Antimatter Measurements with the HEAT Experiment

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XIV^{èmes} Rencontres de Blois
Matter-Antimatter Asymmetry
Blois, France
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Outline:

- Positrons: HEAT-$e^{\pm}$
  - Motivation, prior measurements
  - Astrophysics *vs.* exotics
  - Current results and status
- Antiprotons: HEAT-pbar
  - Motivation, prior measurements
  - Astrophysics *vs.* exotics
  - Current results and status

p, pbar, $e^{\pm}$ in Cosmic Rays

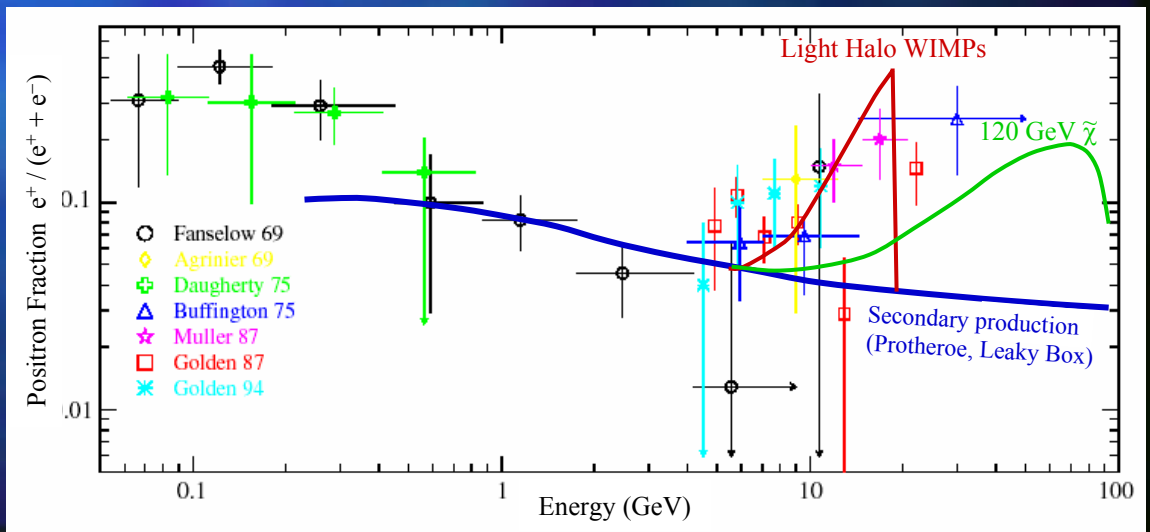
- Primary p, e^{-} produced at CR acceleration sites (e.g. supernova shocks);
- Secondary $e^{\pm}$ produced in equal numbers in the ISM: CR nuclei + ISM $\Rightarrow \pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$;
- Secondary pbars also produced in the ISM;
- Antimatter probes ISM structure and primary nucleon component;
- "Exotic" pbars, $e^{\pm}$?
  - Annihilating dark matter WIMPs (e.g. neutralinos);
  - $\gamma \rightarrow e^{\pm}$ near pulsar magnetic poles;
  - CR nuclei + Giant Molecular Cloud $\rightarrow e^{\pm}$ + reacceleration;
  - Evaporating primordial black holes.

Positron Fraction as of 1995

- Positron fraction $e^+/(e^+ + e^-)$ is small (≈ 10%) ⇒ substantial primary e^- component.
- Below ~7 GeV: data in agreement with secondary predictions (large solar modulation effects below 1 GeV);
- Above ~7 GeV: more antimatter than expected!

  ⇒ additional ("exotic") antimatter component?

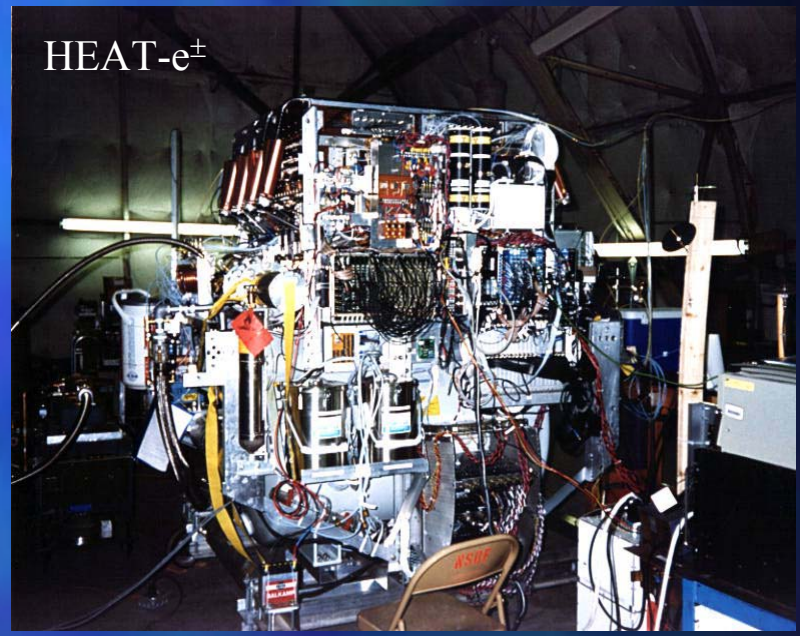
  - Turner/Wilczek light WIMP annihilation (×20);
  - Kamionkowski/Turner heavy WIMP annihilation (×10).
  - Positron line is a "smoking gun" for WIMPs.



HEAT-$e^{\pm}$ (High Energy Antimatter Telescope)

The HEAT-$e^{\pm}$ Collaboration

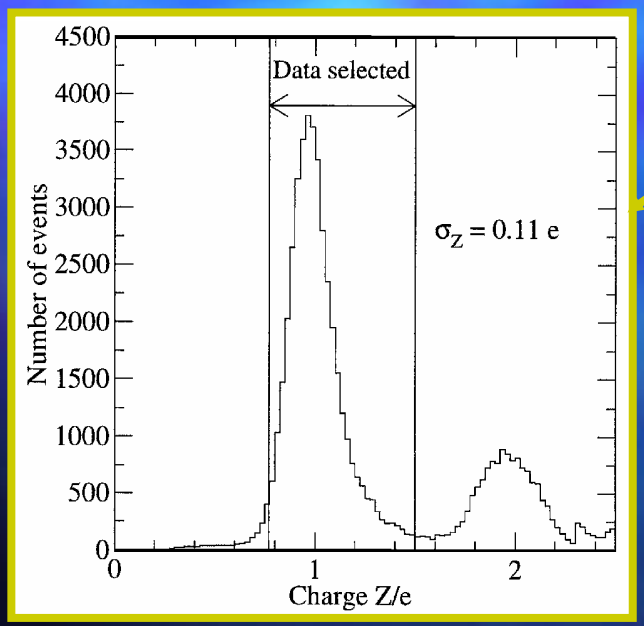
U of Chicago: J. Knapp, D. Müller, S.P. Swordy, E. Torbet
Eastern New Mexico U: S.L. Nutter
Indiana U: C. Bower, J.A. Musser
UC Irvine: S.W. Barwick, E. Schneider
U of Michigan: C. Chaput, S. Coutu, S.P. McKee, G. Tarlé, A.D. Tomasch
Washington U St. Louis: J.J. Beatty, G. de Nolfo, D. Ficenec

