
Fermi Gamma-ray Space Telescope

# Search for Gamma-ray Emission from p-wave Dark matter Annihilation in the Galactic Center

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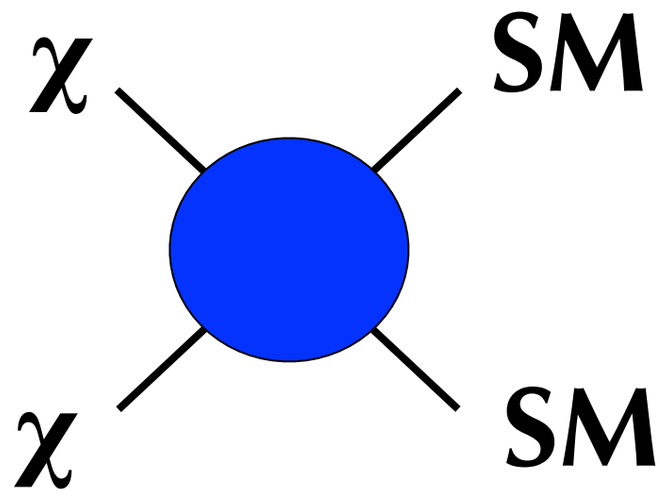
on behalf of the
Fermi-LAT Collaboration

8th Fermi Symposium
Baltimore, MD, USA

# A Brief Dark Matter Intro

- **Standard WIMP picture**
  - **Relic density set by thermal decoupling**
    - **predictive: dwarfs, GC… etc**
    - **complementarity! (Direct detection/Collider)**
  - **Assumption: s-channel annihilation i.e.: velocity independent $\langle \sigma v \rangle$**
    - **Solve Boltzman equation…**
    - **$\langle \sigma v \rangle \rightarrow a + b v^2 + \ldots$**




- **Step Beyond Standard WIMP picture**
  - **DM doesn't have to thermally decouple**
    - **Thermally produced (freeze-out via BSM mediator)**
    - **Non-thermally produced (asymmetric DM)**
  - **s-channel annihilation suppressed or non existent**
    - **BSM Mediators! New search strategy, lower bound on couplings**

# Thermal Dark Matter vs. New Mediator

- DM freeze-out independent of Standard Model until mediator decays
  - however… DM Couplings to SM can be very small (Nightmare DM Scenario)
  - Leading order term (s-wave component) gone!
    - Fermionic DM→dark scaler bosons (DSB)
  - Orders of magnitude less sensitive
    - Complementarity can be doomed
    - Need high densities of DM

- Indirect detection implications
  - Low couplings need high density and high velocity
    - Overcome low DM annihilation couplings: SMBH (AGN or GC)

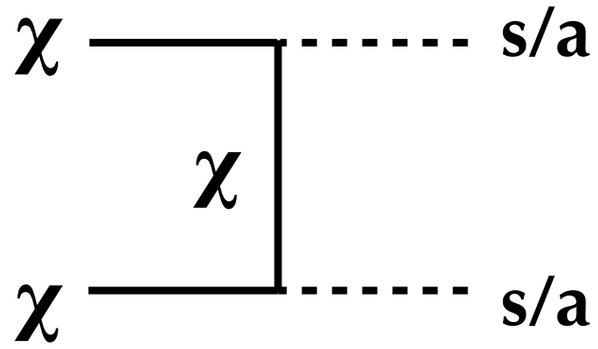
- SMBH offer a *unique* possibility to test these signals

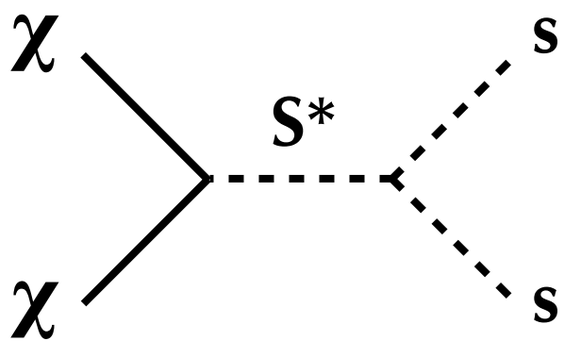
# Models of thermal p-wave Dark Matter

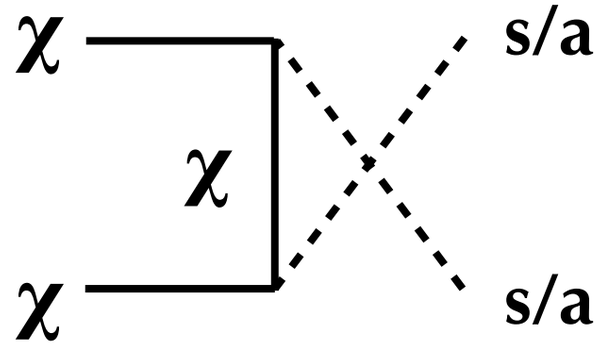
**Models where velocity dependent term is dominant:**

**Hidden Sector Higgs Portal (s)**

**Hidden Sector Axion Portal (a)**




To SM via ε coupling

J. Shelton et. al, PRL 115 (2015) 23
arXiv:1506.04143

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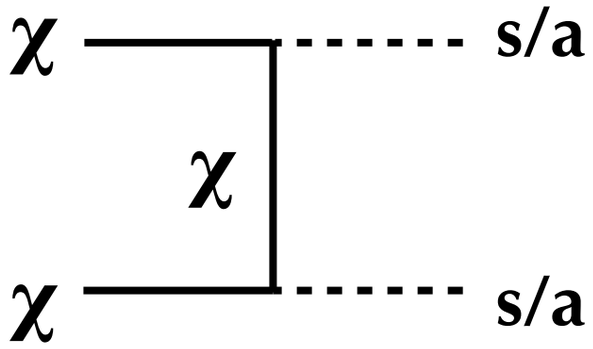


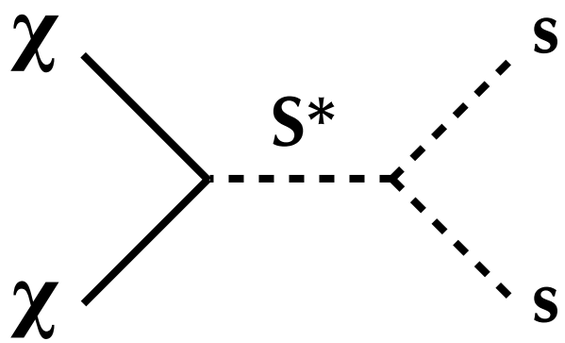


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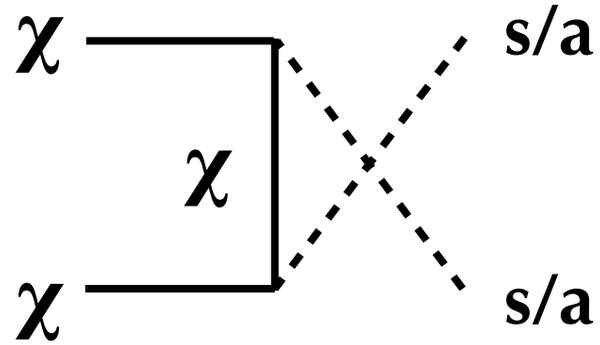


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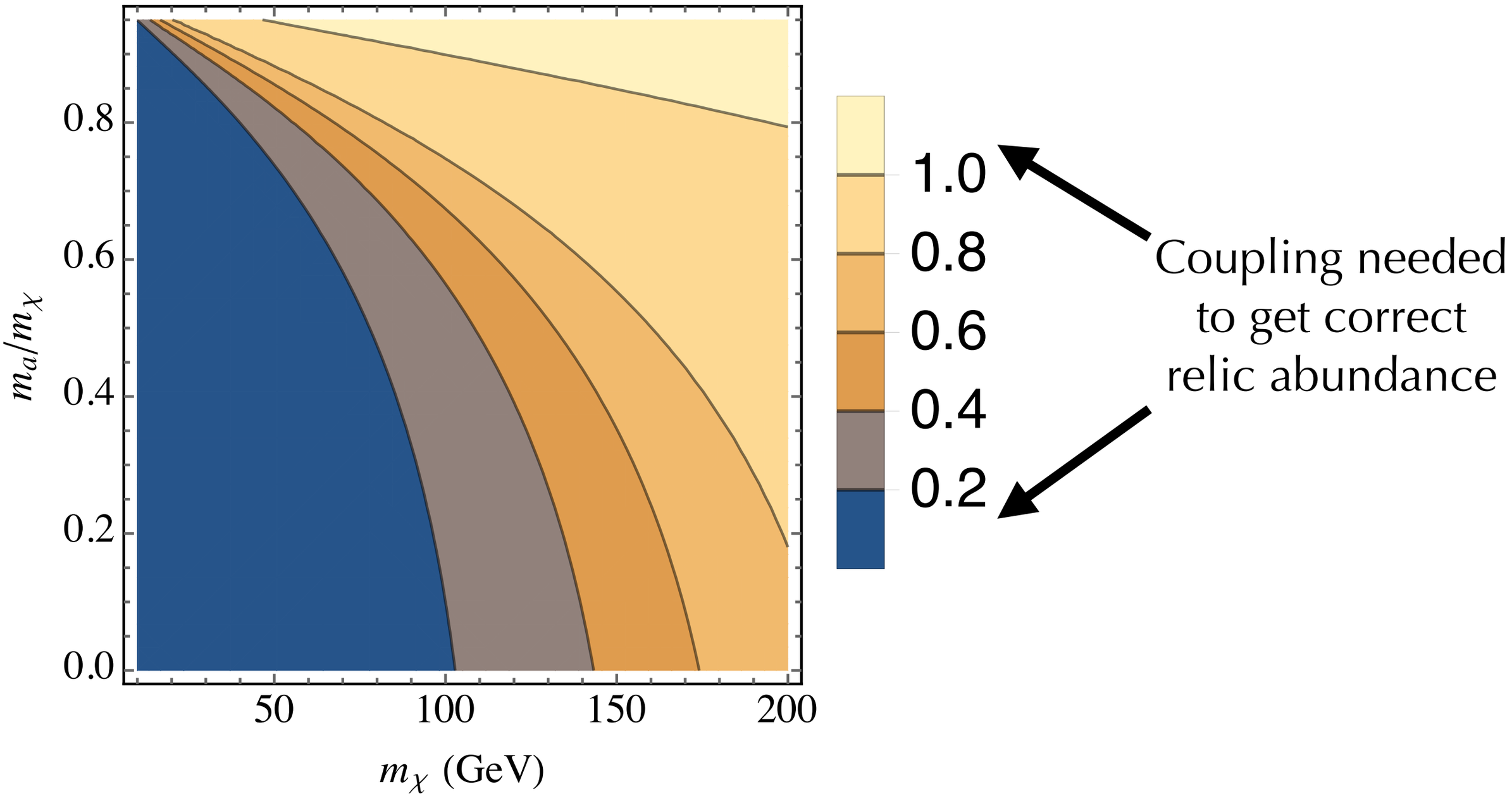
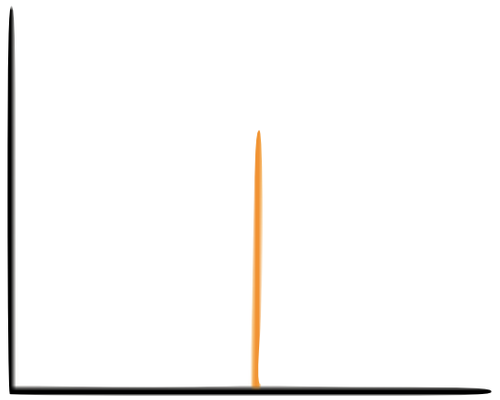


