Gamma Ray Polarization as a possible test of Axion-Like Particles using AMS-like detectors

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Based on work in progress with Yi Jia and Tracy Slatyer

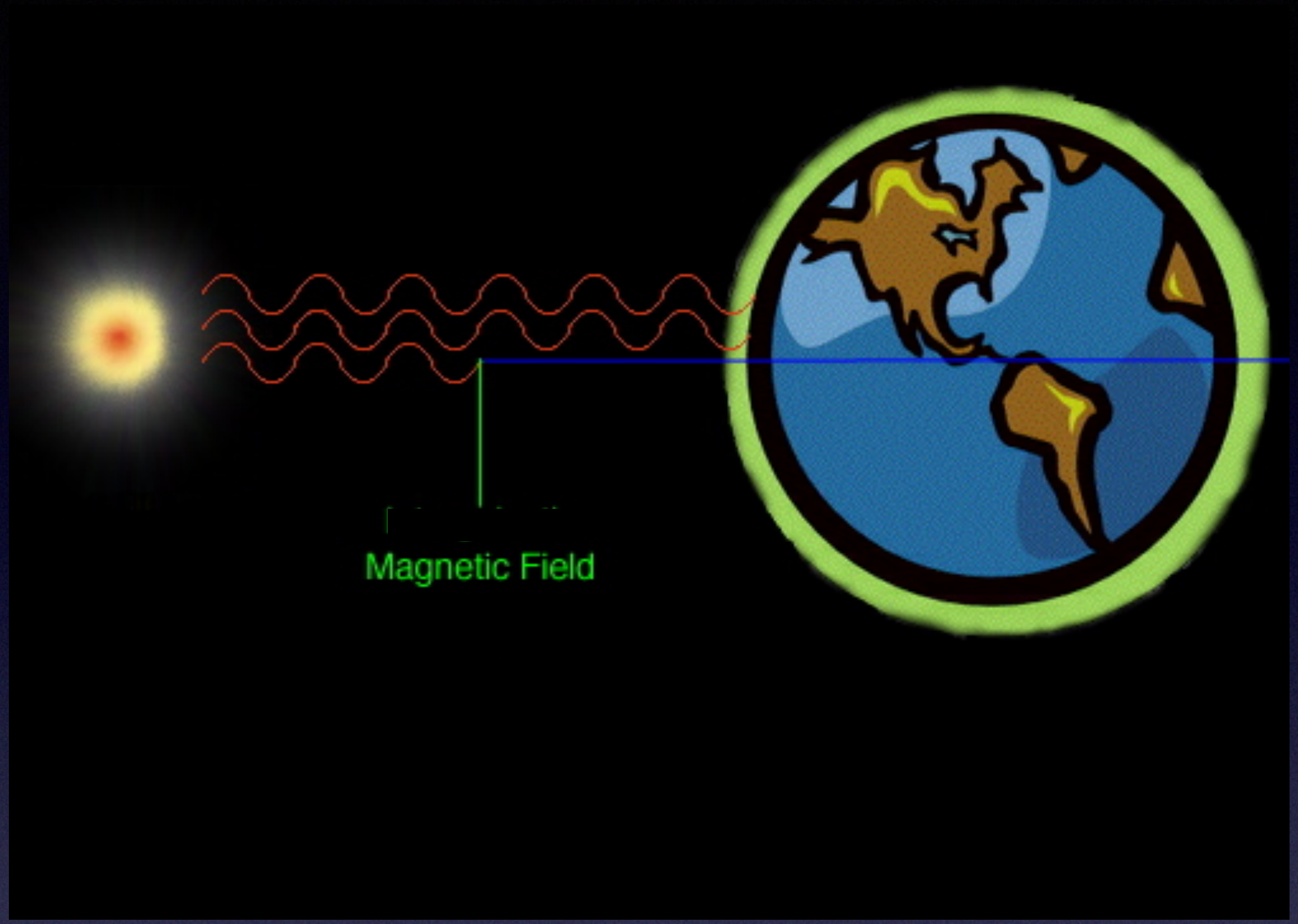
Introduction

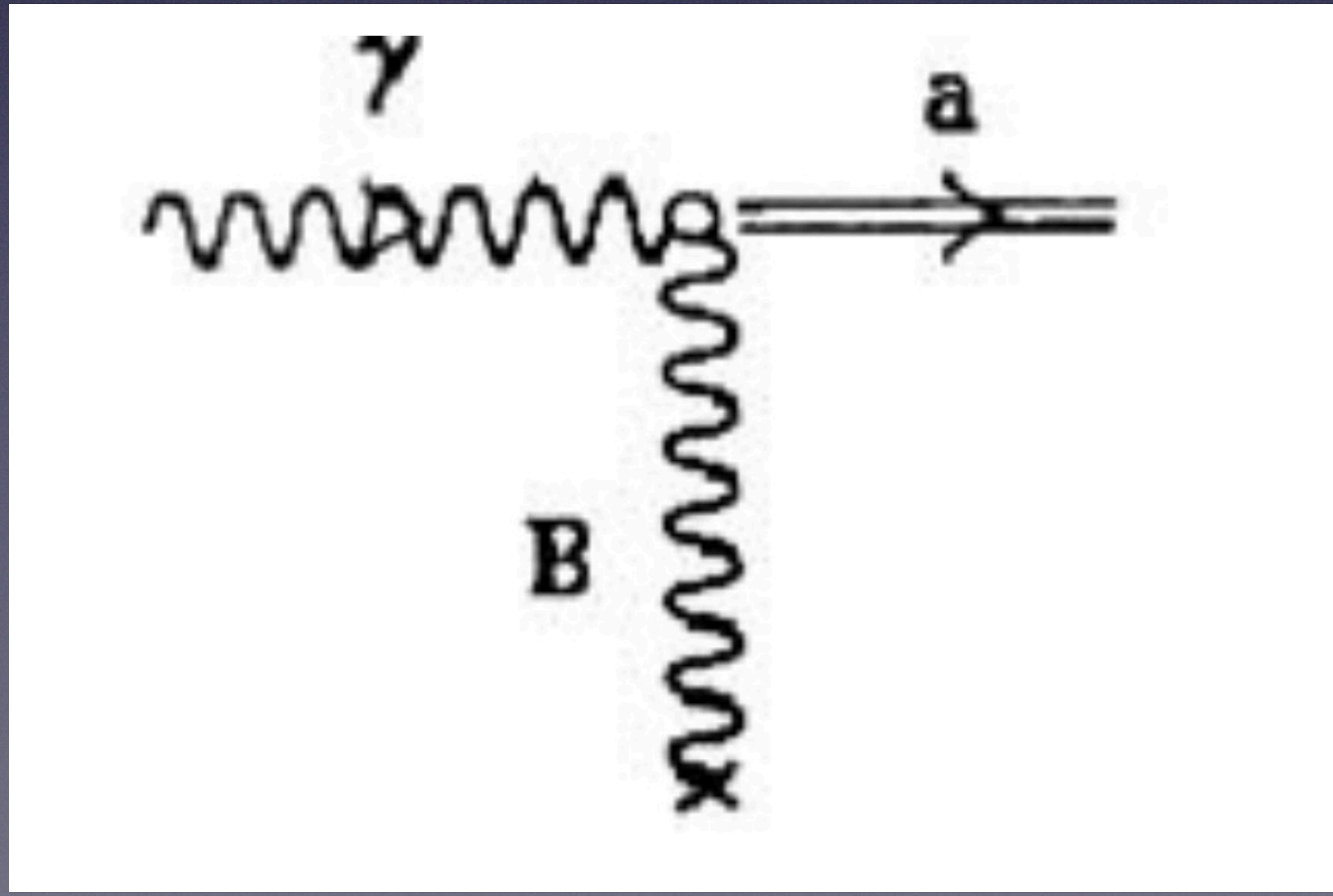
- Photon-ALP mixing: $\mathscr{L} = g_{a\gamma\gamma} a \vec{E} \cdot \vec{B}$

- Polarization of light from astronomical sources can serve as a probe of new physics, like axion-like particles(ALP)

- Previous studies on polarization signals have focused on lower energies, from radio up to the MeV scale. (1801.10557)

- Above the GeV scale, the only studies of ALP effects have been on photon intensity including claims of a modest possible signal(1801.08813)



