The Primary Importance of Secondaries

MeV Dark Matter in Y-rays

Richard Bartels

r.t.bartels@uva.nl

With: Daniele Gaggero & Christoph Weniger

GRAPPA

GRavitation AstroParticle Physics Amsterdam

UNIVERSITY OF AMSTERDAM

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TeVPA 2016, Cern

Introduction

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Why MeV Dark Matter?

- Fermi-LAT has done great for indirect DM searches in the GeV regime
- *"MeV Gap"*

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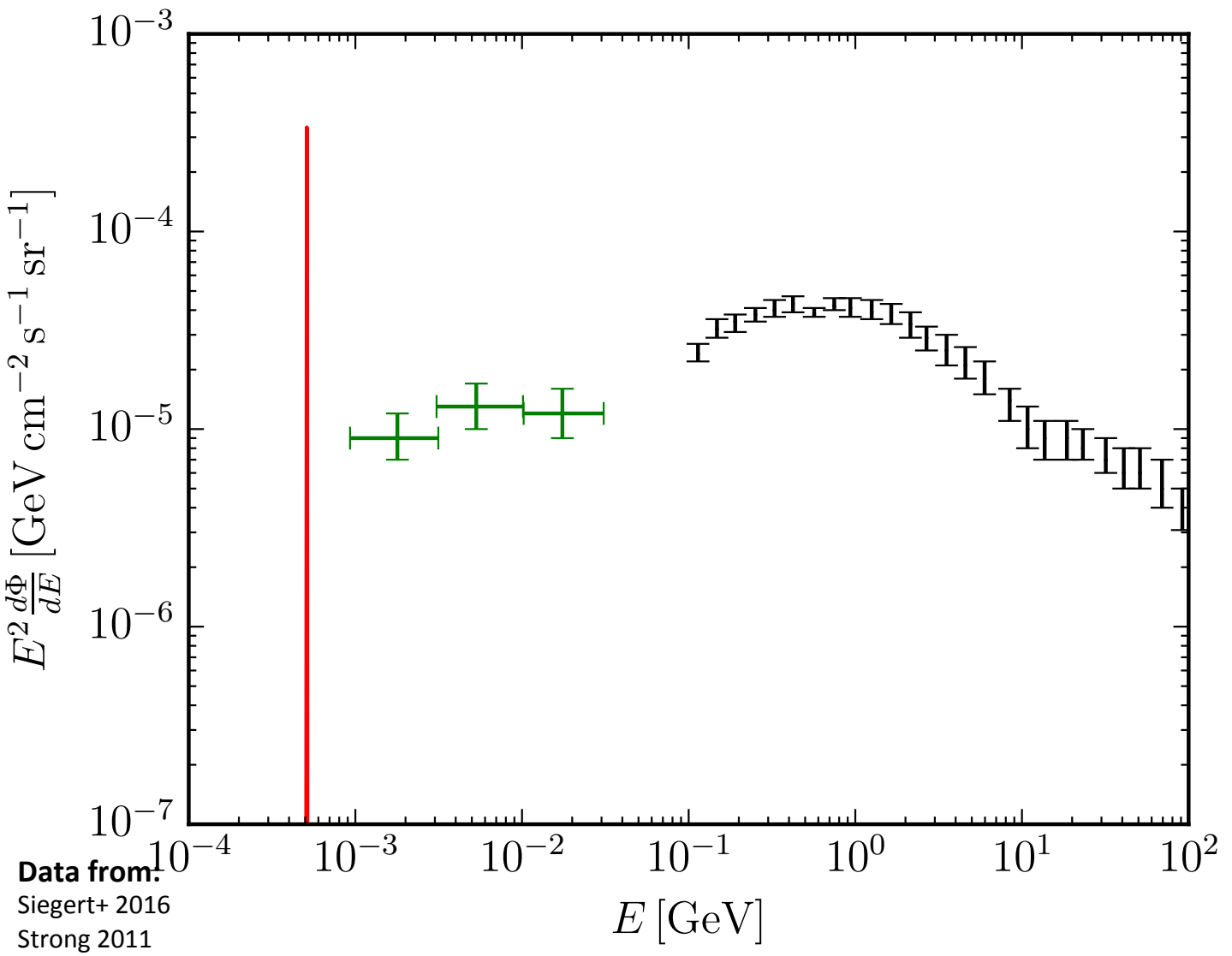
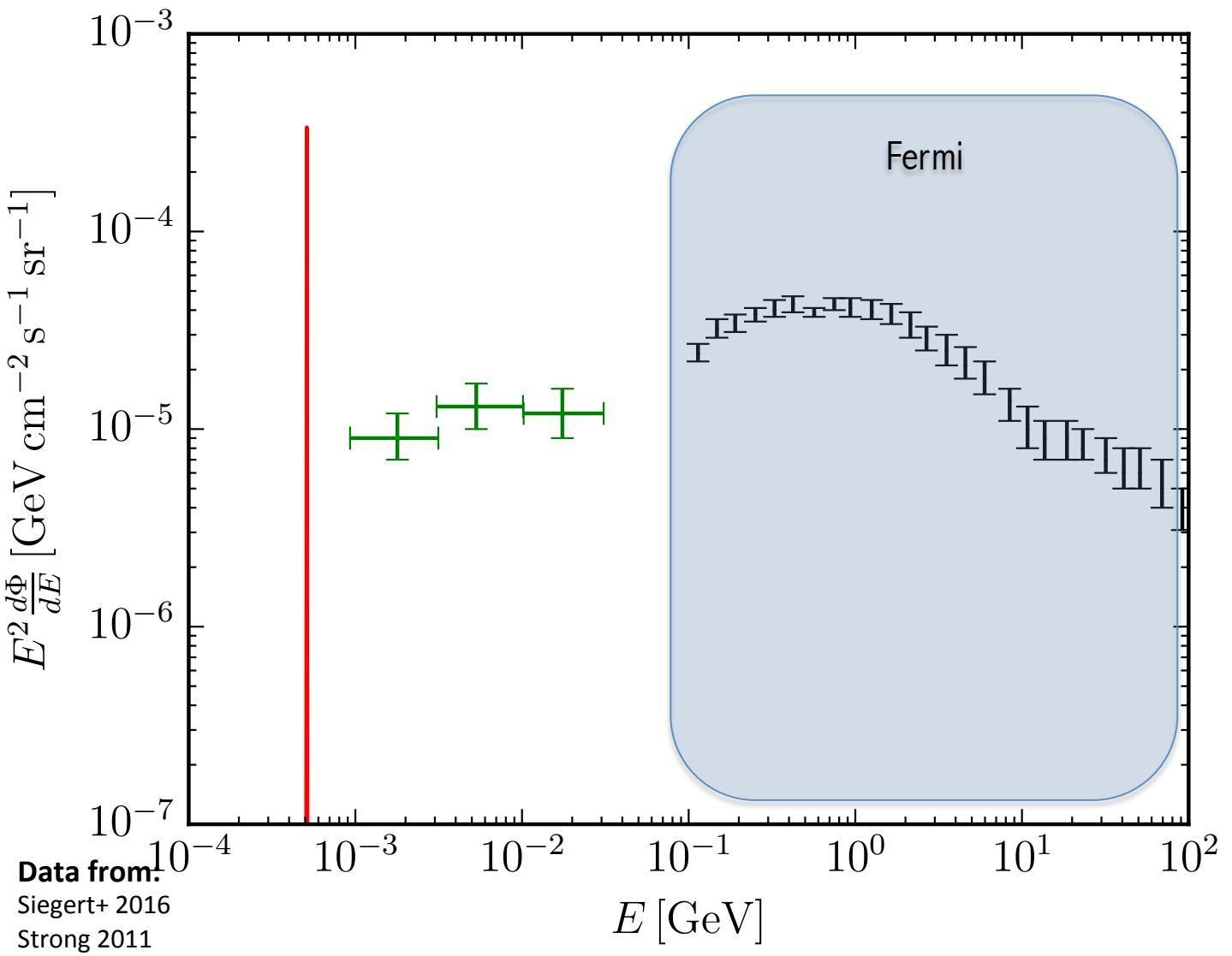
Why Secondaries?

- Because they provide the dominant signal!

The *MeV Gap*


10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
$E^2 \frac{d\Phi}{dE}$ [GeV cm^{-2} s^{-1} sr^{-1}]
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
E [GeV]
Data from:
Siegert+ 2016
Strong 2011

The *MeV Gap*


Fermi
$E^2 \frac{d\Phi}{dE}$ [GeV cm^{-2} s^{-1} sr^{-1}]
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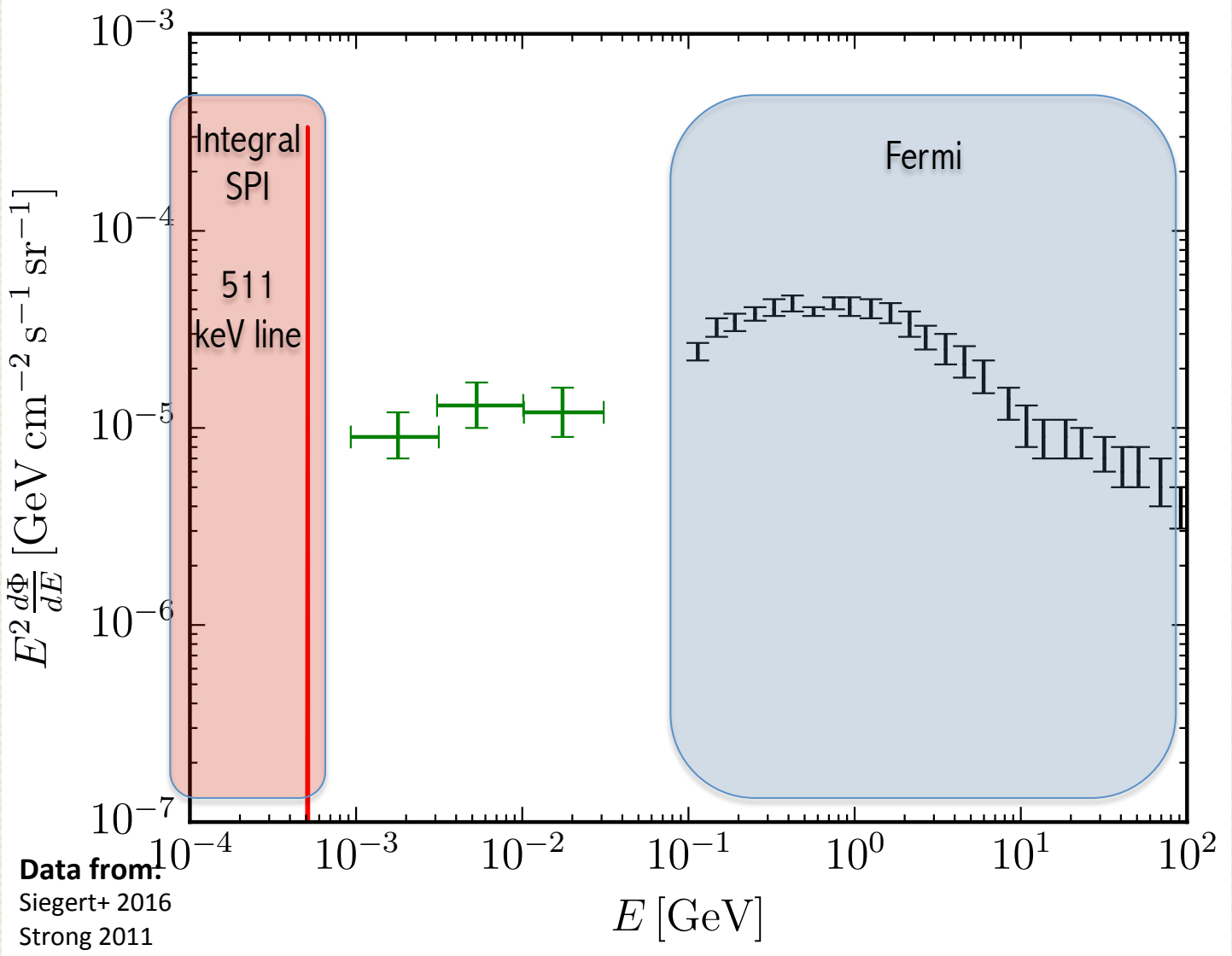
Integral
SPI
511
keV line
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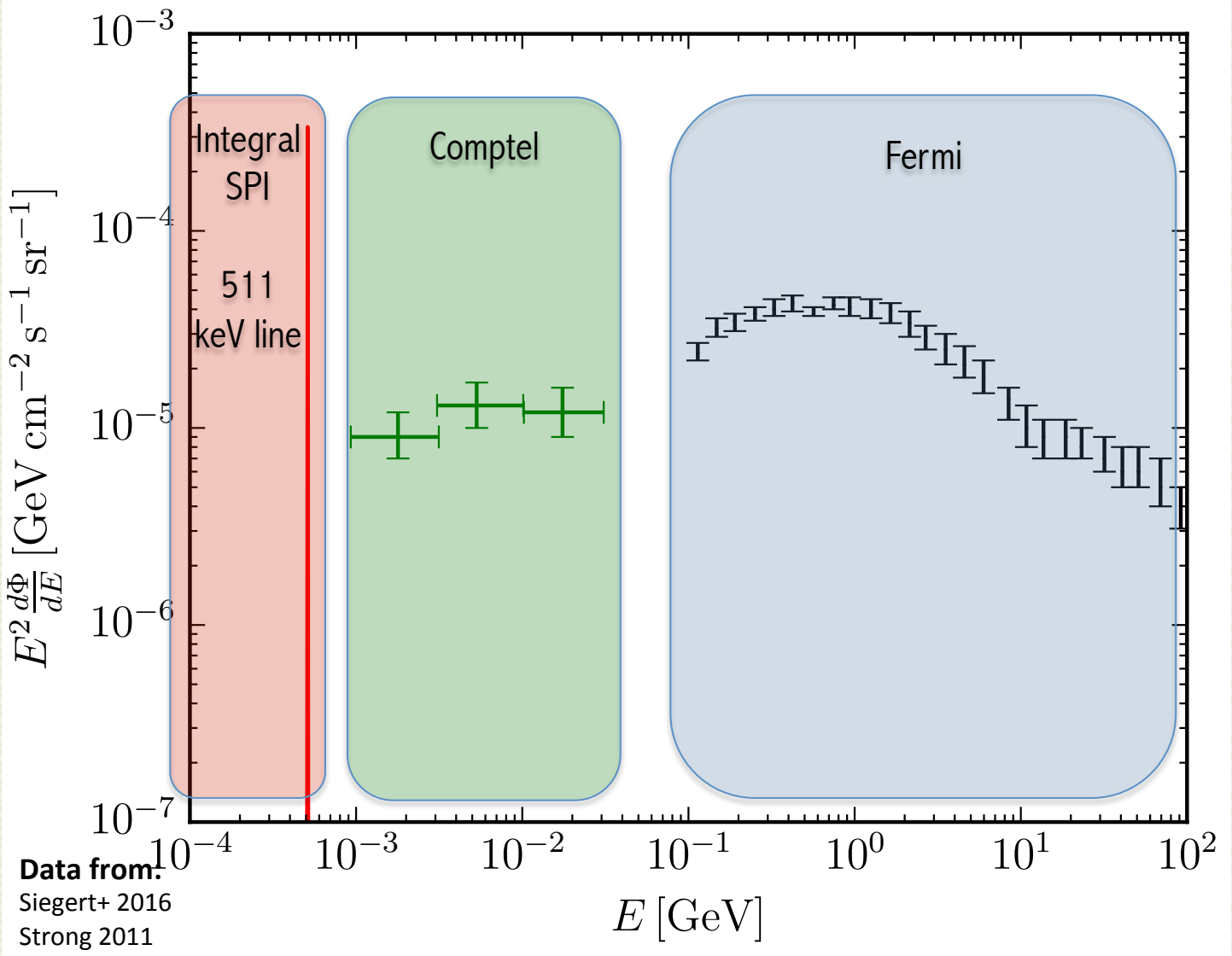
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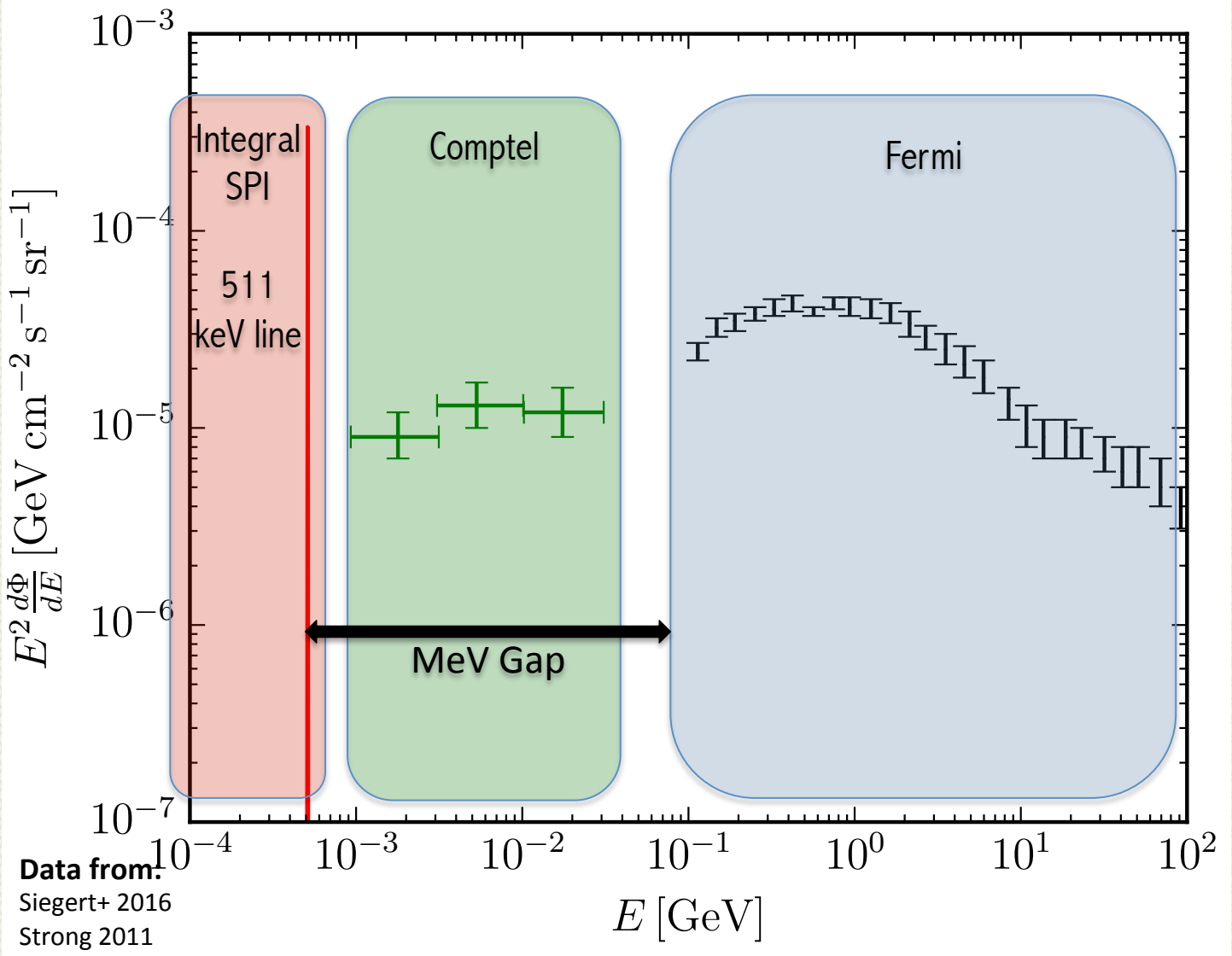


