Cosmic Ray Physics with the Alpha Magnetic Spectrometer

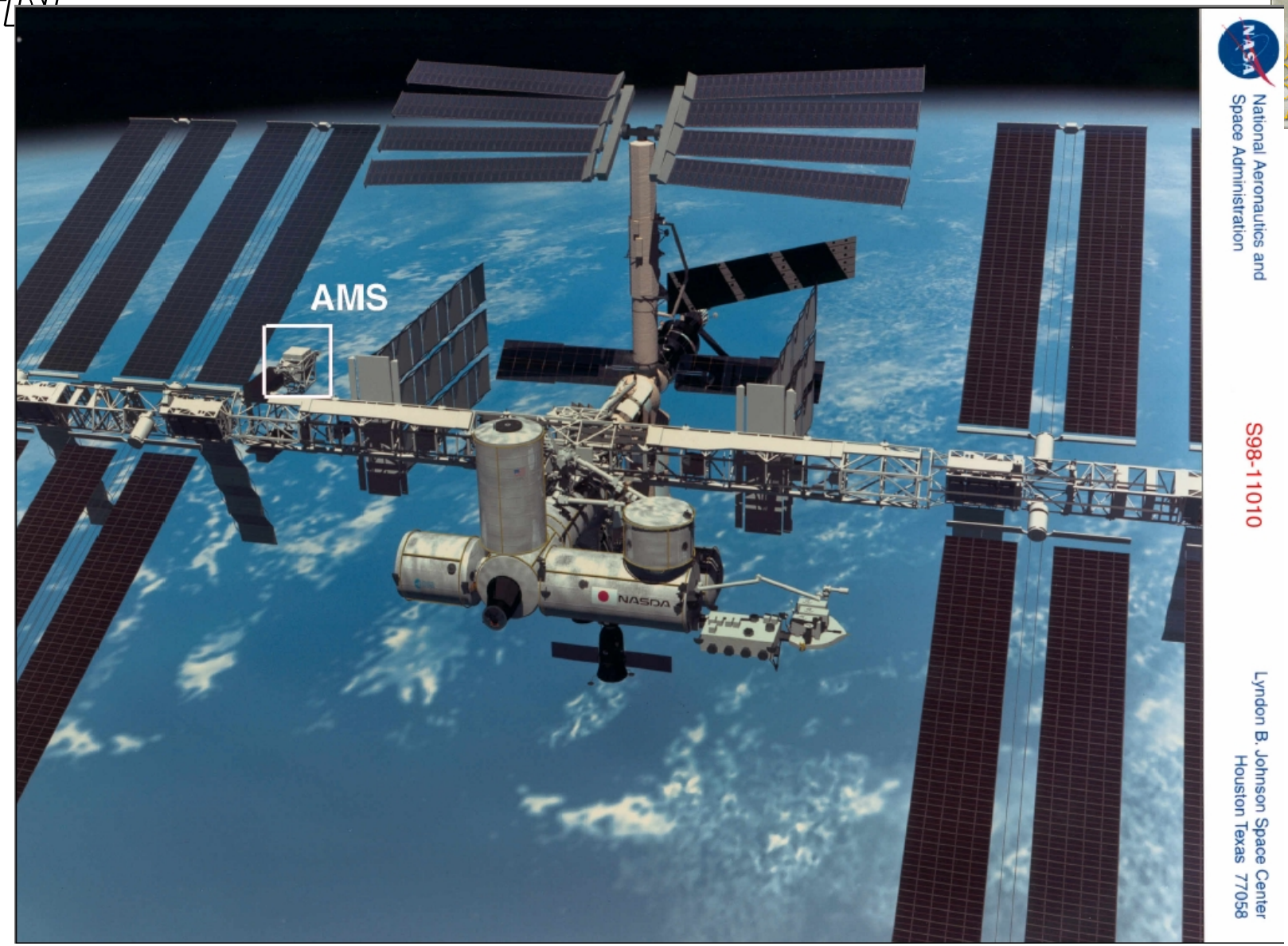
Simonetta Gentile

Università di Roma La Sapienza, INFN

on behalf of AMS Collaboration

Outline

- Introduction
- AMS02 Spectrometer
- Cosmic Rays: origin & propagations:
  - Dominant elements: protons, He …..
  - Light elements: Be, B
  - Heavy elements: C, Fe
  - Cosmic ray clocks : Be
- Gamma Rays
- Search for Antimatter
- Conclusions



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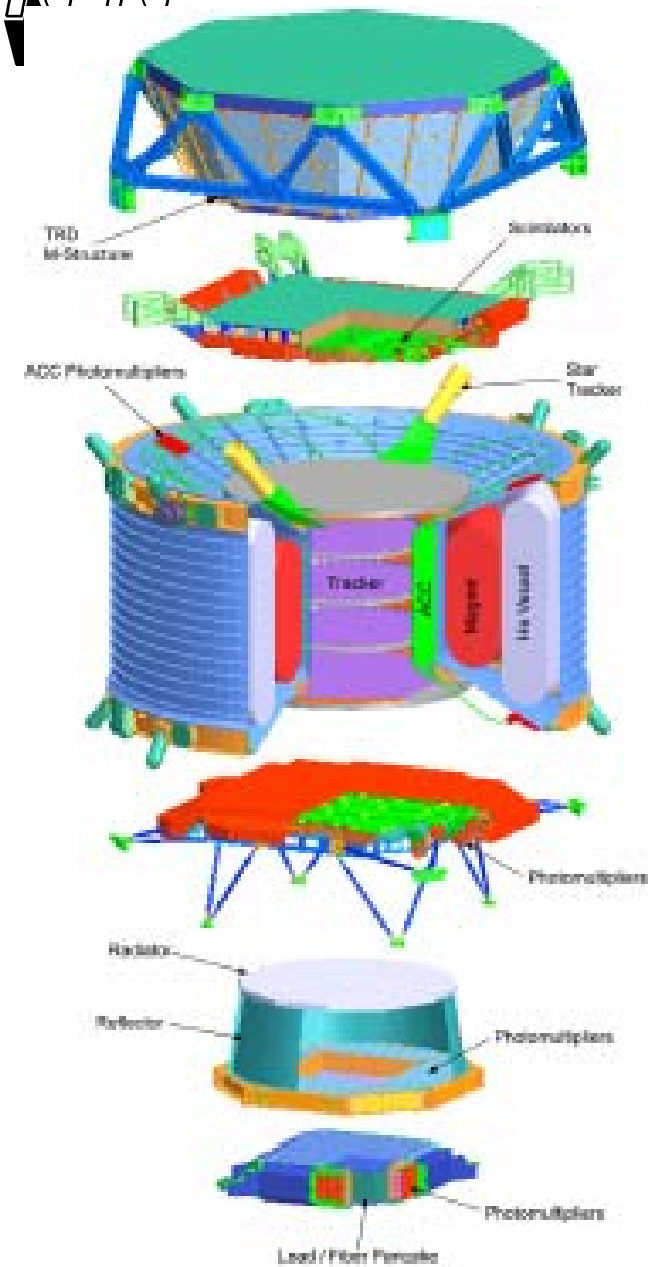
Rencontres du Vietnam,Hanoi 2004

Dimensions 3m x 3mx3m,7 t Large acceptance ~0.5m^{2}sr.



TRD: Transition Radiation Detector

TOF: (s1,s2) Time of Flight Detector

MG: Magnet

TR: Silicon Tracker

ACC: Anticoincidence Counter

AST: Amiga Star Tracker

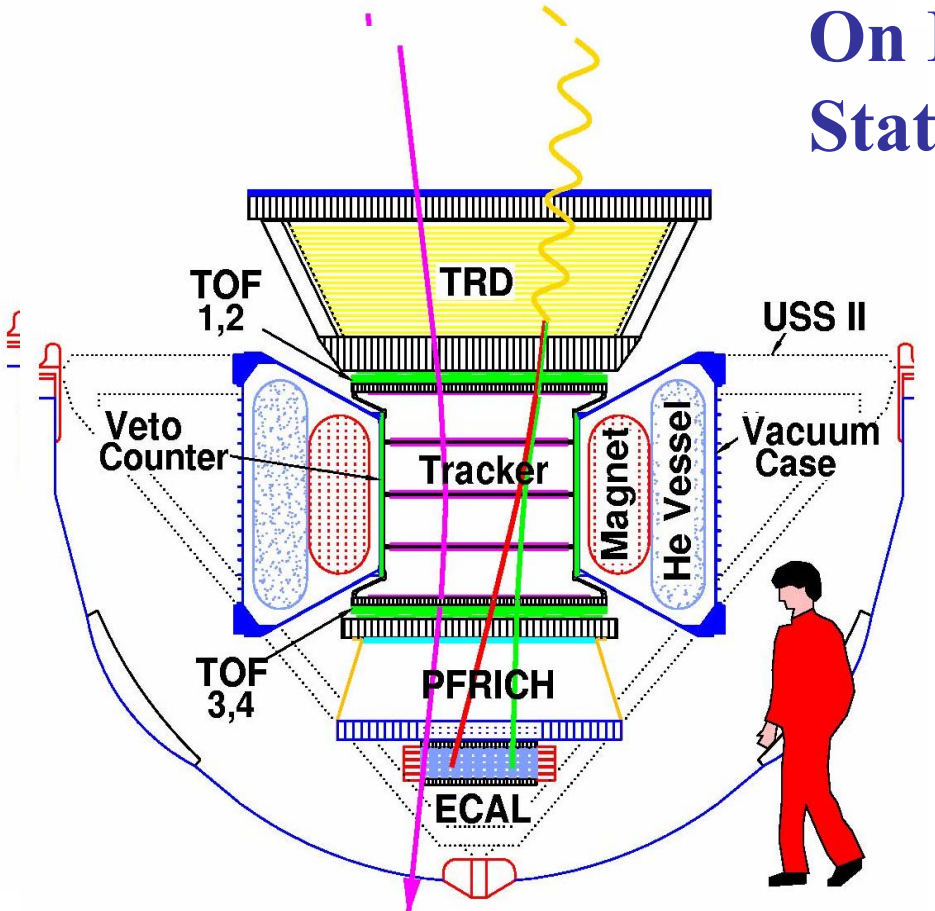
TOF: (s1,s2) Time of Flight Detector

RICH: Ring Image Cherenkov Counter

EMC; Electromagnetic Calorimeter

- **Transition Radiation Detector**
- **Time of Flight scintillator counters**
- **8 layers of Si strip tracker planes in superconducting magnet**
- **Rich Imaging Cerenkov detector**
- **Electromagnetic calorimeter**

The Alpha Magnetic Spectrometer



On International Space Station from beginning 2008

- **Study of charged particles and nuclei with rigidity 0.5 GV– few TV**

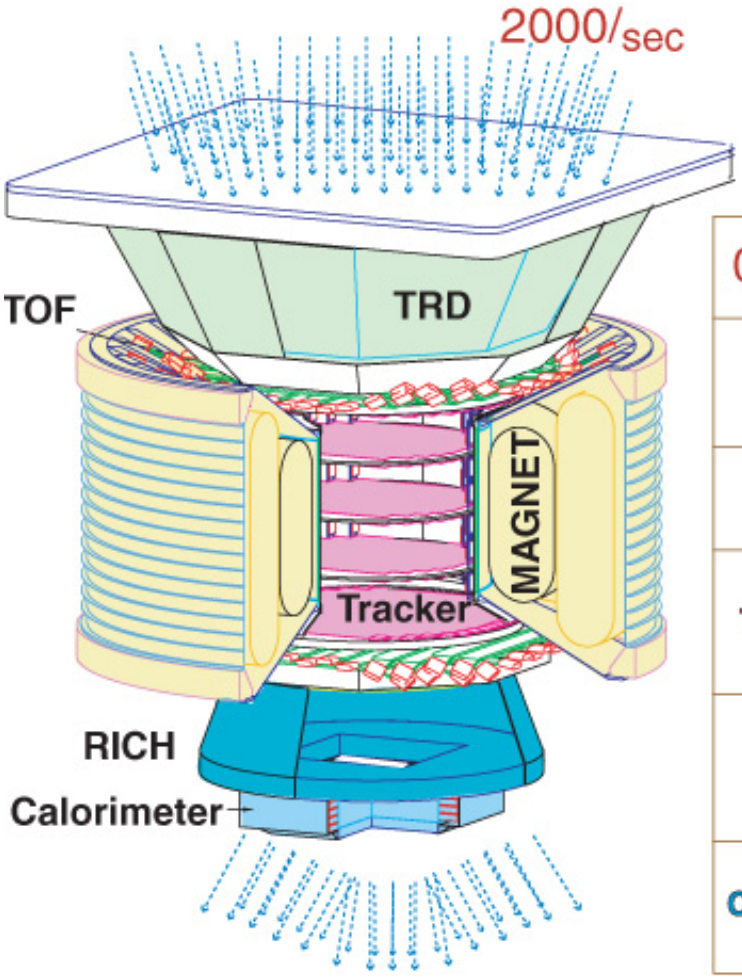
- **Direct search for antimatter (antihelium)**

- **Indirect search for Dark Matter .**

Total statistics expected above 10 ^{10} events

Thorsten Siedenburg's talk in dark matter parallel session

AMS: A TeV Magnetic Spectrometer in Space



0.3 TeV	e⁻	e+	P	$\bar{He}$	γ
TRD					
TOF					
Tracker					
RICH					
Calorimeter					

y2K025 _5 Gamma

Main Design Characteristics

- Minimum amount of matter (X_0) in front of ECAL
- Acceptance 0.5 m2.Sr -> anti-He search.
- Velocity measurement $\Delta\beta/\beta = 0.1$ % to distinguish $^{9}Be, ^{10}Be, ^{3}He, ^{4}He$ isotopes.
- Rigidity R= pc/|Z|e (GV) proton resolution 20% at 0.5 TV and Helium resolution of 20% at 1 TV.
- Antihelium/Helium identification factor 10^{10}.

