Probing Extragalactic Media with VHE γ-rays from Cosmologically Distant Blazars

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The Goal

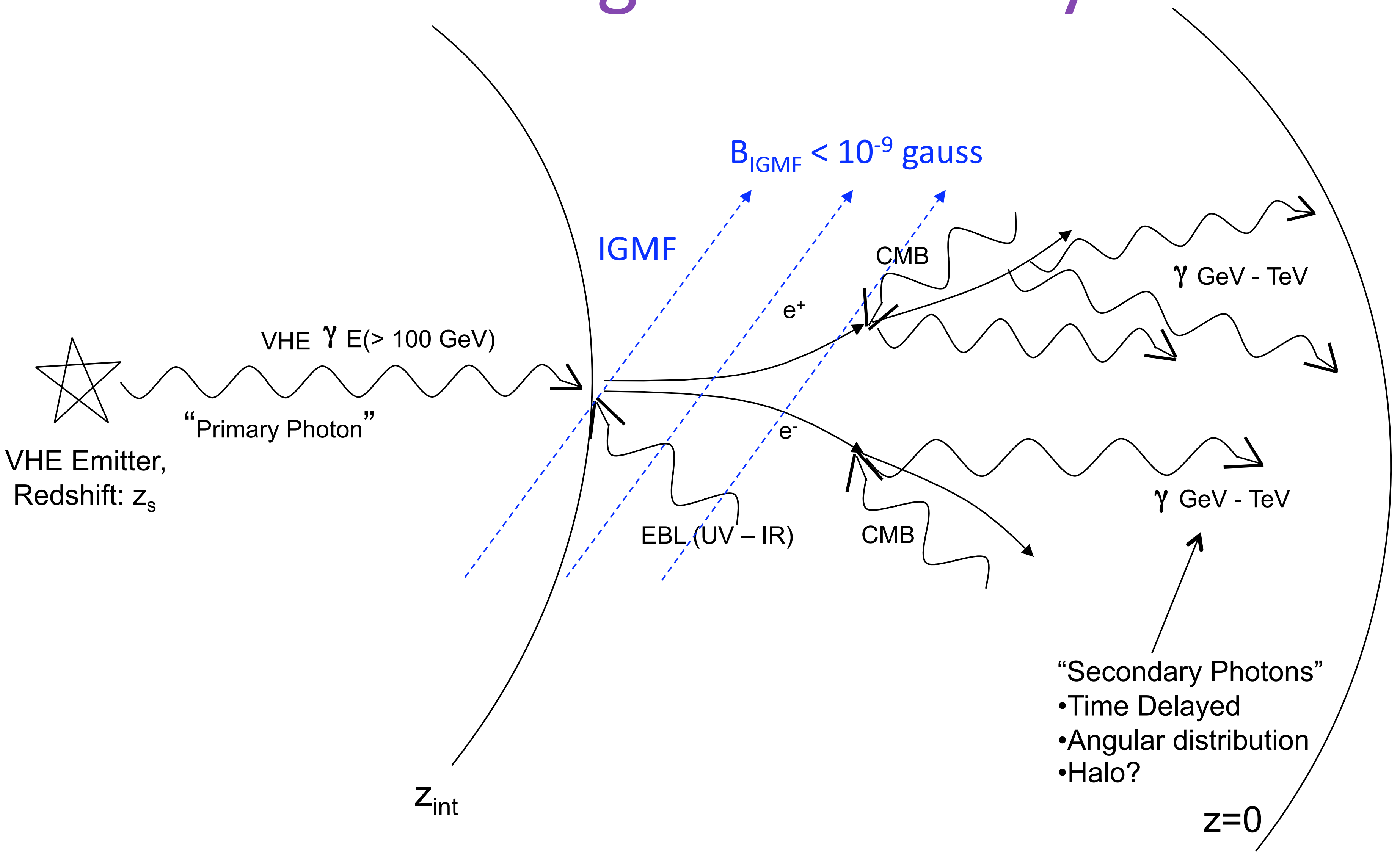
- Use results of numerical simlations of HE-VHE γ-ray blazar emission as a probe for the Intergalactic Magnetic Field (IGMF) strength, and Extragalactic Background Light (EBL) in the UV - IR

Extragalactic Magnetic Fields

- Motivation: Ubiquity of MFs
  - Stars: ~Gauss
  - Galaxies: ~0.1-10 μG
  - Galaxy clusters: 0.1 – 1 μG fields observed in Coma and Virgo clusters
  - Voids - ??
- Physics
  - Origin?
  - Role in structure formation?
  - Evolution?

Image Credit: Burrell Schmidt wide-field telescope, Kitt Peak Az. http://burro.astr.cwru.edu/Schmidt/Virgo/
Artist's impression image from: R. Durrer, *Science* 311, 5762, pp. 787-788

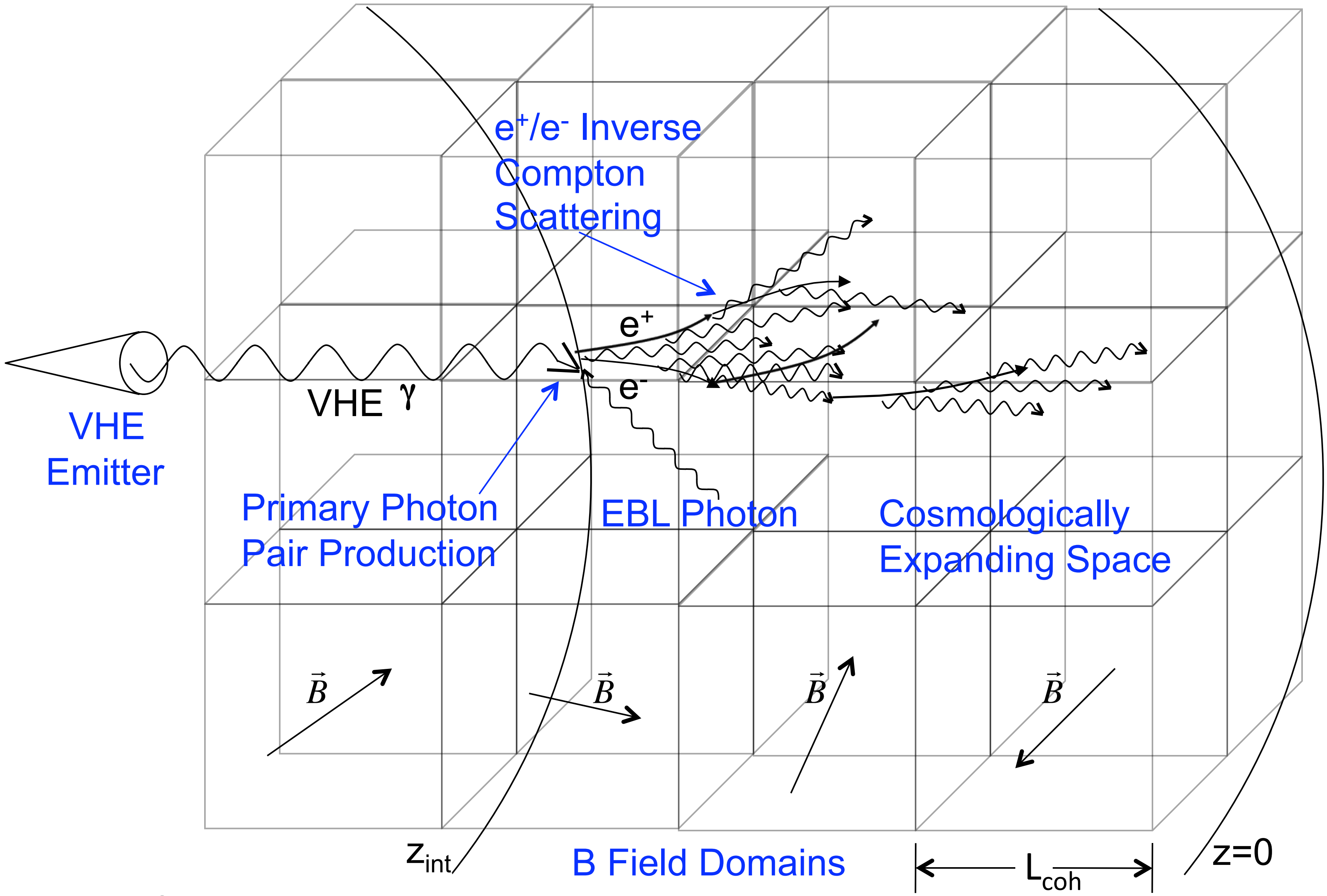
Cascading Gamma Rays



HE/VHE Gamma Ray Observations to Constrain IGMF

- Halo Emission:
  - Aharonian F.A., Coppi P.S., Volk H.J., Ap.J., 423, L5 (1994)
  - Dolag K., Kachelriess M., Ostapchenko S. and Tomas R., arXiv:0903.2842 (2009).
  - Elyiv, Neronov, Semikoz. Astroph arXiv:0903.3649 (2009)
- Time Delay of Secondary Emission:
  - Plaga R., Nature 374, 430 (1995).
  - Murase K., Takahashi K., Inoue S., Ichiki K., Nagataki S., arXiv: 0806.2829 (2008).

