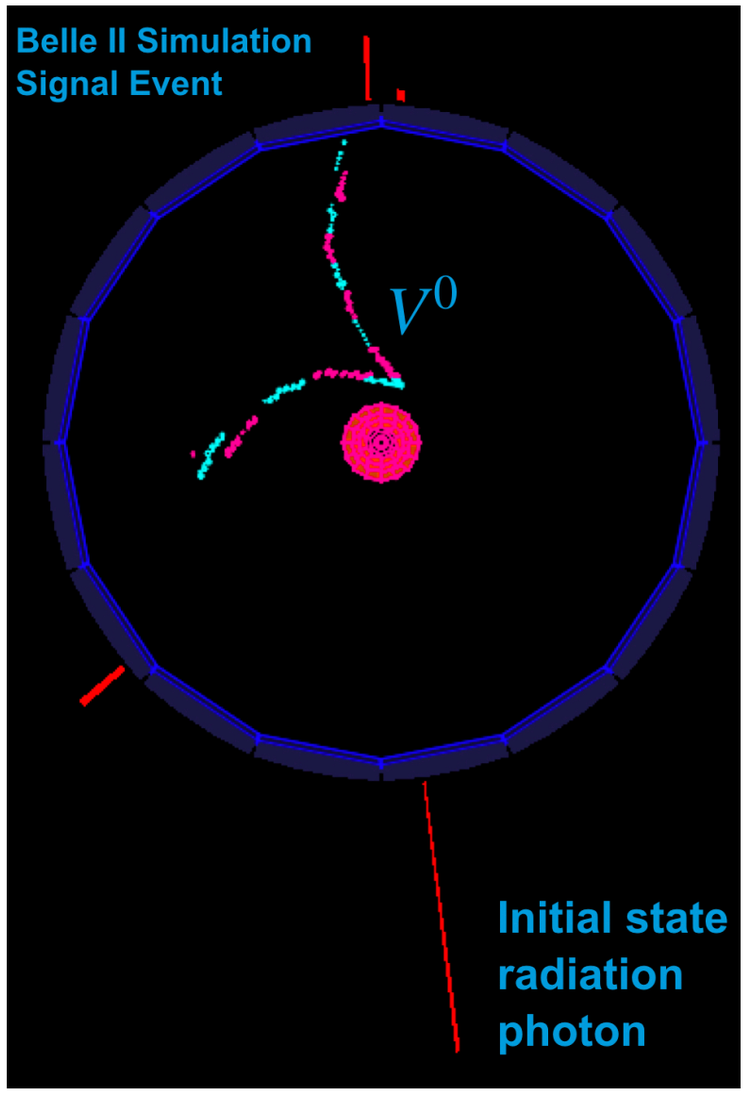
DARK SECTOR IN FLAVOR EXPERIMENTS



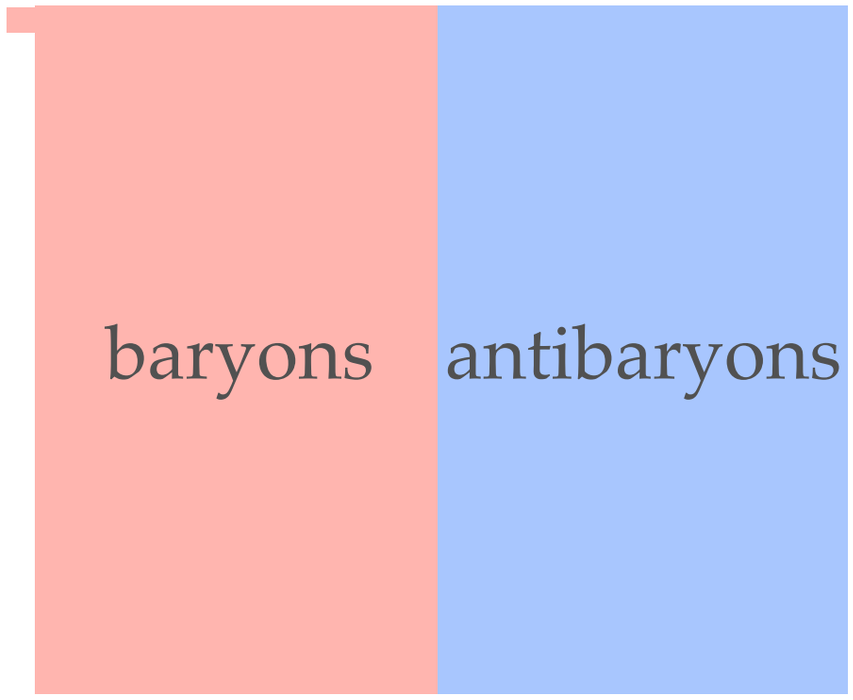
BELLE2-NOTE-PL-2020-029

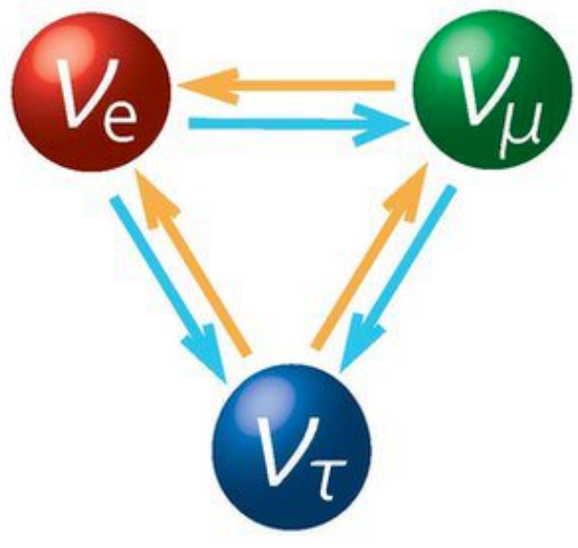
Brian Shuve

FPCP 2022

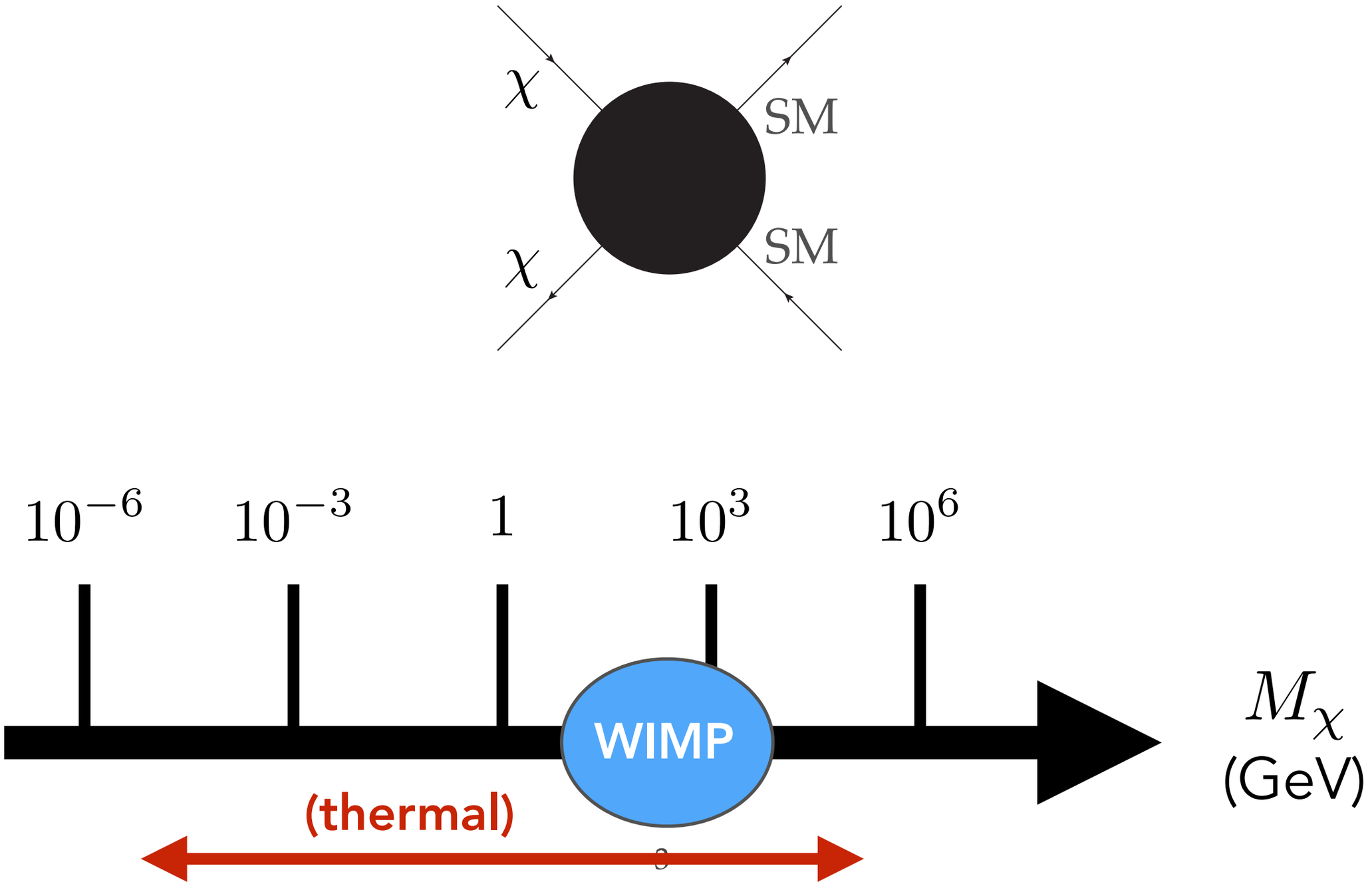
HARVEY MUDD COLLEGE

WHY HIDDEN SECTORS?