# Search Strategy

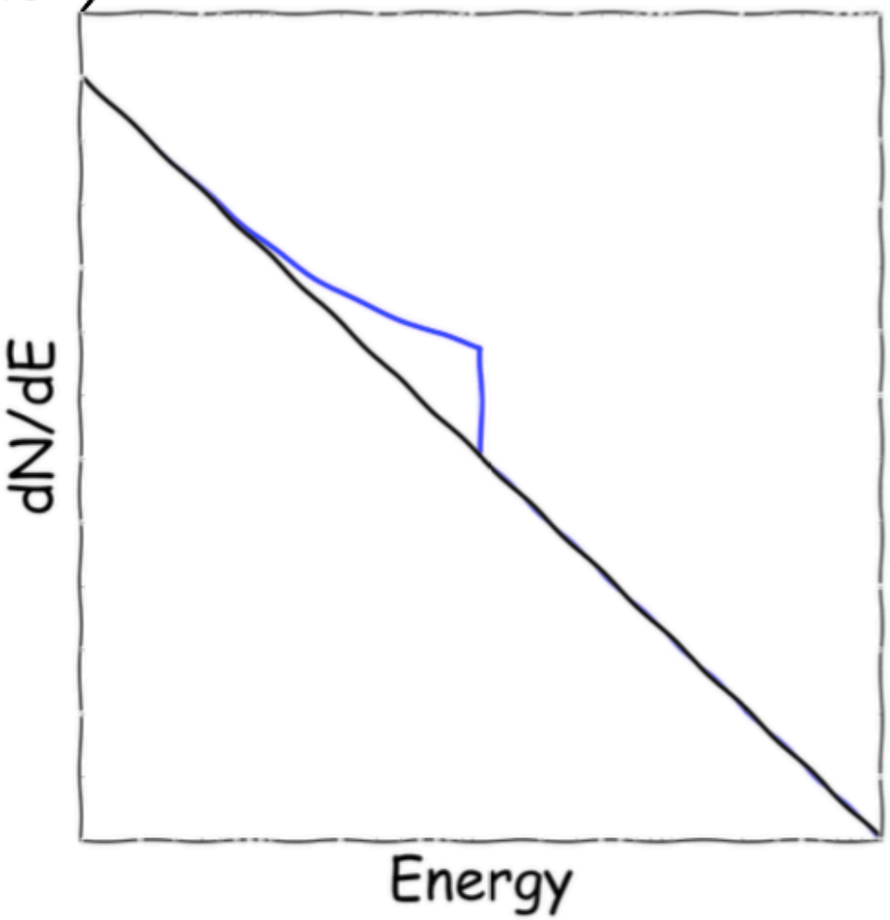


$$\frac{m_\chi}{2}$$

$$\frac{m_\chi}{2}\left(1 \pm \sqrt{1 - \frac{m_{s/a}^2}{m_\chi^2}}\right)$$

Box-like spectrum: consequence of the mediator (a)$\rightarrow \gamma\gamma$ boosted in the Galactic reference frame

Box width depends on mediator mass



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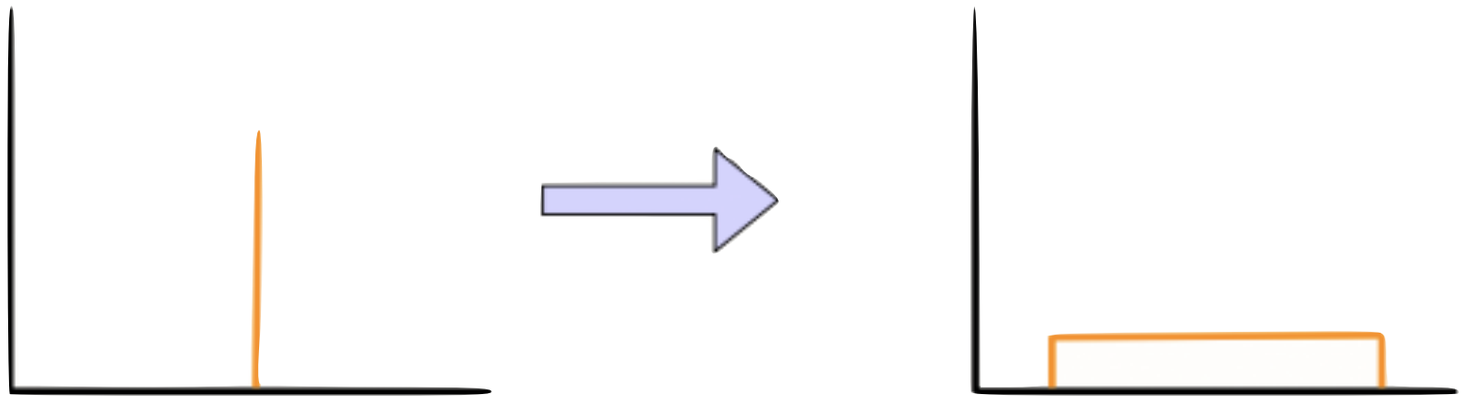

$\frac{m_\chi}{2}$



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Spikes well motivated (Silk&Gondolo 1999)

Box-like spectrum: consequence of the mediator (a)→**γγ** boosted in the Galactic reference frame

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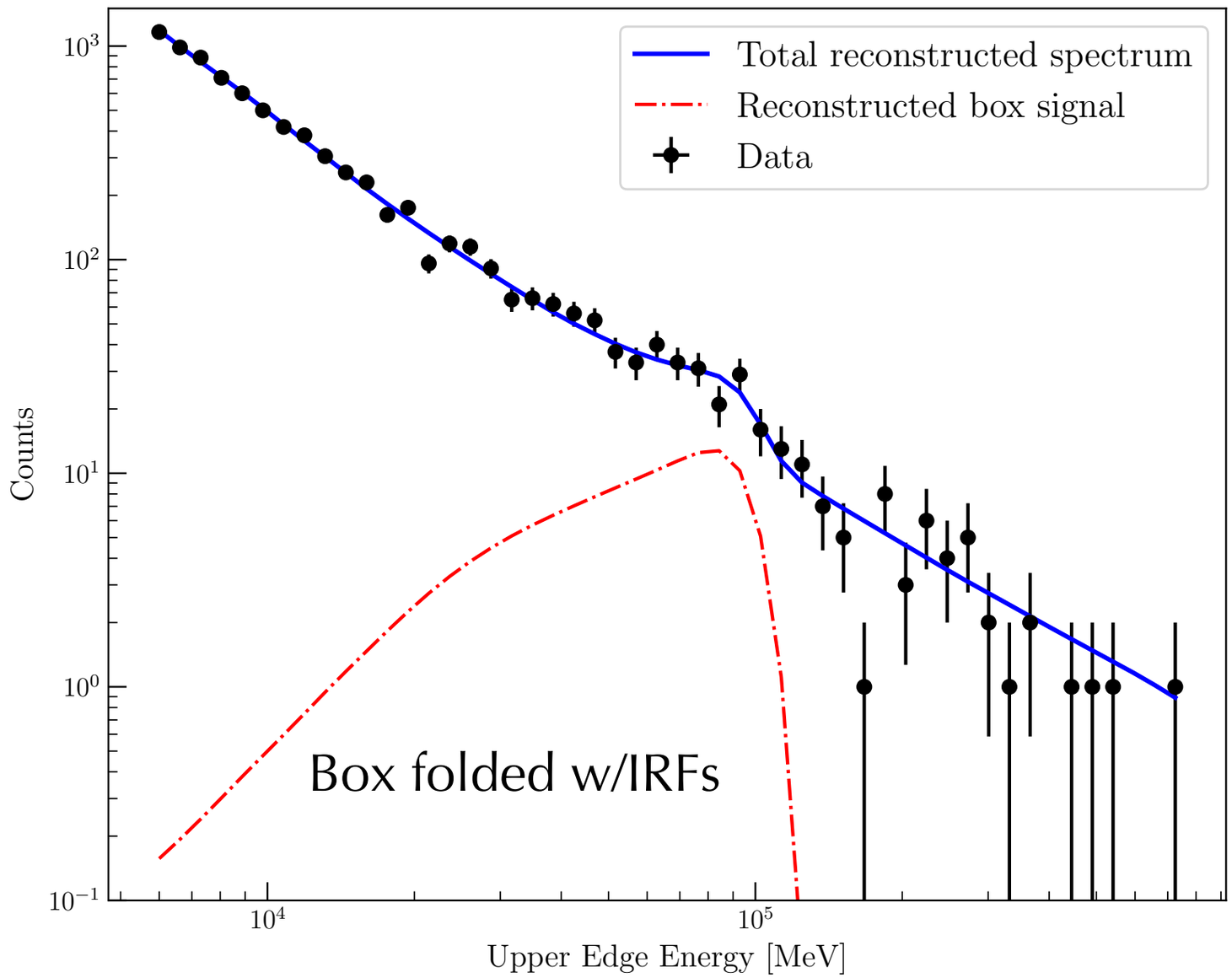

# Closest SMBH: Center of Milky Way

- **DM density profile Steep PL**

- **Input Parameters**
  - $M_{BH} = 4 \times 10^6 M_{sun}$
    - note: fairly known from stellar orbits
  - $v_0 = 105 \pm 20$ km/s
    - note: not quite as well known from stellar population
  - $R_{sun} = 8.46^{+0.42}_{-0.38}$ kpc
  - $\rho_{sun} = 0.3 \pm 0.1$ GeV/cm$^3$
  - $t_{ann} = 10^{10}$ y
  - typical $r_{in}$: $10^{-3}$-$10^{-5}$ pc
- **Free parameters:**
  - Inner/Spike NFW index: $\gamma_c/\gamma_{sp}$

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# Closest SMBH: Center of Milky Way

