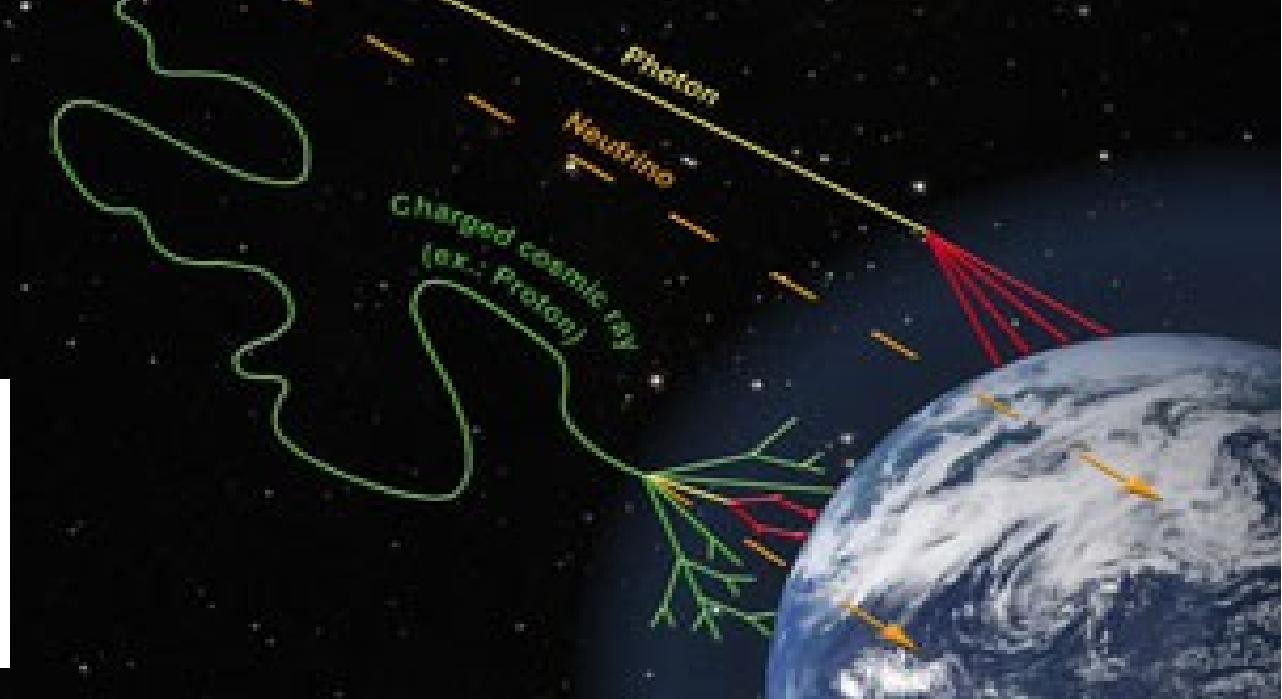




# Dark Matter in Cosmic Rays & The Alpha Magnetic Spectrometer (AMS)

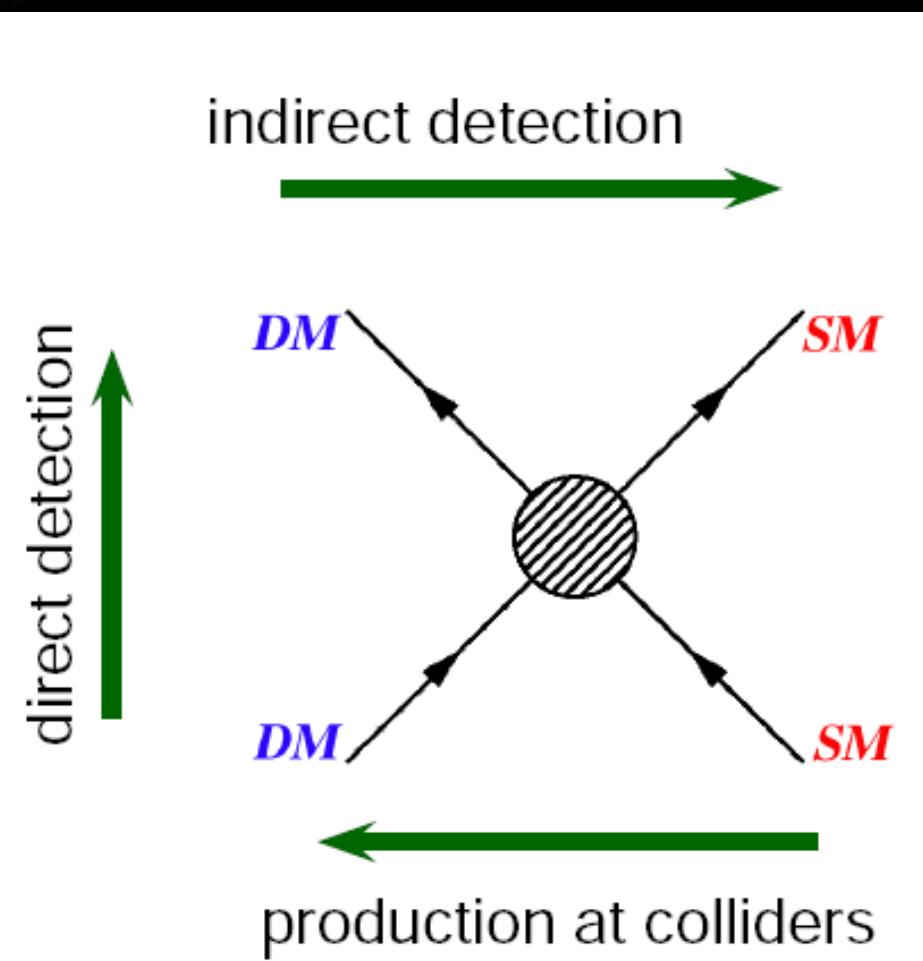
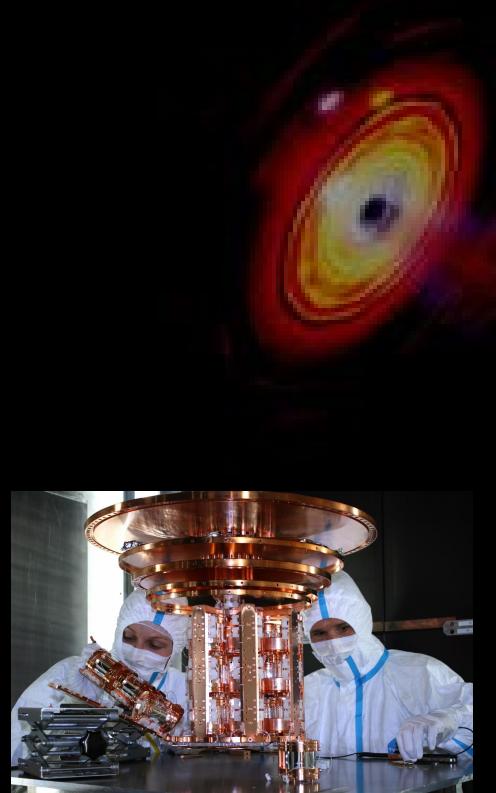
Dr. Matteo Palermo  
University of Hawaii

