Search for the Axion-Like Particle via the Primakoff effect

Igal Jaeglé

Thomas Jefferson National Accelerator Facility

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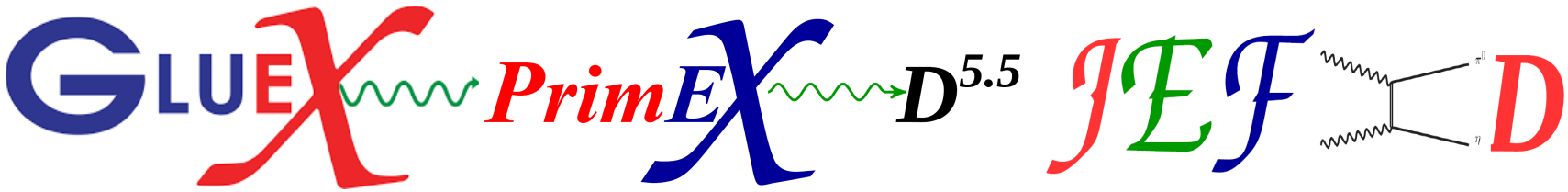

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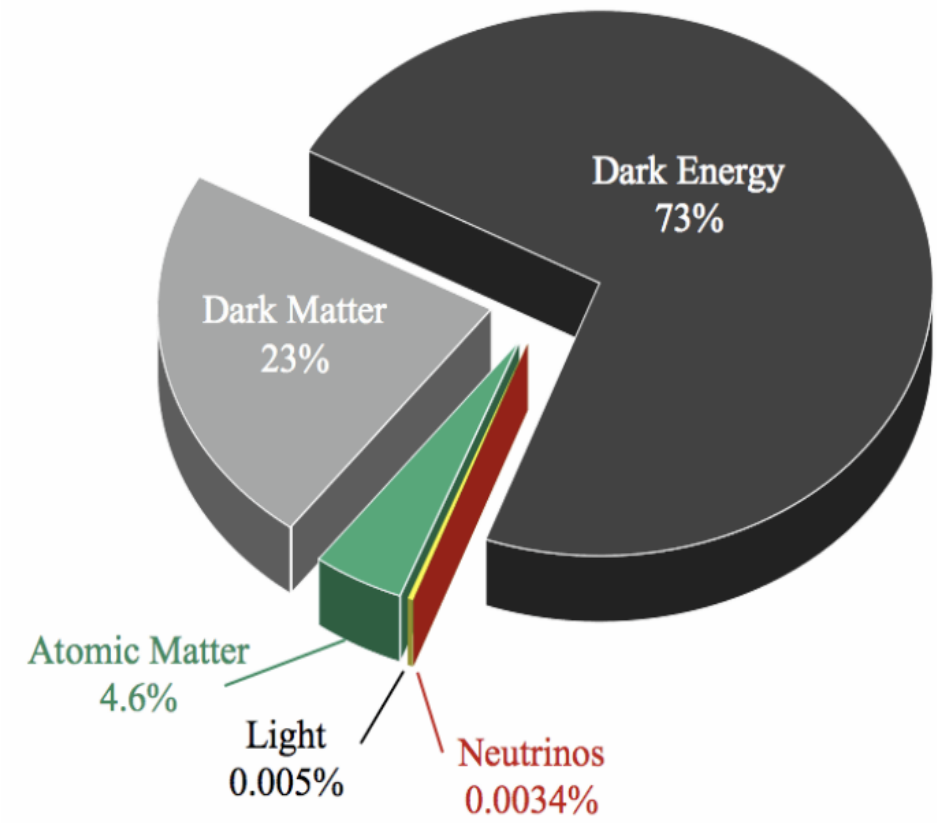
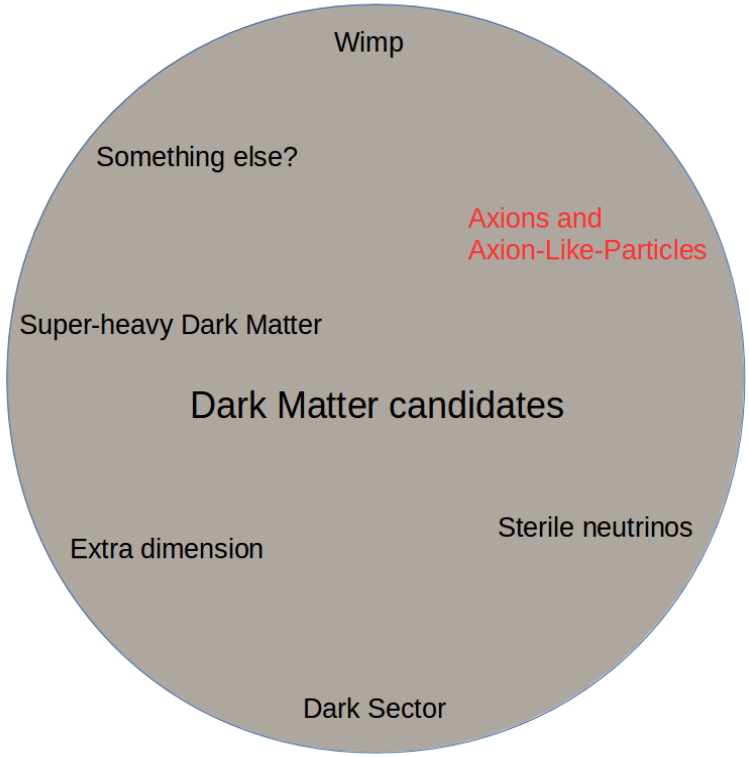
Introduction

