First Evidence for Dark Matter Annihilation

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Outline (see astro-ph/0408272)

- **EGRET Data on diffuse Gamma Rays show excess in all sky directions with the SAME energy spectrum from monoenergetic quarks**

- **WIMP mass between 50 and 100 GeV from spectrum of EGRET excess**

- **Halo distribution from sky map**

- **Data consistent with Supersymmetry**
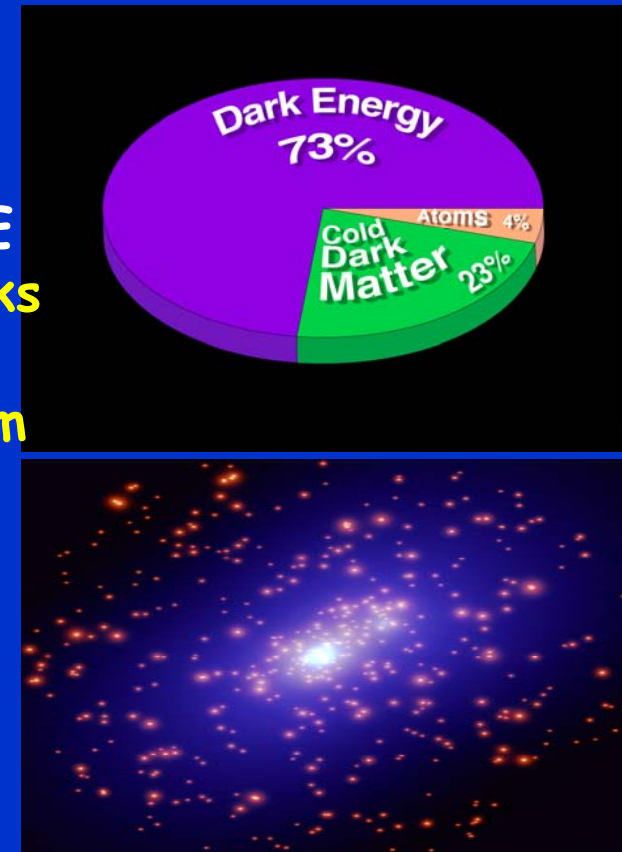
Physics Problems

- **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?
  Why ring of molecular hydrogen at 4 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

- From INTENSITY: halo distribution and rotation curve

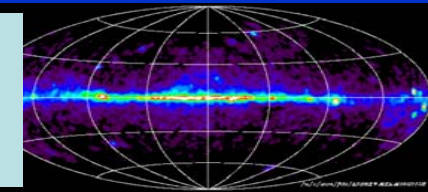- WIMP has properties of supersymmetric lightest particle

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


Strong, Moskalenko, Reimer, to be published
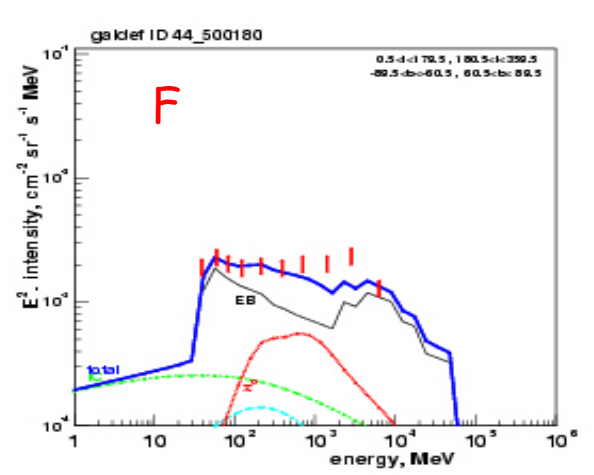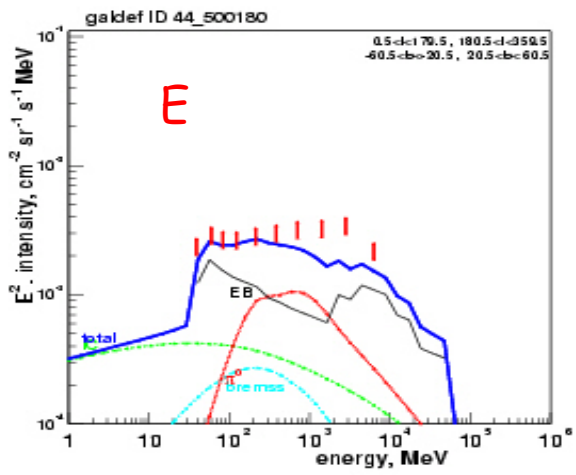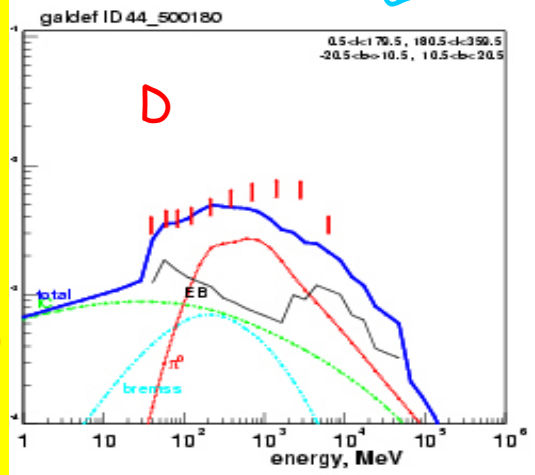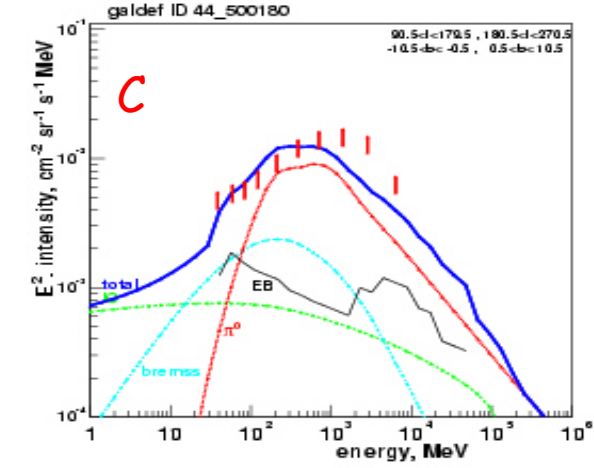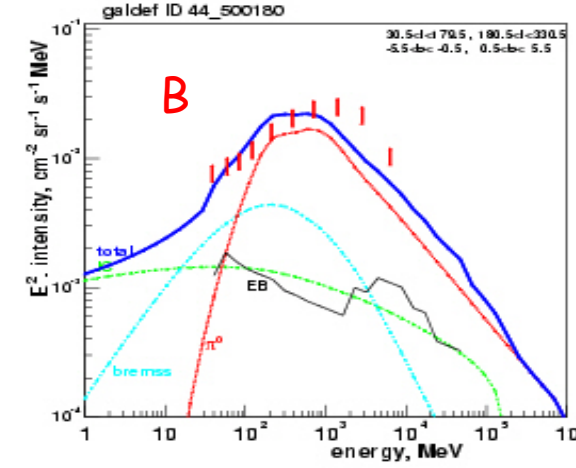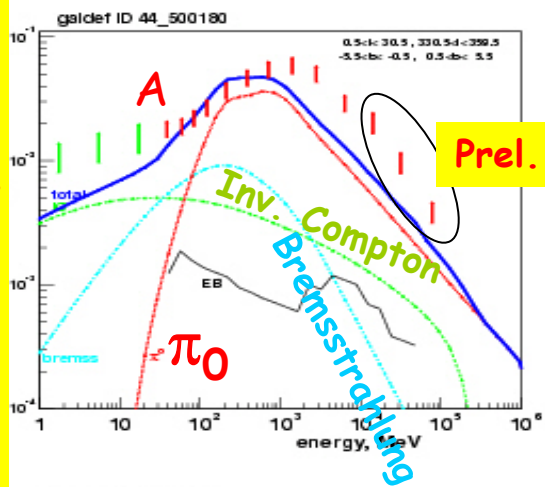
A: inner Galaxy ($l=\pm30^0$, $|b|<5^0$)
B: Galactic plane avoiding A
C: Outer Galaxy

D: low latitude ($10-20^0$)
E: intermediate lat. ($20-60^0$)
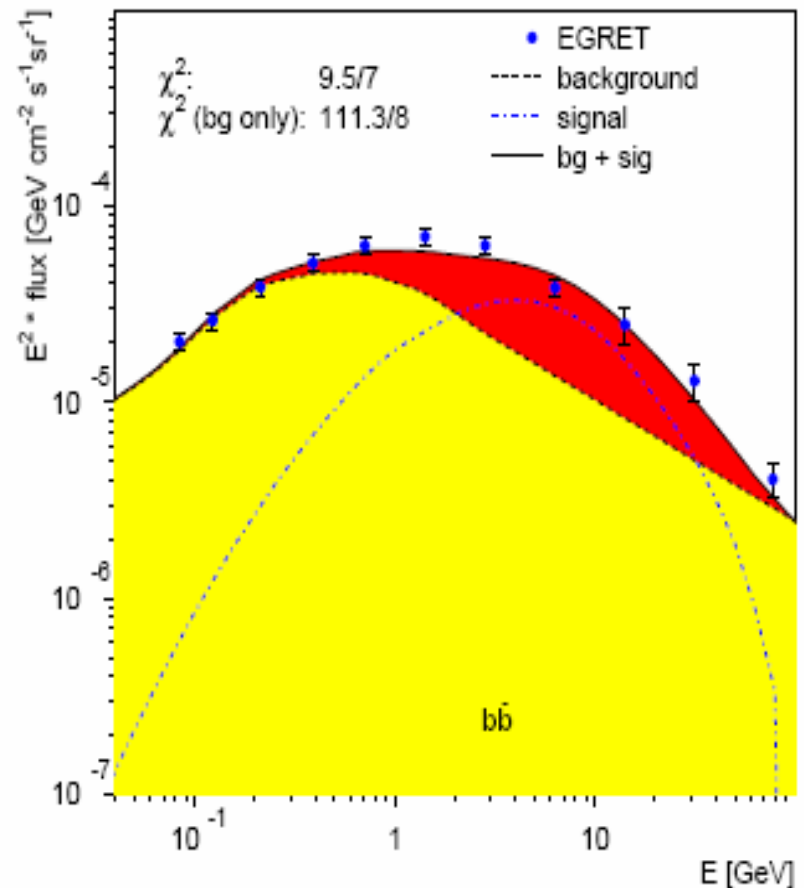F: Galactic poles ($60-90^0$)