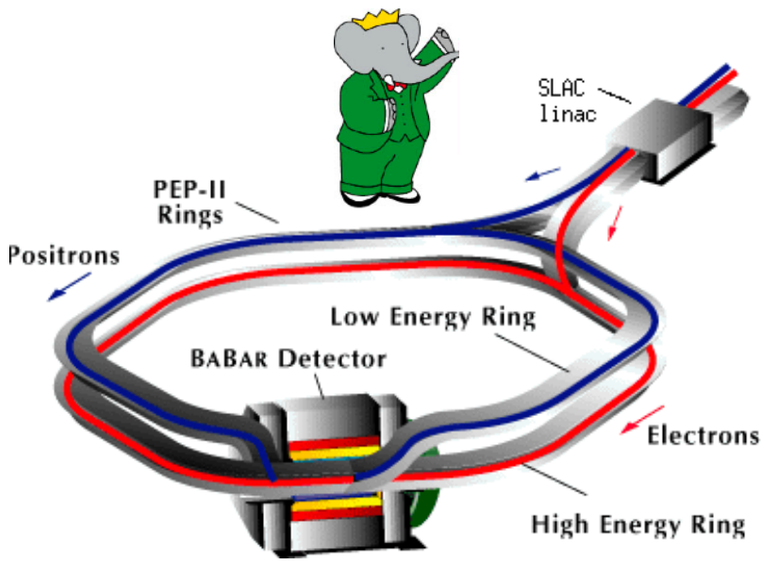


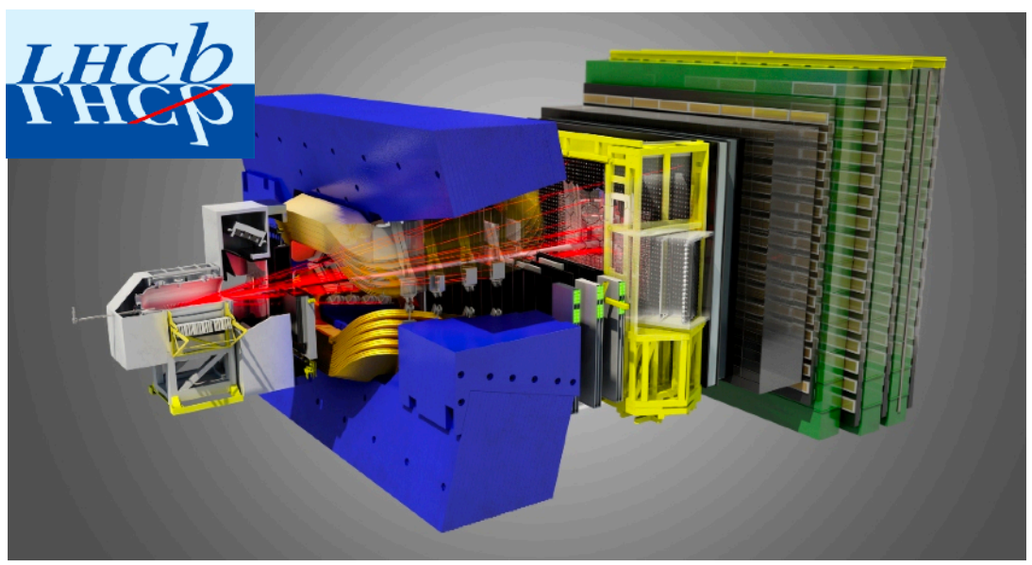


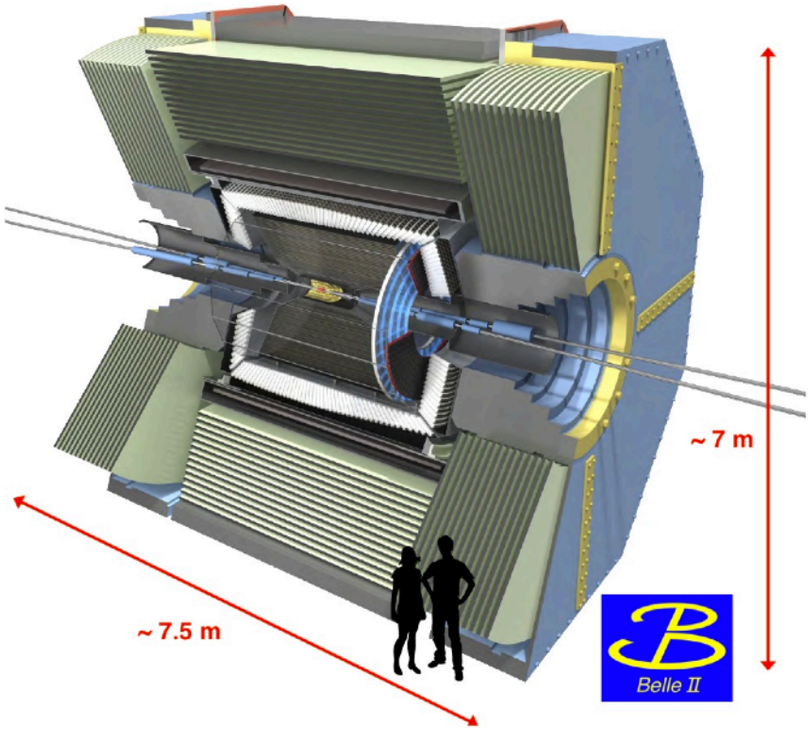
EXAMPLE: THERMAL DM

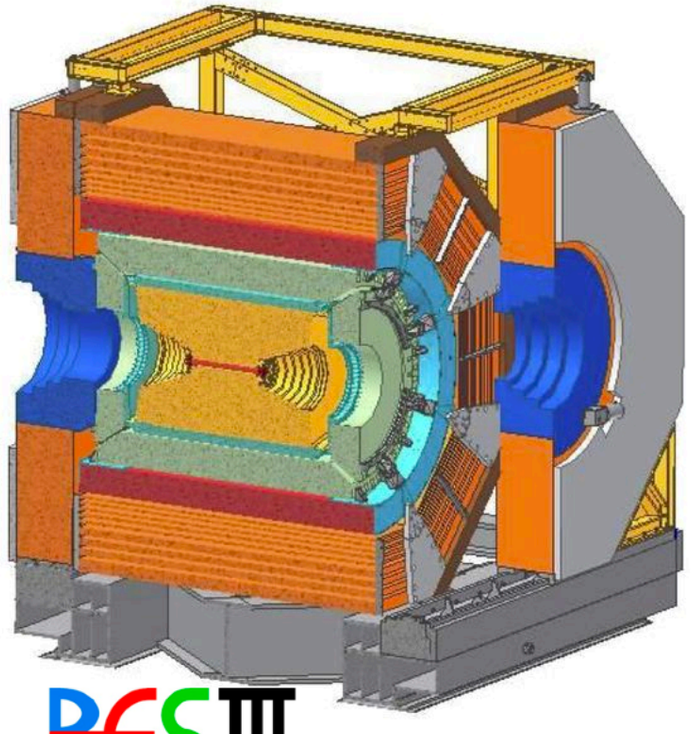


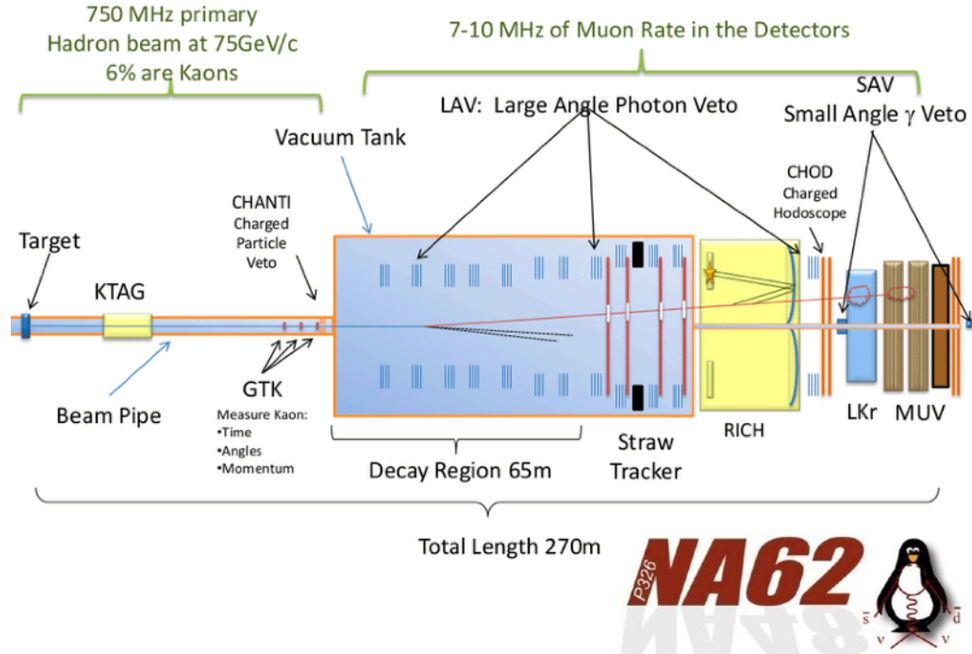
FLAVOR EXPERIMENTS ARE PROMISING!





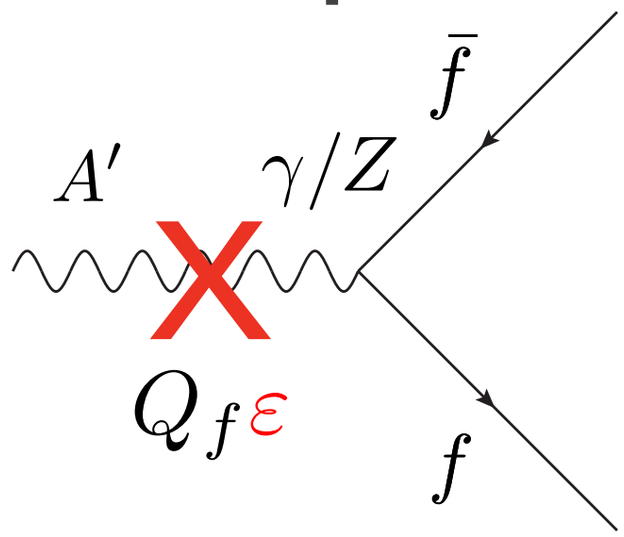




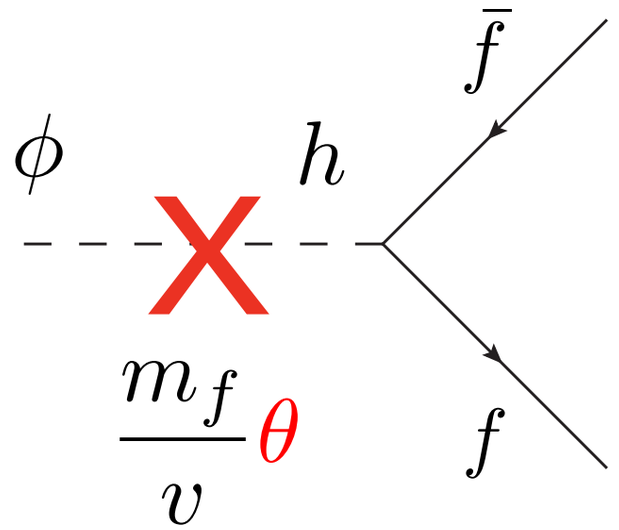


SIMPLEST CASE: PORTALS

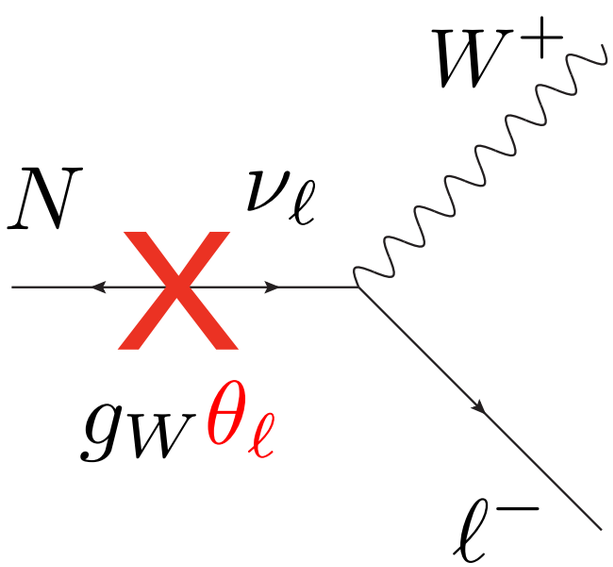
Vector portal



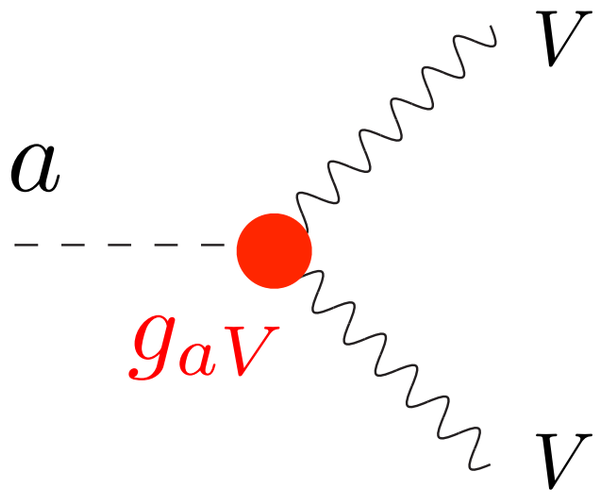
Scalar portal



Neutrino portal

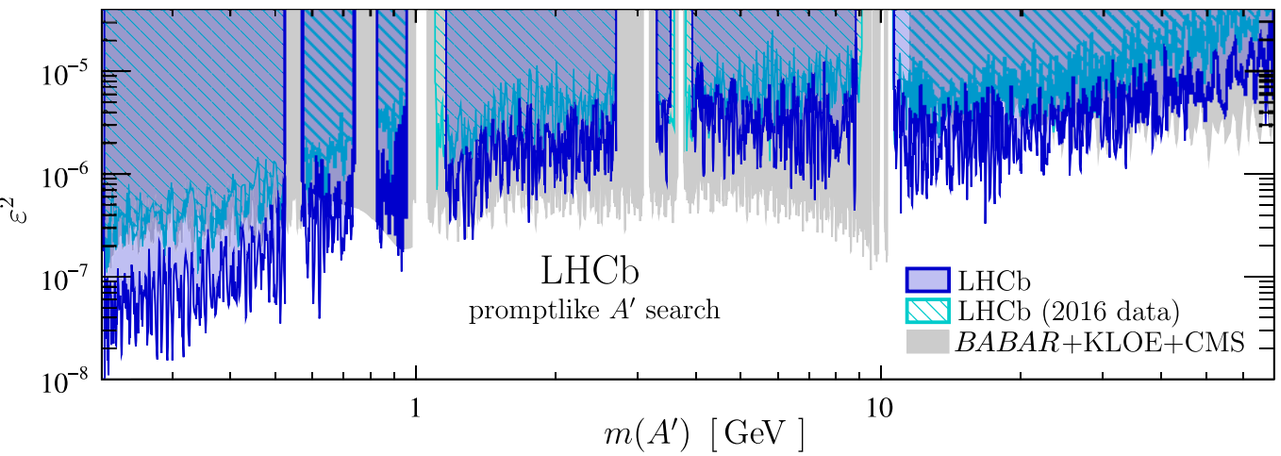


Axion portal

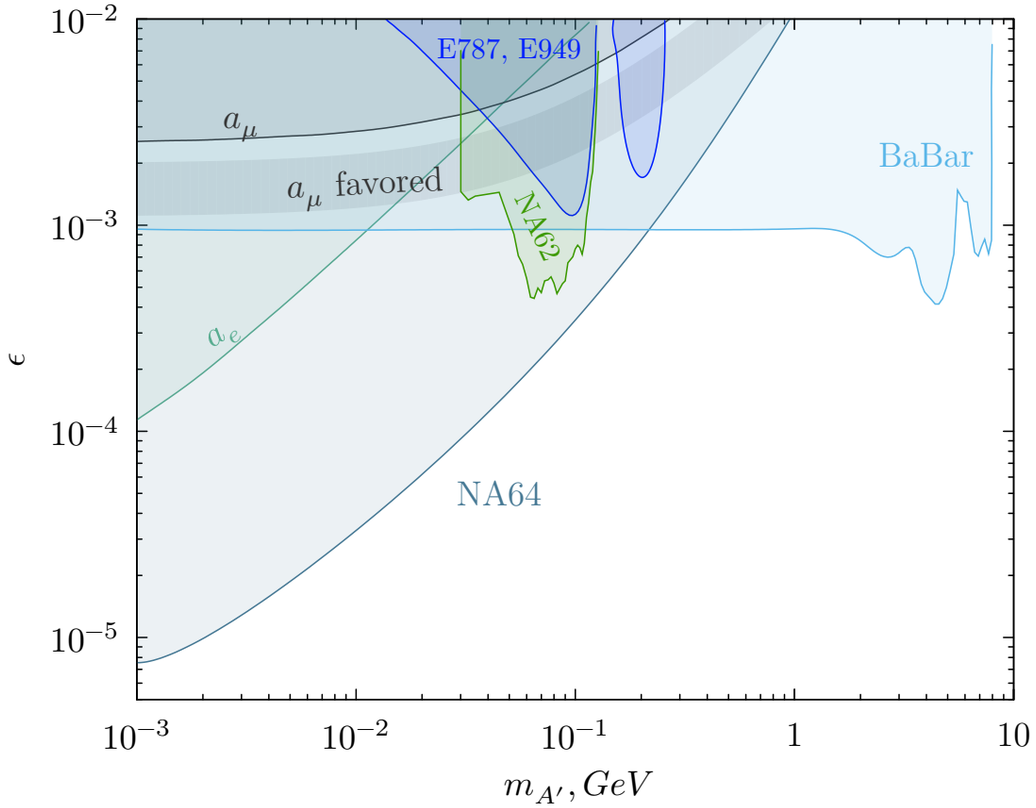


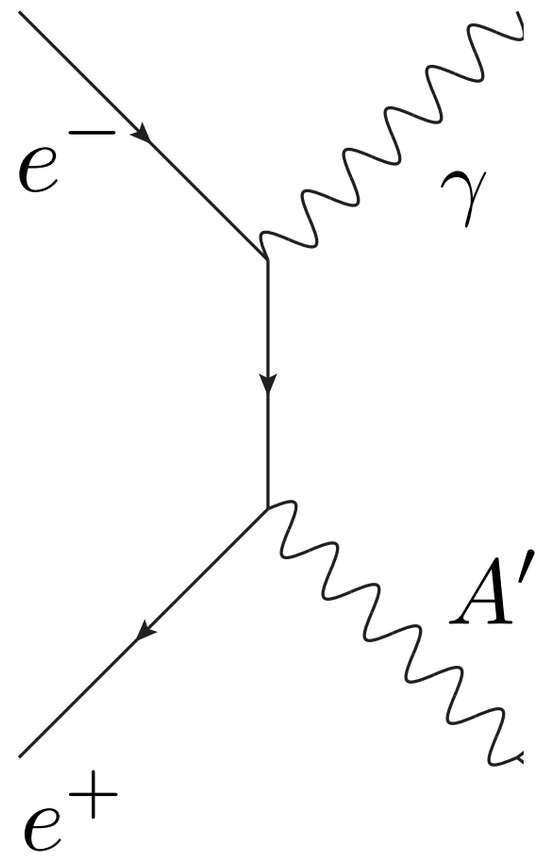
VECTOR PORTAL

$A' \to \ell^+\ell^-$ LHCb, 1910.06926 [PRL]



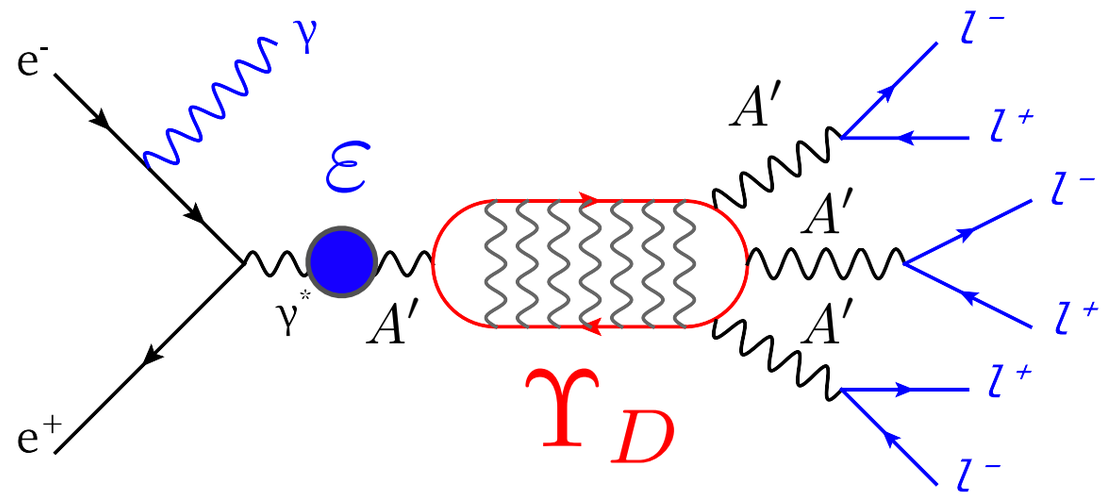
$A' \to$ inv NA64, 1906.00176 [PRL]

