A last chance for kinetic mixing?

Semi-visible dark photon solutions to $(g-2)_\mu$

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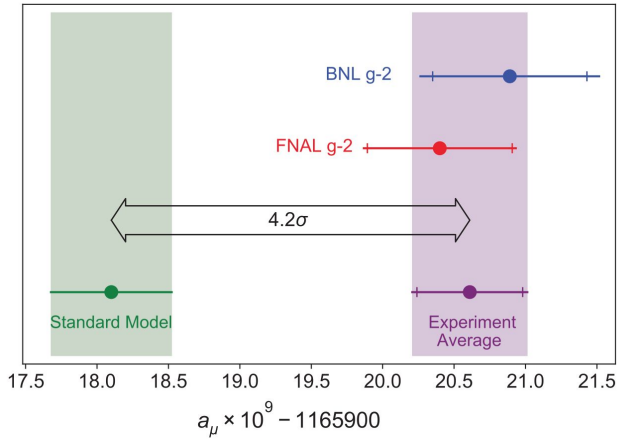
Muon $(g-2)_\mu$: New physics?

FNAL confirms BNL measurement with combined experimental significance of **4.2 sigma**

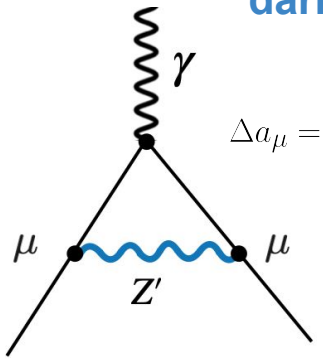
$$\Delta a_\mu = a_\mu^{\mathrm{EXP}} - a_\mu^{\mathrm{SM}} = (251 \pm 59) \times 10^{-11}$$



B. Abi, et al. Phys. Rev. Lett. 126, 141801 (2021)

?

dark photon solution?



$$\Delta a_\mu = \frac{\alpha}{2\pi}\epsilon^2 \int_0^1 dz \frac{2m_\mu^2 z(1-z)^2}{m_\mu^2(1-z)^2 + m_{Z'}^2 z}$$

Positive contribution

Simple and well motivated

M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662, 53 (2008)

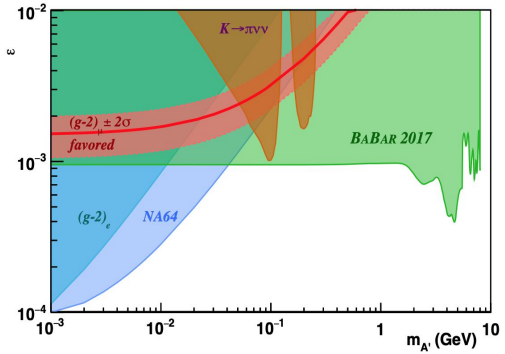
New physics? Many possibilities!

If new physics is below the EW scale

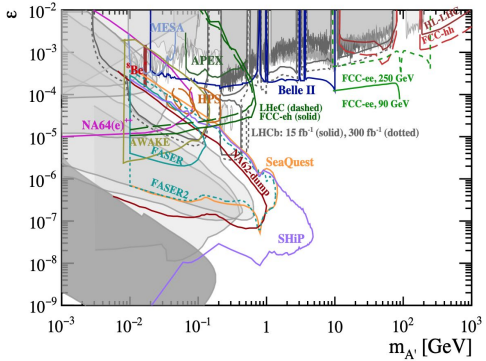
- Dark photons
- Axions, pseudo-scalars, etc.

Dead or Alive?

Invisibly and visibly decaying kinetically mixed dark photons
EXCLUDED



BABAR collaboration, Phys. Rev. Lett. 119, 131804 (2017)



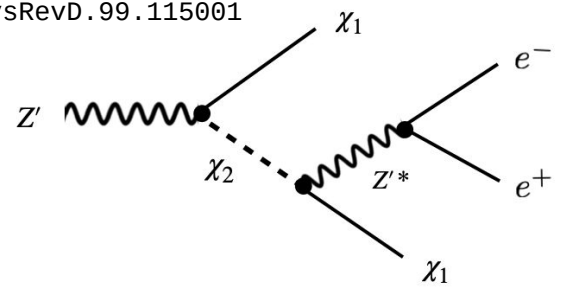
Fabbrichesi, et al. 10.1007/978-3-030-62519-1