Full Simulation



Halo Emission

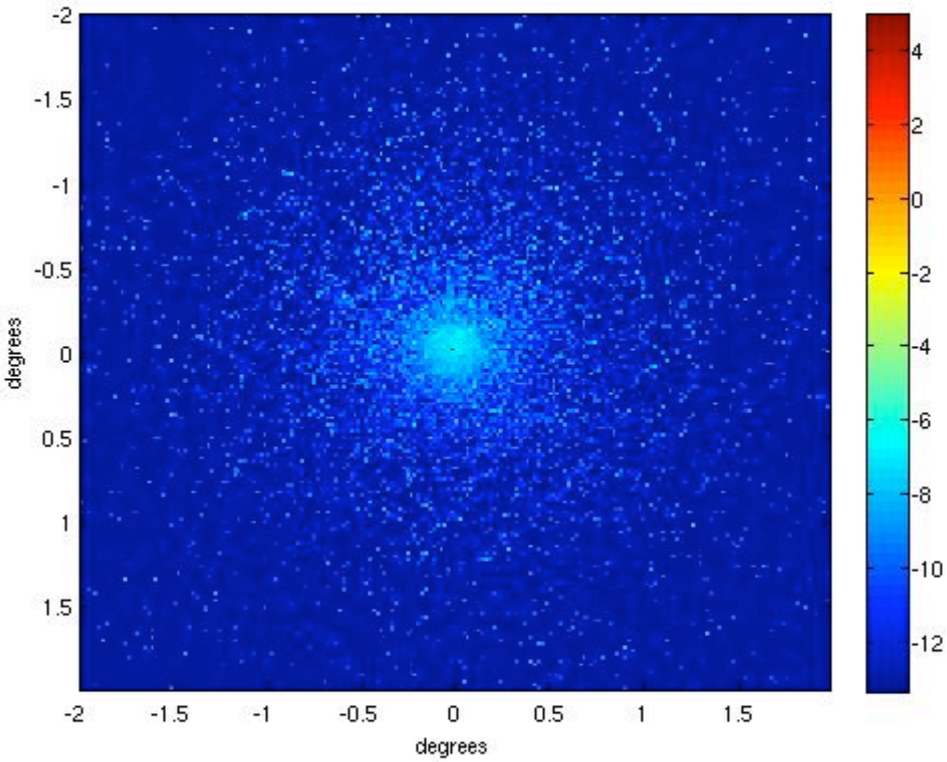
Z = 0.032, B=1x10^{-12} gauss

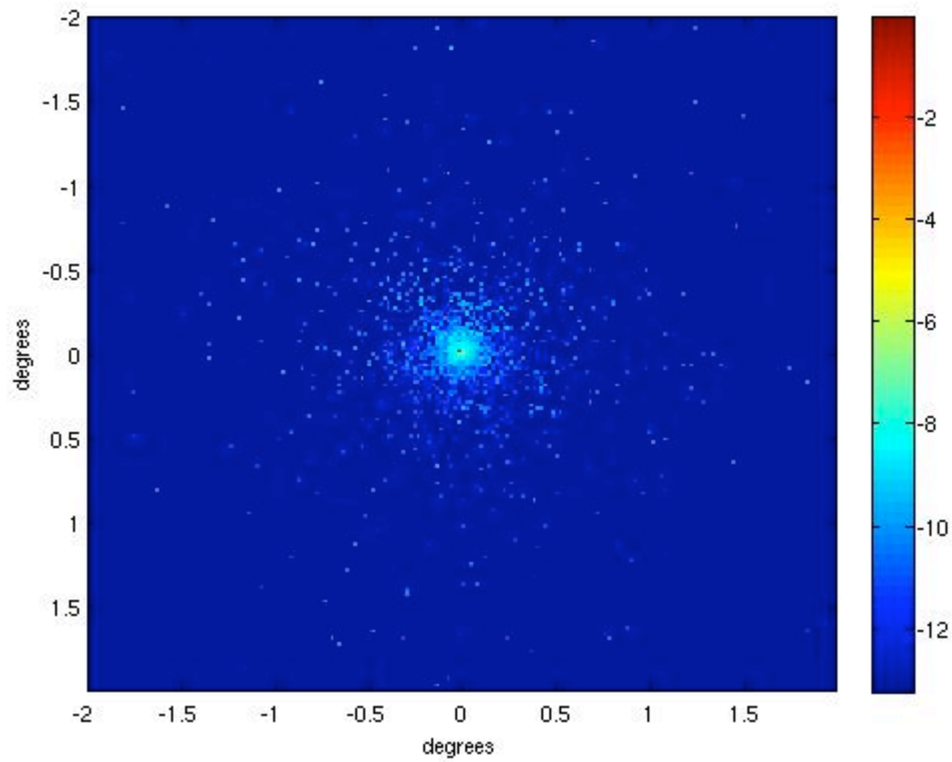
dE/dN$\propto$ E$^{-\alpha}$, α=2.0, Γ = 10

