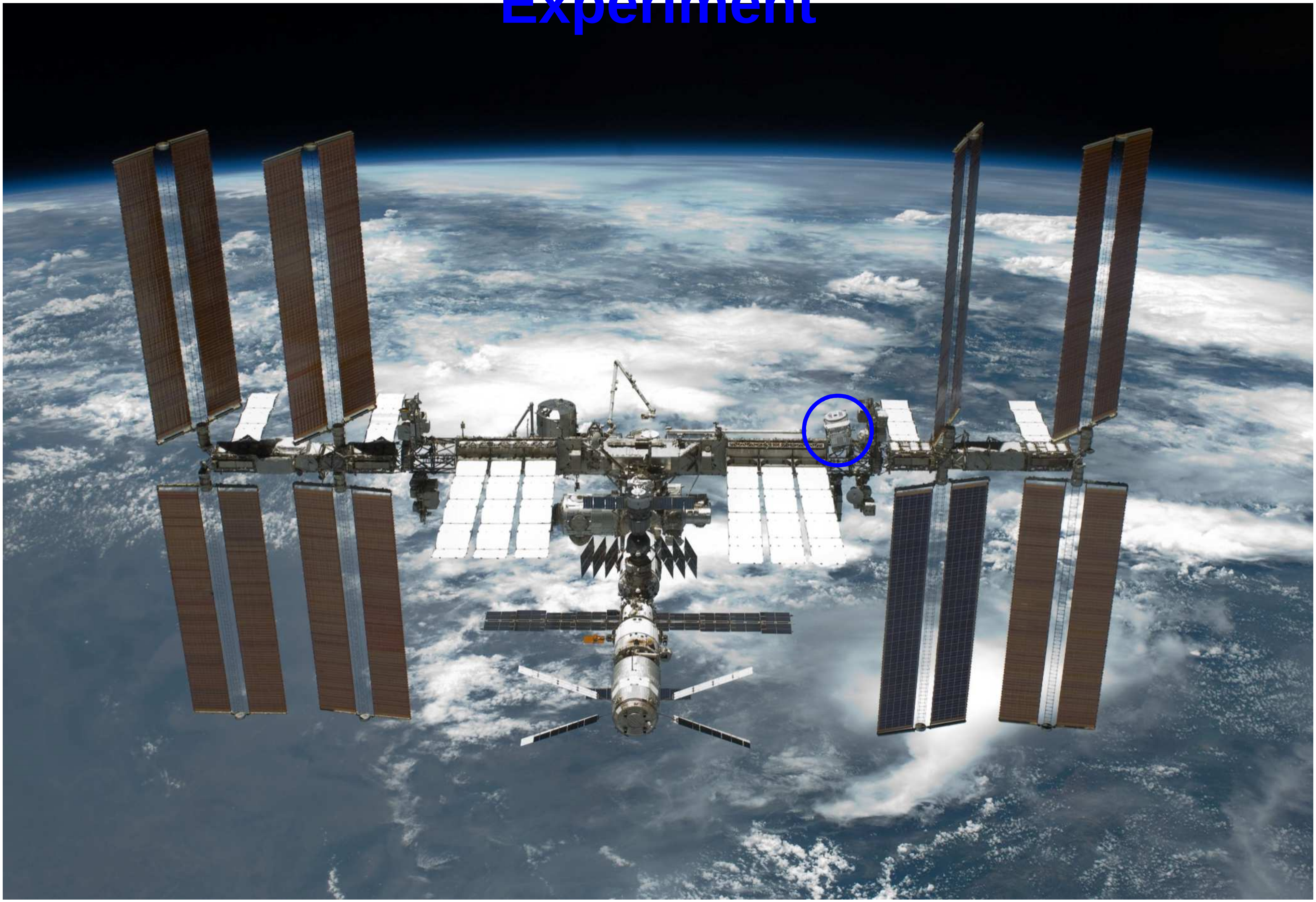
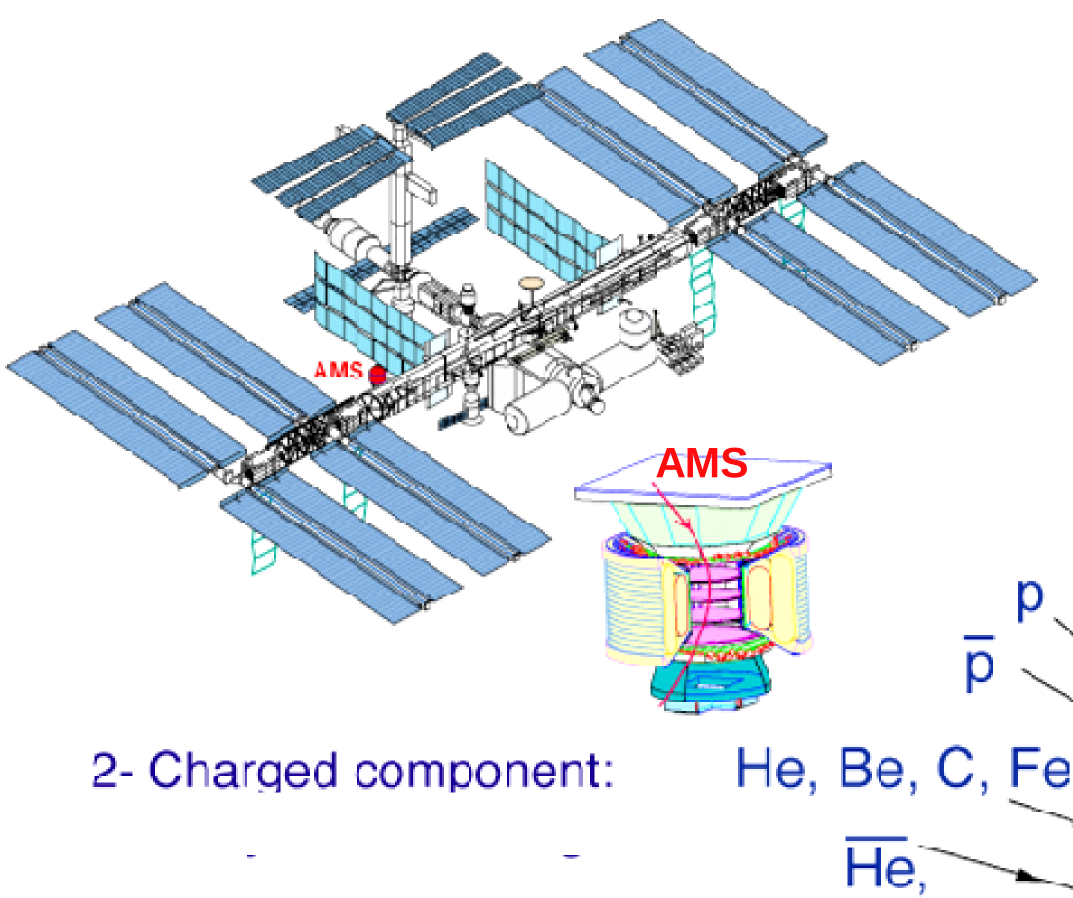
The Alpha Magnetic Spectrometer (AMS) Experiment

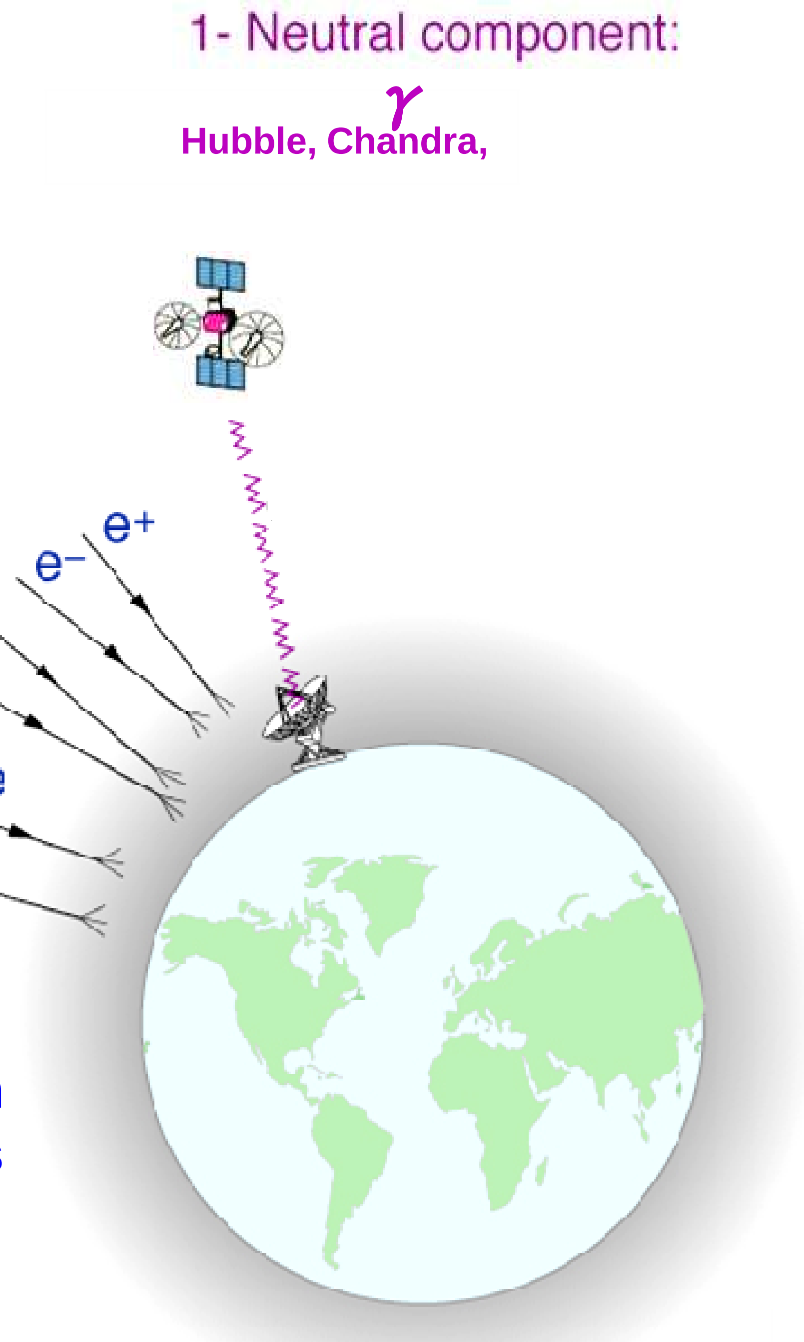


Outline

- Overview of cosmic ray science
- AMS-02 Detector
- Measurements to be made by AMS-02
- Current status of AMS-02

Fundamental Science on the International Space Station



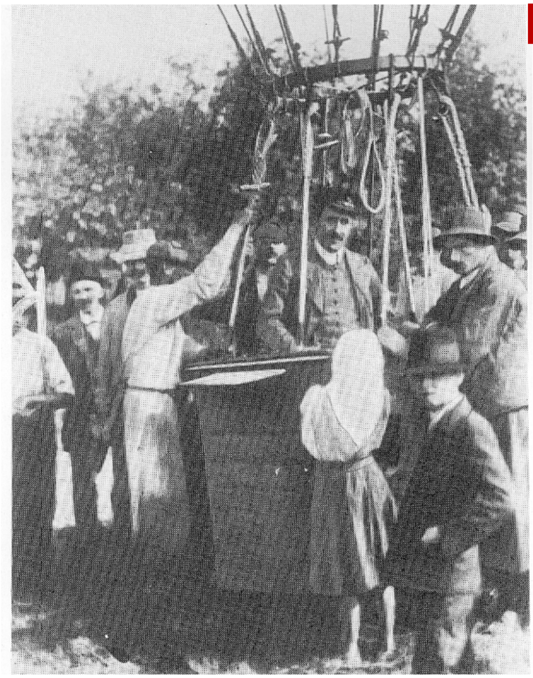


On Earth our atmosphere is an equivalent of 30 feet of water. This absorbs all the charged particles.

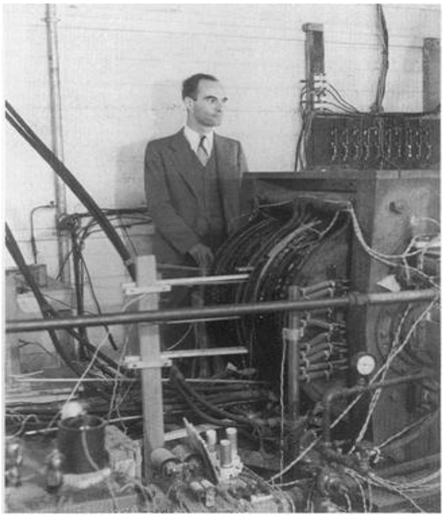
The Highest Energy Particles are Produced in the Cosmos

Cosmic Rays with energies of 100 Million TeV
have been detected by the Pierre Auger Observatory in Argentina, which spans an area of 3,000 km^2.

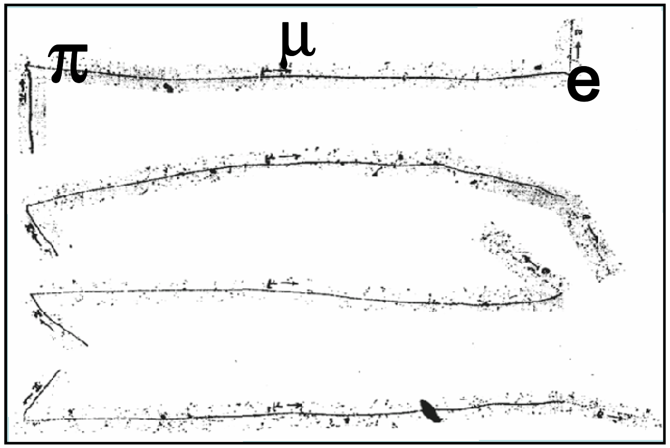
Early History of Fundamental Discoveries from Charged Cosmic Rays in the Atmosphere



1912: Discovery of Cosmic Rays



1932: Discovery of positron



1947: Discovery of pions

Discoveries of

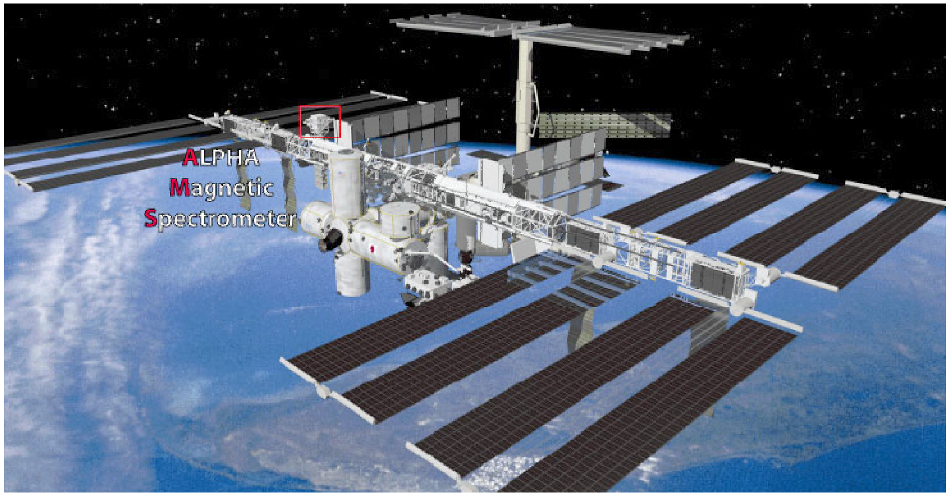
1936: Muon (μ)

1949: Kaon (K)

1949: Lambda (Λ)

1952: Xi (Ξ)

1953: Sigma (Σ)

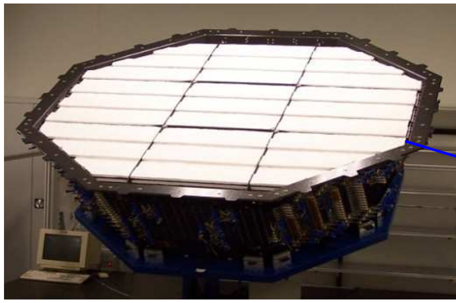


As accelerators have become exceedingly costly, the ISS is a valuable alternative to study fundamental physics.

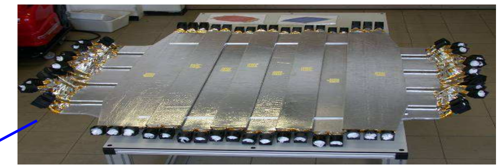
AMS: A TeV precision, multipurpose particle physics spectrometer in space.

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

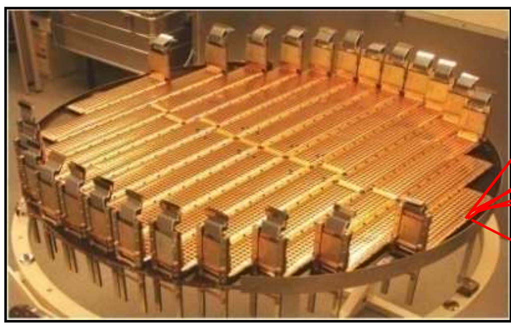
TRD
Identify e+, e-

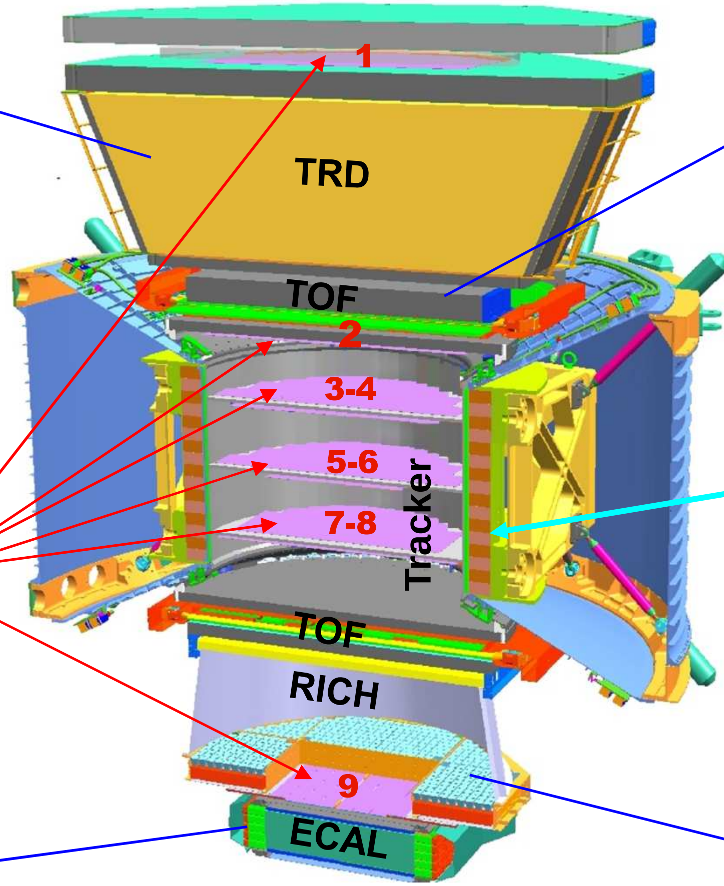


TOF
Z, E

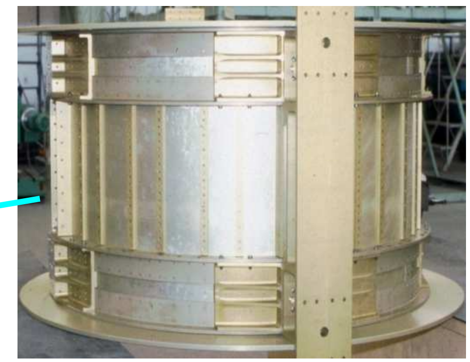


Silicon Tracker
Z, P





Magnet
±Z



RICH
Z, E

ECAL
E of e+, e-, γ

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

Photo Montage!!

Photo Montage!!

Photo Montage!!

Photo Montage!!