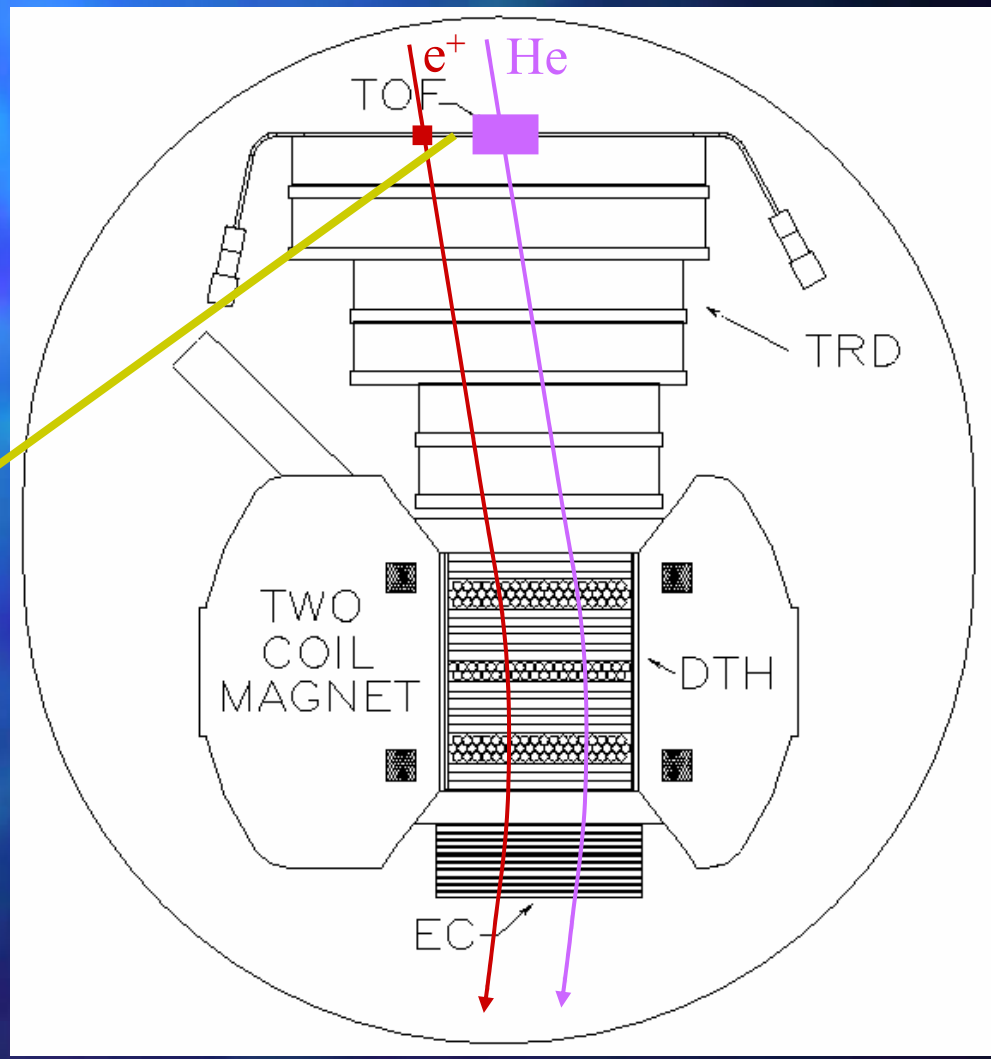


- Superconducting Magnet Spectrometer with Drift Tube Hodoscope (DTH), Electromagnetic Calorimeter (EC), Transition Radiation Detector (TRD) and Time-of-Flight (TOF) system.
- 1) May 1994 flight from Ft. Sumner, NM (29.5 hour flight)
  2) Aug. 1995 flight from Lynn Lake, Manitoba (26 hour flight)

Identifying Positrons with HEAT-$e^{\pm}$

- TOF System:
  - Require Z=1
  - $\beta>0$ (downgoing)





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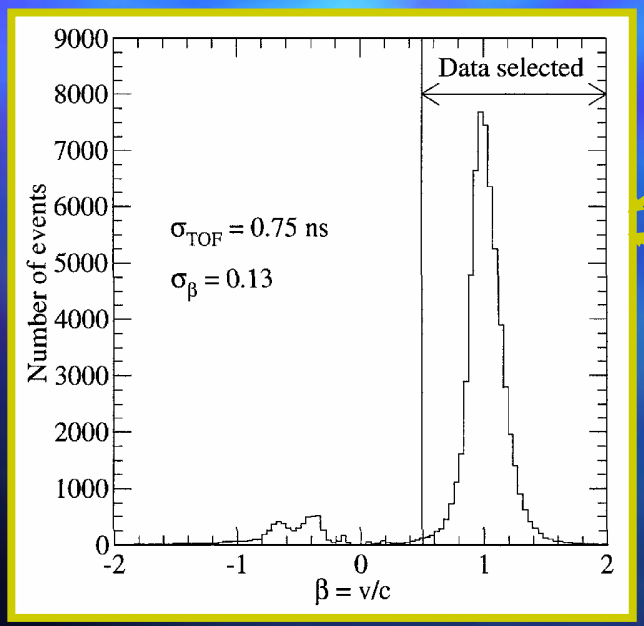
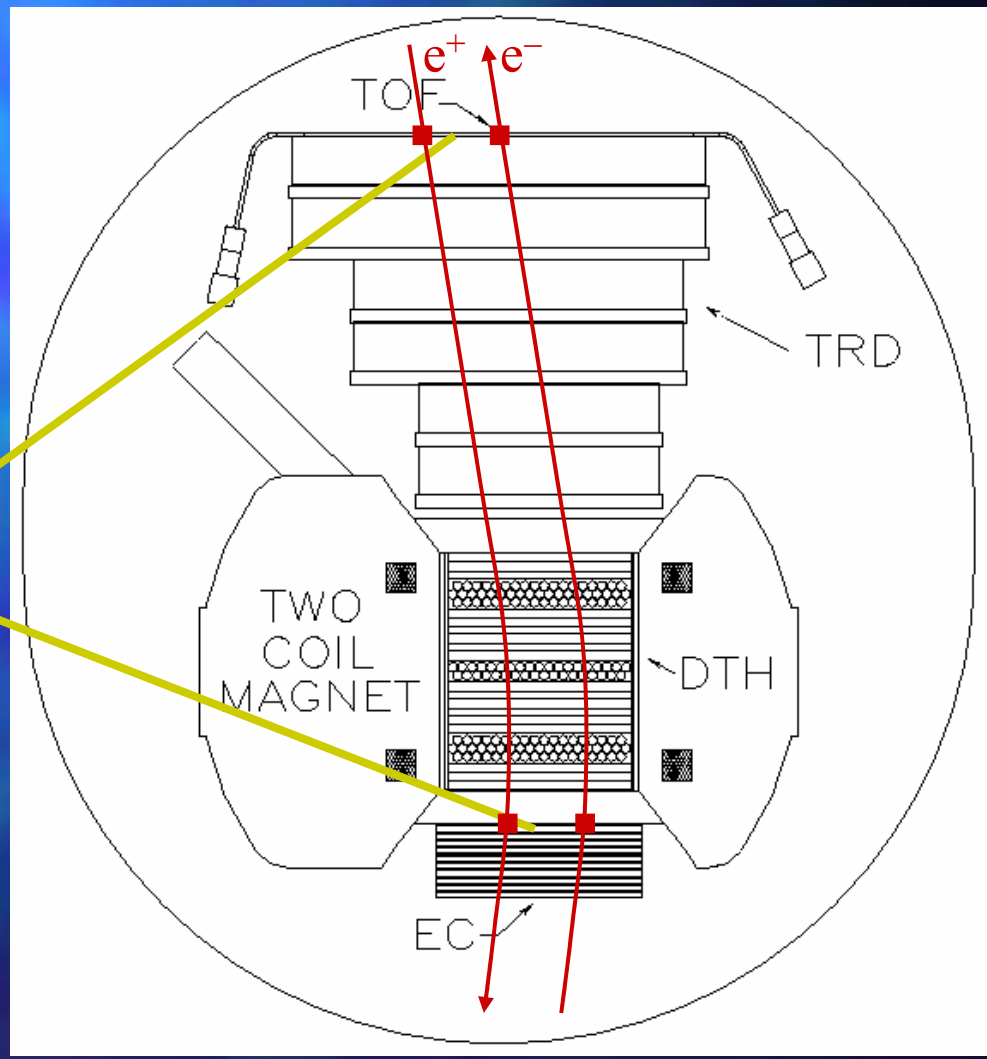
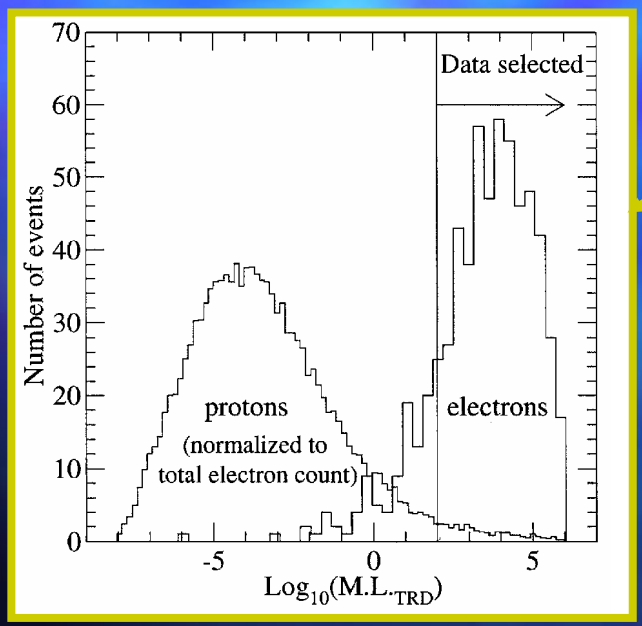
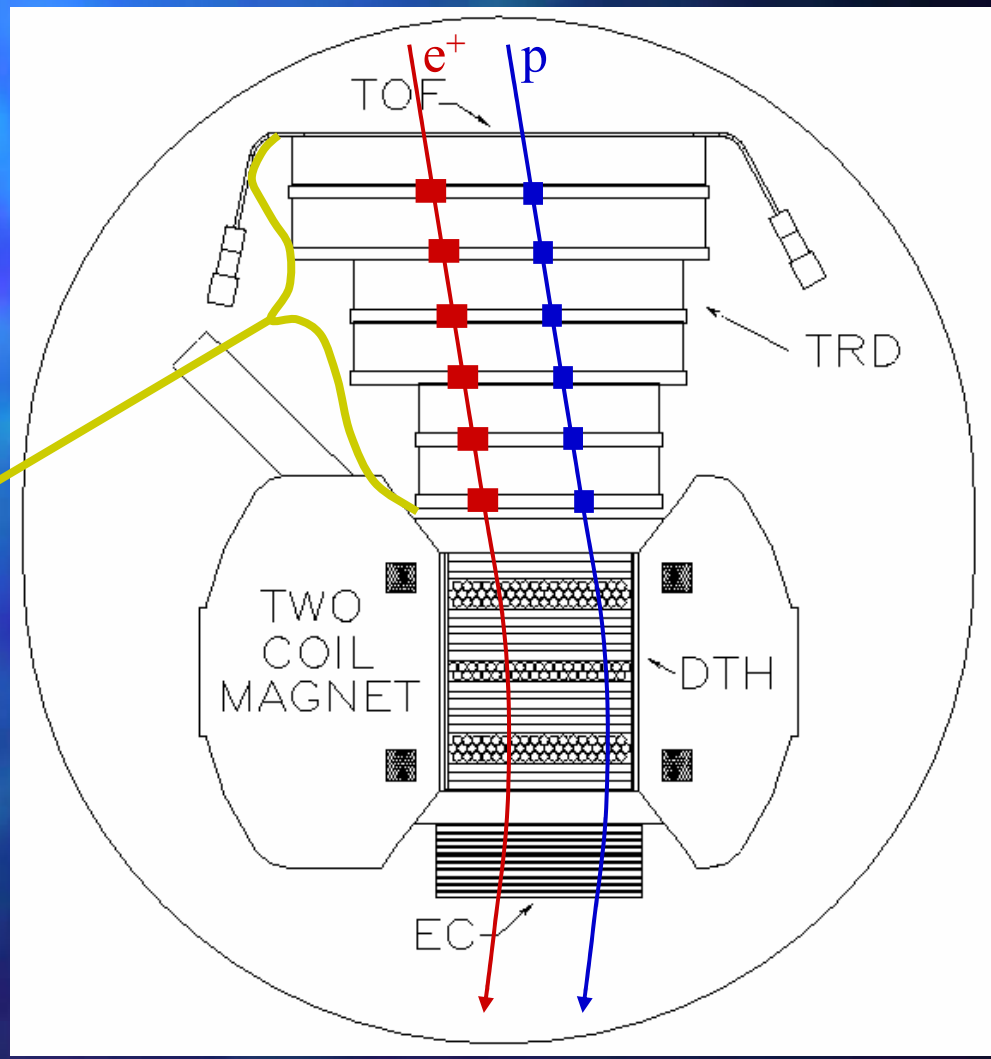




