Evidence for WIMP Dark Matter

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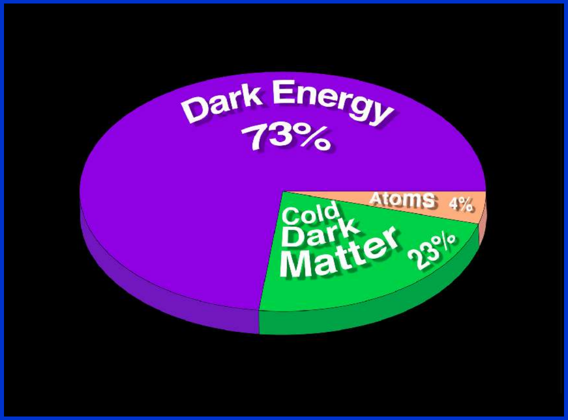
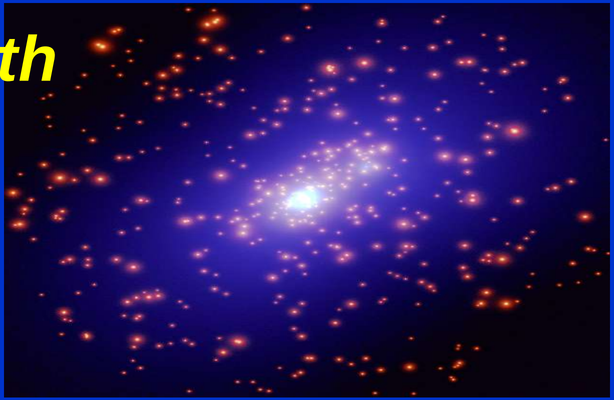


Outline (see astro-ph/0408272, hep-ph/0408166)

- EGRET Data on diffuse Gamma Rays shows excess in all sky directions with the SAME spectrum



- Halo parameters from sky map
- WIMP mass from spectrum

Physics Problems

- ***Cosmologists:***

What is CDM and Dark Energy made of?

- ***Particle physicists:***

Where are the Supersymmetric Particles?

- ***Astrophysicists:***

What is the origin of excess of diffuse Galactic Gamma Rays?

- ***Astronomers:***

Why a change of slope in the galactic rotation curve at 1.1 R_0?

Why ring of stars at 14 kpc so stable?

Proposed Solution

- *DM made of WIMPS annihilating into quarks, which yield hard gammas from π_0 decays*

- *Annihilation cross section given by HUBBLE constant!*

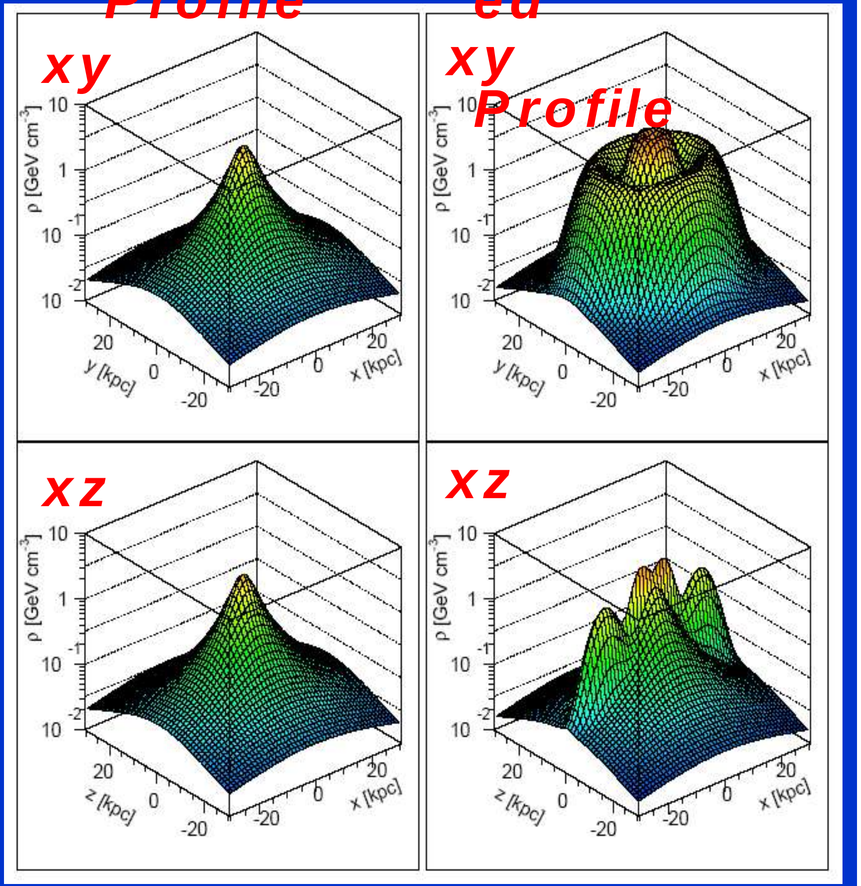
- *Gamma excess correlated with ring of stars at 14-18 kpc thought to originate from infall of a dwarf galaxy and ring of DM at 4 kpc stabilizes ring of hydrogen*

- *From SPECTRUM of excess of gamma rays DM: WIMP mass 50-100 GeV*

Executive Summary

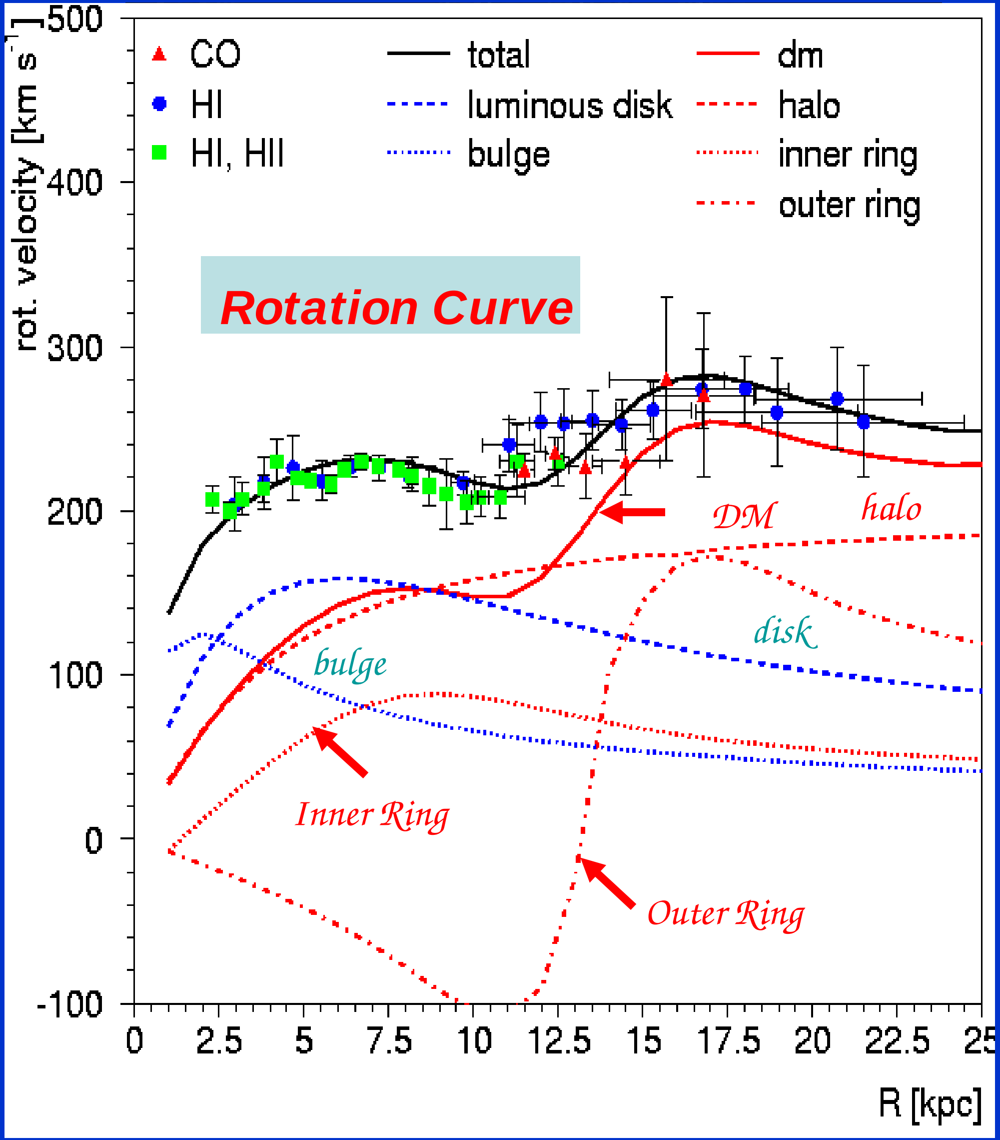
Expected Profile

Observed Profile

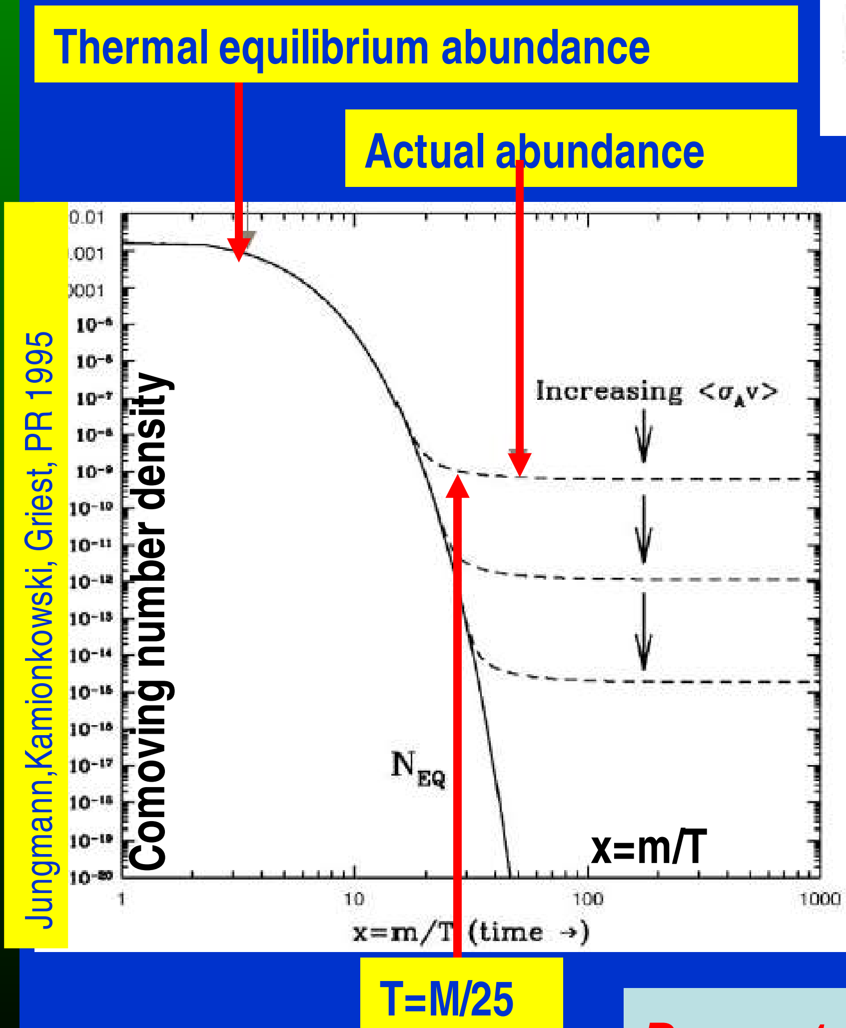


Halo profile

Rotation Curve



WMAP determines WIMP annihilation x-section



$$\frac{dn_\chi}{dt} + 3Hn_\chi = - < \sigma v > (n_\chi^2 - n_\chi^{eq2}),$$

Boltzmann equation:

H-Term takes care of decrease in density by expansion. Right-hand side: Annihilation and Production.