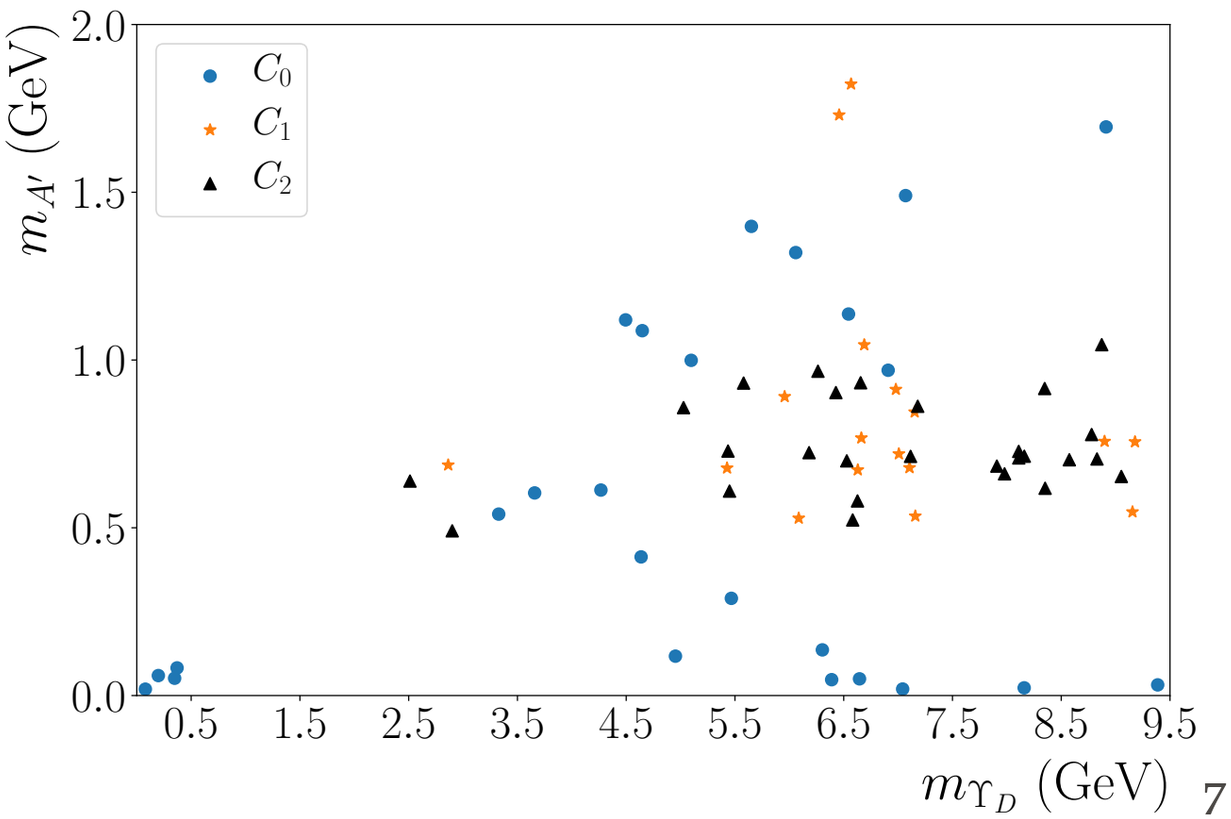


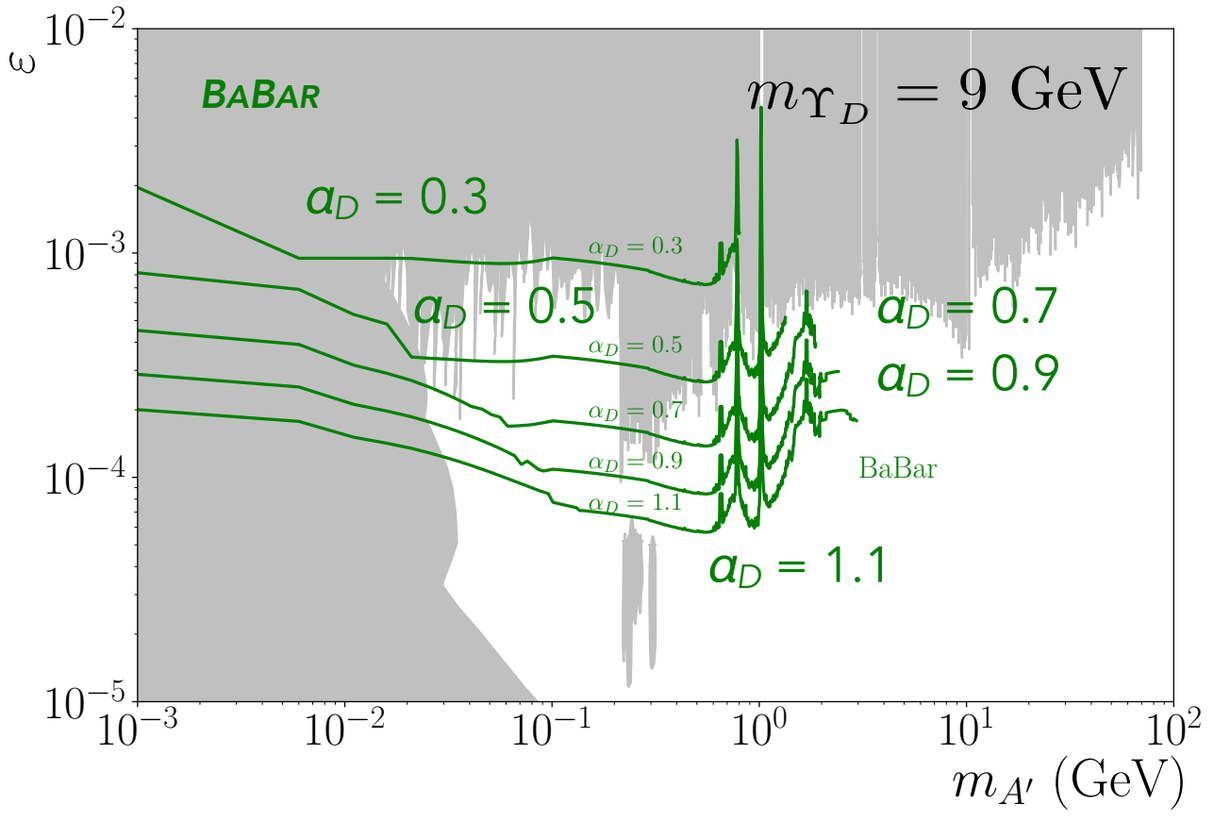


VECTOR PORTAL + DM

- For sufficiently large coupling in the hidden sector, can form dark matter **bound states!**
- Look for 3 sets of resonances that are close together in mass



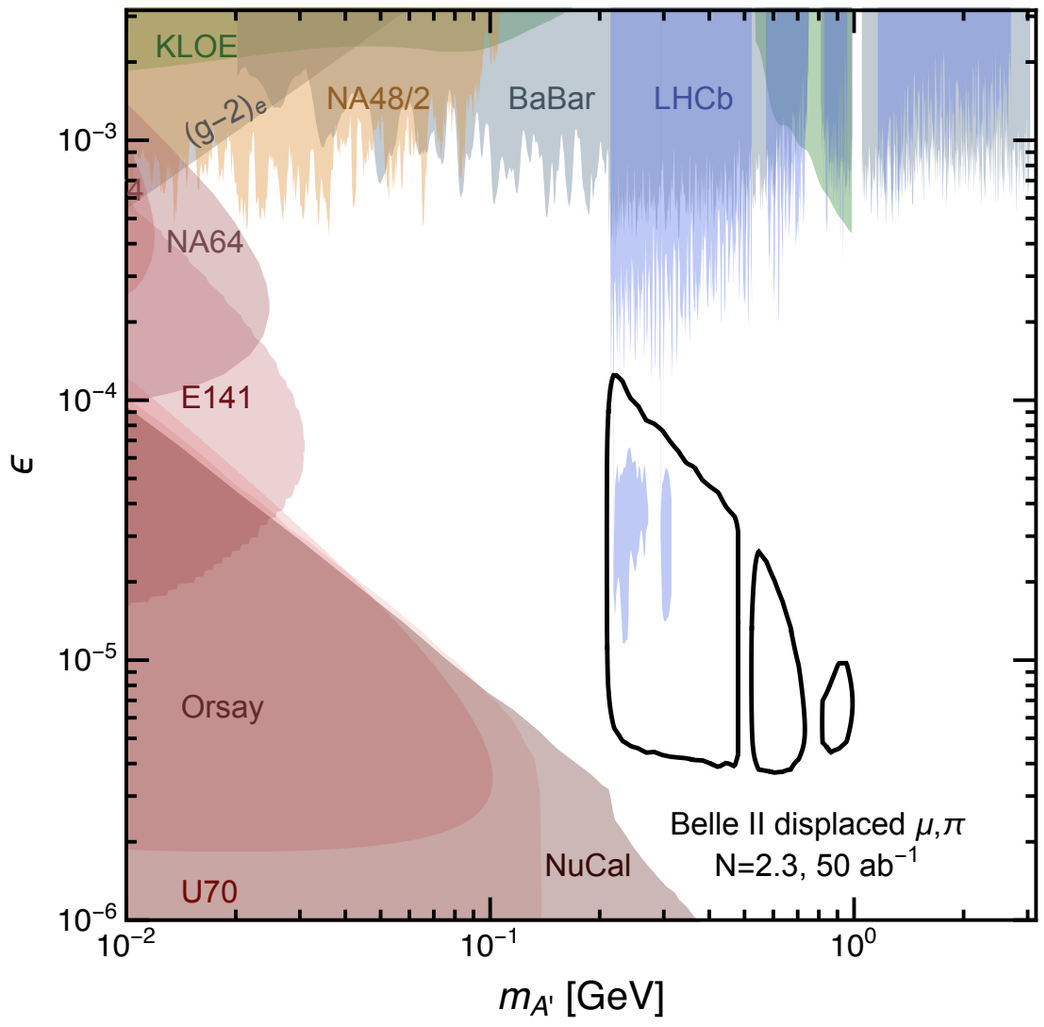


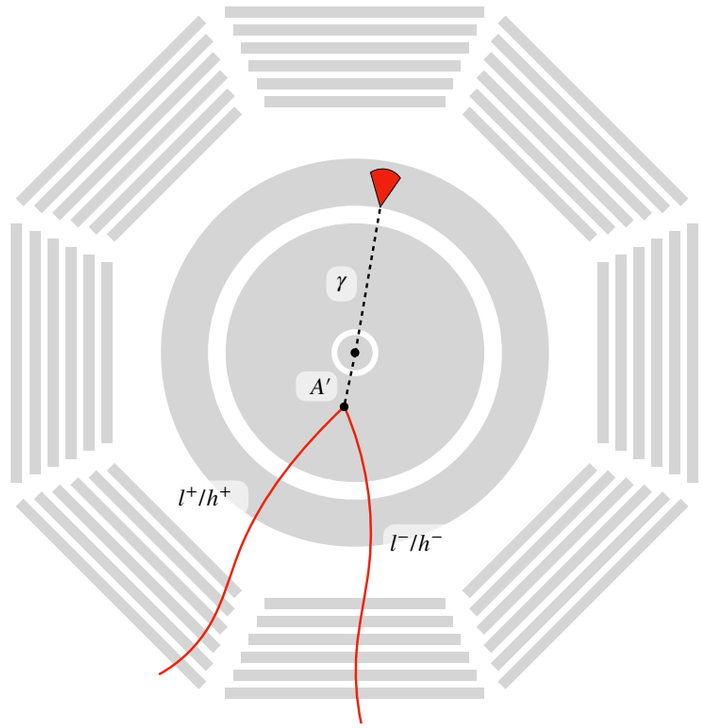


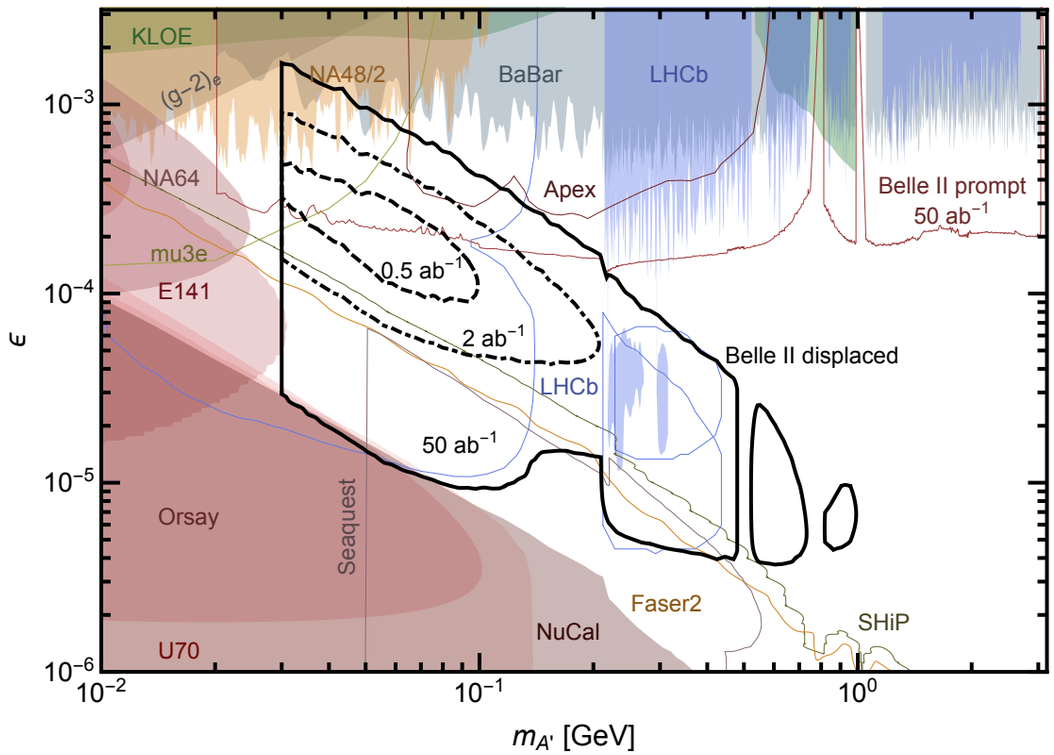
VECTOR PORTAL: PROSPECTS

visible decays: $A' \to \ell^+\ell^-$

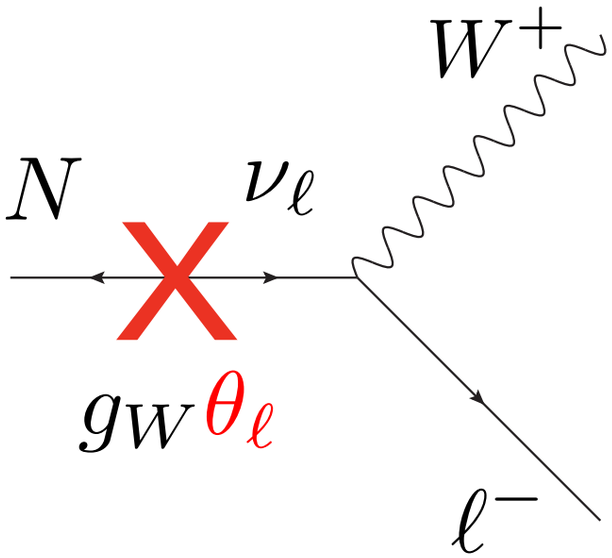
T. Ferber *et al.*, 2202.03452

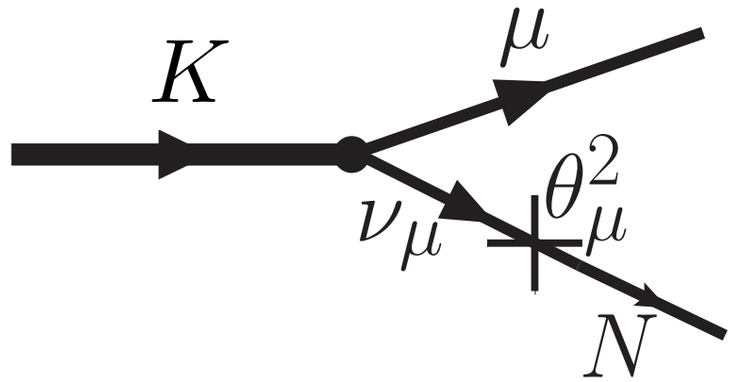






NEUTRINO PORTAL





- Motivated by SM neutrino masses via seesaw mechanism
- Can also explain the matter-antimatter asymmetry!

