Cosmic-Ray Positrons

Michael Schubnell
University of Michigan

October 27, 2008
KICP, Chicago, IL

$e^{\pm}$ in Cosmic Rays

Positrons from secondary production

p-ISM $\rightarrow \pi^{+} \rightarrow \mu^{+} \rightarrow e^{+}$

- $e^{\pm}$ lose energy rapidly $\propto E^2$

  $\rightarrow$ high energy electrons are “local.”

- $e^{\pm}$ produced in pairs (in ISM).

- $e^{+}/(e^{+} + e^{-})$ fraction is small ($\approx$10%)

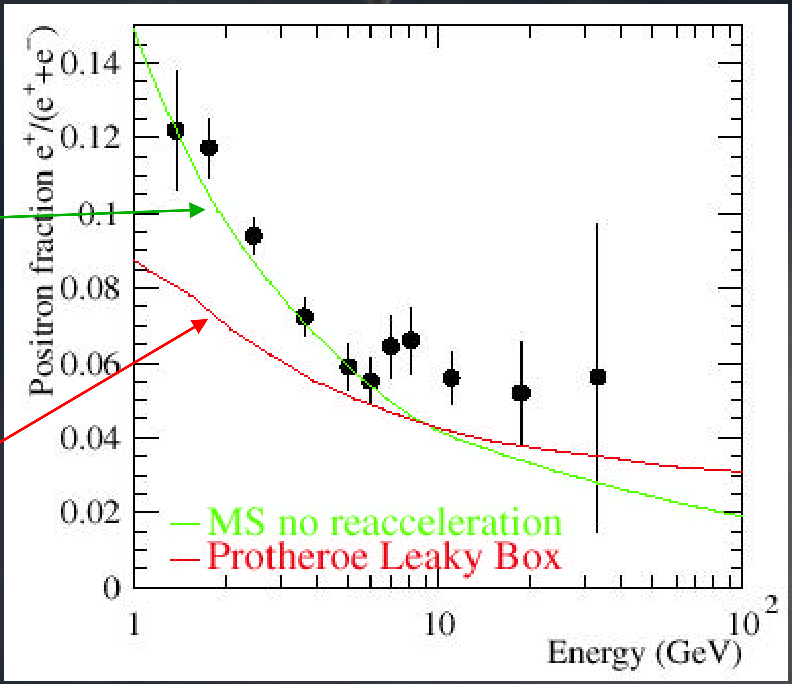
  $\rightarrow$ substantial primary e^{-} component.

Why do we care?

Structure in the CR Positron fraction - as first observed by HEAT instrument - could be DM signature* (or nearby pulsars or...?**)

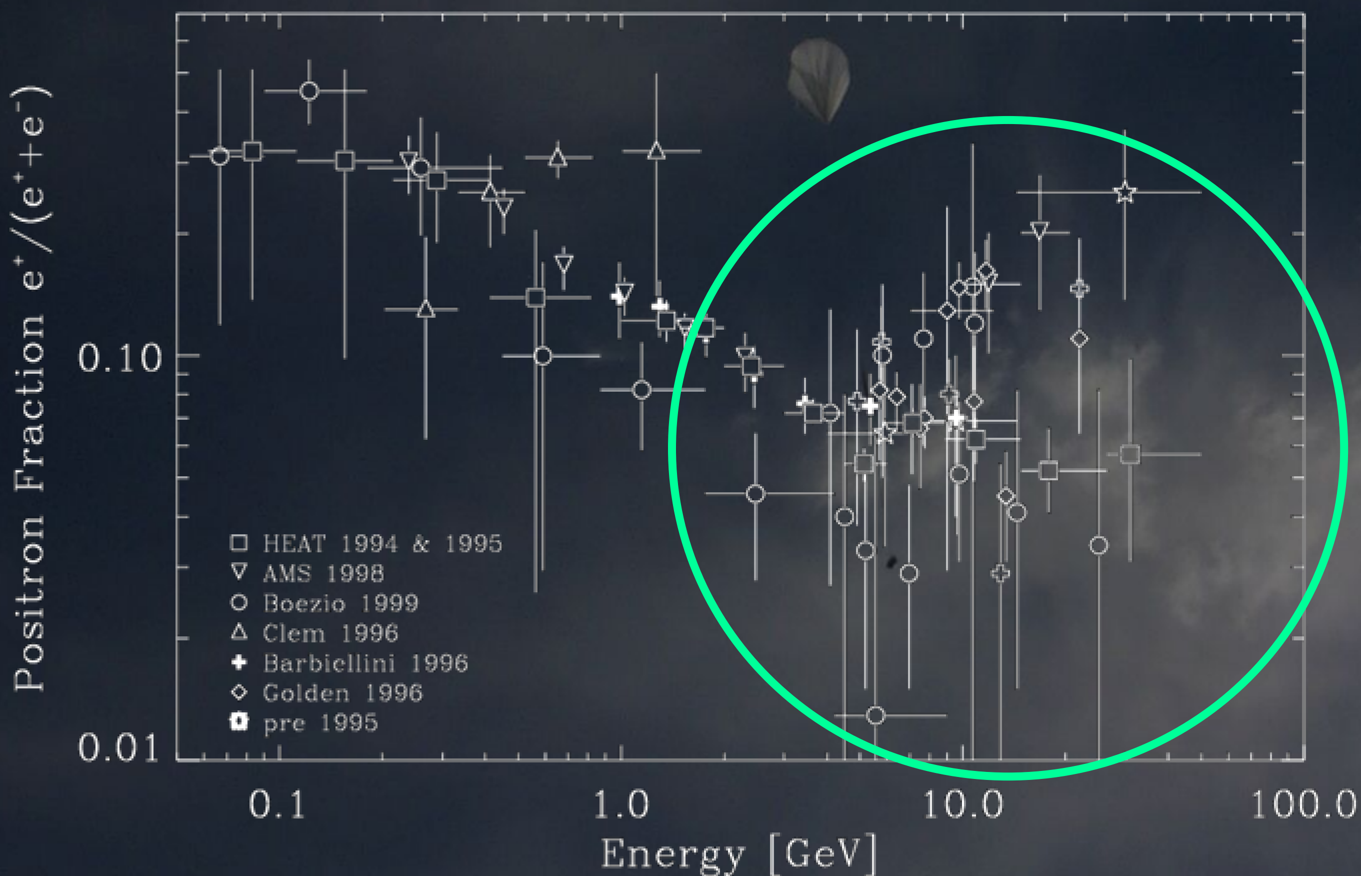
Galactic diffusion model [Moskalenko & Strong, ApJ 493, 694 (1998)]

leaky-box propagation [Protheroe, ApJ 254, 391 (1982)]



* M. Kamionkowski and M. Turner, Phys. Rev. D 43, 1774 (1991)
** S. Coutu *et al.*, Astropart. Phys. 11, 429 (1999).

