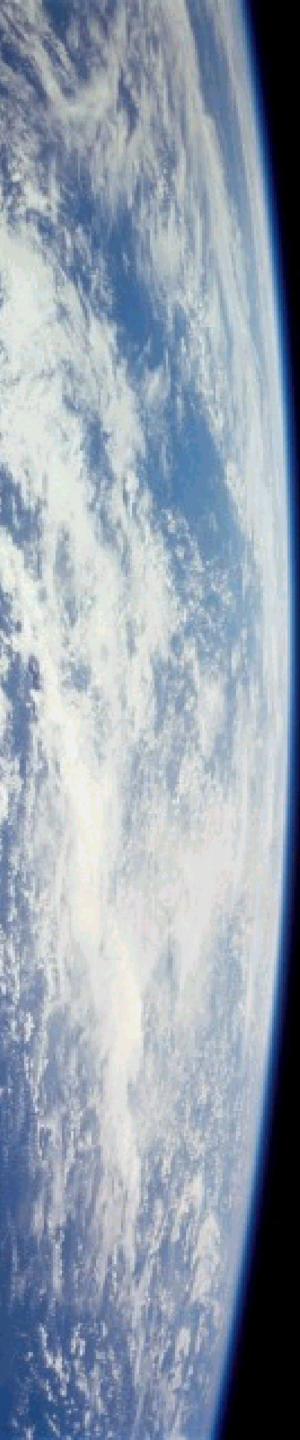

Isotopic separation of cosmic rays with the AMS experiment: the role of the RICH detector

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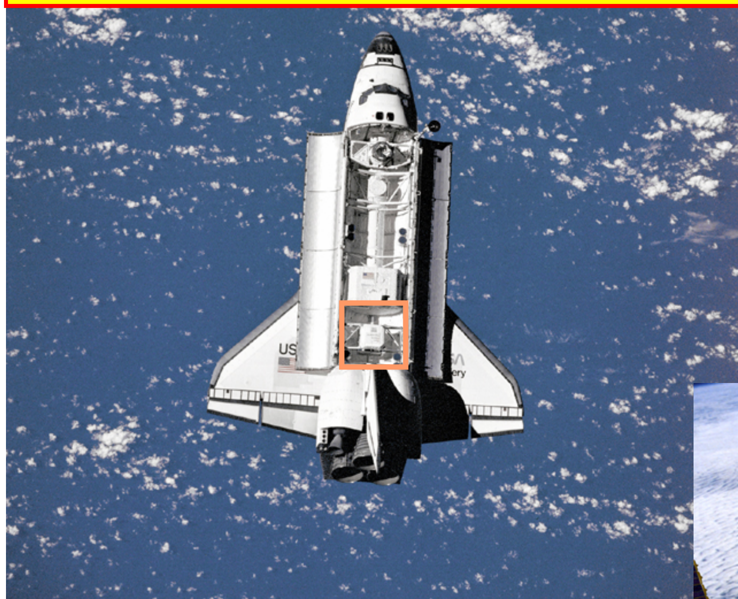
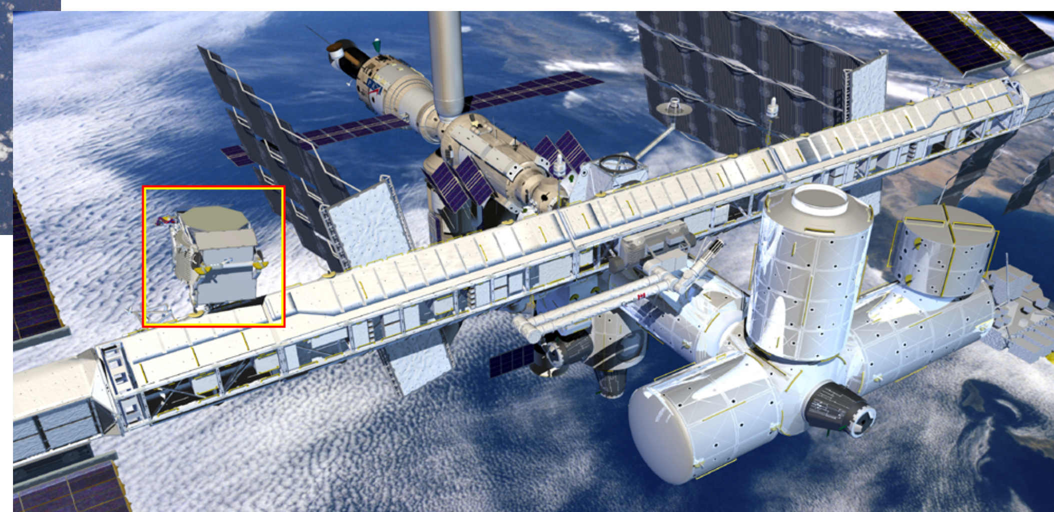
International Predoctoral School, Les Houches, 28 Aug - 9 Sep 2005

