SEARCH FOR SUSY IN SPACE

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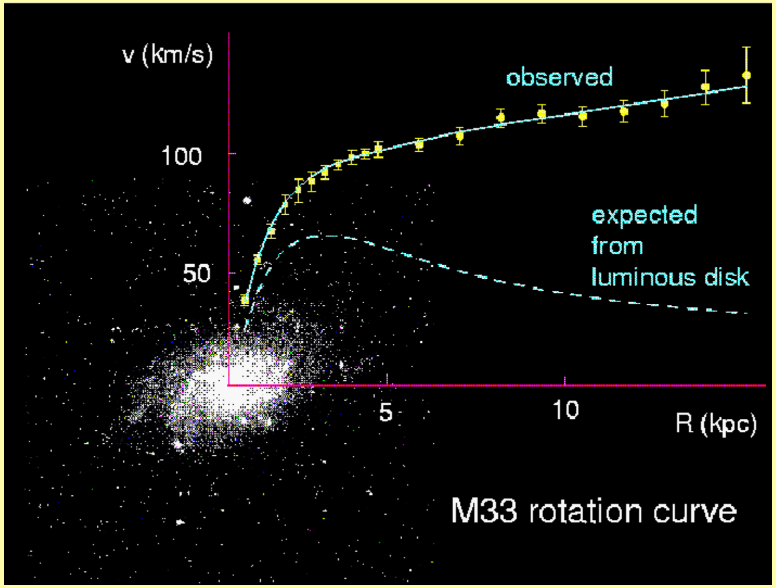
Outline

- Dark Matter in the Universe
- Brief guide to the MSSM
- Constrained MSSM and Dark Matter
- Positron spectrum at high energies
- SUSY contribution to positron spectrum
- SUSY search in space experiments
- Conclusions

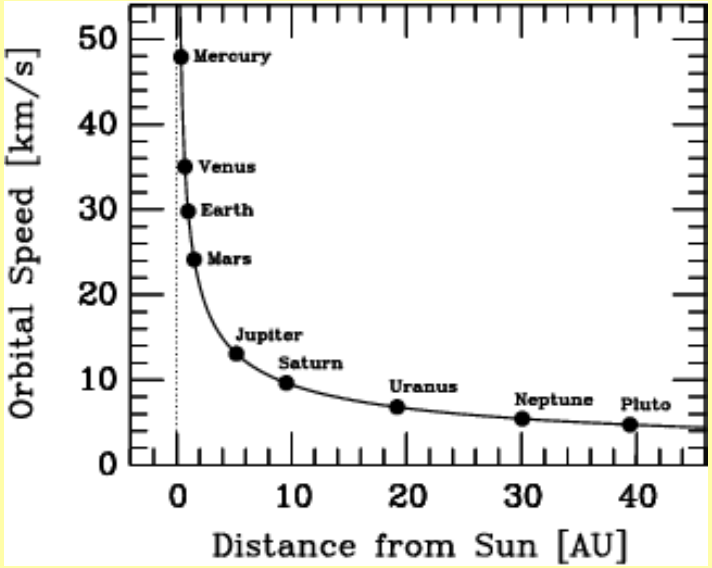
EVIDENCE FOR THE DARK MATTER

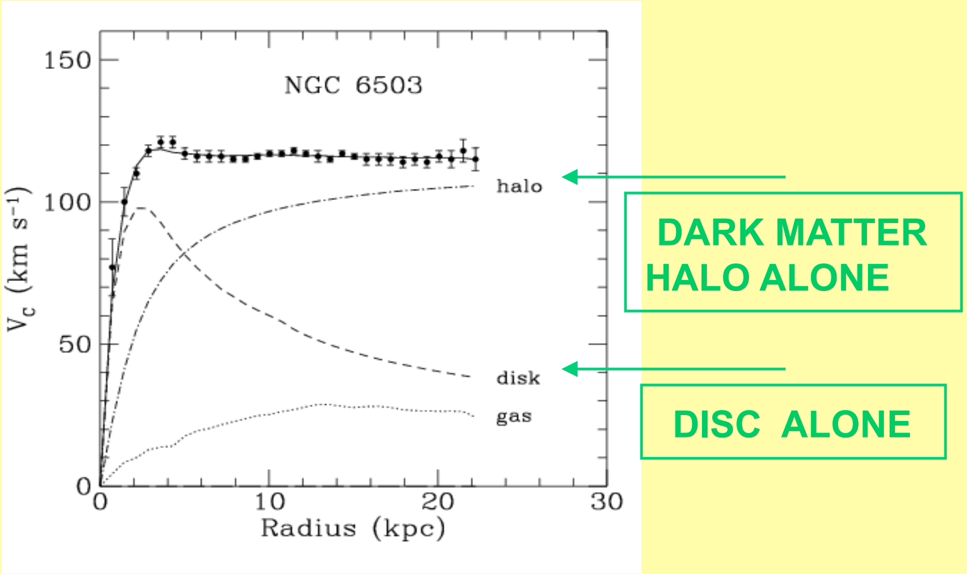


THE FLAT ROTATION CURVES OF SPIRAL GALAXIES PROVIDE THE MOST DIRECT EVIDENCE FOR THE EXISTENCE OF LARGE AMOUNT OF THE DARK MATTER.

SPIRAL GALAXIES CONSIST OF A CENTRAL BULGE AND A VERY THIN DISC, AND SURROUNDED BY AN APPROXIMATELY SPHERICAL HALO OF DARK MATTER

ROTATION CURVES IN SOLAR SYSTEM AND OF THE GALAXIES

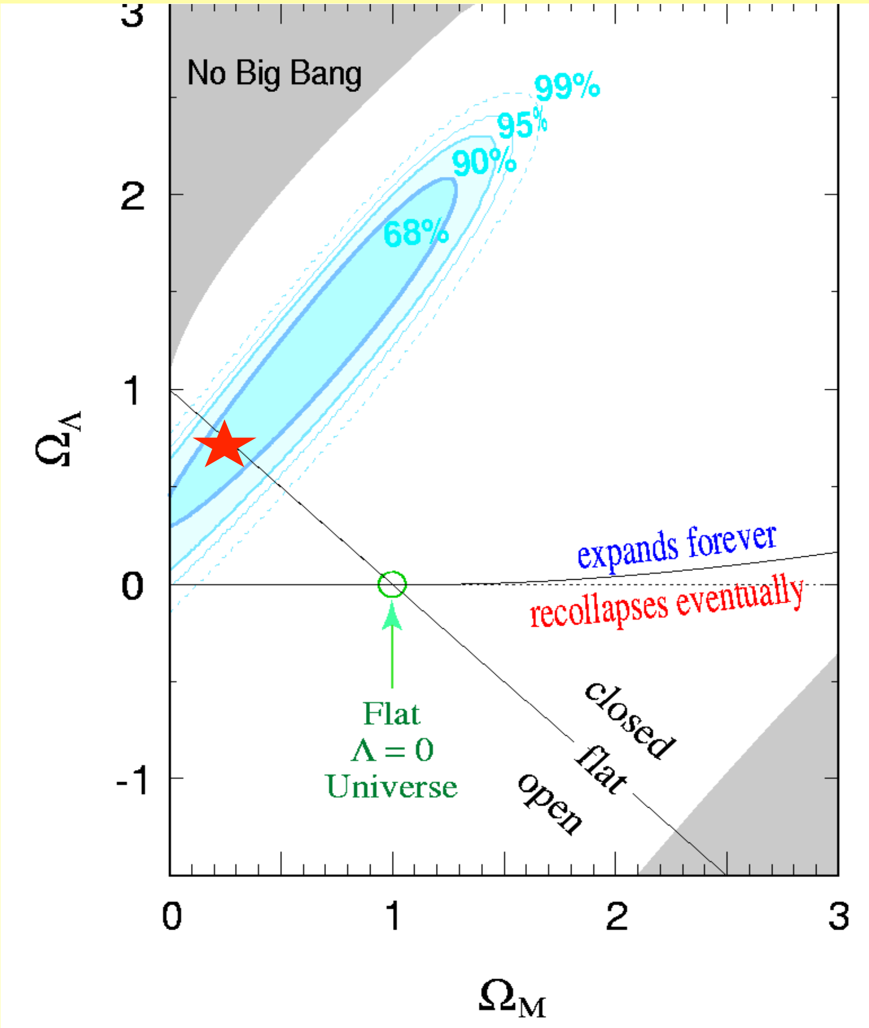




• NOWDAYS, THOUSANDS OF GALACTIC ROTATION CURVES ARE KNOWN, AND ALL SUGGEST THE EXISTENCE OF ABOUT TEN TIMES MORE MASS IN THE HALOS THAN IN THE STARS OF THE DISC

