# Case study: summary plot for dark photon searches

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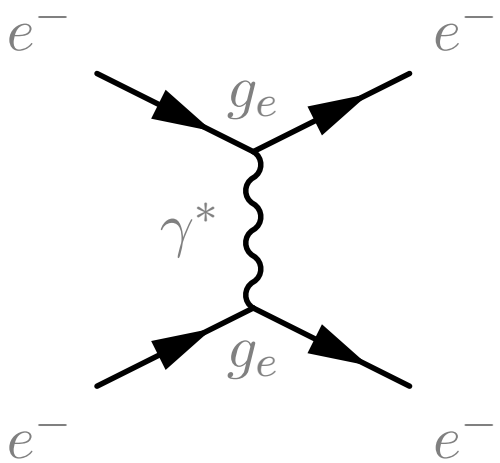
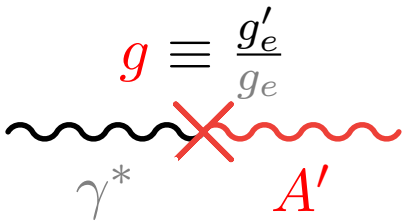
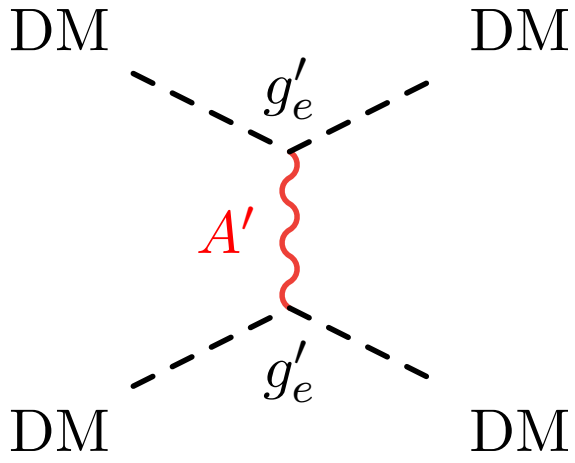
LLP Workshop 11

