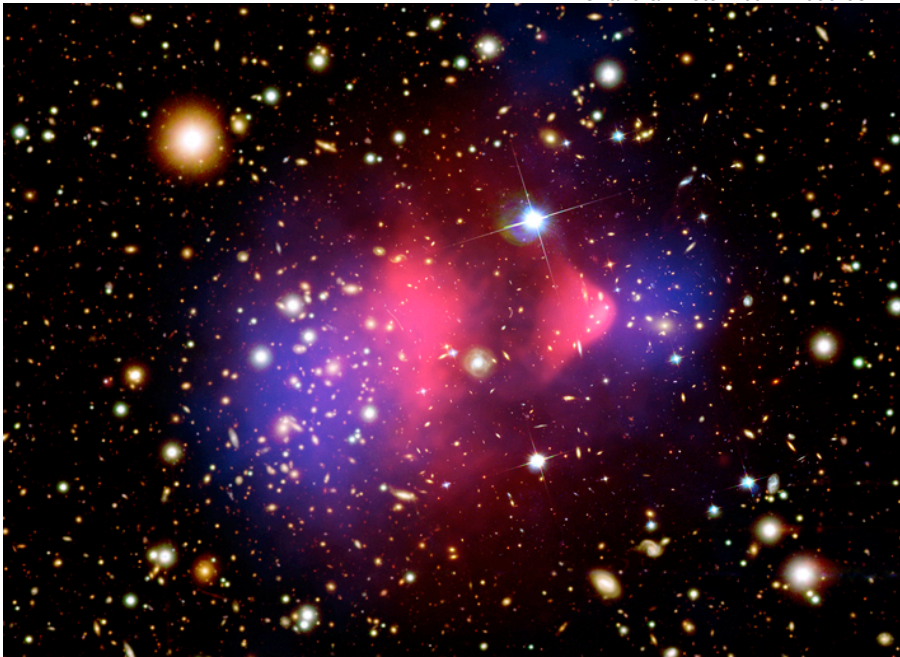The Bullet Cluster - ordinary matter shown by x-ray emission (red); total mass by gravitational lensing (blue)

Current Status of Indirect WIMP Searches

Darren R. Grant
The Pennsylvania State University

Workshop on "Low Energy" Neutrino Physics and Astrophysics with IceCube

PENNSTATE
1855

Dark Matter in the Universe

- Continuing evidence that the universe is primarily dark (~74% Dark Energy, 22% Dark Matter)

- Strong motivation for the Dark Matter component to be Cold (non-relativistic), weakly interacting massive particles (WIMPs). Other candidates include axions, sterile neutrinos, Kaluza-Klein particles....

- This talk will focus on the indirect searches for WIMPs as Dark Matter

  - Further asssume Dark Matter is the Neutralino (χ) - the lightest superpartner in the supersymmetric (SUSY) extension of the Standard Model

Neutralino

$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$
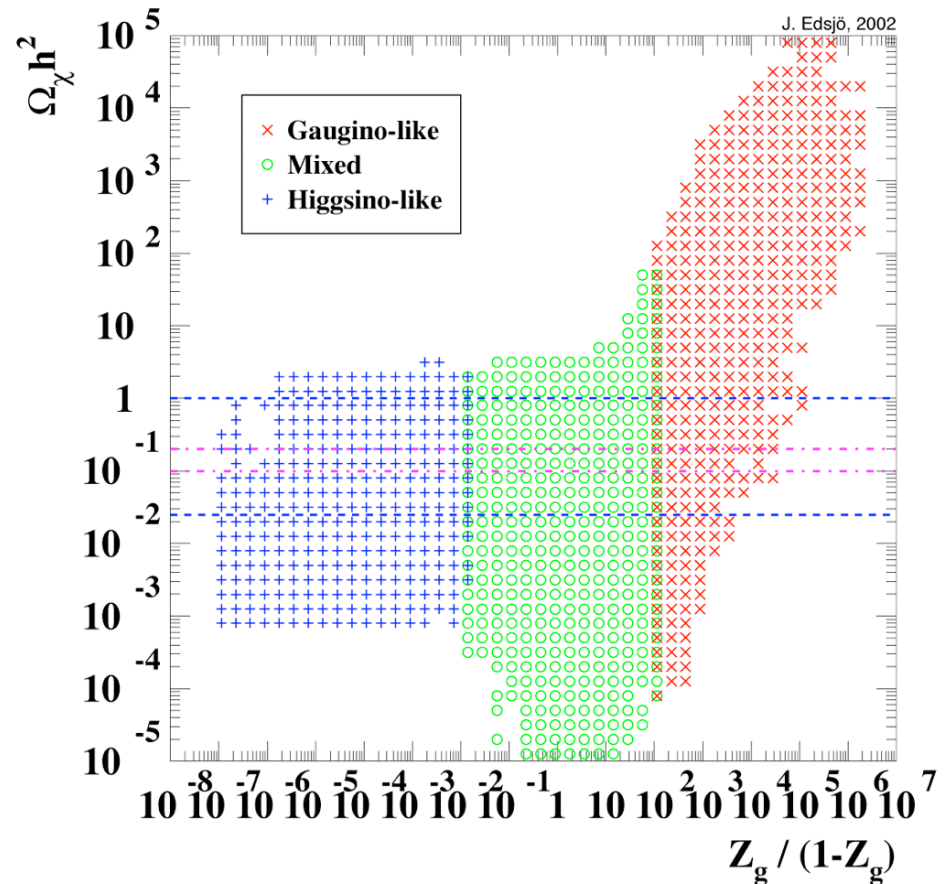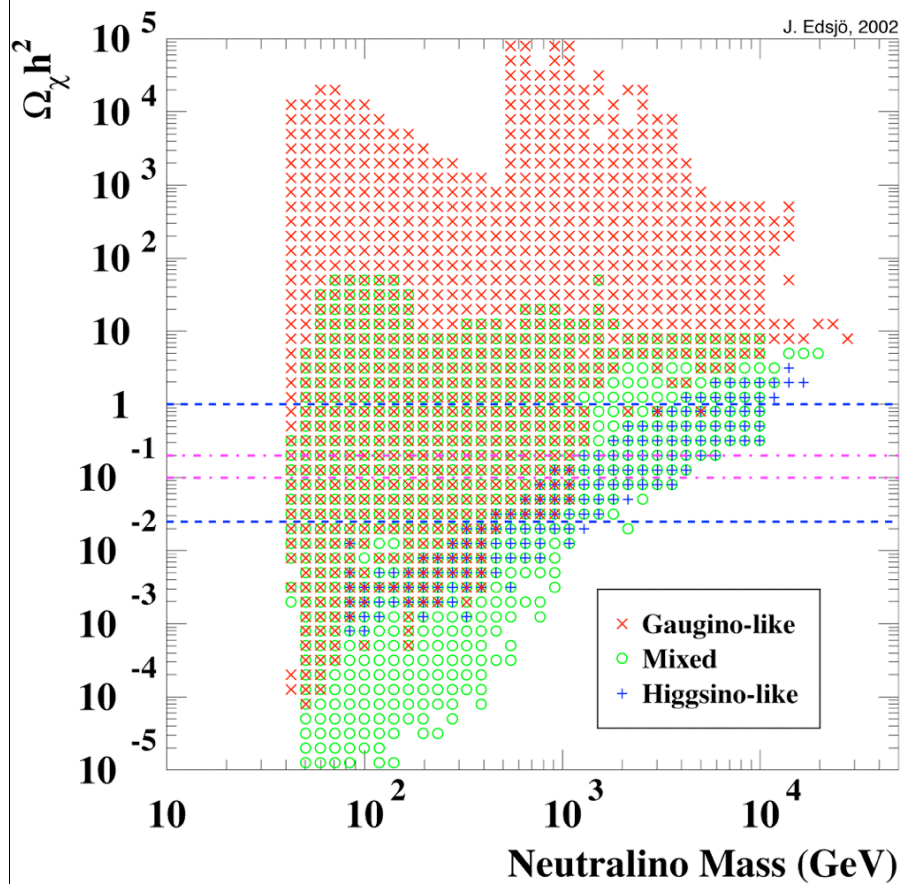
Gaugino fraction
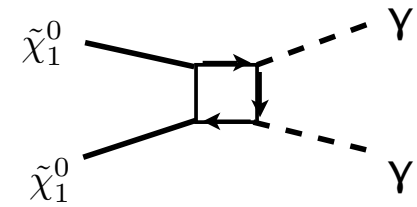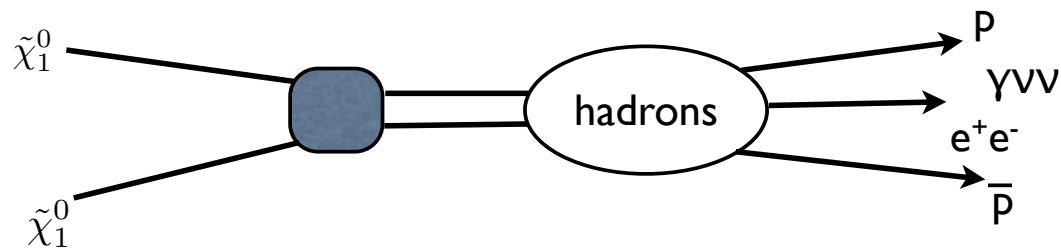
$$Z_g = |N_{11}|^2 + |N_{12}|^2$$

74% DARK ENERGY   22% DARK MATTER

3.6% INTERGALACTIC GAS
0.4% STARS, ETC.
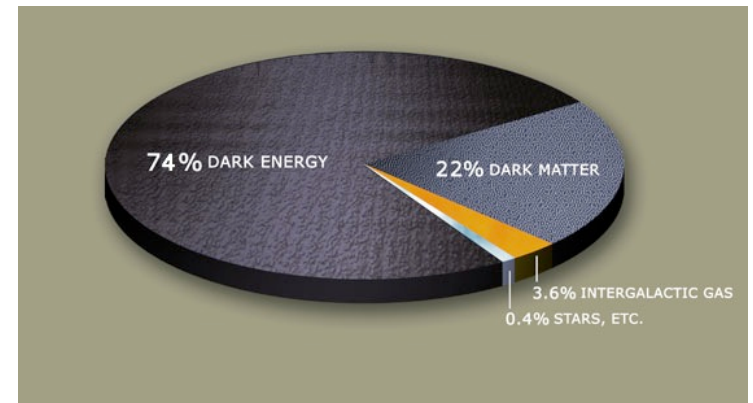
Dark Matter in the Universe - Neutralinos

