Robust Constraints on Dark Matter Annihilation

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2009-11-19

CosPA 2009, Melbourne

Indirect Detection

- Have we seen DM annihilation?
  - EGRET excess, WMAP haze, 511 keV line, positron excess
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  Work out the flux signal, compare with data
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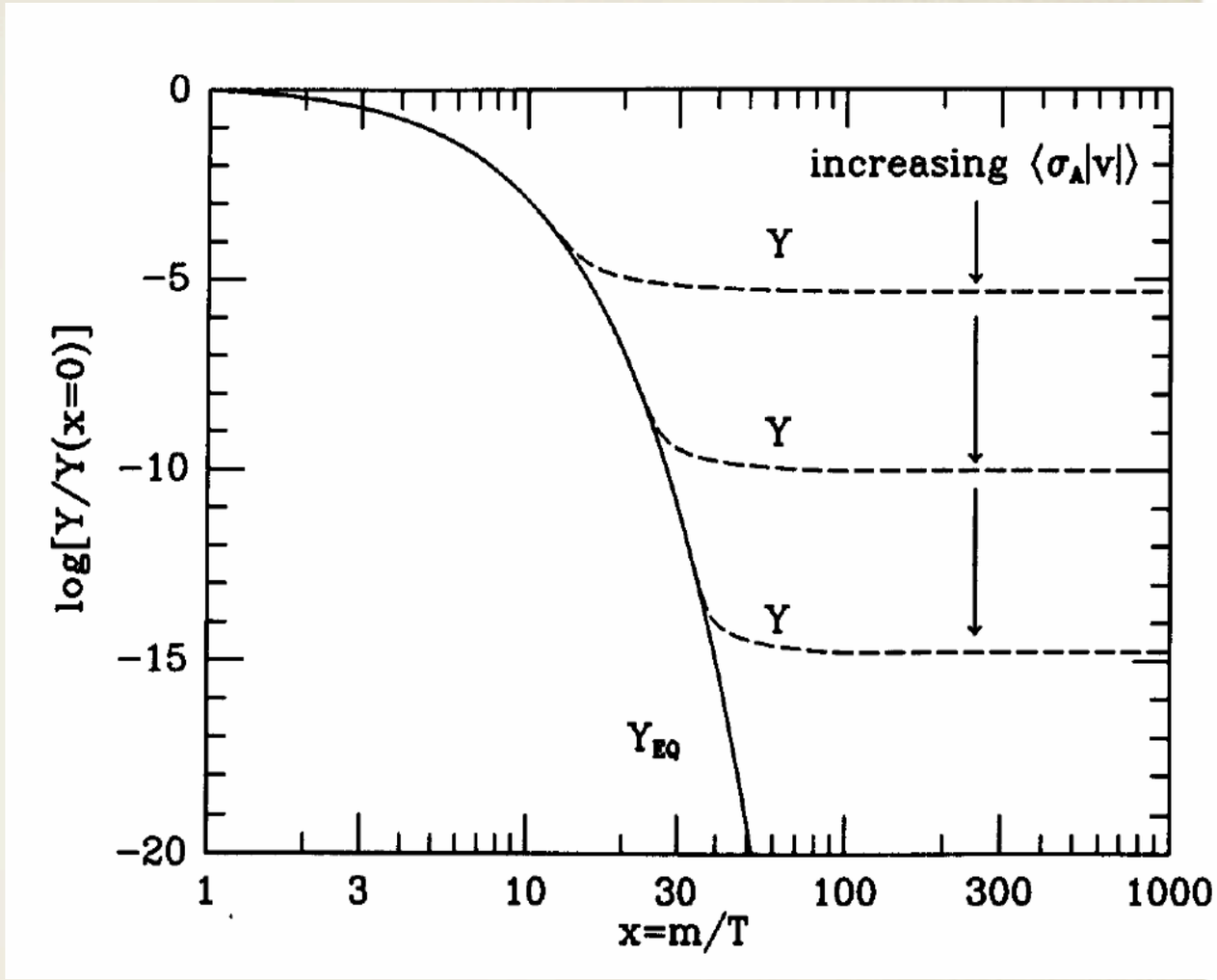
- Great way to test a model:
  Work out the flux signal, compare with data
- Difficult to ***prove*** a model using indirect detection
- Can we deduce something about DM, ***in a model independent way***, from it's annihilation flux?
  - ***Total*** flux of SM particles is an upper limit on the flux from DM annihilation
  - Use this to place upper limits on a fundamental property of DM, the self-annihilation cross section

Thermal Relic DM

- For thermal relic DM, annihilation rate controls abundance at freeze-out
- $\Omega_{DM} \sim 0.3$ corresponds to $\langle \sigma_A v \rangle \sim 3\times10^{-26}\ cm^3\ s^{-1}$



- But this isn't a hard constraint on $\langle \sigma_A v \rangle$

Annihilation Flux

- Annihilation flux from a nearby source:

$$\frac{d\Phi}{dE} = \frac{1}{2}\langle\sigma_A v\rangle \mathrm{Br} \int_0^R \frac{\rho(s)^2}{4\pi m_\chi^2} d\ell \frac{dN}{dE}$$

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Integral along the line of sight of the DM density squared,

The spectrum per annihilation

Annihilation Flux

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$$\frac{d\Phi}{dE} = \frac{\langle \sigma_A v \rangle \mathrm{Br}}{2} \frac{\mathcal{J}_{\Delta\Omega}}{\mathrm{J}_0} \frac{1}{4\pi m_\chi^2} \frac{dN}{dE}$$

Constraining Annihilation

- Total flux of standard model particles provides an upper limit on the flux from DM annihilation

$$\frac{d\Phi}{dE} = \frac{\langle \sigma_A v \rangle \mathrm{Br}}{2} \frac{\mathcal{J}_{\Delta\Omega}}{\mathrm{J}_0} \frac{1}{4\pi m_\chi^2} \frac{dN}{dE}$$

- Use this to find upper limit on the cross section to a particular final state

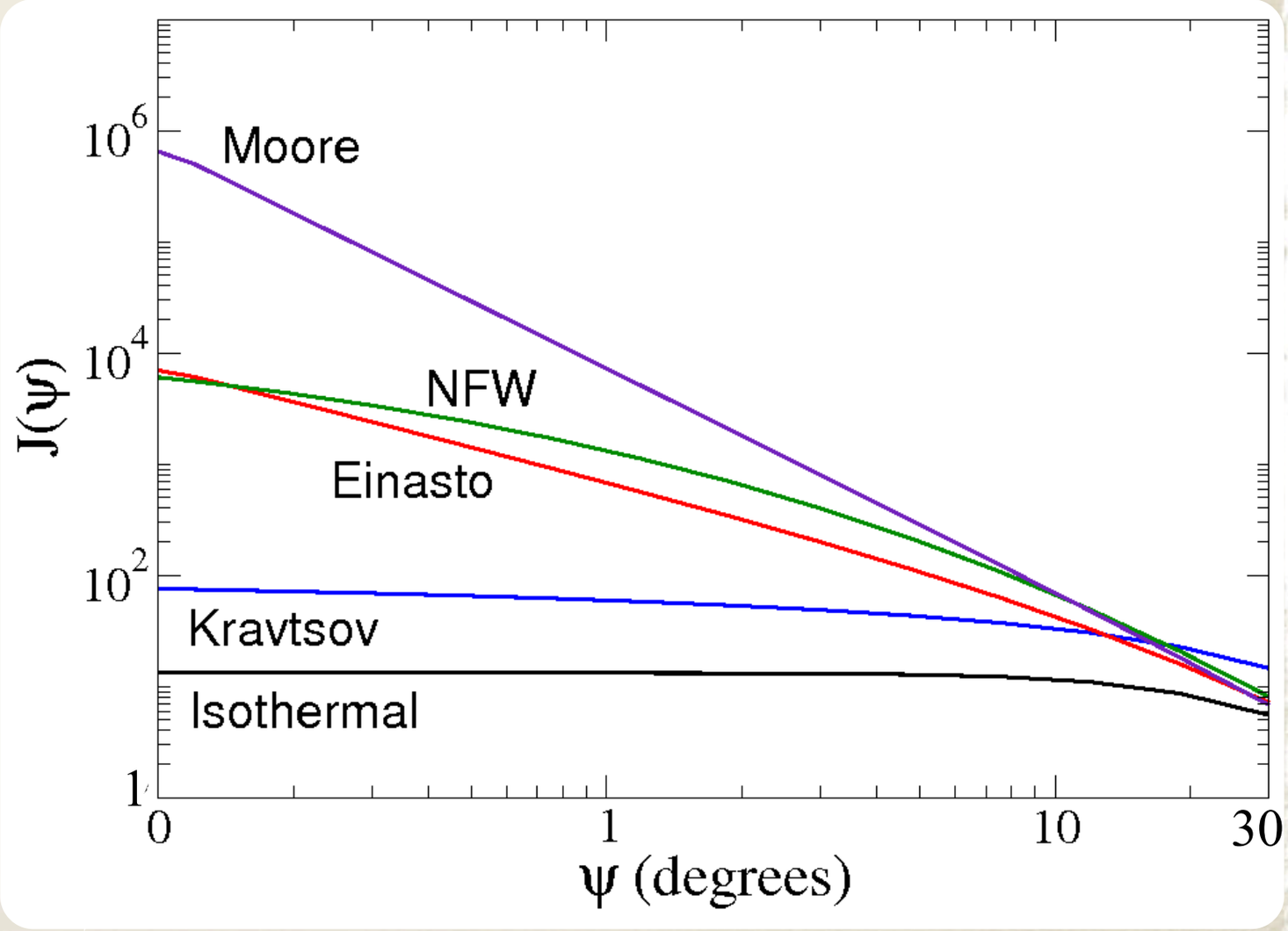
- Model independent, robust

Assumptions

- WIMP DM
- Annihilates to SM particles
- Dirac vs Majorana introduces factor of 2: negligible
- DM density profile