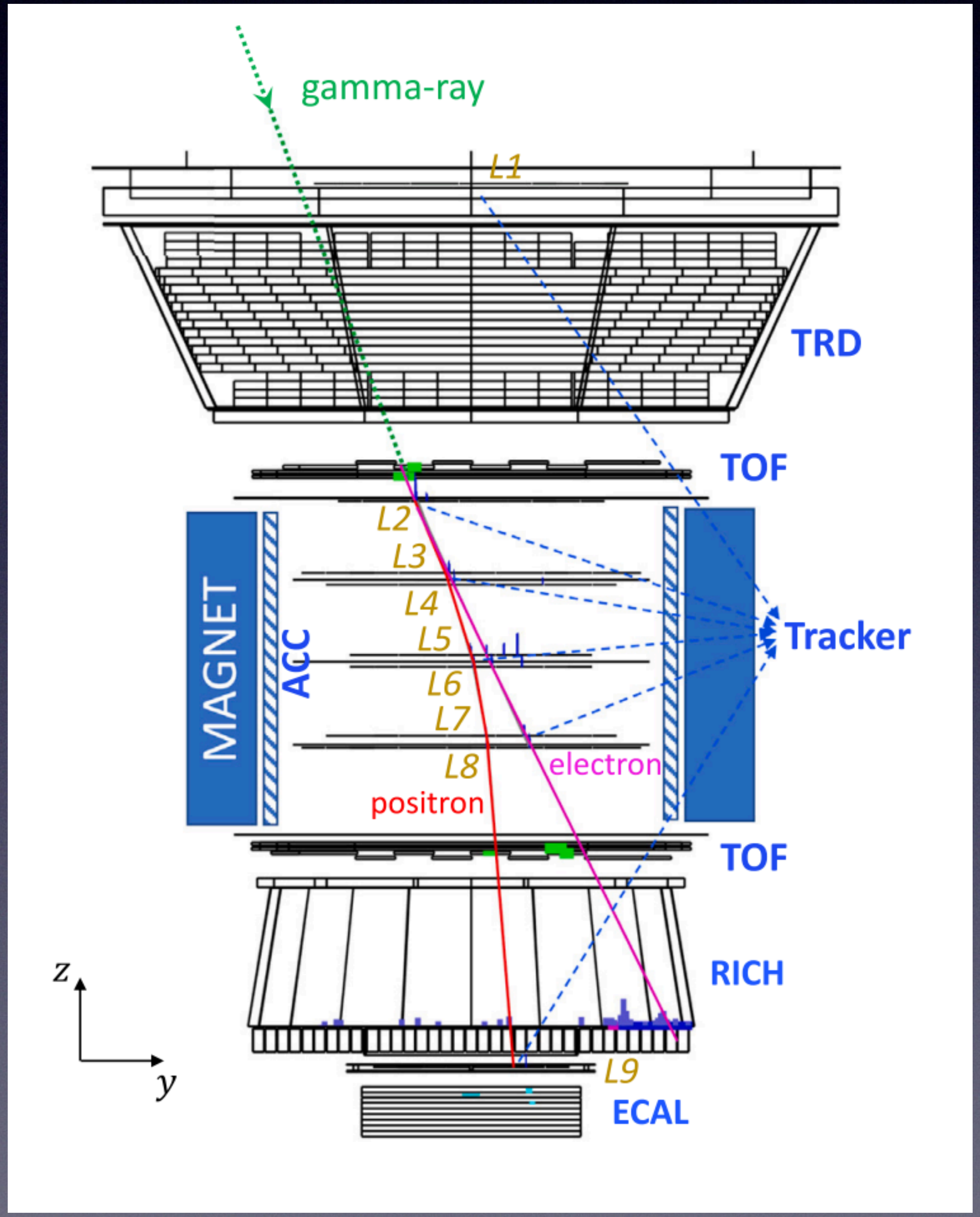


Polarization detection from AMS-like detector

- High energy gamma-ray has a chance of converting into electron-positron pairs.

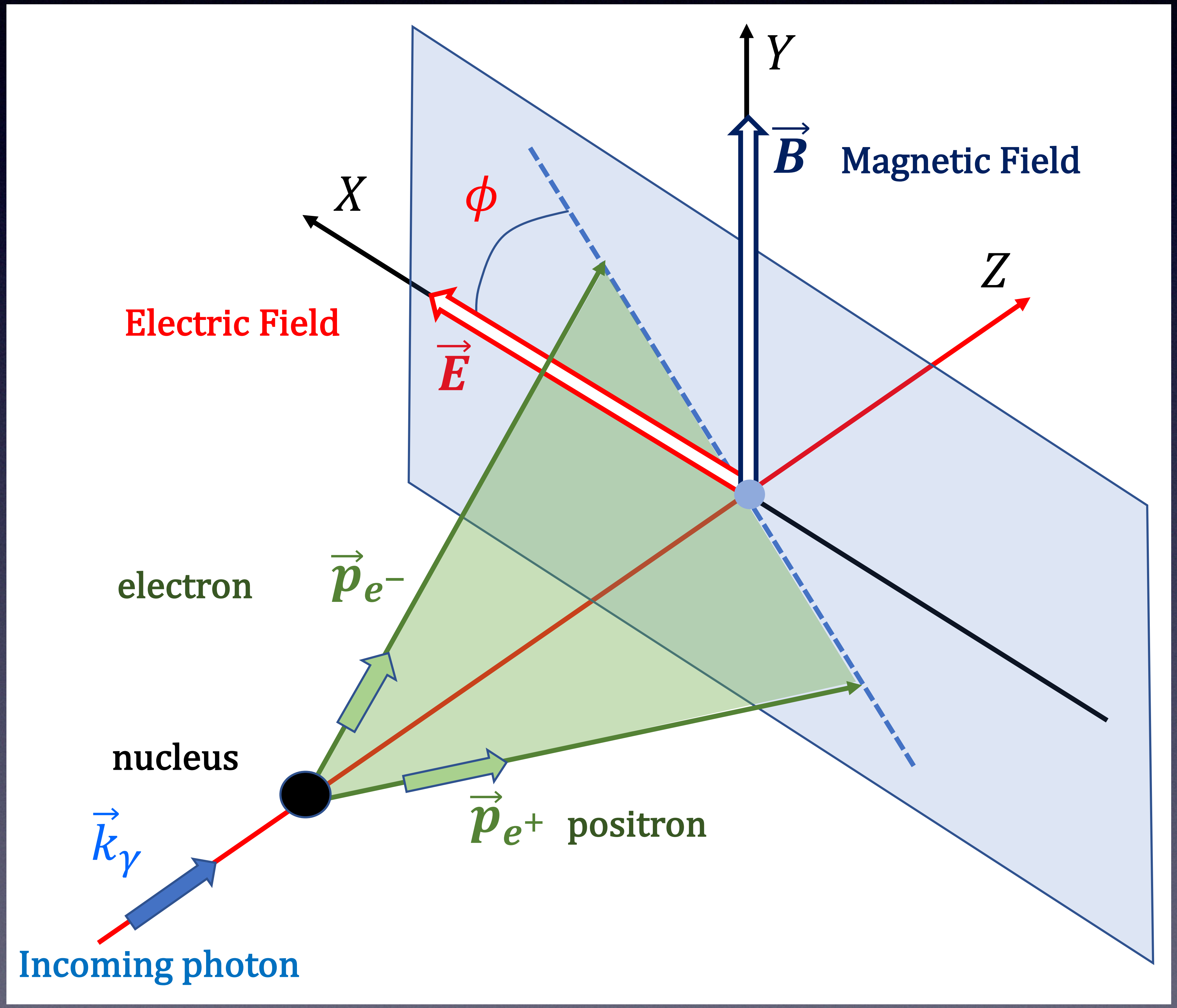
- The conversion probability depends on the total amount of traversed material.

