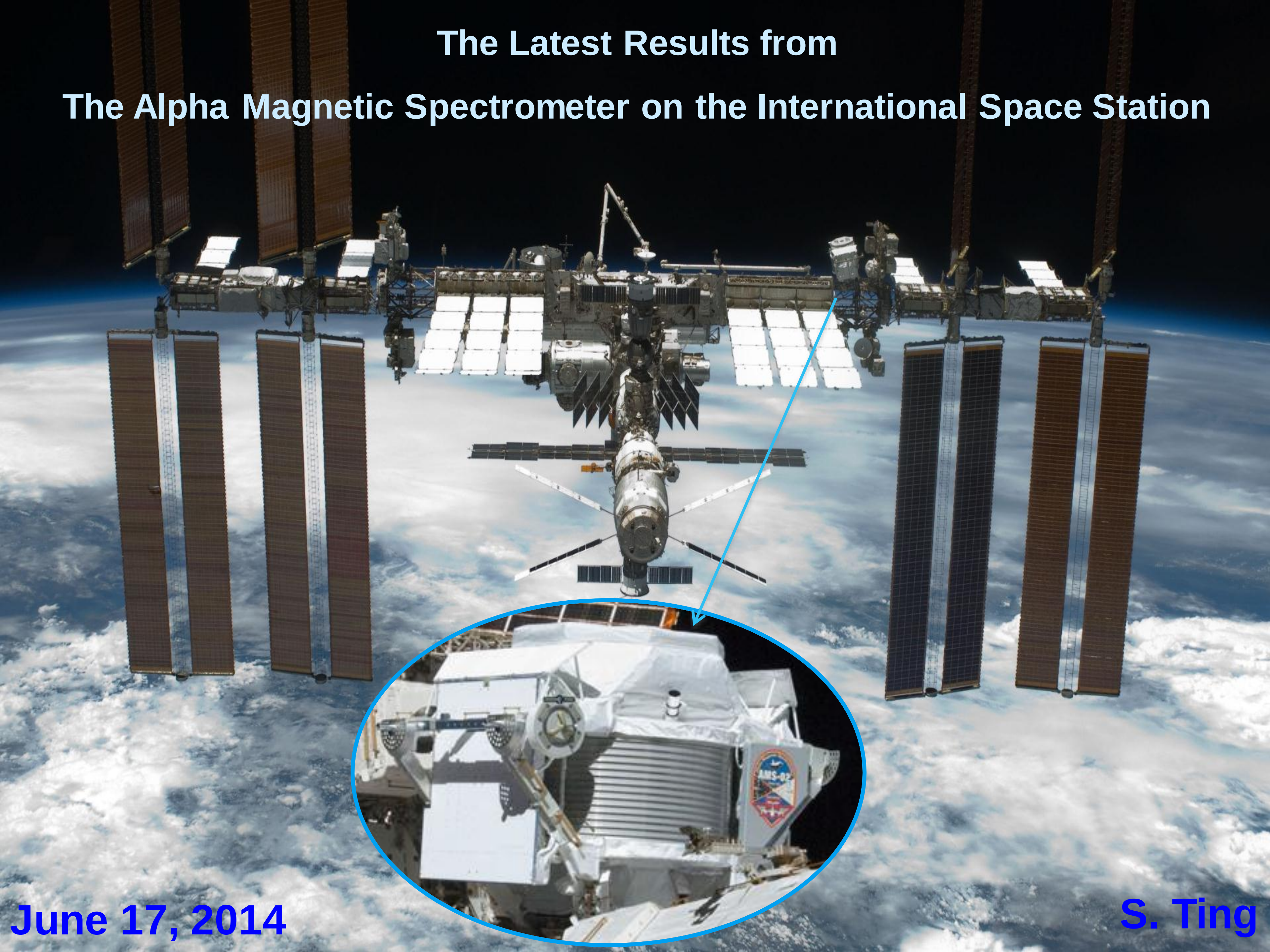
The Latest Results from

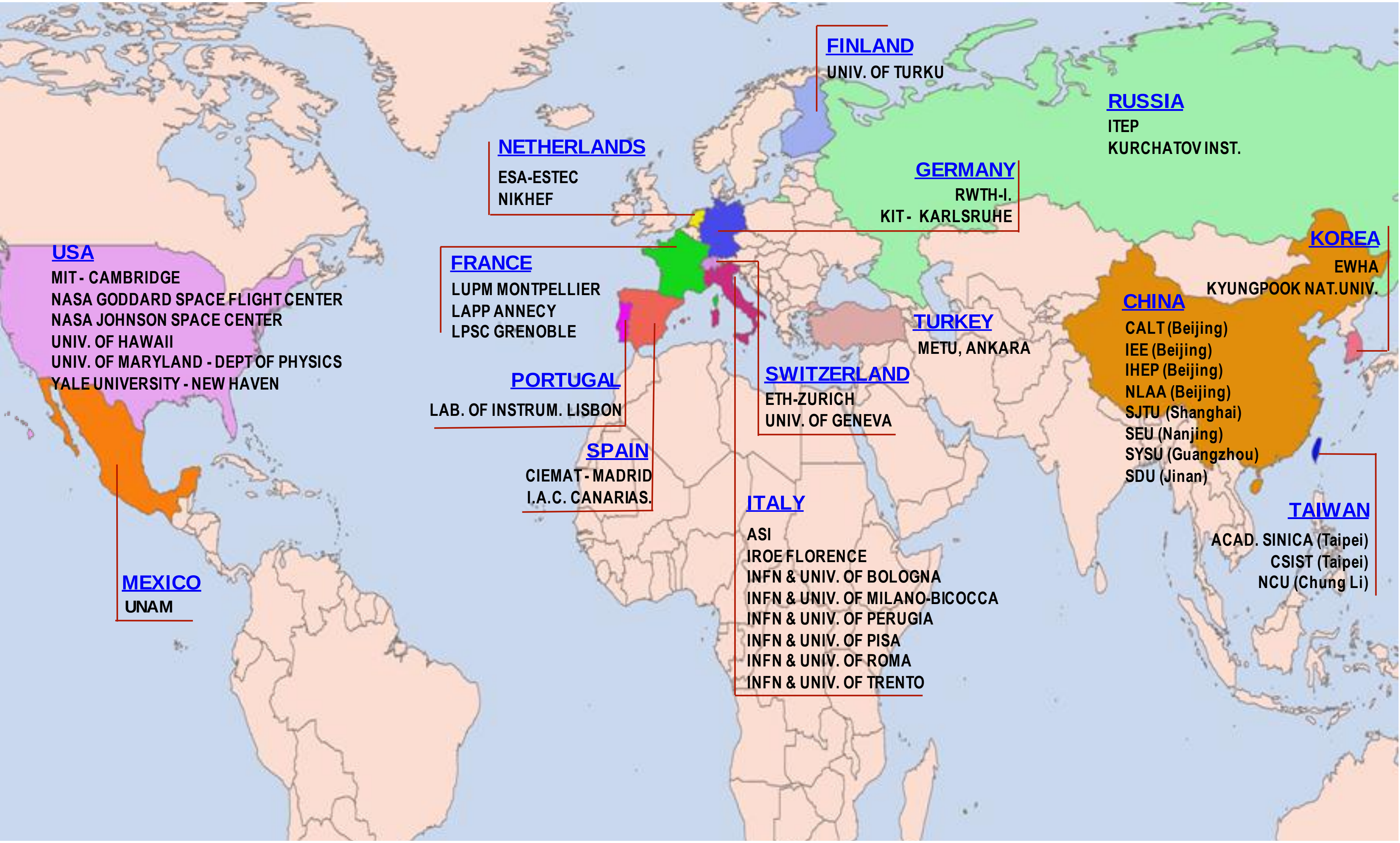
The Alpha Magnetic Spectrometer on the International Space Station



June 17, 2014

S. Ting

AMS: a U.S. DOE led International Collaboration
15 Countries, 44 Institutes and 600 Physicists




May 15, 2011

D. Goldin, former NASA Administrator realized the unique potential of ISS for fundamental science and has supported AMS from the beginning


May 16, 2011


May 09, 1994

NASA support

Mr. William Gerstenmaier has visited AMS regularly More than 10 times, at CERN, KSC, ESTEC .

Mr. Mike Suffredini and Mr. Rod Jones have also strongly supported AMS. Their support has made it possible for AMS to collect data continuously

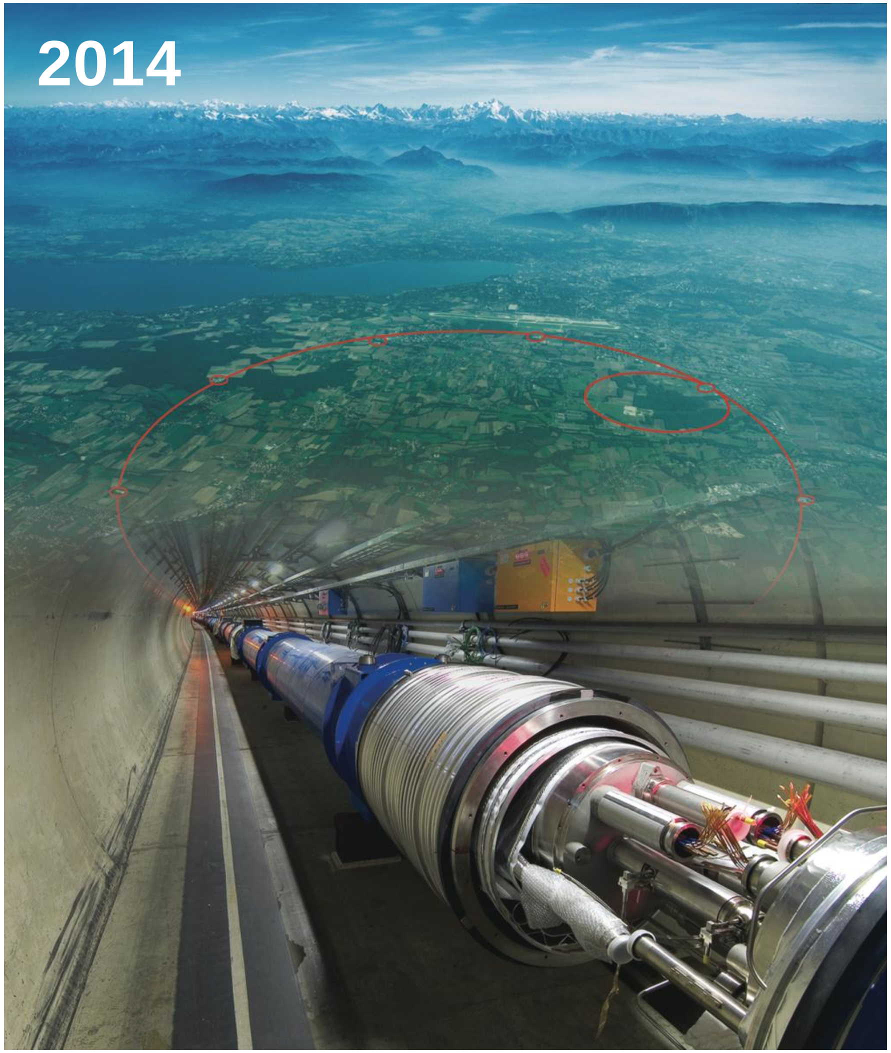
The construction of AMS was, and AMS operations are, supervised continuously by NASA-JSC team of Trent Martin, Ken Bollweg and many others.

Strong support of STS-134 astronauts (Mark Kelly, Gregory H. Johnson, Michael Fincke, Roberto Vittori, Andrew J. Feustel, Gregory Chamitoff)

Development of Accelerators

Energy: 0.0001 *eV*

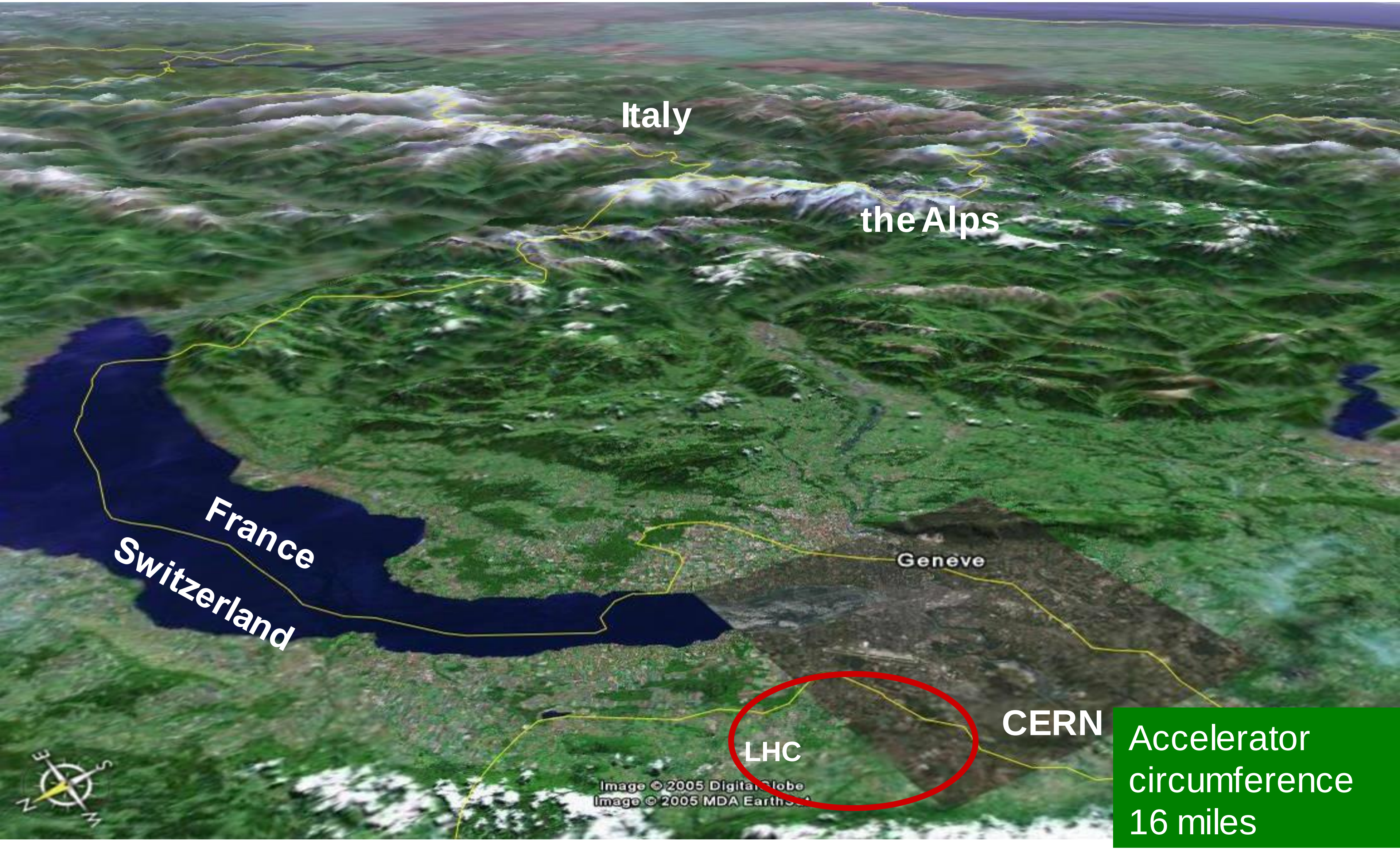
Galileo's work on Gravity



Energy: 7,000,000,000,000 *eV* = *7 TeV*

Study fundamental building blocks of nature

Largest Accelerator on Earth (LHC) can produce particles of 7 TeV

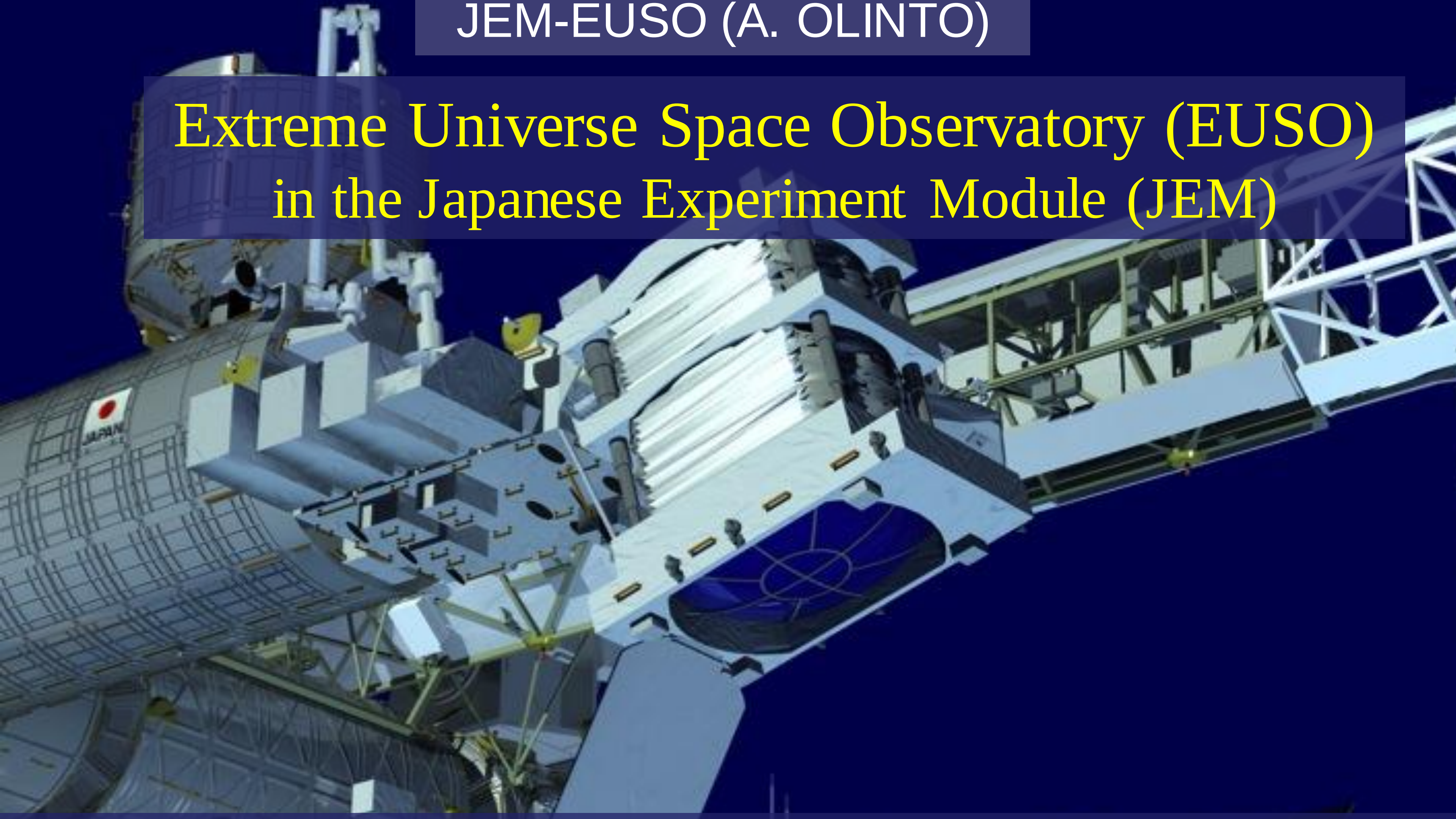


However, Cosmic Rays with energies of 100 Million TeV have been observed.

