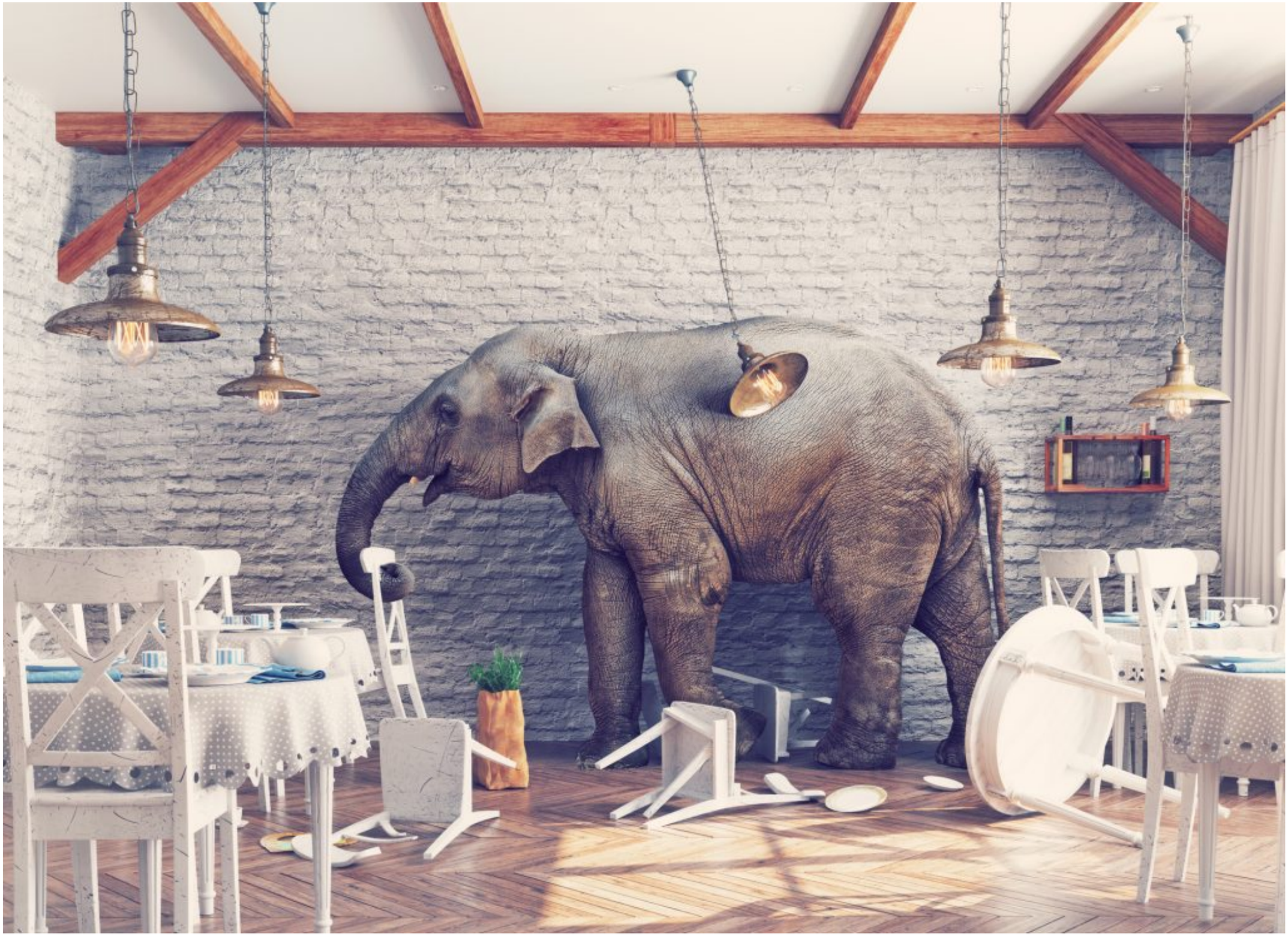
HIDDEN PHYSICS

Jessie Shelton
UIUC
ALPS 2019

THE ELEPHANT IN THE ROOM



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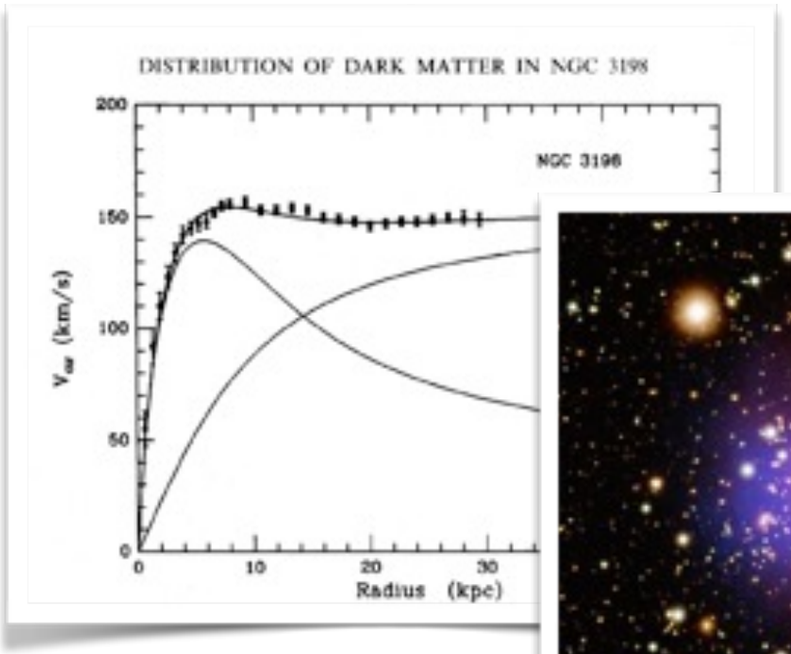
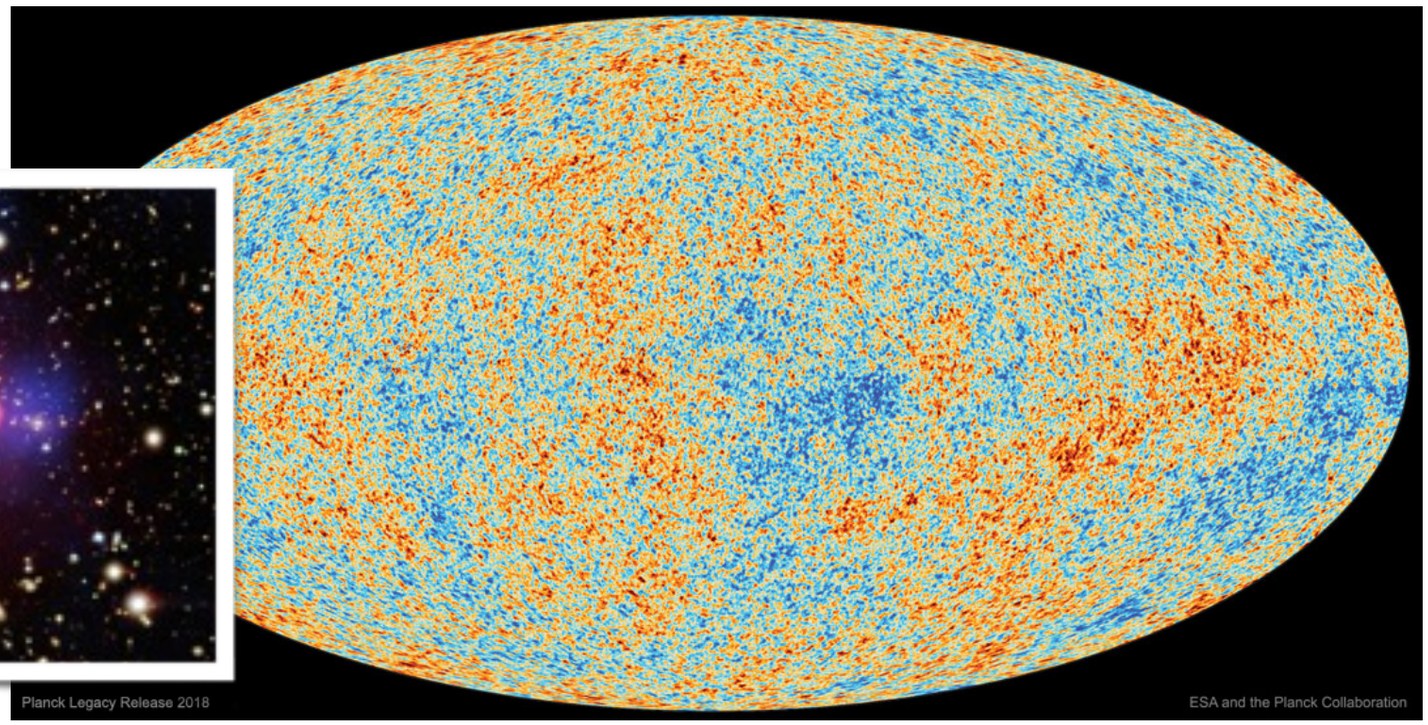
- Clear need for new physics below the Planck scale:

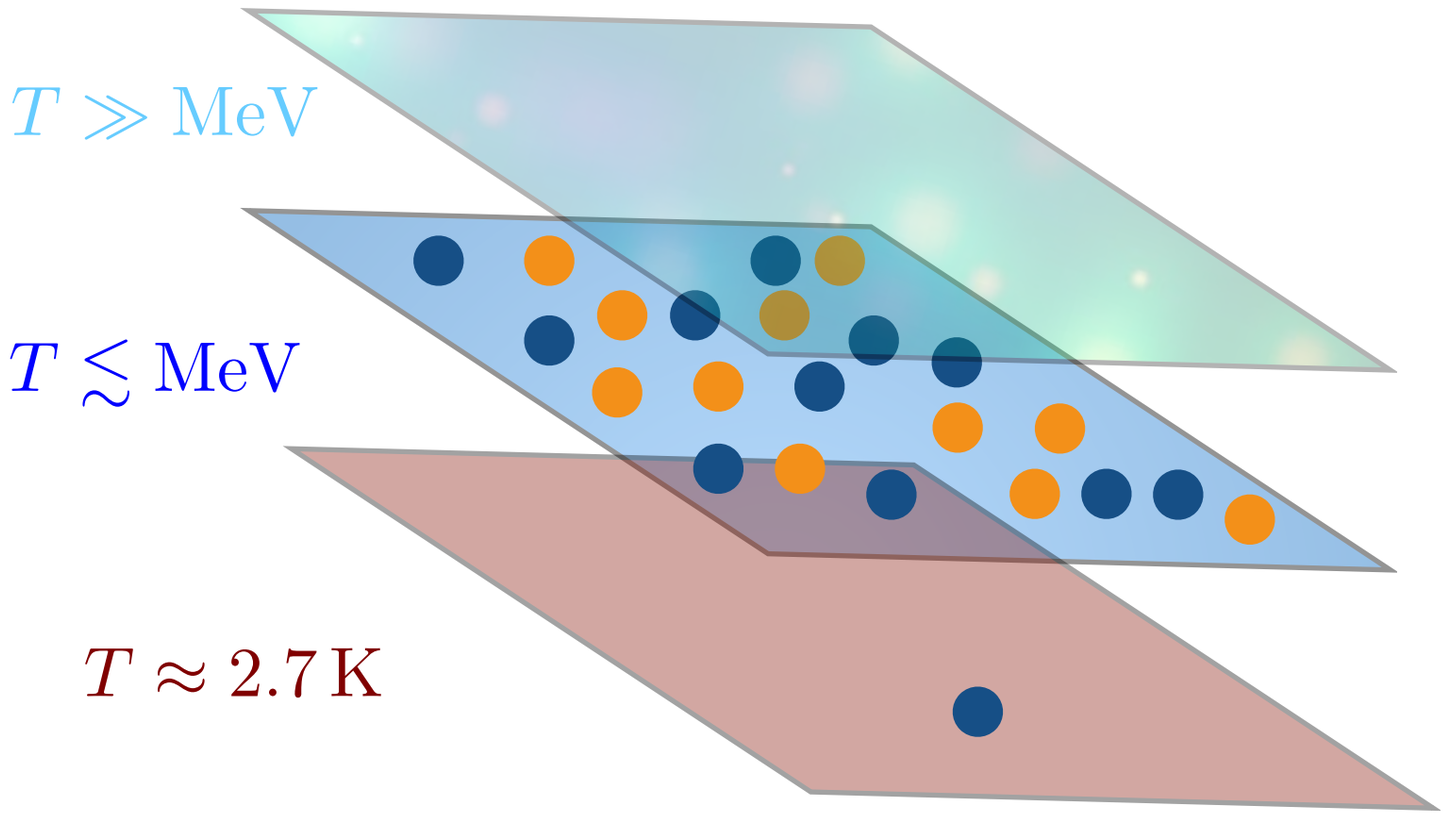




- ample gravitational evidence for dark matter
  - know present-day abundance
  - needs to be sufficiently cold
  - with limited interactions
- Must be something new

THE ELEPHANT IN THE ROOM

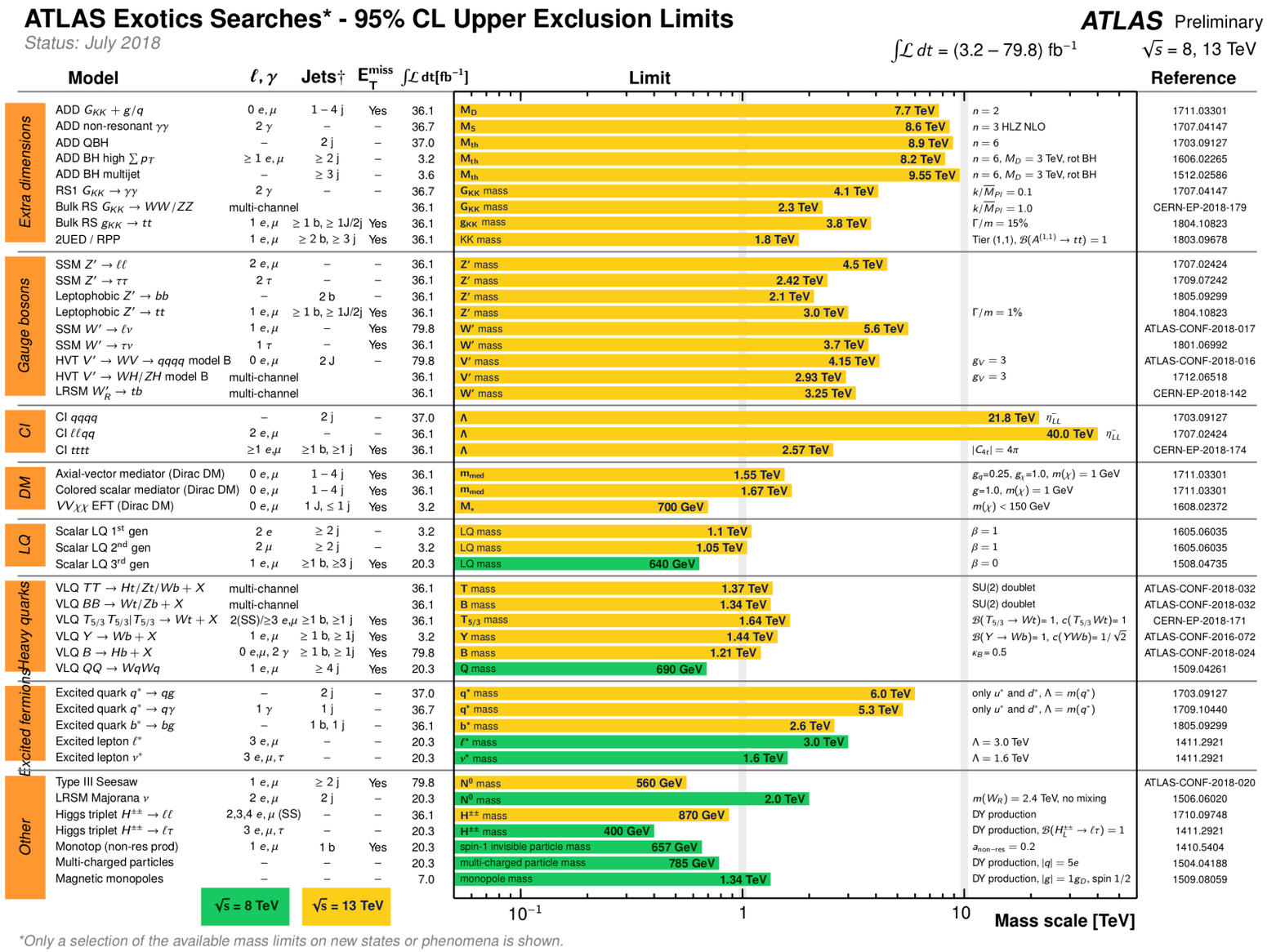
- Clear need for new physics below the Planck scale:
  - need early universe to generate matter-antimatter asymmetry:



