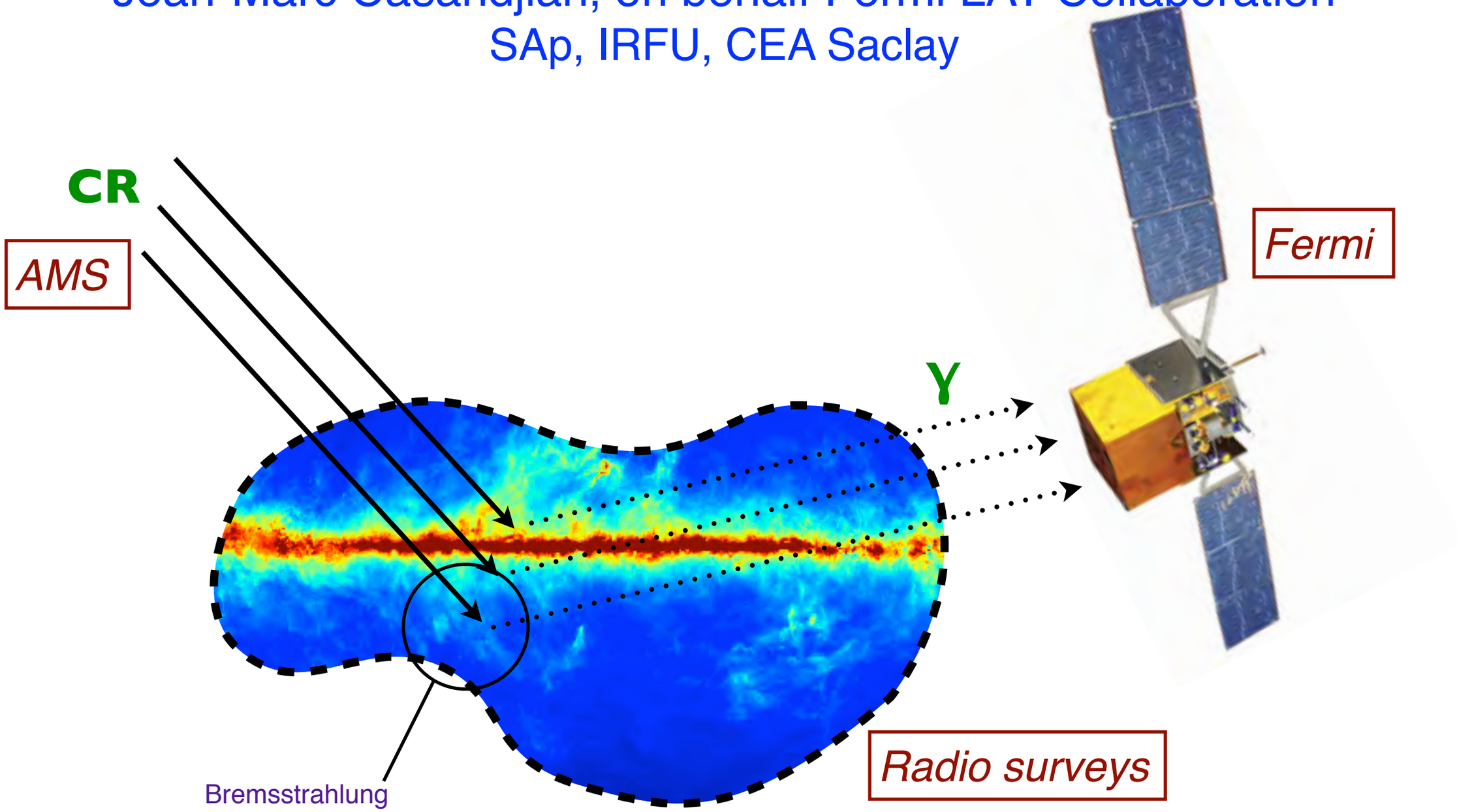
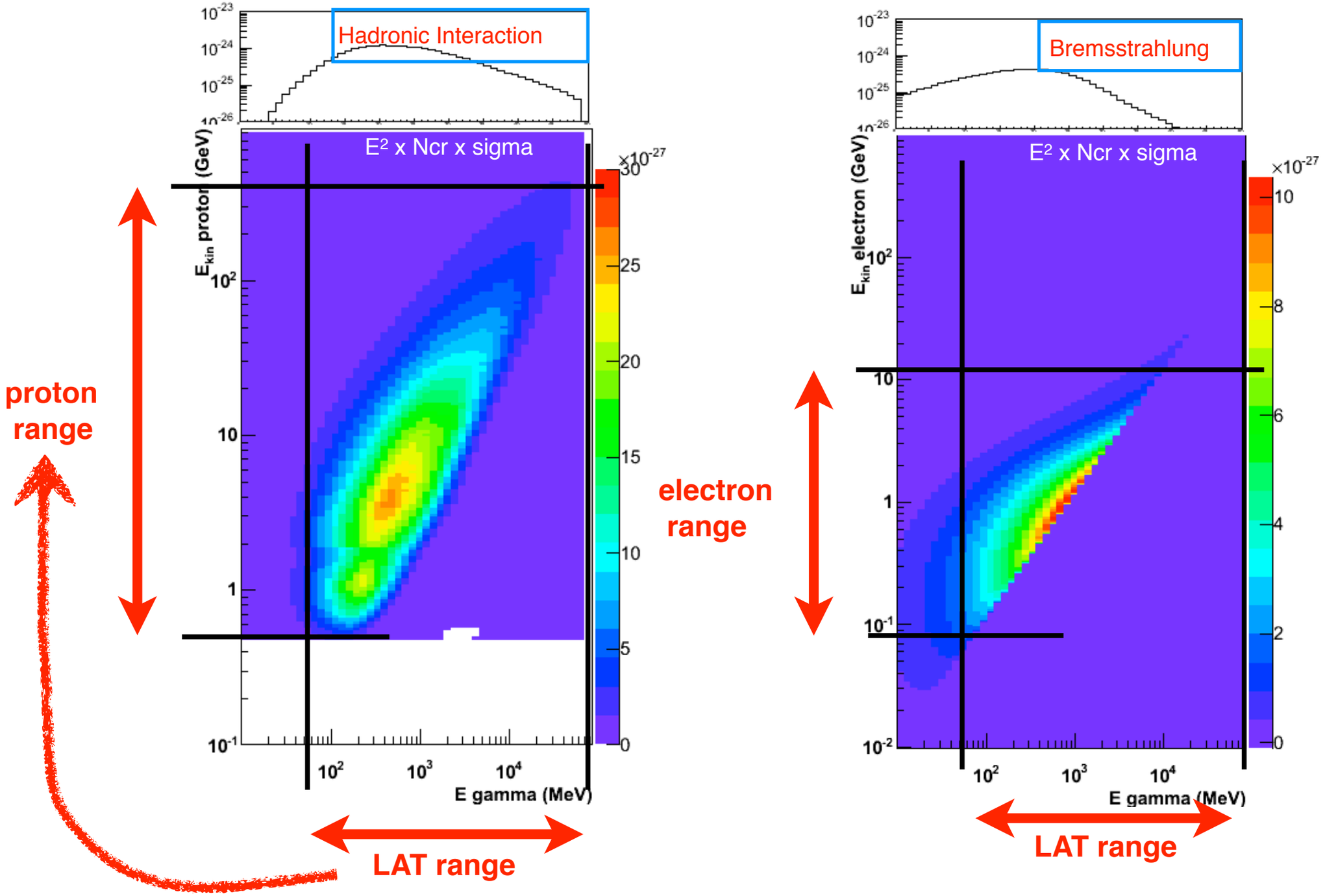
Local HI emissivity and implications for cosmic-ray spectra : improved analysis with Fermi LAT

Jean-Marc Casandjian, on behalf Fermi LAT Collaboration
SAp, IRFU, CEA Saclay

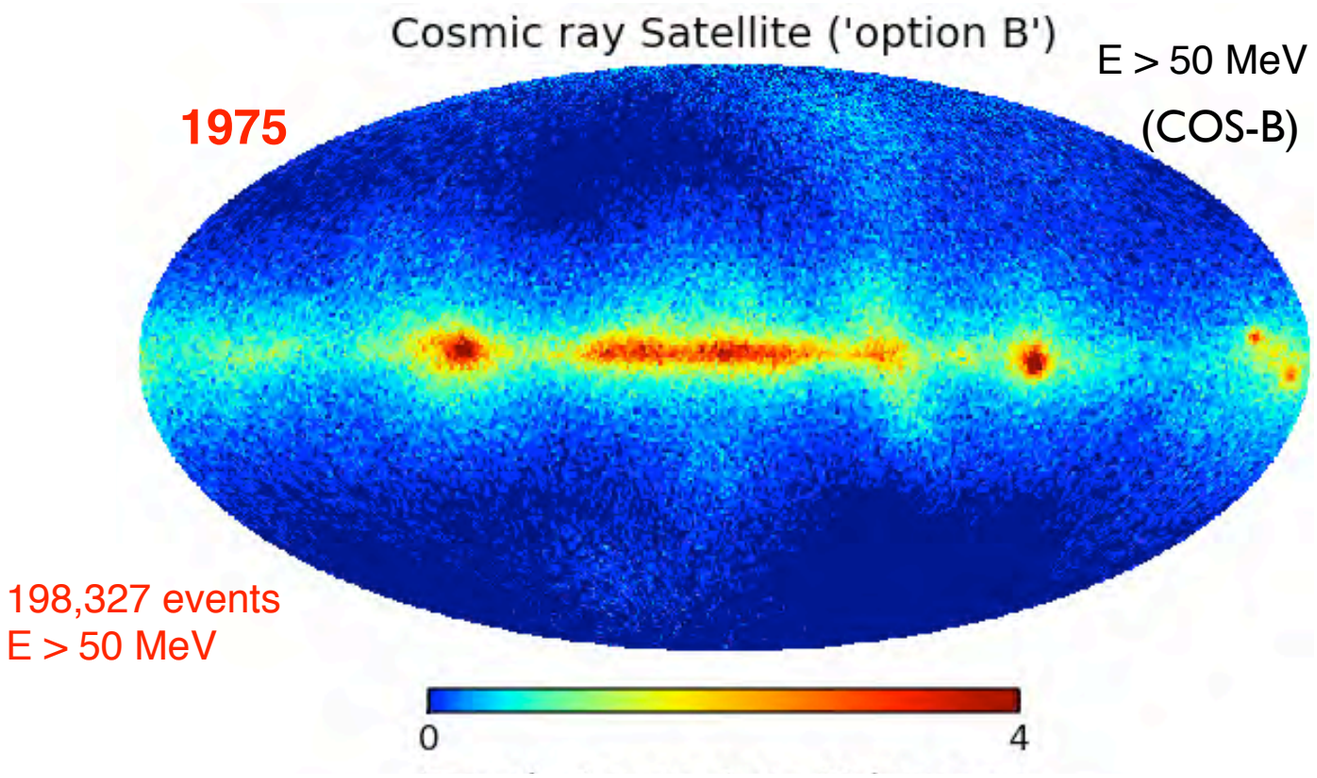


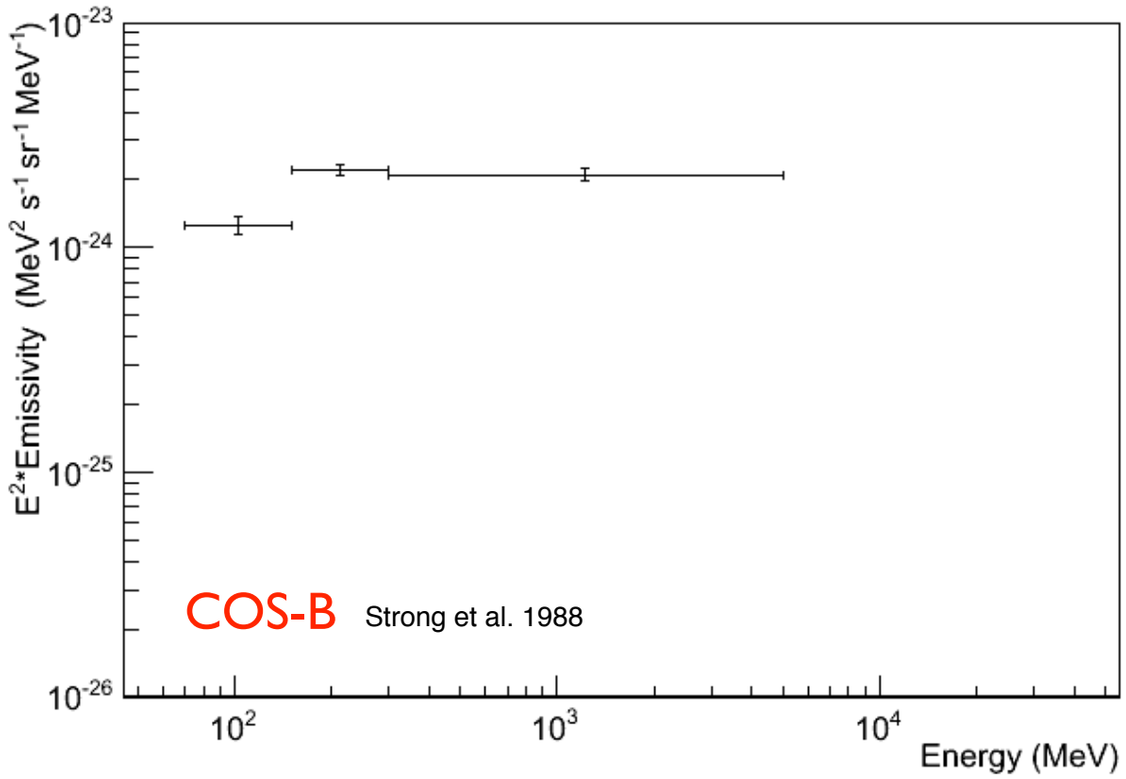
$$q_{HI} \propto F_{CR} \times \sigma_{pp \to \gamma}$$

