Dark Matter interpretation of EGRET excess of diffuse gamma rays

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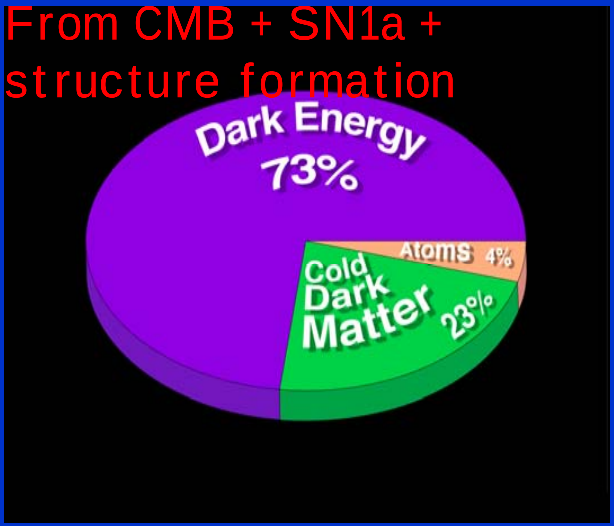
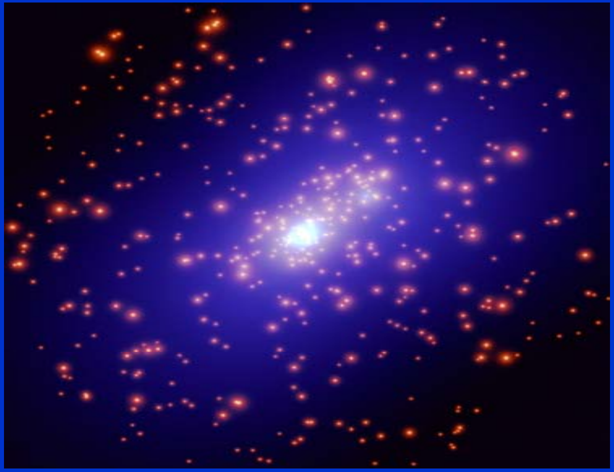
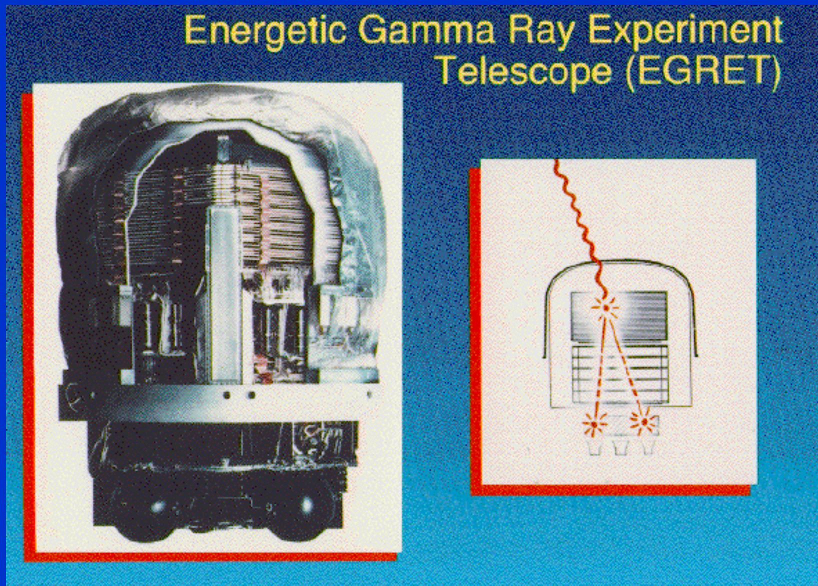


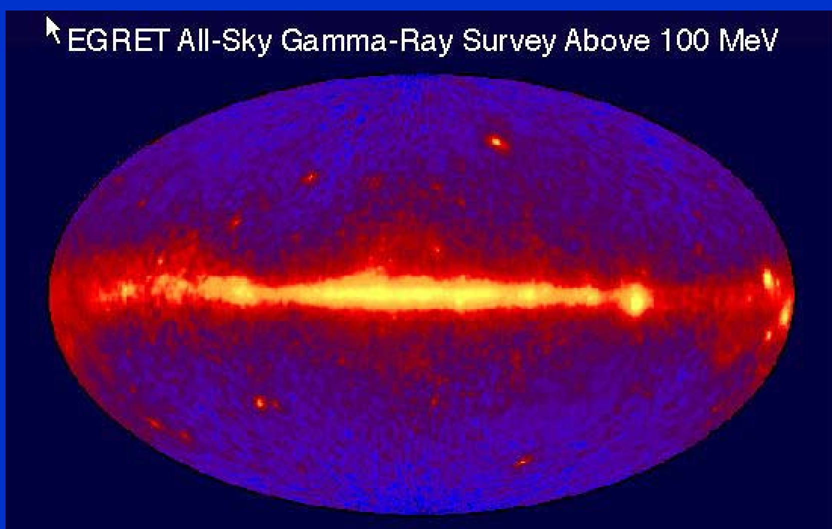
Outline (see astro-ph/0408272)

- EGRET Data on diffuse Gamma rays show excess in all sky directions with the SAME energy spectrum characteristic for hadronisation of monoenergetic quarks
- WIMP mass between 50 and 100 GeV from spectrum of EGRET excess
- Halo distribution from sky map
- Data consistent with Supersymmetry



EGRET on CGRO (Compton Gamma Ray Observ.)





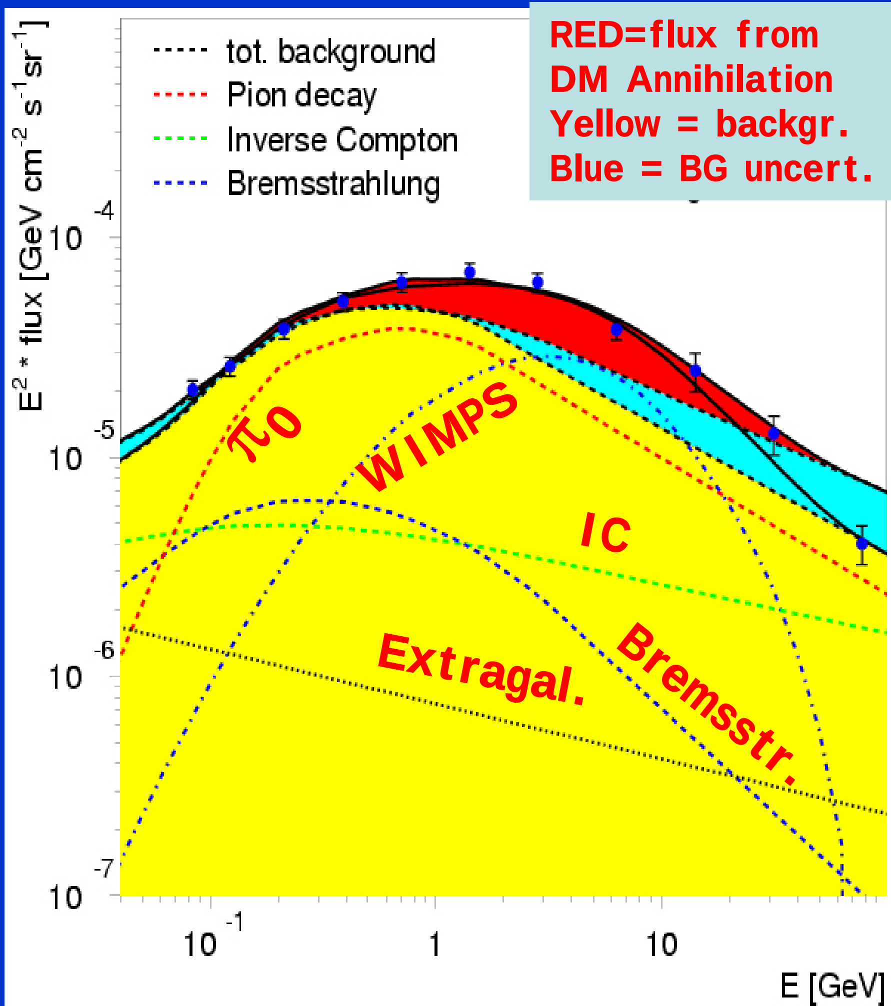
Instrument Parameters and Capabilities

1. **Type:** spark chambers, NaI(Tl) crystals, and plastic scintillators.
2. **Energy Range:** 20 MeV to about 30 GeV.
3. **Energy Resolution:** approximately twenty percent over the central part of the energy range.
4. **Total Detector Area:** approximately 6400 cm^2
5. **Effective Area:** approximately 1500 cm^2 between 200 MeV and 1000 MeV, falling at higher and lower energies.
6. **Point Source Sensitivity:** varies with the spectrum and location of the source and the observing time. Under optimum conditions, well off the galactic plane, it should be approximately 6×10^{-8} $cm^{-2}s^{-1}$ for E > 100 MeV for a full two week exposure.
7. **Source Position Location:** Varies with the nature of the source intensity, location, and energy spectrum from 5 - 30 arcmin.
8. **Field of View:** approximately a gaussian shape with a half width at half maximum of about 20. Note that the full field of view will not generally be used.
9. **Timing Accuracy:** 0.1 ms absolute
10. **Weight:** about 1830 kg (4035 lbs)
11. **Size:** 2.25 m x 1.65 m diameter
12. **Power:** 190 W (including heater power)

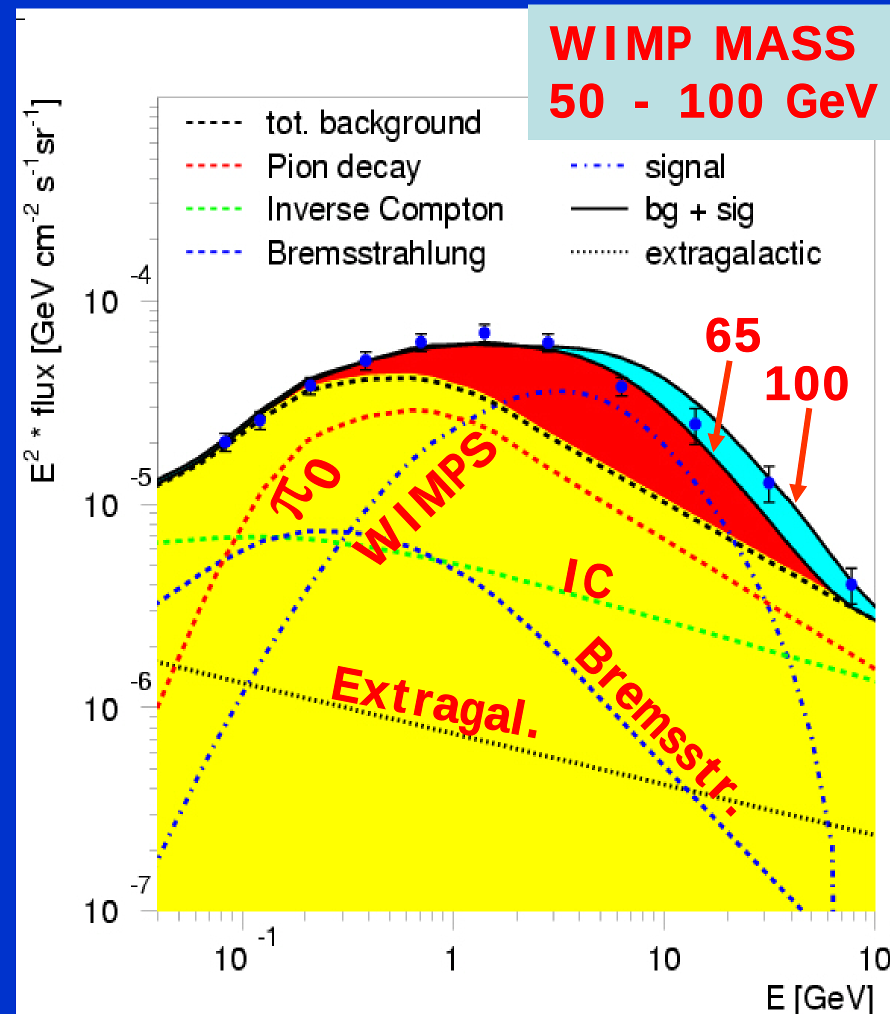
9 yrs of data taken (1991-2000)

Main purpose: sky map of point sources above diffuse BG.