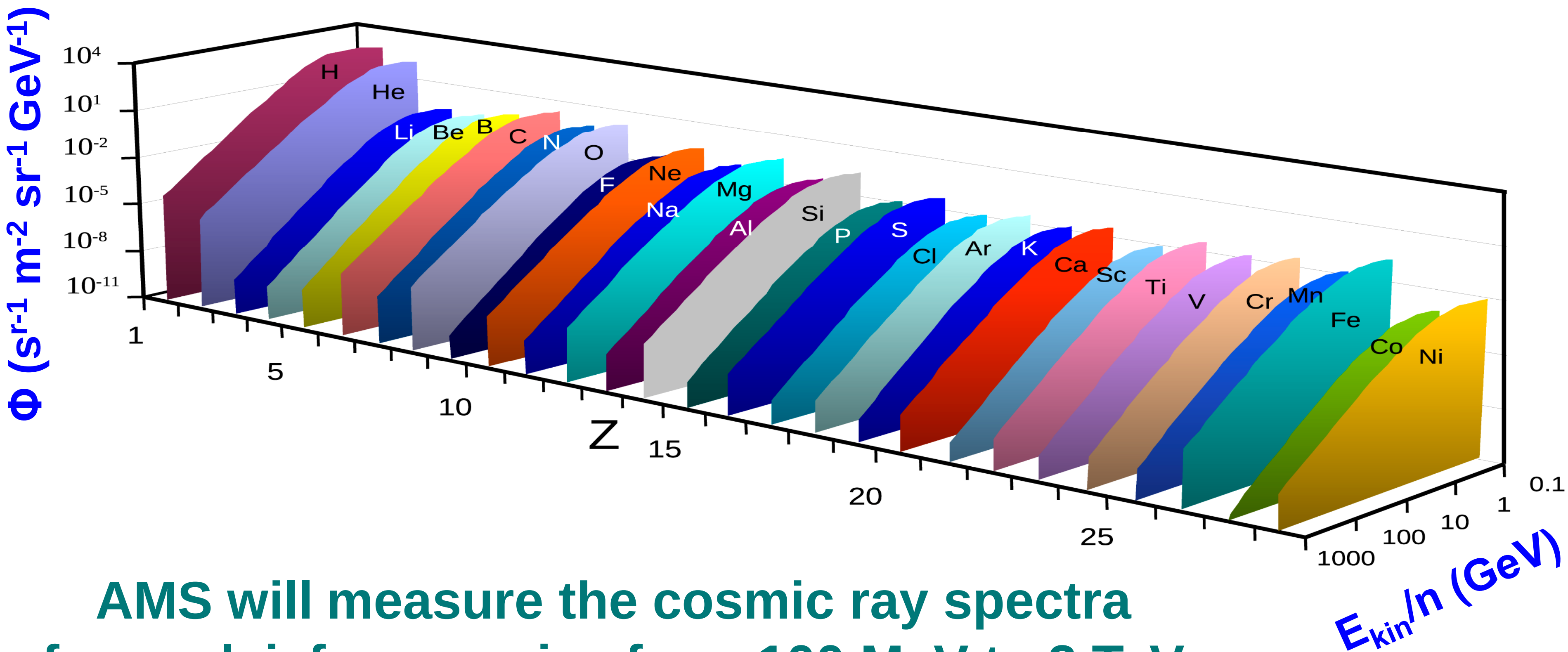
Photo Montage!!

POCC at CERN in Geneva control of AMS

AMS Physics examples

1- Precision study of the properties of Cosmic Rays

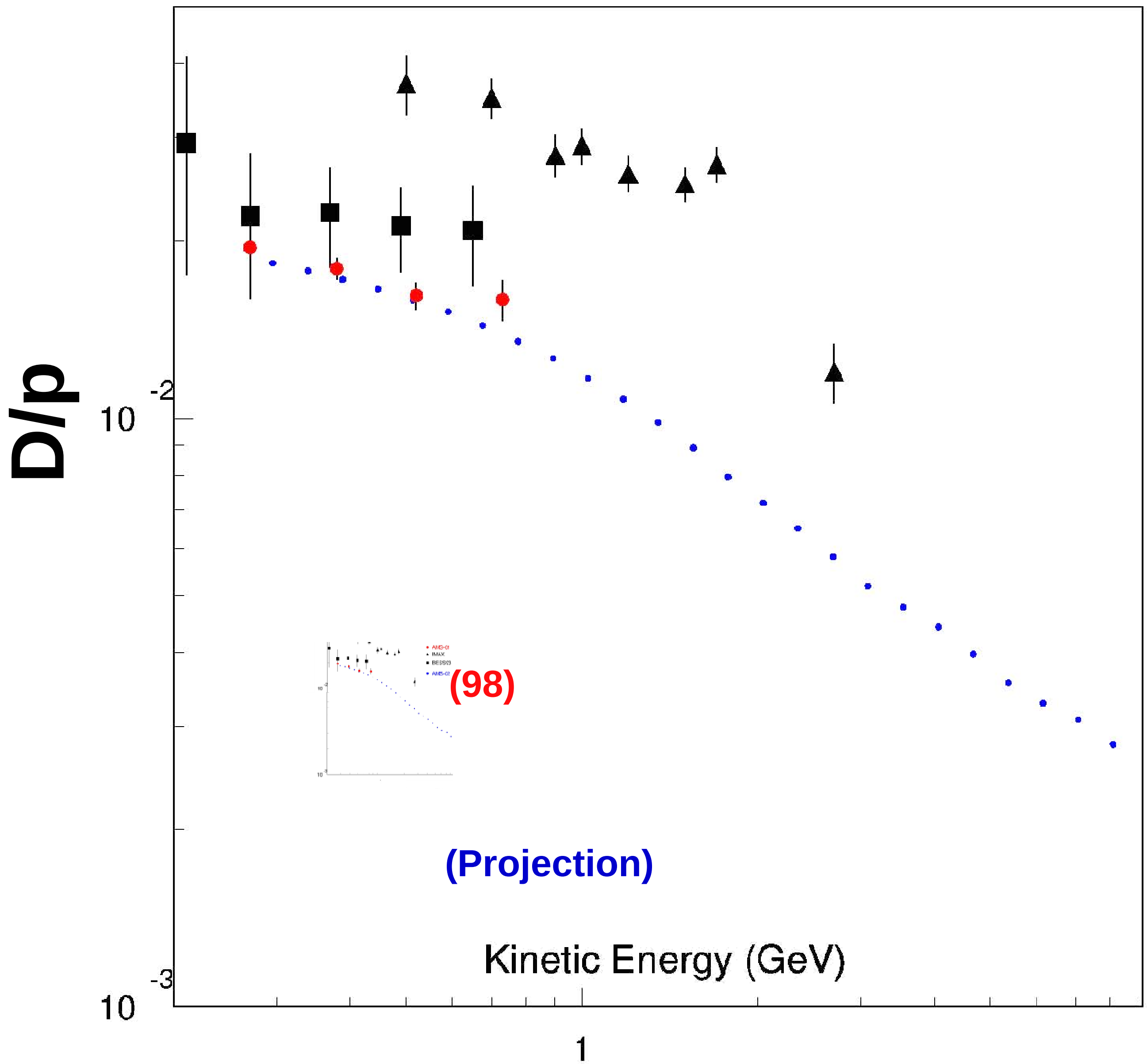
i. Composition at different energies (1 GeV, 100 GeV, 1 TeV)



AMS will measure the cosmic ray spectra for nuclei, for energies from 100 MeV to 2 TeV with 1% accuracy over the 11-year solar cycle.

These spectra will provide experimental measurements of the assumptions that go into calculating the background in searching for Dark Matter, i.e., p + C →e^{+}, p, …

AMS-02 Deuteron to Proton Ratio



Cosmic Ray Propagation

- Necessary to understand how cosmic rays travel from their sources to Earth.

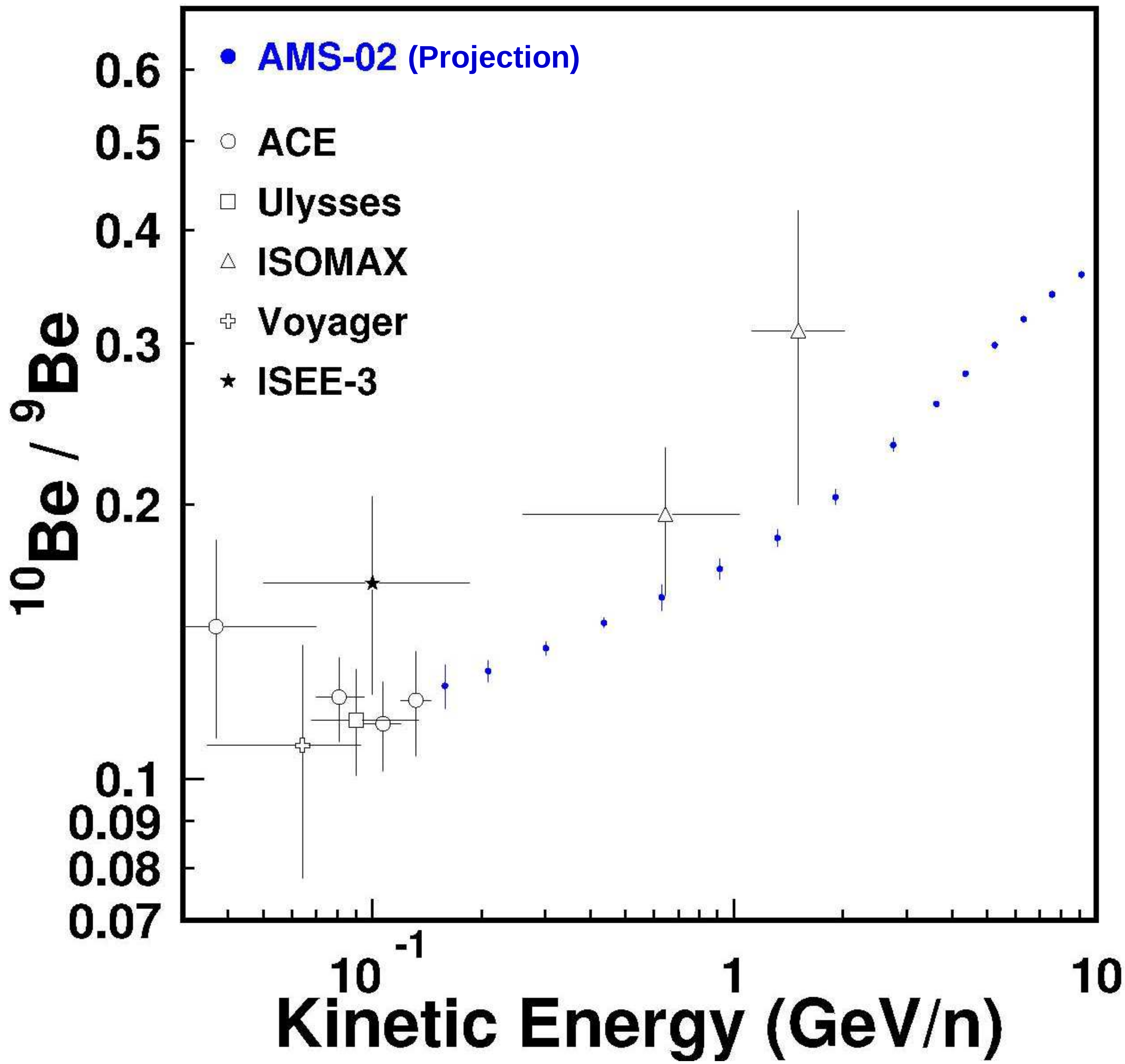
$$\frac{\partial \psi(\vec{r}, p, t)}{\partial t} = q(\vec{r}, p, t) + \vec{\nabla} \cdot (D_{xx} \vec{\nabla} \psi - \vec{V} \psi)$$
$$+ \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{1}{p^2} \psi - \frac{\partial}{\partial p} \left[\dot{p} \psi - \frac{p}{3} (\vec{\nabla} \cdot \vec{V}) \psi \right] - \frac{1}{\tau_f} \psi - \frac{1}{\tau_r} \psi$$

Strong A.W., Moskalenko I.V., Ptsukin V.S. 2007, Annu. Rev. Nucl. Part. Sci. 57, 285-327

- Notably, there are diffusion coefficients, and there are time constants which need to be accurately measured to determine the background cosmic ray flux.

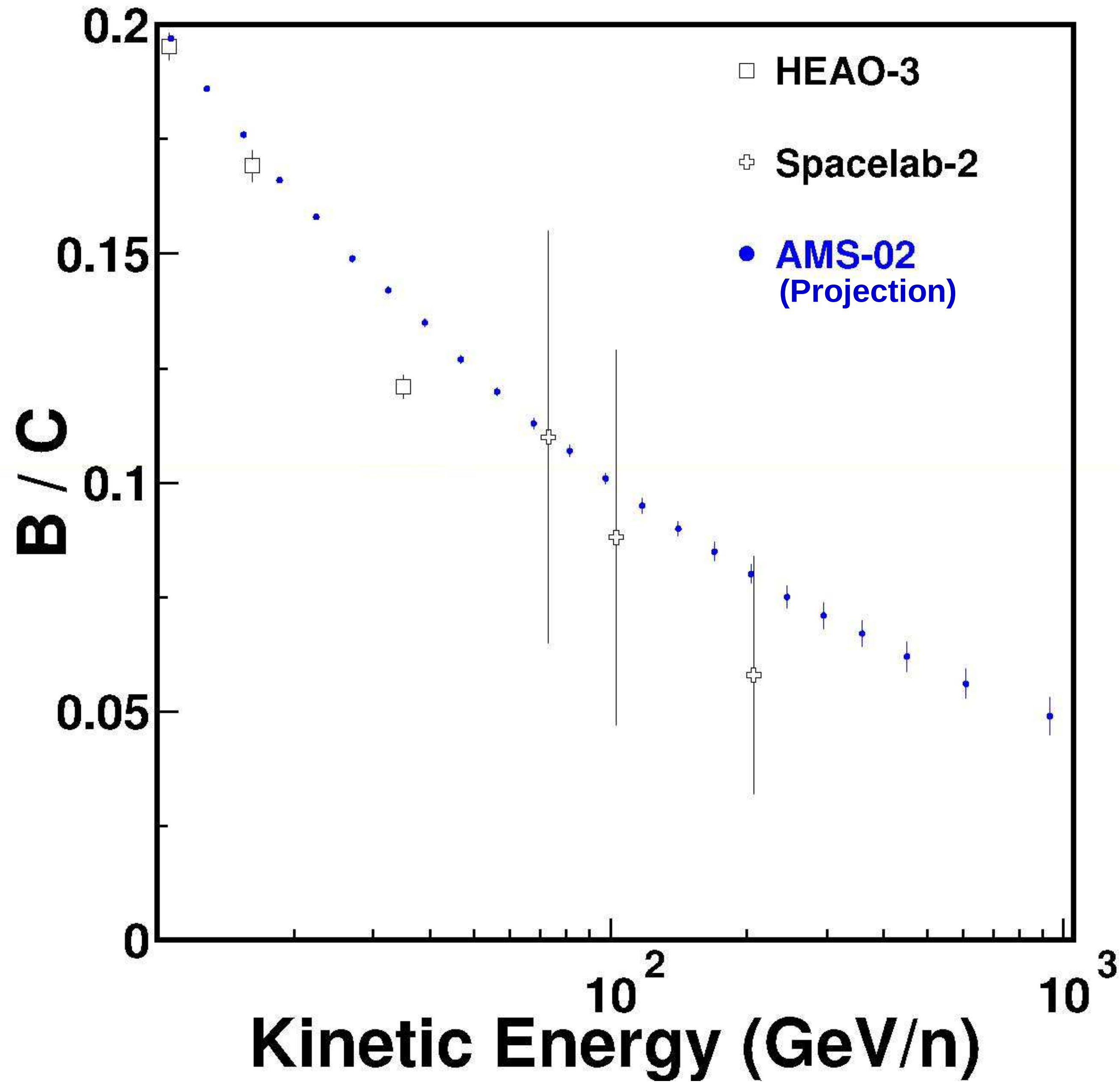
Precision study of the properties of Cosmic Rays

ii. Cosmic Ray confinement time

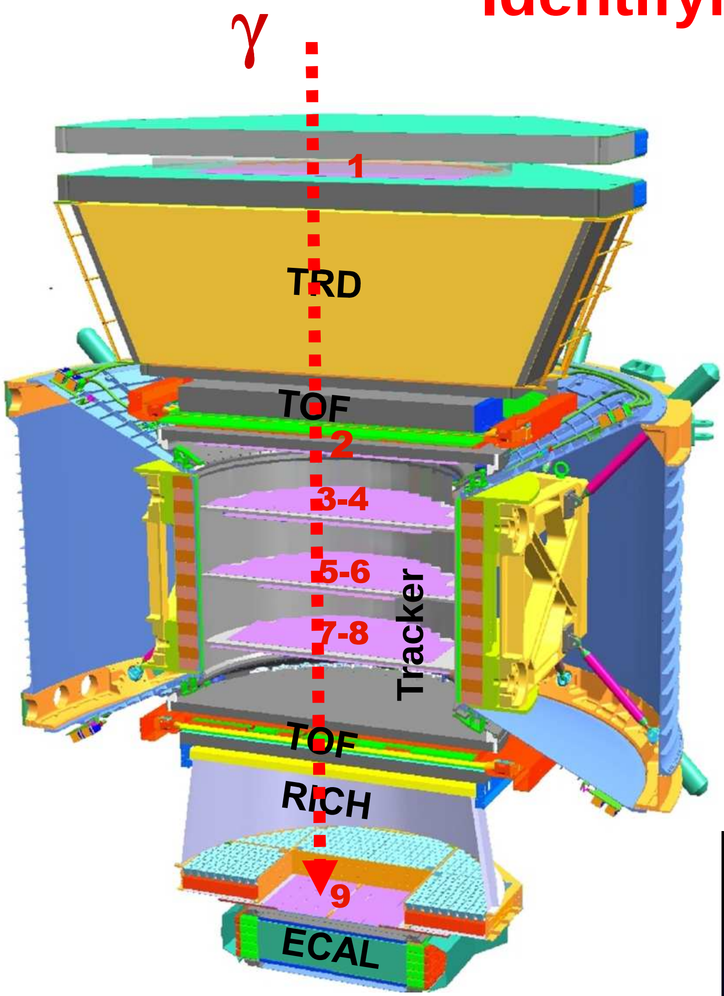


Precision study of the properties of Cosmic Rays

iii. Propagation parameters (diffusion coefficient, galactic winds, …)



Identifying γ Sources with AMS



Unique Features:
17 X_0, 3D ECAL,
Measure γ to 1 TeV,

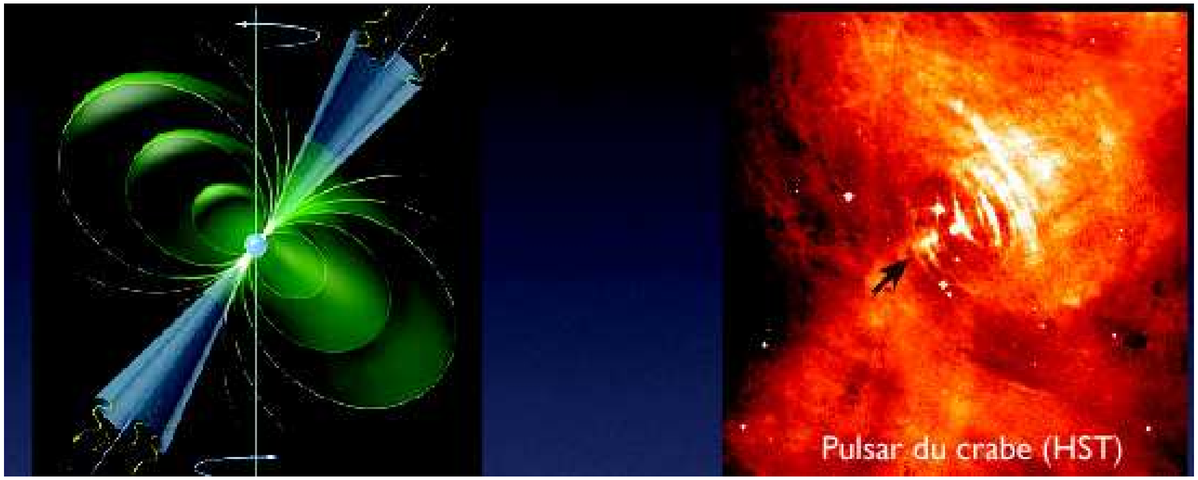
Example: Pulsars in the Milky Way

Neutron star sending radiation in a periodic way.

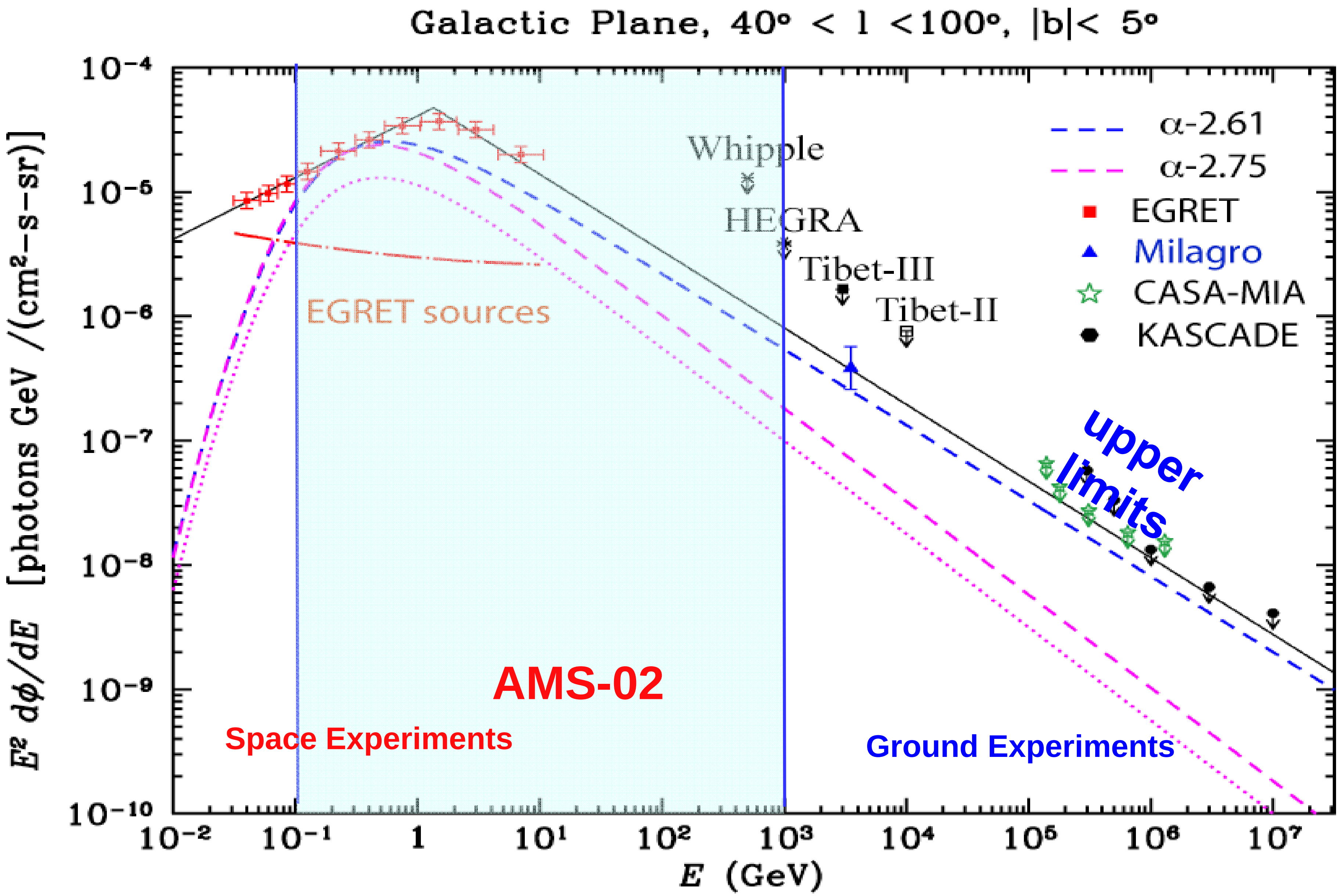
Currently measured to energies of ~ 300 GeV with precision of a μsec.