The highest energy particles are produced in the cosmos

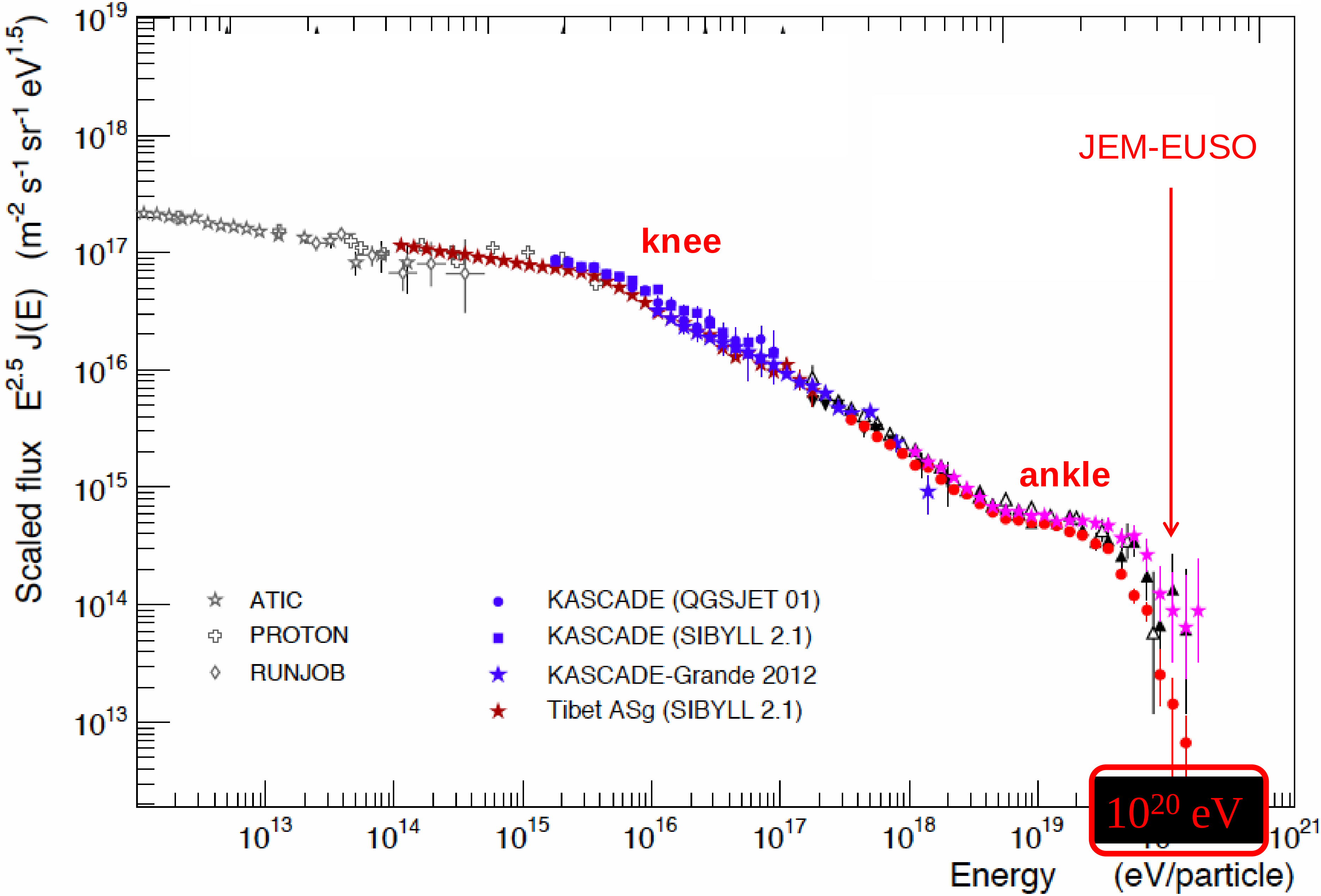
JEM-EUSO (A. OLINTO)

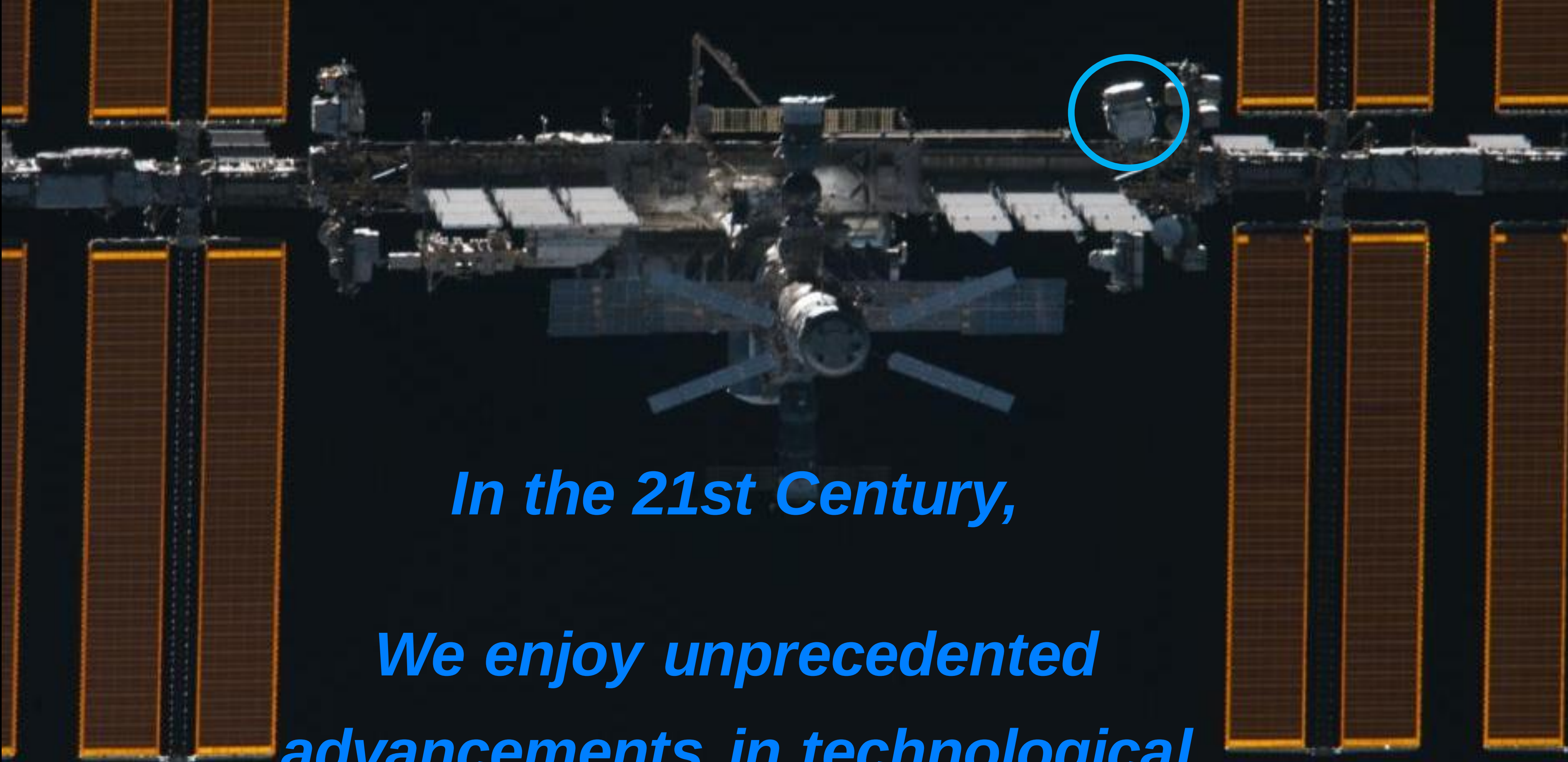
Extreme Universe Space Observatory (EUSO) in the Japanese Experiment Module (JEM)



- Ultraviolet telescope to study origin + interactions of **Extreme Energy Cosmic Rays (EECR)** with $E \sim 10^{20}$ eV
- ISS provides10 x more exposure than ground observatories.

Study of Extreme Energies Sources and Interactions

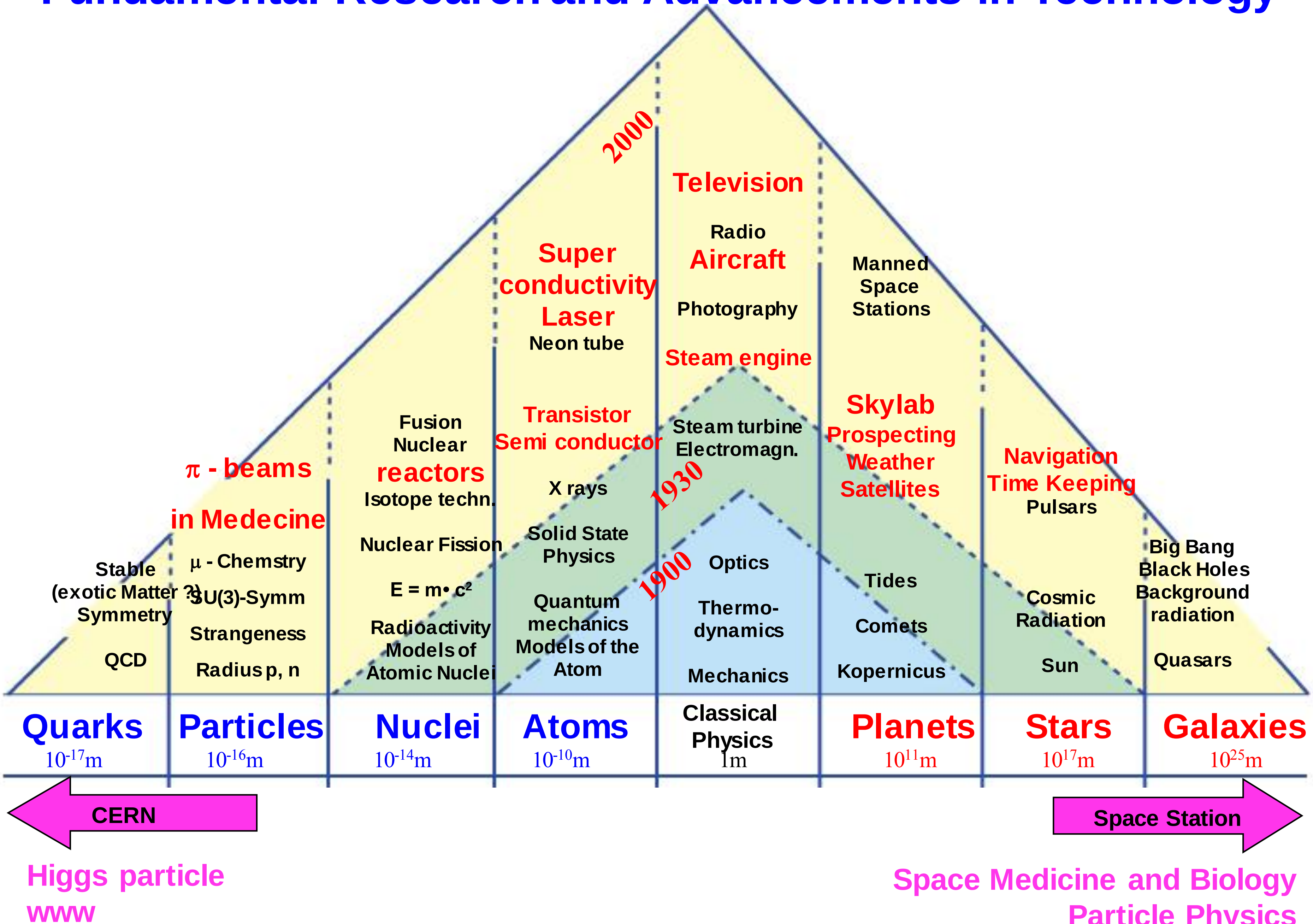




In the 21st Century,

We enjoy unprecedented advancements in technological development such as in the fields of communication, computers, transportation, medicine, etc … which have had dramatic effects on the quality of life.

Fundamental Research and Advancements in Technology

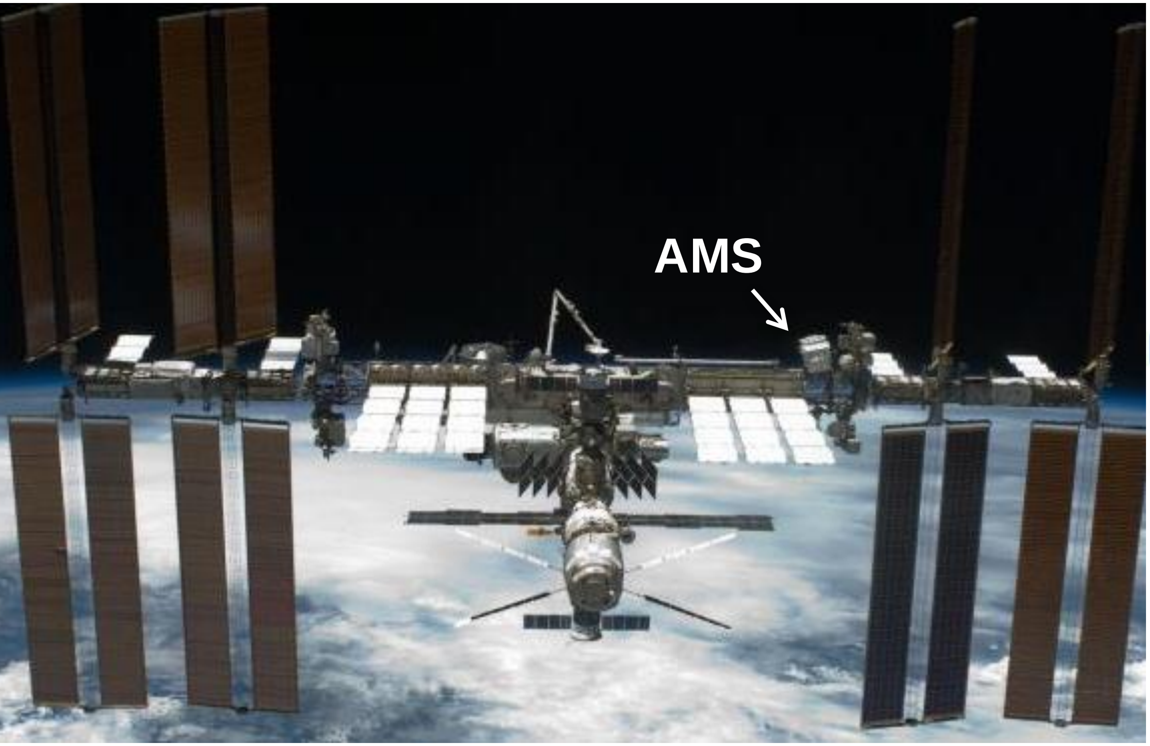


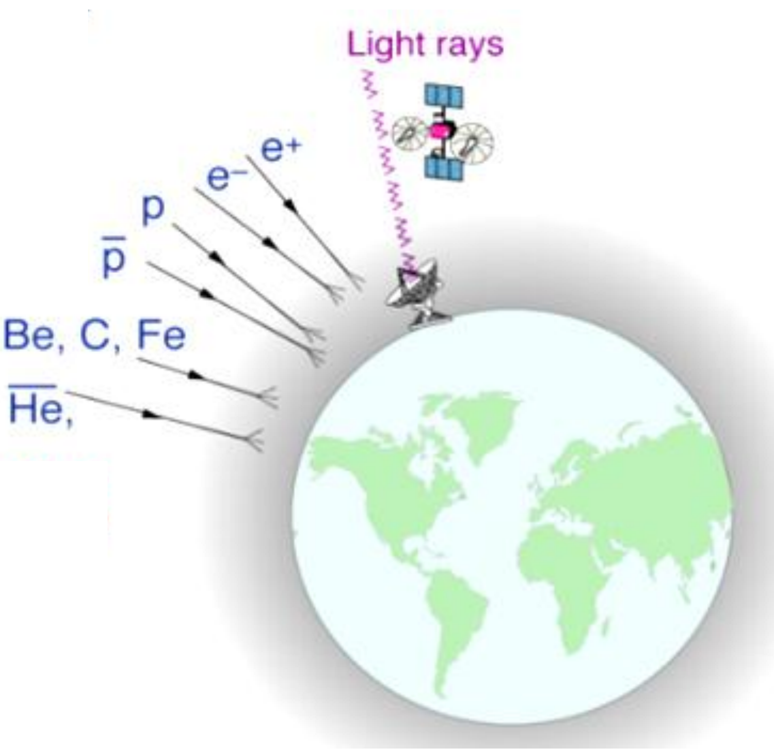
15ft x 12ft x 9ft
7.5 tons

Fundamental Science on the International Space Station (ISS)
There are two kinds of cosmic rays traveling through space

1- Neutral cosmic rays (light rays): have been measured for many years (Hubble, COBE, Planck, WMAP…). Fundamental discoveries have been made.

2- Charged cosmic rays: Using a magnetic spectrometer (AMS) on ISS is a unique way to provide precision long term (10-20 years) measurements of primordial high energy charged cosmic rays.