Basics of background and signal shapes

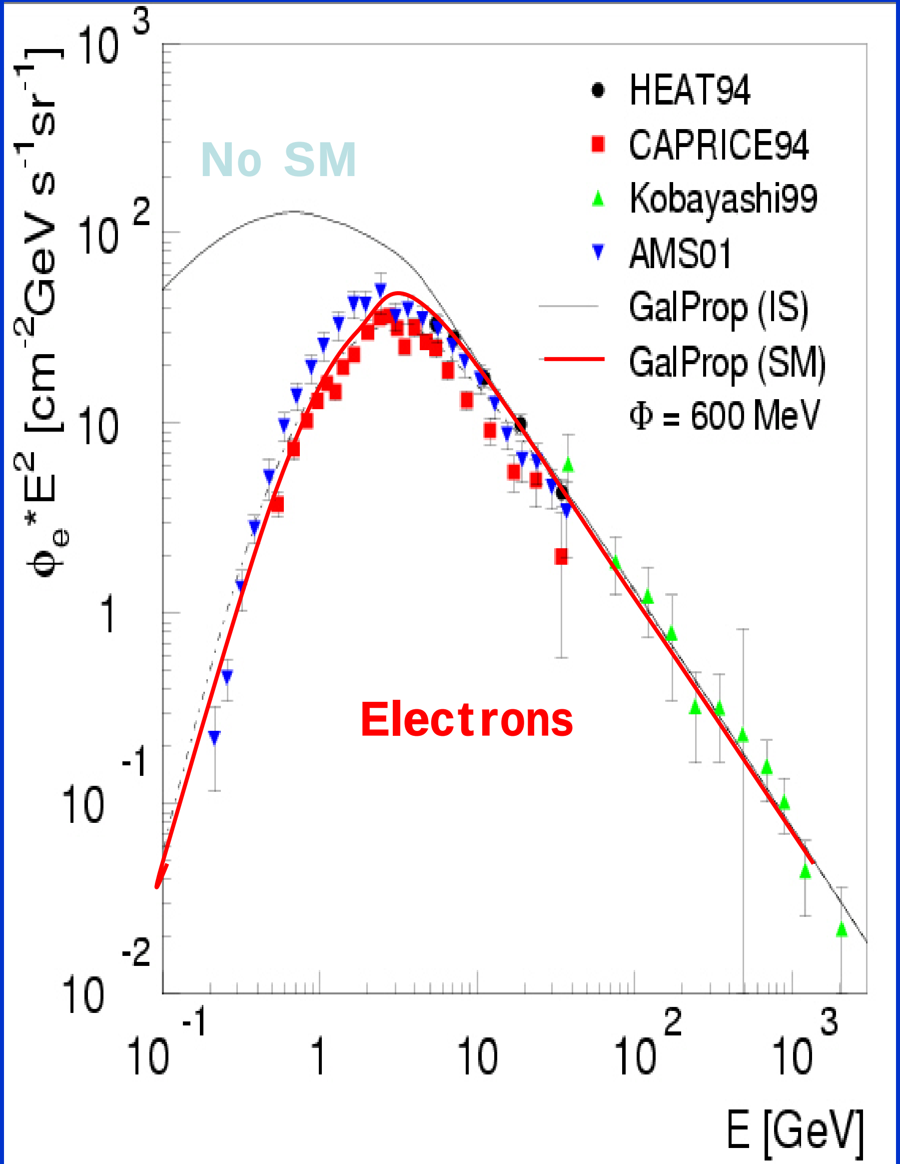


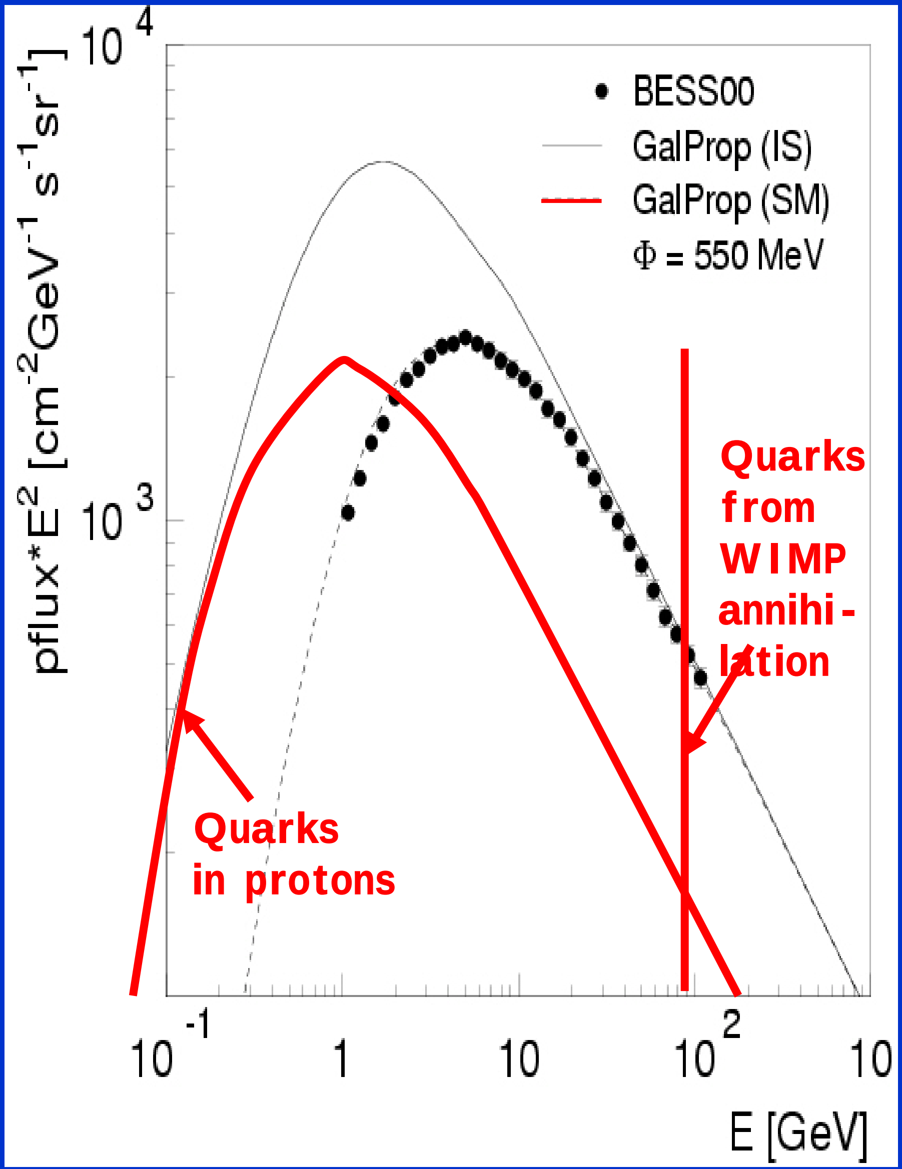
Blue: uncertainty from background shape



Blue: uncertainty from WIMP mass

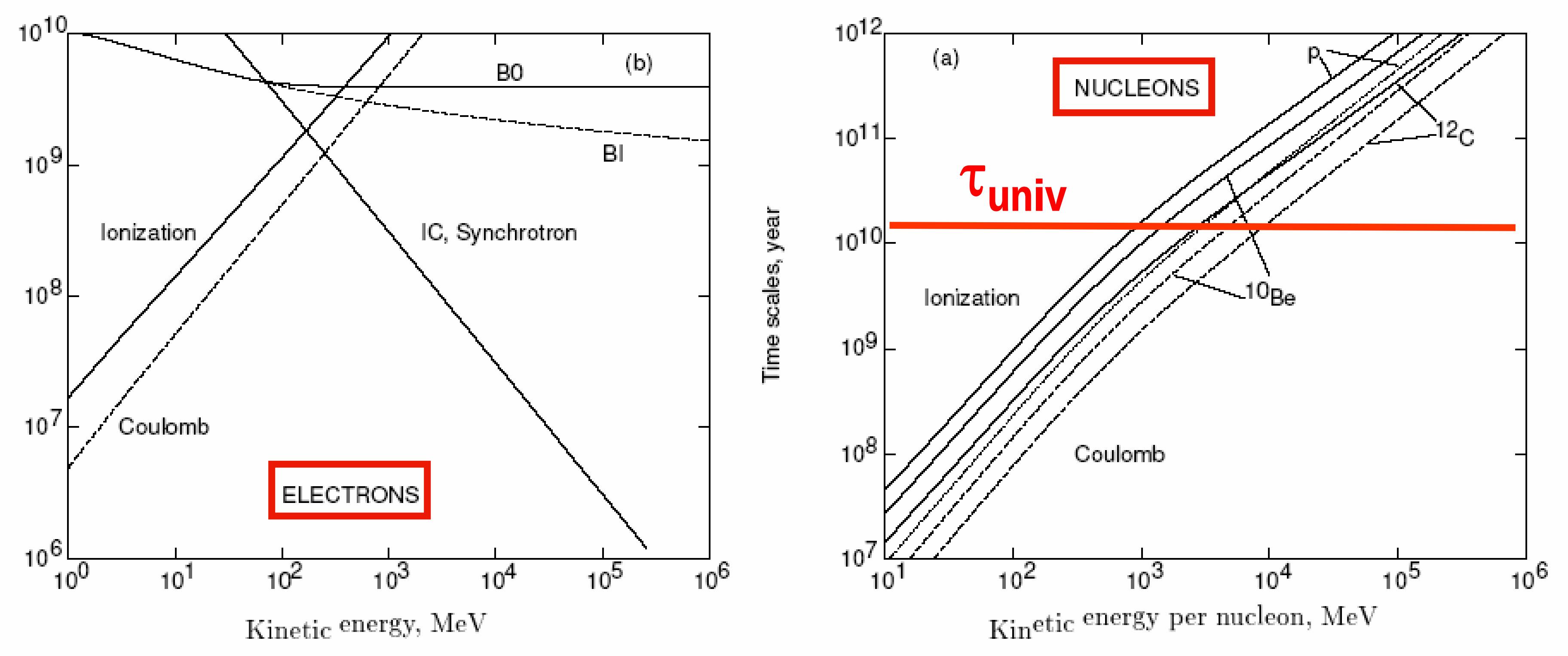
Basics of background and signal shapes





Energy loss times of electrons and nuclei

$$\tau^{-1} = 1/E\, dE/dt$$

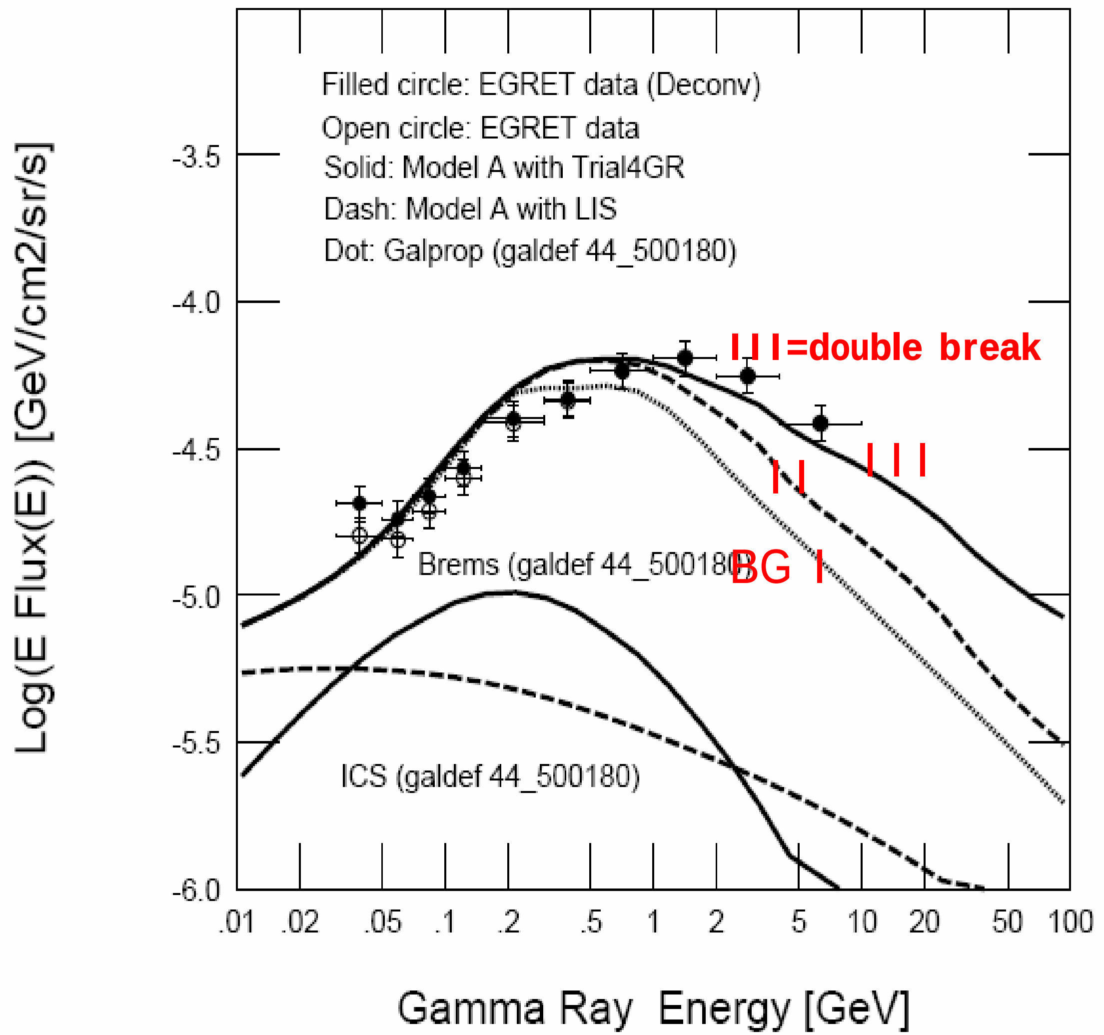


Protons diffuse for long times without loosing energy!

If centre would have harder spectrum, then hard to explain why excess in outer galaxy has SAME shape (can be fitted with same WIMP mass!)

Systematic errors on shape of diffuse background gamma rays

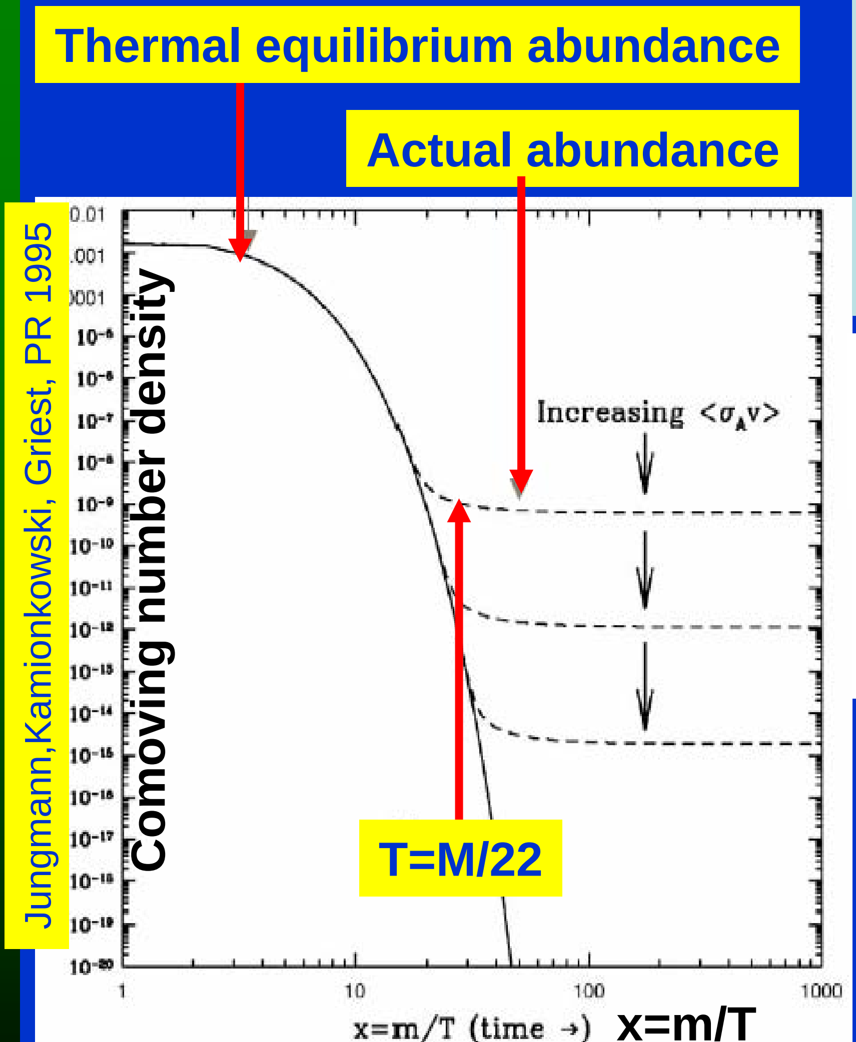
T. Kamae et al, 2004



Main results on halo profile,substructure, and WIMP mass not affected after renormalization to data between 0.1 and 0.5 GeV.

