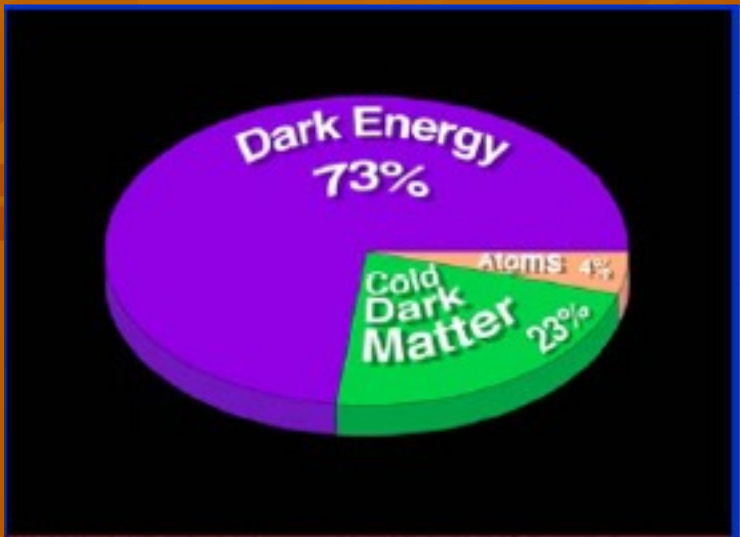
Dark Matter
Particle Physics View

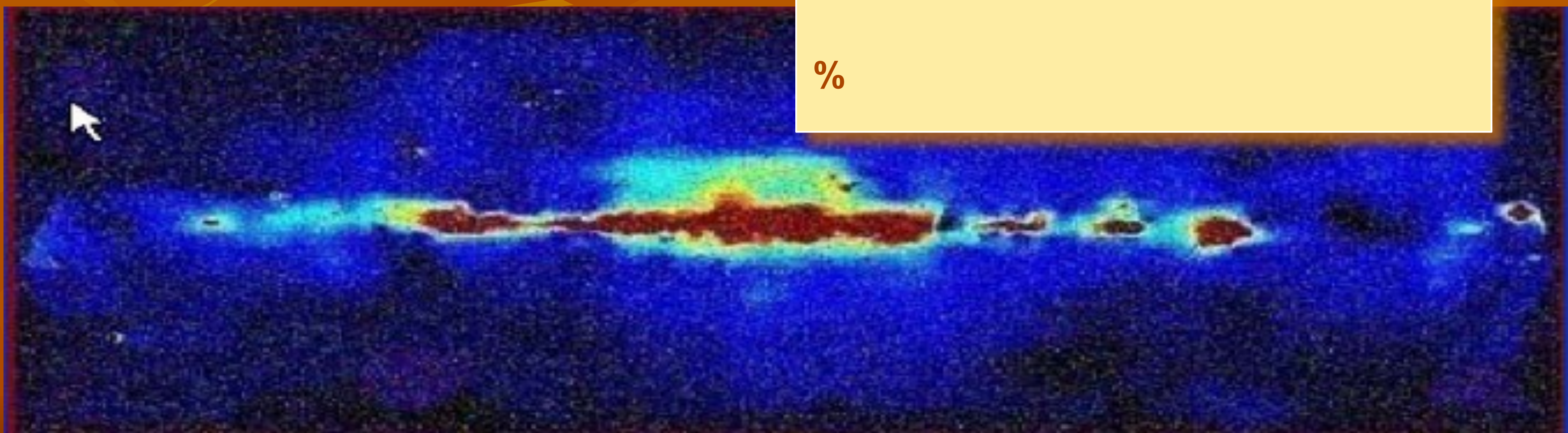
Outline

- DM in the Universe
- Direct DM Search
- Indirect DM Search
- Possible Manifestations
- DM Profile of the Milky Way
- SUSY DM

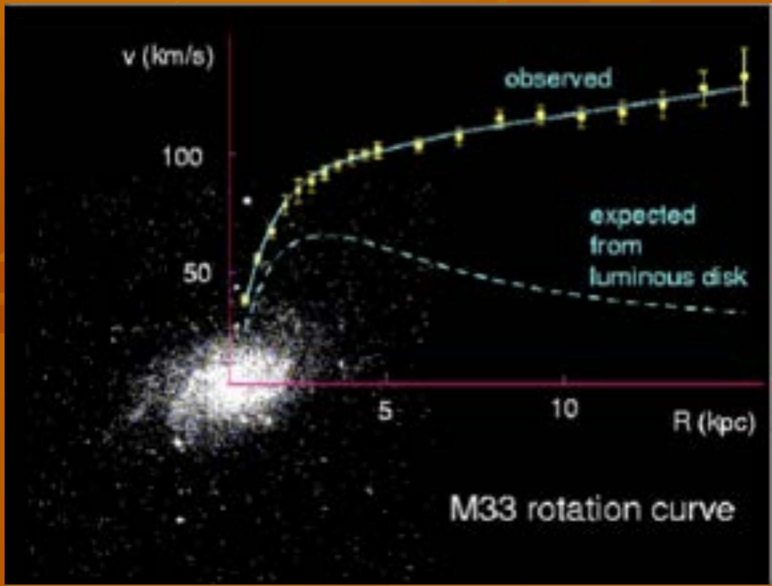
Matter and Energy Content of the Universe



HEAVY ELEMENTS	0.03 %
MASSIVE NEUTRINOS	0.3 %
STARS	0.5 %
H AND He	4 %
DARK MATTER	23 %
DARK ENERGY	72
%	



Evidence for the Dark Matter



THE FLAT ROTATION CURVES OF SPIRAL GALAXIES PROVIDE THE MOST DIRECT EVIDENCE FOR THE EXISTENCE OF LARGE AMOUNT OF THE DARK MATTER.

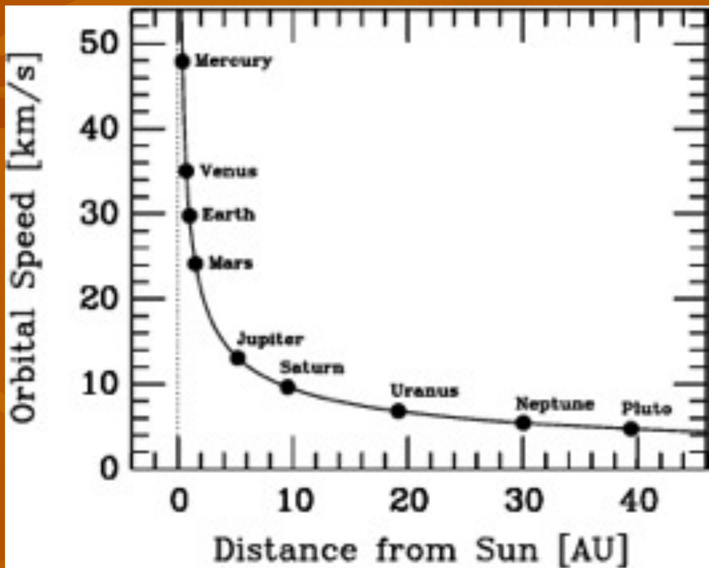
SPIRAL GALAXIES CONSIST OF A CENTRAL BULGE AND A VERY THIN DISC, AND SURROUNDED BY AN APPROXIMATELY SPHERICAL HALO OF DARK MATTER

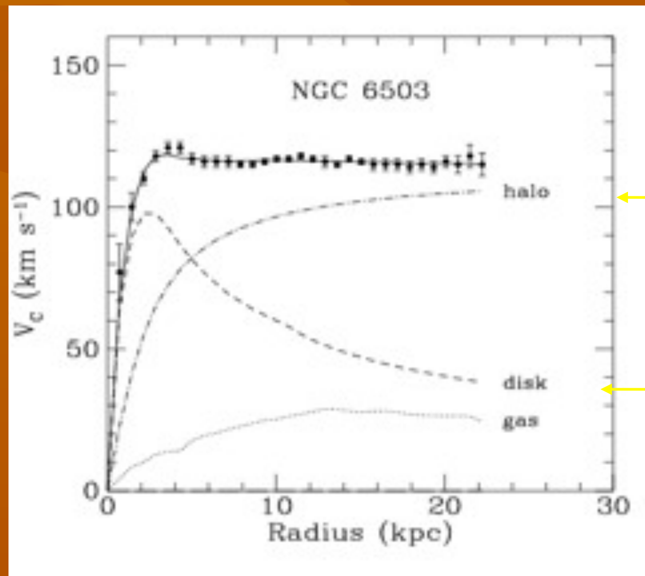
Rotation Curves in the Solar

CENTRIFUGAL FORCE

$$\frac{mv^2}{r} = G\frac{mM(r)}{r^2}$$

GRAVITY FORCE



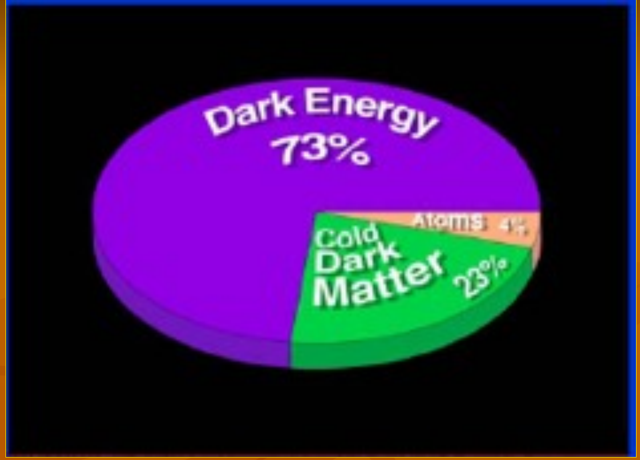


DARK MATTER HALO ALONE

DISC ALONE

- NOWDAYS, THOUSANDS OF GALACTIC ROTATION CURVES ARE KNOWN, AND ALL SUGGEST THE EXISTENCE OF ABOUT TEN TIMES MORE MASS IN THE HALOS THAN IN THE STARS OF THE DISC
- THE ROTATION CURVE OF THE MILKY WAY HAS BEEN MEASURED AND CONFIRMS THE USUAL PICTURE

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-handed neutrino

Non from the SM

- neutralino
- sneutrino
- axion (axino)
- gravitino
- heavy photon
- heavy pseudo-goldstone
- light sterile higgs

DM Detection

Direct detection

DAMA, Zeplin,
CDMS, Edelweiss

No convincing evidence so far
Hope for new results soon

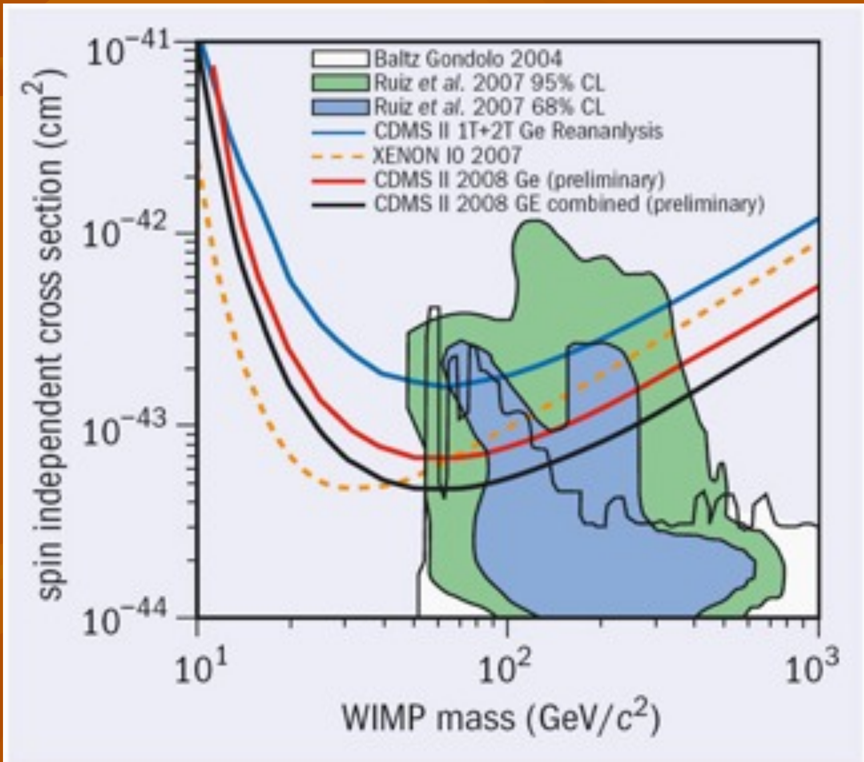
Indirect detection

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

First Evidence of DM annihilation ?!

