SUSY interpretation of the EGRET excess of diffuse Galactic gamma rays and implementation for the LHC

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A&A 444 (2005)17
PL B636 (2006)13
PRL 95 (2005) 209001

Outline

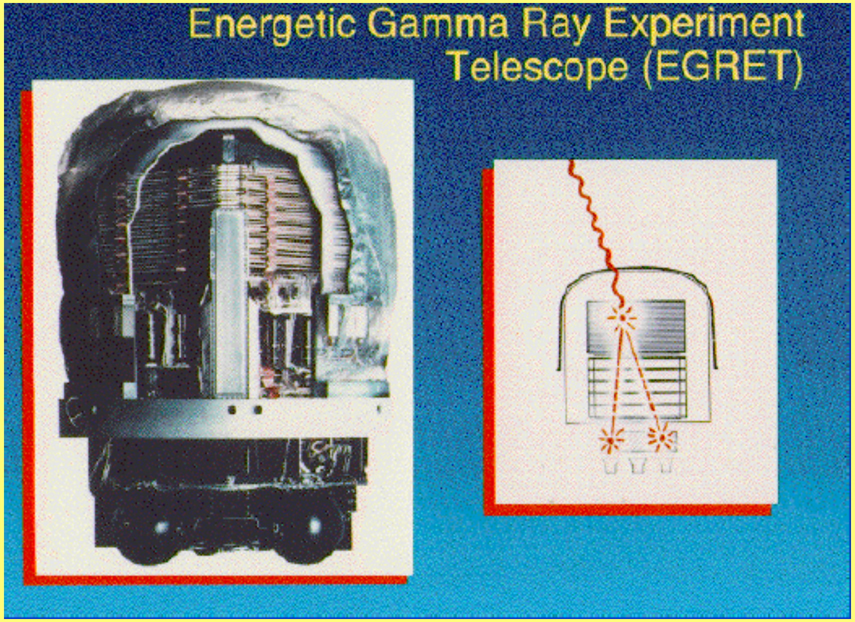
- Diffuse Galactic γ Rays from EGRET
- Reconstruction of the Halo profile
- DM annihilation in the MSSM
- Restriction to SUSY Parameter Space
- SUSY Production at LHC in EGRET Region
- Conclusions

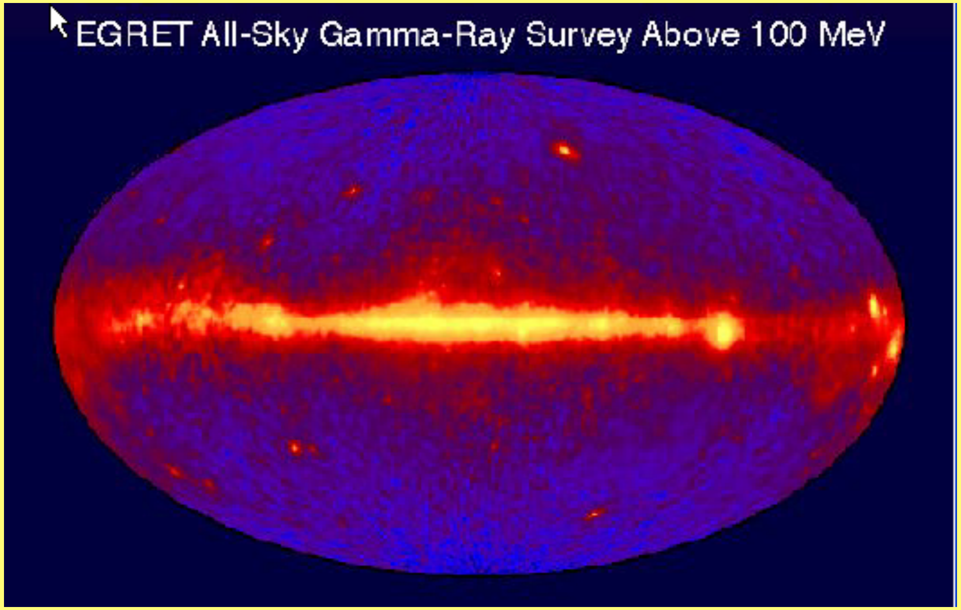
THE AIM

To explore the possibility that we might have already observed the DM annihilation in Galactic halo and to see which consequences it might have

- **<u>optimistic</u> attitude: to find the mass of a WIMP and its spatial distribution**
- **<u>pessimistic</u> attitude: to sink all this in uncertainties and error bars**

DIFFUSE GAMMA RAYS FROM THE SKY





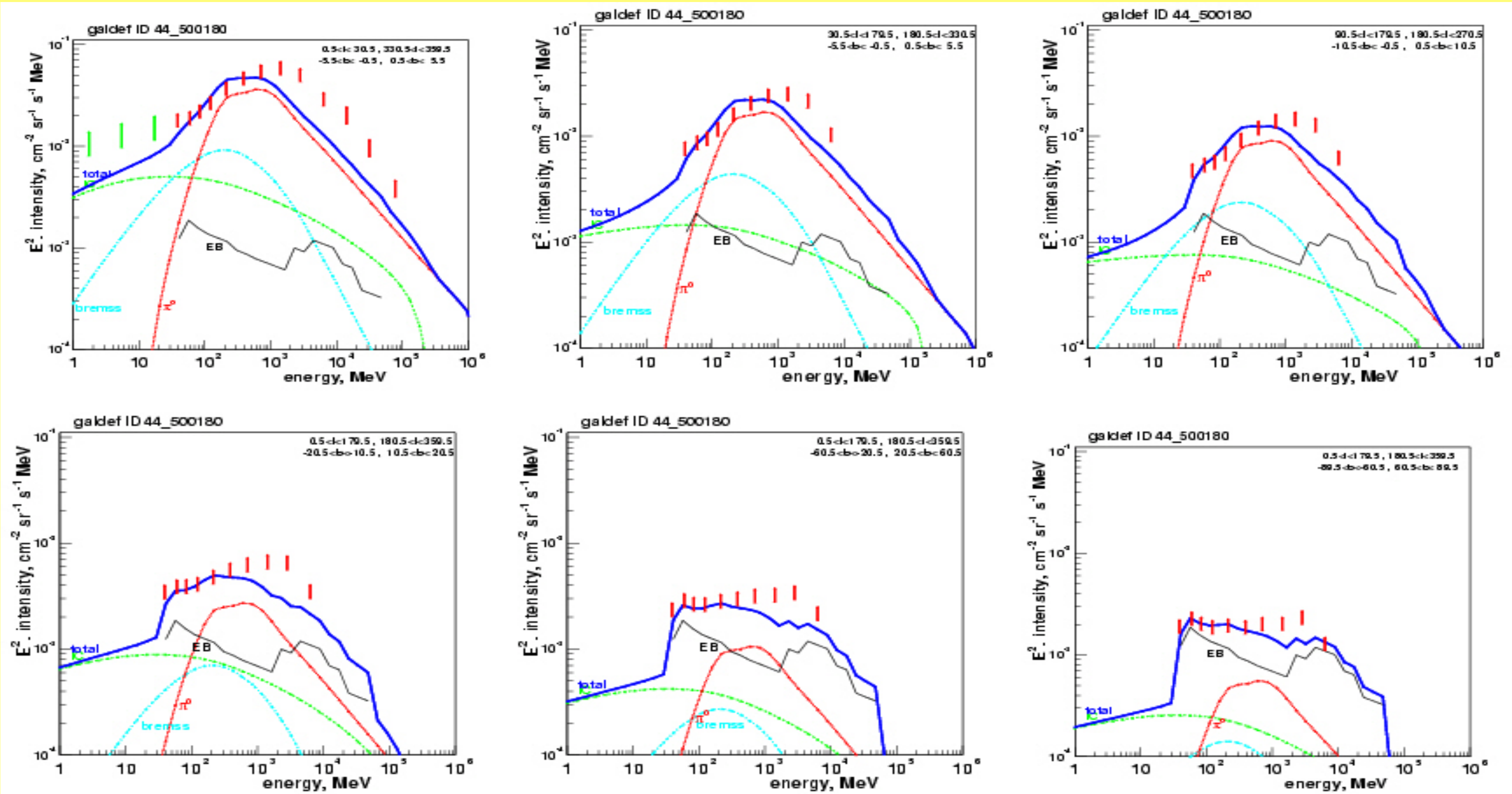
Instrumental parameters:

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

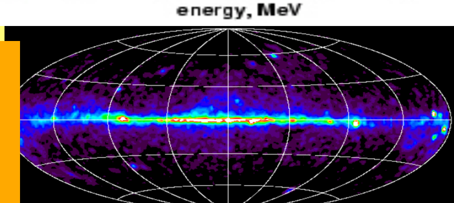
Data taking: 1991-2000

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

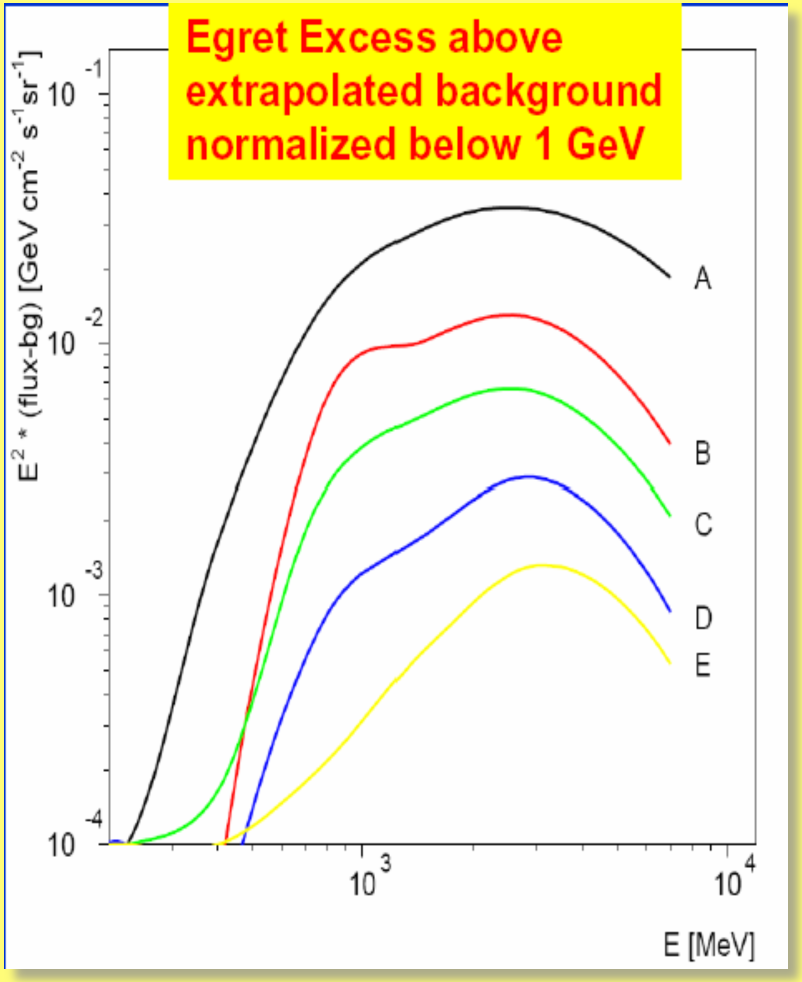
EXCESS OF DIFFUSE GAMMAY RAYS ABOVE 1 GEV

