Compton photo-production of dark particles

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UNIVERSITA' DEGLI
STUDI DI TORINO

First Workshop on New Light Physics
and Photon Beam Experiments
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Outline

- Theory
- Photon beam experiments
- Background processes
- Sensitivities

Theory and Motivation

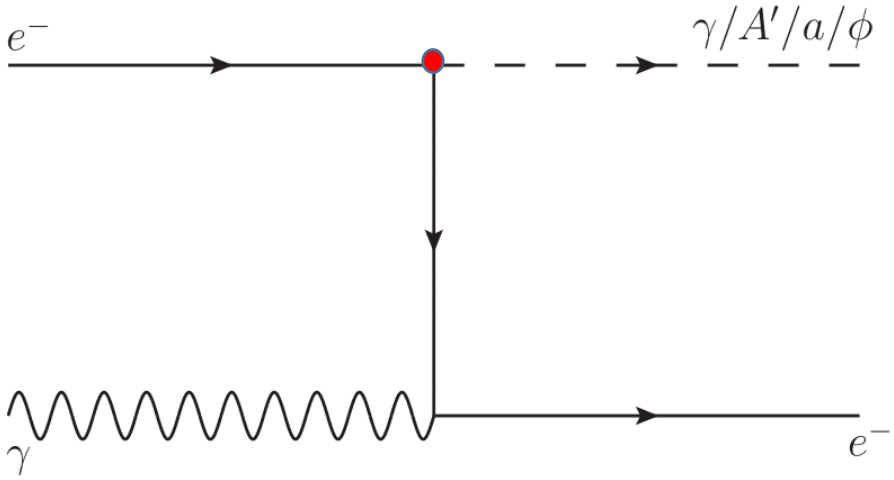
- Production of dark photon (A'), axion-like particle (ALP) (a) and dark scalar (ϕ) in Compton-like scattering processes.
- Relevant coupling terms:

$$\Delta\mathcal{L} \equiv \epsilon e\, \bar{\psi}_e \gamma_\mu \psi_e A'^{\mu}$$

$$\Delta\mathcal{L} \equiv g_{ae}\, \bar{\psi}_e \gamma_5 \psi_e a$$

$$\Delta\mathcal{L} \equiv y_e\, \bar{\psi}_e \psi_e \phi$$

$$\boxed{\gamma + e \rightarrow \gamma / A' / a / \phi + e}$$



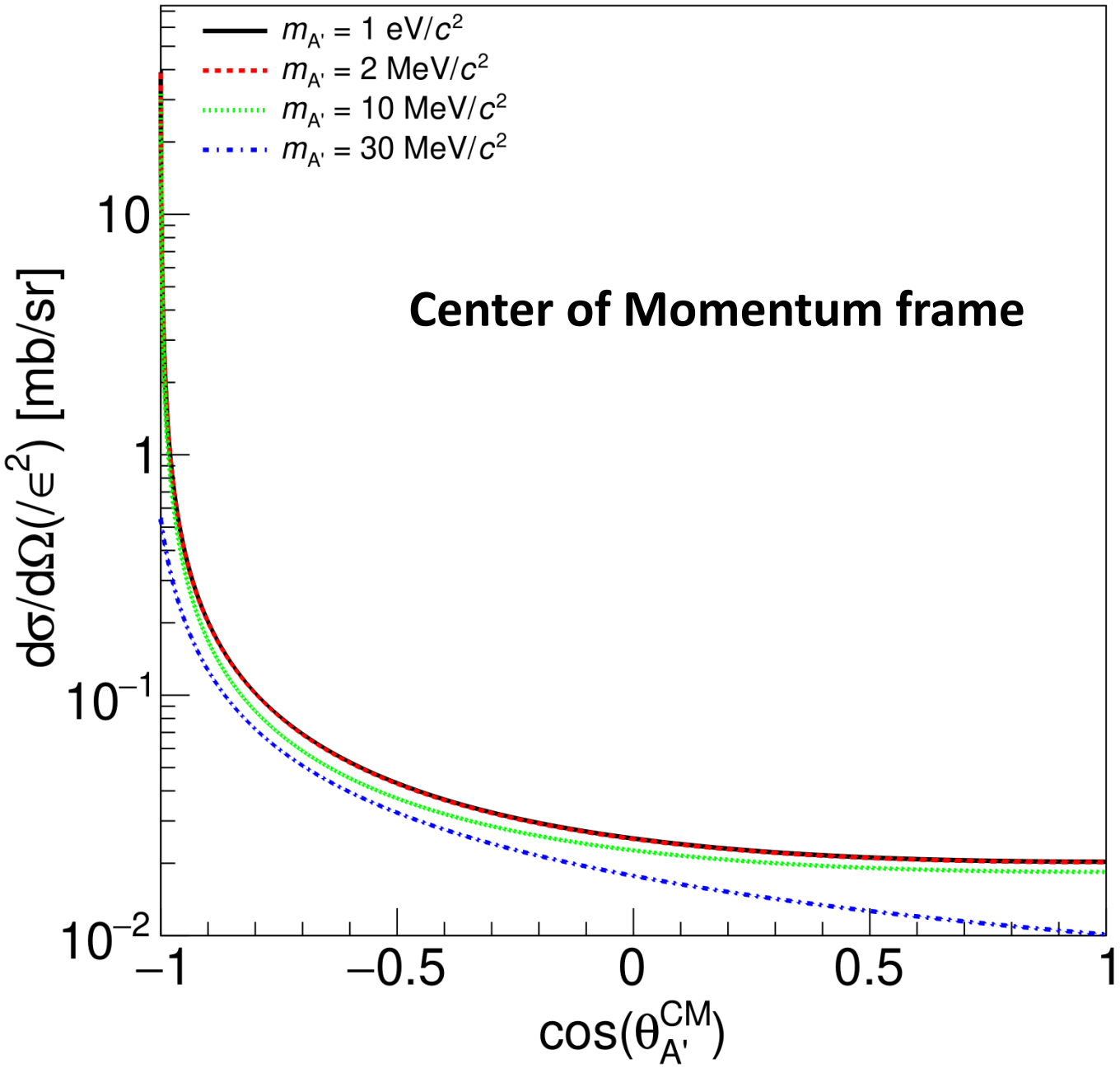
- For low-mass dark photons ($M \lesssim m_e$), the behavior is Compton-like.

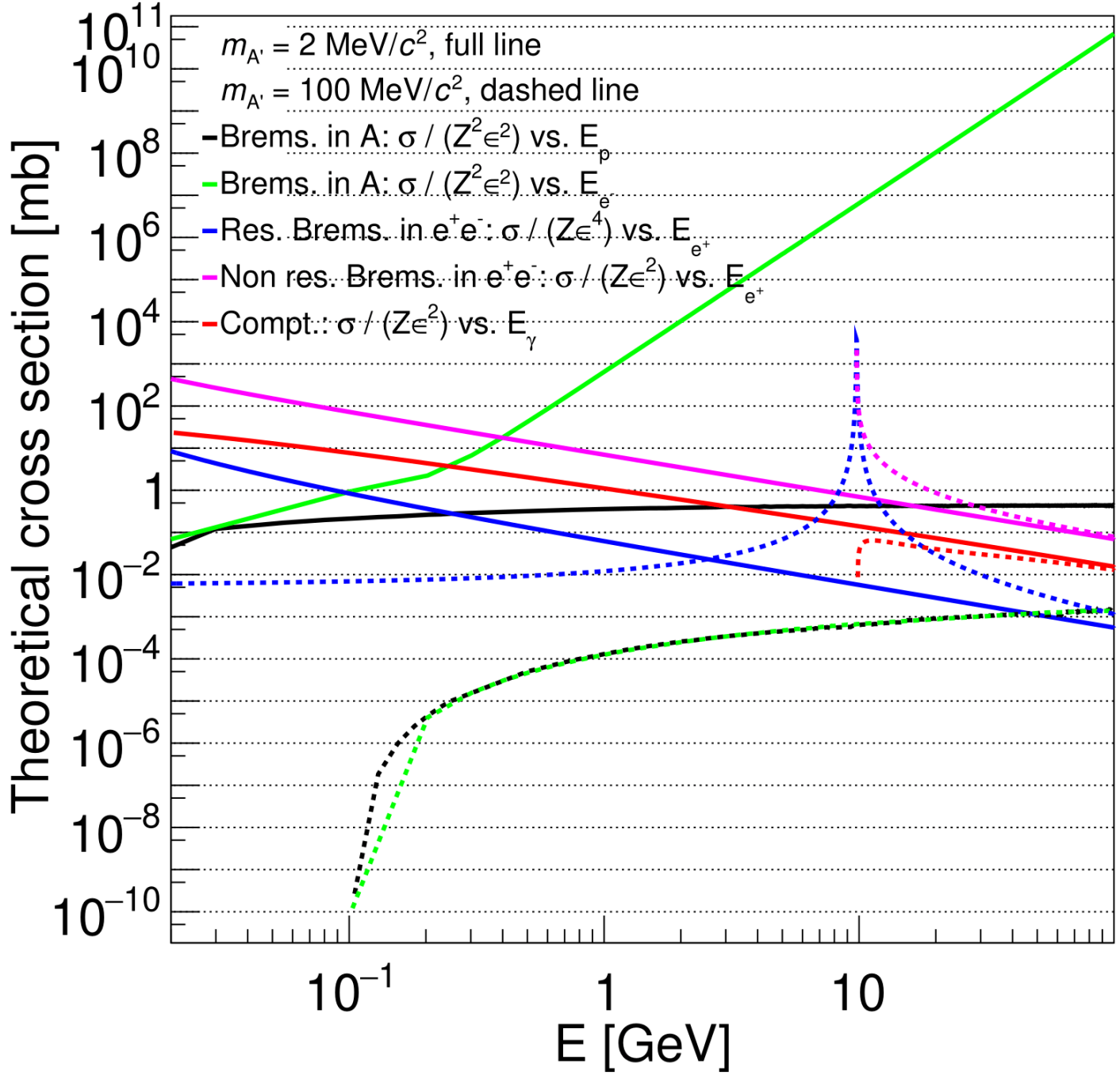
- For **10 GeV photon beam** hitting Hydrogen atom and producing **10 MeV 'dark' particle**:

$$\sigma(\gamma e \to A' e) \sim 1.4\ \text{pb} \left(\frac{\epsilon}{10^{-4}}\right)^2$$

$$\sigma(\gamma e \to a e) \sim 6.5\ \text{pb} \left(\frac{g_{ae}}{10^{-4}}\right)^2$$

$$\sigma(\gamma e \to \phi e) \sim 20.2\ \text{pb} \left(\frac{y_e}{10^{-4}}\right)^2$$