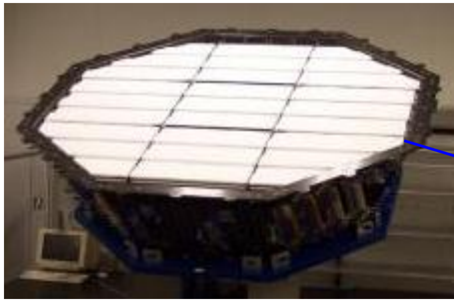




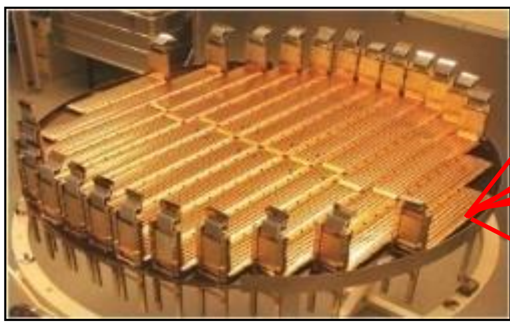
AMS: A TeV precision, multipurpose spectrometer

Particles are defined by their charge (Z) and energy (E) or momentum (P)

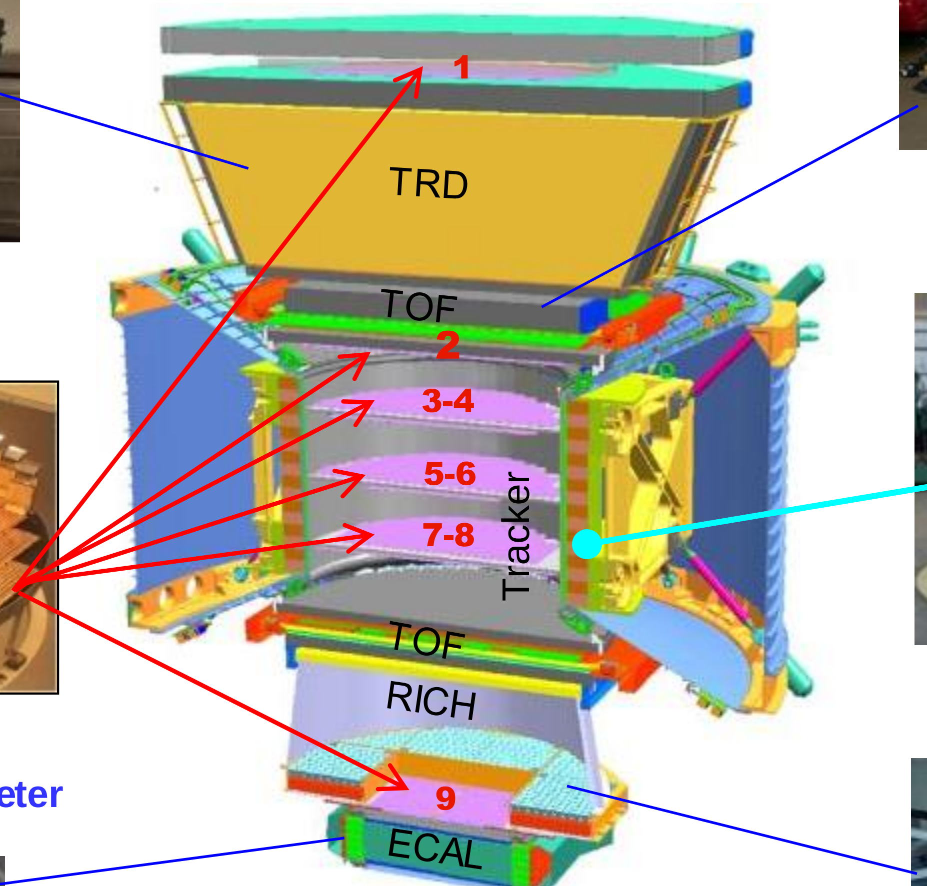
Transition Radiation Detector
Identify electrons



Silicon Tracker
Z, P



Electromagnetic Calorimeter
E of electrons



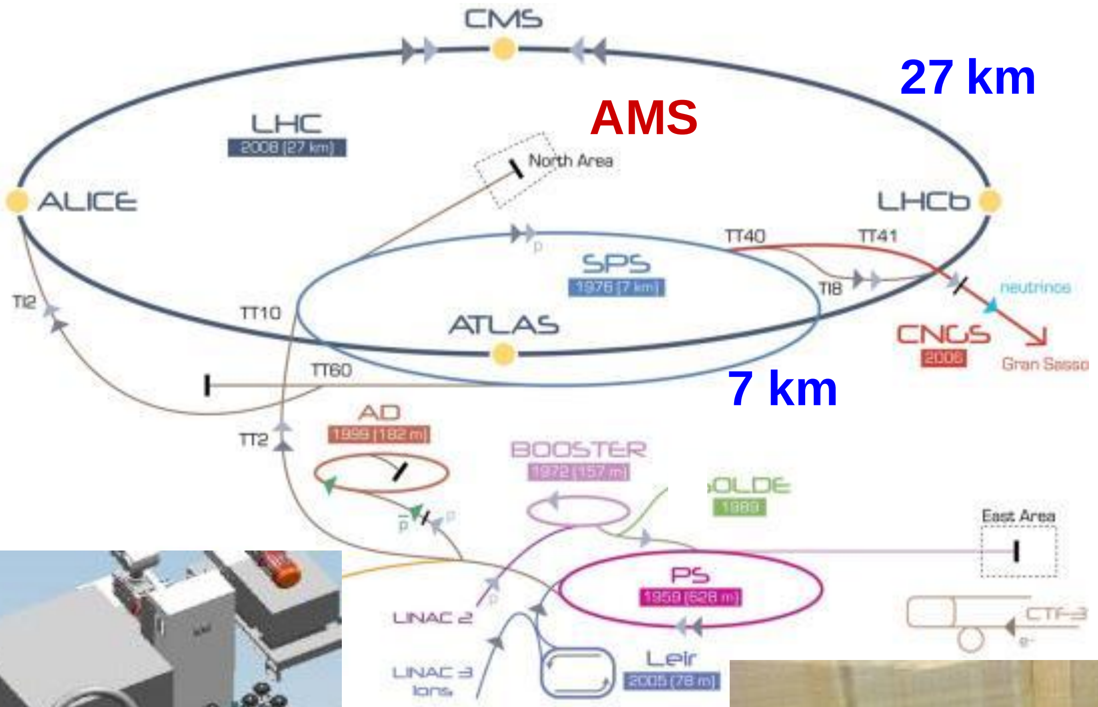
Time of Flight
Z, E

Magnet
±Z

Ring Imaging Cherenkov
Z, E

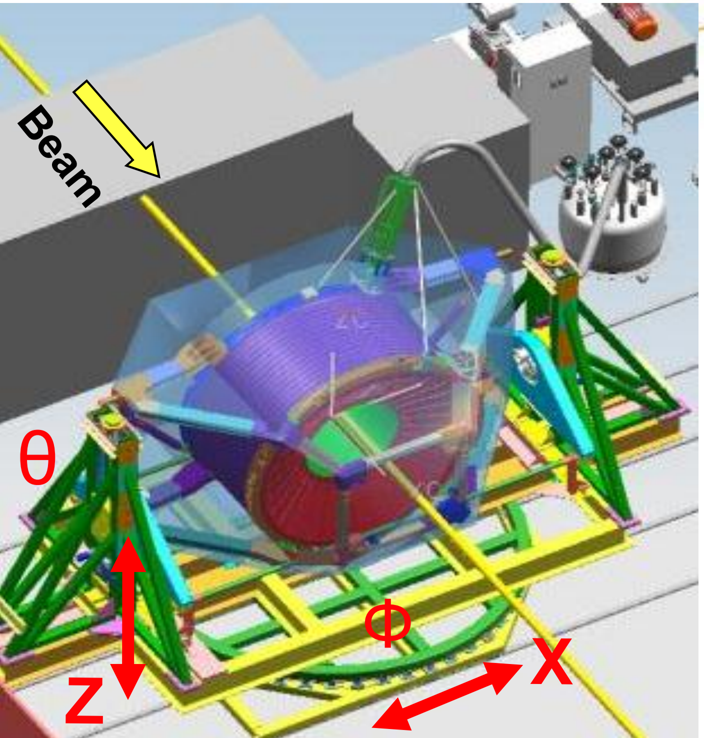
The Charge and Energy (momentum) are measured independently by many detectors

Tests and calibration at CERN
AMS in accelerator test beams Feb 4-8 and Aug 8-20, 2010



p, e+, e-,π

10-400 GeV



2000 positions

May 19, 2011: AMS installation completed.
In 3 years we have collected 50 billion events.
This is much more than all Cosmic Rays collected over last century.

Administrator Charles Bolden inaugurated AMS Payload and Science Operations Centers (POCC), June 23, 2011

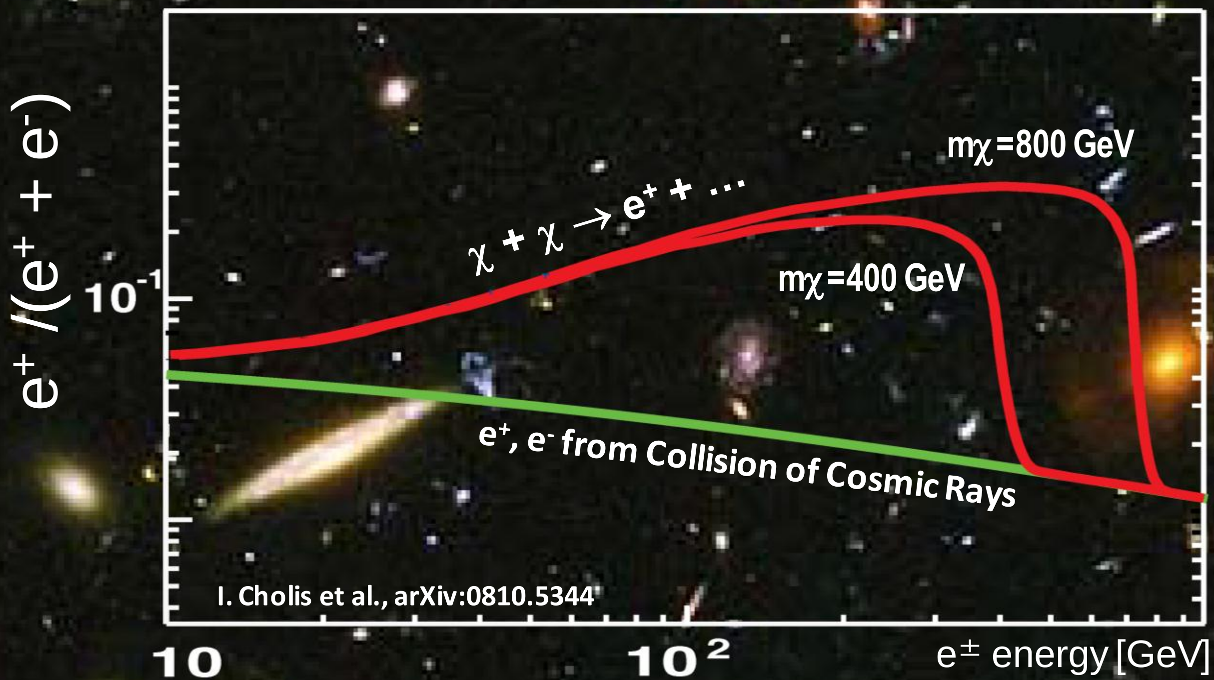
The physics objectives of AMS include:

The Origin of Dark Matter

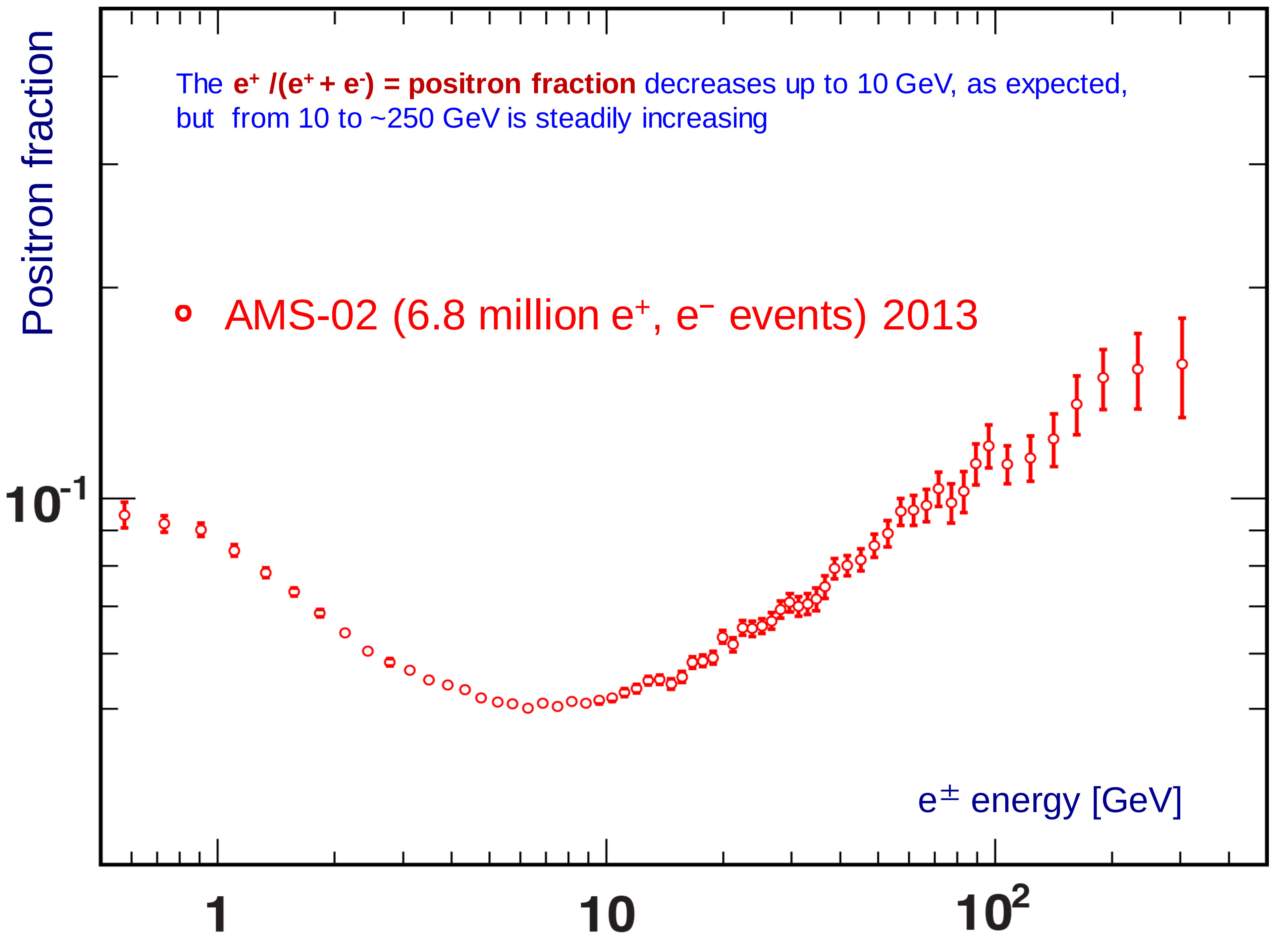
~ 90% of Matter in the Universe is not visible and is called Dark Matter

Collision of “ordinary” Cosmic Rays produce e+, ...

