REVIEW ON PRECISION MEASUREMENTS OF HIGH ENERGY HADRONS

Jorge Casaus
CIEMAT - Madrid

II International Workshop on Matter, Antimatter and Dark Matter
Trento, October 29, 2001

OUTLINE

- Introduction
- Recent Experiments
- Results
- Future Experiments
- Expected Performances
- Conclusions

INTRODUCTION

- Hadrons are the main component in Cosmic Rays (CR)

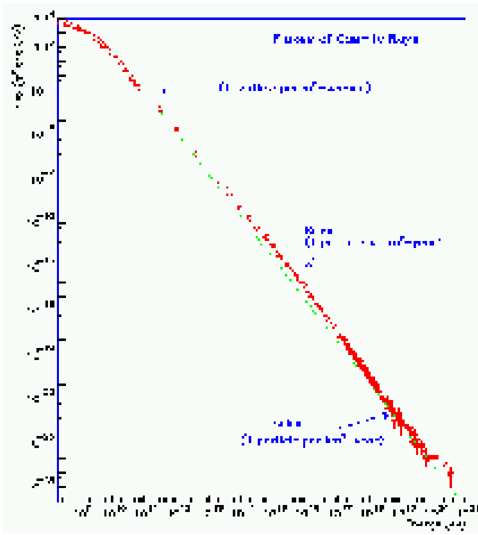
- Precise measurement of abundances and spectra reveal

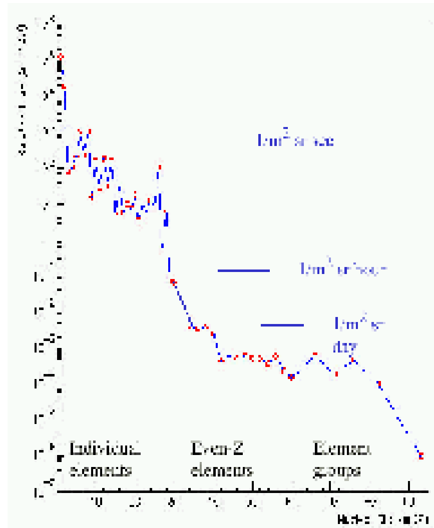
  1. Source Composition
  2. Acceleration Mechanisms $\Longleftrightarrow$ Propagation Models
  3. Interactions with ISM

- Background for searches of exotic CR

- Input for atmospheric neutrino calculations

INTRODUCTION





- Only Experiments with direct detection of CR will be considered
- Direct detection for $E \lesssim 10^{15}$ eV
- Individual charge measurement for $Z < 60$

  Only Even-Z elements for $30 \leq Z \leq 60$
- Strategies to overcome the low expected flux
  1. Large Acceptance *(Balloons)*
  2. Long Duration *(Space)*

BALLOONS vs SPACE-BORNE

	BALLOONS	SPACE-BORNE
Geometrical Acceptance	✓	✓
Flight Duration	✓	✓
Measurement Redundancy	✓	✓
Atmospheric Corrections	✓	✓
Detector Accessibility	✓	✓
Flight Control	✓	✓
Price	✓	✓

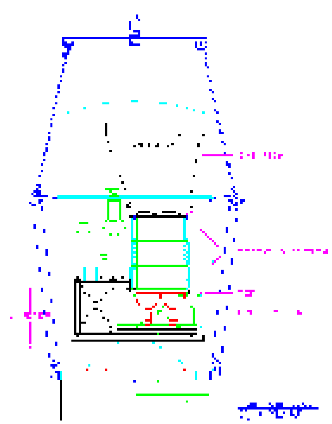
⇒ New Experiments:

Acceptance & Duration

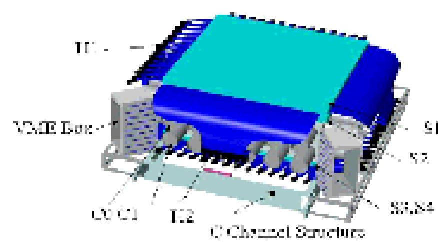
BALLOONS

- Magnetic Spectrometers (R,β,Z)
- Charge Identifiers (Z,β)
- Emulsion Chambers (E,Z)