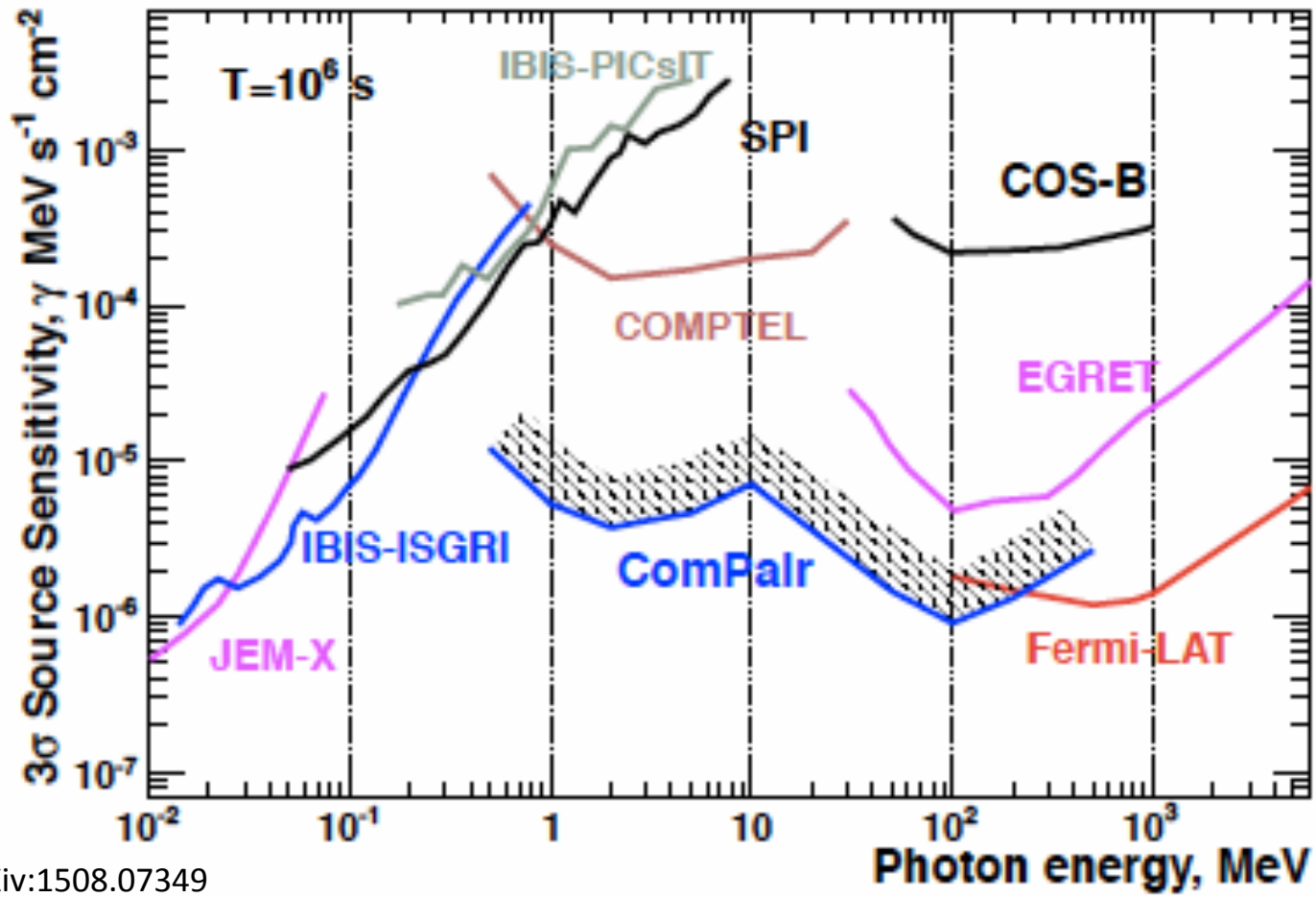
Data from:
Siegert+ 2016
Strong 2011

Next generation instruments

E.g.:

- E-ASTROGAM (http://astrogam.iaps.inaf.it/)
  - ComPair (*arXiv:1508.0734*)

Next generation instruments



arXiv:1508.07349

MeV Dark Matter Models

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Not many channels kinematically available

- Photons
- Pions (>140 MeV) *(Boddy & Kumar, 2015)*
- Neutrinos
- Muons (>105 MeV)
- Electrons & Positrons

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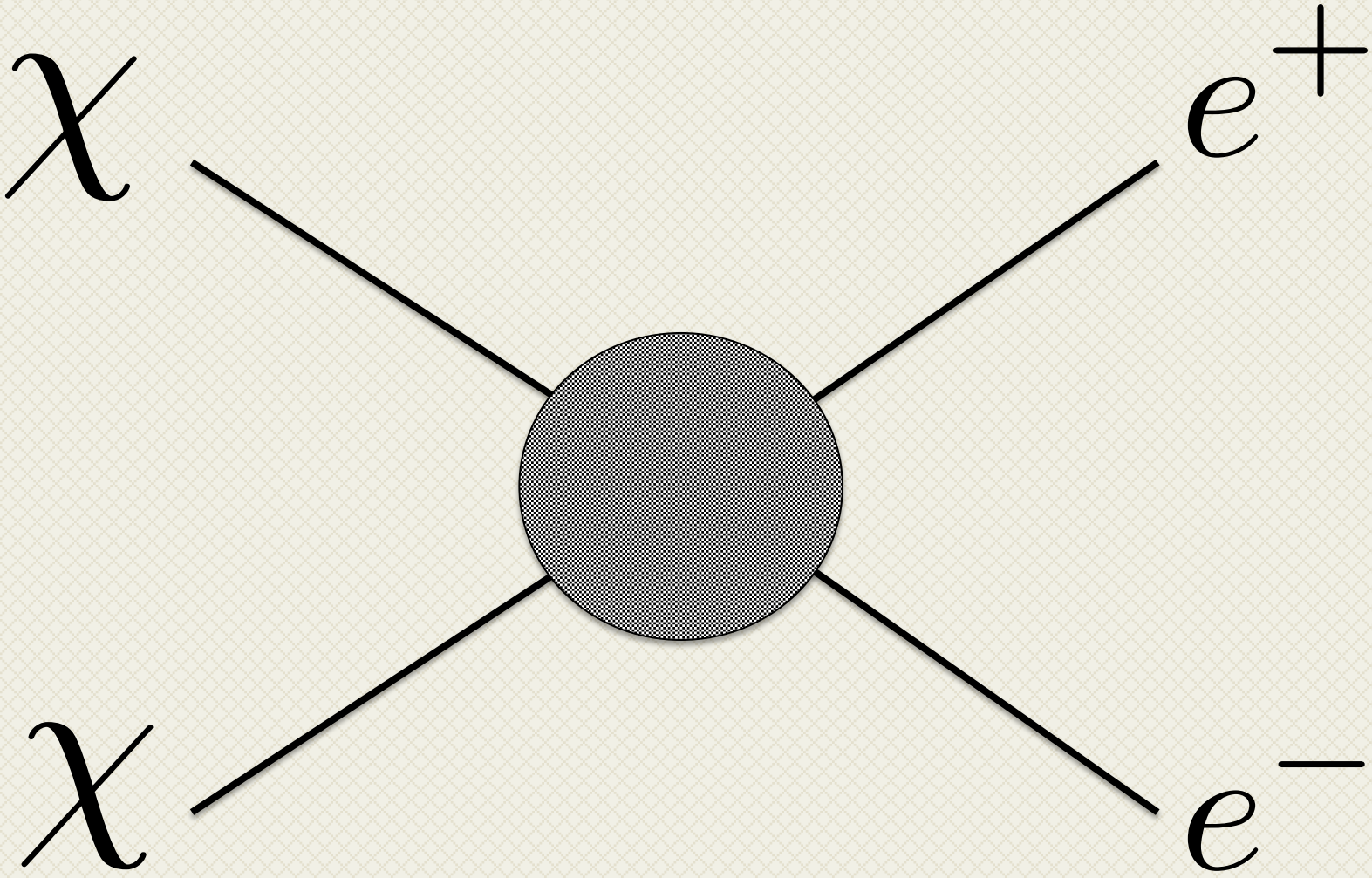

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$$\chi\chi \to e^+e^-$$

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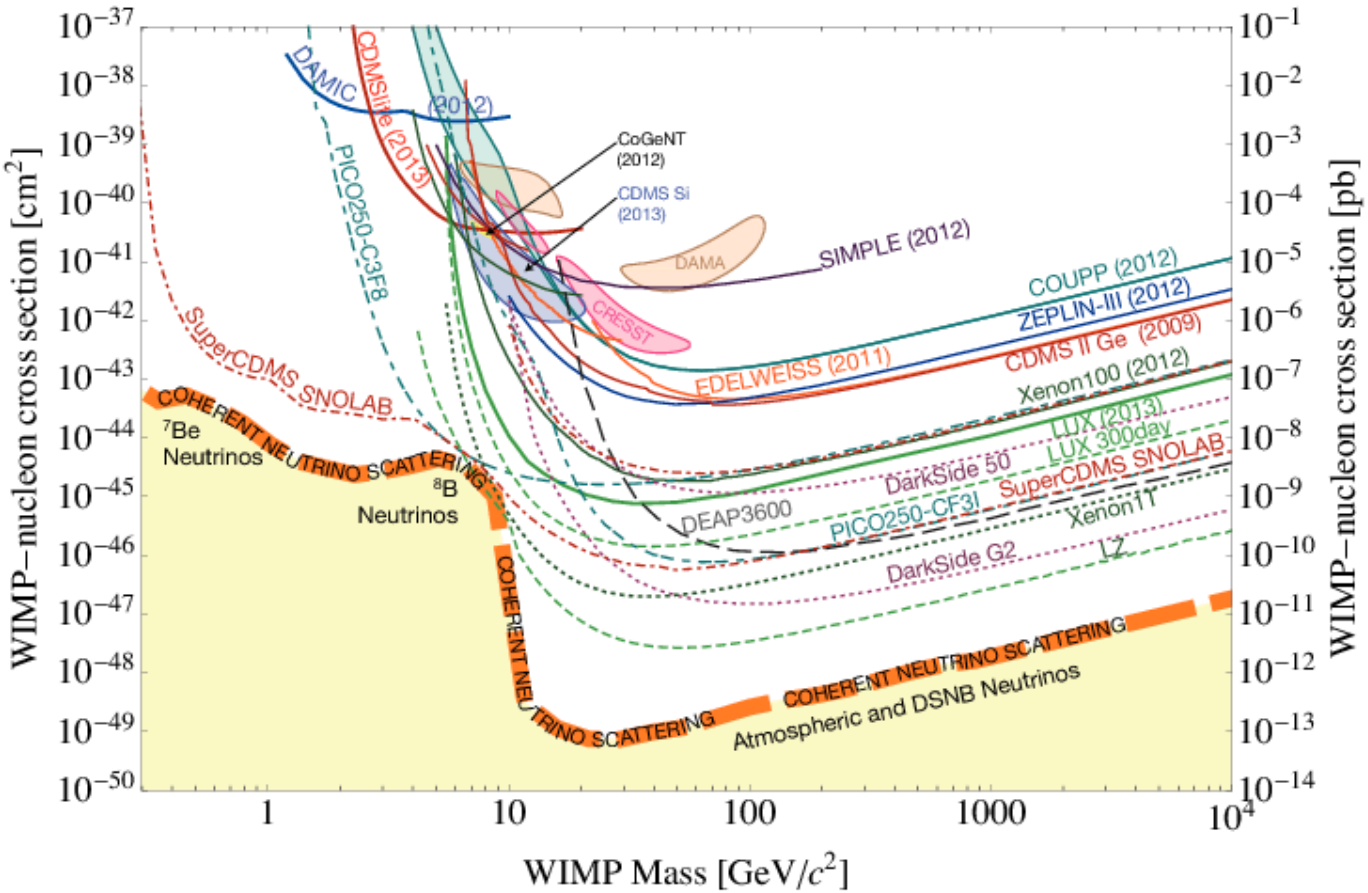
1. MeV dark matter is difficult to detect in direct detection experiments

Why this channel

1.



Cooley (2014)

Why this channel

$$\chi\chi \to e^+e^-$$

1. MeV dark matter is difficult to detect in direct detection experiments
2. Solar wind prevents “direct detection” of electrons & positrons

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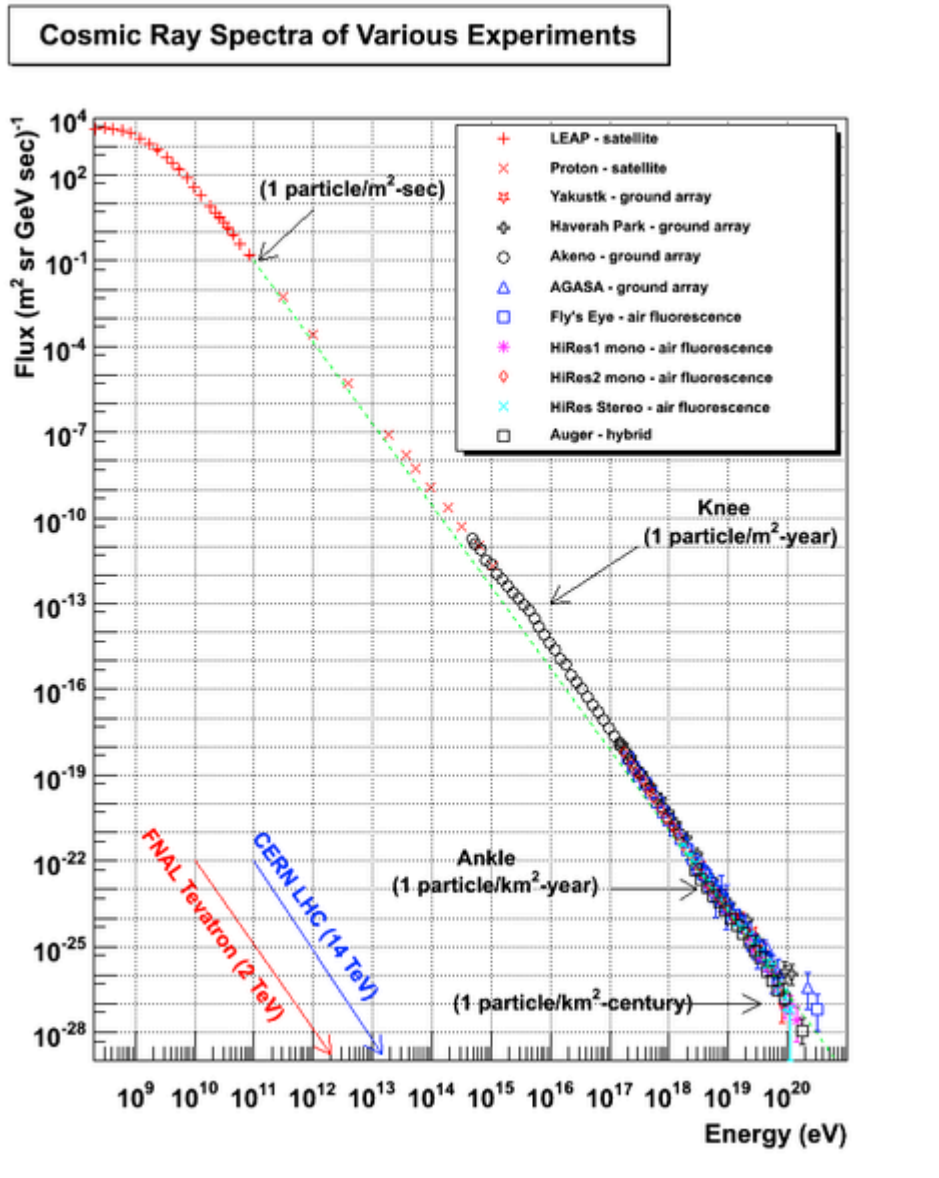
1. MeV da ect in direct c
2. Solar w ion" of electro



Why this channel

$$\chi\chi \to e^+e^-$$

1. MeV dark matter is difficult to detect in direct detection experiments
2. Solar wind prevents “direct detection” of electrons & positrons
3. How far can we go with gamma-rays??