Identifying Positrons with HEAT-$e^{\pm}$

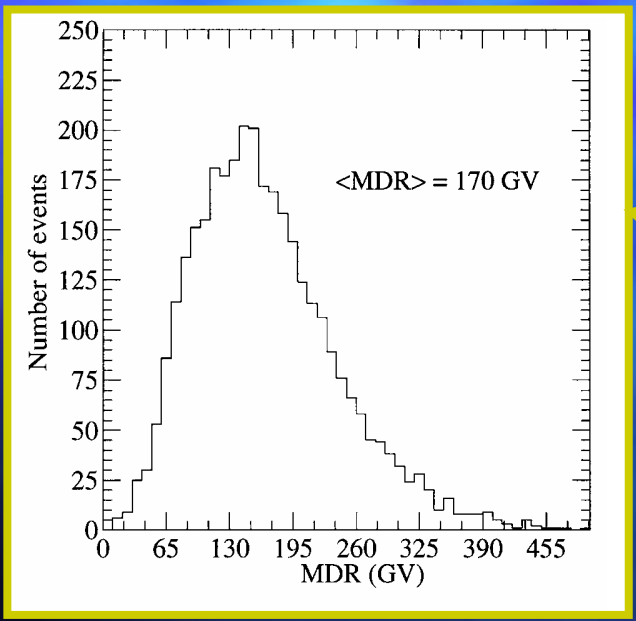
- TRD:
  - dE/dx losses in MWPC
  - TR for $e^{\pm}$ ($\gamma > 4 \times 10^3$)

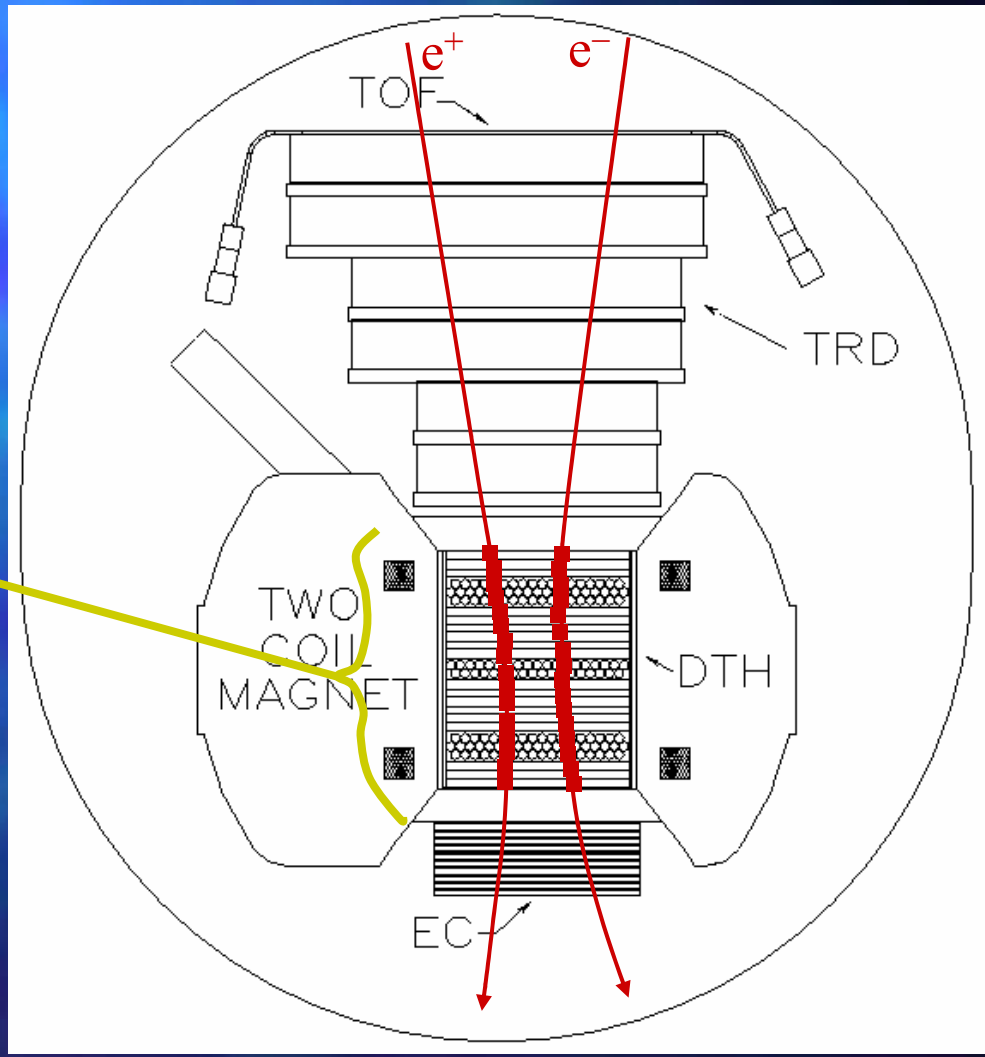




Identifying Positrons with HEAT-$e^{\pm}$

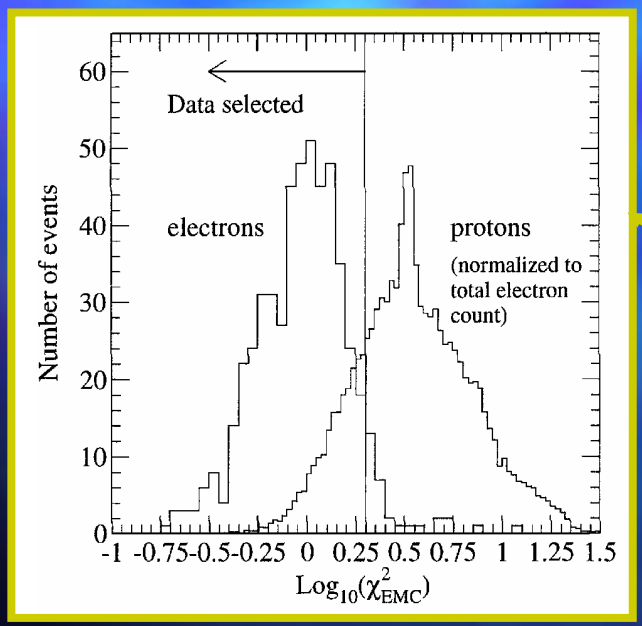
- DTH:
  - p from amount of bending
  - Sign of Z from direction

