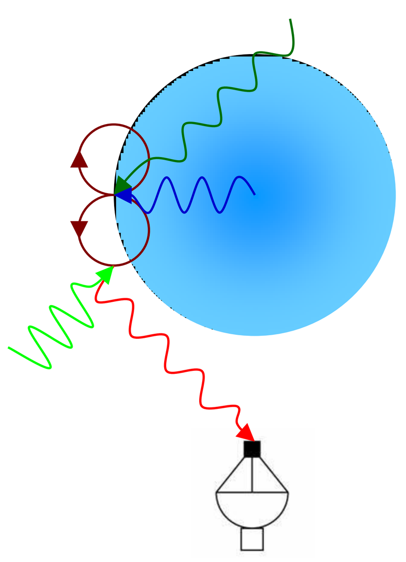
Investigations of pair halos produced by gamma-ray interactions in the intergalactic medium

T. Weisgarber[1], T. C. Arlen[2], V. V. Vassiliev[2], S. P. Wakely[1]
[1]University of Chicago, [2]UCLA

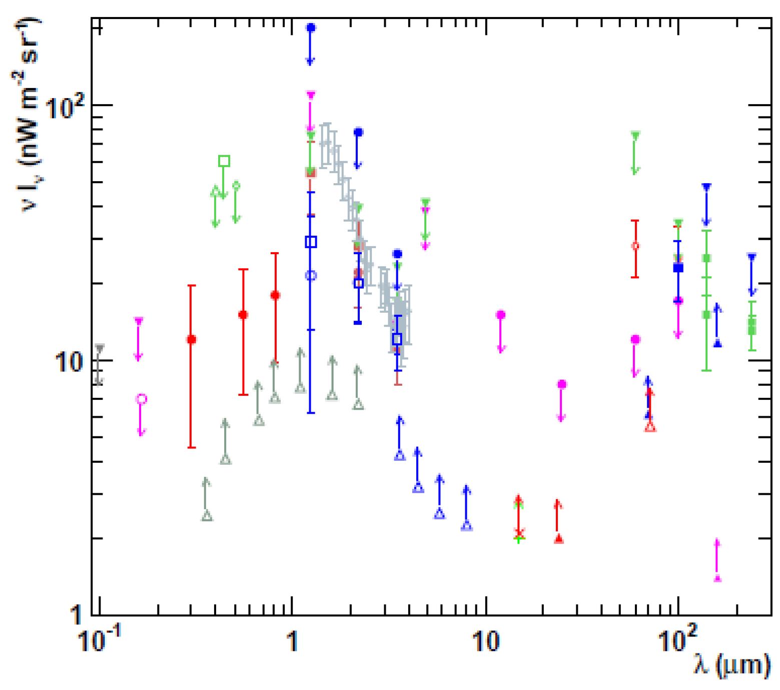
Kavli Institute for Cosmological Physics AT THE UNIVERSITY OF CHICAGO

Scientific Motivation

Primary goals: *Observations of pair halos around extragalactic gamma-ray sources can lead to constraints on the intergalactic magnetic field (IMF) and a better understanding of the extragalactic background light (EBL).*



