Light particles with baryon and lepton numbers

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Particles beyond the SM

- *Heavy* new particles are captured in SMEFT, no matter their quantum numbers.
- *Light* new particles φ require new EFT of SM + φ.
- Need to know the quantum numbers of φ!
  - For m_φ at or below GeV: φ is neutral under U(1)xSU(3).
  - Spin 0: light scalar or pseudoscalar (ALP EFT).
  - Spin ½: sterile neutrino.
  - Spin 1: dark photon or coupled to B/L_α currents.

Can φ carry global symmetries?

Global symmetries

- Simplest case: φ carries a Z_N or dark U(1) or SU(N).
  - EFT operators factorize: $|\varphi|^2$ x (SMEFT operator),...
  - Exhaustively discussed as (light) dark matter.

Global symmetries

- Simplest case: φ carries a Z_N or dark U(1) or SU(N).
  - EFT operators factorize: $|\varphi|^2$ x (SMEFT operator),...
  - Exhaustively discussed as (light) dark matter.
- ~ final possibility: φ carries baryon/lepton number:
  - Fermion N with L = 1: $\overline{L}HN$ coupling, mixing with neutrinos => sterile neutrino.

    [recent collection of constraints: Bolton, Deppisch and Dev, 1912.03058]
  - Fermion χ with B = 1: EFT coupling to e.g. $\overline{\chi}udd/\Lambda^2$, mixing with neutral baryons => sterile neutron.

    [popular for neutron decay anomaly, e.g. Fornal & Grinstein, 2007.13931]

Sterile neutron: fermion with B=1

- Effective Lagrangian:

$$\mathcal{L}_\chi = \bar{\chi}(\mathrm{i}\partial\!\!\!/ - m_\chi)\chi + \left(\frac{u_i d_j d_k \chi_L^c}{\Lambda_{ijk}^2} + \frac{Q_i Q_j d_k \chi_L^c}{\tilde{\Lambda}_{ijk}^2} + \text{h.c.}\right)$$

- For $m_\chi \lesssim m_n$, one has search channels
  - $n \to \chi\,\gamma$, [Davoudiasl, PRL '15; Fornal & Grinstein, 1801.01124]
    hydrogen $\to \chi\,\nu$, [Berezhiani, 1812.11089; McKeen & Pospelov, 2003.02270]
    $p \to \chi\, e^+ \nu$, [McKeen & Pospelov, 2003.02270]
    $n \to \pi^0 \chi$, $p \to \pi^+ \chi$, [Davoudiasl, PRD '13 & PRL '15; Helo et al, 1803.00035]
  - The latter probe $\Lambda_{udd} < 10^{15}$ GeV if $m_\chi \sim 0$.
  - All couplings Λ_{ijk} lead to these channels at loop level!
- Notice that χ is stable here and thus (asymmetric) DM.

