The Alpha Magnetic Spectrometer (AMS-02) on the International Space Station

Henning Gast
RWTH Aachen

Questions to AMS-02:
Are there galaxies made of anti-matter in the Universe?
What is the nature of Dark Matter?
How do cosmic rays propagate in the Galaxy?

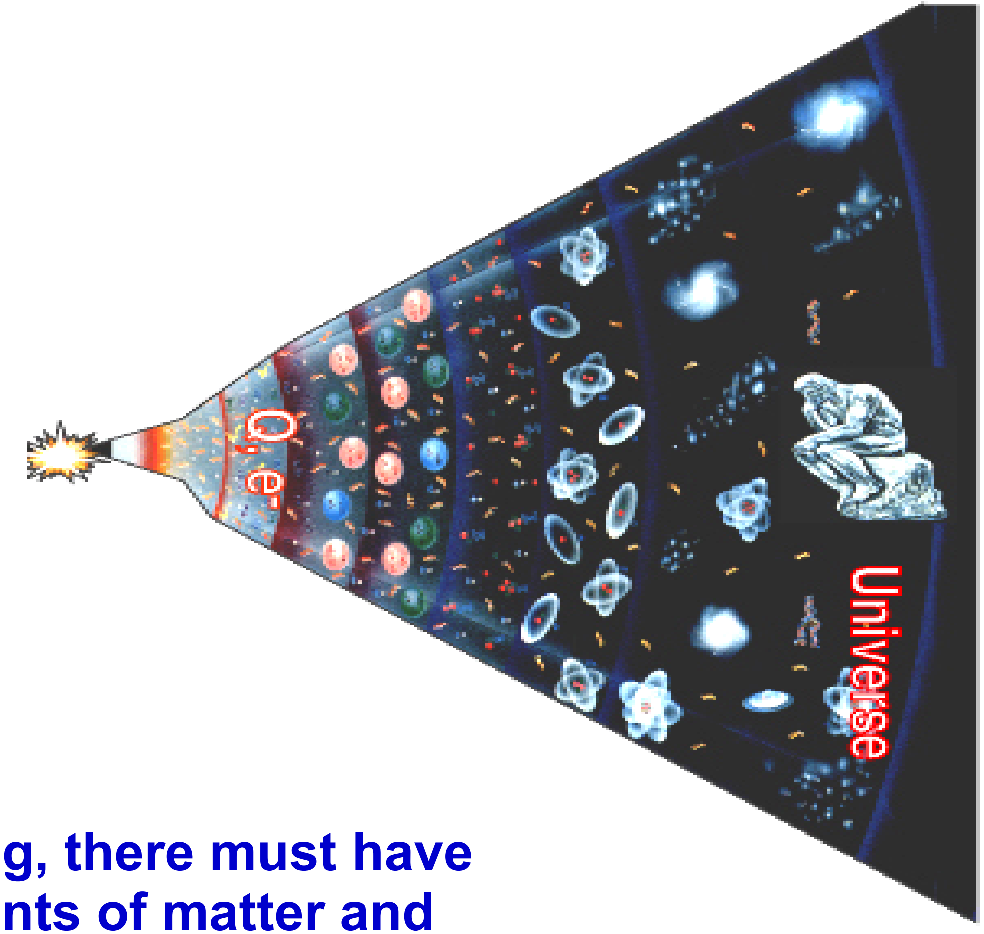
Overview

- Physics with AMS-02
- The AMS-02 detector
- Recent new experimental data from AMS-02
- Model-independent interpretation of AMS data
- Dark Matter models in the light of AMS data

The search for antimatter in the Universe

AMS on the ISS

The Universe was created in the Big Bang.



After the Big Bang, there must have been equal amounts of matter and anti-matter.

The search for antimatter in the Universe

The Universe was created in the Big Bang.

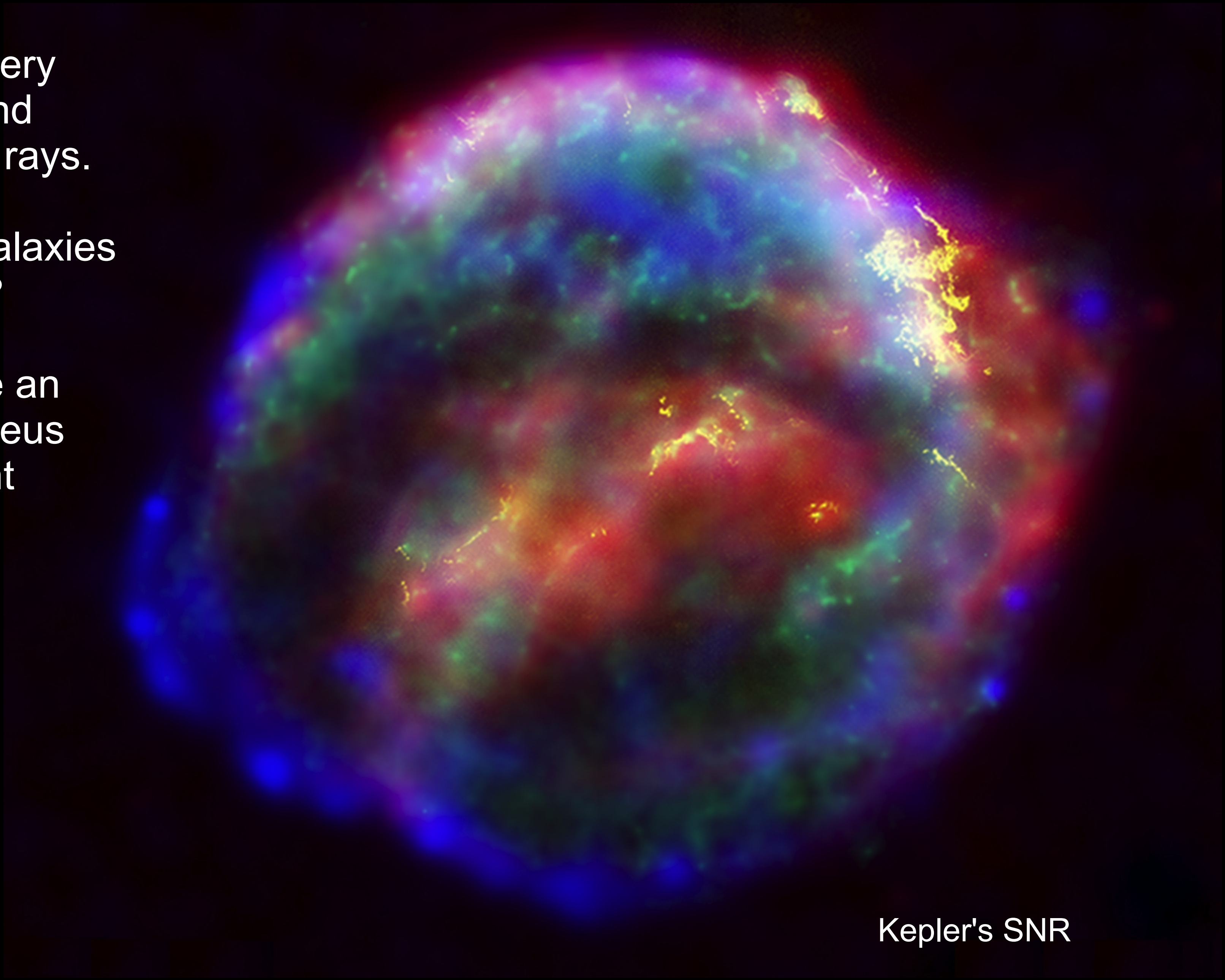
AMS on the ISS

After the Big Bang, there must have been equal amounts of matter and anti-matter.

Atomic nuclei are accelerated in supernovae to very high energies and become cosmic rays.

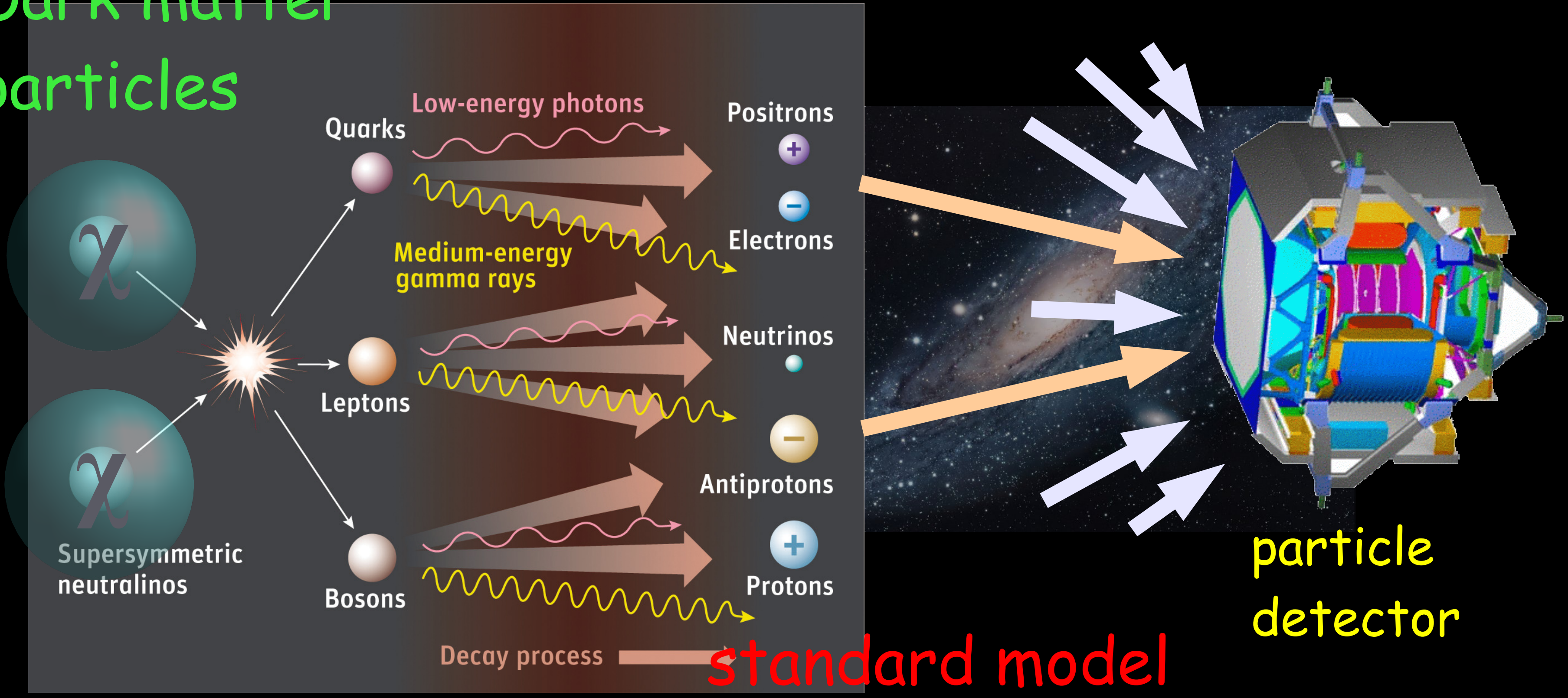
Are there anti-galaxies in the Universe?

Can we observe an anti-carbon nucleus from a far distant supernova?


Kepler's SNR

Dark Matter annihilation

Products of Dark Matter annihilations get injected into cosmic-ray sea:



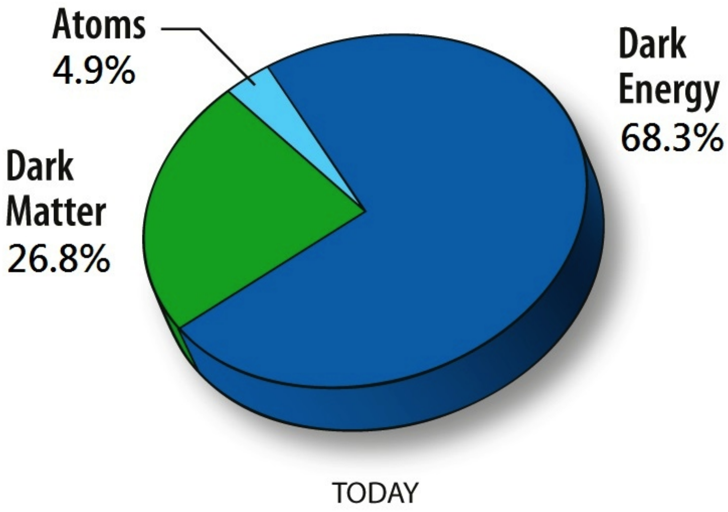
Dark matter particles

standard model particles

particle detector

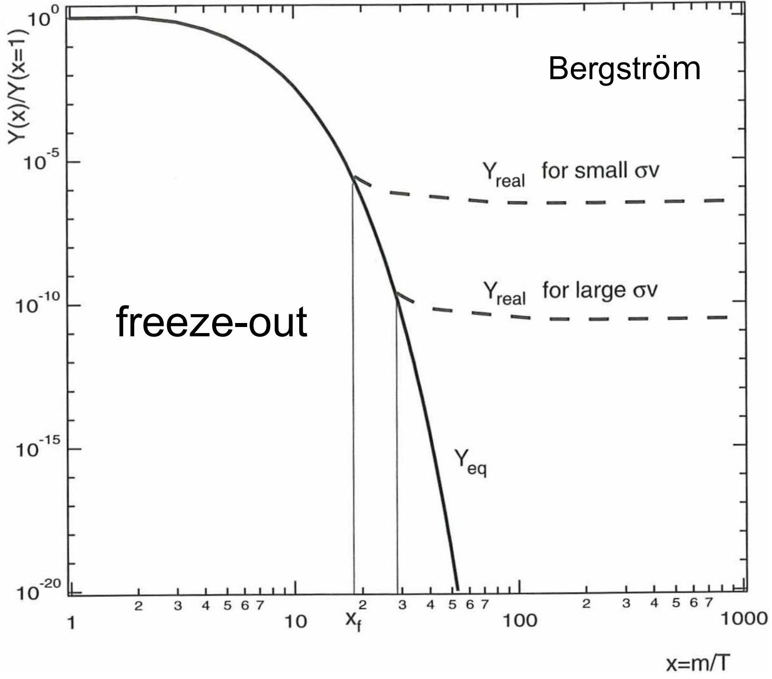
most promising channels: e^+, $\overline{p}$, $\overline{D}$, ($\overline{He}$), (and photons)

Relic Dark Matter particles



Freeze-out in the early Universe

relic density ↔ annihilation cross section



$$\Omega_\chi h^2 \approx 0.1$$

$$\Omega_\chi h^2 \approx \frac{3 \cdot 10^{-27}\,\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v \rangle}$$

Natural scale for cross section:

$$\langle \sigma v \rangle \approx 3 \cdot 10^{-26}\, cm^3\, s^{-1}$$

Cosmic ray physics in a nutshell

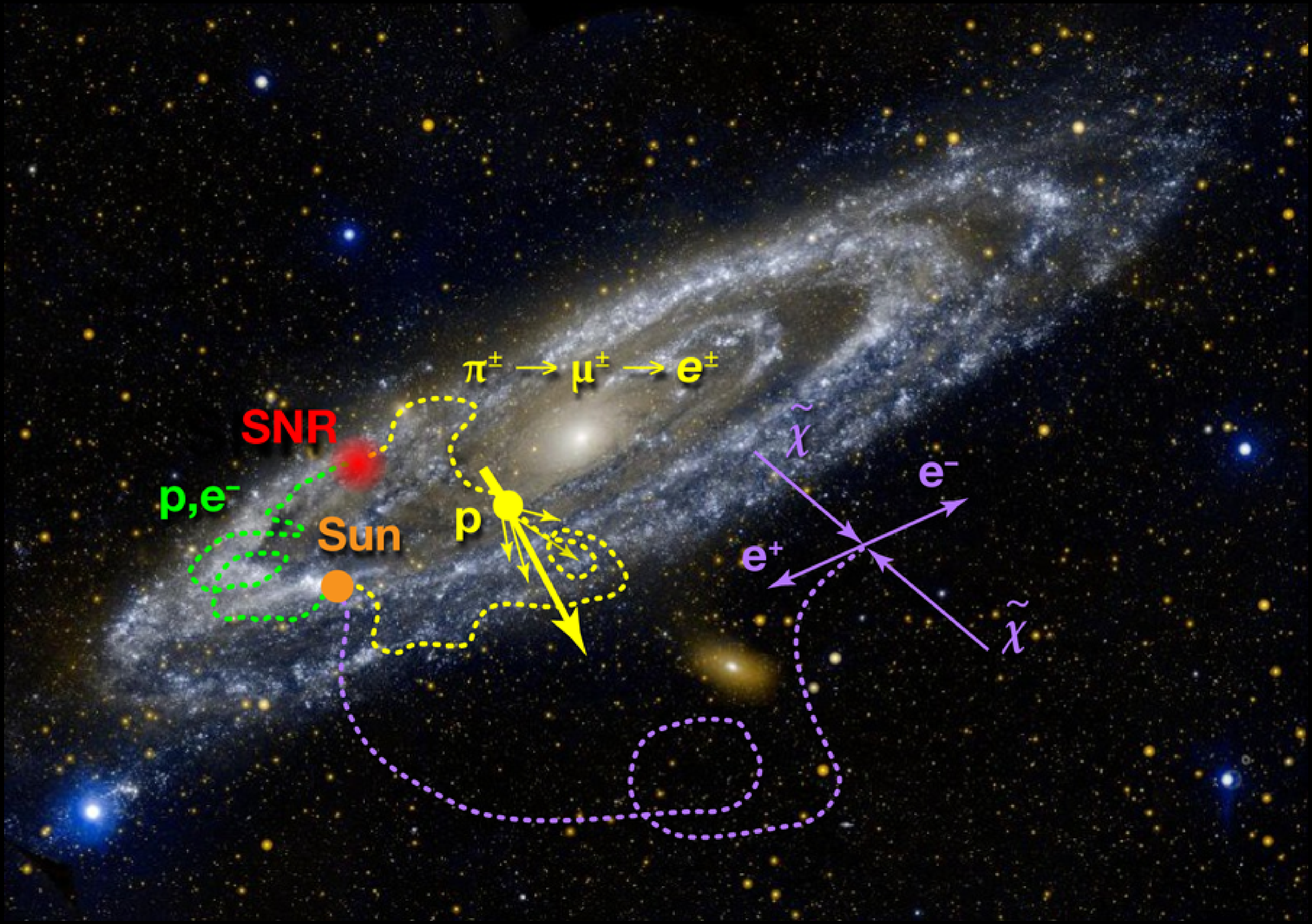
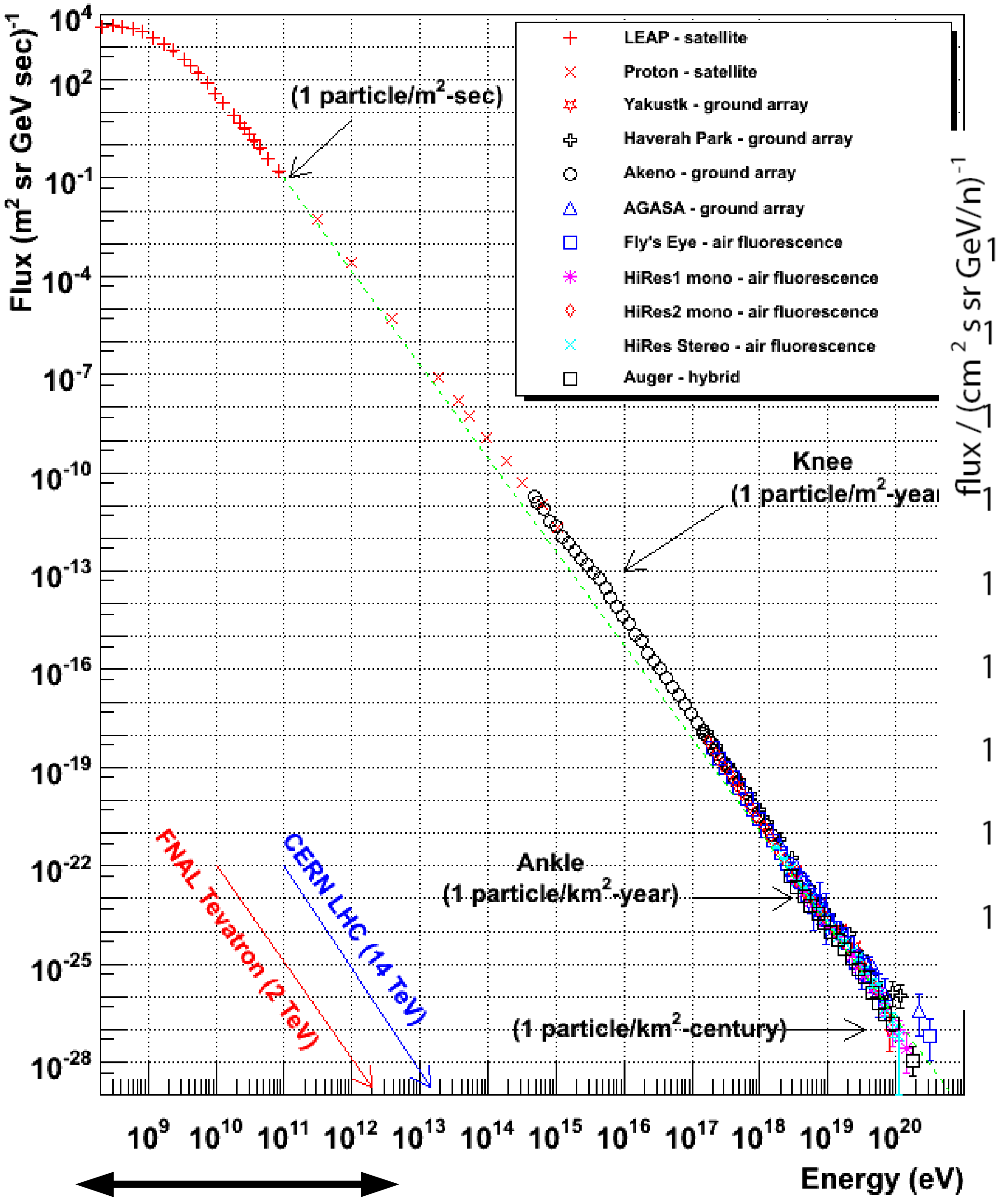
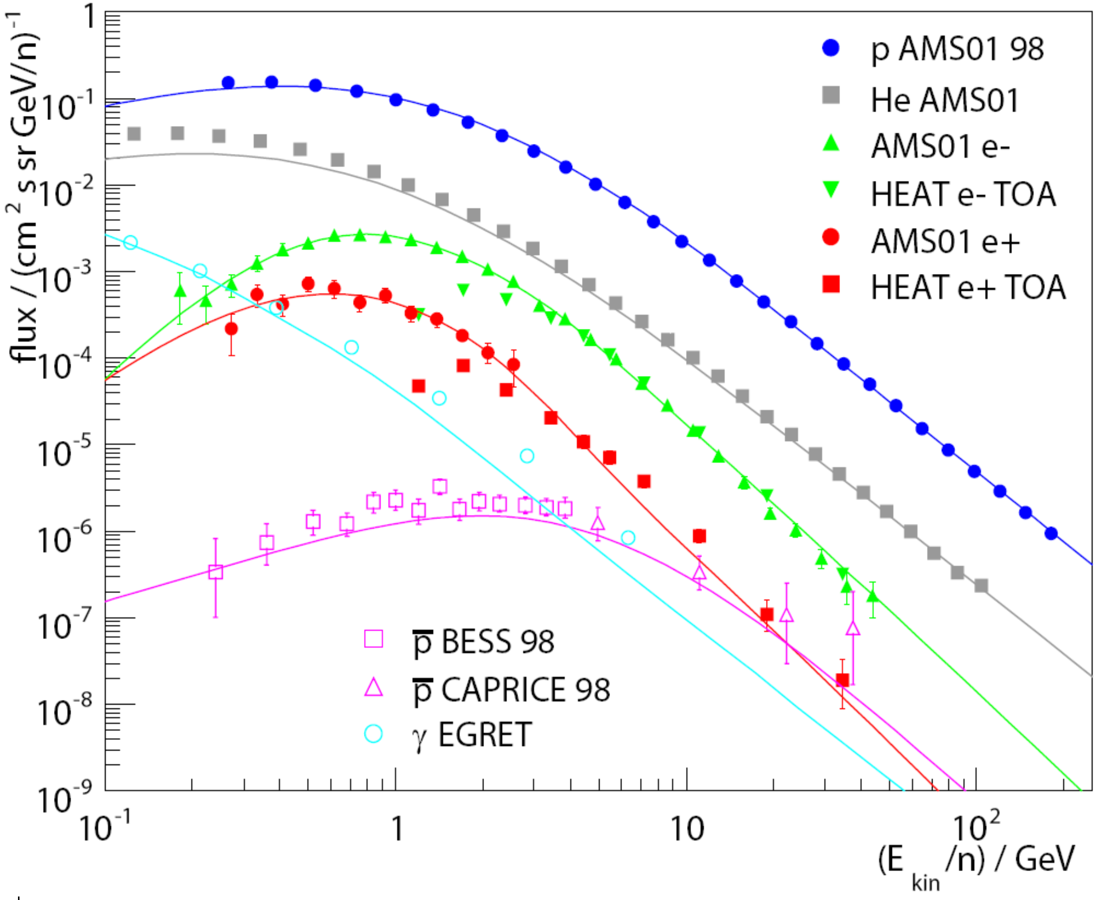