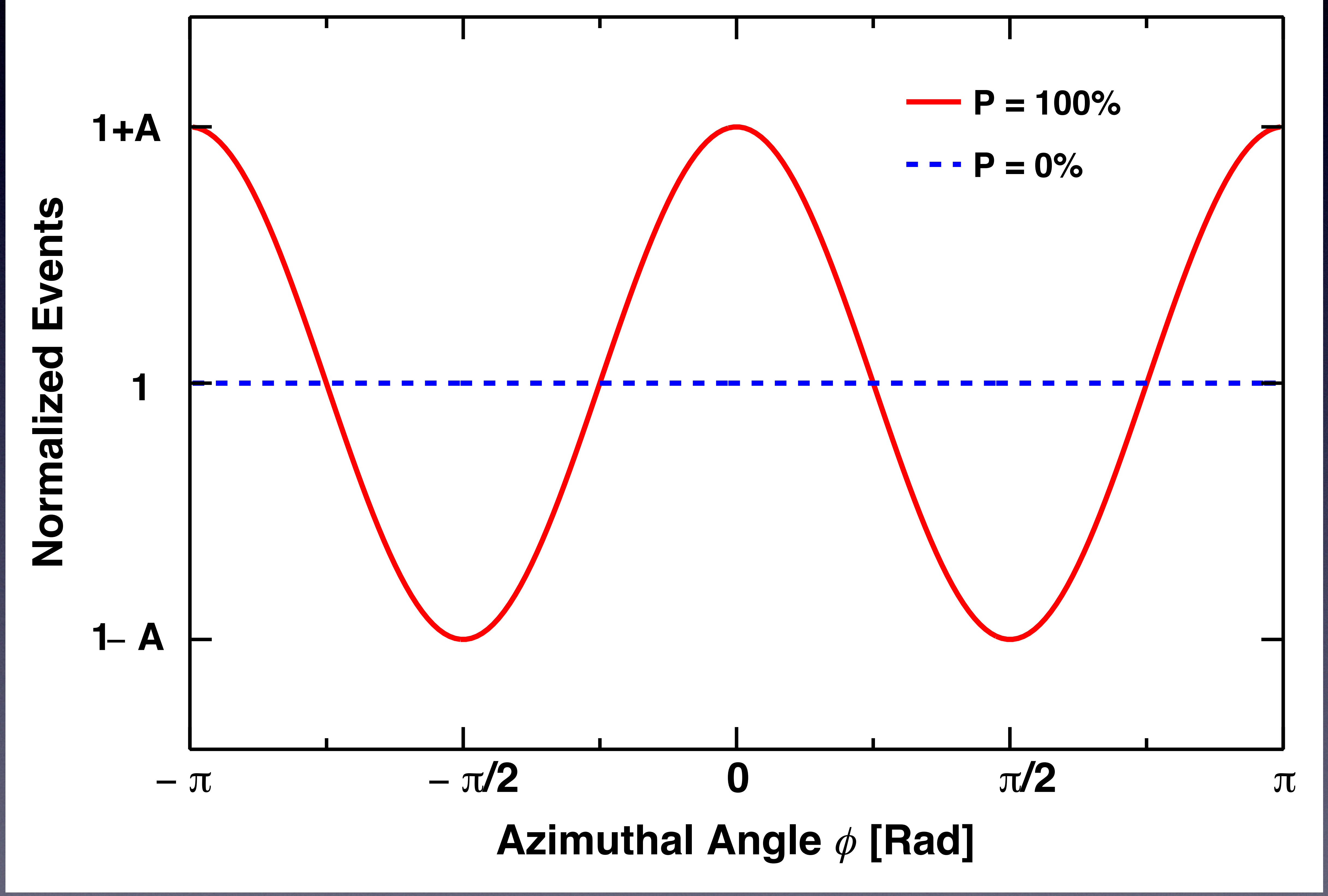
- Electrons and positrons will be bent into different directions by the magnetic field. We can trace back their tracks to determine the polarization angle.



Jinhua Li, Zhaoyi Qu, Weiwei Xu, Nucl. Instrum. Meth(2024)