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

**Egret Excess above extrapolated background from data below 0.5 GeV**

Statistical errors only
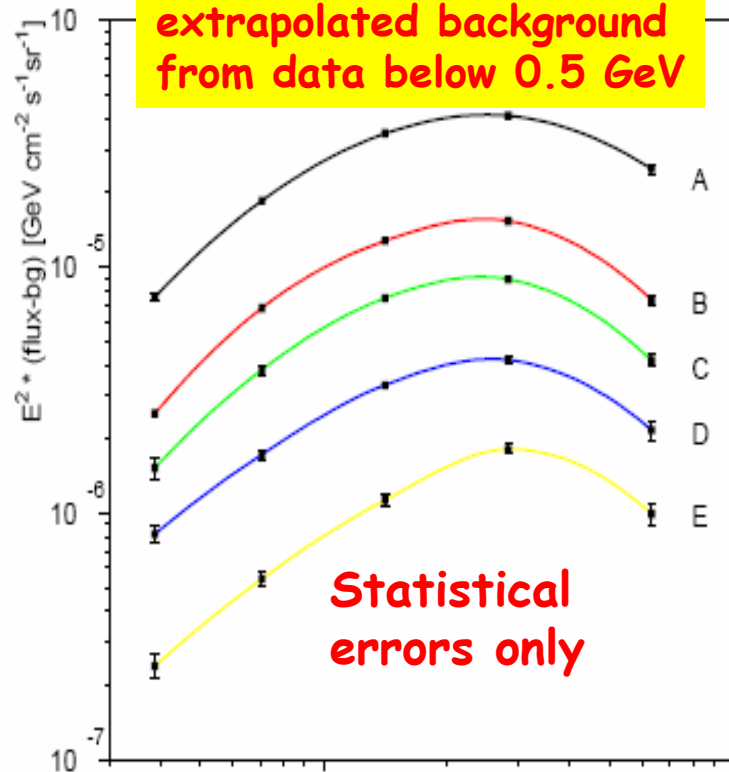
Excess same shape in all regions implying same source everywhere

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 absolute background estimates, BUT ONLY TO THE SHAPE, which is much better known.
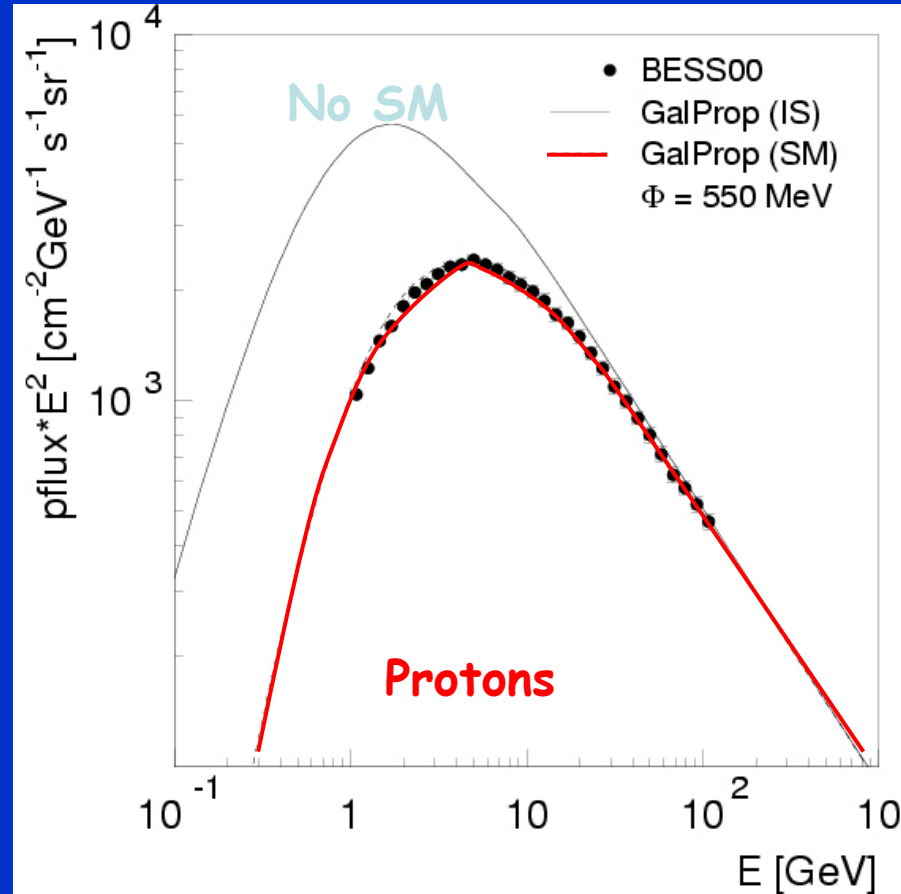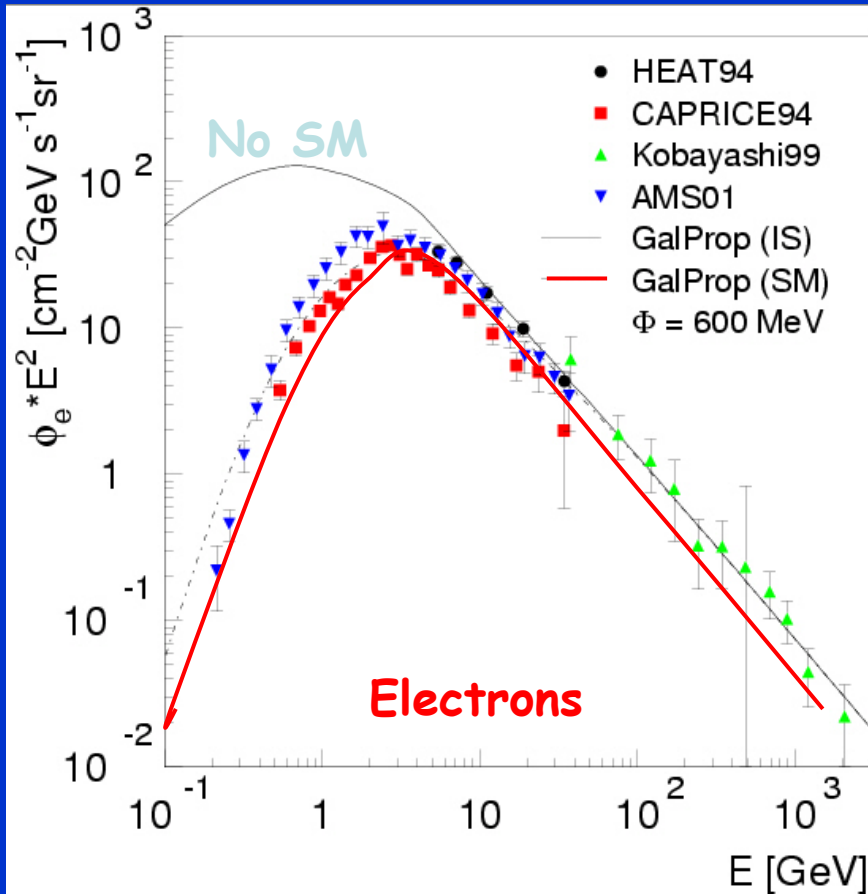
Neutralino Annihilation Final States
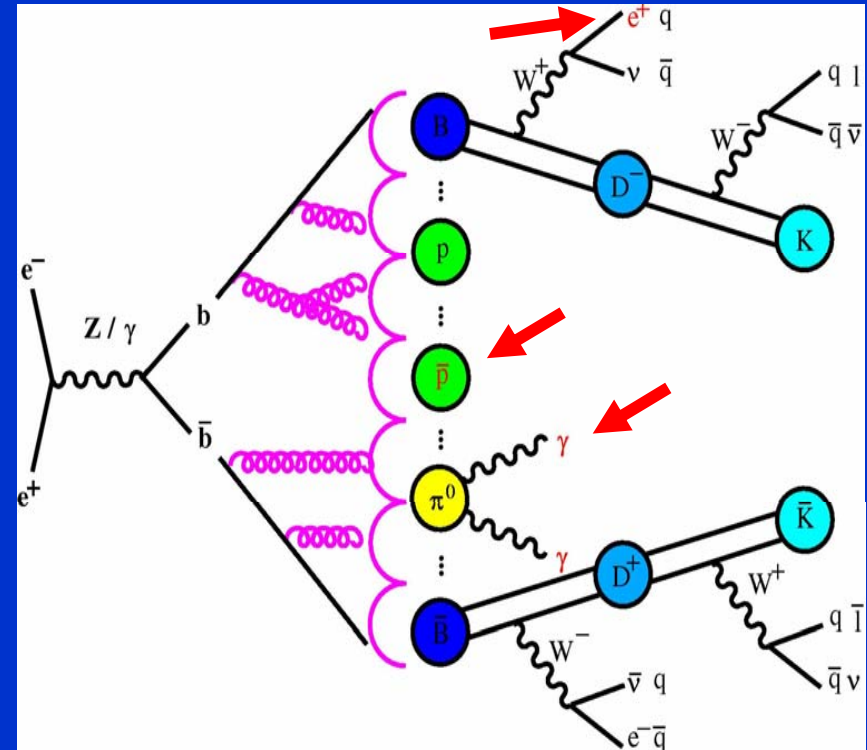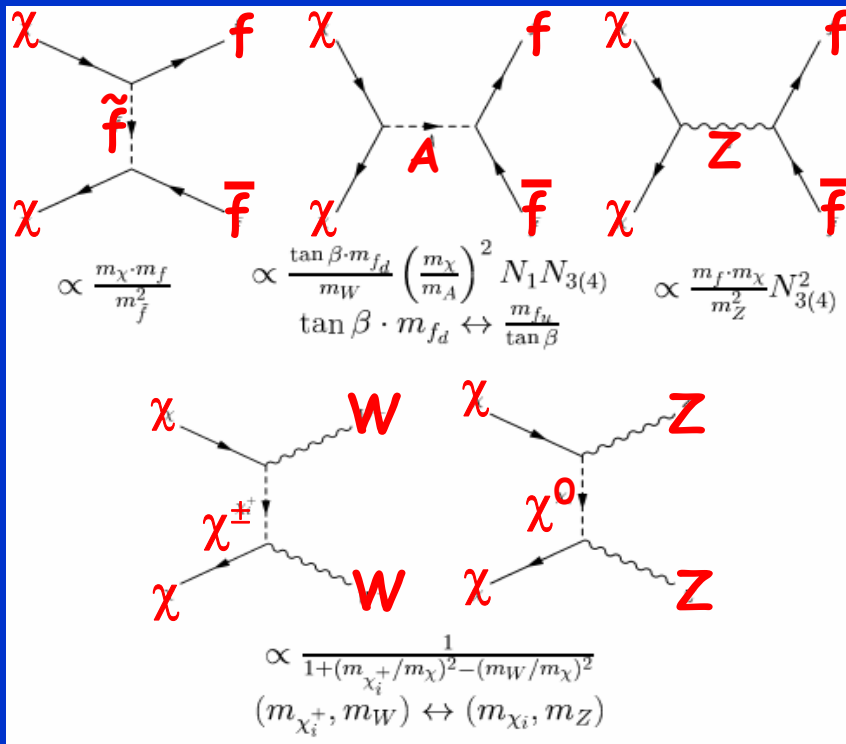
Dominant Diagram for WMAP cross section:
$\chi + \chi \Rightarrow A \Rightarrow$ b bbar quark pair

