New physics and rare decays at the Jefferson Lab Eta Factory

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For the GlueX Collaboration

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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, $e^{-}_{\text{beam}} A_{\text{radiator}} \rightarrow e^{-}_{\text{deflected}} A_{\gamma \text{tagged}}$

Typical integrated luminosity, $\mathcal{L} \sim 200 \text{ pb}^{-1}$ per month for $E_{\gamma} = 8 \rightarrow 11.7 \text{ GeV}$
The JLab Eta Factory

Expected to produce $\sim 5 \times 10^7 \eta$ in 100 days between 8.4 and 11.7 GeV in $E_\gamma$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>total $\eta$</th>
<th>total $\eta'$</th>
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</thead>
<tbody>
<tr>
<td>CB/AGS</td>
<td>$10^7$</td>
<td>-</td>
</tr>
<tr>
<td>CB/MAMI</td>
<td>$2 \times 10^7$</td>
<td>-</td>
</tr>
<tr>
<td>CB/MAMIC</td>
<td>$6 \times 10^7$</td>
<td>$10^6$</td>
</tr>
<tr>
<td>WASA/COSY</td>
<td>$\sim 3 \times 10^7$ (p+d)</td>
<td>$\sim 5 \times 10^8$ (p+p)</td>
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<tr>
<td>KLOE-II</td>
<td>$3 \times 10^8$</td>
<td>$5 \times 10^6$</td>
</tr>
<tr>
<td>BES-III</td>
<td>$\sim 10^7$</td>
<td>$\sim 5 \times 10^7$</td>
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</tbody>
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- Upgraded Forward Calorimeter covers angle between 1 and $8^\circ$ ($\sim 6$ m from target center)
- Compton Calorimeter covers angle between 0.6 and $1^\circ$ ($\sim 12$ m from target center)

Exclusive measurements and large solid angle coverage strongly reducing background
Study rare $\eta'$ decay and in particular $\eta \rightarrow \gamma\gamma\pi^0$, BR = $2.7 \times 10^4$

Search for BSM at very forward angle

- Leptophobic dark vector gauge boson: $\eta' \rightarrow B'\gamma$ with $B' \rightarrow \gamma\pi^0$ or $\pi^+\pi^-\pi^0$ ($0.14 \leq m_{B'} \leq 0.957$ GeV/$c^2$)
- Leptophilic dark vector gauge boson: $\eta' \rightarrow A'\gamma$ with $A' \rightarrow l^+l^-$ ($l = e$ or $\mu$) or $\pi^+\pi^-$
- Dark scalar gauge boson: $\eta' \rightarrow S\pi^0$ ($\eta' \rightarrow \eta S$) with $S \rightarrow \gamma\gamma$ or $l^+l^-$ or $\pi^+\pi^-$ ($0.01 \leq m_S \leq 1$ GeV/$c^2$)
- ALPs: $\eta' \rightarrow \pi\pi a$ with $a \rightarrow \gamma\gamma$ 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

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


$X$ is either invisible or visible i.e. decays $X \rightarrow \gamma \gamma$ or $X \rightarrow l^+ l^-$ ($l =$ lepton)

- Shape/bump search in invariant mass or missing mass distribution

Signal strength much lower than other processes but $S/\sqrt{B}$ highly competitive
\[ \gamma p \rightarrow a p, \mathcal{L} = 170 \text{ pb}^{-1}, \text{Y. Yang et al in preparation} \]

- \( a \rightarrow \gamma\gamma \)
- \( a \rightarrow \pi^+\pi^-\pi^0 \)

Expected to improve dramatically the current limit

**expected sensitivity from this search**
Expected sensitivity for 30 days

Compton dark photon photoprodction, $\gamma e^- \rightarrow A' e^-$, 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, $\gamma p \rightarrow \eta(\rightarrow B'\gamma)p$ 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, $\eta' \rightarrow \pi^0 \gamma \gamma$?

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

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

But recent calculation by Y. Balytzkyi

arxiv:1811.01402

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

JEF can look at this tension between theory and experimental measurements
Rare decay: $\eta \rightarrow \gamma\gamma\gamma$

- SM contribution, $\text{BR}(\eta \rightarrow \gamma\gamma\gamma) < 10^{-9}$ 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 $\text{BR}(\eta \rightarrow \gamma\gamma\gamma) < 10^{-2}$ [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. $\eta \rightarrow \gamma\gamma\gamma$)
- 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