# Dark Photons



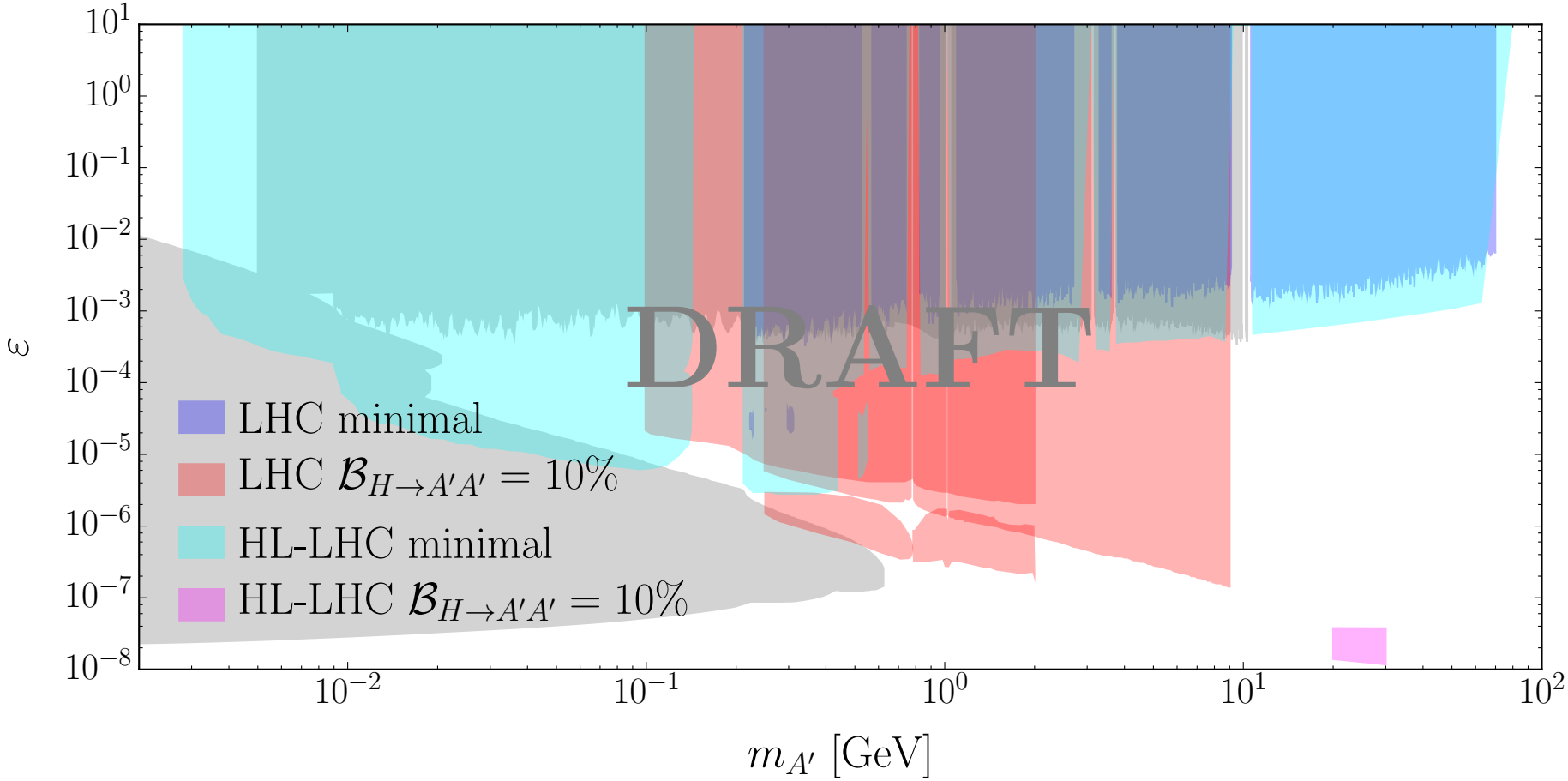



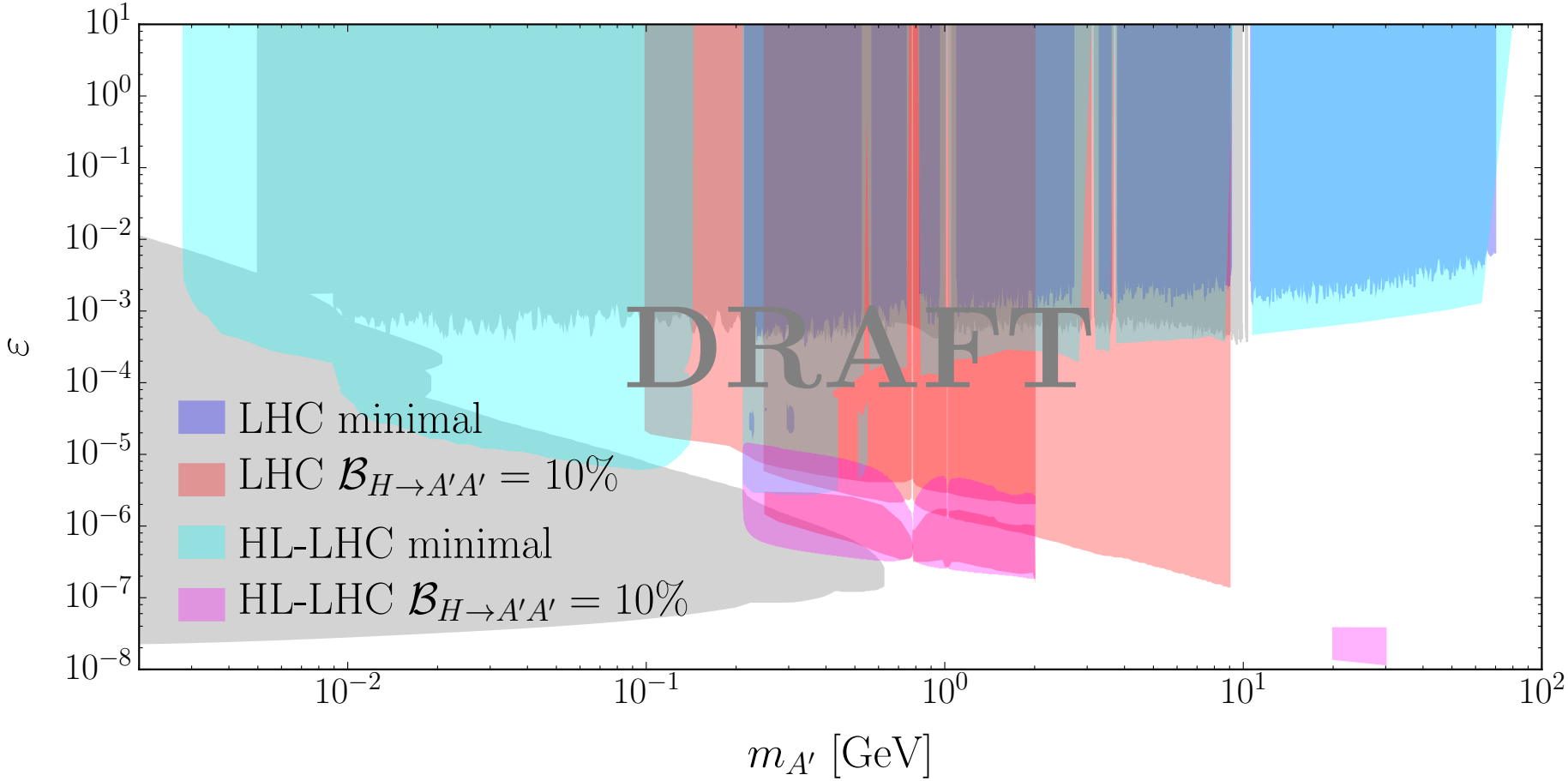

1. mass of the dark photon, $m_{A'}$, and mixing, $g$, are free parameters
2. the dark photon couples like the photon, modified by $g$
3. if $m_{A'} < 2m_{\mathrm{DM}}$ then dark photon decays visibly

- what happens if 2 and 3 are relaxed?
- require $m_{A'}$, $g$, 12 fermion couplings, and a dark width
- *dark photon limits can be recast to any general vector model*

