Dark Matter
Particle Physics View

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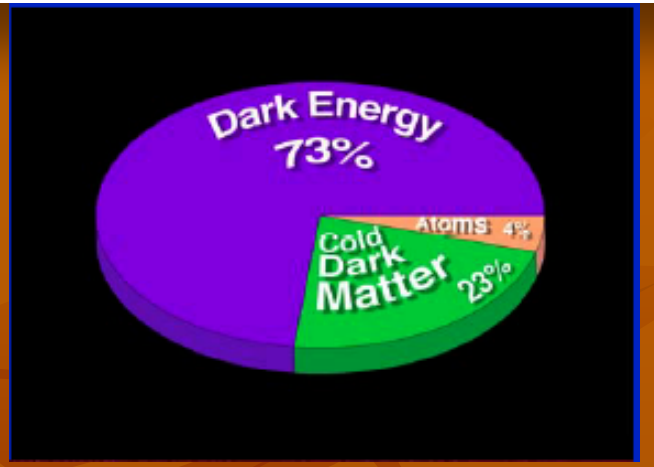
Outline

- DM candidates
- Direct DM Search
- Indirect DM Search
- Possible Manifestations
- DM Profile of the Milky Way

Problem # 3



What is Dark Matter ?

?

DARK TRANSPARENT *INVISIBLE*

What is it made of ?

DM Candidates

The Dark Matter is made of:

- Macro objects – Not seen
- New particles – right neutrino

Non from the SM:
- neutralino
- sneutrino
- axion (axino)
- gravitino
- heavy photon
- heavy pseudo-goldstone
- light sterile higgs

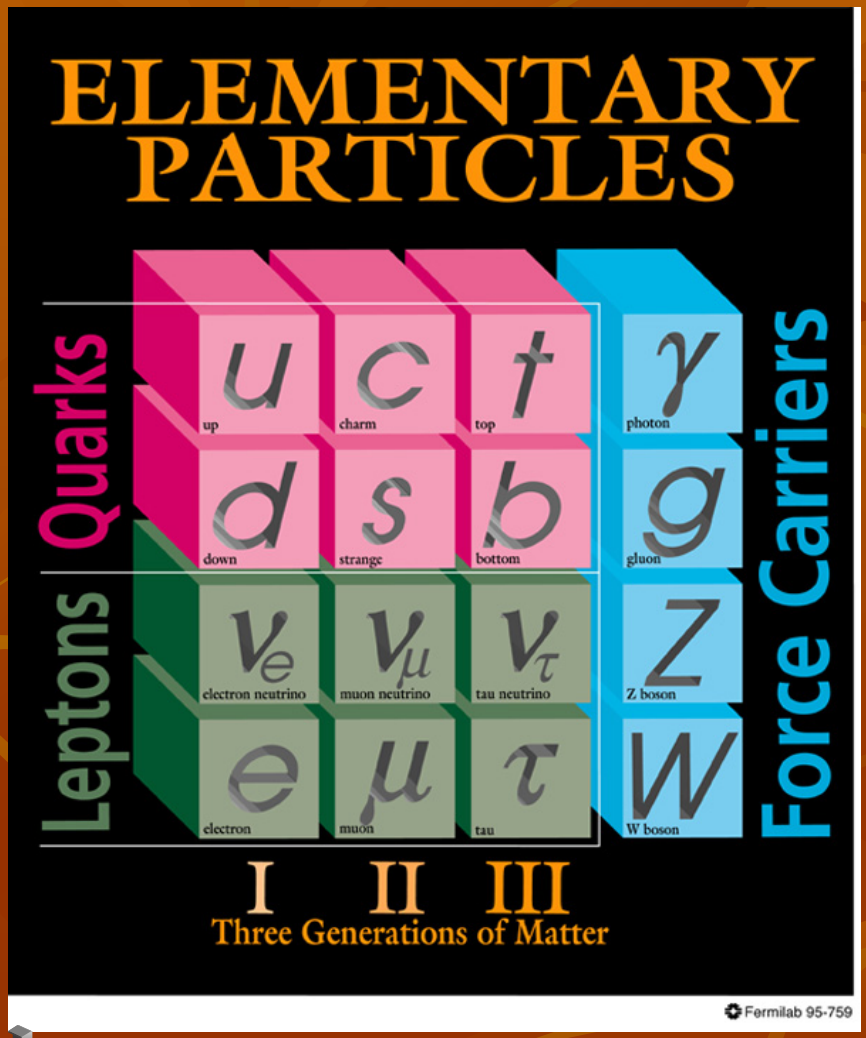
The Standard Model

SU(3)

SU(2)

U(1)

Particles



H

The Higgs boson

Forces

Electromagnetic

Strong

Weak

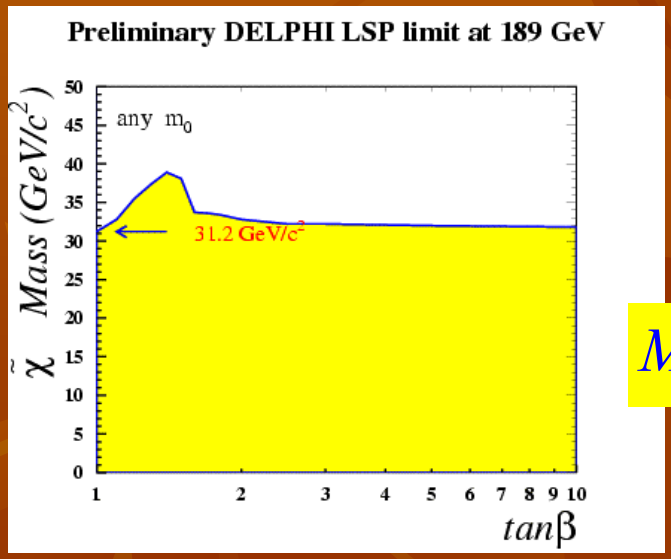
Gravity

SUSY Dark Matter

Neutralino = SUSY candidate for the cold Dark Matter
Neutralino = the Lightest Superparticle (LSP) = WIMP

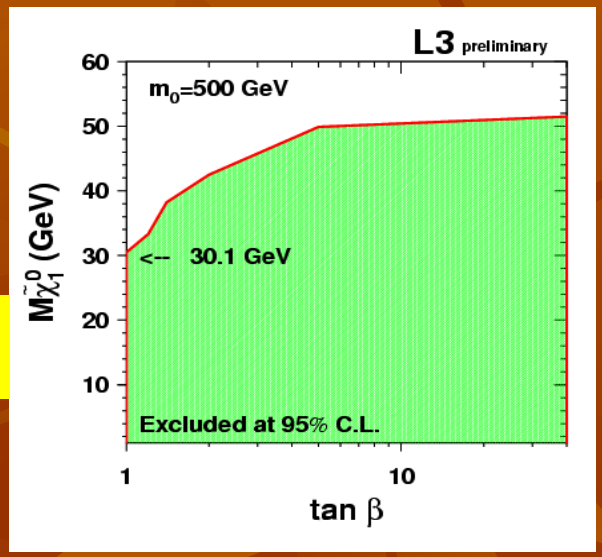
$$\tilde{\chi}^0 = N_1\tilde{\gamma} + N_2\tilde{z} + N_3\tilde{H}_1^0 + N_4\tilde{H}_2^0$$

photino zino higgsino higgsino



$$M_\chi^{exp} \geq 40 \text{ GeV}$$

$$M_\chi^{theor} = 40 \div 400 \text{ GeV}$$



$$R = (-1)^{3(B-L)+2S}$$

$$R_p = +1, \; R_{\not p} = -1$$

- **Superparticles are created in pairs**
- **The lightest superparticle is stable**

DM Detection

Direct detection

DAMA, Zeplin,
CDMS, Edelweiss

No convincing evidence so far
Hope for new results soon

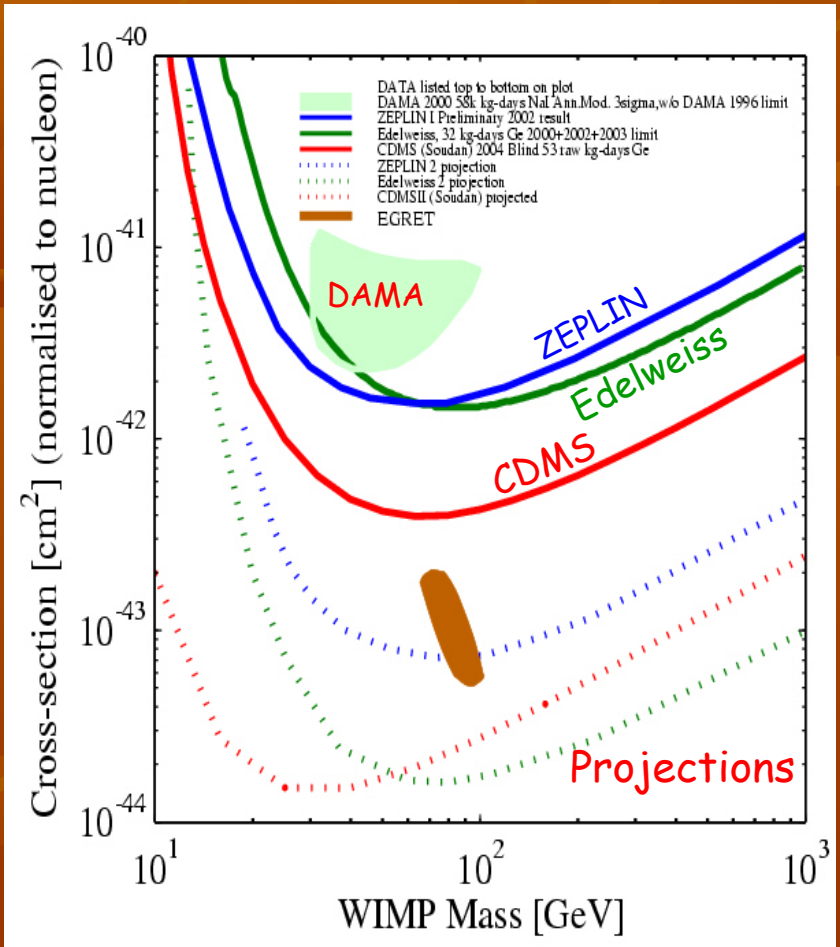
Indirect detection

- EGRET -> GLAST
Diffuse Gamma Rays
- HEAT, AMS01 -> PAMELA
Positrons in Cosmic Rays
- BESS -> AMS02
Antiprotons in Cosmic Rays

