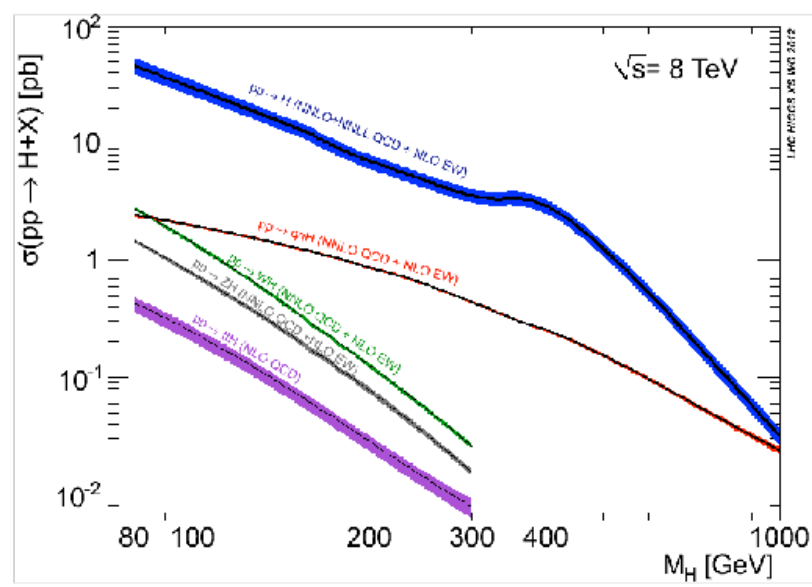
- Signal loss from  $p_T$  thresholds:



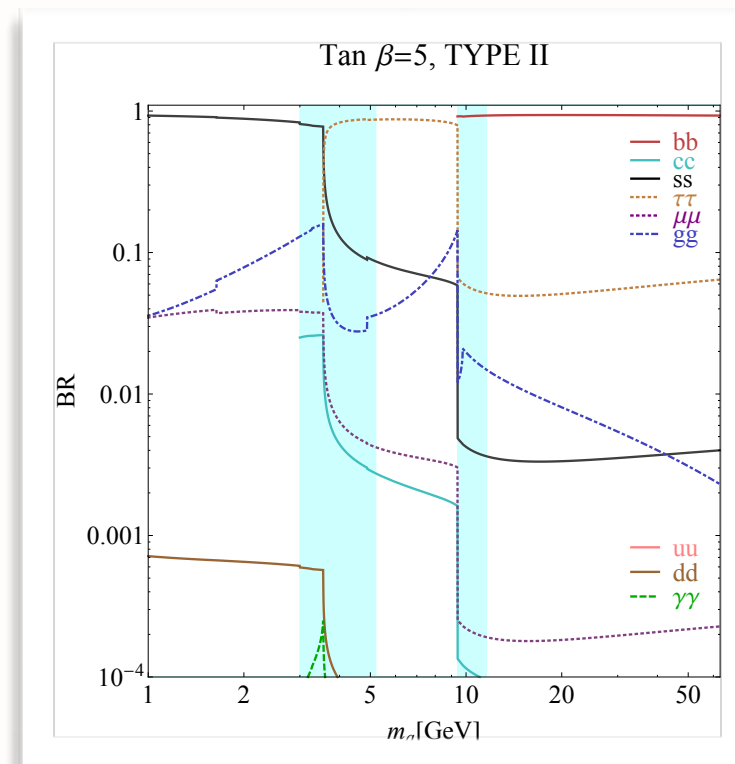


# Extending reach

- Extend sensitivity to  $h \rightarrow aa(ss)$  with other final states: **new trigger strategies**