Density profiles

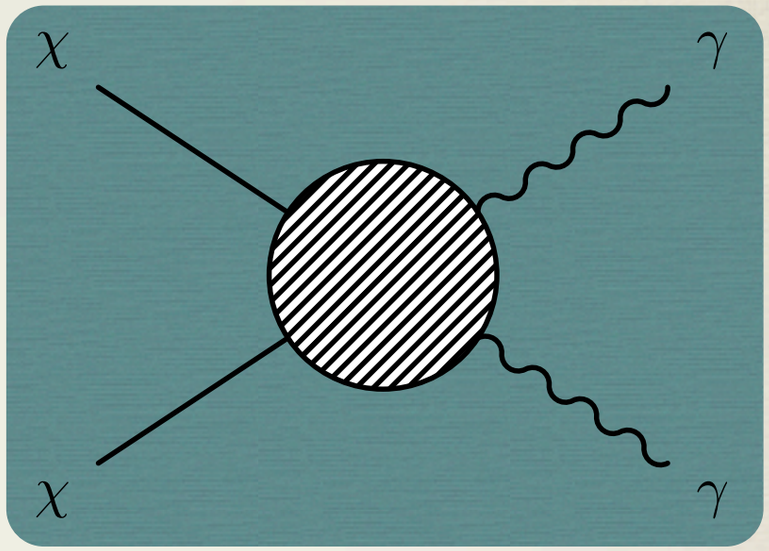
- Minimize uncertainty by looking at large angular regions
- Focus on conservative Kravtsov profile, but show results for other profiles



Observation Regions

- Galactic Center
  - Our main flux source; lots of data
- M31 (Andromeda)
  - Relatively weak upper limits on $\langle \sigma_A v \rangle$
- Cosmic Annihilation
  - Diffuse flux from extragalactic DM annihilation
- Use data from a number of detectors
- Cover broad range of energies

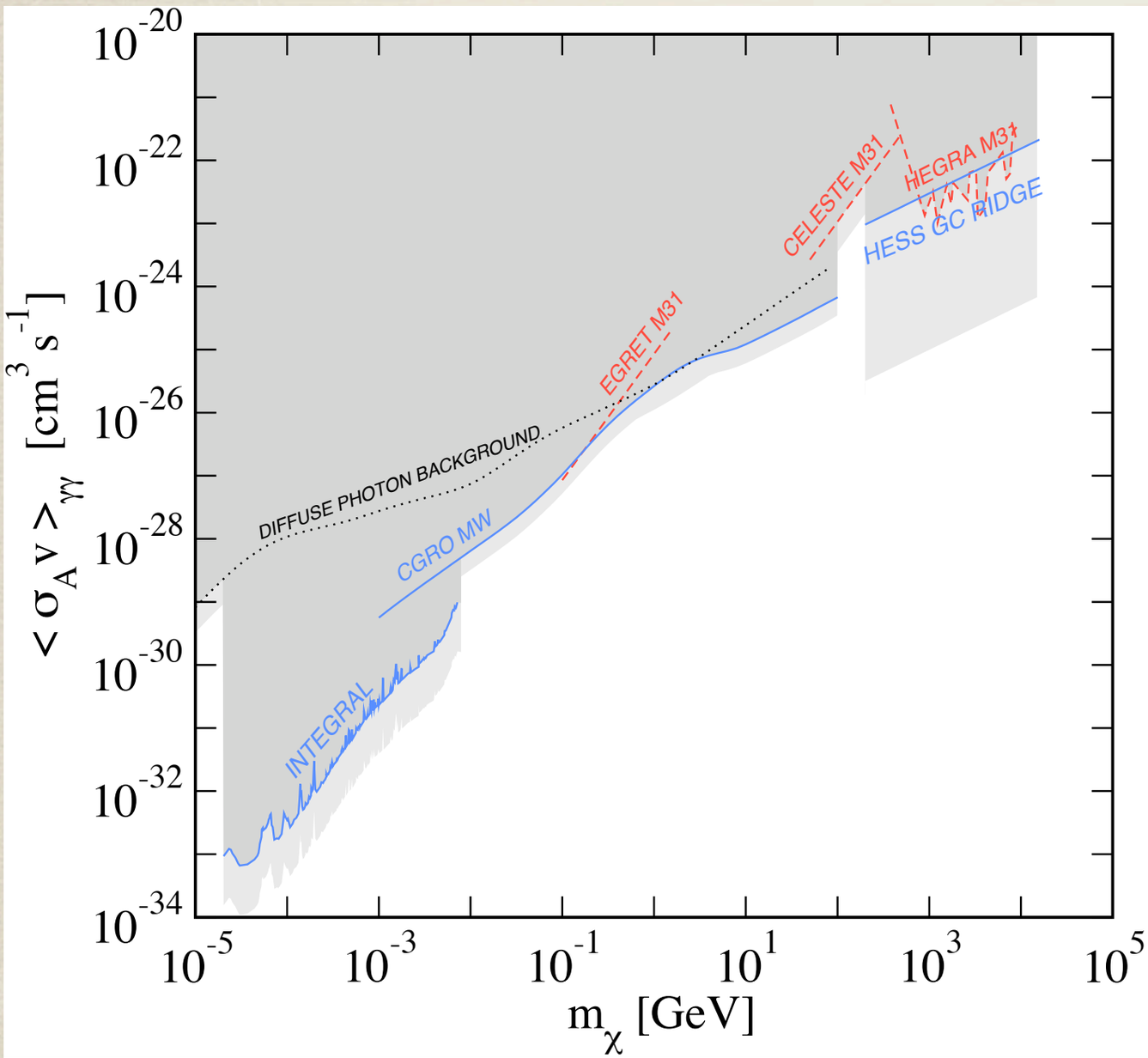
$\gamma\gamma$



- Photon line
  - 'Smoking Gun'
  - Common final state, even if small branching ratio
  - Don't know branching ratio:
    We constrain this channel only

from Mack, Jacques, Beacom, Bell, Yuksel; Phys.Rev.D78:063542 (2008)

γγ Bound



- Very conservative analysis
- Results more general than they appear: We integrate the signal over a large energy bin, so results are valid for an annihilation spectrum as wide as our analysis bin (0.4 in $\log_{10}$ E)
- At worst, our limit would be increased by a factor of several for a broad annihilation spectrum (except for INTEGRAL/HEGRA)

