Can one say SUSY from the window in the sky?

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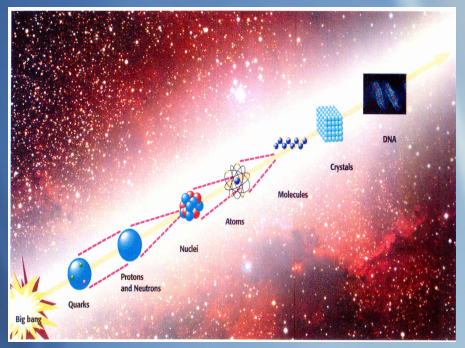
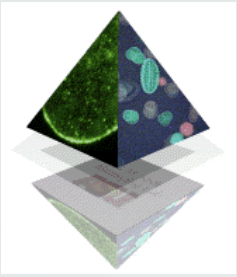


What is SUSY?



- **Supersymmetry** is a boson-fermion sy
that is aimed to unify all forces in N
gravity within a singe frame

$$Q\,|\,boson>=|\,fe \qquad\qquad n>$$

$$[b,b \qquad\qquad (\sigma^{\mu})_{\alpha\dot{\beta}} P_{\mu}$$

First papers in 1971-1972

No evidence in particle physics yet

- Modern y in particle physics
are based o gm, though low energy
manifestatio SY can be found (?) at modern
colliders and in non-accelerator experiments

Particle Content of the MSSM

Superfield	*Bosons*	*Fermions*	$SU_c(3)$	$SU_L(2)$	$U_Y(1)$
Gauge					
G^a	*gluon* g^a	*gluino* $\tilde{\mathrm{g}}^a$	8	1	0
V^k	*Weak* $\mathrm{W}^k(W^\pm, Z)$	*wino, zino* $\tilde{w}^k(\tilde{w}^\pm, \tilde{z})$	1	3	0
V'	*Hypercharge* $\mathrm{B}(\gamma)$	*bino* $\tilde{b}(\tilde{\gamma})$	1	1	0
Matter					
L_i	sleptons $\tilde{L}_i = (\tilde{\nu}, \tilde{e})_L$	leptons $L_i = (\nu, e)_L$	1	2	–1
E_i	sleptons $\tilde{E}_i = \tilde{e}_R$	leptons $E_i = e_R$	1	1	2
Q_i	squarks $\tilde{Q}_i = (\tilde{u}, \tilde{d})_L$	quarks $Q_i = (u, d)_L$	3	2	1/3
U_i	squarks $\tilde{U}_i = \tilde{u}_R$	quarks $U_i = u_R^c$	3^*	1	–4/3
D_i	squarks $\tilde{D}_i = \tilde{d}_R$	quarks $D_i = d_R^c$	3^*	1	2/3
Higgs					
H_1	Higgses H_1	higgsinos $\tilde{H}_1$	1	2	–1
H_2	Higgses H_2	higgsinos $\tilde{H}_2$	1	2	1

Soft SUSY Breaking

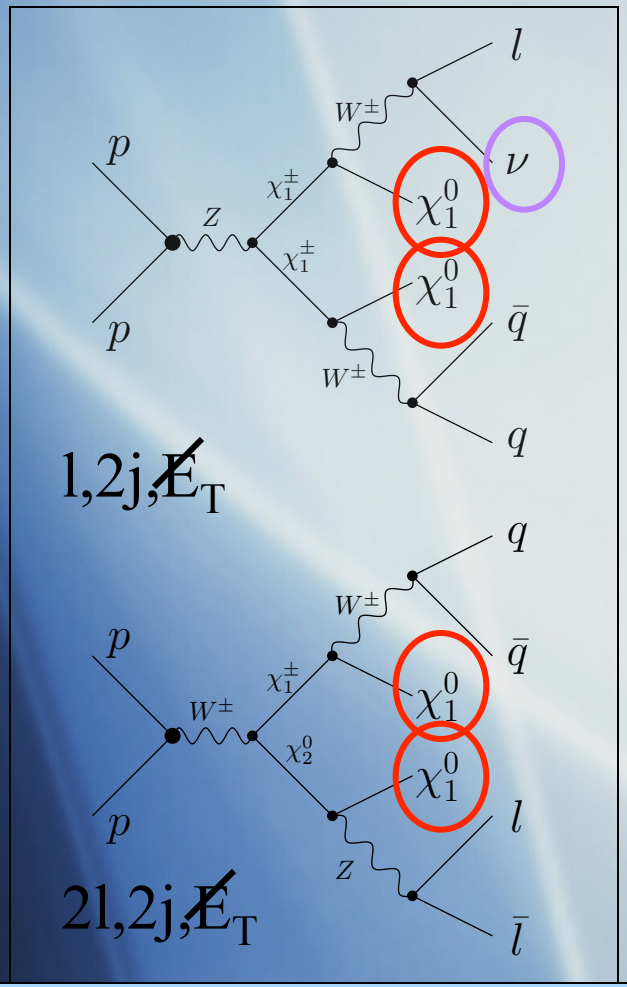
mSUGRA Universality hypothesis (gravity is colour and flavour blind): Soft parameters are equal at Planck (GUT) scale

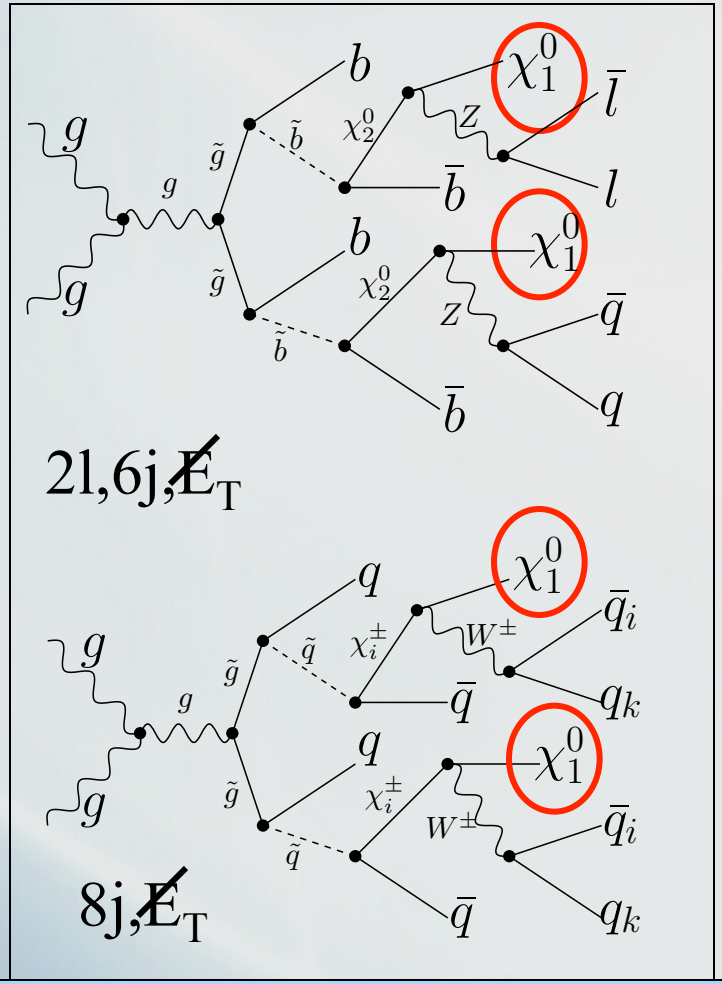
$$-L_{Soft} = A\{y_t Q_L H_2 U_R + y_b Q_L H_1 D_R + y_L L_L H_1 E_R\} + B\mu H_1 H_2$$
$$+ m_0^2 \sum_i |\varphi_i|^2 + \tfrac{1}{2} M_{1/2} \sum_\alpha \tilde{\lambda}_\alpha \tilde{\lambda}_\alpha$$