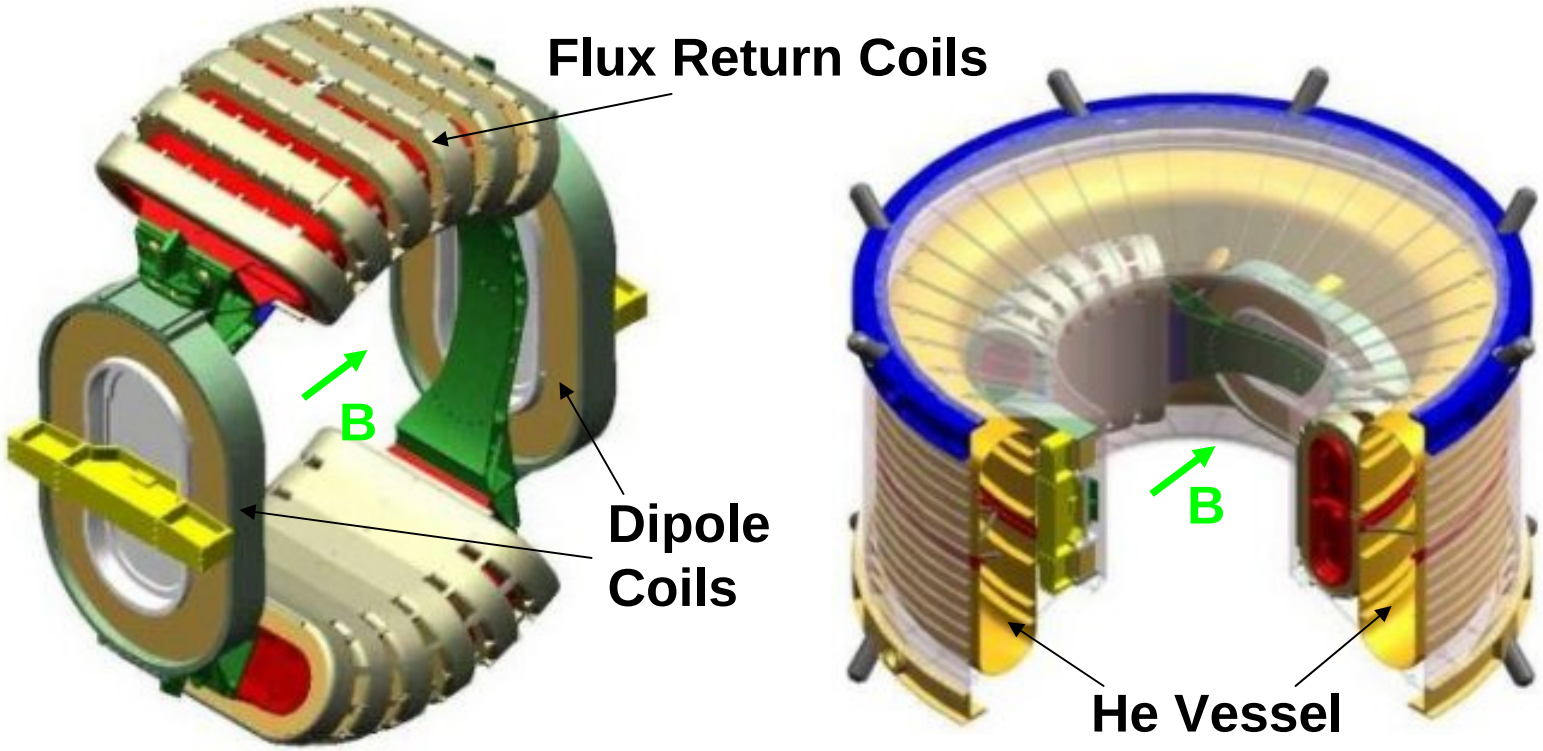
Multiple and independant measurements to reach performances required:

- |Z| measured from Tracker, RICH, TOF.
- Sign of charge Z measured from tracker (8 points).
- Velocity β measured from TOF, RICH.
- Hadron/electron separation from TRD, ECAL.

Contrains on Spatial Experiment Design

- **Thermal Environment** (day/night: $\Delta T \sim 100^{o}C$)
- Vibration (6.8 G RMS) and G-Forces (17G)
- **Limitation : Weight** (14 809 lb) and **Power** (2000 W)
- **Vacuum:** $< 10^{-10}$ Torr
- Reliable for more than 3 years – Redundancy
- Radiation: Ionizing Flux $\sim 1000\ cm^{-2}s^{-1}$
- Orbital Debris and Micrometeorites
- Must operate without services and human Intervention

Superconducting Magnet



2500 Liters Superfluid He

Analyzing power

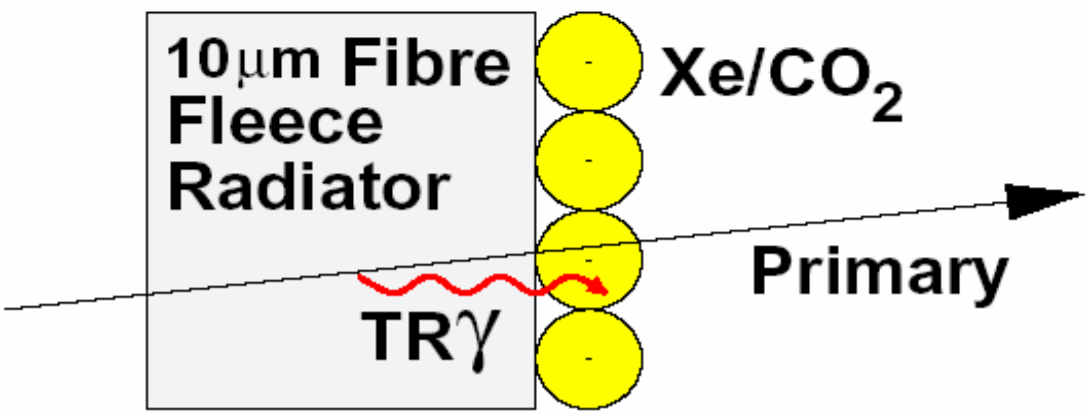
$BL^2 = 0.8\ Tm^2$

AMS-02 Transition Radiation Detector

Transition radiation is produced when particles cross boundaries between materials with different dielectric properties

Significant for relativistic $\gamma = E/m >\sim 1000$

At >~ GeV energies, electrons produce TR x-rays; protons do not: 3 –300GeV

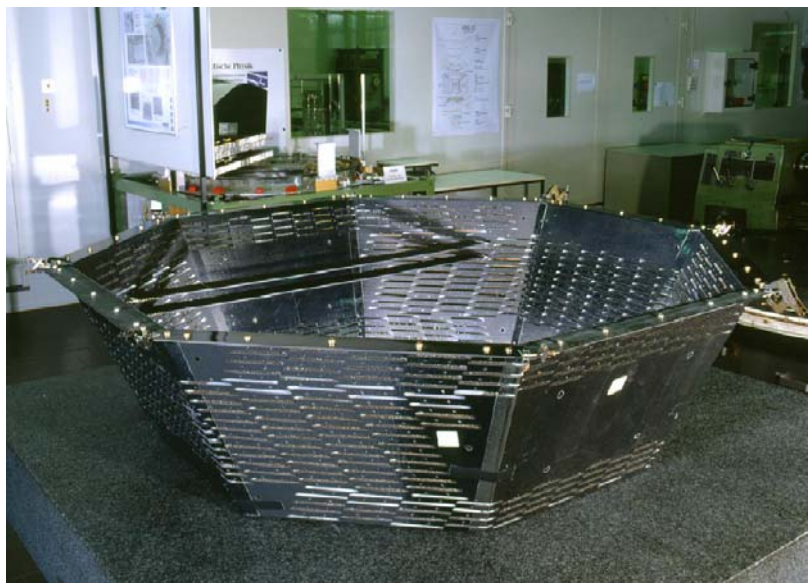


20 layers of Xe/CO_2 filled straw tubes for dE/dx, TR x-ray detection

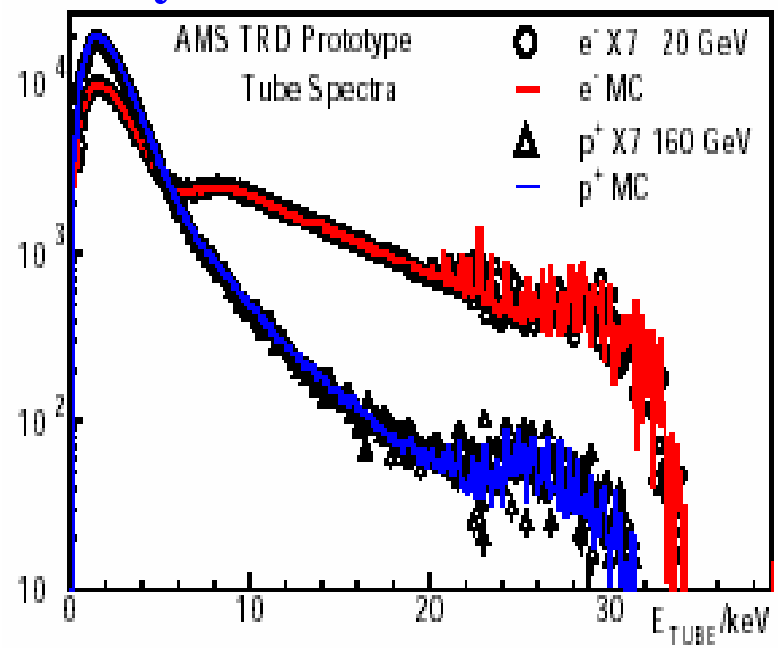
- e+/p rejection 10^2 –10^3 in 1.5 – 300 GeV
- with ECAL e+/p rejection $>10^6$

TRD detector

- 20 layers,328 chambers,5248 tubes
- Mechanical Accuracy <100mm
- Assembly in progress



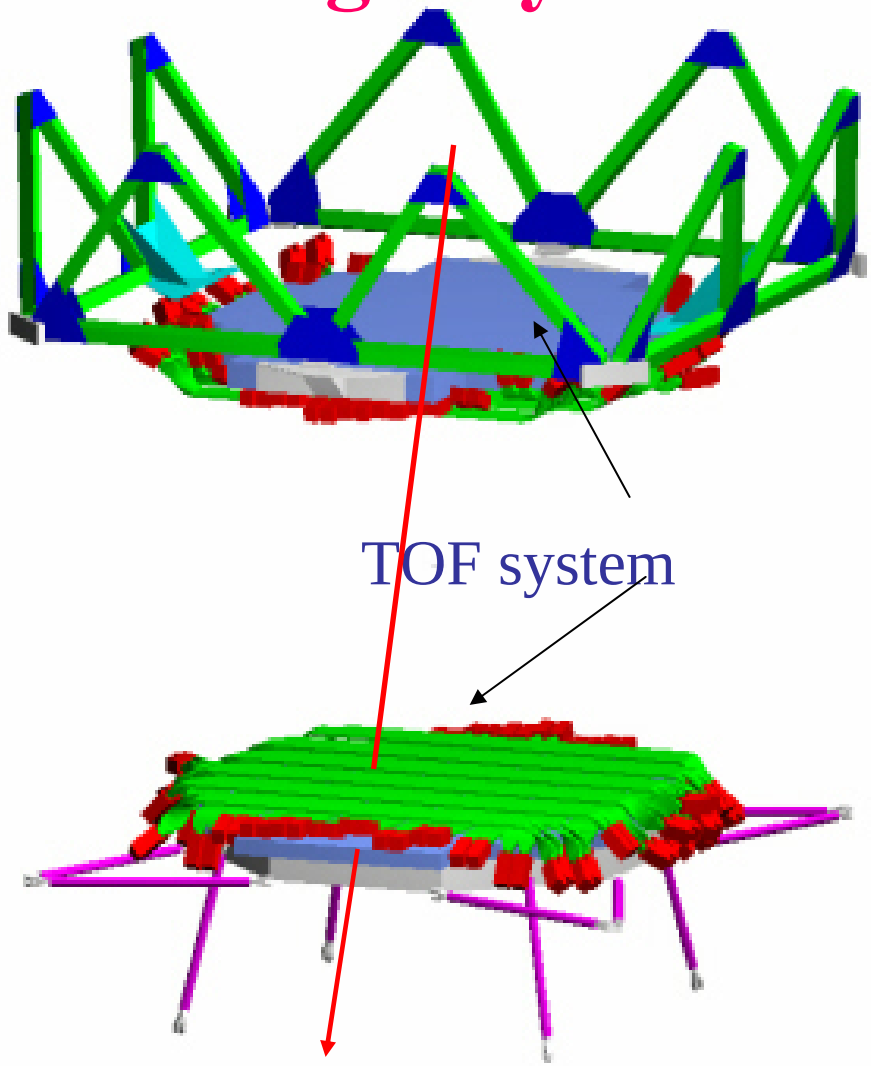
CERN beamtest with TRD prototype: proton rejection > 100 up to 250 GeV at electron efficiency 90% reached



Single tube spectra for p+/e separation.