Robust evidence of new physics and many candidates

- Energy budget



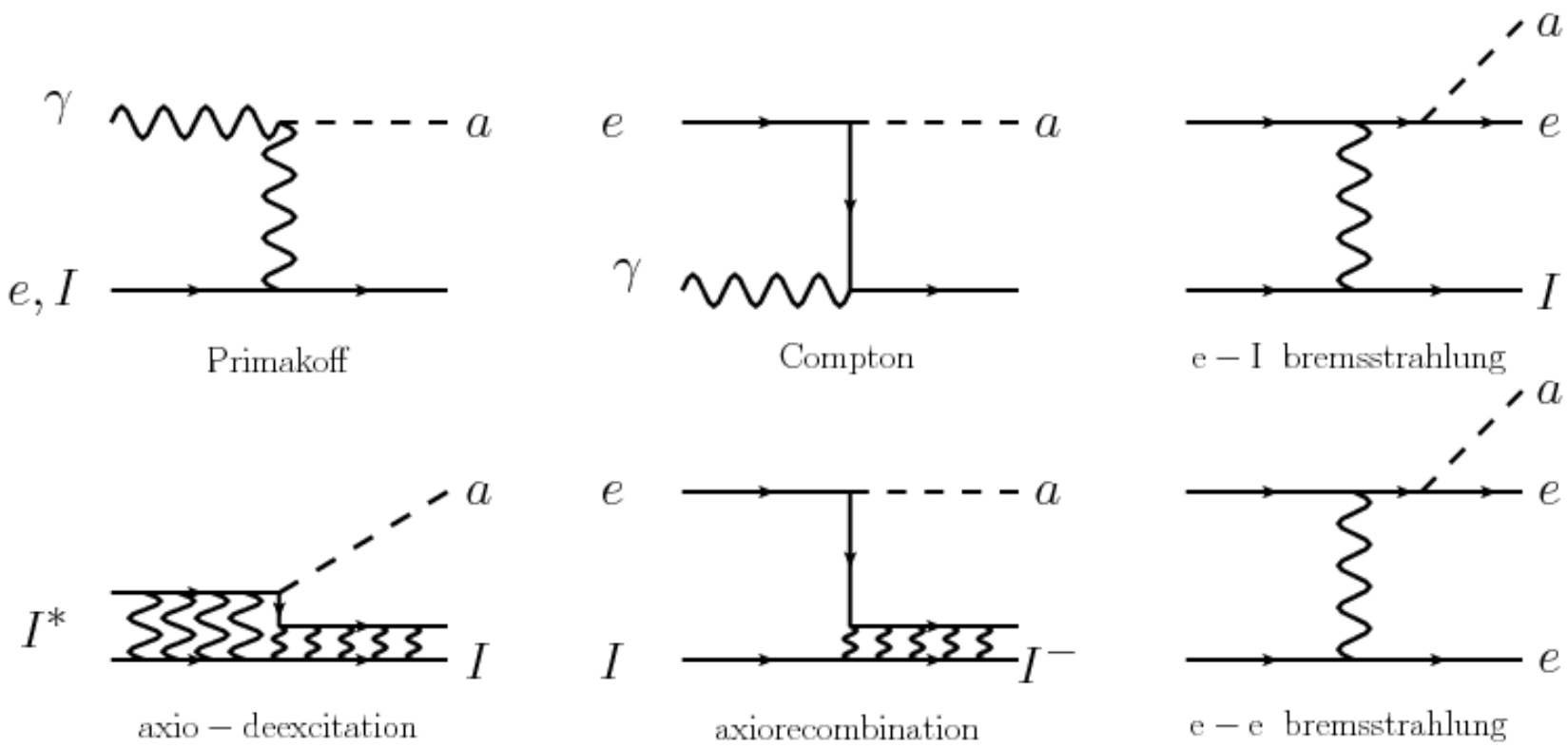
- Dark matter candidates



JLab@22GeV will open new opportunities to probe New Physics Beyond Standard Model

ABC reactions

Atomic recombination and deexcitation, Bremsstrahlung and Compton responsible for the solar axion flux in axion models.



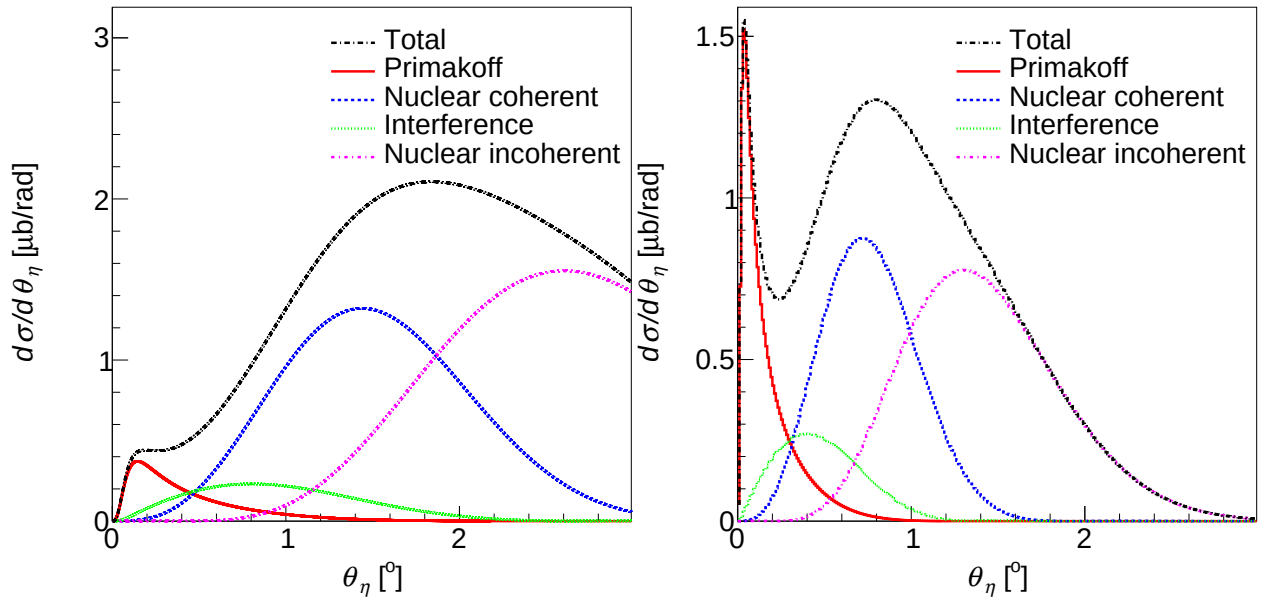
Focus on Primakoff photoproduction process

Analogy to Primakoff photoproduction of η-meson

$\gamma\,^4\mathrm{He} \rightarrow \eta\,^4\mathrm{He}$, theoretical differential cross-section known:

- $\frac{d\sigma_T}{d\Omega} = \frac{d\sigma_P}{d\Omega} + \frac{d\sigma_{NC}}{d\Omega} + 2\sqrt{\frac{d\sigma_P}{d\Omega}\frac{d\sigma_{NC}}{d\Omega}}cos(\phi) + \frac{d\sigma_{NI}}{d\Omega}$
- Primakoff contribution is directly proportional to the $\Gamma_{\eta\rightarrow\gamma\gamma}$ decay width

  $\frac{d\sigma_P}{d\Omega} = \boxed{\Gamma_{\eta\rightarrow\gamma\gamma}}\frac{8\alpha Z^2}{m_\eta^3}\frac{\beta^3 E^4}{Q^4}\left|F_{e.m.}\left(Q\right)\right|^2 \sin^2\left(\theta_\eta^{\mathrm{lab}}\right)$
- Cross-section for $\mathrm{E}_\gamma = 10$ GeV (left) and $\mathrm{E}_\gamma = 20$ GeV (right):
  - $\Gamma_{\eta\rightarrow\gamma\gamma} = 510$ eV and $\phi = 57.5^o$



- Primakoff contribution increases with E_γ ↗
- Overlap between Primakoff and background (Coherent & Interference) decreases with E_γ ↗

Beam energy impacts the measurements

Analogy to Primakoff photoproduction of η-meson

$\gamma^{202}\mathrm{Pb} \rightarrow \eta^{202}\mathrm{Pb}$, theoretical differential cross-section known:

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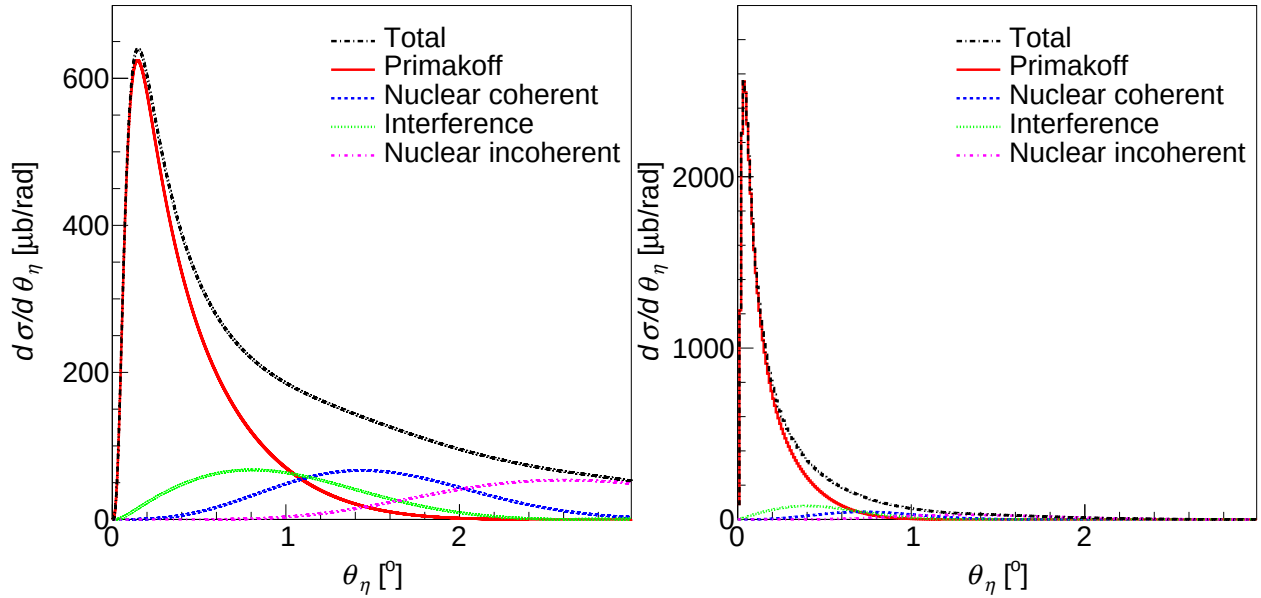