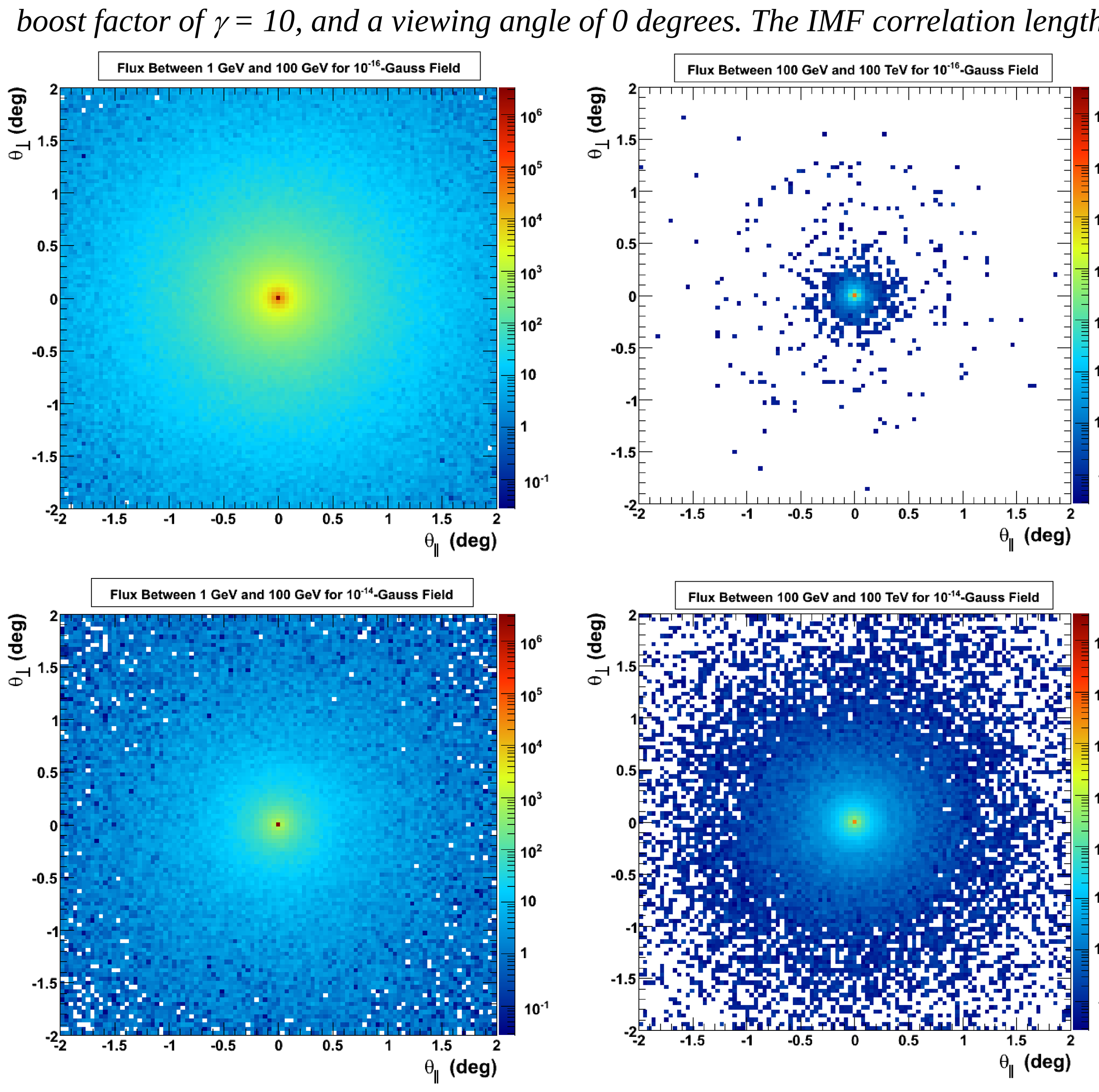
Modeling the interactions (left): *Source gamma rays (dark blue) intercepted by EBL photons (dark green) produce e^+e^- pairs (brown). As the pairs follow curved trajectories in the IMF, they interact with other background photons (light green) to produce pair-halo gamma-rays (red) detected at an angle offset relative to the source position. These photons translate the combined effects of the IMF and EBL into a pair-halo (light blue) around the souce.*



EBL (above): *Current constraints and measurements of the EBL from a variety of experiments. Figure from D. Mazin and M. Raue, Astron. Astrophys.* ***471****, 439 (2007).*