Image: GALEX, JPL-Caltech, NASA;
Drawing: APS/Alan Stonebraker

Cosmic rays: Spectrum and composition





The positron anomaly

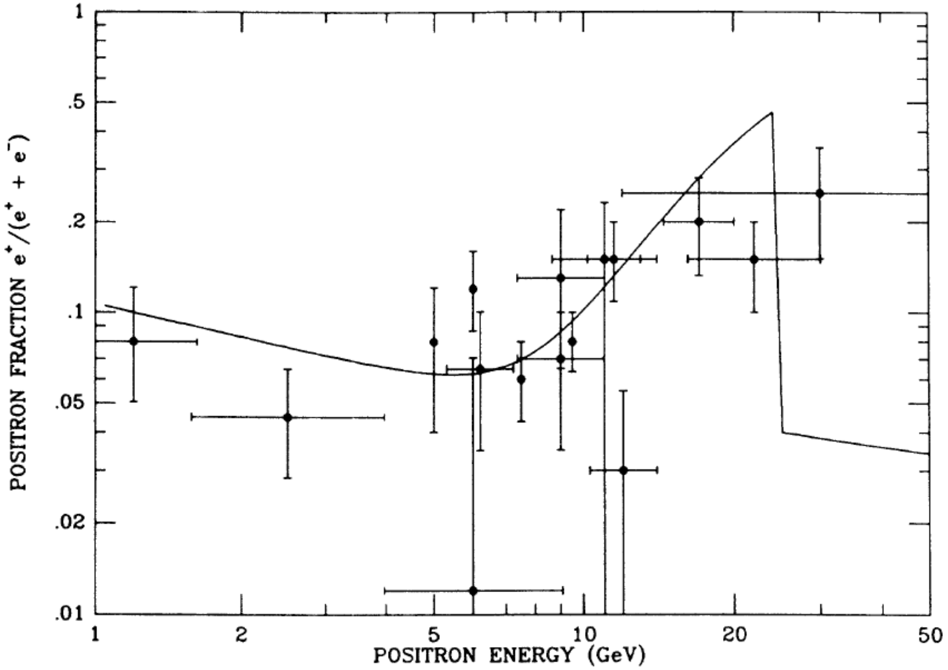
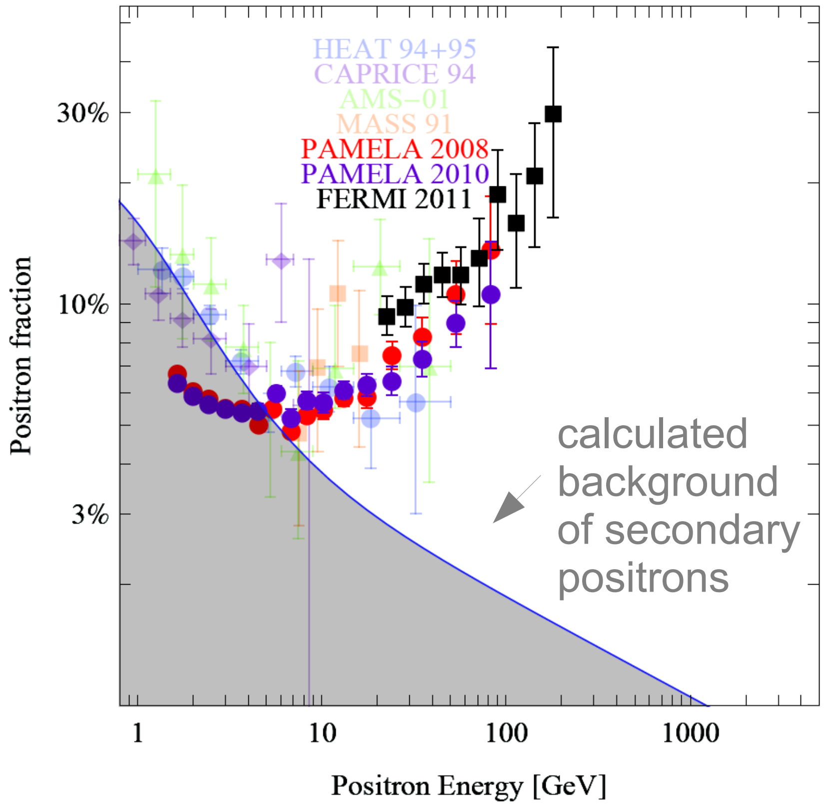


FIG. 1. The predicted positron fraction, $e^+/(e^++e^-)$, and the existing experimental data (from Ref. 14). In calculating the predicted positron fraction we have taken $m=25$ GeV, $r=1$, and *increased* the flux estimate over the fiducial value by a factor of 20 in order to make the comparison to the existing data intriguing. In addition, we have assumed a contribution to the positron fraction from conventional sources of the form, $e^+/(e^+e^-)=0.02+0.10(E/\mathrm{GeV})^{-0.5}$, which is consistent with the models discussed in Ref. 15.

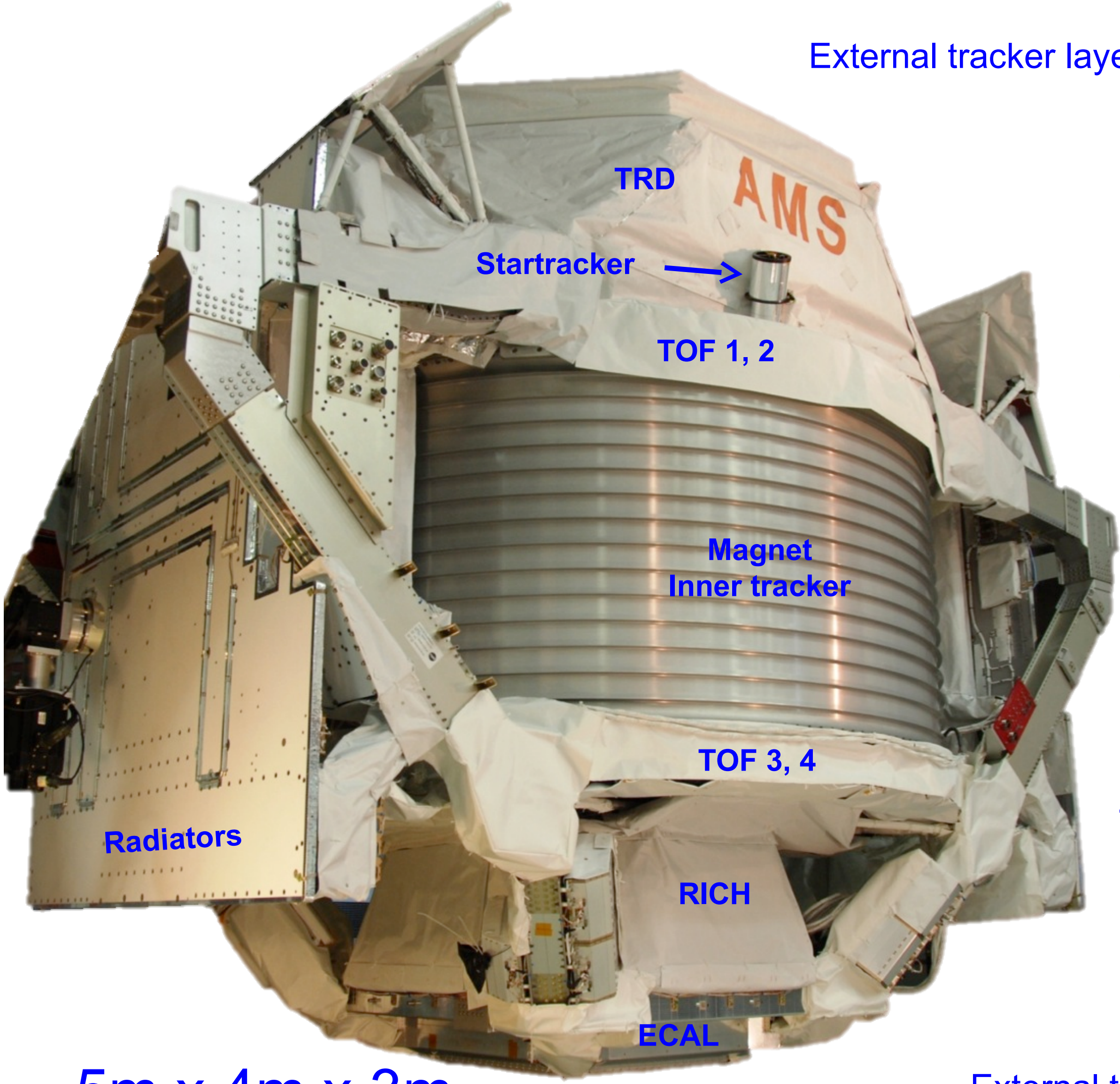
Turner & Wilczek, PRD 42 (1990) 1001

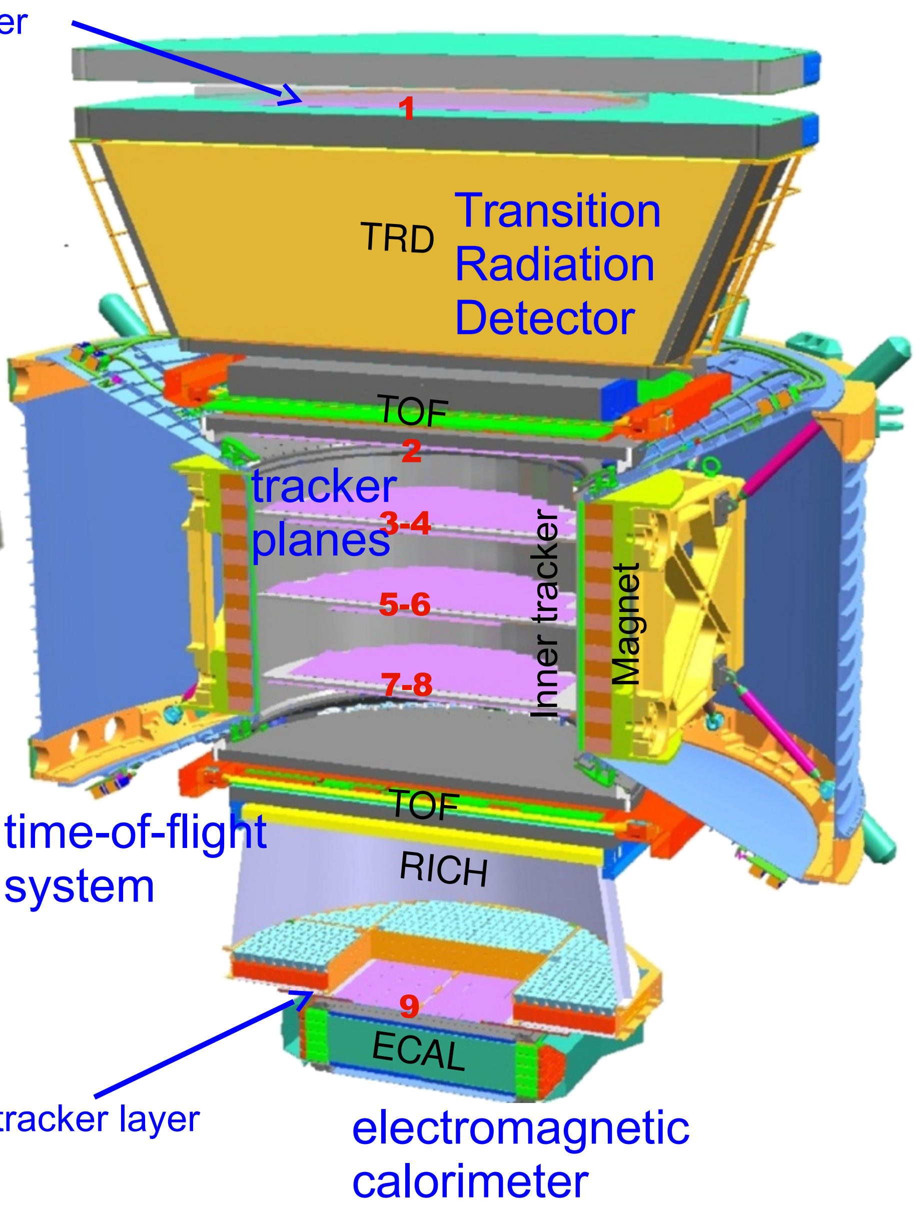


calculated background of secondary positrons

Cirelli (2012), 1202.1454v2

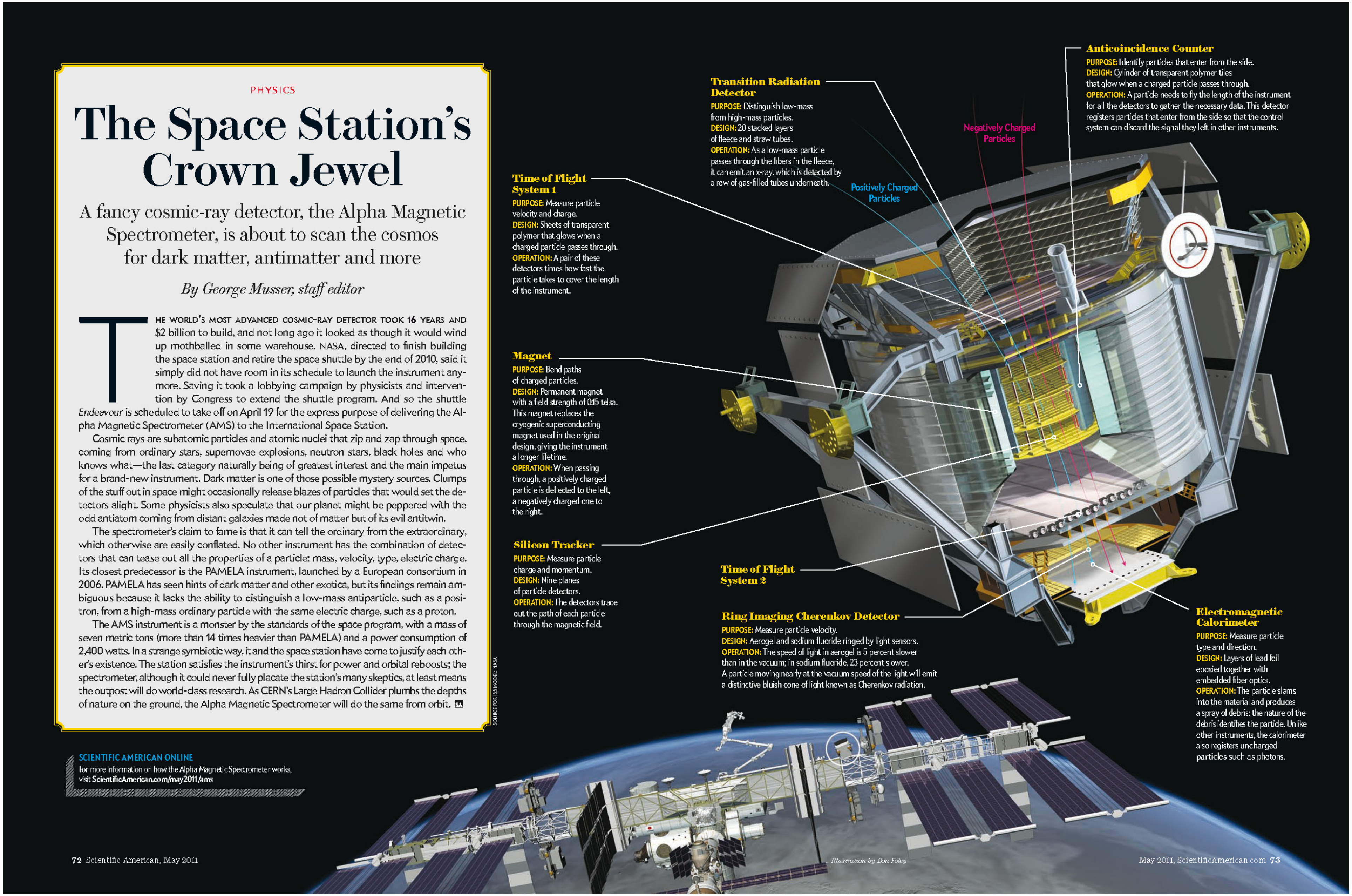
AMS-02





5m x 4m x 3m
7.5 tons

Scientific American, May 2011



PHYSICS

The Space Station's Crown Jewel

A fancy cosmic-ray detector, the Alpha Magnetic Spectrometer, is about to scan the cosmos for dark matter, antimatter and more

By George Musser, staff editor

THE WORLD'S MOST ADVANCED COSMIC-RAY DETECTOR TOOK 16 YEARS AND $2 billion to build, and not long ago it looked as though it would wind up mothballed in some warehouse. NASA, directed to finish building the space station and retire the space shuttle by the end of 2010, said it simply did not have room in its schedule to launch the instrument anymore. Saving it took a lobbying campaign by physicists and intervention by Congress to extend the shuttle program. And so the shuttle *Endeavour* is scheduled to take off on April 19 for the express purpose of delivering the Alpha Magnetic Spectrometer (AMS) to the International Space Station.

Cosmic rays are subatomic particles and atomic nuclei that zip and zap through space, coming from ordinary stars, supernovae explosions, neutron stars, black holes and who knows what—the last category naturally being of greatest interest and the main impetus for a brand-new instrument. Dark matter is one of those possible mystery sources. Clumps of the stuff out in space might occasionally release blazes of particles that would set the detectors alight. Some physicists also speculate that our planet might be peppered with the odd antiatom coming from distant galaxies made not of matter but of its evil antitwin.

The spectrometer's claim to fame is that it can tell the ordinary from the extraordinary, which otherwise are easily conflated. No other instrument has the combination of detectors that can tease out all the properties of a particle: mass, velocity, type, electric charge. Its closest predecessor is the PAMELA instrument, launched by a European consortium in 2006. PAMELA has seen hints of dark matter and other exotica, but its findings remain ambiguous because it lacks the ability to distinguish a low-mass antiparticle, such as a positron, from a high-mass ordinary particle with the same electric charge, such as a proton.

The AMS instrument is a monster by the standards of the space program, with a mass of seven metric tons (more than 14 times heavier than PAMELA) and a power consumption of 2,400 watts. In a strange symbiotic way, it and the space station have come to justify each other's existence. The station satisfies the instrument's thirst for power and orbital reboosts; the spectrometer, although it could never fully placate the station's many skeptics, at least means the outpost will do world-class research. As CERN's Large Hadron Collider plumbs the depths of nature on the ground, the Alpha Magnetic Spectrometer will do the same from orbit. SA

SCIENTIFIC AMERICAN ONLINE
For more information on how the Alpha Magnetic Spectrometer works, visit **ScientificAmerican.com/may2011/ams**

Time of Flight System 1
PURPOSE: Measure particle velocity and charge.
DESIGN: Sheets of transparent polymer that glows when a charged particle passes through.
OPERATION: A pair of these detectors times how fast the particle takes to cover the length of the instrument.

Magnet
PURPOSE: Bend paths of charged particles.
DESIGN: Permanent magnet with a field strength of 0.15 telsa. This magnet replaces the cryogenic superconducting magnet used in the original design, giving the instrument a longer lifetime.
OPERATION: When passing through, a positively charged particle is deflected to the left, a negatively charged one to the right.

Silicon Tracker
PURPOSE: Measure particle charge and momentum.
DESIGN: Nine planes of particle detectors.
OPERATION: The detectors trace out the path of each particle through the magnetic field.

Transition Radiation Detector
PURPOSE: Distinguish low-mass from high-mass particles.
DESIGN: 20 stacked layers of fleece and straw tubes.
OPERATION: As a low-mass particle passes through the fibers in the fleece, it can emit an x-ray, which is detected by a row of gas-filled tubes underneath.

Anticoincidence Counter
PURPOSE: Identify particles that enter from the side.
DESIGN: Cylinder of transparent polymer tiles that glow when a charged particle passes through.
OPERATION: A particle needs to fly the length of the instrument for all the detectors to gather the necessary data. This detector registers particles that enter from the side so that the control system can discard the signal they left in other instruments.

Time of Flight System 2

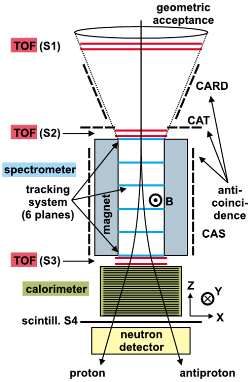
Ring Imaging Cherenkov Detector
PURPOSE: Measure particle velocity.
DESIGN: Aerogel and sodium fluoride ringed by light sensors.
OPERATION: The speed of light in aerogel is 5 percent slower than in the vacuum; in sodium fluoride, 23 percent slower. A particle moving nearly at the vacuum speed of the light will emit a distinctive bluish cone of light known as Cherenkov radiation.

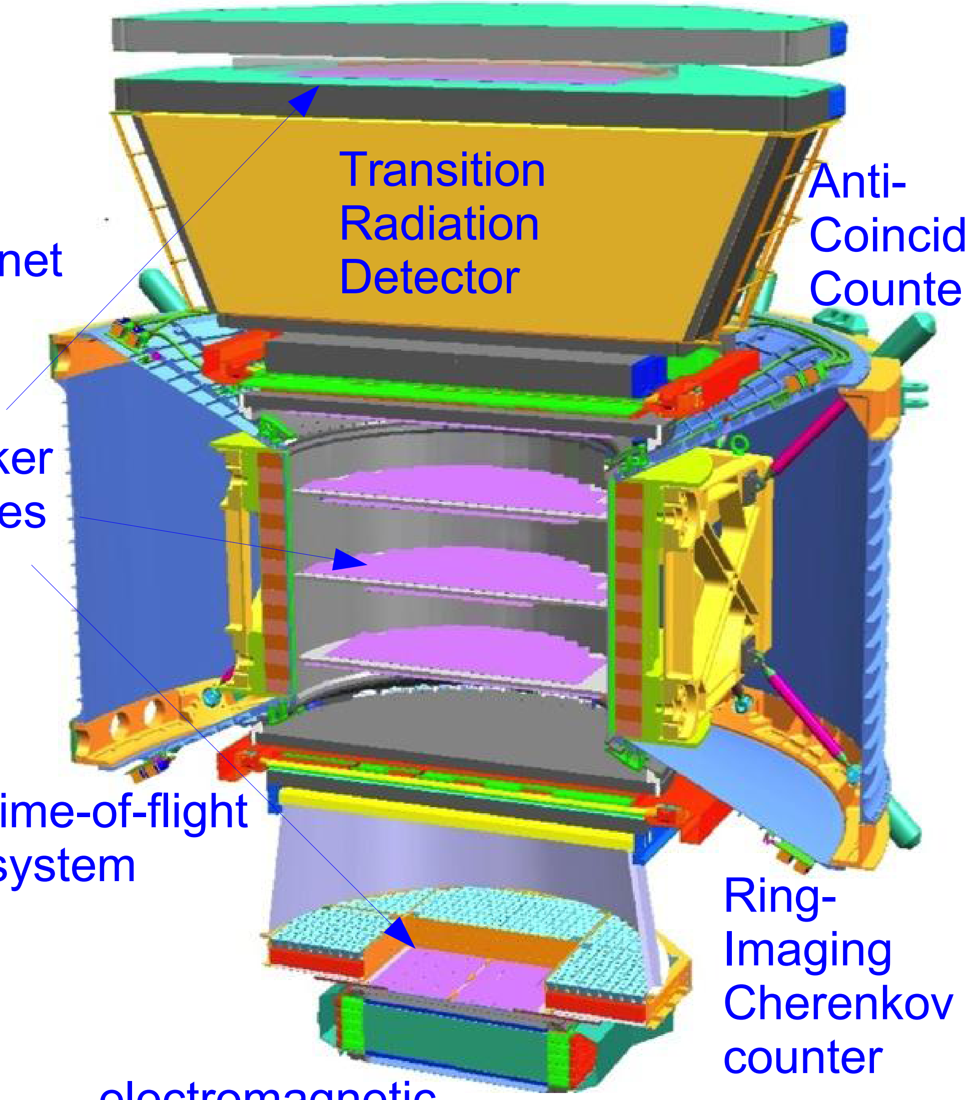
Electromagnetic Calorimeter
PURPOSE: Measure particle type and direction.
DESIGN: Layers of lead foil epoxied together with embedded fiber optics.
OPERATION: The particle slams into the material and produces a spray of debris; the nature of the debris identifies the particle. Unlike other instruments, the calorimeter also registers uncharged particles such as photons.