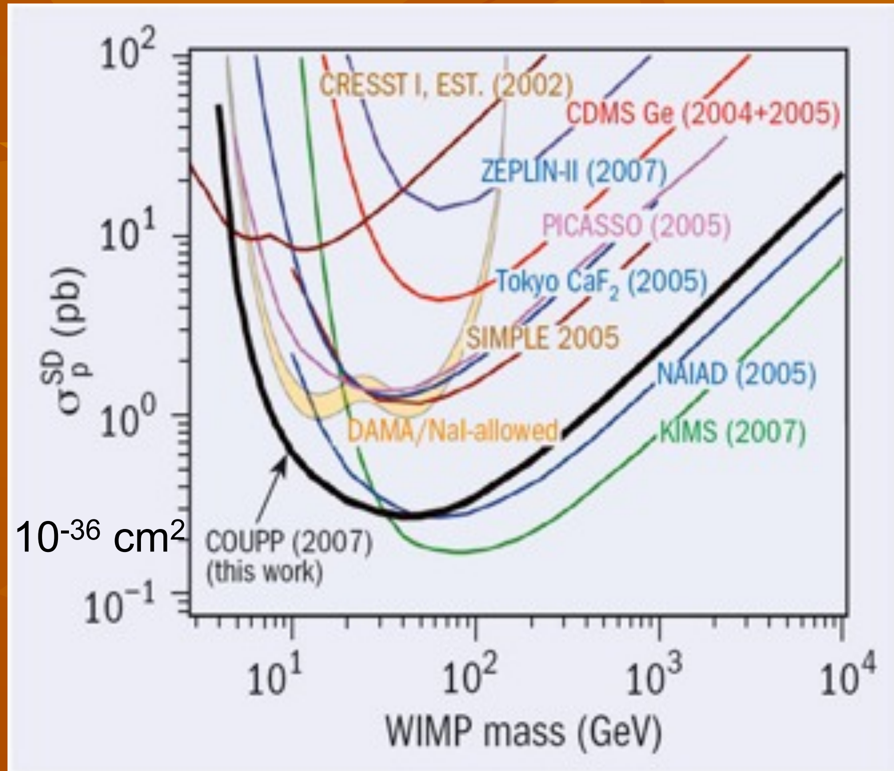
Recent Results on Direct Detection

Spin Independent



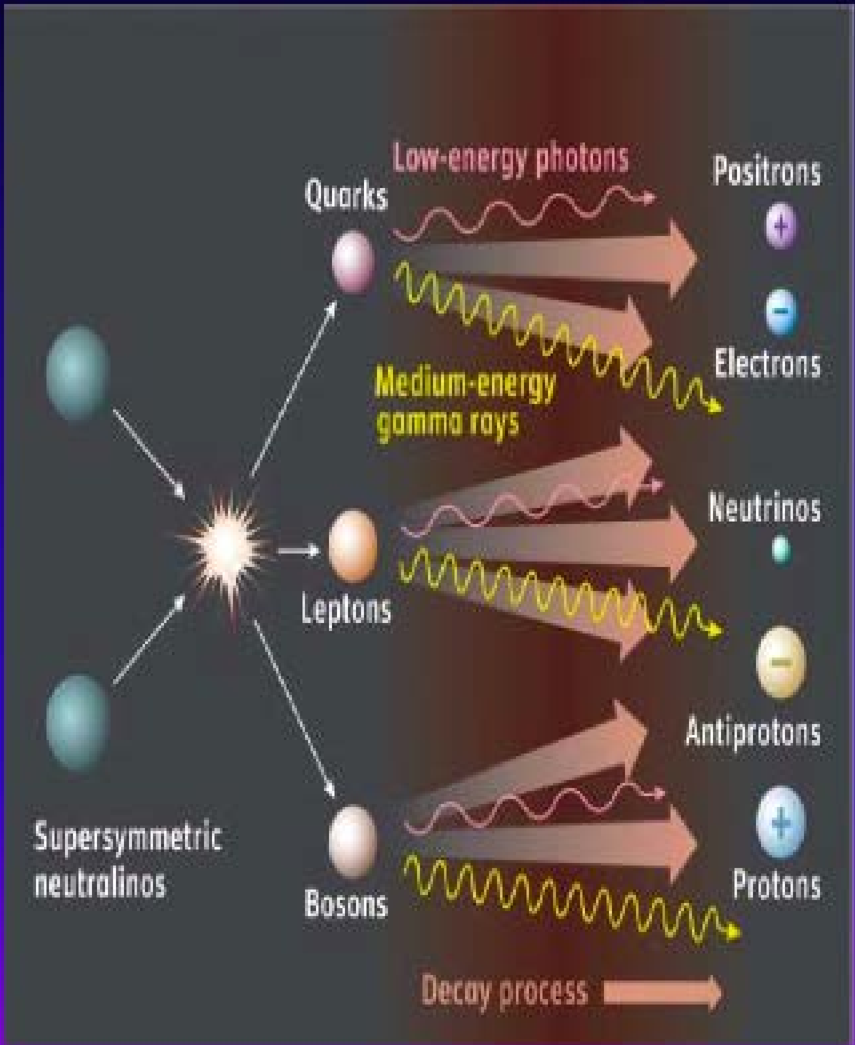
The Chicagoland Observatory for Underground Particle Physics (COUPP)

Spin Dependent



Cryogenic Dark Matter Search (CDMS)

Dark Matter Annihilation



<u>Annihilation products from dark matter annihilation:</u>

<u>Gamma rays</u>
(EGRET, FERMI)

<u>Positrons</u> (PAMELA)

<u>Antiprotons</u> (PAMELA)

e+ + e-
(ATIC, FERMI, HESS, PAMELA)

Neutrinos (Icecube, no results yet)

e-, p drown in cosmic rays?

Why WIMP?

Boltzman Equation

Hubble constant

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -<\sigma v>(n_\chi^2 - n_{\chi,eq}^2), \qquad H = \dot{R}/R$$

Relic Abundance

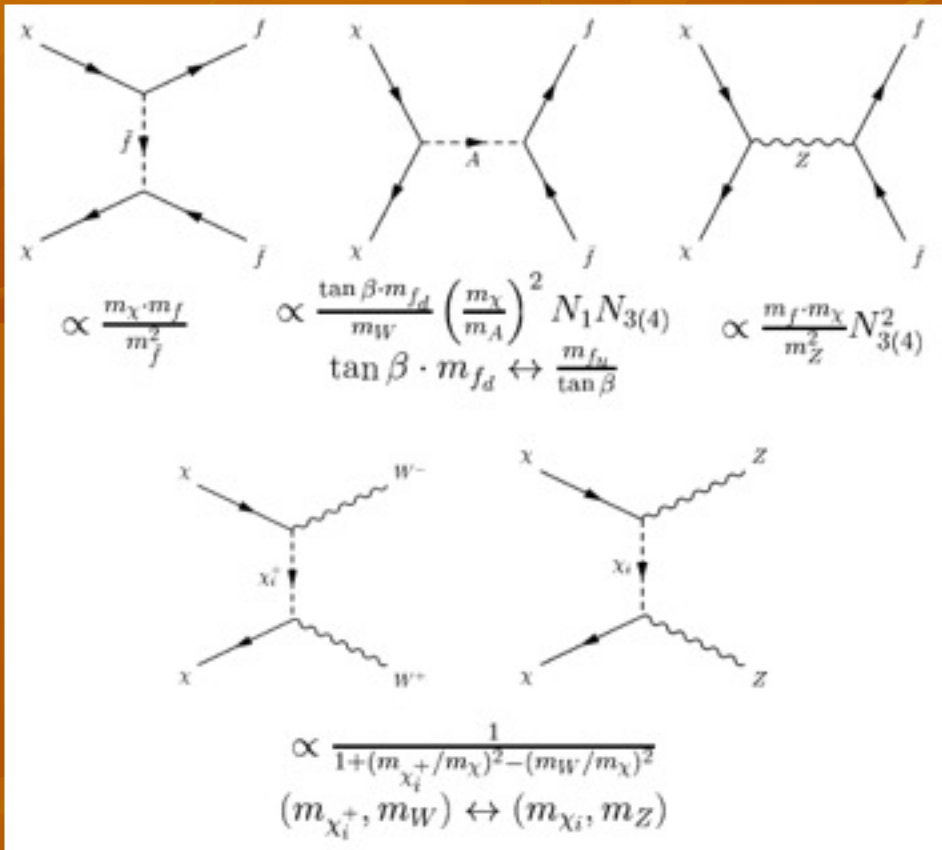
$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \approx \frac{2 \cdot 10^{-27}\, cm^3 \sec^{-1}}{<\sigma v>}$$