$$\text{Note}: R_L \propto \frac{p_\perp}{B}, L_{IC} \approx \text{few kpc}$$

1GeV – 100 GeV

100GeV – 100 TeV





Halo Emission

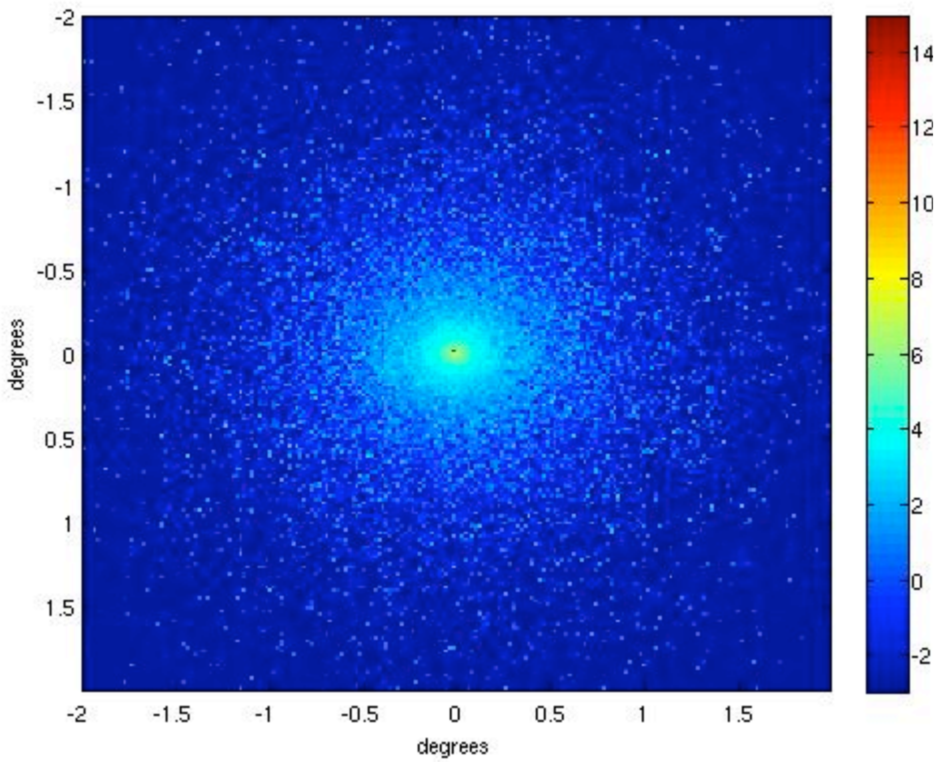
1GeV – 100 GeV

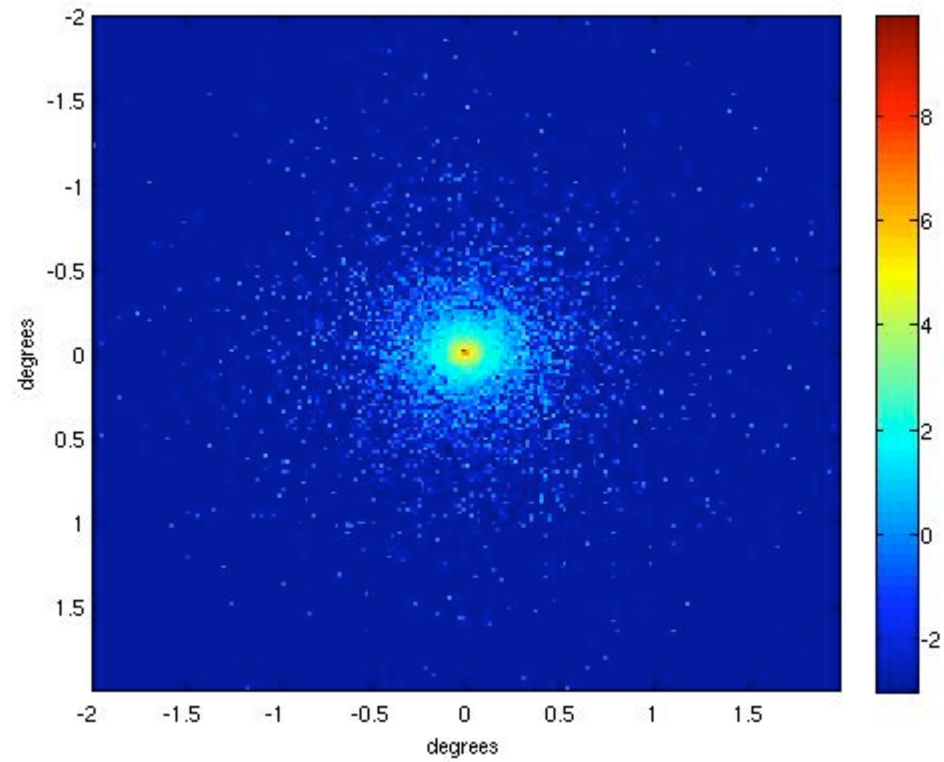
Z = 0.032, B=1x10^{-14} gauss

dE/dN$\propto$ E$^{-\alpha}$, α=2.0, Γ = 10

$$\text{Note}: R_L \propto \frac{p_\perp}{B}, L_{IC} \approx \text{few kpc}$$

100GeV – 100 TeV





Halo Emission

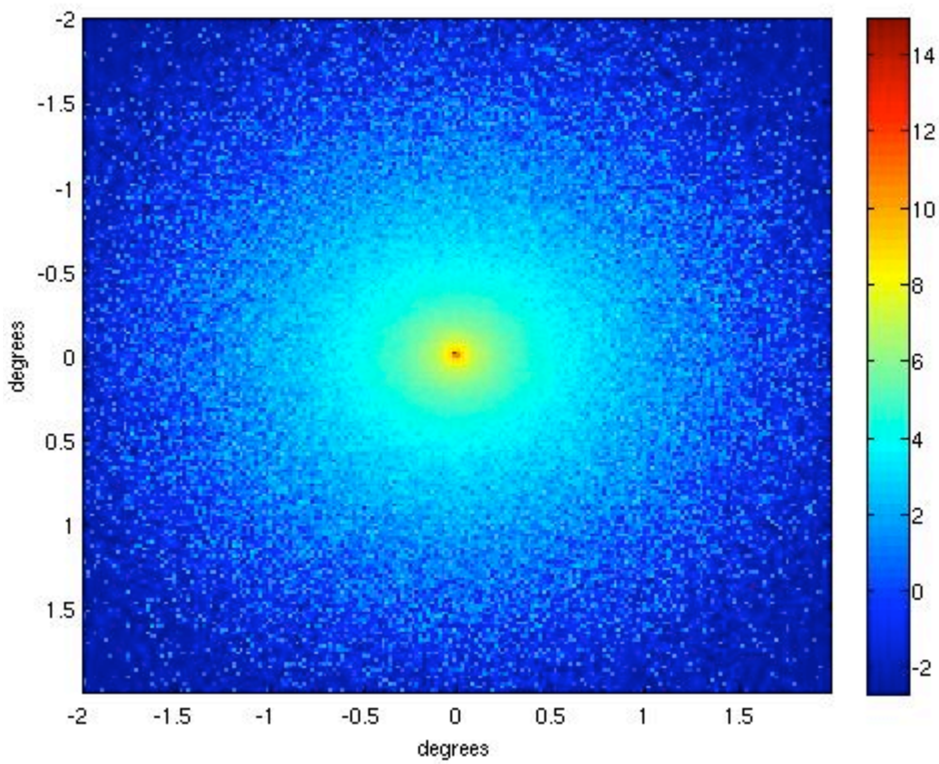
Z = 0.032, B=1x10^{-16} gauss

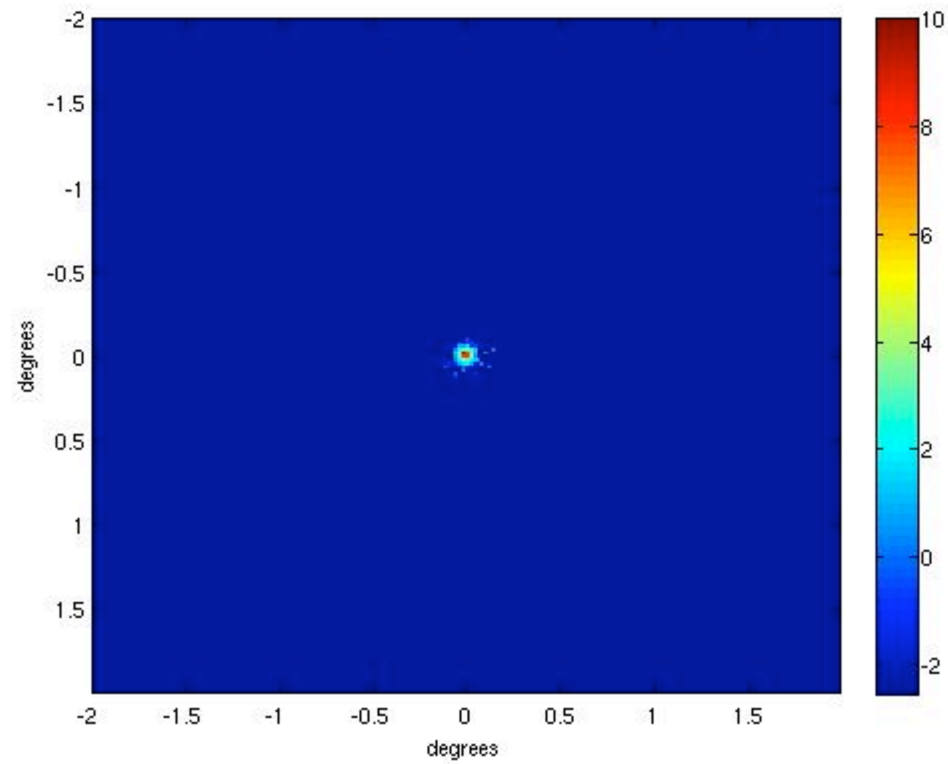
dE/dN$\propto$ E$^{-\alpha}$, α=2.0, Γ = 10