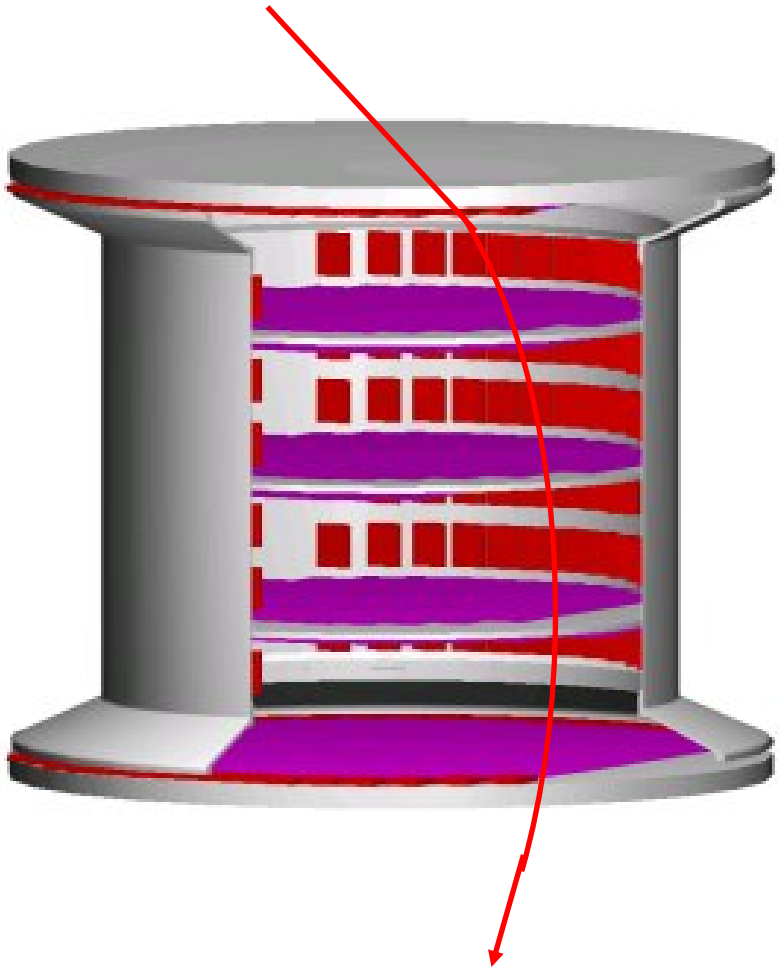
Time-of-flight system

- Trigger
- Time-of-flight (velocity).
- Up/Down Separation
- |Charge| Determination (dE/dx)
- 120 ps Time Resolution (test beam)



- 8 m^2 Total Area
- 4 Planes (2 upper,2 lower)

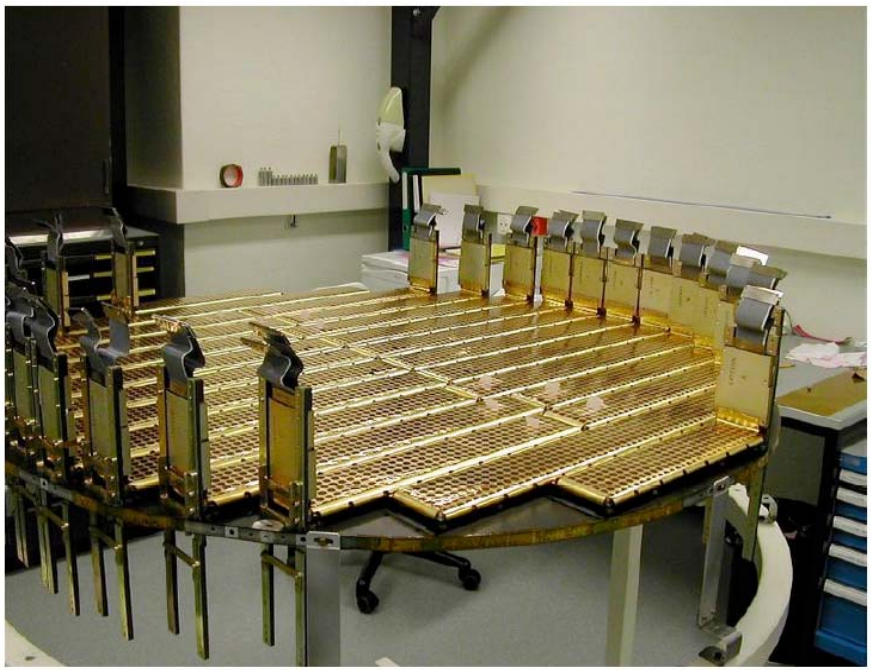
Silicon Tracker

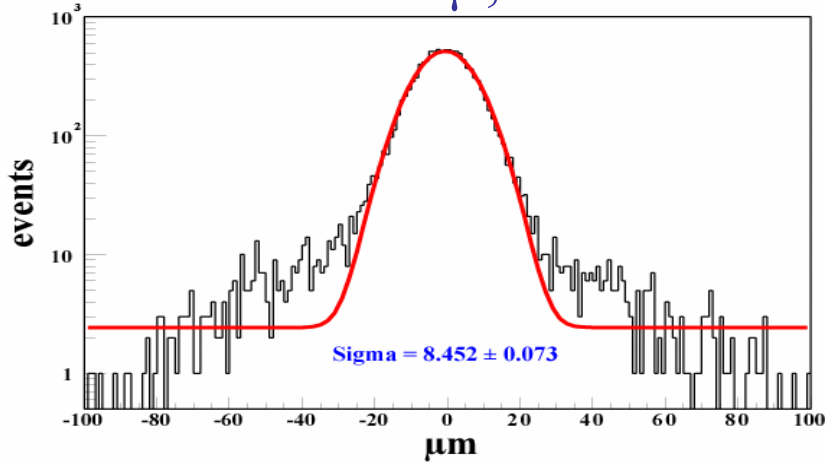


- Rigidity ($\Delta R/R \approx 2\%$ for 1 GeV Protons) with Magnet
- Signed Charge (dE/dx)
- 8 Planes, ~6m^2
- Pitch (Bending): 110 μm (coord. res. 10 μm)
- Pitch (Non-Bending): 208μm (coord. res. 30 μm)
- Charge magnitude up Z ~ 26

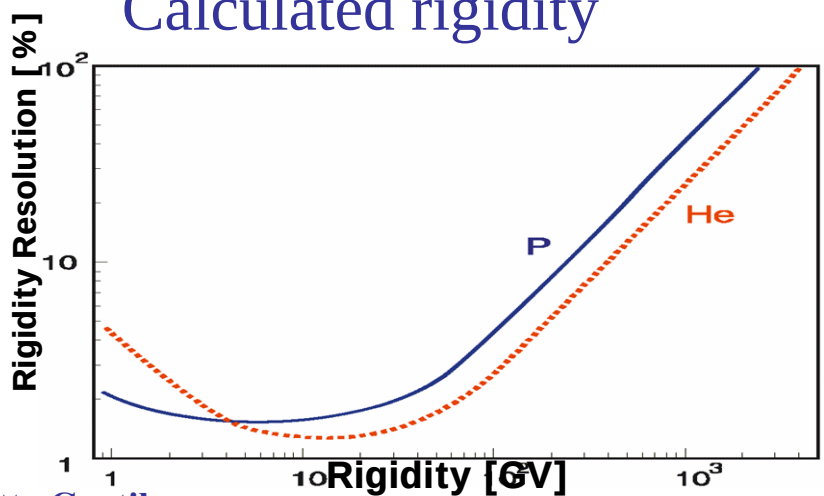
Rigidity measurements

Test of ladders with μ,E=120GeV/c





Calculated rigidity



Resolution on rigidity with $0.8 Tm^2$ magnet field:

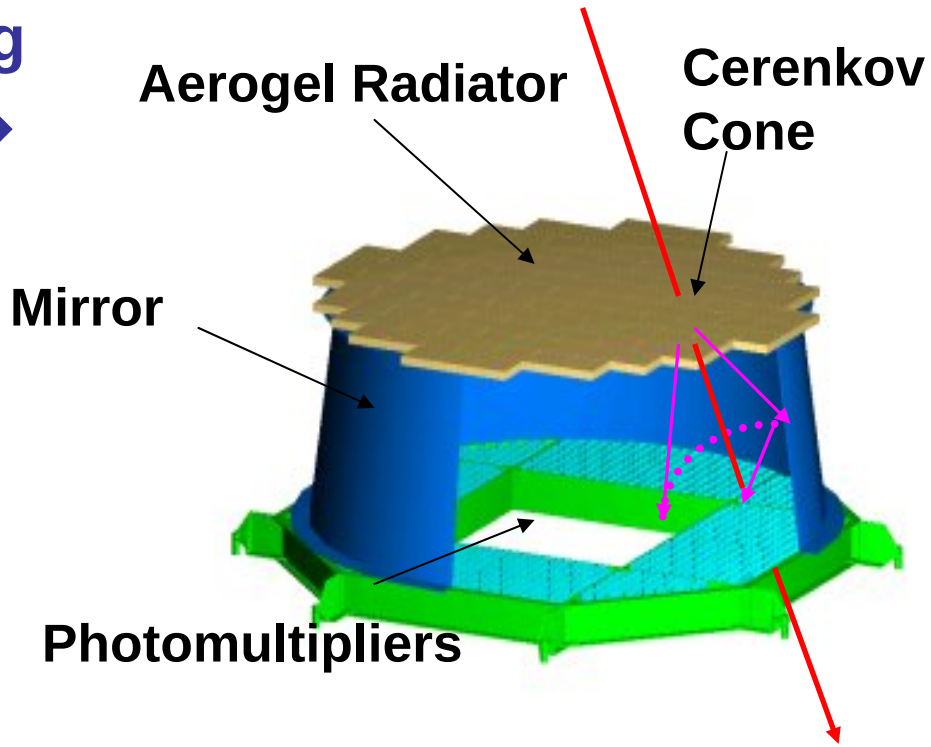
$\sigma(R)/R \sim 1.5\%$ at 10GV

Ring Imaging Cerenkov Counter

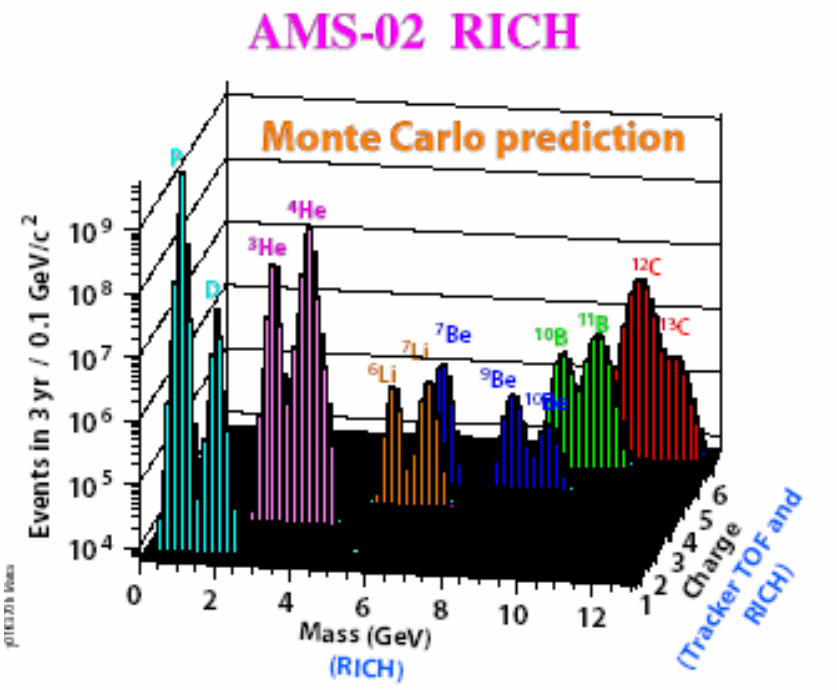
- Accurate Velocity Measurements via Opening Angle of Cerenkov Cone → Isotopic Separation.
- |Q| measurements up Z~ 30
- $\Delta\beta/\beta = (0.67 \pm 0.01) * 10^{-3}\%$