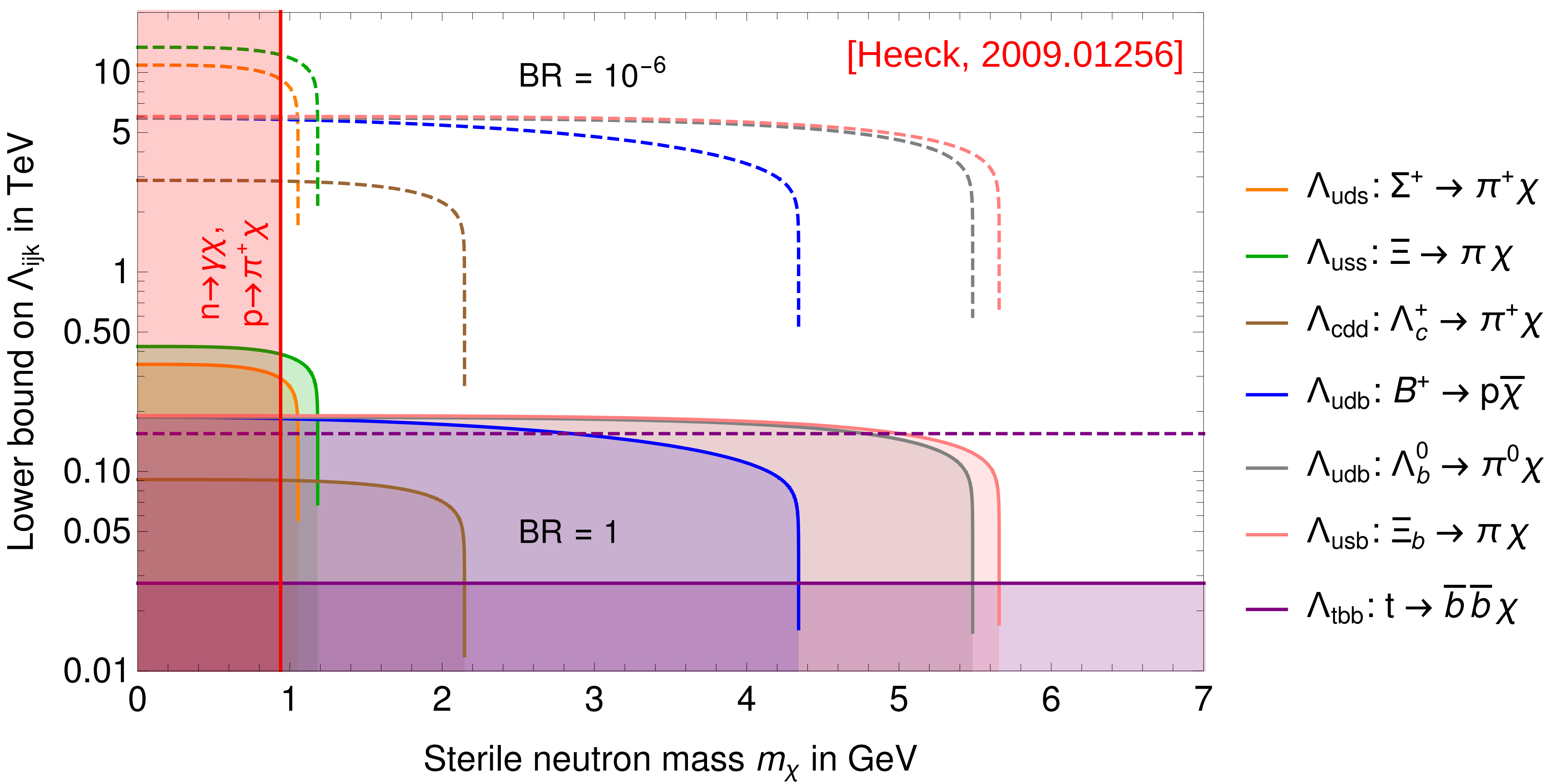
Sterile neutron: fermion with B=1

- For $m_\chi > m_n$, no more proton/neutron decays.
- Still possible to look for rare decays in b/c/τ factories via

$$\text{baryon} \to \text{meson} + \chi$$
$$\text{meson} \to \text{baryon} + \bar{\chi}$$

- Requires χ coupling to 2nd/3rd gen quarks. [Nelson++, PRD '17 & '19]
- Matrix elements <baryon|qqq|meson> unknown.
- χ is unstable, but typically leaves detector; mimics baryon-number violating decays!

New signatures to look for!



Dedicated analyses required to obtain sensitivity, but

LHCb already has 10^{14} Σ^+; HyperCP has 10^9 Ξ^-.

Λ_c abundantly produced at Belle II, BESIII, LHCb.

Belle II will collect $5\text{x}10^{10}$ B-meson decays.

Global symmetries for scalars

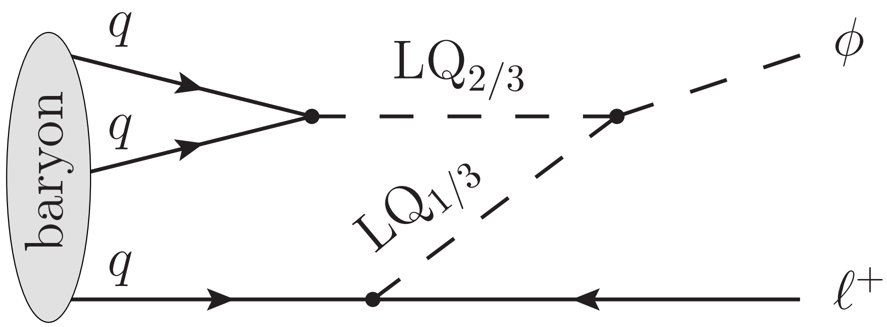
- ~final possibility: scalar φ carries baryon/lepton number:
  - δ with L = 2: EFT coupling to Weinberg op. $\delta(\bar{L}H)^2/\Lambda^2$.
    [Berryman et al, 1802.00009; De Gouvêa et al, 1910.01132]
  - ϕ with B = L = 1: EFT coupling $\bar{\phi}QQQL/\Lambda^3$,
    => sterile leptoquark.
    [McKeen & Pospelov, 2003.02270]
  - ξ with B = 2: EFT coupling $\bar{\xi}(udd)^2/\Lambda^6$.
- Assume that scalars don't get VEVs.

Sterile leptoquark: scalar with B=L=1

- Effective Lagrangian for SM + ϕ:

$$Ł_\phi = |\partial\phi|^2 - m_\phi^2|\phi|^2 + \left(\frac{d_i u_j u_k \ell_l \phi^*}{\Lambda^3_{ijkl}} + \frac{d_i u_j Q_k L_l \phi^*}{\tilde{\Lambda}^3_{ijkl}} + \frac{Q_i Q_j u_k \ell_l \phi^*}{\Lambda'^3_{ijkl}} + \frac{Q_i Q_j Q_k L_l \phi^*}{\tilde{\Lambda}'^3_{ijkl}} + hc \right)$$