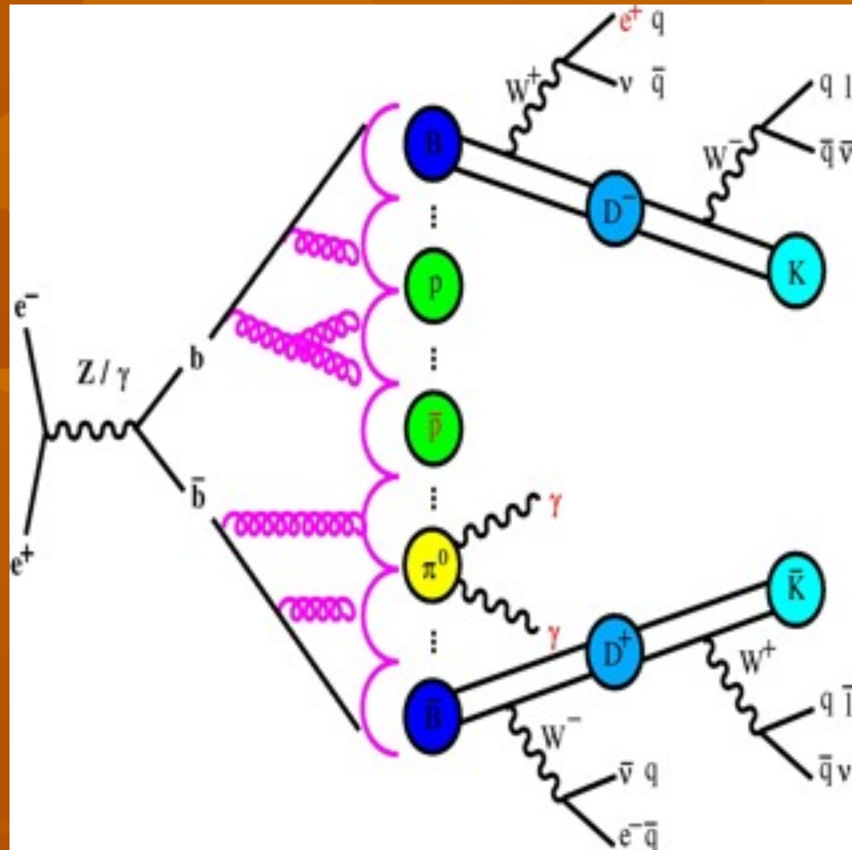
$$\Omega_\chi h^2 \sim 0.113 \pm 0.009,$$
$$v \sim 300\ km/\sec$$

$$\sigma \sim 10^{-34}\, cm^2 = 100\, pb$$

Typical EW cross-section

DM Annihilation

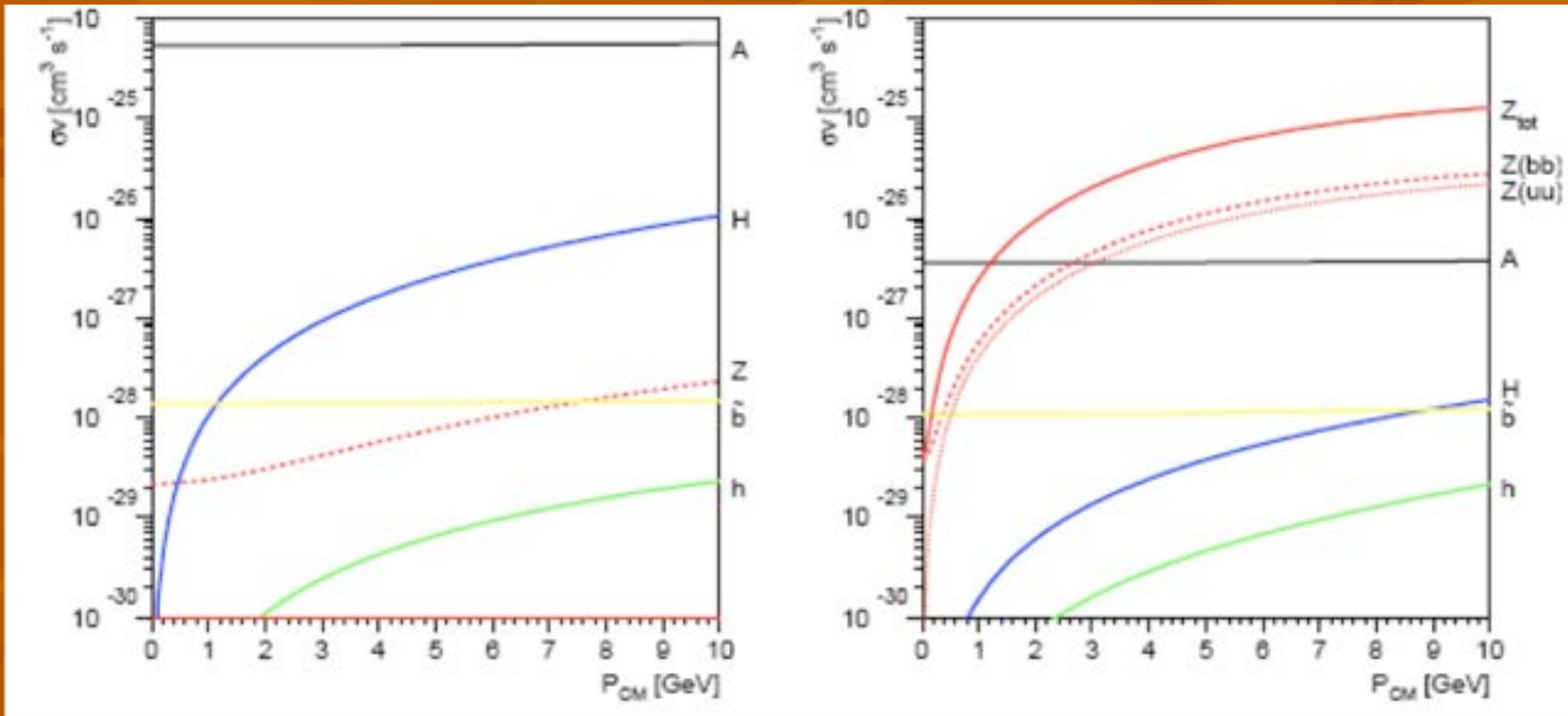




Dominant annihilation x-section:
$\chi + \chi \Rightarrow A \Rightarrow$ bb quark pair
Sum of diagrams should yield
$<\sigma v> = 2.10^{-26}$ cm^3/s to get
correct relic density

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

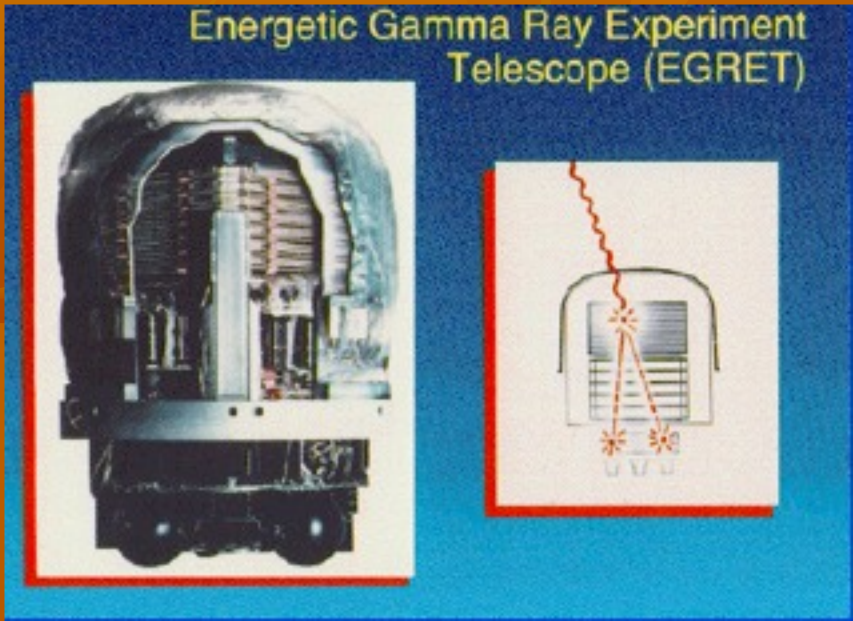
DM Annihilation X-Sections

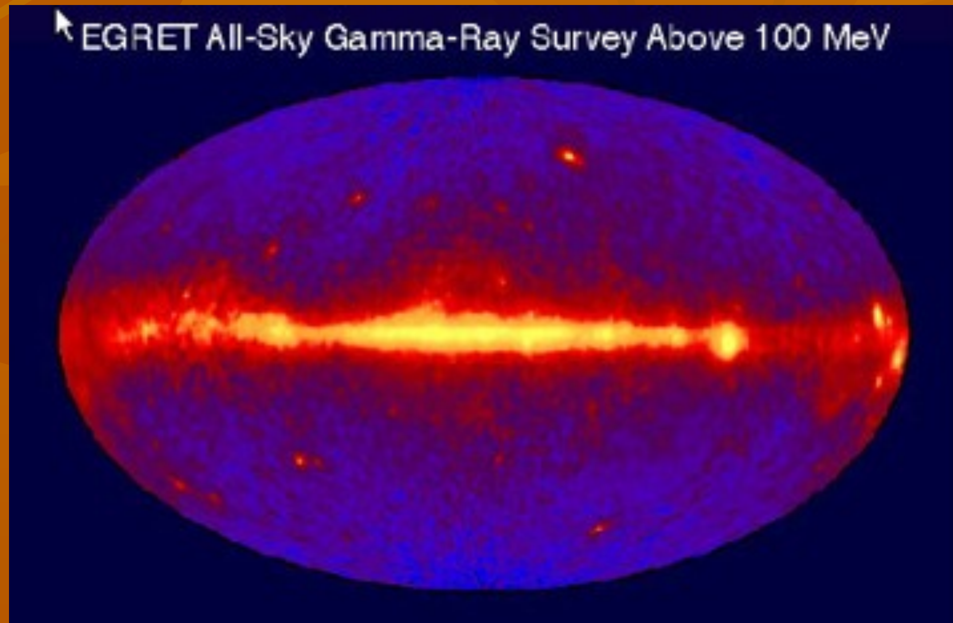


S-wave dominant

P-wave dominant

Diffuse Gamma Rays from the Sky





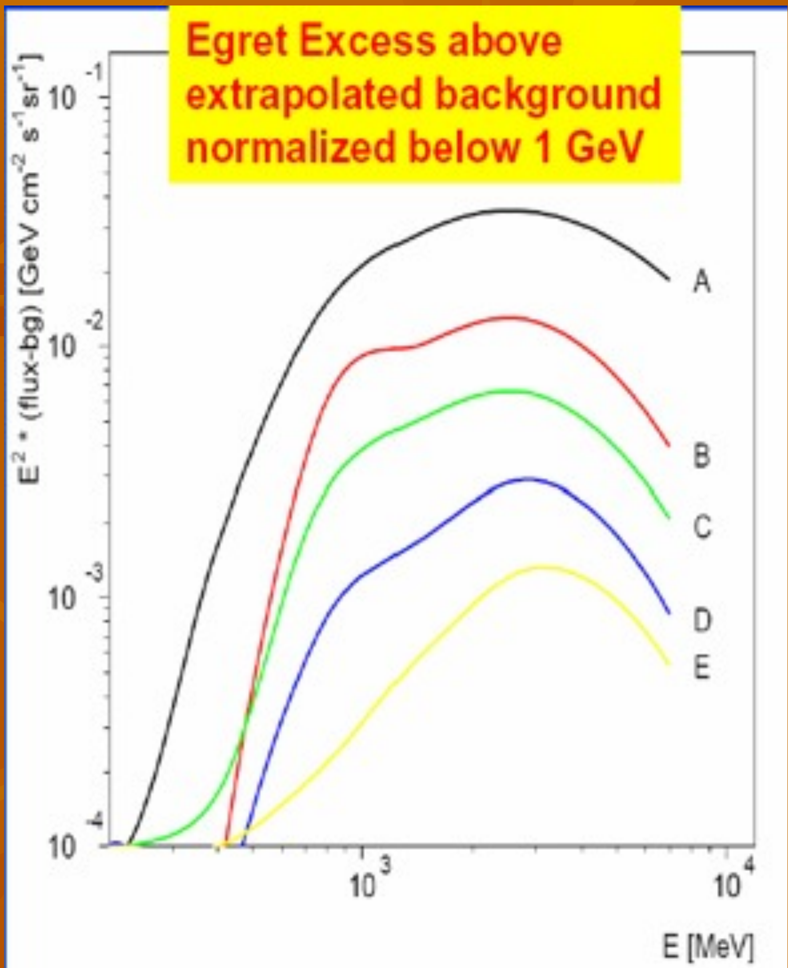
Instrumental parameters:

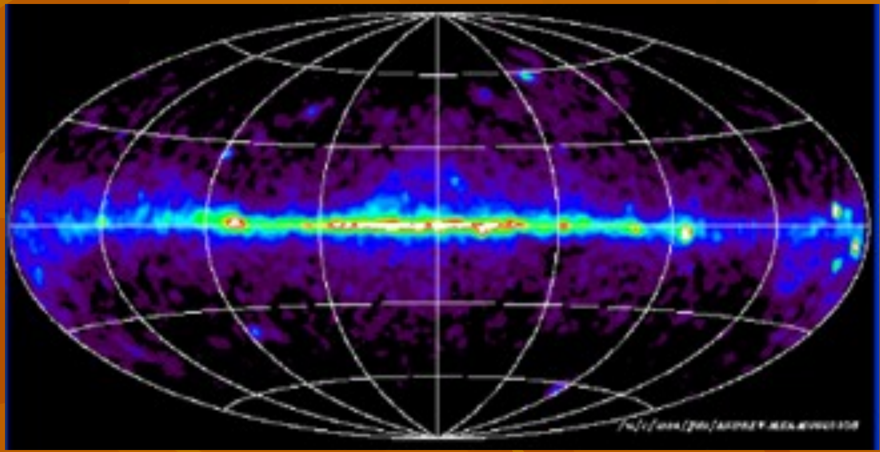
Energy range: 0.02-30 GeV
Energy resolution: ~20%
Effective area: 1500 cm^2
Angular resol.: $<0.5^0$

Data taking: 1991-2000

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

DIFFUSE GAMMA RAYS IN EGRET ENERGY

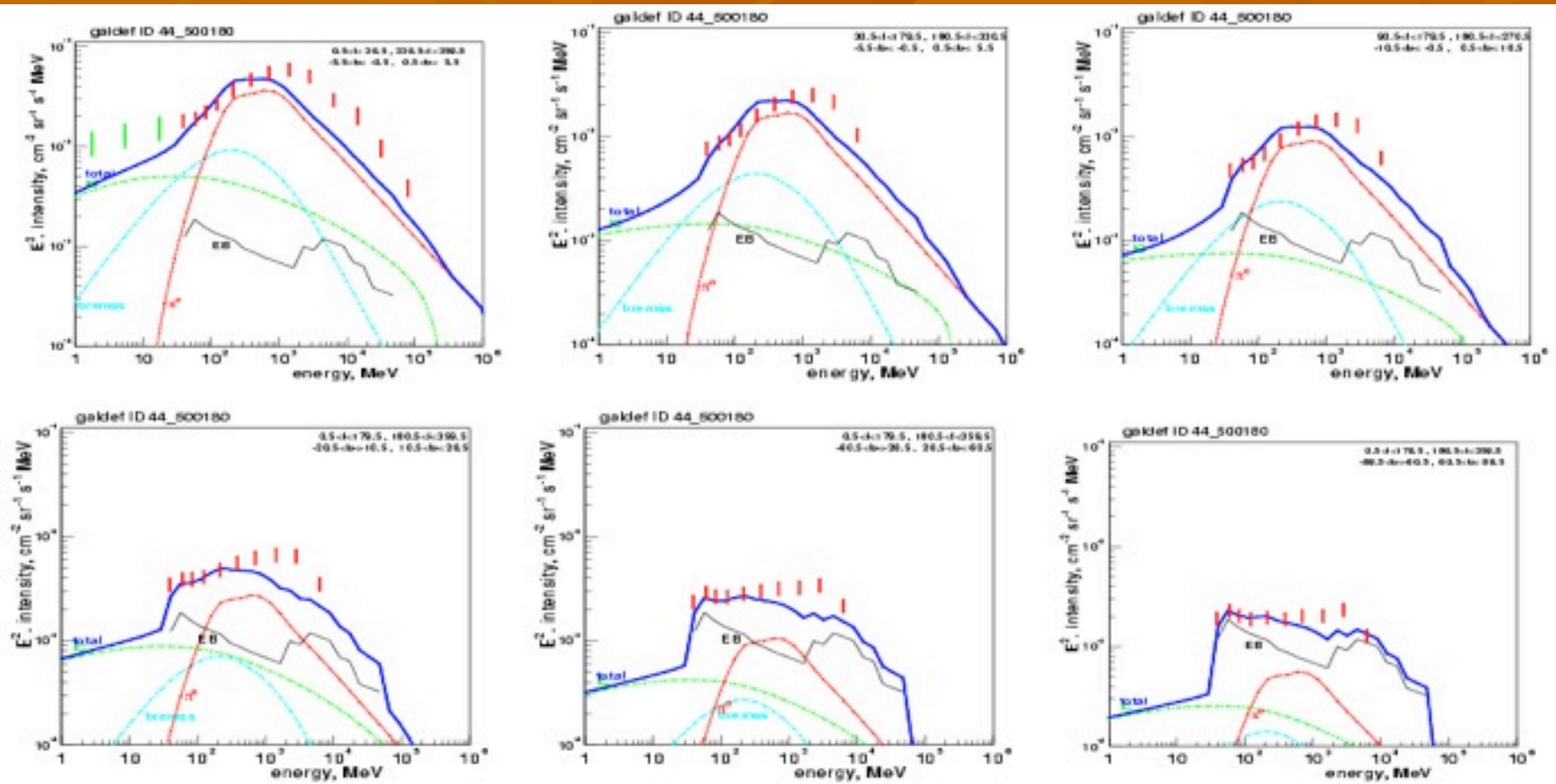


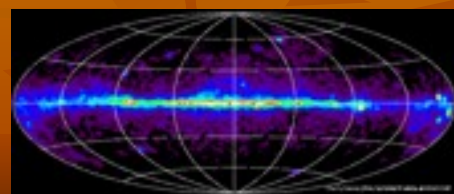


A: inner Galactic plane (±30⁰)
B: Galactic plane avoiding inner Galaxy (30-330⁰)
C: Outer Galaxy (90-270⁰)
D: low Latitude (10⁰-20⁰)
E: intermediate Latitude
F: galactic poles(60⁰-90⁰)

Excess same shape in all regions implying same source everywhere in galaxy

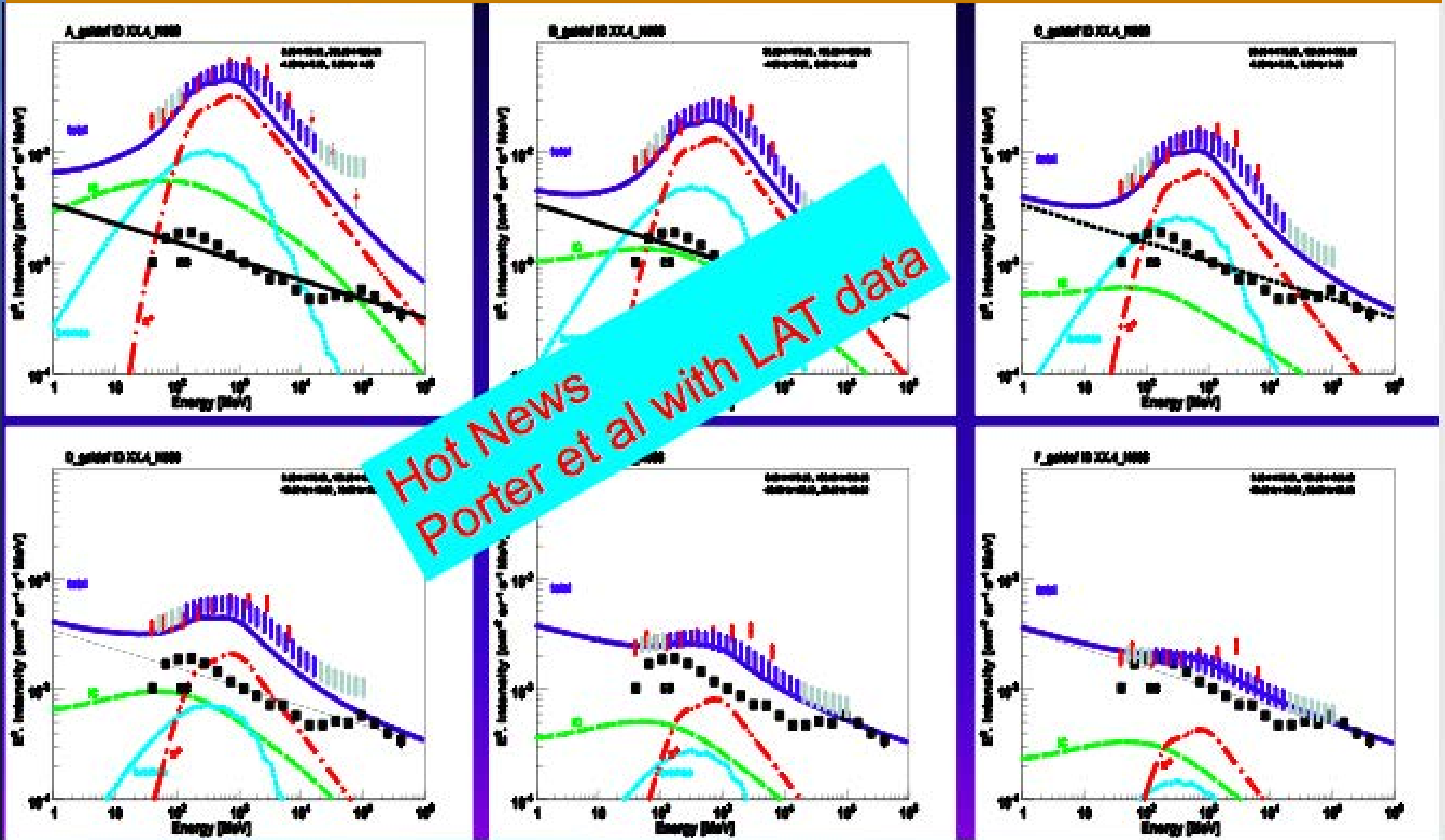
Excess of Diffuse Gamma Rays Above 1 GEV



