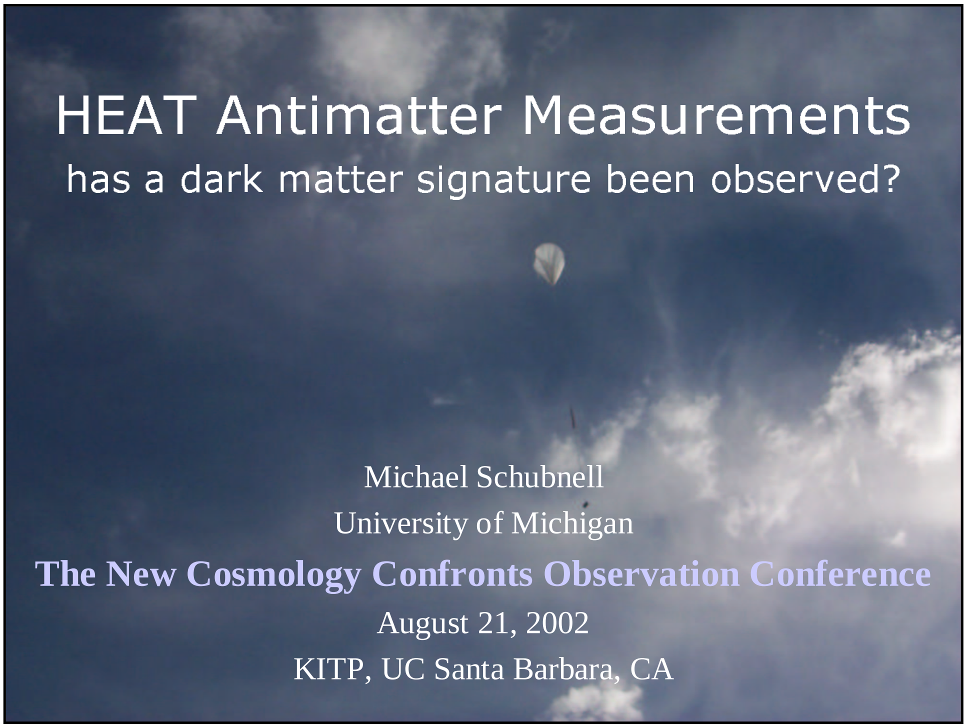


Galactic Cosmic Rays

- Primary p, e^- produced at CR acceleration sites (e.g. supernova shocks);
- Secondary CRs produced in the ISM
- Secondary component includes antimatter particles
- "unusual" sources of 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.

[for a recent review see: Tarlé & Schubnell, Space Science Reviews, v. 99, p. 95-104 (2001).]

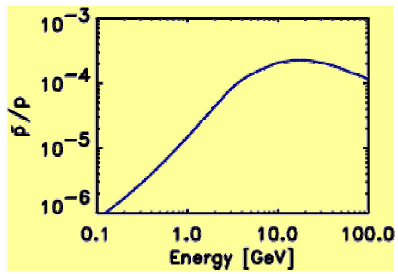
August 21, 2002 Michael Schubnell, University of Michigan


The HEAT Collaboration
Indiana University
C. Bower, J. Musser
Pennsylvania State University
S.Beach, J. Beatty, S.Coutu, M.DuVernois[1], S. Minnick, S.Nutter[2]
University of Chicago
D. Müller, S. Swordy, A. Labrador[3]
University of Michigan
S. McKee, M. Schubnell, G. Tarlé, A. Tomasch
[1]now at University of Minnesota
[2]now at Northern Kentucky University
[3]now at Caltech
August 21, 2002
Michael Schubnell, University of Michigan


Antiprotons
August 21, 2002
Michael Schubnell, University of Michigan

$$p + p \rightarrow p + p + p + \bar{p}$$

- Progenitors are mainly protons & production threshold relatively high → probe the primary nucleon component and CR propagation.
- Measurements are difficult (pbar/p < 10^{-4} and $\bar{p}/e^{-} \sim 10^{-3}$ @ few GeV) → excellent particle ID for background discrimination required
- Good understanding of galactic secondary antiproton spectrum required to detect possible signatures for antiprotons from WIMP annihilation.
- E_{th} = 7 GeV, few antiprotons with kinetic energies < 1 GeV.
- Solar modulation smoothes kinematic cutoff (inside heliosphere)
- IF antiprotons are produced purely as secondaries, antiproton/proton ratio should decrease at high energies.