- Primakoff contribution increases with Z^2

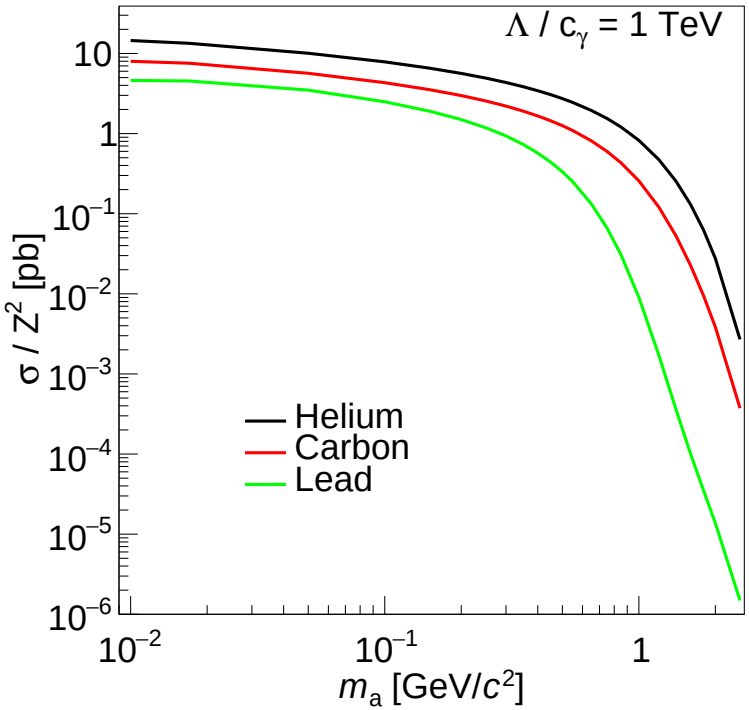
Atomic number impacts the measurements

Primakoff photoproduction of ALP

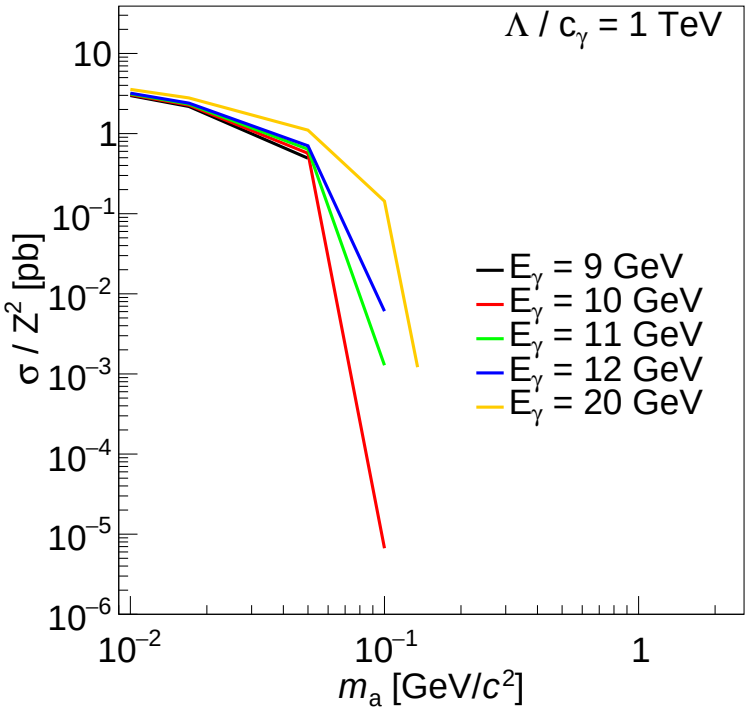
$\gamma A \to Aa$, theoretical cross-section:

- $\frac{d\sigma_P}{d\Omega} = \boxed{\Gamma_{a\to\gamma\gamma}} \frac{8\alpha Z^2}{m_a^3} \frac{\beta^3 E^4}{Q^4} |F_{e.m.}(Q)|^2 \sin^2\left(\theta_{\mathrm{a}}^{\mathrm{lab}}\right)$
- $\Gamma_{a\to\gamma\gamma} = \frac{c_\gamma^2 m_a^3}{64\pi\Lambda^2}$
- $\frac{c_\gamma}{\Lambda}$, axion coupling to photon, unit eV

- Off nuclei and $\mathrm{E}_\gamma = 20$ GeV



- Off Atomic electron



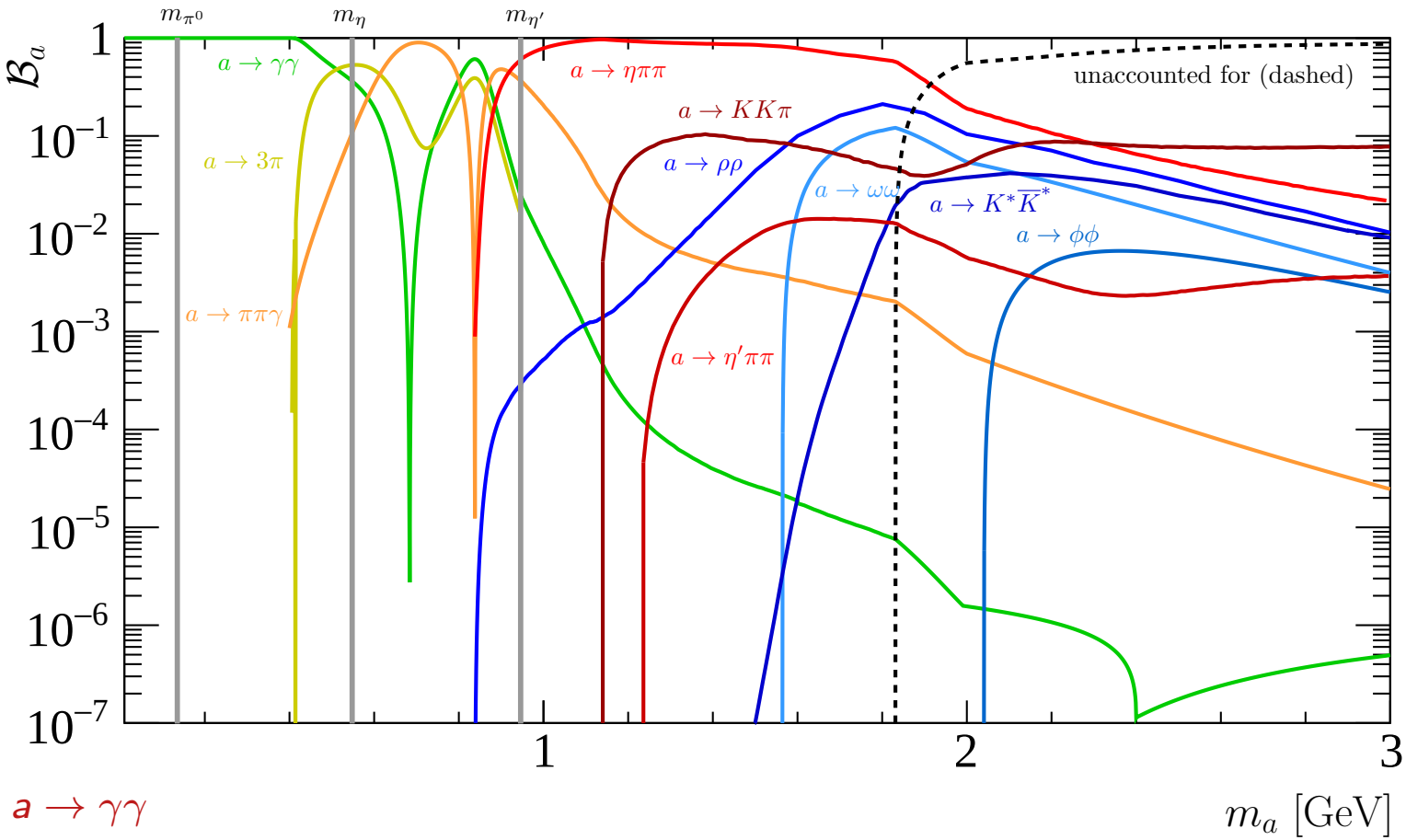
Atomic electron contribution below 50 MeV/c^2 non-negligible

ALP branching ratio

Golden modes for GlueX/JEF:

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

  D. Aloni et al. PRL 123 (2019), arXiv:1811.0347

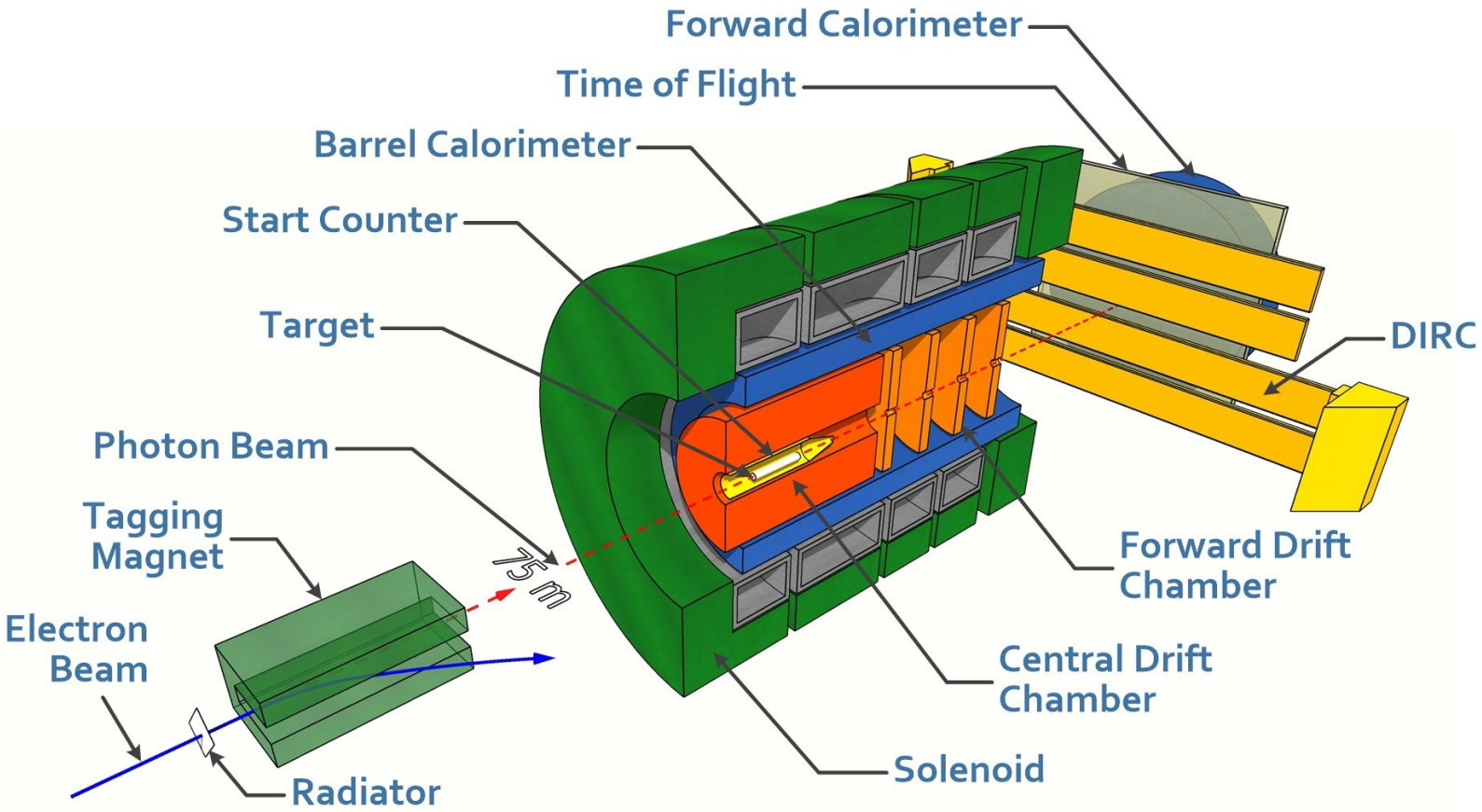


Focus on $a \to \gamma\gamma$

The GlueX setup

Photon-beam produced by (coherent) bremsstrahlung

NIMA 987 164807 (2021) - arxiv:2005.14272



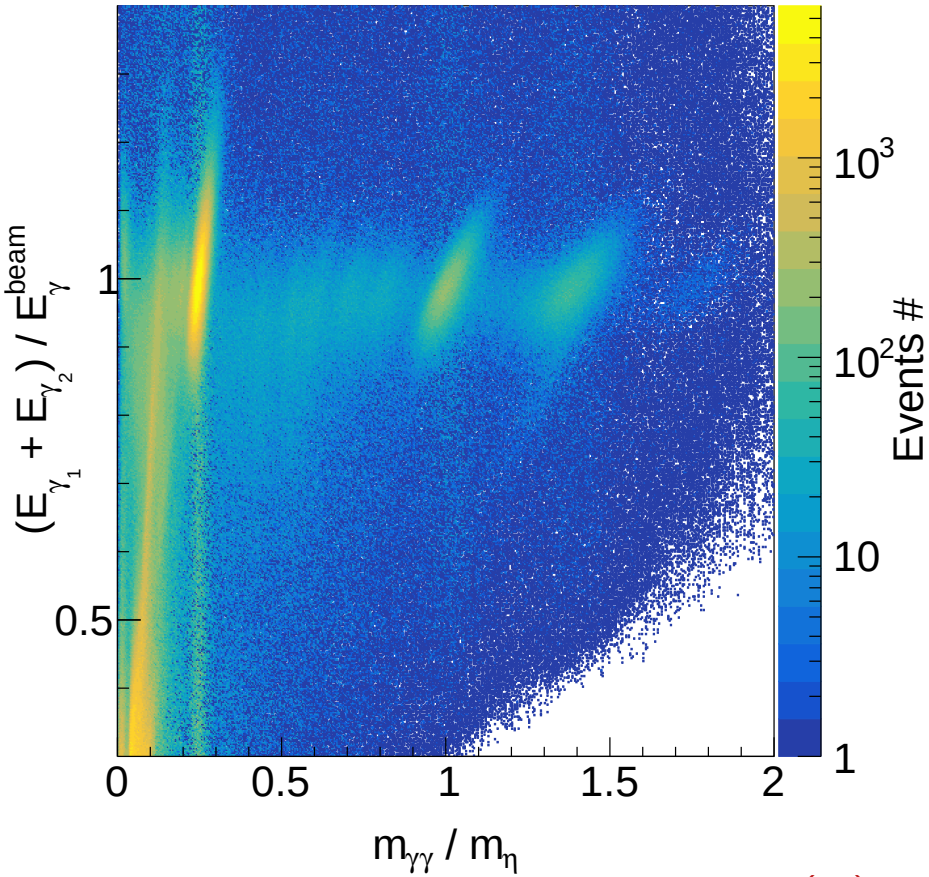
- But, for this study, FDC, air, and DIRC replaced by vacuum
- Lead target (of ∼0.3mm or 4%RL) and FCAL positions optimized for each mass scanned

