Neutrino, Dark Matter, and Axion Physics with **IsoDAR** *at* **Yemilab**

Adrian Thompson *on behalf of the* **IsoDAR** *collaboration*

International Conference for High Energy Physics
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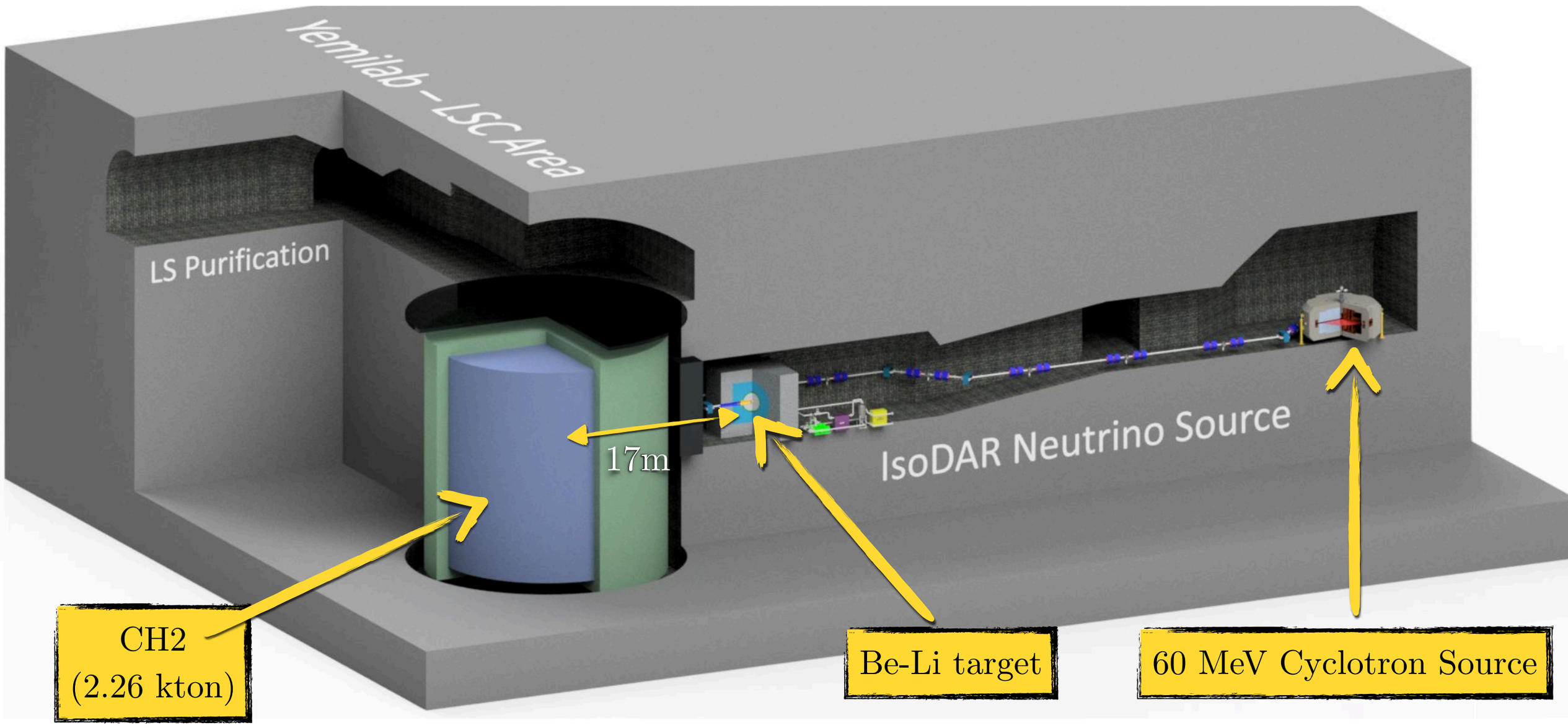
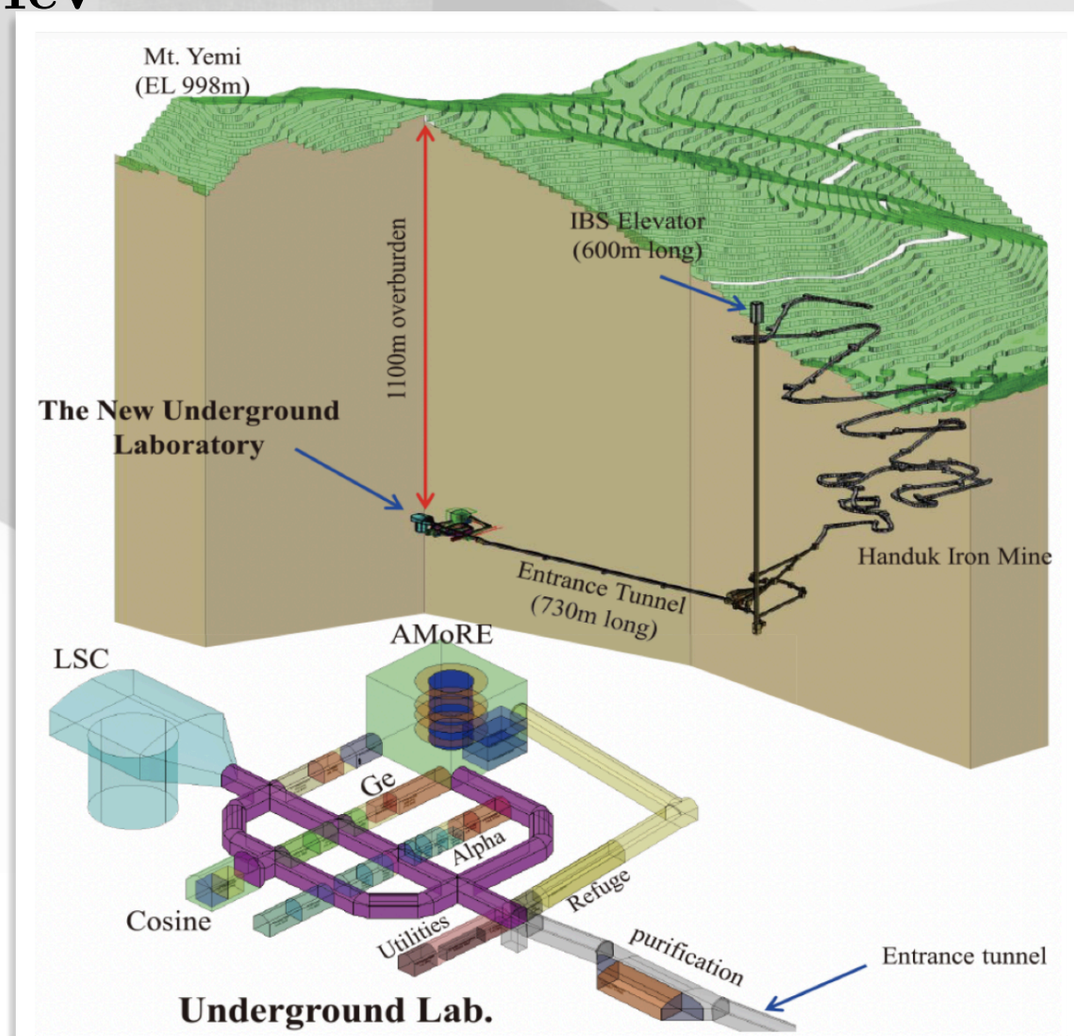
ICHEP 2022

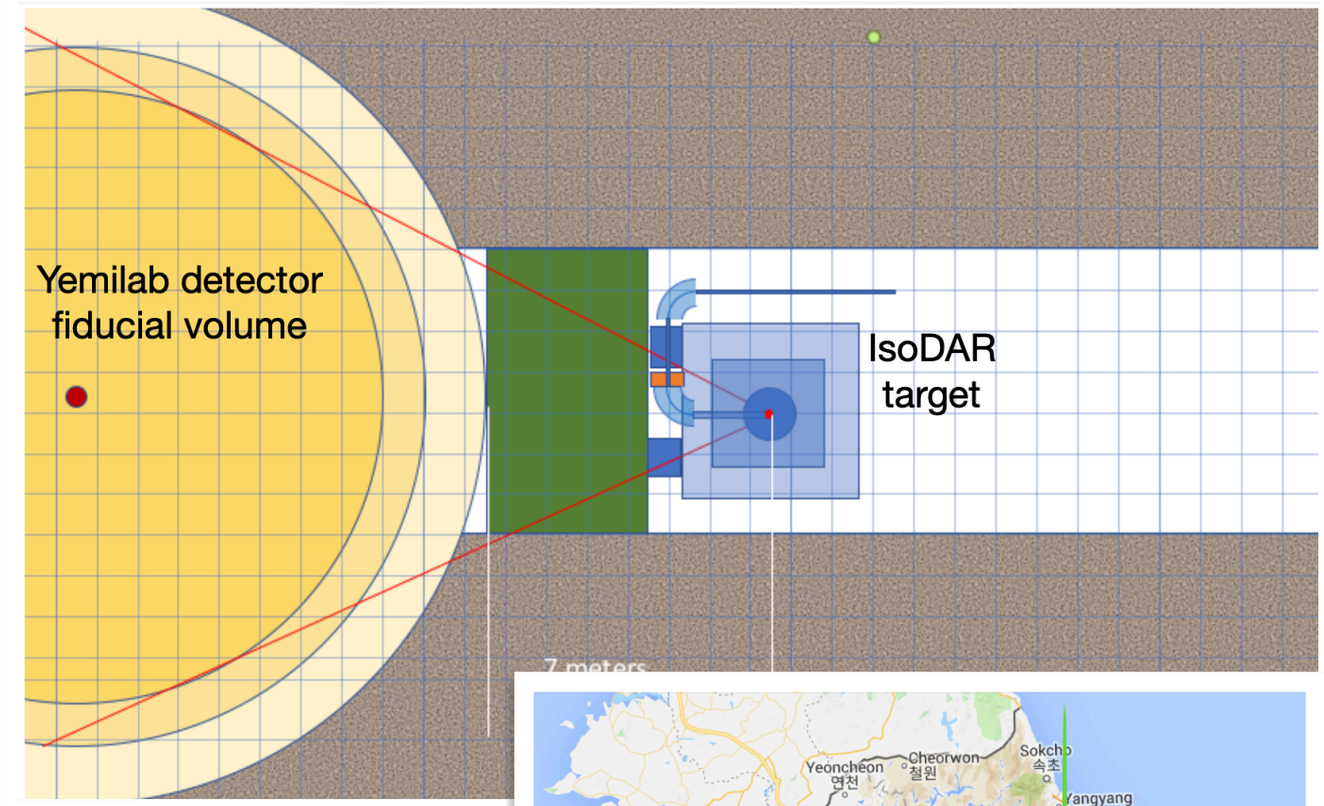
IsoDAR:
The Isotope Decay-at-Rest Experiment



IsoDAR: The Isotope Decay-at-Rest Experiment

- Compact cyclotron to produce **60 MeV protons** on a **Be target with ^{7}Li sleeve**
- Intense source of neutrons get captured on Li8 and induce β-decay of ^{8}Li to produce a neutrino source of **mean $\bar{\nu}_e$energy of 6.4 MeV**