$m_{A'}$ = 2 MeV/c^2, full line
$m_{A'}$ = 100 MeV/c^2, dashed line
Brems. in A: σ / ($Z^2\epsilon^2$) vs. E_p
Brems. in A: σ / ($Z^2\epsilon^2$) vs. E_e
Res. Brems. in e^+e^-: σ / ($Z\epsilon^4$) vs. E_{e^+}
Non res. Brems. in e^+e^-: σ / ($Z\epsilon^2$) vs. E_{e^+}
Compt.: σ / ($Z\epsilon^2$) vs. E_γ
Theoretical cross section [mb]
E [GeV]

- Corrections for atomic electrons:

$$\sigma = \sigma_{\text{free}}\, Z \left(1 + R\,\frac{\sigma(\gamma A \to A e^+ e^-)}{\sigma(\gamma e_A^- \to e_A^- e^+ e^-)}\right)(1 - F^2(q))$$

$R = 0.0093$ (Z-independent radiative correction)

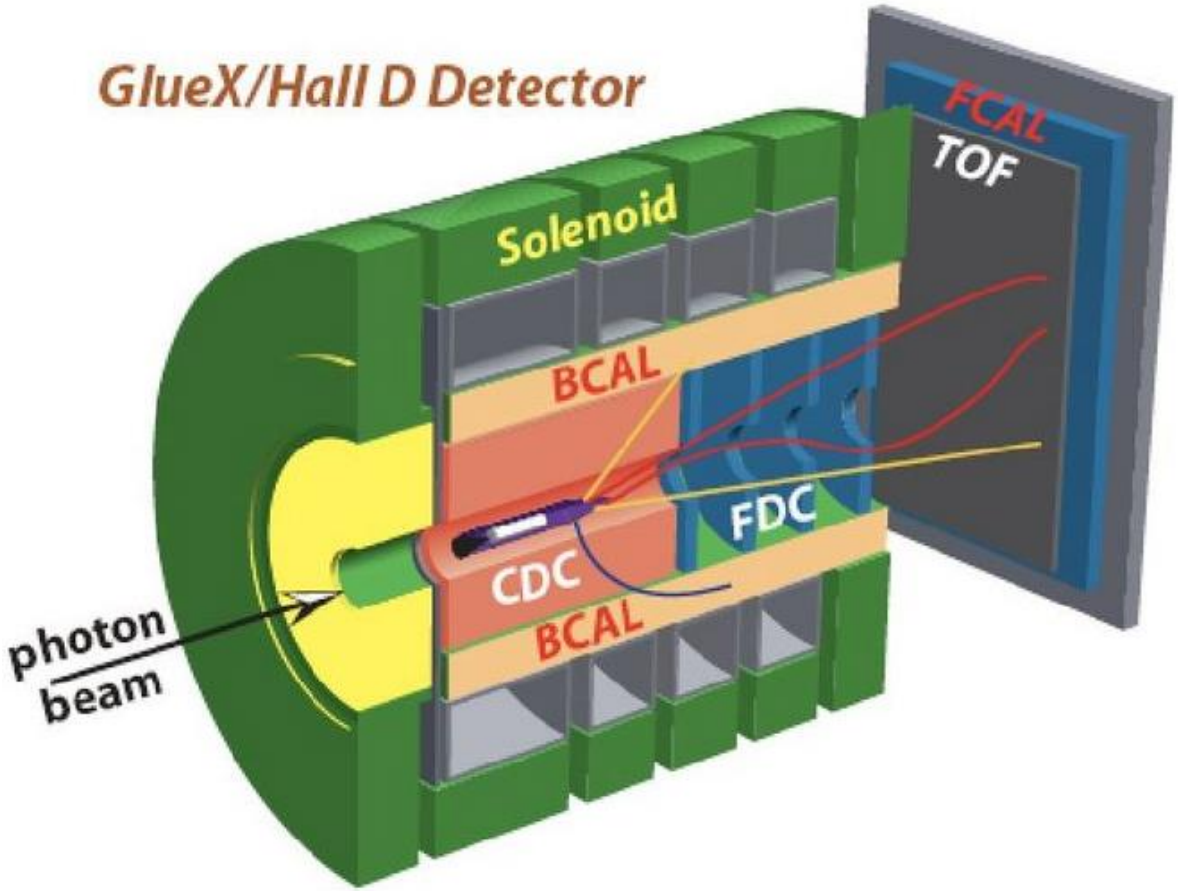
$$F(q) = \left(1 + \frac{a^2 q^2}{4}\right)^{-2}$$ (Hydrogen form factor)

(a: Bohr radius, q: momentum transferred to the recoil electron)

Photon beam experiments

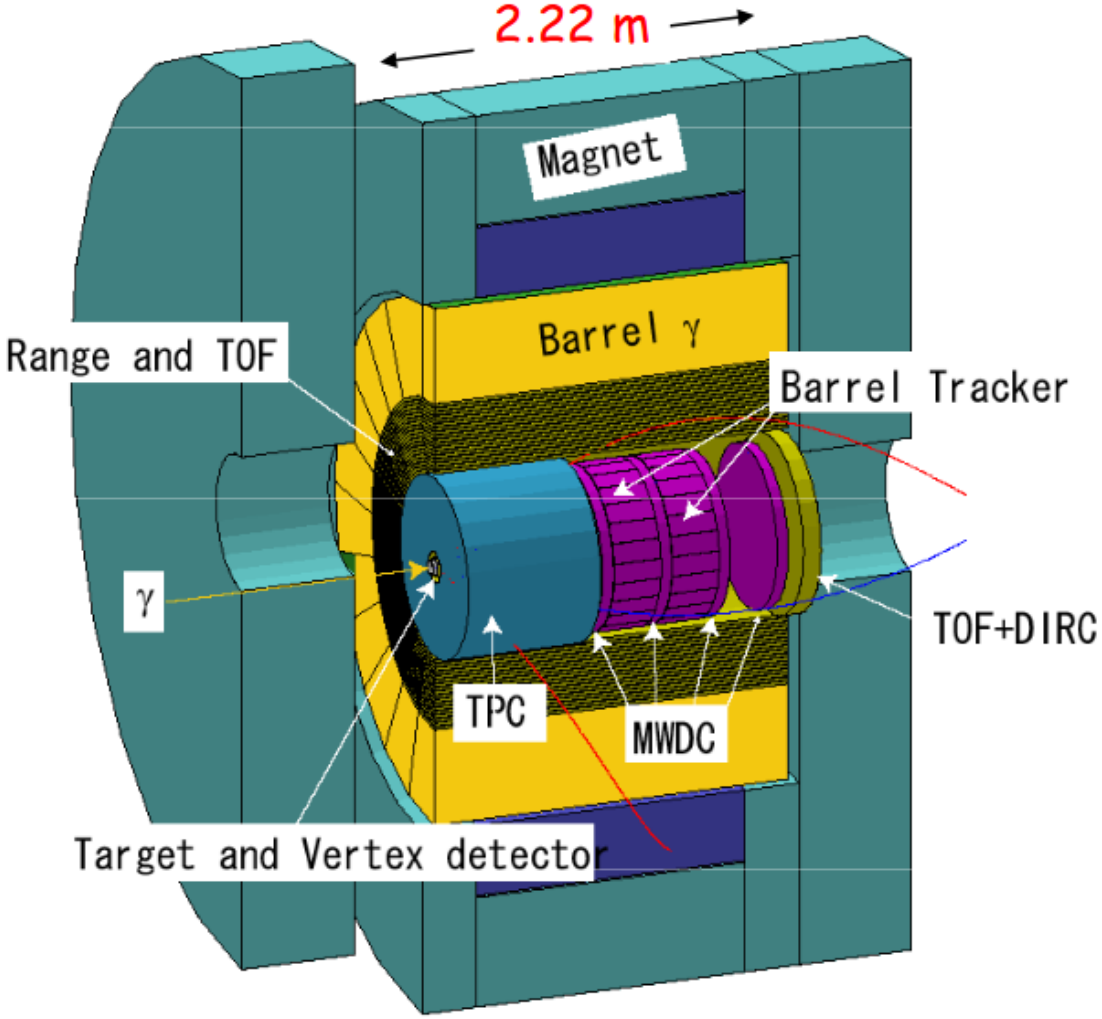
GlueX:

- Located at Hall-D, Jefferson Laboratory, USA
- Photon beam is produced by *bremsstrahlung technique*.
- Tagged between $E_\gamma = (9 - 11)$ GeV with a resolution of $\Delta E_\gamma = 50$ MeV.
- Target: 30 cm long liquid Hydrogen cell
- Photon flux: $\Phi_\gamma = 50$ MHz.
- Charged particles and photons are tracked between polar angles of 1° and 120°.
- Data acquisition is triggered if 600 MeV is deposited in the FCAL.
- Track momentum resolution: $\frac{\Delta p}{p} \sim 3\%$.



LEPS2:

- Located at Spring-8, Sayo, Japan.
- Photon beam is produced by *laser back-scattering technique*.
- Tagged between $E_\gamma = (1.4 - 2.5)$ GeV with a resolution of $\Delta E_\gamma = 12$ MeV.
- Target: 5 cm long liquid Hydrogen cell
- Photon flux: $\Phi_\gamma = 5$ MHz.
- Charged particles are tracked between polar angles of 7° and 120° and photons between 40° and 120°.
- e^+e^- veto counter between 0° and 7°.
- Charged particles with momenta >100 MeV trigger data acquisition.
- Track momentum resolution: $\frac{\Delta p}{p} \sim 5\%$.