- DM density profile Steep PL → 
  - *4 regions of the spike*
  - Inner Halo (gNFW)
    - $\rho(r) = \rho(r_0)(r_0/r)^{\gamma_c}$
  - DM spike region ($r_b \approx 0.2\ r_h$)
    - $\rho(r) = \rho(r_b)(r_b/r)^{\gamma_{sp}}$
  - Annihilation plateau
    - $\rho_{ann}(r) = m_\chi/\langle\sigma v\rangle t$ @ $r \equiv r_{in}$, t~ age of SMBH
  - Inner Spike
    - $\rho_{in}(r) = \rho_{ann}(r_{in}/r)^{1/2}$
    - search still sensitive if no adiabatic spike

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*yields: $r_h$=1.7 pc (0.012°)*

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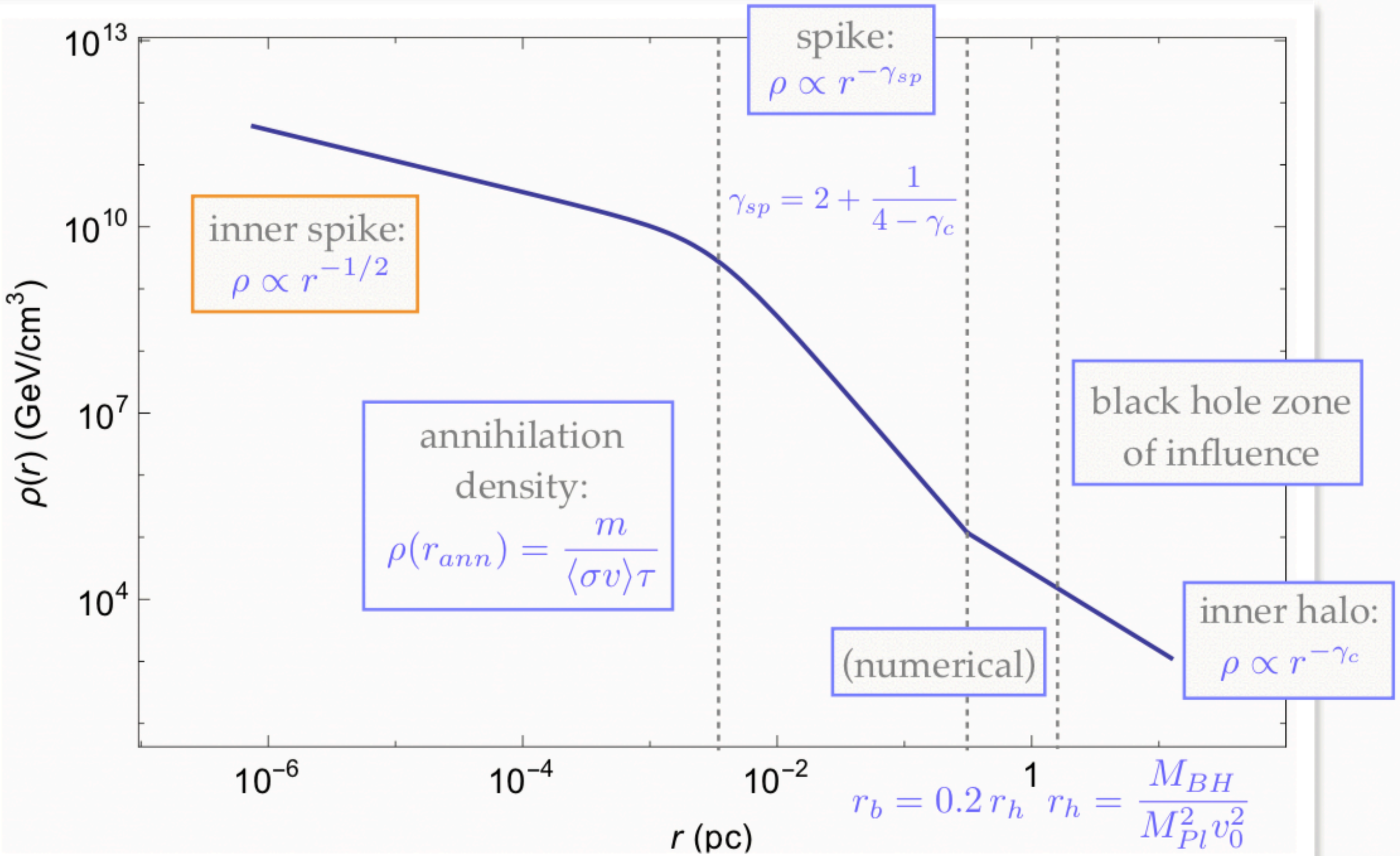
# Milky Way's Spike



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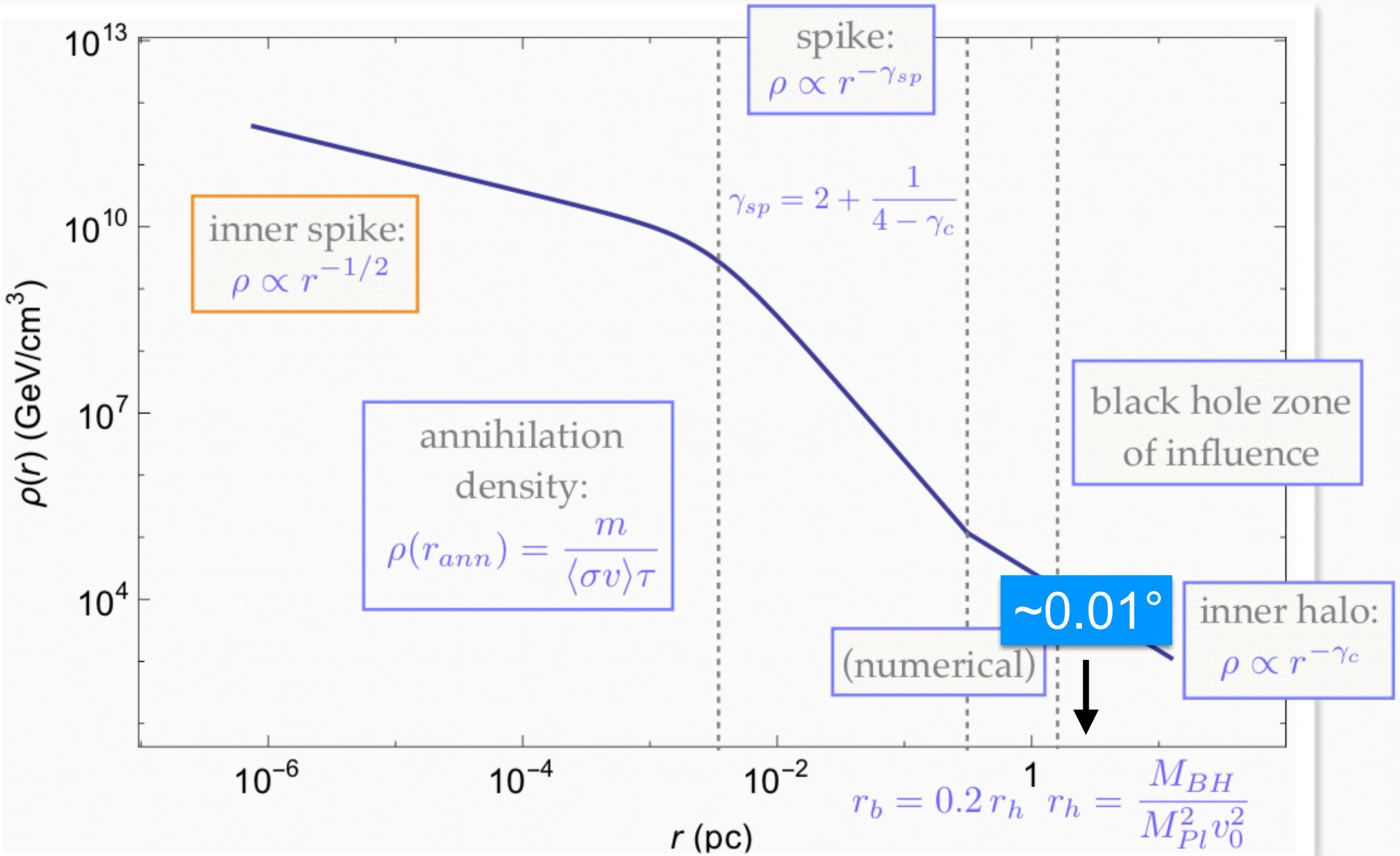
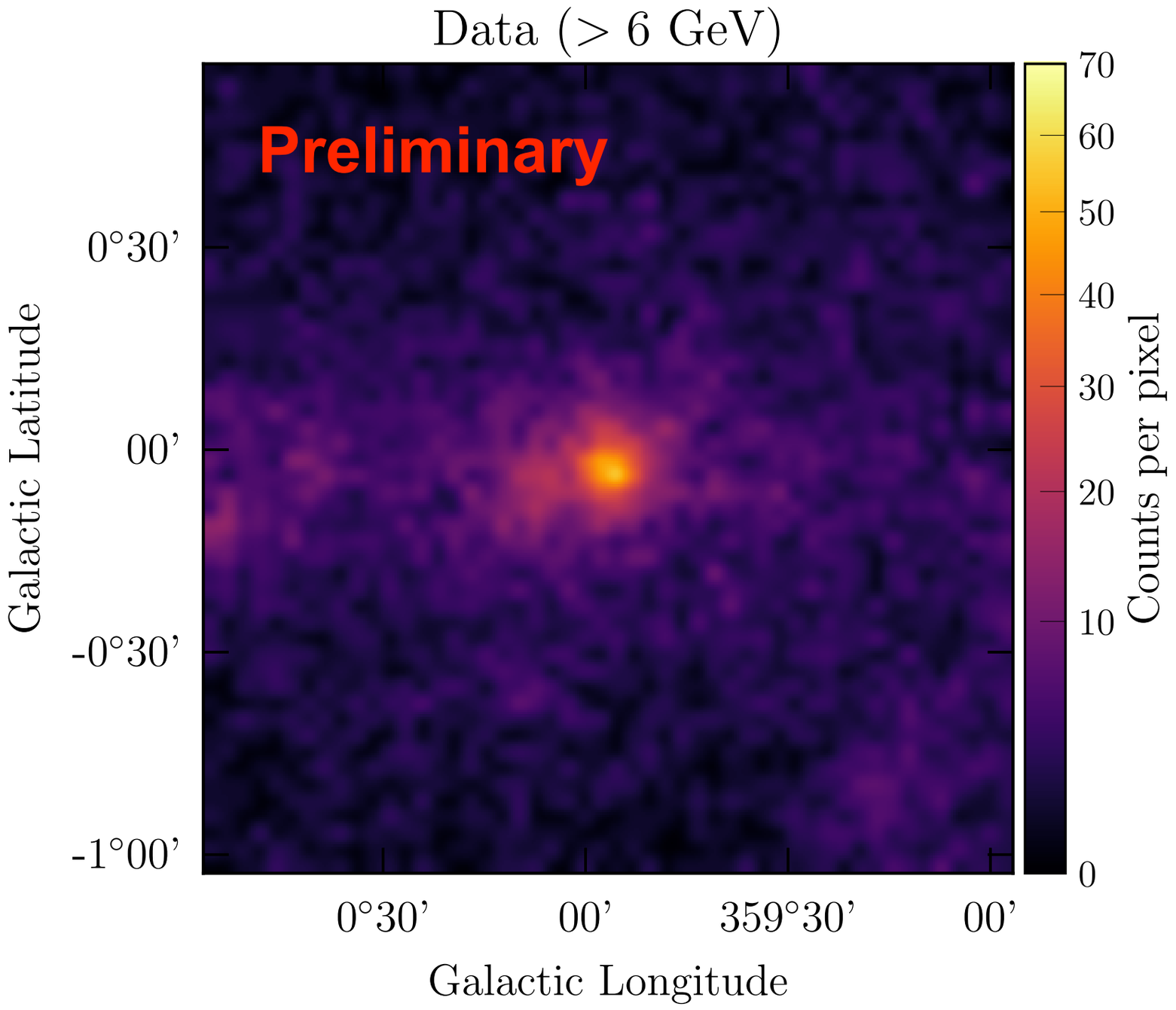