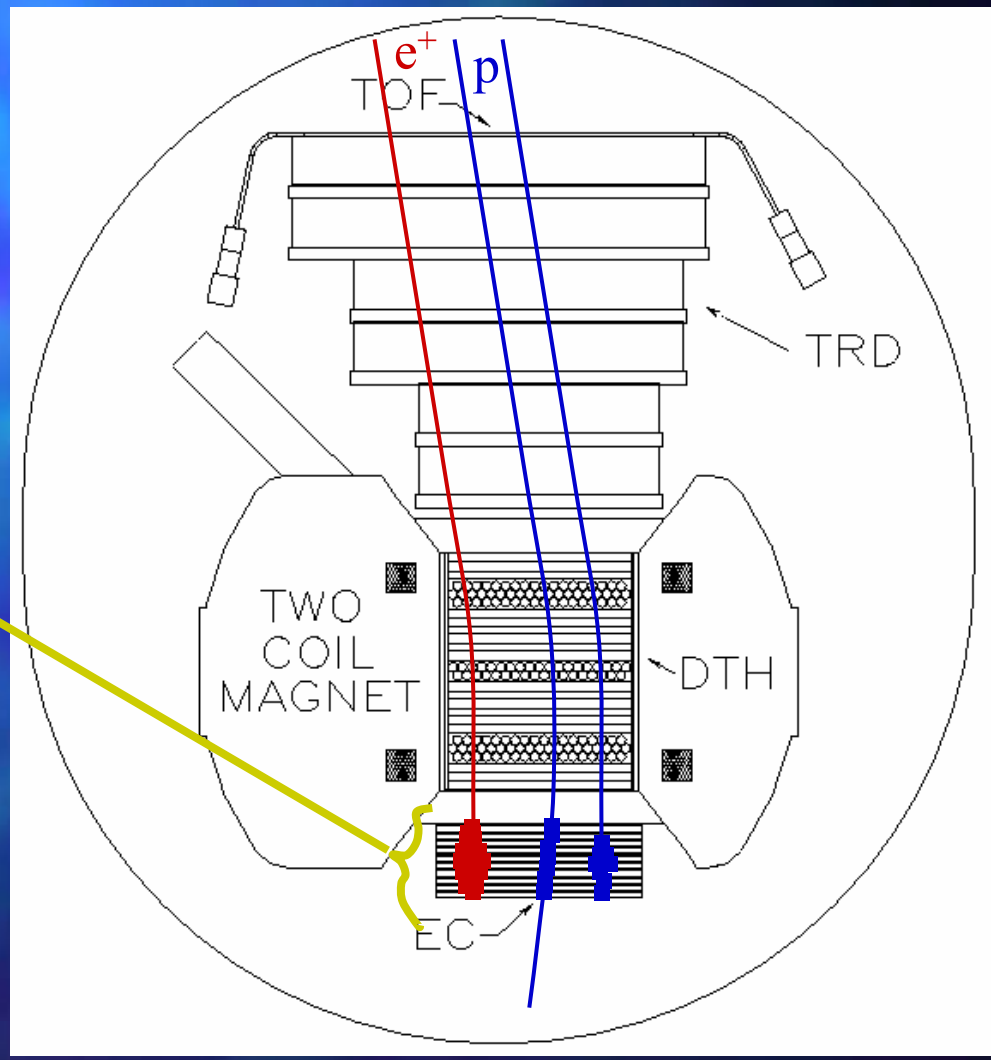




Identifying Positrons with HEAT-$e^{\pm}$

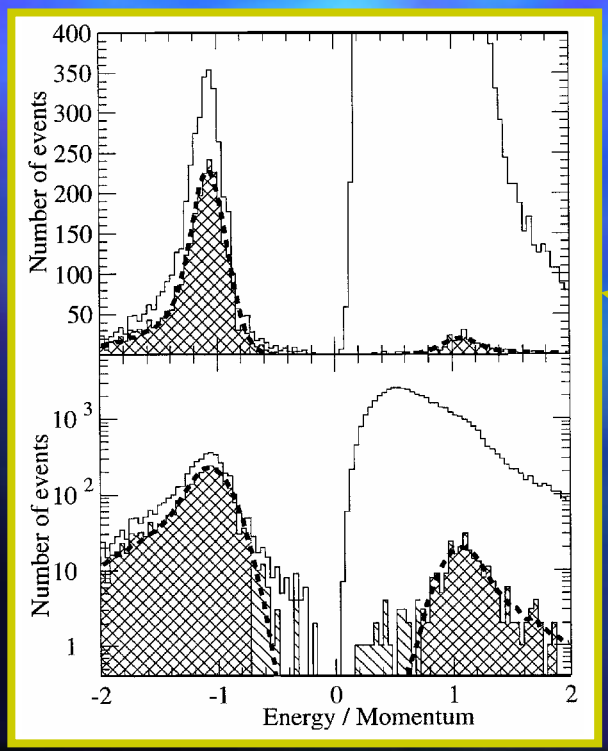
- EC:
  - EM showers for $e^{\pm}$
  - Hadronic or no showers for p

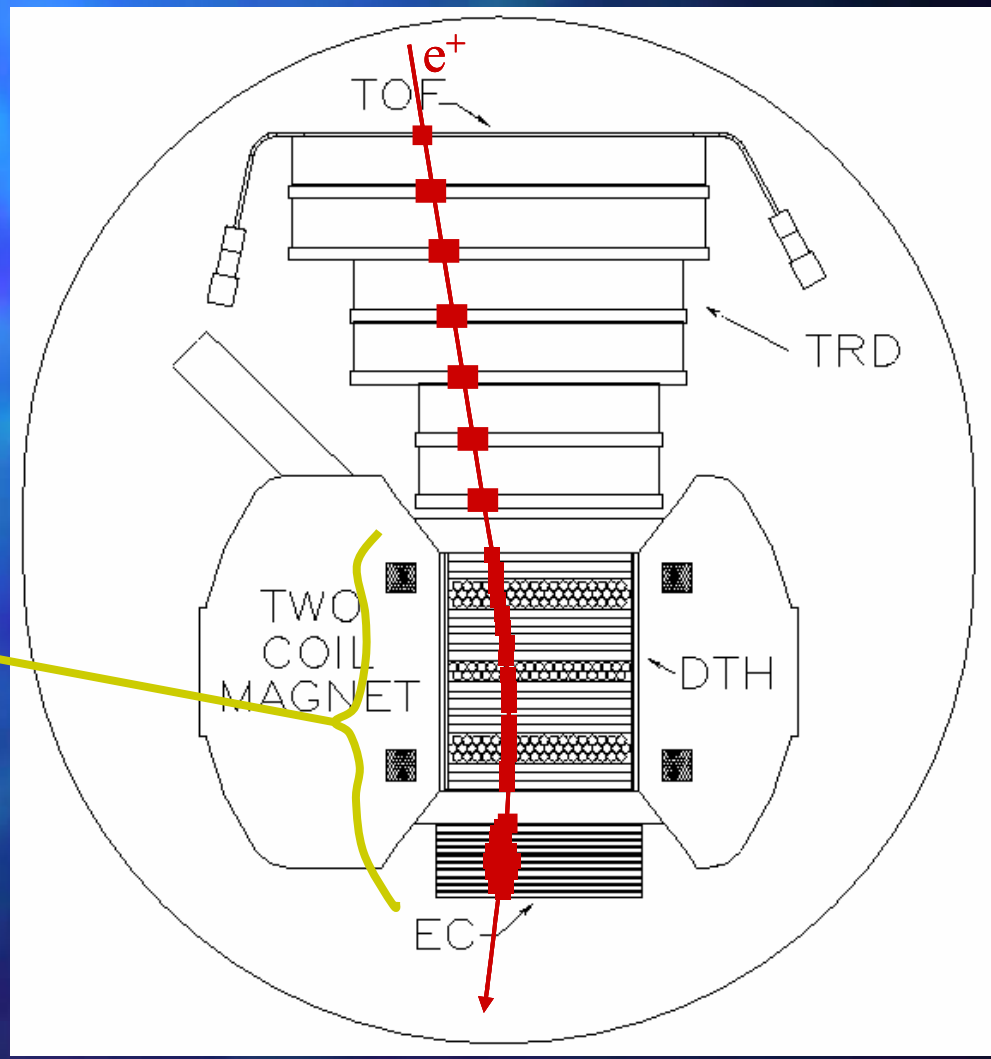




Identifying Positrons with HEAT-$e^{\pm}$

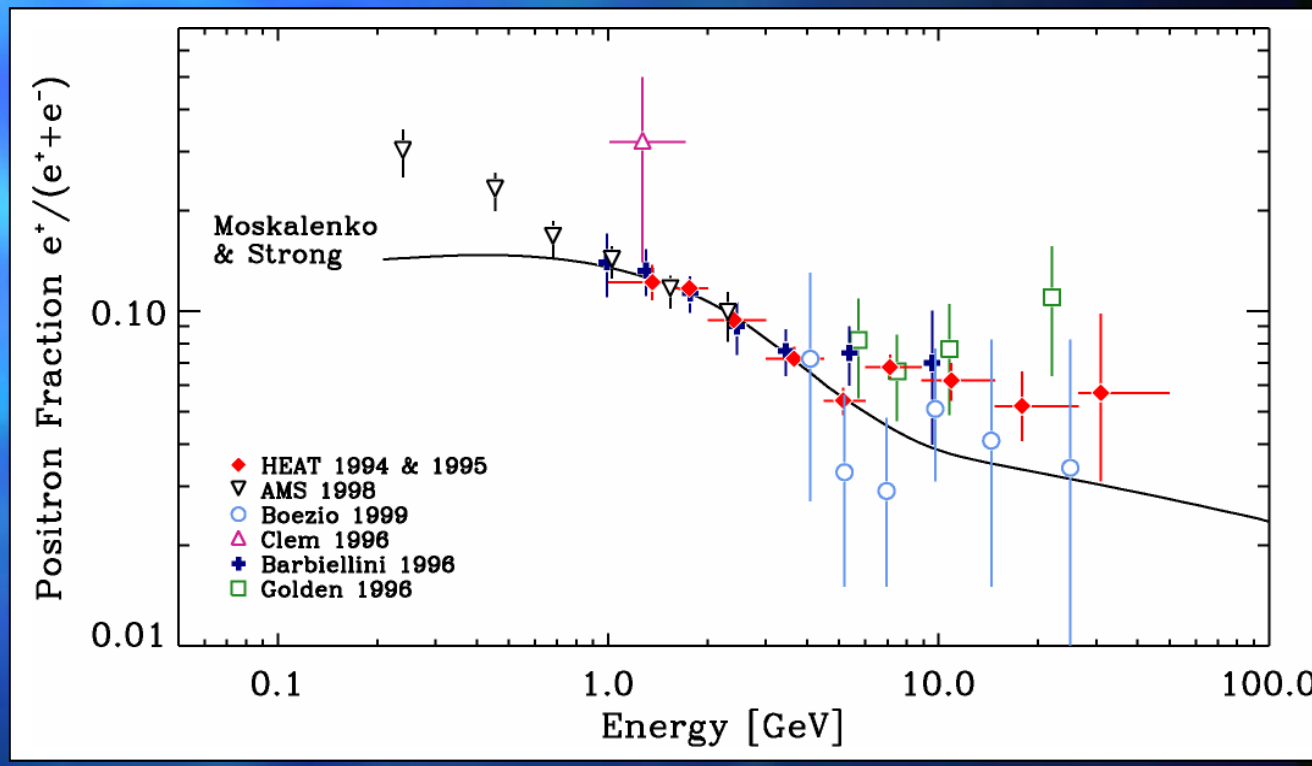
- DTH & EC:
  - E/p agrees with expectations
  - Overall 10^5 p rejection, 33% electron efficiency