$$N_\gamma(l,b) = q_{HI} N_{HI}(l,b) + q_{CO} W_{CO}(l,b) + IC + ..$$



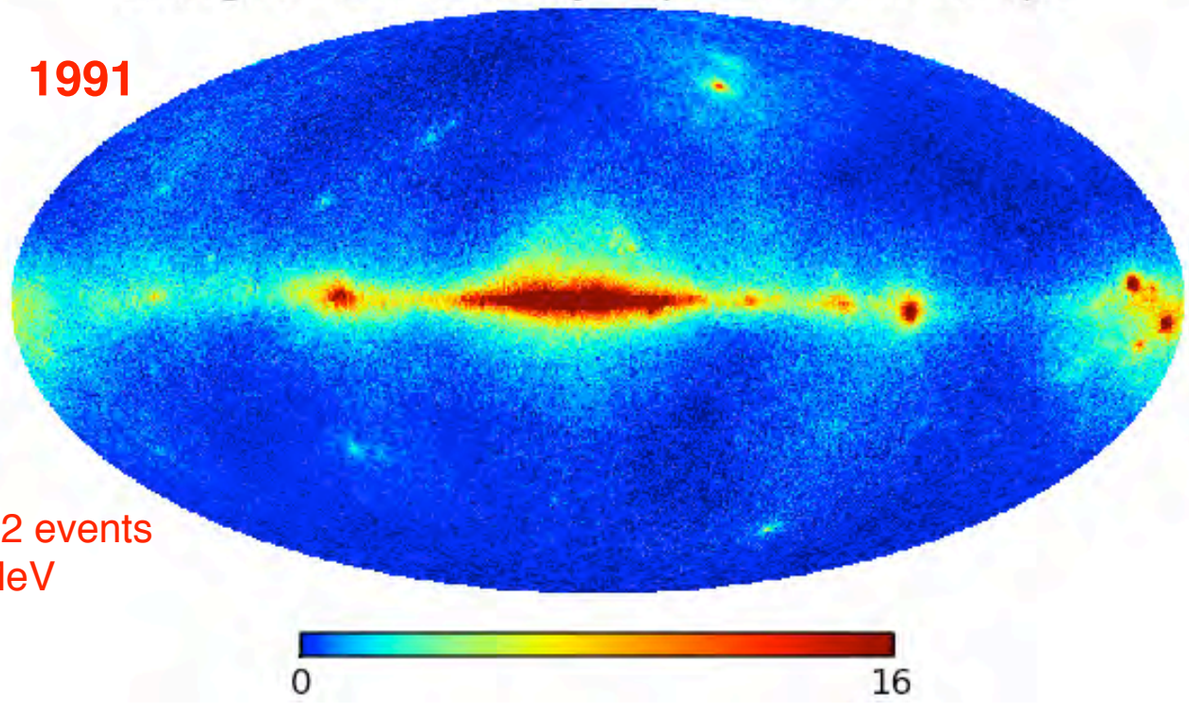
The measure of HI emissivity is an indirect tool to probe a wide range of the electron, proton (and alpha) spectrum.


Cosmic ray Satellite ('option B')
1975
E > 50 MeV
(COS-B)
198,327 events
E > 50 MeV
0
4

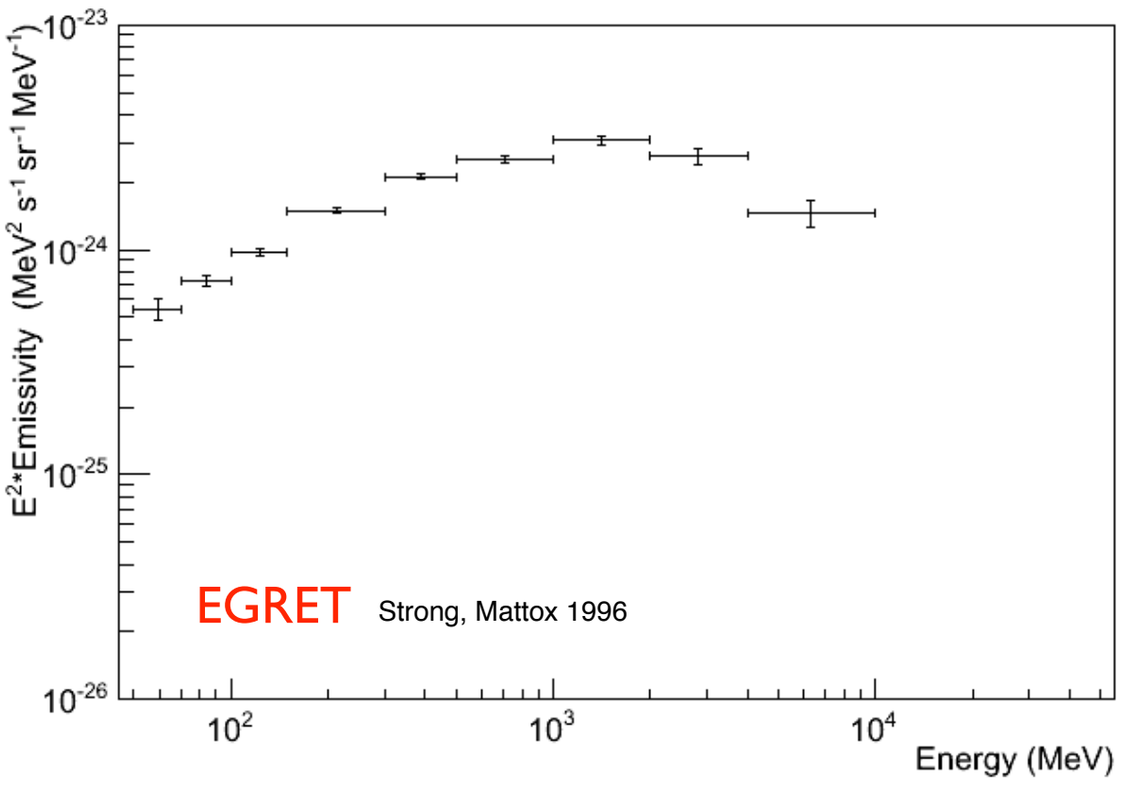

10^{-23}
10^{-24}
10^{-25}
10^{-26}
E^2*Emissivity (MeV^2 s^{-1} sr^{-1} MeV^{-1})
COS-B Strong et al. 1988
10^2
10^3
10^4
Energy (MeV)

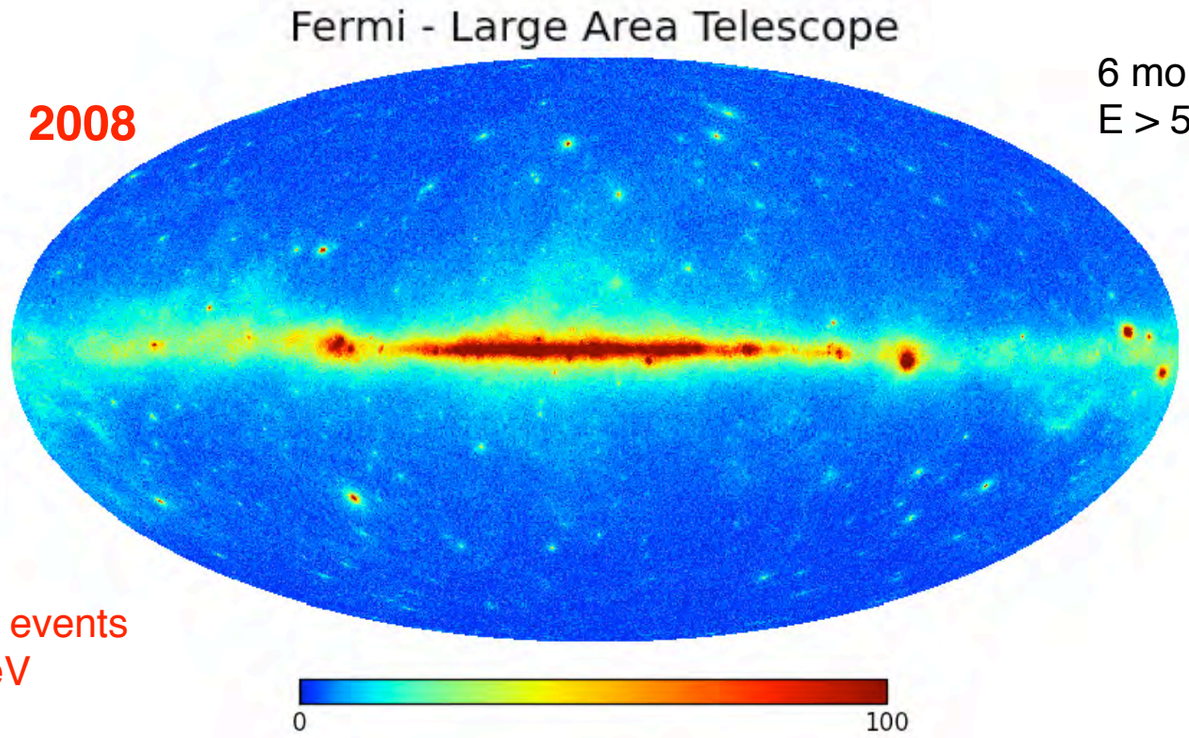
Energetic Gamma Ray Experiment Telescope E > 50 MeV