# The Analysis

| Selection | Criteria |
|---|---|
| Mission Elapsed Time | 9 years |
| Instrument Response Functions | P8R2_SOURCE_V6 |
| Energy Range (GeV) | 6-800 GeV |
| Fit Region | 2°x2°, centered on (RA, DEC)=(266.4°, -29.0°) |
| Zenith Range | $\theta_z < 100°$ |
| Data Quality Cuts | Yes |

# The Galactic Center




| 3FHL Source | Location (RA, DEC) |
|---|---|
| **Galactic Diffuse** | N/A |
| **J1745.6-2900** | (266.42, -29.01) |
| **J1746.2-2852** | (266.56, -28.88) |
| **J1747.2-2959** | (266.80, -30.00) |
| **J1747.2-2822** | (266.82, -28.37) |
| **J1748.1-2903** | (267.04, -29.06) |
| **J1748.6-2816** | (267.16, -28.28) |

Pixel size: 0.04° Gaussian smoothing

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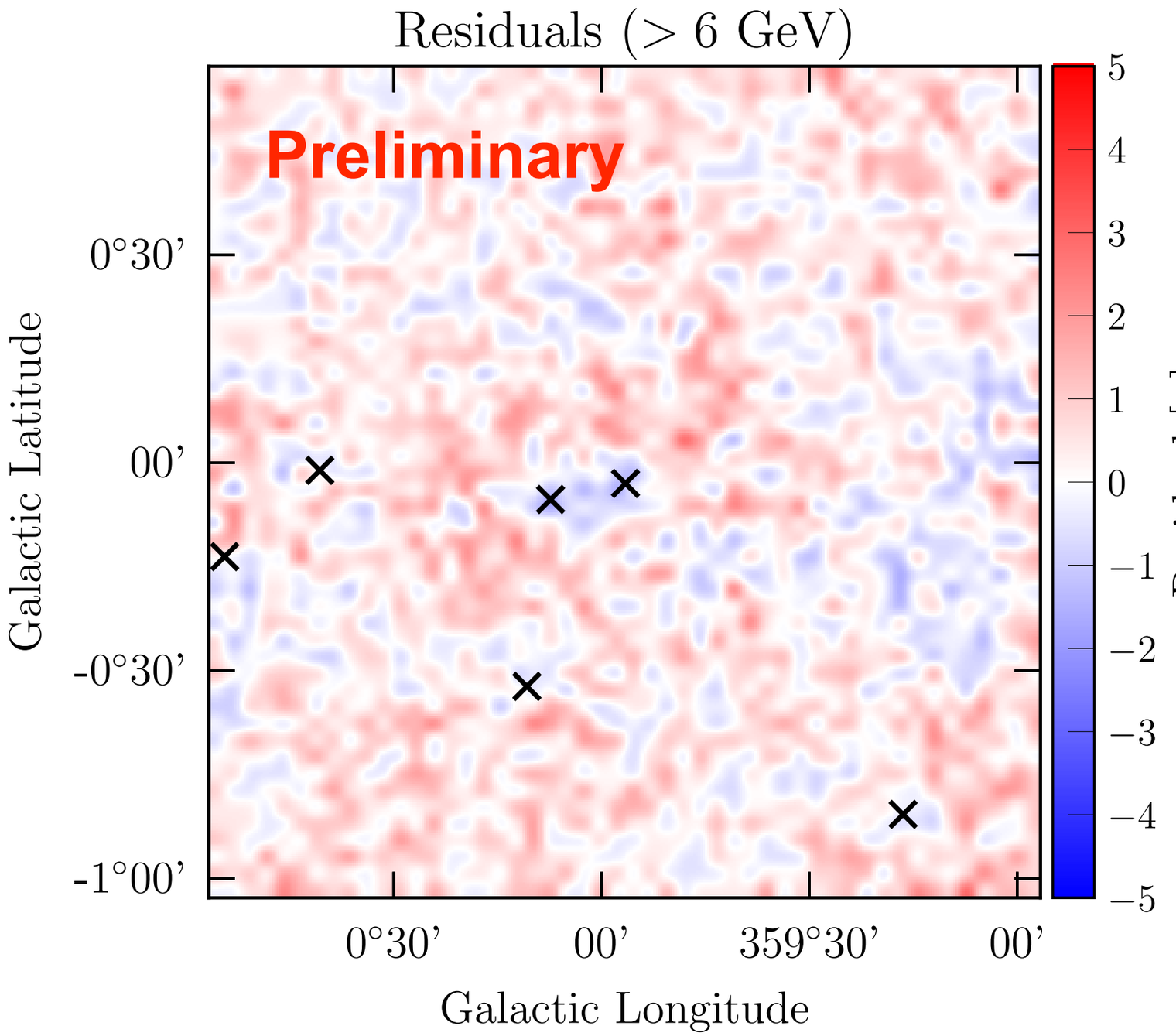


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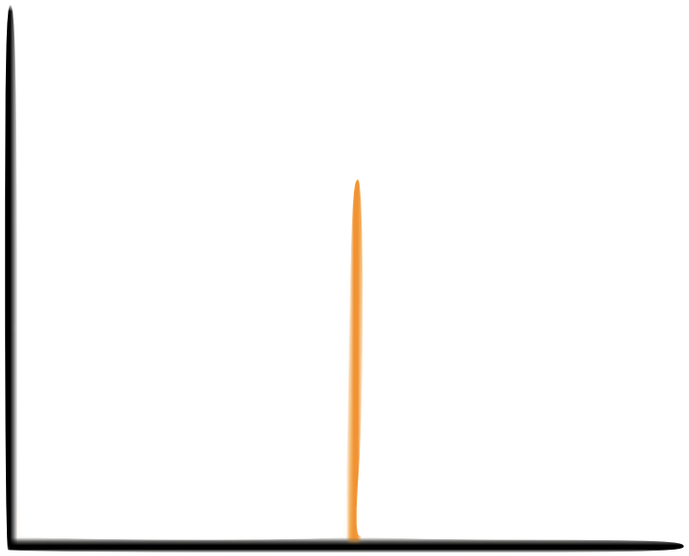
Narrow Box