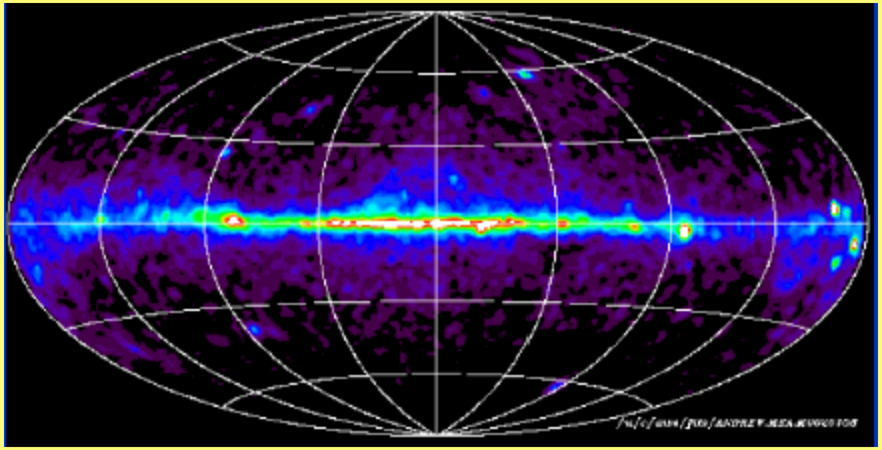


A: inner Galaxy (l=±30^0, |b|<5^0)
B: Galactic plane avoiding A
C: Outer Galaxy
D: low latitude (10-20^0)
E: intermediate lat. (20-60^0)
F: Galactic poles (60-90^0)



DIFFUSE GAMMA RAYS IN EGRET ENERGY RANGE





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

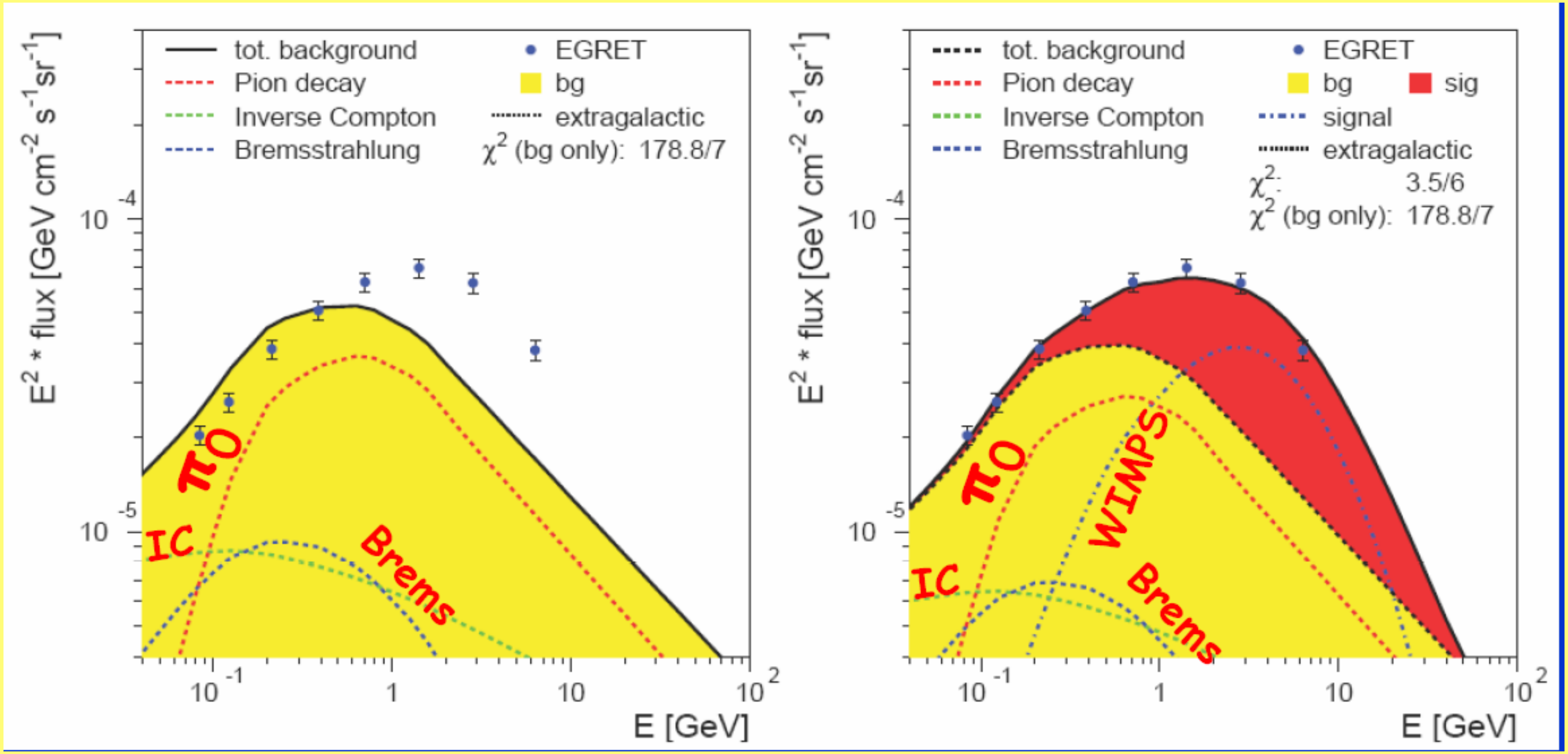
PHYSICS PROBLEMS

- What is the origin of excess of diffuse Galactic Gamma Rays?
- What is Cold Dark Matter made of?
- Where are the Supersymmetric Particles?

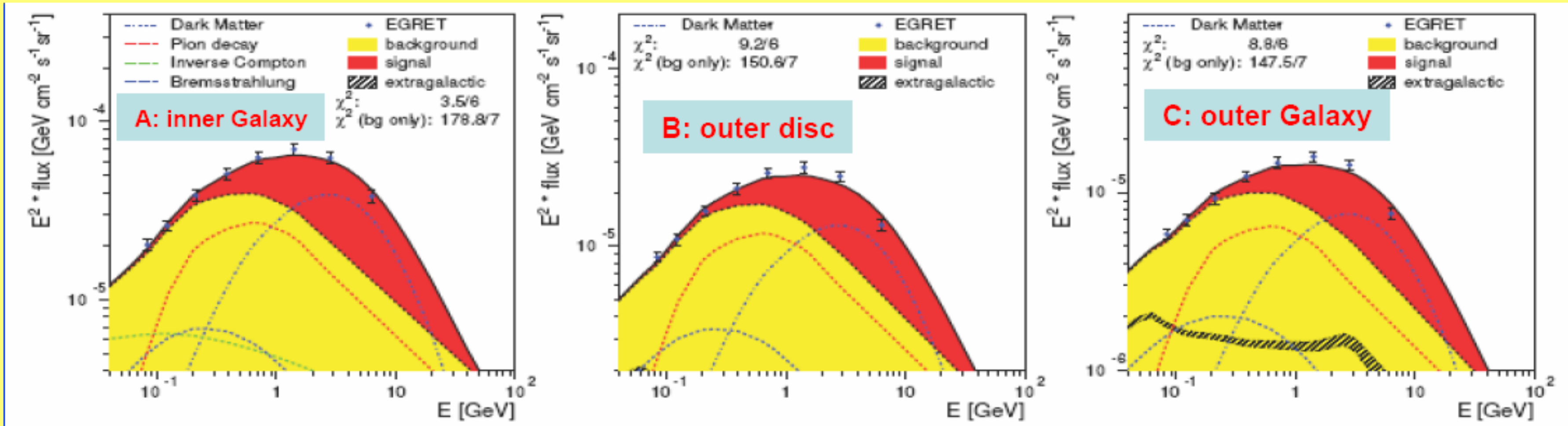
Solution:

- EGRET excess is due to DM annihilation
- DM is made of WIMPs which are SUSY particles distributed in Halo of our Galaxy
- SUSY Neutralinos have a mass around 60 GeV and should be produced at the LHC

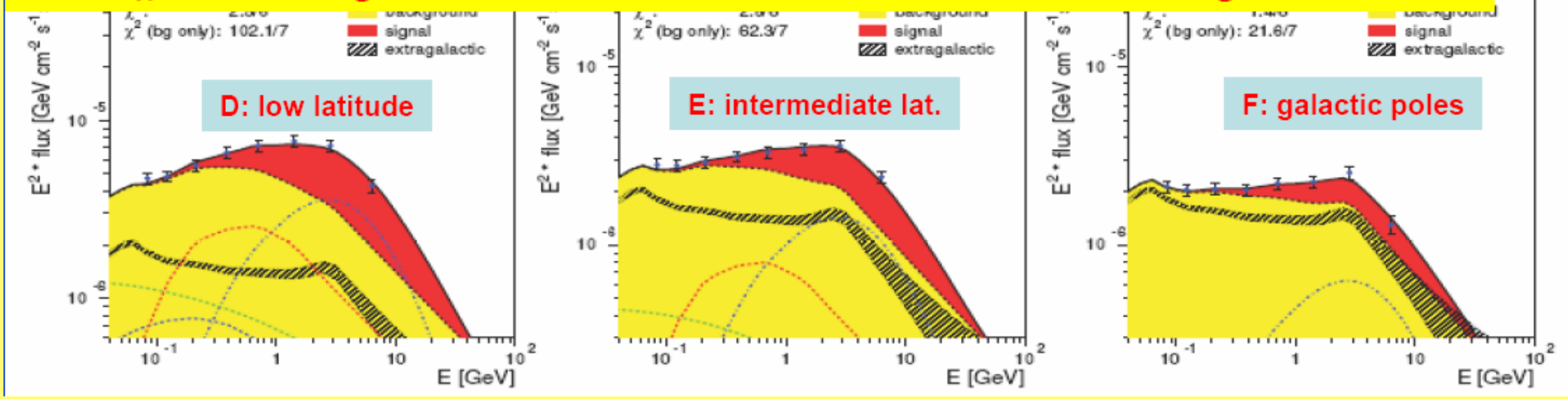
EXCESS OF DIFFUSE GAMMAY RAYS WITH AND WITHOUT DM ANNIHILATION