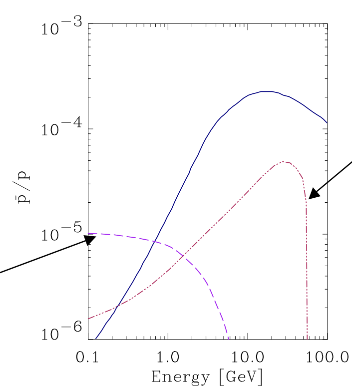


August 21, 2002 Michael Schubnell, University of Michigan

Primary Antiprotons

Are there primary sources of antiprotons in our Galaxy? (astrophysical sources, dark matter annihilation, Primordial black hole evaporation …)

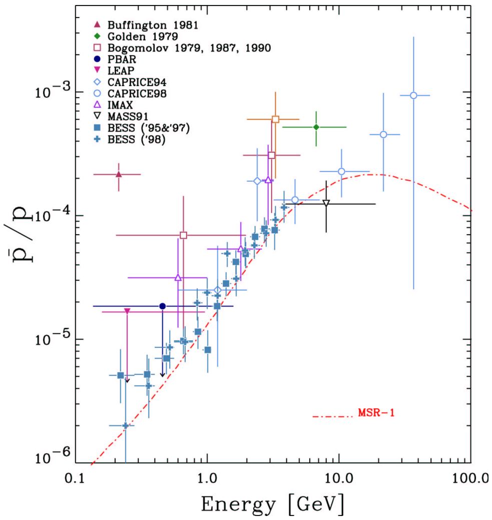
Possible primary component due to evaporating small PBHs [Maki, Mitsui & Orito Phys. Rev. Let. 76 3474 (1996)]



Possible primary component due to annihilation of supersymmetric particles (60 GeV $\tilde{B}$) [Jungman & Kamionkowski Phys. Rev. D 49 2316 (1994)]

August 21, 2002 Michael Schubnell, University of Michigan

Antiproton Results [before 2000]



Most observations below 5 GeV.

E < 5 GeV: BESS measures pbar/p consistent with purely sec. production through repeated balloon flights.

E > 5 GeV: Low statistics; Measurements inconclusive.

Difficult to detect WIMP signal due to uncertainty in interstellar reference spectra and solar modulation.

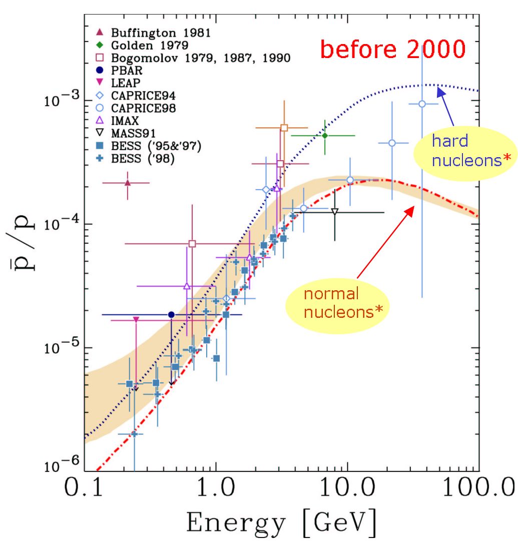
Does pbar/p continue to rise at high energy (CAPRICE)?

High statistics measurements needed in the region 5-50 GeV.

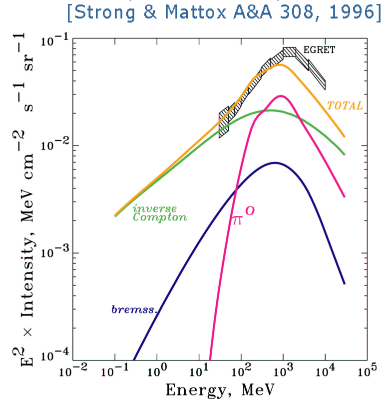
[for a recent review see: Tarlé & Schubnell, Space Science Reviews, v. 99, p. 95-104 (2001).]

August 21, 2002 Michael Schubnell, University of Michigan

Positrons and antiprotons probe the structure of the ISM and the primary nucleon component.



Diffuse γ-ray flux of inner Galaxy measured by EGRET. [Strong & Mattox A&A 308, 1996]



* [Moskalenko, Strong, Reimer, A&A 338, 1998]

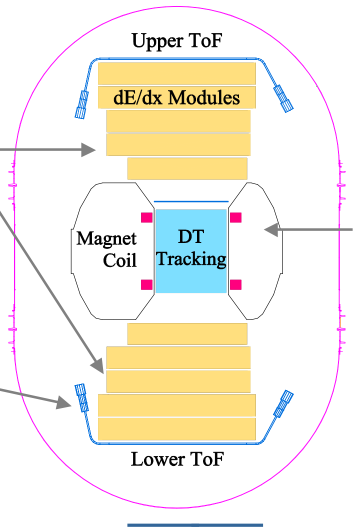
August 21, 2002 Michael Schubnell, University of Michigan

HEAT

Balloon borne HEAT-pbar experiment utilizes multiple energy loss measurements vs. rigidity for CR particle identification in the 4-50 GV range.

140 Multi-wire Proportional Chambers measure energy loss to identify particle species.

Time-of-Flight Scintillators trigger data acquisition, measure particle charge and determine direction of travel.



Superconducting Magnet Spectrometer with Drift Tube Hodoscope (continuous tracking) measures rigidity.

This determines the particle's charge sign and momentum.

