Astrophysics with the AMS-02 experiment

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Astrophysics with AMS-02

- Astrophysics aims
- Physics requirements for AMS
- AMS experiment & AMS-02 detector
- Detector capabilities
  - *Charge measurement*
  - *Velocity measurement*
  - *Mass identification*
- AMS-02 prospects
- Conclusions

Astrophysics aims

- Better knowledge of cosmic ray spectrum is needed
  - *Hadronic component gives information on production, acceleration and propagation mechanisms*
    - Secondary-to-primary ratios (d/p, ^{3}He/^{4}He): test to propagation models
    - Confinement times (^{10}Be/^{9}Be): constraint to galactic halo models
    - Long period of observation will give information on solar cycle variations
  - *Existence of antimatter domains might be inferred from direct detection of antinuclei*
  - *Dark matter signatures may be found in cosmic rays*

Physics requirements for AMS

Astrophysics

Detection of a large range of nuclei (Z)

- **Charge identification in large Z range**
- **Precise velocity measurement**
- **Rigidity measurement**
- **Ability to identify different isotopes**

Antimatter

Detection of antinuclei would be a clear signal of the existence of cosmic antimatter

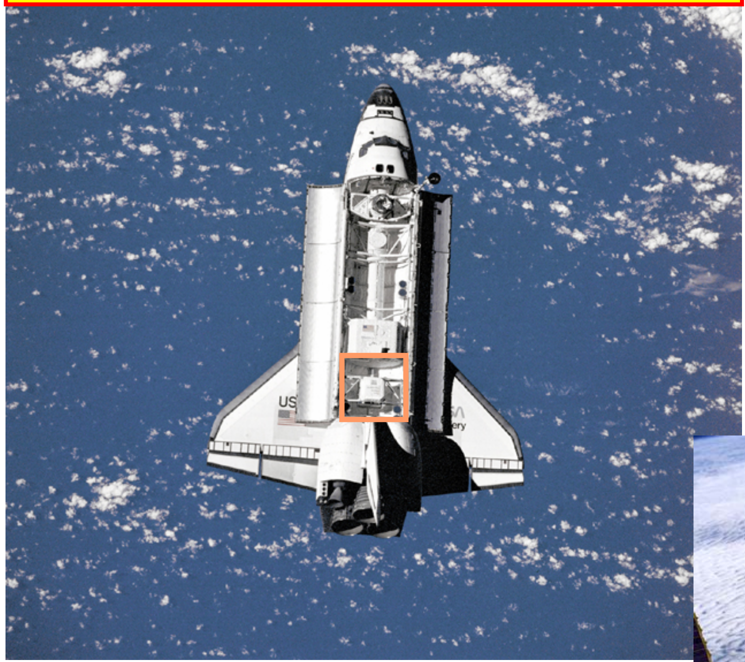
Dark matter

Signals: $\bar{p}$, e^+, γ, $\bar{d}$

- Charge identification
- Velocity & rigidity measurements
- Albedo rejection
- γ detection
- Strong system redundancy