Yemilab, Korea

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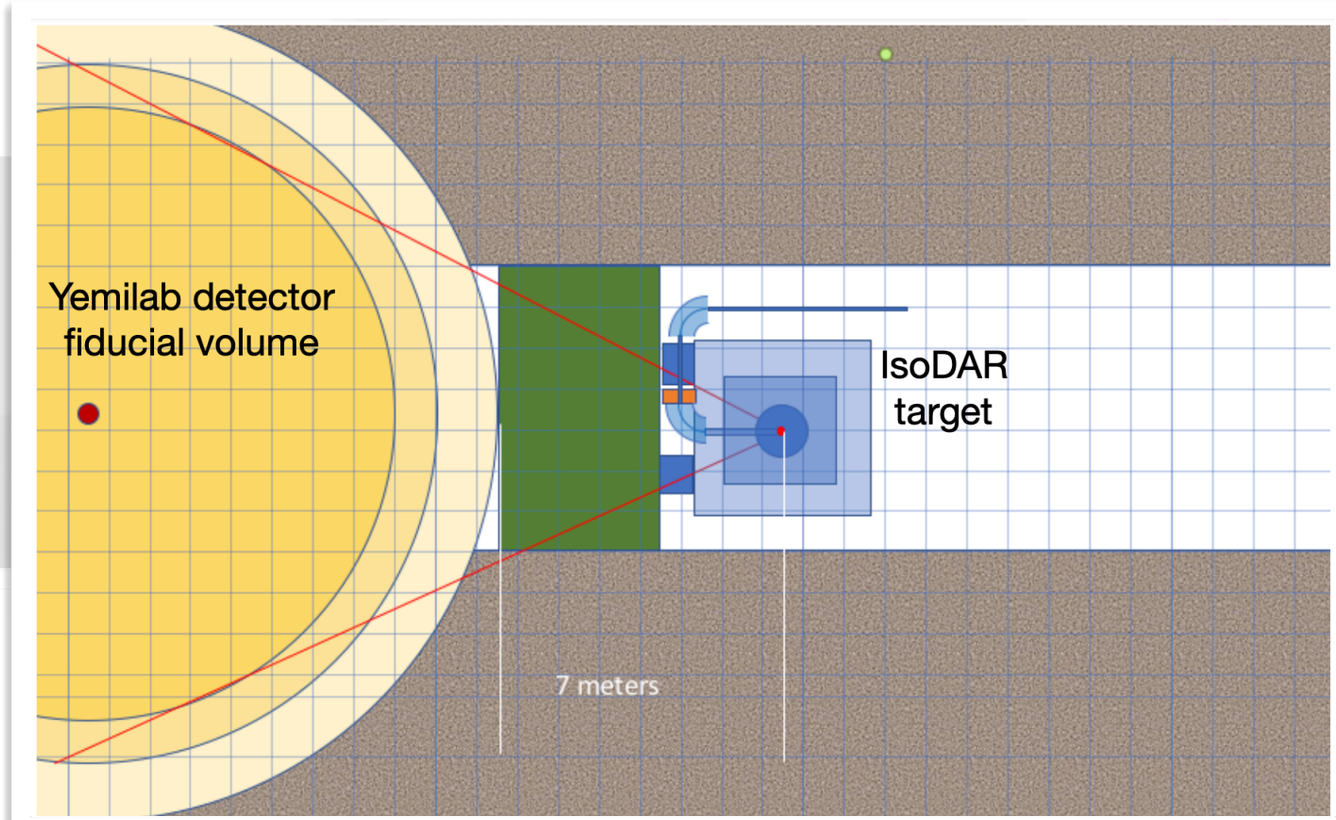
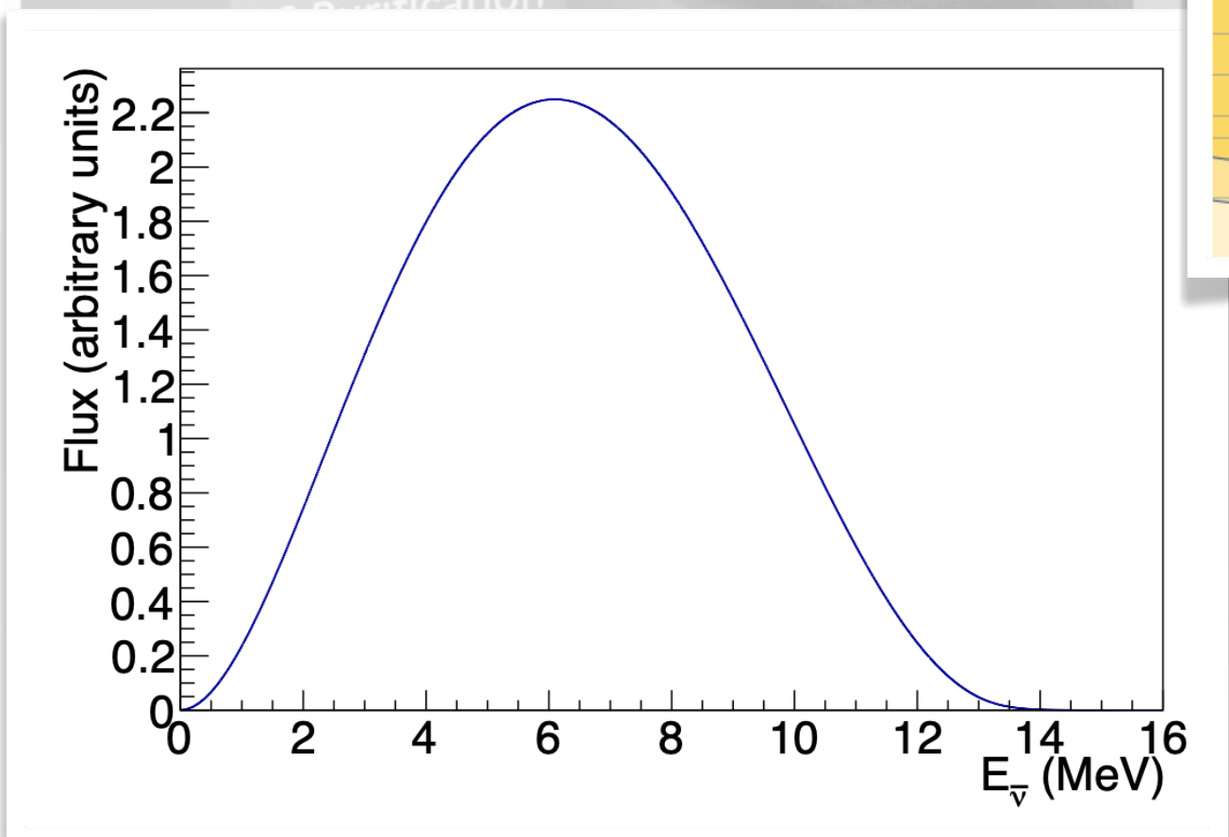




Runtime	5 calendar years
IsoDAR duty factor	80%
Livetime	4 years
Protons on target/year	$1.97 \cdot 10^{24}$
^{8}Li/proton ($\bar{\nu}_e$/proton)	0.0146
$\bar{\nu}_e$ in 4 years livetime	$1.15 \cdot 10^{23}$
IsoDAR@Yemilab mid-baseline	17 m
IsoDAR@Yemilab depth	985 m (2700 m.w.e.)

Rich Physics Program

arXiv:2111.09480

Neutrino Physics Opportunities with the IsoDAR Source at Yemilab

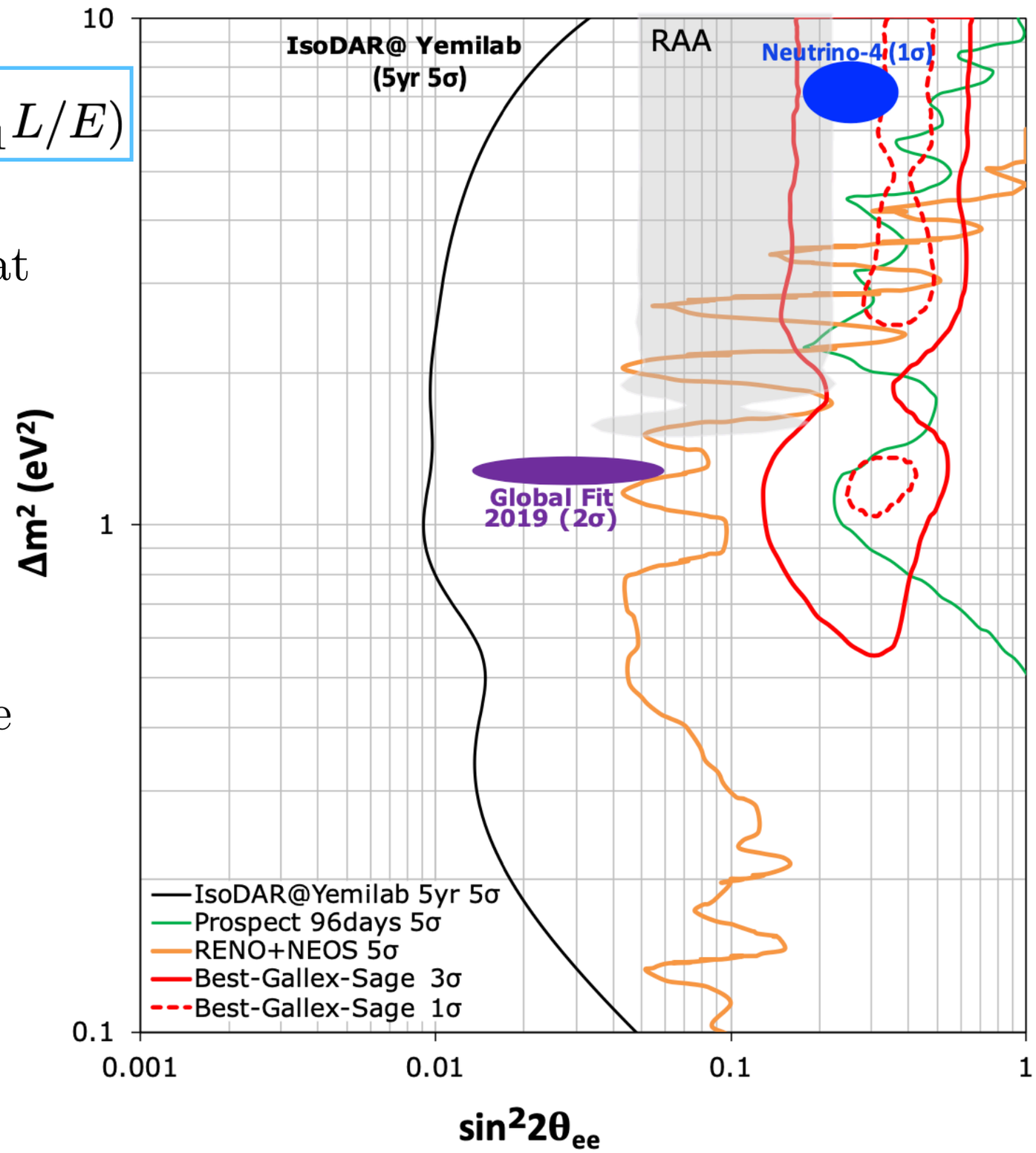
J. Alonso,[1] C.A. Argüelles,[2] A. Bungau,[1] J.M. Conrad,[1] B. Dutta,[3] Y.D. Kim,[4] E. Marzec,[5] D. Mishins,[5] S.H. Seo,[4] M. Shaevitz,[6] J. Spitz,[5] A. Thompson,[3] L. Waites,[1] and D. Winklehner[1]

- Neutrino Oscillation parameters
- Weak mixing angle measurement
- Sterile neutrino searches
- Axion-like Particles
- Neutrino non-standard interactions (NSI)
- Proton decay
- SN, Solar, geo-neutrinos
- More to come!