Quarknet Masterclass  
@ Punahou School





# Dark Matter Searches

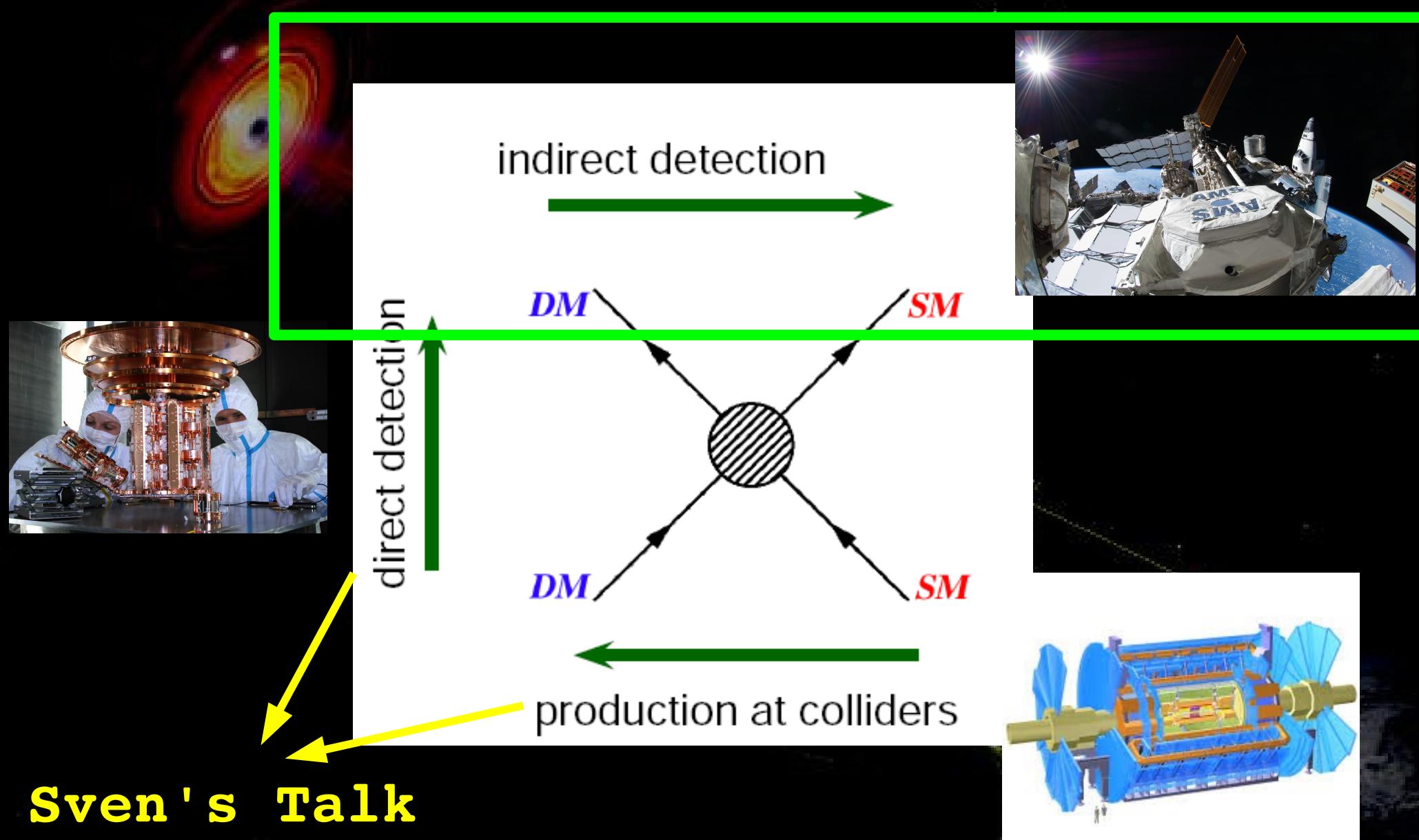




# Dark Matter Searches

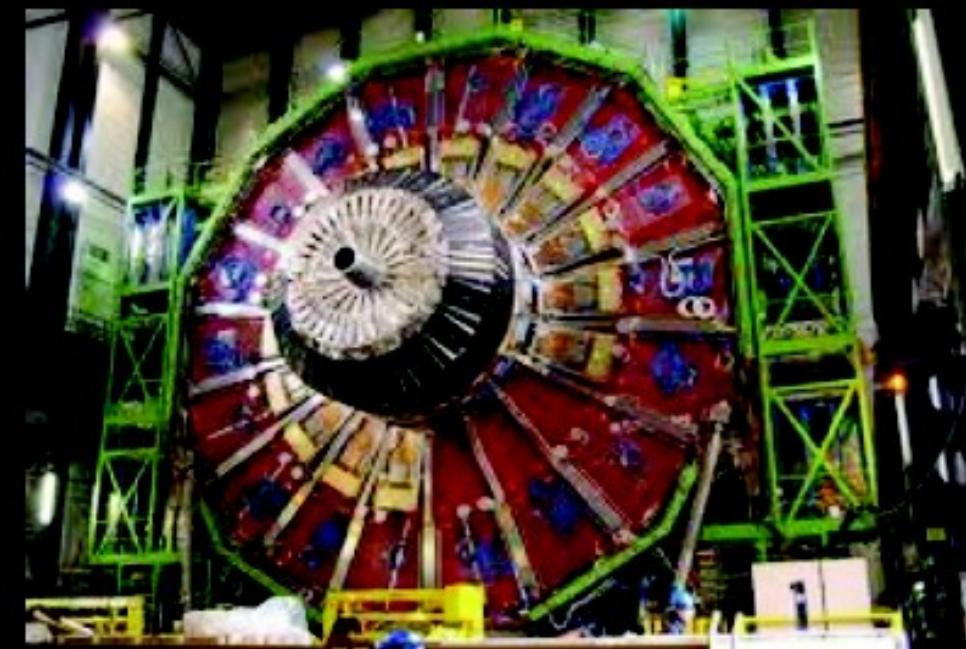


## INDIRECT search



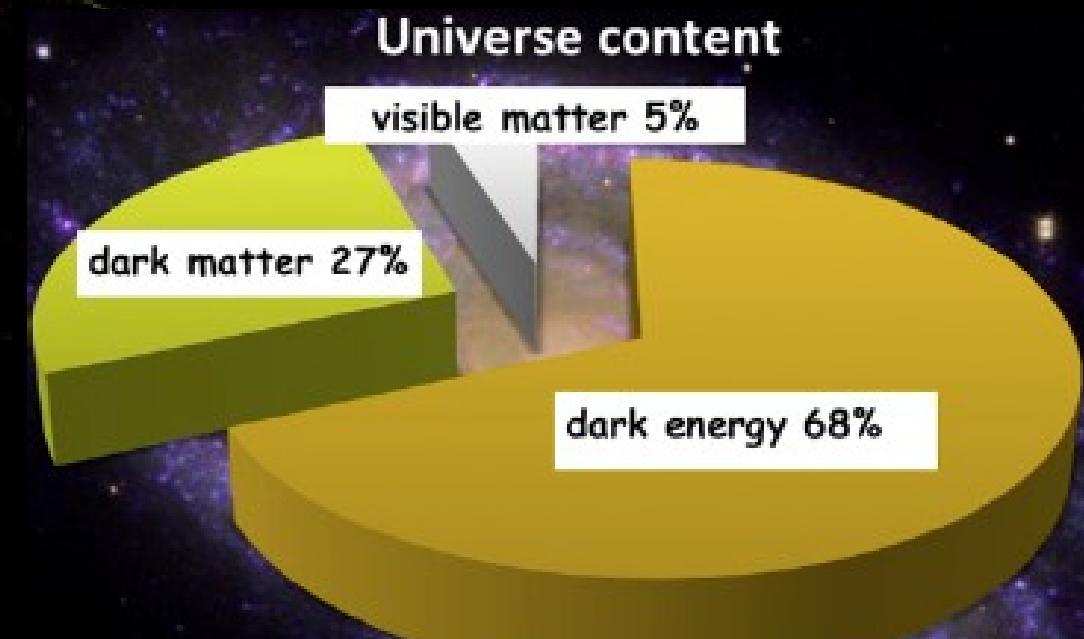


# The Universe: The Most Powerful Accelerator



# Major Questions:

- Are there forms of matter in the Universe that do not exist on Earth?
- Do Anti-Stars or Anti-Galaxies exist?
- What is Dark Matter made of?



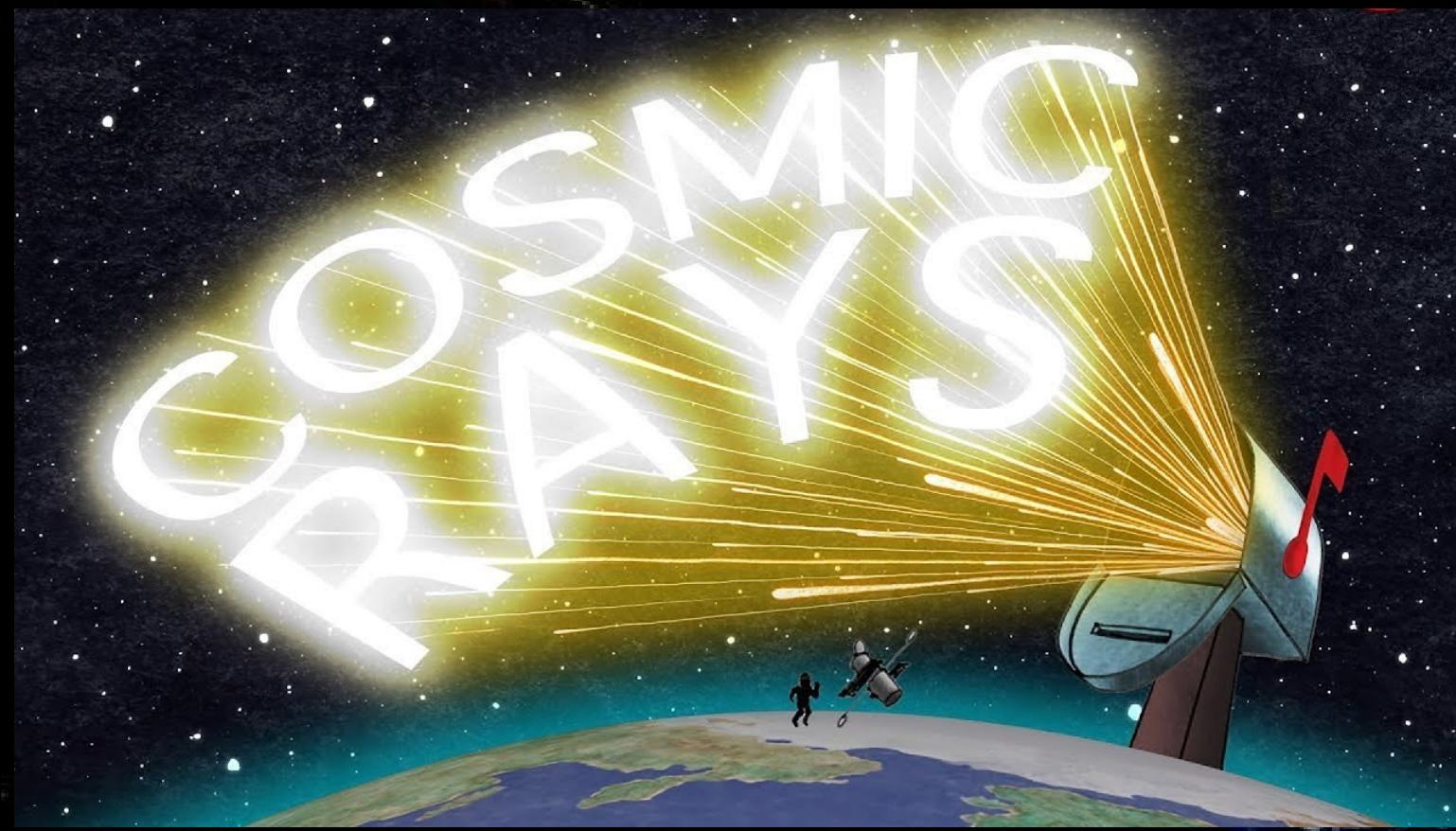


# Answers???





# Cosmic Rays!!!





# What are Cosmic Rays?

...in simple terms



- CRS are tiny particles from outer space
- CRS are invisible to naked eye and carry enormous amount of energy
- CRS travel almost at speed of light.



A Cosmic Ray could zip around the Earth more than 7 times in one second!

