AMS-02

The Alpha Magnetic Spectrometer Experiment

Student Seminar 2018 Spring   May. 11th

Speaker: Yi Tao

Advisor: Prof. Wei Cui

Outline

- AMS Scientific Goal: Fundamental questions in our Universe
- AMS and its “state-of-the-art” design
- Some Results of AMS
- Summary

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Whether or not nuclear antimatter still exists in the universe ? (Baryogenesis)

AMS Science: **Antimatter**

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Experimental evidence: much more **matter** than **antimatter**

Some explanations in theory ?

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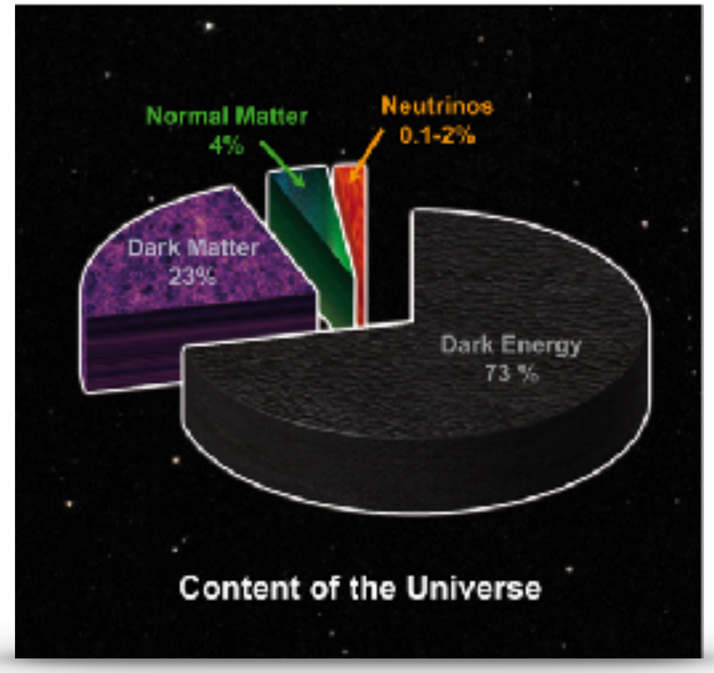
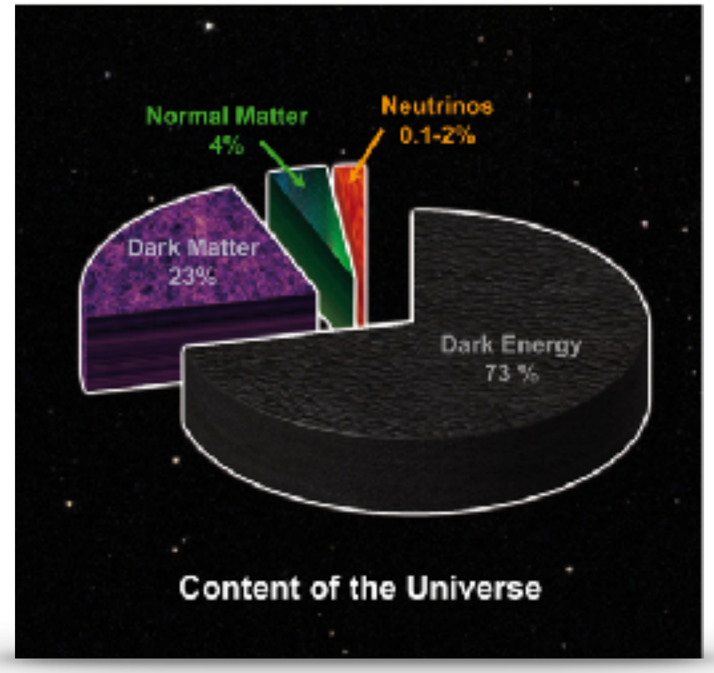

Normal Matter
4%
Neutrinos
0.1-2%
Dark Matter
23%
Dark Energy
73 %
Content of the Universe

WIMPs (Experiment/Observation)
neutralino (Theory)



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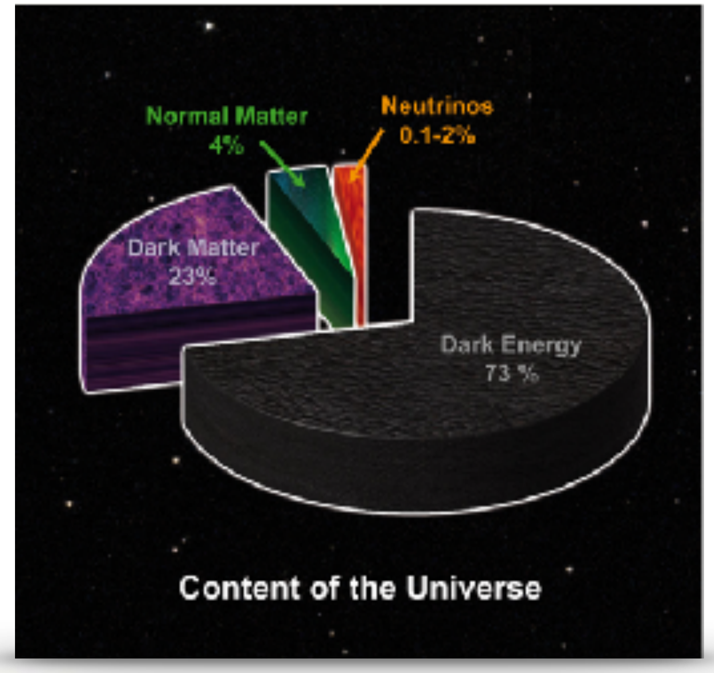
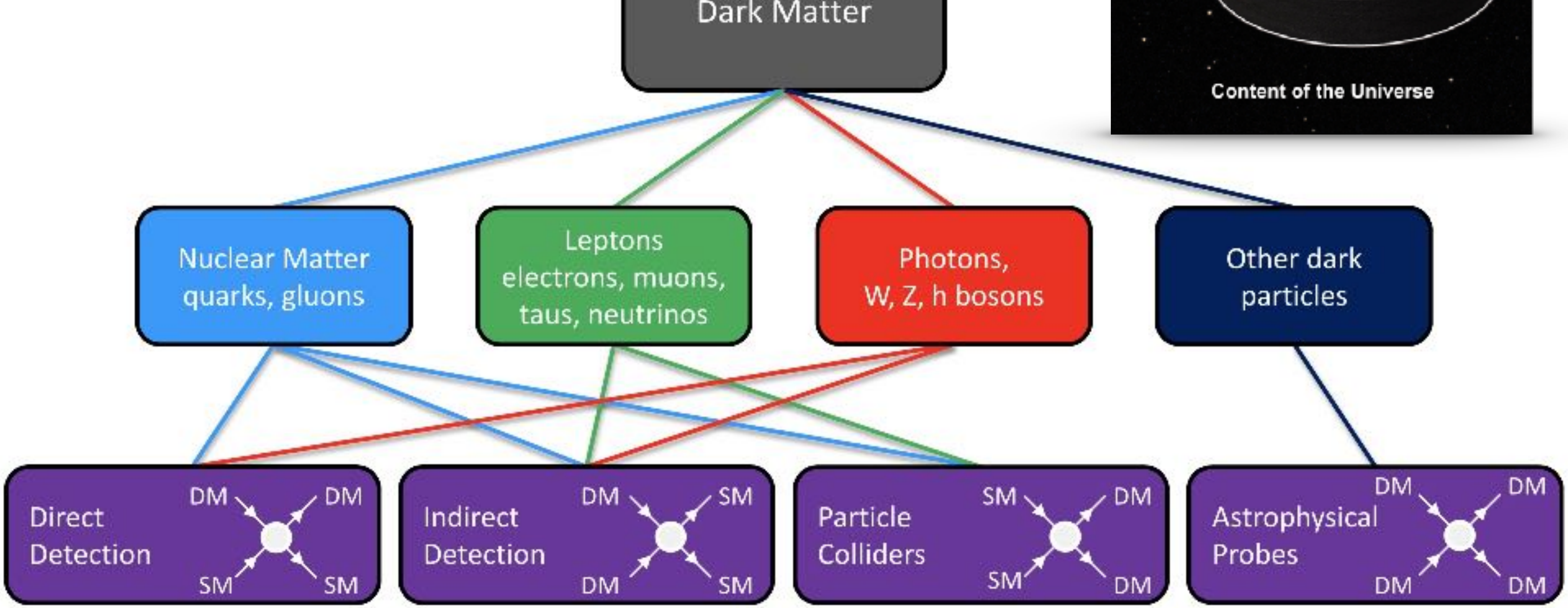


Bauer et al. [arXiv:1305.1605]



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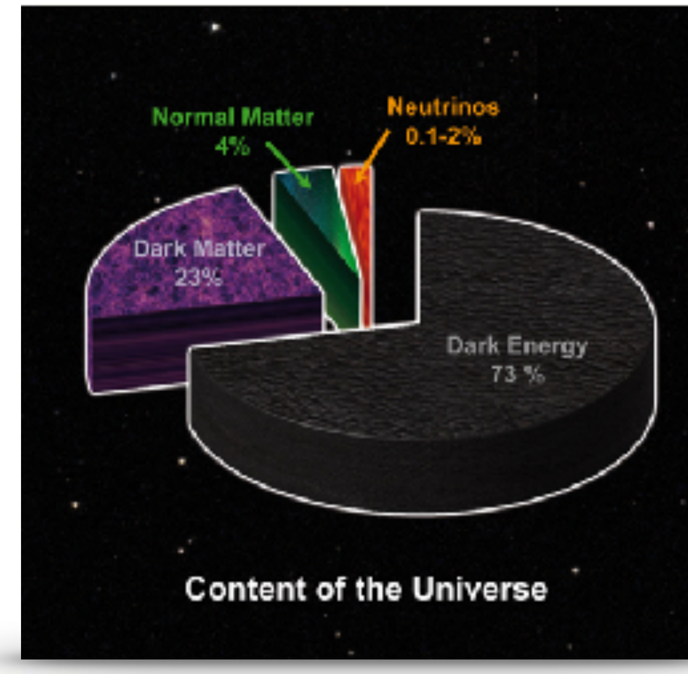
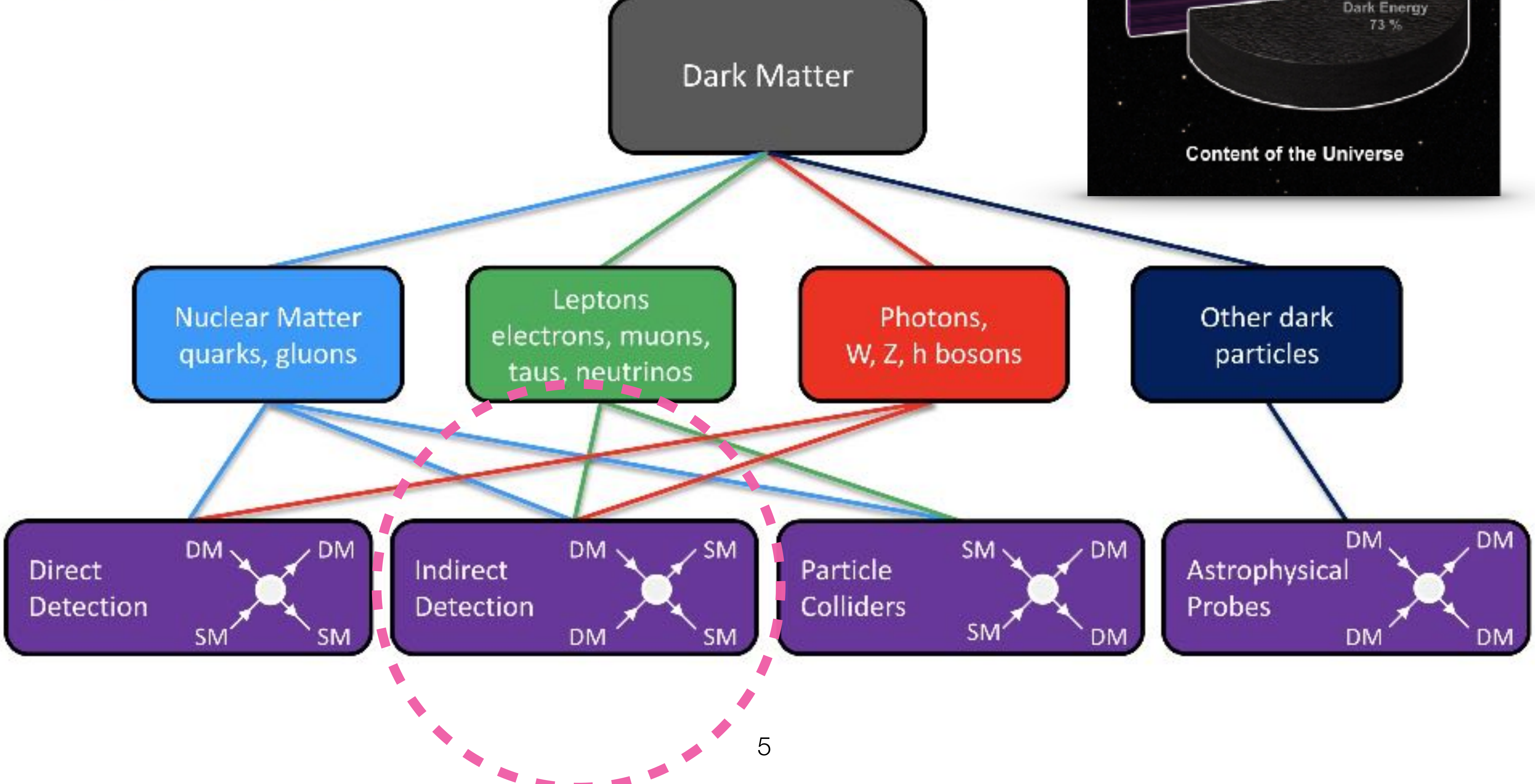
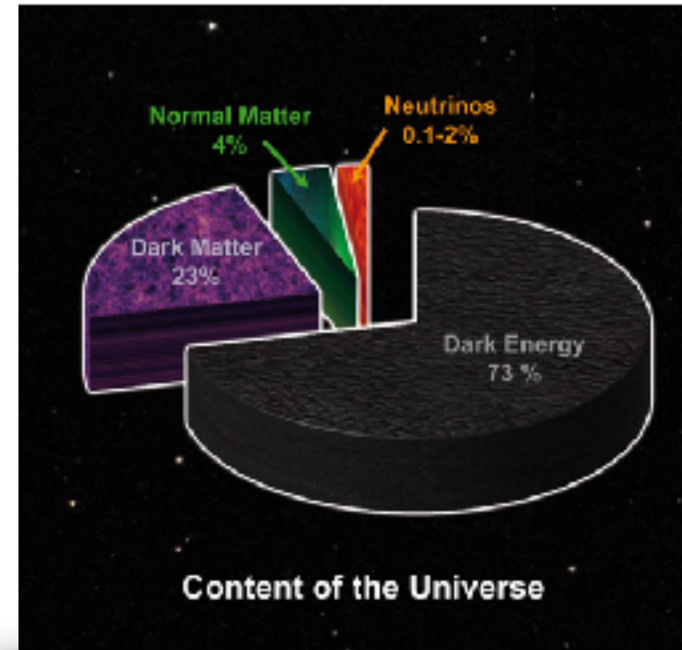




AMS Science: Dark matter(DM)

WIMPs (Experiment/Observation)
neutralino (Theory)



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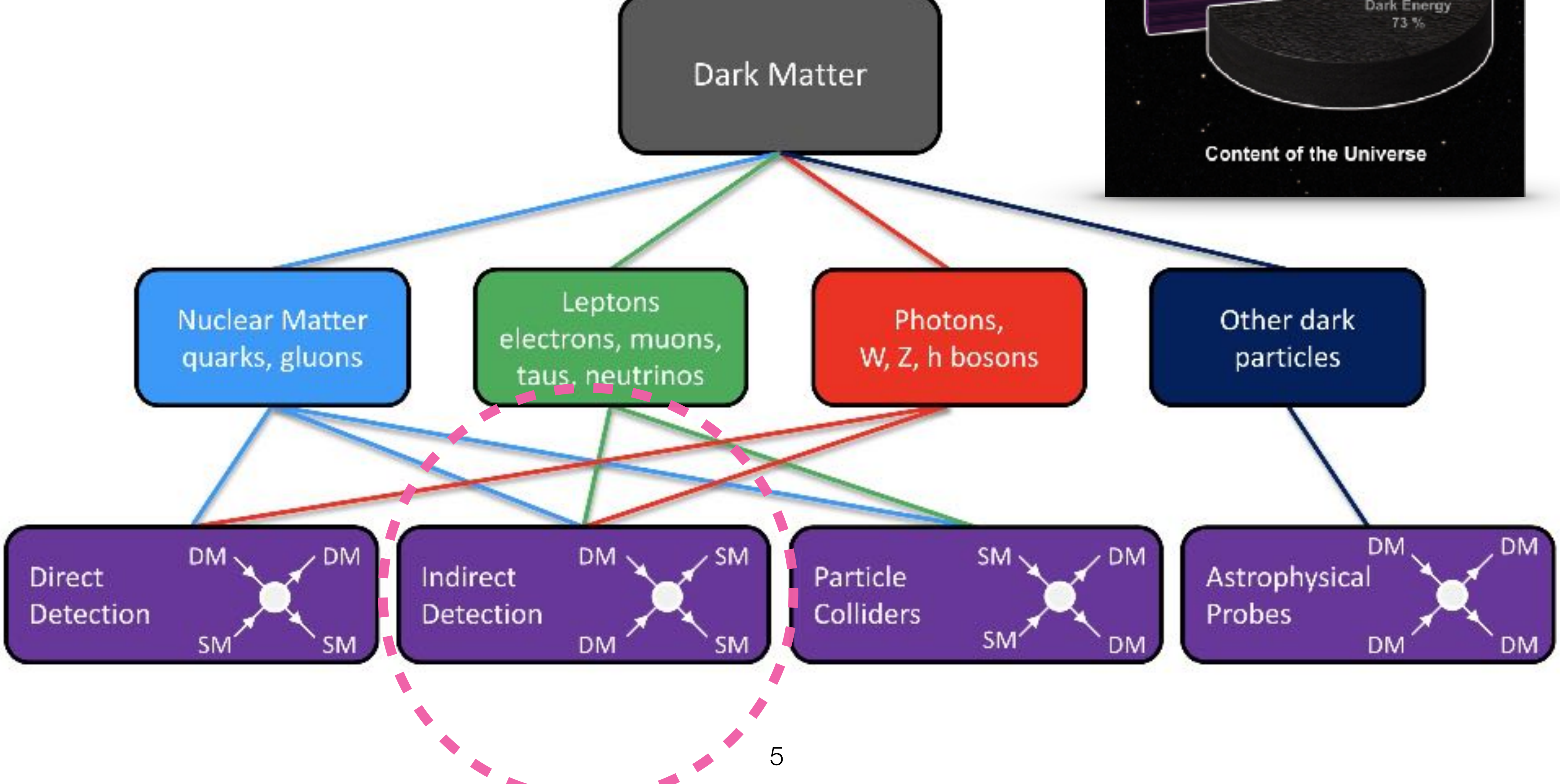
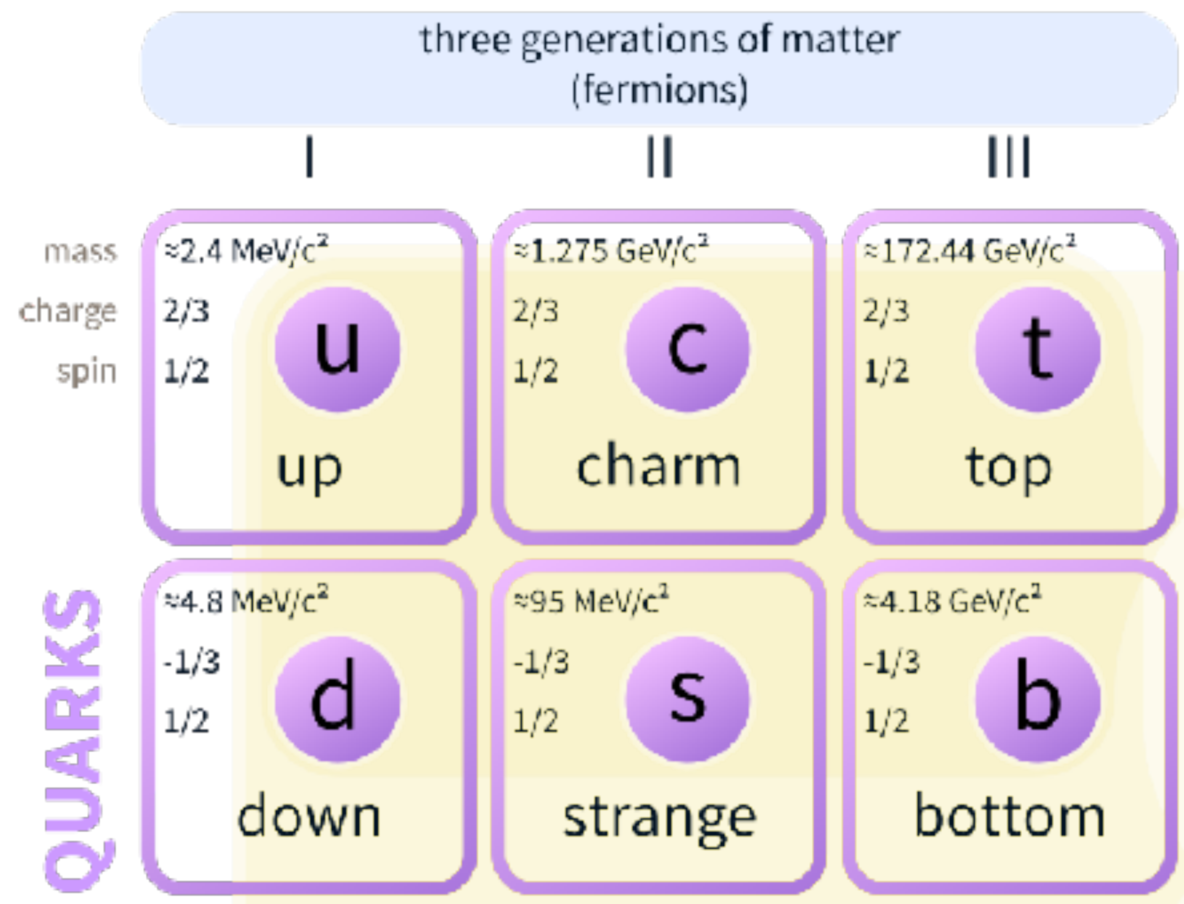
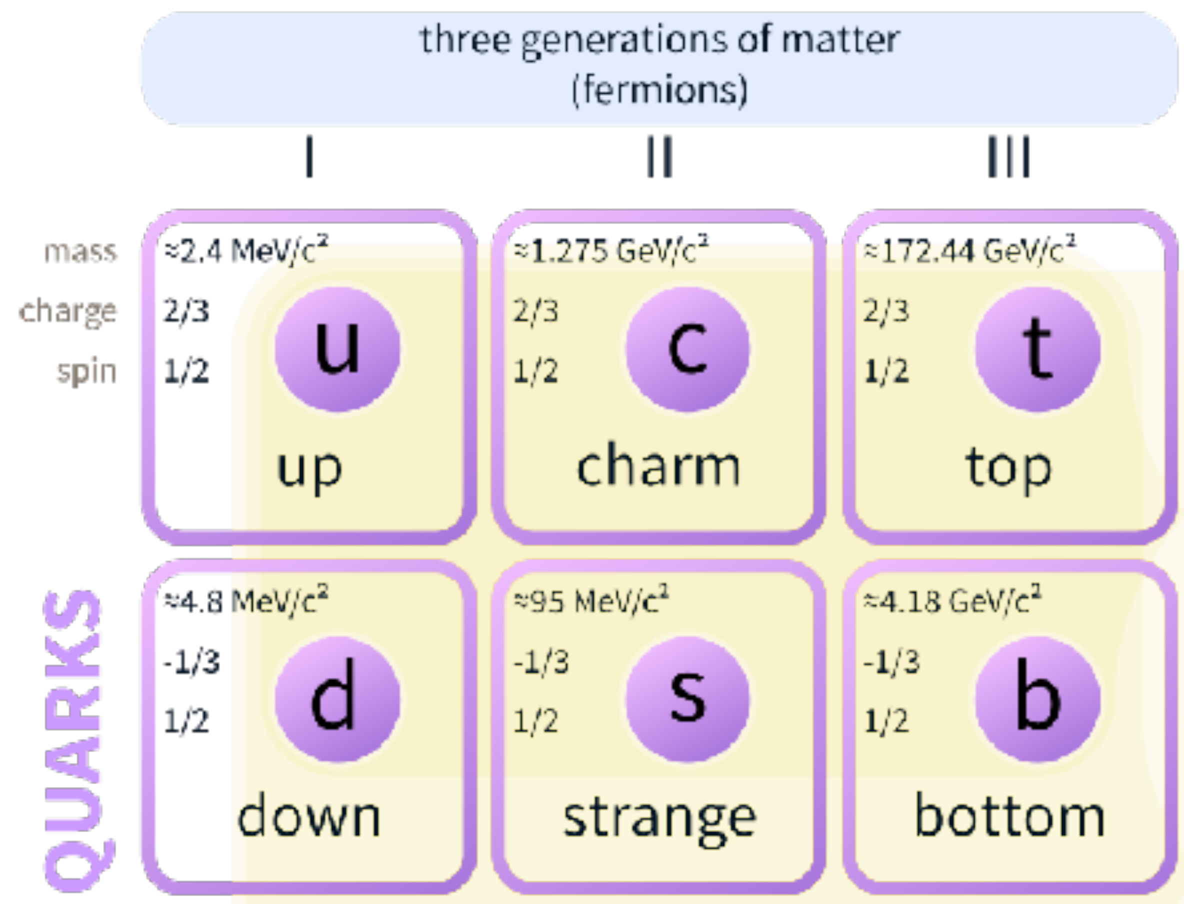
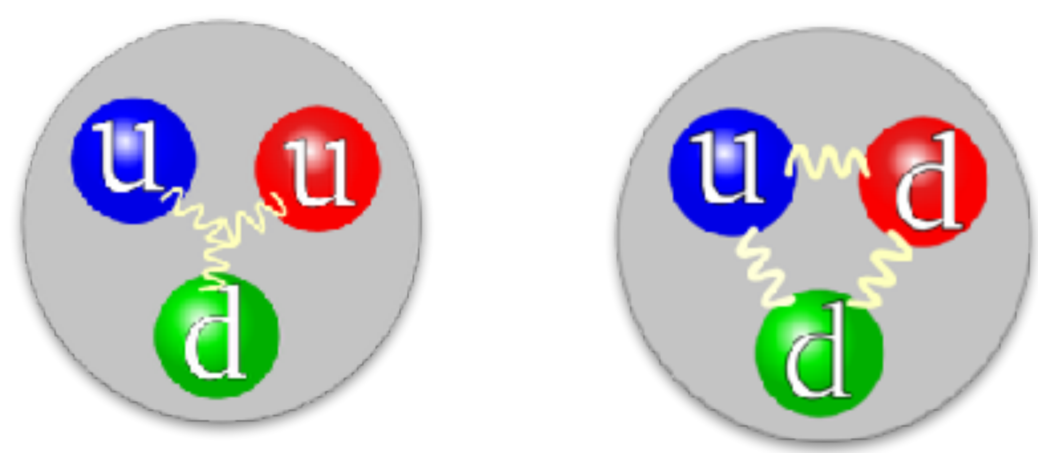