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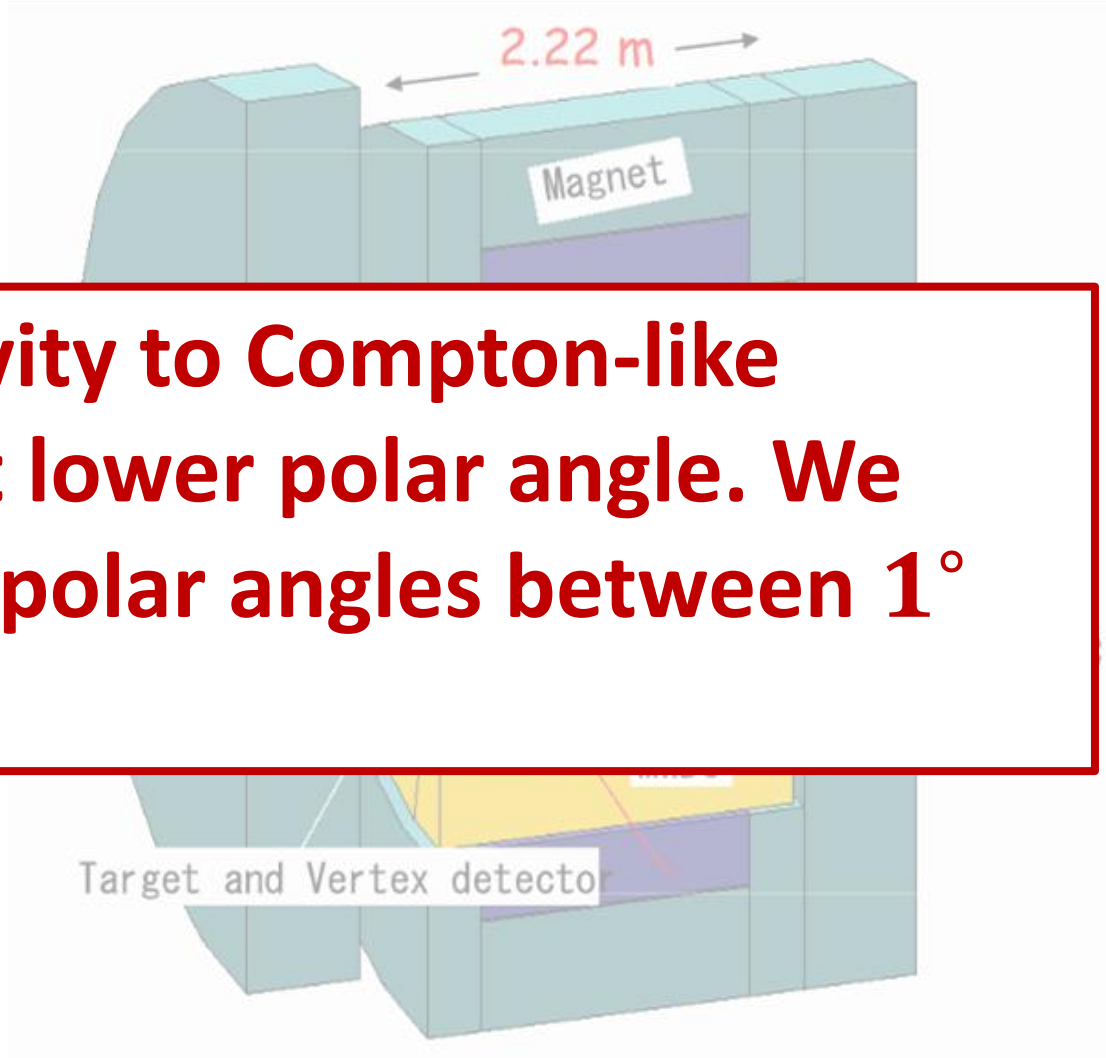

In this set-up, LEPS2 has no sensitivity to Compton-like scattering due to lack of tracking at lower polar angle. We have assumed charged particles at polar angles between 1° and 120° can be tracked.

and 120°.

- e^+e^- veto counter between 0° and 7°.
- Charged particles with momenta >100 MeV trigger data acquisition.
- Track momentum resolution: $\frac{\Delta p}{p} \sim 5\%$.

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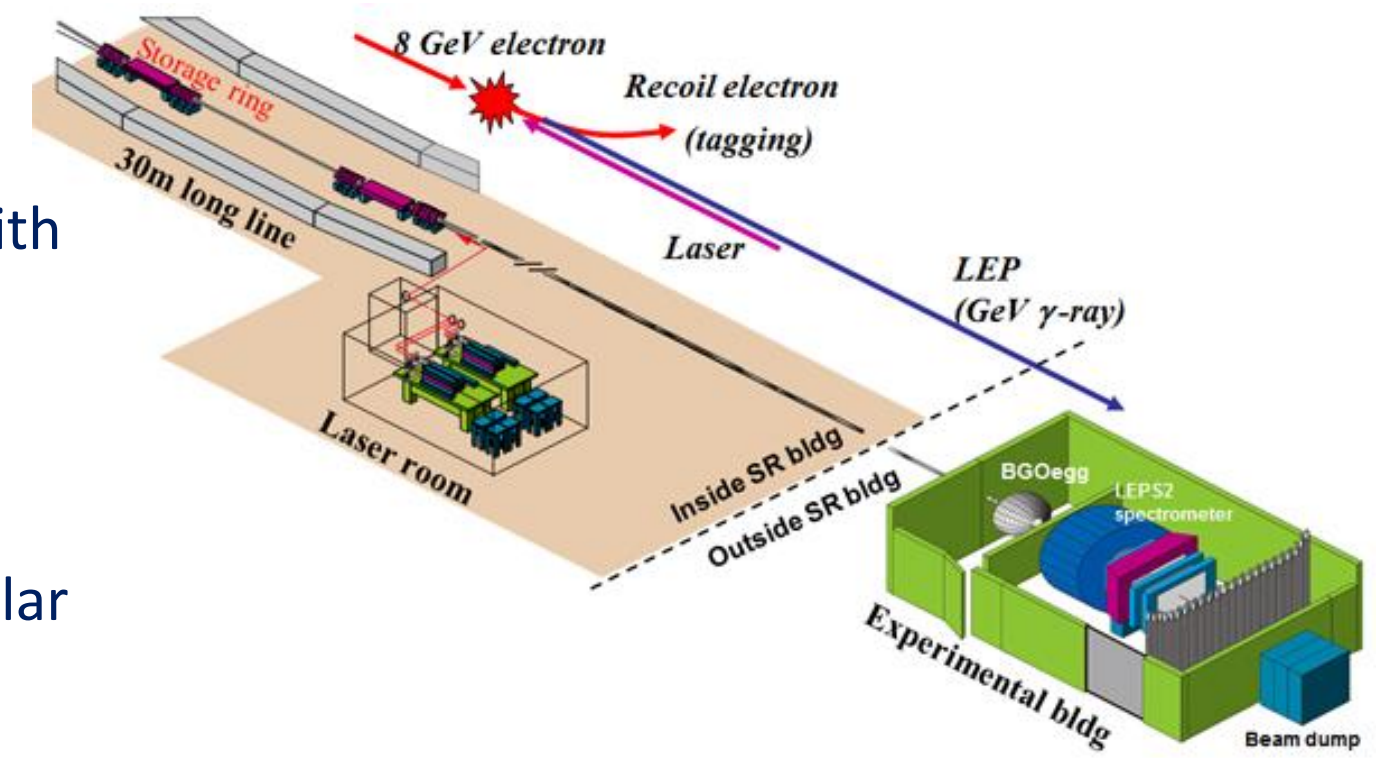
- Photon beam is produced by *laser back-scattering technique*.
- Tagged between $E_\gamma = (1.4 - 2.5)$ GeV with a resolution of $\Delta E_\gamma = 12$ MeV.
- Target: 5 cm long liquid Hydrogen cell
- Photon flux: $\Phi_\gamma = 5$ MHz.
- Charged particles are tracked between polar angles of $-20°$ and $20°$ in the x-direction and between $-10°$ and $10°$ in the y-direction.
- Charged particles with momenta >400 MeV trigger data acquisition.
- Track momentum resolution: $\frac{\Delta p}{p} \sim 0.6\%$.



FOREST:

- Located at ELPH, Tohoku, Japan.
- Photon beam is produced by *bremsstrahlung technique*.
- Tagged between $E_\gamma = (0.8 - 1.2)$ GeV with a resolution of $\Delta E_\gamma = 1$ MeV.
- Target: 5 cm long liquid Hydrogen cell
- Photon flux: $\Phi_\gamma = 4.5$ MHz.
- Charged particles are tracked between polar angles of -0.6° and 0.6° in the x-direction and between -1.2° and 1.2° in the y-direction.
- Charged particles with momenta >400 MeV trigger data acquisition.
- Track momentum resolution: $\frac{\Delta p}{p} \sim 0.6\%$.

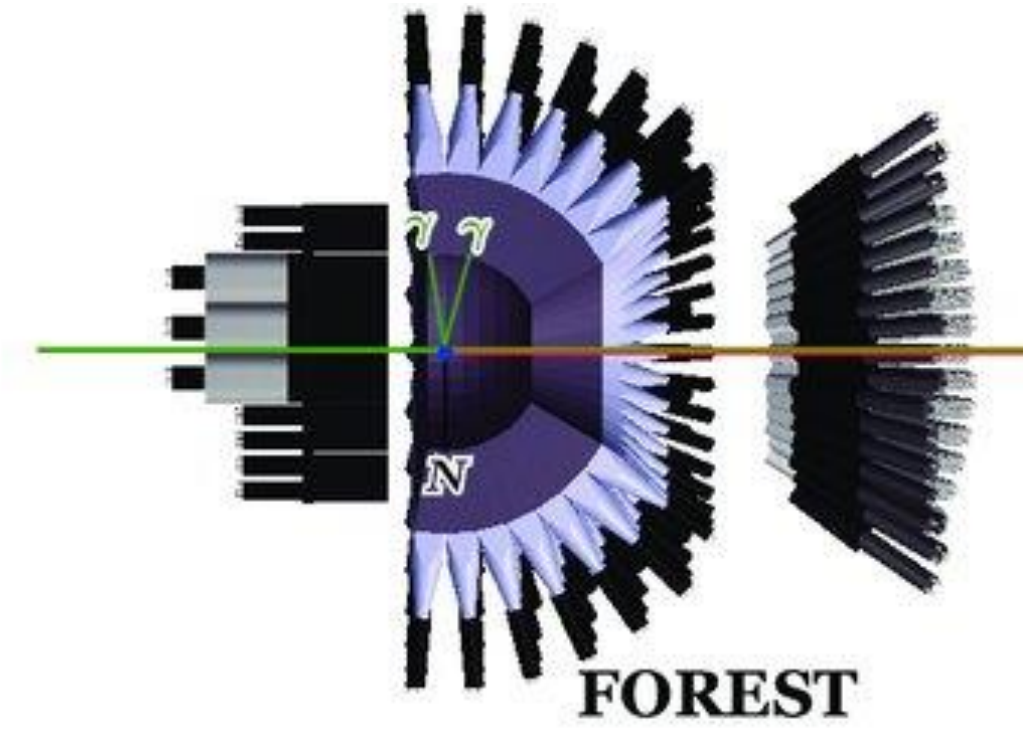


TABLE I. Tagged-photon-beam characteristics

Experiments	ϕ_γ $[\gamma/s]$	E_γ range [GeV]	ΔE_γ [MeV]
GlueX	5×10^7	9 - 11.5	50
LEPS2	5×10^6	1.4 - 2.4	12
LEPS	5×10^6	1.4 - 2.4	12
FOREST	4.5×10^6	0.8 - 1.2	1