$$\text{Note} : R_L \propto \frac{p_\perp}{B}, L_{IC} \approx \text{few kpc}$$

1GeV – 100 GeV

100GeV – 100 TeV





Halo Emission

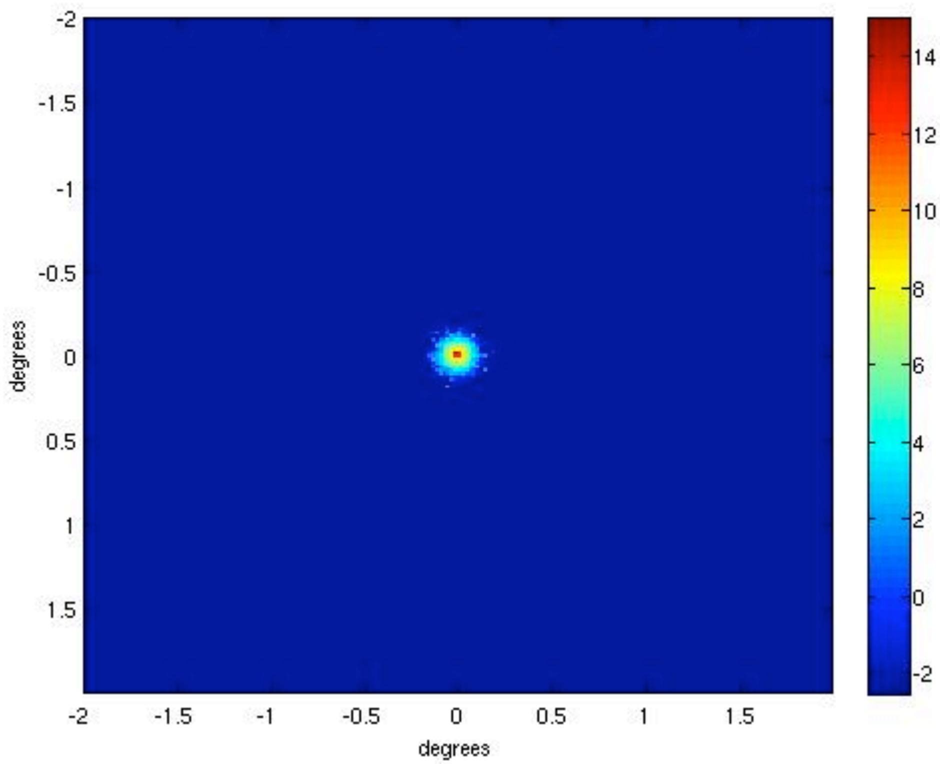
1GeV – 100 GeV

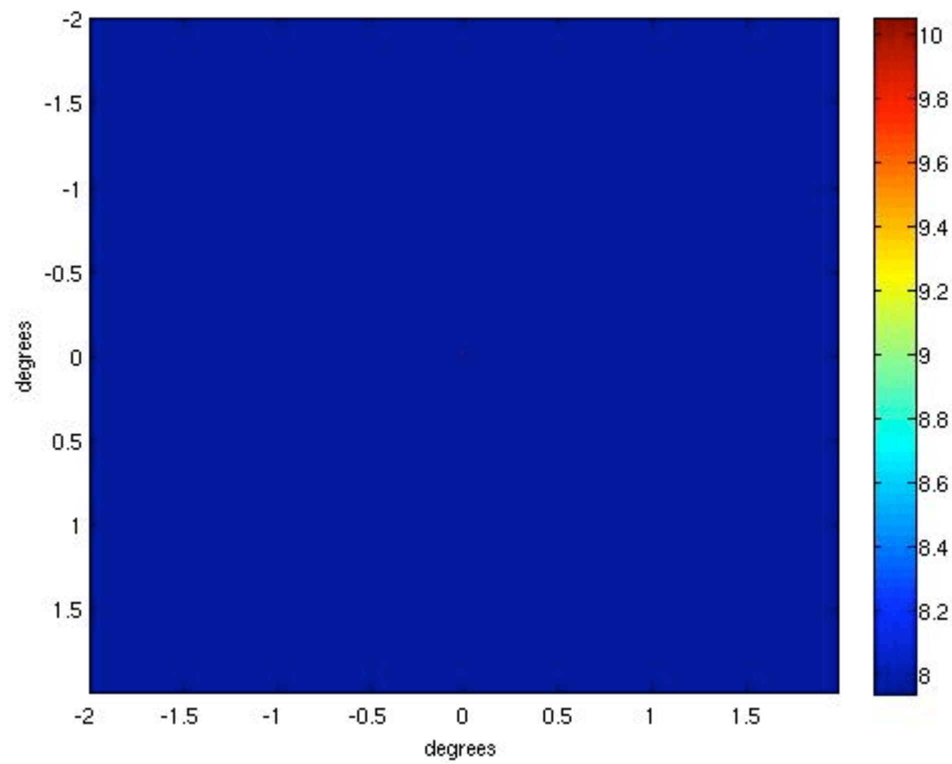
Z = 0.032, B=1x10^{-18} gauss

dE/dN$\propto$ E$^{-\alpha}$, α=2.0, Γ = 10

$$\text{Note}: R_L \propto \frac{p_\perp}{B}, L_{IC} \approx \text{few kpc}$$

100GeV – 100 TeV





Halo Emission

Fermi Gamma-ray Space Telescope

1GeV – 100 GeV

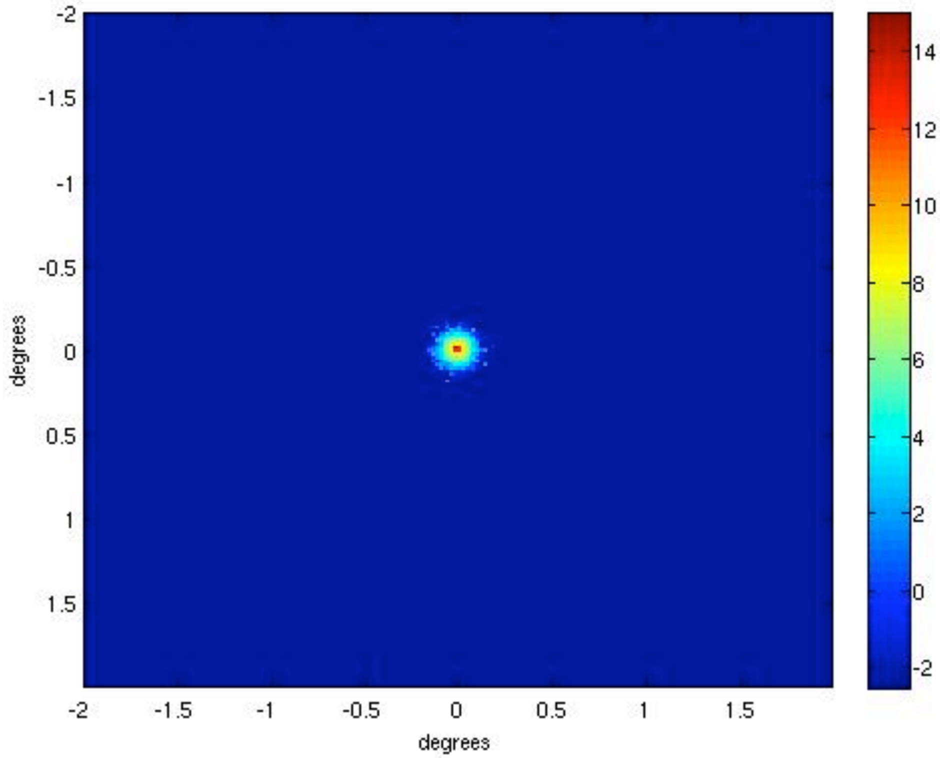
Z = 0.032, B=1x10^{-18} gauss

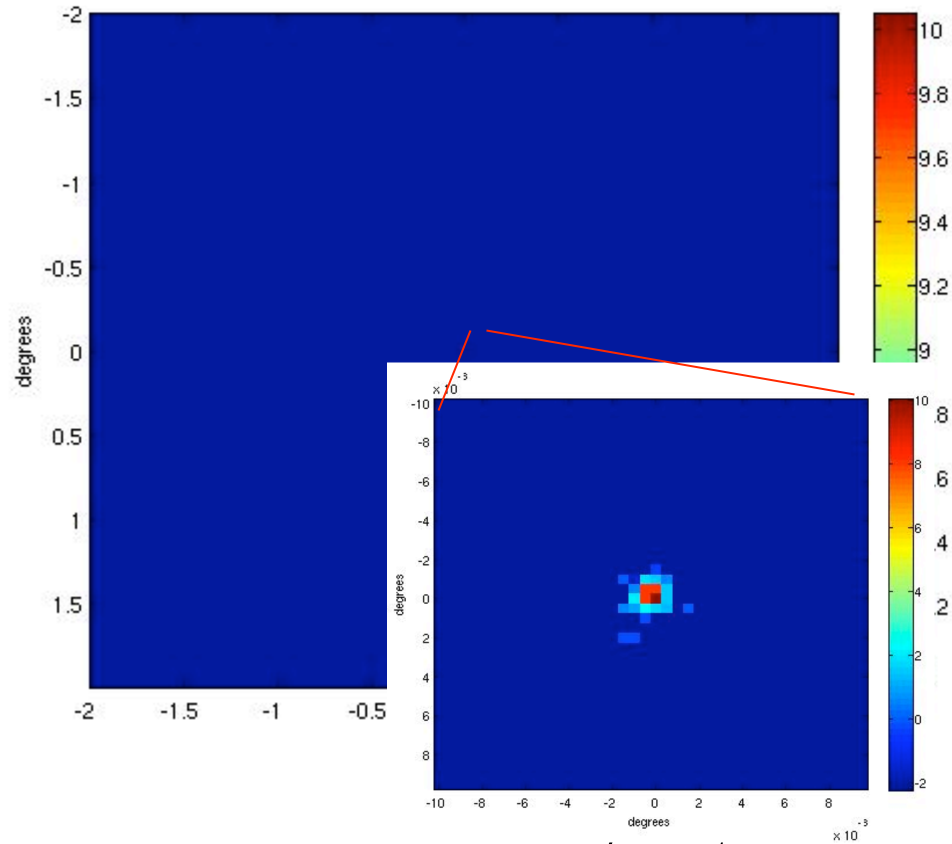
dE/dN$\propto$ E$^{-\alpha}$, α=2.0, Γ = 10