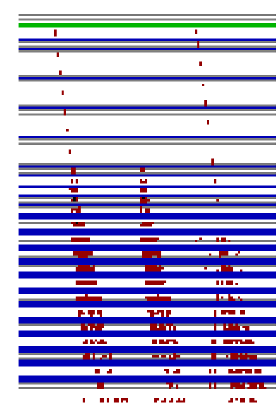
CAPRICE



TIGER



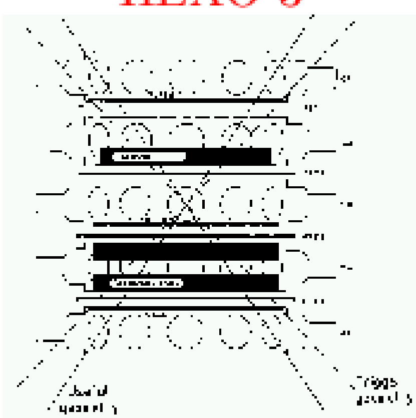
JACEE



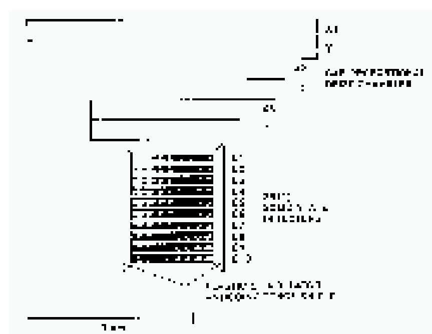
SPACE-BORNE

- Double Cerenkov (Z,β)
- Multiple dE/dx $\oplus$ Total E (Z^2M)
- Magnetic Spectrometers (R,β,Z)

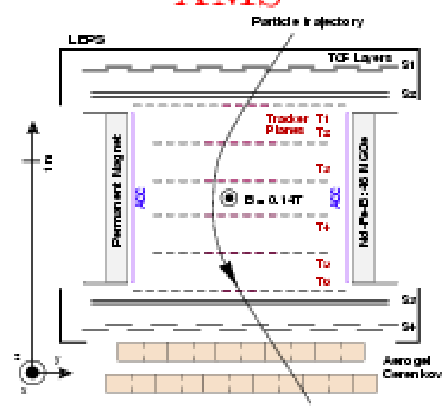
HEAO-3



ISEE-3



AMS



HIDROGEN

- $0.1\ \text{GeV} \lesssim E \lesssim 100\ \text{GeV}$

  Spectrometers: within 5%

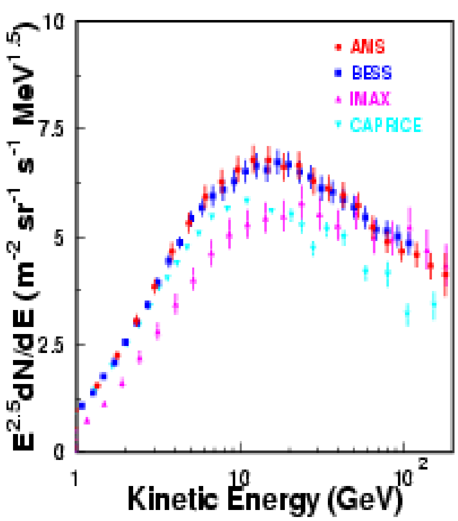
- $100\ \text{GeV} \lesssim E \lesssim 1\ \text{TeV}$

  Calorimeters: within $\approx 25\%$

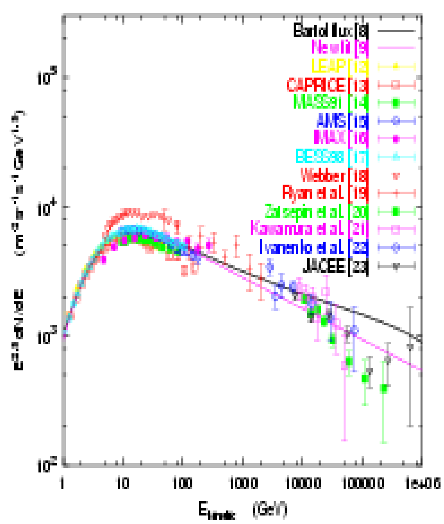
- $1\ \text{TeV} \lesssim E \lesssim 1000\ \text{TeV}$

  Emulsion Chambers: within $\approx 25\%$

$1\ \text{GeV} \lesssim E \lesssim 100\ \text{GeV}$



$1\ \text{GeV} \lesssim E \lesssim 1000\ \text{TeV}$



HELIUM

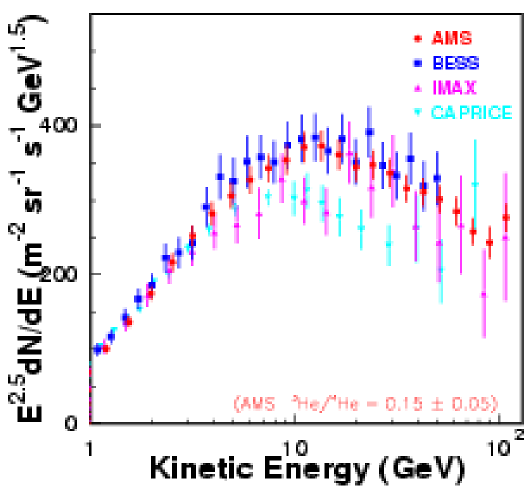
- 0.1 GeV $\lesssim$ E $\lesssim$ 100 GeV