# HL-LHC Dark Photon

arXiv:1812.07831




DRAFT
LHC minimal
LHC $\mathcal{B}_{H\to A'A'} = 10\%$
HL-LHC minimal
HL-LHC $\mathcal{B}_{H\to A'A'} = 10\%$
$\epsilon$
$m_{A'}$ [GeV]
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
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$10^{0}$
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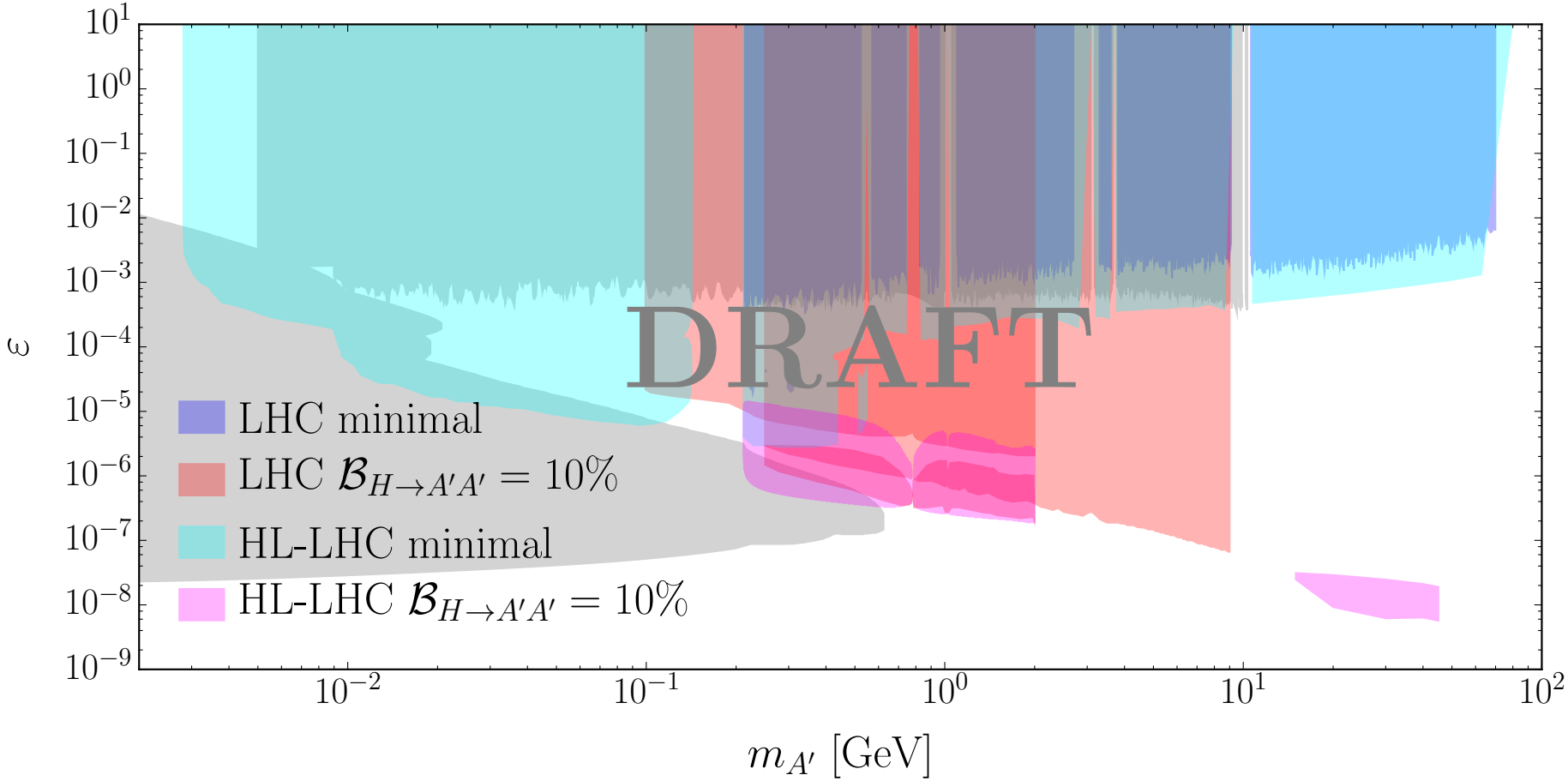