Five universal soft parameters: $A,\ m_0,\ M_{1/2},\ B \leftrightarrow \tan\beta = v_2 / v_1$ and μ

Creation and Decay of Superpartners in Cascade Processes @ LHC

weak int.s



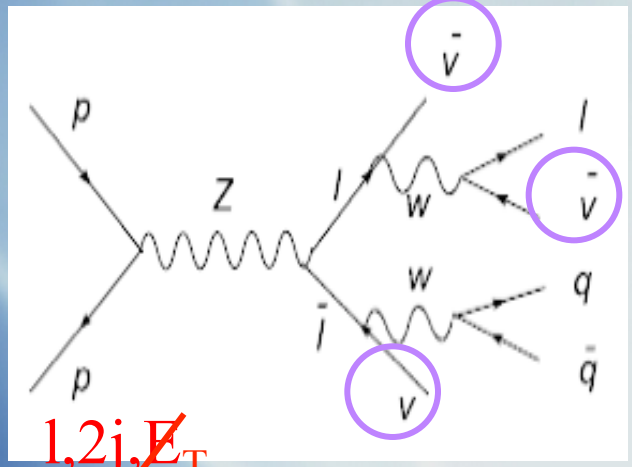


Strong int.s

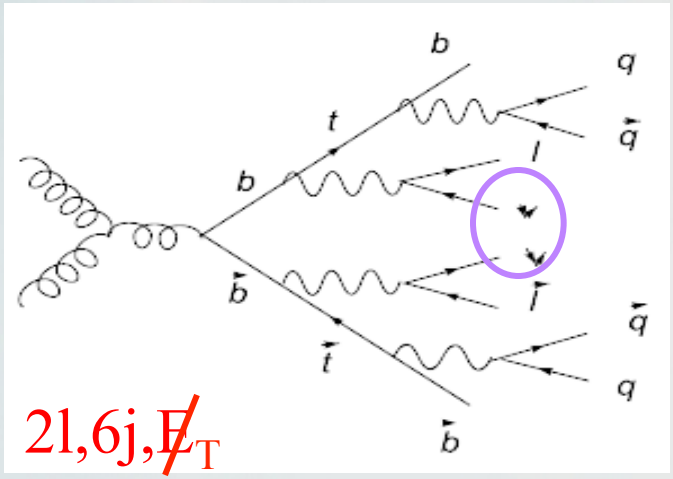
Typical SUSY signature: Missing Energy and Transverse Momentum