A bit of history: DM & the 511 keV line

- 511 keV (e^+e^- annihilation line); hinted at since the late 70s (Review: Prantzos+ 2011)

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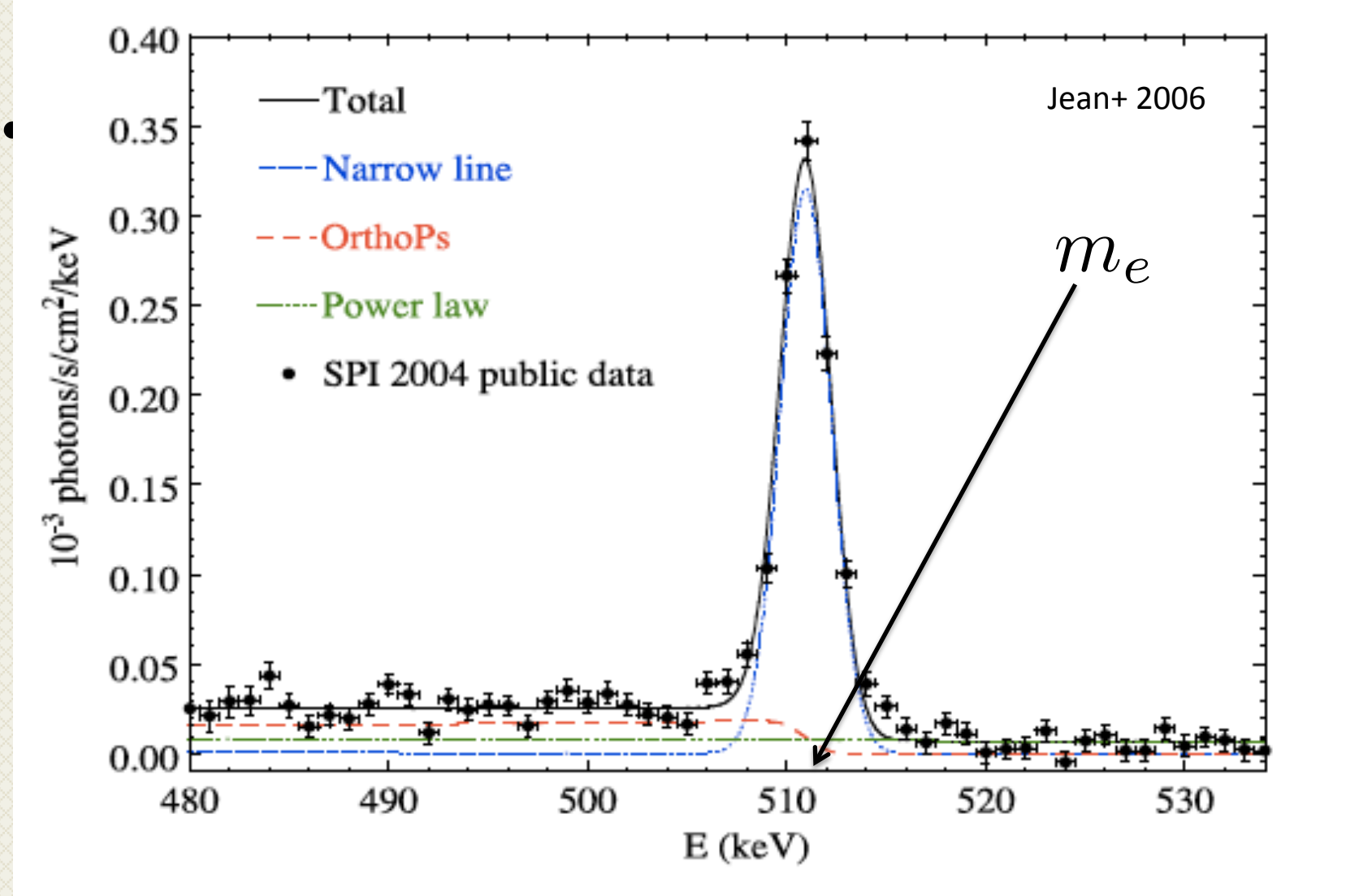
DM & the 511 keV line



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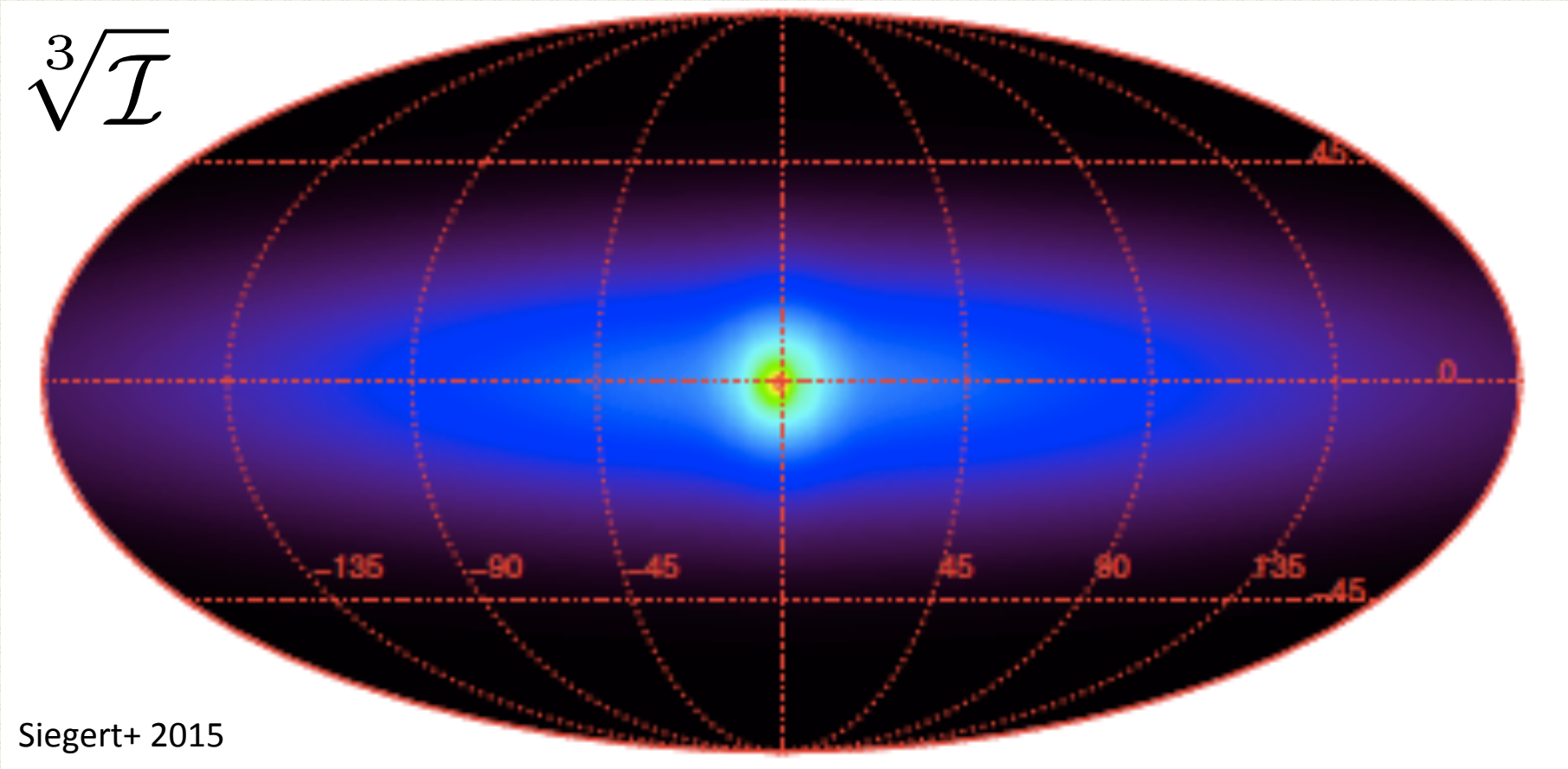

Siegert+ 2015

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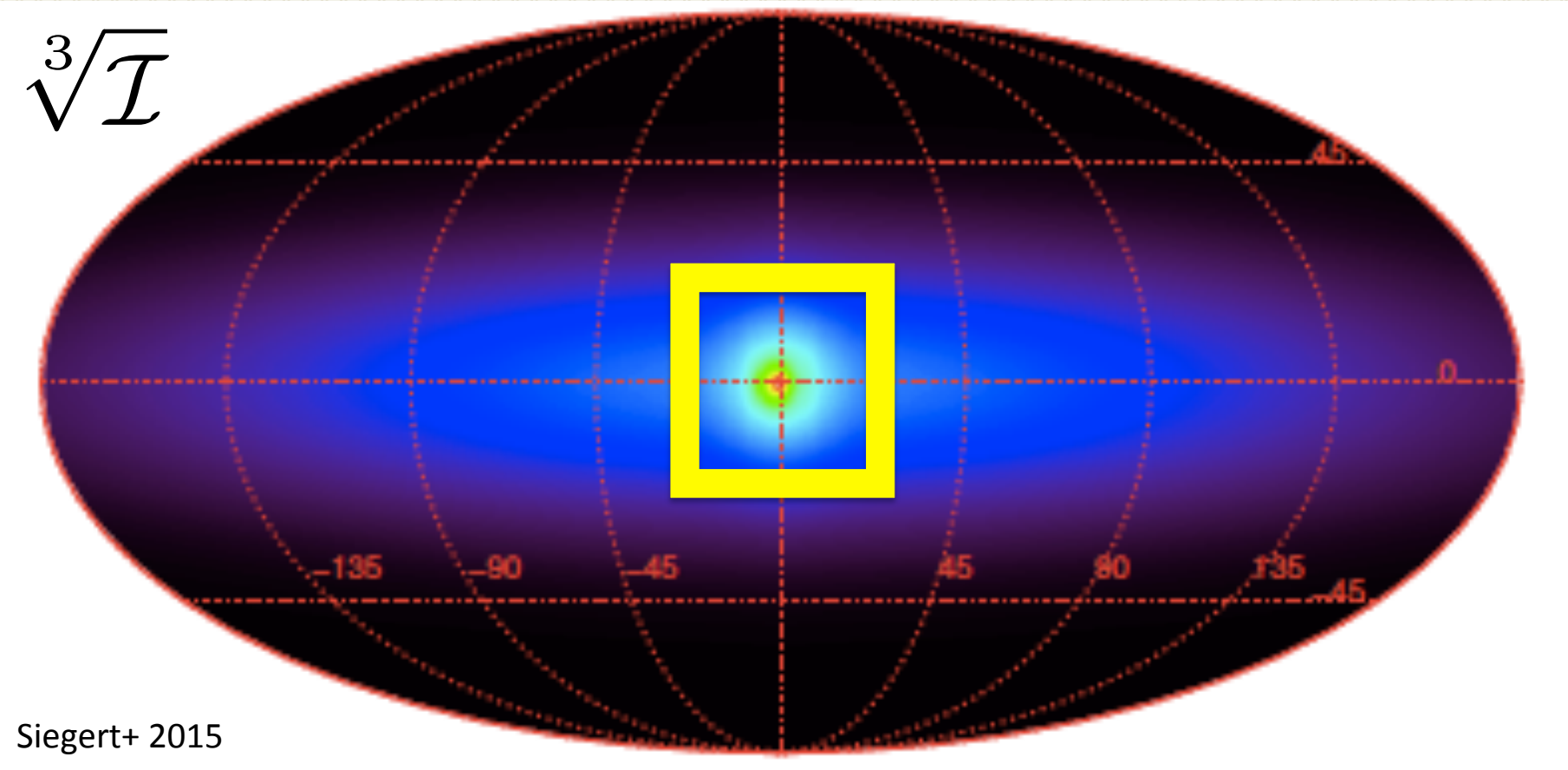

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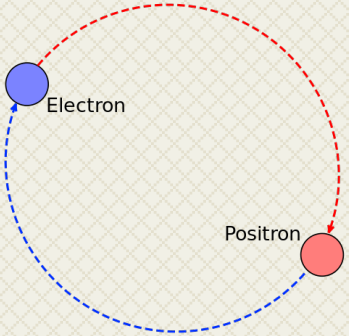
- INTEGRAL/SPI measurement (Knödlseder+ 2005, Weidenspointner+ 2006, Siegert+ 2015)
- Strong Bulge component → DM?

A bit on positron annihilation

1. At low energies $(E_k \sim 100\,\mathrm{eV})$
   Positronium formation
   – *Para-positronium:* $\mathrm{p\text{–}Ps} \to \gamma\gamma$
   – *Ortho-positronium:* $\mathrm{o\text{–}Ps} \to \gamma\gamma\gamma$
   Line: all p-PS!!



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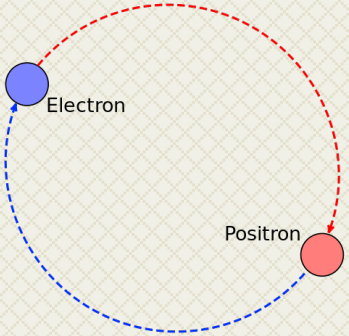

2. Direct or *In-flight* Annihilation (IfA)

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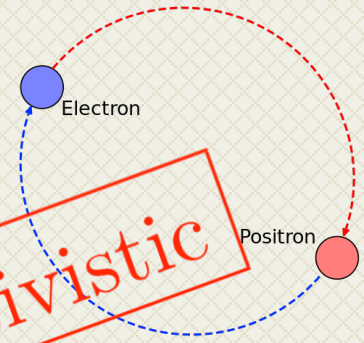


e^+ are non-relativistic

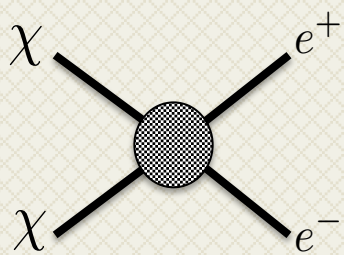
2. Direct or *In-flight* Annihilation (IfA)

$$e^+e^- \to \gamma\gamma$$

This constrains the injection energy

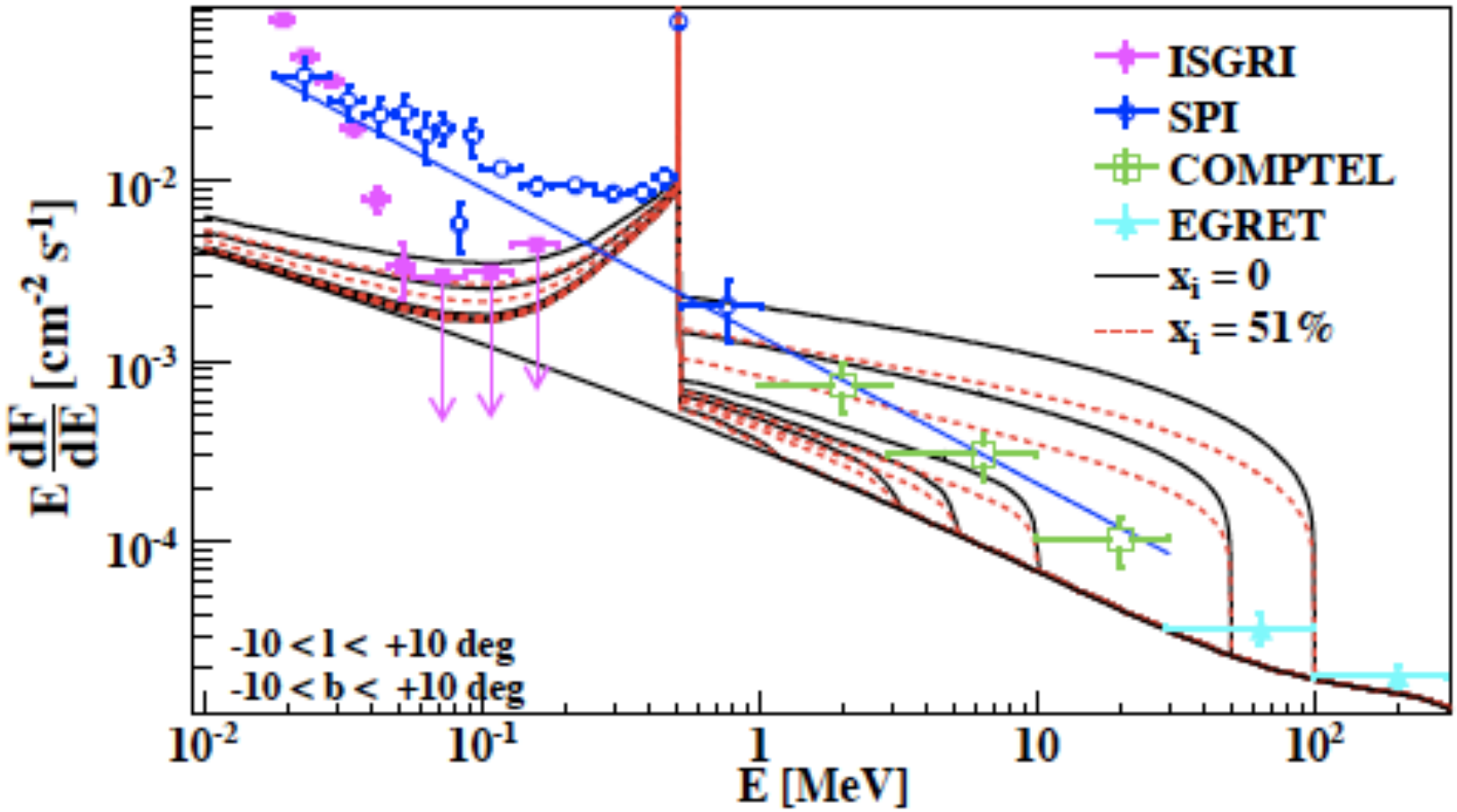
- *Beacom & Yüksel (2005)* and *Sizun+ (2006):*