three generations of matter
(fermions)
I
II
III
mass
charge
spin
≈2.4 MeV/c²
2/3
1/2
u
up
≈1.275 GeV/c²
2/3
1/2
c
charm
≈172.44 GeV/c²
2/3
1/2
t
top
QUARKS
≈4.8 MeV/c²
-1/3
1/2
d
down
≈95 MeV/c²
-1/3
1/2
s
strange
≈4.18 GeV/c²
-1/3
1/2
b
bottom

- All stable matters on Earth are made up of two kinds of quarks: up and down (also leptons). In theory, no reason to forbid matter being made up of strange quarks, together with up and down quarks.





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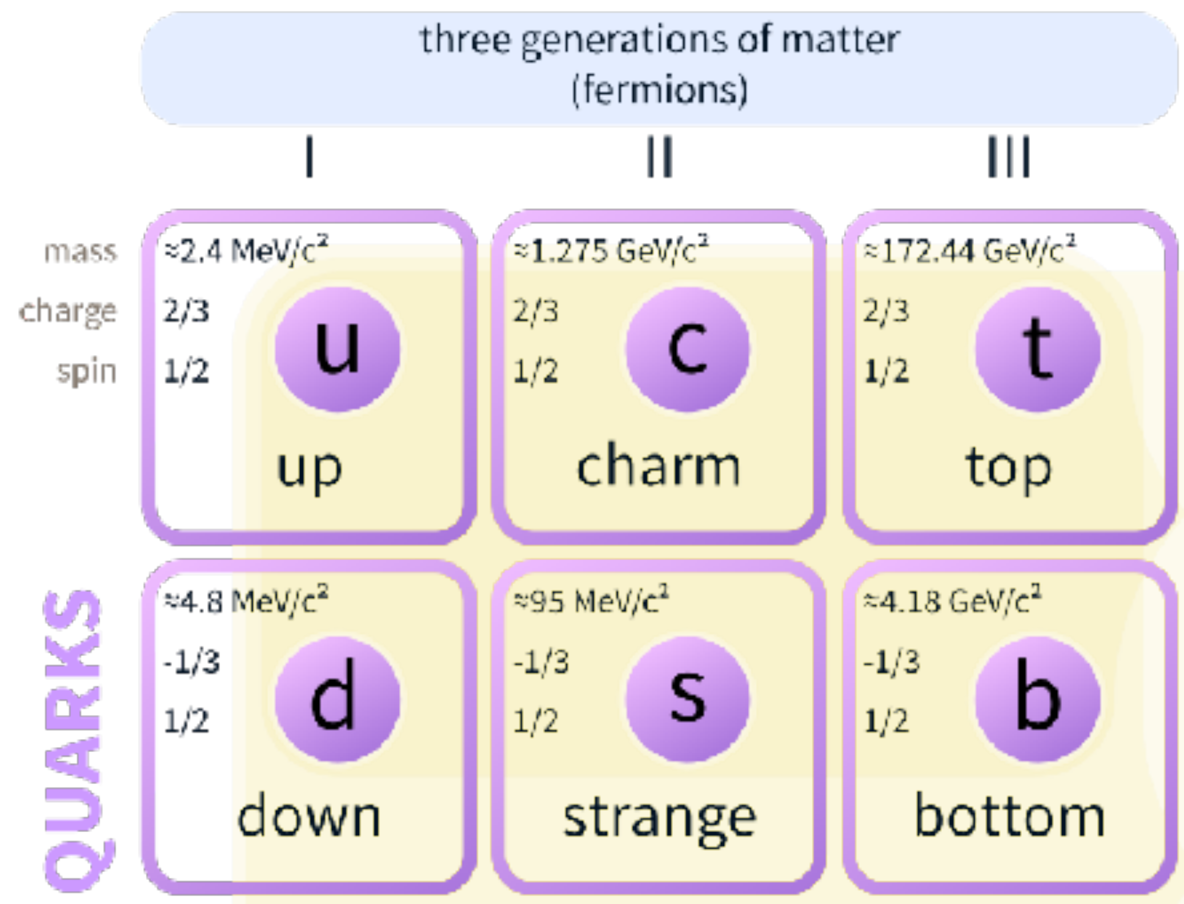

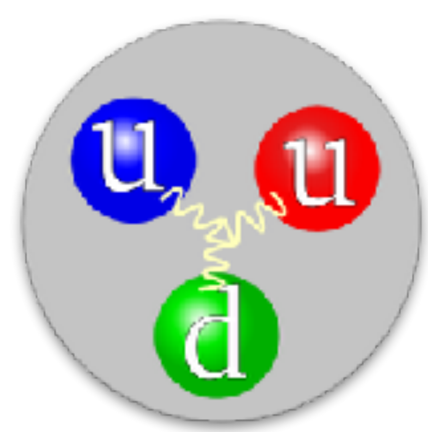

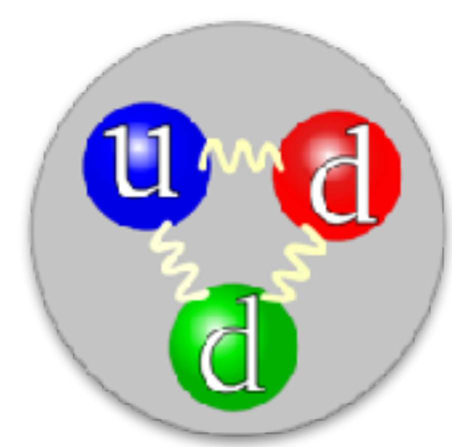

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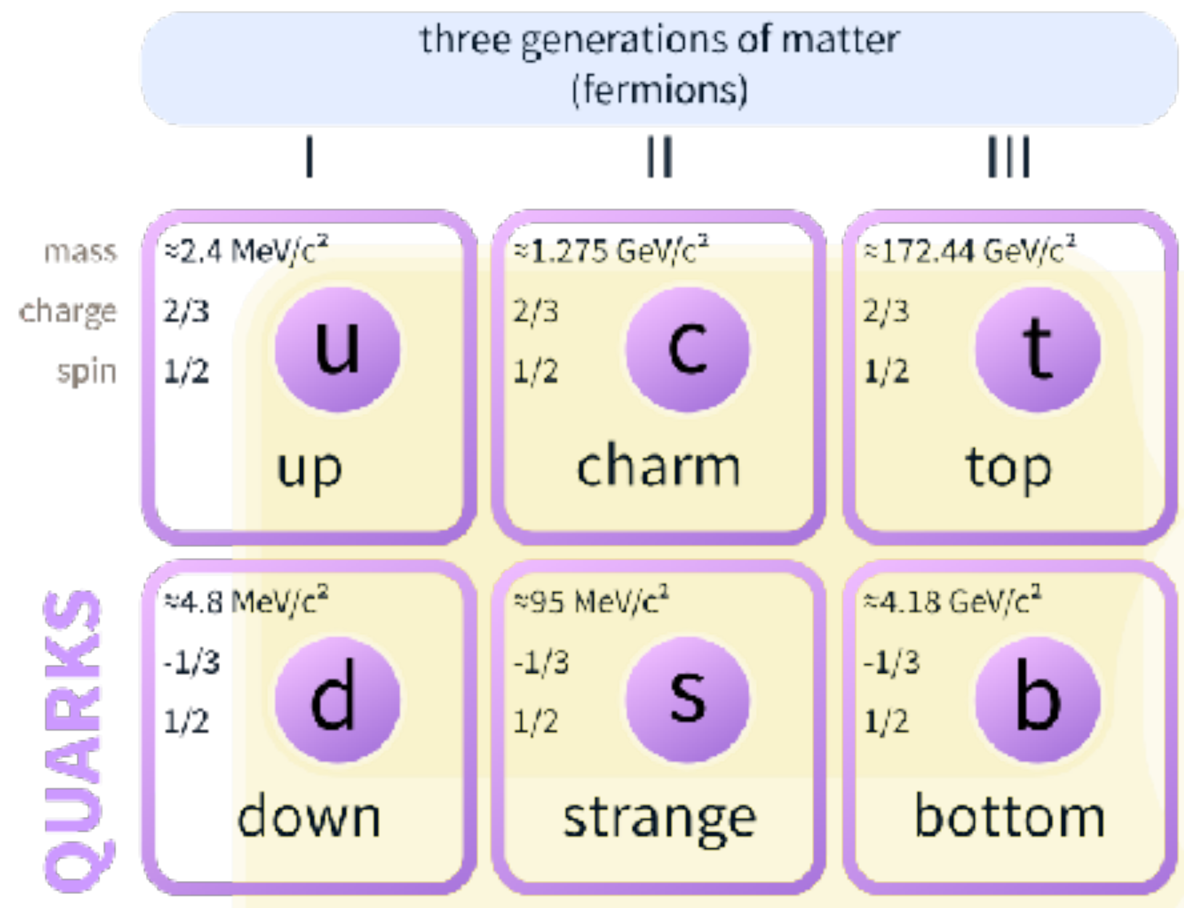
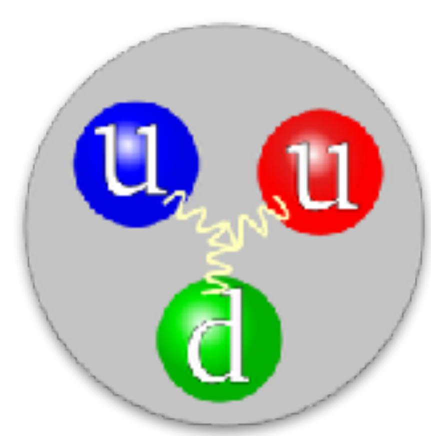
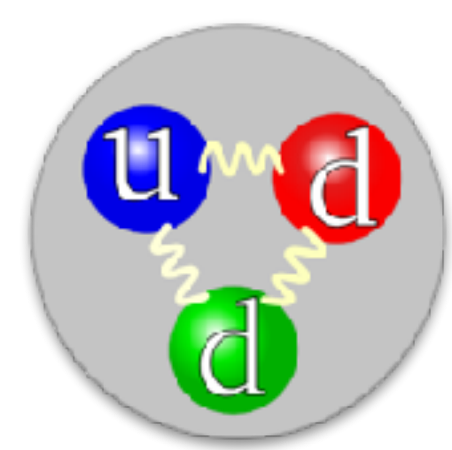
- Determine an extraordinary matter exists or not in our local environment.







AMS Science: Strangelets

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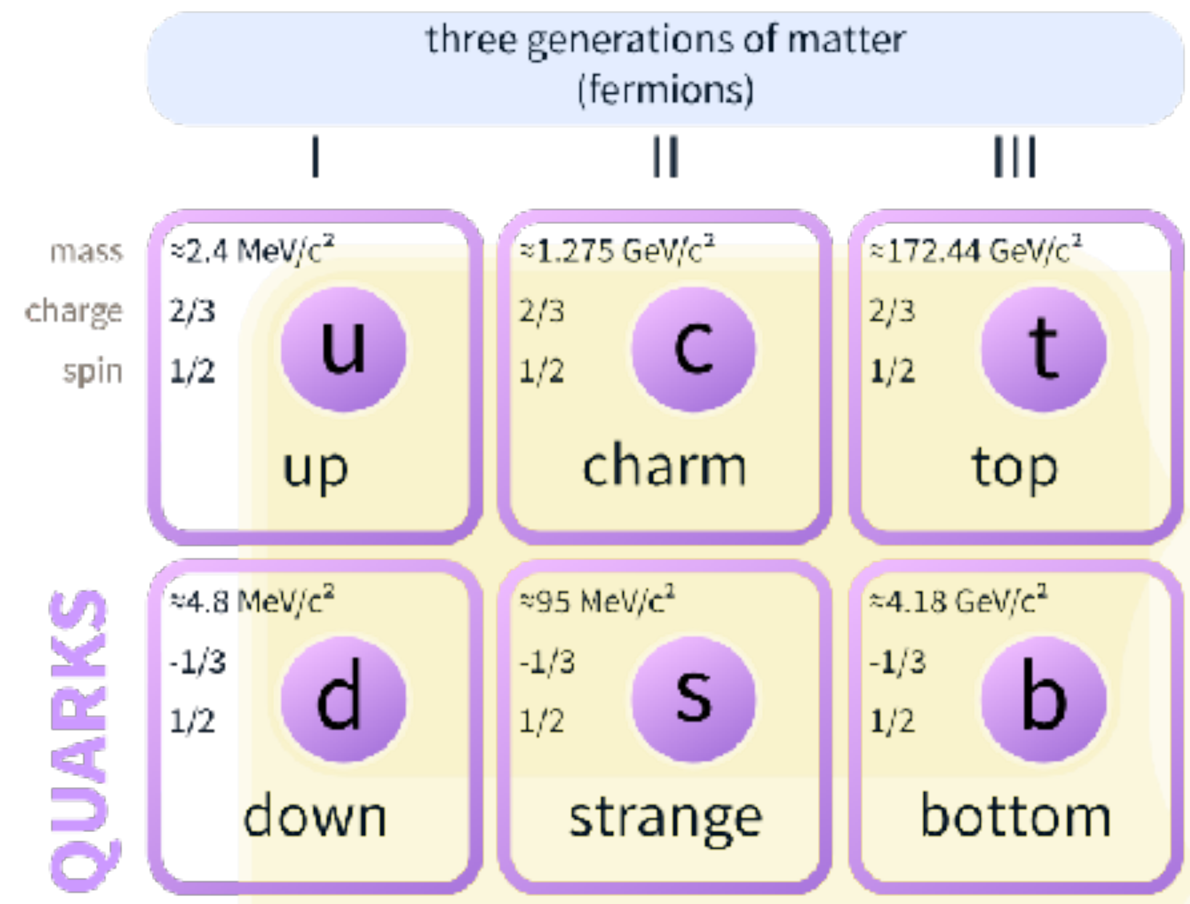