T>>M: f+f̄->M+M; M+M->f+f̄

T<M: M+M->f+f

T=M/25: M decouples, stable density

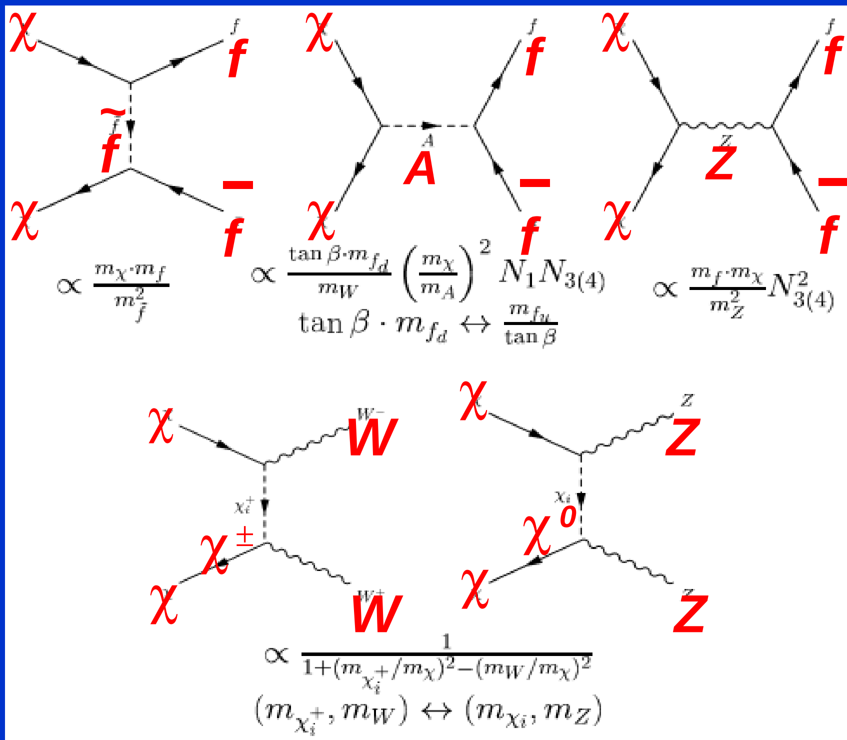
Neutralino annihilation is a strong source of antiprotons,

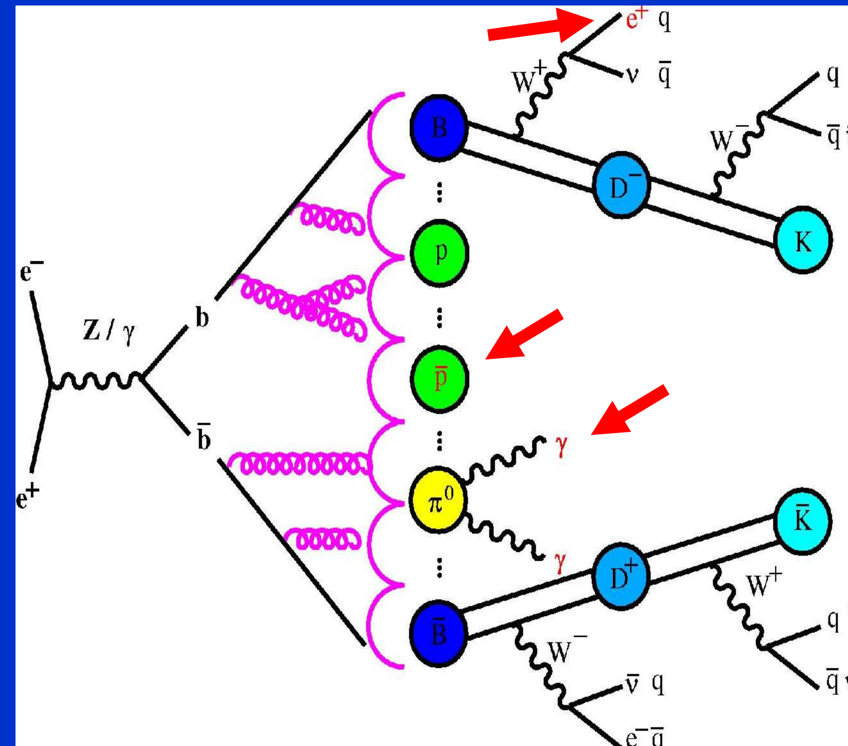
(wenn annihilation rate ≅

annihilation into quarks

Present number density (Ωh^2=0.113±0.009)requires <σv>=2.10^{-26} cm^3/s assuming no coannihilation

Neutralino Annihilation Final States





Dominant Diagram for WMAP cross section:

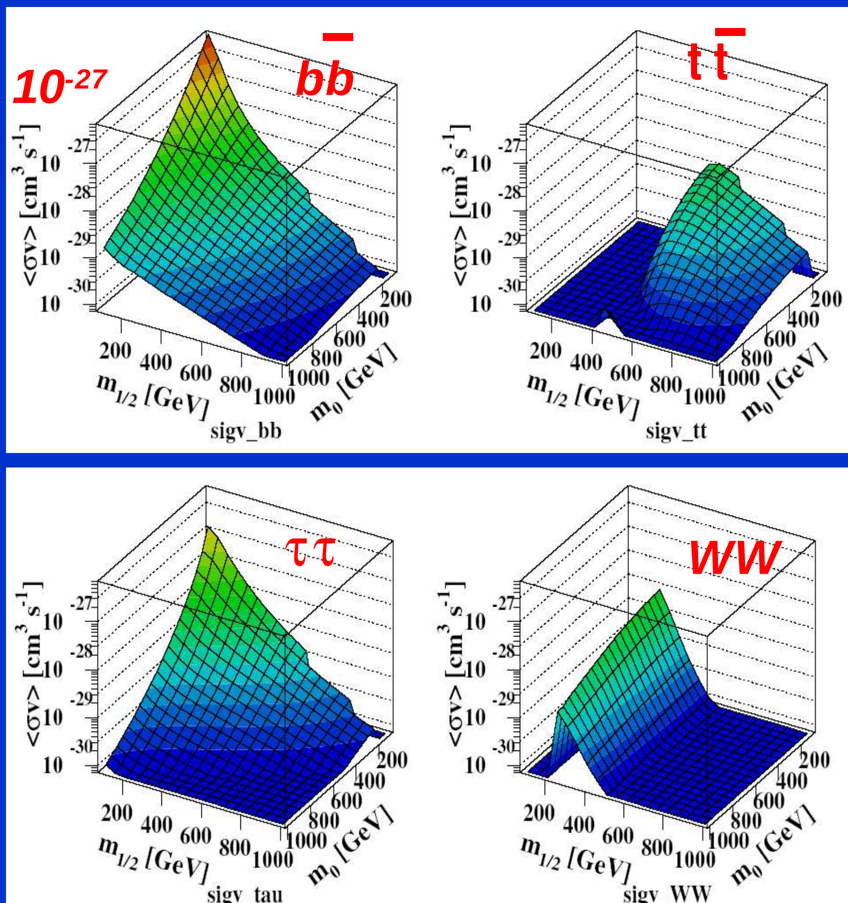
$\chi + \chi \Rightarrow A \Rightarrow$ b bbar quark pair

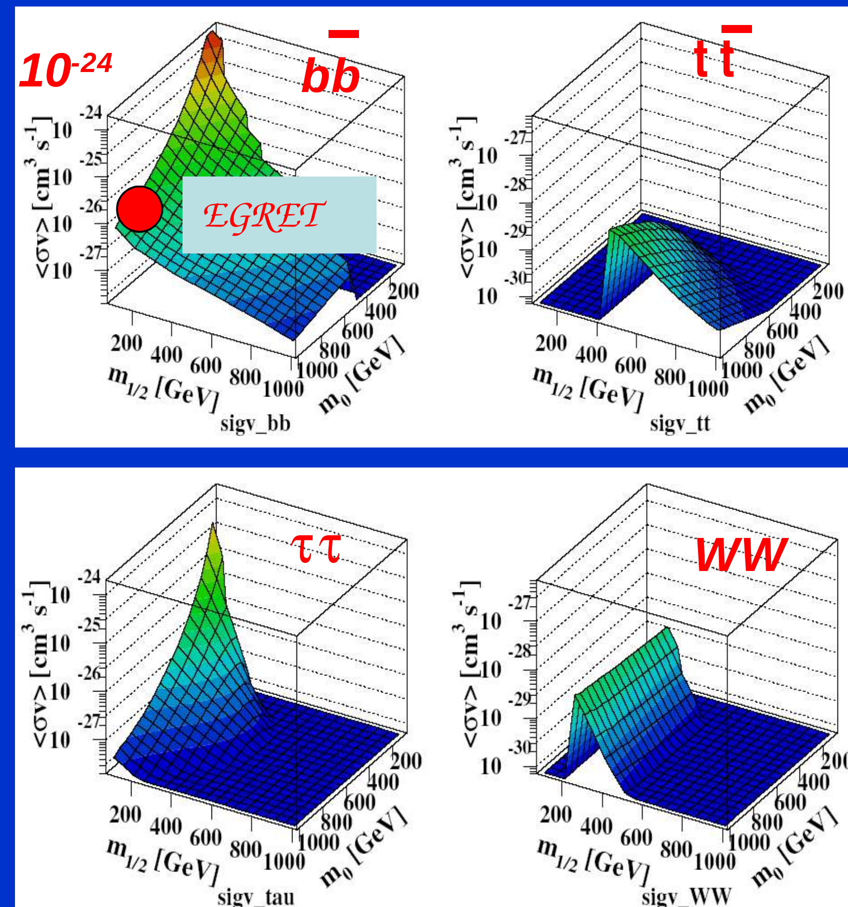
B-fragmentation well studied at LEP!

Yield and spectra of positrons, gammas and antiprotons well known!

Annihilation cross sections in m_0-$m_{1/2}$ plane ($\mu > 0$, $A_0=0$)

