The anomaly in the cosmic-ray positron spectrum

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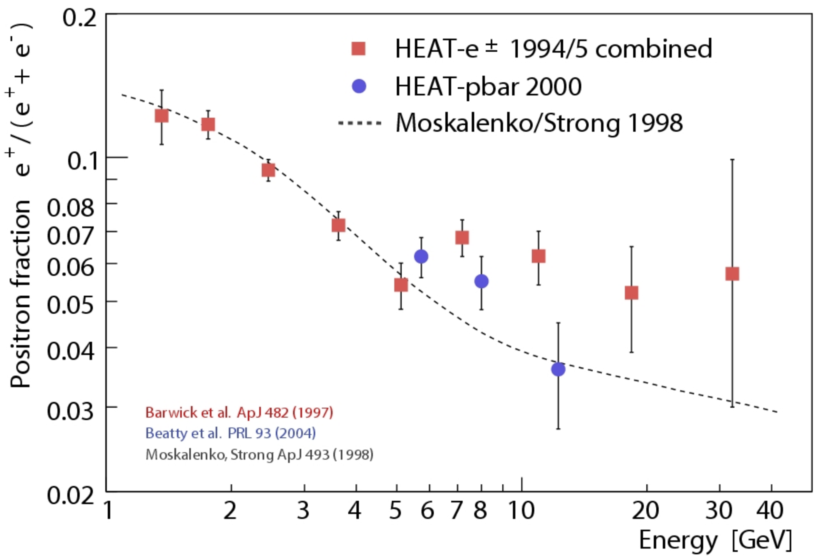
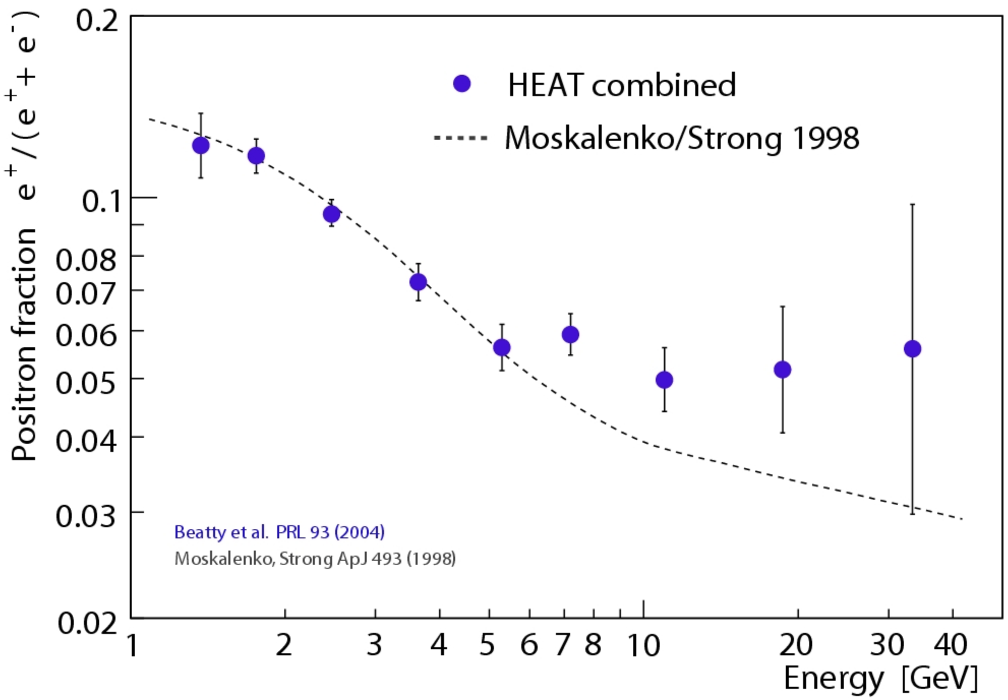
HEAT positron fraction measurements



There were 2 **HEAT** balloon-borne experiments:

- HEAT-e± flown in 1994 and 1995 for a total of 55 hours
- HEAT-pbar flown in 2000 for 22 hours

„There's indication for a small positron flux of nonstandard origin above 5 GeV“
(Beatty et al. PRL 93 (2004) 241102)

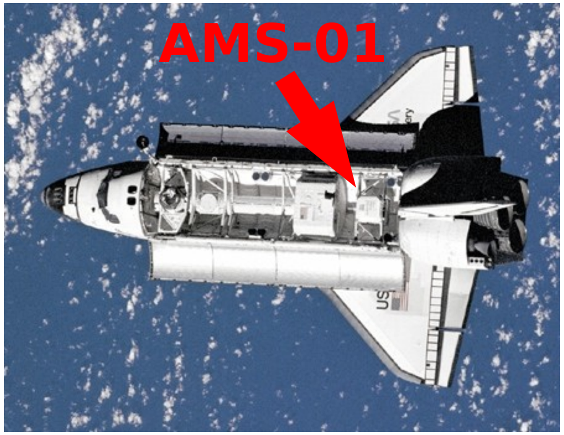


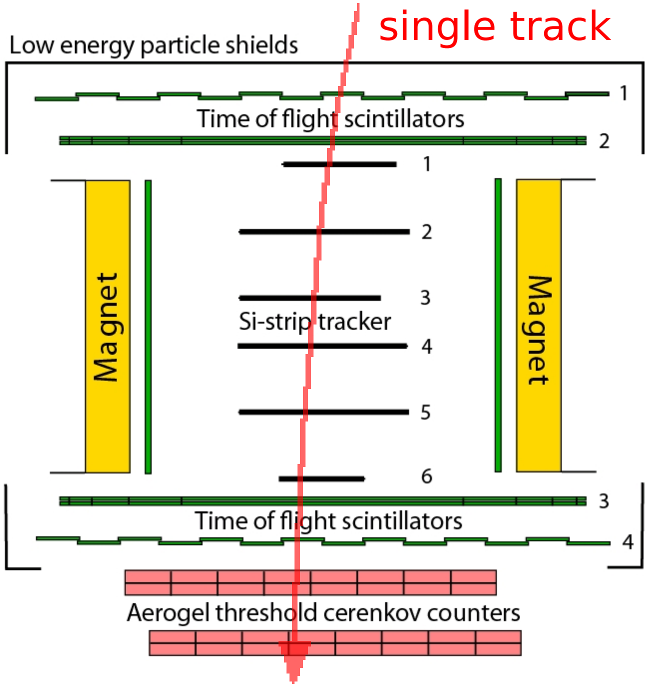
AMS-01 positron fraction (2000)

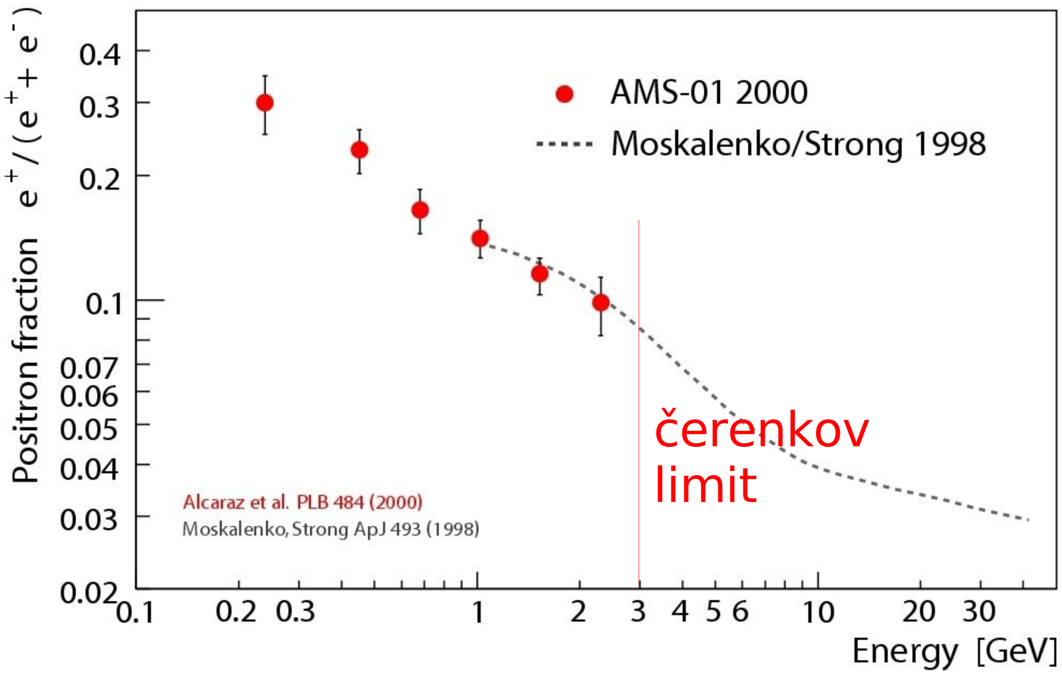
AMS-01: space-borne spectrometer
• flown in June 1998 for 10 days
• altitudes between 320 and 390 km

