Measurements of cosmic ray electrons and positrons: current status and perspectives

- Why Electrons?
- Inclusive electron spectrum
- Electron and positron measurements, ratio
- Arrival anisotropy
- New experiments and scientific perspectives

Alexander Moiseev
CRESST/NASA/GSFC and University of Maryland, College Park

Why Electrons?

- **Due to their low mass, high energy cosmic ray electrons (CRE) lose their energy rapidly (as $-dE/dt \sim E^2$) by synchrotron radiation on Galactic magnetic fields and by inverse Compton scattering on the interstellar radiation field**

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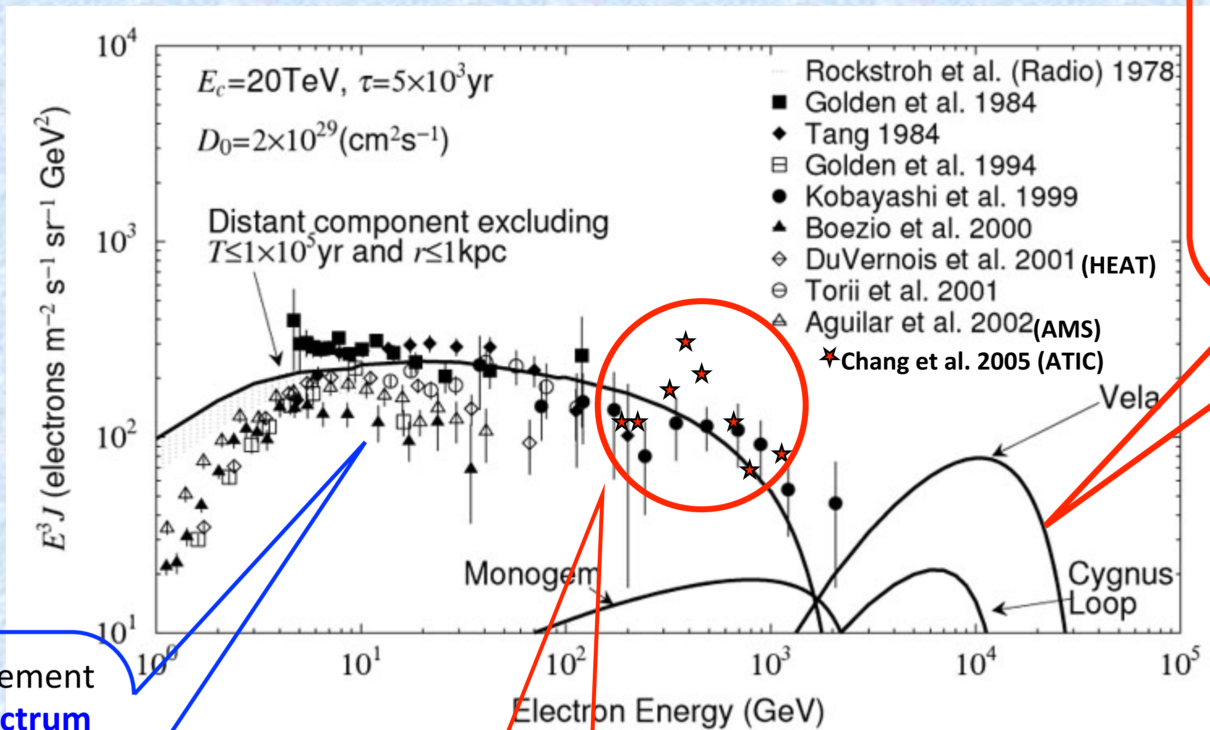
- **Observations of such high-energy CRE imply existence of nearby sources of TeV electrons. This makes CRE a unique tool for probing nearby Galactic space**

$\Downarrow$

- **Long-standing question for cosmic rays: where they are produced and how and where they are accelerated?**

What can be learned from high energy cosmic ray electrons ?

Before Fermi LAT, H.E.S.S. PAMELA and AMS-02 results



Search for the signature of nearby HE electrons sources (believed to be SNR) in the electron spectrum above ~ TeV

Not found so far

Precise measurement of **electron spectrum** above 10 GeV (calibration of IC gamma ray flux model, GALPROP)

DONE

Search for Dark Matter Signatures (KKDM).

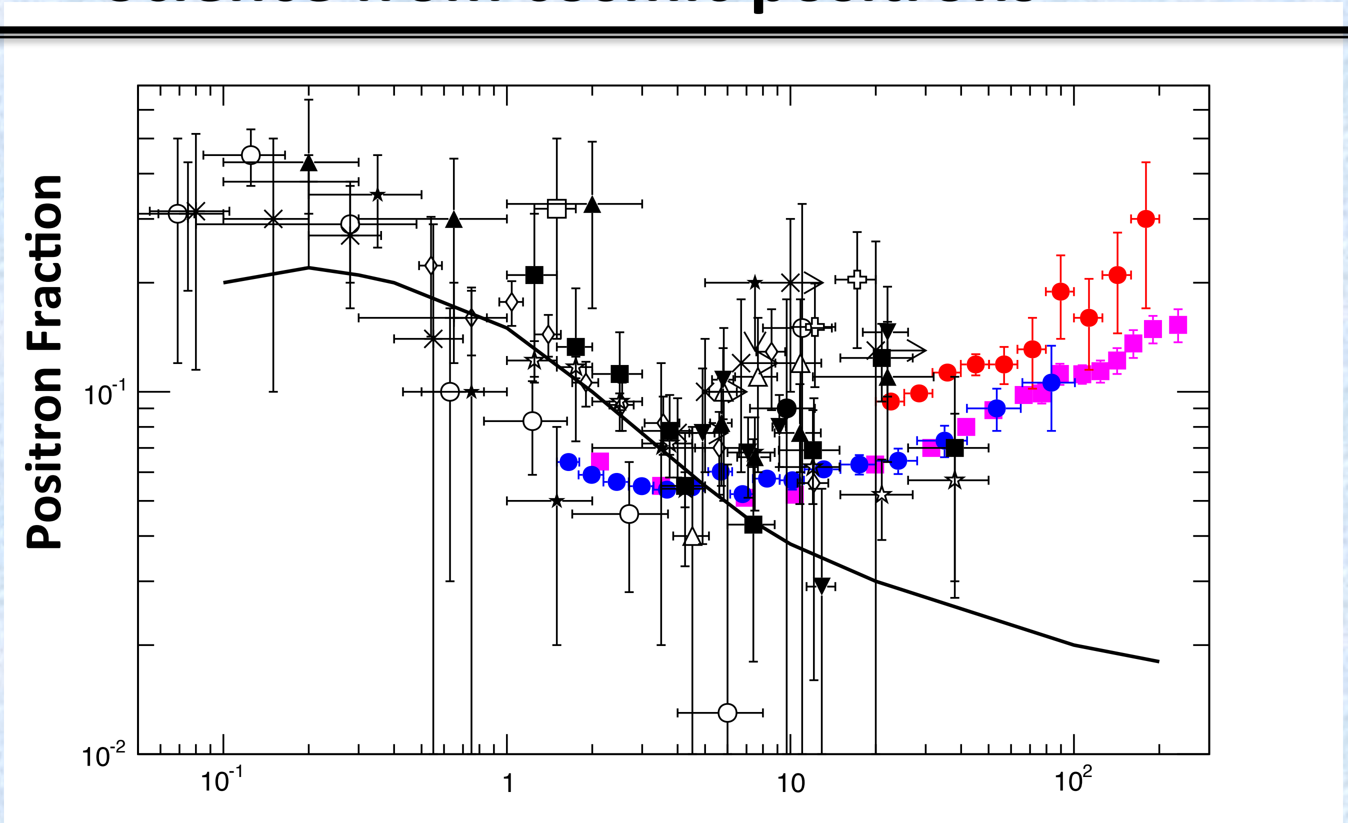
Still going on

Search for **anisotropy** in HE electron flux : nearby sources, streaming of local magnetic fields?

Not found so far.

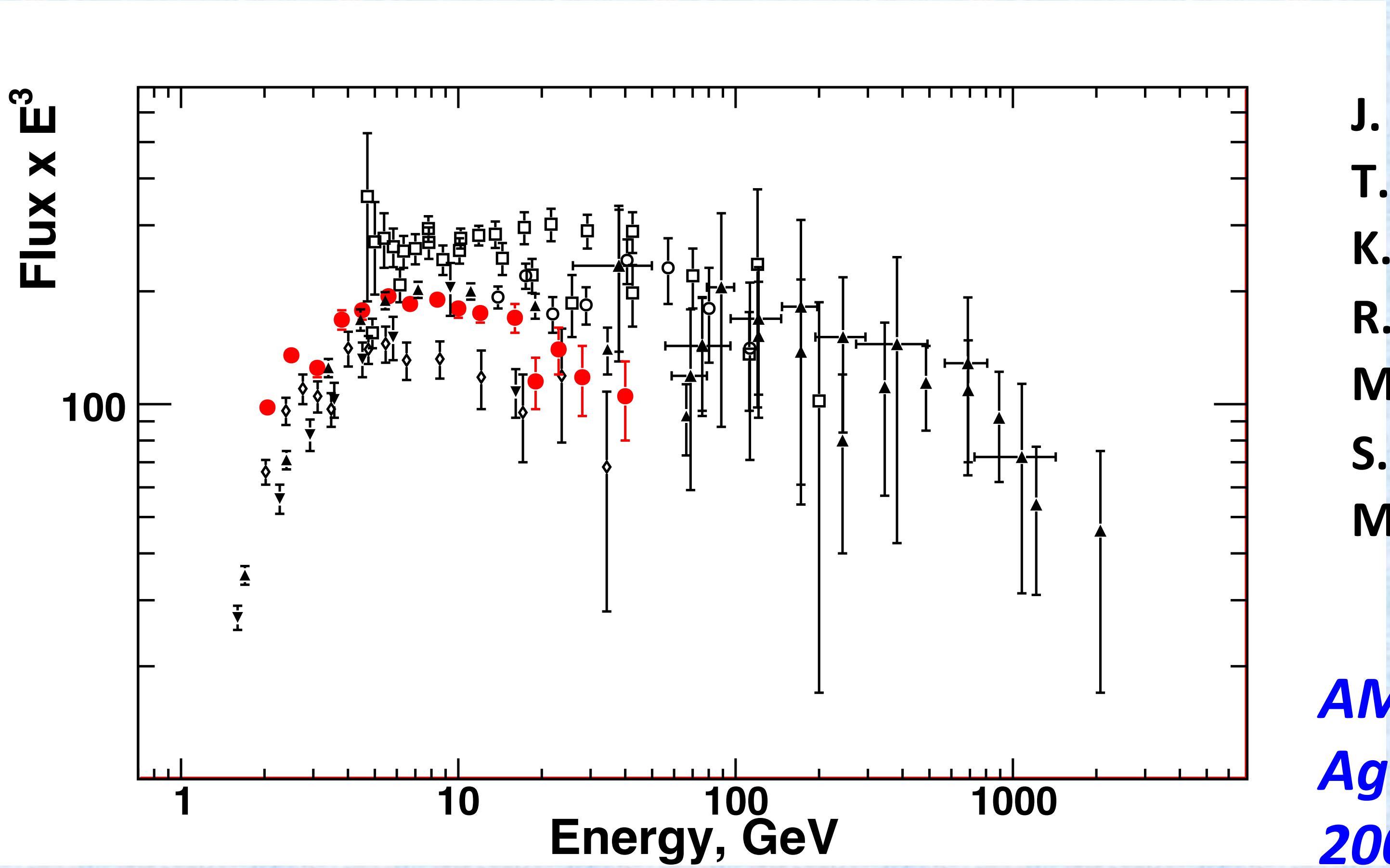
Plot with models is taken from Kobayashi et al., 2004

Science from cosmic positrons



- Electrons are believed to be produced in sources, but **positrons** are believed to be mainly secondary produced in CR – ISM interactions.
- Currently measured ratio clearly departs from that expected if this were truth
- What is it? Contribution from local source? Of what origin: astrophysical or exotic?