  Spectrometers: within 10%

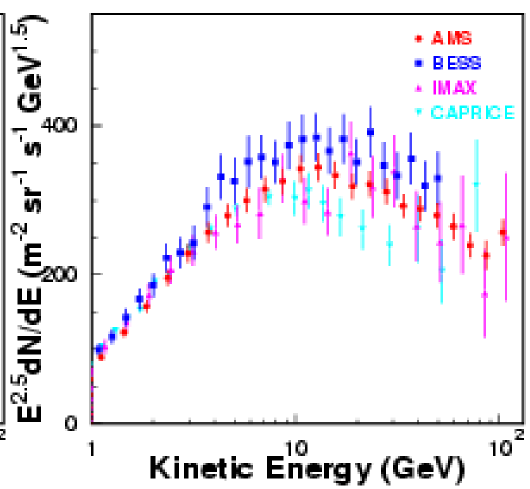
- E $\gtrsim$ 100 GeV

  Emulsion Chambers: Poor statistics

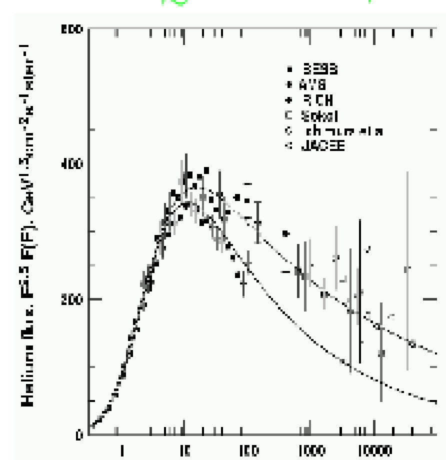
E $\lesssim$ 100 GeV/n



E $\lesssim$ 100 GeV/n



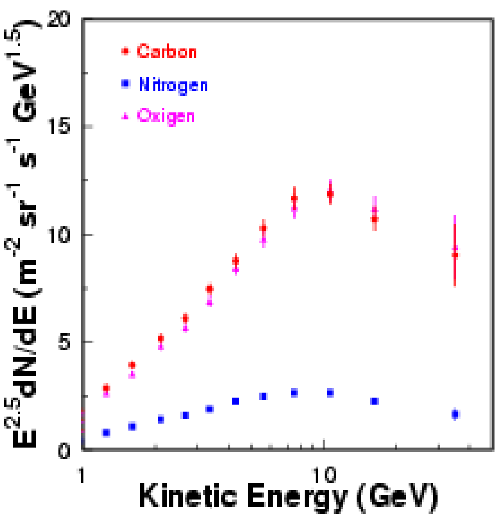
E $\lesssim$ 1000 TeV/n



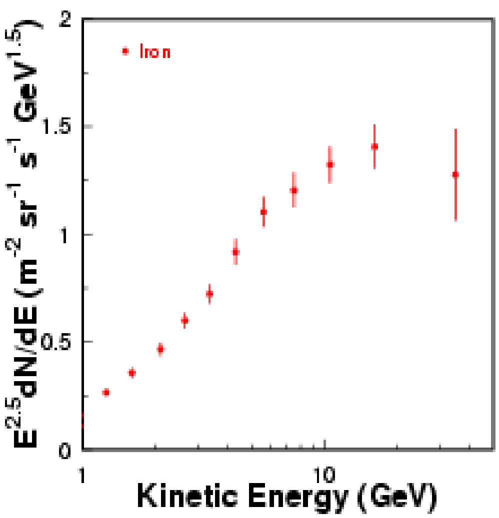
Z > 2

- Most precise measurements from HEAO-3
- Operated for 8 months in 1979 - 1980
- 7 million events with $4 \leq Z \leq 28$
- Charge resolution 0.12 - 0.2 units
- Absolute fluxes from 0.6 to 35 GeV/n
- Systematic Errors $\sim$ 5%