Sterile Neutrino Searches

$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2 2\theta_{ee} \sin^2(1.27 \Delta m^2_{41} L/E)$$

- 2 million IBD events in 5 years at *Yemilab*
- characteristic oscillation wave will be apparent over the length of the detector
- Can exclude large region of parameter space to 5σ confidence over 5 years
- Based on single isotope (8Li decay) which is well understood
- Event-by-event L/E, vertex reconstruction



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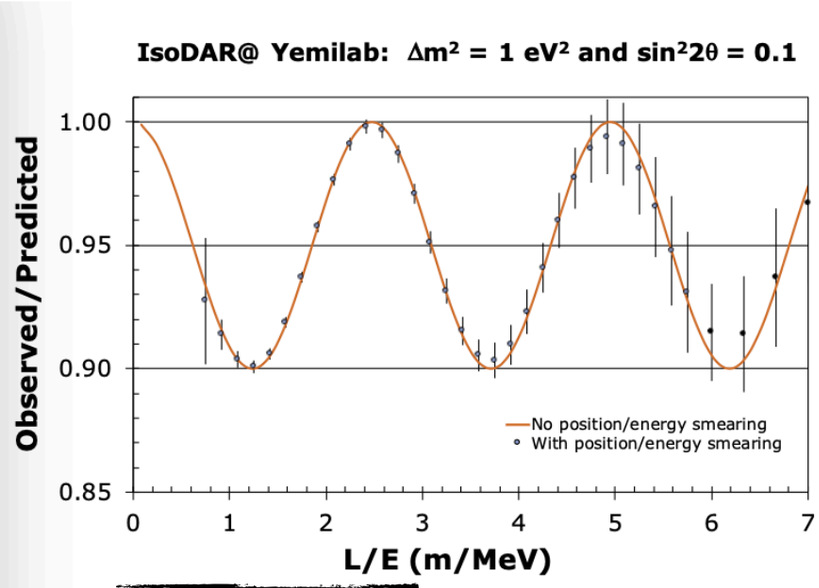
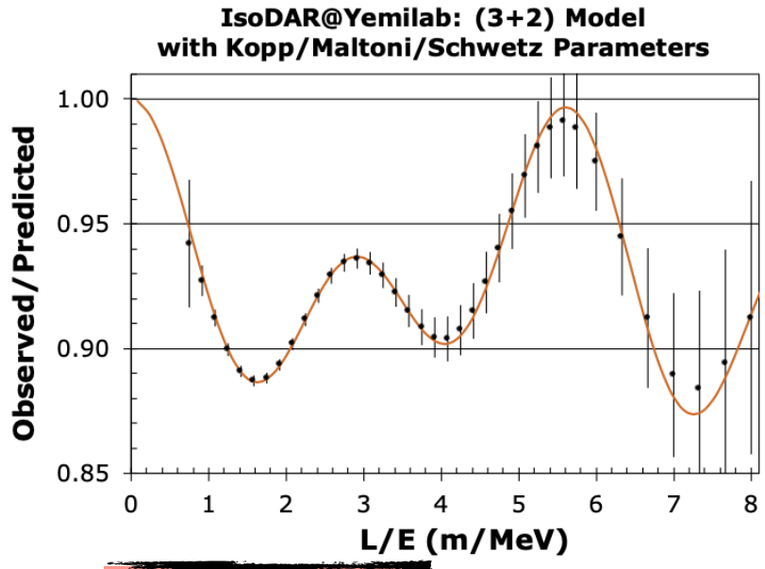
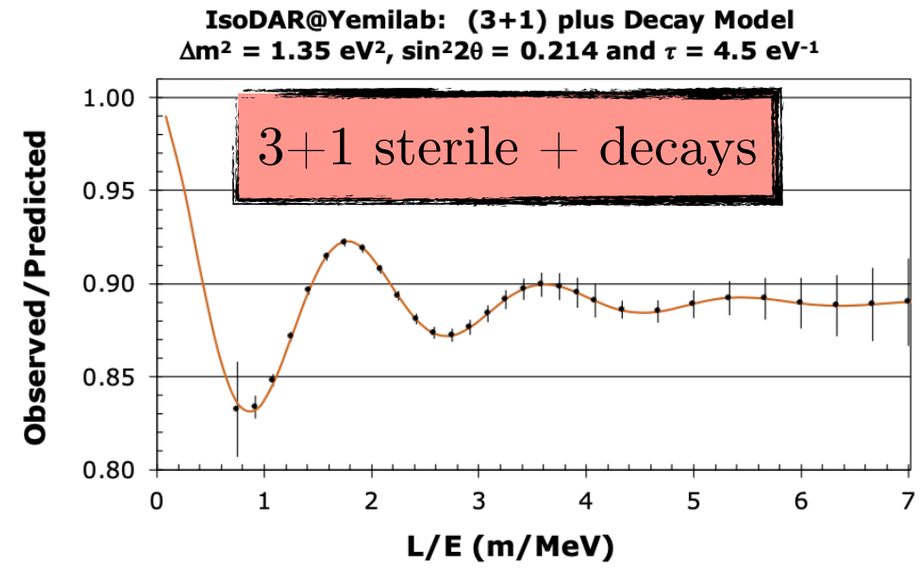


3+1 sterile



3+2 steriles



3+1 sterile + decays

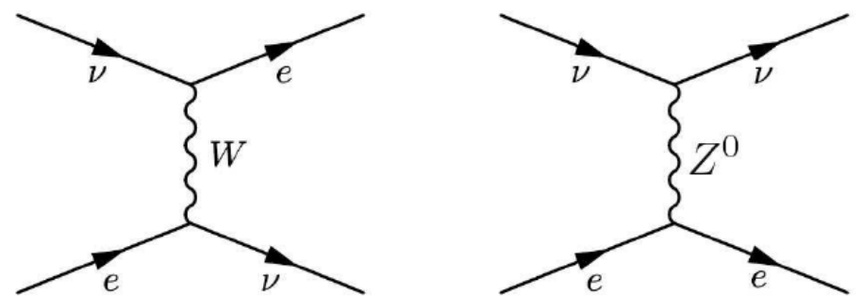
- Good discrimination between 3+1, 3+2, and 3+1 + decay scenarios
- 3+1 + decay: short-lived ν_4 decay, relevant for ameliorating disagreement between appearance and disappearance data

Neutrino-electron NSI

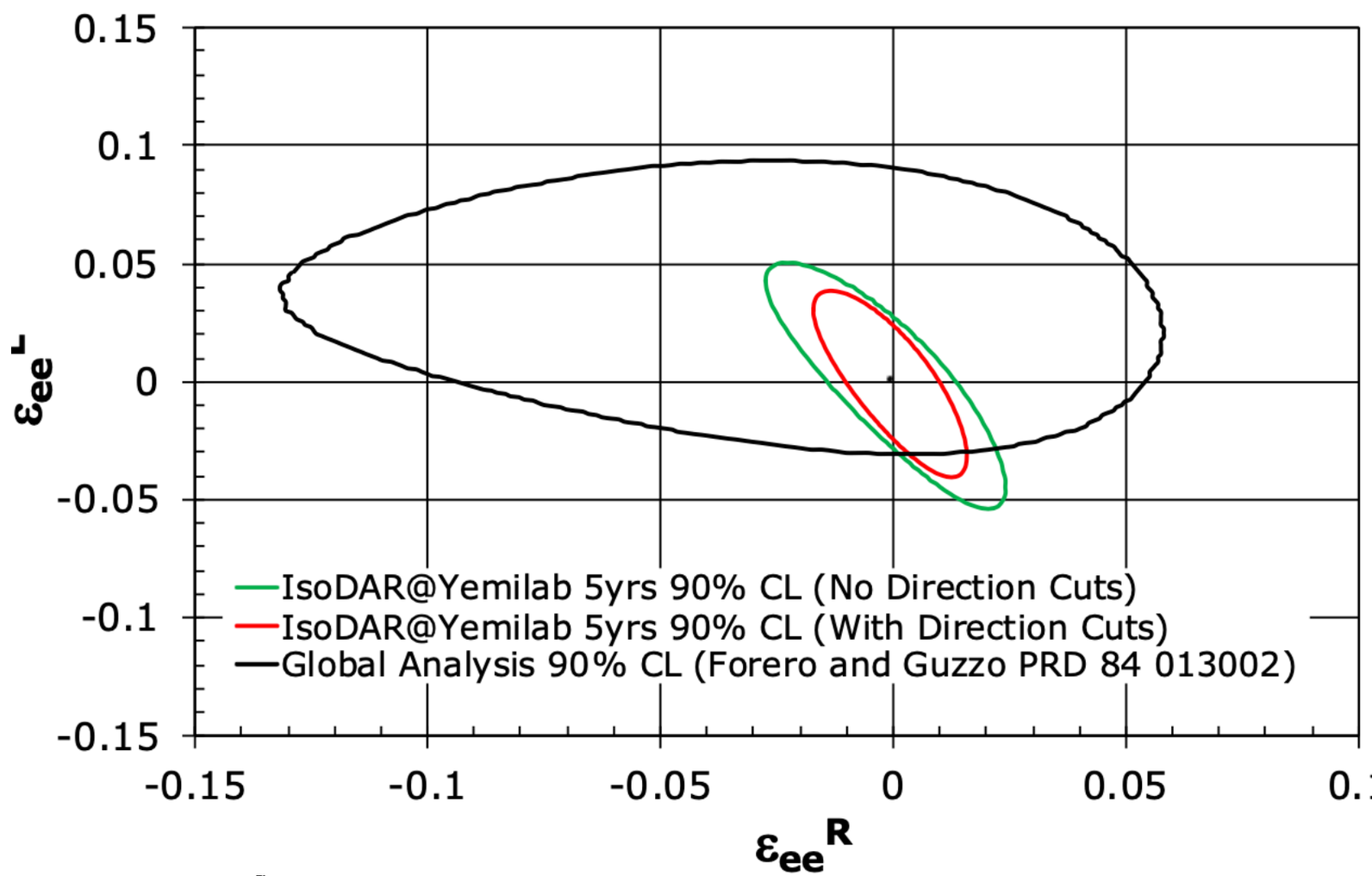
$$\mathscr{L}_{NSI} = -2\sqrt{2}G_F \sum_{\alpha,\beta} \left[\epsilon^{e,L}_{\alpha\beta}(\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta)(\bar{e}\gamma_\mu P_L e) + \epsilon^{e,R}_{\alpha\beta}(\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta)(\bar{e}\gamma_\mu P_R e) \right]$$

- IsoDAR: large volume —> large N number of target electrons
- e^+ / e^- Energy resolution: $6.4\%/\sqrt{E}$ —> good shape discrimination for SI vs NSI effects
- Very important measurement for the big-picture strategy for constraining NSI degeneracies in oscillations

$$\frac{d\sigma(E_\nu, T)}{dT} = \frac{2G_F^2 m_e}{\pi} \left[\left(\tilde{g}_R^2 + \sum_{\alpha \neq e} |\epsilon^{eR}_{\alpha e}|^2 \right) + \left(\tilde{g}_L^2 + \sum_{\alpha \neq e} |\epsilon^{eL}_{\alpha e}|^2 \right) \left(1 - \frac{T}{E_\nu} \right)^2 - \left(\tilde{g}_R\, \tilde{g}_L + \sum_{\alpha \neq e} |\epsilon^{eR}_{\alpha e}||\epsilon^{eL}_{\alpha e}| \right) m_e \frac{T}{E_\nu^2} \right]$$