Collisions of Dark Matter (neutralinos, χ) will produce additional e+, …

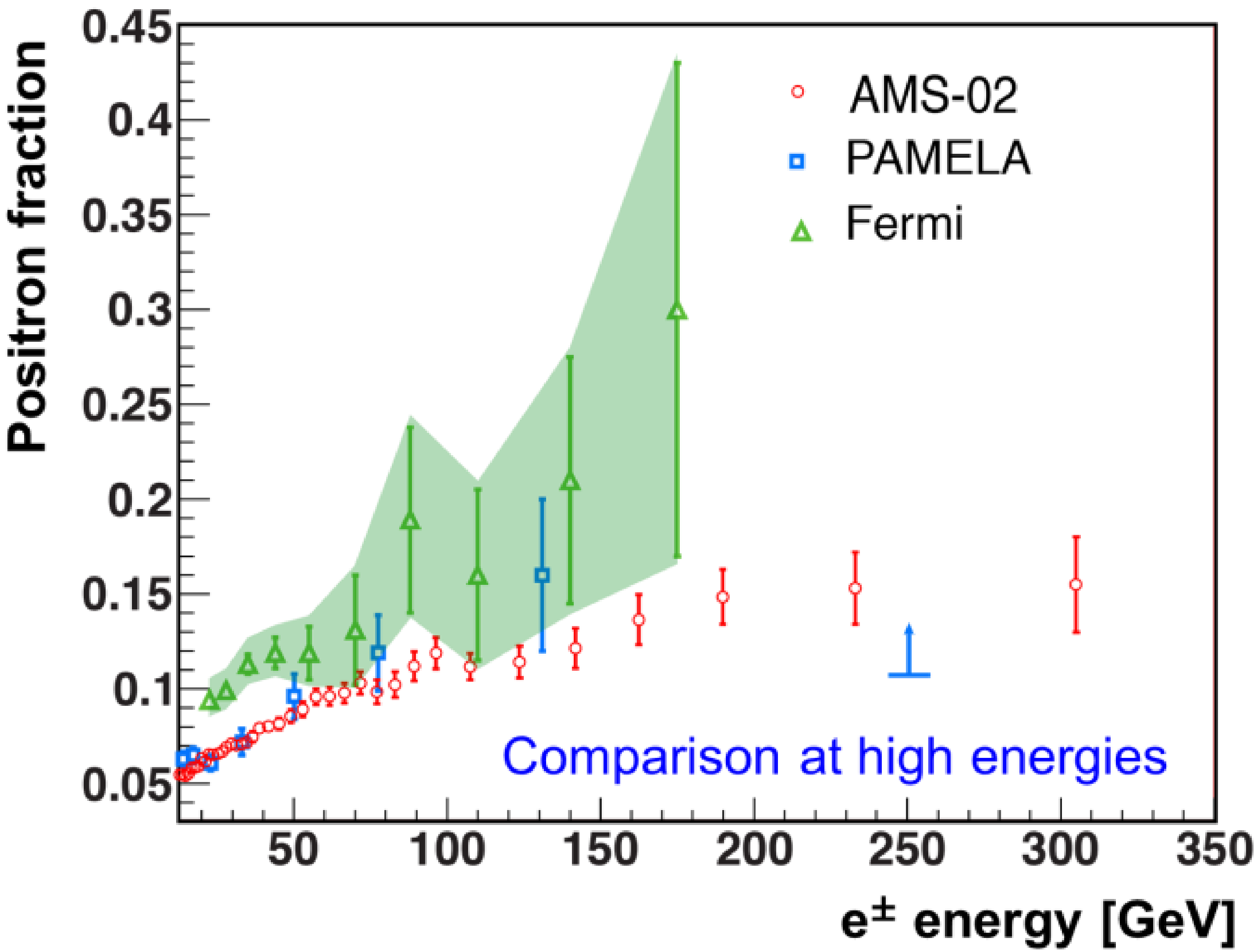


M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 1001



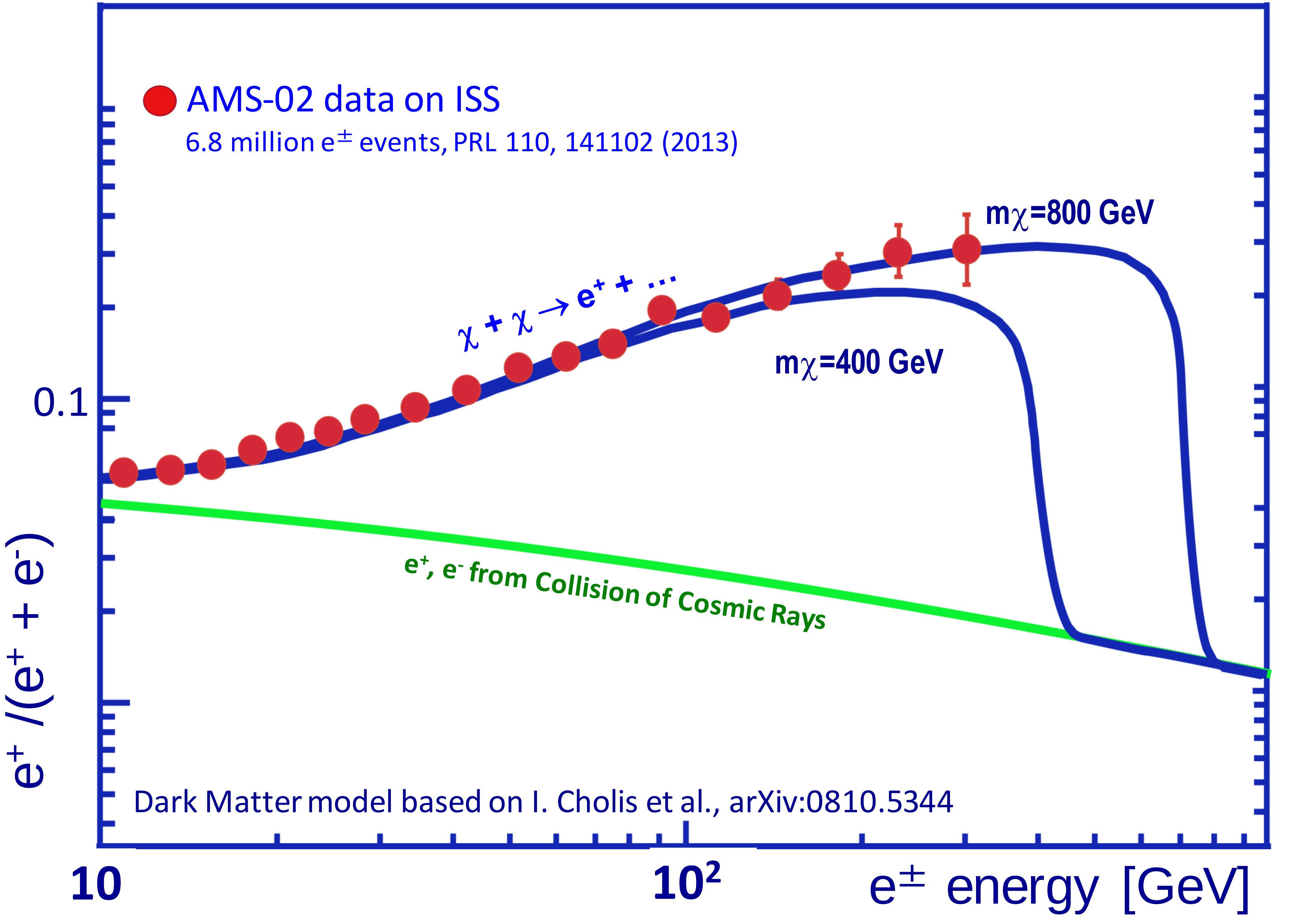
Positron fraction
The e+ /(e+ + e-) = positron fraction decreases up to 10 GeV, as expected,
but from 10 to ~250 GeV is steadily increasing
AMS-02 (6.8 million e+, e− events) 2013
10-1
e± energy [GeV]
1
10
102

AMS Positron Fraction 2013



Low energy measurements include HEAT, CAPRICE, TS93 …

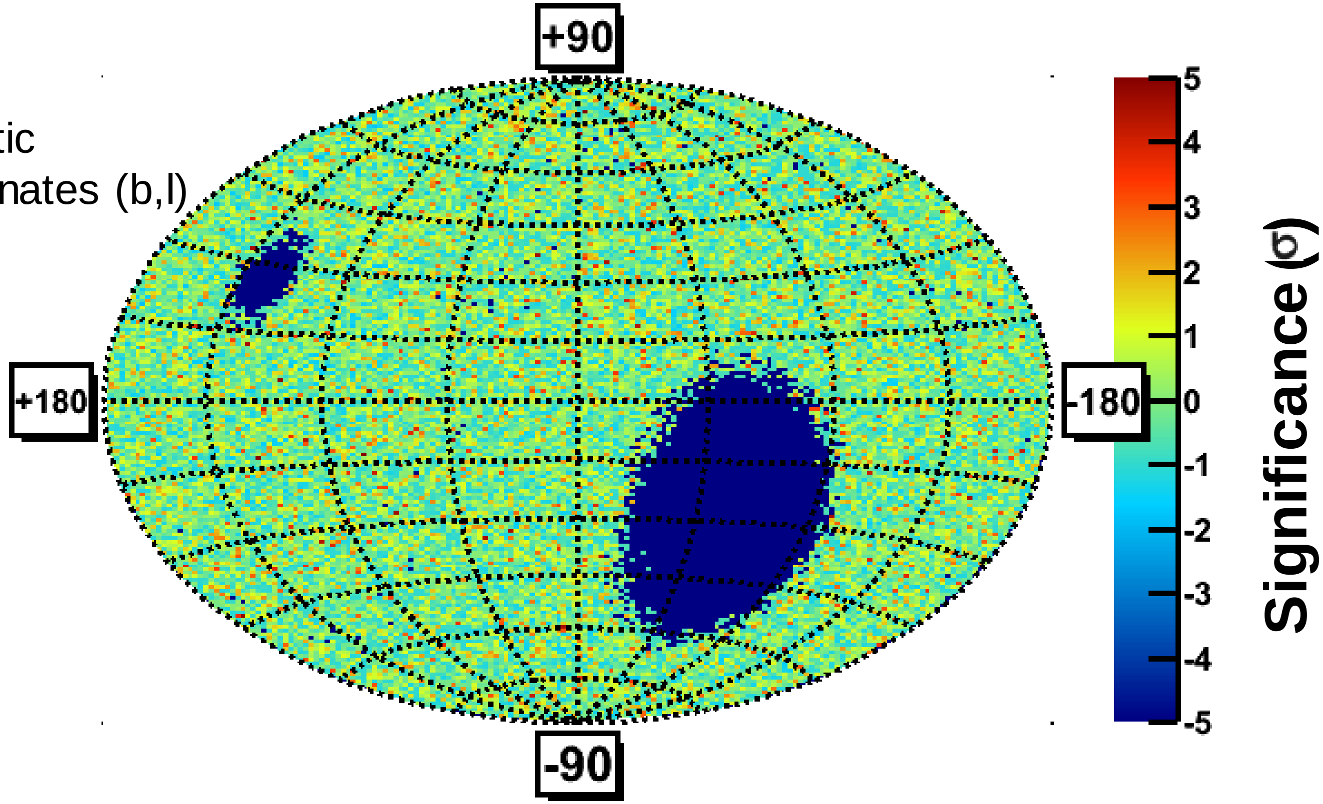
Comparison with theoretical Dark Matter Models



On the origin of excess positrons

If the excess has a particle physics origin, it should be isotropic

Galactic
coordinates (b,l)



The fluctuations of the positron ratio e^+/e^- are isotropic.

The anisotropy in galactic coordinates:

δ ≤ 0.030 at the 95% confidence level

AMERICAN PHYSICAL SOCIETY
EDITORIAL OFFICE
1 Research Road • Ridge, NY 11961-2701 • http://publish.aps.org/
(631) 591-4000 • (631) 591-4141 (fax)

Physical Review Letters • Physical Review • Reviews of Modern Physics • PROLA • Physics

7 May 2013

Dear Dr. Ting,

It is my pleasure to congratulate you on having your paper, "First result from the Alpha Magnetic Spectrometer on the International Space Station: Precision measurement of the positron fraction in primary cosmic rays of 0.5–350 GeV", [Phys. Rev. Lett. **110**, 141102 (2013)] featured in *Physics* (`http://physics.aps.org/`), our new, free online publication. *Physics* features commentary on the most important papers that APS publishes, as judged by its editors in consultation with experts in the field. Your paper was highlighted in a Viewpoint appearing in the 3 April 2013 issue of *Physics* `http://physics.aps.org/v6/40/`.

Let me explain briefly how your paper was selected. During the peer review process one of our editors noted your paper and nominated it to be featured in *Physics*. That week a committee, including the editors of *Physics*, chose your paper as the potential basis of a Viewpoint. The editors of *Physics* then identified and contacted a qualified specialist author to prepare a brief commentary on your paper. That specialist was both willing and able to prepare the piece on short notice, so that your paper and its Viewpoint could be published quickly and simultaneously.

This process is quite selective. The APS published a total of about 18,000 articles last year, but only around 100 Viewpoints will appear each year. This places your paper in an elite subset of our very best papers. More than 16,000 people were alerted to this Viewpoint via email or RSS feed, and many more came directly via the *Physics* website. Readers are even able to view your paper on an open access basis, when they arrive at it through the *Physics* site.

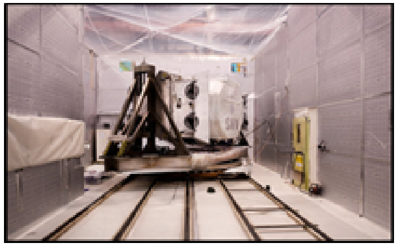
Physics was created to assist readers in identifying and understanding important papers, and to help authors get more notice for their best work. I hope we have accomplished this for you and your colleagues and collaborators, and that you will forward copies of this letter to them. I thank you for submitting to the APS journals.

Yours sincerely,

Gene D. Sprouse
Editor in Chief, American Physical Society

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.

● ● ●

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

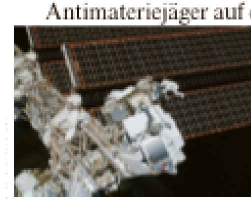
Matière noire ou pulsars ? L'énigme du « chaudron galactique »

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

Frankfurter Allgemeine — 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 sprechen die Daten eine orakelhafte Sprache, und so kommt es darauf an, wie man sie interpretiert.

Seit Jahren suchen Wissenschaftler nach Wimps (Weakly Interacting Massive Particle). 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

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 Spektro-

„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 Pro-

From: Matteo Rini [mrini@aps.org]
Sent: 02 January 2014 19:09
To: Samuel Ting
Subject: your AMS paper as a 2013 Physics Highlights

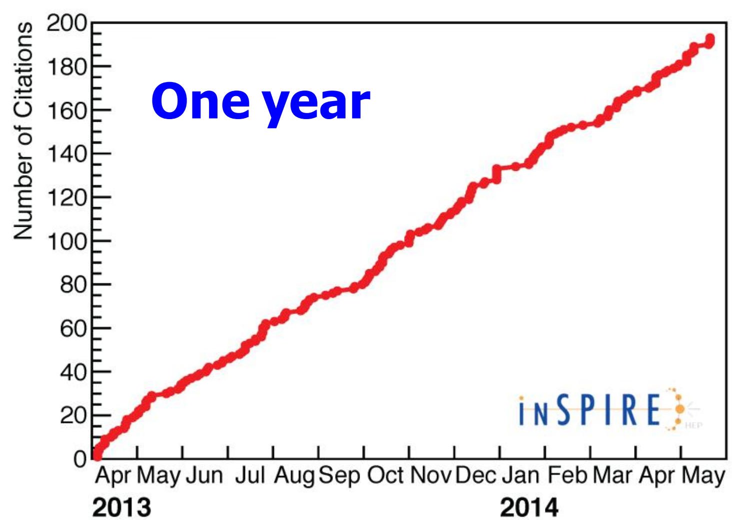
Dear Sam,

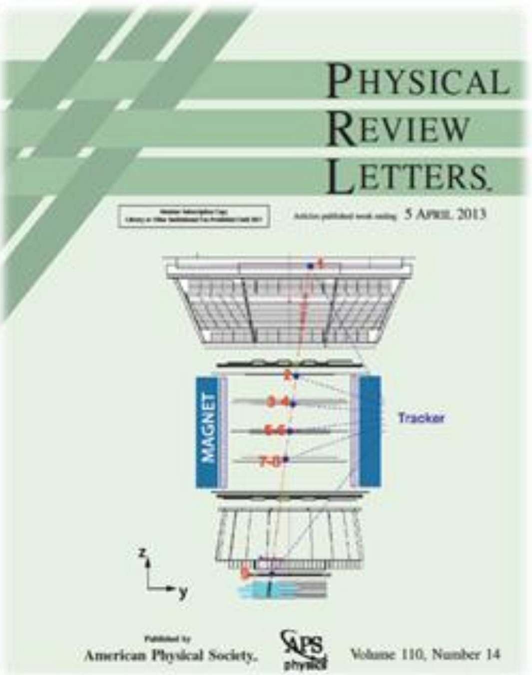
this is just to let you know that your article the first AMS data has been selected in our 2013 APS Physics Highlights (http://physics.aps.org/articles/v6/139).

Congratulation on this work, which has generated a lot attention among our readers, the press and the scientific community.

Best regards,

Matteo

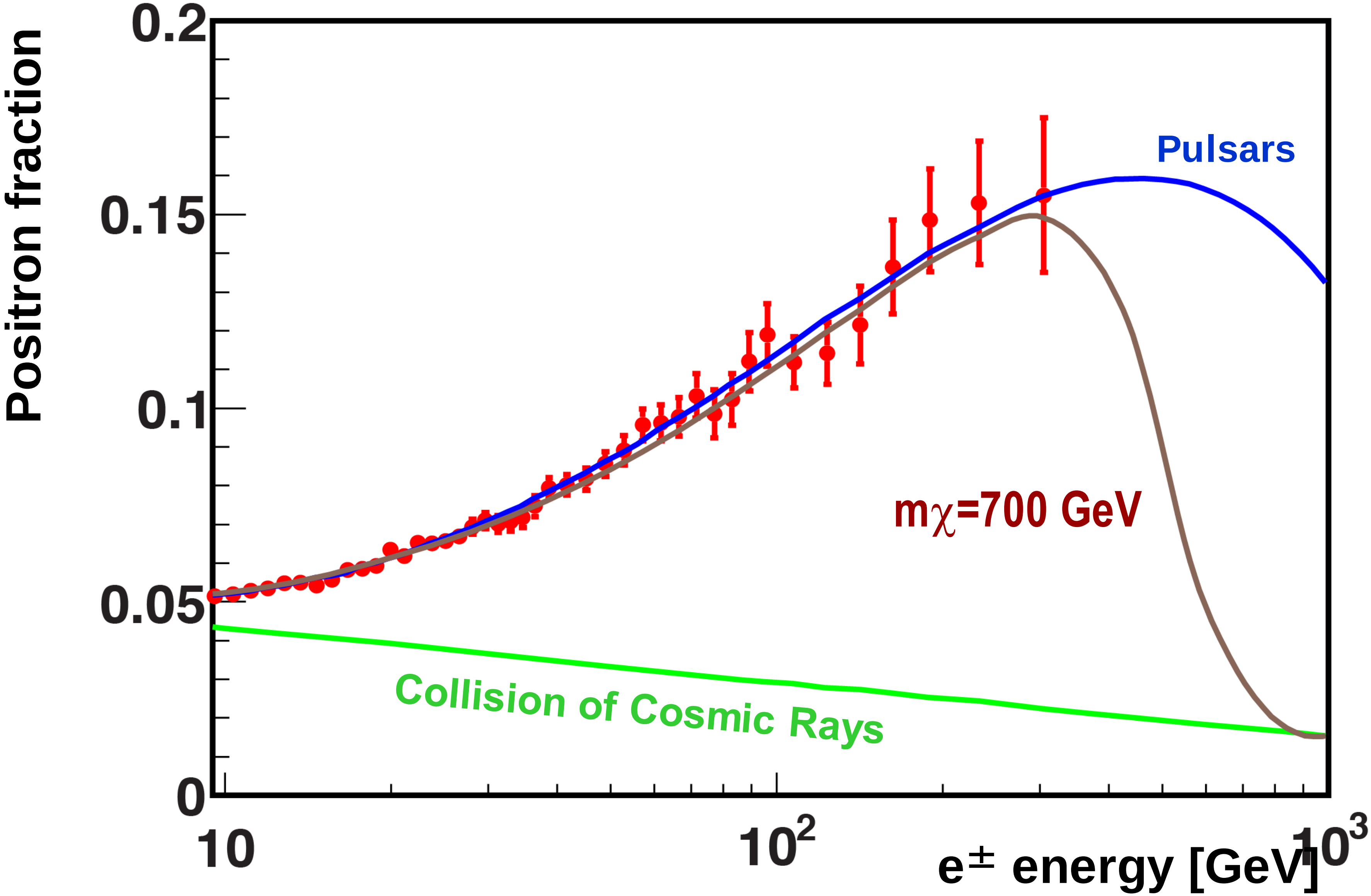




--

Matteo Rini, PhD
Deputy Editor, Physics
mrini@aps.org
http://physics.aps.org

Positron Fraction compared with
Collision of Cosmic Rays plus Dark Matter or Pulsar models



Comment: 3 independent methods to search for Dark Matter

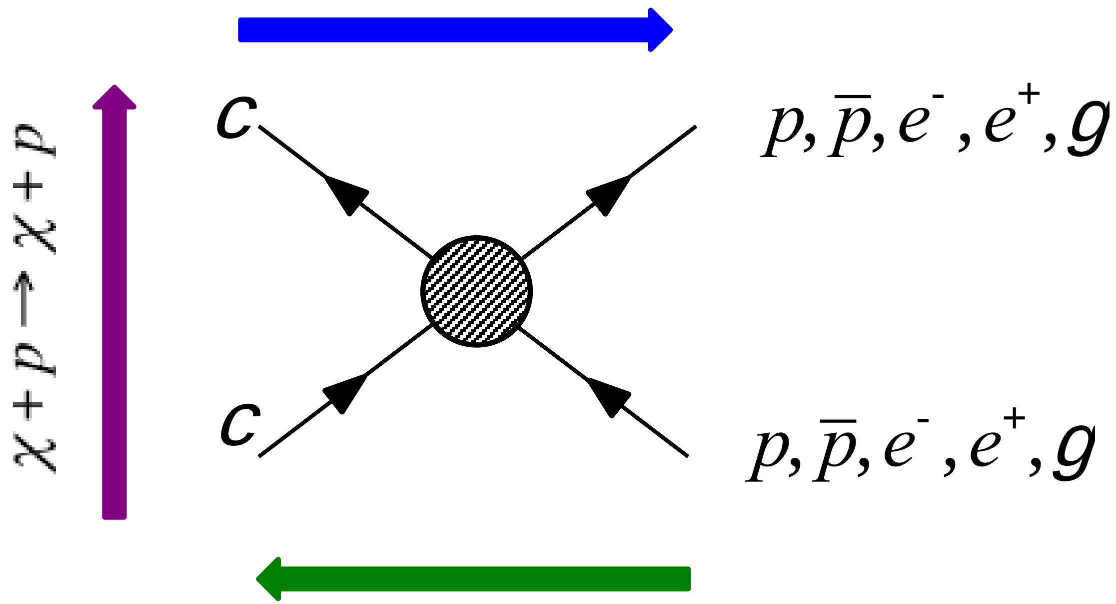
Annihilation (in Space)

$$\chi + \chi \rightarrow e^{+}, \bar{p}, \gamma, \ldots$$

AMS

Scattering (Underground Experiments World Wide):

