Can one say SUSY from the window in the sky?

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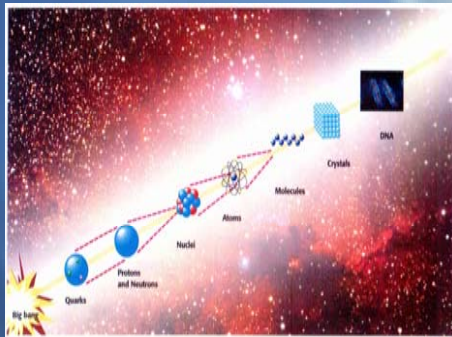
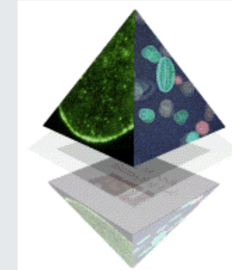


What is SUSY?



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

$Q\,|\,boson>=|\ fe\ldots$ … $\ldots on>$

$[b,b\ldots$ … $\ldots 2\delta^{ij}(\sigma^{\mu})_{\alpha\dot{\beta}}P_{\mu}$

First papers in 1971-1972

No evidence in particle physics yet

- Modern … …ry in particle physics are based o… …gin, though low energy manifestatio… …SY can be found (?) at modern colliders and i… 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 $\tilde{g}^a$	8	1	0
V^k	Weak $W^k (W^\pm, Z)$	wino, zino $\tilde{w}^k (\tilde{w}^\pm, \tilde{z})$	1	3	0
V'	Hypercharge $B(\gamma)$	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

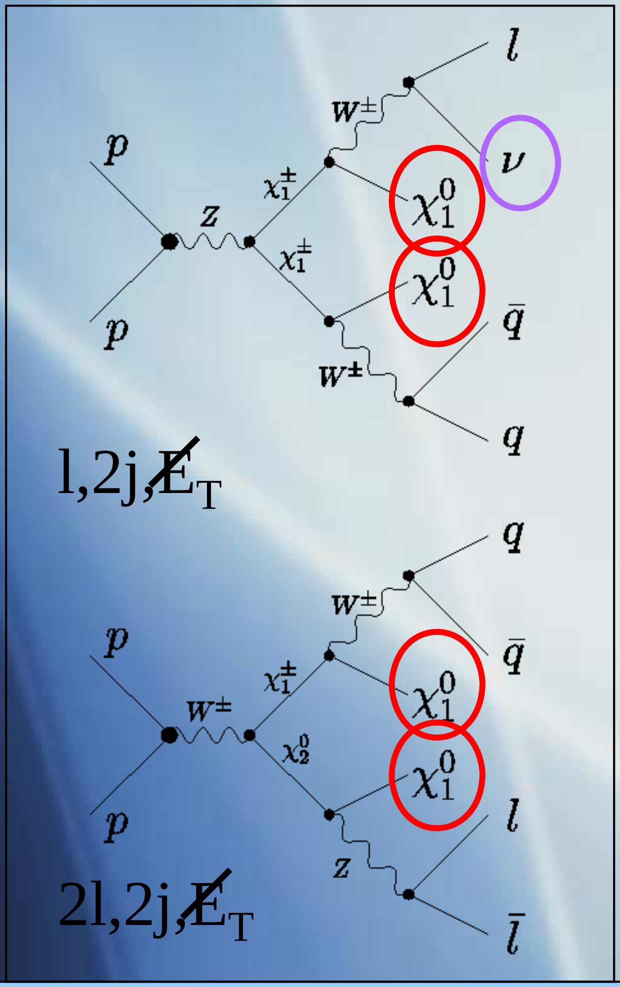
mSUGRA Universality hypothesis (gravity is colour and flavour blind):
Soft parameters are equal at Planck (GUT) scale

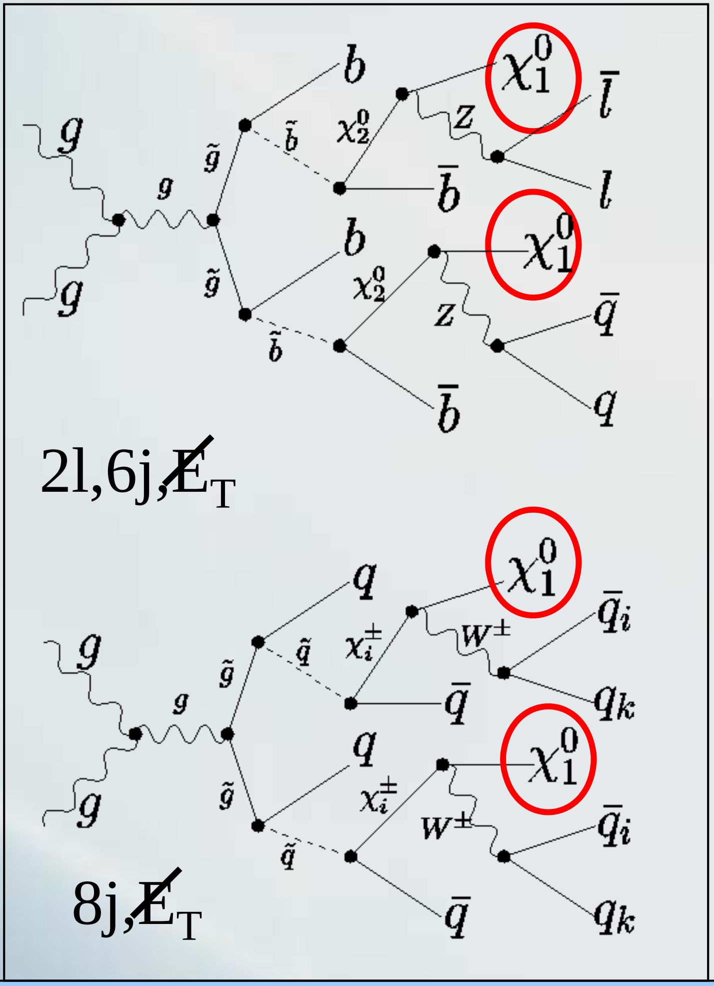
$$-L_{Soft} = A\{y_t Q_L H_2 U_R + y_b Q_L H_1 D_R + y_L L_L H_1 E_R\} + B\mu H_1 H_2$$
$$+ m_0^2 \sum_i |\varphi_i|^2 + \tfrac{1}{2} M_{1/2} \sum_\alpha \tilde{\lambda}_\alpha \tilde{\lambda}_\alpha$$