tan=5 tan=50

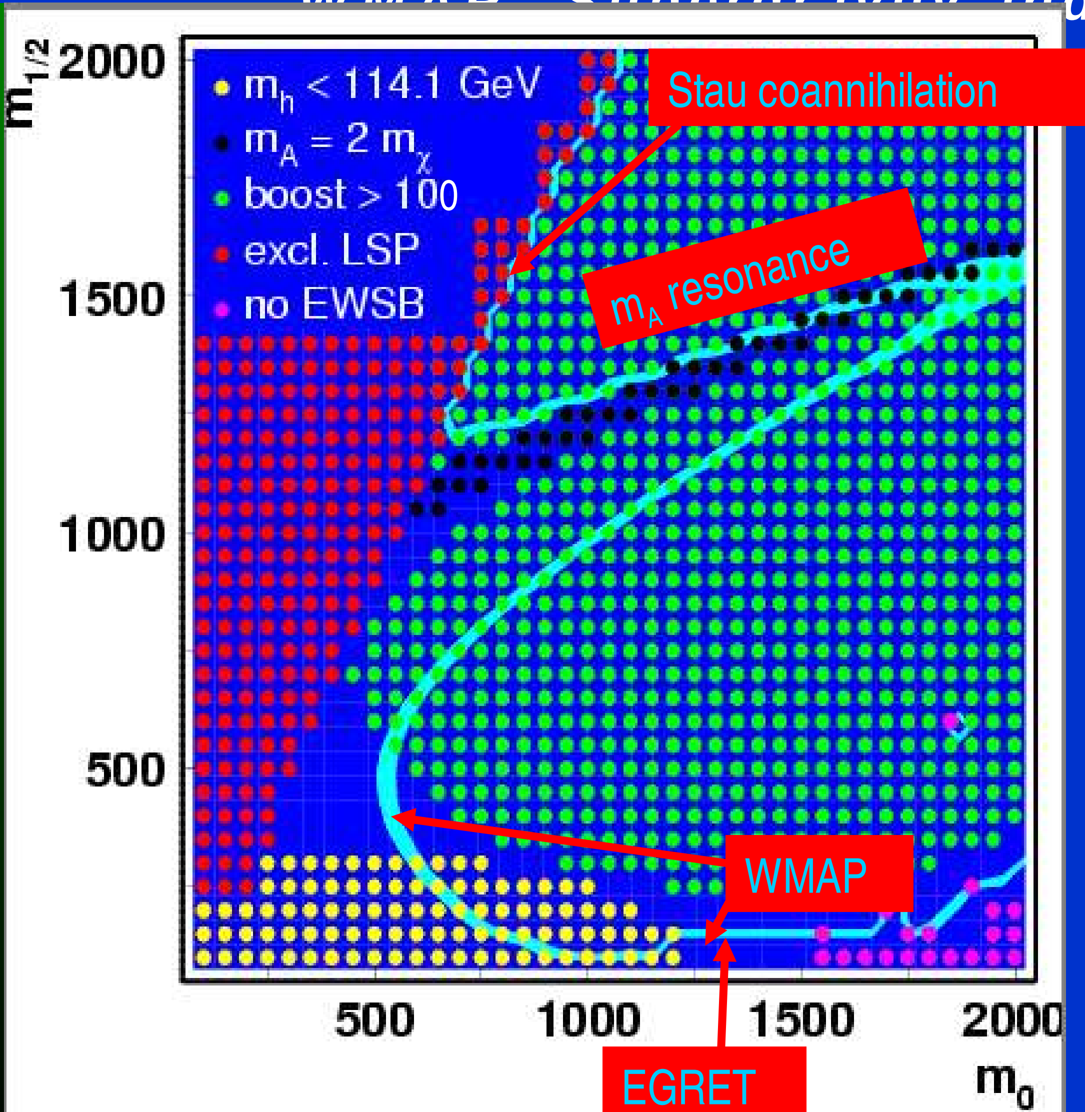




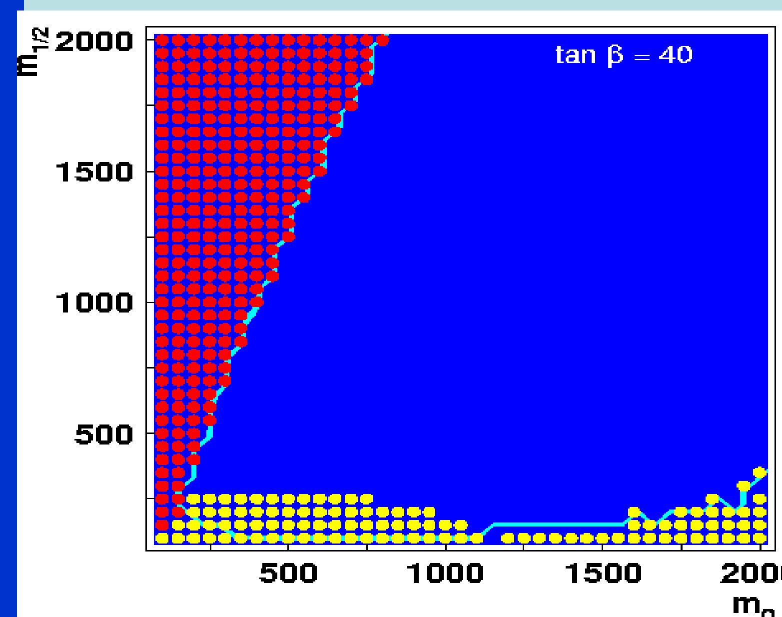
For WMAP x-section of $\langle\sigma v\rangle \cong 2.10^{-26}$ cm^3/s one needs large

in bulk region (no coannihilation, no resonances)

EGRET excess interpreted as DM consistent with WMAP, Supergravity and



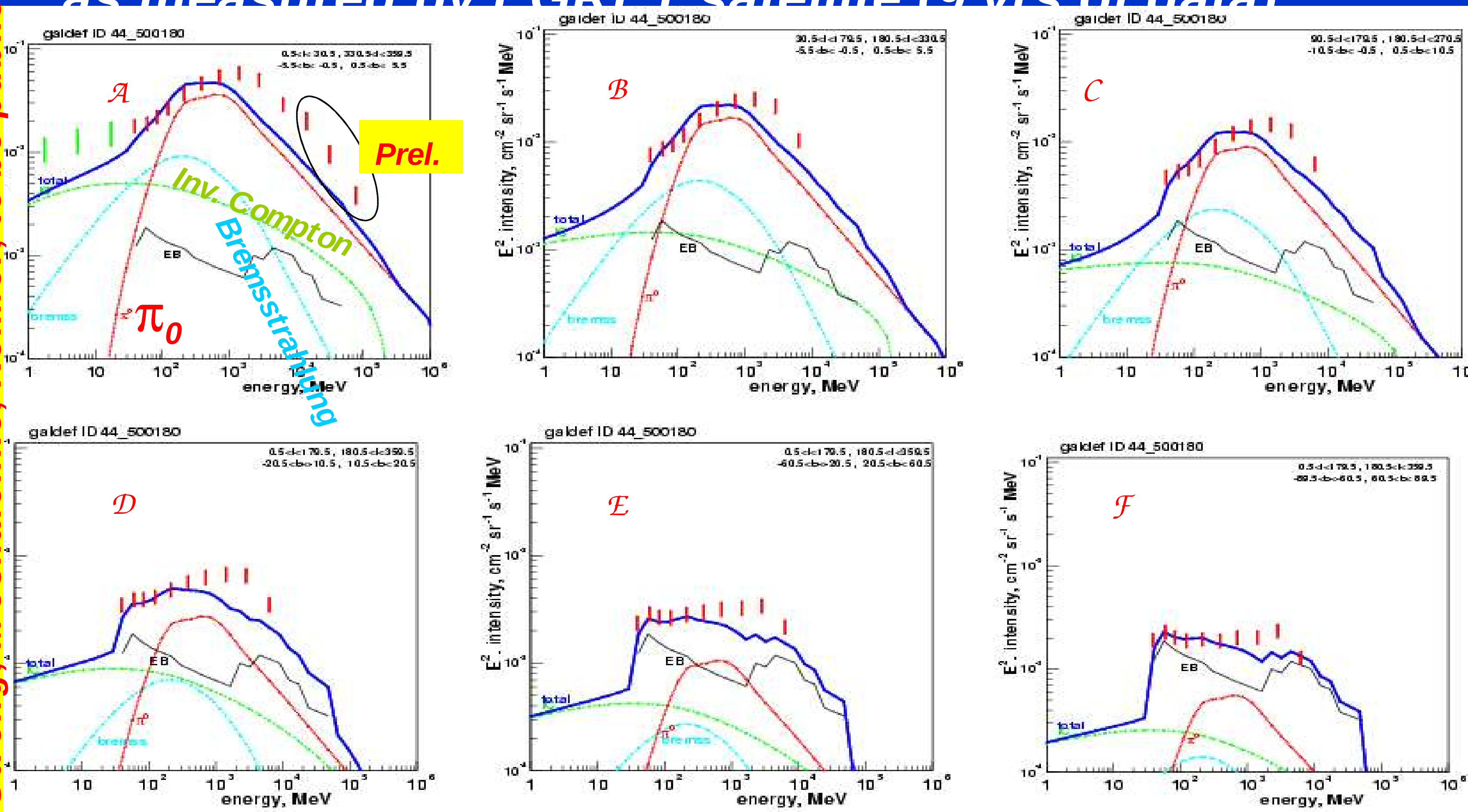
MSUGRA can fulfill all constraints from WMAP, LEP, b->sγ, g-2 and EGRET

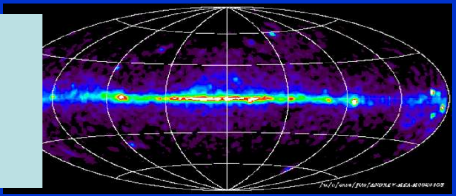


squarks and sleptons

Excess of Diffuse Gamma Rays above 1 GeV as measured by EGRET satellite (9 yrs of data)

Strong, Moskalenko, Reimer, to be published





A: inner Galaxy ($l=\pm30^0$, $|b|<5^0$)

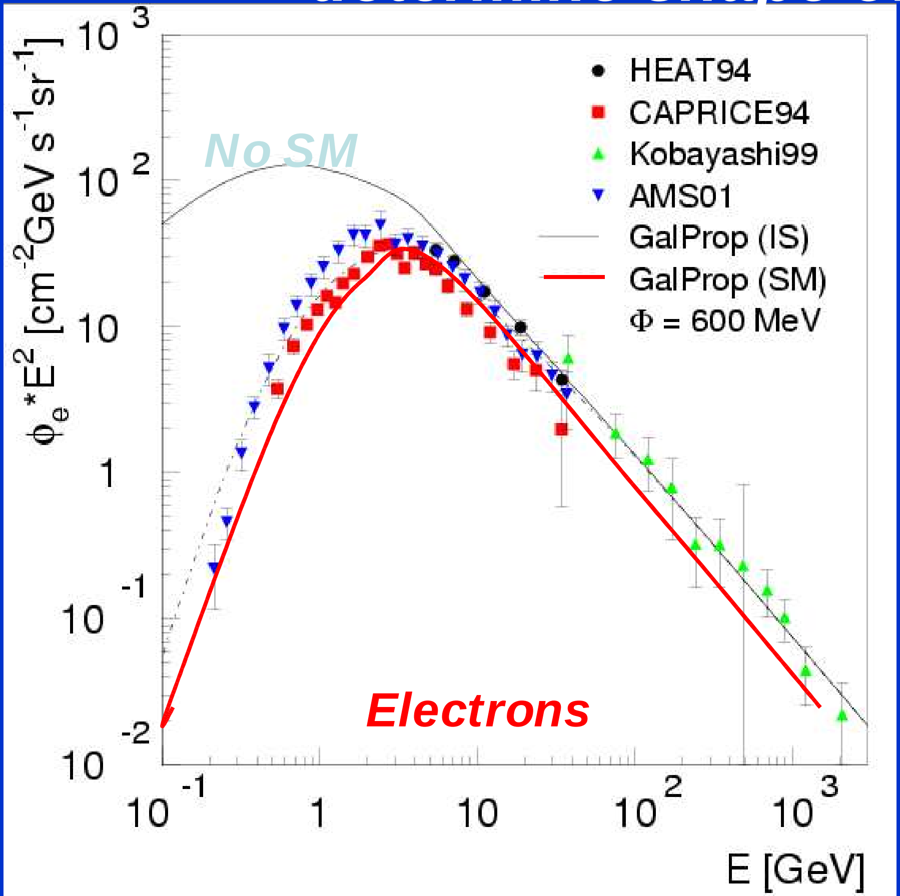
B: Galactic plane avoiding A

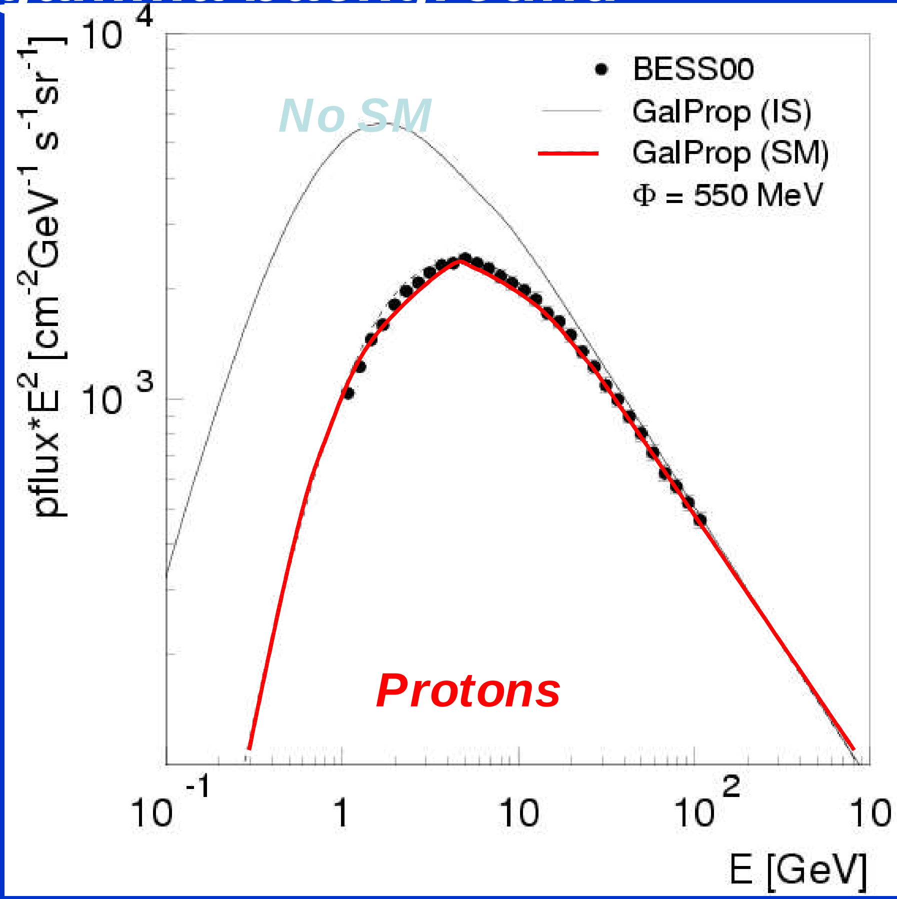
D: low latitude ($10-20^0$)

