HIDDEN SECTORS & LOW-ENERGY EXPERIMENTS
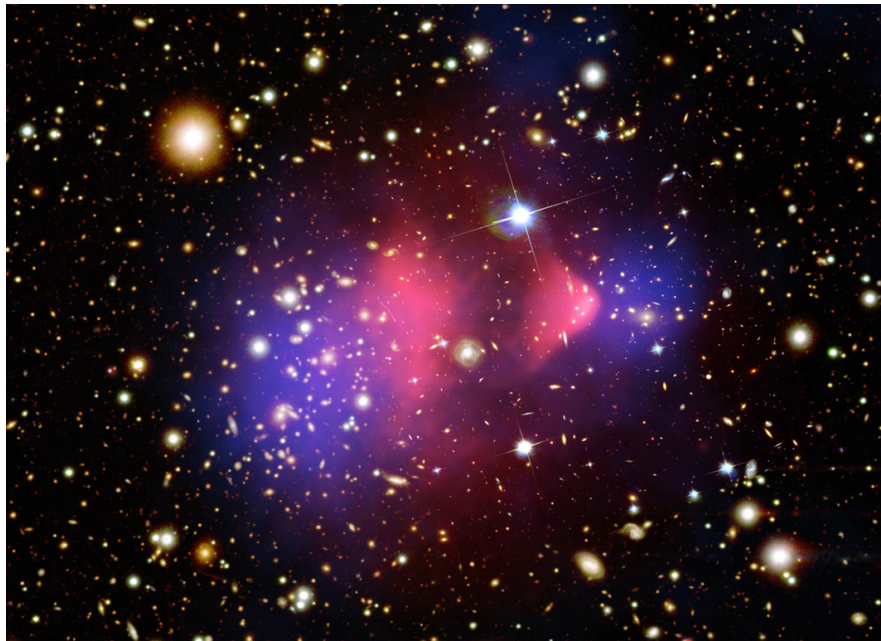

Brian Shuve
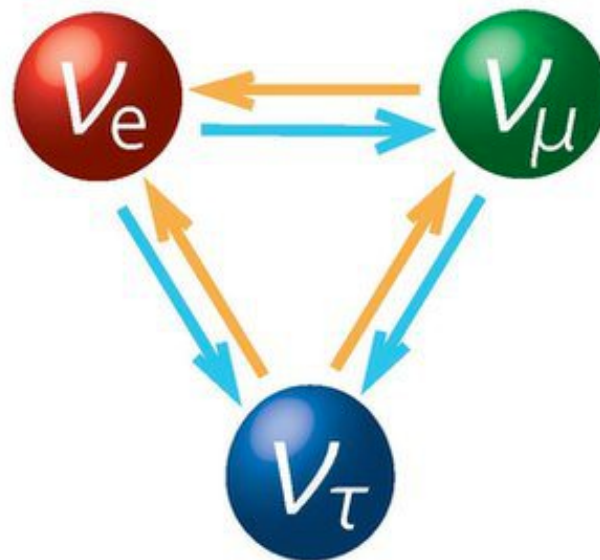
FPCP 2019

HARVEY MUDD COLLEGE
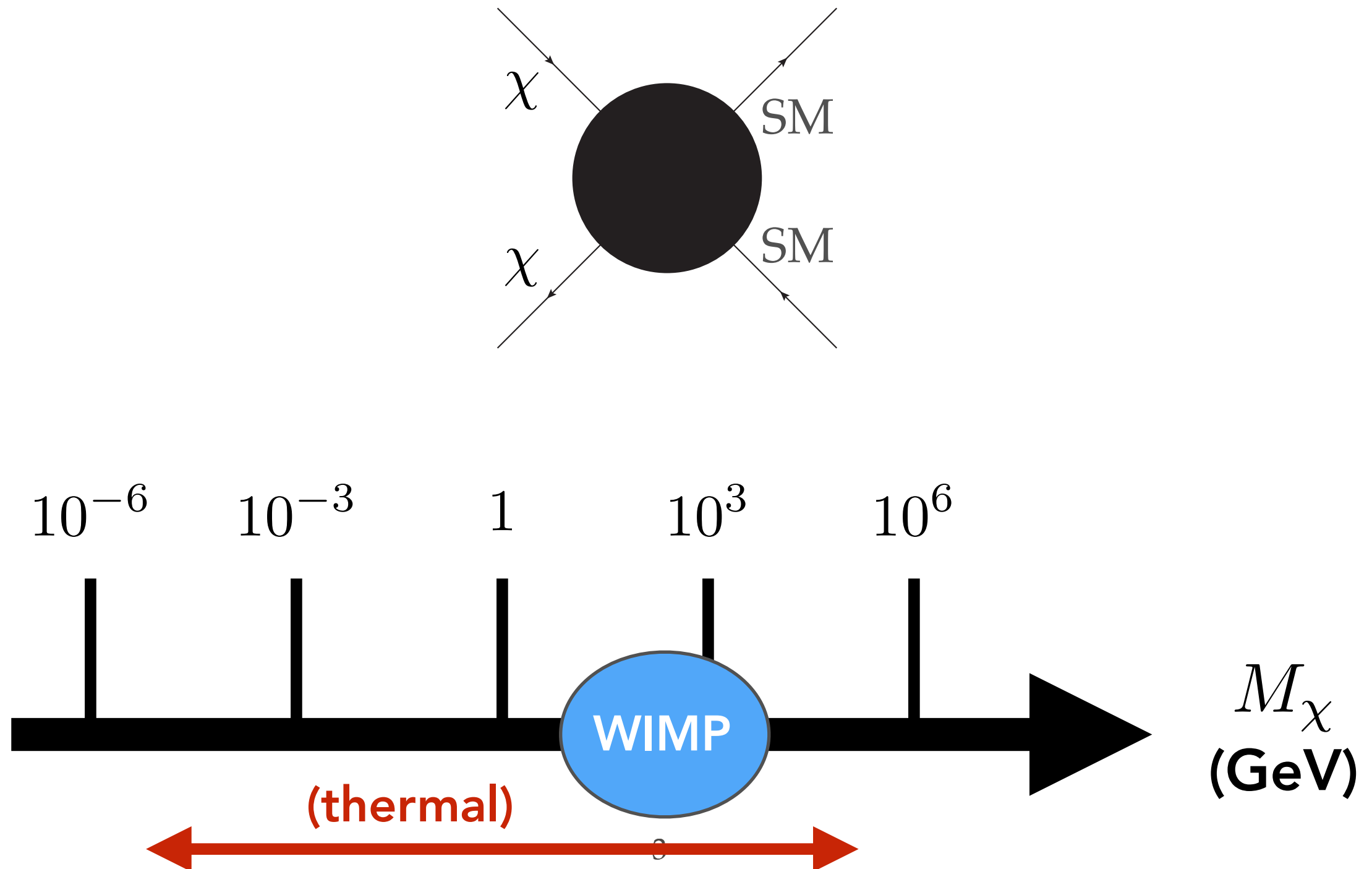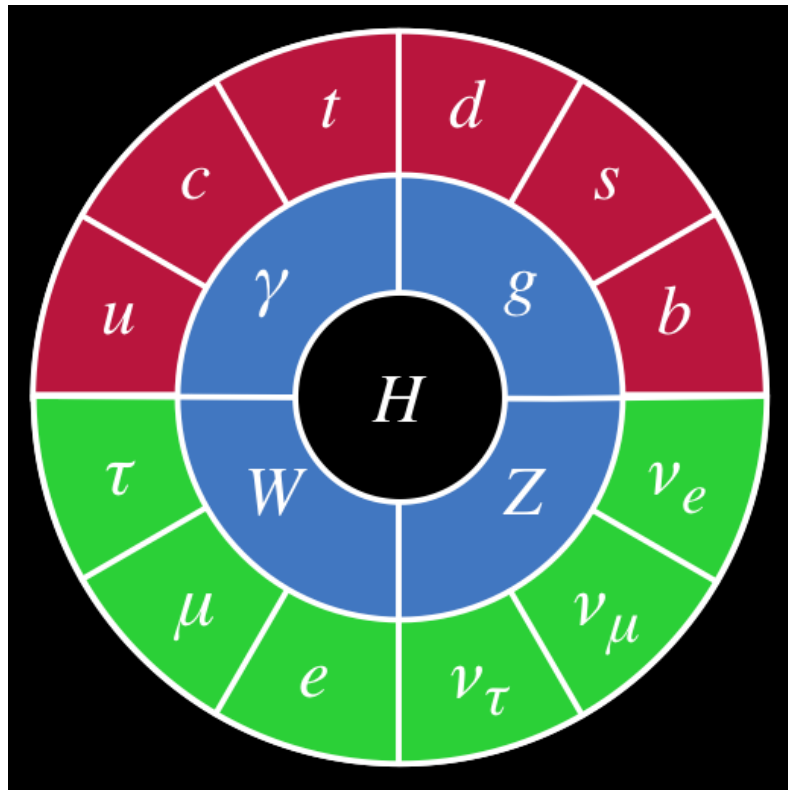
UCR

WHY HIDDEN SECTORS?

baryons   antibaryons

EXAMPLE: THERMAL DM

EXAMPLE: THERMAL DM

- For dark matter masses below a few GeV, the "weak"/Higgs portals can't give large enough annihilation rate
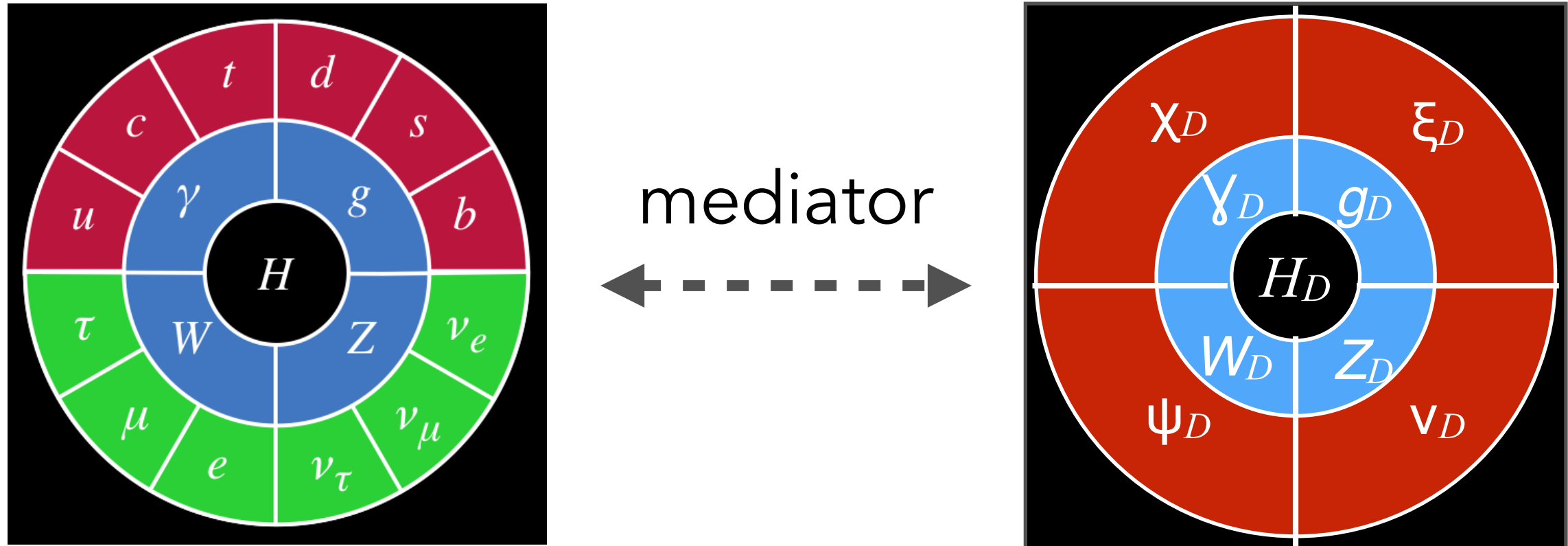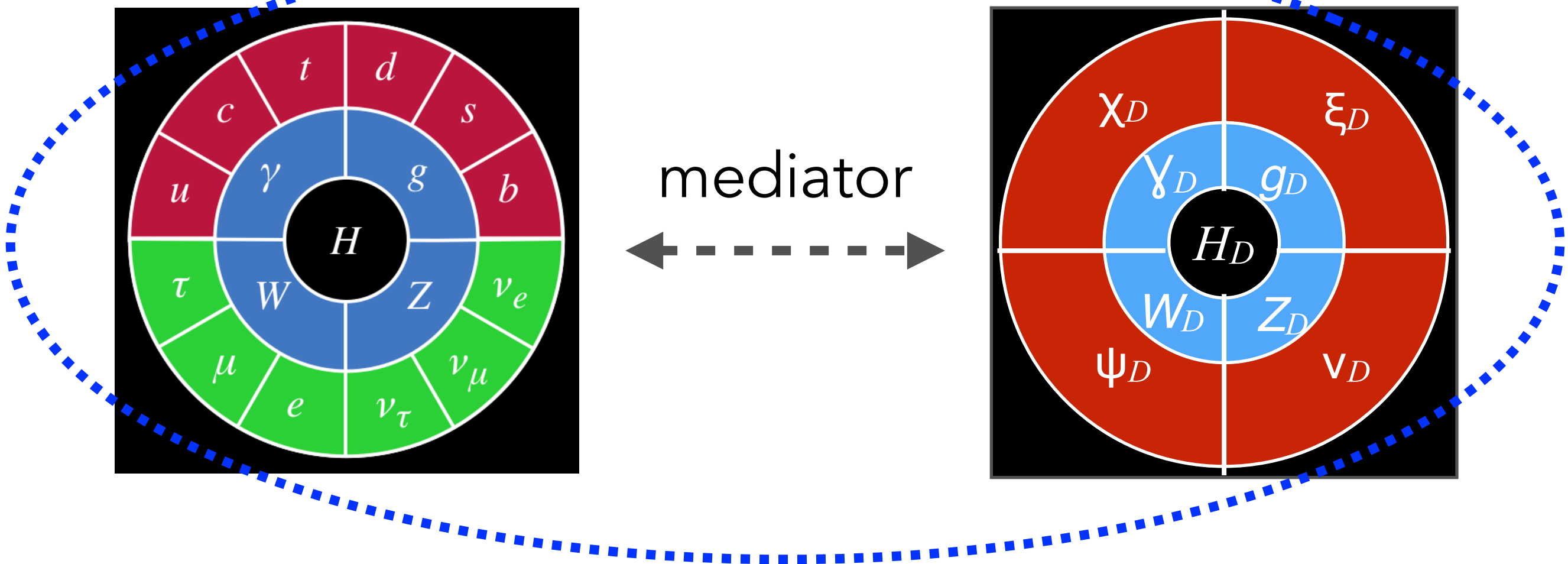
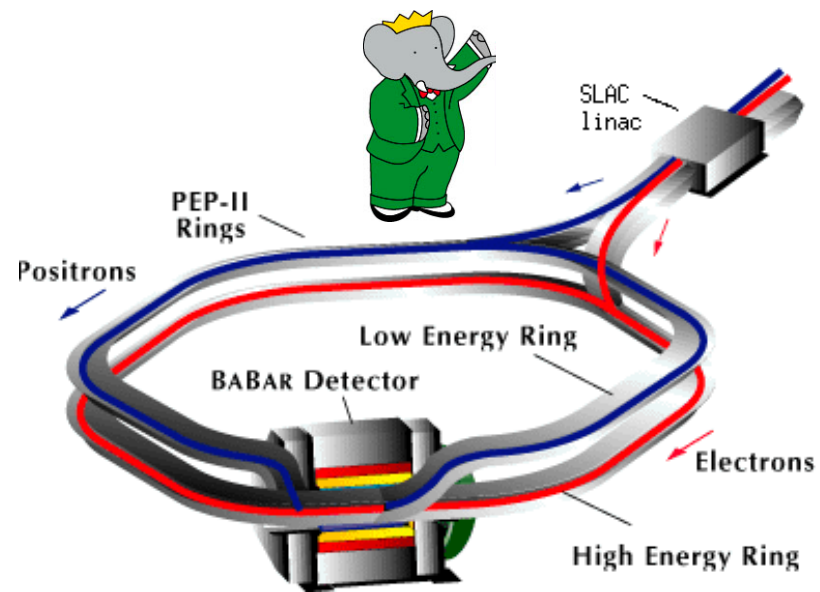 Lee, Weinberg 1977 [PRL]