Earlier results on inclusive electron spectrum from balloon flights

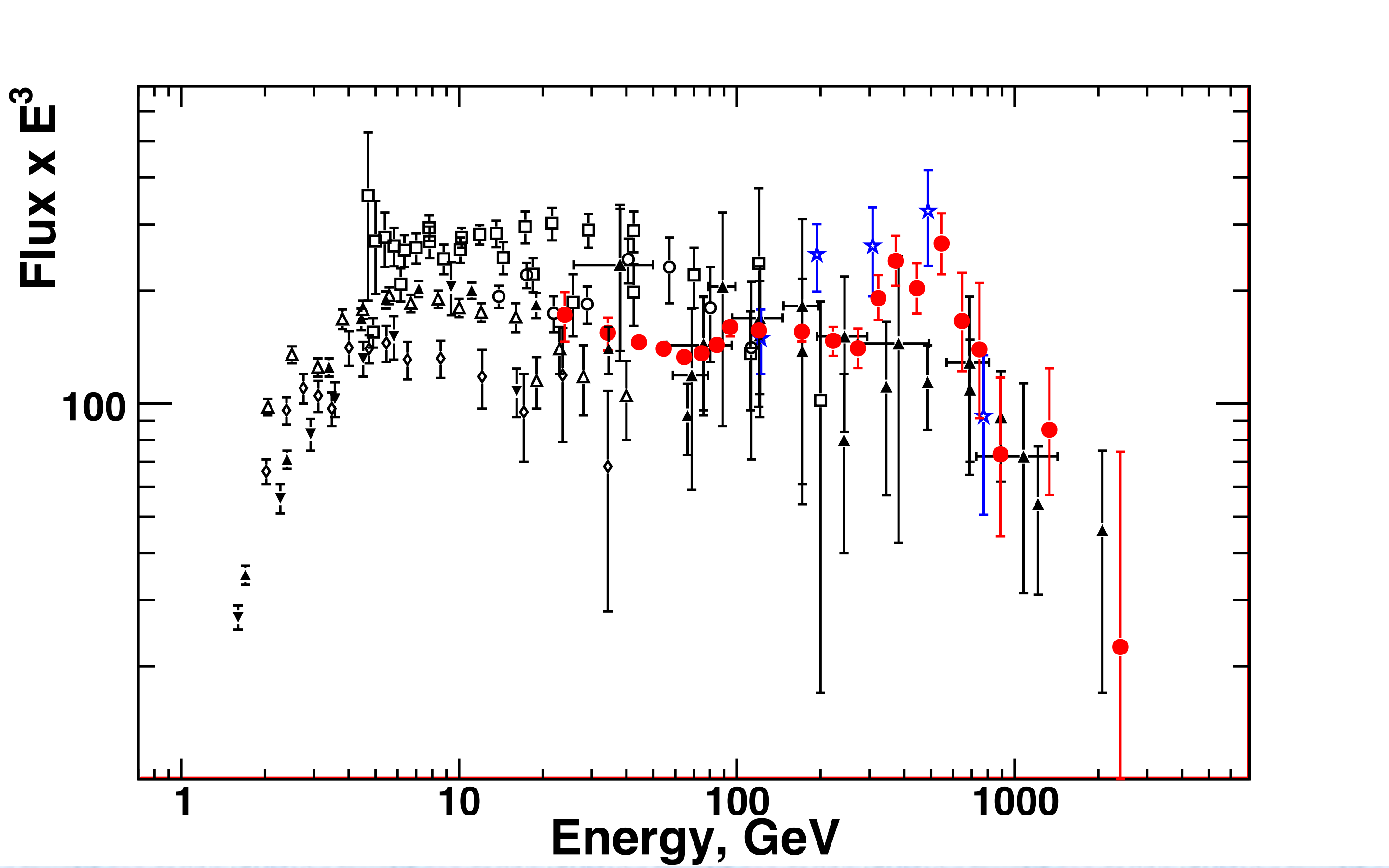


J. Nishimura
T. Kobayashi
K.-K. Tang
R. Golden
M. Boezio
S. Torii
M. DeVernois

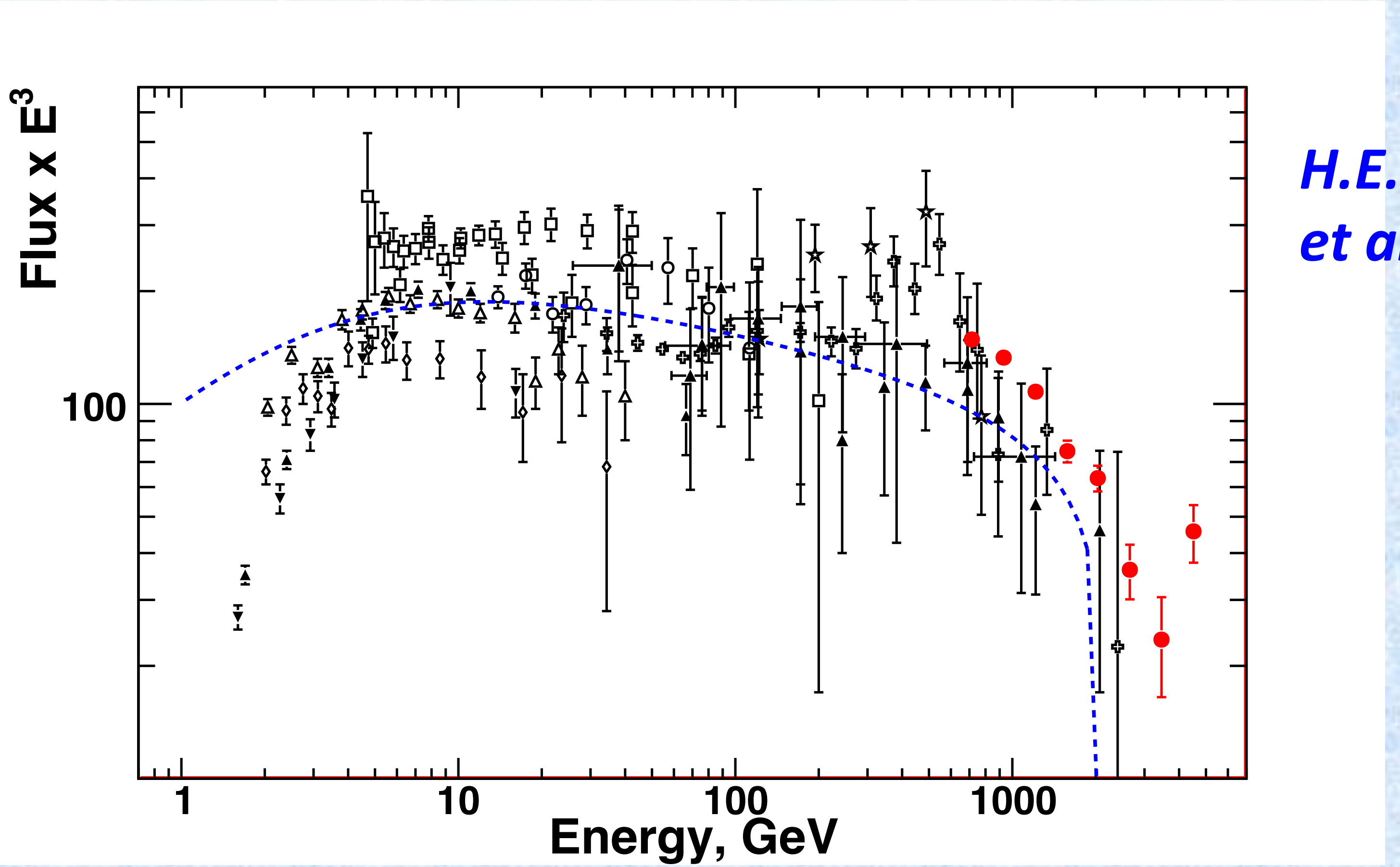
AMS 01: Aguilar et al. 2002

First measurement in space: Space Shuttle Discovery STS-91 flight in June 1998 with AMS -1

Excitement: PPB BETS and ATIC. Signature of dark matter?



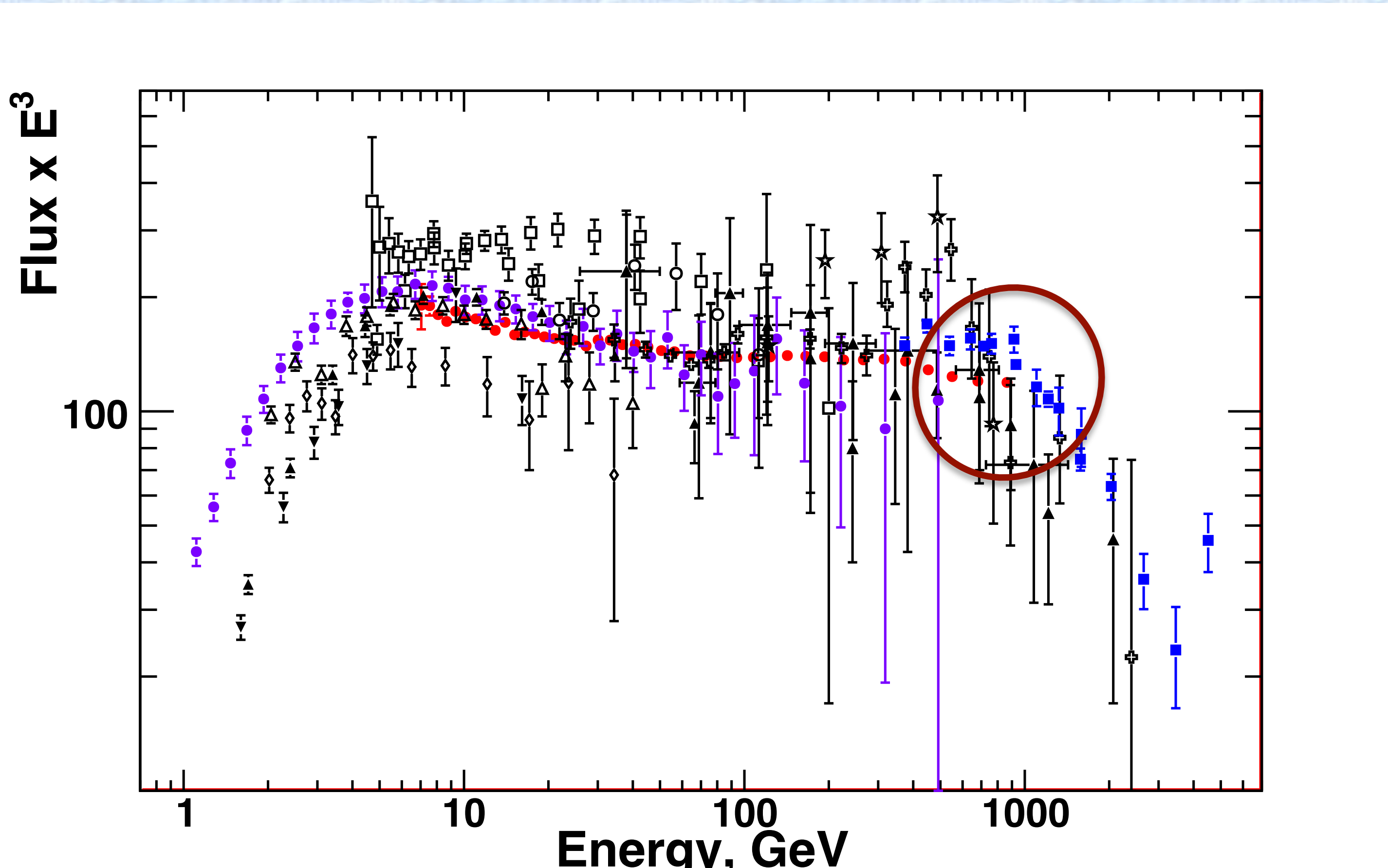
First measurement by ground-based gamma-ray telescope



H.E.S.S.: Aharonian et al. 2008

Long waited Spectral cut-off ?