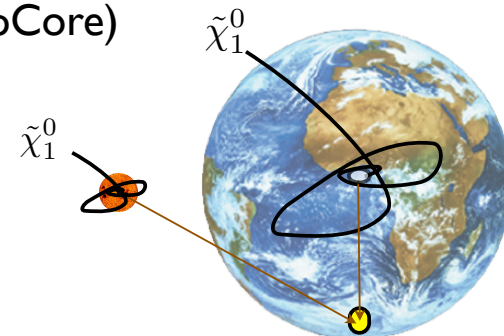## Relic density vs. mass and composition
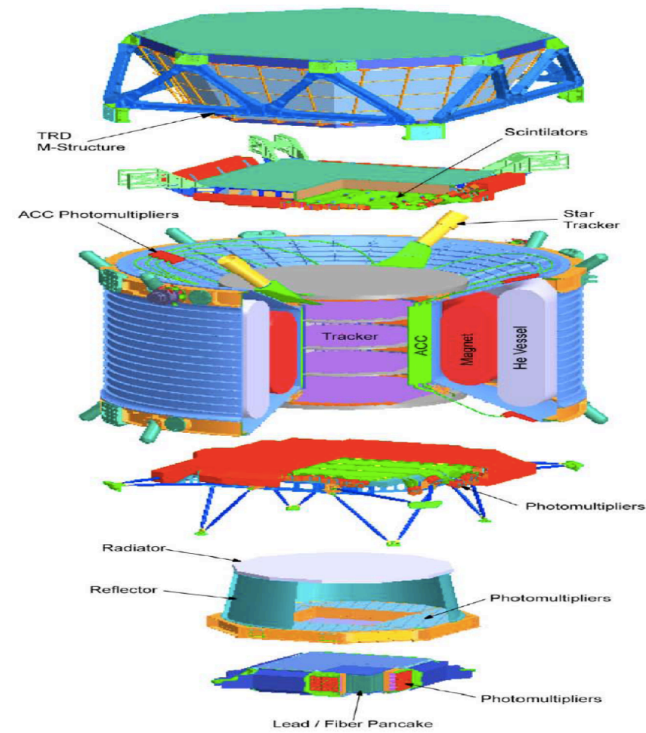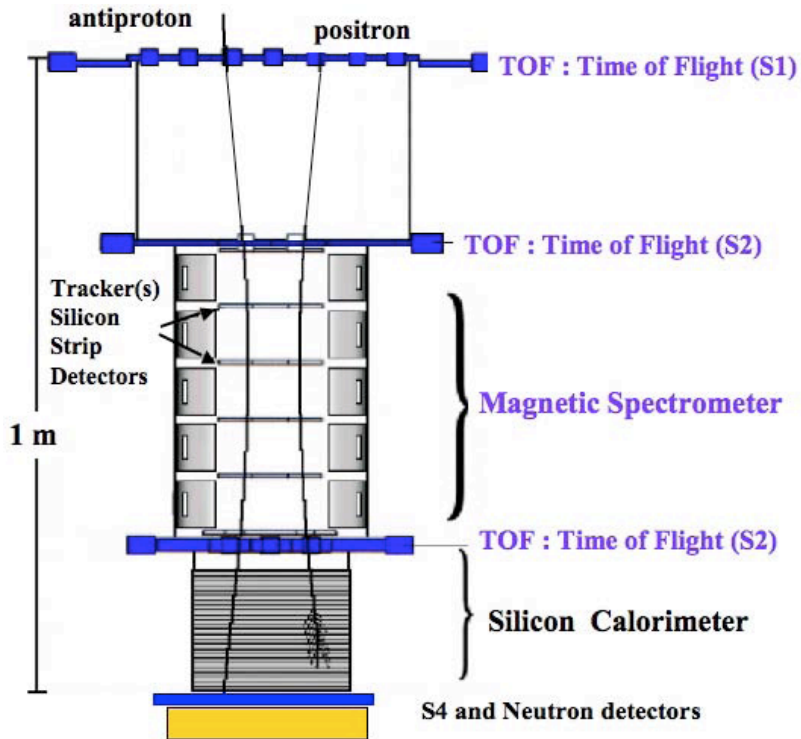
Dark Matter Searches

- Production (ie. @LHC)

- Direct Detection (CDMS/XENON)

- Indirect Detection: Assume the Neutralino is a Majorana fermion.

  - positrons/antiprotons/antideutrons/gamma rays (Fermi, PAMELA, ATIC...)

  - neutrinos from the Earth/Sun (IceCube/DeepCore)

Indirect Searches with....Positrons/Antiprotons

PaMeLa
a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

R.Becker 09/05/03

TRD:
Transition
Radiation
Detector

TOF: (s1,s2)
Time of Flight
Detector

MG:
Magnet
TR:
Silicon Tracker
ACC:
Anticoincidence
Counter
AST:
Amiga Star
Tracker

TOF: (s1,s2)
Time of Flight
Detector

RICH:
Ring Image
Cherenkov Counter

EMC;
Electromagnetic
Calorimeter

AMS Alpha Magnetic Spectrometer
Integration

Indirect Searches with....Positrons/Antiprotons

- fd = Clumping factors needed to disentangle a neutralino induced component in the antiproton flux

  - f = dark matter fraction concentrated in clumps

 - d = overdensity due to a clump with respect to the local halo density

A. Moreselli
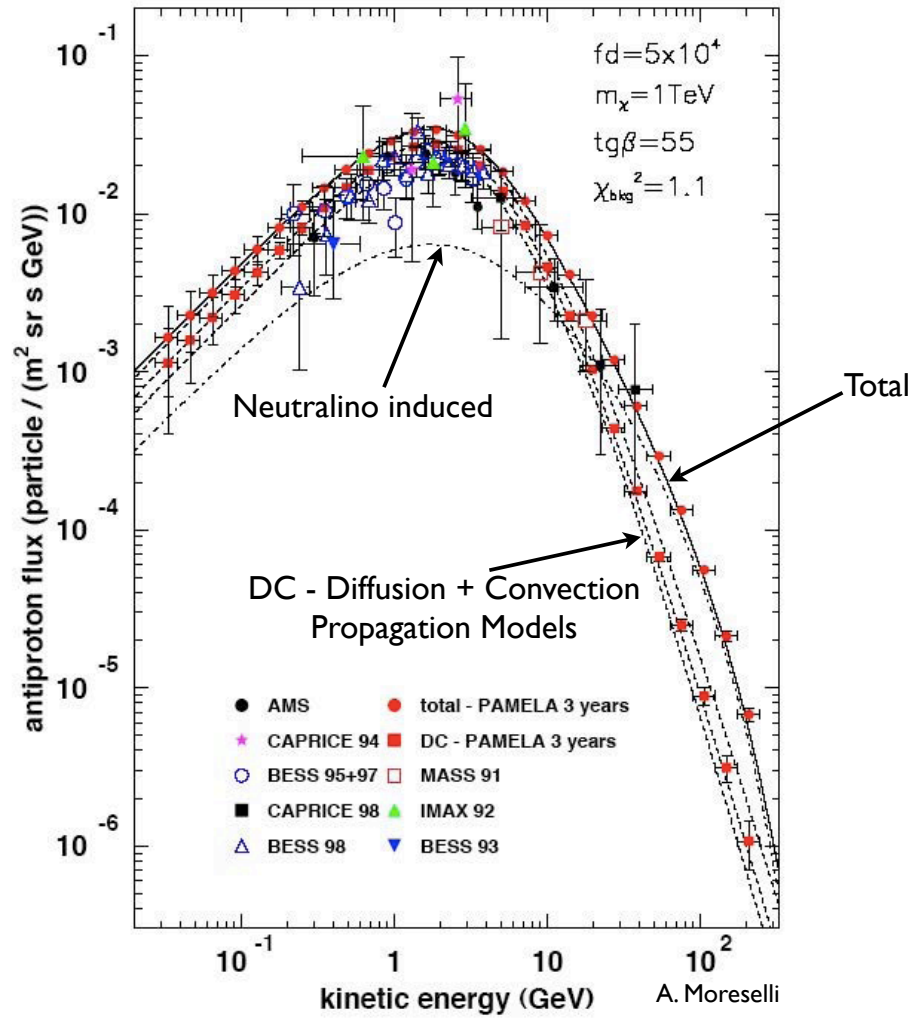
Indirect Searches with....Positrons/Antiprotons

arXiv:0810.4994
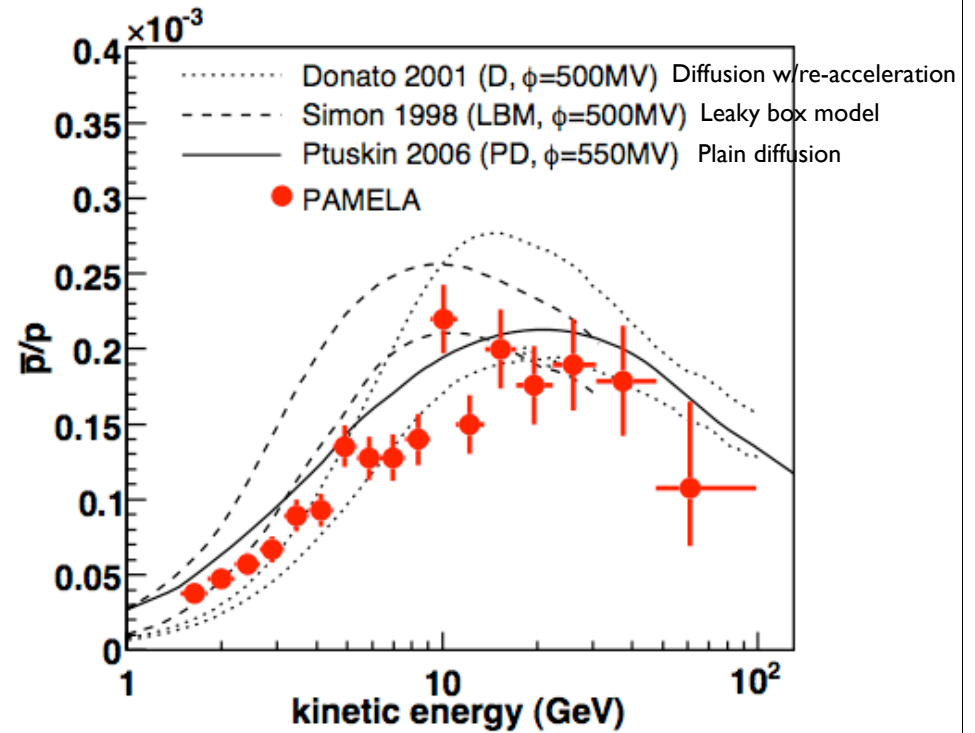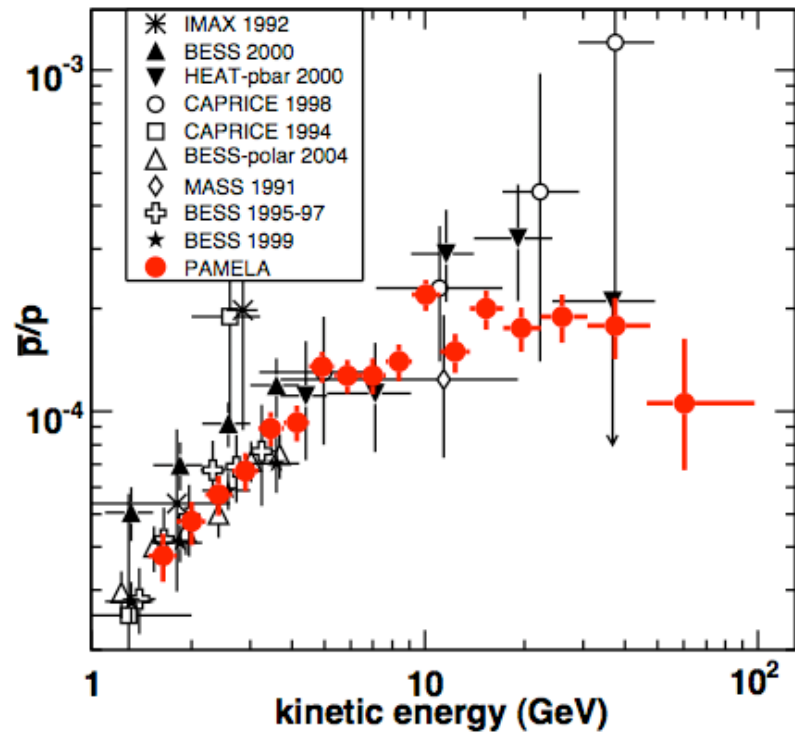
Theoretical curves assume a pure secondary production of antiprotons during the propagation of cosmic rays in the galaxy