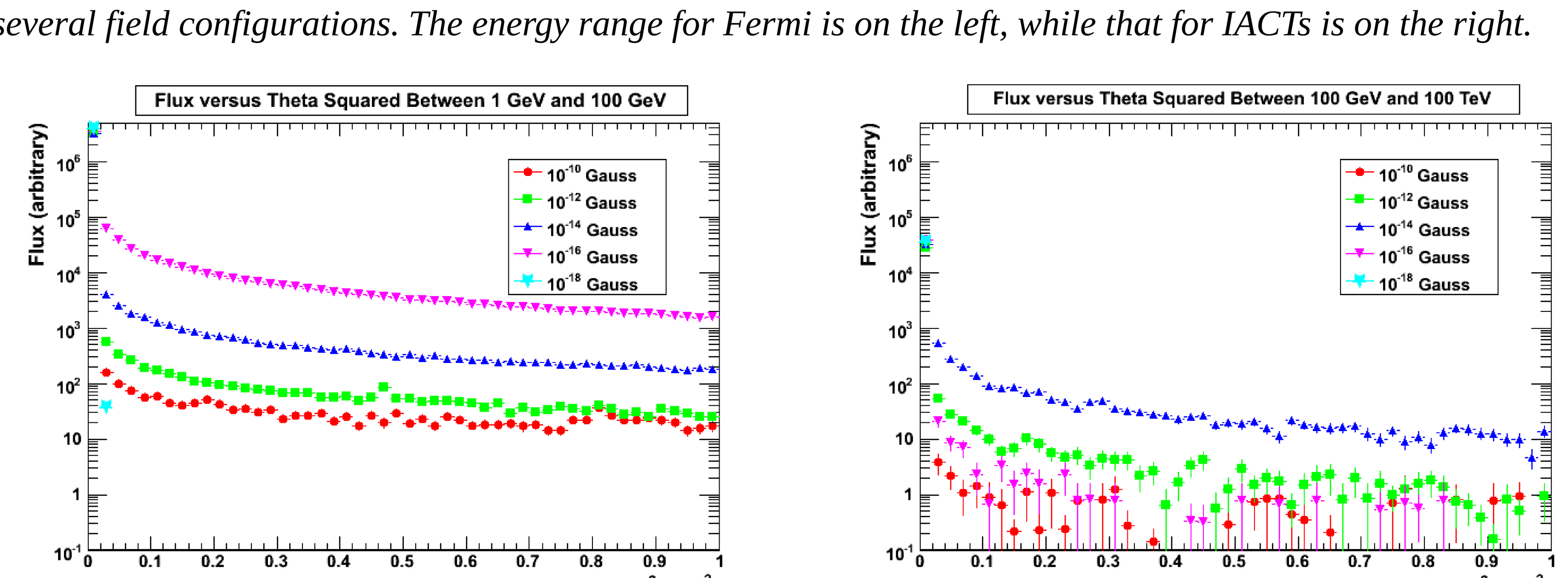
Preliminary Angular Distribution Calculations

Fiducial source: *The results below are for a gamma-ray source at z = 0.03 with a spectral index of α = 2, a boost factor of γ = 10, and a viewing angle of 0 degrees. The IMF correlation length is 1 Mpc.*



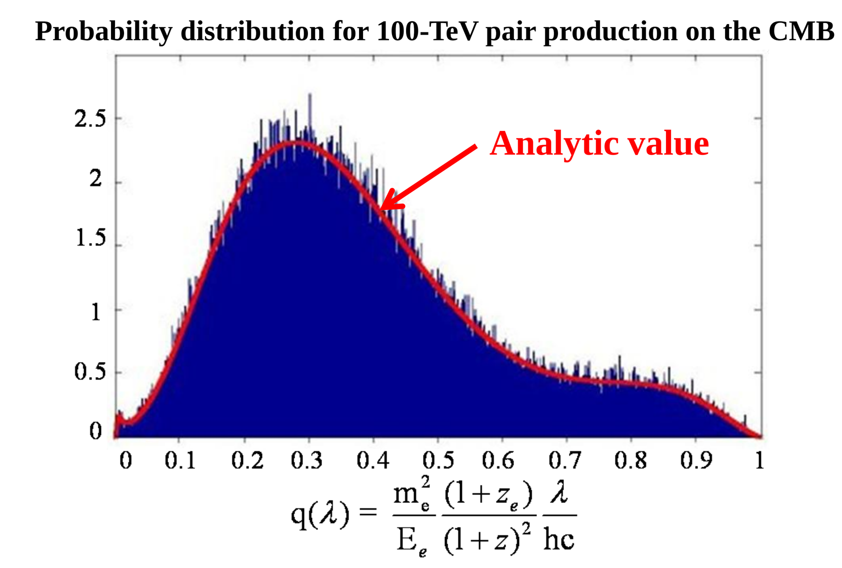
Pair halos (left): *The differences between the distributions in the Fermi energy range (1 GeV - 100 GeV, left) and the energy range for imaging atmospheric Cherenkov telescopes (IACTs) such as VERITAS (100 GeV - 100 TeV, right) depend on the field strength. Different energy regimes become pointlike at different field strengths. The color scale is in units of arbitrary flux normalized to the same value for all the plots. The field for the upper plots is 10^{-16} Gauss, while that for the lower is 10^{-14} Gauss.*