Note: point-to-point errors only half of plotted errors of 15%. Statistical errors negligible.

Basics from cosmology: Hubble const. determines WIMP annihilation x-section



T>>M: $f+\bar{f} \to M+\bar{M}$; $M+\bar{M} \to f+\bar{f}$

T<M: $M+\bar{M} \to f+\bar{f}$

T=M/22: M **decoupled**, stable density (**wenn annihilation rate ≅ expansion rate, i.e. $\Gamma = <\sigma v> n_\chi(x_{fr}) \cong H(x_{fr})$!**)

More precisely by solving Boltzmann eq

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

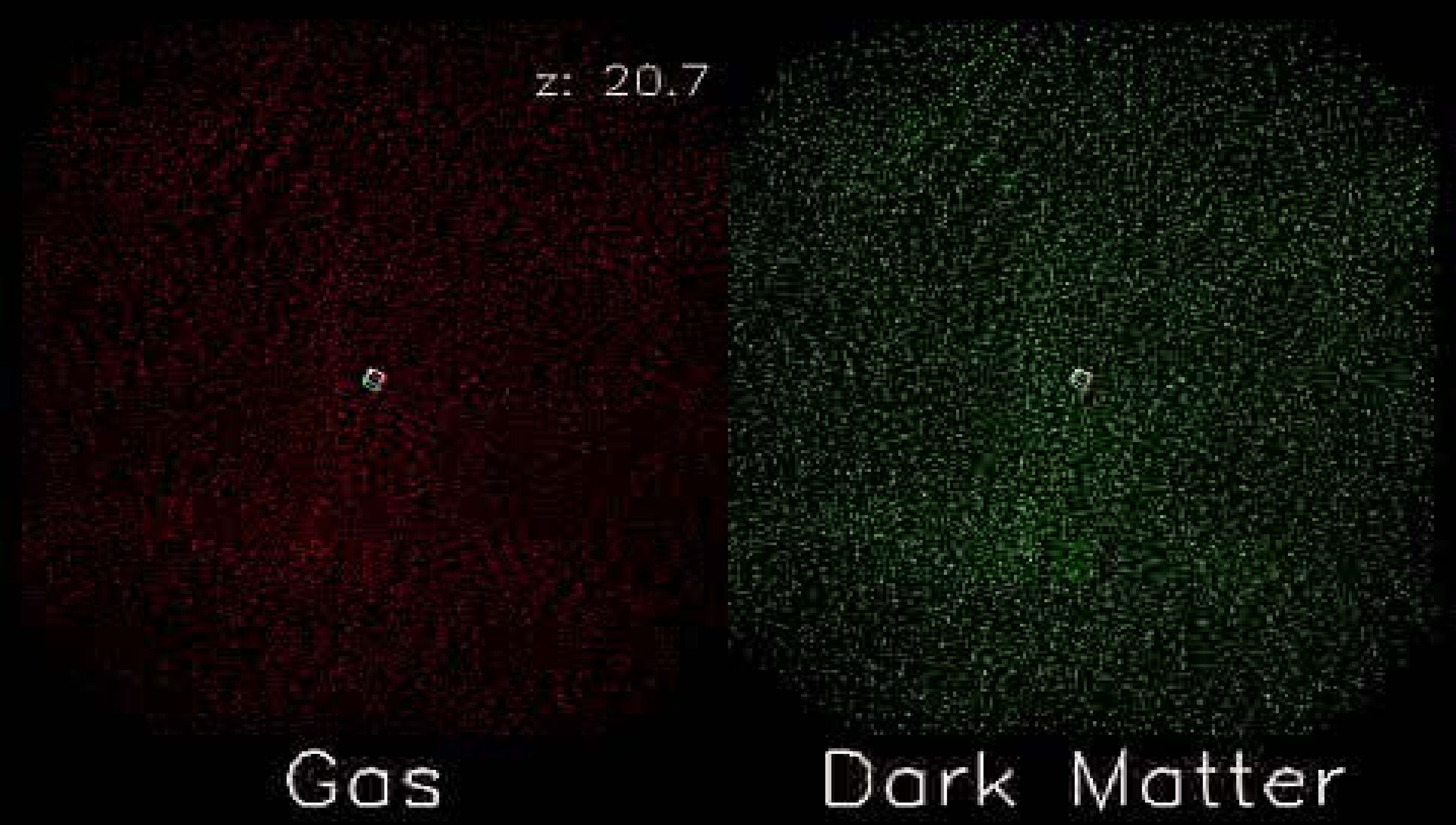
***H*-Term takes care of decrease in density by expansion. Right-hand side: annihilation and production.**

$$\Omega h^2 = m_\chi n_\chi / \rho_c \approx 2.10^{-27}\ [cm^3/s] / <\sigma v>$$

($<\sigma v>$ independ. of m_χ!)

Present WMAP $\Omega h^2 = 0.113 \pm 0.009$ requires $<\sigma v> \approx 2.10^{-26}\ cm^3/s$

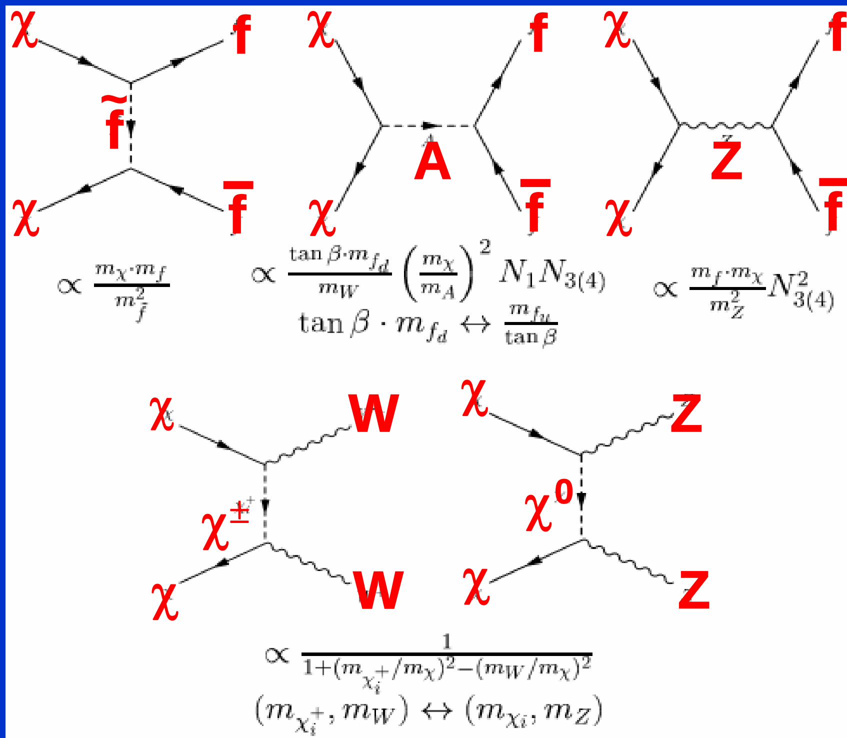
**DM density increases locally after galaxy formation.
In this room: ≈1 WIMP/coffee cup ≈10^5 averaged density.**

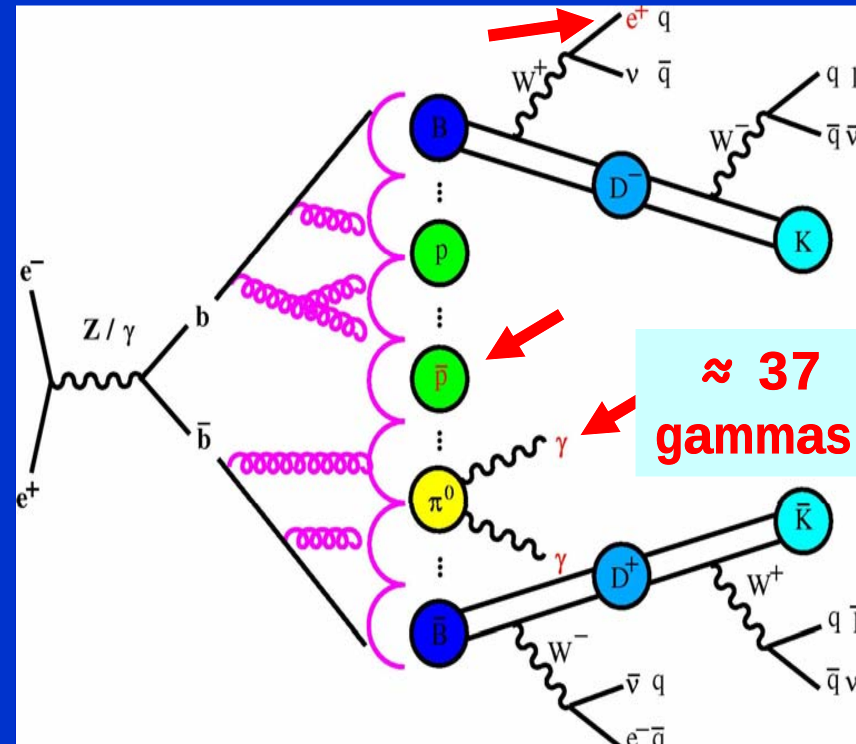


Clustering enhances flux from DMA by factor 20-200 (Dokuchaev et al.

Movie from M. Steinmetz, Potsdam

DM annihilation in Supersymmetry





Dominant diagram for WMAP cross section in MSSM:
$\chi + \chi \Rightarrow A \Rightarrow$ b bbar quark pair

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

Galaxy = SUPER-B-factory with luminosity some 40 orders of magnitude above man-made B-factories

Basics of astro-particle physics

Gamma Ray Flux from WIMP annihilation in given direction ψ:

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

Similar expressions for:

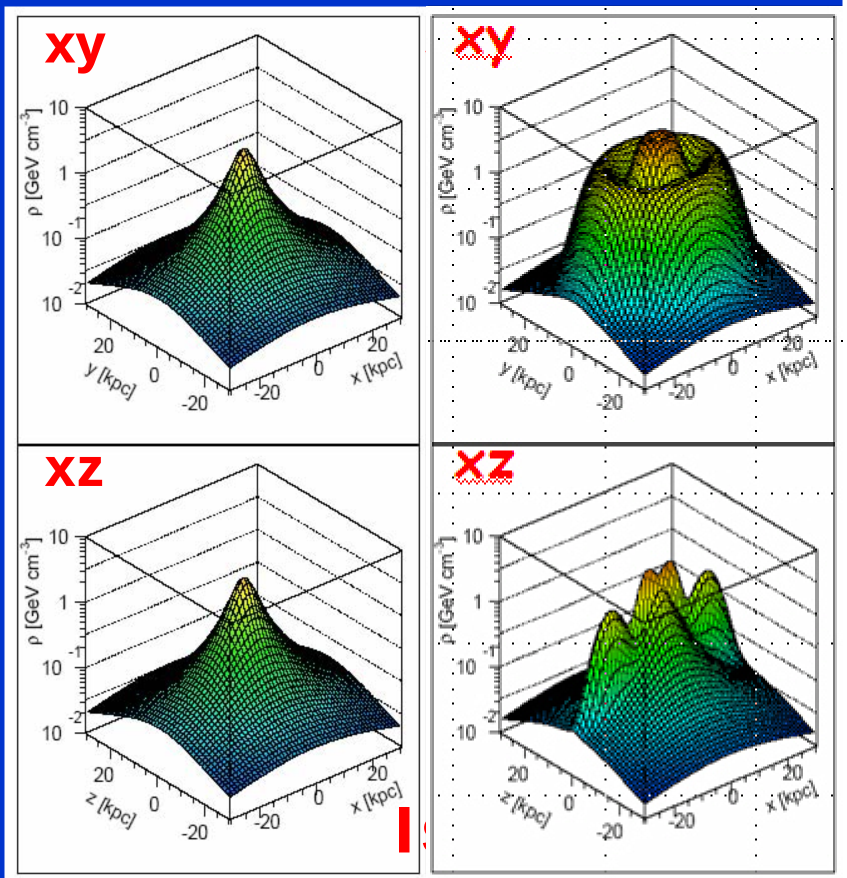
$pp \to \pi_0 + x \to \gamma\gamma + x$, ($\rho$ given by gas density, highest in disc)
$e\gamma \to e\gamma$, $eN \to e\gamma N$, (ρ given by electron/gamma density, highest in disc)
Extragalactic Background (isotropic)
DM annihilation ($\rho \propto 1/r^2$ for flat rotation curve)
All have very different, but known energy spectra.
Cross sections known. Densities not well known, so keep absolute normalization free for each process.

Fit shape of various contributions with free normalization, but normalization limited by experimental overall normalization error, which is 15% for EGRET data. Point-to-point errors $\cong$ 7% (yields good χ^2).