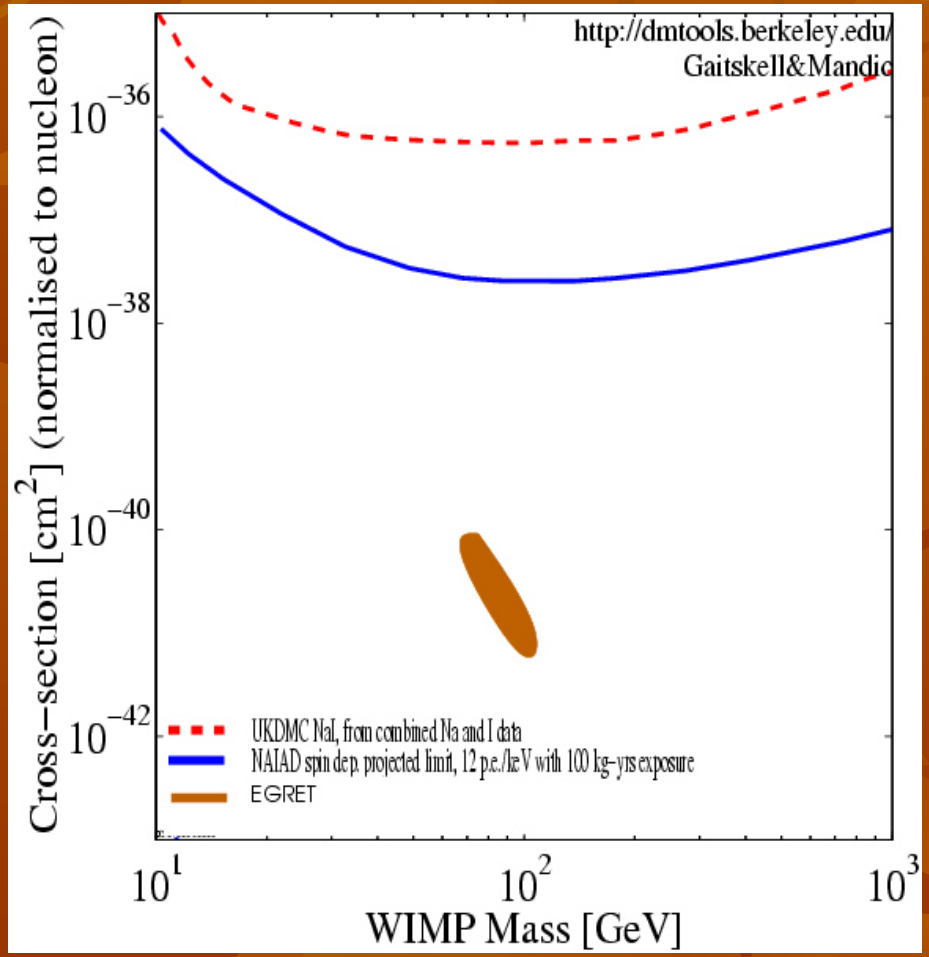
First Evidence of DM annihilation!