• THE ROTATION CURVE OF THE MILKY WAY HAS BEEN MEASURED AND CONFIRMS THE USUAL PICTURE

AMOUNT OF THE DARK MATTER FROM SUPERNOVA DATA

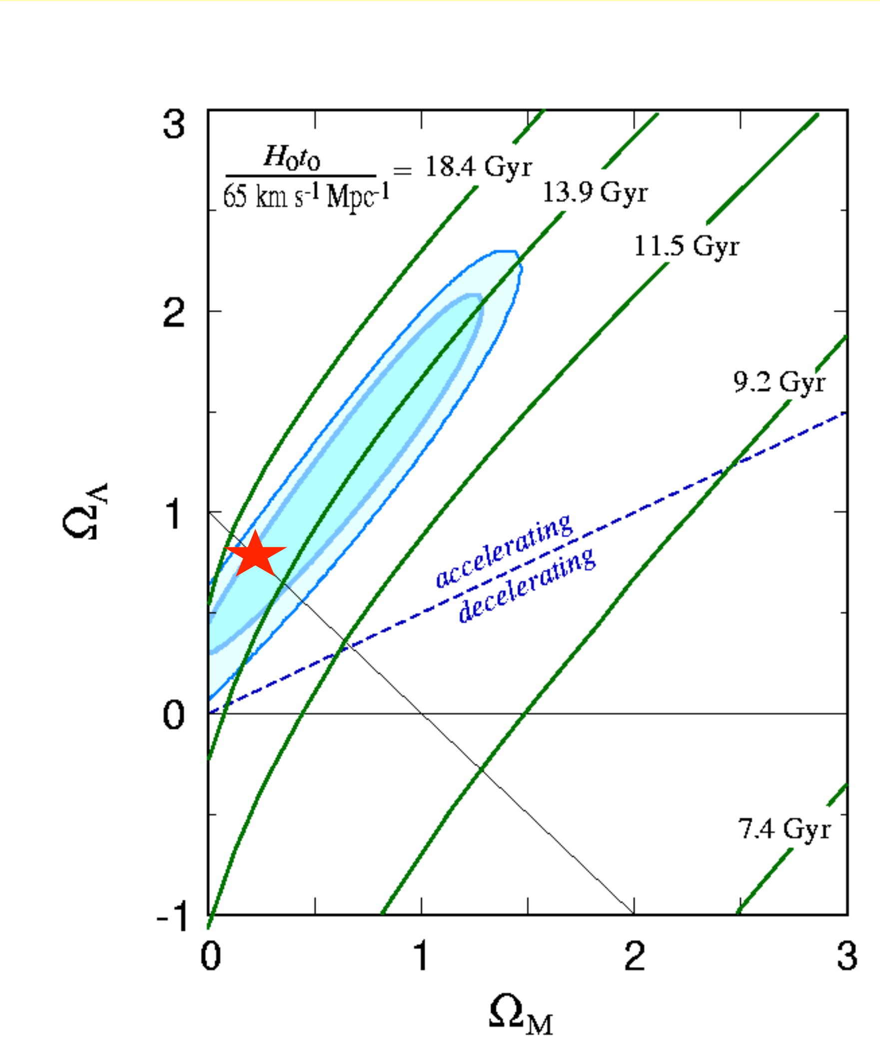


THE BEST FIT CONFIDENCE REGIONS (68% -99%) IN THE Ω_M , Ω_Λ PLANE FOR THE SUPERNOVA RESULTS

$$\Omega_M = 0.28 \begin{smallmatrix} +0.09 \\ -0.08 \end{smallmatrix} \begin{smallmatrix} +0.05 \\ -0.04 \end{smallmatrix}$$

$$\Omega_\Lambda = 0.72 \begin{smallmatrix} +0.08 \\ -0.09 \end{smallmatrix} \begin{smallmatrix} +0.04 \\ -0.05 \end{smallmatrix}$$

AMOUNT OF THE DARK MATTER FROM THE AGE OF THE UNIVERSE

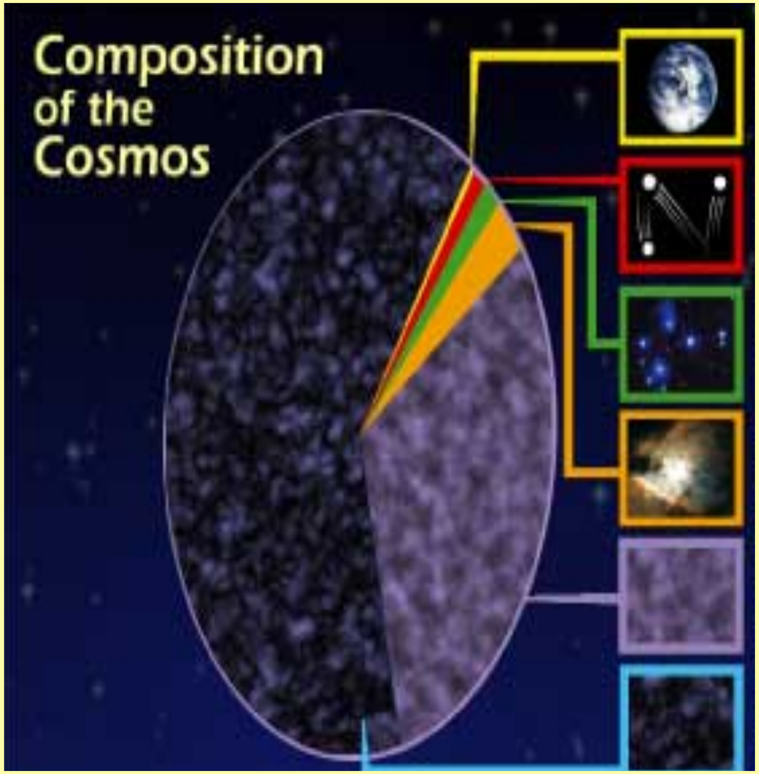


THE ISOCHRONES OF THE AGE OF THE UNIVERSE IN THE Ω_M , Ω_Λ PLANE.

THE BEST FIT GIVES FOR THE AGE OF THE UNIVERSE

$$14.4^{+1.4}_{-1.1}\left(0.65\,h^{-1}\right)\text{Gyr}$$

MATTER AND ENERGY CONTENT OF THE UNIVERSE



HEAVY ELEMENTS	0.03 %
MASSIVE NEUTRINOS	0.3 %
STARS	0.5 %
H AND He	4 %
DARK MATTER	23 %
DARK ENERGY	72 %

WHAT THE DARK MATTER IS MADE OF ?

POSSIBLE CANDIDATES FOR MACHOs

- **NORMAL STARS** **NO**, SINCE THEY WOULD BE LUMINOUS
- **HOT GAS** **NO**, SINCE IT WOULD SHINE
- **BURNT-OUT STELLAR REMNANTS** **SEEMS IMPLAUSIBLE** , SINCE THEY WOULD ARISE FROM A POPULATION OF NORMAL STARS OF WHICH THERE IS NO TRACE IN THE HALO
- **NEUTRON STARS** **NO** , SINCE THEY WOULD ARISE FROM SUPERNOVA EXPLOSIONS AND THUS EJECT HEAVY ELEMENTS INTO THE GALAXY
- **WHITE DWARFS** (STARS WITH A MASS WHICH IS NOT ENOUGH TO REACH THE SUPERNOVA PHASE) **POSSIBLE**, COULD BE PLENTIFUL ENOUGH TO EXPLAIN THE DARK MATTER IF YOUNG GALAXIES PRODUCED WHITE DWARFS. BUT THE PRODUCTION OF LARGE NUMBERS OF WHITE DWARFS IMPLIES THE PRODUCTION OF A LARGE AMOUNT OF HELIUM, WHICH IS NOT OBSERVED

- **BROWN DWARFS** (STARS TEN TIMES LIGHTER THAN THE SUN)

POSSIBLE, HOWEVER,THERE IS AS YET NO EVIDENCE THAT BROWN DWARFS ARE ANYWHERE NEAR AS ABUNDANT AS THEY WOULD HAVE TO BE TO ACCOUNT FOR THE DARK MATTER IN OUR GALAXY

- **PRIMORDIAL BLACK HOLES** CREATED IN THE EARLY UNIVERSE

POSSIBLE, THOUGH NO ENOUGH EVIDENCE

SUSY PROVIDES THE BEST CANDIDATES FOR **WEAKLY INTERACTING MASSIVE PARTICLES** -- NEUTRALINOS ,COMING FROM SUPERSYMMETRIC EXTENSIONS OF THE STANDARD MODEL

WIMPS COULD HAVE BEEN PRODUCED IN THE BIG BANG ORIGIN OF THE UNIVERSE IN THE RIGHT AMOUNTS AND WITH THE RIGHT PROPERTIES TO EXPLAIN THE DARK MATTER