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



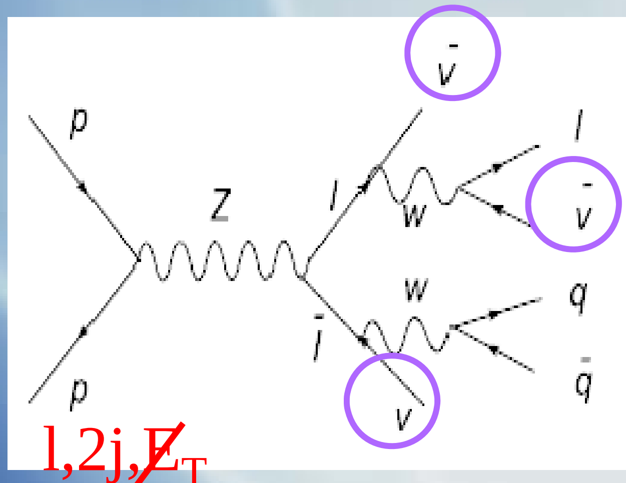


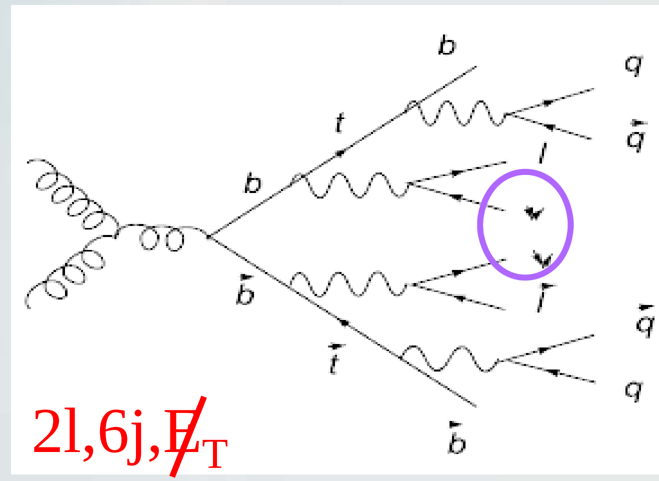
strong int's

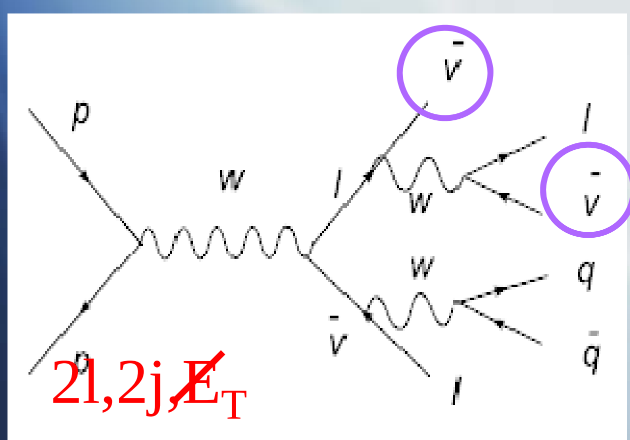
Typical SUSY signature: Missing Energy and Transverse Momentum

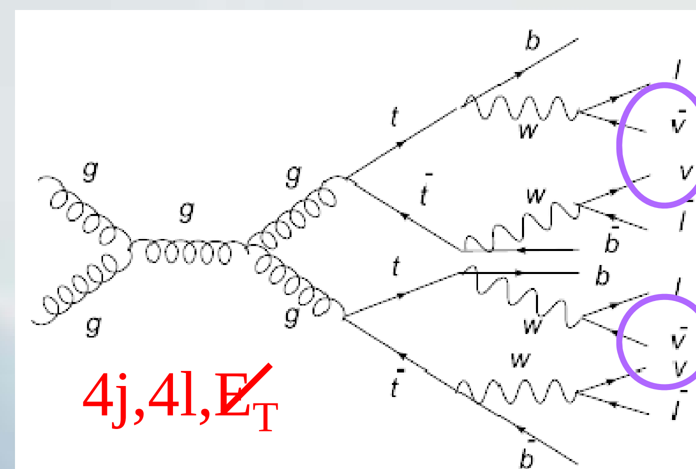
Background Processes of the SM for creation of Superpartners

weak ints.



