New physics and rare decays at the Jefferson Lab Eta Factory

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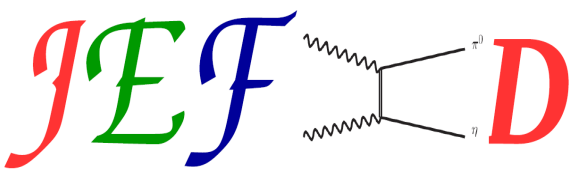
For the GlueX Collaboration

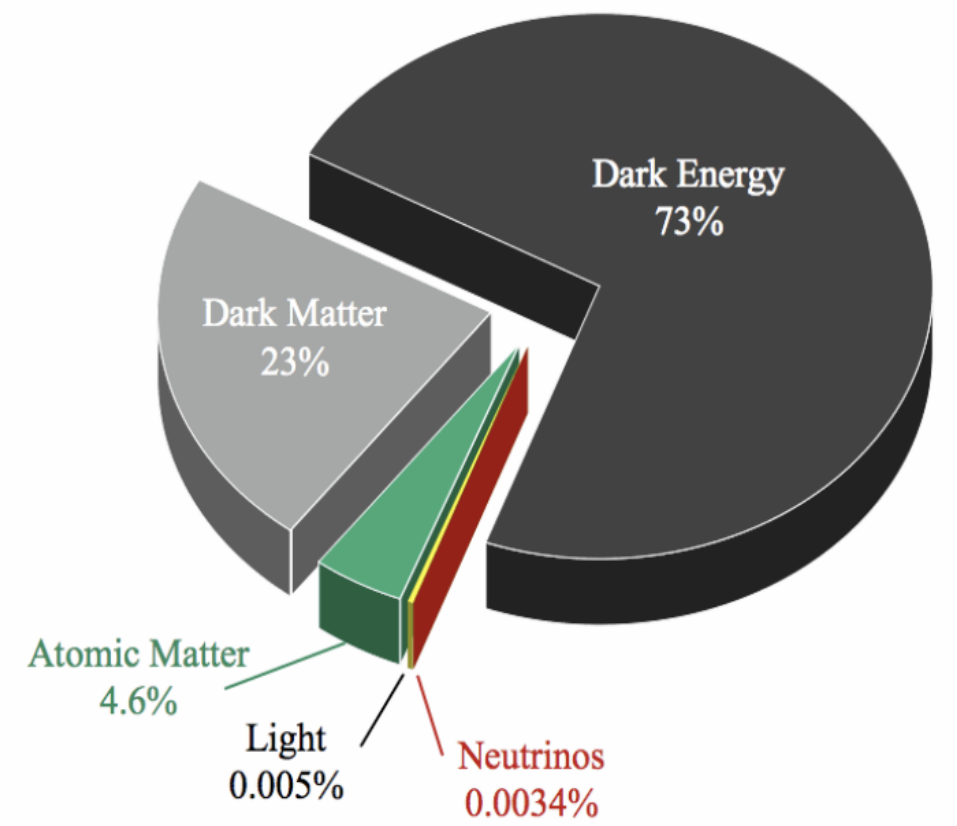
April 13, 2021
9th Workshop of the APS Topical Group on Hadronic Physics