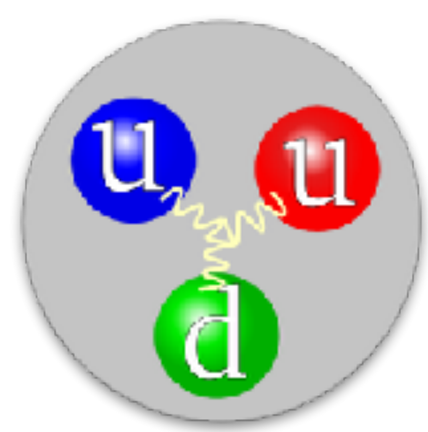

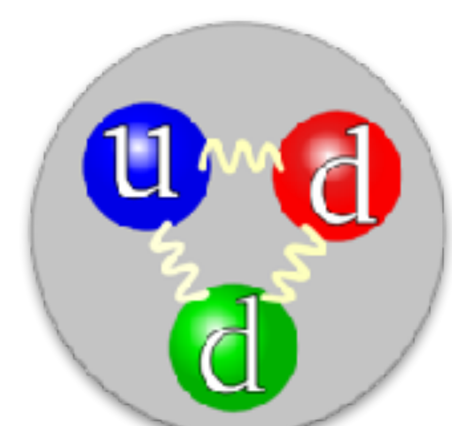

AMS Science: **Cosmic rays(CR) composition and fluxes**

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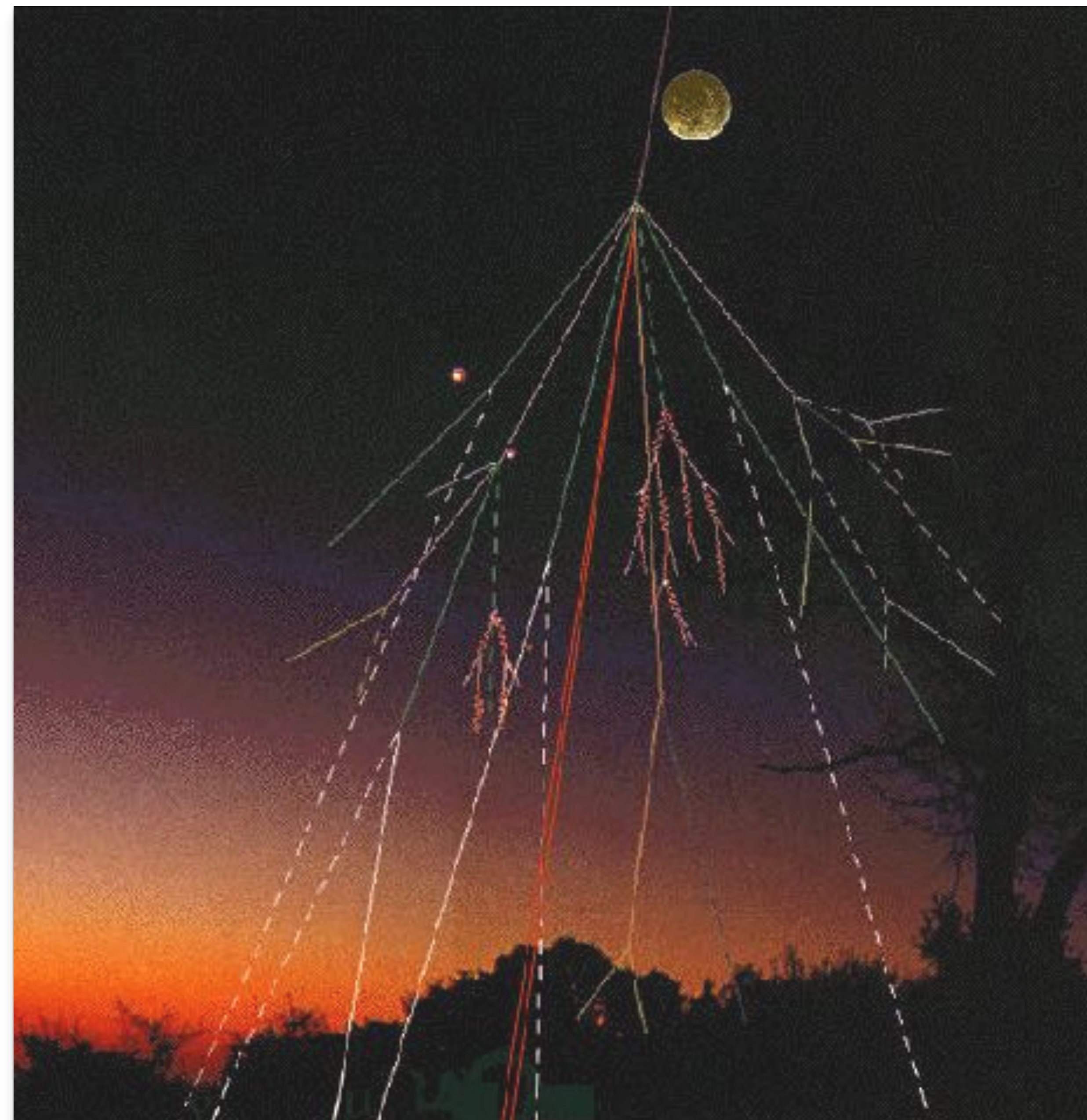
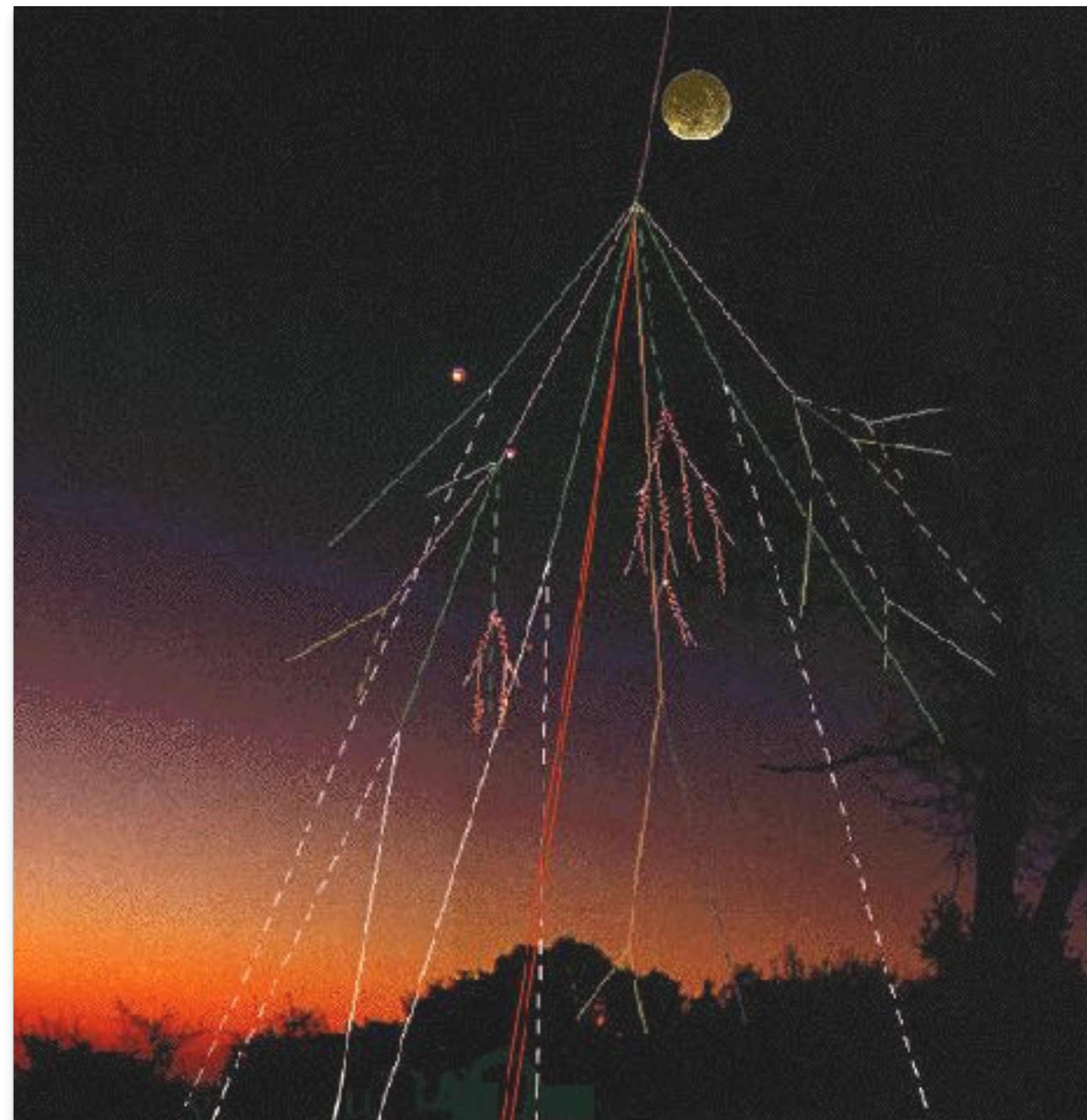


AMS Science: Cosmic rays(CR) composition and fluxes

- Gather a huge amount of data and determine long term variations of the CRs fluxes and composition
- Improve understanding of the interstellar propagation and of the mechanisms at the origins of CRs.
- Accurately understanding cosmic radiation is required for manned interplanetary flight



AMS Science

"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"

"NEVER IN THE HISTORY OF SCIENCE WE WERE SO AWARE OF OUR IGNORANCE: WE KNOW THAT WE DO NOT KNOW ANYTHING ABOUT WHAT MAKES 95% OF OUR UNIVERSE"

— S.C.C. Ting

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What is AMS ?

- **A**lpha **M**agnetic **S**pectrometer
- Particle detector mounted on International Space Station (ISS)
- Measure: matter and antimatter particles in cosmic rays
- Goal: searching for antimatter, dark matter while performing precision measurements of cosmic rays composition and flux.

S.C.C. Ting

www.ams-02.org

AMS-02 Schedule

- Suppose to launch in 2005. Postponed.
- Thermal vacuum, electromagnetic compatibility and electromagnetic interference testing at ESTEC (Netherlands) and underwent final alignment at CERN since 16 February 2010.
- Delivered to Kennedy Space Center in Florida on August 26 2010.
- The launch of Space Shuttle ***Endeavour*** flight STS-134 carrying AMS-02 took place on 16 May 2011.
- The spectrometer was installed on 19 May 2011.

STS: Space Transportation System

AMS-02 on the International Space Station (ISS)

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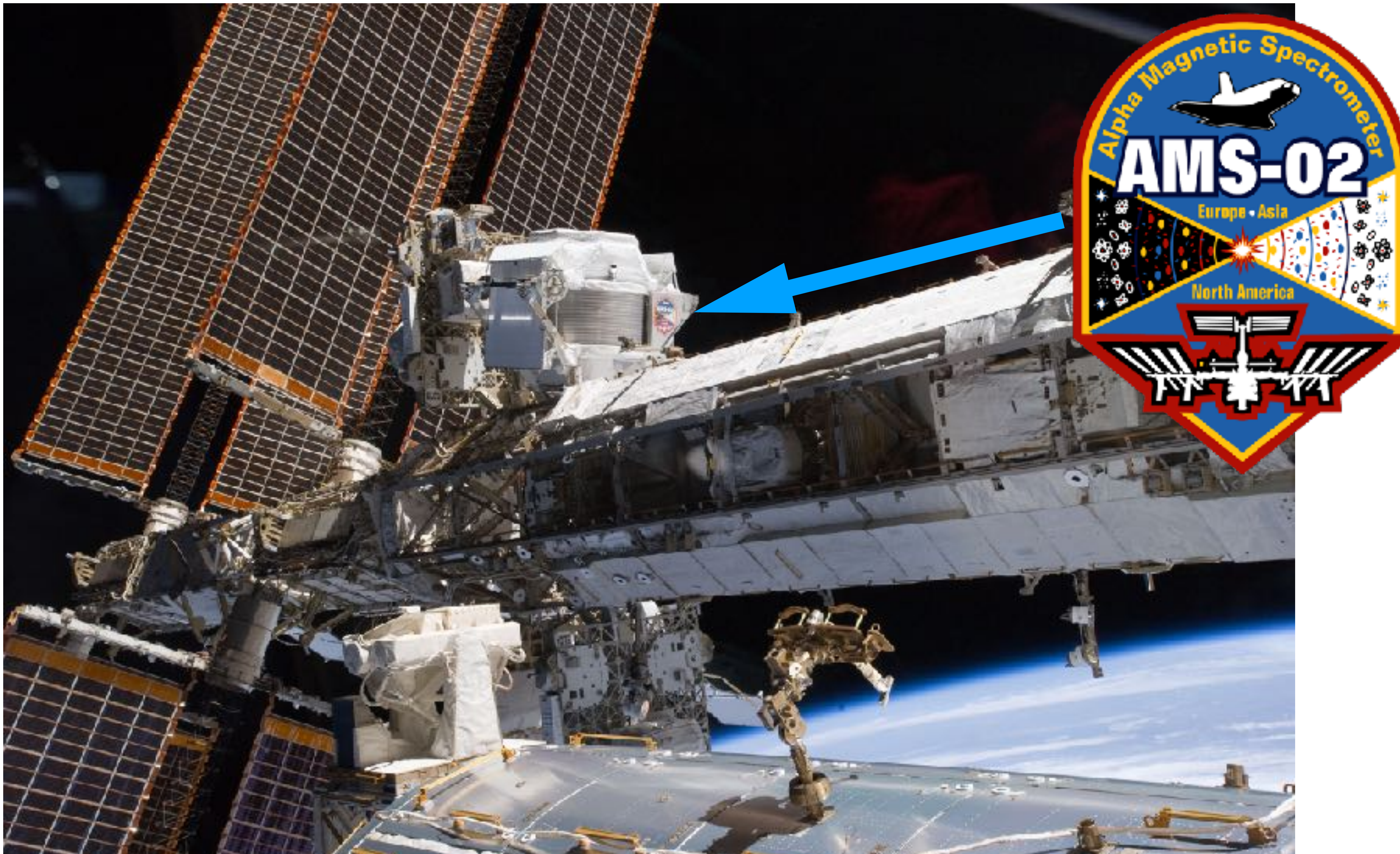
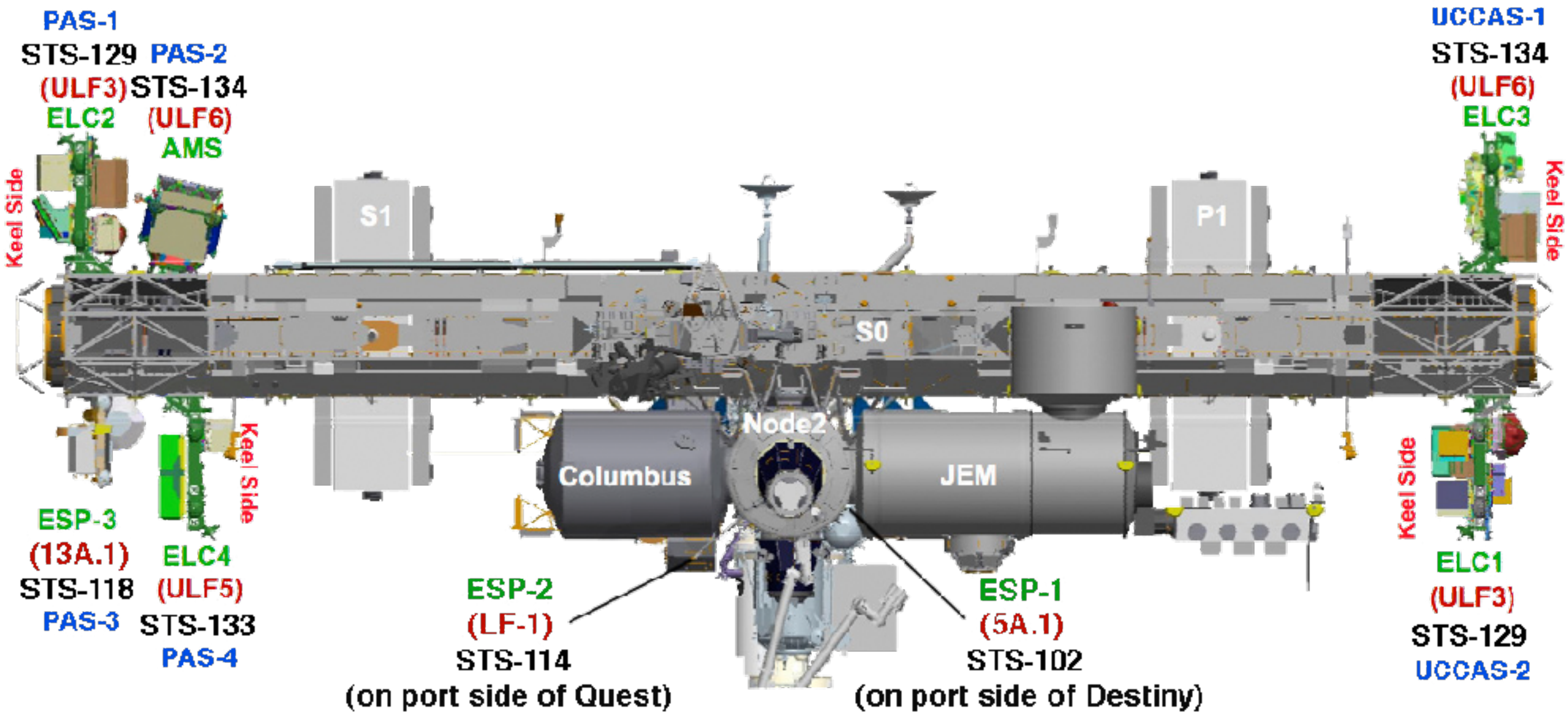


ISS (International Space Station)



- unpressurized platforms:

ELC1 - 4: ExPRESS Logistics Carrier
ESP1 – 3: External Storage Platform

AMS: Alpha Magnetic Spectrometer
ULF: Utilization and Logistics Flight

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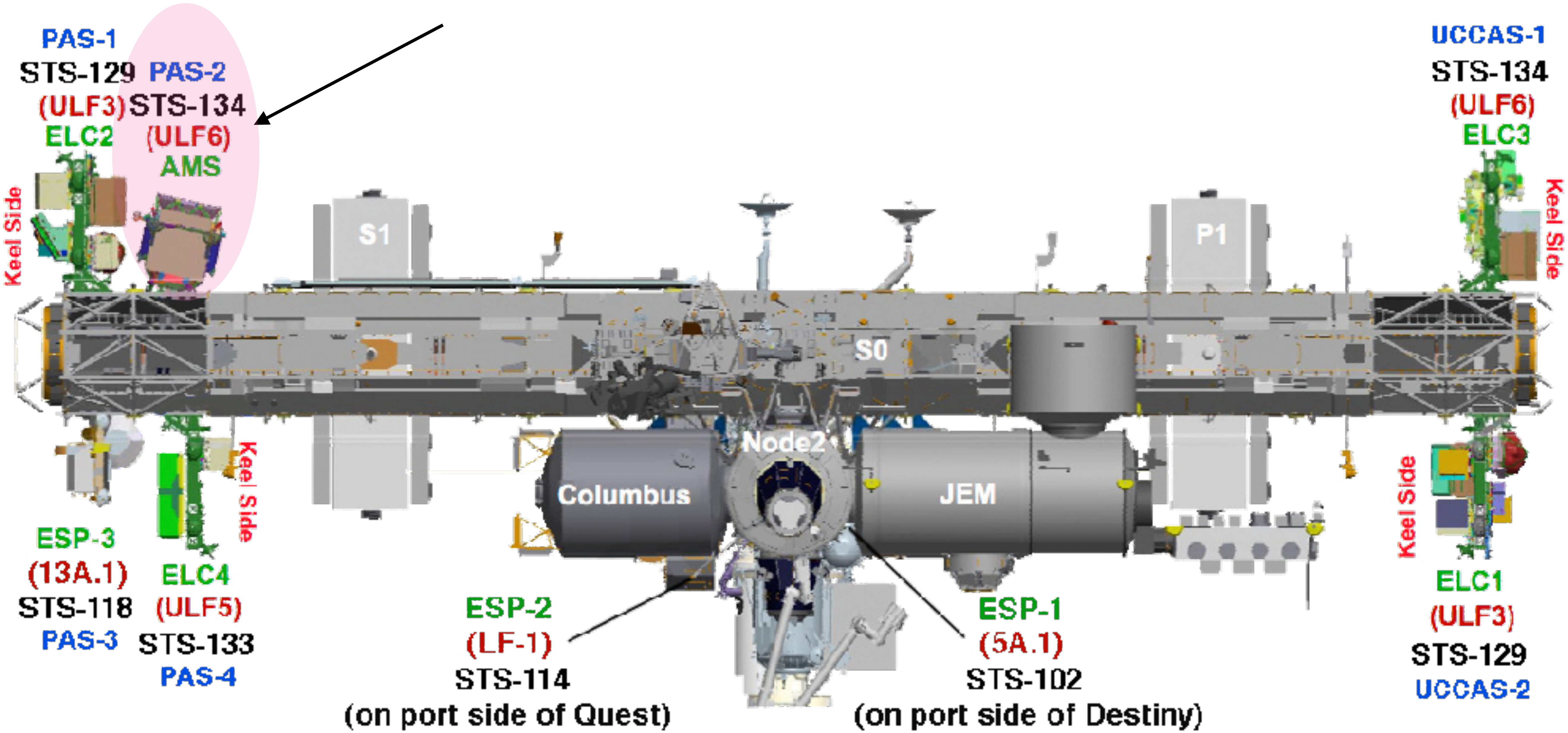

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Specifications of AMS-02

Detector	AMS-02
Weight	8500 kg
Volume	64 m^3
Power	2.5 kW
Data downlink	average 9 Mbps
Magnetic material	**1200 kg of Neodymium alloy ($Nd_2Fe_{14}B$)**
Magnetic field intensity	**0.15 Tesla** (4 times stronger than the Earth field)
Subsystem	15 among particle detectors and supporting subsystems
Launch	16th May 2011, 08:56 am EDT
Mission duration	through the lifetime of the ISS, until 2020 or longer
Construction	1999-2010
Cost	**$ 1.5~2 billion** (estimated)

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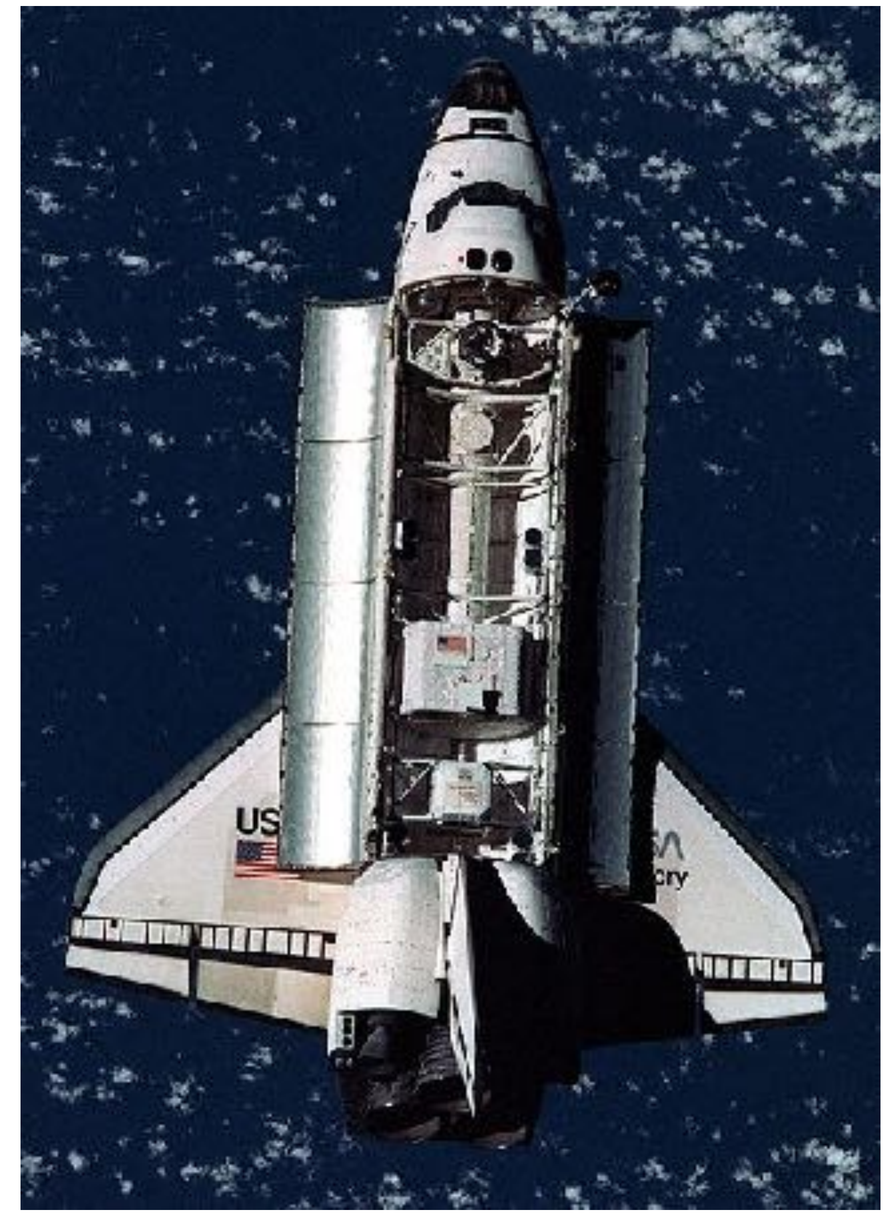
} **Strong Field** (Magnetic material, Magnetic field intensity)

→ **Expensive** (Cost)

Why “02” ?