The AMS experiment

AMS-01: test flight - 10 days in 1998



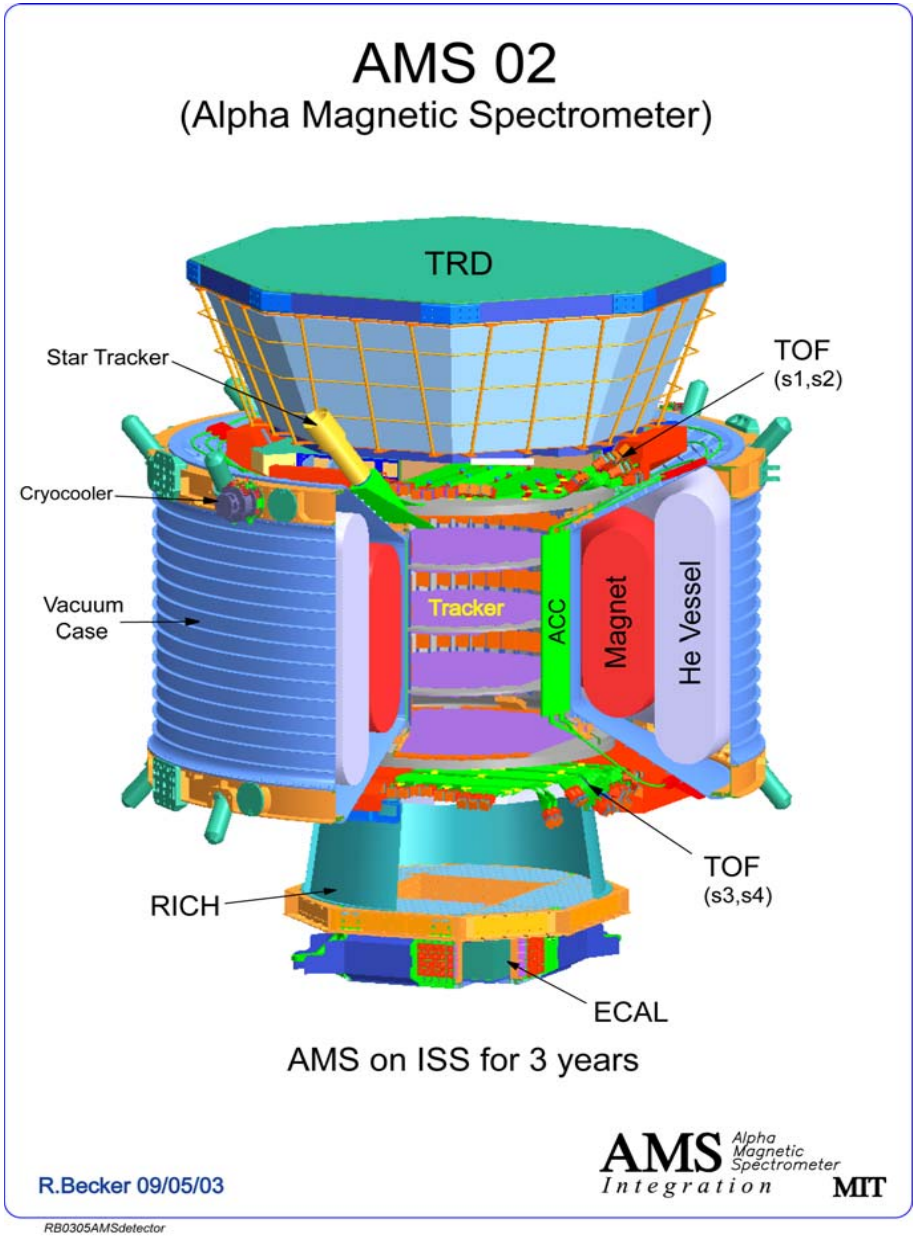
- AMS is a broad international collaboration (~ 500 members) for the detection of primary cosmic rays in space
- Successful test flight aboard space shuttle Discovery in June 1998
- Detector integration at CERN in 2006

AMS-02: detector to be installed in the ISS in 2008

- Final detector to be installed in the International Space Station

AMS-02 detector

- Has the following subdetectors:
  - *Transition Radiation Detector*
  - *Time-of-Flight detector*
  - *Silicon Tracker*
  - *Ring Imaging Cherenkov detector*
  - *Electromagnetic Calorimeter*
  - *Anti-Coincidence Counter*
- Detector capabilities:
  - *Particle bending*
    - Superconducting magnet (0.9 T)
  - *Measurements of particle:*
    - **Rigidity** (Tracker)
    - **Direction** (TOF, Tracker, RICH)
    - **Velocity** (RICH, TOF, TRD)
    - **Charge** (RICH, Tracker, TOF)
  - *Trigger*
    - TOF, ECAL, ACC
- Total statistics: > 10^{10} events



Charge measurement

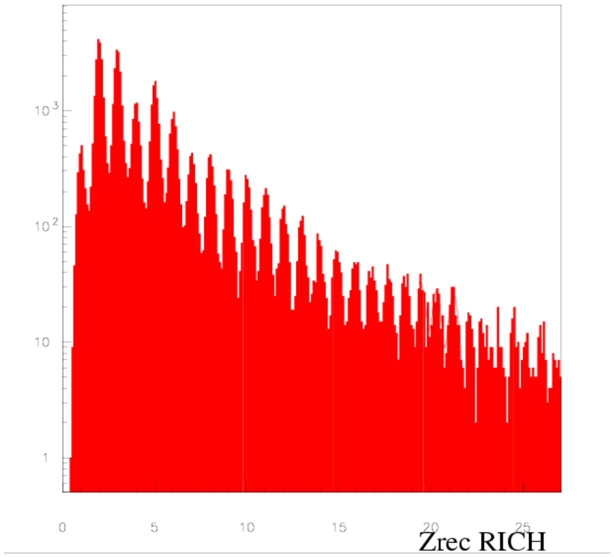
- Charge magnitude
  - *Tracker, TOF give charge value by direct sampling of particle energy deposition:*