C N O



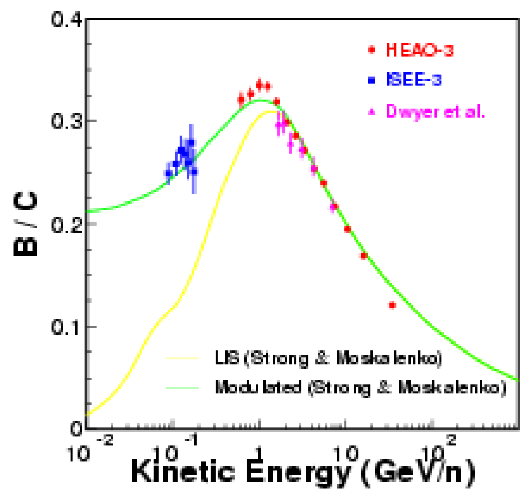
Fe



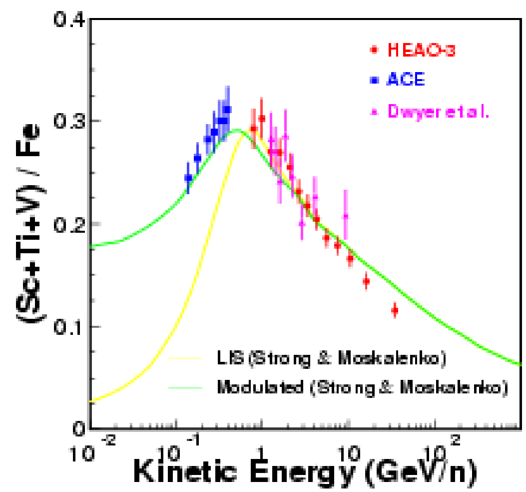
SECONDARY CR

- B/C and sub(Fe)/Fe measured for 0.1 GeV/n $\lesssim$ E $\leq$ 35 GeV/n
- Precision of $\sim$ 5% for B/C and $\sim$ 10% for sub(Fe)/Fe
- Data consistent with 9 g cm^{-2} crossed by primary CR

B/C



(Sc+Ti+V)/Fe



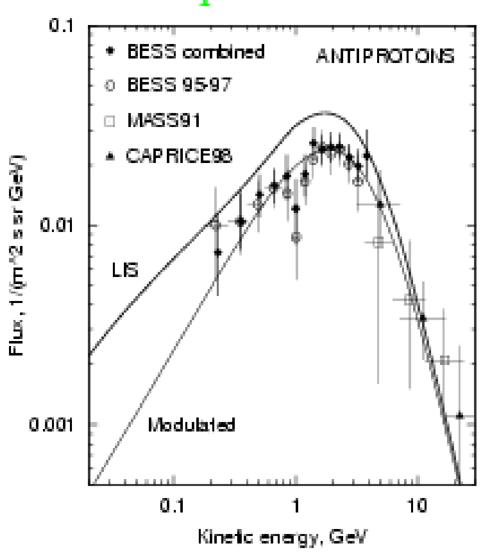
$\bar{p}$

- Main hadronic antimatter expected in CR
- Deviations from secondary spectrum

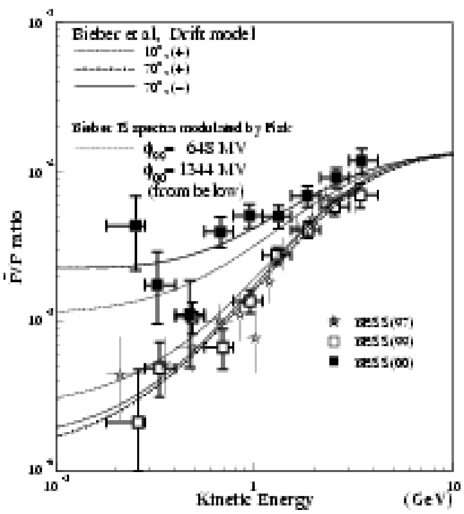
$\Rightarrow$ new physics

- World statistics $\approx 2000\ \bar{p}$
- Energy range $0.2\ \text{GeV} \lesssim E \leq 50\ \text{GeV}$

$\bar{p}$ flux



$\bar{p}$/p ratio



$\Rightarrow$ Data consistent with secondary production

Light Isotopes (1/2)

- Magnetic Spectrometer measurements in the energy range

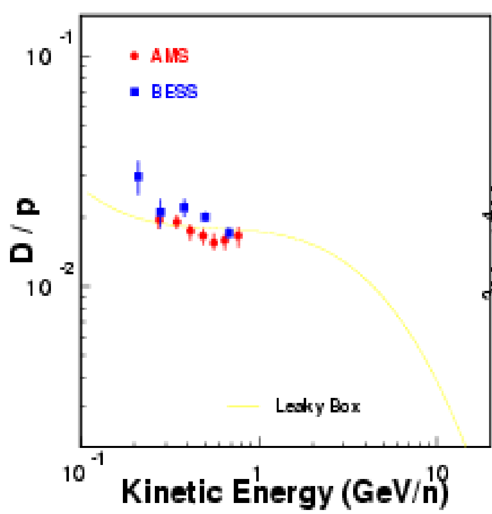
D/p: $0.2\ \text{GeV/n} \lesssim E \lesssim 0.8\ \text{GeV/n}$