Indirect Searches with....Positrons/Antiprotons

A. Moreselli

Indirect Searches with....Positrons/Antiprotons

A. Moreselli

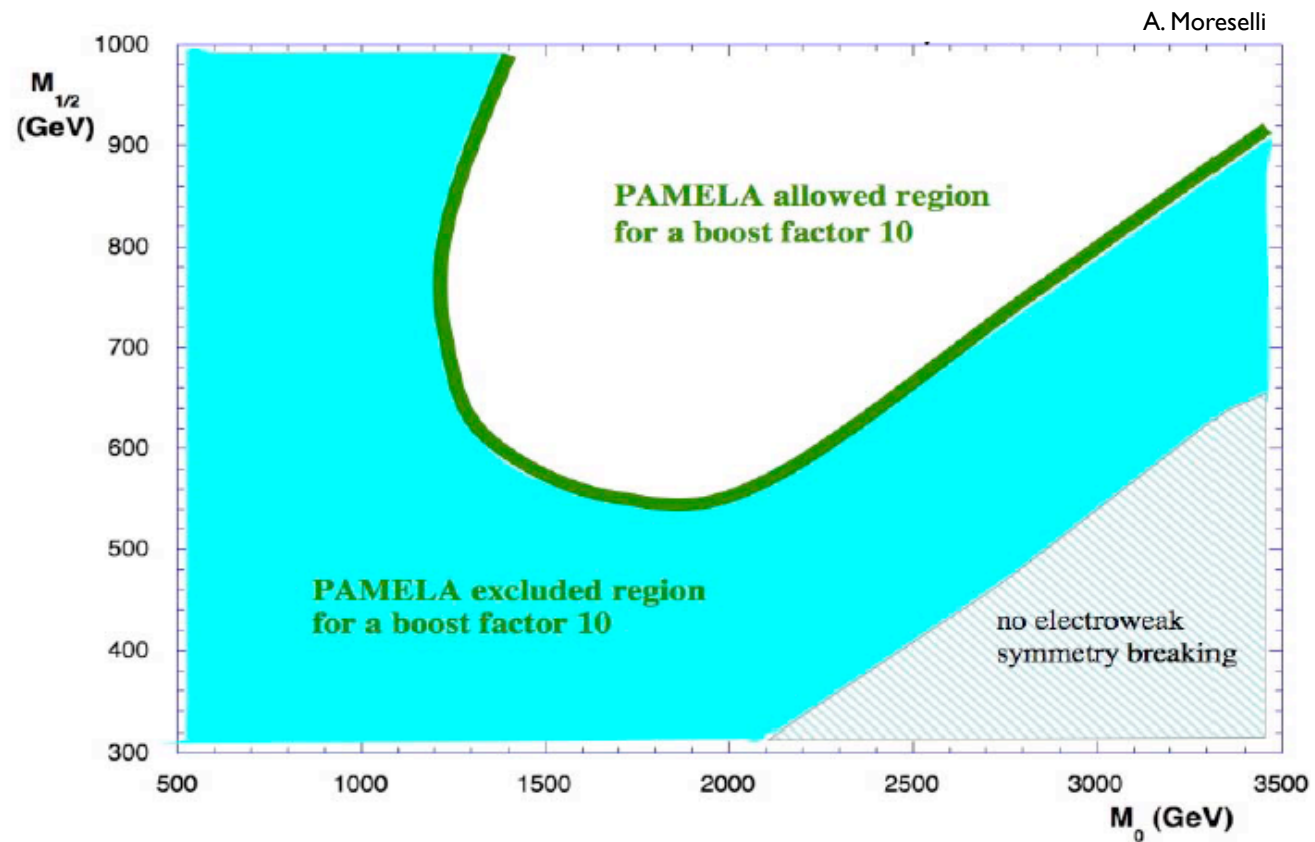# Indirect Searches with....Positrons/Antiprotons