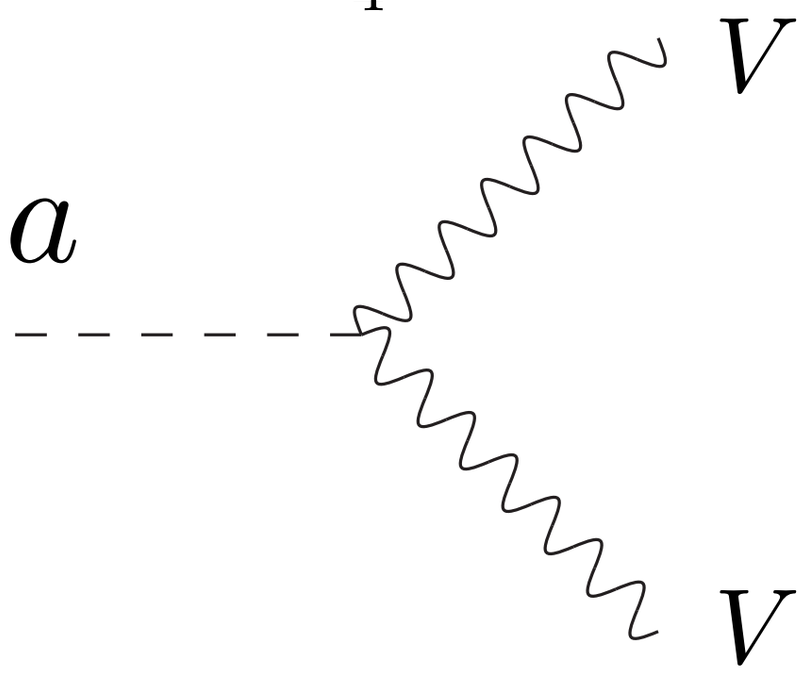
Akhmedov, Rubakov, Smirnov, *PRL* 81 (1998)
Asaka, Shaposhnikov, *PLB* 620 (2005)

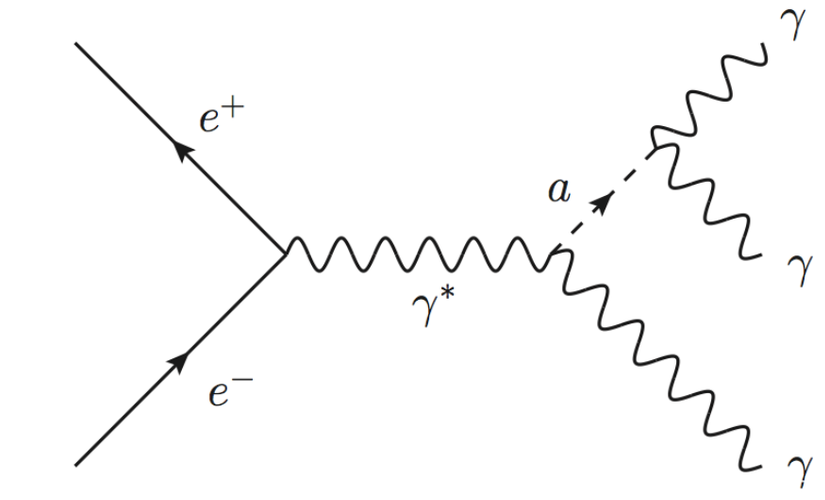
- See yesterday's talk by Sophie Middleton, incl. new BABAR result!

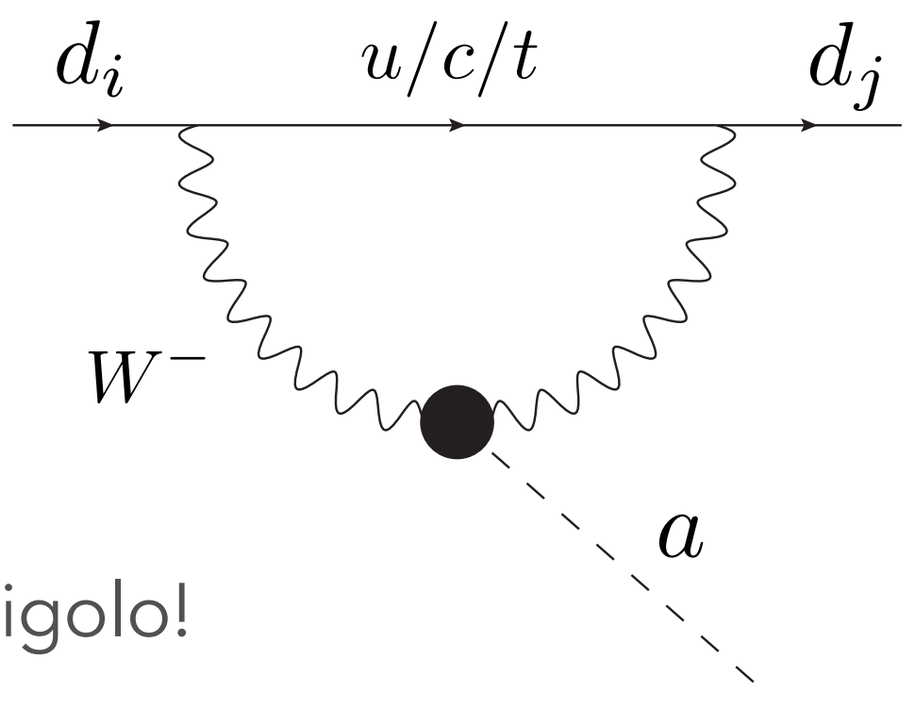
AXION PORTAL

- Axionlike particles are naturally light & feebly interacting, well-motivated in UV models and great hidden sector mediators!

$$\mathcal{L} = c_{aV}\,\frac{a}{4} V_{\mu\nu}\tilde{V}^{\mu\nu}$$





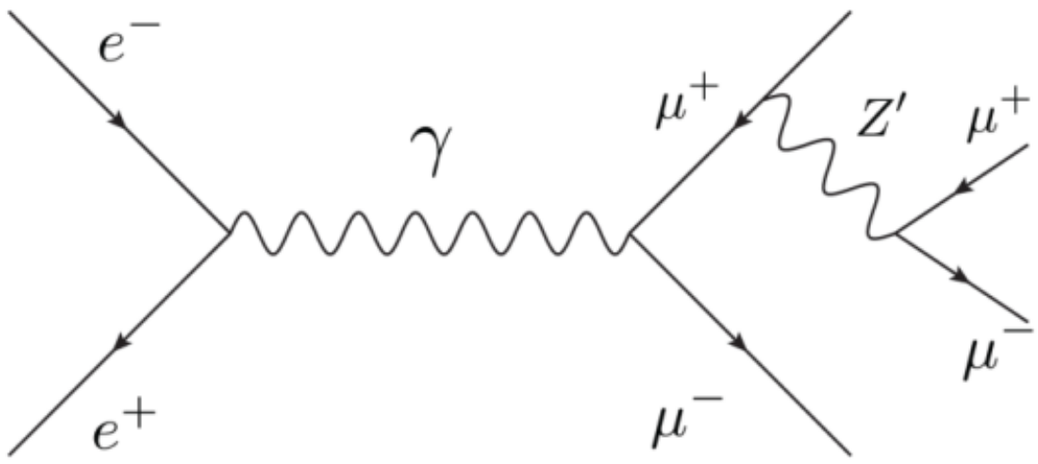


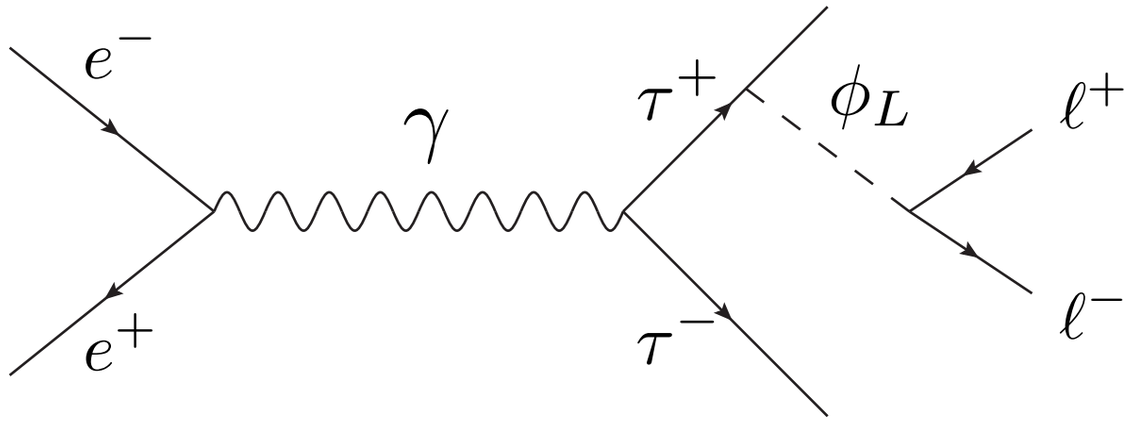
- See this morning's talk by Diego Redigolo!

He *et* al., 1991 [PRD]; Batell *et* al., 1103.0721 [PRL]; Batell *et al.*, 1606.04943 [PRD]; Chen *et al.*, 1511.04715 [PRD]

NON-MINIMAL COUPLINGS

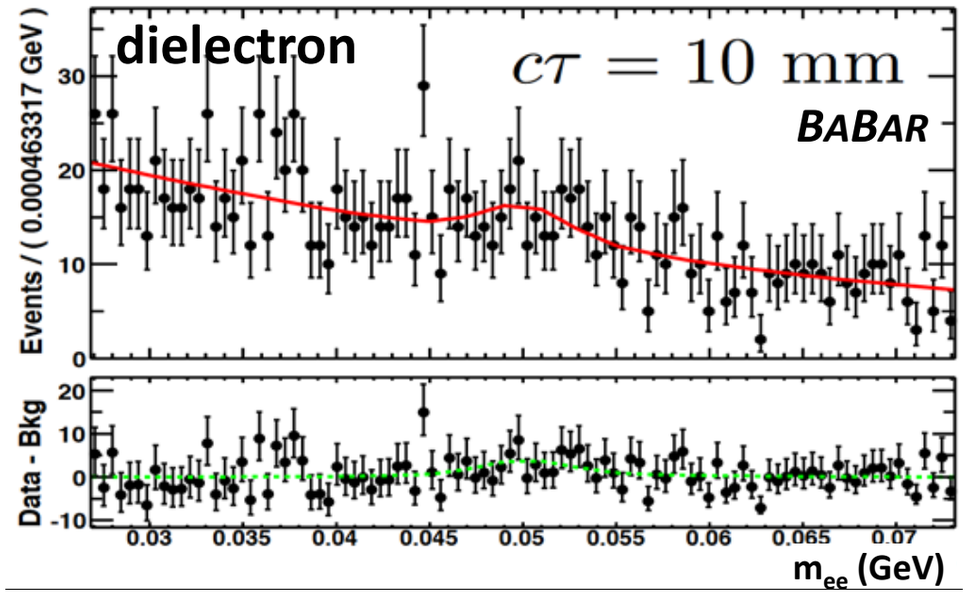
- Most hidden-sector explanations for *g*-2 anomaly are **ruled out** unless couplings to quarks and electrons are suppressed
- However, viable models still exist with preferential coupling to heavy flavor leptons!
- Flavor experiments produce huge numbers of heavy-flavor leptons, giving them good sensitivity!