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	0	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 $\tilde{L}_i = (\tilde{\nu}, \tilde{e})_L$	$L_i = (\nu, e)_L$	1	2	-1
E_i	$\tilde{E}_i = \tilde{e}_R$	$E_i = e_R$	1	1	2
Q_i	squarks $\tilde{Q}_i = (\tilde{u}, \tilde{d})_L$	$Q_i = (u, d)_L$	3	2	$1/3$
U_i	$\tilde{U}_i = \tilde{u}_R$	$U_i = u_R$	3^*	1	$-4/3$
D_i	$\tilde{D}_i = \tilde{d}_R$	$D_i = d_R$	3^*	1	$2/3$
Higgs					
H_1	H_1	higgsinos $\tilde{H}_1$	1	2	-1
H_2	H_2	$\tilde{H}_2$	1	2	1

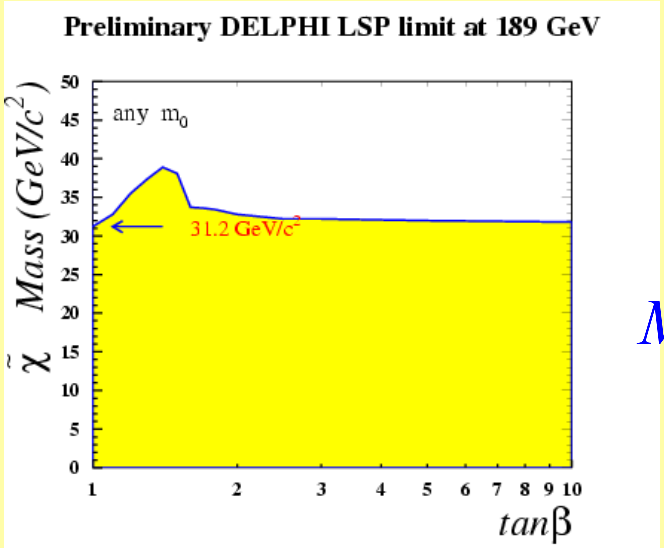
SUSY associates known bosons with new fermions
and known fermions with new bosons

SUSY DARK MATTER

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

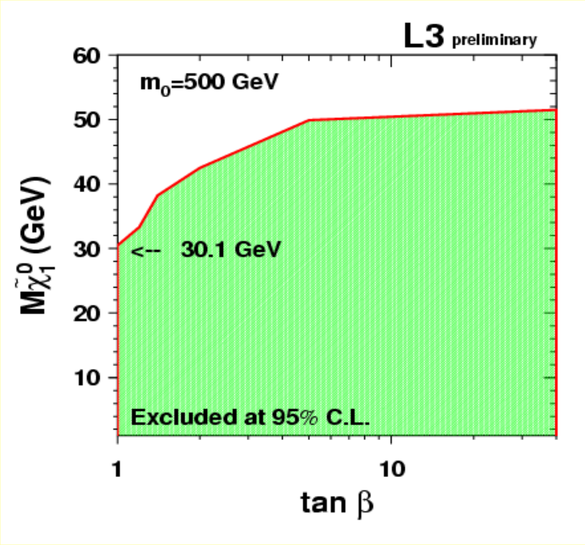
$$\tilde{\chi}^0 = N_1 \tilde{\gamma} + N_2 \tilde{Z}^0 + N_3 \tilde{H}_1^0 + N_4 \tilde{H}_2^0$$

photino zino higgsino higgsino



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

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



R-parity:

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

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

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

THE CONSTRAINED MSSM

Requirements:

- Unification of the gauge couplings
- Radiative EW Symmetry Breaking
- Heavy quark and lepton masses
- Rare decays (b -> sγ)
- Anomalous magnetic moment of muon
- LSP is neutral
- Amount of the Dark Matter
- Experimental limits from direct search

Allowed region in the parameter space of the MSSM

$$A_0, m_0, M_{1/2}, \mu, \tan\beta$$

Parameter space:

$$100\ Gev < m_0, M_{1/2}, \mu < 2\ Tev$$
$$-3m_0 < A_0 < 3m_0, 1 < \tan\beta < 70$$

CMSSM FIT PROCEDURE

$$\chi^2 = \sum_{i=1}^{3} \frac{(\alpha_i^{-1}(M_Z) - \alpha_{MSSMi}^{-1}(M_Z))^2}{\sigma_i^2}$$

$$+ \frac{(M_Z - 91.18)^2}{\sigma_Z^2} + \frac{(M_t - 174)^2}{\sigma_t^2}$$

$$+ \frac{(M_b - 4.94)^2}{\sigma_b^2} + \frac{(M_\tau - 1.7771)^2}{\sigma_\tau^2}$$

$$+ \frac{(\mathrm{Br}(b \to s\gamma)\text{-}3.14\times 10^{-4})^2}{\sigma^2(b \to s\gamma)}$$

$$+ \frac{(a_\mu^{SUSY}\text{-}420\times 10^{-14})^2}{\sigma_{a_\mu}^2}$$

$$+ \frac{(\Omega h^2 - 1)^2}{\sigma_\Omega^2} \quad (\text{for } \Omega h^2 > 1)$$

$$+ \frac{(M\%\text{-}M\%_{exp})^2}{\sigma_{M\%}^2} \quad (\text{for } M\% < M\%_{exp})$$

$$+ \frac{(m\%_{LSP}\text{-}m\%_{\chi})^2}{\sigma_{LSP}^2} \quad (\text{for } m\%_{LSP} \text{ charged})$$

Minimize χ^2

Exp.input data	Fit low tan β	Parameters high tan β
$\alpha_1, \alpha_2, \alpha_3$		
m_t	M_{GUT}, α_{GUT}	M_{GUT}, α_{GUT}
m_b	$Y_t^0, Y_b^0 = Y_\tau^0$	$Y_t^0 = Y_b^0 = Y_\tau^0$
m_τ	$m_0, m_{1/2}$	$m_0, m_{1/2}$
M_Z	$\tan\beta$	$\tan\beta$
$b \to s\gamma$	μ	μ
a_μ	(A_0)	A_0
$\tau_{Universe}$		

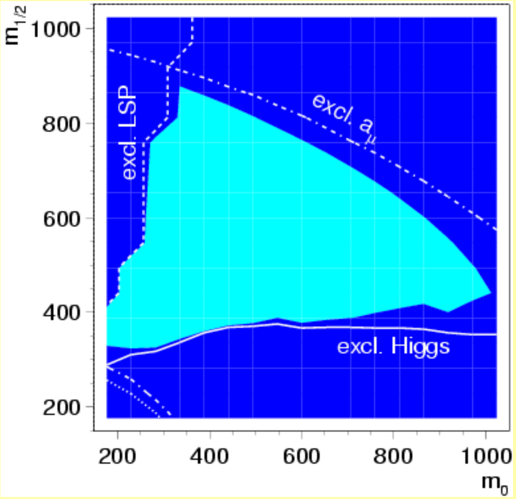
ALLOWED REGIONS OF PARAMETER SPACE

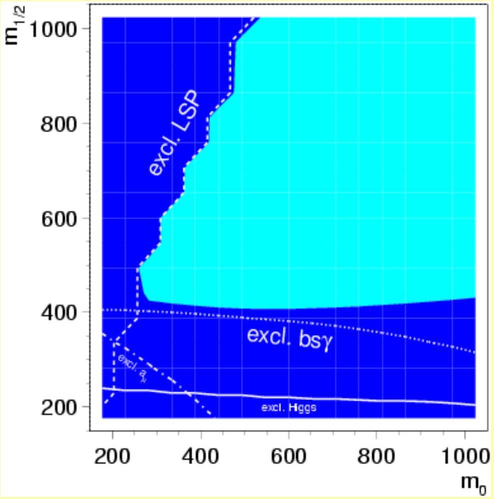
- $\tan\beta > 4$

From the Higgs searches

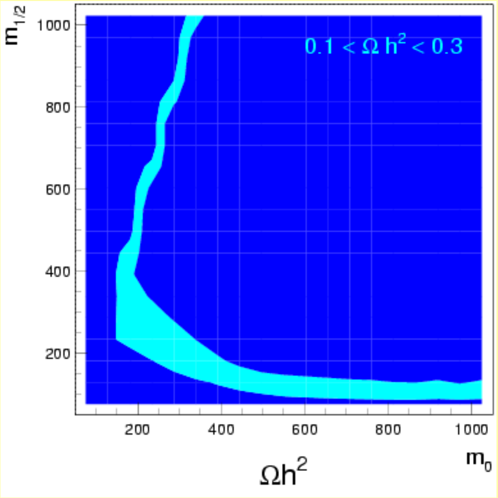
- $\mu > 0$

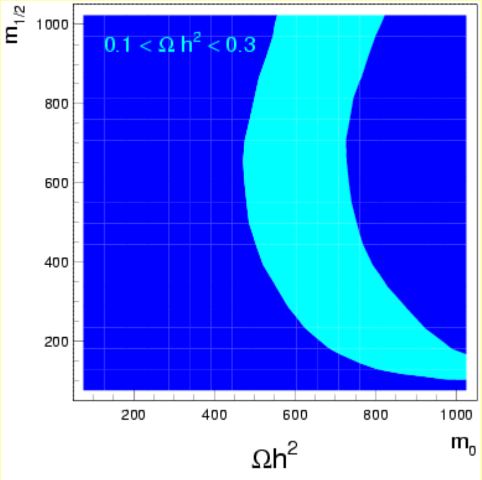
From a_μ measurement





Fit to all constraints





$\tan\beta = 35$

Fit to Dark Matter constraint

$\tan\beta = 50$

POSITRONS FROM THE DARK MATTER ANNIHILATION

- The Flux

$$\frac{dF}{dE} = <\sigma v> \frac{\rho_0^2}{m_\chi^2} \int d\varepsilon \; G(E,\varepsilon) \sum_i B_i f_i(\varepsilon)$$

neutralino density (ρ_0^2); thermal averaging ($<\sigma v>$); propagator ($G(E,\varepsilon)$); branching (B_i); spectrum ($f_i(\varepsilon)$)