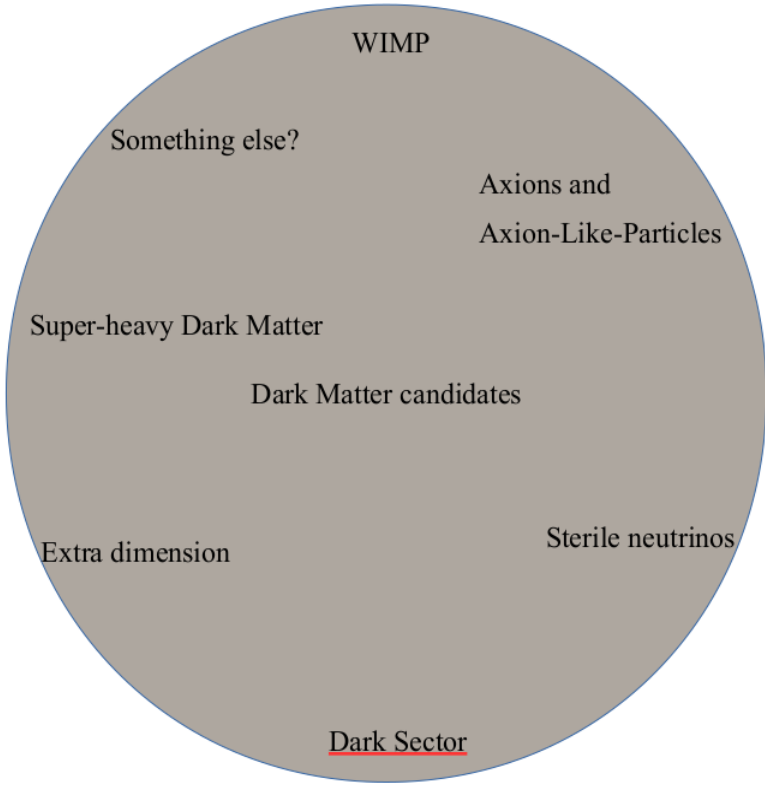
Introduction

Robust evidence of new physics and many candidates

- Energy budget



- Dark matter candidates

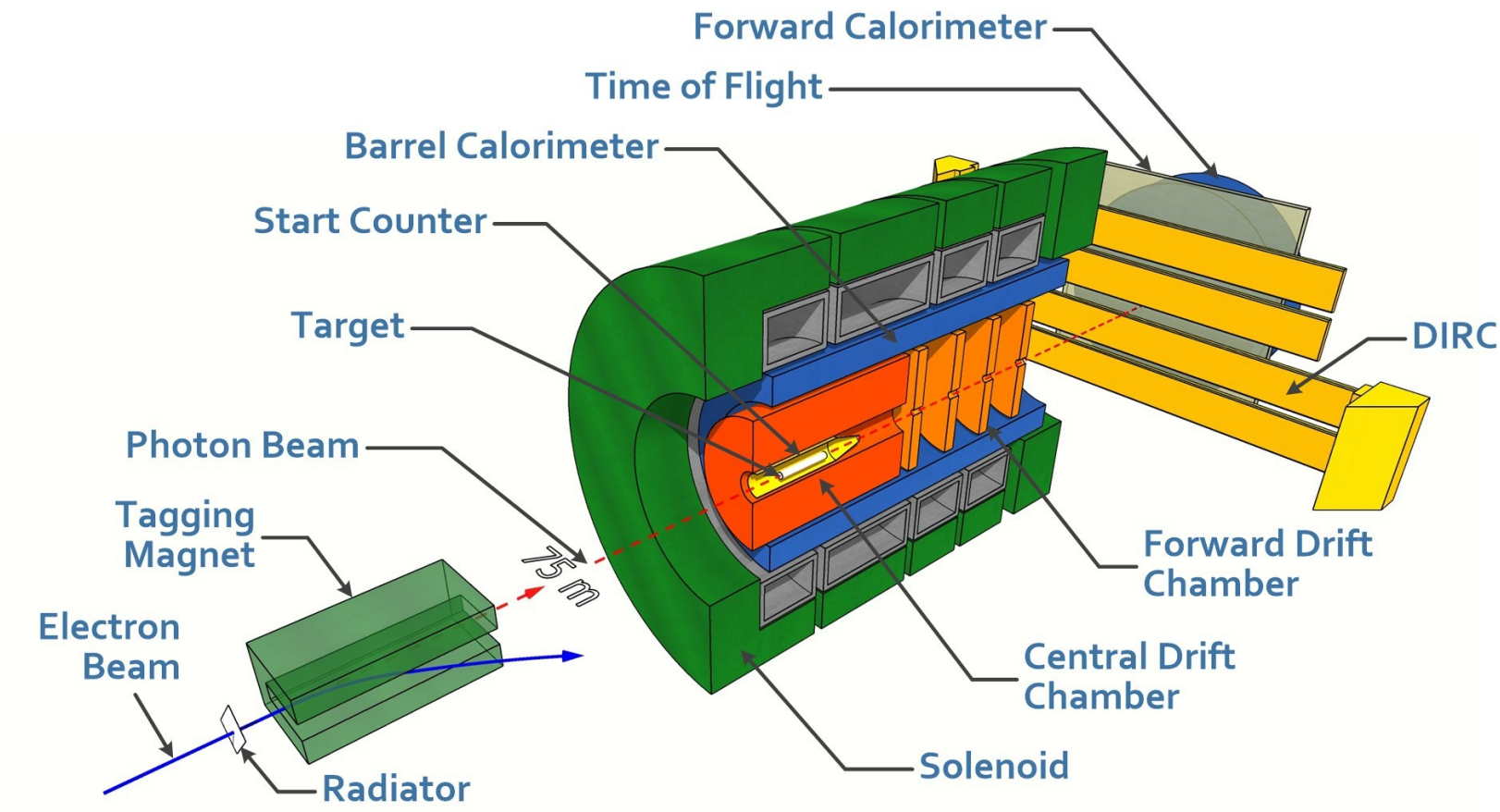


Jefferson Lab Eta Factory will probe different Dark Sector Models, $\mathcal{L} = c\, \mathcal{O}_{\text{visible}}\, \mathcal{O}_{\text{hidden}}$

The GlueX setup

Photon-beam produced by (coherent) bremsstrahlung, $e^-_{\text{beam}} A_{\text{radiator}} \to e^-_{\text{deflected}} A\gamma_{\text{tagged}}$