1991



1,151,662 events
E > 50 MeV

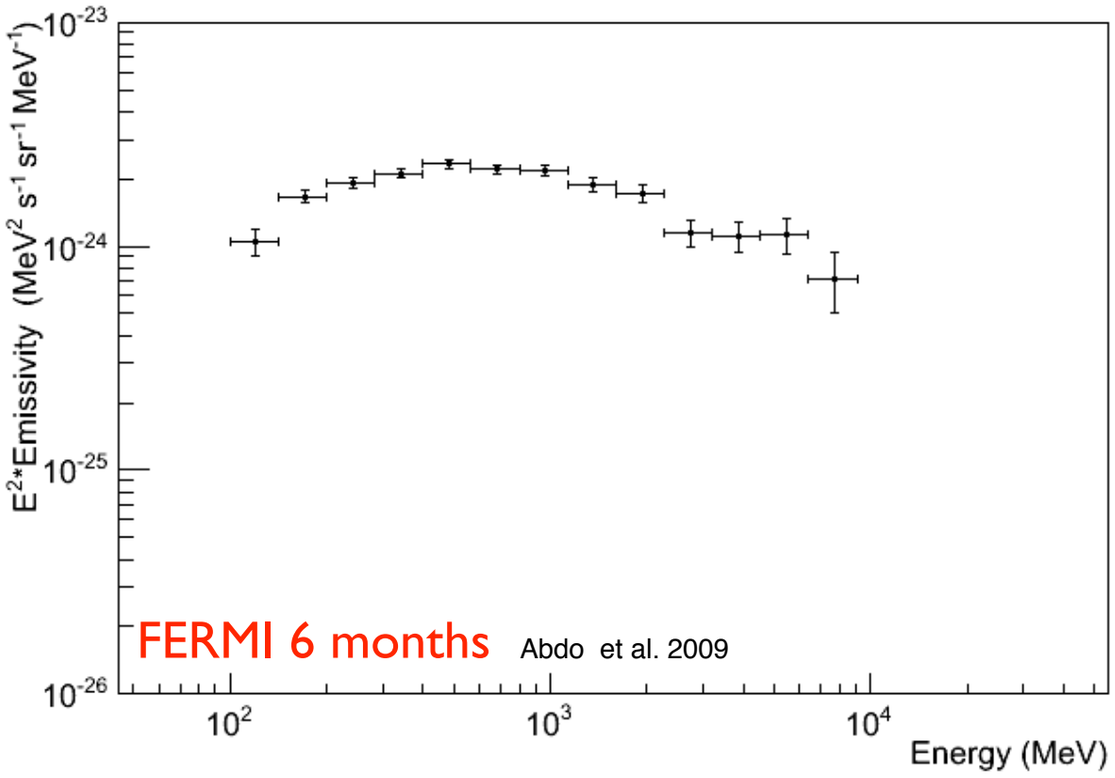




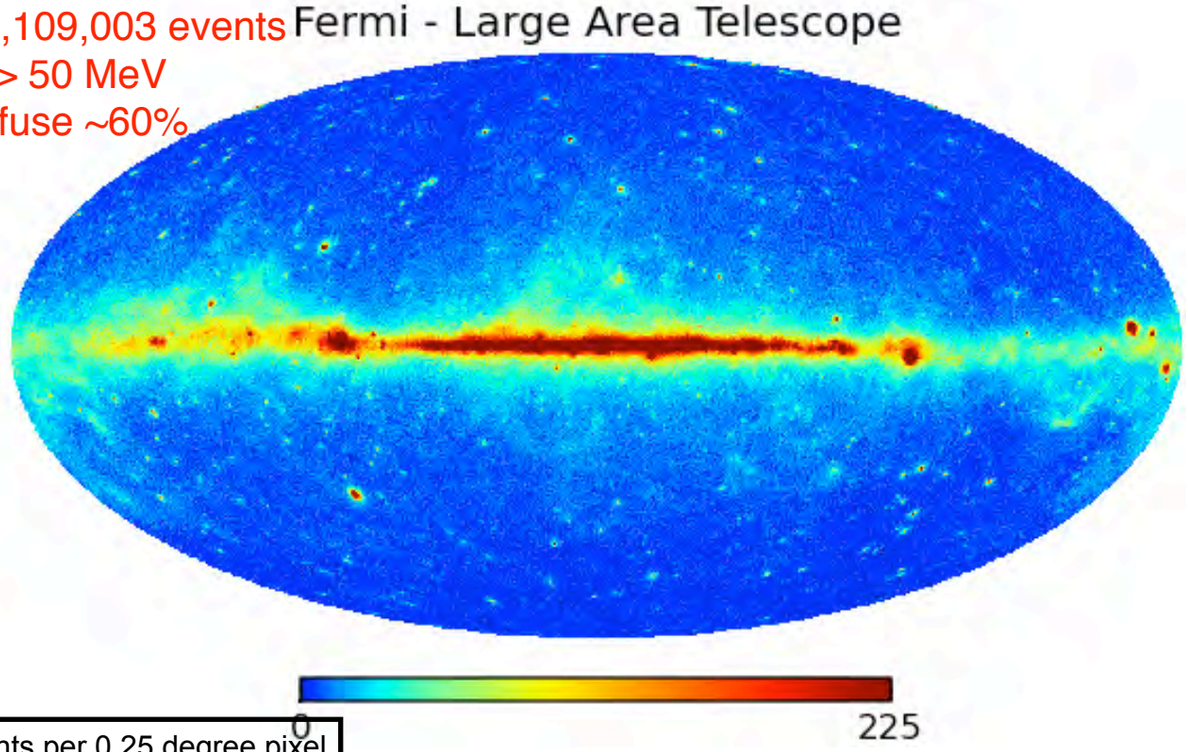
2008

6 months of data
E > 50 MeV

6,644,665 events
E > 50 MeV



43,109,003 events
E > 50 MeV
diffuse ~60%

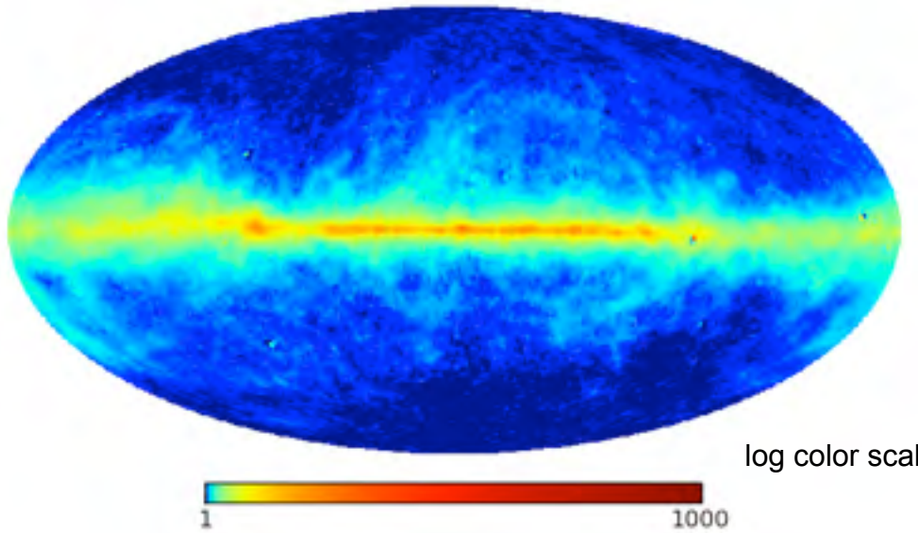


counts per 0.25 degree pixel
sqrt color scaling
E>360MeV

$$N_\gamma(l,b) = q_{HI} N_{HI}(l,b) + q_{CO} W_{CO}(l,b) + IC + ..$$

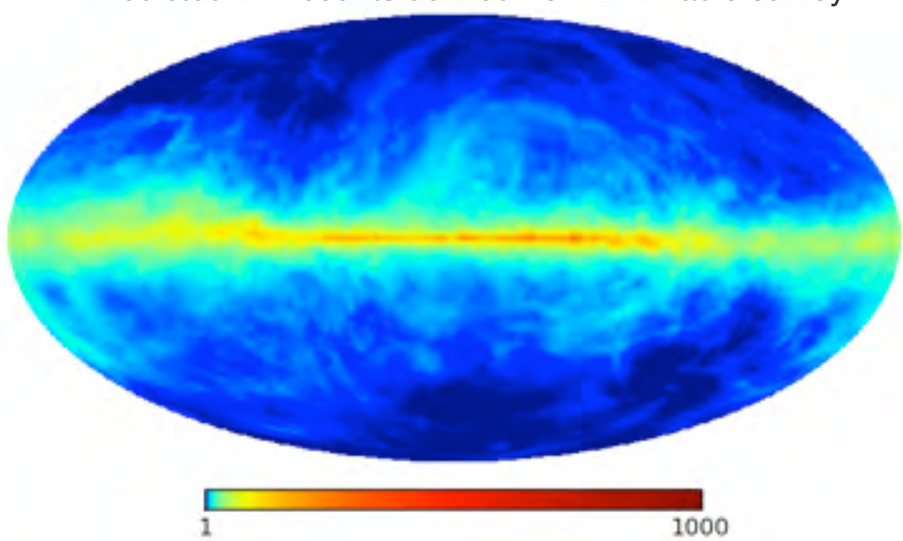
$$N_\gamma(l,b) - q_{CO} W_{CO}(l,b) - IC - .. = q_{HI} N_{HI}(l,b)$$

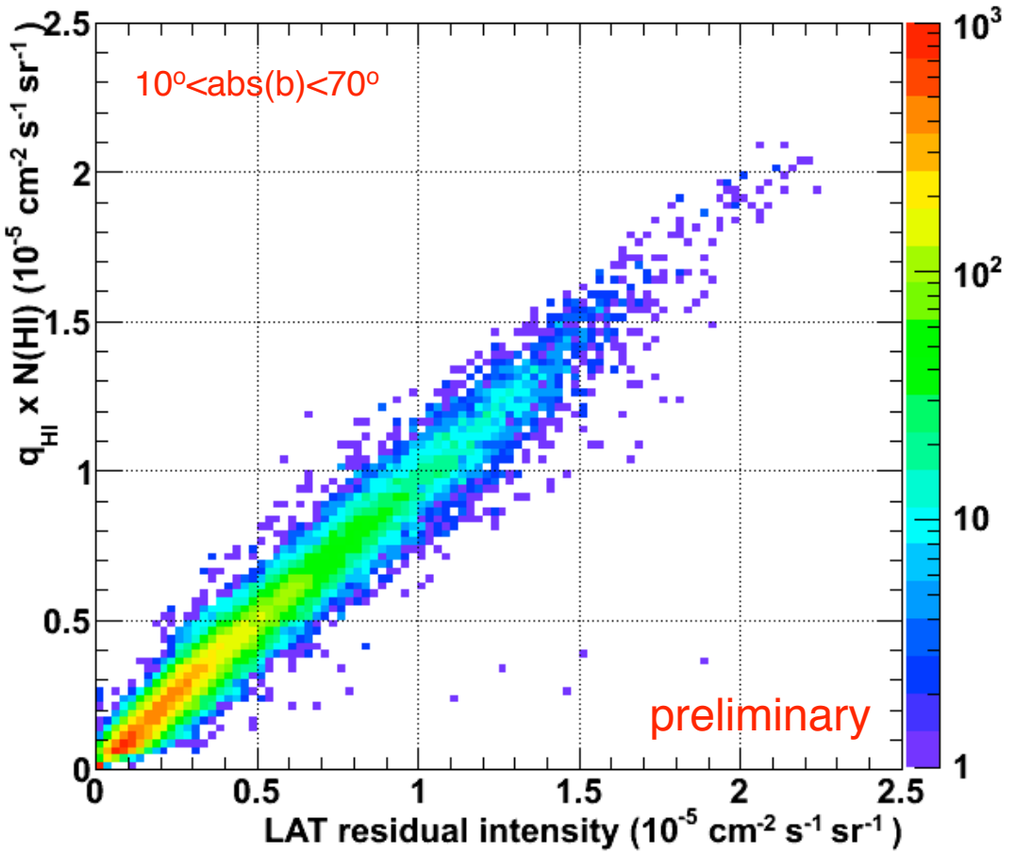
LAT counts correlated with atomic hydrogen



log color scaling

Predicted LAT counts derived from LAB radio survey.





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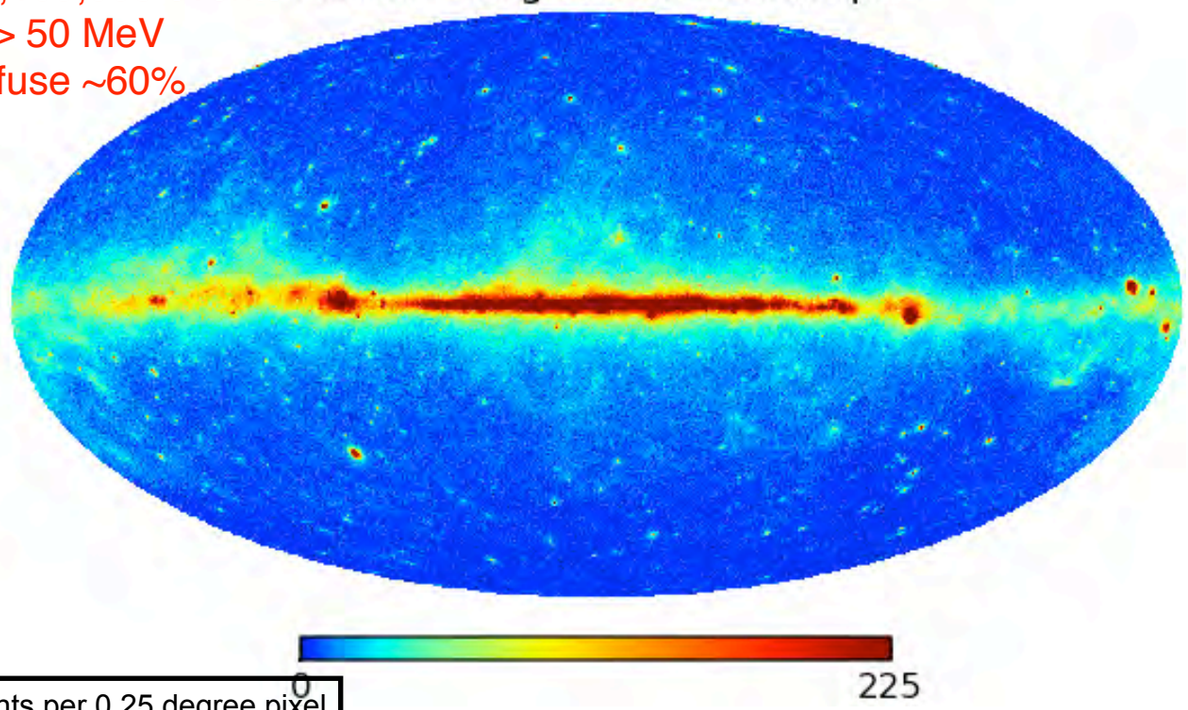

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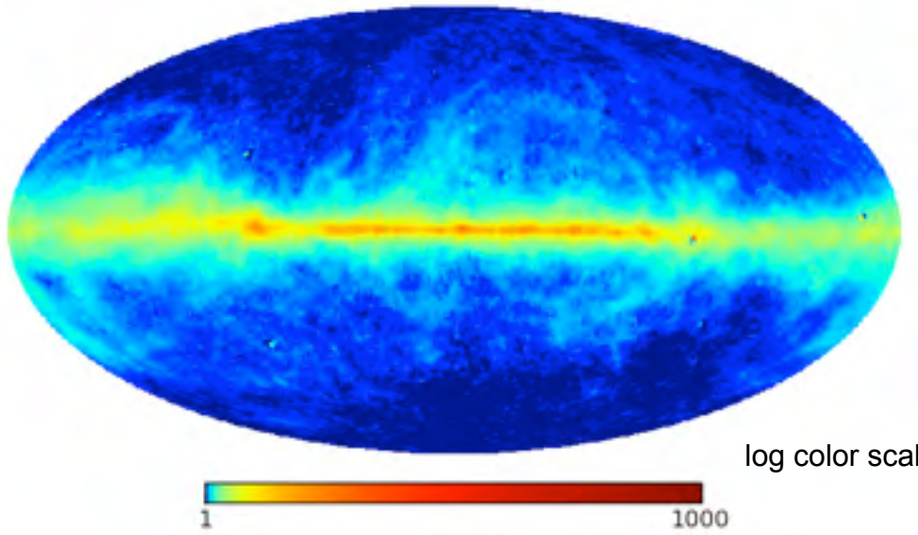

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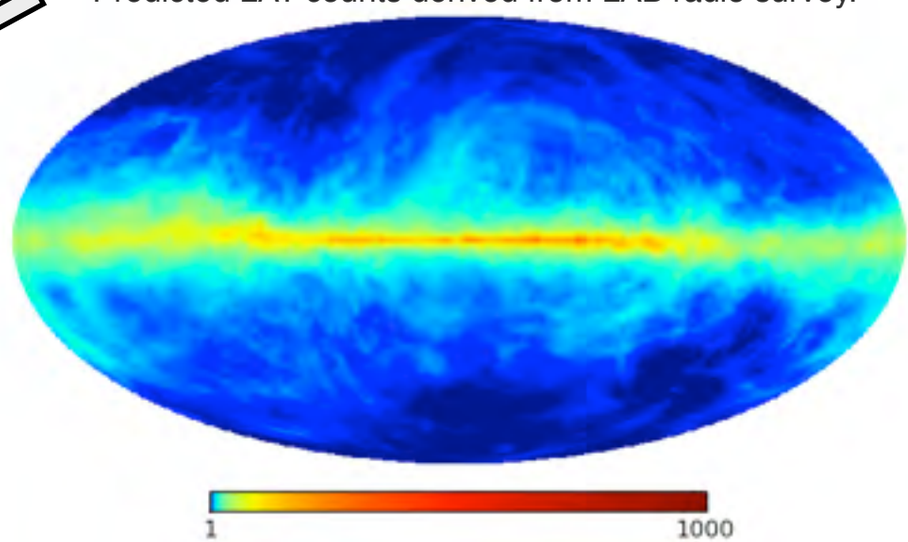
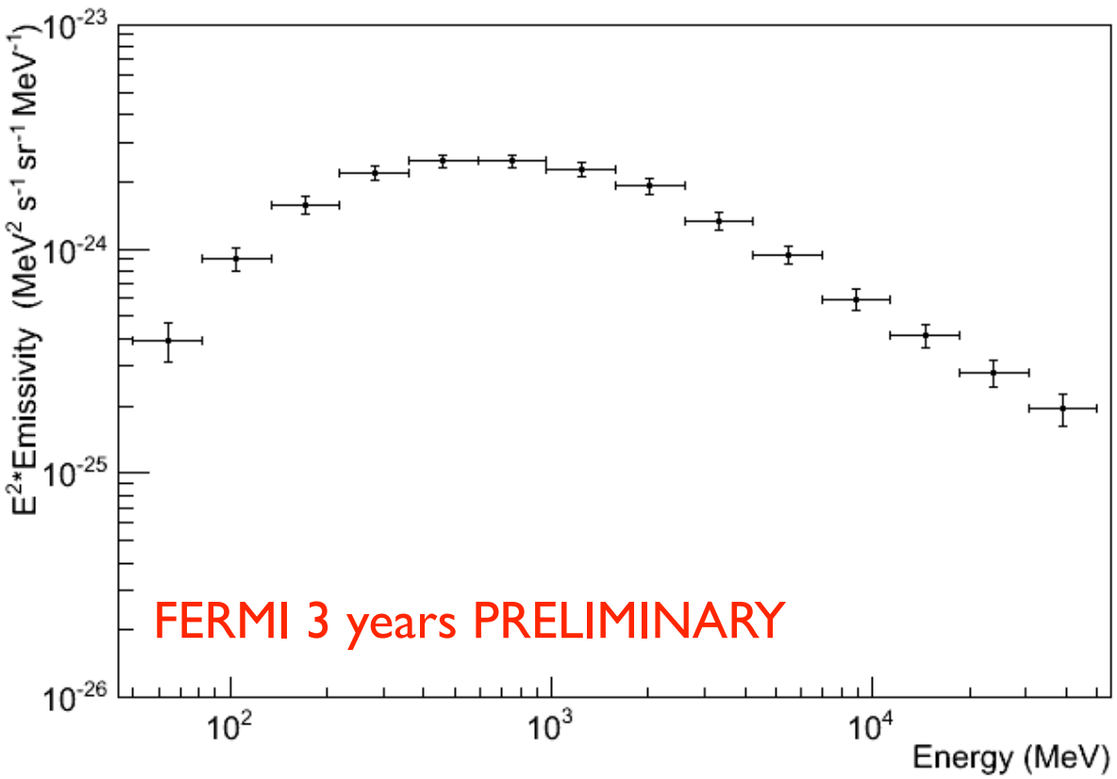