$$\text{Note}: R_L \propto \frac{p_\perp}{B}, L_{IC} \approx \text{few kpc}$$

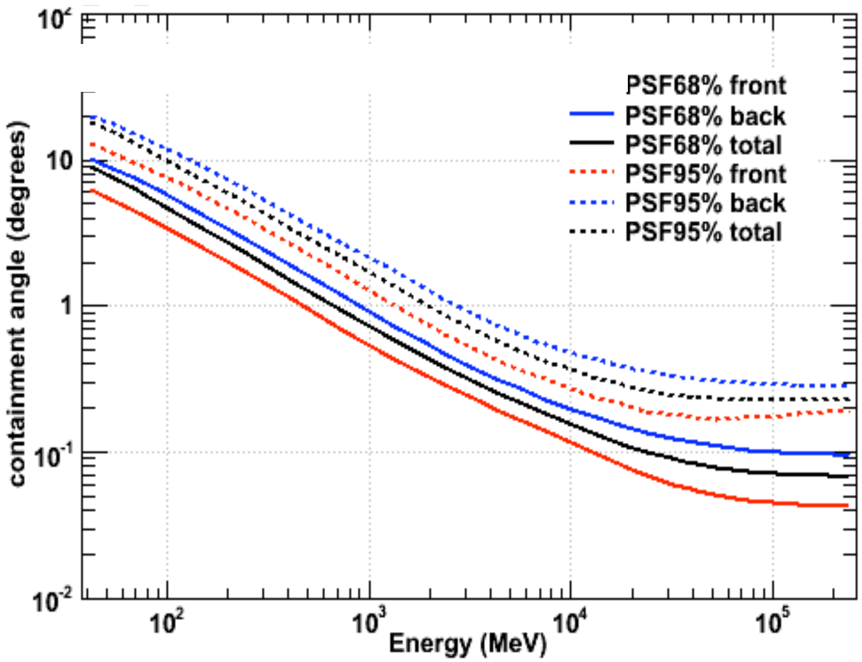
VERITAS

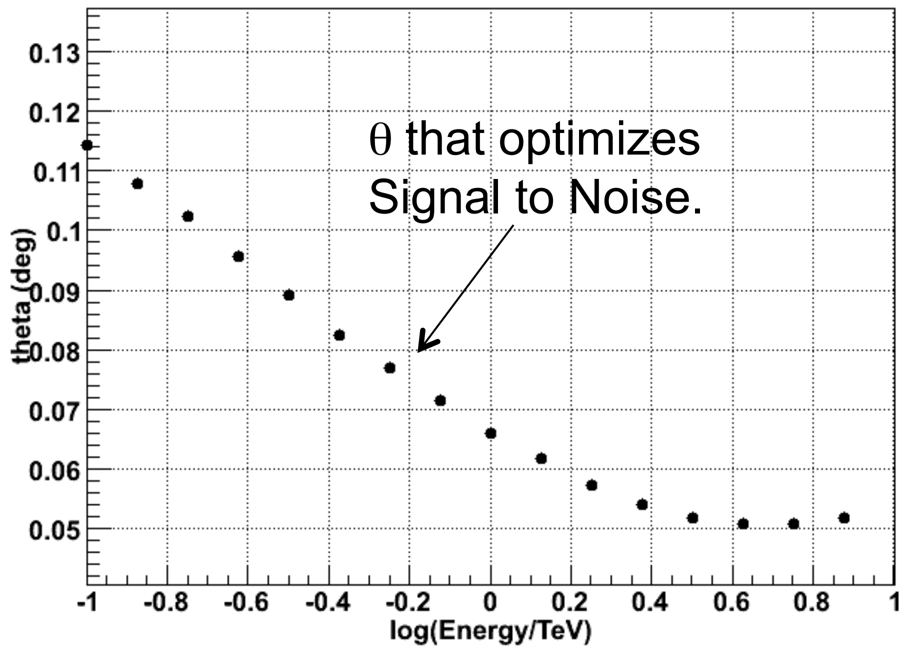
100GeV – 100 TeV



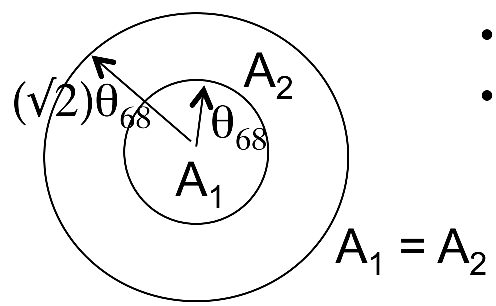


Angular Resolution





- θ_{68}(100 GeV) ≅ 0.05-0.07°
- θ_{68}(1 GeV) ≅ 0.5°

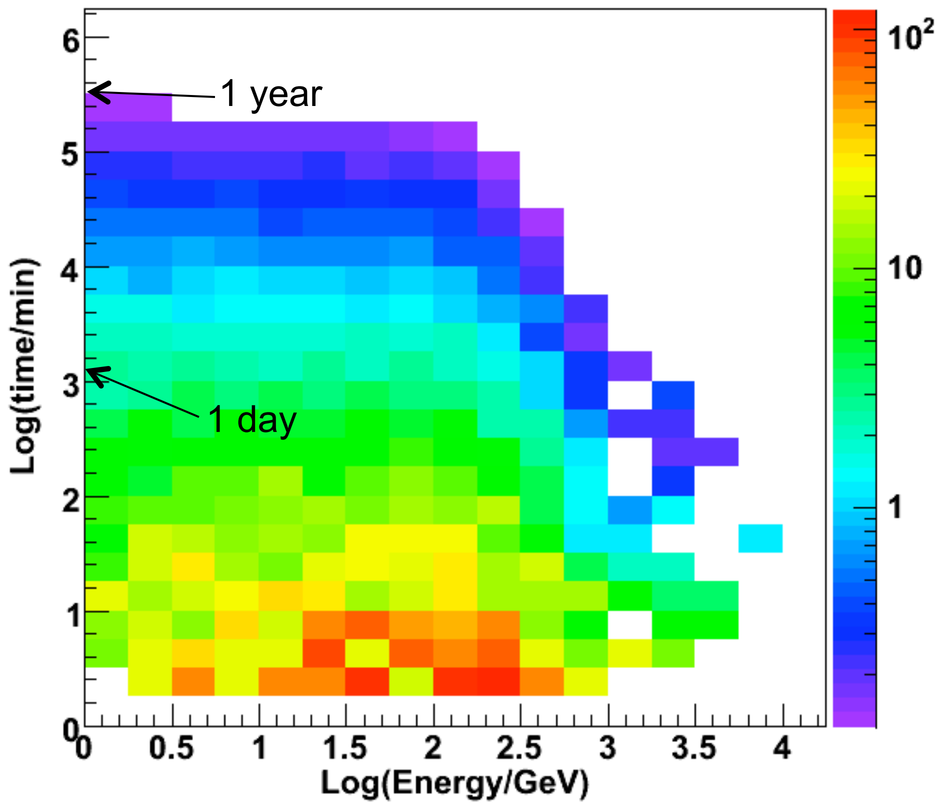


- θ(100 GeV) ≅ 0.12°
- θ(1 TeV) ≅ 0.065°

Secondary Emission Time Scale

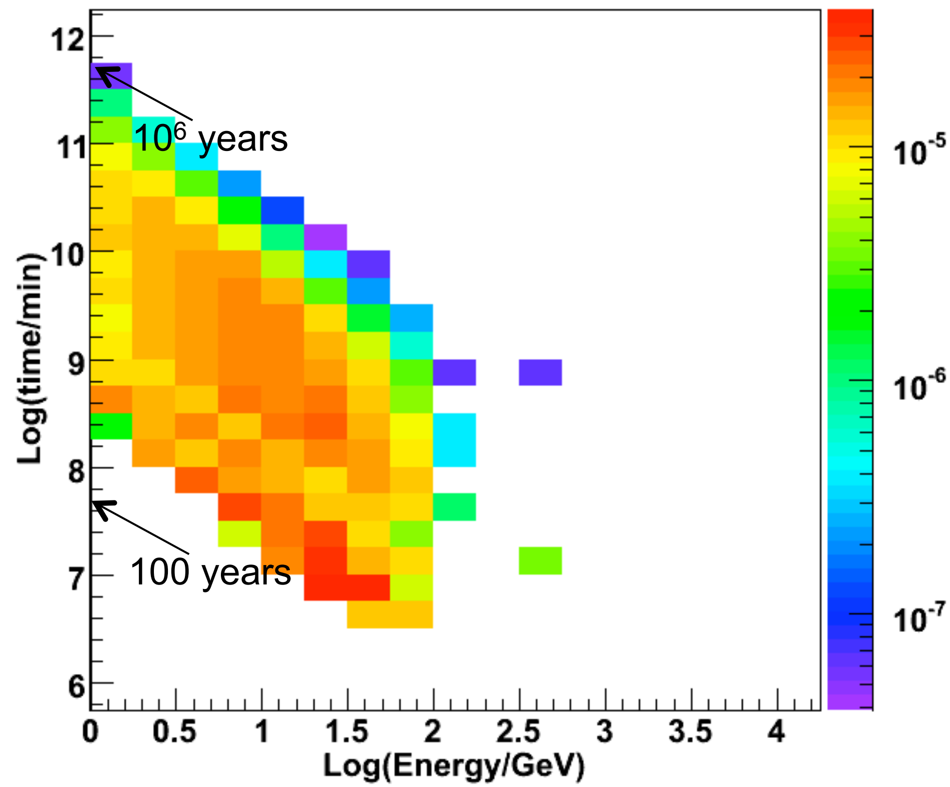
“Secondary Pt Source”