arXiv:0810.4995
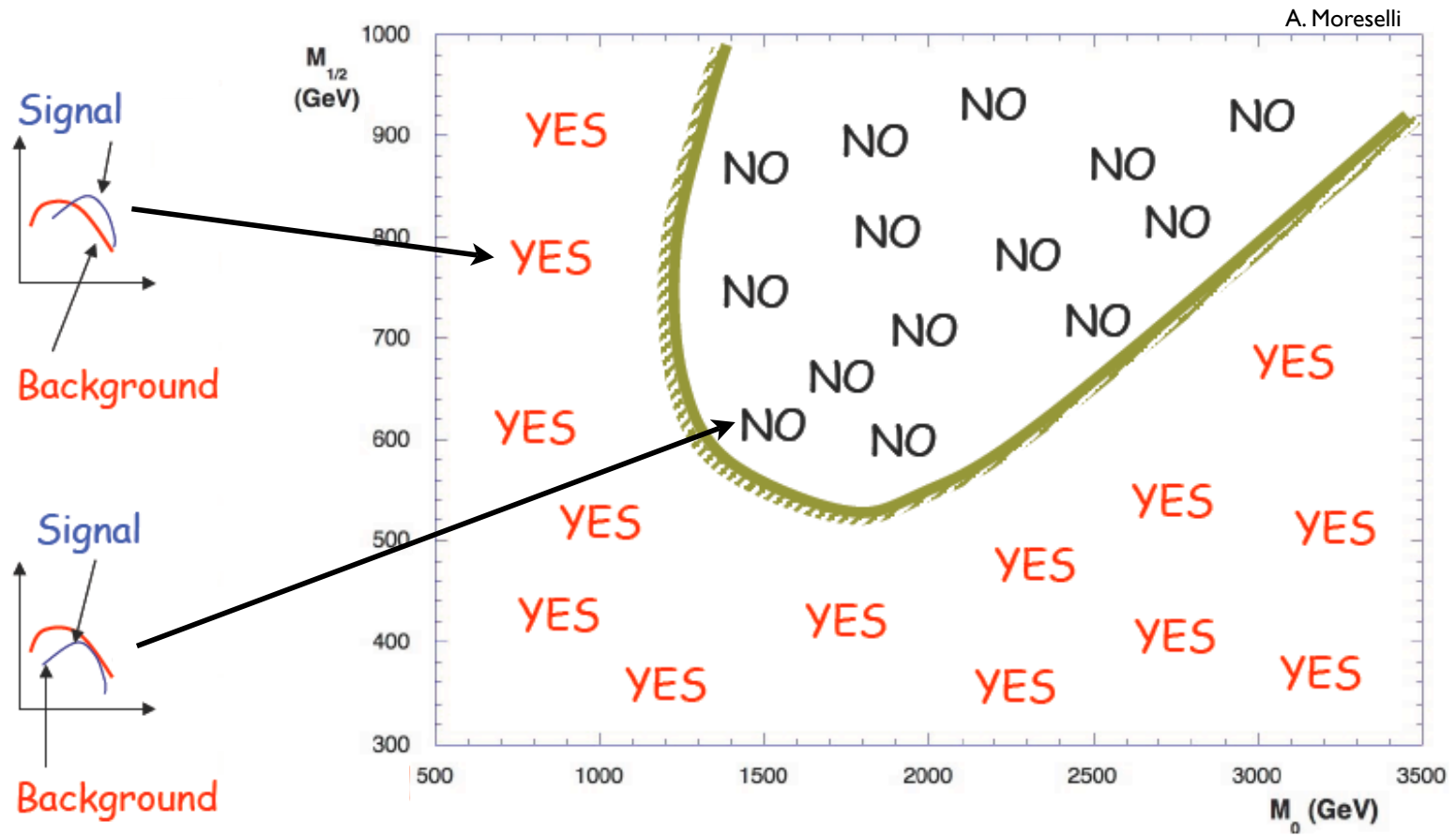
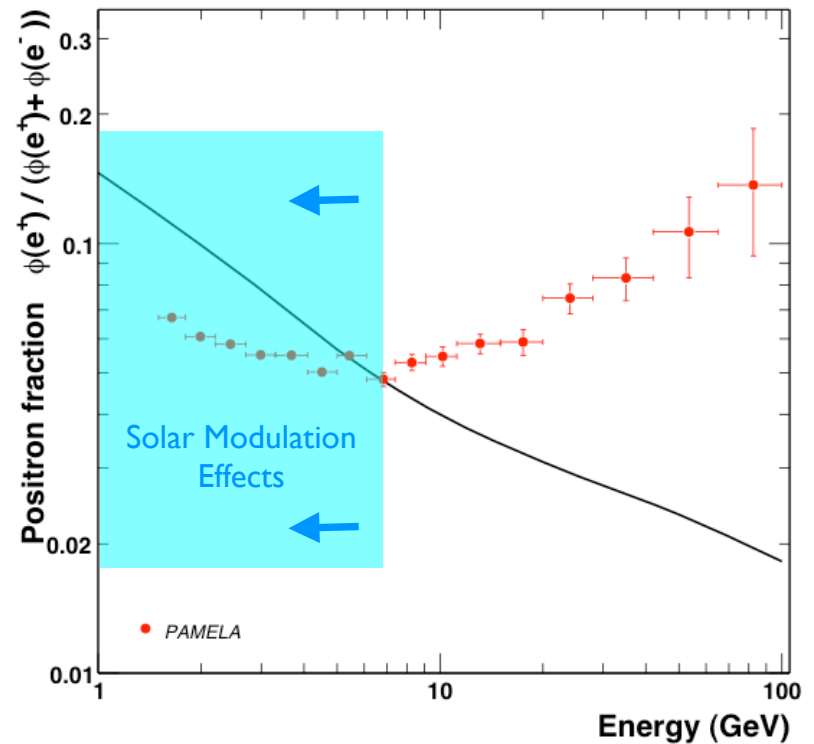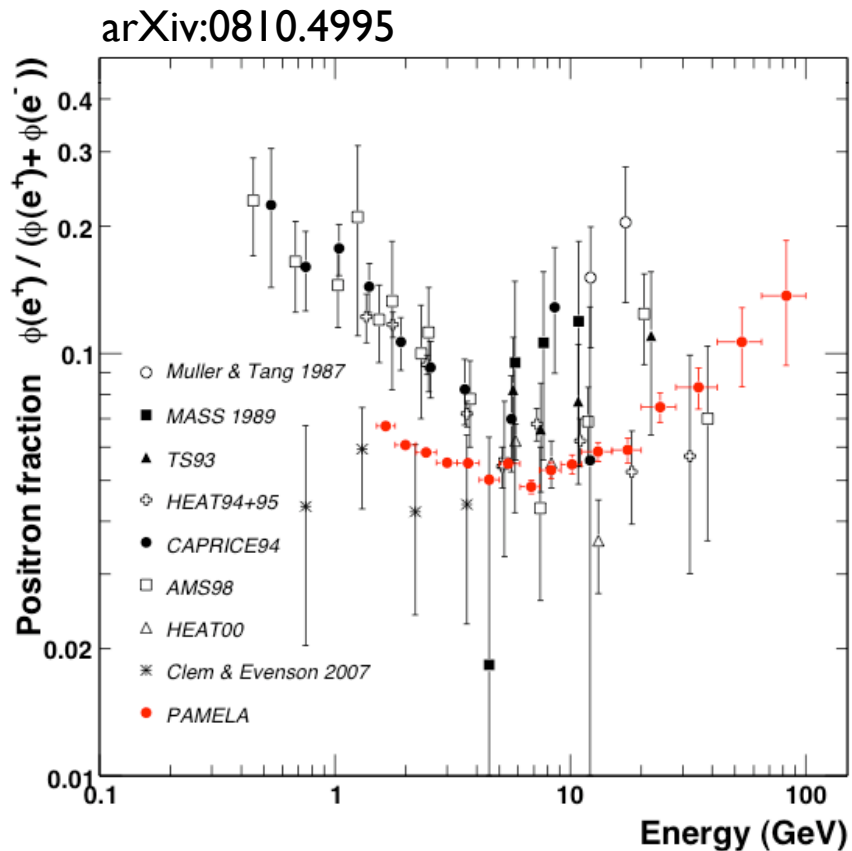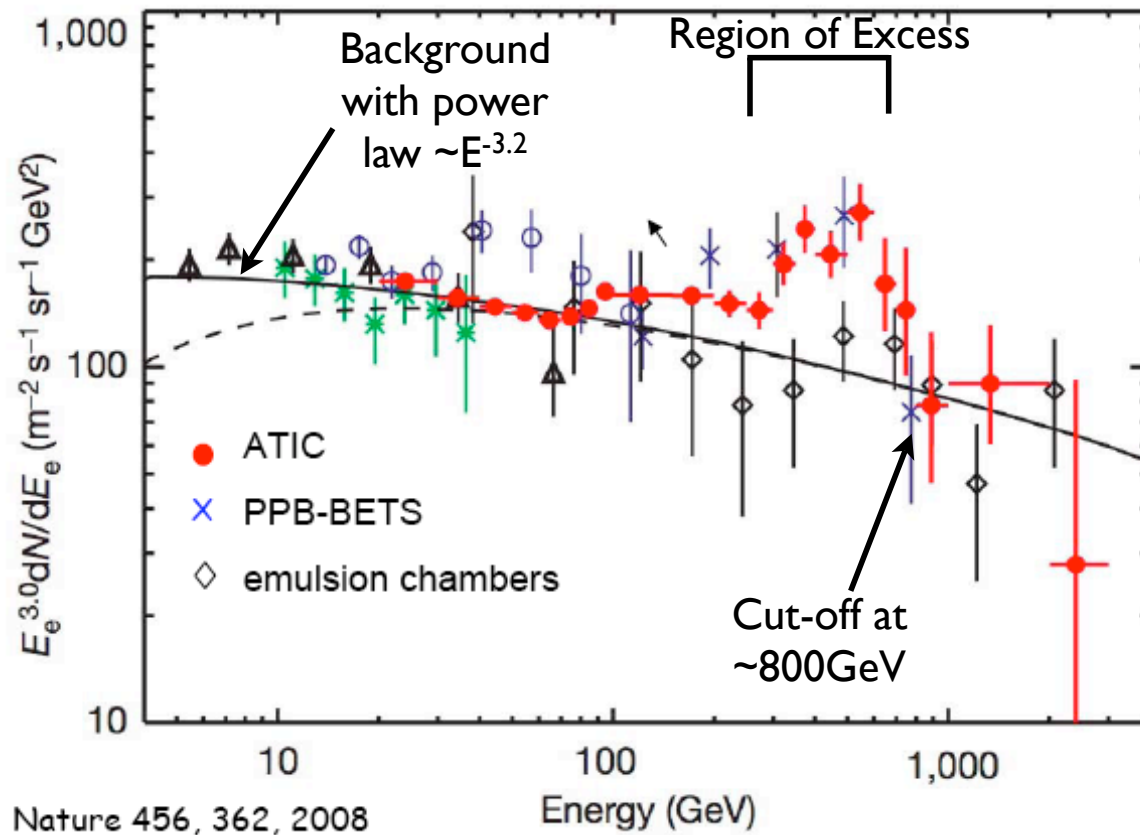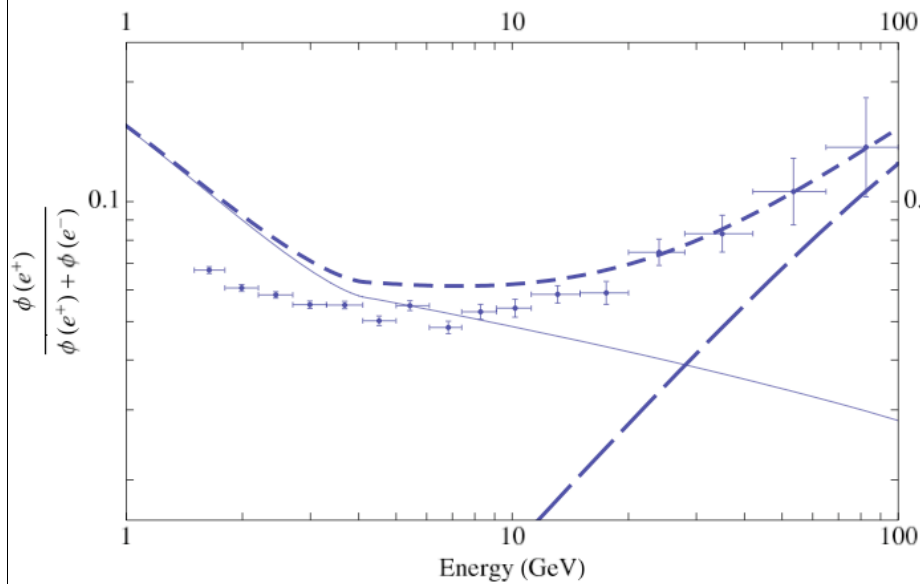Theoretical curves assume a pure secondary production of positrons during the propagation of cosmic rays in the galaxy

Indirect Searches with....Positrons/Antiprotons
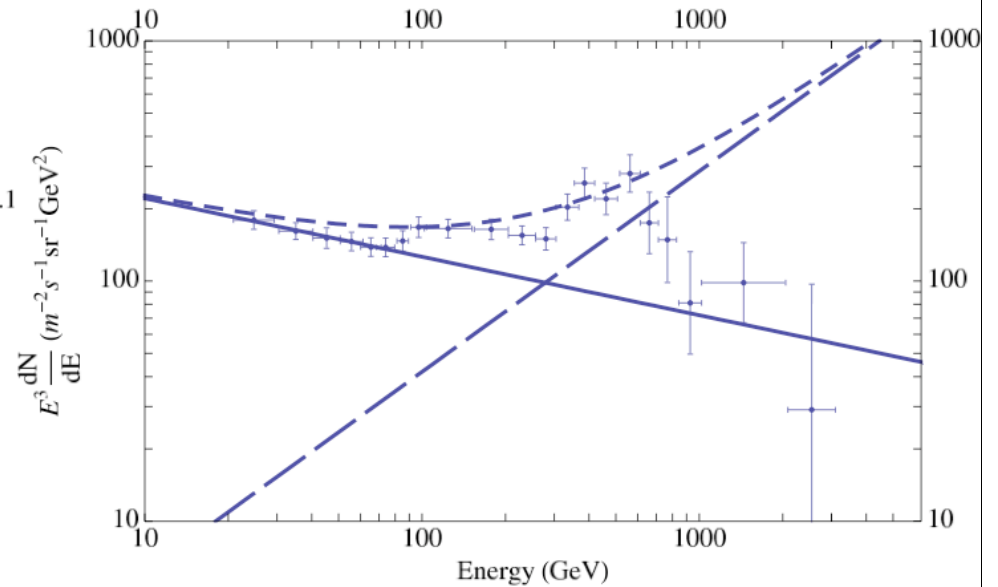

Nature 456, 362, 2008

Indirect Searches with....Positrons/Antiprotons
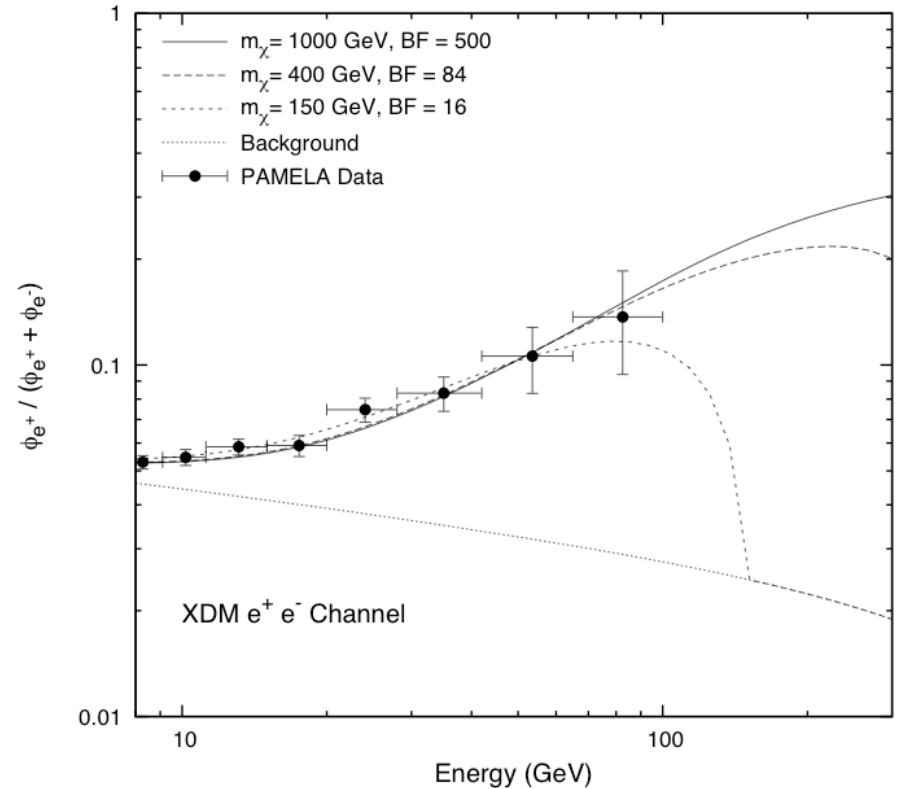
PAMELA

ATIC

arXiv:0811.3641

Extrapolation of the signal from PAMELA leads to a natural excess in the ATIC energy range similar to that observed - same source?   Nearby astrophysical objects (ie. pulsars)? Dark Matter Annhilations?