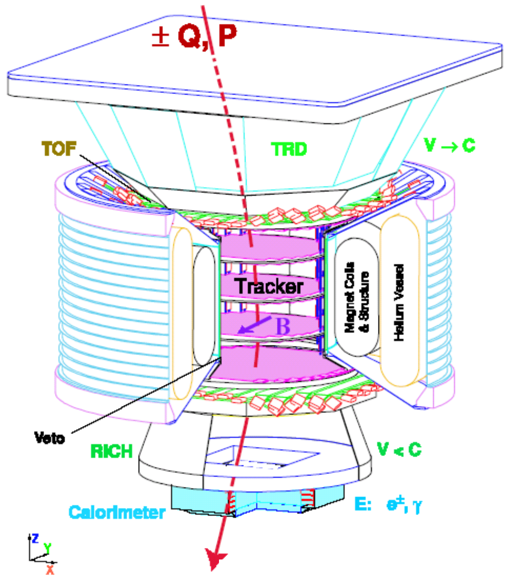
$$\boxed{\Delta E \propto Z^2}$$

  - *RICH:*
    - Charge estimated from number of photons in Cherenkov ring (also function of velocity):

$$\boxed{N_\gamma \propto Z^2\,\Delta L\left(1-\frac{1}{\beta^2 n^2}\right)}$$

    - Ring acceptance and other effects (e. g. mirror reflectivity) must be taken into account
- Charge signal
  - *Particle bending information from Tracker*
  - *Albedo rejection from TOF, RICH*





Velocity measurement

- TOF:
  - *Crossing time between scintillator planes is measured:*

$$\boxed{\beta \propto \frac{\Delta L}{\Delta t}}$$

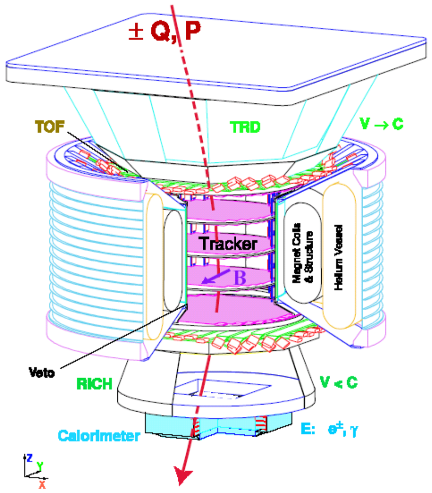
- RICH:
  - *Opening of Cherenkov cone is function of velocity:*

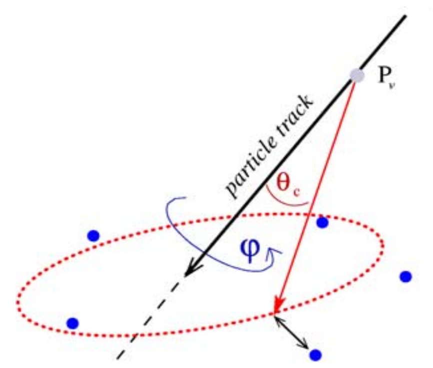
$$\boxed{\cos \theta_c = \frac{1}{\beta n}}$$

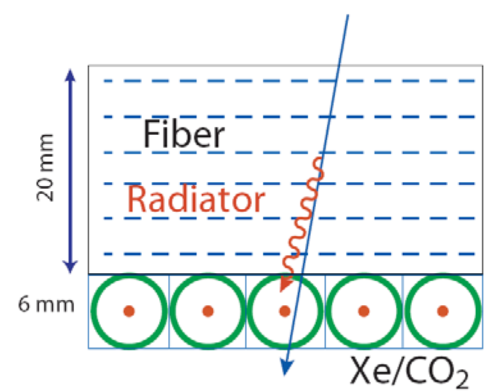
- TRD:
  - *Energy of transition radiation is roughly proportional to the particle's Lorentz factor:*