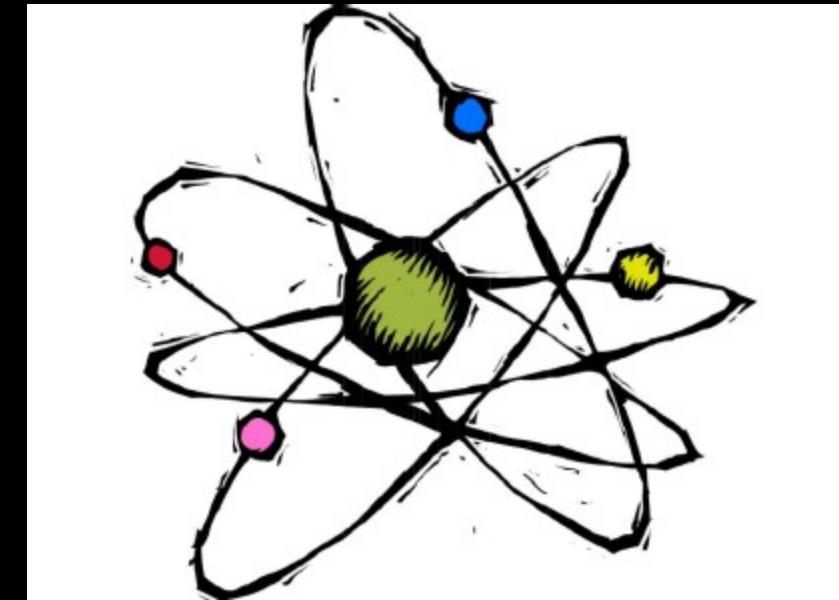




# What are Cosmic Rays?



Neutral particles



Charged particles

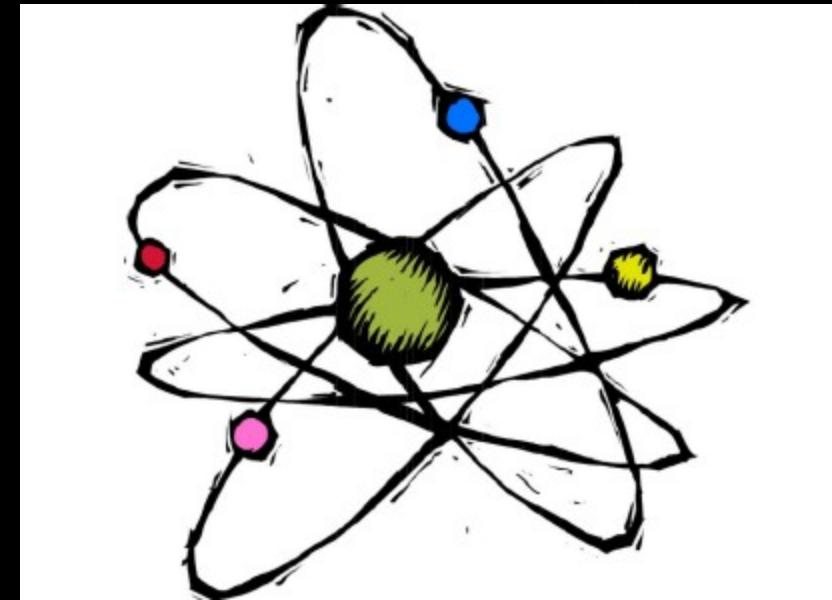




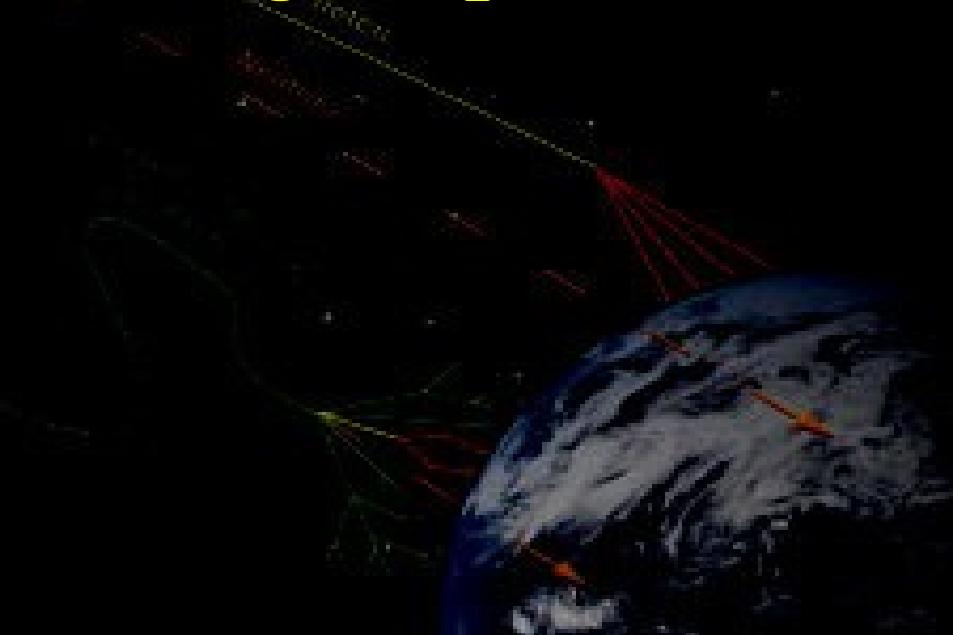
# What are Cosmic Rays?



Neutral particles



Charged particles

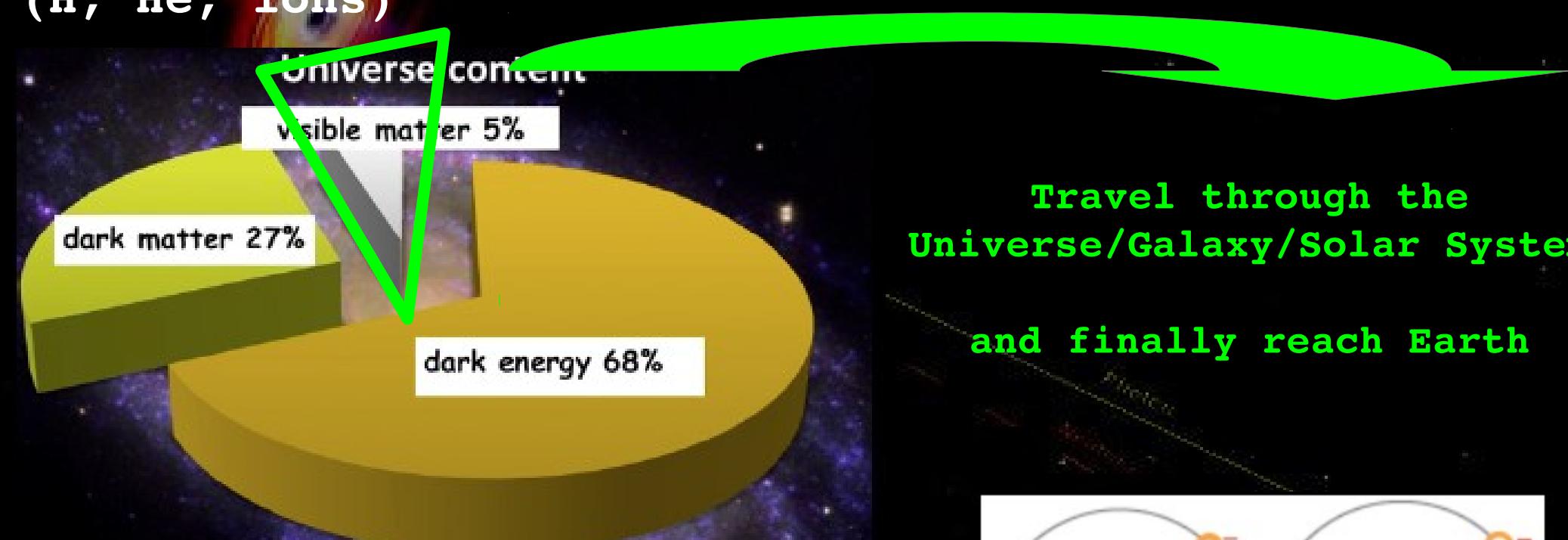




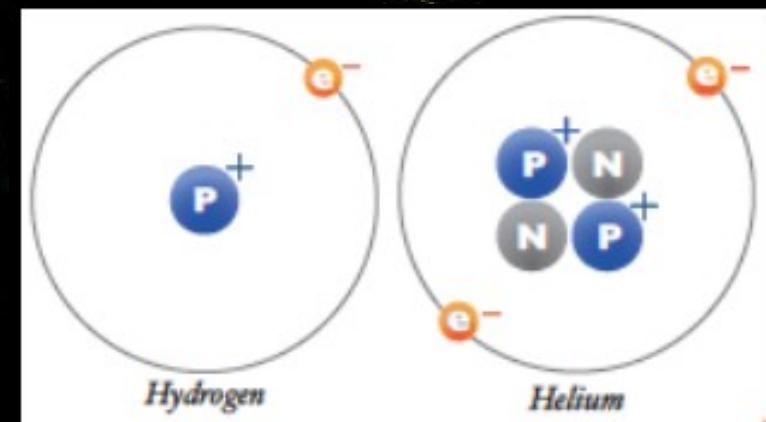
# What are Cosmic Rays?



CRs are mainly charged particles composed of the same subatomic particles that make up all matter on Earth (H, He, ions)