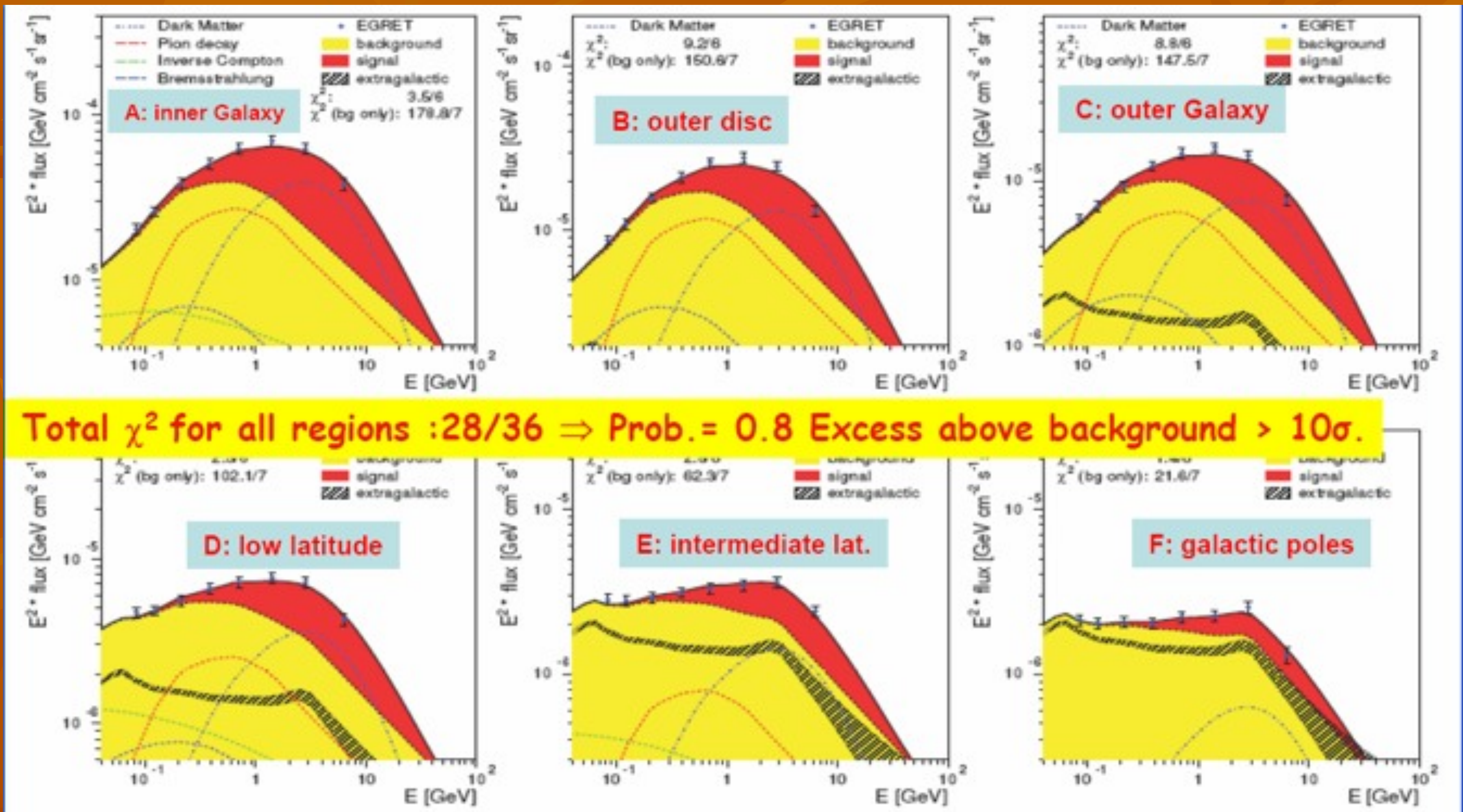


A: inner Galaxy ($l=\pm30^0$, $|b|<5^0$)
B: Galactic plane avoiding A
C: Outer Galaxy
D: low latitude ($10-20^{0)}$
E: intermediate lat. ($20-60^0$)
F: Galactic poles ($60-90^0$)

Comparison of EGRET-FERMI Data

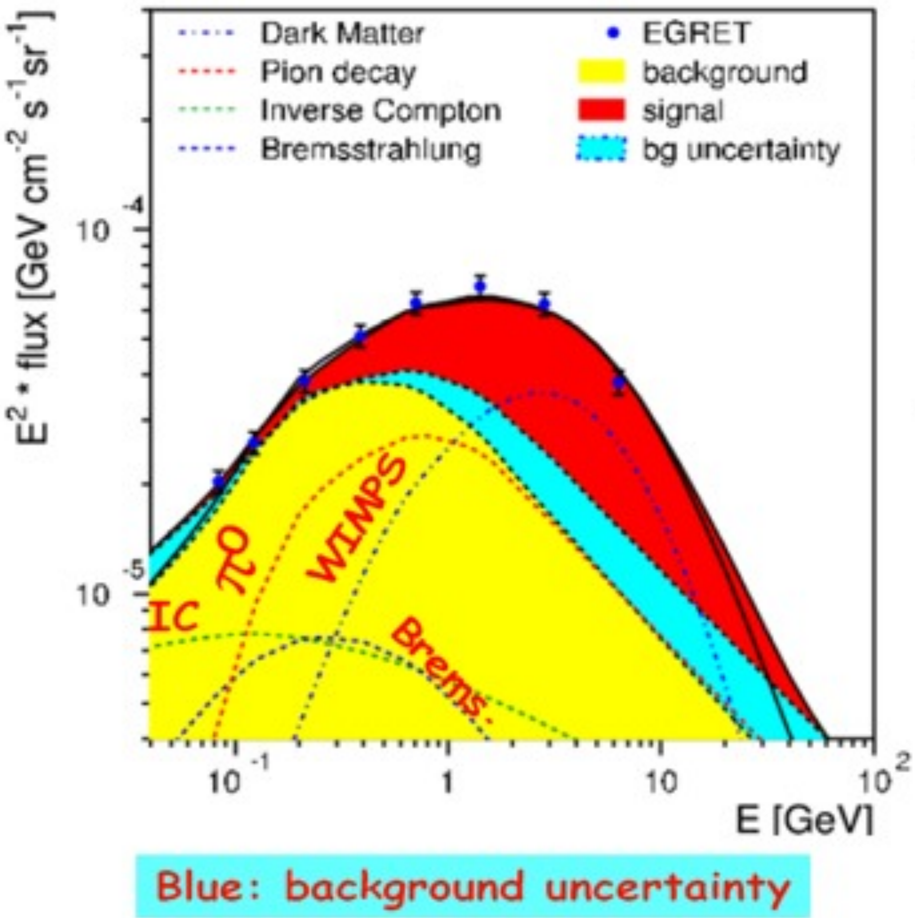


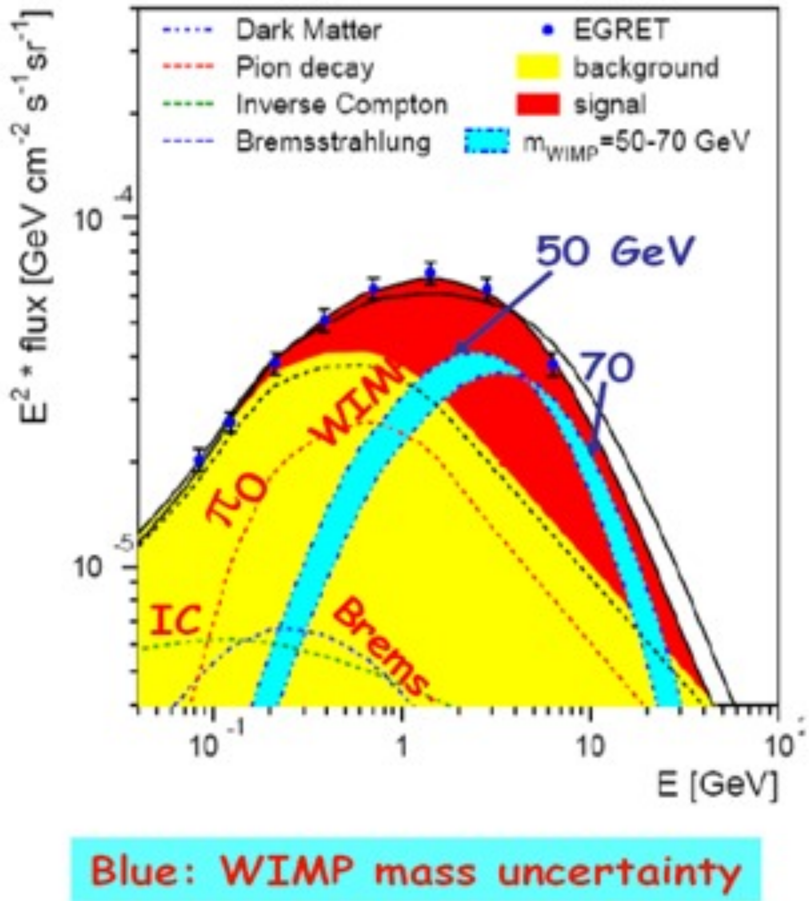
Analysis of EGRET Data in 6 Sky Directions



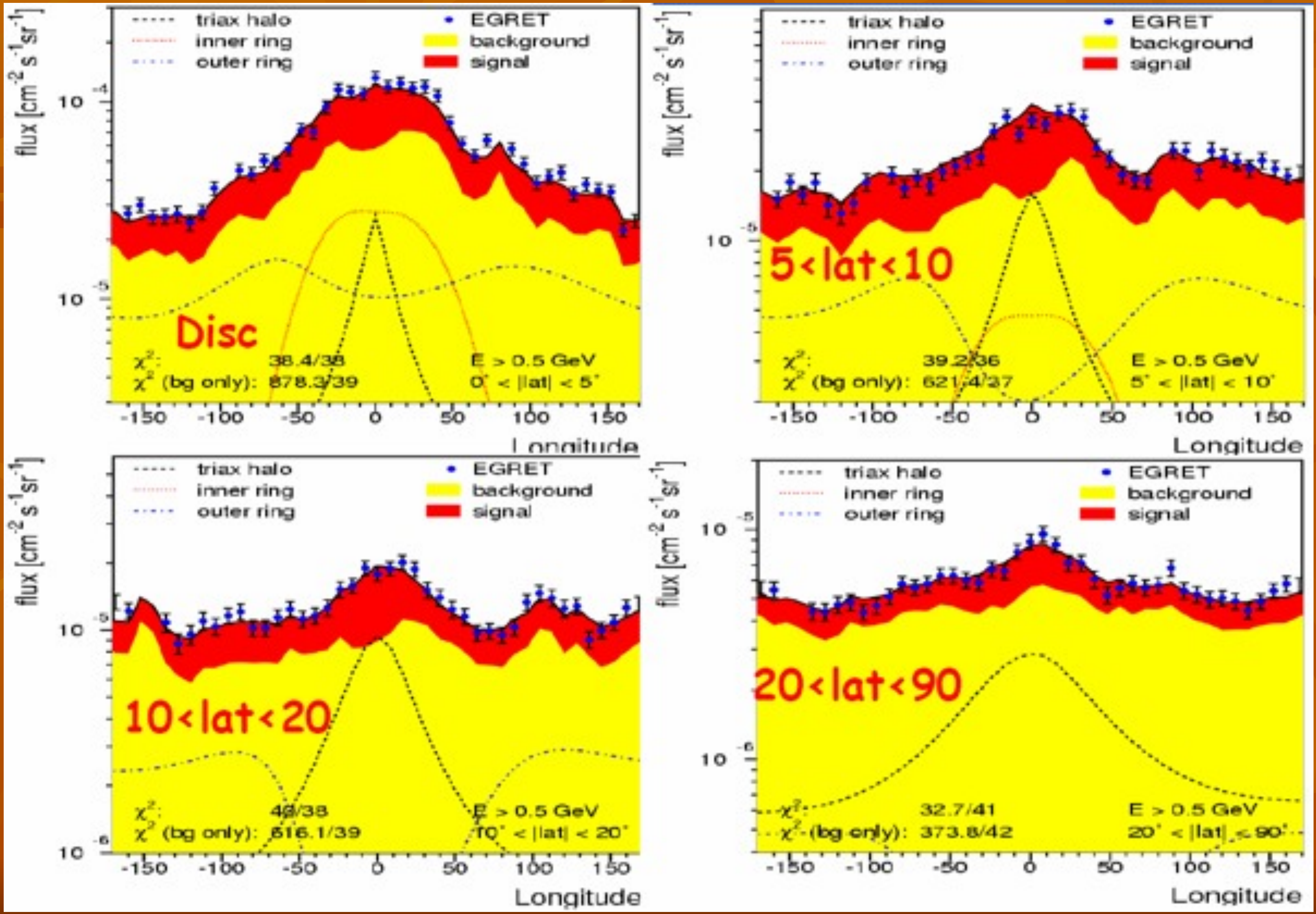
Total χ^2 for all regions :28/36 $\Rightarrow$ Prob.= 0.8 Excess above background > 10σ.