AMS-01



- The subdetectors installed on AMS-01 were:
    - ***Silicon Detector***, to measure the sign of the charge and the momentum of the charged particles
    - ***Time of Flight***, to measure the velocity of the charged particles and to provide the trigger of the experiment
    - ***An Anticounter system***, to veto particles traversing the spectrometer but crossing the magnet walls
    - ***A threshold Cerenkov detector***, to separate low velocity from high velocity particles

Goal:
1. test spectrometer design principles
2. gain experience under real space flight condition

AMS-01 status

Main result:

By not detecting any antihelium the AMS-01 established an upper limit of 1.1×10^{-6} for the antihelium to helium flux ratio and proved that the detector concept worked in space

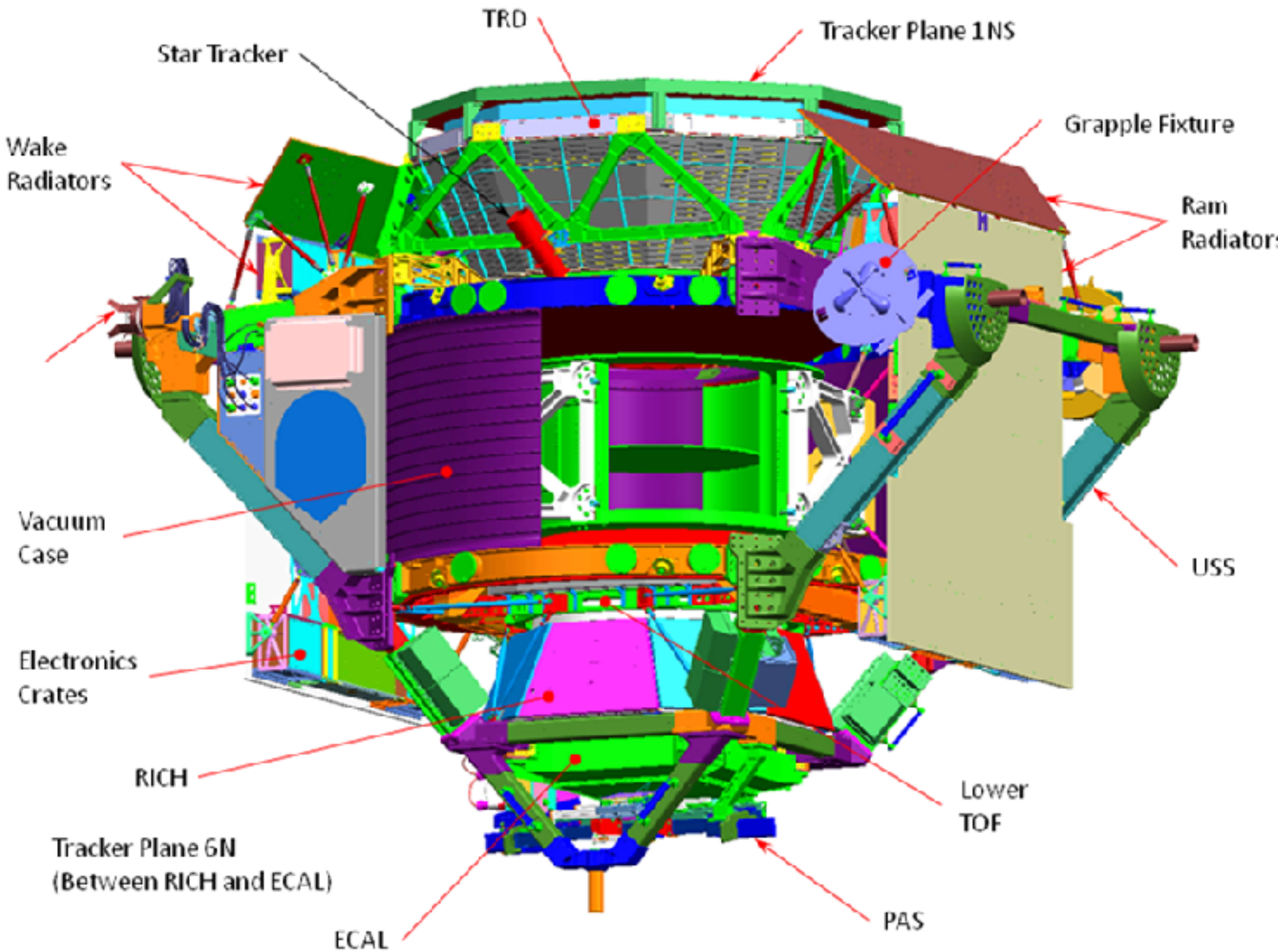
Main difference from AMS-02:

No effort was made to select especially high energy $e^{\pm}$ or low energy antiprotons.

Others:

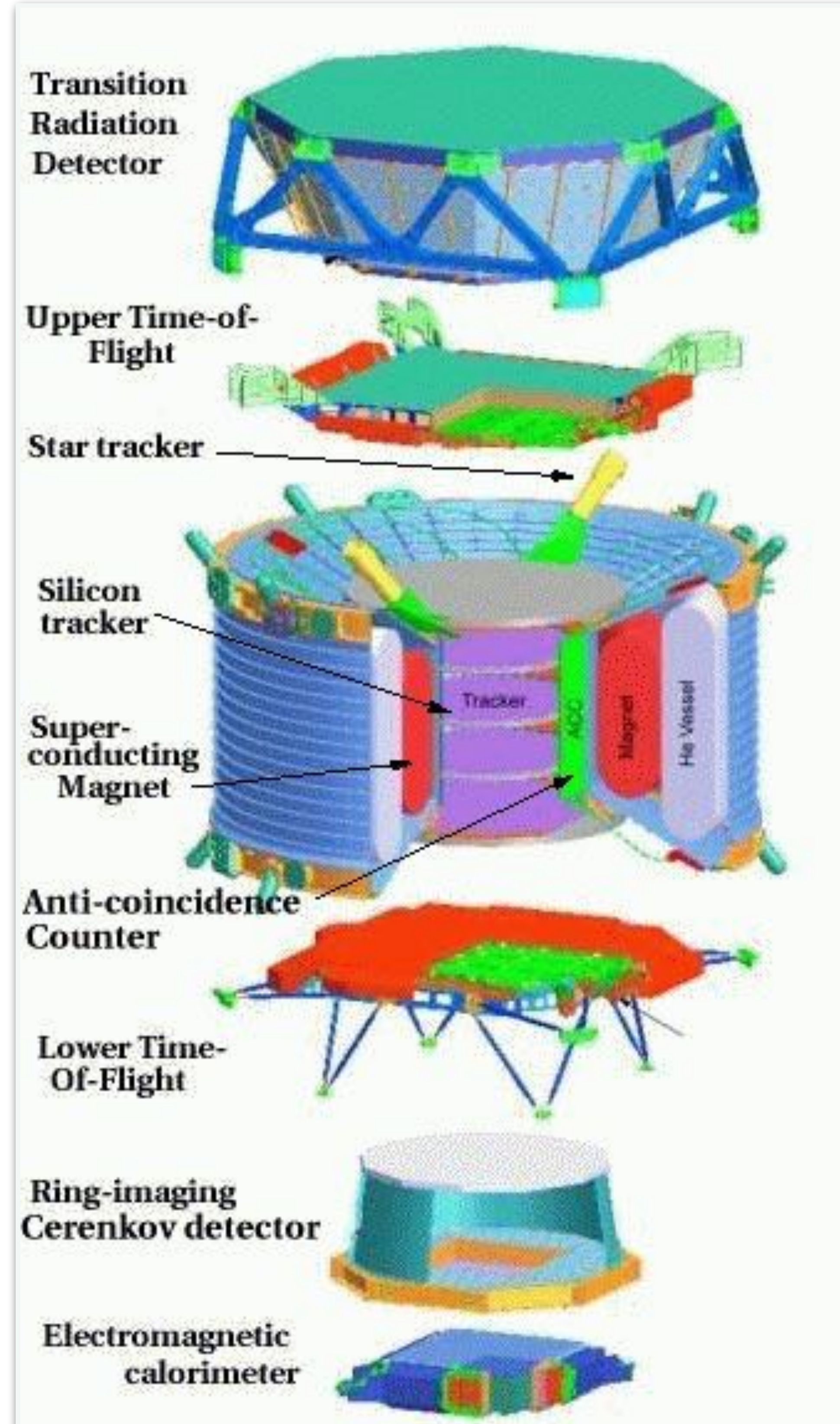
This shuttle mission was the last shuttle flight to the *Mir* Space Station

Design of AMS-02

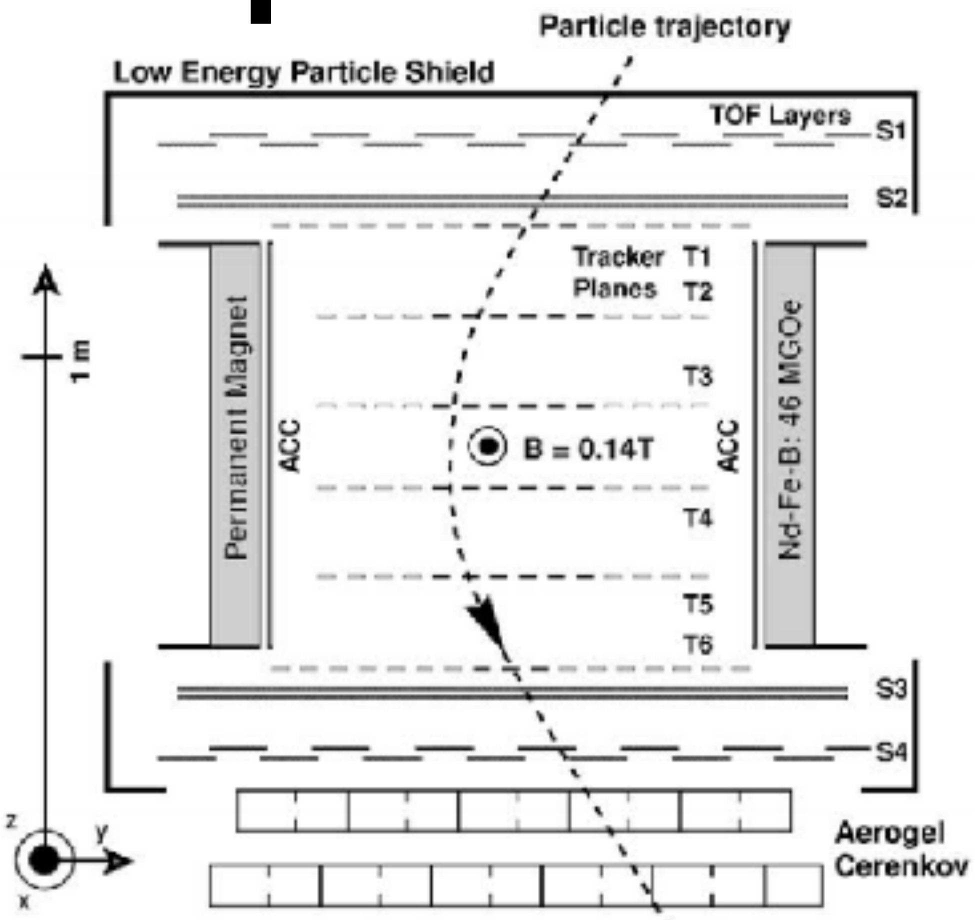


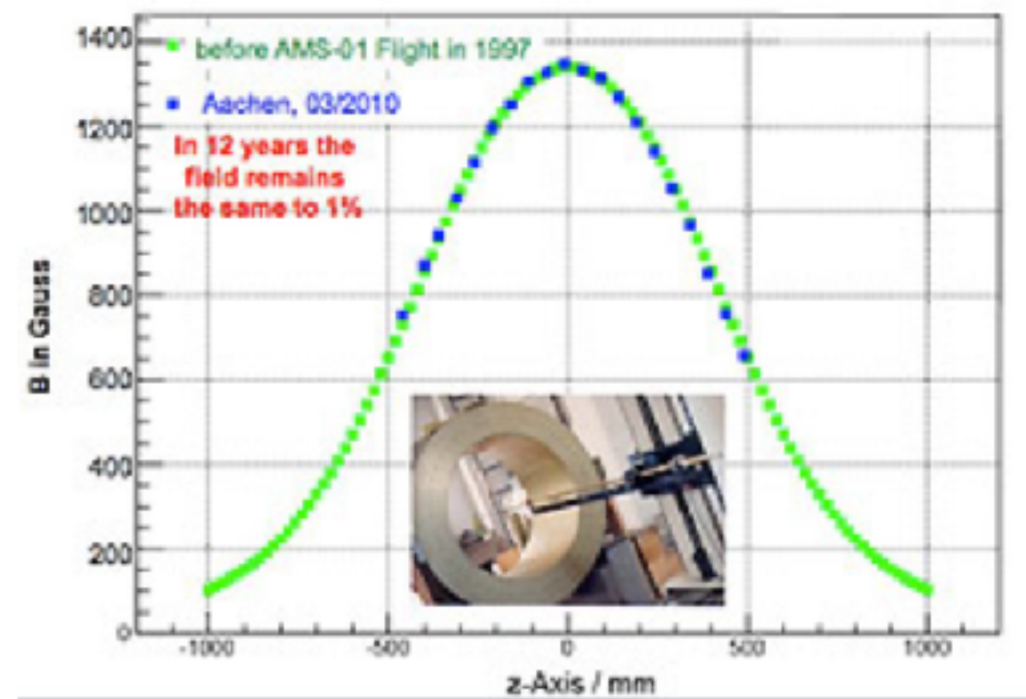
Design of AMS-02

- transition radiation detector (TRD)
- silicon tracker (Tracker)
- superconducting magnet
- 2 time-of-flight counters (ToF)
- 2 star tracker cameras
- ring-imaging Cerenkov detector (RICH)
- electromagnetic calorimeter (ECAL)
- anti-coincidence veto counter (ACC)
- Other support systems



Permanent Magnetic & Superconducting Magnetic

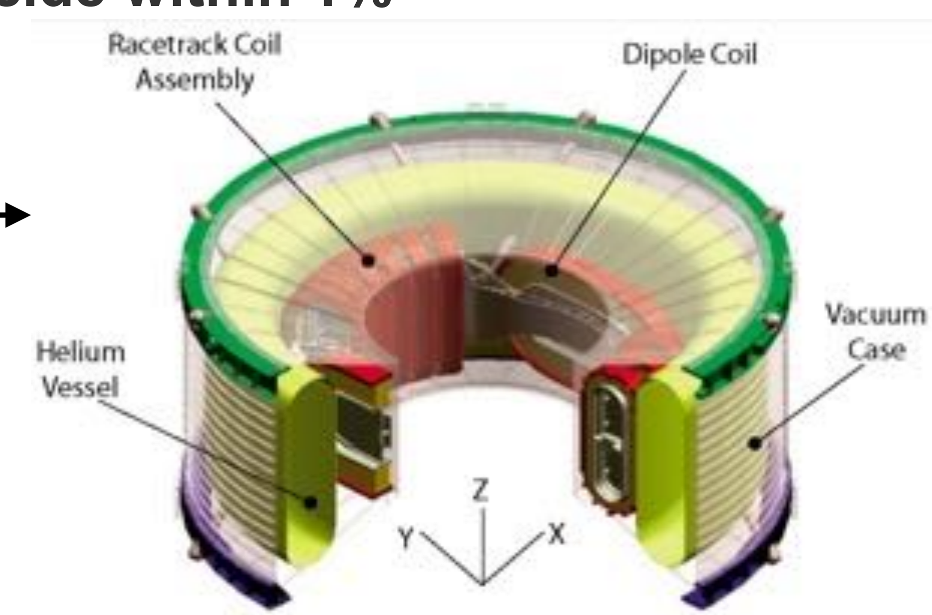


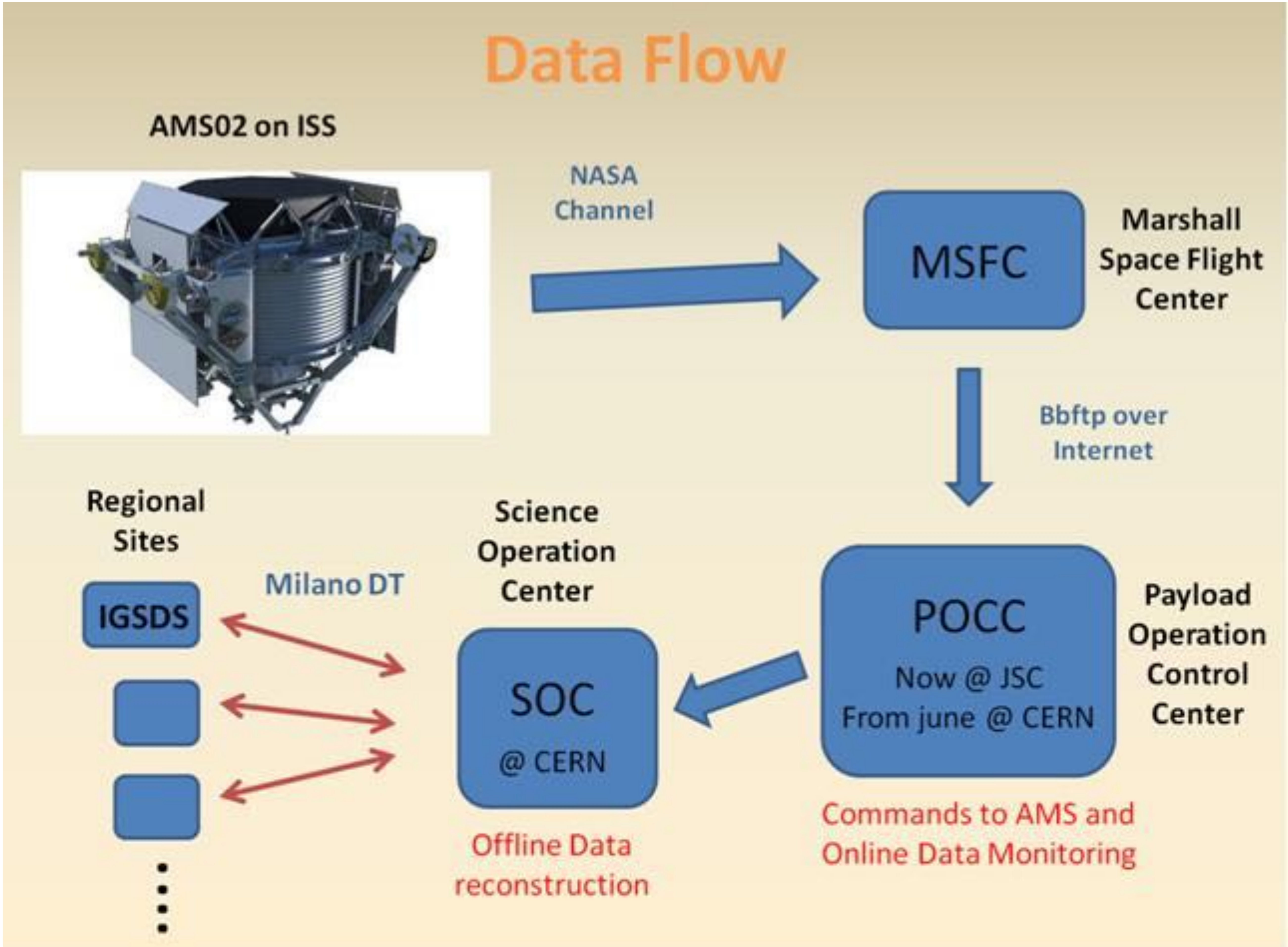


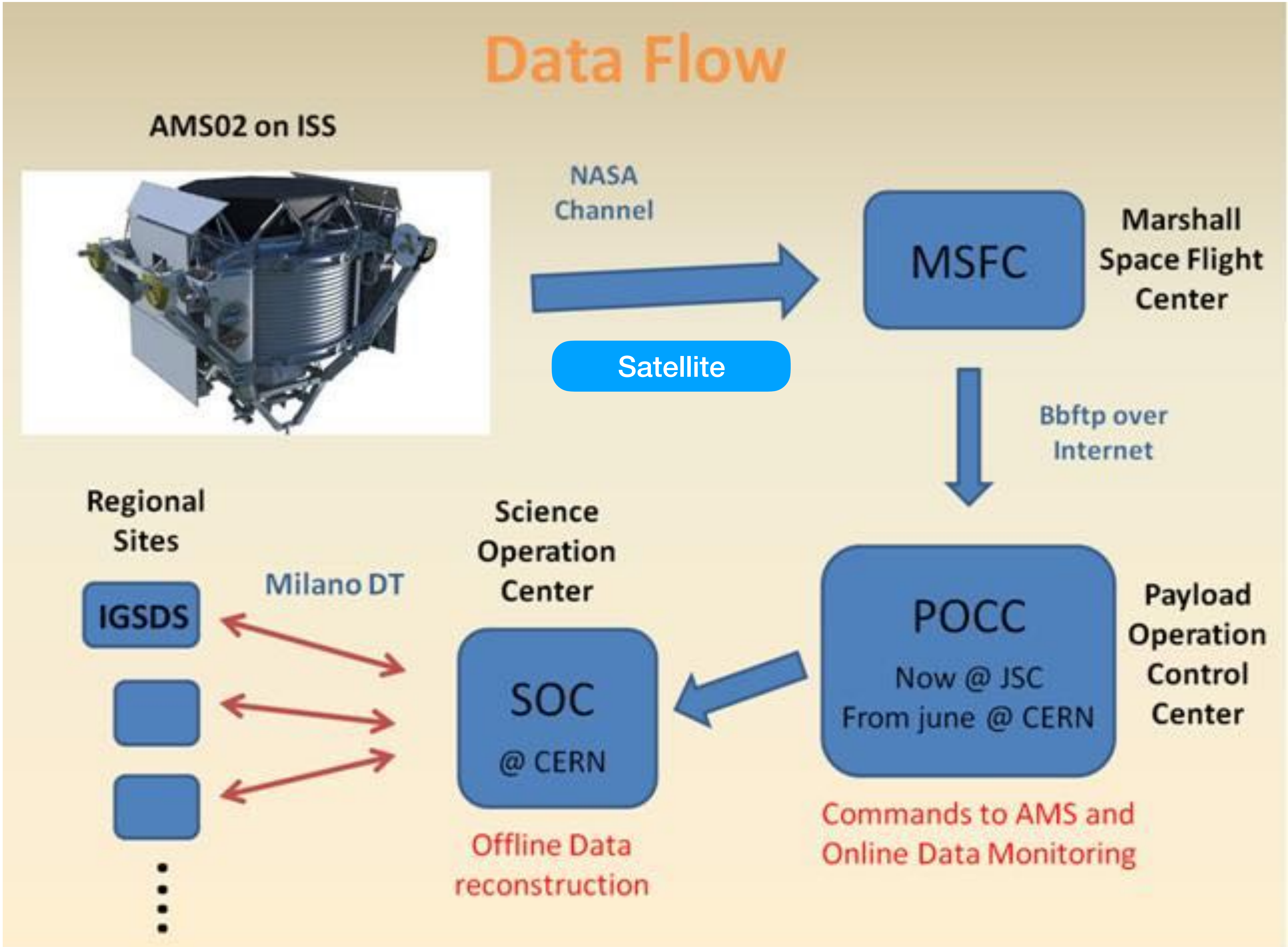
The 1997 and 2010 measurements coincide within 1%