SOURCE FOR ISS MODEL: NASA

Illustration by Don Foley

PAMELA vs AMS-02





Transition Radiation Detector

Anti-Coincidence Counter

magnet

tracker planes

time-of-flight system

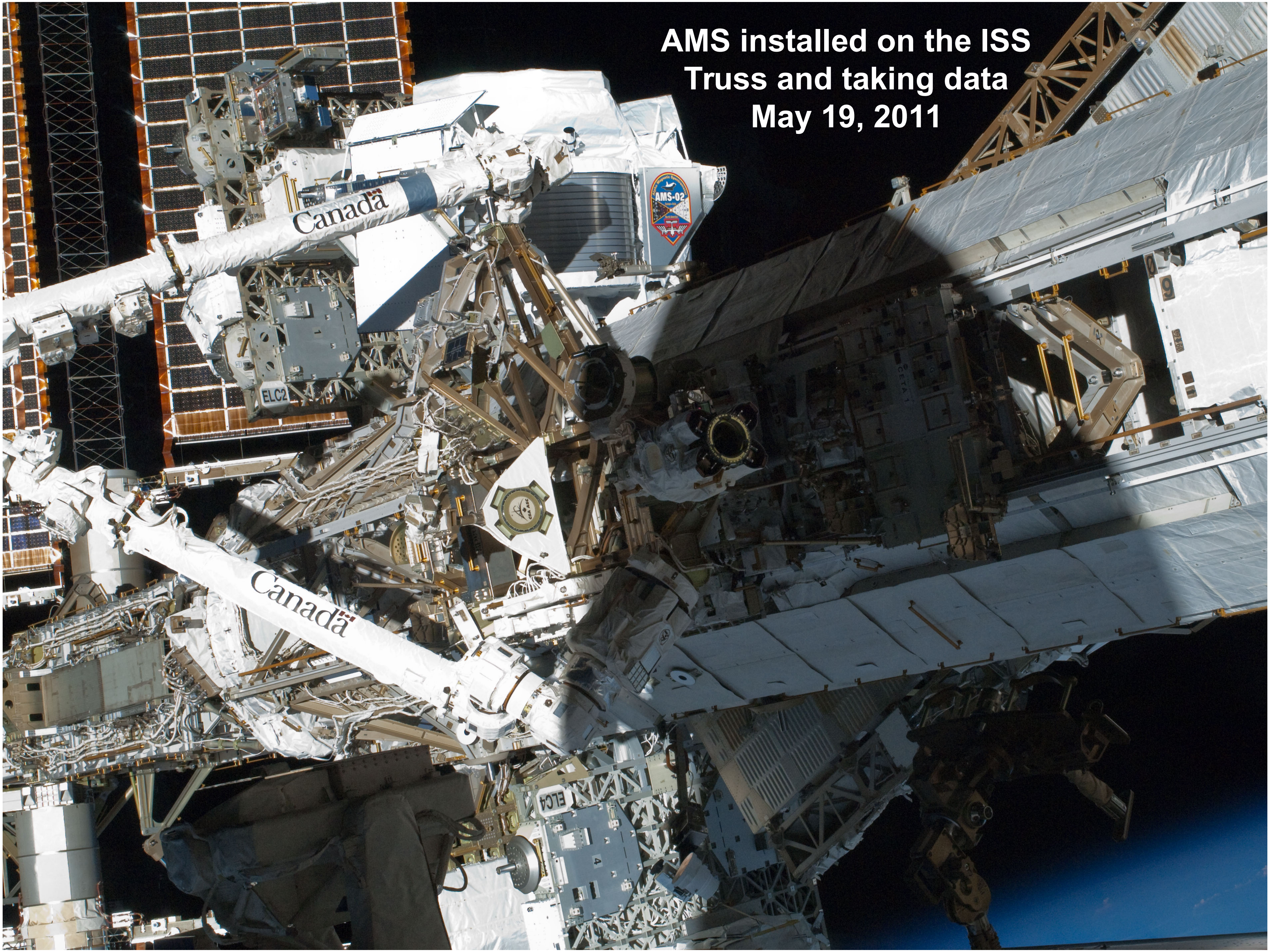
Ring-Imaging Cherenkov counter

electromagnetic calorimeter

GF: 21.5 cm^2 sr

GF: 250 – 3500 cm^2 sr, depending on physics analysis

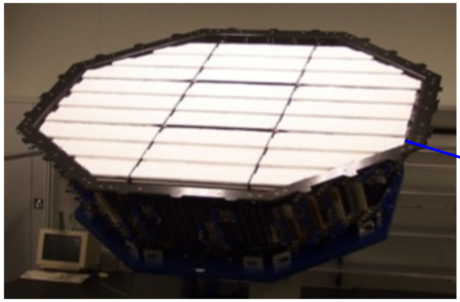
Endeavour approaches the International Space Station



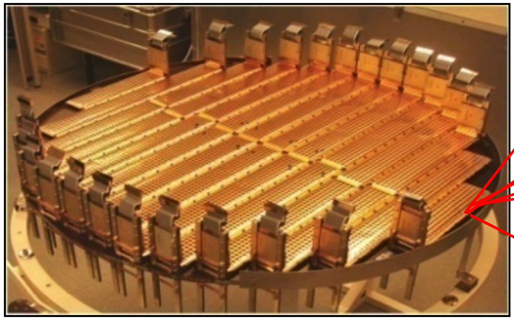
AMS installed on the ISS
Truss and taking data
May 19, 2011

AMS-02 overview

TRD
Identify e+, e-

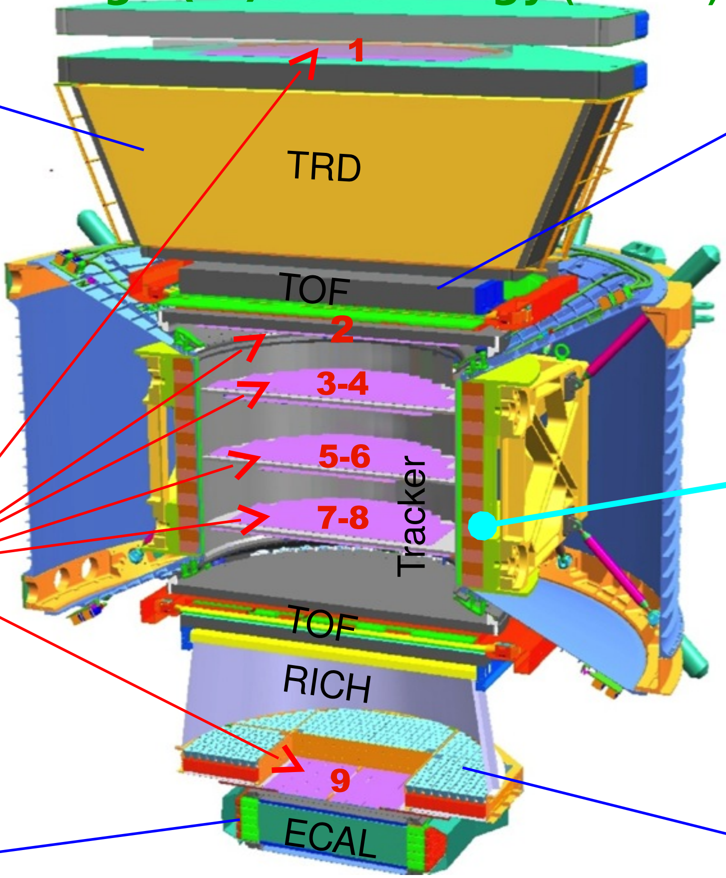


Silicon Tracker
Z, P



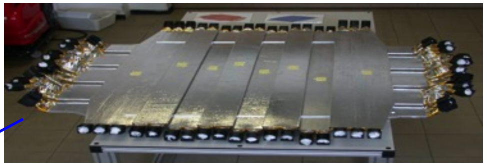
ECAL
E of e+, e-, γ

Particles and nuclei are defined by their charge (Z) and energy (E ~ P)

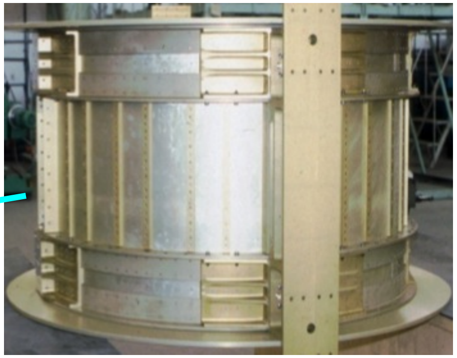


Z, P are measured independently by the Tracker, RICH, TOF and ECAL

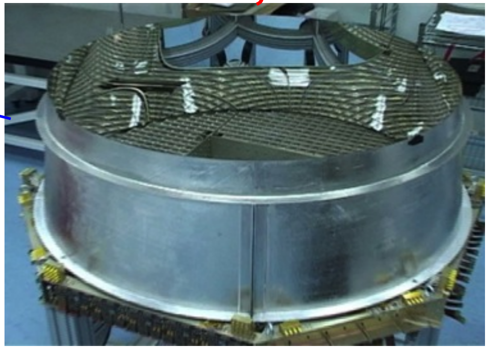
TOF
Z, E



Magnet
±Z

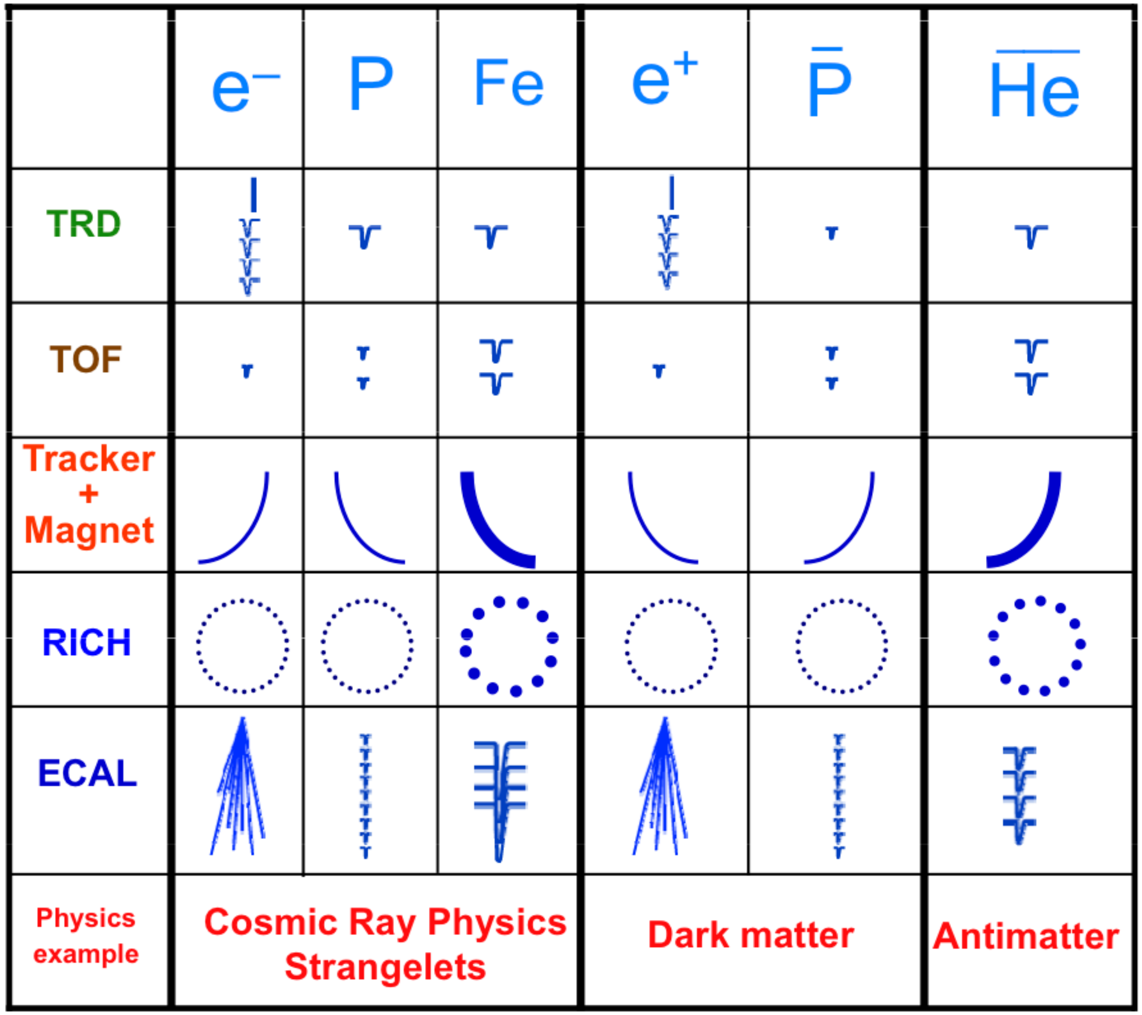


RICH
Z, E



AMS-02 particle identification

- Particle ID requires complex algorithms for each subdetector.
- Combine information from all subdetectors.
- Example: proton rejection 1:1,000,000

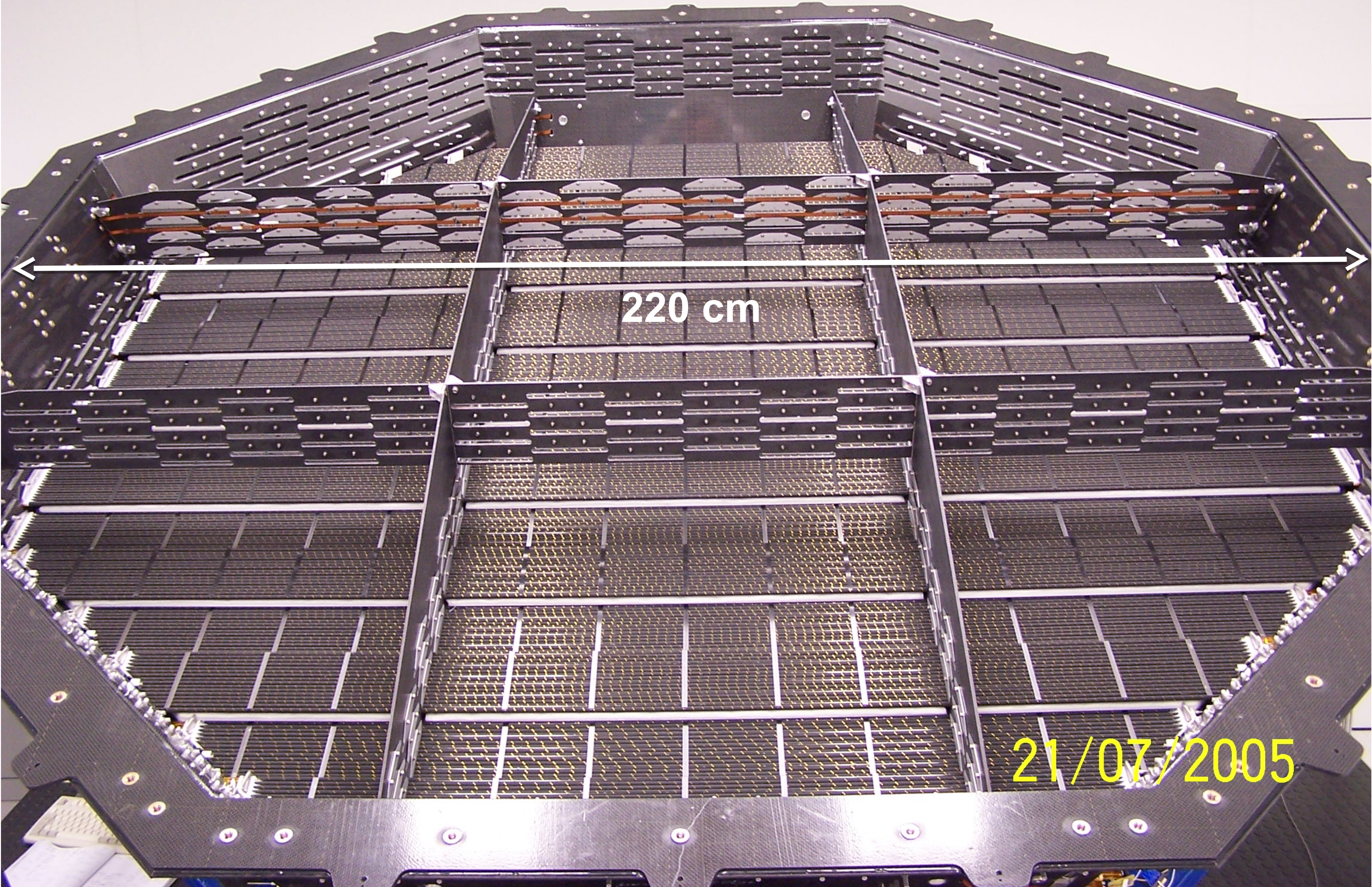


	e^-	P	Fe	e^+	$\bar{P}$	$\overline{He}$
TRD						
TOF						
Tracker + Magnet						
RICH						
ECAL						
Physics example	**Cosmic Ray Physics Strangelets**			**Dark matter**		**Antimatter**

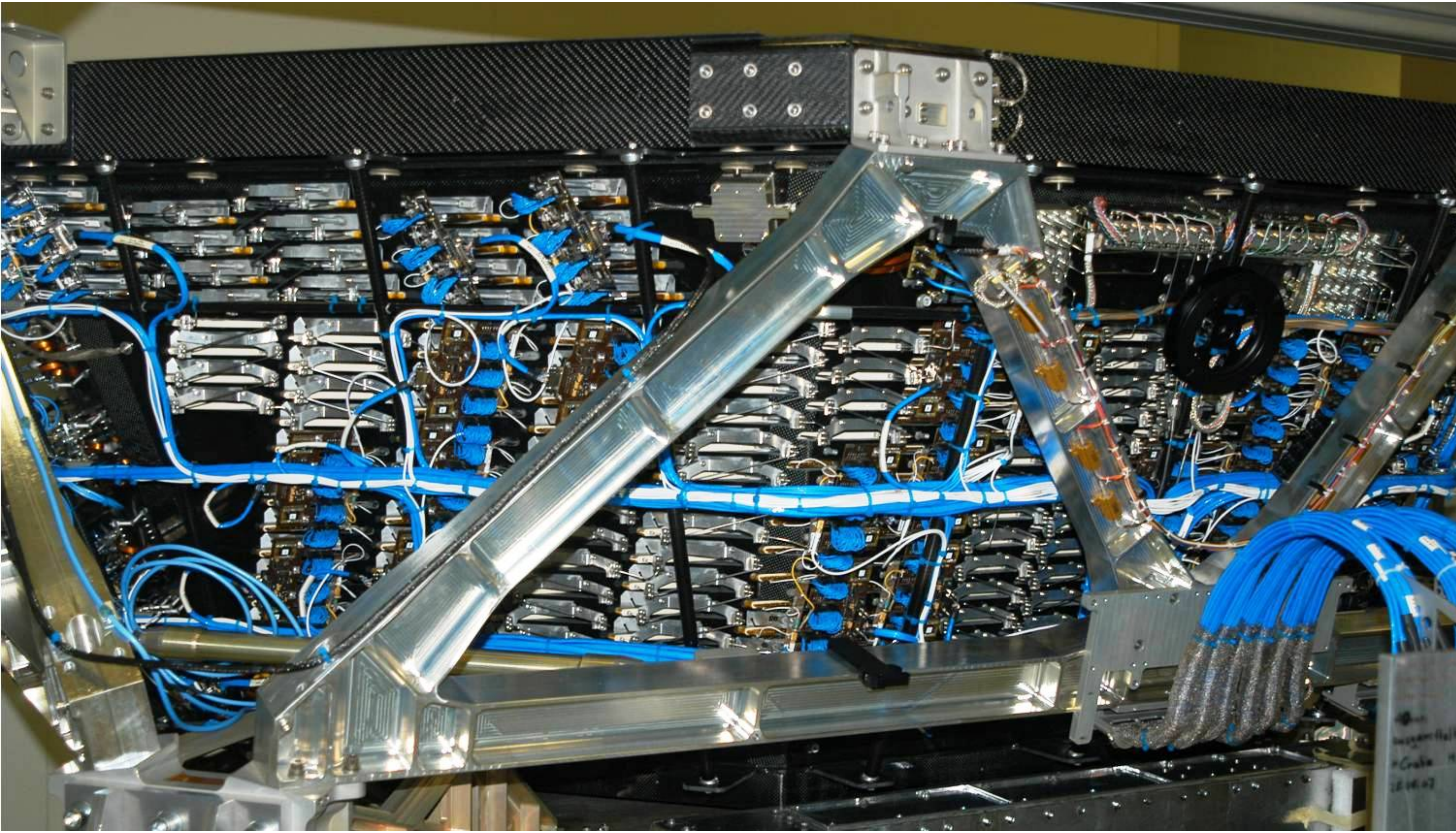
Cosmic rays are measured at up to 2 KHz and data is generated at ~7 Gbit/s, reduced on board to an average of ~10 Mbit/s.

- For every year of AMS flight:
- 20 TB raw data
- 160 TB reconstructed event data
- Data handling non-trivial!

AMS-02 Transition Radiation Detector



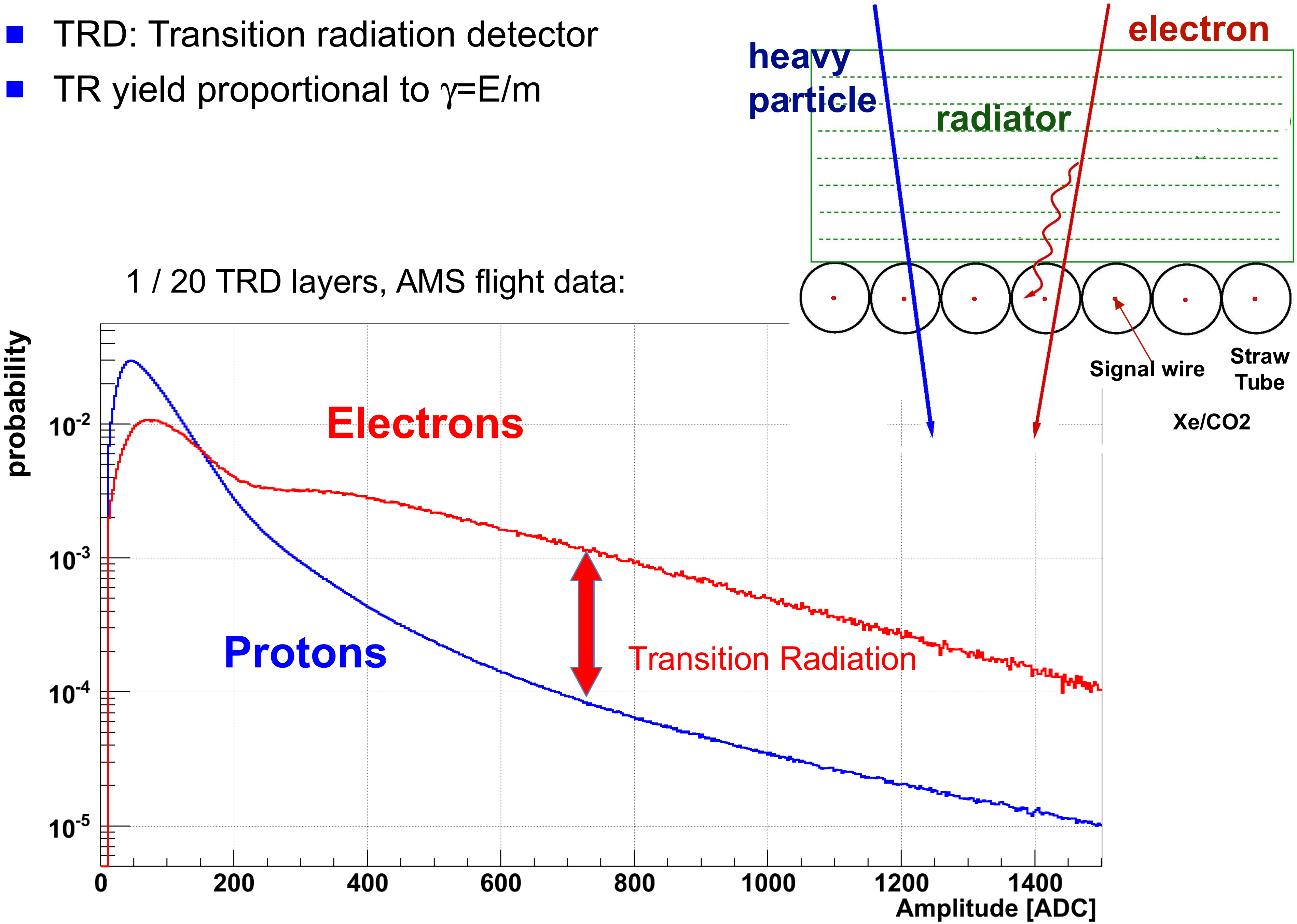
AMS-02 Transition Radiation Detector



Misidentifies only 1 in 10000 protons as a positron.