$10^{2}$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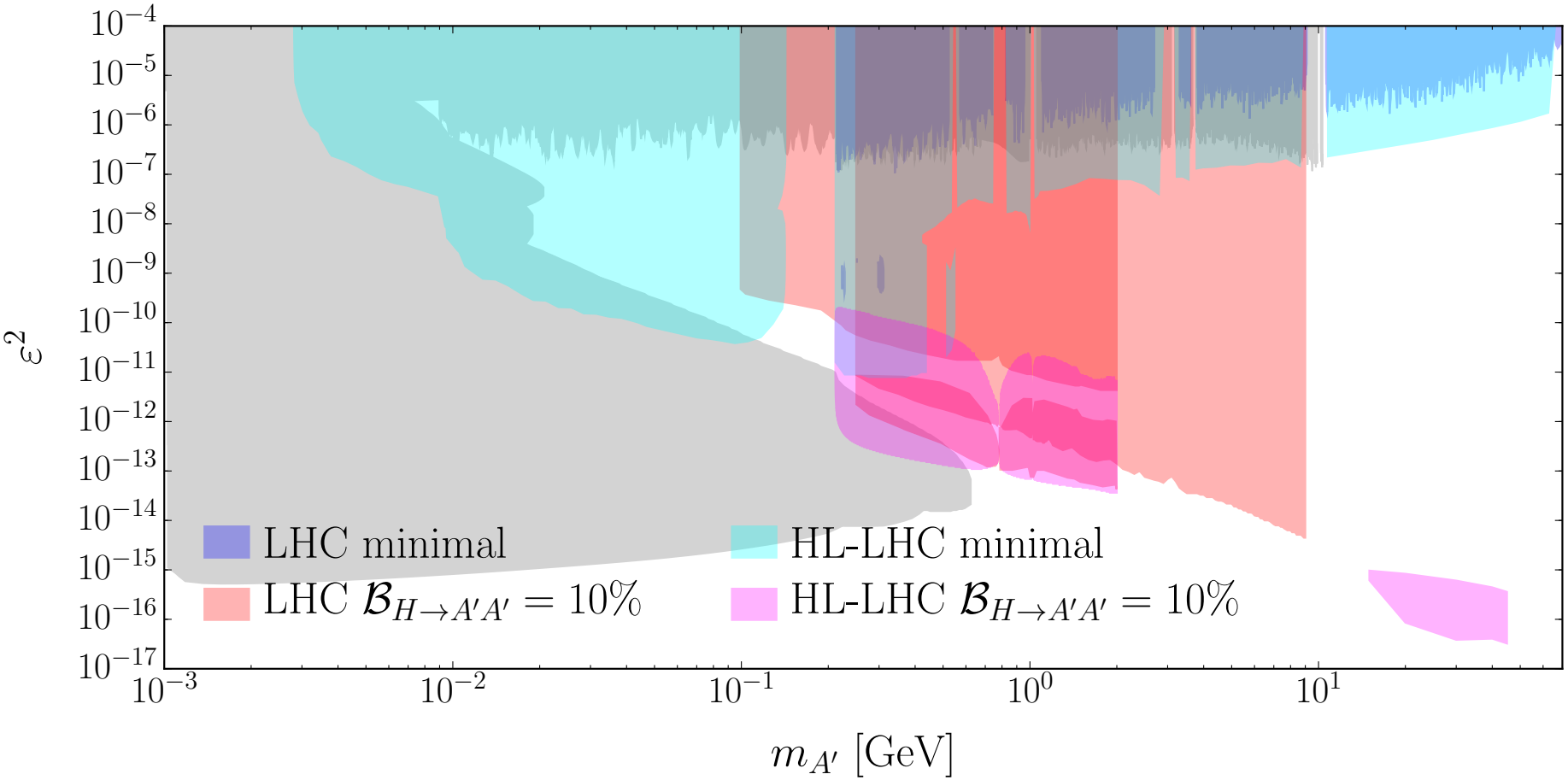
$10^{-4}$
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$10^{-12}$
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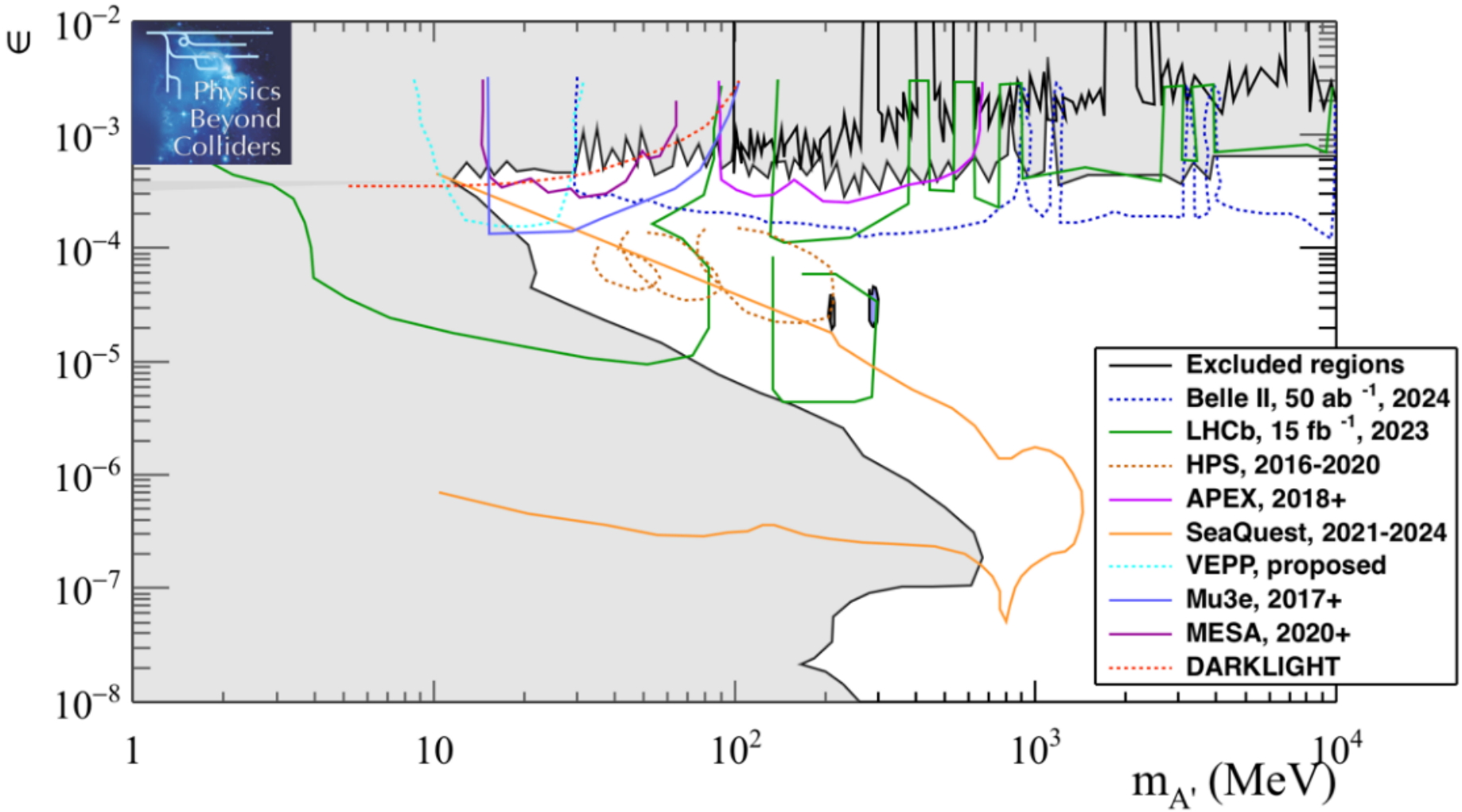
$10^{-15}$
$10^{-16}$
$10^{-17}$
$\varepsilon^2$
$10^{-3}$
$10^{-2}$
$10^{-1}$
$10^{0}$
$10^{1}$
$m_{A'}$ [GeV]
LHC minimal
HL-LHC minimal
LHC $\mathcal{B}_{H\to A'A'} = 10\%$
HL-LHC $\mathcal{B}_{H\to A'A'} = 10\%$