E: intermediate lat. ($20-60^0$)

F: Galactic poles ($60-90^0$)

Local electron and proton spectra determine shape of gamma background



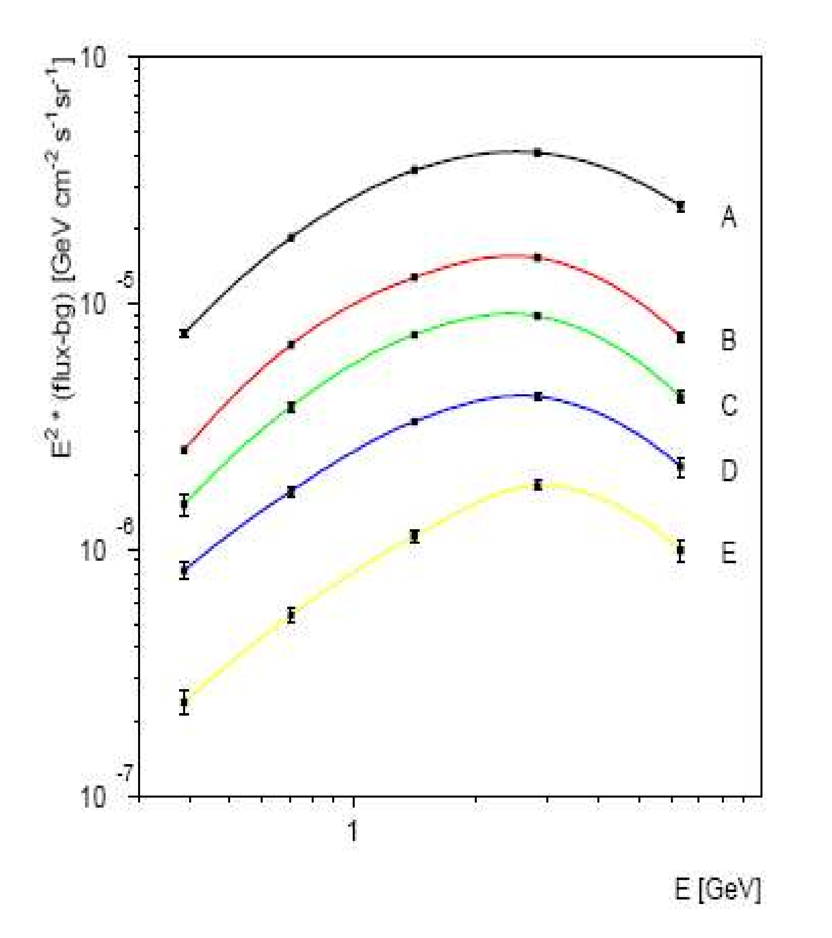


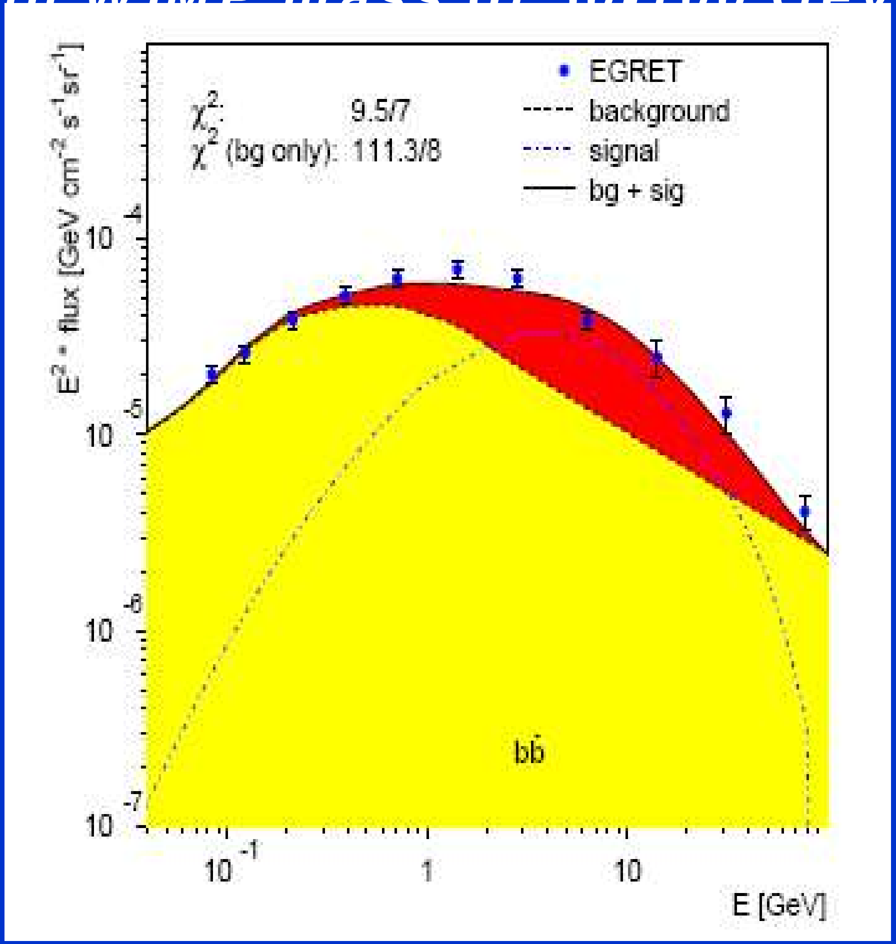
Solar modulation (SM) important below 10 GeV

Proton and electron spectra above 10 GeV well measured ⇒

Gamma spectrum well known, unless one assumes " local bubble" ,

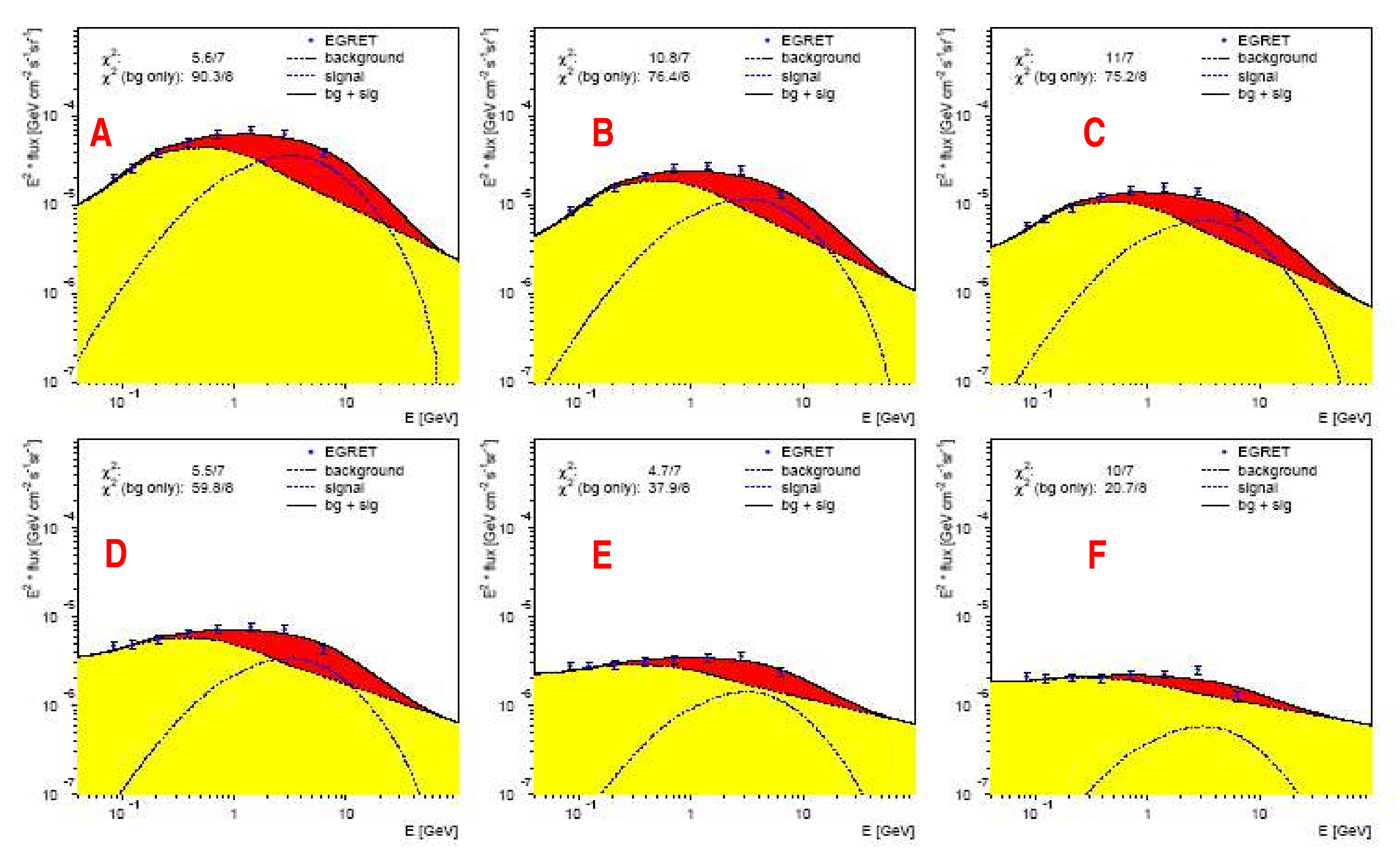
Excess of Diffuse Gamma Rays has same spectrum in all directions, compatible with WIMP mass of 50-100 GeV





Important: if experiment measures gamma rays down to 0.1 GeV, then normalizations of DM annihihilation and background can both be left free, so one is not sensitive to abso- lute background estimates, BUT ONLY TO THE

Diffuse Gamma Rays for different sky regions



DMA $\propto$ Boostfactor $\langle\rho^2\rangle$ If boost factor, i.e. clustering, sim

in all directions, then signal strength determines DM dens

Why LIGHT traces DM in disc

Reasons for enhanced DM in plane of galaxy:

3) Adiabatic compression of halo by gravity from disc

(Blumenthal, Kalnajs, Wilkinson,…..)

(halo distribution may be modified by resonant interactio

between bar and halo, Athanassoula, Weinberg,..)