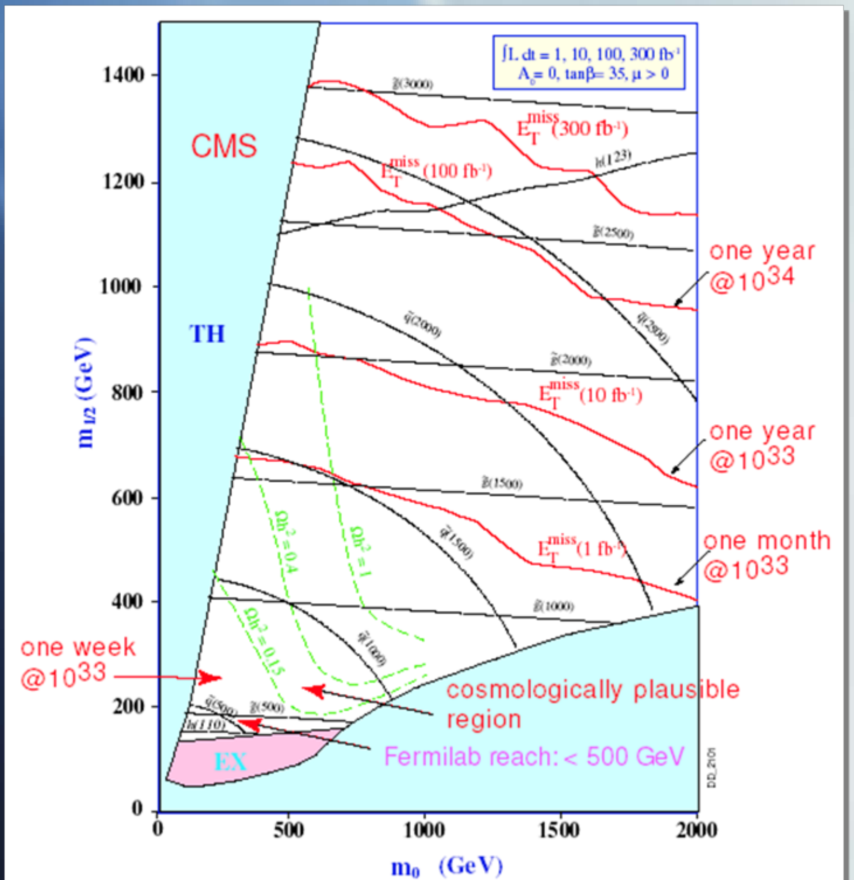




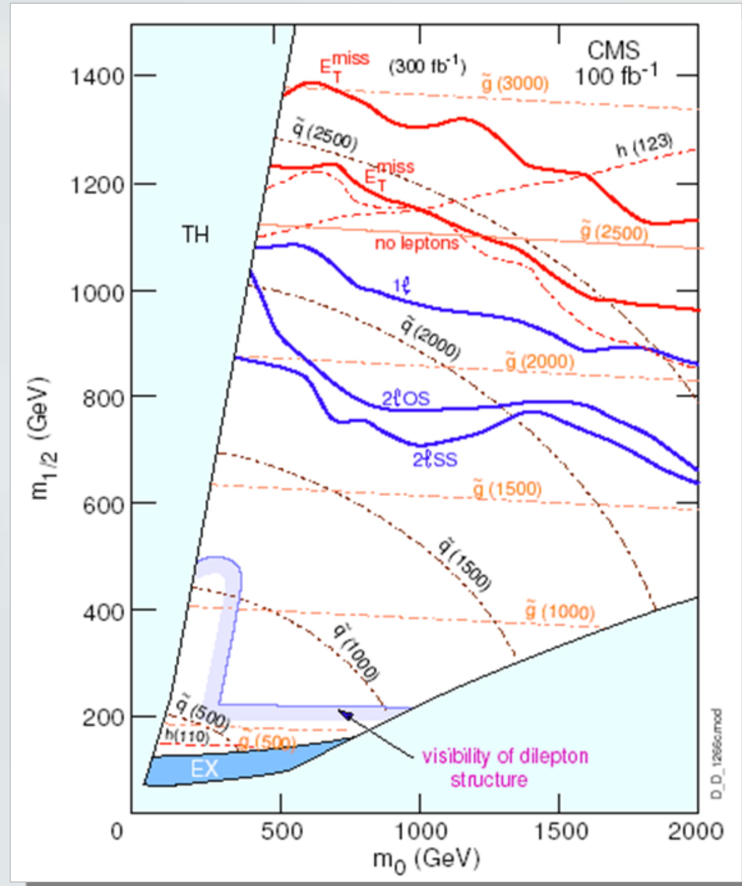


strong ints.

Search for Supersymmetry @ LHC



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



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

The Lightest Superparticle

		property	signature
• Gravity mediation	$\mathrm{LSP} = \chi_1^0$	stable	jets/leptons $+ \not{E}_T$
• Gauge mediation	$\mathrm{LSP} = G$	stable	$\not{E}_T$
	$\mathrm{NLSP} = \begin{cases} \chi_1^0 \\ \tilde{l}_R \end{cases}$	$\chi_1^0 \to \gamma G, hG, ZG$ $\tilde{l}_R \to \tau G$	photons/jets $+ \not{E}_T$ lepton $+ \not{E}_T$
• Anomaly mediation	$\mathrm{LSP} = \begin{cases} \chi_1^0 \\ \tilde{\nu}_L \end{cases}$	stable stable	lepton $+ \not{E}_T$
• R-parity violation	LSP is unstable -> SM particles		

Rare decays

Neutrinoless double β decay

Cosmological Constraints

Precise cosmological data

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

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

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

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

- Supernova Ia explosion
- CMBR thermal fluctuations

(from WMAP)

Dark Matter in the Universe:

Hot DM
(not favoured by
galaxy formation)

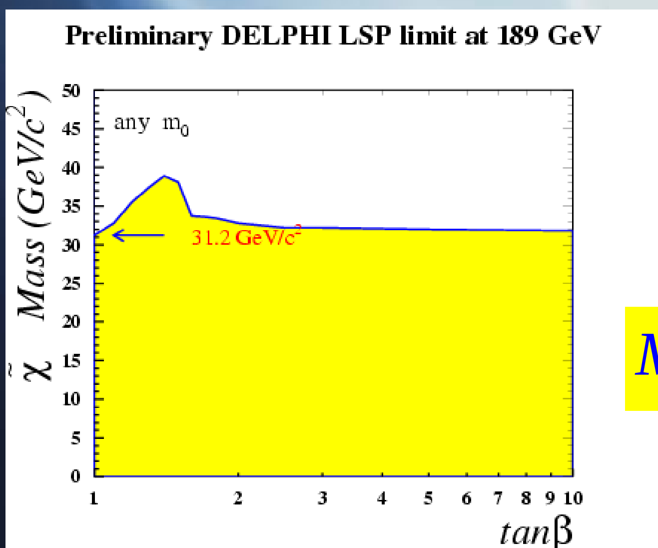
Cold DM ← SUSY
(rotation curves
of Galaxies)