$(m_\phi/m_\chi)^2 = 0.999$

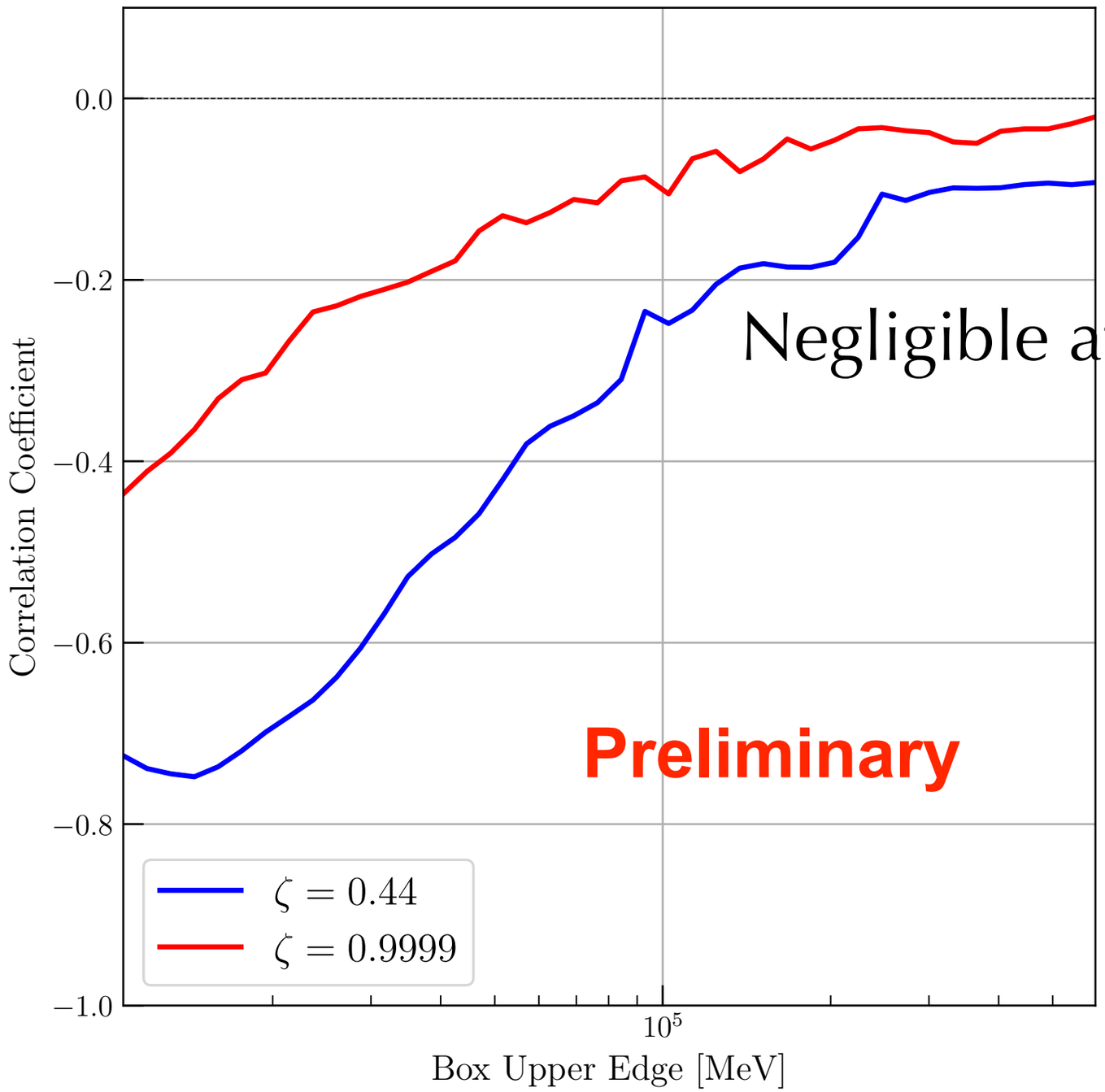
Wide Box

$(m_\phi/m_\chi)^2 = 0.44$

# Correlation with The Galactic Center Source

Upper edge of DM Signal Box : the GC source

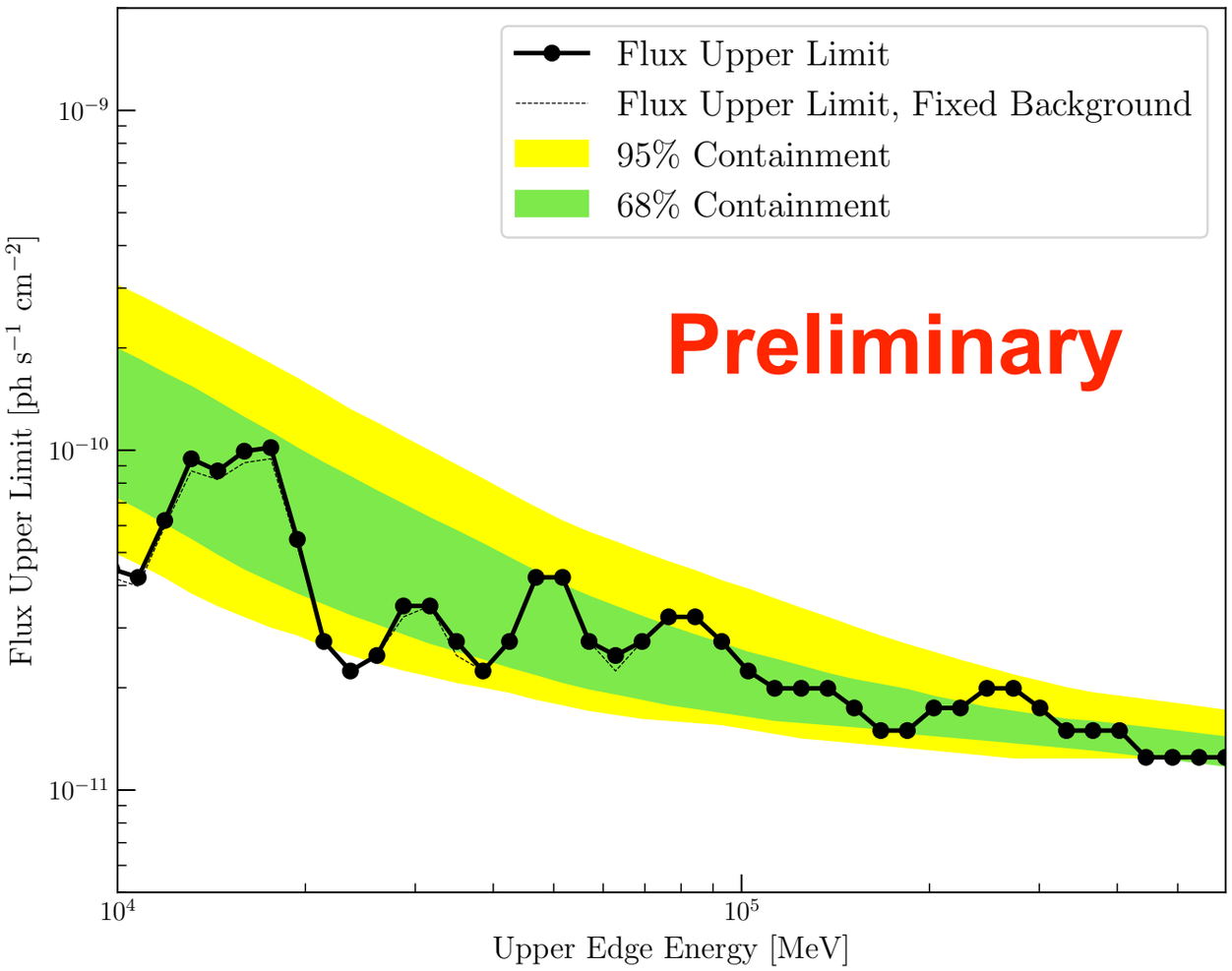
Sources are spatially coincident




Negligible at high energies

# Results

## Narrow Box

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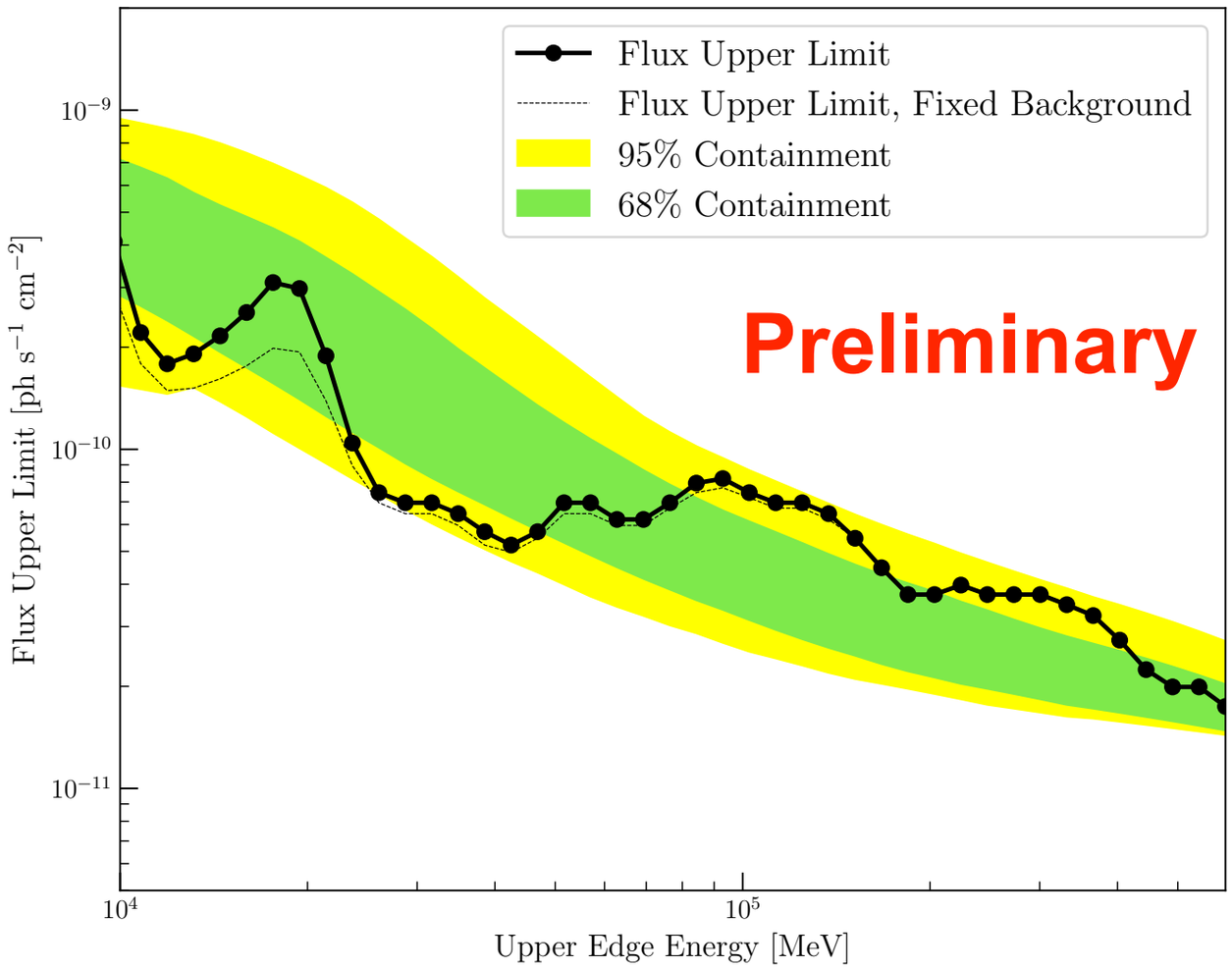
## Wide Box