^{3}He/^{4}He: $0.1\ \text{GeV/n} \lesssim E \lesssim 3.4\ \text{GeV/n}$

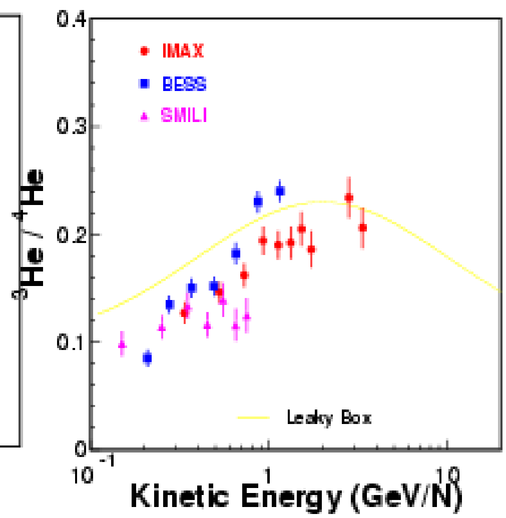
- Statistical errors $\gtrsim$ 5 - 10%

- Sensitive to propagation history of p and ^{4}He

D/p



^{3}He/^{4}He



Light Isotopes (2/2)

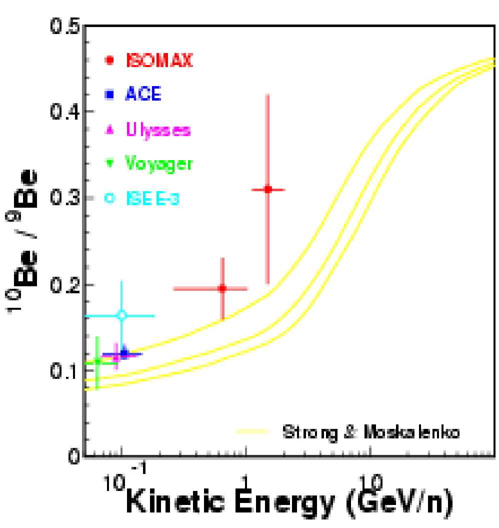
- Radioactive nuclei ≡ *CR Chronometers*
- ^{10}Be ($t_{1/2}$ = 1.51 Myr)
  ^{26}Al ($t_{1/2}$ = 4.08 Myr)
- Measurements in space

$$E \approx 100 \text{ MeV/n}$$

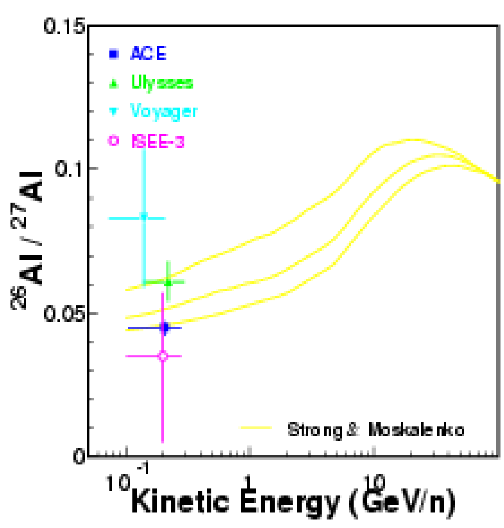
- Balloon measurement

$$0.3 \text{ GeV/n} \lesssim E \lesssim 2 \text{ GeV/n}$$

^{10}Be/^{9}Be



^{26}Al/^{27}Al



CONCLUSIONS (1/2)

- CR spectra are determined with precision in the energy range

$$\mathrm{E} \lesssim 100 \ \mathrm{GeV/n} \ \ \& \ \ \mathrm{Z} < 30$$

- CR abundances are accurately measured for

$$\mathrm{Z} < 30 \ \text{ and } \ \text{Even-Z for } 30 < \mathrm{Z} < 60$$

- Light Isotope Spectra are measured for

$$\mathrm{E} \lesssim 1 \ \mathrm{GeV/n}$$

⇒ In order to overcome current limitations:

Long Duration & Large Acceptance & Multipurpose Experimets

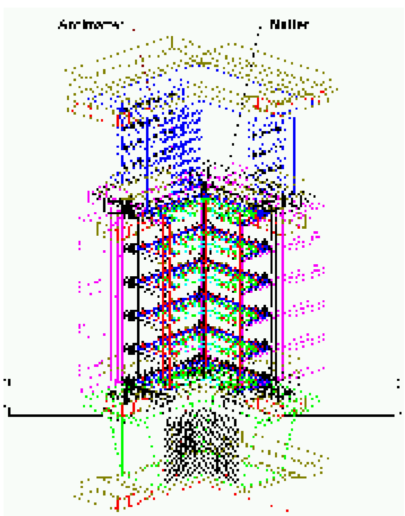
FUTURE EXPERIMENTS

- Balloons

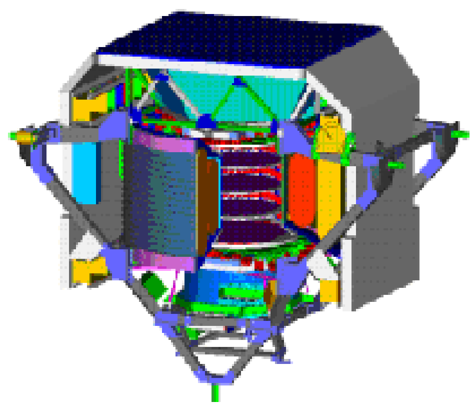
  Ultra Long Duration Balloon program
  (ULDB)