DIRECT DM SEARCHES

Spin-independent



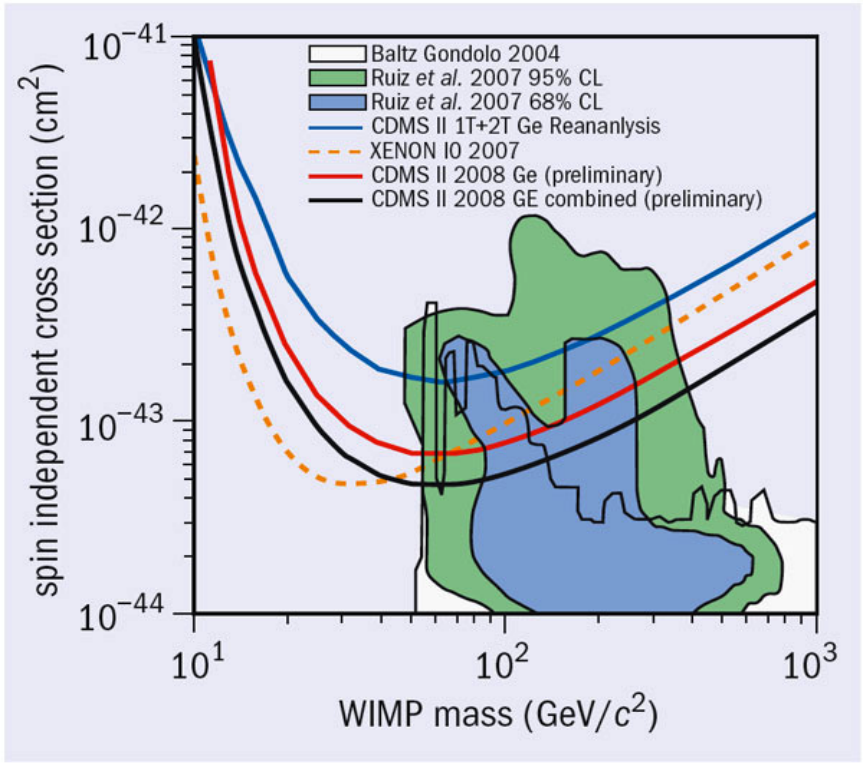
Spin-dependent



Predictions from EGRET data assuming Supersymmetry

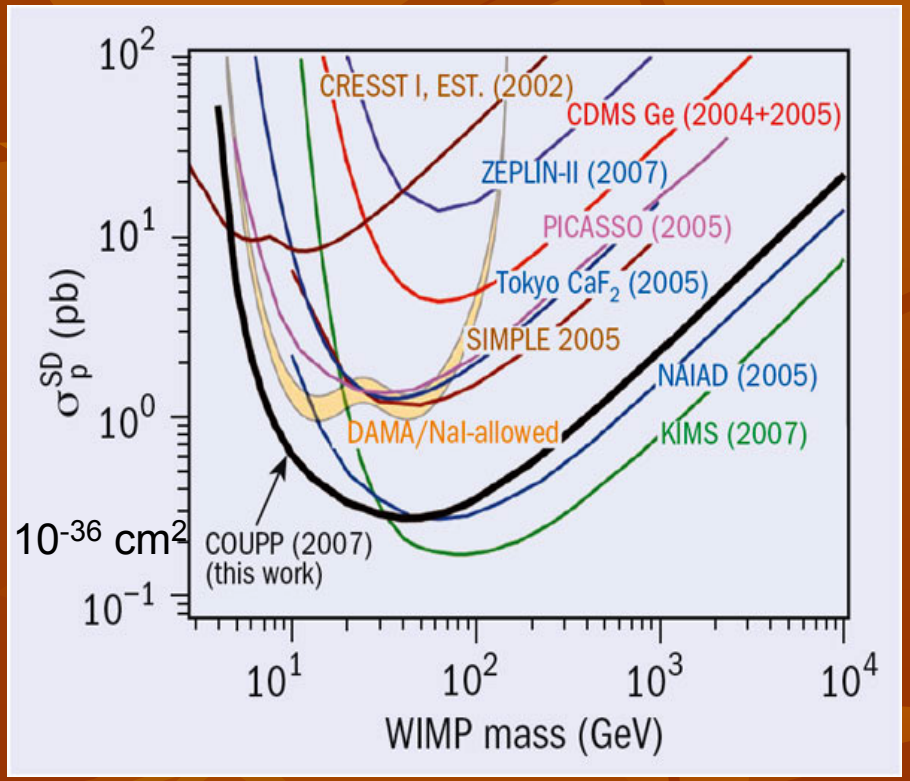
Recent Results on Direct Detection

Spin Independent



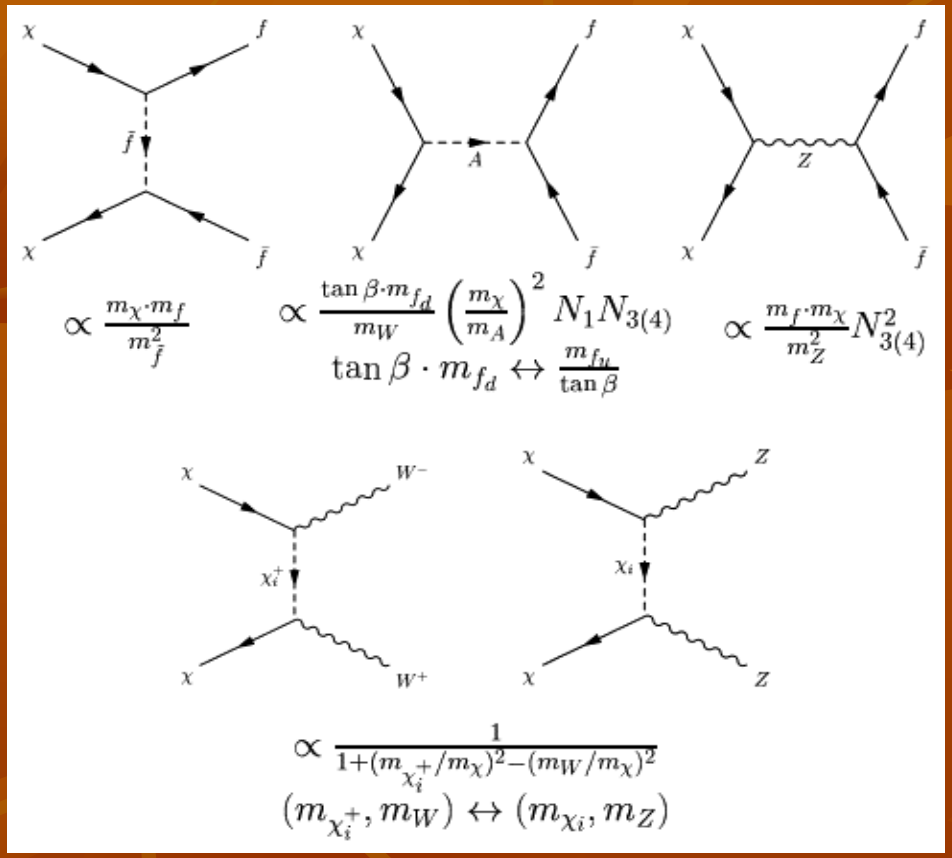
The Chicagoland Observatory for Underground Particle Physics (COUPP)

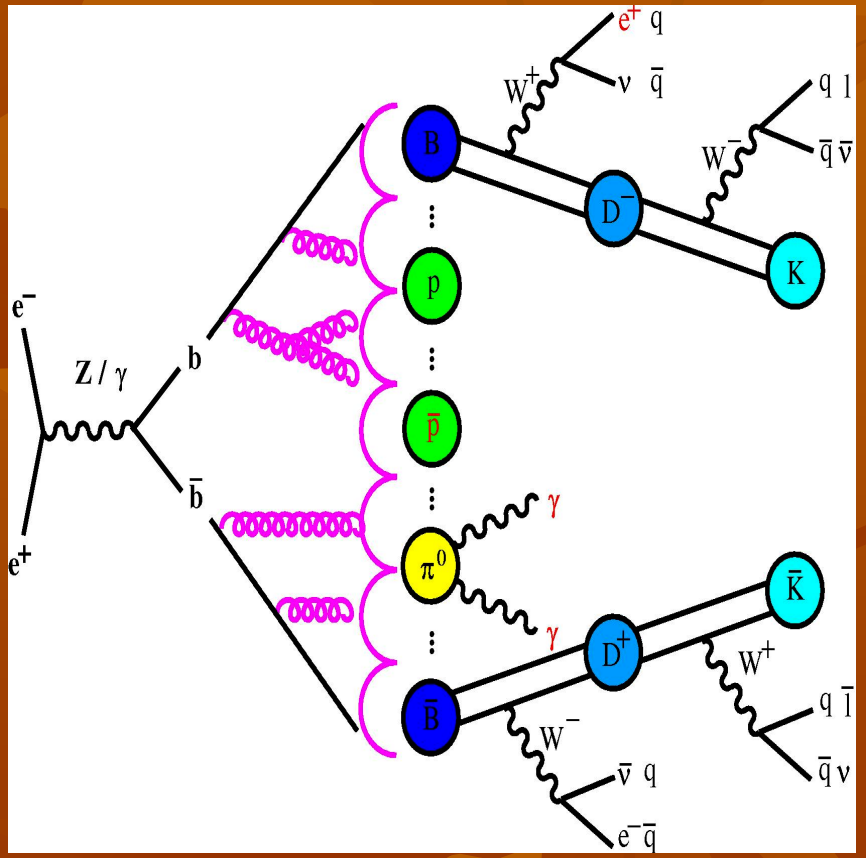
Spin Dependent



Cryogenic Dark Matter Search (CDMS)

DM Annihilation



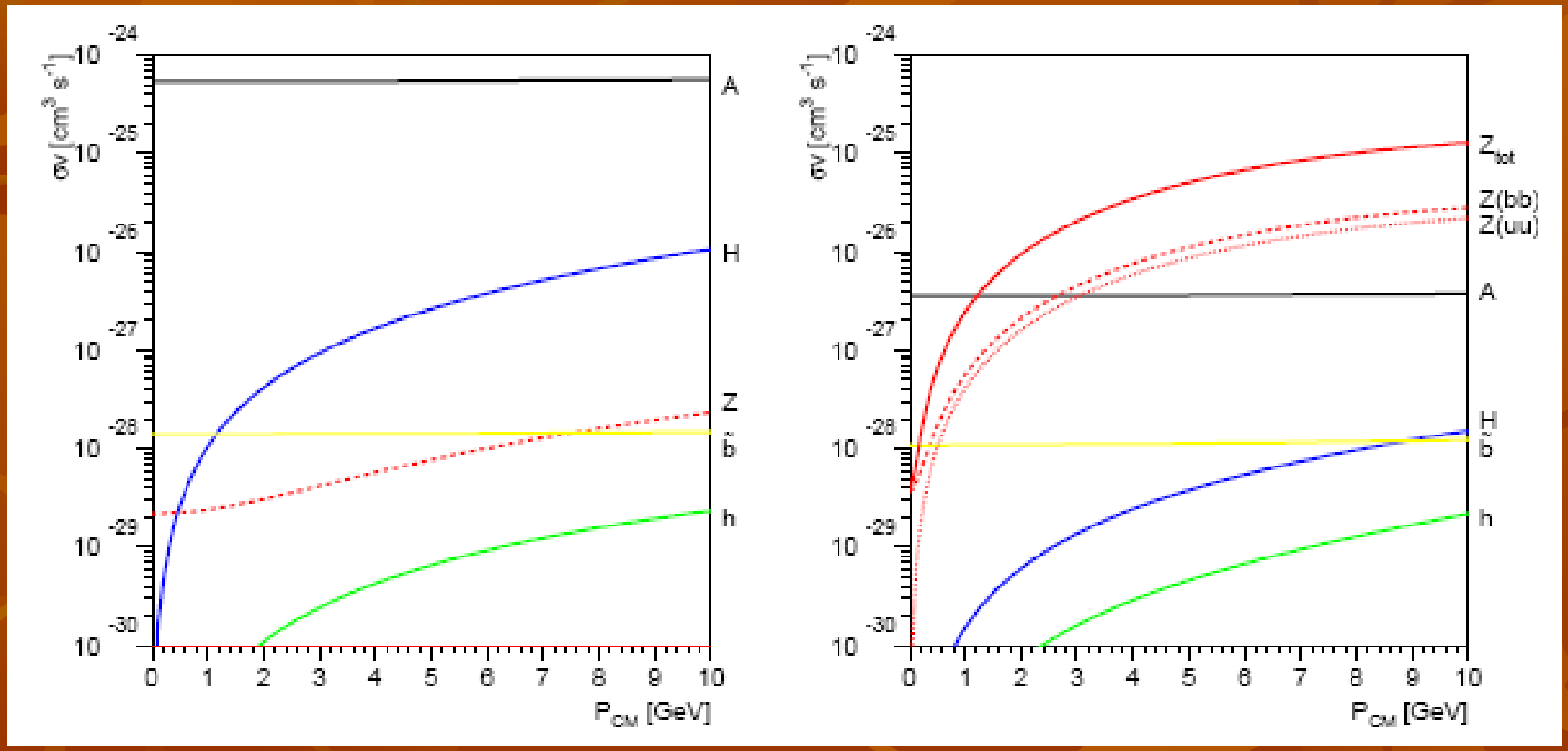


Dominant annihilation x-section:
$\chi + \chi \Rightarrow A \Rightarrow$ bb quark pair

Sum of diagrams should yield $\langle\sigma v\rangle = 2.10^{-26}$ cm³/s to get correct relic density

B-fragmentation well studied at LEP!
Yield and spectra of positrons, gammas and antiprotons well known!