Background Processes of the SM for creation of Superpartners

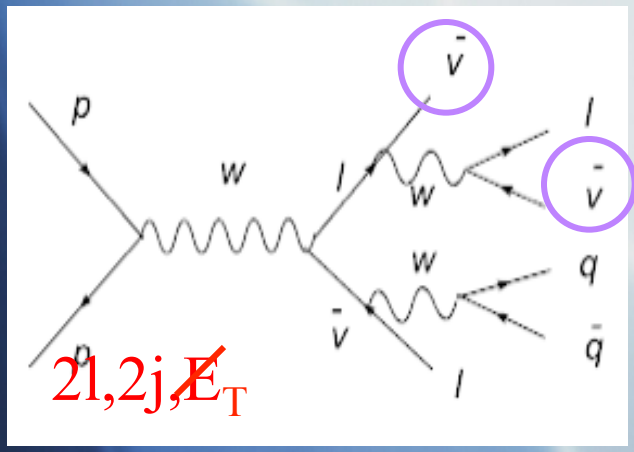
weak int.s



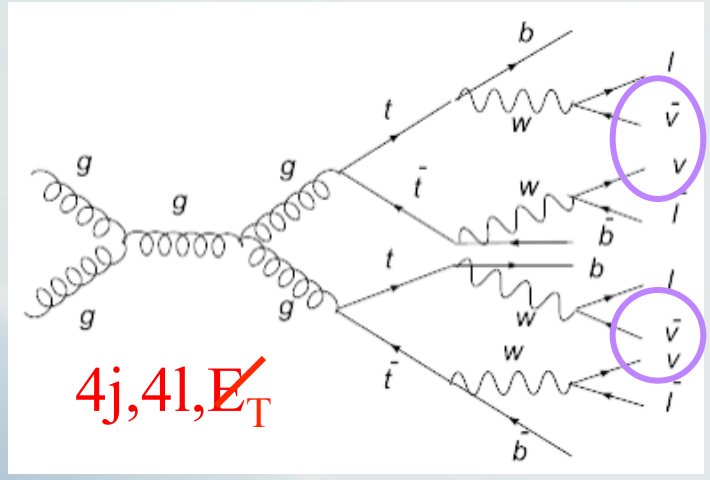
$l,2j,\not{E}_T$



$2l,6j,\not{E}_T$



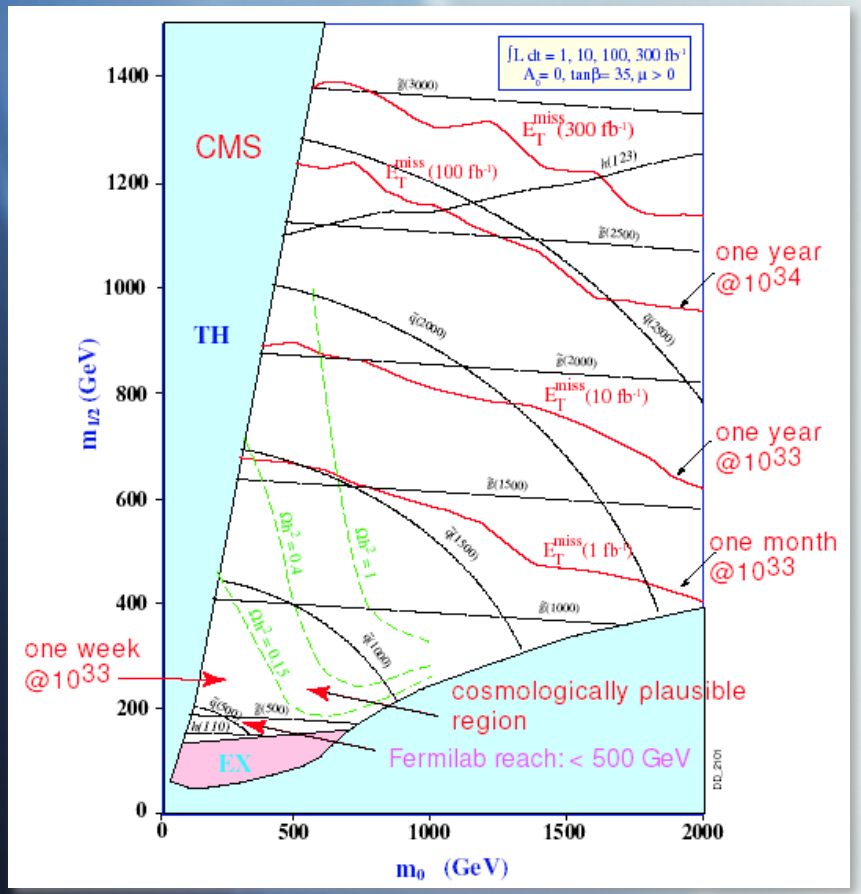
$2l,2j,\not{E}_T$

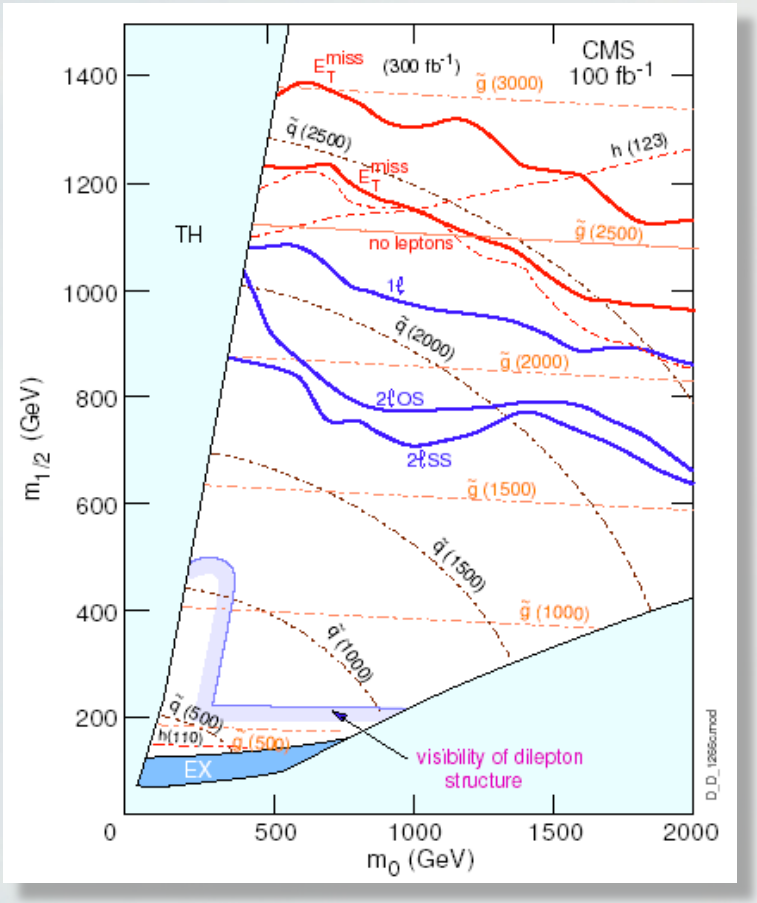


$4j,4l,\not{E}_T$

Strong int.s

Search for Supersymmetry @ LHC





5 σ reach in jets $+\not{E}_T$ channel

Reach limits for various channels at 100 fb $^{-1}$

The Lightest Superparticle

		property	signature
• Gravity mediation	$\mathrm{LSP} = \tilde{\chi}_1^0$	stable	jets/leptons $+\not{E}_T$
• Gauge mediation	$\mathrm{LSP} = \tilde{G}$	stable	$\not{E}_T$
	$\mathrm{NLSP} = \tilde{\chi}_1^0$	$\tilde{\chi}_1^0 \to \gamma\tilde{G}, h\tilde{G}, Z\tilde{G}$	photons/jets $+\not{E}_T$
	$\mathrm{NLSP} = \tilde{l}_R$	$\tilde{l}_R \to \tau\tilde{G}$	lepton $+\not{E}_T$
• Anomaly mediation	$\mathrm{LSP} = \tilde{\chi}_1^0$	stable	lepton $+\not{E}_T$
	$\mathrm{LSP} = \tilde{\nu}_L$	stable	
• R-parity violation	LSP is unstable -> SM particles		

Rare decays
Neutrinoless double β decay

Cosmological Constraints

Precise cosmological data

$$\Omega h^2 = 1 \iff \rho = \rho_{crit}$$

$$\Omega_{vacuum} \approx 73\%$$

$$\Omega_{DarkMatter} \approx 23 \pm 4\%$$

$$\Omega_{Baryon} \approx 4\%$$

- Supernova Ia explosion
- CMBR thermal fluctuations

(from WMAP)

Dark Matter in the Universe:

Hot DM
(not favoured by
galaxy formation)

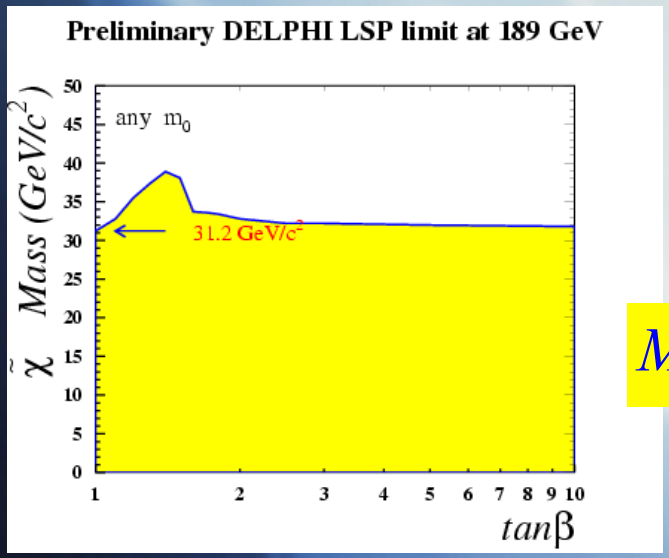
Cold DM ← SUSY
(rotation curves
of Galaxies)

SUSY Dark Matter

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

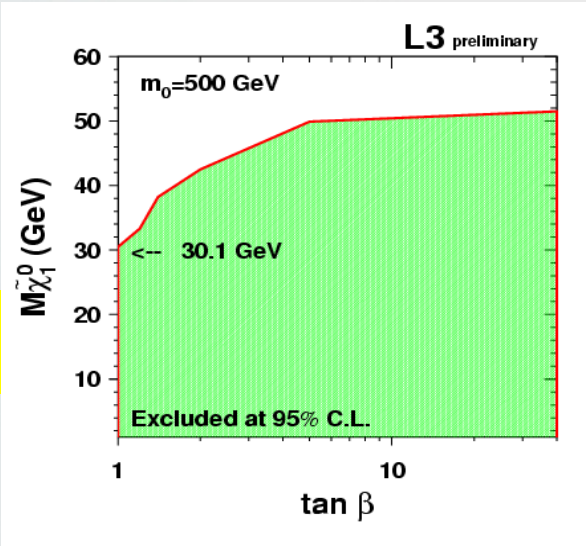
$$\tilde{\chi}^0 = N_1\tilde{\gamma} + N_2\tilde{z} + N_3\tilde{H}_1^0 + N_4\tilde{H}_2^0$$