Indirect Searches with....Positrons/Antiprotons

ATIC

PAMELA
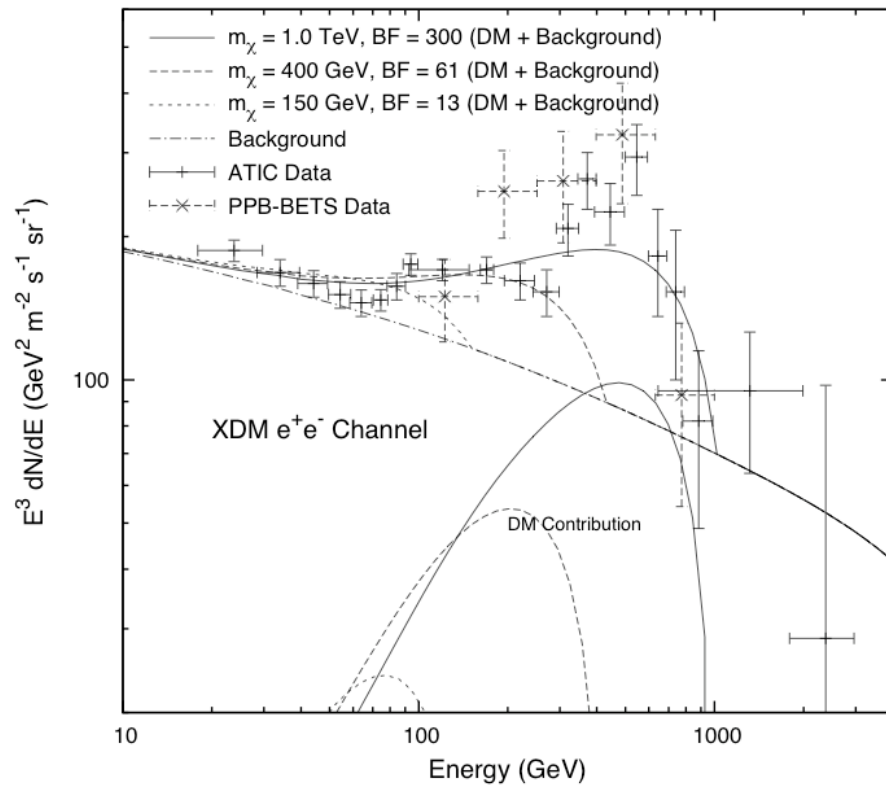
Cholis, Dobler, Finkbeiner, LG, Weiner   arXiv:0811.3641

There are single models for DM annihilations into charged leptons directly or through a light mediator (XDM) that can explain the PAMELA and ATIC anomalies with similar but large boost factors.

Indirect Searches with....Positrons/Antiprotons

PAMELA Positron Fraction
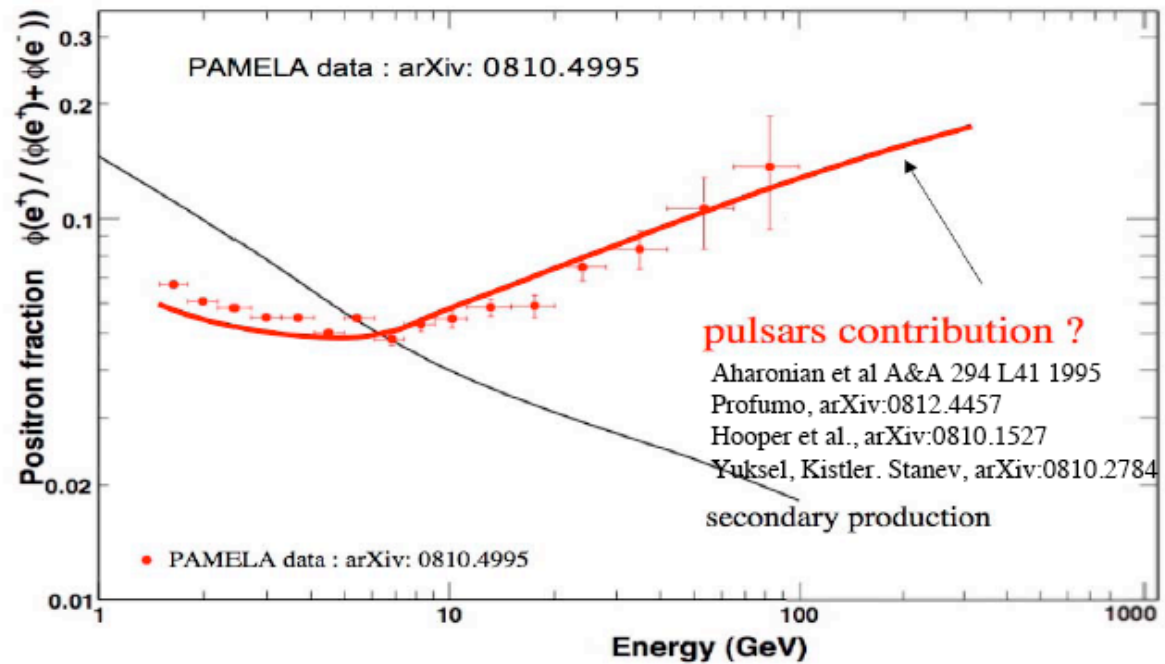
Indirect Searches with....Gamma Rays

- Historically an excess of galactic gamma rays has been observed with the EGRET detector

- EGRET has very little sensitivity above 10GeV. This is the energy range for FERMI

Indirect Searches with....Gamma Rays
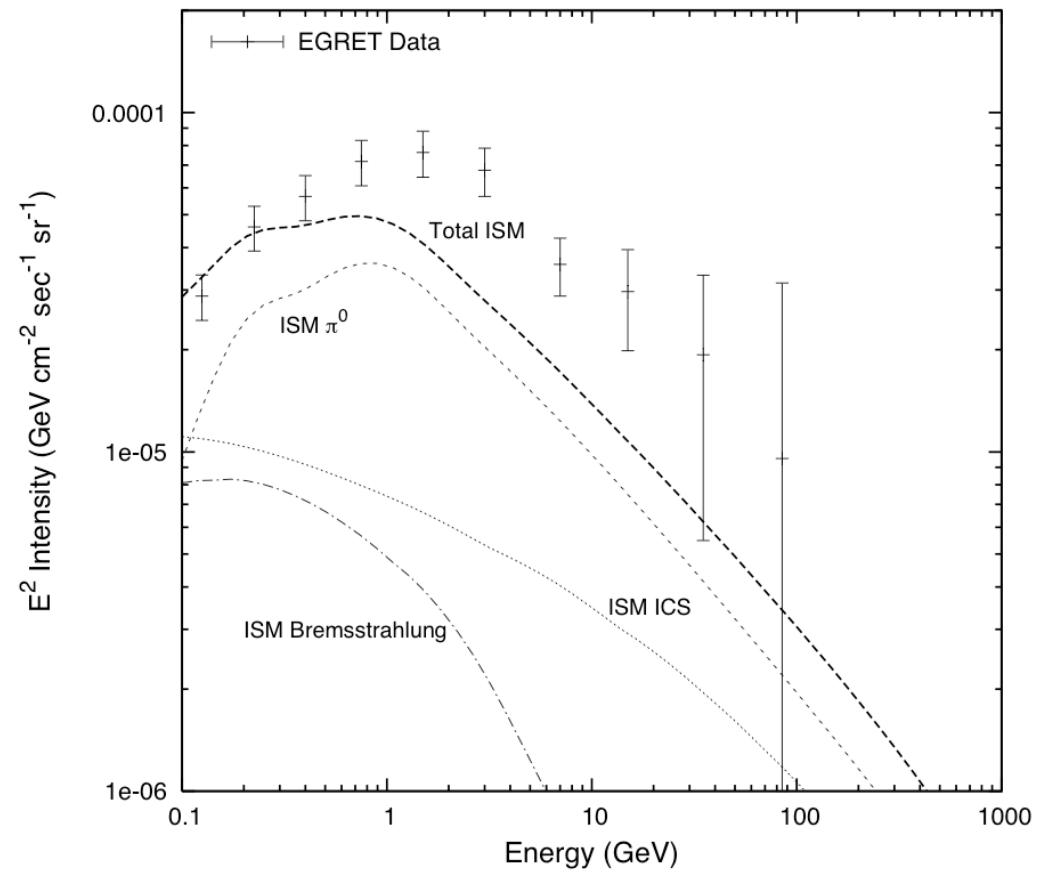
- Historically an excess of galactic gamma rays has been observed with the EGRET detector

- EGRET has very little sensitivity above 10GeV. This is the energy range for FERMI

EGRET data

Gamma cont Flux $(GeV^{-1} cm^{-2} s^{-1} sr^{-1})$

Annihilation channel W^+W^-
m_χ=80.3 GeV

- - - - Background
·········· WIMP annihilation
——— Total contribution

Energy (GeV)

