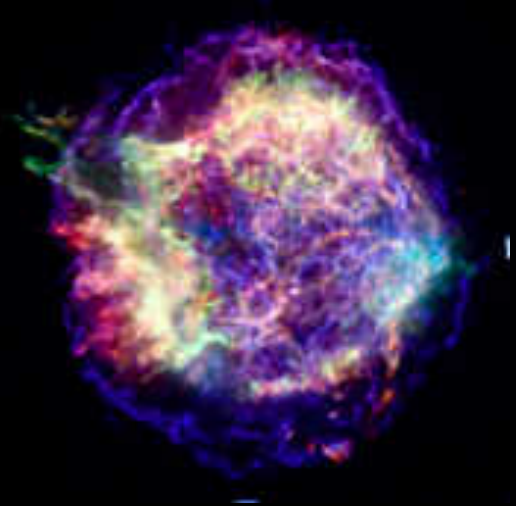


Inclusive electron+positron measurements

Pier Simone Marrocchesi

Univ. of Siena and INFN-Pisa

Propagation of cosmic-ray electrons in the Galaxy

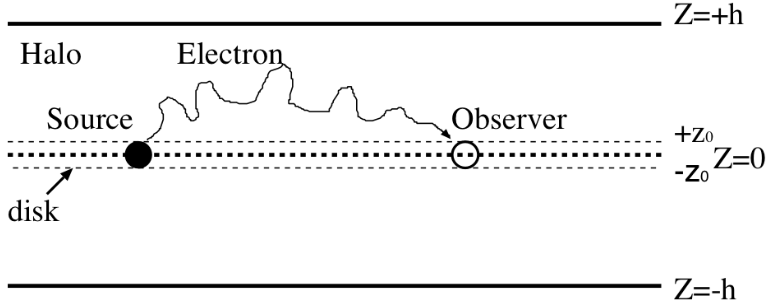
- Energy losses:
  - Inverse Compton scattering with interstellar photons
  - Synchrotron radiation with interstellar magnetic field (B~6μG)

  $\Rightarrow$ $dE/dt = -bE^2$

- Life time of electrons
  $T=1/(bE) \approx 2.5\times10^5 yr/E(TeV)$

- Propagation distance in the Galaxy
  $R=(2DT)^{1/2} \approx 0.4 \div 0.8 kpc$ (@E=1TeV)
  - Diffusion coeff.: $D=(1\text{-}4)\times10^{29}(E/TeV)^{0.3}(cm^2/s)$

Propagation



(Diffusion model)

↓

Observations

High-energy cosmic-ray electrons observations

- TeV electrons from distant sources with

  R > ~ 1kpc or T > ~10^5yr

  – Cannot reach the solar system

- TeV electrons from nearby sources with

  R < ~ 1kpc and T < ~10^5yr

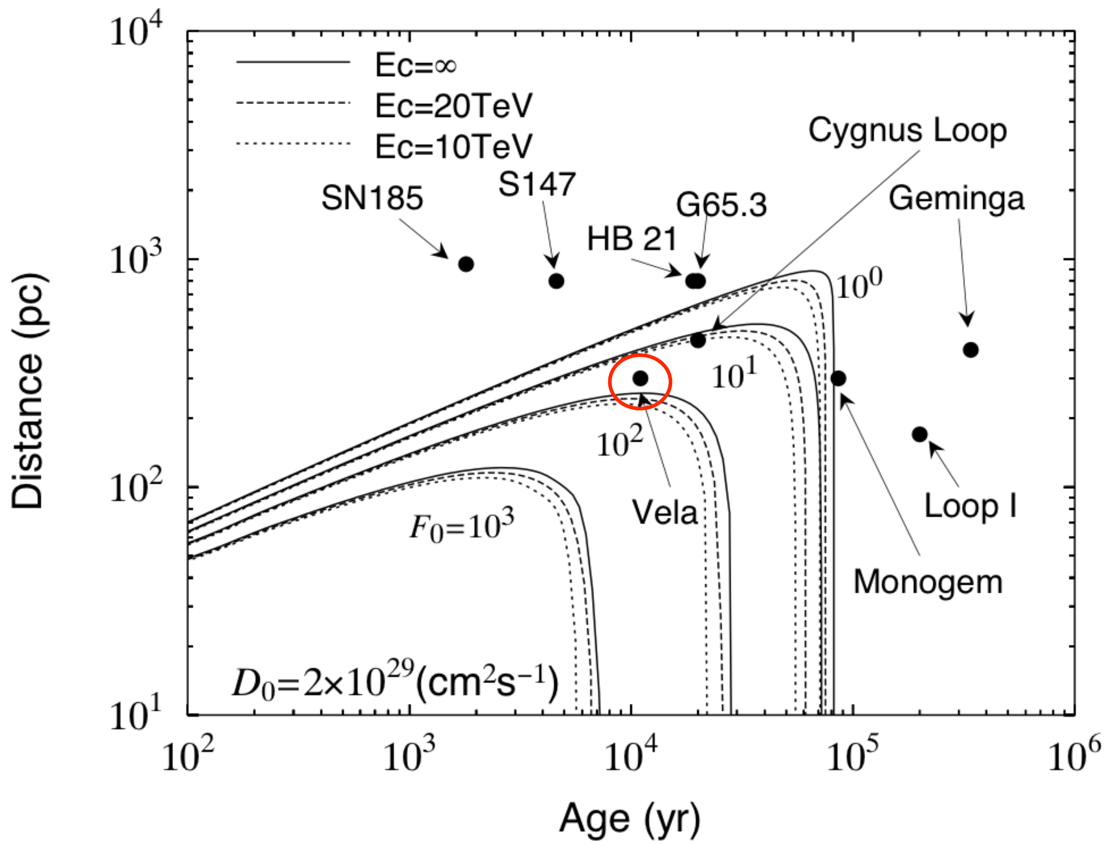
  – Identifiable structure(s) in the spectrum

  – Anisotropy of arrival direction of electrons

- Identification of specific cosmic-ray sources

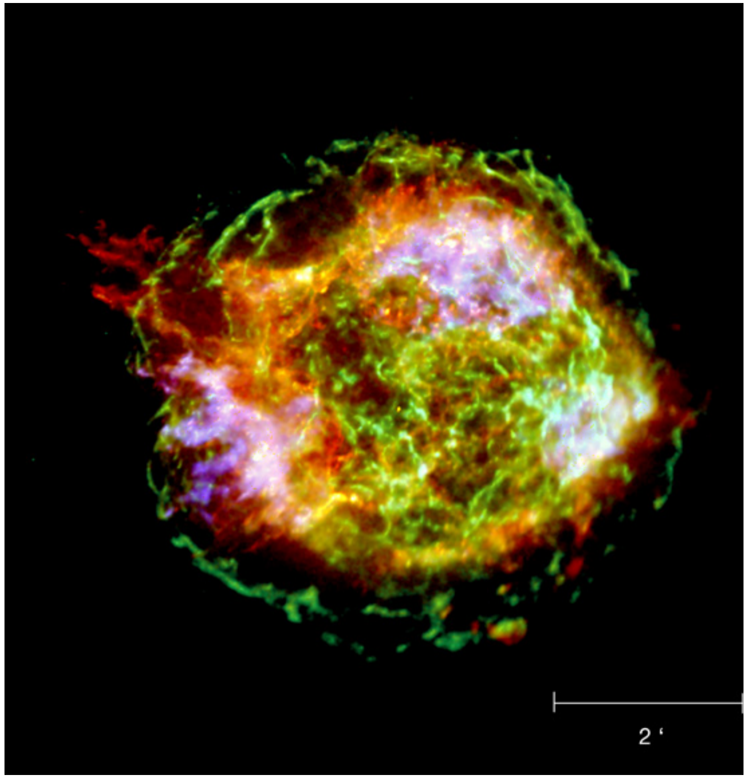
Nearby SNRs

SNR	R(kpc)	T(yr)
SN185	0.95	1.8×10^3
S147	0.80	4.6×10^3
HB 21	0.80	1.9×10^4
G65.3+5.7	0.80	2.0×10^4
Cygnus Loop	0.44	2.0×10^4
Vela	0.30	1.1×10^4
Monogem	0.30	8.6×10^4
Loop1	0.17	2.0×10^5
Geminga	0.4	3.4×10^5

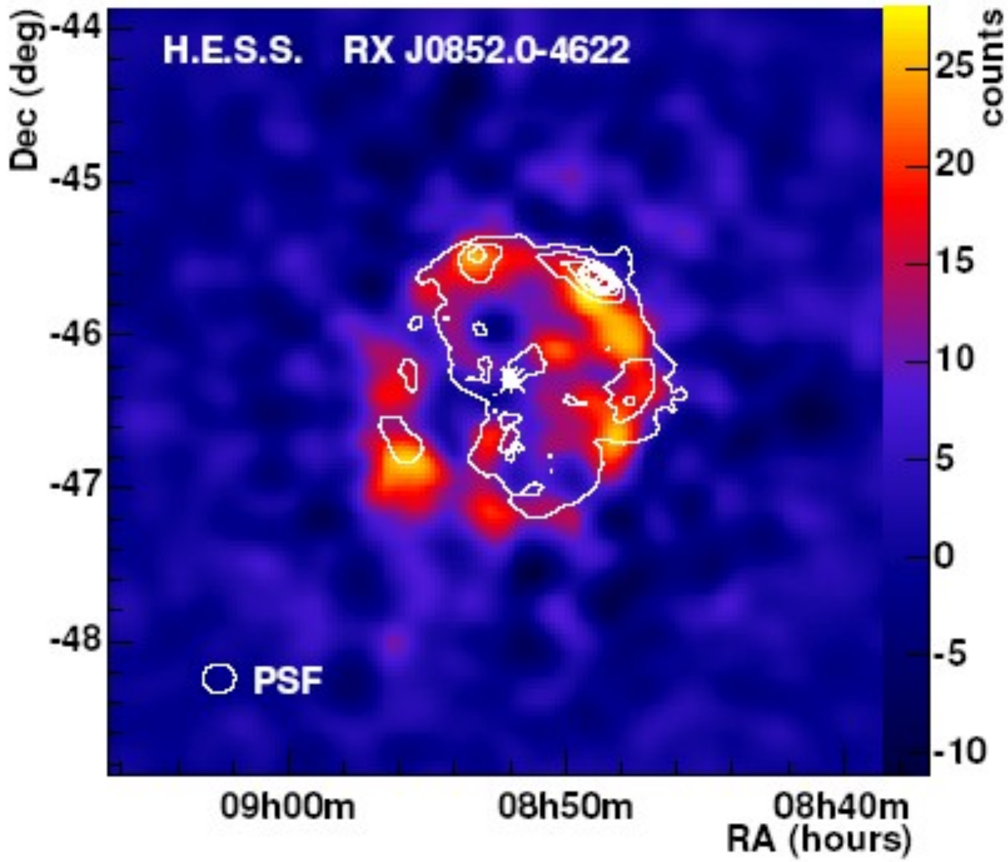


Contour of electron flux distance vs. age (E=3TeV)

Acceleration of electrons



X-ray image of Cas A

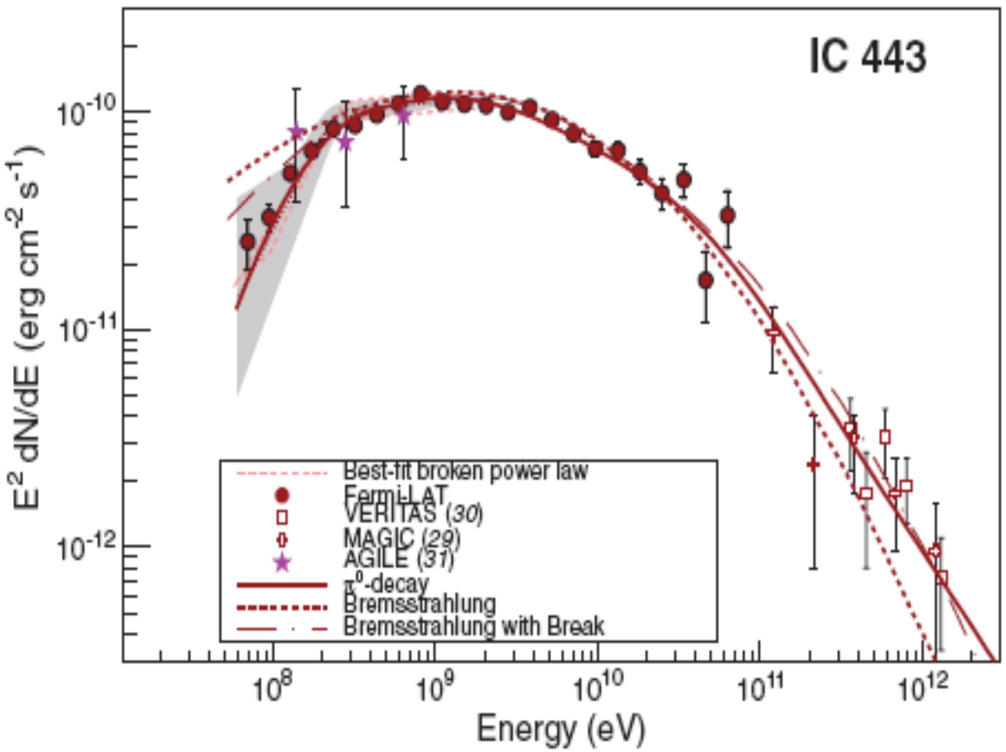


Gamma-ray image of RX J0852.0-4622

- Evidence of high-energy electrons in SNRs from X-ray observations
- Electron or hadron? from gamma-ray observations