- The propagator

$$G(E,\varepsilon) = 10^{25}[10^{a\log^2 E + b\log E + c}\,\theta(\varepsilon - E) + 10^{w\log^2 E + x\log E + y}\,\theta(E-\varepsilon)]$$

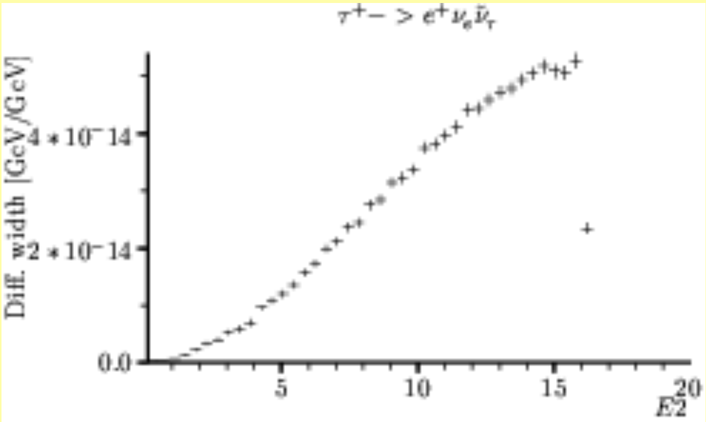
- The Spectrum

Two body decay (boosted)

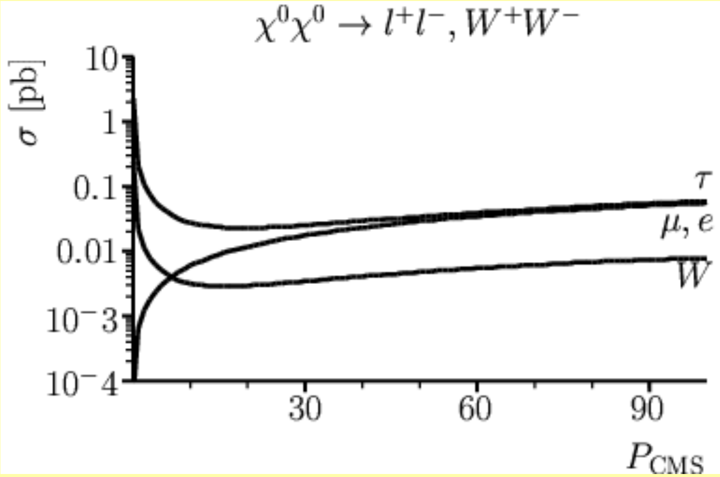
$$f_W(\varepsilon) = \frac{1}{m_\chi \beta_W}\theta(\varepsilon - \varepsilon_-)\theta(\varepsilon - \varepsilon_+)$$

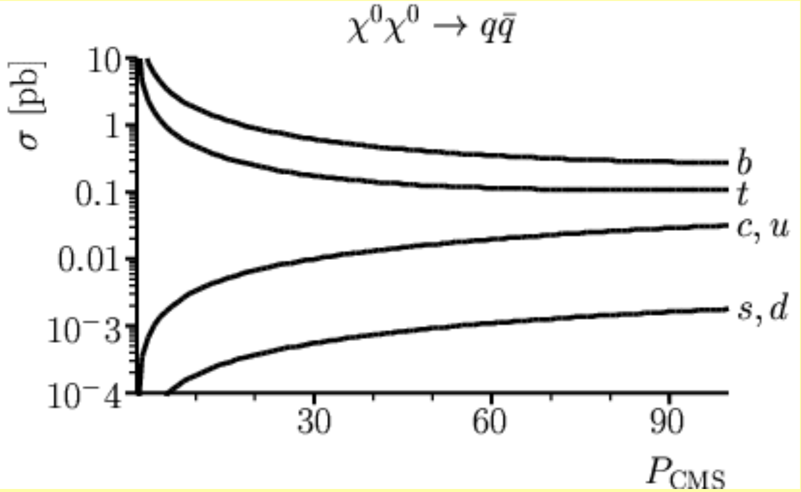
$$\varepsilon_\pm = \tfrac{1}{2} m_\chi (1 \pm \beta_W), \quad \beta_W \approx \sqrt{1 - M_W^2 / m_\chi^2}$$

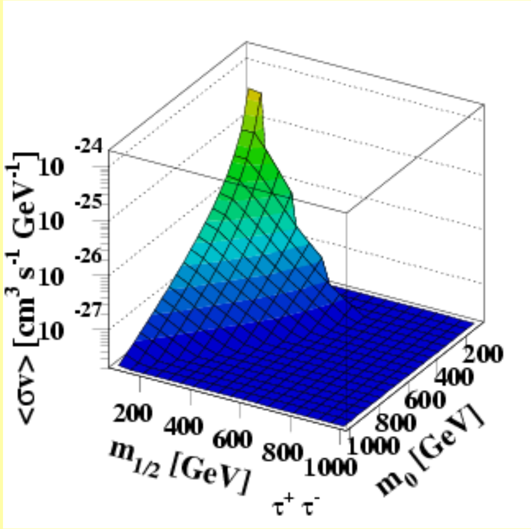
The W three body decay (for p=50 GeV)