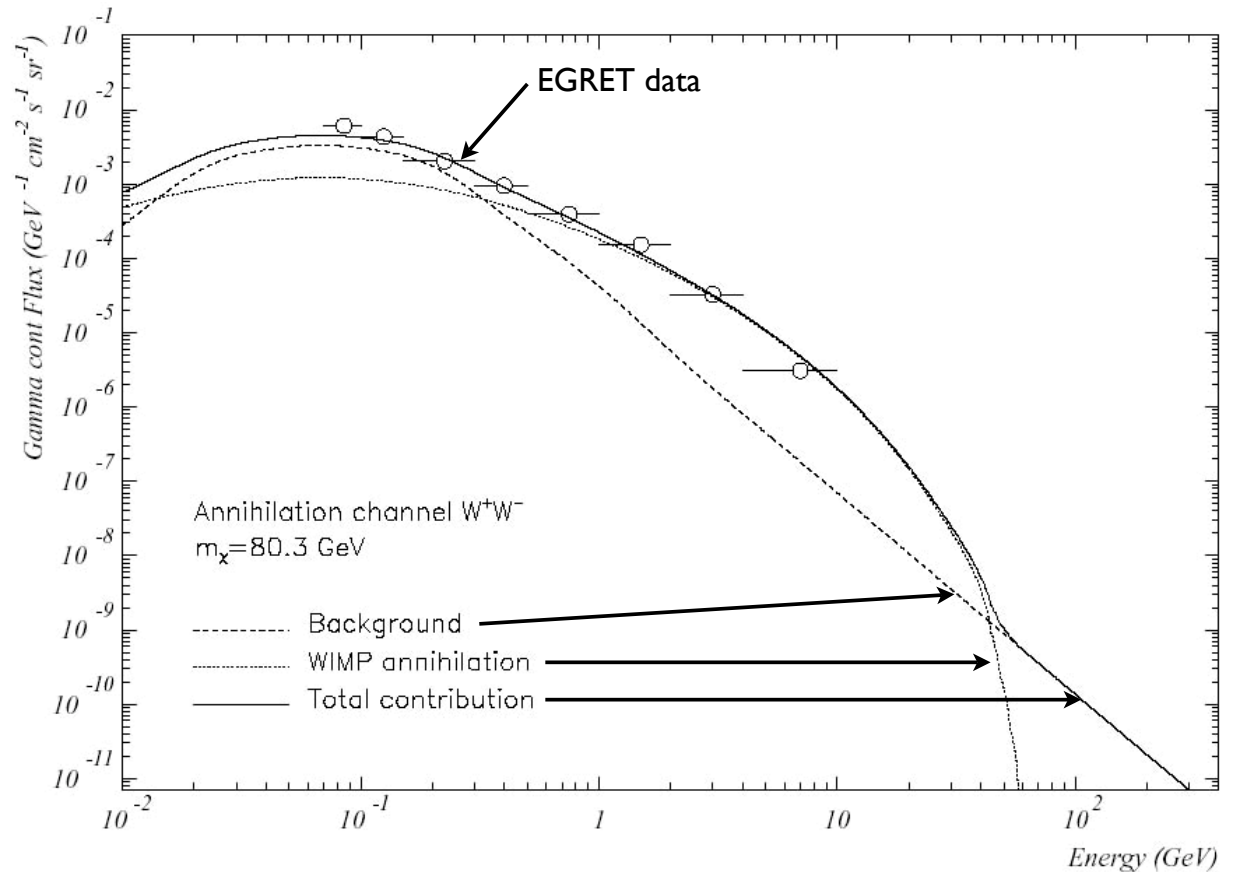A.Morselli, A. Lionetto, A. Cesarini, F. Fucito, P. Ullio, astro-ph/0211327
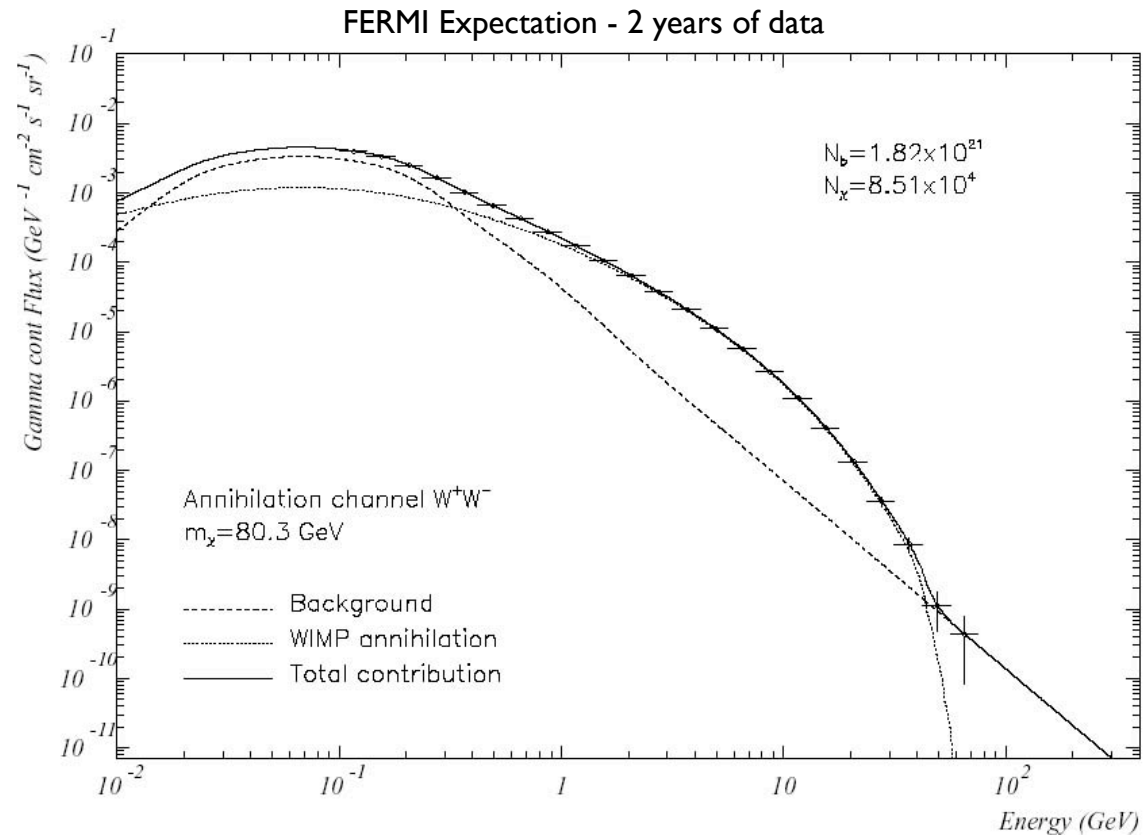
Indirect Searches with....Gamma Rays

- Historically an excess of galactic gamma rays has been observed with the EGRET detector

- EGRET has very little sensitivity above 10GeV. This is the energy range for FERMI

FERMI Expectation - 2 years of data

$N_b = 1.82 \times 10^{21}$

$N_x = 8.51 \times 10^{4}$

Annihilation channel W^+W^-
$m_x = 80.3$ GeV

--------- Background
.... WIMP annihilation
——— Total contribution

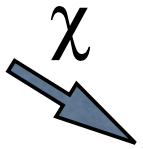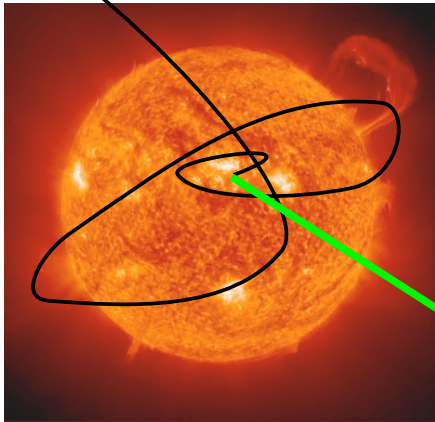Gamma cont Flux (GeV^{-1} cm^{-2} s^{-1} sr^{-1})

Energy (GeV)

A.Cesarin, F.Fucito, A.Lionetto, A.Morselli, P.Ullio, Astroparticle Physics, 21, 267-285, June 2004 [astro-ph/0305075]
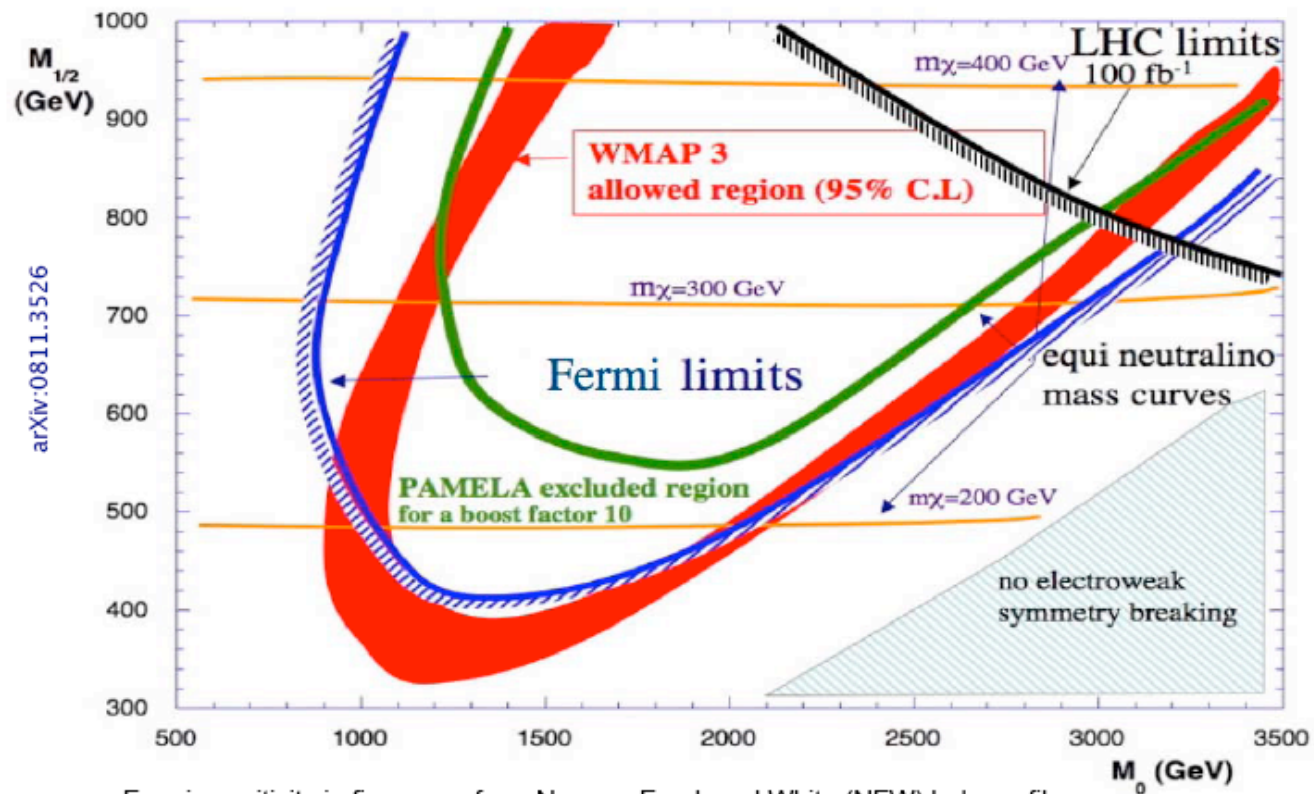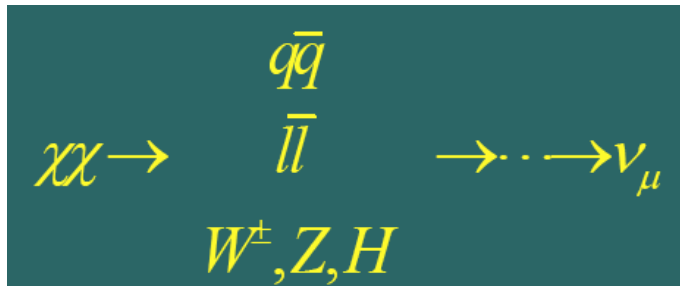
Fermi sensitivity in five years for a Navarro Frank and White (NFW) halo profile
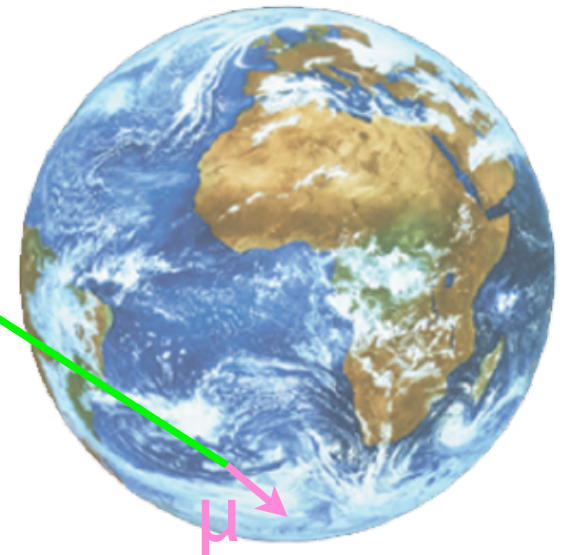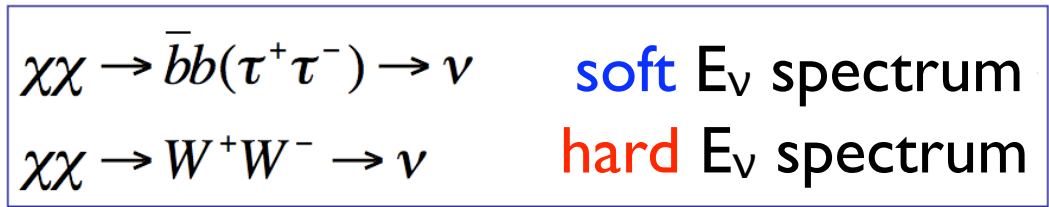
Indirect Searches with....Neutrinos

χ

- Search for neutrinos produced in the annihilation of dark matter collected in massive astrophysical objects (Sun, centre of Earth...)