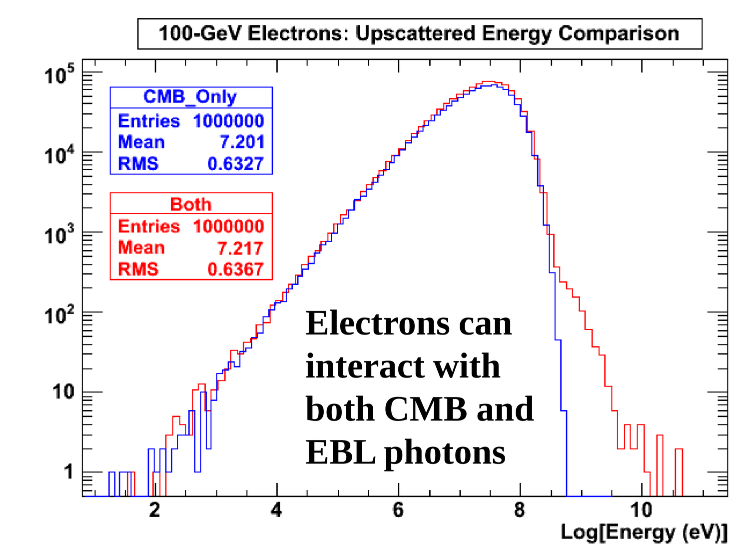
Angular distributions (below): *The plots below show the number flux versus squared angle from the source for several field configurations. The energy range for Fermi is on the left, while that for IACTs is on the right.*

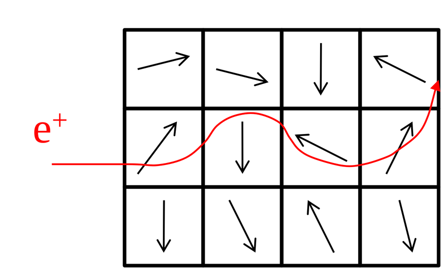


Simulation Details

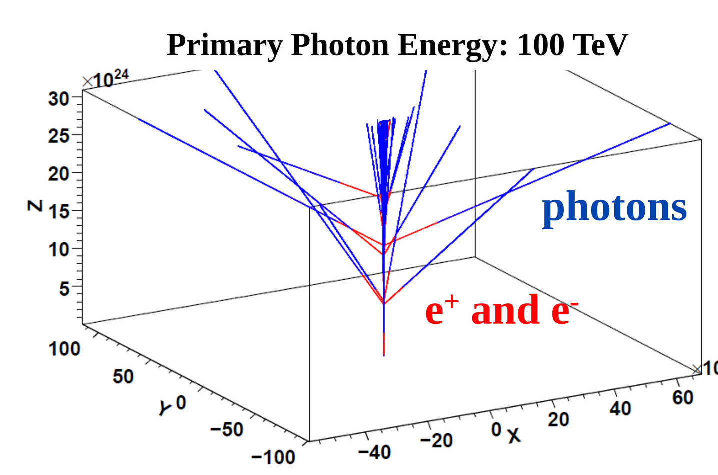
Particle kinematics (below): *The full relativistic cross sections are used for both the pair production and inverse-Compton scattering processes to determine the kinematic variables for the products from each interaction.*