- Space-Borne
  - Magnetic Spectrometers

PAMELA

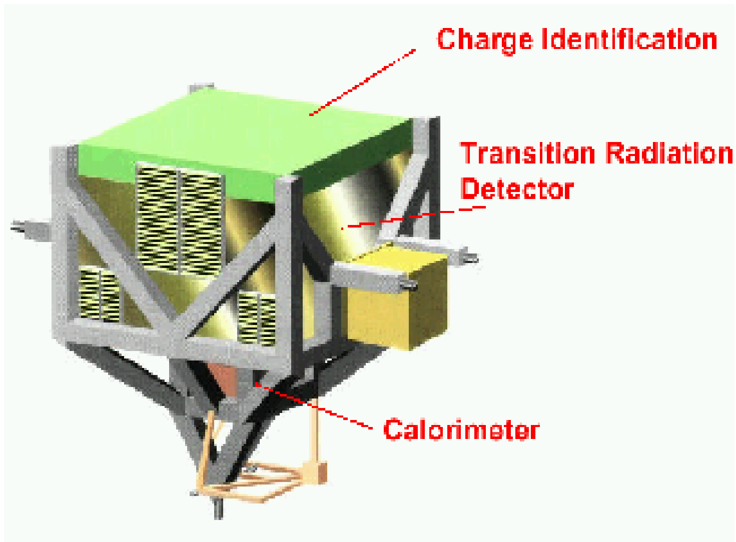


AMS-02



FUTURE EXPERIMENTS

– ACCESS



* Energy Spectra

$$1 \leq Z \leq 28 \text{ for } E \lesssim 10^{15} \text{ eV}$$

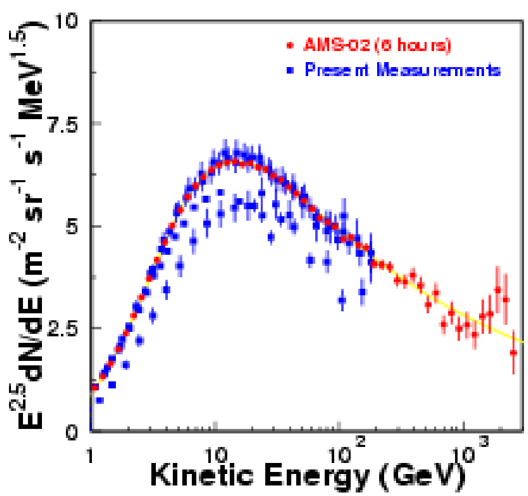
* Individual Element Abundances

$$Z > 28$$

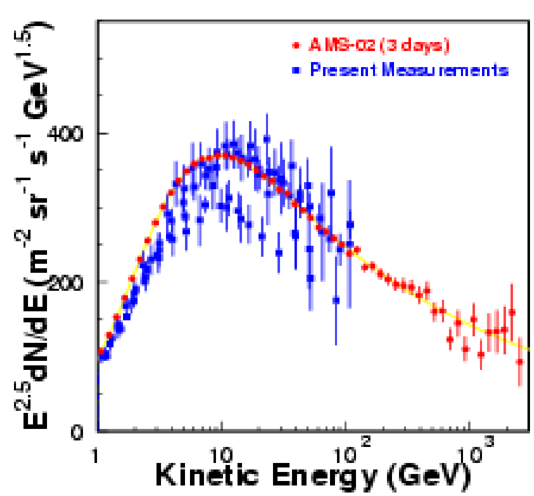
Prospects H & He

- AMS-02 after 3 years will collect $\approx 10^8$ H with $E > 100$ GeV and $\approx 10^7$ He with $E > 100$ GeV/n
- AMS-02 will measure the Hidrogen and Helium flux for $E \lesssim 1$ TeV