AMS-02 performance: TRD spectra

- TRD: Transition radiation detector
- TR yield proportional to $\gamma = E/m$

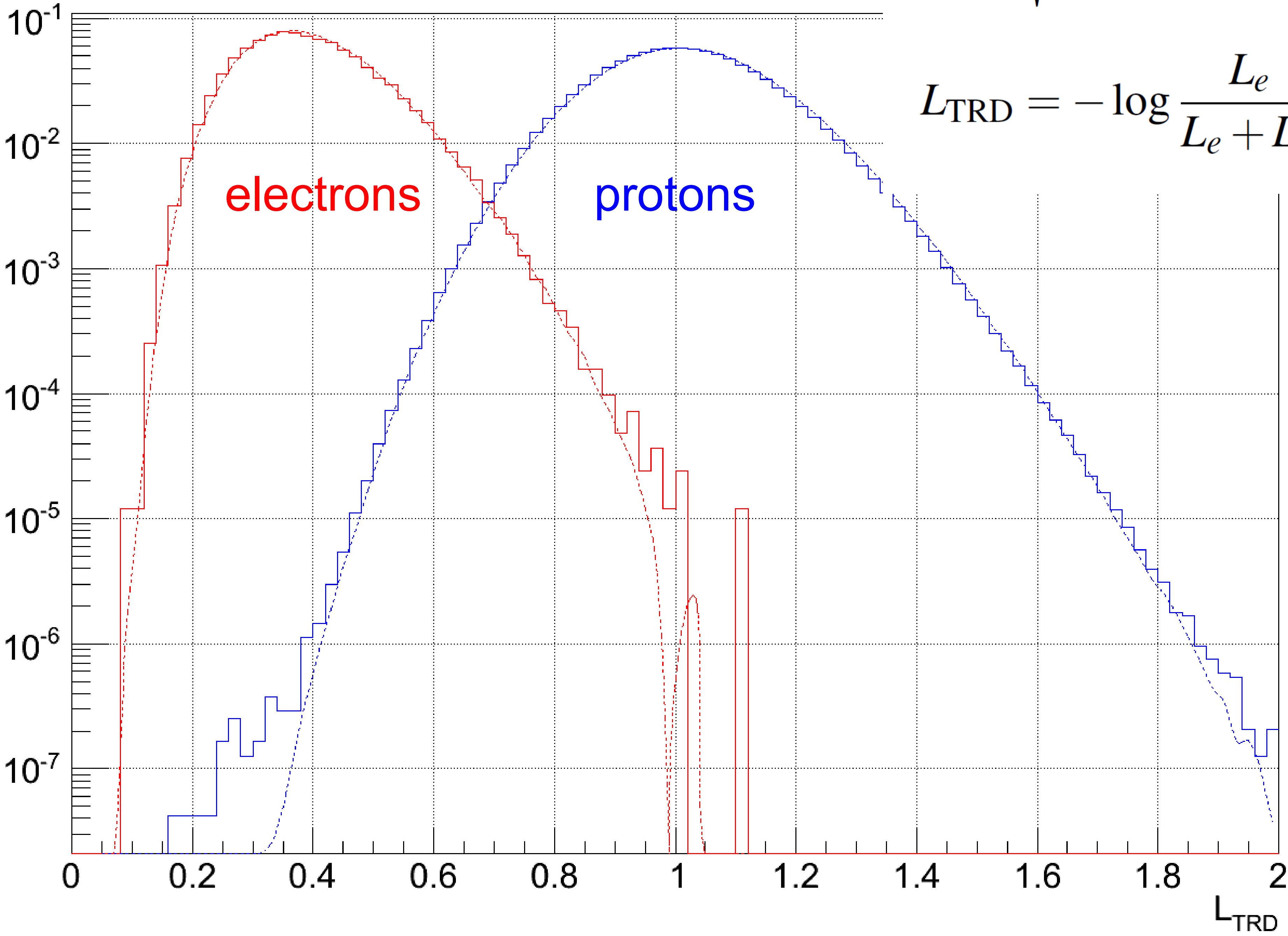


1 / 20 TRD layers, AMS flight data:

TRD electron-proton separation

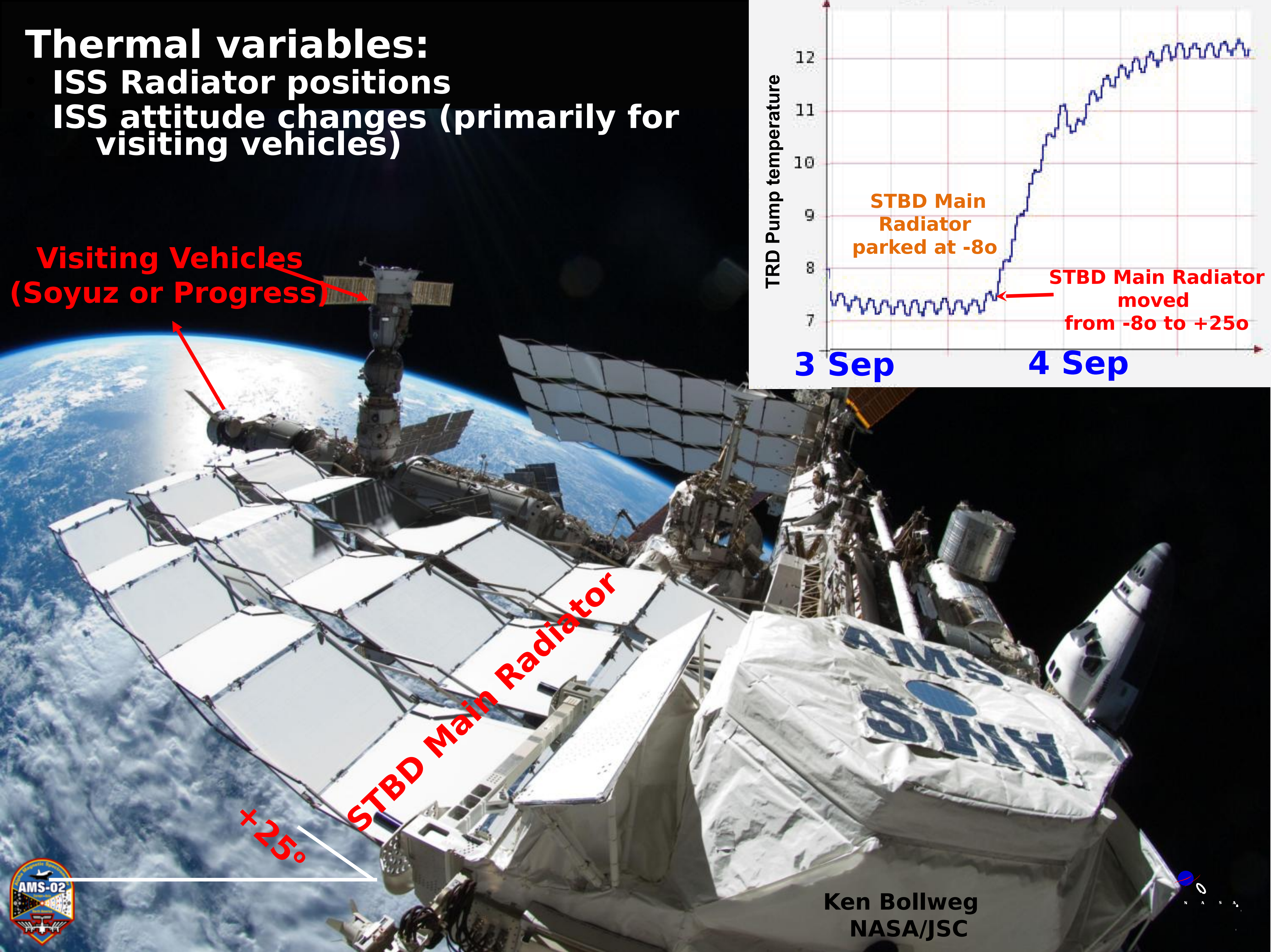
$$L_{e,p} = \sqrt[n]{\prod_i^n p_{e,p}(dE_i/dx_i)}$$

$$L_{\mathrm{TRD}} = -\log \frac{L_e}{L_e + L_p}$$



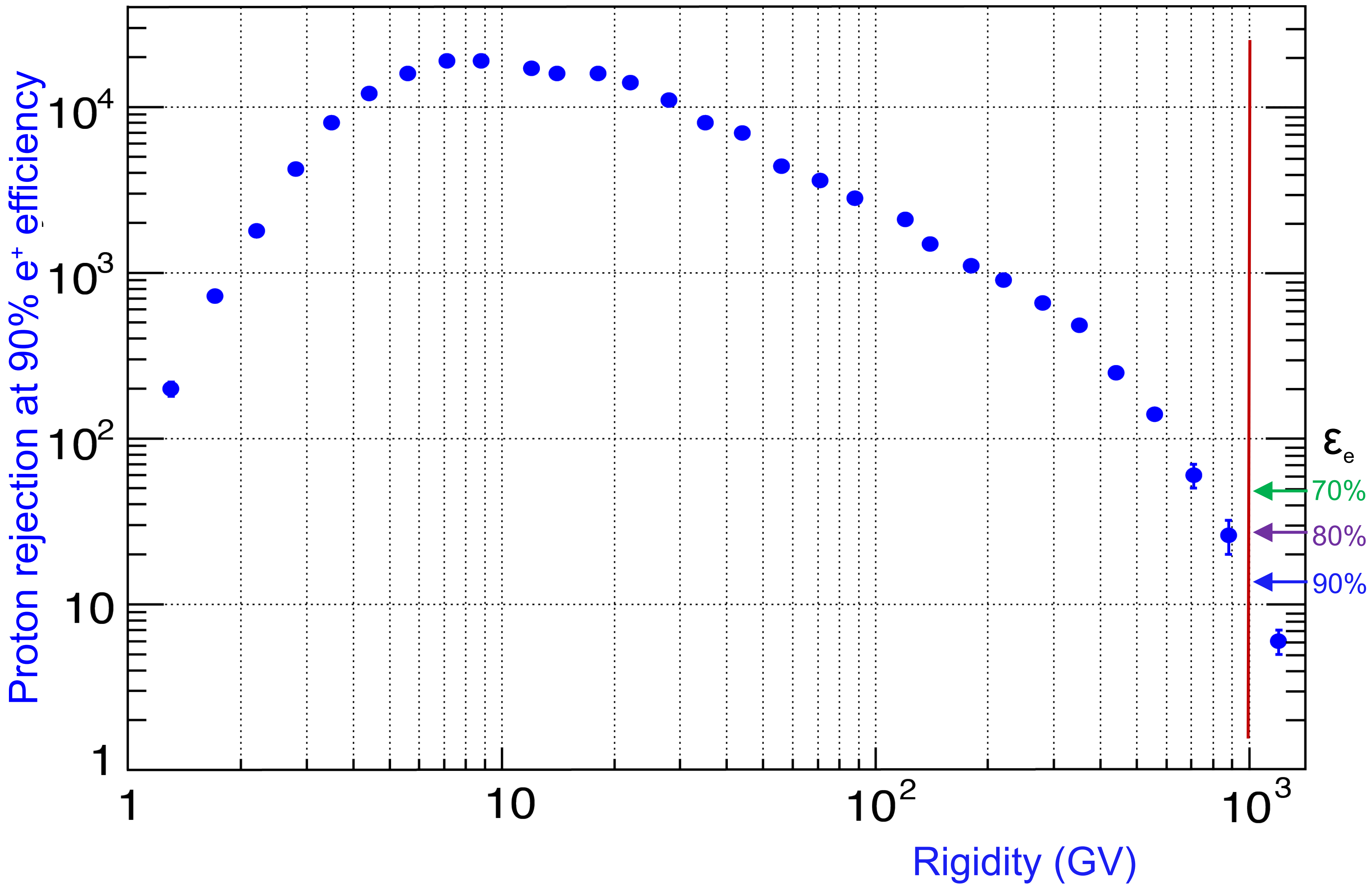
Thermal variables:

- ISS Radiator positions
- ISS attitude changes (primarily for visiting vehicles)



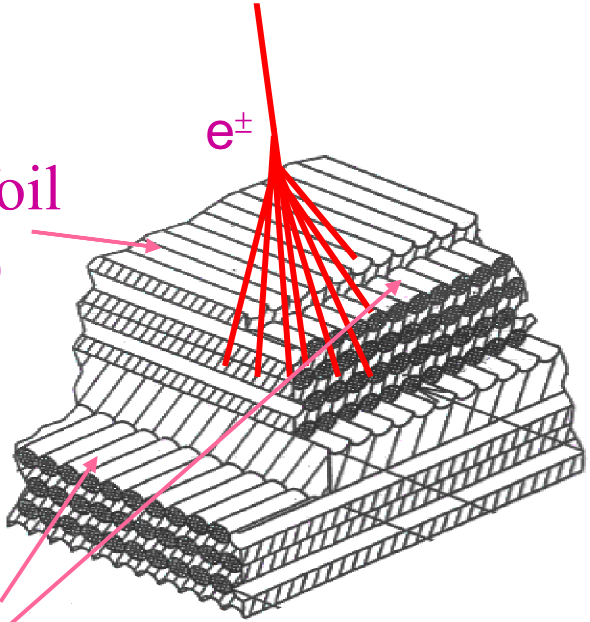
Ken Bollweg NASA/JSC

TRD proton rejection



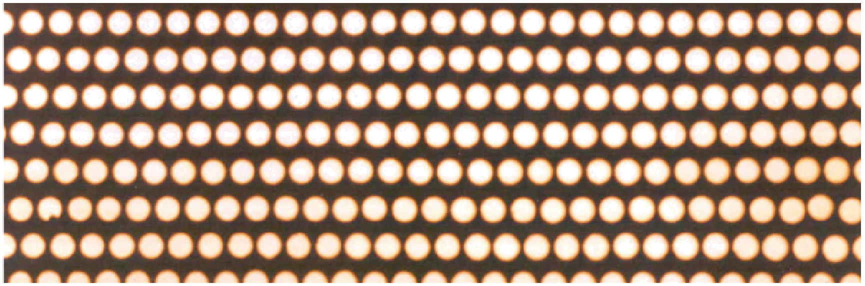
Calorimeter (ECAL)

A precision, 3-D measurement of the directions and energies of light rays and electrons up to 1 TeV



Lead foil (1mm)

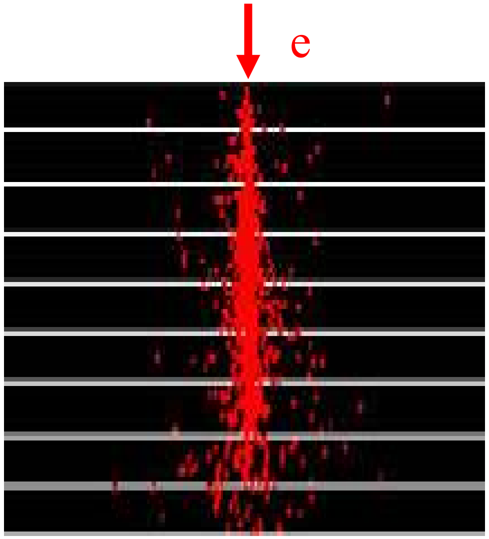
Fibers (ϕ1mm)



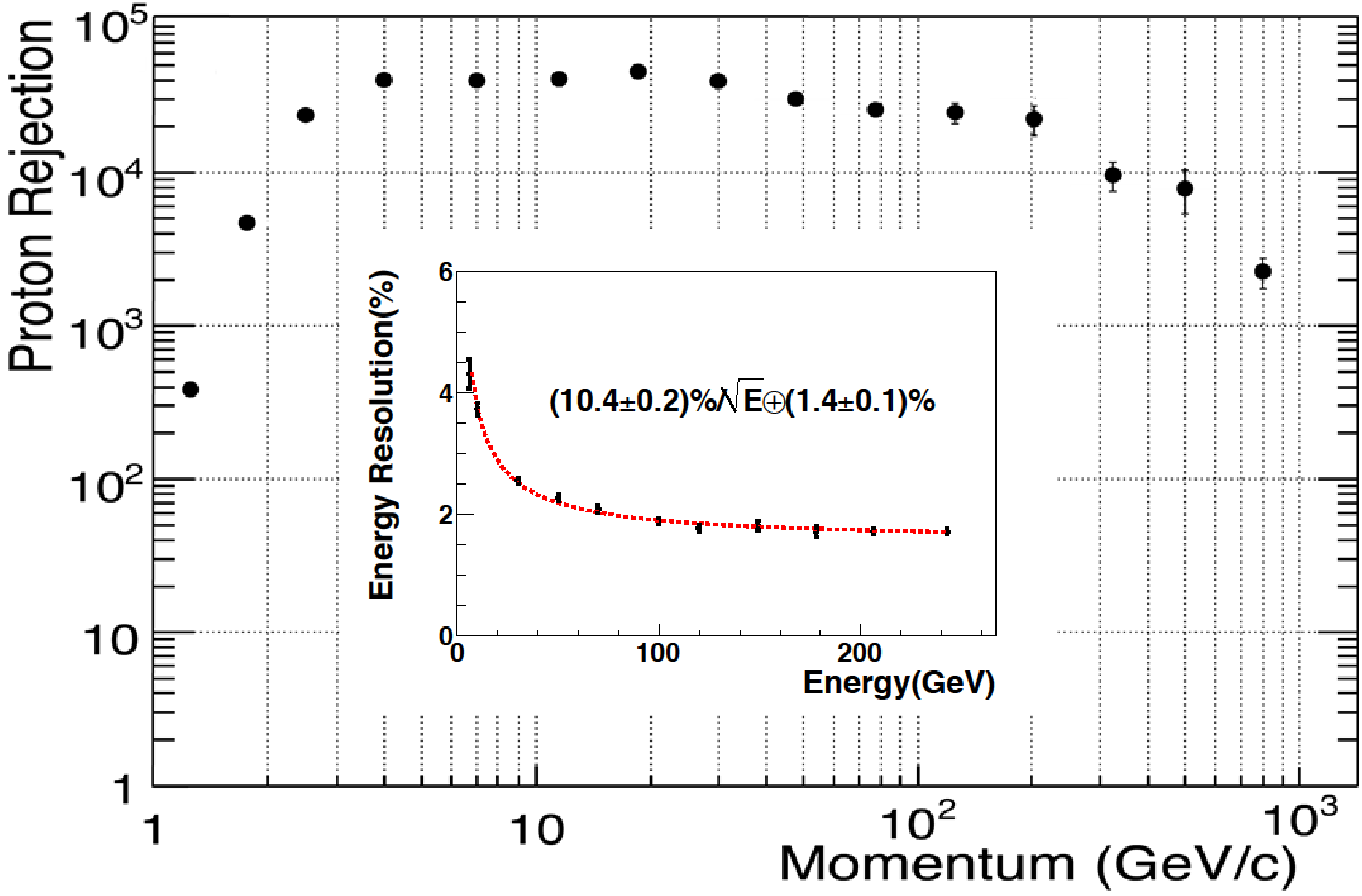
50,000 fibers, $\phi = 1$ mm

distributed uniformly Inside 600 kg of lead

Total 17 X_0

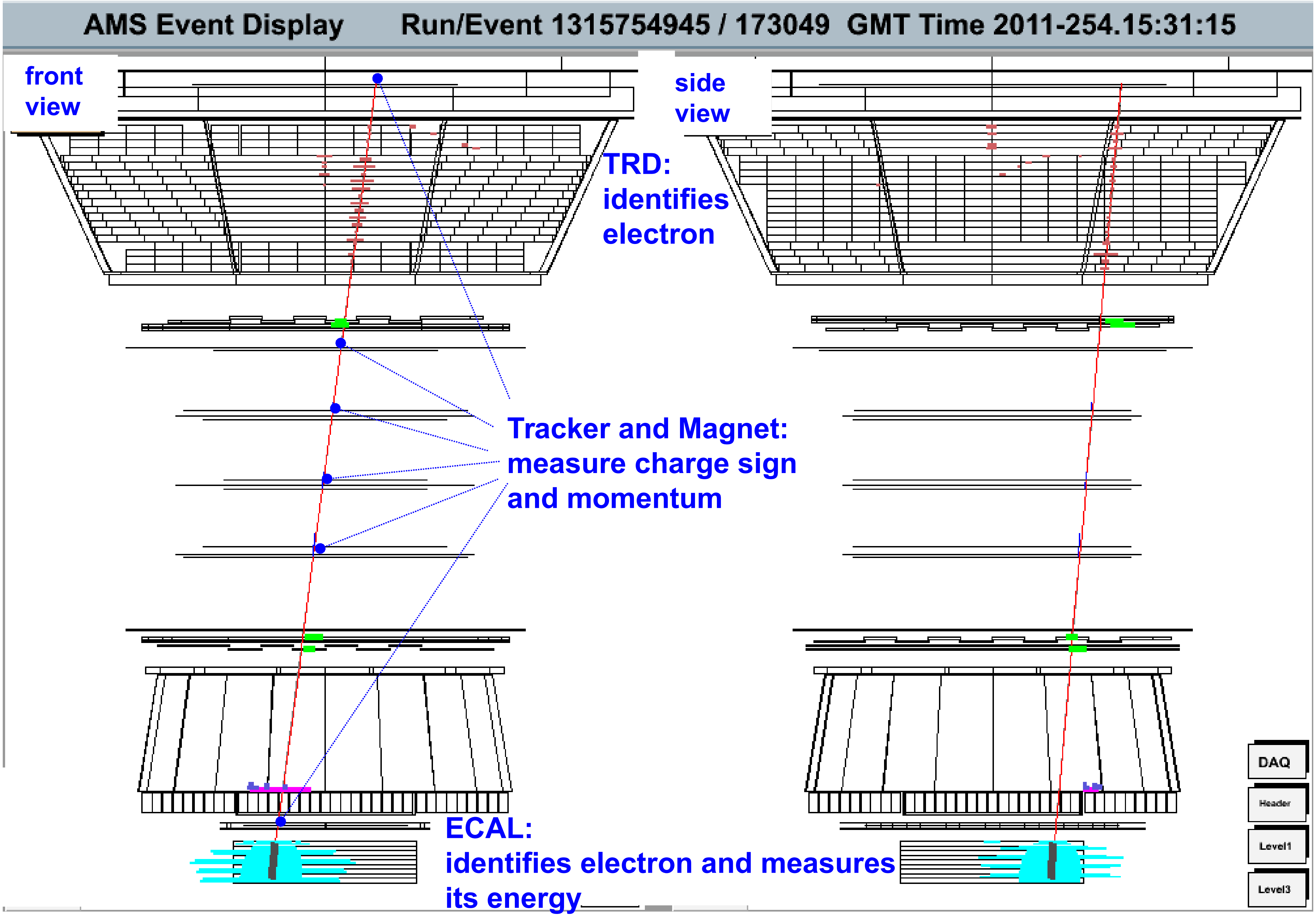


ECAL: proton rejection and energy resolution



1 out of 60,000,000,000 events:

1.03 TeV electron



TRD: identifies electron

Tracker and Magnet: measure charge sign and momentum

ECAL: identifies electron and measures its energy

AMS Computing on JUROPA at Julich Supercomputing Centre

Production of reconstructed AMS-02 event files for first AMS-02 publication performed on JUROPA supercomputer within 12 days of time.