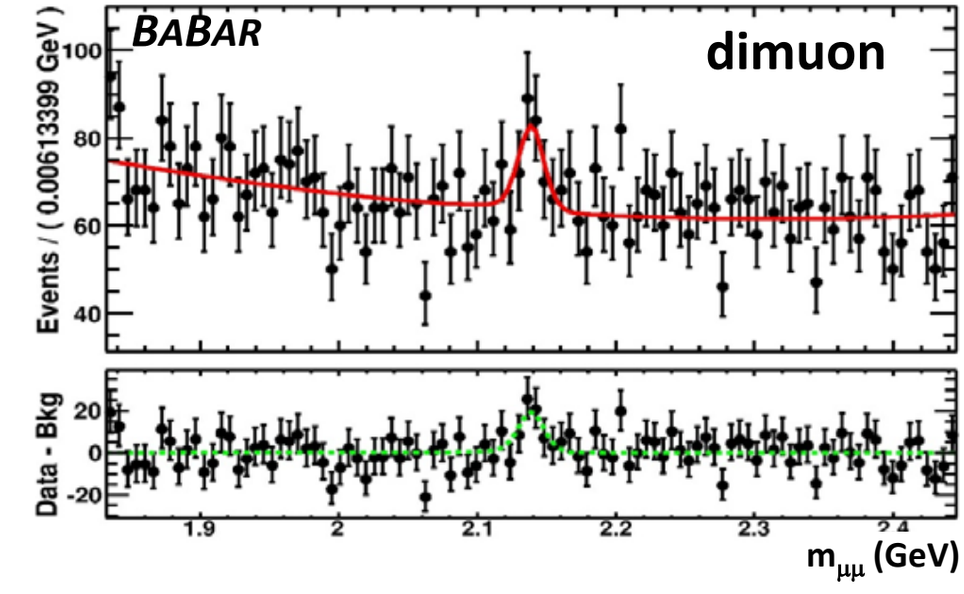


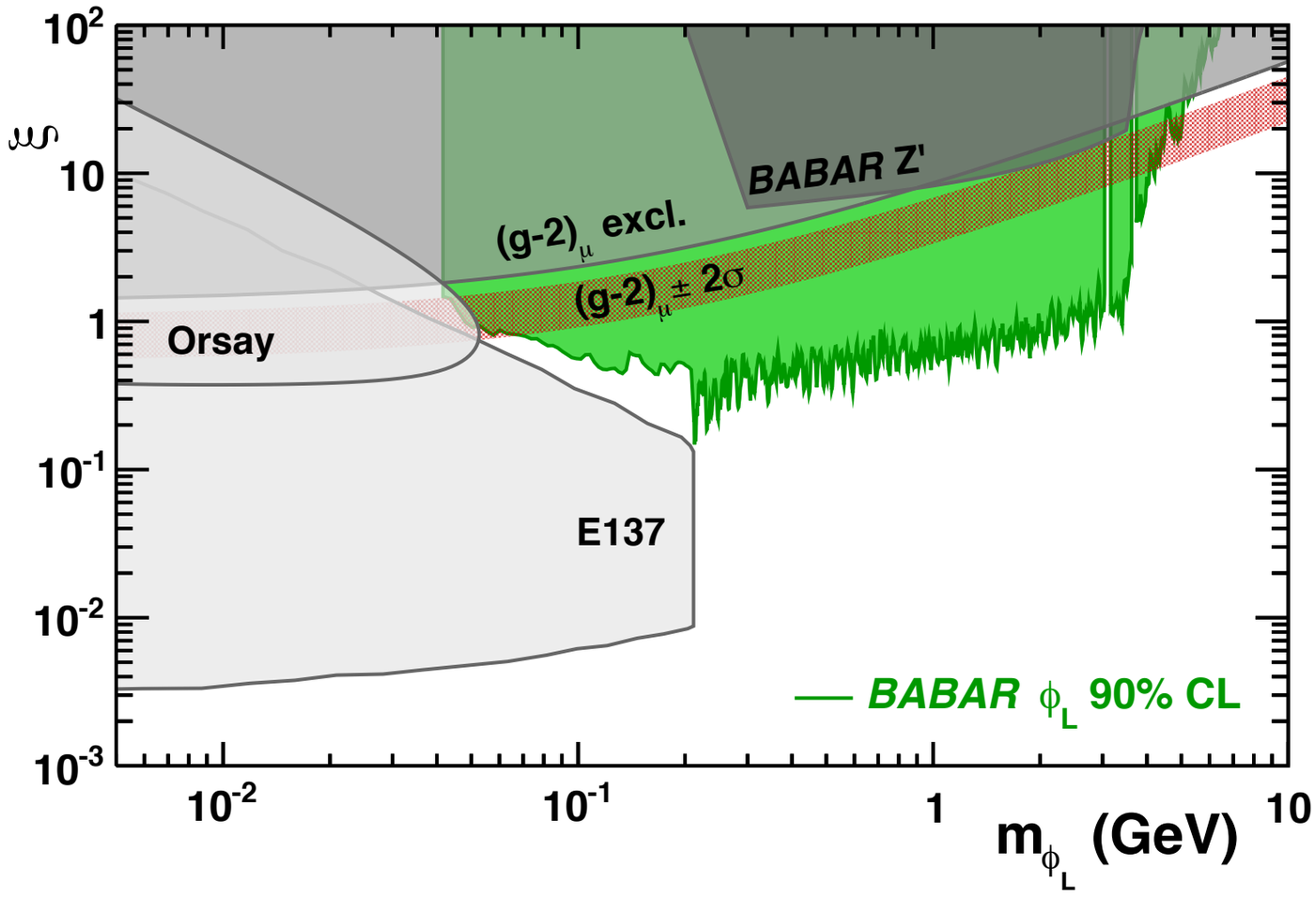


LEPTONIC SCALARS

- Look for a dilepton resonance in association with single-track tau decays





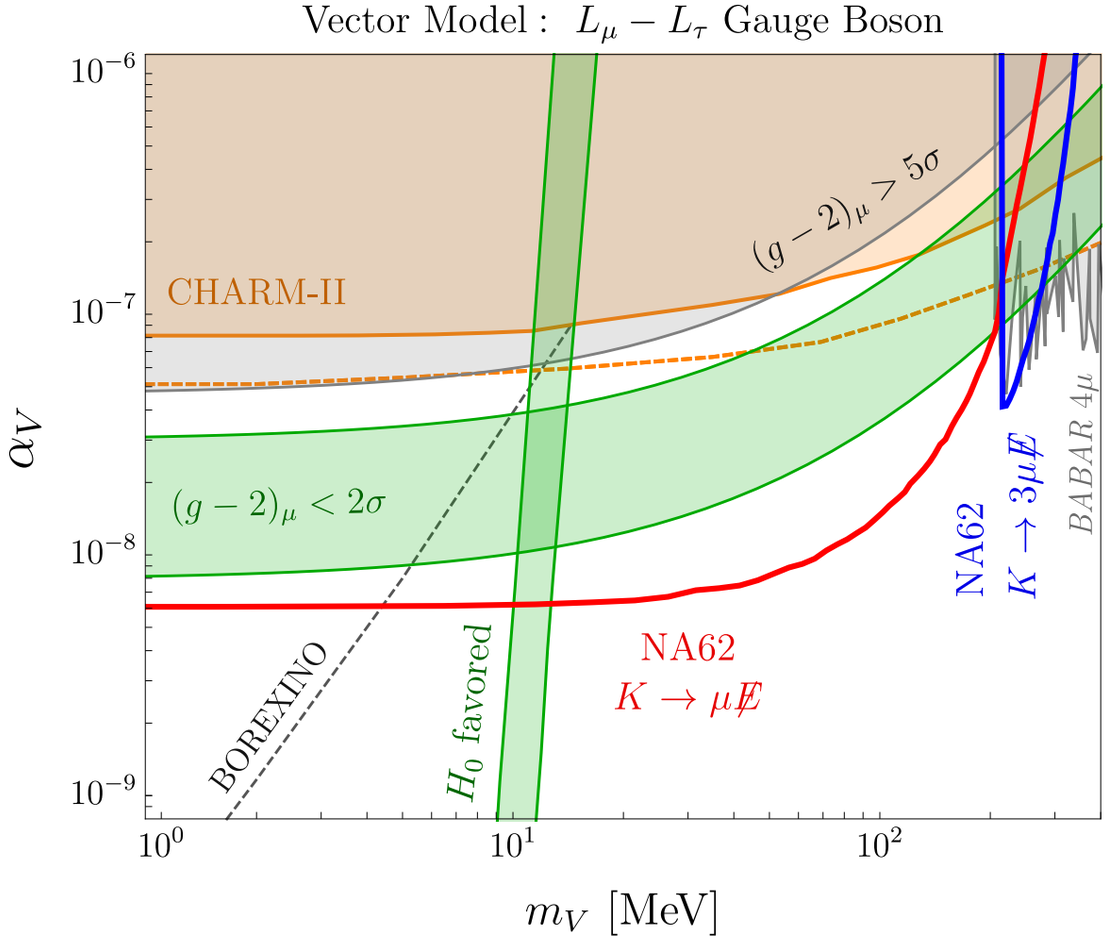


LOW MASS LEPTONIC FORCES

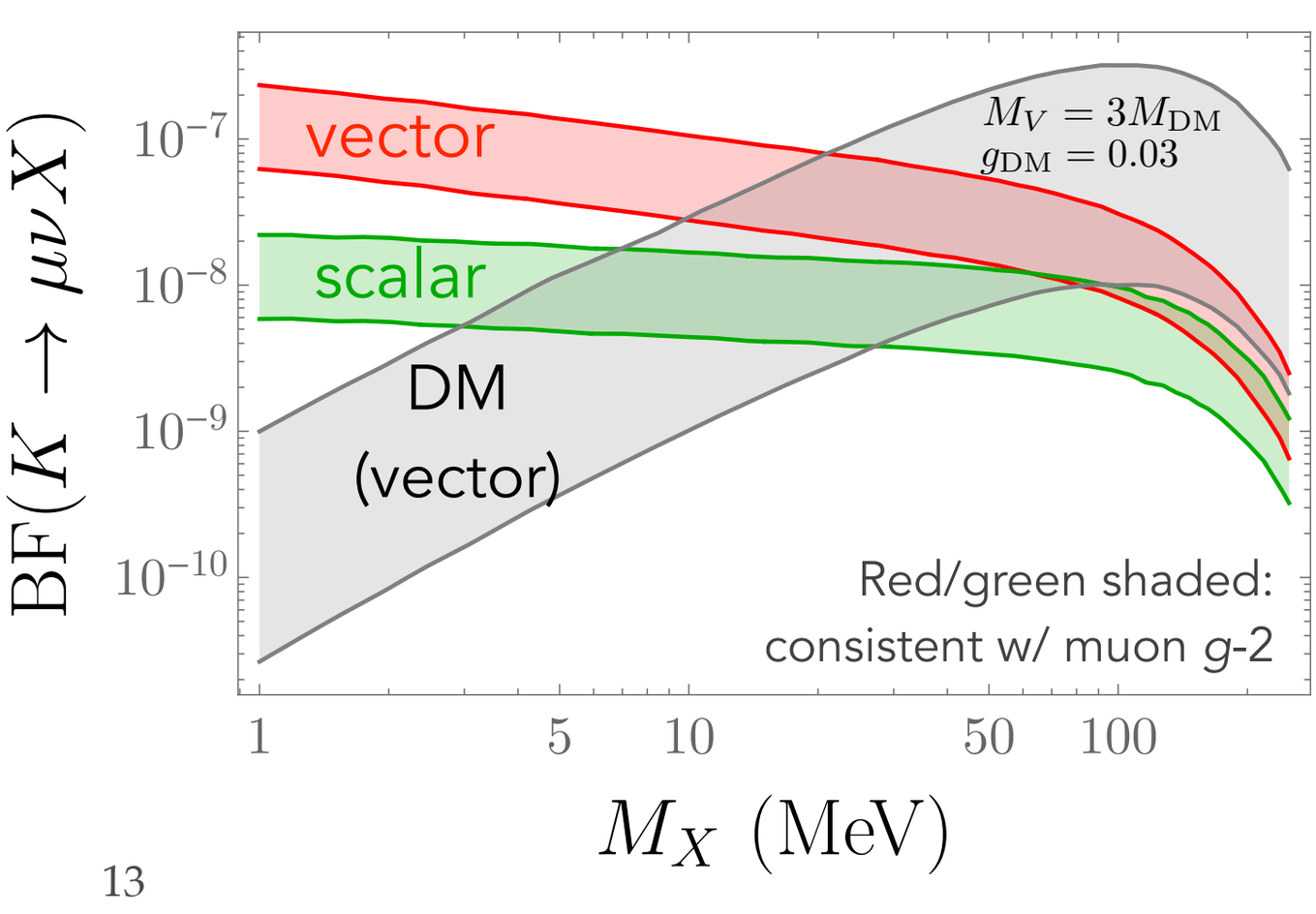
- In general, low mass region near/below dimuon threshold is hard for *B*-factories: kaon factories play an important role!

$$K^{\pm} \to \mu^{\pm} \nu X,\ X \to \mu^+\mu^-, e^+e^-, \gamma\gamma, \text{inv.}$$

Krnjaic *et al.*, 1902.07715 [PRL]



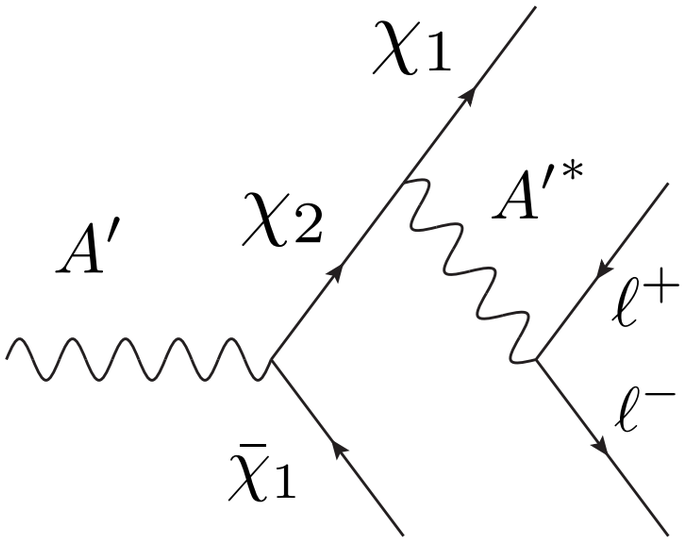
Goudzovski *et al.*, 2201.07805



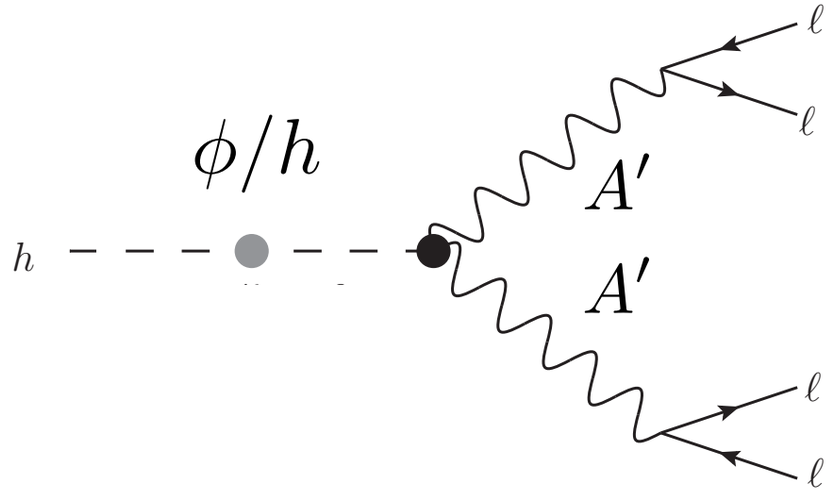
MULTI-PARTICLE SECTORS

- No one said life would be this simple!
- *More is different* - highly optimized searches for single-portal couplings would miss more realistic hidden sectors
- Balance search coverage with specificity

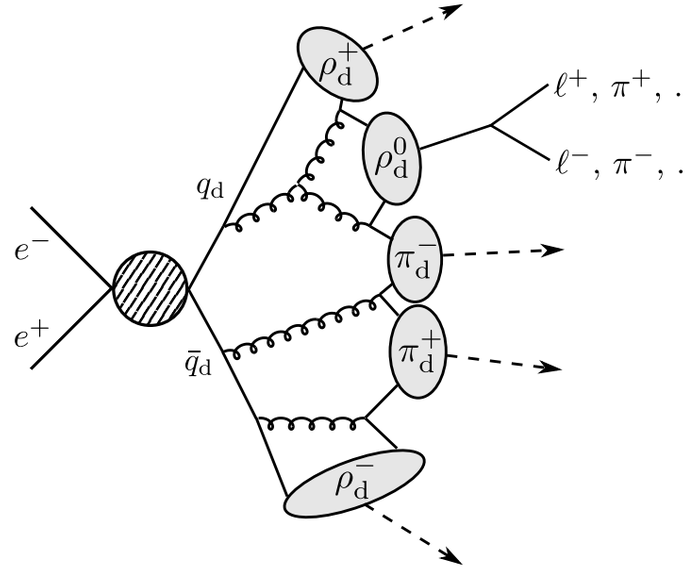
semi-visible



cascade



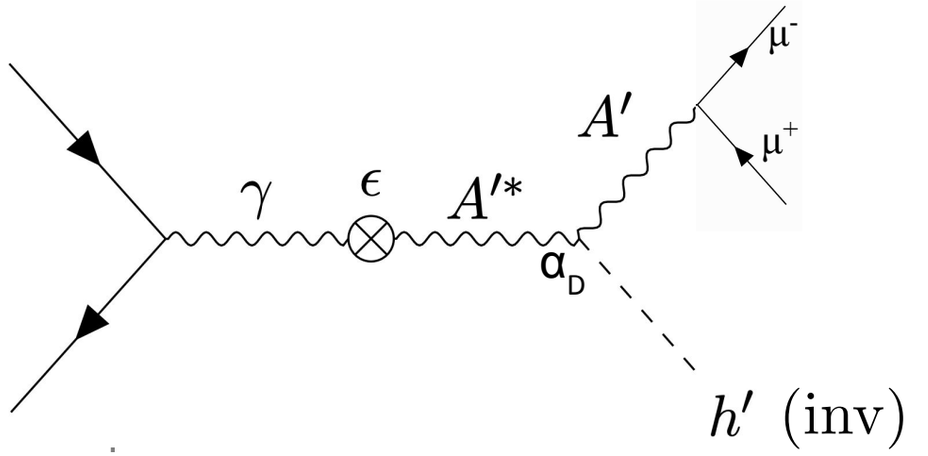
shower



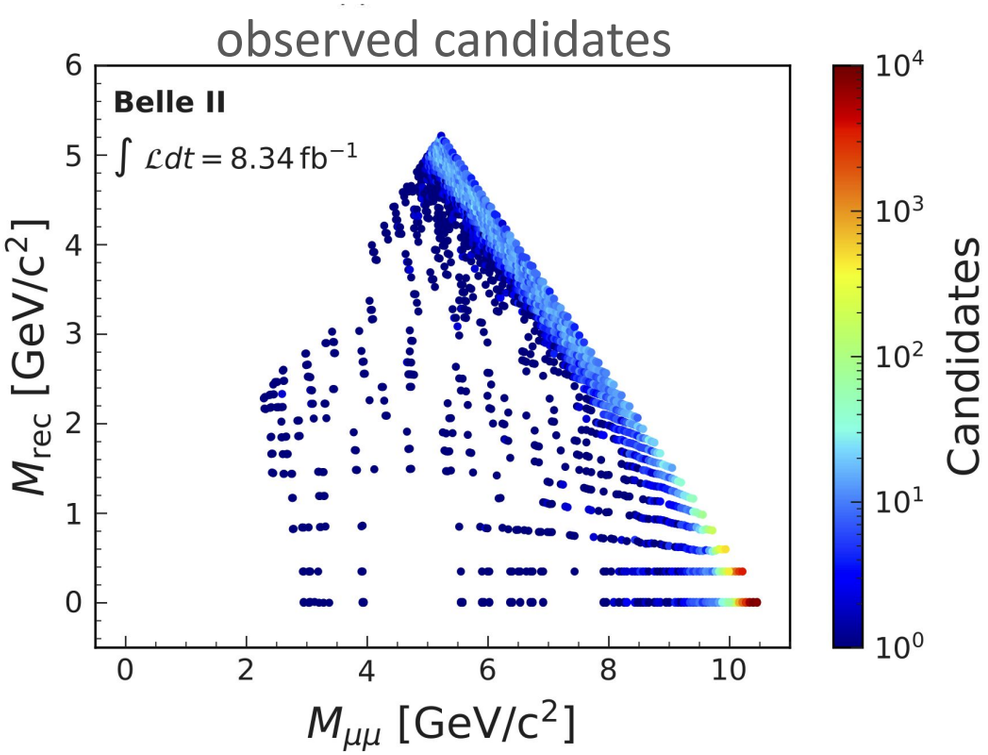
Batell, Pospelov, Ritz, 0903.0363 [PRD]