Positron Fraction since 1995

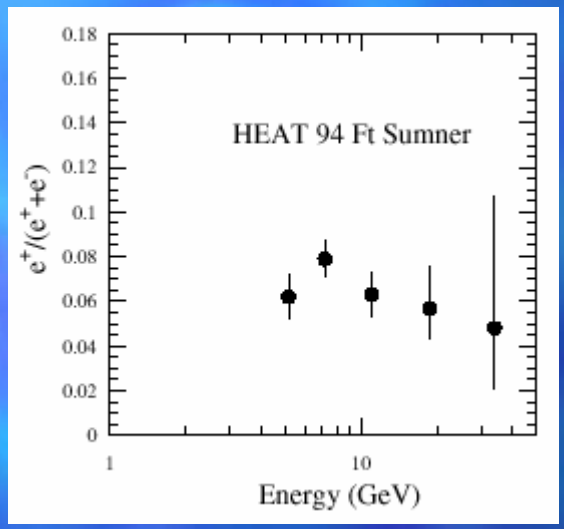
- New positron fraction measurements are more statistically significant, with much improved hadron rejection power;
- Rise beyond about 10 GeV *not* confirmed!
- New detailed model predictions of e^+, pbar, γ production and propagation;
- Results much closer to secondary production expectations.

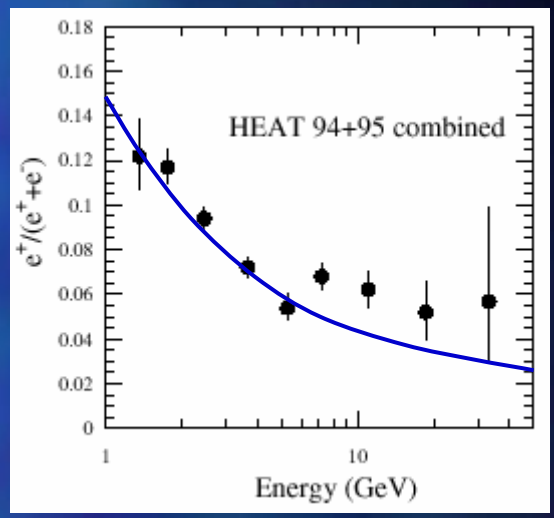


HEAT Positron Fraction $e^+/(e^+ + e^-)$

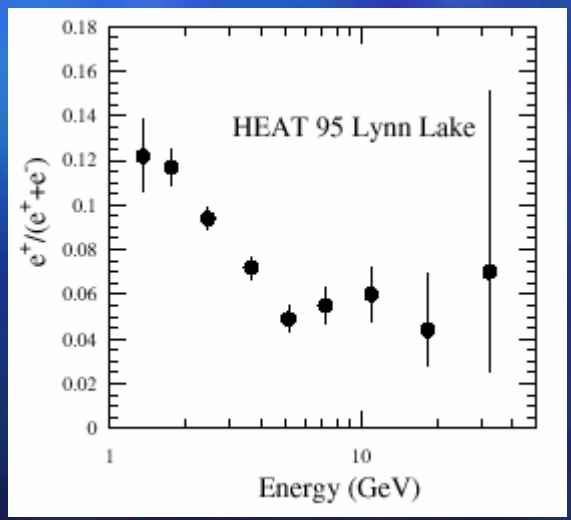
Moskalenko & Strong, ApJ **493,** 694 (1998); Galactic diffusion calculation

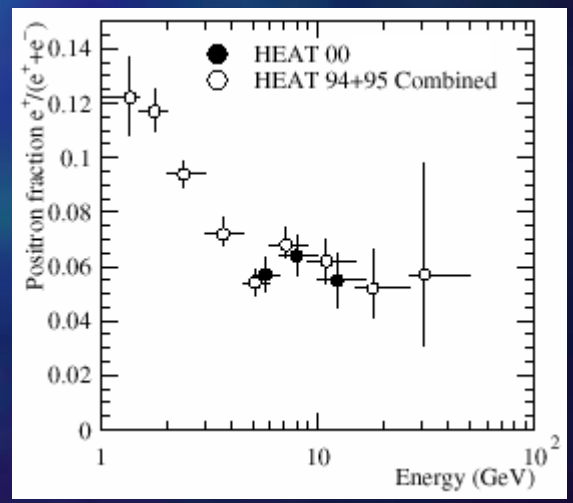
May 3-5 1994
PRL **75**, 390 (1995)





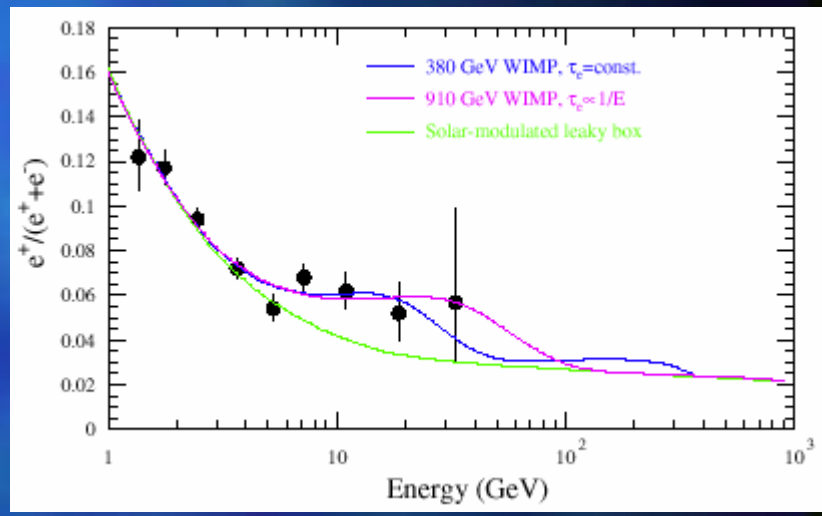
August 23-24 1995
ApJ **482**, L191 (1997)



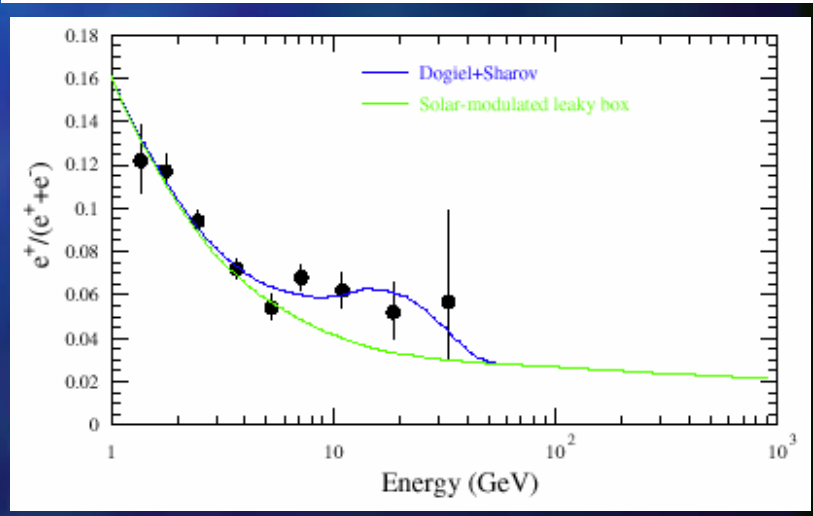


Primary Positrons?