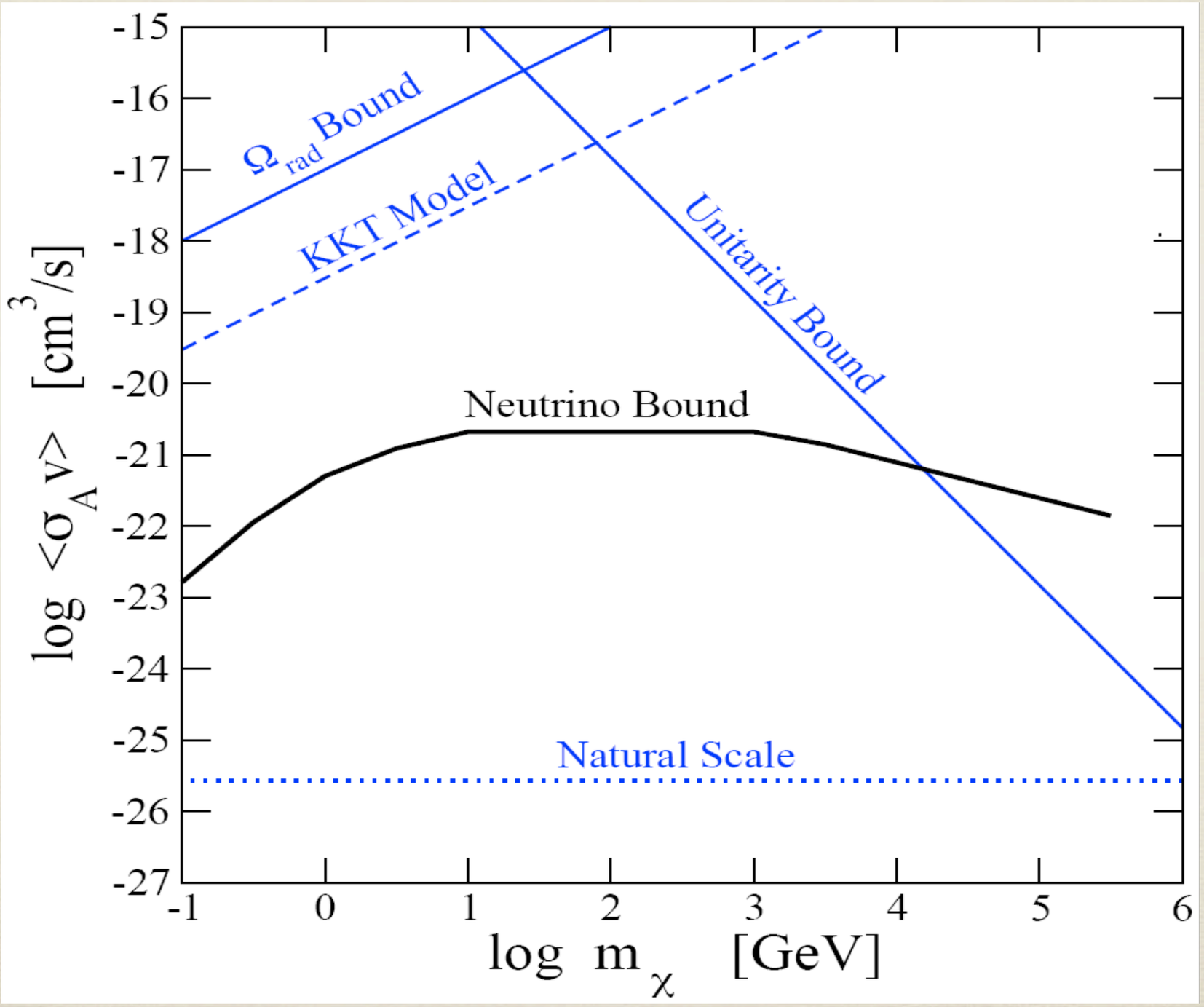
Neutrino Bound

- Look at $\chi\chi \rightarrow \nu\bar{\nu}$
- Sets bound on ***total*** cross section: Don't need branching ratio
  - Any other final state produces gamma rays, which are much more detectable, and will set a stronger upper limit
  - So upper limit on $\langle \sigma_A v \rangle \times$ Br sets upper limit on $\langle \sigma_A v \rangle$
  - Use diffuse atmospheric neutrino background as the upper limit on the signal
  - Cosmic annihilation

Beacom, Bell, & Mack,
Phys. Rev. Lett. 99, 231301, 2007.

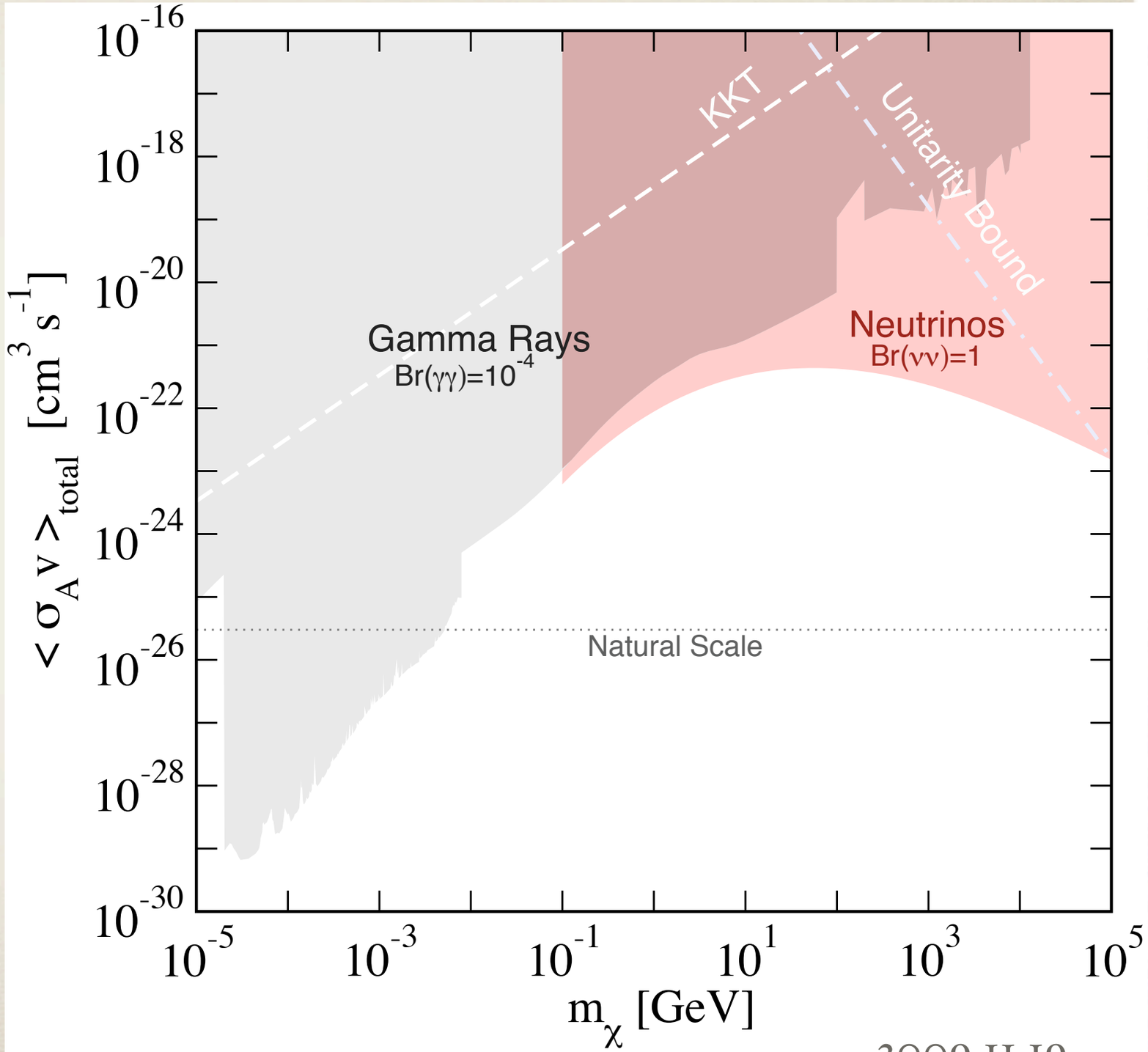
Yuksel, Horiuchi, Beacom, & Ando,
PRD 76, 123506, 2007.