Polarization measurement by pair production



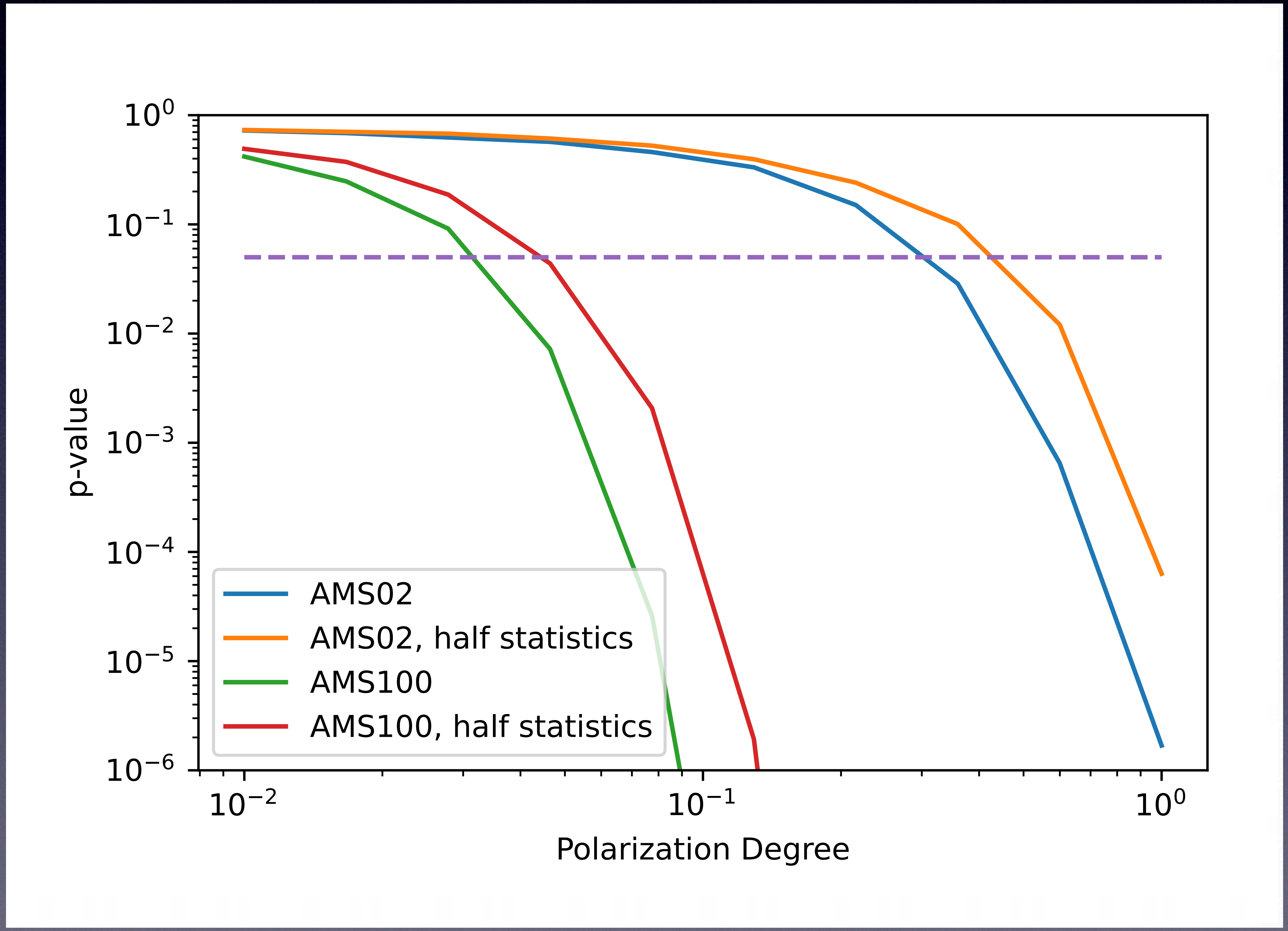


Minimal detectable polarization for AMS-like detectors

- For statistics matching the expected counts from the supernova remnant W44 accumulated for 10 years, AMS-02 can distinguish a signal with a polarization fraction greater than 0.3 from an unpolarized signal.

- Subdividing the total statistic into bins will further restrict AMS-02's ability to distinguish polarization fractions and make it hard to detect polarization variation as a function of energy from galactic sources

- Future detectors like AMS100 will have enough sensitivity.