NIMA 987 164807 (2021) - arxiv:2005.14272



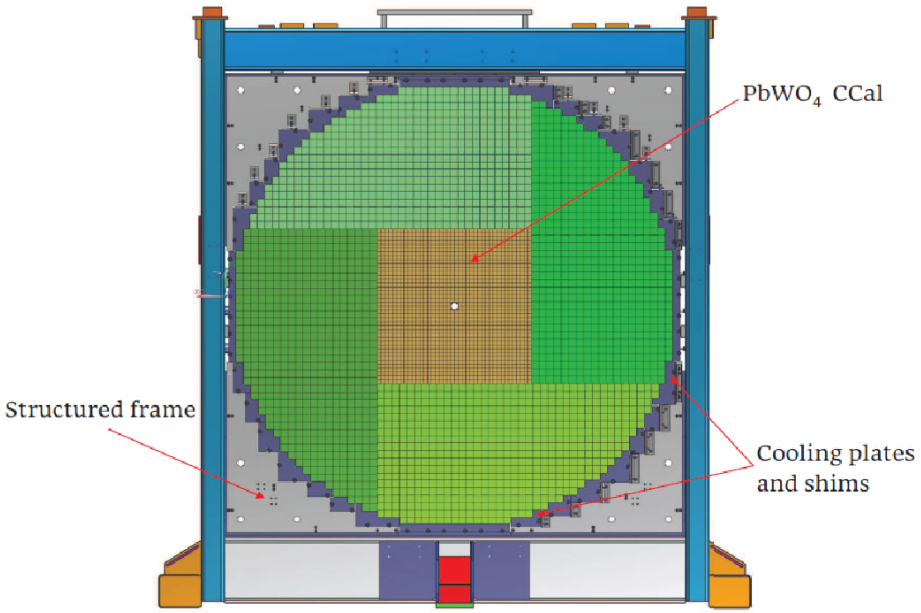
Typical integrated luminosity, $\mathcal{L} \sim 200$ pb^{-1} per month for $E_\gamma = 8 \to 11.7$ GeV

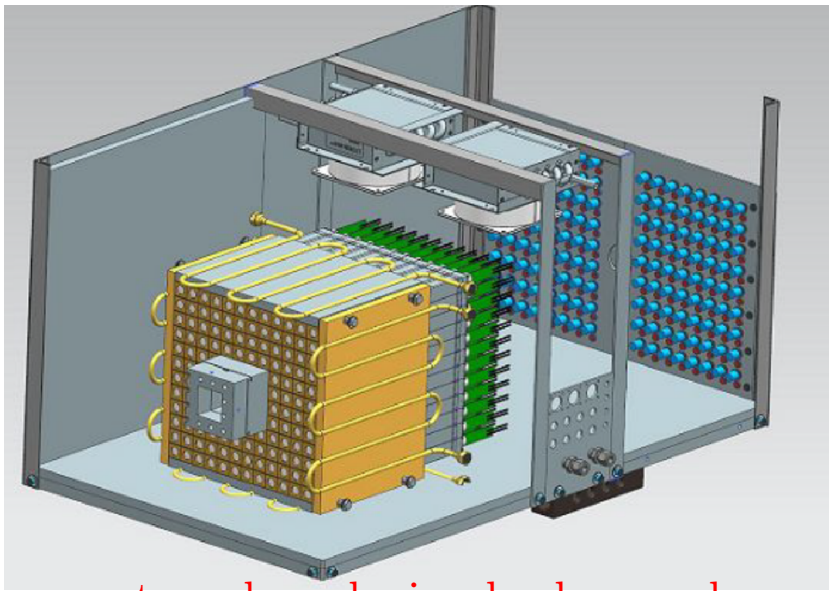
The JLab Eta Factory

Expected to produce $\sim 5 \times 10^7$ η in 100 days between 8.4 and 11.7 GeV in E_γ

Experiment	total η	total η'
CB/AGS	10^7	-
CB/MAMI	2×10^7	-
CB/MAMIC	6×10^7	10^6
WASA/COSY	$\sim3\times10^7$ (p+d) $\sim5\times10^8$ (p+p)	-
KLOE-II	3×10^8	5×10^6
BES-III	$\sim10^7$	$\sim5\times10^7$

- Upgraded Forward Calorimeter covers angle between 1 and 8^o ($\sim$6 m from target center)
- Compton Calorimeter covers angle between 0.6 and 1^o ($\sim$12 m from target center)