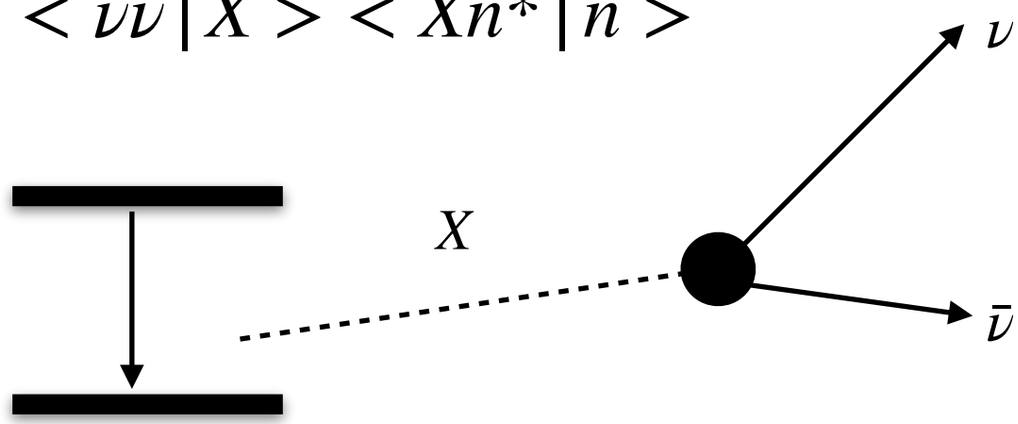


+ heavy, neutral, vector mediator

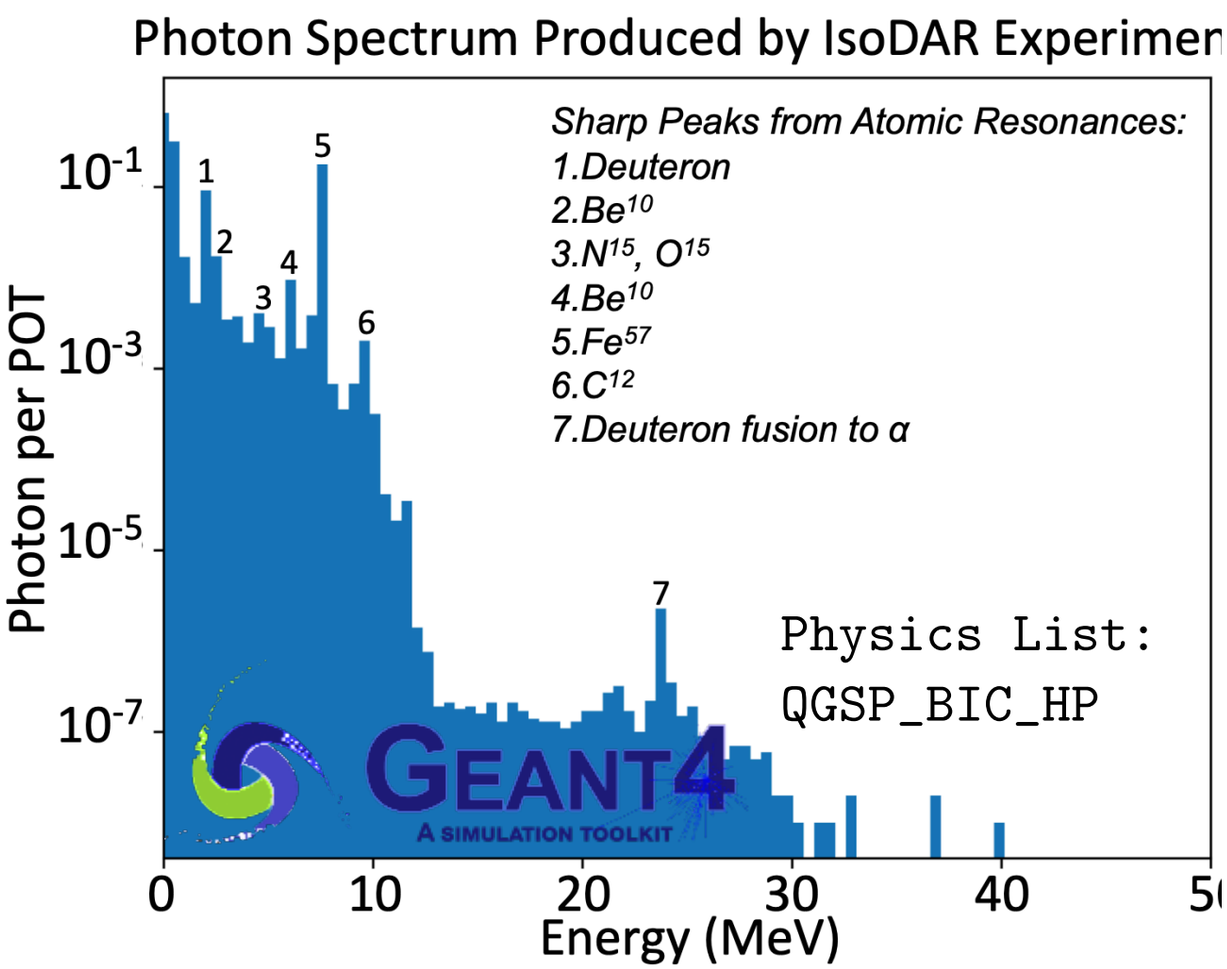


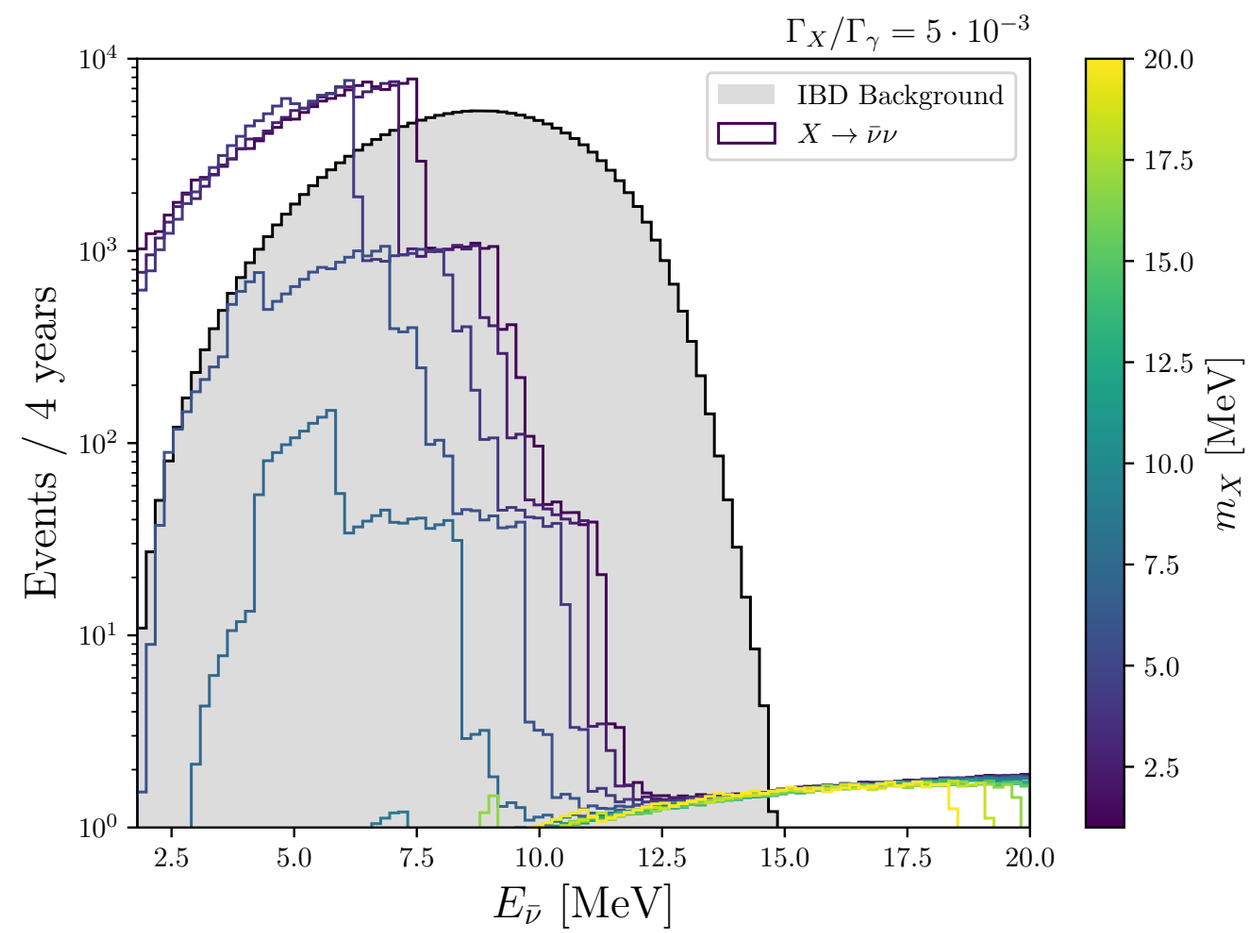
Search for Bosonic States from Nuclear Transitions

$< \bar{\nu}\nu \,|\, X > < Xn^* \,|\, n >$



- Massive X boson produced from nuclear transitions, prompt decay to $\nu - \bar{\nu}$
- Look for bumps/features in the IBD spectrum





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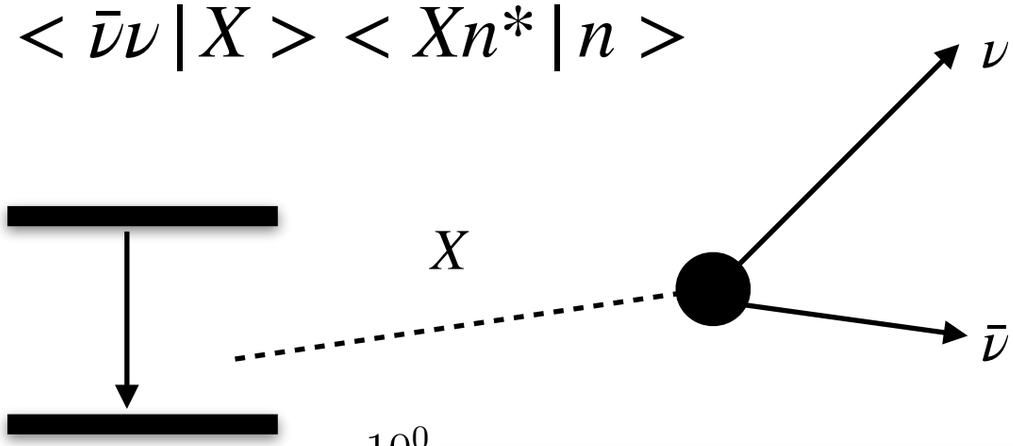