SUSY Dark Matter

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

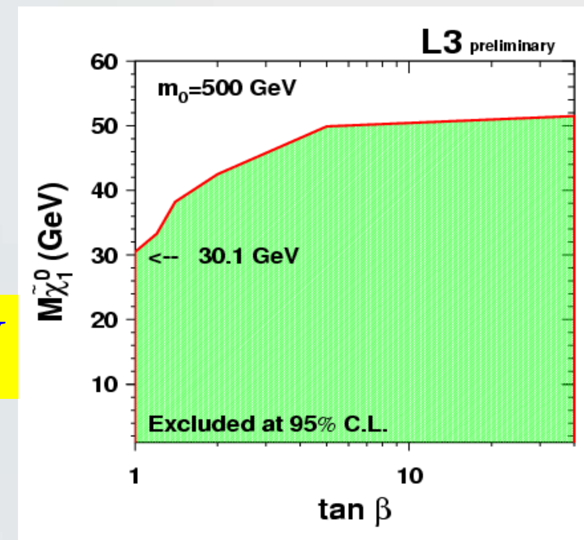
$$\tilde{\chi}^0 = N_1\tilde{\gamma} + N_2\tilde{Z} + N_3\tilde{H}_1^0 + N_4\tilde{H}_2^0$$

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

Indirect detection

- EGRET -> GLAST(FERMI)

Diffuse Gamma Rays

QuickTime™ and a decompressor are needed to see this picture.

- HEAT, AMS01 -> PAMELA

Positrons in Cosmic Rays

- BESS -> AMS02

Antiprotons in Cosmic Rays

Evidence of DM annihilation!

Why WIMP?

Boltzman Equation

Hubble constant

$$\frac{dn_\chi}{dt} + 3Hn_\chi = -<\sigma \mathrm{v}>(n_\chi^2 - n_{\chi,eq}^2), \qquad H = \dot{R}/R$$

Relic Abundance

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

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

$$\mathrm{v} \sim 300\ km / \sec$$

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

Typical EW x-section

DM Neutralino Annihilation Final States

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decompressor
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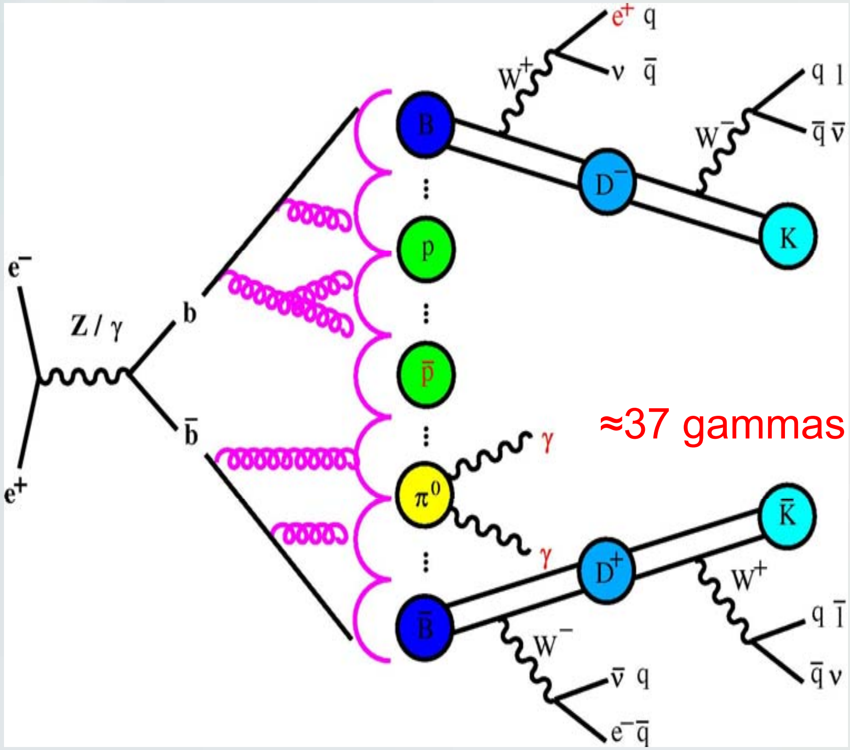

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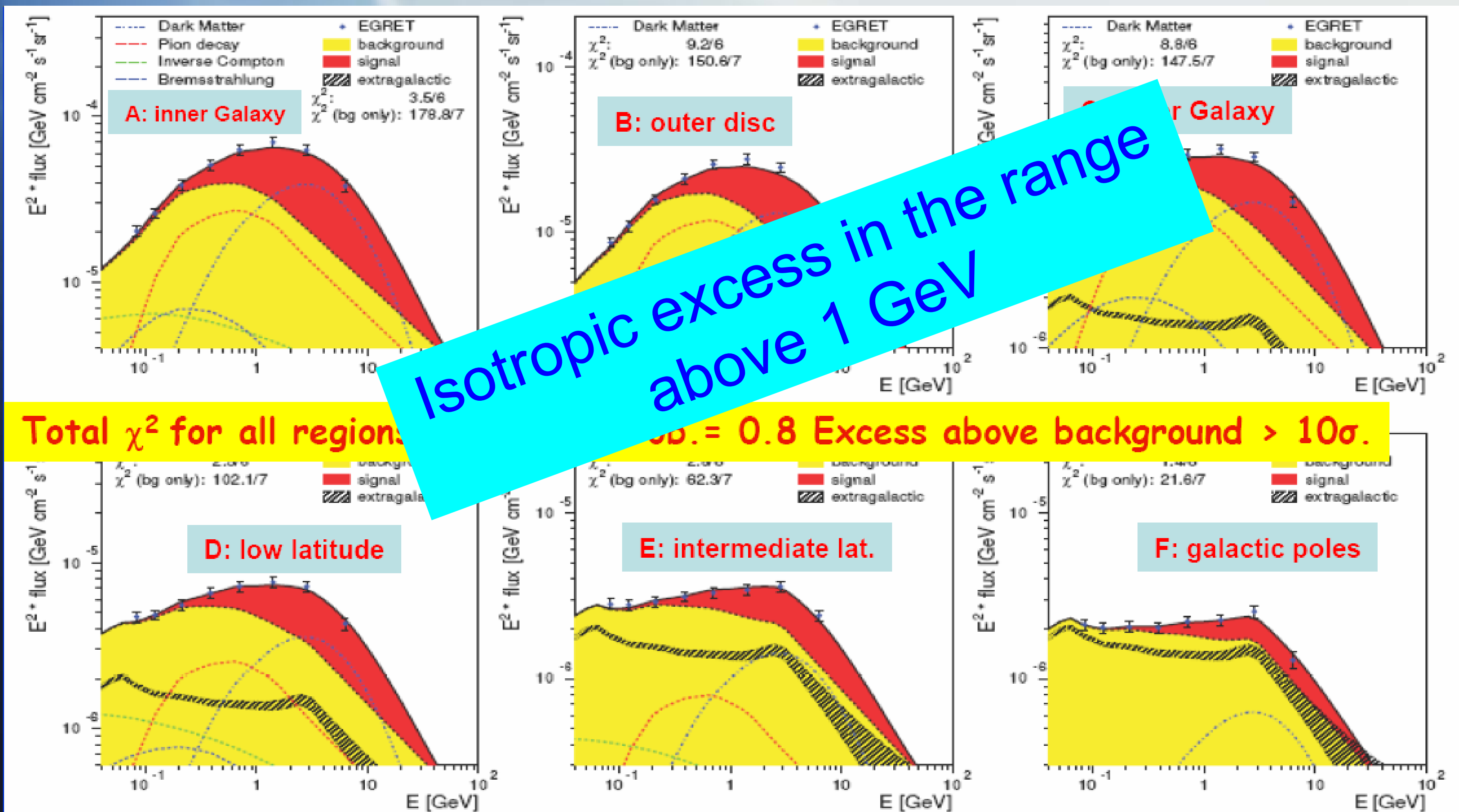
Analysis of EGRET Data in 6 Sky Directions