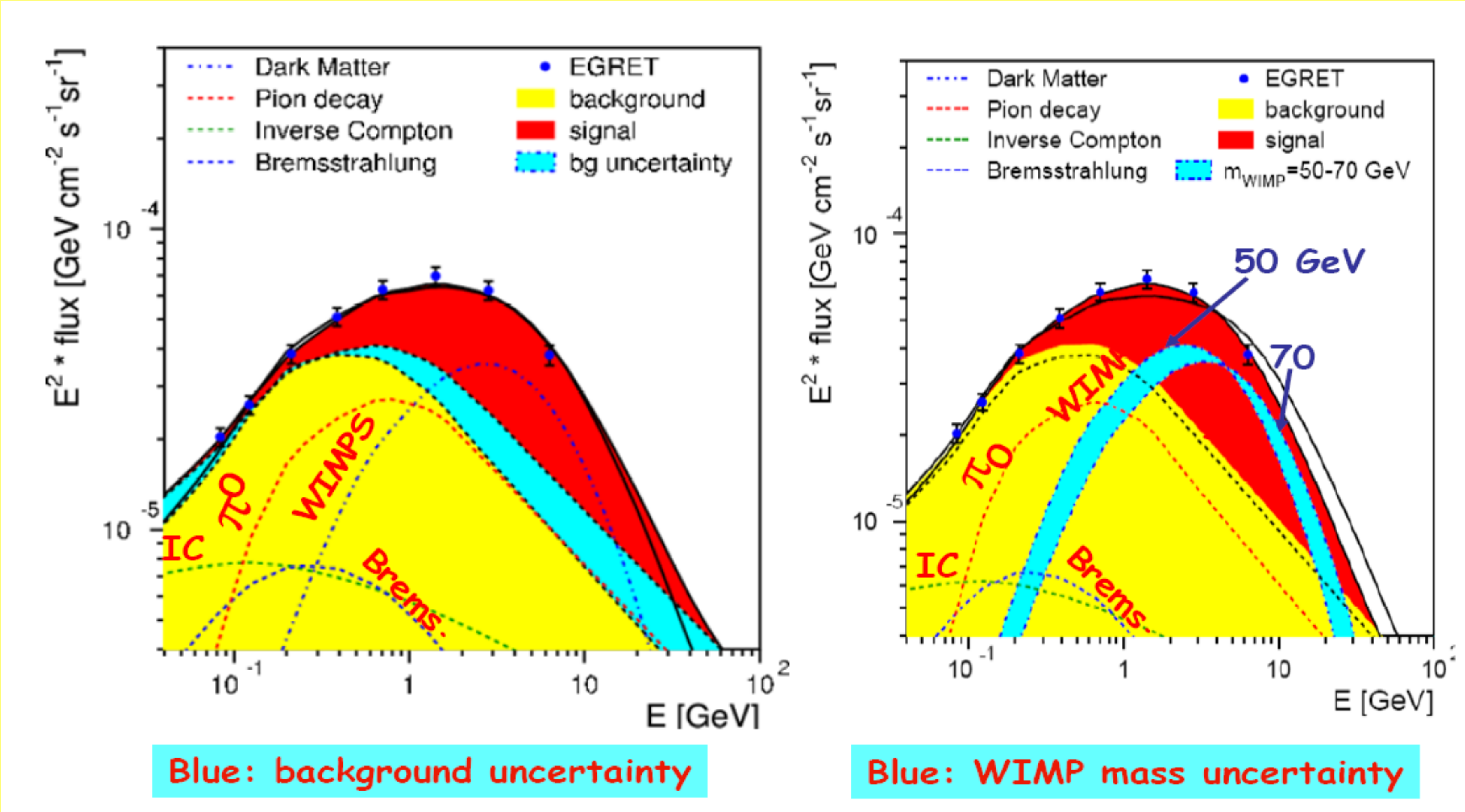
ANALYSIS OF EGRET DATA IN 6 SKY DIRECTIONS



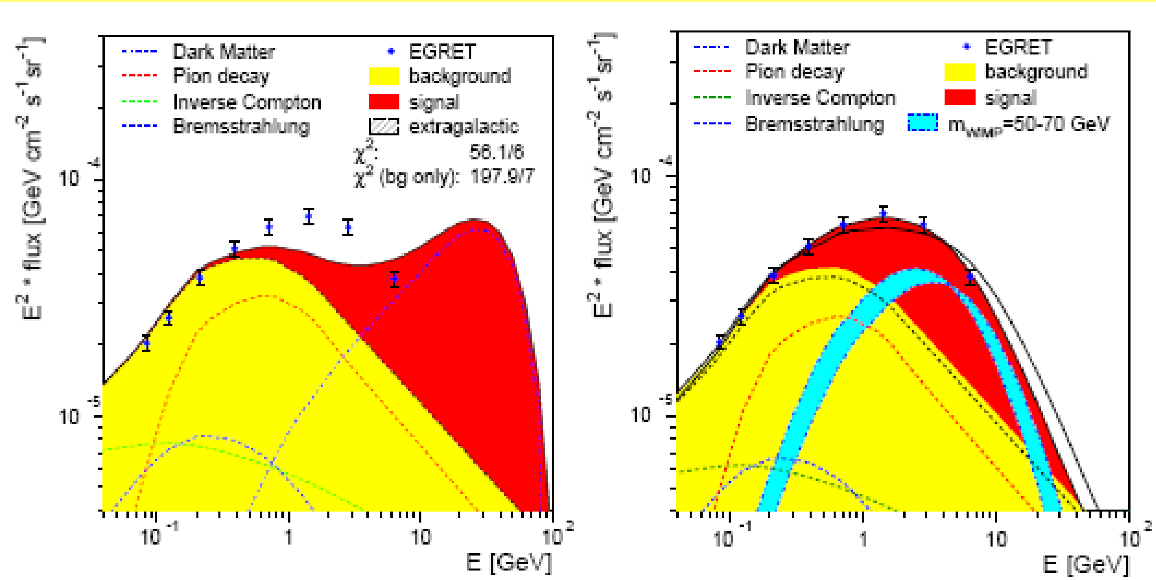
Total χ^2 for all regions :28/36 $\Rightarrow$ Prob.= 0.8 Excess above background > 10σ.

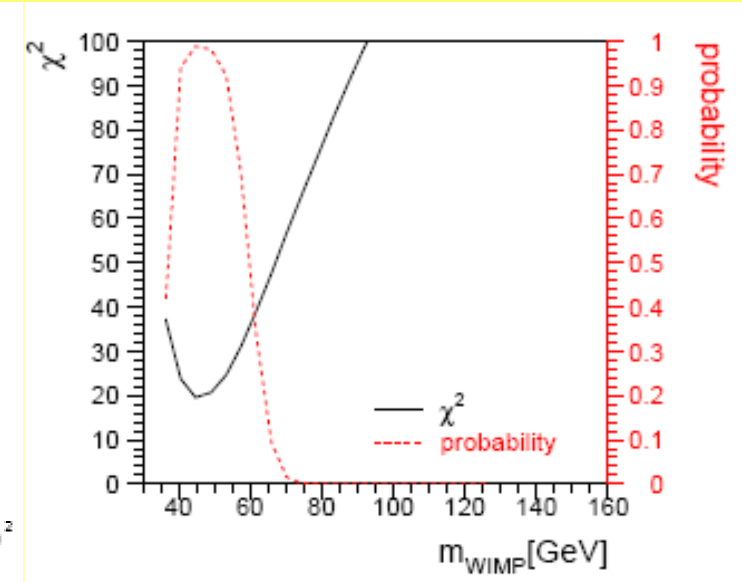


BACKGROUND + SIGNAL DESCRIBE EGRET DATA



FIT TO WIMP MASS

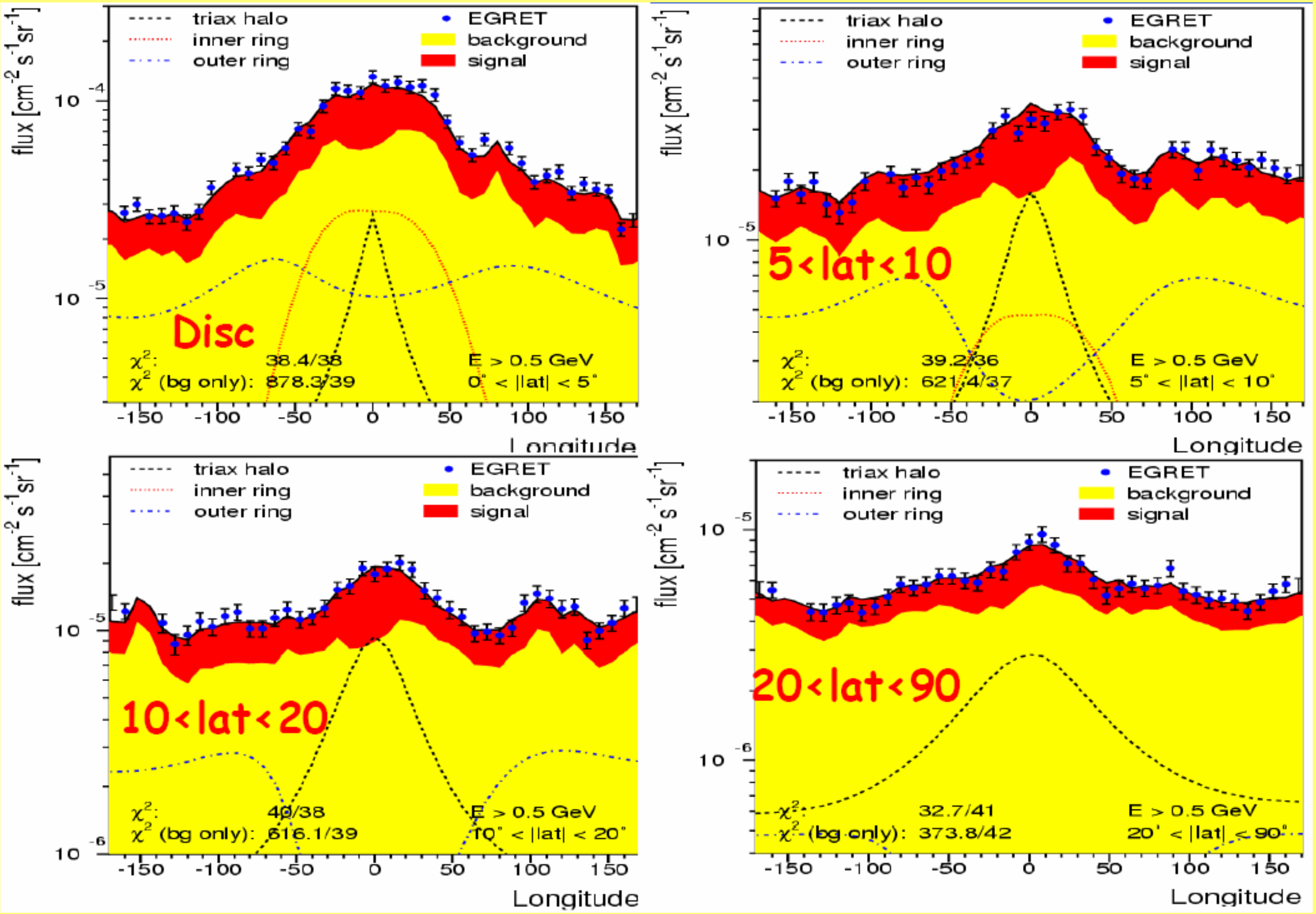




Heavy neutralino M_χ ~ 50-80 GeV

Heavy WIMP is excluded

DIFFUSE GAMMA RAYS IN EGRET ENERGY RANGE



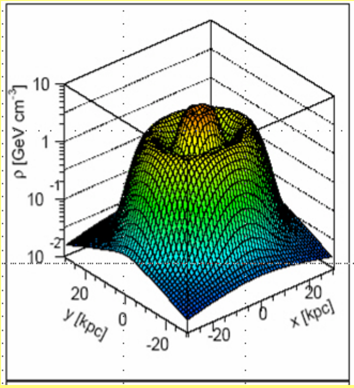
FITTED HALO PARAMETERS

Gamma Ray Flux: (<σv> from WMAP)