- Complementarity with direct Dark Matter detection experiments

ν_μ

$$\chi\chi \rightarrow \begin{array}{c} q\bar{q} \\ \bar{l}l \\ W^{\pm},Z,H \end{array} \rightarrow \cdot\cdot \longrightarrow \nu_\mu$$

$\chi\chi \rightarrow \bar{b}b(\tau^+\tau^-) \rightarrow \nu$ soft E_ν spectrum

$\chi\chi \rightarrow W^+W^- \rightarrow \nu$ hard E_ν spectrum

μ

Indirect Searches with....Neutrinos
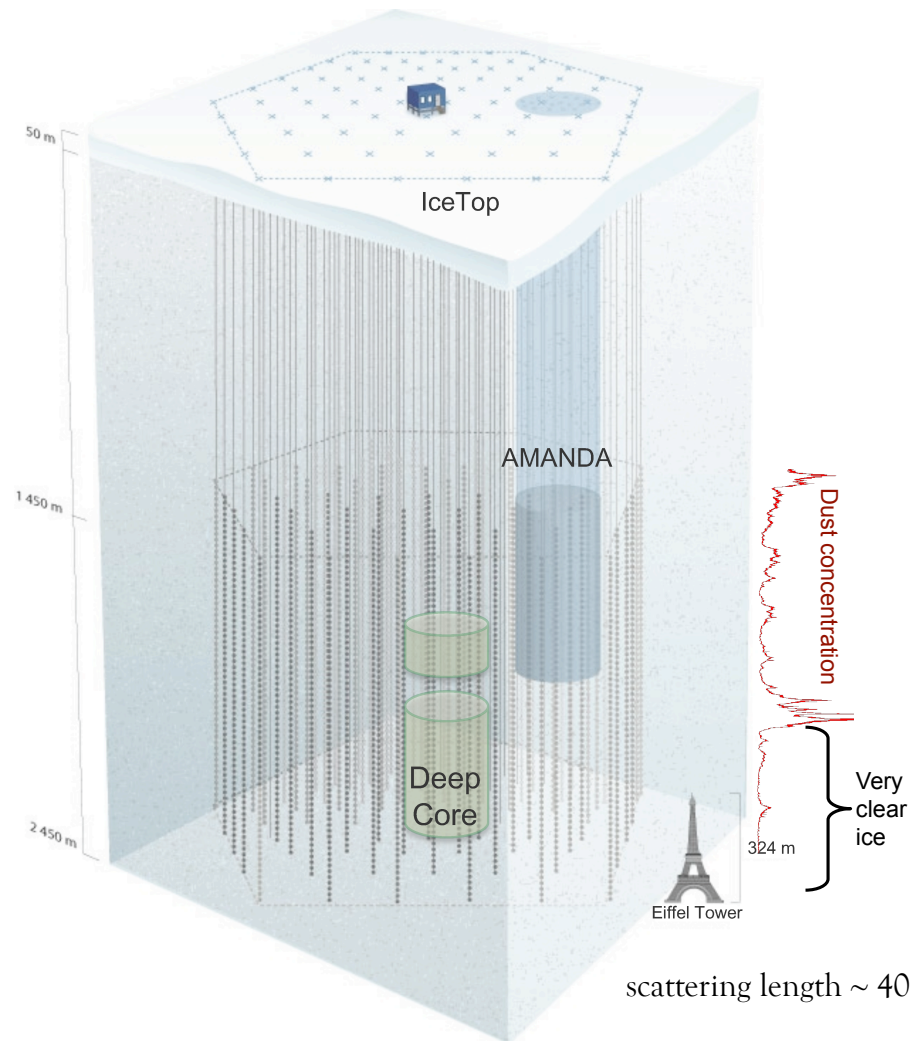
$$\chi\chi \rightarrow \bar{b}b(\tau^+\tau^-) \rightarrow \nu \quad \text{soft } E_\nu \text{ spectrum}$$

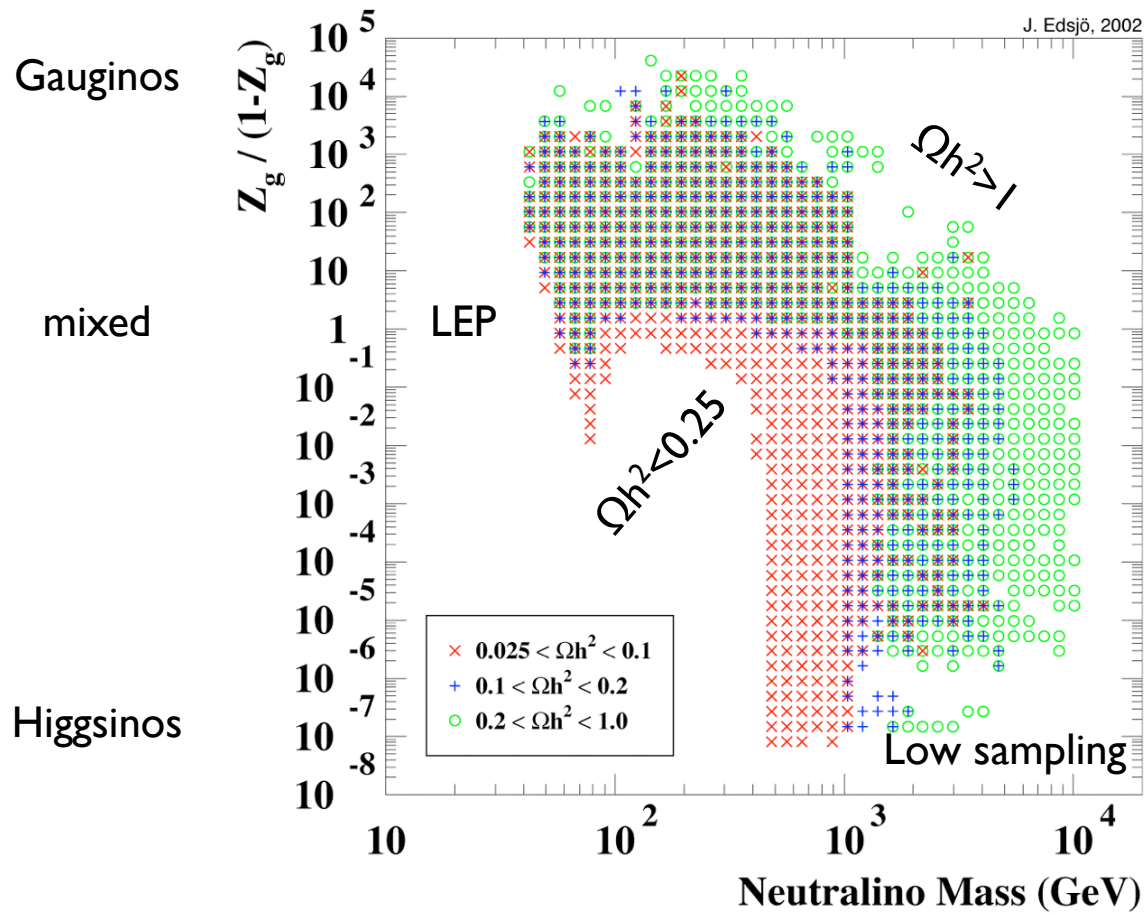$$\chi\chi \rightarrow W^+W^- \rightarrow \nu \quad \text{hard } E_\nu \text{ spectrum}$$
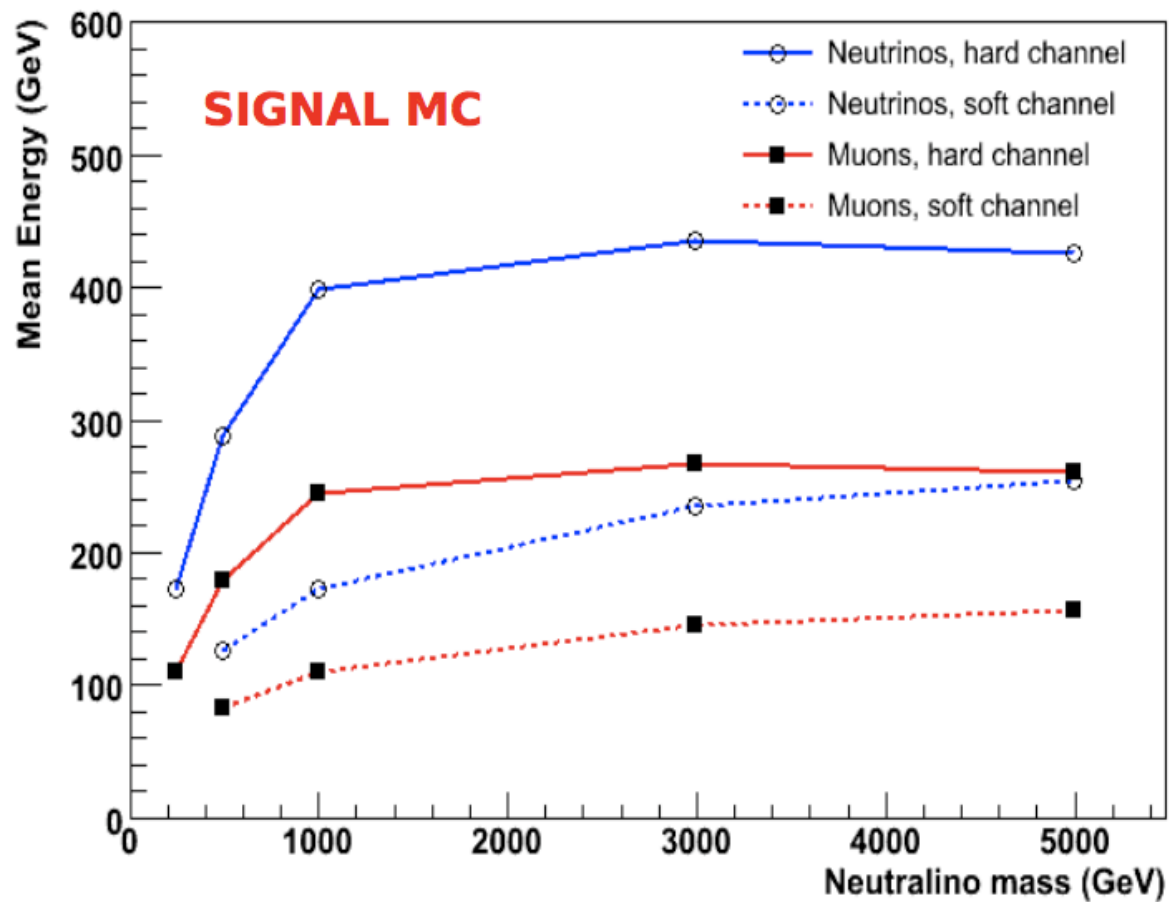
Indirect Searches with....Neutrinos

IceCube/DeepCore - see next talk by C. Rott

Comparing the different indirect searches...