DM Annihilation X-Sections

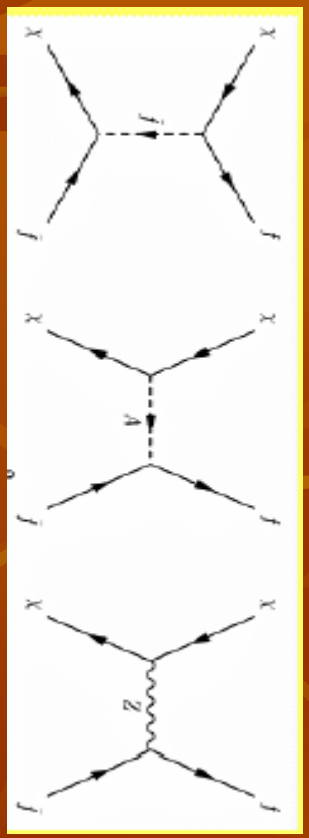


S-wave dominant

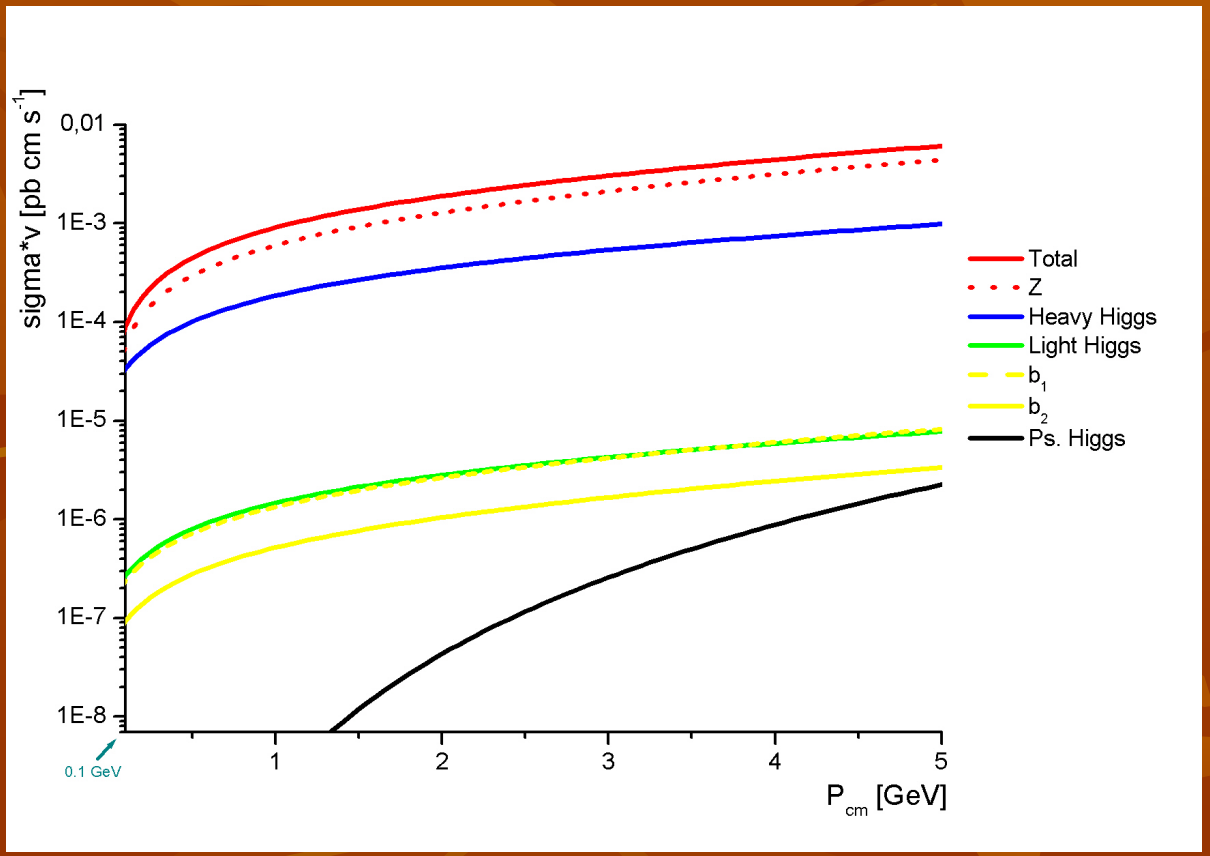
P-wave dominant

DM Interactions with Matter

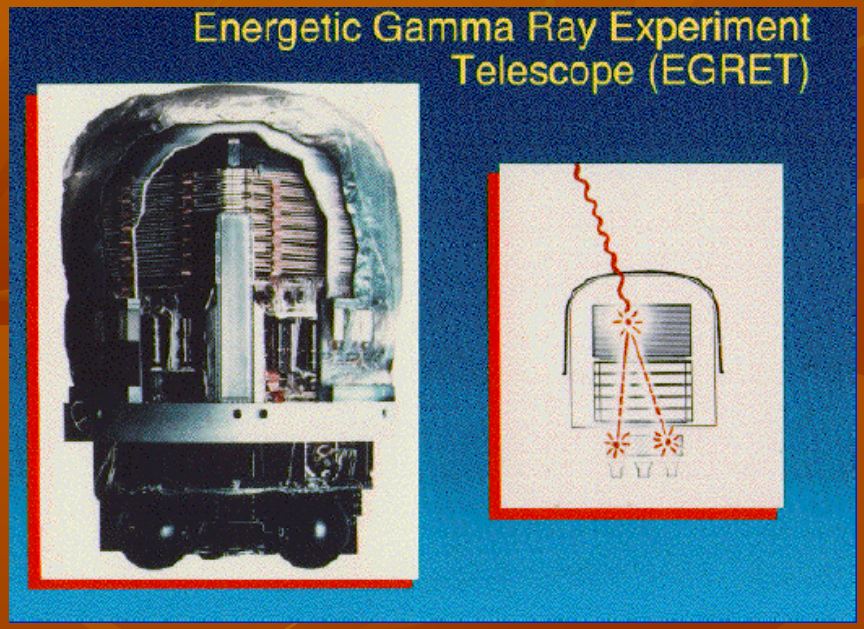
Main Diagrams

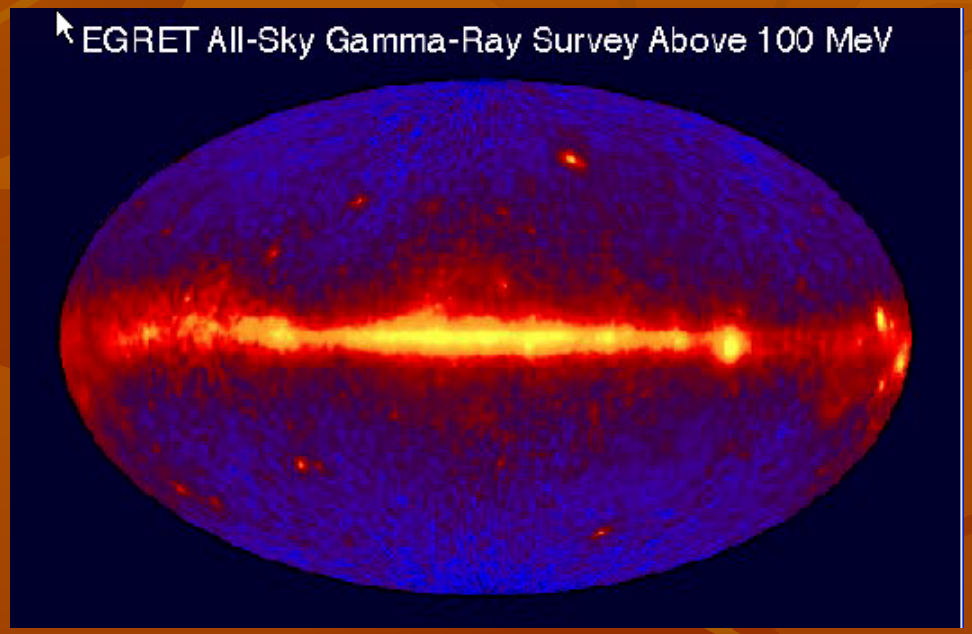


Cross-section for quark subprocess



Diffuse Gamma Rays from the Sky





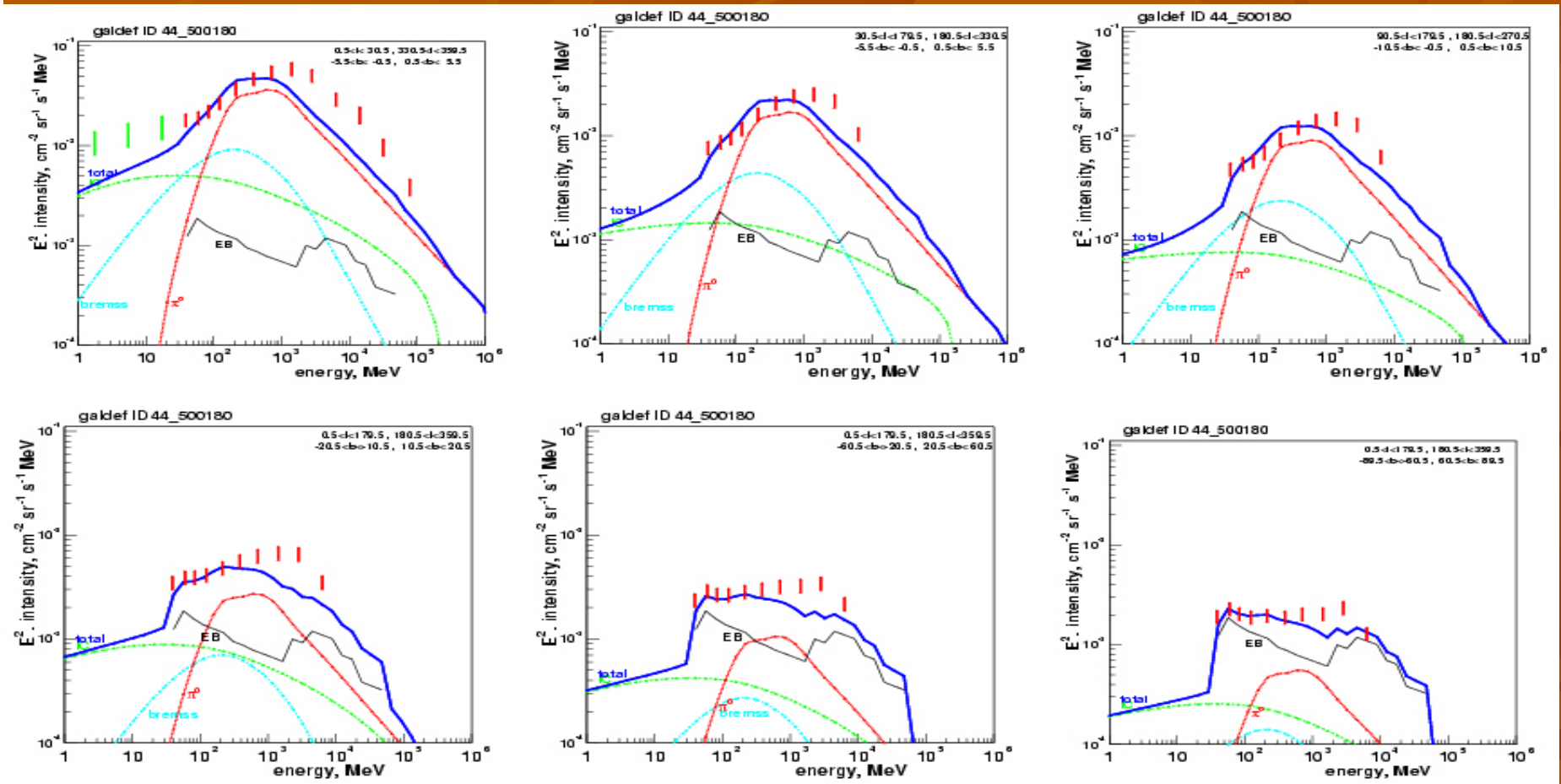
Instrumental parameters:

Energy range: 0.02-30 GeV
Energy resolution: ~20%