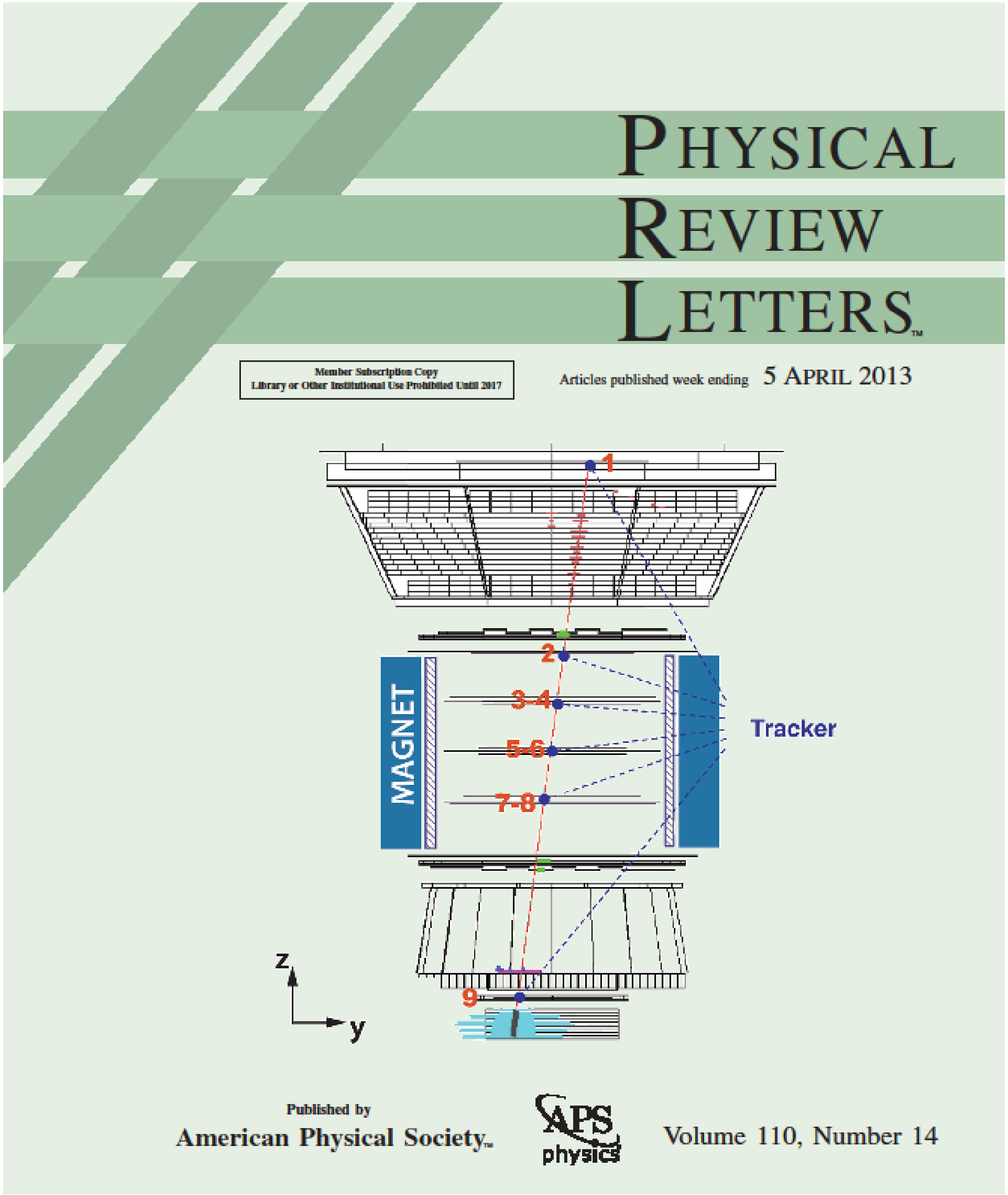
First results from AMS

1) Measurement of the positron fraction in primary cosmic rays of 0.5-350 GeV.
Selected for a Viewpoint in Physics and an Editors' Suggestion.
Phys. Rev. Lett. 110 (2013) 141102

2) Measurement of the positron fraction in primary cosmic rays of 0.5-500 GeV.
Selected for an Editors' Suggestion.
Phys. Rev. Lett., 113 (2014) 121101

3) Electron and positron fluxes in primary cosmic rays,
up to 700 GeV (e-) and
up to 500 GeV (e+).
Selected for an Editors' Suggestion.
Phys. Rev. Lett., 113 (2014) 121102

4) Precision Measurement of the e+ + e- Flux in Primary Cosmic Rays from 0.5 GeV to 1 TeV with the Alpha Magnetic Spectrometer on the International Space Station.
Phys. Rev. Lett., 113 (2014) 221102



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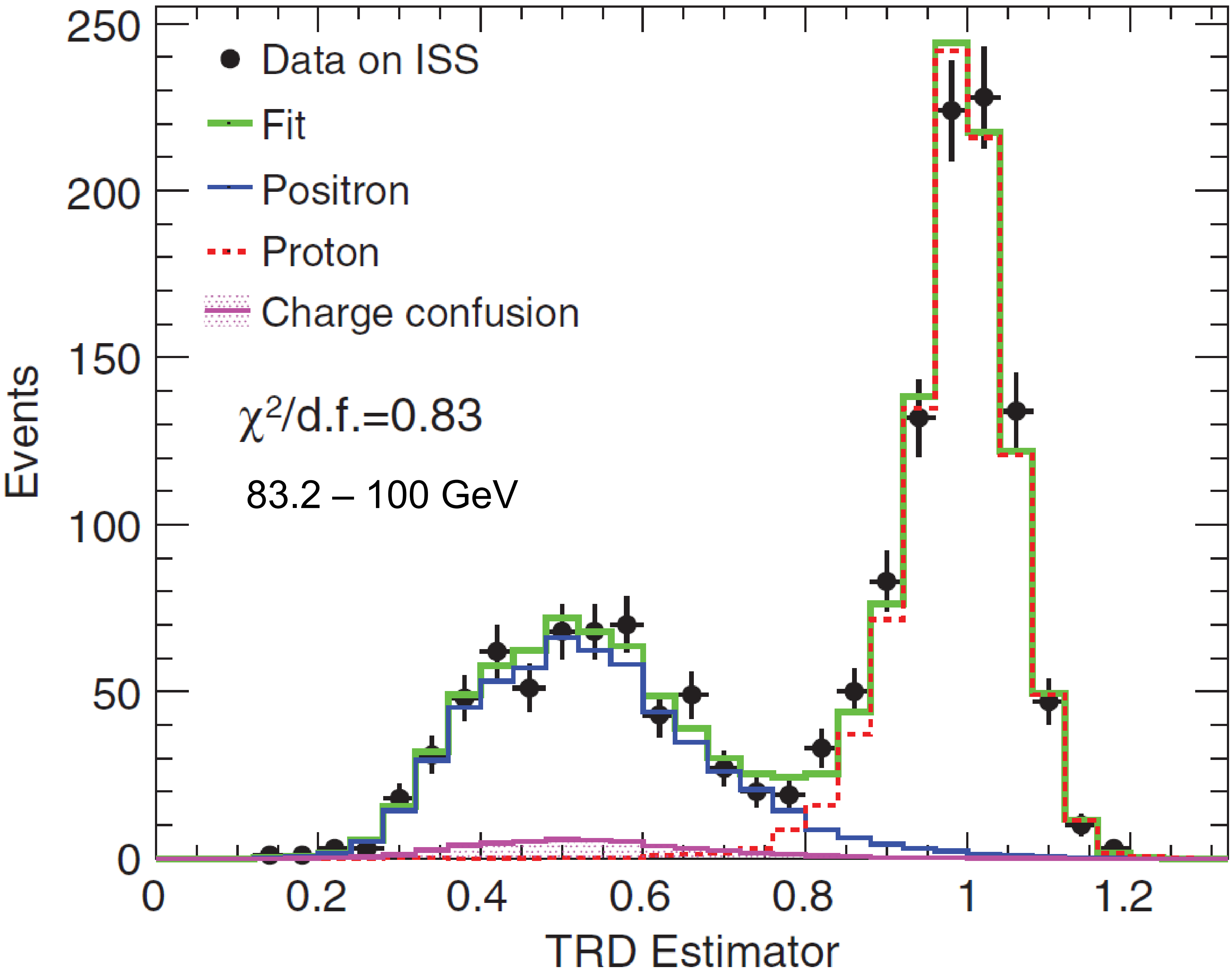
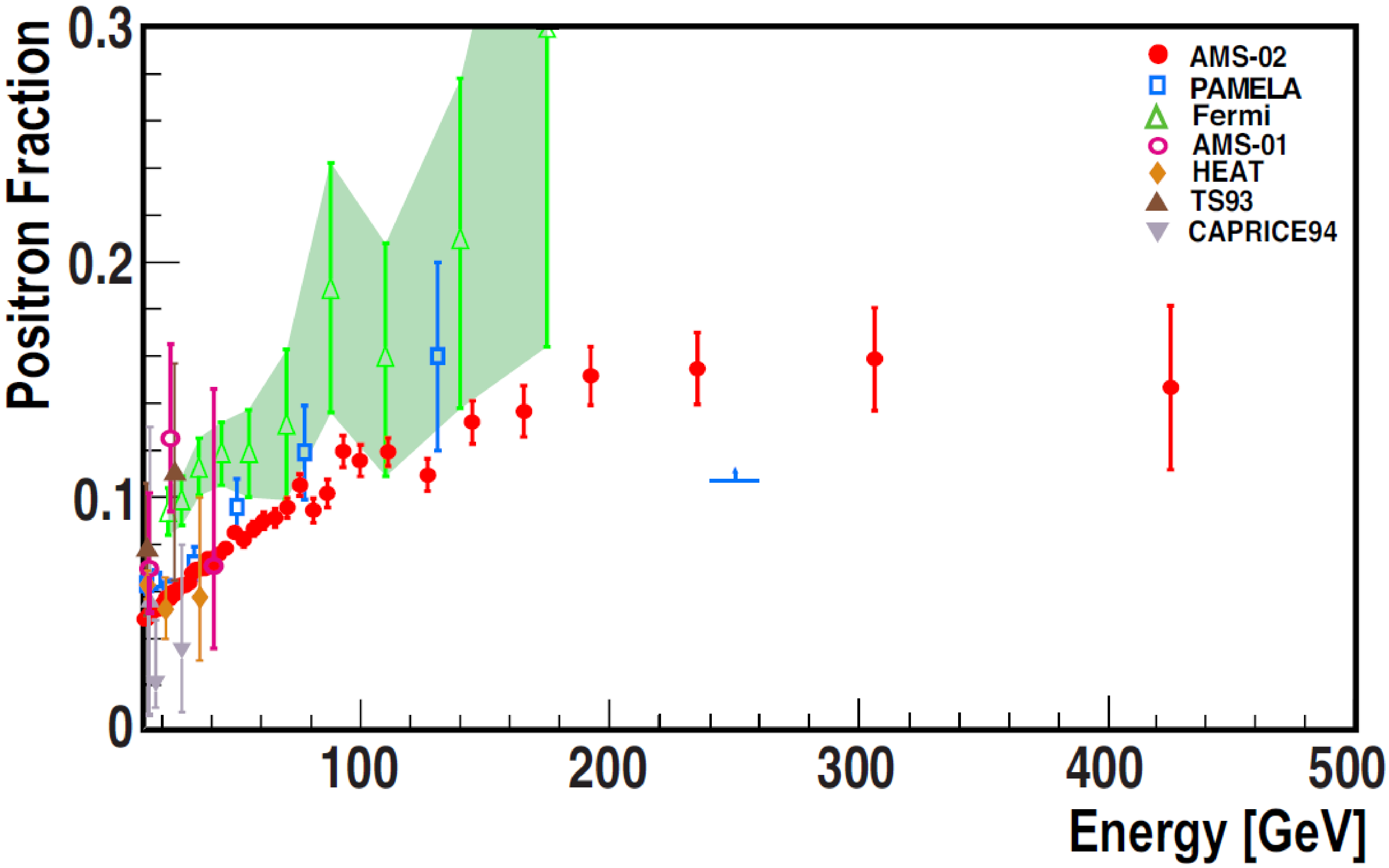
Example of positron selection

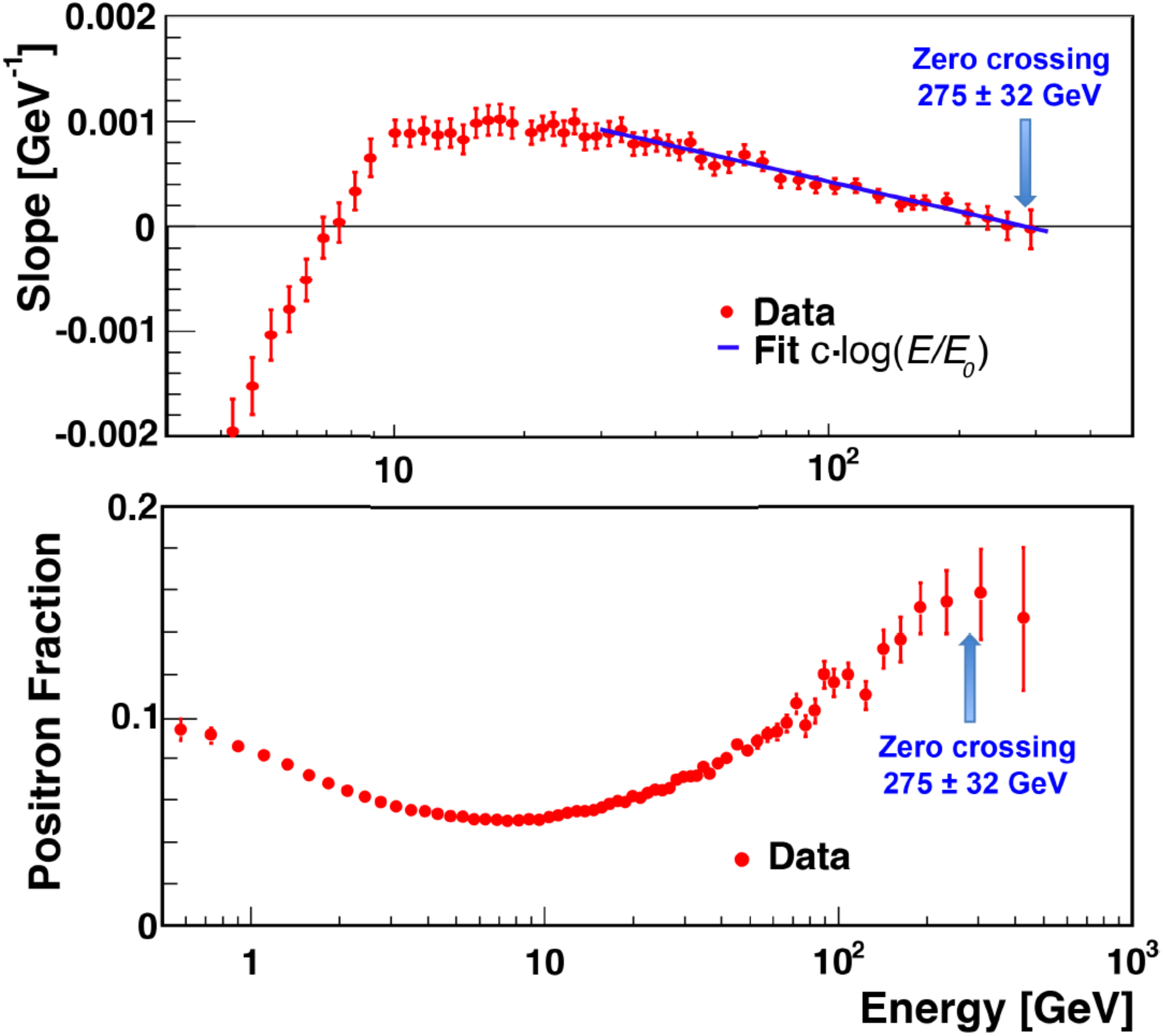


Positron fraction in primary cosmic rays measured by AMS



Above ~200 GeV, positron fraction no longer exhibits increase with energy. No sharp structures are observed.

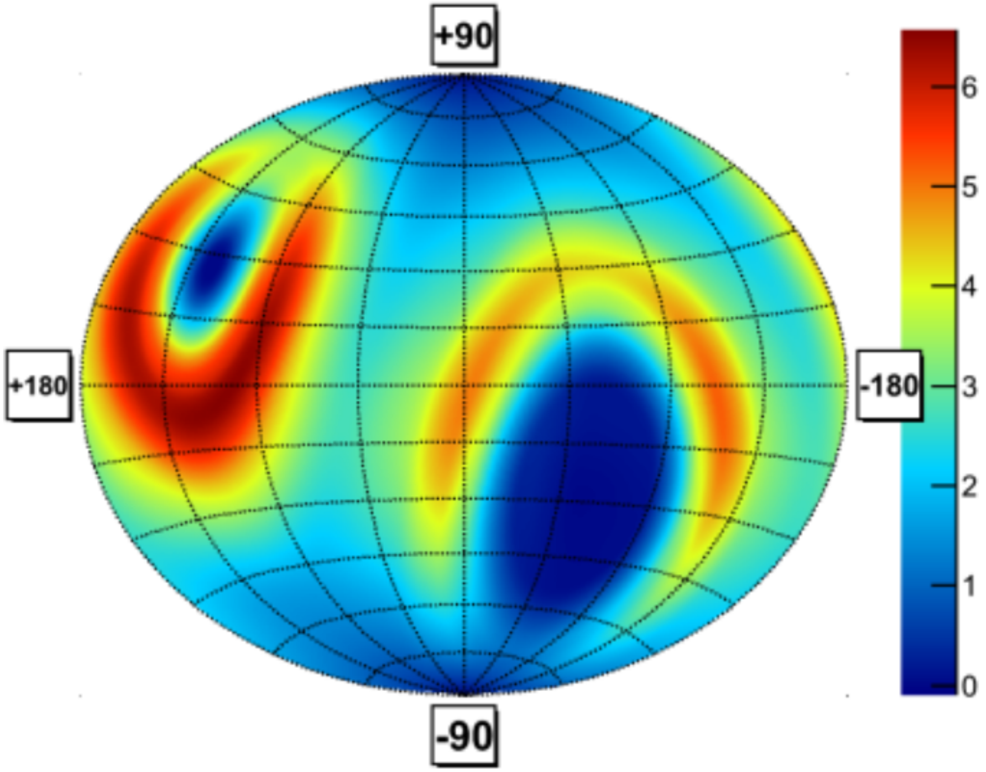
Positron fraction slope seen by AMS-02



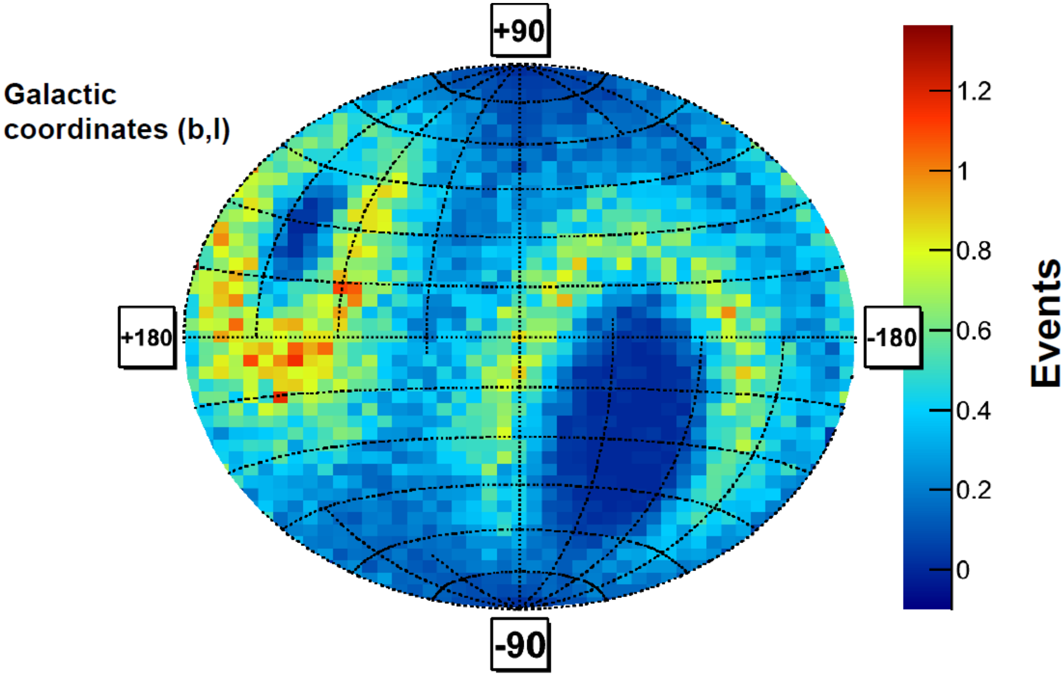
Search for dipole anisotropy in positrons

- Data are consistent with isotropic distribution of arrival directions.

Expected Isotropic Distribution

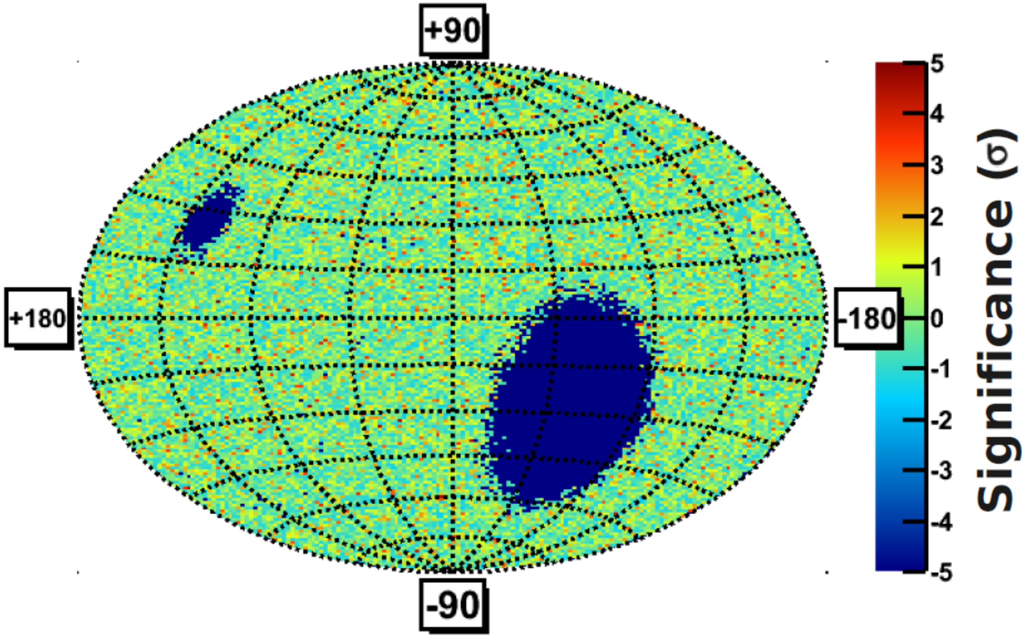


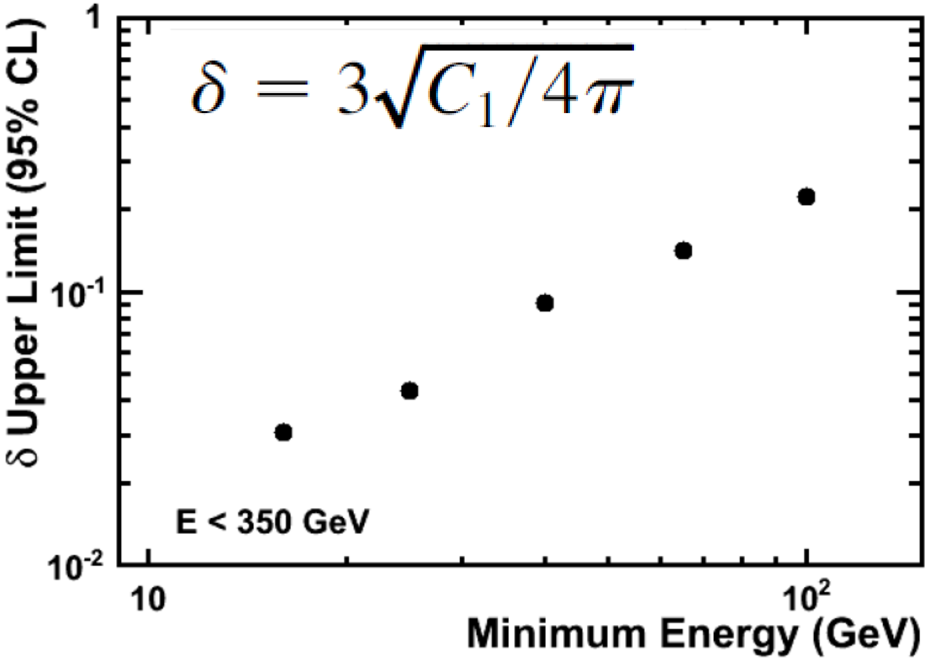
Positrons at high energies



Limit on dipole anisotropy

- Data are consistent with isotropic distribution of arrival directions.