Local HI emissivity: 10°<abs(b)<70° corresponding to 8<r<10 kpc
Uncertainty includes systematics



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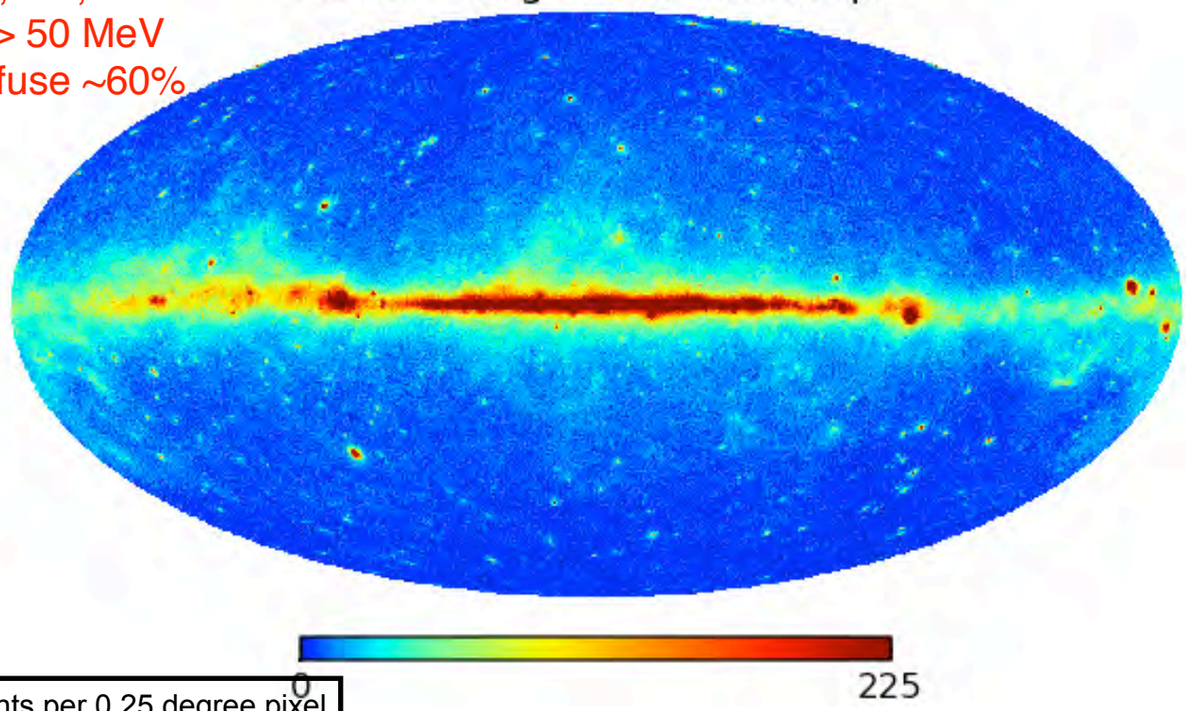

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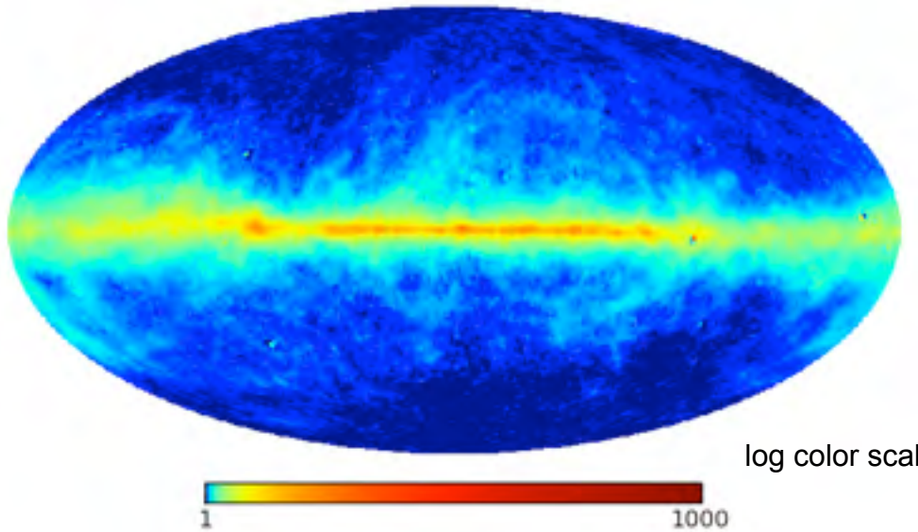

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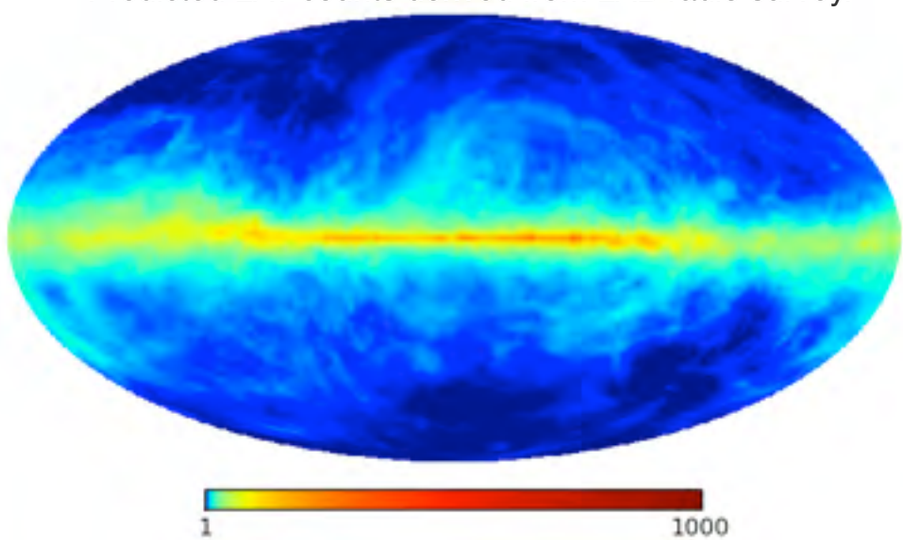
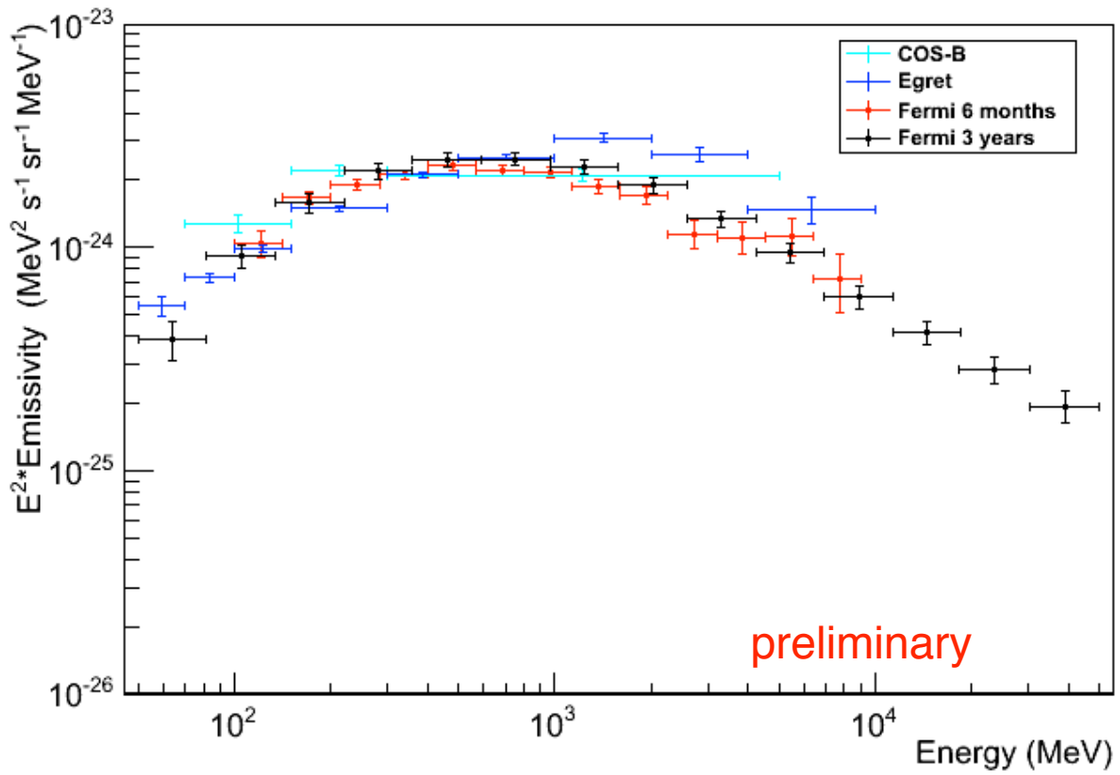
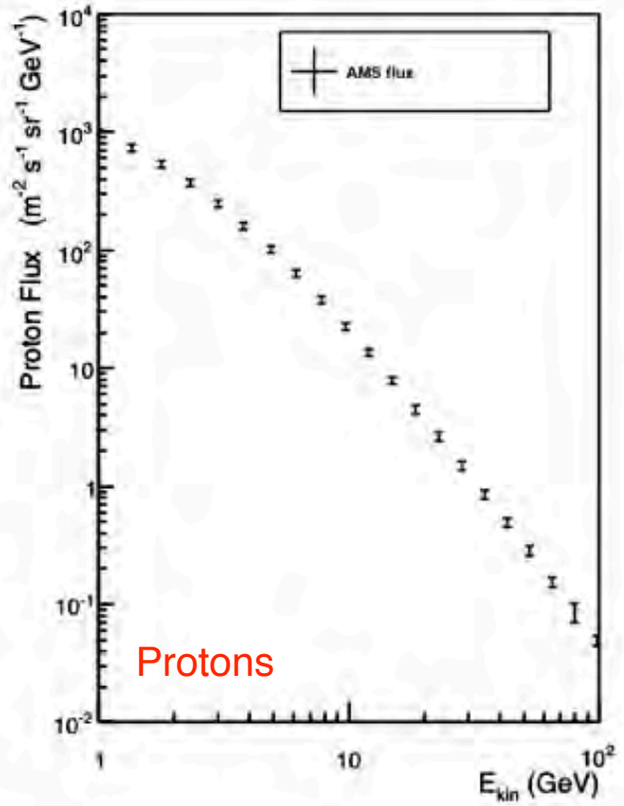


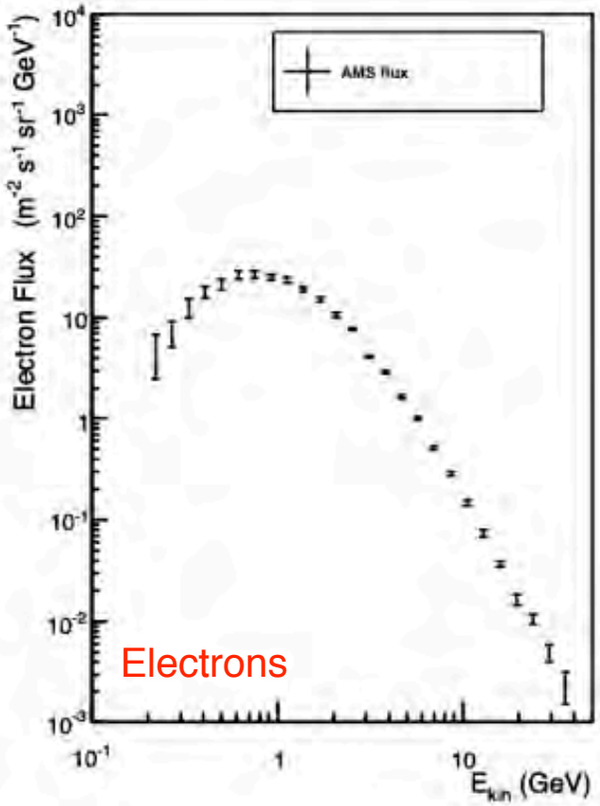


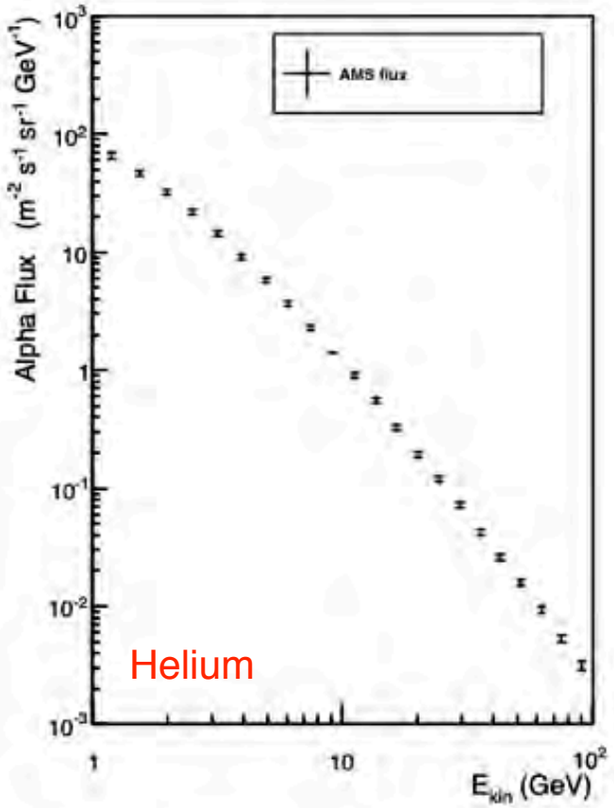
$$q_{HI} \propto F_{CR} \times \sigma_{pp \to \gamma}$$