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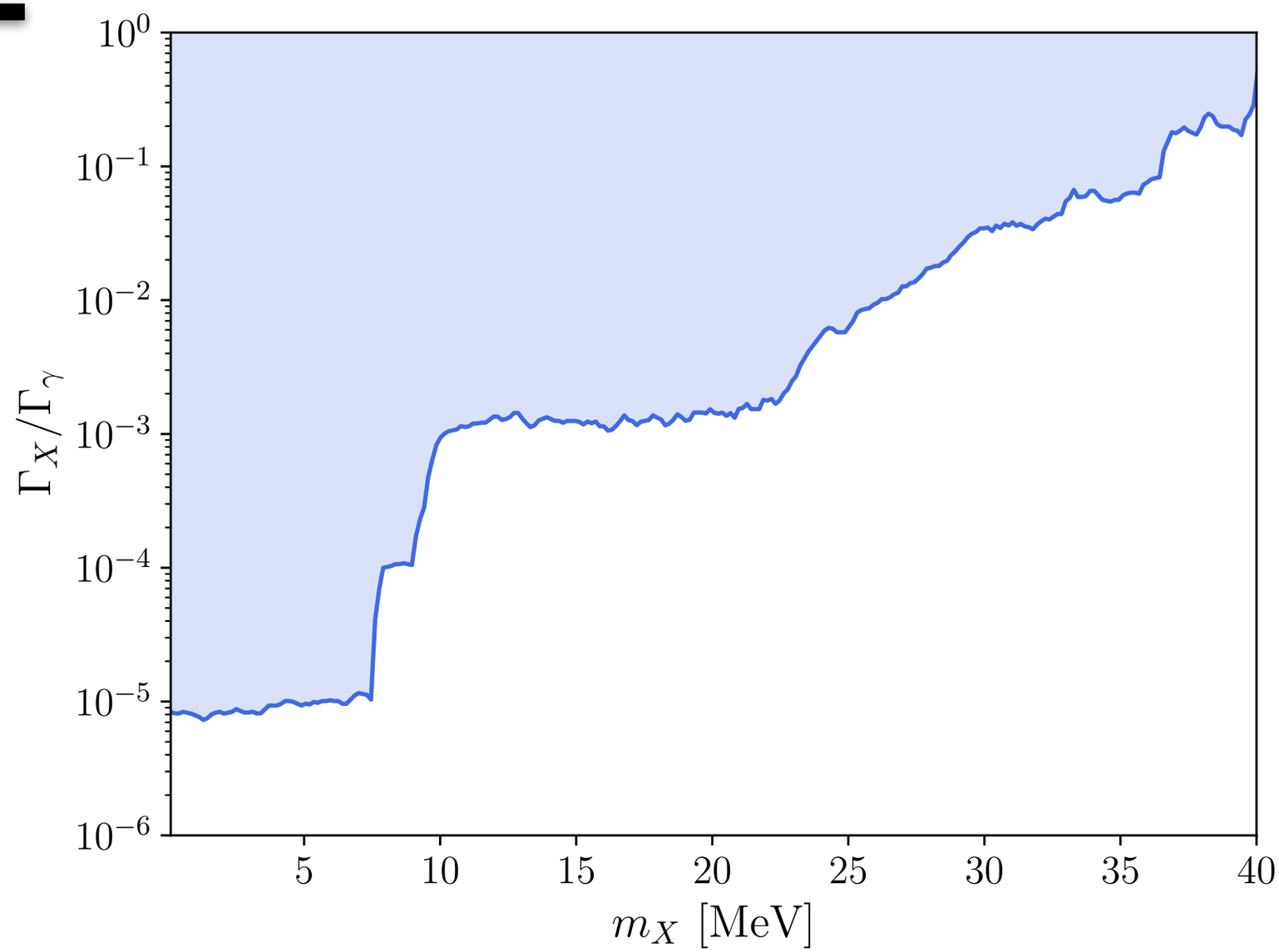
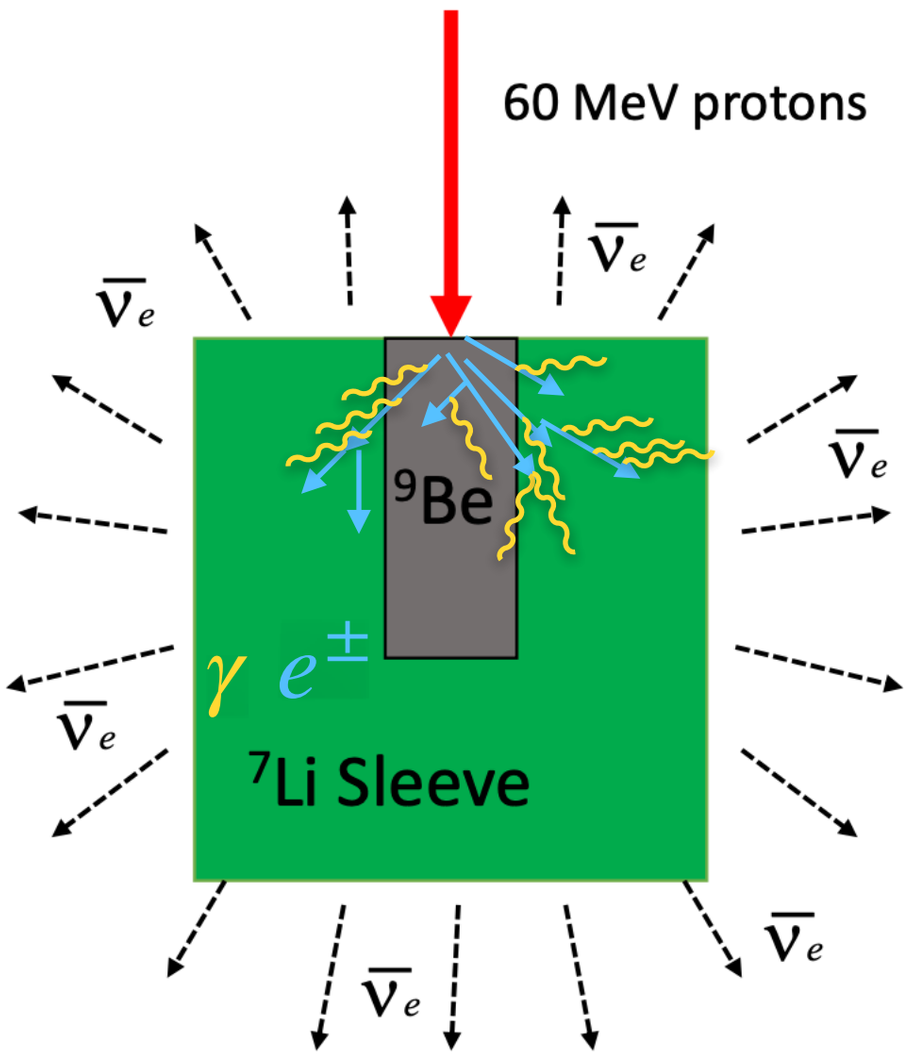


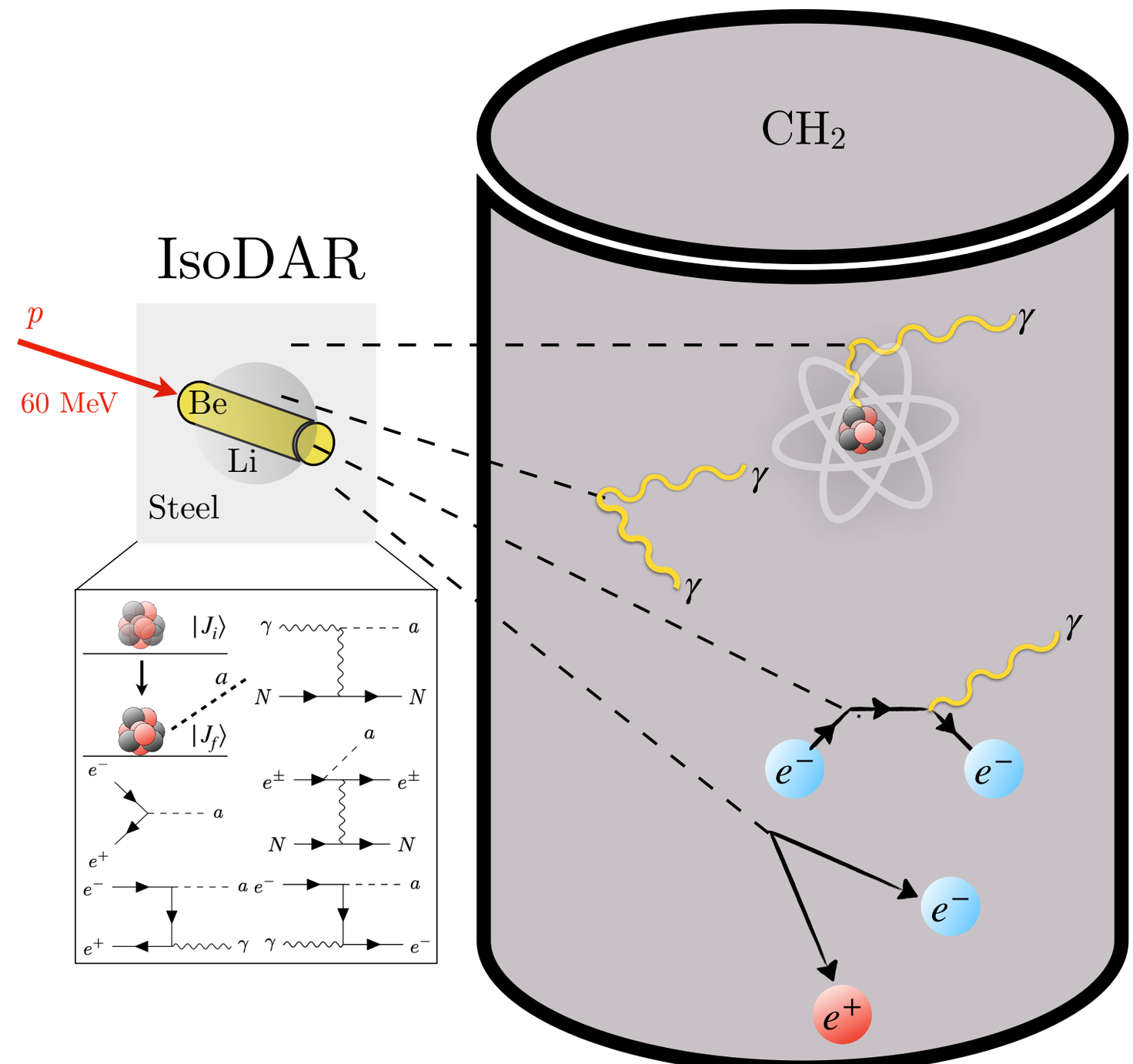
Coming soon to arXiv!