EXAMPLE: THERMAL DM

- For dark matter masses below a few GeV, the "weak"/Higgs portals can't give large enough annihilation rate

Lee, Weinberg 1977 [PRL]

mediator

EXAMPLE: THERMAL DM

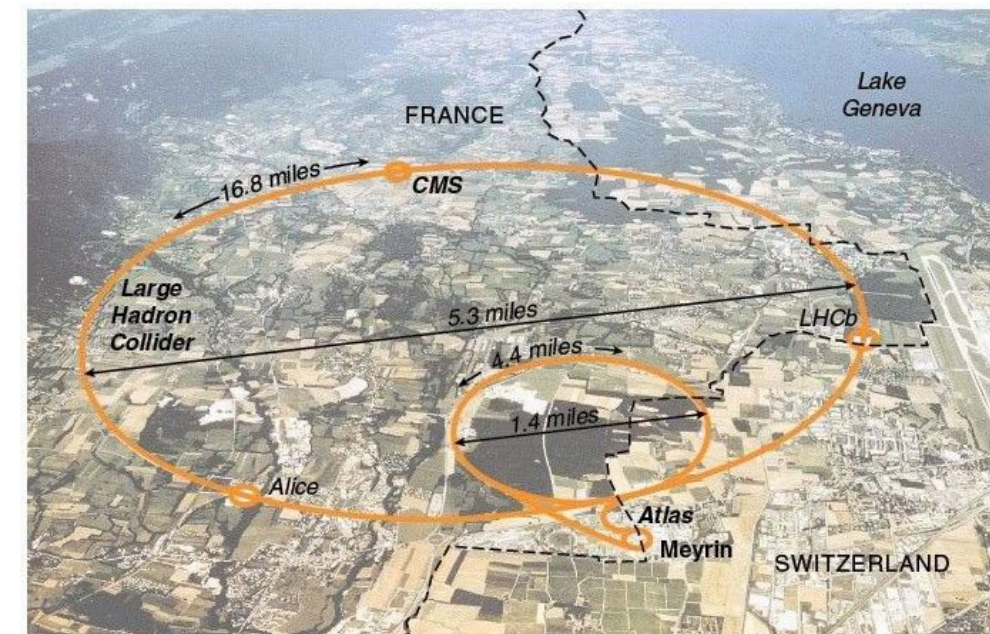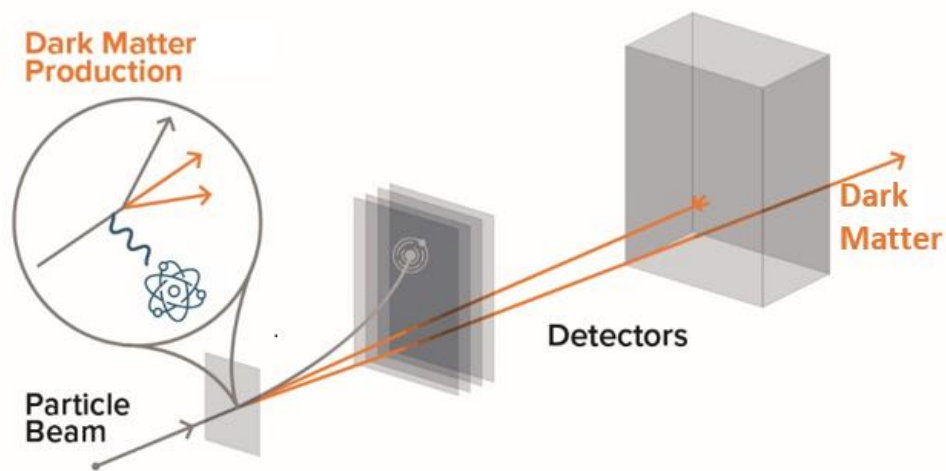- For dark matter masses below a few GeV, the "weak"/Higgs portals can't give large enough annihilation rate

Lee, Weinberg 1977 [PRL]

??

mediator

WHERE CAN WE LOOK?

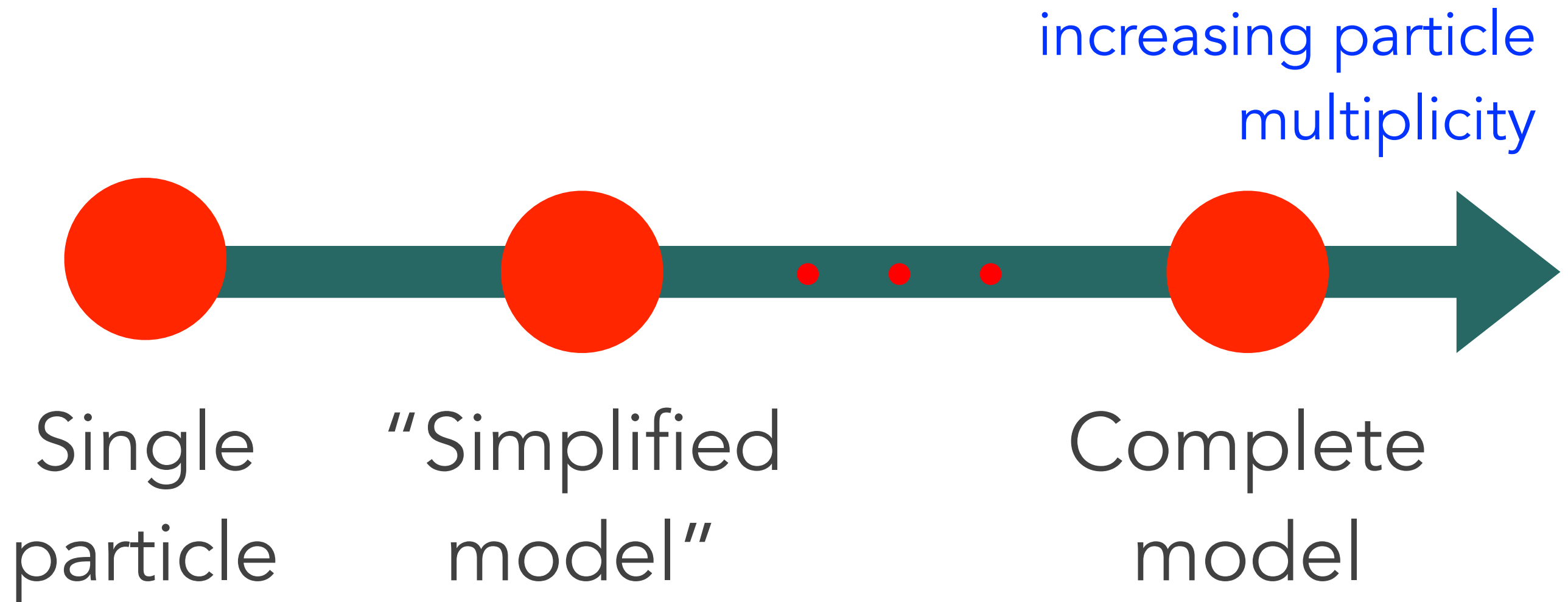
mass/energy

MODEL ORGANIZATION

increasing particle multiplicity

Single particle

"Simplified model"

Complete model

MODEL ORGANIZATION

increasing particle multiplicity

Single particle

"Simplified model"

Complete model

Dark photon
Singlet Higgs
Sterile Neutrino

Dark U(1)+Higgs
Z' + sterile neutrino
Dark photon + DM

Dark-sector SUSY
nuMSM
LR-symmetric model
Twin Higgs, dark QCD

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MODEL ORGANIZATION

Single particle

"Simplified model"

Complete model

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Singlet Higgs
Sterile Neutrino

*Dark U(1)+Higgs*
Z' + sterile neutrino
Dark photon + DM

Dark-sector SUSY
nuMSM
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Twin Higgs, dark QCD

MODEL ORGANIZATION

("generic")

("model-specific")

Single particle

Dark photon
Singlet Higgs
Sterile Neutrino

"Simplified model"

Dark U(1)+Higgs
Z' + sterile neutrino
Dark photon + DM

Complete model

Dark-sector SUSY
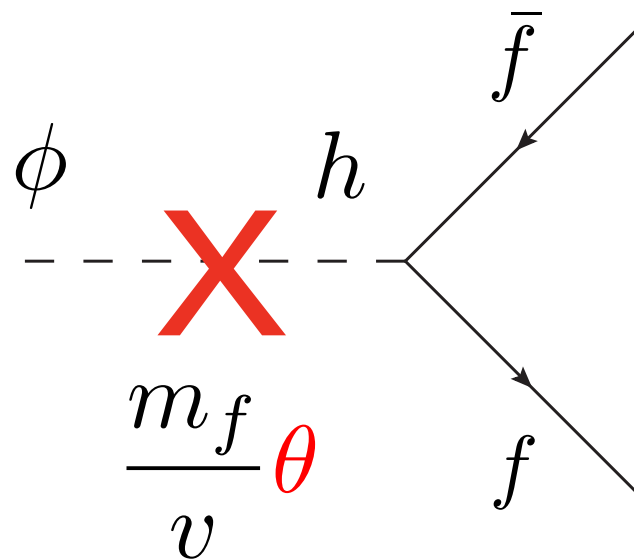*nuMSM*
LR-symmetric model
Twin Higgs, dark QCD

SIMPLEST CASE: PORTALS

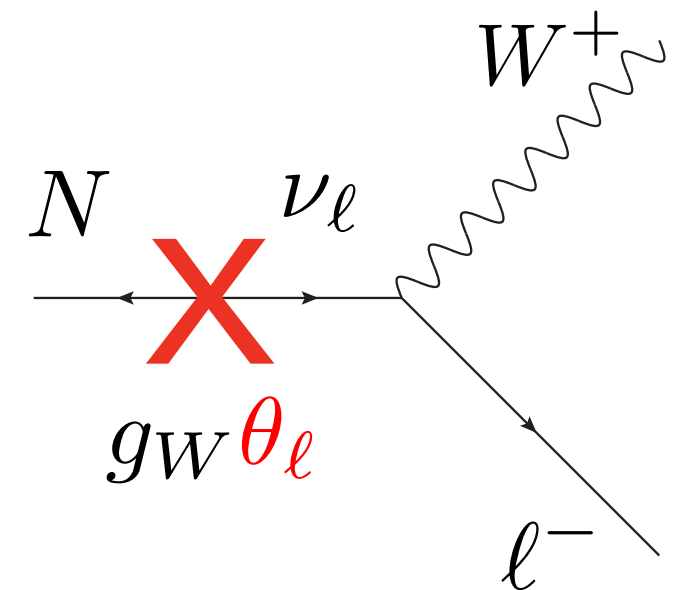- Single mediator couples to SM via **renormalizable portal**

Vector portal

A' γ/Z $\bar{f}$

$Q_f\,\varepsilon$ f

Scalar portal

ϕ h $\bar{f}$

$\dfrac{m_f}{v}\,\theta$ f

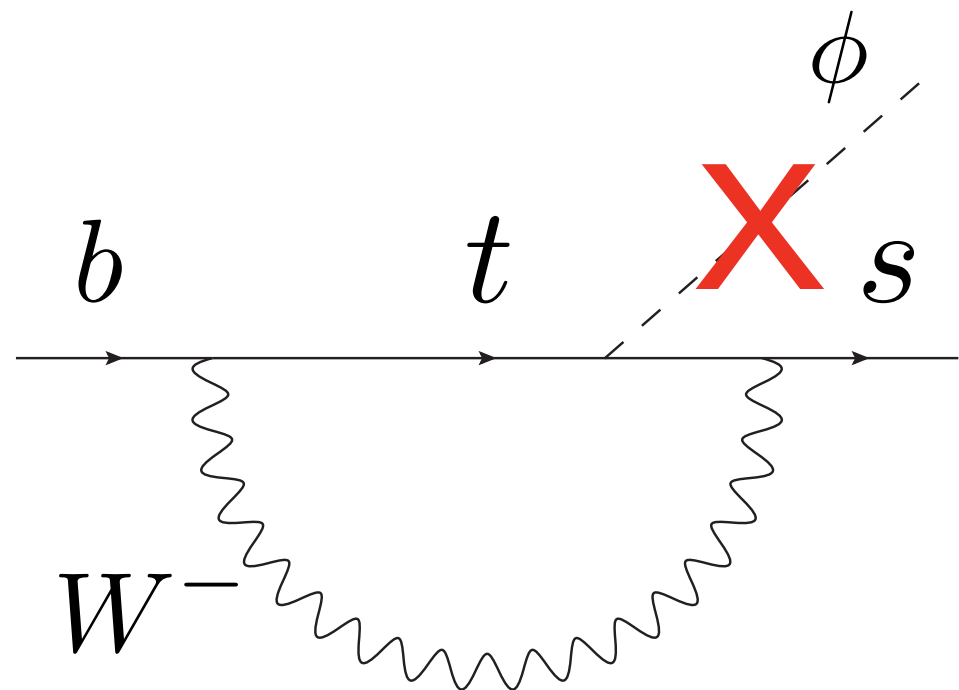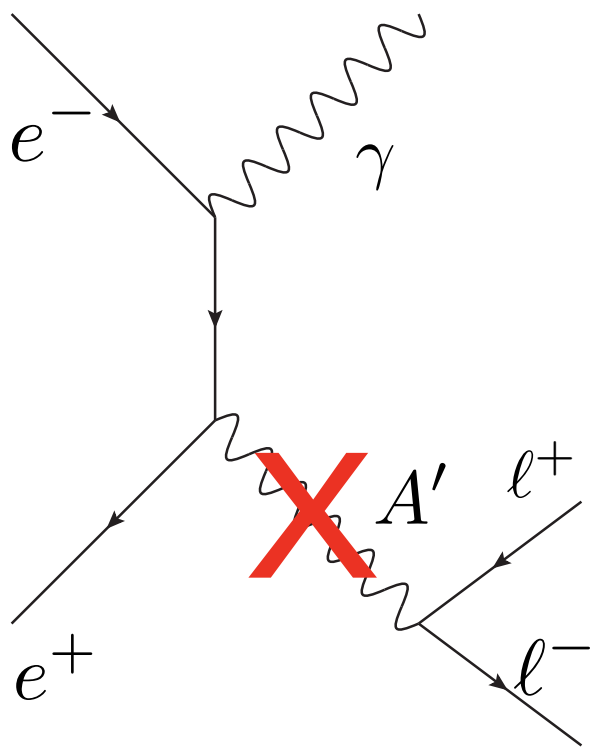### Neutrino portal