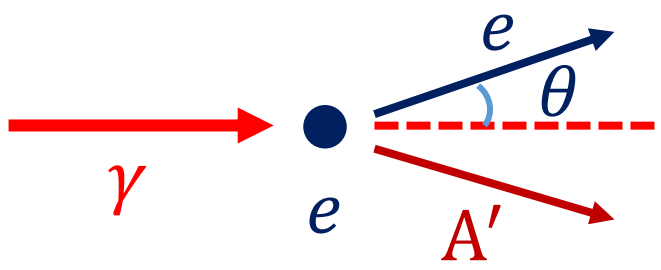
TABLE II. Existing setup characteristics

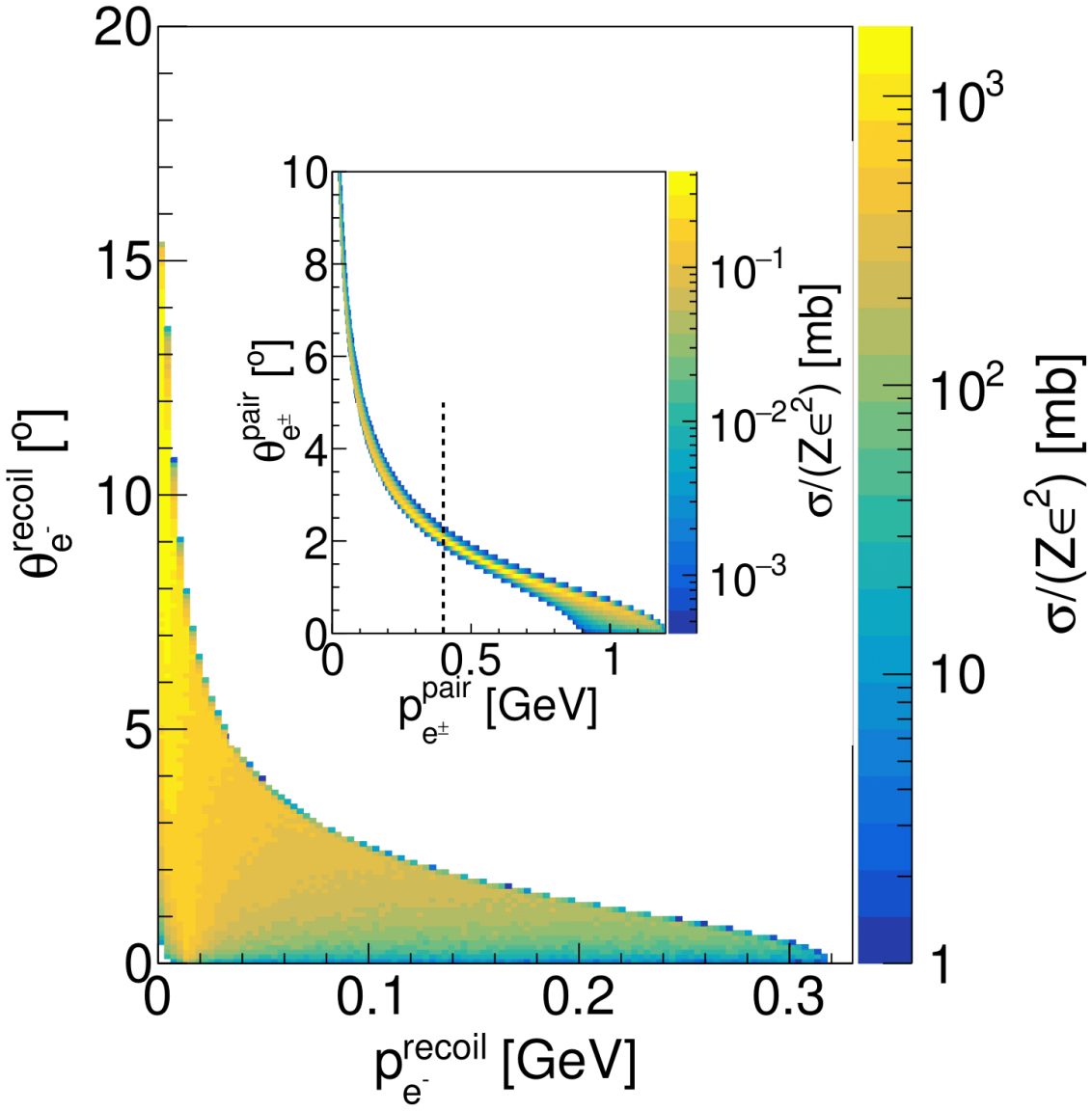
Experiment	θ range [°]	$\Delta p/p$ [%]	$p_{\mathrm{T}}^{\mathrm{track}}$ [MeV/c]
GlueX	1 - 120	3	50
LEPS2	7 - 120	5	100
LEPS	0 - 10	0.6	400
FOREST	0 - 0.6	0.6	400

Kinematics:

- The recoil electron with a certain momentum cannot be emitted at arbitrarily large polar angle.

- Also, momentum and polar angle are strongly correlated for $A' \rightarrow e^+e^-$.





For 10 MeV dark photon

Background processes

- Standard Model Compton: $\gamma + e^- \rightarrow \gamma + e^-$.
- Pair production: $\gamma + A \rightarrow e^+e^- + A$.
- Triplet photoproduction: $\gamma + e^- \rightarrow e^+e^- + e^-$.

- Measuring a single track
- Assuming one month of beam time.
- Reconstructing the missing mass squared:

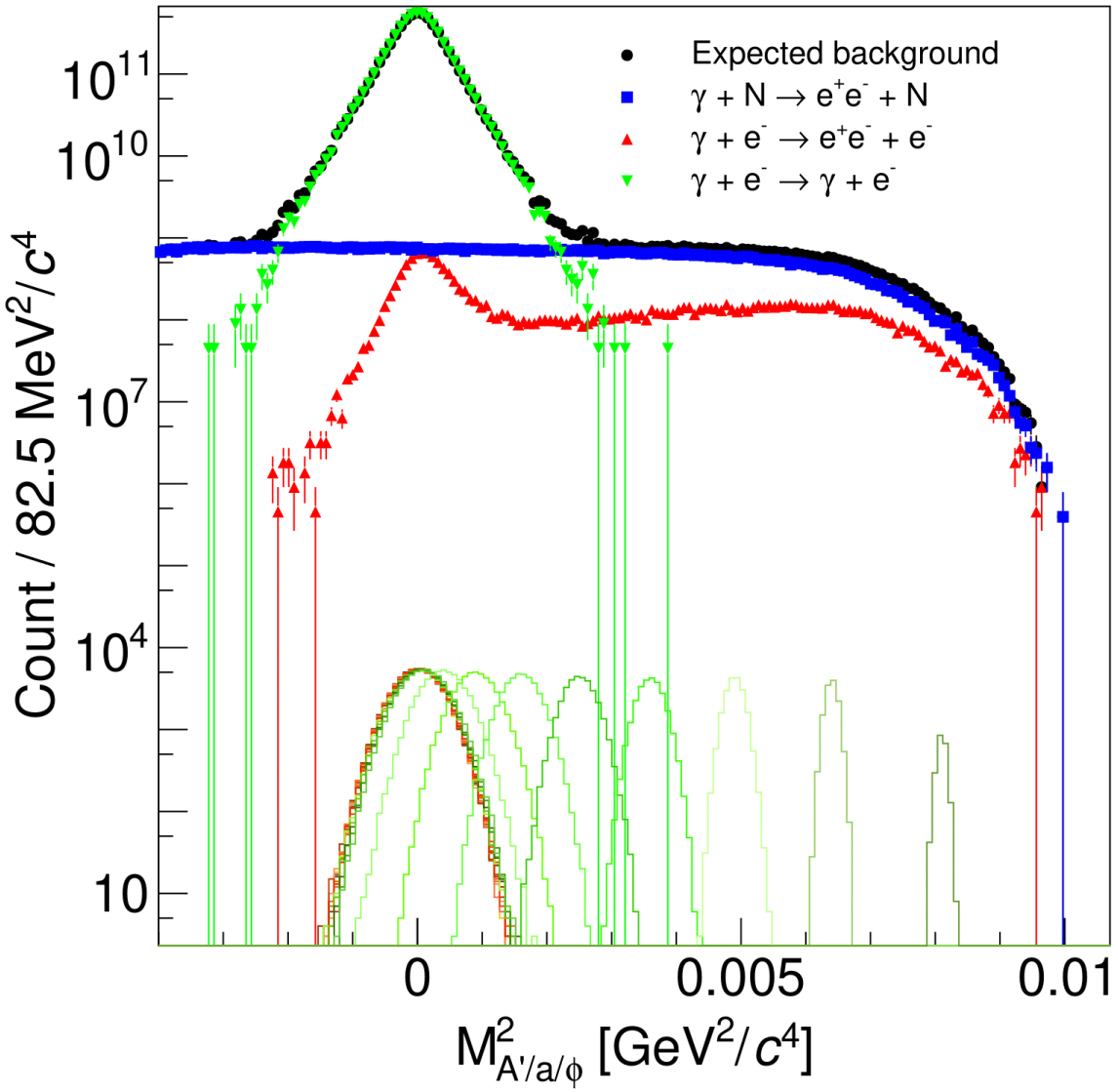
$$M^2 = s + m_e^2 - 2E_e^*\sqrt{s}$$

($\sqrt{s}$: total energy in the COM frame, E_e^*: energy of the recoil electron in the COM frame)