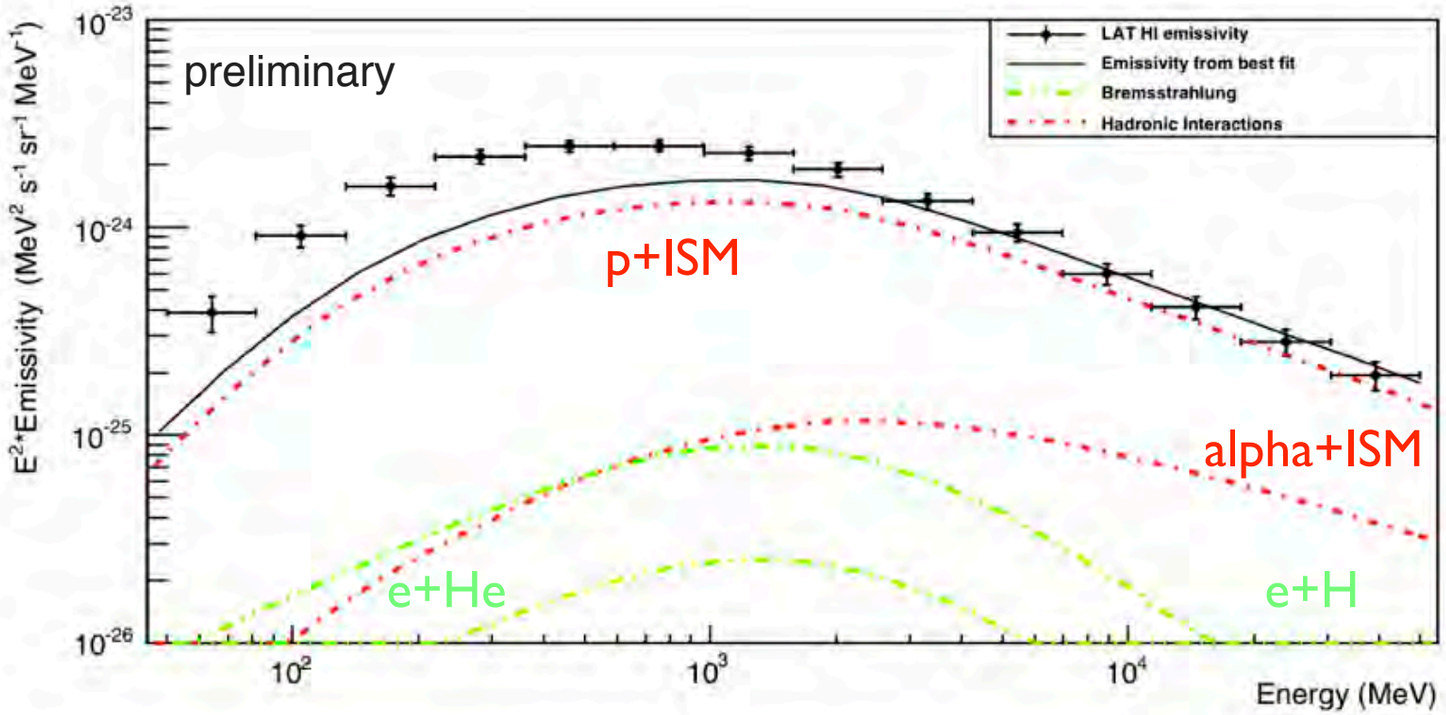
Kamae *et al.*, 2006
Huang *et al.*, 2007
Mori *et al.*, 2009

talk by Chuck Dermer includes studies of production cross sections









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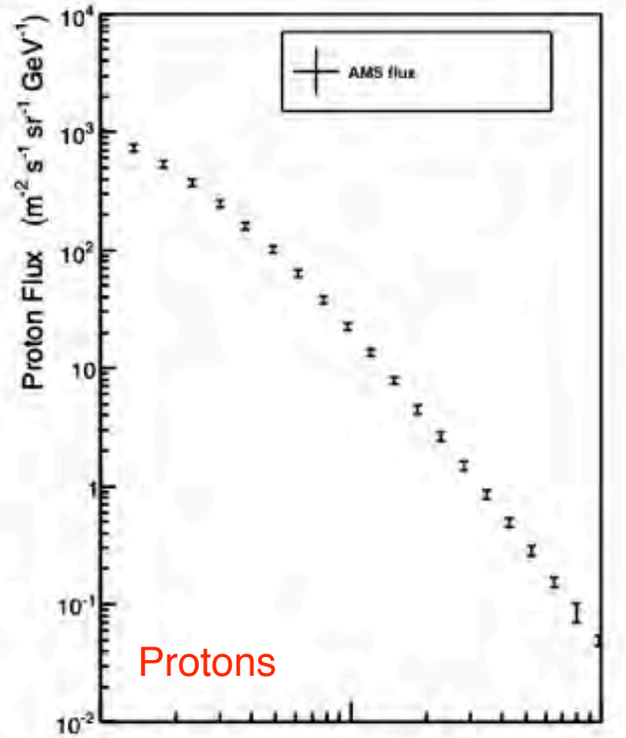
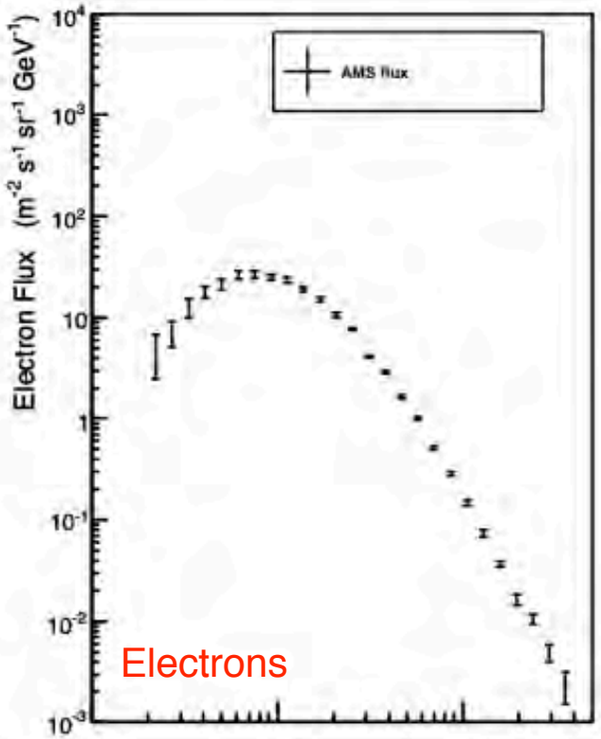
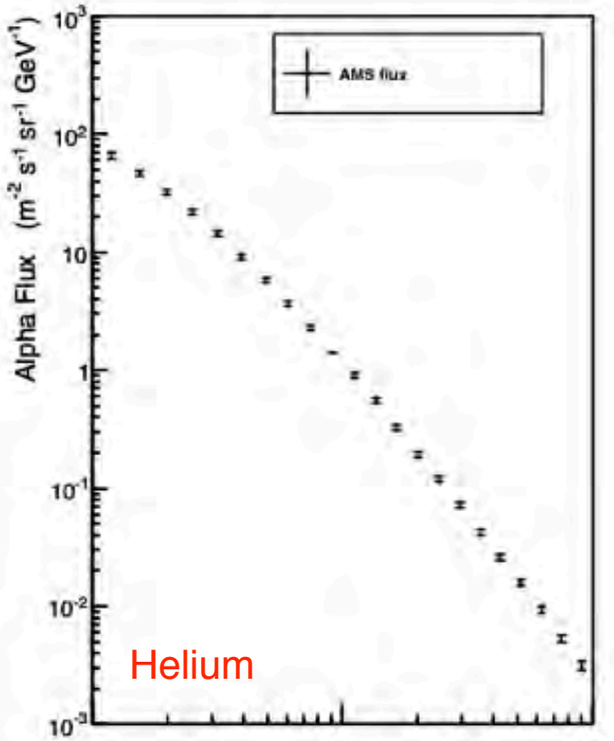
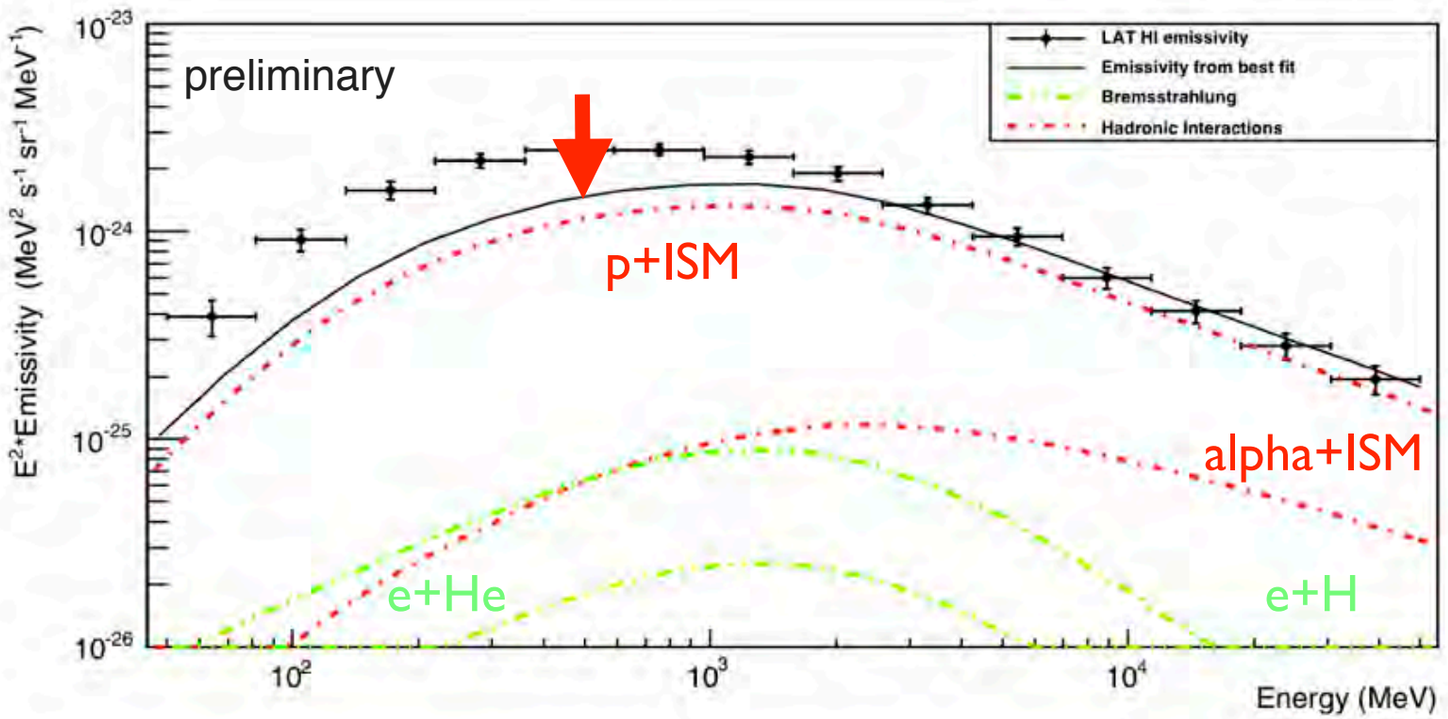






Solar modulation !



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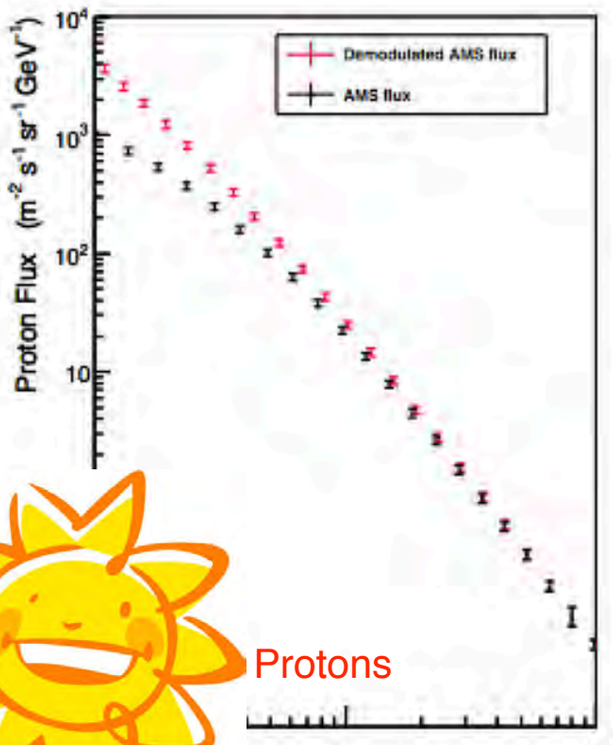
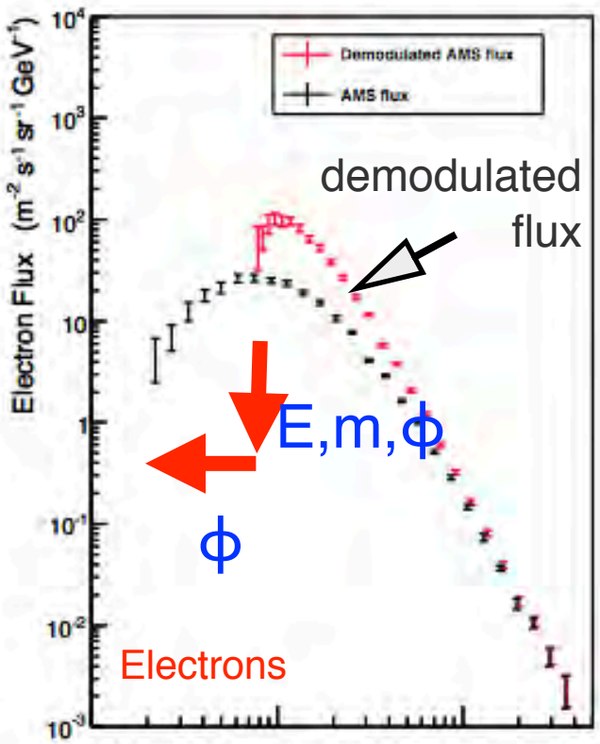
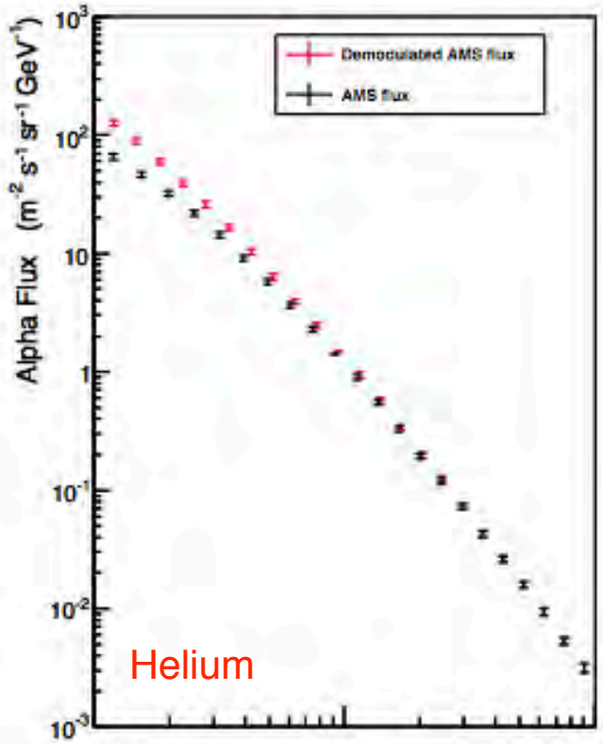