photino zino higgsino higgsino



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

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



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

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

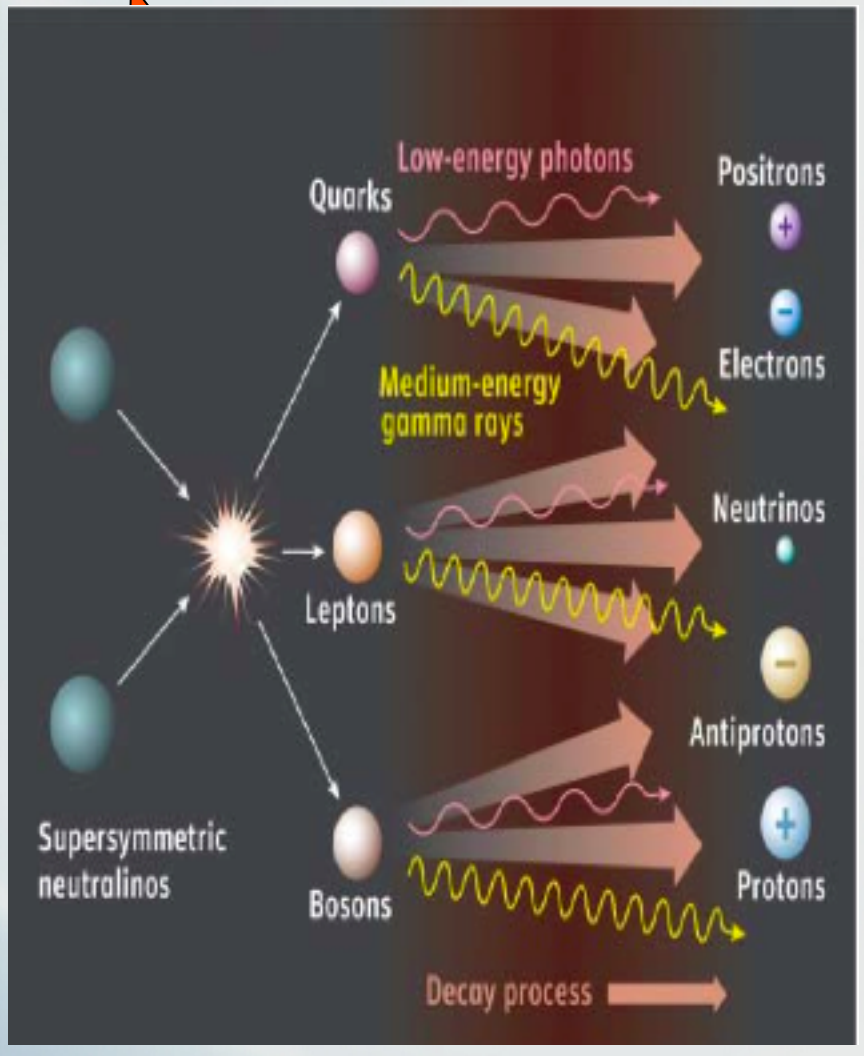
- **Superparticles are created in pairs**
- **The lightest superparticle is stable**

Dark Matter Detection

Direct detection

DAMA, Zeplin,
CDMS, Edelweiss

No convincing evidence so far
Hope for new results soon



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

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

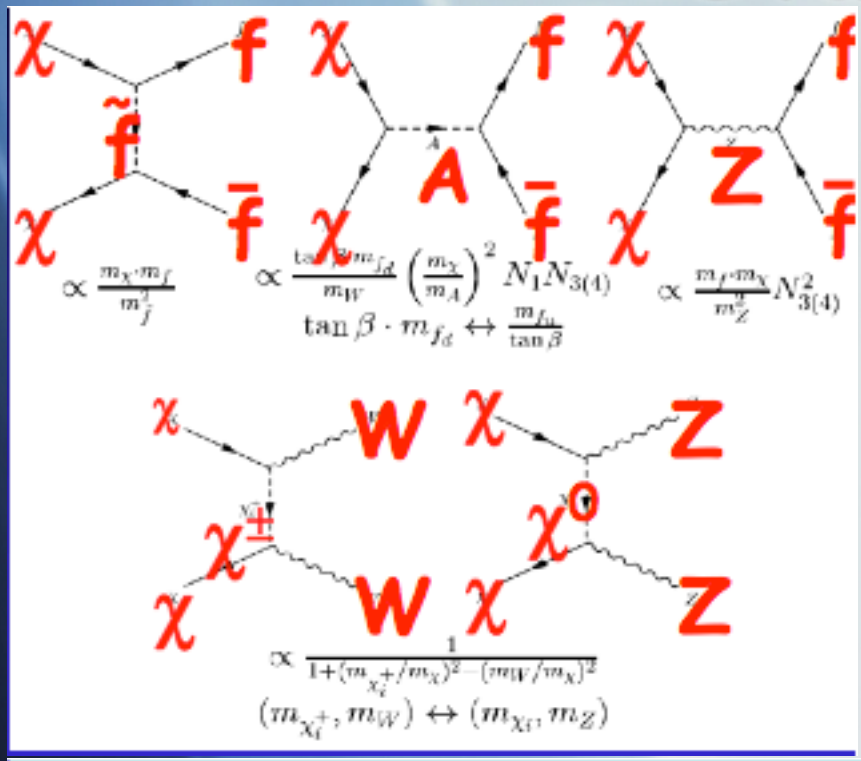
$$\Omega_\chi h^2 \sim 0.113 \pm 0.009,$$