Fermi LAT and PAMELA with measurements from space



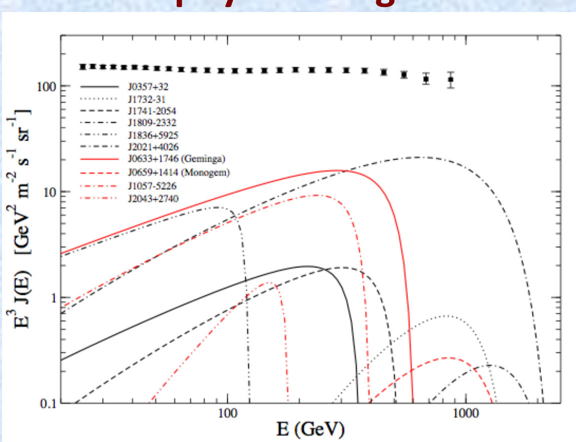
What is needed:

- **Accurate spectral measurement to search for spectral structure**
- **Extend measurement to higher energy to confirm H.E.S.S. result on spectral break**

Conclusions from current result on Inclusive e^+ and e^- spectrum

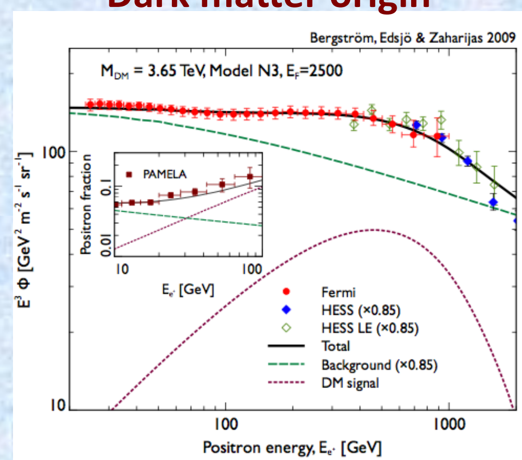
- Spectral shape of the current inclusive electron spectrum is consistent with presence of nearby source(s). It can be astrophysical or exotic such as dark matter clump(s)
- At the same time, the current inclusive electron spectrum can also be explained by only propagation, adjusting the injection spectra, without introducing different mechanisms of electron production in the sources or different type of sources (see e.g. D. Grasso et al., Astroparticle Physics 32, 2,2009 and references therein)
- Search for small irregularities in inclusive electron spectrum will contribute to the understanding of its origin

Astrophysical origin



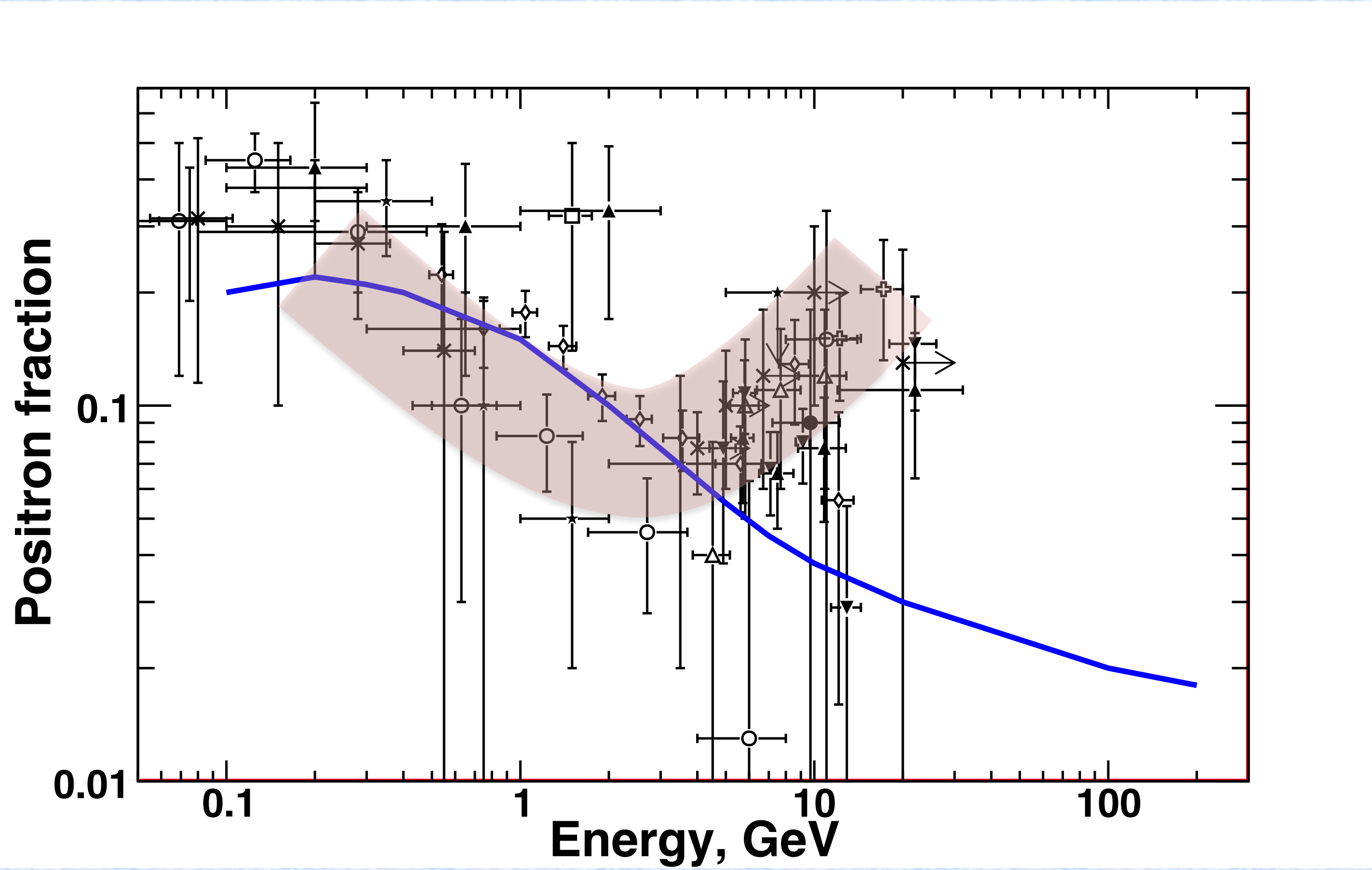
Gendelev, Profumo and Dormody 2010: 6 of the new Fermi-discovered pulsars could contribute to the measured spectrum, assuming impulsive injection at $\tau = 10^4$ yr

Dark matter origin



Bergström, Edsjö & Zaharijas 2009: explanation by dark matter (also explains PAMELA result)

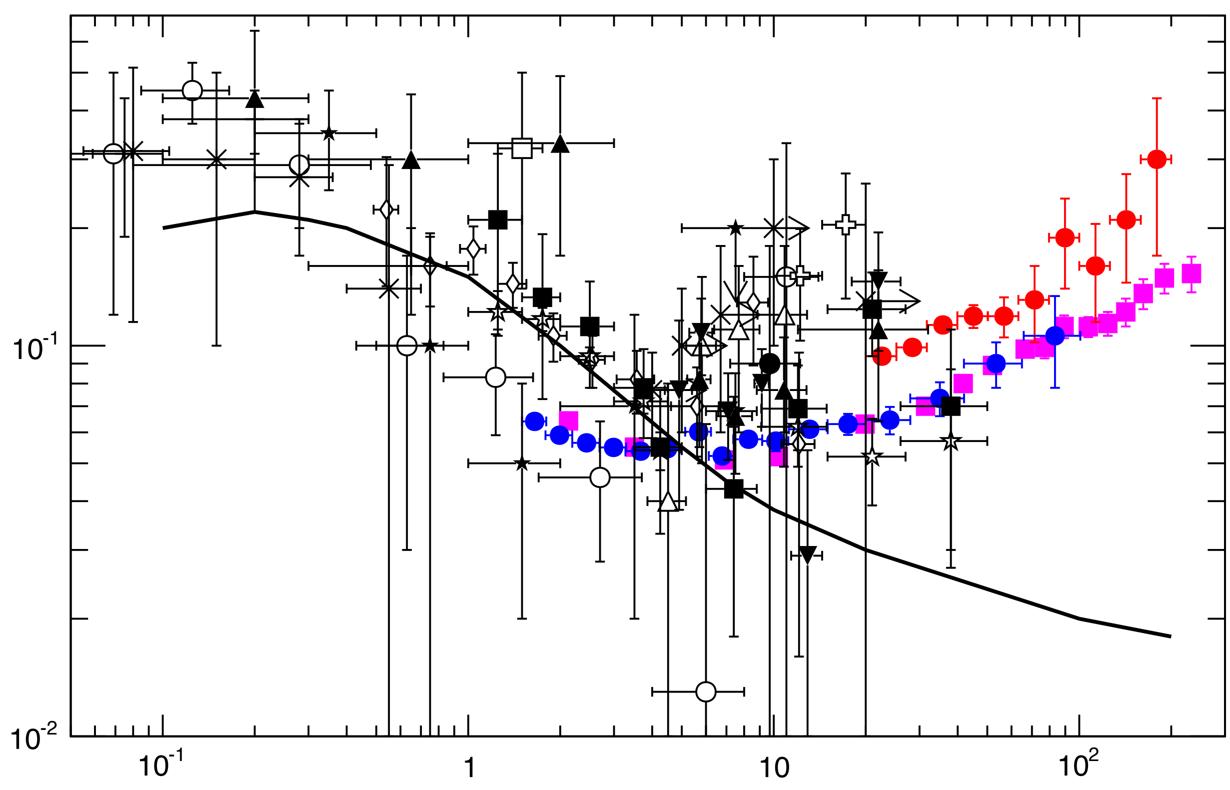
Positron fraction at the end of 1996: all results look consistent, strongly disagreeing with secondary origin of CR positrons



Unaccounted residual proton contamination?

Or indication of the presence of primary positrons?

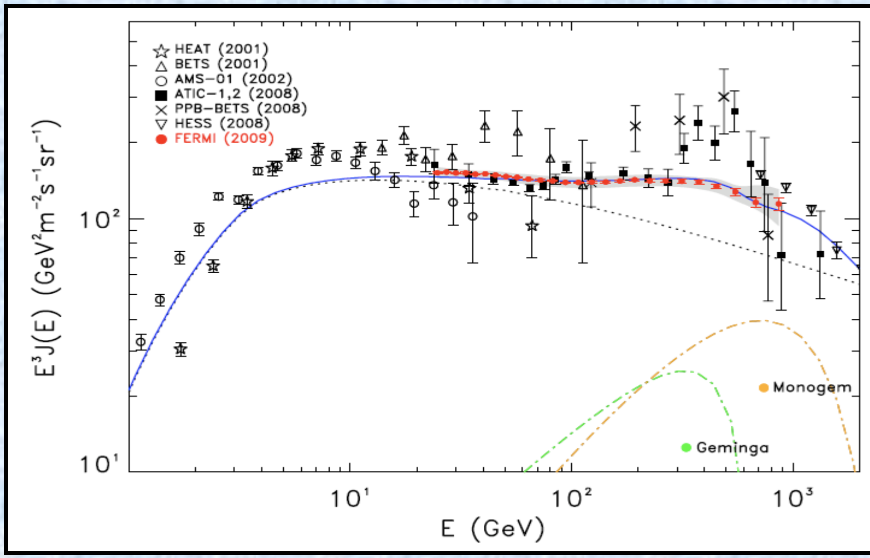
Current results with PAMELA, Fermi LAT and AMS - 02