B-fragmentation well studied at LEP! Yield and spectra of positrons, gammas and antiprotons well known!
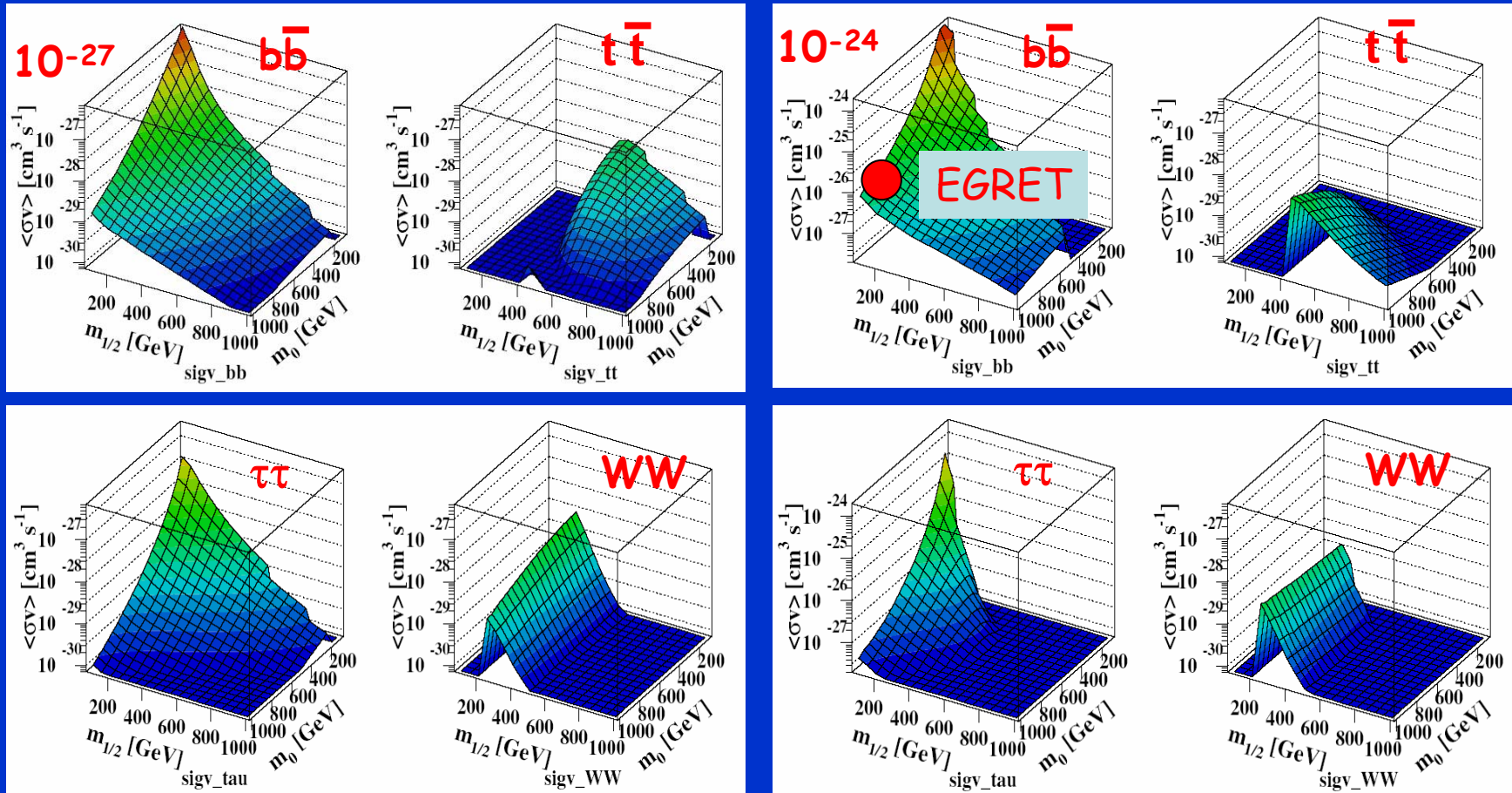
Solar modulation (SM) important below 10 GeV
Proton and electron spectra above 10 GeV well measured $\Rightarrow$
Gamma spectrum well known, unless one assumes "local bubble",
i.e. spectra in galaxy different from locally measured ones.

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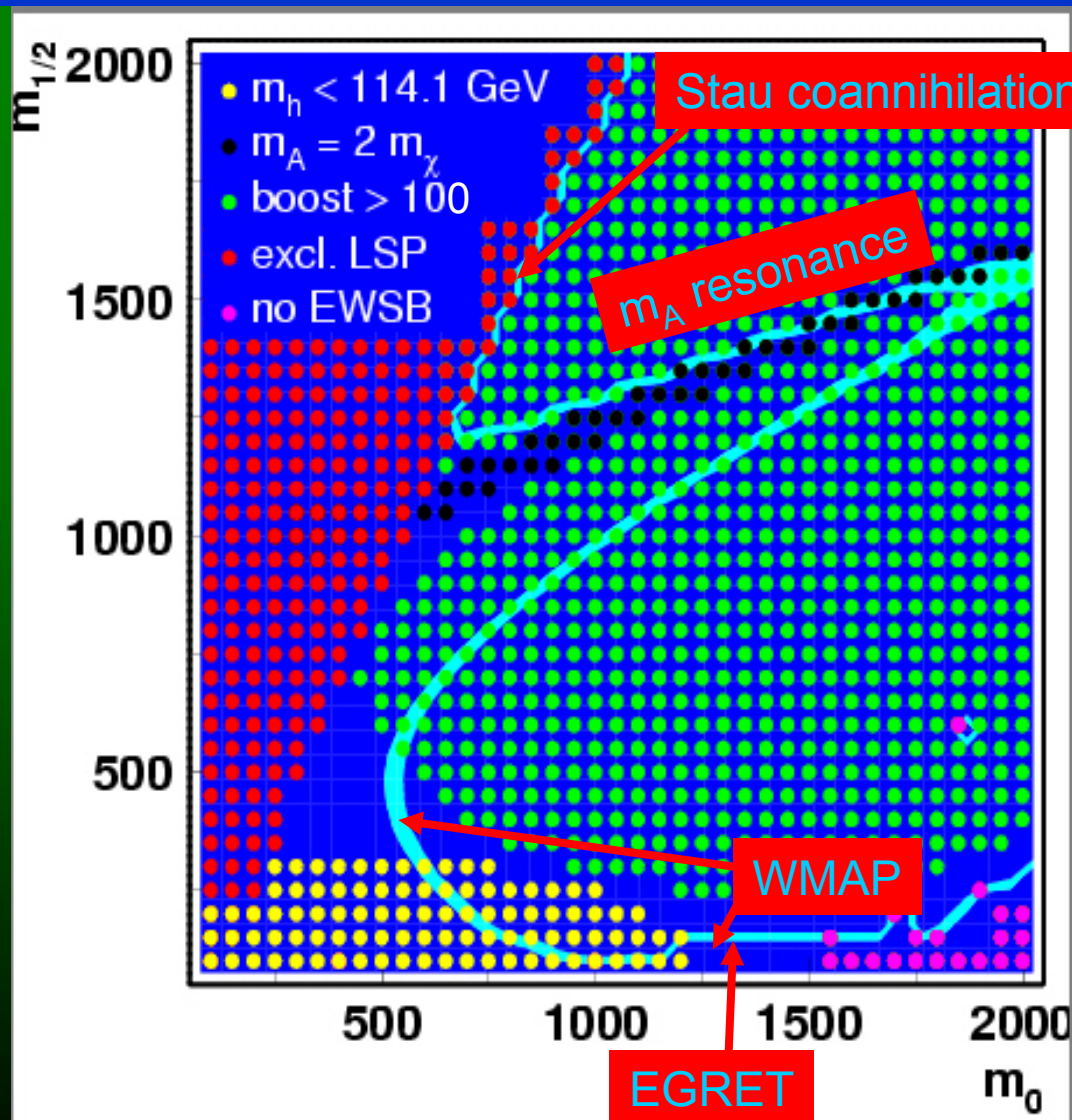## in m_0-$m_{1/2}$ plane ($\mu > 0$, $A_0 = 0$)

tanβ=5

tanβ=50

For WMAP x-section of $\langle \sigma v \rangle \cong 2 \cdot 10^{-26}$ cm³/s one needs large tanβ in bulk region (no coannihilation, no resonances)