Travel through the  
Universe/Galaxy/Solar System  
and finally reach Earth

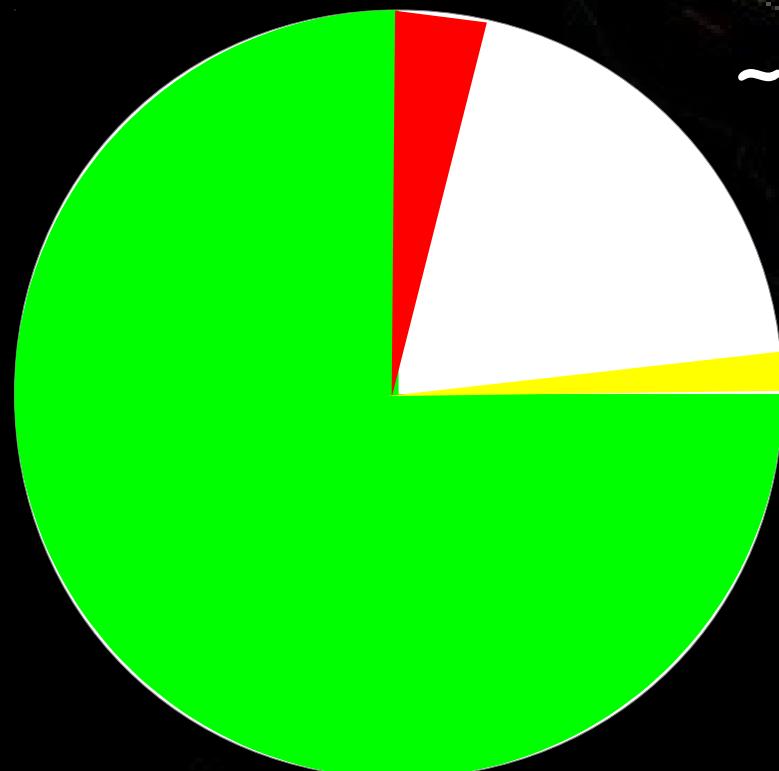




# Cosmic Ray Composition



**~2% Electrons and Antimatter**



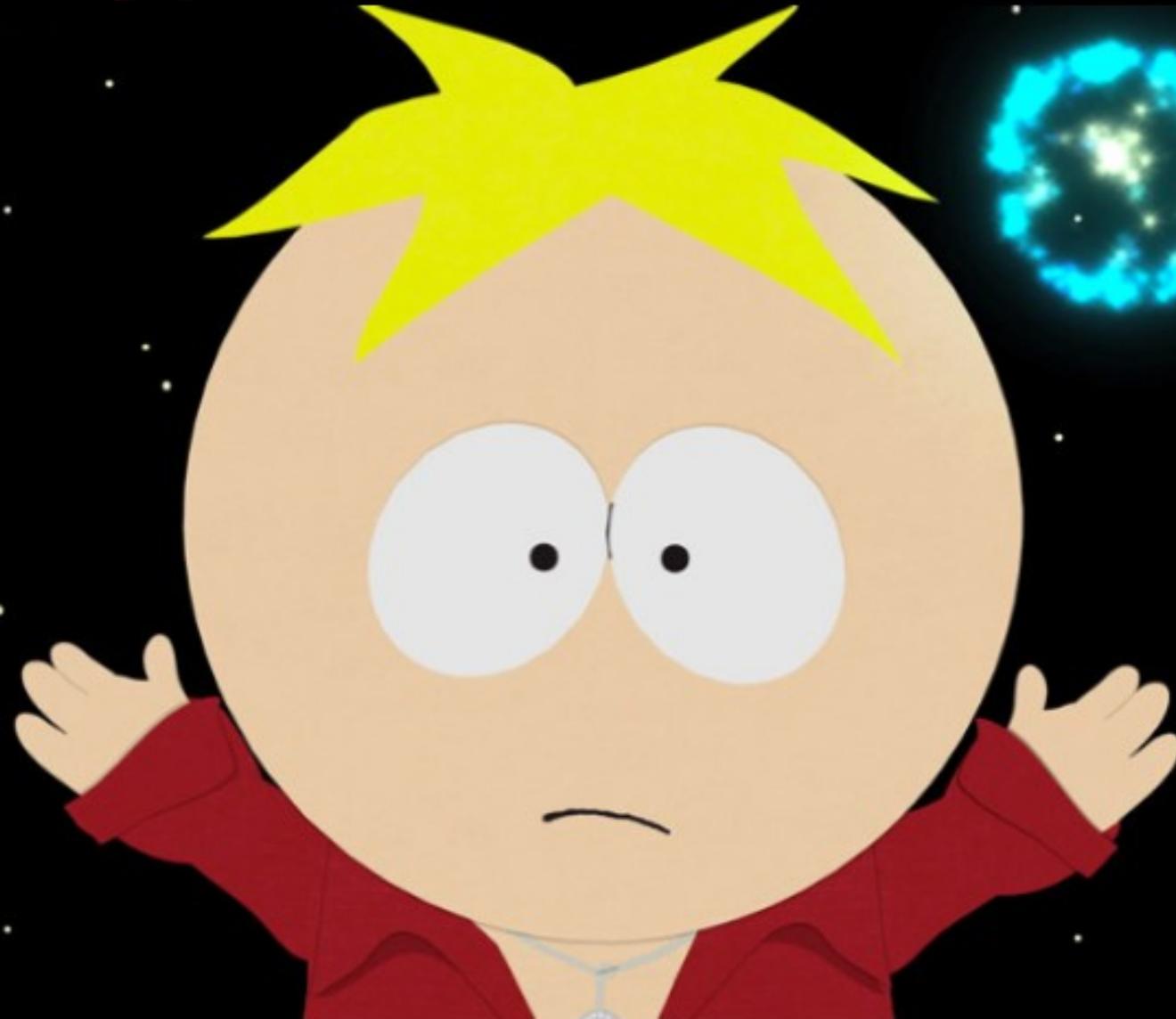
**~12% Helium Nuclei**

**~1% Heavier Nuclei**

**~85% Hydrogen Nuclei  
(protons)**



# Where do CRs come from?





# Where do CRs come from?



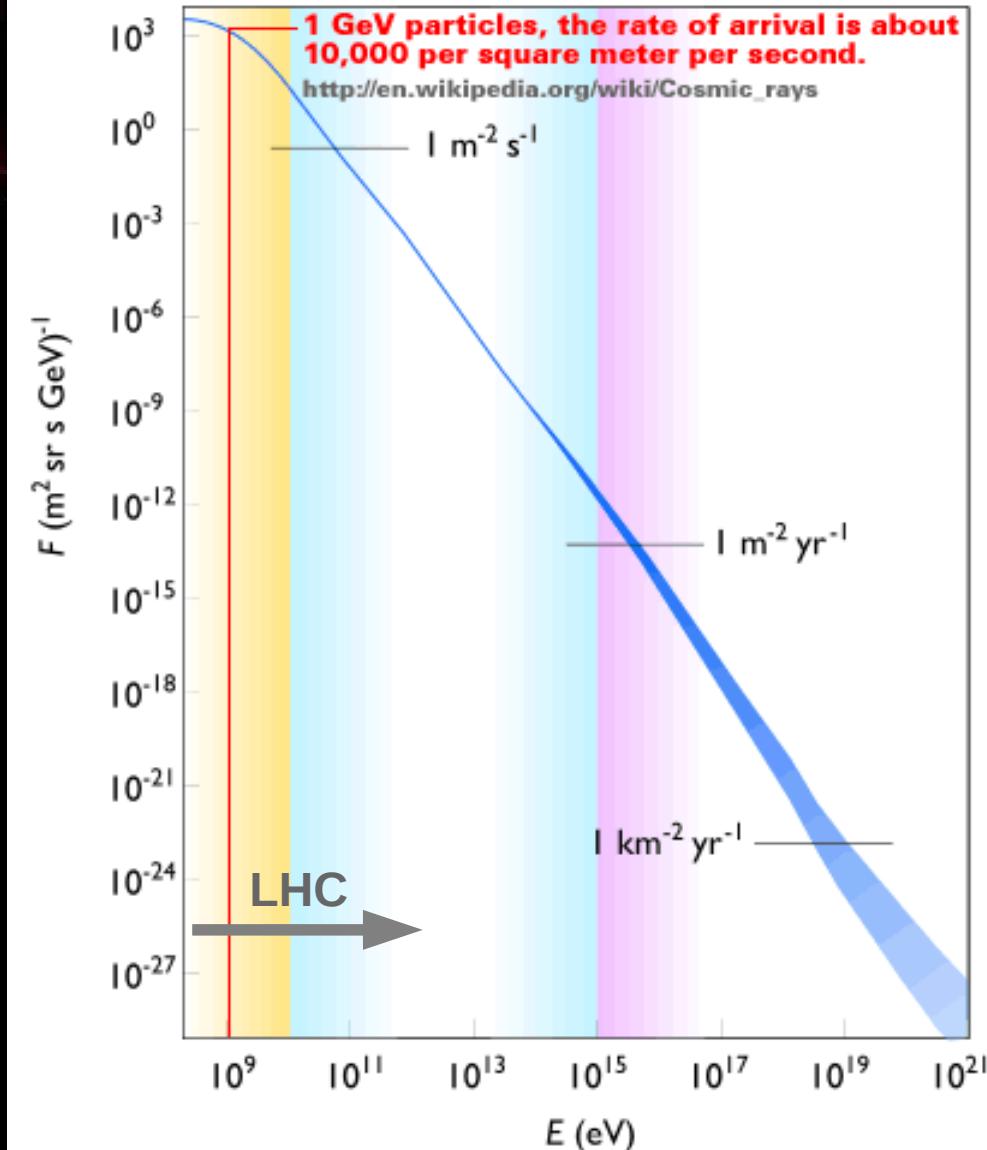
3 main regions:

Solar CR

Galactic CR

Extragalactic CR

## Cosmic Ray Flux versus Particle Energy



**Yellow Zone**  
Mainly attributed to  
Solar cosmic rays

**Blue Zone**  
Mainly attributed to  
Galactic cosmic rays

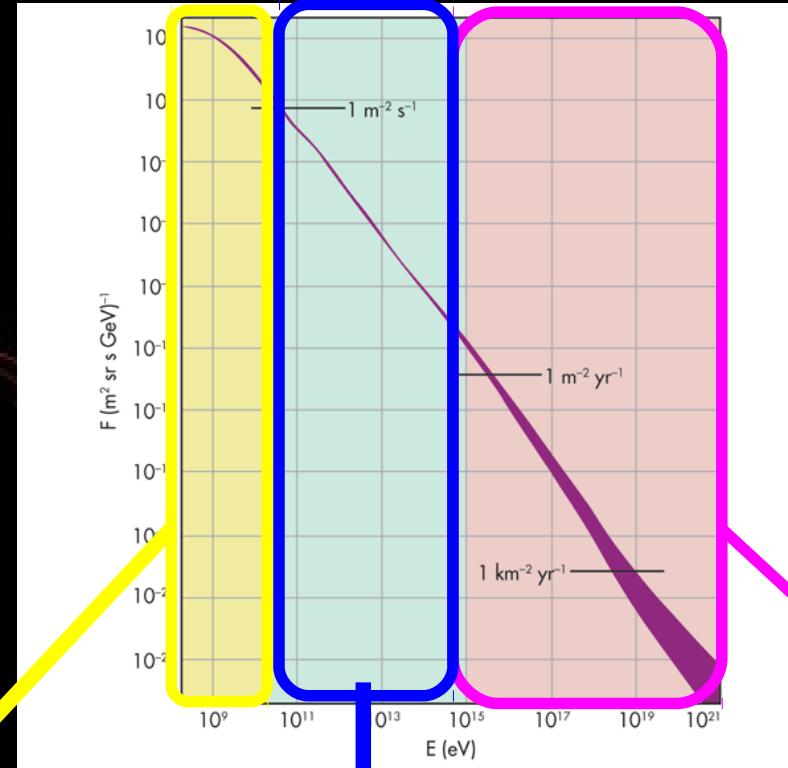
**Purple Zone**  
Mainly attributed to  
Extragalactic cosmic rays

**Flux** – number of arriving particles per (unit area x unit time)  
**eV** – (very small) unit of energy

- one volt times the charge of a single electron
- $1 \text{ eV} = 1.609 \times 10^{-19} \text{ joules}$



# Where do CRs come from?



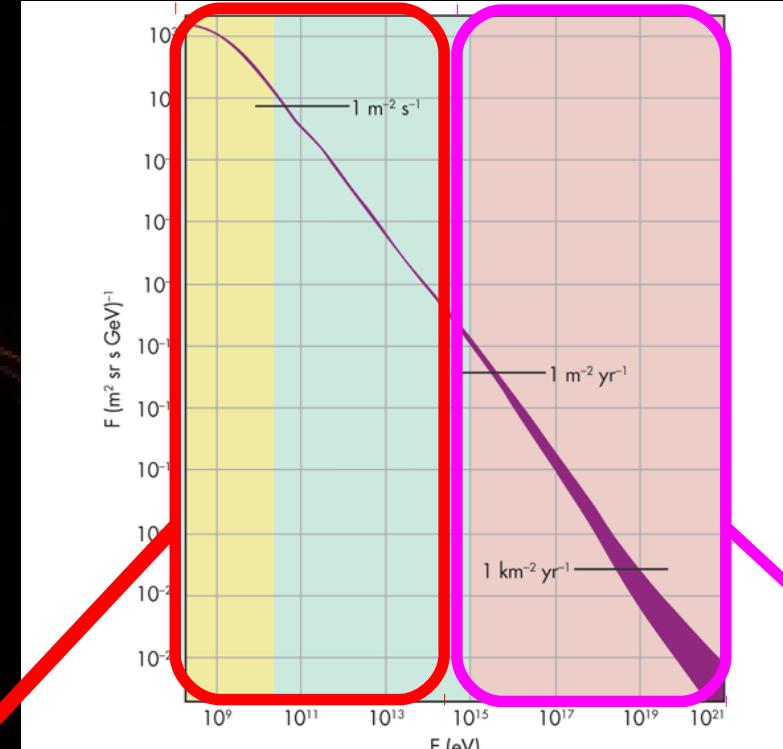
**SOLAR  
origin**

**Galactic  
origin**

**Extragalactic  
origin**



# How do we Detect CRs?



**DIRECT**

**Measurements:**

- **SPACE born**
- **Balloon born**

(Primary Cosmic Rays)