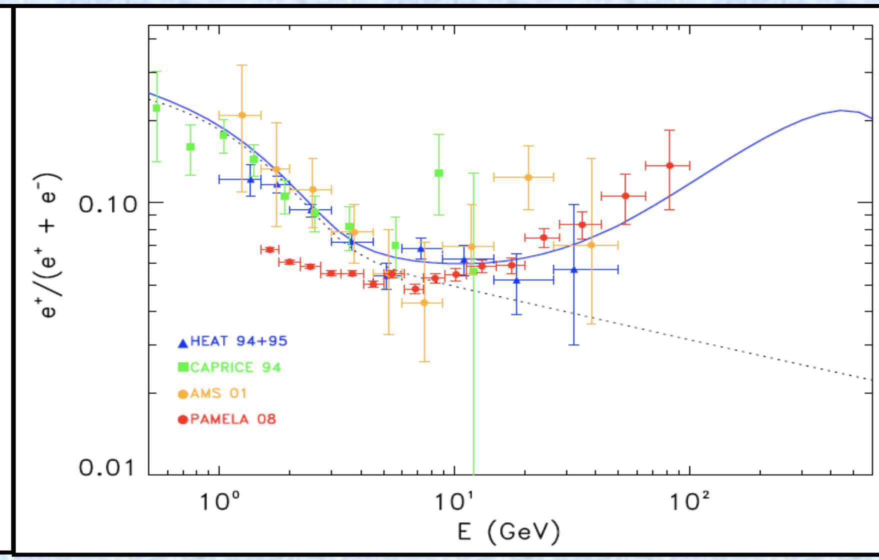


What is needed: extend measurement to higher energy and see if (where) the fraction rolls over

Now combining results on inclusive CRE spectrum and positron fraction

Example of fit to both Fermi and Pamela data with Monogem and Geminga pulsars





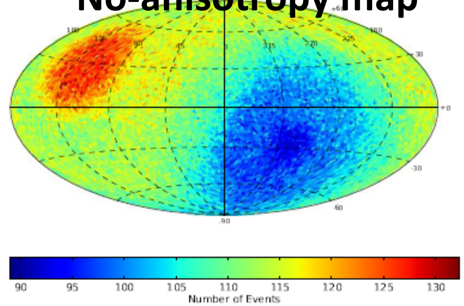
It is assumed that additional sources (here Monogem and Geminga) provide equal amount of e^+ and e^-

It appears difficult to explain both, inclusive and separate electron spectra without introducing at least two components in the spectrum

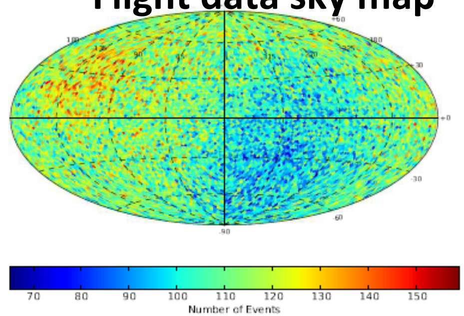
Question: why are the e^+ e^- sources not seen at lower energy, where the positron fraction agrees with their pure secondary origin (CR interactions with ISM) ?

Fermi LAT measurement of CR Electrons Anisotropy

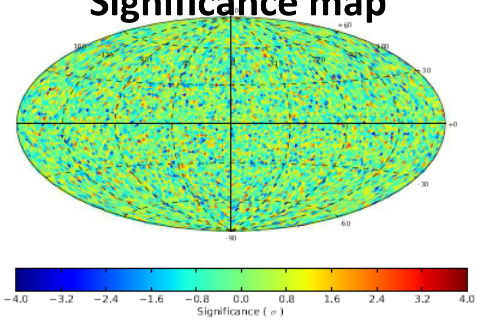
No-anisotropy map



Flight data sky map



Significance map



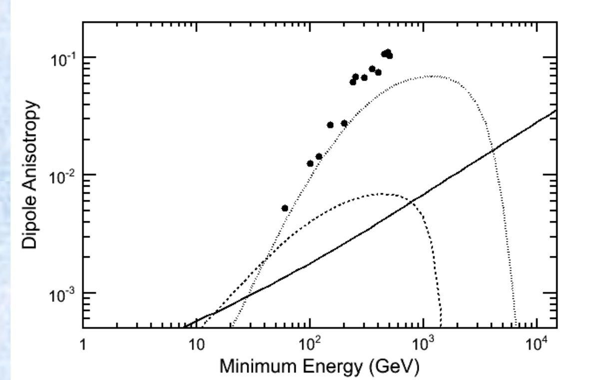
Ackermann et al., Phys Rev D82, 2009

Search for CR electrons anisotropy can provide information on:

- **Local CR sources and their distribution in space**
- **propagation environment**
- **heliospheric effects**
- **presence of dark matter clumps producing $e^+ e^-$**

Result:

- **More than 1.6 million electron events with energy above 60 GeV have been analyzed on anisotropy**
- **Upper limit for the dipole anisotropy has been set to 0.5 – 5% (depending on the energy)**
- **Upper limit on fractional anisotropic excess ranges from a fraction to about one percent (depending on the minimum energy and the anisotropy's angular scale)**
- **Our upper limits lie roughly on or above the predicted anisotropies**



Dipole anisotropy vs. minimum energy. Solid line: Galprop spectrum, dashed line – Monogem, dotted line – Vela Circles: Fermi LAT 95 % CL data

AMS - 02

On the origin of excess positrons

Limits on the amplitude of a dipole anisotropy in any axis in galactic coordinates on the positron to electron ratio in the energy range from 16 GeV to 350 GeV

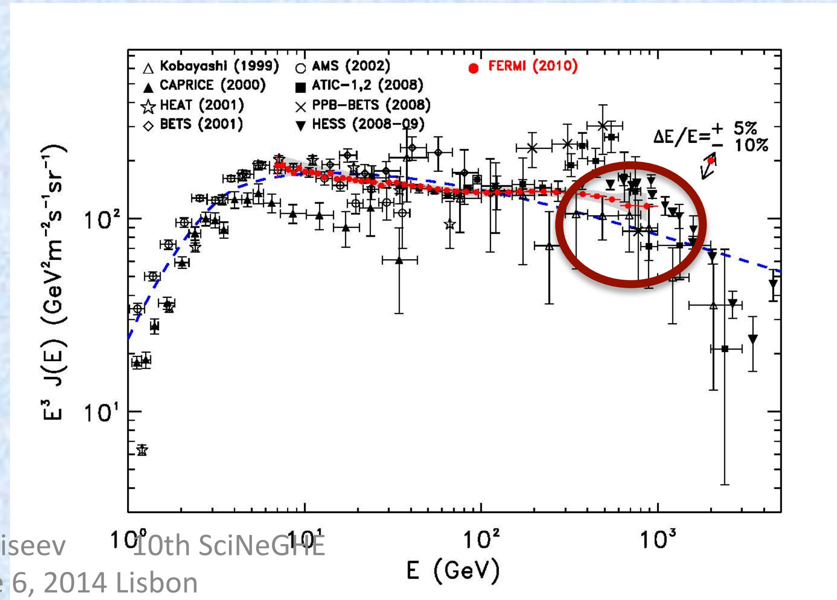
$\delta \leq 0.030$ at the 95% confidence level

S. Ting, 33rd ICRC, 2013

FUTURE

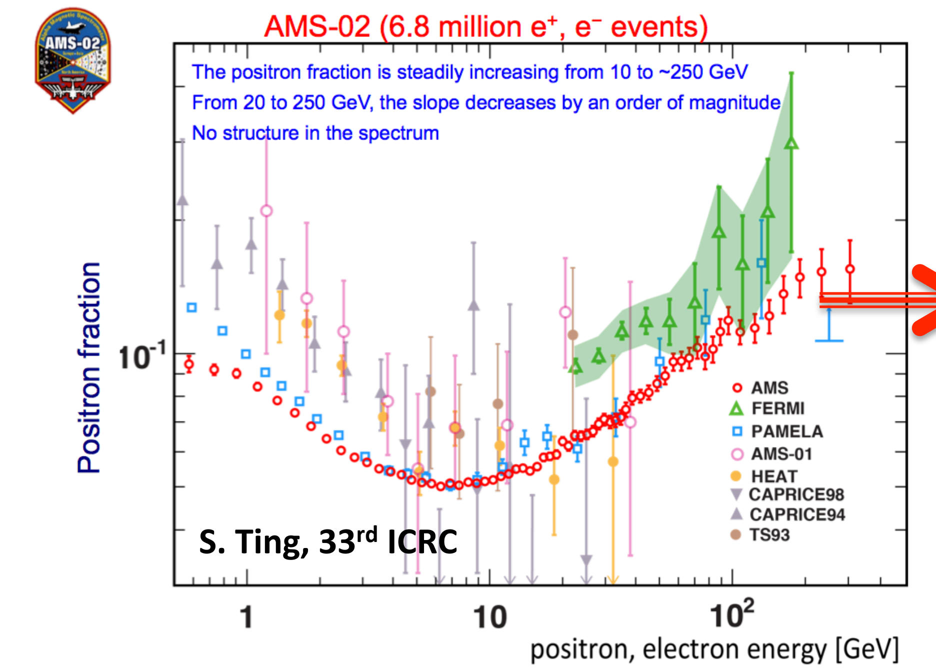
Fermi LAT:

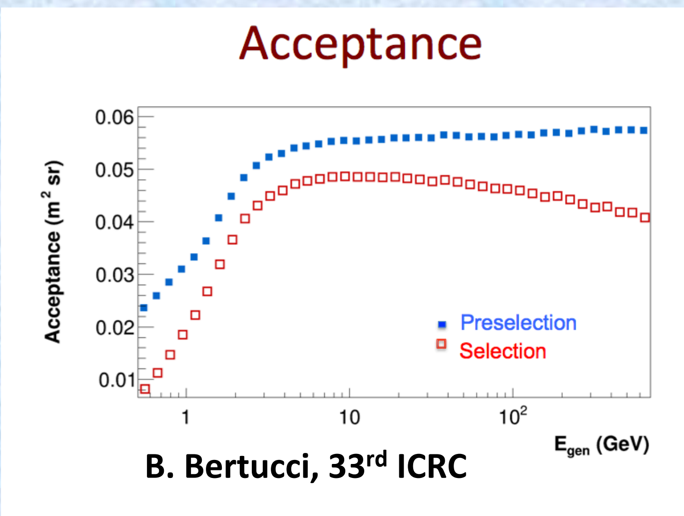
- **Continuation of study of high-energy cosmic-ray electrons with new (Pass 8) event analysis**
- **Increased statistics (currently 6 years on the orbit already)**
- **Improved knowledge of systematic errors**
- **Extended energy range**

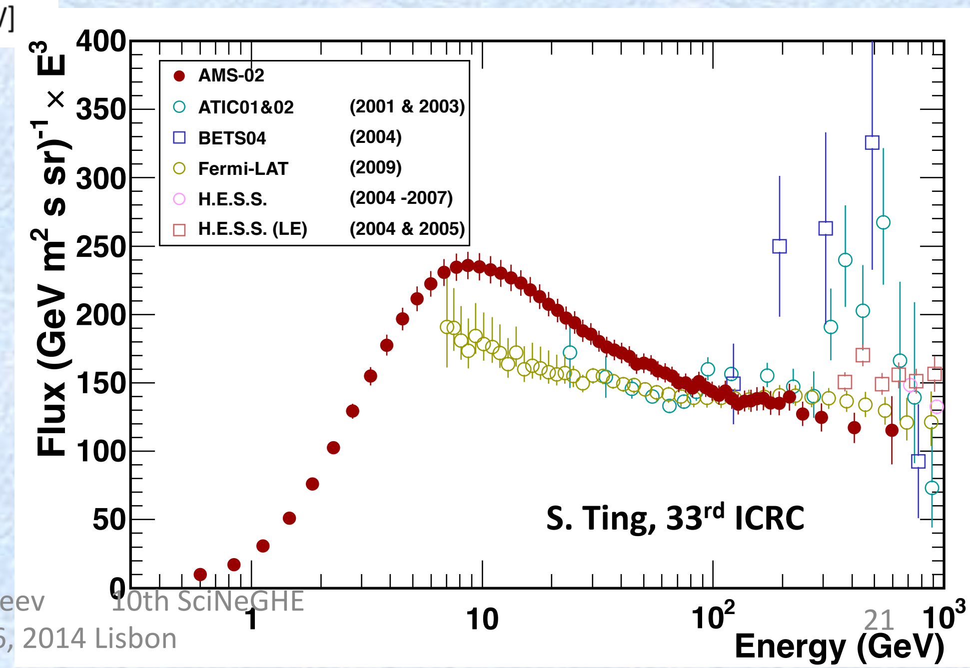


AMS-02

- Extension of the energy range for positron fraction
- New papers on positron fraction and flux are expected to appear soon