AMS: energy spectrum up to 1 TeV and pulsar periods measured with μsec precision

A factor of 10 improvement in Energy



The diffuse gamma-ray spectrum of the Galactic plane



T.Prodanovi´c et al., astro-ph/0603618 v1 22 Mar 2006

Testing Quantum Gravity with photons

- **Two approaches are trying to elaborate quantum gravity: Loop Quantum Gravity && String Theory.**
- **Both of them predict the observed photon velocity depends on its energy.**
- **Loop Quantum Gravity: it might imply the discrete nature of space time tantamount to an "intrinsic birefringence" of quantum space time.**

$$E_{\pm} = \mathrm{Re}((e_1 \pm ie_2)e^{i(\Omega_{\pm}t - k \bullet x)})$$

$$\Omega_{\pm} = \sqrt{k^2 \mp 4\chi l_{planck} k^3}$$

For a gamma ray burst at 10 billion ly away and energy of ~200keV: A delay between the two group velocities of both polarizations that compose a plane wave of 10ms.

Testing String Theory with Photons

➢**String Theory: Photon's foamy structure at the scale of Planck length →A non-trivial refractive index when propagating in vacuum.**

$$c^2 p^2 = E^2 (1 + \xi \frac{E}{E_{QG}} + O(\frac{E^2}{E_{QG}^2}))$$

$$v = \frac{\partial E}{\partial p} \approx c(1 - \xi \frac{E}{E_{QG}})$$

We also need to take into account the red shift effect. The time lag is:

$$\Delta t = H_0^{-1} \frac{\Delta E}{E_{QG}} \int_0^{z0} \frac{(1+z)dz}{\sqrt{\Omega_\Lambda + \Omega_M (1+z)^3}}$$

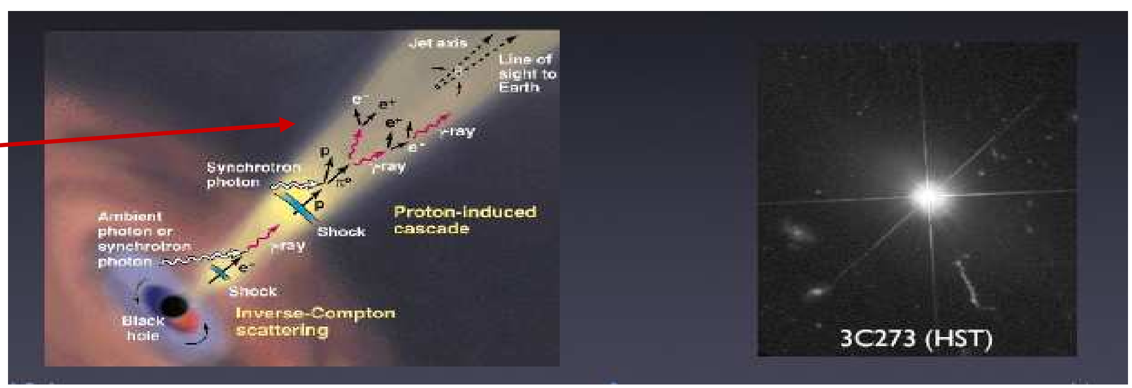
Blazars + Gamma Ray Bursts

- Blazar: an Active Galactic Nuclei with Radio and Gamma emission and a jet oriented towards the Earth
- Strong emission from radio to gamma wavelengths during Flares
- Examples: Mrk421, Mrk501, 3C273 detected by
  Air-shower Cerenkov Telescopes

<u>Physics:</u>
- astrophysical studies (jet production, inter-galactic absorption)
- from flares (periods of strong emission) access to Quantum Gravity

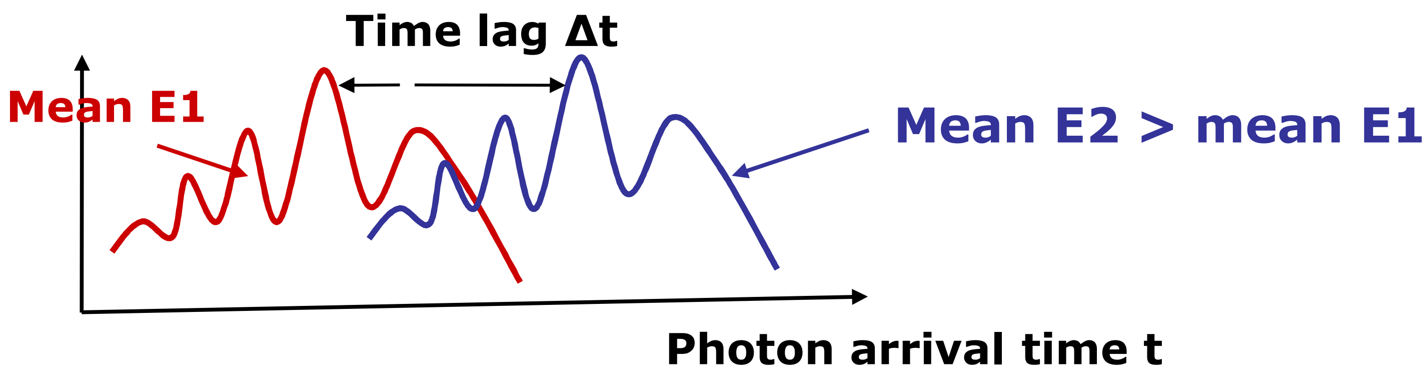
<u>AMS:</u> energy spectrum for blazars in the 100 MeV – 1 TeV and
pointing precision of few arcsec
>5 GRBs/year in GeV range with 1% precision in energy
and time-lags with μsec time precision (from GPS)

Jet



Quantum Gravity – time lags

- The Time Lags as a function of Energy with photons emitted by Blazars or GRBs may be seen in light curves measured for 2 different energy range:

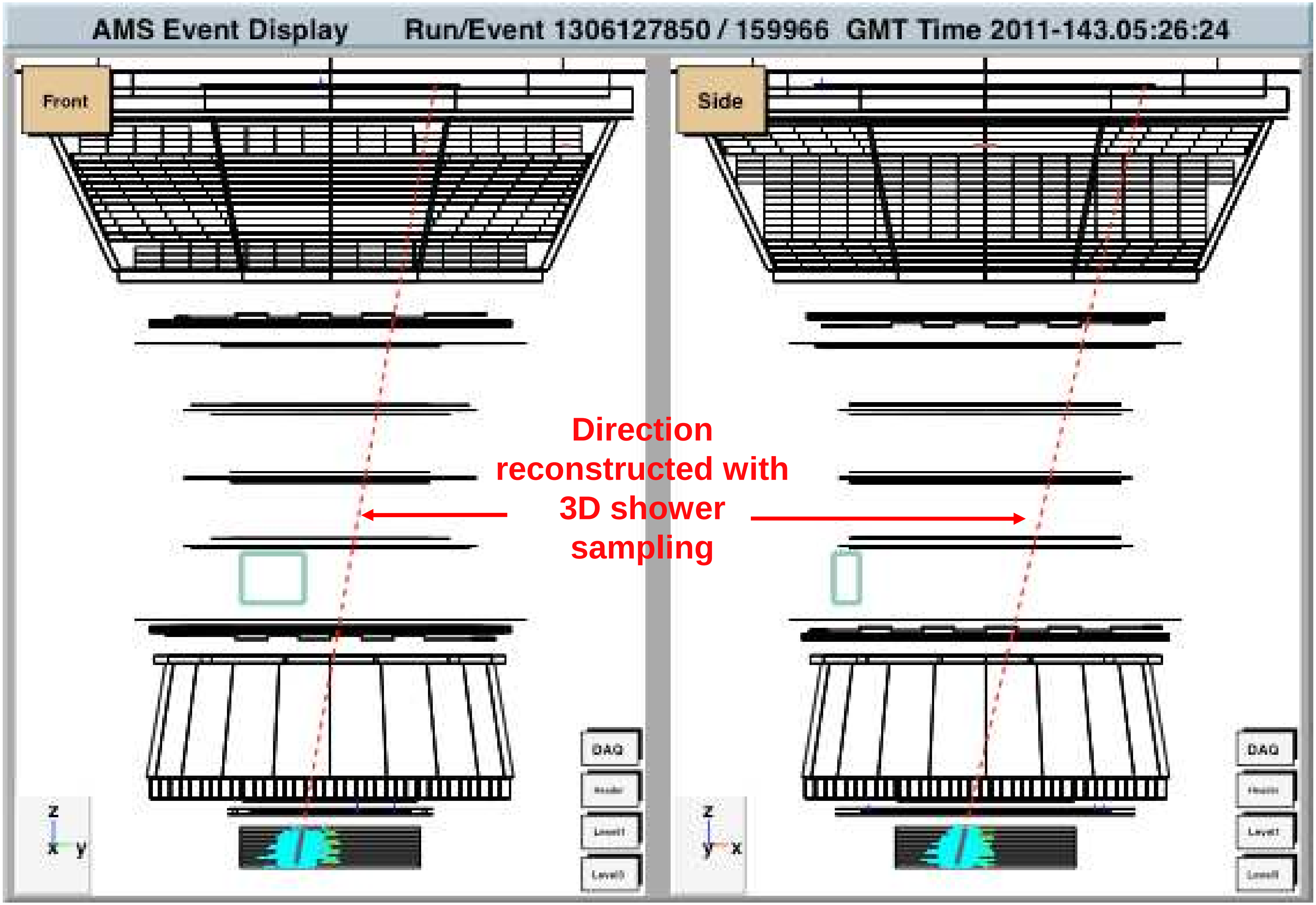


- Basic formula:

$$\boxed{\text{mean time lag} = \Delta t = L/c \ \Delta E/E_{QG}}$$

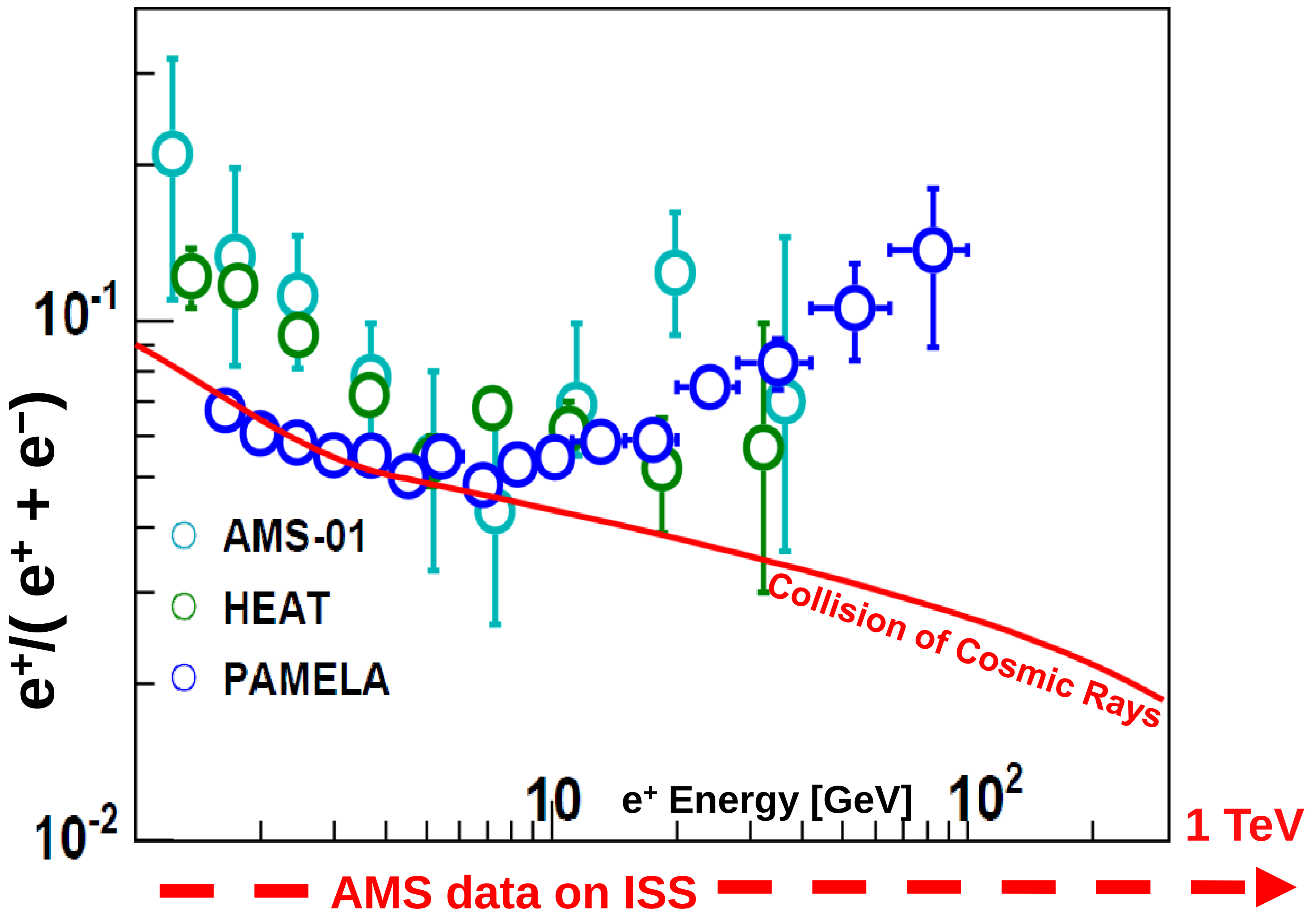
(L distance of the source, ΔE is mean energy difference and E_{QG} is Quantum Gravity scale)

AMS data on ISS Photon 40 GeV, 23 May

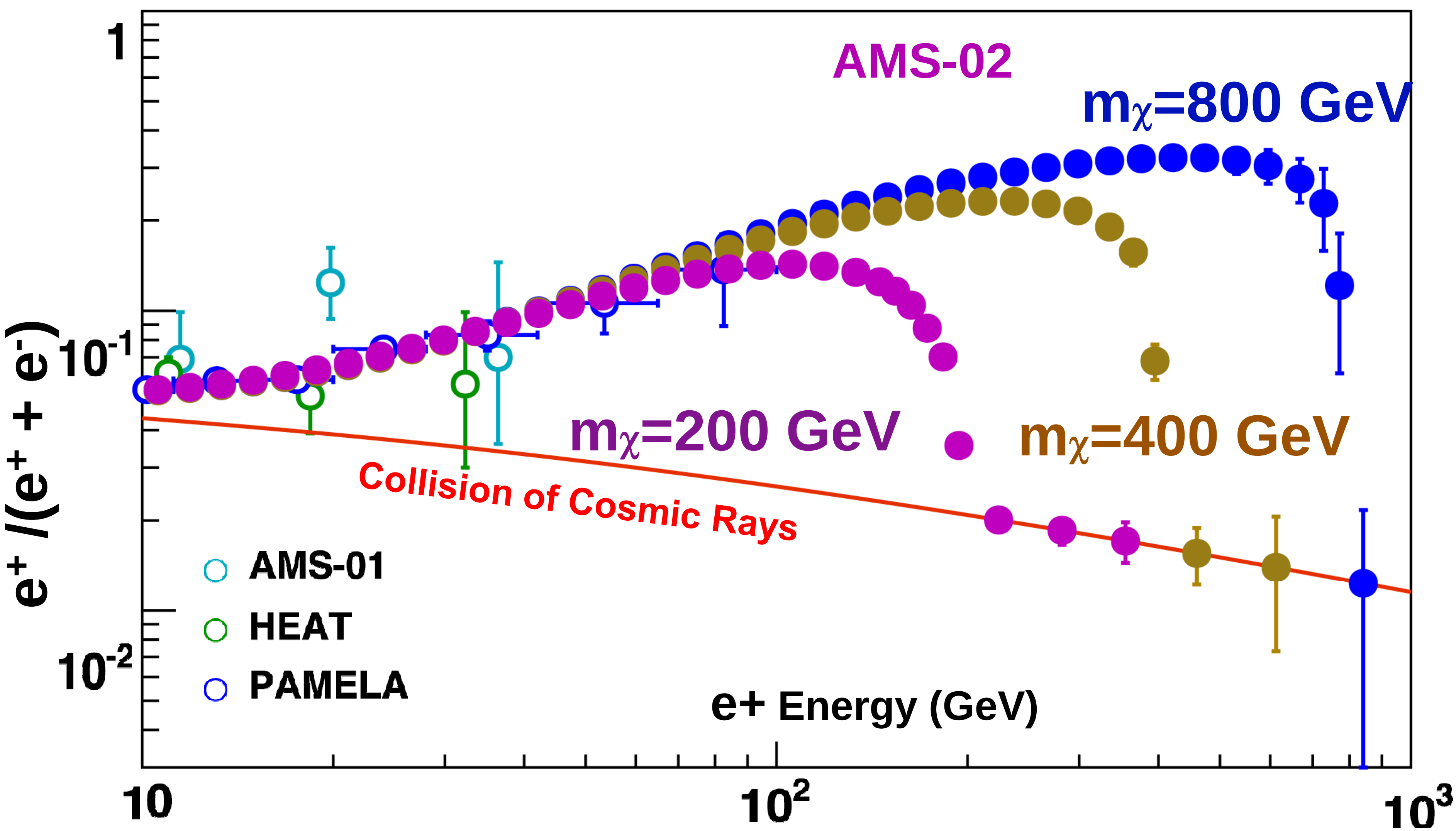


The leading candidate for Dark Matter is a SUSY neutralino (χ^0)

Collisions of χ^0 will produce excess in the spectra of e^+ different from known cosmic ray collisions