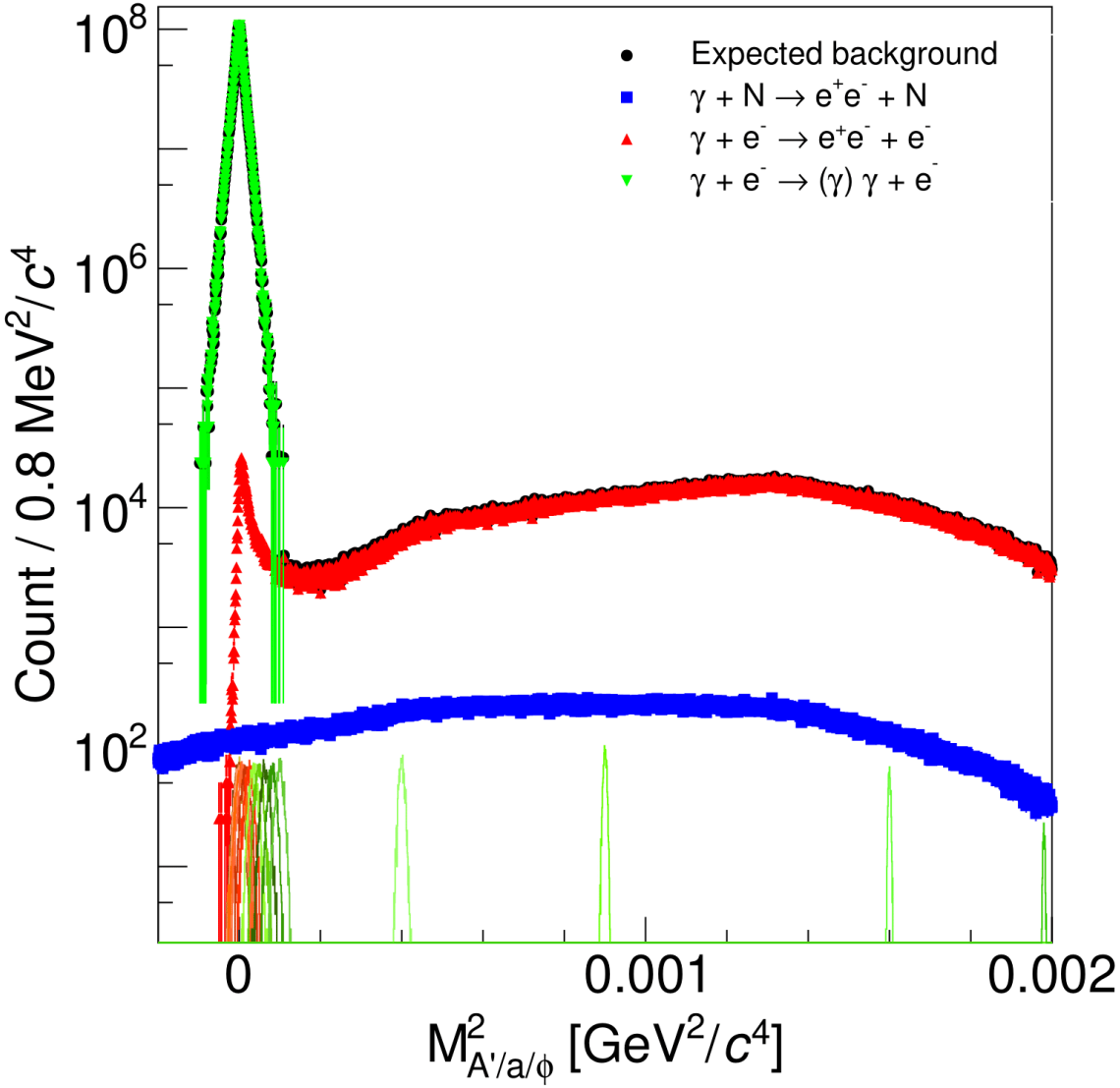
- Cuts to maximize signal to background: transverse momentum of A' is below 60, 26, 25, 10 MeV for GlueX, LEPS2, LEPS, FOREST.