**INDIRECT**

**Measurements:**

- **Ground based**  
*(Atmosphere in between!!)*



# The Alpha Magnetic Spectrometer (AMS-02)



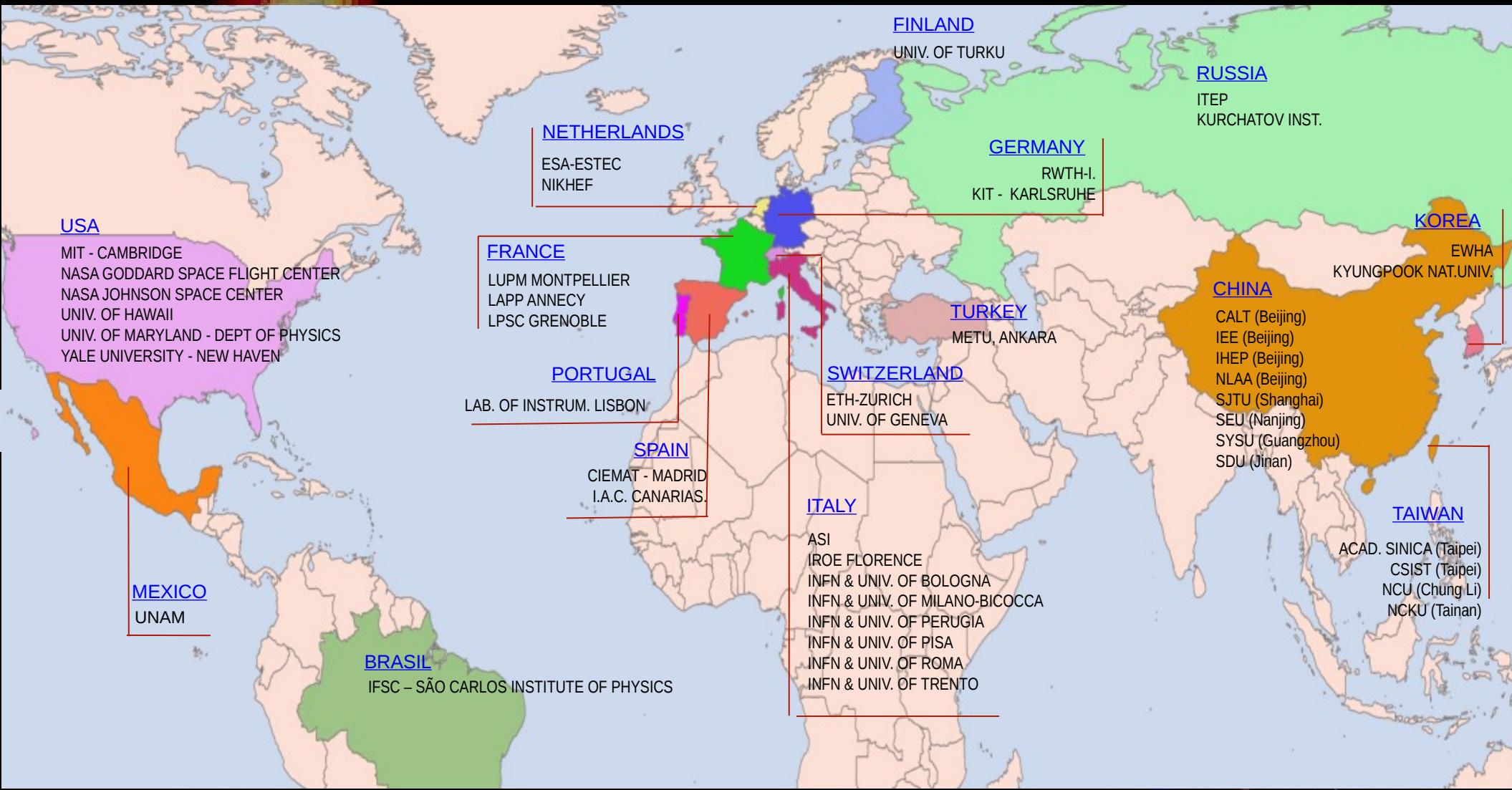
...the experiment I am  
working on at  
UH Manoa





# AMS-02 Collaboration

## 16 Countries, 57 Institutes





# AMS-02 on the ISS



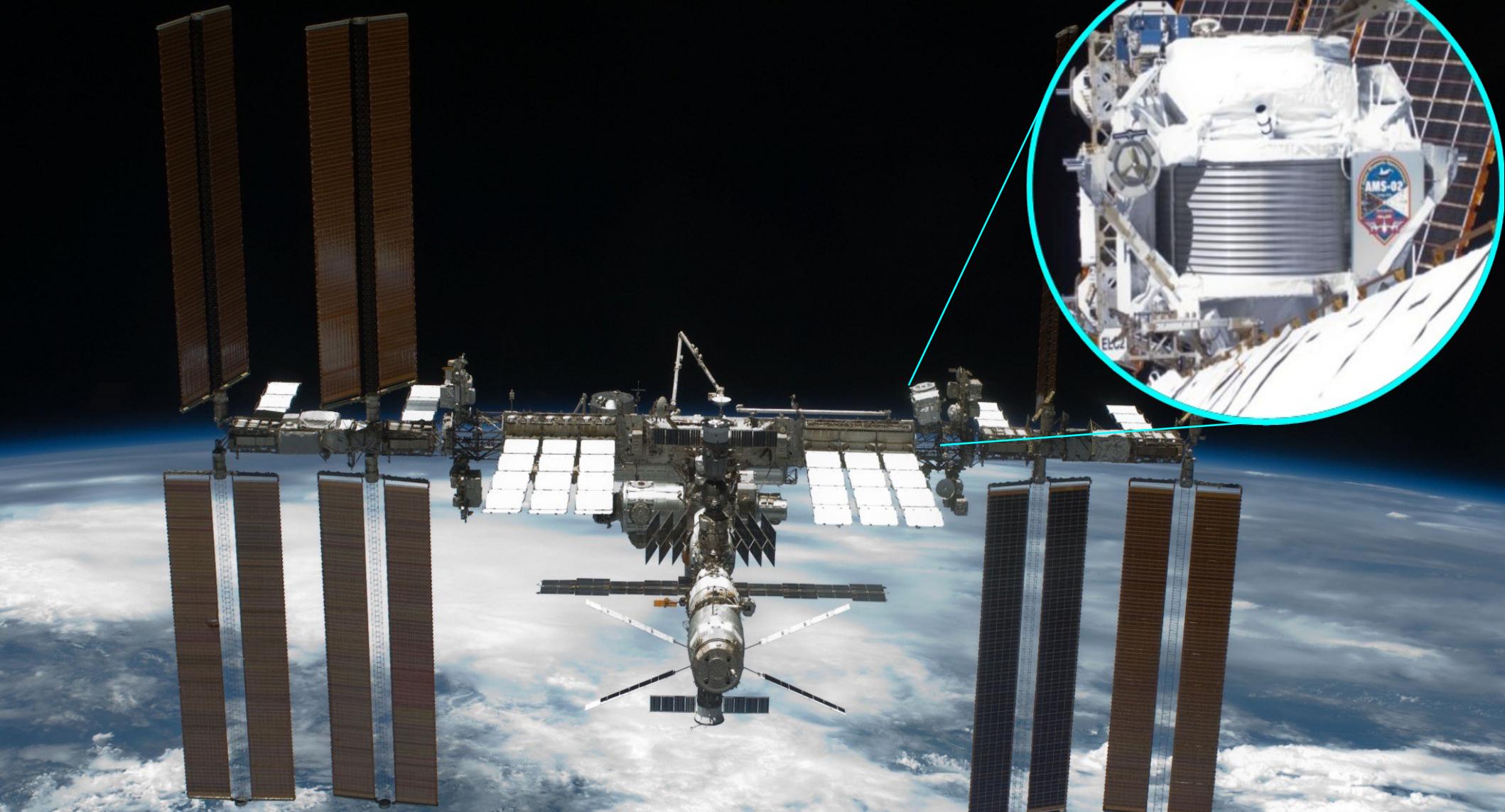
May 16, 2011: AMS Flight, Space Shuttle Endeavor