Effective area: 1500 cm^2
Angular resol.: $<0.5^0$

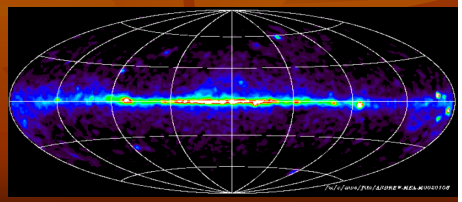
Data taking: 1991-2000

Main EGRET results:
Catalogue of point sources
Excess in diffuse gamma rays

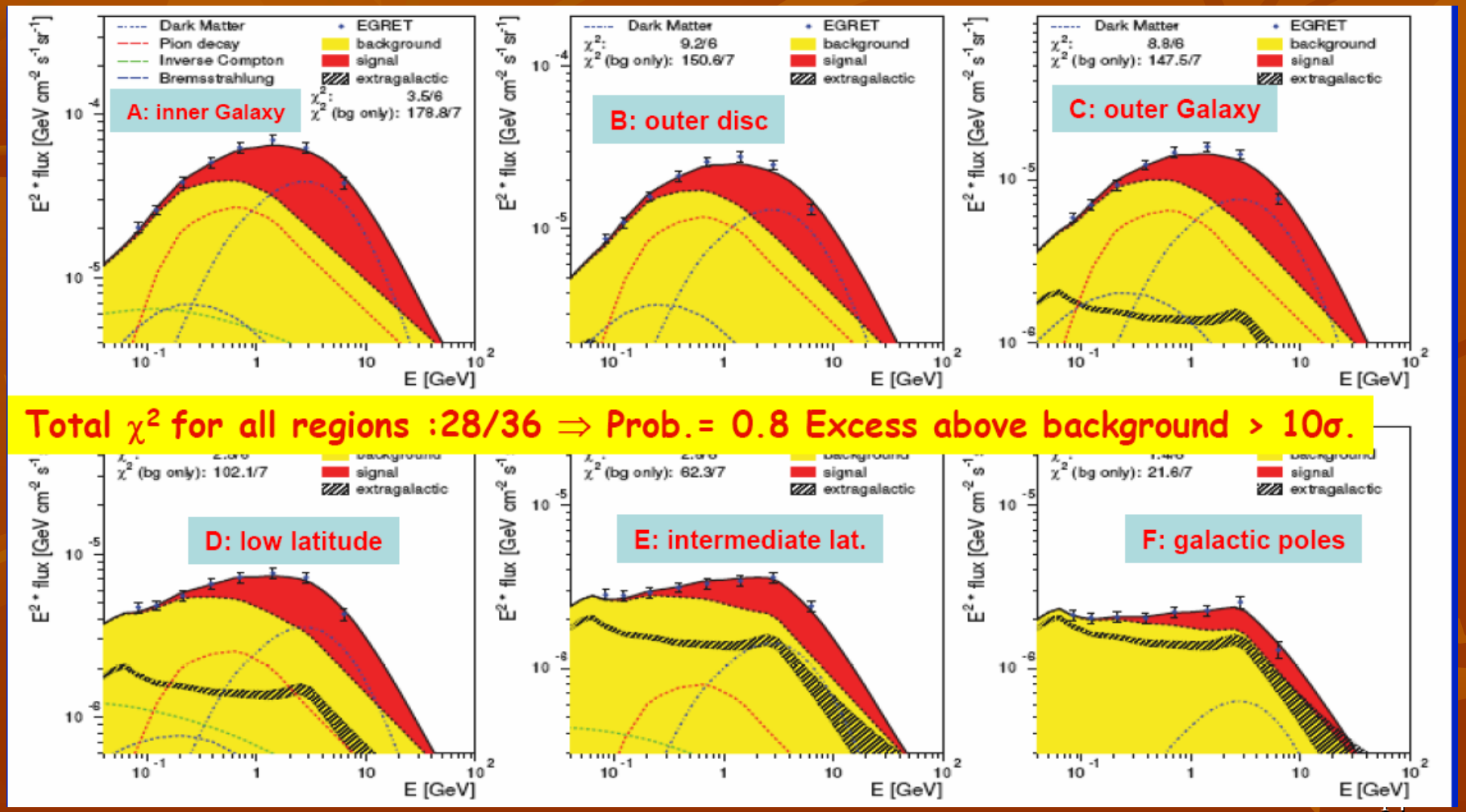
Excess of Diffuse Gamma Rays Above 1 GEV



A: inner Galaxy ($l=\pm30^0$, $|b|<5^0$)
B: Galactic plane avoiding *A*
C: Outer Galaxy
D: low latitude ($10\text{-}20^0$)
E: intermediate lat. ($20\text{-}60^0$)
F: Galactic poles ($60\text{-}90^0$)