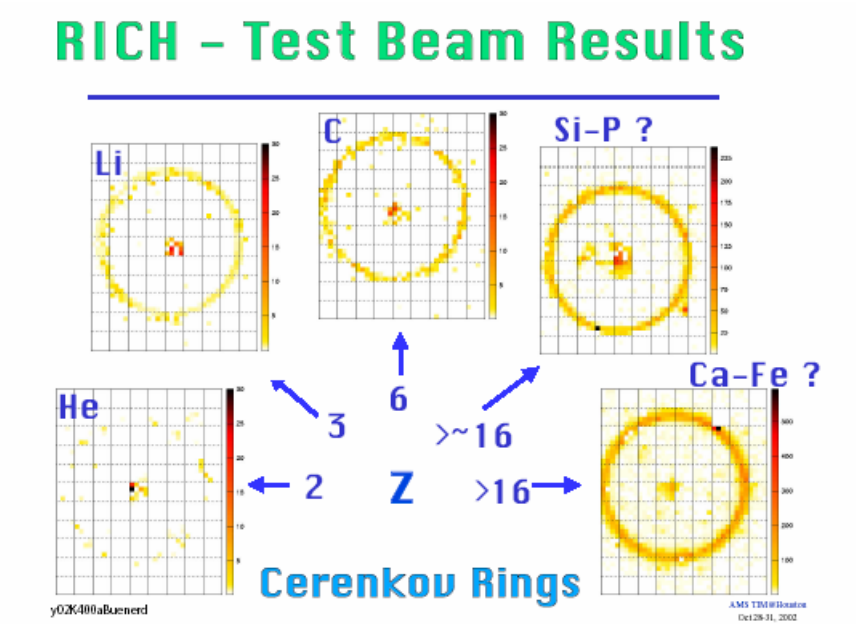
(test beam)

- Additional Particle Identification capability



Ring Imaging Cerenkov Counter





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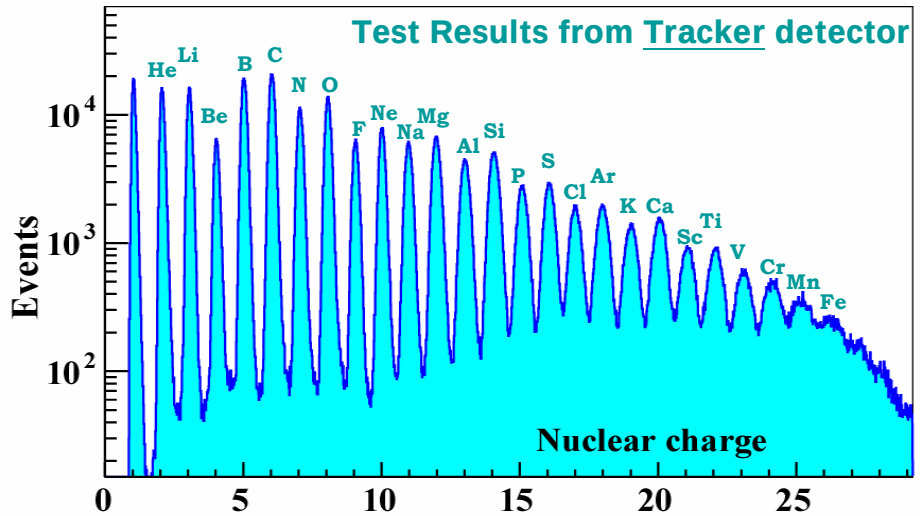
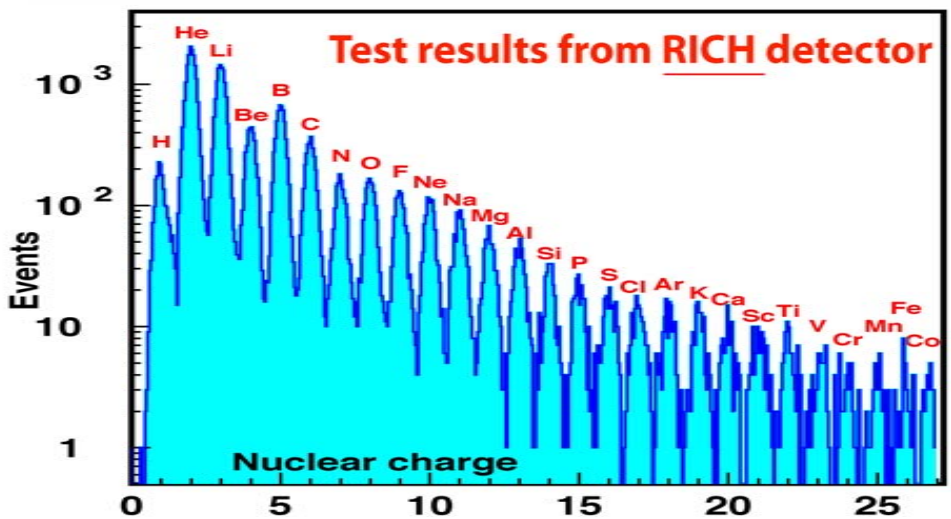
Rencontres du Vietnam,Hanoi 2004

Charge measurements

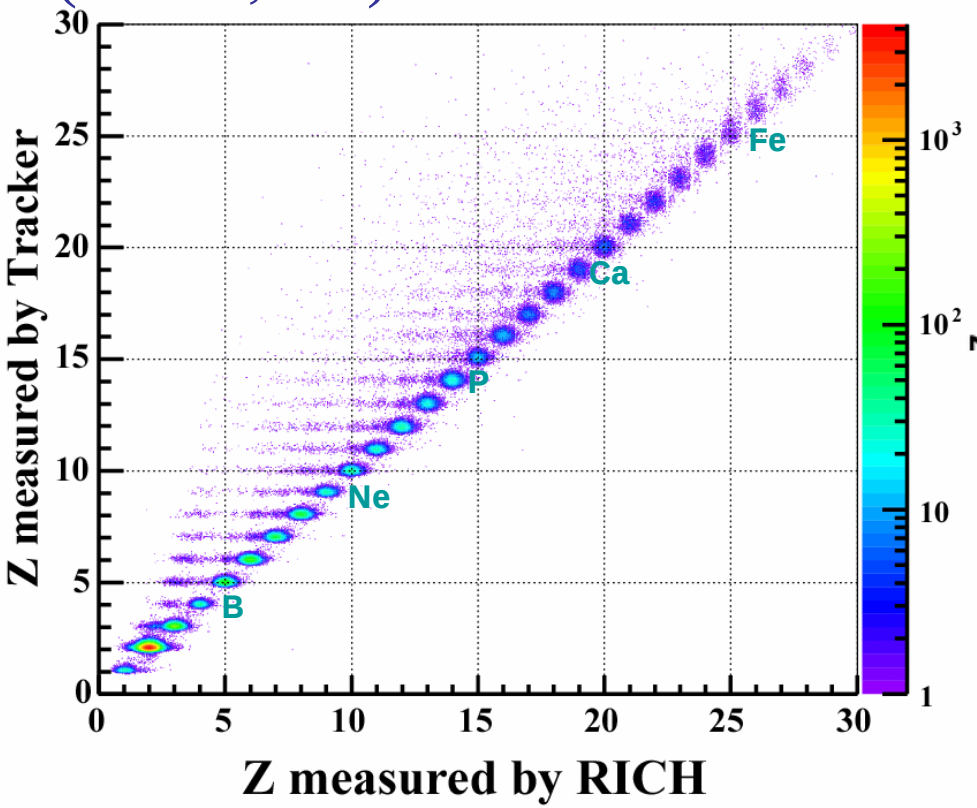
- **Measured by TOF, Tracker and RICH.**
- **Verified by heavy ion beam tests at CERN & GSI.**
- **Nuclei can be identified up *Z=26 (Fe)* .**

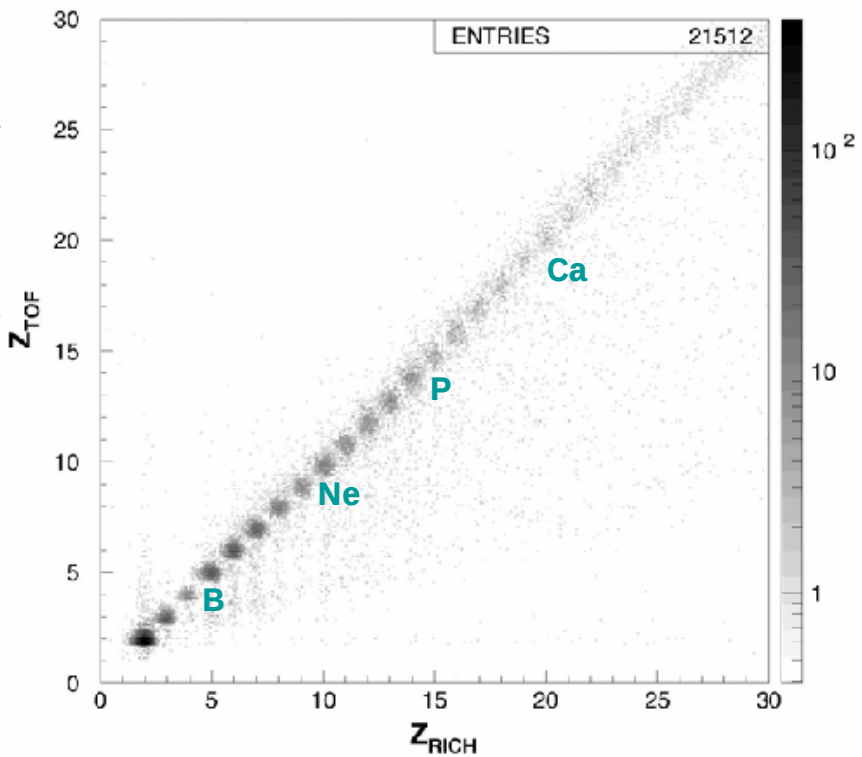




Charge measurements

- ToF, Tracker, RICH performance verified at heavy ion test beam (CERN,GSI)





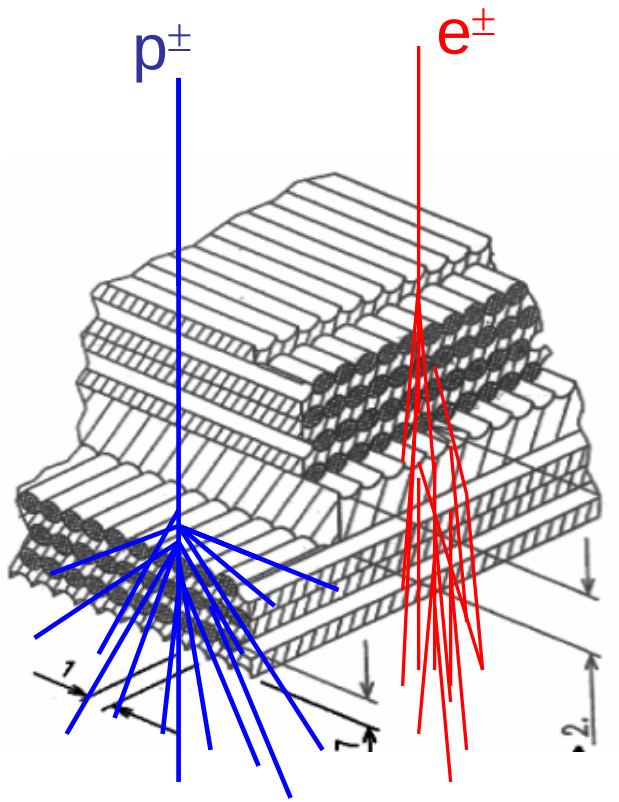
Electromagnetic Calorimeter

3D sampling calorimeter

•9 superlayers of 10 fiber/lead planes each alternate in x and y scintillating fibers viewed by PMT

• 16.4 X_0 radiation length

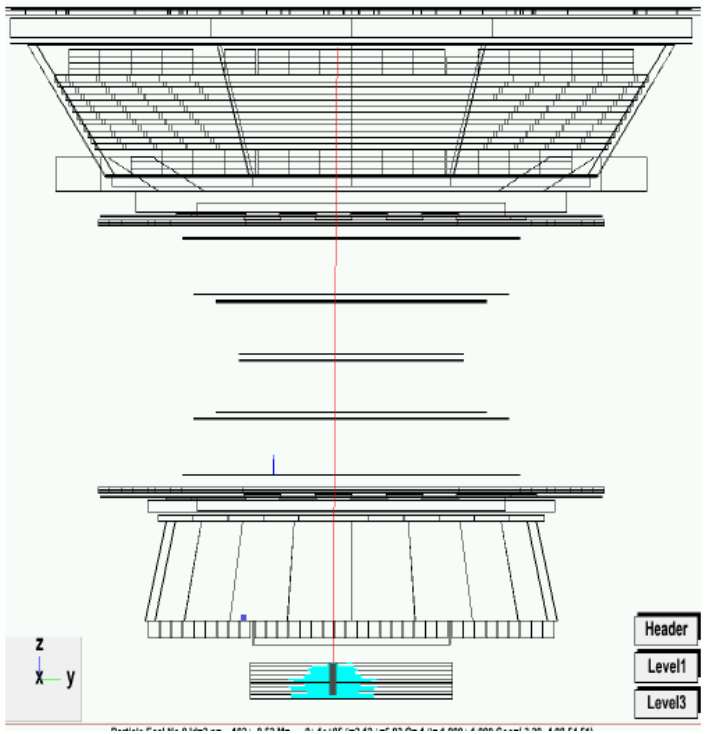
• **Measure energy** (few % resolution) and angle (1° - 0.5° angular resolution) of γ, e^+,e^-