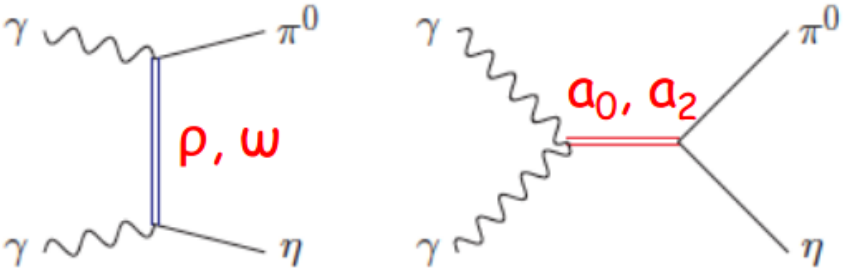


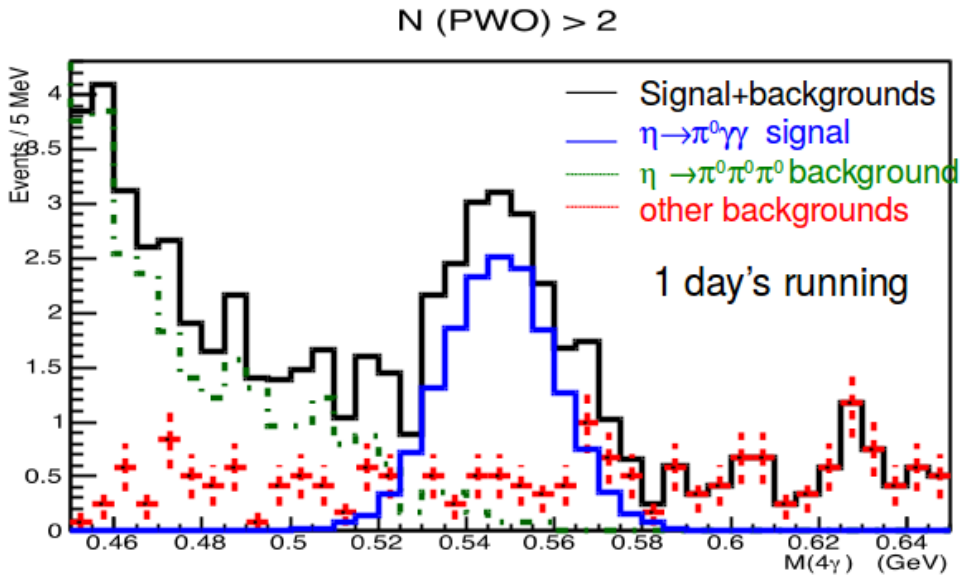


Exclusive measurements and large solid angle coverage strongly reducing background

$\eta^{(\prime)}$ photoproduction at JEF

$\gamma p \to \eta^{(\prime)} p$, boosted $\eta^{(\prime)}$ decaying into photons





- Study rare $\eta^{(\prime)}$ decay and in particular $\eta \to \gamma\gamma\pi^0$, BR $= 2.7\times10^4$
- Search for BSM at very forward angle
  - Leptophobic dark vector gauge boson: $\eta^{(\prime)} \to B'\gamma$ with $B' \to \gamma\pi^0$ or $\pi^+\pi^-\pi^0$ $(0.14 \leq m_{B'} \leq 0.957\ \mathrm{GeV}/c^2)$
  - Leptophilic dark vector gauge boson: $\eta^{(\prime)} \to A'\gamma$ with $A' \to l^+l^-$ ($l = e$ or μ) or $\pi^+\pi^-$
  - Dark scalar gauge boson: $\eta^{(\prime)} \to S\pi^0$ ($\eta' \to \eta S$) with $S \to \gamma\gamma$ or l^+l^- or $\pi^+\pi^-$ $(0.01 \leq m_S \leq 1\ \mathrm{GeV}/c^2)$
  - ALPs: $\eta^{(\prime)} \to \pi\pi a$ with $a \to \gamma\gamma$ or e^+e^-

Background is highly suppressed - JEF and GlueX physics programs will run in parallel

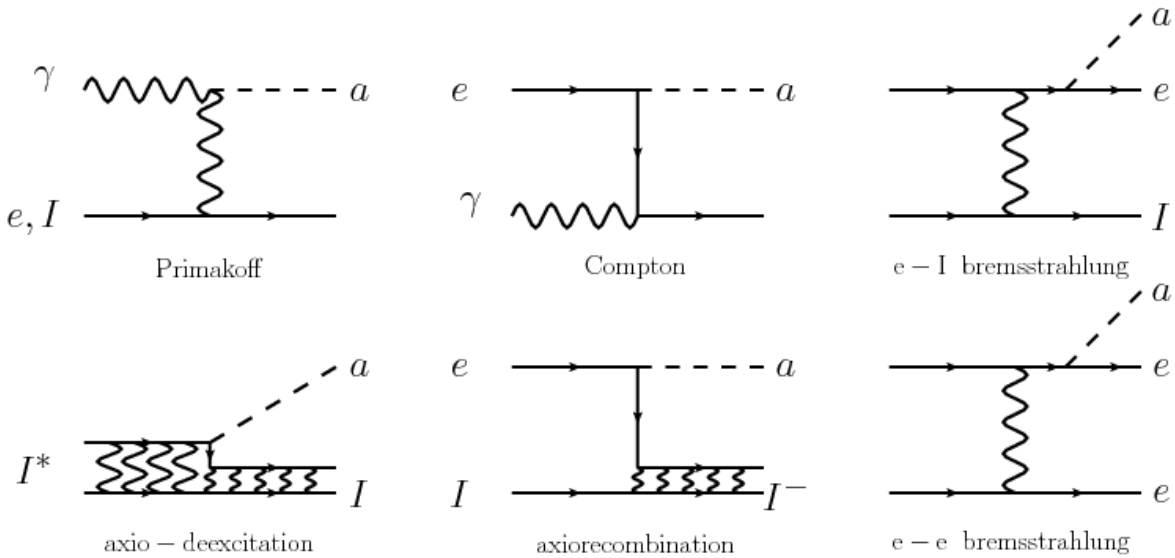
Photon-beam and new light physics searches