Protons



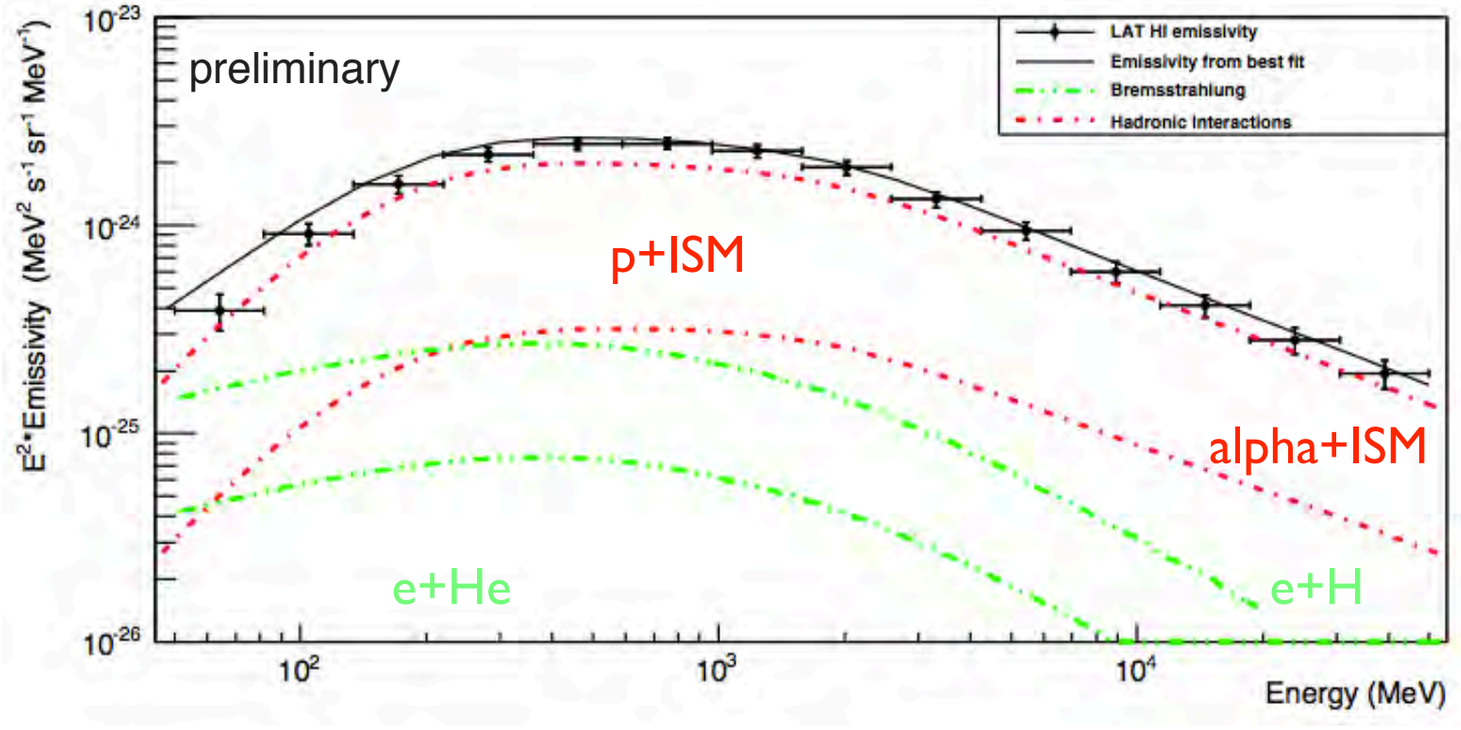
Electrons



Helium

$$\frac{J(r,\mathfrak{E},t)}{\mathfrak{E}^2 - \mathfrak{E}_0^2} = \frac{J(\infty,\mathfrak{E}+\Phi)}{(\mathfrak{E}+\Phi)^2 - \mathfrak{E}_0^2}$$

Force field approximation
Gleeson, Axford, 1968



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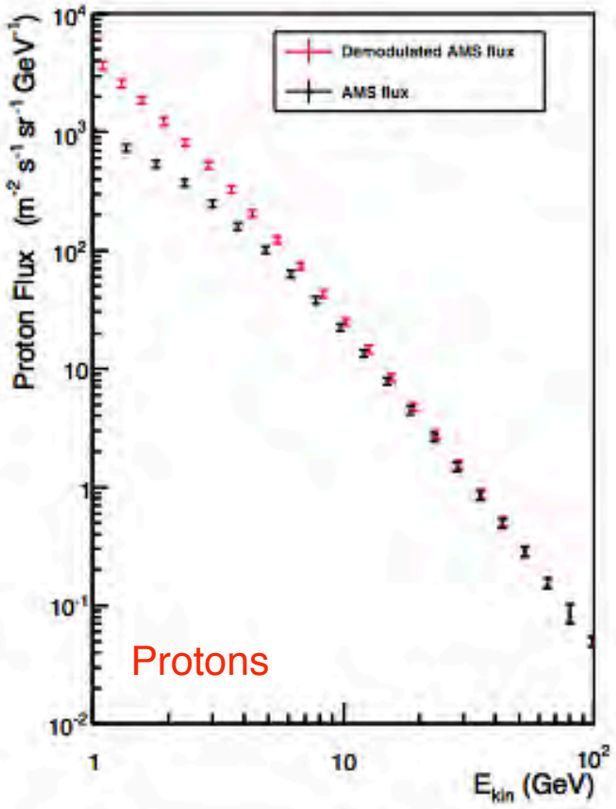