LUX
DARKSIDE
XENON 100
CDMS II
…



LHC

$$\chi + \chi \leftarrow p + p$$

Production (in Accelerators)

Physics of electrons and protons

Annihilation

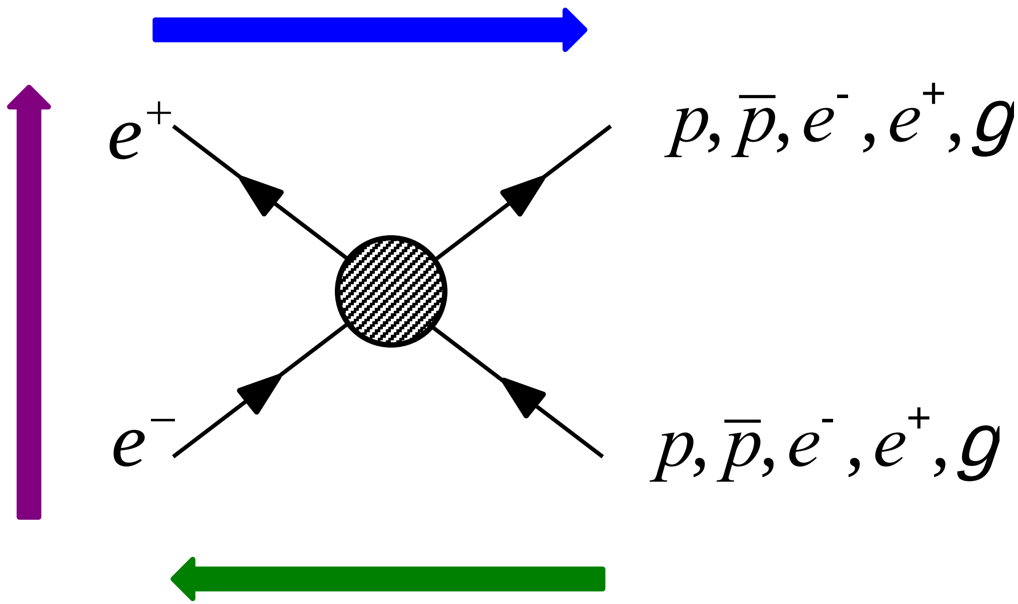
$$e^+ + e^- \rightarrow p, \bar{p}, e^-, e^+, \gamma$$