Total χ^2 for all regions … ob.= 0.8 Excess above background > 10σ.

Isotropic excess in the range above 1 GeV

Diffuse gamma rays from FERMI

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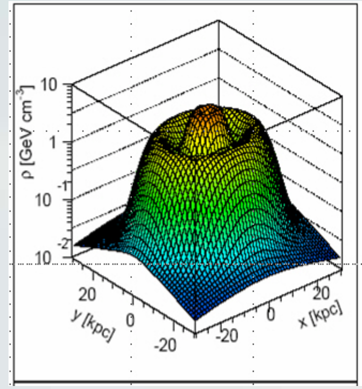
Fitted Hallo Parameters

Gamma Ray Flux: (<σv> from WMAP)

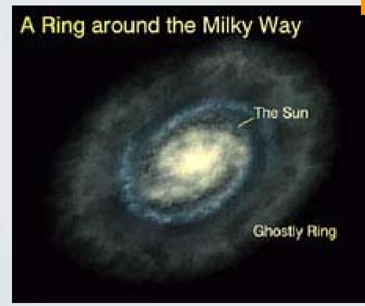
$$\phi_\chi(E,\psi) = \frac{\langle\sigma v\rangle}{4\pi}\sum_f \frac{dN_f}{dE} b_f \int_{line\ of\ sight} B_l \frac{1}{2}\frac{\langle\rho_\chi^2\rangle}{M_\chi^2} dl_\psi$$

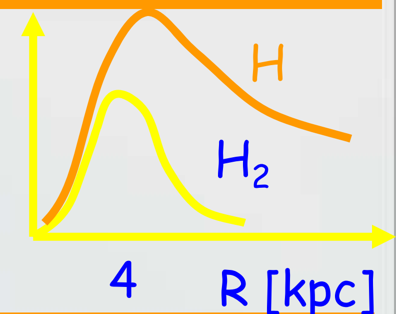
$$\rho_\chi(\tilde{r}) = \rho_0\left(\frac{R_0}{\tilde{r}}\right)^\gamma \left[\frac{1+\left(\frac{\tilde{r}}{a}\right)^\alpha}{1+\left(\frac{R_0}{a}\right)^\alpha}\right]^{\frac{\gamma-\beta}{\alpha}} + \sum_{n=1}^{N}\rho_n \exp\left(-\frac{(\tilde{r}_{gc}-R_n)^2}{2\sigma_{R_n}^2} - \frac{(z_n)^2}{2\sigma_{z_n}^2}\right)$$