- SM particles and interactions can’t do the job

THE ELEPHANT IN THE ROOM

- No clear signs of departures from the SM in terrestrial experiments*



*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

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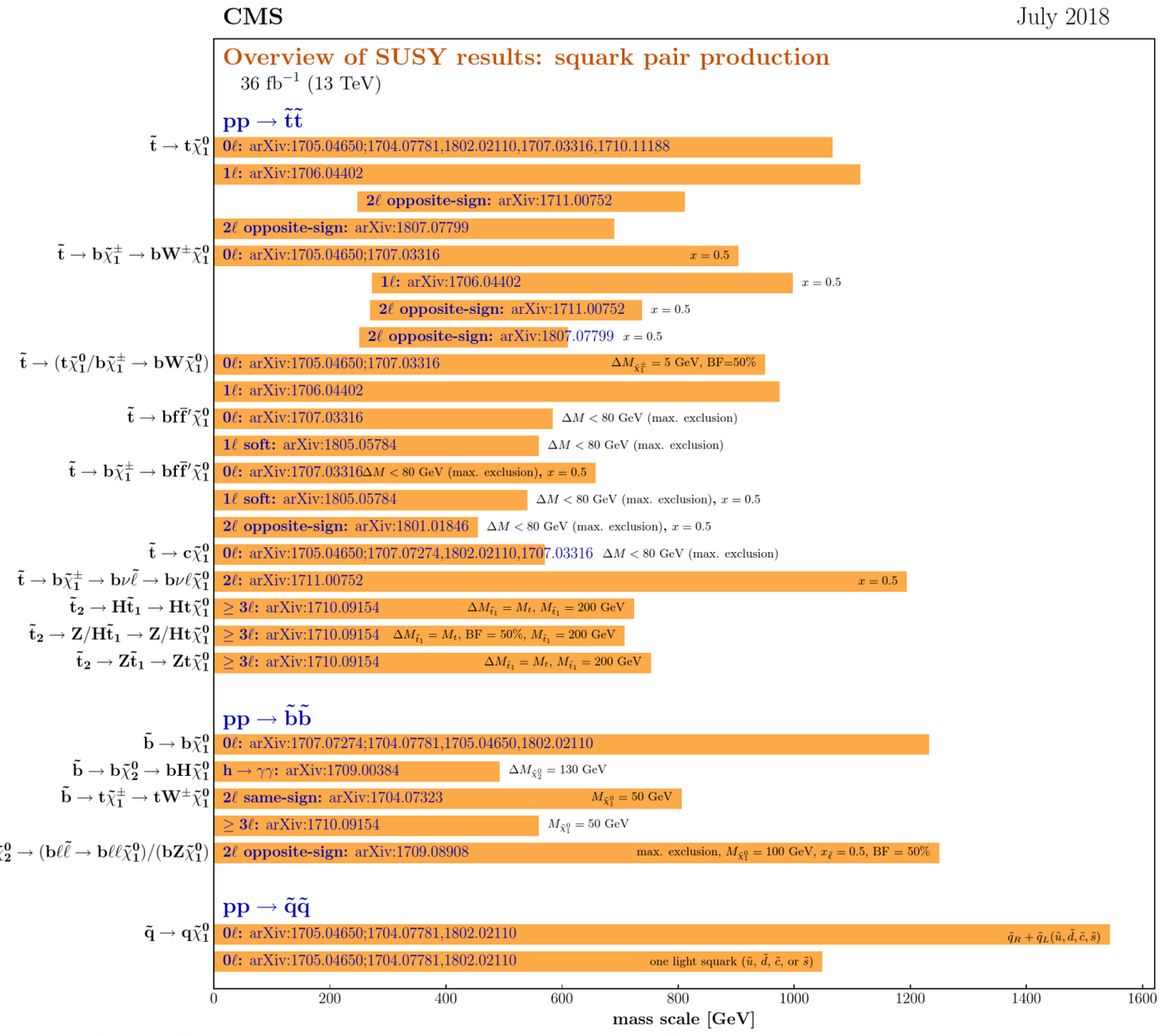

Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

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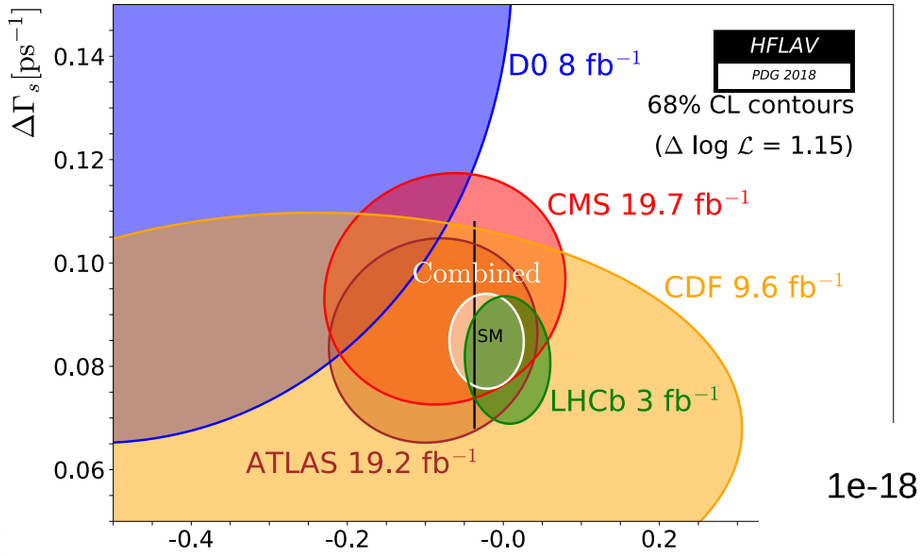

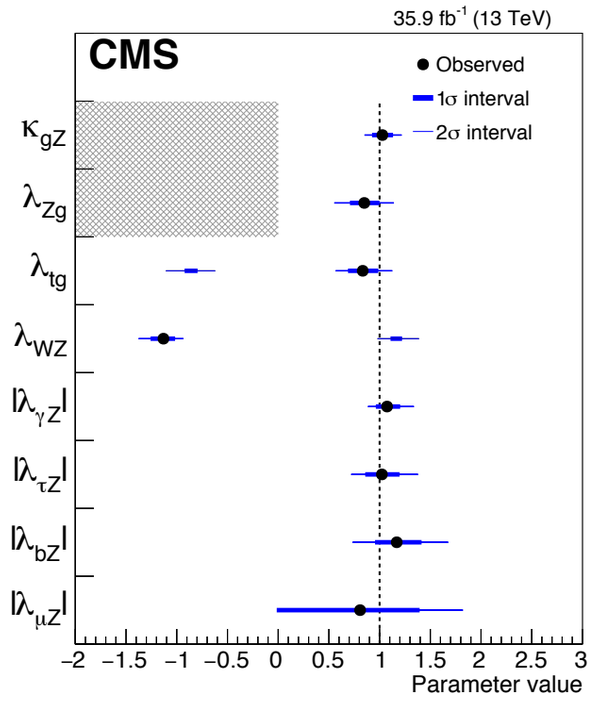

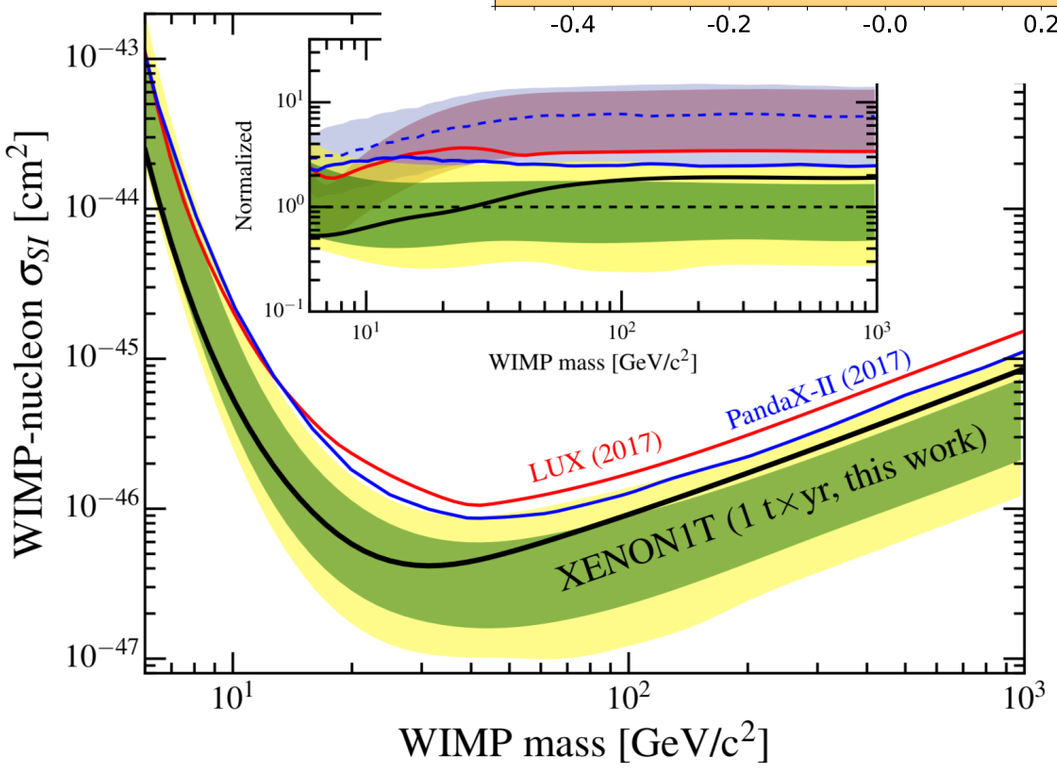

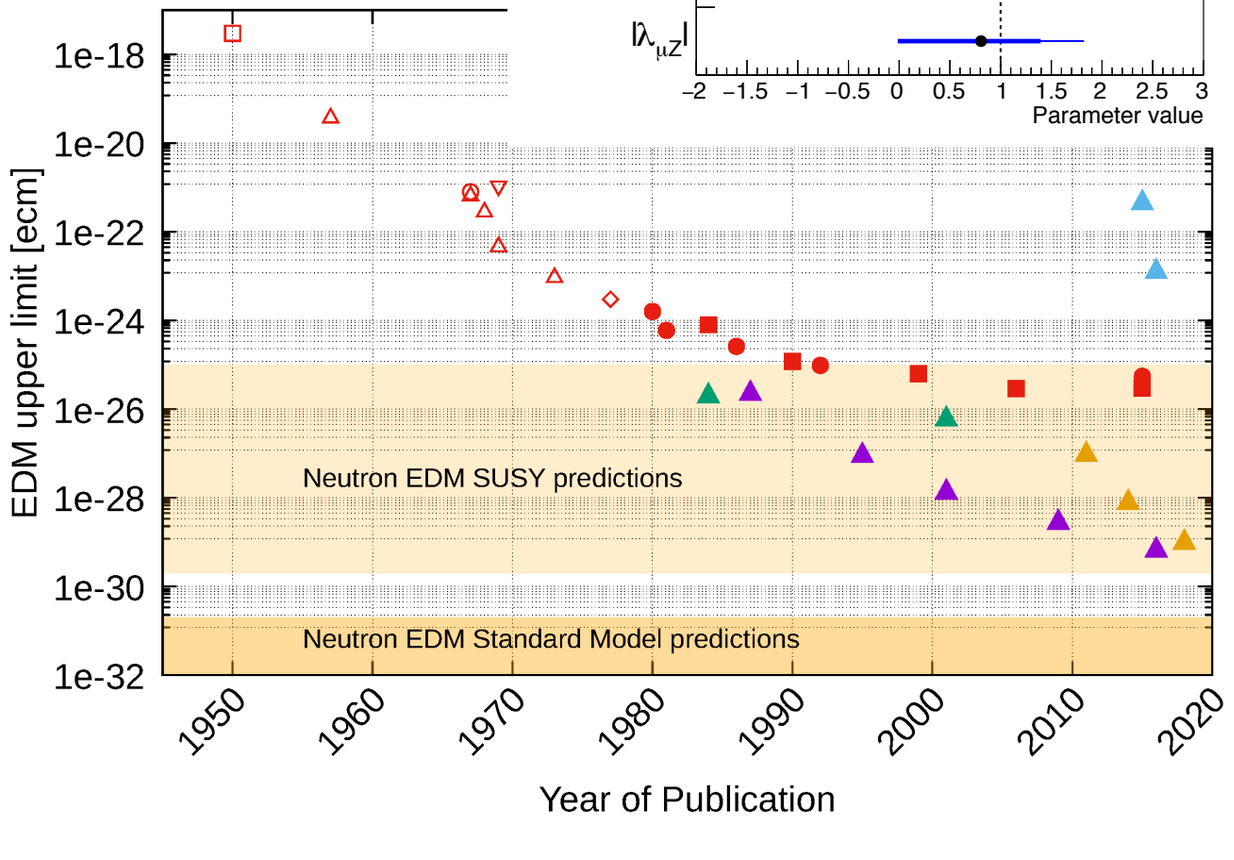

HIDDEN PHYSICS

- is it time to stop thinking about new ways to discover BSM physics at the LHC?