A number of measurements have been made .. some as early as mid 1960s

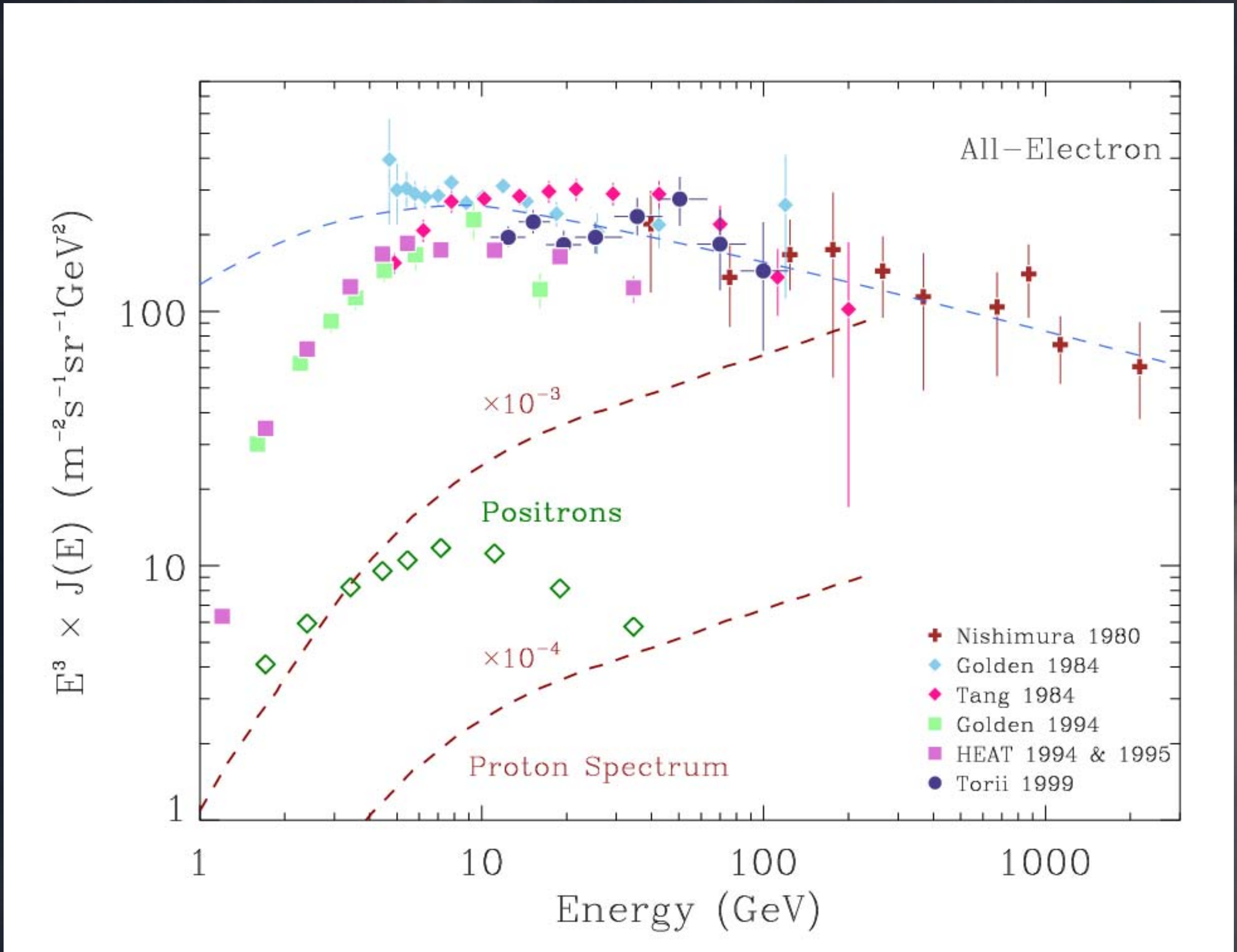


CR Positron measurements are challenging

Flux of CR protons in the energy range 1 – 50 GeV exceeds that of positrons by a factor of 5×10^4

Proton rejection of 10^6 is required for a positron sample with less than 1% proton contamination.

The single largest challenge in measuring CR positrons is the discrimination against the vast proton background!



All−Electron
$E^3 \times J(E)$ $(m^{-2}s^{-1}sr^{-1}GeV^2)$
Energy (GeV)
$\times 10^{-3}$
Positrons
$\times 10^{-4}$
Proton Spectrum
Nishimura 1980
Golden 1984
Tang 1984
Golden 1994
HEAT 1994 & 1995
Torii 1999

CR positron measurements
The early years: 1965 - 1984

1965, 1966: Manitoba

(Fanselow, Hartman, Hildebrand, Meyer, 1969)

1967: Italy

(Agrinier et al. 1969)

1972: Manitoba

(Daugherty, Hartman, Schmidt, 1975)

1972: Texas

(Buffington, Orth, Smoot, 1974)

1974: Manitoba

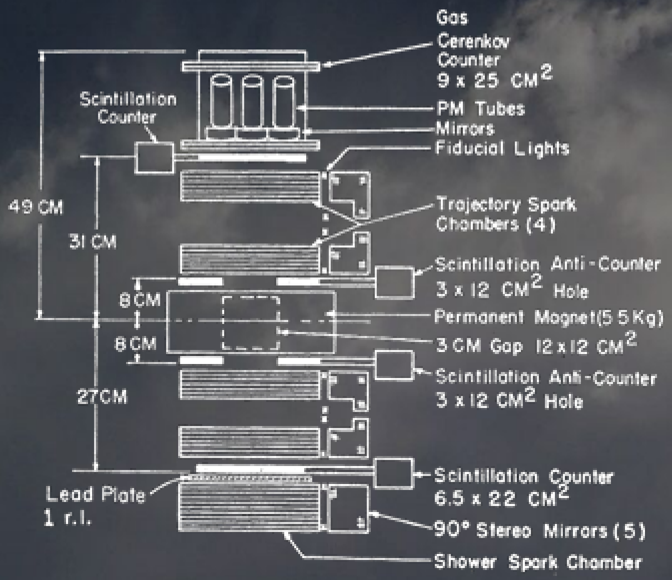
(Hartman and Pellerin, 1976)

1976: Texas

(Golden et al., 1987)