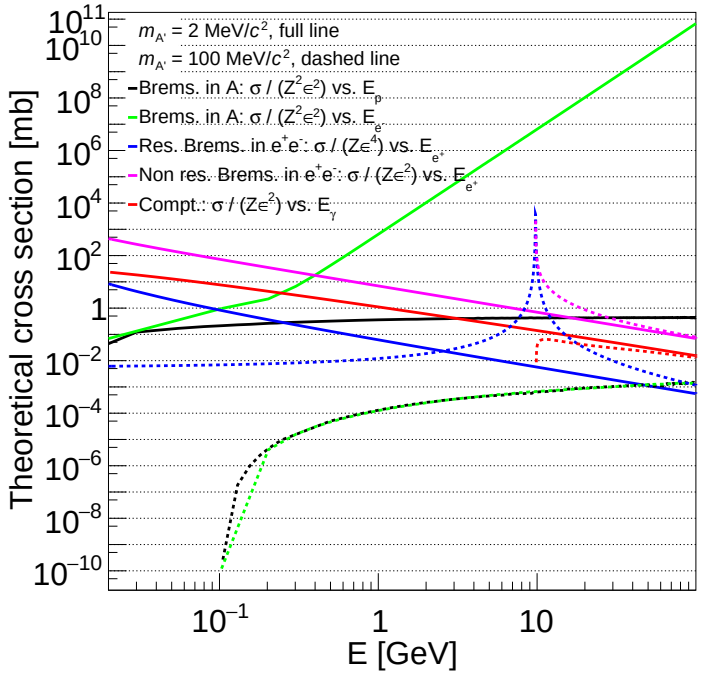
New light physics produced off a nucleon, nucleus, or atomic electron

- $\gamma N \to XN$ (D. Aloni et al. PRL 123 (2019), arXiv:1811.03474 but for ALP case)
- $\gamma A \to XA$ (D. Aloni et al. PRL 123 (2019), arXiv:1811.03474 but for ALP case)
- $\gamma e^- \to Xe^-$ S. S. Chakrabarty et al. arxiv:arXiv:1903.06225

  Where: X = dark scalar, pseudo-scalar, vector, or pseudo-vector - N: nucleon - A: nucleus - e^-: electron

  X is either invisible or visible i.e. decays $X \to \gamma\gamma$ or $X \to l^+l^-$ (l = lepton)
- Shape/bump search in invariant mass or missing mass distribution



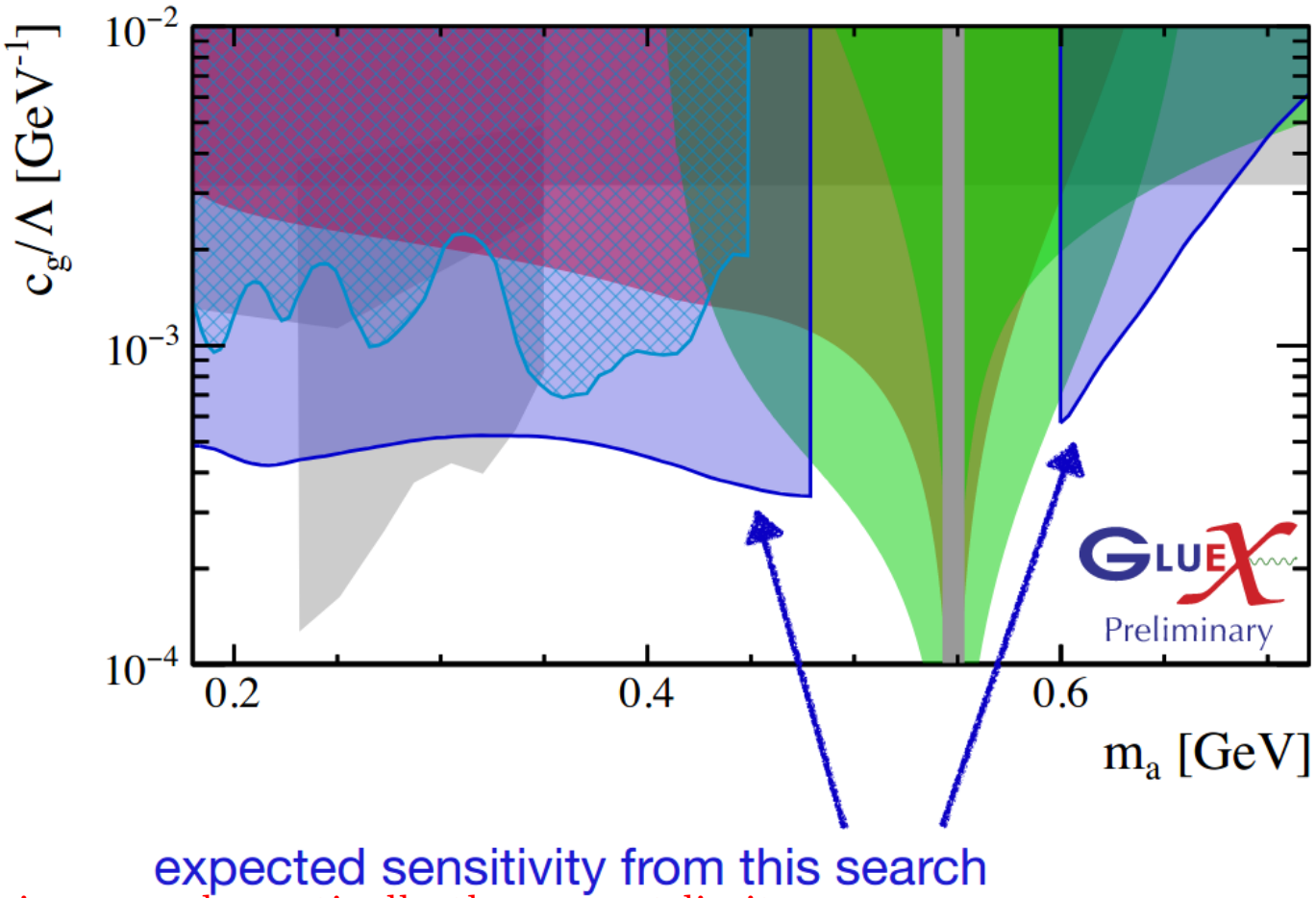


Signal strength much lower than other processes but $S/\sqrt{B}$ highly competitive