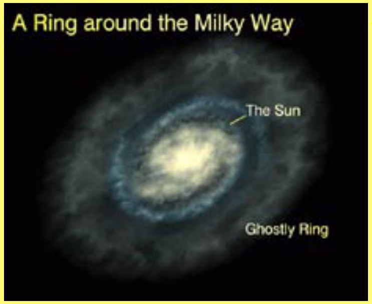
$$\phi_\chi(E,\psi) = \frac{\langle\sigma v\rangle}{4\pi}\sum_f \frac{dN_f}{dE} b_f \int_{line\ of\ sight} B_l \frac{1}{2}\frac{\langle\rho_\chi^2\rangle}{M_\chi^2} dl_\psi$$

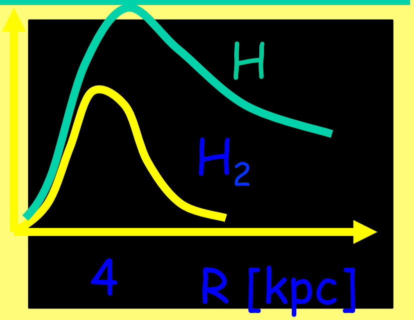
$$\rho_\chi(\tilde{r}) = \rho_0 \left(\frac{R_0}{\tilde{r}}\right)^\gamma \left[\frac{1+\left(\frac{\tilde{r}}{a}\right)^\alpha}{1+\left(\frac{R_0}{a}\right)^\alpha}\right]^{\frac{\gamma-\beta}{\alpha}} + \sum_{n=1}^{N} \rho_n \exp\left(-\frac{(\tilde{r}_{gc}-Rn)^2}{2\sigma_{Rn}^2} - \frac{(z_n)^2}{2\sigma_{z_n}^2}\right)$$

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

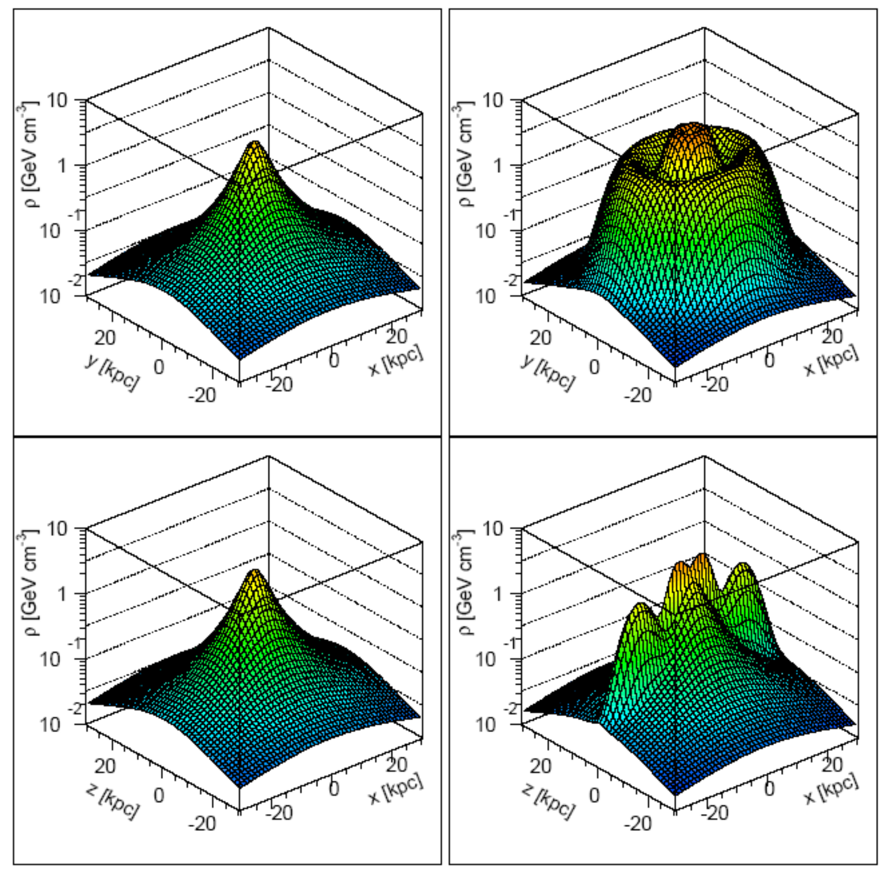




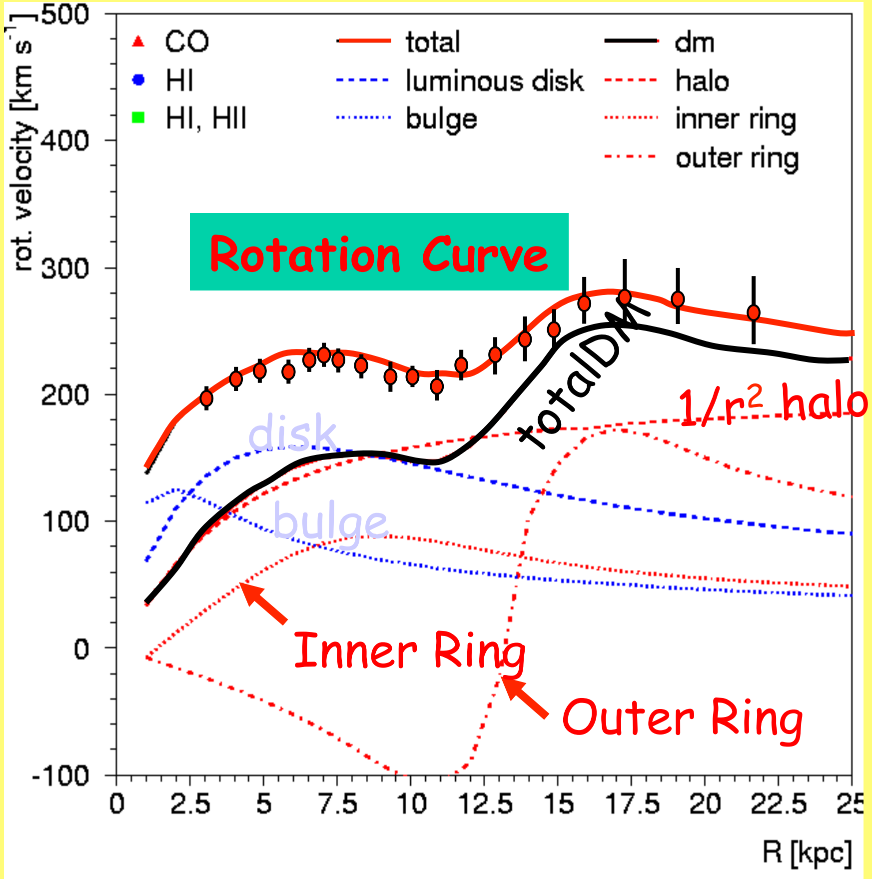
14 kpc coincides with ring of stars at 14-18 kpc due to infall of dwarf galaxy

4 kpc coincides with ring of neutral hydrogen molecules!