Challenge of positron measurements:
huge proton background $O(10^4 \times e^+)$

Single track positron identification
limited to < 3 GeV by čerenkov threshold



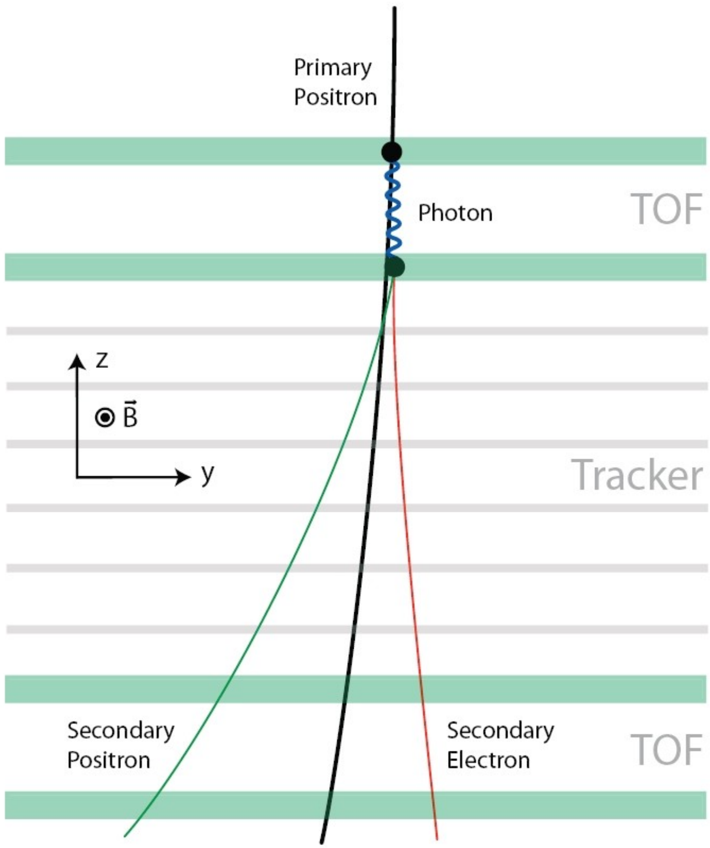




AMS-01 data reanalysis (2007)

using bremsstrahlung conversion

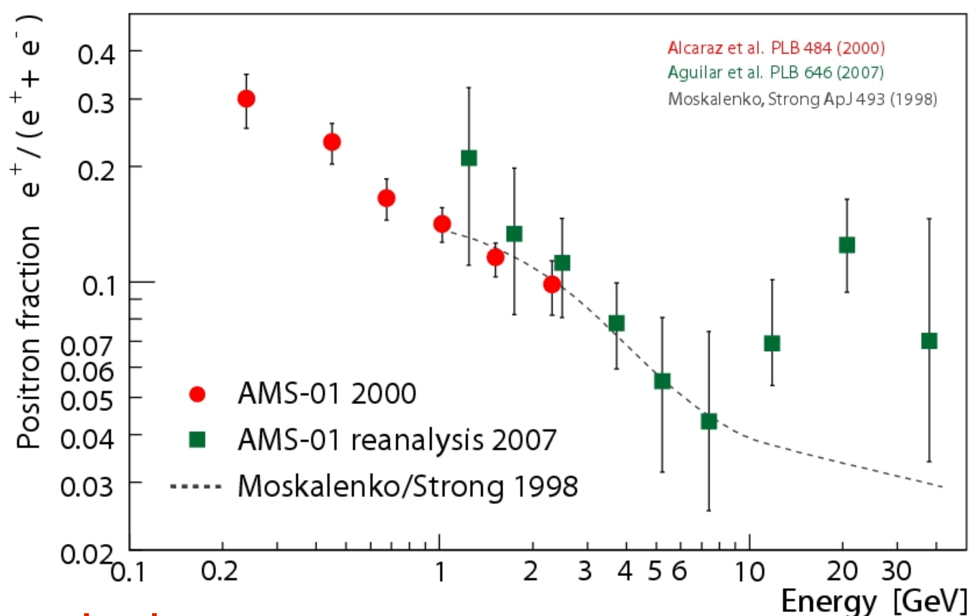
PLB **646**(2007)145 (astro-ph/0703154)



- Positron radiates bremsstrahlung photon
- Photon converts into e^+ e^- pair: **3 tracks**

$$\sigma_{brems} \sim 1/m^2$$

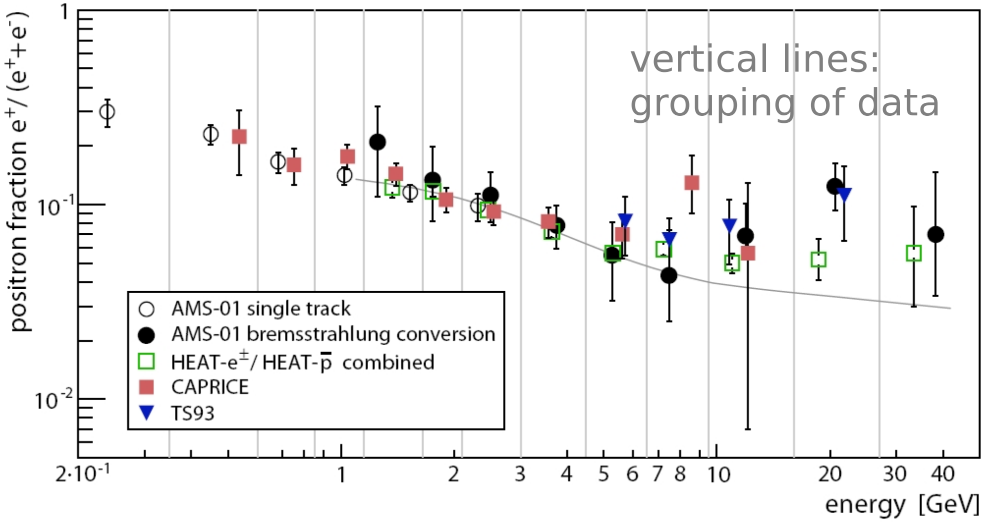
→ proton background suppressed by > $3 \cdot 10^6$



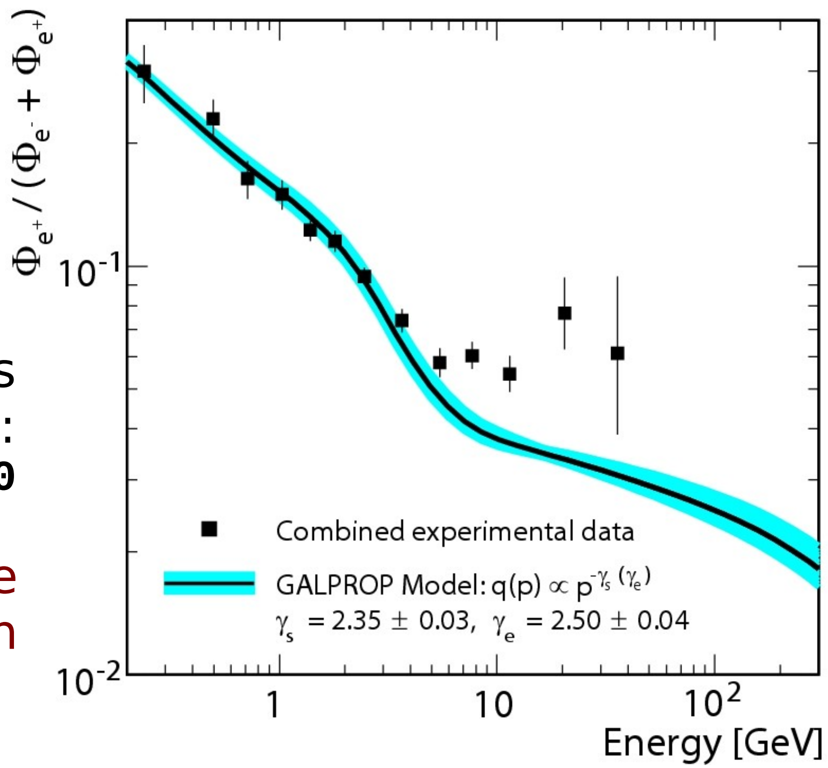
Positron excess above few GeV now indicated by data from two different experiments / analysis techniques

Combined positron fraction data

Combination of recent data from AMS-01, HEAT, CAPRICE and TS93:



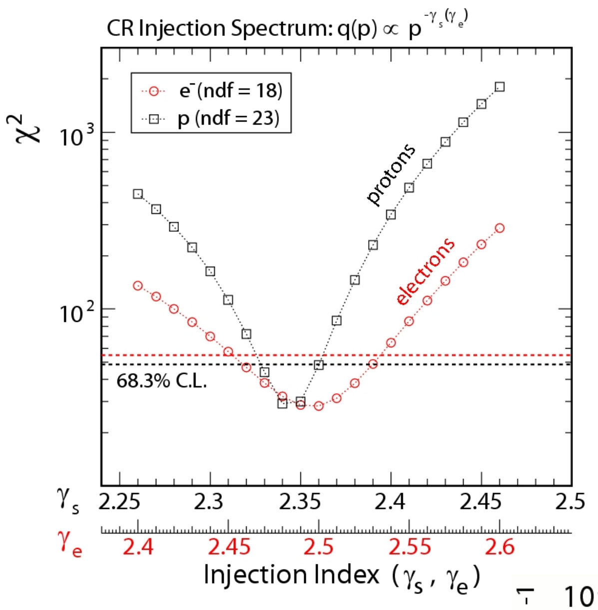
AMS-01, Alcaraz et al. PLB 472 (2000)
AMS-01, Aguilar et al. PLB 646 (2007)
HEAT, Beatty et al. PRL 93 (2004)
CAPRICE, Boezio et al. ApJ 532 (2000)
TS93, Golden et al. ApJ 457 (1996)



Algorithm considers asymmetric errors
(basically as used by PDG), see:
`R. Barlow, physics/0406120`