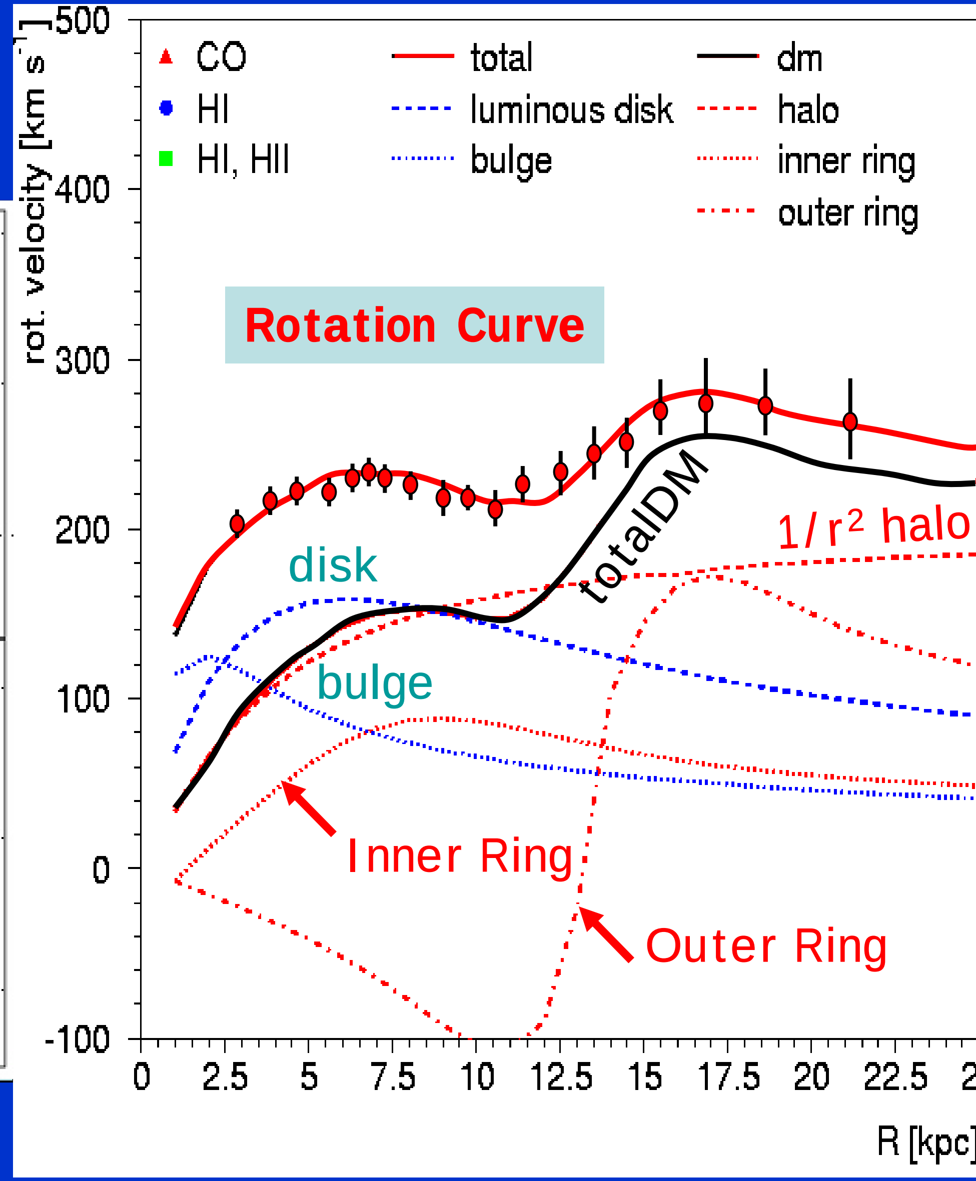
Executive Summary for fits in 360 sky directions

Expected Profile

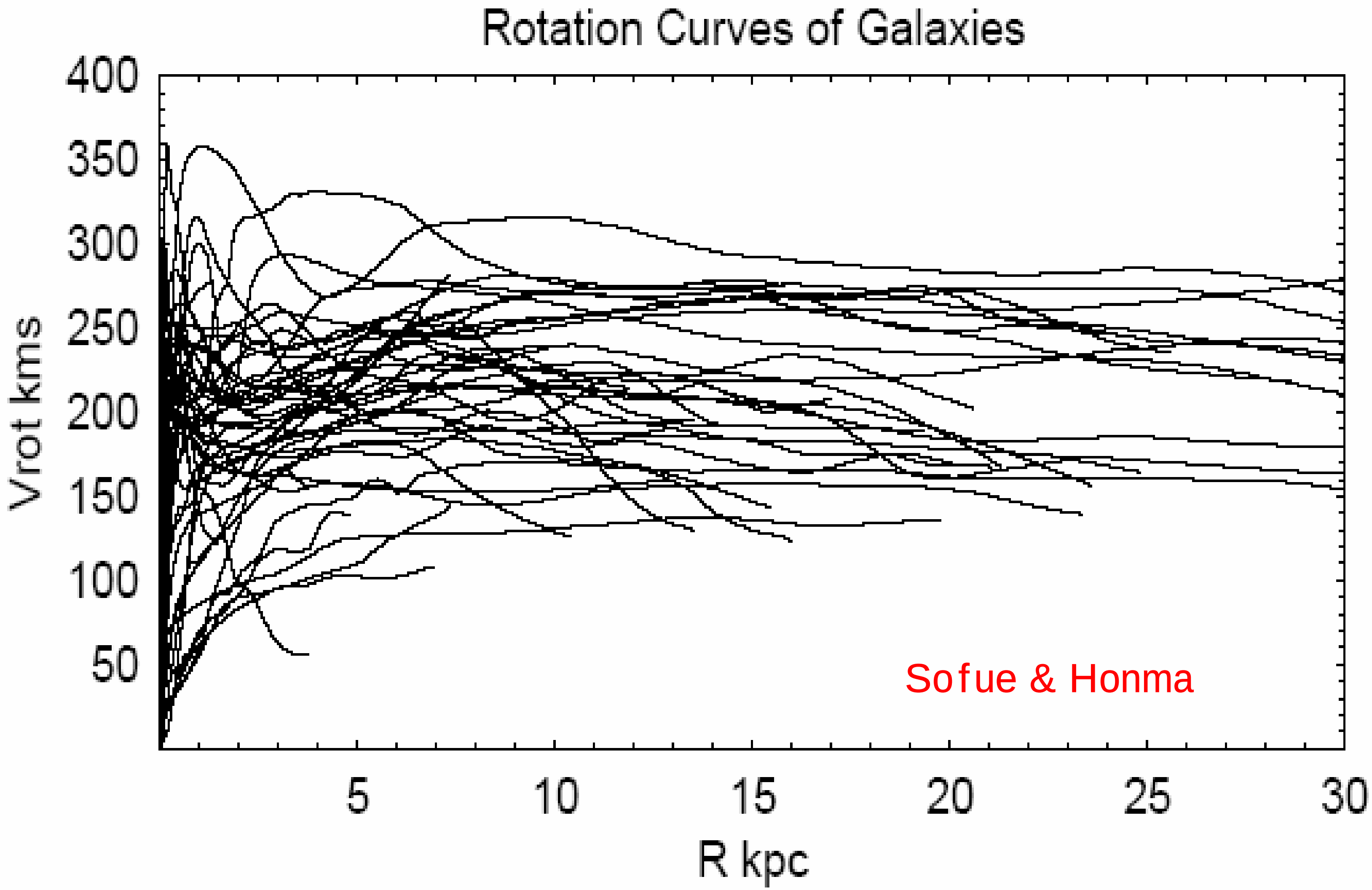
Observed Profile



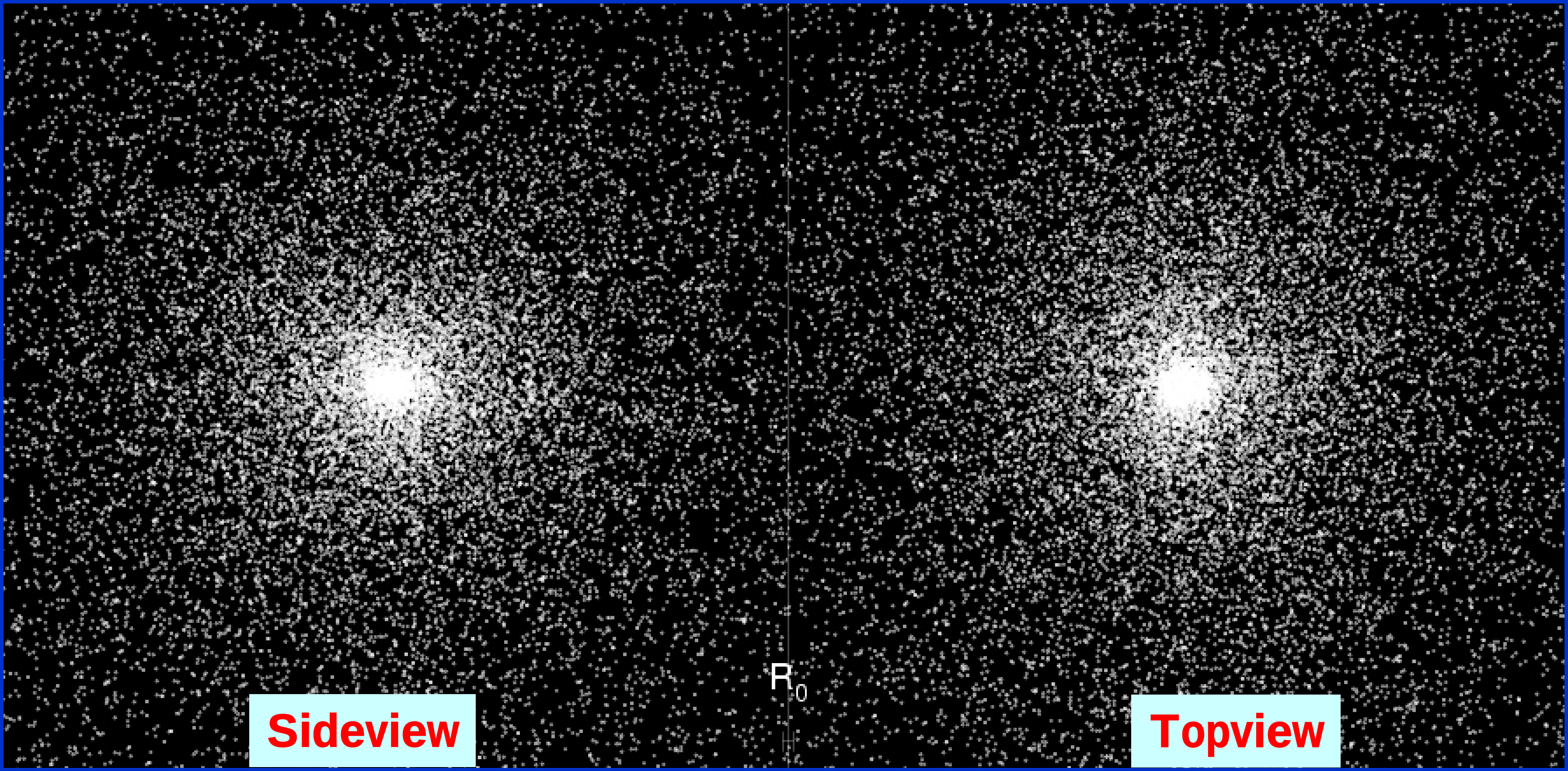
Halo profile



Do other galaxies have bumps in rotation curves?