The MSSM (Z_g-M_χ) Parameter Space

Comparing the different indirect searches...

The MSSM (Z_g-M_χ) Parameter Space
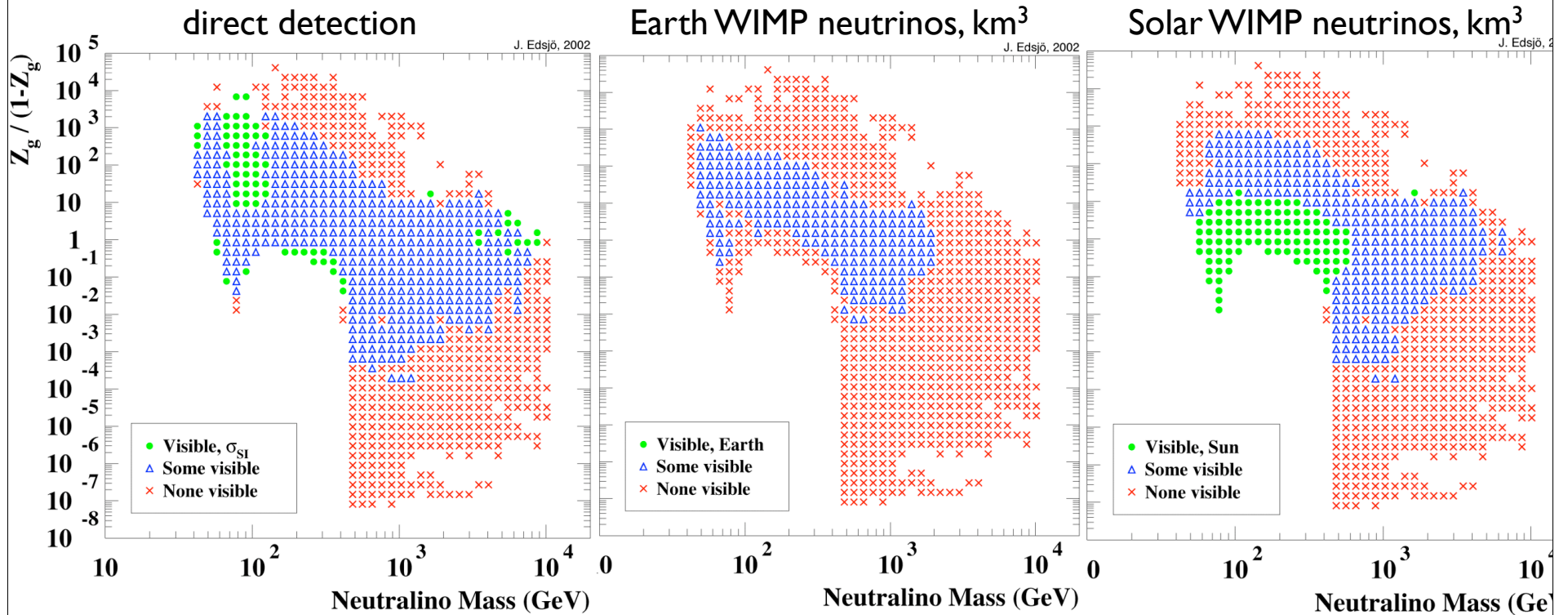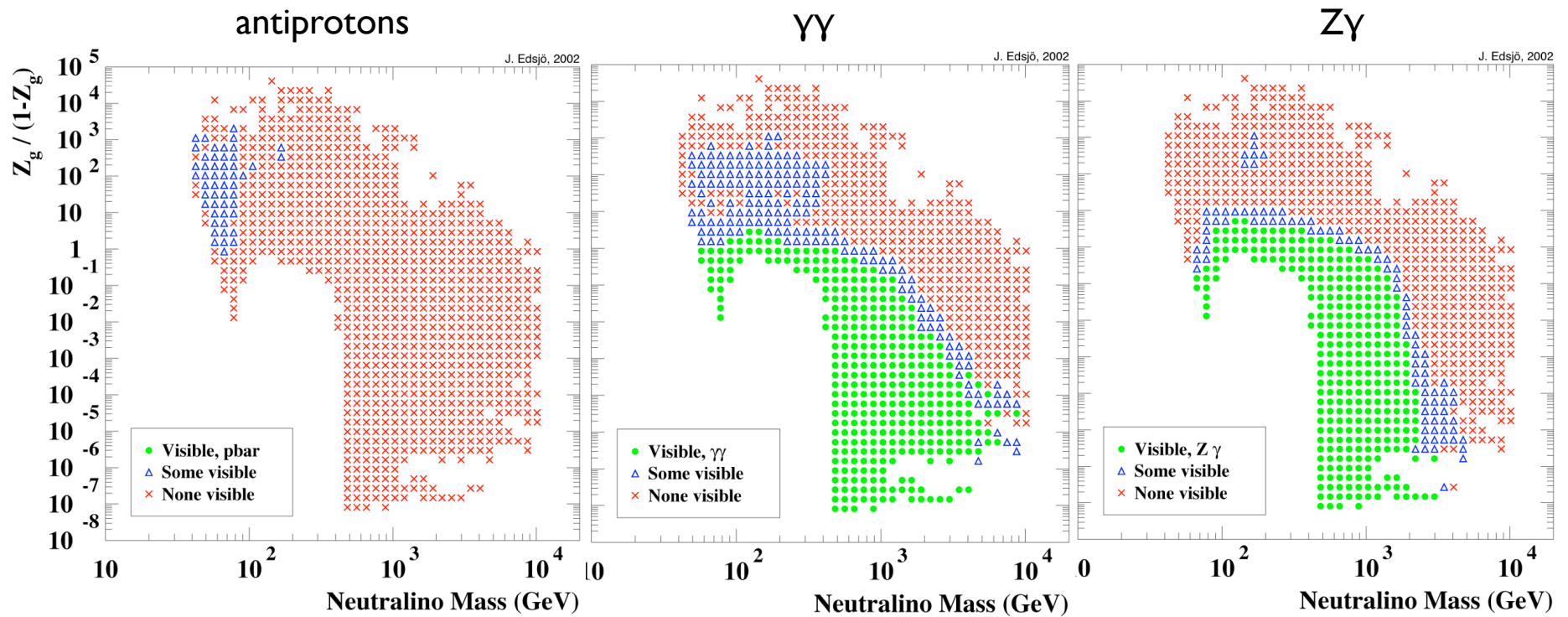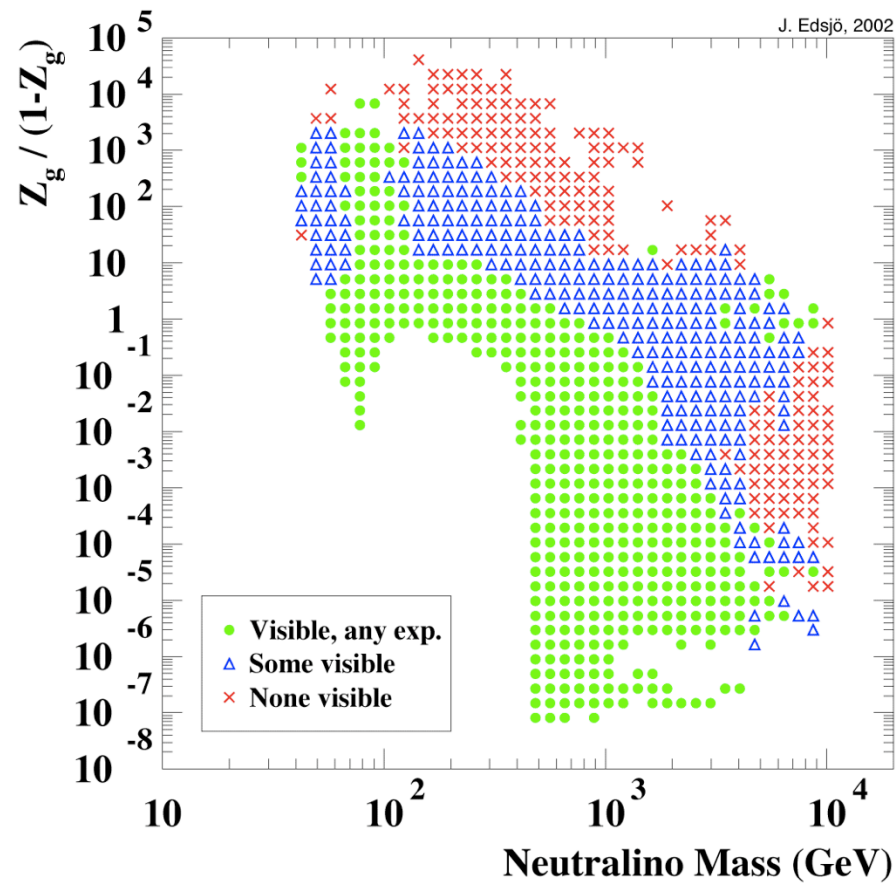
Comparing the different indirect searches...

The MSSM (Z_g-M_χ) Parameter Space

Comparing the different indirect searches...

The MSSM (Z_g-M_χ) Parameter Space

All Dark Matter Searches

Summary

- Large number of indirect searches are underway. The past 6 months has seen a wealth of results come forward:

  - Positrons: Excesses have been observed over background expectations historically in HEAT, Caprice and MASS; more recently in PAMELA and ATIC..The excess appears to be from a single source. Fits are reasonable with neutralinos and large boost factors. Also may be explained by pulsar contributions.

  - Antiprotons: fairly easy to get high rates and fit the spectrum but requires heavy WIMPs or large boost factors.

  - Gammas: Strong feature observed with EGRET but primarily in an energy where the detector has largely reduced sensitivity. Should be readily testable with coming data from Fermi.

  - Neutrino telescopes: Are complementary to the direct detection searches.

- Significant search of the MSSM parameter space has begun and future results should probe large portions of the allowable regions.