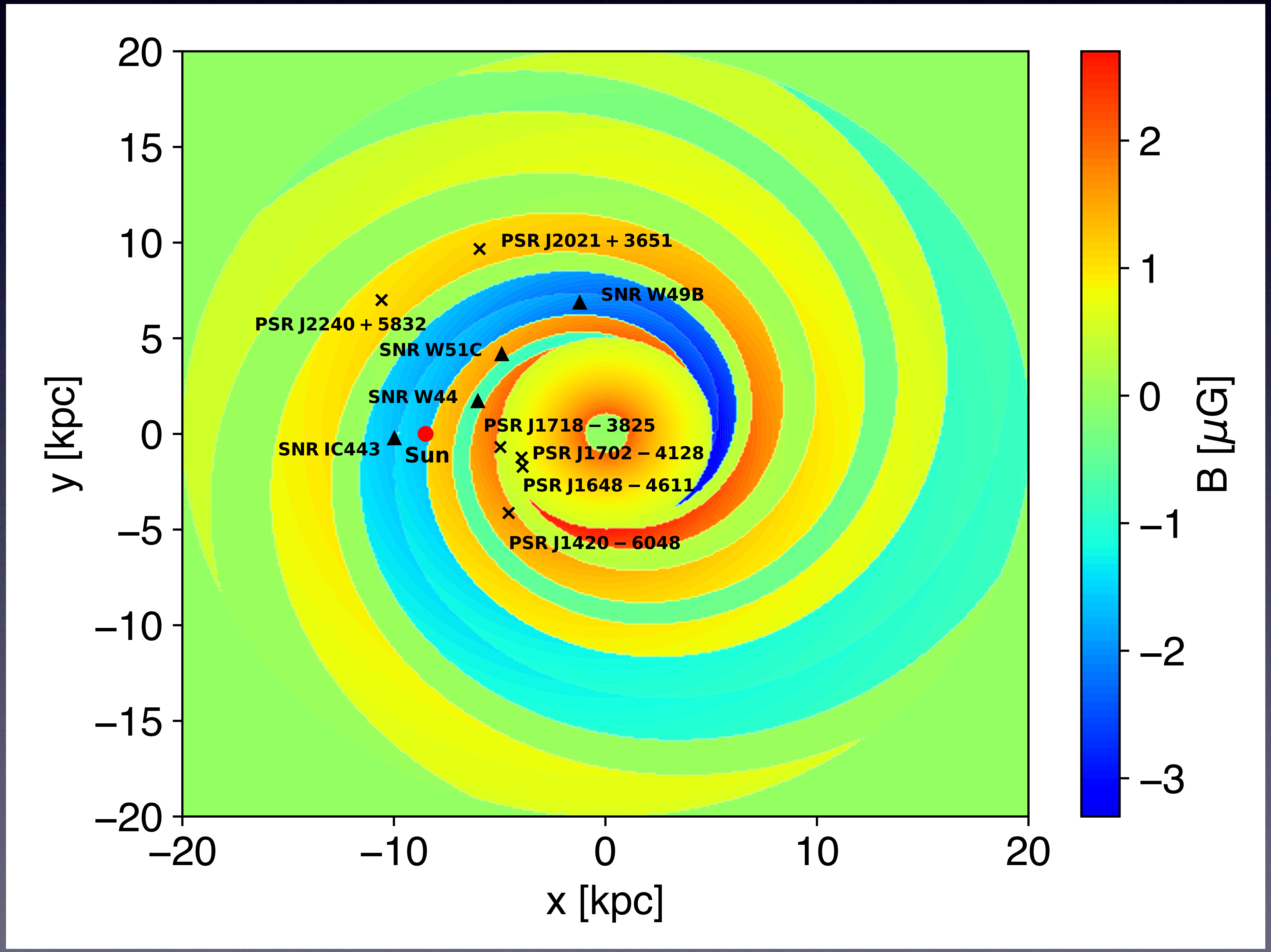


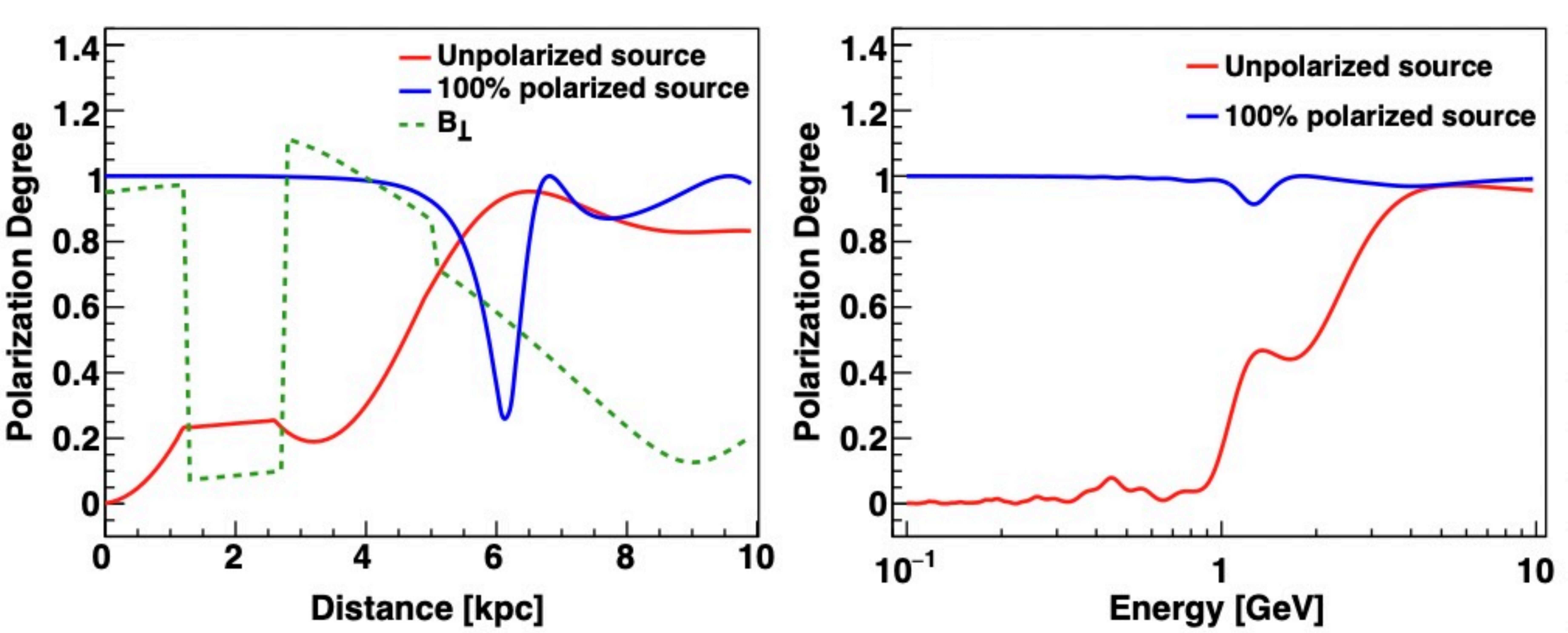
Galactic magnetic field modeling and sources selection

- We use Jansson and Farrar's Galactic Magnetic Field model(1204.3662), with an updated set of parameters from the Planck Collaboration(1601.00546)

- We prefer bright sources with low latitudes with relatively large and well-determined distances

- We consider the six best pulsars and four best supernova remnants according to these criteria