SPEAR, PEP, PETRA, LEP, … ***Ψ, τ***

Scattering

$$e + p \rightarrow p, \bar{p}, e^-, e^+, \gamma$$

SLAC … ***partons, electroweak***



BNL, FNAL, LHC … ***CP, J, Y, T, Z, W, h^0***

$$\ldots + e^+ + e^- \leftarrow p + p$$

Production

Latest AMS Results and Future Plans

Cosmic rays

Proton spectrum

Helium spectrum

Electron Spectrum

Boron Spectrum

Carbon Spectrum

Boron/Carbon ratio

Oxygen

Dark Matter

Positron Fraction

Anisotropy

Positron Flux

Antiproton Ratio

Future Plans

Positron Fraction

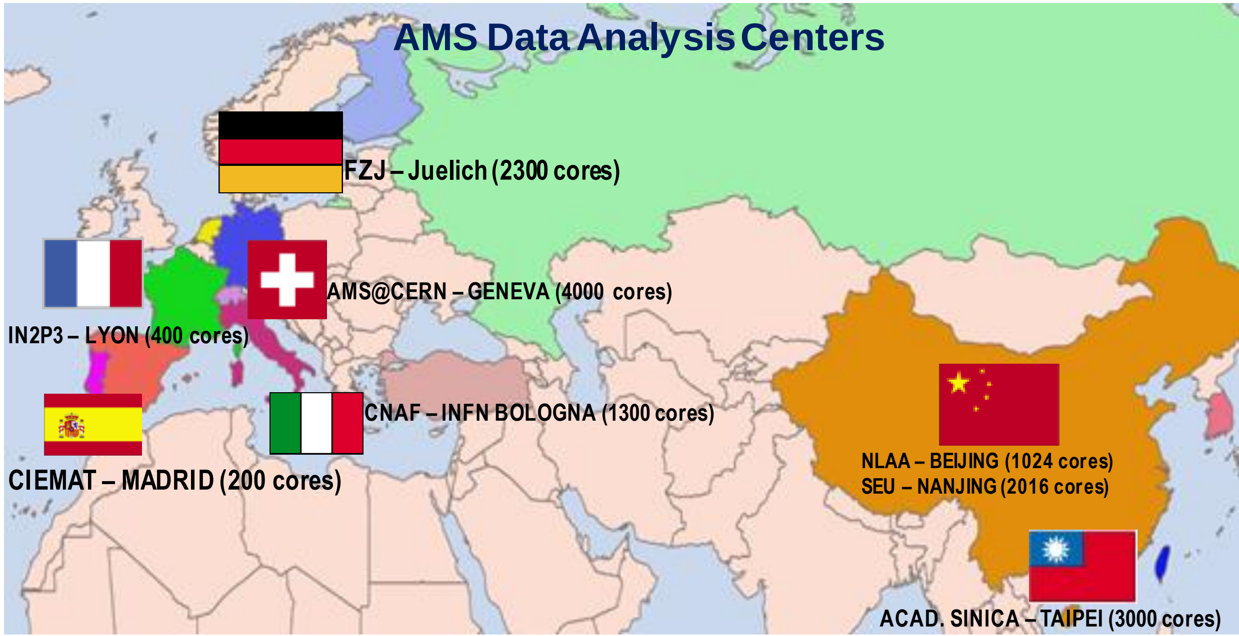
Anisotropy

Antiproton Ratio

Photons

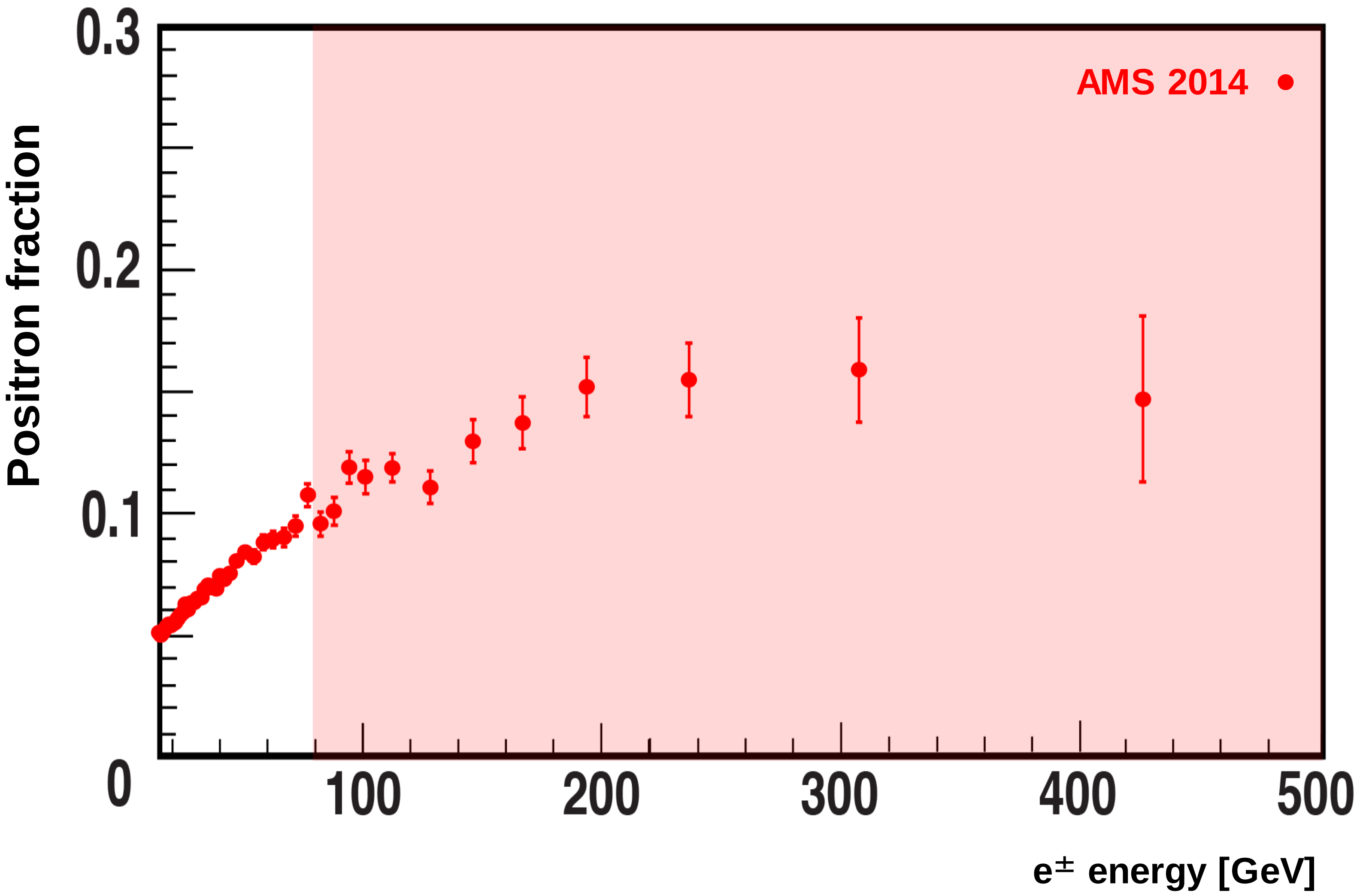
Antimatter Search

Strangelets Search

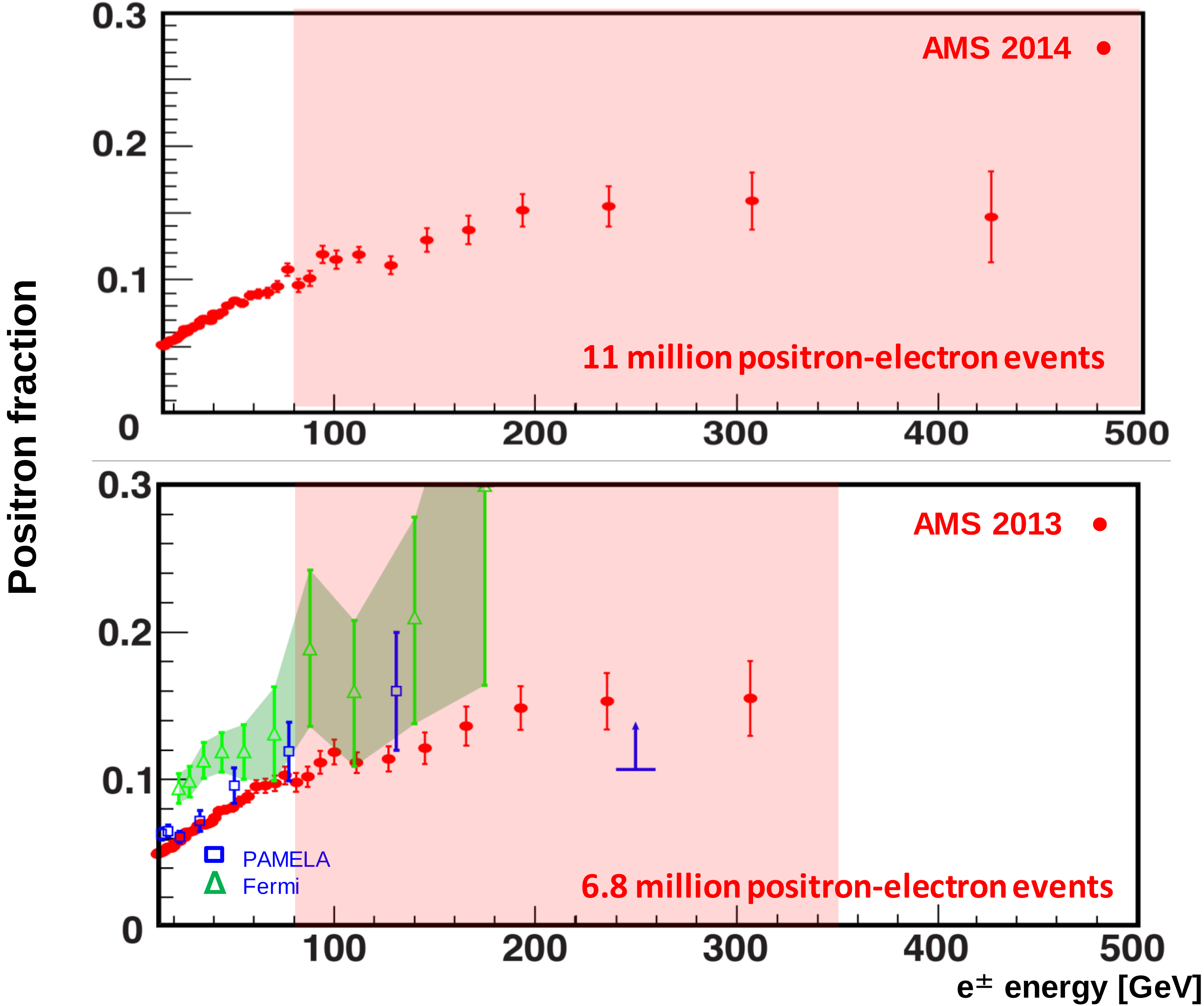


New Results on Positron Fraction

1. At much higher energy (up to 500 GeV)



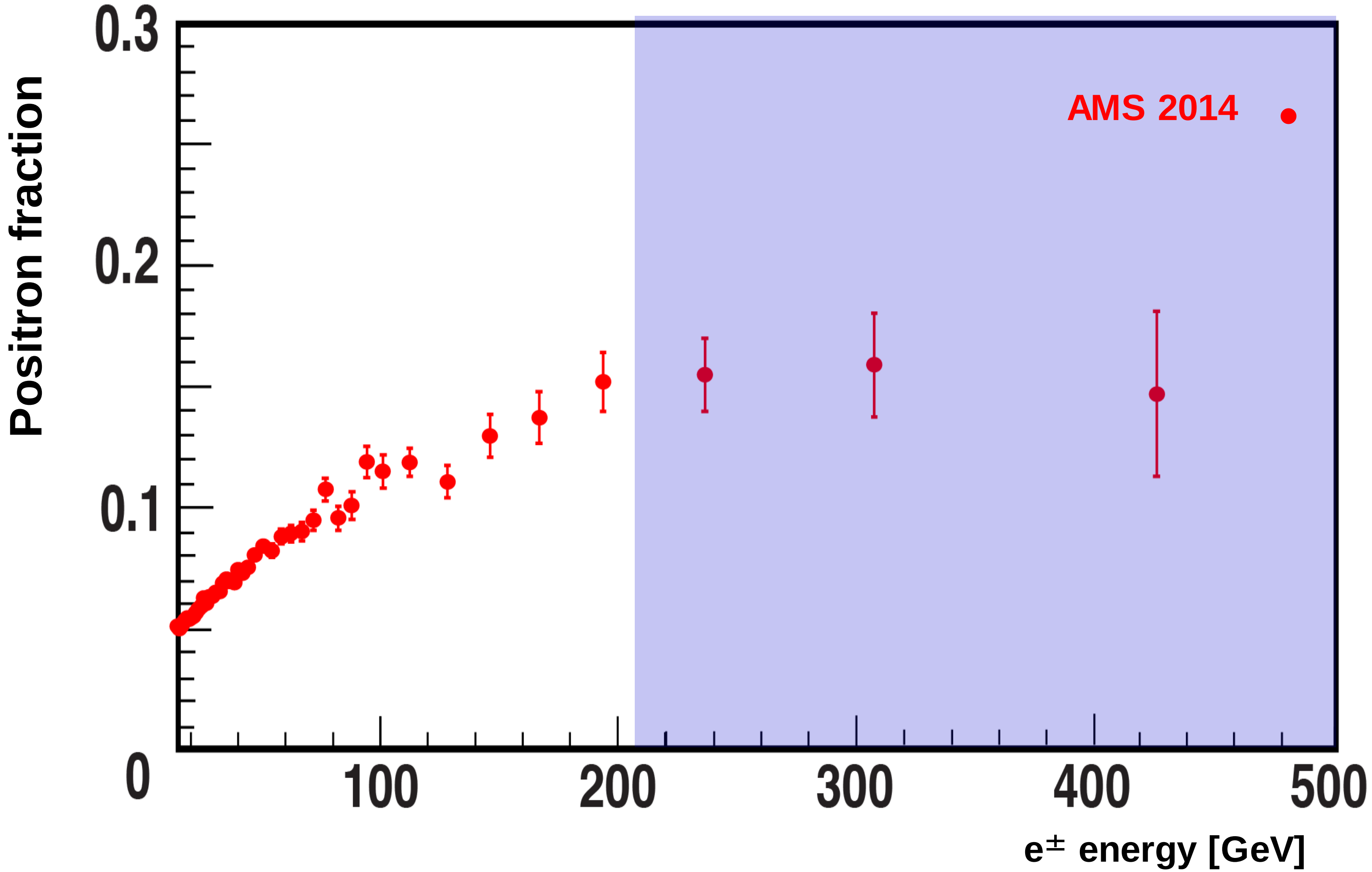
2. With much higher statistics



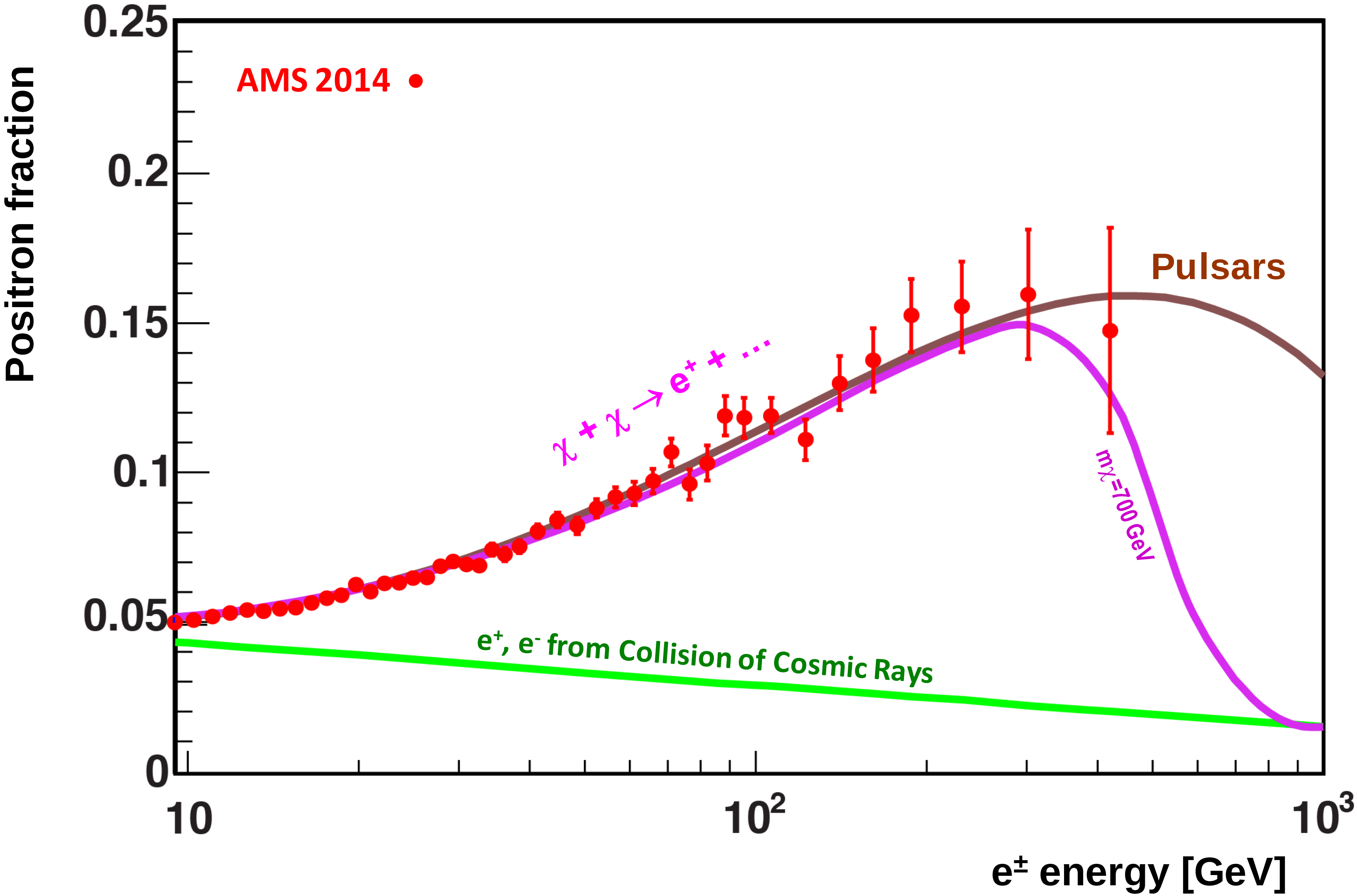
3. Above 206 GeV, Positron Fraction is independent of $e^{\pm}$ energy

In the energy region 206 – 500 GeV, we fit the Positron Fraction with a straight line equation: positron fraction = a+b·E

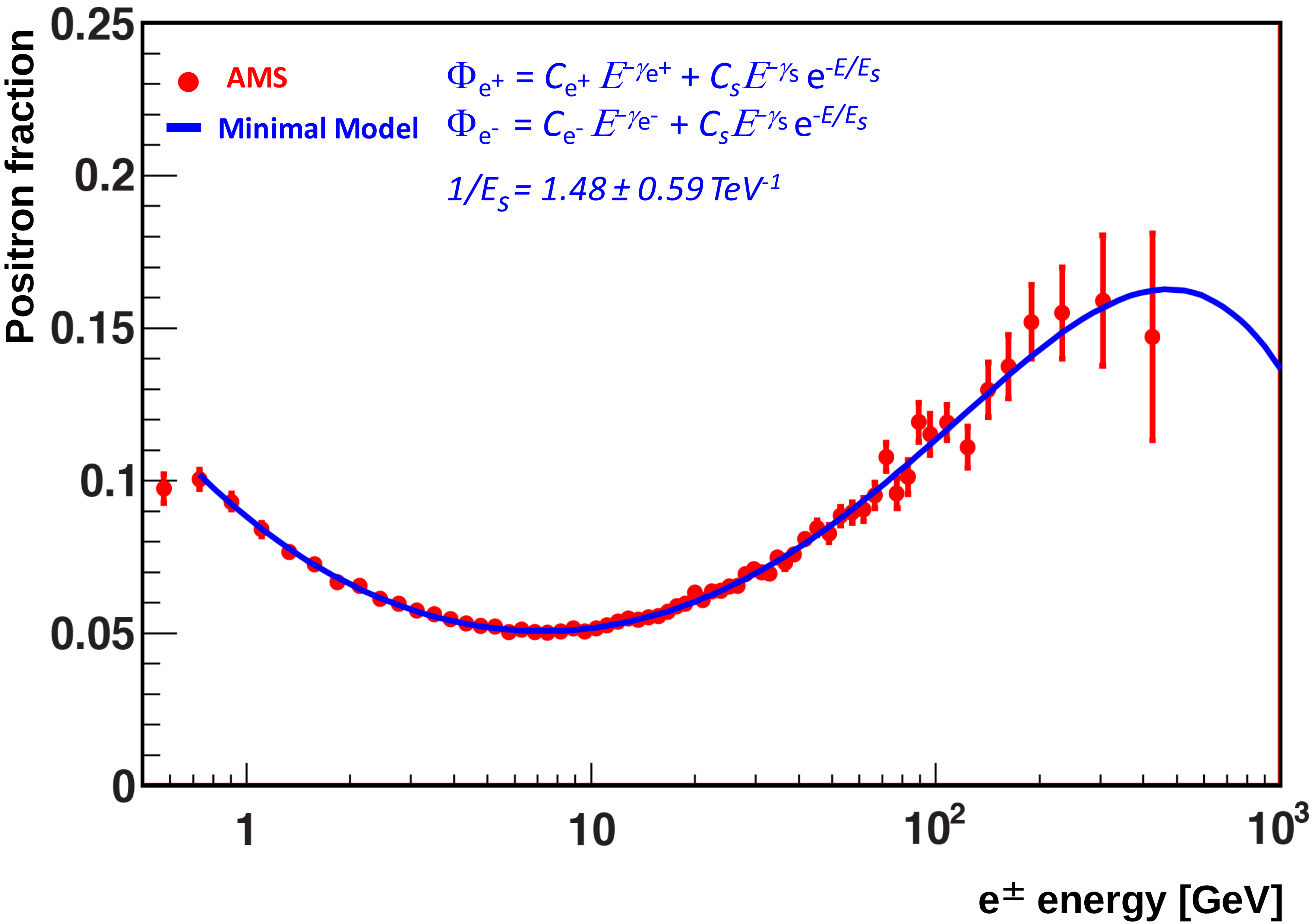
then $b = -(2.6 \pm 18.4)\ 10^{-5}$

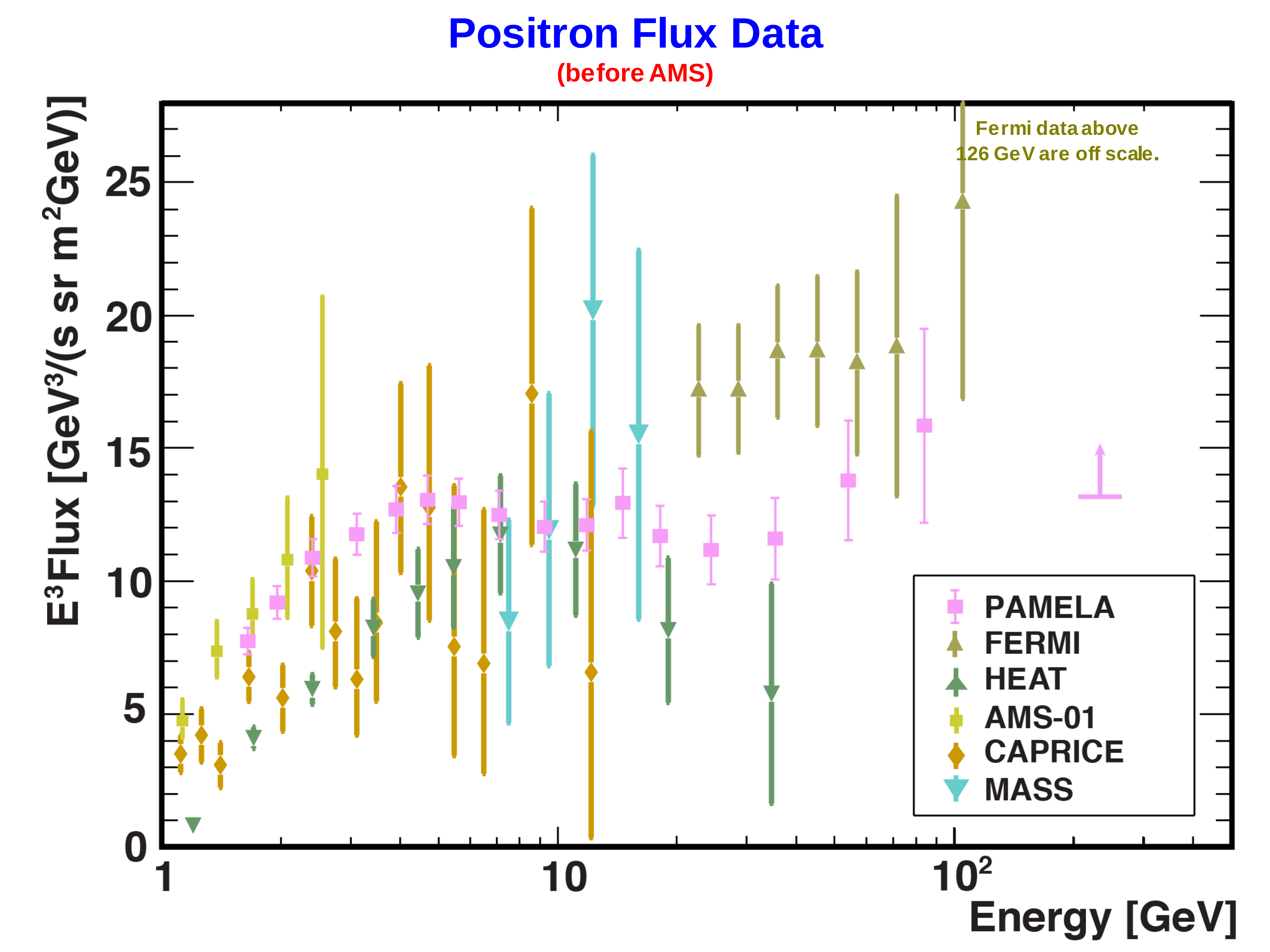


New Positron Fraction results compared with models



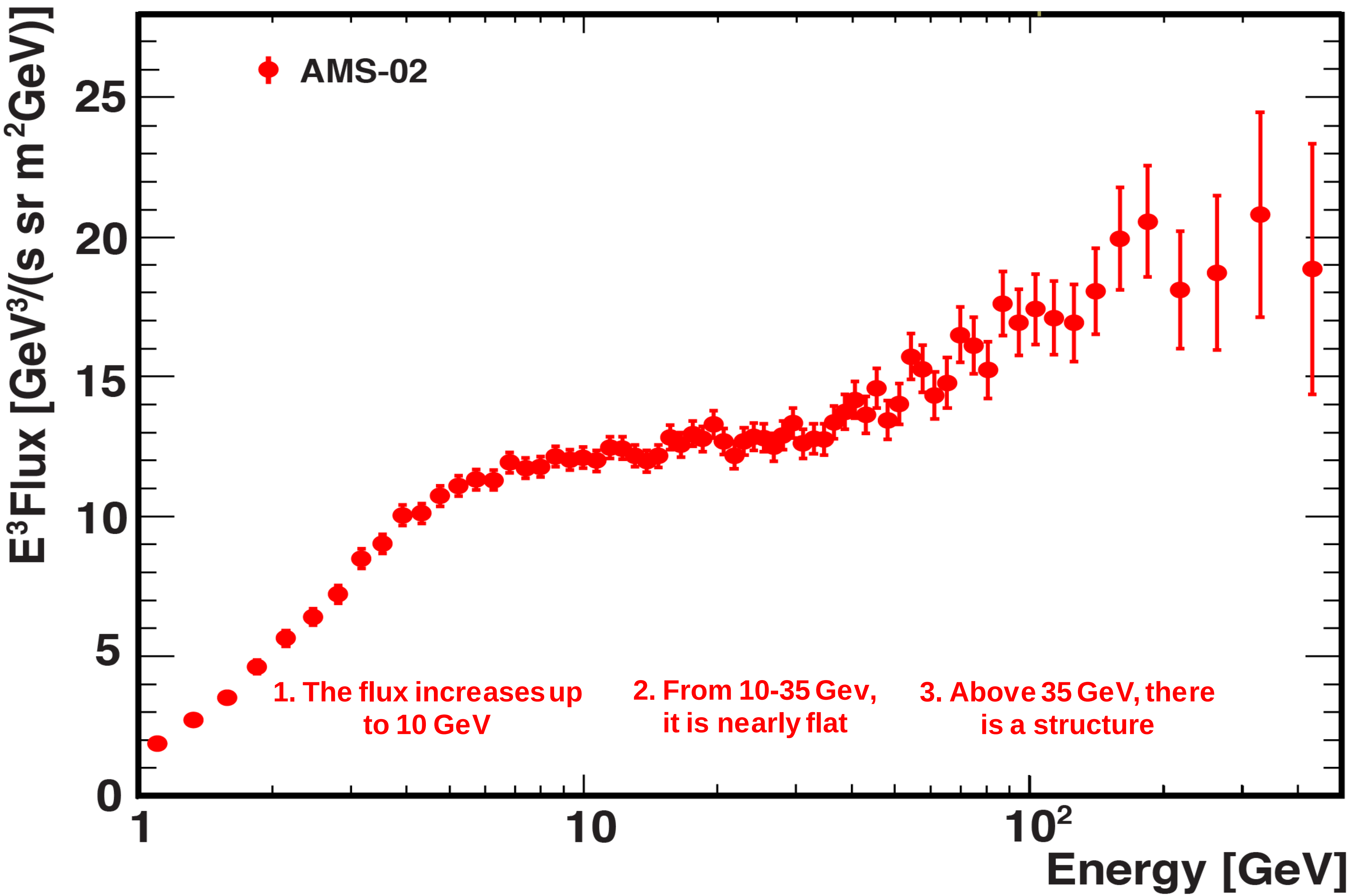
New Position Fraction Results compared with Minimal Model