Detection of High Mass Dark Matter from ISS

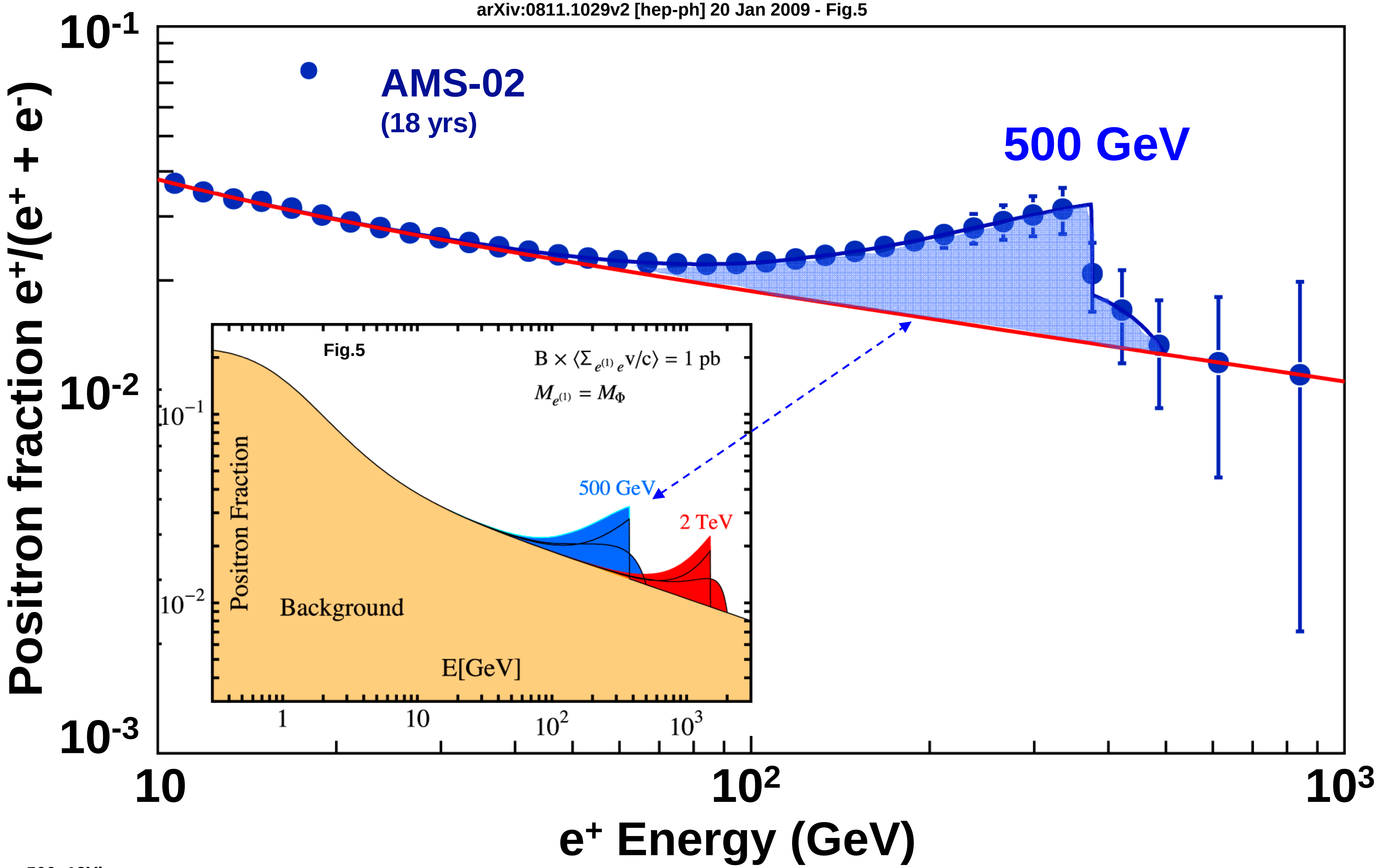


Kaluza-Klein Bosons are also Dark Matter candidates

case 2 TeV Scale Singlet Dark Matter

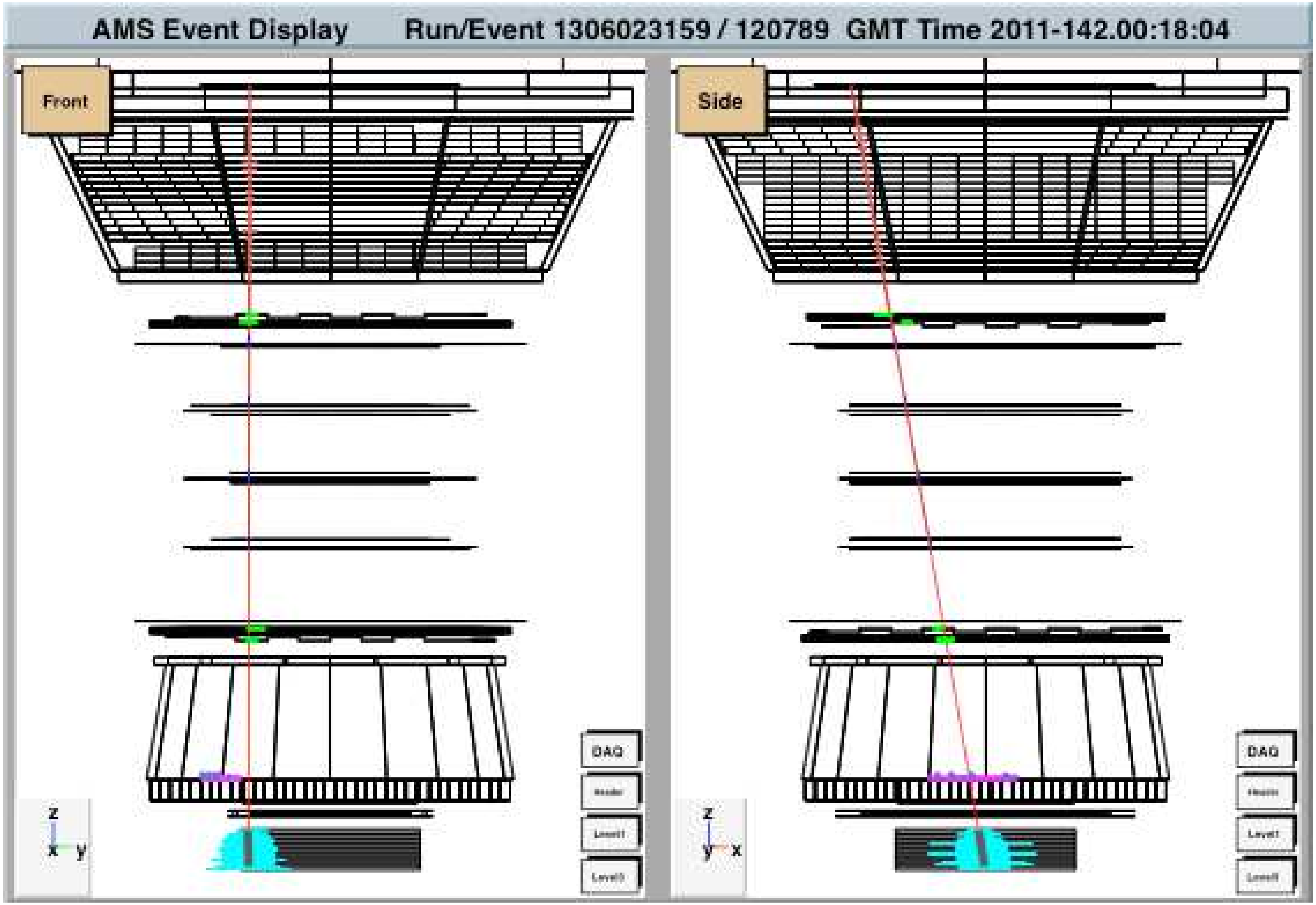
Eduardo Pontón and Lisa Randall

arXiv:0811.1029v2 [hep-ph] 20 Jan 2009 - Fig.5



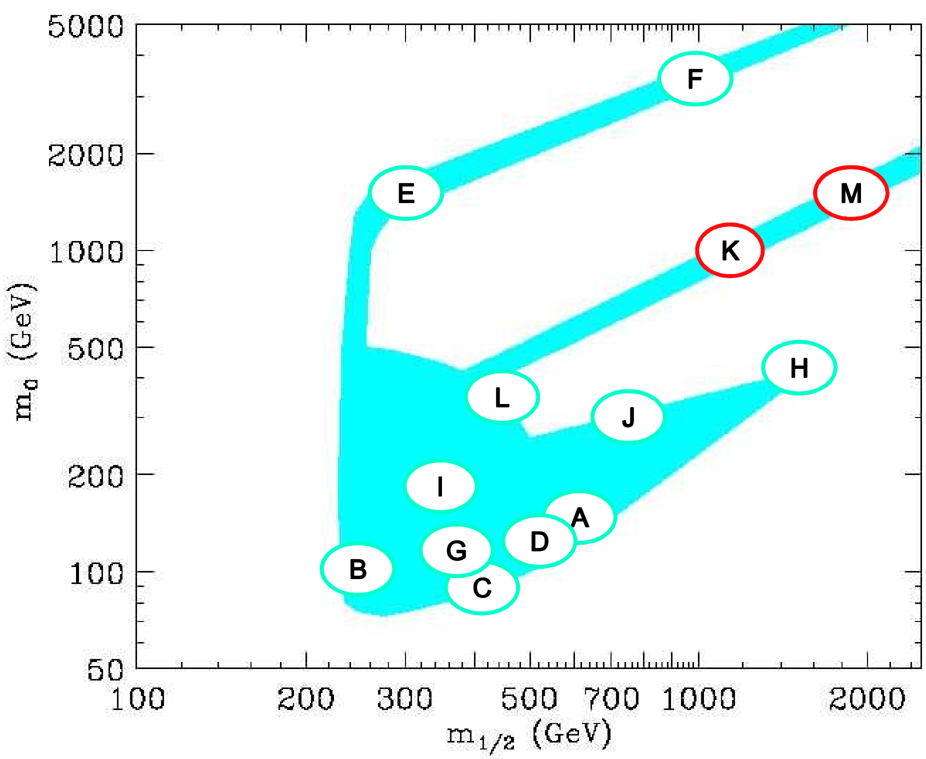
sdm_500_18Yb

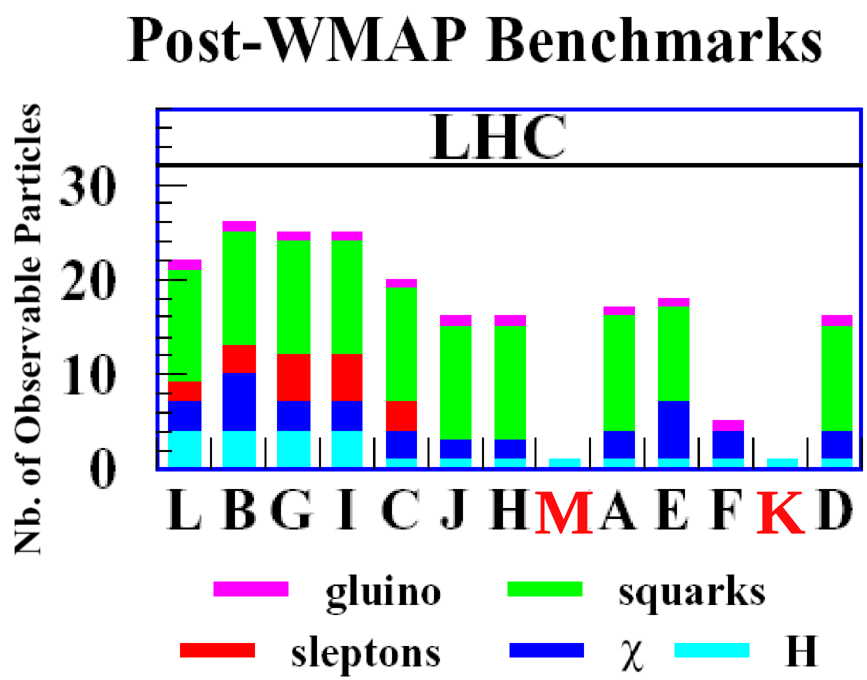
AMS data on ISS Electron 240 GeV, 22 May



AMS is sensitive to SUSY parameter space that is difficult to study at LHC (large m_0, $m_{1/2}$ values)

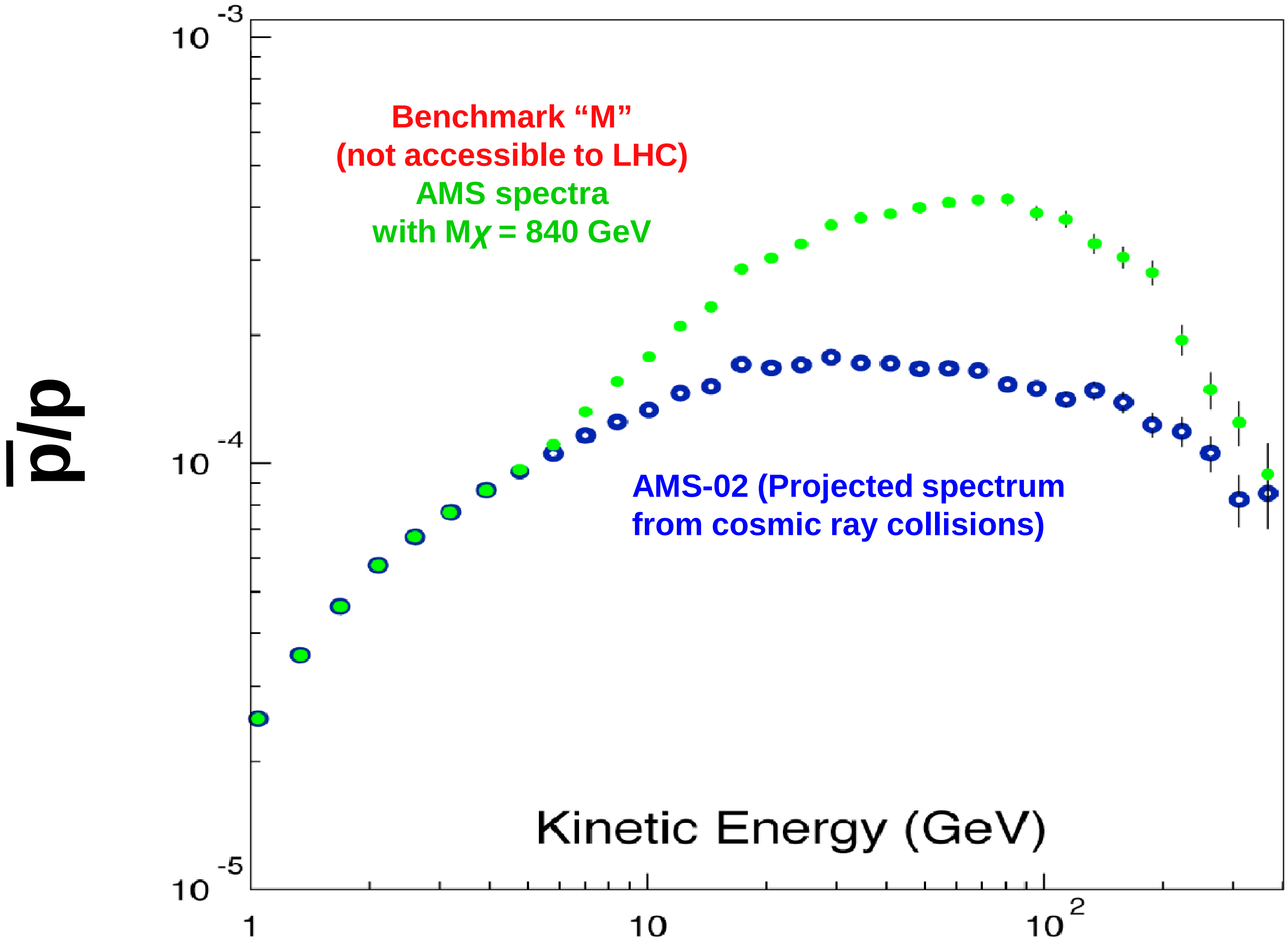
Shaded region allowed by WMAP, etc.





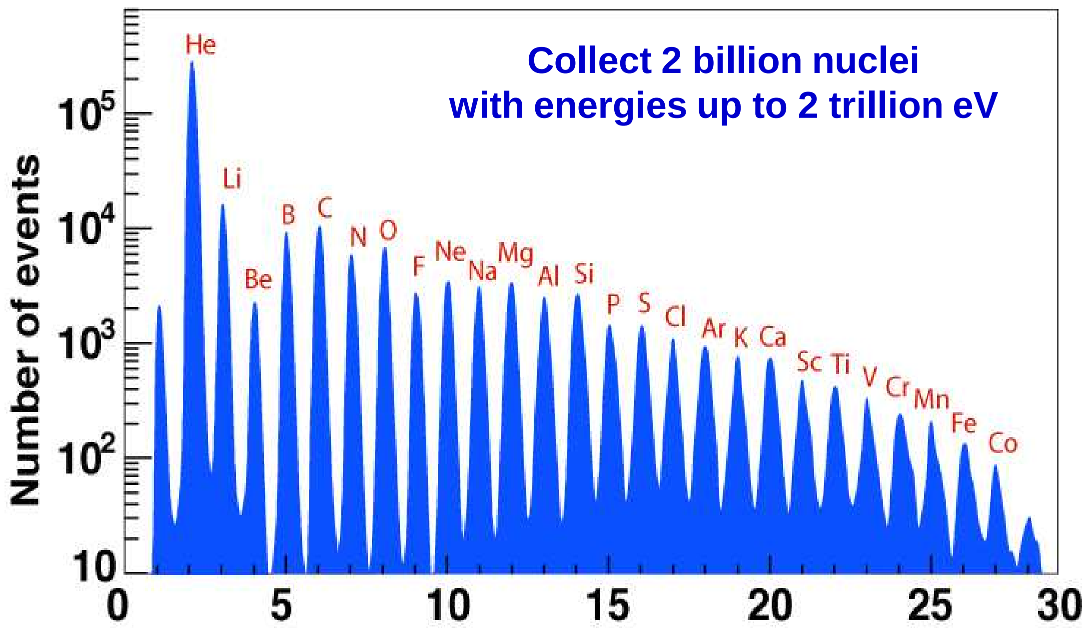
At benchmarks "K" & "M" Supersymmetric particles are not visible at the LHC.

M. Battaglia et al., hep-ph/0112013
M. Battaglia et al., hep-ex/0106207
M. Battaglia et al., hep-ph/0306219
D.N. Spergel et al., astro-ph/0603449


Benchmark “M”
(not accessible to LHC)
AMS spectra
with Mχ = 840 GeV
AMS-02 (Projected spectrum
from cosmic ray collisions)
Kinetic Energy (GeV)
p̄/p
10^{-3}
10^{-4}
10^{-5}
1
10
10^{2}

y06K318

Direct search for antimatter: AMS on ISS



Sensitivity of AMS: If no antimatter is found => there is no antimatter to the edge of the observable universe (~ 1000 Mpc).

The physics of antimatter in the universe is based on:

The existence of a new source of CP Violation
The existence of Baryon, Lepton Number Violation
Grand Unified Theory
Electroweak Theory
SUSY

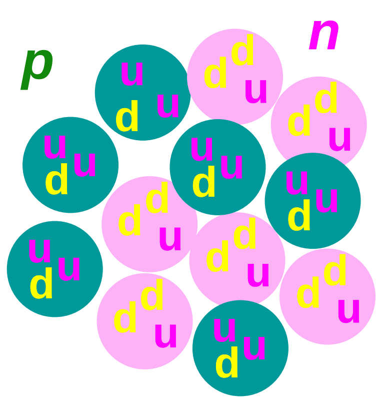
the Foundations of Modern Physics

These are central research topics for the current and next generation of accelerators world wide

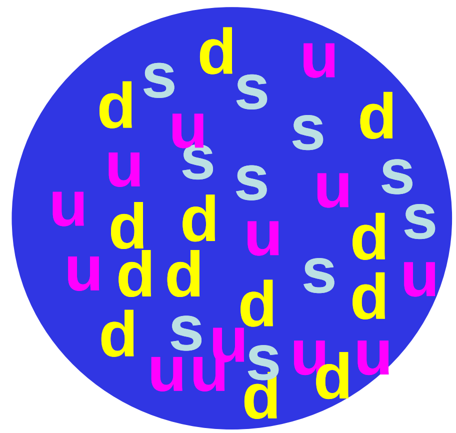
Physics Example
5 - Search for New Matter in the Cosmos

Carbon Nucleus

Z/A ~ 0.5



Strangelet



Z/A < 0.12

Strangelets: a single "super nucleon" with many u, d & s

- **Stable for masses A > ~10, with no upper limit**
- **"Neutron" stars may be composed of one big strangelet**

Searches

with terrestrial samples – low sensitivity.

with lunar samples – limited sensitivity.

in accelerators – cannot be produced at an observable rate.