2

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

from infall of dwarf gala)

$$\tilde r = \sqrt{\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}}, \qquad \tilde r_{gc} = \sqrt{\frac{x^2}{\tilde a^2}+\frac{y^2}{\tilde b^2}},$$

Parametrize with at least 2 ring

Inner ring for 1) Outer ring for 2

Fit results of halo parameters

Gamma Ray Flux (<σv> from WMAP)

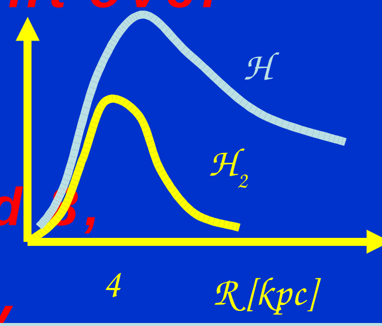
$$\phi_\chi(E,\psi) = \frac{\langle\sigma v\rangle}{4\pi}\sum_f \frac{dN_f}{dE} b_f \int_{line\ of\ sight} B_l \frac{1}{2}\frac{\langle\rho_\chi^2\rangle}{M_\chi^2} dl_\psi$$

Halo Parameters: (assuming boost fct B same in all directions, comes out B>≅20)

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

2 rings with maximum intensity at 4 and 14 kpc

Enhancement over ... d B, respectively

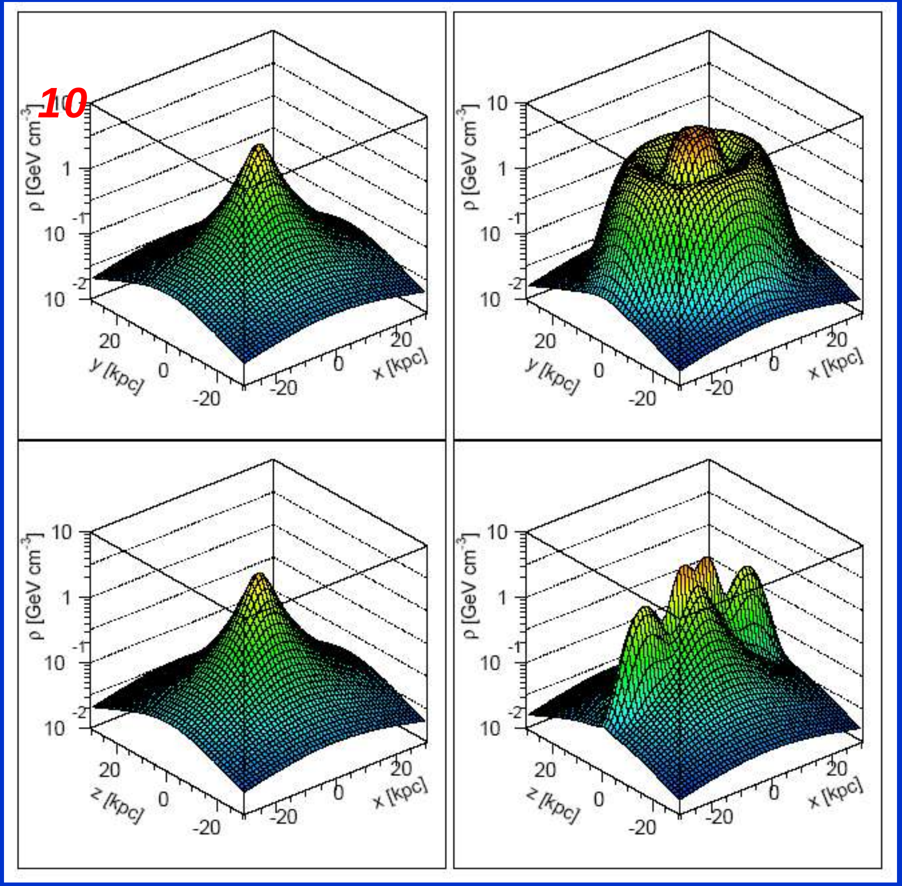


14 kpc coincides with rin of stars at 14-18 kpc due to infall of dwarf galaxy (Yanny, Ibata, ...)