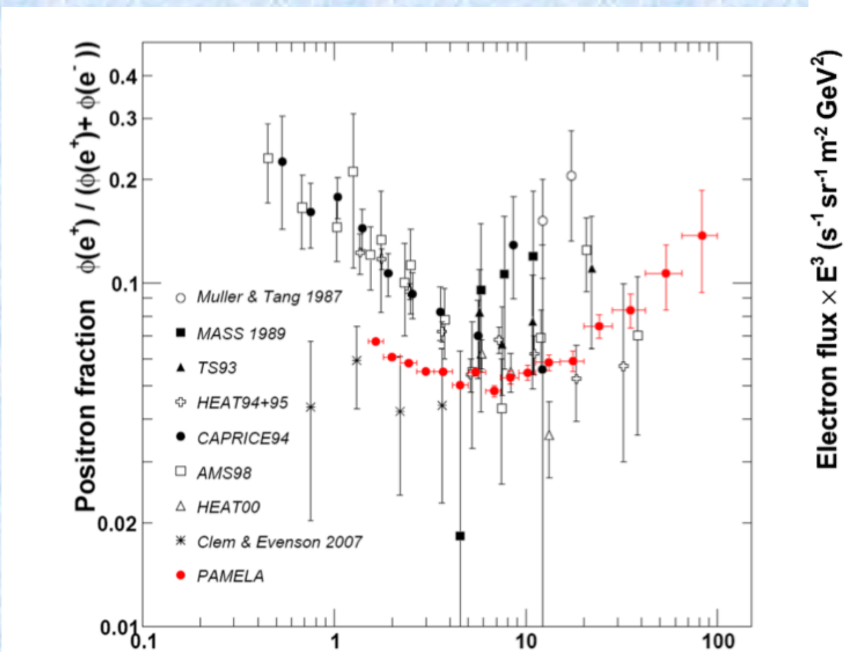




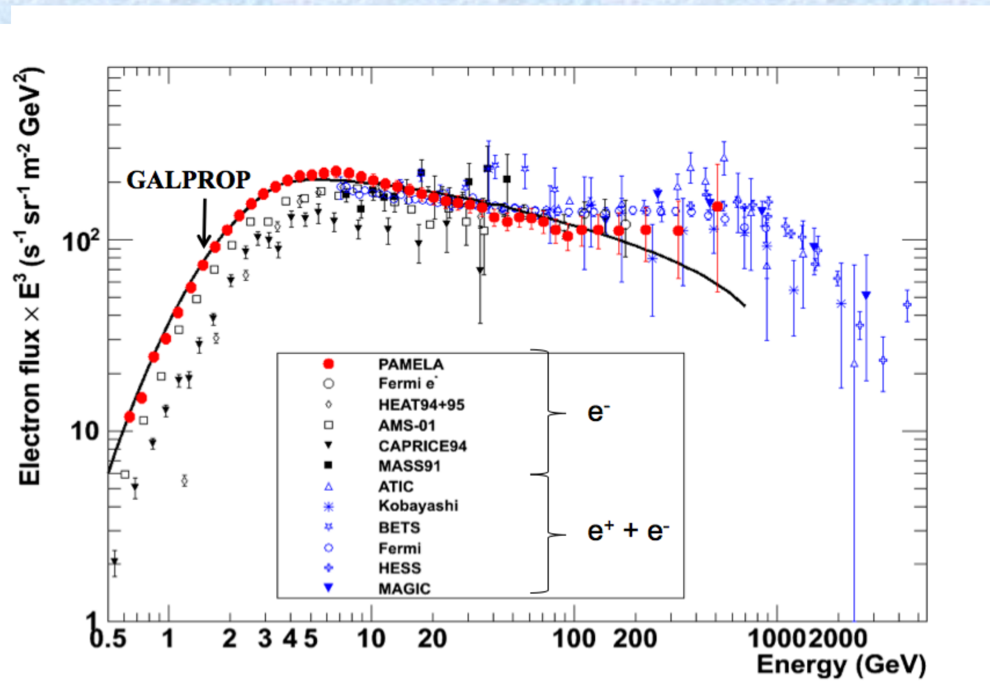
PAMELA

Still in operation: on June 15 the PAMELA team will celebrate the beginning of its 9^{th} year on orbit!

Data collection continues …..



Nature ***458****, 607-609 (2 April 2009)*



M. Casolino, 33^{rd} ICRC

CALET International Collaboration Team

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Aoyama Gakuin University
Hirosaki University
Institute for Cosmic Ray Research , University of Tokyo
Ibaraki University
JAXA/Space Environment Utilization Center
JAXA/ Institute of Aerospace and Astronautical Sciences
Kanagawa University
Kanagawa University of Human Services
High Energy Accelerator Research Organization (KEK)
STE, Nagoya University
National Inst. of Radiological Sciences
Nihon University
Ritsumeikan University
Saitama University
Shibaura Institute of Technology
Shinshu University
Tokiwa University
Tokyo Technology Inst.
Waseda University
Yokohama National University

ITALY
University of Siena
University of Florence & IFAC (CNR)
University of Pisa
University of Roma Tor Vergata
University of Padova

USA
NASA/GSFC
CRESST/NASA/GSFC and University of Maryland
CRESST/NASA/GSFC and Unicersity Space Research Association
Louisiana State University
Washington University in St Louis
University of Denver

Support Agencies

JAXA 宇宙航空研究開発機構 Japan Aerospace Exploration Agency

JAXA/SEUC

Waseda University
with JSPS, MEXT

ASI

NASA

CALET Observation

Calorimeter (CALET/CAL)

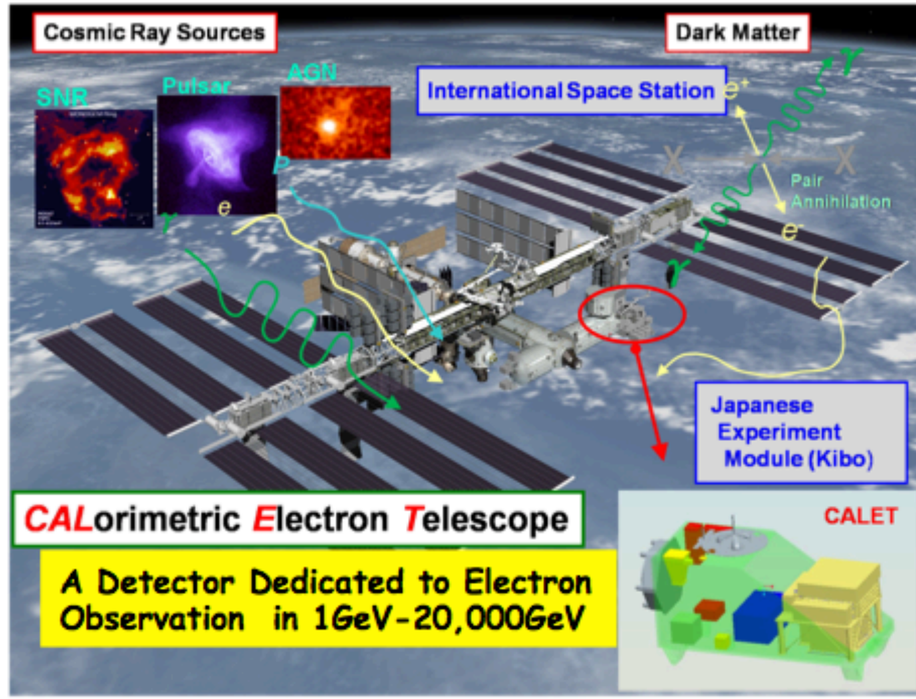
- Electrons: 1 GeV – 20 TeV
- Gamma-rays: 4 *GeV – 10 **TeV
  (Gamma-ray Bursts: > 1 GeV)
- Protons and Heavy Ions:
  10's of GeV – 1,000** TeV
- Ultra Heavy (Z>28) Nuclei:
  E> 600 MeV/nucleon

(* 50% efficiency, ** statistical dependent)

Gamma-ray Burst Monitor (CGBM)

- X-rays/Soft Gamma-rays:
  7keV – 20MeV

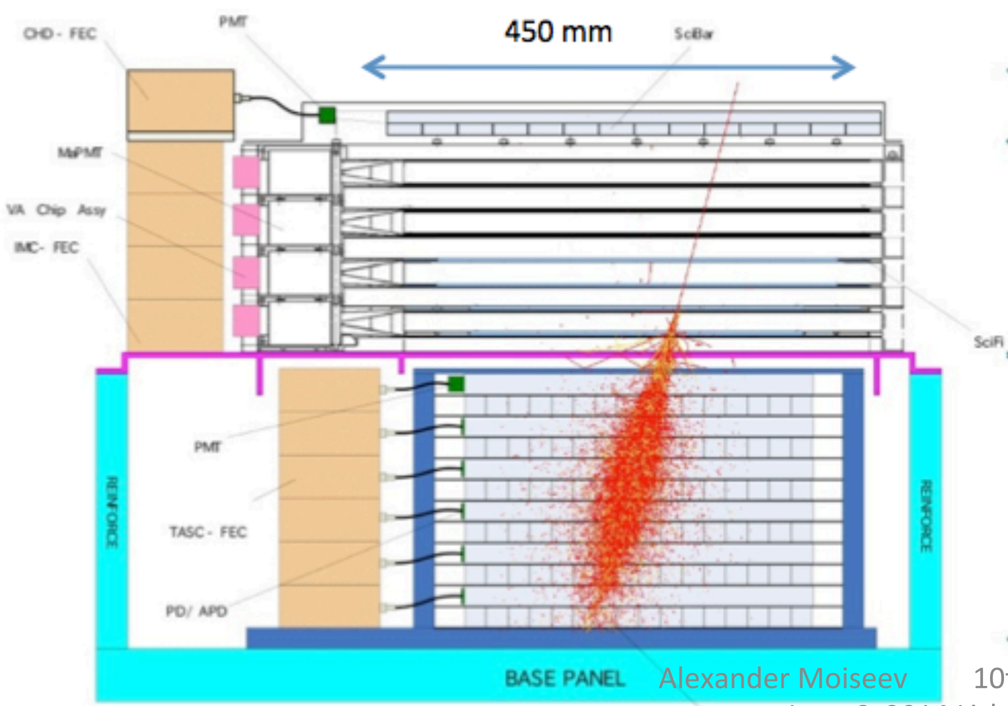
K.Yamaoka Poster:1007



Science Objectives	Observation Targets
Nearby Cosmic-ray Sources	Electron spectrum in trans-TeV region
Dark Matter	Signatures in electron/gamma energy spectra in 10 GeV – 10 TeV region
Origin and Acceleration of Cosmic Rays	p-Fe over several tens of GeV, Ultra Heavy Nuclei
Cosmic -ray Propagation in the Galaxy	B/C ratio up to several TeV /n
Solar Physics	Electron flux below 10 GeV
Gamma-ray Transients	Gamma-rays and X-rays in 7 keV – 20 MeV

Main High-Energy Particle Telescope

The unique feature of CALET is its thick, fully active calorimeter that allows measurements well into the TeV energy region with excellent energy resolution, coupled with a fine imaging upper calorimeter to accurately identify the starting point of electromagnetic showers. Combined, they powerfully separate electrons from the abundant protons: selection power $\sim 10^5$.