Typical integrated luminosity, $\mathcal{L} \sim 200$ pb^{-1} per 100 days

Selection criteria

Two clusters in Forward Calorimeter:

- Barrel Calorimeter used to veto hadronic backgrounds
- Time-Of-Flight wall used to veto charged particles
- Elasticity required
- $\theta_{\gamma\gamma}^{\mathrm{lab}} \leq 0.5^0$ and 1^o for $\mathrm{E}_\gamma = 10$ GeV and 20 GeV, respectively



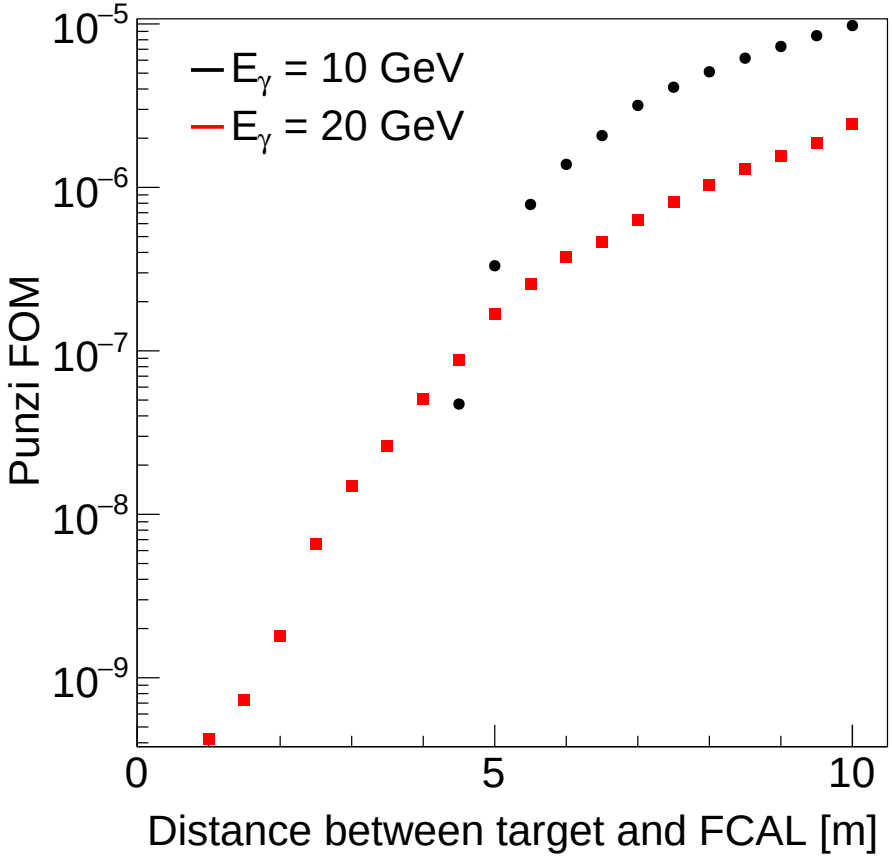
Example with Carbon target, SRC data set
$\gamma_{\mathrm{beam}}\,{}^{12}\mathrm{C} \rightarrow \eta/\pi^0\,{}^{12}\mathrm{C}$ and $\eta/\pi^0 \rightarrow \gamma_1\gamma_2$
In Primakoff process, most of the energy is transferred to η-meson
$=> \mathrm{E}_\gamma^{\mathrm{beam}} - \mathrm{E}_{\gamma_1}^{\mathrm{cluster}} - \mathrm{E}_{\gamma_2}^{\mathrm{cluster}} \sim 0$ (elasticity)

Clear signal but includes Primakoff and (in)coherent events, and non-negligible backgrounds mainly target (hadronic) and beamline

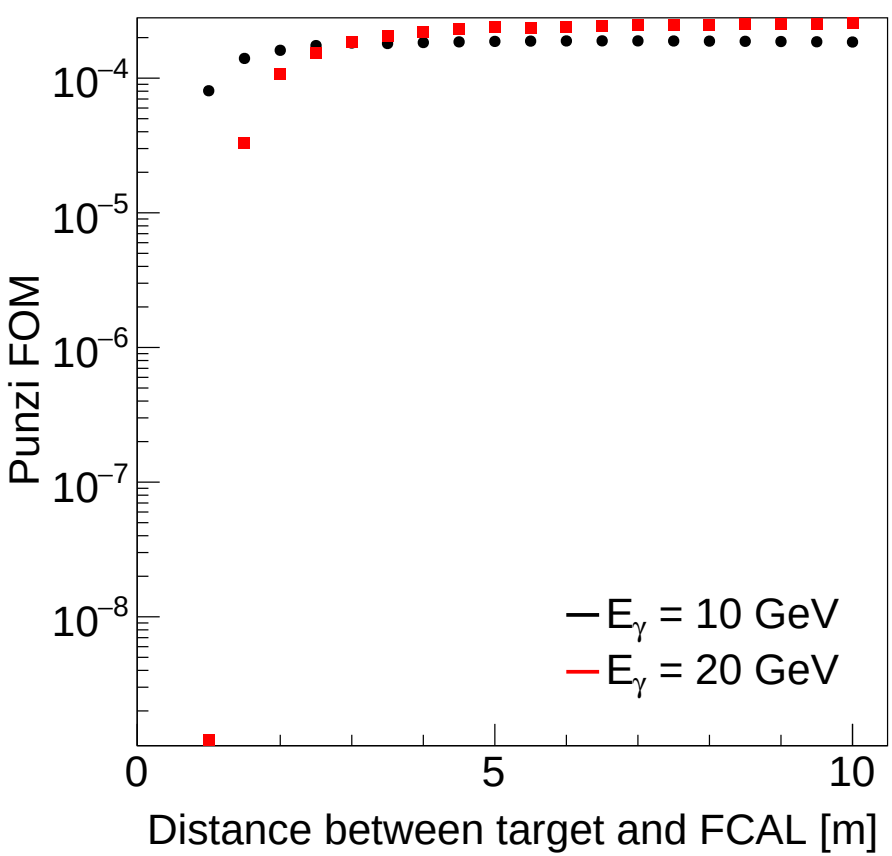
Optimized positions

For the target and FCAL

- Punzi FOM $= \frac{\epsilon}{\sqrt{a+B}}$, ϵ signal detection efficiency, a $= 3$ (significance) and B: hadronic background coming from Pb target
- 16 positions for 16 mass regions to scan
- Punzi FOM for $m_a = 17$ MeV/c^2