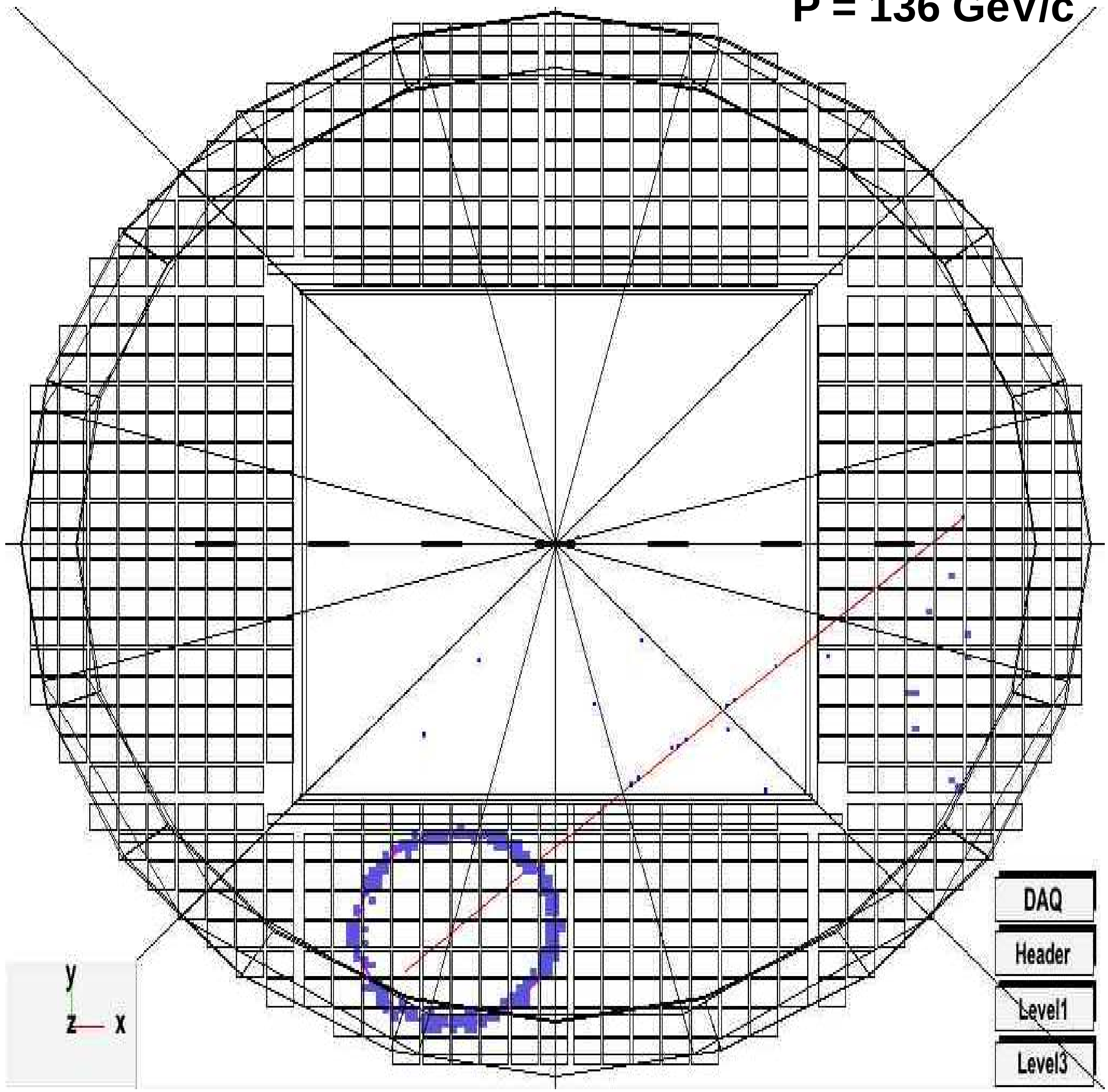
in space – candidates…

Stable strange quark matter was first proposed by E. Witten, Phys. Rev. D,272-285 (1984)

***Jack Sandweiss*, Yale**

AMS data on ISS

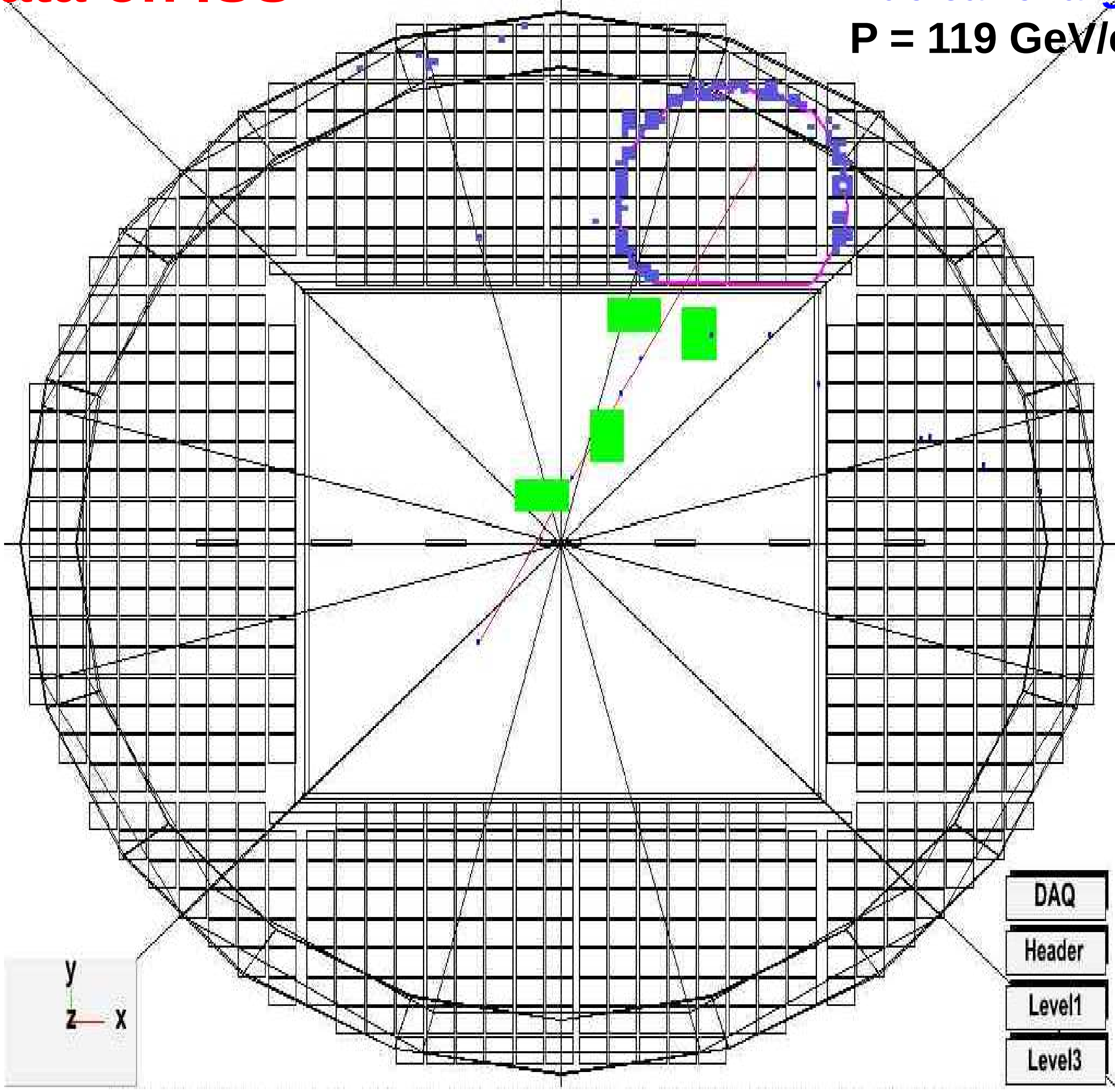
Nuclear charge Z=14, Si
P = 136 GeV/c

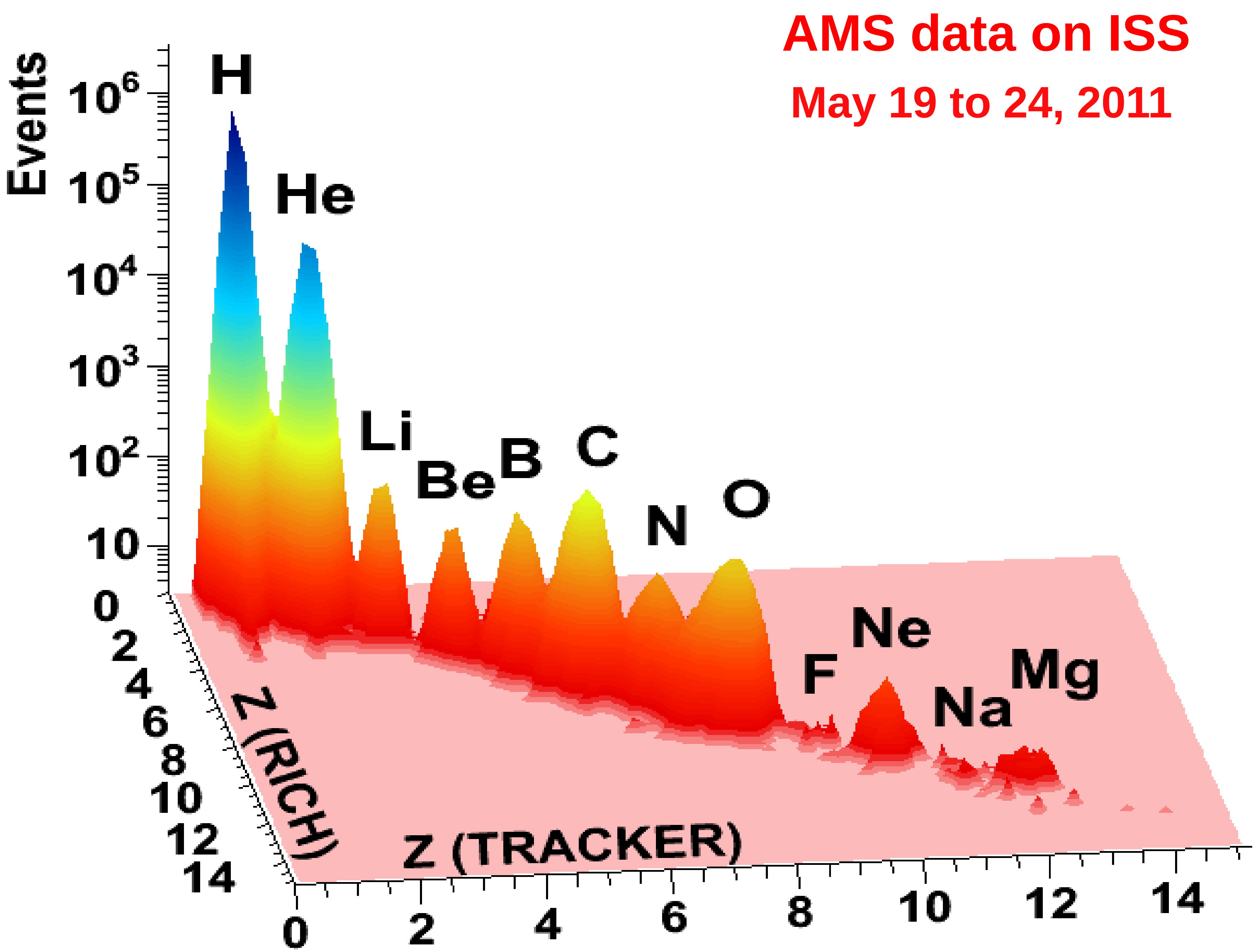


AMS data on ISS

Nuclear charge **Z=8, O**

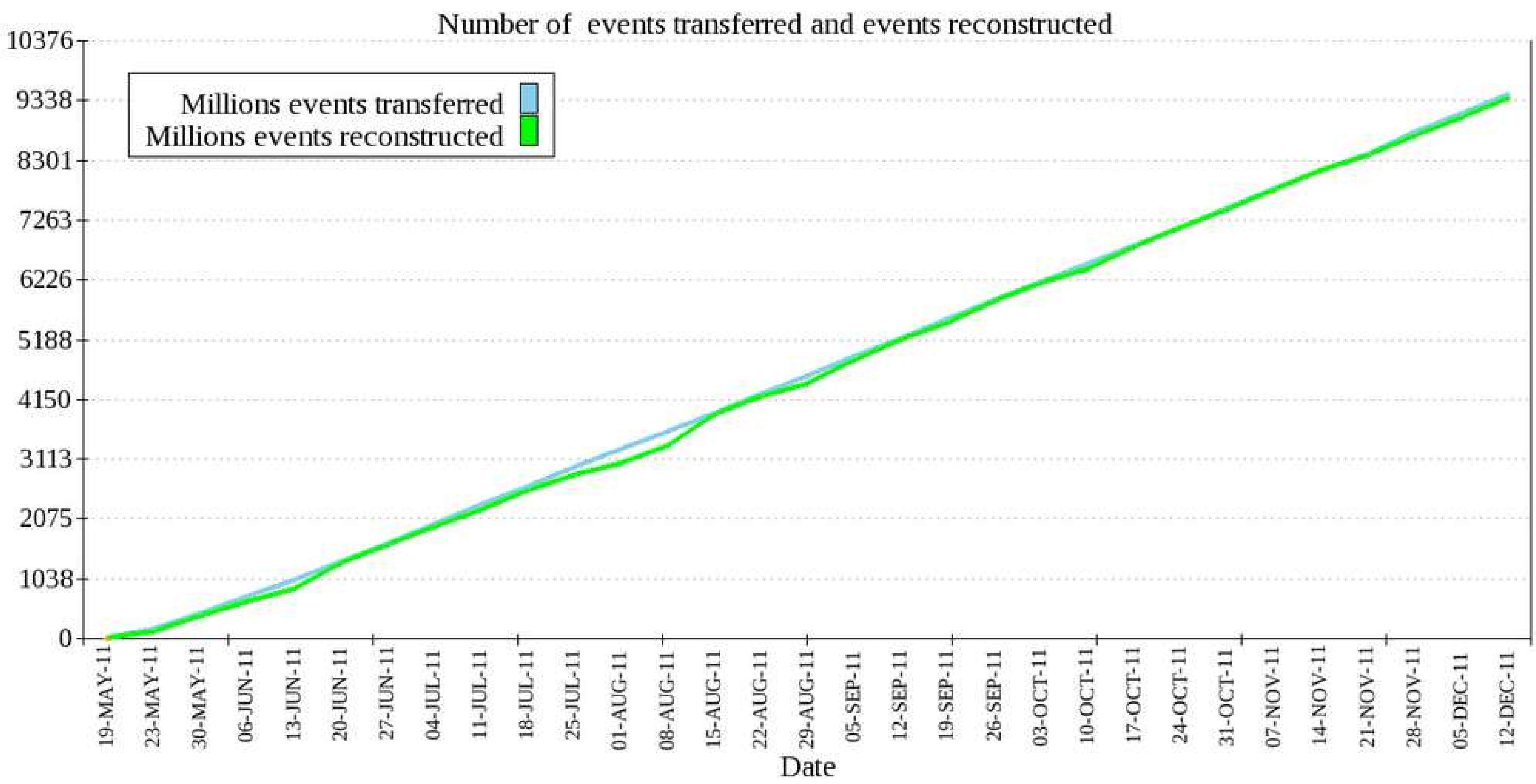
P = 119 GeV/c





AMS data on ISS
May 19 to 24, 2011
Events
10^6
10^5
10^4
10^3
10^2
10
0
H
He
Li
Be
B
C
N
O
F
Ne
Na
Mg
Z (RICH)
Z (TRACKER)
0
2
4
6
8
10
12
14

AMS has collected over 9 billion events



First 9 months of AMS operations

First Data from AMS and detector performance

The detectors function exactly as designed.

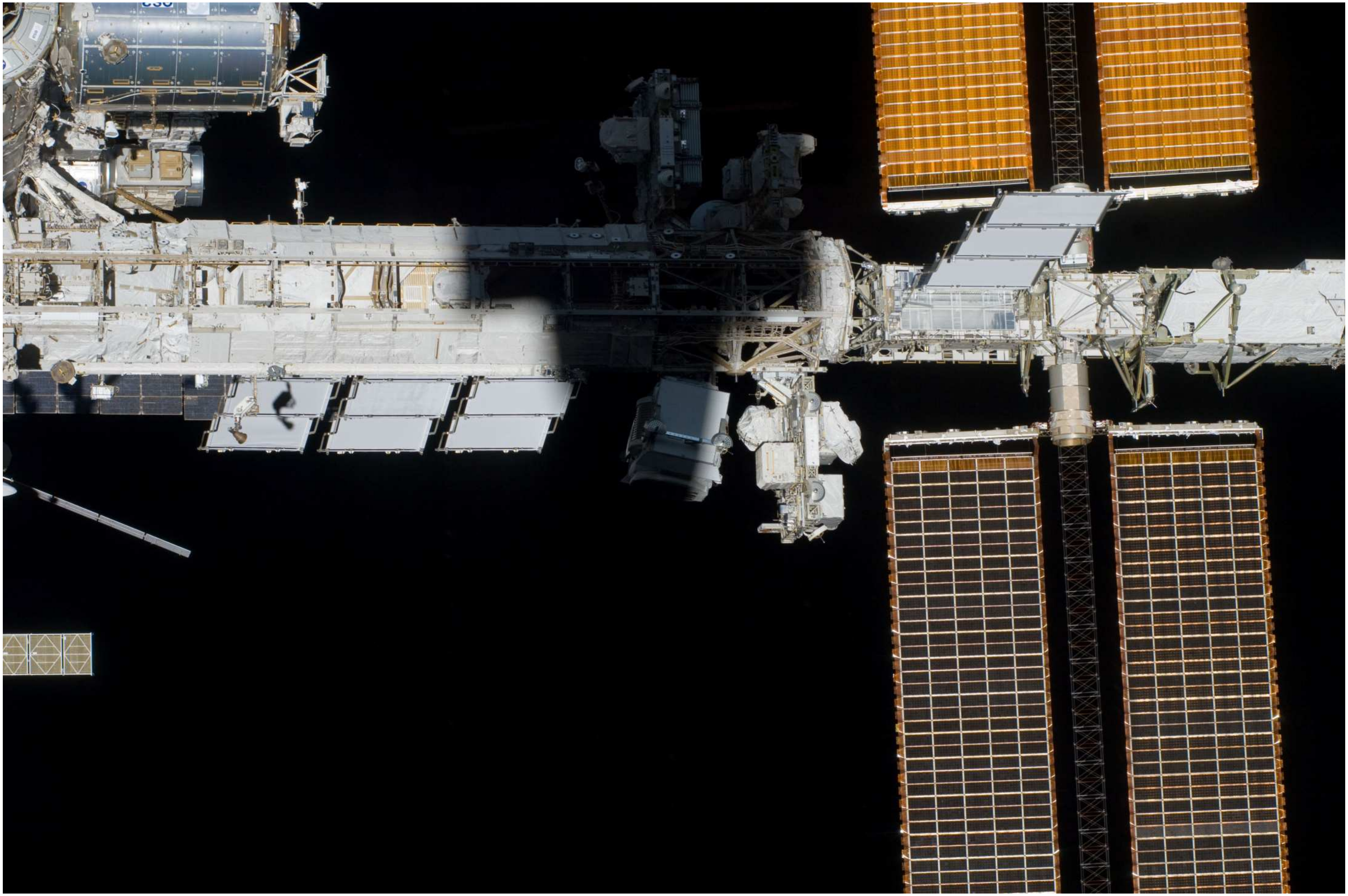
Therefore, every year, we will collect $1.5*10^{+10}$ triggers and in 20 years we will collect $3*10^{+11}$ triggers.

This will provide unprecedented sensitivity to search for new physics.

What is AMS doing now?

- Calibration, Calibration, Calibration!
  - AMS aims to measure charged particles up to 1TV rigidity, this requires one to know the position of the tracker to better than 5 microns in order to claim a sagitta measurement down to 10 microns!
  - AMS is heated unevenly, and to great extremes, Movements created by different heating conditions must also be known to better than 5 microns.

Uneven Heating of AMS aboard the ISS



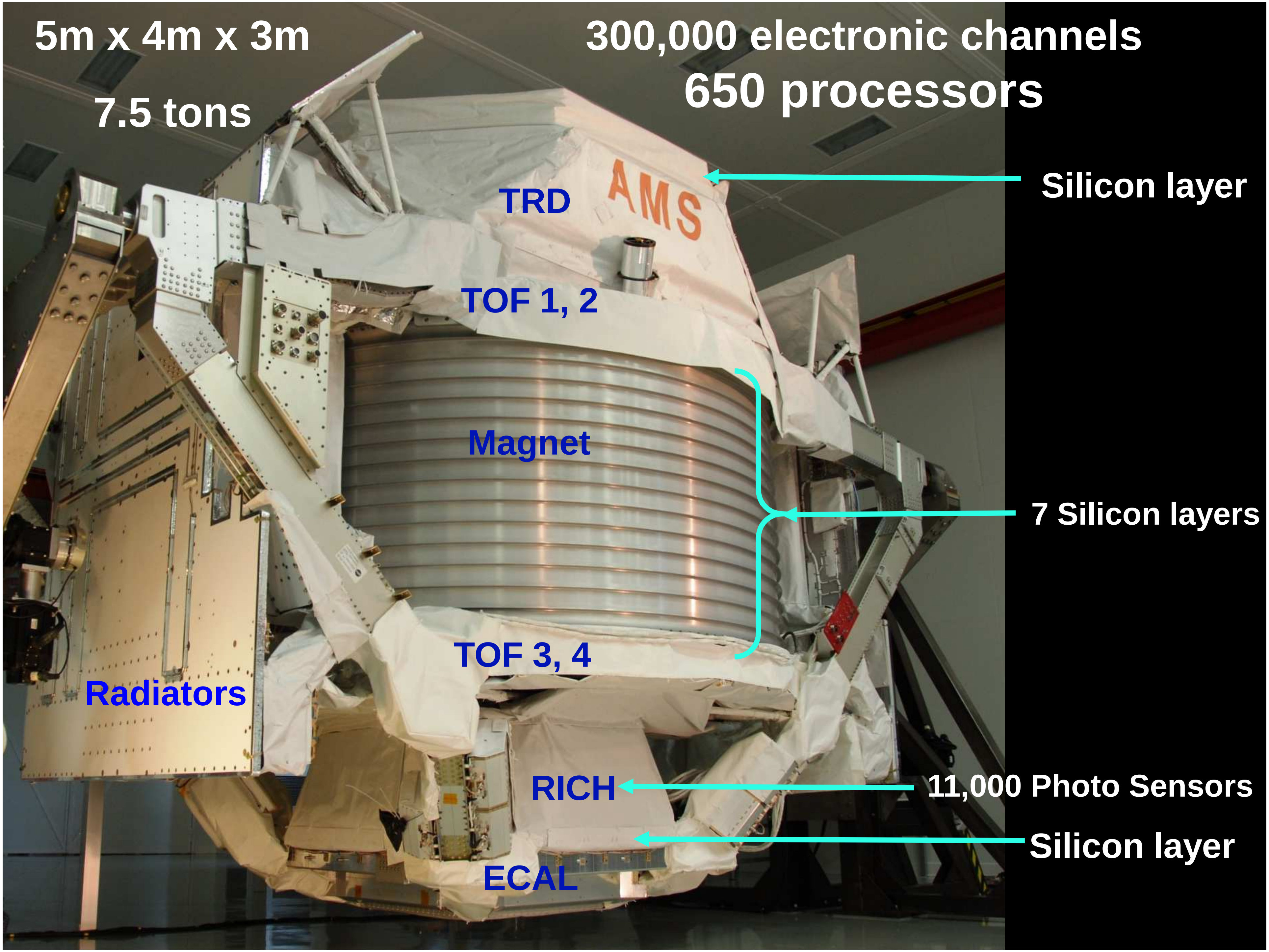
When will the data be ready?

