Dark Photons from Nuclear Transitions

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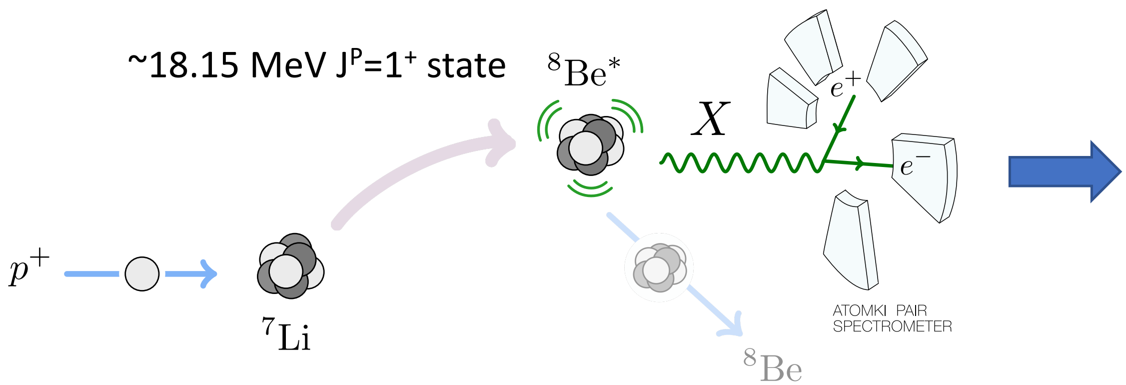
Based on **JK**, 1708.06349

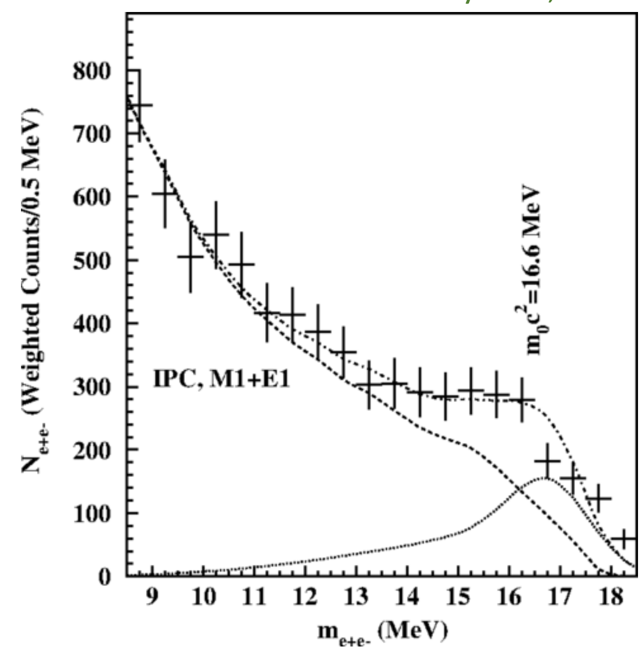
A New Particle in ^{8}Be Decays?

Atomki search for internal pair creation ($e^+ e^-$ production) in excited states of ^{8}Be sees a bump

Feng et al, 2016



Krasznahorkay et al, 2015



Bump consistent with emission of new light boson around 17 MeV

$$m = 16.7 \pm 0.35(\text{stat}) \pm 0.5(\text{syst})\,\text{MeV}, \qquad \frac{\Gamma(^8\text{Be}^* \to ^8\text{Be}X)}{\Gamma(^8\text{Be}^* \to ^8\text{Be}\gamma)} BR(X \to e^+e^-) \simeq 5.8 \times 10^{-6}$$

A New Particle in ^{8}Be Decays?

Possible interpretations:

-Can't be a dark photon (ruled out by NA48/2) (Feng et al, 2016: PRL + PRD)

-New protophobic vector? E.g. coupling to *B* or *B-L* (Feng et al, 2016)

-New axial vector? Requires smaller couplings than the vector case, no protophobic requitement (JK, Morrissey, and Stroberg, 2016)

-New pseudoscalar? Studied in Ellwanger + Moretti, 2016

Future experiments required to independently confirm results.