  if all bulge 511-keV emission comes from



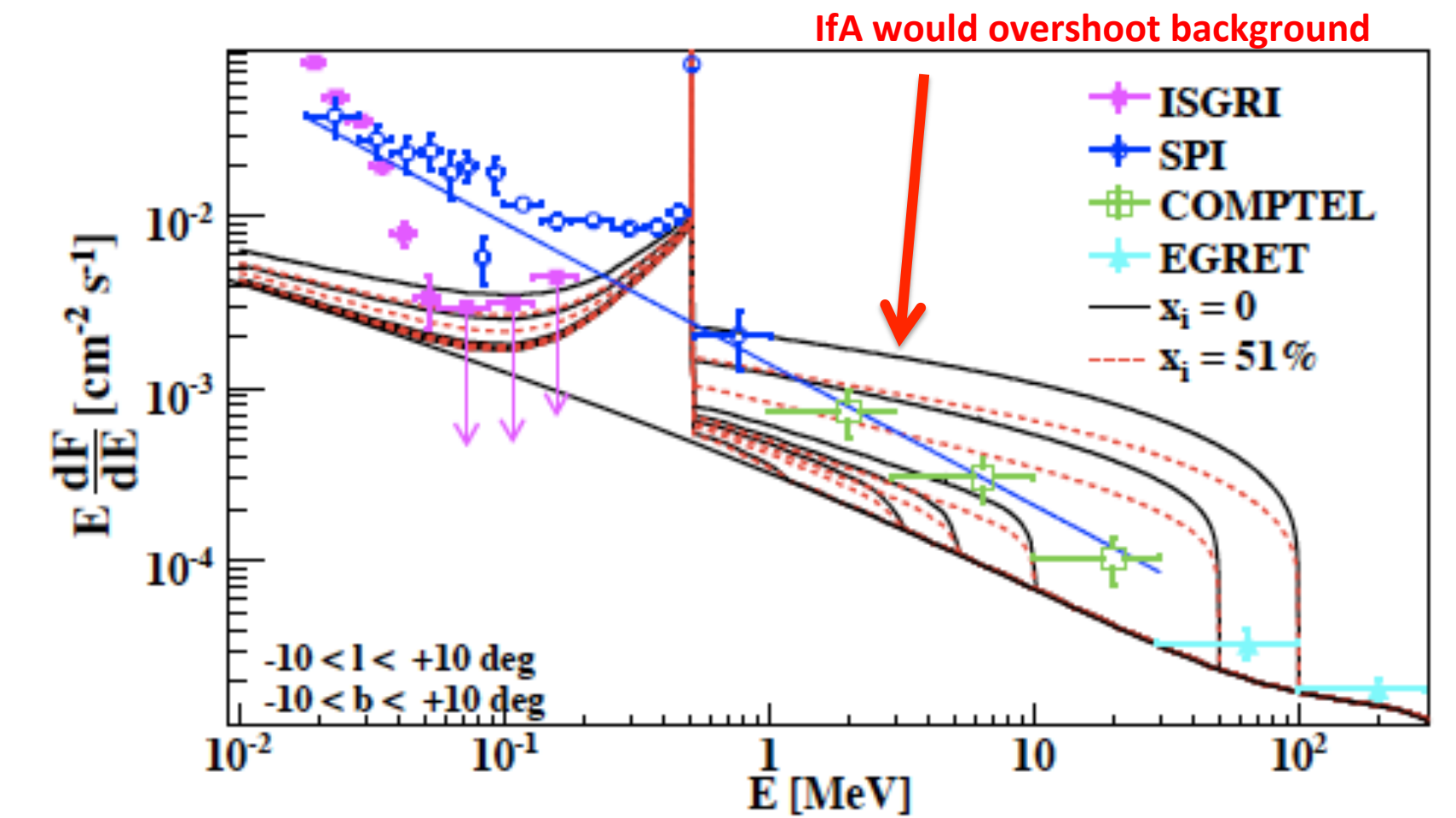
then, $M_\chi \lesssim 10\,\mathrm{MeV}$

This constrains the injection energy



Sizun+ 2006

This constrains the injection energy



Sizun+ 2006

511 keV summary

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1. Difficult to explain with DM
   - Low injection energy required
   - Strong constraints from CMB (Wilkinson+ 2016)

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   - Low injection energy required
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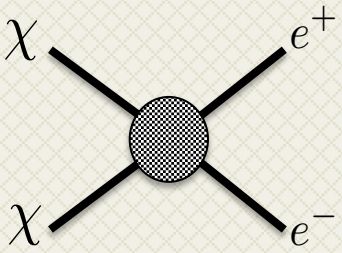
2. Other sources (probably a few contribute substantially):
   - Radioactive isotopes (present in the disk)
   - Microquasars (Siegert+ 2016)
   - Etc…

So, how to detect: 

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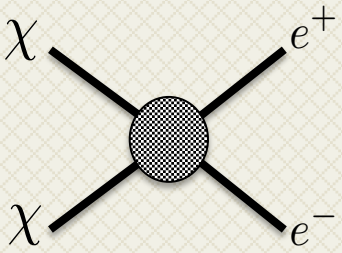
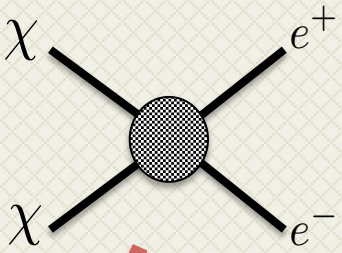
So, how to detect:  ?

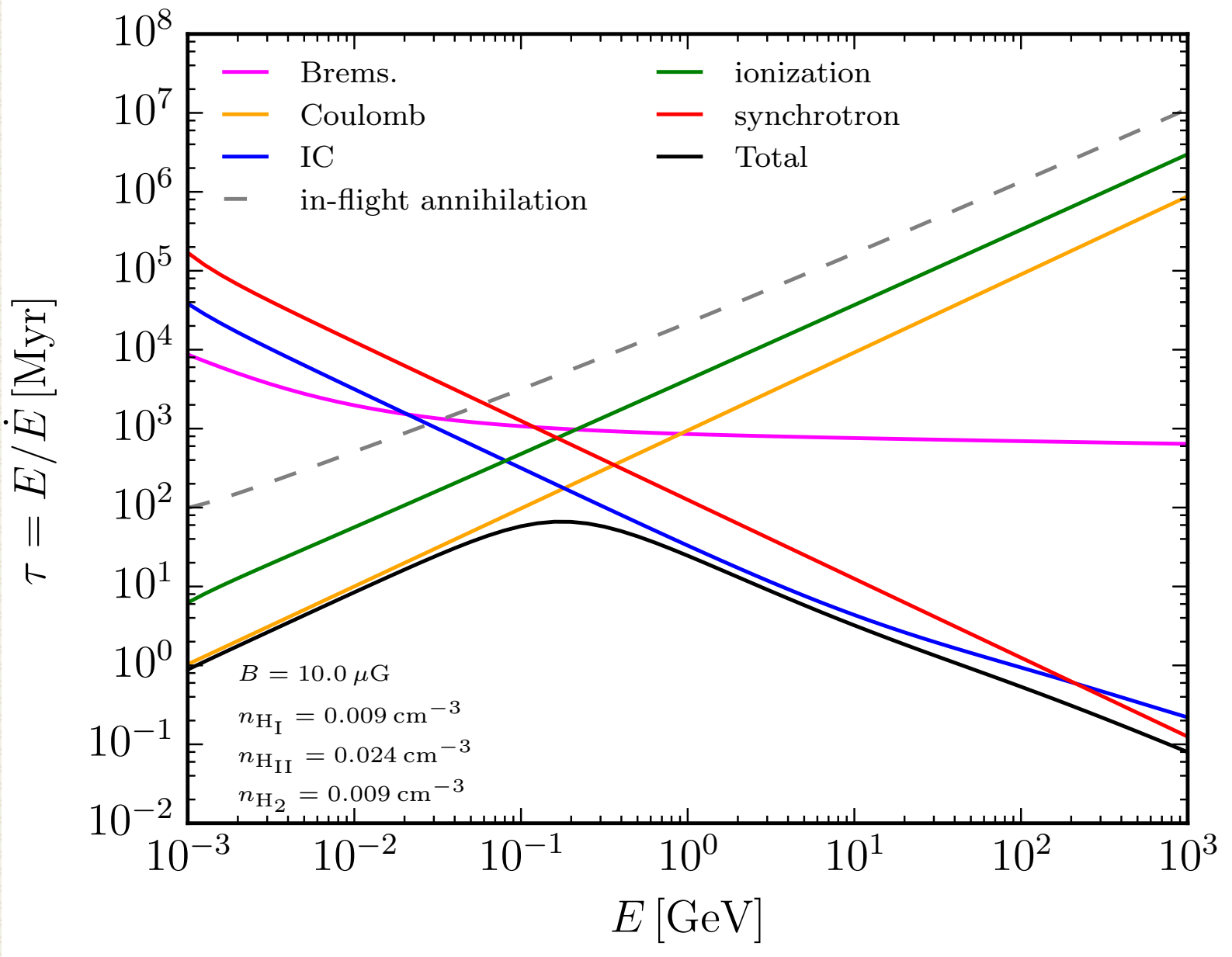
1. e^+e^- injection: secondary emission
   - Can this have distinctive spectral features, e.g. like from IfA??

So, how to detect:  ?

1. e^+e^- injection: secondary emission
   - Can this have distinctive spectral features, e.g. like from IfA??

and some other models ☺

Timescales


Brems.
Coulomb
IC
in-flight annihilation
ionization
synchrotron
Total
$B = 10.0\,\mu\mathrm{G}$
$n_{\mathrm{H_I}} = 0.009\,\mathrm{cm}^{-3}$
$n_{\mathrm{H_{II}}} = 0.024\,\mathrm{cm}^{-3}$
$n_{\mathrm{H_2}} = 0.009\,\mathrm{cm}^{-3}$
$\tau = E/\dot{E}\,[\mathrm{Myr}]$
$E\,[\mathrm{GeV}]$
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
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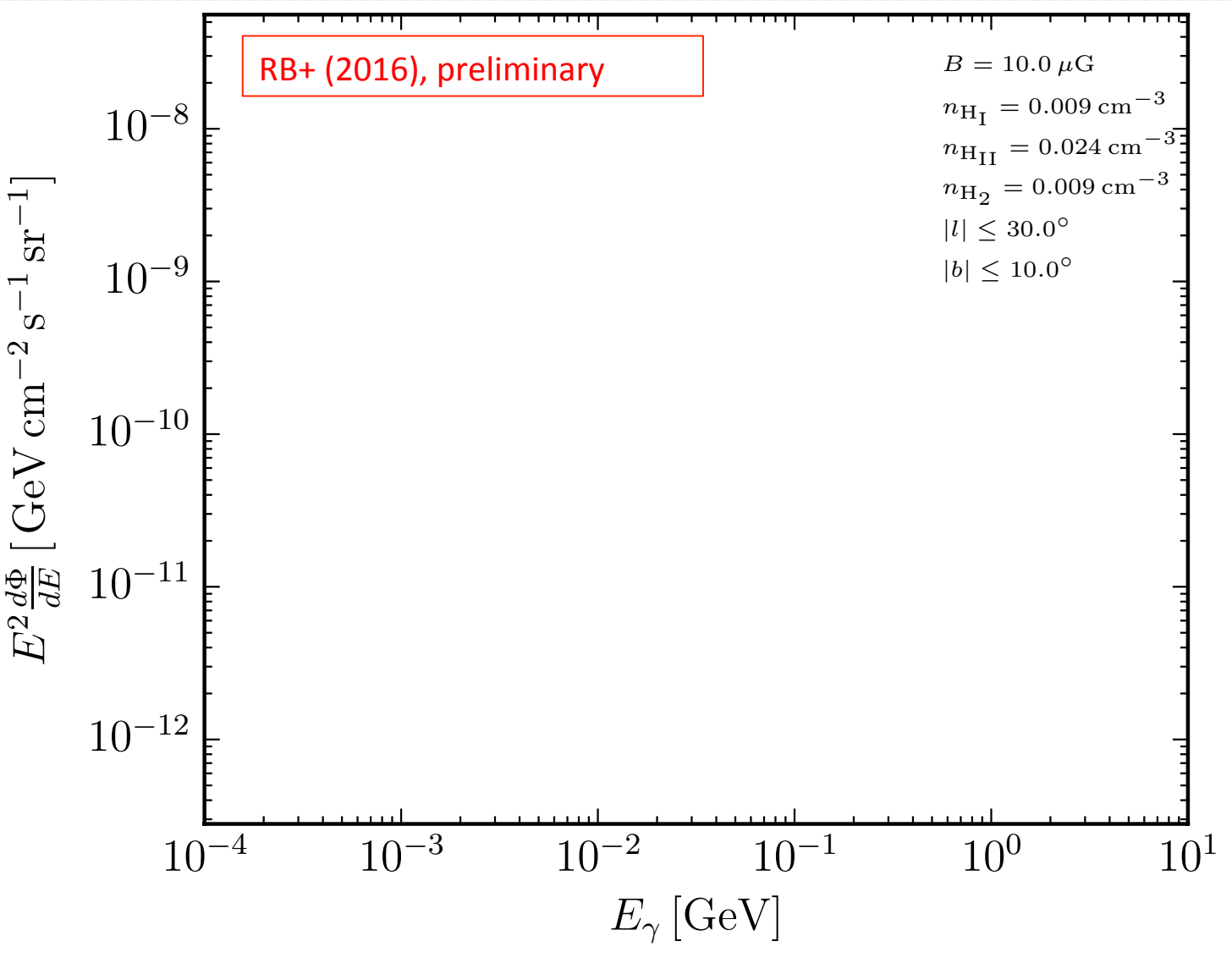
10^{0}
10^{1}
10^{2}
10^{3}

Example: $M_\chi = 100\,\mathrm{MeV}.$



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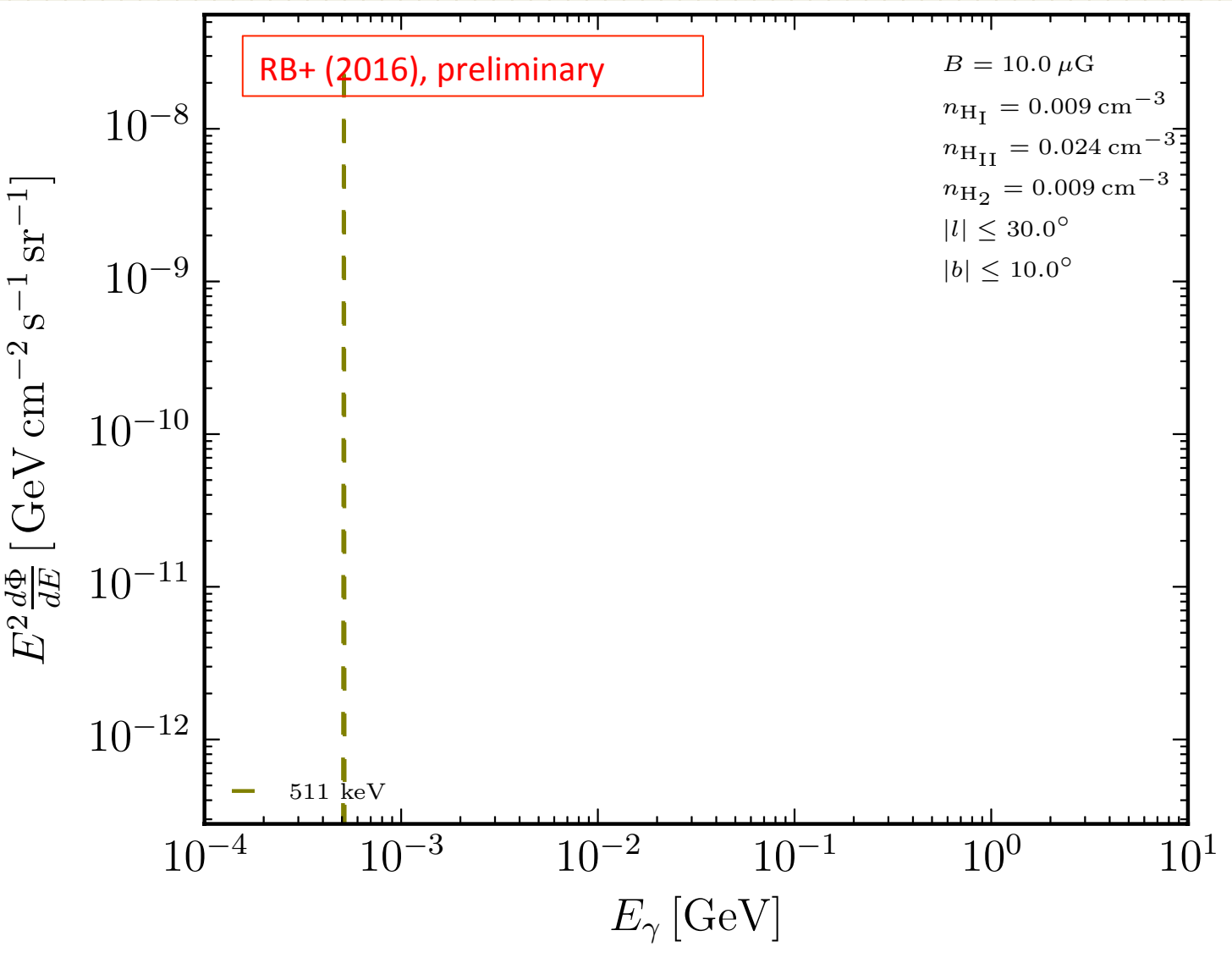