Background + Signal Describe EGRET Data





Diffuse Gamma Rays in EGRET Energy Range



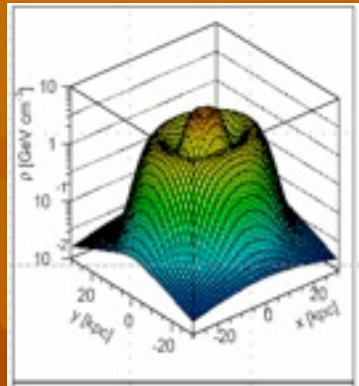
Fitted Halo Parameters

Gamma Ray Flux: (<σv> from WMAP)

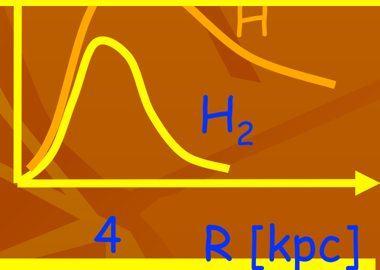
$$\phi_\chi(E,\psi) = \frac{\langle\sigma v\rangle}{4\pi}\sum_f \frac{dN_f}{dE} b_f \int_{line\ of\ sight} B_l \frac{1}{2}\frac{\langle\rho_\chi^2\rangle}{M_\chi^2}\, dl_\psi$$

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

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



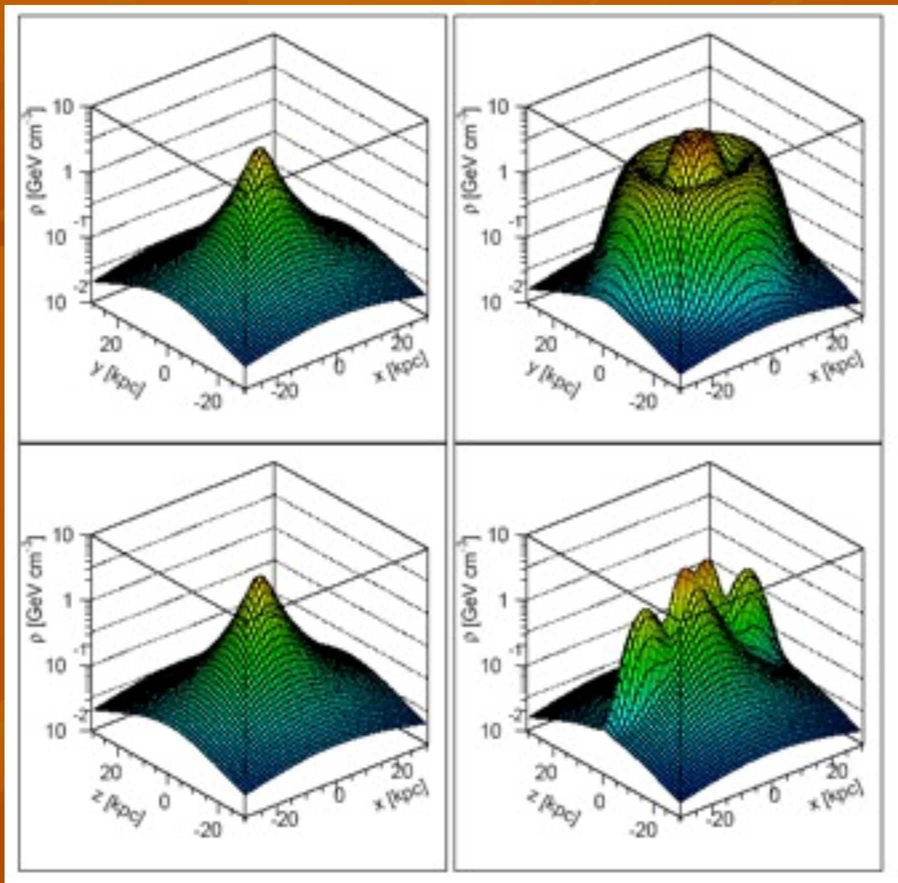
Enhancement of rings over $1/r^2$ profile 2 and 7, respectively. Mass in rings 1.6 and 0.3% of total DM



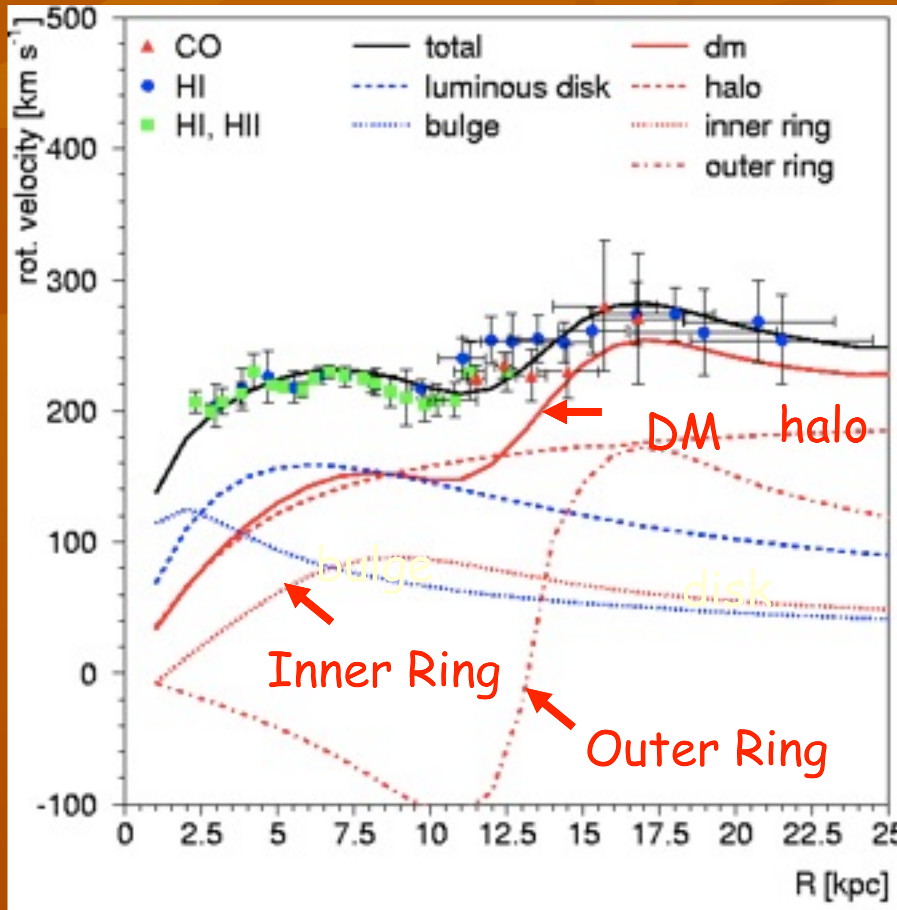
14 kpc coincides with ring of stars at 14-18 kpc due to infall of dwarf galaxy

4 kpc coincides with ring of neutral hydrogen molecules!