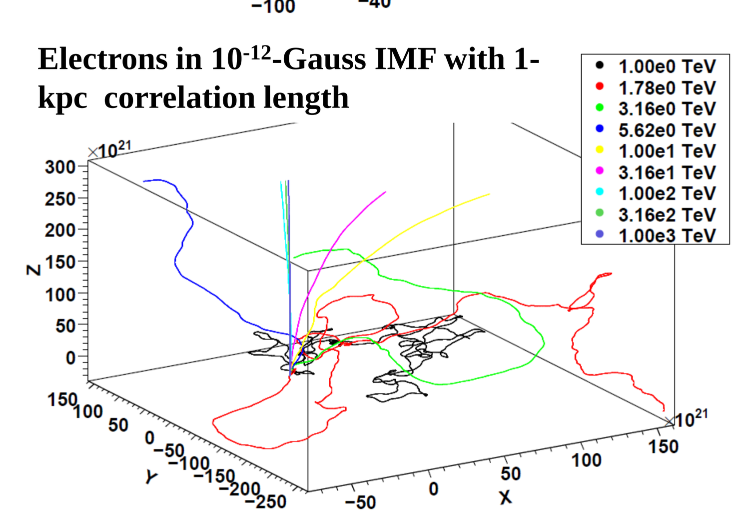




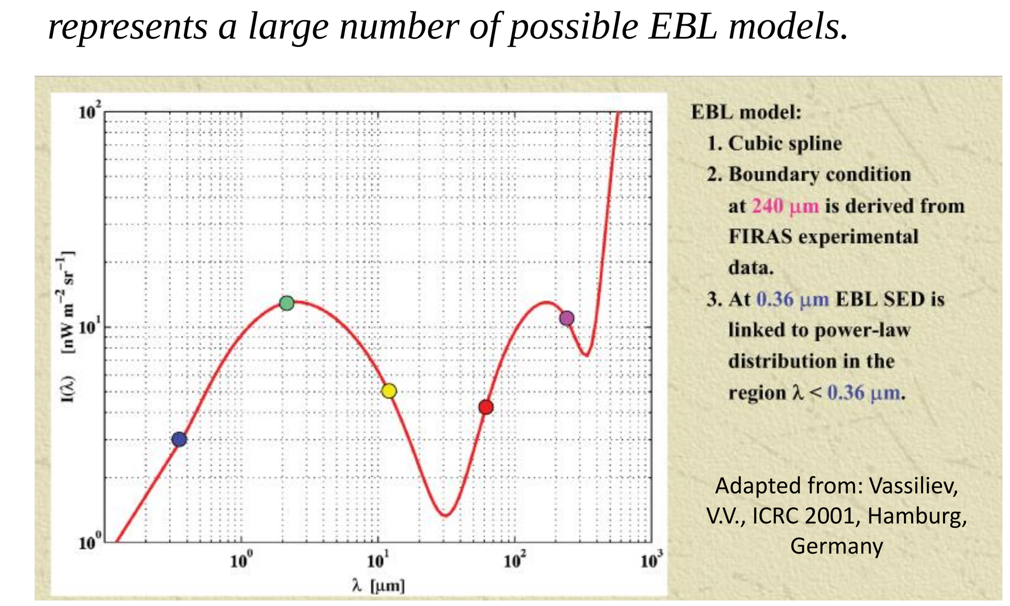
IMF (left): *The magnetic field in intergalactic voids is modeled with cubes whose sides are equal to the correlation length. Each cube has a constant field oriented randomly with respect to the other cubes.*



Particle tracking (left): *All photons down to 1 GeV are tracked. The equation of motion for electrons in the IMF is solved numerically for an arbitrary ΛCDM-cosmology. Distances are in cm.*