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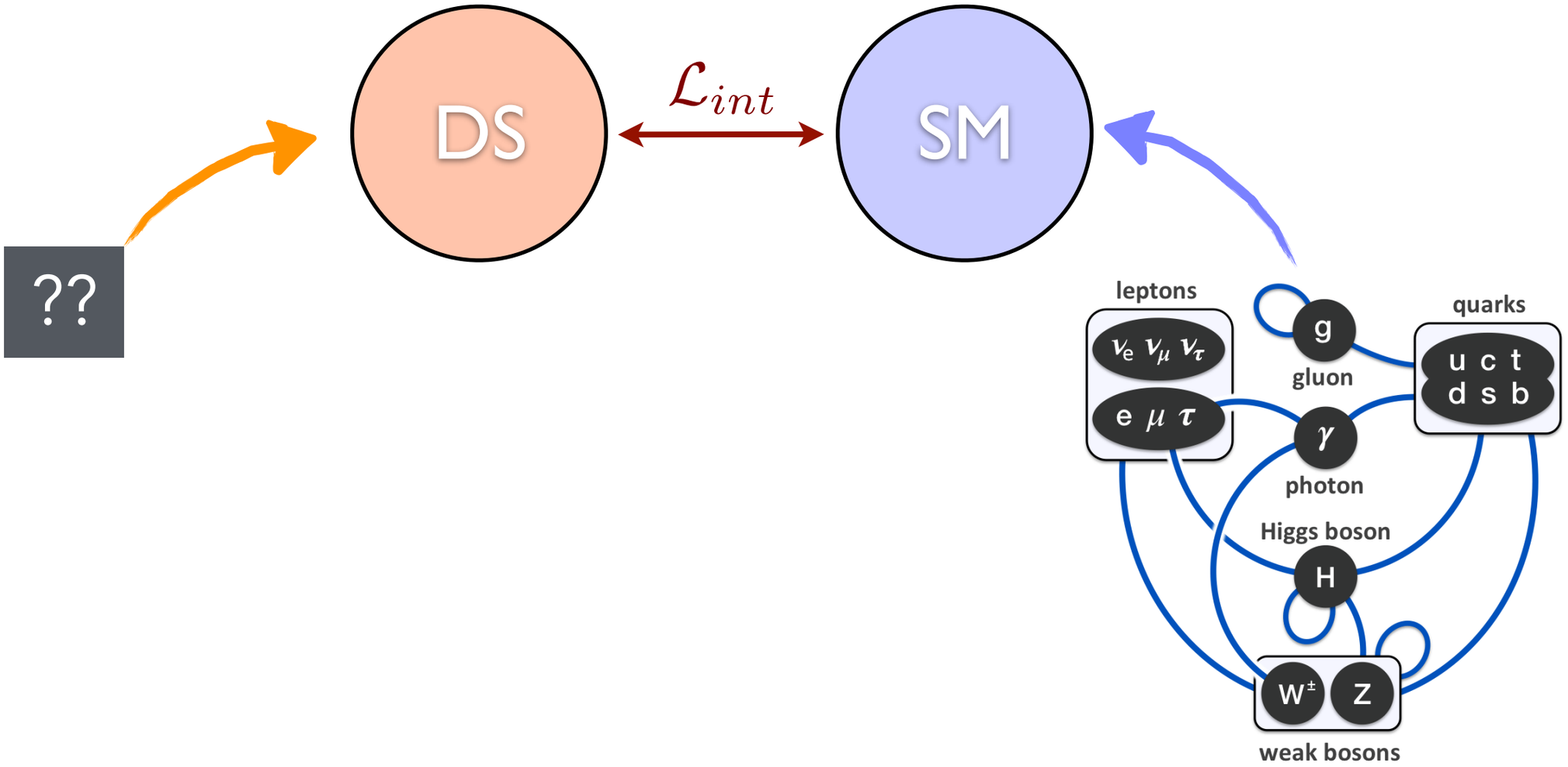
- is it time to stop thinking about new ways to discover BSM physics at the LHC?

Of course not.

HIDDEN PHYSICS

- New physics could live in hidden sectors:



[image credit Eric Dressler]

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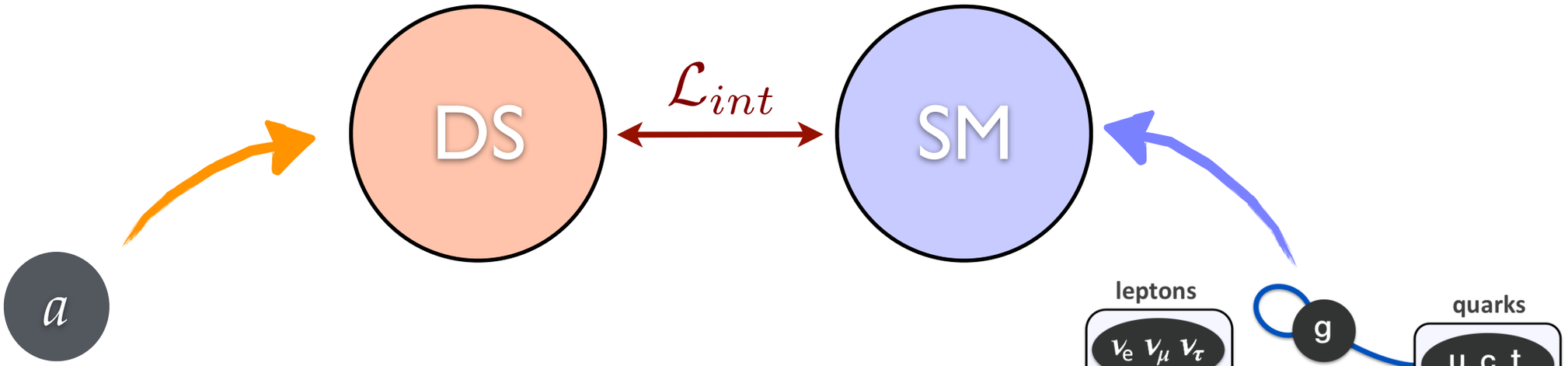
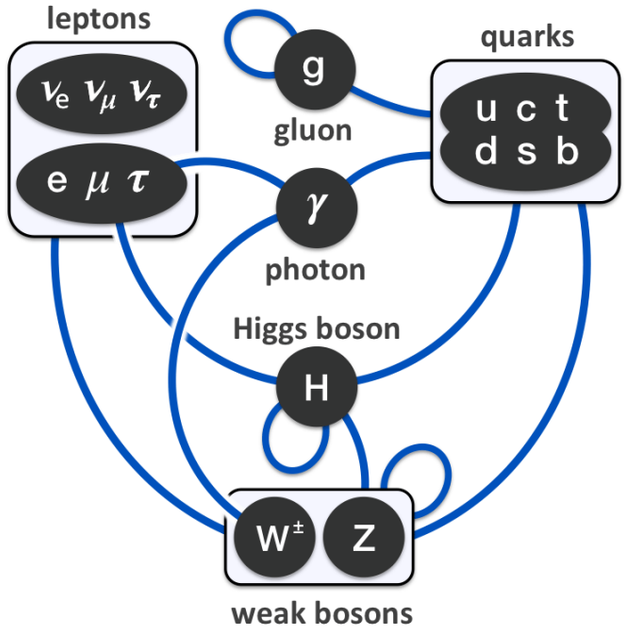


- new name for long-standing ideas (axions, sterile neutrinos, singlet scalars)



[image credit Eric Dressler]

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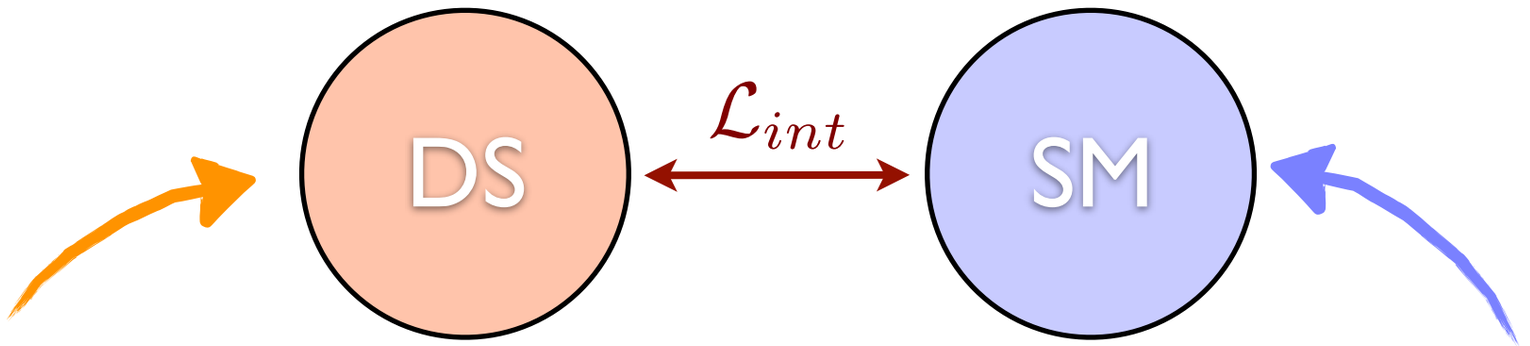
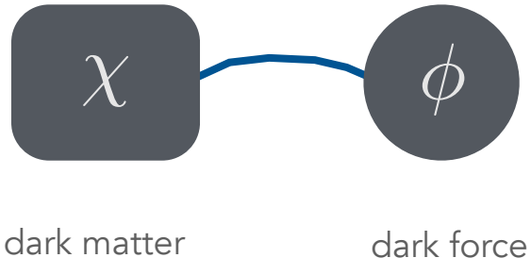
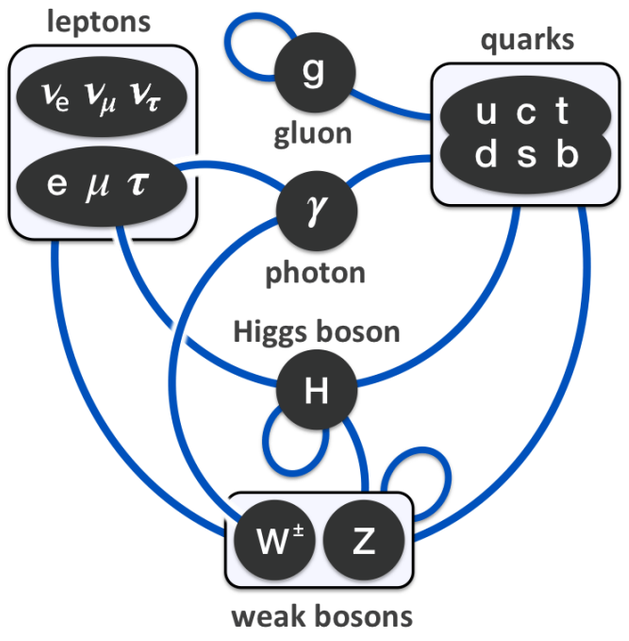




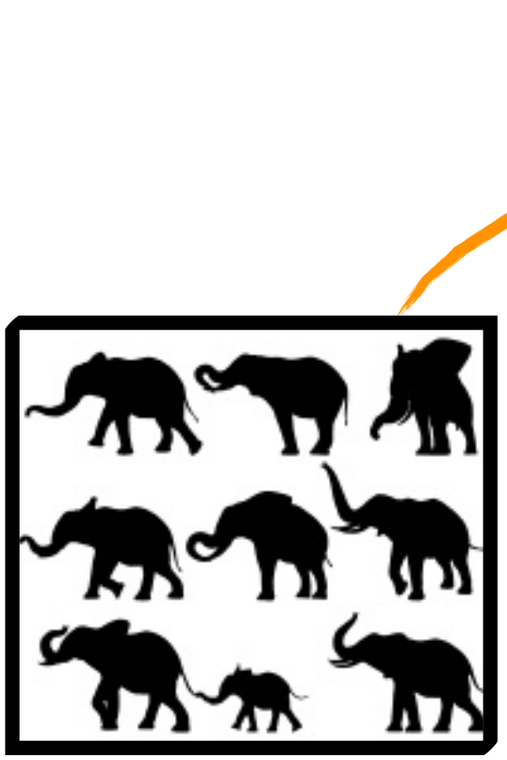
- new name for long-standing ideas (axions, sterile neutrinos, singlet scalars)
- dark matter

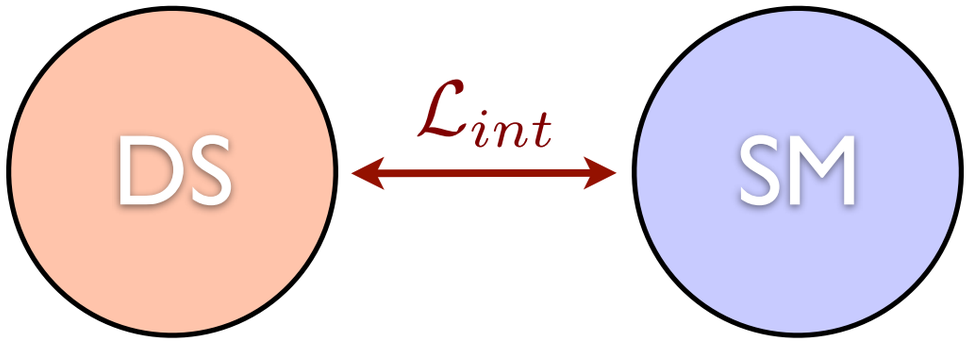


[Pospelov, Ritz, Voloshin; Arkani-Hamed, Finkbeiner, Slatyer, Weiner; Feng, Kumar; ...]

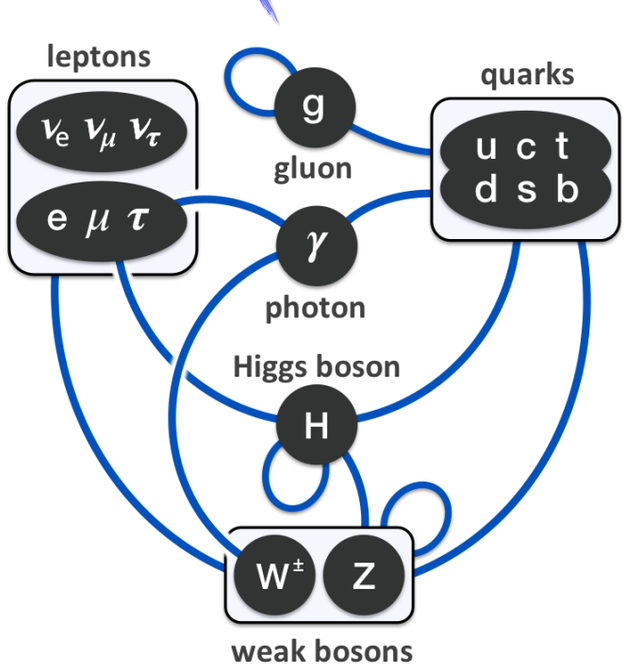
HIDDEN PHYSICS

➤ New physics could live in hidden sectors:





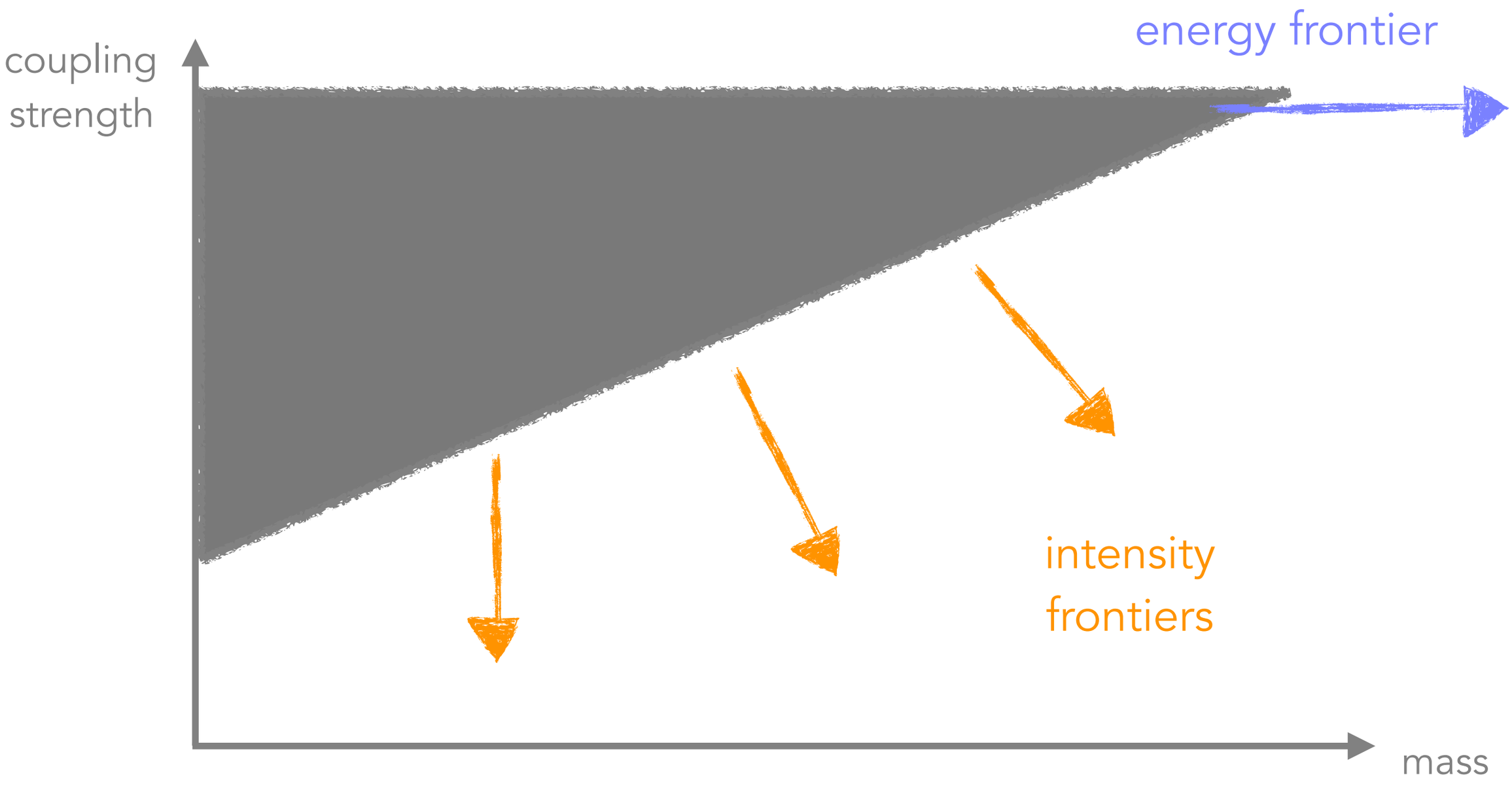
- new name for long-standing ideas (axions, sterile neutrinos, singlet scalars)
- dark matter
- matter-antimatter asymmetry
- hierarchy problem