another possibility

→ **semi-visibly decaying dark photons**

Izaguirre, et al.
10.1103/PhysRevD.96.055007

G.Mohlabeng,
10.1103/PhysRevD.99.115001

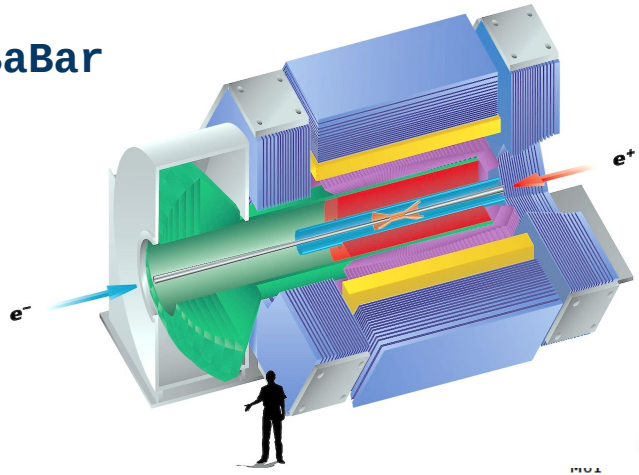


Characterised by **missing energy**
+
visible final states in detector

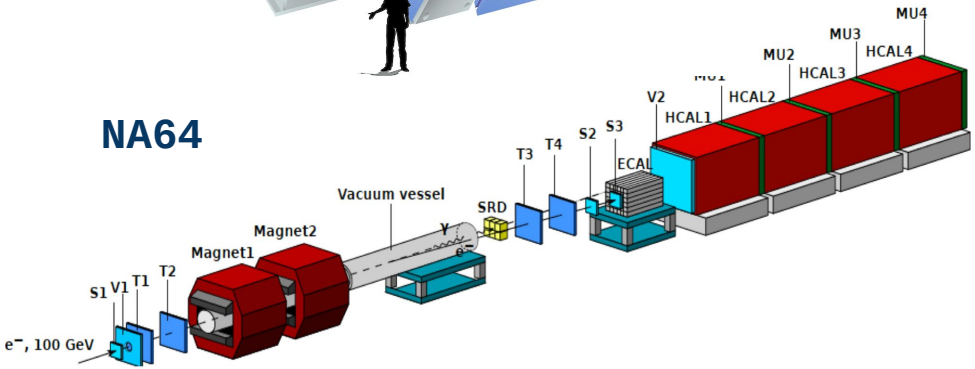
Revised constraints on semi-visible DP

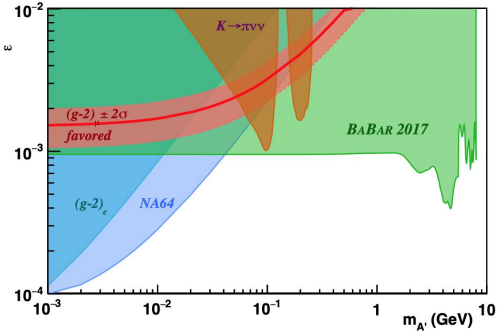
Strongest bounds on 100 MeV-GeV semi-visible DP from beam dumps and B factories

BaBar



NA64



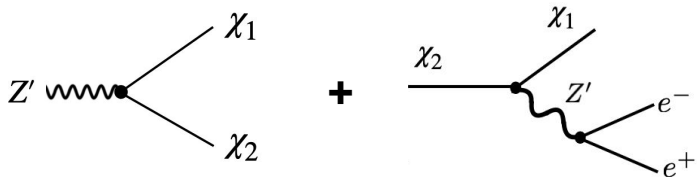


Simulating the decays of semi-visible DPs at both BaBar and NA64, we recast these constraints for a range of scenarios:

- **Inelastic dark matter (iDM)** (minimal + extended)
- **Heavy neutral leptons (HNL)**

Revised constraints on semi-visible DP

Scenario 1: Minimal Majorana iDM ($Z' \to \chi_1\chi_2$ ONLY)