Acceleration test

Superconducting Magnetic




Data Flow
AMS02 on ISS
NASA Channel
MSFC
Marshall Space Flight Center
Bbftp over Internet
Regional Sites
IGSDS
Milano DT
Science Operation Center
SOC
@ CERN
Offline Data reconstruction
POCC
Now @ JSC
From june @ CERN
Payload Operation Control Center
Commands to AMS and Online Data Monitoring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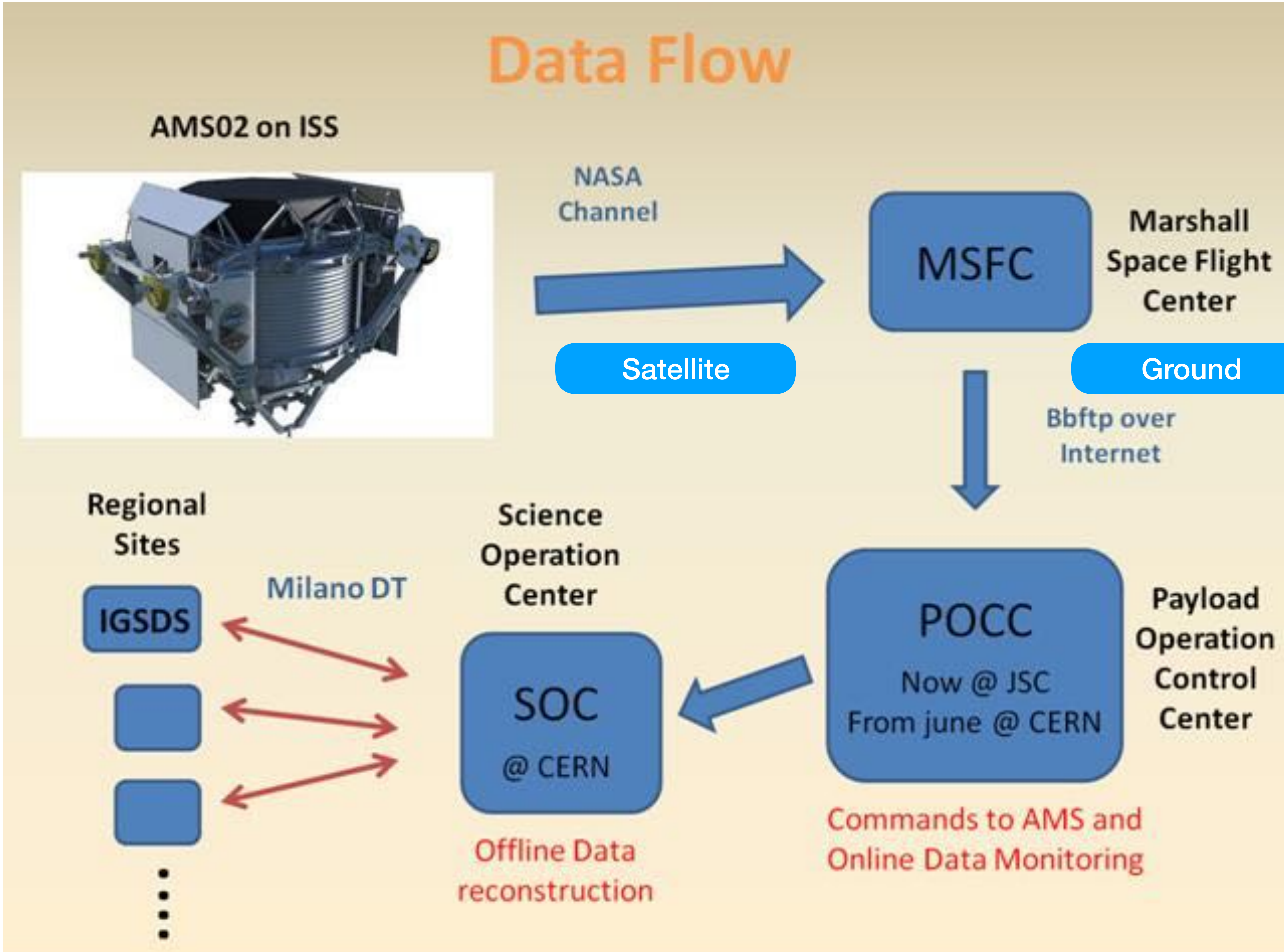
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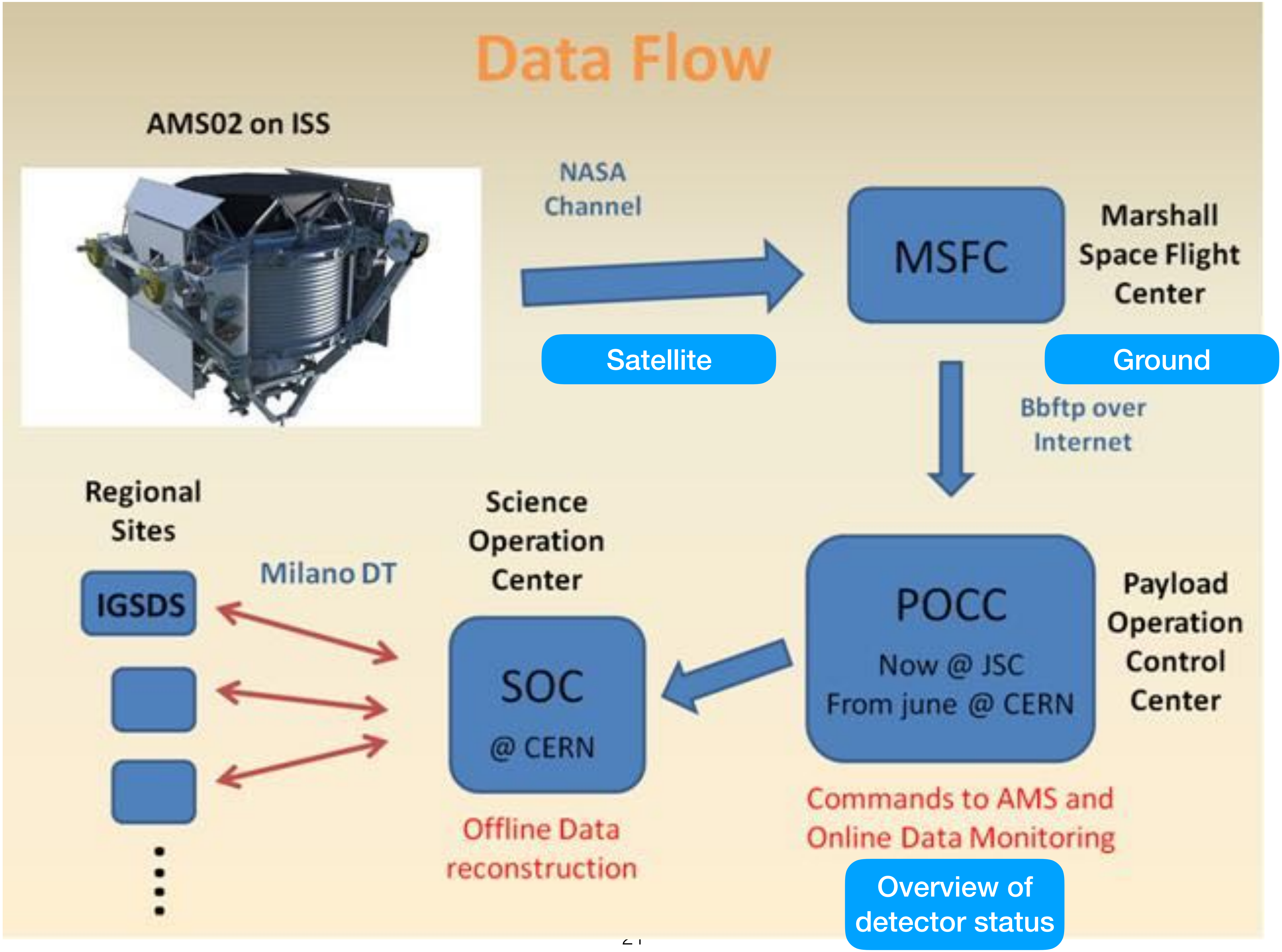
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Overview of detector status

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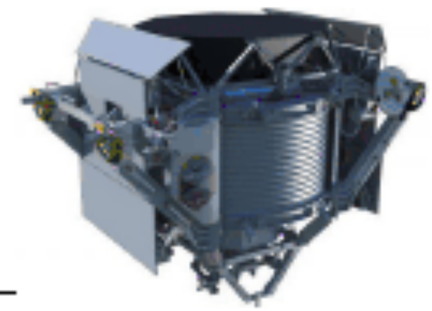
AMS Sensitivity to Spectral Features in Cosmic Rays

Mission Elapsed Time:

1 DAY



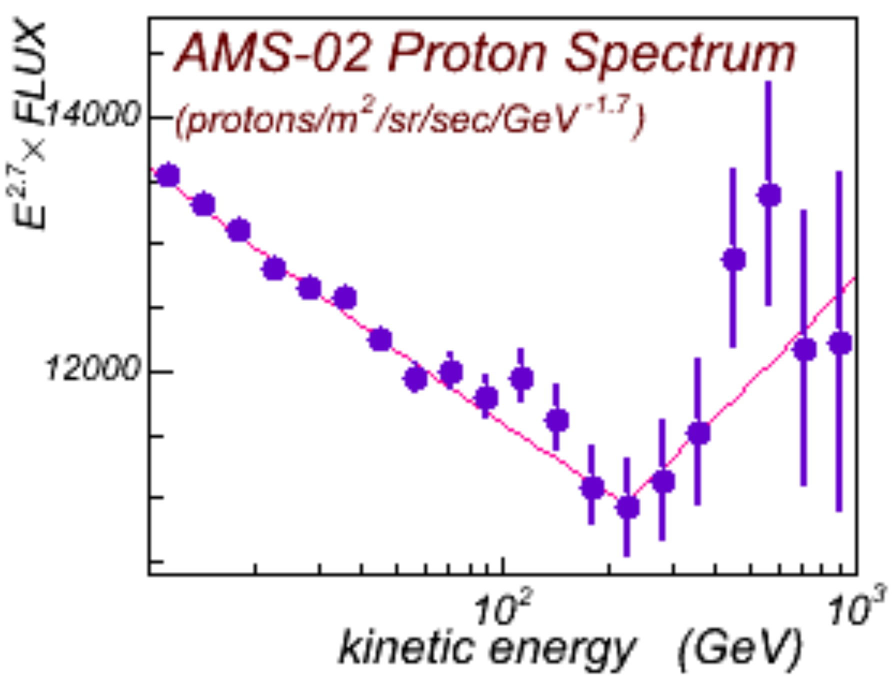
Benchmark CR spectrum: power law with high energy break

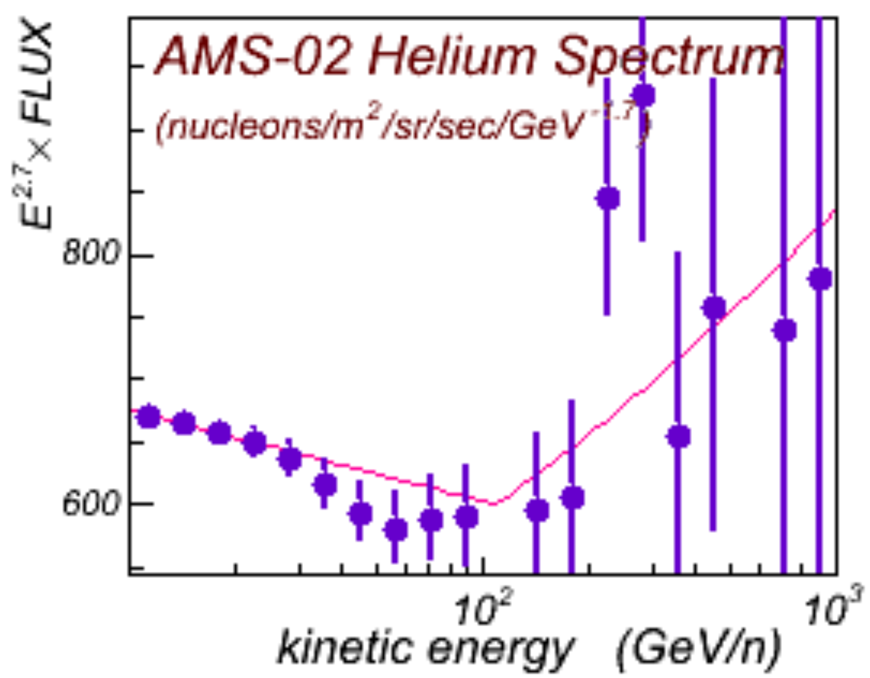
- *flux normalization (from AMS-01 data)*
- *energy break value E_B (protons: 220 GeV; helium: 110 GeV/n)*
- *spectral indices below/above break: γ_1/γ_2 (p: 2.77/2.60; He: 2.74/2.55)*

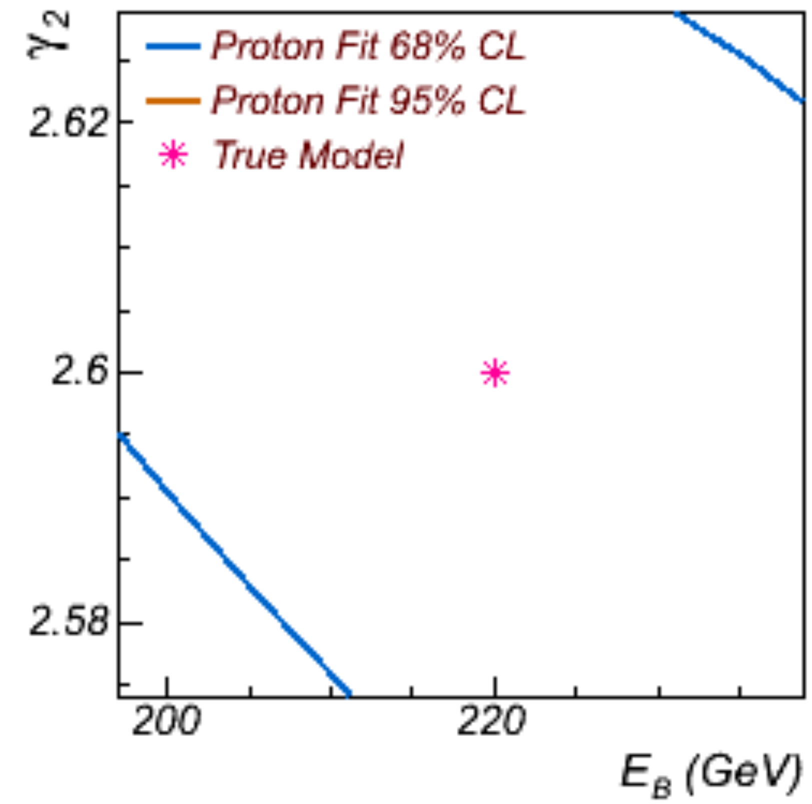
AMS-02 Projected Measurements

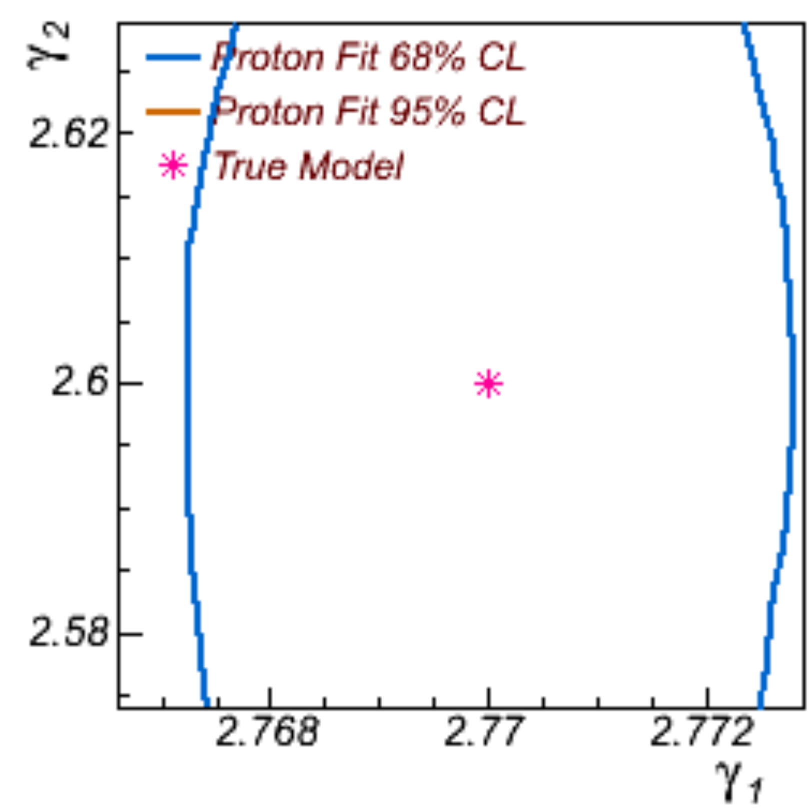
→ proton energy spectrum in 10 - 1000 GeV

→ helium energy spectrum in 10 - 1000 GeV









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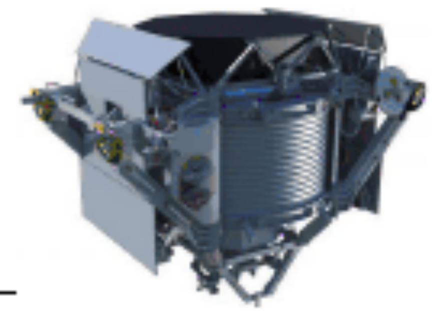

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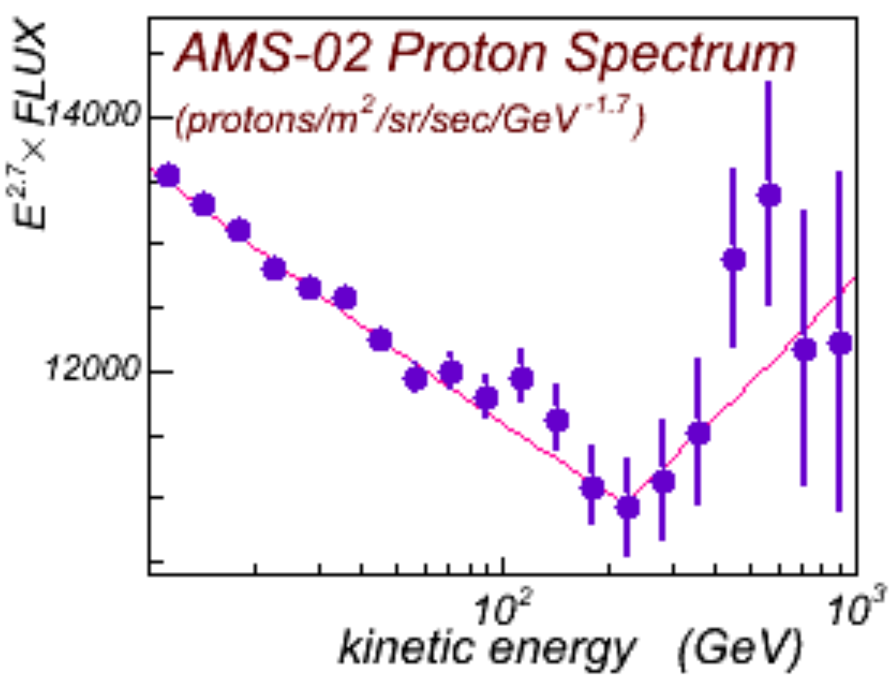
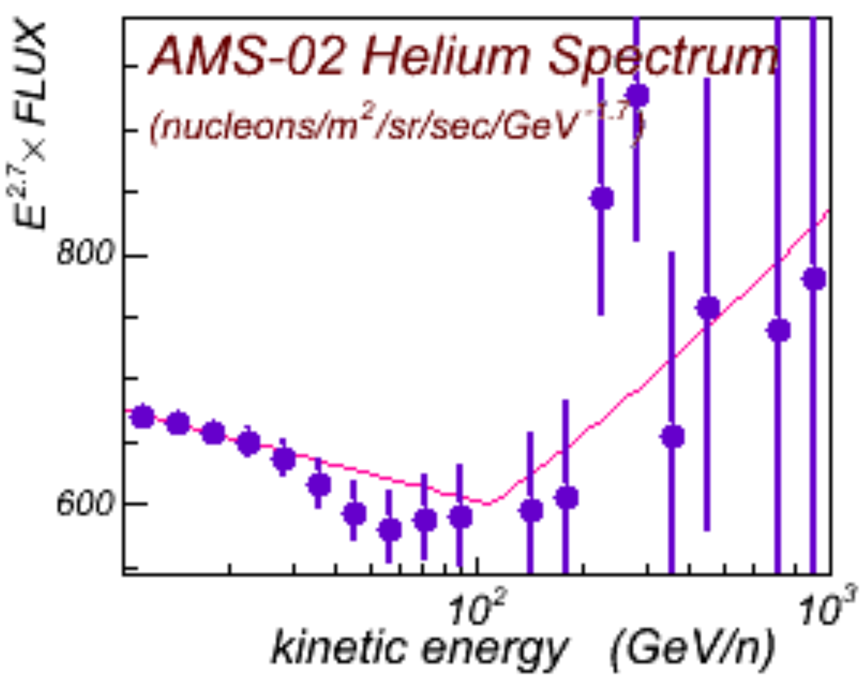
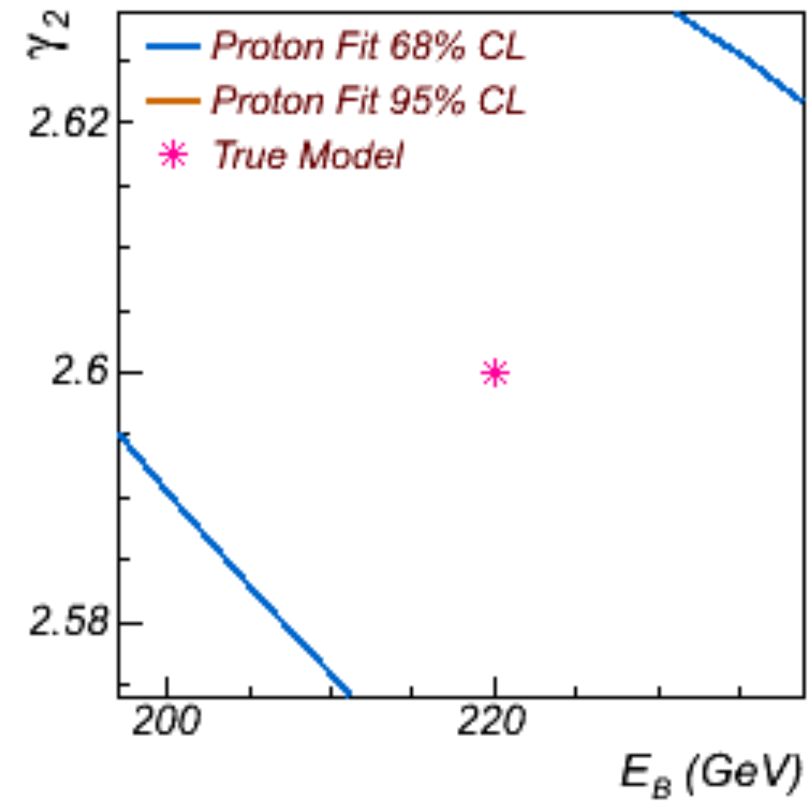
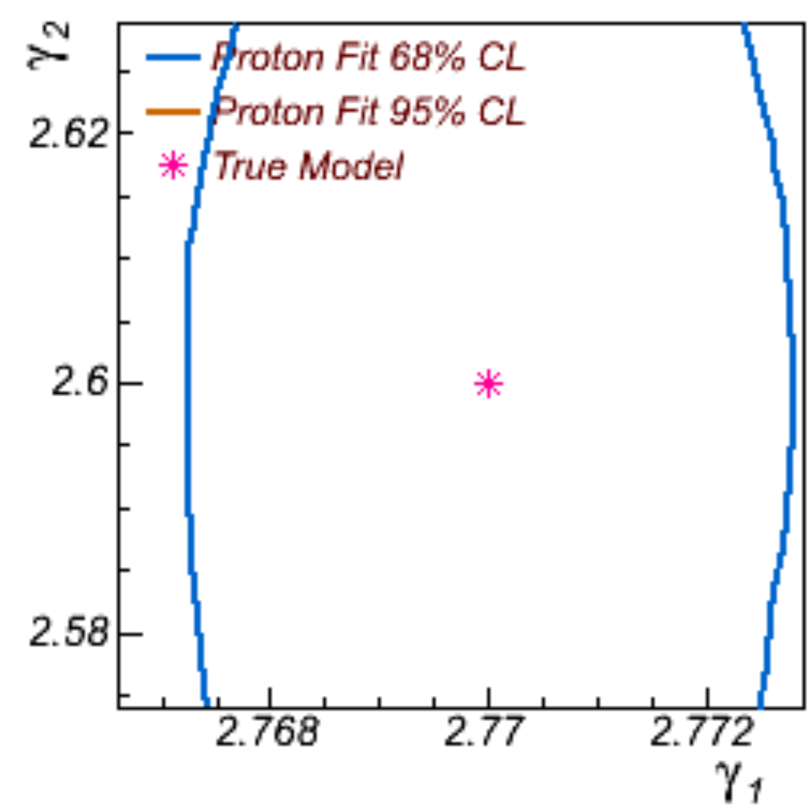