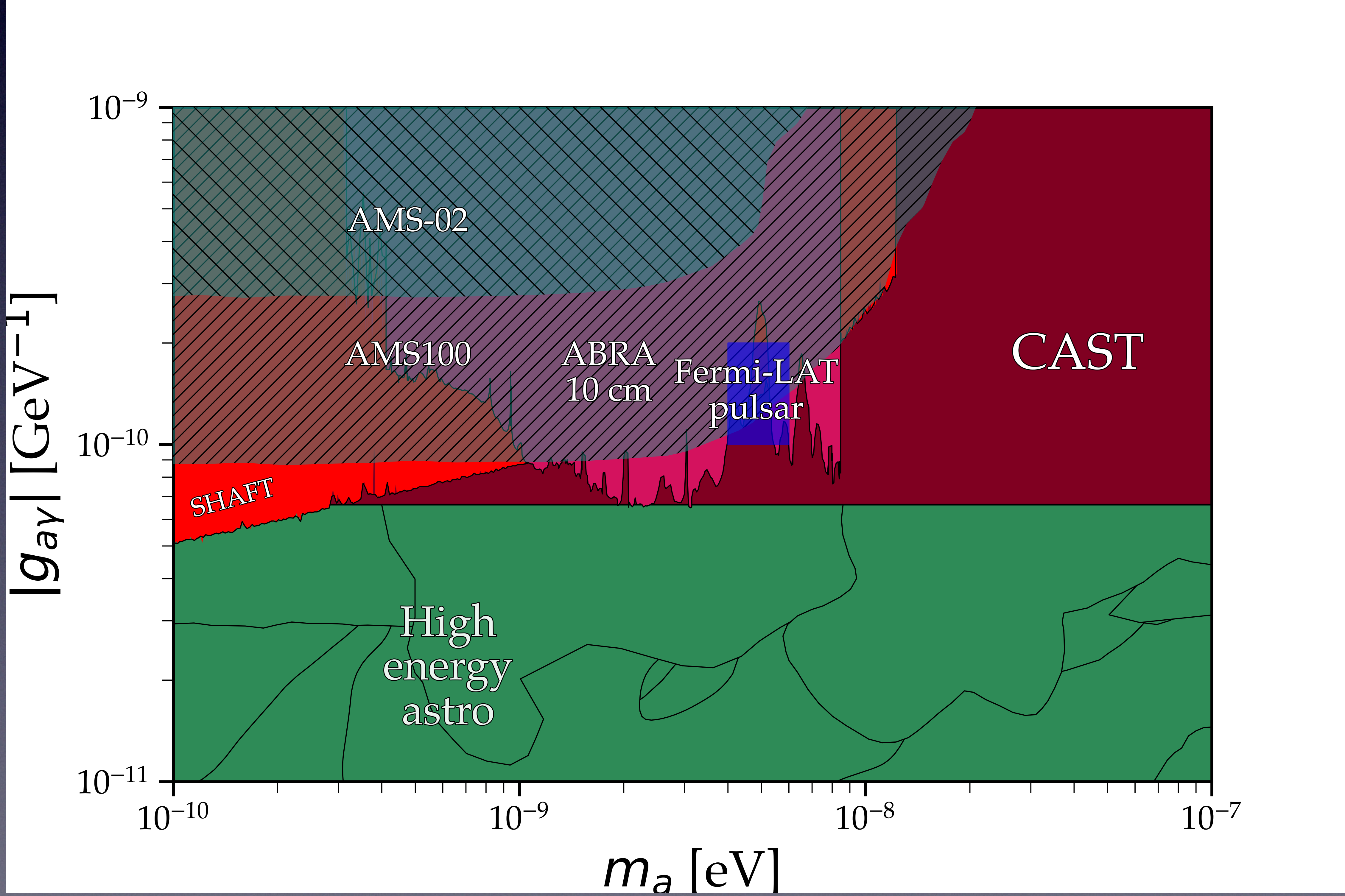




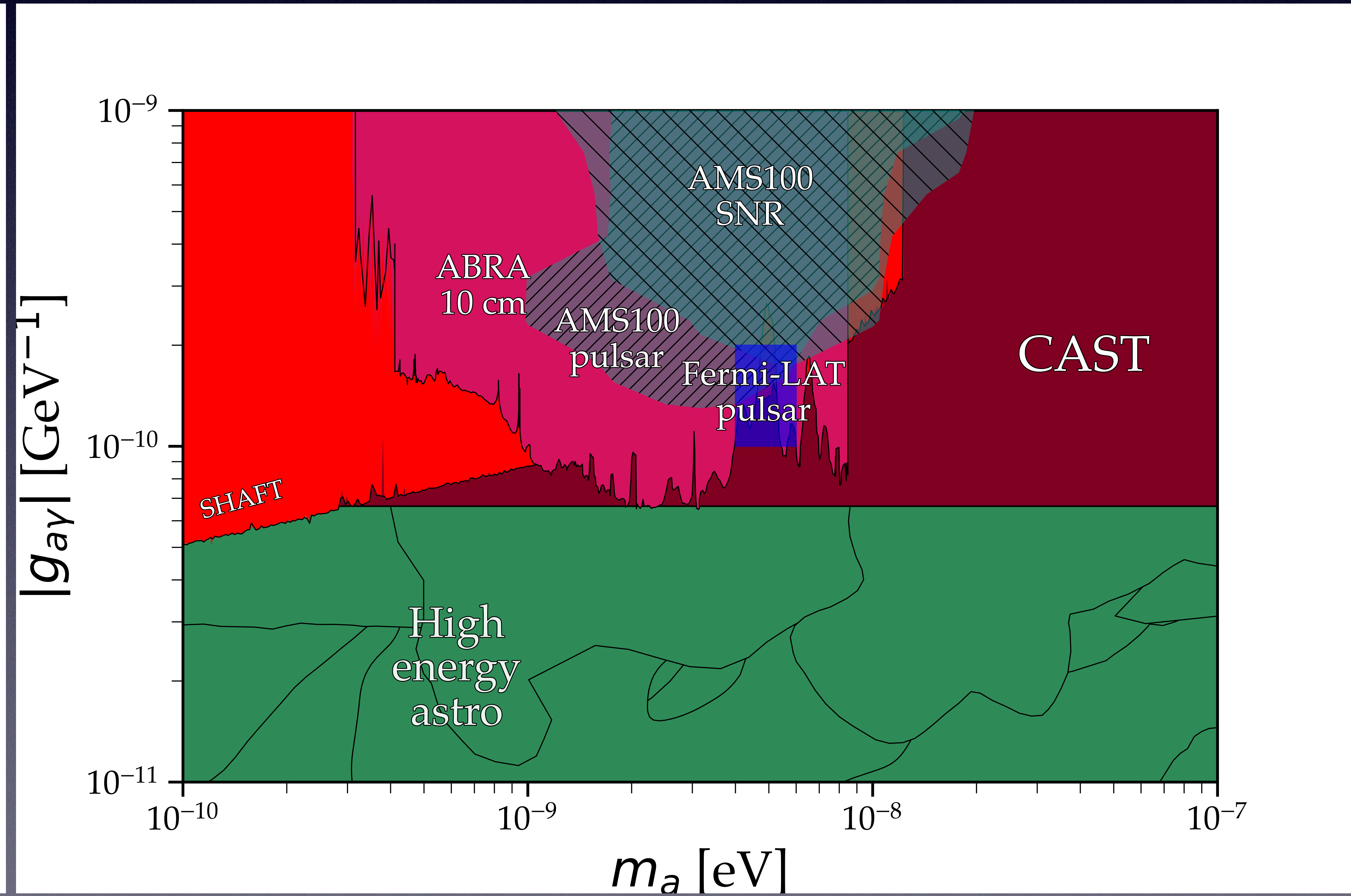
Unpolarized source
100% polarized source
B⊥
Polarization Degree
Distance [kpc]
Unpolarized source
100% polarized source
Polarization Degree
Energy [GeV]

Sensitivity Projection

Non-zero polarization detection projection



Polarization variation in energy detection projection



Conclusion

- AMS-02 detector paves a new way into detecting gamma ray polarization in GeV range.

- With increased statistics from a future AMS-like detector, it would be possible to measure varying of polarization as a function of energy from Galactic gamma-ray sources and thus put limit on the Axion-like particle parameter space.

- Such a measurement could provide an independent test for the axion-like particles, e.g. with respect to a claimed ALP hint in Fermi gamma-ray intensity measurements (although requires model-building to avoid exclusion by CAST + other probes)

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- $$(E + \mathscr{M} - i\partial_z)\begin{pmatrix} |\gamma_x\rangle \\ |\gamma_y\rangle \\ |a\rangle \end{pmatrix} = 0 \qquad \mathscr{M} = \begin{pmatrix} \Delta_\perp & 0 & 0 \\ 0 & \Delta_\parallel & \Delta_{\gamma a} \\ 0 & \Delta_{\gamma a} & \Delta_a \end{pmatrix}$$