X

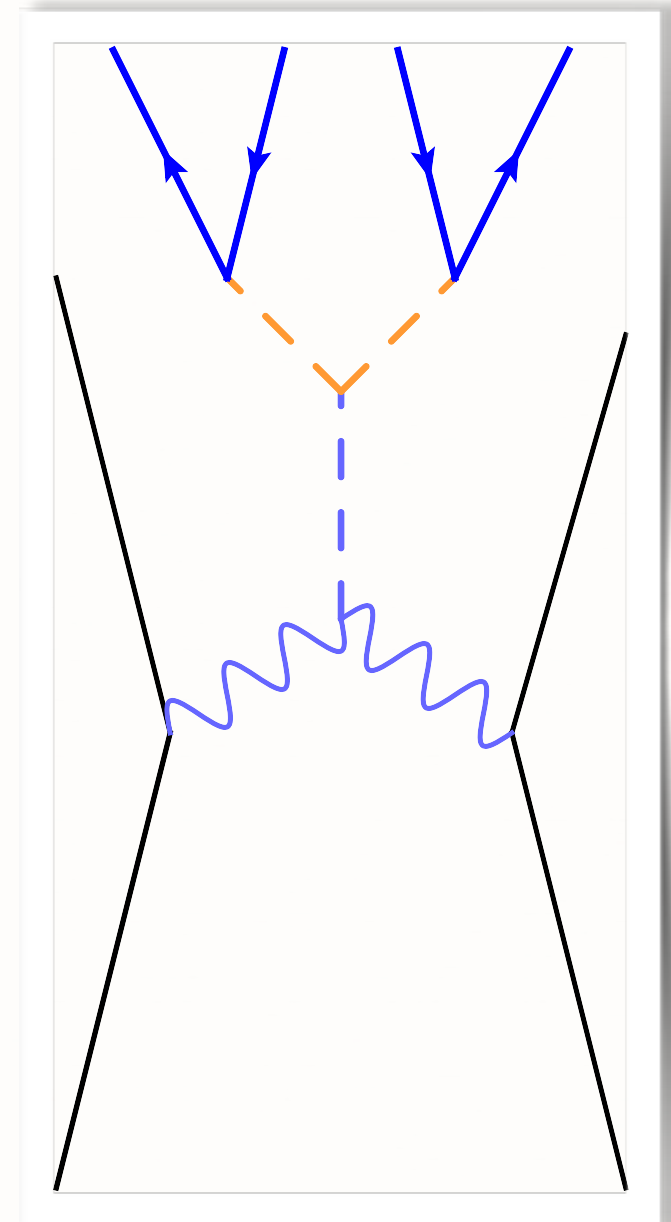


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- Combination triggers?