[JS, Zurek; Chako, Goh, Harnik; Strassler, Zurek; Vattis, Koushiappas, Loeb; …]

THE LHC AS AN INTENSITY FRONTIER MACHINE

a non-exhaustive cartoon



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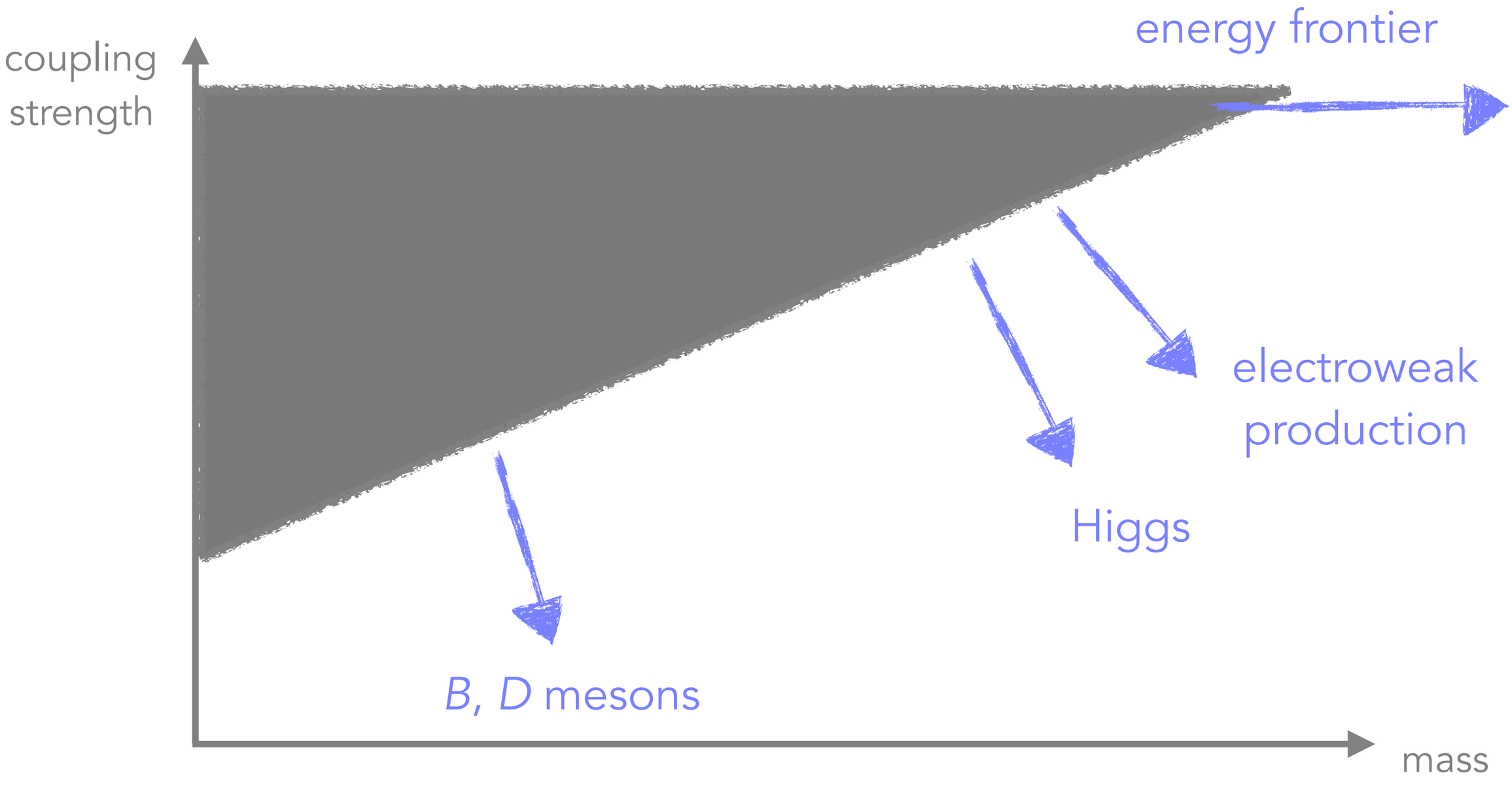

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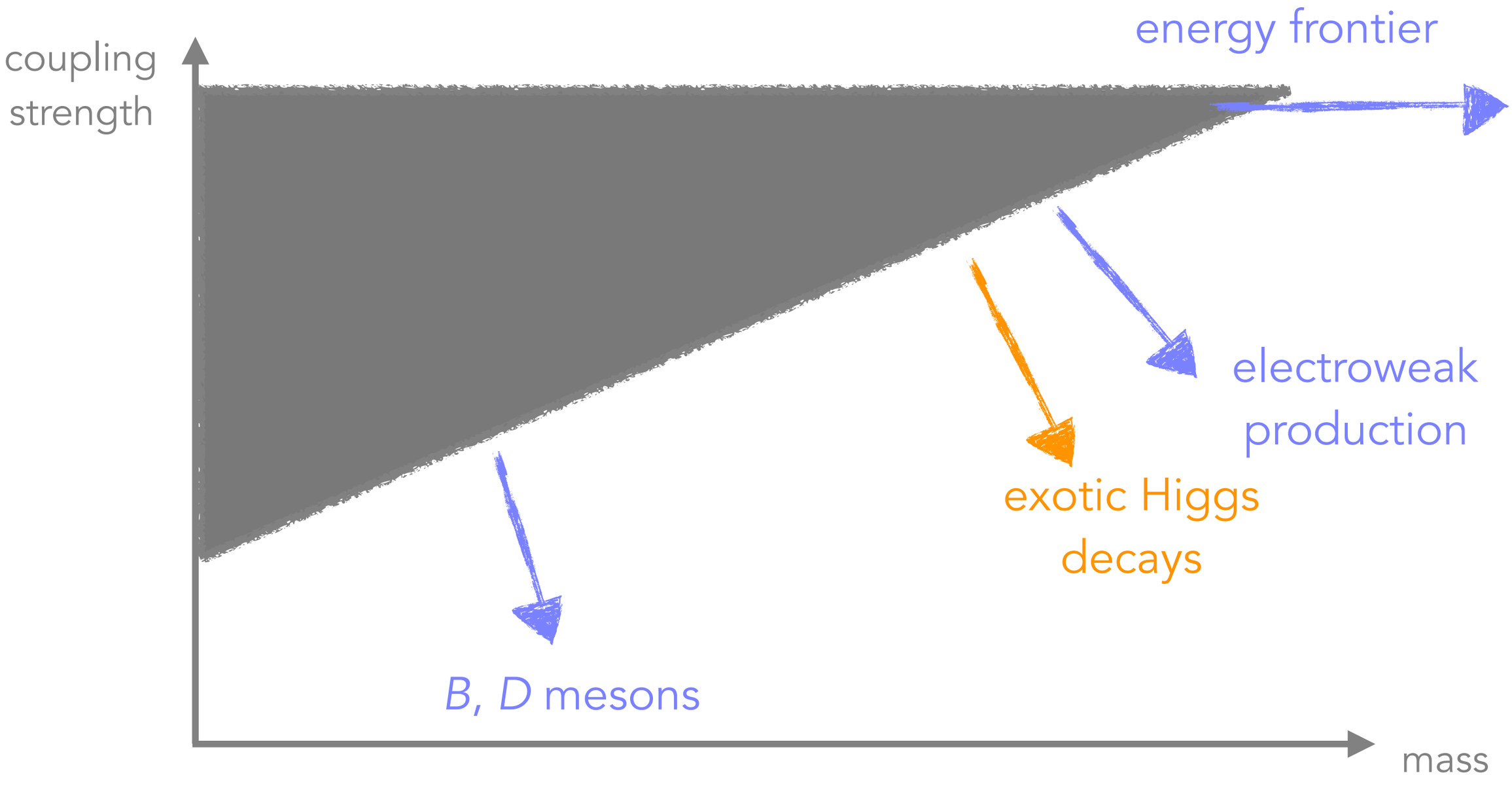

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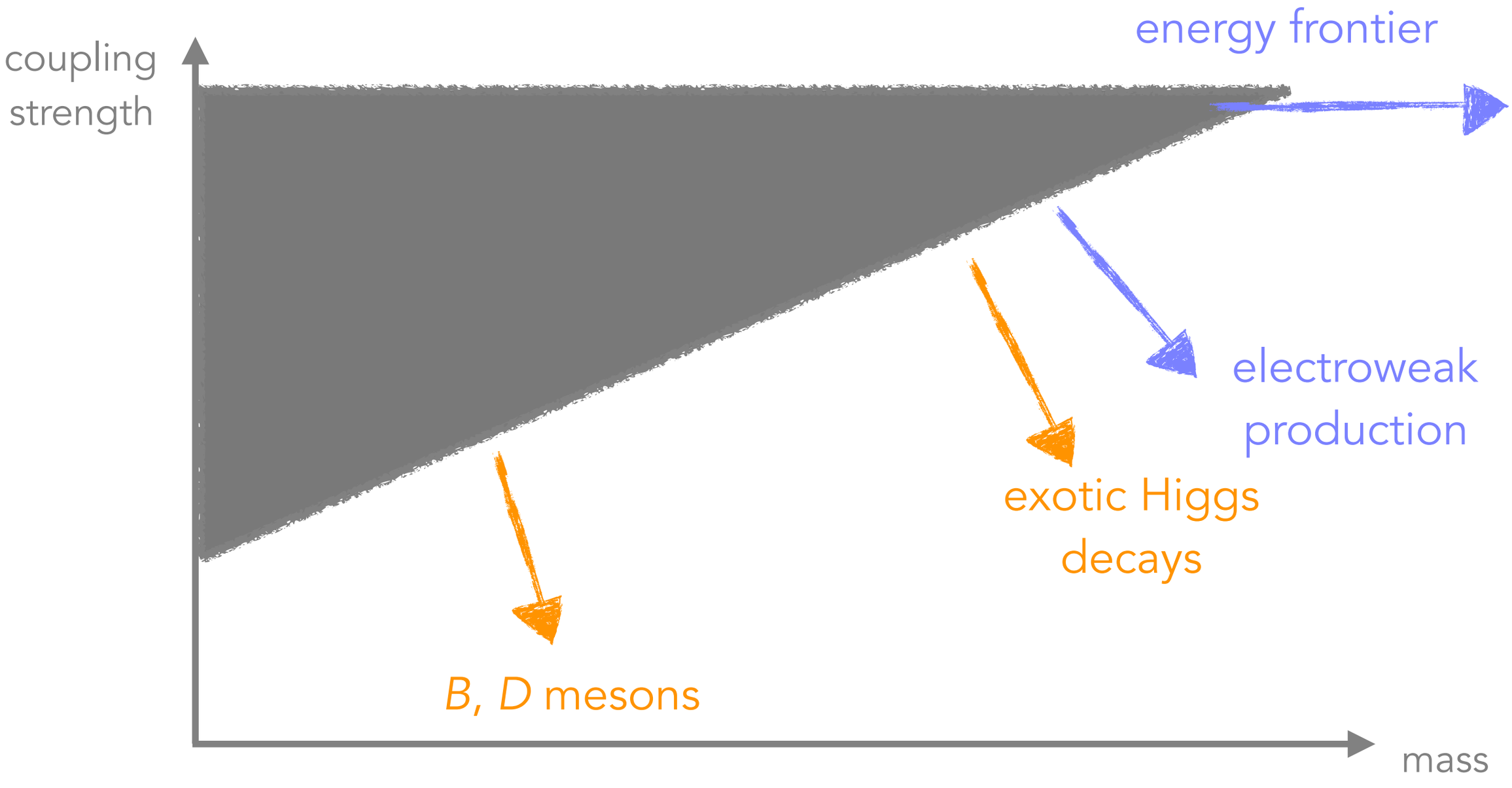

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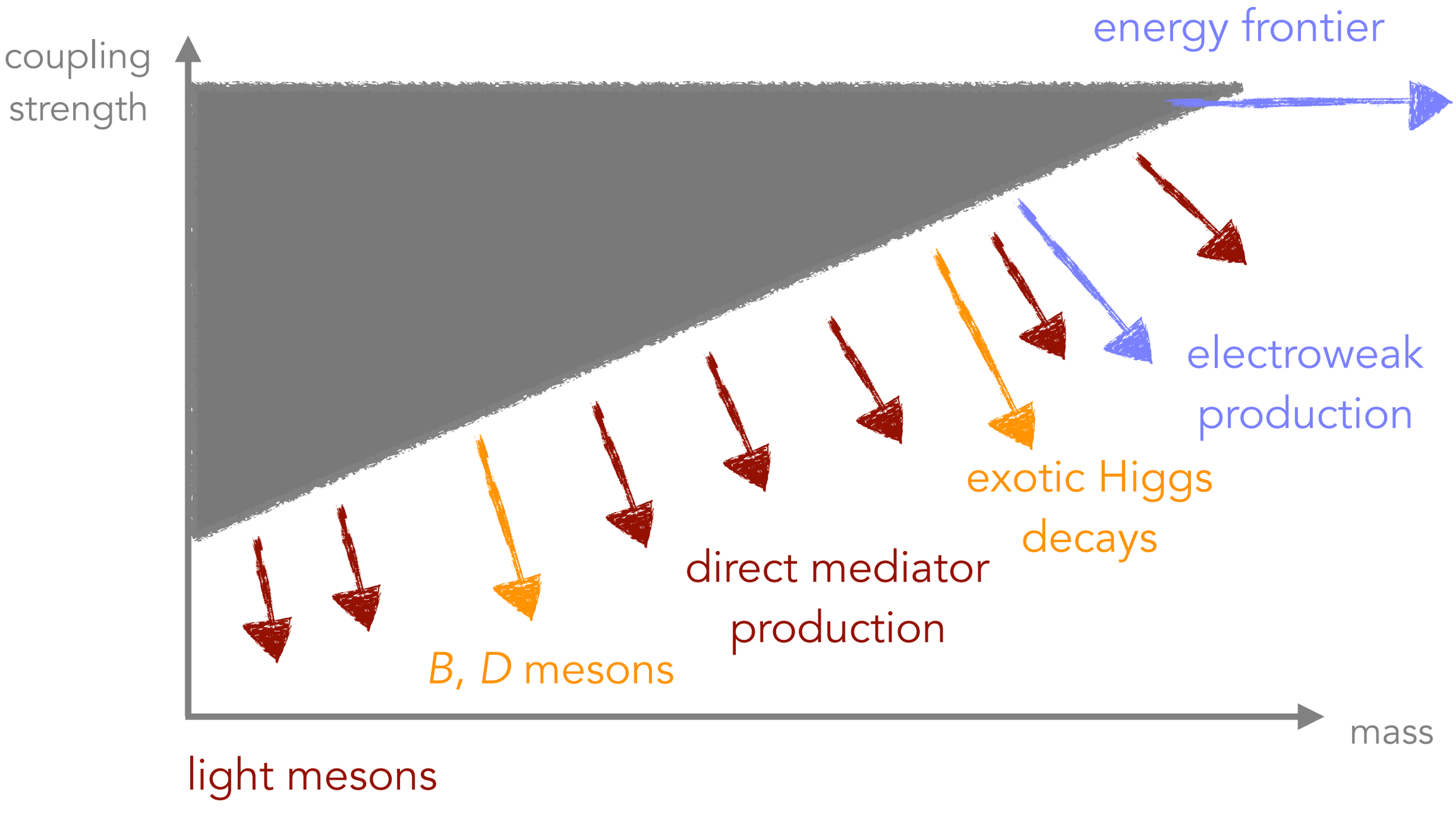