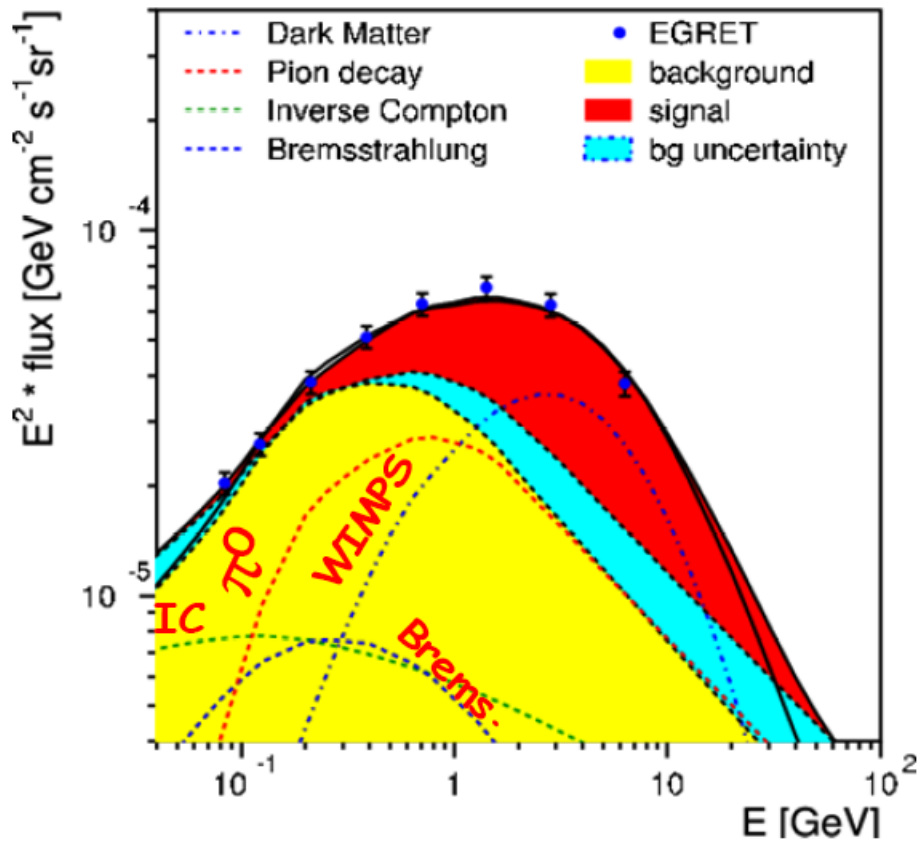


Analysis of EGRET Data in 6 Sky Directions

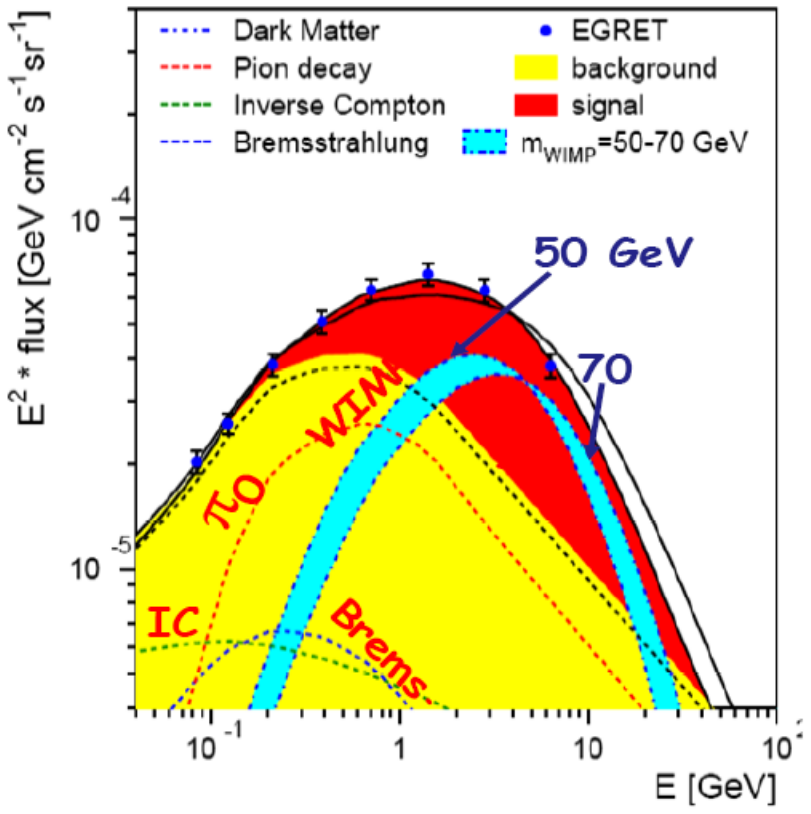


Total χ^2 for all regions :28/36 $\Rightarrow$ Prob.= 0.8 Excess above background > 10σ.

Background + Signal Describe EGRET Data

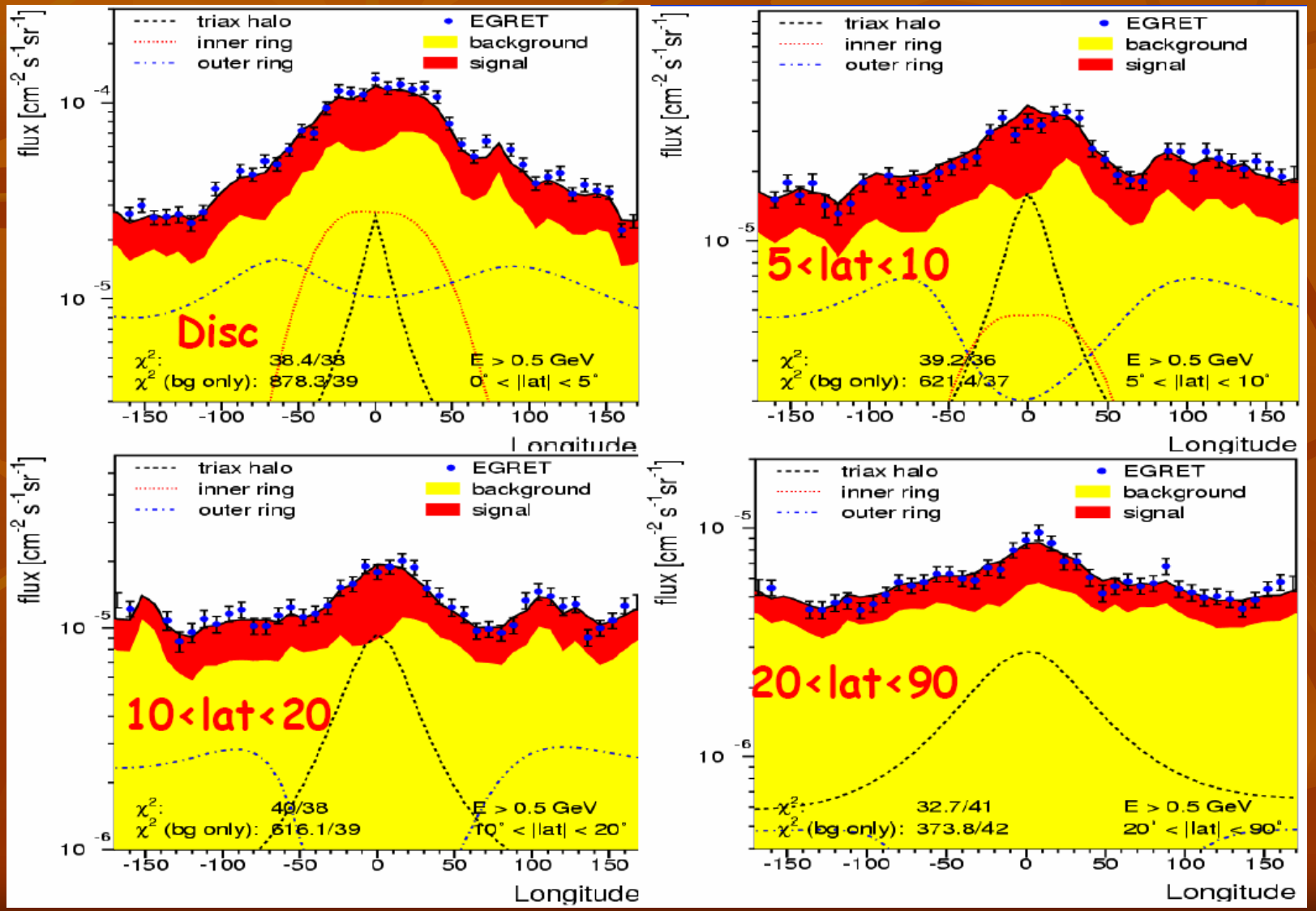


Blue: background uncertainty



Blue: WIMP mass uncertainty

Diffuse Gamma Rays in EGRET Energy Range



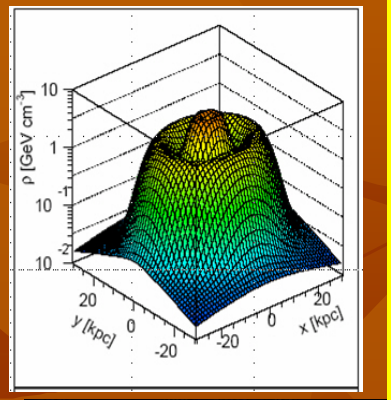
Fitted Halo Parameters

Gamma Ray Flux: (<σv> from WMAP)

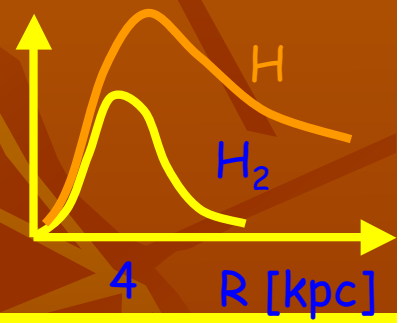
$$\phi_\chi(E,\psi) = \frac{\langle\sigma v\rangle}{4\pi}\sum_f \frac{dN_f}{dE} b_f \int_{line\ of\ sight} B_l \frac{1}{2}\frac{\langle\rho_\chi^2\rangle}{M_\chi^2} dl_\psi$$

$$\rho_\chi(\tilde{r}) = \rho_0 \left(\frac{R_0}{\tilde{r}}\right)^\gamma \left[\frac{1+\left(\frac{\tilde{r}}{a}\right)^\alpha}{1+\left(\frac{R_0}{a}\right)^\alpha}\right]^{\frac{\gamma-\beta}{\alpha}} + \sum_{n=1}^{N} \rho_n \exp\left(-\frac{(\tilde{r}_{gc}-Rn)^2}{2\sigma_{Rn}^2} - \frac{(z_n)^2}{2\sigma_{zn}^2}\right)$$

Parameter	Value	Parameter	Value
α	2	R_a	4.3 kpc
β	2	$\sigma_{R,a}$	3.4 kpc
γ	0	$\sigma_{z,a}$	0.3 kpc
R_0	8.5 kpc	ρ_b	2.3 GeV cm^{-3}
a	4 kpc	R_b	14 kpc
ρ_0	0.47 GeV cm^{-3}	$\sigma_{R,b}$	2.1 kpc
ρ_a	3.3 GeV cm^{-3}	$\sigma_{z,b}$	1.3 kpc
b/a	0.9	c/a	0.8