B = 1e-16 gauss, z = 0.1



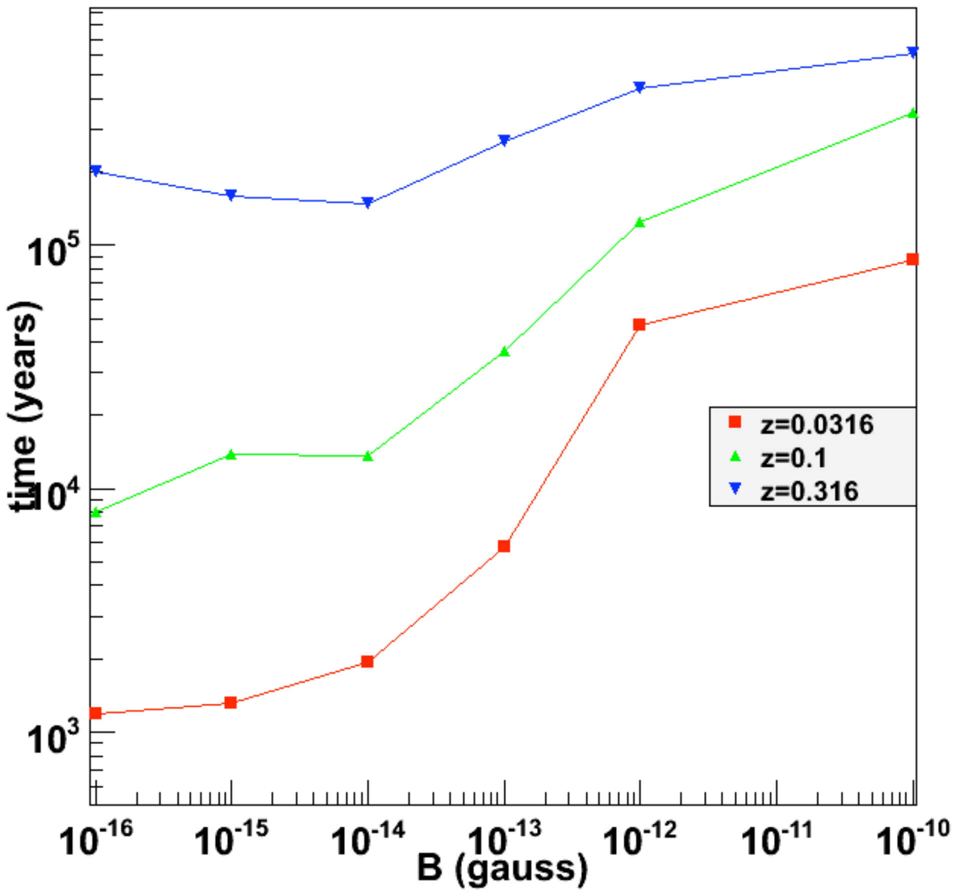
“Halo”