# Some Comments

- this summary plot is unusual, mixes the minimal model with a specific model
- in the minimal model, the Higgs channel has no sensitivity since $\mathcal{B}_{H\to\gamma\gamma} \approx 1\%$ and $\sigma_H \approx 55$ pb
- in contrast, $\mathcal{B}_{\eta\to\gamma\gamma} \approx 40\%$ and $\sigma_\eta \approx 1000$ mb
- direct Yukawa coupling ($m_{A'}$ dependent) also has limited sensitivity
- the $\mathcal{B}_{H\to A'A'} \approx 10\%$ was chosen by existing $\mathcal{B}_{H\to\text{invisible}}$ limit
- focus was on HL-LHC, so no other projections shown

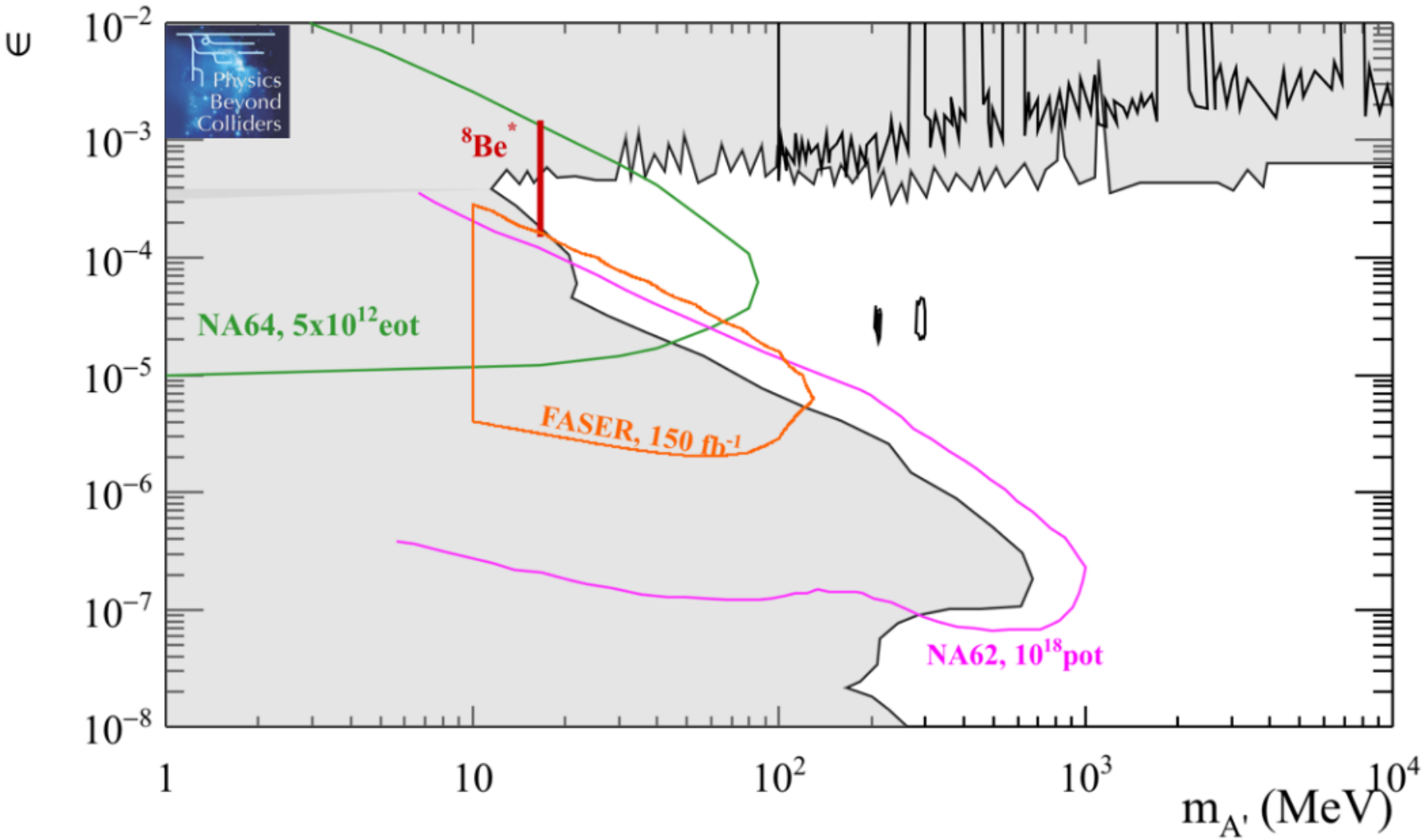
# Physics Beyond Colliders

arXiv:1901.09966



# Physics Beyond Colliders

arXiv:1901.09966



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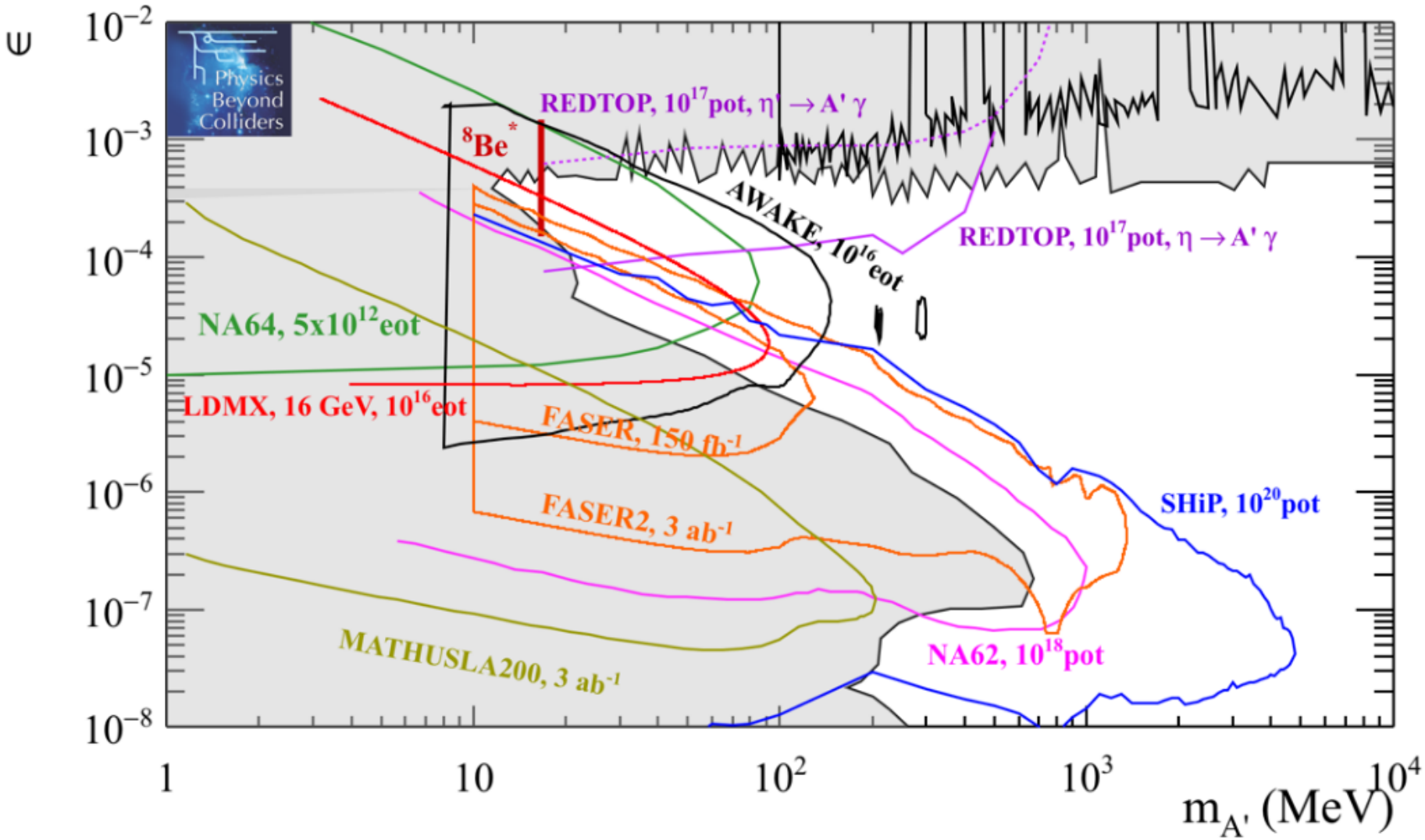
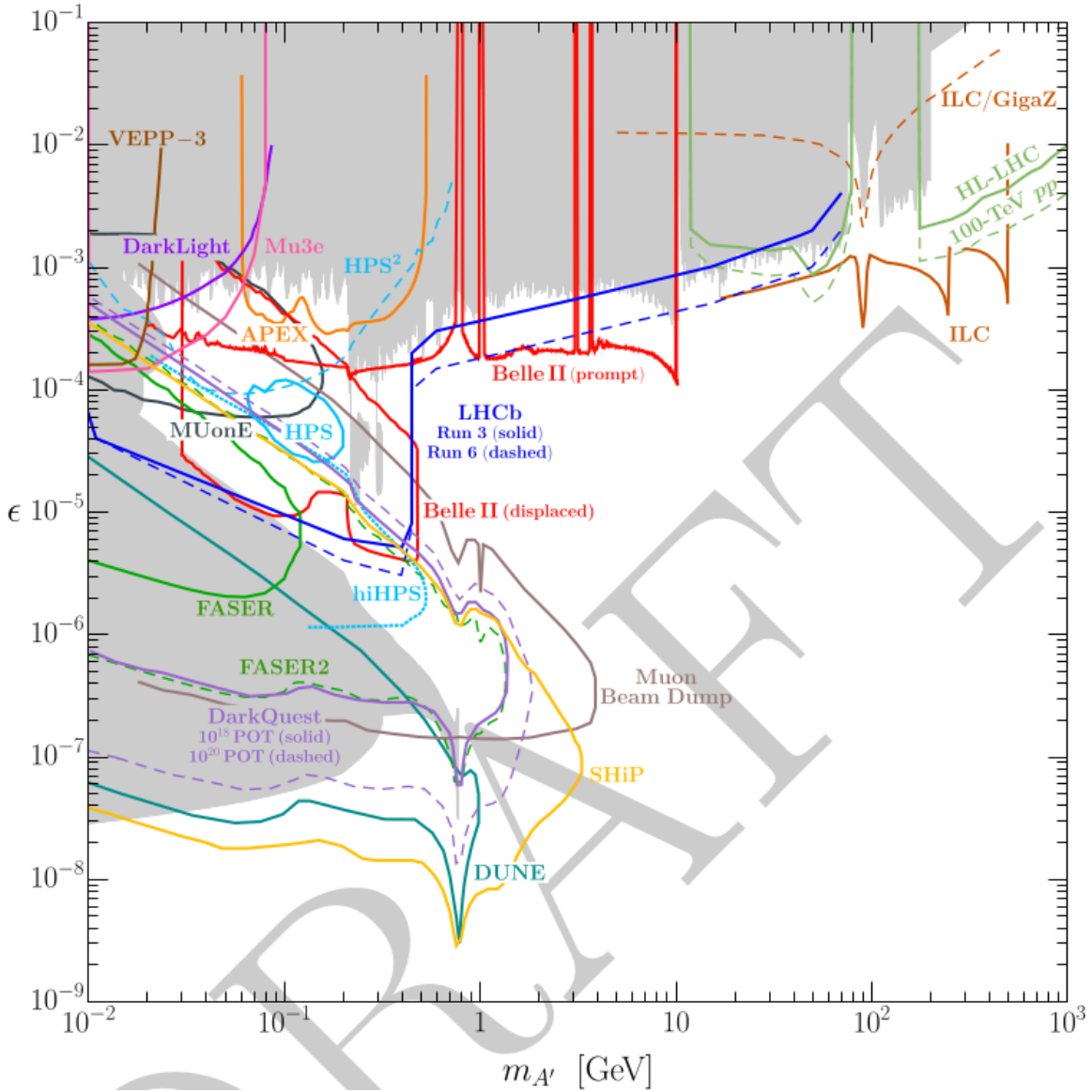


