The anomaly in the cosmic-ray positron spectrum

J. Olzem,
C.H. Chung, H. Gast, S. Schael

1. Physikalisches Institut B, RWTH Aachen

15th SUSY Conference, Karlsruhe
July 26th, 2007
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


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

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

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

→ proton background suppressed by $> 3 \cdot 10^6$
Combined positron fraction data

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

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

Positron data clearly not compatible with background expectation
Background uncertainty

\[ \Phi \propto p^{-\gamma(S,e)} \]

\( \chi^2 \) of background fit to the p / e\(^{-} \) flux data (DR model, halo size 4 kpc):

- Nuclei injection index \( \gamma_S = 2.35 \pm 0.03 \)
- Electron injection index \( \gamma_e = 2.50 \pm 0.04 \)

→ estimate the background uncertainty from the 1\( \sigma \) intervals
Combined antiproton flux data

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

Antiproton flux is widely in agreement with background expectation

BESS97, Orito et al. PRL 84 (2000)
BESS00, Asaoka et al. PRL 88 (2002)
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

- 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  $\text{sign } \mu = +1$

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

$\chi^2$ of MSSM fit to cosmic-ray data
MSSM fits to cosmic-ray data

- Combined Exp. Data
- Background Only
- SUSY Signal
- Background + SUSY

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Jan Olzem

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Cosmic-ray preferred MSSM parameters

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Consistent with current limits:
- Dark matter density: $\Omega_{DM} h^2 = 0.094$
  $0.0915 < \Omega_{DM} h^2 < 0.1129$ (2$\sigma$)
  (from WMAP, Spergel et al. astro-ph/0603449)
- $\mu$ magnetic moment: $\Delta a_\mu = 7.35 \cdot 10^{-10}$
  $6.8 \cdot 10^{-10} < \Delta a_\mu < 43.6 \cdot 10^{-10}$ (2$\sigma$)
  (from E821@BNL, Bennett et al. hep-ex/0602035)
- Limits on $BR(b \rightarrow s\gamma)$: $BR = 3.14 \cdot 10^{-4}$
  $2.87 \cdot 10^{-4} < BR(b \rightarrow s\gamma) < 4.21 \cdot 10^{-4}$ (2$\sigma$)
  (from PDG & HFAG, hep-ex/0603003)
- Limits on $BR(B_S \rightarrow \mu\mu)$: $BR = 0.0287 \cdot 10^{-7}$
  $BR(B_S \rightarrow \mu\mu) < 1.5 \cdot 10^{-7}$
Some implications

Parameters preferred by cosmic-ray data:
- $m_0 = 1520$ GeV
- $m_{1/2} = 260$ GeV
- $\tan \beta = 40$ ($A_0 = 0$, sign $\mu = +1$)

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

Strong dependence on $m_{\text{top}}$ and $\tan \beta$: **no reliable prediction of** $m_{\chi}$
Prospects for indirect detection experiments: AMS-02, PEBS, PAMELA

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

AMS-02
Statistical errors only
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

$\tan \beta = 10$, $A_0 = 0$, $\mu > 0$

same-sign dileptons + jets + $E_T^{\text{miss}}$

systematic uncertainties included

most preferred
(approximate)

NO EWSB

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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 $m_\chi$ and $\tan\beta$: 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 $\tan \beta$

$A_0 = 0$, $\text{sign}(\mu) = +1$, $m_t = 172.5$ GeV

n.d.f. = 33
Dependence on $m_{\text{top}}$
Fits of individual particle fluxes

\[ e^+/(e^++e^-) \]
only

\[ A_0 = 0, \quad \text{sign}(\mu) = +1, \quad m_t = 172.5 \text{ GeV} \]

\[ \gamma \text{-rays} \]
only

\[ n.d.f. = 12 \]
Dependence on $A_0$

$\chi^2$ (n.d.f. = 33) vs $m_{\chi^0}$ [GeV]

$m_h = 111.4$ GeV, BR($b \to s\gamma$), WMAP3 + 2dFGRS (2 $\sigma$)
The PEBS experiment

**positron-electron balloon spectrometer**

**High acceptance** - 4000 cm$^2$ sr - **balloon-borne spectrometer**

(see H. Gast, talk at ICRC07)

First flight foreseen for 2009

- 0.8 T superconducting magnet
- Scintillating fiber tracker
- SiPM readout
- Xe/CO$_2$ straw tube
- TRD
- Tungsten ECAL
- solar panels

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