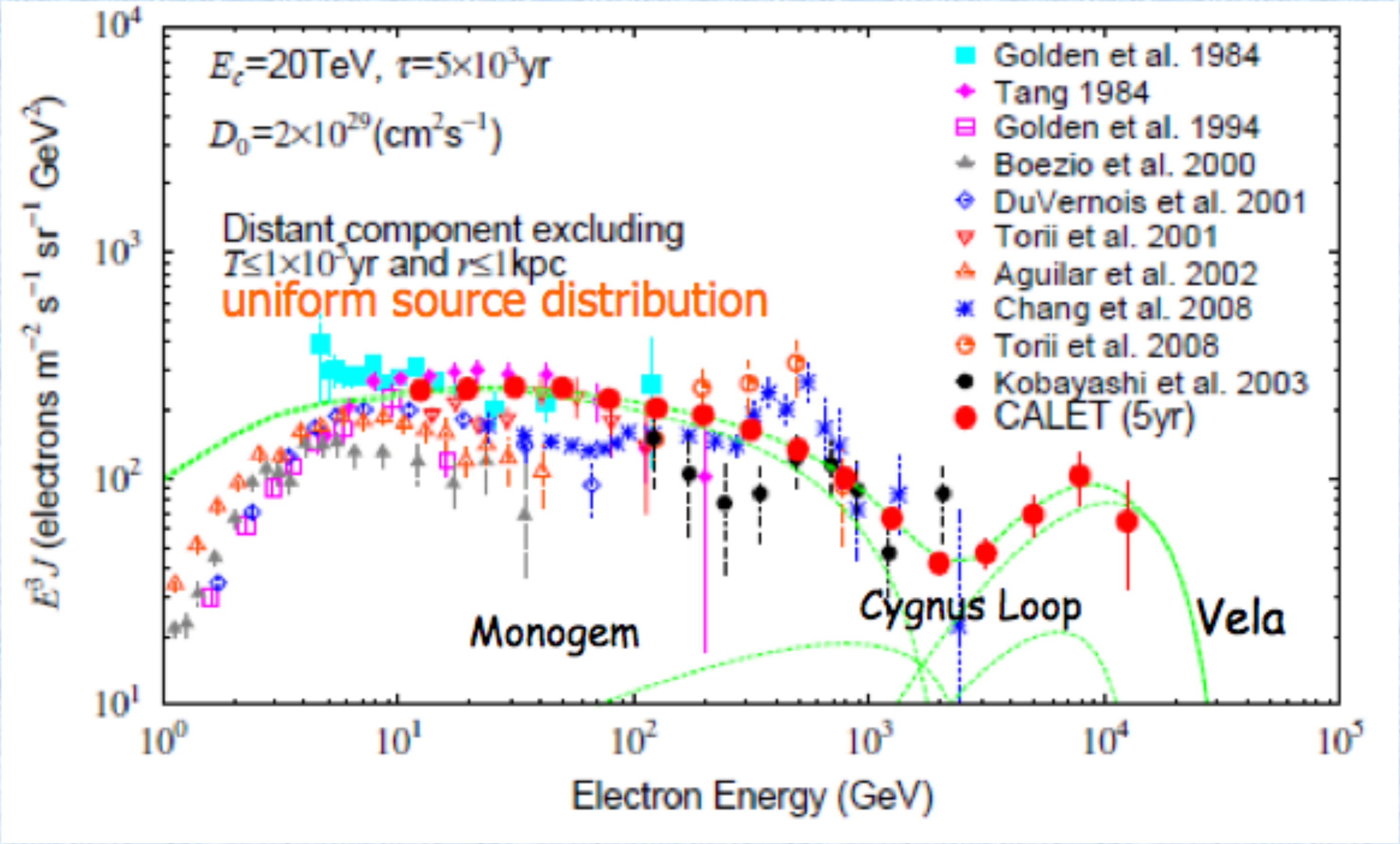


CHD — Plastic Scintillator : 14 × 1 layer (x,y)
Unit Size: 32mm x10mmx450mm

IMC — SciFi : 448 x 8 layers (x,y) = 7168
Unit size: 1mmsq x 448 mm
Total thickness of Tungsten: 3 r.l.

TASC — PWO log: 16 x 6 layers (x,y)= 192
Unit size: 19mm x 20mm x 326mm
Total Thickness of PWO: 27 r. l.

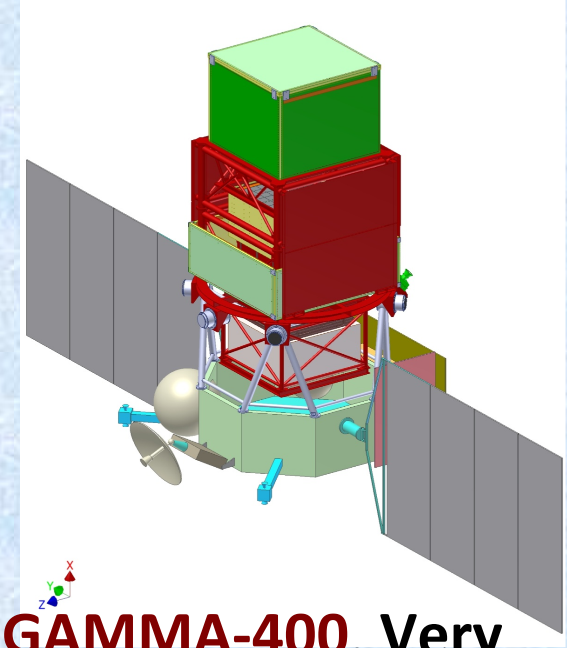
CRE spectrum as expected to be measured by CALET for 5 years of observations



The launch is expected by the end of March 2015 – very soon, stay tune!

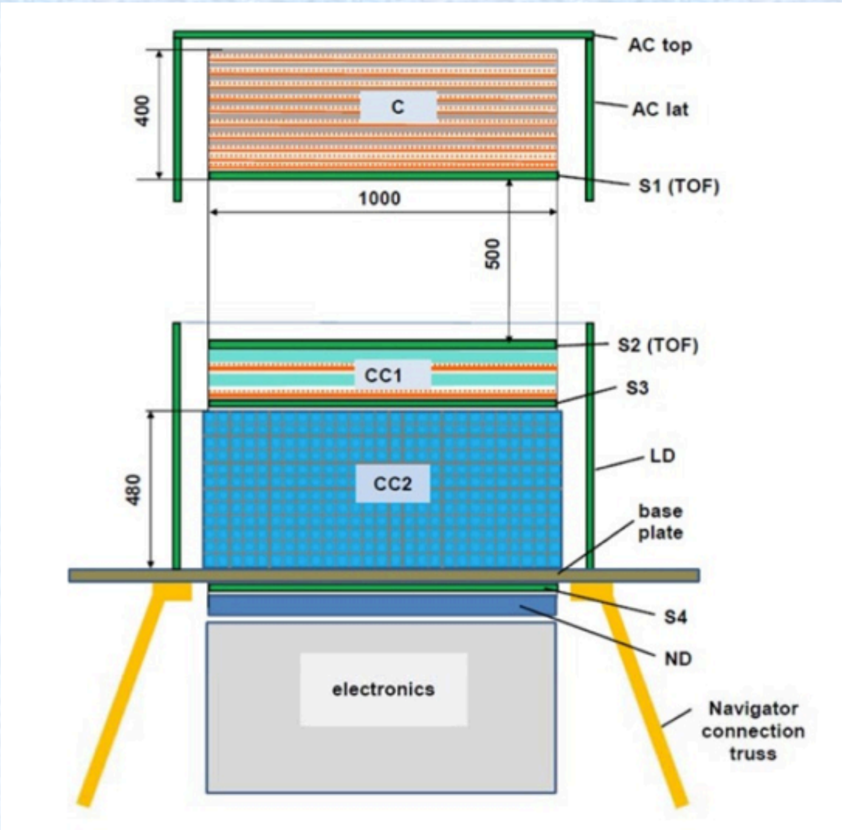
GAMMA-400

- A new high-energy space γ-ray telescope. Approved and fully funded by Russian Space Agency
- **GAMMA-400 goals:** follow and deepen the findings of Fermi LAT (similar energy range and instrument overall capabilities)



- **Search for dark matter is the main goal for GAMMA-400**. Very suitable for the search for WIMPs. Enhanced performance at high energy (> 10 GeV): PSF and energy resolution
- **Launch is planned for 2018-2019**

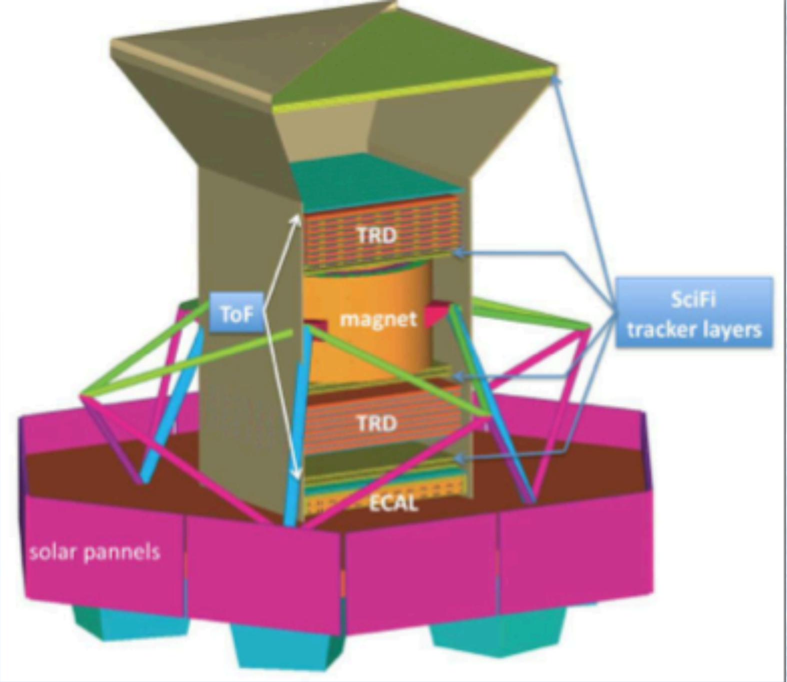
GAMMA-400 Concept



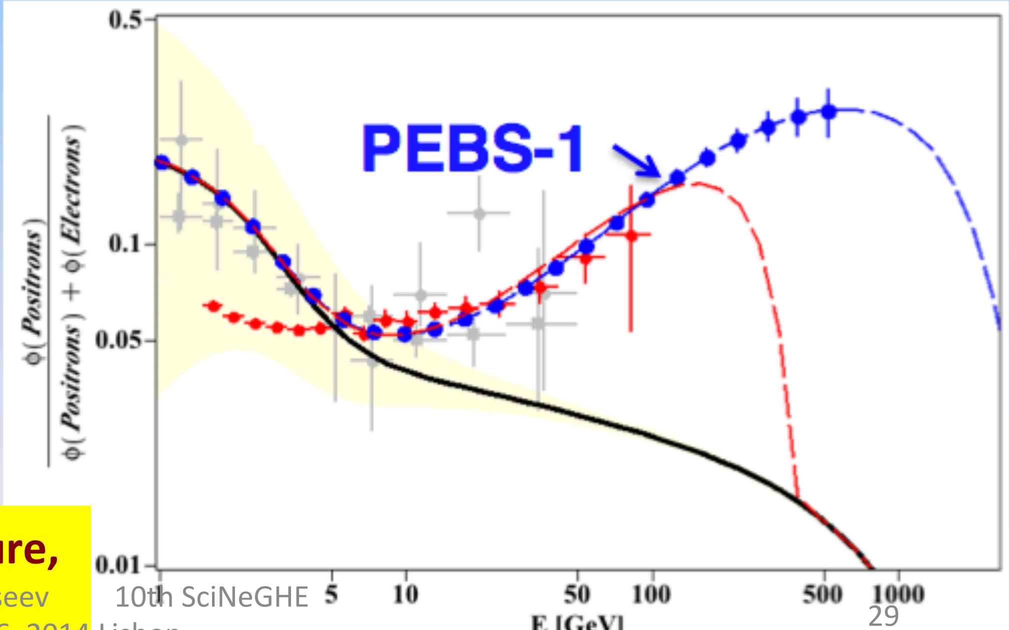
Energy range	100 MeV – 3000 GeV
Field-of-view, sr (E > 1 GeV)	~1.2
Effective area, cm^2 (E > 1 GeV)	~5,000
Energy resolution (E > 10 GeV)	~1%
Angular Resolution (E >100 GeV)	~0.01°
Converter-tracker thickness	~ $1X_0$
Calorimeter thickness	~ 25 X_0
Proton rejection factor	~ 10^6
Telemetry downlink volume, GB/day	100
Total mass, kg	2,600
Maximum dimensions, m	2.0 x 2.0 x 3.0
Power consumption, W	2,000