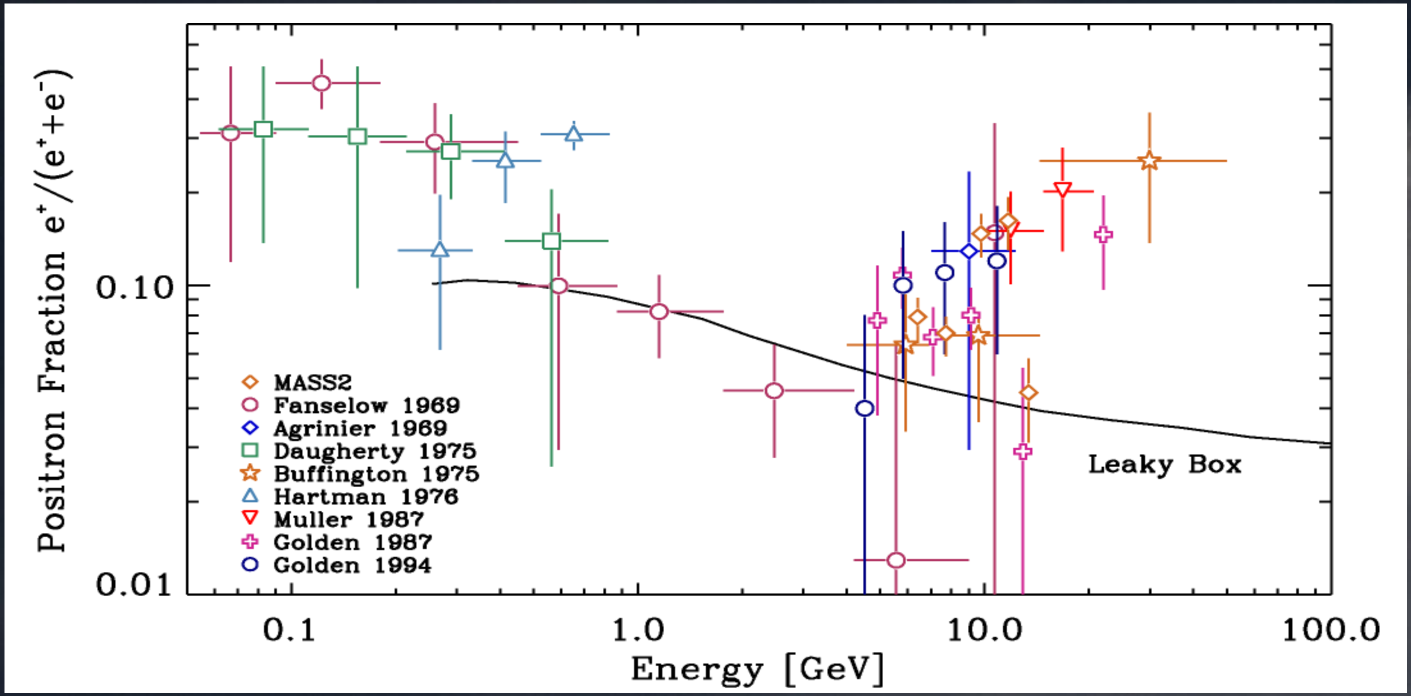
1984: Hawaii

(Müller and Tang, 1987)



CR positron measurements
The early years: 1965 - 1984

Dramatic rise at high energies?



CR positron measurements: The 90s

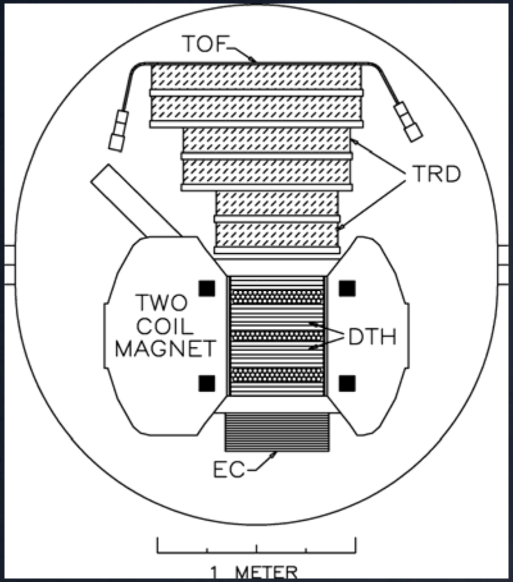
1989: Saskatchewan
(MASS - Golden et al., 1994)
1991: New Mexico
(MASS - Grimani et al., 2002)
1993: New Mexico
(Golden et al., 1996)
1994: New Mexico
(Heat – Barwick et al., 1995)
1994: Manitoba
(CAPRICE - Barbiellini et al., 1996;
Boezio et al 2002)
1994: Manotoba
(AESOP – Clem & Evanson 1996)
1995: Manitoba
(HEAT – Barwick et al., 1997)

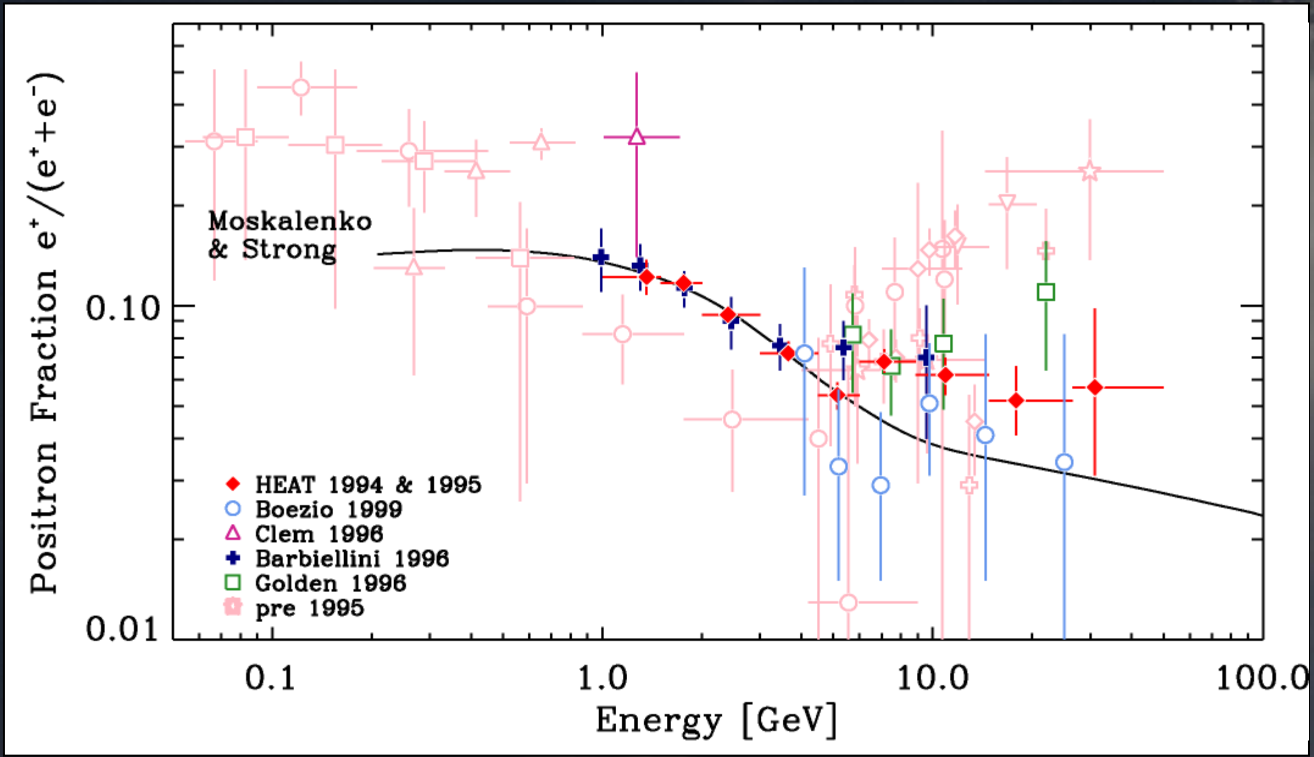
1998: New Mexico
(CAPRICE – Boezio et al., 1999)
1999: Manitoba
(AESOP – Clem & Evanson, 2002)
2000: New Mexico
(HEAT – Beatty et al, 2004)
2000: Manitoba
(AESOP – Clem & Evanson, 2002)
2002: Manitoba
(AESOP – Clem & Evanson, 2004)

A *feature* presentation

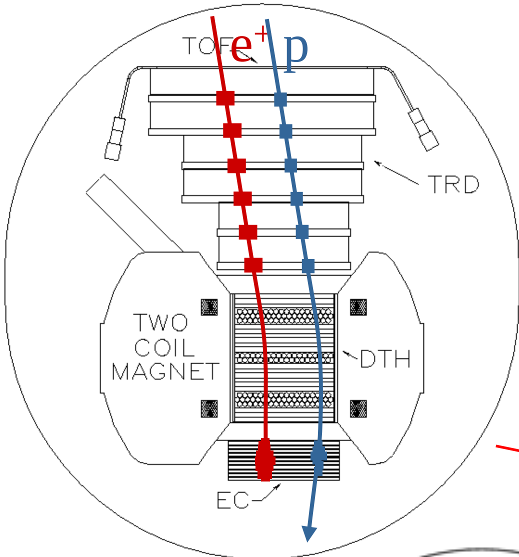
- HEAT-e± was first to employ powerful particle ID (rigidity vs. TRD vs. EM shower development) resulting in improved hadron rejection (≥ 10^{-5}).
- Trend consistent with secondary production [Moskalenko & Strong ApJ 493, 694 (1998)] (but high energy data lies above the curve.)
- Solar modulation only affects low energy.