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



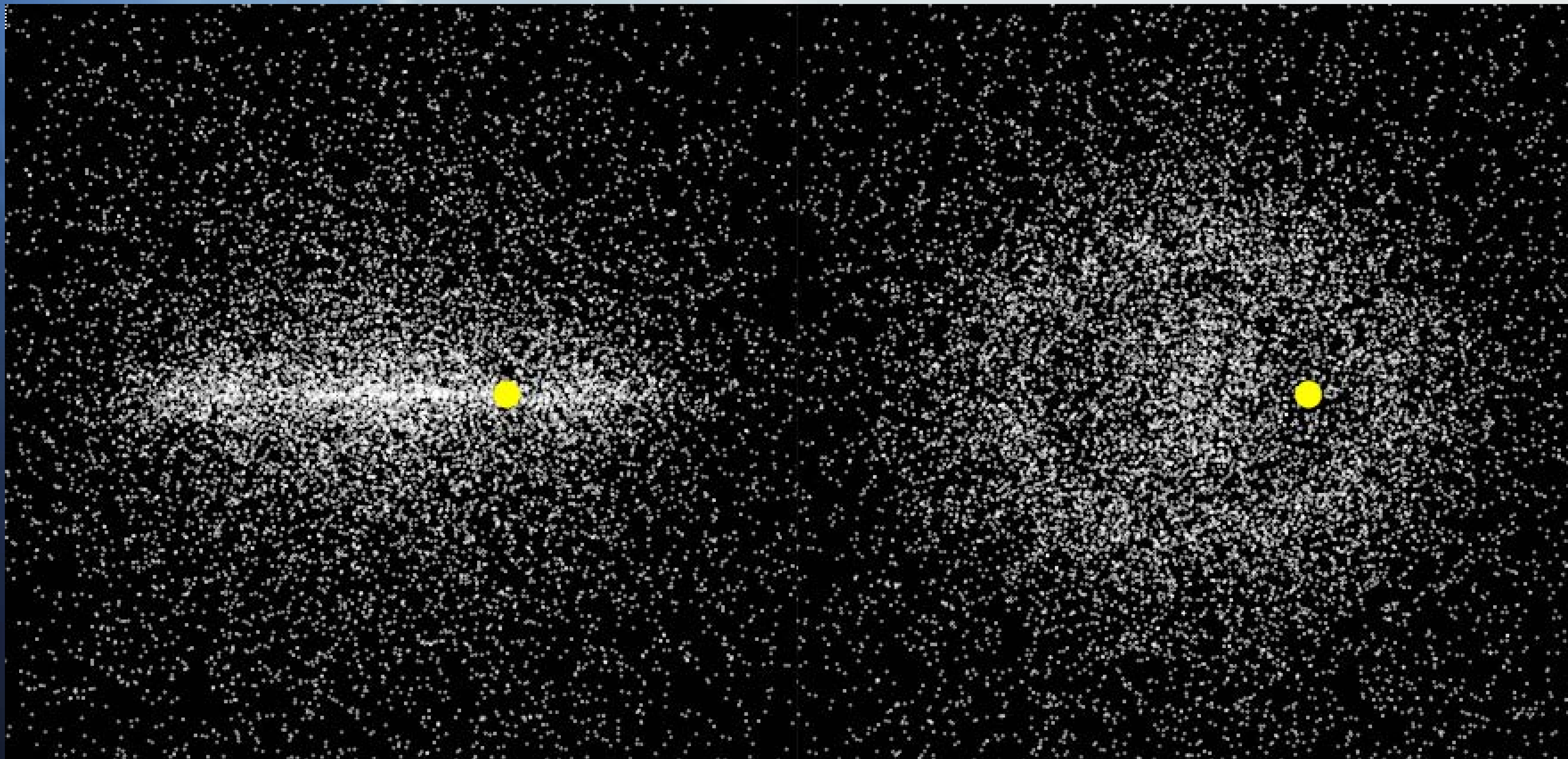


14 kpc coincides with ring of stars at 14-18 kpc due to infall of dwarf galaxy

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

Top view

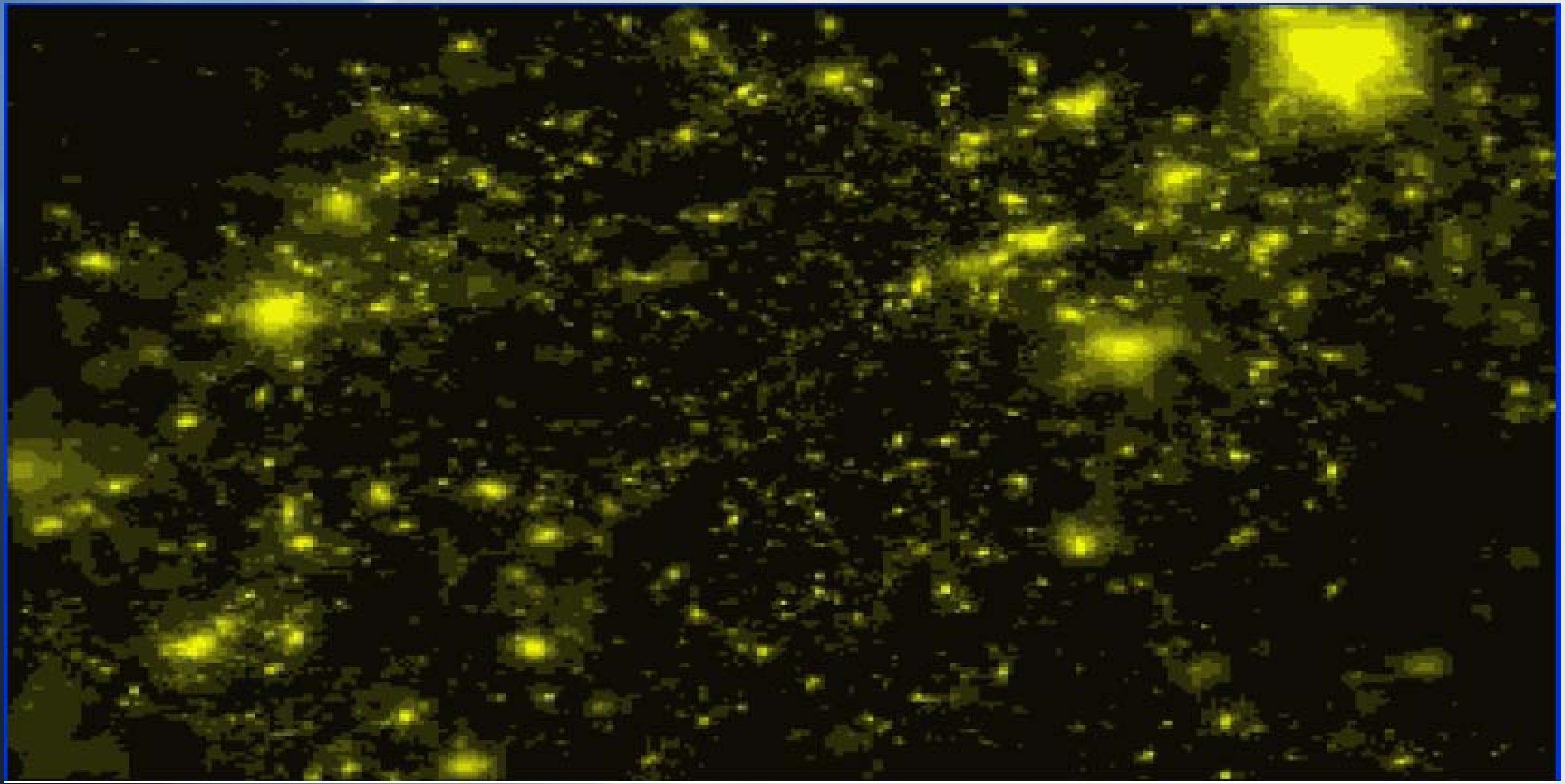
	Isother.	NFW
R200	295 kpc	145 kpc
DM:	$3.10^{12}\ M_\odot$	$3.10^{11} M_\odot$