Positron data clearly not compatible
with background expectation

Background uncertainty



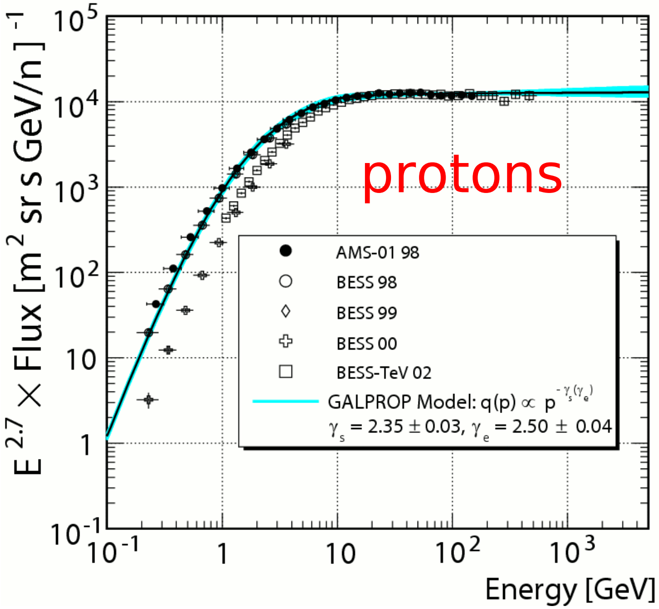
$$\Phi \propto p^{-\gamma(\gamma_S,\gamma_e)}$$

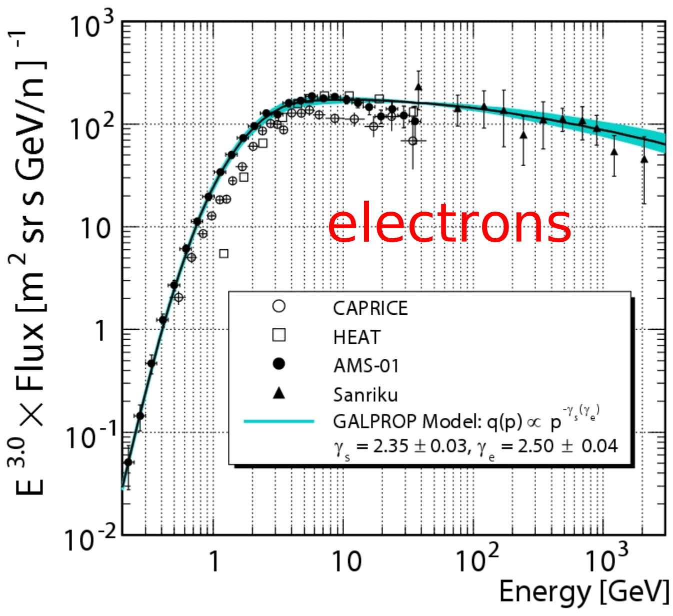
χ2 of background fit to the p / e⁻ flux data (DR model, halo size 4 kpc):

Nuclei injection index **γ_S = 2.35 ± 0.03**

Electron injection index **γ_e = 2.50 ± 0.04**

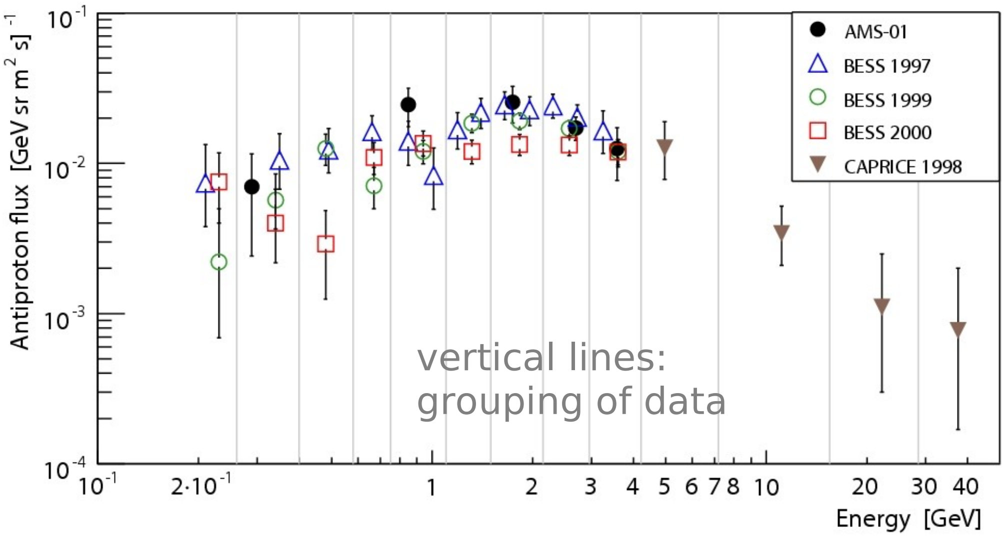
→ estimate the background uncertainty from the 1σ intervals



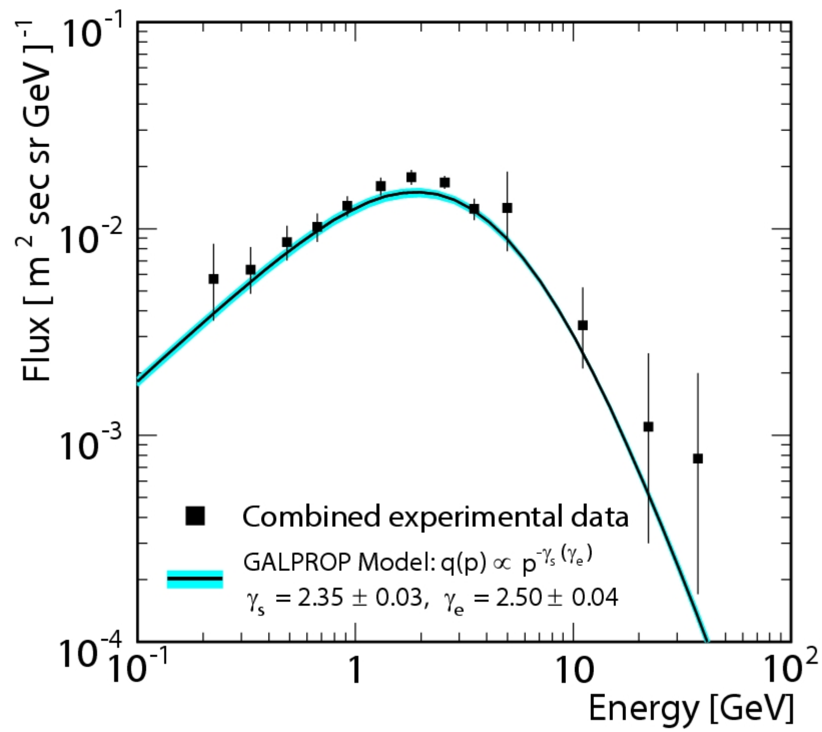


Combined antiproton flux data

Combination of recent data from AMS-01, BESS and CAPRICE:

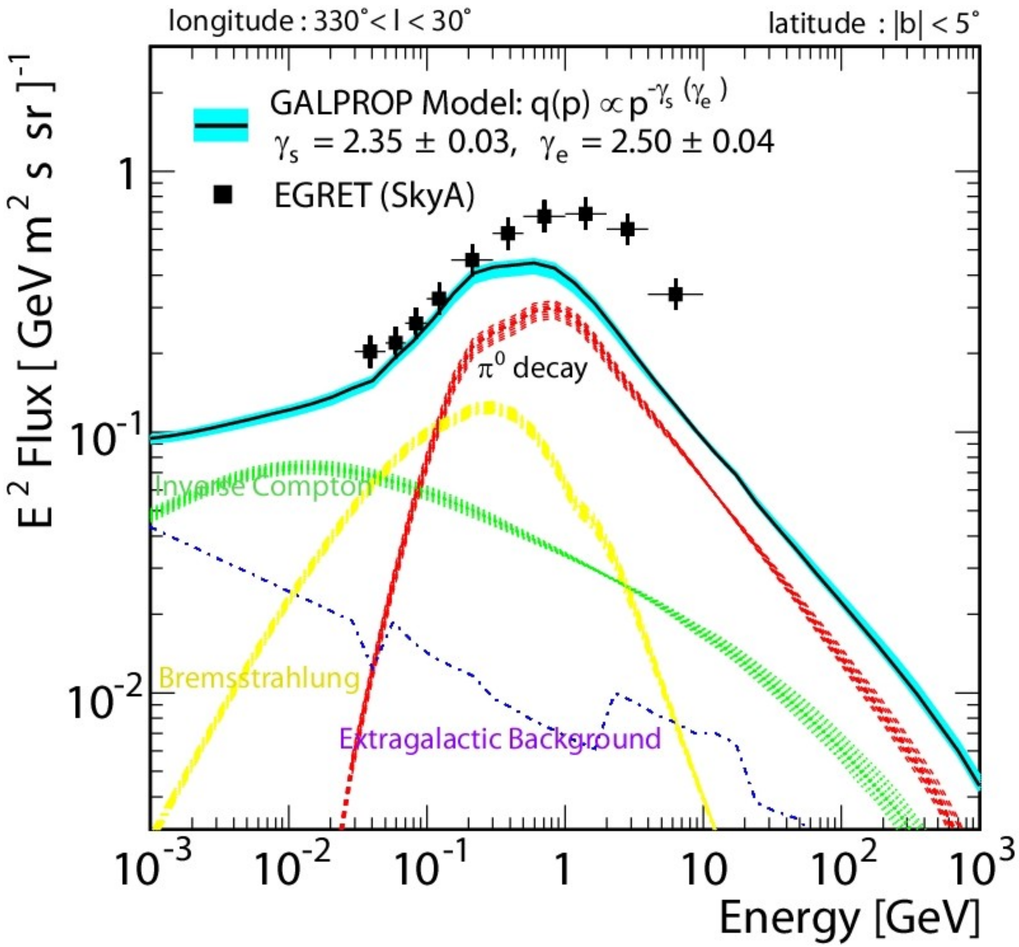


AMS-01, Aguilar et al. PhysRep 366 (2002)
BESS97, Orito et al. PRL 84 (2000)
BESS99, Asaoka et al. PRL 88 (2002)
BESS00, Asaoka et al. PRL 88 (2002)
CAPRICE, Boezio et al. ApJ 561 (2001)