Halo Profile and Rotation Curve

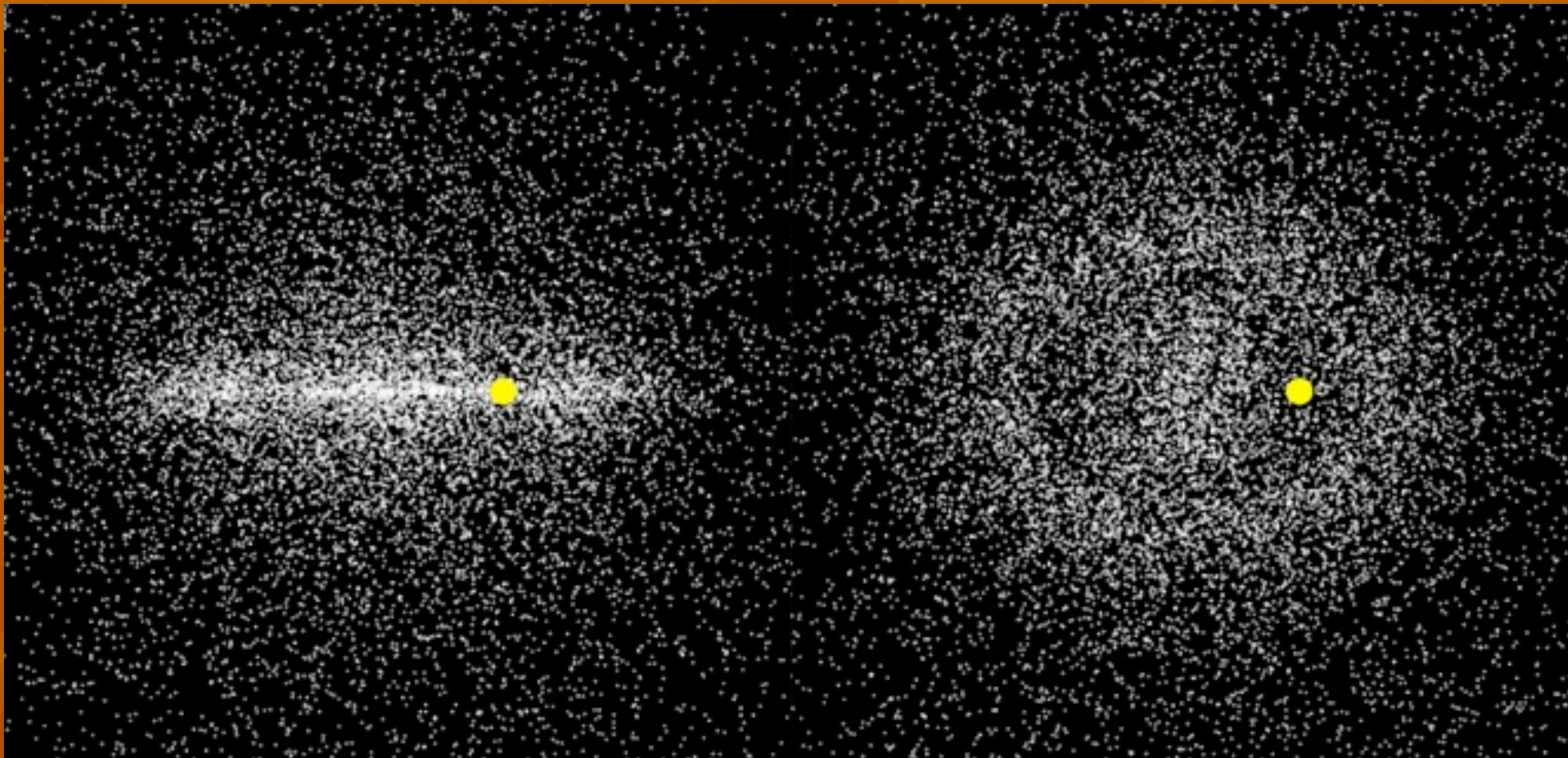


Halo profile with rings of DM



Rotation curve of the Milky Way

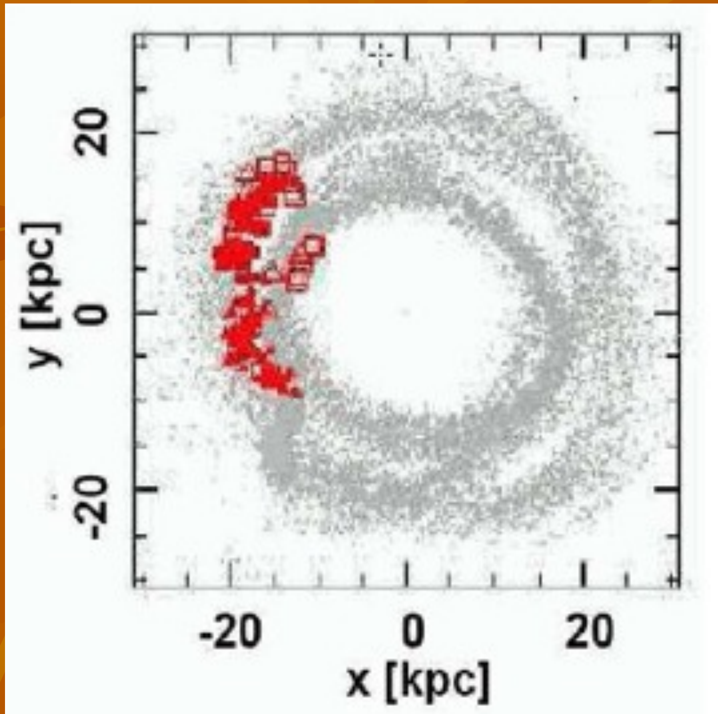
Halo Density on scale of 30 kpc

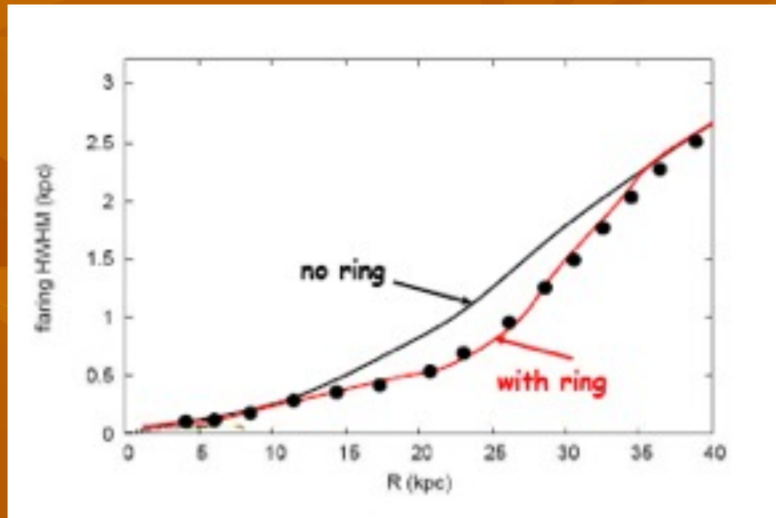


Sideview

Topview

Support for the Ring Structure

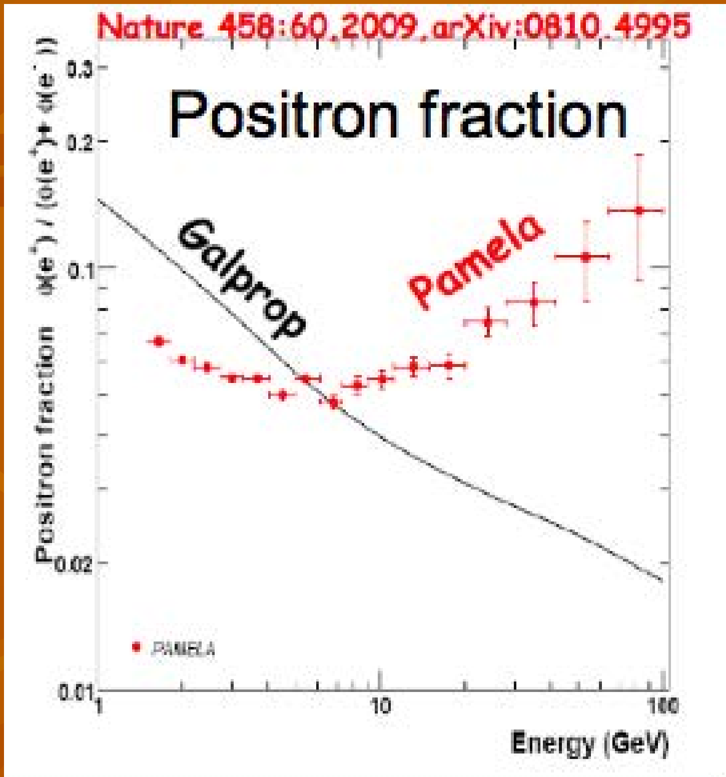




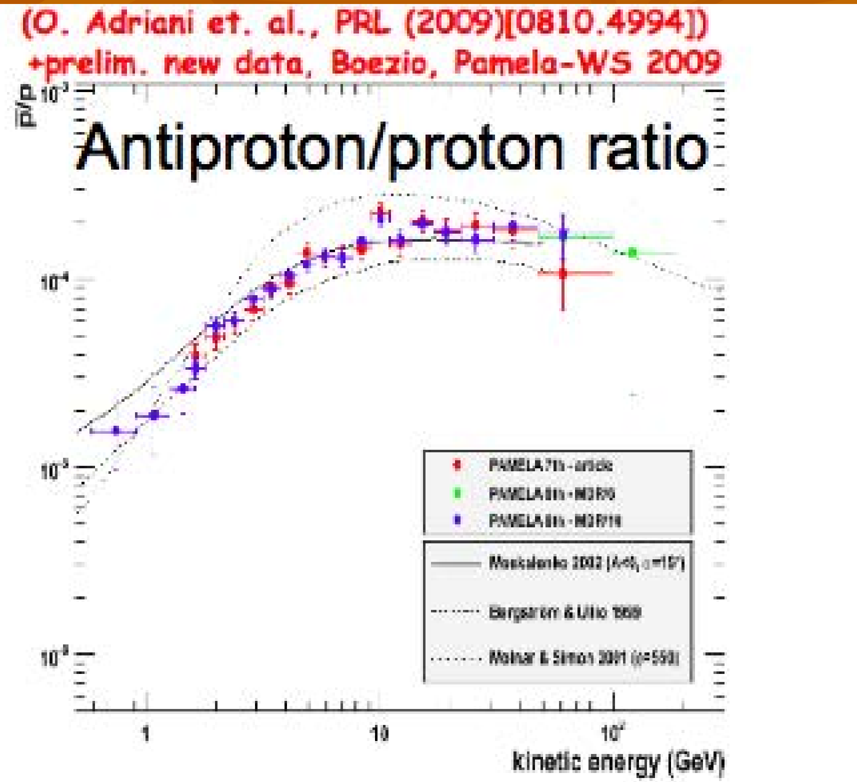
N-body simulation of the tidal disruption of the Canis Major dwarf Galaxy fitted to the observed stars (red points). The simulation predicts a ringlike structure of dark matter with a radius of 13 kpc

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

PAMELA: positron and antiproton measurements



Positrons: excess



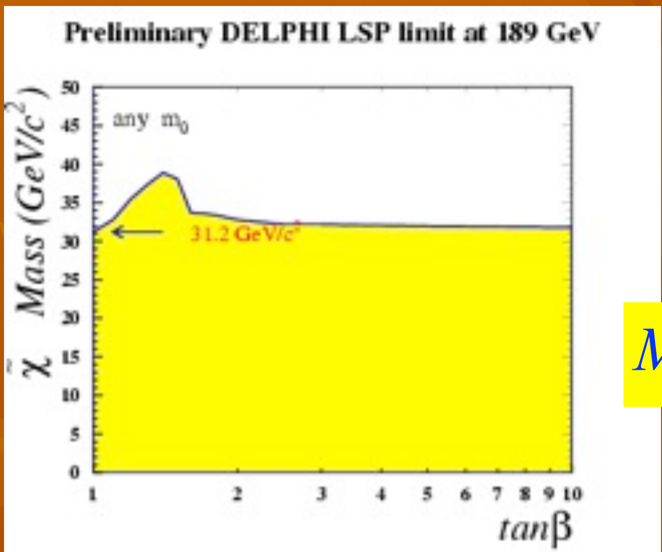
Antiprotons: NO excess

SUSY Dark Matter

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

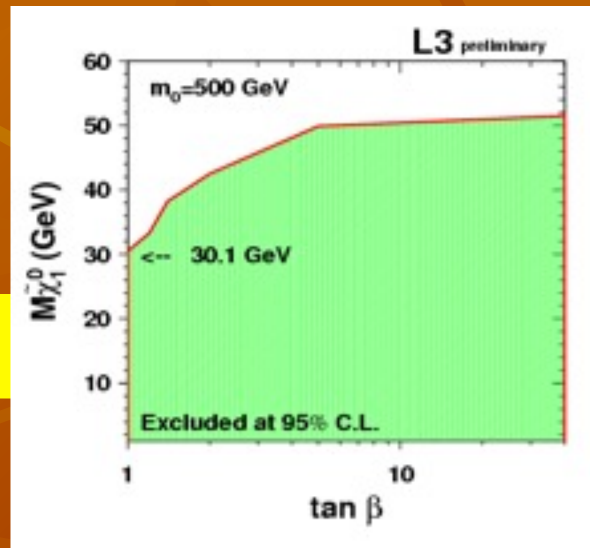
$$\tilde{\chi}^0 = N_1 \tilde{\gamma} + N_2 \tilde{z} + N_3 \tilde{H}_1^0 + N_4 \tilde{H}_2^0$$