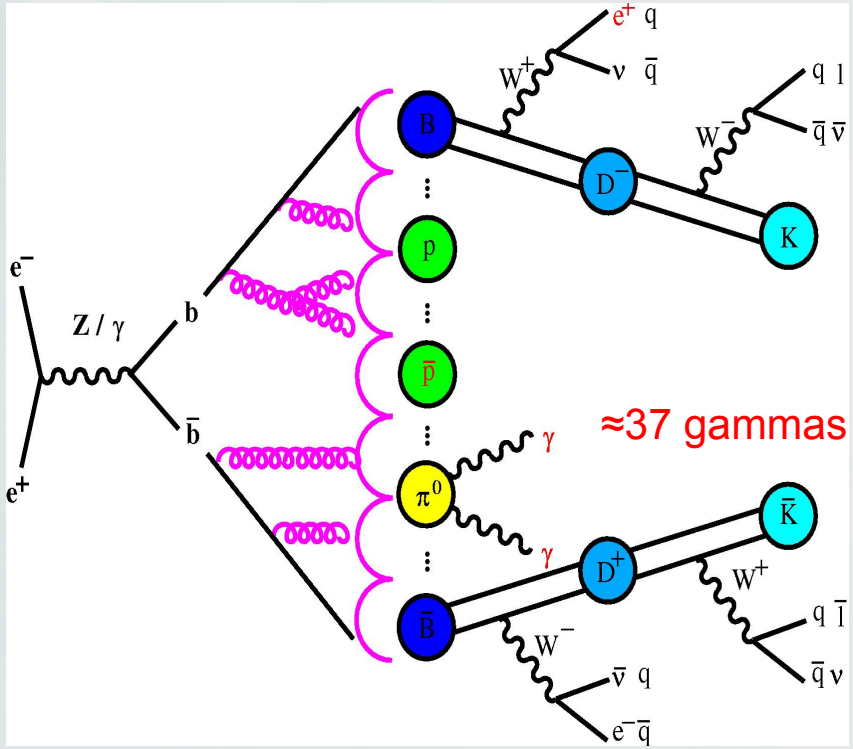
$$v \sim 300\ km/\sec$$

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

Typical EW x-section

DM Neutralino Annihilation Final States

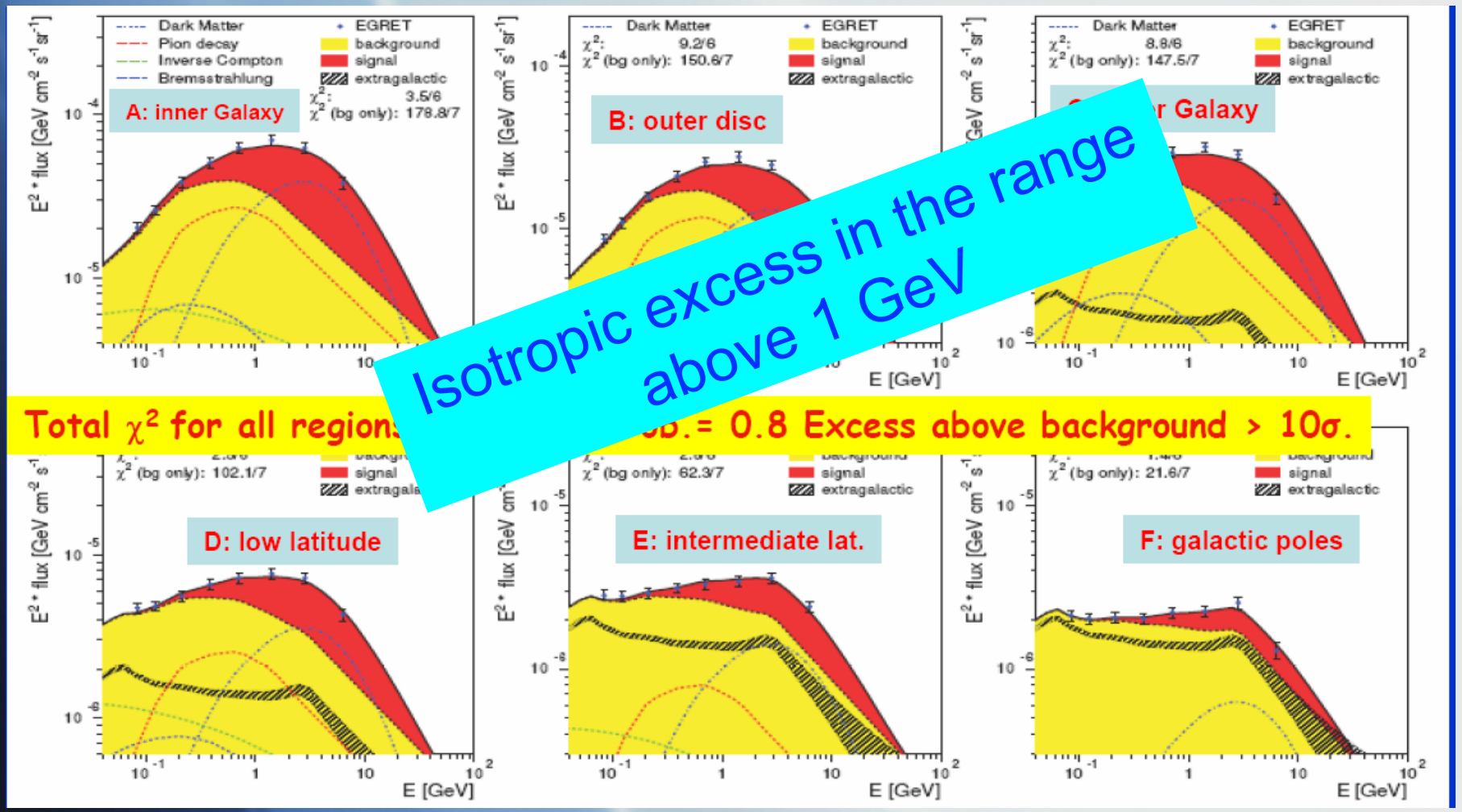




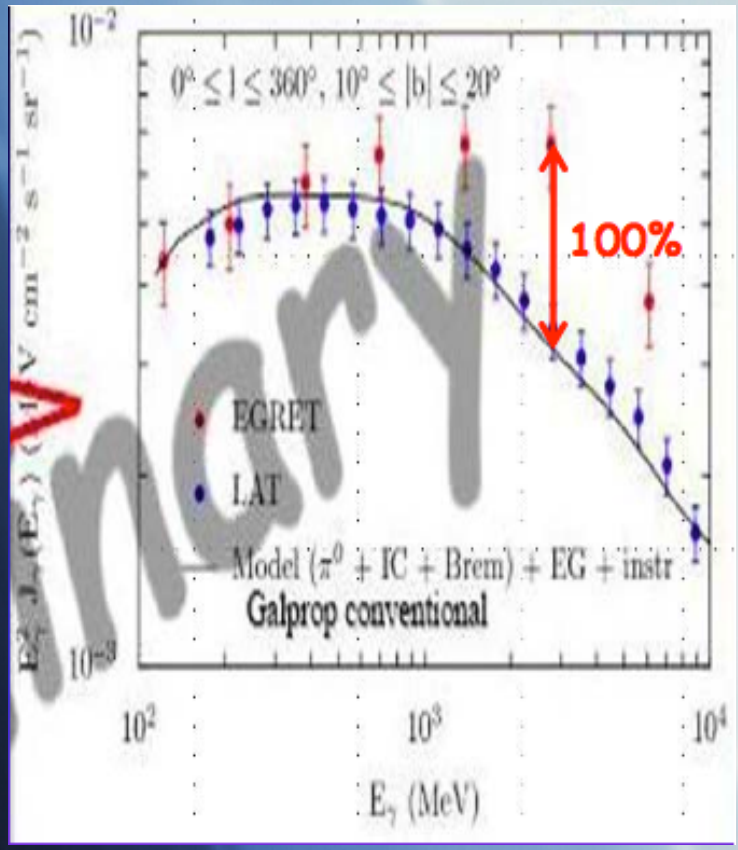
Dominant
$\chi + \chi \Rightarrow A \Rightarrow$ b bbar quark pair
Sum of diagrams should yield
$\langle\sigma v\rangle = 2.10^{-26}$ cm^3/s to get correct relic density

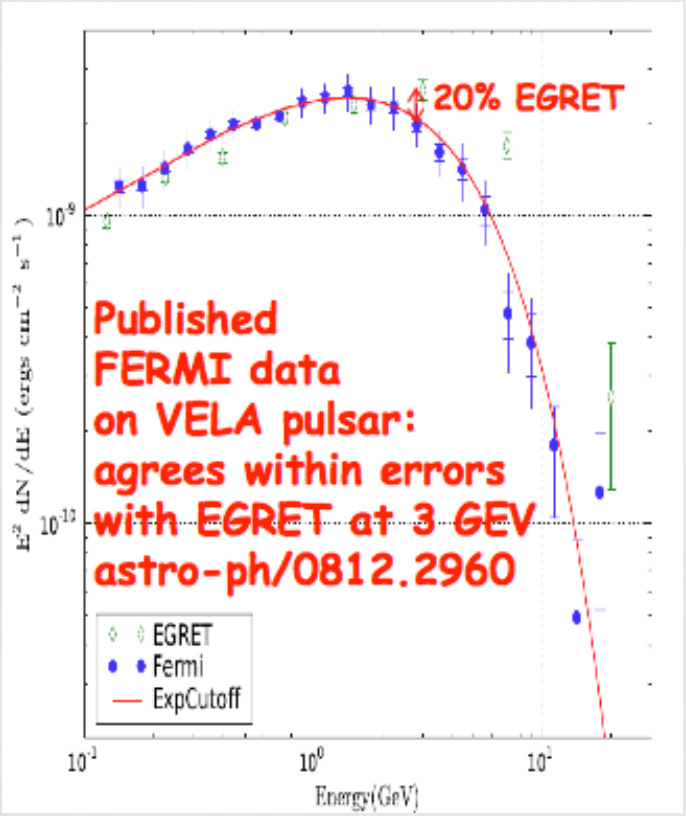
Quark-fragmentation known!
Hence spectra of positrons, gammas and antiprotons known!
Relative amount of γ,p,e+ known as well.

Analysis of EGRET Data in 6 Sky Directions



Diffuse gamma rays from FERMI





Why diffuse spectrum disagrees 100% with EGRET at 3 GeV while VELA spectrum agrees with EGRET at 3 GeV within 20%?