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

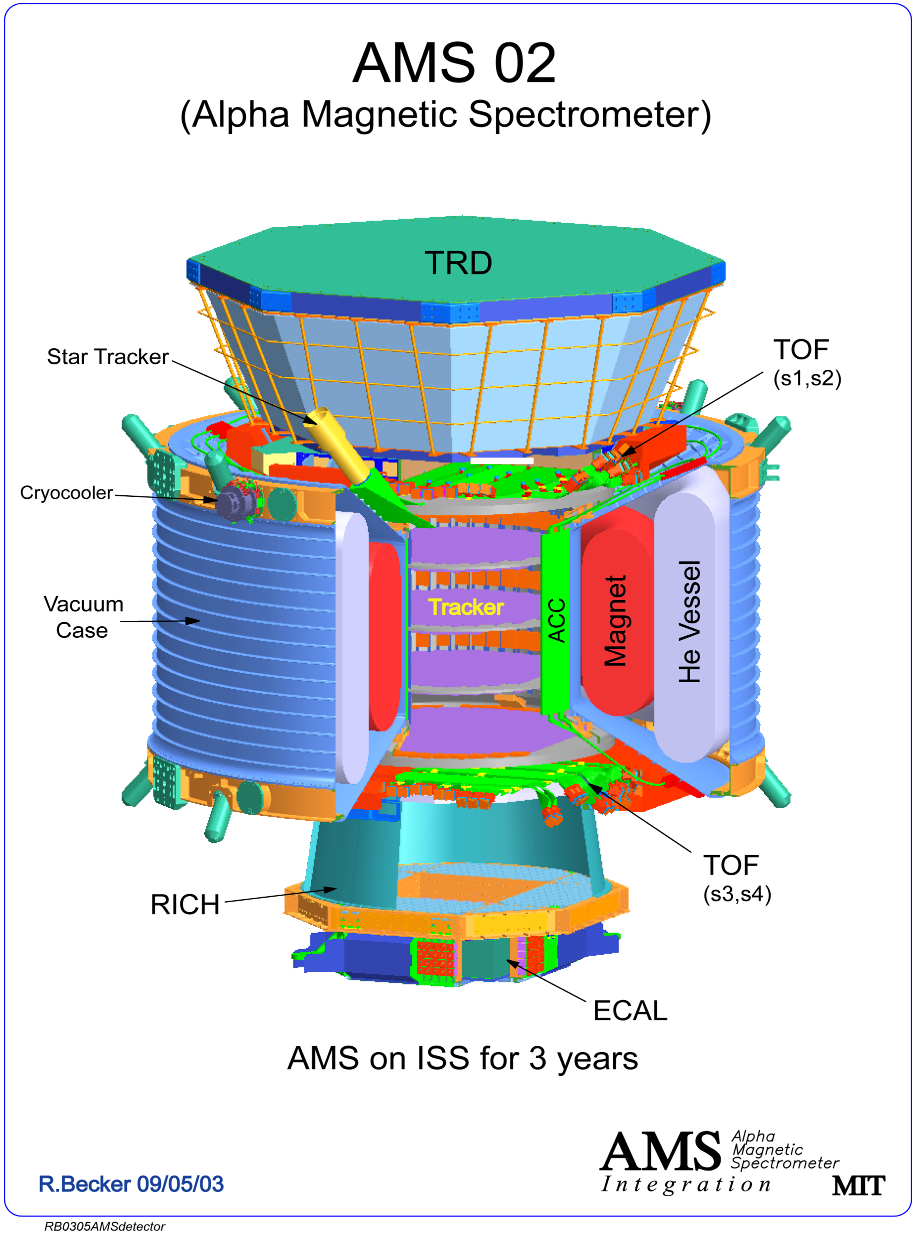
- Final detector to be installed in the International Space Station