photino zino higgsino higgsino



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

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

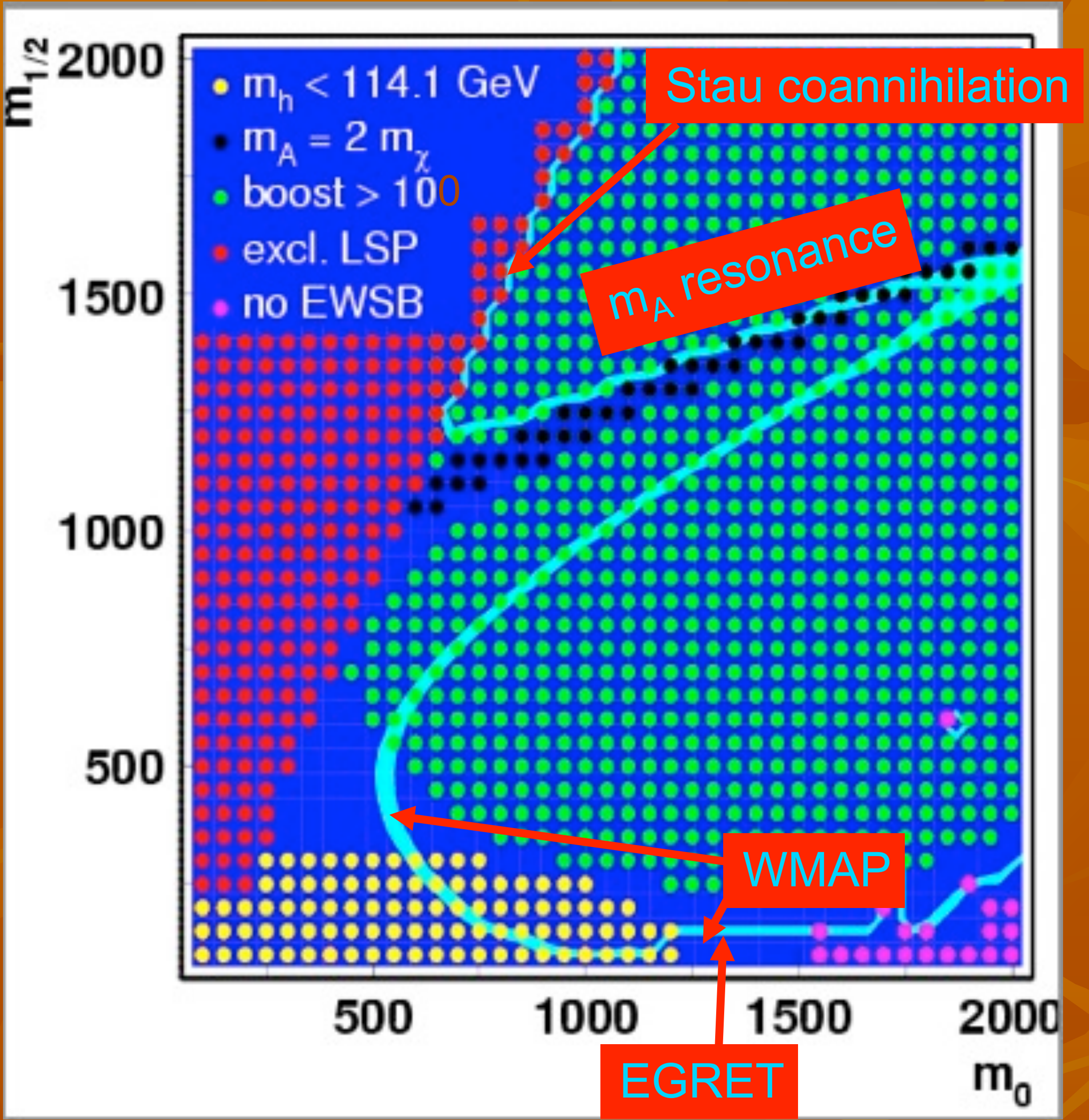


$$R = (-1)^{3(B-L)+2S}$$

$$R_p = +1, \ R_{\tilde{p}} = -1$$

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

ALLOWED SUSY PARAMETER SPACE



MSUGRA can fulfill all constraints from WMAP, LEP, b->sγ, g-2 and EGRET simultaneously, if DM is neutralino with mass in range 50-100 GeV and squarks and sleptons are O(1 TeV)

m_0 common spin 0 mass

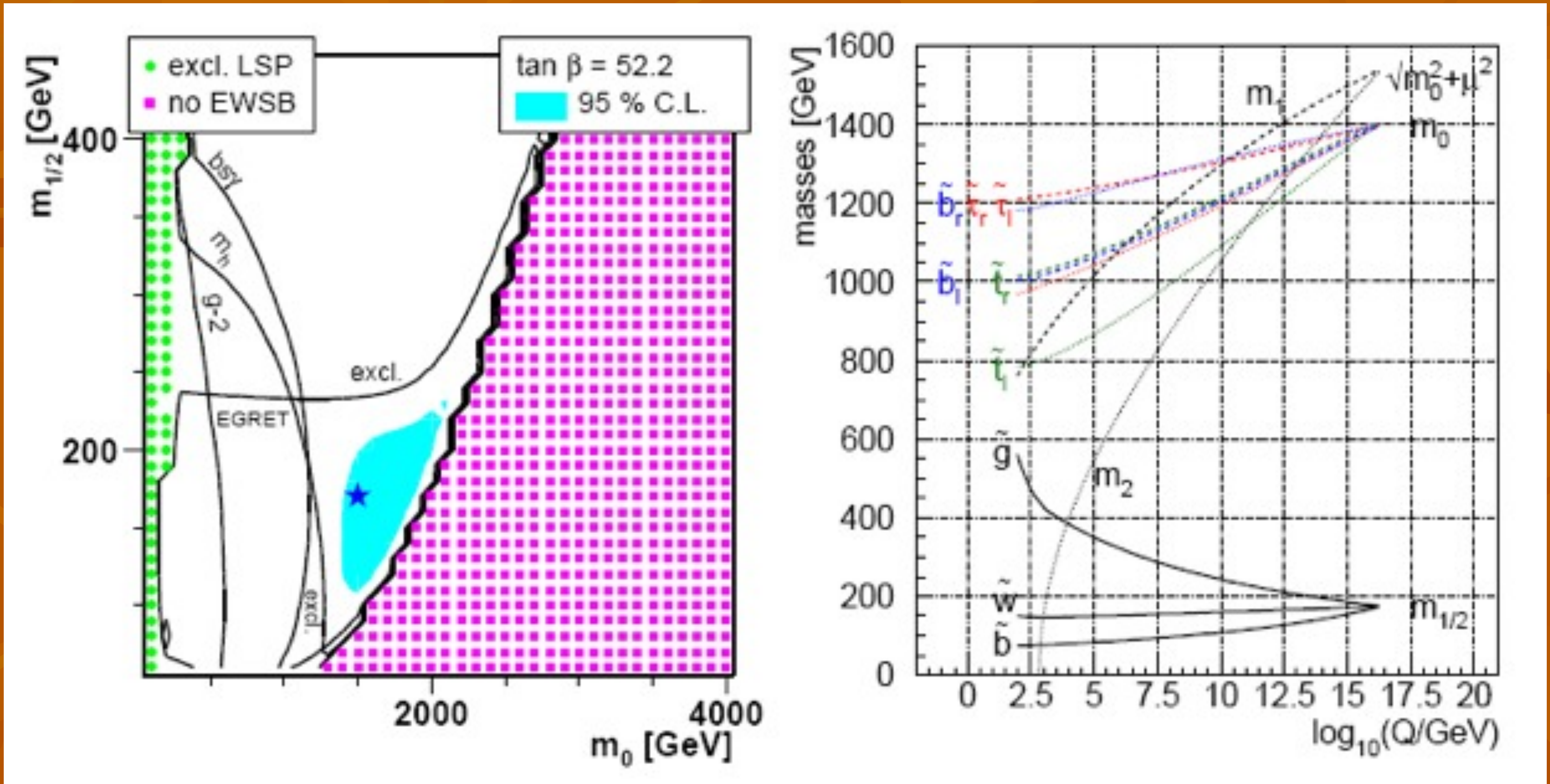
$m_{1/2}$ common spin ½ mass

$\tan\beta = v_2/v_1$

High $\tan\beta$ solution

$\tan\beta$ = 50

EGRET POINT AND MASS SPECTRUM



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SUSY Mass Spectrum

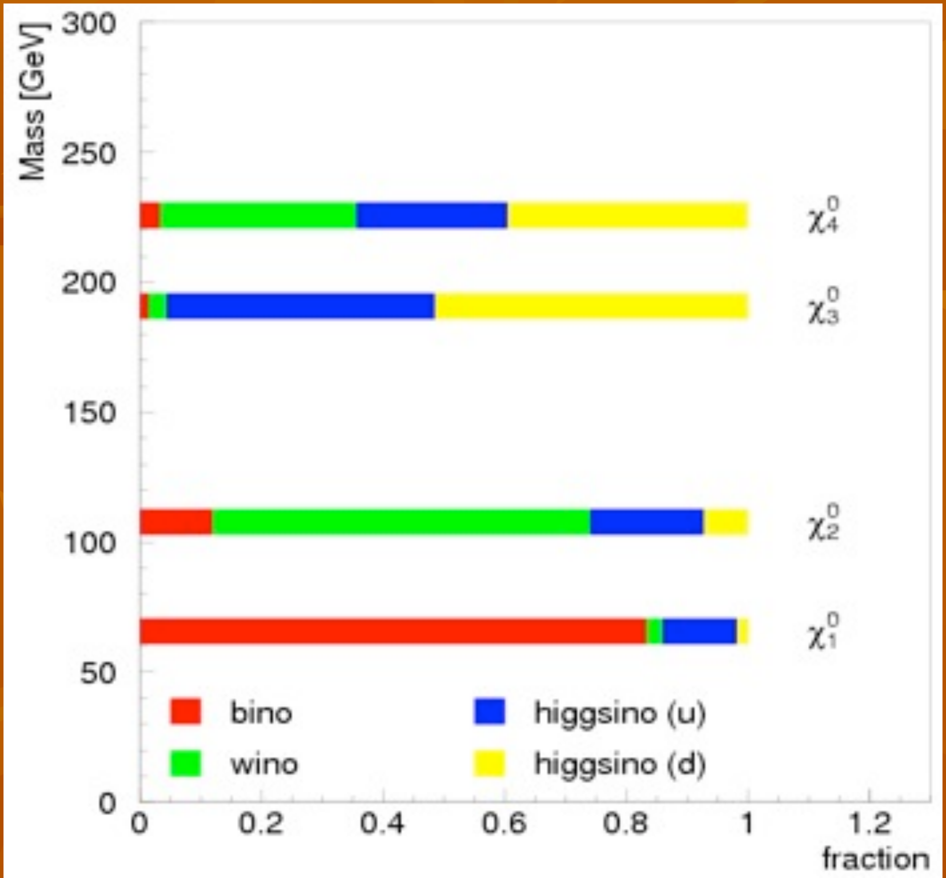
Fitted SUSY Parameters

Parameter	Value
tan β	52.2
m_0	1500
$m_{1/2}$	170
Sign μ	+
A(0)	0
$\alpha_s(M_Z)$	0.122
$\alpha_{em}(M_Z)$	0.0078153697
$Sin^2\theta_W \|_{\overline{MS}}$	0.2314
m_t	175 GeV
m_b	4.214 GeV

SUSY Masses in GeV

Particle	Mass
$\tilde{\chi}^0_{1,2,3,4}$ →	64, 113, 194, 229
$\tilde{\chi}^{\pm}_{1,2}$, $\tilde{g}$ →	110, 130, 516
$\tilde{u}_{1,2} = \tilde{c}_{1,2}$	1519, 1523
$\tilde{d}_{1,2} = \tilde{s}_{1,2}$	1522, 1524
$\tilde{t}_{1,2}$	906, 1046
$\tilde{b}_{1,2}$	1309, 1152
$\tilde{e}_{1,2} = \tilde{\mu}_{1,2}$	1497, 1499
$\tilde{\tau}_{1,2}$	1305, 1288
$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$	1495, 1495, 1286
h, H, A, $H^{\pm}$ →	115, 372, 372, 383

GAUGINO CONTENT OF THE LIGHTEST NEUTRALINO



	$\tilde{b}^0$	$\tilde{w}^0$	$\tilde{h}_1^0$	$\tilde{h}_2^0$
$\tilde{\chi}_1^0$	0.833	0.026	0.122	0.018
$\tilde{\chi}_2^0$	0.119	0.621	0.187	0.072
$\tilde{\chi}_3^0$	0.014	0.030	0.442	0.515
$\tilde{\chi}_4^0$	0.033	0.323	0.249	0.395

The lightest neutralino is almost bino – the superpartner of a photon

DM = superpartner of the CMB

DM is the Window to the

What the future may bring?