HALO PROFILE AND ROTATION CURVE

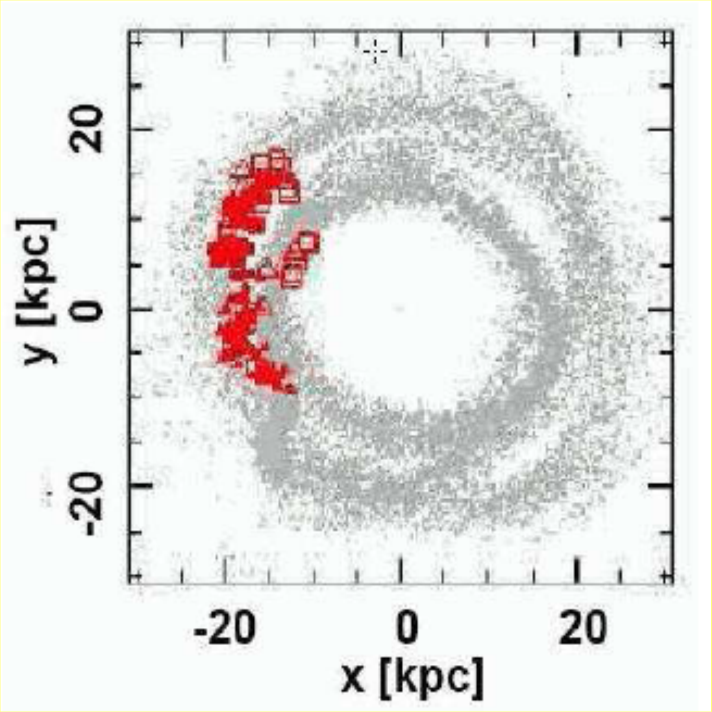


Halo profile with rings of DM

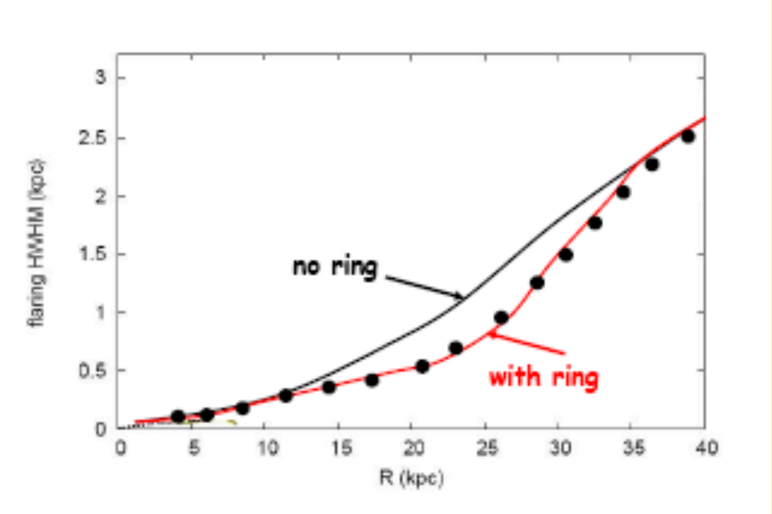


Rotation curve of the Milky Way

SUPPORT FOR THE RUNG 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



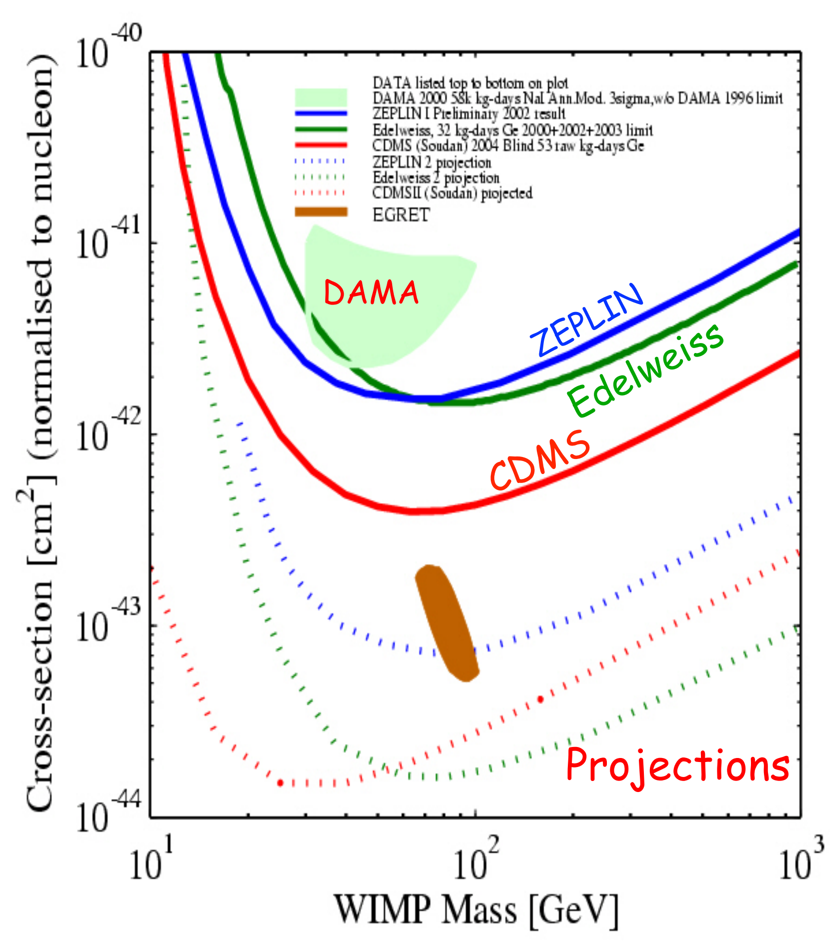
The gas layer of the Galactic Disk as function of the distance from the Galactic center.

OPEN PROBLEMS & POSSIBLE ANSWERS

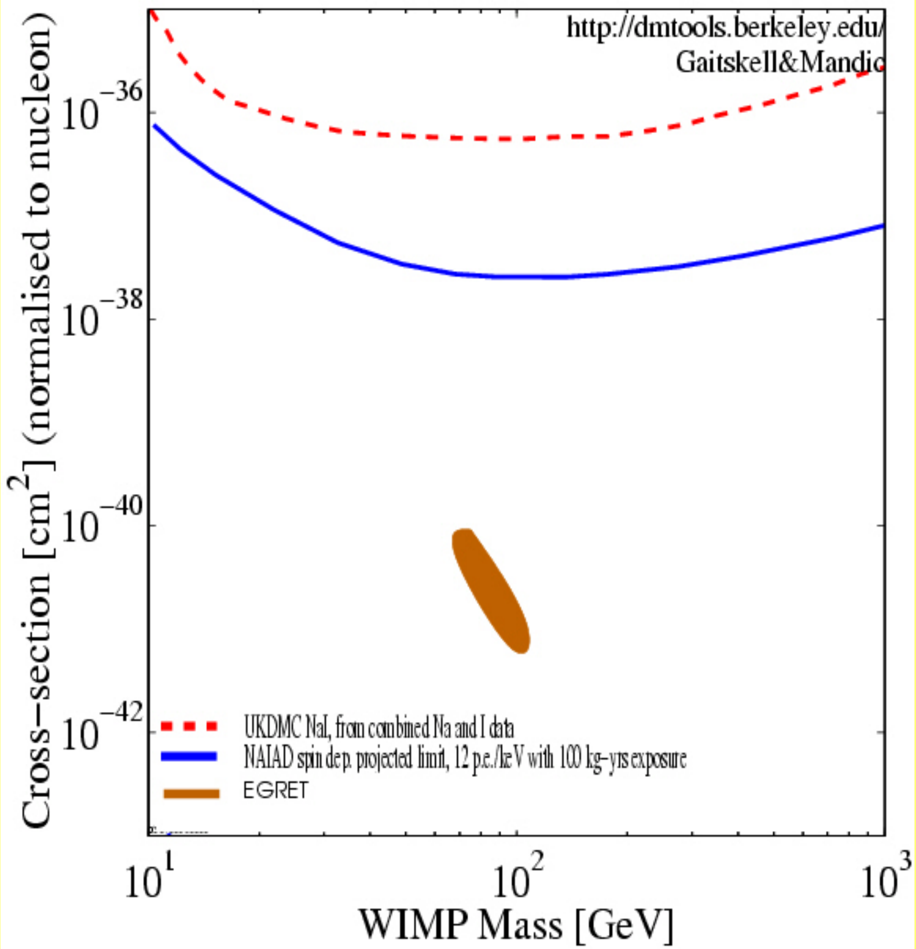
- The Origin of Rings: merge with dwarf galaxy
- Absolute flux boosting: clumpiness of DM
- Excess in Charged particle spectrum (positrons, antiprotons): galactic magnetic fields
- Direct DM search: x-section + flux

DIRECT DM SEARCHES

Spin-independent



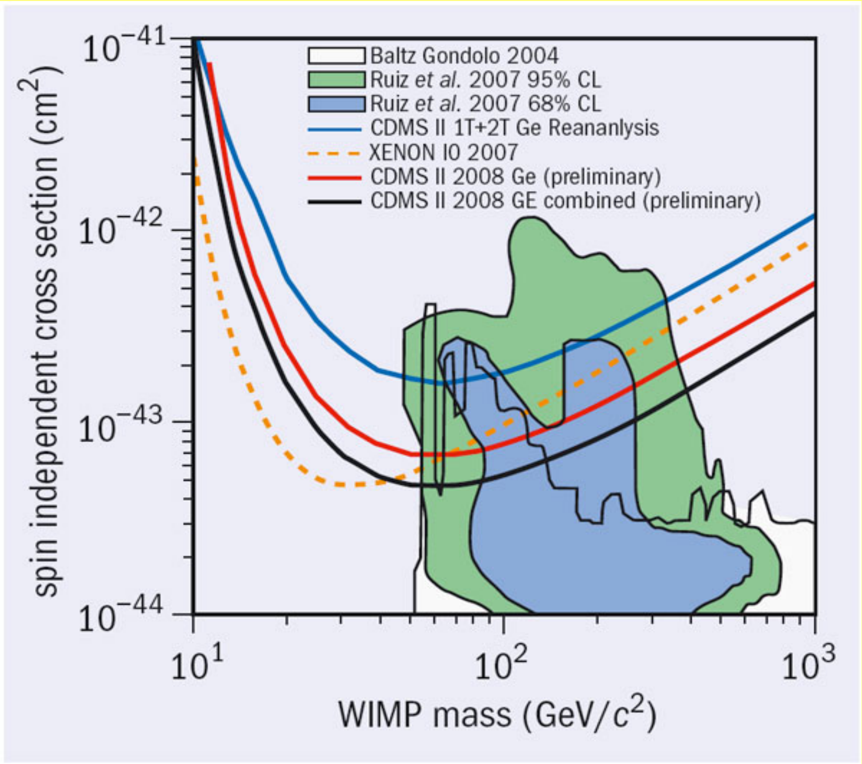
Spin-dependent



Predictions from EGRET data assuming Supersymmetry

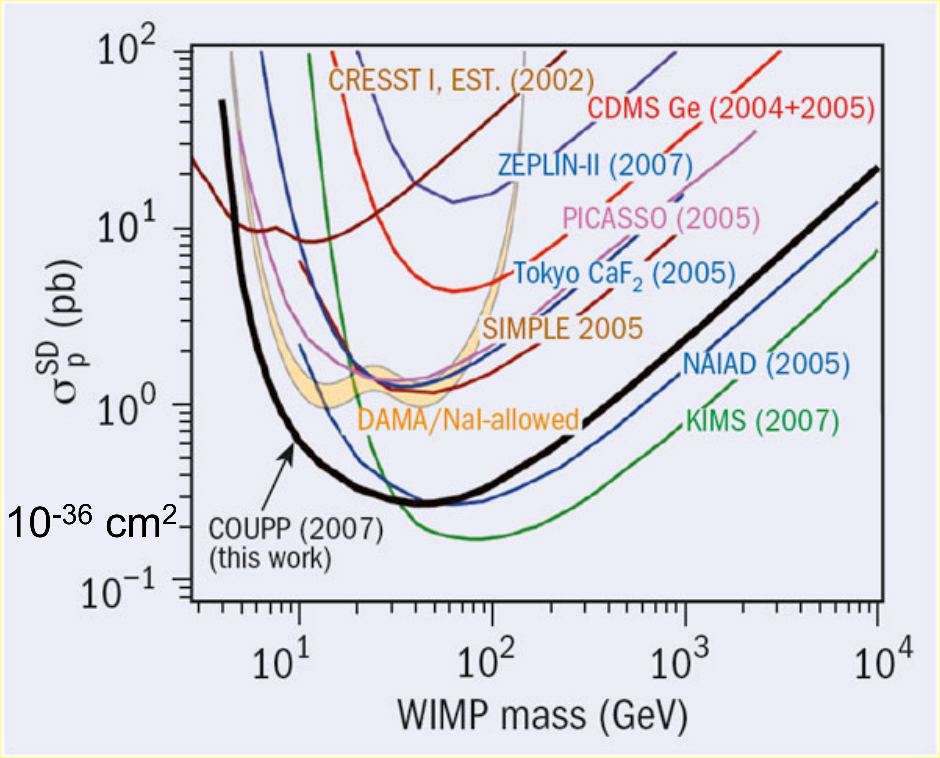
Recent Results on Direct Detection

Spin Independent



The Chicagoland Observatory for Underground Particle Physics (COUPP)