# Snowmass

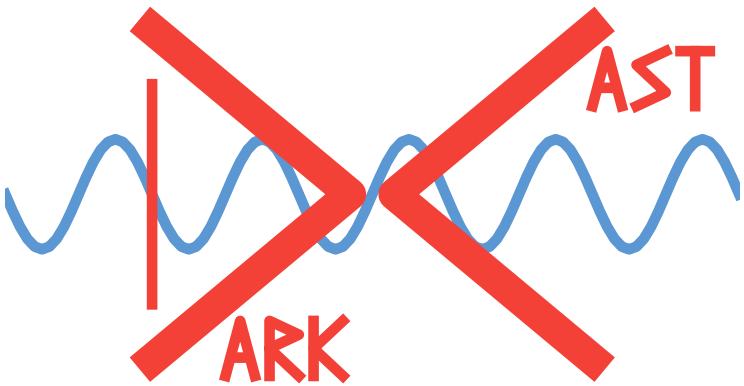

VEPP−3
DarkLight
Mu3e
HPS²
APEX
MUonE
HPS
Belle II (prompt)
LHCb
Run 3 (solid)
Run 6 (dashed)
Belle II (displaced)
hiHPS
FASER
FASER2
DarkQuest
10¹⁵ POT (solid)
10²⁰ POT (dashed)
Muon
Beam Dump
SHiP
DUNE
ILC/GigaZ
HL-LHC
100-TeV pp
ILC
DRAFT
$\epsilon$
$m_{A'}$ [GeV]

# Some More Comments

- both Physics Beyond Colliders and Snowmass only show minimal models
- coupling rather than coupling squared used
- limits vary on space being highlighted
- proposed experiment space is messy, requires some organization
- Physics Beyond Colliders chose three plots: summary, relevant near term, relevant long term
- the Snowmass plot is being reworked, but will most likely remain as a single plot with some timescale indication

# DarkCast

- recast to any general model, *e.g.* 27 free parameters
- **models with axial couplings can now be recast!**




- available at `gitlab.com/darkcast/releases`
- accompanying papers *Serendipity in dark photon searches* and *Axial vectors in DarkCast*

```
import darkcast
model = darkcast.Limit("B_boson.py")                    # Load a model.
limit = darkcast.Limit("LHCb_Aaij2017rft_displaced") # Load a limit.

# Recast the limit.
recast = limit.recast(model)

# Write out the recast.
recast.write("darkcast.lmt")

# Plot the recast.
for x, y in recast.plots(): pyplot.fill(x, y)
```

# How it Works

- given $(m, g_A)$ for model $A$, solve to find $(m, g_B)$ for model $B$

$$\sigma_A(m, g_A)\mathcal{B}_A(m)\varepsilon\big(\tau_A(m, g_A)\big) = \sigma_B(m, g_B)\mathcal{B}_B(m)\varepsilon\big(\tau_B(m, g_B)\big)$$

- absolute values can be tricky, ratios are easier

$$\frac{\sigma_A(m, g_A)}{\sigma_B(m, g_B)} \frac{\varepsilon\big(\tau_A(m, g_A)\big)}{\varepsilon\big(\tau_B(m, g_B)\big)} \frac{\mathcal{B}_A(m)}{\mathcal{B}_B(m)} = 1$$

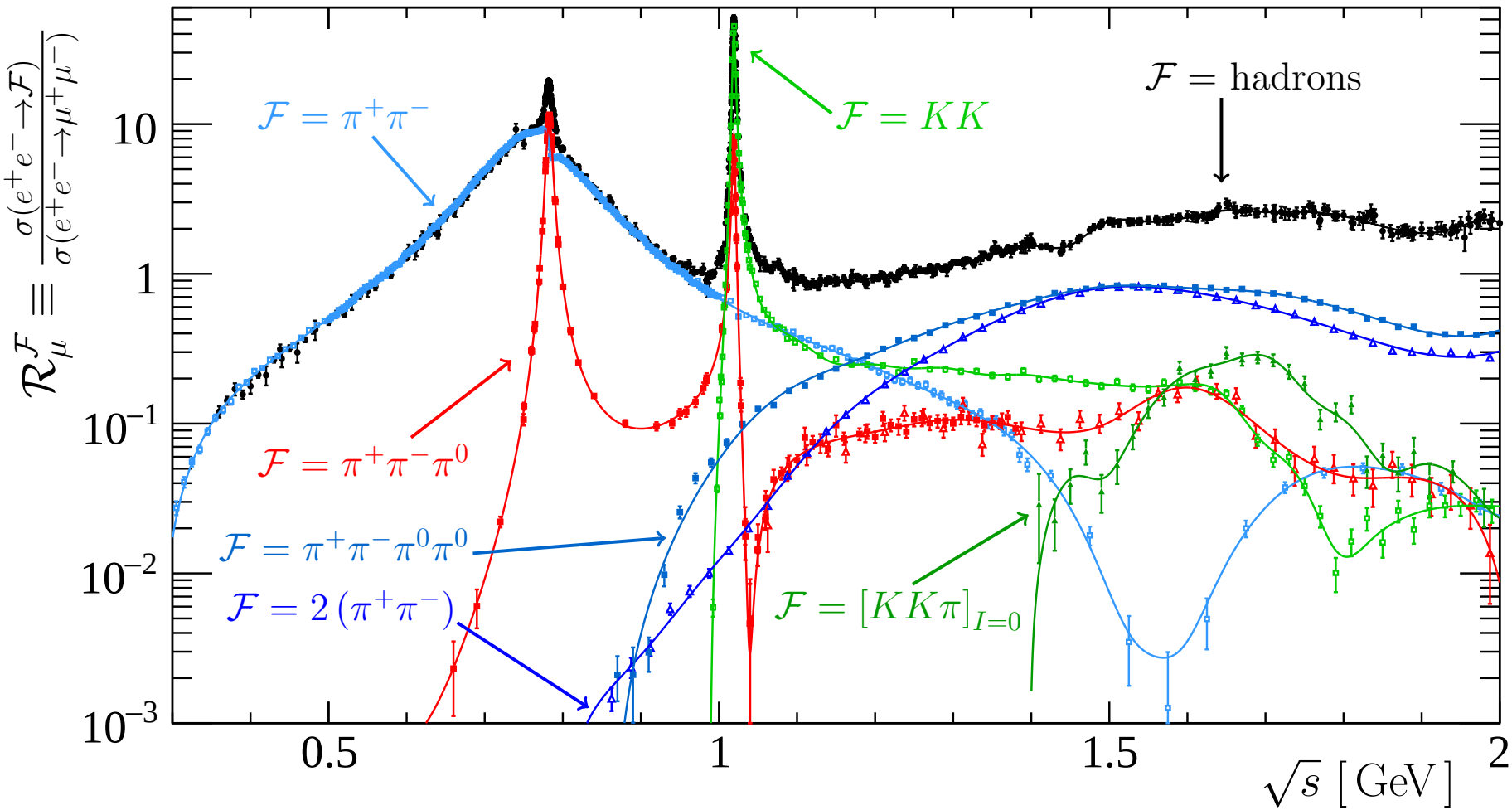
1. branching fraction ratio: use $\mathcal{R}_\mu$ and $a_1^{(s)}$ from data
2. cross-section ratio