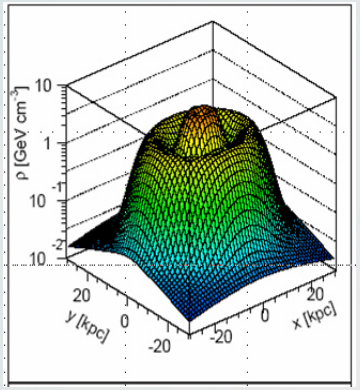
Fitted Hallo Parameters

Gamma Ray Flux: (<σv> from WMAP)

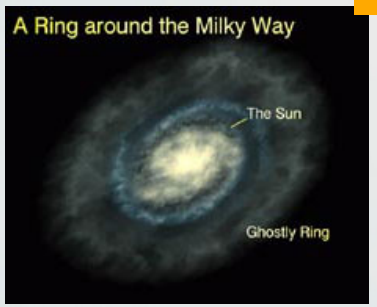
$$\phi_\chi(E,\psi) = \frac{\langle\sigma v\rangle}{4\pi}\sum_f \frac{dN_f}{dE} b_f \int_{line\ of\ sight} B_l \frac{1}{2}\frac{\langle\rho_\chi^2\rangle}{M_\chi^2} dl_\psi$$

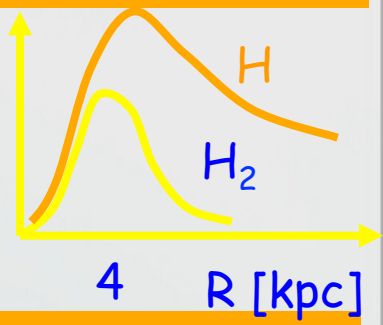
$$\rho_\chi(\tilde{r}) = \rho_0 \left(\frac{R_0}{\tilde{r}}\right)^\gamma \left[\frac{1+\left(\frac{\tilde{r}}{a}\right)^\alpha}{1+\left(\frac{R_0}{a}\right)^\alpha}\right]^{\frac{\gamma-\beta}{\alpha}} + \sum_{n=1}^{N} \rho_n \exp\left(-\frac{(\tilde{r}_{gc}-Rn)^2}{2\sigma_{Rn}^2} - \frac{(z_n)^2}{2\sigma_{z_n}^2}\right)$$

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



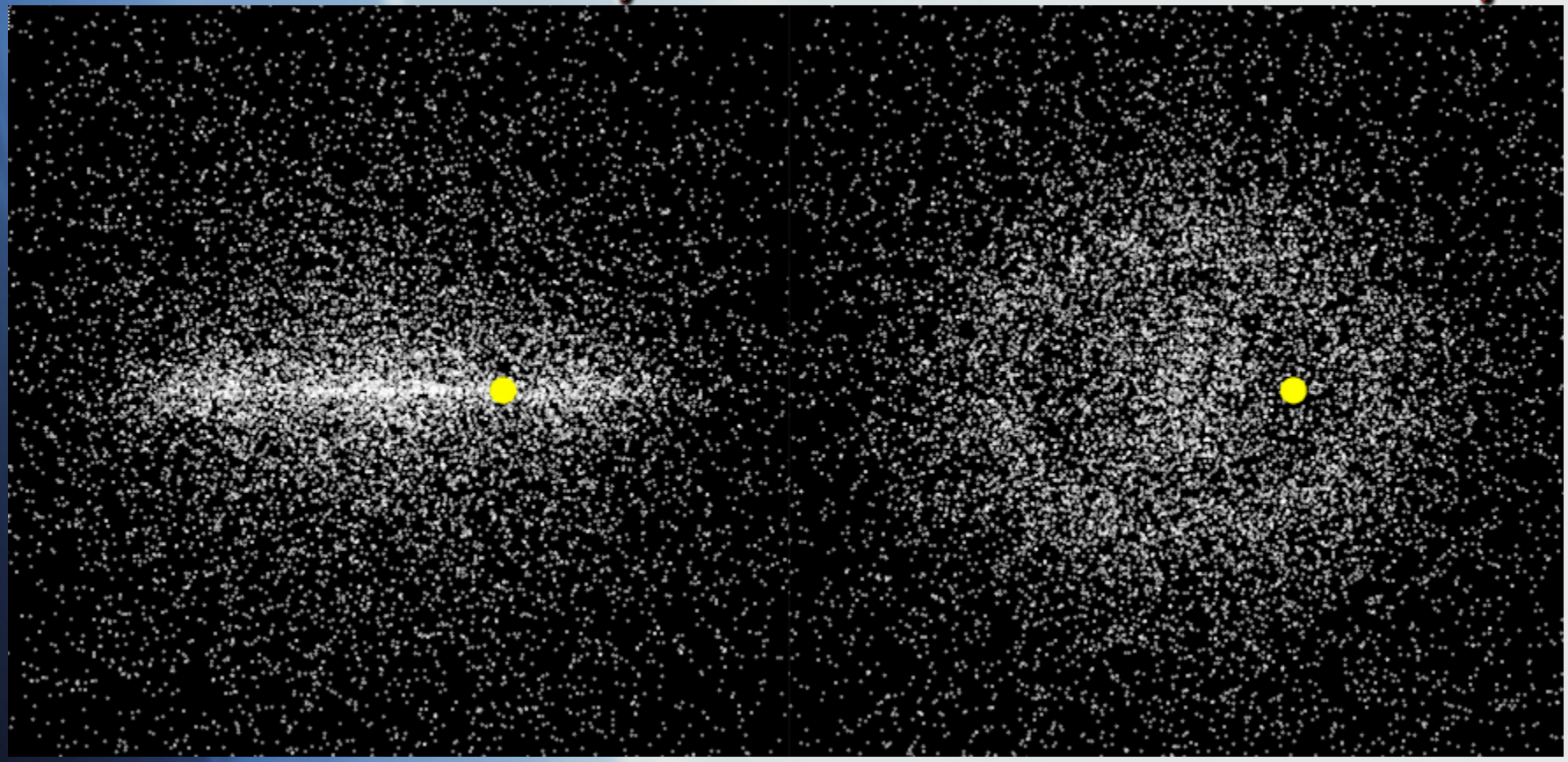


14 kpc coincides with ring of stars at 14-18 kpc due to infall of dwarf galaxy

4 kpc coincides with ring of neutral hydrogen molecules!

W.de Boer, C.sander, V.Zhukov, A.Gladyshev, and D.Kazakov, A&A 444 (2005)17

Hallo Density on Scale of 30 Kpc



Side view

	Isother.	NFW
R200	295 kpc	145 kpc
DM:	3.10^{12} $M_\odot$	$3.10^{11} M_\odot$
Vis.:	6.10^{10} $M_\odot$	
Outer Ring:	3.10^{10} $M_\odot$	
Inner Ring:	3.10^{9} $M_\odot$	