W^+

N ν_ℓ
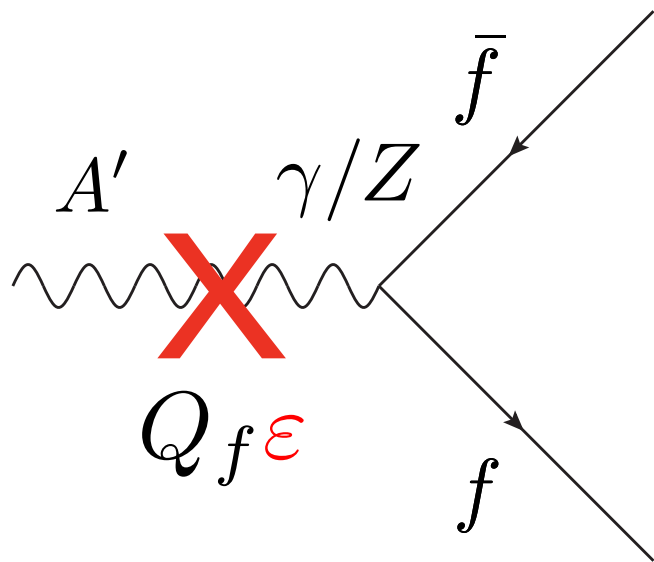
$g_W\,\theta_\ell$ ℓ^-
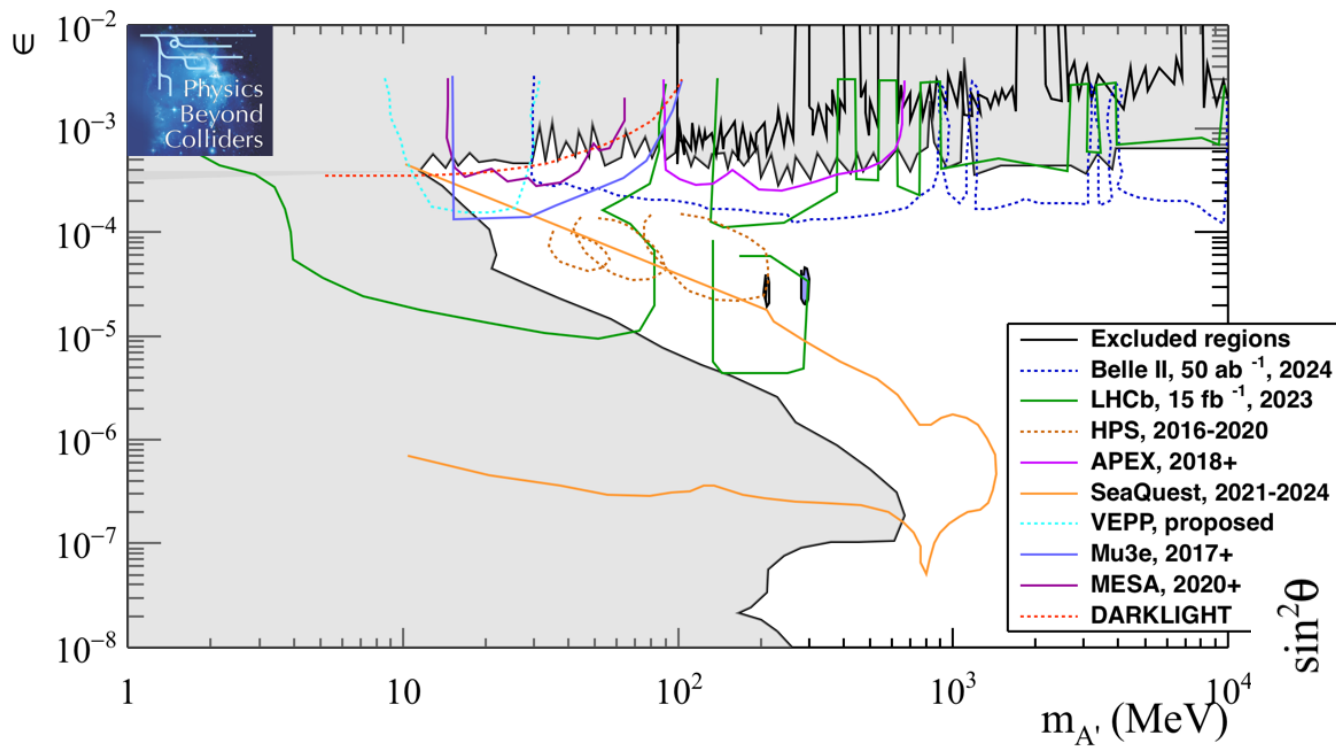
SIMPLEST CASE: PORTALS

- Portal models give straightforward, predictive phenomenology

- See next talk by S. Robertson!

CONSTRAINTS ON PORTALS
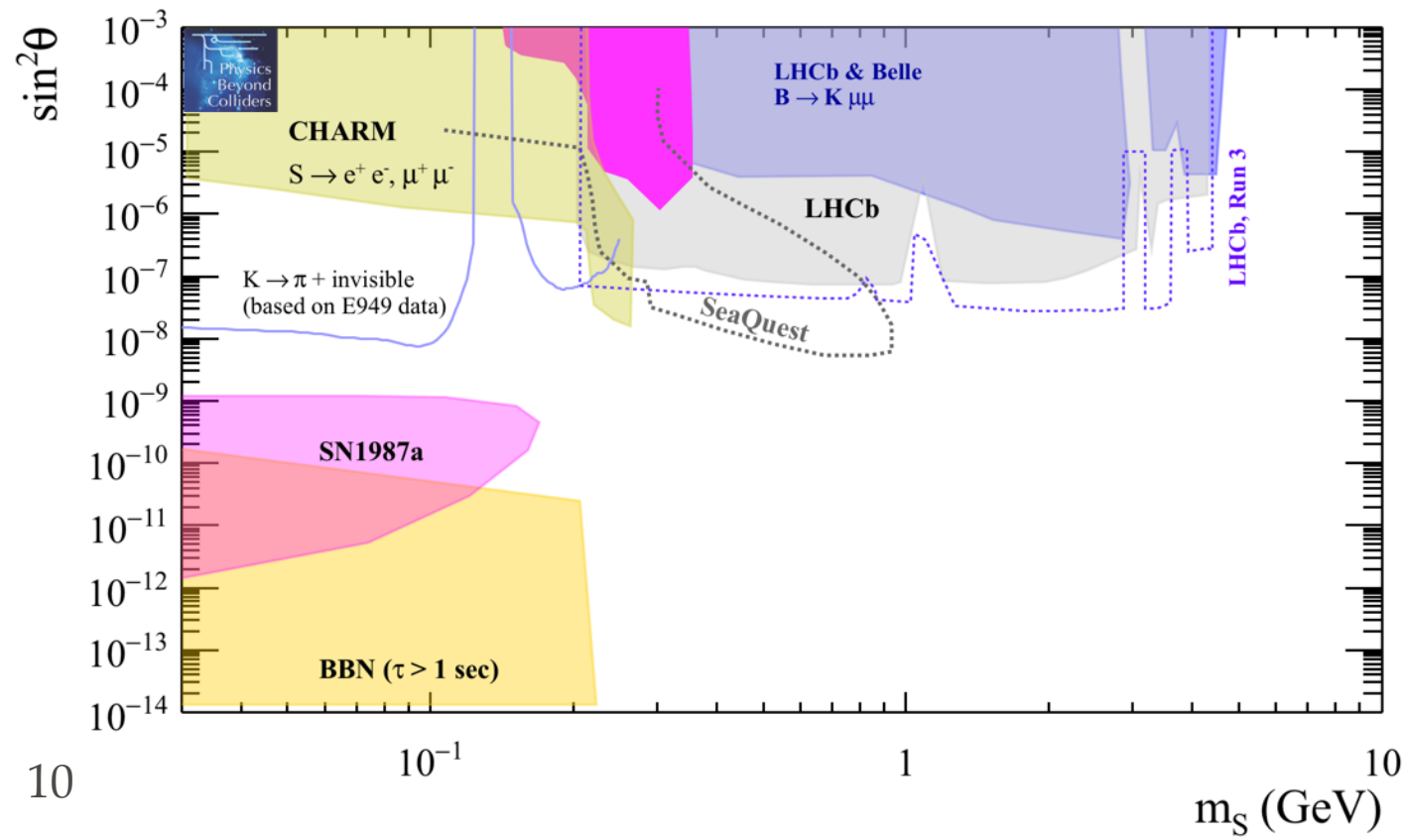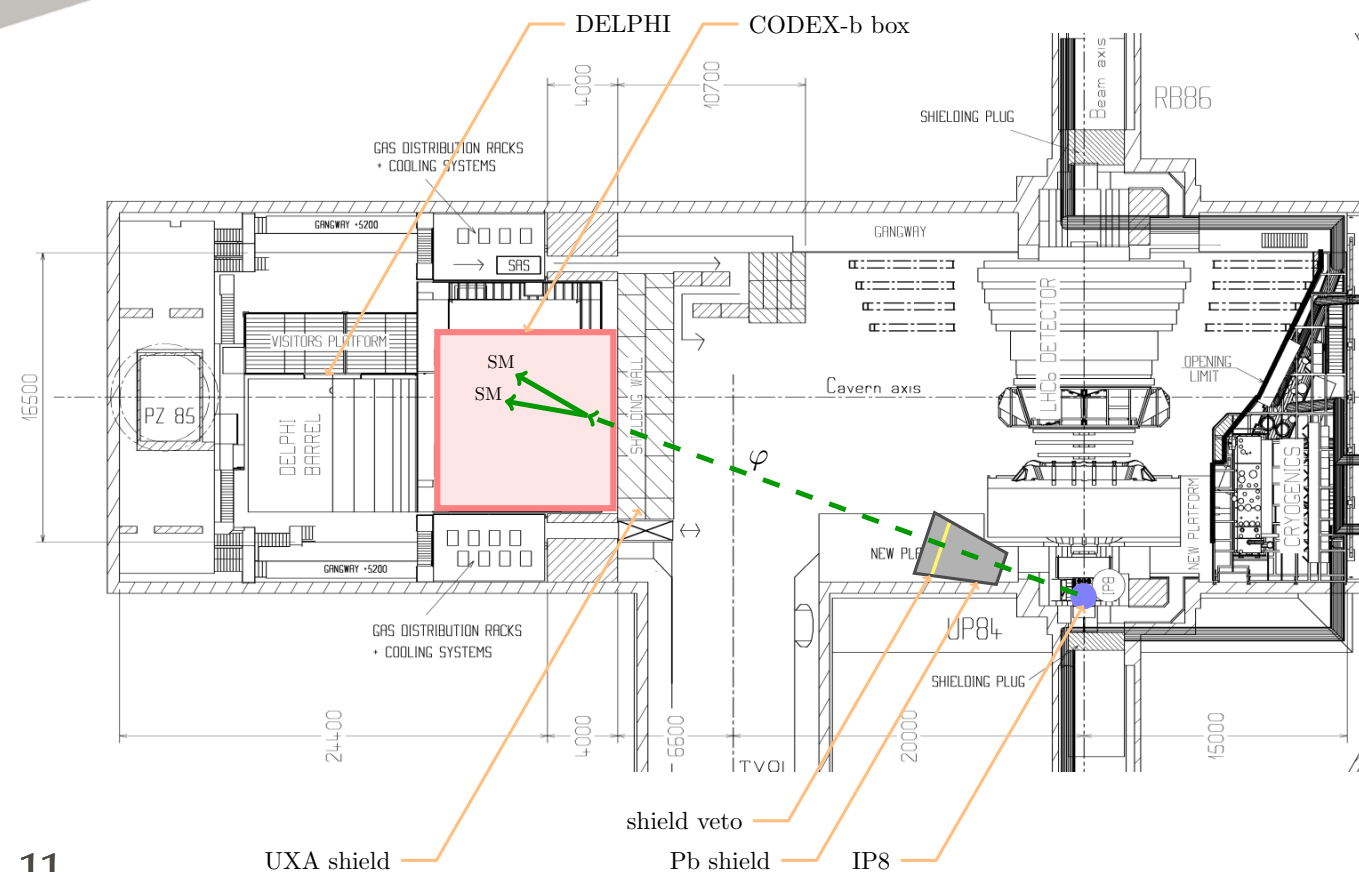
Vector portal

Scalar portal
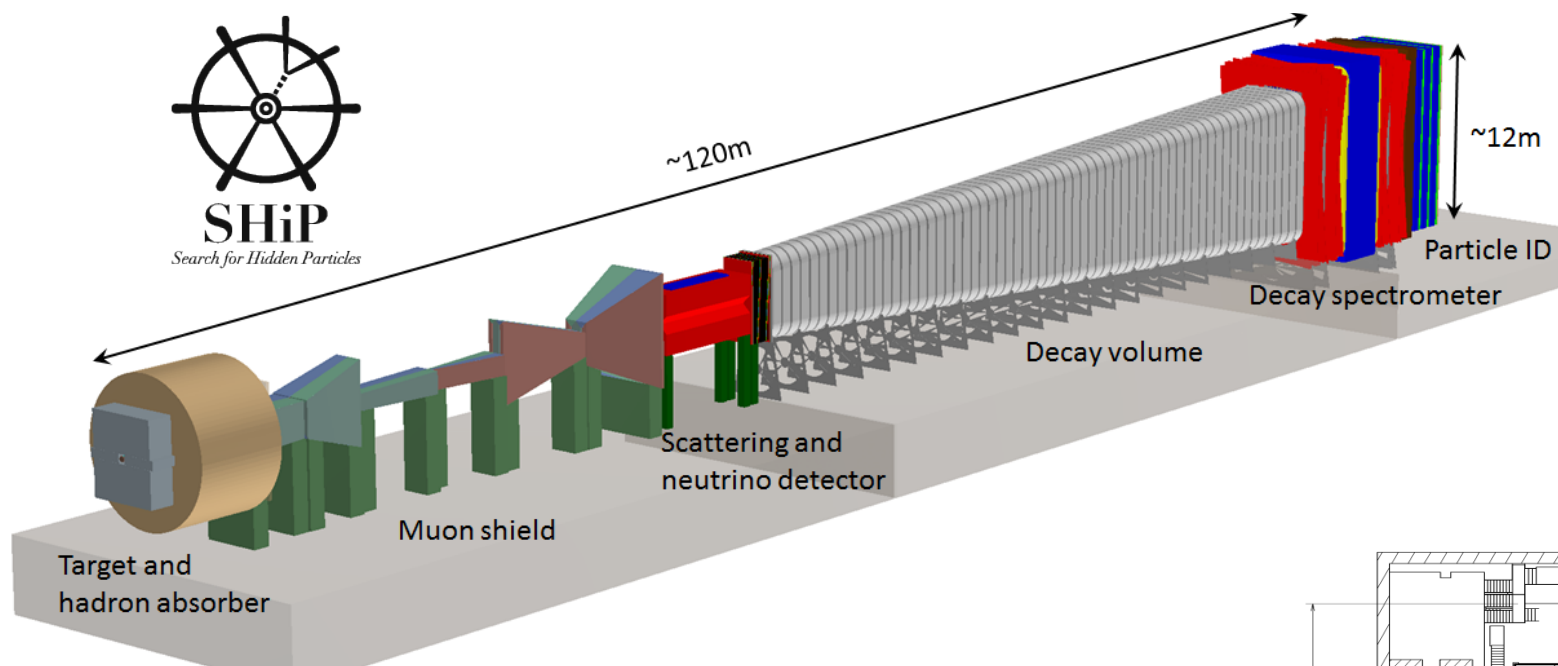

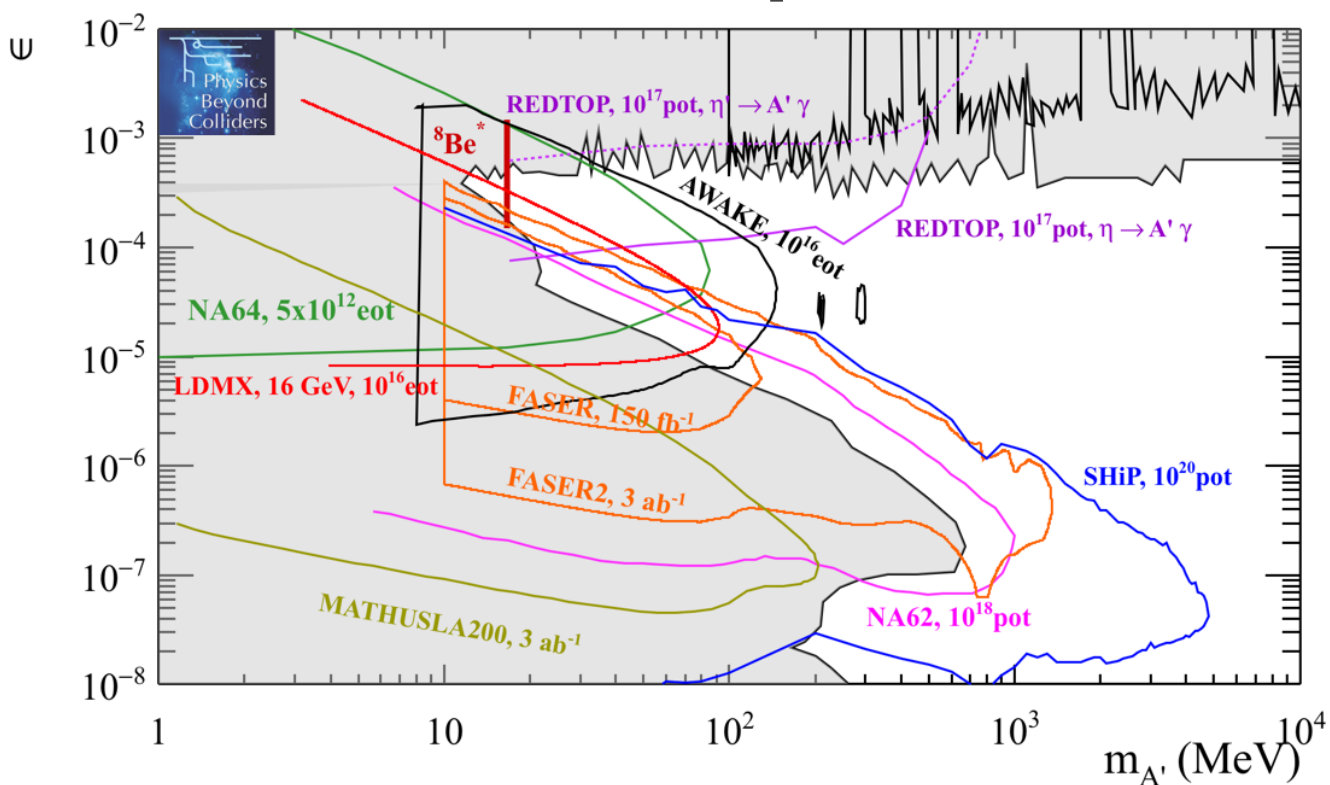- Expected improvements from Belle II and LHCb