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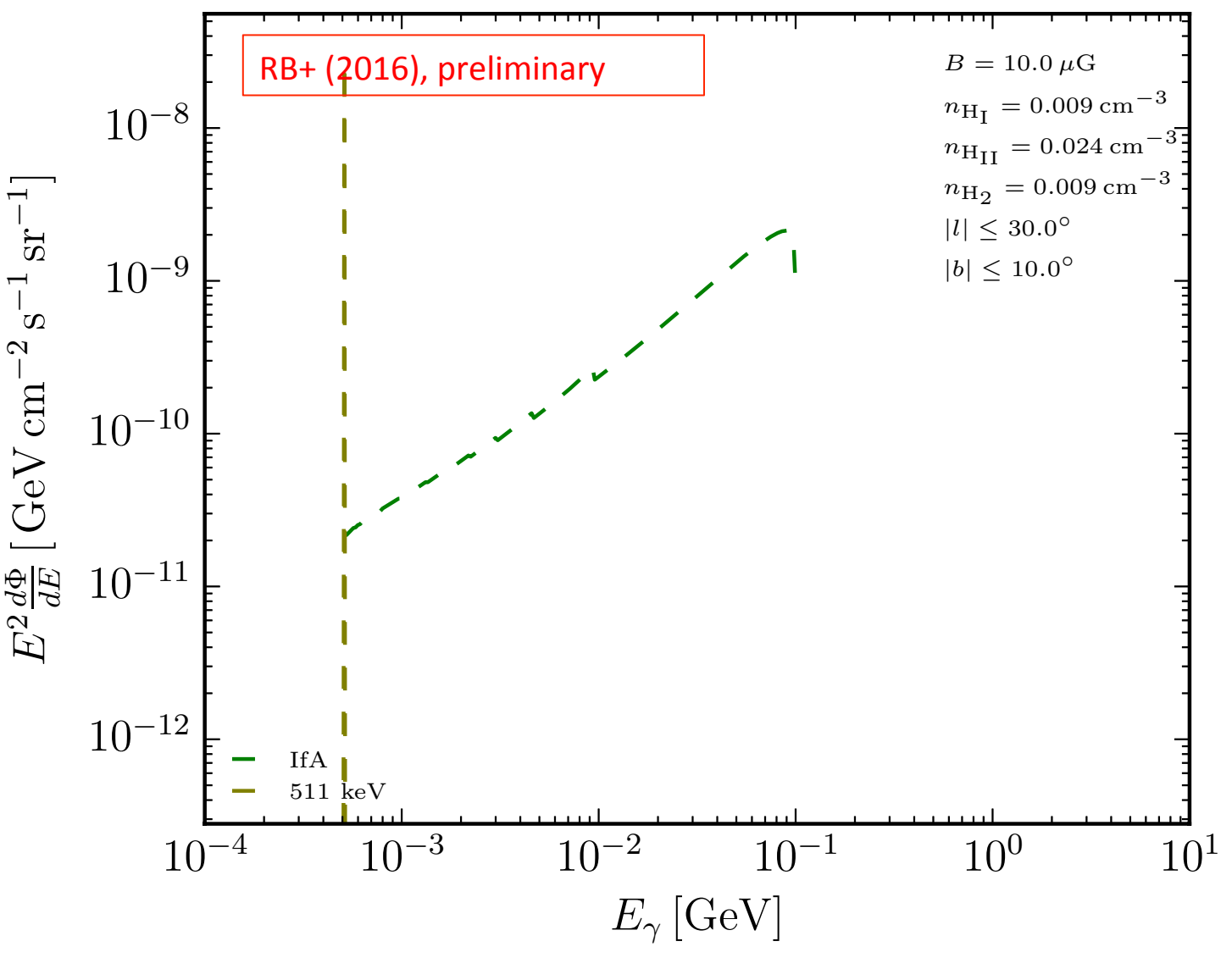

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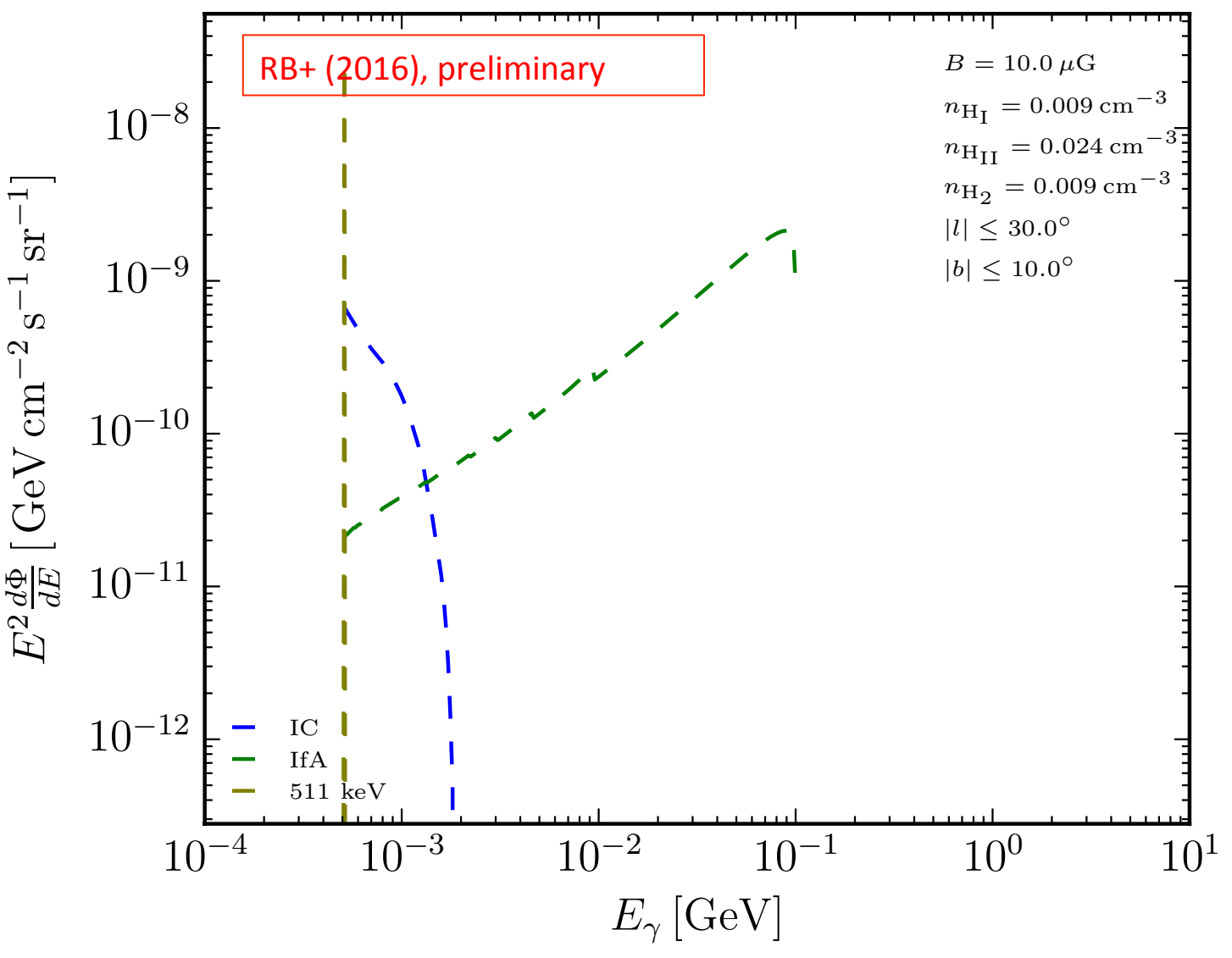

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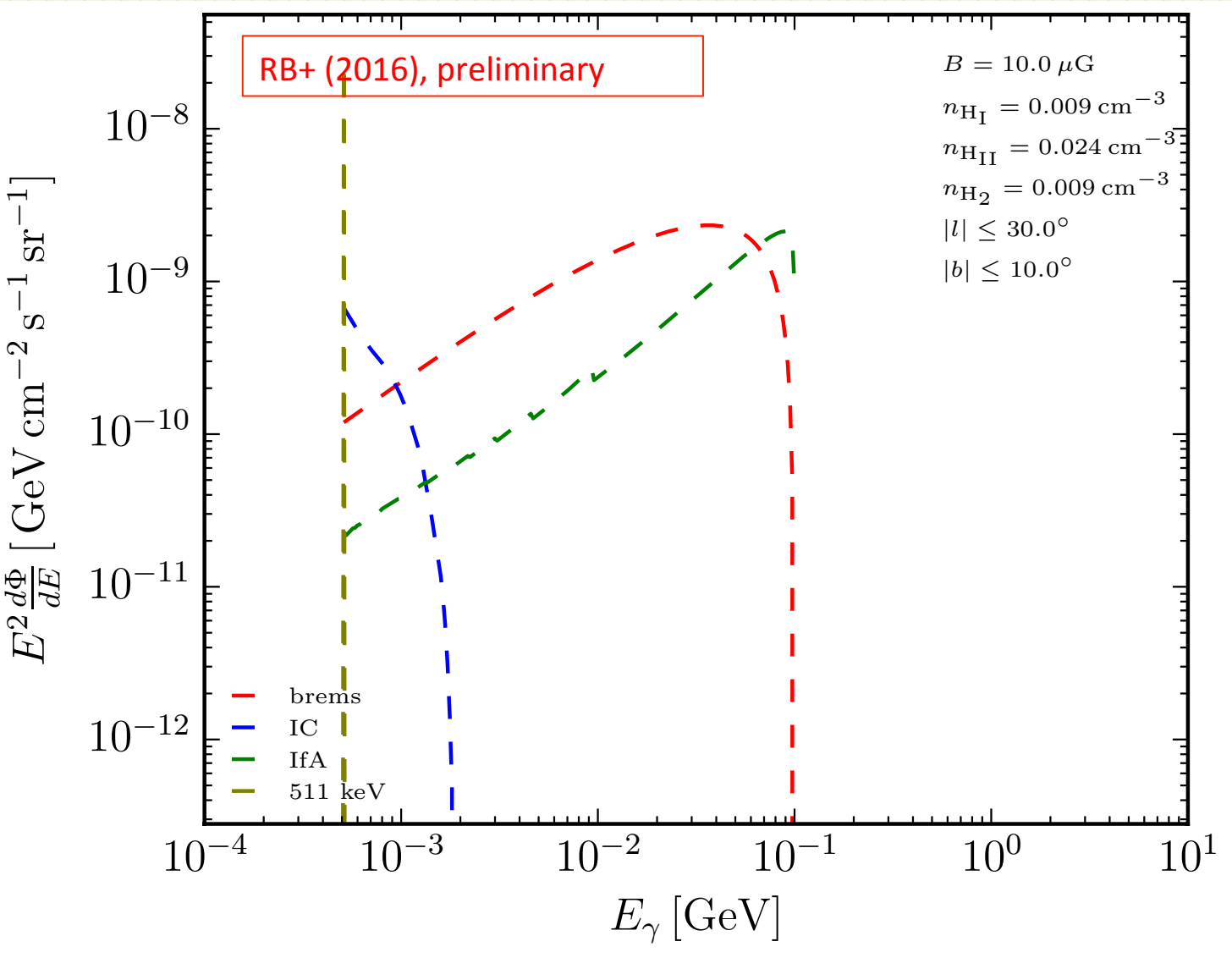

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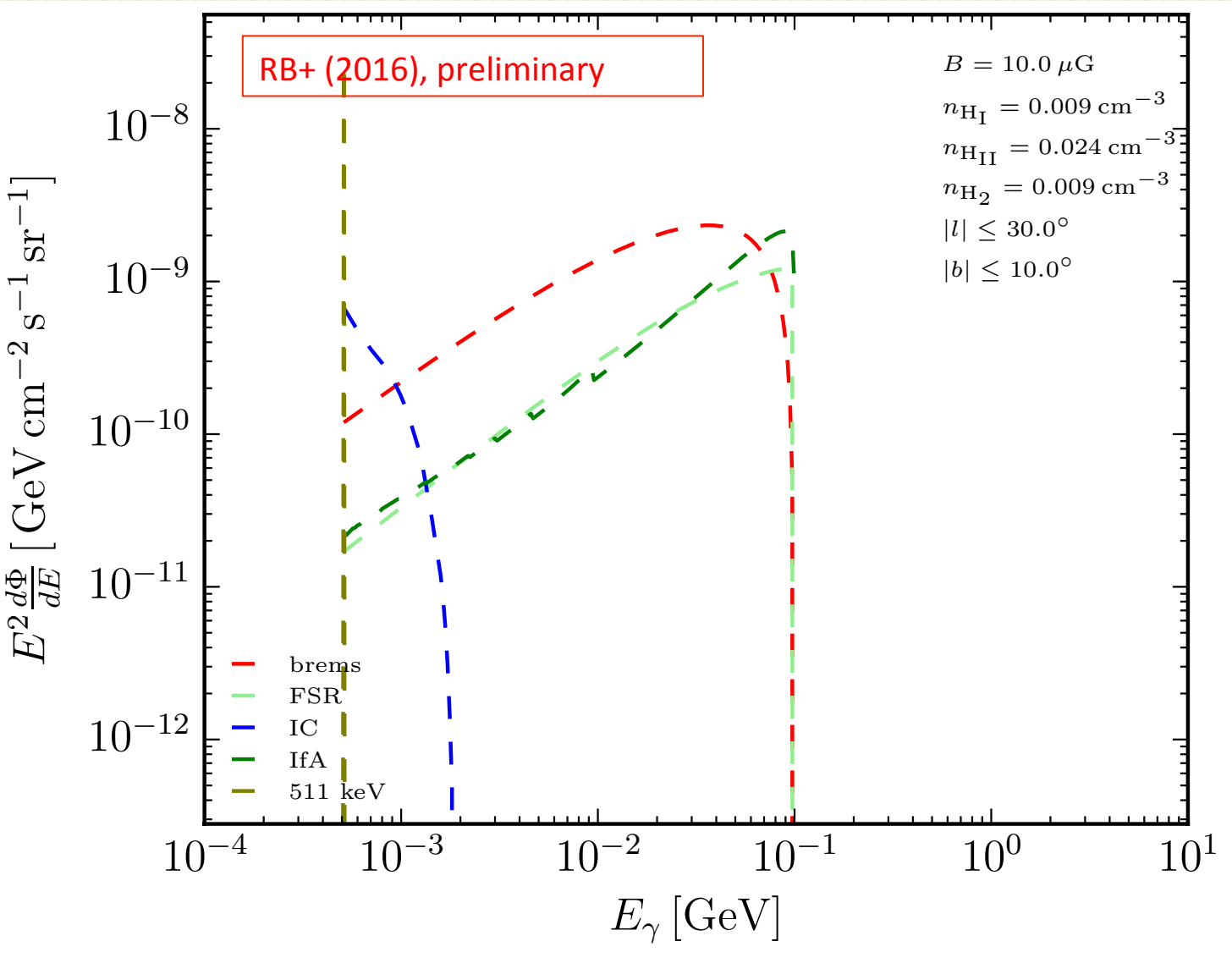

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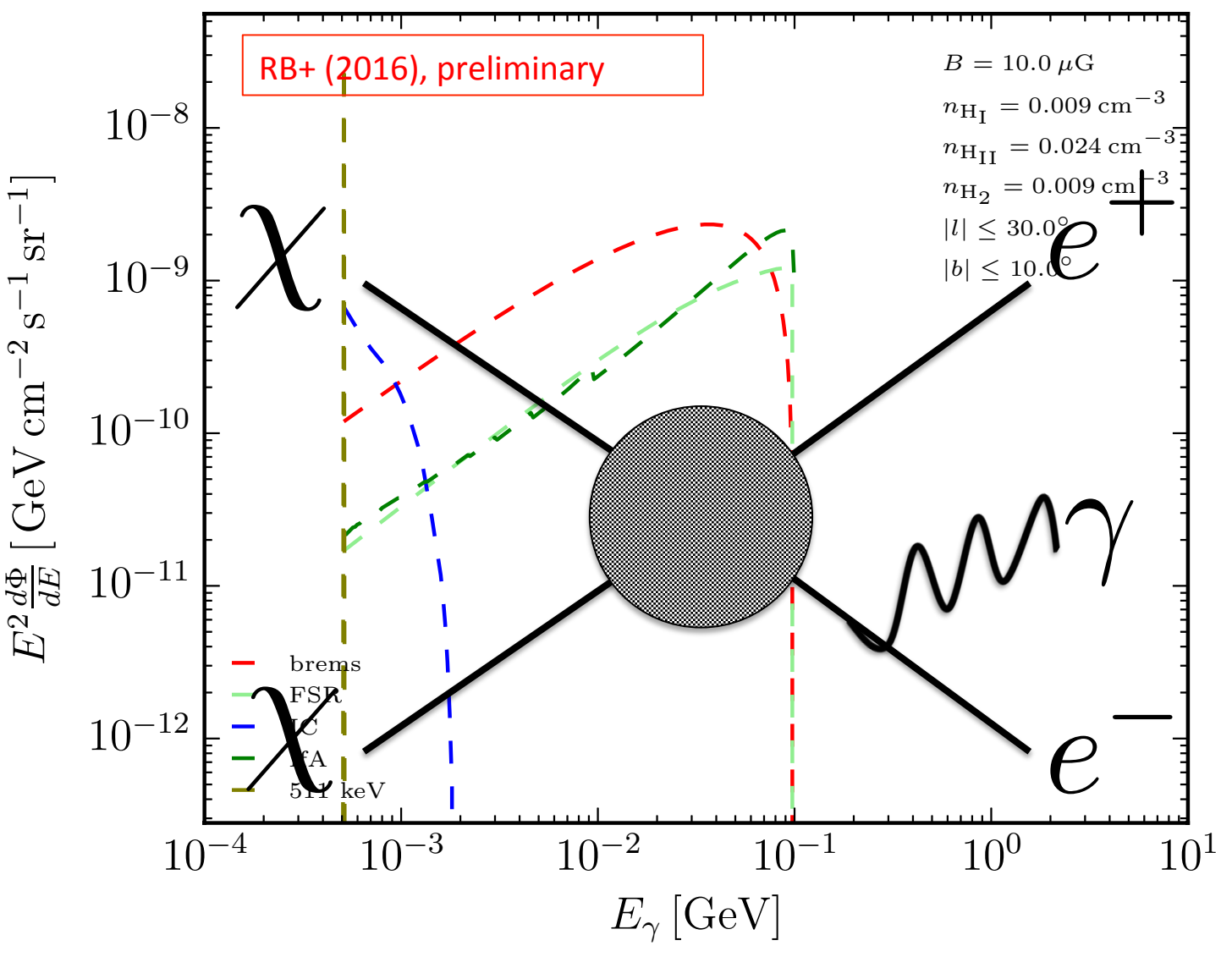