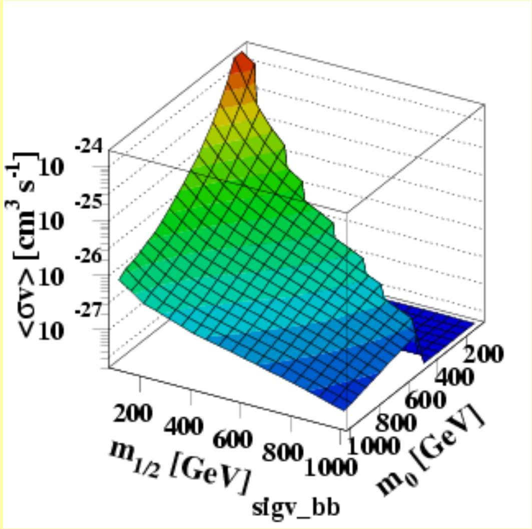


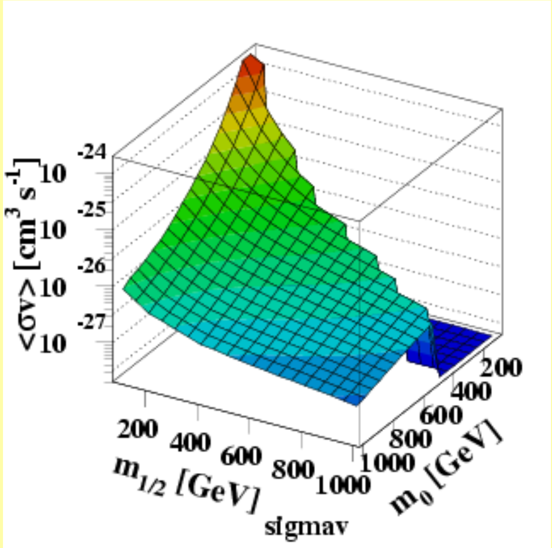
NEUTRALINO ANNIHILATION X-SECTIONS





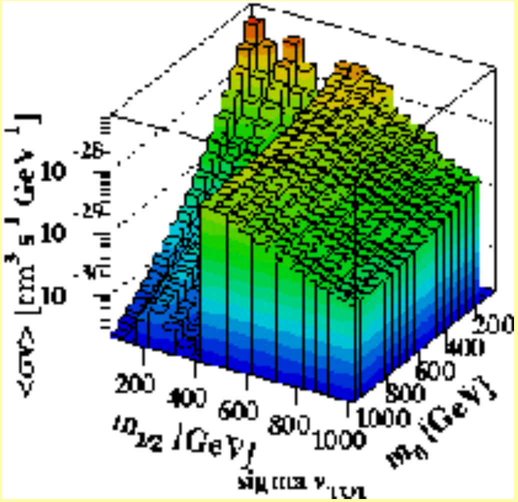


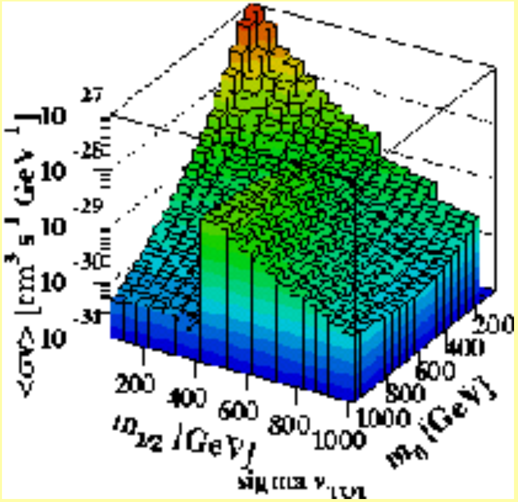


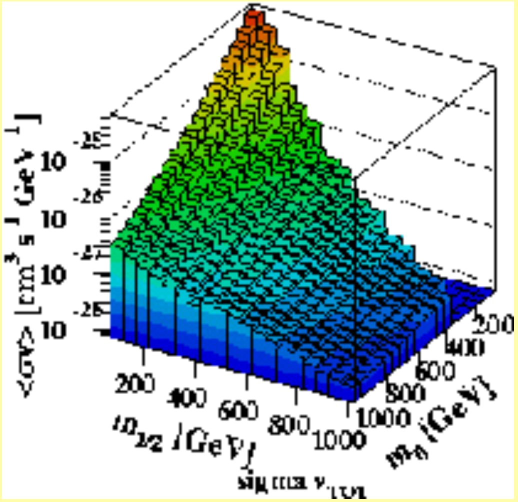


THERMALLY AVERAGED X-SECTIONS

$$<\sigma v>= \frac{\int_0^\infty dp p^2 4p\sqrt{4p^2+4m_\chi^2}K_1(\frac{\sqrt{4p^2+4m_\chi^2}}{T})\sigma(p)}{m_\chi^4 T[K_2(\frac{m}{T})]^2}$$

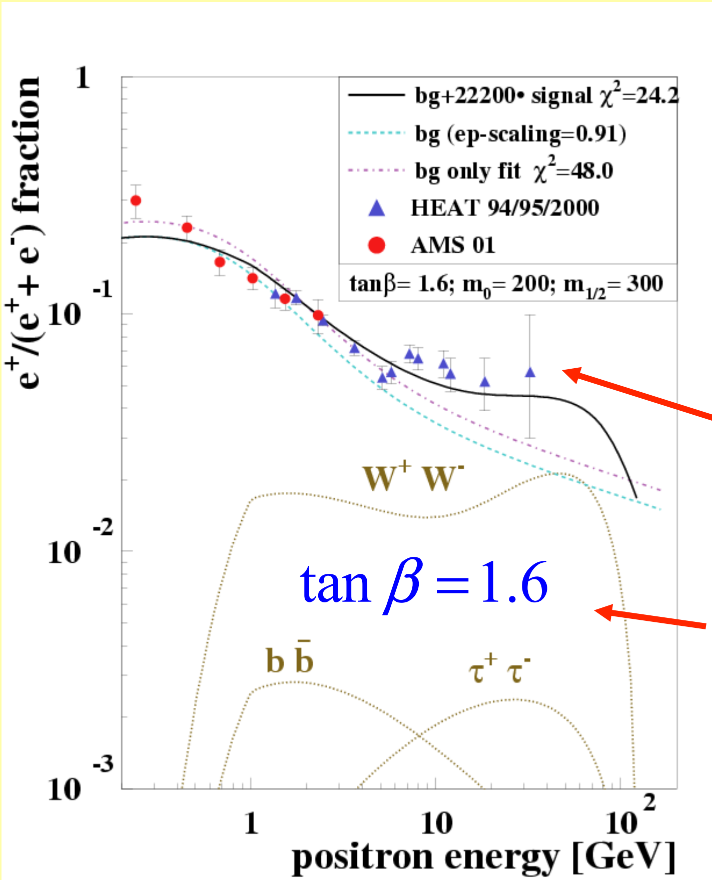






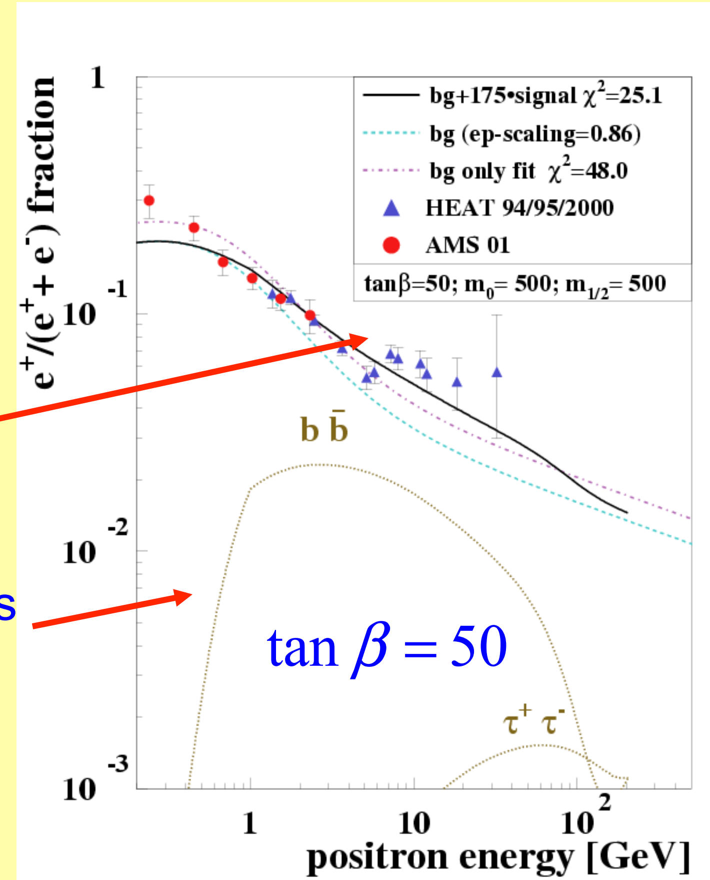
$\tan\beta = 1.6$ $\tan\beta = 5$ $\tan\beta = 35$

POSITRON SPECTRUM AT HIGH ENERGIES



Excess

Extra contributions due to neutralino annihilation

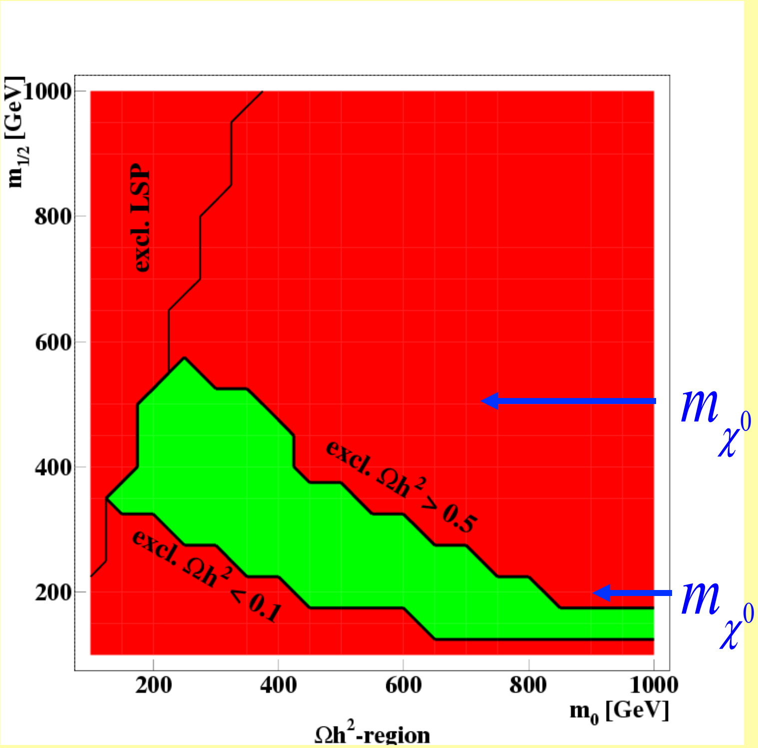


HEAT and AMS-01 balloon experiments show some excess of data at E > 7 GeV, which may indicate at extra source of positrons