Spin Dependent



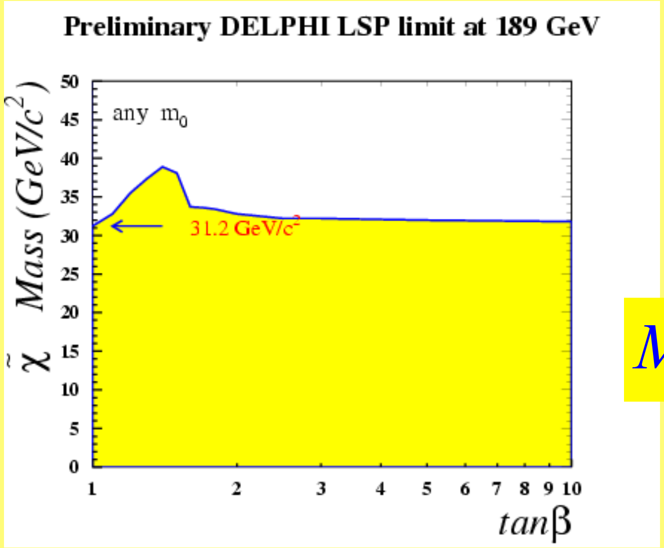
Cryogenic Dark Matter Search (CDMS)

SUSY DARK MATTER

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

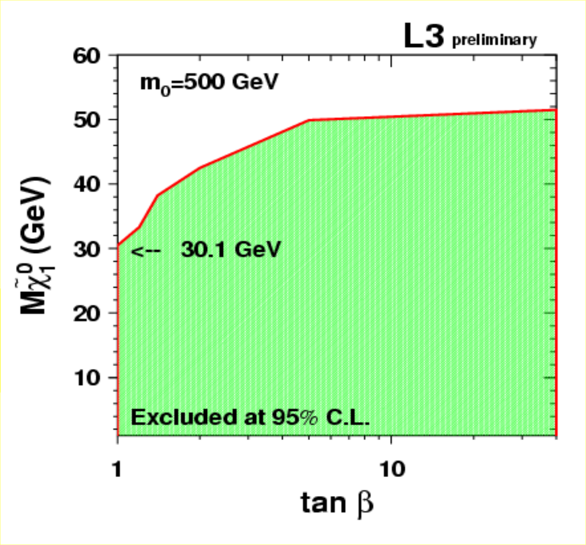
$$\tilde{\chi}^0 = N_1 \tilde{\gamma} + N_2 \tilde{z} + N_3 \tilde{H}_1^0 + N_4 \tilde{H}_2^0$$

photino zino higgsino higgsino



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

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

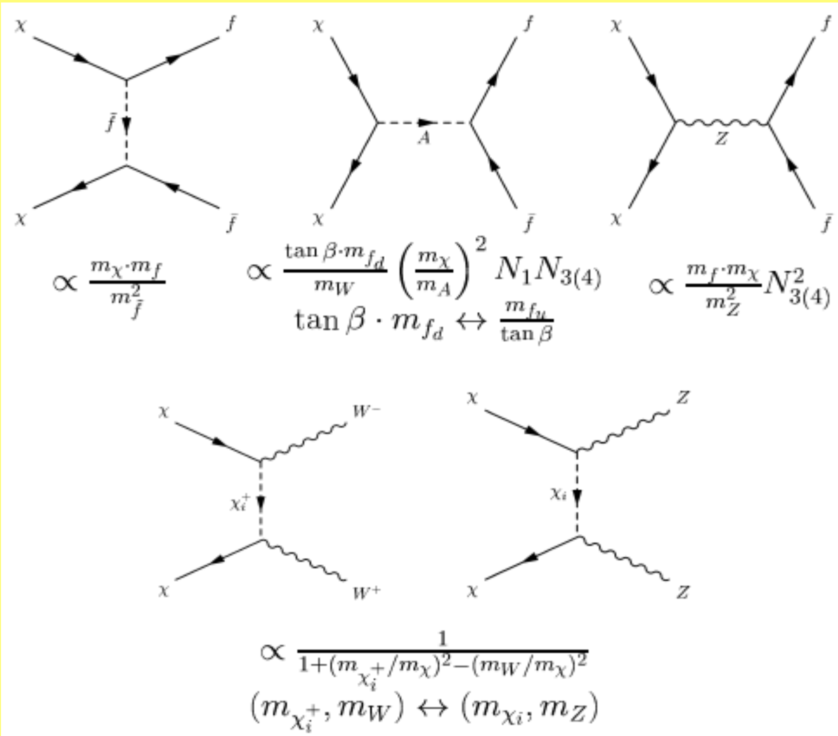


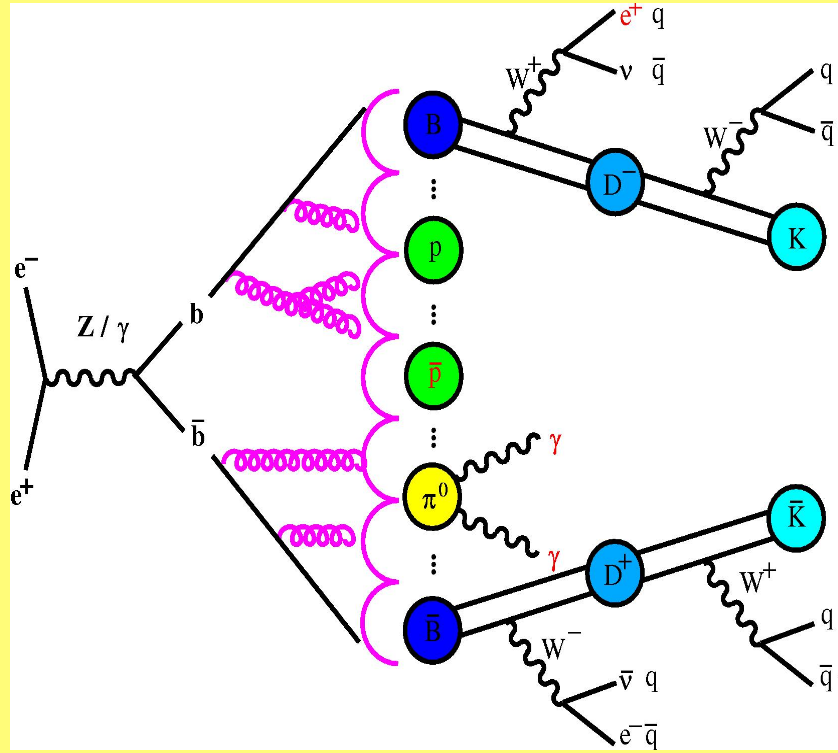
$$R = (-1)^{3(B-L)+2S}$$

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

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

DM NEUTRALINO ANNIHILATION FINAL STATES



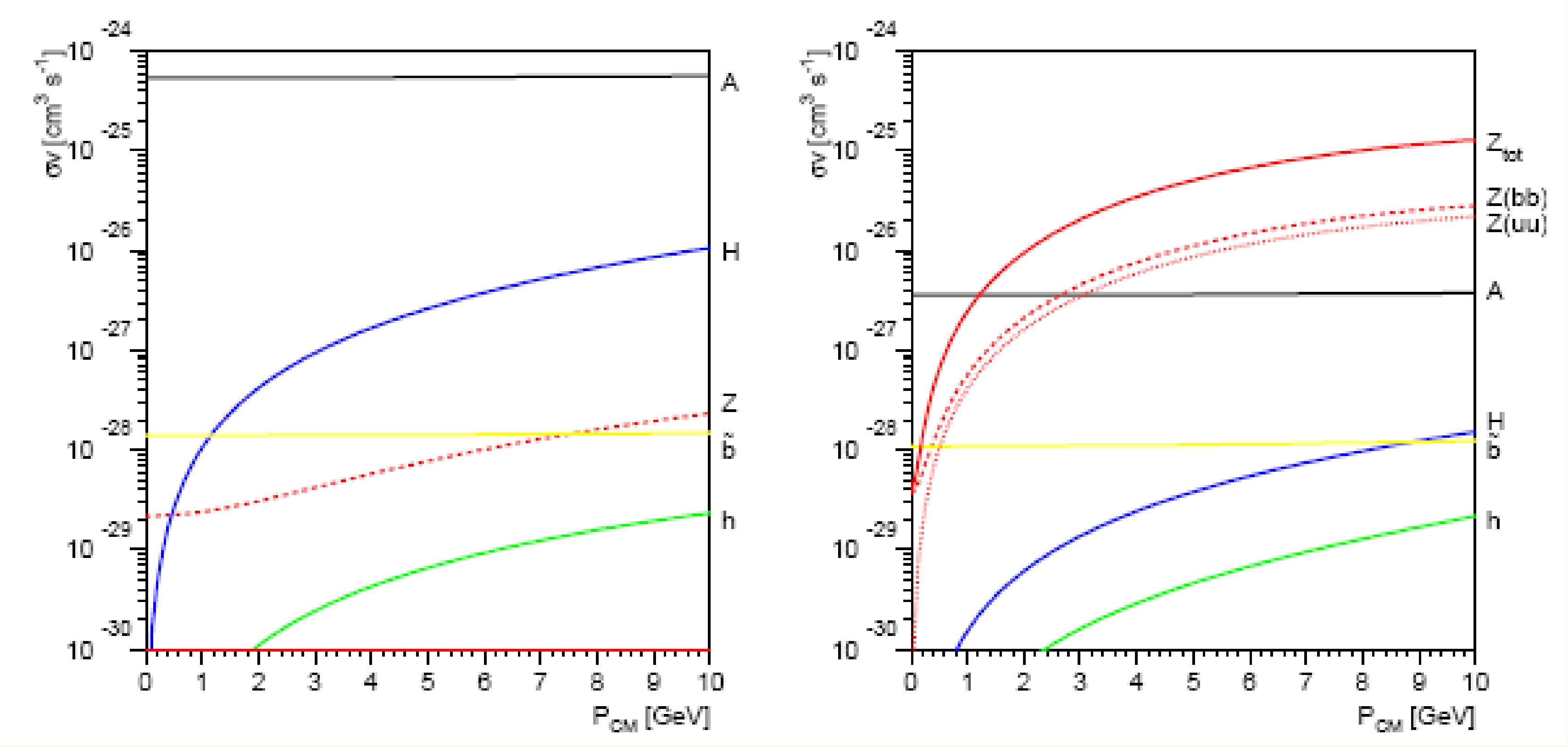


Dominant annihilation x-section:
$\chi + \chi \rightarrow A \rightarrow b\bar{b}$ quark pair

Sum of diagrams should yield $\langle\sigma v\rangle = 2.10^{-26}$ cm^3/s to get correct relic density