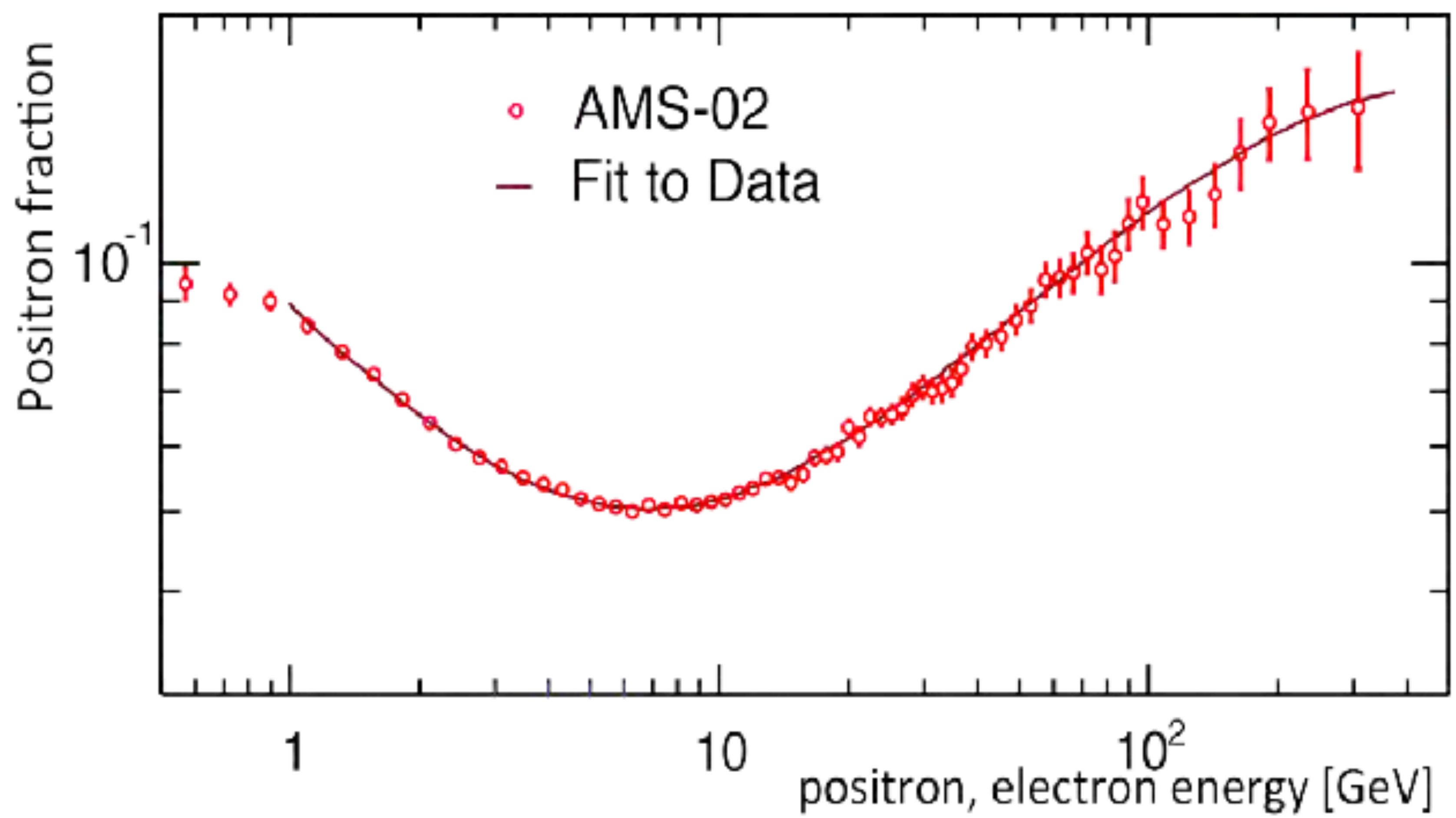




AMS Results

— positron fraction spectrum

- Time independent
- No anisotropy



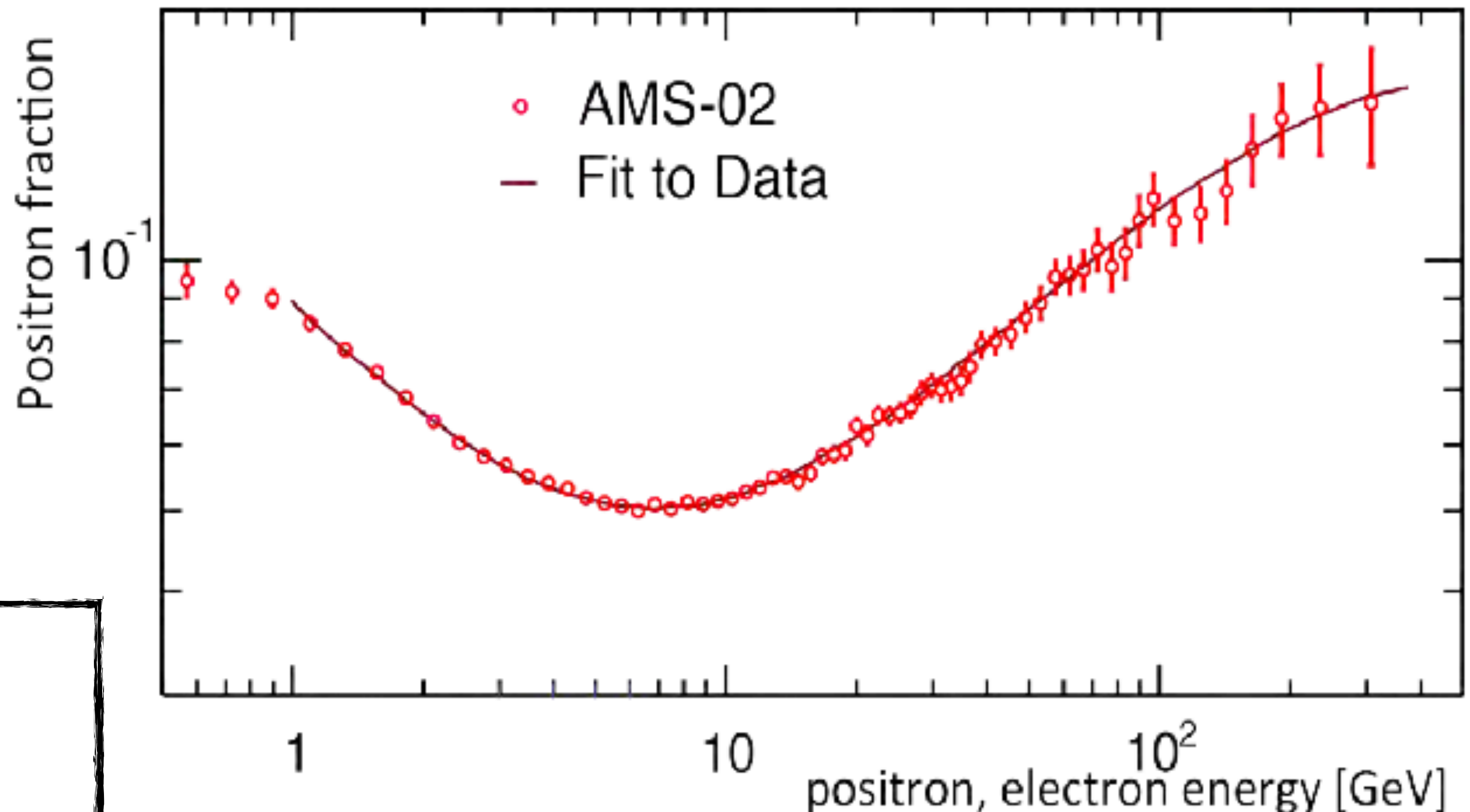
AMS-02 Collaboration, 2013

Positron fraction: ratio of the positron flux to the combined flux of positrons and electrons

AMS Results
— positron fraction spectrum

- Time independent
- No anisotropy

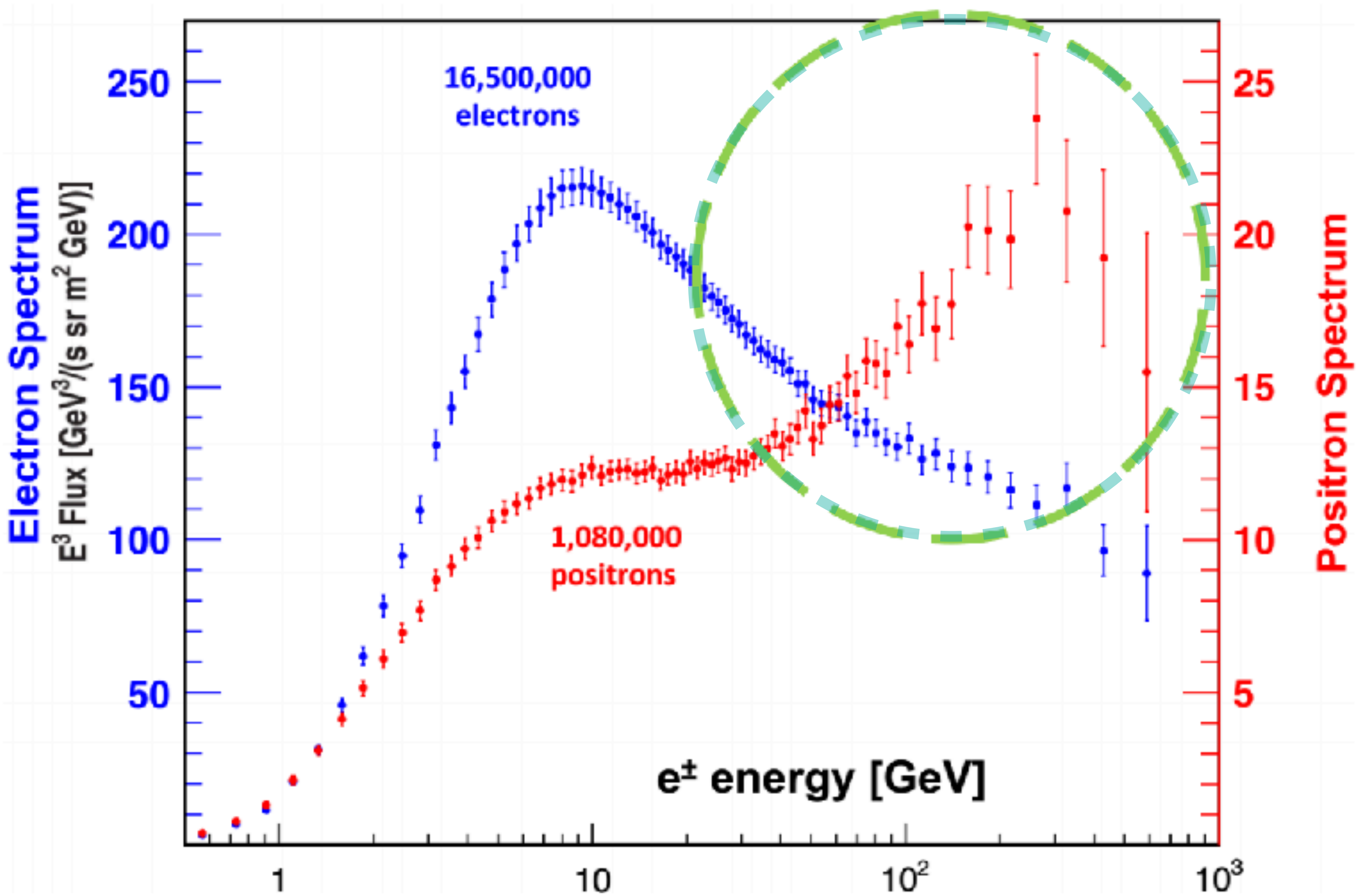
Evidence of a new physics phenomena: **consistent with the positrons originating from the annihilation of dark matter particles in space**



AMS-02 Collaboration, 2013

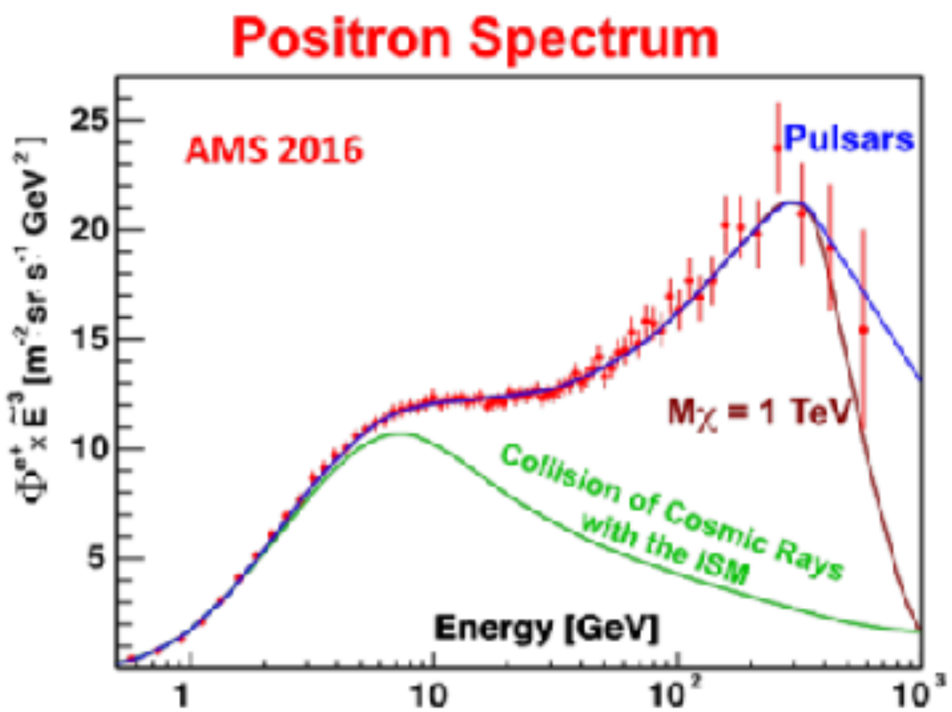
Positron fraction: ratio of the positron flux to the combined flux of positrons and electrons