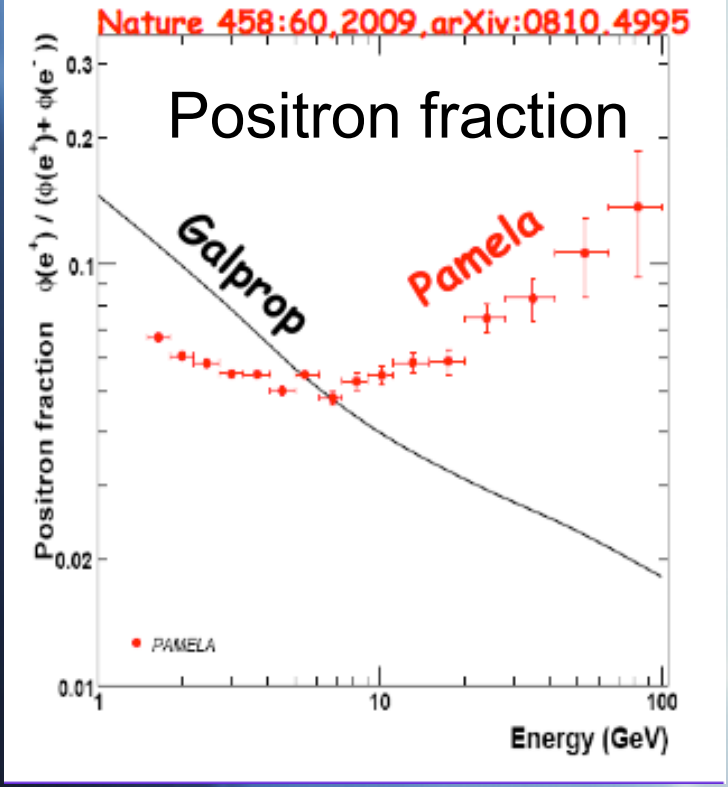
Top view

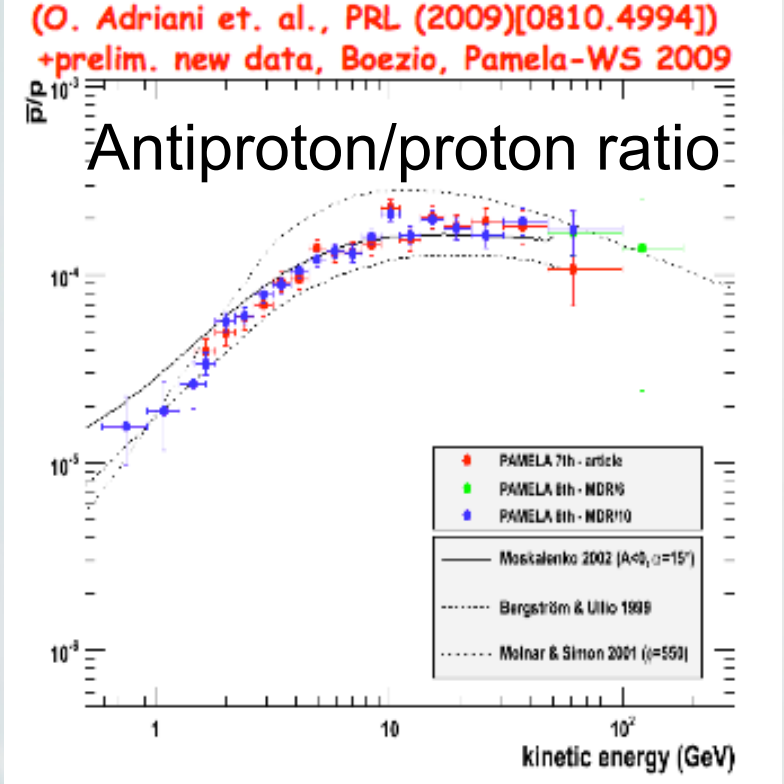
Clustering of of Dark Matter

Cluster size: ≈ Solar system?
$M_{min} \cong 10^{-8} - 10^{-6}\ M_\odot$?
Steeply falling mass spectrum.
Boost factor ~ $\langle\rho^2\rangle/\langle\rho\rangle^2$ ~ 20-2000
From fit: B≈100 for WIMP of 60 GeV

Clumps with M_{min} -> dominant contribution -> MANY clumps in given direction -> same boostfactor in all directions