Axion-like Particle Searches

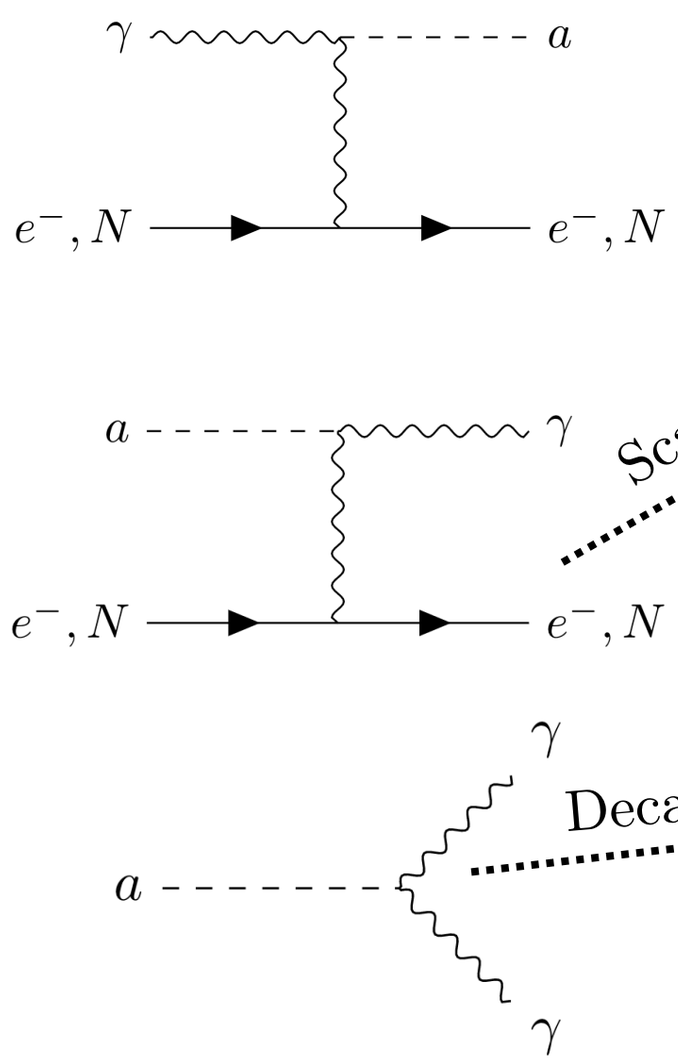
$$\mathscr{L} \supset -\frac{1}{4} g_{a\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} + i g_{ae} a \bar{\psi}_e \gamma^5 \psi_e + i a \bar{\psi}_N \gamma_5 (g^0_{aNN} + g^1_{aNN} \tau_3) \psi_N$$