See O. Adriani's talk for details

PEBS Summary



- A dedicated balloon experiment could provide a competitive measurement of the cosmic ray electron & positron flux.
- The spectrometer is based on a scintillating fiber tracker with SiPM readout and a permanent magnet.
- The proton rejection of ~10^6 can be achieved by a combination of ToF, TRD, ECAL and Tracker.
- Key parameters:
  Acceptance: ~1200 cm^2 sr
  Weight: ~2000 kg
  Power: ~900 Watt
- R&D Phase:
  ongoing – testbeam successful…
- Construction Phase:
  Detector components exist

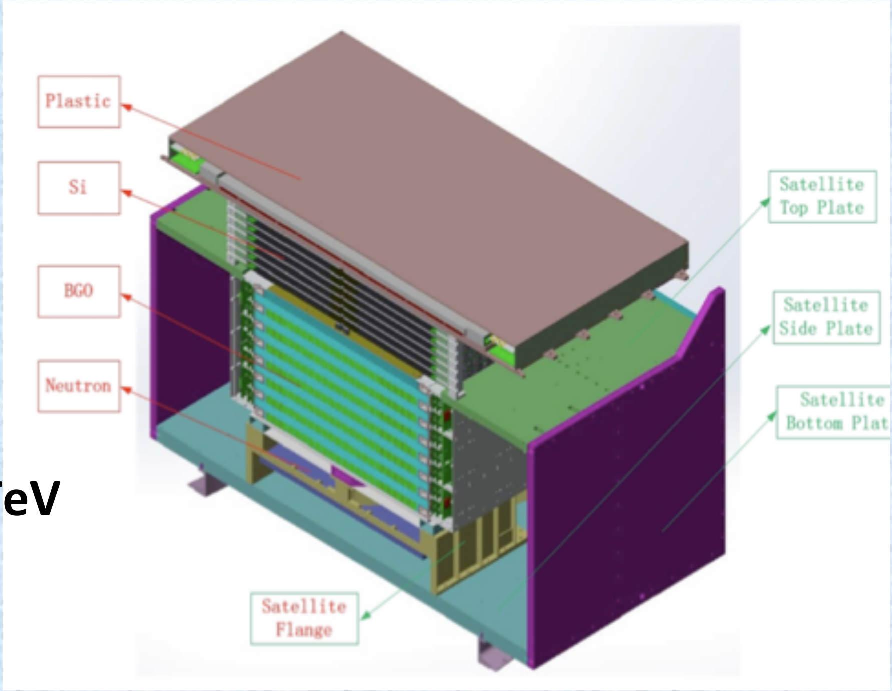


- **Potential experiment in the nearest future, currently on hold**

DAMPE (China): space telescope for high energy gamma-ray, electron and cosmic rays, potential launch in 2015-2016

- Plastic ACD
- Si-W tracker-converter
- BGO Imaging Calorimeter, 31 X_0 thick

- Energy range for electrons: 5 GeV – 10 TeV
- dE/E ~ 1% at 800 GeV
- Geom. Factor ~ 0.3 m^2 sr



See G. Ambrosi's talk for details

Cosmic Ray Electron Synchrotron Telescope (CREST) status report

Scott Nutter
for the CREST collaboration:

Indiana University:	C. R. Bower, J. Musser
Northern Kentucky University:	S. Nutter
Pennsylvania State University:	S. Coutu, M. Geske
University of Chicago:	D. Muller, S. Wakely, N. H. Park
The University of Michigan:	J. Gennaro, M. Schubnell, G. Tarle

8 July 2013
ICRC Rio de Janeiro

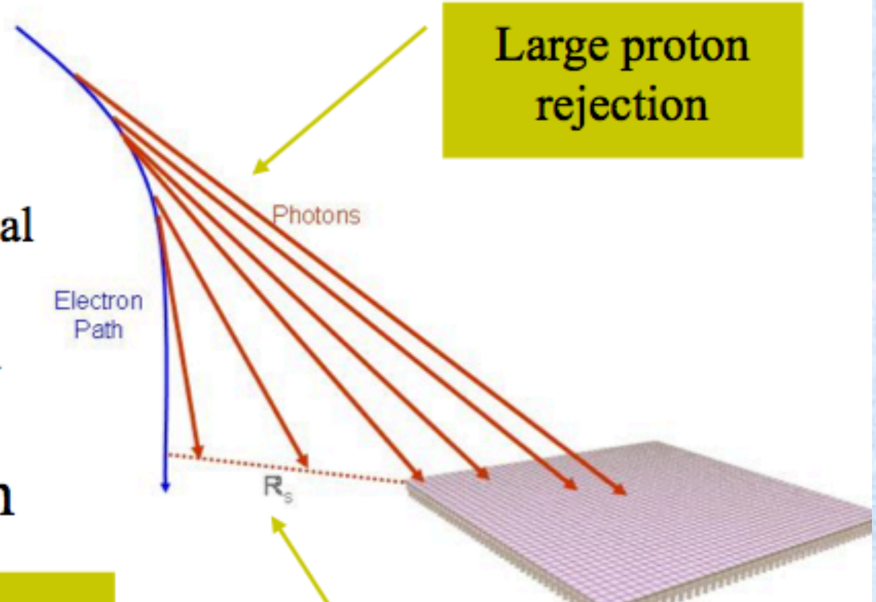
S. Coutu

CREST: Cosmic Ray Electron Synchrotron Telescope

- Technique: Detect synchrotron radiation of primary electron as it passes through Earth's magnetic field
  - Effective area of instrument greatly increased.
    - Area determined by R_S, not physical size.
  - Vast proton background rejected
- Exposure: Antarctic long duration balloon flights

Balloon-borne

Large proton rejection



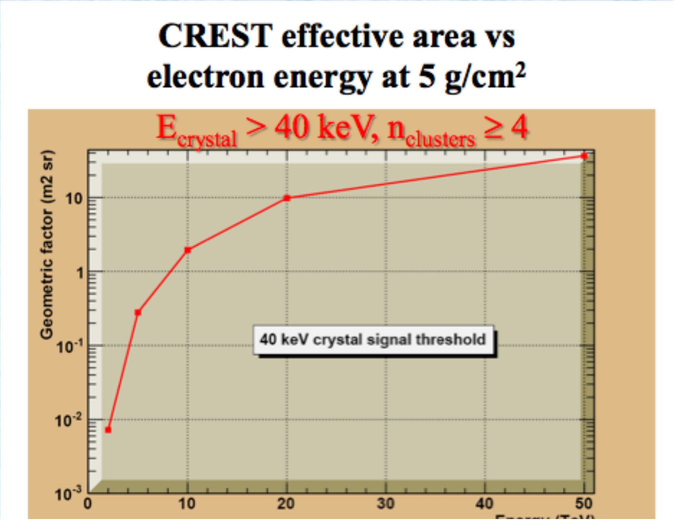
Long exposure time

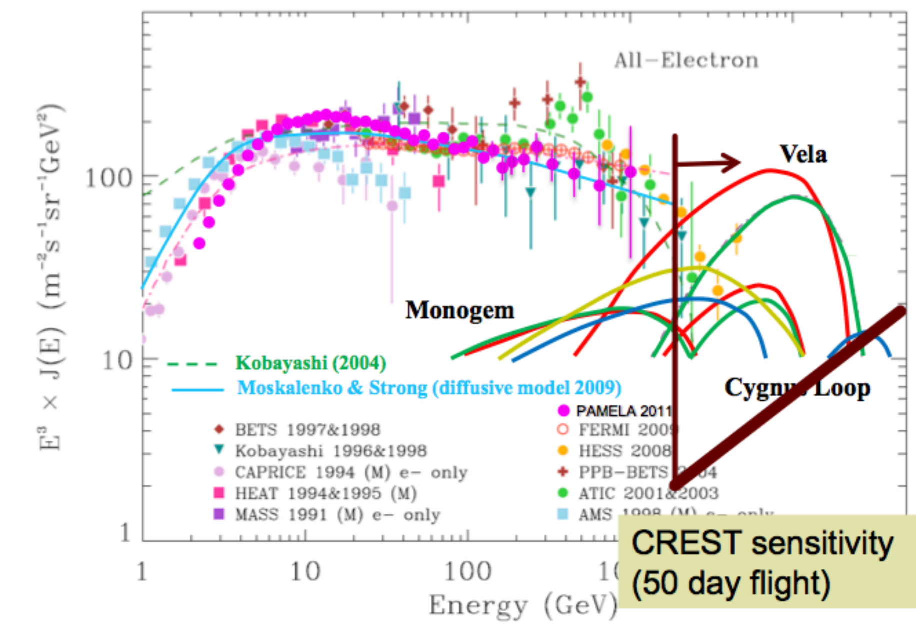
Large acceptance

CREST: "Pathfinder" or "Discovery" experiment

Method:
- Prilutskiy, O.F., Pisma ZhETF, 16,320, (1972).
- Stephens S.A., Balasubrahmanyan V.K., J. Geophys. Res., A10, 7822 (1983).

S. Coutu, 33^{rd} ICRC





Electron Energy (TeV)	Number of electrons for a 28 day flight
2 - 5	31
5 - 10	11.2
10 - 20	5.6
20 - 50	2.8
> 50	2.2