B = 1e-16 gauss, z = 0.1

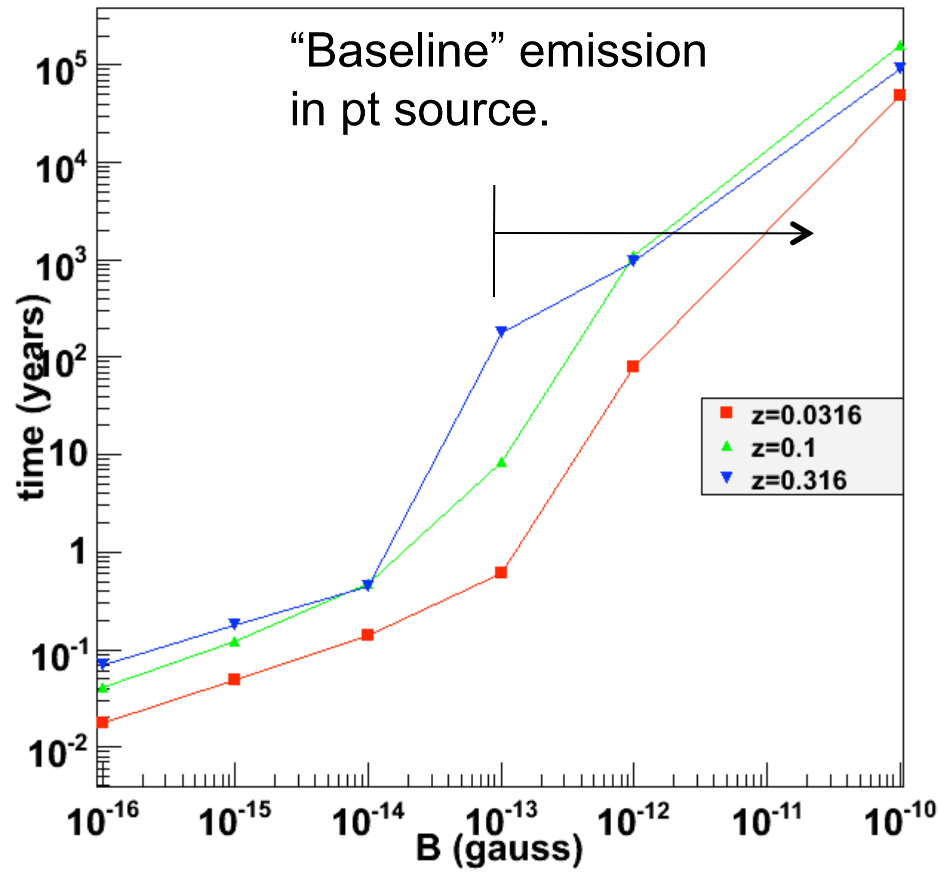


Mean Secondary Arrival Times

$\langle T \rangle_{halo}$

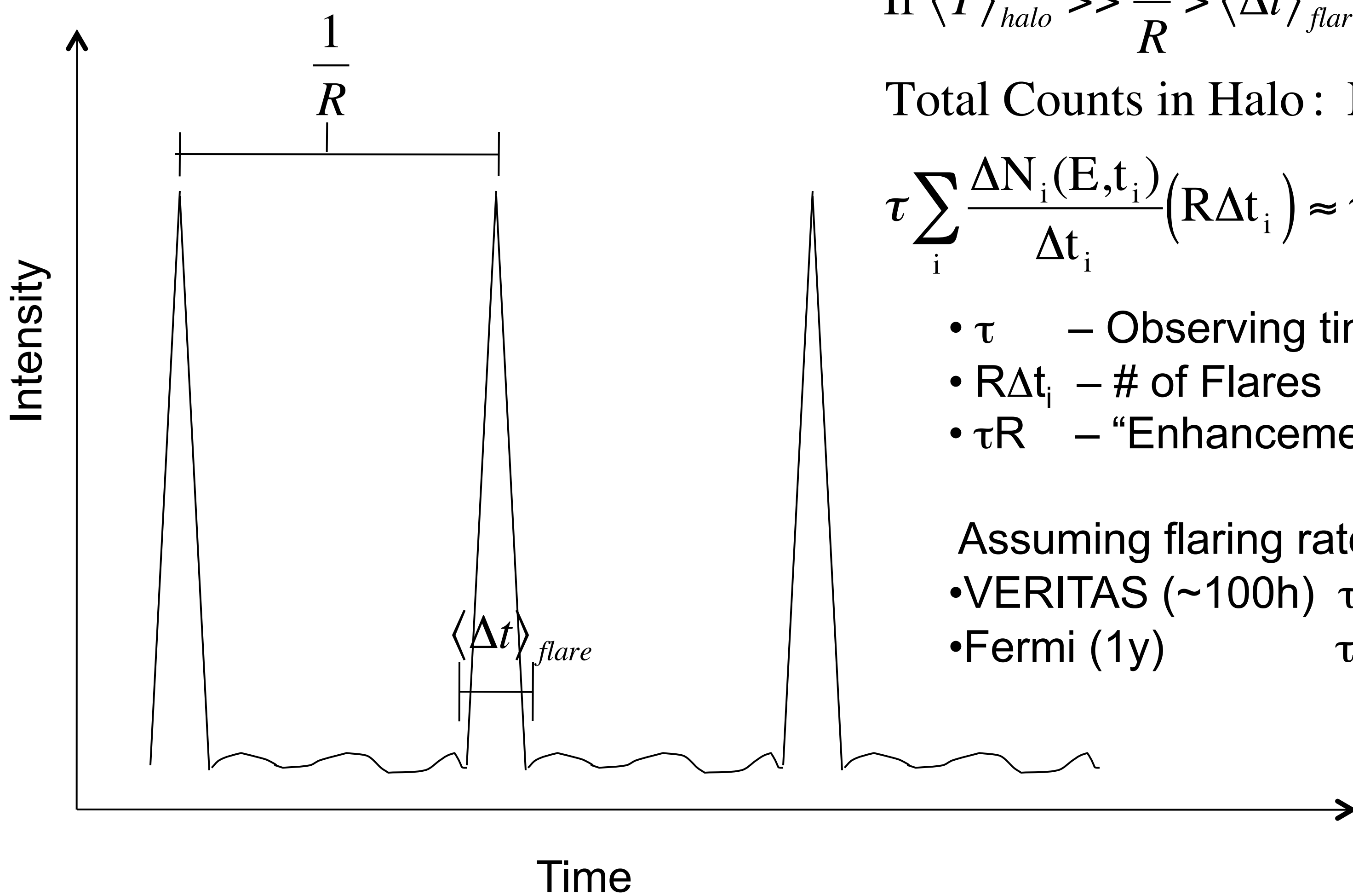


$\langle T \rangle_{pt\ source}$



Blazar Flaring

Model



If $\langle T \rangle_{halo} >> \frac{1}{R} > \langle \Delta t \rangle_{flare}$,

Total Counts in Halo: $N_{halo}(E,\tau) \approx$

$$\tau \sum_i \frac{\Delta N_i(E,t_i)}{\Delta t_i}\left(R\Delta t_i\right) \approx \tau R \sum_i \Delta N_i(E,t_i)$$

- τ – Observing time
- $R\Delta t_i$ – # of Flares
- τR – "Enhancement factor"

Assuming flaring rate of ~ 10/y:

- VERITAS (~100h) $\tau R \sim 0.1$
- Fermi (1y) $\tau R \sim 1$

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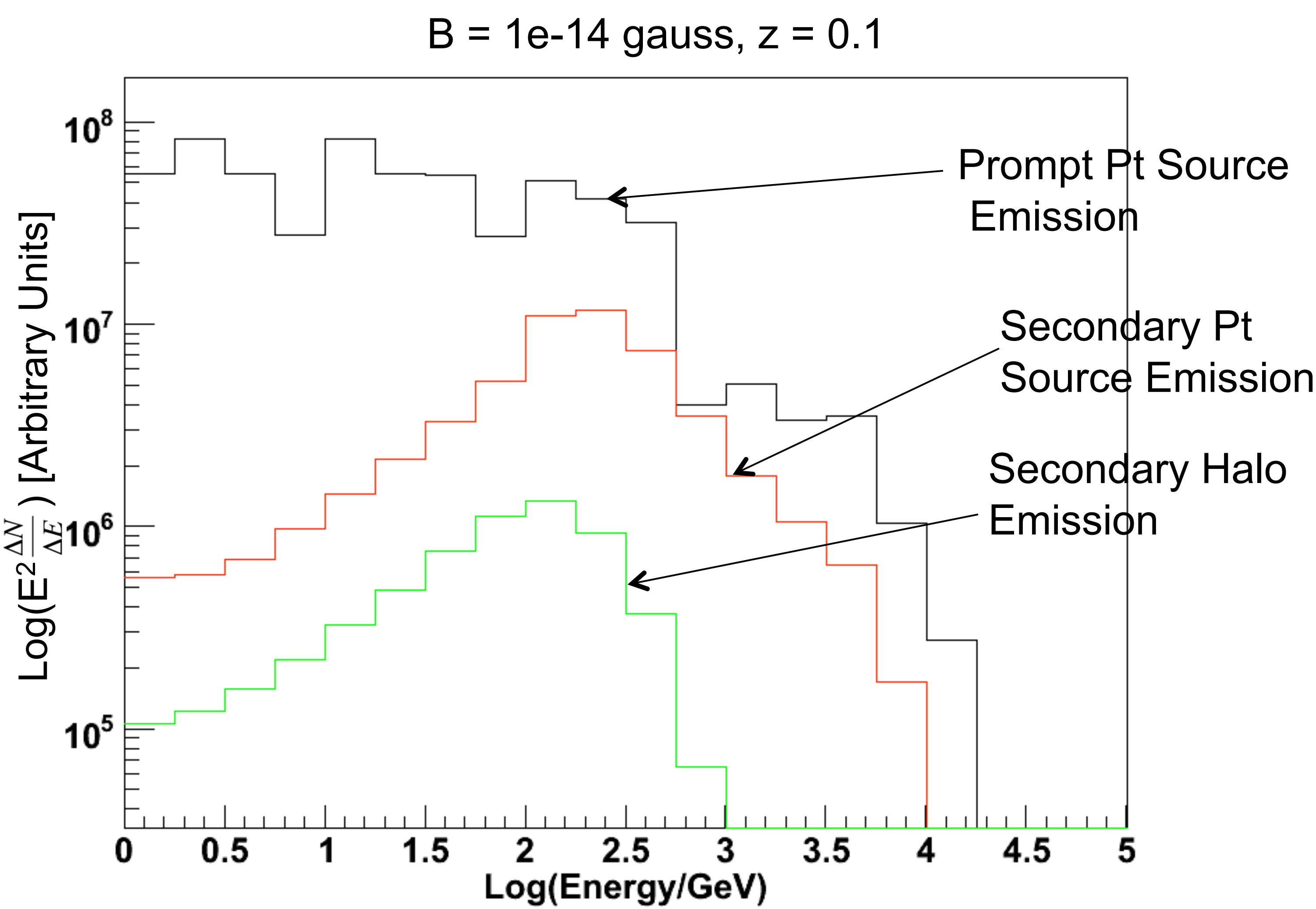
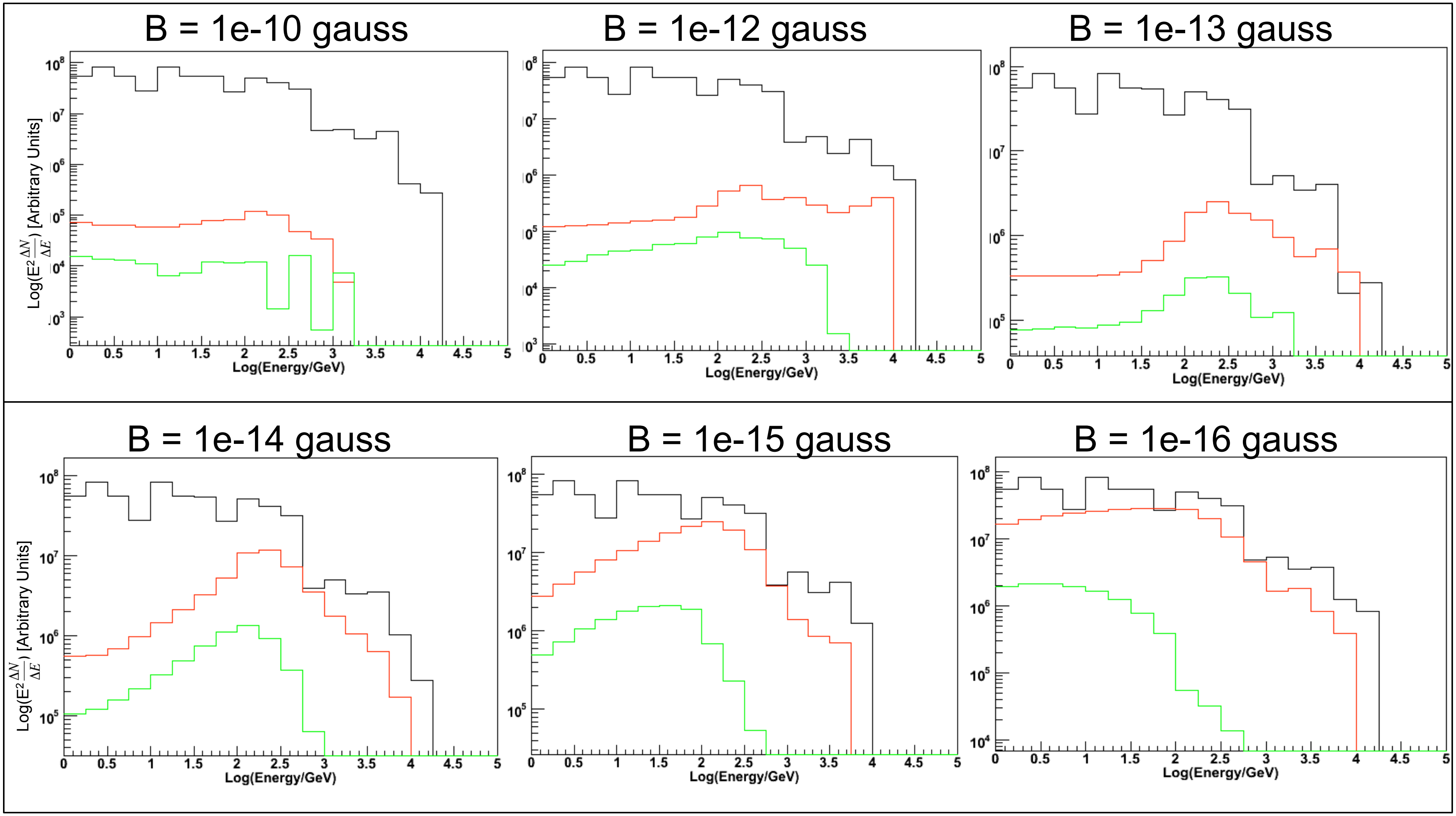
Energy Spectrum Modification