2013: FERMI claims evidence for proton acceleration in SNRs

SCIENCE VOL 339 15 FEBRUARY 2013



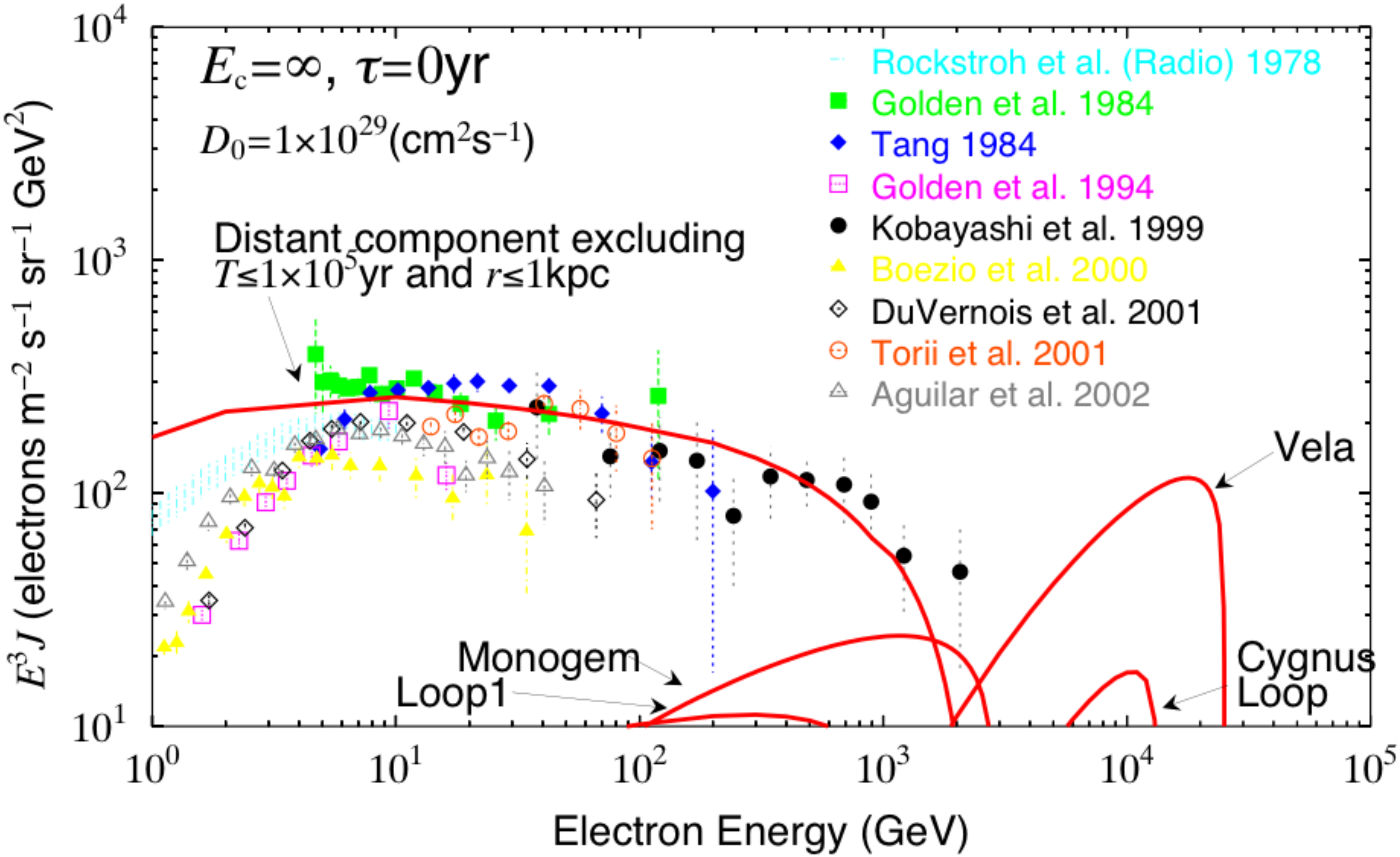
- We detected the characteristic pion-decay feature in the gamma-ray spectra of two SNRs, IC 443 and W44, with the Fermi Large Area Telescope.
- This detection provides direct evidence that cosmic-ray protons are accelerated in SNRs."

$p + p \rightarrow \pi^0$ + other products,
followed by $\pi_0 \rightarrow 2\gamma$,
each having an energy
of $m_{\pi 0}/2 = 67.5$ MeV

" The identification of pion-decay gamma rays has been difficult because high-energy electrons also produce gamma rays via bremsstrahlung and inverse Compton scattering."

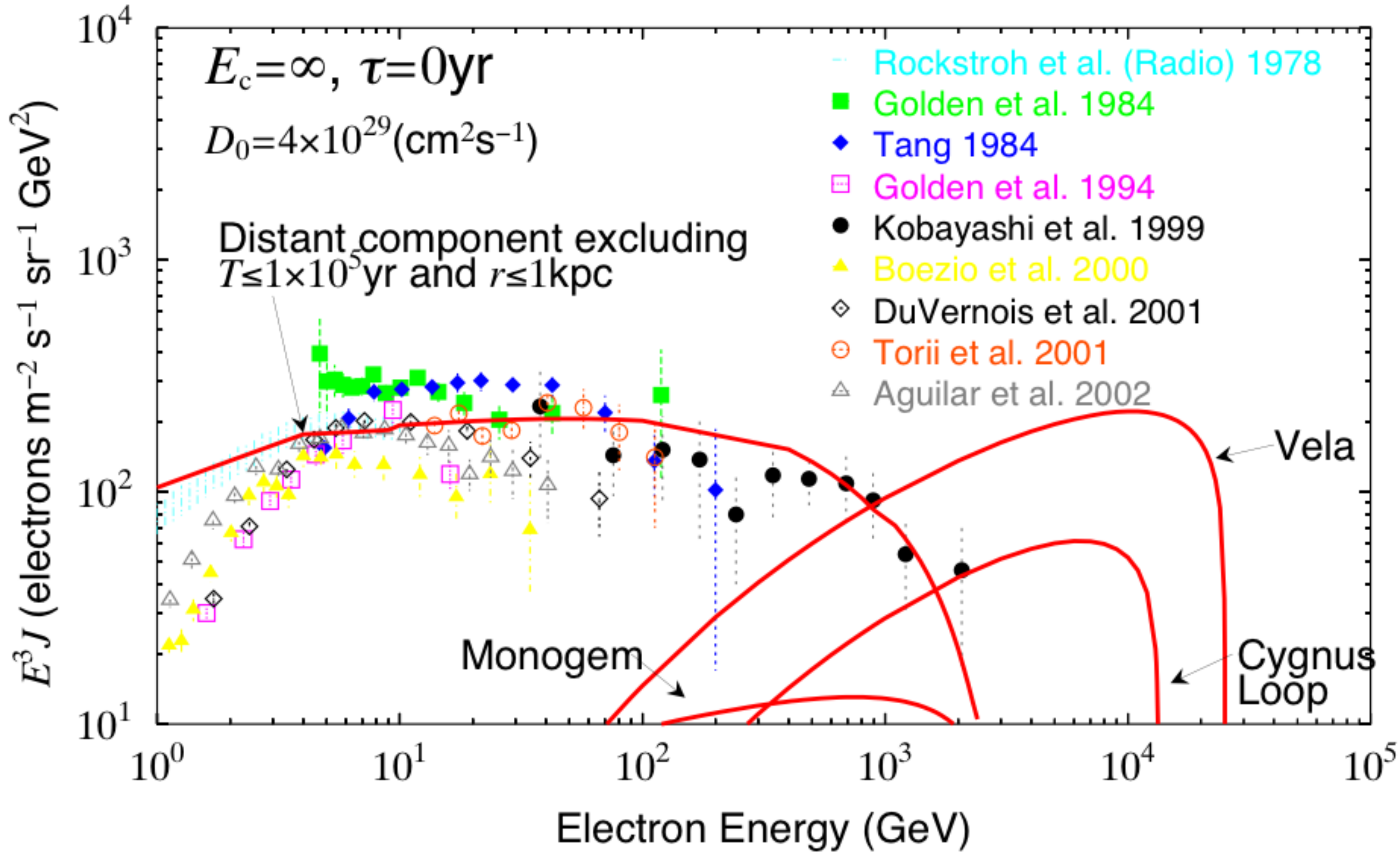
Energy spectra vs. diffusion coefficient

D = 1 x 10^{29} cm^2s^{-1}@1TeV K.Yoshida

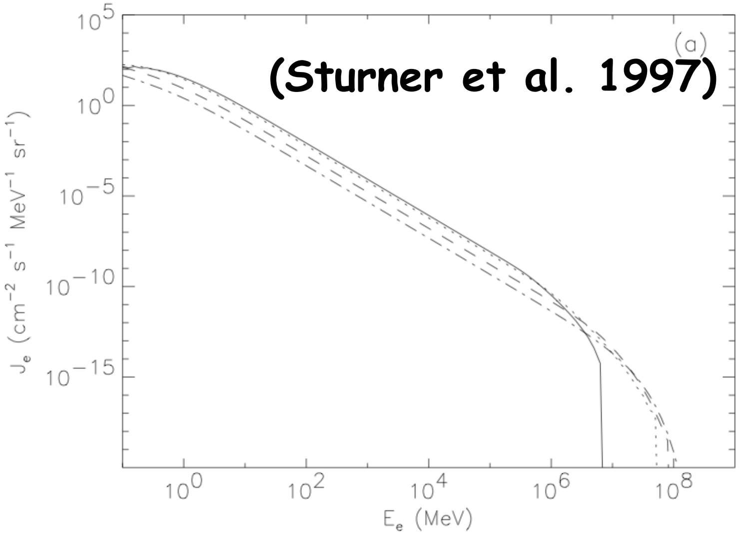


Energy spectra vs. diffusion coefficient

D = 4 x 10^{29} cm^2s^{-1}@1TeV K.Yoshida



Cutoff in the energy spectrum of electrons at sources



Electron energy spectrum at SNR

$E^{-\gamma} \exp(-E/E_c)$

$\gamma = 2.1 \sim 2.4$

$E_c = 10 \sim 100$TeV

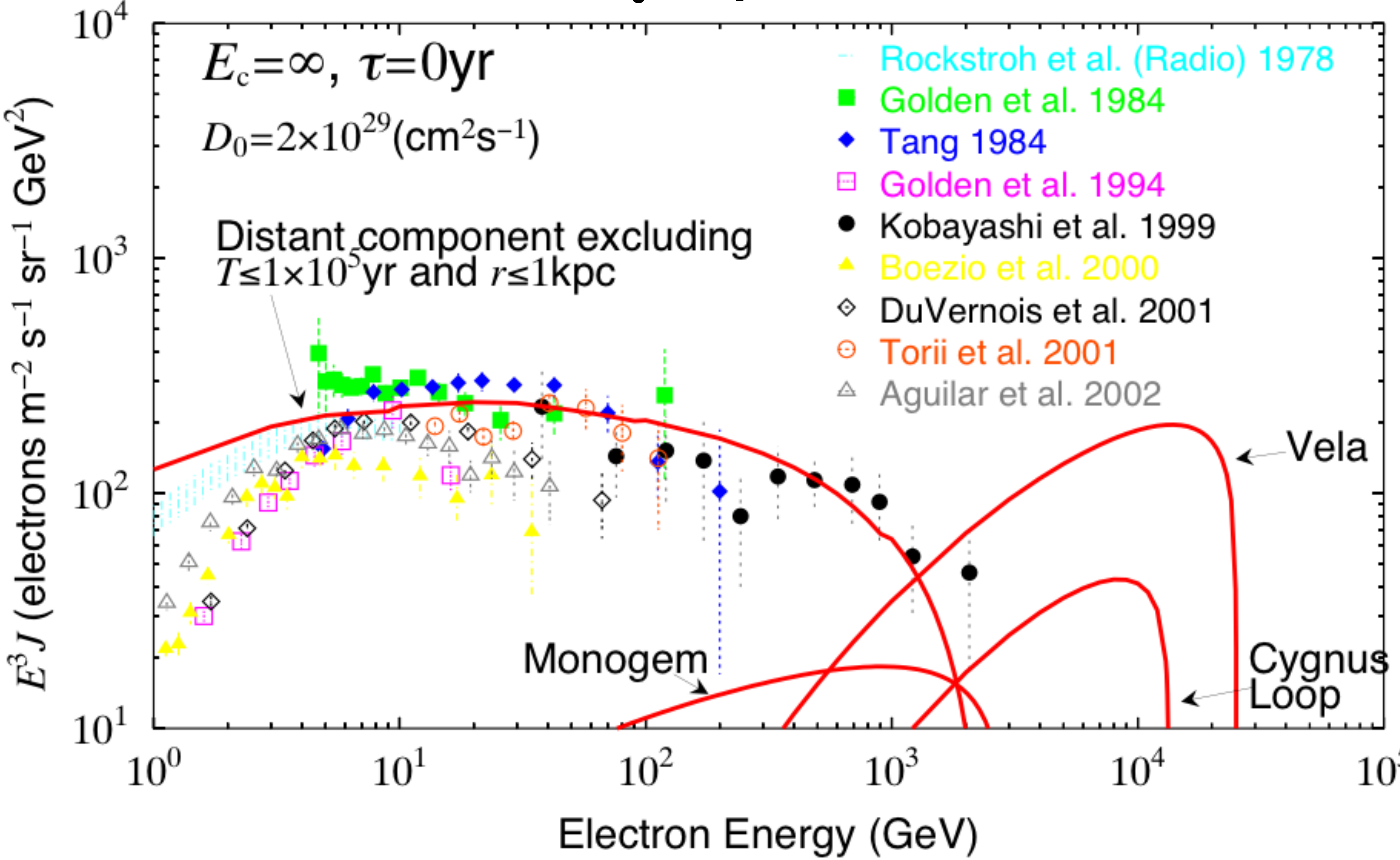
Rolloff Frequency and Maximum Electron Energy Upper Limits

Object	$\nu_{rolloff}$ (10^{16} Hz)	$\nu_{rolloff}$ (keV)	$E_{max}[(B/10\mu G)]^{1/2}$ (ergs)	$E_{max}[(B/10\mu G)]^{1/2}$ (TeV)
Kes 73[a]	150	6	290	200
Cas A............	32	1	130	80
Kepler	11	0.5	79	50
Tycho	8.8	0.4	70	40
G352.7−0.1......	6.6	0.3	60	40
SN 1006[b]	6	0.2	57	40
3C 397...........	3.4	0.1	43	30
W49 B...........	2.4	0.1	36	20
G349.7+0.2......	1.8	0.07	31	20
3C 396...........	1.6	0.07	30	20
G346.6−0.2......	1.5	0.06	29	20
3C 391...........	1.4	0.06	28	20
SN 386[a]	1.2	0.05	26	20
RCW 103[a]	1.2	0.05	26	20