Remaining background and signal for $\epsilon = 10^{-4}$

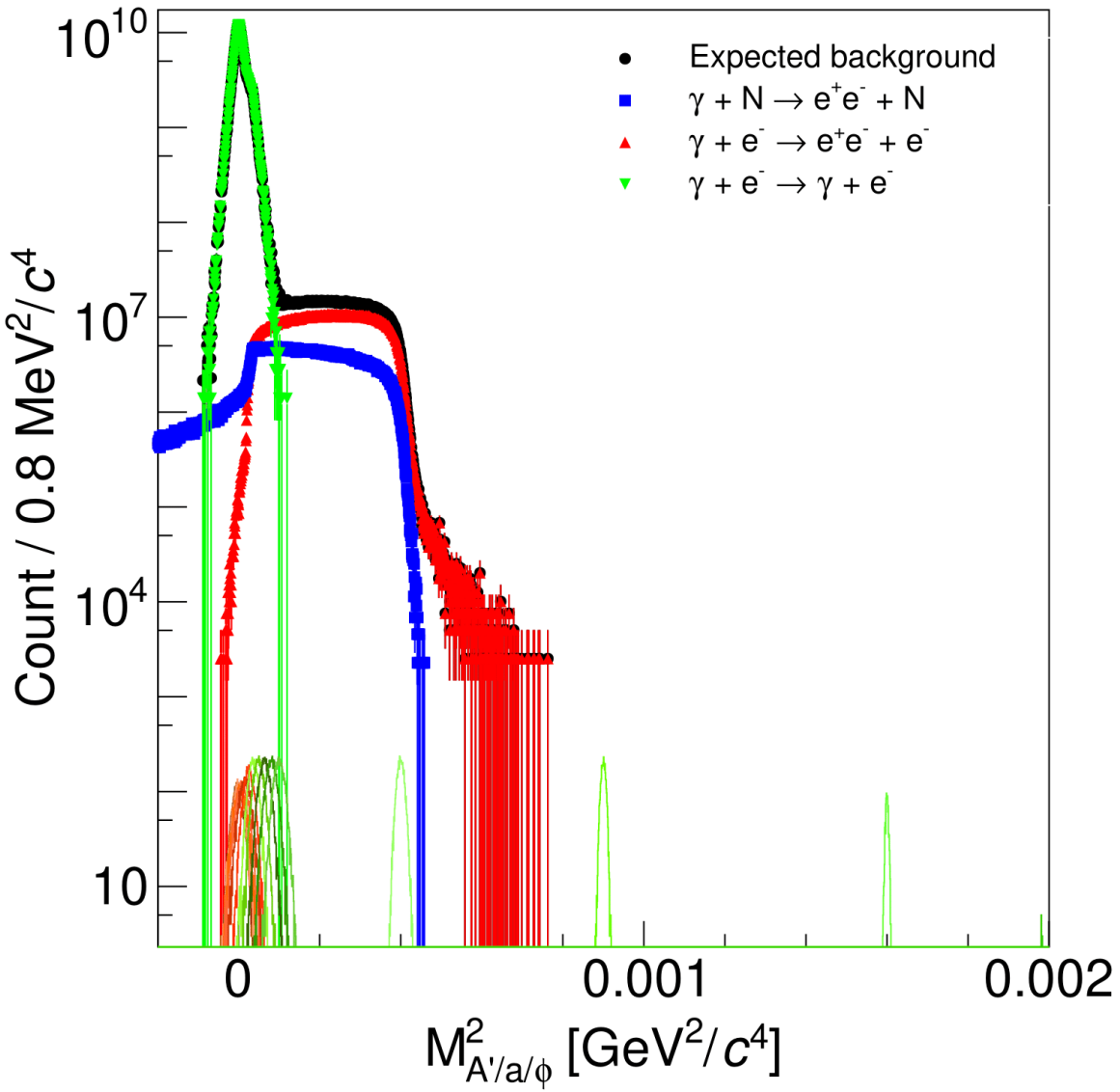
GlueX



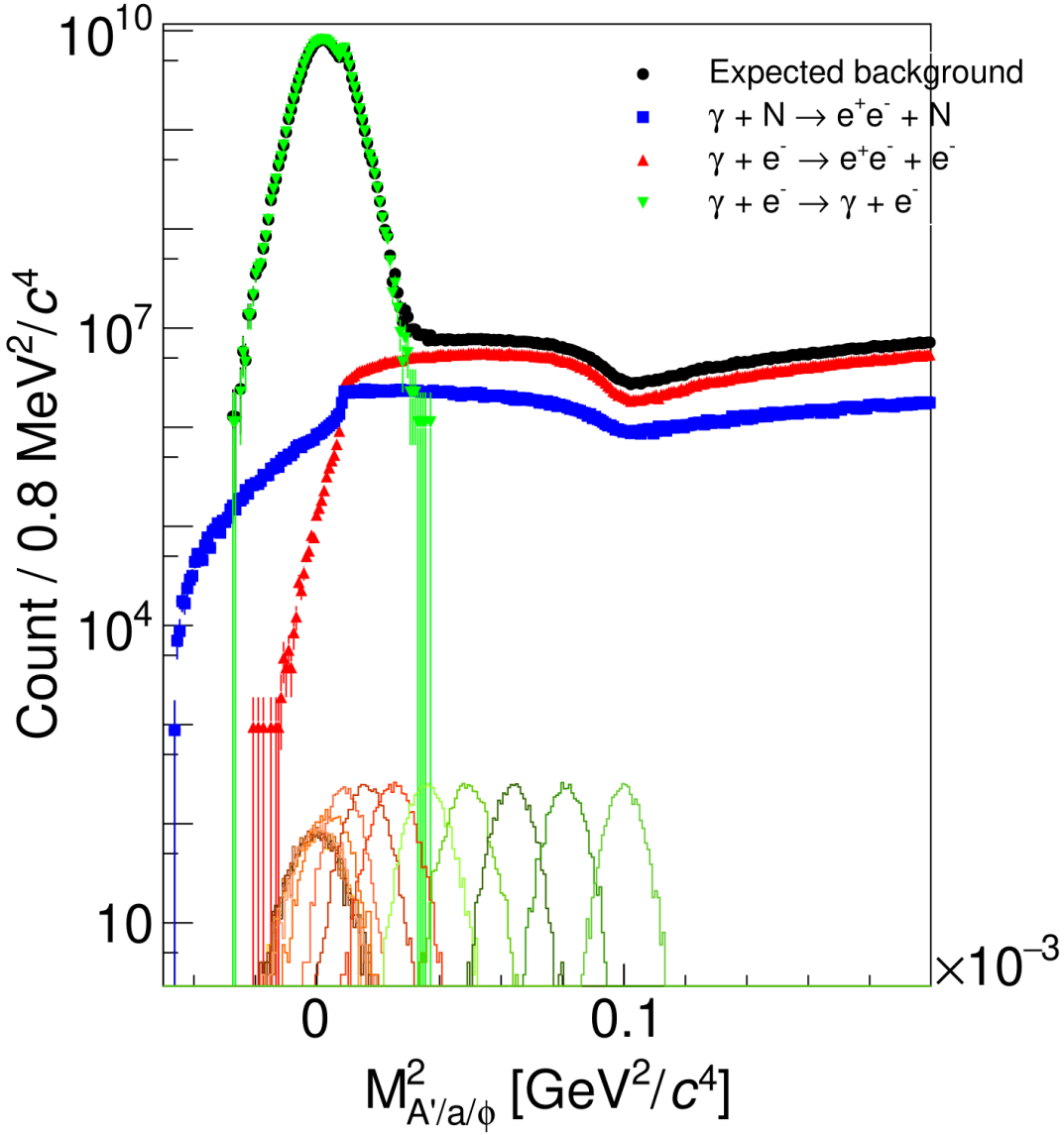
LEPS2



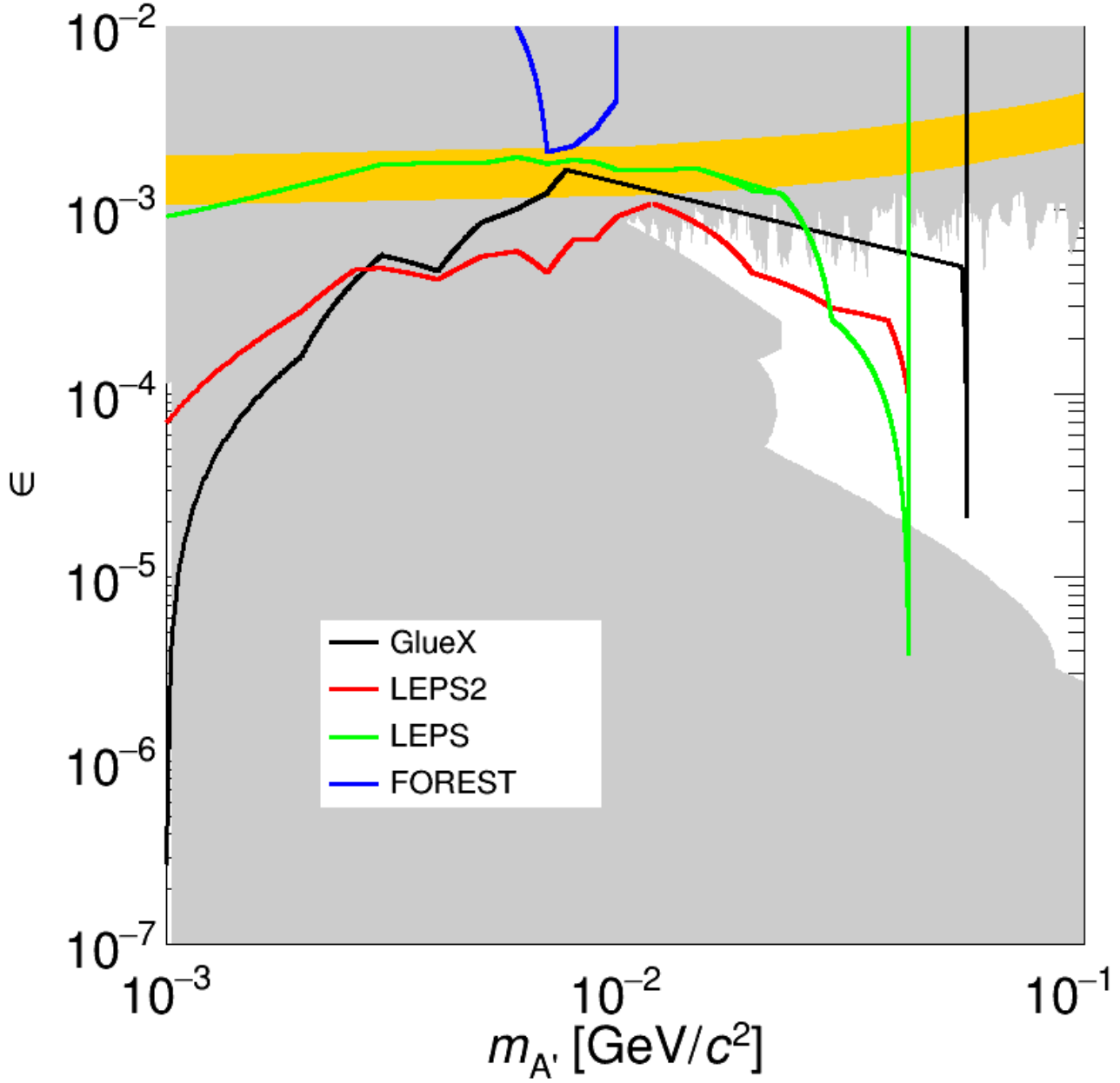
LEPS


Expected background
γ + N → e+e- + N
γ + e- → e+e- + e-
γ + e- → γ + e-
Count / 0.8 MeV²/c⁴
M²A'/a/ϕ [GeV²/c⁴]

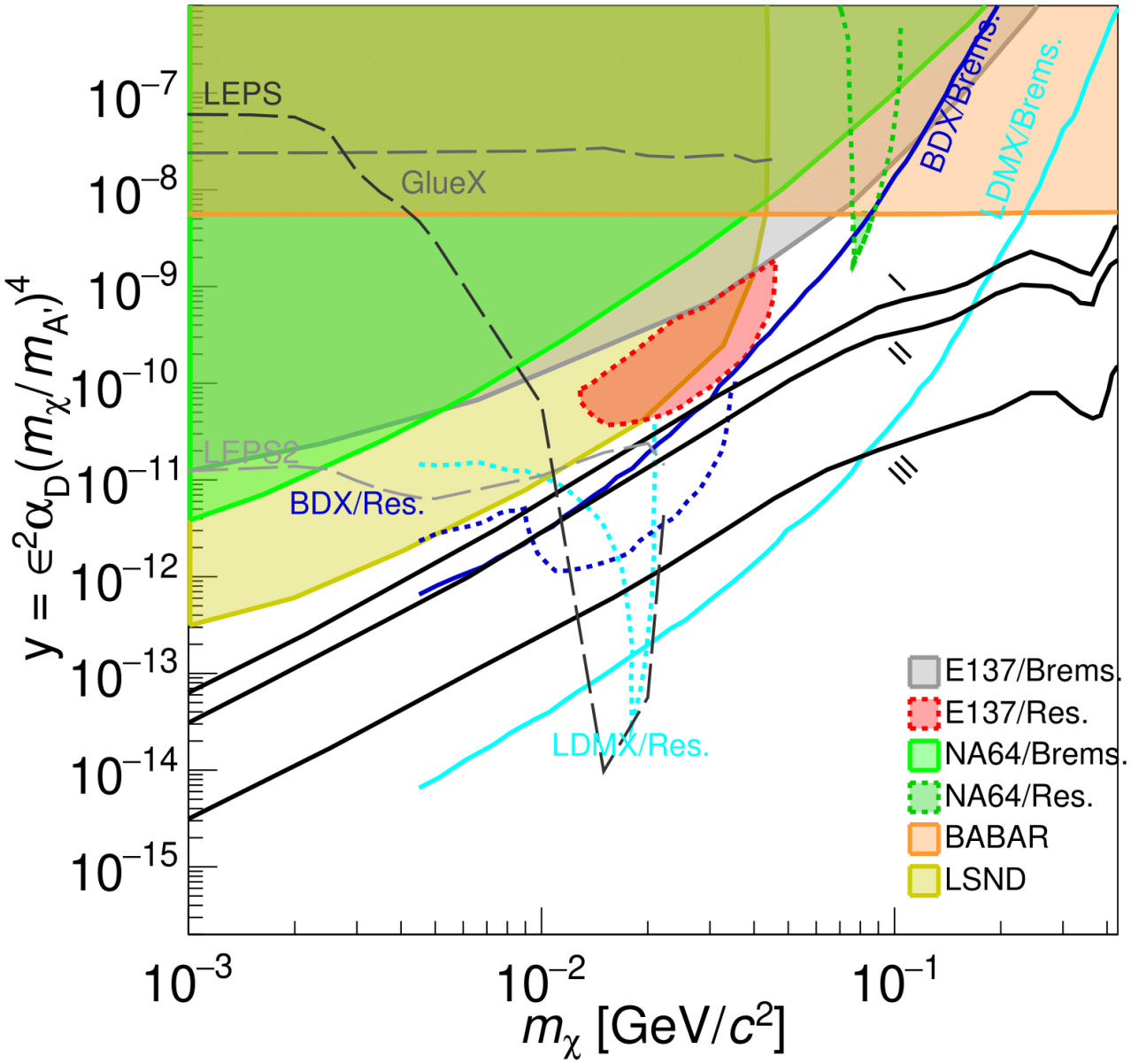
FOREST


Expected background
γ + N → e+e- + N
γ + e- → e+e- + e-
γ + e- → γ + e-
Count / 0.8 MeV²/c⁴
×10⁻³
M²A'/a/ϕ [GeV²/c⁴]