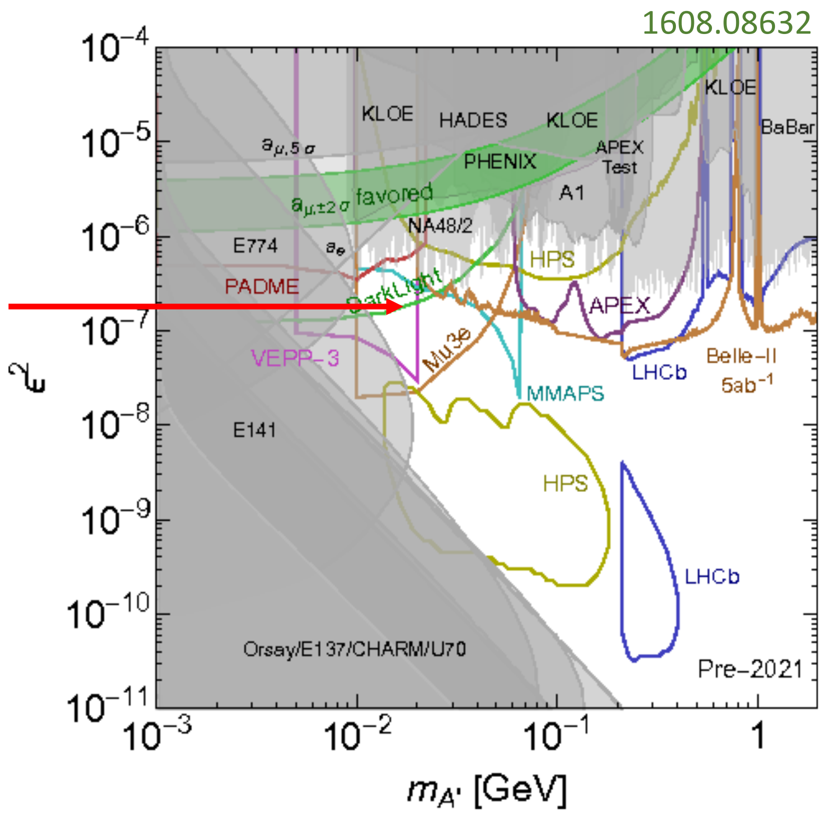
Proposals being finalized (see also U.S. Cosmic Visions dark matter whitepaper, 1707.04591)

This talk: **what else can these future experiments do?**

Dark Photons from Nuclear Decays

New experiments could be sensitive to currently unexplored regions of the dark photon parameter space

Nuclear Decays?



Dark Photons from Nuclear Decays

Massive dark photon couples to SM via kinetic mixing with hypercharge

$$\mathcal{L} = -\frac{1}{4} X_{\mu\nu} X^{\mu\nu} + \frac{1}{2} m_X^2 X_\mu X^\mu - X^\mu J_\mu \,, \quad J_\mu = \epsilon J_\mu^{\rm EM}$$ (After diagonalizing kinetic terms)

Consider dark photon production through the process:

$$p + {}^7\mathrm{Li} \to {}^8\mathrm{Be}^* \to e^+ e^- + {}^8\mathrm{Be}$$ (18.15 MeV transition)

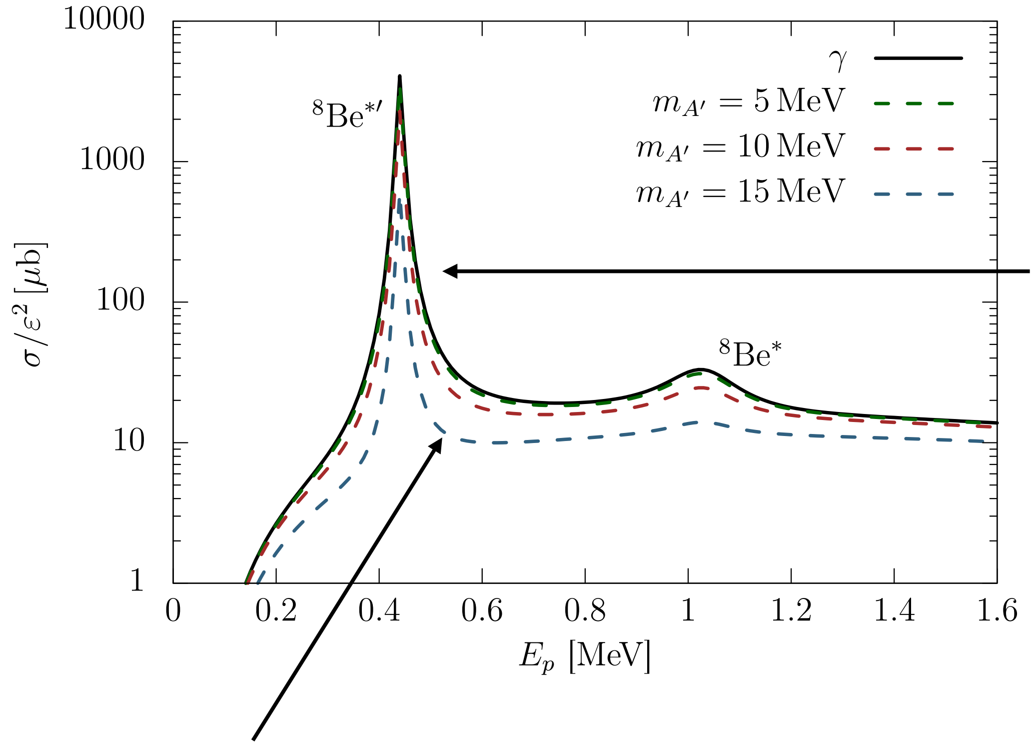
$$p + {}^7\mathrm{Li} \to {}^8\mathrm{Be}^{*\prime} \to e^+ e^- + {}^8\mathrm{Be}.$$ (17.64 MeV transition)