The dark matter profiles are fitted to the rotation curves

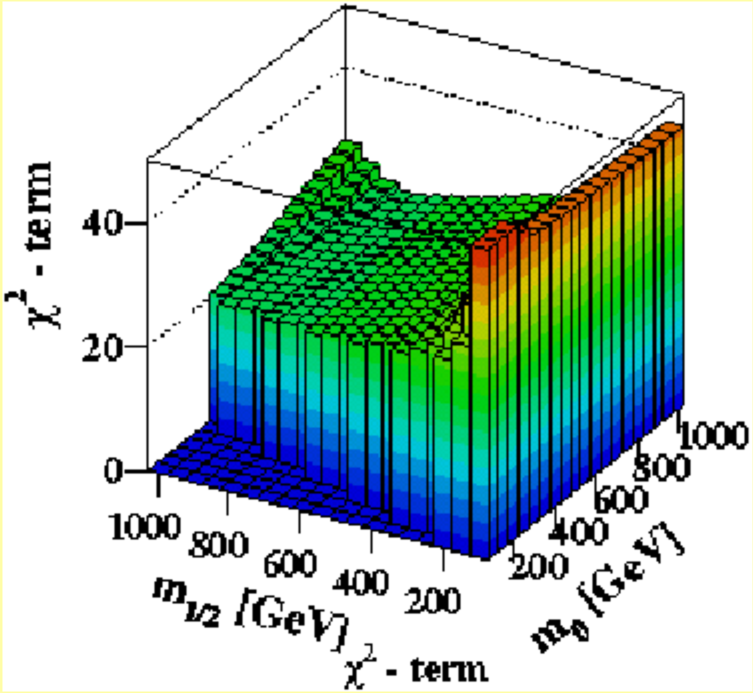
$\rho_0 : 0.4\ \mathrm{GeV\ cm^{-3}}$ = 1 neutralino per coffee cup

PREFERED REGION IN PARAMETER SPACE



m_{χ^0} : 250 GeV

m_{χ^0} : 50 GeV

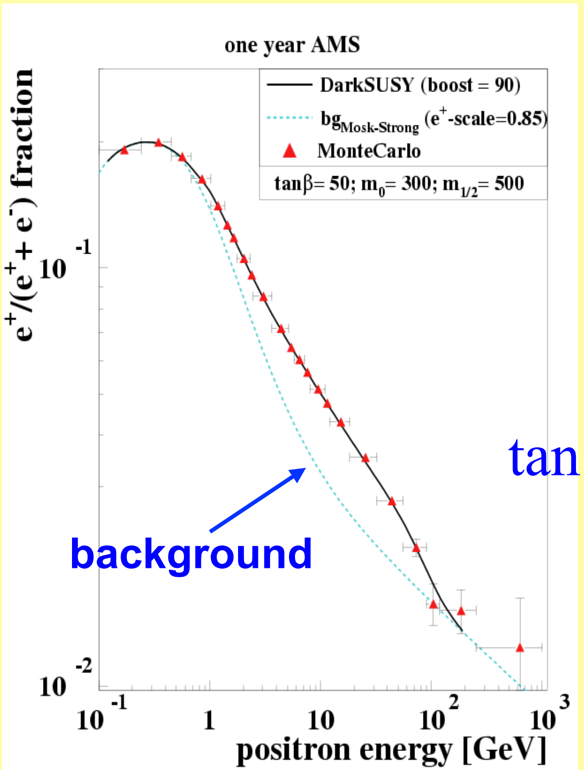


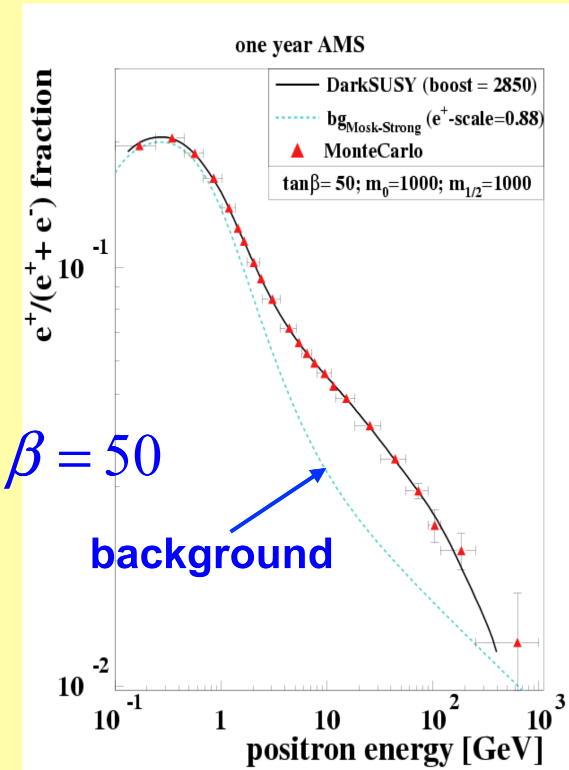
The prefered region

The χ^2 distribution

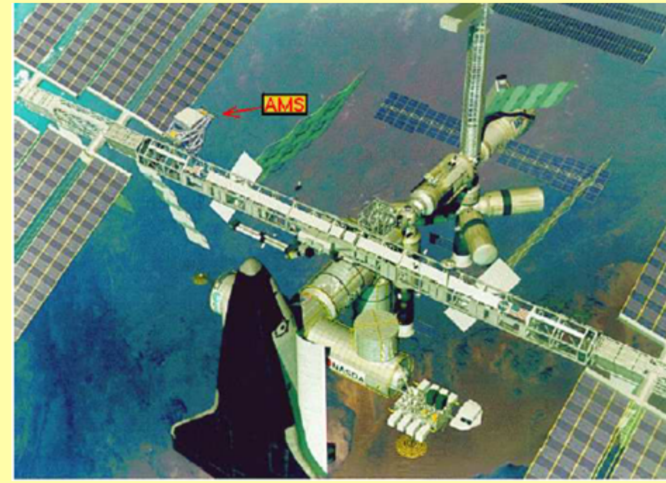
In allowed region one fulfills all the constraints simultaneously and has the suitable amount of the dark matter