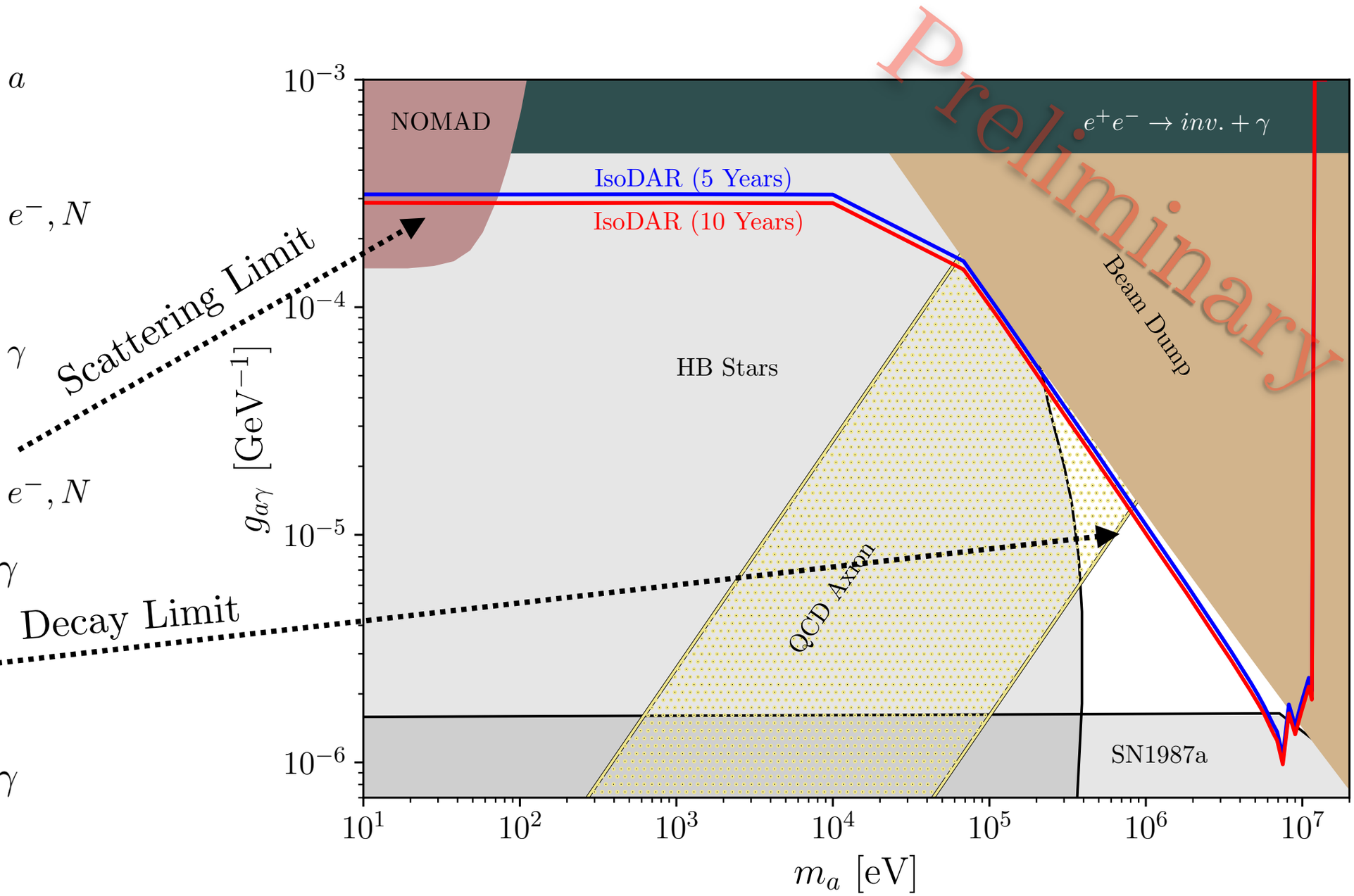


QGSP_BIC_HP

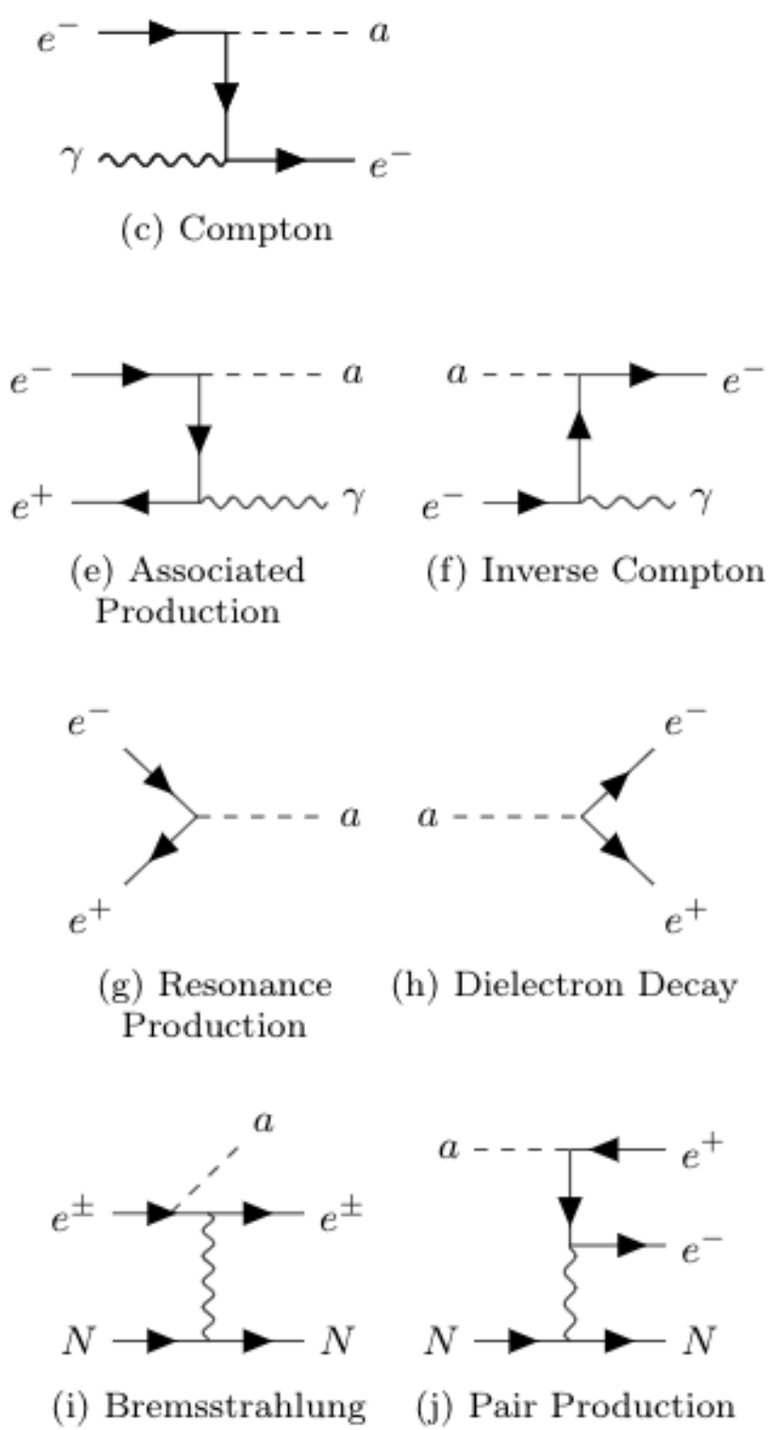


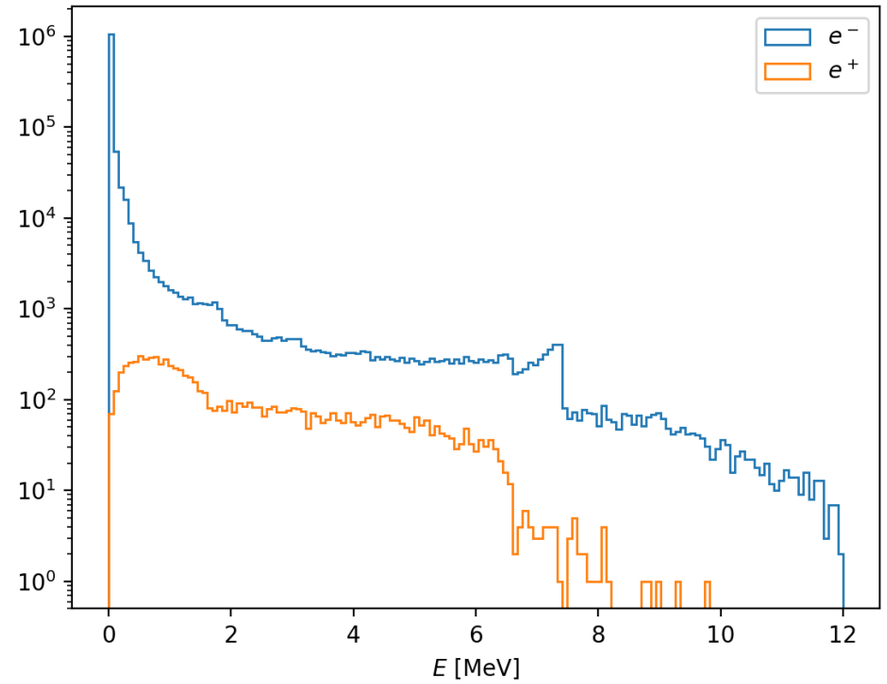
Axion-photon Coupling

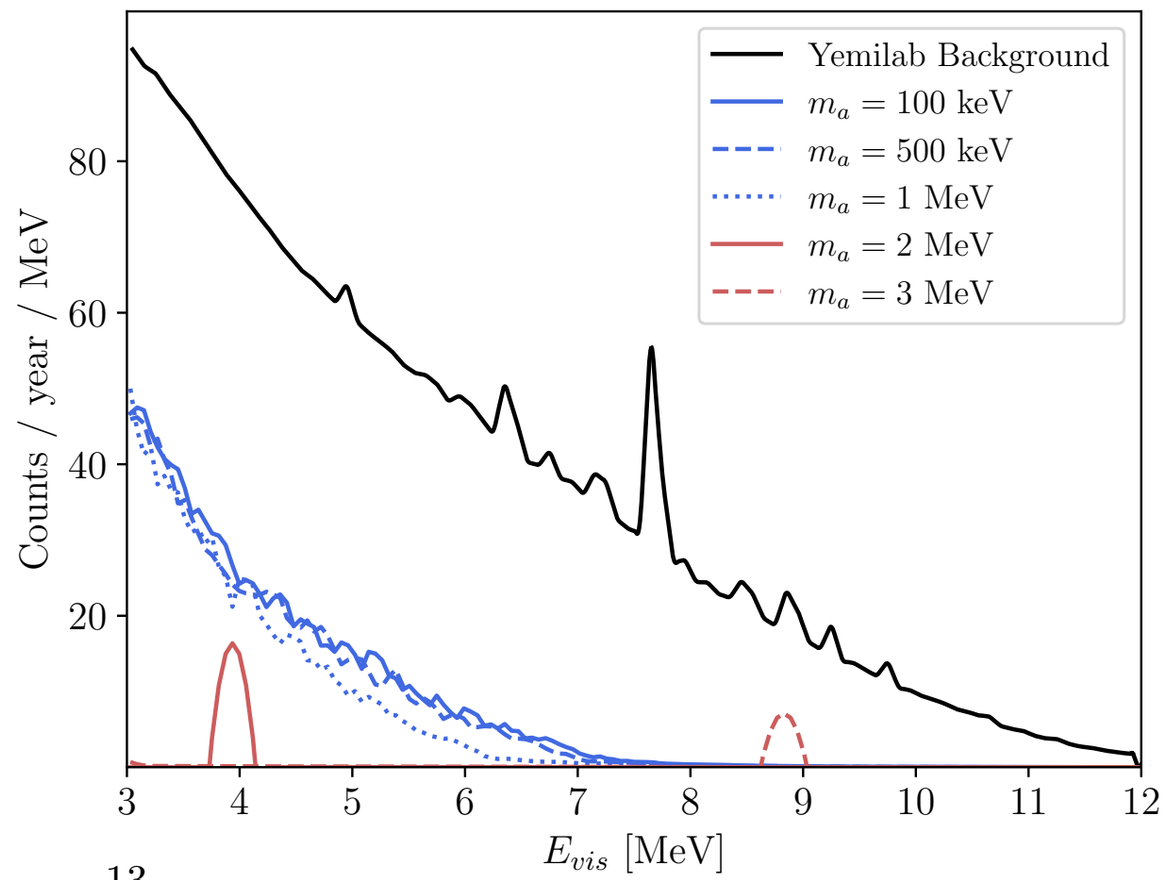




Axion-electron Coupling







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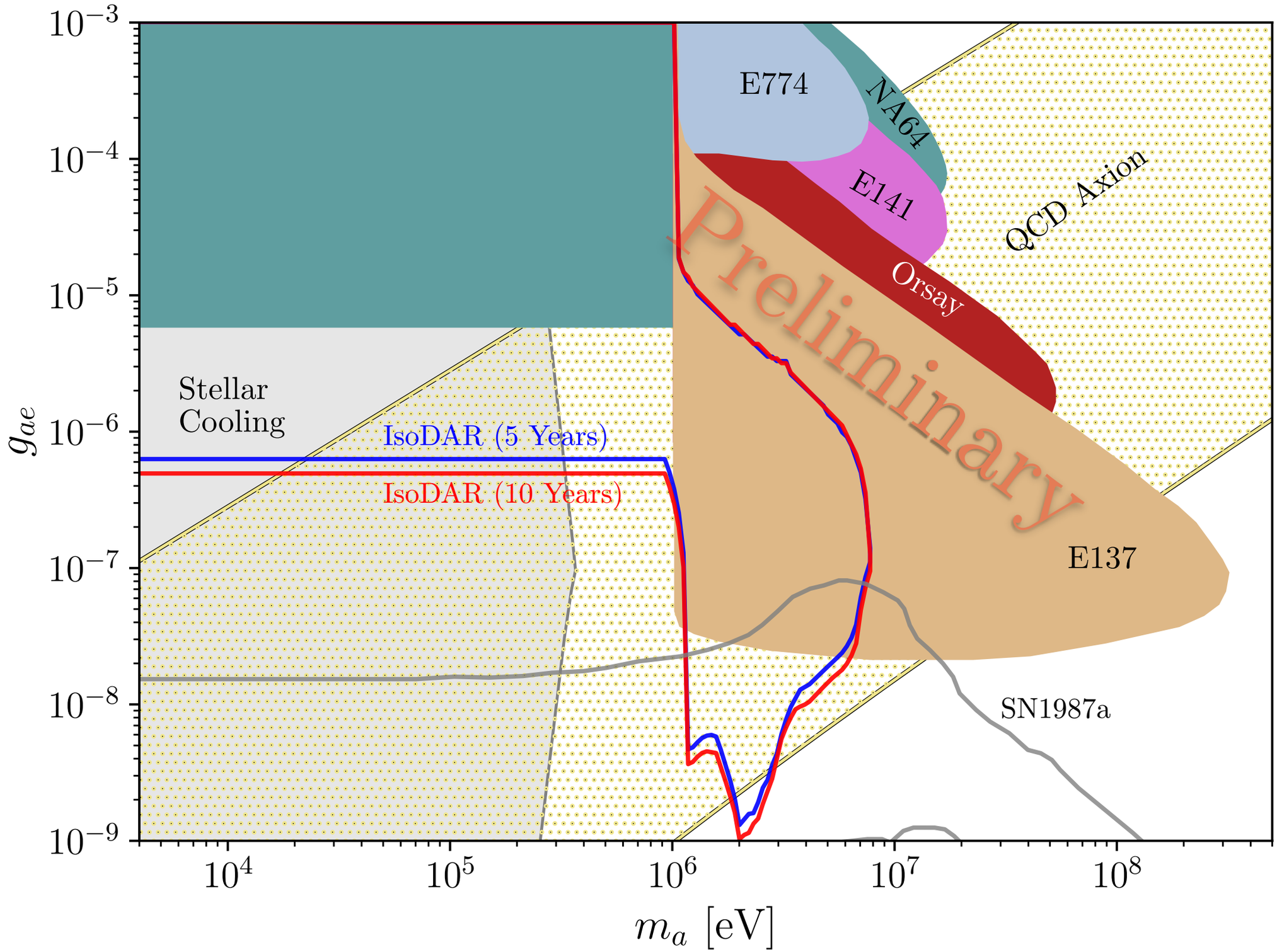
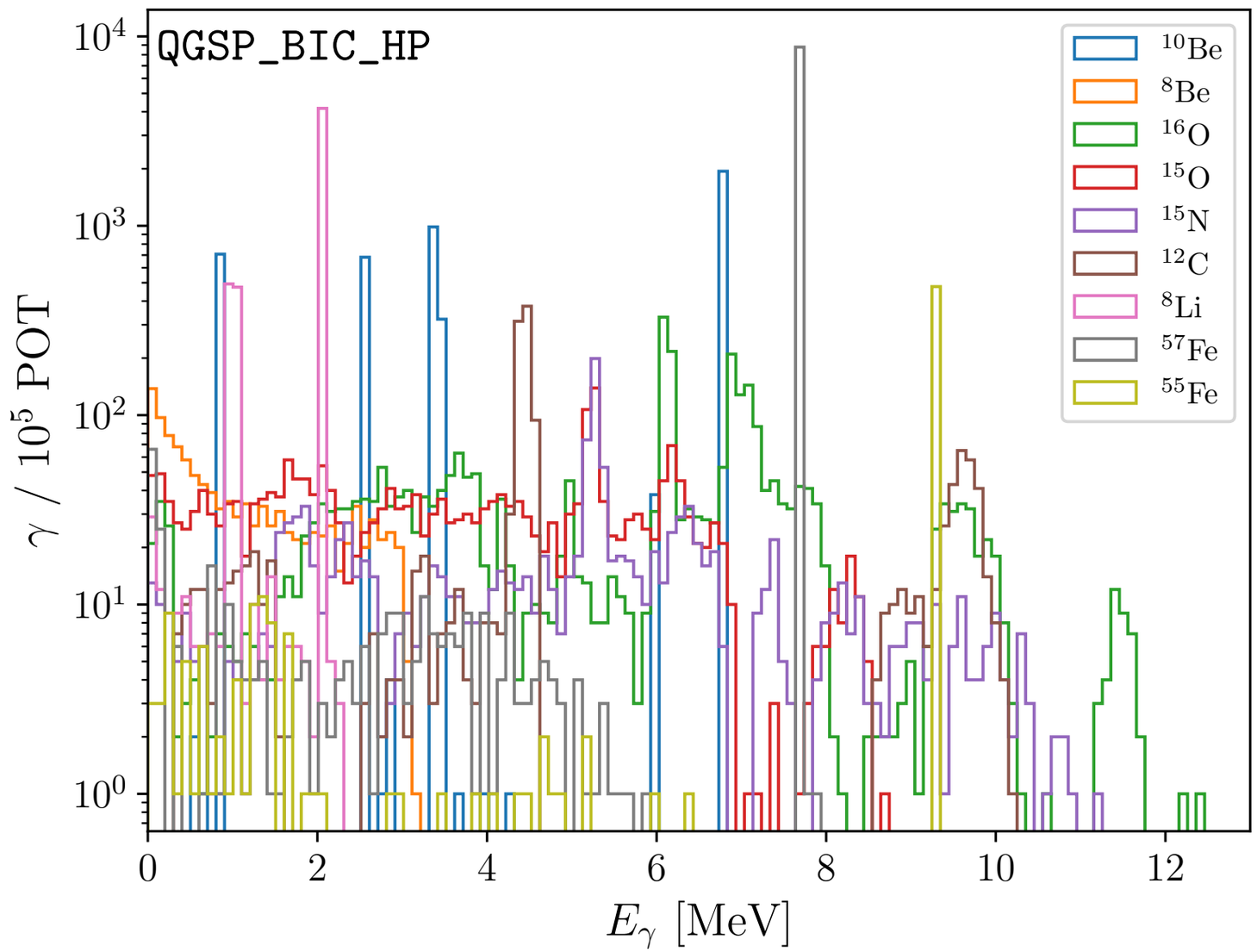


Axion-nucleon Coupling

$$\left(\frac{\Gamma_a}{\Gamma_\gamma}\right)_{\mathrm{MJ}} = \frac{1}{\pi\alpha}\frac{1}{1+\delta^2}\frac{J}{J+1}\left(\frac{|\vec{p}_a|}{|\vec{p}_\gamma|}\right)^{2J+1}\left(\frac{g_{ann}(1+\beta)}{(\mu_0-1/2)\beta+\mu_1-\eta}\right)^2,$$