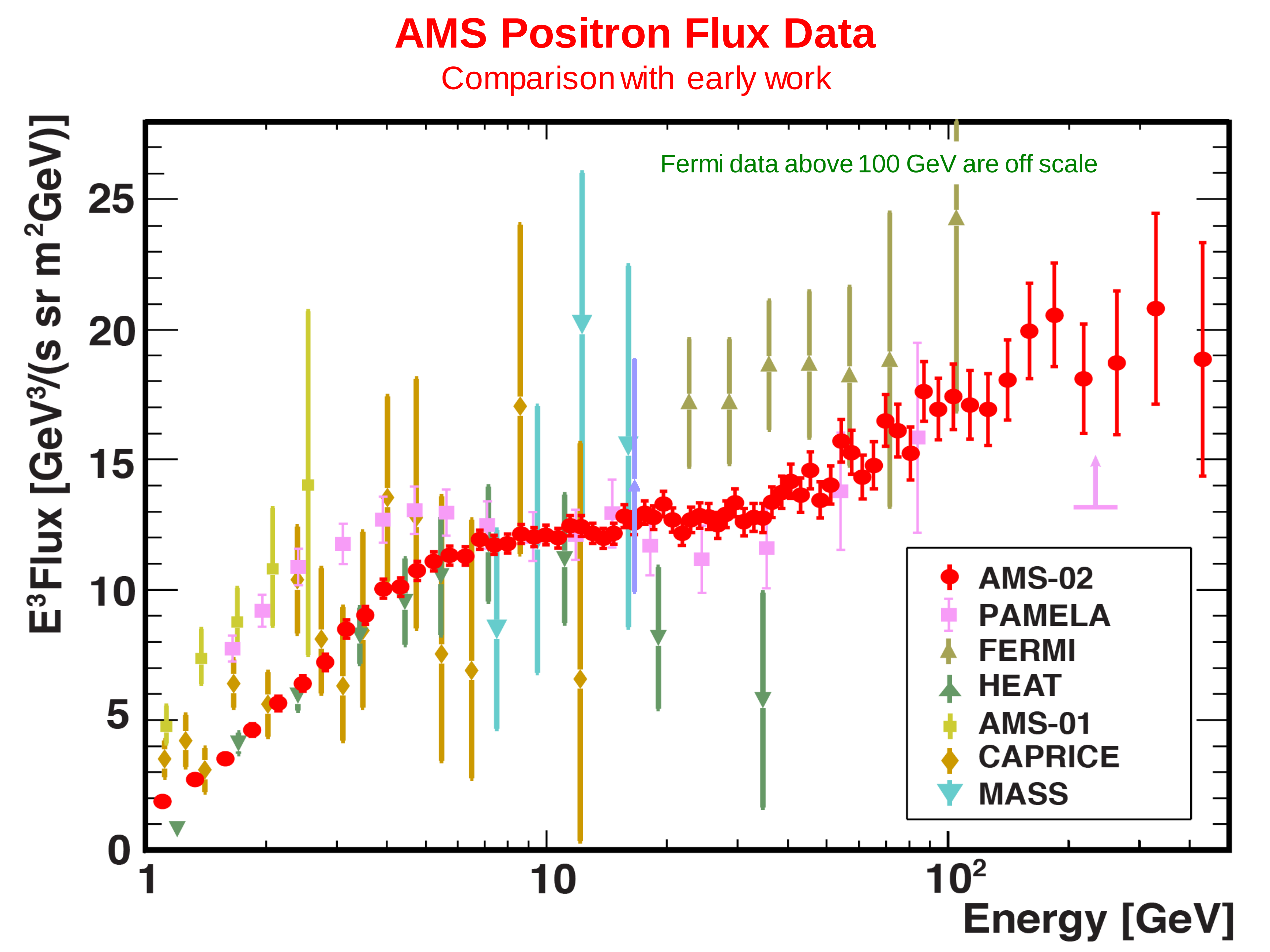




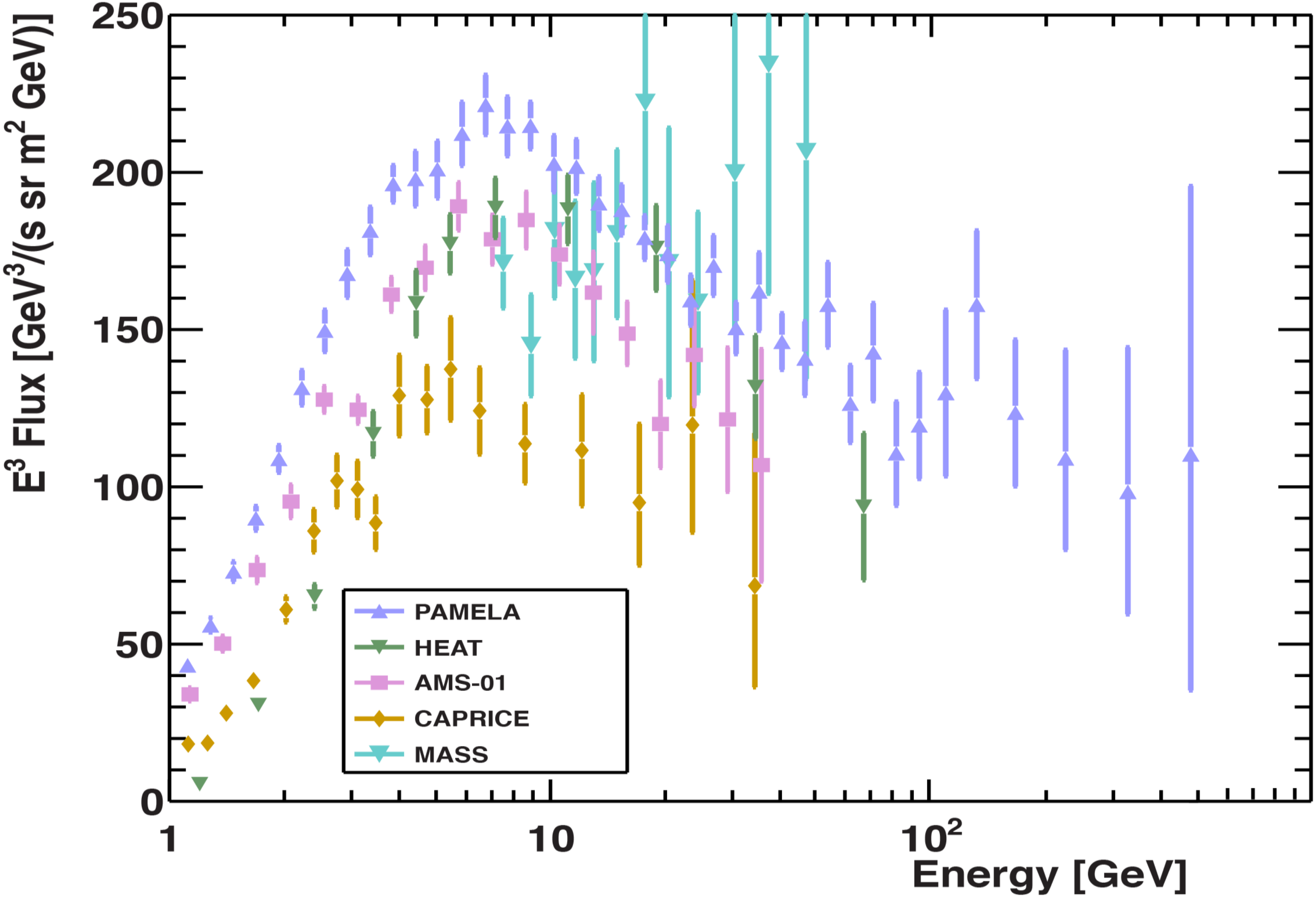
Positron Flux Data
(before AMS)
Fermi data above
126 GeV are off scale.
E^3Flux [GeV^3/(s sr m^2GeV)]
Energy [GeV]
PAMELA
FERMI
HEAT
AMS-01
CAPRICE
MASS
0
5
10
15
20
25
1
10
10^2

New AMS Results: Measurement of Positron Flux.
The Positron Flux exhibits 3 unexpected behaviours

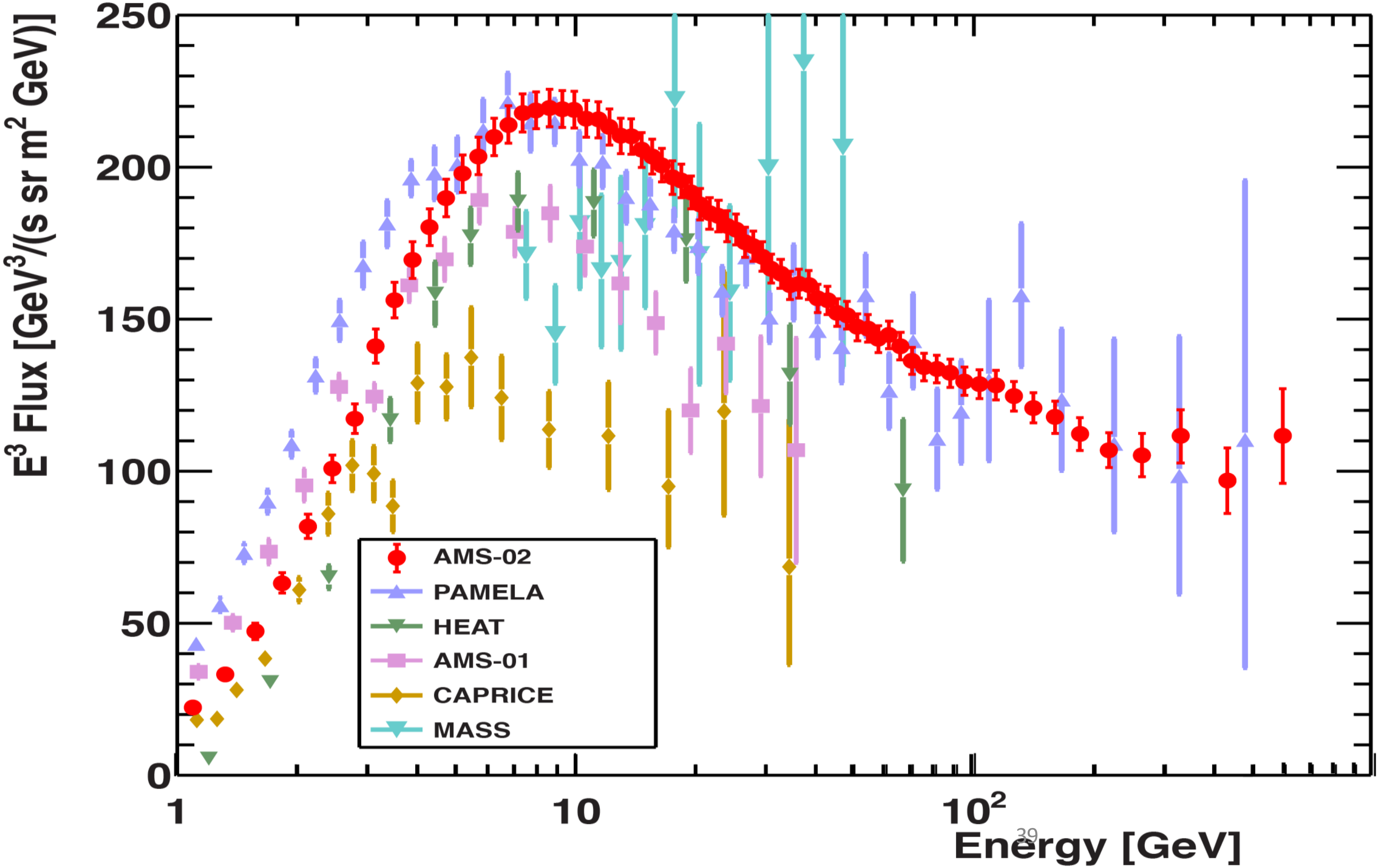



AMS Positron Flux Data
Comparison with early work
Fermi data above 100 GeV are off scale
E³Flux [GeV³/(s sr m²GeV)]
25
20
15
10
5
0
1
10
10²
Energy [GeV]
AMS-02
PAMELA
FERMI
HEAT
AMS-01
CAPRICE
MASS

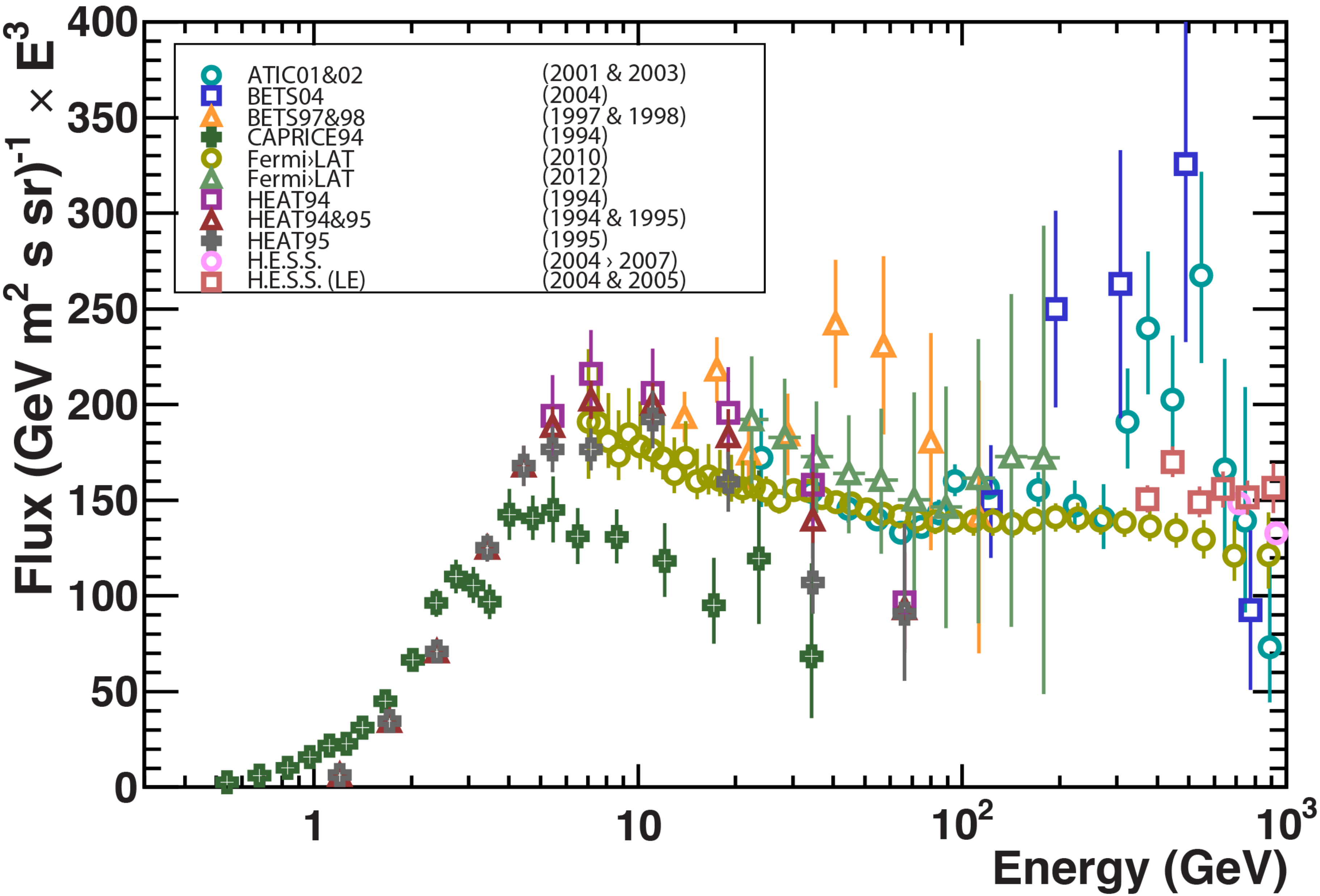
Electron flux measurement before AMS



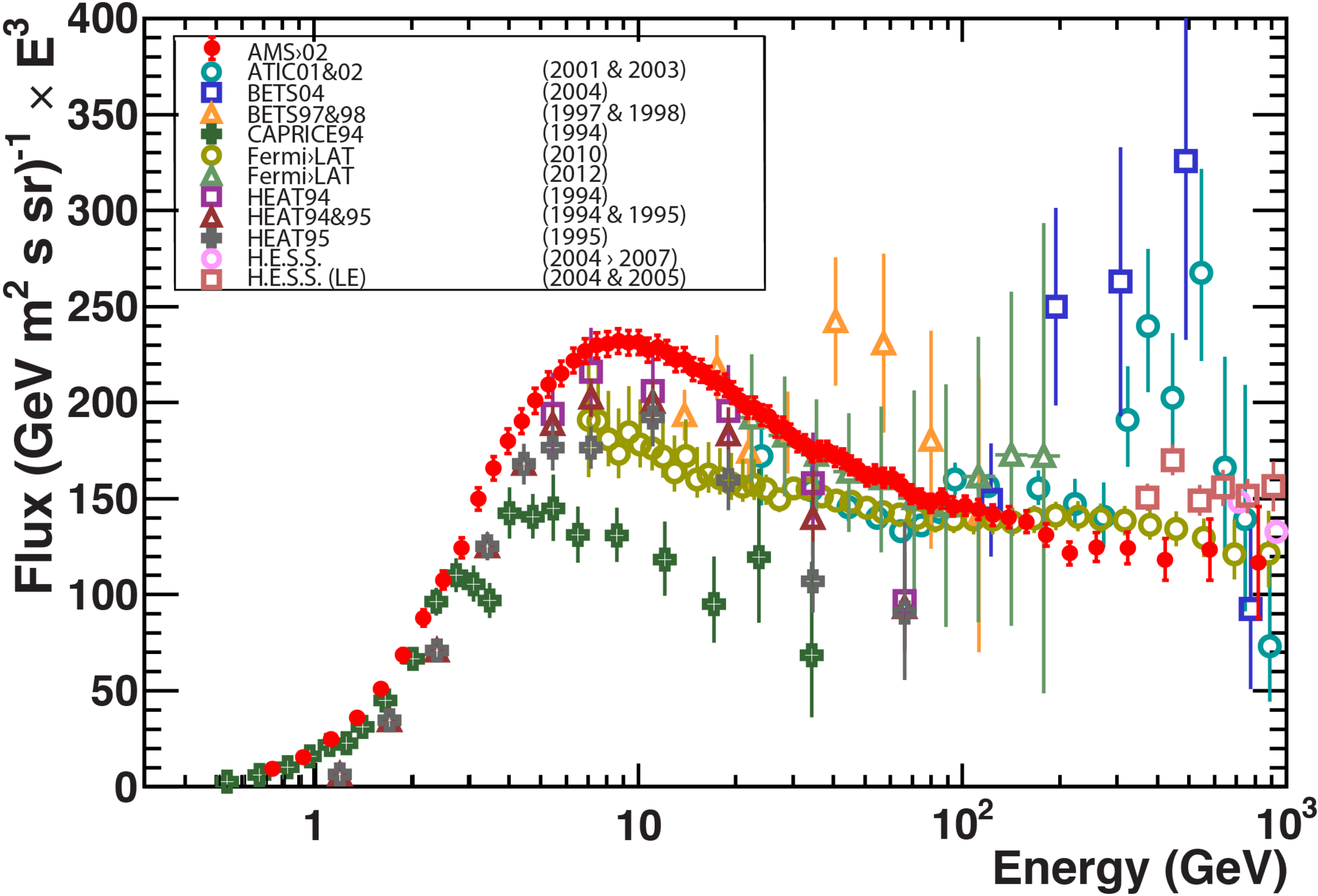
AMS Electron flux measurement compared with early work



$(e^+ + e^-)$ flux measurement before AMS



AMS ($e^+ + e^-$) flux - New Understanding



In the past hundred years, measurements of charged cosmic rays by balloons and satellites have typically contained ~30% uncertainty.

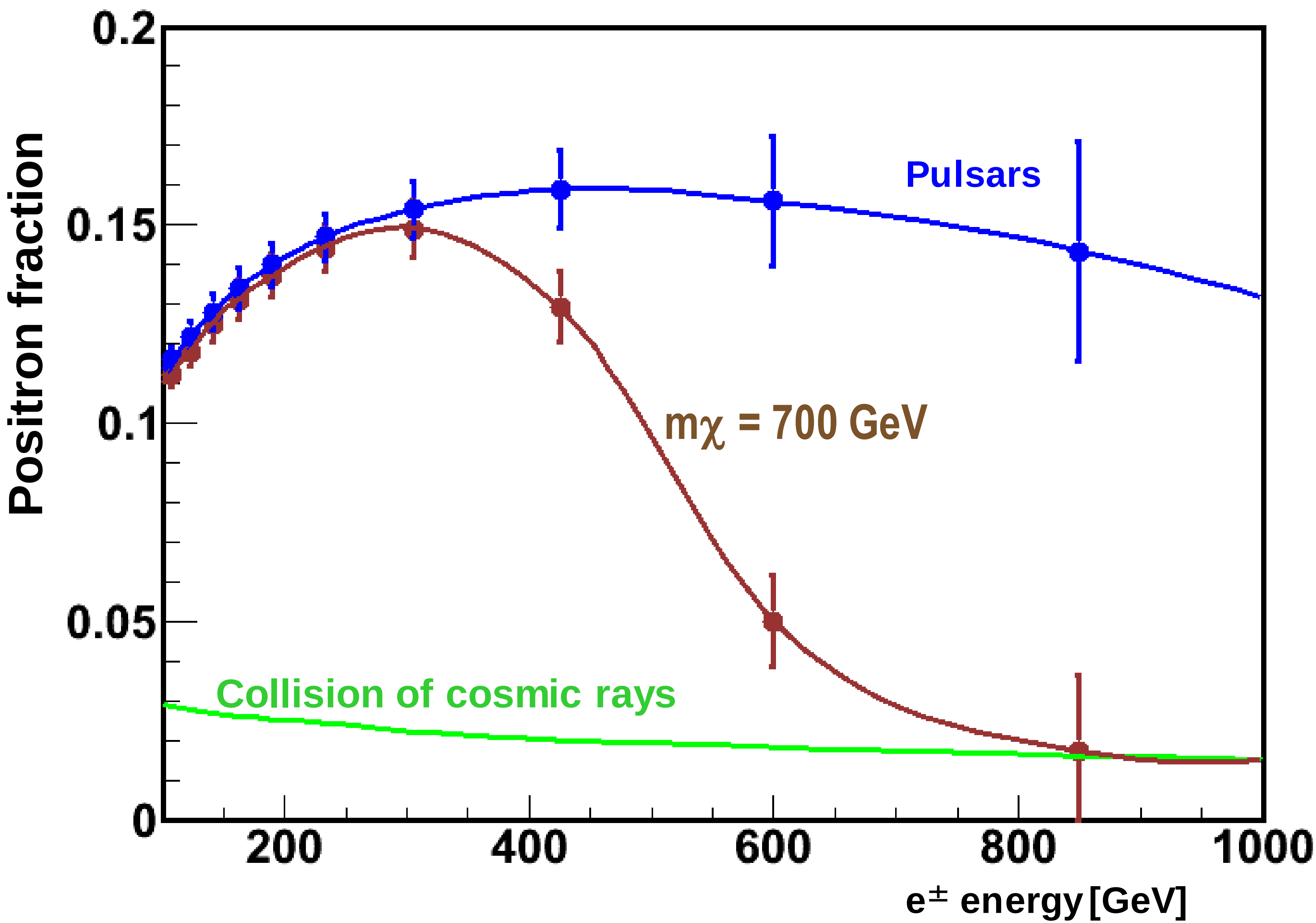
AMS will provide cosmic ray information with ~1% uncertainty.