Vis.: $6.10^{10}\ M_\odot$

Outer Ring: $3.10^{10}\ M_\odot$

Inner Ring: $3.10^{9}\ M_\odot$

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

Positron fraction

Antiproton/proton ratio

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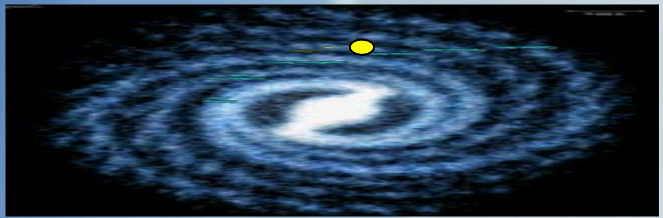
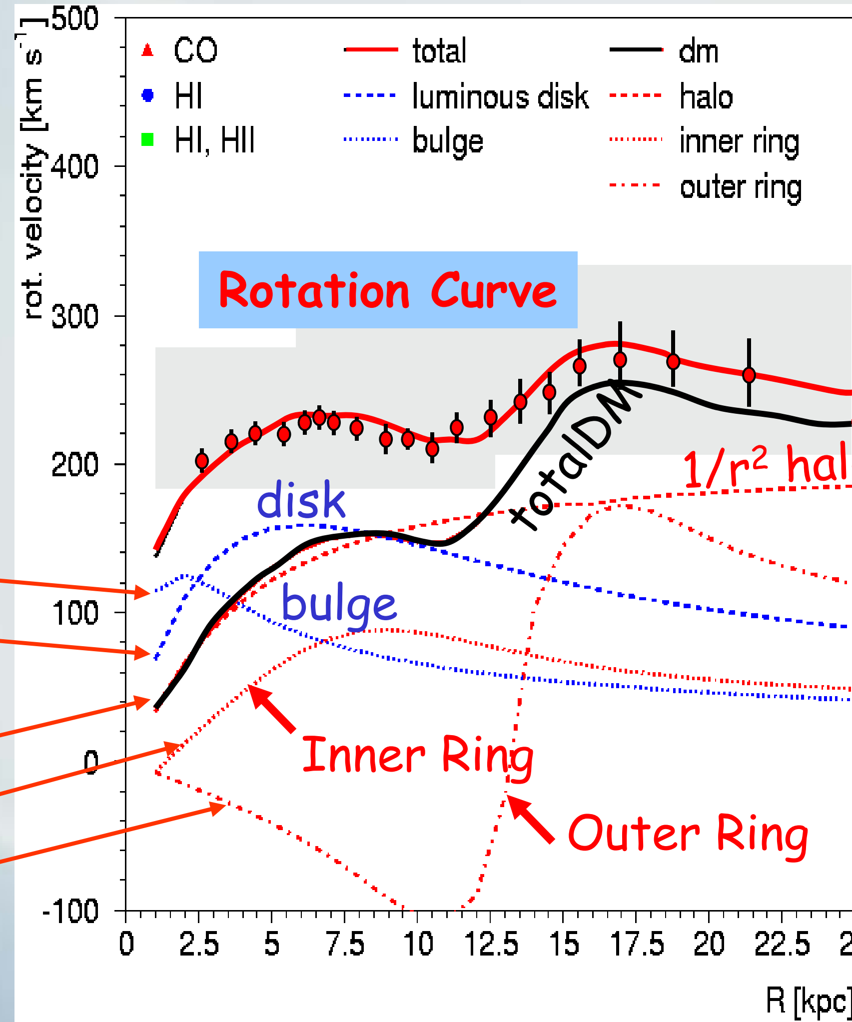
Rotation Curve for the Milky Way



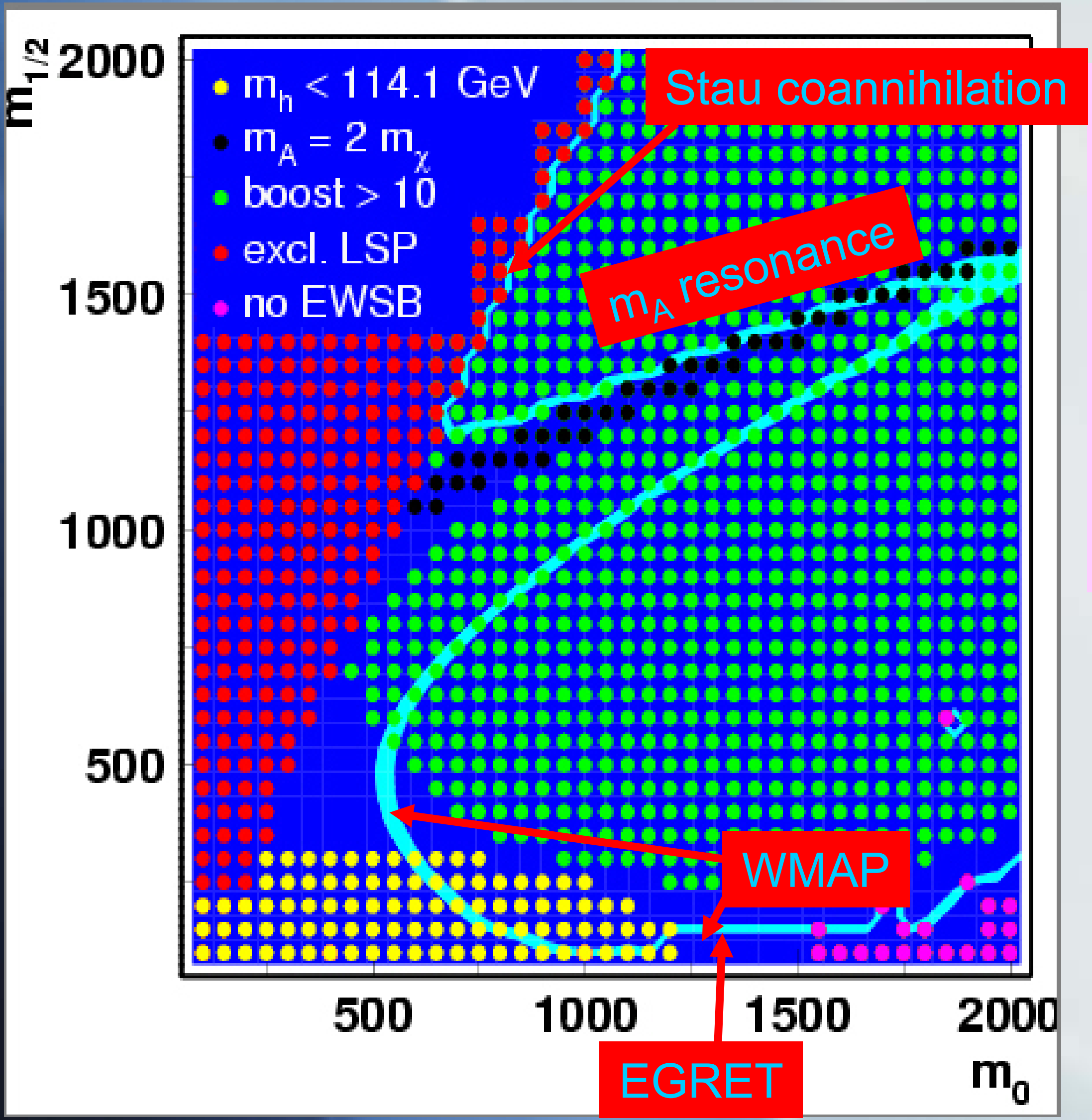
- Contributions to the rotation curve of the Milky Way from
  - Visible bulge
  - Visible disk
  - Dark halo
  - Inner dark ring
  - Outer dark ring