The AMS experiment

- Delivery to ISS scheduled for 2008
  - *Data taking time: 3 years minimum*
- Main goals:
  - *Detailed study of cosmic ray spectra*
    - AMS will provide an unprecedented statistics of charged cosmic ray measurements
    - Precise velocity measurement allows isotope separation in a large energy range
  - *Search for dark matter*
    - Anomalies in cosmic ray spectra may provide information on dark matter constituents
  - *Search for antinuclei*
    - The presence of heavy antinuclei in cosmic rays may signal the existence of antimatter domains in the Universe

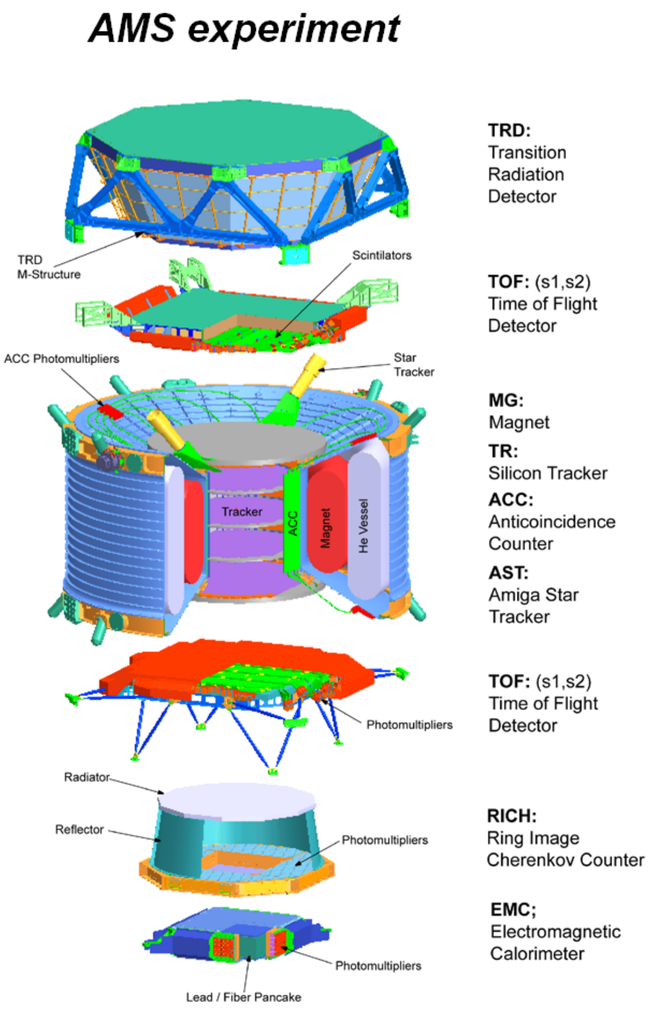