# ISS

**Altitude:** ~400 km

**Orbit:** 90 minutes

**Size:** 70m x 110m x 20m



# AMS-02

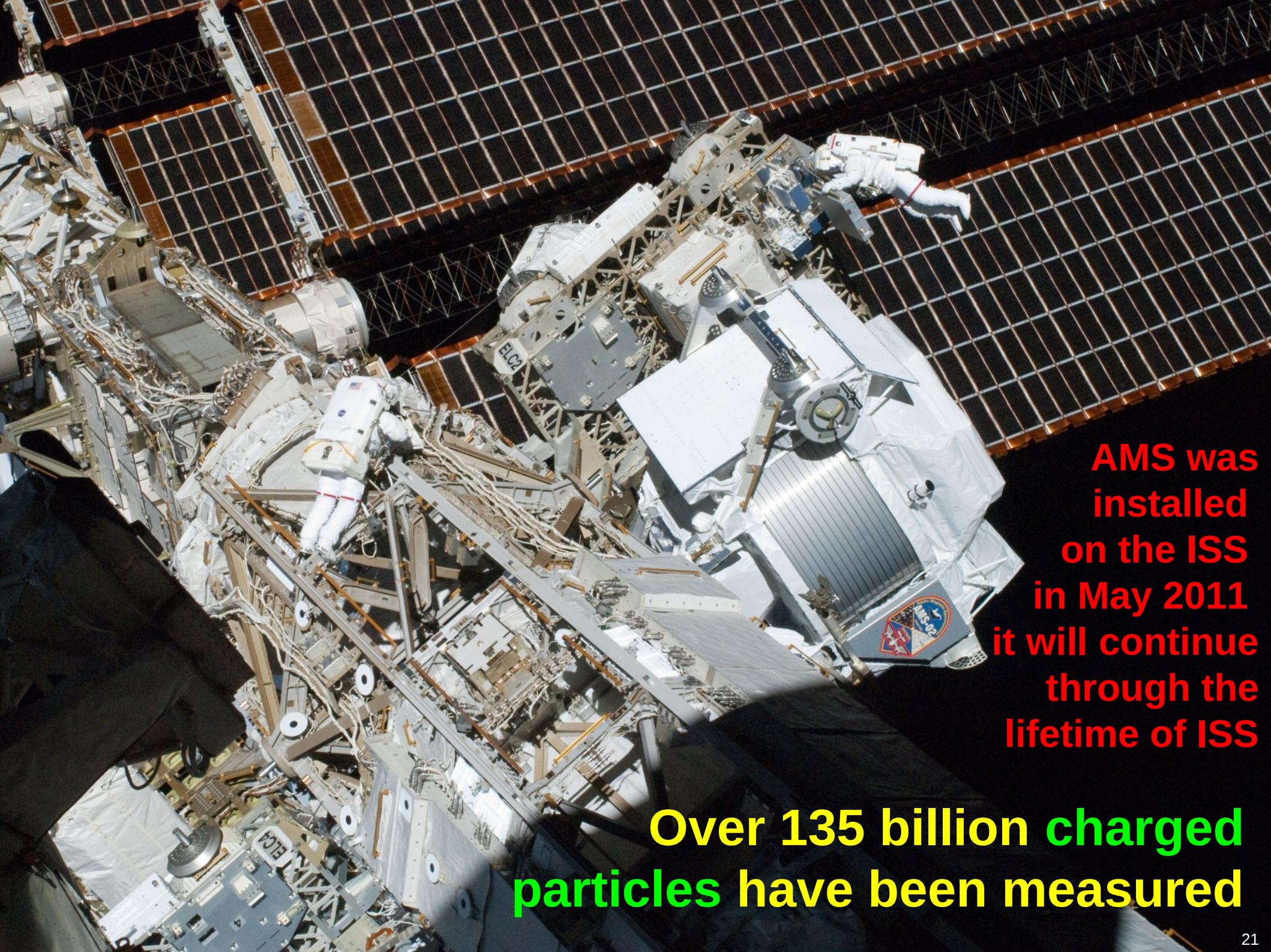
**Size:** 5m x 4m x 3m

**Weight:** 7 ton

**Power:** 2.4 kW



**International Space Station**



**AMS was  
installed  
on the ISS  
in May 2011  
it will continue  
through the  
lifetime of ISS**

**Over 135 billion charged  
particles have been measured**



# AMS POCC located at CERN

Payload Operation Control Center



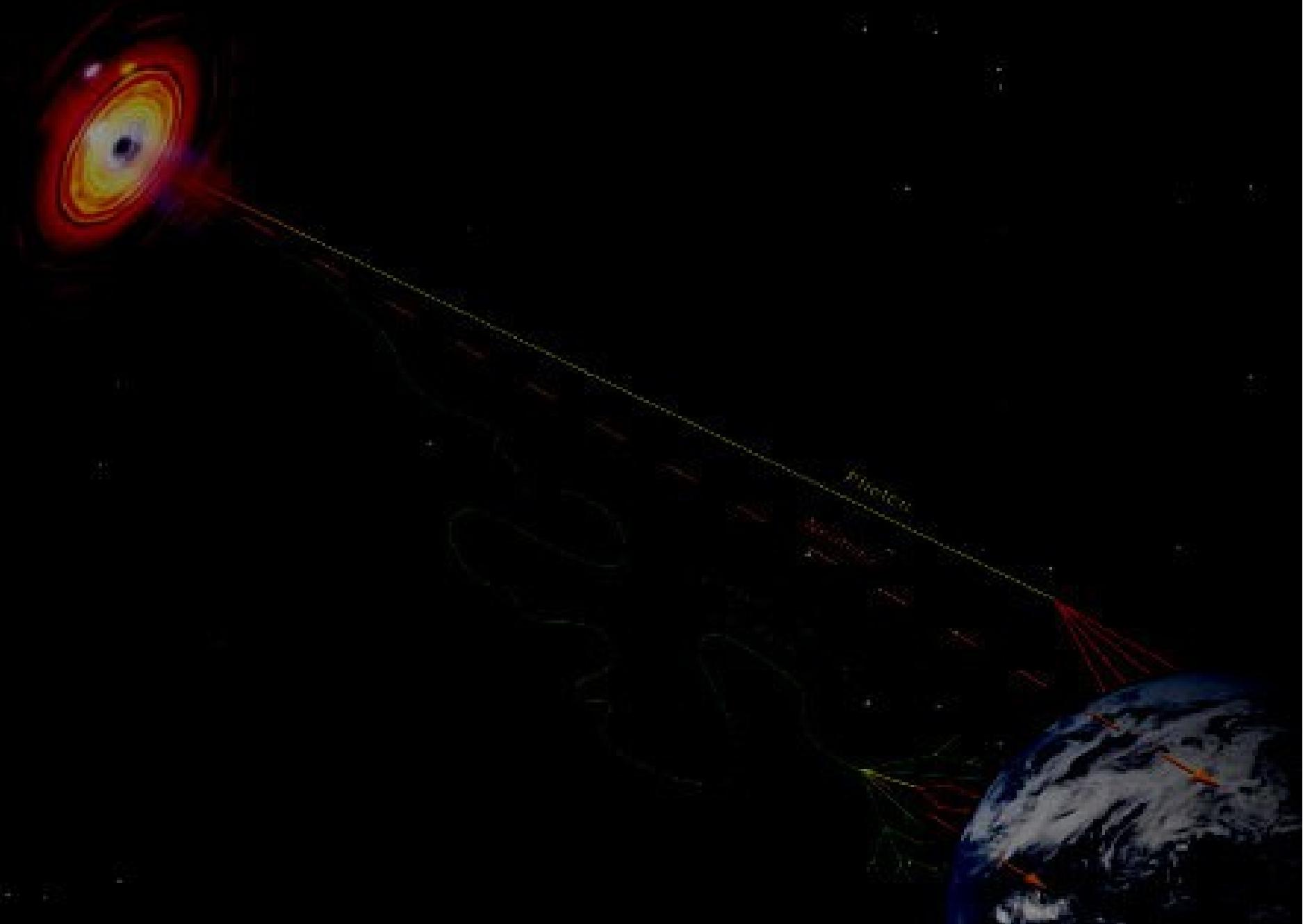


# AMS Scientific Goals

- Galactic CR Nuclei Spectra  
(from H to Fe and above)
- Indirect Dark Matter Search
- Primordial Antimatter  
(e.g. Anti-Nuclei)
- Solar Activity
- Space Radiation  
(necessary for the future space manned mission to the Moon and Mars)



# Indirect Dark Matter Search





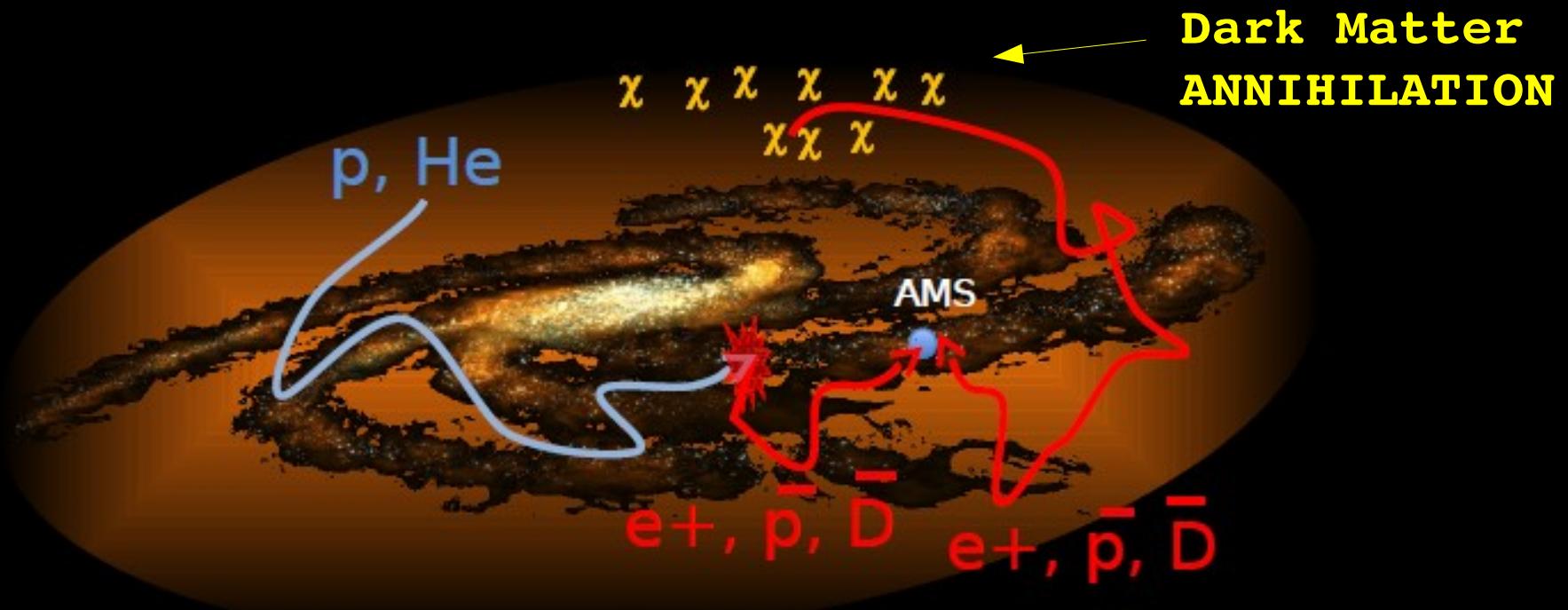
# Indirect Dark Matter Search



Collision of Cosmic Rays with Interstellar Matter produces  $e^+$ ,  $\bar{p}$ ,  $\bar{D}$

Dark Matter annihilation also produces light antimatter:  $e^+$ ,  $\bar{p}$ ,  $\bar{D}$

The excess of  $e^+$ ,  $\bar{p}$ ,  $\bar{D}$  from Dark Matter annihilations can be measured by AMS





# What does AMS measure?

- ENERGY or MOMENTUM





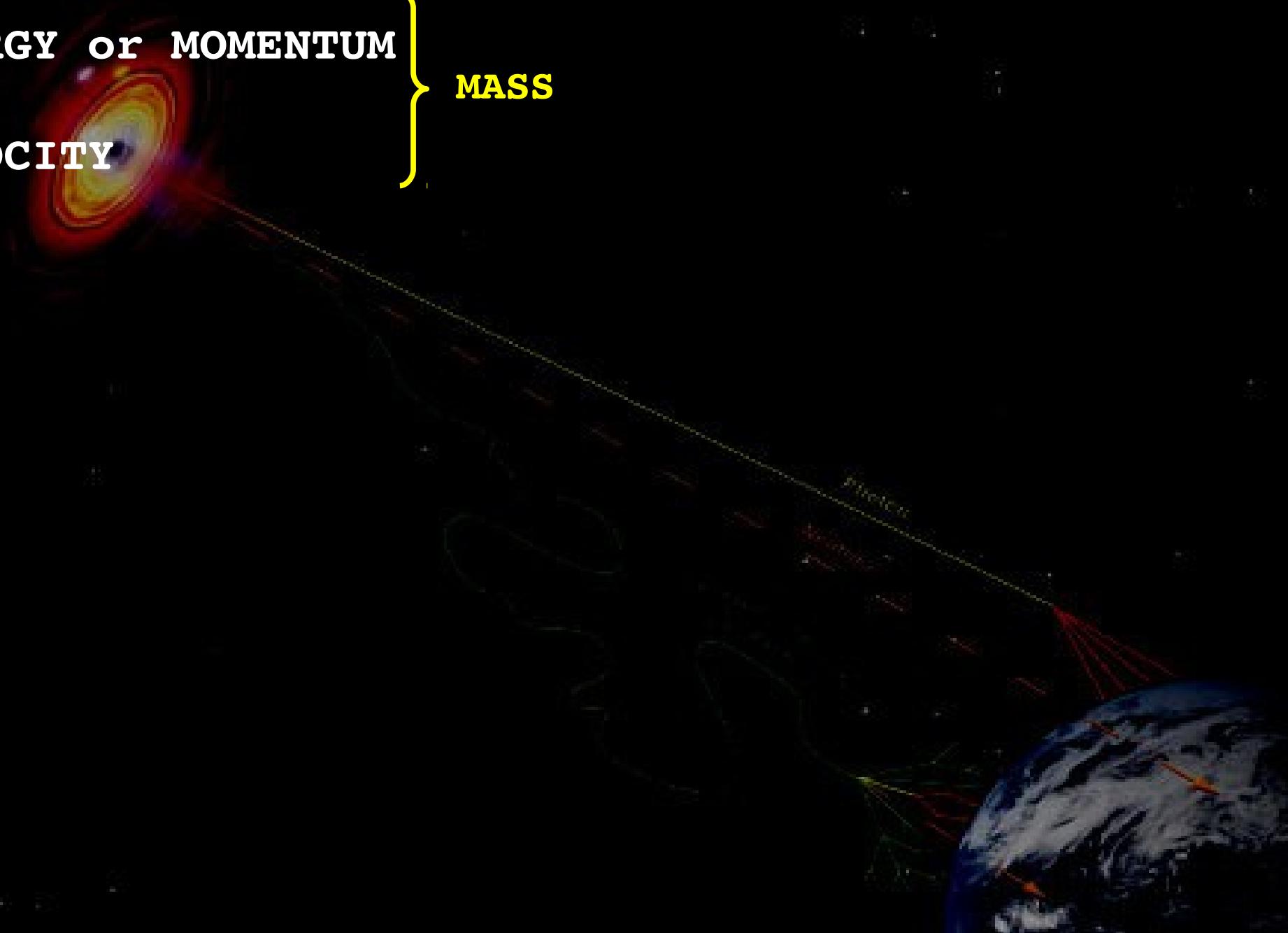
# What does AMS measure?

- ENERGY or MOMENTUM
- VELOCITY





# What does AMS measure?

- ENERGY or MOMENTUM
  - VELOCITY
- 
- A dark background image showing a particle collision. A central, multi-colored (yellow, orange, red) elliptical region represents a particle interaction, with a long, thin, luminous tail extending towards the bottom left. In the lower right corner, there is a complex, multi-colored (blue, green, red) spray of particles, with several orange arrows pointing towards the center of the interaction.
- Particle
- }
- MASS



# What does AMS measure?

- ENERGY or MOMENTUM
  - VELOCITY
  - incoming DIRECTION
- 
- A dark background image showing a particle collision. A central, multi-colored elliptical region (red, yellow, green) represents the interaction point. Several thin, colored lines radiate outwards from this center, representing the paths of individual particles. One prominent red line extends towards the bottom right, labeled "Particle" above its path. Another blue line extends towards the top left. The overall scene is set against a dark, textured background that suggests a particle detector environment.