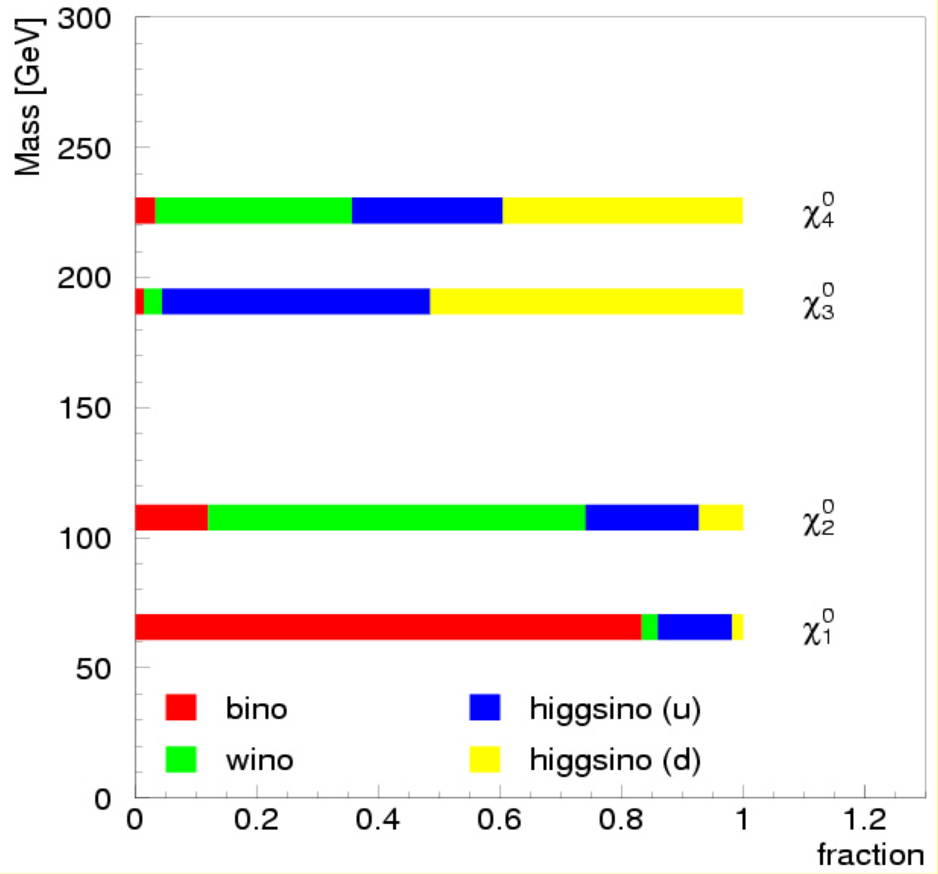
B-fragmentation well studied at LEP! Yield and spectra of positrons, gammas and antiprotons well known!

DM NEUTRALINO ANNIHILATION CROSS-SECTION



Dominant annihilation x-section:
χ + χ → A → bb quark pair

GAUGINO CONTENT OF THE LIGHTEST NEUTRALINO

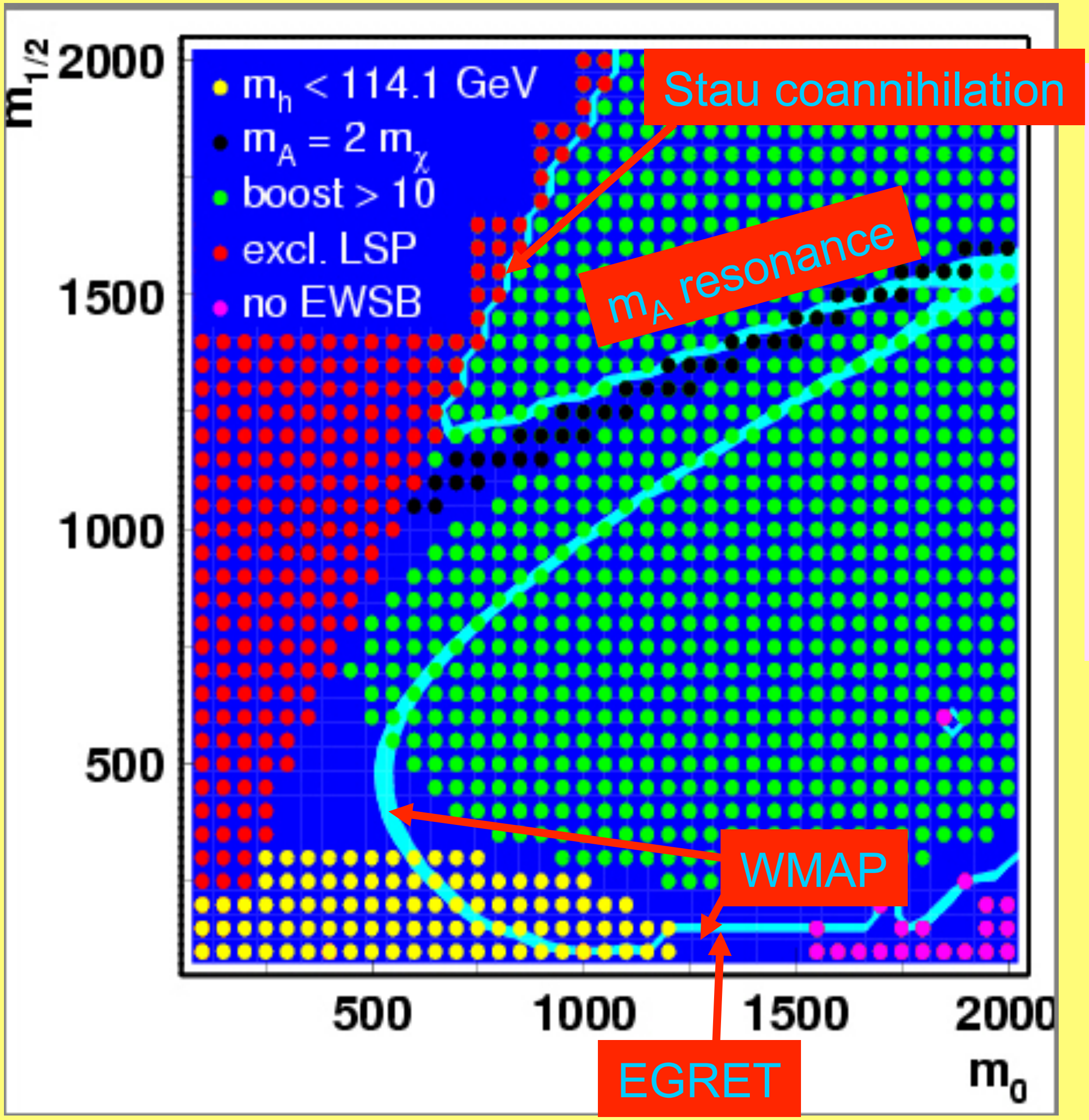


	$\tilde{b}^0$	$\tilde{w}^0$	$\tilde{h}_1^0$	$\tilde{h}_2^0$
$\tilde{\chi}_1^0$	0.833	0.026	0.122	0.018
$\tilde{\chi}_2^0$	0.119	0.621	0.187	0.072
$\tilde{\chi}_3^0$	0.014	0.030	0.442	0.515
$\tilde{\chi}_4^0$	0.033	0.323	0.249	0.395

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

DM = superpartner of the CMB

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)