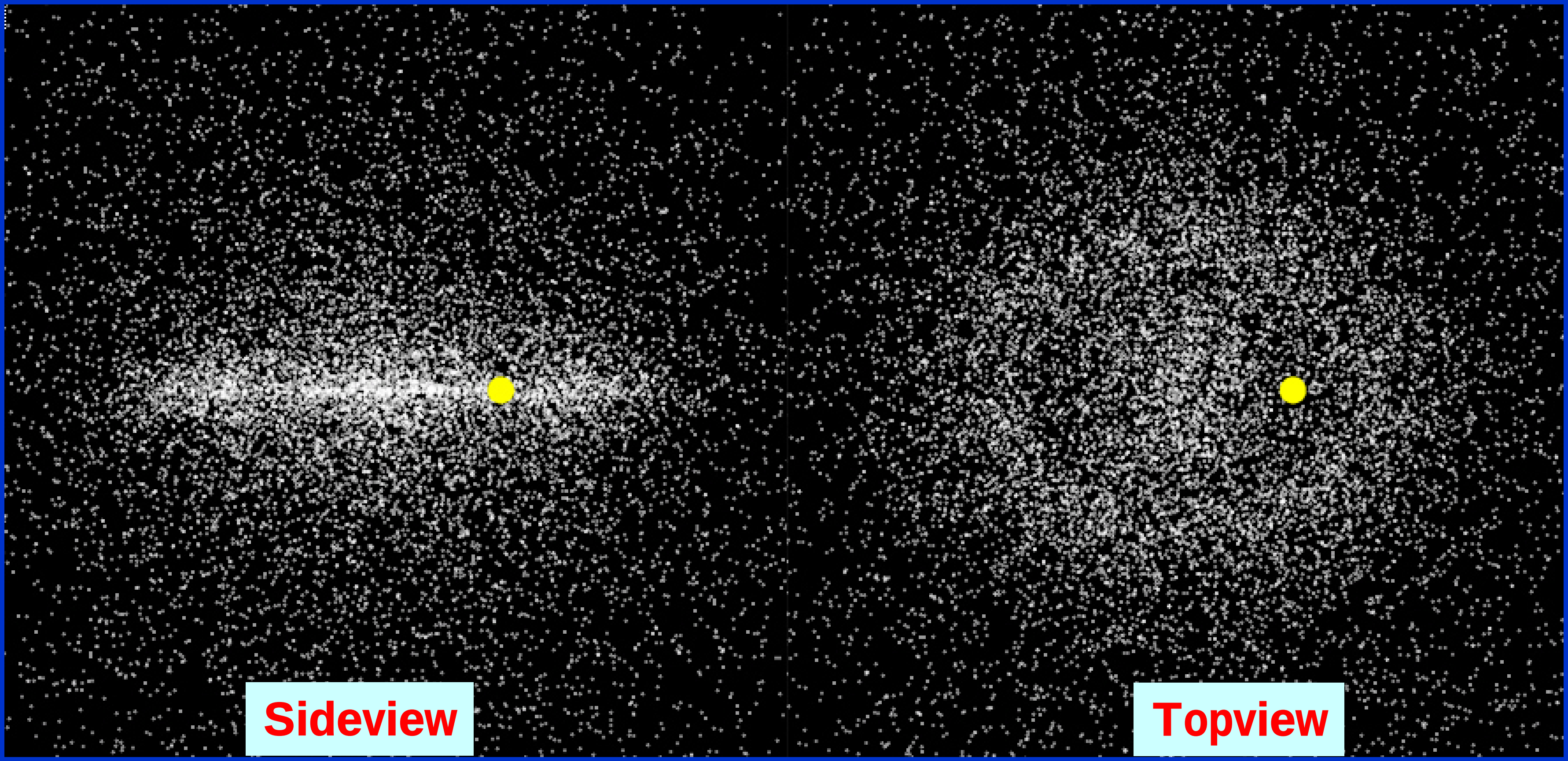


Halo density on scale of 300 kpc



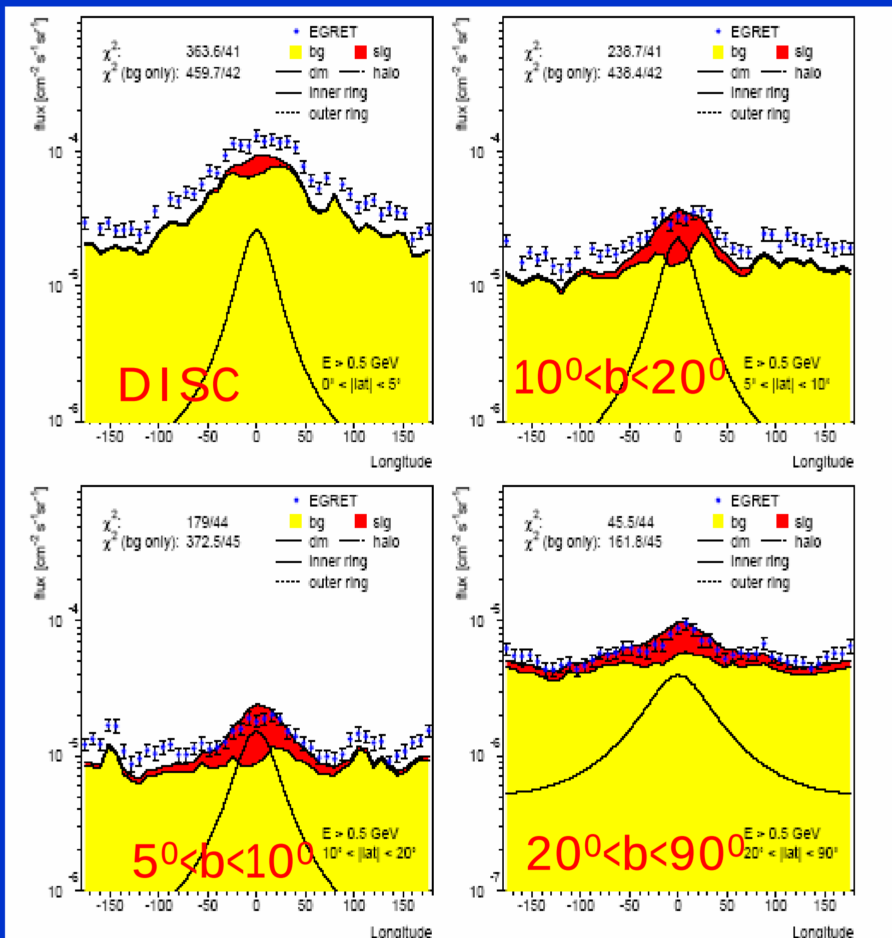
Cored isothermal profile with scale 4 kpc
Total mass: 3.10^{12} solar masses

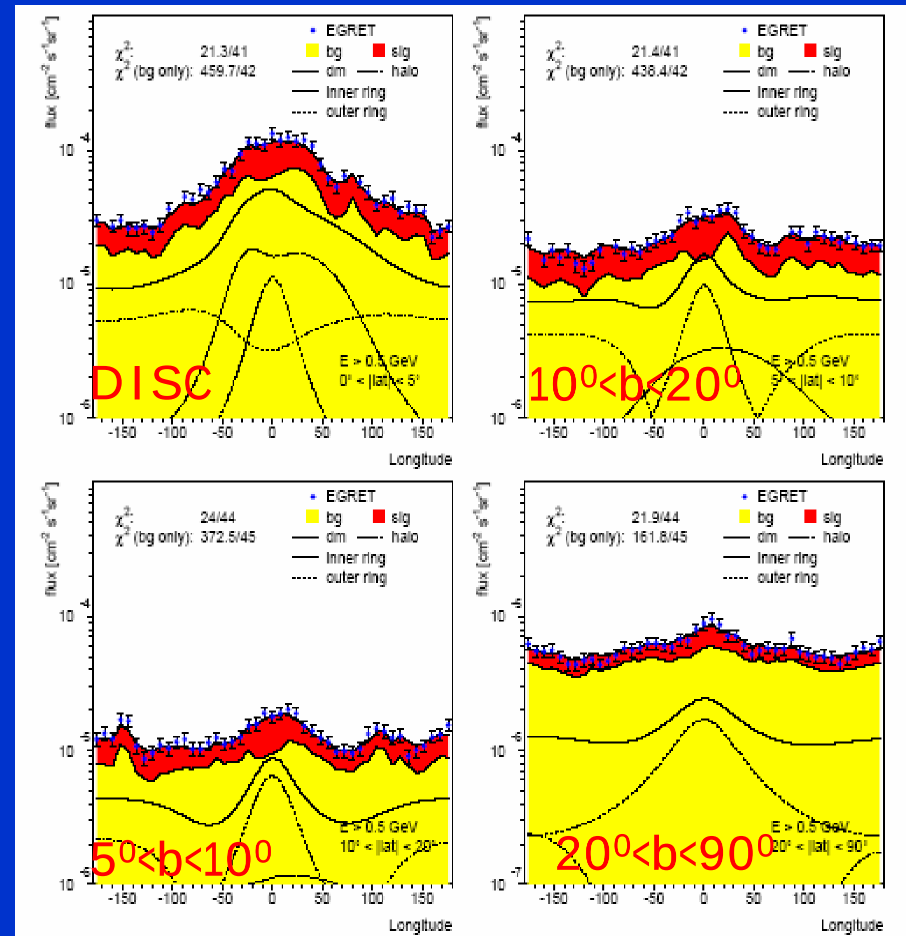
Halo density on scale of 30 kpc



Longitude fits for $1/r^2$ profile with/w.o. rings

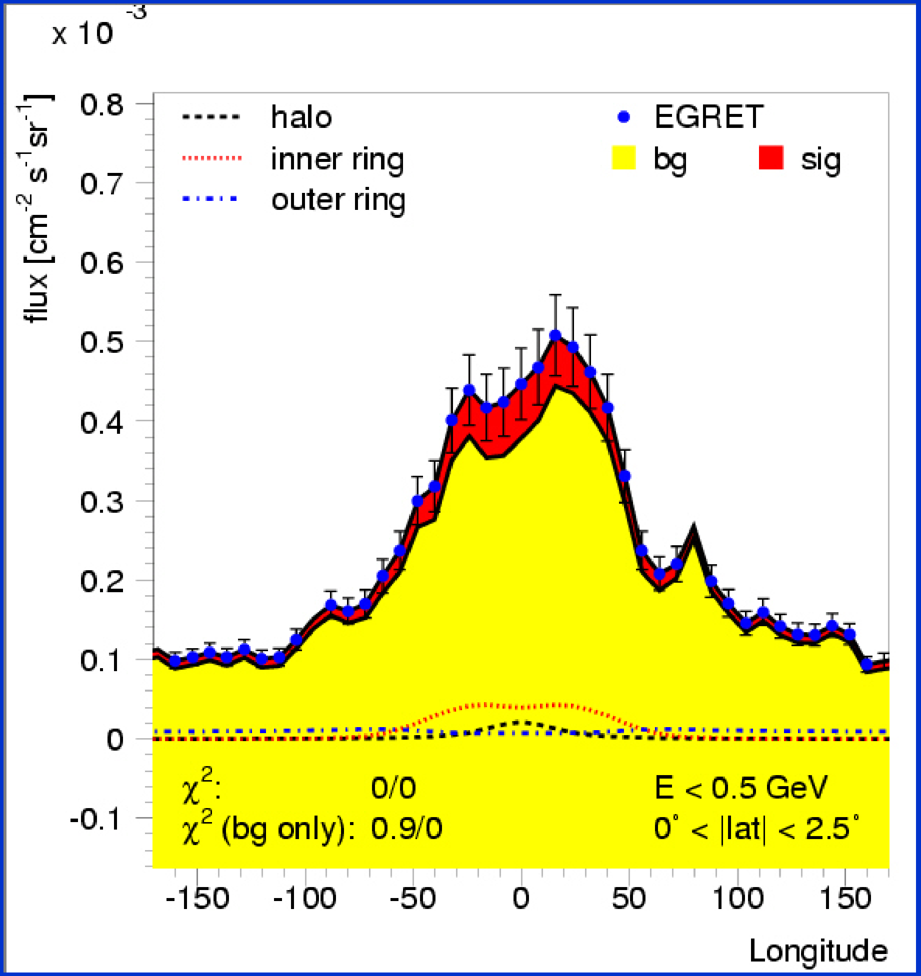
WITHOUT rings | **E > 0.5 GeV** | **WITH 2 rings**



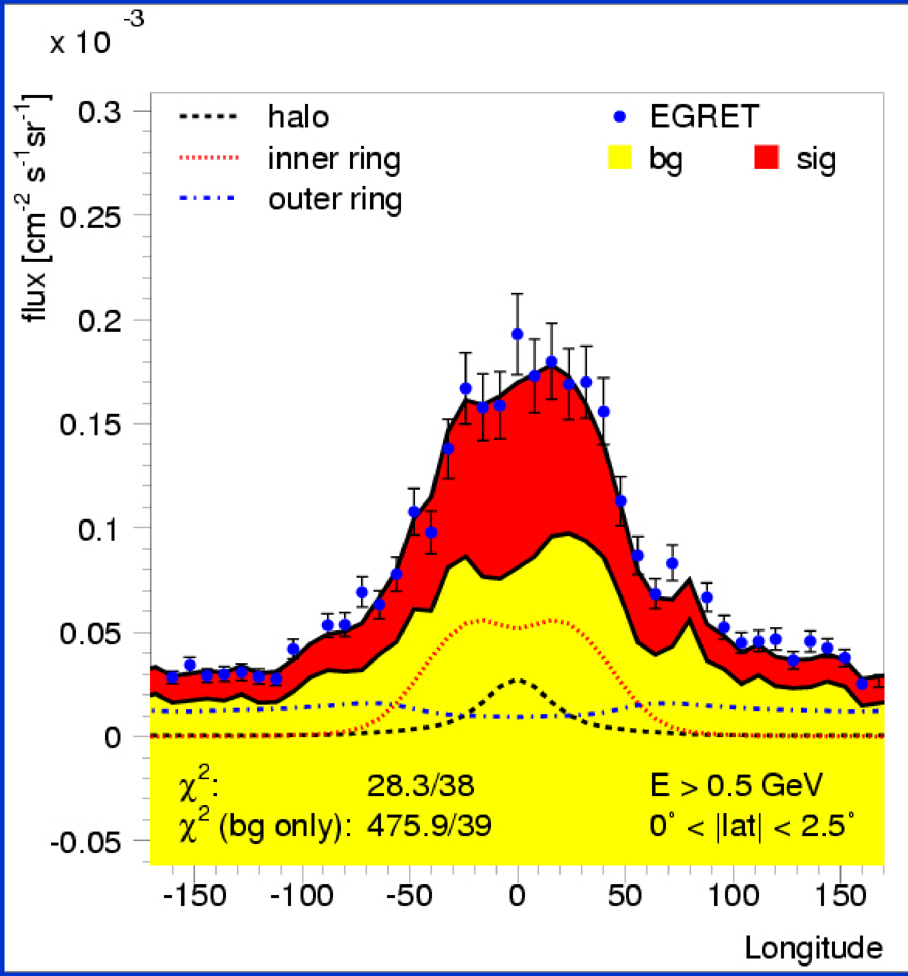


Halo parameters from fit to 180 sky directions: 4 long. profiles for latitudes <5^0, 5^0<b<10^0, 10^0<b<20^0, 20^0<b<90^0 (=4x45=180 directions)