- 10 kG field
- MDR extends to ~350 GV
- 65 μm tracking accuracy

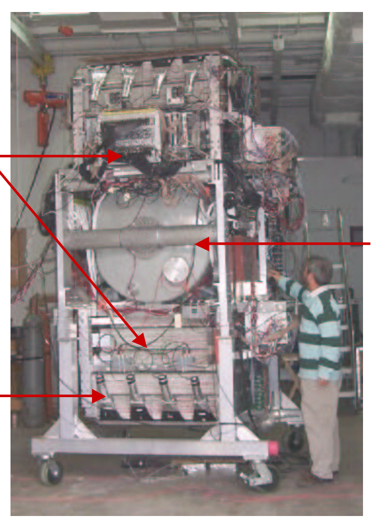
1 METER

August 21, 2002 Michael Schubnell, University of Michigan

Balloon borne HEAT-pbar experiment utilizes multiple energy loss measurements vs. rigidity for CR particle identification in the 4-50 GV range.

140 Multi-wire Proportional Chambers measure energy loss to identify particle species.

Time-of-Flight Scintillators trigger data acquisition, measure particle charge and determine direction of travel.



Superconducting Magnet Spectrometer with Drift Tube Hodoscope (continuous tracking) measures rigidity.

This determines the particle's charge sign and momentum.

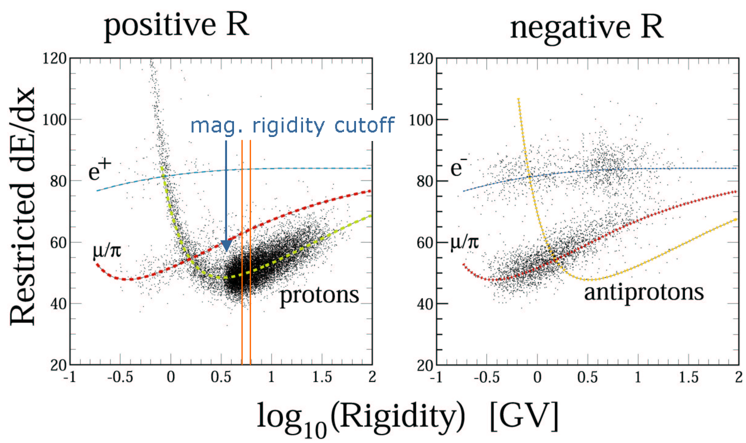
- 10 kG field
- MDR extends to ~350 GV
- 65 μm tracking accuracy

1 METER

August 21, 2002 Michael Schubnell, University of Michigan

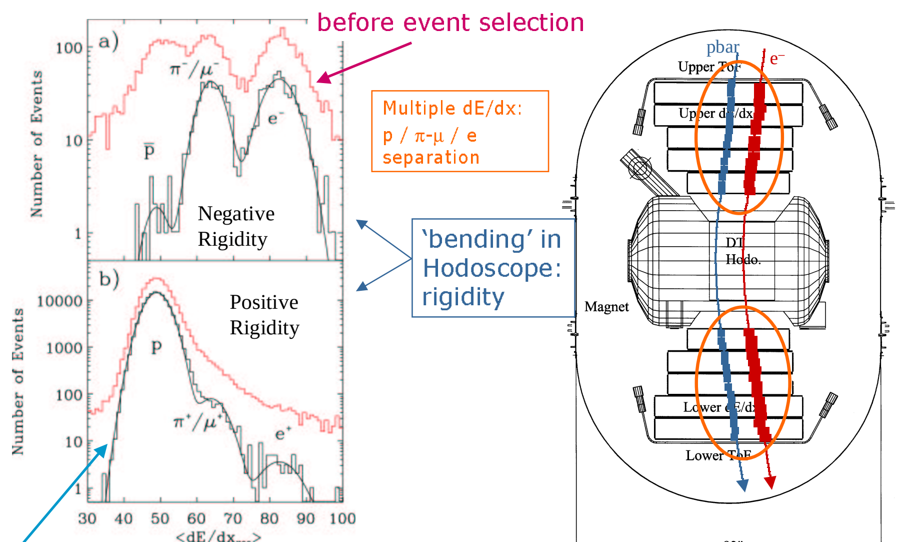
Particle ID using dE/dx vs. Rigidity

- To provide mass discrimination HEAT-pbar measures multiple samples of the ionization loss.
- Technique exploits the logarithmic rise in the mean rate of energy loss.