} MASS



# What does AMS measure?

- ENERGY or MOMENTUM
  - VELOCITY
  - incoming DIRECTION
  - TRAJECTORY
- 
- A dark background image showing a particle collision. A central point of impact is surrounded by concentric, multi-colored rings of light (yellow, orange, red) representing energy or momentum. From this central point, several thin, straight lines extend outwards at different angles, representing the trajectory and direction of particles. The overall effect is a dramatic, high-energy event captured in a scientific detector.

MASS

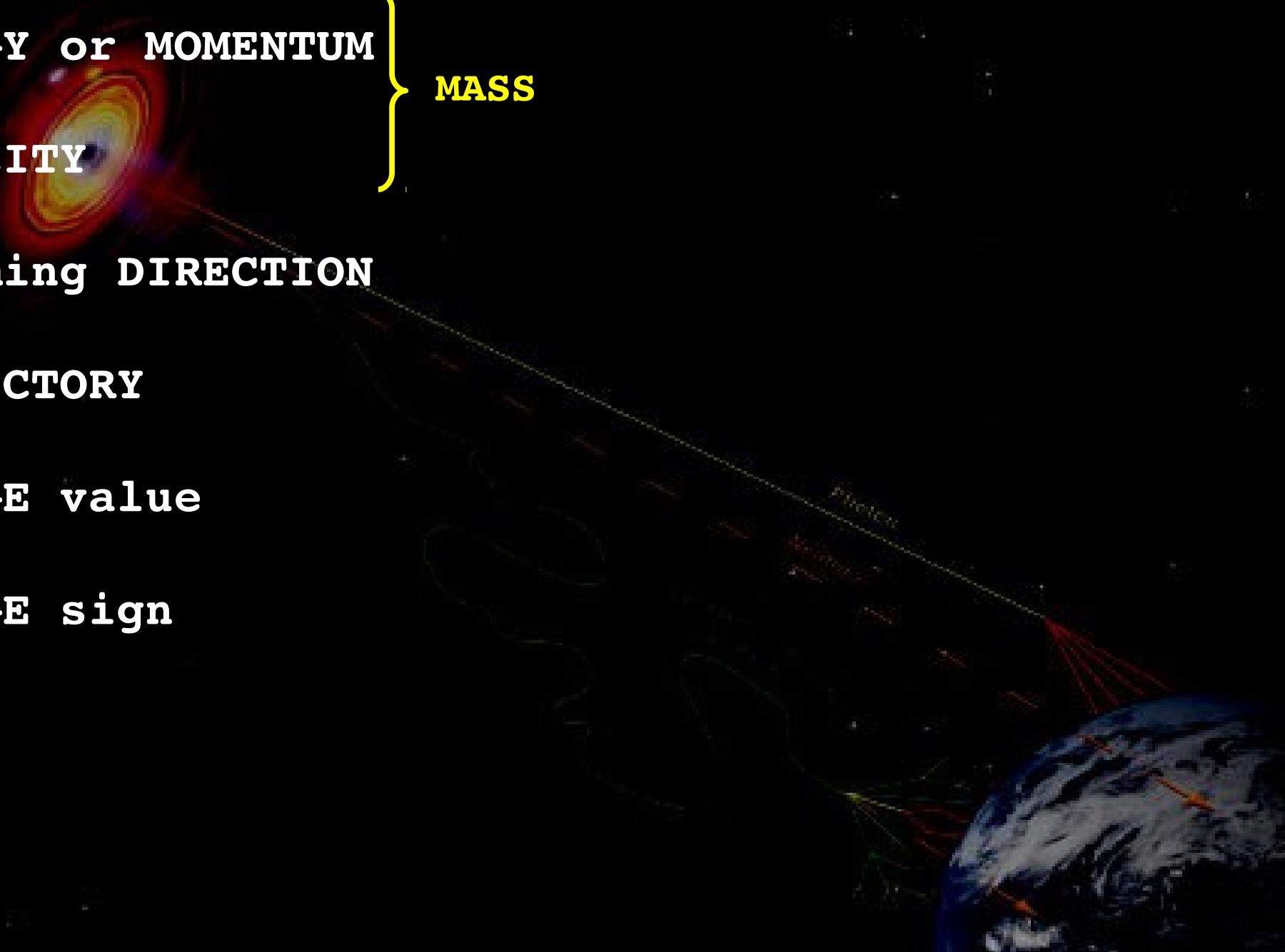


# What does AMS measure?

- ENERGY or MOMENTUM
  - VELOCITY
  - incoming DIRECTION
  - TRAJECTORY
  - CHARGE value
- MASS



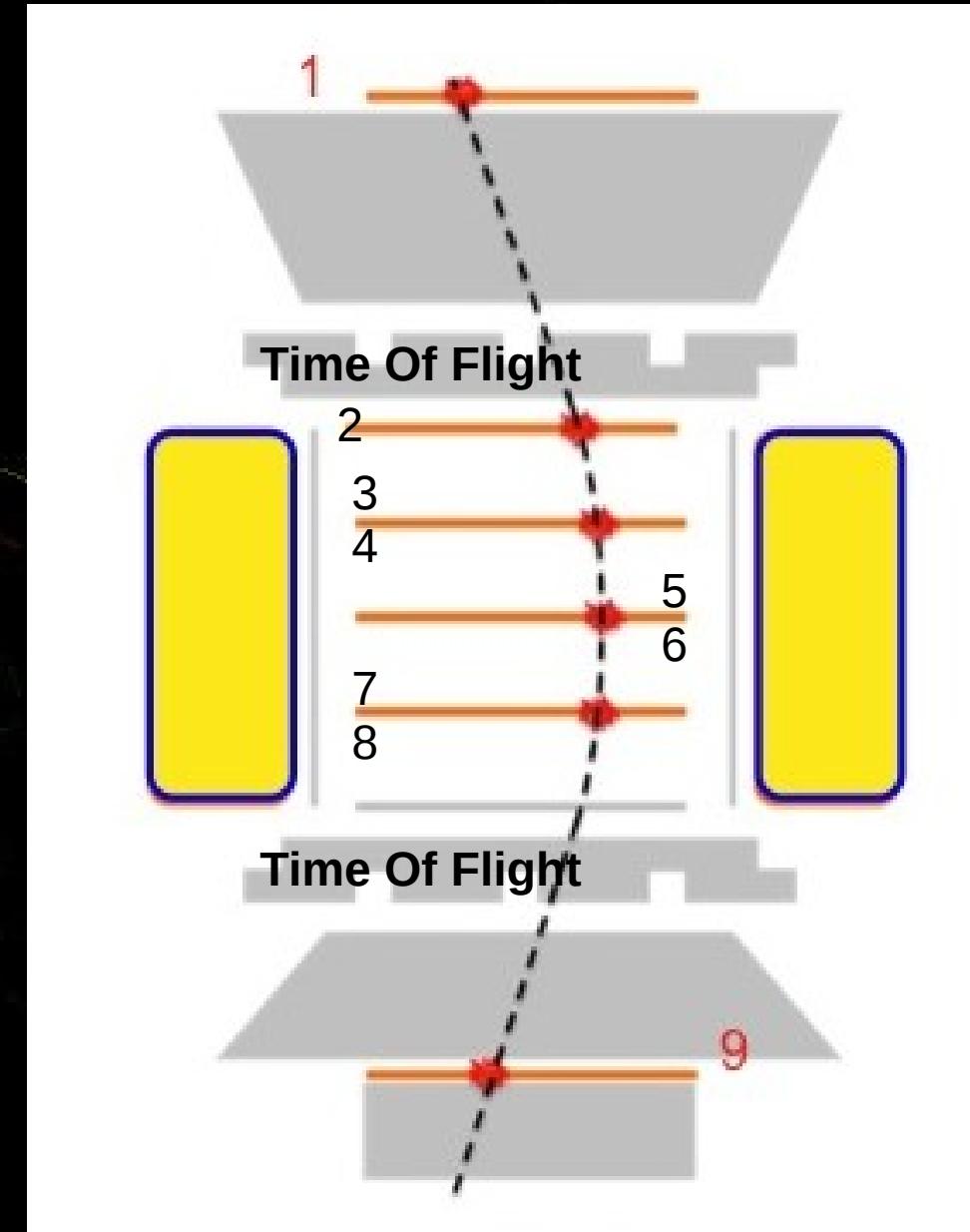
# What does AMS measure?

- ENERGY or MOMENTUM
  - VELOCITY
  - incoming DIRECTION
  - TRAJECTORY
  - CHARGE value
  - CHARGE sign
- 
- A dark background image showing a particle detector's internal structure. It features a central cylindrical core with concentric layers of sensors and a complex network of wires and chambers extending towards the bottom right. A bright, multi-colored particle track is visible, starting from the center and branching out into several paths, illustrating the interaction of particles within the detector.

MASS

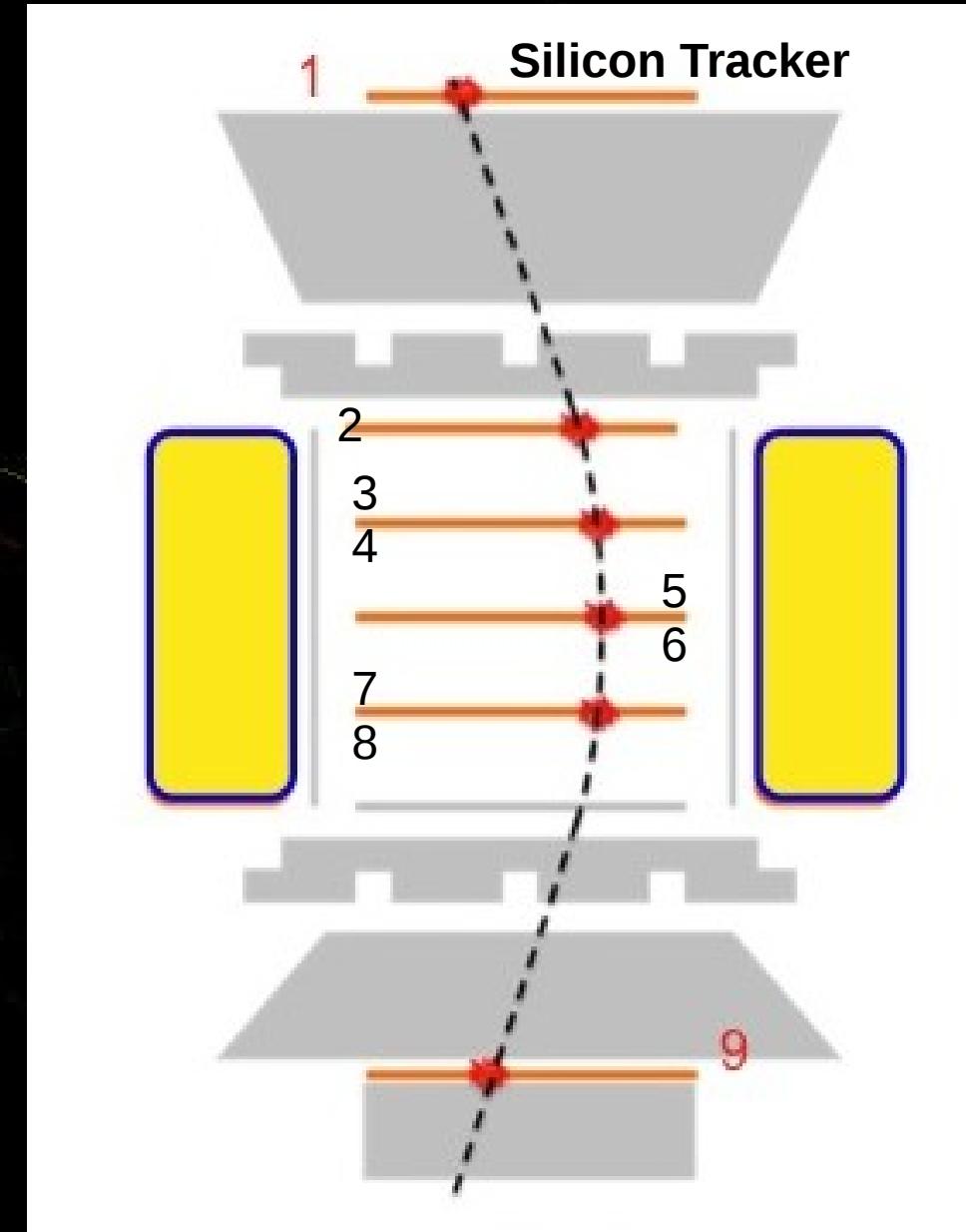
# How does AMS measure?