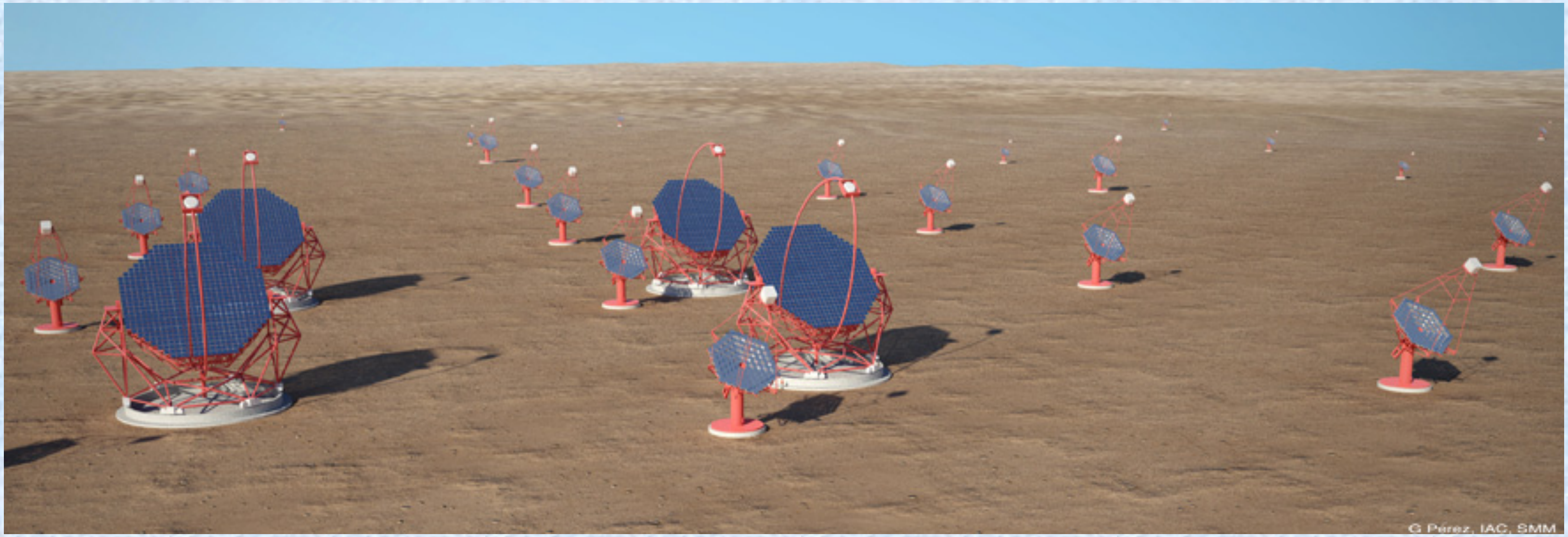
About 2 events/day above 2 TeV

Assumes $E^{-3.3}$ spectrum with no cutoff

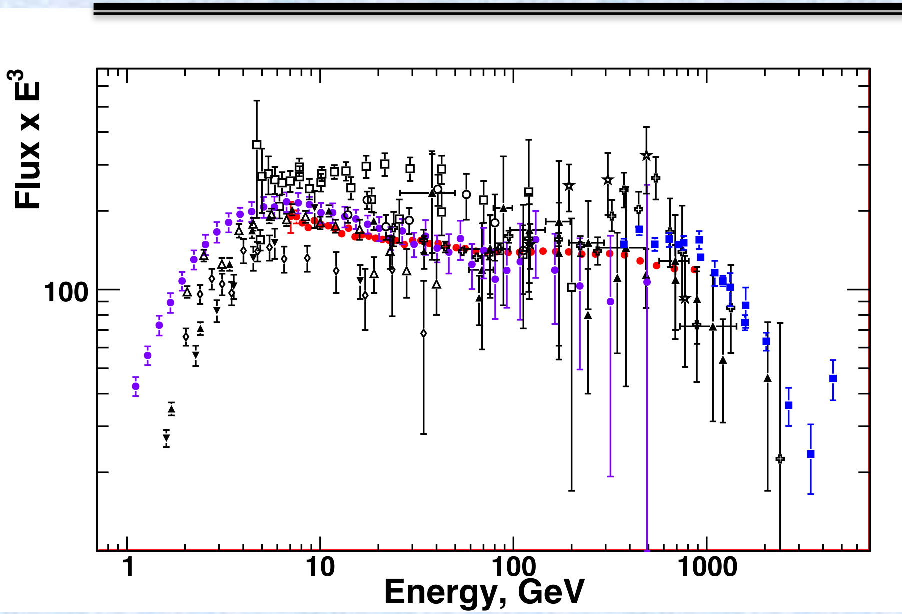
Expect ~factor of 2 energy resolution

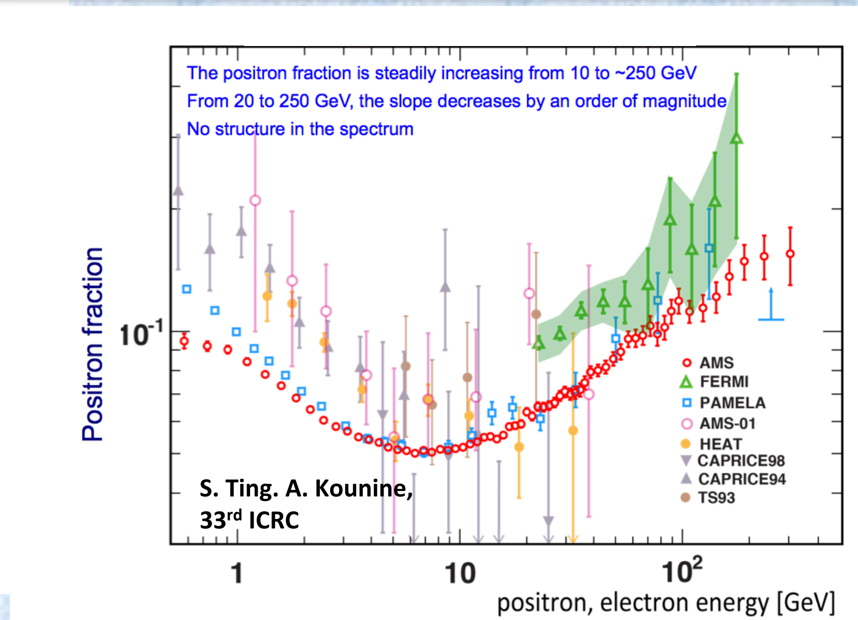
S. Coutu, 33rd ICRC

CTA (2018): all electrons up to ~10 TeV



SUMMARY I





- Real breakthrough during last few years in cosmic ray electrons: ATIC, H.E.S.S., Pamela, Fermi LAT and finally AMS-02. New quality data have made it possible to start quantitative modeling.

- With the new data more puzzles than before; <u>need "multi-messenger" campaign</u>: electrons, positrons, gammas, X-ray, radio, neutrino…

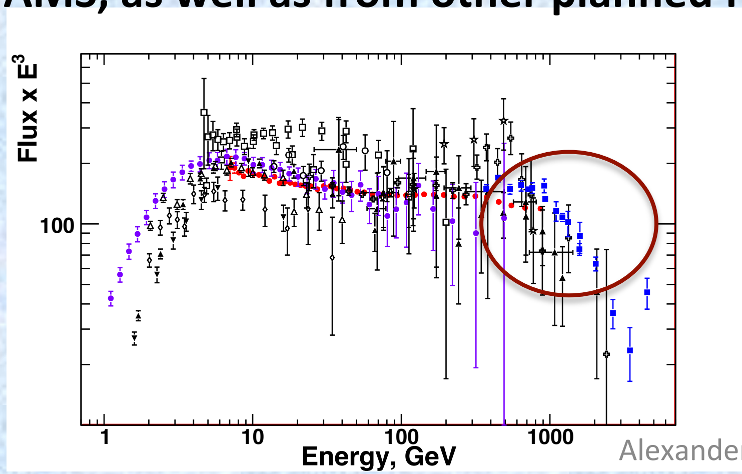
SUMMARY II

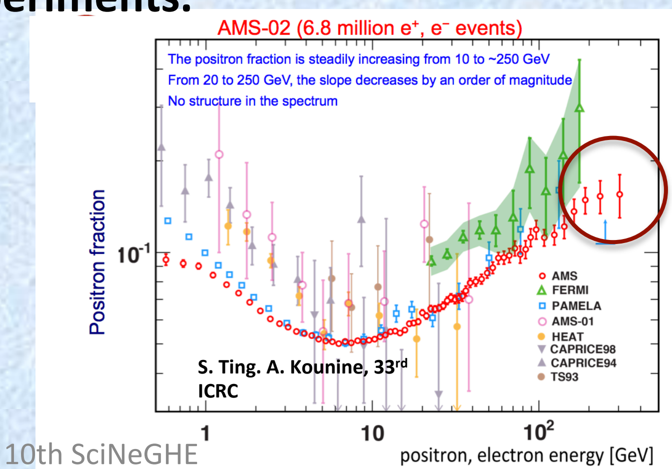
- We may be coming close to the first direct detection of cosmic ray sources

- Now we can discuss not only the origin of CR electrons, but also constraints of pulsar models based on these results.

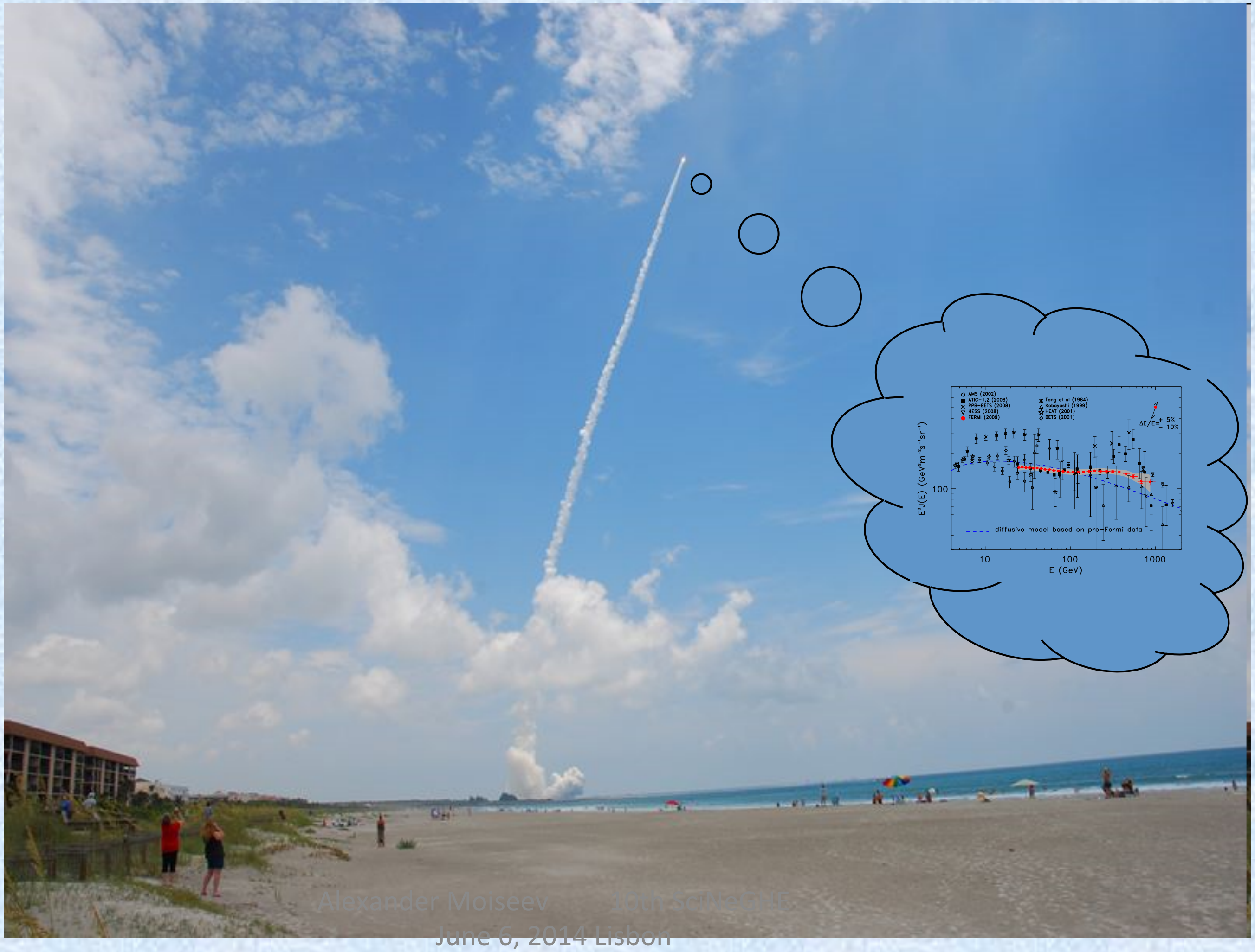
- It is viable that we are dealing with at least two distinct mechanisms of “primary” electron (both signs) production. One produces softer spectrum of negative electrons, and the other produces a harder spectrum of both e^++e^-. Exotic (e.g. DM) origin is not ruled out.

- Critical new results on the positron fraction at higher energy are expected soon from AMS, as well as from other planned future experiments.





THANK YOU !



AMS (2002)
ATIC-1,2 (2008)
PPB-BETS (2008)
HESS (2008)
FERMI (2009)
Tang et al (1984)
Kobayashi (1999)
HEAT (2001)
BETS (2001)
$\Delta E/E = ^{+\ 5\%}_{-\ 10\%}$
$E^3J(E)$ ($GeV^2m^{-2}s^{-1}sr^{-1}$)
100
diffusive model based on pre-Fermi data
10
100
1000
E (GeV)