CONSTRAINTS ON PORTALS

- Many planned or proposed new experiments, especially to take advantage of long lifetime of hidden particles
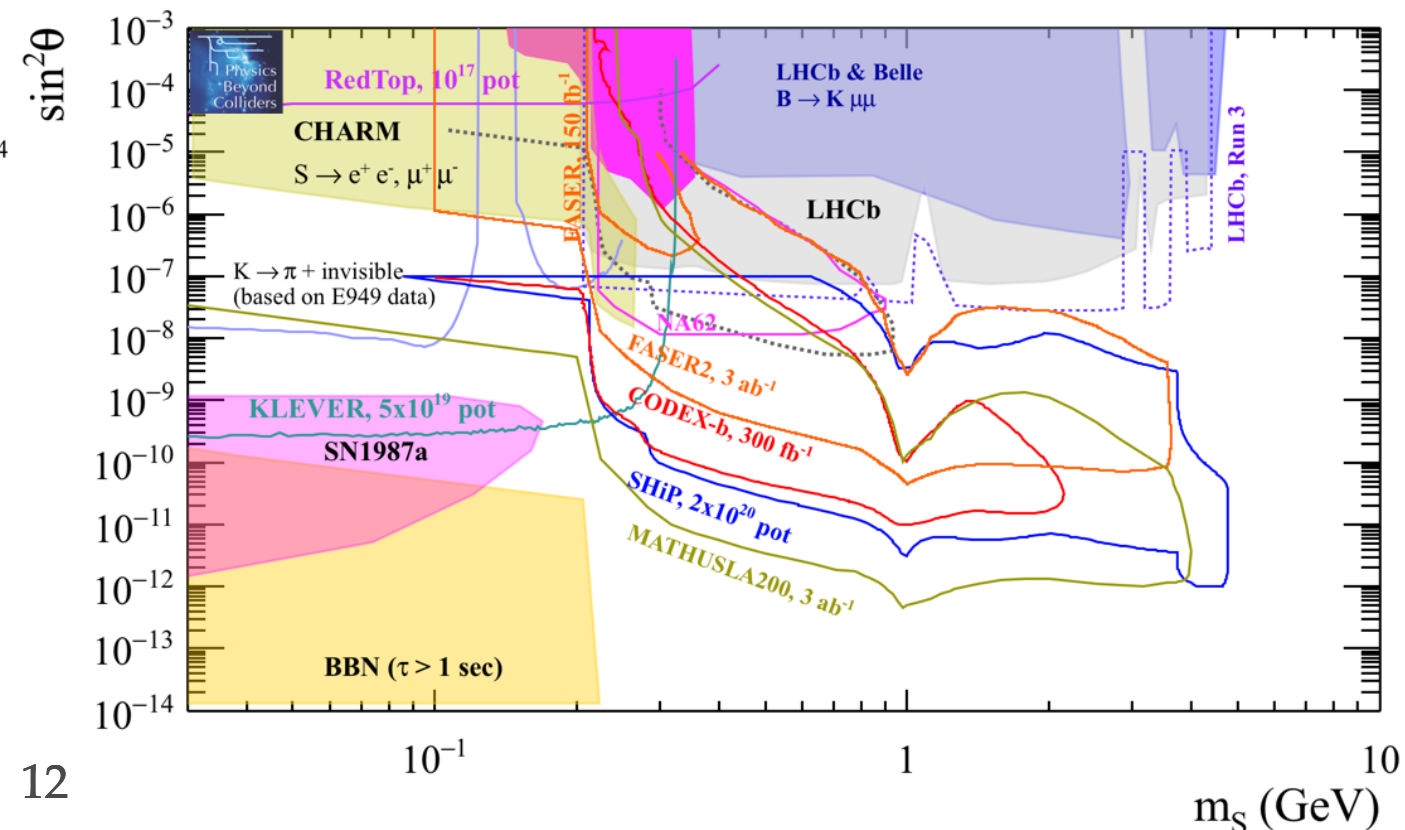
PORTALS: FUTURE POTENTIAL

Vector portal

- Improvements in coverage based on PBC proposal

Scalar portal

- FASER experiment approved & funded for installation in LHC LS2!

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HIDDEN SM STATES

- Standard Model particle that has not yet been discovered! True muonium (in spin-1 state) kinetically mixes with photon

$c\tau = 0.54$ mm

TM

μ^-

γ

e^-

μ^+

e^+
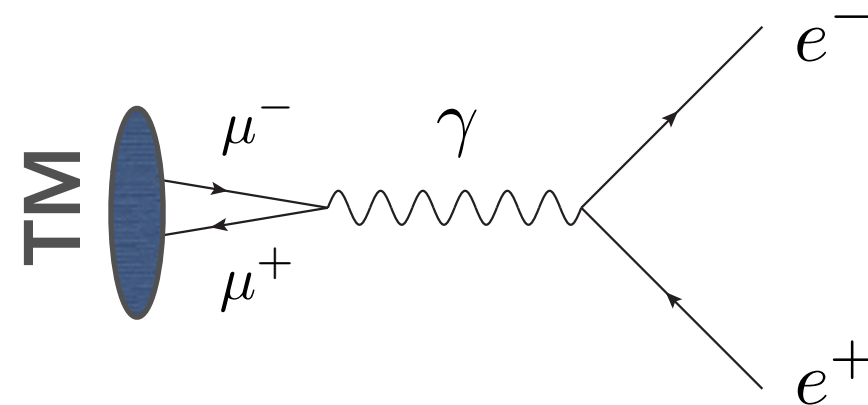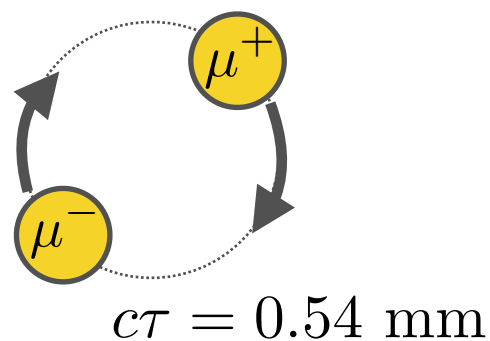
- Due to displacement & known mass/coupling, can be discovered using upgraded triggerless readout at LHCb (15/fb)

signal
signal w/out $\mathcal{P}_{dis}$
background

probability of decay

radial TM decay position (mm)

(also potentially RedTop, HPS: Ji, Lamm, 1810.00233 [PRD]; Banburski, Schuster, 1206.3961 [PRD])

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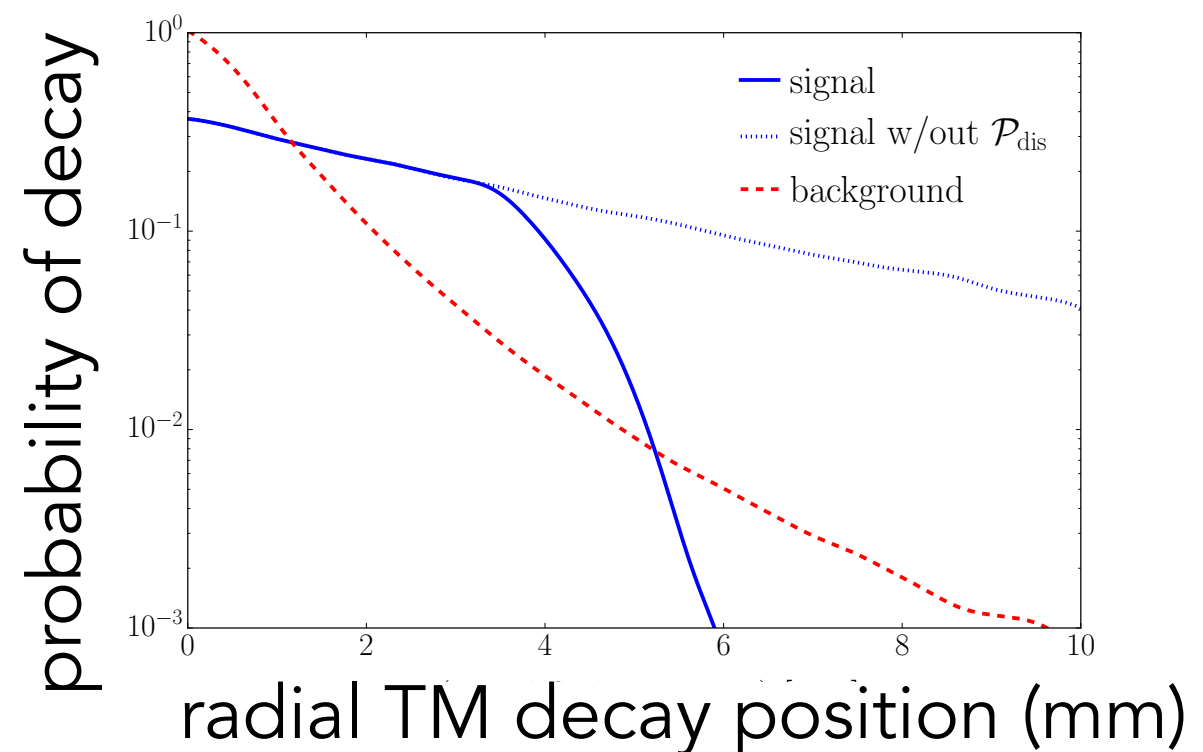
OTHER PORTALS?

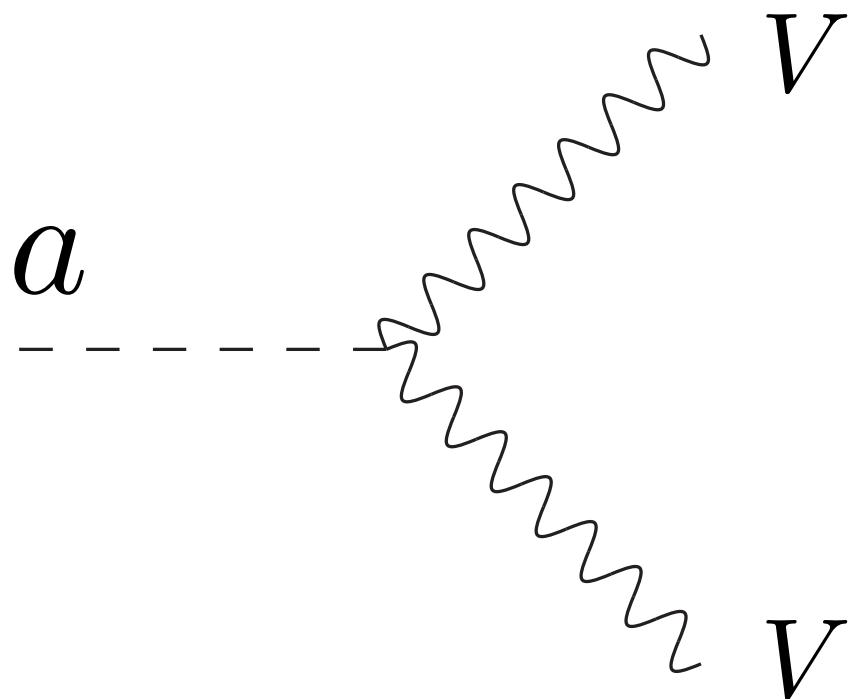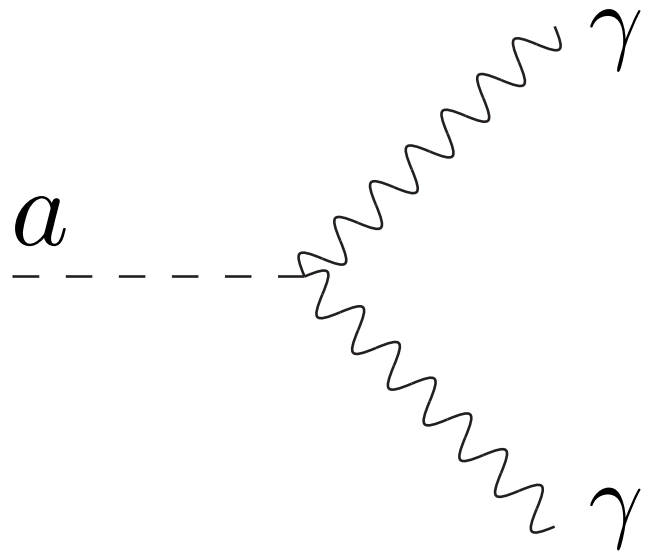- Non-renormalizable portals can have comparable rates if UV completion is not far above the weak scale