Antiproton flux is widely in agreement with background expectation

Diffuse gamma ray data from EGRET



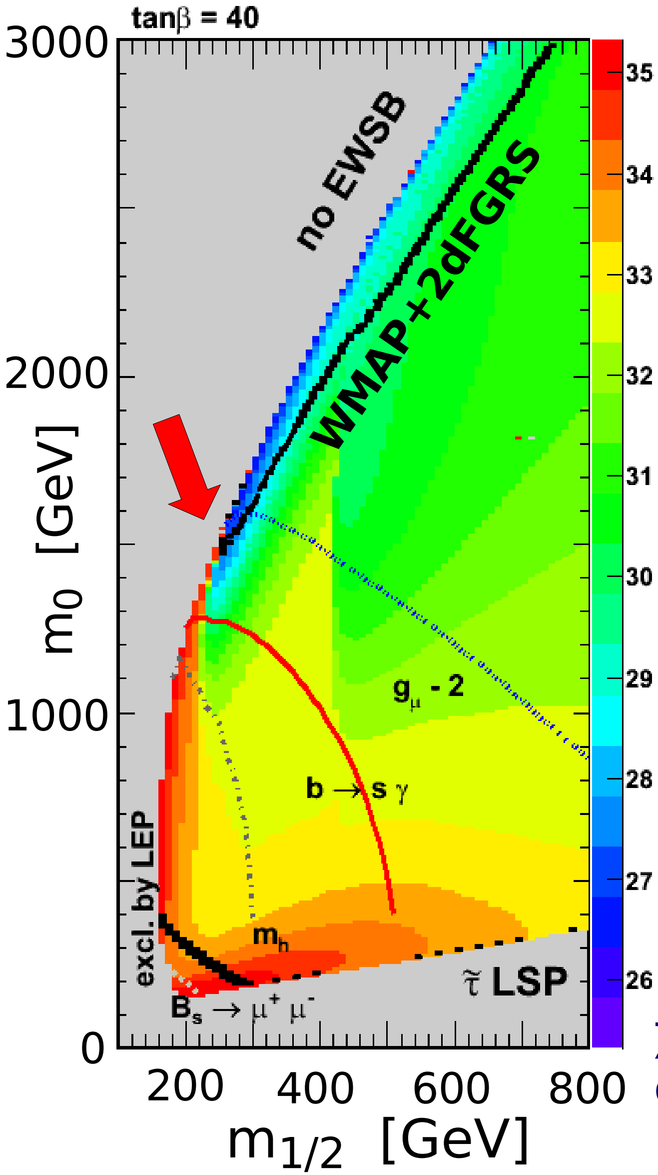
EGRET data: excess with respect to background expectation above ~ 1 GeV

SUSY signal?
de Boer et al. PLB 636 (2006) 13

Energy miscalibration?
Stecker et al. arXiv:0705.4311

Resolvable by model tuning?
Strong et al. ARNPS 57 (2007) 285

MSSM parameter scan using cosmic-ray data



χ2 of MSSM fit to cosmic-ray data

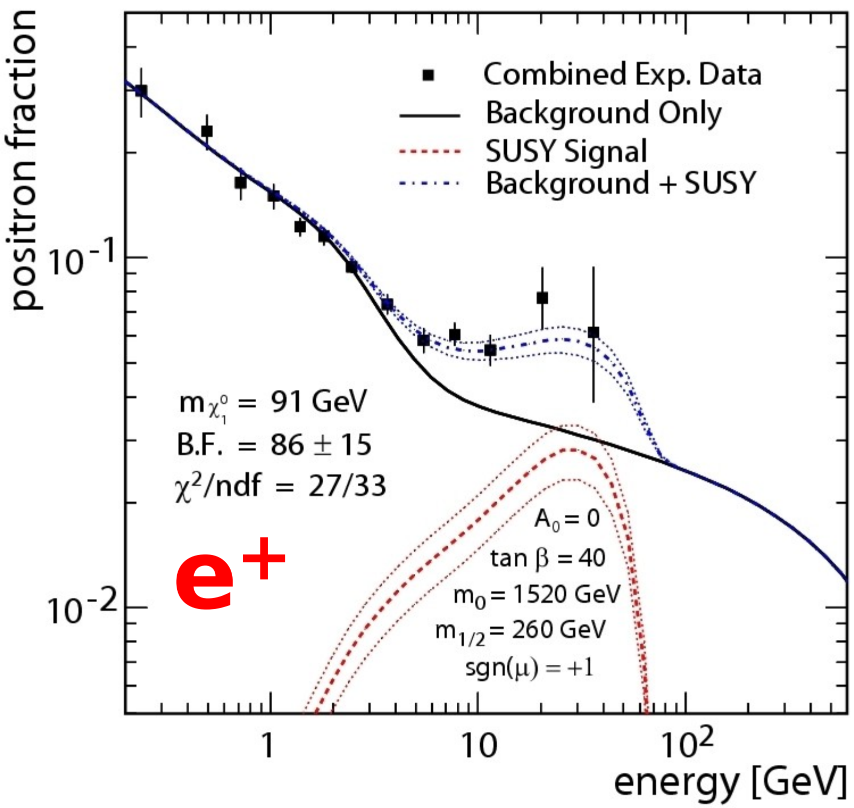
- Combined fit to **positron** fraction, **antiproton** flux and **gamma-ray** flux using MicrOMEGAs 1.3.5 → Isajet 7.74 (mod), DarkSUSY 4.1, GALPROP v50 (DR model)
- Isothermal **halo model**, $\rho_0 = 0.3$ GeV/cm^3
- Amplitudes of SUSY signals treated as fit parameters (DM distribution unknown) → **3 boost factors** (BF)

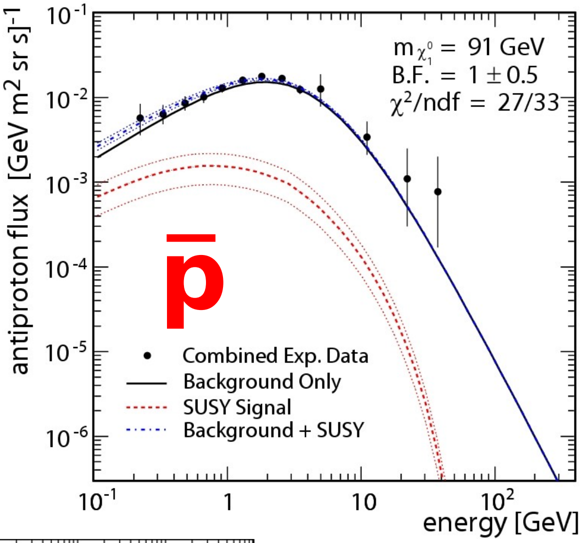
Parameters preferred by cosmic-ray data:

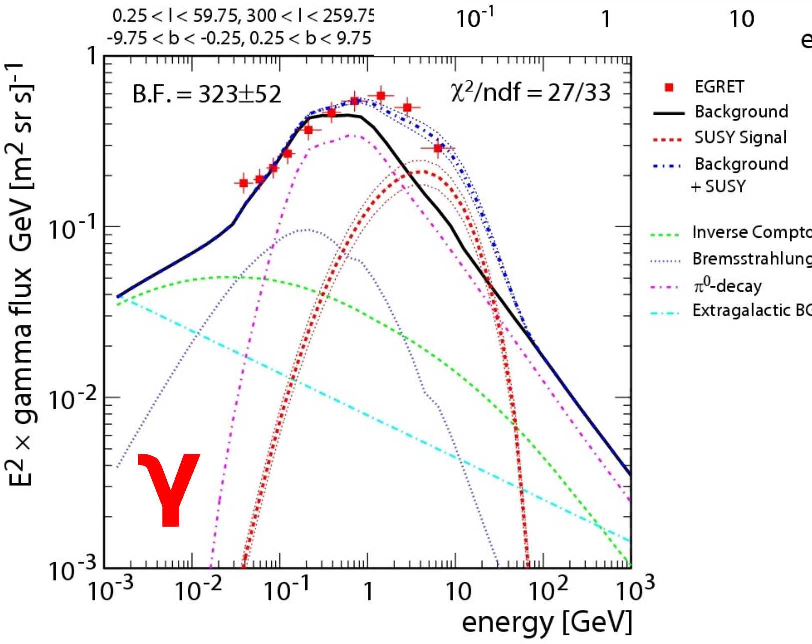
- m_0 = 1520 GeV $\tan\beta = 40$, $A_0 = 0$
- $m_{1/2}$ = 260 GeV   sign $\mu = +1$

χ has significant higgsino component, annihilation dominantly via $\chi^{\pm}$ (t-channel) into WW pairs