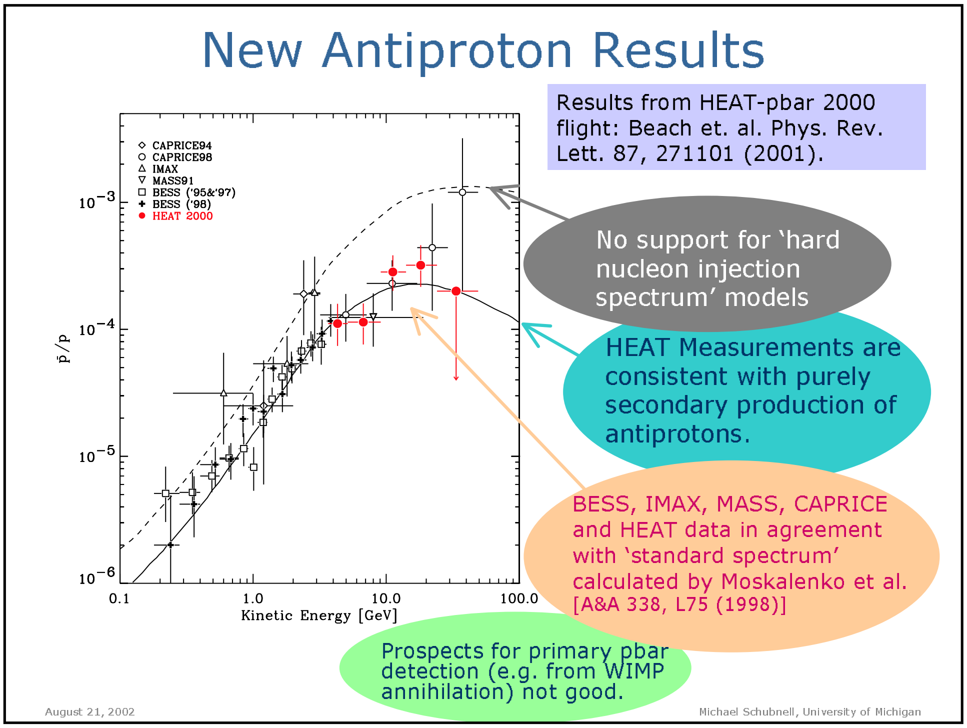


Identifying Particle Mass with HEAT-pbar

Select Rigidity bands and fit restricted average dE/dx distributions



Highly Gaussian shape allows for good particle separation/count.

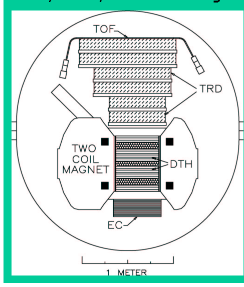

New Antiproton Results
Results from HEAT-pbar 2000 flight: Beach et. al. Phys. Rev. Lett. 87, 271101 (2001).
CAPRICE94
CAPRICE98
IMAX
MASS91
BESS ('95&'97)
BESS ('98)
HEAT 2000
p̄/p
Kinetic Energy [GeV]
0.1
1.0
10.0
100.0
No support for 'hard nucleon injection spectrum' models
HEAT Measurements are consistent with purely secondary production of antiprotons.
BESS, IMAX, MASS, CAPRICE and HEAT data in agreement with 'standard spectrum' calculated by Moskalenko et al. [A&A 338, L75 (1998)]
Prospects for primary pbar detection (e.g. from WIMP annihilation) not good.
August 21, 2002
Michael Schubnell, University of Michigan

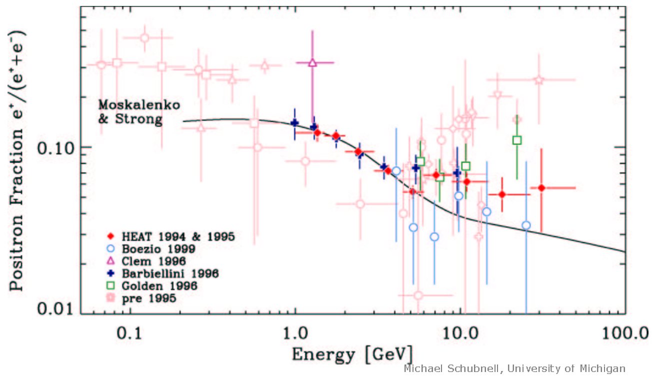

Positrons
August 21, 2002
Michael Schubnell, University of Michigan

e$^{\pm}$ in Cosmic Rays

- Secondary e$^{\pm}$ produced in equal numbers in the ISM: CR nuclei + ISM $\Rightarrow \pi^{\pm} \rightarrow \mu^{\pm} \rightarrow e^{\pm}$;
- e$^{\pm}$ unique-lose energy rapidly $\propto E^2$. High energy electrons are "local."
- $e^+/(e^+ + e^-)$ fraction is small (about 10%) $\rightarrow$ substantial primary e$^-$ component.
- New balloon instruments with powerful particle ID resulted in improved hadron rejection ($\geq 10^5$).
- Trend consistent with secondary production [Moskalenko & Strong ApJ 493, 694 (1998)] (but high energy data lies above the curve.)
- Solar modulation only affects low energy.