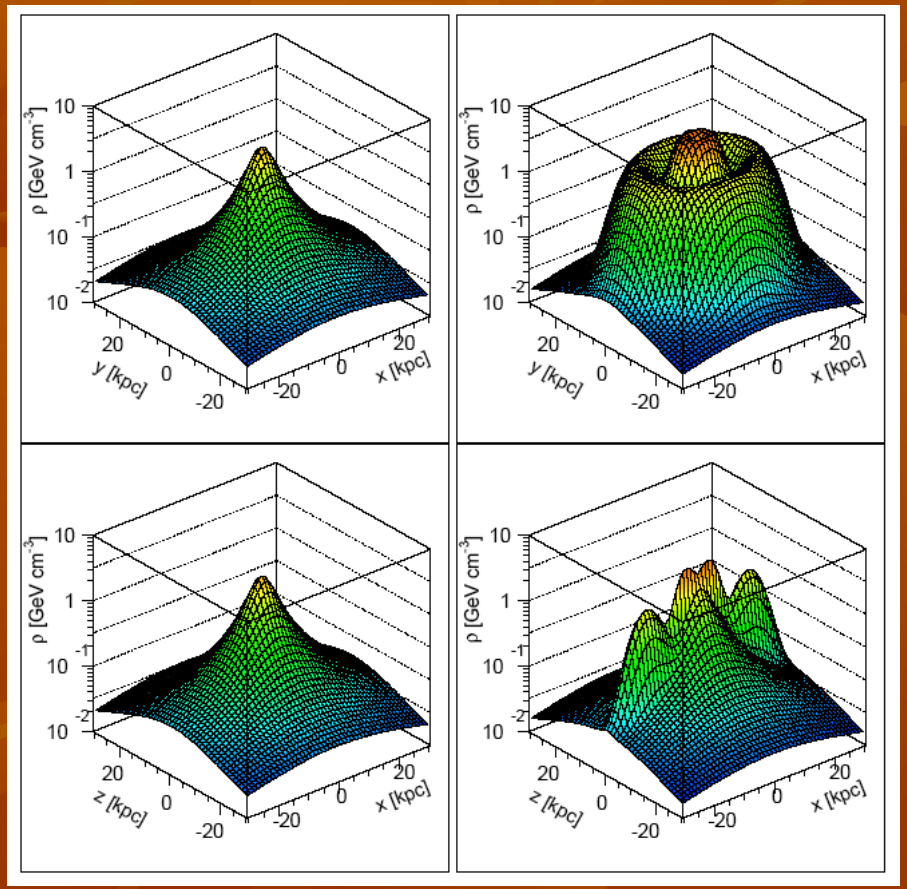
Enhancement of rings over $1/r^2$ profile 2 and 7, respectively. Mass in rings 1.6 and 0.3% of total DM



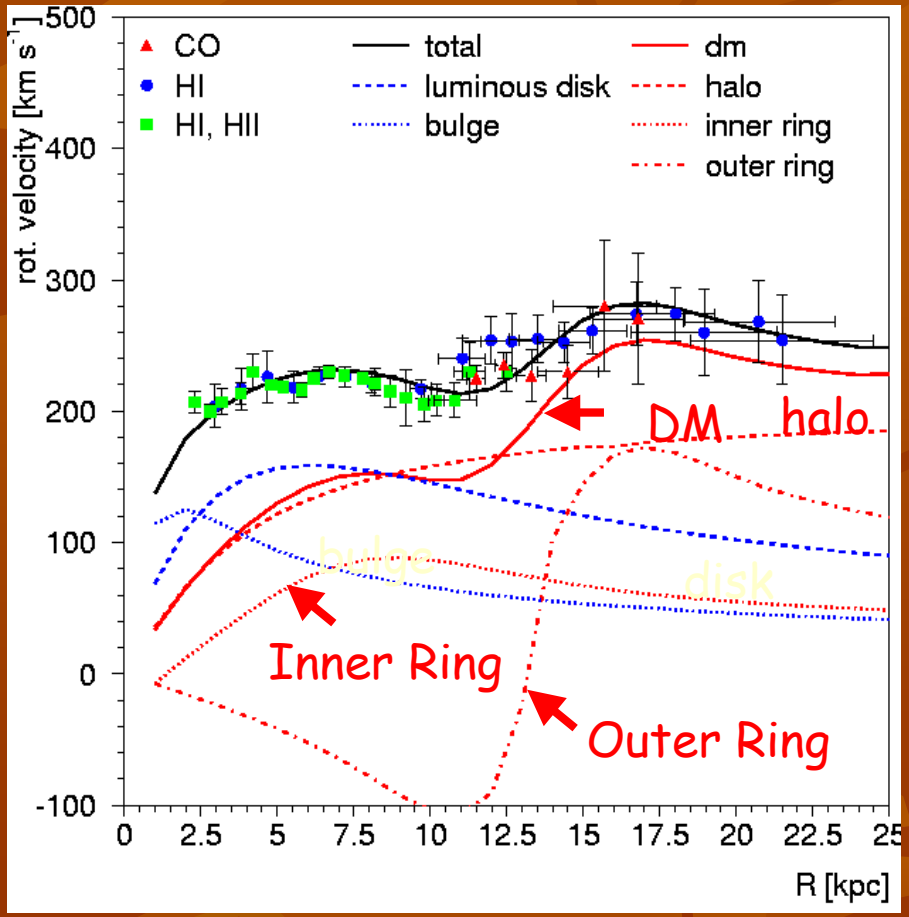
14 kpc coincides with ring of stars at 14-18 kpc due to infall of dwarf galaxy

4 kpc coincides with ring of neutral hydrogen molecules!