- **Example: the axion portal**

- Pseudoscalar can naturally be much lighter than other UV states due to approximate global symmetry

a ⋯⋯ V V

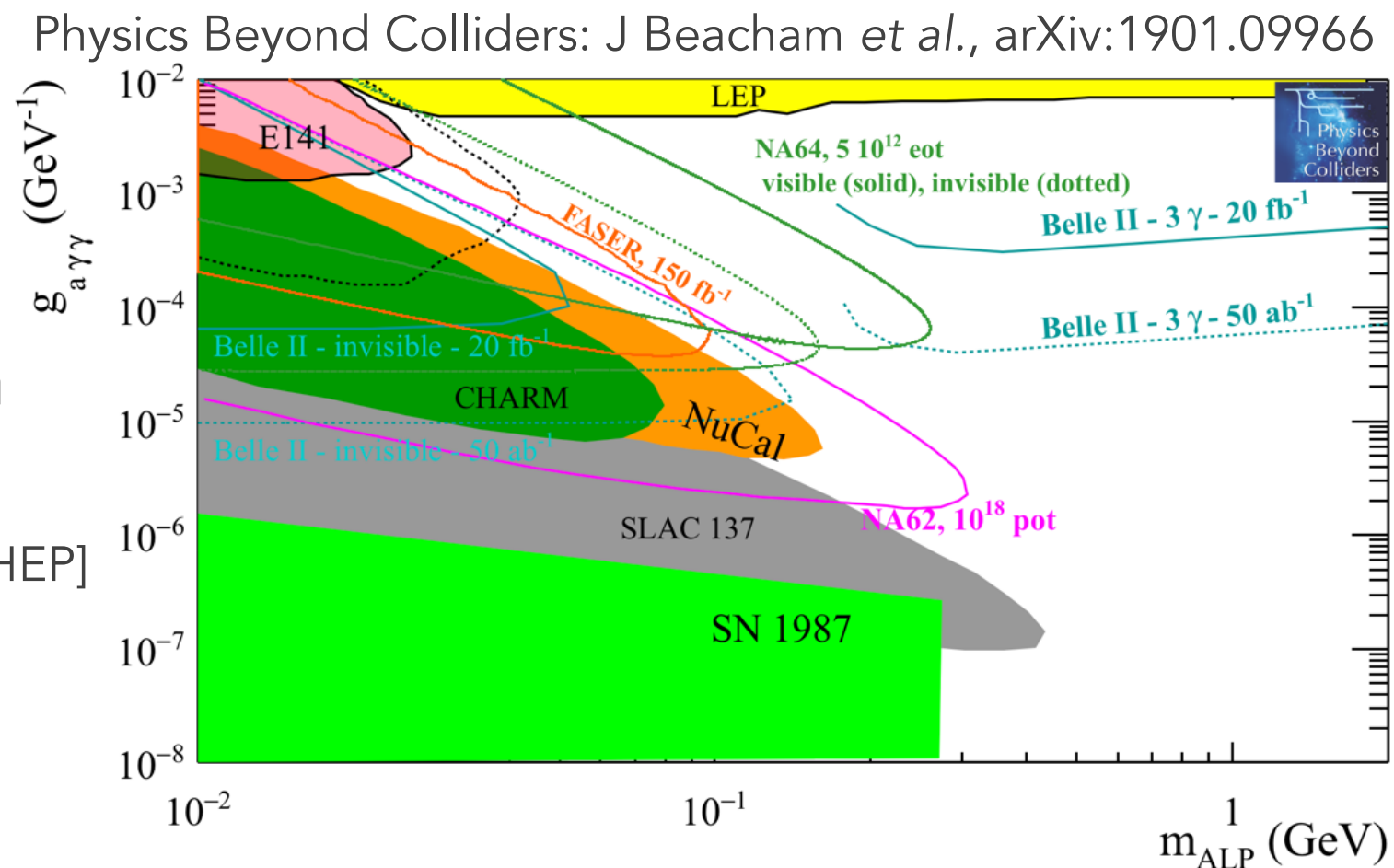- Also can have coupling to fermions, but pheno similar to scalar portal

AXION PORTAL: PHOTON

a —————

γ

γ

- ALP produced via photon fusion or in association with real photon

Physics Beyond Colliders: J Beacham *et al.*, arXiv:1901.09966

- Improvement expected with first Belle II data!
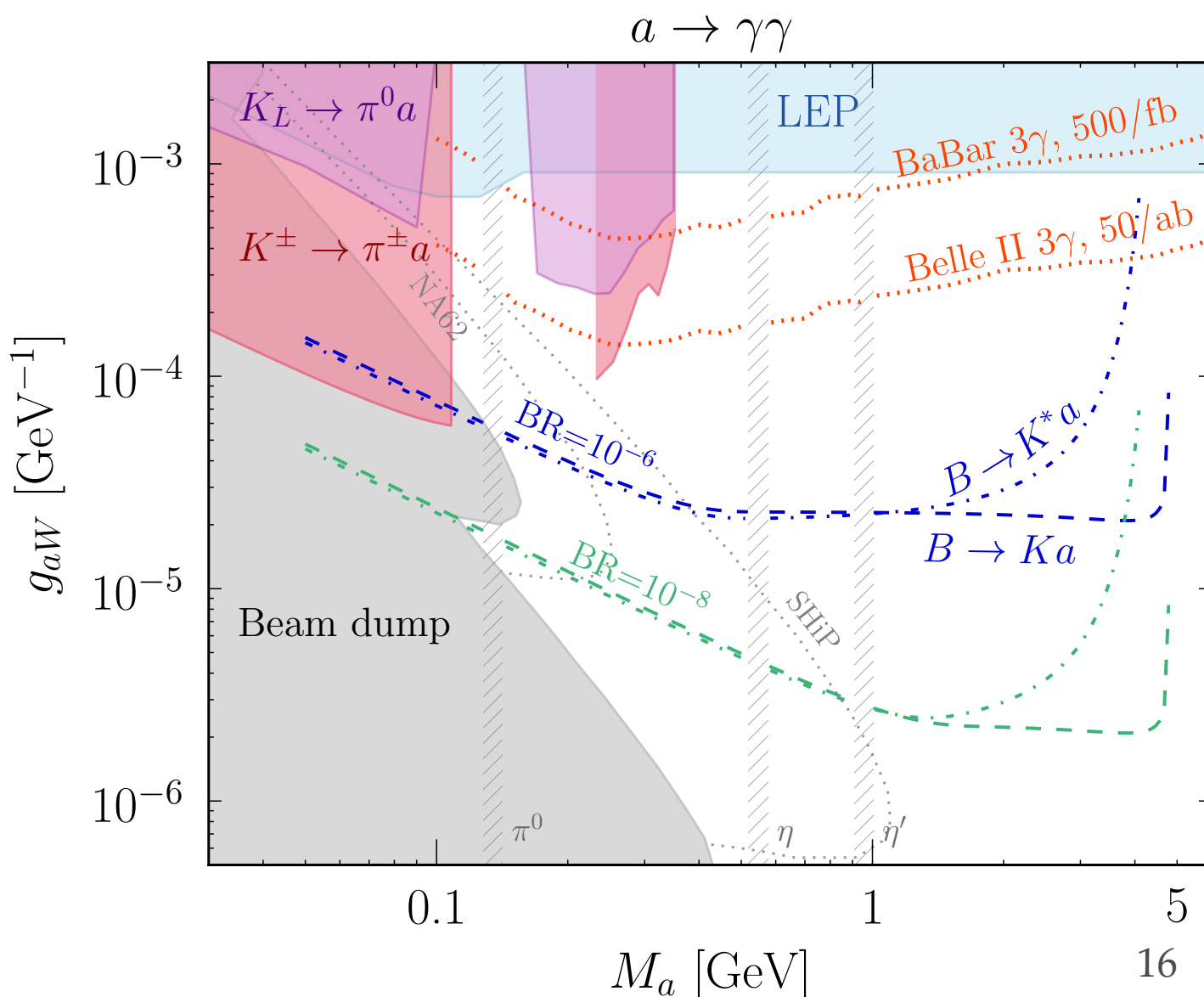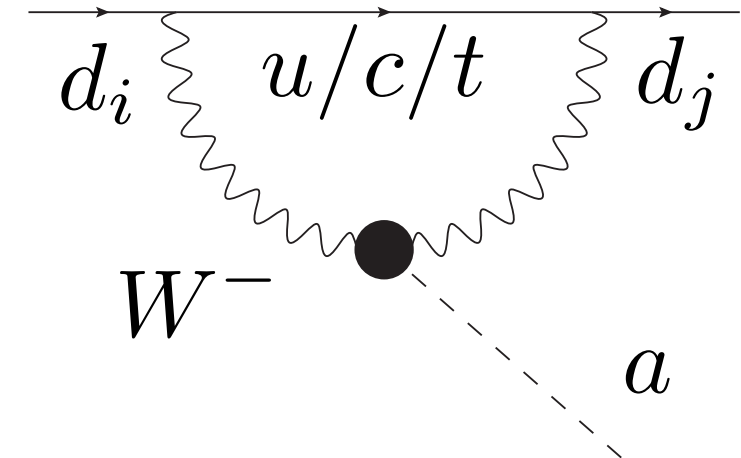
  Dolan *et al.*, 1709.00009 [JHEP]

- See talk on Thurs. by C. Hearty

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see also B. Döbrich *et al.*, 1512.03069 [JHEP];
D. Aloni *et al.*, 1903.03586,…

AXION PORTAL: WEAK

- Weak couplings can lead to FCNC production of axions
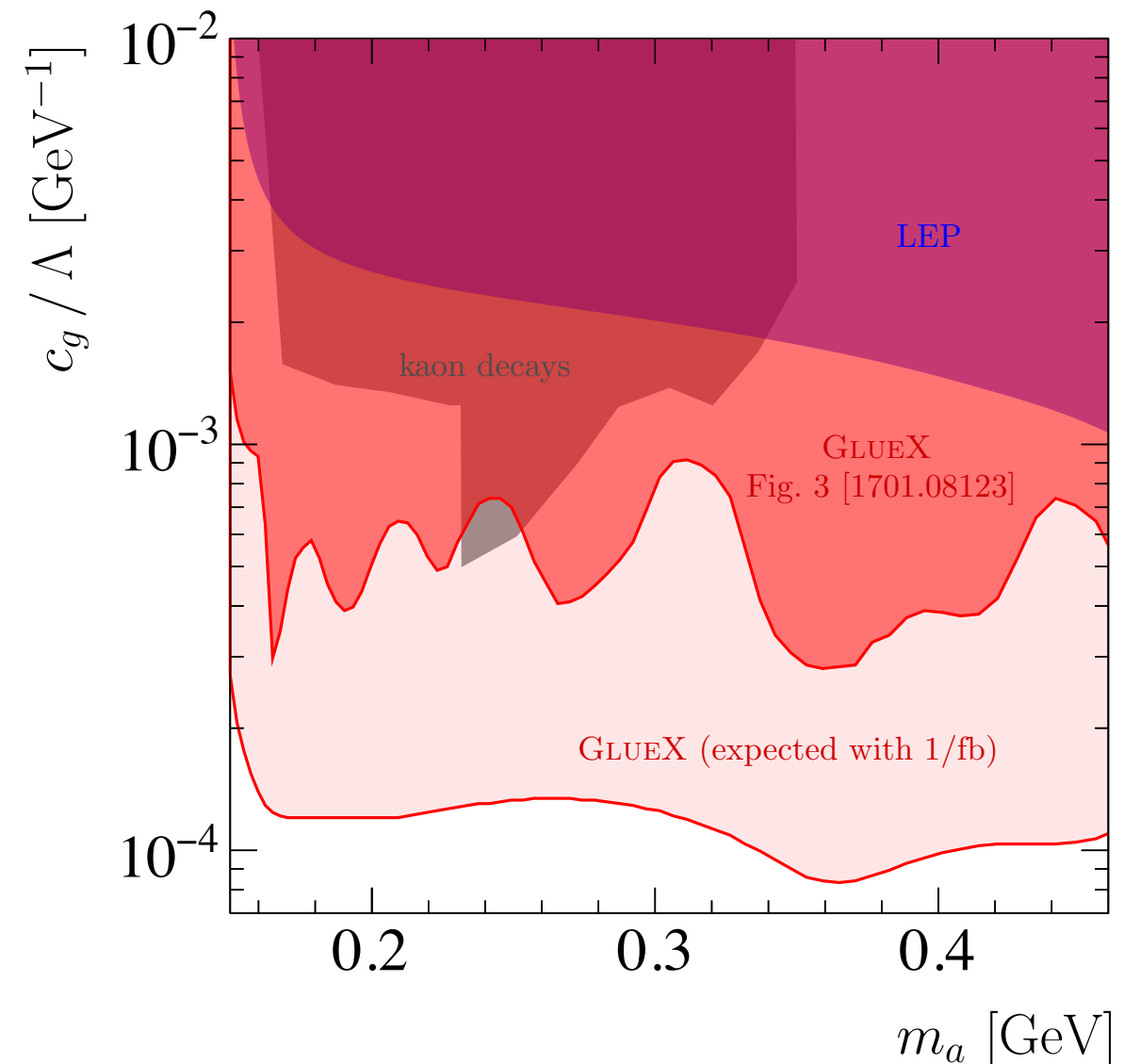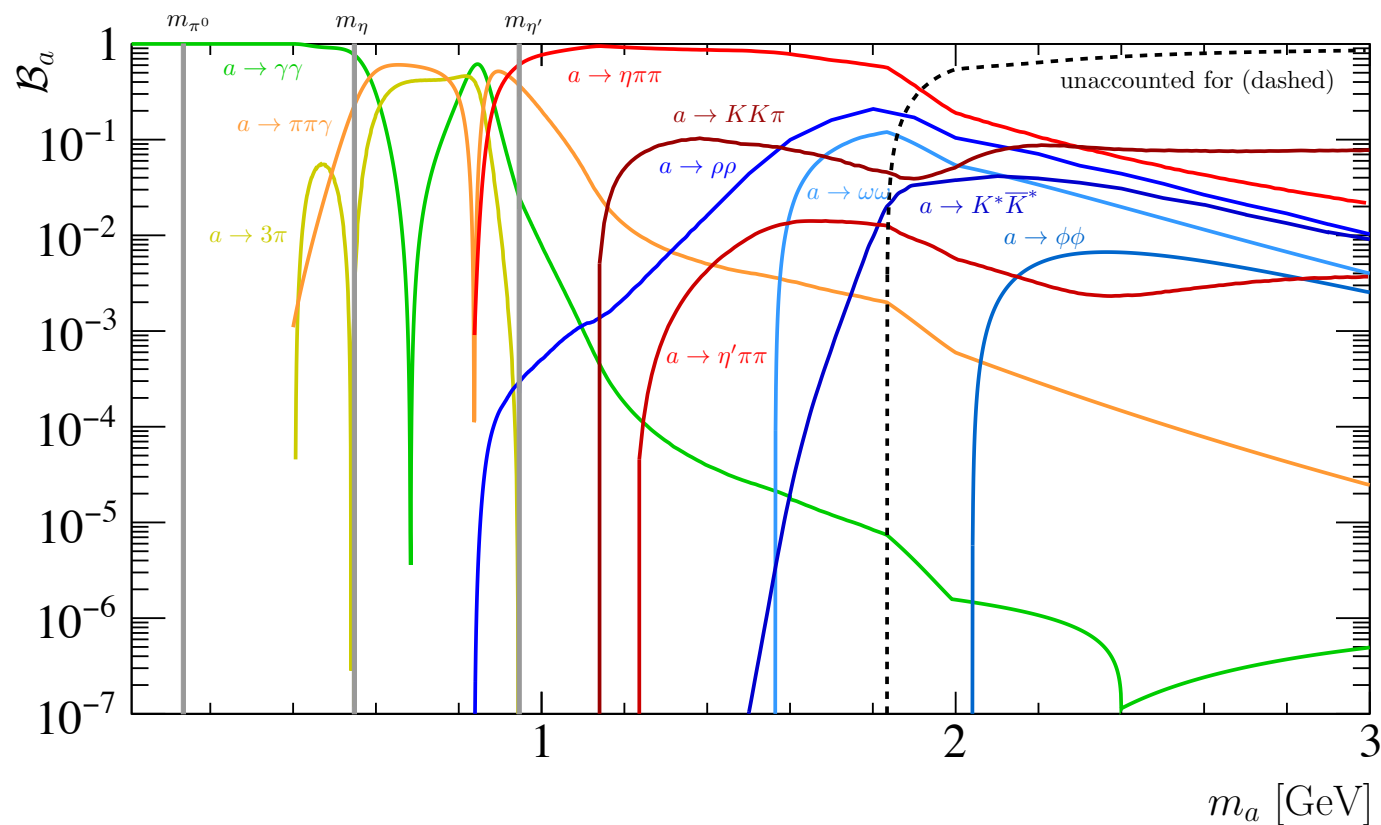

- Channels: $B^{\pm} \to K^{\pm} a$, $K^{\pm} \to \pi^{\pm} a$

- Possibility of several orders of magnitude improvement in sensitivity

also production in h/Z decays: M. Bauer, M. Neubert, A.Thamm, arXiv:1704.08207 [PRL]; …
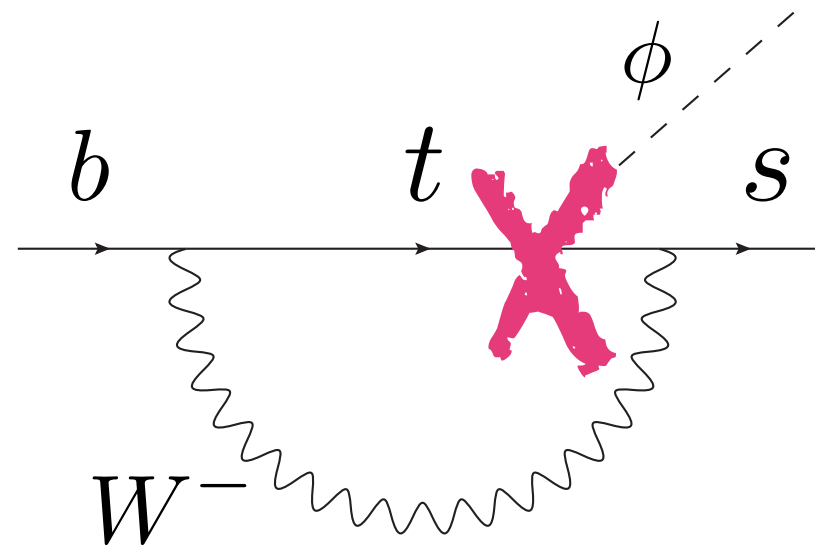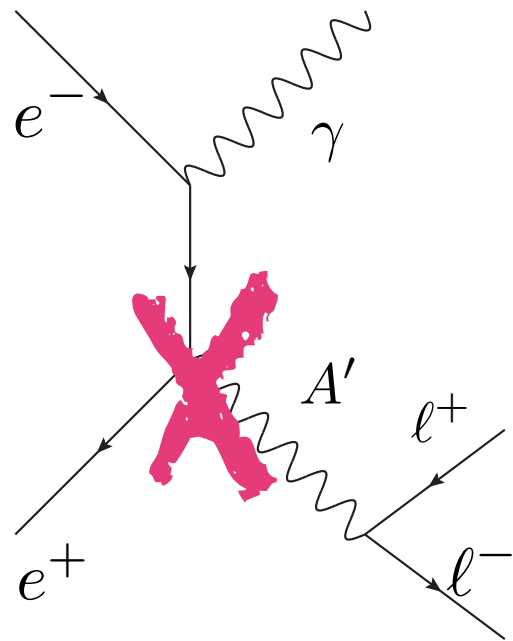

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AXION PORTAL: GLUON

- More like the QCD axion!