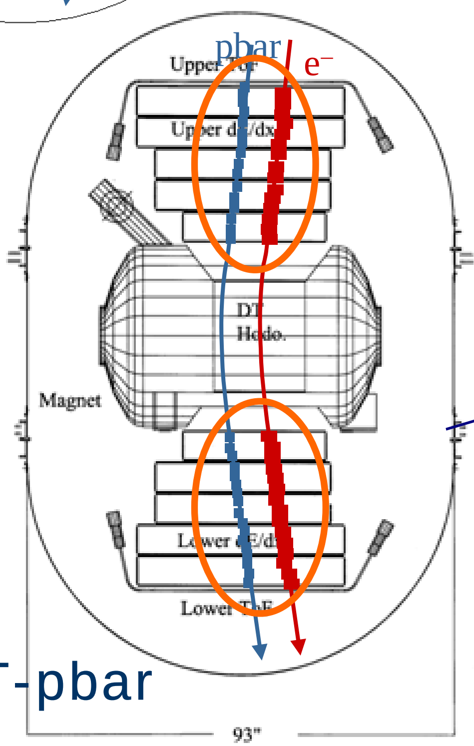
HEAT-e± Collaboration U. Chicago, Indiana U., UCI, PSU, U. of Michigan

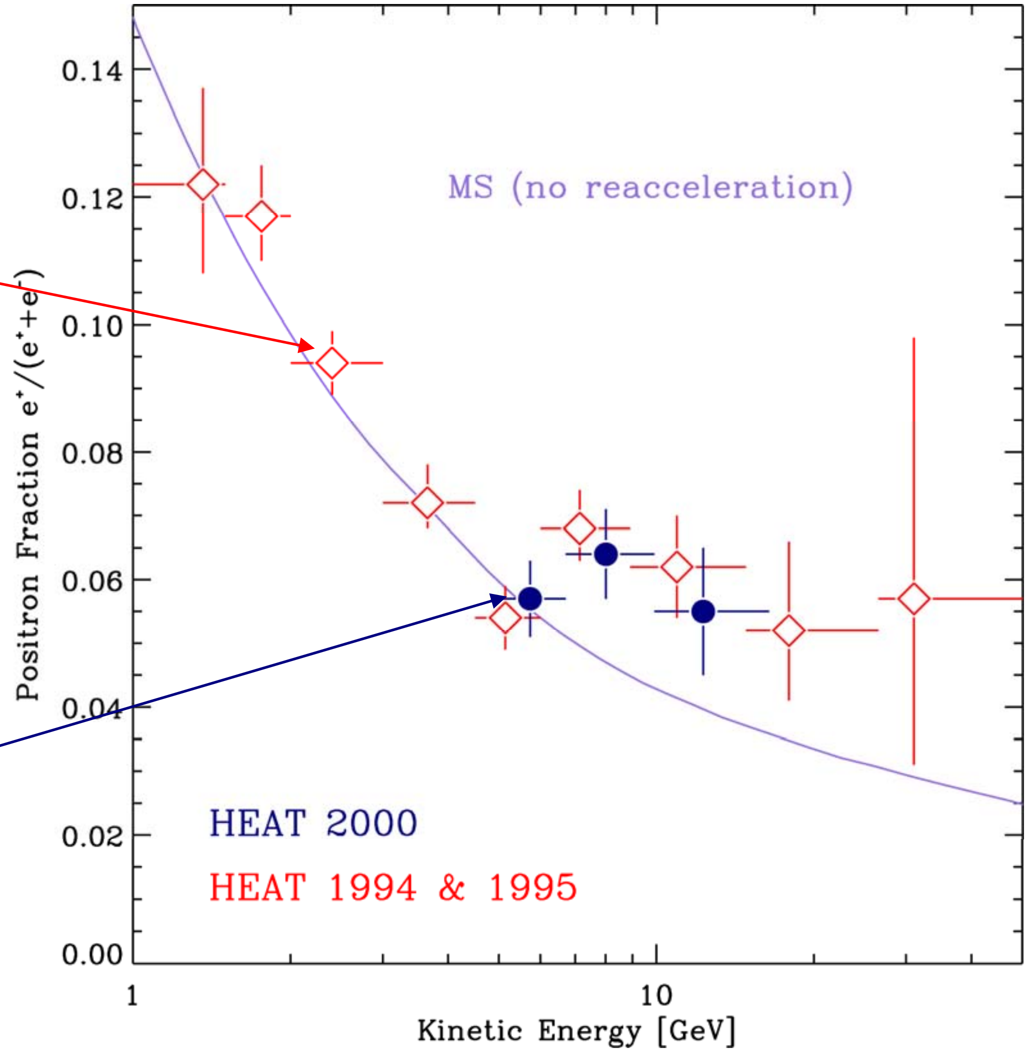




HEAT- e±
(1994 & 1995)