Lightest state is stable

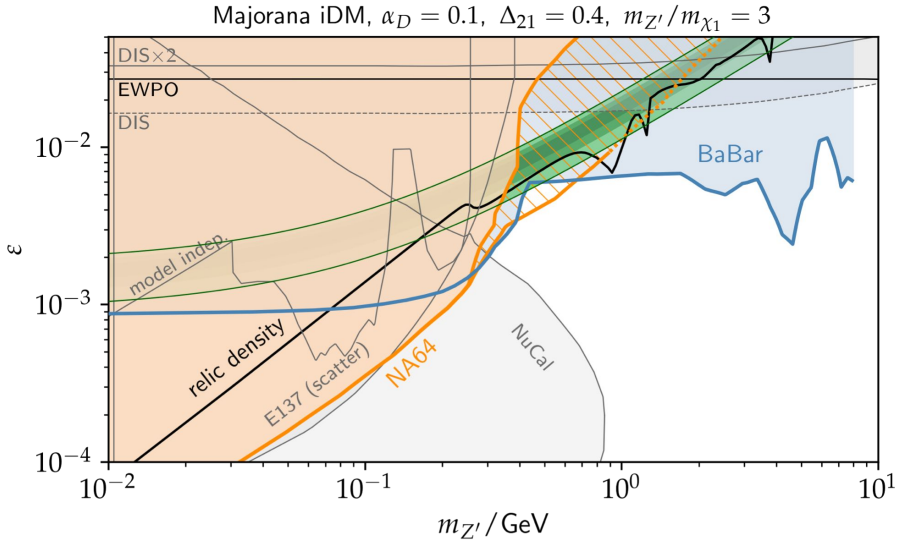
DM relic abundance from co-annihilations

Requirements at BaBar:

1) Lepton **energies > 100 MeV** in instrumented regions of detector
2) Leptons are not produced in the direction of the pipeline

Requirements at NA64:

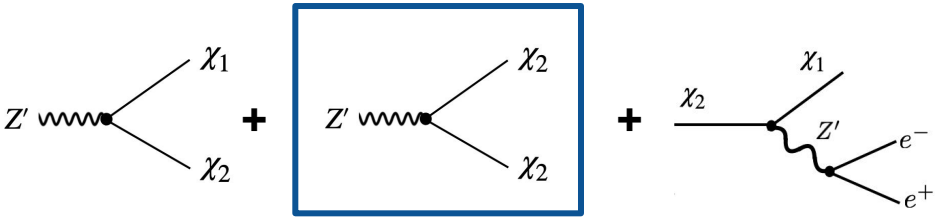
1) Decays in the ECAL, or HCAL, pass the relevant energy threshold for veto.



Minimal iDM model for (g-2) is **EXCLUDED** due to energy resolution of BaBar detector

Revised constraints on semi-visible DP

Scenario 2: Pseudo-Dirac fermions ($Z' \to \chi_1\chi_2$ AND $Z' \to \chi_2\chi_2$)



NEW

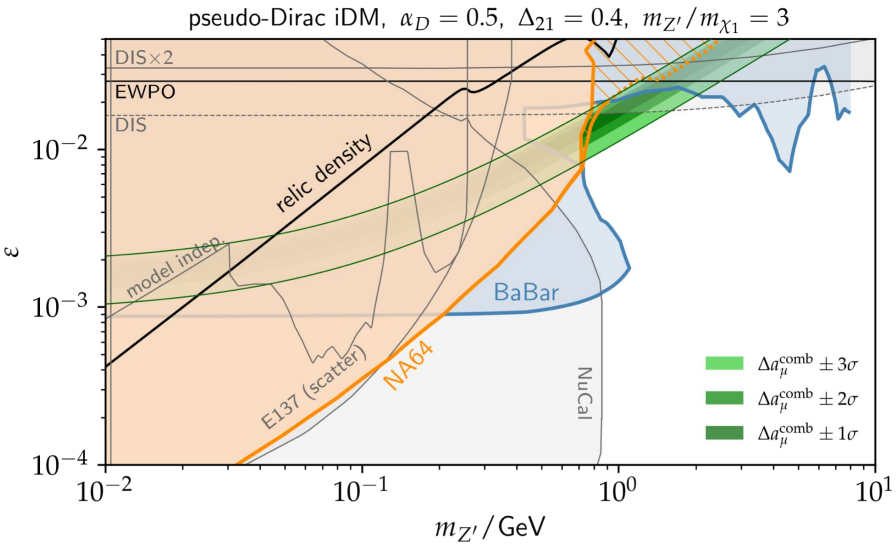
Tip: Decouple DM and B factory constraints!