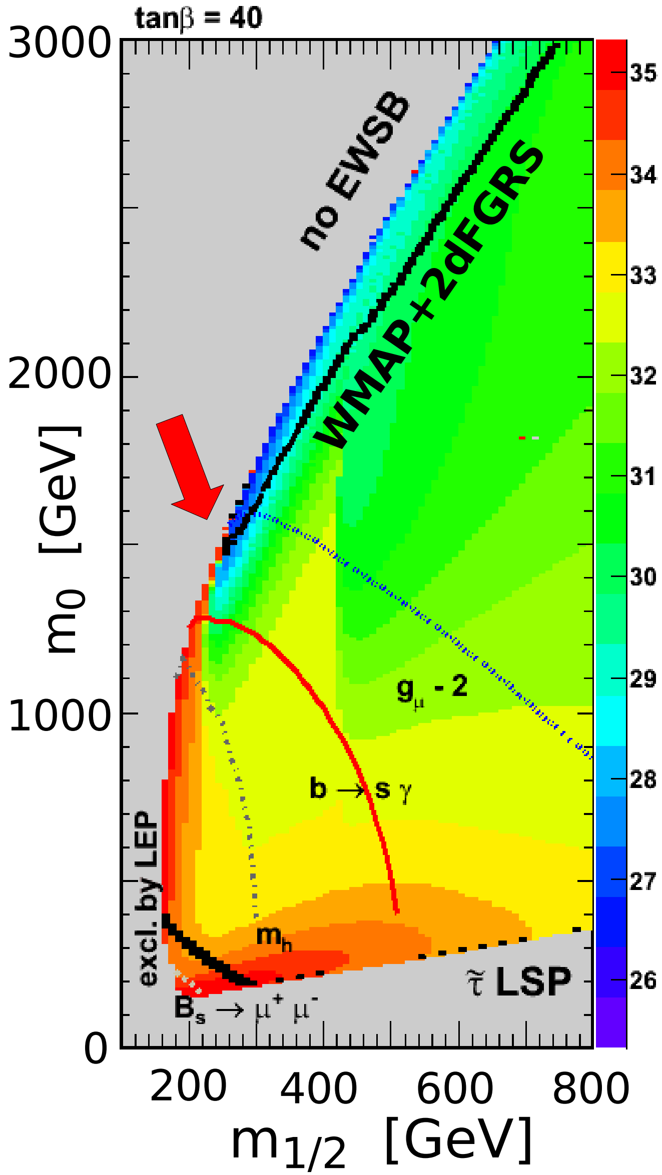
MSSM fits to cosmic-ray data







Cosmic-ray preferred MSSM parameters



Parameters preferred by cosmic-ray data:

- m_0 = 1520 GeV
- $m_{1/2}$ = 260 GeV

tan β = 40 (A_0 = 0, sign μ = +1)

Consistent with current limits:

- Dark matter density: $\Omega_{DM}h^2 = 0.094$
  $0.0915 < \Omega_{DM}h^2 < 0.1129$ (2σ)
  (from WMAP, Spergel et al. astro-ph/0603449)
- μ magnetic moment: $\Delta a_\mu = 7.35 \cdot 10^{-10}$
  $6.8 \cdot 10^{-10} < \Delta a_\mu < 43.6 \cdot 10^{-10}$ (2σ)
  (from E821@BNL, Bennett et al. hep-ex/0602035)
- Limits on BR(b→sγ): $BR = 3.14 \cdot 10^{-4}$
  $2.87 \cdot 10^{-4} < BR(b\to s\gamma) < 4.21 \cdot 10^{-4}$ (2σ)
  (from PDG & HFAG, hep-ex/0603003)
- Limits on BR(B_S→μμ): $BR = 0.0287 \cdot 10^{-7}$
  $BR(B_S\to\mu\mu) < 1.5 \cdot 10^{-7}$
  (from PDG, Yao et al. J. Phys. G **33** (2006) 1)

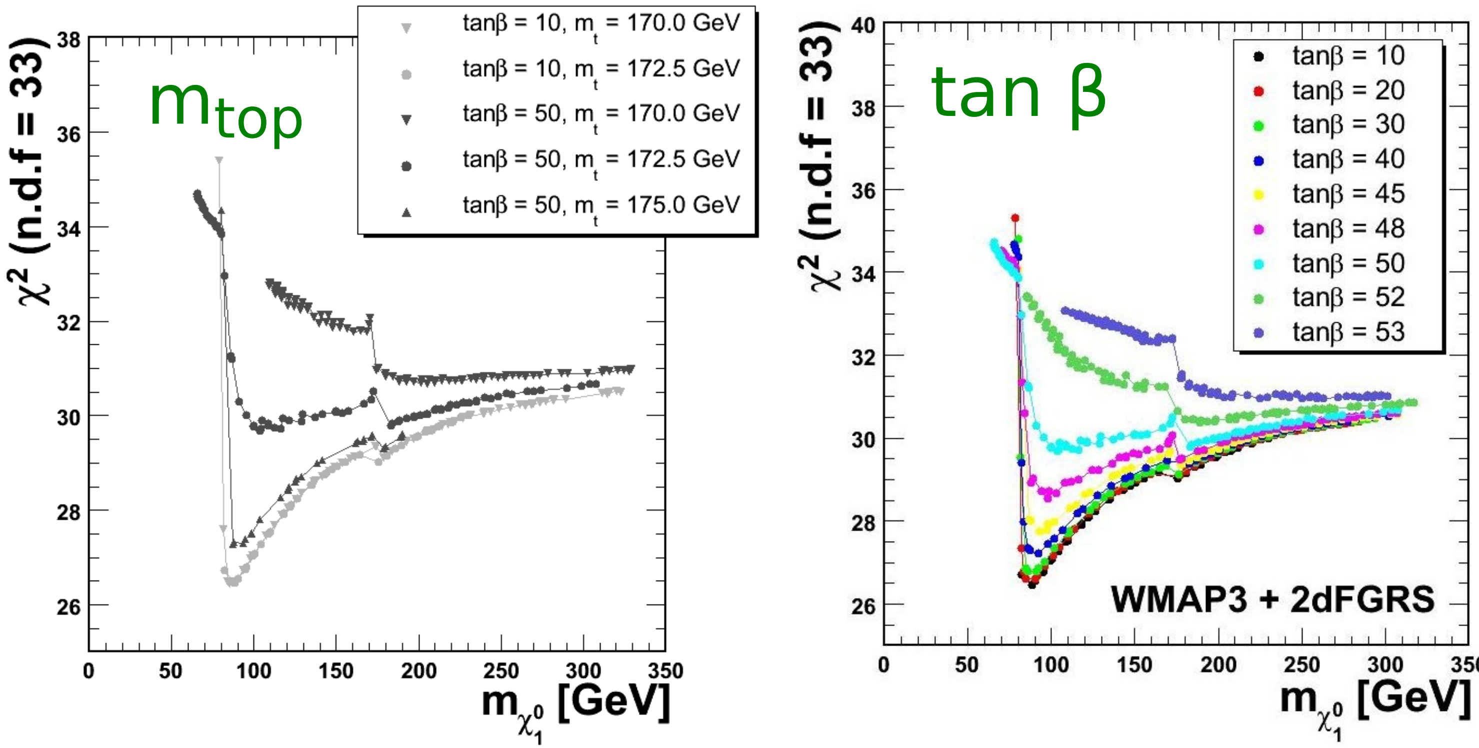
Some implications

Parameters preferred by cosmic-ray data:
- m_0 = 1520 GeV
- $m_{1/2}$ = 260 GeV

tan β = 40 (A_0 = 0, sign μ = +1)

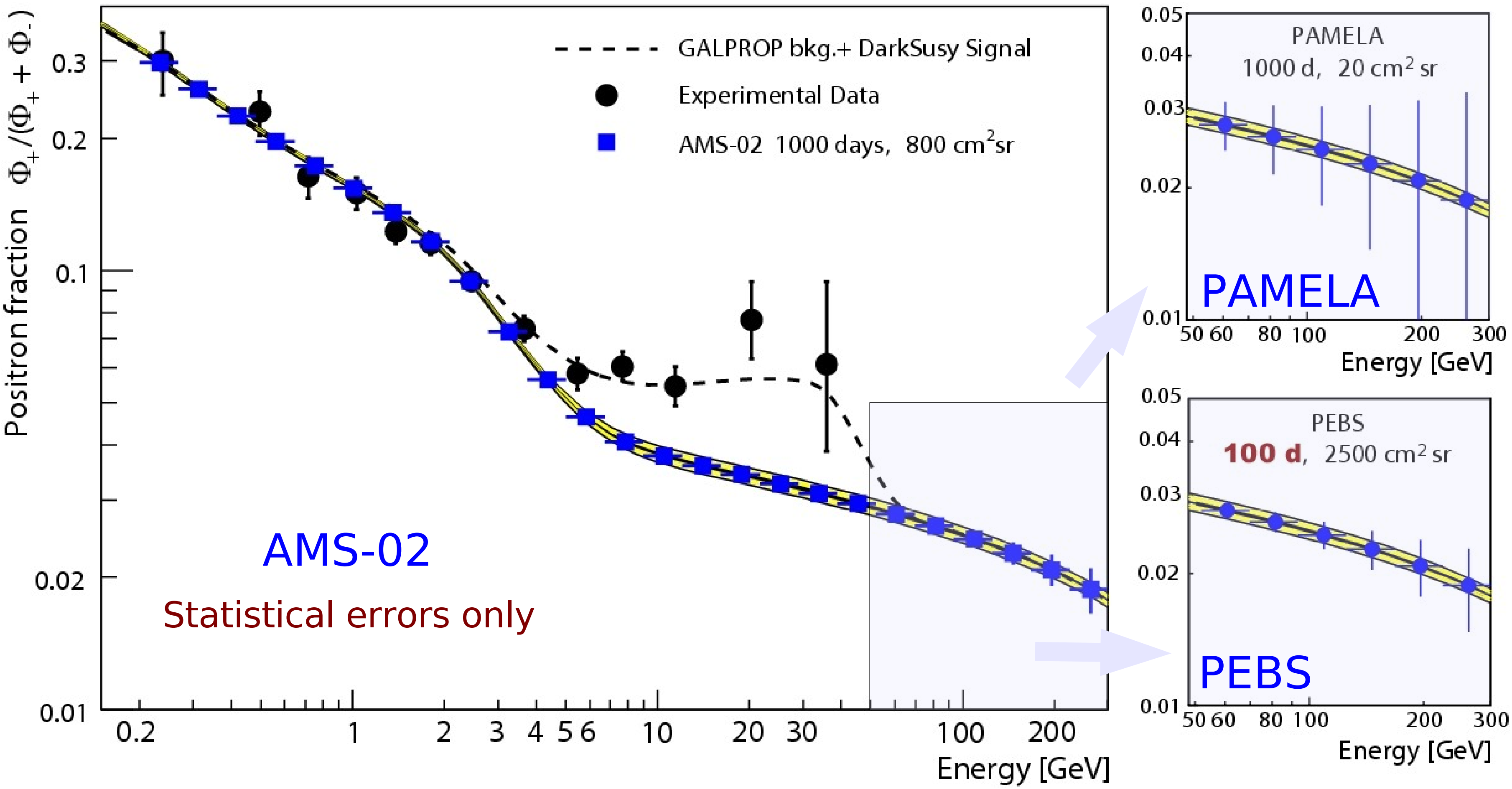
$m_{\chi_1^0}$ = 91 GeV
f_g = 66%, f_h = 34%
BR(χχ→WW) = 79%
m_h = 113.7 GeV