Production cross-section: $$\frac{d\sigma}{d\Omega} = \frac{\mu\, q}{64\, \pi^2\, p} \sum_{a,\sigma,\lambda} \left| \epsilon_\mu^* \mathcal{M}^\mu \right|^2 , \quad \mathcal{M}^\mu \equiv \langle\, {}^8\mathrm{Be} \,|\, J_{\rm EM}^\mu \,|\, {}^7\mathrm{Li} + p \,\rangle$$

Use existing EFT results (Zhang+Miller, 2017) to compute matrix element (couplings normalized to data for electromagnetic decays)

Dark Photons from Nuclear Decays

Comparing photon and dark photon production cross-sections

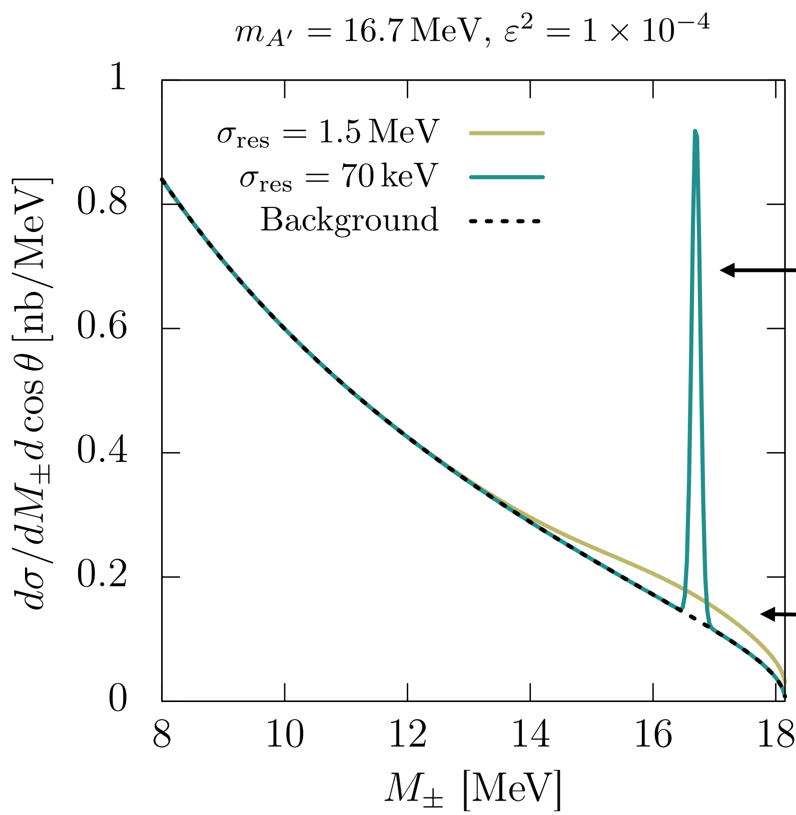


17.64 MeV peak much narrower → **larger rate**

Kinematic suppression for massive vectors close to threshold

Dark Photons from Nuclear Decays

Use EFT results from Zhang + Miller, 2017 to compute irreducible background (SM e^+e^- production through off-shell photon) and compare to signal