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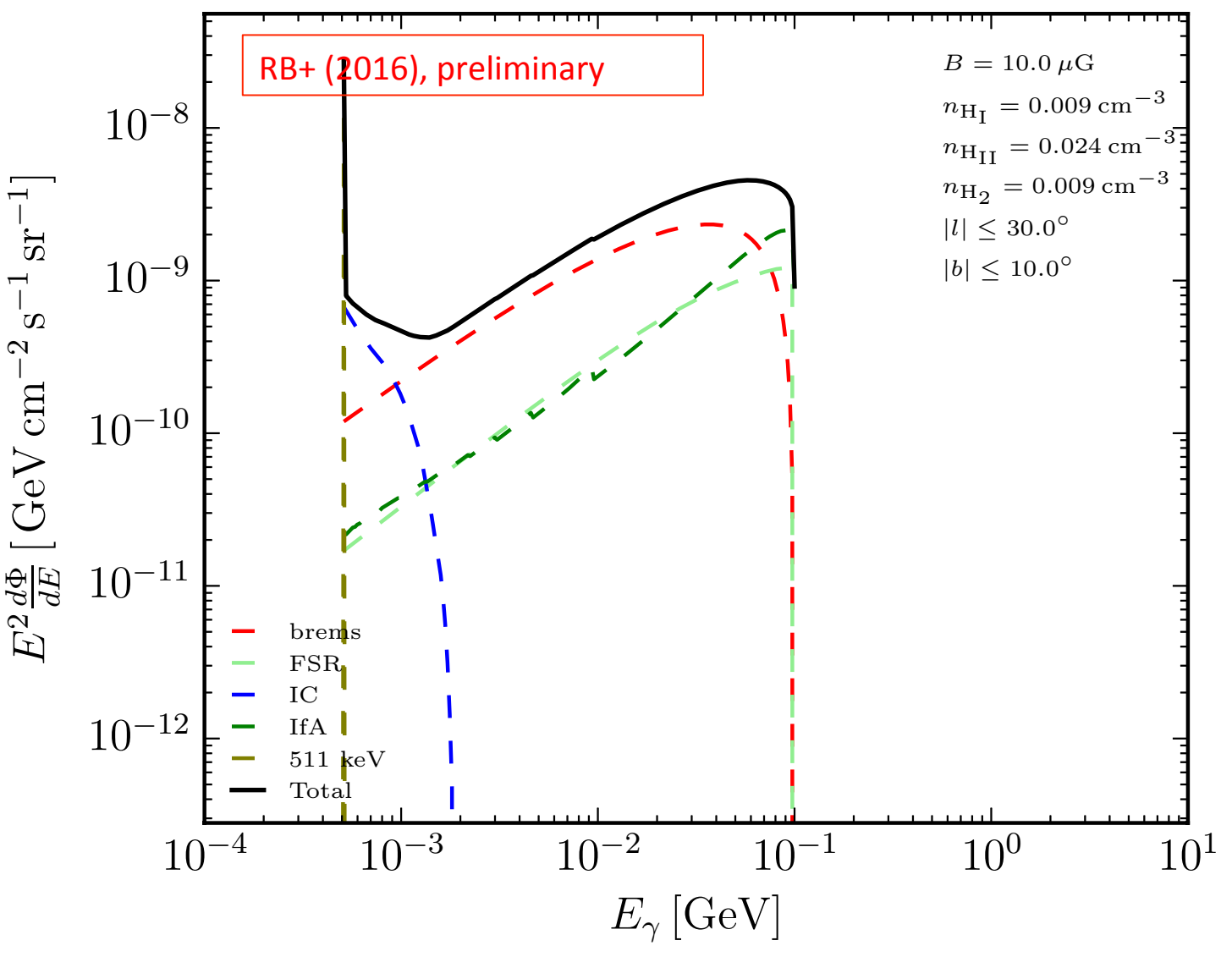

Gamma-Ray Signals

- In-flight annihilation
- Bremsstrahlung (Also see *Cirelli+ 2013)*
- Final-State Radiation

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- In-flight annihilation
- Bremsstrahlung (Also see *Cirelli+ 2013)*
- Final-State Radiation

- Contribute at roughly similar levels
- Similar spectra

The Future

- How well can an E-ASTROGAM/ComPair experiment do?

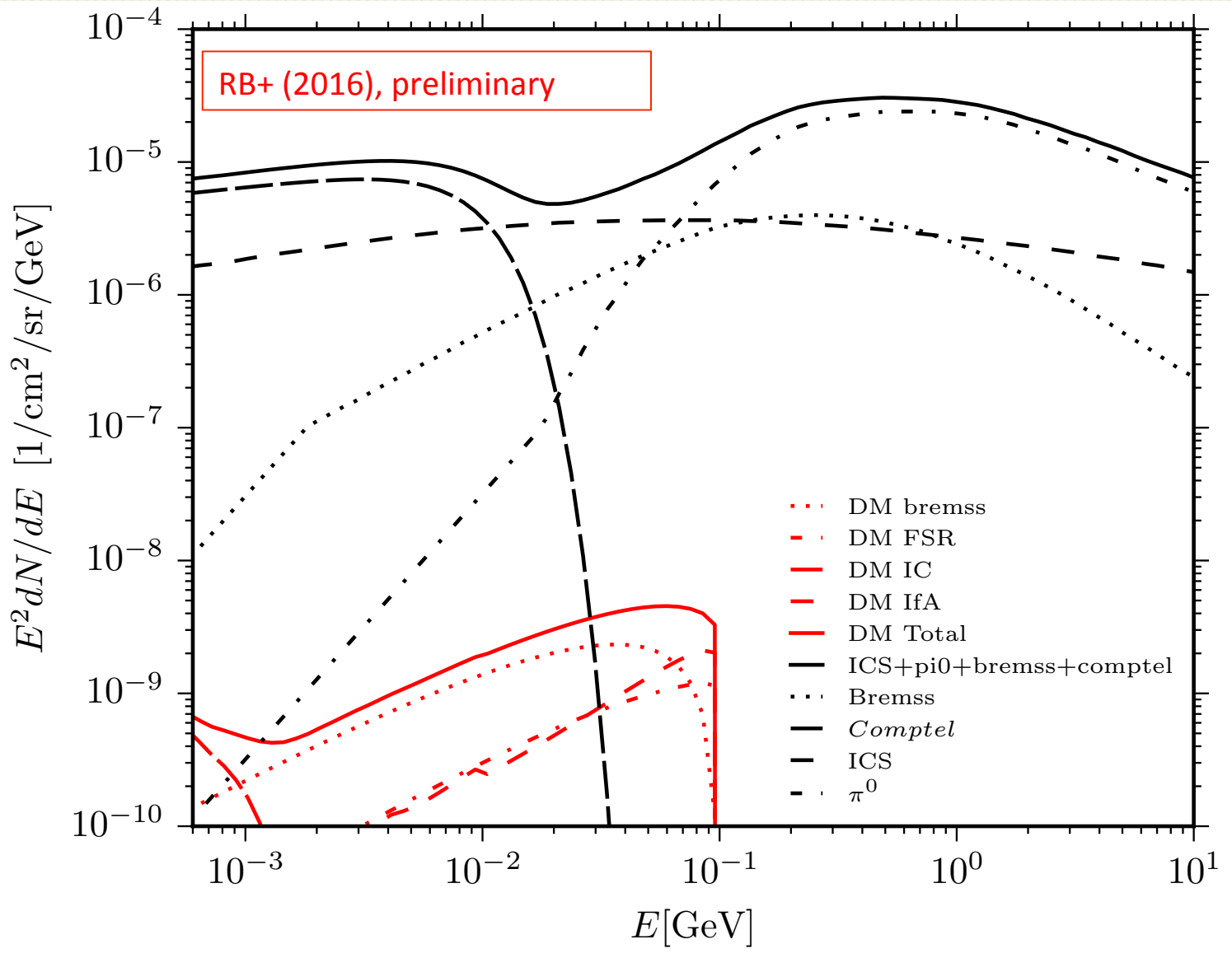
The Future

- How well can an E-ASTROGAM/ComPair experiment do?

<u>We assume</u>

- Effective area: $\sim \mathrm{few} \times 100\,\mathrm{cm}^2\,\mathrm{s}$
- Energy resolution: $\Delta E/E = 0.3$

Spectral analysis



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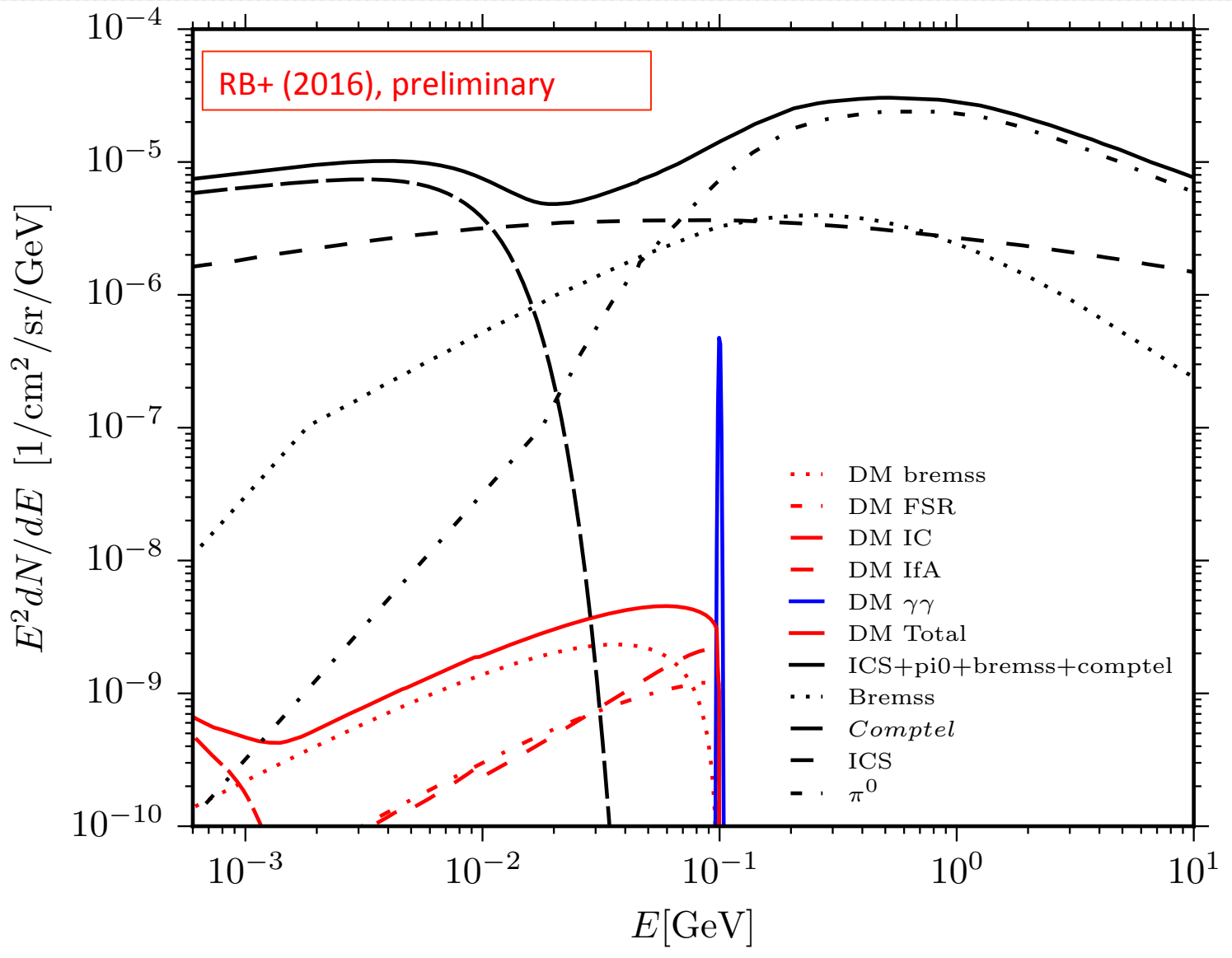

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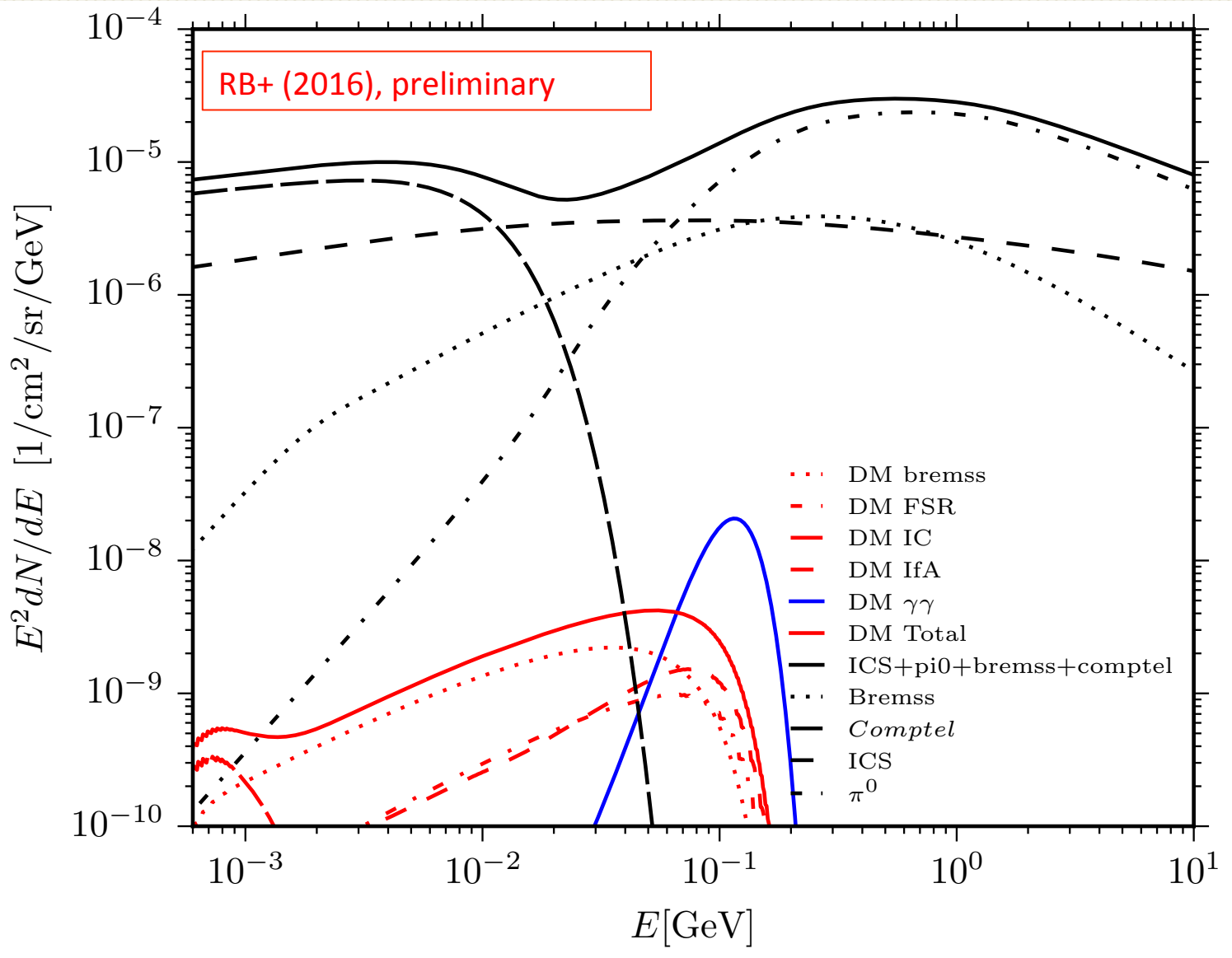