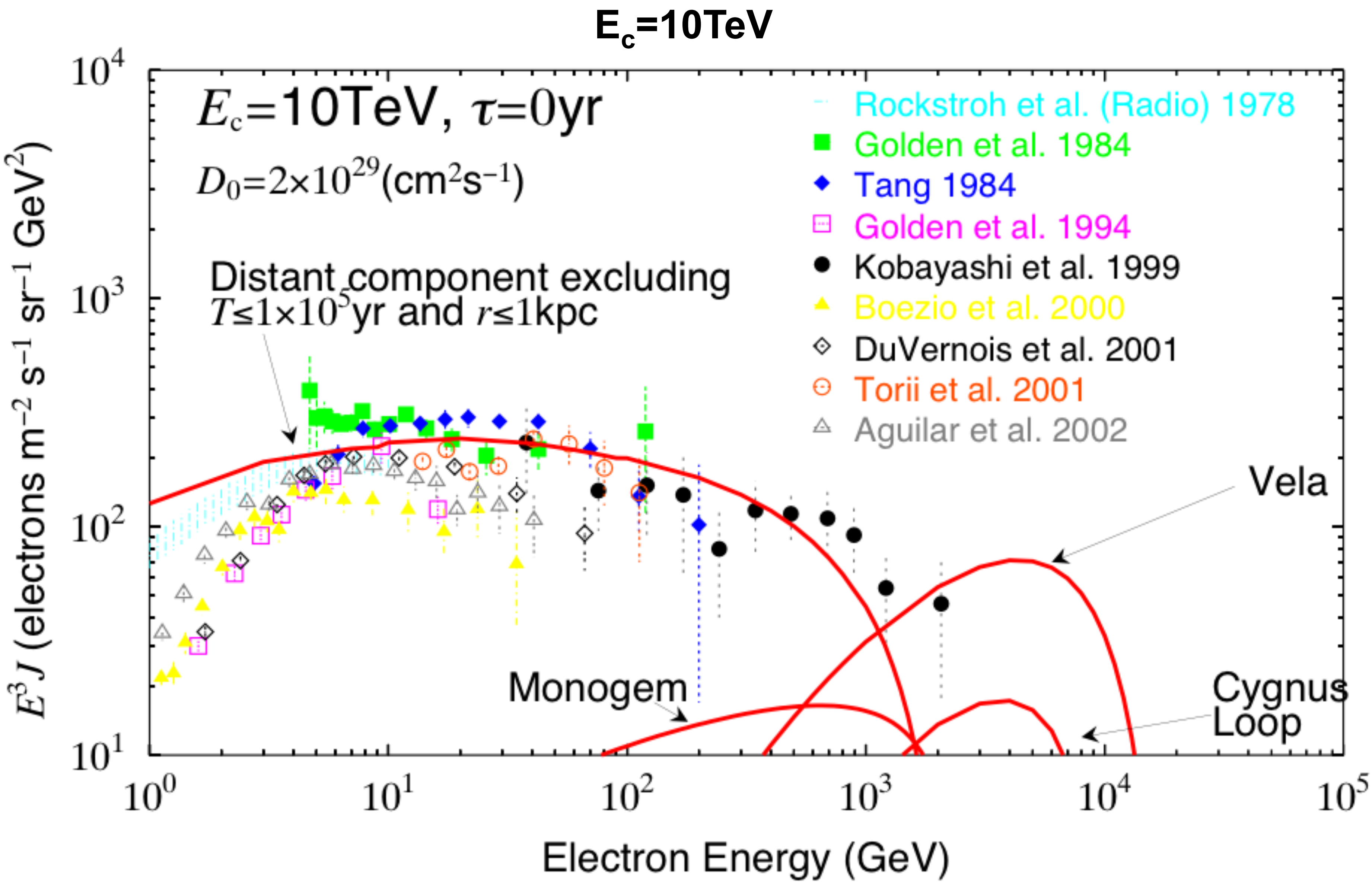
(Reynolds et al. 1999)

Higher cut-off energies => Higher flux in TeV region

E_c=infty



Electron spectra vs. cut-off energies



Relevance of cosmic-ray electron observations for astrophysics

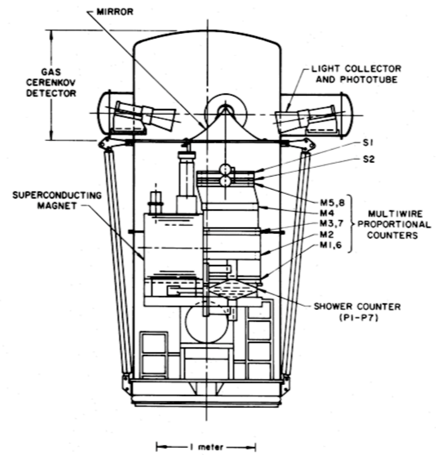
- E < 10GeV
  - Solar modulation
- E = 10GeV-100GeV
  - Propagation characteristics in the Galaxy
  - Information on sources
- E > 100GeV
  - Identification of cosmic-ray sources
  - Acceleration mechanisms
  - Dark matter search

High-energy electron observations

- Direct electron observations since 1960's
  - Daniel&Stephens 1965, Bleeker 1965,…
- As the energy increases:
  - Lower electron flux
  - Larger proton backgrounds
- Requirements for instruments
  - Large geometrical factor (SΩ)
  - Long exposures
  - High proton rejection power

Two kinds of instruments

Golden et al. published 1984



- Separation between e^- and e^+
  - Magnetic spectrometers:

    starting from B. Golden's 1976 flight

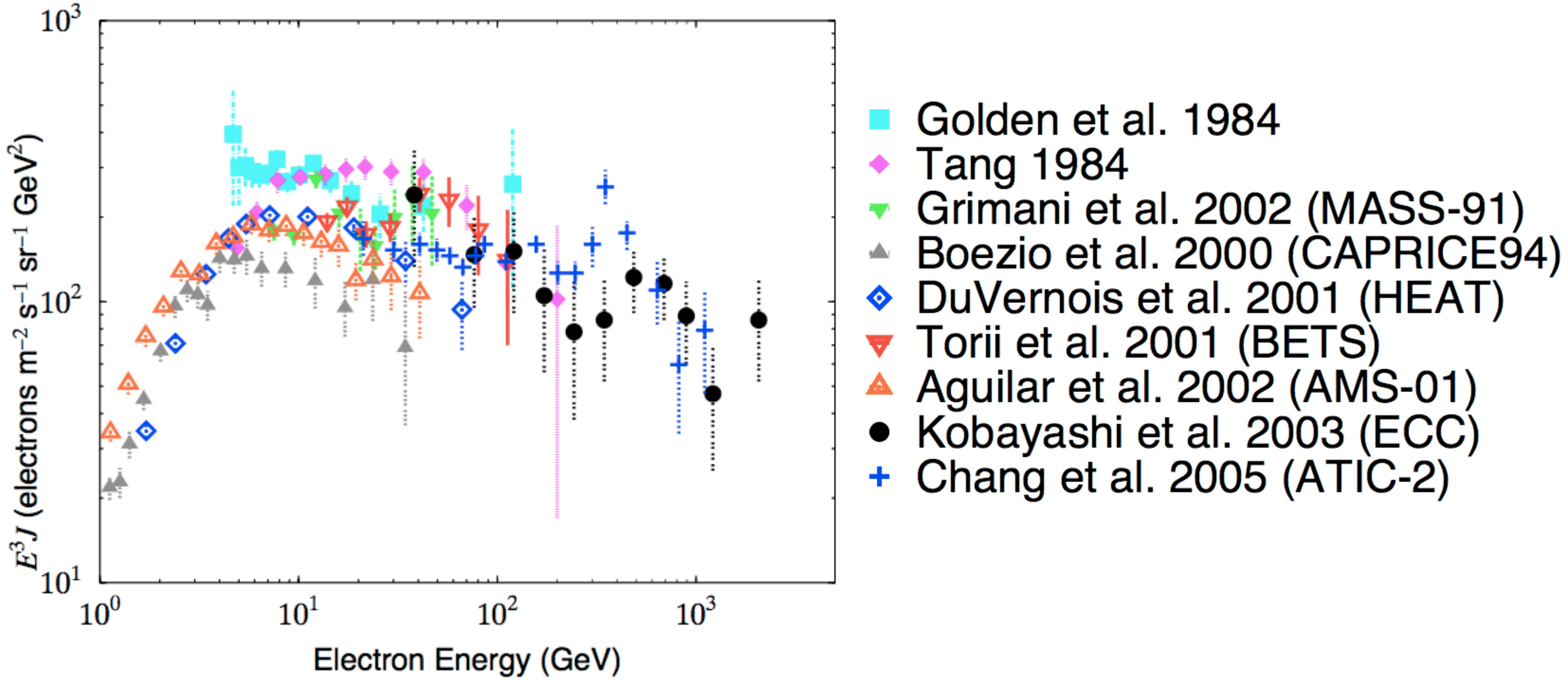
    mainly ballon experiments (e.g.: MASS, CAPRICE, HEAT)

    followed by space experiments e.g.:(AMS-01, PAMELA, AMS-02)

- No-separation between e^- and e^+
  - Calorimeters without magnets:
    - balloons (most recent ones include e.g.: BETS, ATIC)
    - space (e.g.: FERMI*, CALET, DAMPE...)
    - ground experiments (e.g.: HESS)

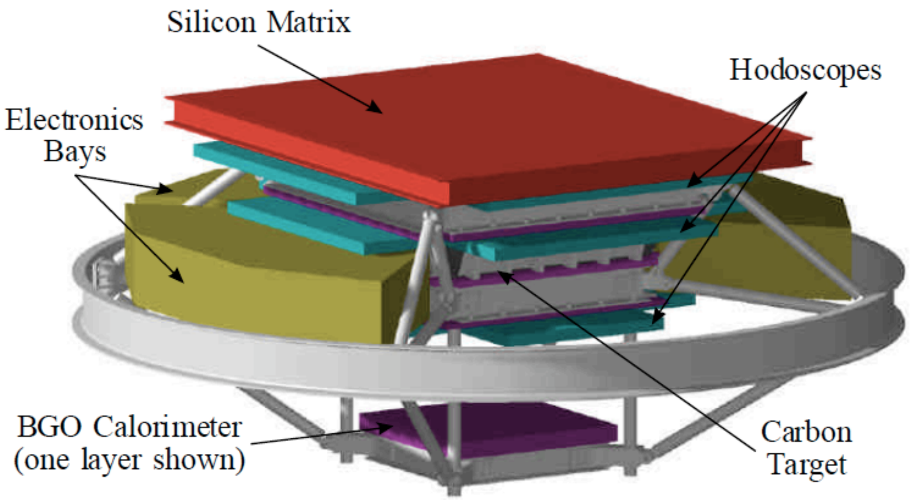
(*) Fermi analysis uses the Earth magnetic field to separate the two charges)

Compiled electron energy spectra (1984-2005) mostly balloon experiments



- Variation in the flux: factor 2~3
- Few observations above 100 GeV region

ATIC balloon instrument

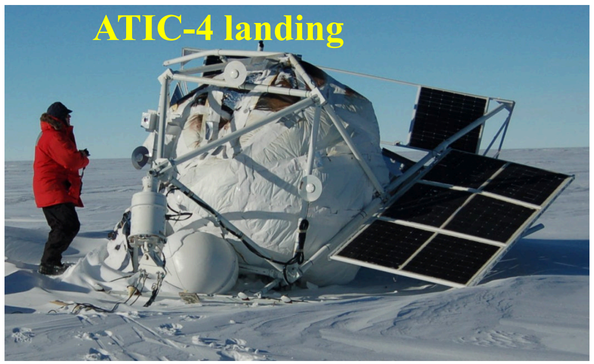


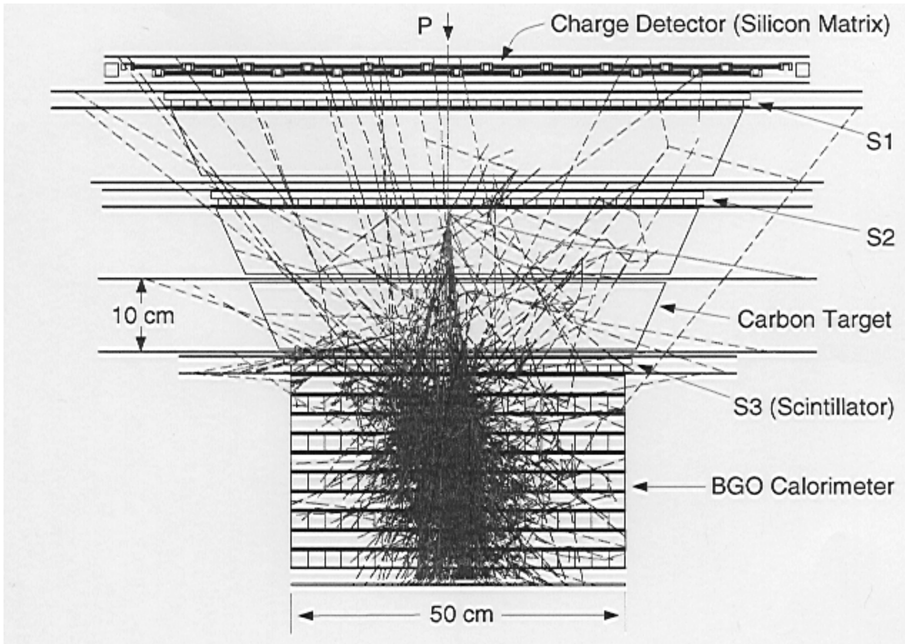
Si-Matrix: 4480 pixels (each 2 cm x 1.5 cm) to measure GCR charge in presence of backscattered shower particles.

Plastic scintillator hodoscope, embedded in **Carbon target**, provides event trigger, charge and particle tracking.

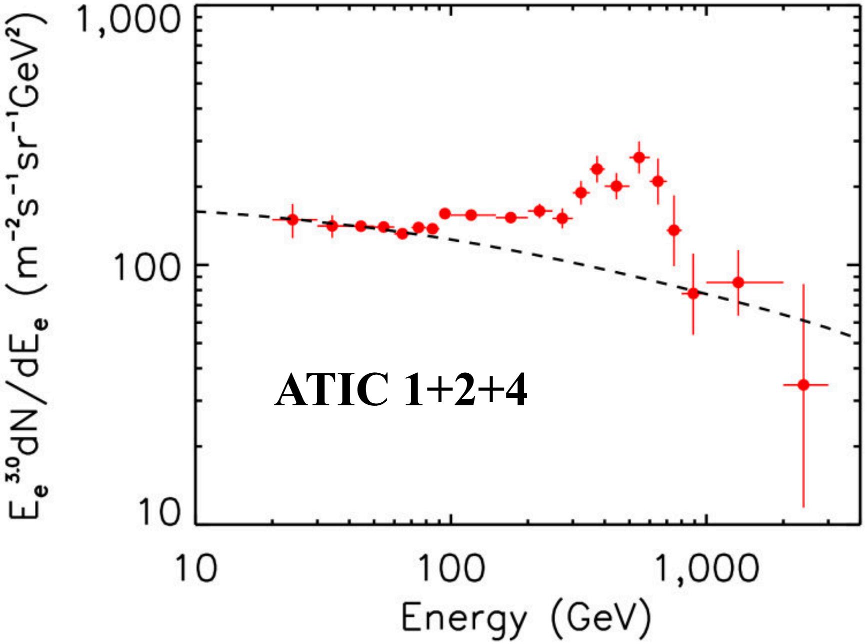
Calorimeter: 10 layers BGO crystals, 40 per layer. Total depth 22 X_0, 1.14 λ. Measure the electromagnetic core of the nuclear shower.