Two pairs of pseudo-Dirac states:
1 neutral, 1 charged (under U(1)')

$$\mathcal{J}_D^\mu = s_\theta^2 \overline{\psi_1}\gamma^\mu\psi_1 + s_\theta c_\theta \overline{\psi_2}\gamma^\mu\psi_1 + c_\theta^2 \overline{\psi_2}\psi_2$$

For small theta, **large 22 vertex** and **suppression of invisible decays**

*If lightest state is stable, it *could* be DM

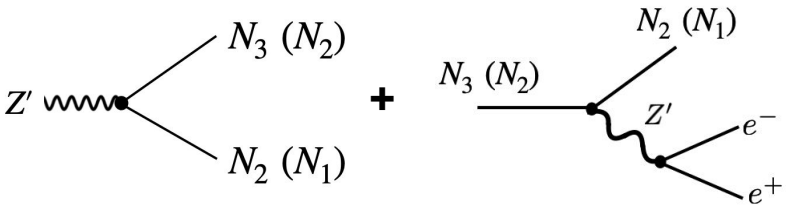


Pseudo-Dirac fermions **allowed** for Z' masses ~ 1 GeV

Revised constraints on semi-visible DP

Scenario 3: Heavy Neutral Leptons ($Z' \to N_1 N_2$ AND $Z' \to N_3 N_2$)

AA, M.Hostert, S.Pascoli
arXiv: 2007.11813

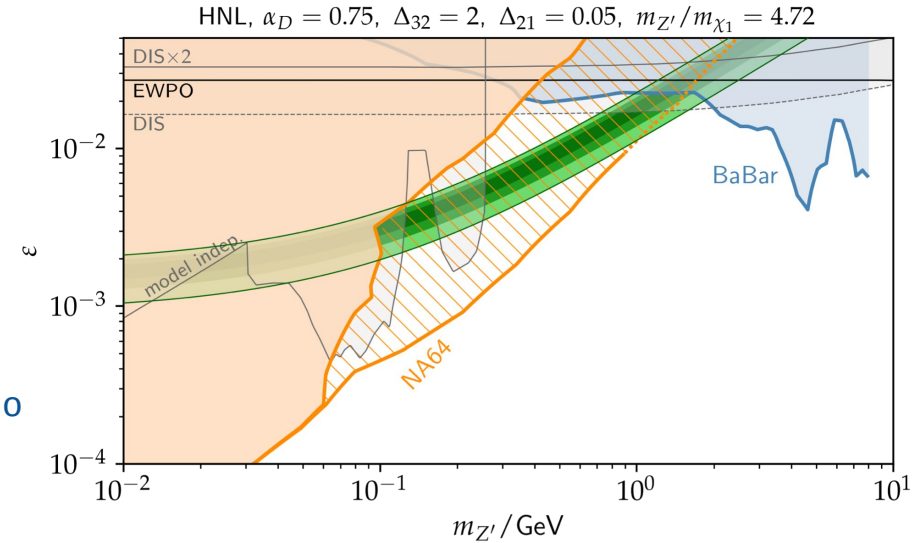


Pair of dark fermions + 1 sterile neutrino

Can be shown to be:

1) Compatible with light neutrino masses

2) Possible solution to other anomalies (e.g. MiniBooNe)



Possibility of opening up large regions of (g-2) parameter space!

Note: subject to NA64 shower identification uncertainties

Summary

With this work, we conclude that:

1) Minimal Majorana iDM scenario is **excluded**. Lepton pairs from decay are too soft and do not pass BaBar's energy threshold of 100 MeV.

2) **Pseudo-Dirac fermions** with additional decay channel $Z' \rightarrow \Psi_2\ \Psi_2$ is **allowed** due to increased visible energy in the detector.

3) Scenarios with **dark sector HNLs** can give **significant relaxation** of the parameter space up to uncertainties in NA64's shower identification, and can simultaneously be linked to neutrino masses and SBL anomalies.

Thank you for listening!