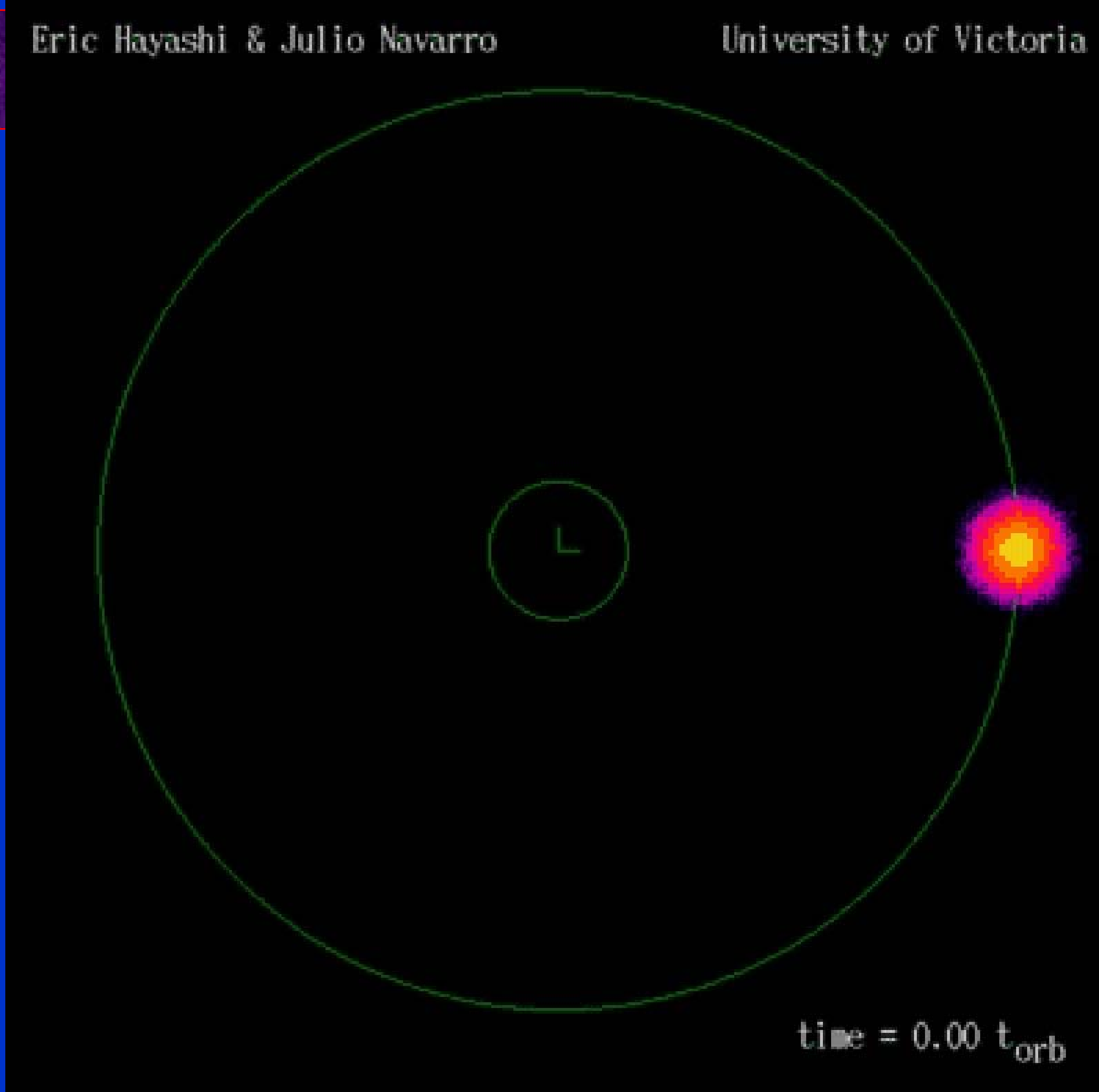
Longitude on linear scale



BELOW 0.5 GeV



ABOVE 0.5 GeV



From Eric Hayashi

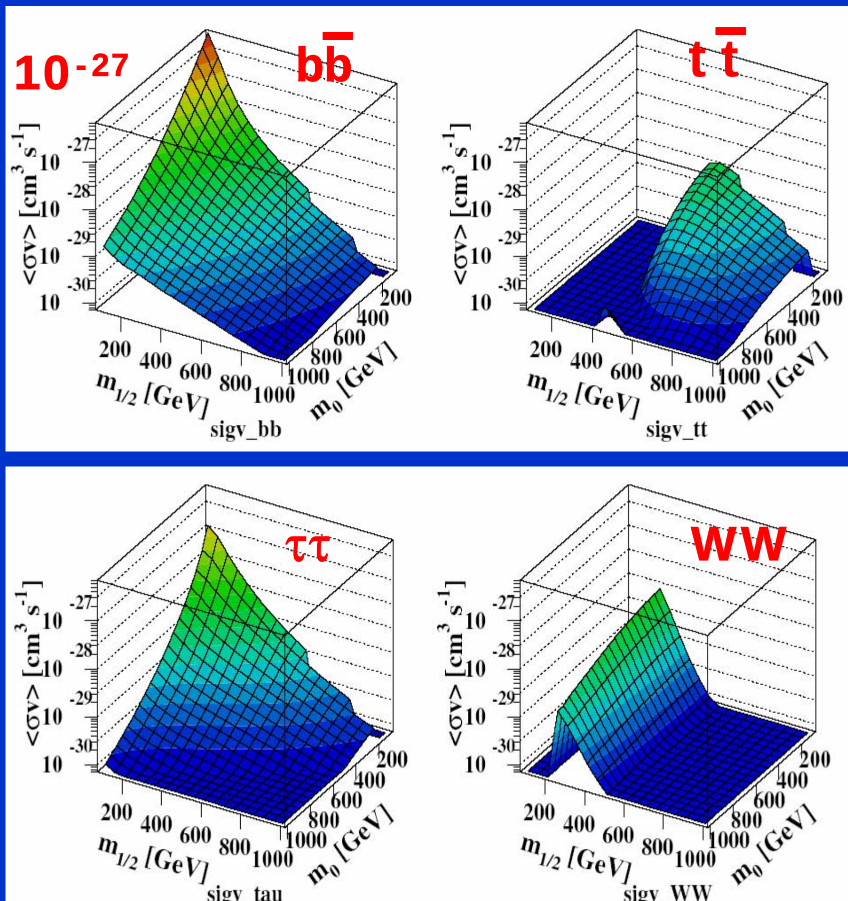
What about Supersymmetry?

Assume mSUGRA

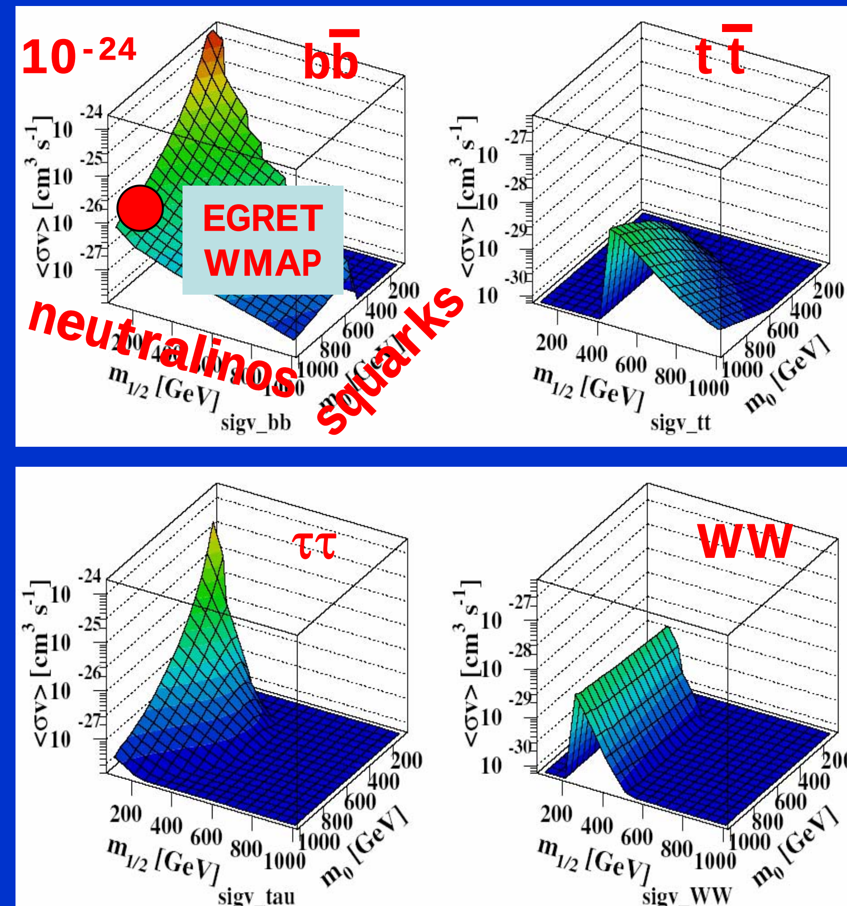
5 parameters: m_0, $m_{1/2}$, tanb, A, sign μ

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

tan=5

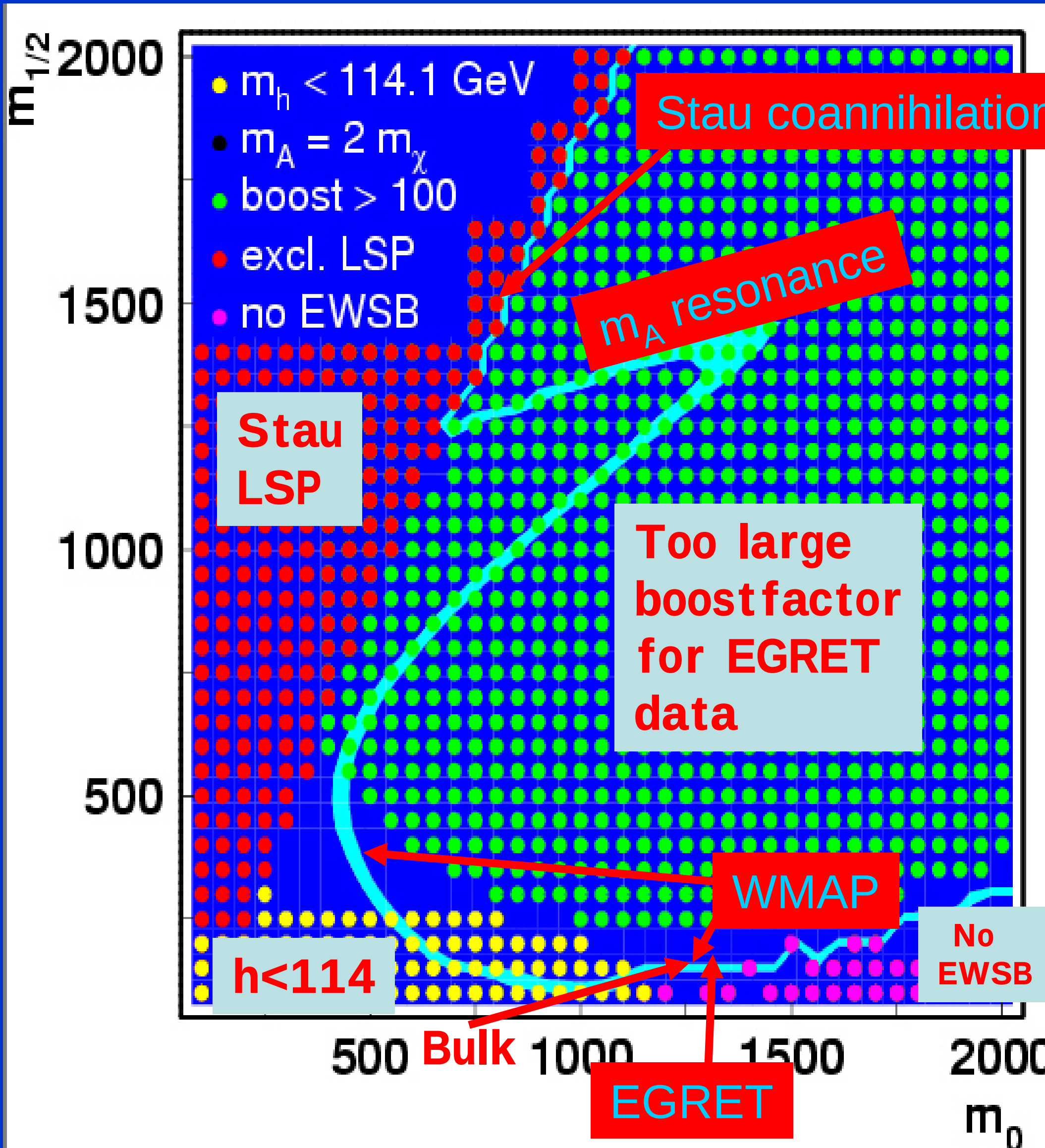


tan=50

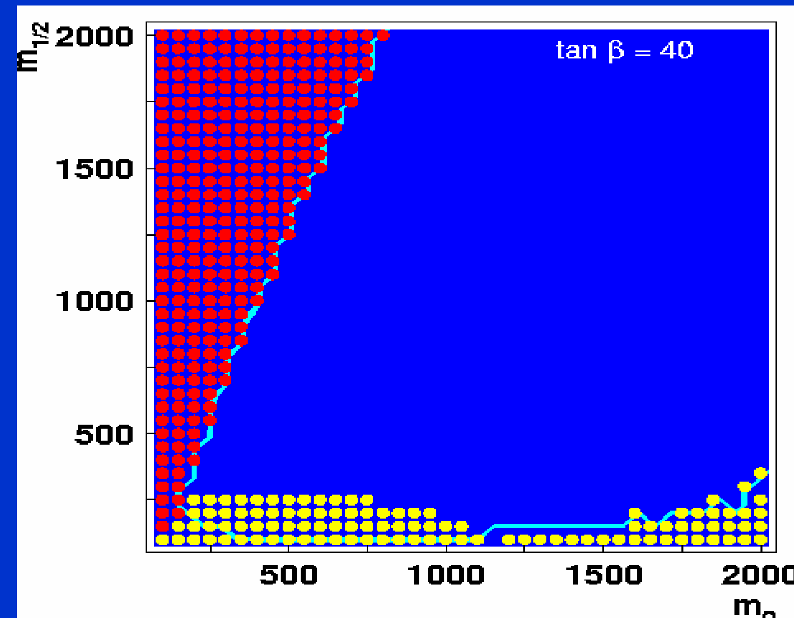


For WMAP x-section of $<\sigma v> \cong 2.10^{-26}$ cm^3/s one needs large tanβ

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



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)