- $$E_c = 2.5GeV \frac{|m_a^2 - \omega_{pl}^2|}{(1neV)^2}(\frac{B_\perp}{\mu G})^{-1}(\frac{g_{a\gamma\gamma}}{10^{-11}GeV^{-1}})^{-1}$$

- $$l_{osc} = 32kpc\sqrt{1 + (E_c/E)^2}(\frac{B_\perp}{\mu G})^{-1}(\frac{g_{a\gamma\gamma}}{10^{-11}GeV^{-1}})^{-1}$$

Backup Slides

$$\Delta_{\mathrm{pl}} = -1.1 \times 10^{-7} \left(\frac{N_e}{10^{-3}\mathrm{cm}^{-3}} \right) \left(\frac{E}{\mathrm{GeV}} \right)^{-1} \mathrm{kpc}^{-1},$$

$$\Delta_{\mathrm{QED}} = 4.1 \times 10^{-9} \left(\frac{E}{\mathrm{GeV}} \right) \left(\frac{B_\perp}{\mu\mathrm{G}} \right)^{2} \mathrm{kpc}^{-1},$$

$$\Delta_{a} = -7.8 \times 10^{-2} \left(\frac{m_a}{\mathrm{neV}} \right)^{2} \left(\frac{E}{\mathrm{GeV}} \right)^{-1} \mathrm{kpc}^{-1},$$

$$\Delta_{\gamma a} = 1.52 \times 10^{-2} \left(\frac{g_{a\gamma\gamma}}{10^{-11}\mathrm{GeV}^{-1}} \right) \left(\frac{B_\perp}{\mu\mathrm{G}} \right) \mathrm{kpc}^{-1}.$$

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