DARK HIGGSSTRAHLUNG

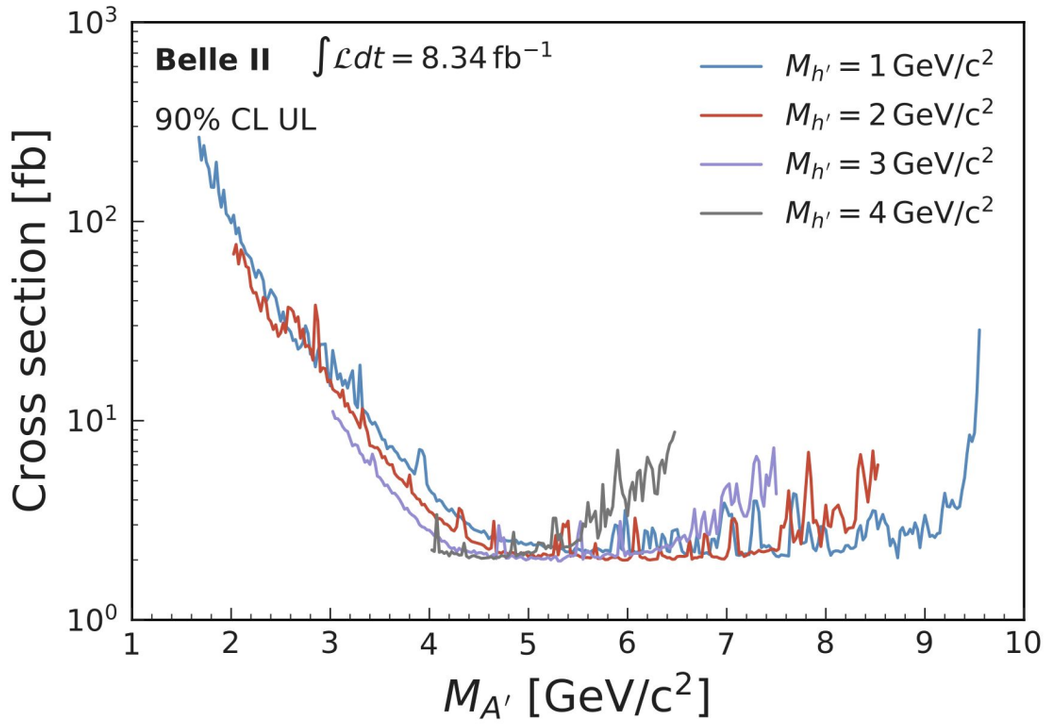
- In dark Higgs-dark photon model, can look for associated production of dark Higgs + dark photon



observed candidates

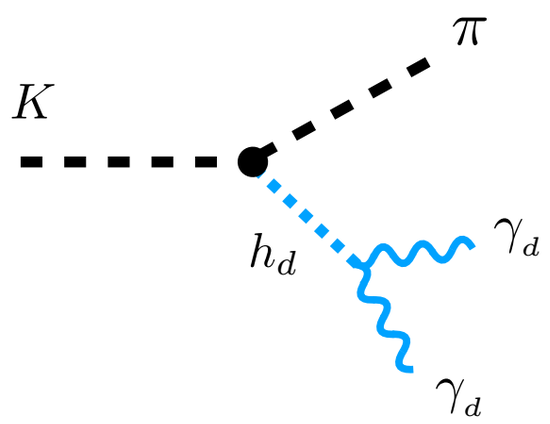


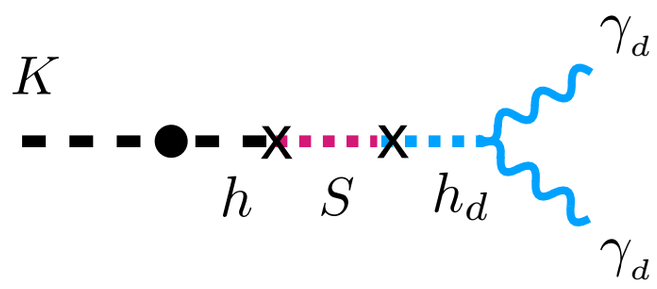
Belle II, Navid Rad talk at Moriond EW '22

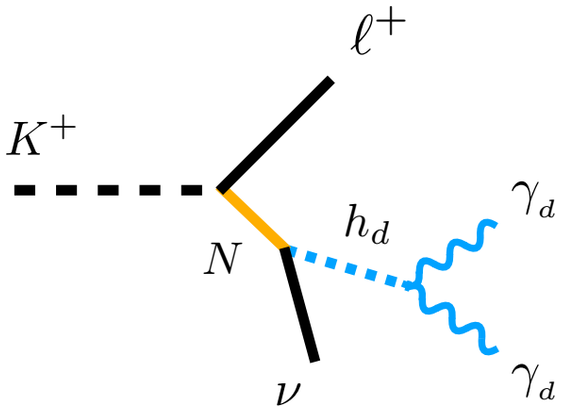


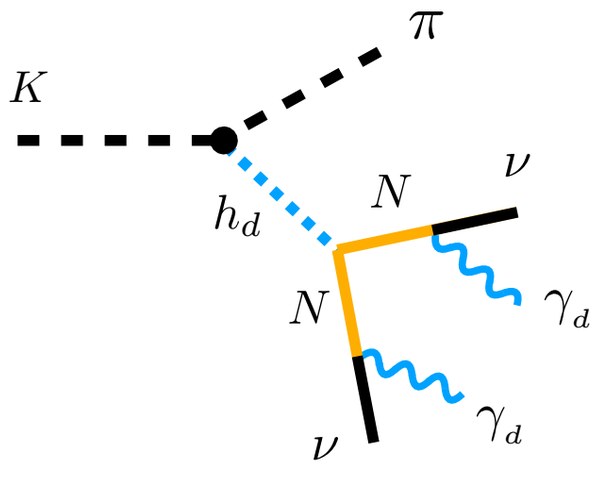
MULTI-LEPTONS IN MESON DECAYS

- Hidden sector models can easily give 2 or more lepton pairs in decays of kaons and pions!



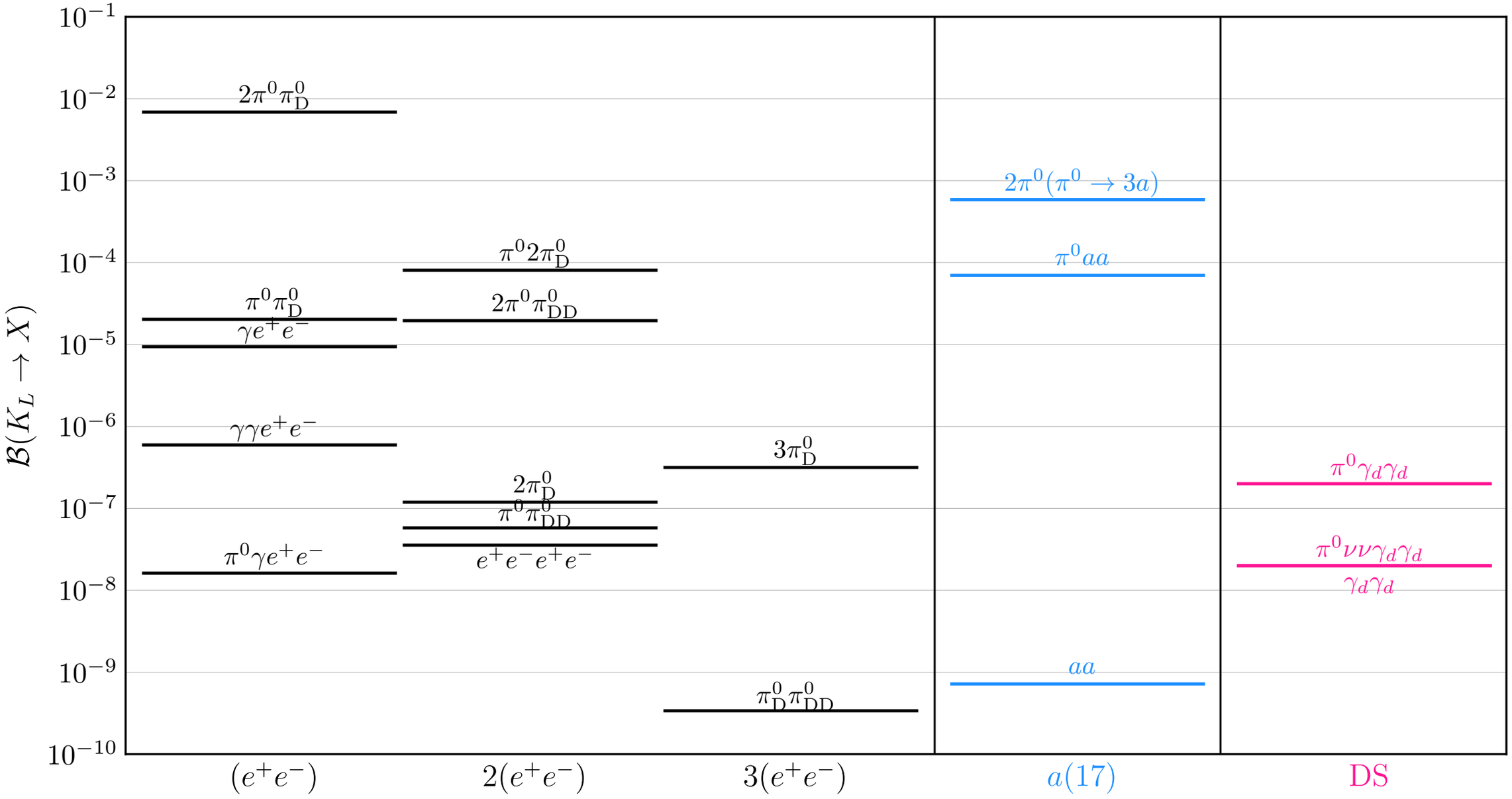






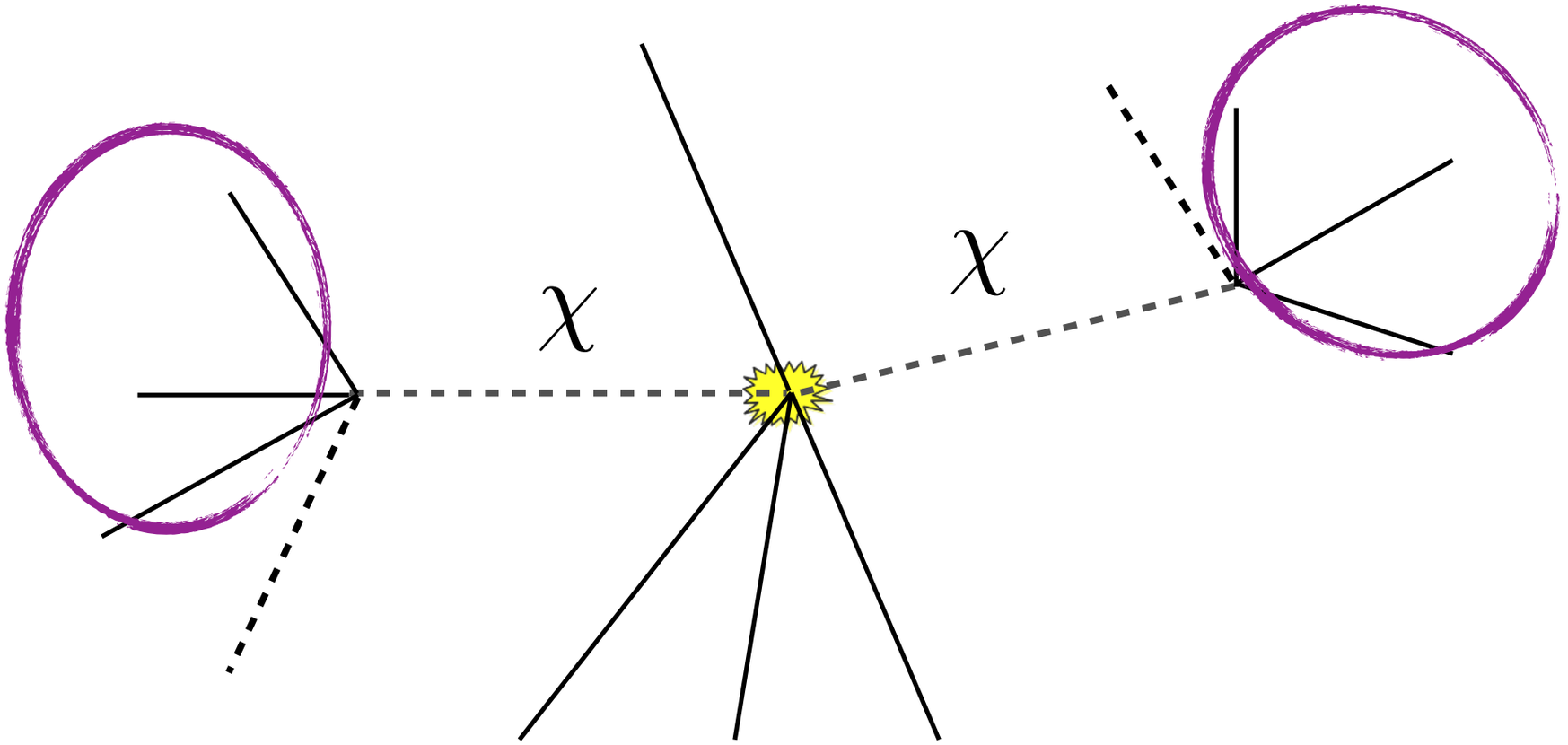
MULTI-LEPTONS IN MESON DECAYS

- Many BSM decay rates can be *above* corresponding SM rates



MORE INCLUSIVE SEARCHES

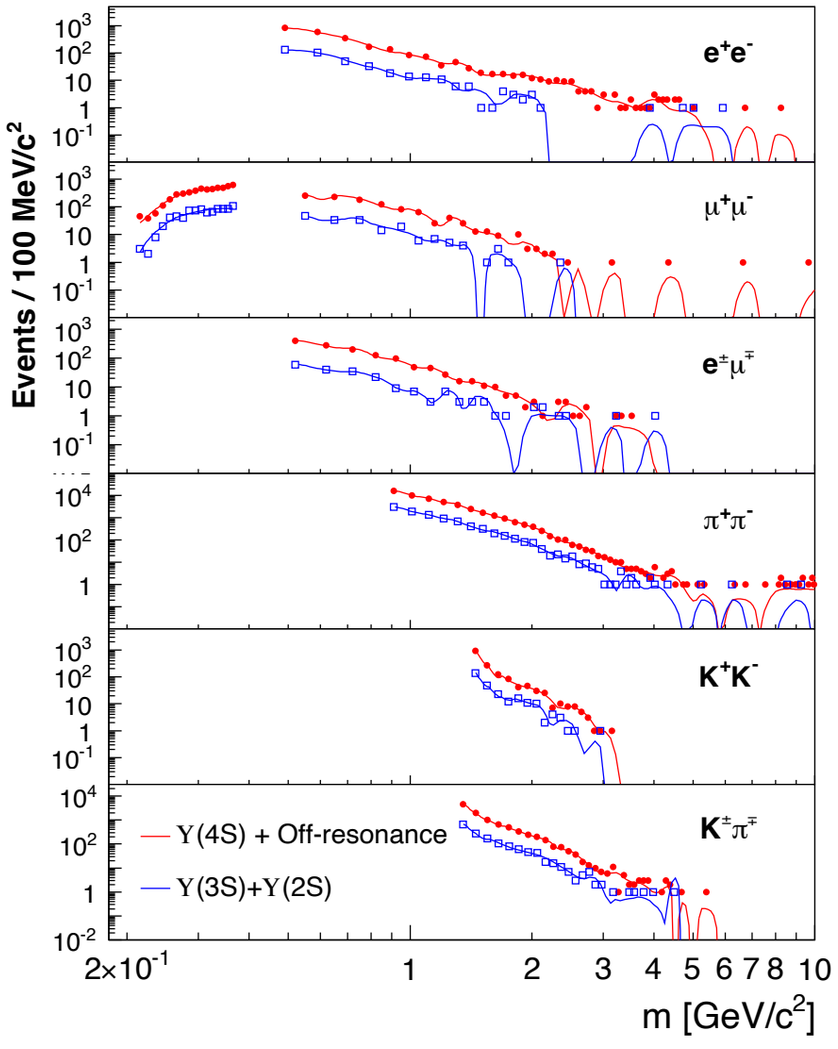
- All of these searches are hyper-targeted for specific production and decay of a new particle
- Can we design something that can cover more general possibilities?