When will the data be ready?

As Late as possible!!

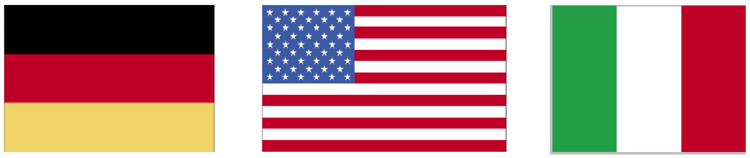
Thanks for your attention!

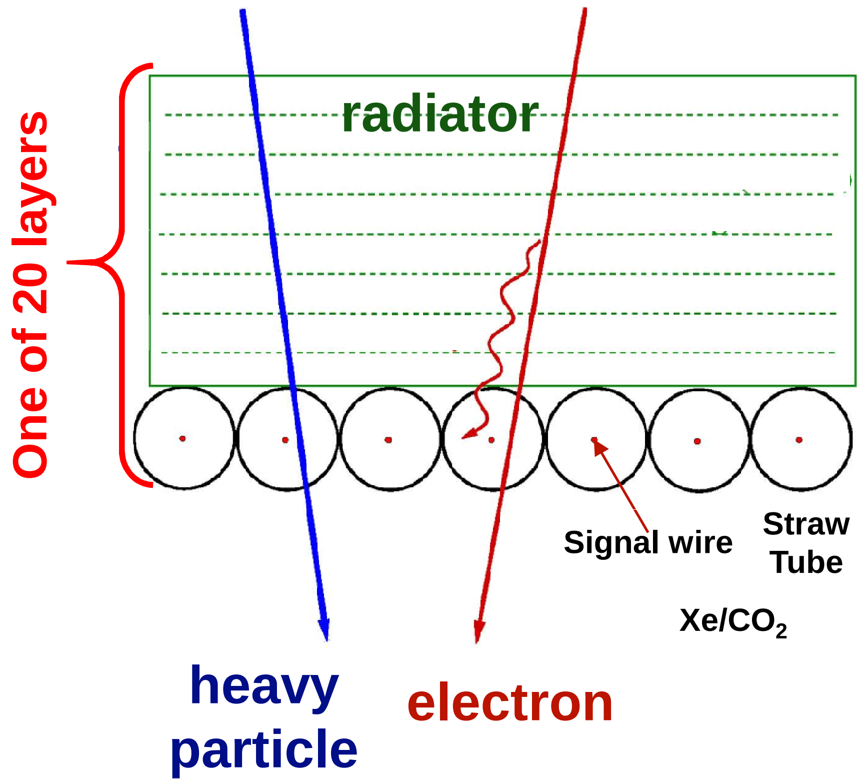
- Questions?

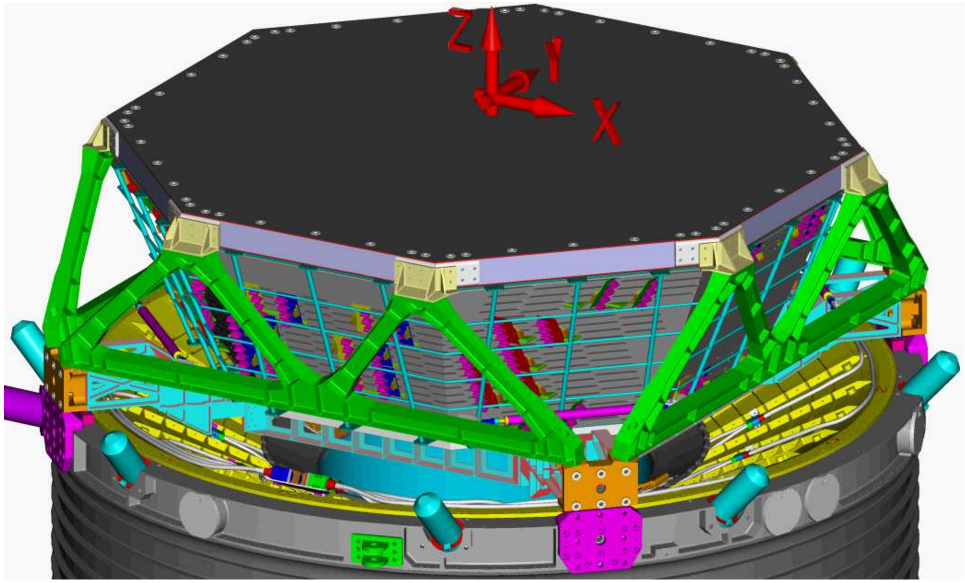


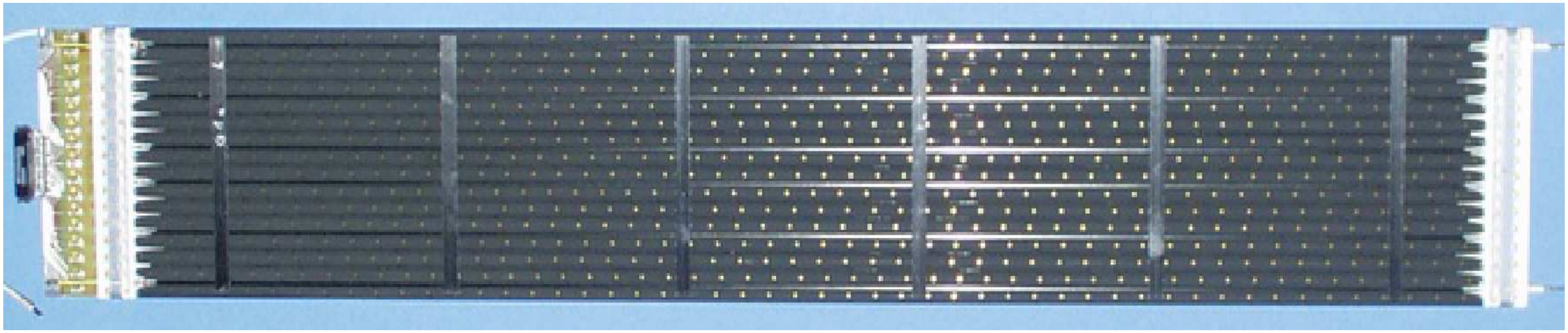
5m x 4m x 3m
7.5 tons
300,000 electronic channels
650 processors
AMS
TRD
Silicon layer
TOF 1, 2
Magnet
7 Silicon layers
TOF 3, 4
Radiators
RICH
11,000 Photo Sensors
Silicon layer
ECAL