$$V \in (\rho, \omega, \phi, K^*, \bar{K}^*) \text{ generated from } U(3)_V$$

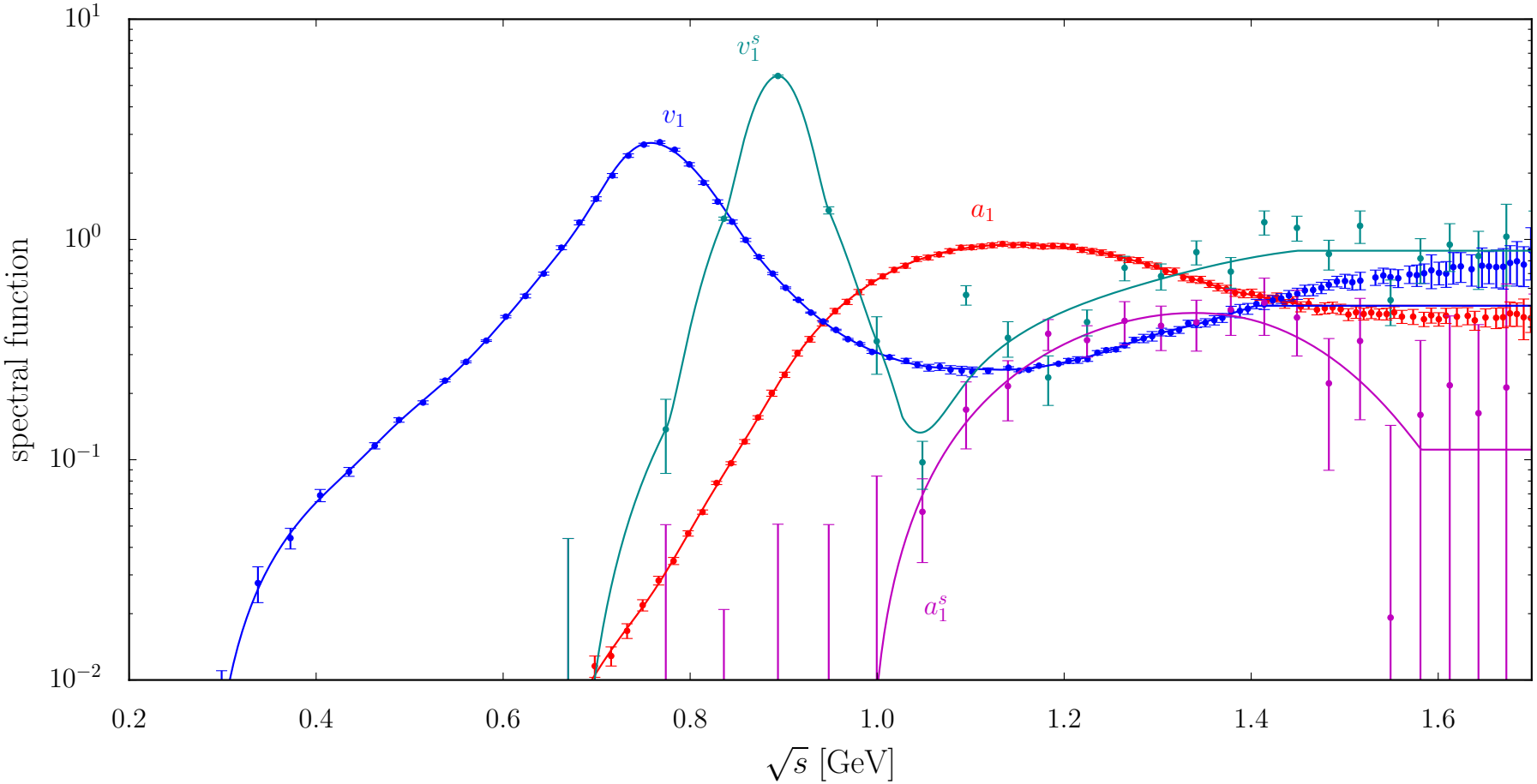
3. efficiency ratio: define proper time fiducial region with $t_0$ and $t_1$