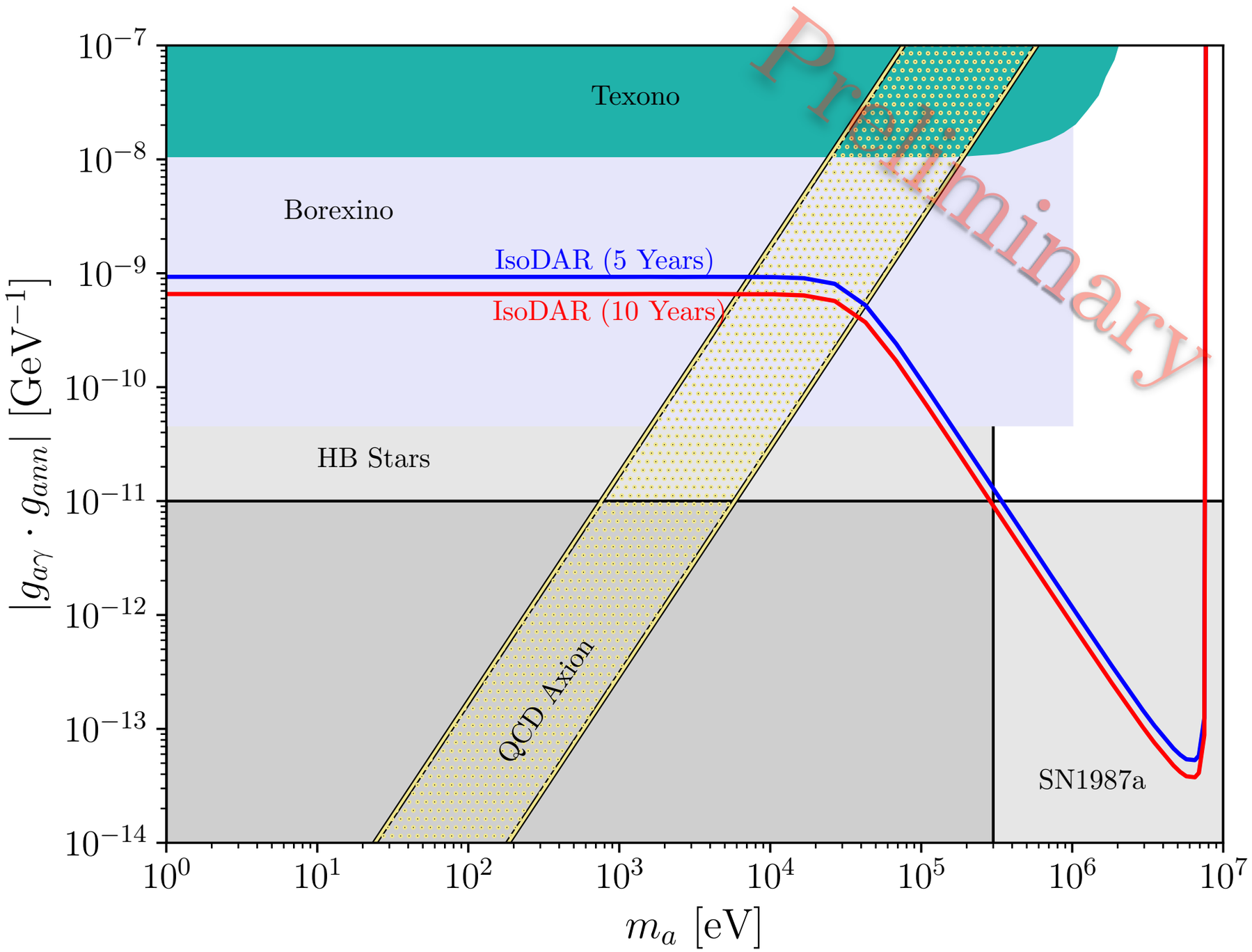
- Magnetic moment transitions with angular momentum change J
  - *e.g.* M1, M2 transitions
- Produces monoenergetic ALP flux in place of the usual gamma peak

Nucleus	Energy in MeV	Type	β	η
Fe57	7.606	M1	0.7071	-0.3111
Li8	1.009	M1	1	-0.0260
Li8	2.053	M1	1	-0.1034
O15	5.281	M2	1	0.5



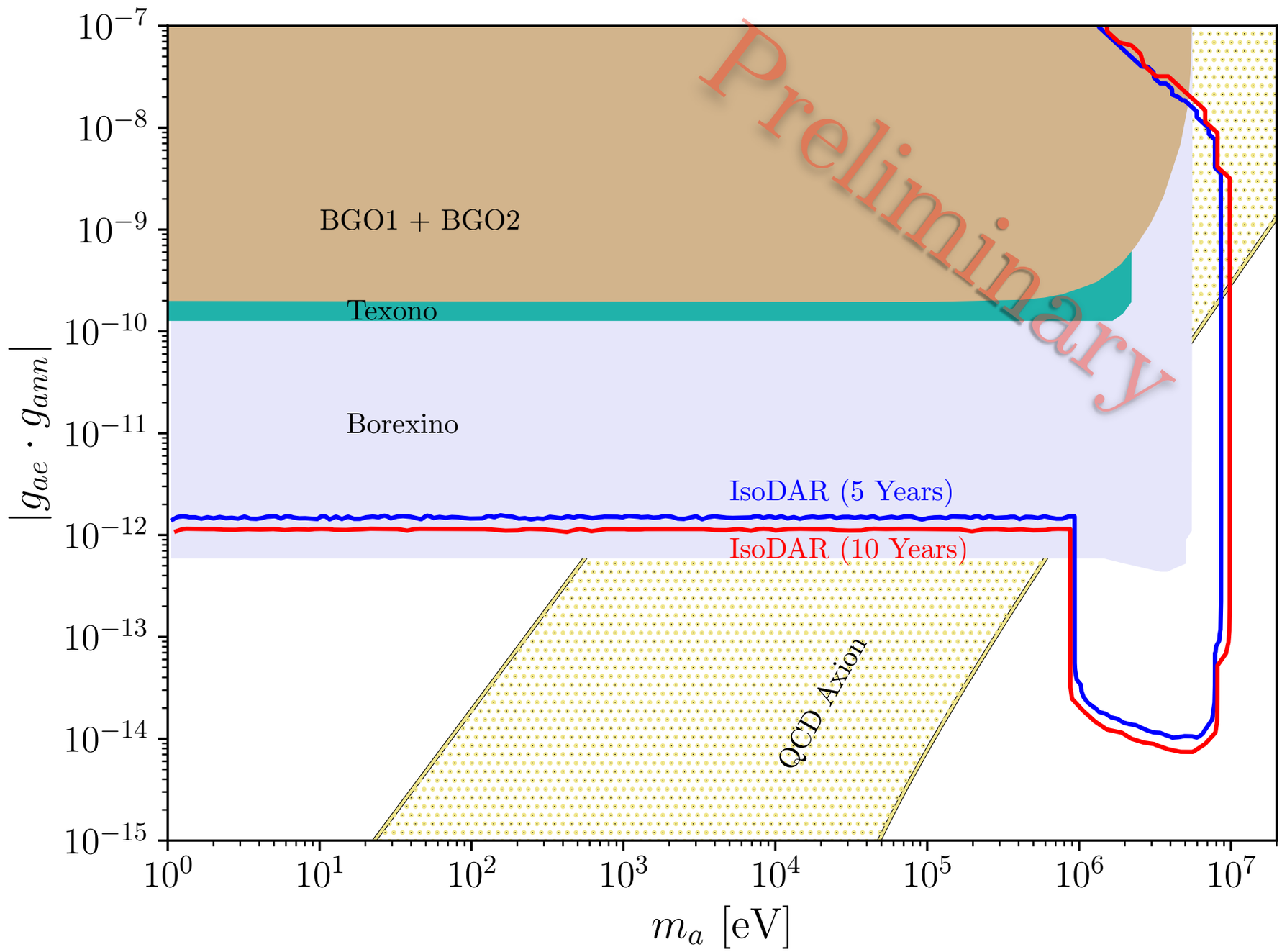
Axion-nucleon Coupling

Detection via Coupling to Photons



Axion-nucleon Coupling

Detection via Coupling to Electrons



IsoDAR Outlook:

- Positioned well to not only make measurements of weak physics, neutrino physics, but also to test short baseline anomalies
- Exciting search opportunities for sterile neutrinos, axion-like particles, and many other BSM signatures
- Exploiting the clear nuclear transition spectra at the IsoDAR target, in addition to the electromagnetic cascades, opens up lots of phenomenological probes into BSM physics to compliment the neutrino program
- Excavation of LSC hall at Yemilab completed, construction underway!

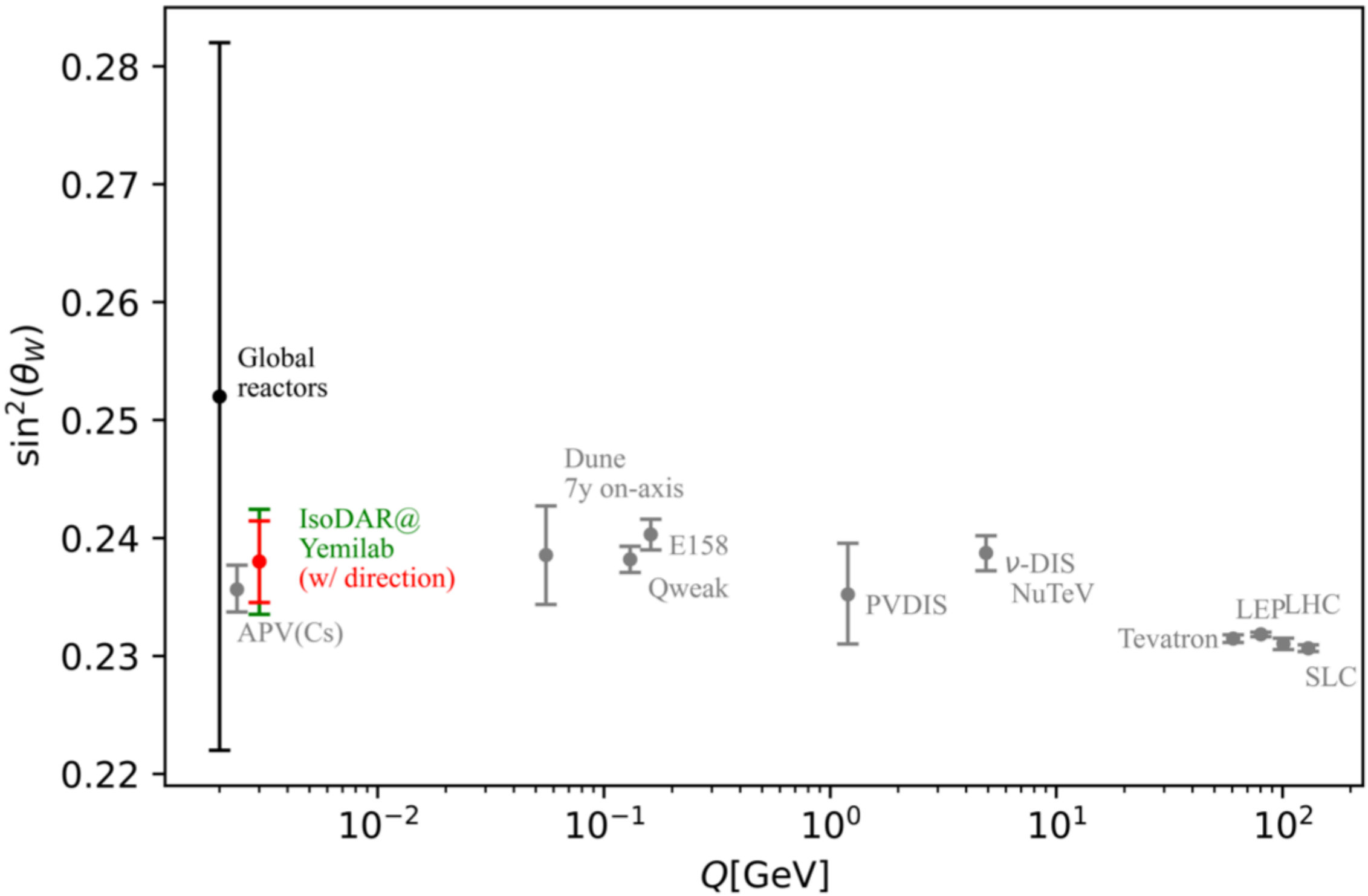
Thank you!

Close collaborators:

Janet Conrad
Loyd Waites
Bhaskar Dutta
Wei-Chih Huang
Joshua Spitz
Doojin Kim
Adriana Bungau
Michael Shavitz

Backup Slides

Weak Mixing Angle Measurement



Electron Scattering Measurement