EGRET excess interpreted as DM consistent with WMAP, Supergravity and electroweak constraints
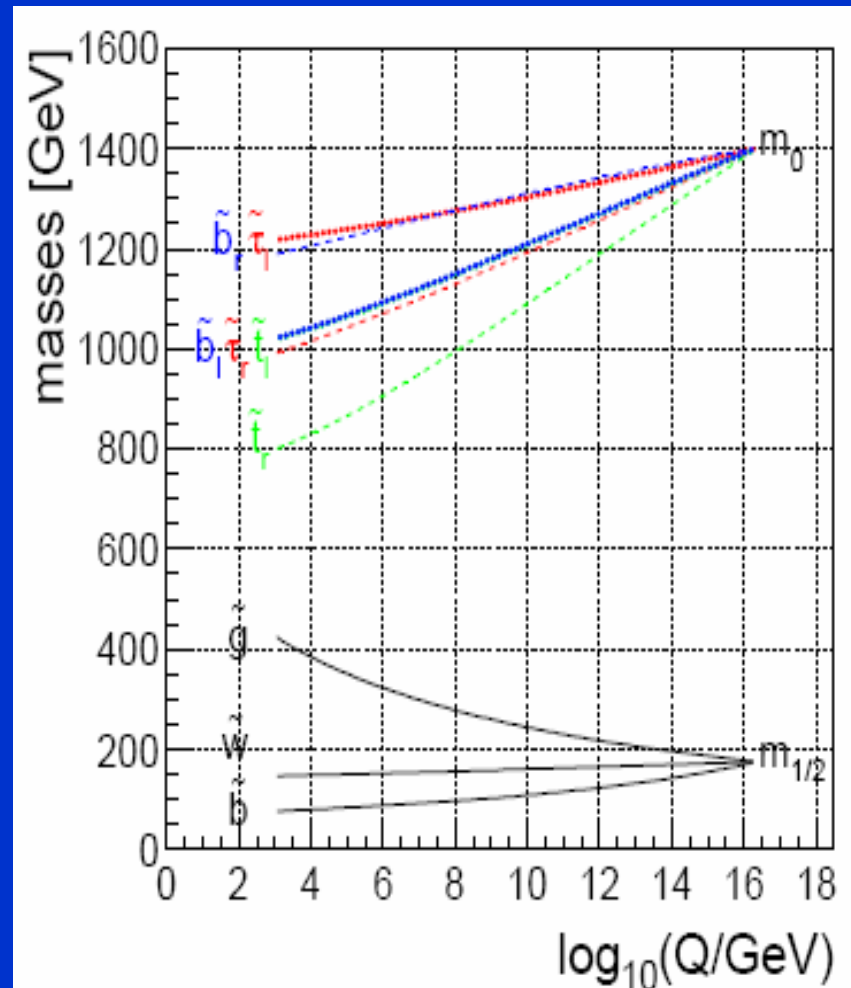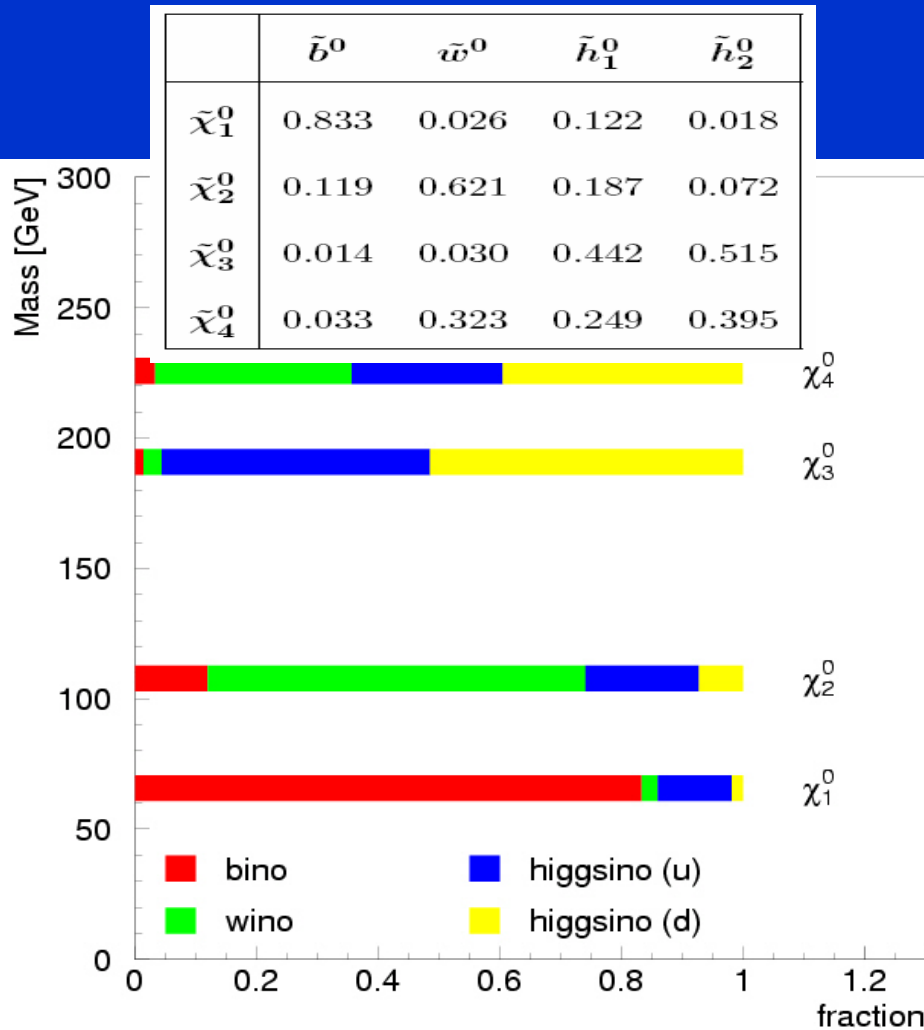

- $m_h < 114.1$ GeV
- $m_A = 2 m_\chi$
- boost > 100
- excl. LSP
- no EWSB

Stau coannihilation

m_A resonance

WMAP

EGRET

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
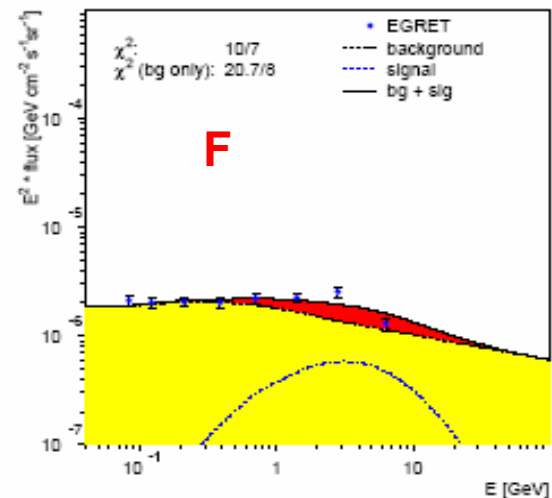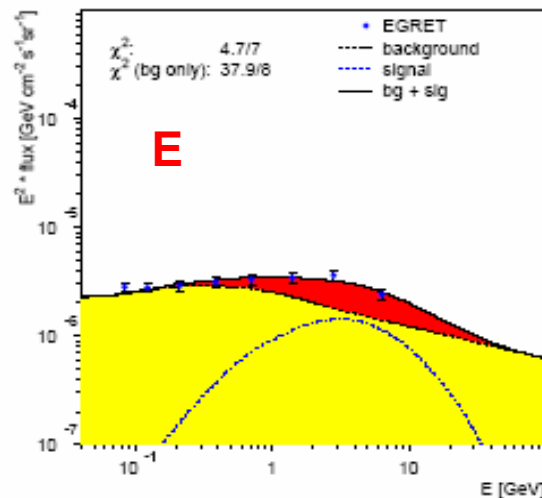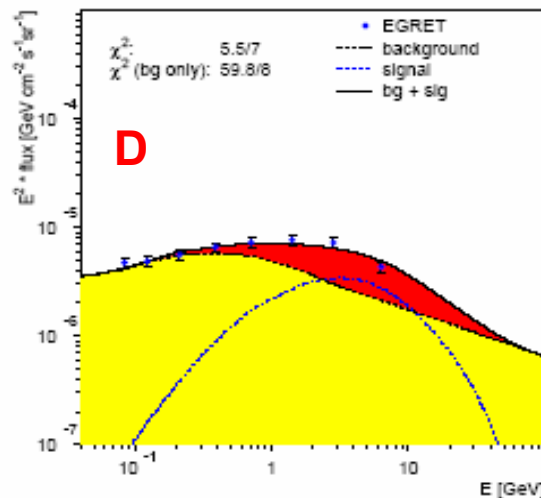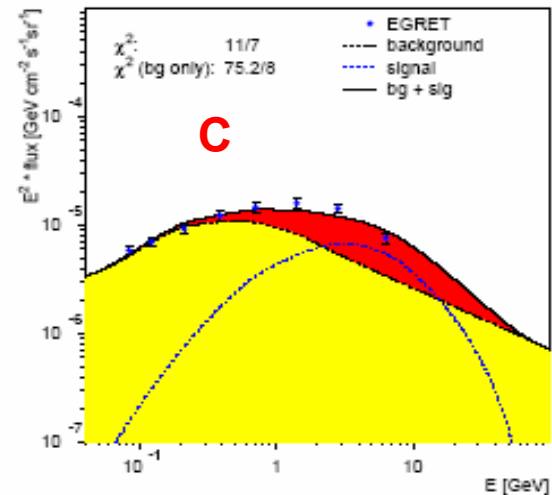$\tan\beta = v_2/v_1$