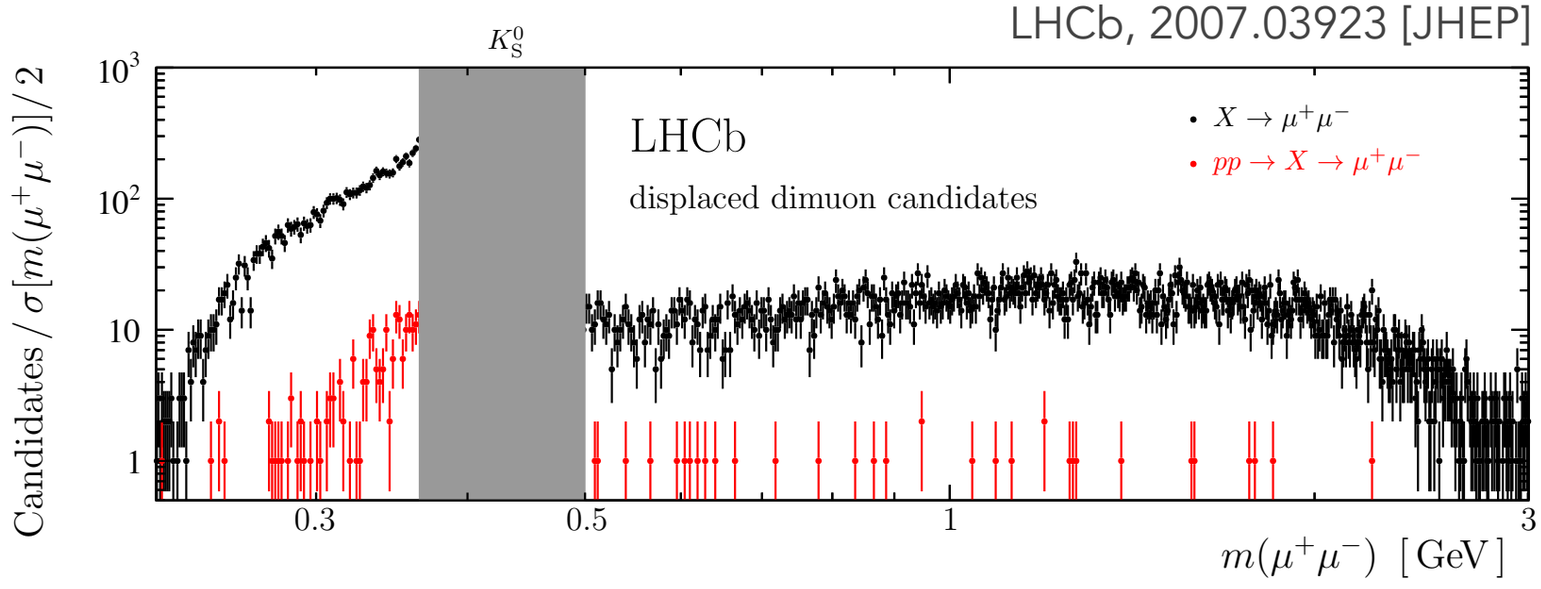
MORE INCLUSIVE SEARCHES

- There are a few searches for 2-body long-lived decays that are inclusive of production, but require reconstruction of a resonance and some final-state combinations are missing $(\ell^{\pm} h^{\mp})$

BABAR, 1502.02580 [PRL]



LHCb, 2007.03923 [JHEP]



- Proposal for similar search at Belle II to cover dark shower model

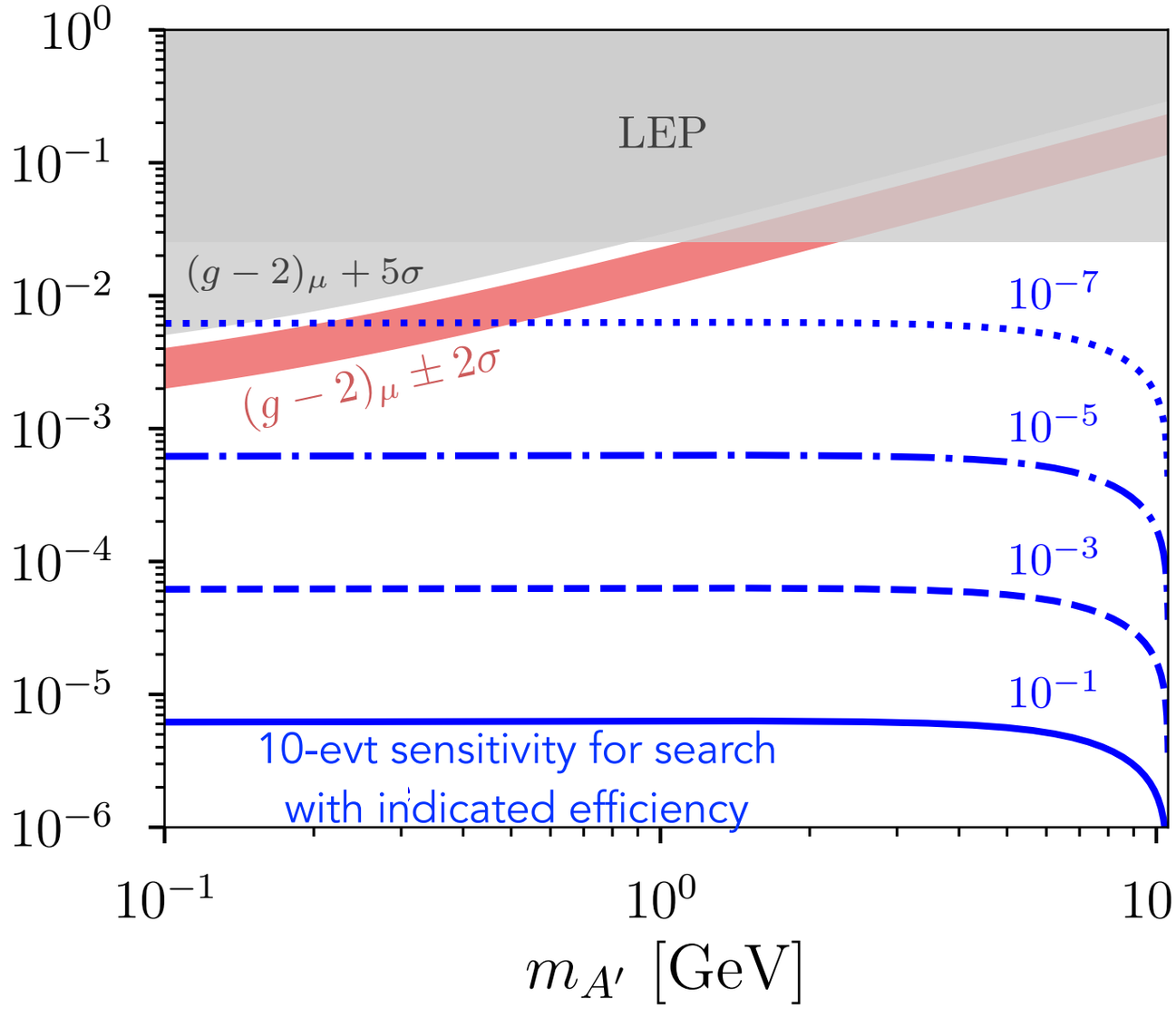
Bernreuther *et al.*, 2203.08824

MORE INCLUSIVE SEARCHES

- What could we be missing? Consider simple model of dark photon decaying into long-lived particles, $A' \to \bar{\chi}\chi$

- If we take away all **model-dependent** searches that rely on exclusive χ decay modes, lots of open parameters!

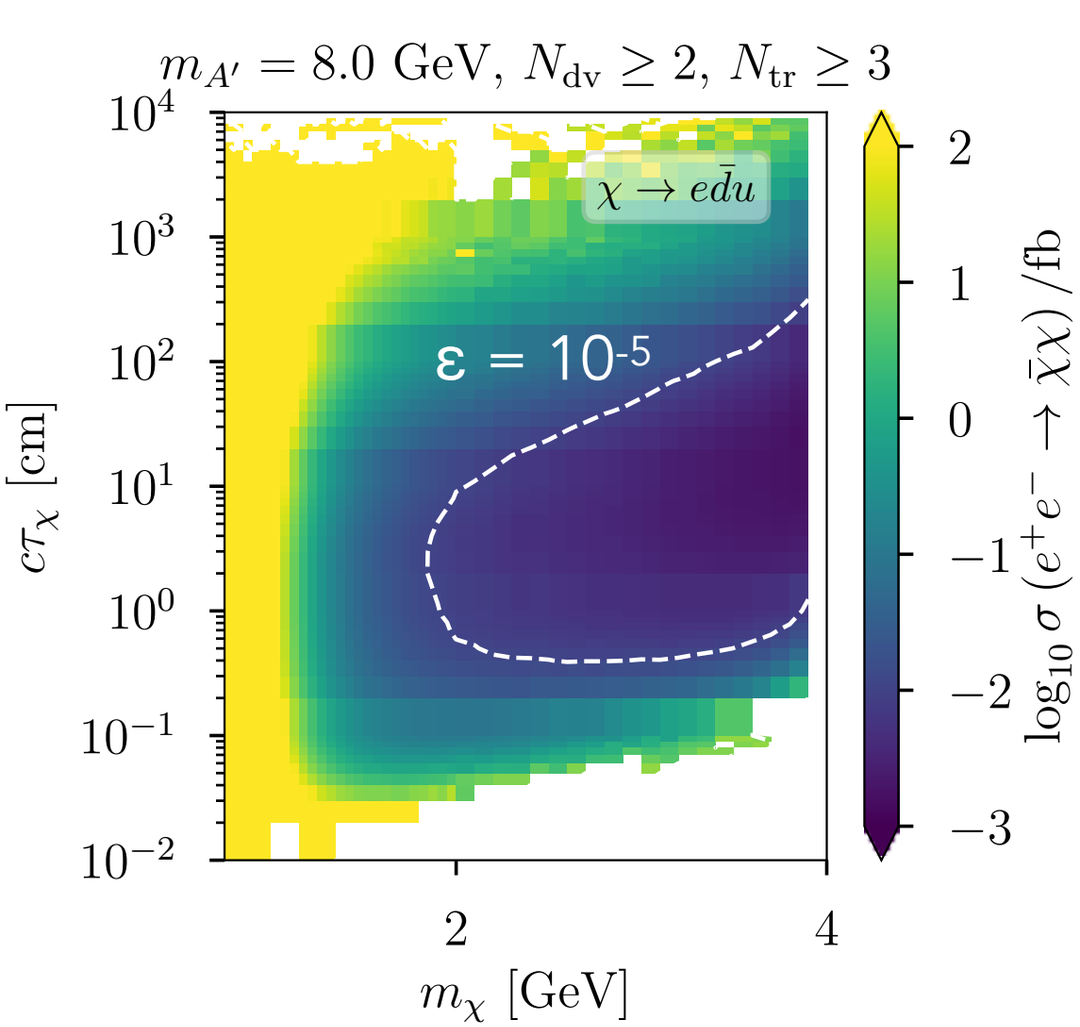
- Consider Belle II, 50/ab reach



M. Acevedo, A. Blackburn, N. Blinov, B. Shuve, M. Stone, 2105.12744 [JHEP]

MORE INCLUSIVE SEARCHES

- Requiring at least 2 displaced vertices with 3 or more tracks can almost completely eliminate background *without* exclusive reconstruction of final state decay
- Studied range of production modes, and decays (classified by EFT)

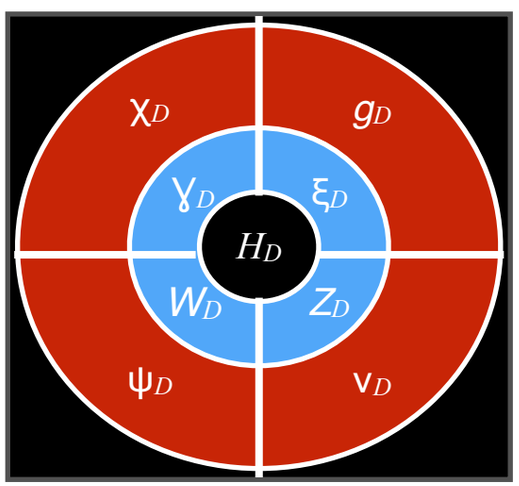


$$A' \to \bar{\chi}\chi, \chi \to e\bar{d}u$$

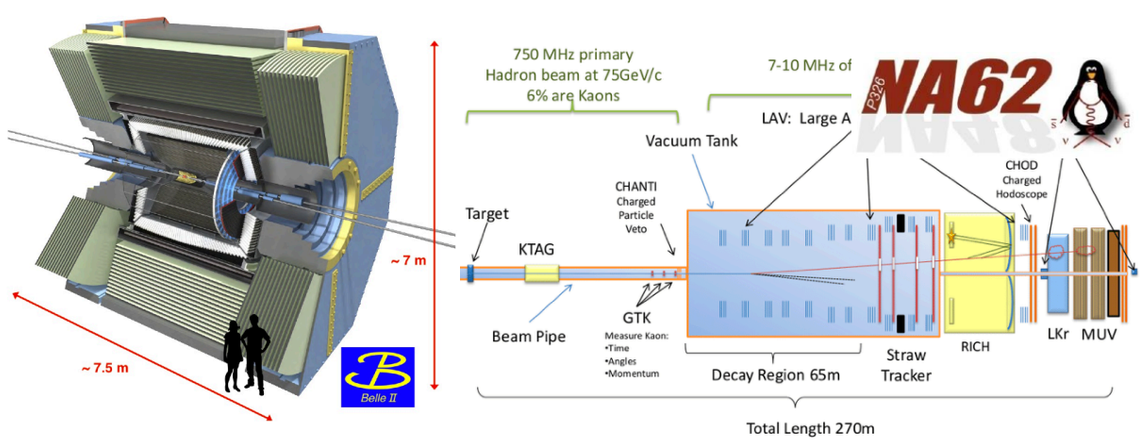
$$10 \text{ evt}, 50 \text{ ab}^{-1} \text{ at Belle II}$$

- Cover wide range of scenarios (including with invisible final states) with a single search!

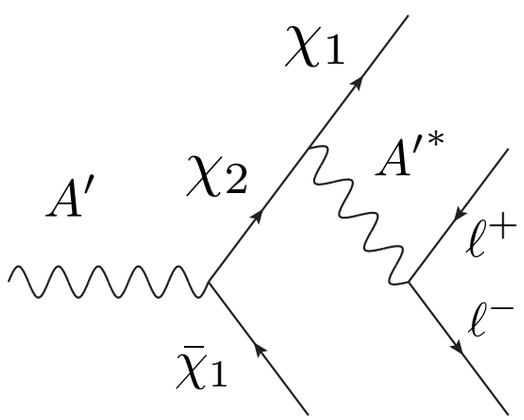
Hidden sectors among the best motivation for new (low-mass) physics



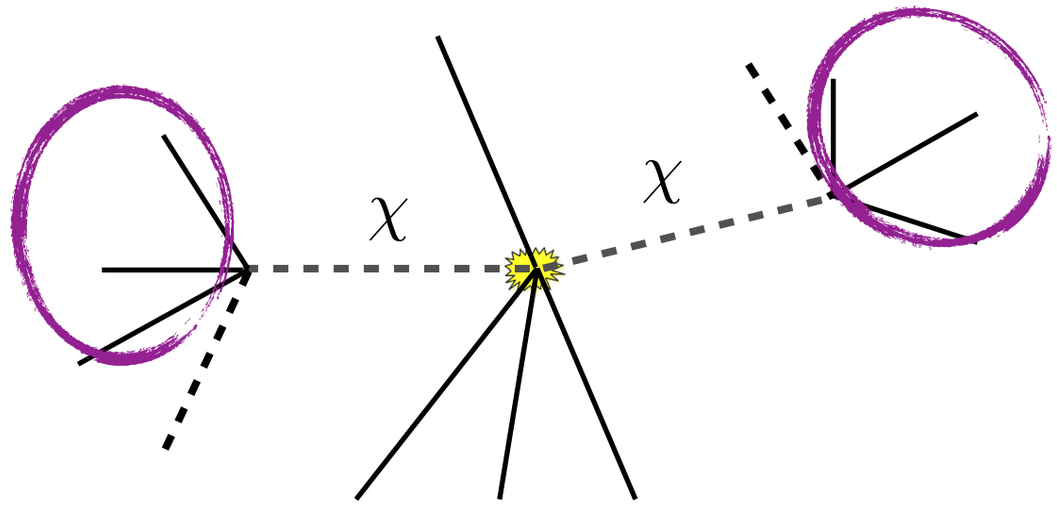
Flavor experiments ideal for hidden sector searches