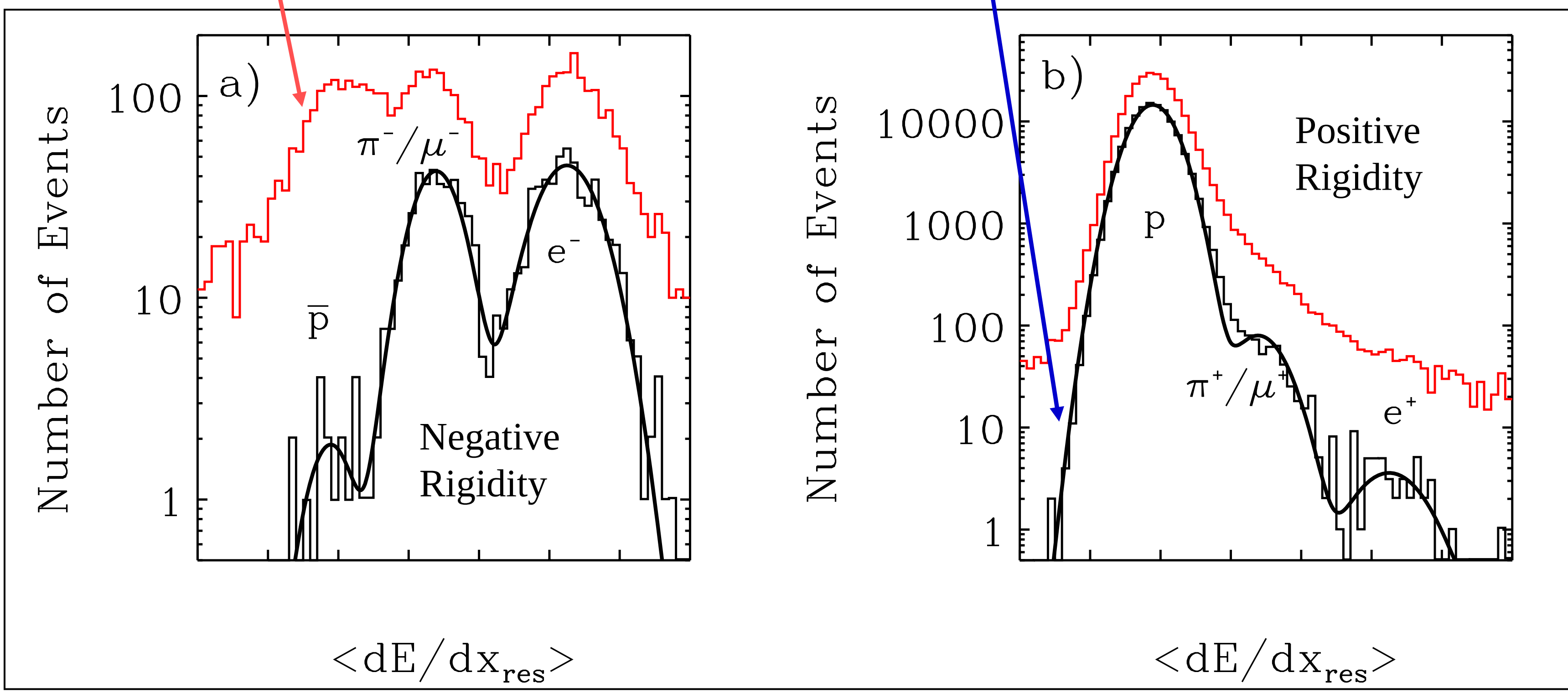
HEAT-pbar
2000

Mass Resolution

Select rigidity bands and fit restricted average dE/dx distributions.

before event selection

Highly Gaussian shape allows for good particle separation/count.



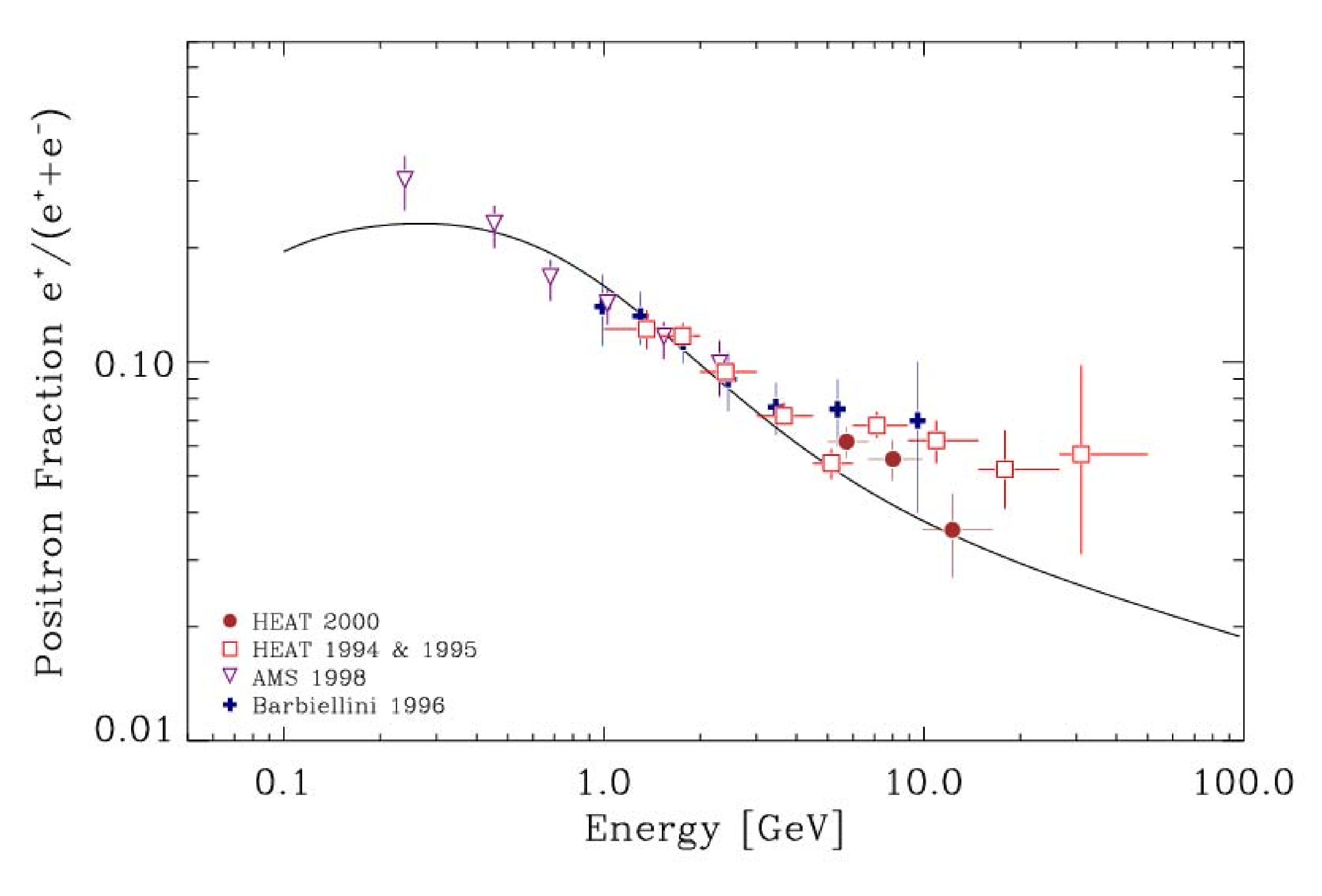
CR positron measurements: Space

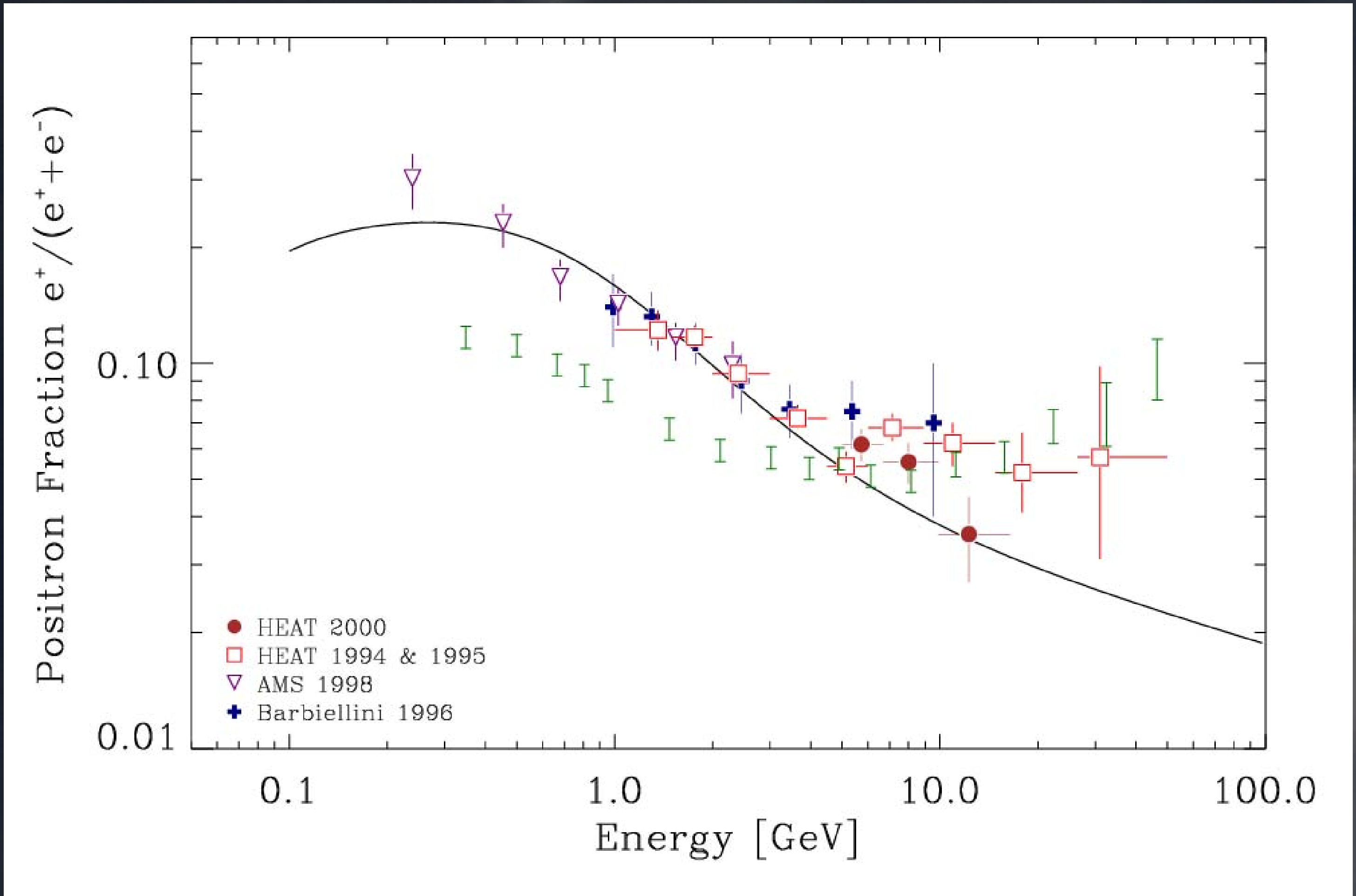
1998: Low Earth Orbit (shuttle)