Improved resolution will allow for significantly higher reach

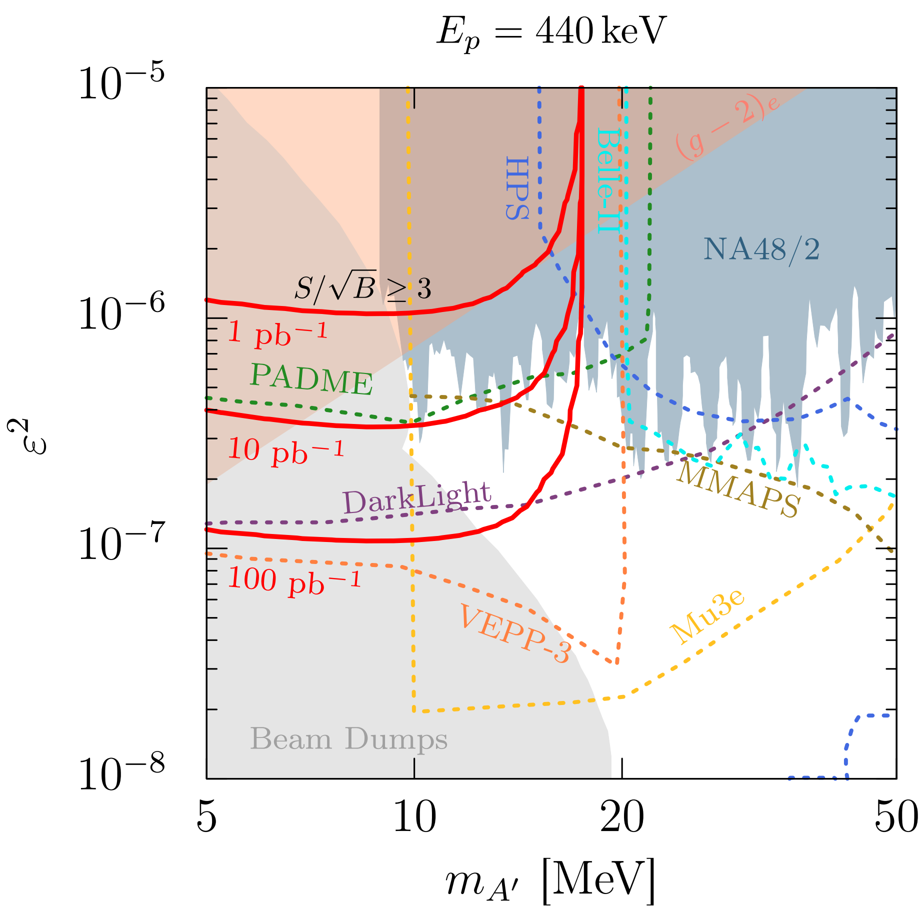
Resolution expected for follow-up experiments using HPGe detectors

Atomki resolution

Projections

Follow-up ^{8}Be experiments can be competitive with other upcoming fixed target and collider experiments

Atomki: ~1 pb^{-1} for ~one week of running



Advantages:

-Cheap, and can be done with existing equipment

-Sensitive to leptonic and hadronic couplings

-Probes nuclear properties

-Definitive scrutiny of Atomki results

Takeaways

Follow-up ^{8}Be experiments can:

- provide a probe of new MeV-scale physics competitive with existing proposals
- be sensitive to both hadronic and leptonic couplings of new particles (most other pre-2021 proposals probe only leptonic couplings)
- likely be constructed and run for $\mathcal{O}(\$1\,\mathrm{M})$