Coannihilations vs selfannihilation of DM

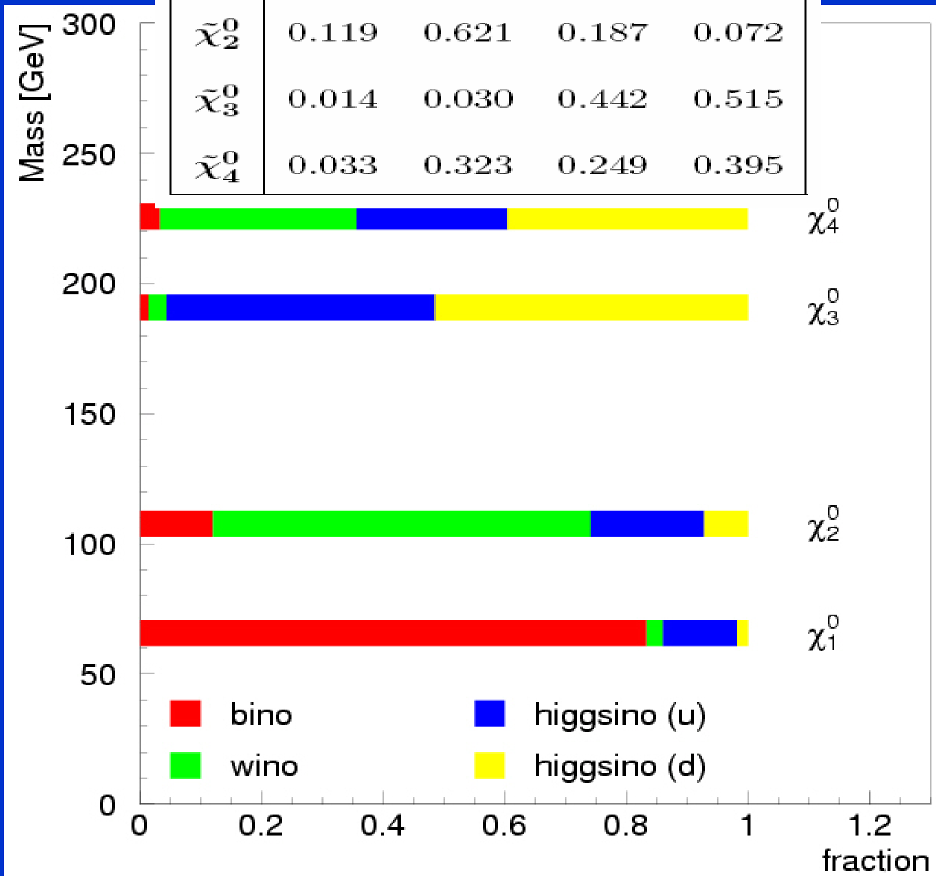
If it happens that other SUSY particles are around at the freeze-out time, they may coannihilate with DM.
E.g. Stau + Neutralino -> tau
Chargino + Neutralino -> W

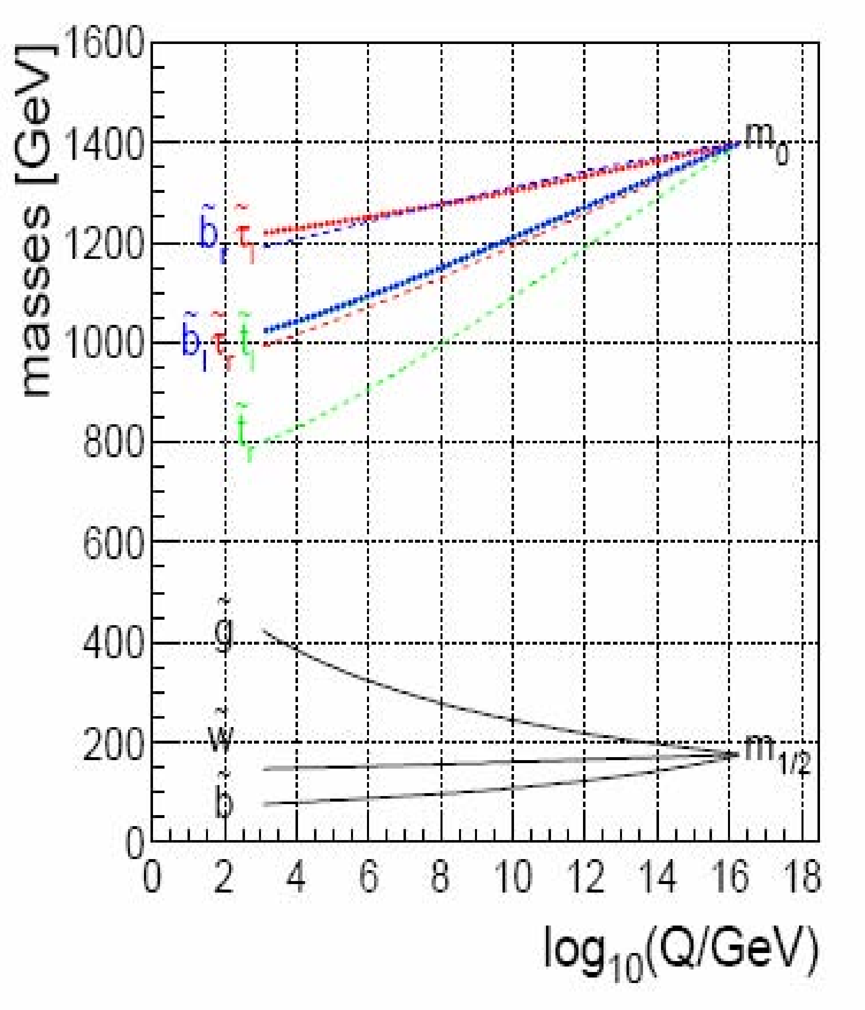
However, this requires extreme fine tuning of masses, since number density drops exponentially with mass.

But more serious: coannihilation will cause excessive boostfactors
$\sigma_{anni} = \sigma_{coanni} + \sigma_{selfanni}$ must yield $<\sigma v>=2.10^{-26}$ cm^3/s.
This means if coannihilation dominates, selfannihilation $\cong 0$
In present universe only selfannihilation can happen, since only lightest neutralino stable, other SUSY particles decayed, so no coannihilation. If selfannihilation x-section 0, no indirect detection. CONCLUSION: EGRET data excludes largely coannih.

SUSY Mass spectra in mSUGRA compatible with WMAP AND EGRET

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



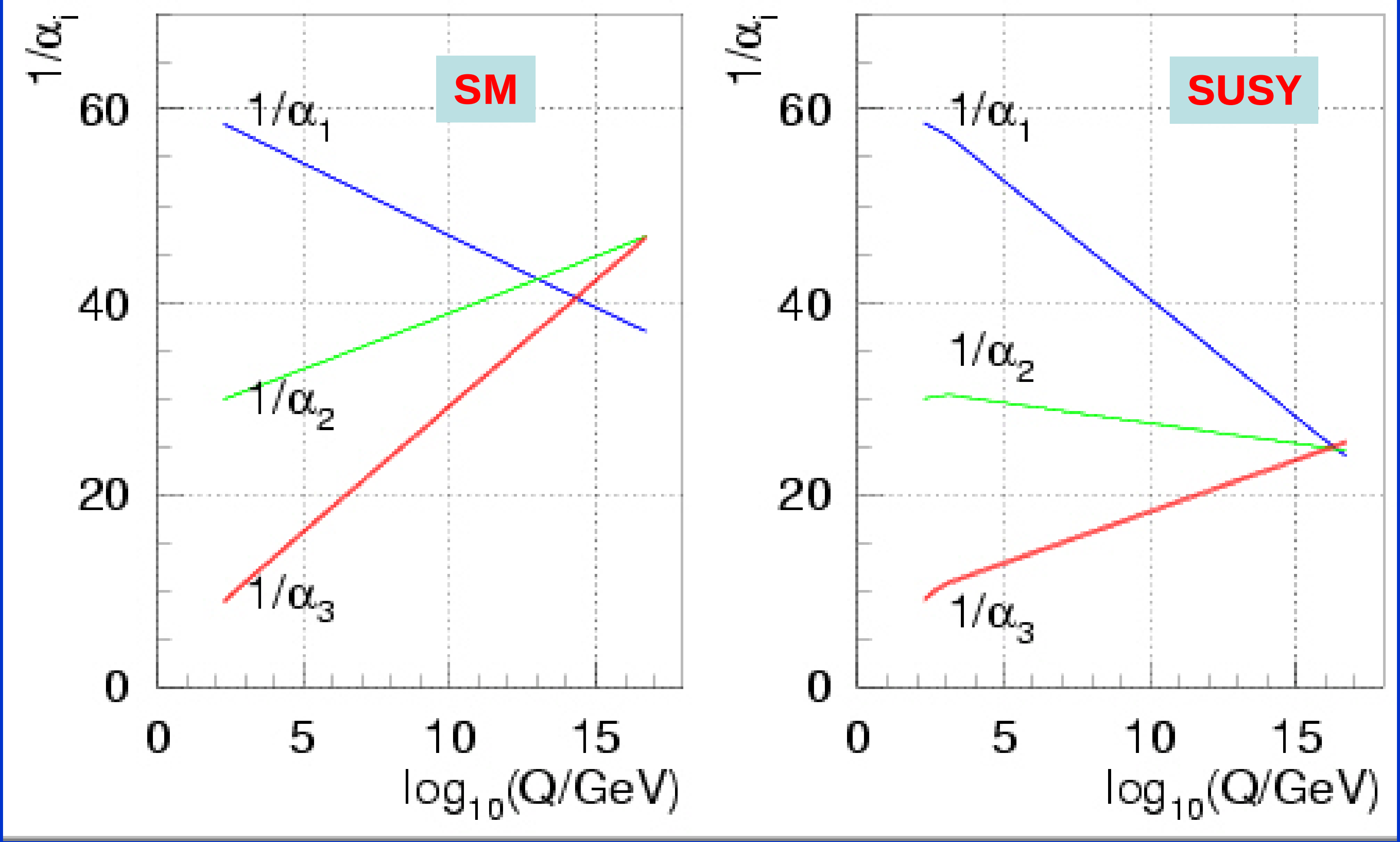


LSP largely Bino ⇒ DM is supersymmetric partner of CMB

Charginos, neutralinos and gluinos light

Unification of gauge couplings

Update from Amaldi, dB, Fürstenau, PLB 260 1991



With SUSY spectrum from EGRET data and start values of couplings from final LEP data perfect gauge coupling unification possible

What determines mSUGRA spectrum in this analysis?

EGRET excess: LSP light
Higgs mass: squarks and sleptons heavy

Question: which diagram dominates LSP annihilation?

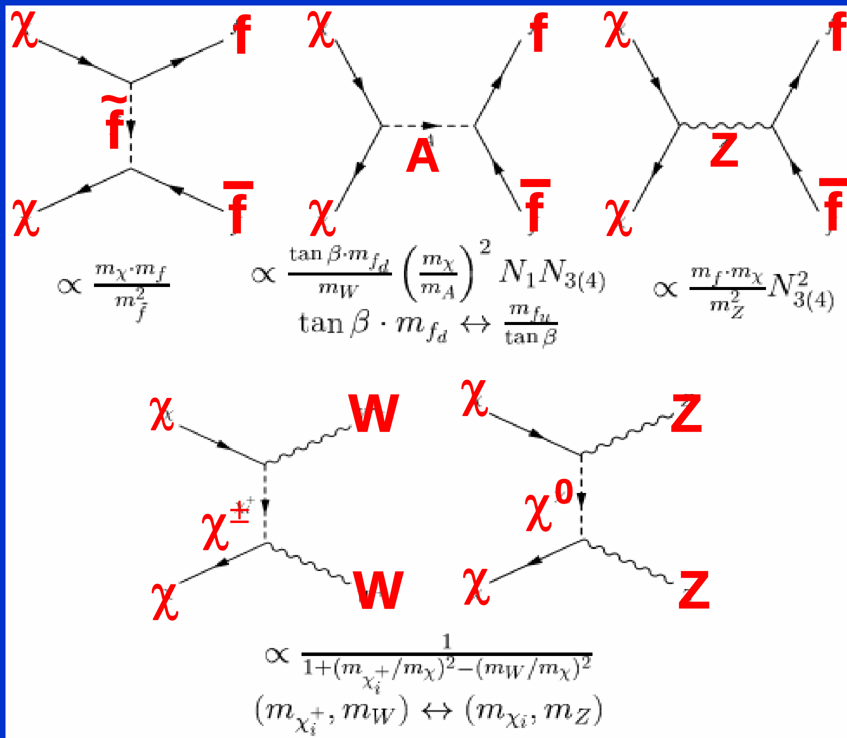
Answer: pseudoscalar Higgs exchange, since

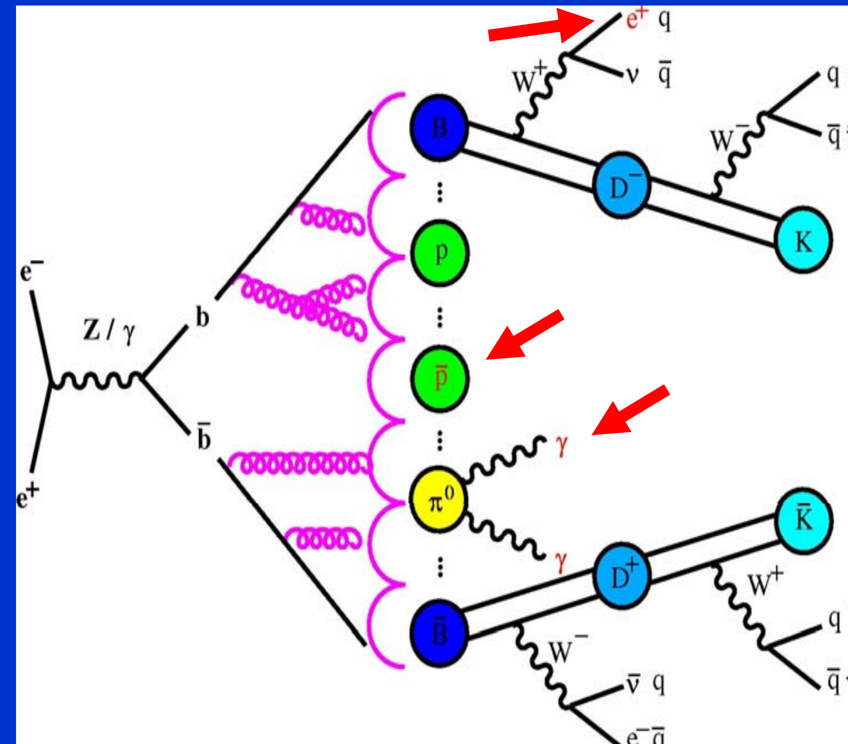
a) sfermion exchange suppressed by heavy sfermions
b) Z-exchange and coannihilation suppressed
by requiring boostfactor below 200
c) W,Z production suppressed by phase space
(and couplings)

Can get estimate on pseudo scalar Higgs masses
WITHOUT relying on EWSB.and RGE by combining

a) WMAP relic density
b) DM interpretation of EGRET excess
c) Chargino limits to limit |μ|