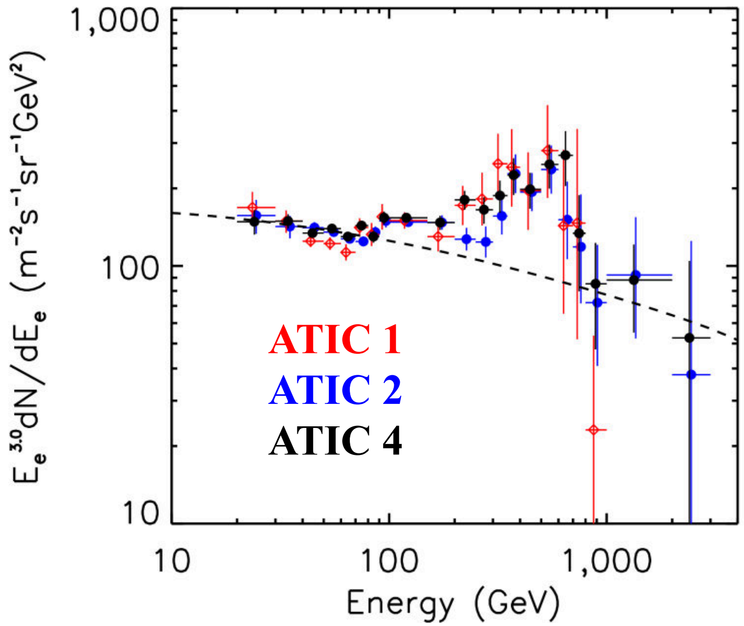
- Geometrical factor: 0.45 m^2 sr (calorimeter top) to 0.24 m^2 sr (calorimeter bottom)
- 3 successful Antarctic flights: 2000, 2002, 2007 (~57 days in total)





All three ATIC flights are consistent



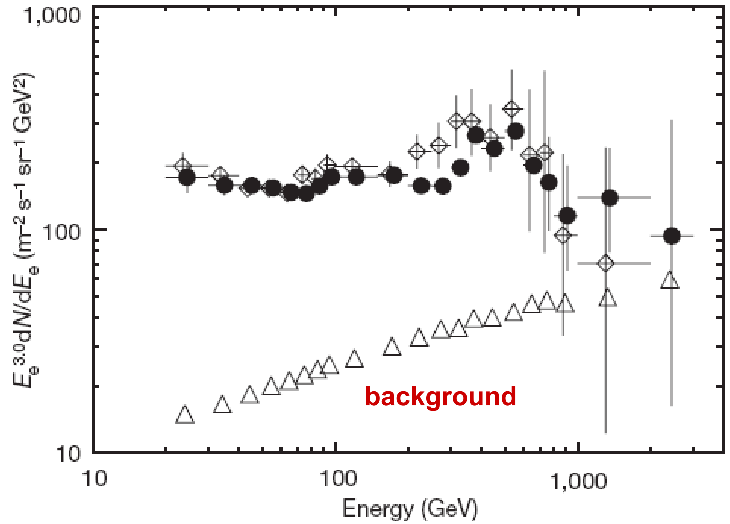


"Source on/source off" significance of bump for ATIC1+2 is about 3.8 sigma

ATIC-4 with 10 BGO layers has improved e , p separation. **(~ 4 x lower background)**

"Bump" is seen in all three flights.

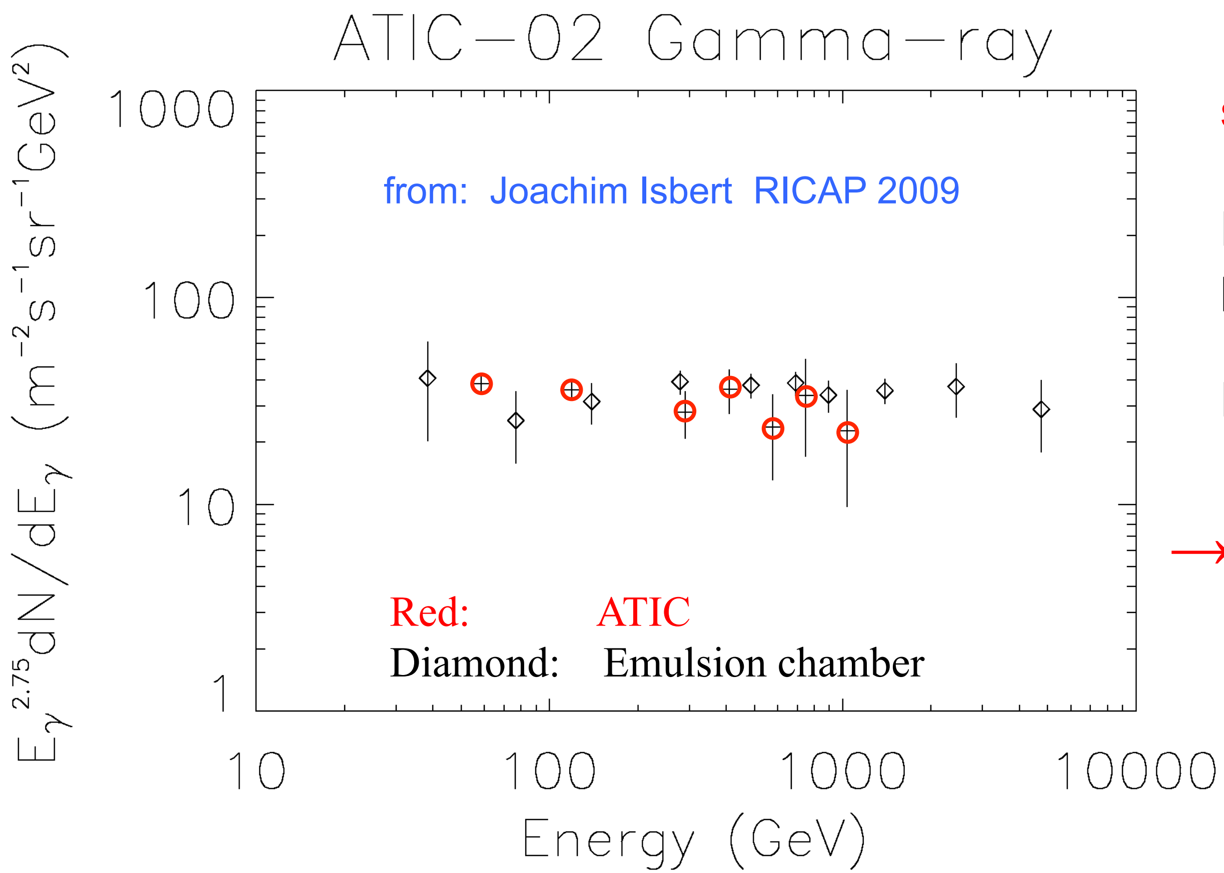
Significance for ATIC1+2+4 is 5.1 sigma



from: Joachim Isbert RICAP 2009

ATIC - atmospheric Gamma-rays:

Test of the electron selection method



same electron selection:

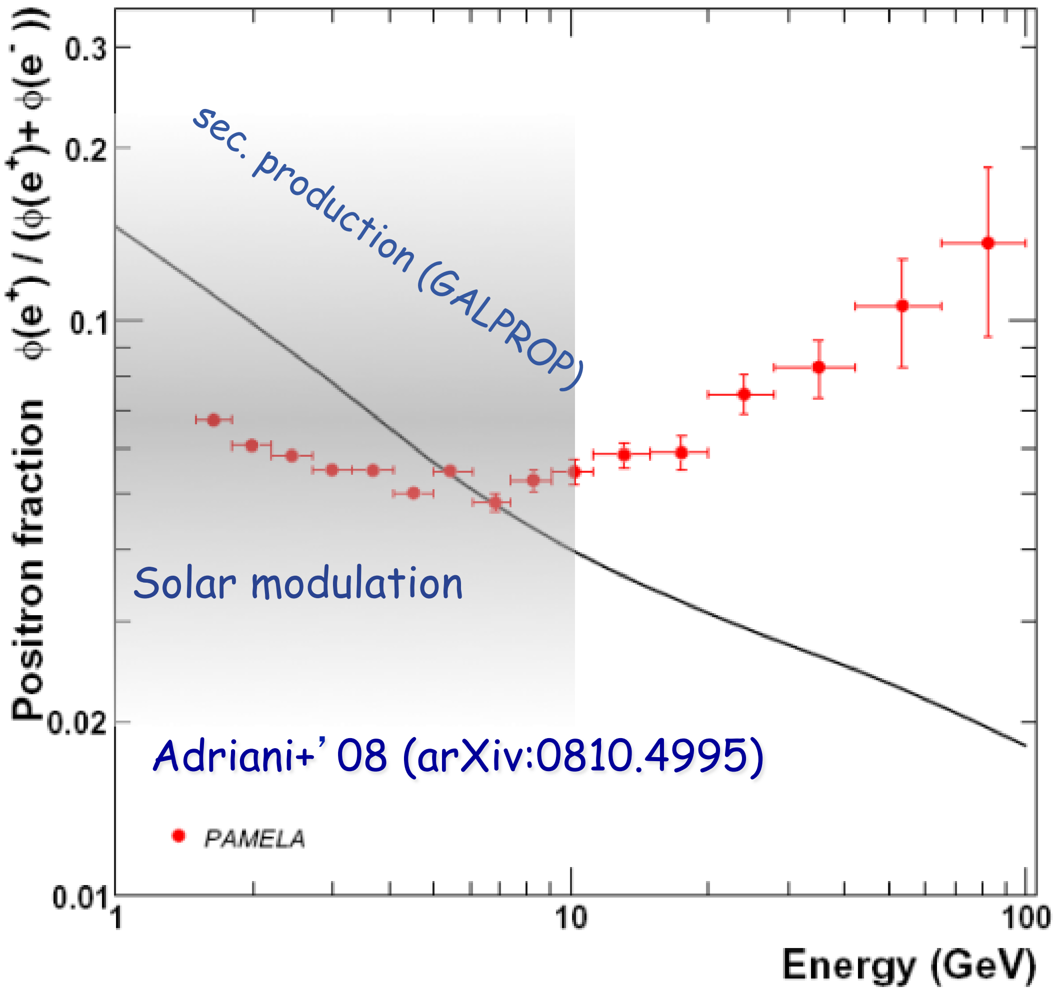
Reject all but 1 in 5000 protons

Retain 85% of all electrons

→ NO BUMP seen in γ-rays

PAMELA: positron fraction

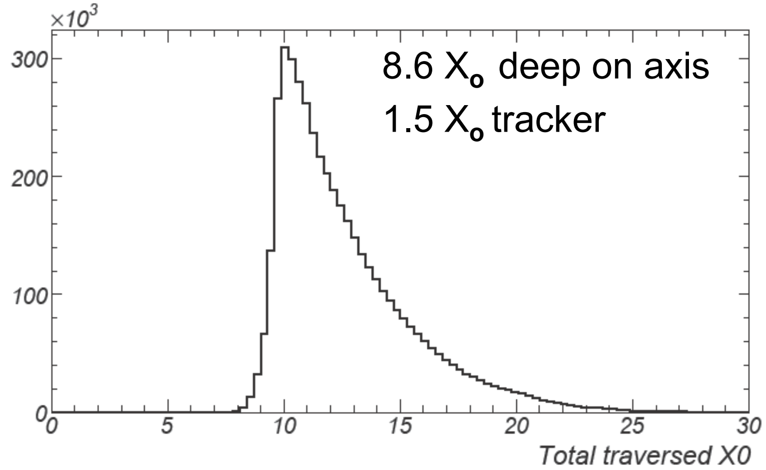
2008: Excess in positron is confirmed and extended to higher energies



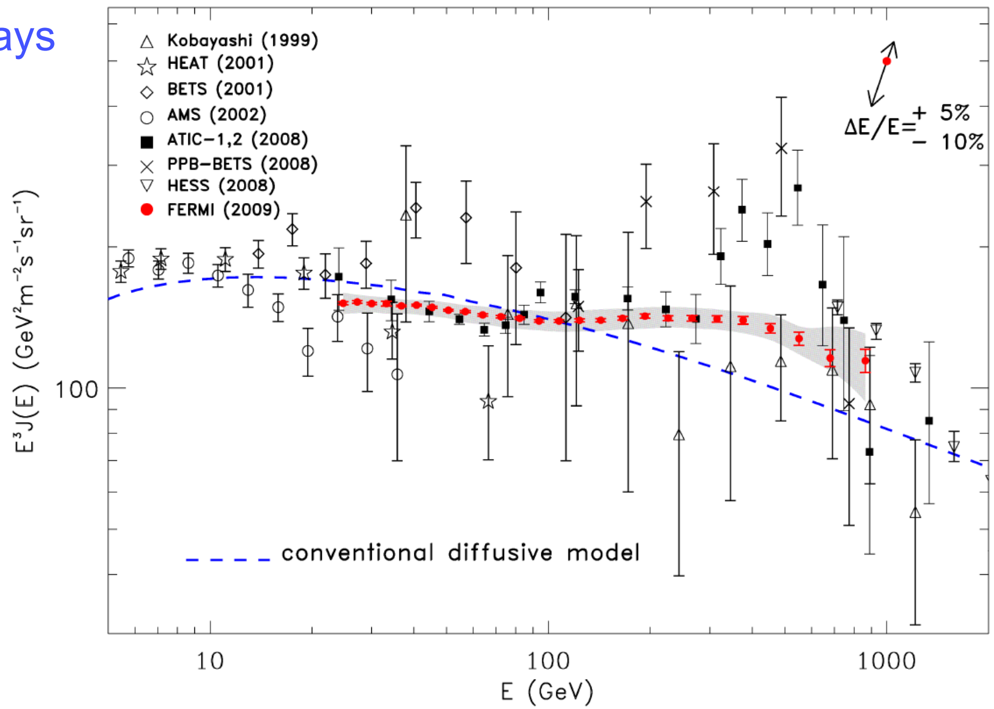
Fermi LAT: $e^+ + e^-$ spectrum

- FERMI: fantastic instrument for gamma-rays
- BUT: not optimized for electrons above a few hundreds GeV:

▼ only ~12.5 X_0 traversed on average

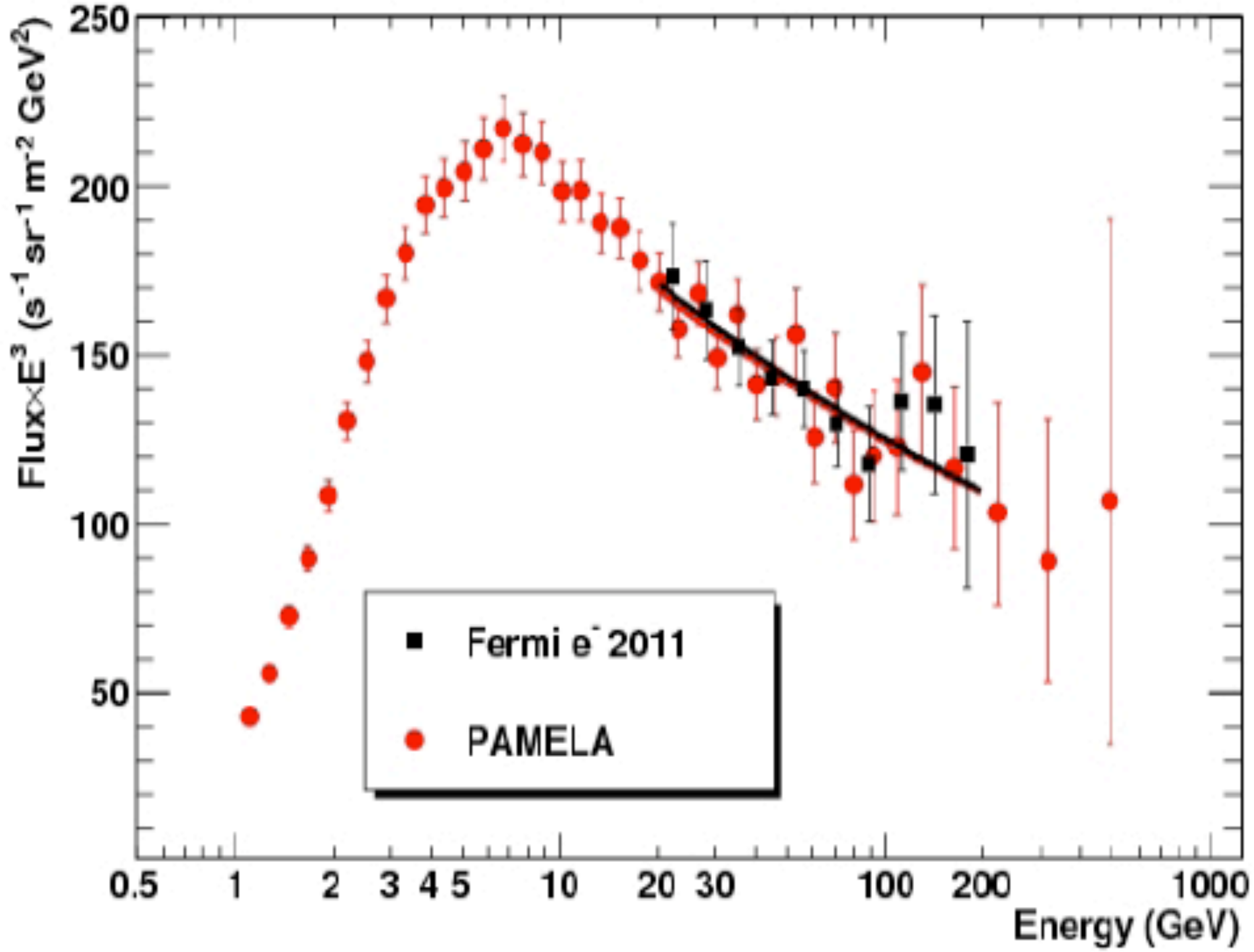


▲ high granularity in the tracker helps



- no prominent spectral features between 20 GeV and 1 TeV
- significantly harder spectrum $E^{-3.04}$ above 100 GeV

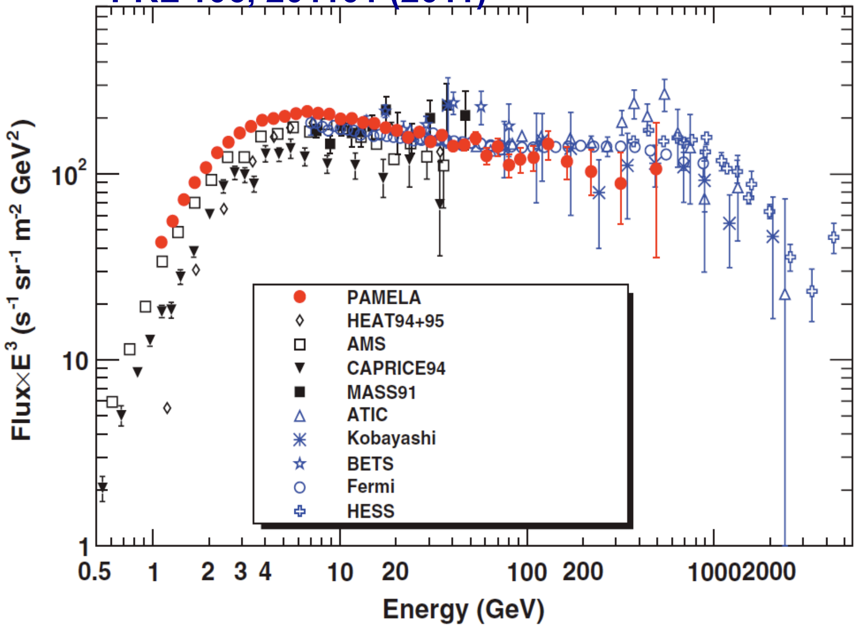
PAMELA and FERMI electrons (2011/2012)



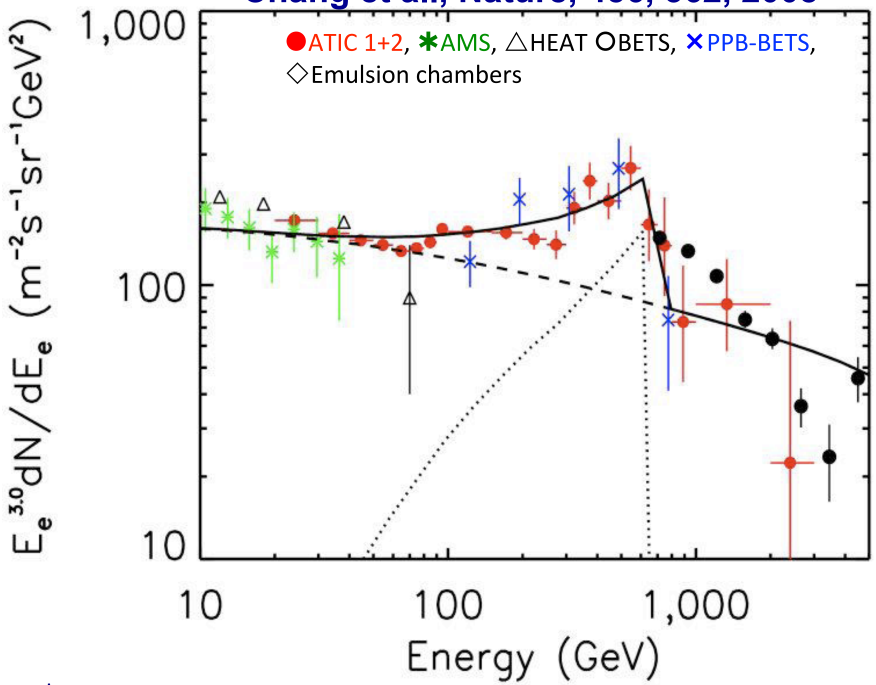
Adriani et al., Phys. Rev. Lett. 106, 201101 (2011)
Ackermann et al., Phys. Rev. Lett. 108, 011103 (2012)

The inclusive electron (+ positron) spectrum in 2011

PRL 106, 201101 (2011)



Chang et al., Nature, 456, 362, 2008



The electron spectrum puzzle:

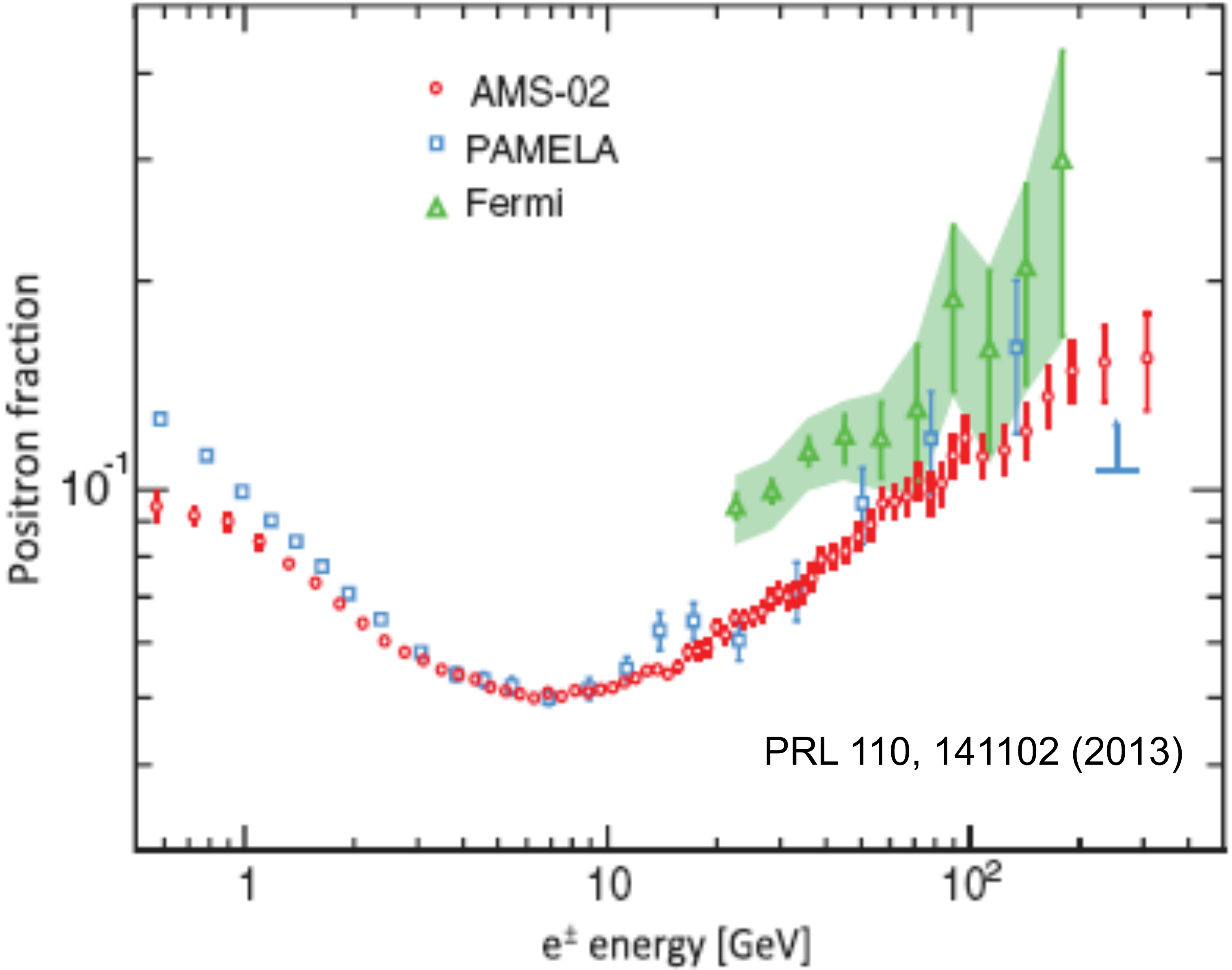
- **Cannot be reproduced with a single power-law injection spectrum**
- **ATIC reported an excess of CR electrons at energies between 300–800 GeV**
- **ATIC spectral feature not confirmed by Pamela and Fermi**

✧ **Hints:**

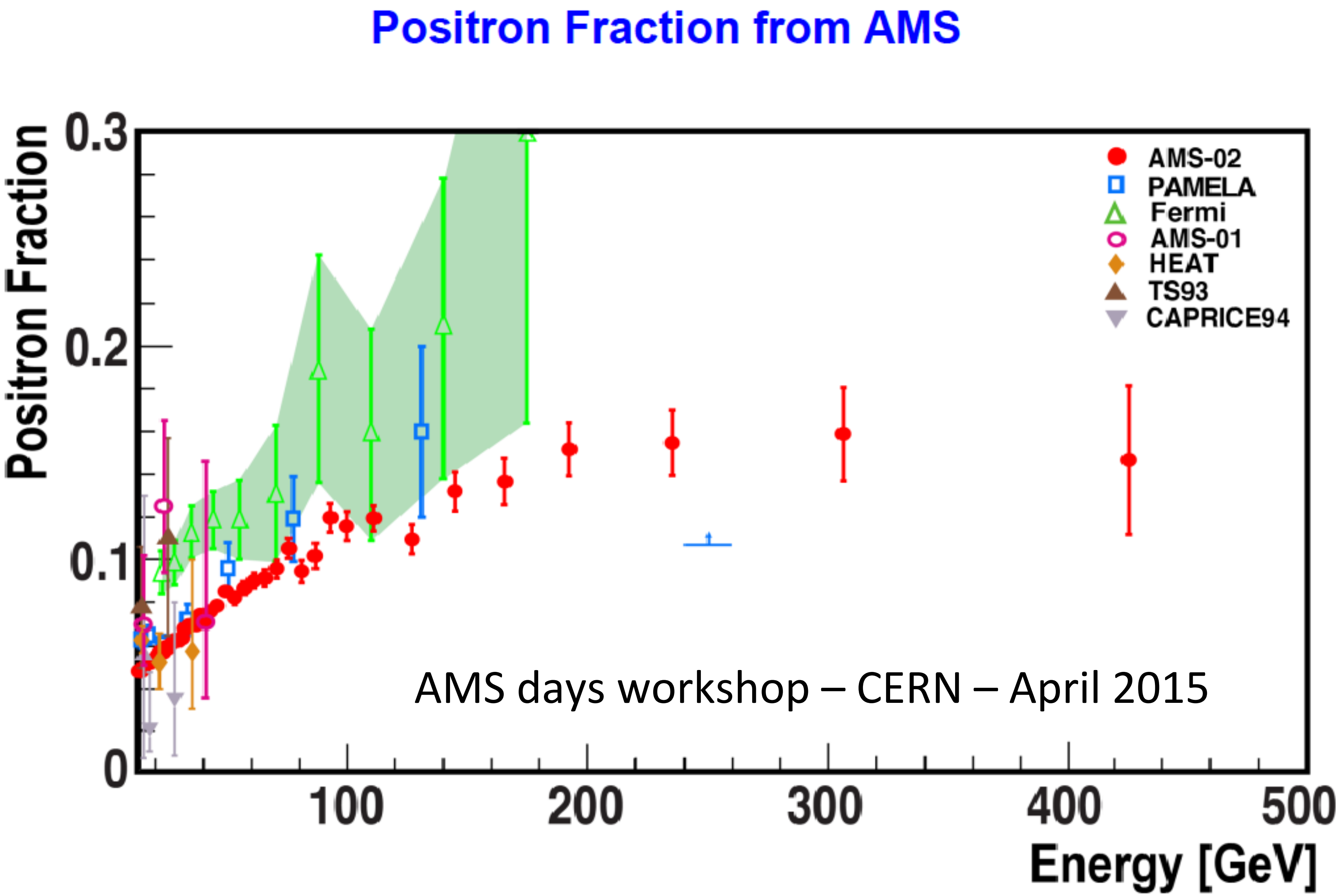
- **nearby sources of energetic electrons (SNR, pulsar, micro-quasar) ?**
- **annihilation of dark matter particles ?**
- perhaps needs a second component with hard spectrum (positrons?)