$$\varepsilon(\tau) = e^{-t_0/\tau} - e^{-t_1/\tau}$$

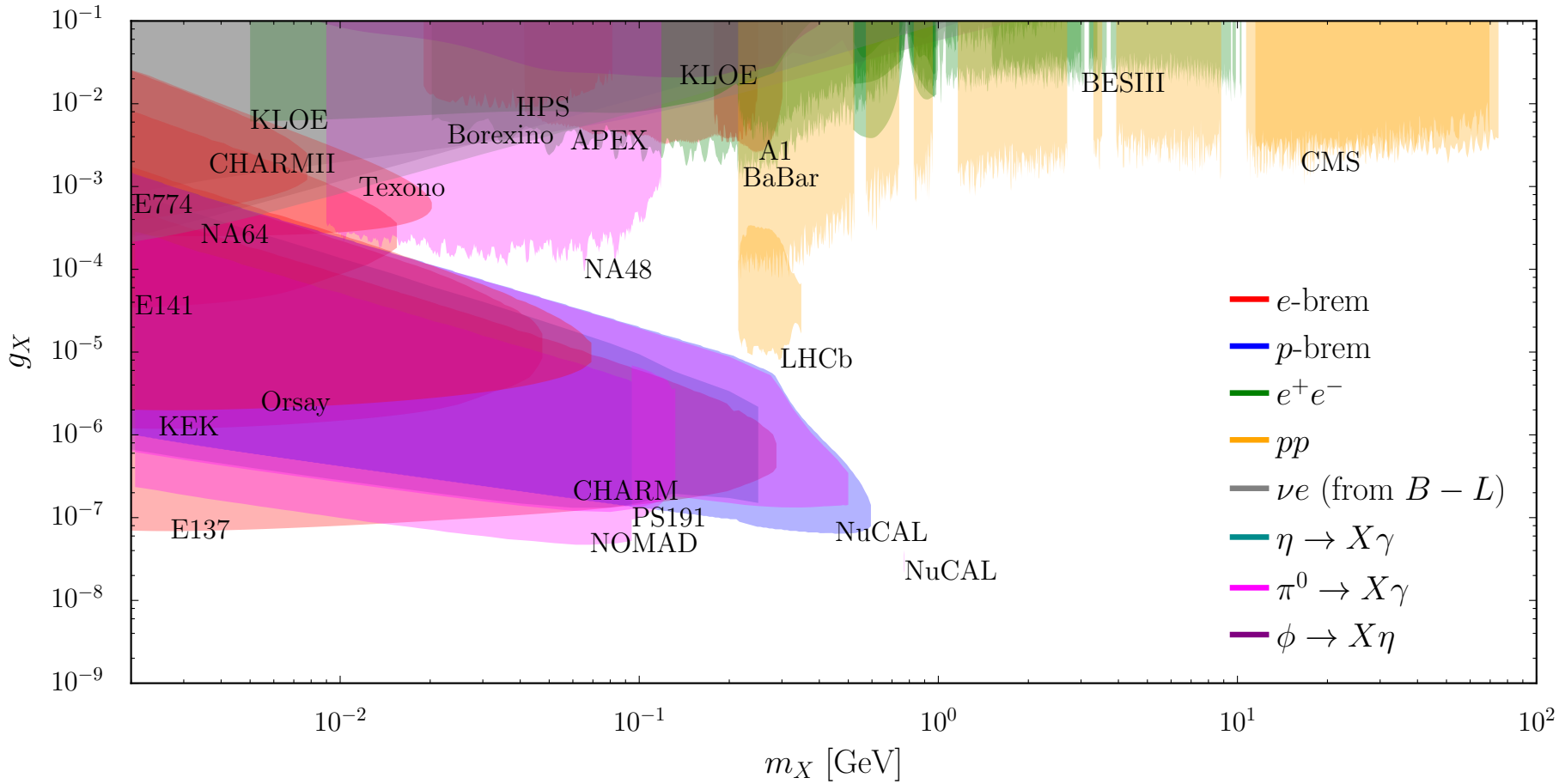
# Ratio of Hadrons to Muons



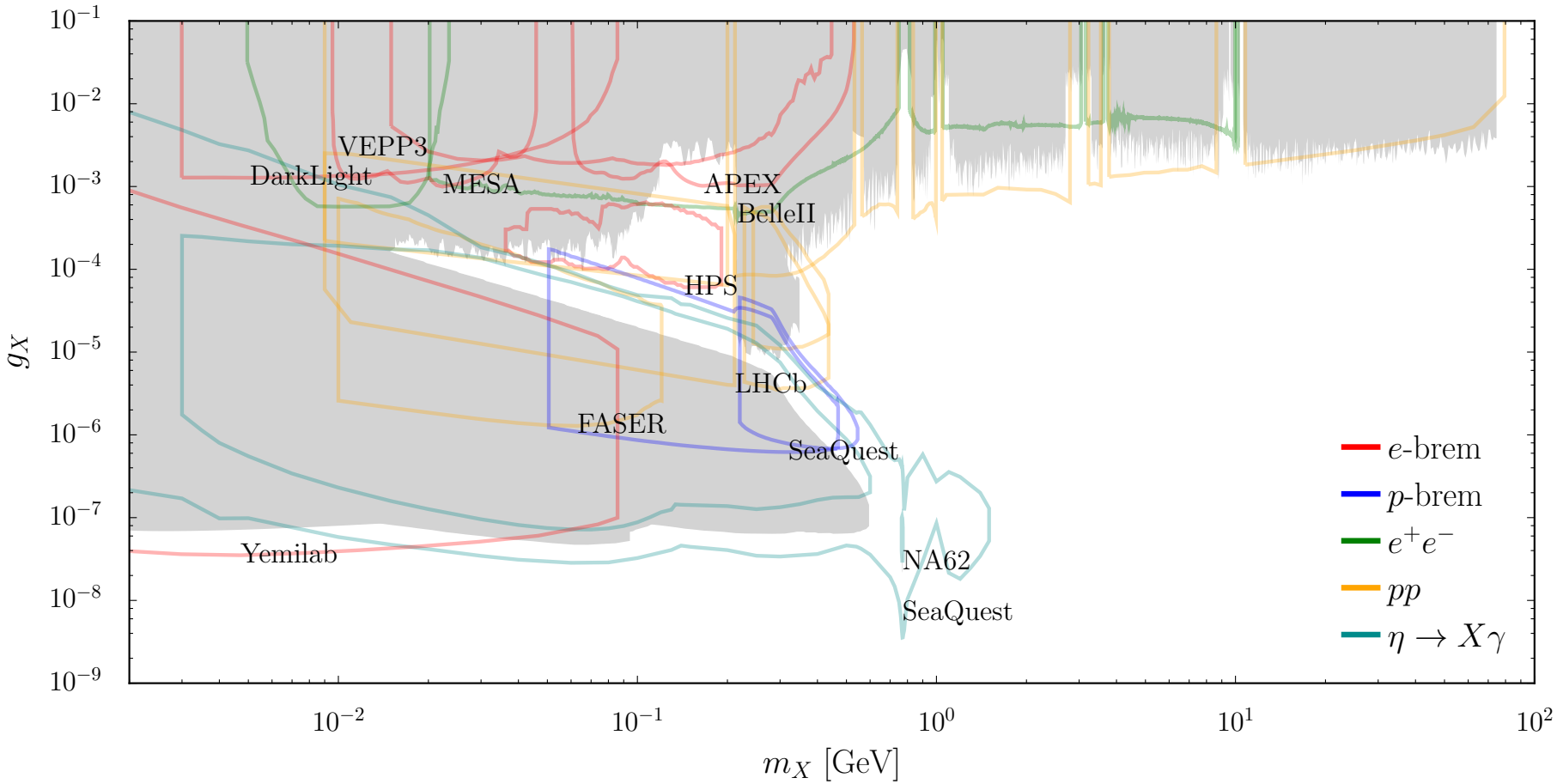
# Spectral Functions from Tau Decays



# An Example - 2 Higgs Doublet (Current)



# An Example - 2 Higgs Doublet (Future)



# Some Closing Comments

- **deciding on the summary plots is hard**
- **formatting the summary plots is hard**
- both depend on the purpose of the exercise
- **technically producing the plot can be less hard**
- tools like DarkCast hopefully make this easier
- if there are missing projections/limits in DarkCast, send them my way!