Transition Radiation Detector (TRD): identifies Positron and Electron

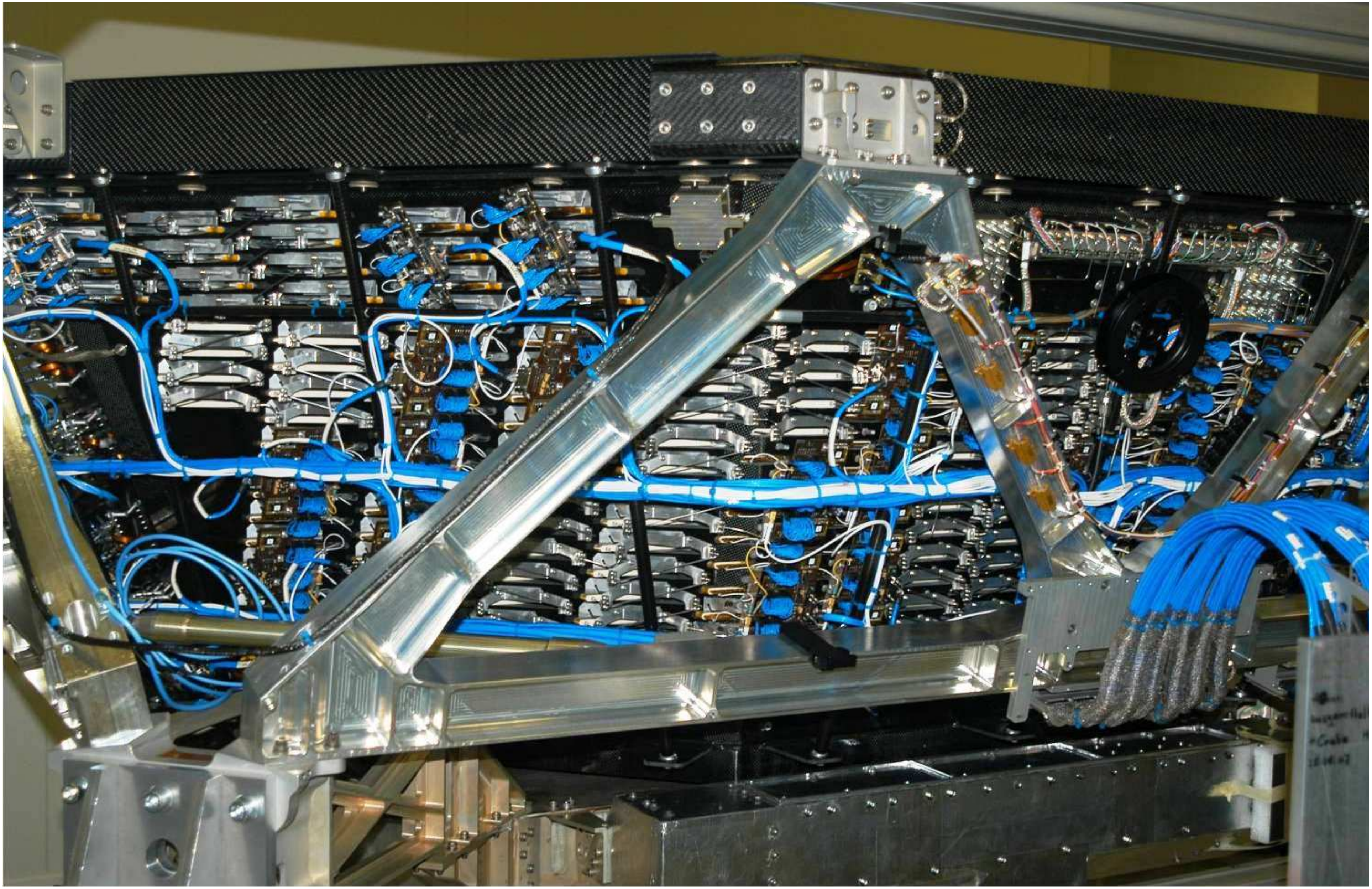




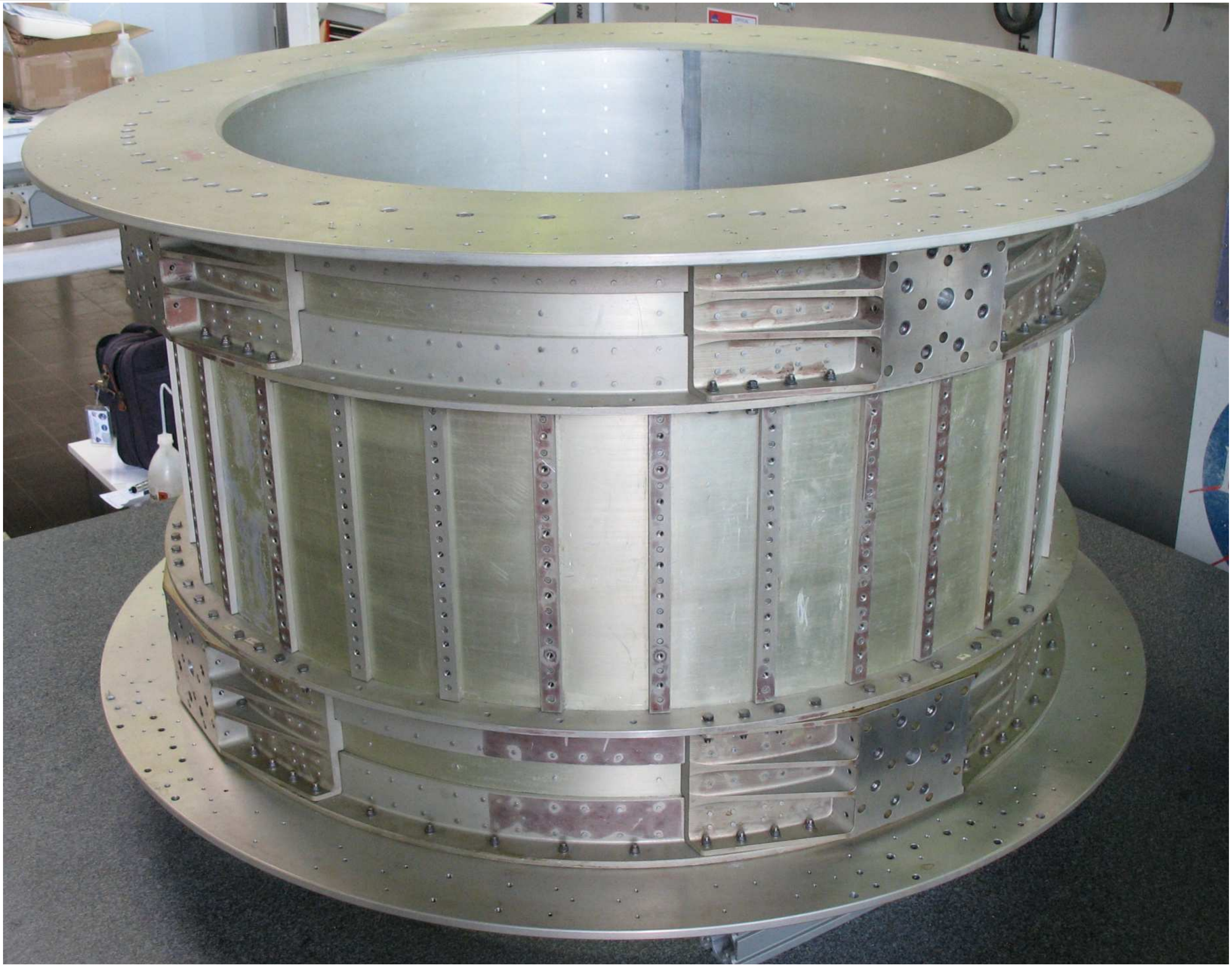




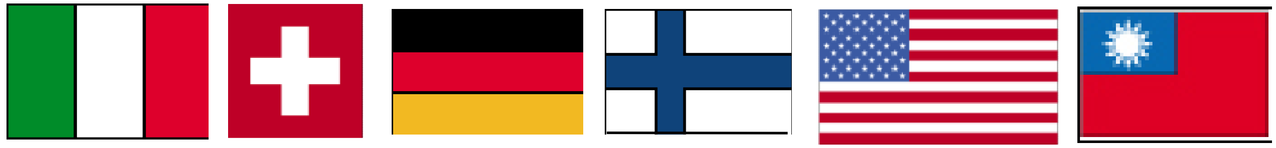
Transition Radiation Detector: TRD

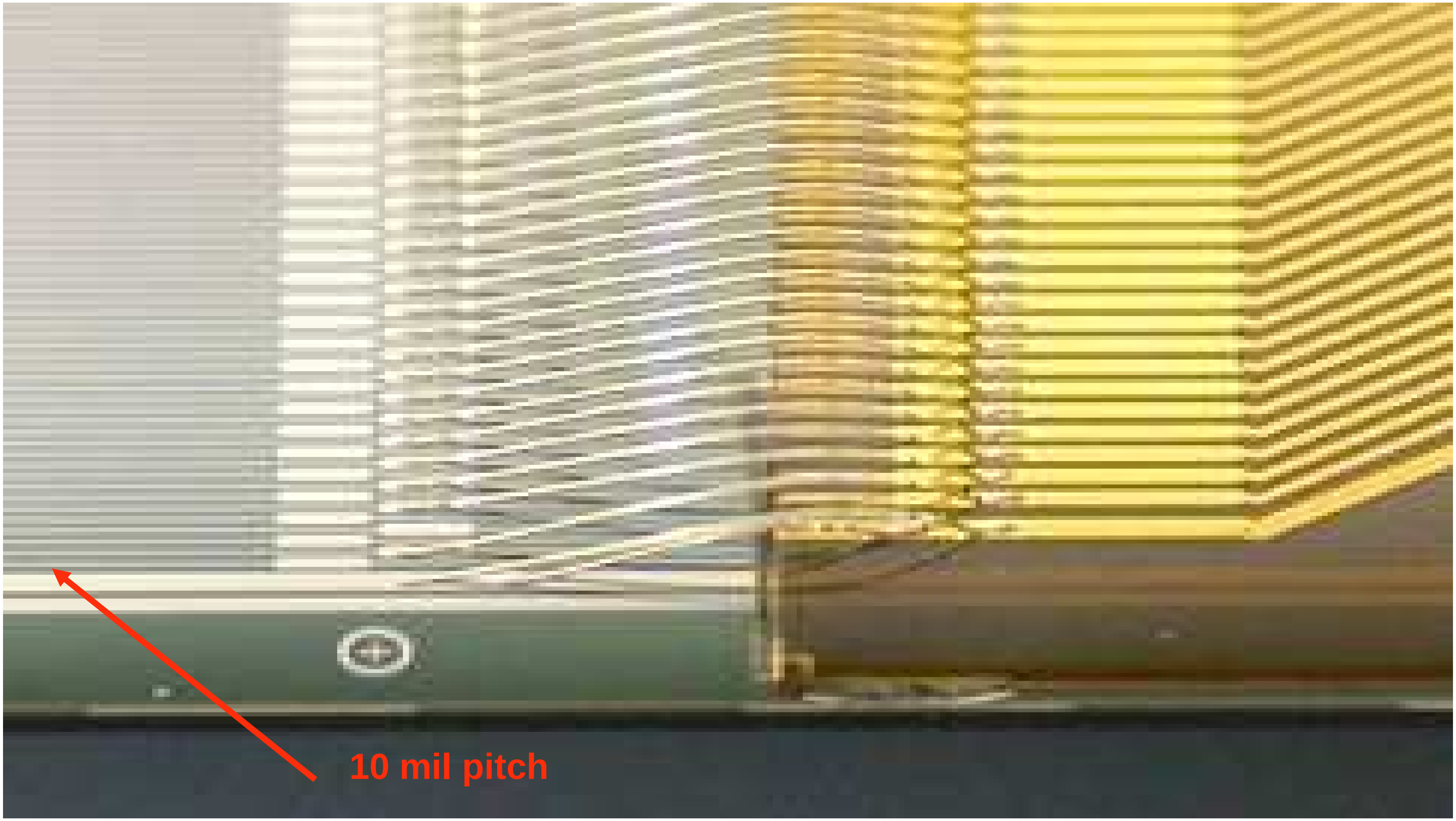


The Permanent Magnet:
on the Shuttle - AMS-01 and on ISS – AMS-02



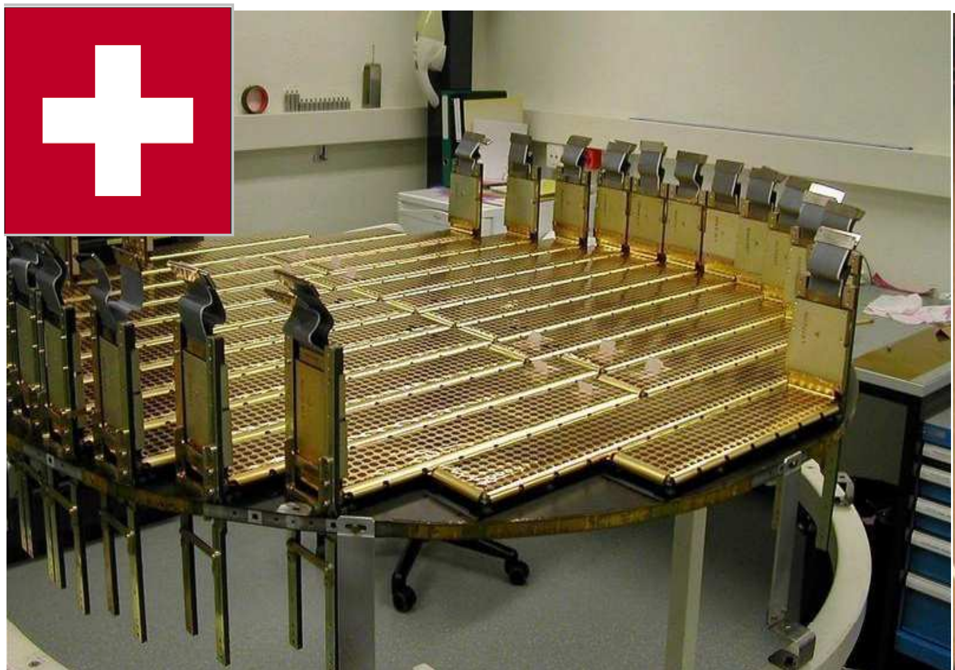
Silicon Tracker

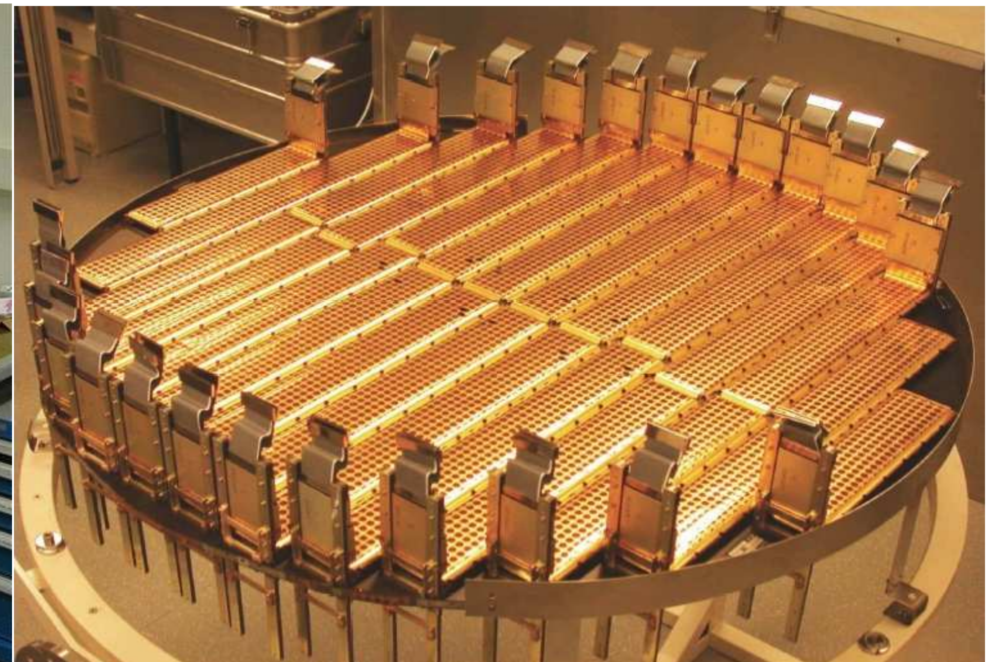


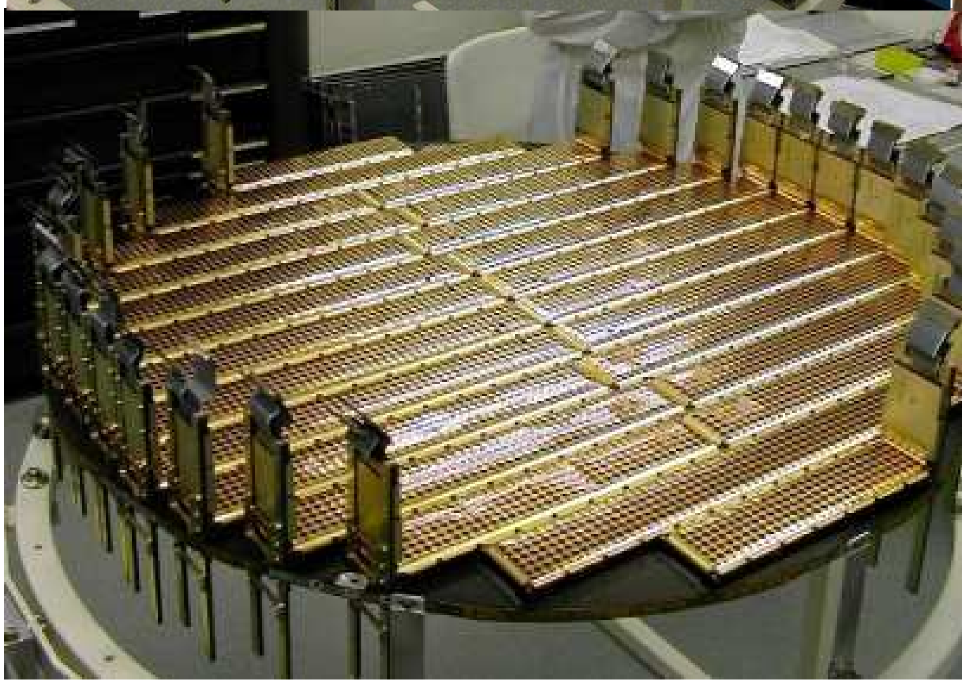


The coordinate resolution is 10 micron

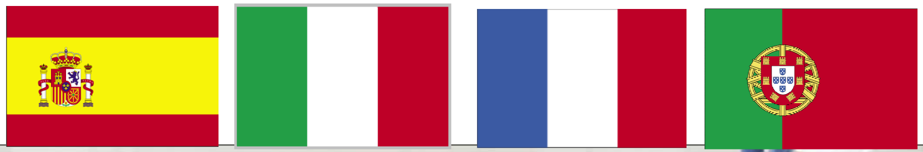
There are 9 planes with 200,000 channels aligned to 3 microns

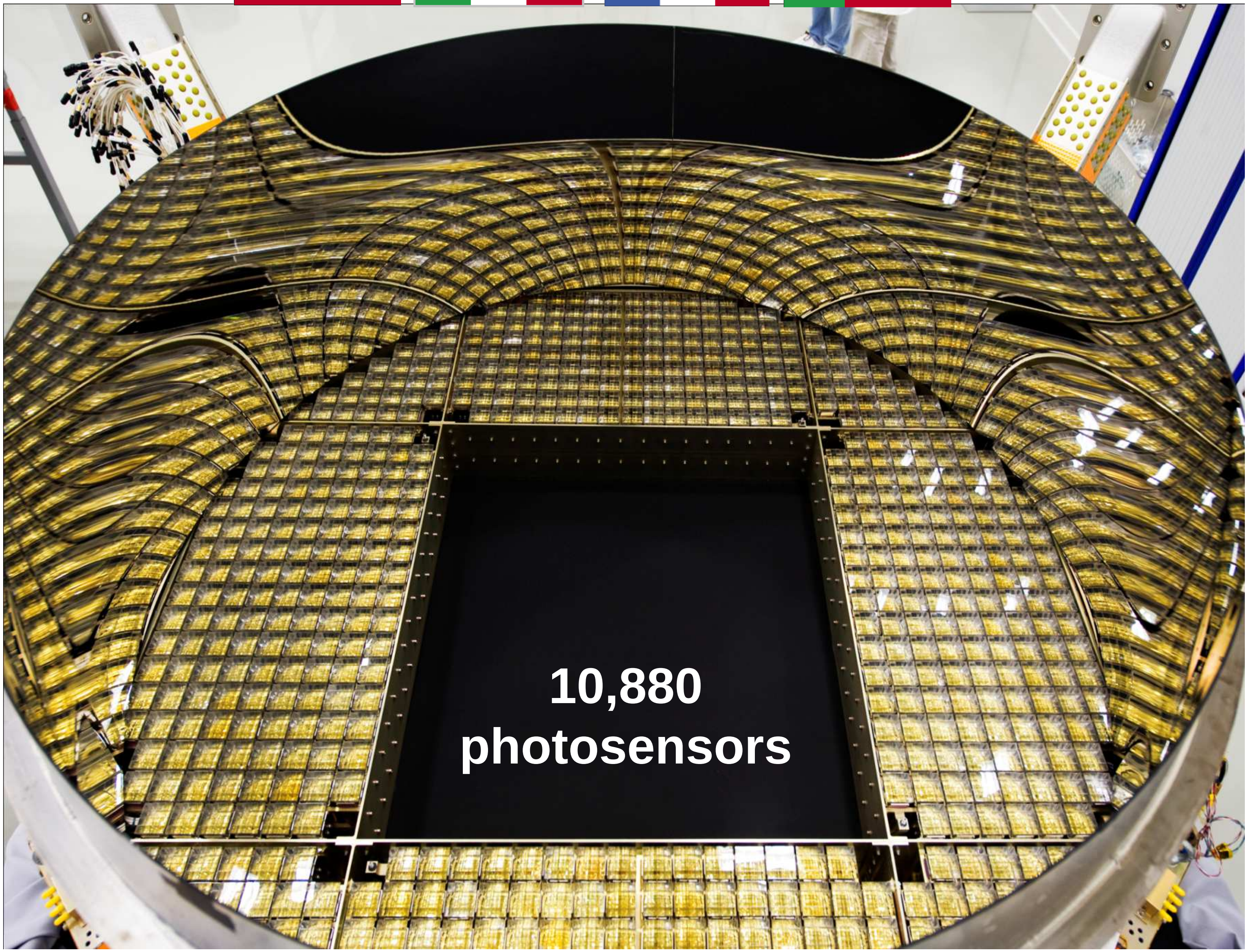


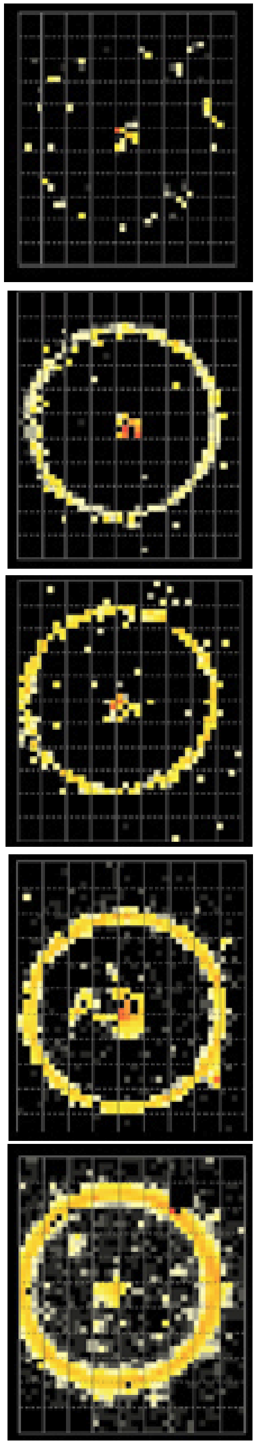




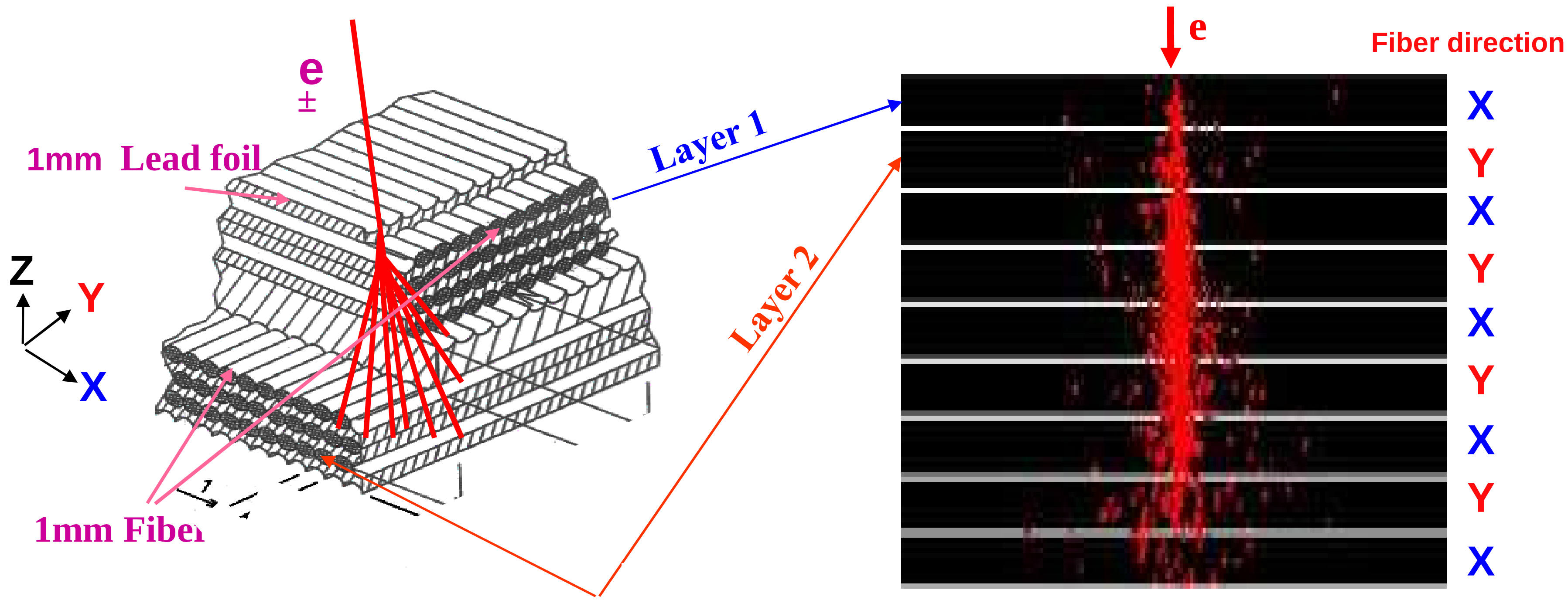
Ring Imaging CHerenkov (RICH)

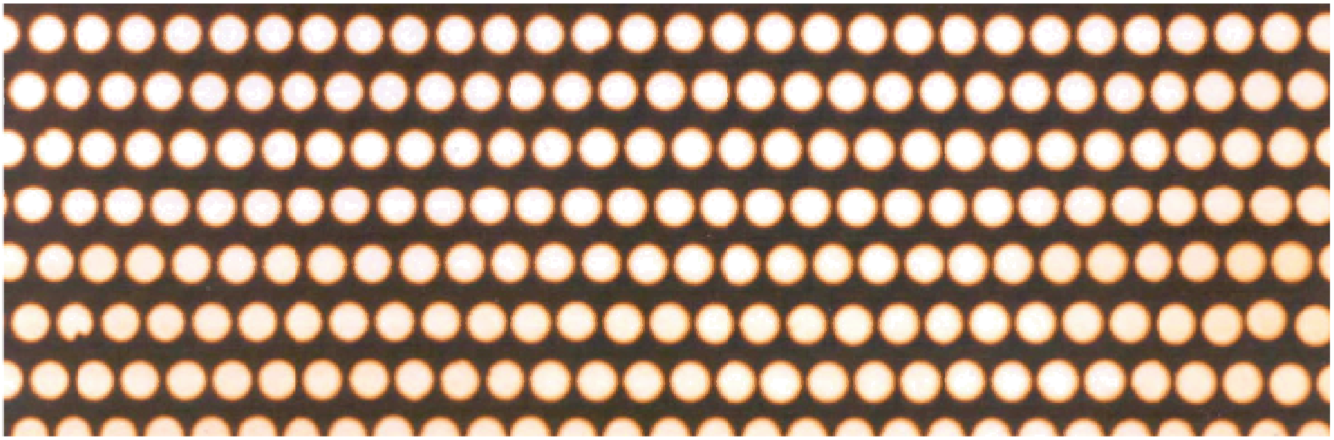




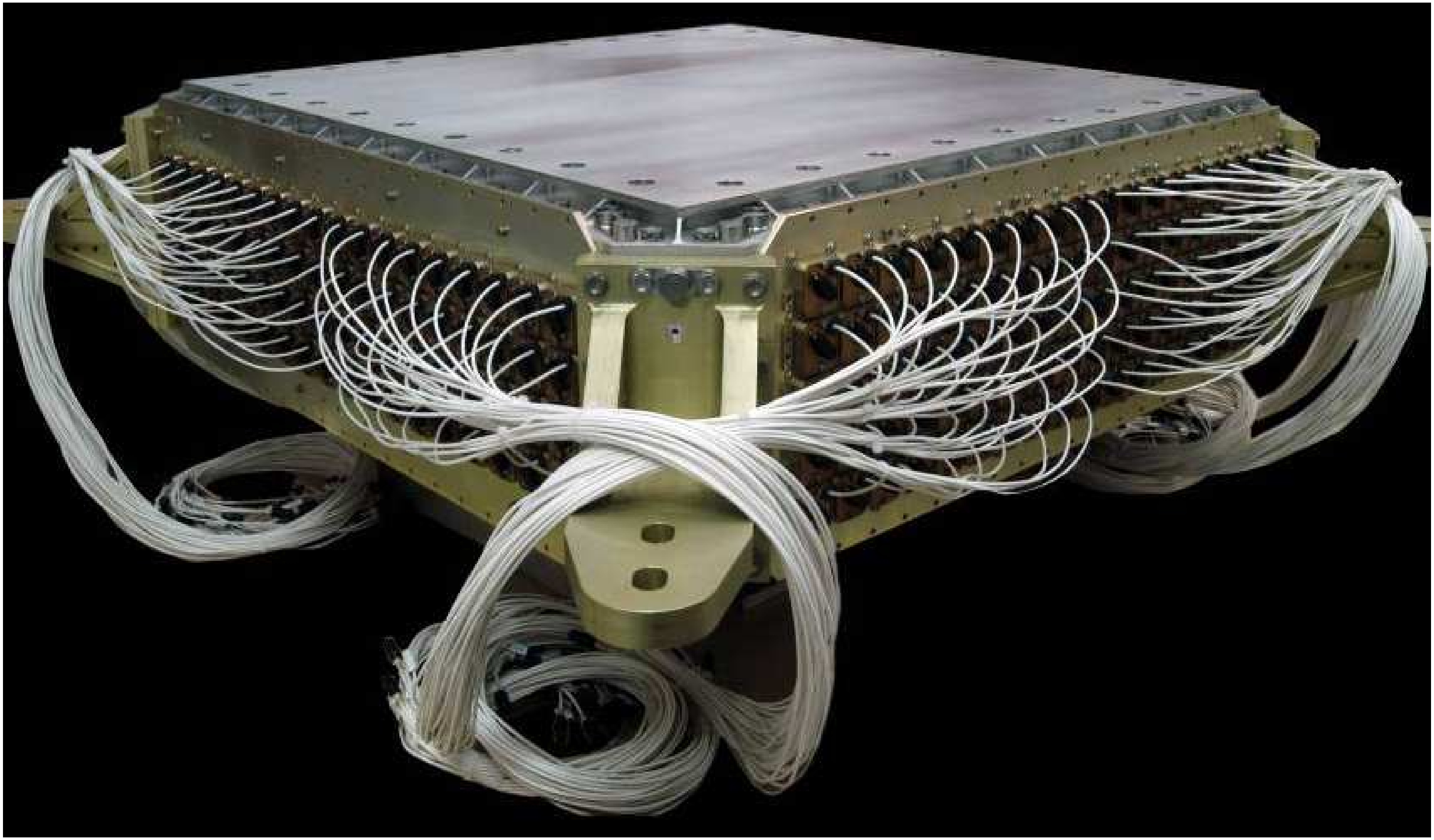


Calorimeter (ECAL)





9 super layers provide 3D measurement of shower profile

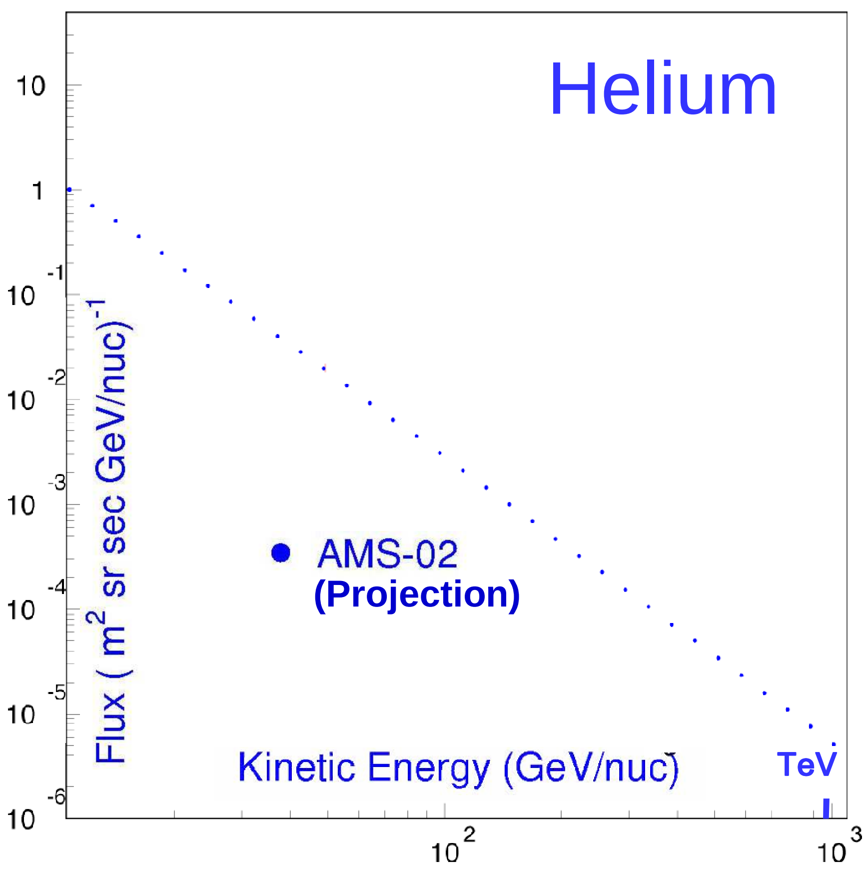


50,000 fibers, $\phi = 1$mm, distributed uniformly inside 1,200 lb of lead which provides a precision, 3-dimensional, $17X_0$ measurement of the directions and energies of light rays and electrons up to 1 TeV