Neutrino Bound

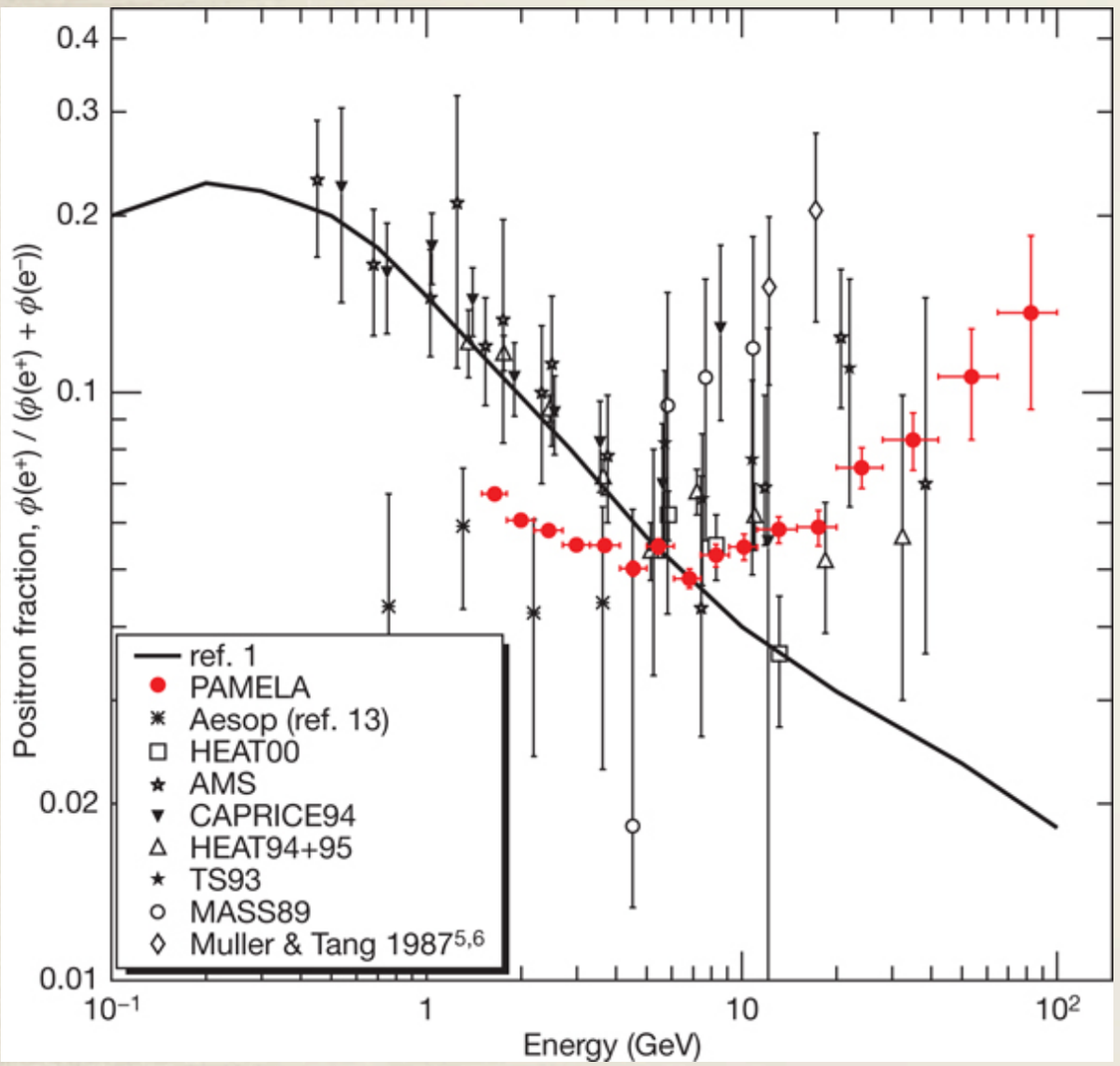


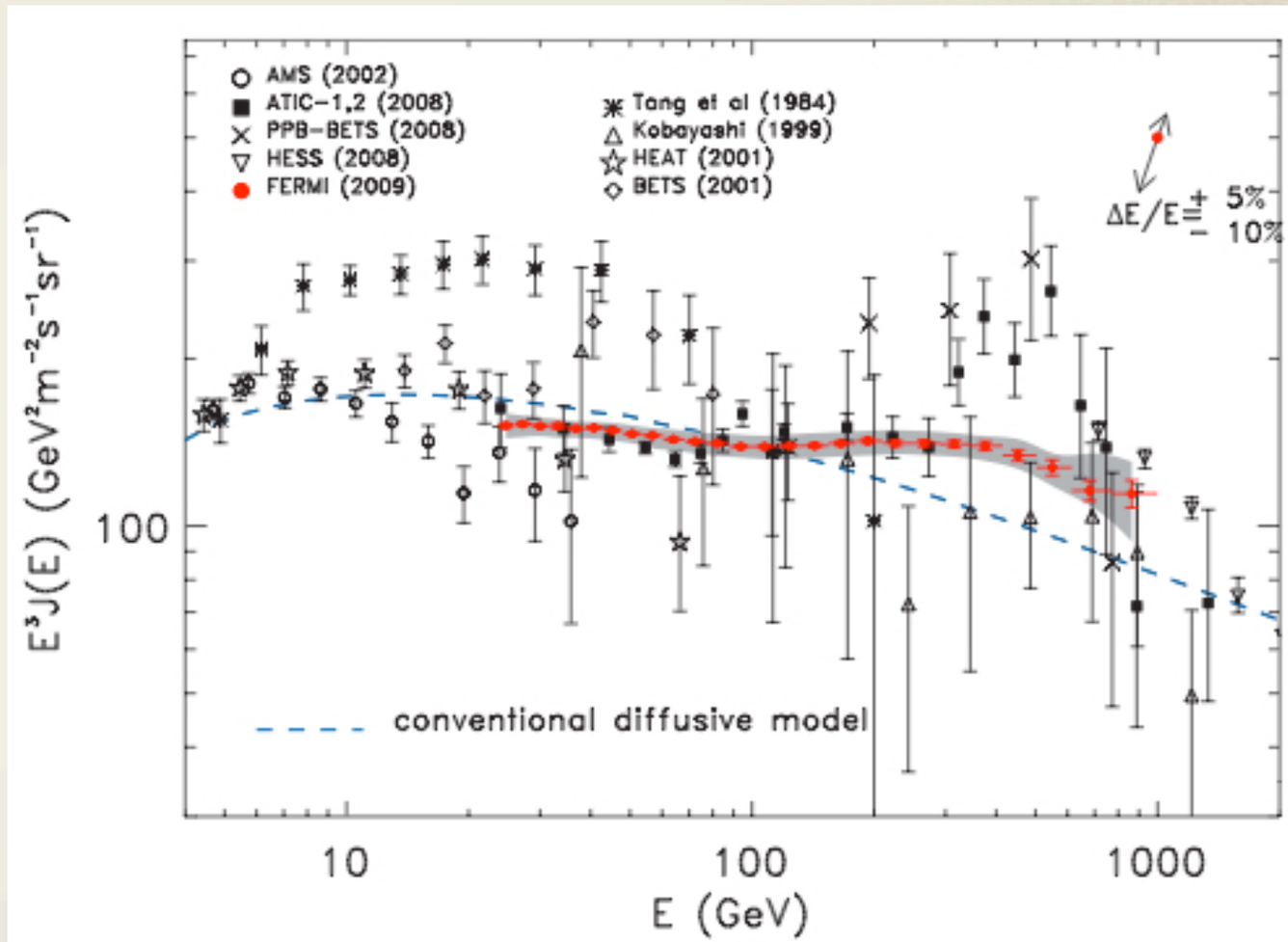
Constraints

- Using $Br(\gamma\gamma) = 10^{-4}$, find a limit on the total cross section



Positron Excess

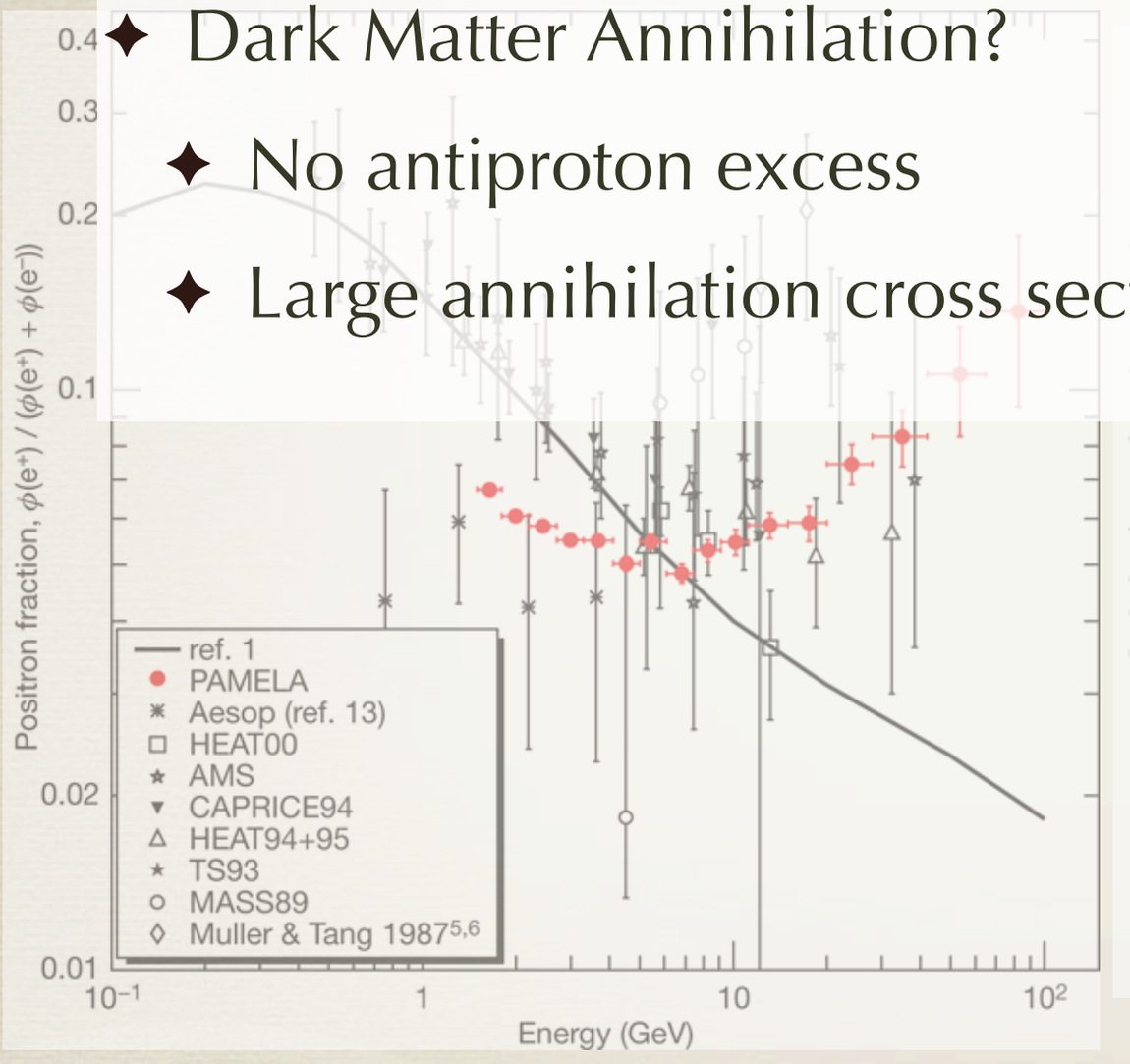


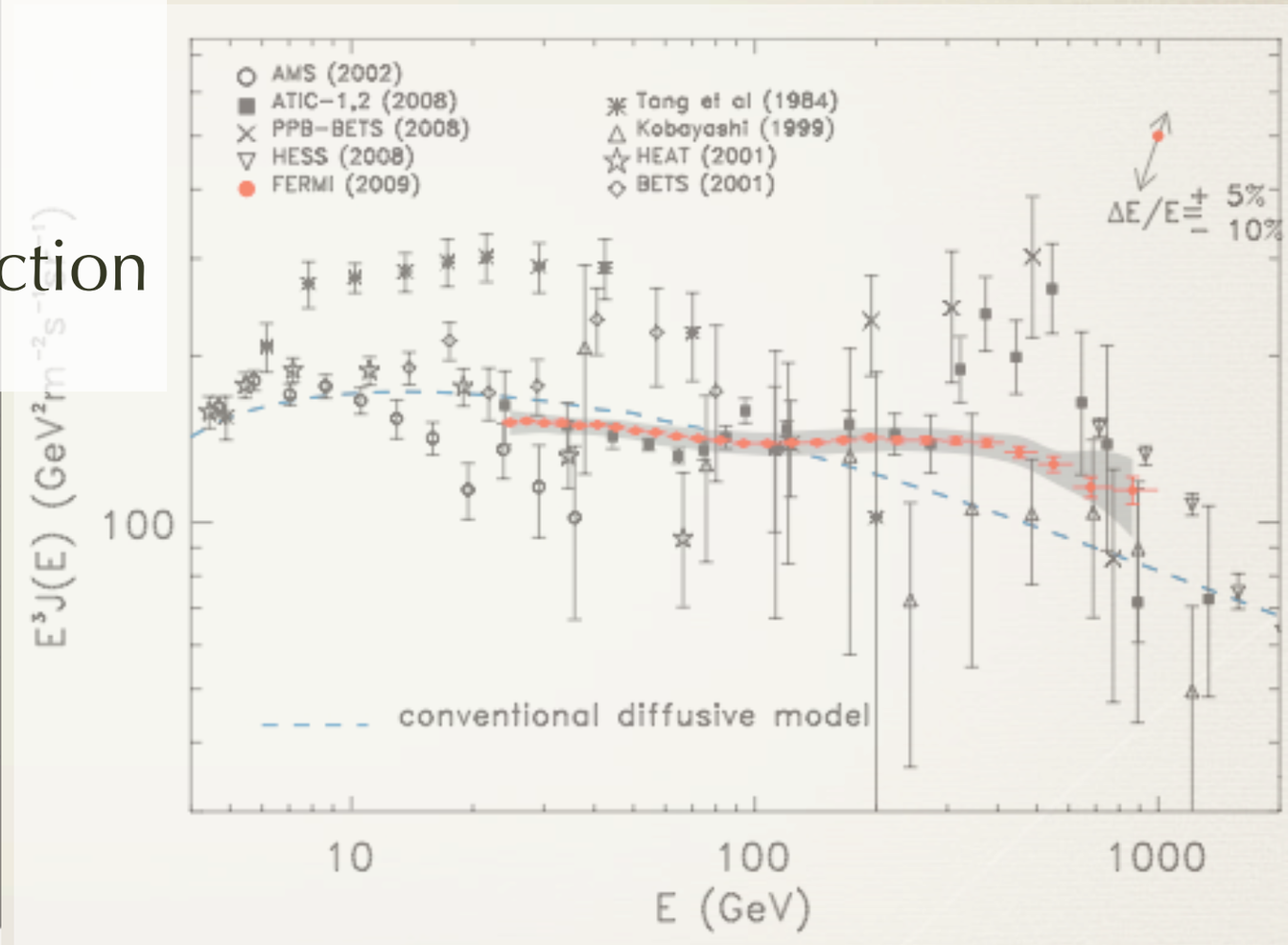