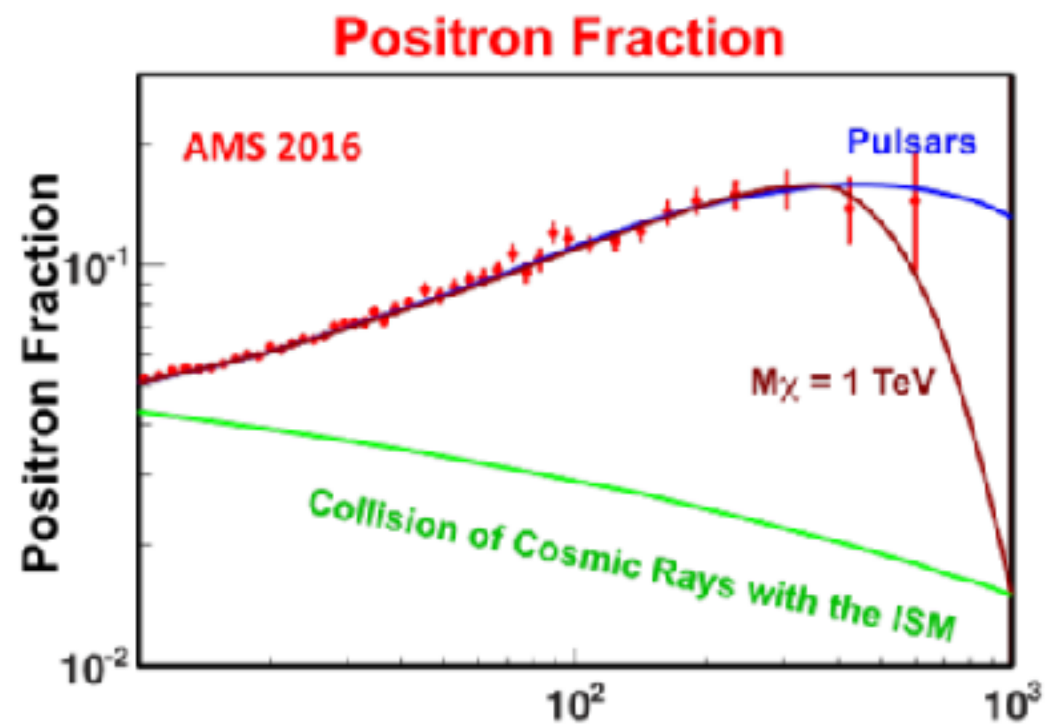
AMS Results — positron excess

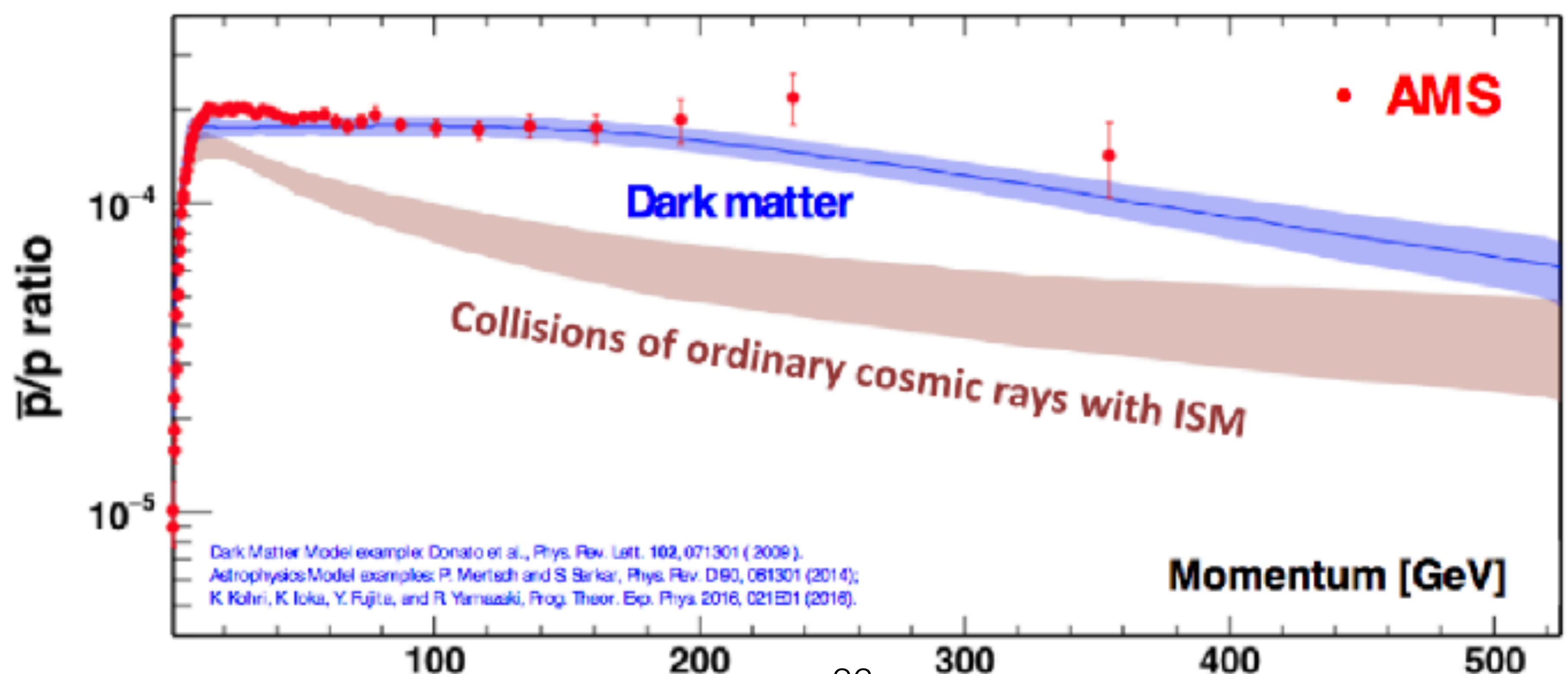


AMS-02 Collaboration, 2016

AMS Results
— dark matter or other explanation

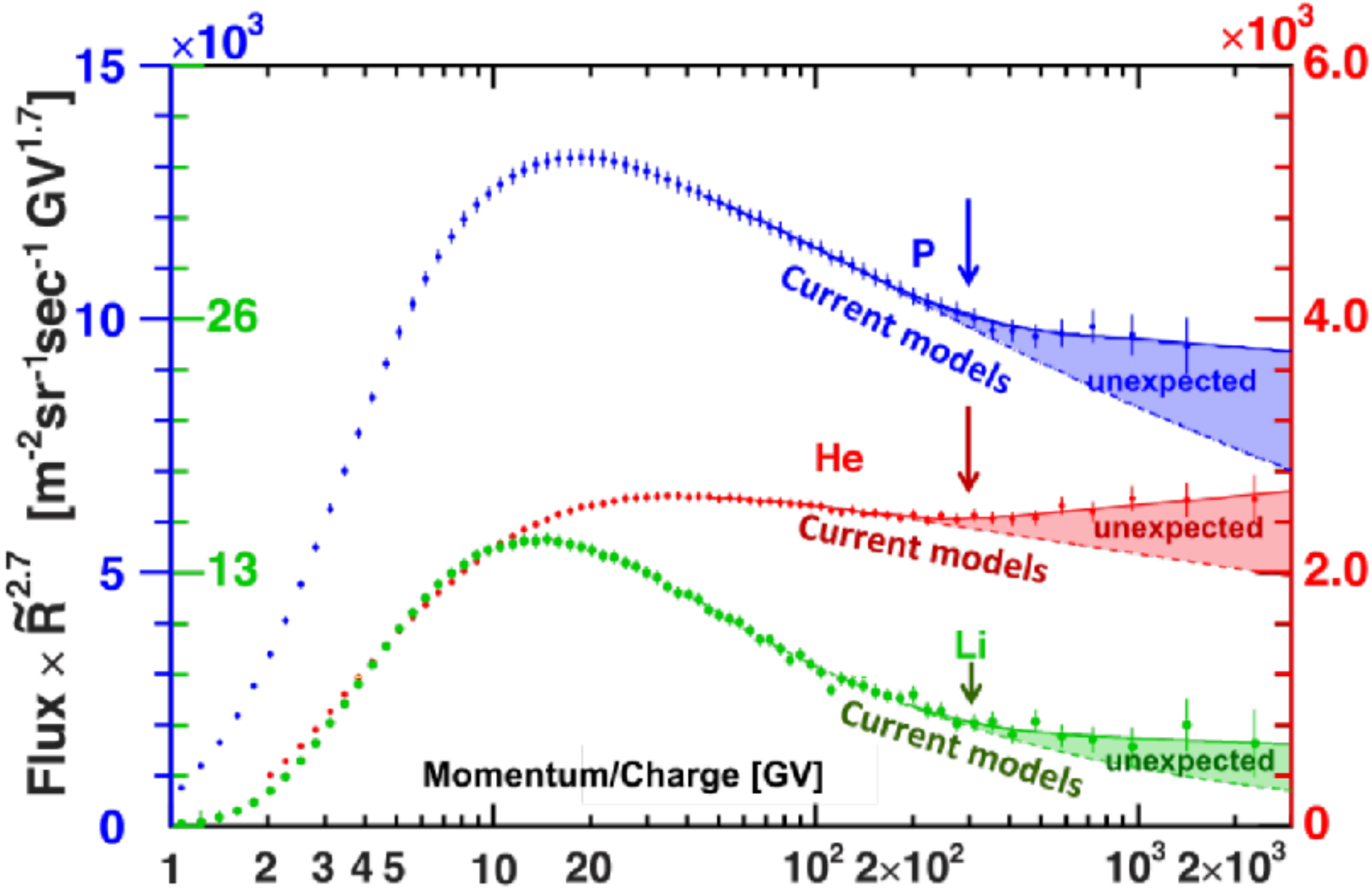






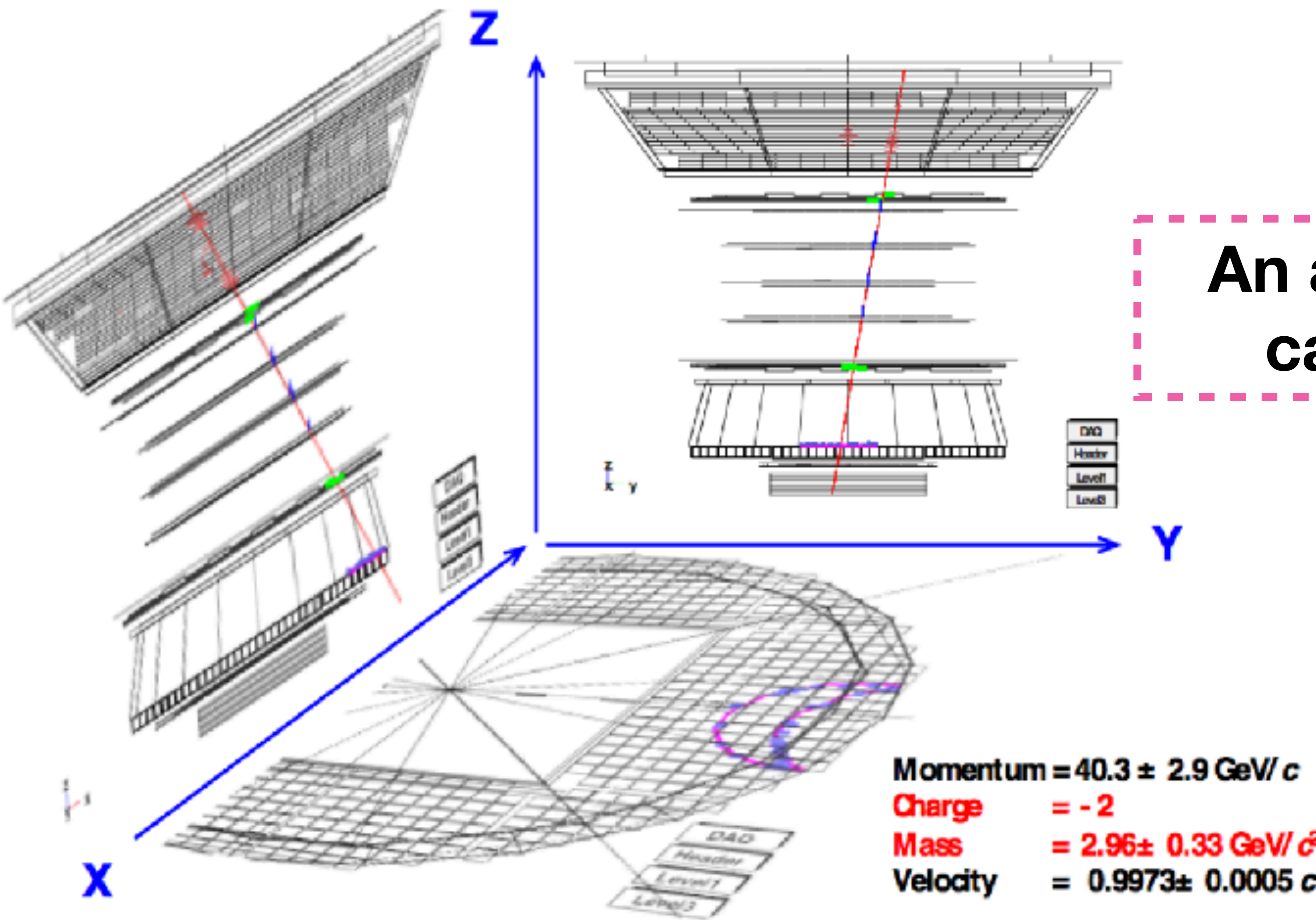
AMS-02 Collaboration, 2016

AMS Results
— nuclei in Cosmic Rays



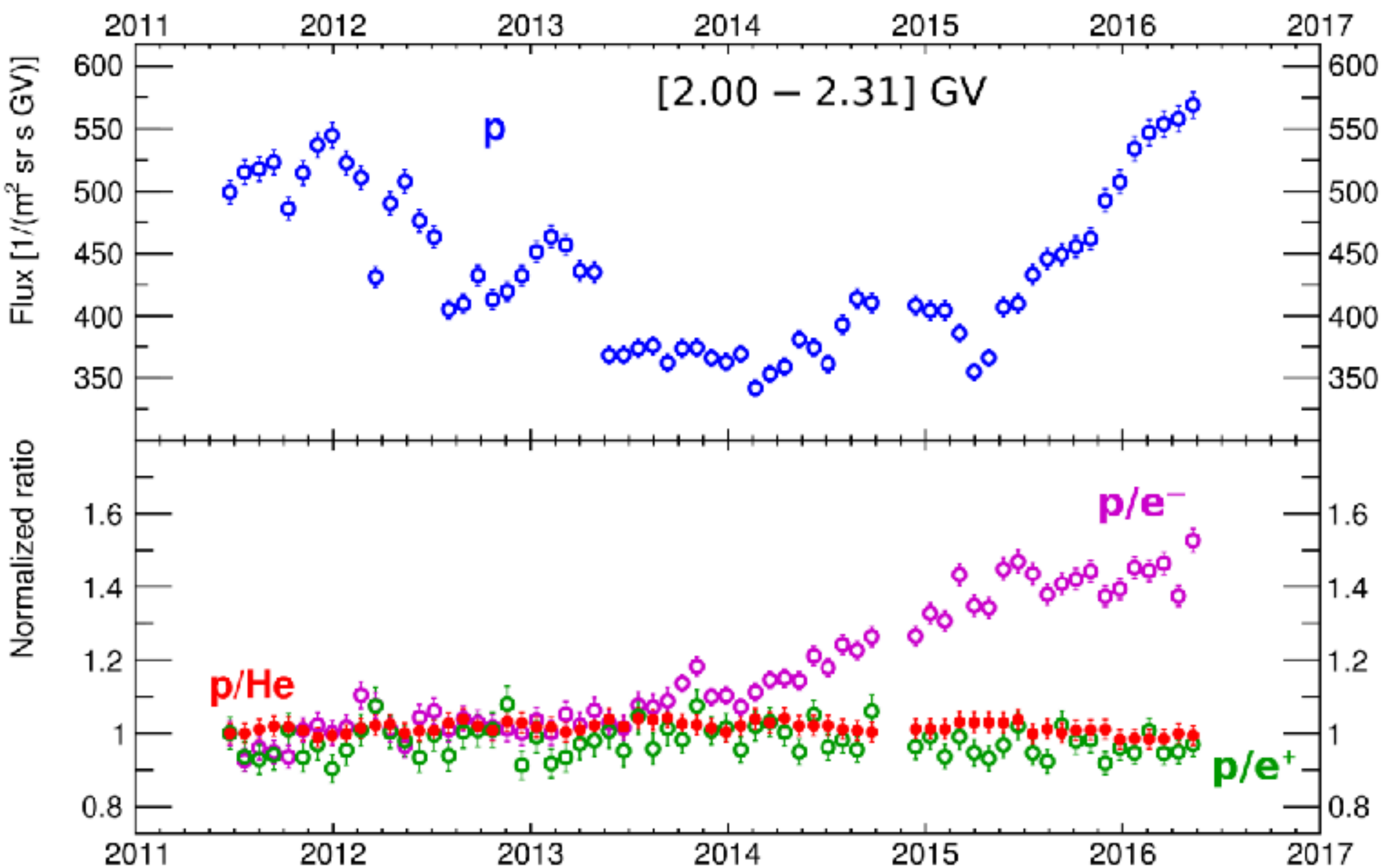
AMS-02 Collaboration, 2015

AMS Results — antimatter search



An antihelium candidate

AMS Results — about solar physics

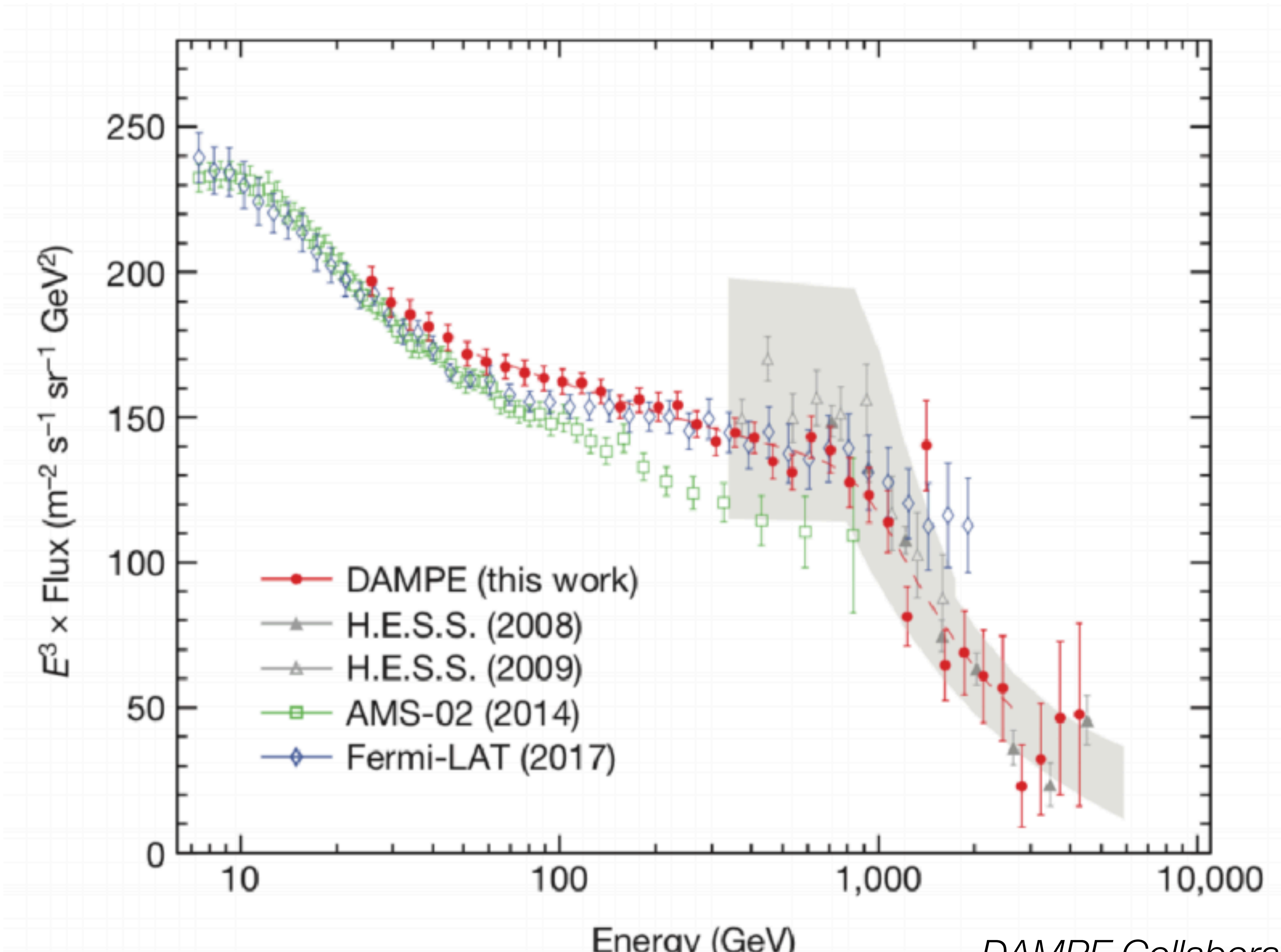


AMS-02 Collaboration, 2016

AMS-02 Publications

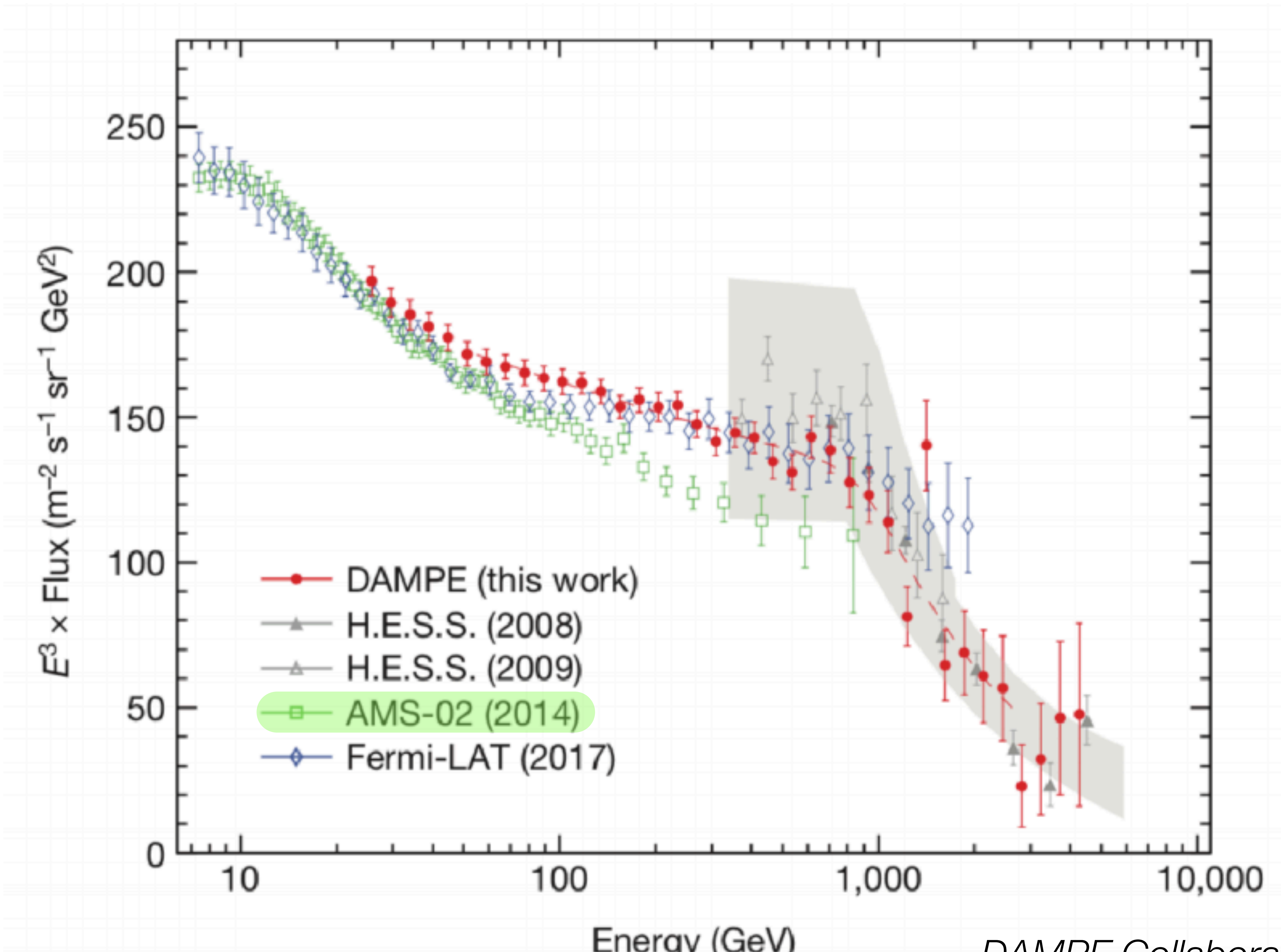
#	Title	Details	arXiv e-Print	Link	Download
01	**"First Result from the Alpha Magnetic Spectrometer on the International Space Station: Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–350 GeV"**	Phys. Rev. Lett. **110**, 141102 (2013)			
02	**"Electron and Positron Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station"**	Phys. Rev. Lett. **113**, 121102 (2014)			
03	**"High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5–500 GeV with the Alpha Magnetic Spectrometer on the International Space Station"**	Phys. Rev. Lett. **113**, 121101 (2014)			
04	**"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**, 221102 (2014)			
05	**"Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station"**	Phys. Rev. Lett. **114**, 171103 (2015)			
06	**"Precision Measurement of the Helium Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station"**	Phys. Rev. Lett. **115**, 211101 (2015)			
07	**"Antiproton Flux, Antiproton-to-Proton Flux Ratio, and Properties of Elementary Particle Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station"**	Phys. Rev. Lett. **117**, 091103 (2016)			
08	**"Precision Measurement of the Boron to Carbon Flux Ratio in Cosmic Rays from 1.9 GV to 2.6 TV with the Alpha Magnetic Spectrometer on the International Space Station"**	Phys. Rev. Lett. **117**, 231102 (2016)			
09	**"Observation of the Identical Rigidity Dependence of He, C, and O Cosmic Rays at High Rigidities by the Alpha Magnetic Spectrometer on the International Space Station"**	Phys. Rev. Lett. **119**, 251101 (2017)			
10	**"Observation of New Properties of Secondary Cosmic Rays Lithium, Beryllium, and Boron by the Alpha Magnetic Spectrometer on the International Space Station"**	Phys. Rev. Lett. **120**, 021101 (2018)			

Compare with other projects



DAMPE Collaboration

Compare with other projects



DAMPE Collaboration

Summary

- The scientific goal of AMS is to study the fundamental problems in our Universe (Antimatter, Dark matter, Strangelets, Cosmic rays).
- The “state-of-the-art” design is shown as a sophisticated and amazing scientific detector on ISS.
- Many precise measurement of different particles in space has been done and find important features from those spectrum.
- The excess of positron is consistent with the positrons originating from the annihilation of dark matter particles in space. (Though not yet sufficiently conclusive to rule out other explanations) And other results from AMS give hints to new physics as well.