Many interesting signals un(der)explored



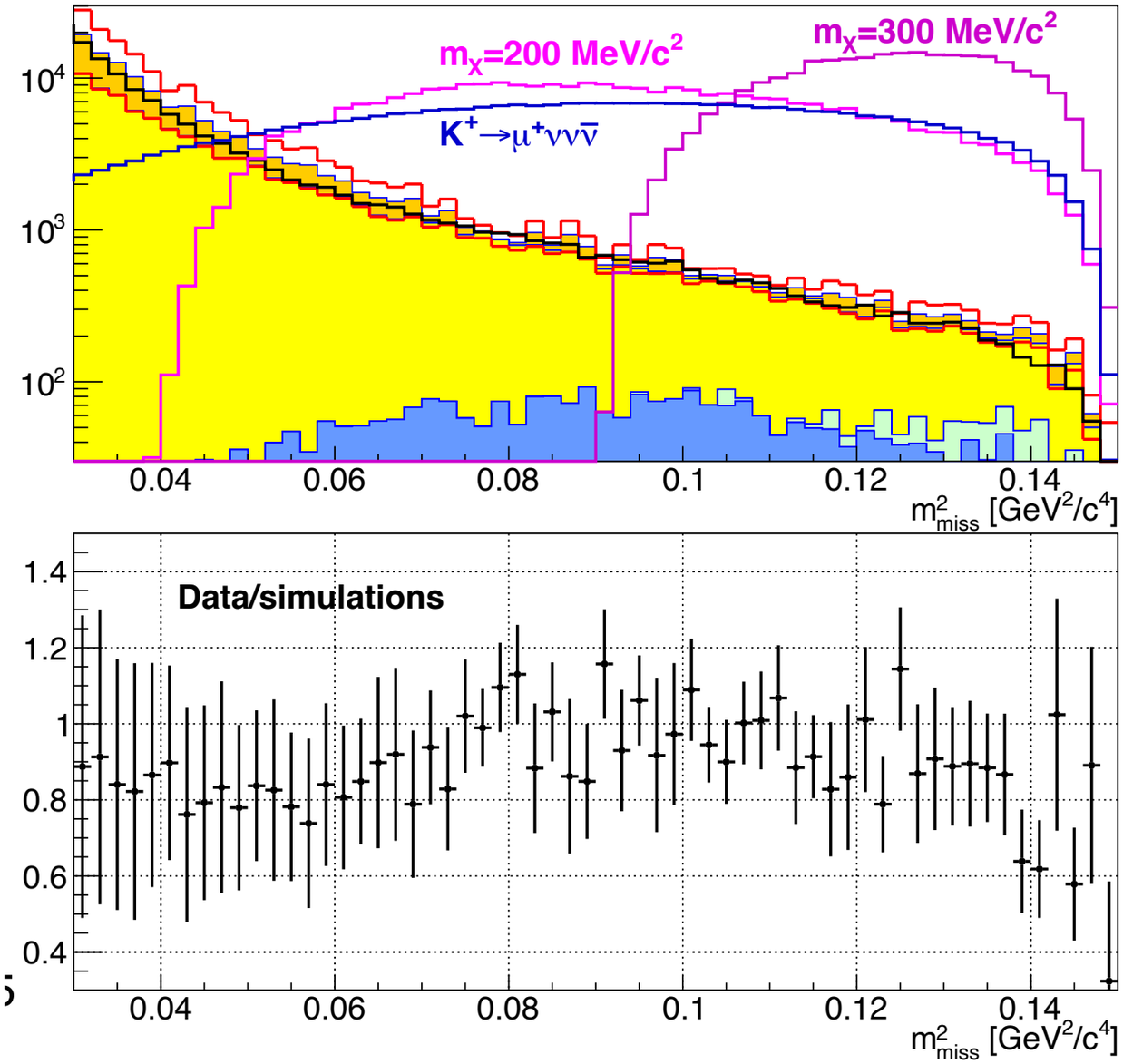
Combination of targeted & inclusive searches can lead to new discoveries!

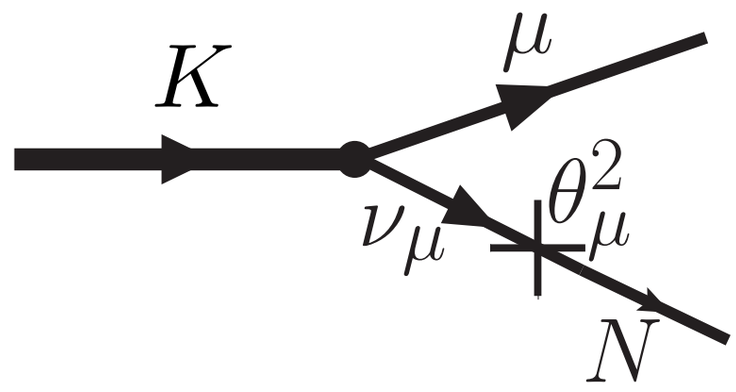


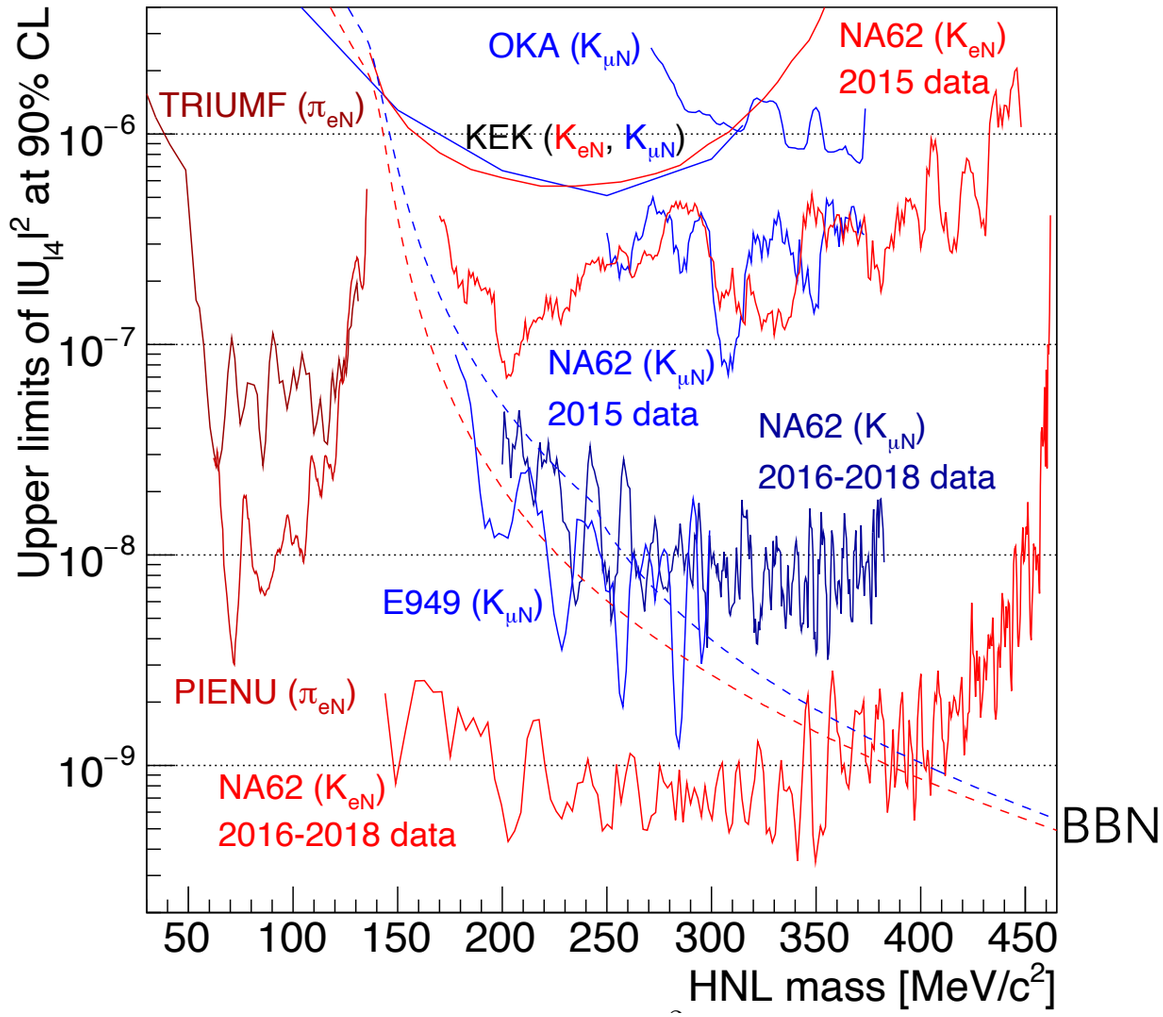
BACKUP SLIDES

NEUTRINO PORTAL

NA62, 2101.12304 [PLB]







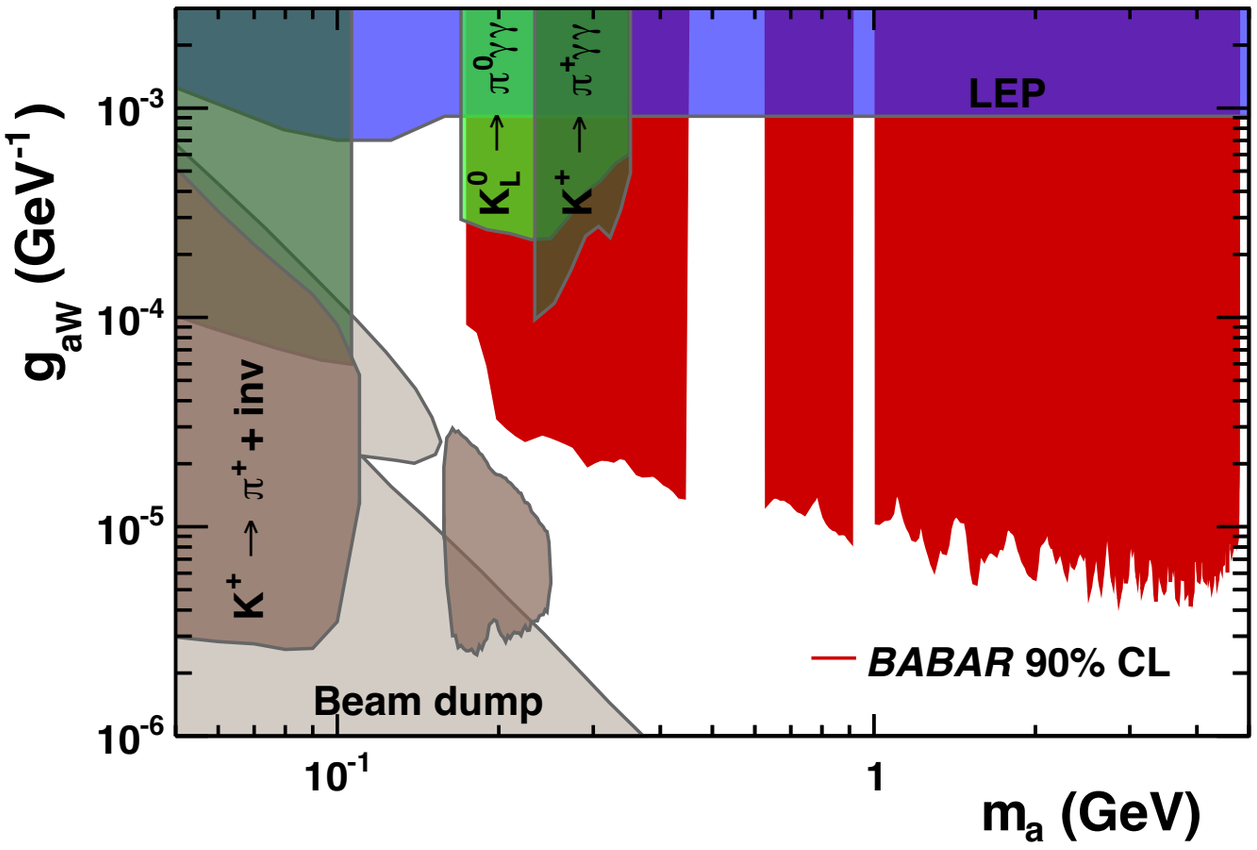
Izaguirre, Lin, BS, 1611.09355 [PRL]; Dolan *et al.*, 1709.00009 [JHEP]; Bertholet *et al.*, 2108.10331 [PRD]…

AXION PORTAL

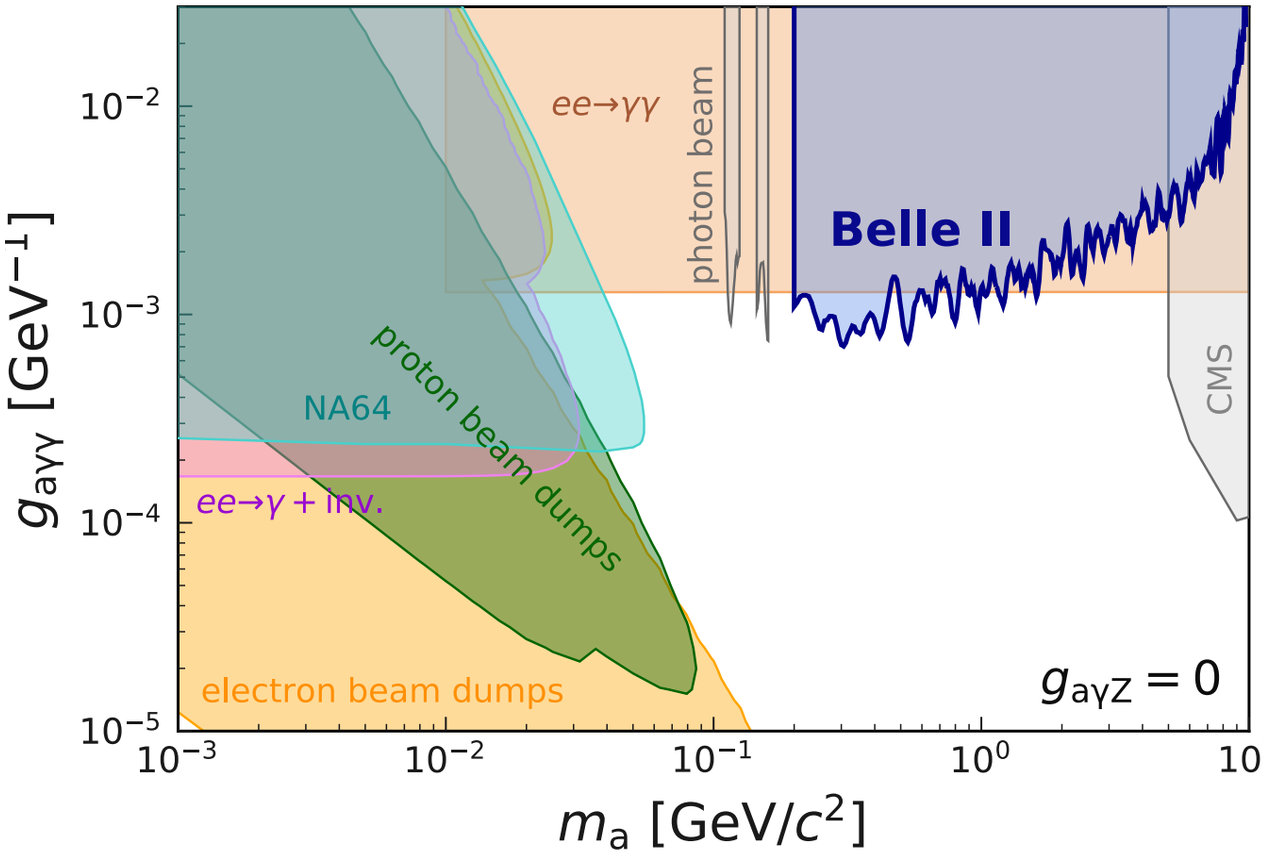
$$B^{\pm} \to K^{\pm} a,\ a \to \gamma\gamma$$

$$e^+e^- \to \gamma^* \to \gamma a, a \to \gamma\gamma$$

BABAR, arXiv:2111.01800 [PRL]



Belle II, arXiv:2007.13071 [PRL]



- See this morning's talk by Diego Redigolo!

MULTI-LEPTONS IN MESON DECAYS

- Many BSM decay rates can be *above* corresponding SM rates