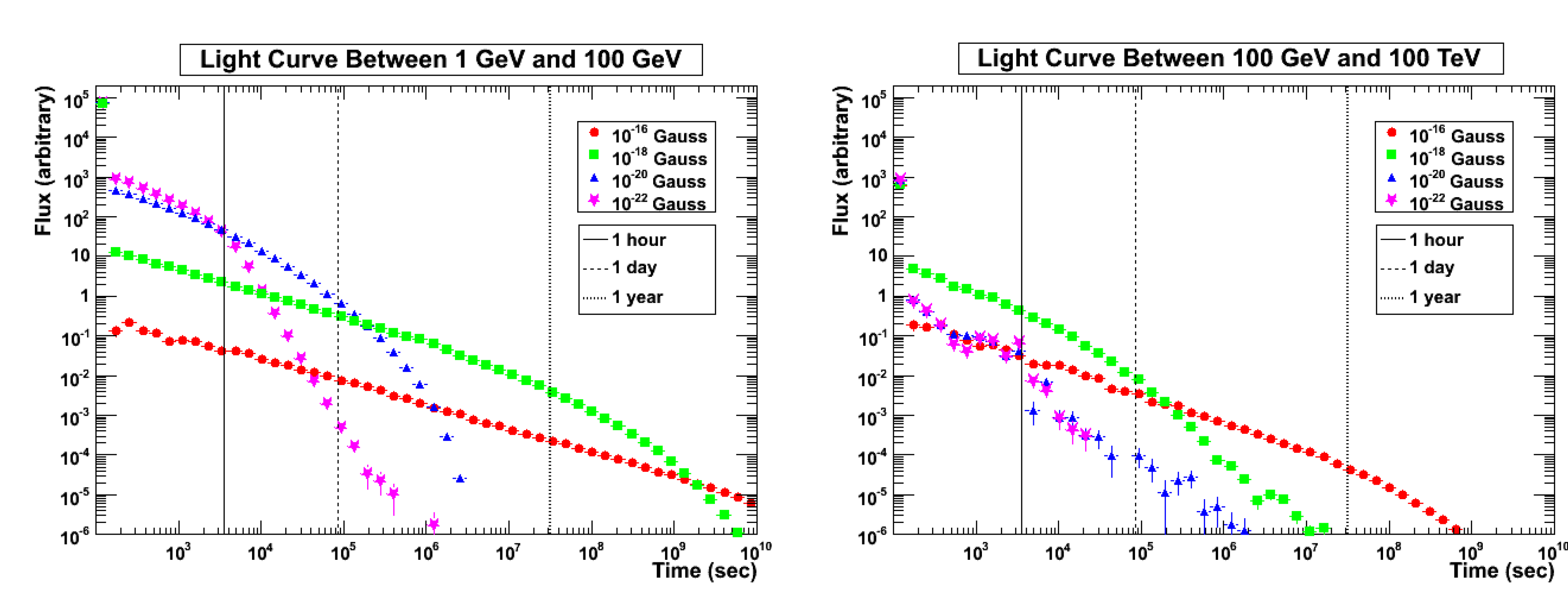


EBL modeling (below): *A cubic spline fit to 5 points represents a large number of possible EBL models.*



Preliminary Time Delay Calculations

Timing distributions (below): *Light curves in the Fermi (left) and IACT (right) energy ranges are shown for a constant-flux flare with a duration of 100 seconds and the same spectral distribution as the steady source used in the angular distributions. Timing analysis, which is relevant for flaring blazars and gamma-ray bursts, is sensitive to IMF strengths lower than those probed by the angular distributions. The number flux within 0.1 degrees of the source position is plotted.*



Future Investigations

Standard physics: *The immediate goals are to determine good metrics for measuring or constraining the IMF from observations by Fermi and IACTs. Determining how the EBL, IMF, and source properties affect the observed angular and time distributions will facilitate making these constraints.*

Exotic physics: *The code can also be adapted to model other effects such as Lorentz invariance violation, axion-like particles, or other exotic physics. This will be the subject of future investigations.*

References

F. A. Aharonian, P. S. Coppi and H. J. Volk, Astrophys. J. **423**, L5 (1994). arXiV:astro-ph/9312045

K. Dolag, M. Kachelriess, S. Ostapchenko and R. Tomas, Astrophys. J. **703**, 1078 (2009) arXiv:0903.2842

A. Elyiv, A. Neronov and D. V. Semikoz, Phys. Rev. D **80**, 023010 (2009). arXiv:0903.3649

D. Grasso and H. R. Rubinstein, Phys. Rept. **348**, 163 (2001). arXiv:astro-ph/0009061

M. G. Hauser and E. Dwek, Ann. Rev. Astron. Astrophys. **39**, 249 (2001) arXiv:astro-ph/0105539

K. Ichiki, S. Inoue and K. Takahashi, arXiv:0711.1589

R. Plaga, Nature **374**, 430 (1995).

The National Science Foundation

THE KAVLI FOUNDATION