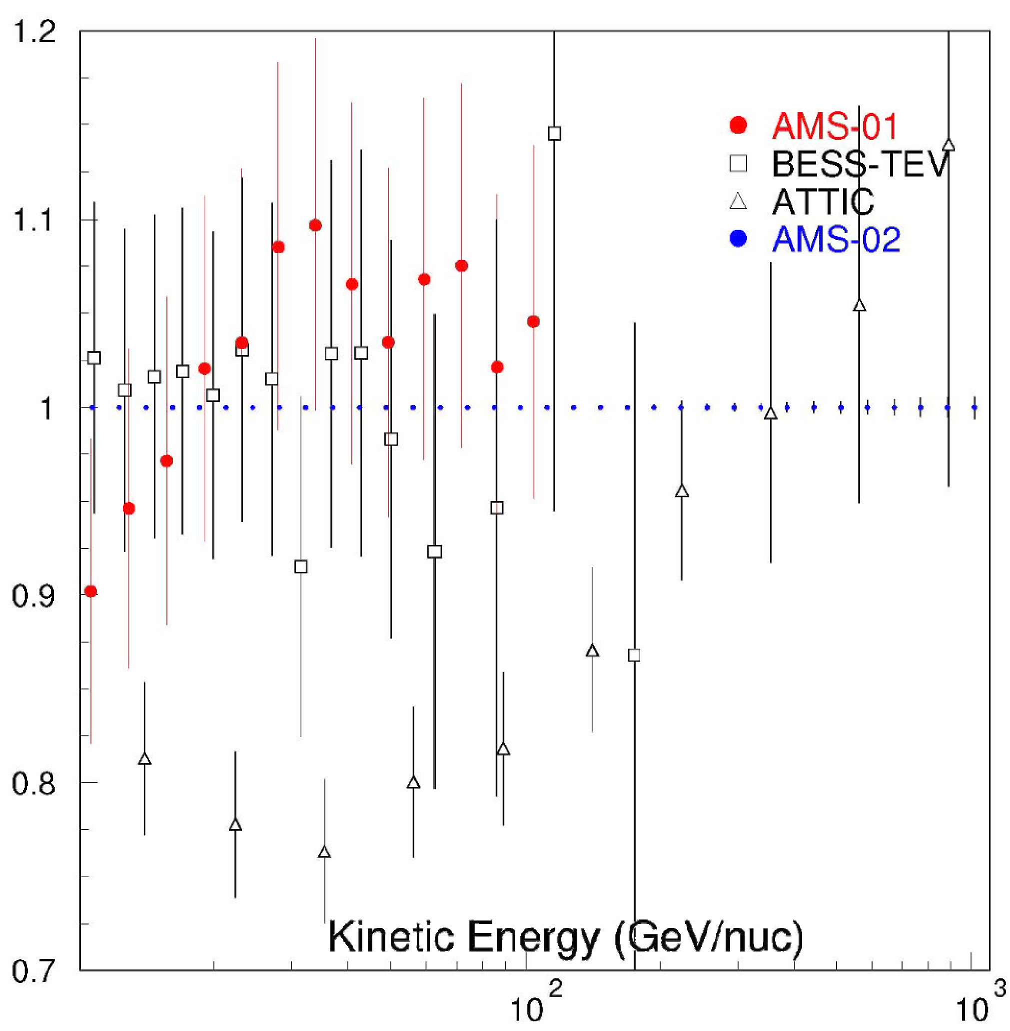
The completed flight electronics
(650 microprocessors, 300,000 channels)

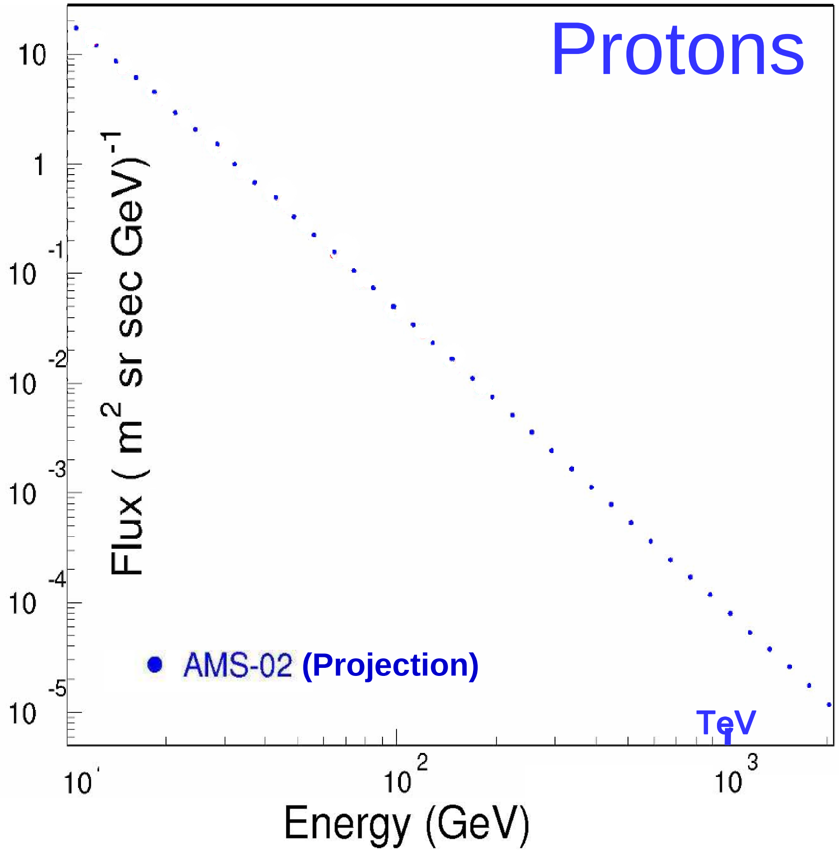
AMS in the Space Station Processing Facility (SSPF), ready for installation into the Space Shuttle

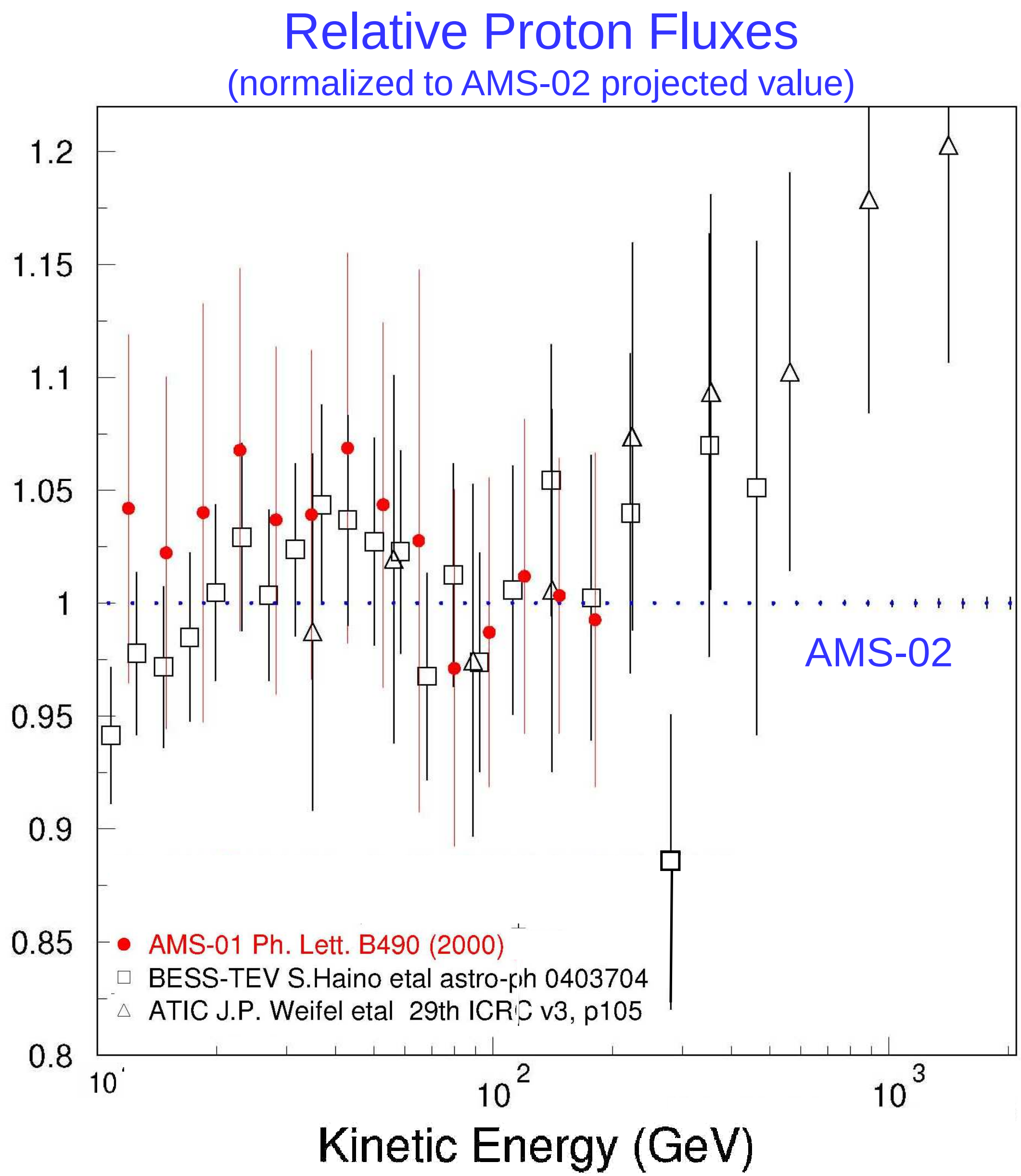
The AMS experiment will perform accurate, high statistics (10^9–10^{10}), long duration (3 years) measurements of energetic (0.1 GeV to 2 TeV) cosmic ray spectra in space.



Relative He Fluxes

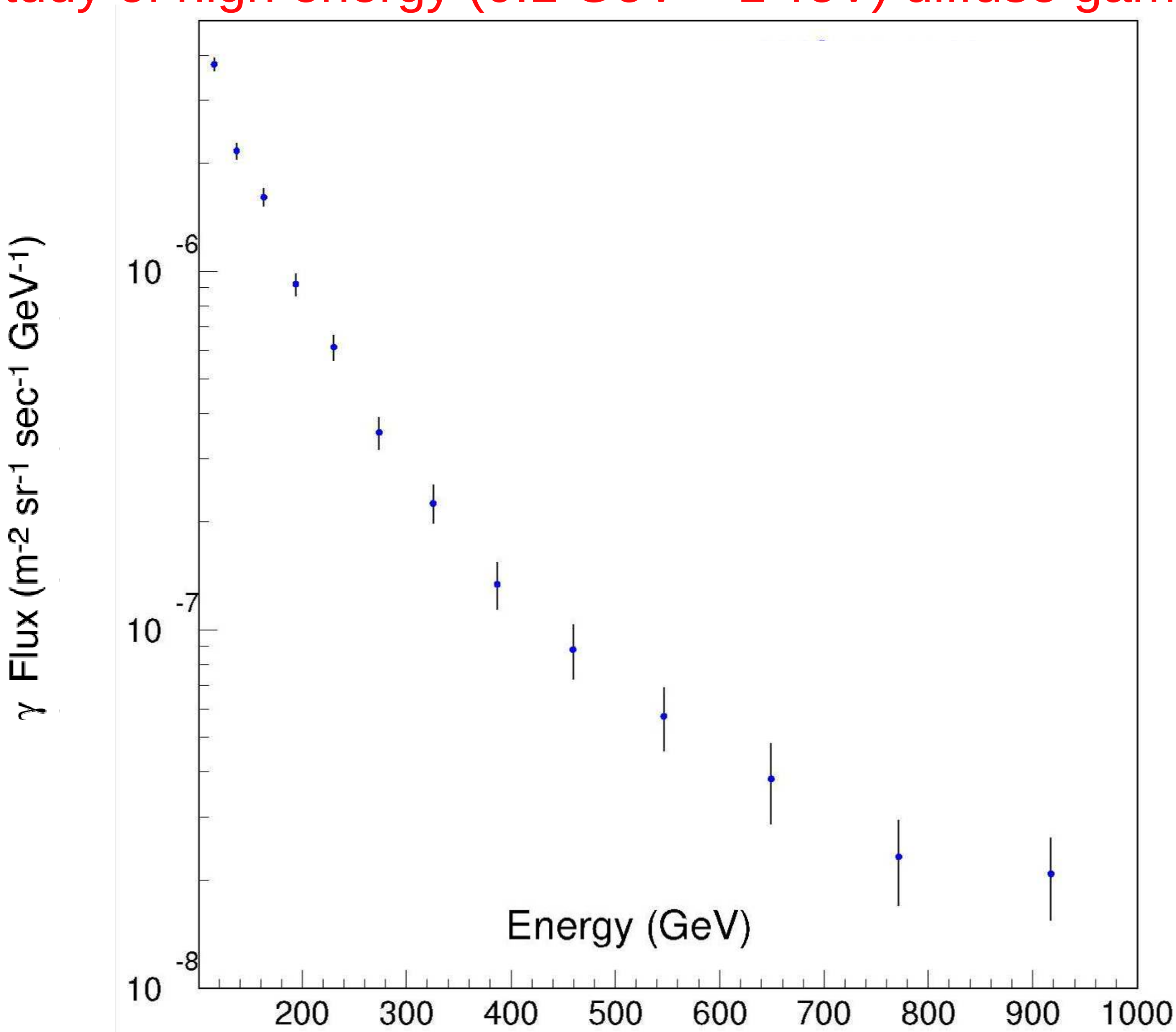



Protons
Flux (m^2 sr sec GeV)$^{-1}$
AMS-02 (Projection)
TeV
Energy (GeV)


Relative Proton Fluxes
(normalized to AMS-02 projected value)
AMS-02
AMS-01 Ph. Lett. B490 (2000)
BESS-TEV S.Haino etal astro-ph 0403704
ATIC J.P. Weifel etal 29th ICRC v3, p105
Kinetic Energy (GeV)

AMS Physics example

2- Study of high energy (0.1 GeV – 1 TeV) diffuse gammas



AMS-02
10 years

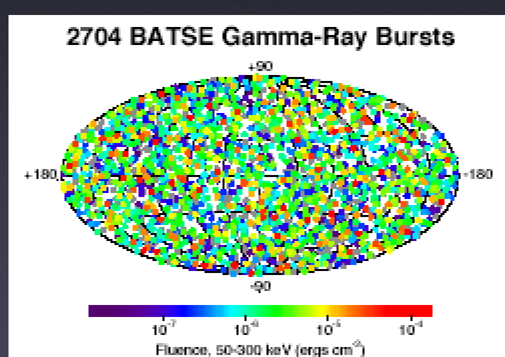
Gamma Ray Bursts

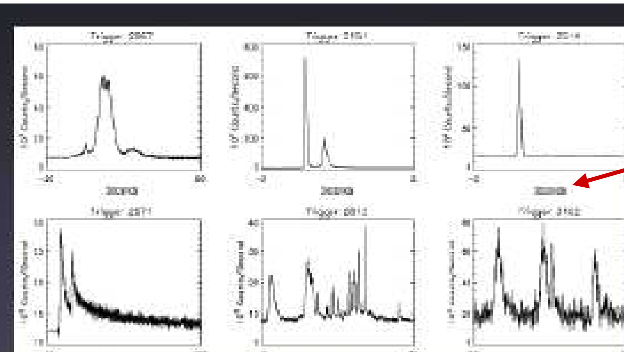
- <u>Energetic and variable cosmological sources</u>: detected for redshift values $0.0085 \leq z < 7$
- Prompt γ emission followed by afterglow in radio, visible, X and gamma
- Uniformly distributed in the sky maps
- Emission spikes in the Light Curves

<u>**Physics:**</u>

- Quantum Gravity scale (10^{15} GeV $< E_{QG} < E_{PLANK}$) from time-lags between photons as a function of ΔE:
  Δt = time lag ~ $(L/c)\,(\Delta E/E_{QG})$, L- distance to the source

<u>**AMS:**</u> >5 GRBs/year in GeV range with 1% precision in energy and time-lags with μsec time precision (from GPS)





Light Curves

Physics example

3- Search for Cold Dark Matter

Many candidates from Particle Physics:

- SUSY neutralinos (χ^0)
- Kaluza-Klein bosons (B)
- …

$\chi^0\chi^0 \rightarrow q\bar{q}$, WW, ZZ, $\gamma\gamma$, $l\bar{l}$ $\rightarrow$ structures in the spectra of

e^+, $\bar{p}$, $\bar{D}$, γ

J. Ellis et al., Phys. Lett. B, 214 (1988) 3

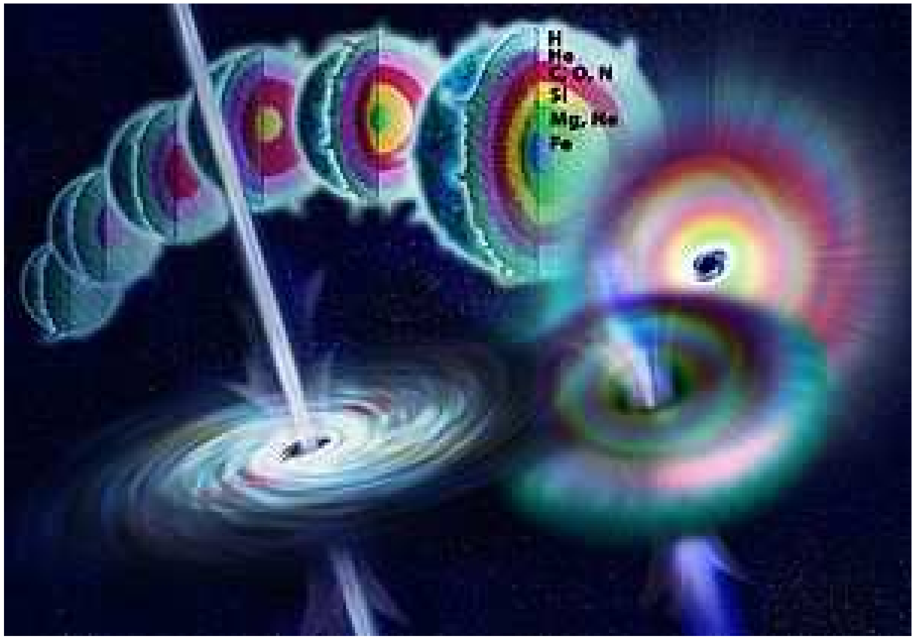
M. Turner and F. Wilczek, Phys. Rev. D42 (1990) 4

J. Ellis, CERN-PH-TH/2005-070

What can be used as a photon source?

➢Gamma ray burst (e.g. blazar) is suitable for this study:

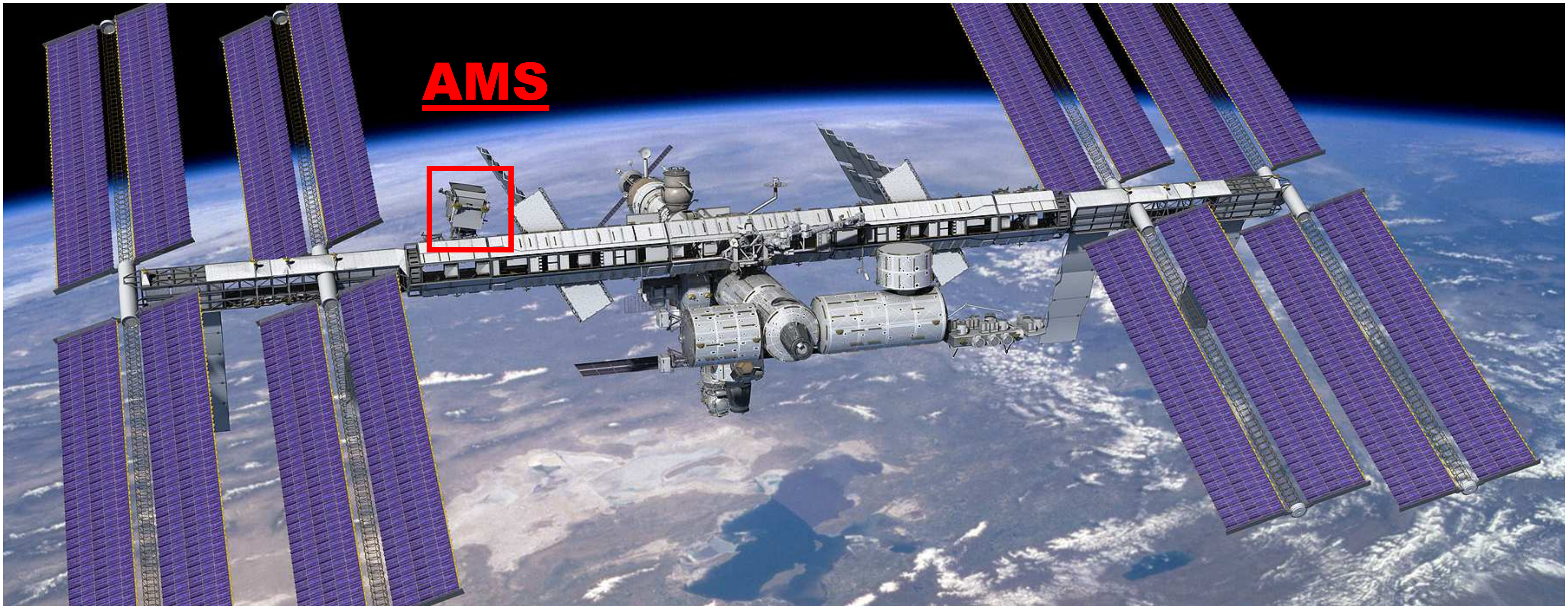
1. Very bright – good for statistics and trigger;
2. Cosmological Distance – large enough time lags;
3. The light curves have spikes – easy to measure the time lags.



The Cosmos is the Ultimate Laboratory.

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

The issues of antimatter in the universe and the origin of Dark Matter probe the foundations of modern physics.



AMS is the only large scientific experiment to study these issues directly in space.