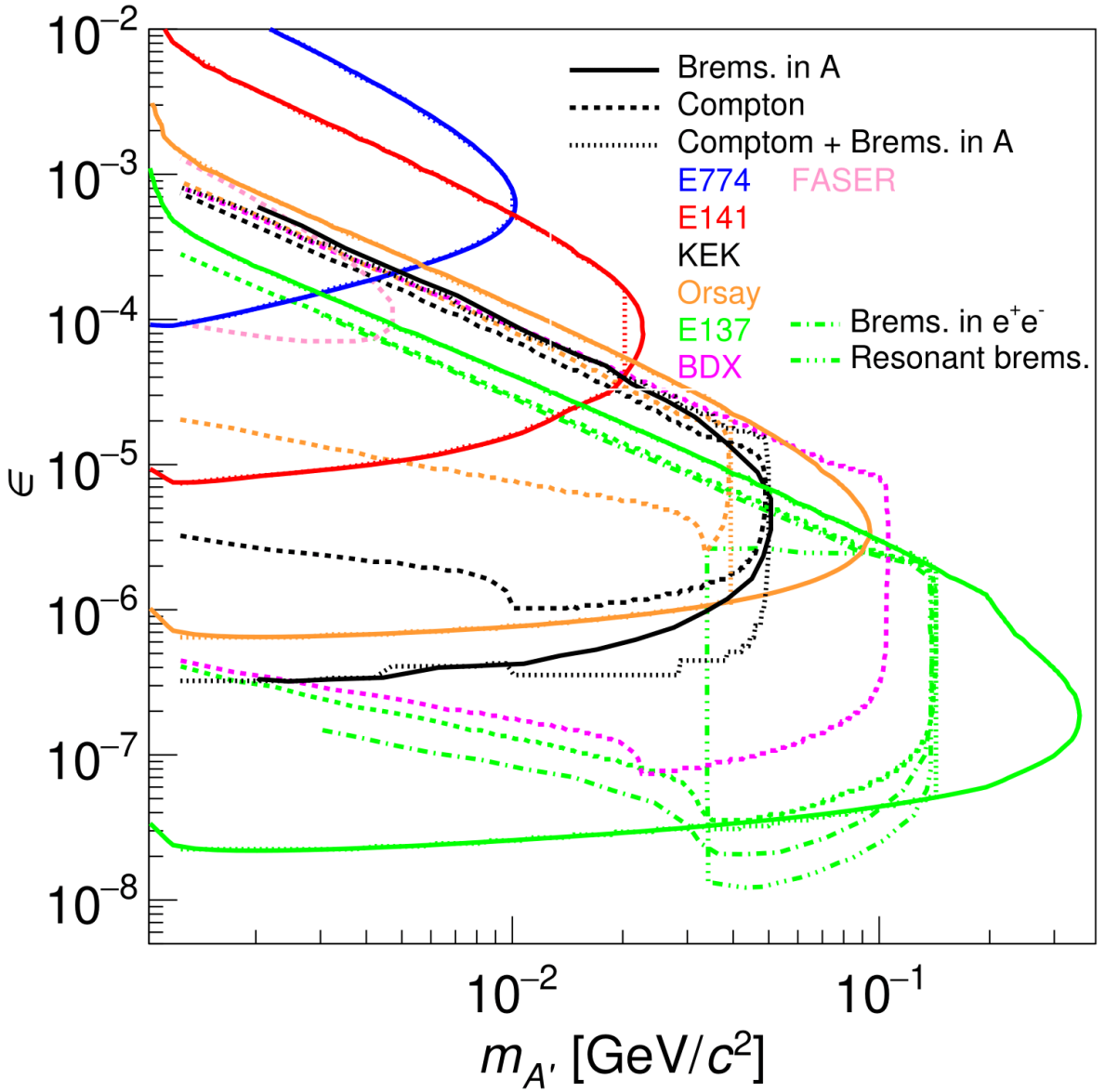
Expected sensitivities

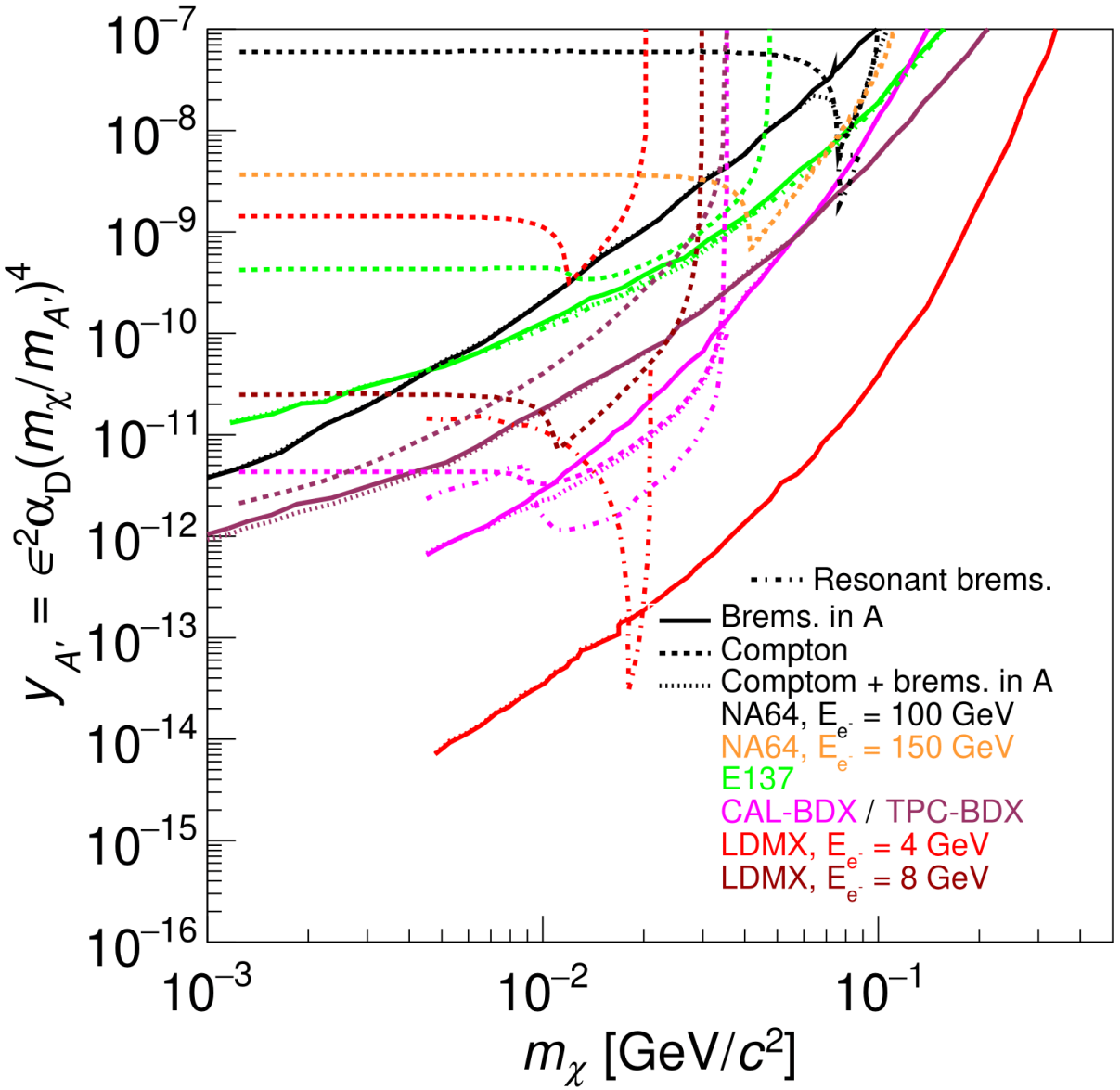


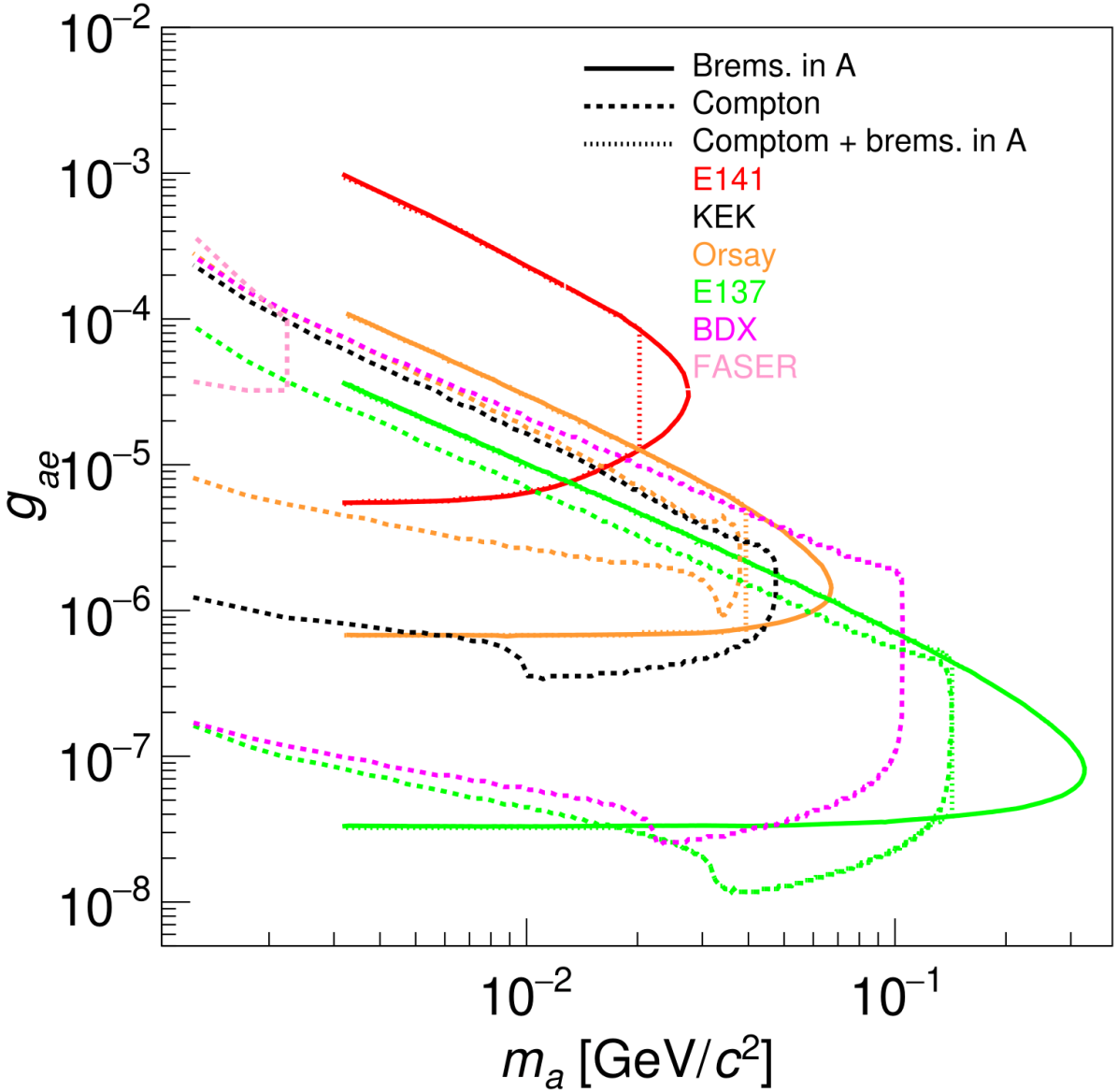
Similar sensitivities for invisible decay