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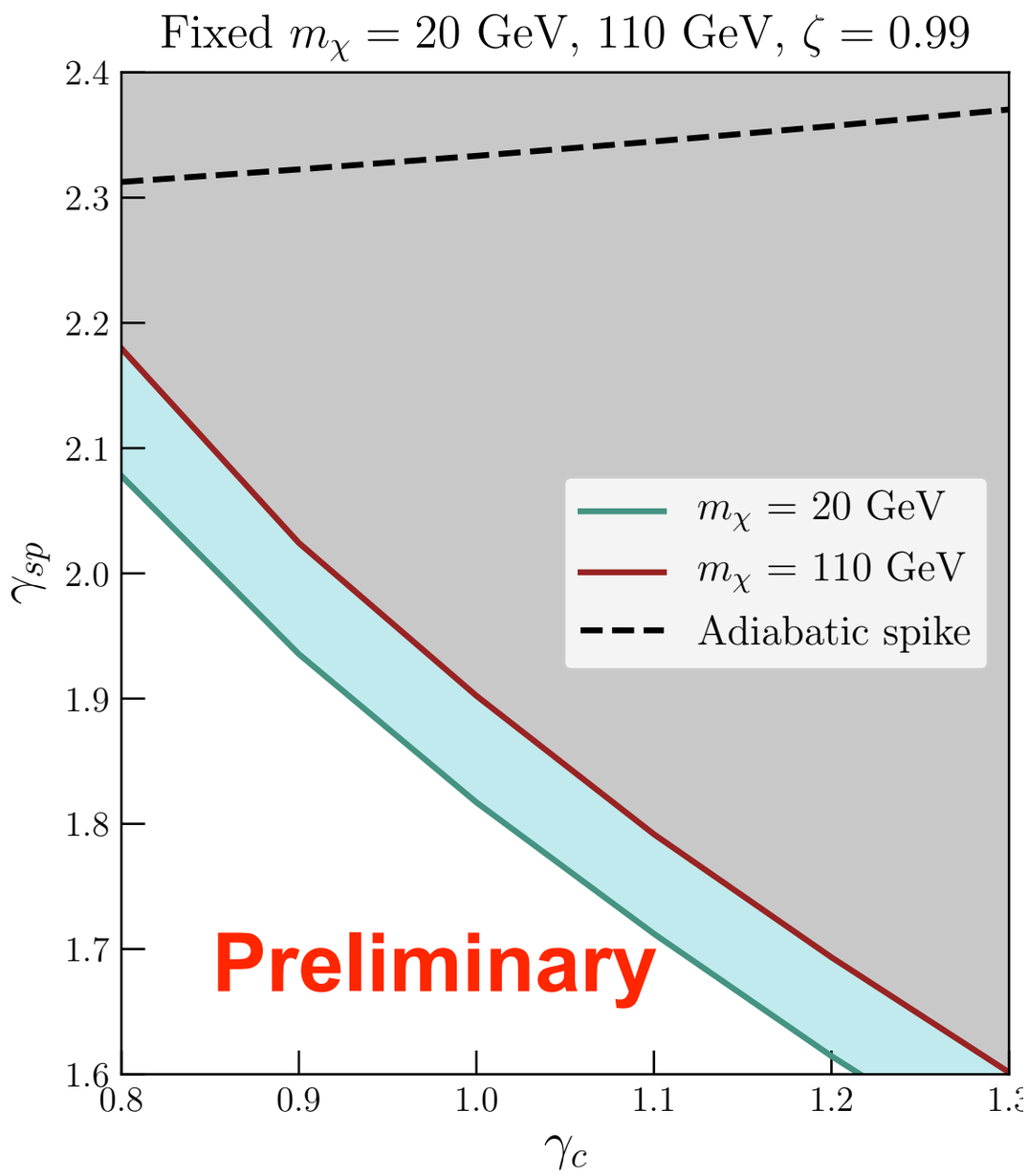
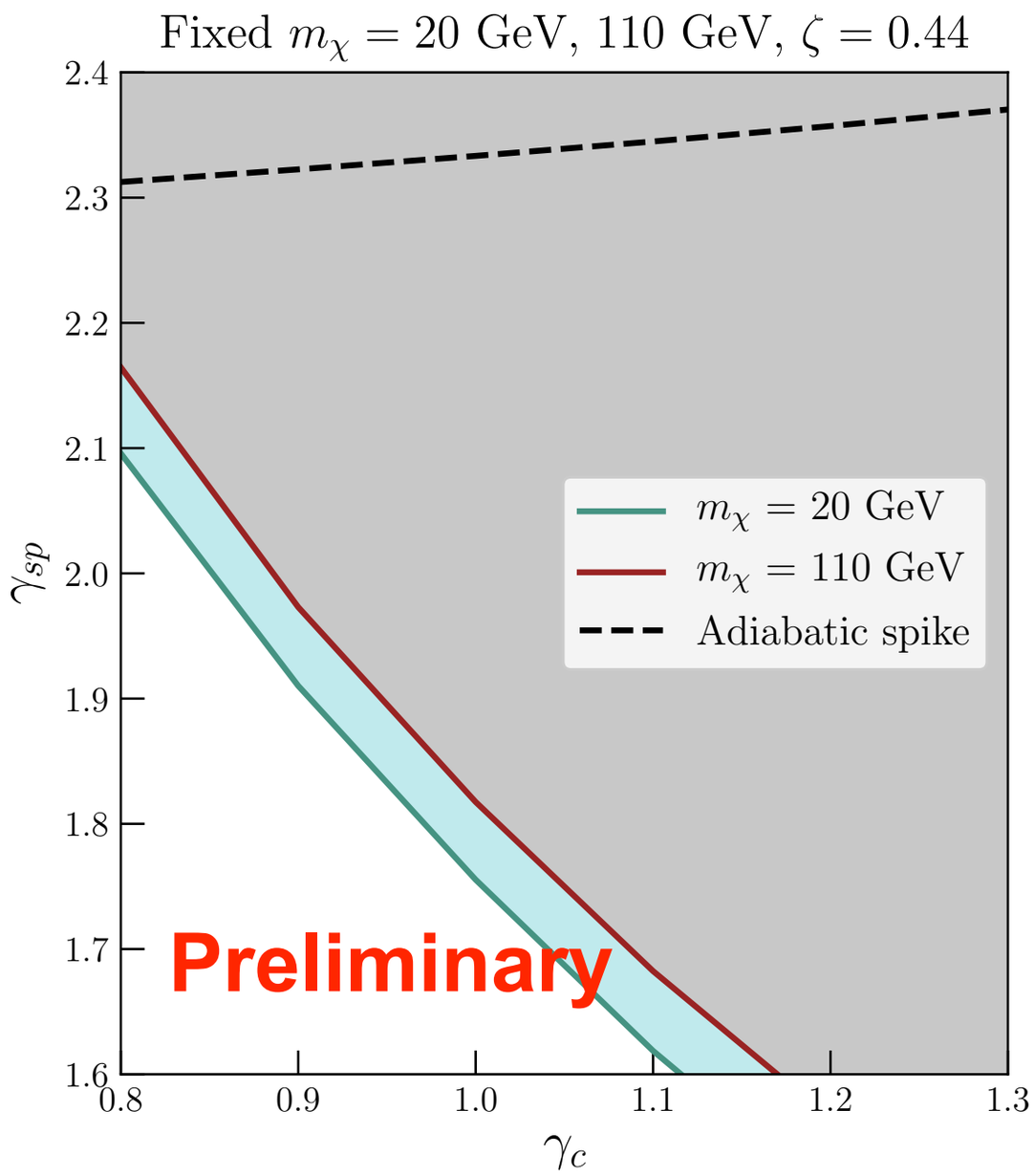
# Interpretation



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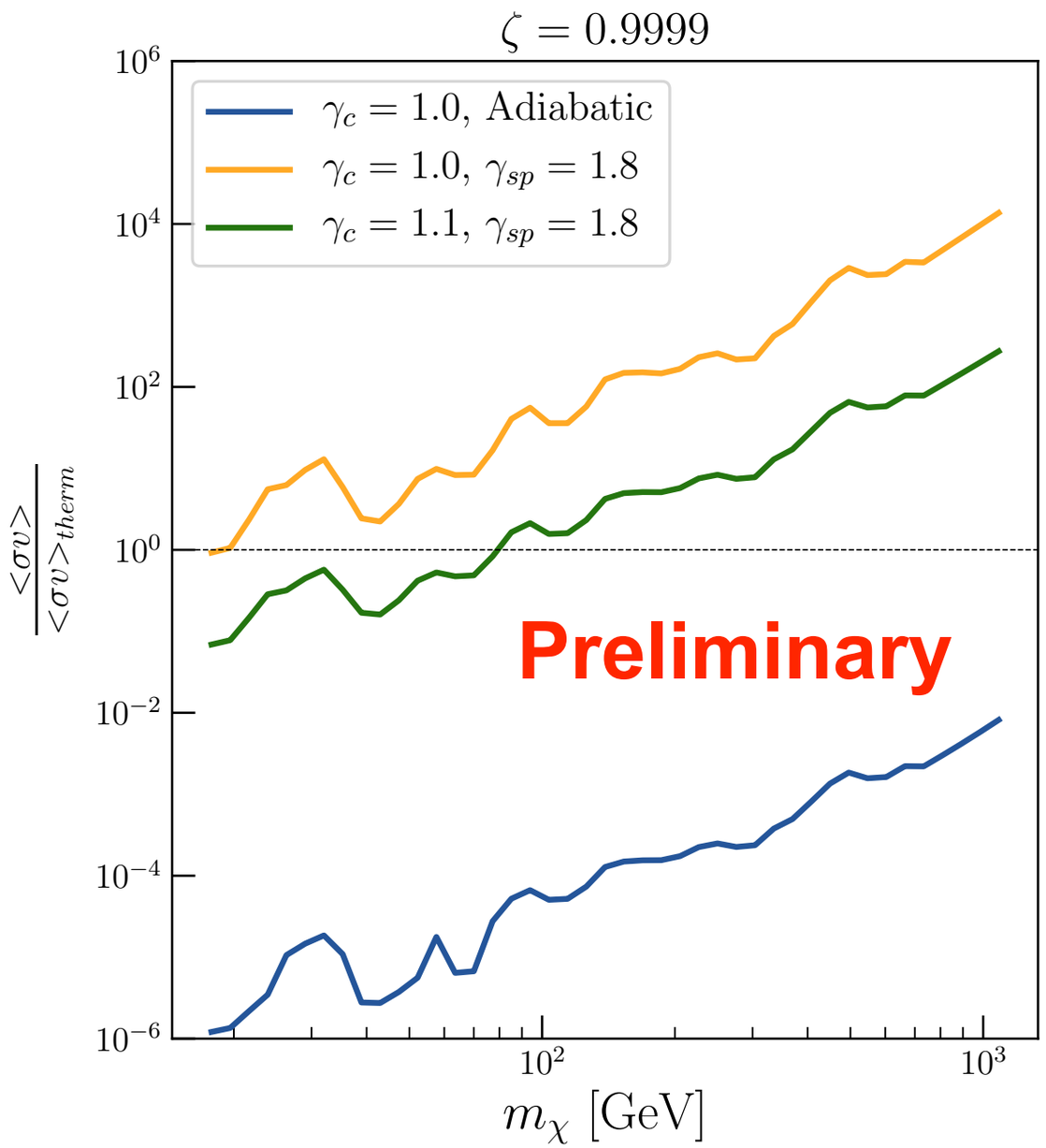
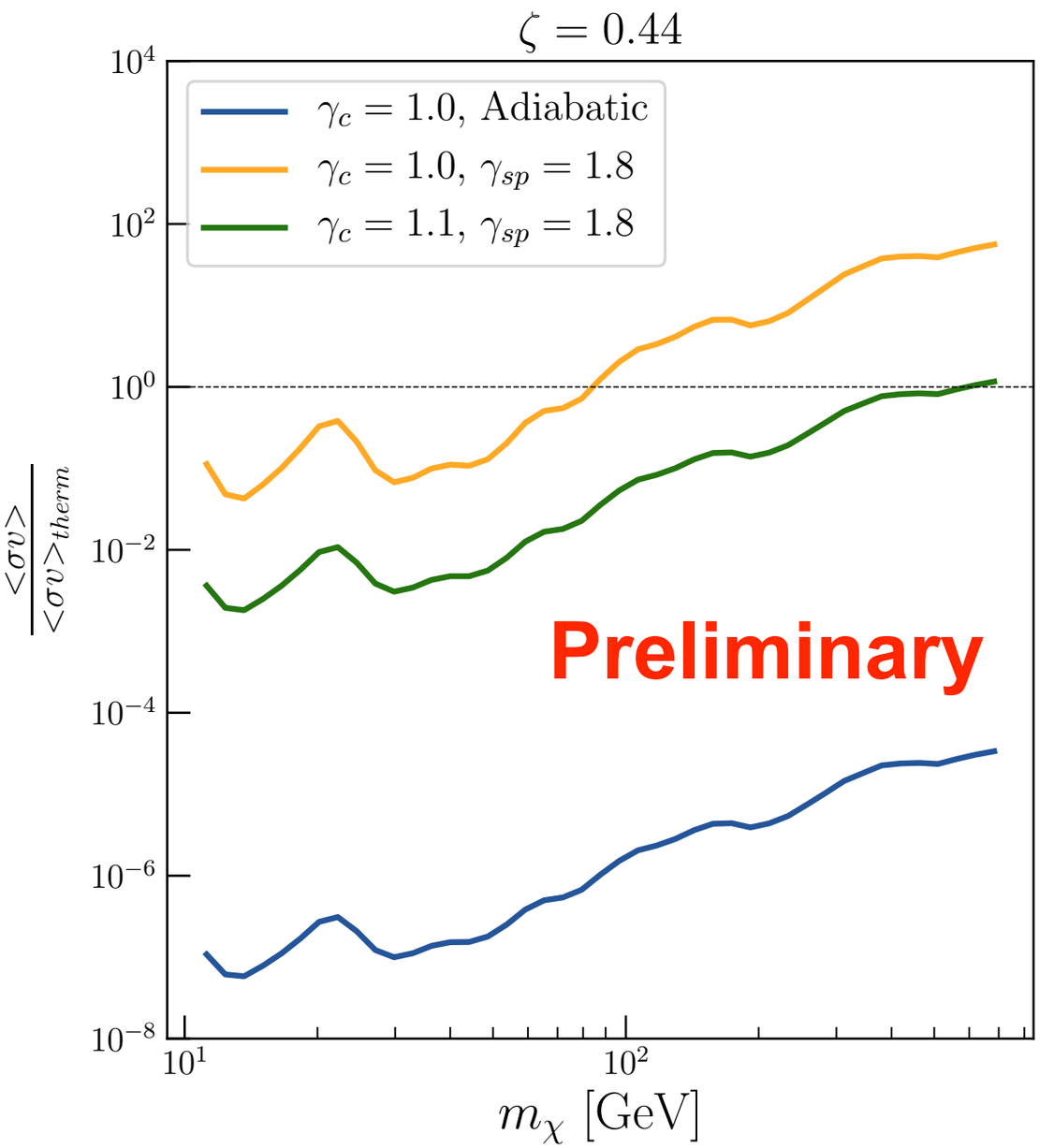
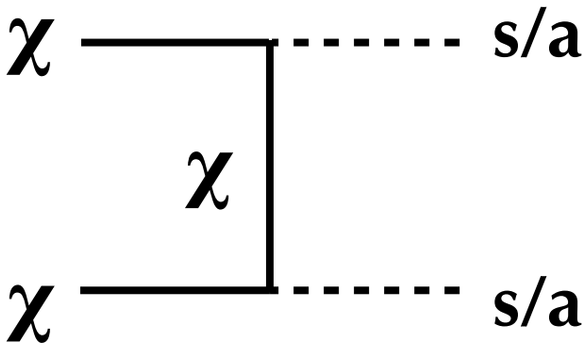