- Need to match onto low-energy effective QCD; still have large diphoton decay rate

OTHER PORTALS?

- We can also have models with **non-universal couplings**

- Dramatically different phenomenology if suppressed coupling to electrons and quarks

- **Leptophilic gauge boson** (gauged $L_\mu - L_\tau$ or RH muon)

  He *et al.*, 1991 [PRD]; Batell, McKeen, Pospelov, 1103.0721 [PRL]
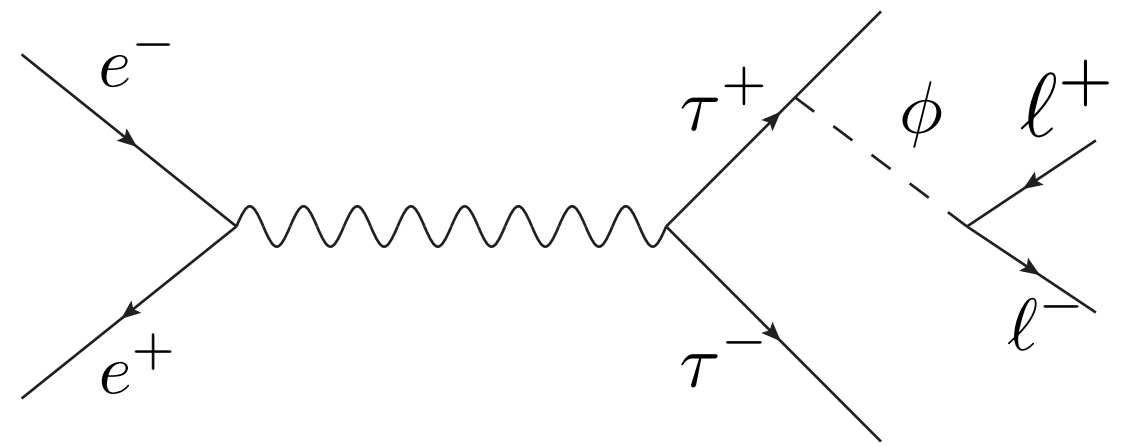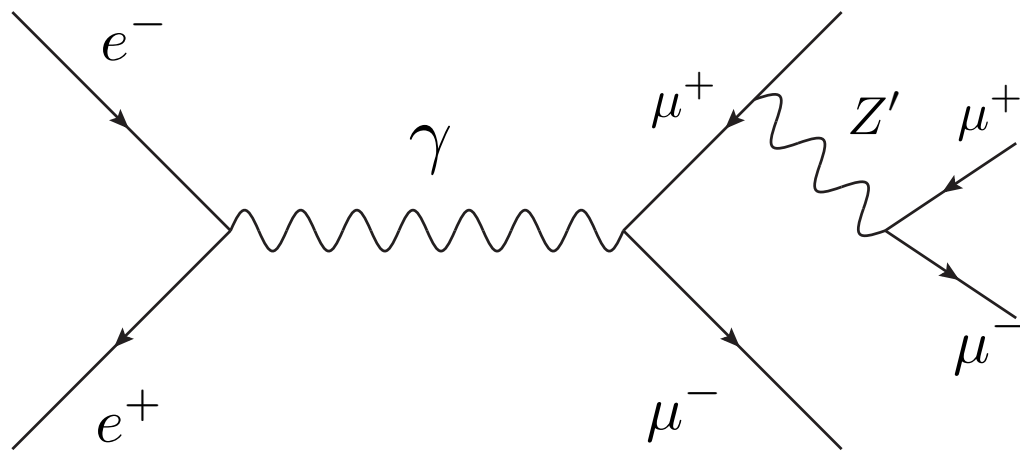
- **Leptophilic scalar**

  Chen *et al.*, 1511.04715 [PRD]; Batell *et al.*, 1606.04943 [PRD]

LEPTONIC FORCES

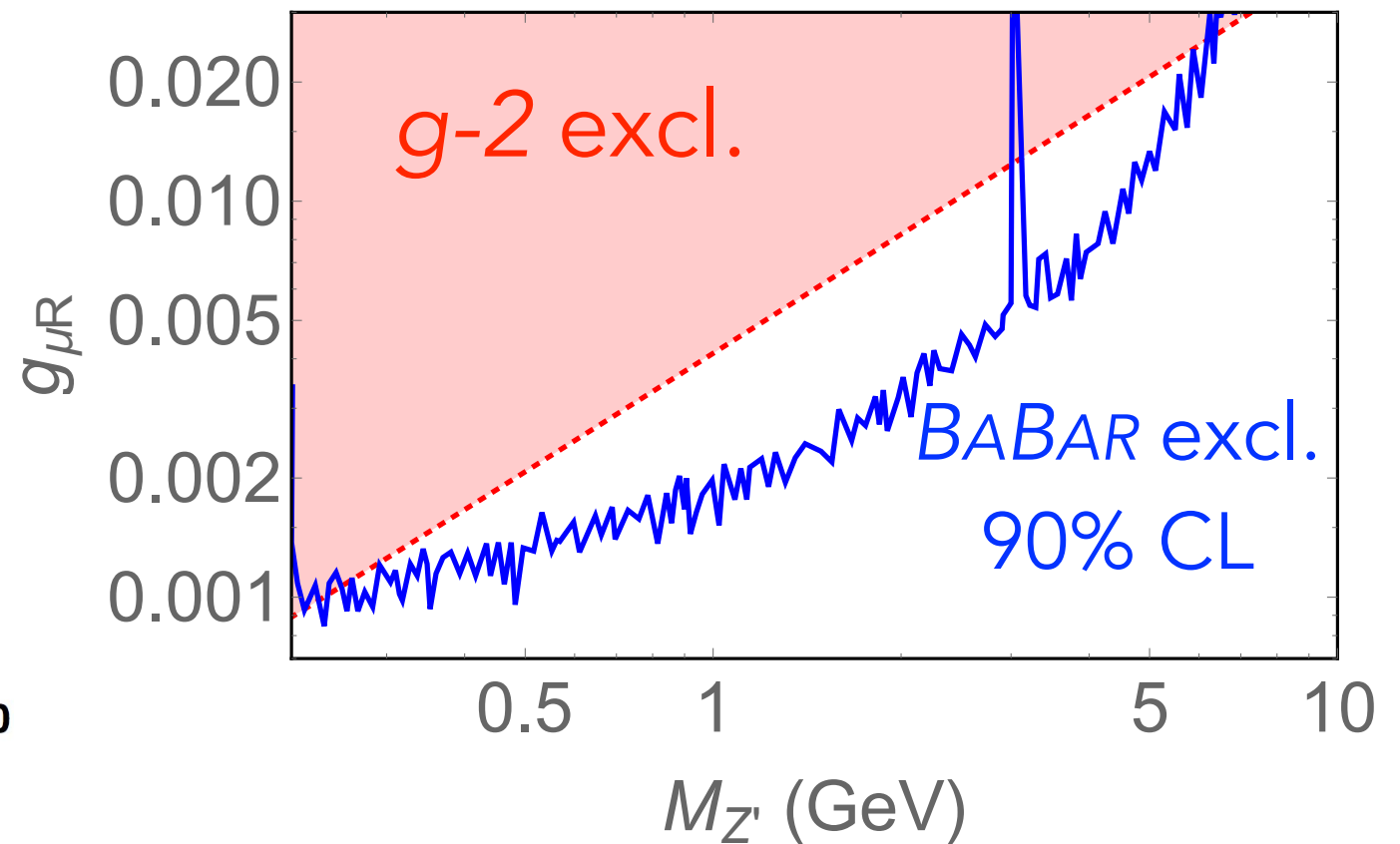- Flavour experiments can be great place to look for these leptonic forces
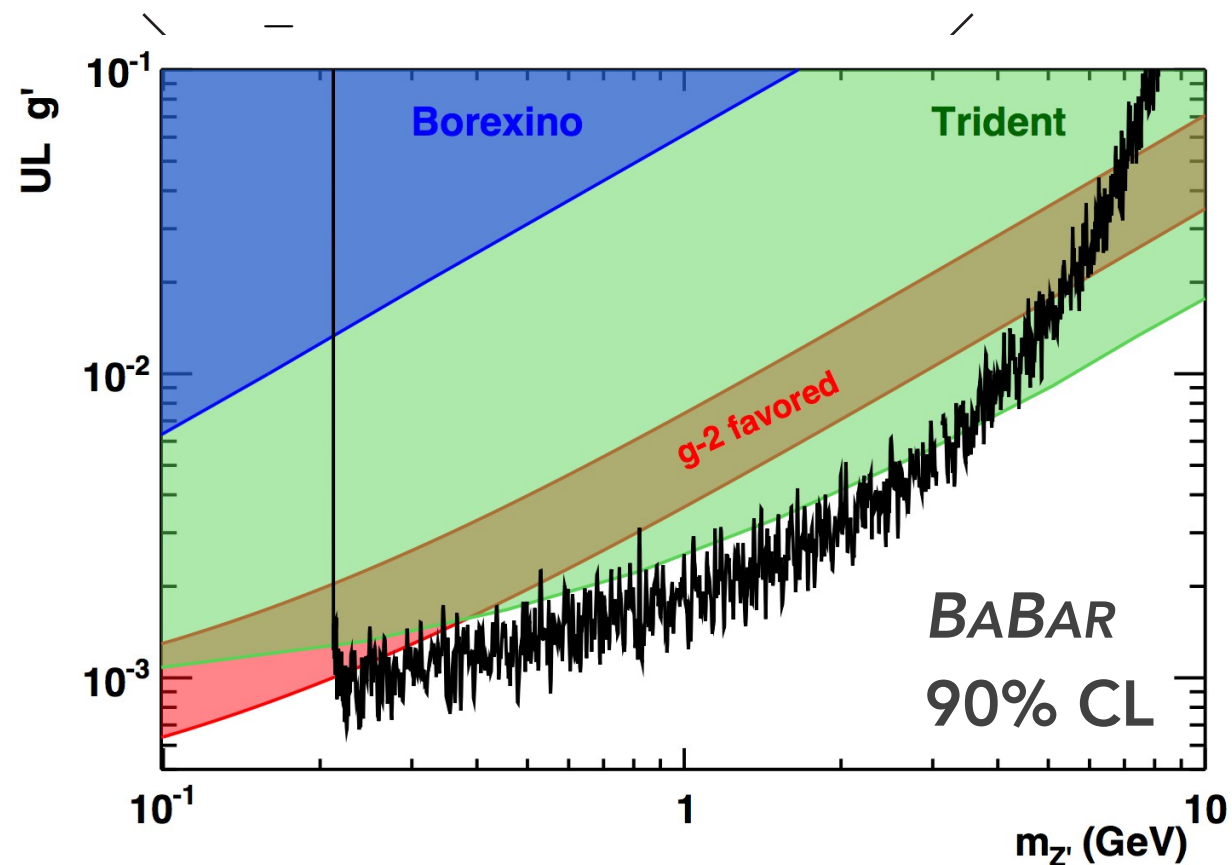
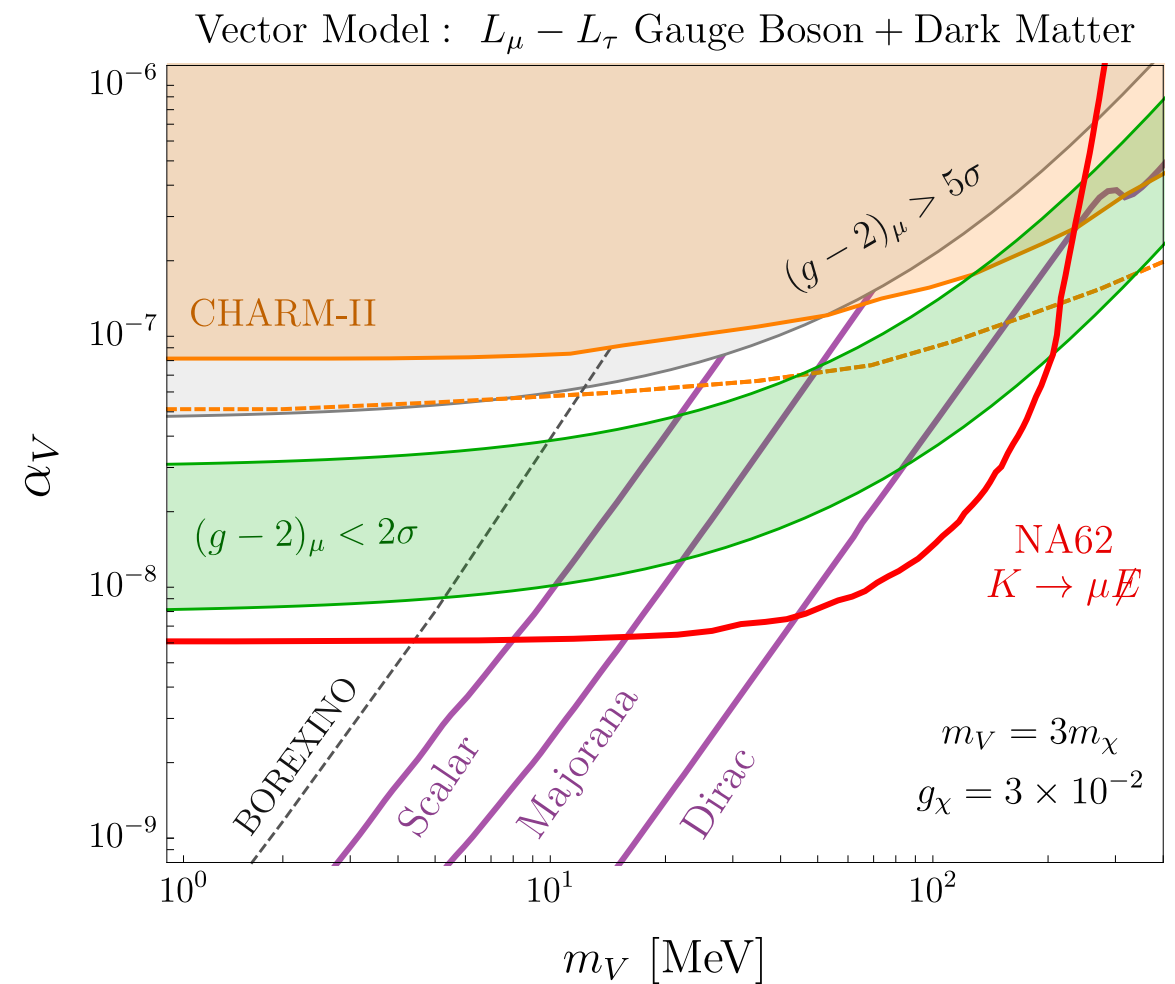Batell *et al.*, 1606.04943