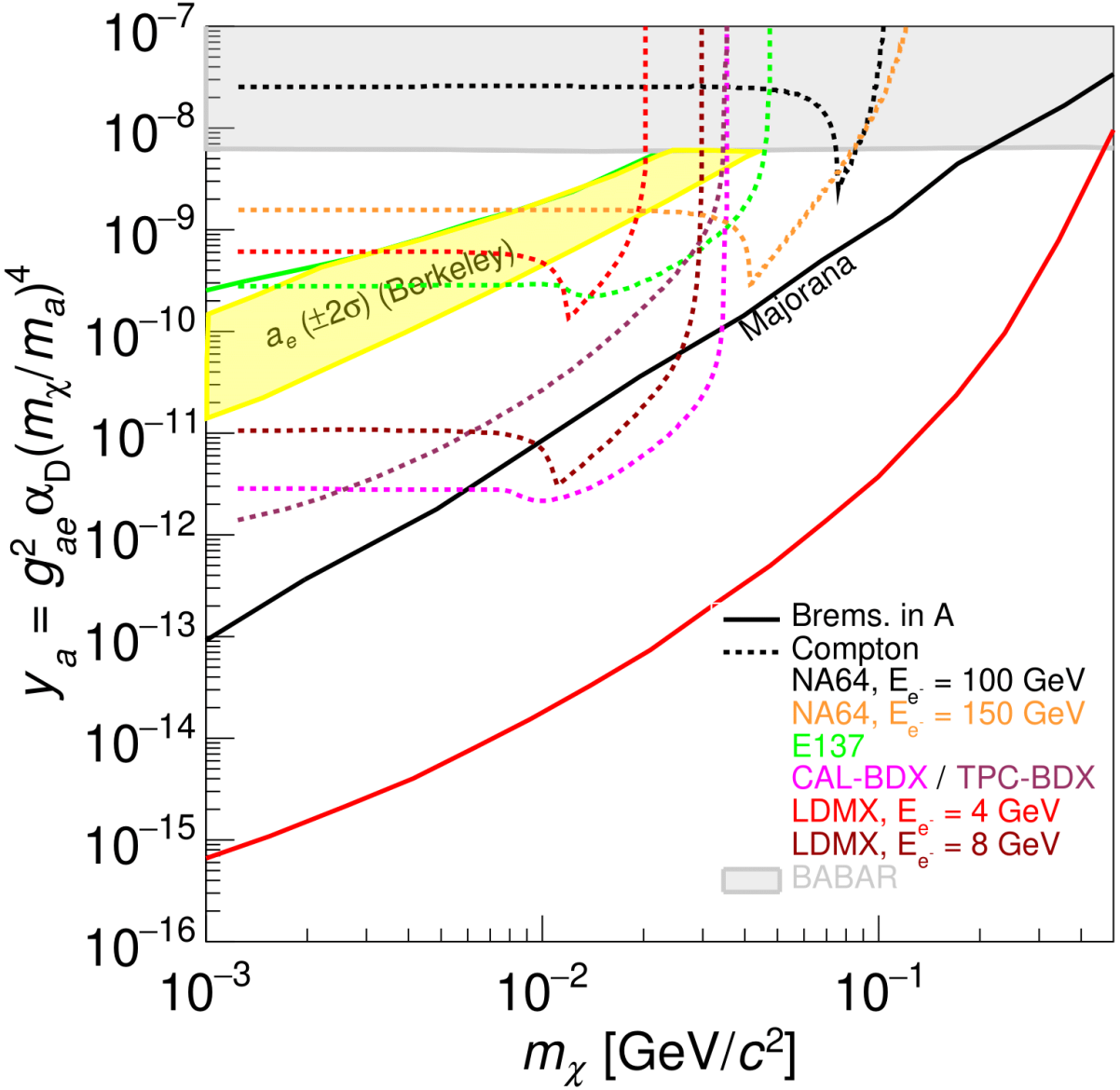


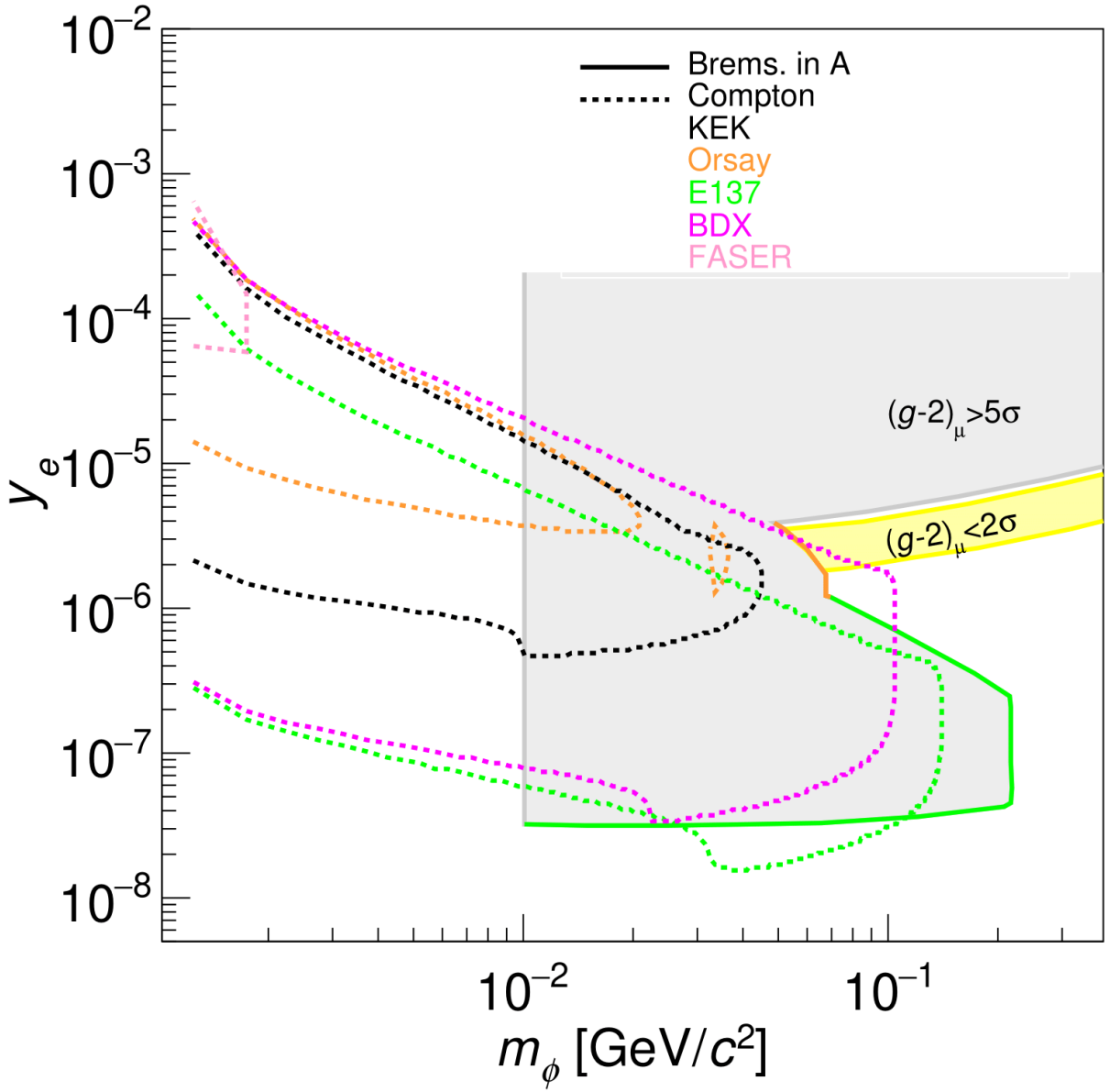
For Beam Dump Experiments

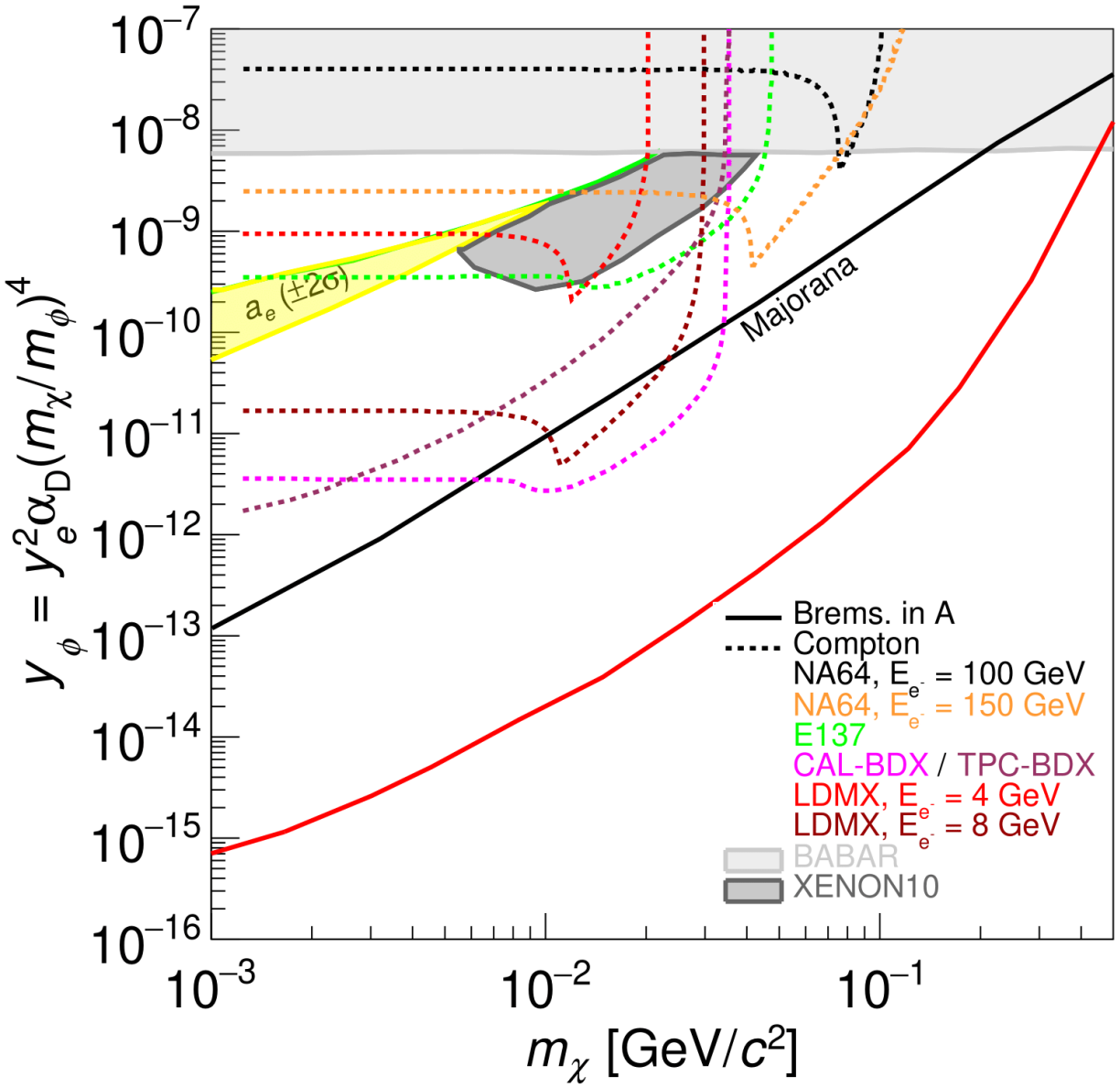





Brems. in A
Compton
Comptom + brems. in A
E141
KEK
Orsay
E137
BDX
FASER
g_{ae}
m_a [GeV/c^2]


$y_a \equiv g_{ae}^2 \alpha_D (m_\chi/m_a)^4$
a_e ($\pm 2\sigma$) (Berkeley)
Majorana
Brems. in A
Compton
NA64, E_{e^-} = 100 GeV
NA64, E_{e^-} = 150 GeV
E137
CAL-BDX / TPC-BDX
LDMX, E_{e^-} = 4 GeV
LDMX, E_{e^-} = 8 GeV
BABAR
m_χ [GeV/c^2]


Brems. in A
Compton
KEK
Orsay
E137
BDX
FASER
$(g\text{-}2)_\mu$>5σ
$(g\text{-}2)_\mu$<2σ
y_e
m_ϕ [GeV/c^2]


a_e (±2σ)
Majorana
Brems. in A
Compton
NA64, E_{e^-} = 100 GeV
NA64, E_{e^-} = 150 GeV
E137
CAL-BDX / TPC-BDX
LDMX, E_{e^-} = 4 GeV
LDMX, E_{e^-} = 8 GeV
BABAR
XENON10
$y_\phi = y_e^2 \alpha_D (m_\chi/m_\phi)^4$
m_χ [GeV/c^2]