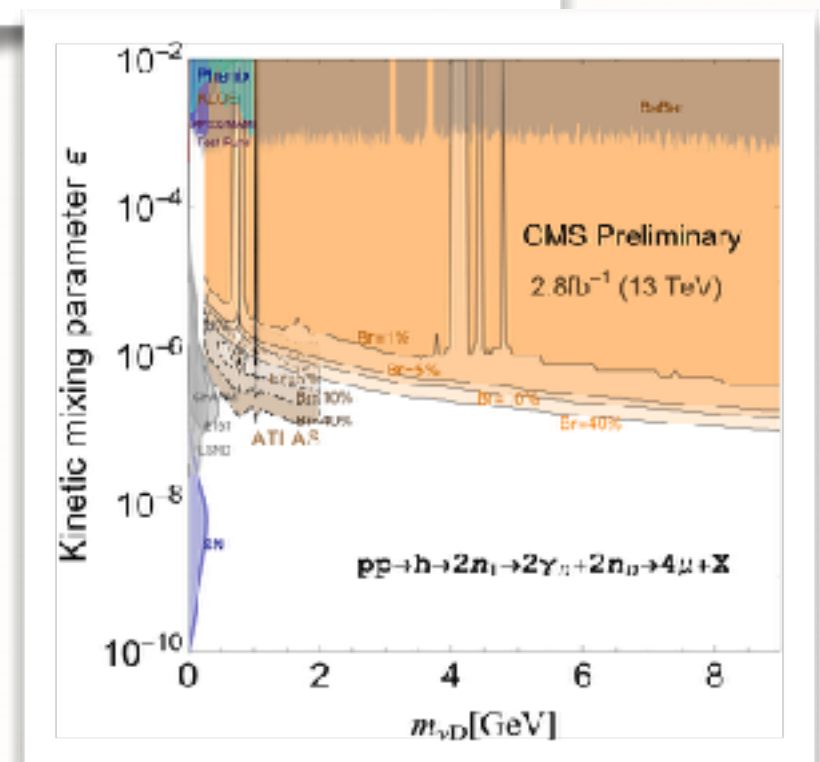
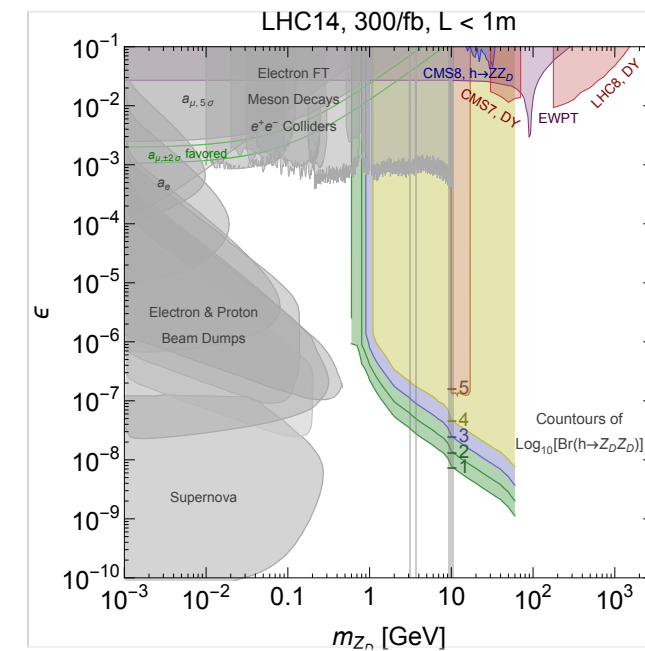
# Extending reach

- $h \rightarrow bb\tau\tau$
- Estimating QCD fake rates for low-mass di-tau a challenge for theorists
- VBF + soft lepton trigger?
  - also useful for electroweak SUSY
  - Not obviously slam-dunk: a lot depends on thresholds. Kinematic study needed
  - Multilepton triggers alternate possibility



# 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: **triggering**
  - Again, major obstacle is low mass scale of Higgs events