- Annihilating Dark Matter Neutralinos (Kamionkowski/Turner, Phys. Rev. D **43**, 1774 (1991))
- Heavy $\Rightarrow$ resonant ZZ or W^+W^- production, then decay
- Remove arbitrary enhancement factor



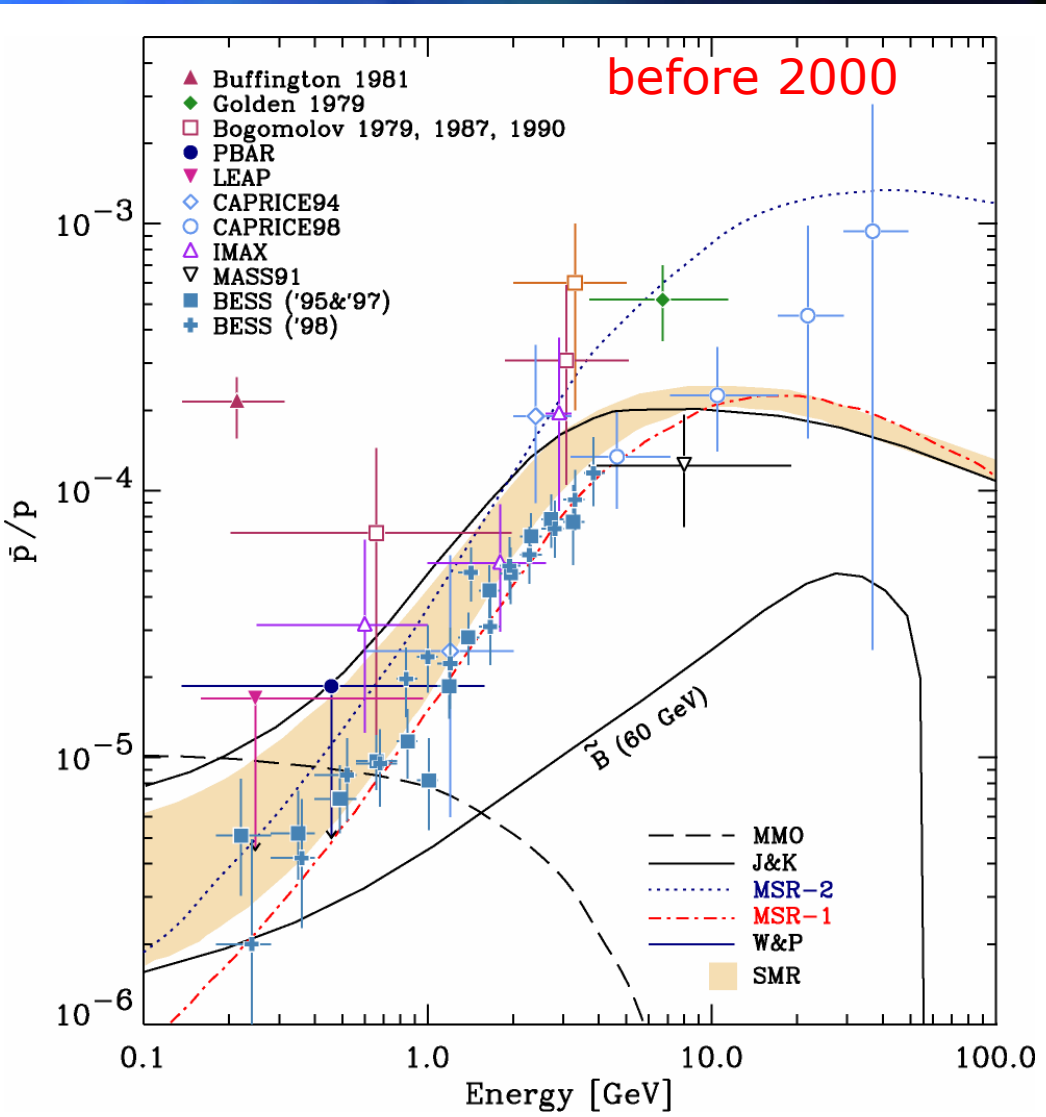
- CR + Giant Molecular Clouds (Dogiel/Sharov, A&A **229**, 259 (1990))
- p-stuff $\rightarrow \pi^+ \rightarrow \mu^+ \rightarrow e^+$; Fermi acceleration by gas turbulence.



Small primary positron component possible !

pbar Measurements as of 2000

- Excellent BESS measurements below ~few GeV
- Several secondary production models, *e.g.*:
  MSR-1: local nucleon spectrum,
  MSR-2: hard nucleon spectrum
  (explains EGRET data)
- Primary pbar predictions agree that the contribution is small at best



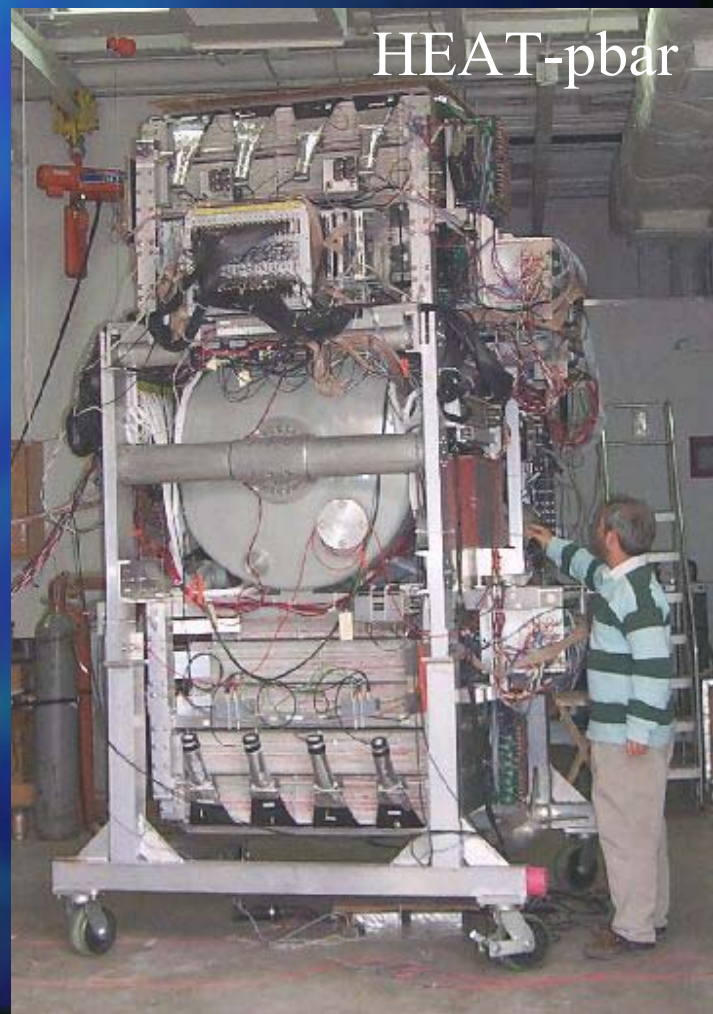
HEAT-pbar (High Energy Antimatter Telescope)

The HEAT-pbar Collaboration

U of Chicago: A. Labrador, D. Müller, S.P. Swordy
Northern Kentucky U.: S.L. Nutter
Indiana U: A. Bhattacharyya, C. Bower, J.A. Musser
U of Michigan: S.P. McKee, M. Schubnell, G. Tarlé, A.D. Tomasch
Penn State U.: A.S. Beach, J.J. Beatty, S. Coutu, S. Minnick
U. Minnesota: M. DuVernois

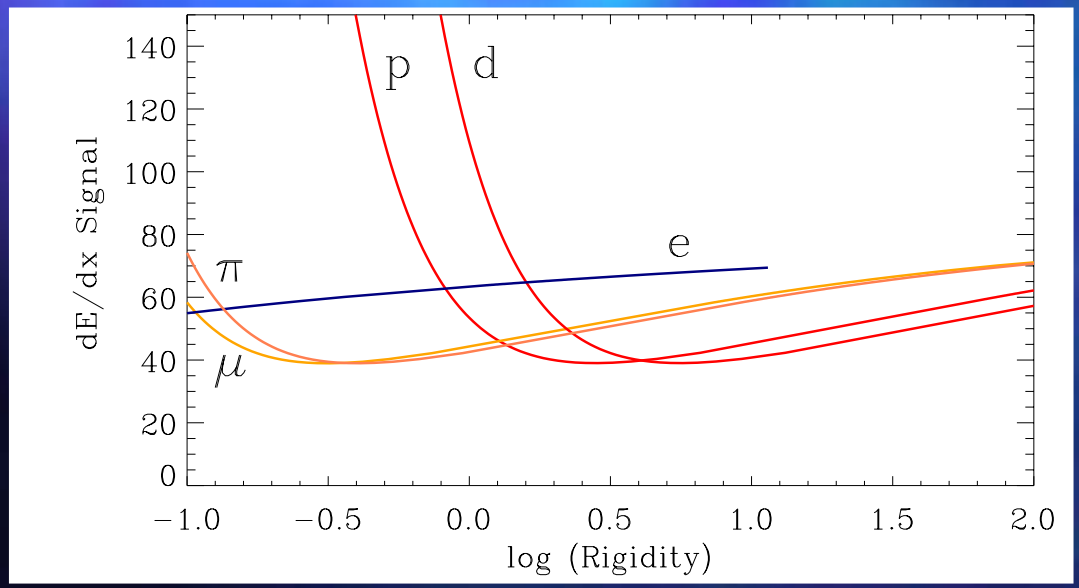
- Superconducting Magnet Spectrometer with Drift Tube Hodoscope (DTH), Multiple Ionization (dE/dx) Detector and Time-of-Flight (TOF) system.
- 1) Jun. 2000 flight from Ft. Sumner, NM (22 hour flight)