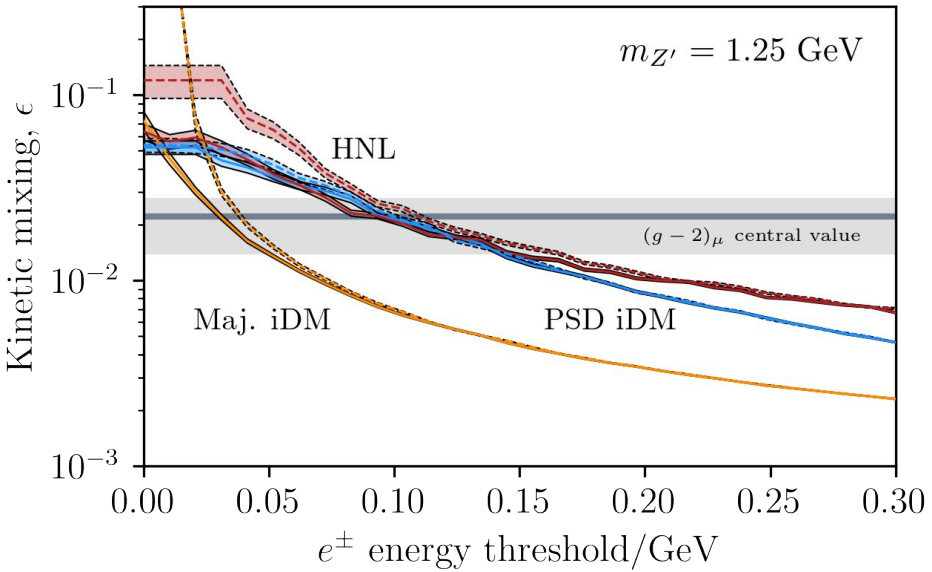
Back-up: Energy thresholds at BaBar

Right:

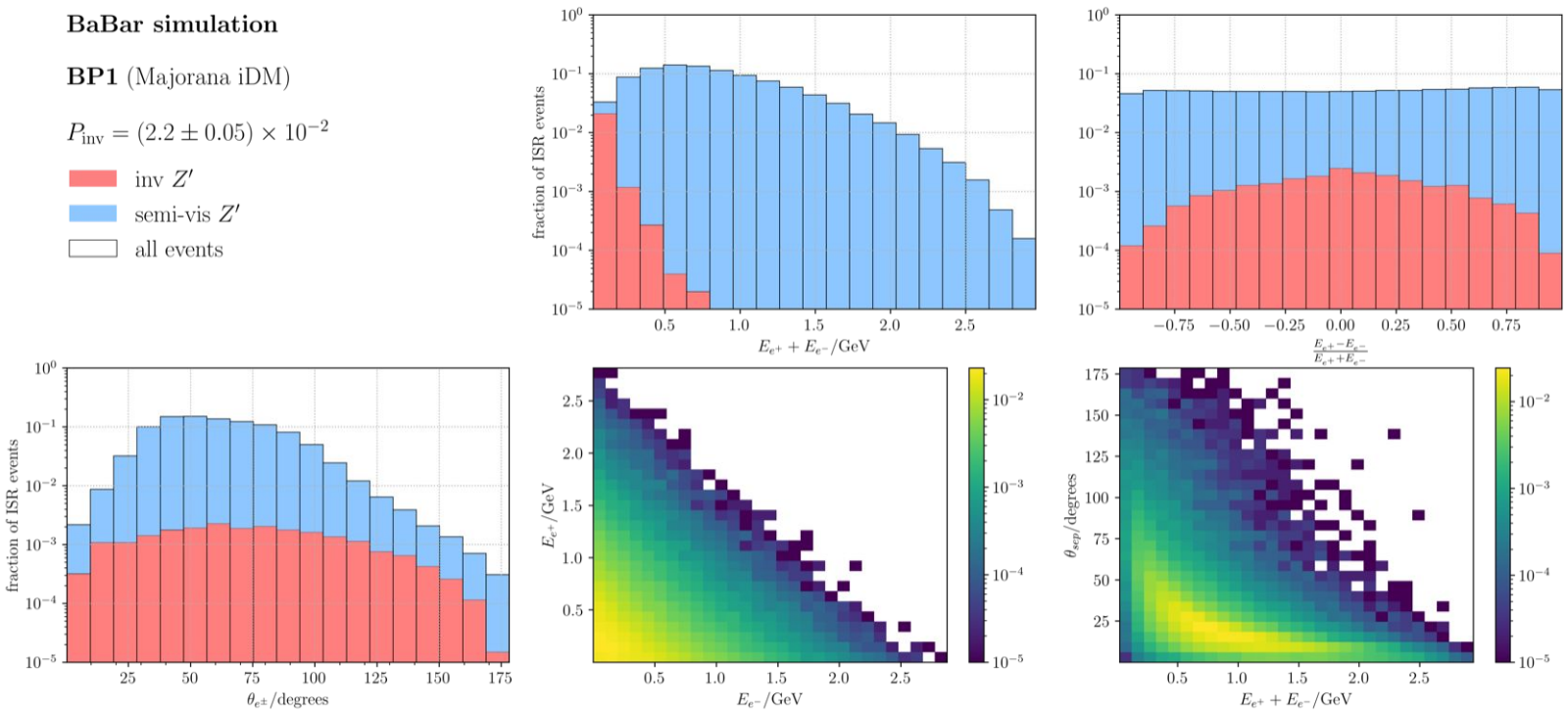
Rescaled bound on the kinetic mixing parameter as a function of the energy threshold of the BaBar detector.