10^{-3} $p^{\pm}$ Rejection at 95% $e^{\pm}$ Efficiency Via Shower Profile
1 GeV - 1 TeV

Gamma Rays detection

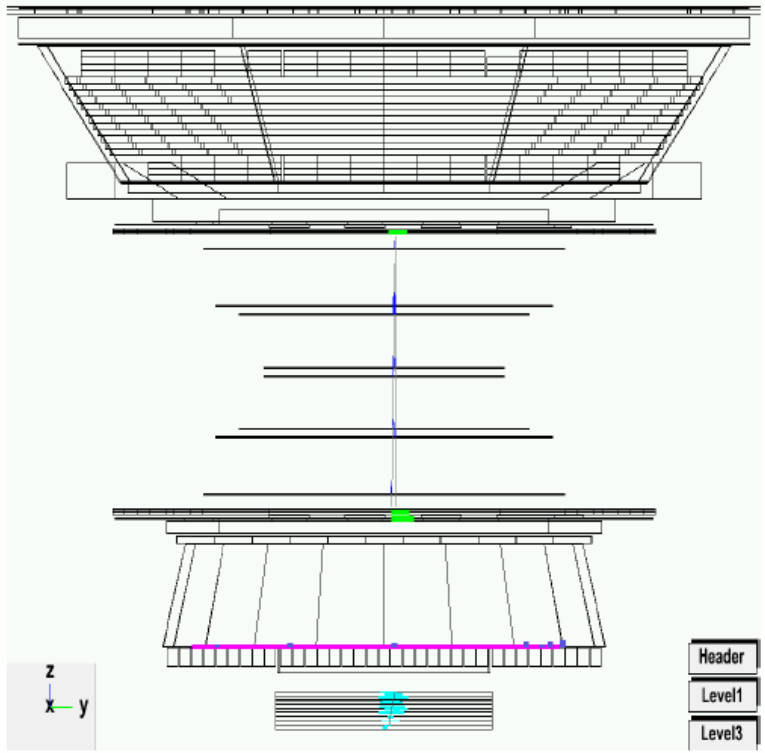
Electromagnetic Calorimeter



≈ 1° angular accuracy

few % energy resolution

Tracker

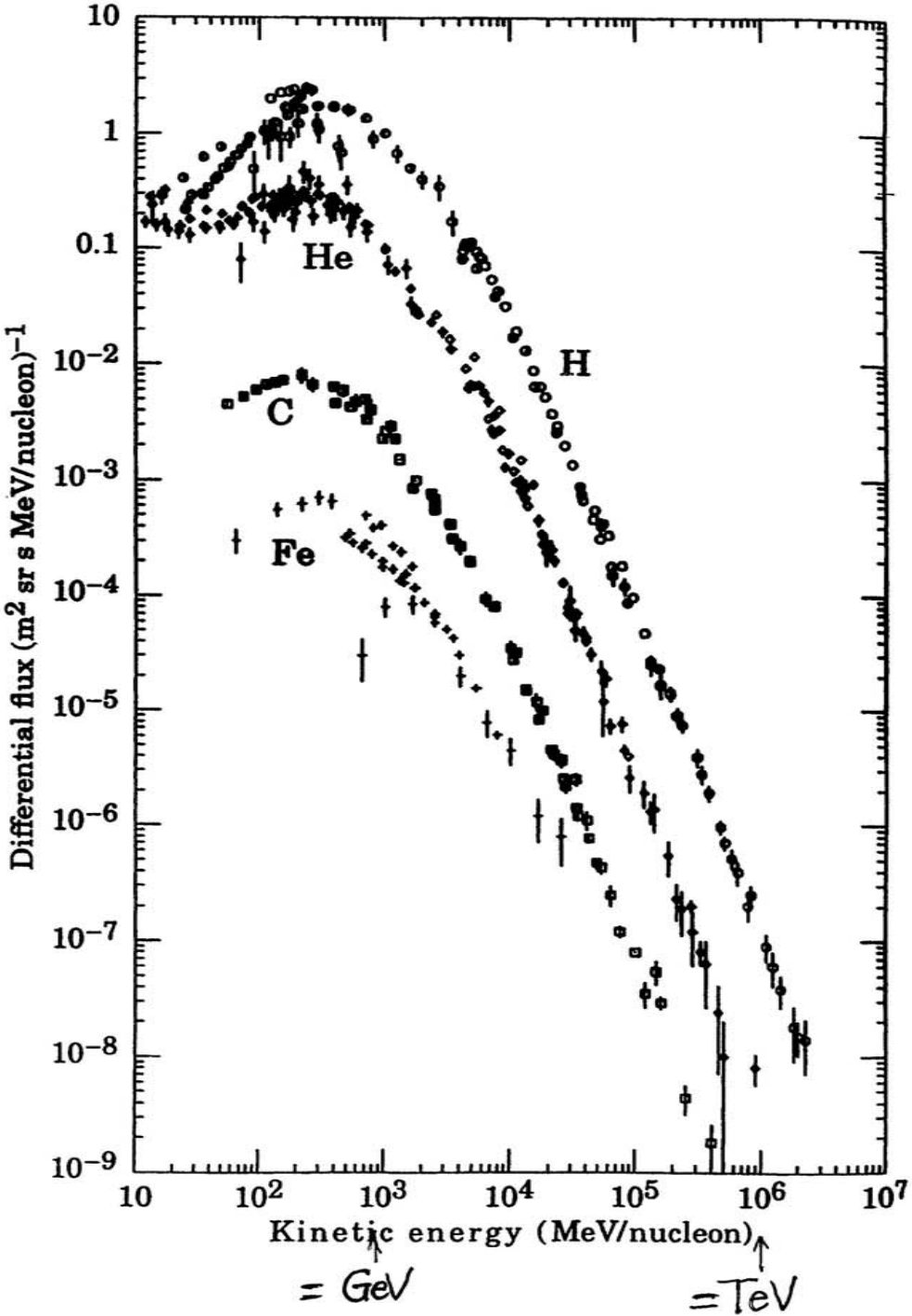


≈ 0.02° angular accuracy

few % energy resolution

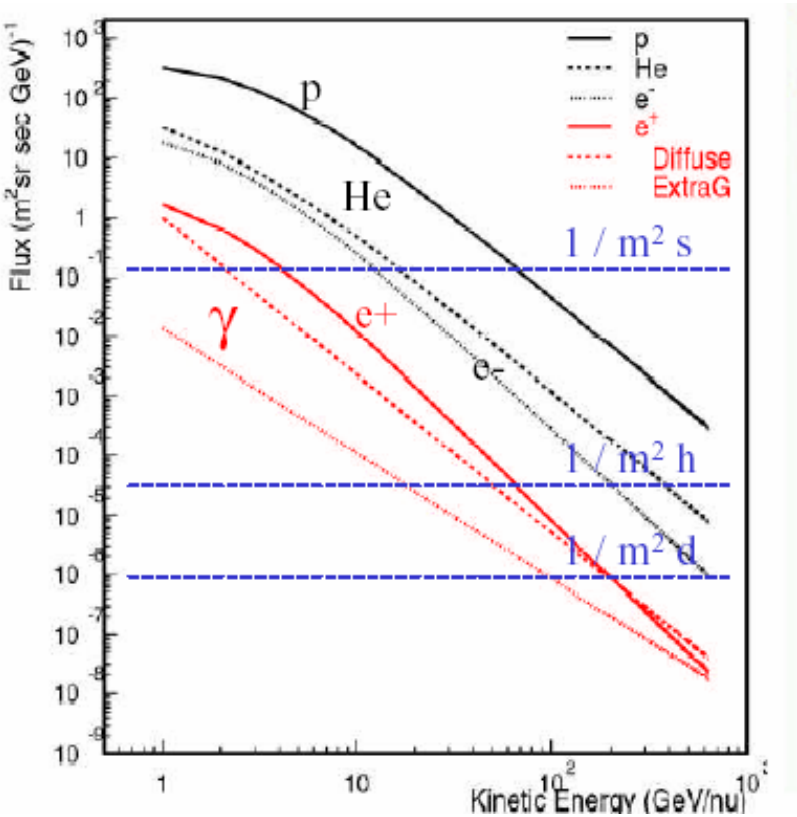
Motivations

- *p and He nuclei are **dominant** (90% p, 9% He)*
- *All elements are present up to Uranium*
- *Atoms reach heliosphere **fully ionized***
- *Absolute fluxes and spec-trum shapes are funda-mental for **calculation of atmospheric ν fluxes***



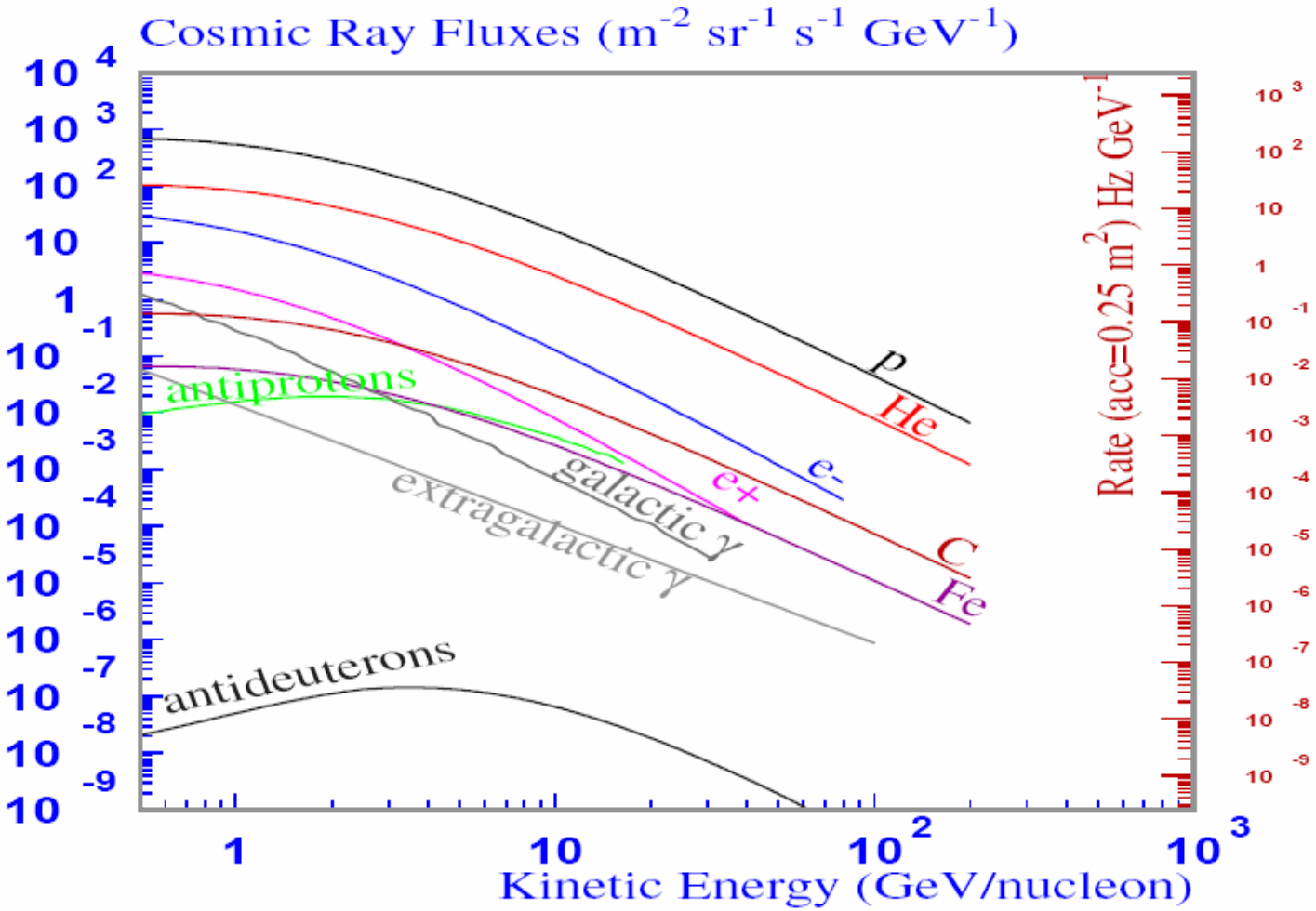
Cosmic Rays

- Cosmic Rays spectrum follows a power law E^{-x} x = 2-3.
- Protons Dominant Component: protons 89%, electrons 1%. He 5% of protons flux at 10 GeV p- ~ 10^{-3} % of proton flux
- Ordinary matter (p,He,electrons): backgrounds.
- Heavy Ions measurements to constrain propagation/acceleration model
- New physics:Antimatter and gamma rays, anti-D signal