HIDDEN PHYSICS

- There are no guaranteed discoveries.
- Any new state directly produced at the LHC would have been in thermal equilibrium with the SM in the early universe
- But: a variety of reasons for new physics to appear at accessible energy scales
  - electroweak symmetry breaking
  - the “WIMP miracle”
- The LHC is still our best general-purpose discovery machine

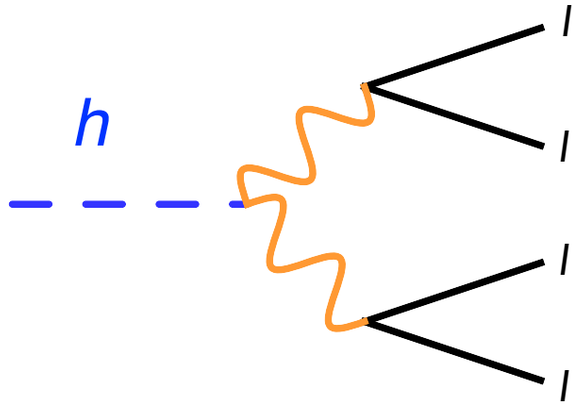
[Evans, Gori, JS; Kahlhofer]

THE LHC AS AN INTENSITY FRONTIER MACHINE

- One does not generally imagine constructing "general purpose" intensity frontier machines…

THE LHC AS AN INTENSITY FRONTIER MACHINE

- Exotic Higgs decays:
  - Higgs production cross-section at 13 TeV: ~50 pb
  - integrated luminosity: ~70+45 /fb
    - ~5 750 000 Higgs bosons in Run II
  - If: reasonable reconstruction efficiency, good *S/B*: statistics for branching fractions ~10^{-5}



[Curtin, Essig, Gori, Jaiswal, Katz, Liu, Liu, McKeen, JS, Strassler, Surujon, Tweedie, Zhong]

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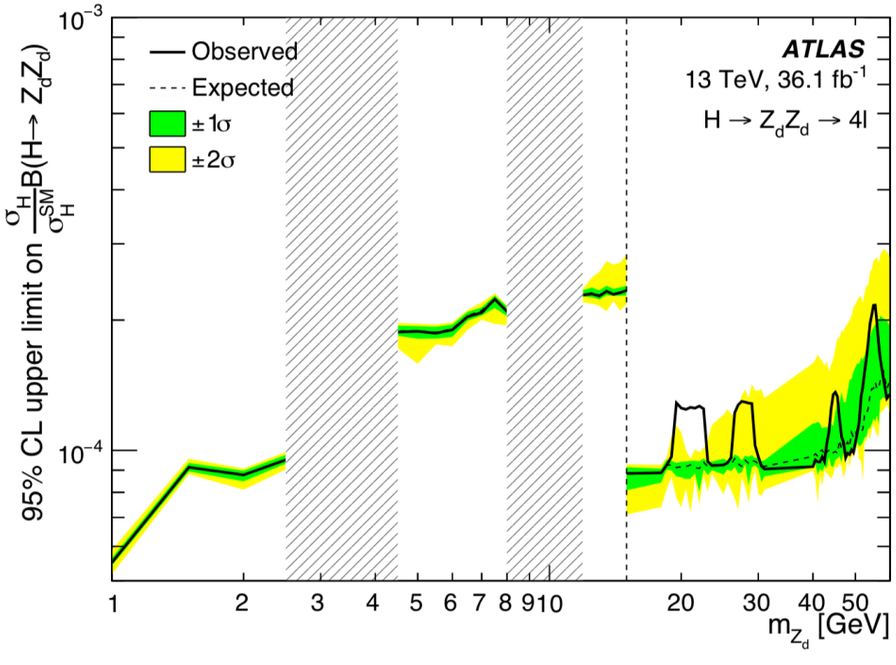

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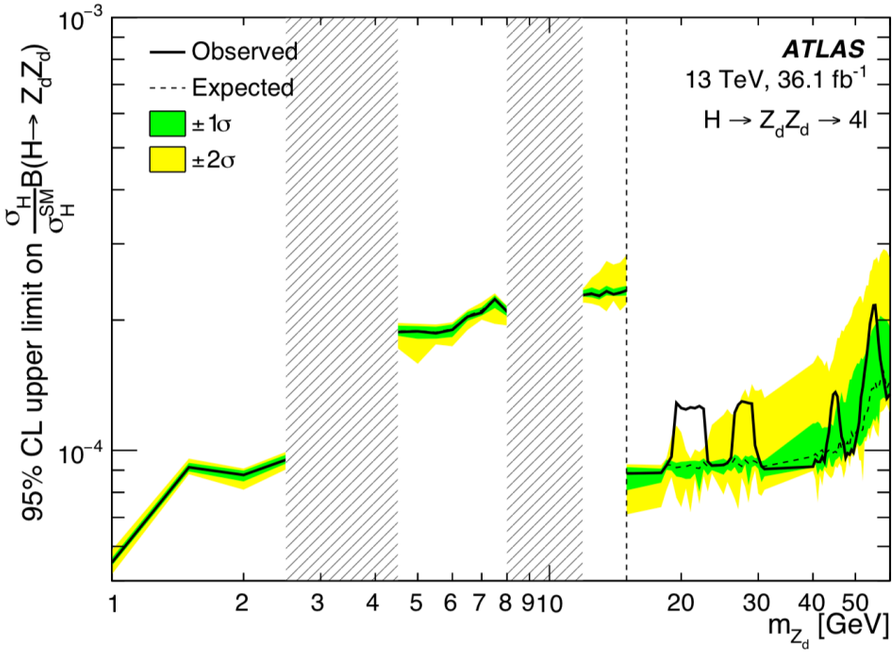

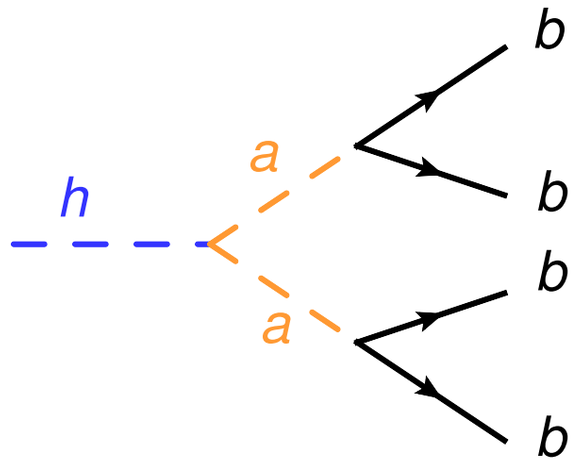

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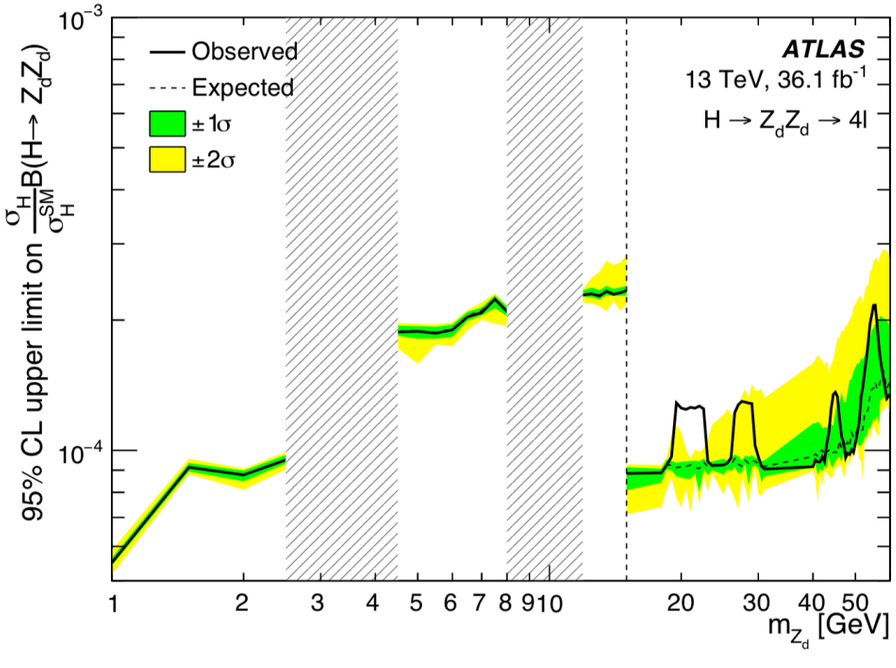
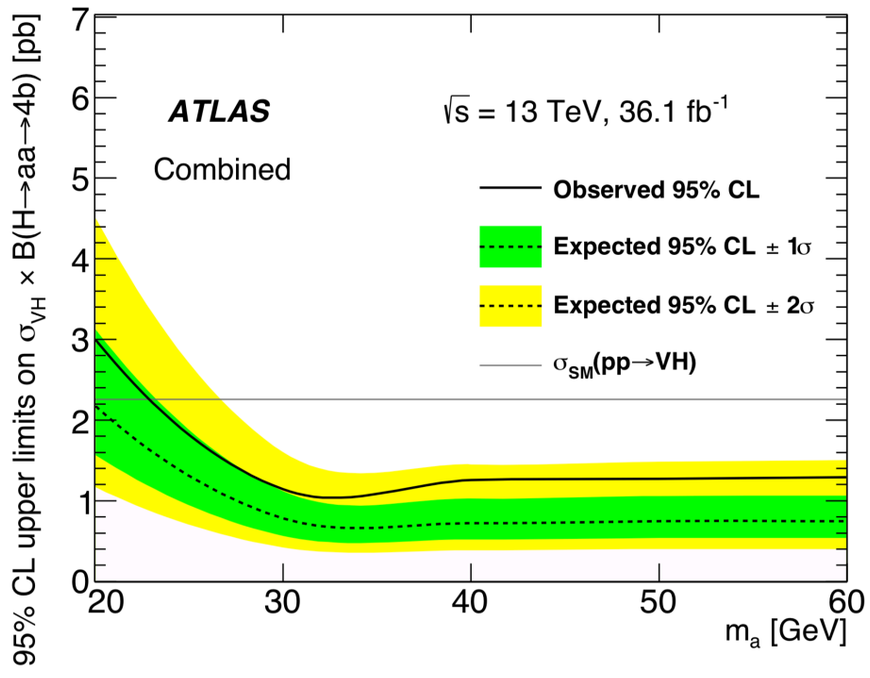
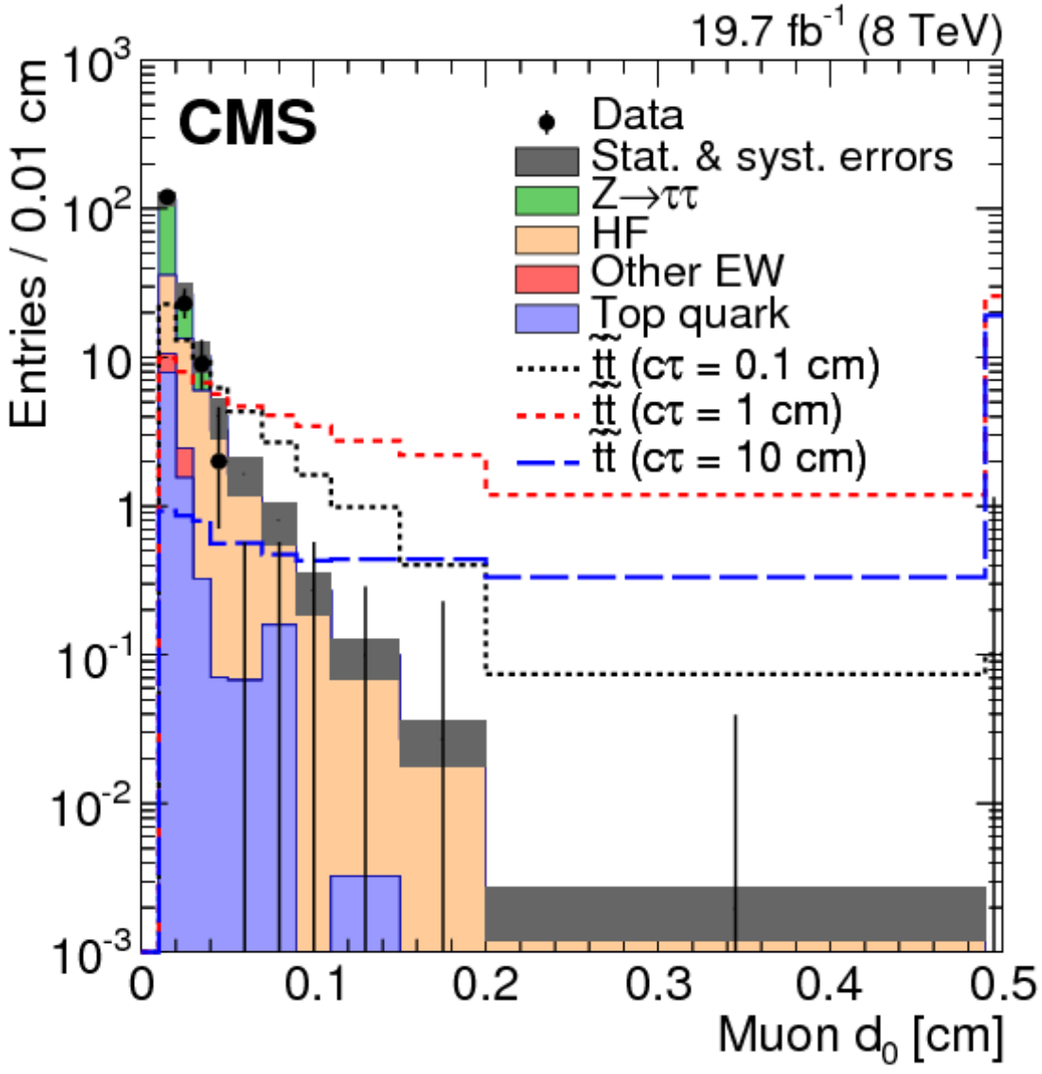