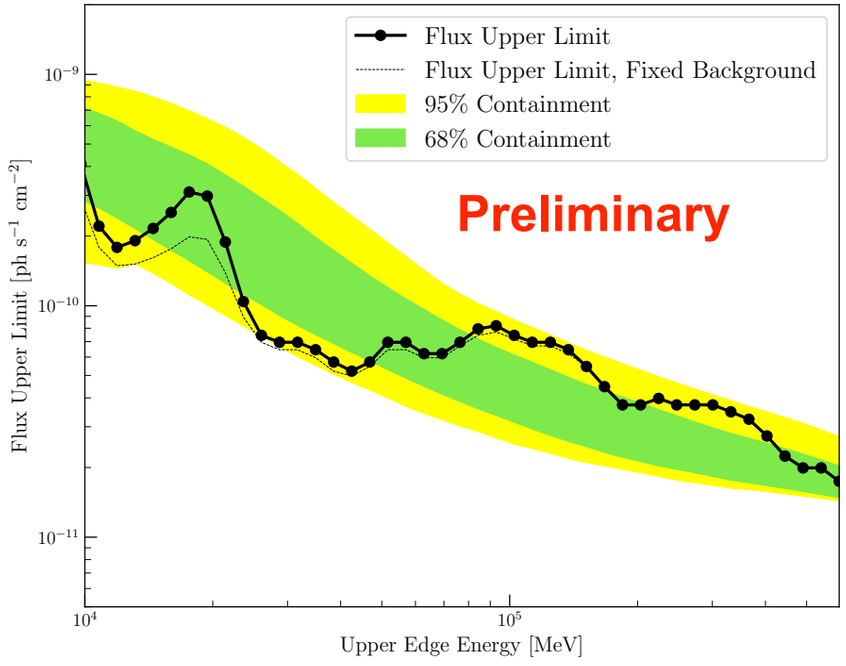



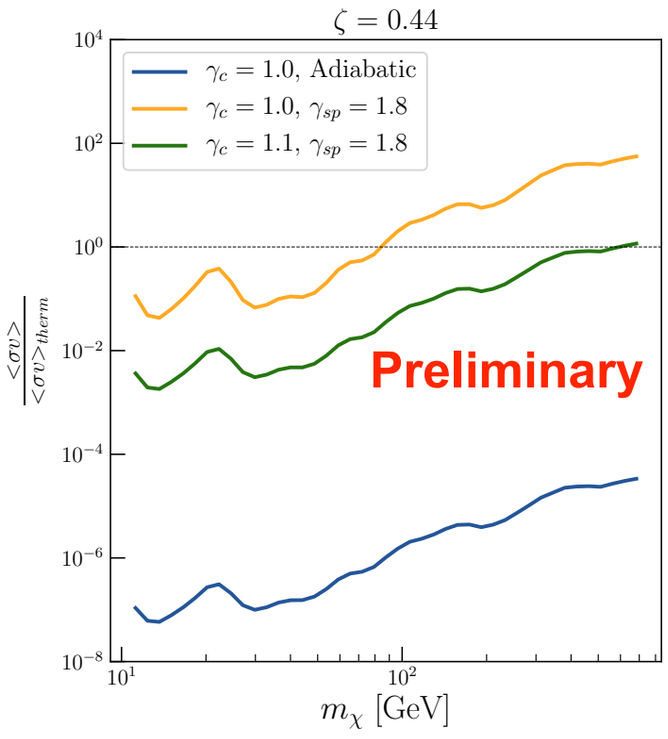
# Summary and Conclusions

- **Considered a dark matter paradigm where the standard assumption about the annihilation cross section is suppressed**

- **Found no evidence of a dark matter signal and placed an upper limit on the total γ-ray flux from p-wave annihilation**