Astroparticle studies embedded in Cosmic Ray Physics

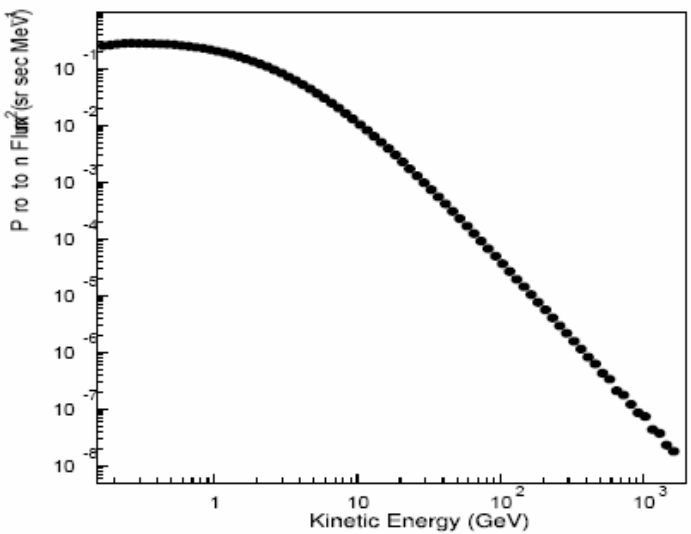
AMS-02 Cosmic Ray measurement capabilities

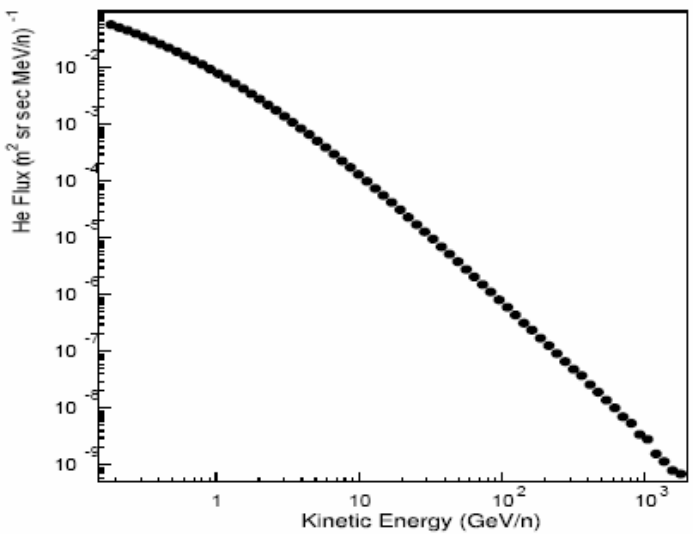


Proton & Helium

Accurate background determination up few TeV:

after 3 years will collect ≈10^7 He with E > 100 GeV/n



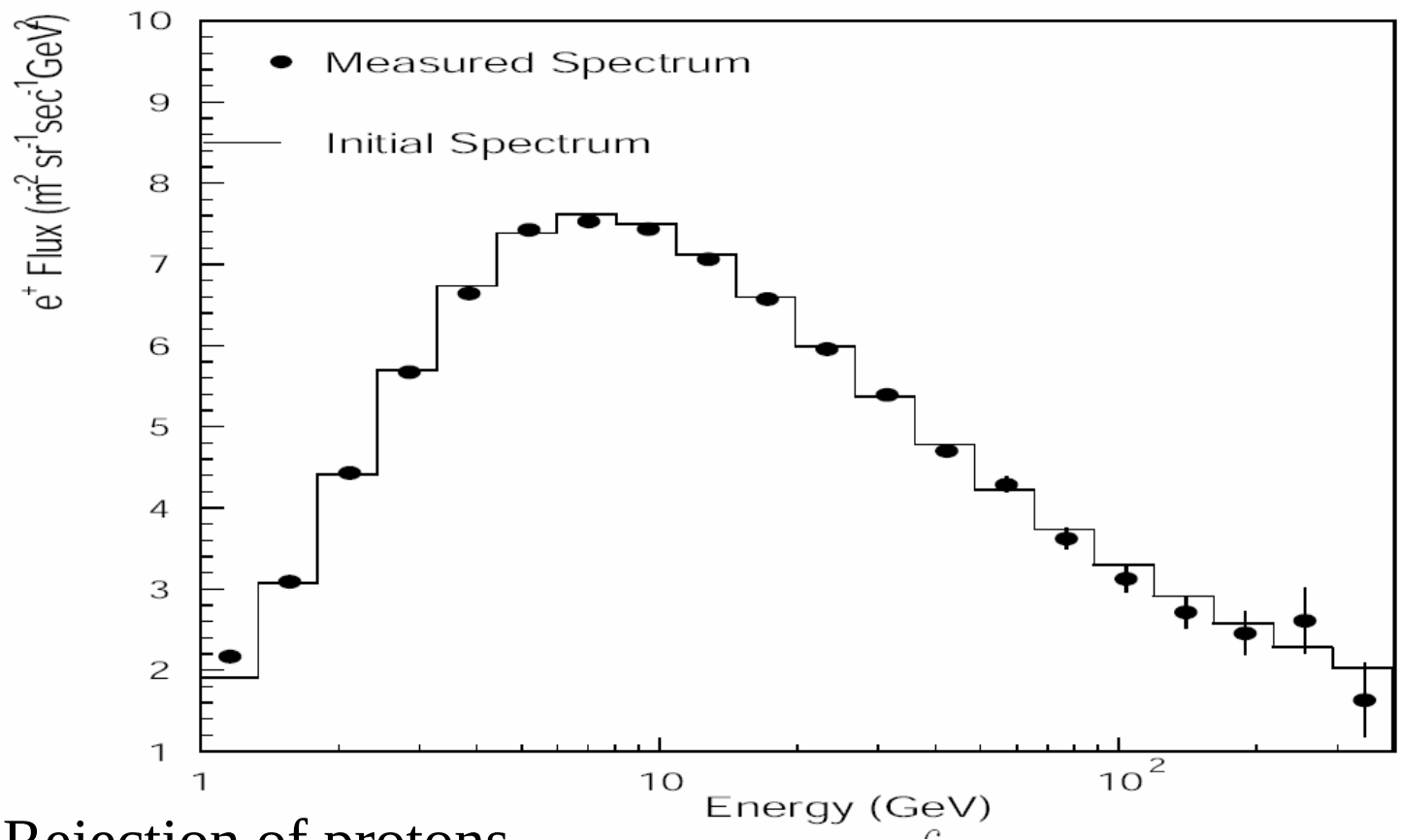


Proton flux measurements after 1 week

He flux measurement after 1 month

Positrons

positron flux after 3 years of data taking

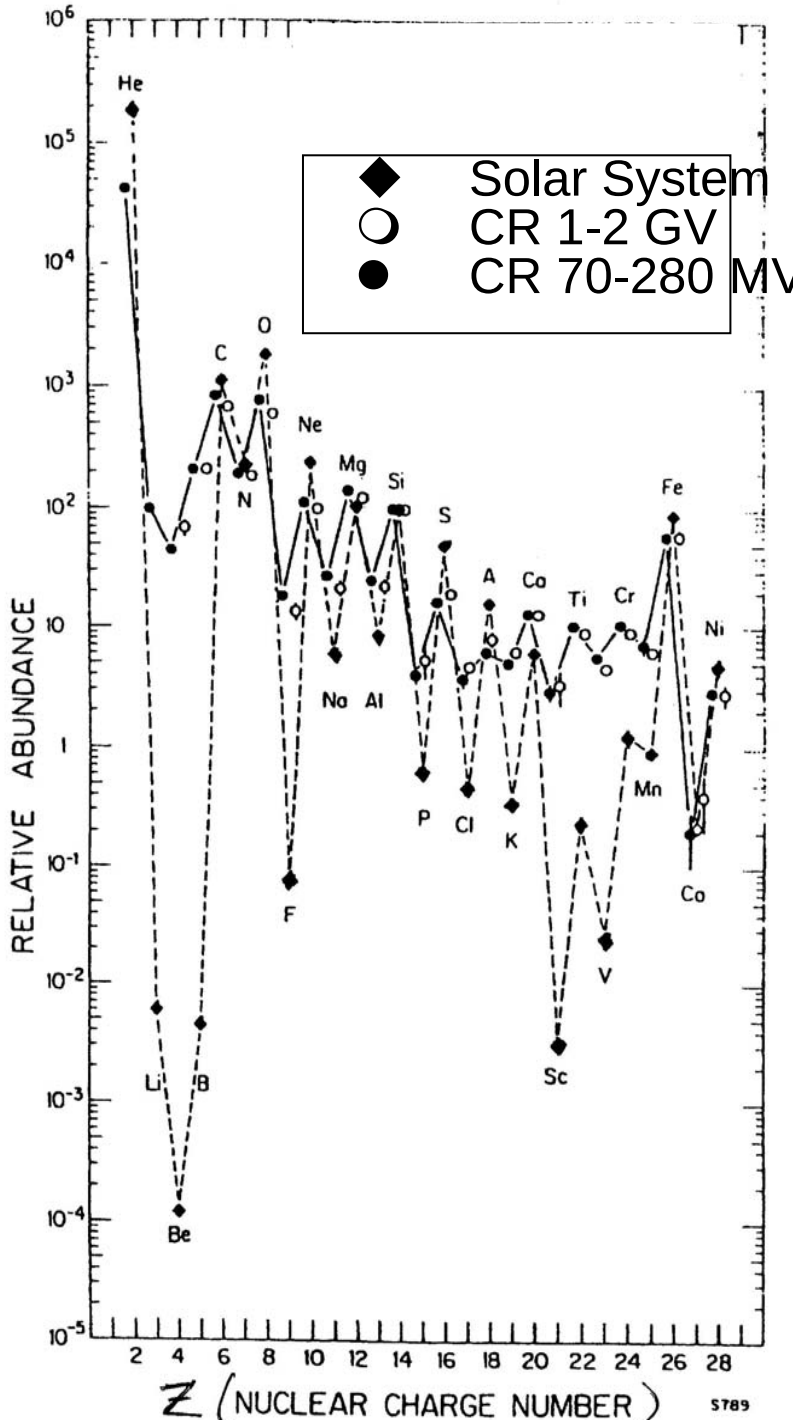


350GeV

Rejection of protons (TRD,ECAL)10^{6}

Cosmic Ray Composition

- ***Chemical composition of CR similar to solar elements, but:***
  - ***1) Li, Be, B*** *enriched*
  - *2) Sc, Ti, V, Cr, Mn enriched*
- ***These ions (apart*** *Li)* ***are not produced in primordial nucleo-synthesis, nor in stars***
  - *1) produced by spallation reactions between p, α with C, N, O in supernovae explosions*
  - *2) spallation from Fe, produced in interstellar medium*