2013: AMS-02 confirms Pamela findings + extension to 350 GeV

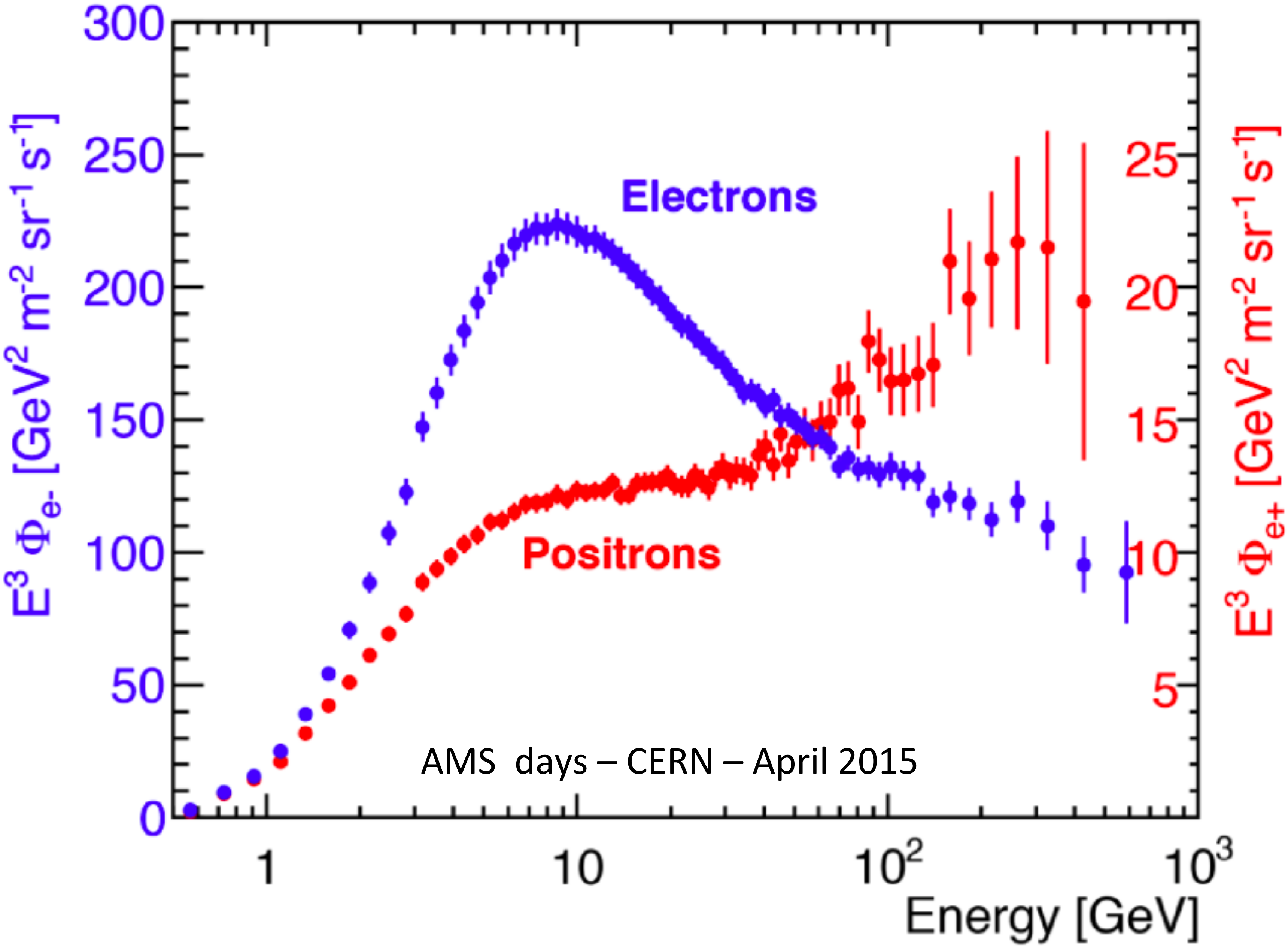
Positron fraction



2015: AMS-02 extension to ~ 400 GeV



2015: AMS-02 individual electron and positron spectra

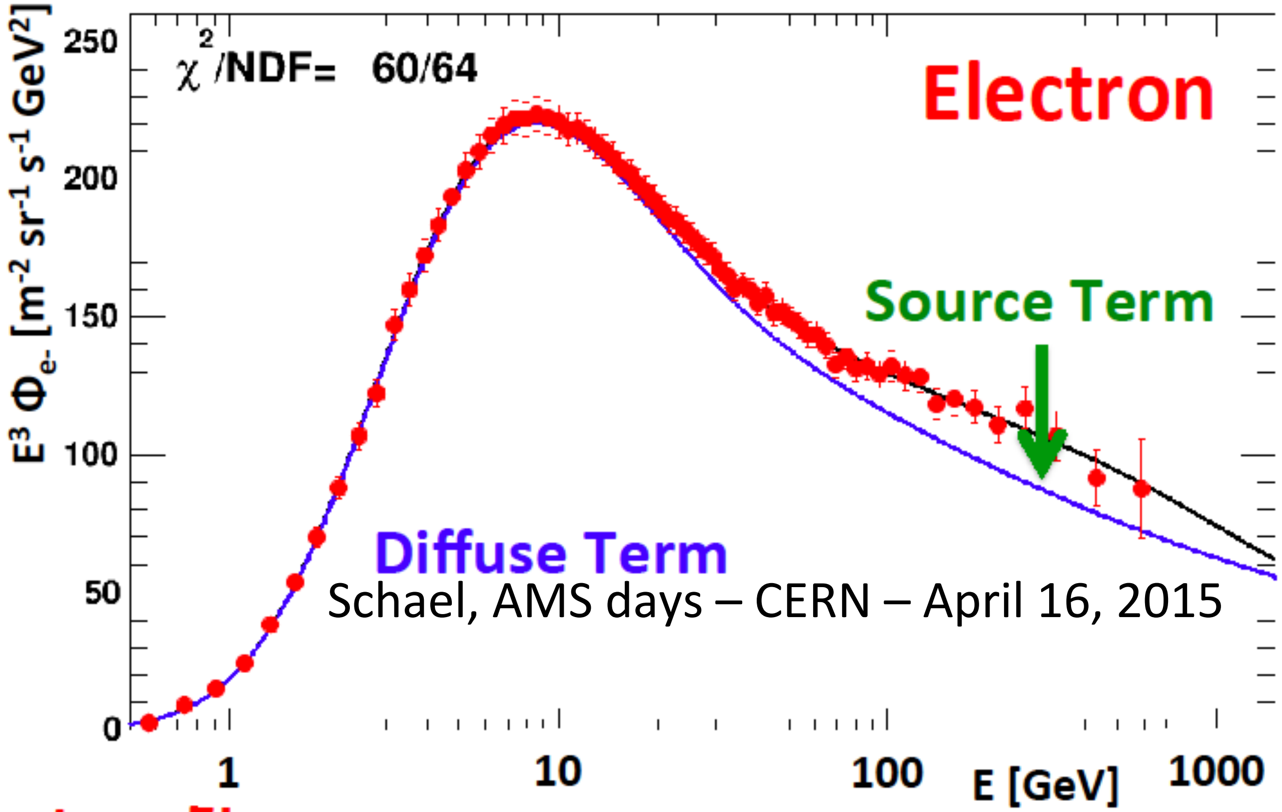


2015: AMS-02 Possible interpretation with a source term

The spectral index of the diffuse term has to become energy dependent:

$$\Phi_{e-}(E) = \frac{E^2}{\hat{E}^2}\left[C_{e-}\hat{E}^{\gamma_{e-}(\hat{E})} + C_s\hat{E}^{\gamma_s}\exp(-\hat{E}/E_s)\right]$$

The source term parameters are constrained from the positron flux fit.

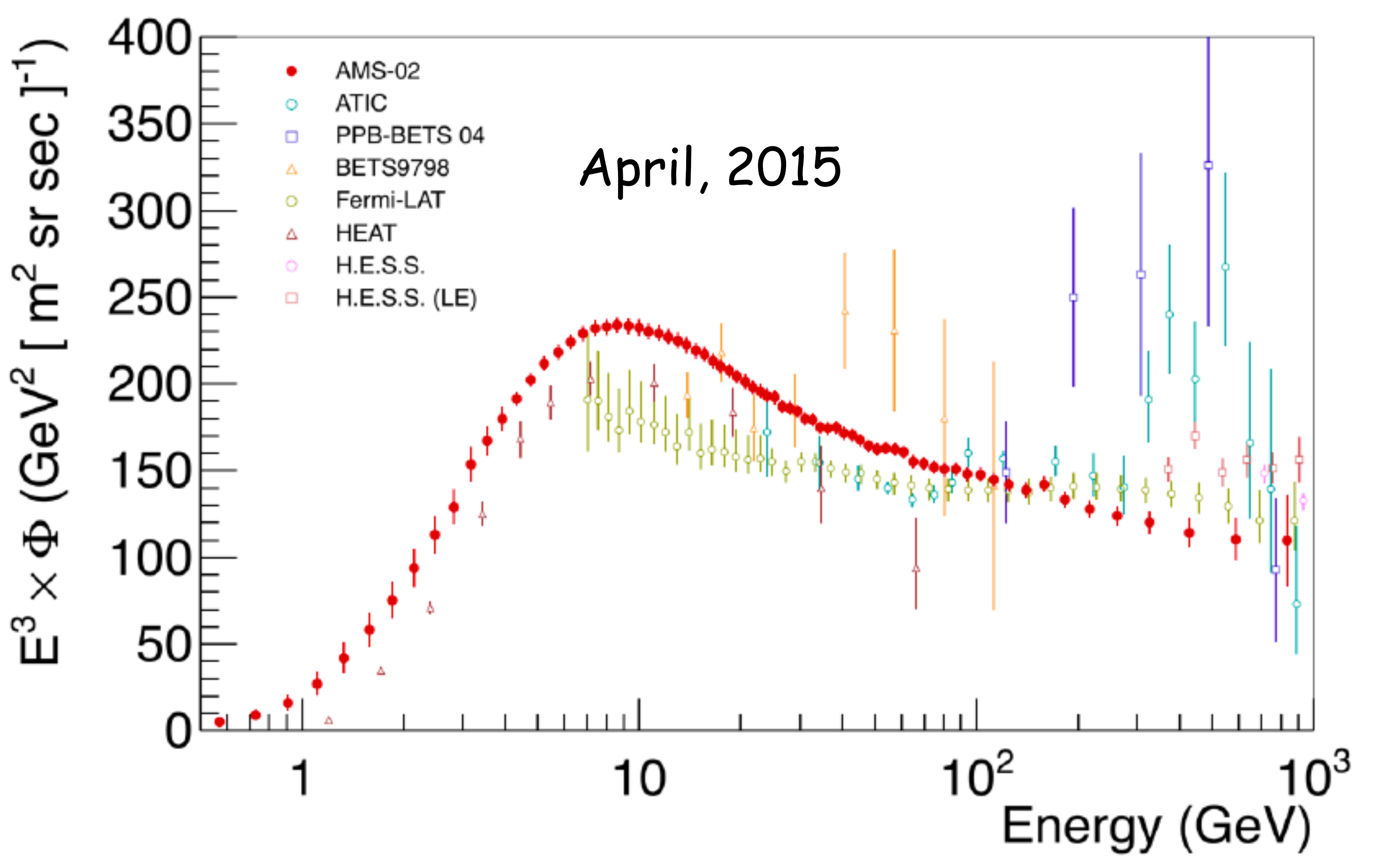


The Electron Flux

- has no sharp structures and is dominated by the diffuse term.
- is consistent with a charge symmetric source term.

2015: AMS02 inclusive electron+positron

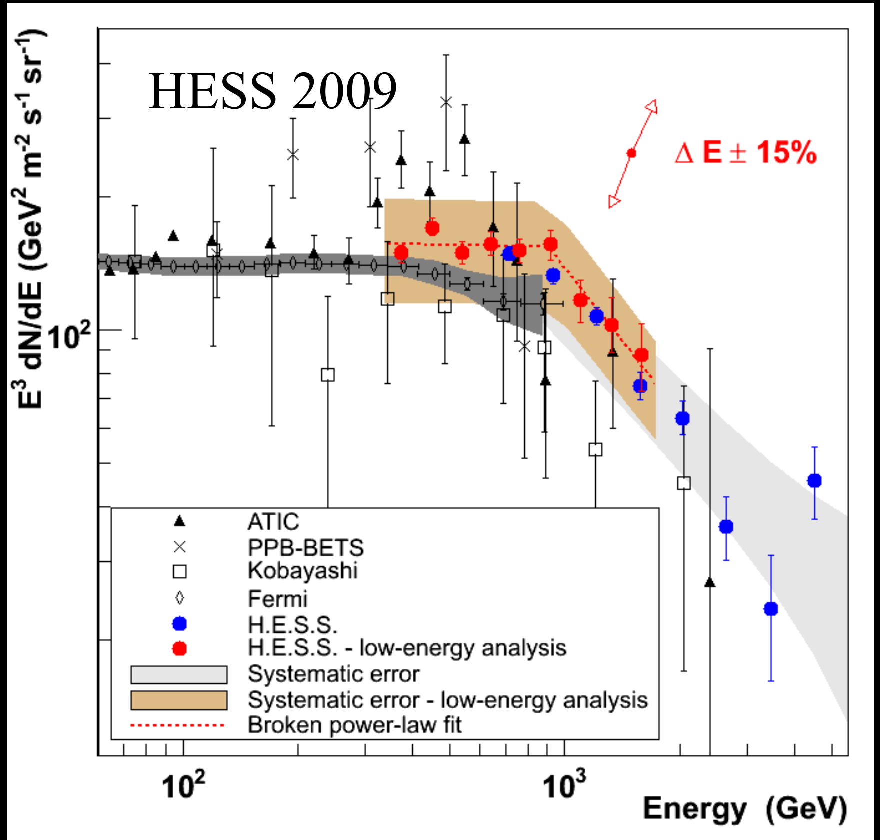
Results: the flux after AMS



The electron spectrum above 1 TeV

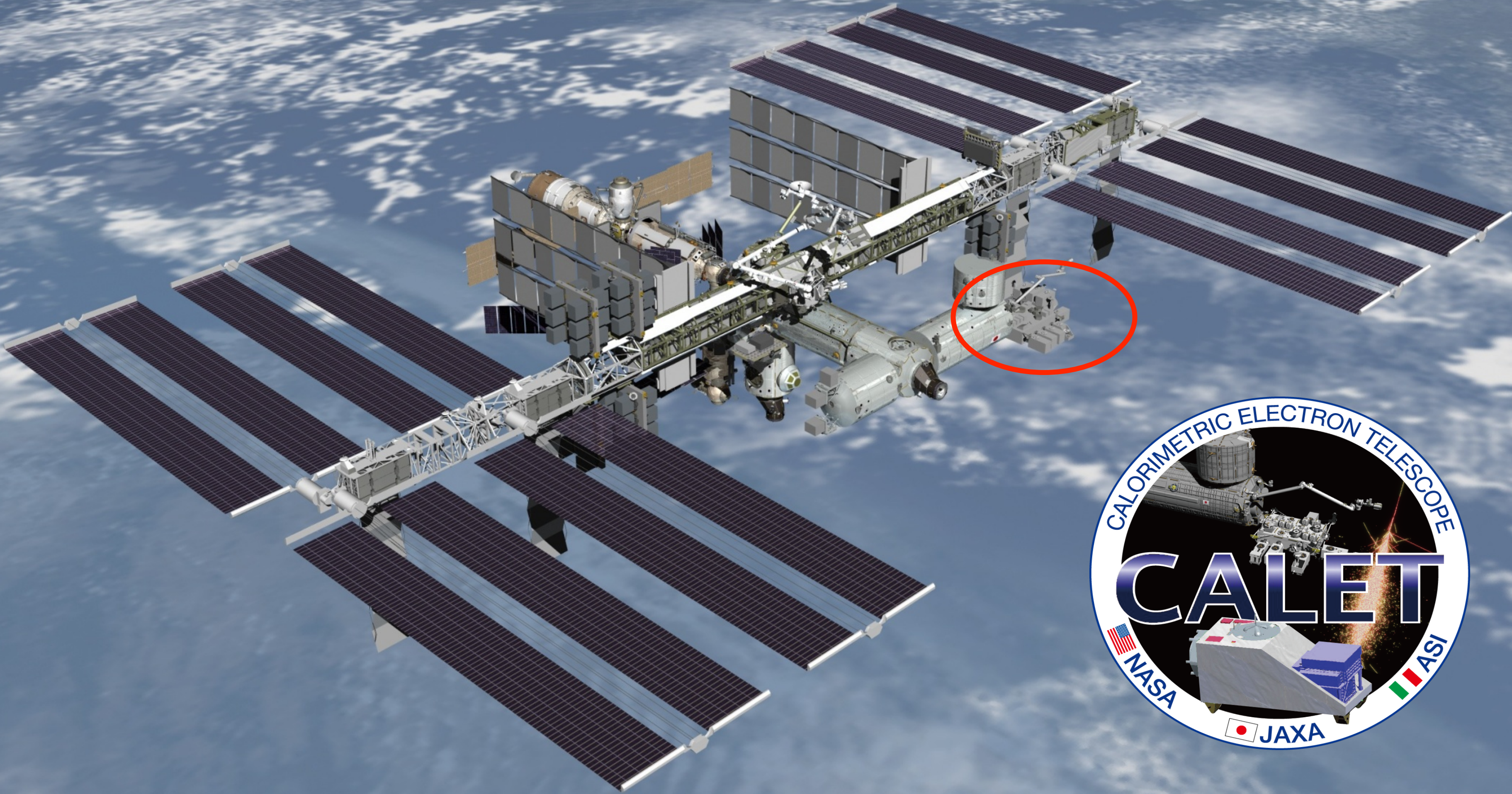
- HESS electron (ground) measurements: 340 GeV → 5 TeV