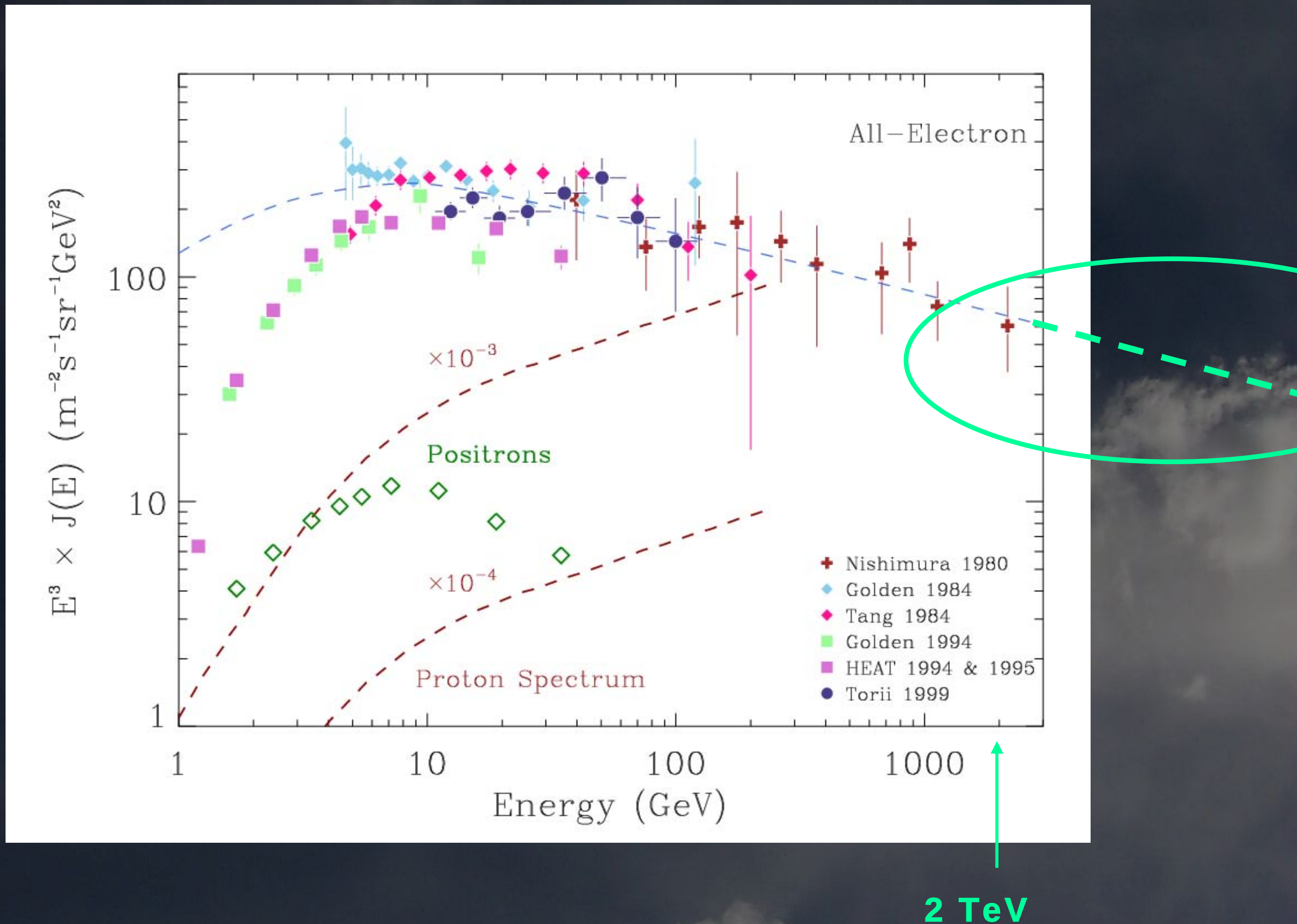
(AMS-01 - Aguilar et al., 2007)

2006 - ?: Low Earth Orbit (satellite)

(PAMELA - Grimani et al., 2002)


Positron Fraction e+/(e++e-)
0.10
0.01
0.1
1.0
10.0
100.0
Energy [GeV]
HEAT 2000
HEAT 1994 & 1995
AMS 1998
Barbiellini 1996

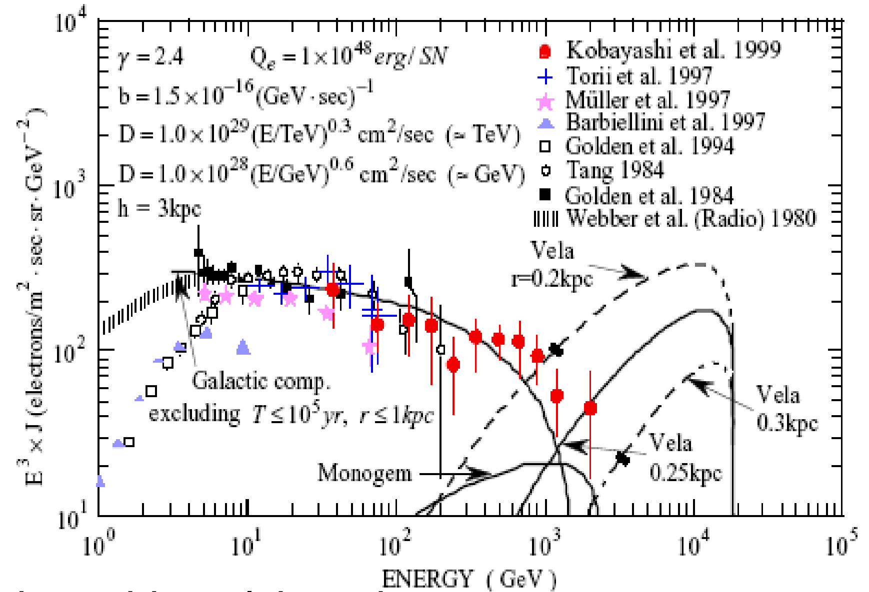

Positron Fraction e⁺/(e⁺+e⁻)
0.10
0.01
0.1
1.0
10.0
100.0
Energy [GeV]
HEAT 2000
HEAT 1994 & 1995
AMS 1998
Barbiellini 1996


All−Electron
Positrons
×10−3
×10−4
Proton Spectrum
Nishimura 1980
Golden 1984
Tang 1984
Golden 1994
HEAT 1994 & 1995
Torii 1999
E3 × J(E) (m-2s-1sr-1GeV2)
Energy (GeV)
1
10
100
1000
2 TeV

Predicted Electron Spectrum

- Spectral shape of HE electrons should be strongly affected by the number of nearby sources, and their distance distribution.
- If no such features in the high-energy electron spectrum are observed it will call into question our understanding of CR sources and propagation

Assuming a 20 TeV cut off energy, diffusion parameters, and source power, shown.