Halo profiles

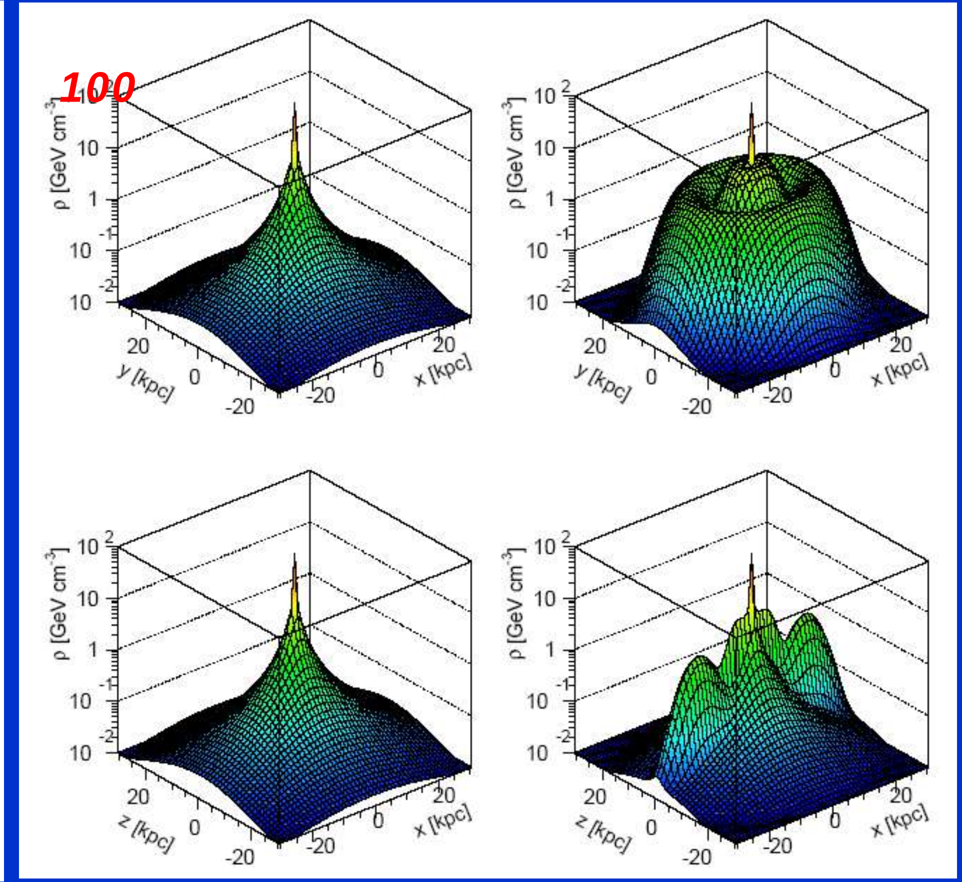
Isothermal cored profile

WITHOUT rings | *WITH rings*



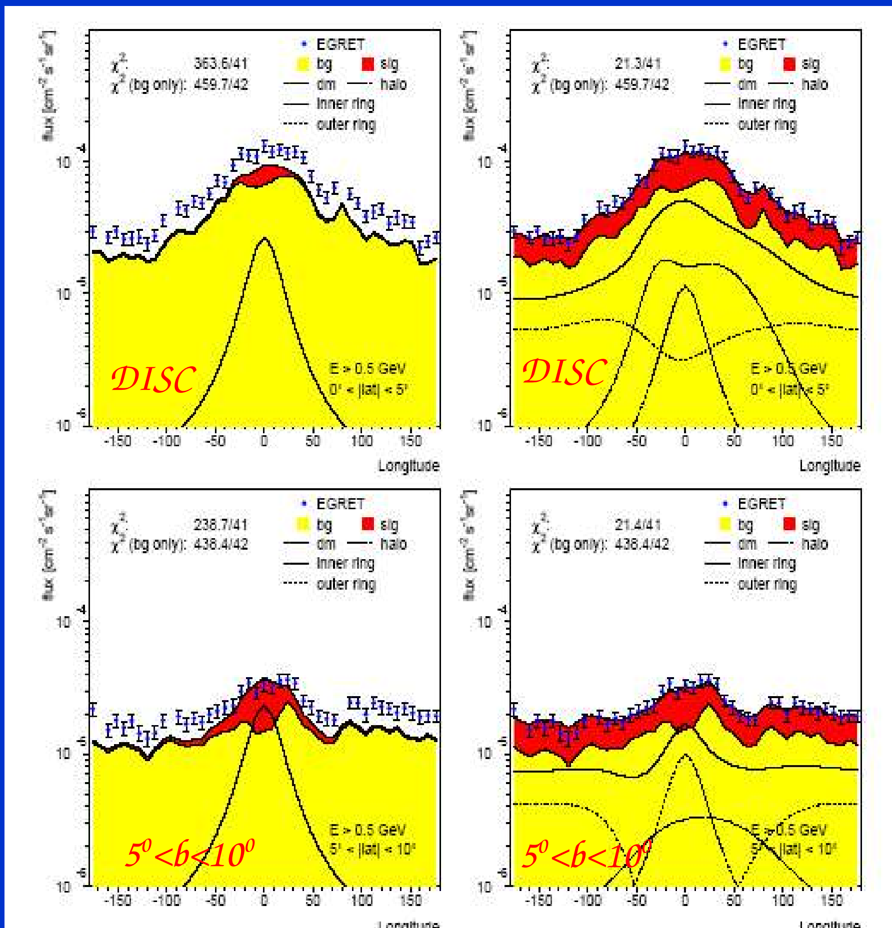
NFW cuspy profile

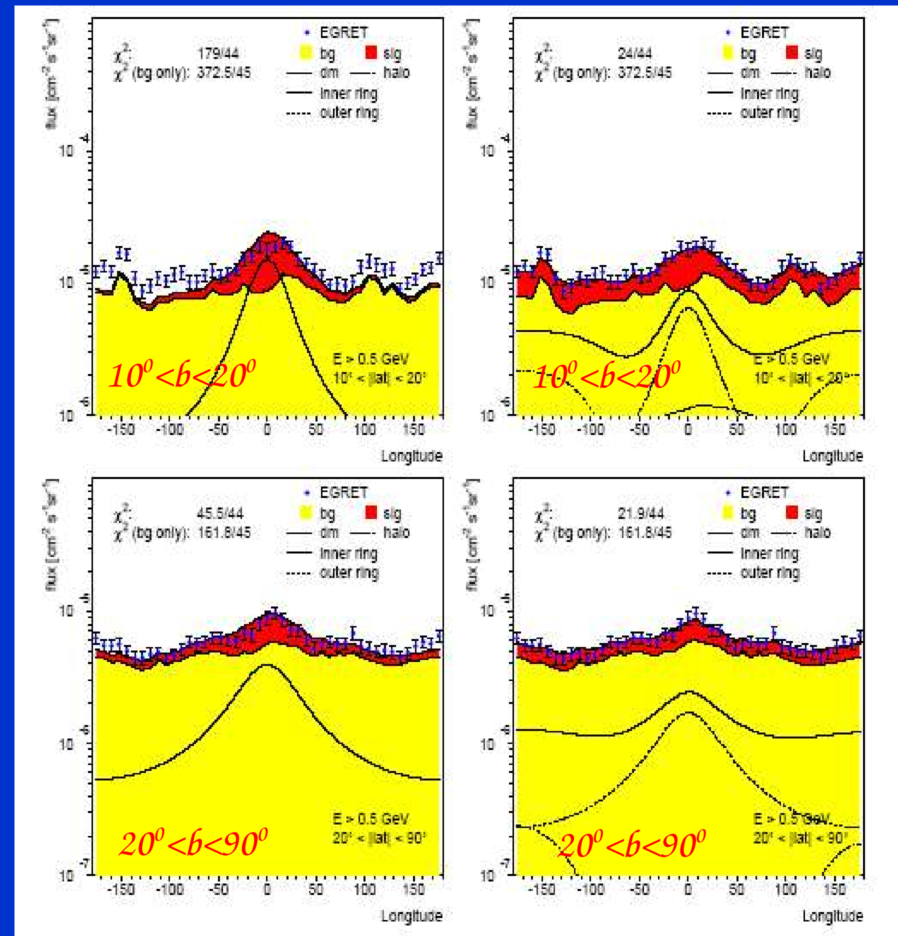
WITHOUT rings | *WITH rings*



Longitude fits for isothermal (cored) profile

WITHOUT rings | *WITH 2 rings* | *WITHOUT rings* | *WITH 2 rings*



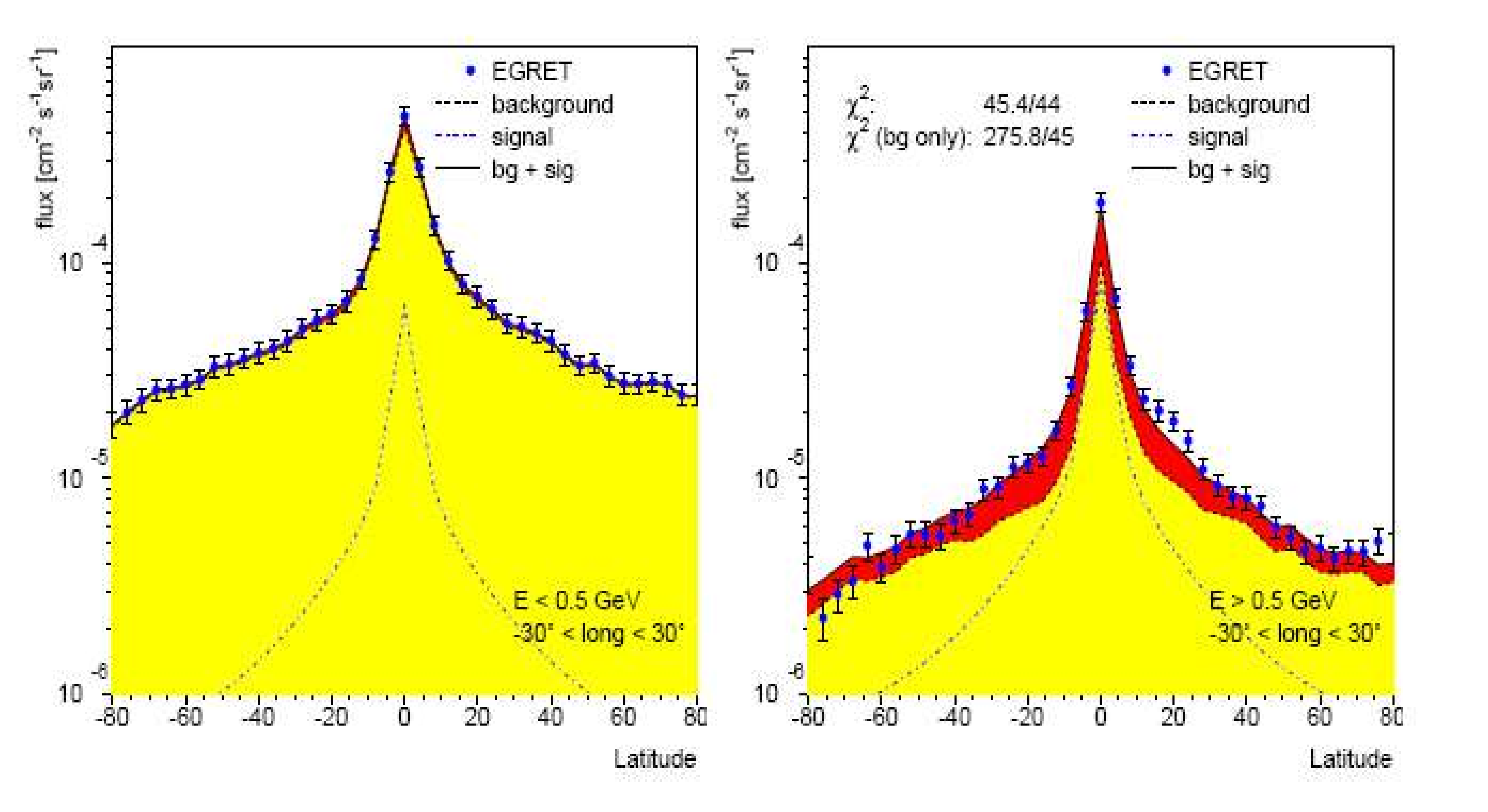


Halo parameters from fit to 180 sky directions: 4 long. profil

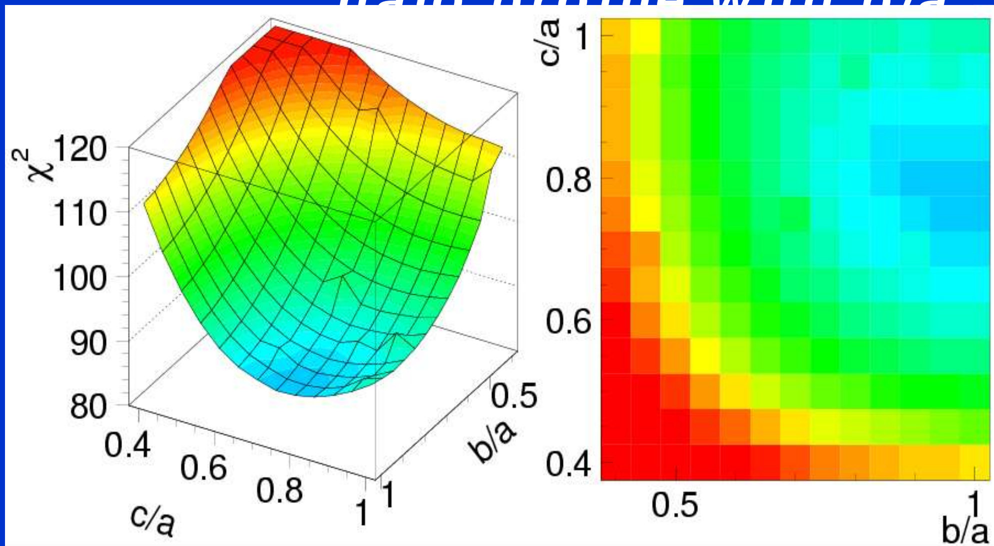
latitudes <5⁰, $5^0<b<10^0$, $10^0<b<20^0$, $20^0<b<90^0$ (=4x45=180 direc

Latitude fits for isoth. Profile with |long|<30⁰

0.1 < Eγ < 0.5 GeV | **Eγ > 0.5 GeV**



EGRET data compatible with prolate isothermal halo profile with b/a ~ 0.9, c/a ~ 0.8



W. de Boer et al., astro-ph/0408272

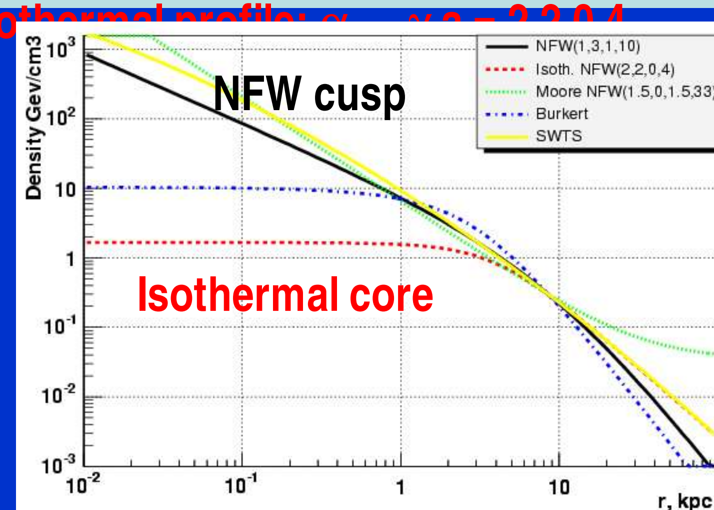
$$\rho(r)=\rho_0\left(\frac{r}{a}\right)^{-\gamma}\left[1+\left(\frac{r}{a}\right)^{\alpha}\right]^{\frac{\gamma-\beta}{\alpha}}$$

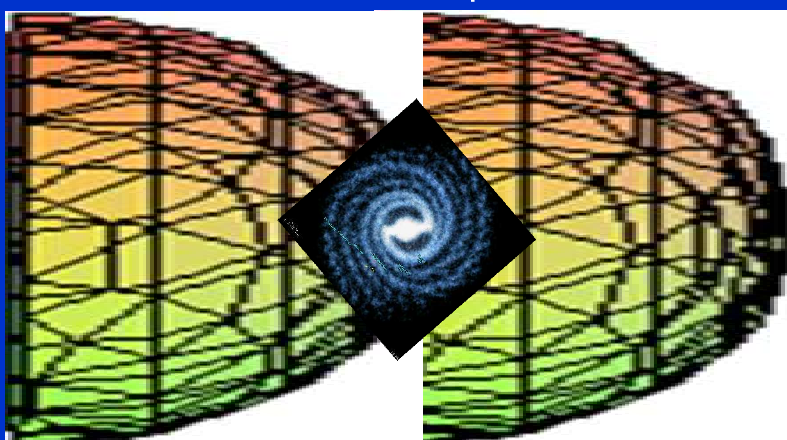
(α,β,γ) – define the slope

ρ_0 - local density 0.3-0.7 GeV/cm^3

a -scale parameter (depends on ρ_0)

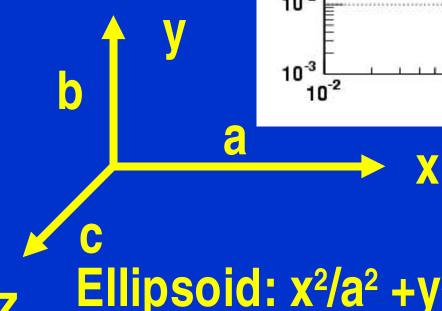
Isothermal profile:





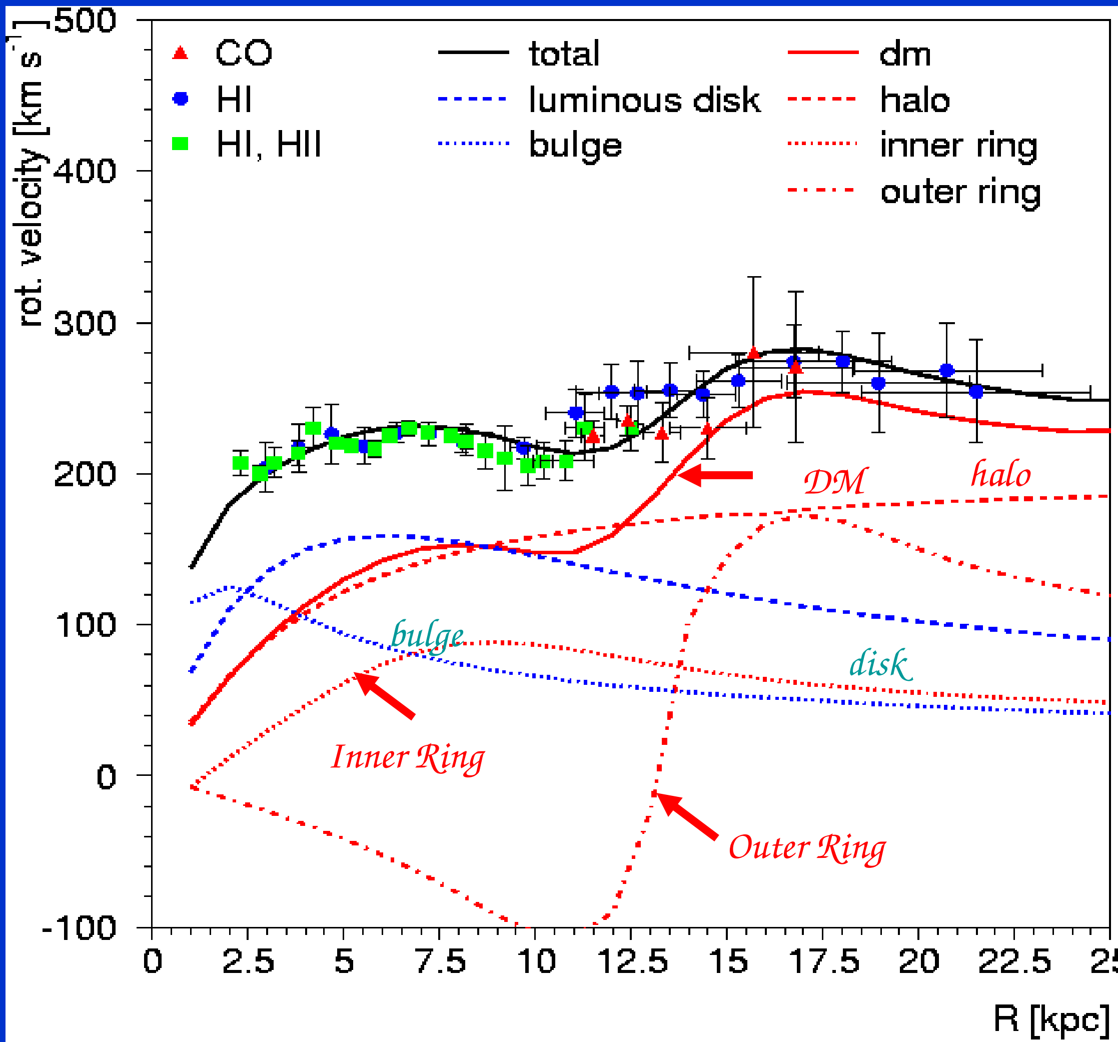
Preferred structure

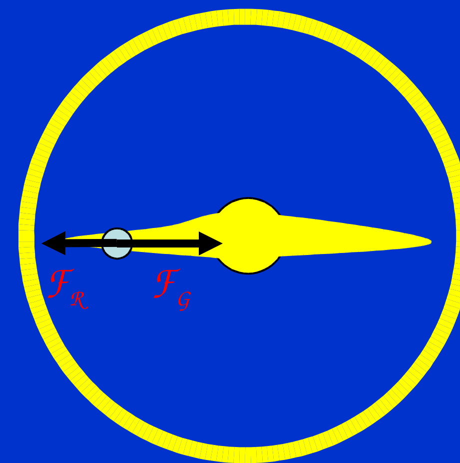
(Bailin, Steinmetz,astro-ph/0408163

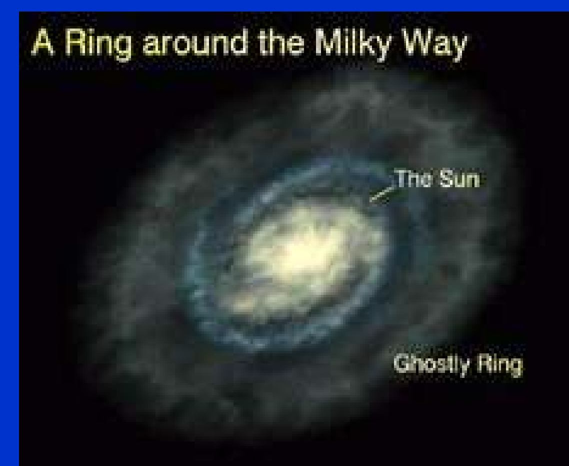


Ellipsoid: $x^2/a^2 + y^2/b^2 + z^2/c^2 = c$

Rotation curve of our galaxy







Rotation curve shows there is a ring of CDM with a mass of a few 10^{10} $M_\odot$

Local surface density ?

Height distribution and velocity dispersion σ of local stars determine local gravitational potential (just like decrease in atmospheric density is determined by gravity of earth).

Decrease in rotation curve suggests little Dark Matter.

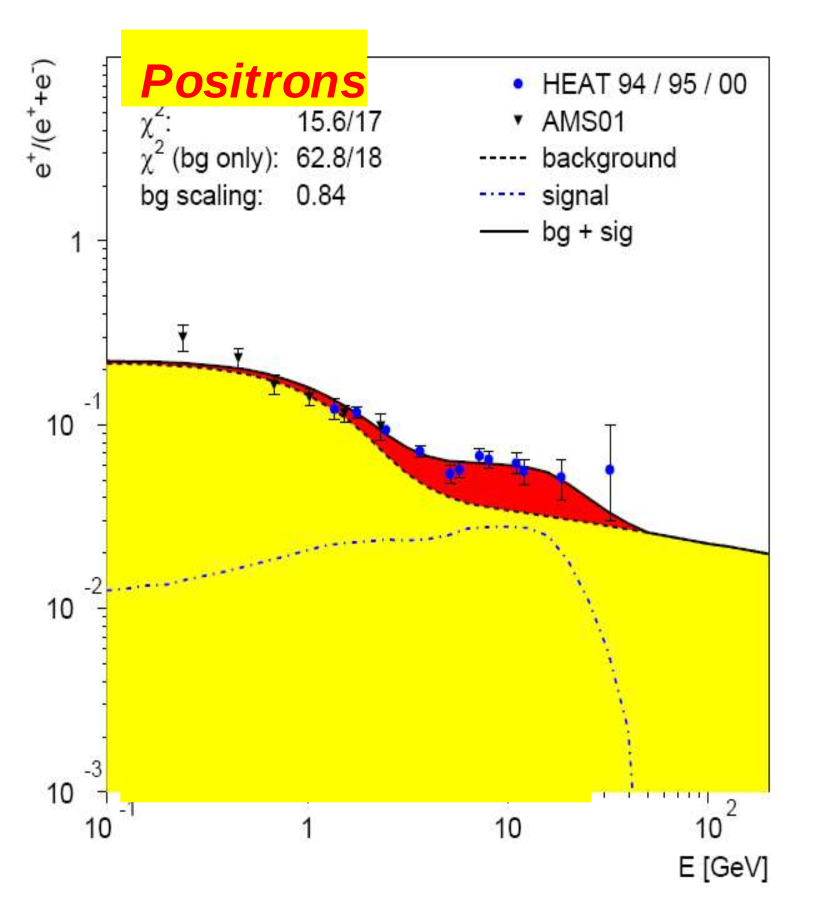
First measurements:
van Oort in 1932: assuming constant σ: repulsive gravity.

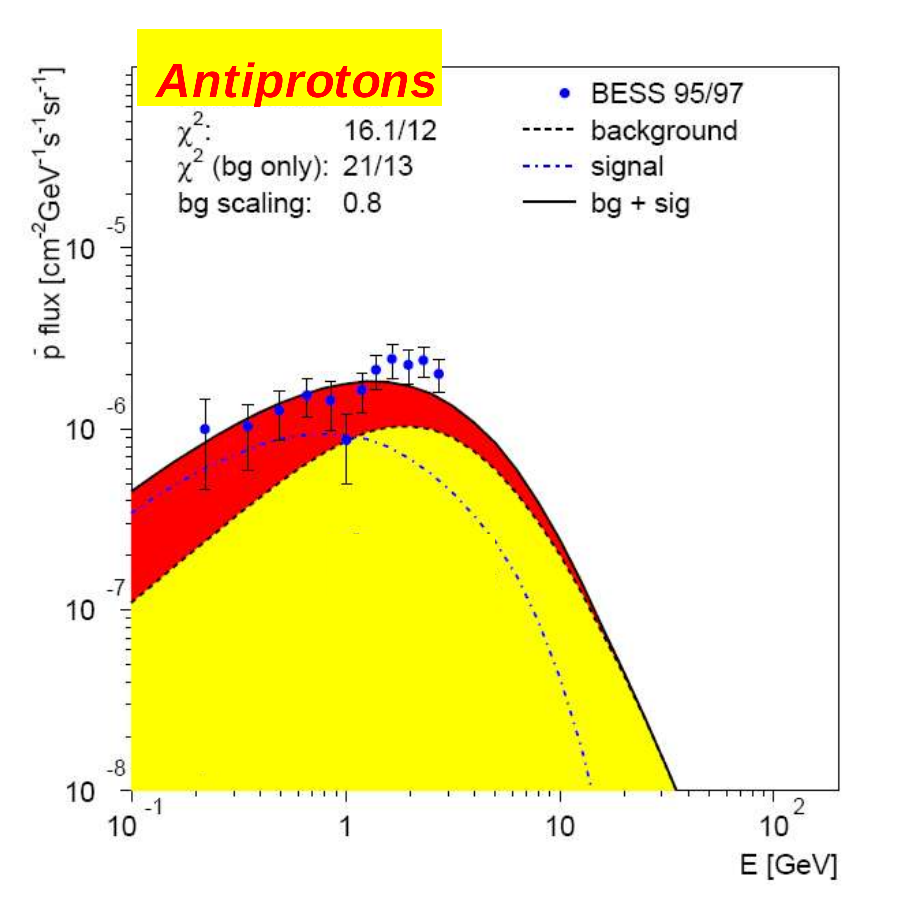
Later: σ(z) ⇒ E.g. ? = ?ρdz = 71±6 M⊙/pc^{-2} for z_{max}=1.1 kpc by Kuijken+ Gilmore, 1991. They assumed constant DM density and very little of it. So they were stretching visible matter by brown dwarfs etc.

2001: Olling +Merrifield: consensus value of ? from visible matter: 35±10
2002: Bienayme et al.: ? = 85±? Error strongly dependent on assumptions of DM distributions.

2004: de Boer et al.: $?_{DM}$=60 $?_{baryonic}$=30 M?/pc^{-2} with steeply varying DM density steep function of z (on slope of ring!)