$$\boxed{E_\gamma \sim \gamma \text{ (eV)}}$$

  - *This allows to distinguish very high velocity particles*







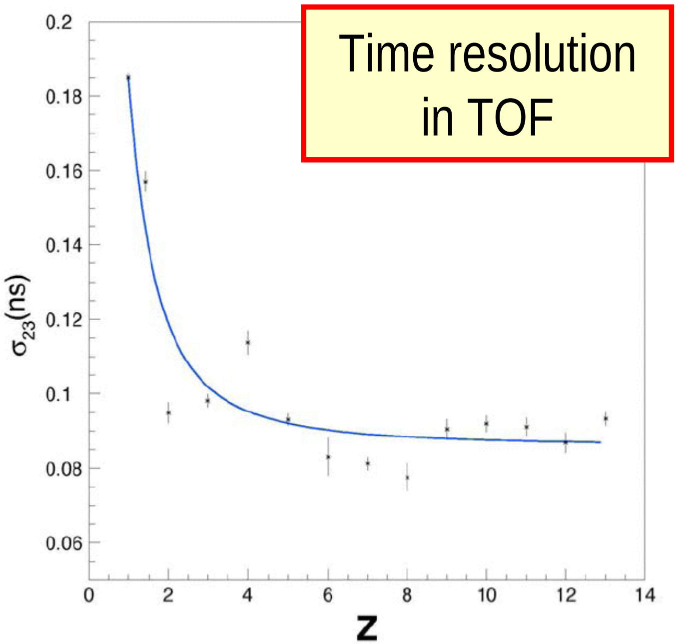
Velocity resolution

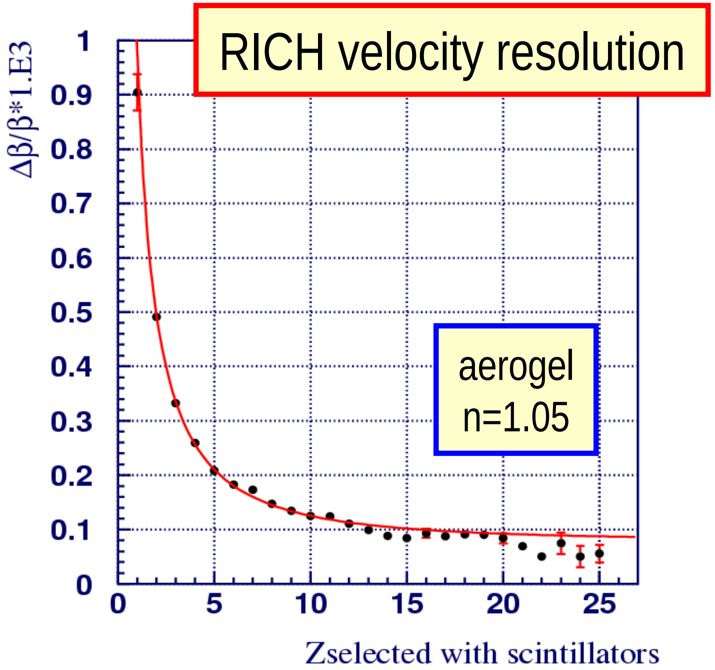
TOF

- ***Expected in AMS-02 (4 planes):***
  - *Z=1: Δt ~ 130 ps, Δβ/β ~ 4%*
- ***2003 test beam (2 planes):***
  - *Δt ~ 180 ps, Z=1*
  - *Δt ~ 100 ps for Z≥2*

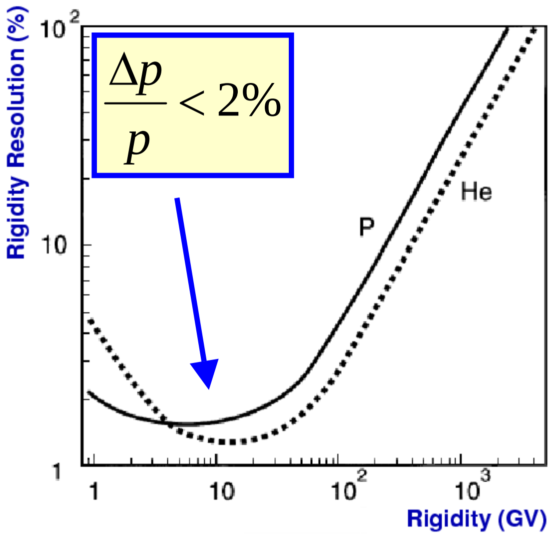
RICH

- ***Expected in AMS-02:***
  - *Δβ/β ~ 0.1% for Z=1*
  - *Δβ/β ~ 0.01% for Z>10*
- ***2003 test beam:***
  - *Δβ/β = 0.09% for Z=1*