Neutralino Annihilation Final States

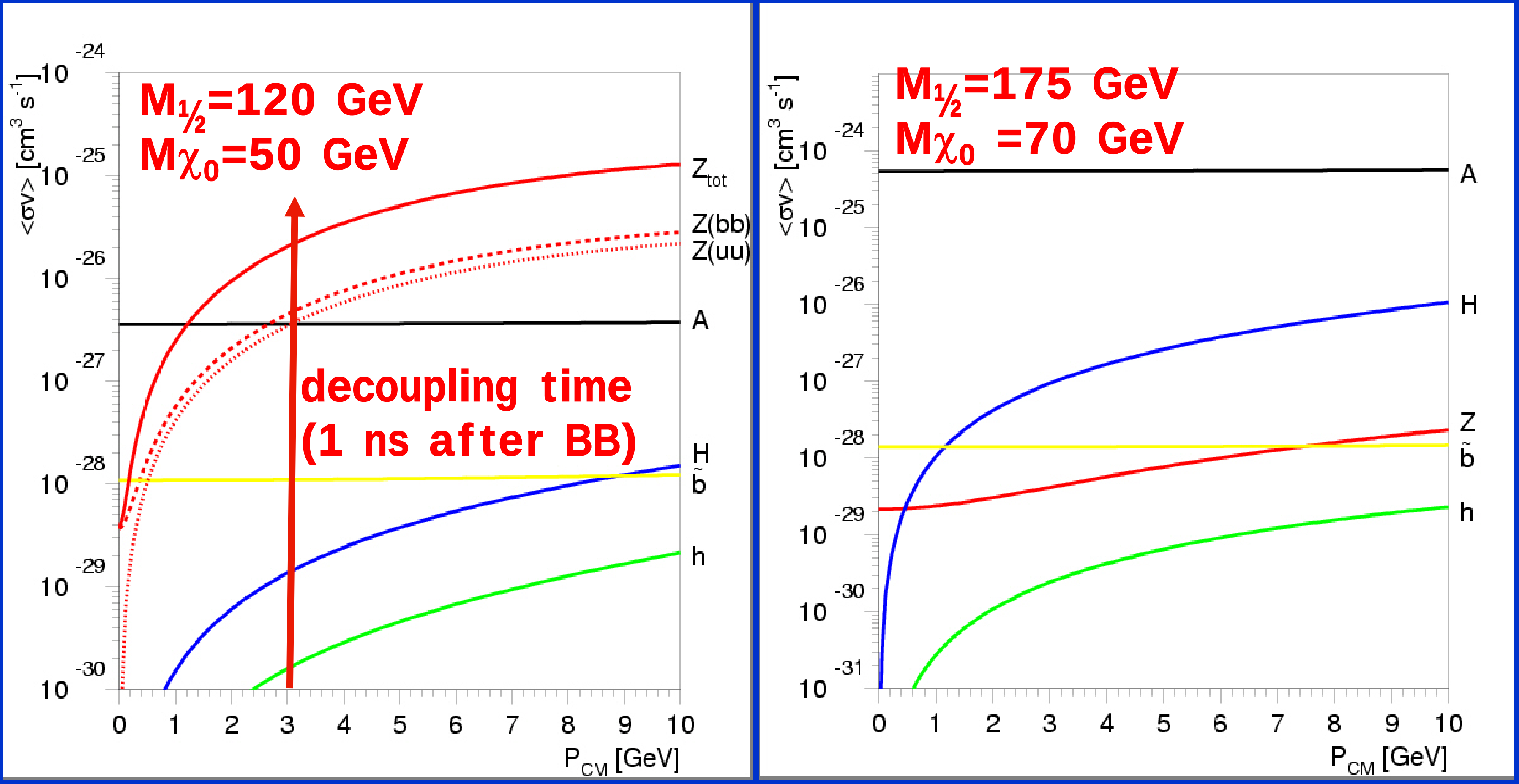




Dominant Diagram for WMAP cross section:
χ + χ ⇒ A ⇒ b bbar quark pair

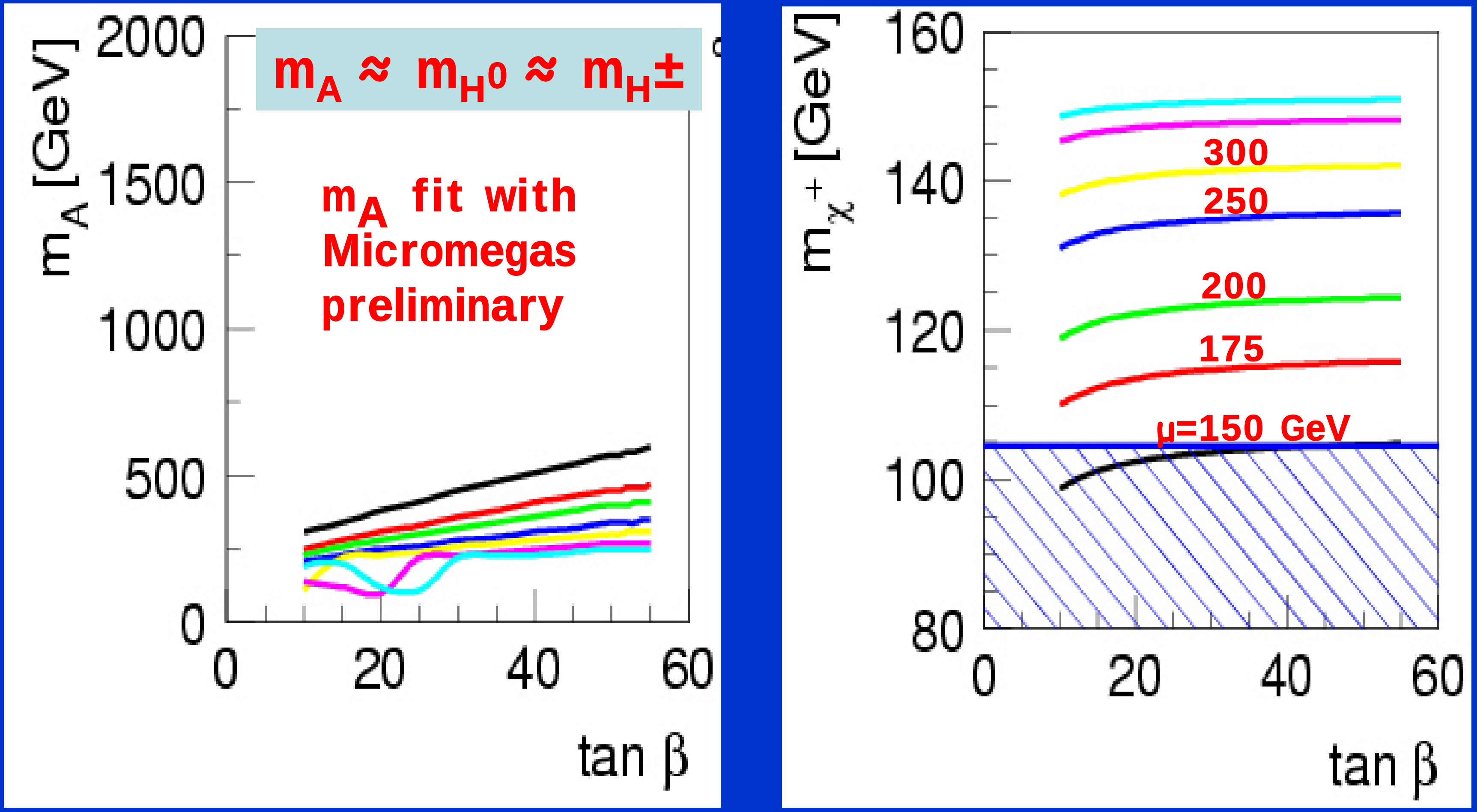
B-fragmentation well studied at LEP!
Yield and spectra of positrons, gammas and antiprotons well known!

Momentum dependence of contributions to DM annihilation



Z-exchange $\propto N^2_{3,4}$ with both s- and p-wave
A-exchange $\propto N_1 N_{3,4}$ only s-wave (p-independent)

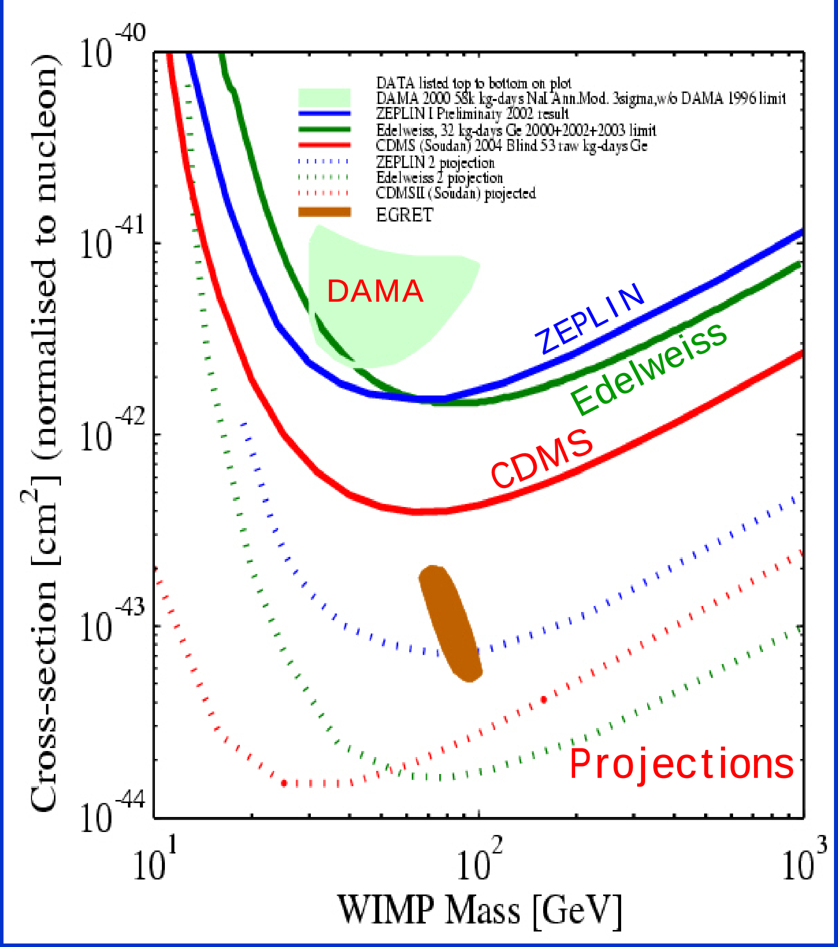
Heavy Higgses below 500 GeV for 70 GeV LSP



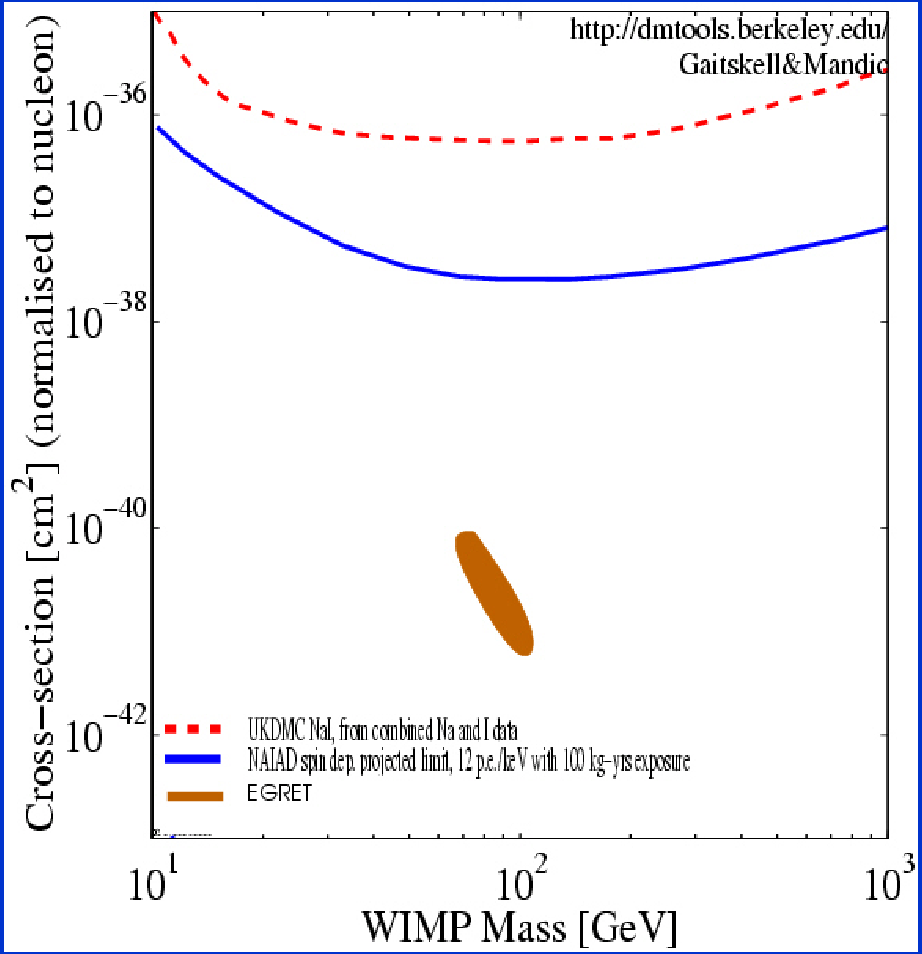
M_A around 200-500 GeV for <σv>=2.10^{-26} cm^3/s
AND chargino > 104 GeV. INDEPENDENT of EWSB and RGE.

Comparison with direct DM Searches

Spin-independent



Spin-dependent



Predictions from EGRET data assuming Supersymmetry

SUMMARY

EGRET EXCESS TRACES DM, AS DEMONSTRATED BY PREDICTION OF ROTATION CURVE FROM GAMMA RAYS.

THEREFORE THIS IS FIRST ($>10\sigma$) INTRIGUING HINT OF DMA.

SUMMARY

This result is INDEPENDENT of galactic models, only dependent on the SHAPES of contributions to diffuse gamma ray spectrum! Fitted normalizations consistent with expectations.

Conventional models CANNOT explain spectrum of gamma rays in ALL directions, DM density profile, peculiar shape of rotation curve, stability of ring of stars at 14 kpc, stability of ring of molecular hydrogen at 4 kpc,…

SUMMARY

Predicted SUSY spectrum from EGRET and WMAP VERY favourable for linear collider:

- **light Higgs, charged Higgs, chargino, and top all within reach of TeV ILC**
- **Squarks and sleptons for LHC**