ANTIMATTER SEARCH IN SPACE at ISS: AMS-02





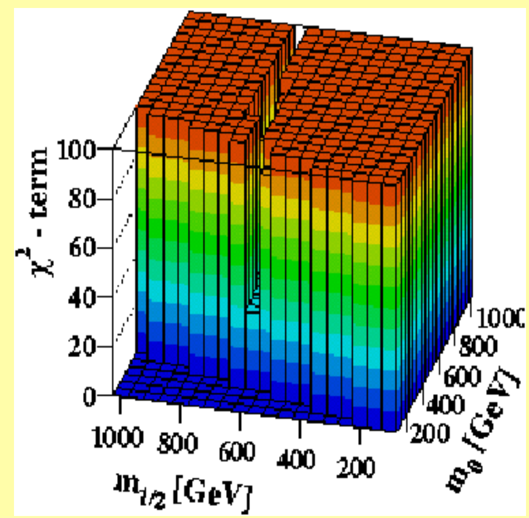
$\tan\beta = 50$



$m_0 = 300,\ m_{1/2} = 500$

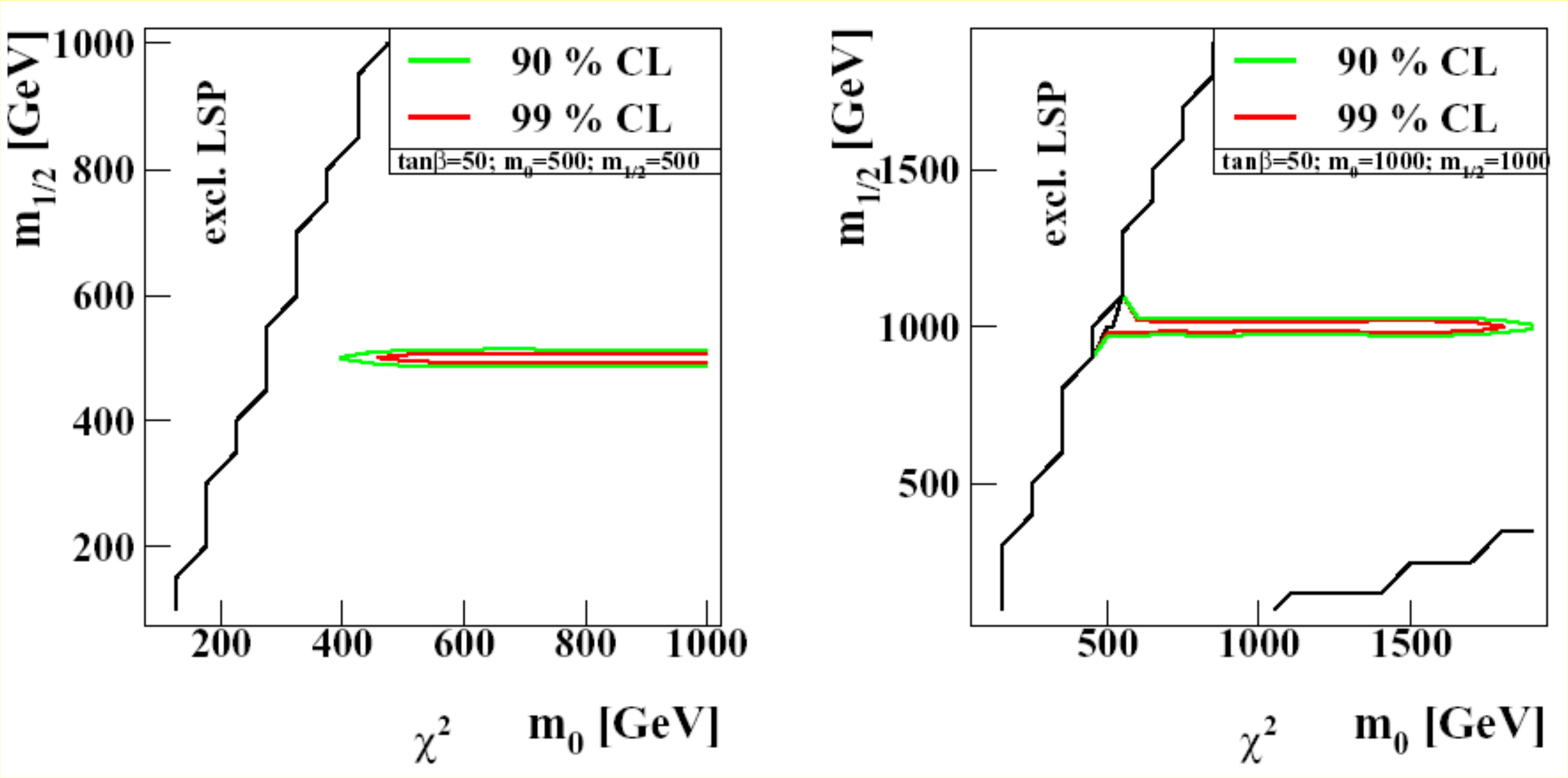
$m_0 = 1000,\ m_{1/2} = 1000$

Expected statistics



The χ^2 distribution

NEUTRALINO MASS FROM THE POSITRON SPECTRUM AFTER ONE YEAR OF AMS-02

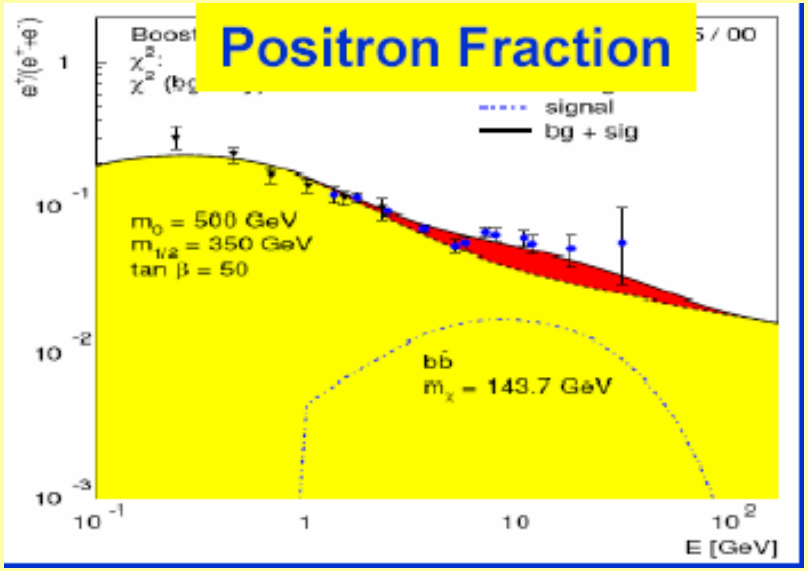


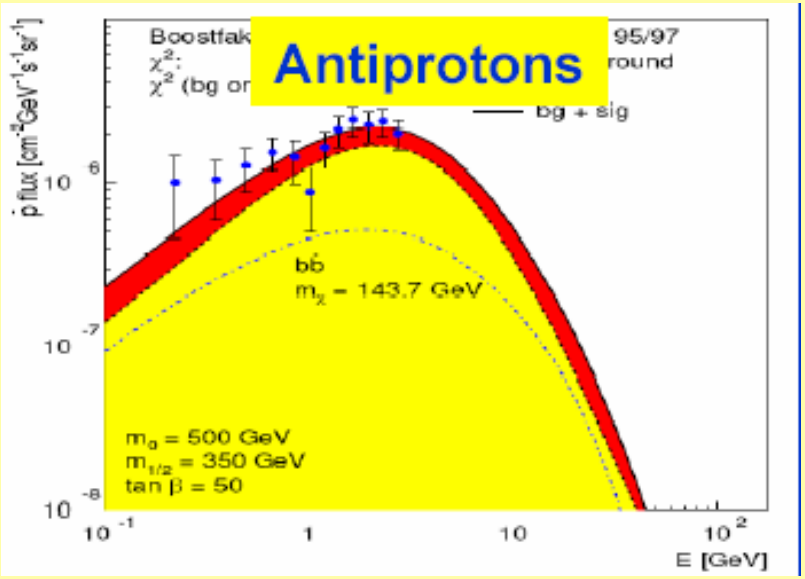
$$m_{\chi^0} = 200 \text{ GeV}$$

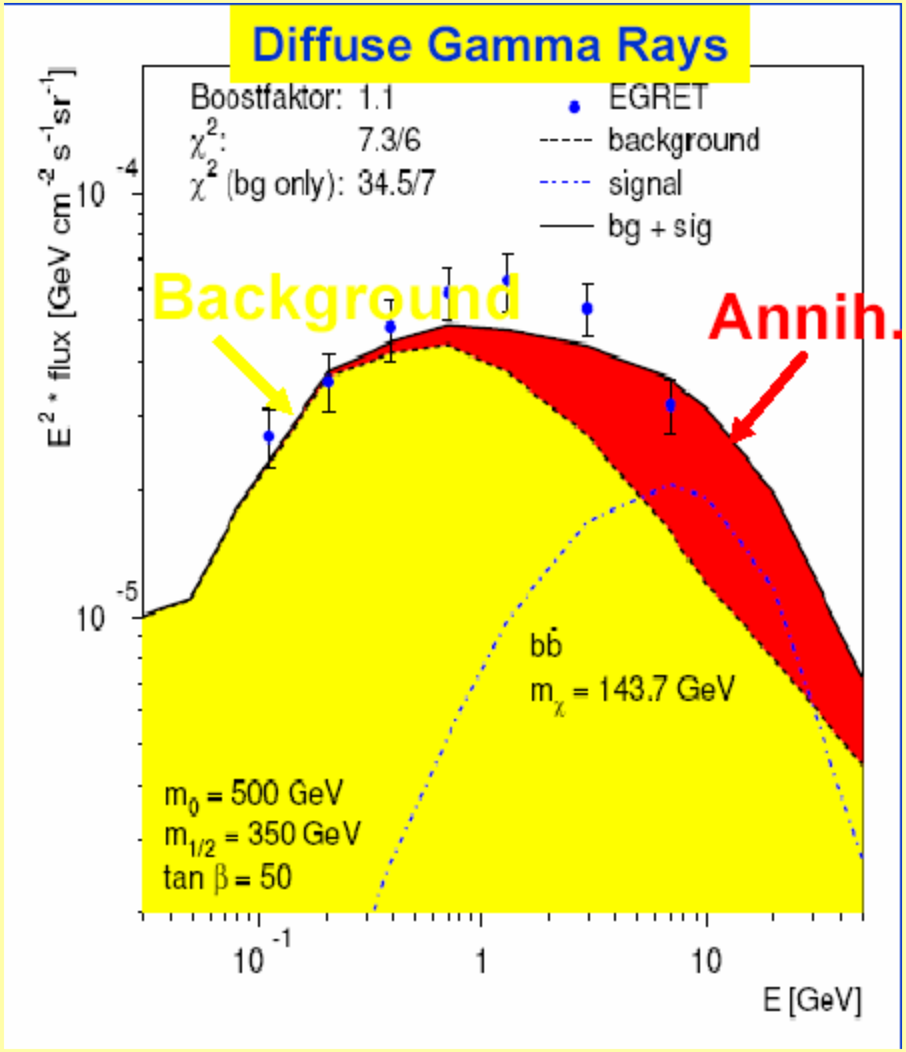
$$m_{\chi^0} = 400 \text{ GeV}$$

$$\tan\beta = 50$$

COMBINED FIT FOR EXCESS OF POSITRONS, ANTIPROTONS AND GAMMA RAYS







SUMMARY

The General statements

- The MSSM is not only reasonable, but is the subject of tests
- The Constrained MSSM satisfies all the requirements simultaneously and provides the allowed region in parameter space
- Non-observations of SUSY at colliders puts forward non-accelerator and astrophysics experiments
- SUSY provides a promising candidate for dark matter – neutralino – the LSP
- Manifestation of the neutralino can be found in cosmic experiments