High $\tan\beta$ solution
$\tan\beta = 50$

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

Diffuse Gamma Rays for different sky regions
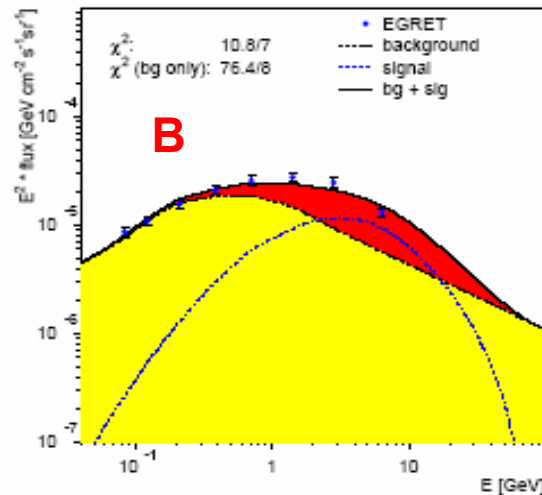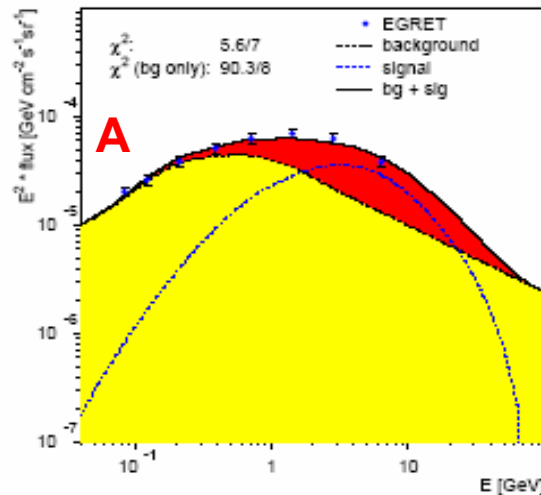
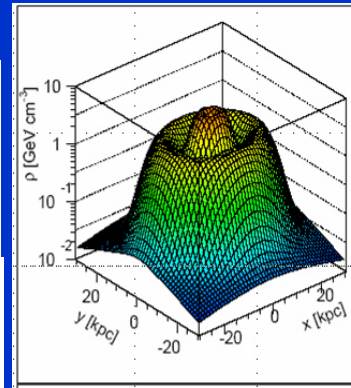**DMA ∝ Boostfactor <ρ²> If boost factor, i.e. clustering, similar in all directions, then signal strength determines DM density ρ**

Fit results of halo parameters

Gamma Ray Flux: (<σv> from WMAP)

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

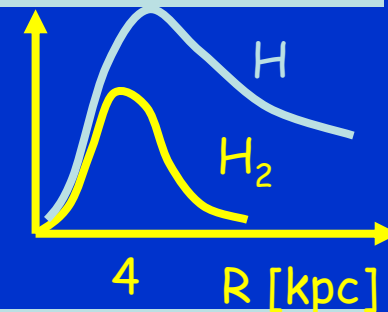$$\rho_\chi(\tilde{r}) = \rho_0 \left(\frac{R_0}{\tilde{r}}\right)^\gamma \left[\frac{1 + \left(\frac{\tilde{r}}{a}\right)^\alpha}{1 + \left(\frac{R_0}{a}\right)^\alpha}\right]^{\frac{\gamma - \beta}{\alpha}} + \sum_{n=1}^N \rho_n \exp\left(-\frac{(\tilde{r}_{gc} - Rn)^2}{2\sigma_{R_n}^2} - \frac{(z_n)^2}{2\sigma_{z_n}^2}\right)$$

∝ **1/r²**   **2 Gaussian rings**

A Ring around the Milky Way
The Sun
Ghostly Ring

Enhancement of rings over 1/r² profile 2 and 7, respectively. Mass in rings 1.6 and 0.3% of total DM

H
H₂
4   R [kpc]

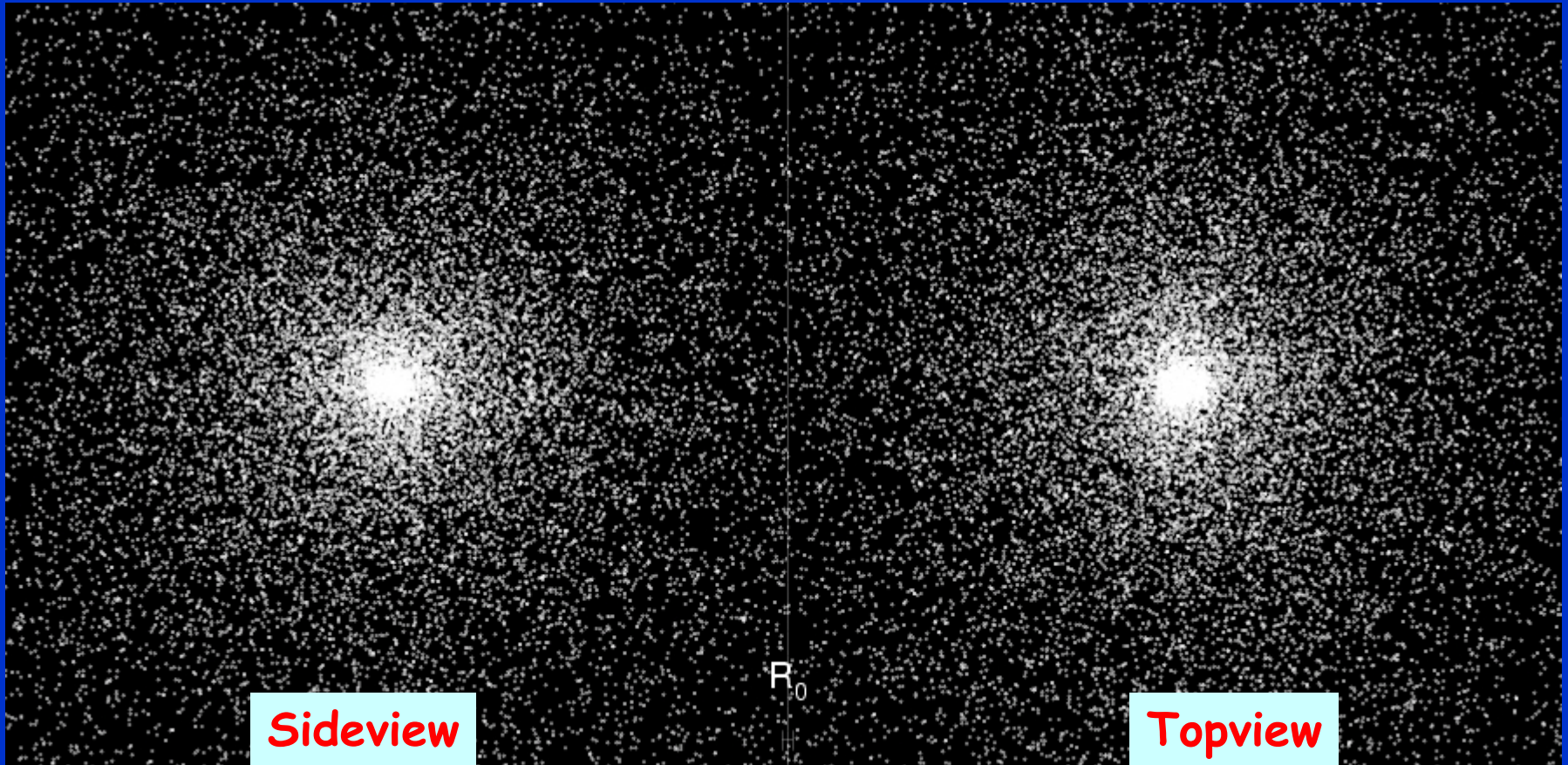| Parameter	Value	Parameter	Value
α	2	R_a	4.3 kpc
β	2	$\sigma_{R,a}$	3.4 kpc
γ	0	$\sigma_{z,a}$	0.3 kpc
R_0	8.5 kpc	ρ_b	2.3 GeV cm⁻³
a	4 kpc	R_b	14 kpc
ρ_0	0.47 GeV cm⁻³	$\sigma_{R,b}$	2.1 kpc
ρ_a	3.3 GeV cm⁻³	$\sigma_{z,b}$	1.3 kpc
b/a	0.9	c/a	0.8