LEPTONIC FORCES

- Flavour experiments can be great place to look for these leptonic forces

Batell *et al.*, 1606.04943

LEPTONIC FORCES

- Cosmology, parameters for dark matter different in these models

BS, I. Yavin, arXiv:1403.2727 [PRD]; Krnjaic *et al.*, arXiv:1902.07715
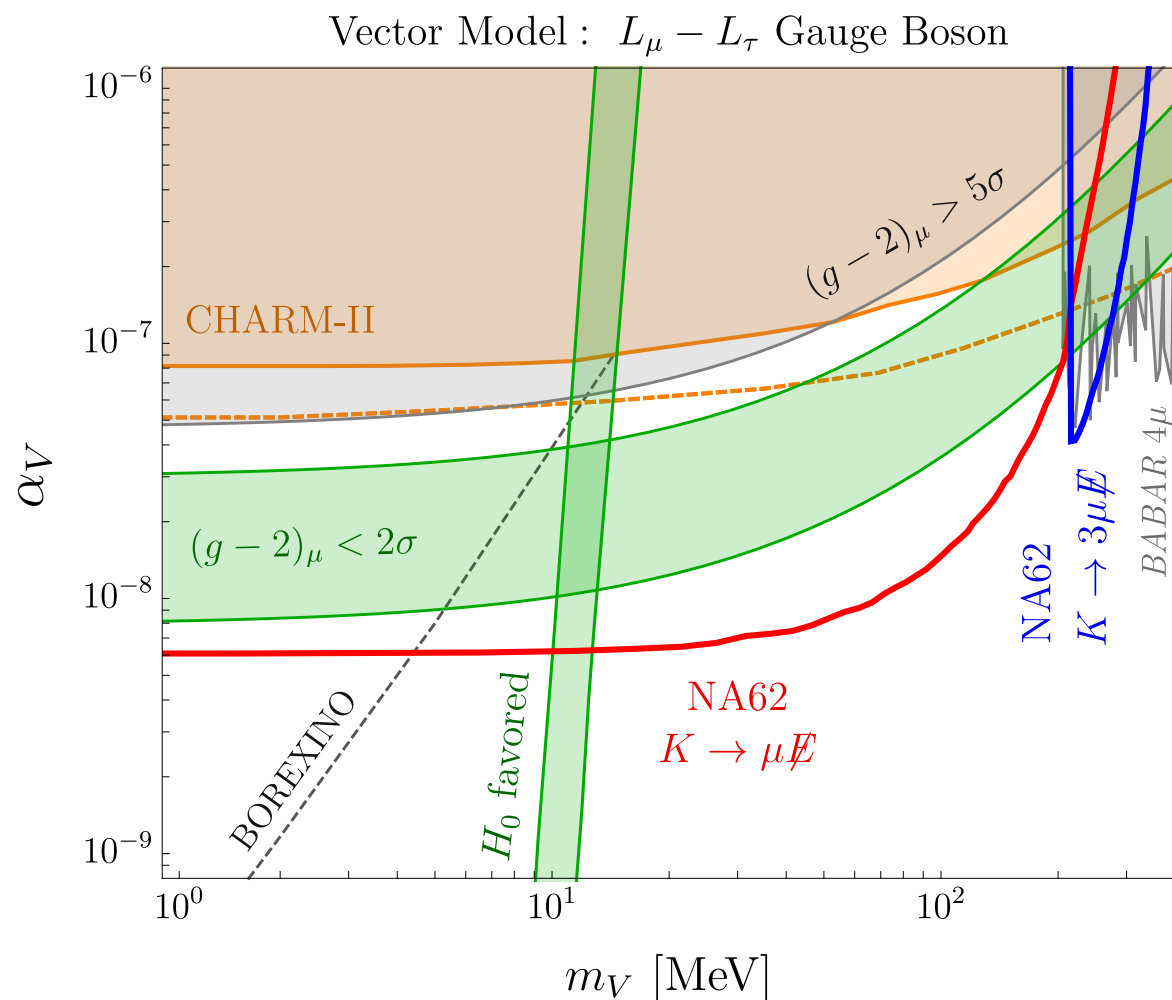
MODEL ORGANIZATION

("generic")

("model-specific")

Single particle

Dark photon
Singlet Higgs
Sterile Neutrino

"Simplified model"

Dark U(1)+Higgs
Z' + sterile neutrino
Dark photon + DM

Complete model

Dark-sector SUSY
nuMSM
LR-symmetric model
Twin Higgs, dark QCD

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MODEL ORGANIZATION

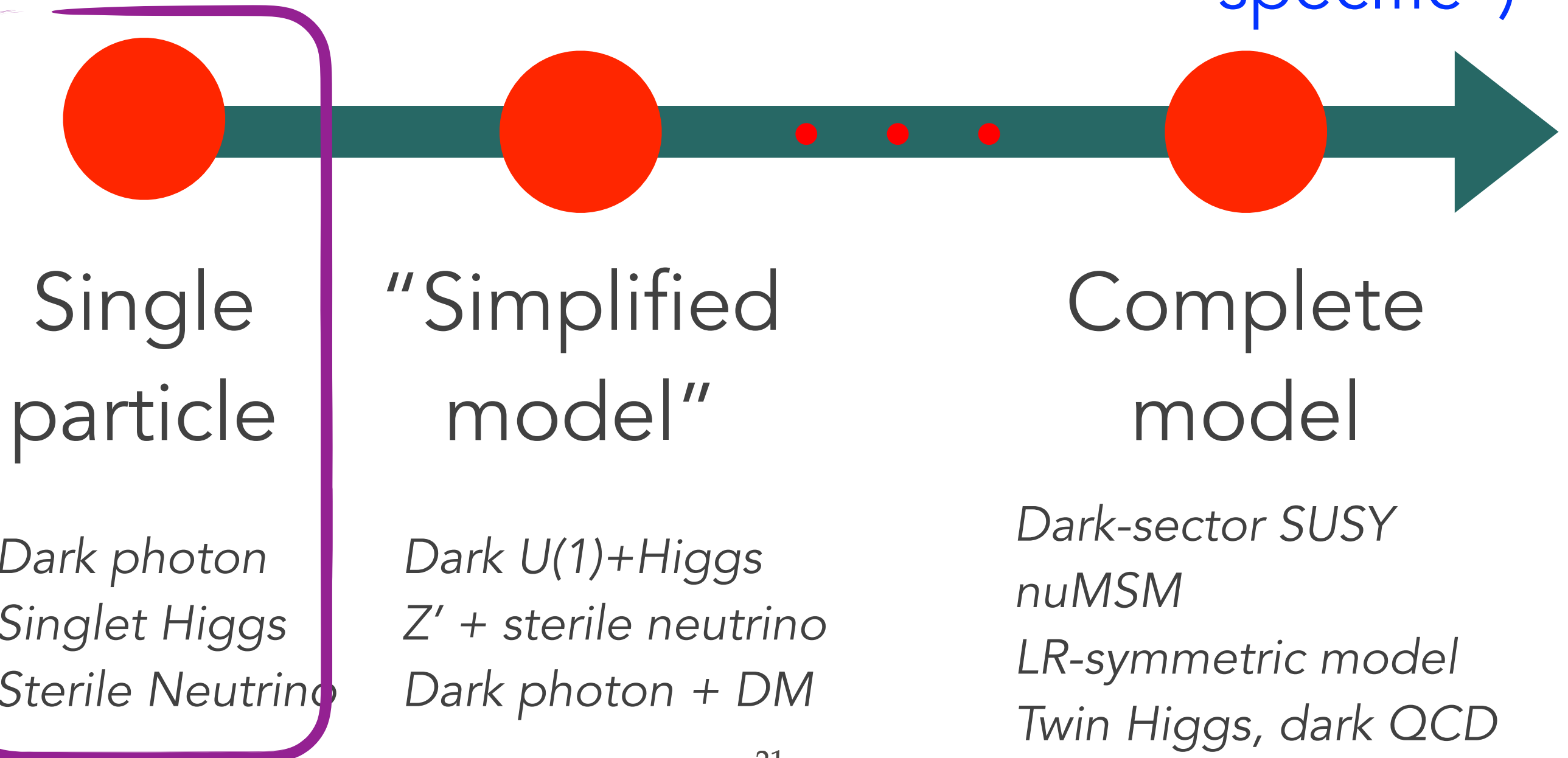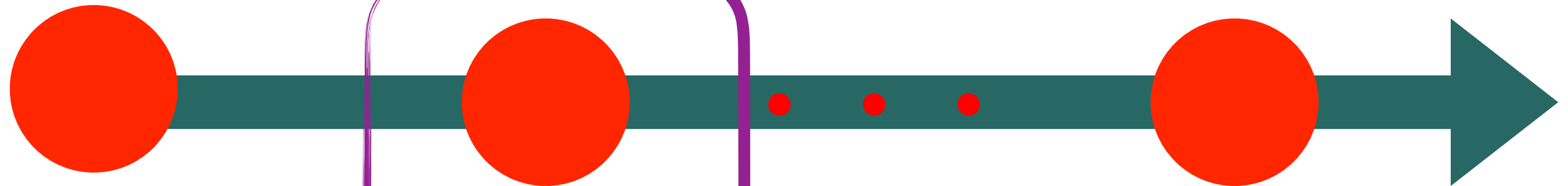("generic")

("model-specific")

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nuMSM
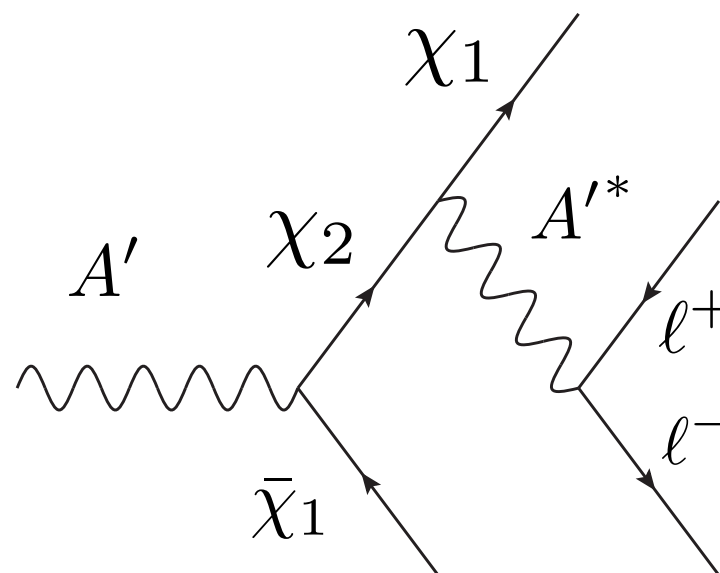*LR-symmetric model*
Twin Higgs, dark QCD

SIMPLIFIED HIDDEN SECTORS

- In single-particle model, decays happen through tiny coupling

- Easily overwhelmed by decays into **other** hidden sector particles (if they exist)