Strong dependence on m_{top} and tan β: **no reliable prediction of m_χ**

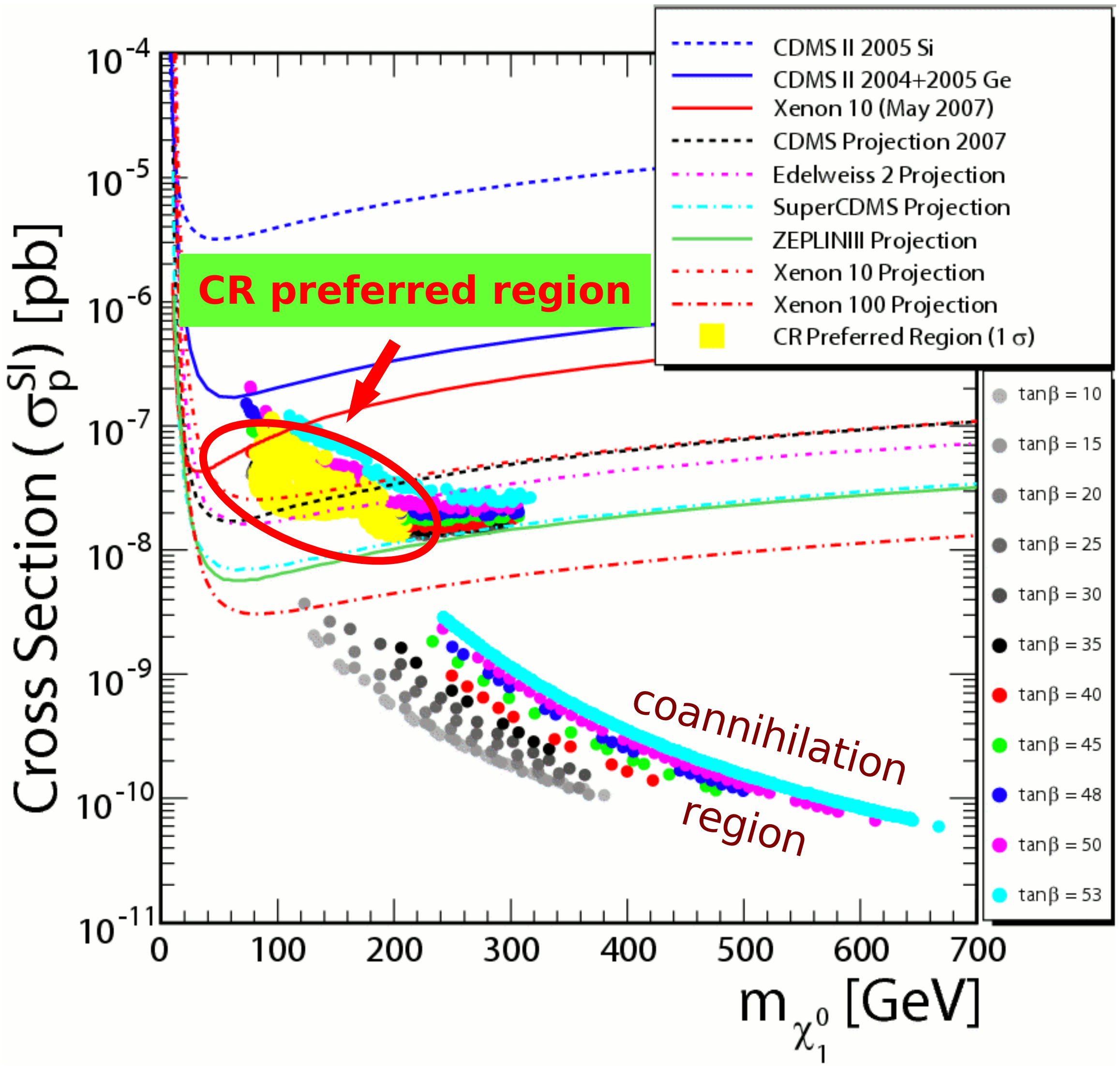


Prospects for indirect detection experiments: AMS-02, PEBS, PAMELA

Energy range above ~50 GeV is crucial to verify the background modeling!



Prospects for direct detection experiments

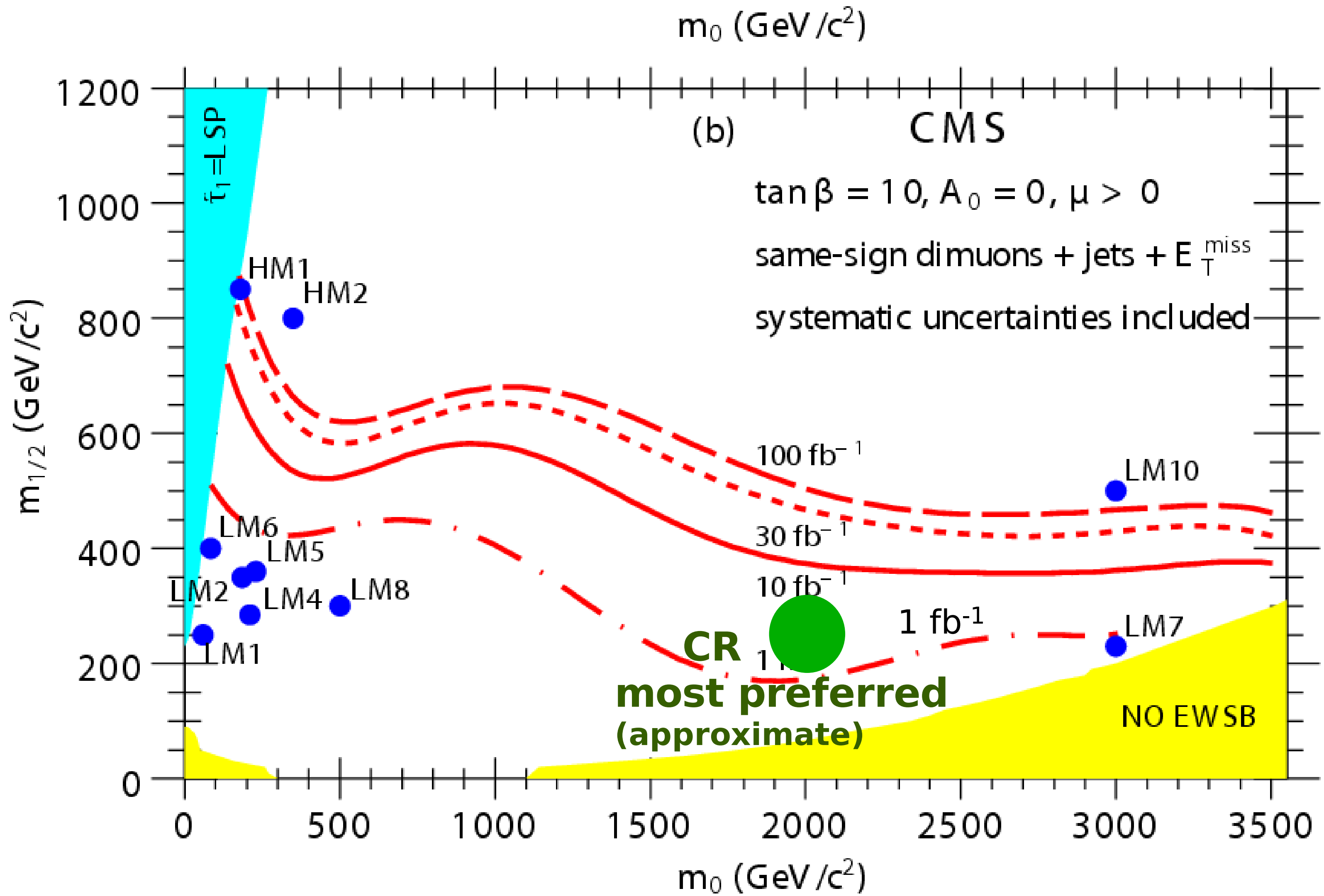


Current experiments will already cover parts of the region soon:
CDMS II, XENON-10, EDELWEISS II, ...

Fully covered within the next few years:
SuperCDMS, XENON-100, ZEPLIN III, ...

2σ prediction from cosmic-ray data

Discovery at the LHC?