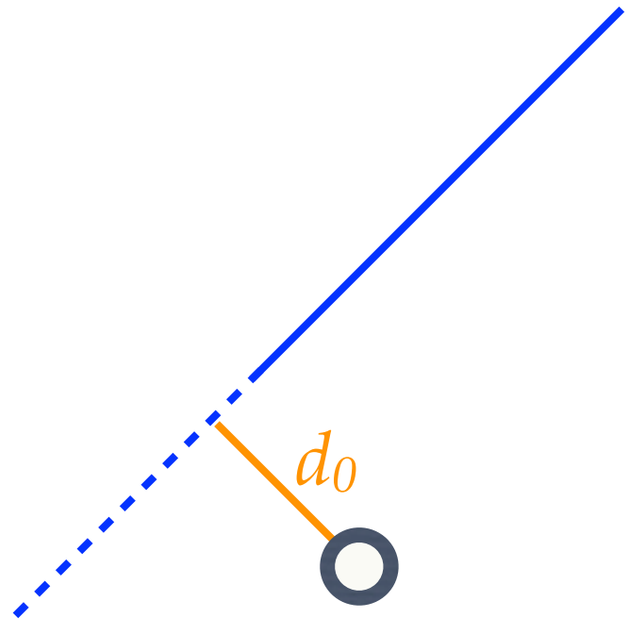


[Curtin, Essig, Gori, Jaiswal, Katz, Liu, Liu, McKeen, JS, Strassler, Surujon, Tweedie, Zhong]

LONG-LIVED PARTICLES

- General and powerful way to separate signal from background: macroscopic proper lifetimes





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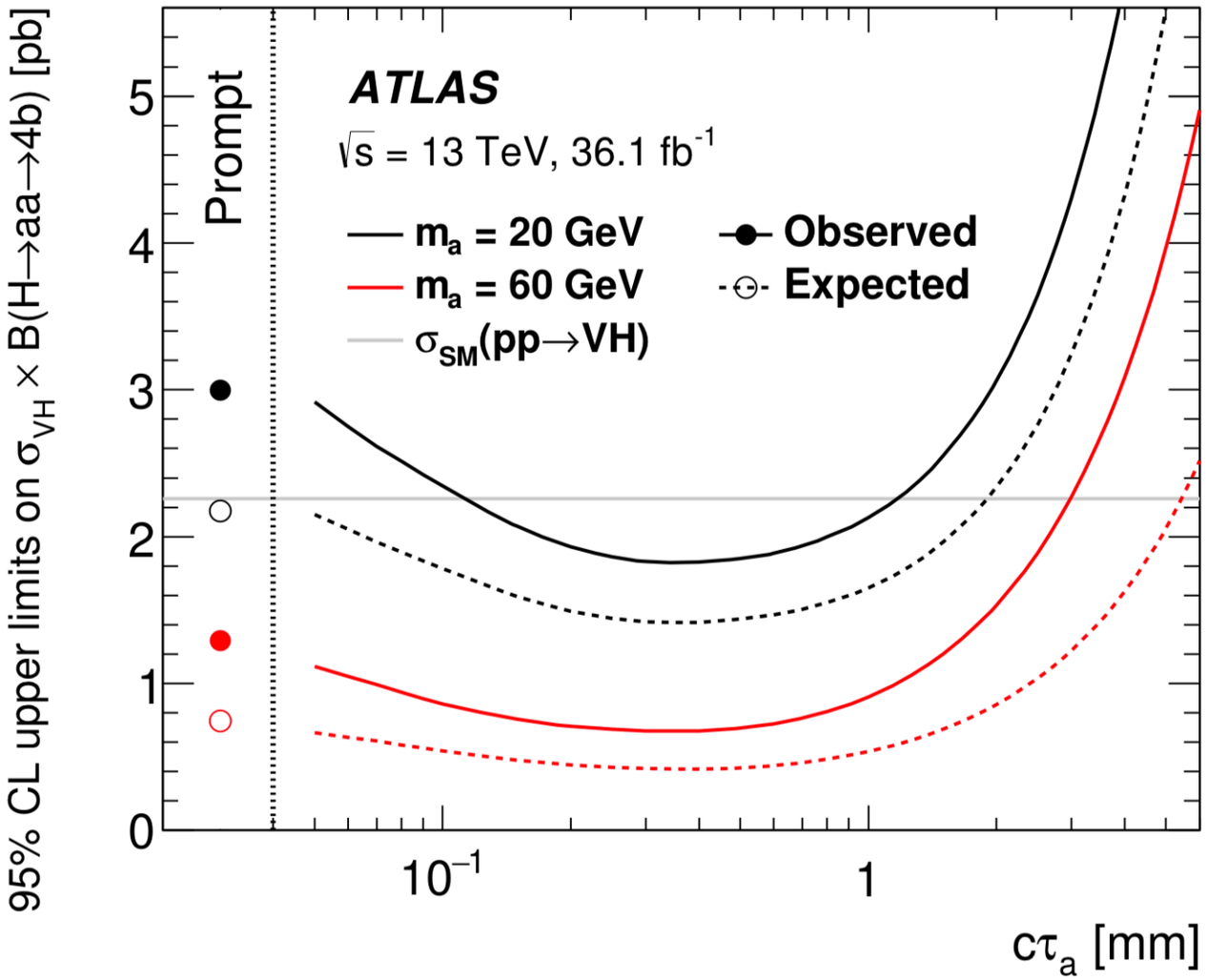
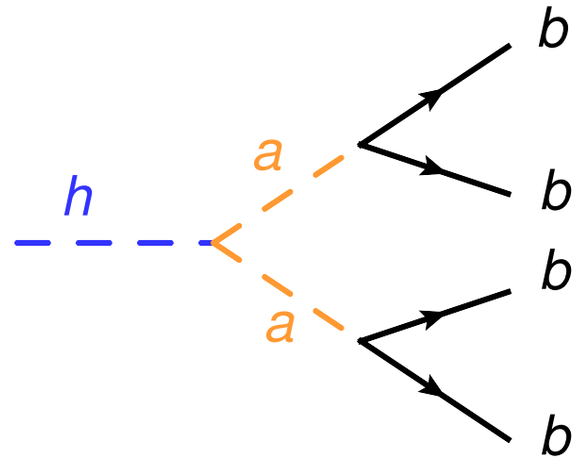


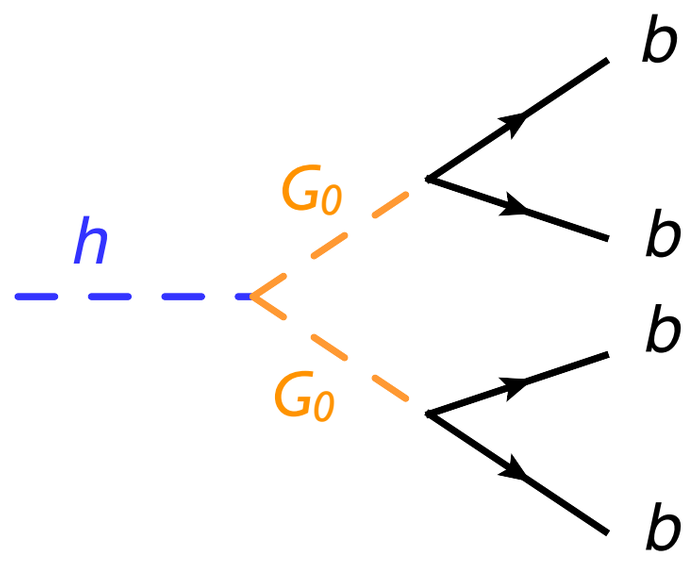


LONG-LIVED PARTICLES

- Macroscopic lifetimes:

$$\Gamma = \frac{1}{2m} \int d\Pi_f |\mathcal{M}|^2$$

  - small matrix element: small couplings
  - high mass scales



[see e.g. MATHUSLA physics case, eds. Curtin, Drewes, McCullough, Meade, Mohapatra, JS, Shuve]

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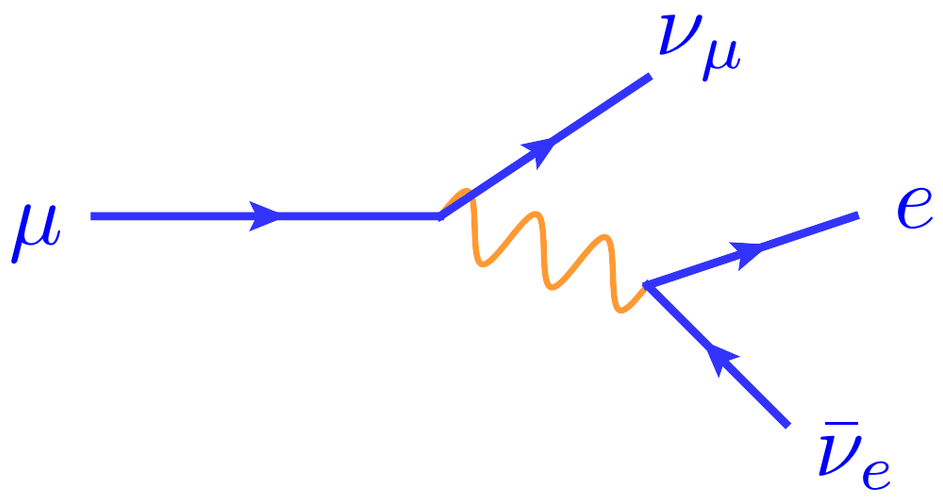

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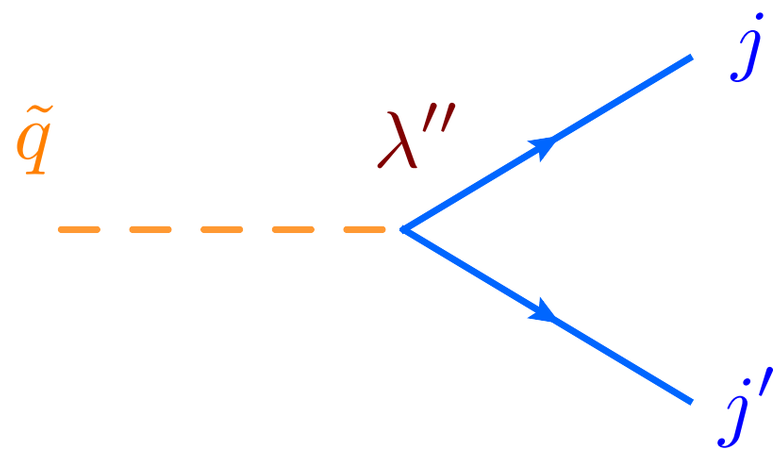

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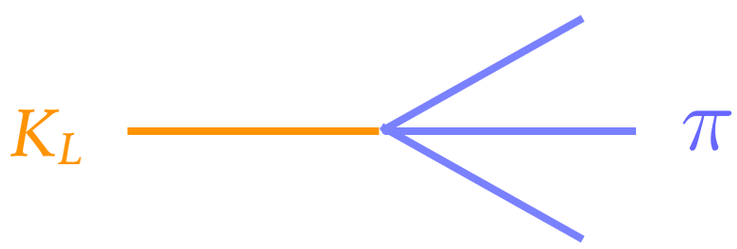

LONG-LIVED PARTICLES

- Macroscopic lifetimes:

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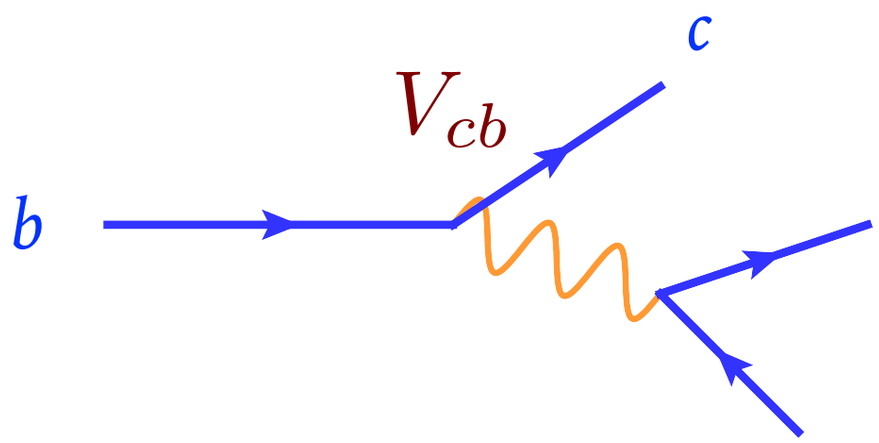
  - small matrix element: small couplings
  - or both



LONG-LIVED PARTICLES

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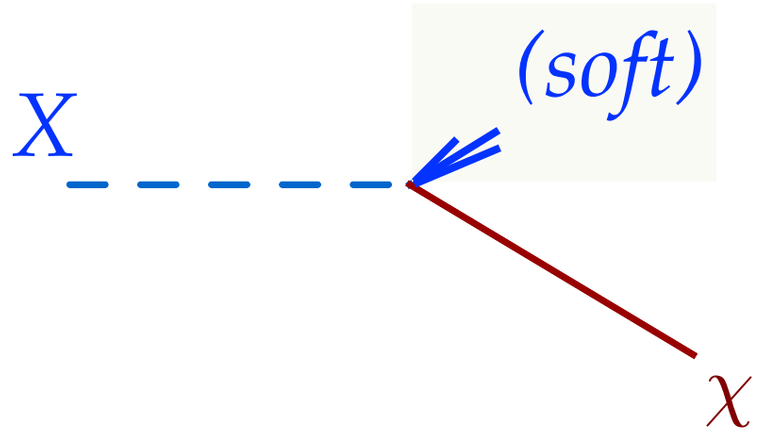
  - small phase space:



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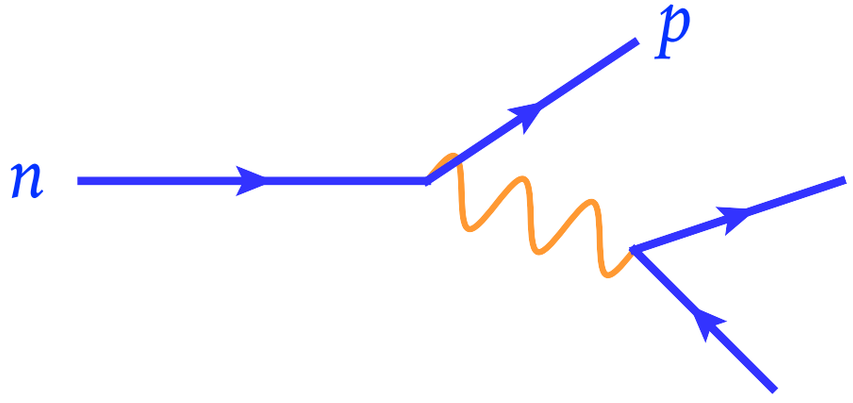


LONG-LIVED PARTICLES

- Macroscopic lifetimes:

$$\Gamma = \frac{1}{2m} \int d\Pi_f |\mathcal{M}|^2$$

  - wide range of familiar examples in SM
  - natural and common feature of BSM theories as well
    - …especially in post-LHC Run I era