Other systems? ^{4}He could extend reach up to 20-30 MeV masses

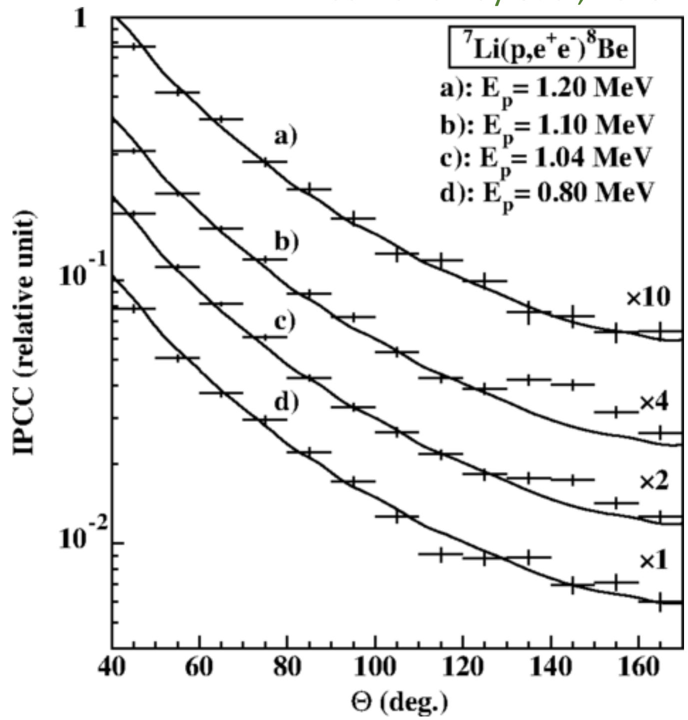
Proposal coming soon!

Backup

A New Particle in ^{8}Be Decays?

Some consistency checks:

Krasznahorkay et al, 2015



Clear excess seen in angular distribution on the 18.15 MeV resonance, but disappears moving off of it

Bump-like feature, difficult to explain with interference from other states

Recent Atomki results indicate an excess in the 17.64 MeV transition as well

Interpretation put forth by collaboration: **new light boson**

$$m = 16.7 \pm 0.35(\mathrm{stat}) \pm 0.5(\mathrm{syst})\,\mathrm{MeV}$$

$$\frac{\Gamma(^8\mathrm{Be}' \to ^8\mathrm{Be}X)}{\Gamma(^8\mathrm{Be}' \to ^8\mathrm{Be}\gamma)}\mathrm{Br}(X \to e^+e^-) = 5.8 \times 10^{-6}$$

Estimating Sensitivity

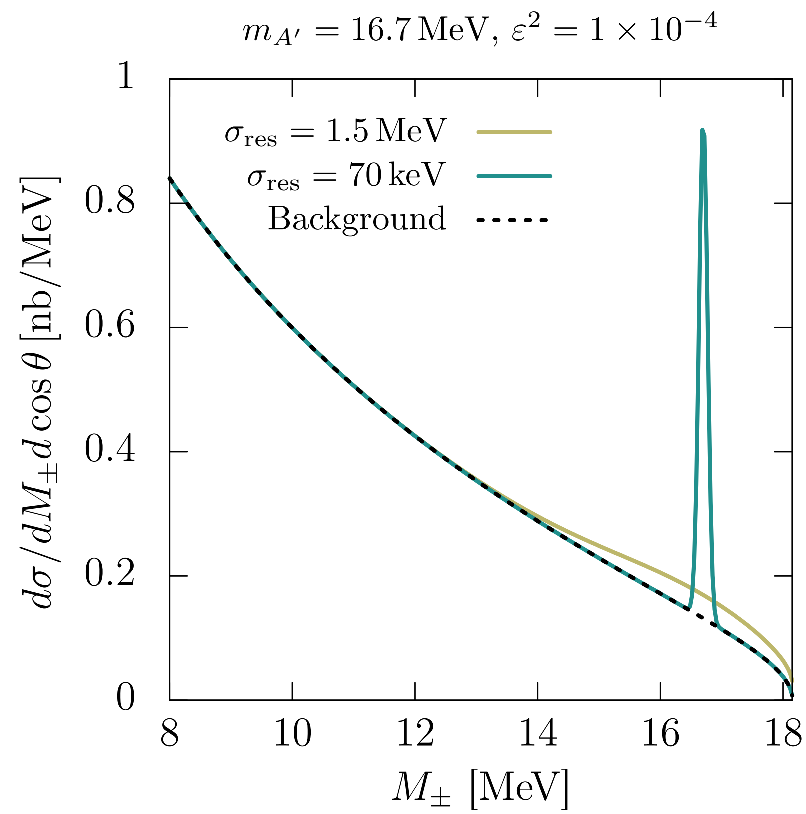
Two methods:

1. Cut-and-count: compute $S/\sqrt{B}$ in a window around a given mass value

Downside: sensitive to overall normalization of background

2. Background-agnostic bump-hunt: scan over distribution and in each narrow window fit line and line+ Gaussian. Then construct log-likelikhood

Advantage: allows for mis-modeled background; insensitive to overall normalization and shape



Both methods yield similar results