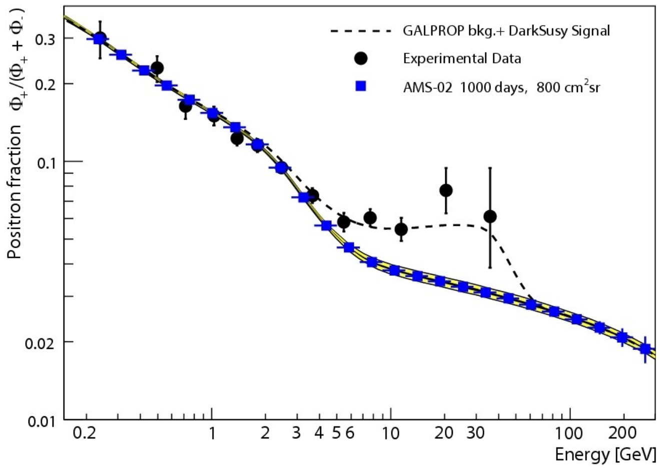


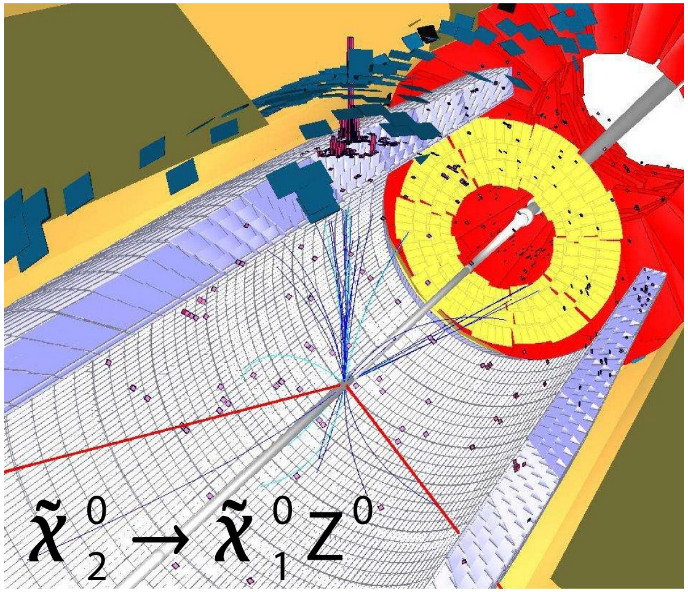
Pakhotin et al. CMS Note 2006/134

Conclusions

• AMS-01 reanalysis: confirmation of the **cosmic-ray positron excess** previously seen by HEAT: now a significant effect

• MSSM interpretation: scenario which simultaneously explains the **positron**, **antiproton** and **gamma-ray spectra** and matches the current constraints from cosmology and accelerator experiments.





• Yet large uncertainties of m_t and tanβ: no reasonable predictions of the neutralino mass. CR data prefer focus point region.

• Good prospects for indirect dark matter search: AMS-02 and PEBS will have sufficient statistics at high energy, not clear for PAMELA. PEBS can do it in 100 days.

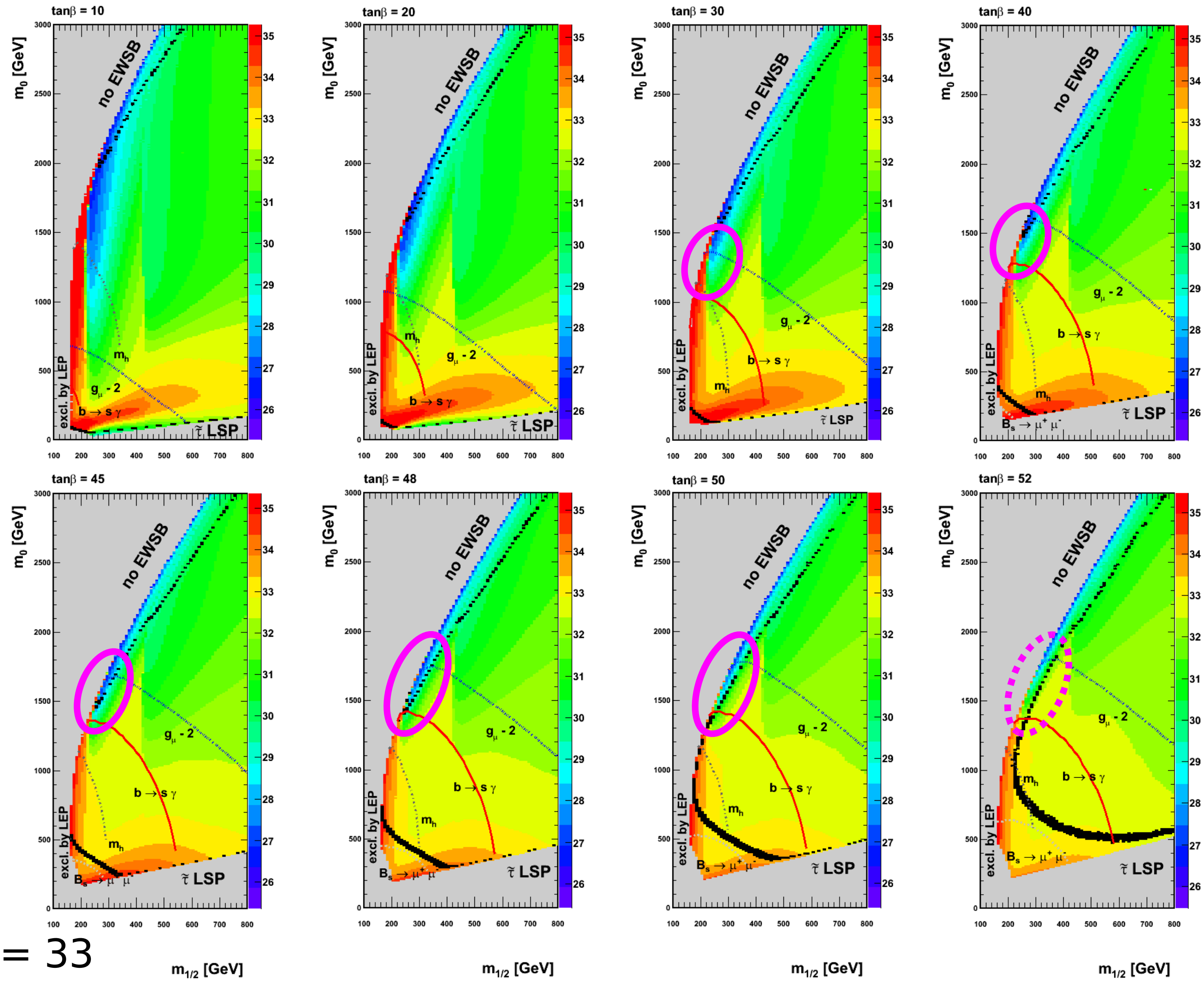
• Direct detection: Signal may be visible to current experiments, next generation should do.

• LHC: Signal could be seen in first year's data.