Solid (dashed) lines show the constraints after (before) accounting for pipeline cuts on the lepton angles.

At BaBar's threshold of 100 MeV, only the HNL and pseudo-Dirac fermions (labelled "PSD iDM" in the plot) are compatible with the (g-2) region, with leptons in the Majorana iDM scenario being too soft.



Back-up: Kinematical distributions of e+e-



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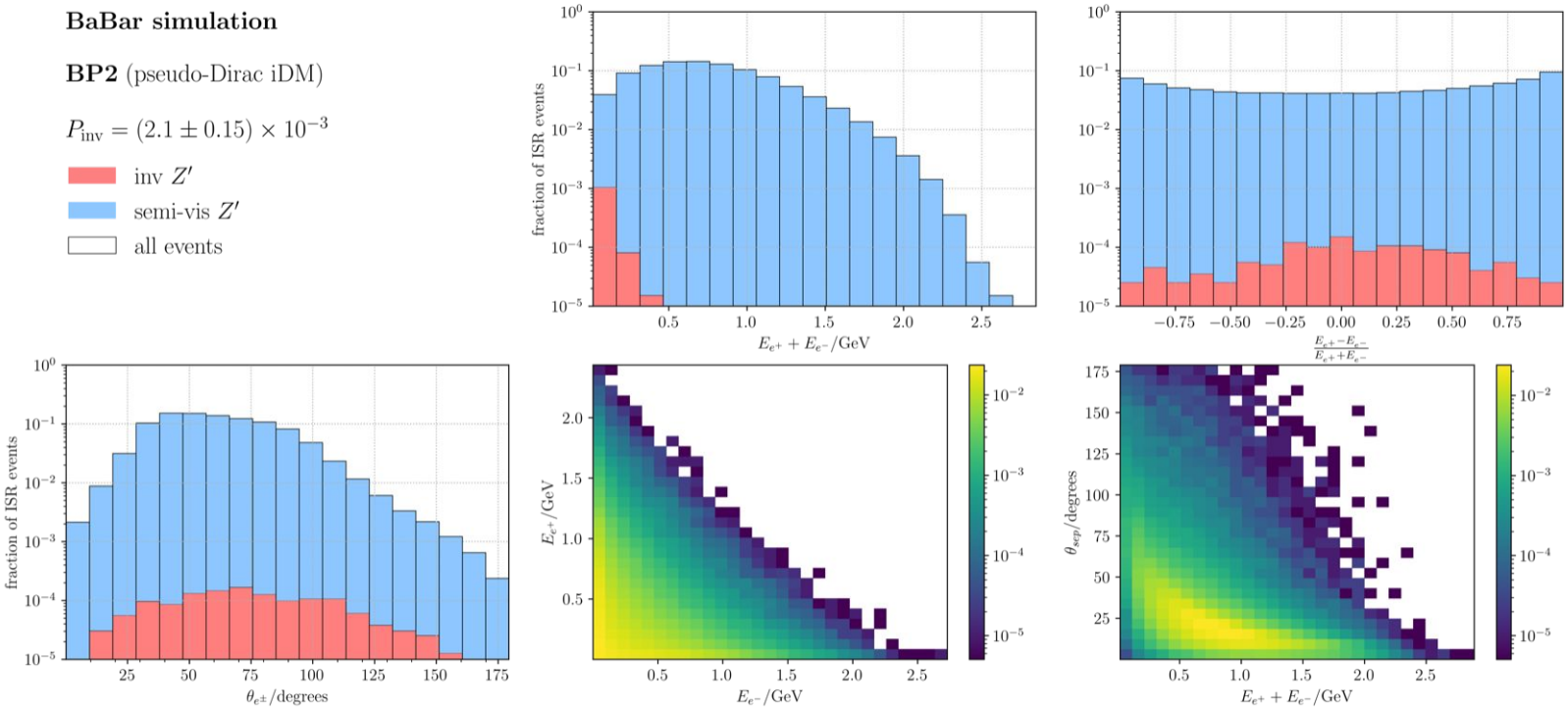

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