  - Evidence of a cutoff in the spectrum with index: 3.9 ± 0.1(stat) ± 0.3(syst.)
  - No contradiction to ATIC data due to HESS energy scale uncertainty of 15%
  - unable to confirm ATIC bump



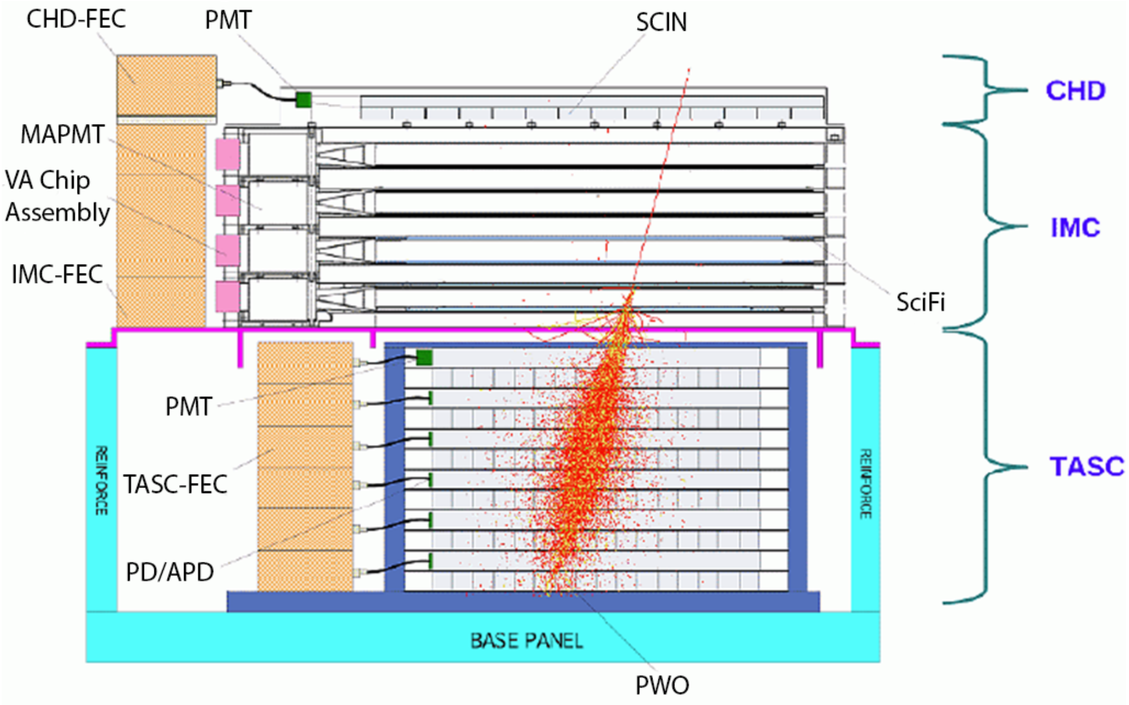
Large systematic uncertainties from ground experiments !

CALorimetric Electron Telescope



Launch scheduled in August 2015 !!!

Overview of CALET INSTRUMENT



CHarge Detector (CHD)
(Charge Measurement in Z=1-40)

Imaging Calorimeter (IMC)
(Particle ID, Direction)
Total Thickness of Tungsten (W): $3X_0$, $0.11\ \lambda_I$
Layer Number of Scifi Belts: 8 Layers × 2(X,Y)

Total Absorption Calorimeter (TASC)
(Energy Measurement, Particle ID)
PWO 20mm x 20mm x 320mm
Total Depth of PWO: $27\ X_0$ (24 cm) , $1.35\ \lambda_I$

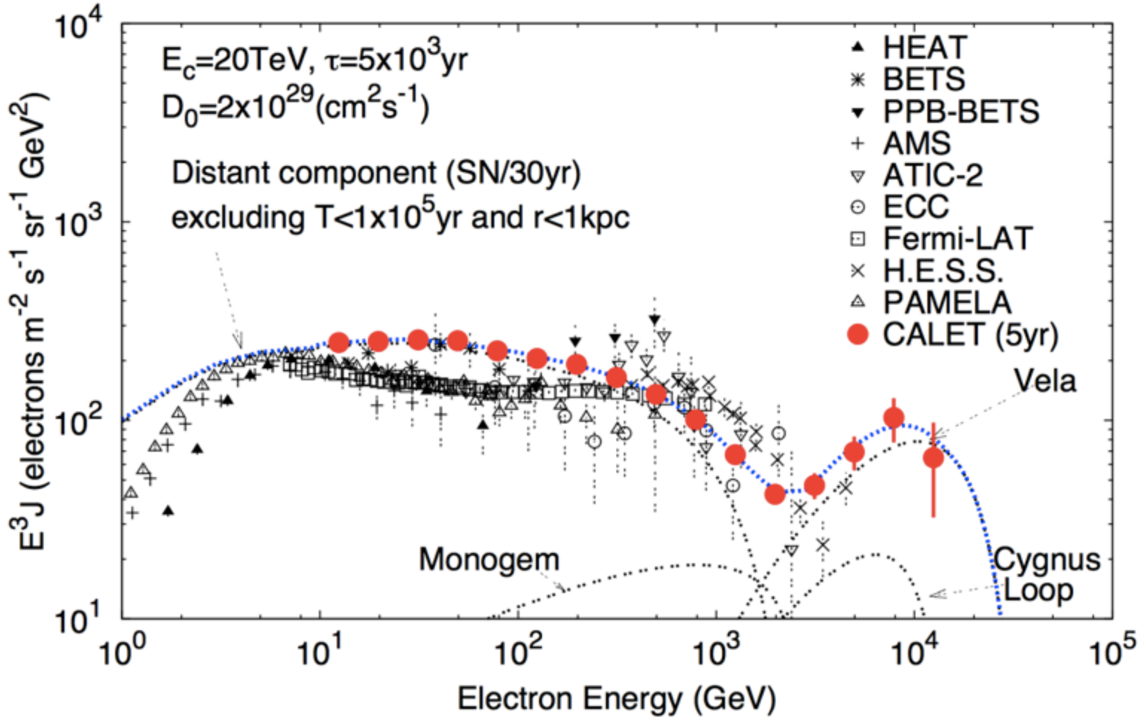
	CHD (Charge Detector)	IMC (Imaging Calorimeter)	TASC (Total Absorption Calorimeter)
Function	Charge Measurement (Z=1-40)	Arrival Direction, Particle ID	Energy Measurement, Particle ID
Sensor (+ Absorber)	Plastic Scintillator : 2 layers Unit Size: 32mm x 10mm x 450mm	SciFi : 16 layers Unit size: $1mm^2$ x 448 mm Total thickness of Tungsten: $3\ X_0$	PWO log: 12 layers Unit size: 19mm x 20mm x 326mm Total Thickness of PWO: 27 X_0
Readout	PMT+CSA	64 -anode PMT+ ASIC	APD/PD+CSA PMT+CSA (for Trigger)

CALET Main Target: Identification of Electron Sources

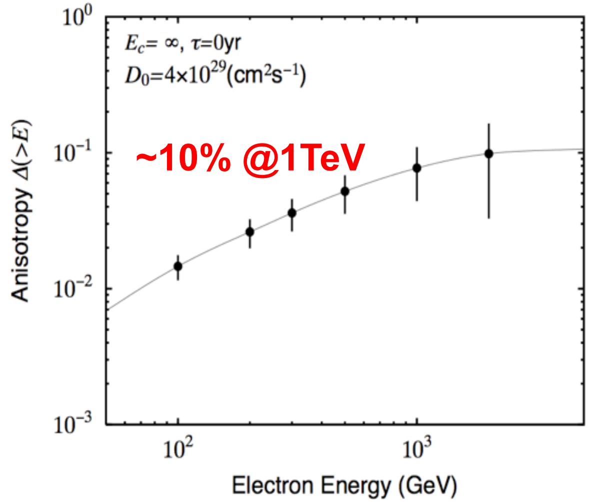
Some nearby sources, e.g. Vela SNR, might have unique signatures in the electron energy spectrum in the TeV region (Kobayashi et al. ApJ 2004)

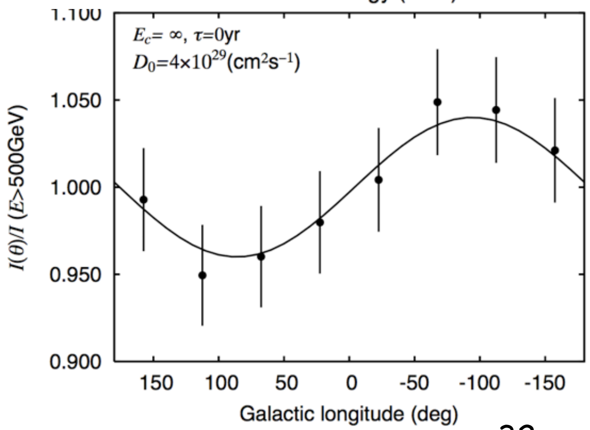
Expected flux for 5 year mission

> 10 GeV	~ 2.7 x 10^7
>100 GeV	~ 2.0 x 10^5
>1000 GeV	~ 1.0 x 10^3



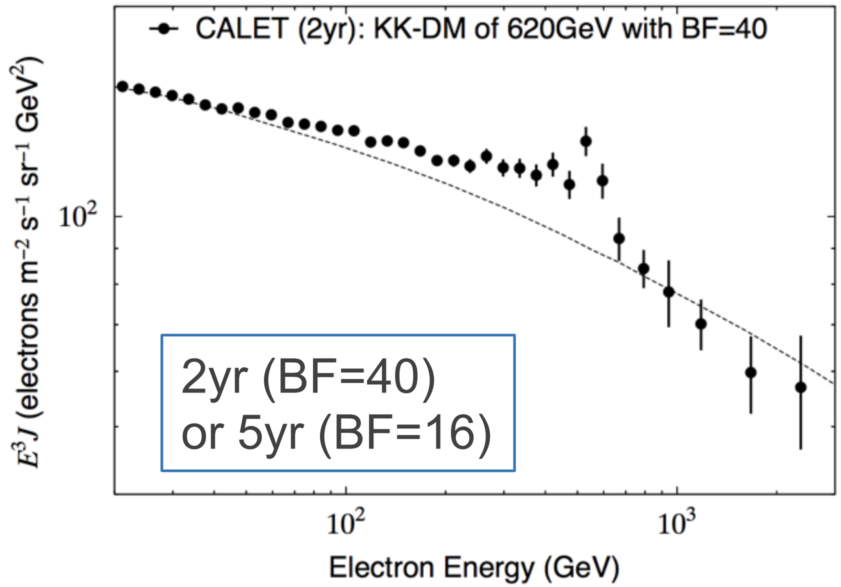
Expected Anisotropy from Vela SNR

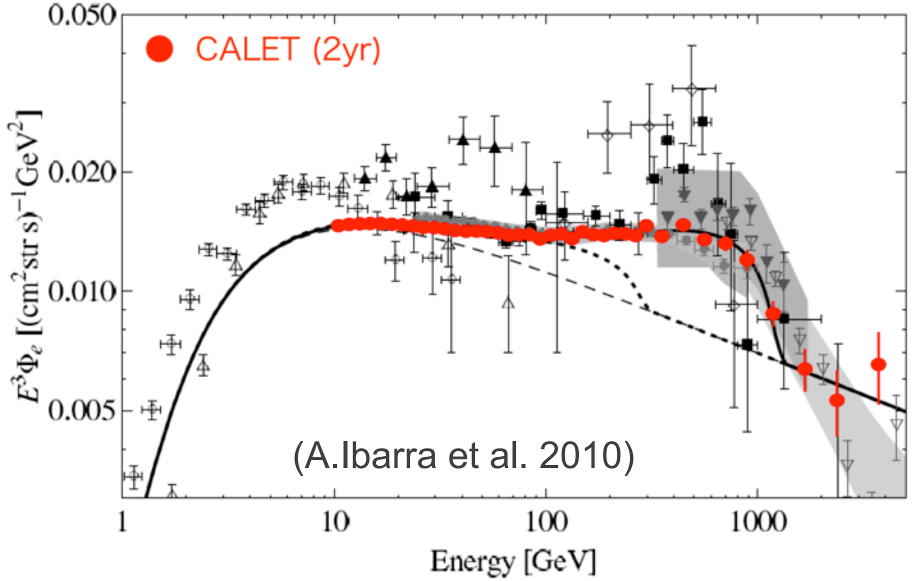




► Identification of the unique signature from nearby SRNs, such as Vela in the electron spectrum by CALET