HEAT-e$^{\pm}$ Collaboration
U. Chicago, Indiana U., UCI, PSU, U. of Michigan

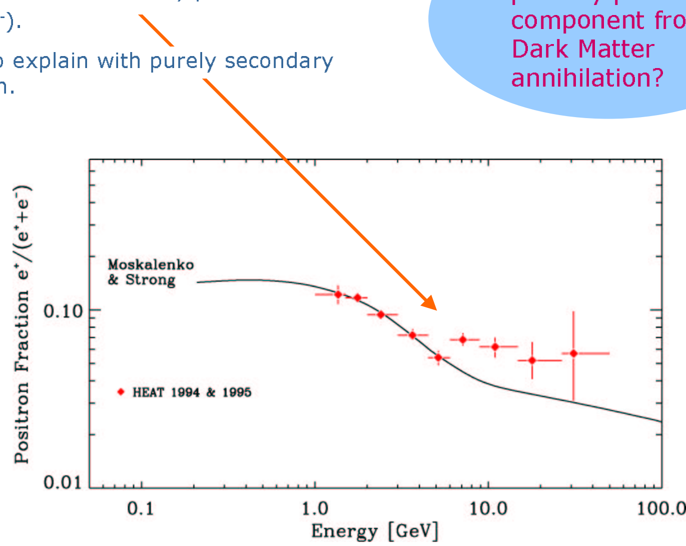




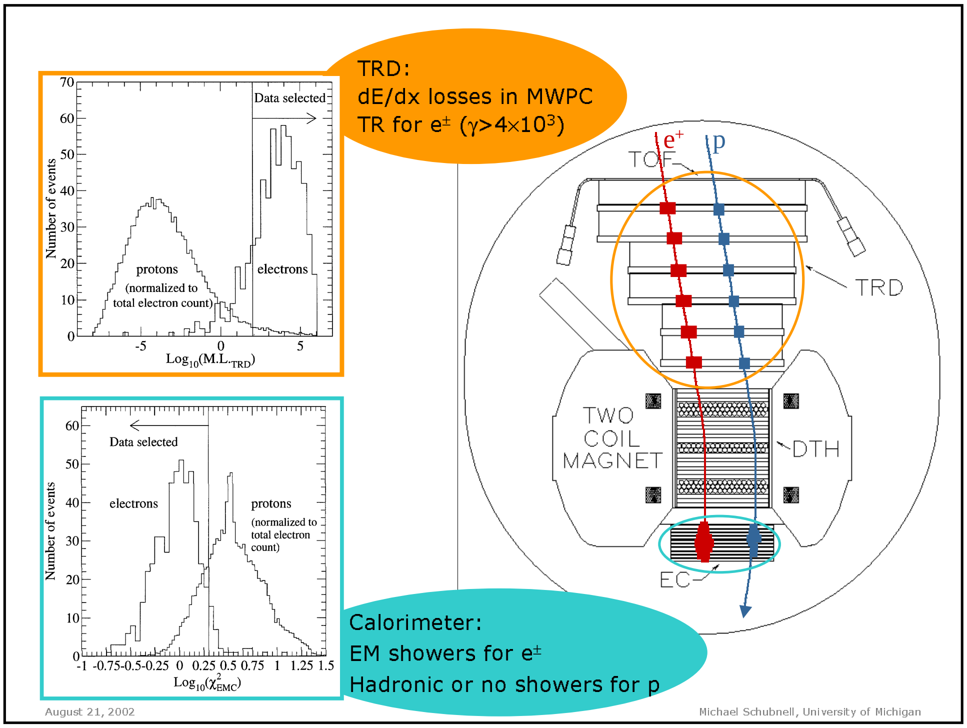
August 21, 2002 Michael Schubnell, University of Michigan

- Two flights of the HEAT-e$^{\pm}$ instrument had shown hint of additional structure in the energy spectrum of the cosmic ray positron fraction $e+/(e^+ + e^-)$.
- Difficult to explain with purely secondary production.

Is this structure a primary positron component from Dark Matter annihilation?



August 21, 2002 Michael Schubnell, University of Michigan



HEAT Positron Fraction '94 & '95

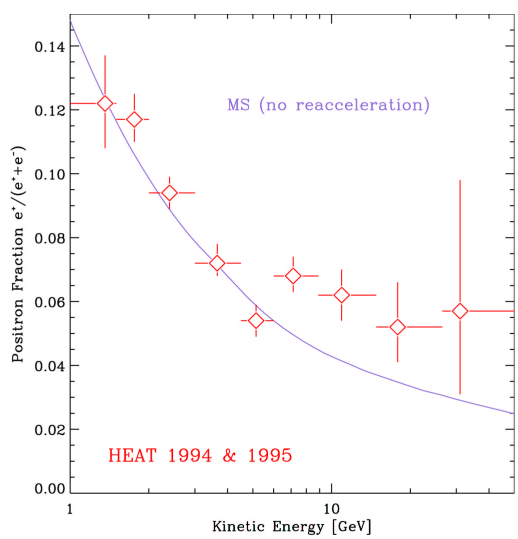
HEAT-e± Instrument

- Ft. Sumner, NM (May 1994)
- Lynn Lake, Manitoba (August 1995)

near solar minimum

residual atmosphere: 3.8 - 7.4 g/cm²

vertical geomagnetic cutoff rigidity:
4.0 - 4.4 GV (1994)
~1 GV (1995)