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

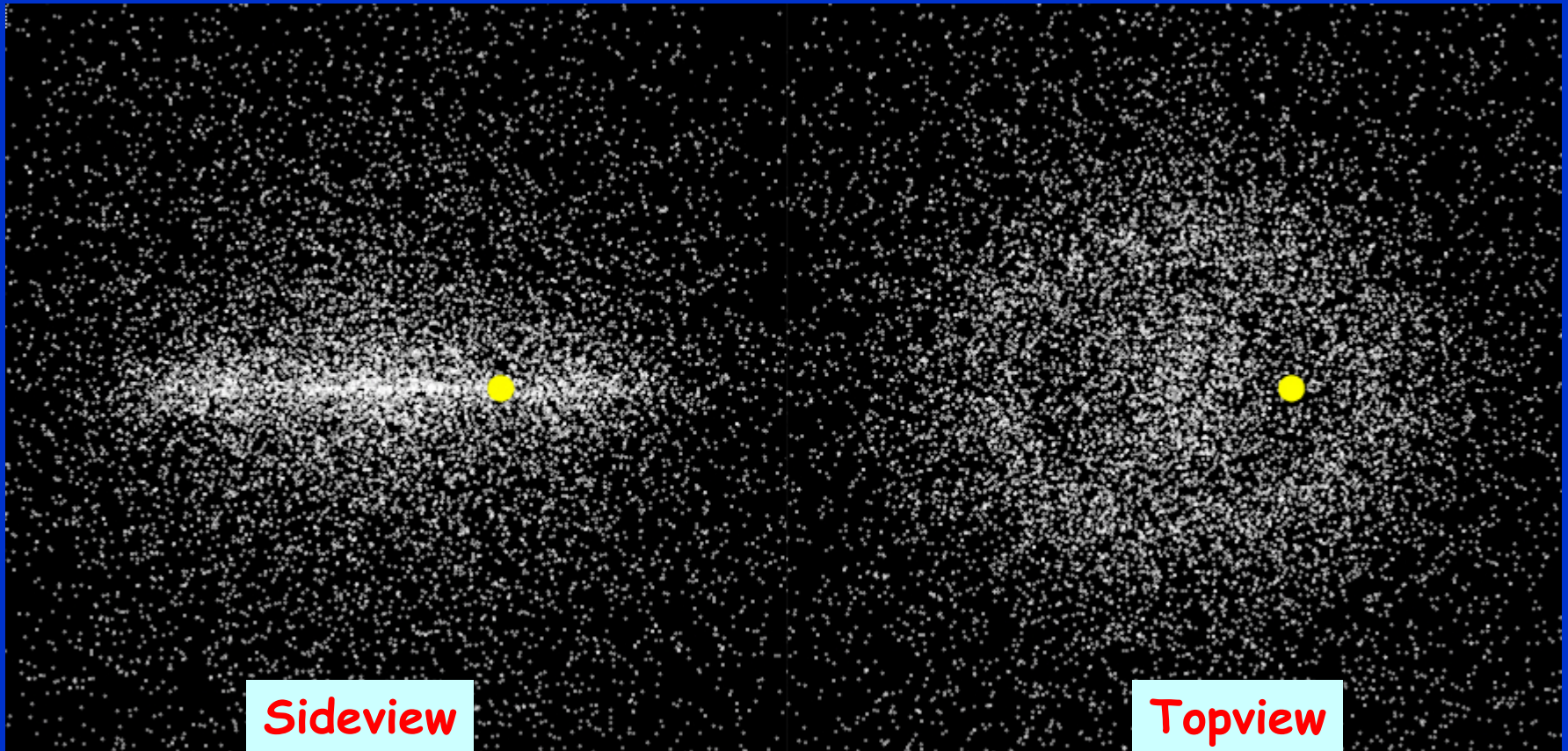**4 kpc coincides with ring of neutral hydrogen molecules!**

Halo density on scale of 300 kpc

Sideview

Topview

R_0

Cored isothermal profile with scale 4 kpc
Total mass: 3.10^{12} solar masses

Halo density on scale of 30 kpc

Sideview

Topview

Halo profiles

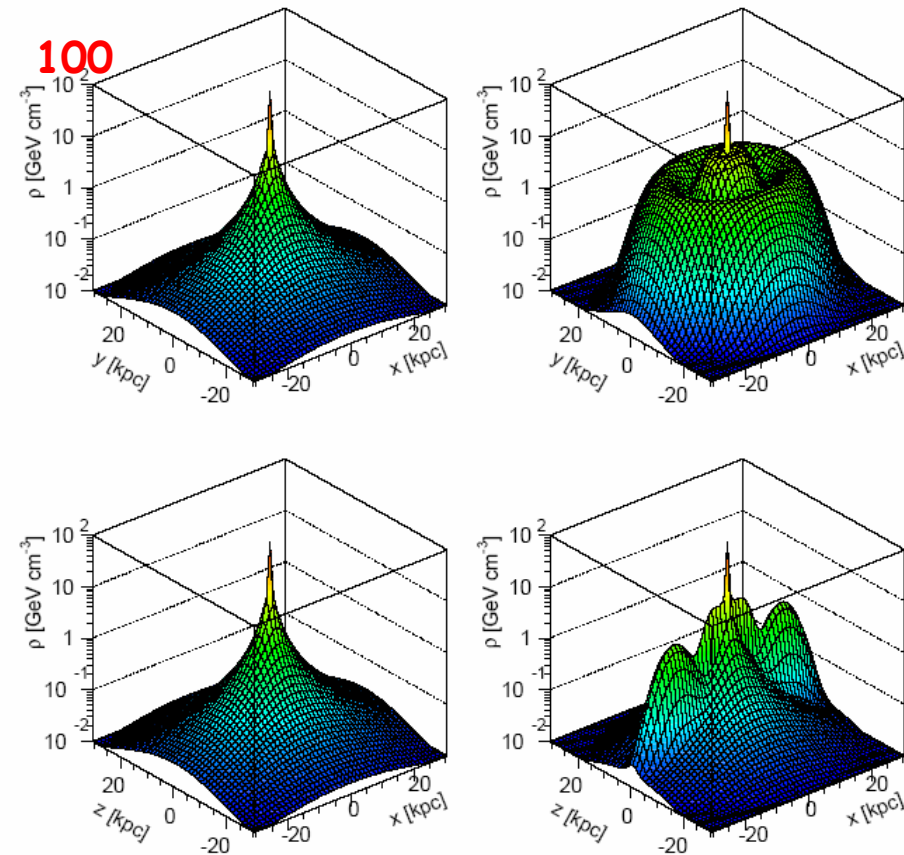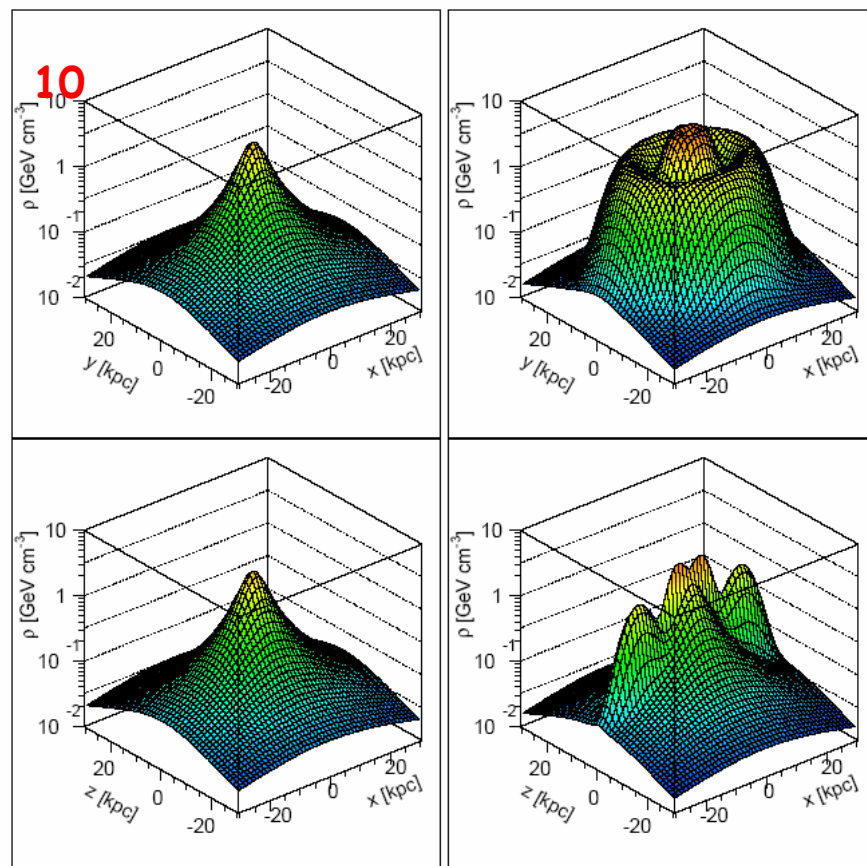## Isothermal cored profile