Positron fraction and antiprotons from DM annihilation



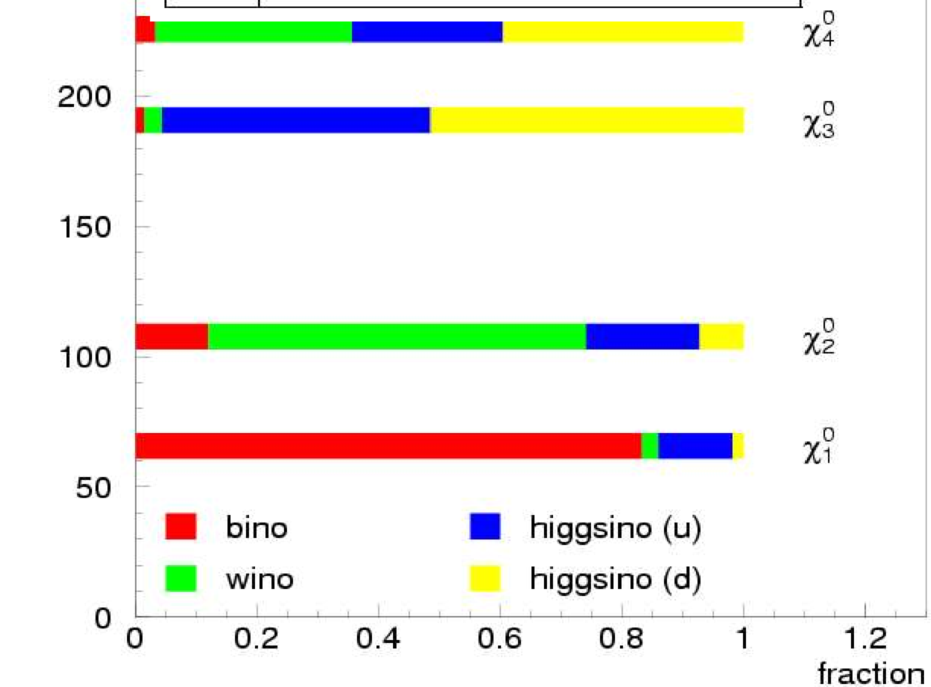


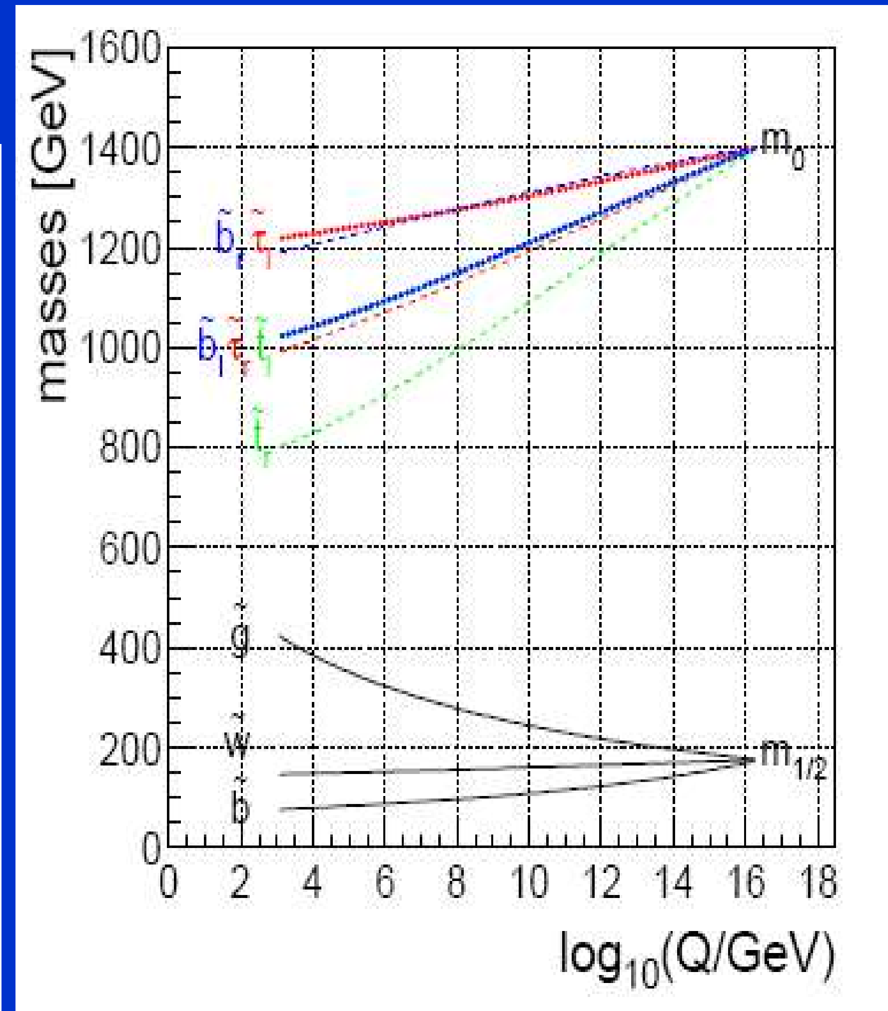
SAME Halo and WIMP parameters as for GAMMA RAYS

but fluxes strong function of propagation models!

SUSY Mass spectra in mSUGRA

	$\tilde{b}^0$	$\tilde{w}^0$	$\tilde{h}_1^0$	$\tilde{h}_2^0$
$\tilde{\chi}_1^0$	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





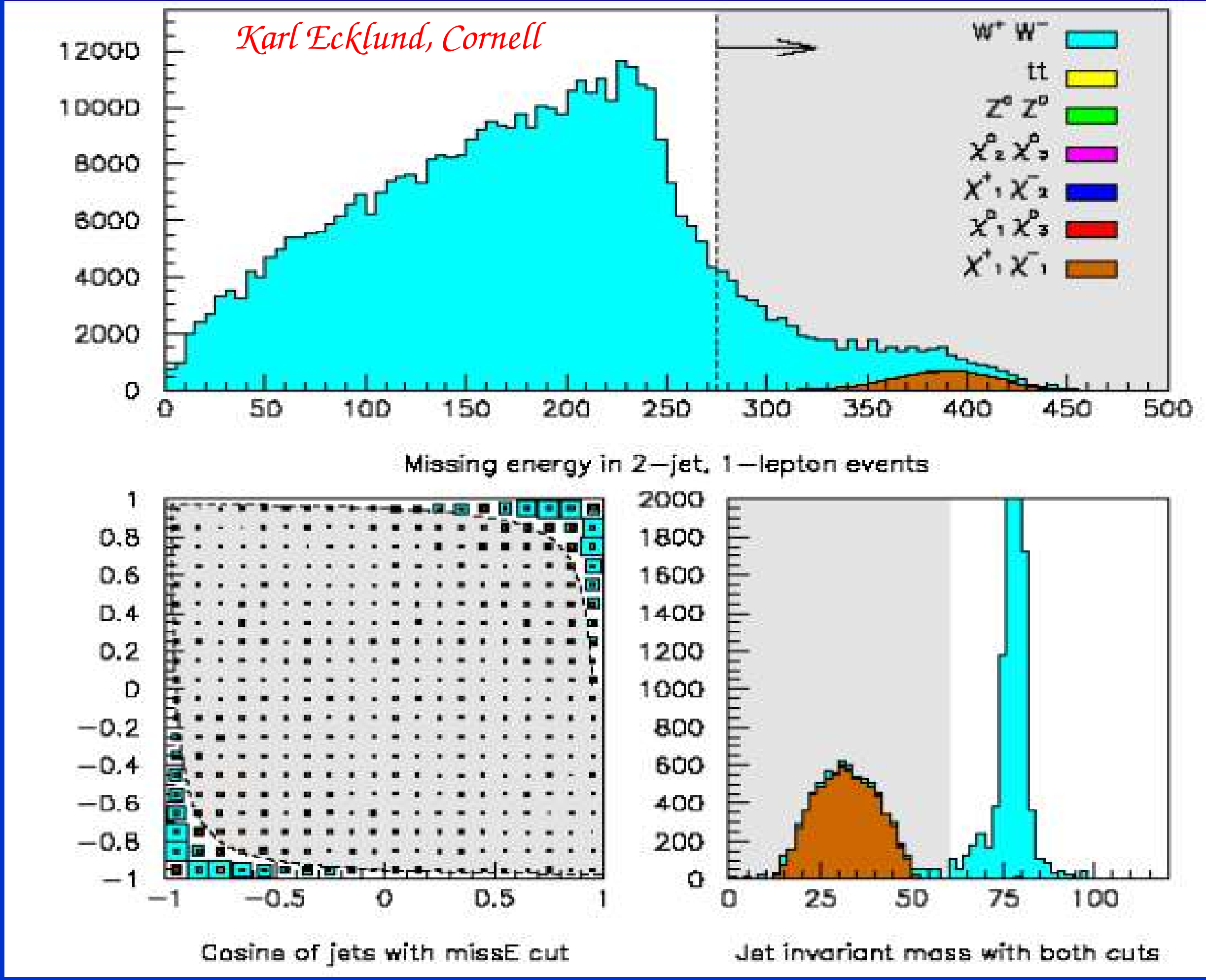
LSP largely Bino ⇒ DM may be supersymmetric partner of CMB

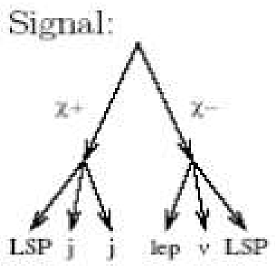
Charginos, neutralinos and gluinos light

Supersymmetry at linear collider

$e^+e^- \rightarrow \chi_1^+\chi_1^- \rightarrow \chi_1^0 jj \chi_1^0 \ell\nu$

pb x-section!





- Clear signal seen
- Can fit M(jj) for endpoint

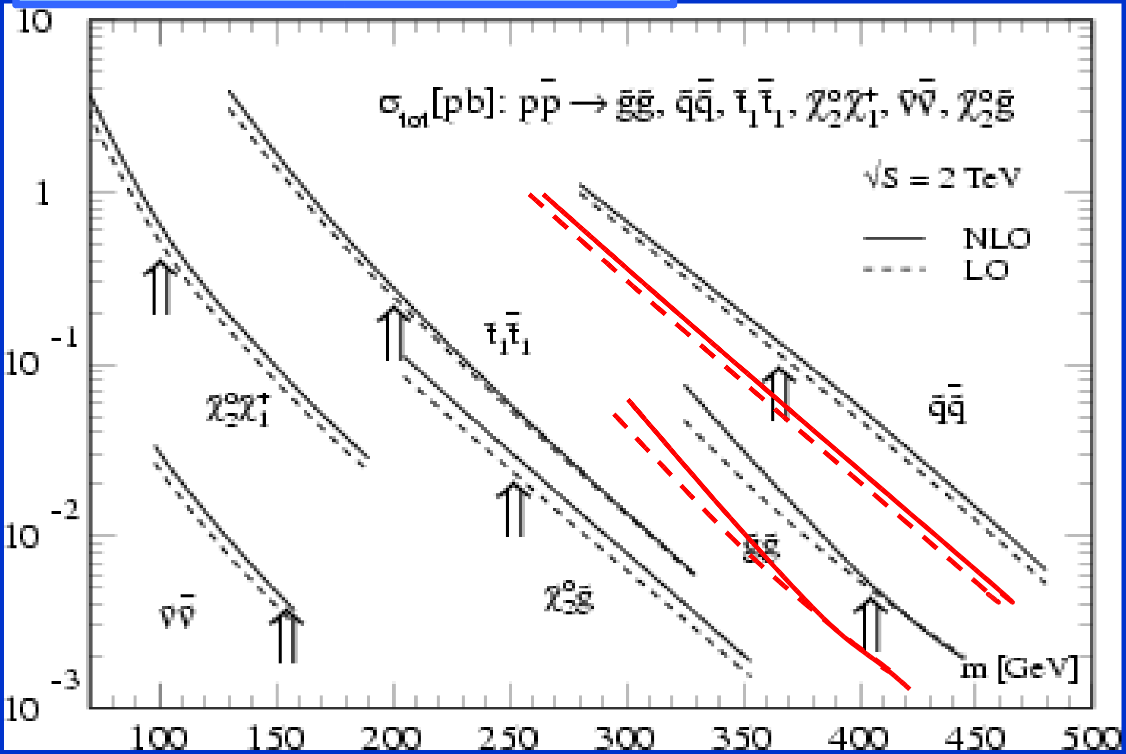
$\Delta M = M\chi_1^+ - M\chi_1^0$ $= 52$ GeV

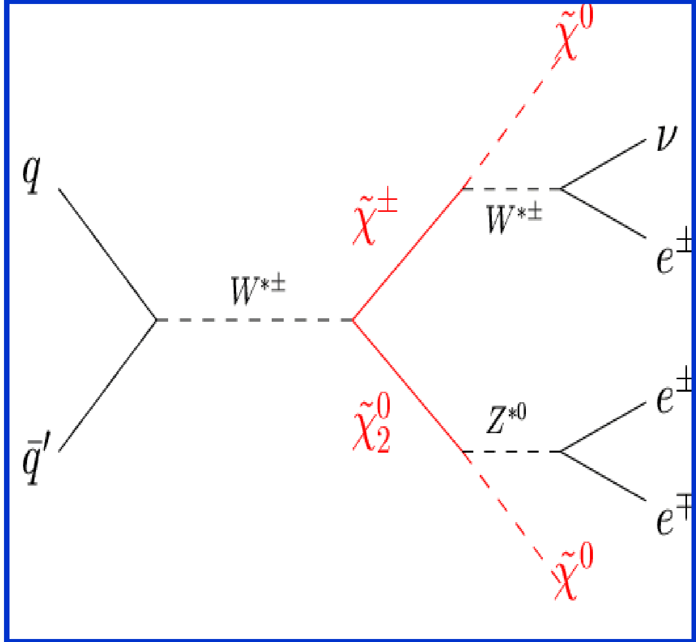
- Analysis to be optimized

Supersymmetry at proton collider

Typical cross-sections (pb)

Silke Duensing





m [GeV]

$$p\bar{p} \longrightarrow \chi_1^{\pm}\chi_2^0 \Rightarrow l^{1,2,3} + \not{E}_T + X$$

pb x-section with very little background!

Summary

1. Significant Excess (>10σ) of EGRET diffuse gamma

2. Excess outside disk follows cored (isothermal) halo

3. Independent evidence that EGRET excess indeed originates from DM annihilation follows from:

c) Strong signal from region with ring of stars at 14-18 kpc,

4. Alternative "conventional" models cannot explain stabil

ring of stars at 14 kpc and H_2 ring of molecular gas at 4

nor change of slope of rotation curve, nor halo shape of

Summary of summary

EGRET galactic gamma ray data provides intriguing hin

- since WIMP has properties of a spin ½ photon -

DM is the Supersymmetric Partner of the CMB

This conclusion is INDEPENDENT of the absolute normal

only dependent on the SHAPE of diffuse gamma ray spec