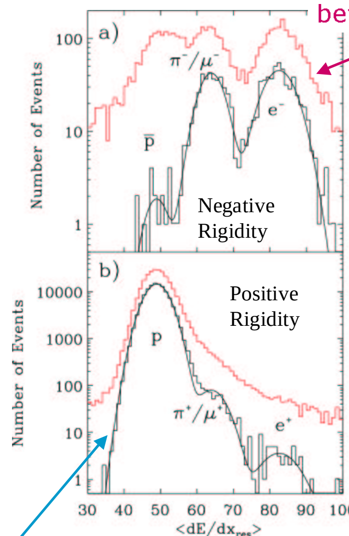


August 21, 2002 Michael Schubnell, University of Michigan

Identifying Particle Mass with HEAT-pbar

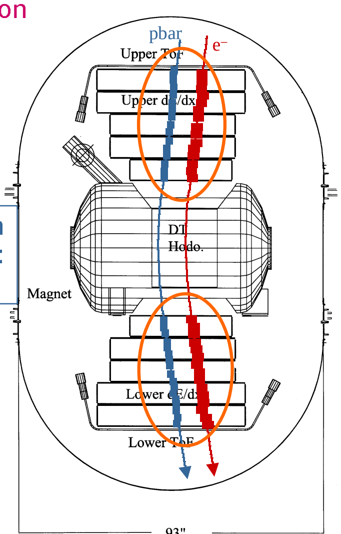
Select Rigidity bands and fit restricted average dE/dx distributions

before event selection



Multiple dE/dx: p / π-μ / e separation

'bending' in Hodoscope: rigidity



Highly Gaussian shape allows for good particle separation/count.

August 21, 2002 — Michael Schubnell, University of Michigan

HEAT Positron Fraction 2000

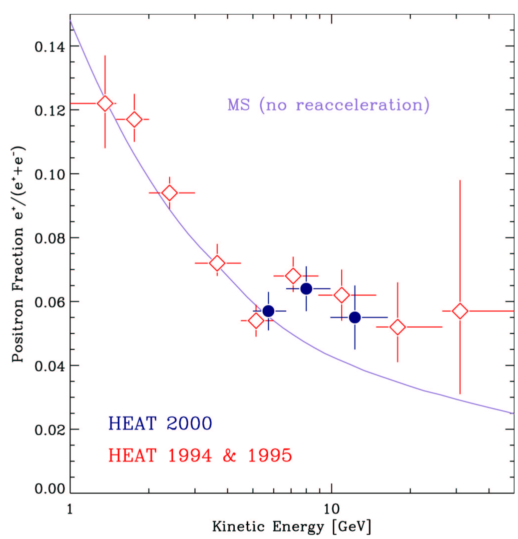
HEAT-pbar Instrument

- Ft. Sumner, NM (May 2000)

near solar maximun

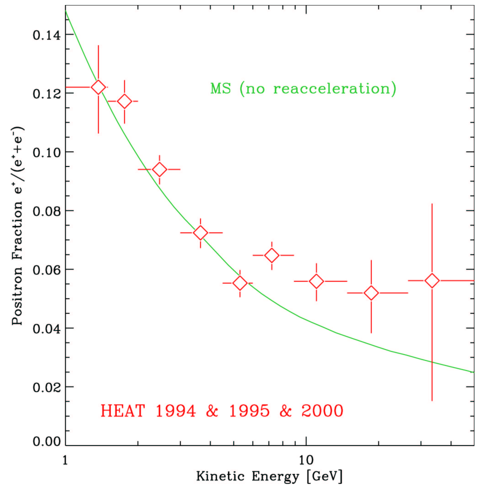
residual atmosphere: 4.5 - 11 g/cm^2

vertical geomagnetic cutoff rigidity: ~4 GV



August 21, 2002 — Michael Schubnell, University of Michigan

HEAT Positron Fraction
(3 flights)



Flight	May 1994	August 1995	May 2000
Instrument	HEAT- e±	HEAT- e±	HEAT-pbar
Geomagnetic cutoff rigidity	~ 4 GV	~ 1 GV	~ 4 GV
Solar cycle epoch	near min	near min	near max

August 21, 2002 Michael Schubnell, University of Michigan

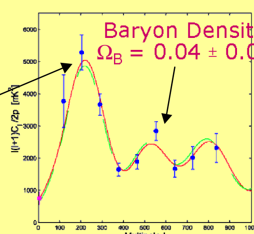
Cold Dark Matter Exists

DASI – Boomerang - MAXIMA
Location of peaks in CMB power spectrum

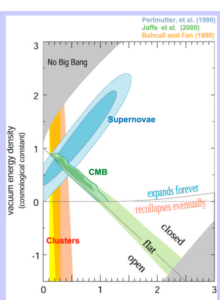
Flat Universe
Ω_{TOT} = 1.00 ± 0.04

Ω_M = 0.40 ± 0.15
Ω_Λ = 0.60 ± 0.15

Baryon Density
Ω_B = 0.04 ± 0.01



Non-baryonic DM
- Some Galactic DM may be in MACHOs but insufficient to account for entire amount
- Hot Dark Matter (HDM), e.g. light neutrinos, does not account for small-scale structure.
- Cold Dark Matter (CDM), e.g. WIMPs or Axions, preferred non-baryonic candidate.
- Neutralino (Lightest Supersymmetric Particle) prime candidate for CDM