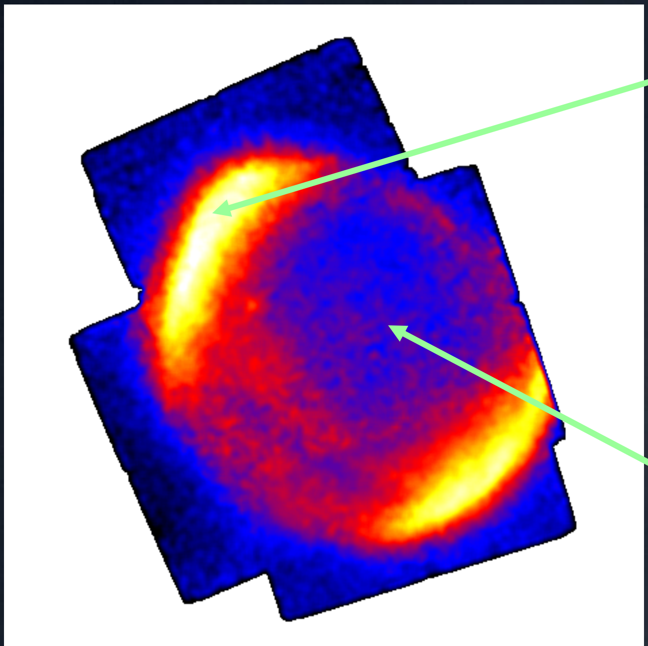


Kobayashi et al (2004)

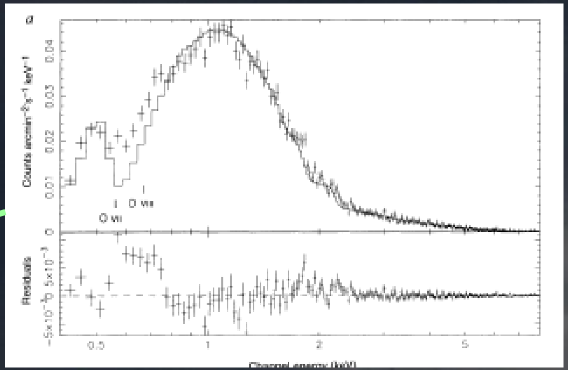
Galactic Cosmic Ray Electrons

- Strong (indirect) evidence for supernova shock acceleration of galactic CR electrons through observations of non-thermal X-rays and TeV gamma rays from SN remnants.

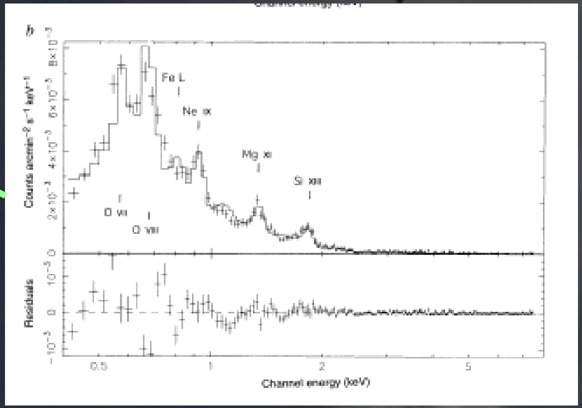
Synchrotron emission from SN1006



Koyama et al (1995)

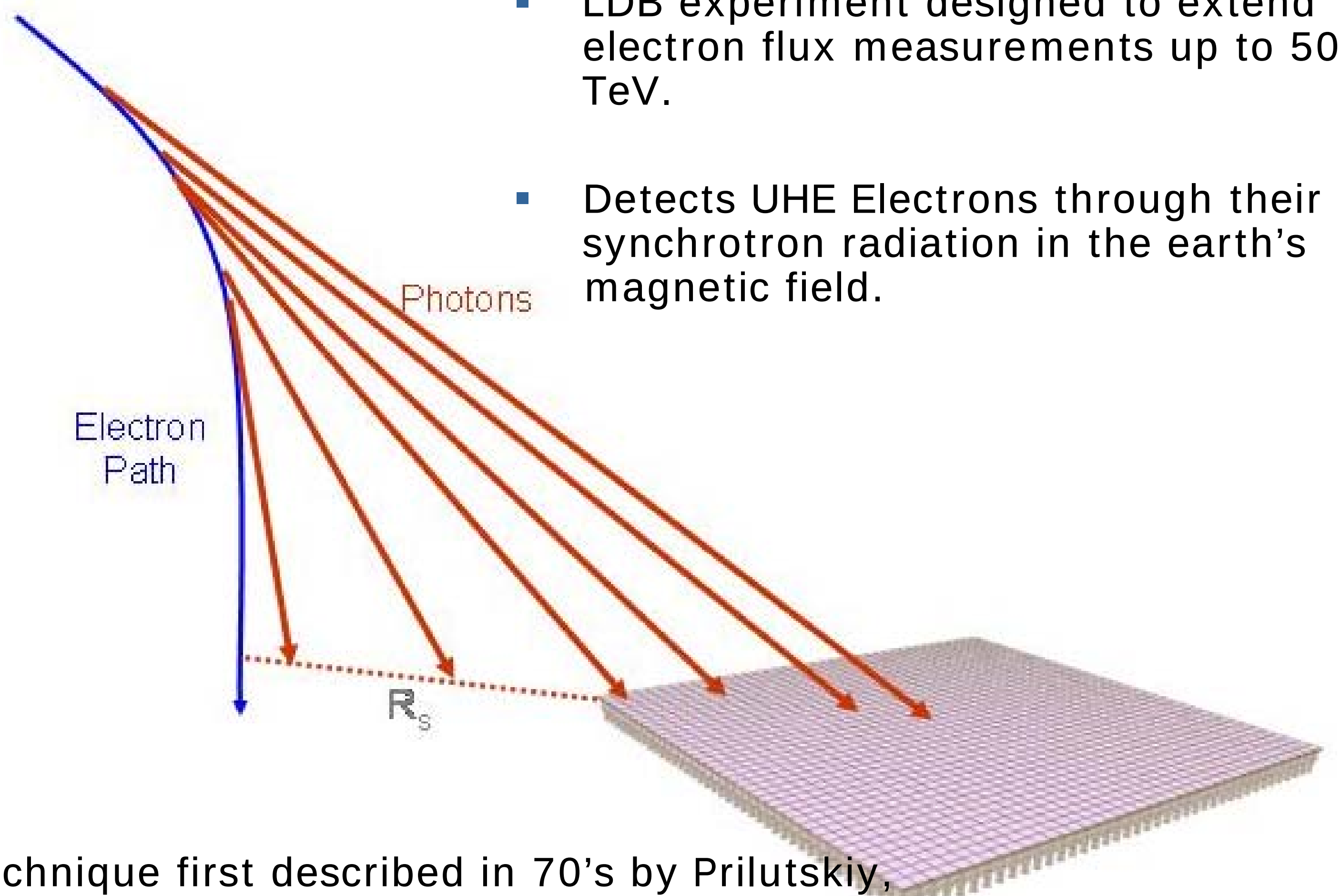


Non-thermal emission from rim.
Morphology correlates well between x-ray and radio bands