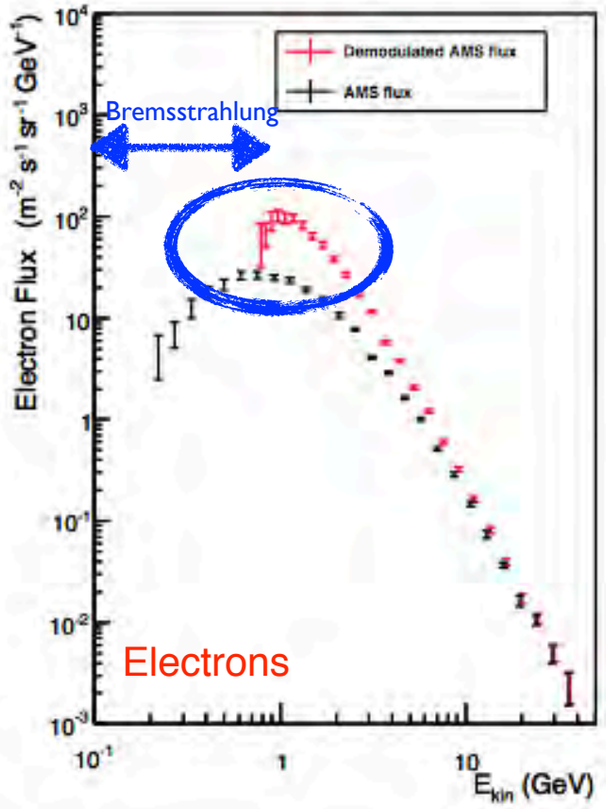

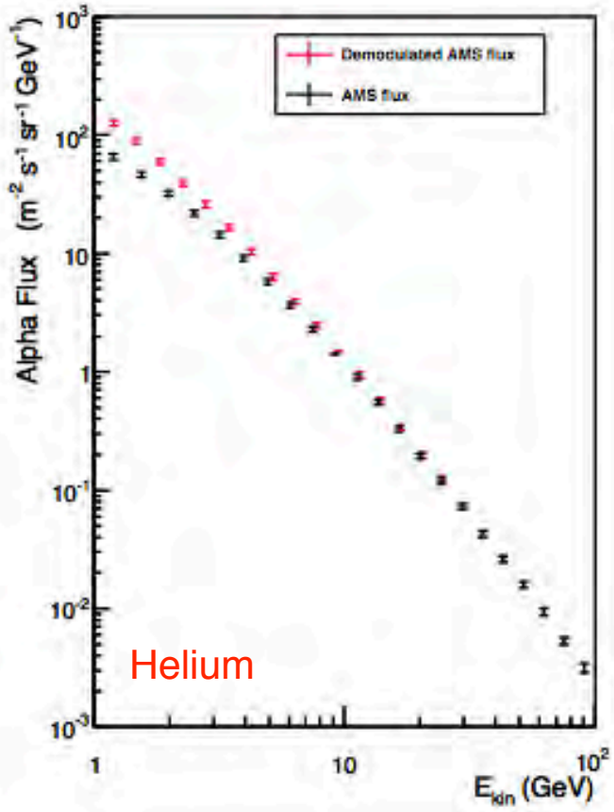

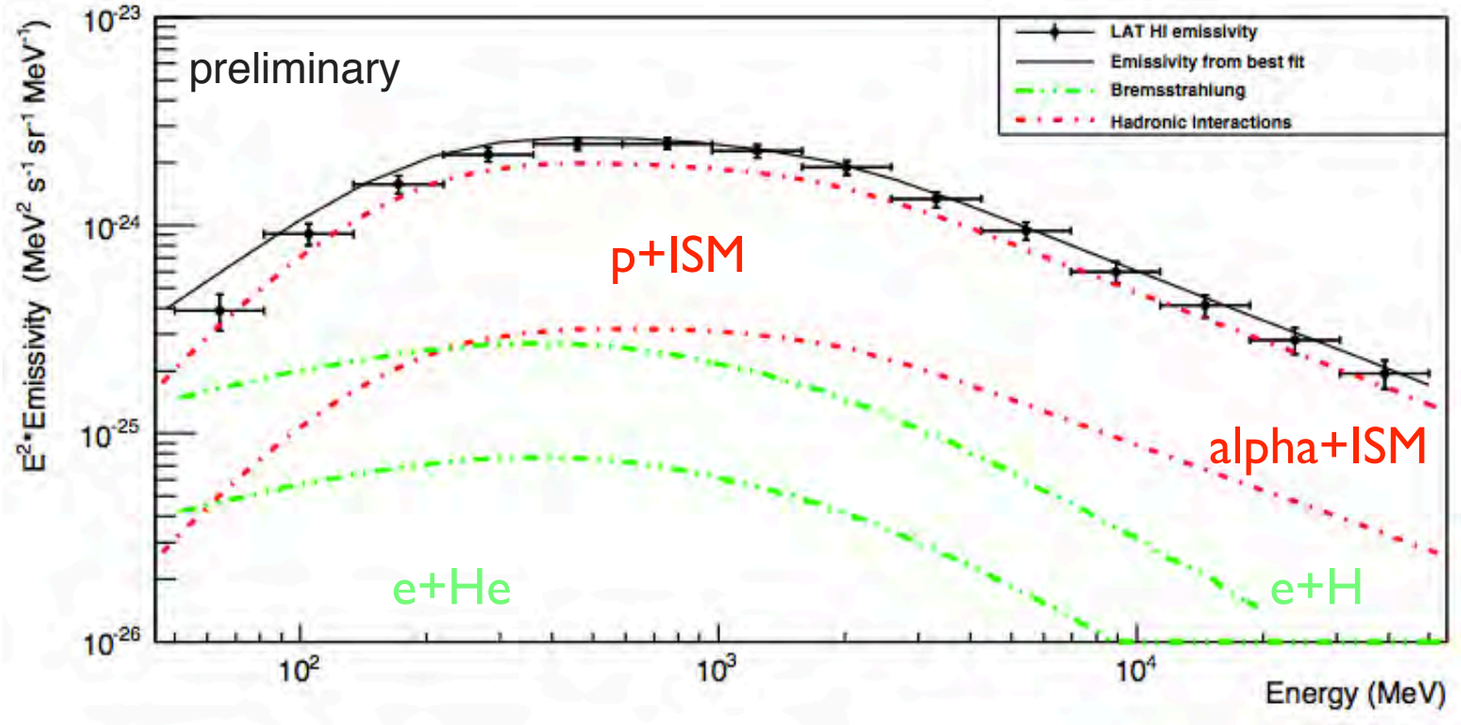

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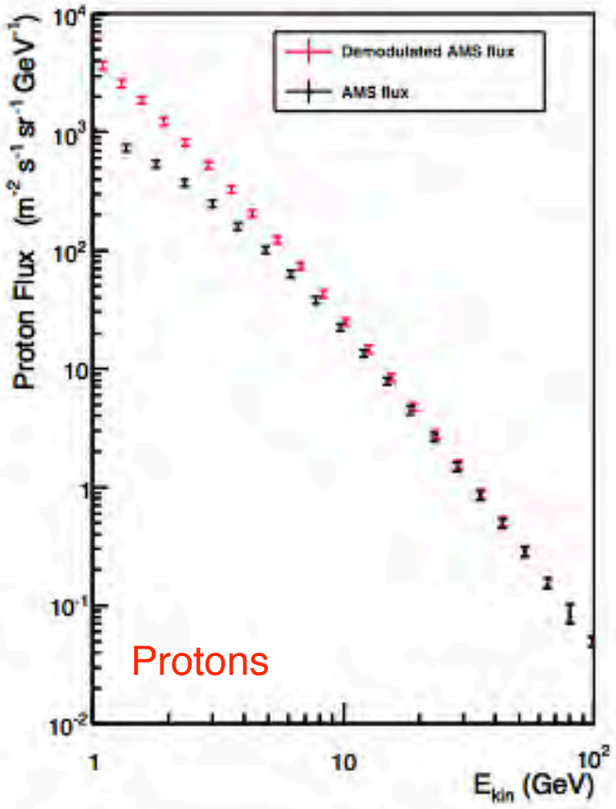
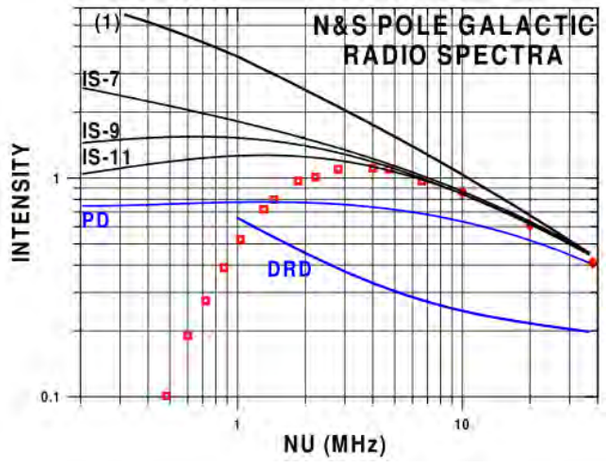
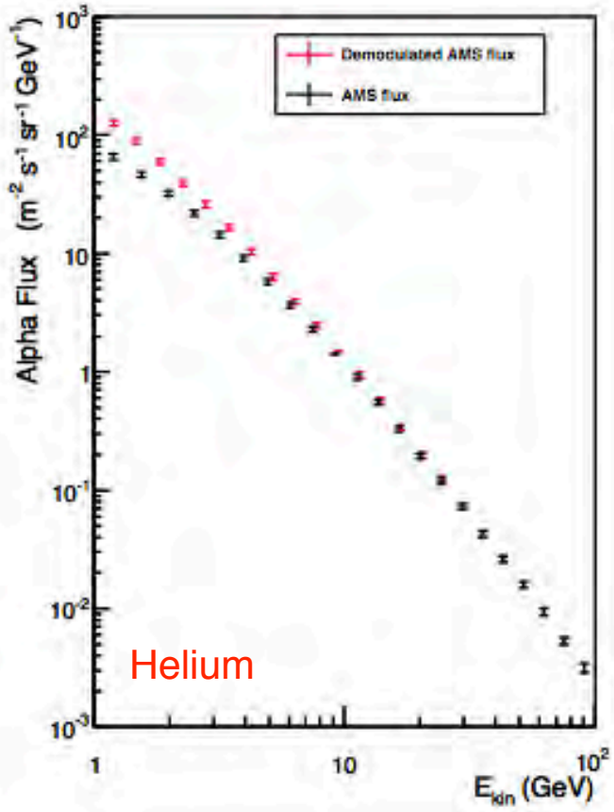
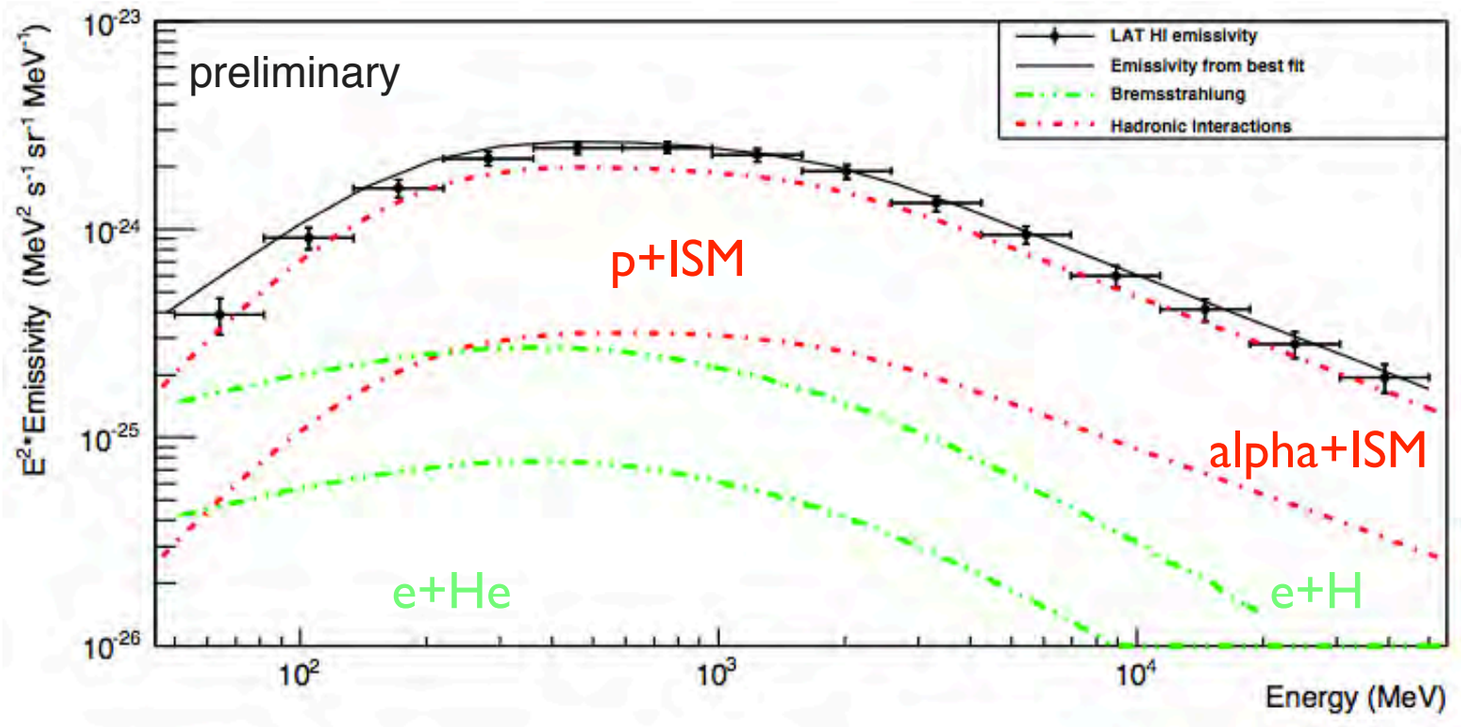


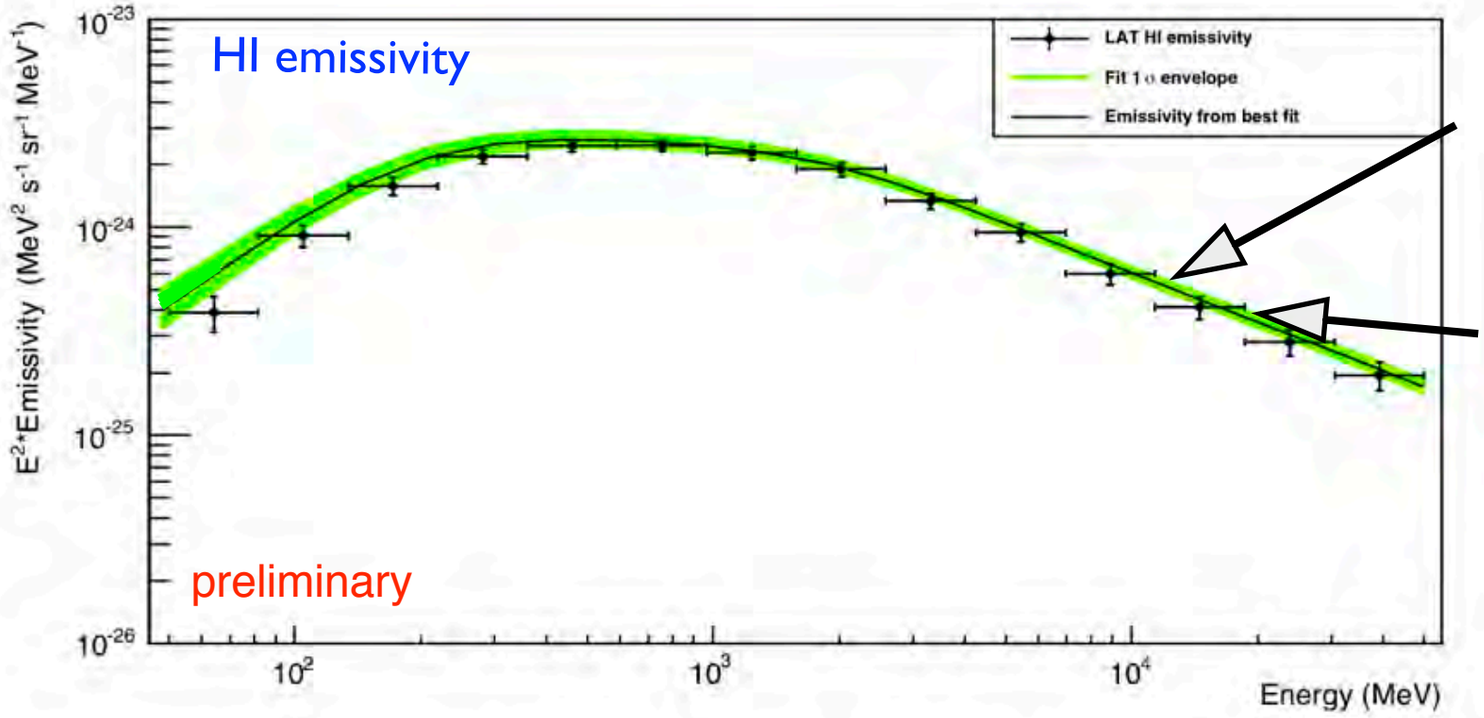
Electron spectrum
from synchrotron:

Webber & Higbie 2008,
JGR, 113, 11106



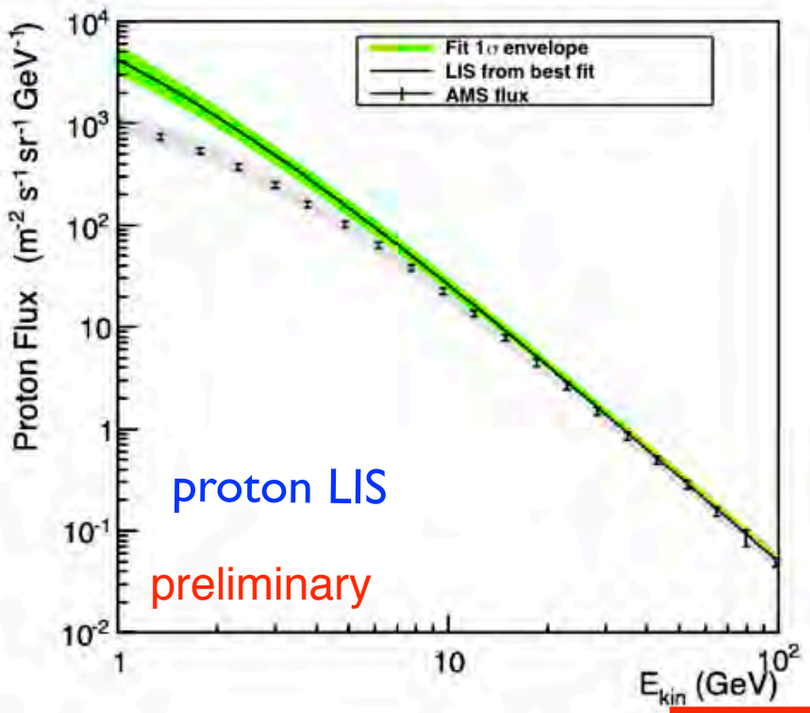


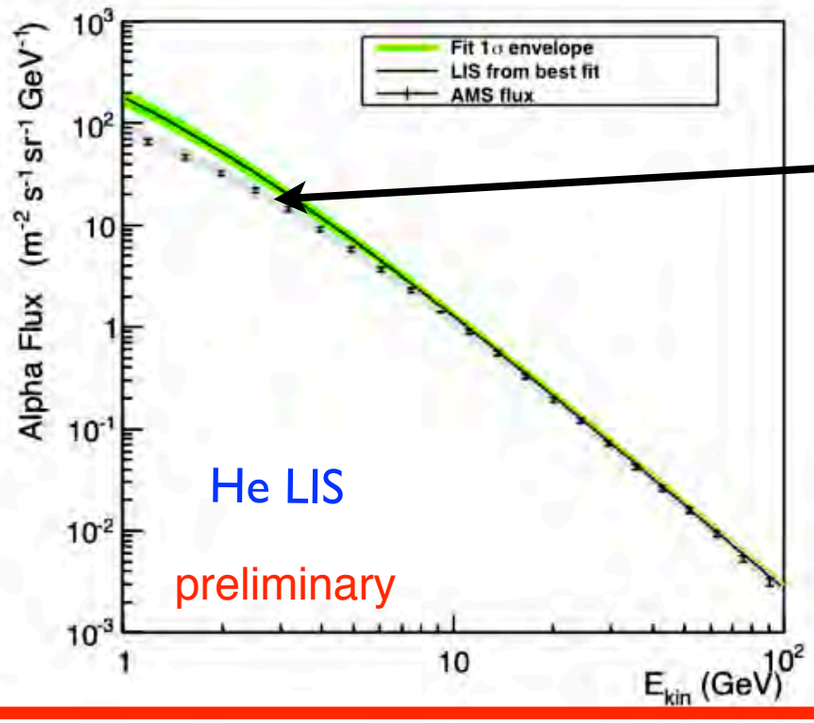




best fit

1 sigma contour includes statistical and systematics for data and model.