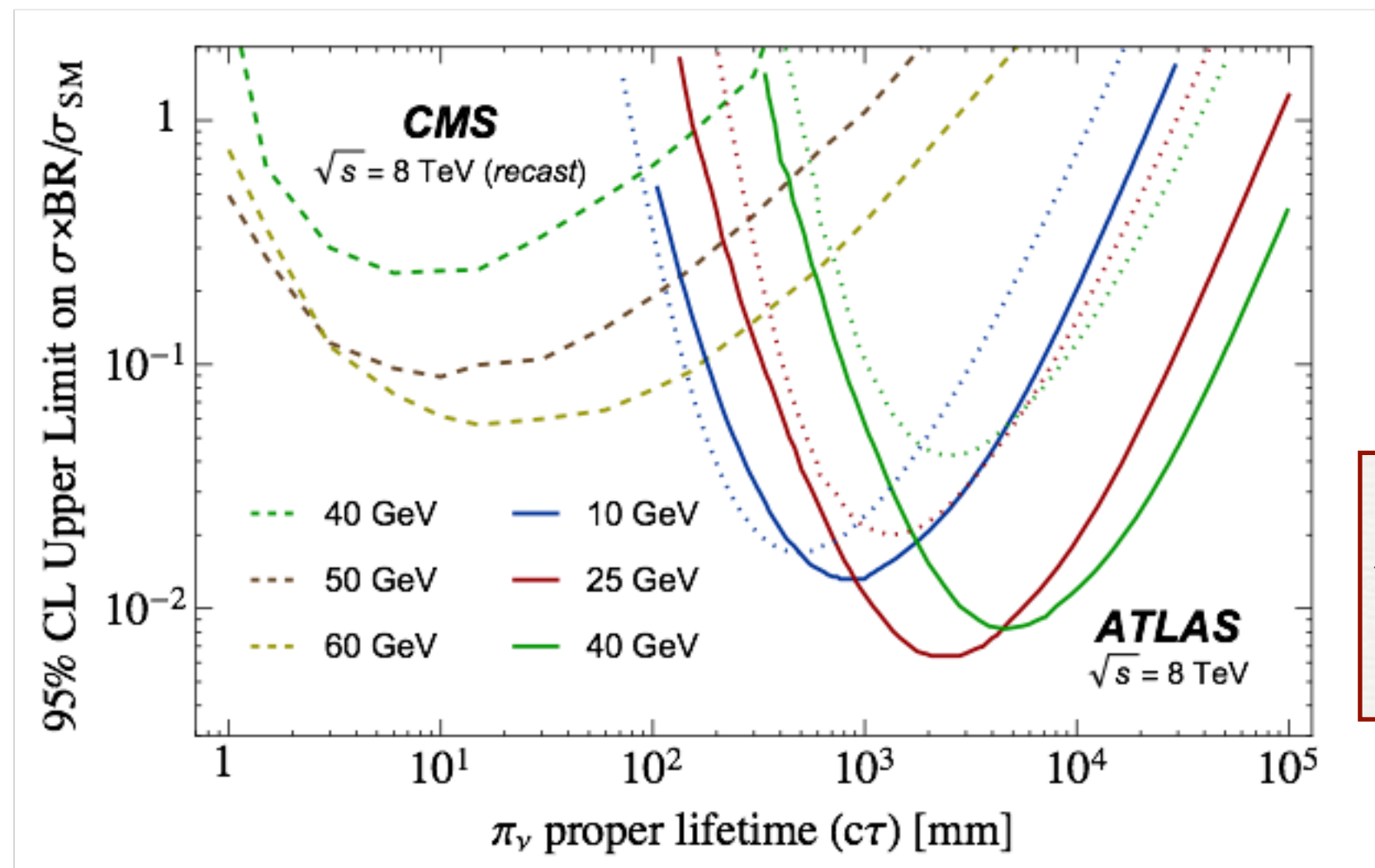




# Displaced decays

- Run I results for exotic Higgs decays:

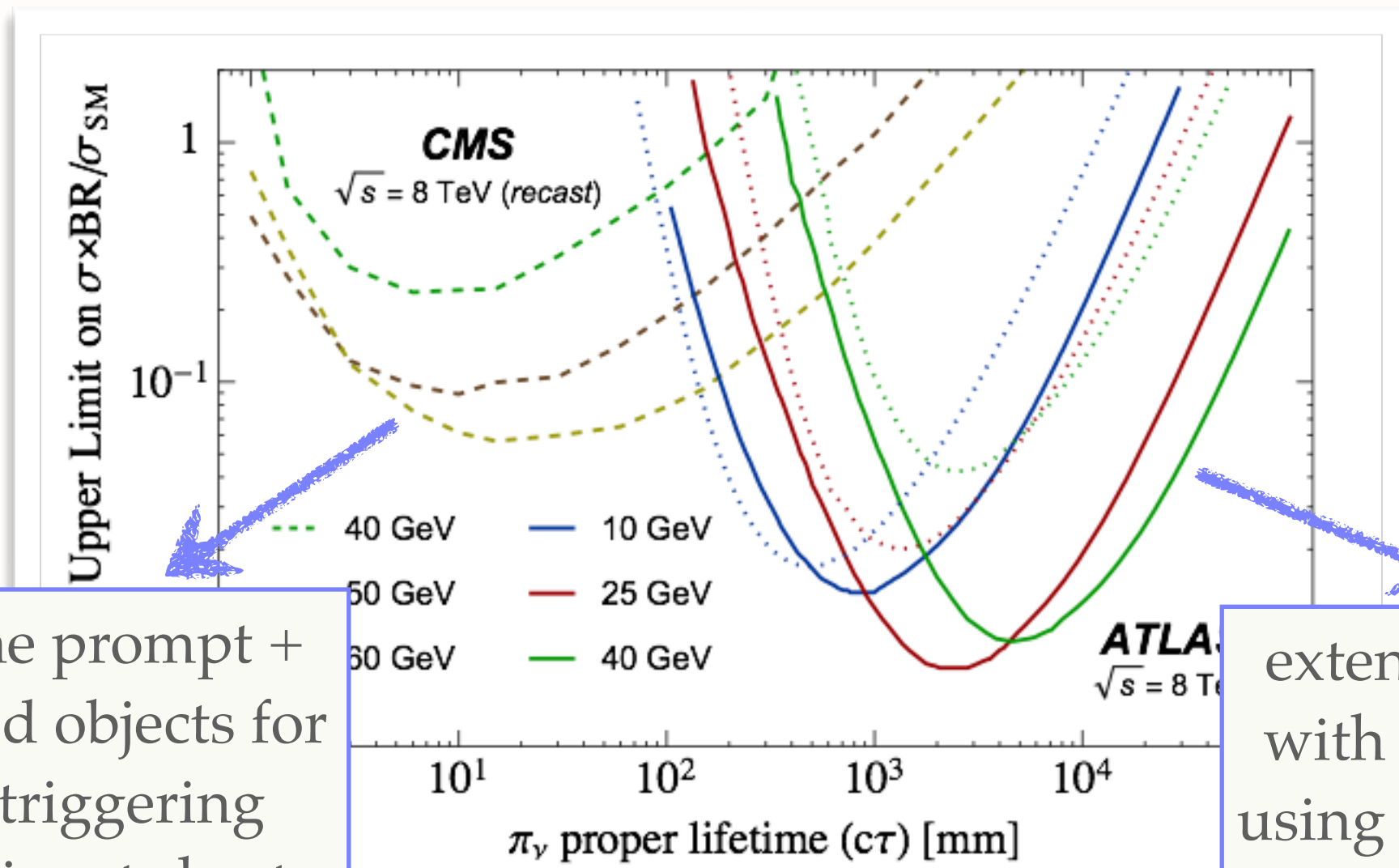
high HT requirement in trigger limits sensitivity at low mass, short lifetime



requirement of 2 DVs limits sensitivity at long lifetime

# Displaced decays

- Two essential strategies to increase reach:

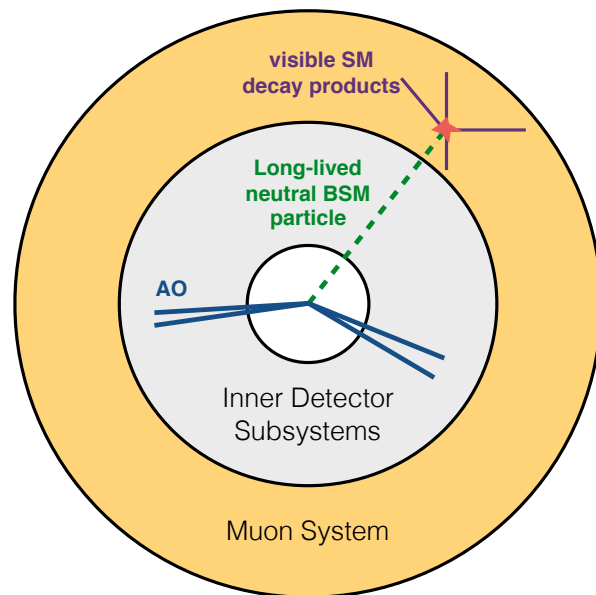


combine prompt + displaced objects for more triggering strategies at short lifetimes, low masses