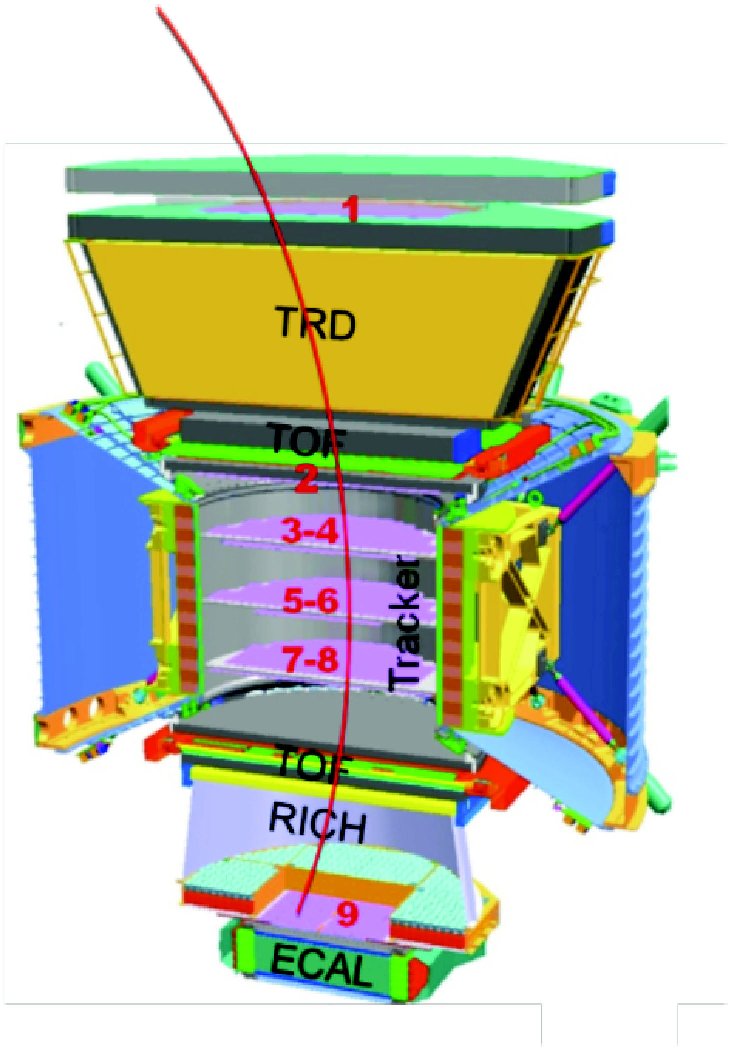




AMS-02:

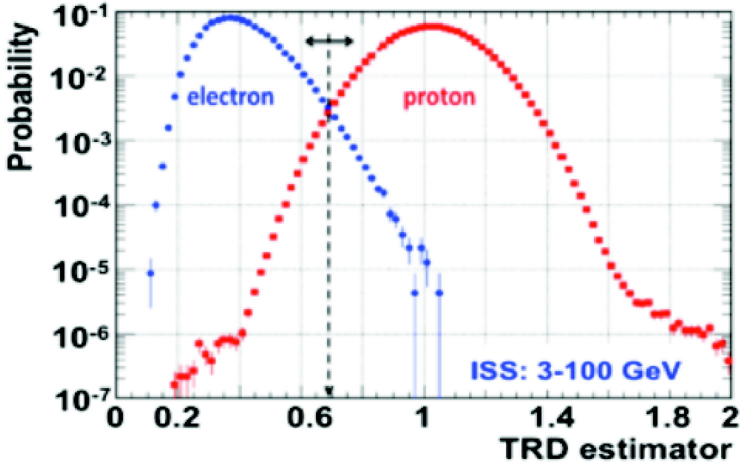
δ < 0.03 at the 95% confidence level.

Measuring electron and positron fluxes



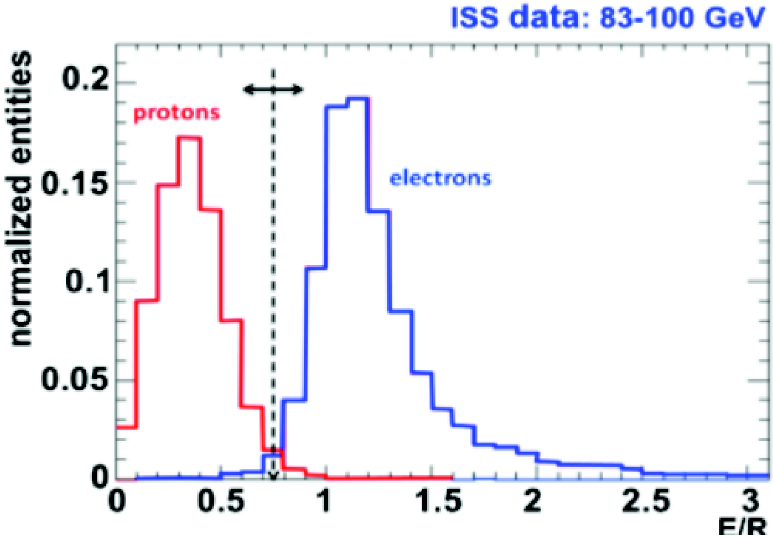
TRD

(transition radiation)



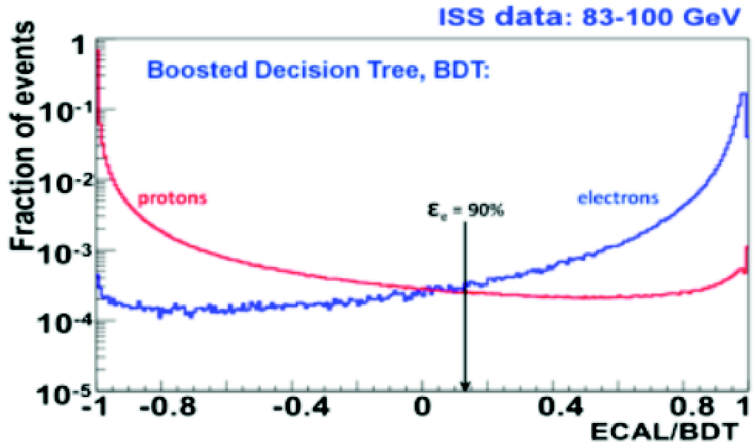
ECAL/Tracker

(E/p matching)



ECAL

(shower shape)



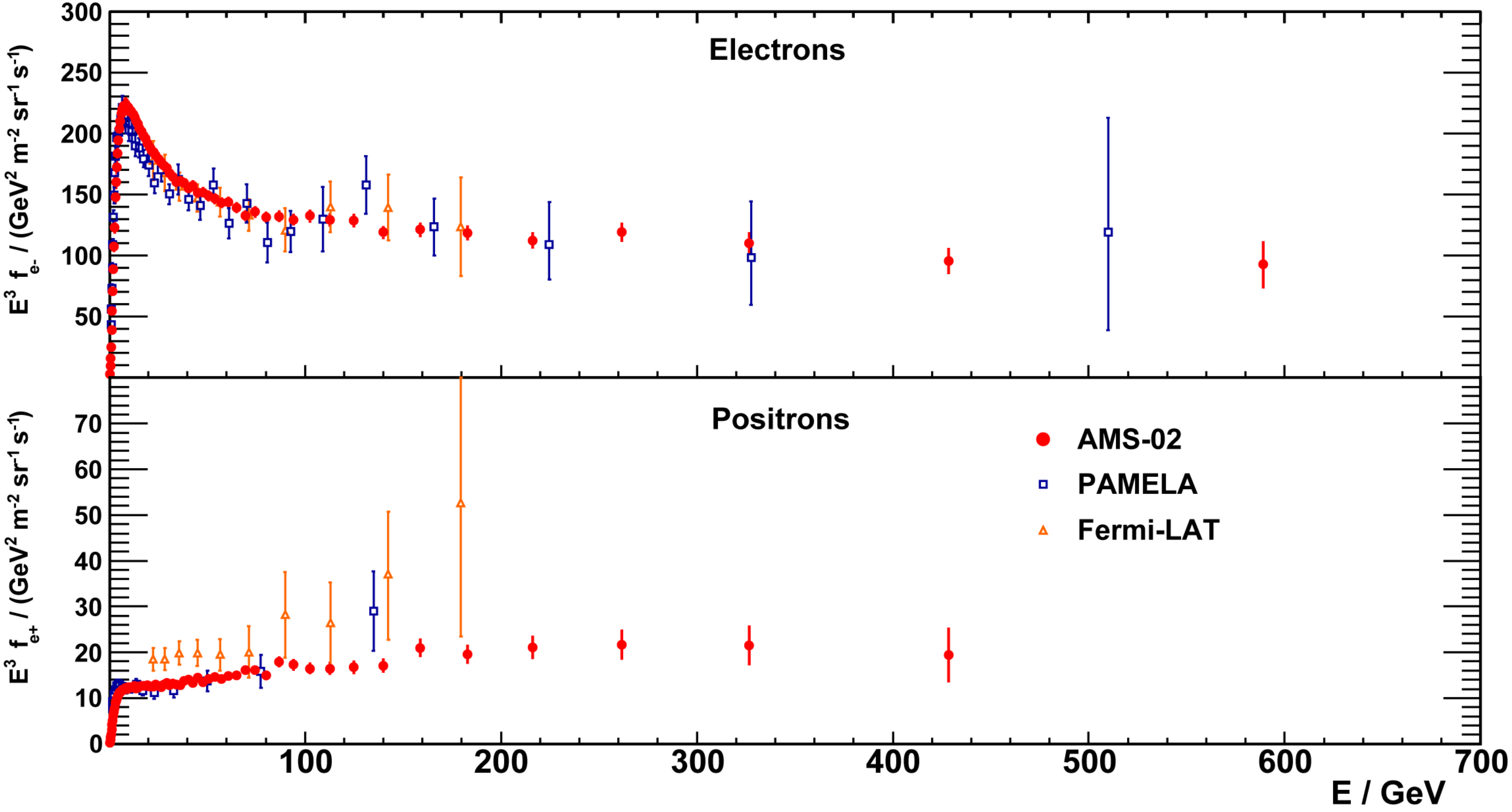
TRD, TOF, tracker, and ECAL define:

1)Geometric acceptance, A_{GEOM}, ~ 550 cm^2sr

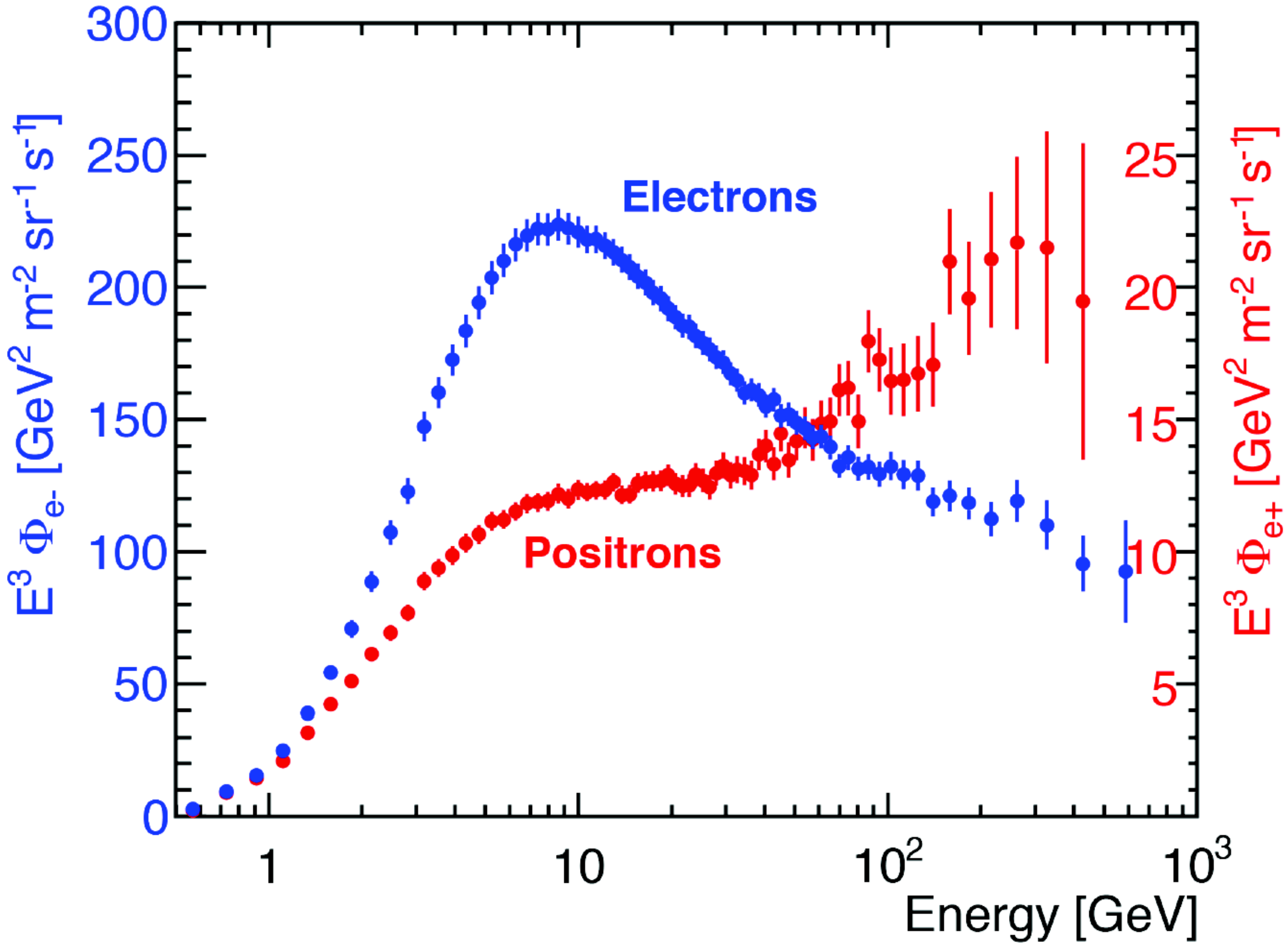
2)Selection efficiency, ε_{SEL} for downward |Z|=1 track

3)Identification efficiency, ε_{ID}, for $e^{\pm}$

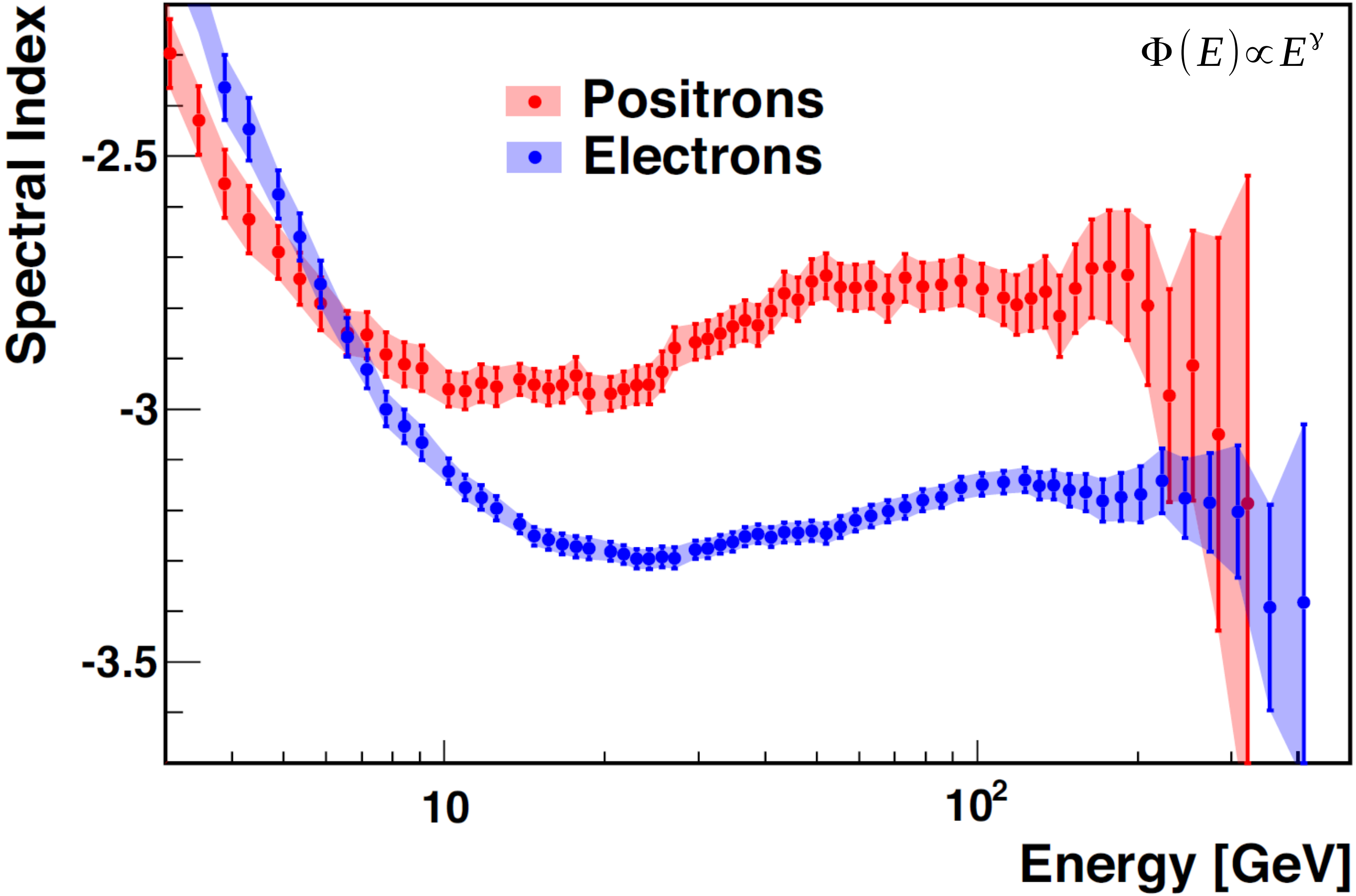
A new era of precision: e± fluxes from AMS



A new era of precision: e± fluxes from AMS

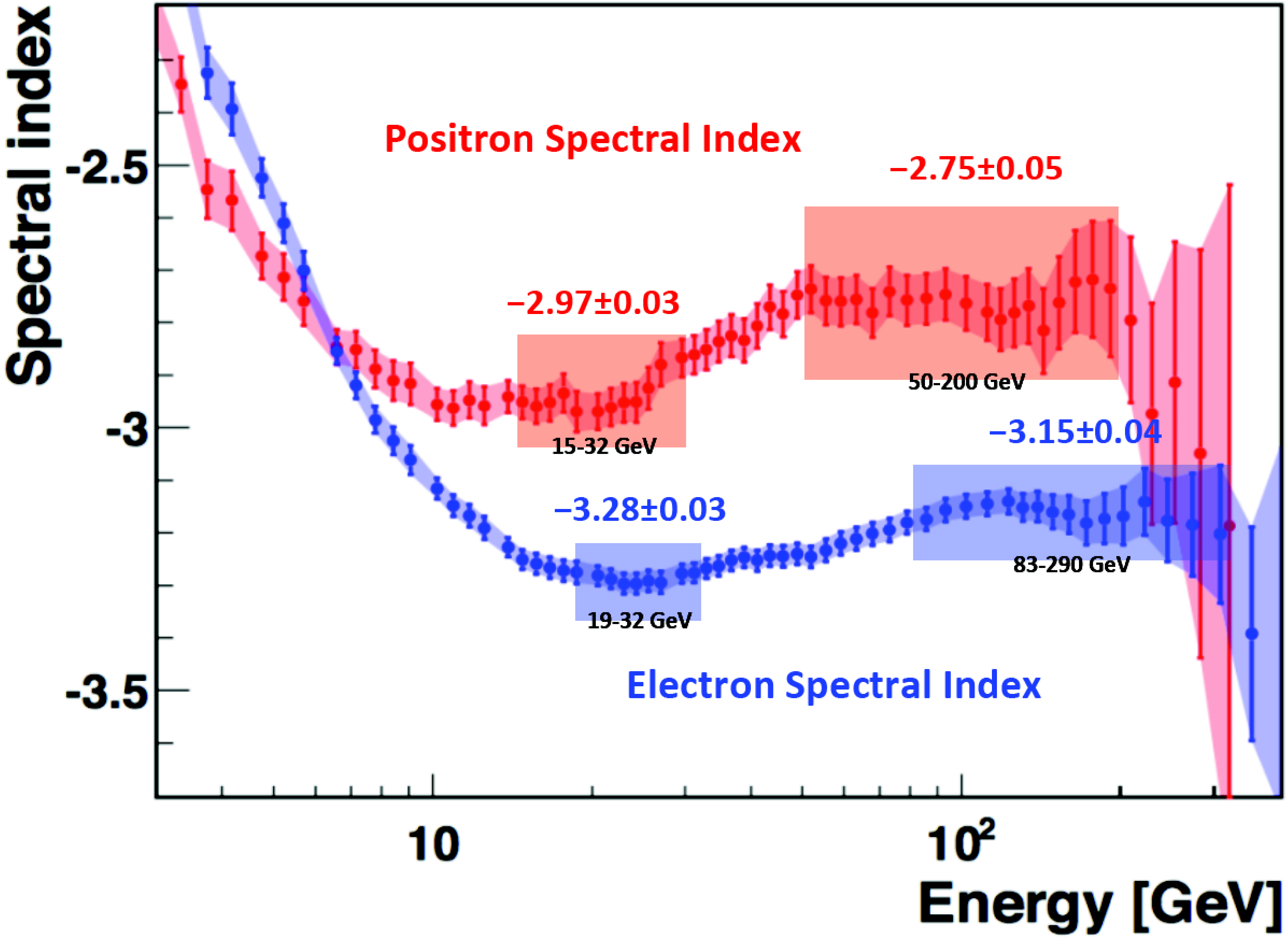


Spectral index in sliding windows



Below 10 GeV: solar modulation.
Neither spectrum described by single power law.
20 to 200 GeV: positron flux significantly harder than electron flux
Differing behavior of the spectral indices vs energy.
Above ~200 GeV: positron flux shows tendency to soften.

Change of spectral index for positron flux and electron flux



Summary:
Precision Measurements of the Electron and Positron Fluxes

1. Both the electron flux and the positron flux are significantly different in their magnitude and energy dependence.

2. Both spectra cannot be described by single power laws.

3. Both the electron and positron fluxes change their behaviors at about 30 GeV.

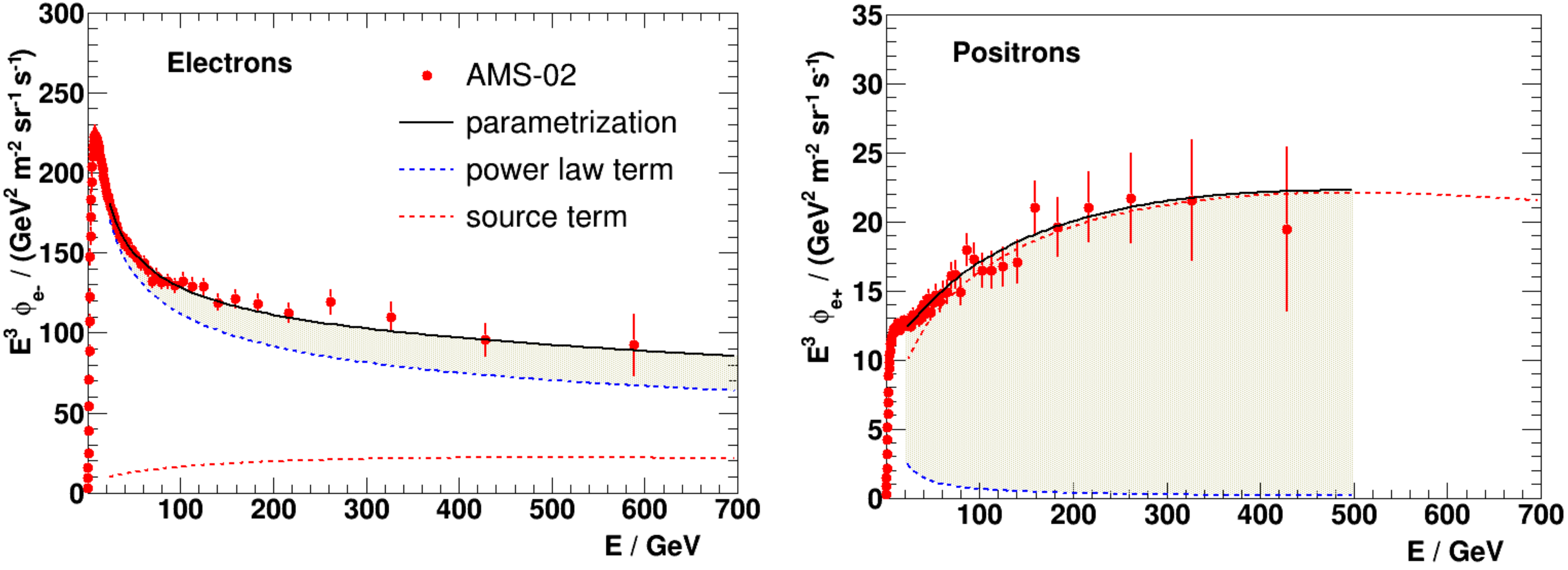
4. Between 20 and 200 GeV the positron spectral index is significantly harder than the electron spectral index and this causes the rise in the positron fraction (not the loss of electrons).