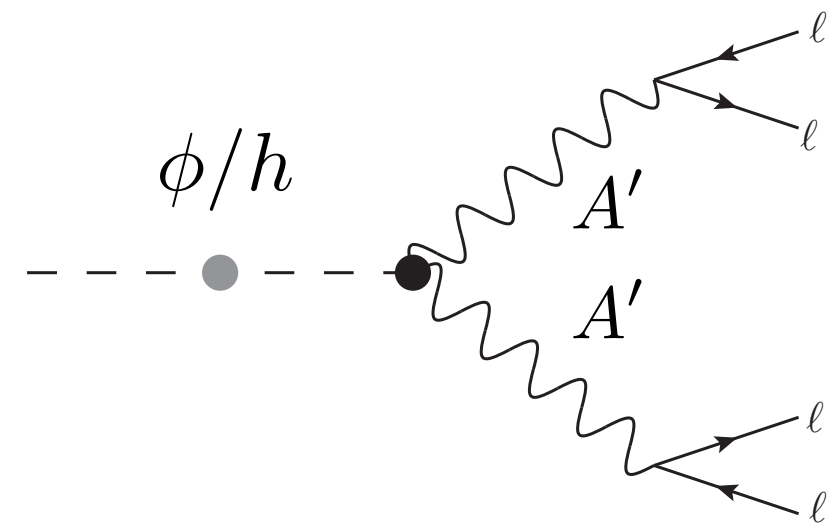- To capture these effects, consider 1-2 extra states
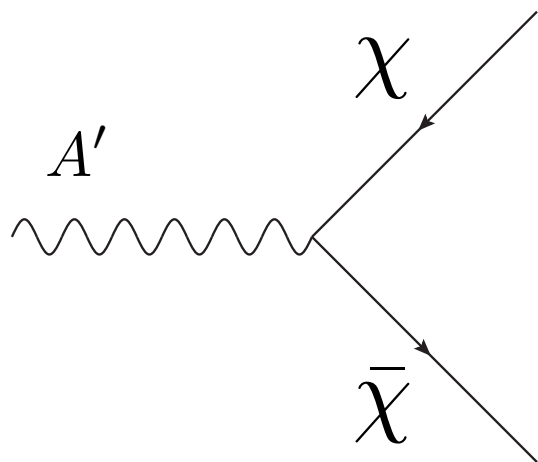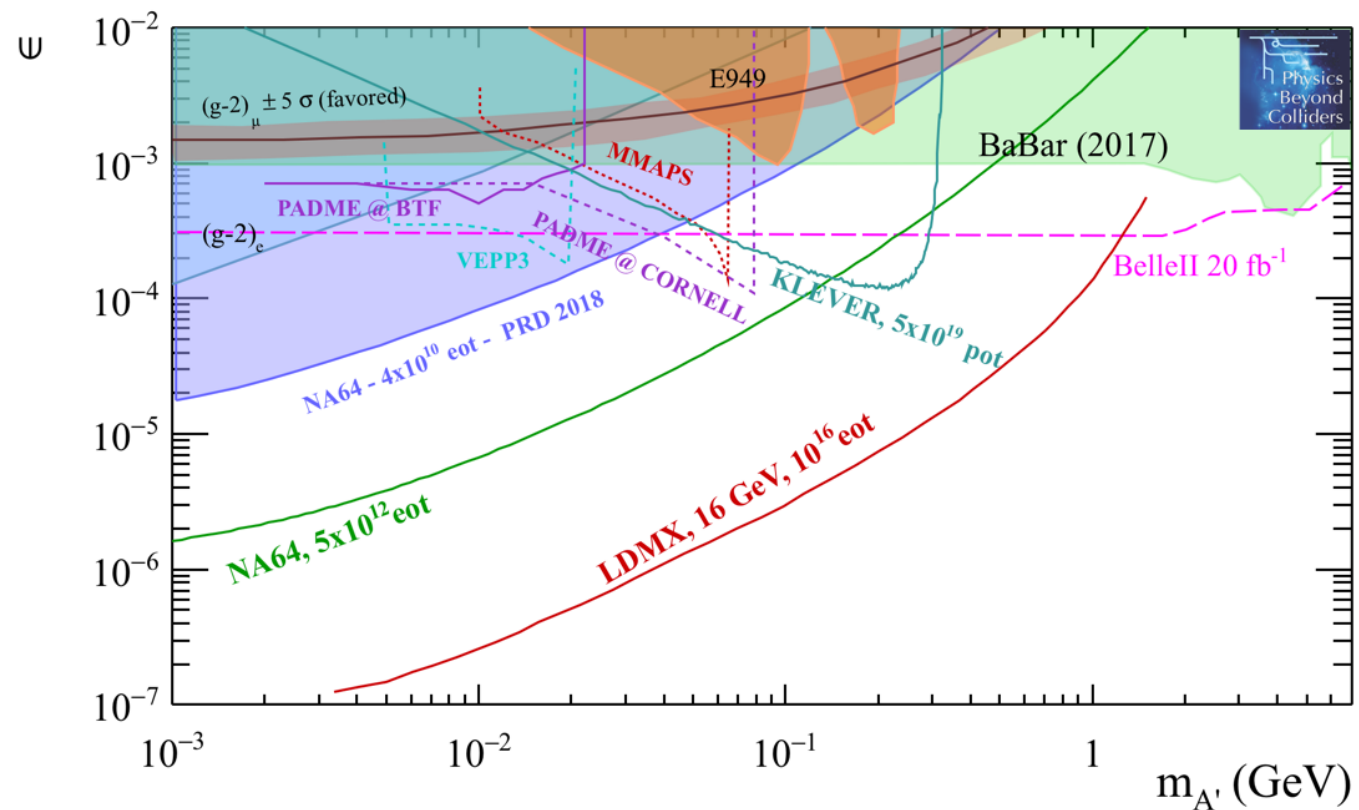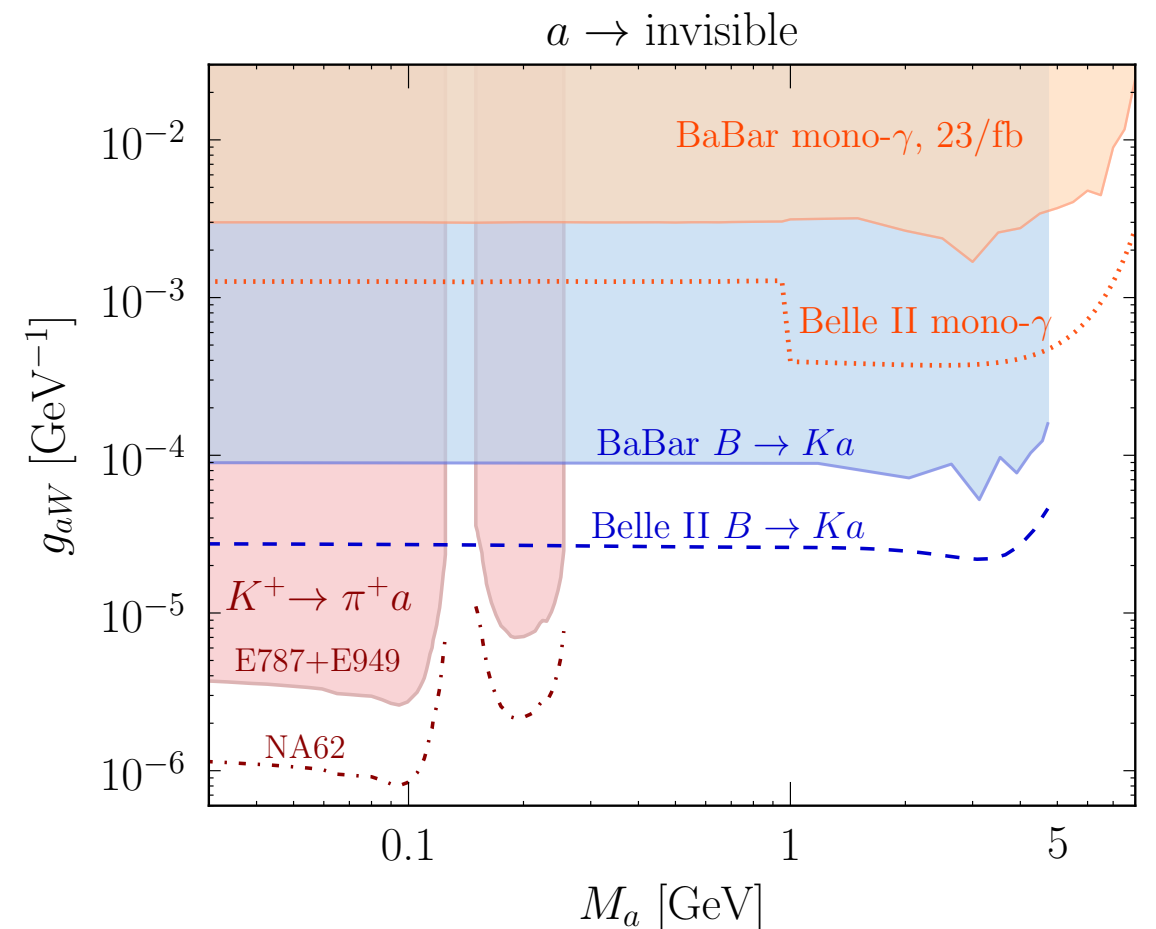
invisible   **semi-visible**   **cascade**

INVISIBLE MEDIATORS

- Search for missing momentum or energy

Vector portal

Axion portal - weak

(SEMI-)VISIBLE DECAYS

- Many current searches may not apply! Need comprehensive search strategies akin to LHC

- One approach: more inclusive searches

- **Example: *BABAR* search for long-lived particles** *BABAR*, arXiv:1502.02580 [PRL]

  - Model-independent limits set as function of detector efficiencies

  - Moderate backgrounds because only looking for 2 tracks

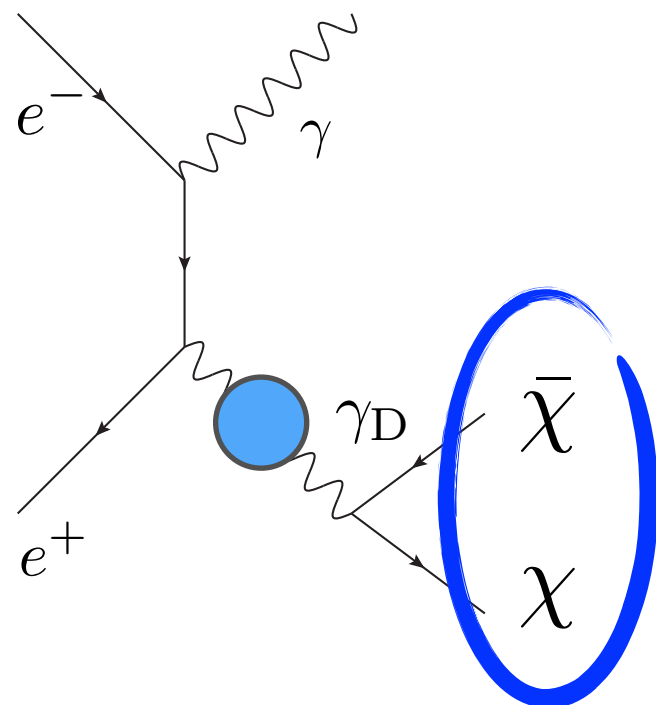 - Sensitive to particular exclusive decays
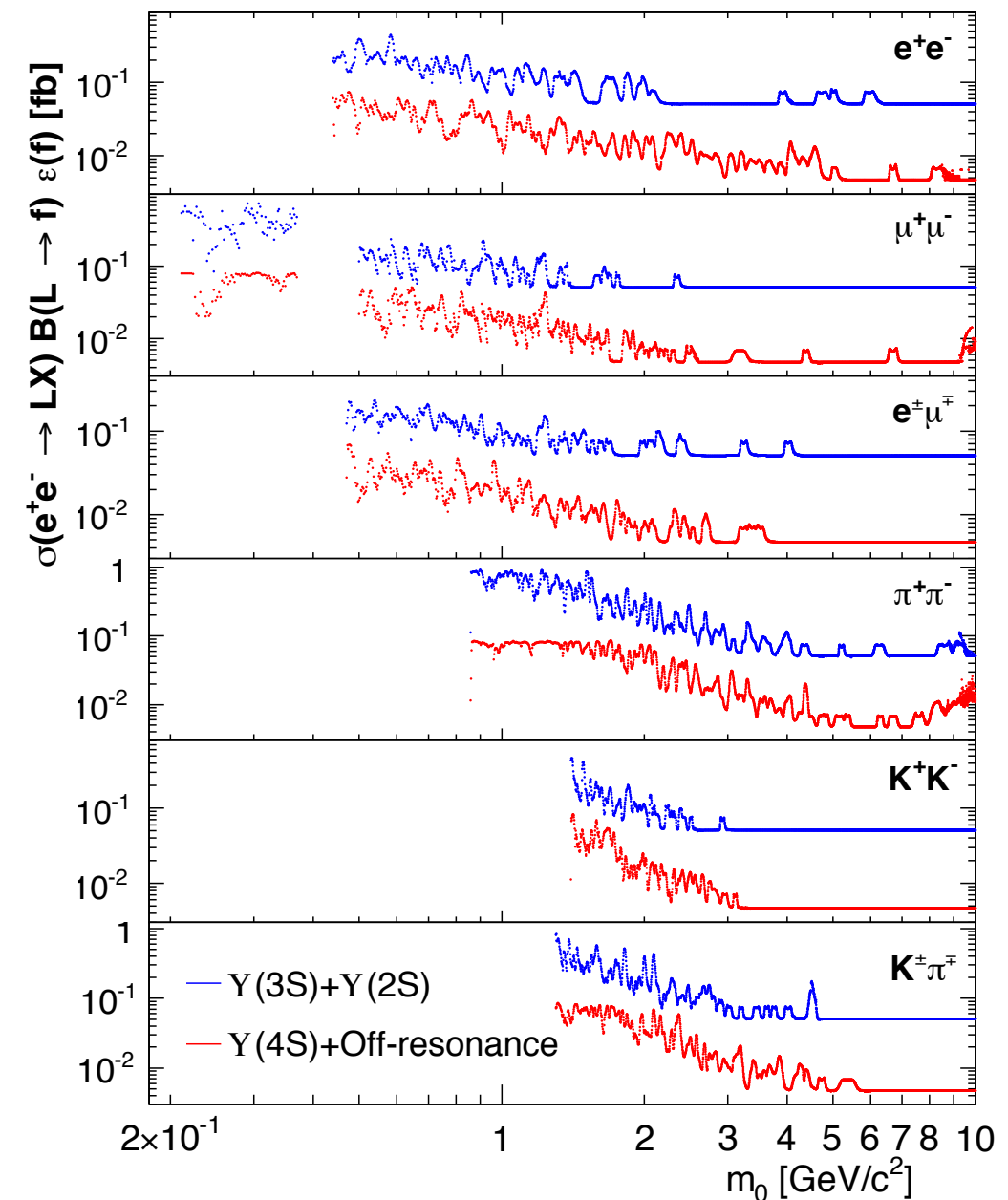
(SEMI-)VISIBLE DECAYS

see also: Berlin *et al.*, 1801.05805 [PRD]; Ballett *et al.*, 1903.07590; …

- What could we be missing?
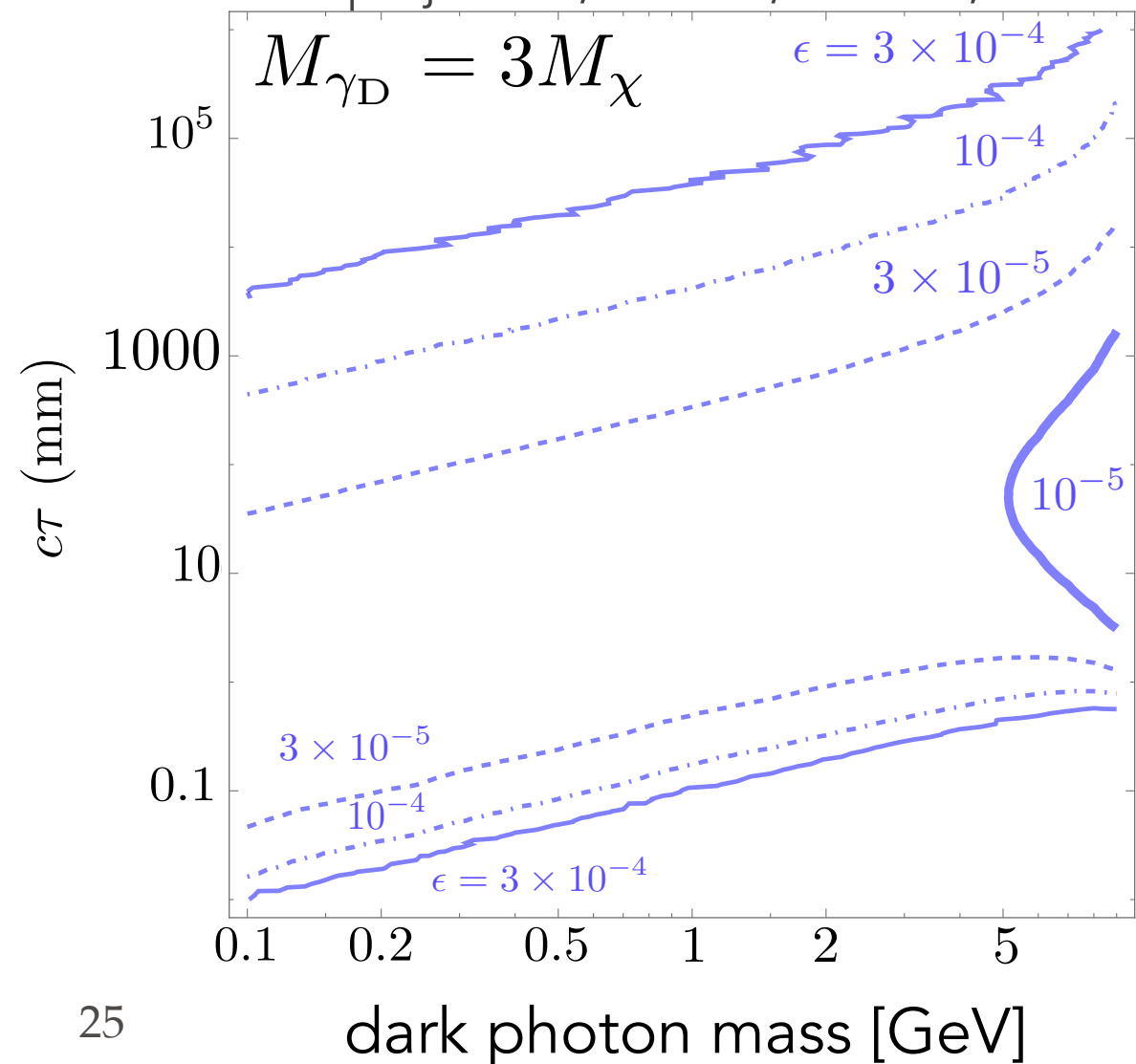
- Want to make sure of **comprehensive** coverage

    example: recent LHC long-lived particles white paper, ed. J. Beacham and BS, arXiv:1903.04497

- Illustrative example:

long-lived particles

Belle II projection, 10 evts, 25% eff, 50/ab

$M_{\gamma_{\mathrm{D}}} = 3 M_\chi$

$\epsilon = 3 \times 10^{-4}$

10^{-4}

3×10^{-5}

10^{-5}

3×10^{-5}

10^{-4}

$\epsilon = 3 \times 10^{-4}$

$c\tau$ (mm)

dark photon mass [GeV]

HIDDEN SECTORS WRAP-UP

Single particle   "Simplified model"   Complete model

- Lots of ongoing theory, pheno, and experimental work to look for hidden sectors wherever they may be lurking

- Impressive progress, but only now moving beyond the simplest examples of hidden sectors! **What new ideas do you have?**