References

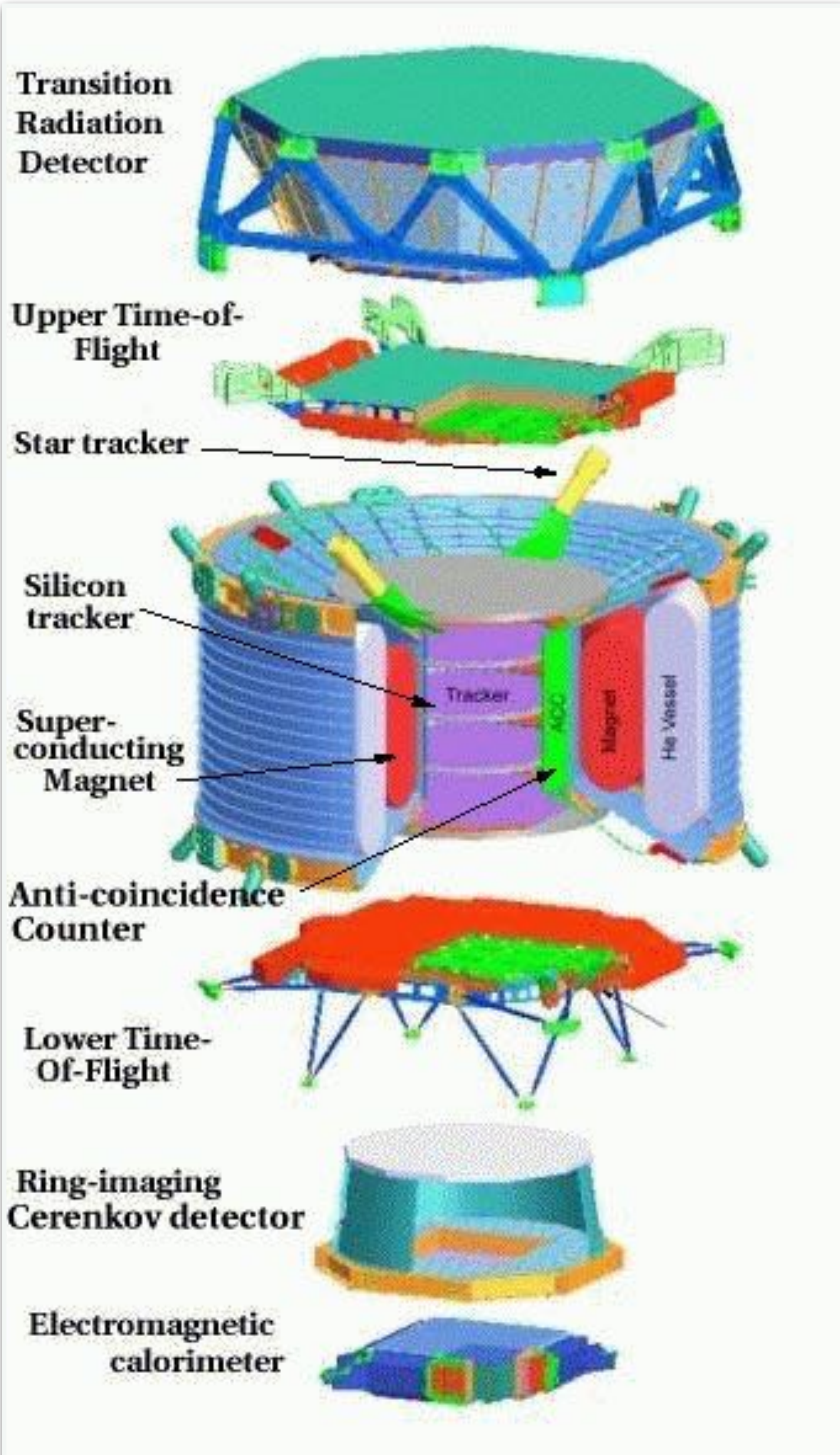
- http://www.ams02.org/
- http://cyclo.mit.edu/ams/
- “First Result from the Alpha Magnetic Spectrometer on the International Space Station : Precision Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-350 GeV”, M. Aguilar et al., Phys. Rev. Lett. 110, 141102 (2013).
- “High Statistics Measurement of the Positron Fraction in Primary Cosmic Rays of 0.5-500 GeV with the Alpha Magnetic Spectrometer on the International Space Station”, L. Accardo et al., Phys. Rev. Lett. 113, 121101 (2014)
- “Electron and Positron Fluxes in Primary Cosmic Rays Measured with the Alpha Magnetic Spectrometer on the International Space Station”, M. Aguilar et al., Phys. Rev. Lett. 113, 121102 (2014)
- . “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”, M. Aguilar et al., Phys. Rev. Lett. 113, 221102 (2014).
- “Precision Measurement of the Proton Flux in Primary Cosmic Rays from Rigidity 1 GV to 1.8 TV with the Alpha Magnetic Spectrometer on the International Space Station”, M. Aguilar et al., Phys. Rev. Lett. 114, 171103 (2015)
- “Precision Measurement of the Helium Flux in Primary Cosmic Rays of Rigidities 1.9 GV to 3 TV with the Alpha Magnetic Spectrometer on the International Space Station”, M. Aguilar et al., Phys. Rev. Lett., 115, 211101 (2015) .
- “Observation of New Properties of Secondary Cosmic Rays Lithium, Beryllium, and Boron by the Alpha Magnetic Spectrometer on the International Space Station”, M. Aguilar et al., Phys. Rev. Lett. **120**, 021101 (2018)
- Several items on Wikipedia.

Thank you!

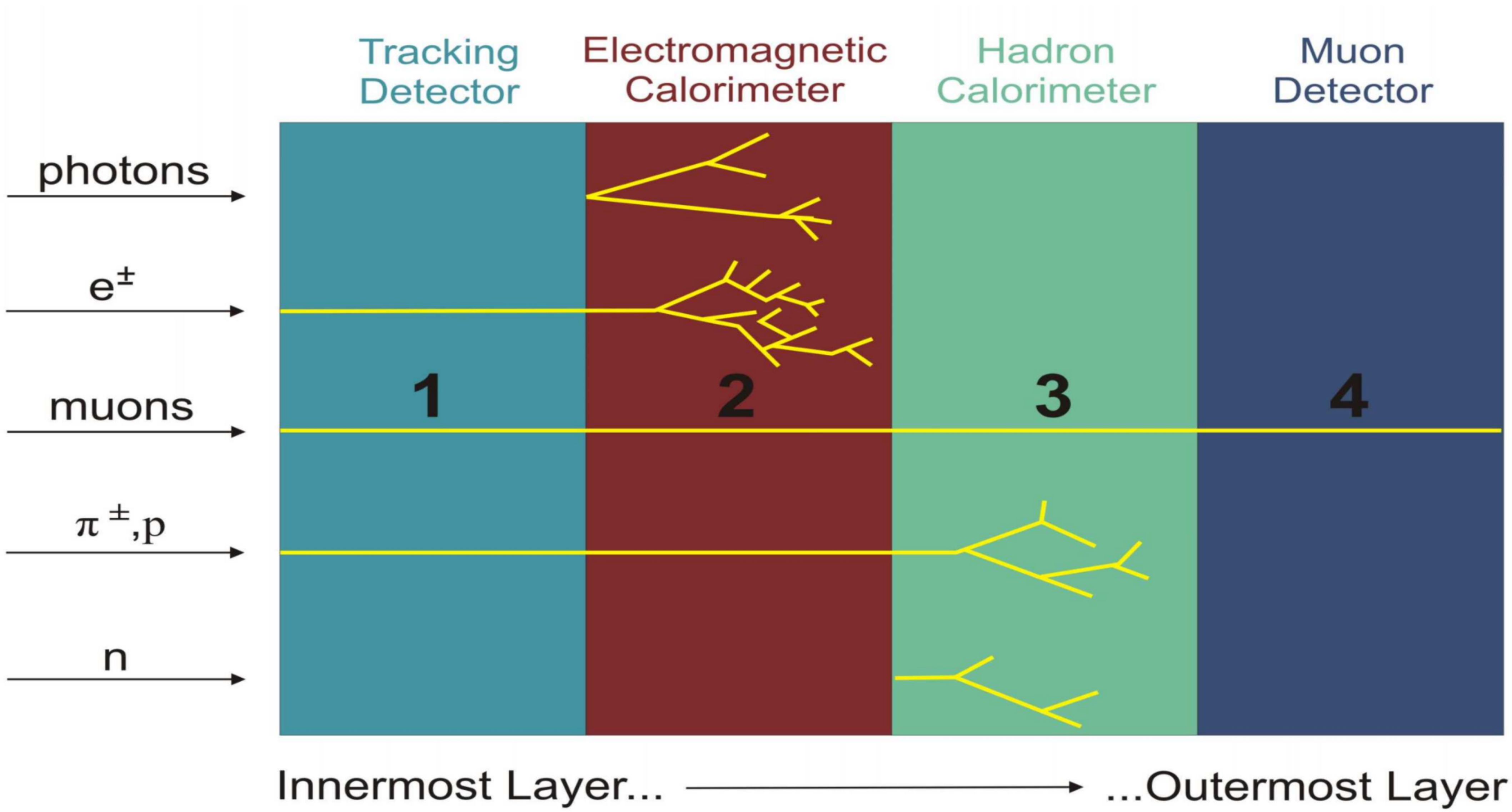
Backup Slides

Detailed designs of AMS-02

- On top of AMS, a **transition radiation detector** tells us the velocities the highest–energy particles.
- The **silicon tracker** follows a particle's path through the instrument.
- A **superconducting magnet** makes the particle's path curve.
- Two **time–of–flight counters** tell us lower–energy particles' speeds.
- Two **star tracker cameras** measure AMS's orientation in space.
- Underneath AMS, a **ring–imaging Cerenkov detector** makes an extremely–accurate velocity measurement for fast particles.
- Some particles crash violently into the **electromagnetic calorimeter**, which measures their energy and type.
- An anti–coincidence veto counter notices stray particles sneaking through AMS sideways.

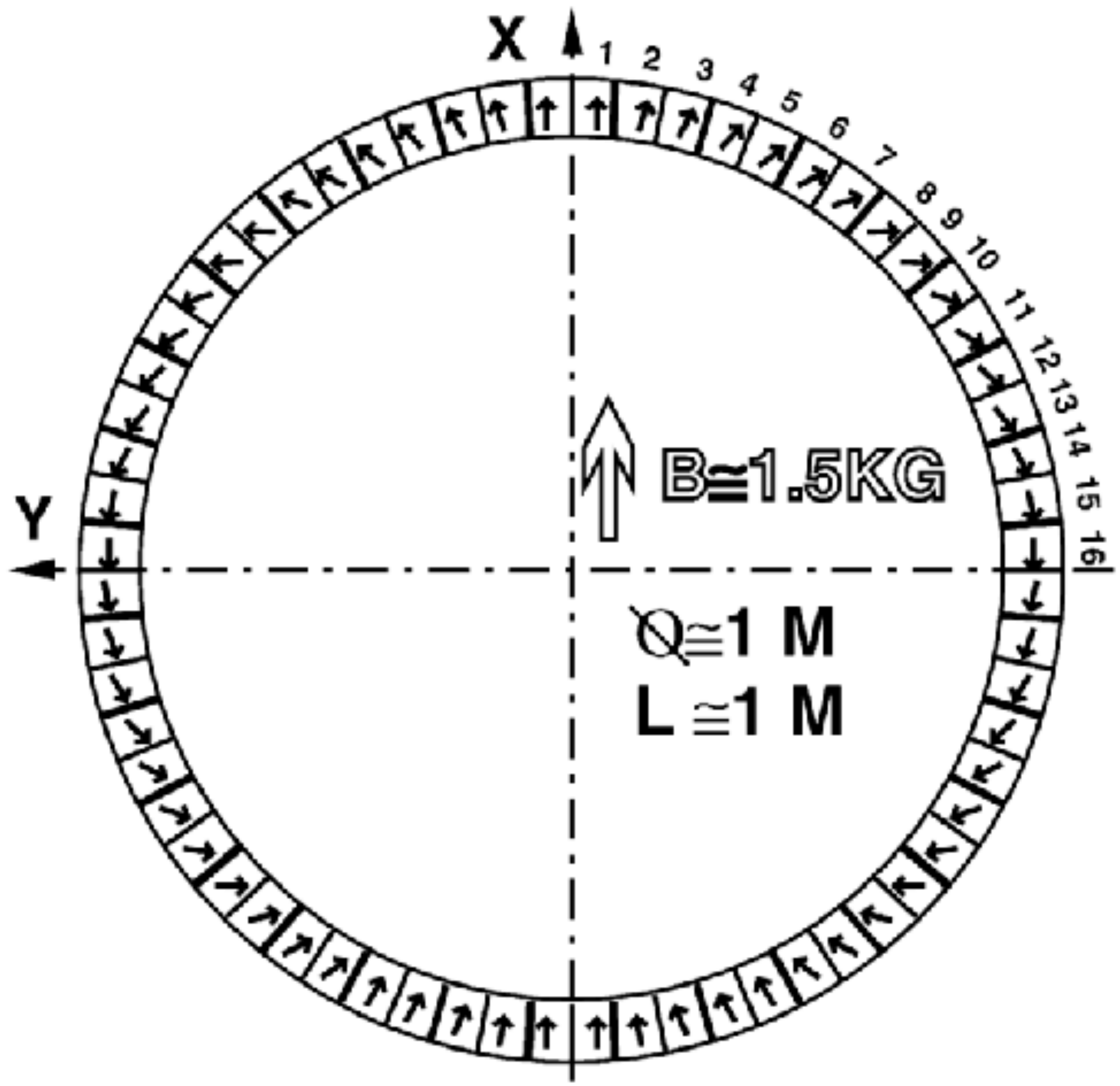


Example of particle identification



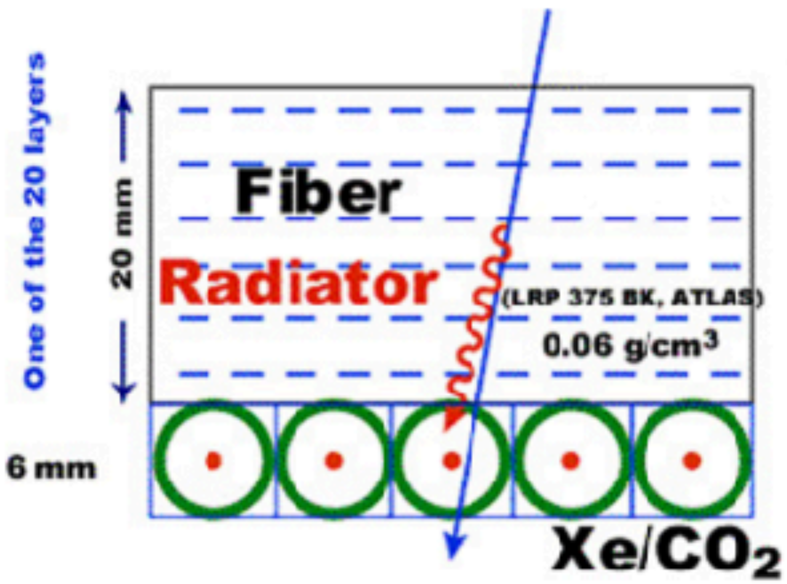
AMS

Magnetic Field



TRD

- How the detector works



At low energies, the TRD sees a small difference between an electron and a proton: At high energies, the electron will emit X-rays while crossing the detector, and the proton will not. The X-rays are generated whenever the particle crosses an "interface" – in this case, the interface between a piece of plastic and a vacuum. Each particle passes through many hundreds of interfaces when it crosses a batt of plastic cloth or felt.

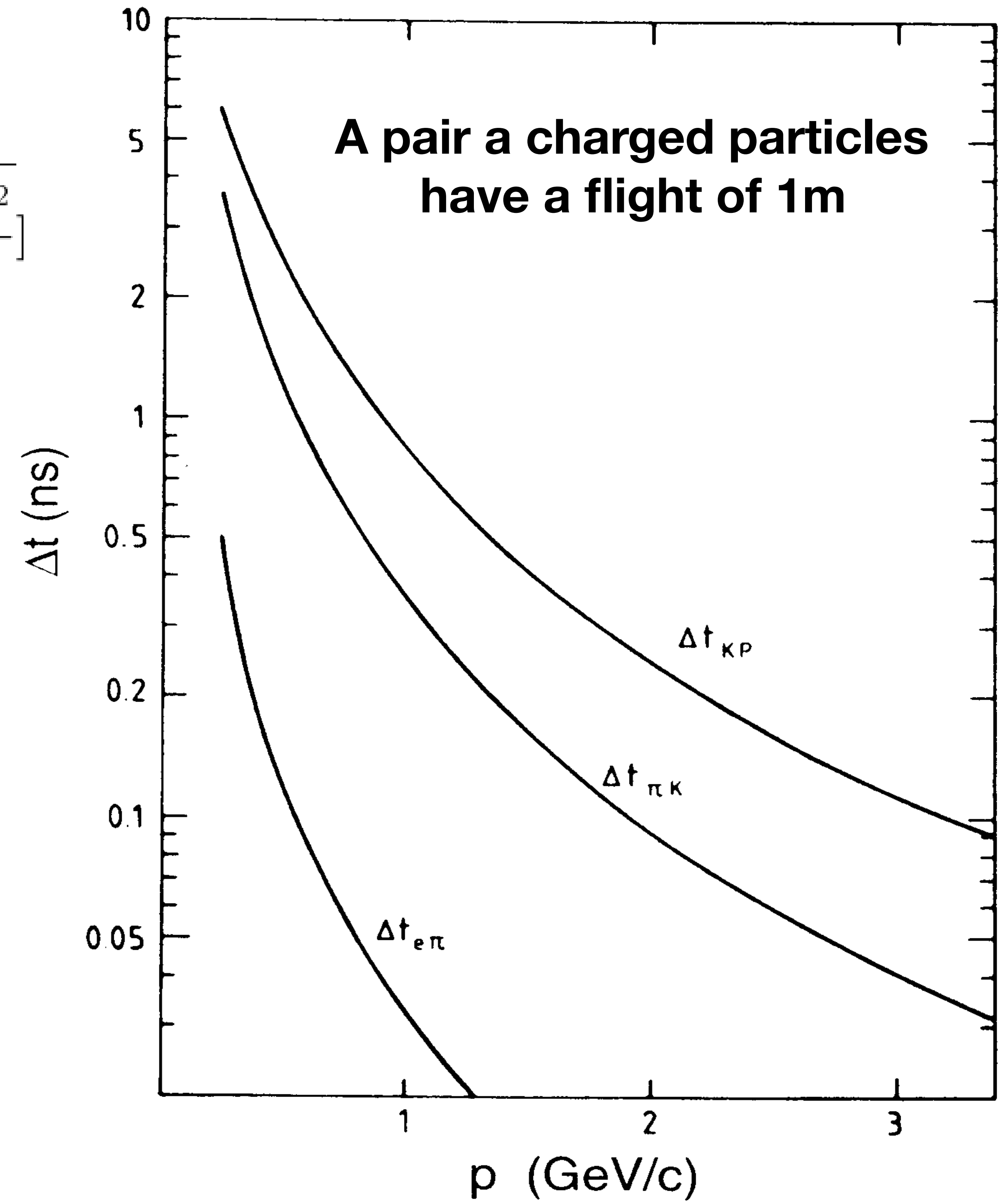
The X-rays pass through the fabric, and they ionize a mixture of gases (Xenon, which is easy to ionize, and CO2, which regulates the size of the signal) in a tube with a high-voltage wire. The ionized gas experiences a little "cascade" – sort of the beginning of a spark – as the free electrons rush towards the high-voltage wire, and the result is a signal that can be read out at the end of the wire. Every particle will make a signal as it passes through, but we will look for the *enhancement* of the signal due to the extra transition-radiation X rays.

Time of Flight(ToF)

$$\Delta t = \frac{L}{\beta_1 c} - \frac{L}{\beta_2 c} = \frac{L}{c}[\sqrt{1 + \frac{m_1^2 c^2}{p^2}} - \sqrt{1 + \frac{m_2^2 c^2}{p^2}}]$$

When v -> c,

$$\Delta t \approx \frac{Lc}{2p^2}({m_1}^2 - {m_2}^2)$$



AMS results —2018

Rigidity:
R = p/q

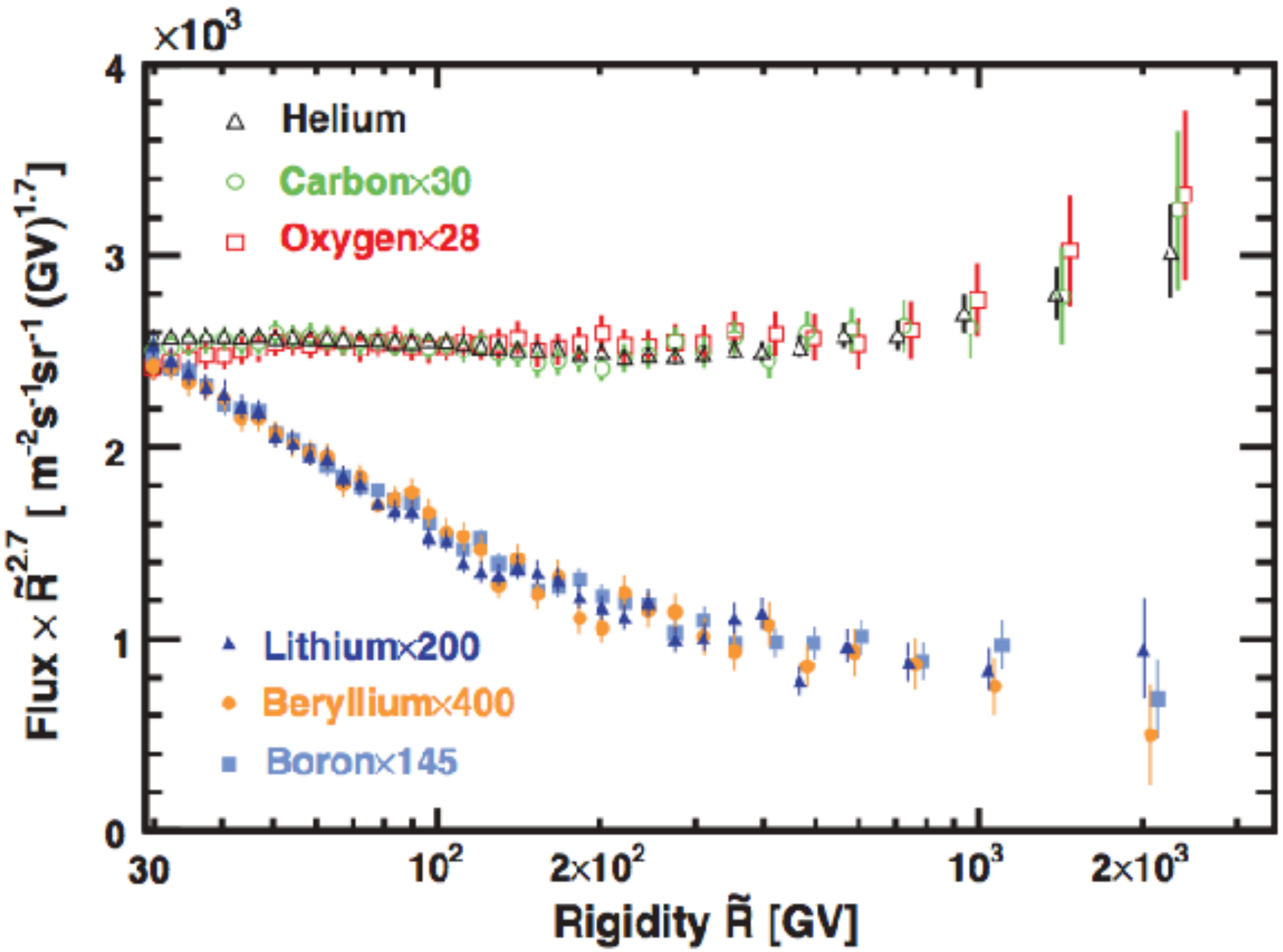


FIG. 4. Comparison of the secondary cosmic ray fluxes [21] with the AMS primary cosmic ray fluxes [14] multiplied by $\tilde{R}^{2.7}$ with their total error as a function of rigidity above 30 GV. For display purposes only, the C, O, Li, Be, and B fluxes were rescaled as indicated. For clarity, the He, O, Li, and B data points above 400 GV are displaced horizontally. As seen, the three secondary fluxes have an identical rigidity dependence above 30 GV, as do the three primary fluxes above 60 GV. The rigidity dependences of primary cosmic rays fluxes and of secondary cosmic rays fluxes are distinctly different.