WITHOUT rings
WITH rings

NFW cuspy profile

WITHOUT rings
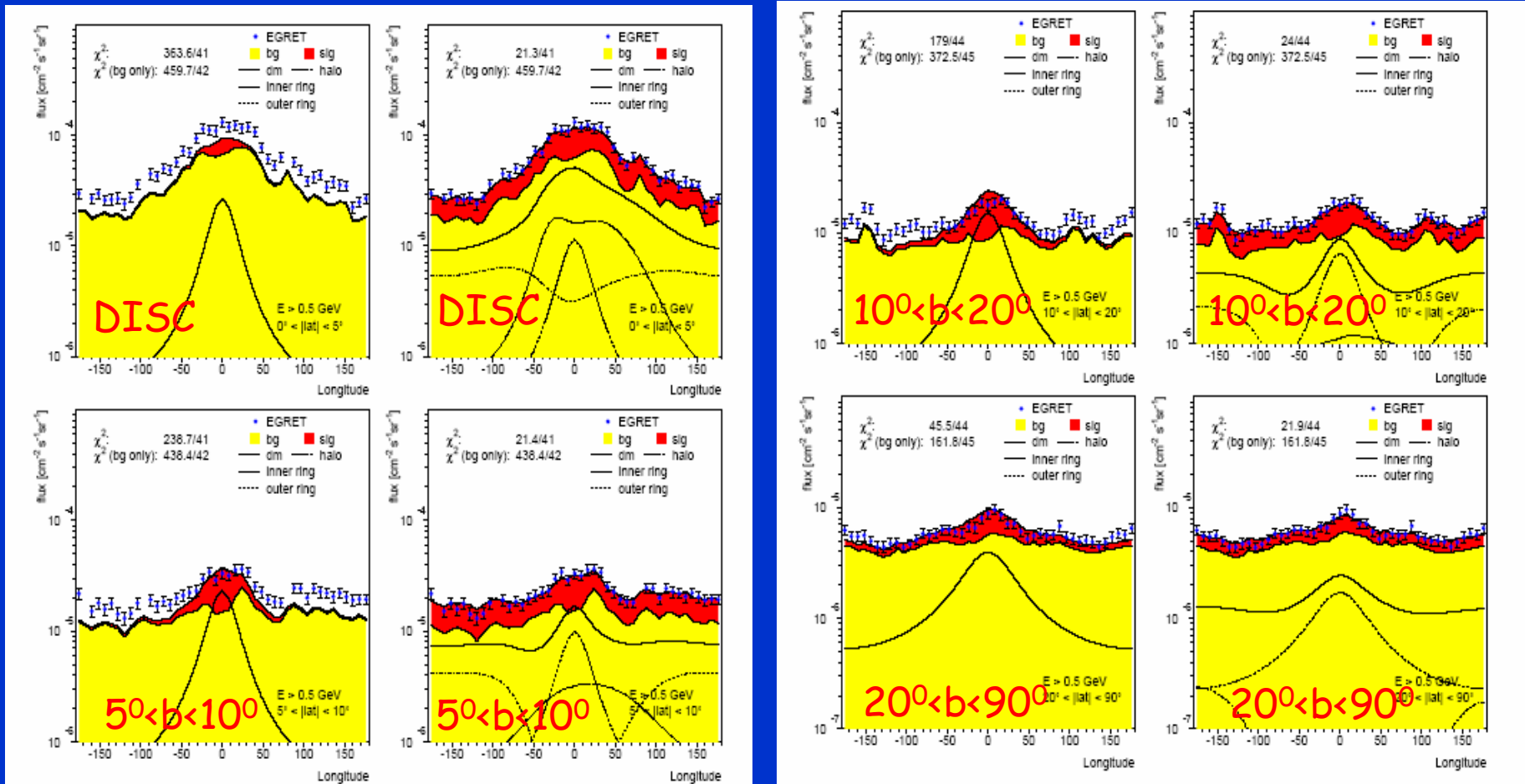### WITH rings

Longitude fits for isothermal (cored) profile

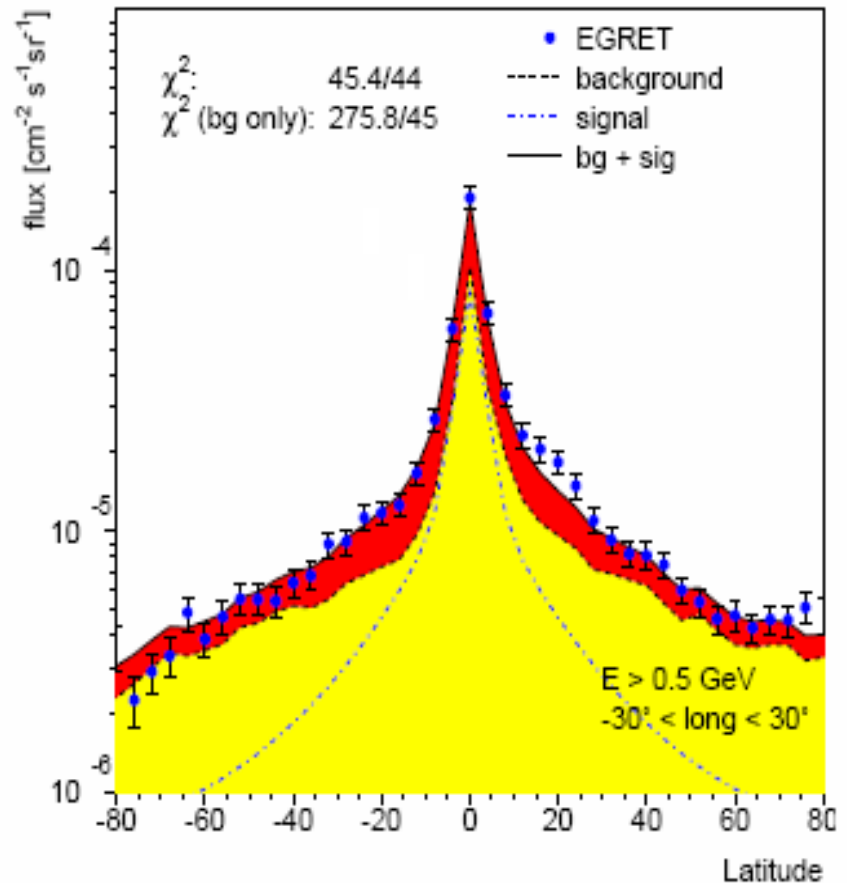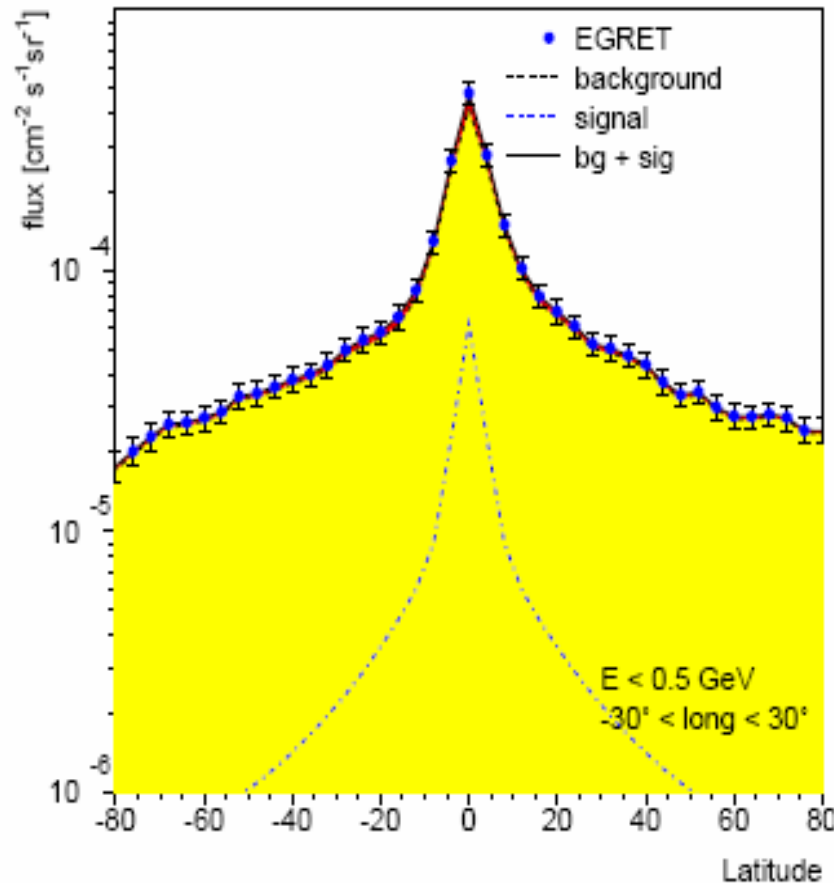**WITHOUT rings** **WITH 2 rings** **WITHOUT rings** **WITH 2 rings**