CALET: dark matter search with electrons

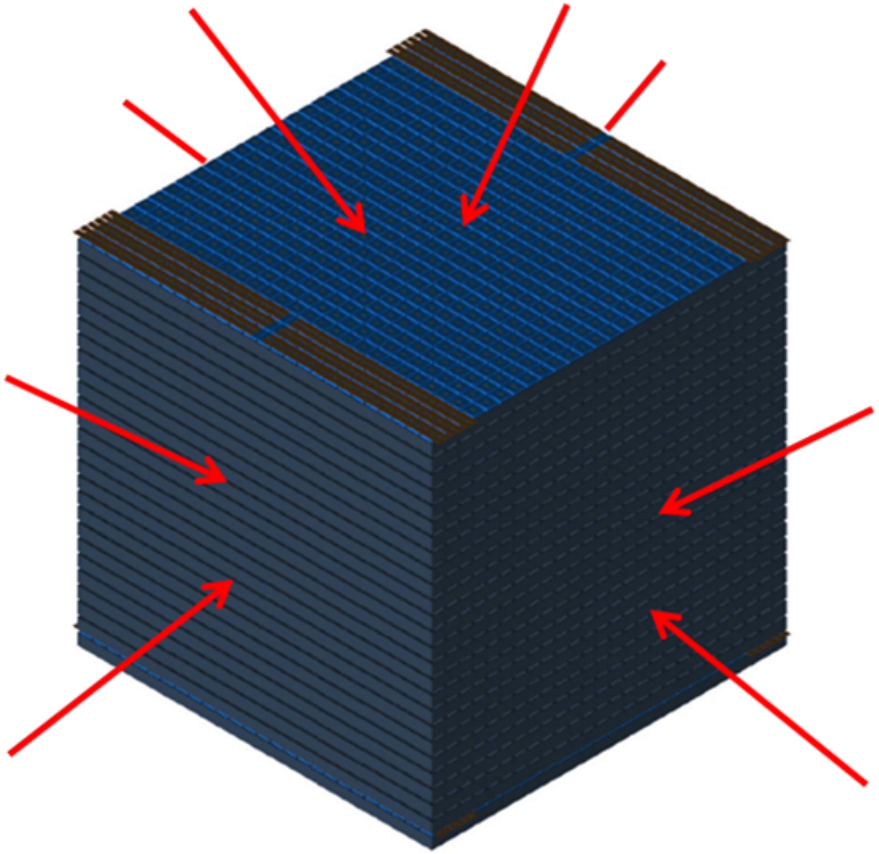




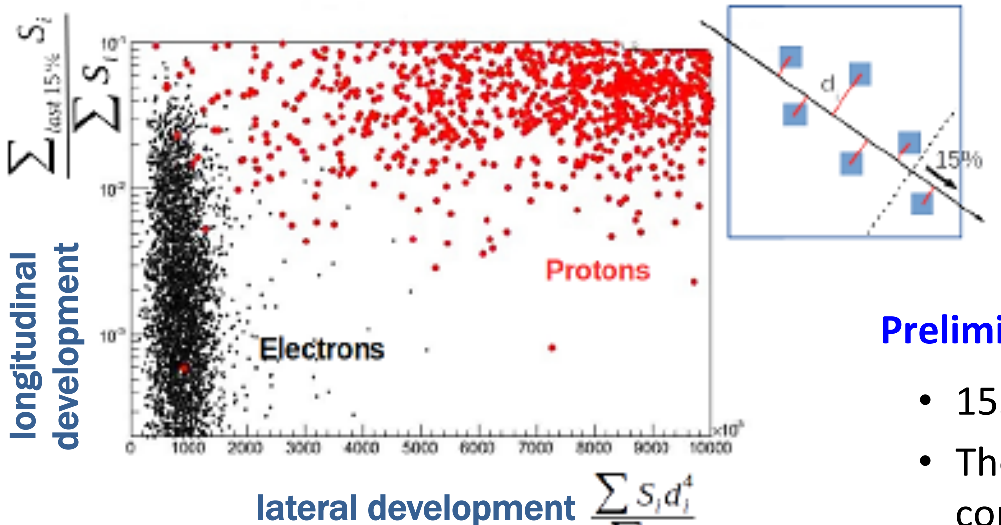
Simulated e^++e^- spectrum for 2yr from Kaluza-Klein dark matter annihilations with m = 620GeV and BF=40.

Simulated e^++e^- spectrum for 2yr from decaying dark matter for a decay channel of D.M.-> $l^+l^-\nu$ with:
M = 2.5TeV
τ = 2.1x10^{26} s

How about inclusive electron detection with Gamma-400?



Proton rejection factor with Calocube

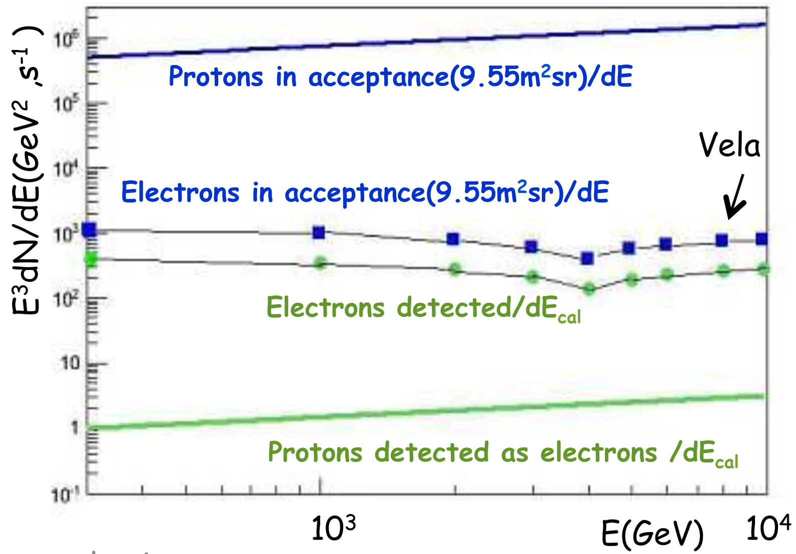


S_i is the signal from crystal i.
d_i is the distance between crystal i and the shower axis

- Geometrical cuts for shower containment
- Cuts based on longitudinal and lateral development

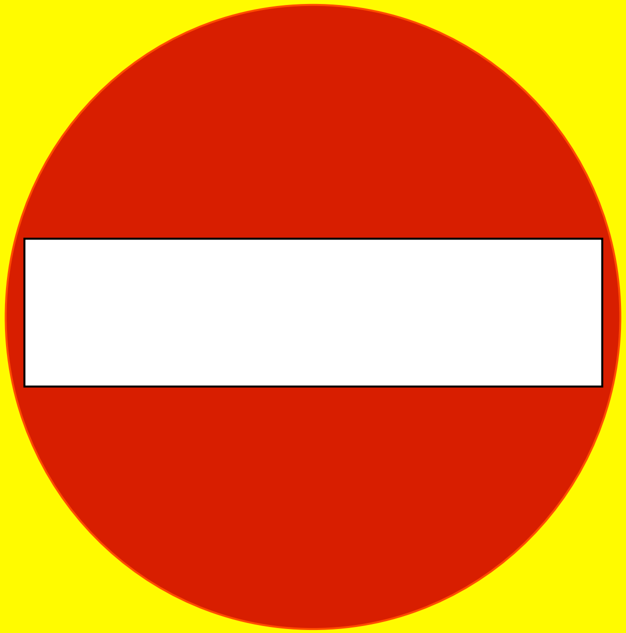
Preliminary study:

- 155.000 protons @ 1 TeV: only 1 survives
- The corresponding electron efficiency is 37% almost constant with energy above 500 GeV
- Energy dependence of selection efficiency



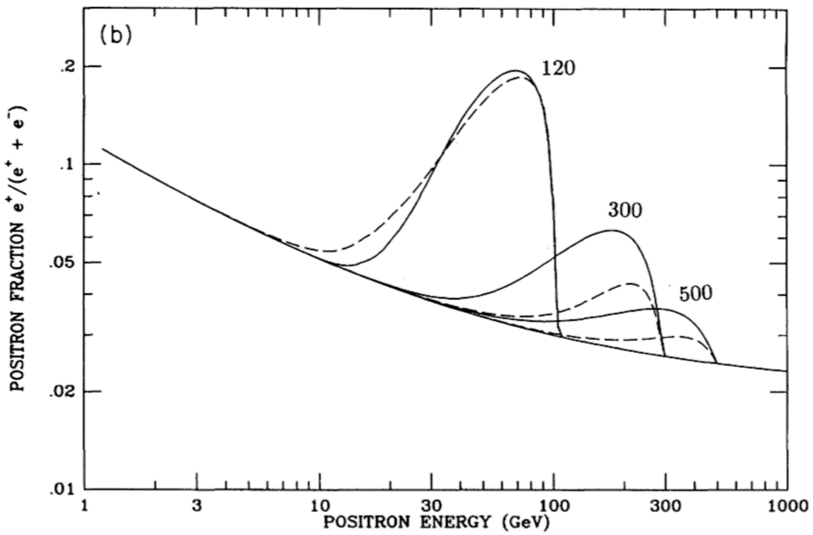
- Proton contamination:
  0.5% at 1 TeV
  2% at 4 TeV
- Rejection power = $\varepsilon_{el} / \varepsilon_p \sim$ **2 10^5**

  (using calorimeter information only)



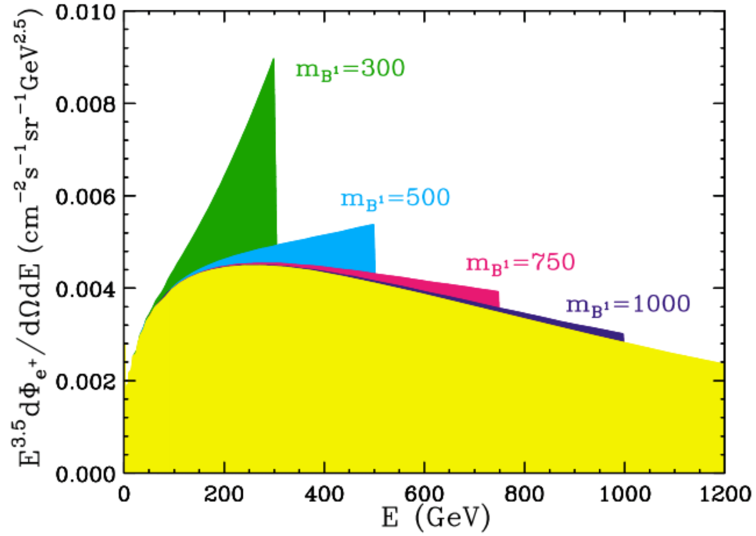
e^+, e^- from Dark Matter annihilation

SUSY Dark Matter



Kamionkwoski et al. (1991)

Kaluza-Klein Dark Matter

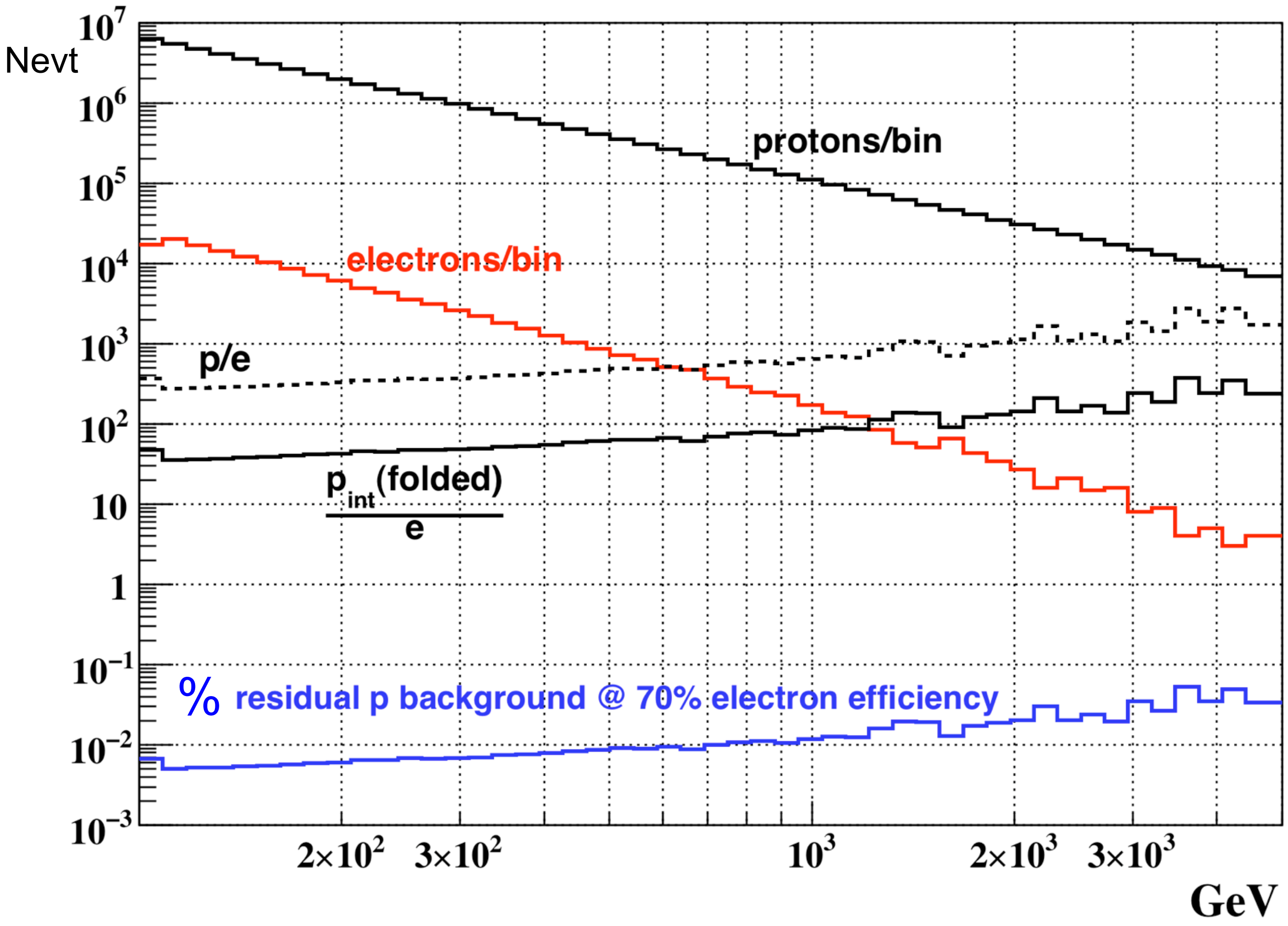


Cheng et al. (2002)

- Distinctive structures in the spectrum from D.M. annihilation
- Dark matter search from e^-,e^+ observations

Residual Proton Background

- Proton differential spectrum as: $E^{-2.70}$
- Electron broken power law: $E^{-3.9}$ as measured by HESS above 1 TeV



takes into account:

- non-compensating e/h ~ 2.5
- proton resolution ~ 40% (at 1 TeV)

Total Rejection Power (improved cuts in IMC+TASC):
~ 10^5 @ 1 TeV
(~1 % residual protons)
@ 70 % electron efficiency

~1% @ 1 TeV ~8% @ 4 TeV background

P. Marrocchesi - Gamma400 - 2013/5/3