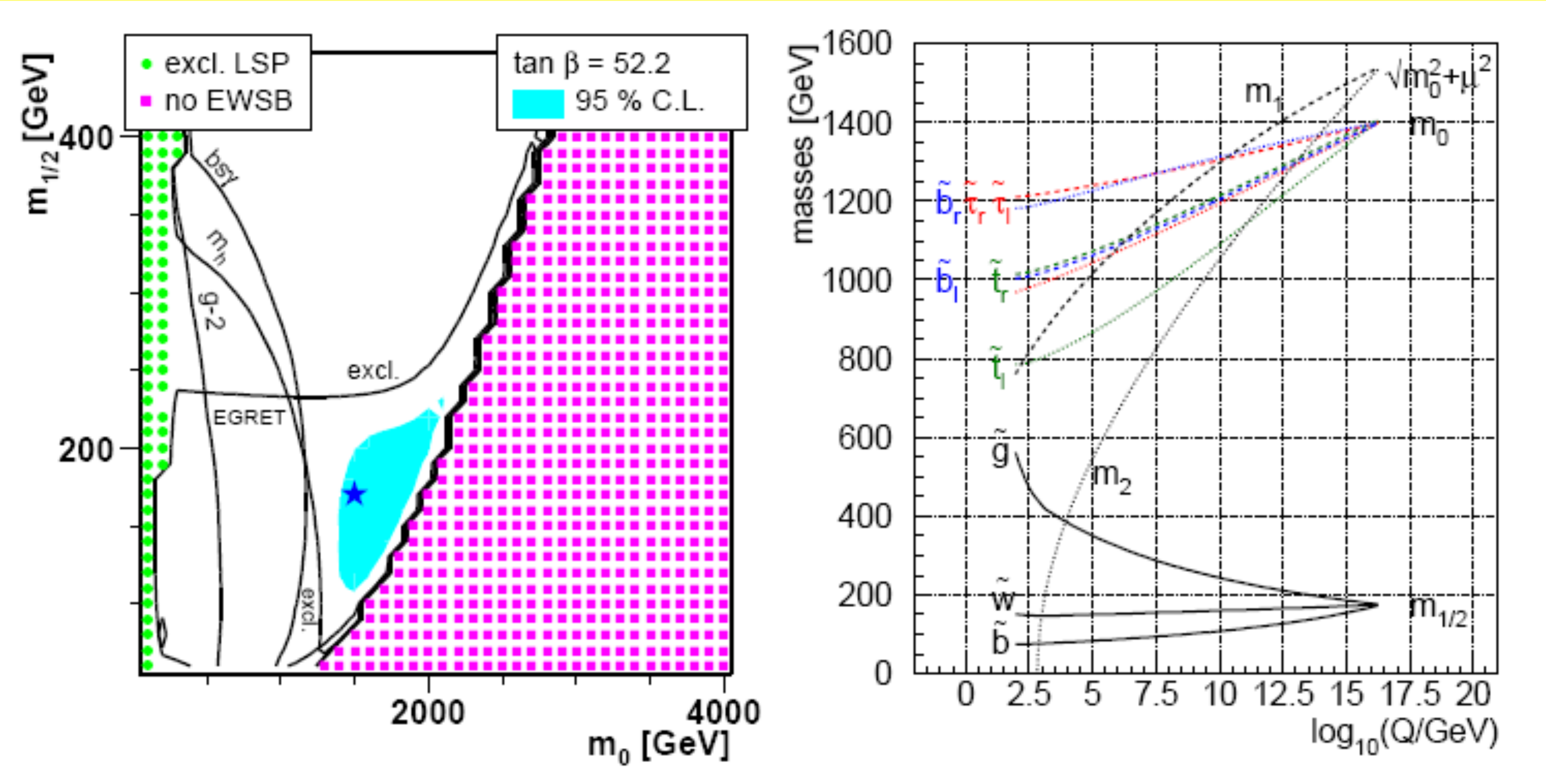
m_0 common spin 0 mass

$m_{1/2}$ common spin ½ mass

$\tan\beta = v_2/v_1$

High tanβ solution
$\tan\beta = 50$

EGRET POINT AND MASS SPECTRUM



SUSY MASS SPECTRUM

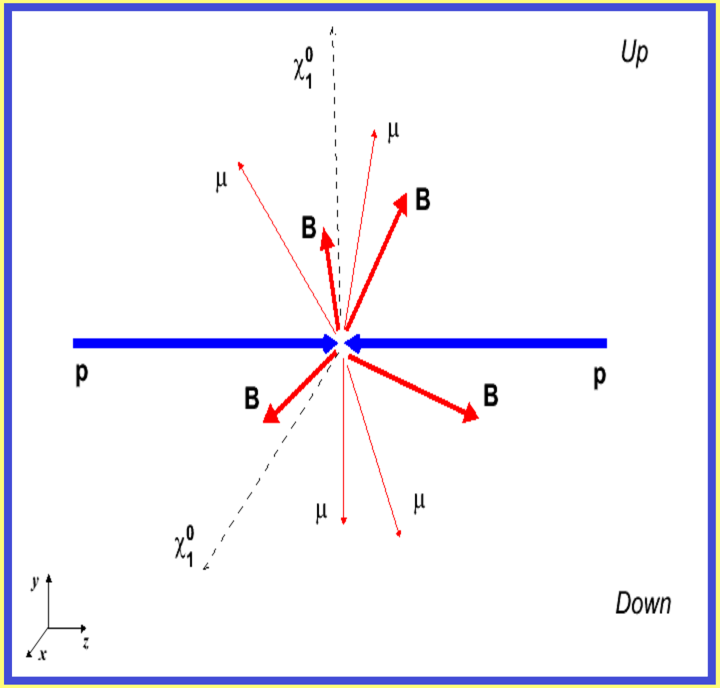
Fitted SUSY Parameters

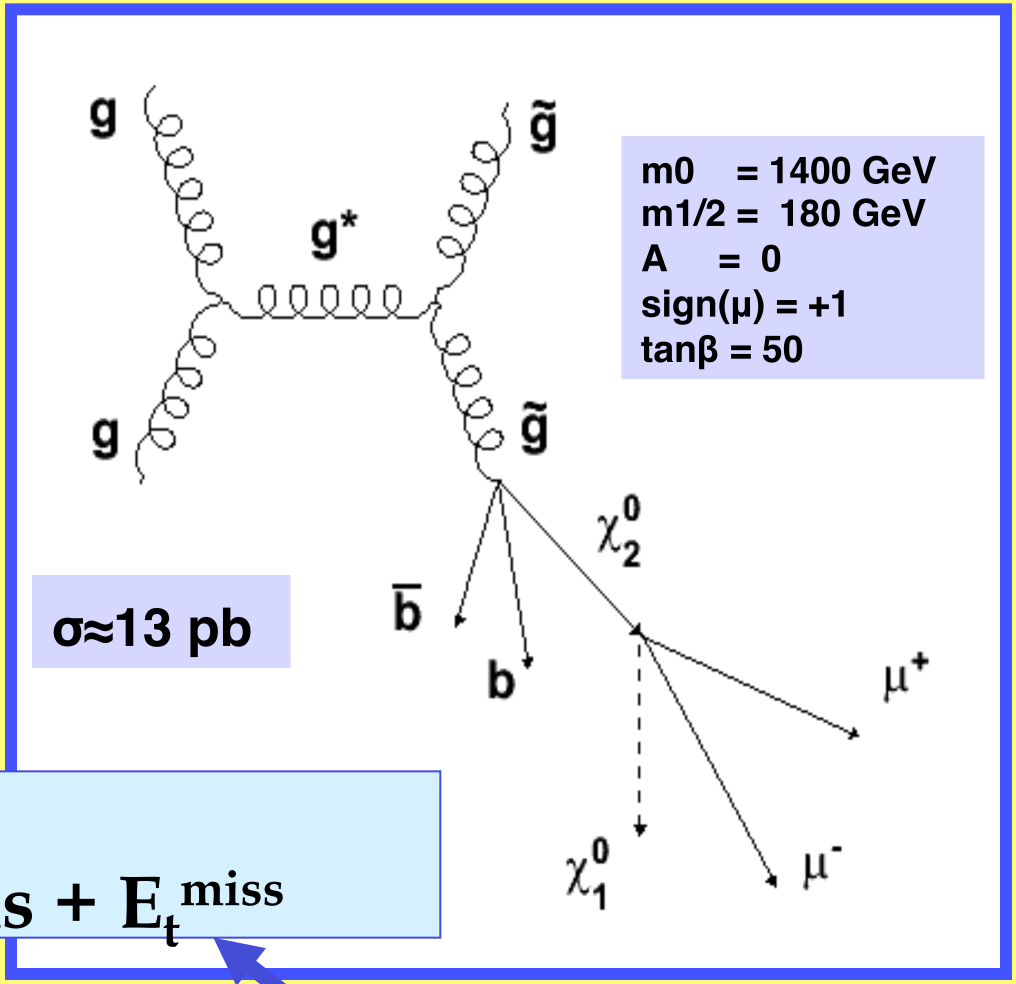
Parameter	Value
Tan β	52.2
m_0	1500
$m_{1/2}$	170
Sign μ	+
A(0)	0
$\alpha_s(M_Z)$	0.122
$\alpha_{em}(M_Z)$	0.0078153697
$Sin^2\theta_W \|_{\overline{MS}}$	0.2314
m_t	175 GeV
m_b	4.214 GeV

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

SUSY PRODUCTION AT LHC



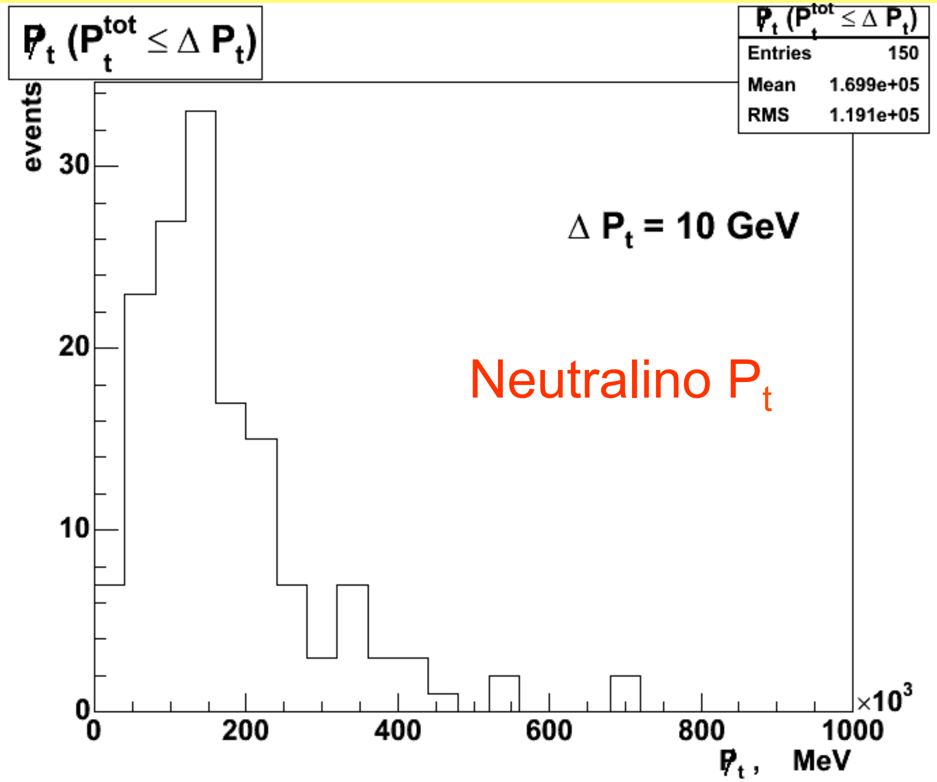


SIGNATURE:

4 b-jets + 4 muons + E_t^{miss}

LARGE!

SUSY gg -> ğğ IN ATLAS



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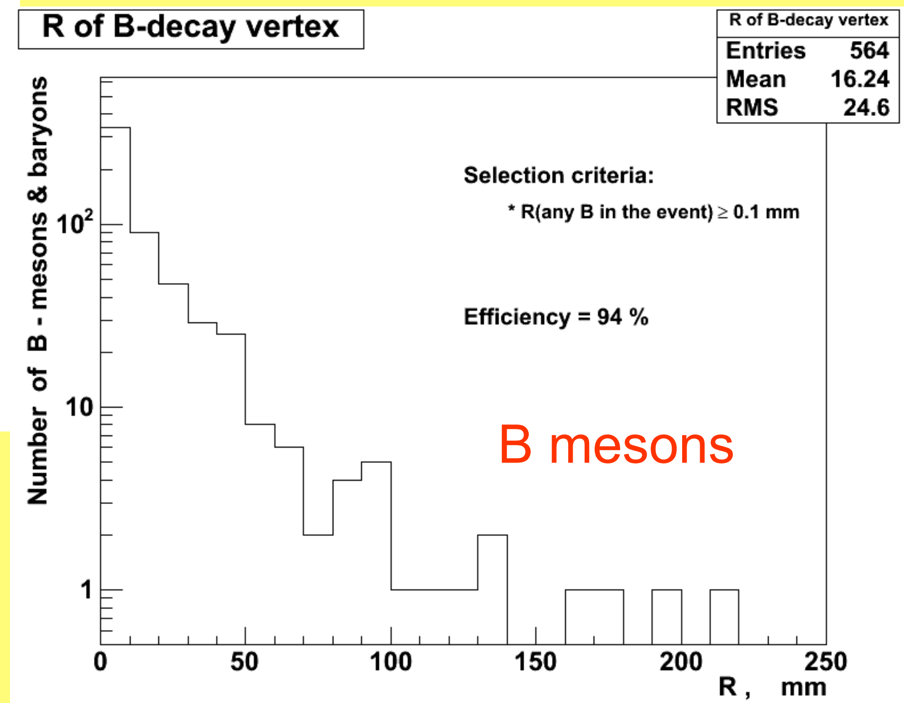
Pythia within ATHENA,

B-vertex taging



$$\sum P_t^{B,B,\mu,\mu} \text{ (down)} \; - \; \sum P_t^{B,B,\mu,\mu} \text{ (up)} \; = \; \not{P}_t \equiv \not{E}_t$$

CONCLUSIONS

If one accepts:

• the interpretation of excess in diffuse galactic gamma rays as a signal of the DM annihilation

• the interpretation of the Cold Dark Matter as SUSY neutralino particles

Then:

• SUSY provides simultaneous consistent description of all observable data including astrophysics

• Parameter space of SUSY is highly restricted

• In the narrow allowed region the SUSY mass spectrum may be predicted

• Light superpartners are observable at the LHC