- Punzi FOM for $m_a = 300$ MeV/c^2

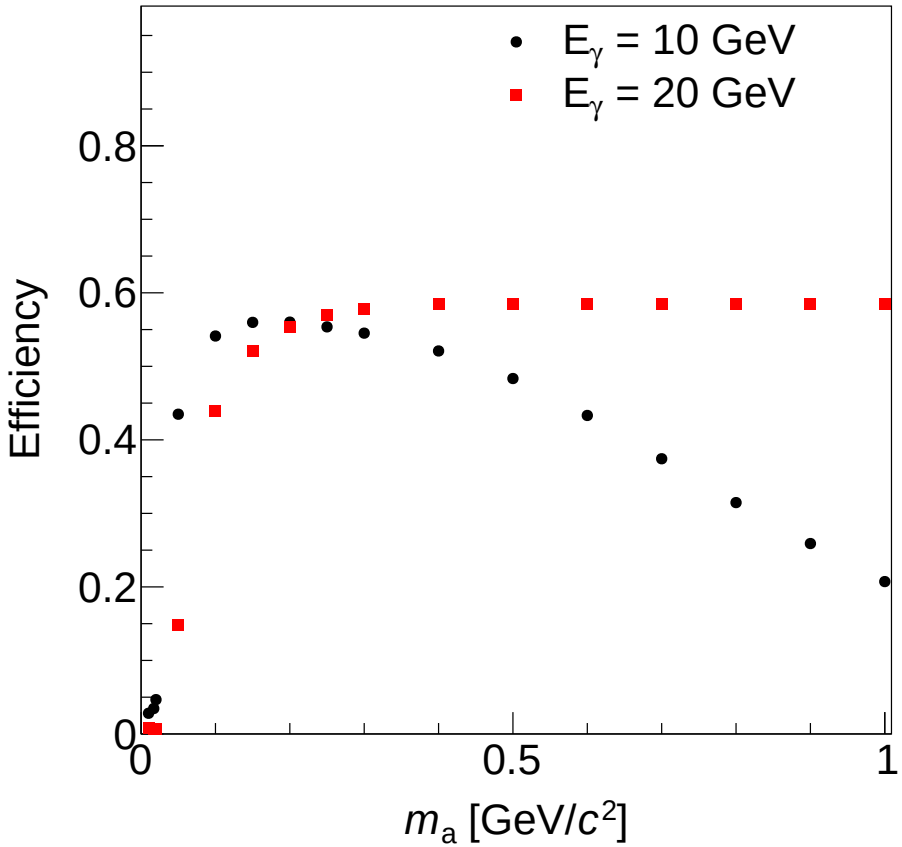


For each position 12.5 pb^{-1} collected

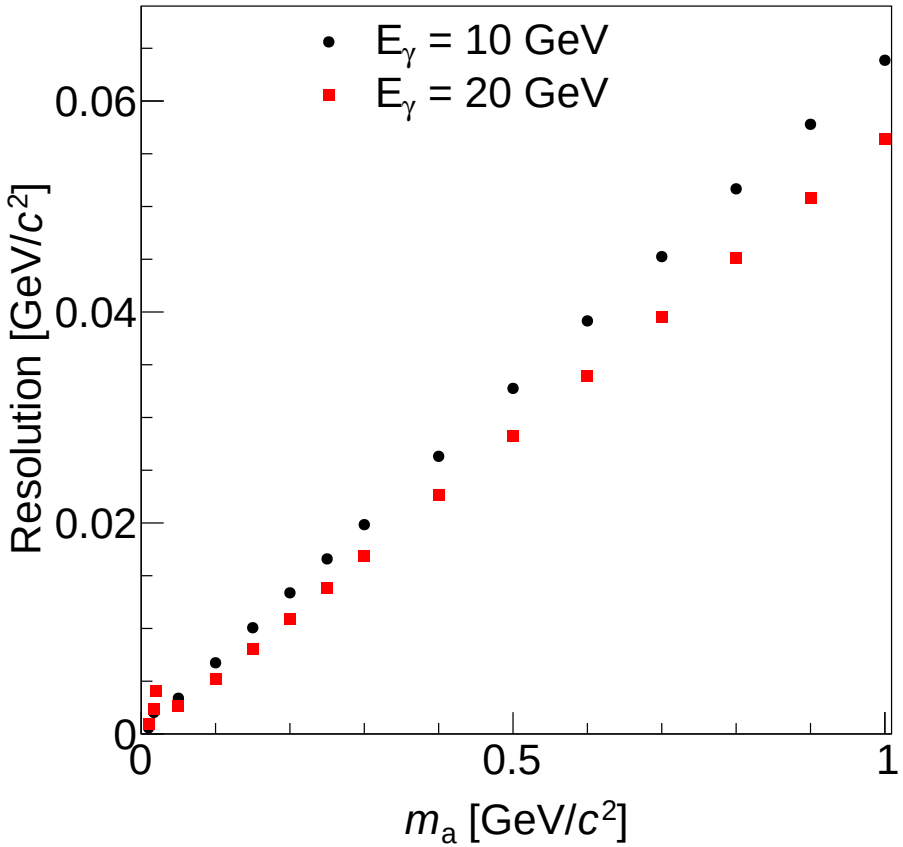
Signal detection efficiency and resolution