HIDROGEN



HELIUM



Prospects Secondary CR

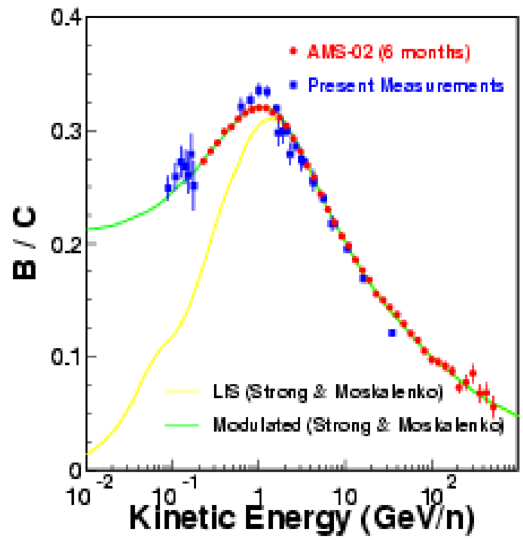
- AMS-02 will measure the spectrum of light nuclei for

$$E \lesssim 1 \text{ TeV/n}$$

- AMS-02 after 3 years will collect

$$\approx 10^5 \text{ C with } E > 100 \text{ GeV/n}$$
$$\approx 10^4 \text{ B with } E > 100 \text{ GeV/n}$$

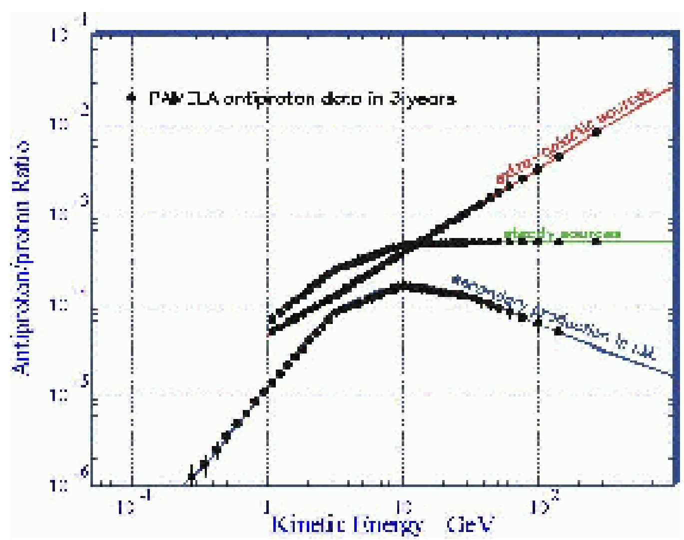
B/C



Prospects $\overline{p}$

- PAMELA will measure the $\overline{p}$ flux $E \lesssim 200$ GeV
- after 2 years will collect $\approx 10^4$ $\overline{p}$