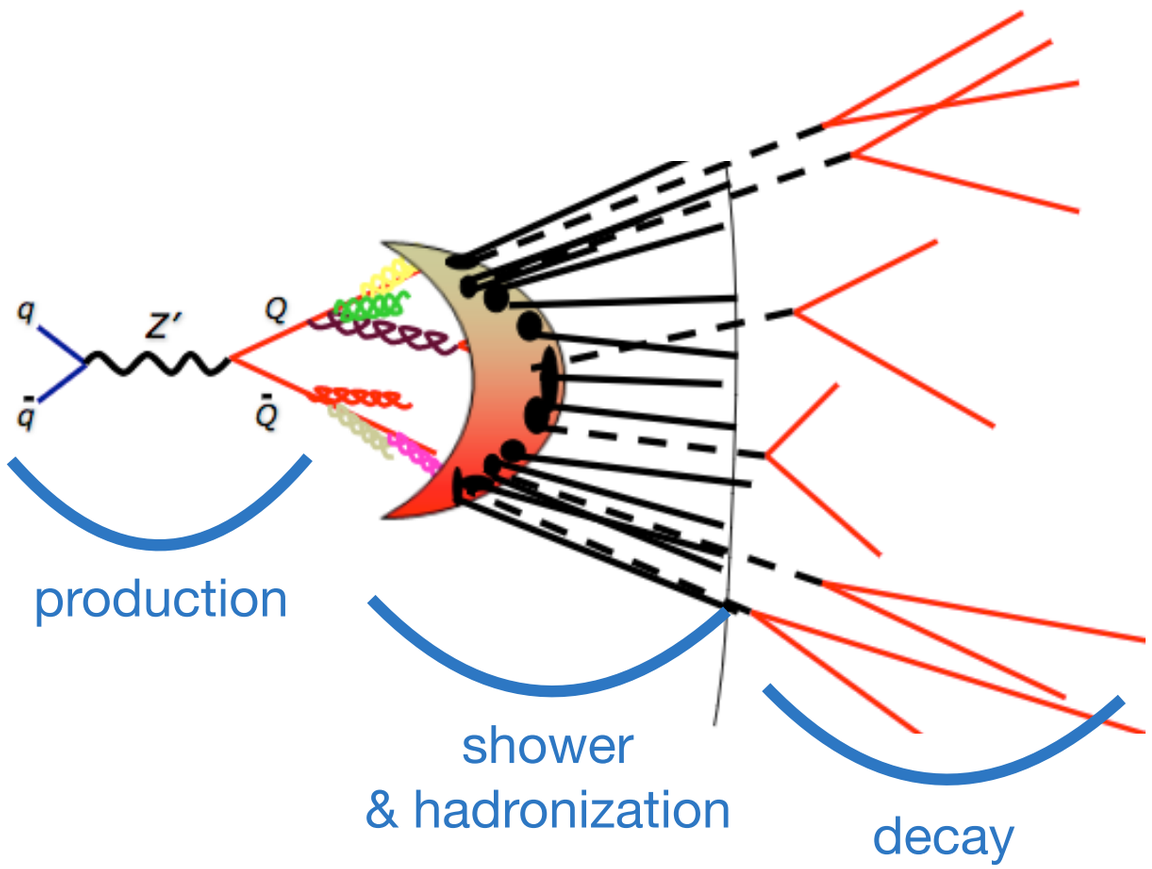
LONG-LIVED PARTICLES

- At the LHC, the challenge of signal separation from overwhelming backgrounds begins at trigger level
- Long-lived signals: using detectors off-label
  - bespoke analyses: reconstruction, signal efficiencies, background estimation
    - often computationally intensive
      - → info allowing signal/background separation not available in time for trigger decisions
- When triggers are available: low backgrounds allow powerful, inclusive searches

DARK SHOWERS

- Inclusivity: especially useful for confining hidden sectors
  - broad classes of theories with striking signatures but enormous theoretical uncertainties

familiar menu of options: h, Z′, bifundamentals, etc.



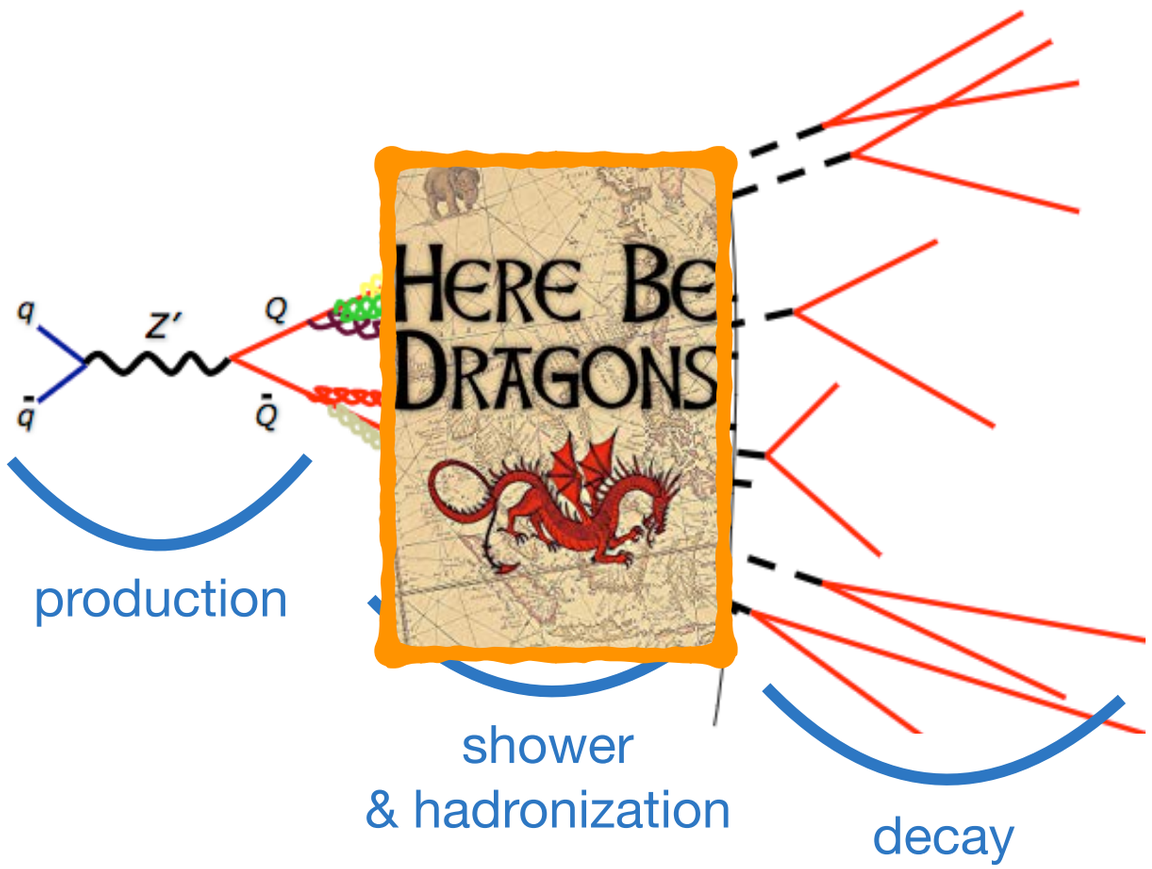
portal to SM controls final particle abundances (leptons, hadrons, photons, MET…)

[figure thanks to Strassler, Knapen; Strassler; Schwaller, Stolarski, Weiler; Knapen, JS+ in LHC LLP white paper; …]

DARK SHOWERS

- Inclusivity: especially useful for confining hidden sectors
  - broad classes of theories with striking signatures but enormous theoretical uncertainties

familiar menu of options: h, Z′, bifundamentals, etc.



portal to SM controls final particle abundances (leptons, hadrons, photons, MET…)

[figure thanks to Strassler, Knapen; Strassler; Schwaller, Stolarski, Weiler; Knapen, JS+ in LHC LLP white paper; …]

DARK SHOWERS

- characteristic features of complex hidden sectors:
  - variable and potentially large particle multiplicity
  - hierarchy of proper lifetimes
  - LLP decays may very well not pass standard isolation criteria, either from each other and/or prompt objects
    - non-SM patterns of energy flow, species multiplicity
- Enormous model dependence and theoretical uncertainties in making detailed predictions for pretty much any non-QCD confining theory
  - → exploit high multiplicity to construct inclusive low-background searches

[Knapen, JS+ in LLP white paper; Knapen, JS, Xu (in progress)]

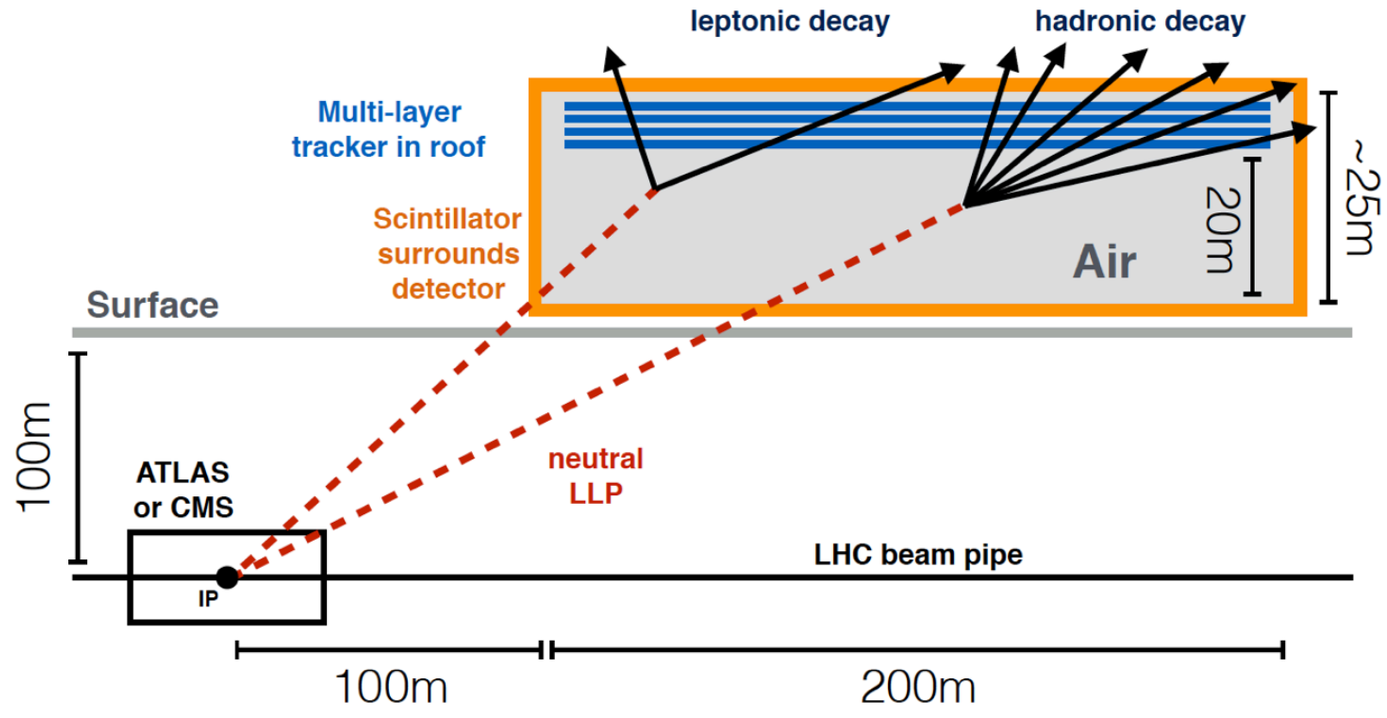
DARK SHOWERS

- First challenge: triggering
  - Target production in exotic Higgs decays
    - theory: highly motivated by neutral naturalness solutions to hierarchy problem
    - pheno: one of the best-motivated ways to produce, decay hidden states
    - experiment: low-mass final state is a challenge; this search would catch production through heavier mediators as well
- many new triggers under development for Run III
  - preliminary: promising options including displaced muons

[Craig, Katz, Strassler, Sundrum; …; CMS emerging jets; LHC LLP white paper; Knapen, JS, Xu (in progress)]

AUXILIARY DETECTORS

- Other ways to suppress background: build a new detector
- Proposed surface detector: MATHUSLA

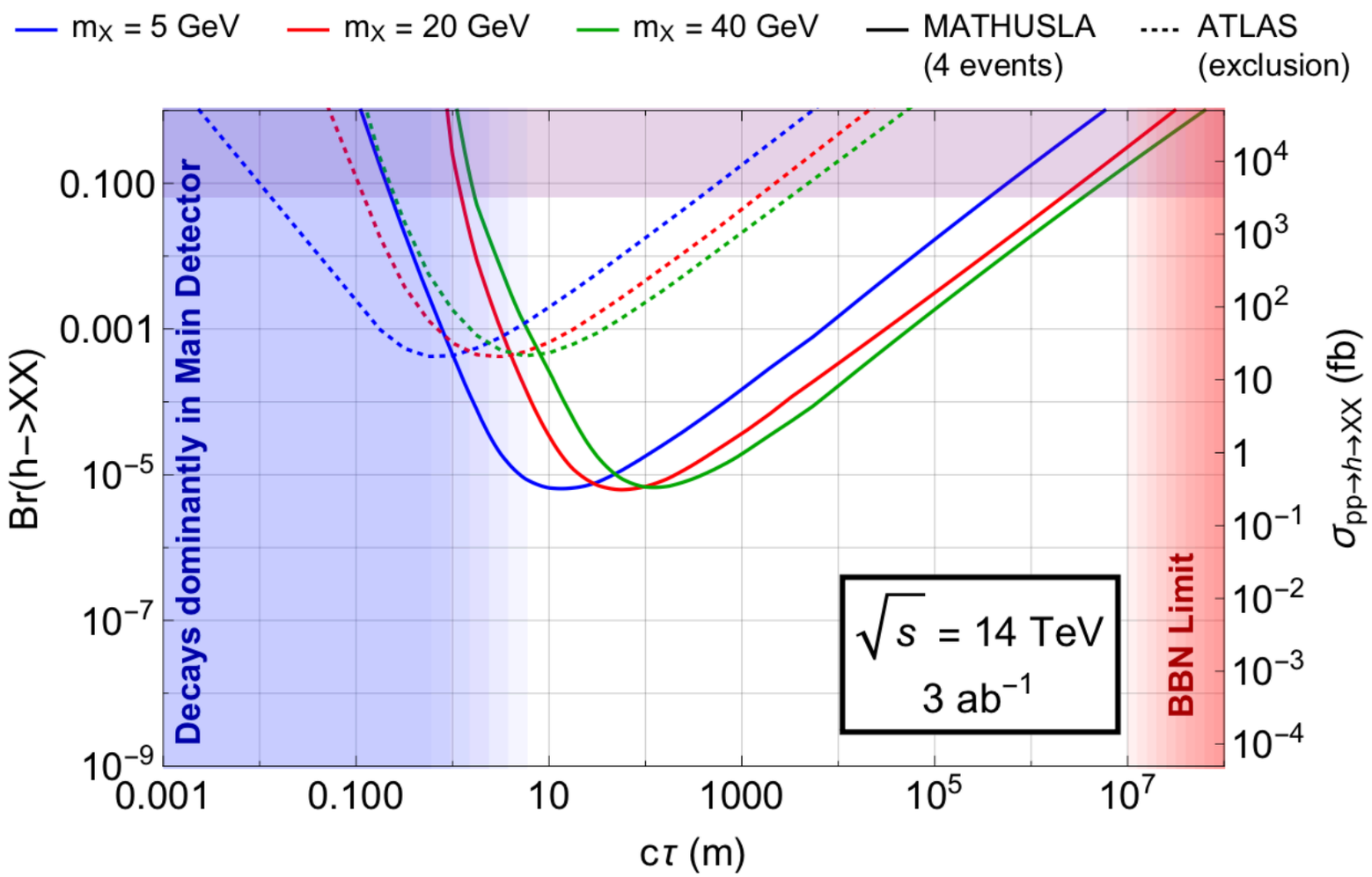


- advantage: fully exploit unmatchable energy reach of LHC
- disadvantage: huge instrumented volume

[Chou, Curtin, Lubatti; Curtin, Peskin;
Curtin, Drewes, McCullough, Meade, Mohapatra, JS, Shuve (eds), MATHUSLA physics case]

AUXILIARY DETECTORS

- Would push sensitivity to exotic Higgs decays to very long lifetimes:



[Chou, Curtin, Lubatti; Coccaro, Curtin, Lubatti, Russell, JS; see also Liu, Liu, Wang]