Mass identification

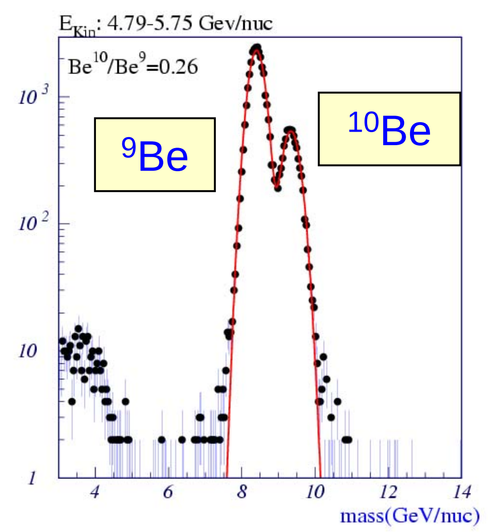


- Rigidity (R) measurement from Tracker
  - *Signal in tracker planes indicates particle bending in magnetic field*
- Charge + rigidity $\Rightarrow$ momentum:

$$\boxed{p = RZ}$$

- Momentum + velocity $\Rightarrow$ mass:

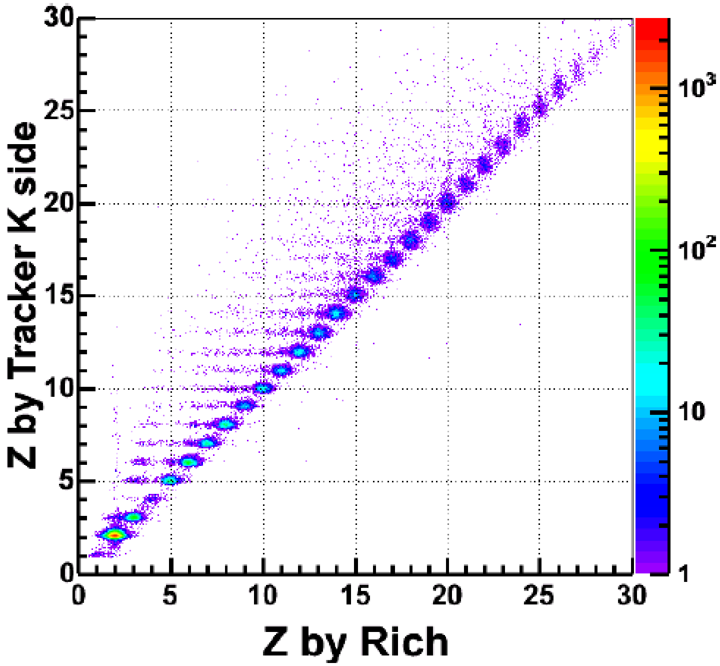
$$\boxed{m = \frac{p}{\gamma\ v}} \qquad \boxed{\frac{\Delta m}{m} = \frac{\Delta p}{p} \oplus \gamma^2 \frac{\Delta \beta}{\beta}}$$



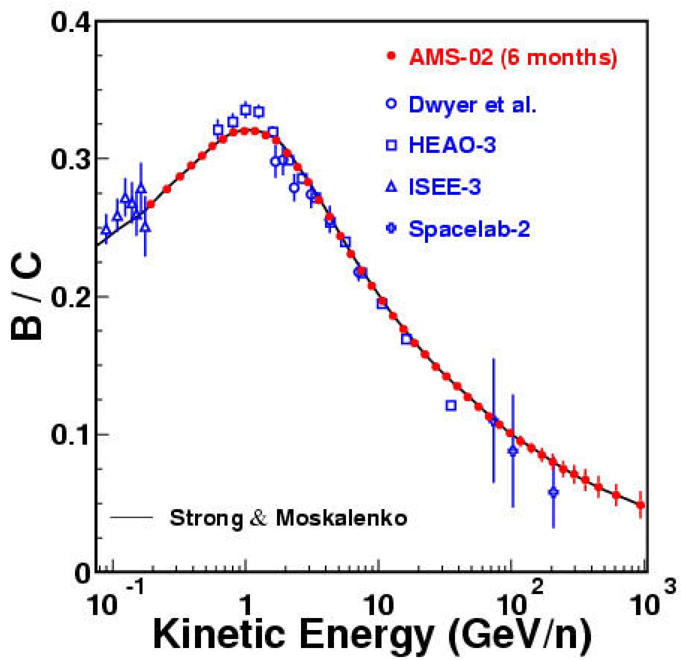
- Isotopic separation relies on accurate mass identification