5. These new observations provide important information on the origin of cosmic ray electrons and positrons.

Generic model fits

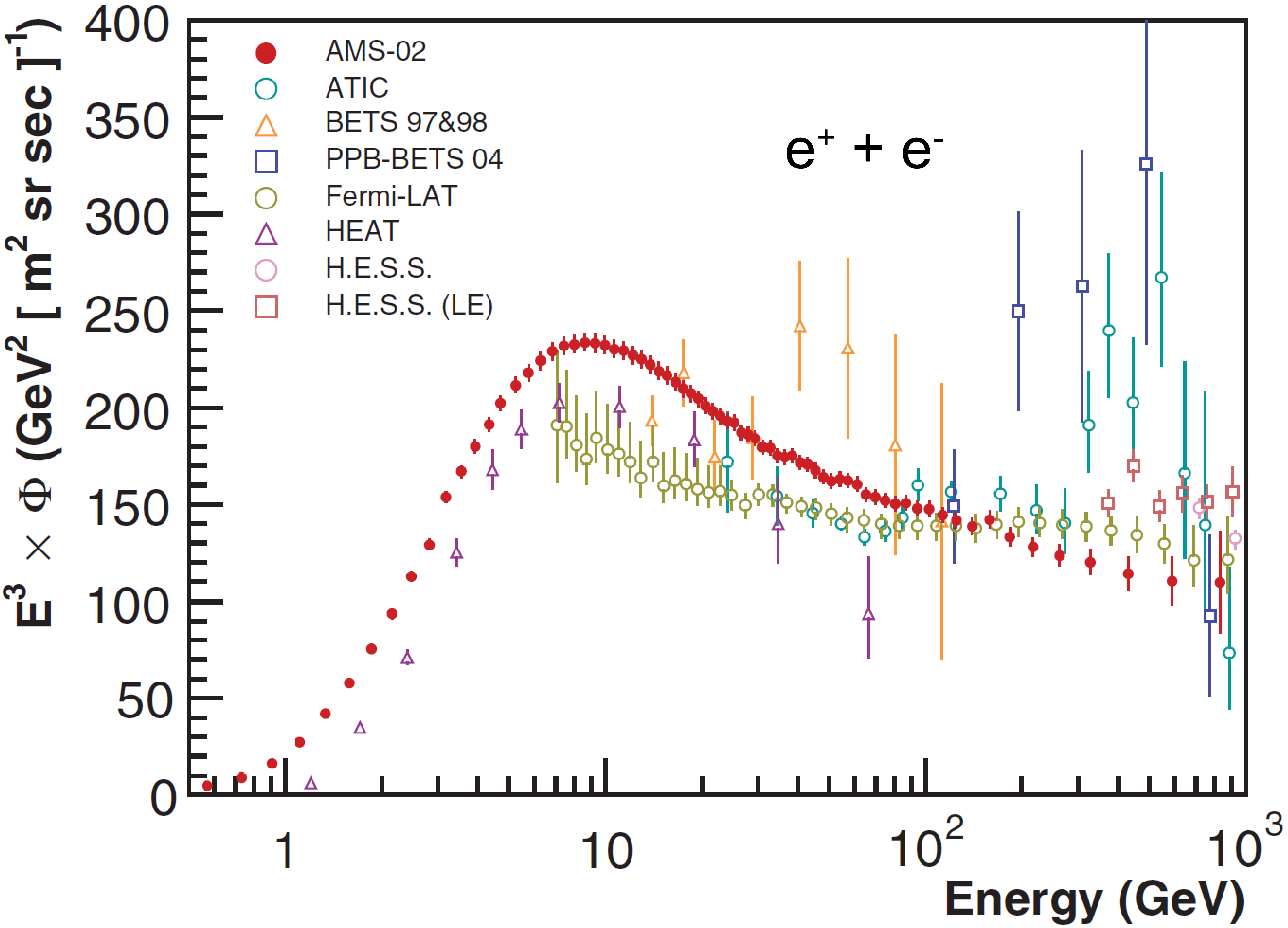
$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$



Simultaneous fit to electron and positron above 15 GeV, positron fraction below.

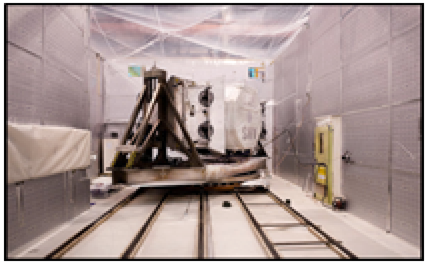
AMS measurement of $(e^{+}+e^{-})$ flux



The New York Times

Space & Cosmos

Tantalizing New Clues Into the Mysteries of Dark Matter



Fred Merz for The New York Times

The Alpha Magnetic Spectrometer under construction in 2010 at the European Organization for Nuclear Research in Geneva.

By DENNIS OVERBYE

Published: April 3, 2013

The dark side of the universe is whispering, but scientists are still not sure what it is saying.

Samuel Ting, a professor at the Massachusetts Institute of Technology and a Nobel laureate particle physicist, said Wednesday that his $1.6 billion cosmic ray experiment on the International Space Station had found evidence of "new physical phenomena" that could represent dark matter, the mysterious stuff that serves as the gravitational foundation for galaxies and whose identification would rewrite some of the laws of physics.

The results, he said, confirmed previous reports that local interstellar space is crackling with an unexplained abundance of high energy particles, especially positrons, the antimatter version of the familiar electrons that comprise electricity and chemistry. They could be colliding particles of dark matter. Or they could be coming from previously undiscovered pulsars or other astronomical monsters, throwing off wild winds of radiation.

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THE WALL STREET JOURNAL.

U.S. NEWS

Updated April 3, 2013, 6:50 p.m. ET

Hint of Dark Matter Found

By GAUTAM NAIK

The $2 billion particle detector, or AMS, is mounted to the international space station's exterior to gather data.

A space experiment may have identified a new particle that is the building block of dark matter, the mysterious stuff said to pervade a quarter of the universe that neither emits nor absorbs light. The results are based on a small amount of data and are far from definitive, scientists said Wednesday. Yet, they provide a provocative hint that the puzzle of dark matter—a cosmic prize as eagerly sought as the now-discovered Higgs boson—may also be on its way to being solved.

The results are the first obtained by a $2 billion particle detector, known as Alpha Magnetic Spectrometer, or AMS, that is mounted on the exterior of the international space station. It collects and identifies charged cosmic rays arriving from the far reaches of space.

The experiment is sponsored by the U.S. Department of Energy. It is led by Nobel laureate Samuel Ting of the Massachusetts Institute of Technology and involves hundreds of scientists from all over the world. The latest data will be published in the journal Physical Review Letters.

• • •

Le Monde

Samedi 6 avril 2013

SCIENCE & TECHNO | ACTUALITÉ

Matière noire ou pulsars ? L'énigme du « chaudron galactique »

ASTROPHYSIQUE | L'expérience AMS embarquée sur la Station spatiale internationale apporte de nouvelles données confirmant que la Voie lactée abrite une source inconnue de particules

DAVID LAROUSSERIE

Il y a bien quelque chose de bizarre dans notre galaxie. Quelque chose comme un chaudron d'où jailliraient plus de particules que ce que la théorie attendrait. Mais de quoi est fait ce chaudron ?

La question était au centre des résultats présentés par le Prix Nobel de physique 1976, Samuel Ting, dans un amphithéâtre de l'Organisation européenne de physique nucléaire (CERN), en Suisse, mercredi 3 avril. Ce chercheur est le porte-parole de l'expérience internationale AMS-02, installée sur la Station spatiale internationale depuis mai 2011 à quelque 330 kilomètres d'altitude. Cet instrument de huit tonnes et demie, fruit d'une collaboration principalement américaine et européenne, détecte l'ensemble des rayons cosmiques comme les électrons, les protons, l'hélium mais aussi leurs antiparticules, sortes de sœurs jumelles de charges électriques opposées, positon, antiproton ou antihélium.

Ces flux de matière constituent ce qu'on appelle les rayons cosmiques, violentes émissions de particules à l'origine d'ailleurs encore inconnue depuis leur détection par Victor Hess en 1912, à bord d'un ballon.

Les dix-huit mois d'enregistrement d'AMS-02 ont permis de voir passer plus de 25 milliards de particules. Et parmi celles-ci, à haute énergie, les chercheurs observent quelque 400 000 antiélectrons, ou positons. Soit un excès d'environ dix fois ce qui était attendu dans des scénarios conventionnels.

Frankfurter Allgemeine

ZEITUNG FÜR DEUTSCHLAND

Natur und Wissenschaft

Antimateriejäger auf der Raumstation

Mit dem Betrieb des AMS-Detektors hat die Ära der Präzisions-Astroteilchenphysik begonnen. Jetzt hat man die ersten Daten vorgelegt. Hinweise auf Dunkle Materie liefern sie nicht, lassen aber Raum für Interpretationen.

Von Jan Hattenbach

Lange ließ Samuel Ting seine Zuhörer im großen Hörsaal des europäischen Forschungszentrums Cern in Genf am Mittwoch in der vergangenen Woche warten. Der Physik-Nobelpreisträger vom Massachusetts Institute of Technology hat während der vergangenen zwei Jahrzehnte, die er dem Bau des größten je im All betriebenen Teilchendetektors gewidmet hat, gelernt, geduldig zu sein. Da ließ er es sich nicht nehmen, zunächst ausführlich auf die technischen Details des Antimaterie-Spektrometers AMS (Alpha Magnetic Spectrometer) und die bewegten Zeiten einzugehen, die es auf seinem Weg zur Internationalen Raumstation (ISS) durchlebt hat. Dann erst sprach er über die mit Spannung erwarteten ersten Resultate. Eine Sensation konnte Ting allerdings nicht verkünden. Wer Neues in Sachen Dunkle Materie, gar den Nachweis der „Wimps" – jene hypothetischen Teilchen gelten als Kandidaten für die das Universum durchziehende unsichtbare und noch unbekannte Materieform – erwartet hatte, wurde enttäuscht. Selbst von Hinweisen zu sprechen, wäre übertrieben: „Als Experimentalphysiker richten wir uns nach dem, was die Daten sagen." Leider sprachen die Daten eine orakelhafte Sprache, und so kommt es darauf an, wie man sie interpretiert.

Seit Jahren suchen Wissenschaftler nach Wimps (Weakly Interacting Massive Particles). Die massereichen Partikeln, die keine Ladung tragen und nur äußerst selten mit ihrer Umgebung interagieren, haben sich jedoch bislang allen Nachweisversuchen entzogen. Theorien zufolge könnten sie bei Kollisionen zerstrahlen und dabei energiereiche Teilchen erzeugen – etwa Positronen, die Antiteilchen der Elektronen –, die sich mit empfindlichen Detektoren aufspüren ließen. Ein Überschuss von Positronen in der kosmischen Teilchenstrahlung bis zu einem bestimmten Energiewert, einem „Knick" im Energiespektrum, wäre ein Hinweis auf die Existenz Dunkler Materie.

Tatsächlich, so verkündete Ting, hat das Spektrometer nach 18 Monaten im All einen Positronenüberschuss gefunden („Physical Review Letters", Bd. 110, Nr. 141102). Begeisterungsstürme rief diese Nachricht jedoch nicht hervor, schließlich hatte der Satellit „Pamela" bereits vor drei Jahren den gleichen Befund erbracht. Und dem Energiespektrum, das Ting präsentierte, fehlte der erhoffte Knick. Zwar muss es für den signifikanten Positronenüberschuss eine noch unbekannte Quelle geben, aber genauso wahrscheinlich wie die Dunkle Materie – und für viele Experten noch wahrscheinlicher – kommen Pulsare dafür in Frage. Die Sache ist also verzwickt: Weder liefern die Daten von AMS klare Hinweise auf Wimps, noch kann man deren Existenz ausschließen. Eine magere Ausbeute also? Immerhin hat das fünf Meter hohe und sieben Tonnen schwere Spektrometer rund 1,5 Milliarden Euro gekostet. Doch die Klage von der teuren Raumfahrt ist unangebracht. Nie zuvor hat ein derart komplexes Spektrometer die kosmische Strahlung im Weltall untersucht. Mit AMS beginnt die Ära der „Präzisions-Astroteilchenphysik" – vom Stellenwert etwa zu vergleichen mit den beiden Weltraummissionen WMAP und Planck, die Astronomen gerne als den Beginn der Präzisionskosmologie werten (siehe F.A.Z. vom 27. März).

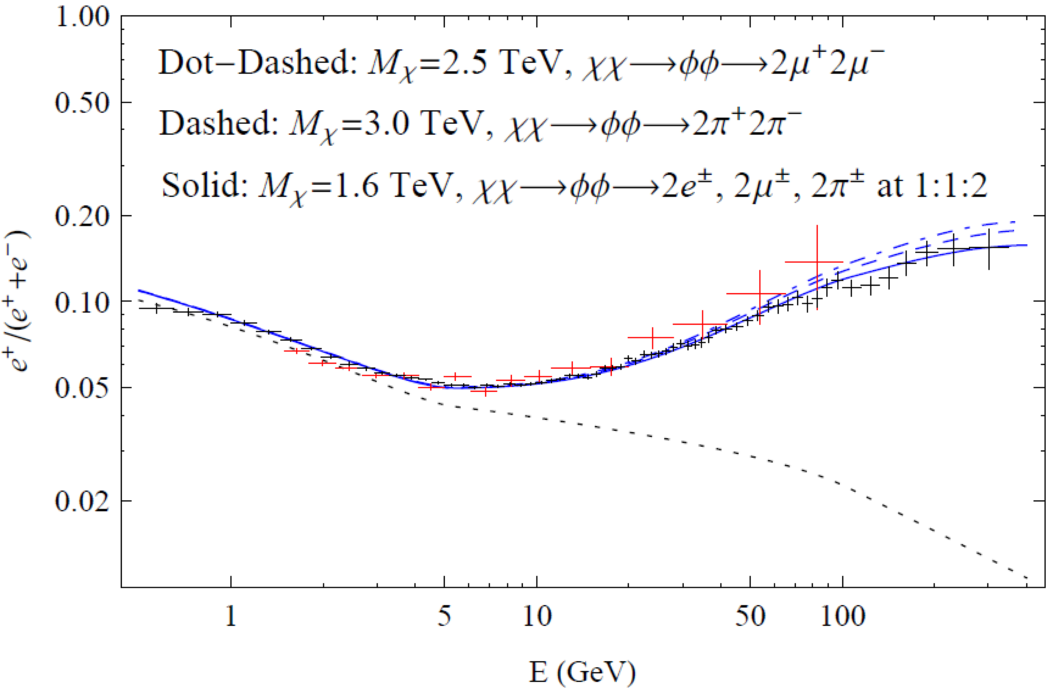
Stefan Schael von der RWTH Aachen und Leiter der deutschen AMS-Gruppe, gibt sich zufrieden: „Wir haben es geschafft, einen Detektor auf die Raumstation zu bringen, der die kosmische Strahlung deutlich präziser vermessen kann als alle Instrumente vorher." Das war keine leichte Aufgabe. Die kosmische Strahlung besteht zu 95 Prozent aus Protonen und Heliumkernen, Positronen enthält sie nur in Spuren. Um die Antielektronen herauszufischen, charakterisiert ein ganzes Arsenal von kleineren Geräten alle durch das AMS-Spektrometer fliegenden Teilchen nach Ladung, Masse und Energie. Schael und seine Kollegen haben dazu ein spezielles Instrument konstruiert, das die positiv geladenen Positronen von den zehntausendfach häufigeren, ebenfalls positiv geladenen Protonen unterscheiden kann. „Wir können ausschließen, dass es sich bei den gemessenen Positronen um fehlinterpretierte Protonen handelt", erklärt Schael: „Das war bei den früheren Experimenten nicht der Fall." Zudem sind in die ersten Ergebnisse gerade einmal acht Prozent des insgesamt zu erwartenden Datenvolumens eingeflossen.

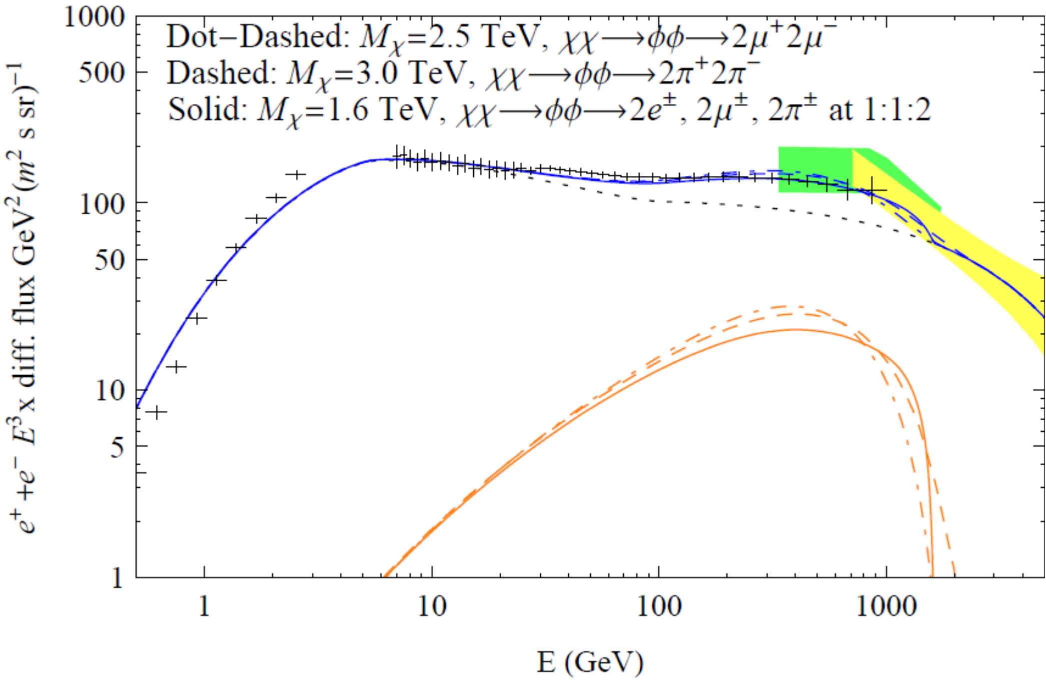
Dark Matter models in the light of AMS data

Dark matter in the light of AMS-02 results

Many models explain rise in positron fraction by Dark Matter annihilation, e.g.: Cholis and Hooper, PRD 88 (2013) 023013

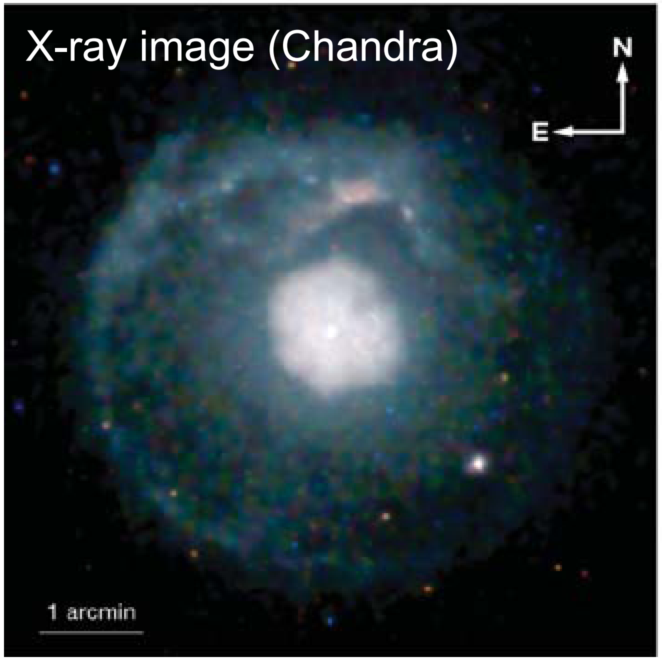
- Dark matter annihilating directly to $e^+ e^-$ or $\mu^+ \mu^-$ no longer capable of describing observed rise in positron fraction.
- Annihilation via light intermediate states into muons and pions consistent with data, for DM masses of 1.5 – 3 TeV, <σv> as high as (6 – 23) x 10^{-24} cm^3/s
- Describing the Fermi all-electron spectrum at the same time requires spectral break in cosmic-ray electrons.

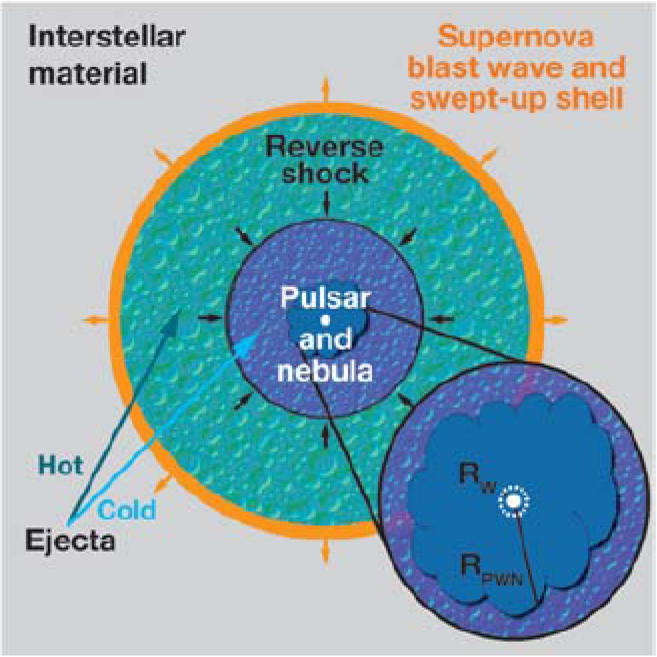




Astrophysical sources for positrons

Positrons inevitably produced in magnetosphere of pulsars and accelerated in pulsar wind nebula.

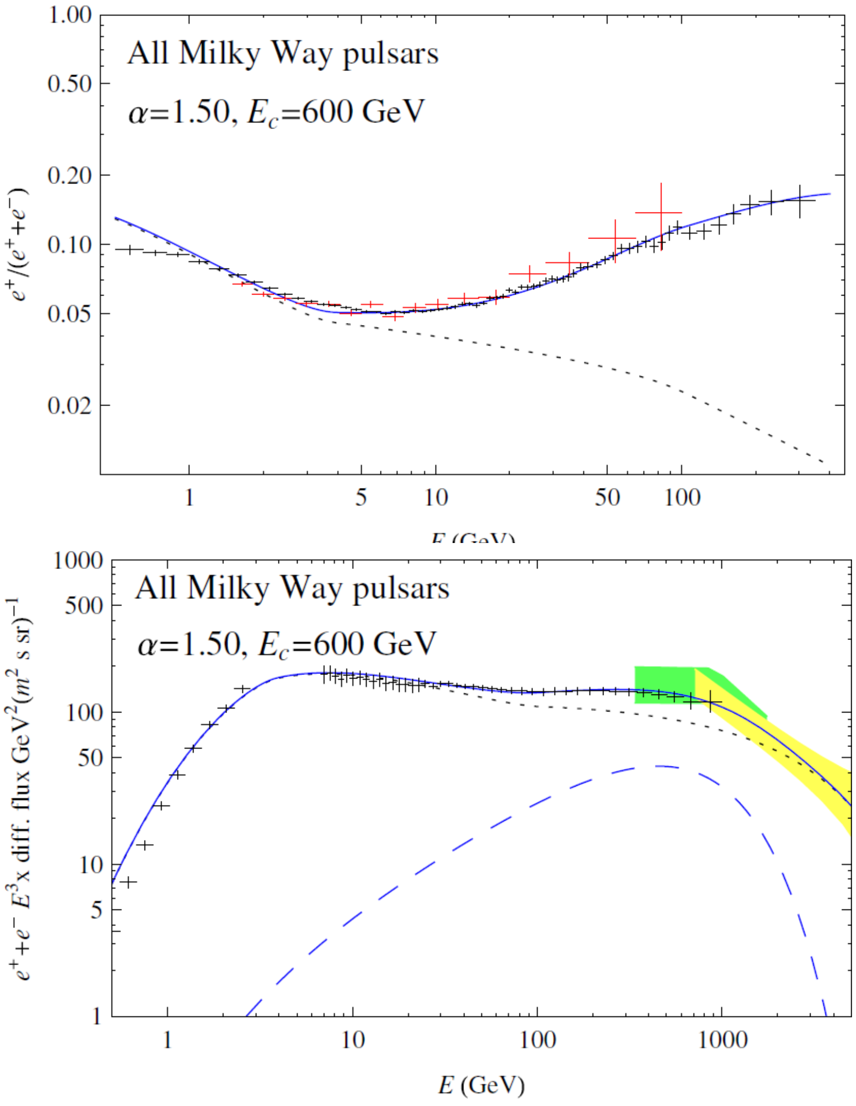




Gaensler & Slane 2006

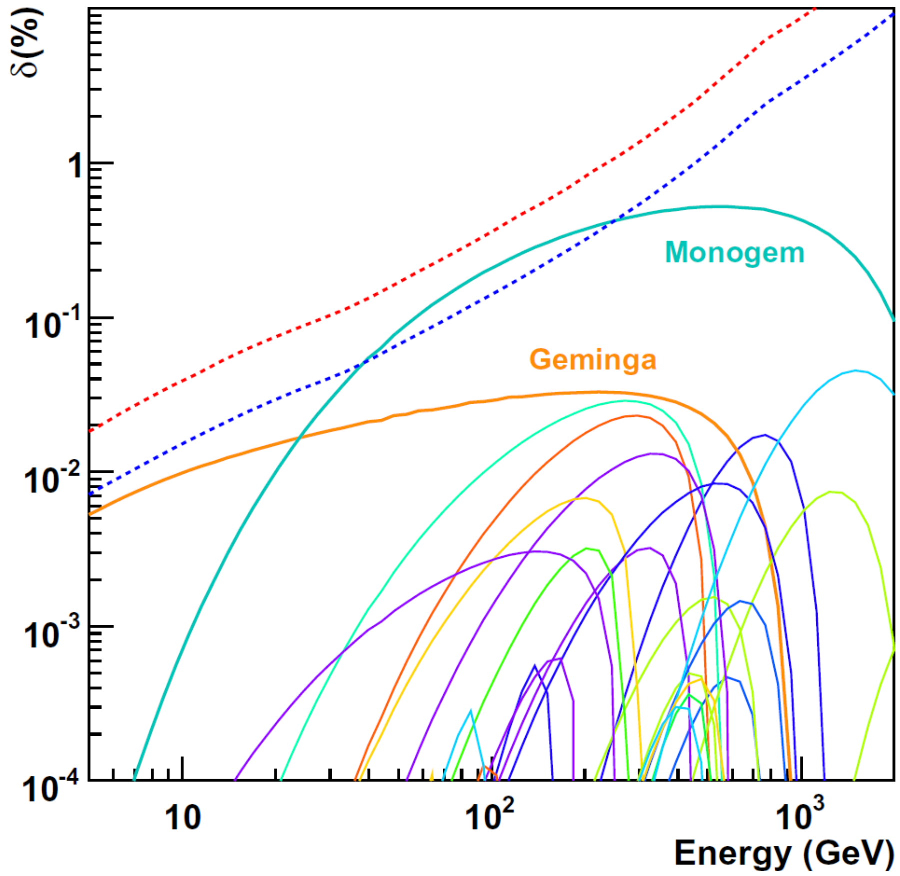
Pulsar models also explain rising positron fraction!