from N. Bell & T. Jacques; Phys.Rev.D79:043507 (2008)

Positron Excess

- Dark Matter Annihilation?
  - No antiproton excess
  - Large annihilation cross section





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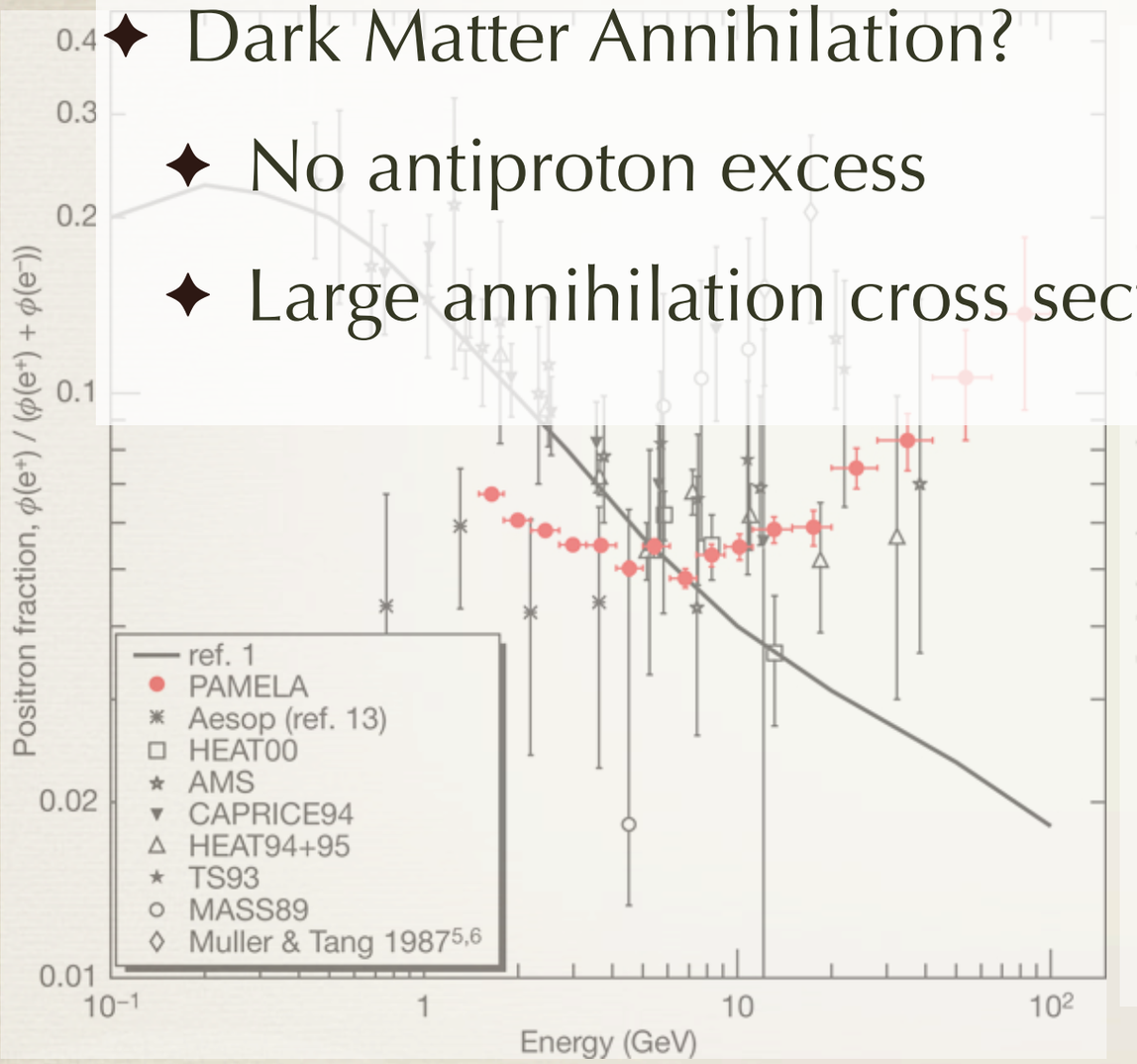
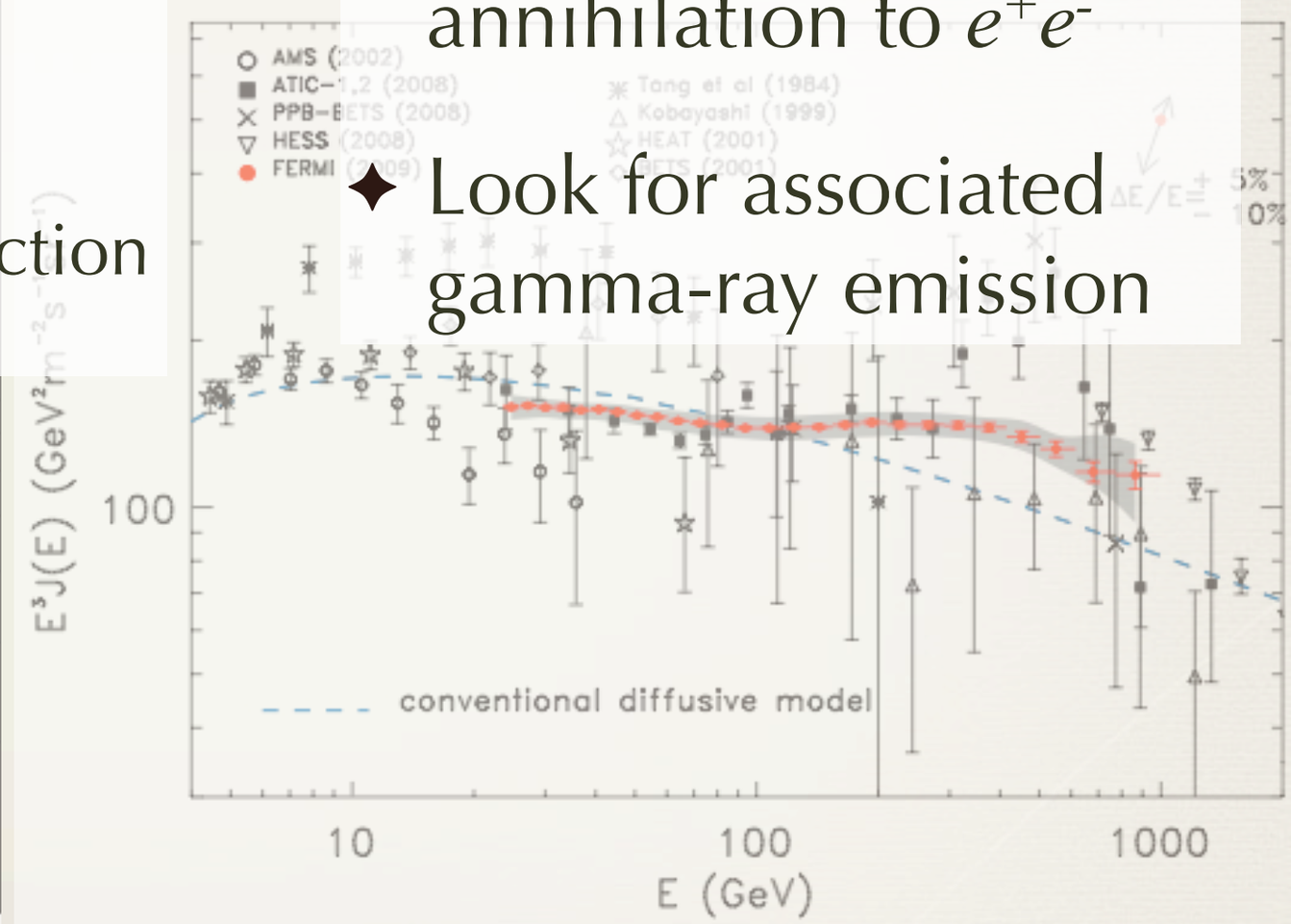