Thermal emission from core

CREST: Cosmic Ray Electron Synchrotron Telescope

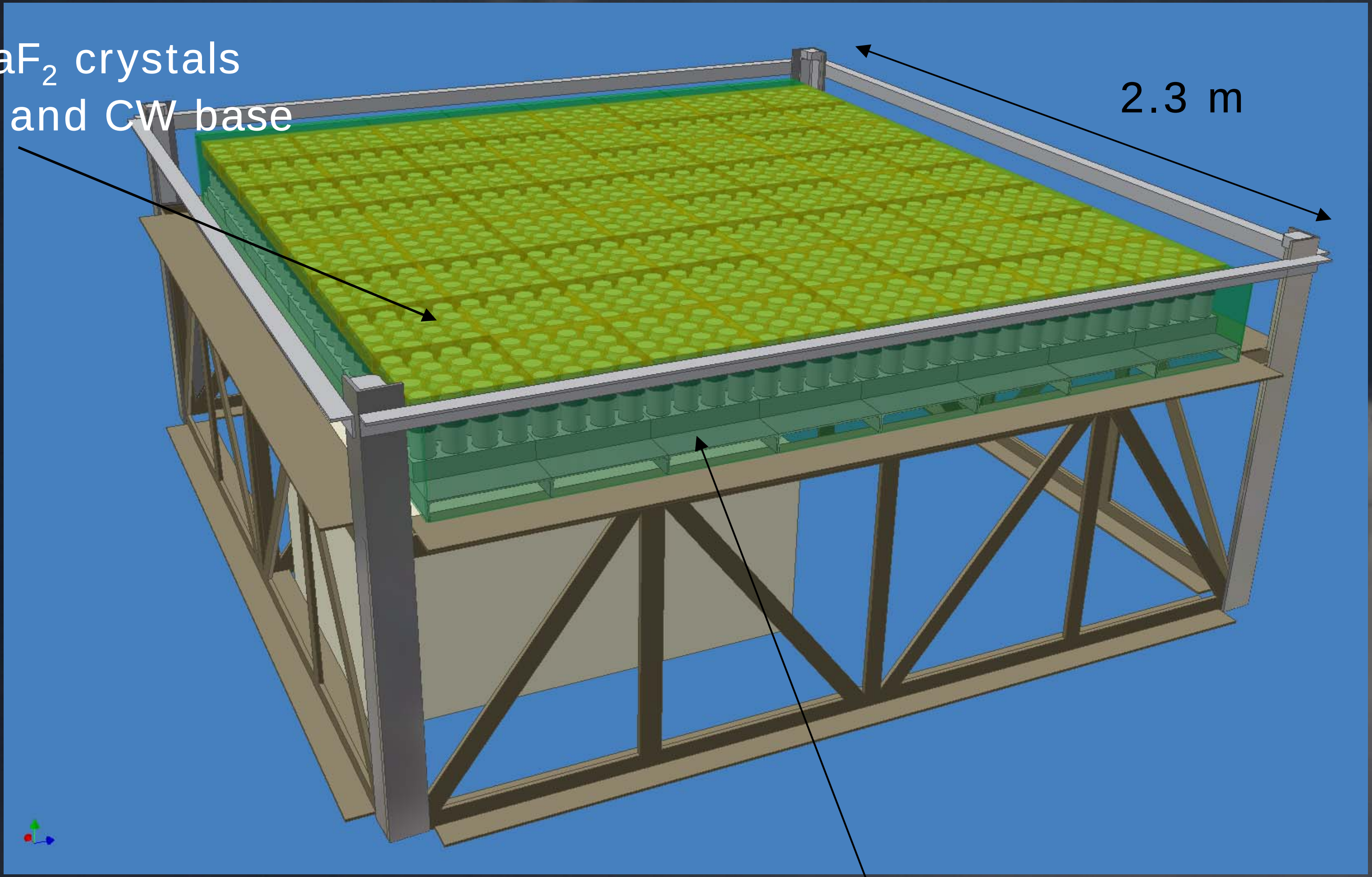


- LDB experiment designed to extend electron flux measurements up to 50 TeV.
- Detects UHE Electrons through their synchrotron radiation in the earth's magnetic field.
- Technique first described in 70's by Prilutskiy, and fully developed in 80's by Stephens & V.K. Balasubrahmanran

Mechanical Layout

1024 BaF_2 crystals
w/ PMT and CW base

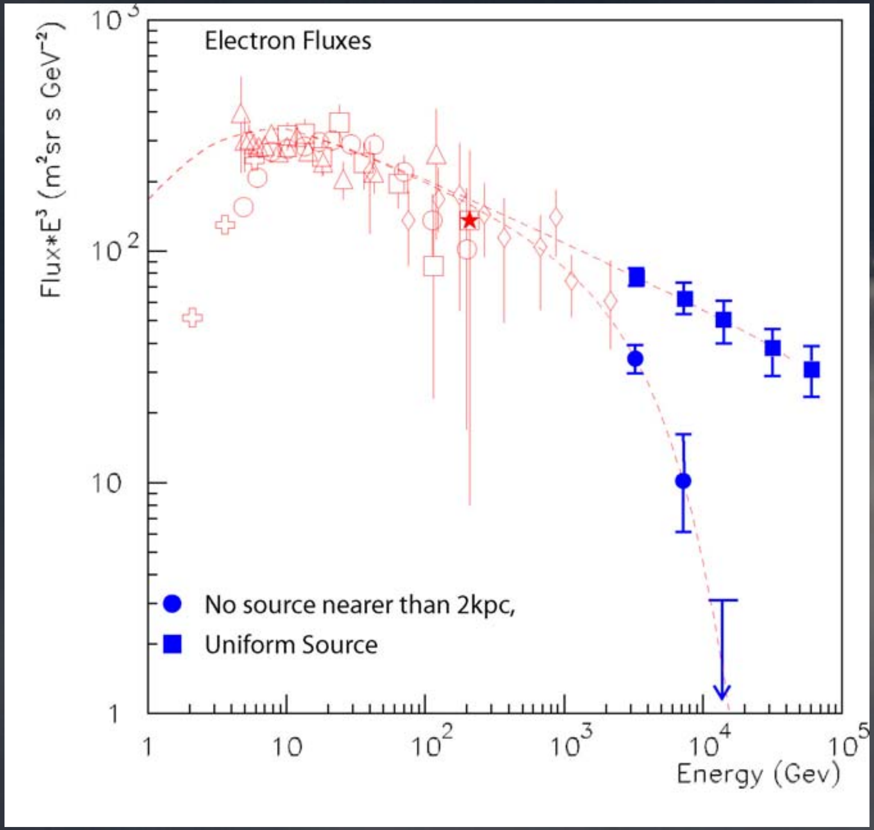
2.3 m



4 π plastic scintillator shield (0.5 cm thick)

Spectral Sensitivity

Two curves represent the expected result for 100 days of exposure for two extremes: no source, and for a uniform distribution of sources.




END