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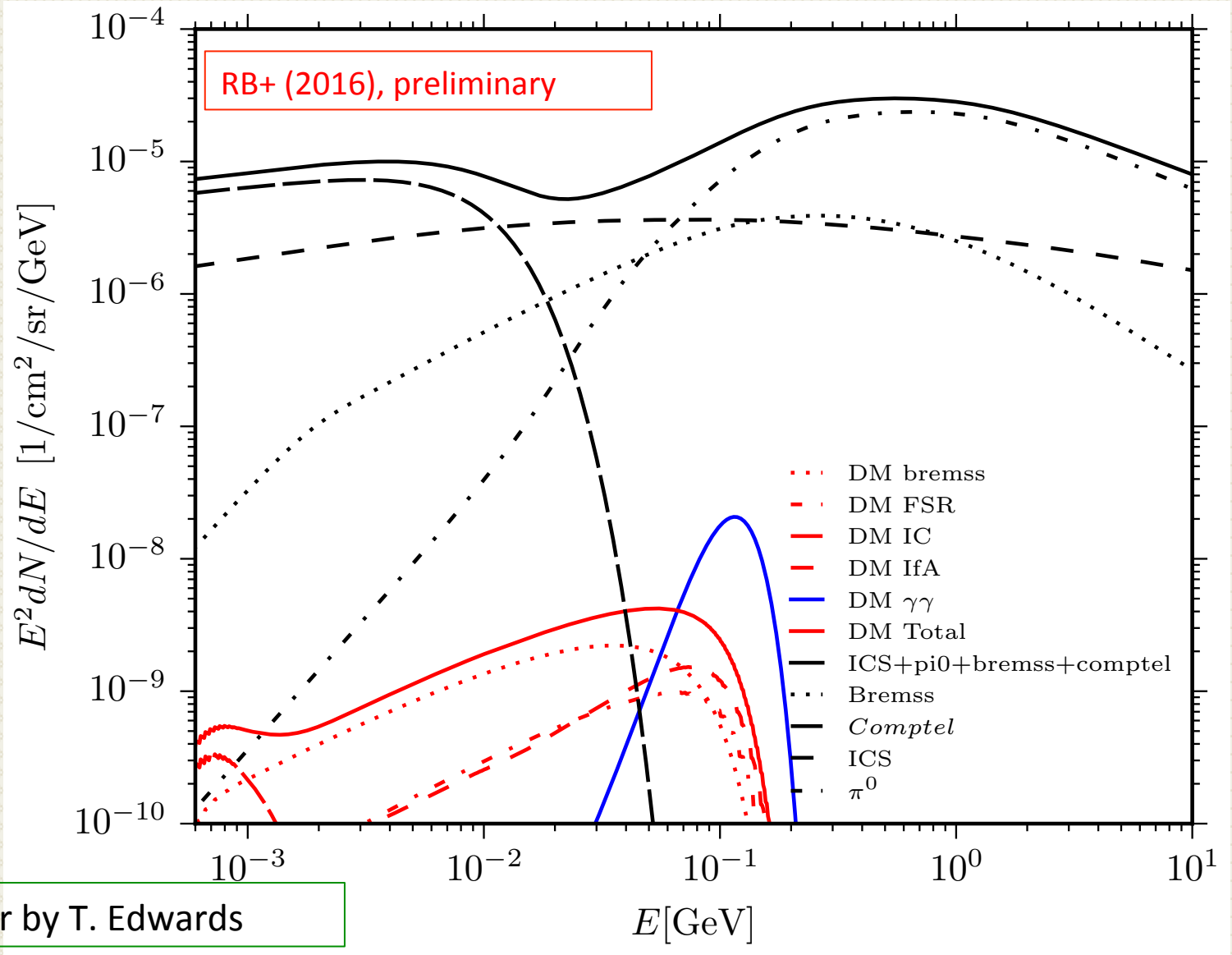
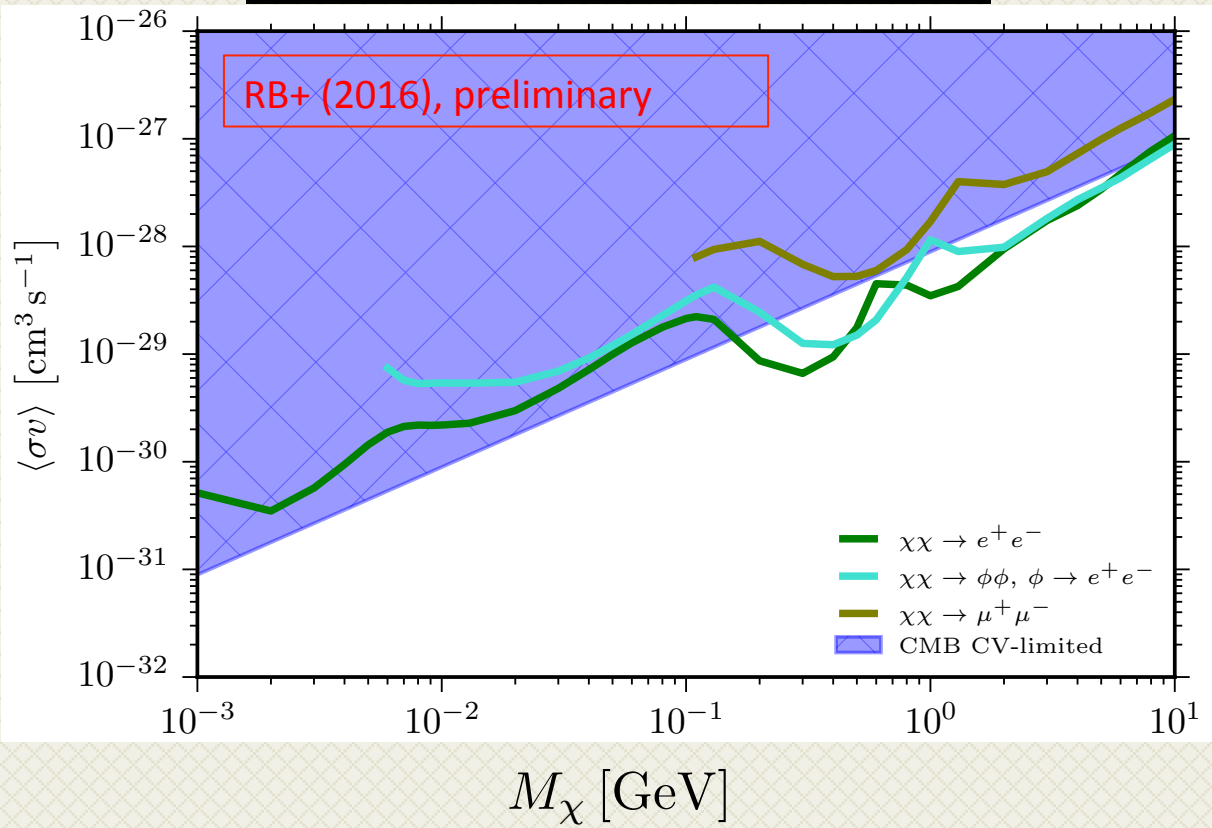


See poster by T. Edwards

Projected limits



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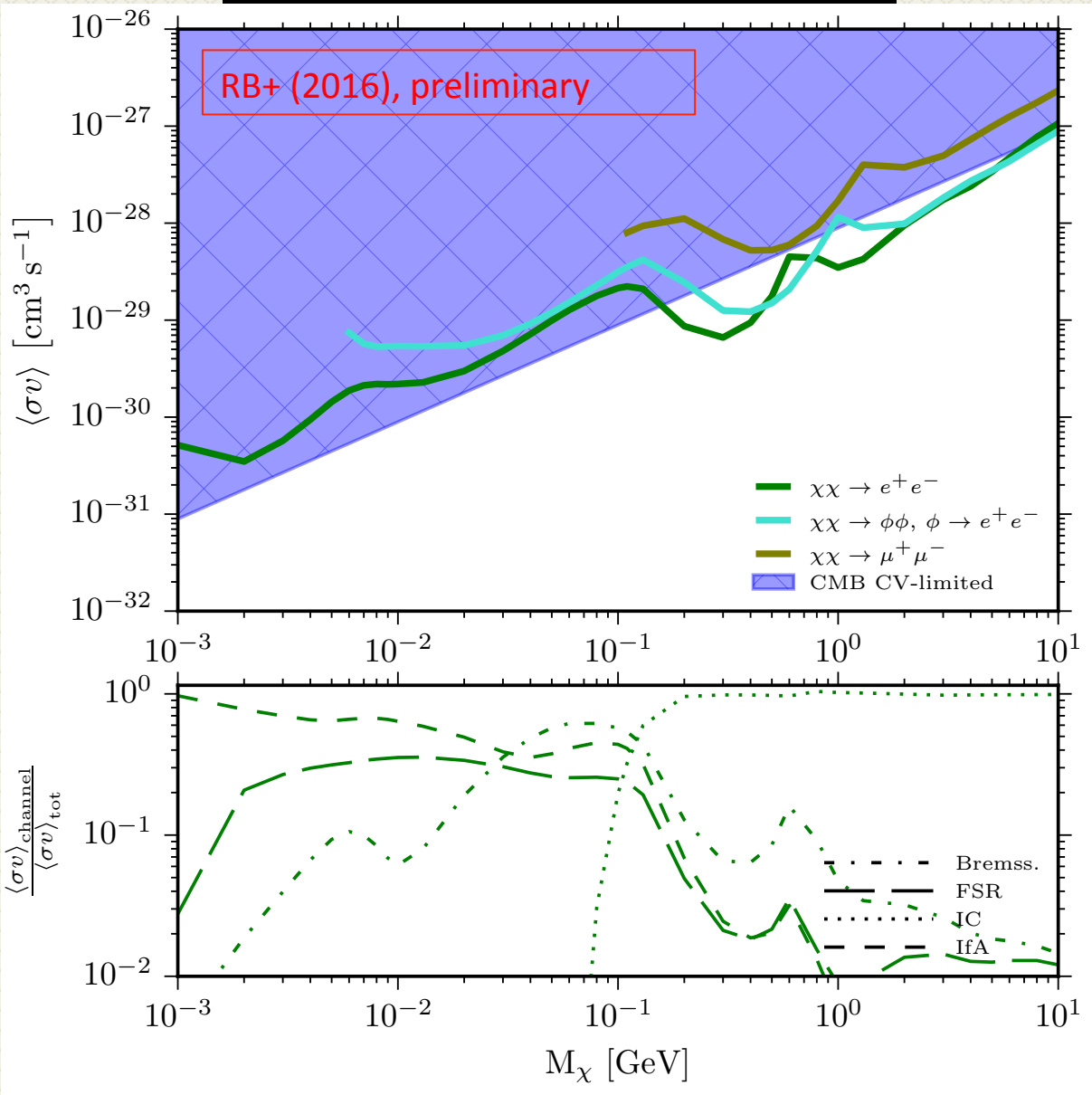

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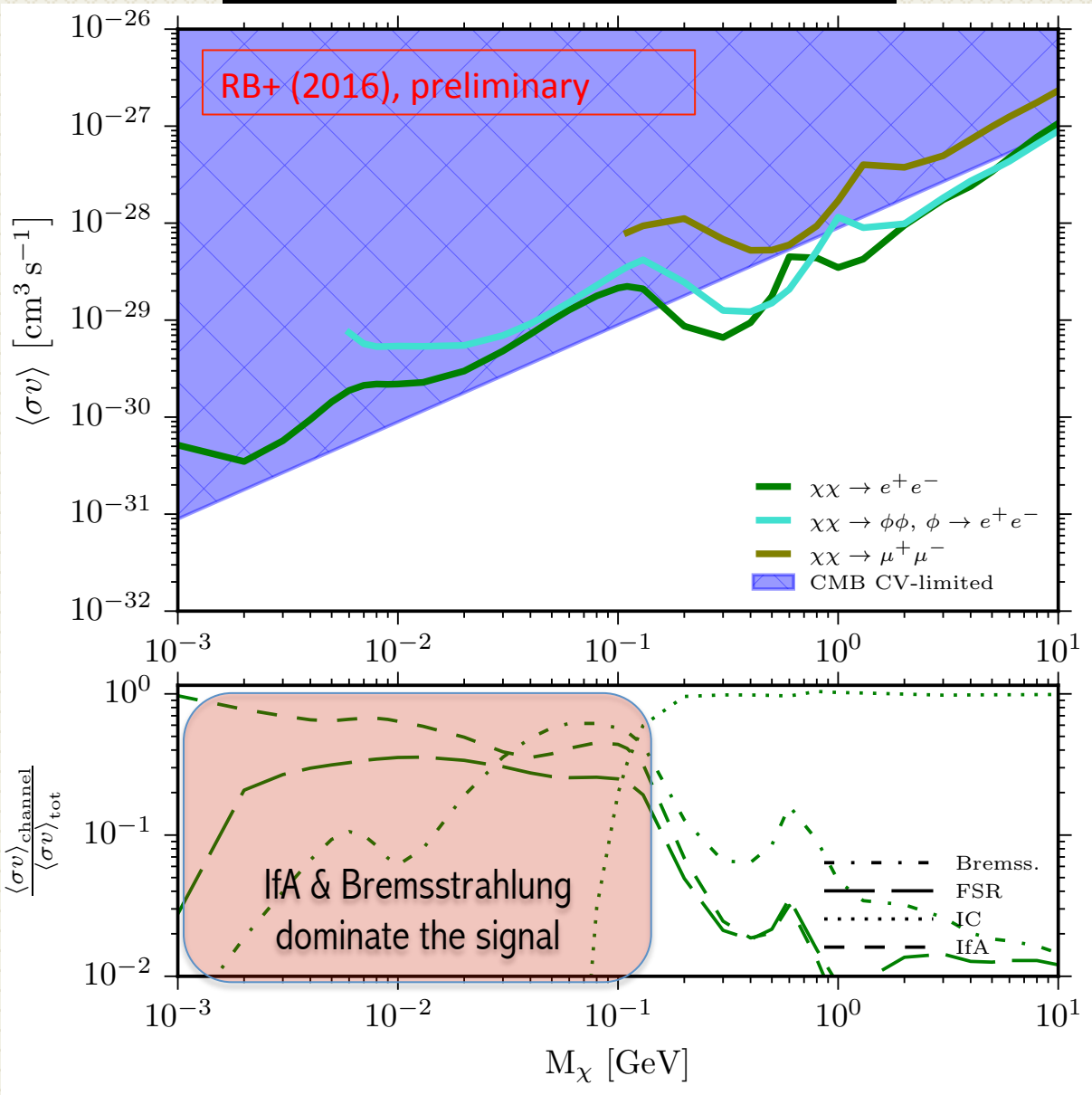

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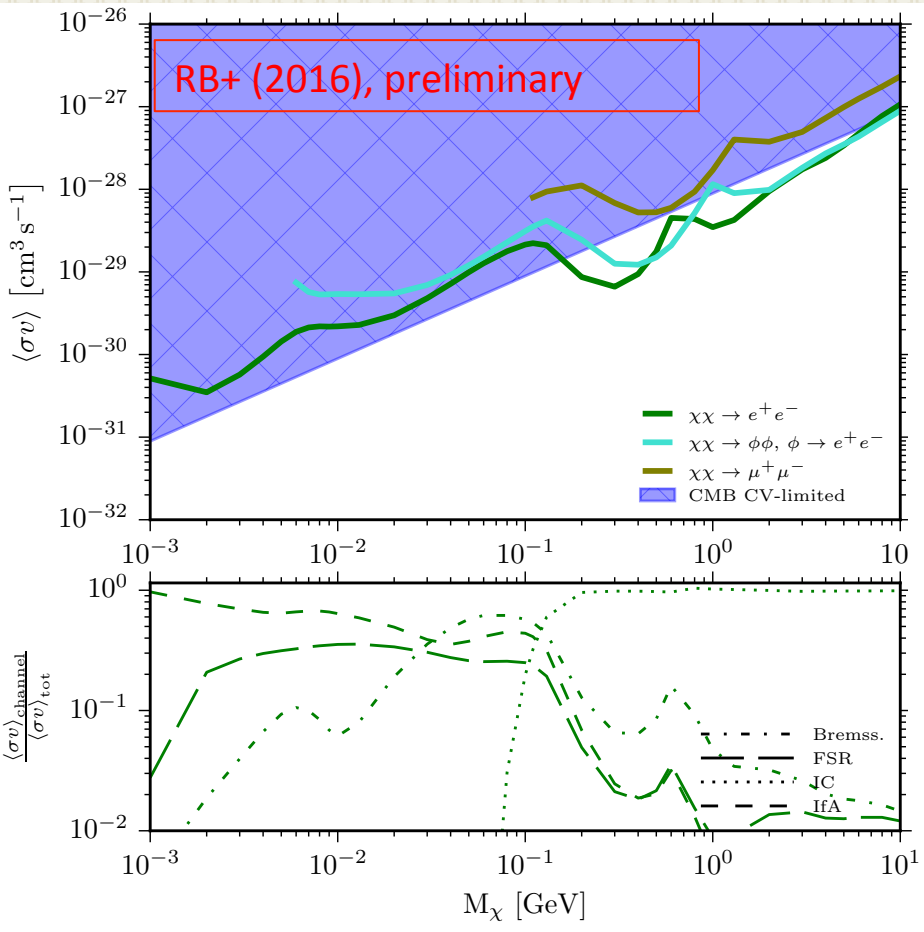
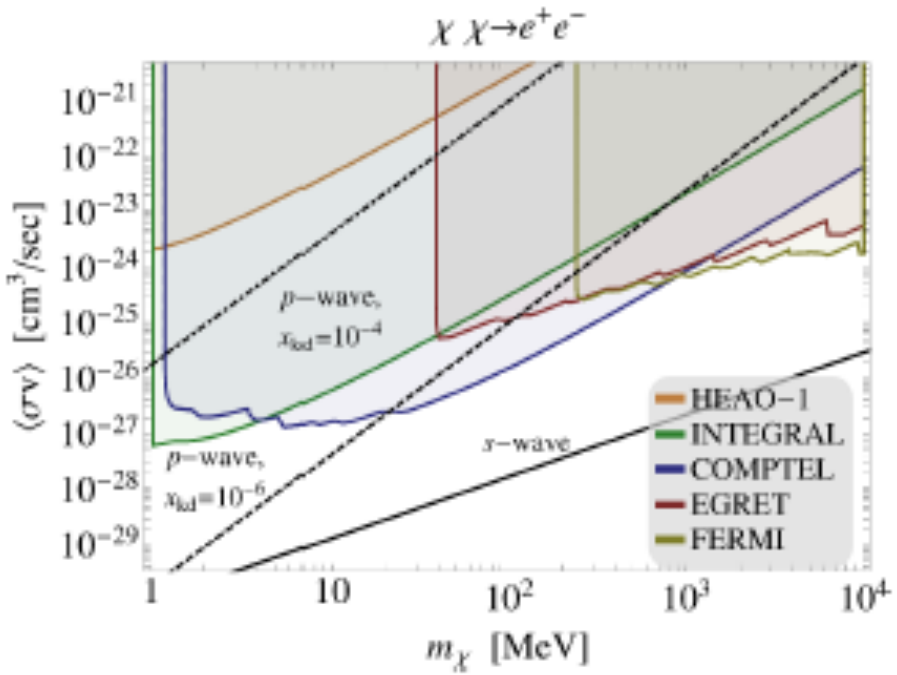
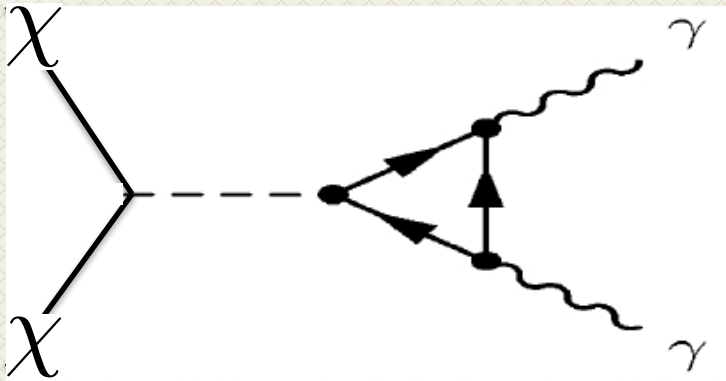