AMS-02 prospects: B/C ratio

- Data from 2003 beam test:
  - *Charge identification up to Z ~ 30 from both Tracker & RICH*
- B/C may be identified in a large energy range
  - *Result is significant for knowledge of cosmic ray propagation*



charge reconstruction

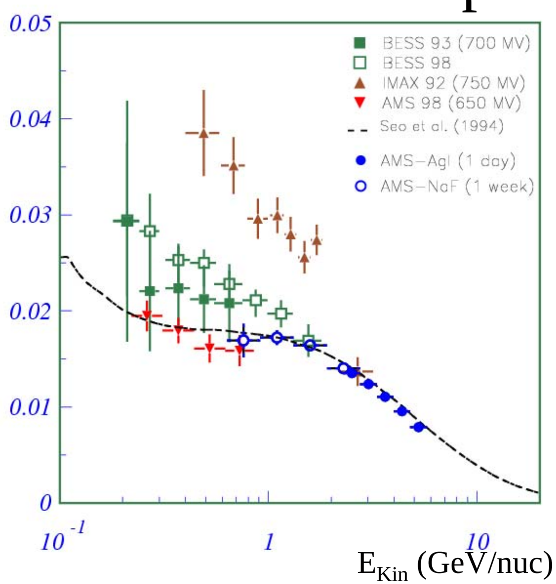


B/C, 6 months

AMS-02 prospects: isotopic ratios

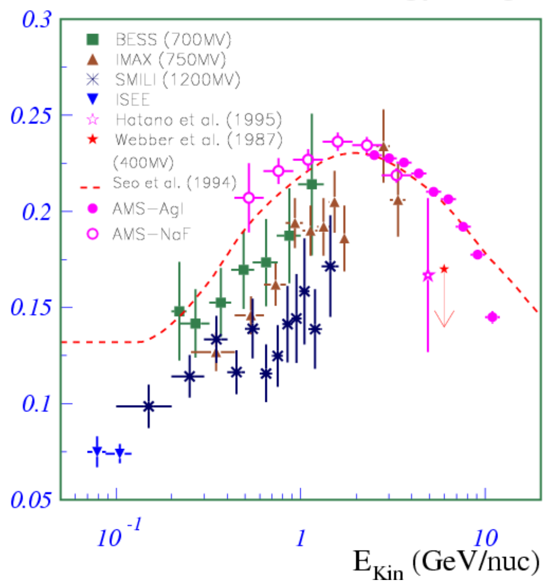
- Expected in AMS-02
  - *Isotopic separation of H, He, Be up to ~ 10 GeV/nucleon: major improvement on current data*
- AMS data provide insight on cosmic ray physics
  - *d/p, ^{3}He/^{4}He, B/C: information on cosmic ray propagation*
  - *^{10}Be/^{9}Be: confinement times, galactic halo models*

d/p



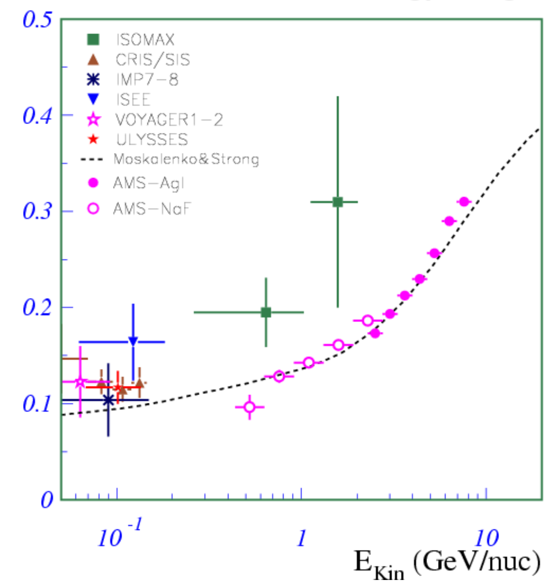
d/p, 1 week / 1 day

^{3}He/^{4}He



^{3}He/^{4}He, 1 day

^{10}Be/^{9}Be



^{10}Be/^{9}Be, 1 year

Conclusions

- AMS-02 will be installed on the International Space Station in 2008 to operate for a minimum of 3 years
- Data collected by AMS will have unprecedented precision and statistics:
  - *Total of > 10^{10} events*
  - *Charge separation up to Z ~ 30*
  - *Velocity reconstruction with $\Delta\beta/\beta \sim 0.1\%$ for Z=1*
  - *Isotopic separation up to ~ 10 GeV/nucleon*
- AMS results will address key issues in cosmic ray astrophysics:
  - *Propagation models*
  - *Confinement times*
  - *Solar cycle*