AUXILIARY DETECTORS

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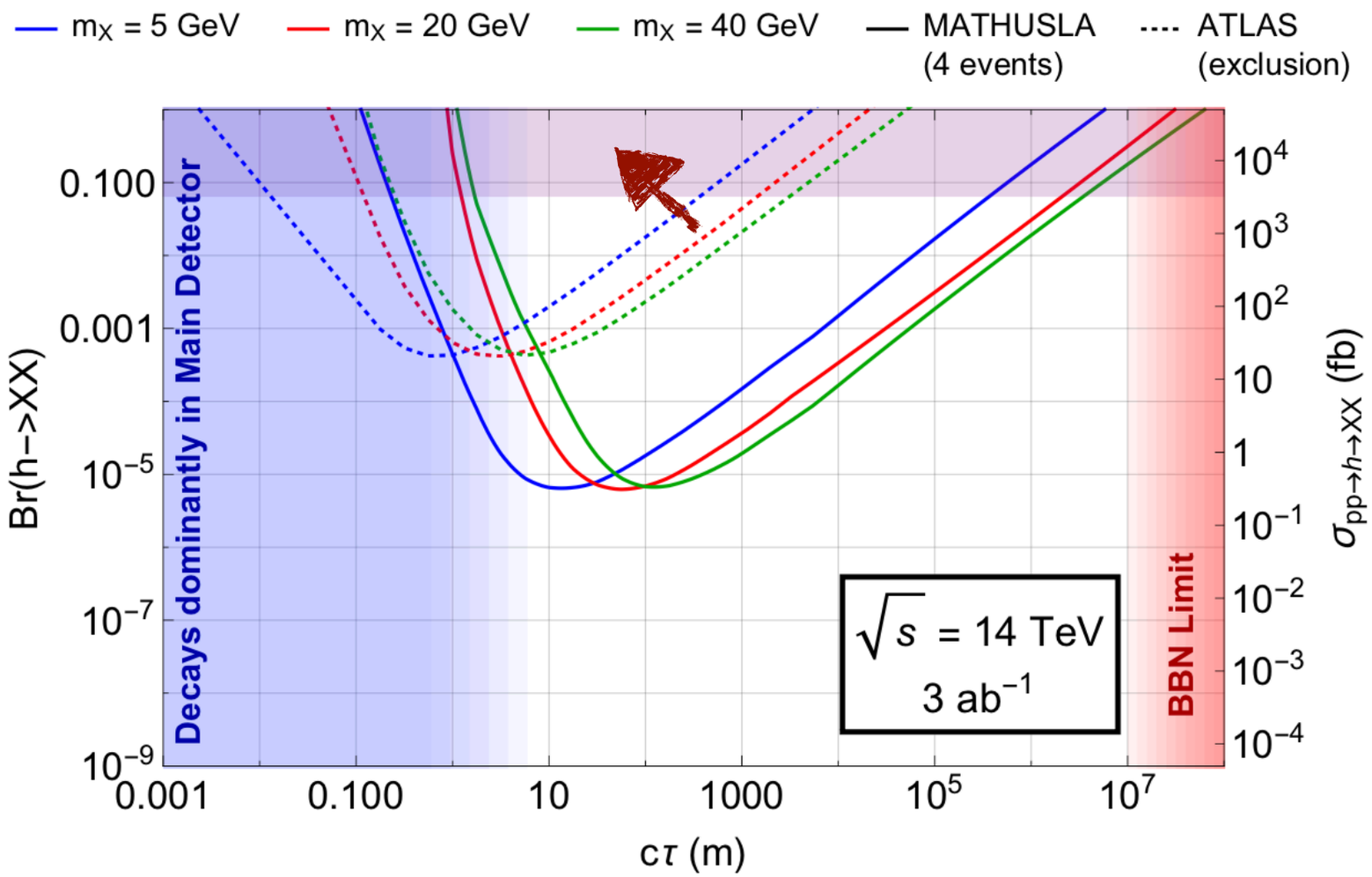
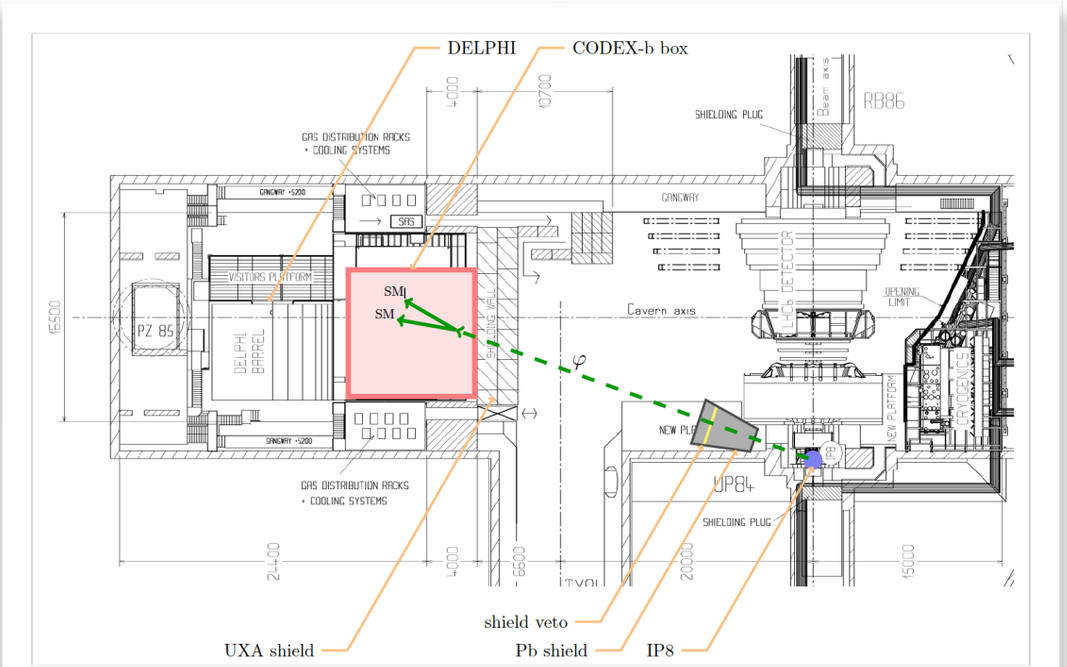


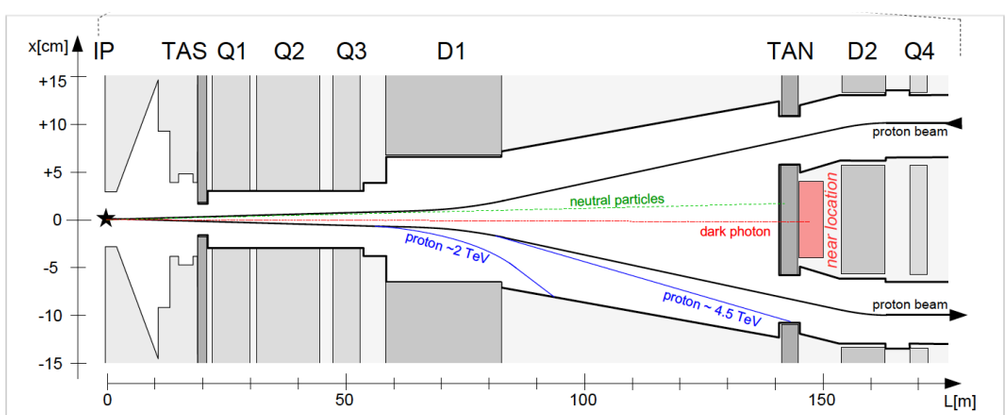
[Chou, Curtin, Lubatti; Coccaro, Curtin, Lubatti, Russell, JS; see also Liu, Liu, Wang]

AUXILIARY DETECTORS

➤ Other proposals:

CODEX-b: dedicated LLP detector near LHCb interaction point





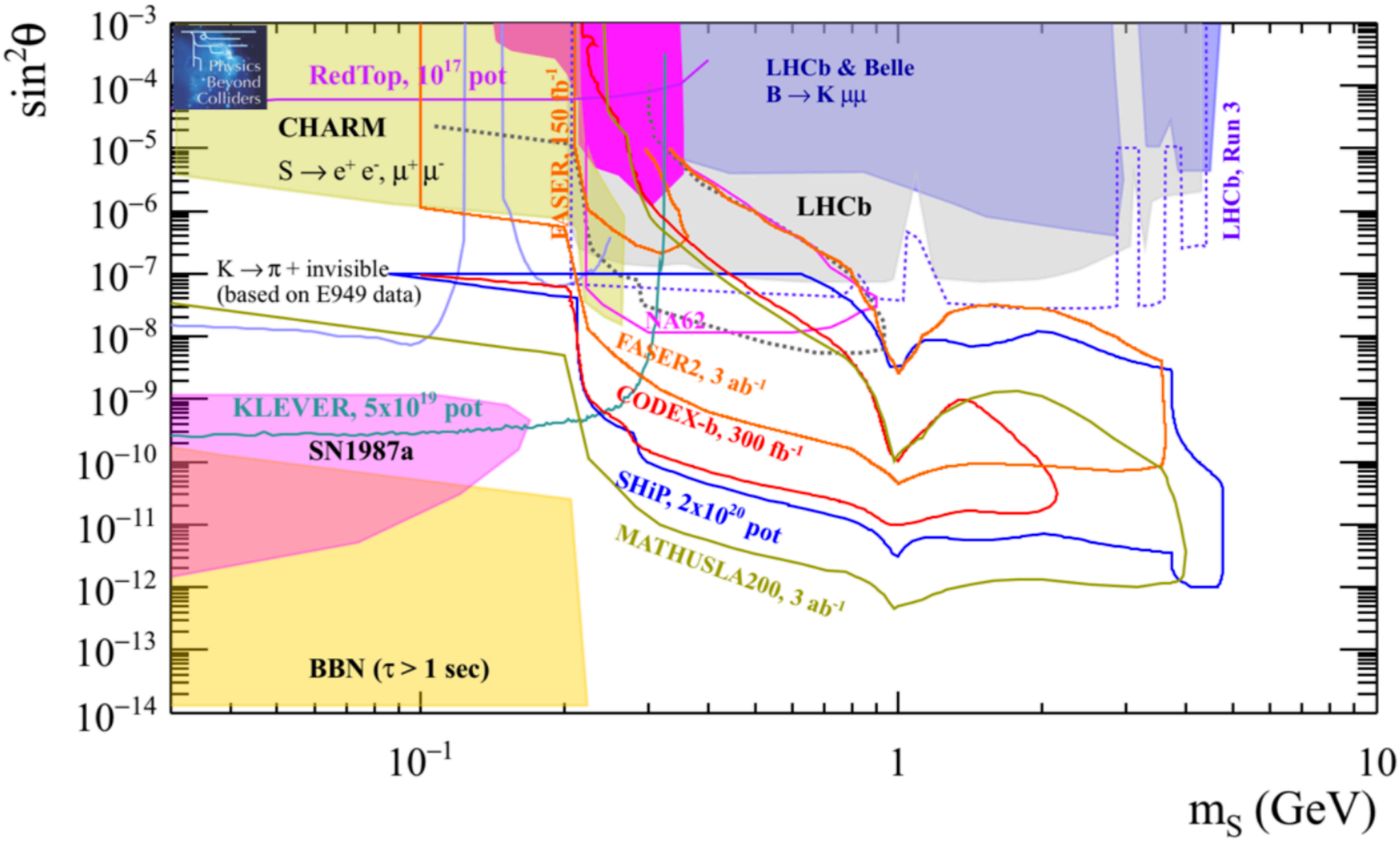
FASER: dedicated forward detector near interaction point: approved

➤ and for light LLPs a host of other, non-LHC probes

[Gligarov, Knapen, Papucci, Robinson; Feng, Galon, Kling, Trojanowski; Physics Beyond Colliders report]

AUXILIARY DETECTORS

- Ex: light scalar mixing with SM Higgs



[Physics Beyond Colliders report]

AUXILIARY DETECTORS

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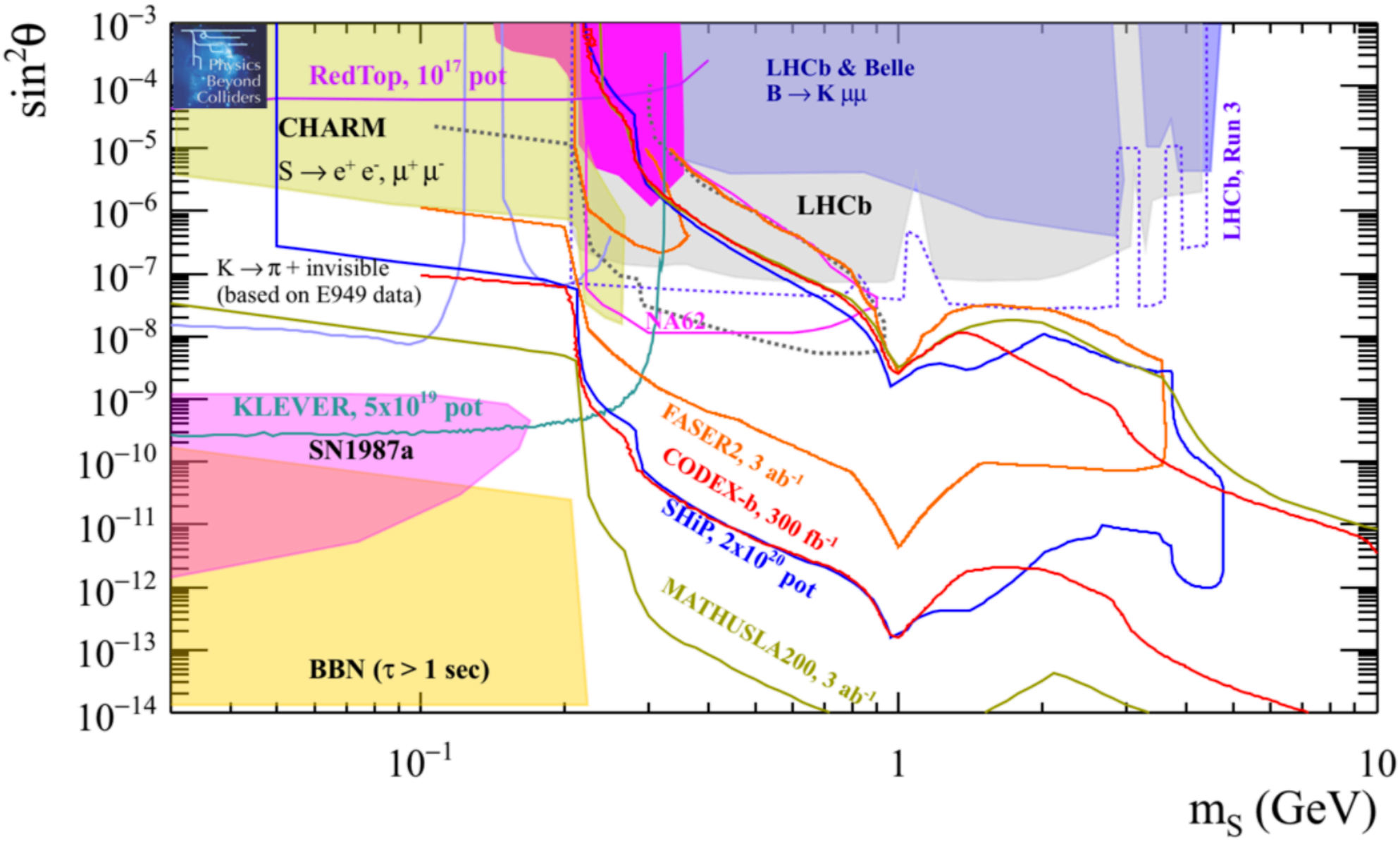

[Physics Beyond Colliders report]

LOOKING AHEAD

- LHC is and will continue to be an unprecedented way to open windows on our universe
- active theory/experiment interaction critical
  - LHC Higgs Cross-Section working group
  - LHC LLP working group
- Upcoming long shutdown, start of Run III:
  - excellent time to think creatively, exploit new experimental capabilities, large upcoming data sets