Normalize to solar velocity of 220 km/s

R [kpc]

Allowed SUSY Parameter Space

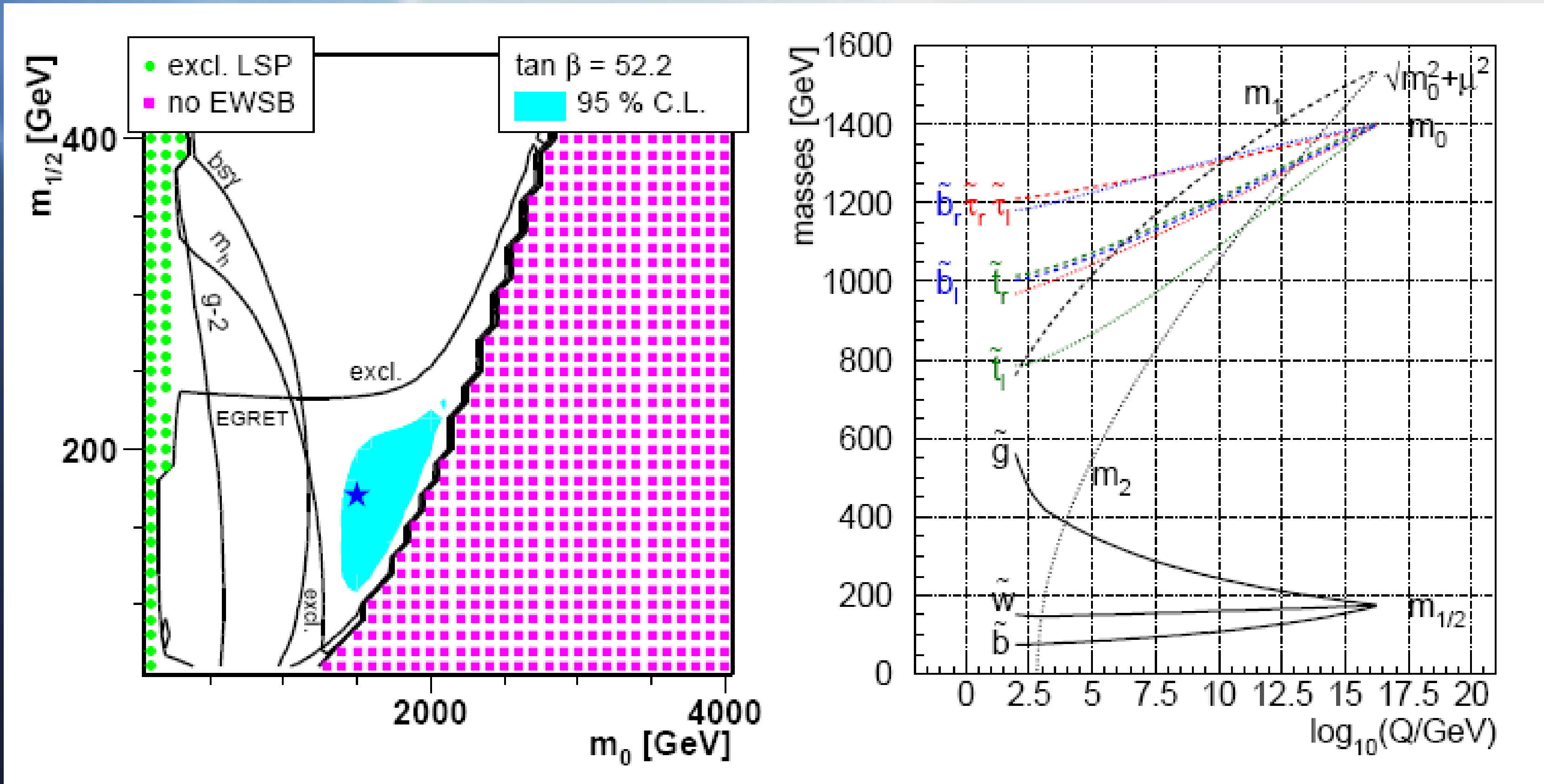


MSUGRA can fulfill all constraints from WMAP, LEP, b->sγ, g-2 and EGRET simultaneously, if DM is neutralino with mass in range 50-100 GeV and squarks and sleptons are O(1 TeV)

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**