Very preliminary

- Efficiency



- Resolution

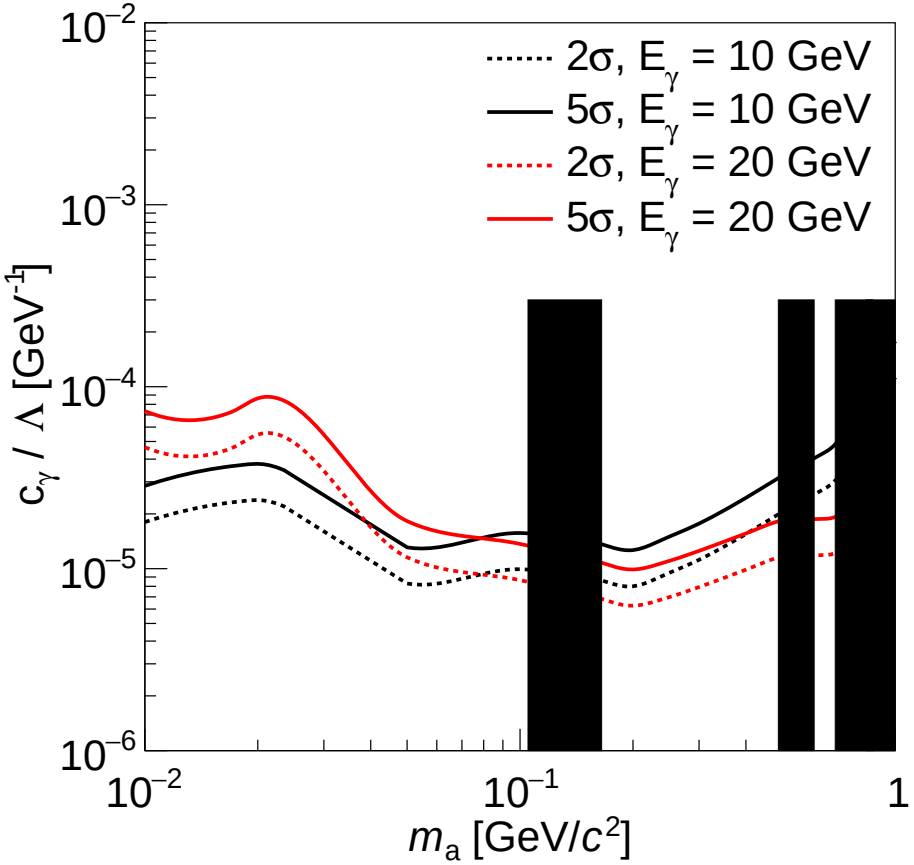


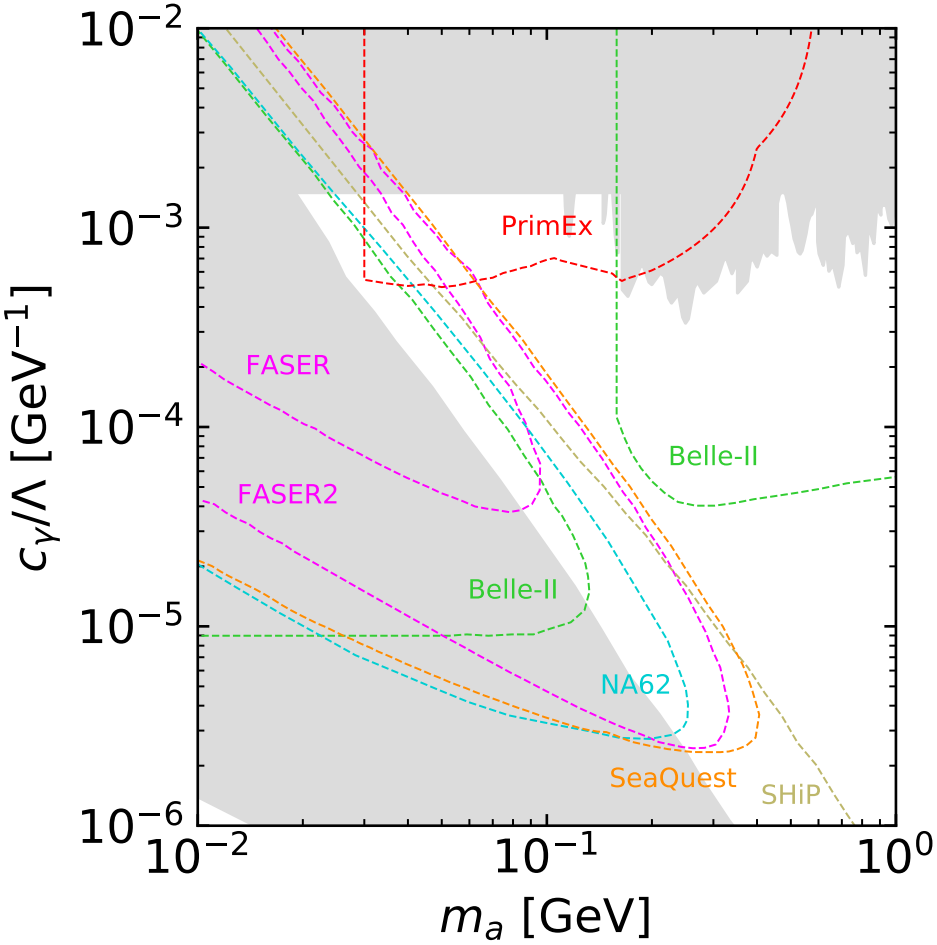
- Detection efficiency above 100 MeV/c^2 is improved with E_γ $\nearrow$
- Resolution for all masses is improved with E_γ $\nearrow$

Background coming from the target estimated for each mass scanned $\pm 3\sigma$

Very preliminary expected sensitivity

No bump search possible at π^0, η, ω, and η' masses





- Expected sensitivity for 200fb^{-1} and Lead target

JLab@22GeV is competitive

Conclusion

JLab@22GeV will open new opportunities to probe New Physics Beyond Standard Model

- Many different models can be tested (and will be studied in the coming weeks)
- Preliminary study for $a \to \gamma\gamma$ is presented
- Note, other decays are possible and will be studied in the coming weeks
- A 22GeV beam is naturally increasing Primakoff cross-section
- A heavy target is also naturally increasing Primakoff cross-section

For 200pb^{-1} collected at 16 different distances between target and FCAL

- A competitive sensitivity is expected
- If background is coming from the target only ie FDC, air, and DIRC are replaced by vacuum