- Want to constrain annihilation to e^+e^-
- Look for associated gamma-ray emission



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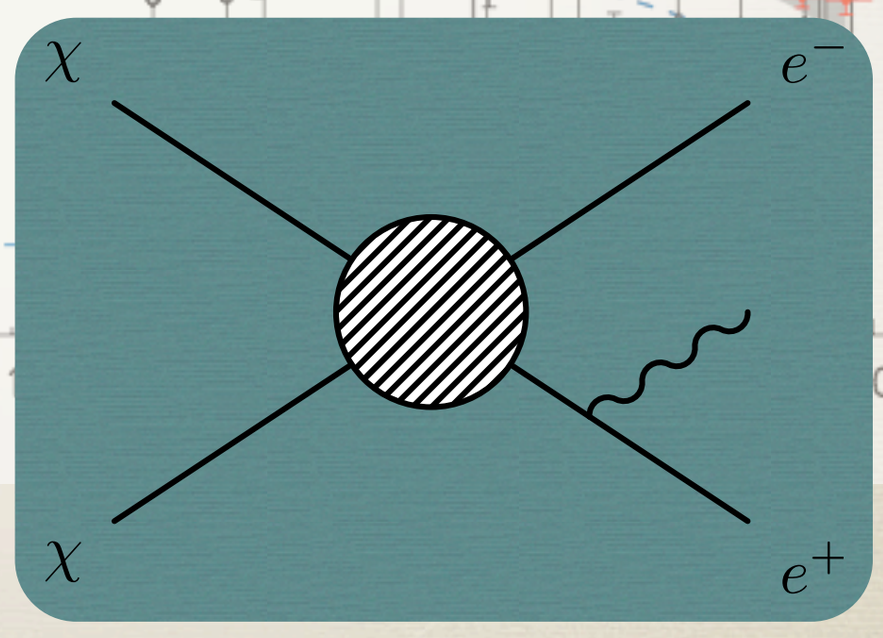
Positron Excess

- Dark Matter Annihilation?
  - No antiproton excess
  - Large annihilation cross section
- **Internal Bremsstrahlung**
  - No dependence on Magnetic field, ISRF, Diffusion
  - Hard gamma rays near the endpoint, and background decreases with energy

- Want to constrain annihilation to e^+e^-
- Look for associated gamma-ray emission



from N. Bell & T. Jacques; Phys.Rev.D79:043507 (2008)

Internal Brem Spectrum

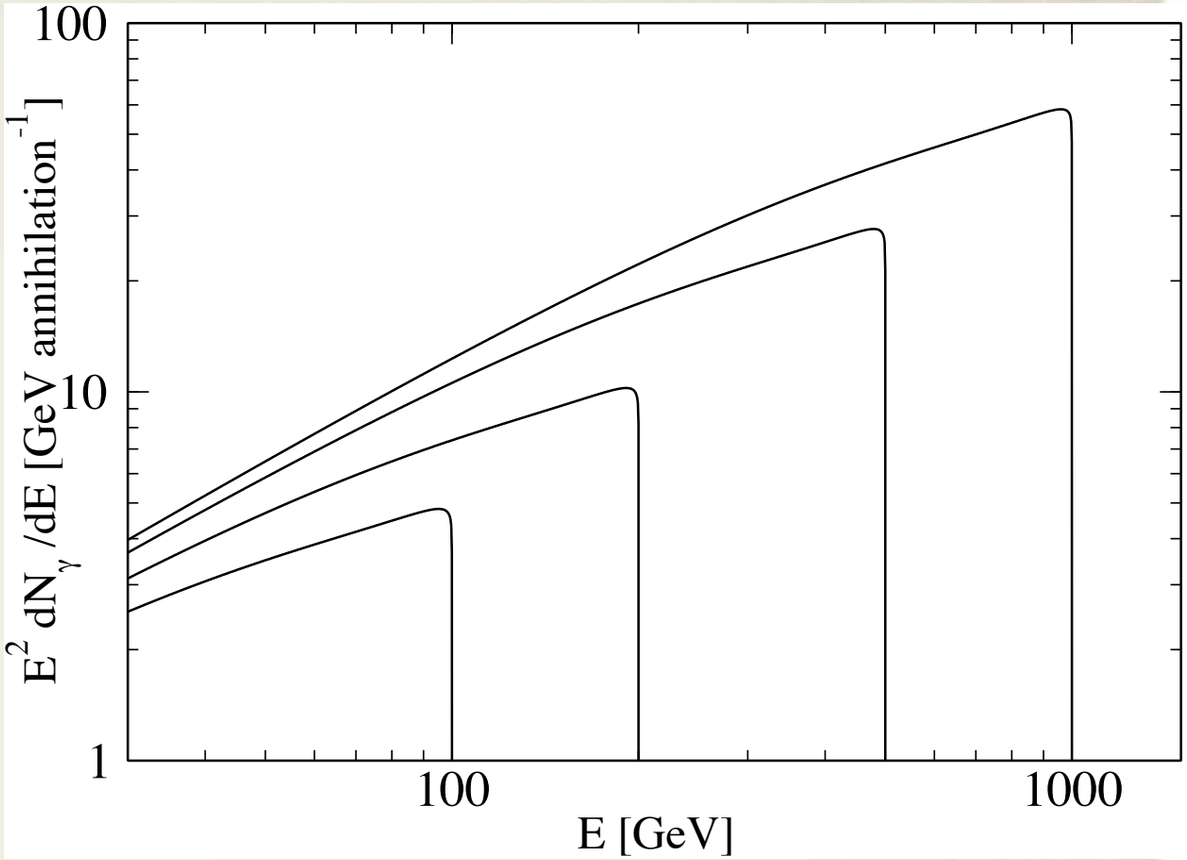
- Similar to analysis for gamma-gamma case
- Different spectrum

$$\frac{d\Phi_\gamma}{dE} = \frac{\langle \sigma_A v \rangle}{2} \frac{\mathcal{J}_{\Delta\Omega}}{\mathrm{J}_0} \frac{1}{4\pi m_\chi^2} \frac{dN_\gamma}{dE}$$

$$\frac{dN_\gamma}{dE} = \frac{1}{\sigma_{\mathrm{tot}}} \frac{d\sigma_{\mathrm{IB}}}{dE_\gamma}$$