Energy Spectrum, z = 0.1

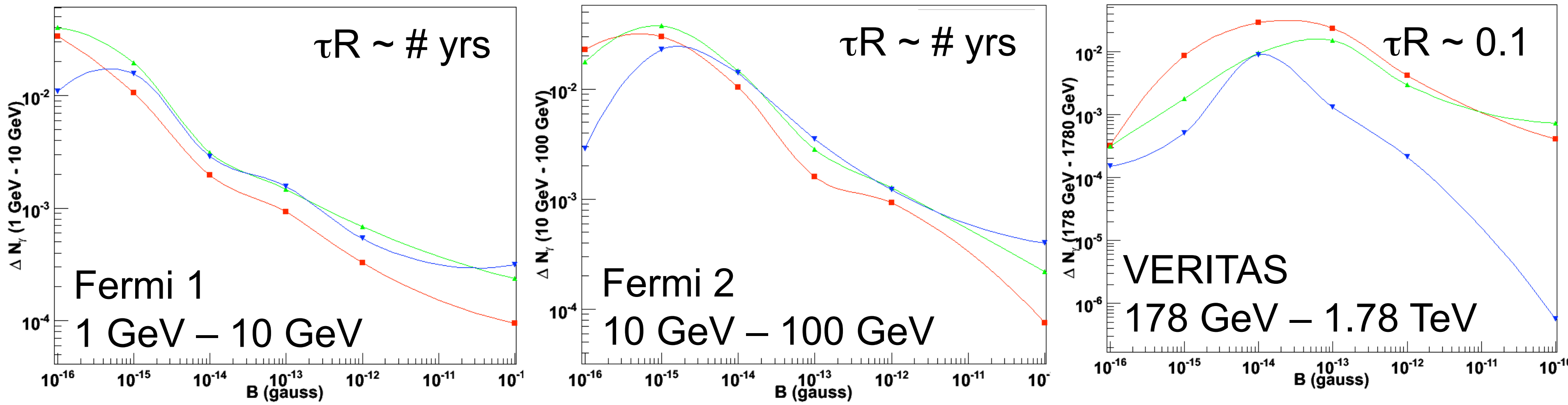
- Prompt
- Sec Pt Source
- Halo



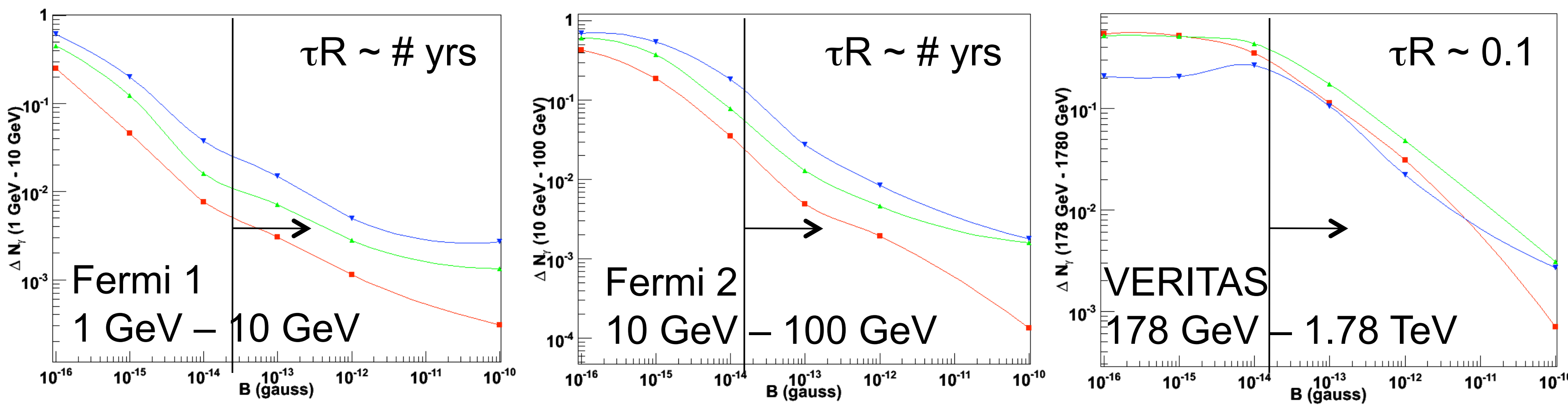
Energy Spectrum Ratios

• z = 0.032
• z = 0.1
• z = 0.32

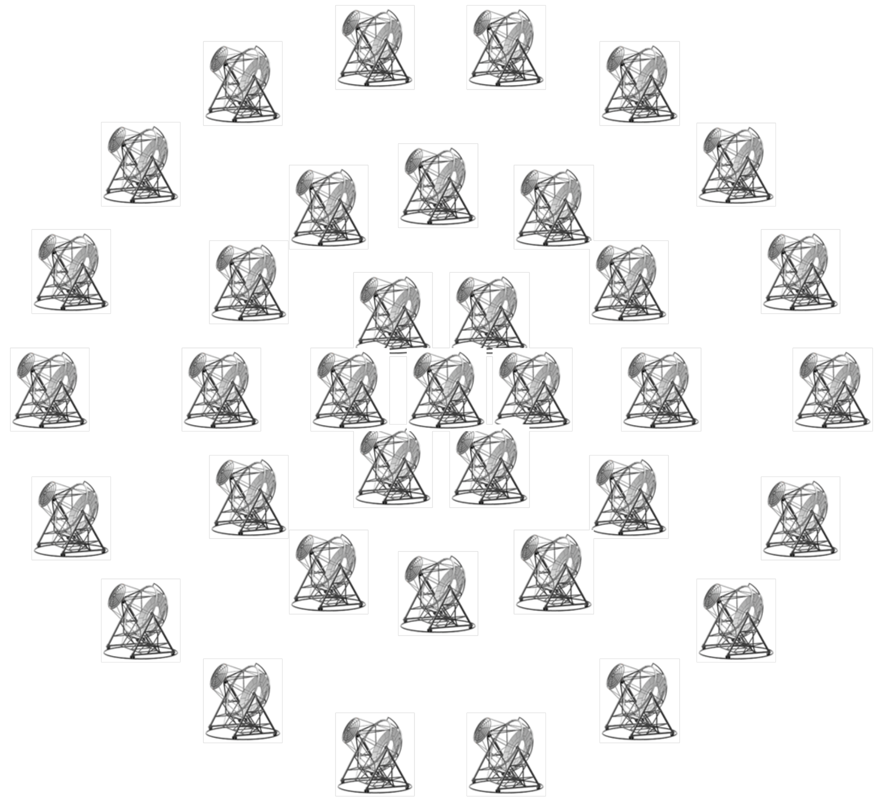
Ratio of Halo to Prompt Emission



Ratio of Secondary Point Source to Prompt Emission



AGIS/CTA



•Collecting Area > 1 km^2
•Telescope – 11.5m Schwarzschild-Couder
•FOV – 8 deg
•Angular Resolution – few arcminutes
•Sensitivity – 0.1 % Crab (50 hr)

Proposed as the next generation ground-based γ-ray observatory

Conclusions

- Halo and "sec pt source" (baseline) fluxes provide information about: IGMF, intrinsic source spectra, and EBL SED.
- For Hard source spectra:
  - For IGMF ~10^{-14} – 10^{-16} gauss, Fermi may be able to detect halo flux in a few years of observations.
  - For IGMF ~10^{-12} – 10^{-14} gauss, VERITAS may be able to detect halo or pt source baseline emission, given deep observations (≥ 100 hr).
- AGIS/CTA will be able to detect these effects with lower exposure, from softer spectrum sources, at larger redshifts. In addition, its energy range is extended to < 100 GeV, which is critical for such observations of IGMF effects.

Conclusions