- ENERGY or MOMENTUM
- VELOCITY
- incoming DIRECTION
- TRAJECTORY
- CHARGE value
- CHARGE sign



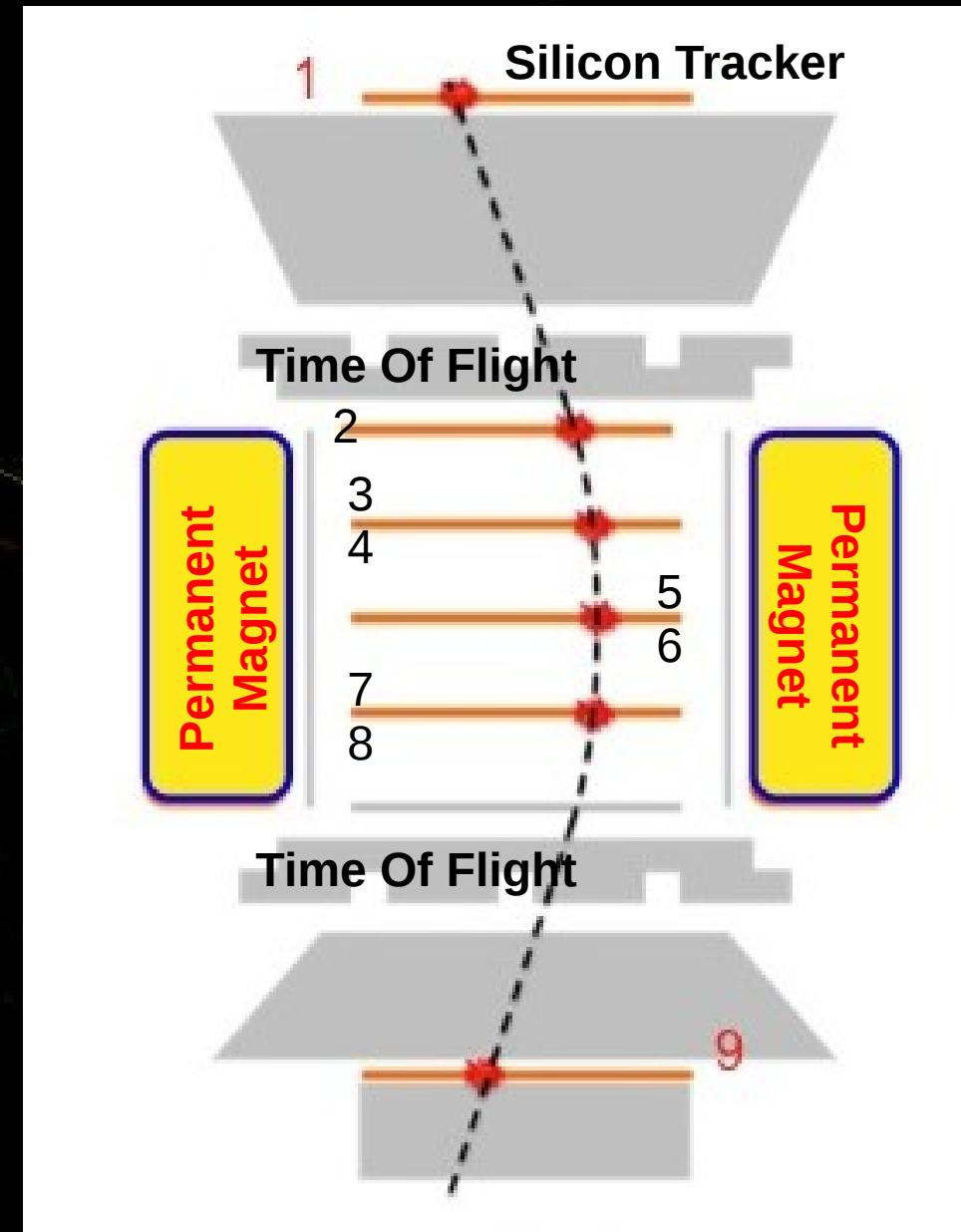
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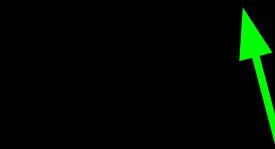
# How does AMS measure?

- ENERGY or MOMENTUM
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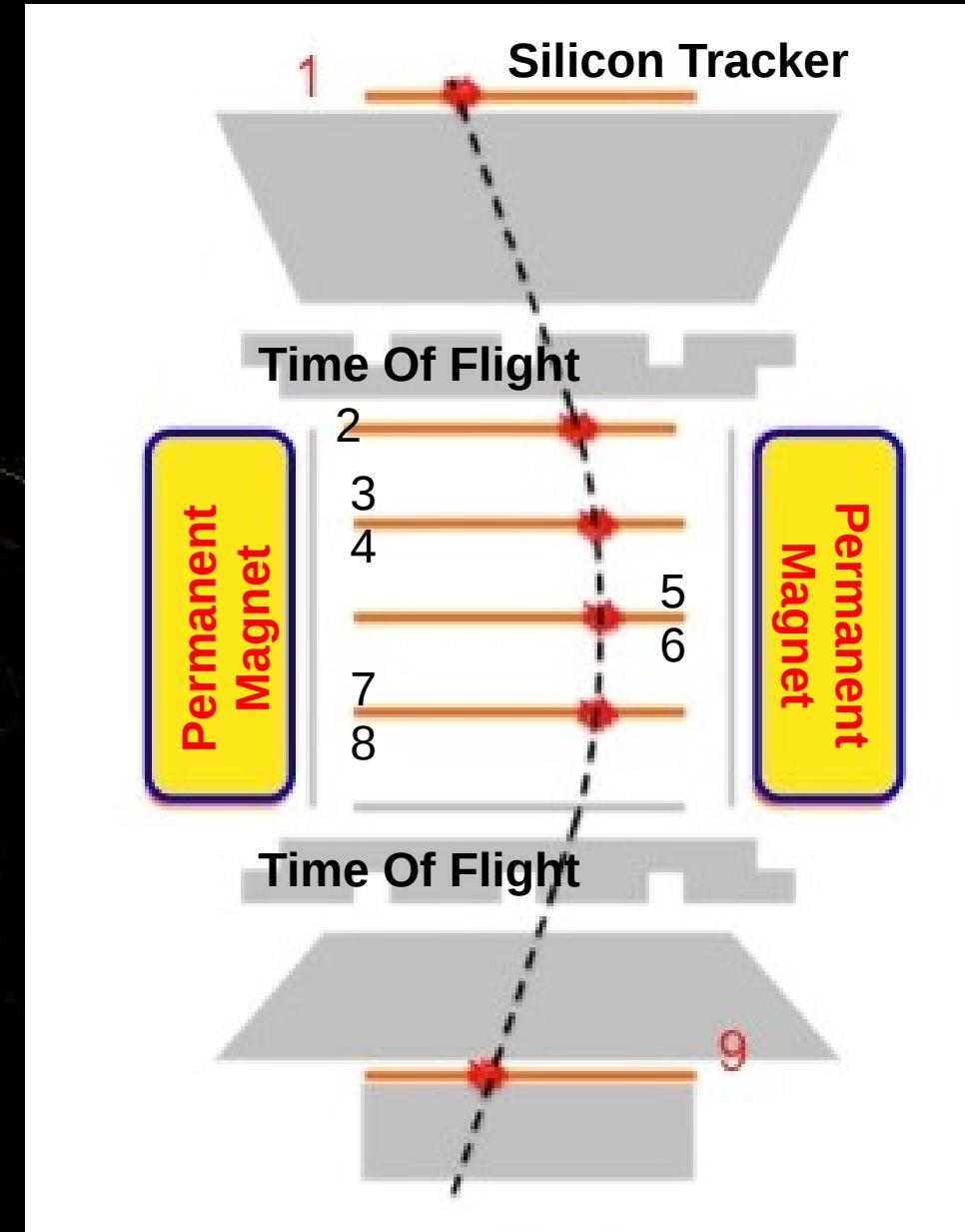


# How does AMS measure?

- ENERGY or MOMENTUM
- VELOCITY
- incoming DIRECTION
- TRAJECTORY
- CHARGE value
- CHARGE sign



Fundamental to look  
for Dark Matter





# Particle Identification with AMS-02



TRD: Identify e+, e-, Z

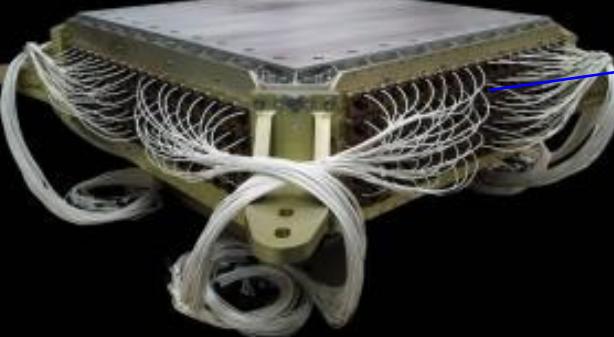


Particles and nuclei are defined by their charge (Z)  
and energy (E)  
or momentum (P).  
 $R = P/Z$

Silicon Tracker: Z, P



ECAL: E of e+, e-



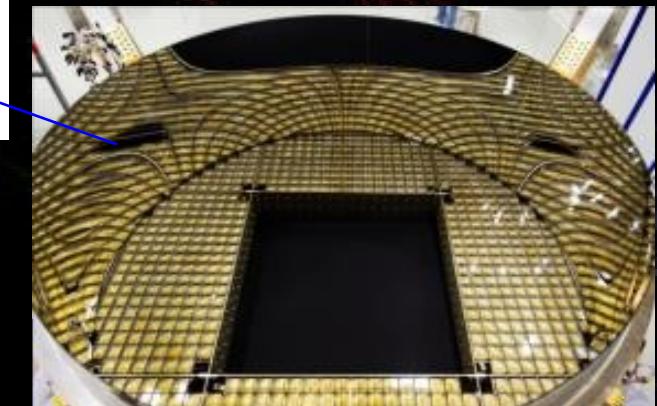
TOF: Z, E



Magnet:  $\pm Z$



RICH: Z, E



Z and P

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