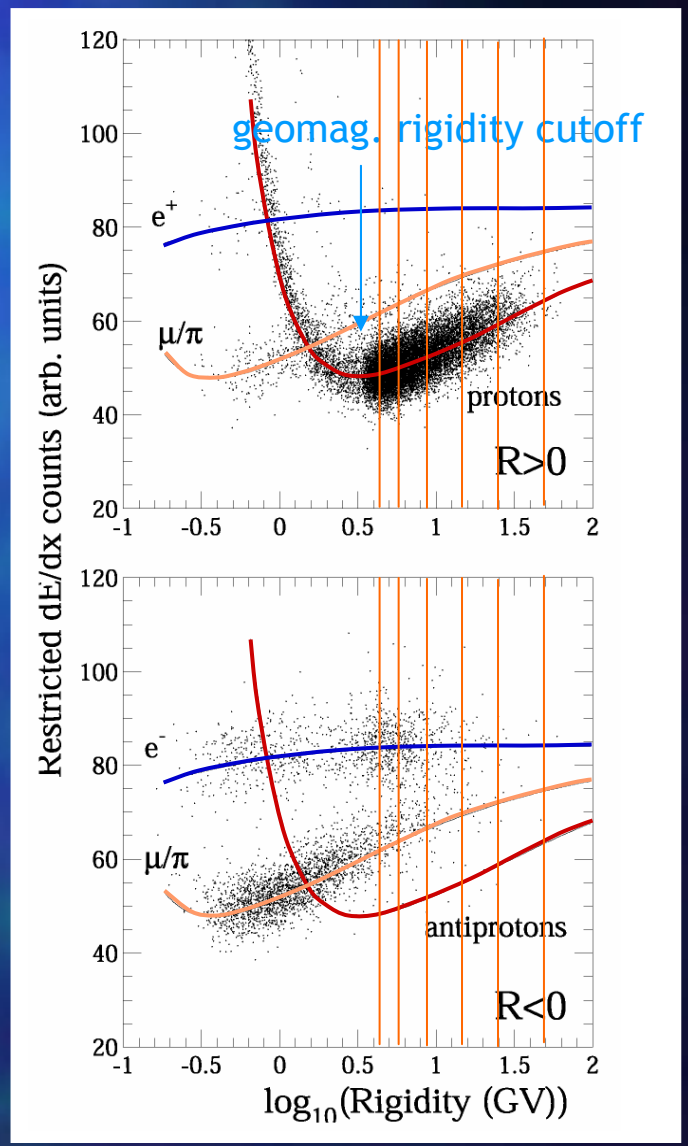
  2) May 2002 flight from Ft. Sumner, NM (6 hour flight; failed balloon)



Identifying Antiprotons with HEAT-pbar

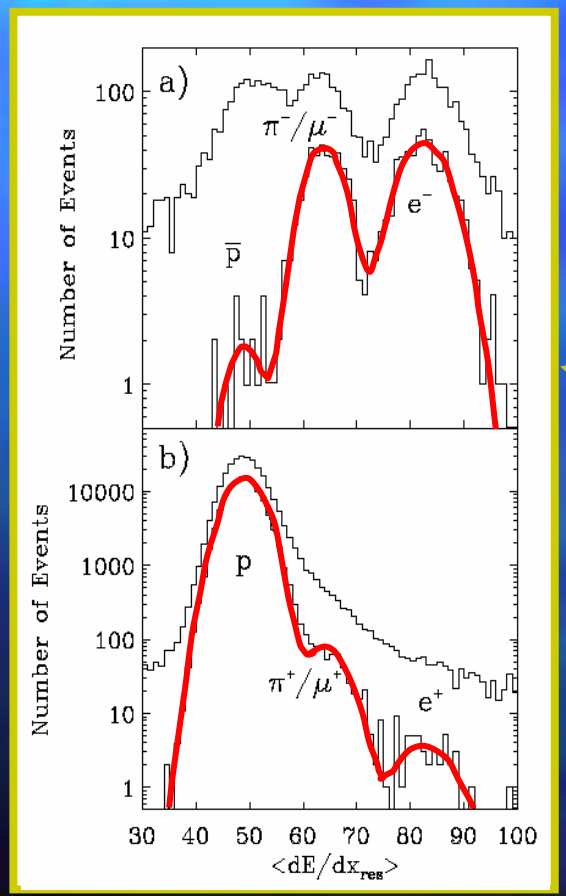
- Multiple samples of the ionization loss measured;
- Technique exploits the logarithmic rise in the mean rate of energy loss.