$s=4m_\chi^2$

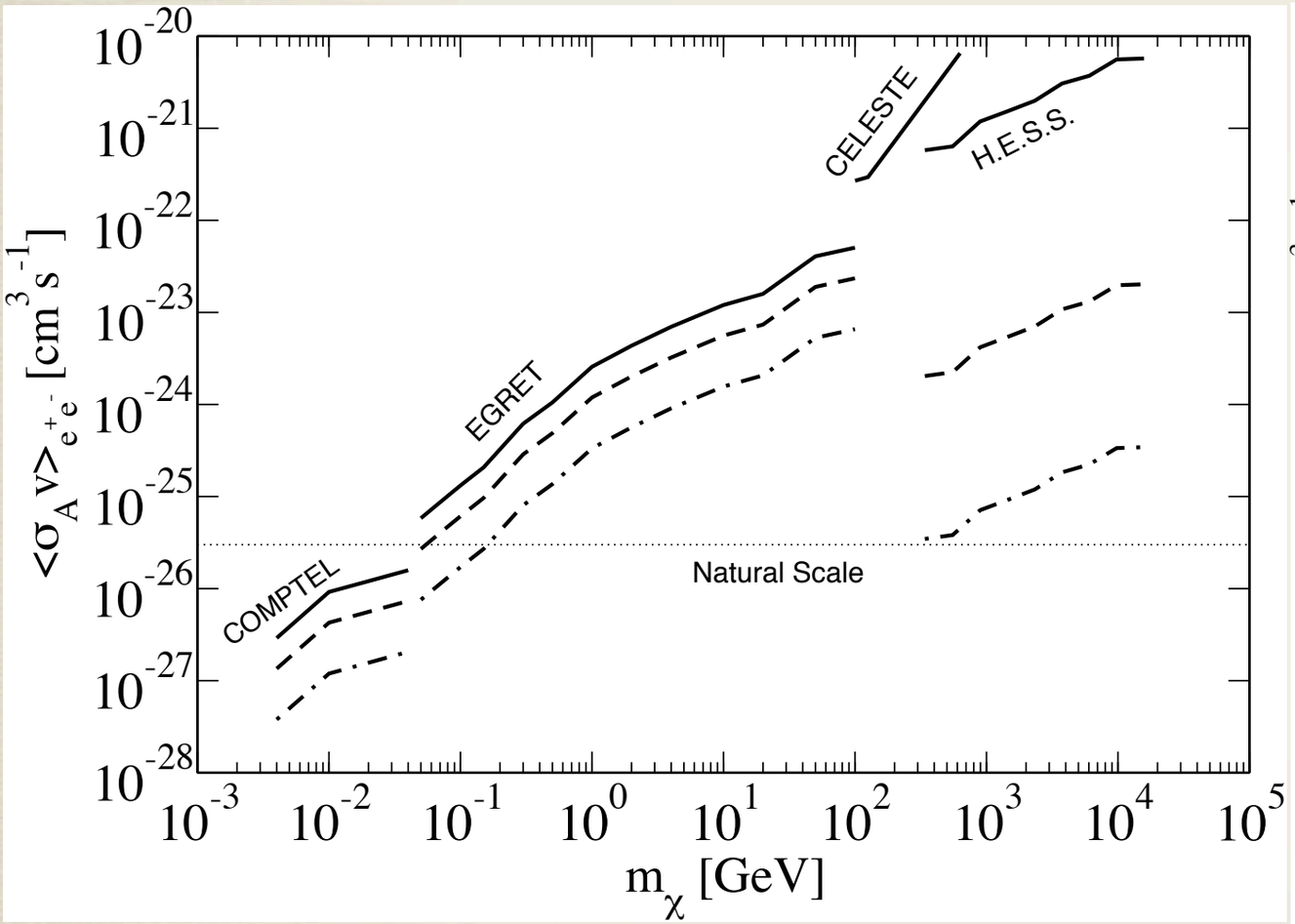
$s'=4m_\chi(m_\chi-E)$

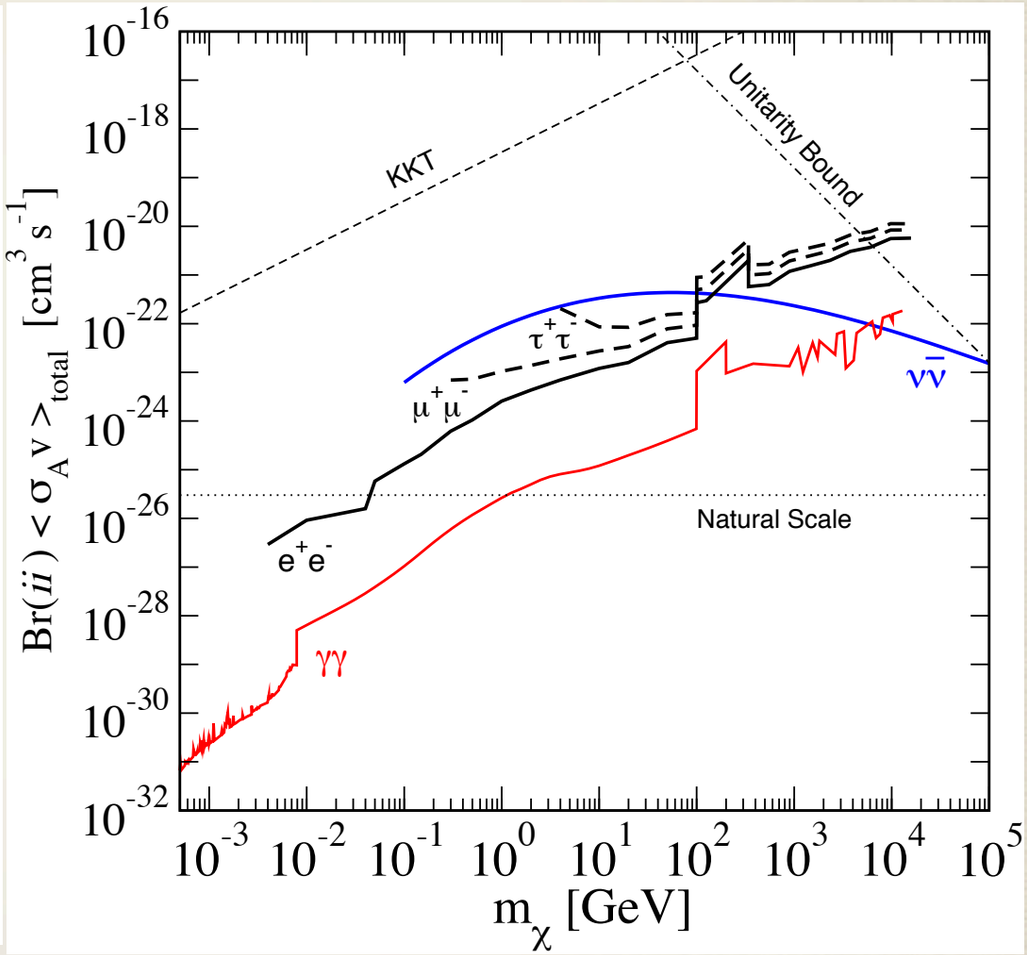


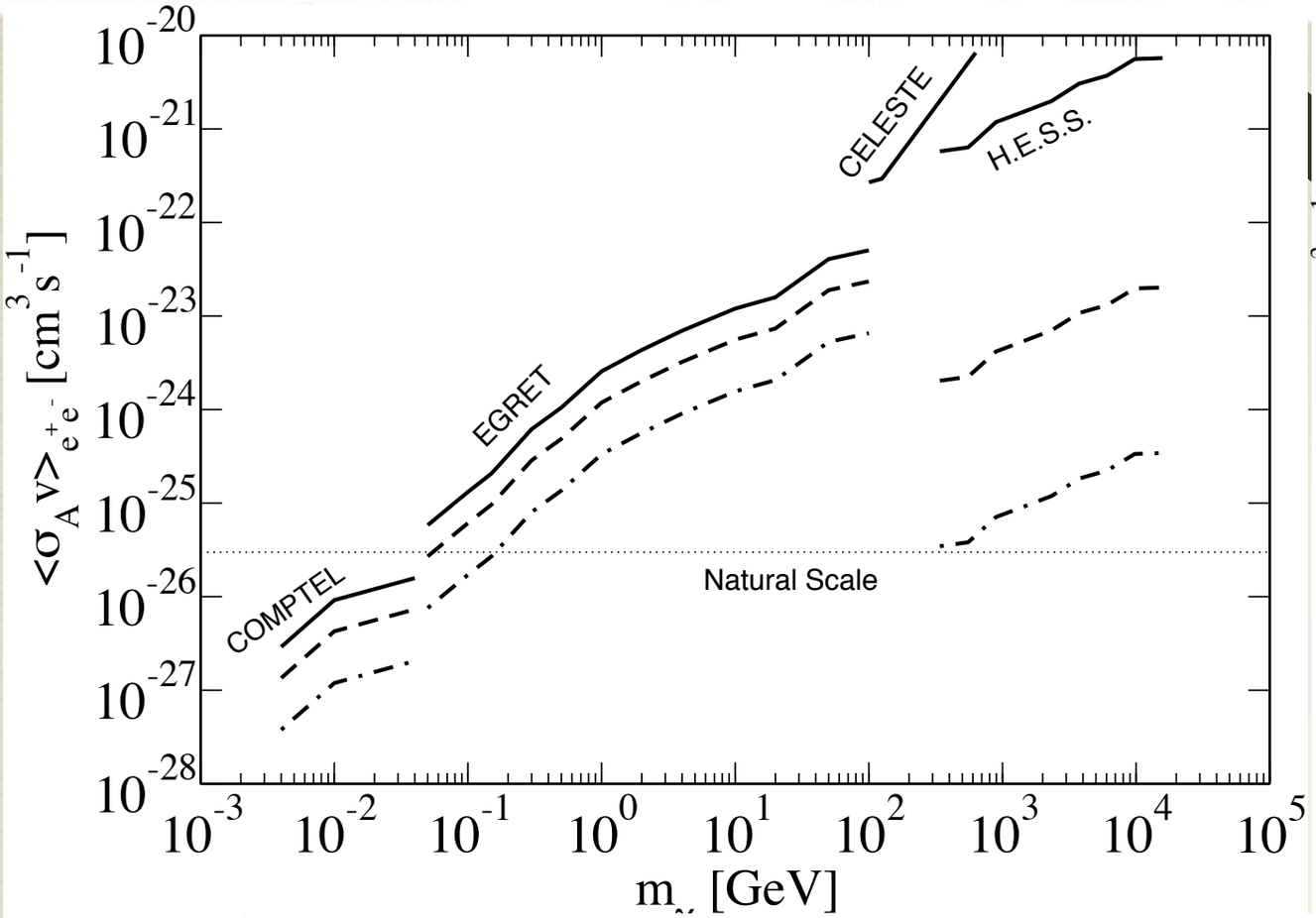
$$\frac{d\sigma_{\mathrm{IB}}}{dE} = \sigma_{\mathrm{tot}} \times \frac{\alpha}{E\pi}\left[\ln\left(\frac{s'}{m_e^2}\right) - 1\right]\left[1 + \left(\frac{s'}{s}\right)^2\right]$$