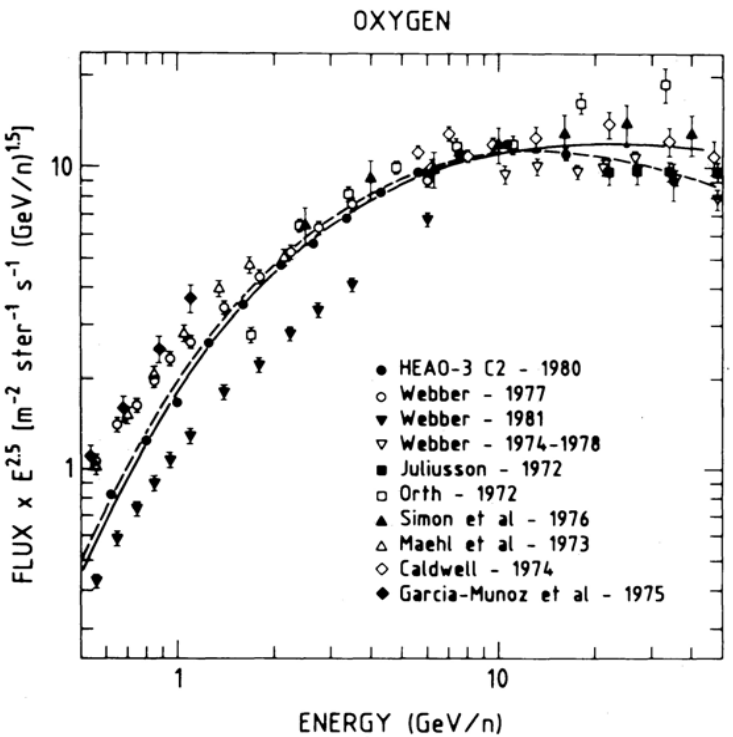


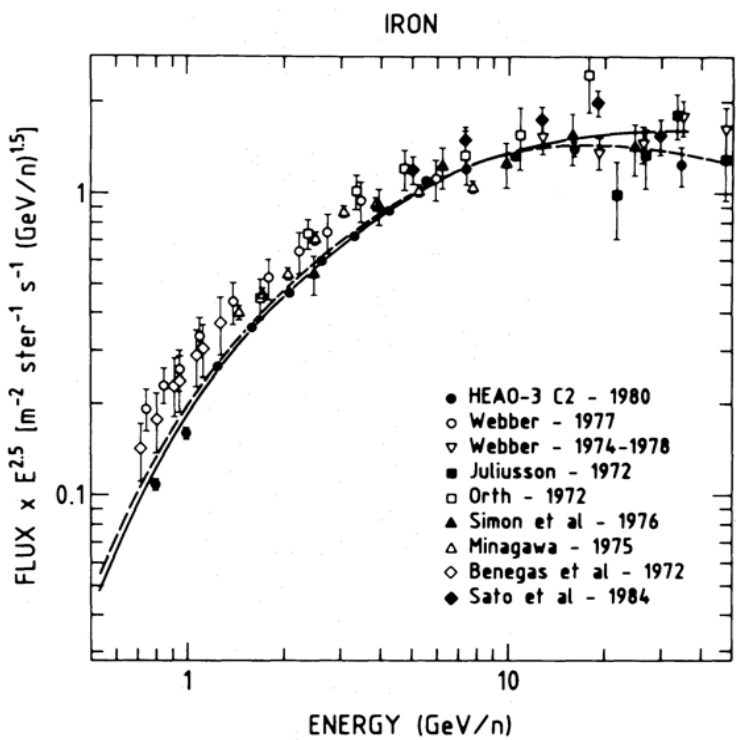
Cosmic Ray Propagation

- The goal of the propagation models is to achieve a reliable physical description of the CR propagation through the Galaxy
- From the measured fluxes in the heliosphere derive source composition, injection spectra & galactic parameters
- Reliable propagation model is needed for accurate background evaluation for rare signal searches in CR
- Particularly useful measurements to validate propagation models and to constrain their free parameters are flux measurements in a wide energy range of
  - Primary (injected at CR sources)
  - Secondary (products of CR interactions with the ISM)
  - Radioactive (provide time information)

Galactic Cosmic Ray Nuclei

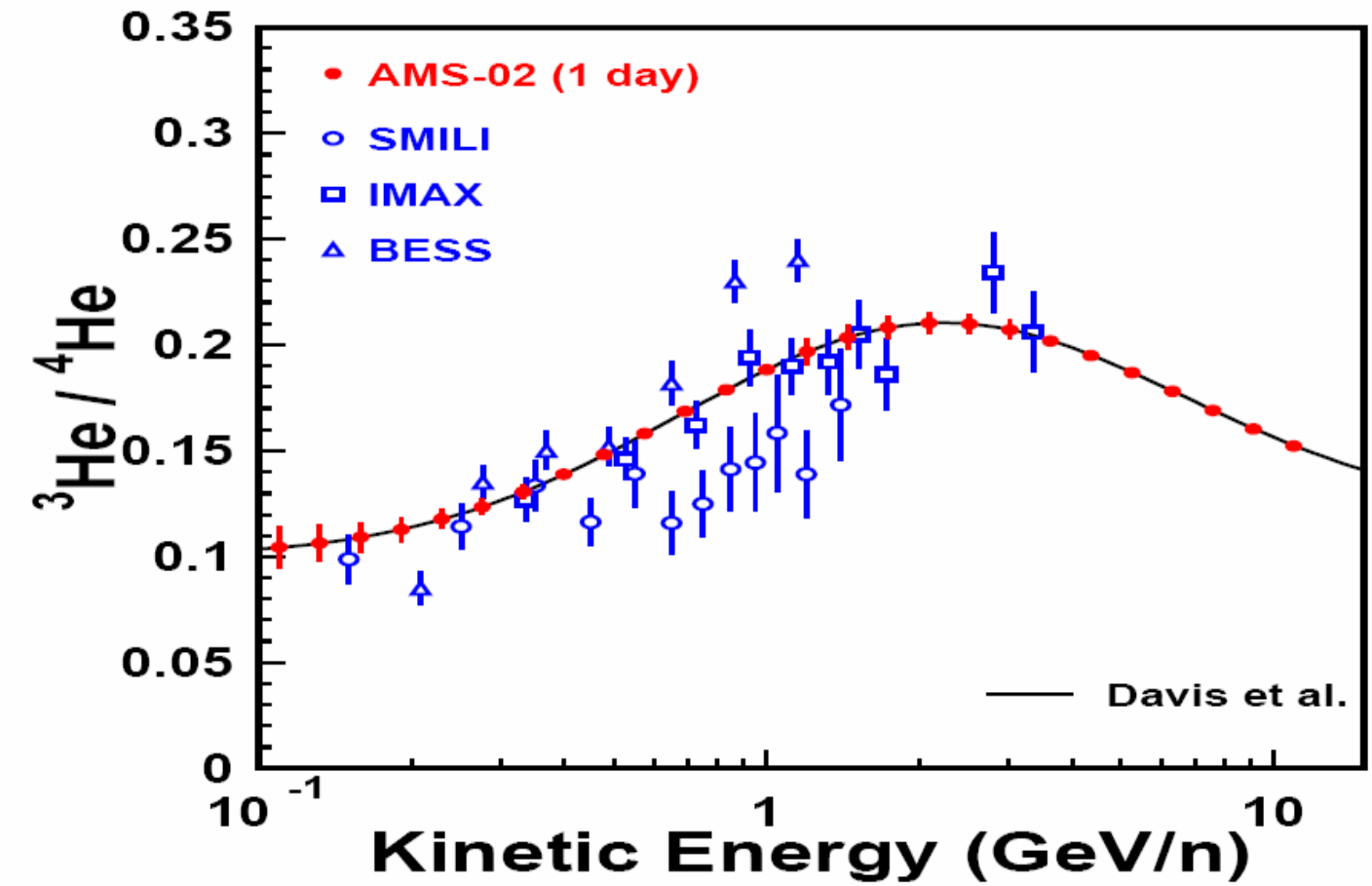
- **Cosmic Ray Nuclei energy spectrum:**
  - Previous measurements with limited accuracy
  - Lack of info about the time variation.
- **Important for the understanding of space environment.**





Helium

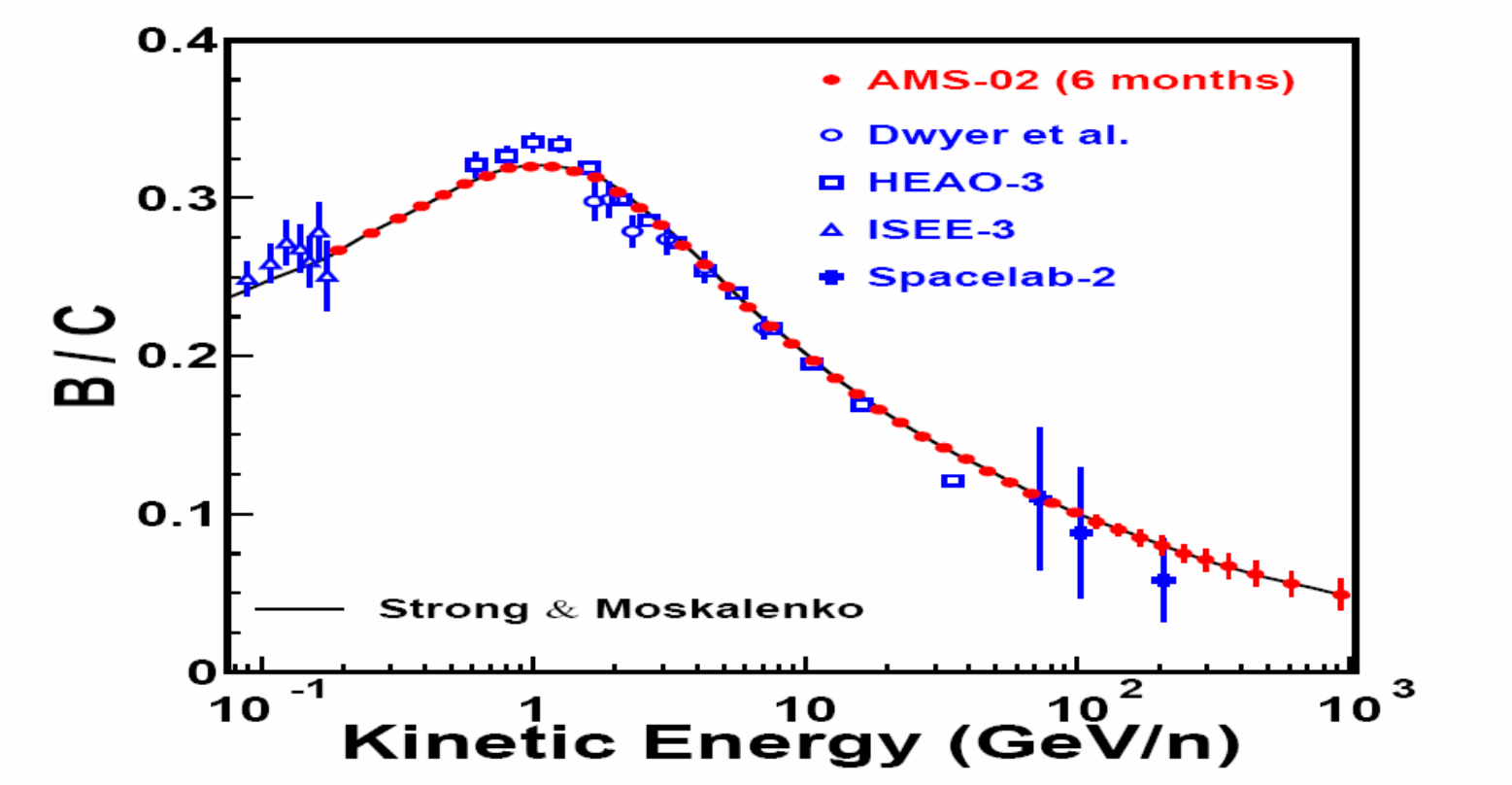
AMS will identify ^{3}He up to 10 GeV/n
after 3 years will collect ≈10^8 ^{3}He



Light Ions

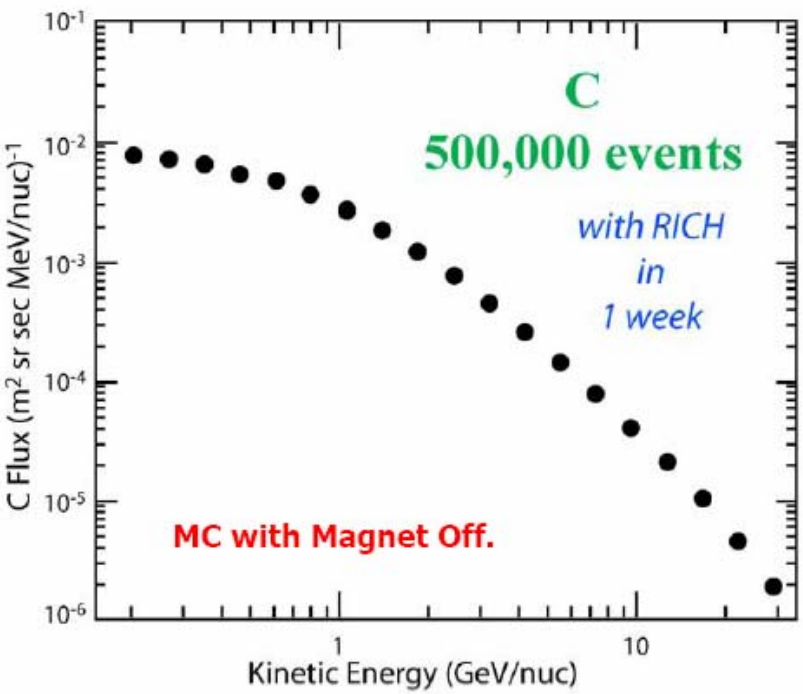
Measurements of B/C ratio will give information on CR diffusion.