Supernova Cosmology Project:
$\Omega_\Lambda \approx 0.72$

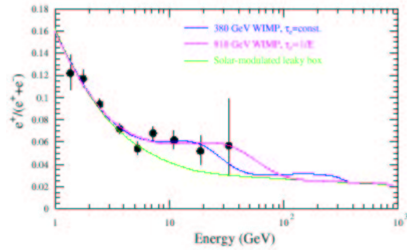
New Standard Cosmology:
~ 2/3 Dark Energy
~ 1/3 Dark Matter
0.5% Bright Stars

Matter: 29% CDM, 4% Baryons, 0.3% νs

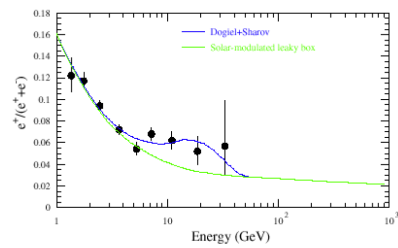
August 21, 2002 Michael Schubnell, University of Michigan

Primary Positrons?

- Annihilating Dark Matter Neutralinos
  [Kamionkowski &Turner, Phys. Rev. D **43**, 1774 (1991)]
- Heavy $\tilde{\chi} \Rightarrow$ resonant ZZ or W^+W^- production, then decay



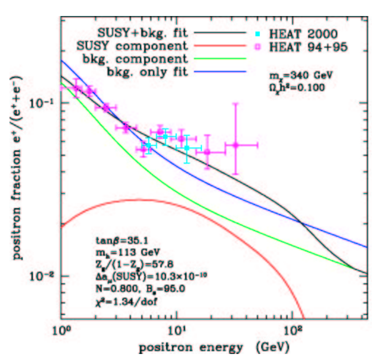
- CR + Giant Molecular Clouds
  [Dogiel & Sharov, A&A **229**, 259 (1990)]
- p-stuff $\rightarrow \pi^+ \rightarrow \mu^+ \rightarrow \varepsilon^+$; Fermi acceleration by gas turbulence.

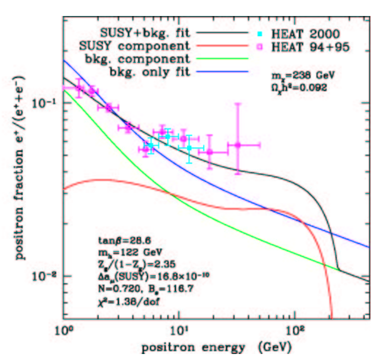


Small primary positron component possible !
[Coutu et al. Astroparticle Phys. 11 (1999) 429]

Positrons from Annihilating Galactic Halo WIMPs (Revisited)

- Large region of MSSM space explored
- Continuum and monochromatic $e^{\pm}$ Production
- Thermal production in early universe
- Substantial boost factors required to explain HEAT data (e.g. clumpy halo)
- Galactic diffusion model + solar modulation
- e^+ enhancement not as good a fit to HEAT data as Kamionkowski and Turner.
- None of these models can be observed at Tevatron, LHC unclear.

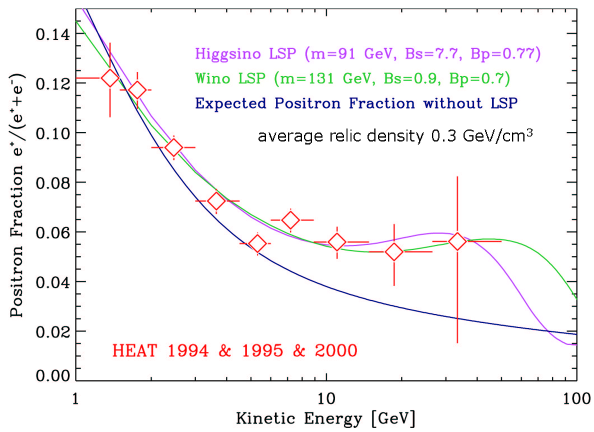




[Baltz/Edsjö, Phys. Rev. D **59** 023511 (1999)
and Baltz, Edsjö, Freese & Gondolo, Phys. Rev. D **65** 063511 (2002)]

Positron Excess and General SUSY Models

For $m_\chi > m_W$, $\chi\chi \rightarrow WW$ annihilation leads to peak at ~ $M_W/2$ but μ, τ cascades, π decays and Galactic propagation "wash out" peak towards lower energy.
$e^+/(e^+ + e^-)$ enhancement at ~ 10 GeV (insensitive to WIMP mass!)