The 30 times improvement in accuracy will provide new insights.

The Space Station has become a unique platform for precision physics research.

During the life time of ISS we expect to obtain 300 billion events
Examples of Future Physics

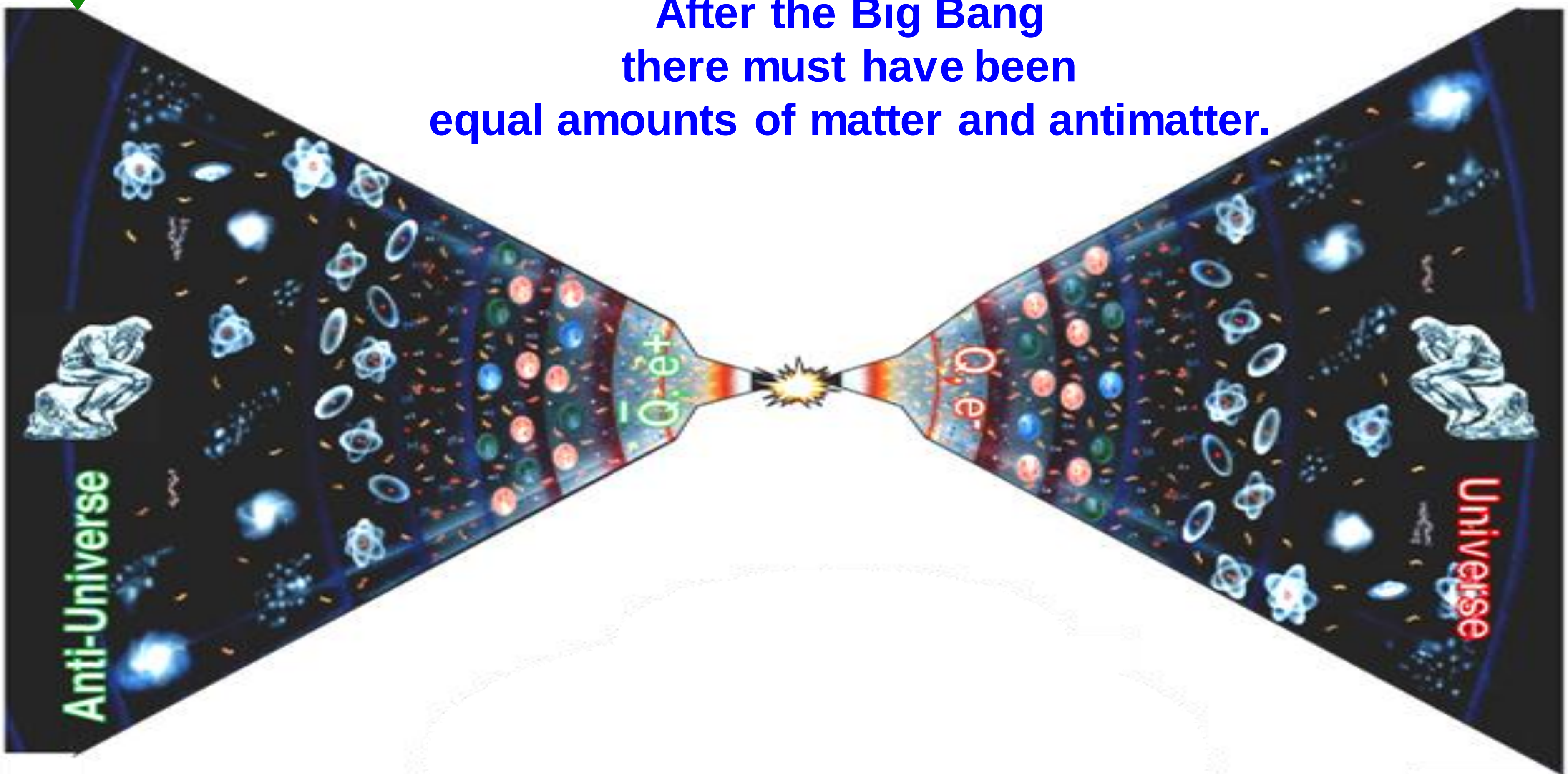
1. Ascertain the origin of the positron fraction



2. Search for Antimatter Universe

AMS on ISS

The Universe began with the Big Bang.
After the Big Bang
there must have been
equal amounts of matter and antimatter.



AMS on the Space Station for ~10 years will search for the existence of antimatter to the edge of the universe

CARL D. ANDERSON

The production and properties of positrons

Nobel Lecture, December 12, 1936

(The discovery of the first antimatter)

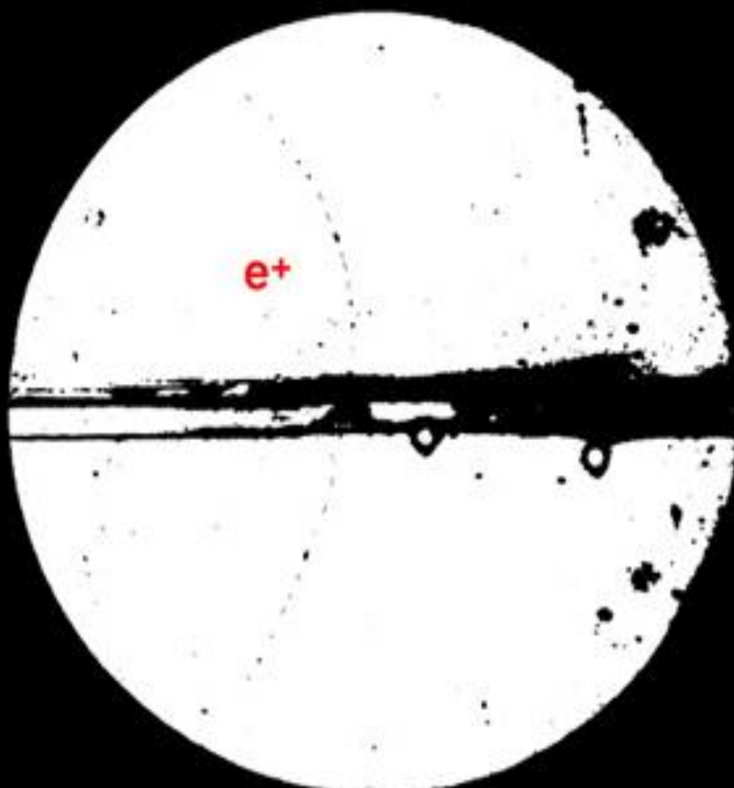


Fig. 1. A 63 million electron-volt positron passing through a 6 mm lead plate and emerging with an energy of 23 million electron-volts. The length of this latter path is at least ten times greater than the possible length of a proton track of this curvature. (Magnetic field 15,000 gauss.) *In all the photographs the magnetic field is directed into the paper.*

From accelerators results we found that every particle has its antiparticle:

Matter	**Antimatter**
electron	positron
proton	antiproton
neutron	antineutron
helium	anti helium
π^+	π^-
K^+	K^-

Question: is there Antimatter Universe?

Universe

He

C

Anti-Universe ?

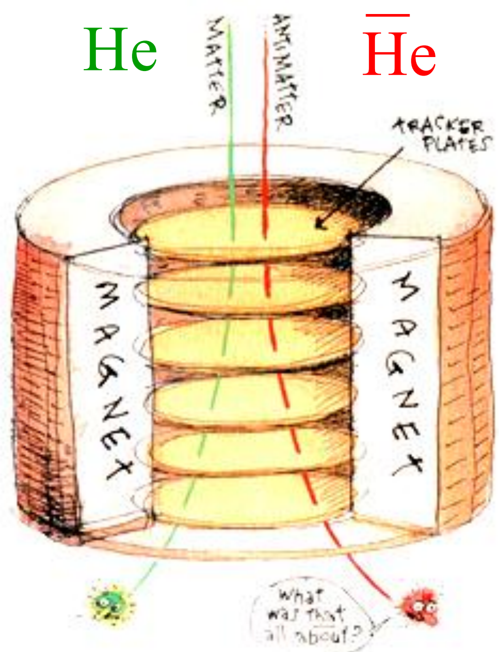
$\overline{\text{He}}$

$\overline{\text{C}}$

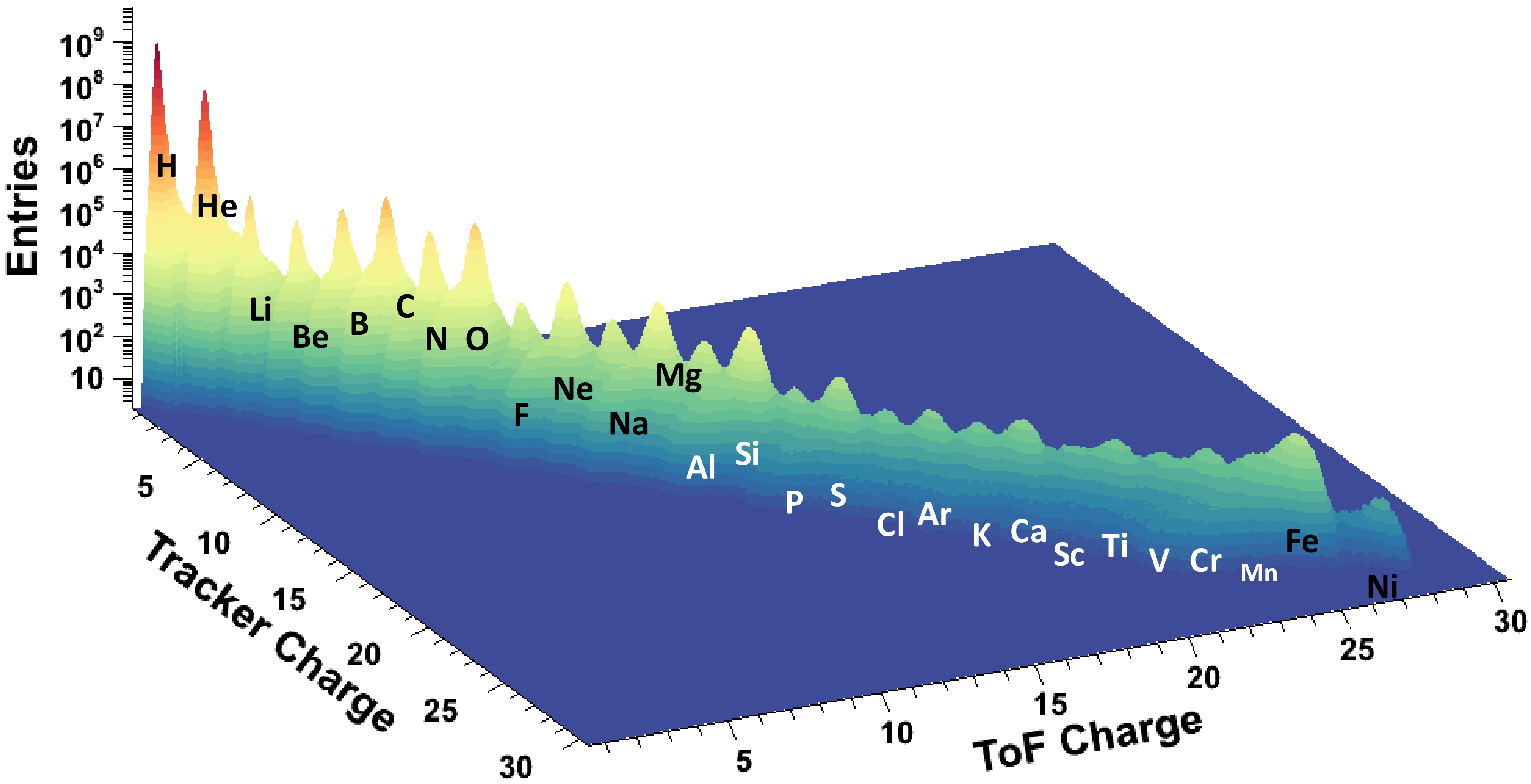
Detection of Antimatter Universe

1. Cosmic antimatter cannot be detected on earth because matter and antimatter will annihilate each other in the atmosphere.

2. Matter and antimatter have opposite electric charges. We need a magnetic detector to measure the charge of antimatter.



AMS Measurement of Periodic Table



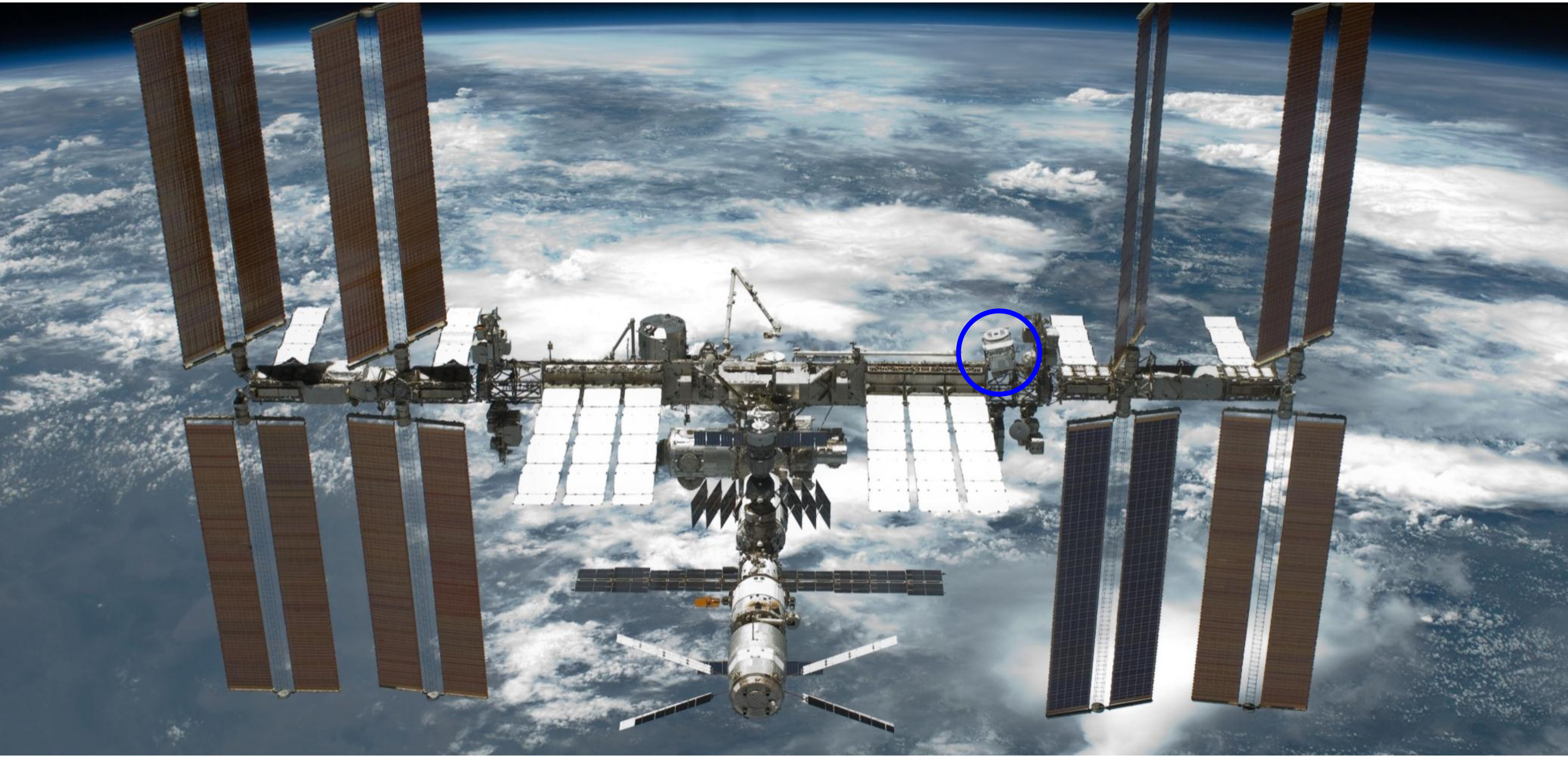
Discoveries in Physics

Facility	Original purpose, Expert Opinion	Discovery with Precision Instrument
30 GeV Proton Accelerator (1960's) CERN	Nuclear force	Neutral Currents -> Z, W
30 GeV Proton Accelerator (1960's) Brookhaven	Nuclear force	2 types of neutrinos Break down of time reversal symmetry New form of matter
400 GeV Proton Accelerator (1970's) FNAL	Neutrino physics	*5th and 6th types of quark*
Electron Positron Collider (1970's) SLAC Spear	Properties of quantum electricity	Quark inside protons 4th family of quarks 3rd kind of electrons
Electron Positron Collider (1980's) PETRA	6th kind of quark	*Gluon*
Large Underground Cave (2000) Super Kamiokande	Proton life time	Neutrino has mass
Hubble Space Telescope (1990's)	Galactic survey	*Curvature of the universe, dark energy*
AMS on ISS	Dark Matter, Antimatter,…	***?***

Exploring a new territory with a precision instrument is the key to discovery.

The Cosmos is the Ultimate Laboratory.

Cosmic rays can be observed at energies higher than any accelerator.



The most exciting objective of AMS is to probe the unknown; to search for phenomena which exist in nature that we have not yet imagined nor had the tools to discover.