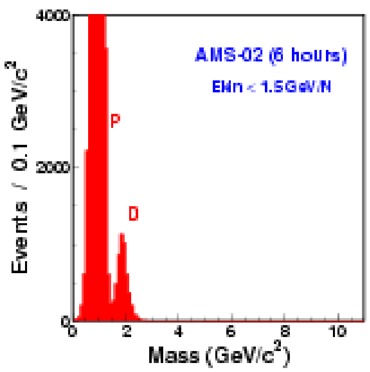
$\overline{p}$

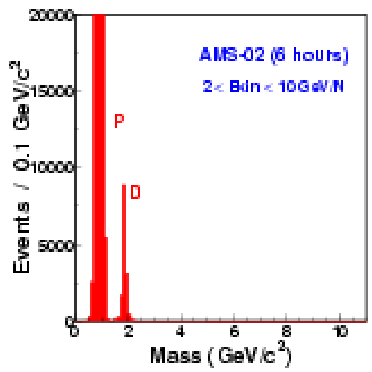


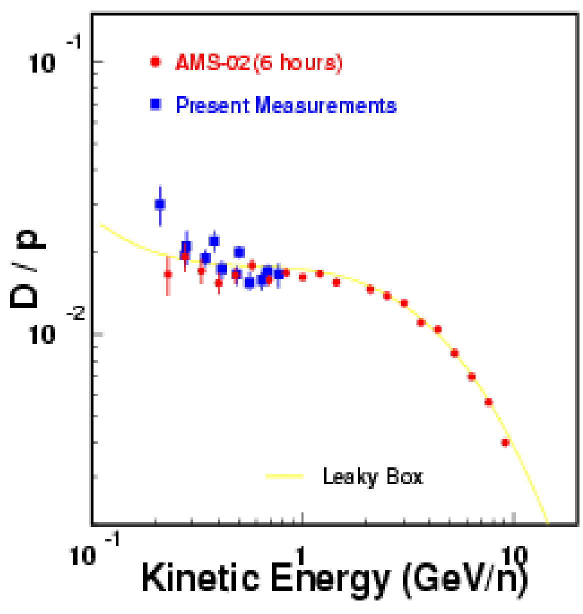
Prospects Light Isotopes

- AMS-02 will identify D up to 10 GeV/n
- AMS-02 after 3 years will collect

$$\approx 10^8 \text{ D}$$



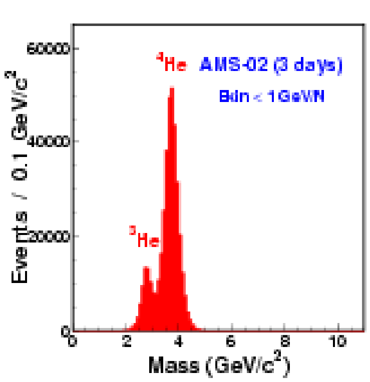


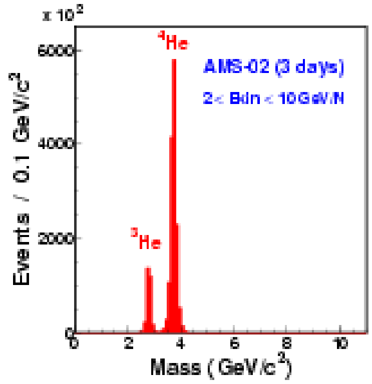


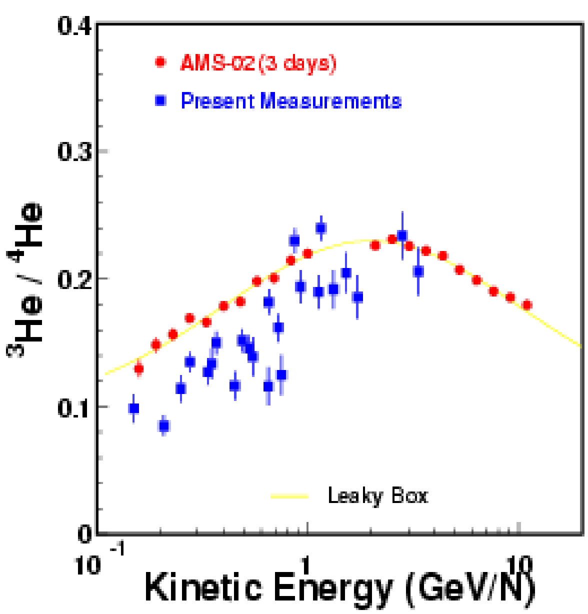
Prospects Light Isotopes

- AMS-02 will identify ^{3}He up to 10 GeV/n
- AMS-02 after 3 years will collect

$$\approx 10^8 \ {}^3\text{He}$$







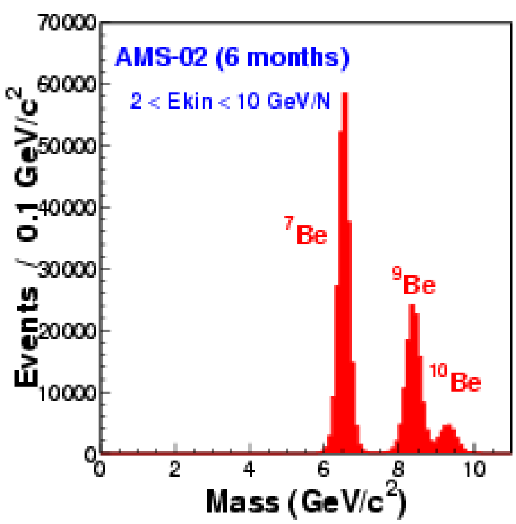
Prospects $^{10}Be/^{9}Be$

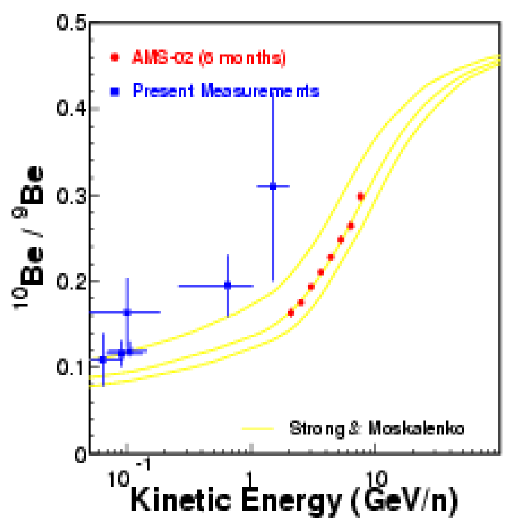
- AMS-02 will separate ^{10}Be from ^{9}Be for

$$2 \text{ GeV/n} < E < 10 \text{ GeV/n}$$

- AMS-02 after 3 years will collect

$$\approx 10^5 \ ^{10}\text{Be}$$





CONCLUSIONS (2/2)

- Precise knowledge of the hadronic component of CR is required for
  - CR production, acceleration & propagation
  - Understanding backgrounds for searches in CR
  - Atmospheric ν
- Precise measurements of hadrons in CR are limited to *low* E and *low* Z
- Near future experiments
  - ULDB
  - Large Acceptance, sensitive experiments in space

  will improve dramatically our knowledge of CR