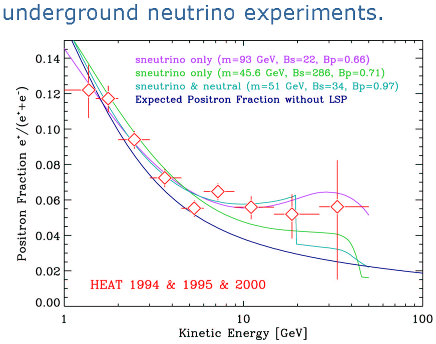
Kane, Wang and Wells
[Phys.Rev. D65 (2002) 057701]
Kane, Wang and Wang
[Phys. Lett. B 536 (2002) 263]

August 21, 2002 Michael Schubnell, University of Michigan

Positron excess and special SUSY models

Strong peaking in the positron energy spectrum can be achieved by fine tuning special models.
Kane, Wang & Wang [Phys. Lett. B 536 (2002) 263], Kane, Wang & Wang [in preparation, 2002]

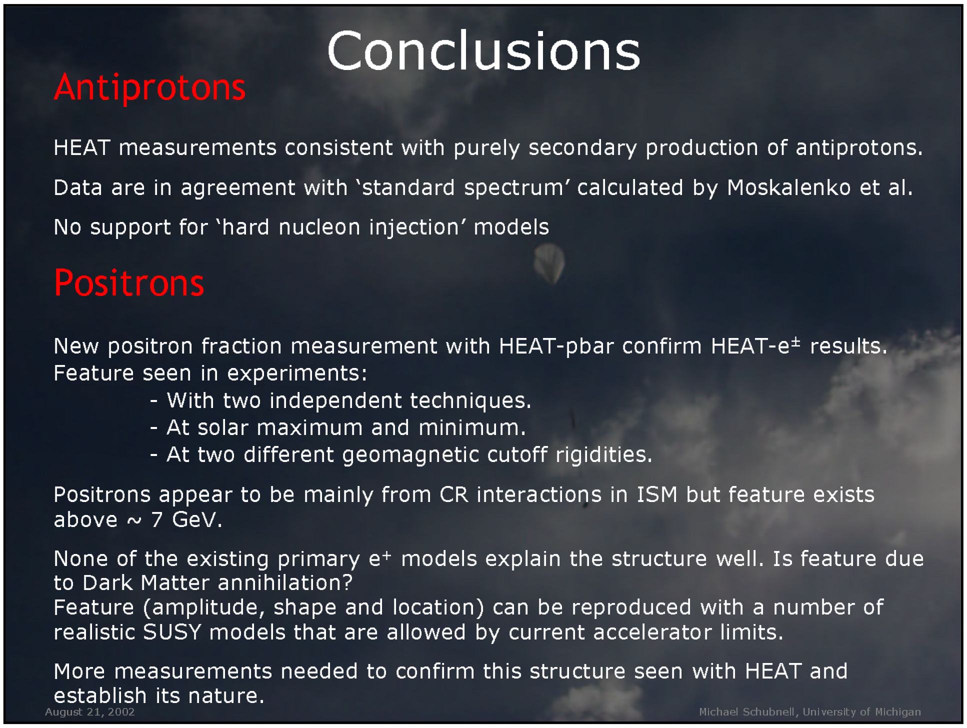
Electron sneutrino ~ stable if its mass is very close to LSP mass (within m_n).
Decays shown produce sharp peak in positron injection spectrum at E = $m_c(1-m_W^2/4m_c^2)$. For peak at ~ 8 GeV: $m_n + m_c \approx m_W + 10$ GeV.
Propagation washes sharp peak out towards lower energies.
Detectability: Tevatron, simple models excluded by direct searches and underground neutrino experiments.



Light sneutrino (< M_W)
Detectability: Tevatron, simple models already excluded by direct searches and underground neutrino experiments.

Heavy sneutrino (m > M_W)
Detectability: Tevatron, simple models already excluded by direct searches and underground neutrino experiments.

August 21, 2002 Michael Schubnell, University of Michigan


Conclusions
Antiprotons
HEAT measurements consistent with purely secondary production of antiprotons.
Data are in agreement with 'standard spectrum' calculated by Moskalenko et al.
No support for 'hard nucleon injection' models
Positrons
New positron fraction measurement with HEAT-pbar confirm HEAT-$e^{\pm}$ results.
Feature seen in experiments:
- With two independent techniques.
- At solar maximum and minimum.
- At two different geomagnetic cutoff rigidities.
Positrons appear to be mainly from CR interactions in ISM but feature exists above ~ 7 GeV.
None of the existing primary e^{+} models explain the structure well. Is feature due to Dark Matter annihilation?
Feature (amplitude, shape and location) can be reproduced with a number of realistic SUSY models that are allowed by current accelerator limits.
More measurements needed to confirm this structure seen with HEAT and establish its nature.
August 21, 2002
Michael Schubnell, University of Michigan