Halo parameters from fit to 180 sky directions: 4 long. profiles for latitudes <5⁰, 5⁰<b<10⁰, 10⁰<b<20⁰, 20⁰<b<90⁰ (=4x45=180 directions)
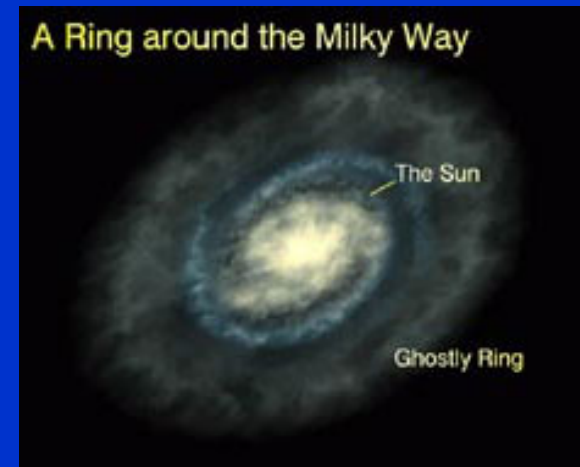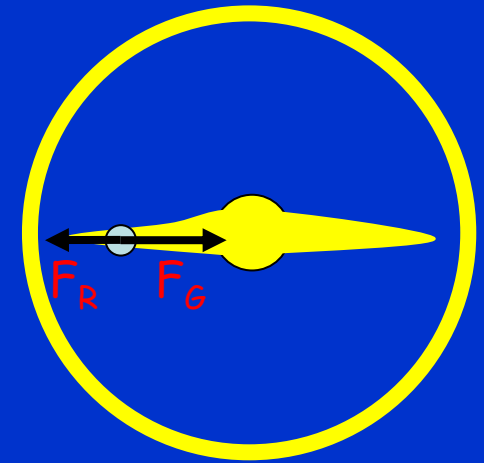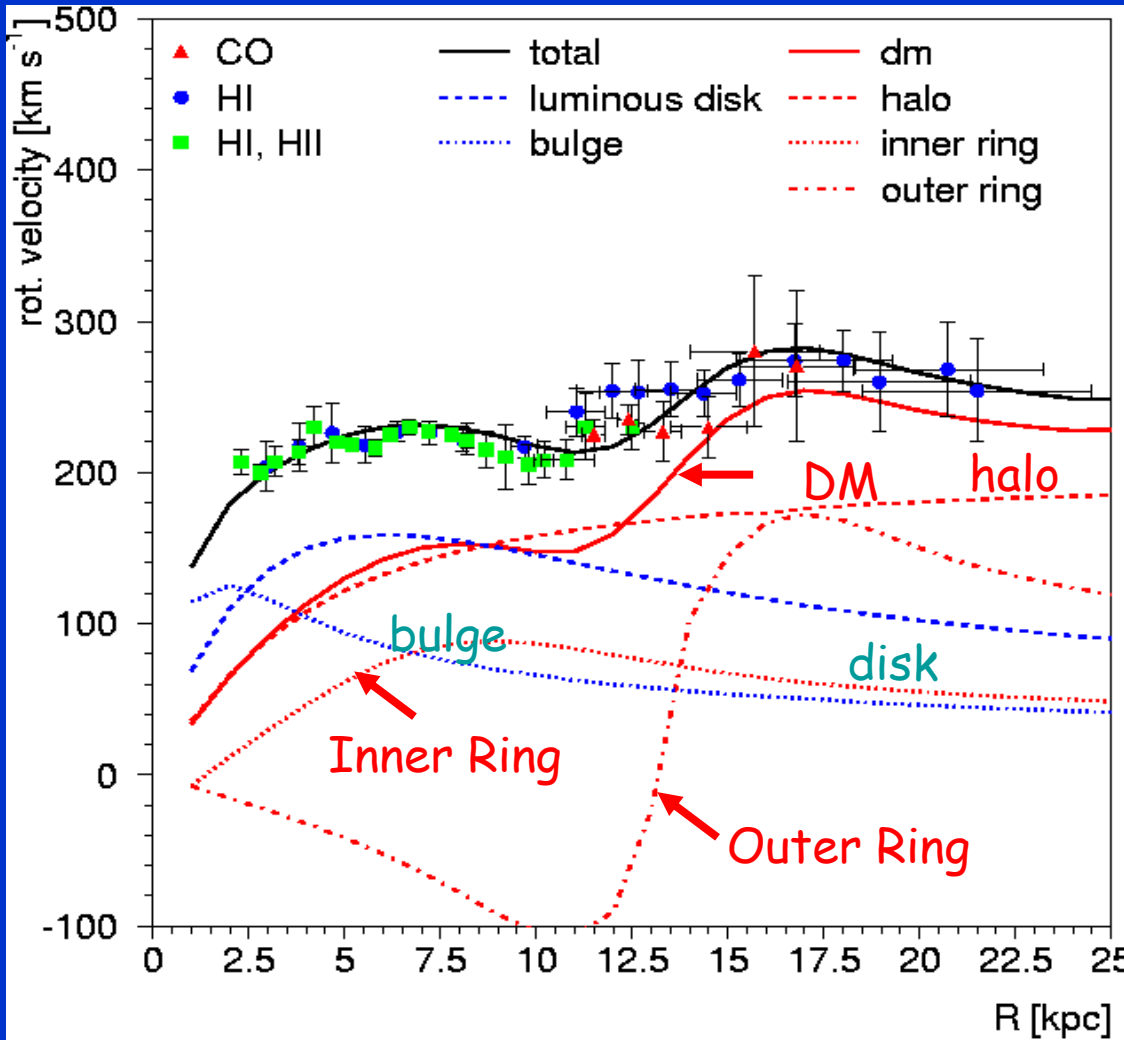
Latitude fits for isoth. Profile with |long|<30⁰

0.1 < Eγ < 0.5 GeV
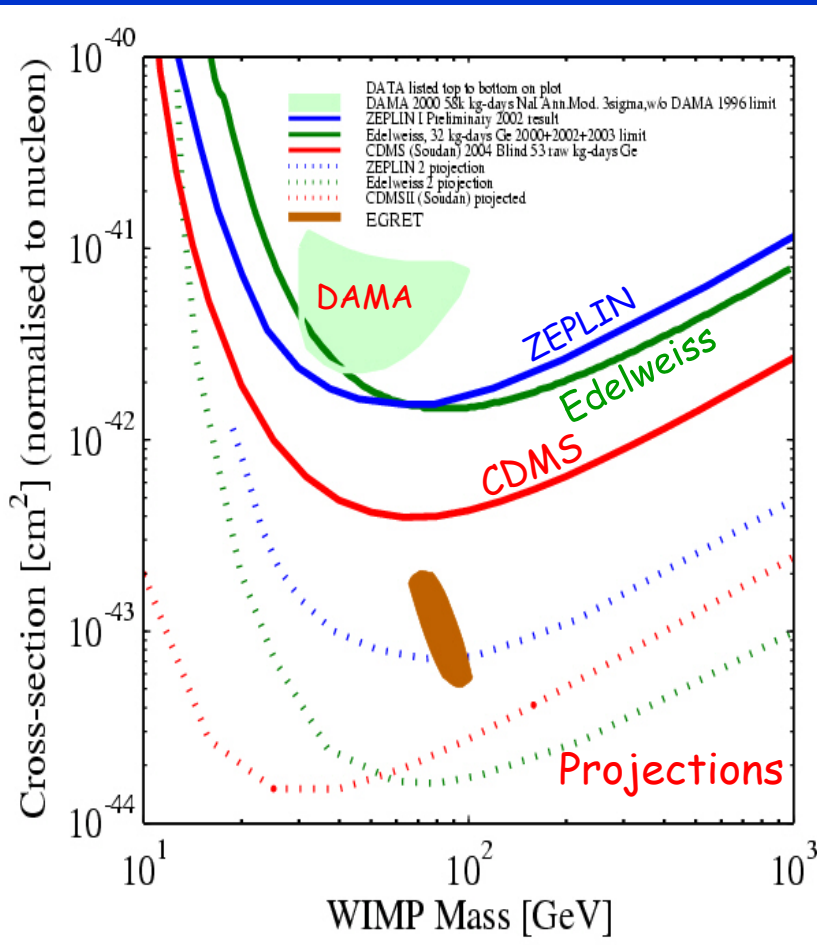
Eγ > 0.5 GeV

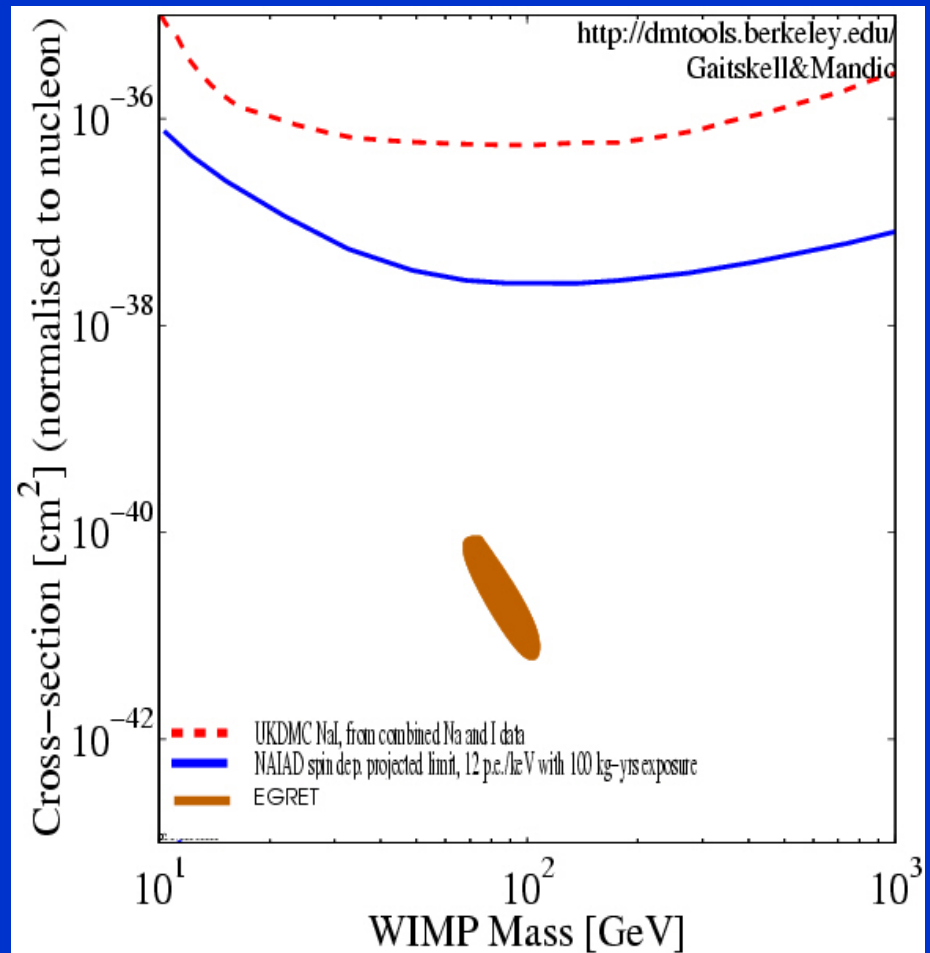# Rotation curve of our galaxy

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

Comparison with direct DM Searches

Spin-independent

Spin-dependent

Predictions from EGRET data assuming Supersymmetry

Summary

EGRET excess shows all key features from DM annihilation:

Excess has same shape in all sky directions: everywhere it is perfectly (only?) explainable with superposition of background AND mono-energetic quarks of 50-100 GeV Results in perfect agreement with SUPERSYMMETRY

Excess follows expectations from galaxy formation: $1/r^2$ profile with substructure, visible matter/DM$\approx$0.02

Excess connected to MASS, since it can explain peculiar shape of rotation curve

These combined features provide FIRST ($>10\sigma$) EVIDENCE that DM is not so dark and follow ALL DMA expectations imagined so far.

Conventional models CANNOT explain above points SIMULTANEOUSLY, especially spectrum of gamma rays in all directions, shape of rotation curve, stability of ring of stars at 14 kpc,..

EGRET galactic gamma ray data provides intriguing hint that – since WIMP has properties of a spin ½ photon –

DM is the Supersymmetric Partner of the CMB