BACKUP SLIDES

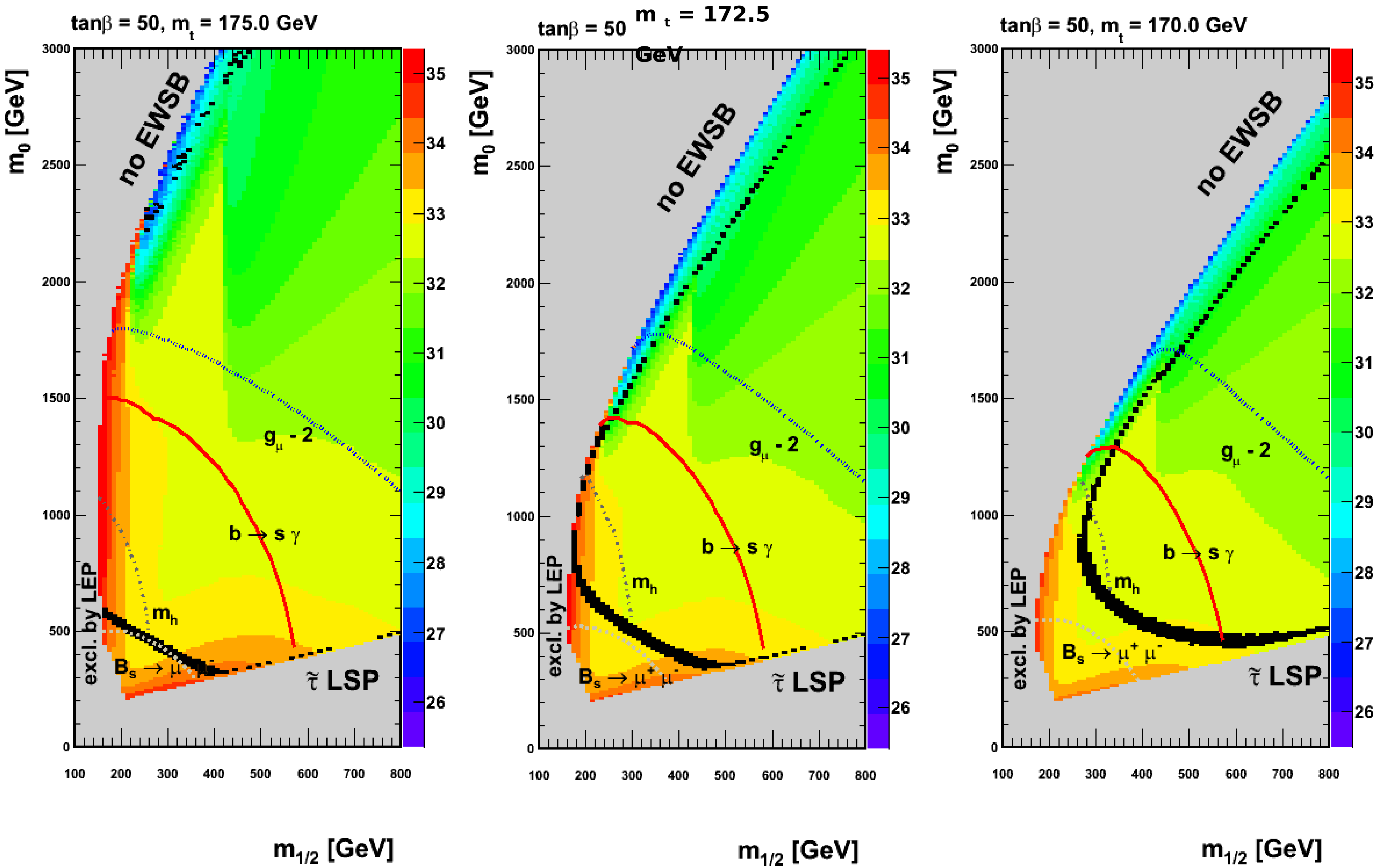
Dependence on tan β

$A_0 = 0$, sign(μ) = +1, m_t = 172.5 GeV



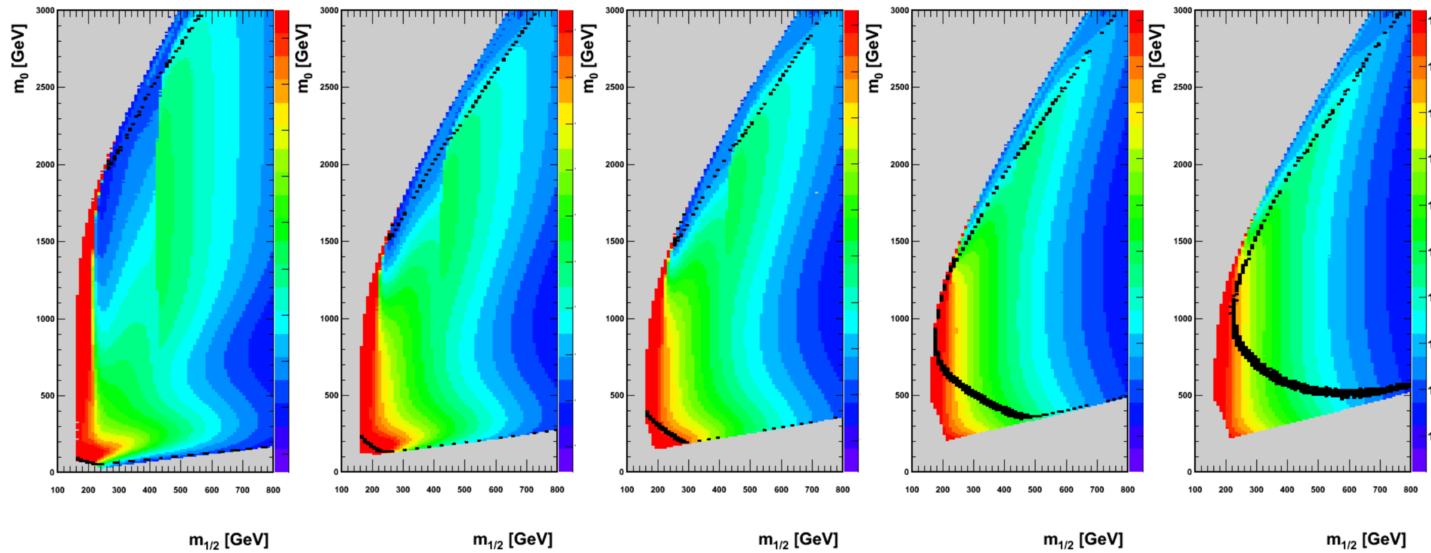
n.d.f. = 33

Dependence on m_{top}



Fits of individual particle fluxes

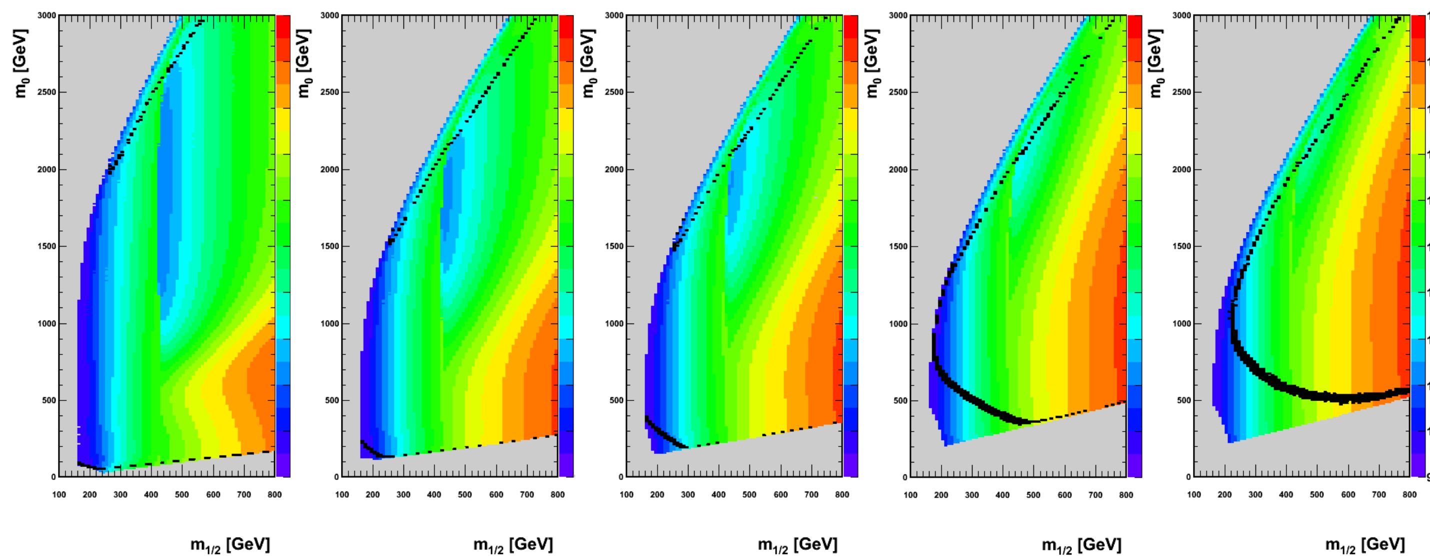
$e^+/(e^+ + e^-)$ only



$A_0 = 0$, sign(μ) = +1, m_t = 172.5 GeV

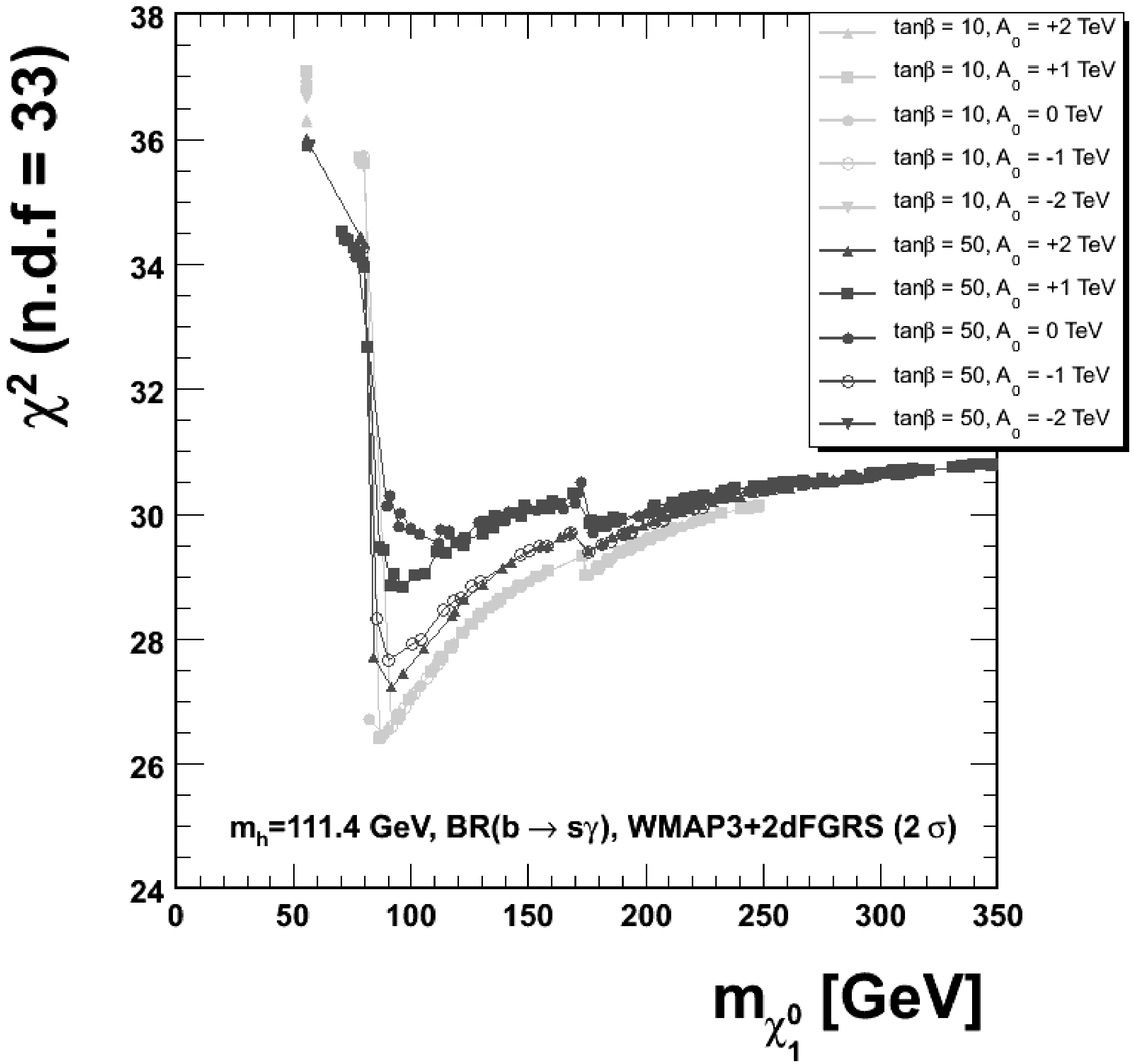
tanβ=10 tanβ=30 tanβ=40 tanβ=50 tanβ=52

γ–rays only



n.d.f. = 12

Dependence on A_0



The PEBS experiment

positron-**e**lectron **b**alloon **s**pectrometer

High acceptance - 4000 cm^2 sr - **balloon-borne spectrometer**
(see H. Gast, talk at ICRC07)

First flight foreseen for 2009