Halo Profile and Rotation Curve

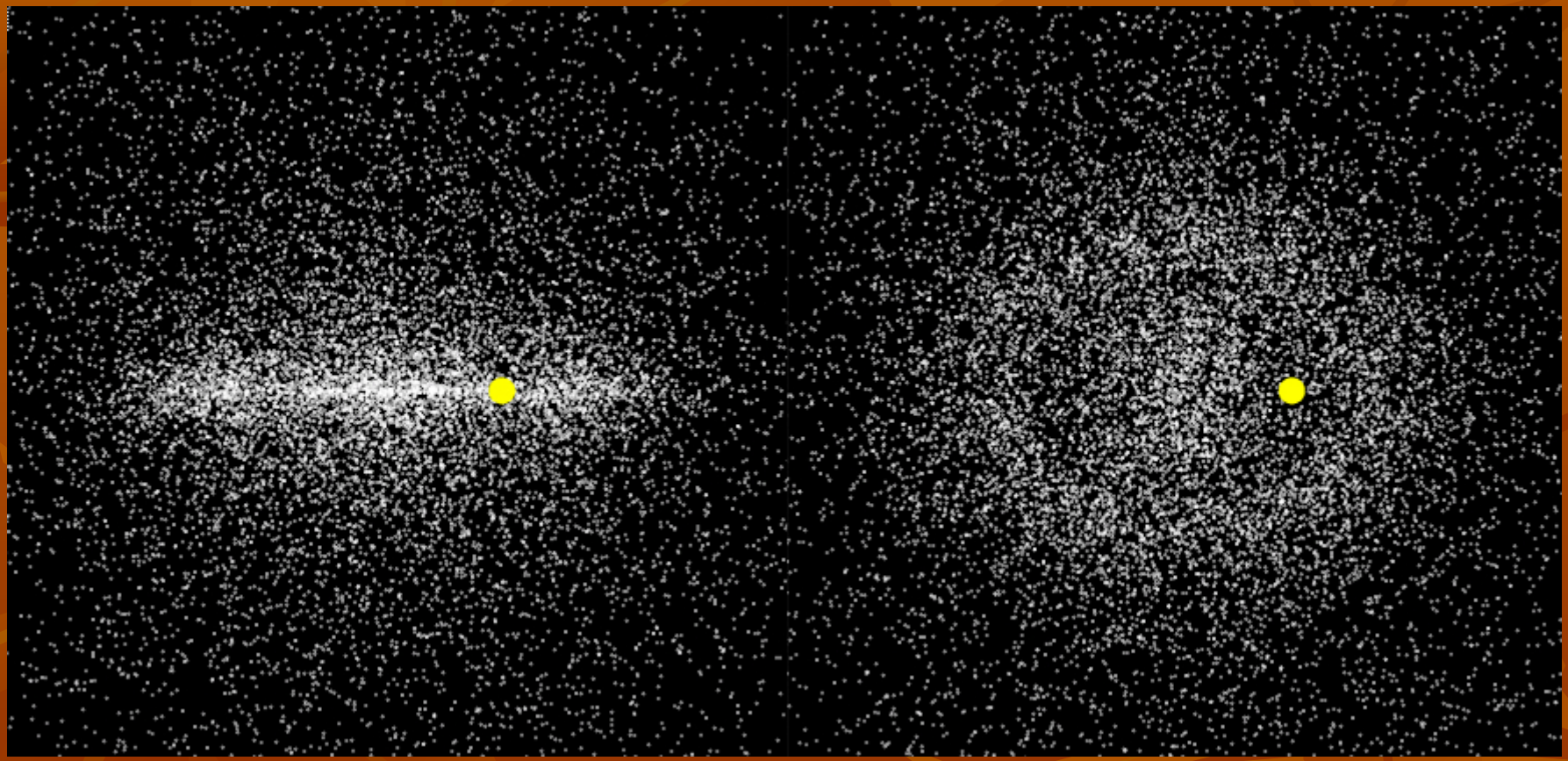


Halo profile with rings of DM



Rotation curve of the Milky Way

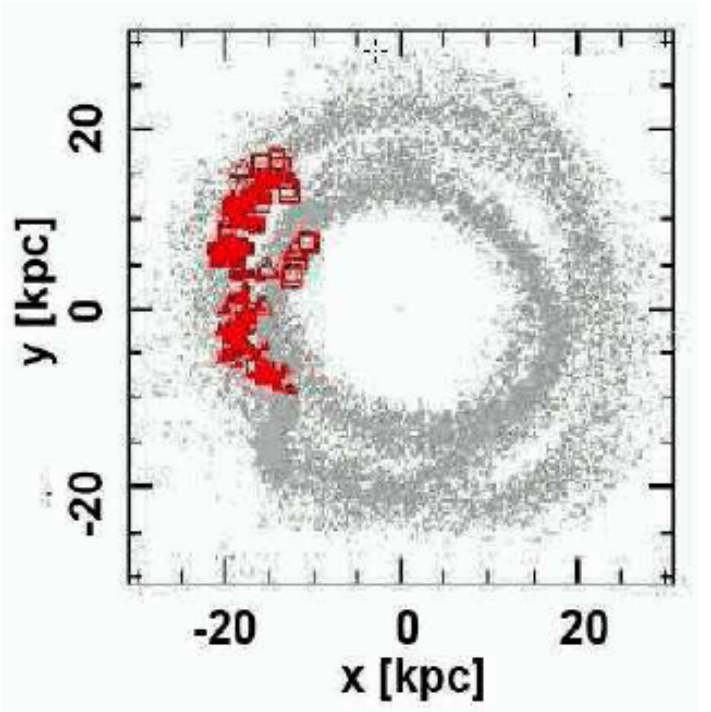
Halo density on scale of 30 kpc



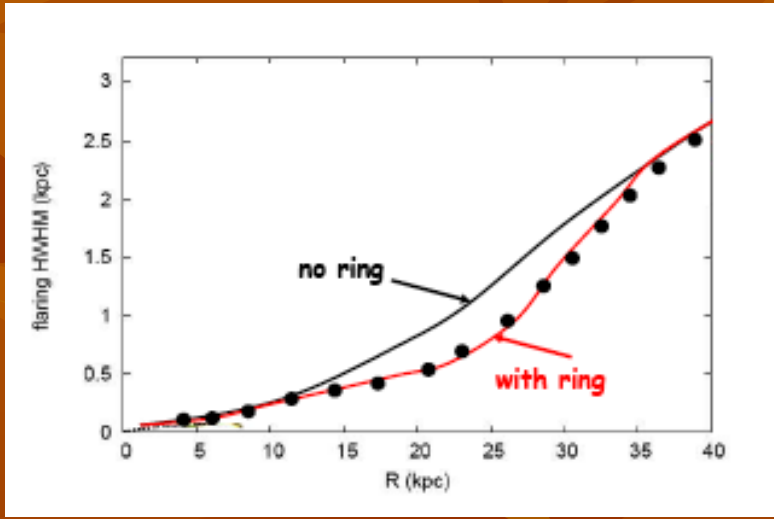
Sideview

Topview

Support for the Ring Structure



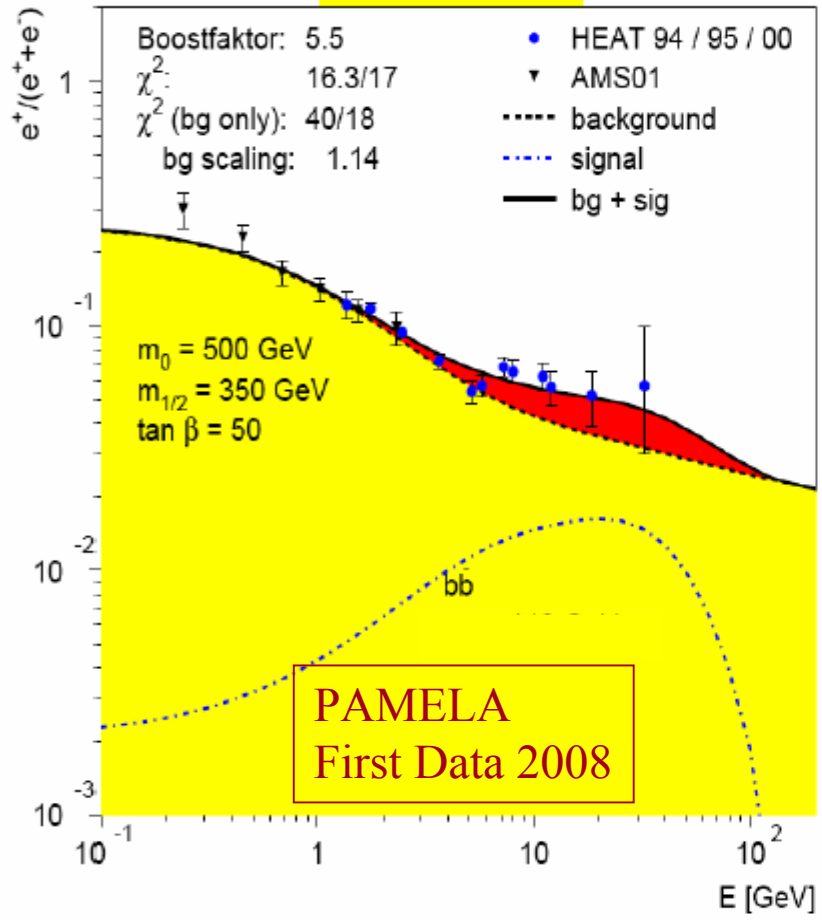
N-body simulation of the tidal disruption of the Canis Major dwarf Galaxy fitted to the observed stars (red points). The simulation predicts a ringlike structure of dark matter with a radius of 13 kpc



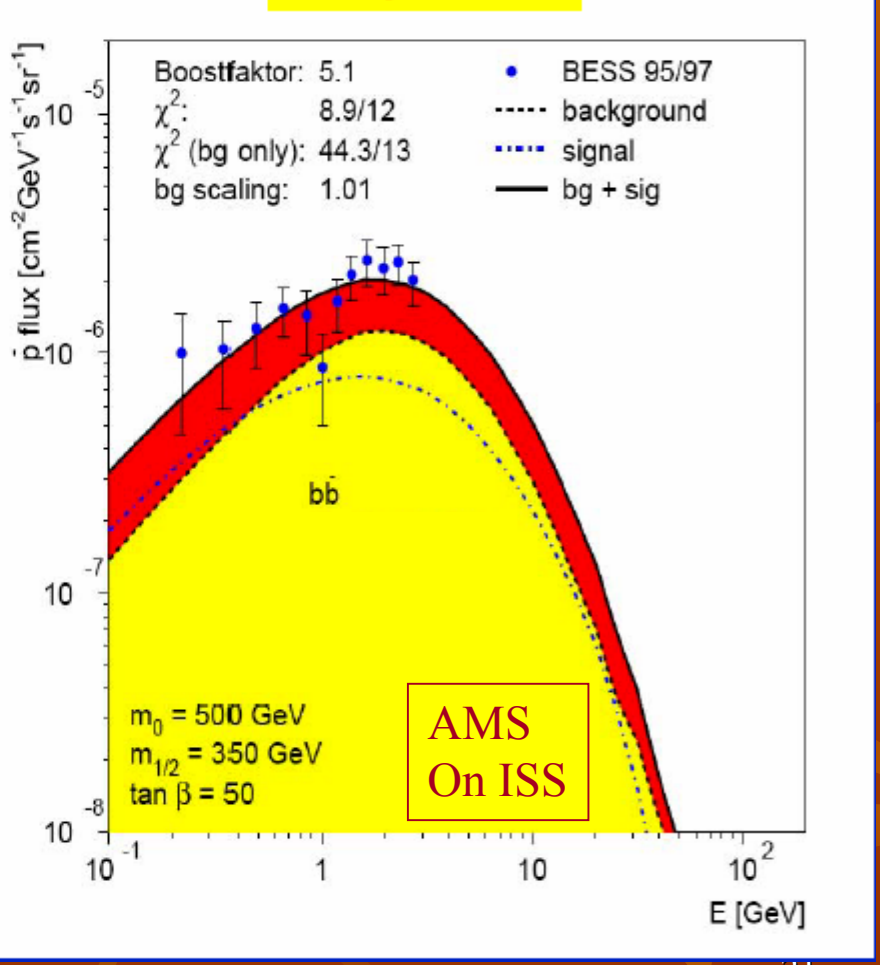
The gas layer of the Galactic Disk as function of the distance from the Galactic center.

Positron Fraction and Anatiprotons from DM Annihilation

Positrons



Antiprotons



DM is the Window to the Physics beyond the SM

What the future may bring?