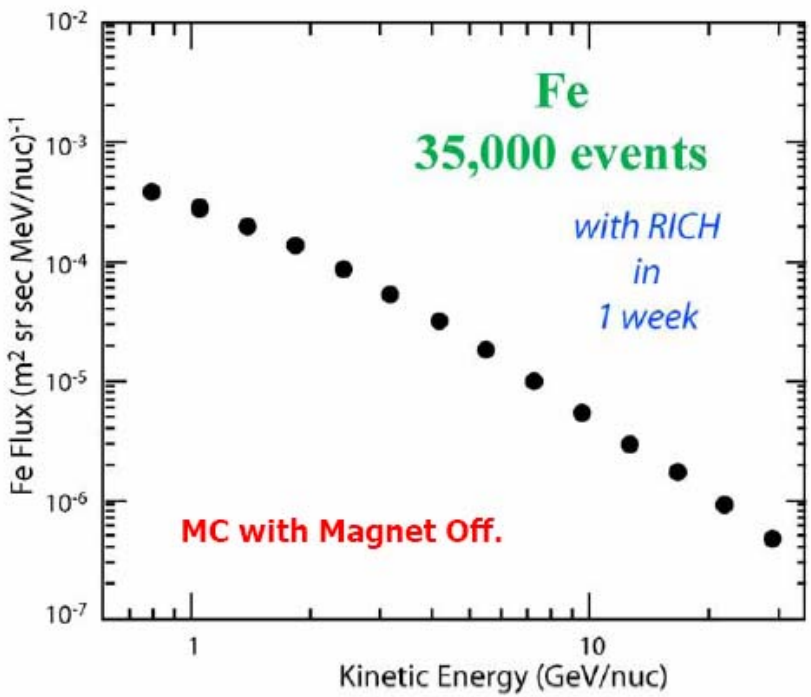
After 3 years will collect ≈10^5 C with E > 100 GeV/n and ≈10^4 B with E > 100 GeV/n



Cosmic Ray Nuclei

Measurements of the nuclei energy spectra up to Fe in the energy range from 0.1 GV to 100 GV.

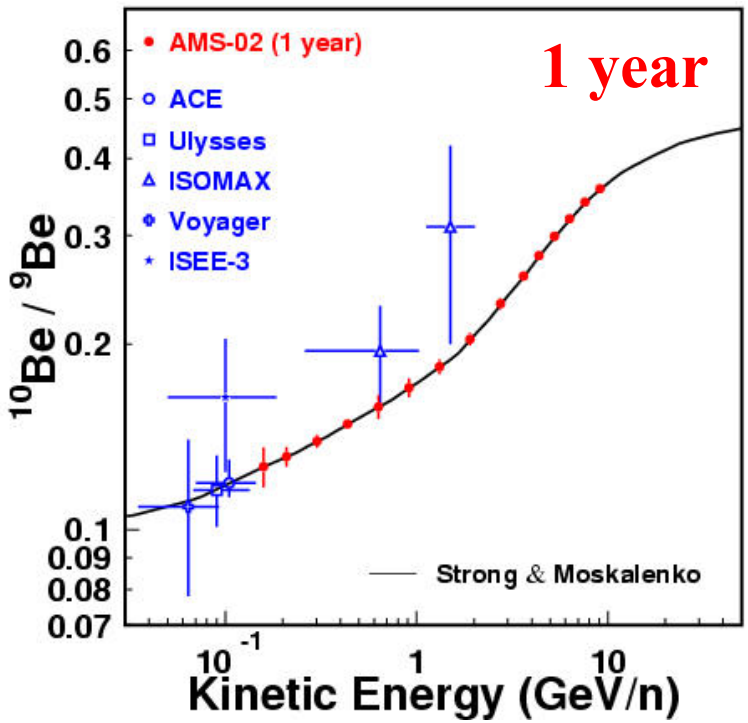




Radioactive Isotopes

^{10}Be ($t_{1/2}$ = 1.51 Myr) is the lightest β-radioactive secondary isotope having a half-life comparable with the CR confinement time in the Galaxy.

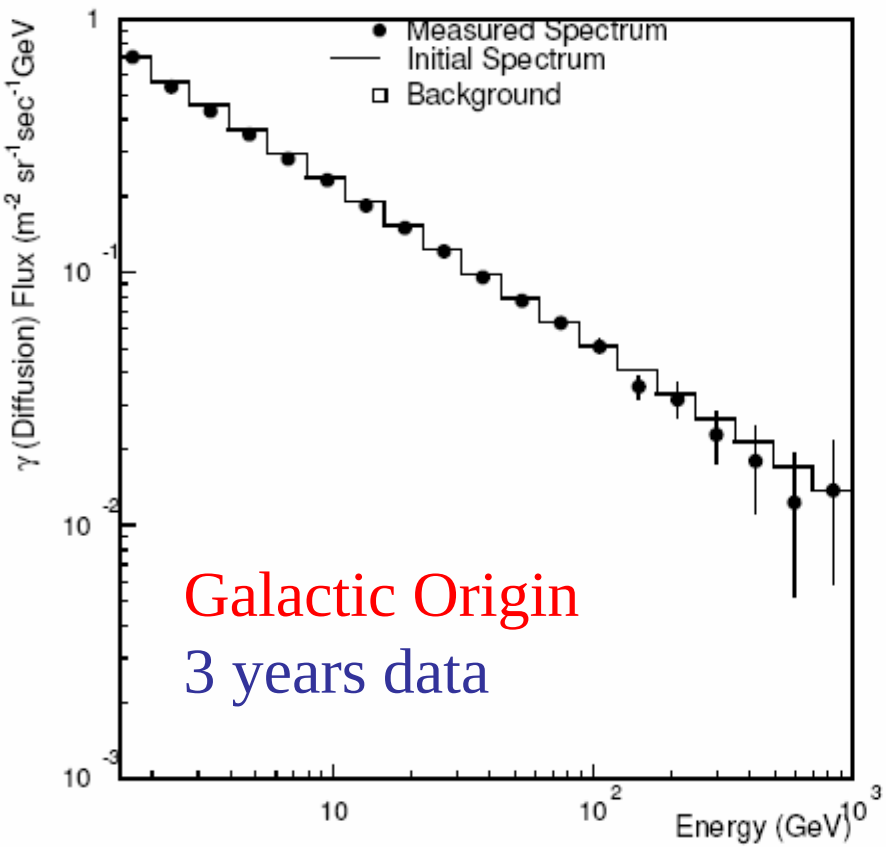
In diffusion models, the ratio ^{10}Be/^{9}Be is sensitive to the size of the halo and to the properties of the local interstellar medium

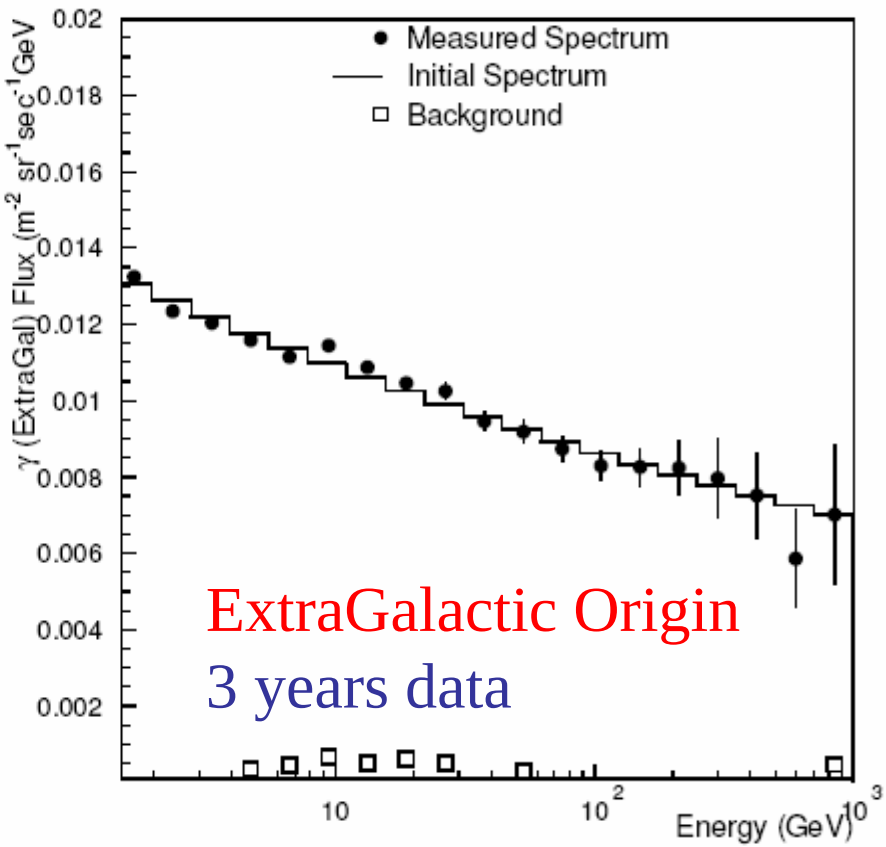


AMS will separate ^{10}Be from ^{9}Be for
0.15 GeV/n < E < 10 GeV/n
after 3 years will collect ≈10^5 ^{10}Be

Gamma Rays

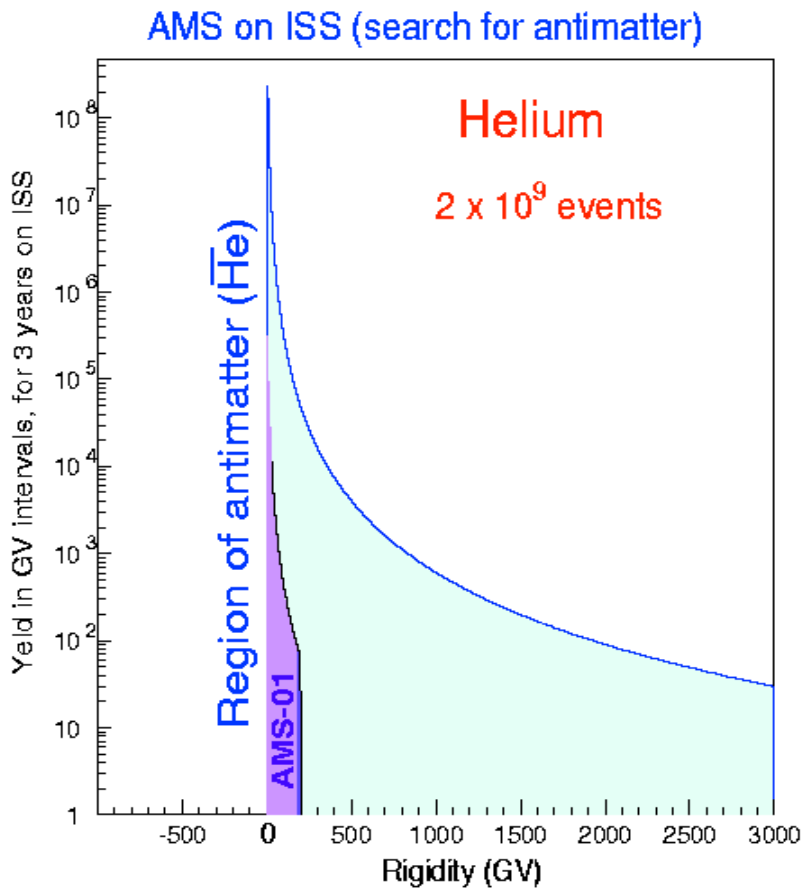
Measurements of γ rays up to 1000 GeV

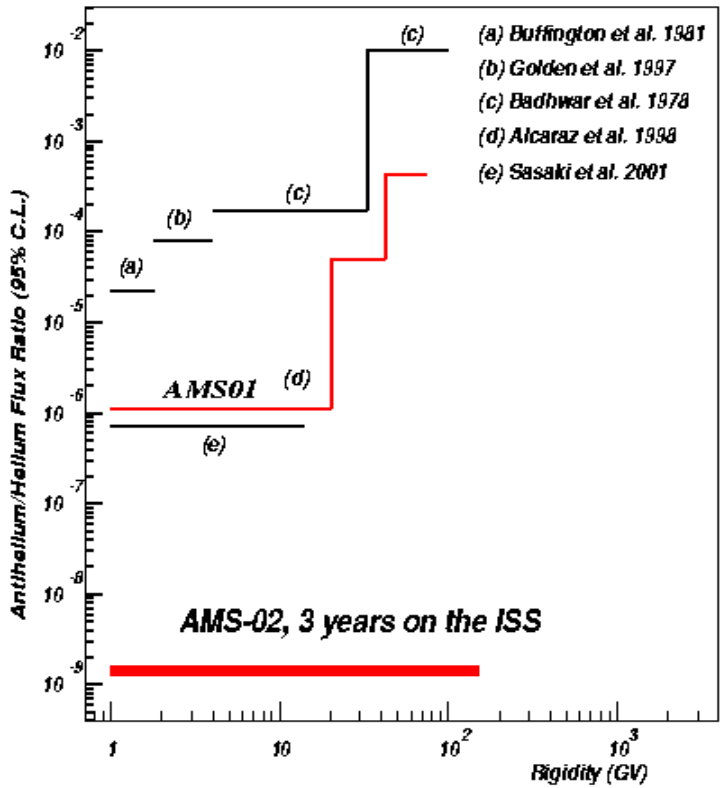




for example 90 γ's of Extragalactic origin with energies above 100 GeV per year

Search for Antimatter





Possible Sources: Primordial baryogenesis AntiMatter Stars

Summary

•AMS02 is magnetic spectrometer on International Space Station, starting take data on beginning 2008:

- Large Acceptance
- Long term operation (>3 years)

AMS02 will provide:

→ Precise Cosmic Ray elemental and isotopic fluxes in a wide energy range

→ These measurements will validate and constrain the free parameters of CR propagation models which will, in turn, provide more reliable estimates for the backgrounds in rare signal searches in Cosmic Ray.