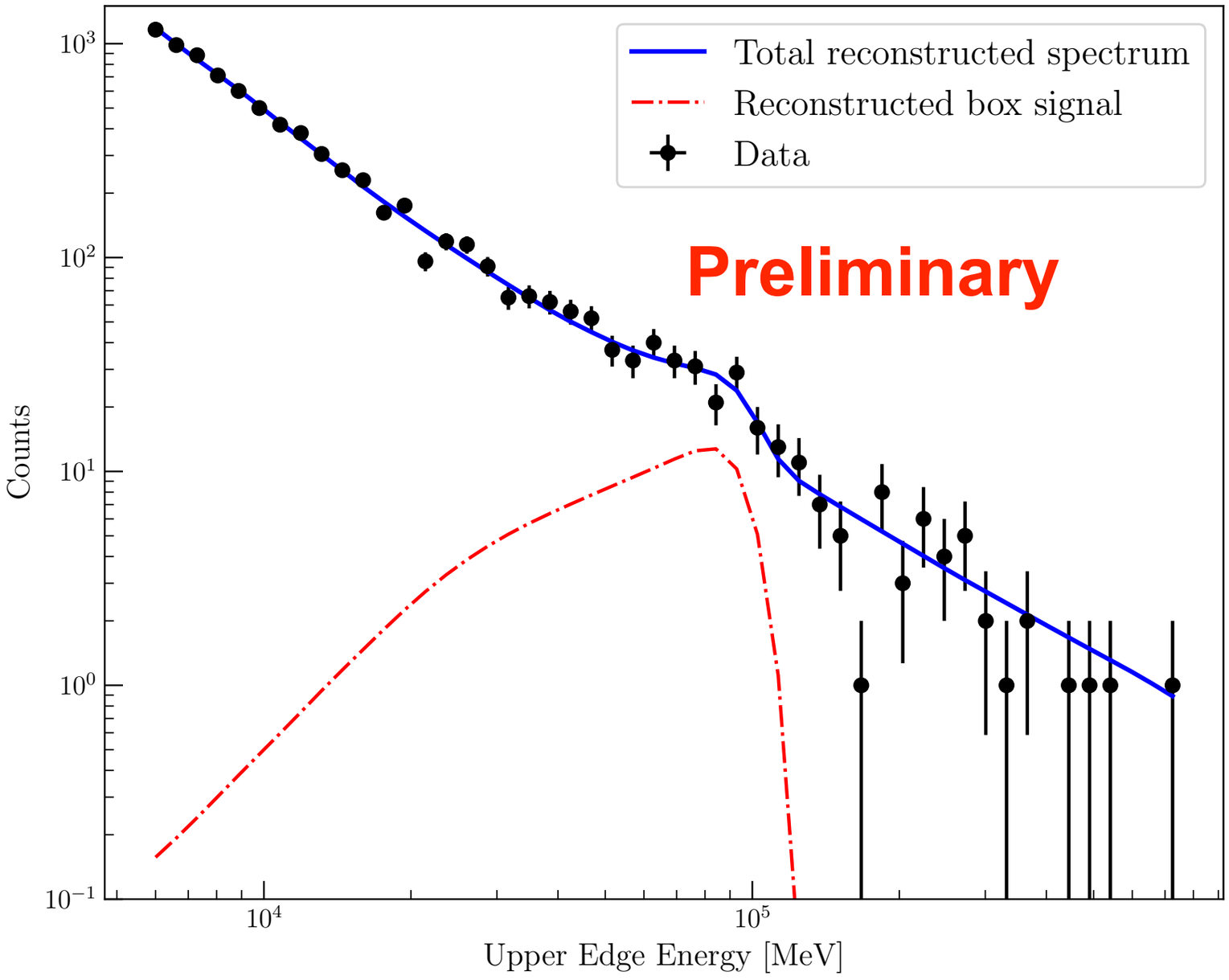


# Bonus Slides!

# Injecting a Dark Matter Signal




Upper edge 100 GeV
flux: $1.5 \times 10^{-11}$ ph/cm$^2$/s

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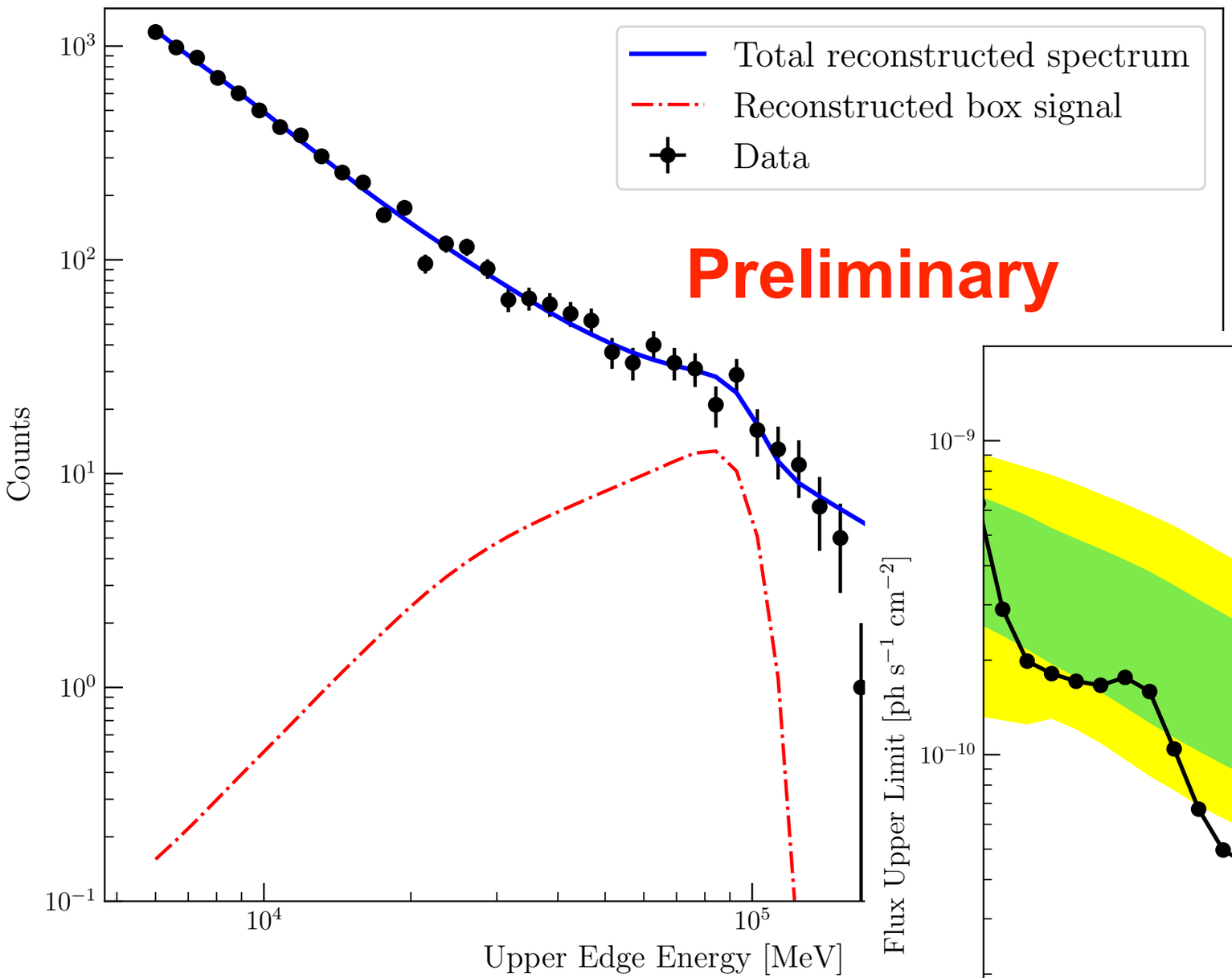


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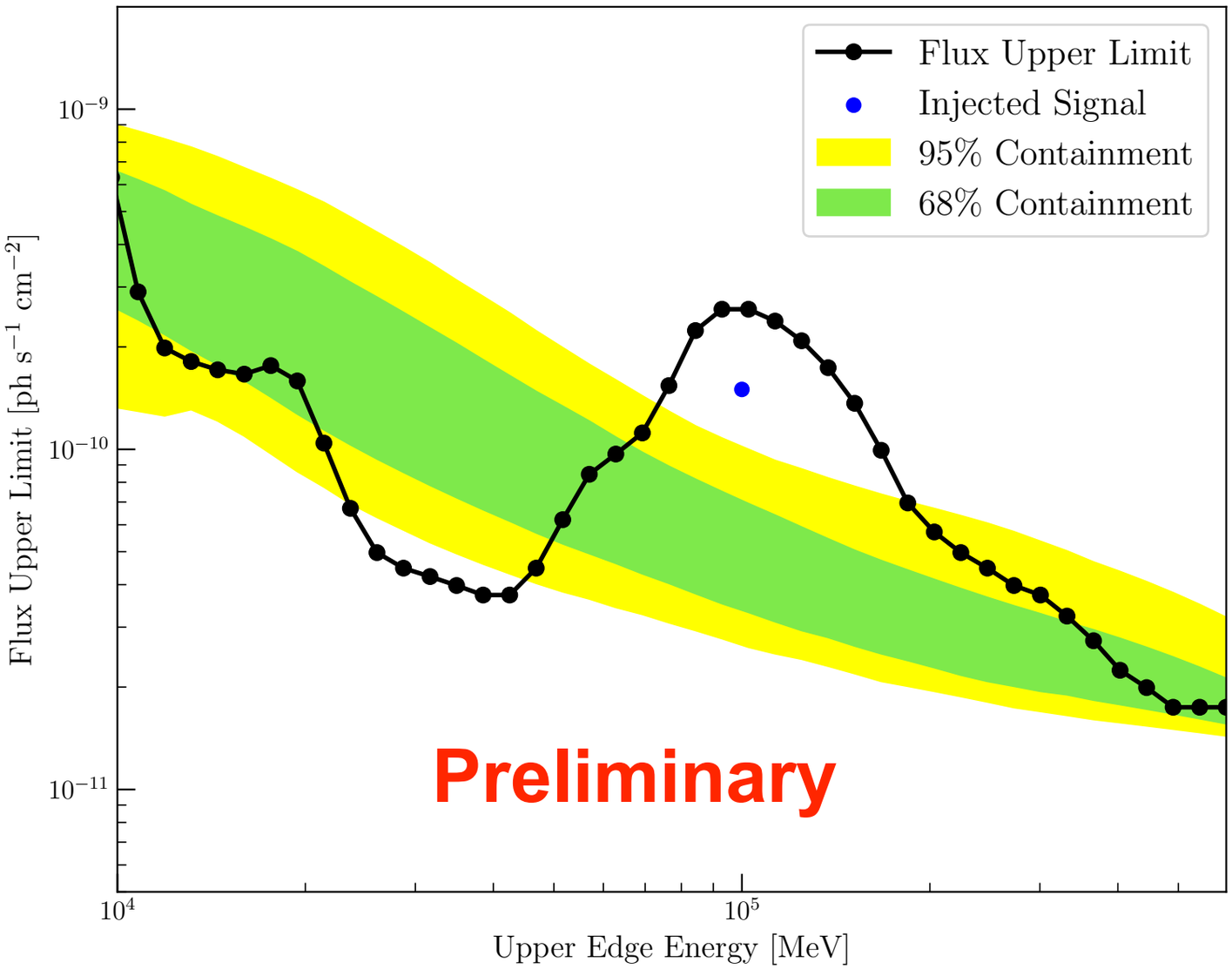

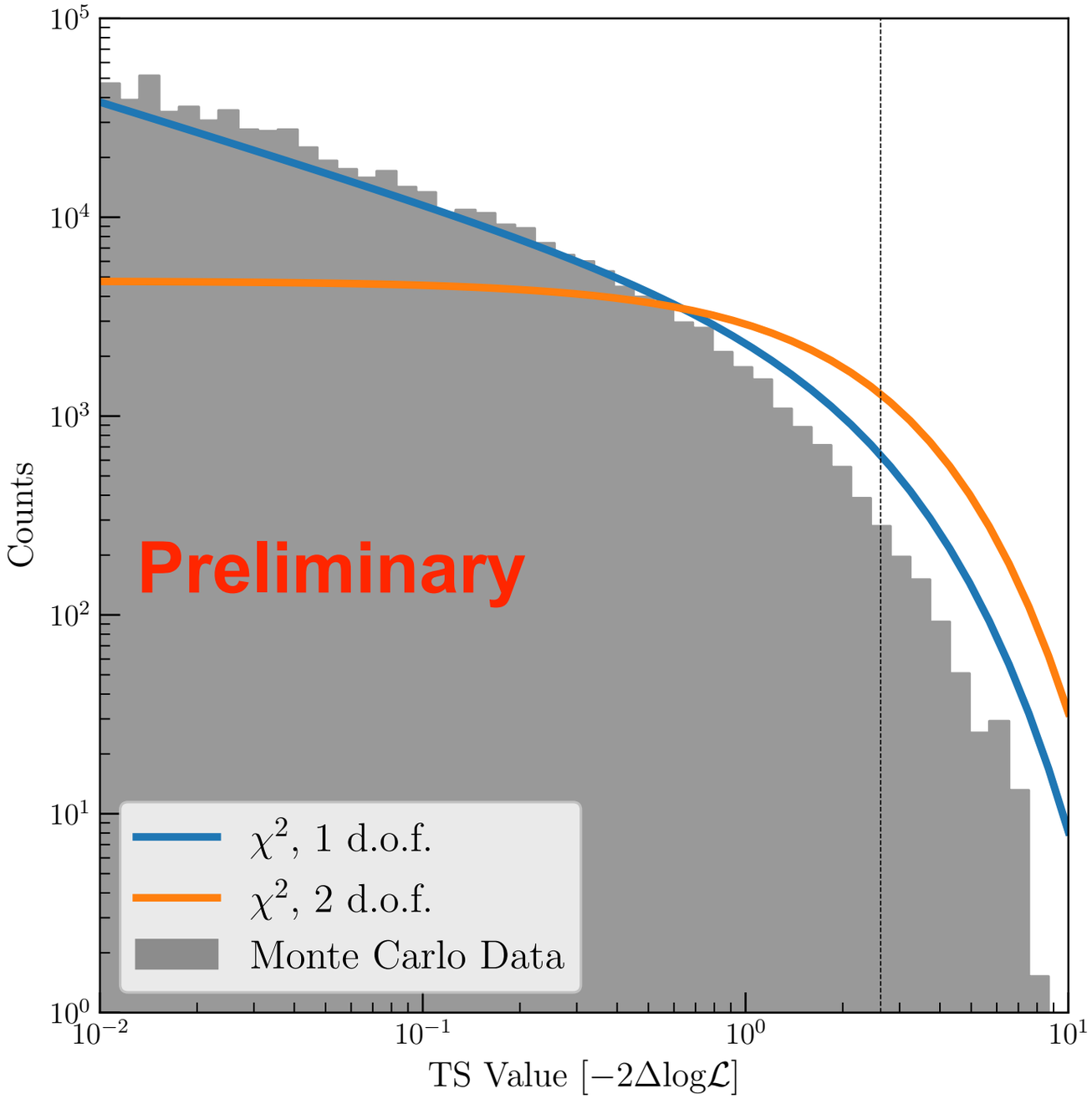
Counts
TS Value $[-2\Delta\log\mathcal{L}]$
Preliminary
$\chi^2$, 1 d.o.f.
$\chi^2$, 2 d.o.f.
Monte Carlo Data
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
$10^{-2}$
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$10^0$
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