Expected GlueX sensitivity on ALP coupling to gluons

$\gamma p \to ap$, $\mathcal{L} = 170$ pb^{-1}, Y. Yang et al in preparation

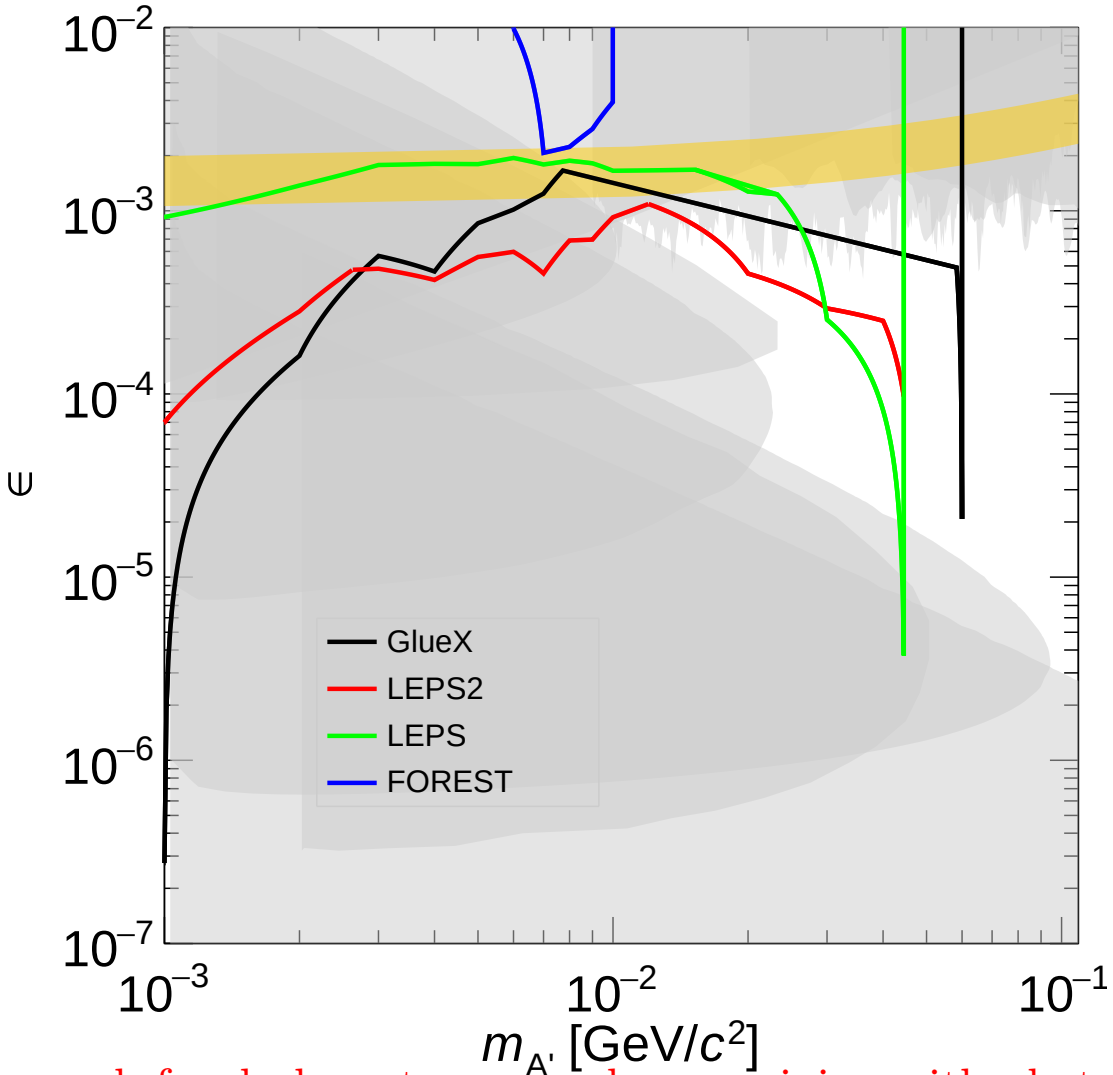
- $a \to \gamma\gamma$
- $a \to \pi^+\pi^-\pi^0$