PAMELA: positron and antiproton measurements

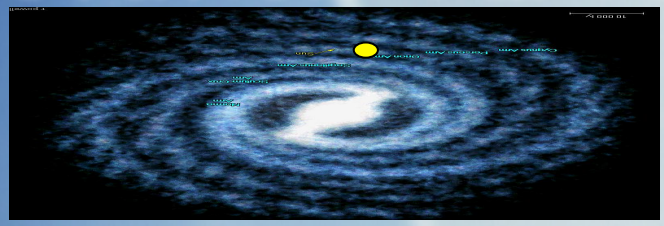




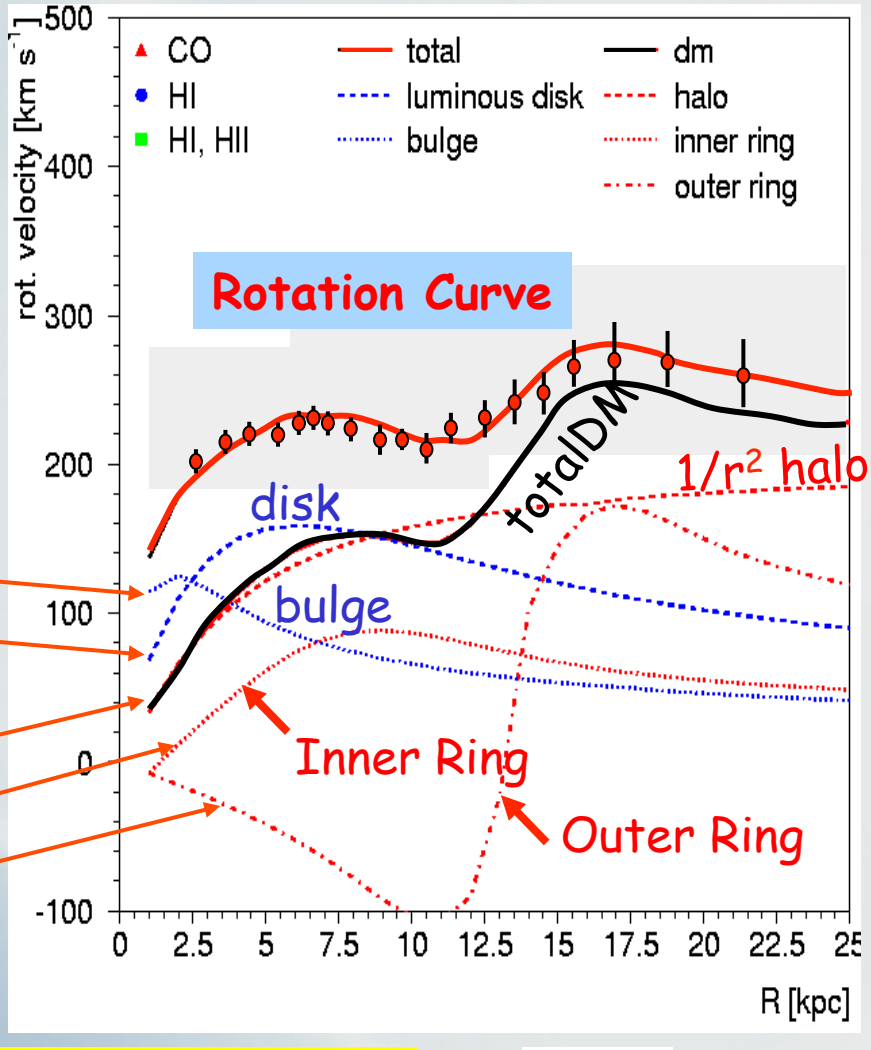
Positrons: excess

Antiprotons: NO excess

Rotation Curve for the Milky Way



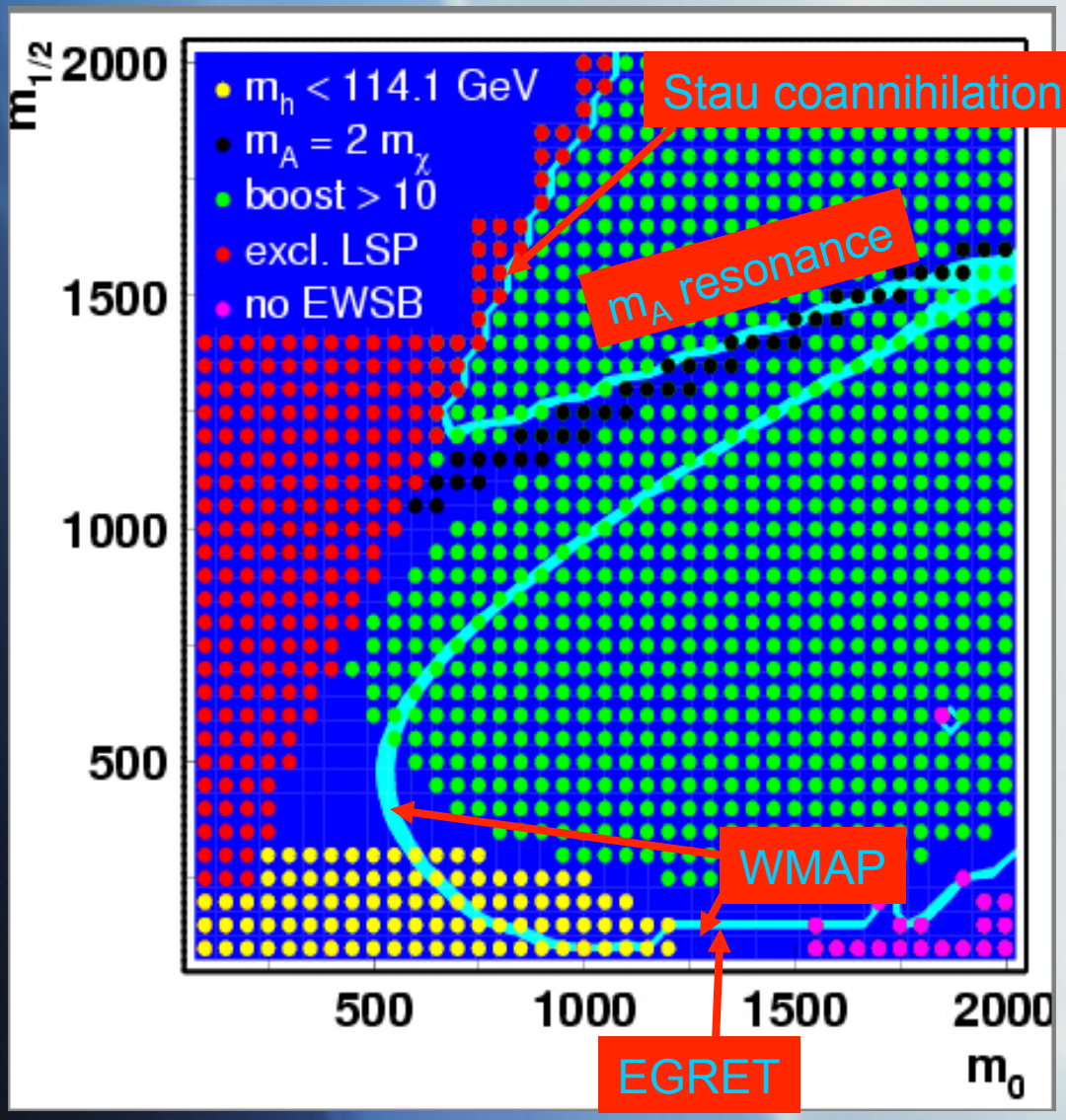
- Contributions to the rotation curve of the Milky Way from
  - Visible bulge
  - Visible disk
  - Dark halo
  - Inner dark ring
  - Outer dark ring



Normalize to solar velocity of 220 km/s

R [kpc]

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)

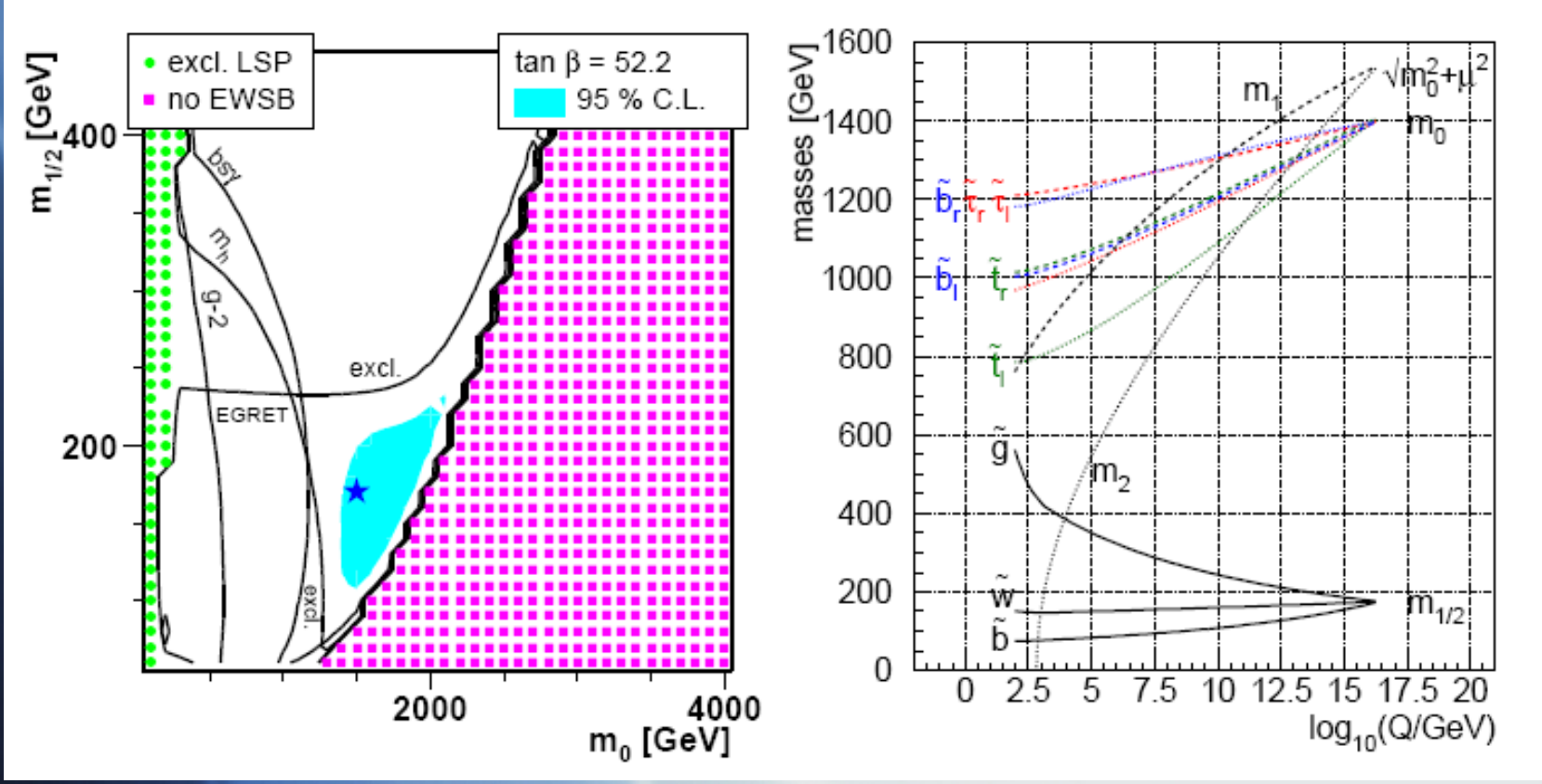
m_0 common spin 0 mass

$m_{1/2}$ common spin ½ mass

$\tan\beta = v_2/v_1$

High tanβ solution
tanβ = 50

EGRET Point and Mass Spectrum



W.de Boer, C.sander, V.Zhukov, A.Gladyshev, and D.Kazakov, PL B636 (2006)13

PHYSICS PROBLEMS

- Cosmologists:

  What is CDM and Dark Energy made of?

- Astrophysicists:

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

- Particle physicists :

  Where are the Supersymmetric Particles?

- Astronomers:

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

Solution: **DM is made of WIMPs which are SUSY particles distributed in Halo of our Galaxy with a mass around 70 GeV**