- Sum of known pulsars, assuming
    - exponentially cutoff power law spectra
    - 10-20% of spin-down power converted to CR acceleration
    - break in CR electron spectrum



Cholis and Hooper,
PRD 88 (2013) 023013

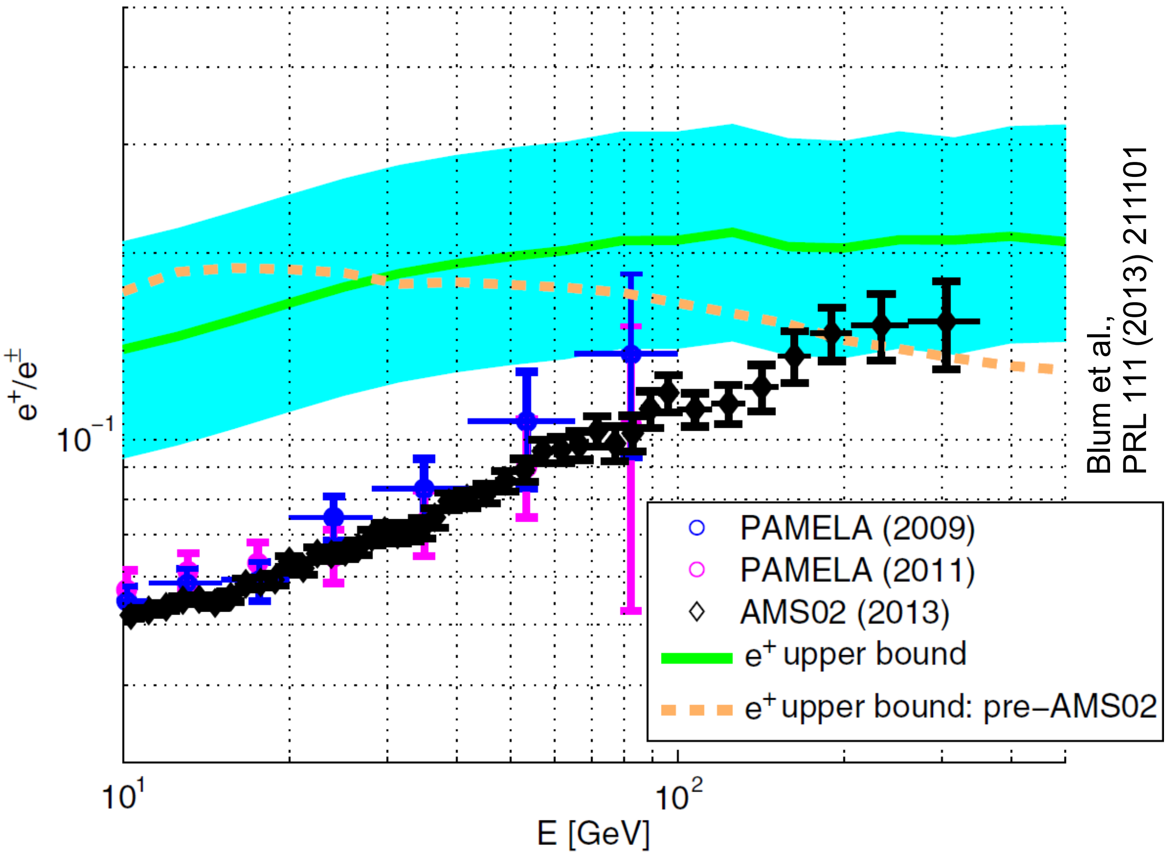
Pulsar models predict e± anisotropy!



Cernuda, Astropart. Phys.
34 (2010) 59

More ideas

- Supernova remnants (radioactive nuclei from supernova ejecta) as positron sources (Erlykin & Wolfendale)
- Acceleration of secondary e± produced through pp interactions inside the primary sources (Ahlers et al.)
- Propagation effects (Blum et al.)

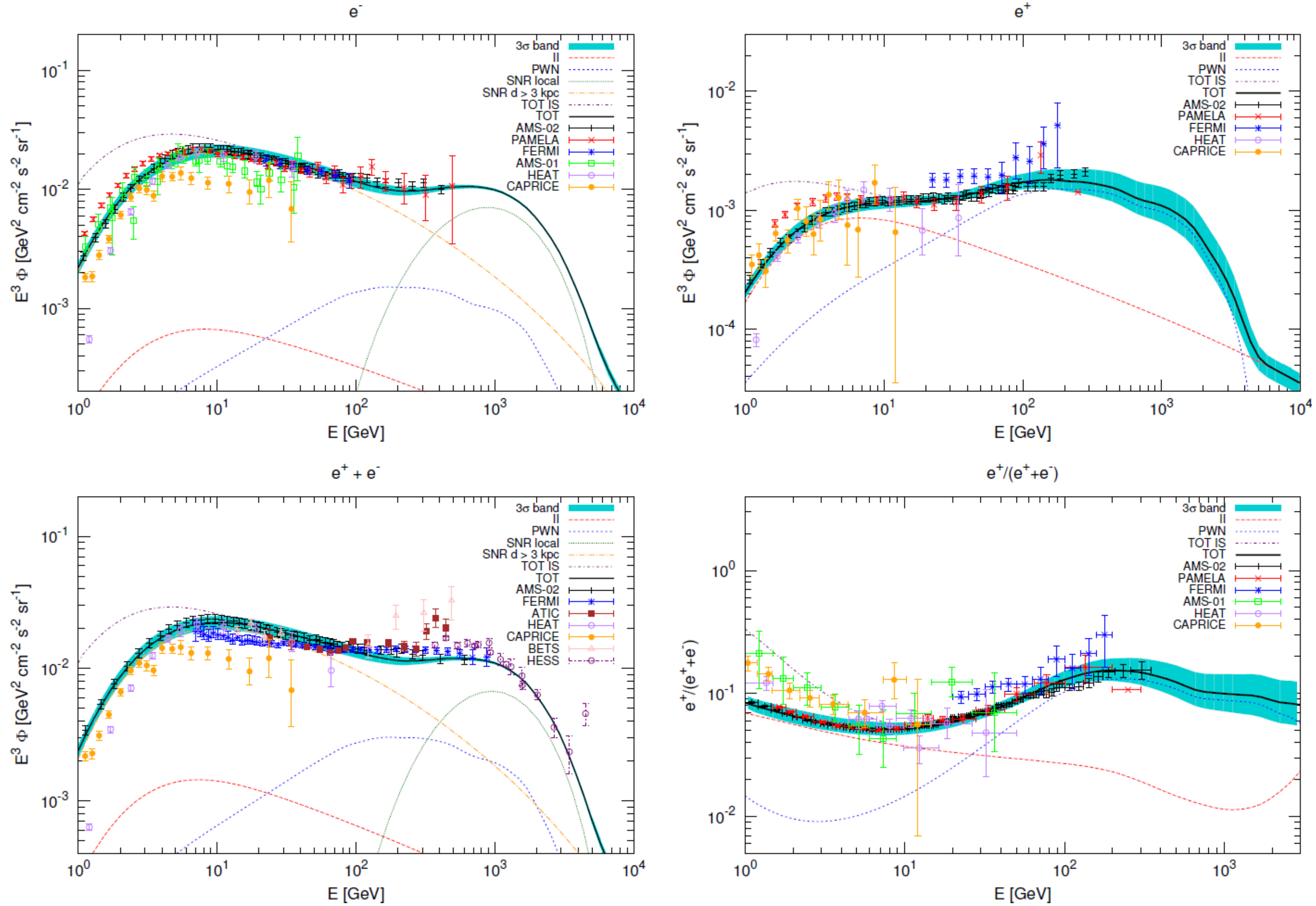


Blum et al., PRL 111 (2013) 211101

Full astrophysical model

Di Mauro et al.,
JCAP04 (2014) 006

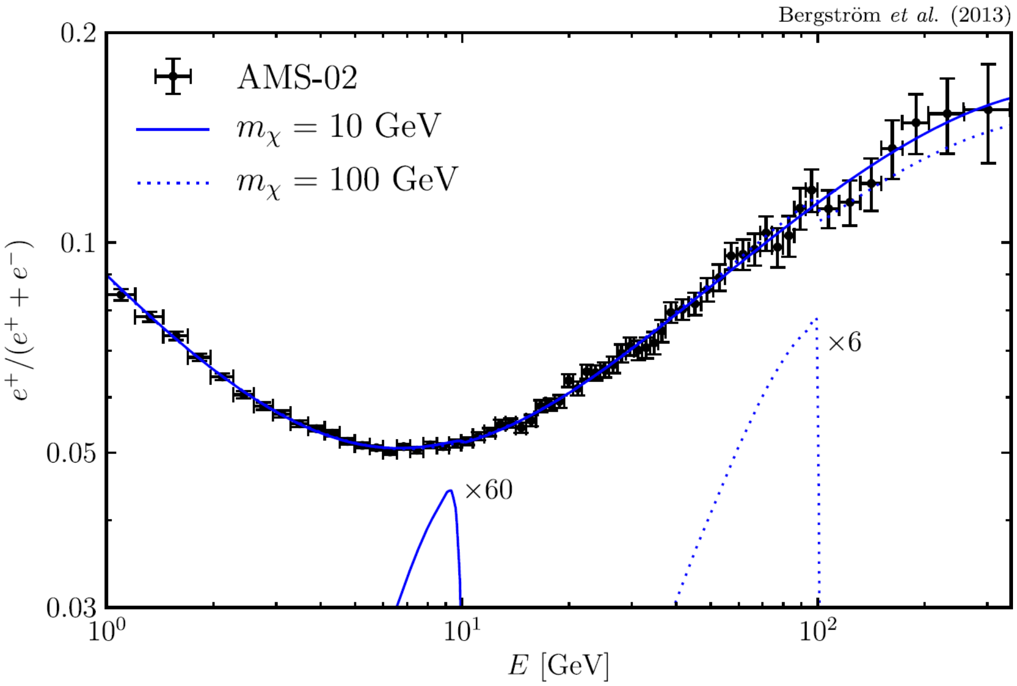
- Contributions from all known astrophysical sources
  - Primary electrons from SNRs
  - Electrons and positrons from PWNe
  - Secondary positrons and electrons from proton and helium
  - No contribution from Dark Matter required.

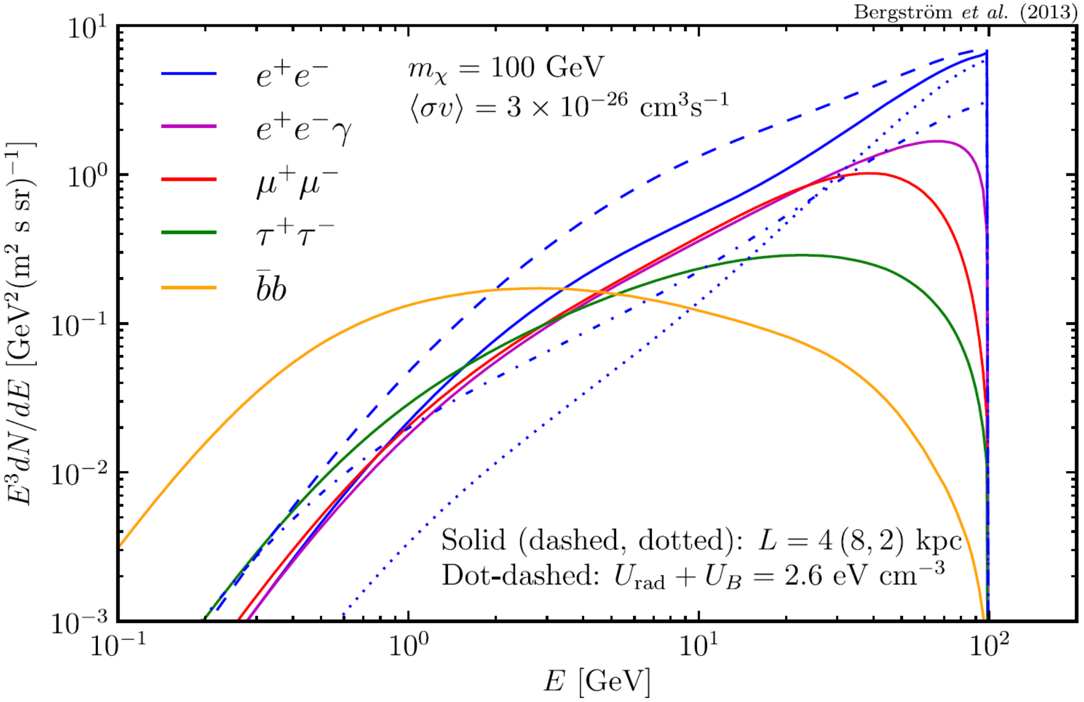


Dark matter in the light of AMS-02 results

A different approach: Search for Dark Matter signal on top of astrophysical source and secondary background,
e.g.: Bergström et al., PRL 111 (2013) 171101

- Try to fit lepton spectra from annihilating dark matter to AMS positron fraction:

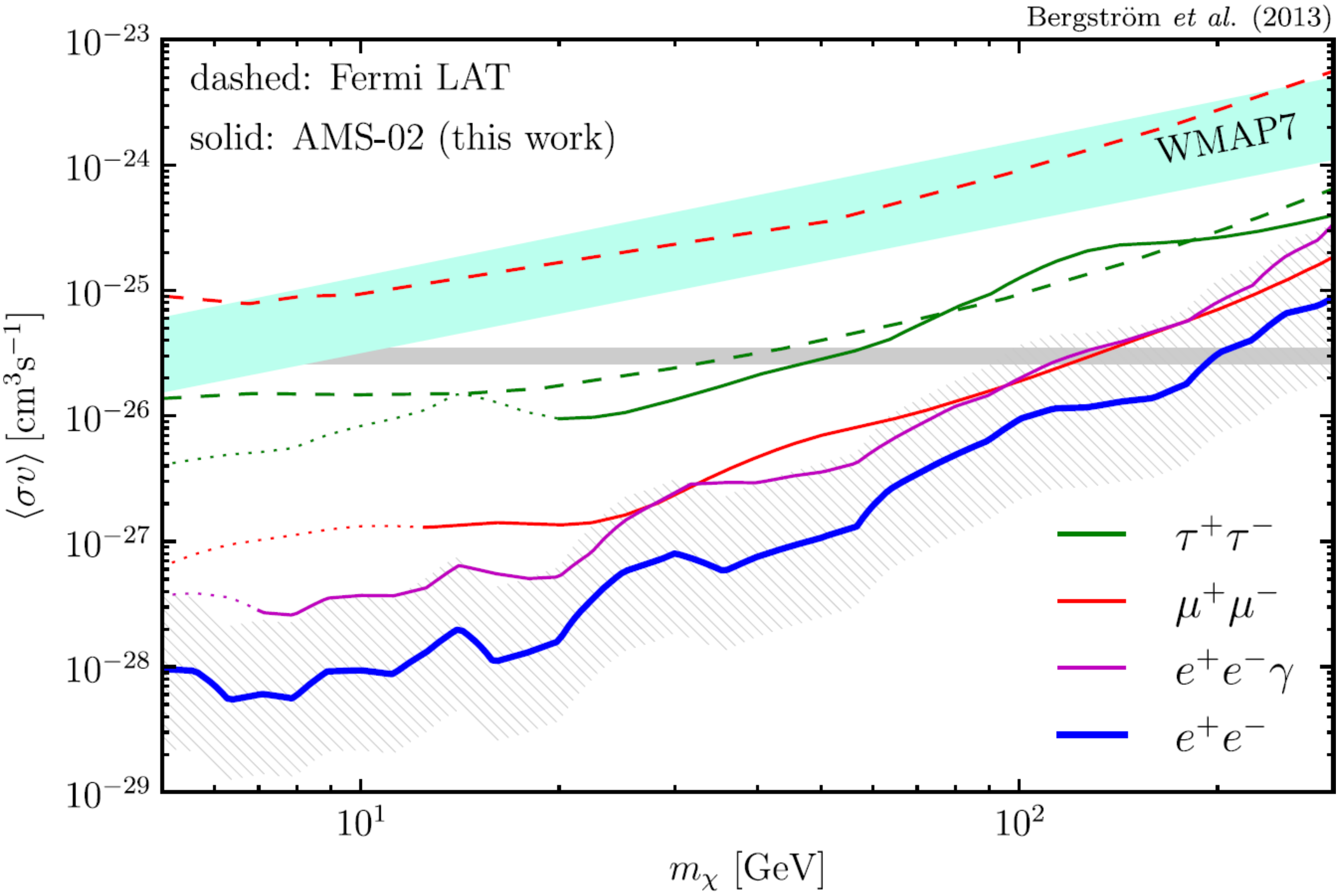




Dark matter in the light of AMS-02 results

Bergström et al., PRL 111 (2013) 171101

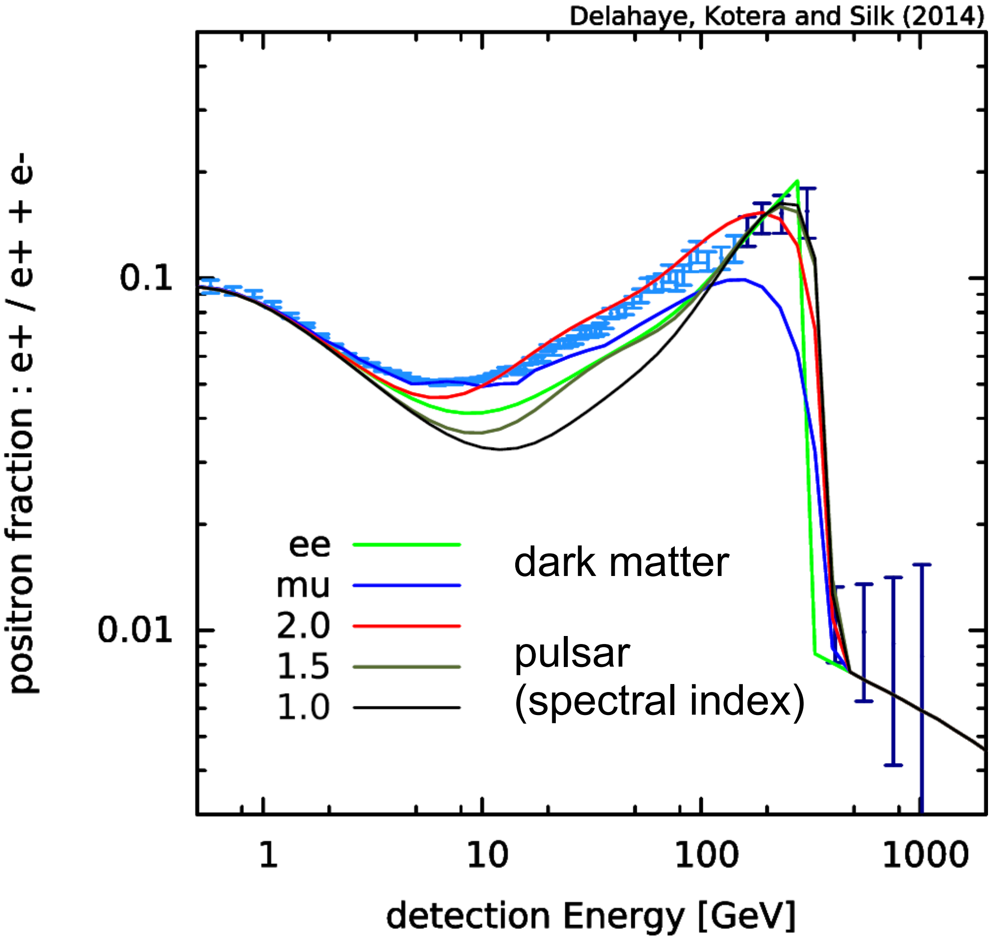
- Strong limits on Dark Matter annihilation derived in this case.

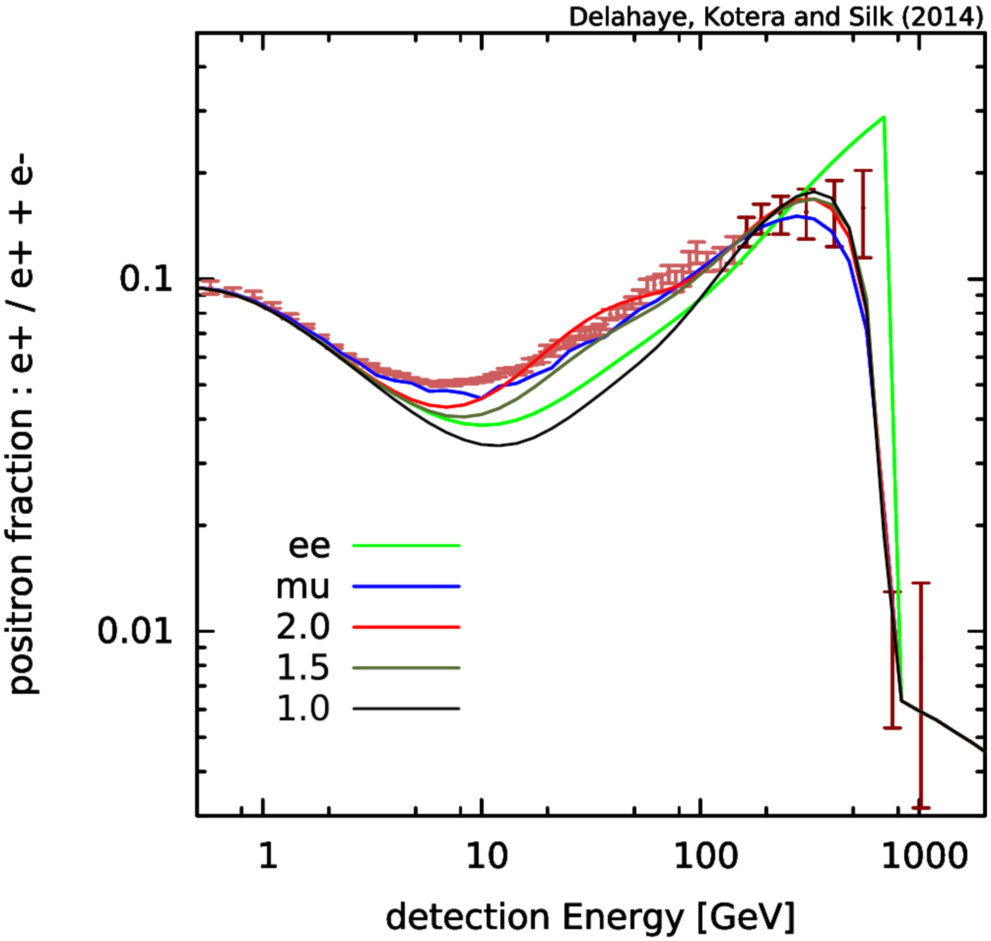


What could we learn from a sharply falling positron fraction?

Delahaye et al.,
ApJ 794 (2014) 168

- Mock data above 350 GeV
- Surprising conclusion: sharp cutoff not necessarily smoking gun for dark matter.





Conclusions

- AMS-02: Field of charged cosmic rays in the GeV regime now data-driven.
  - first experimental observation of positron fraction maximum
  - no sharp structures observed in positron fraction
  - behaviour of e- and e+ fundamentally different in magnitude and energy dependence

- Theoretical refinements needed:
  - solar modulation
  - propagation models
- Important input from AMS-02 to come:
  - primary spectra (protons, Helium)
  - B/C
  - antiprotons
  - search for positron anisotropy
- Dark Matter models offer viable explanation for observations of charged cosmic rays. But astrophysical explanation is equally good or better!

The Cosmos is the Ultimate Laboratory.