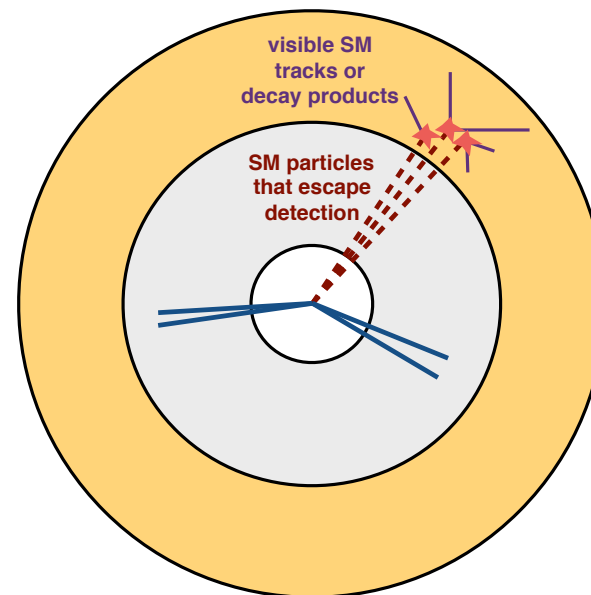
extend acceptance with new searches using less restrictive ID criteria

# Decays to very long-lived particles

- To get better sensitivity to long lifetimes, **single-vertex search** in muon system. Not background-free!
- Can't compute background from first principles  $\Rightarrow$  estimate from data
  - ...but even getting the needed control sample on tape can be challenging



signal arrives on dedicated trigger



need special trigger to record these events too!

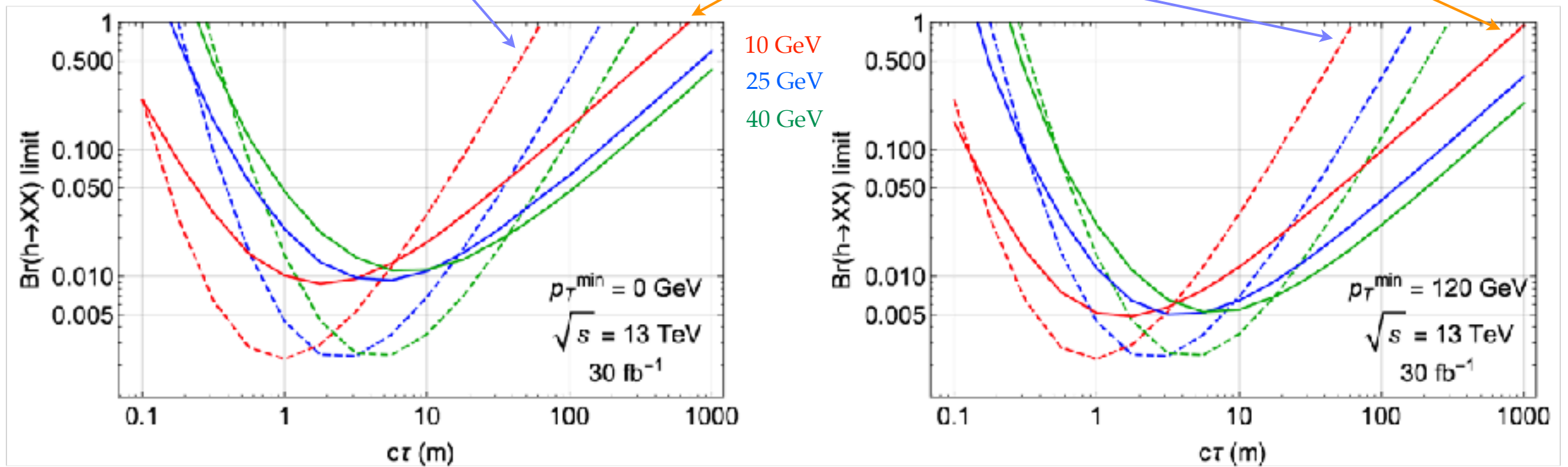


# Decays to very long-lived particles

- Notable gains in sensitivity at long lifetime:

Projected 13 TeV 2DV search,  
assumed background free

Our estimate for 1DV  
search sensitivity



# Conclusions

- LHC has unique opportunity to look for new physics in decays of the 125 GeV Higgs boson
  - phenomenal HL-LHC data set will allow deep tests of Higgs couplings to dark sectors...
  - ...provided the events are actually recorded
- Challenge of Higgs physics is always object thresholds
  - combine objects in triggers to keep thresholds as low as possible
  - new displaced triggers of very high interest for Higgs physics