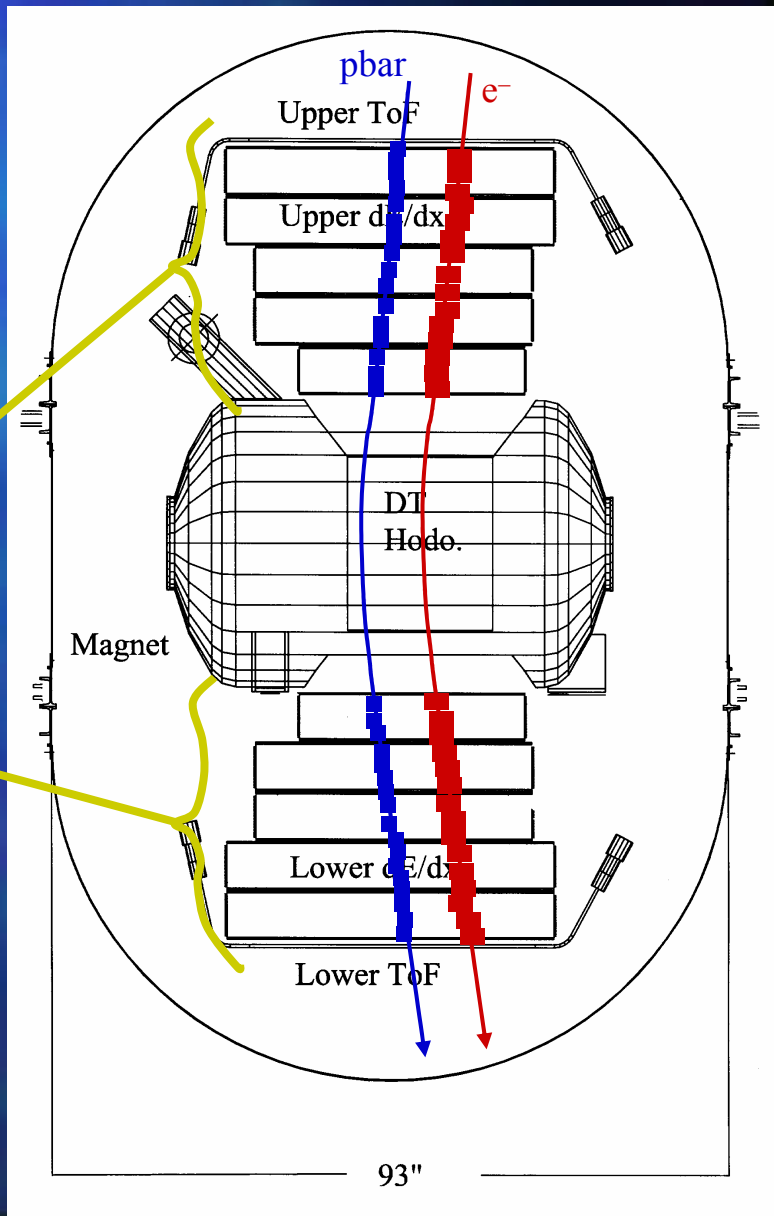




Identifying Antiprotons with HEAT-pbar

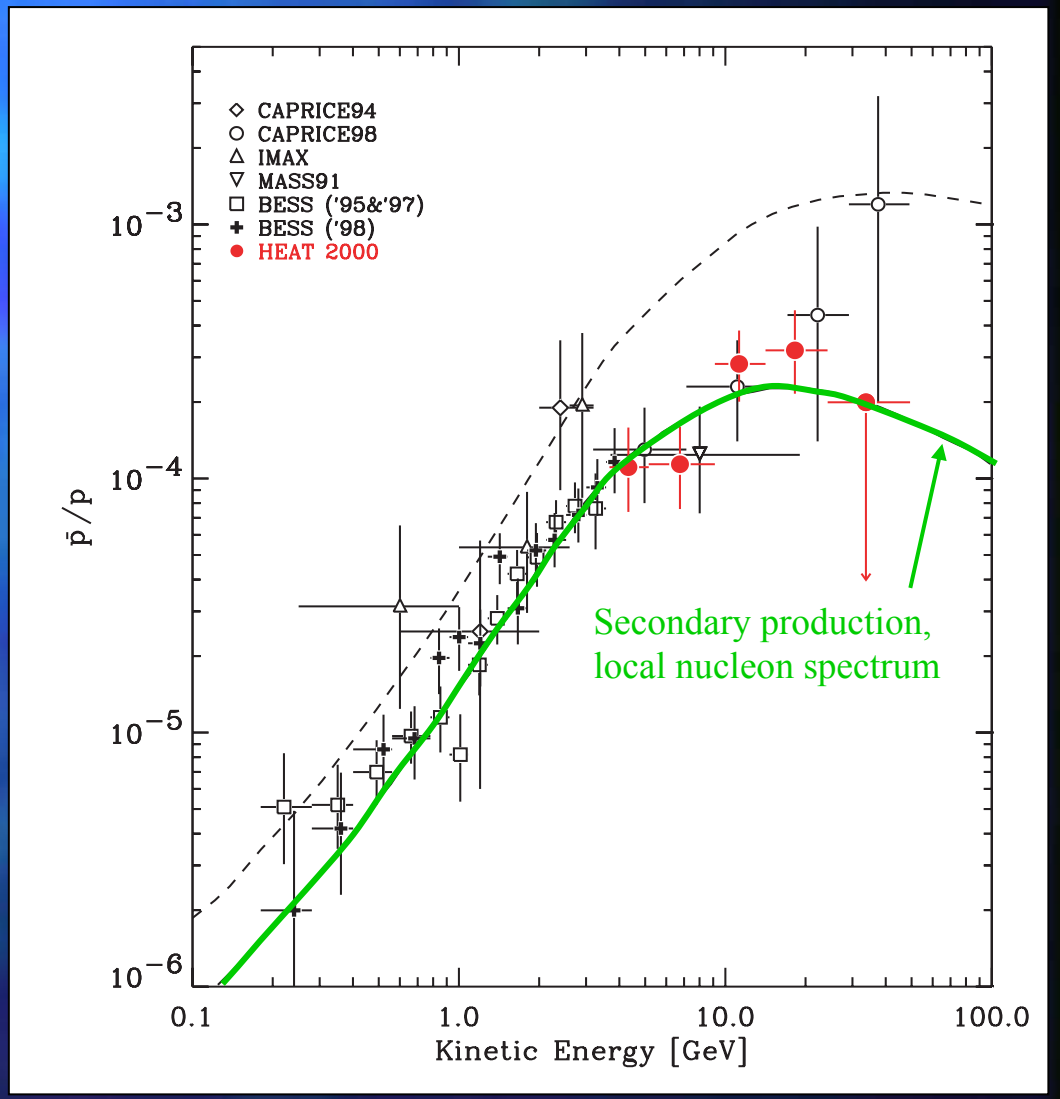
- TOF, DTH: same as HEAT-$e^{\pm}$
- Multiple dE/dx: p / π-μ / e separation





New Antiproton Results

- BESS, IMAX, MASS, CAPRICE and HEAT data in agreement with secondary production expectations;
- No support for 'hard nucleon injection spectrum' models;
- Prospects for primary pbar detection (e.g. from WIMP annihilation) not good;
- Good agreement with model lends weight to positron feature.



Conclusions

Positrons

- Measurements and model calculations have improved tremendously in the last ~5 years; HEAT highest statistics at 1 – 50 GeV.
- e^+ appear to be mainly from CR interactions in ISM.
- More measurements needed to confirm `feature' seen with HEAT and establish its nature. Is there truly a primary e^+ component? Signature for WIMP annihilation??

Antiprotons

- Excellent progress here also (measurements, model calculations). HEAT highest statistics at 5 - 50 GeV.
- pbars seem to be from CR interactions in ISM.
- Prospects for exotic physics (e.g., WIMPs) not good.

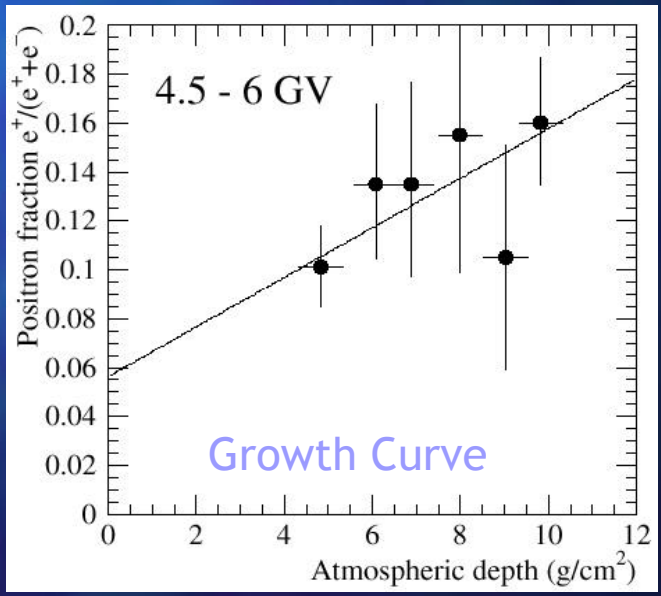
Correcting for Background

Atmospheric secondaries contribution estimated by GEANT-based Monte Carlo:

- electron correction: 5-6%; positron correction: 44-52%
- systematic uncertainty: ~30% => $e^+/(e^+ + e^-)$ systematics: ~ 1%
  pbar / p systematics: ~ 4%

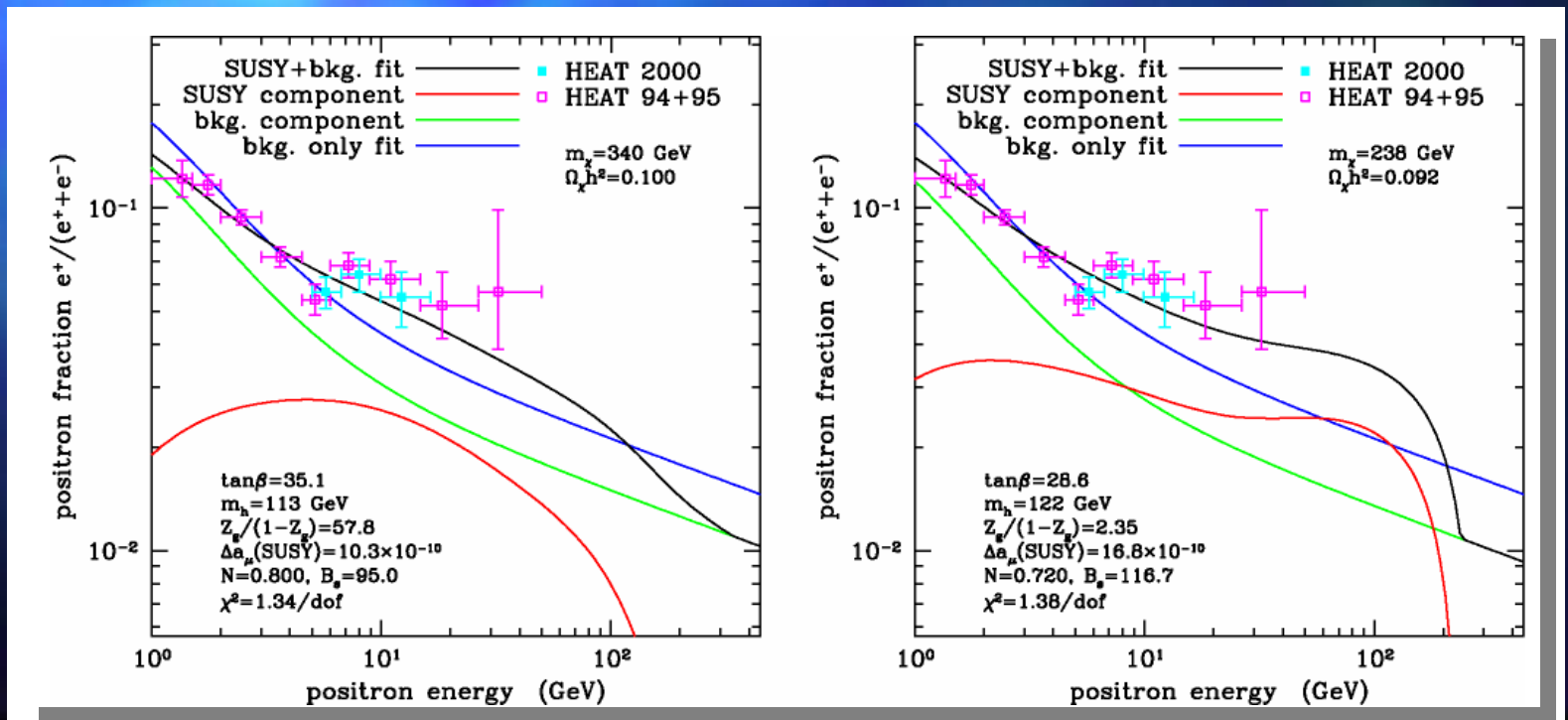
Positron fraction:

- from growth curve:
  0.056 ± 0.038
- from data with MC corrections:
  0.057 ± 0.006



Positrons from Annihilating Galactic Halo WIMPs

- Baltz/Edsjö, Phys. Rev. D **59**, 023511 (1999); Baltz, Edsjö, Freese & Gondolo, astro-ph/0109318 (2001);
- Large region of MSSM space explored;
- Continuum and monochromatic $e^{\pm}$ Production;
- Galactic diffusion model + solar modulation;
- e^{+} enhancement not as good a fit as KT, but helps.



Outlook

- Continuing balloon spectrometer measurements: BESS, HEAT.
- New space experiments:
  - PAMELA (Satellite, 2003 launch from Baikonur, 3 year mission, 0.4 – 150 GeV?);
  - AMS (ISS, 2003 launch on STS, 3 year mission, 0.1 – 200 GeV?).

PAMELA Russian-Italian Mission
2003 Baikonur launch
3 yrs: ~ 30 × balloon exposure

AMS
2003 STS launch
3 yrs: ~ 900 × balloon exposure