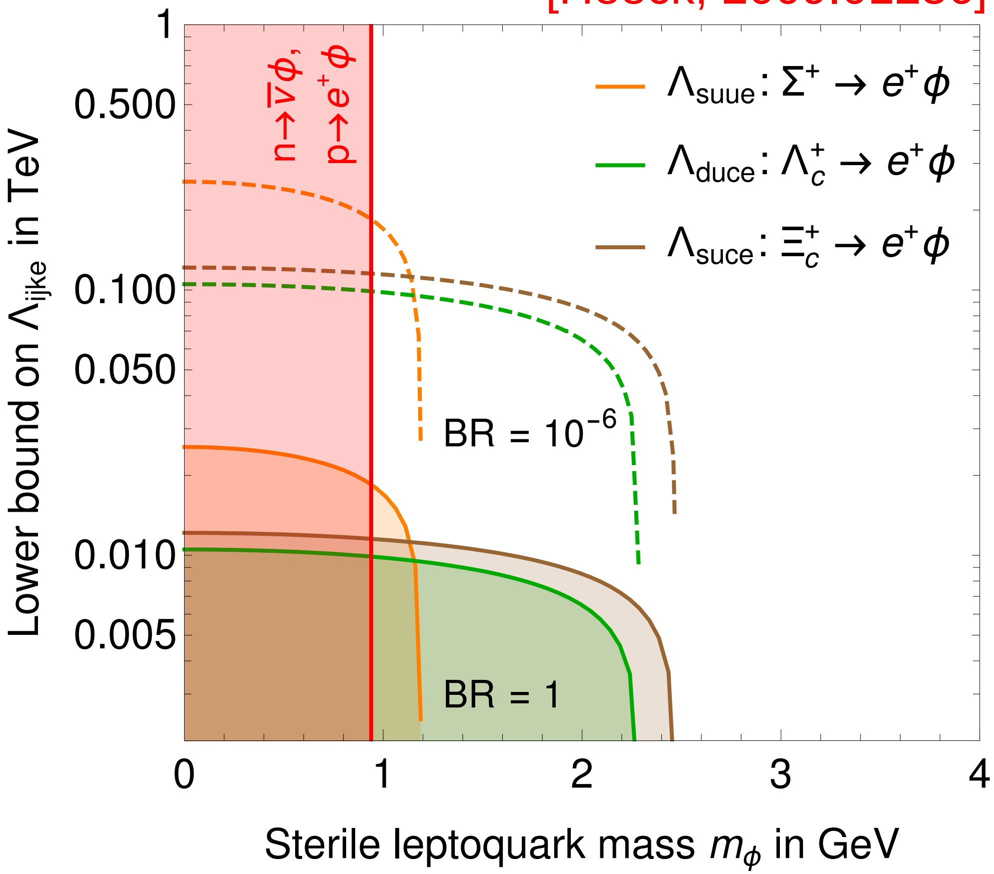
- Further restriction possible by assigning lepton flavor.
- Low energy: $\frac{\Lambda^3_{QCD}}{\Lambda^3_{udde}} pe\phi^* + \dots$
- Possible UV completion with leptoquarks:



Sterile leptoquark: scalar with B=L=1

- For $m_\phi < m_n$, we have
  $n \to \phi\, \nu$
  for all Λ_{ijkl} indices!
  For lighter ϕ: $p \to \phi\, \ell^+$
  [for mϕ = 0: Super-K, PRL '15]
- Can be improved with inclusive searches.
  [Heeck & Takhistov, 1910.07647]
- Mass close to H: hydrogen $\to \phi\, \gamma$.
  [McKeen & Pospelov, 2003.02270]
- $m_\phi > m_n$ difficult to probe in rare decays, better constrained by LQ searches at LHC.

[Heeck, 2009.01256]



Larger B and L?

- E.g. scalar ξ with B = 2: EFT coupling $\bar{\xi}(udd)^2/\Lambda^6$.
  - Light ξ can give $nn \to \xi\, \pi^0$ or $(A,Z) \to (A-2,Z) + \xi$.
  - Heavier ξ difficult to probe, *unless it is dark matter!*

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- DM with B/L could decay specific antimatter final states:
  - ϕ with B=-2 and L=-1: $\mathcal{L} = \frac{\overline{\phi}^c n \overline{p}^c e}{\Lambda^2} + \text{h.c.}$
  - For $m_\text{d} < m_\phi < m_\text{n} + m_\text{p}$,
    DM decays into anti-deuteron + e^+, not into $\bar{p}$.
  - Same trick to generate anti-helium without $\bar{p}$,
    might explain AMS events.

  [Heeck & Rajaraman, 1906.01667]

Summary

- Light new particles becoming more popular, e.g. dark photons, sterile neutrinos, ALPs.
- Often overlooked: new particles could carry B or L.
  - Changes allowed couplings and pheno.
  - For sub-GeV masses: neutron and proton decays, can be improved in SK, HK, JUNO, DUNE.
  - Invisible n decays ($n \to \phi\, \nu$, $nn \to \xi$) powerful probe.
  - For m > GeV, hadron decays testable in b/c/τ factories
  - Often kinematically stable, forms (asymmetric) DM.
  - DM decays can produce odd anti-matter signals.

More baryons & leptons out there?!

Backup