Compare with Essig+ (2013) who consider Final State radiation only:



Projected limits: model with line

$$\mathcal{L} \supset \frac{\mathcal{C}_U F_A}{2m_U^2} \bar{\chi}\gamma_\mu\gamma_5\chi\bar{\psi}_e\gamma^\mu\gamma_5\psi_e$$ [*Pullen+ 2006*]



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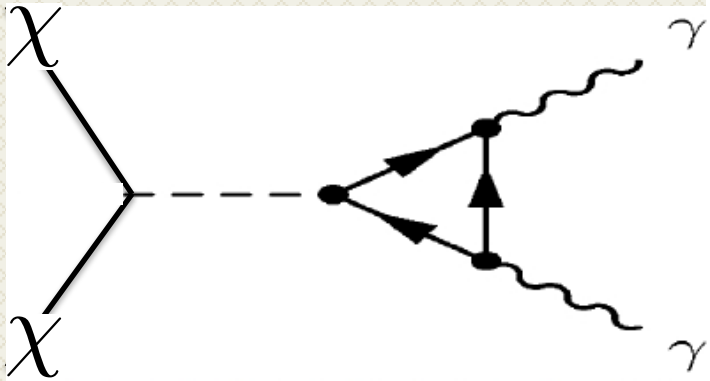
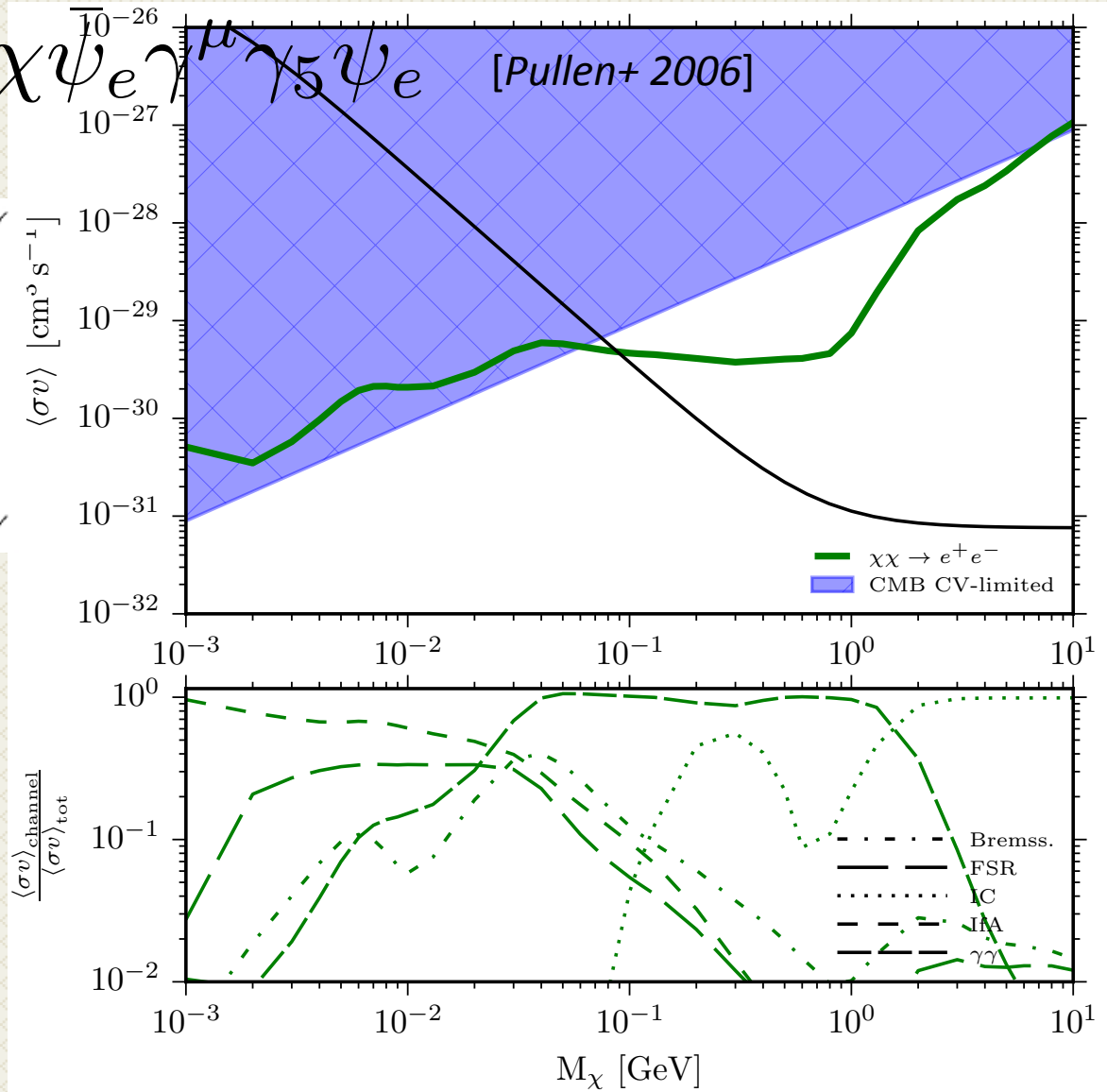
$$\mathcal{L} \supset \frac{C_U F_A}{2m_U^2} \bar{\chi}\gamma_\mu\gamma_5\chi\bar{\psi}_e\gamma^\mu\gamma_5\psi_e$$

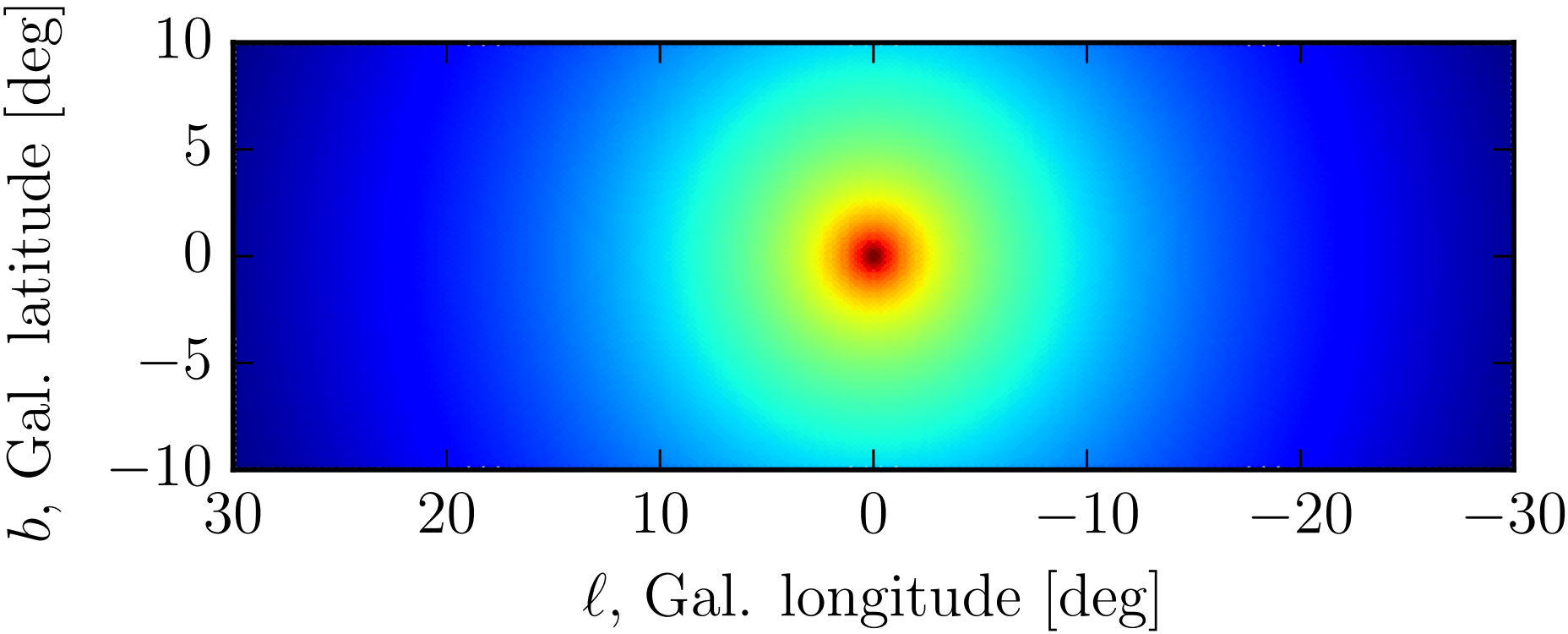




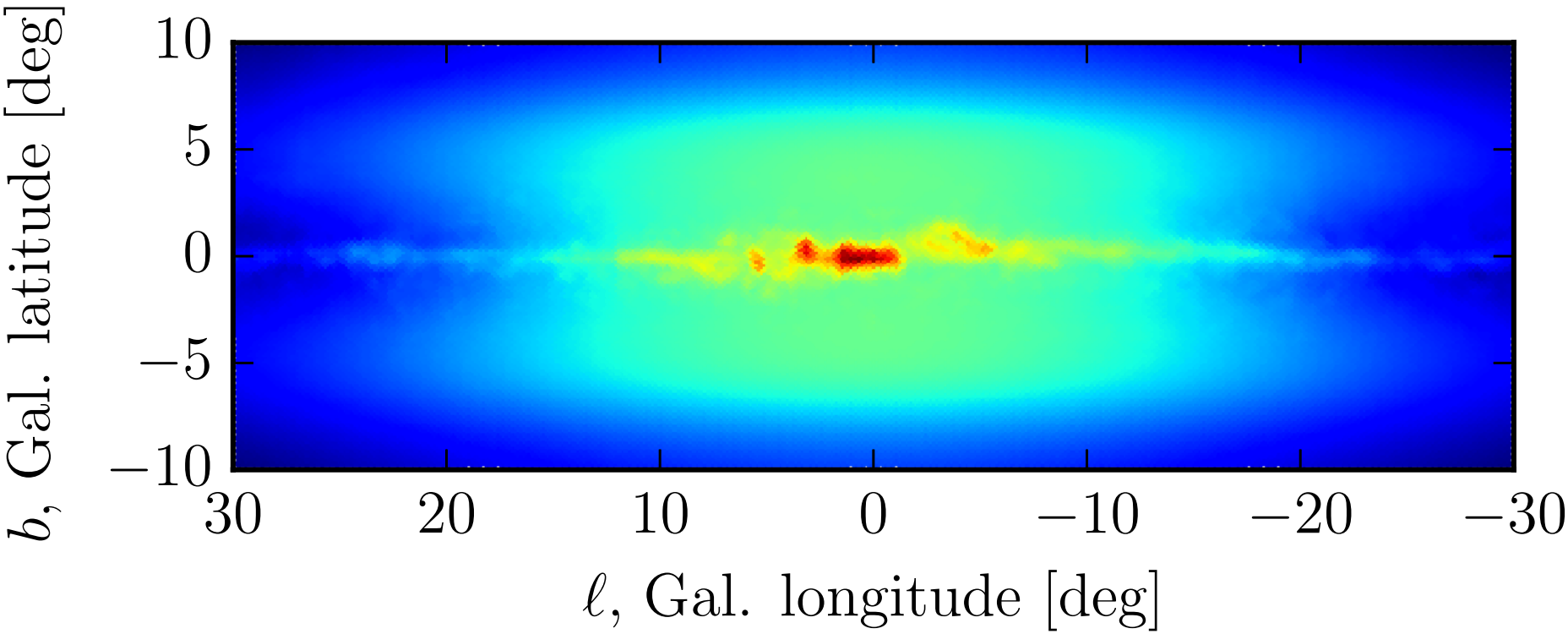
Dragon implementation

- Account for variations in gas, ISRF and B-field
- Study the impact of diffusion on the results
  - Unconstrained at these low energies!
- Study morphology of the signal

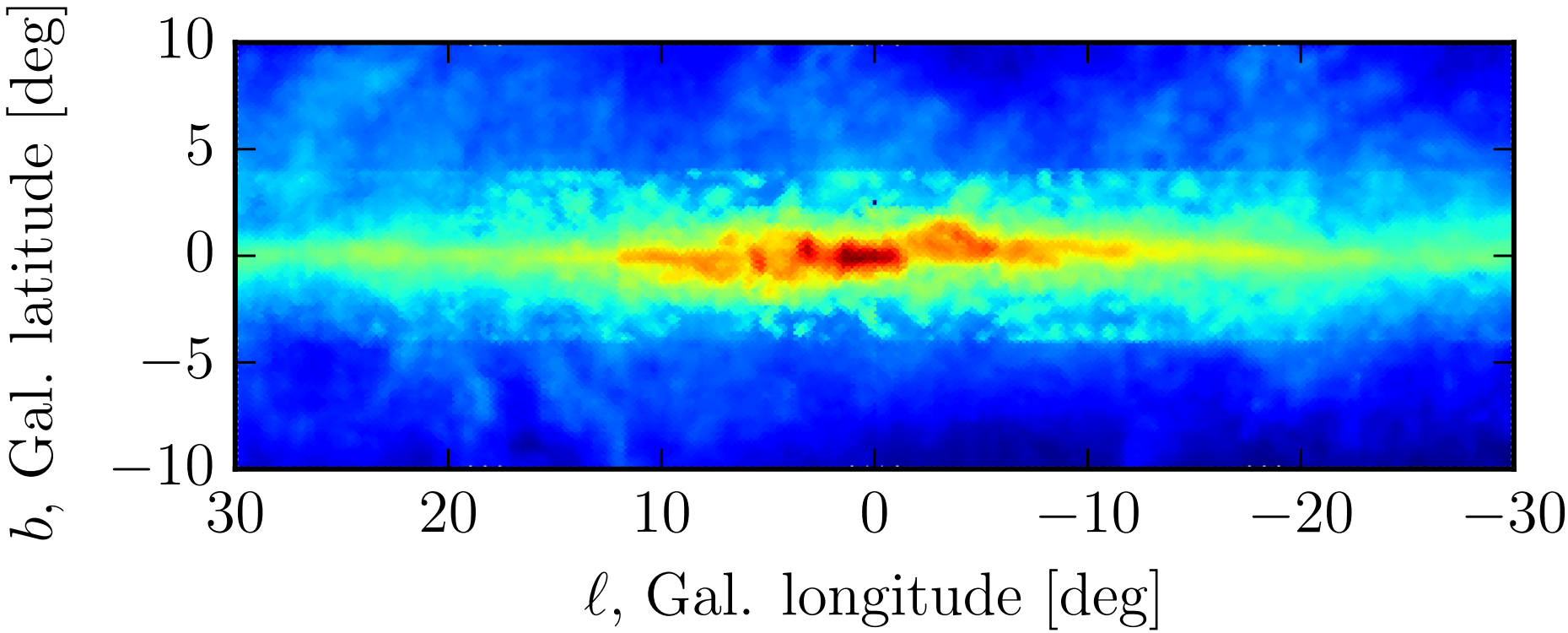
Morphology: FSR



Morphology: IfA



Morphology: Bremss.



Conclusion

- Future gamma-ray experiments can look for spectral features from MeV dark matter

- Secondaries dominate the spectrum below $\sim 100\,\mathrm{MeV}$

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- Detection presented at ~~TeVPA~~ MeVPA 2026??

Thank you ☺