Expected to improve dramatically the current limit

Expected sensitivity for 30 days

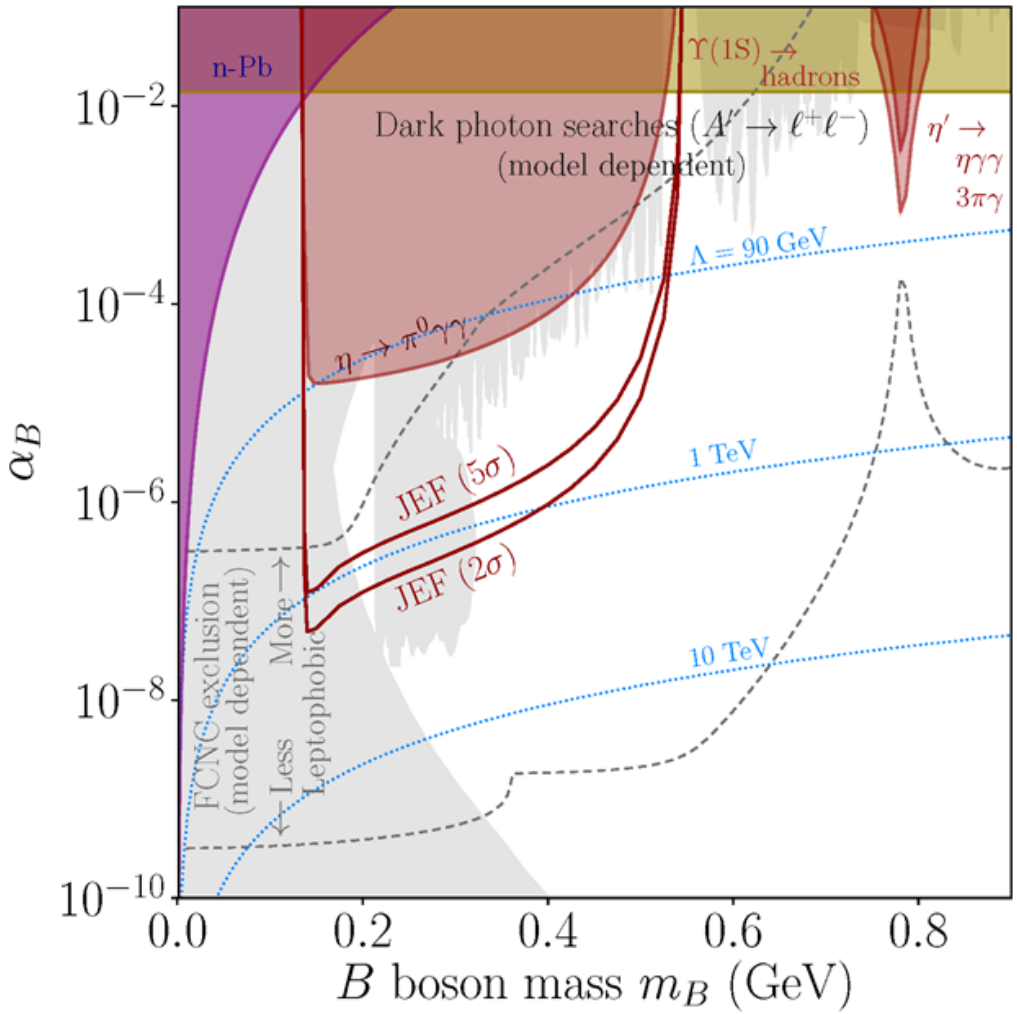
Compton dark photom photoprodction, $\gamma e^- \to A' e^-$, S. S. Chakrabarty et al.
(Yellow band corresponds to the old g-2 results)



JEF competitive to search for dark vector gauge boson mixing with photon

Expected sensitivity for 100 days

Leptophobic dark photon, $\gamma p \to \eta(\to B'\gamma)p$ A. E. Nelson et al. PLB 221 80 (1989) and S. Tulin PRD 89 114008 (2014)

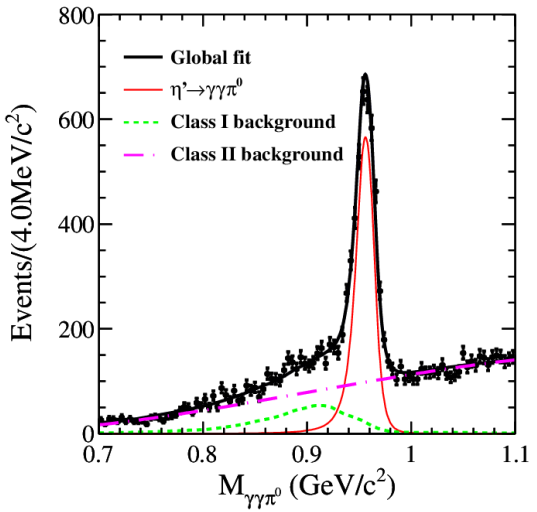


JEF competitive to search for dark vector gauge boson coupling preferentially to quarks

New physics in so rare decay, $\eta' \to \pi^0\gamma\gamma$?