The Future perspectives

- If the neutralino mass is within the region 50 [illegible] 300 GeV it may be indirectly observed by precise measurement of the positron spectrum at high energies:

PAMELA – Russian satellite – 2004

AMS-02 – International Space Station - 2006

THE COSMOLOGICAL CONSTANT

THE COSMOLOGICAL CONSTANT IS A TERM IN THE EINSTEIN EQUATIONS THAT CORRESPONDS TO THEENERGY DENSITY OF THE VACUUM OF THE QUANTUM FIELD THEORY

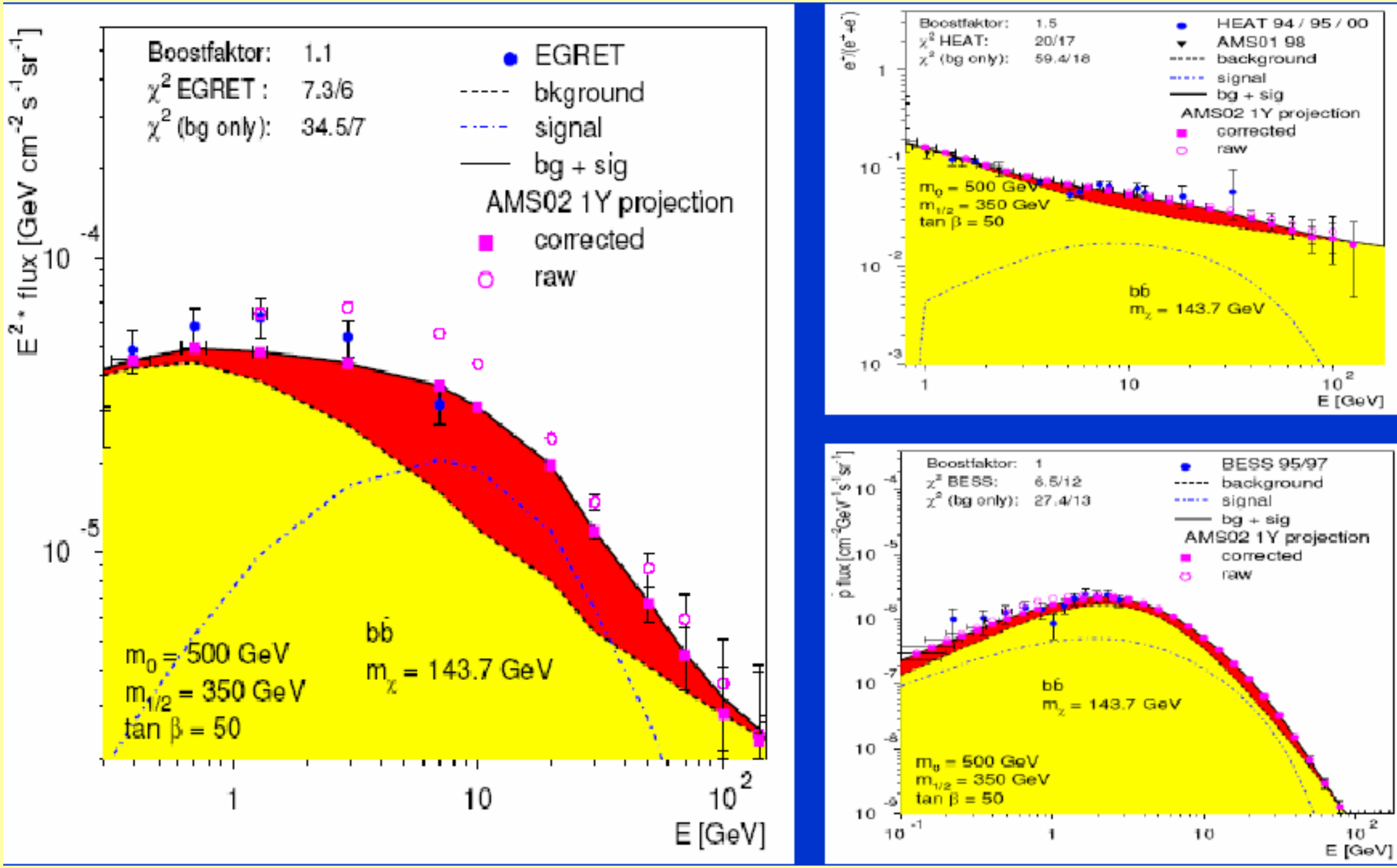
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu} \qquad \Lambda \equiv 8\pi G \rho_v$$

THEORY PREDICTS A VALUE OF ORDER

$$\rho_v : M_{Pl}^4 ; 5 \times 10^{93} \text{ g/cm}^3$$

123 ORDERS OF MAGNITUDE LARGER THAN THE CRITICAL DENSITY !

THIS DISCREPANSY IS ONE OF THE BIGGEST PROBLEMS OF THEORETICAL PHYSICS



Boostfaktor: 1.1
χ² EGRET : 7.3/6
χ² (bg only): 34.5/7
EGRET
bkground
signal
bg + sig
AMS02 1Y projection
corrected
raw
m0 = 500 GeV
m1/2 = 350 GeV
tan β = 50
bb̄
mχ = 143.7 GeV
E² * flux [GeV cm⁻² s⁻¹ sr⁻¹]
E [GeV]
Boostfaktor: 1.5
χ² HEAT: 20/17
χ² (bg only): 59.4/18
HEAT 94 / 95 / 00
AMS01 98
background
signal
bg + sig
AMS02 1Y projection
corrected
raw
m0 = 500 GeV
m1/2 = 350 GeV
tan β = 50
bb̄
mχ = 143.7 GeV
e⁺/(e⁺+e⁻)
E [GeV]
Boostfaktor: 1
χ² BESS: 6.5/12
χ² (bg only): 27.4/13
BESS 95/97
background
signal
bg + sig
AMS02 1Y projection
corrected
raw
bb̄
mχ = 143.7 GeV
m0 = 500 GeV
m1/2 = 350 GeV
tan β = 50
p̄ flux [cm⁻²GeV⁻¹s⁻¹sr⁻¹]
E [GeV]

THE MOST NATURAL EXPLANATION FOR THIS IS THE PRESENCE OF A **COSMOLOGICAL CONSTANT**, A DIFFUSE VACUUM ENERGY THAT PERMITS ALL THE SPACE, AND GIVES THE UNIVERSE ACCELERATION THAT TENDS TO SEPARATE GRAVITATIONALLY BOUND SYSTEMS FROM EACH OTHER

THE BEST FIT RESULTS FROM

THE SUPERNOVA COSMOLOGY PROJECT

GIVES FOR THE FLAT UNIVERSE

$$\Omega_M = 0.28 \begin{array}{cc} +0.09 & +0.05 \\ -0.08 & -0.04 \end{array}$$

$$\Omega_\Lambda = 0.72 \begin{array}{cc} +0.08 & +0.04 \\ -0.09 & -0.05 \end{array}$$

STATISTICAL ERROR

SYSTEMATICAL ERROR

CONCLUSIONS. THE NEW COSMOLOGY

WE HAVE BRIEFLY DISCUSSED THE MAIN INGREDIENTS OF THE STANDARD COSMOLOGICAL MODEL (THE BIG BANG MODEL)

THE BIG BANG MODEL APPEARS TO BE SUCCESSFUL IN DESCRIBING THE UNIVERSE AFTER THE INFLATION

THE MODEL IS TESTABLE EXPERIMENTALLY (OBSERVATIONS)

IN RECENT YEARS THERE IS A LOT OF NEW OBSERVATIONS WHICH HAVE CHANGED OUR UNDERSTANDING OF THE UNIVERSE

THE NEW STANDARD COSMOLOGY IS CHARACTERIZED BY

- **FLAT ACCELERATING UNIVERSE**

- EARLY PERIOD OF RAPID EXPANSION

- DENSITY INHOMOGENEITIES PRODUCED FROM QUANTUM FLUCTUATIONS DURING INFLATION

- COMPOSITION

COMPOSITION	**2 / 3rds**	**DARK ENERGY**
	1 / 3rd	**DARK MATTER**
	1/ 200th	**BRIGHT STARS**

THERE ARE INDEPENDENT LINES OF EVIDENCE THAT THE

UNIVERSE IS ACCELERATING

- HIGH RED-SHIFT
  SUPERNOVA
  EXPERIMENTS

- MEASUREMENTS OF
  THE COMPOSITION
  OF THE UNIVERSE
  USING OTHER METHODS