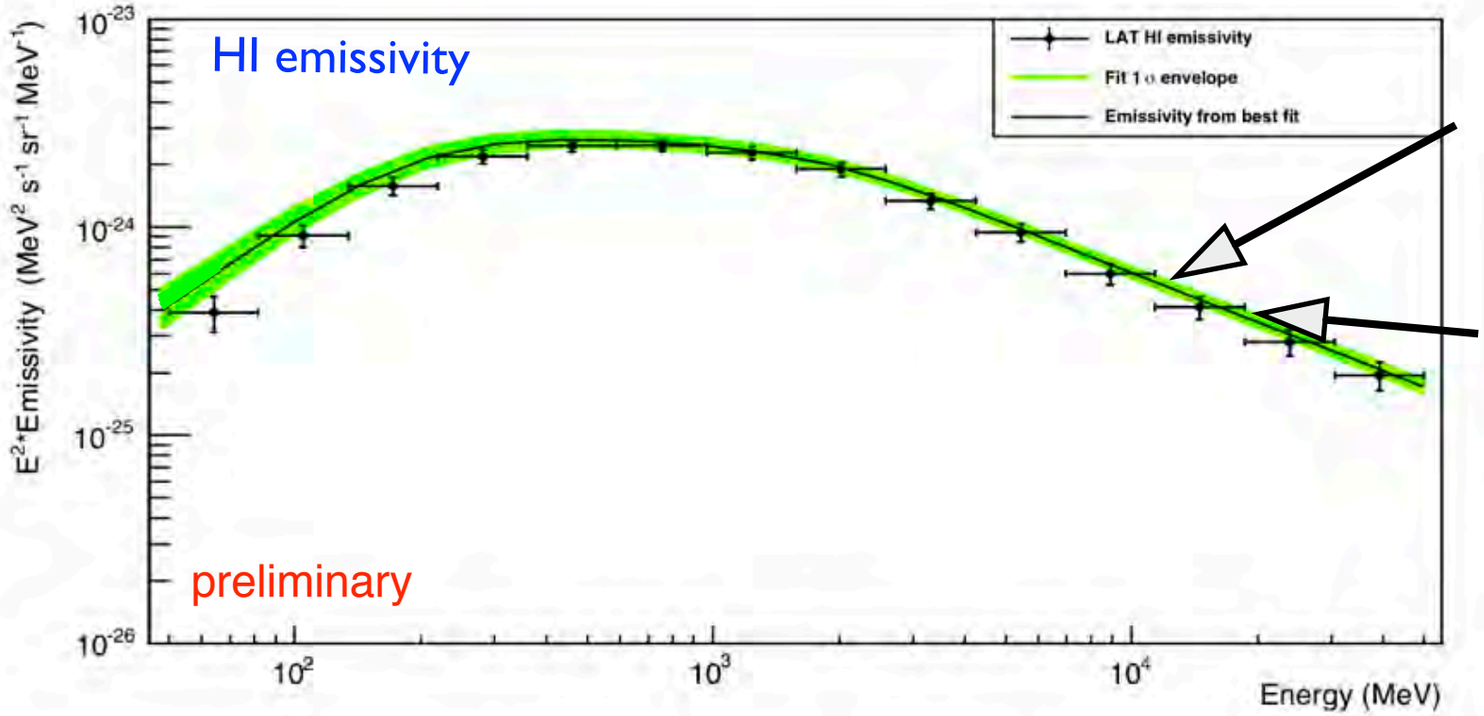
The grey contours are the force-field solar modulated green contours.

$F = A.\beta^{p1}.p^{p2}$

p : A=2.2e4 p2=2.82 p1=2.1

He : A= 7.7e3 p2=2.77 p1=2.5

and $\phi = 560 \pm 80$ MV (Aguilar *et al.* 2002: 650 ± 40 MV)



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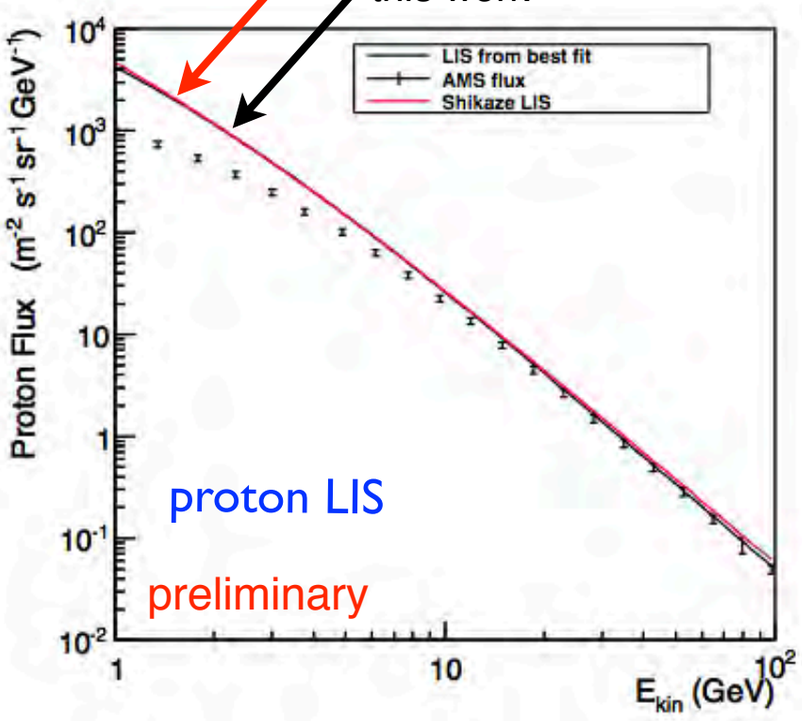
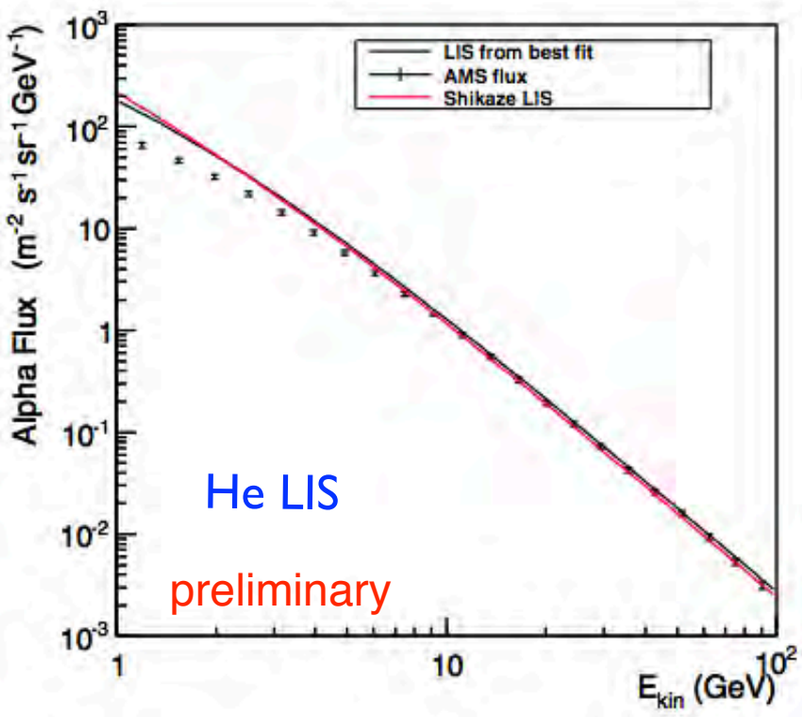
Shikaze, 2007

this work





Conclusion

Measure:

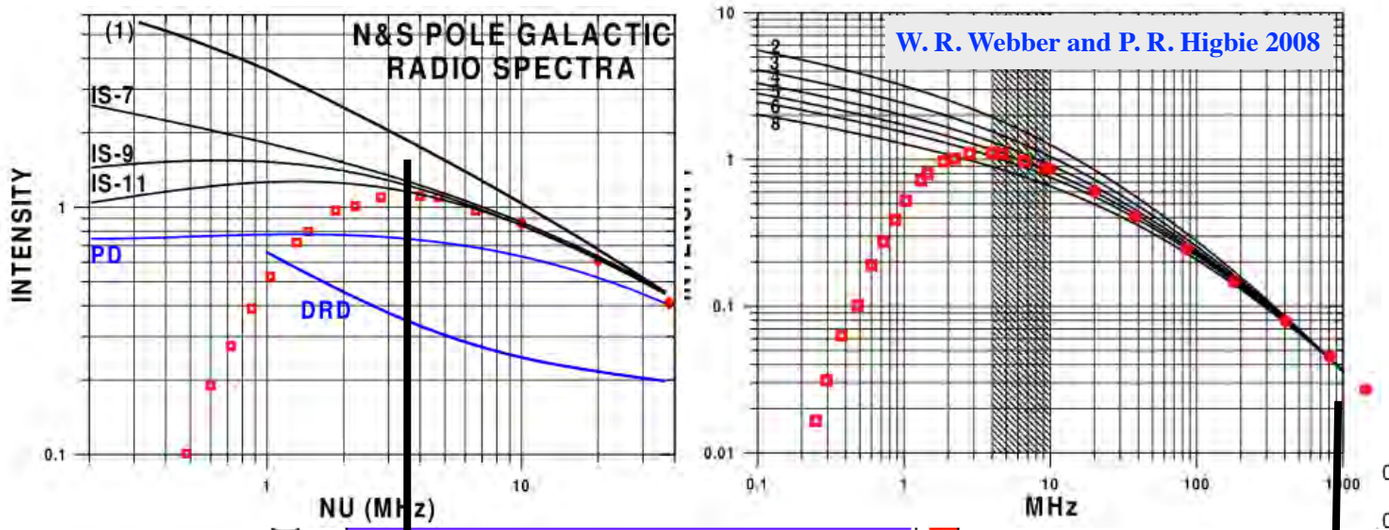
- Fermi-LAT with its large effective area, good angular resolution, energy range and survey scanning mode is an ideal instrument for precise diffuse studies like the HI emissivity.
- We have measured the γ-ray HI emissivity from 50 MeV to 50 GeV.
- Those emissivities agree with previous measurements except for the Egret GeV excess.

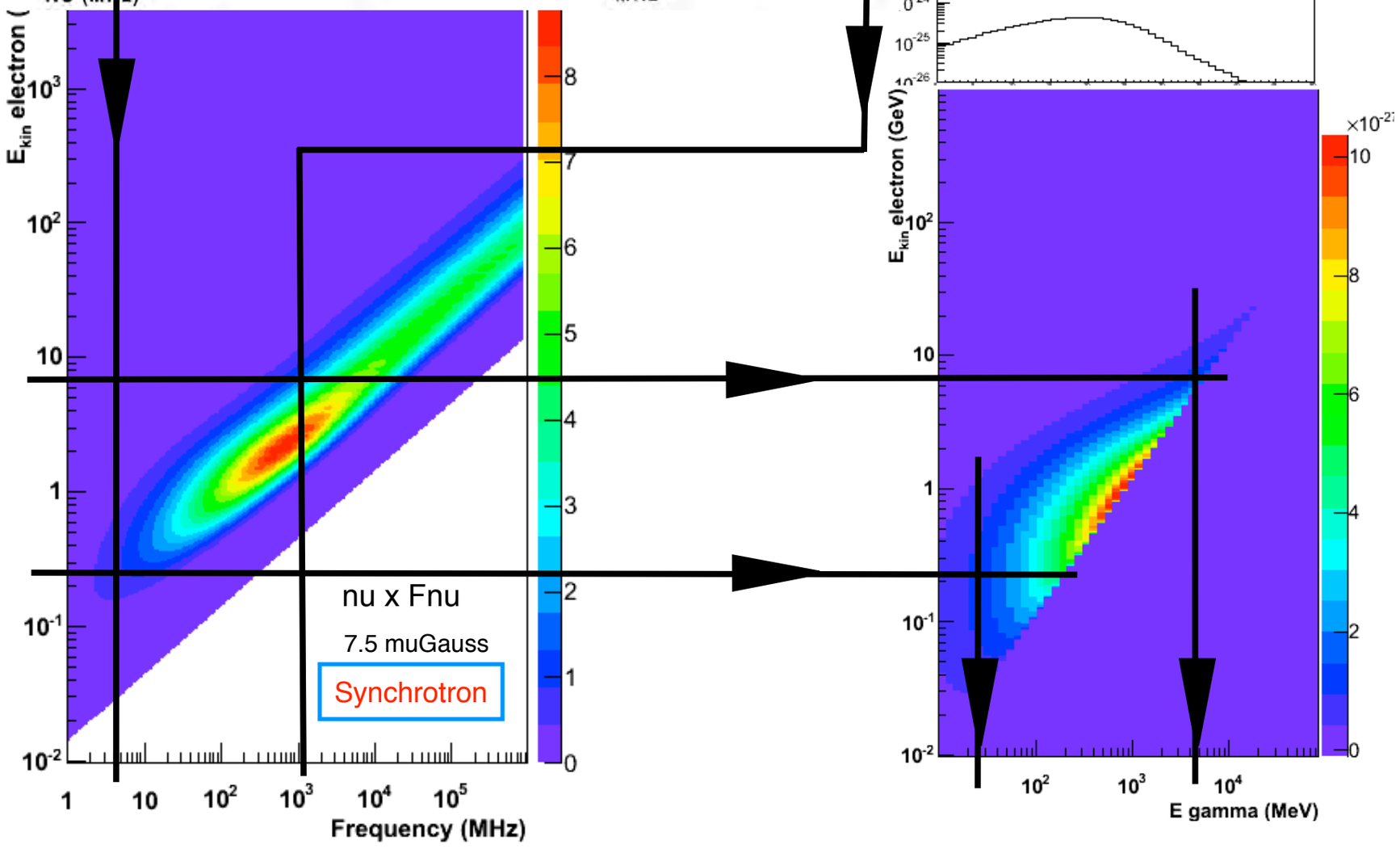
Interpretation:

- We have proven that the sun modulates the CR fluxes.
- We have derived the proton and helium local interstellar spectra from HI emissivity and AMS-01 heliospheric fluxes. Our LIS agrees with Shikaze 2007 (BESS) spectra.
- We have validated the force field approximation for proton and helium.
- We have measured the solar modulation parameter corresponding to AMS-01 flight period.

Don’t miss talk by Chuck Dermer tomorrow about similar studies !

Electron LIS from synchrotron



< 10 MHz: Radio Astronomy Explorer (RAE)
10-1400 MHz : 8 frequencies from higher angular resolution ground-based arrays

Bremsstrahlung