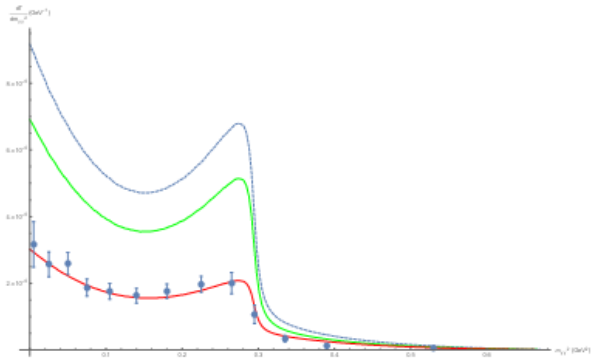
BES-III collected over a 1B J/ψ and look at J/$\psi \to \gamma\eta'$, PRD 96 012005

- Doubly-decay measyred for the first time
- BR(inclusive) = [3.2 $\pm$ 0.07 (stat) $\pm$ 0.23 (sys)] $\times 10^{-3}$
- BR($\eta' \to \gamma\omega$) = [23.7 $\pm$ 1.4 (stat) $\pm$ 1.8 (sys)] $\times 10^{-4}$
- BR(non-resonant) = [6.16 $\pm$ 0.64 (stat) $\pm$ 0.67 (sys)] $\times 10^{-4}$



But recent calculation by Y. Balytzkyi
arviv:1811.01402

- VMD + (ChPT or linear sigma model) highly suppressed
- Theory result, $\Gamma(\eta' \to \pi^0\gamma\gamma) = 1.6$ to 3 keV, desagrees with
- BES-III result, $\Gamma(\eta' \to \pi^0\gamma\gamma) = 0.64$ keV
- Evidence for leptophobic dark photon, B'? Increase mass range for B' search?

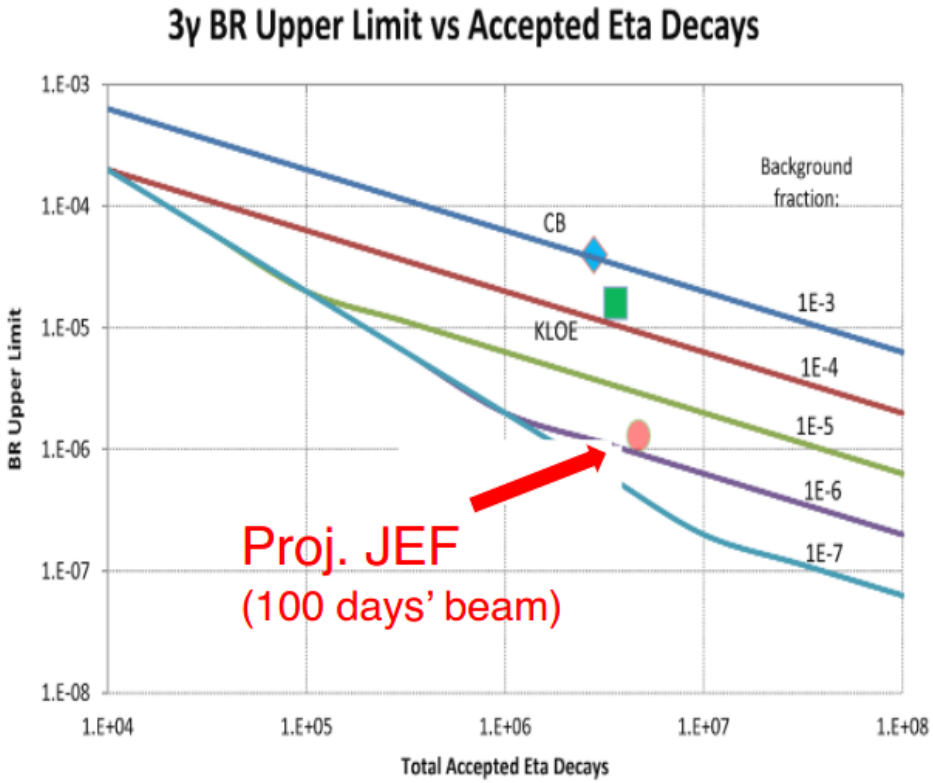


$$\frac{d\Gamma^{VMD+L\sigma M}_{\eta' \to \pi^0\gamma\gamma}}{dm^2_{\gamma\gamma}} \text{ vs. } m^2_{\gamma\gamma}$$

JEF can look at this tension between theory and experimental measurements

Rare decay: $\eta \to \gamma\gamma\gamma$

- SM contribution, BR($\eta \to \gamma\gamma\gamma$) $< 10^{-9}$ through P-violating weak interaction
- Bernstein and al. [PR 139 B1650 (1965)] proposed a new C- and T-violating and P-conserving interaction
- Tarasov's calculation gives BR($\eta \to \gamma\gamma\gamma$) $< 10^{-2}$ [SJNP 5 445 (1967)]



JEF will improve UL on BR by one order of magnitude to directly tighten the constraint on CVPC new physics

Conclusions

JEF will produce boosted $\eta(')$ with unprecedent rate
Competitive sensivity to physics BSM for a variety of Dark Sector Models:

- GlueX expected sensitity on ALP coupling to gluons should improve dramatically world limit
- Exclusive or missing mass measurements
- Through $\eta^{(')}$ decay
- Direct photoproduction off nucleon, nucleus or atomic electron

Rare decays will also be studied

- Discrete symmetries violations studies (e.g. $\eta \to \gamma\gamma\gamma$)
- Study relation between VMD and scalar resonances in ChPT (e.g. $\eta(')\pi^0\gamma\gamma$)

Data taking is expected to start in 2024

- FCAL insert is under construction
- Simulation/analysis already on going in preparation for data

GlueX acknowledges the support of several funding agencies and computing facilities:
`http://www.gluex.org/thanks`

Thank you for your attention