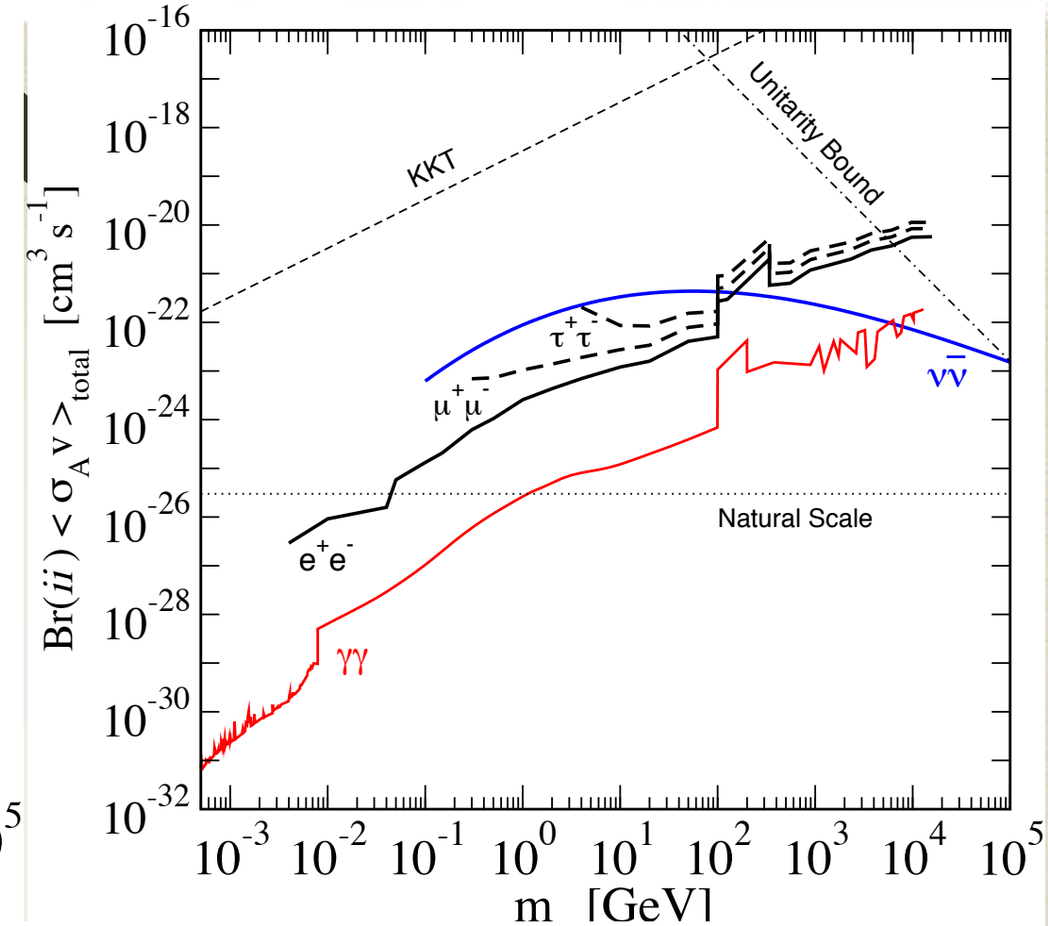
Beacom, Bell, Bertone, Phys.Rev.Lett.94:171301 (2005)

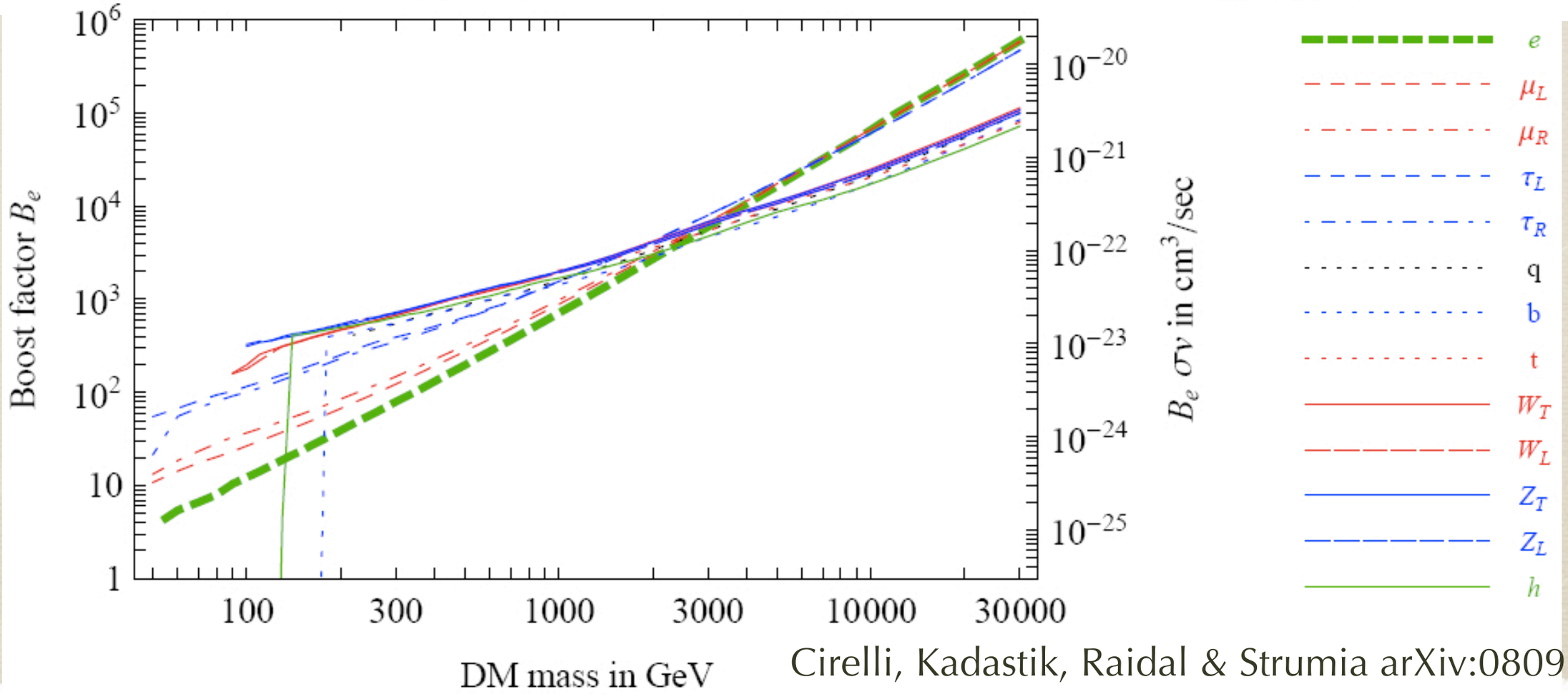
Constraints











Cirelli, Kadastik, Raidal & Strumia arXiv:0809.2409

Summary

- We have placed model independent constraints on the Dark Matter annihilation cross section to various final states
- Examined $\gamma\gamma, \nu\bar{\nu}$, e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$
- $\gamma\gamma$ constraints valid for moderately broad annihilation spectra
- Extremely conservative analysis