AMS-02 detector

- 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



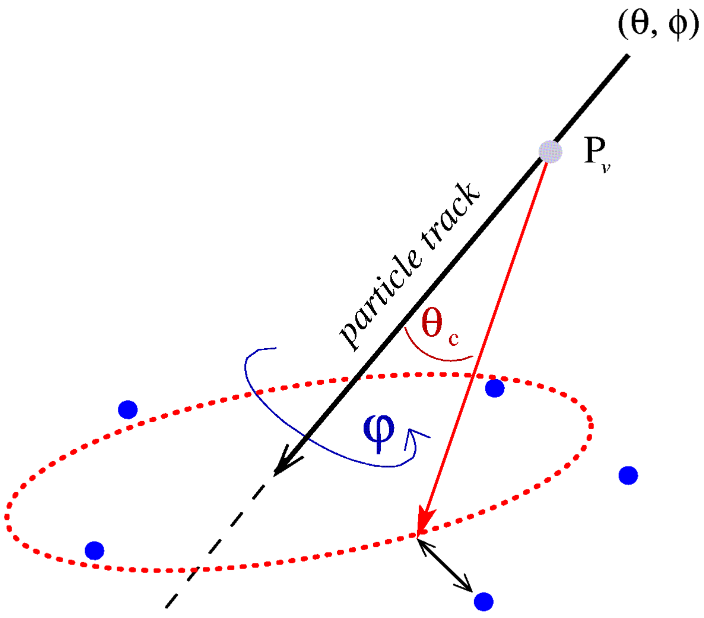
AMS-02 detector

- Major advantages of AMS:
  - *Out of atmosphere*
  - *Particle discrimination up to TeV region*
  - *Very good velocity resolution (~10^{-3})*
  - *Charge separation up to Z~26*
  - *Large acceptance (0.5 m^2 sr)*
  - *Long duration (3 years minimum)*
  - *Detector redundancy*

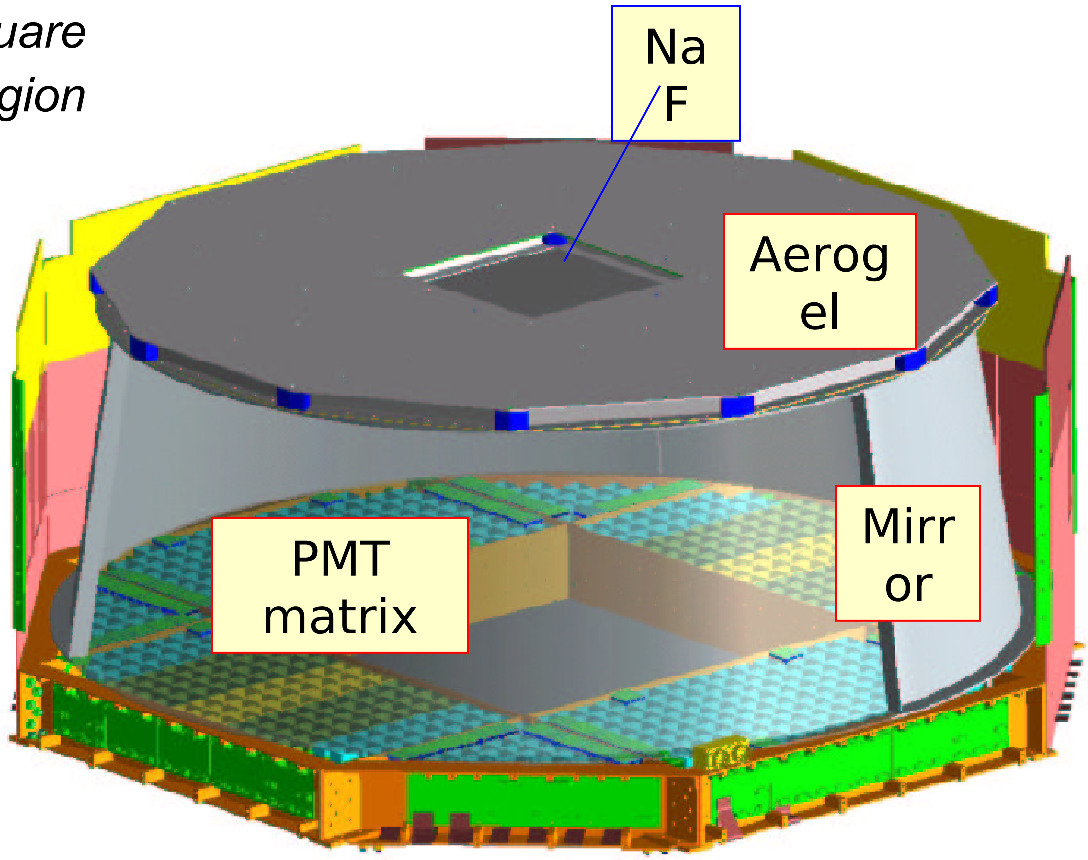


RICH detector

- Proximity focusing detector based on Cherenkov effect
- Two radiators
  - *NaF (n=1.334) – central square*
  - *Aerogel (n=1.05) – outer region*



Cherenkov ring



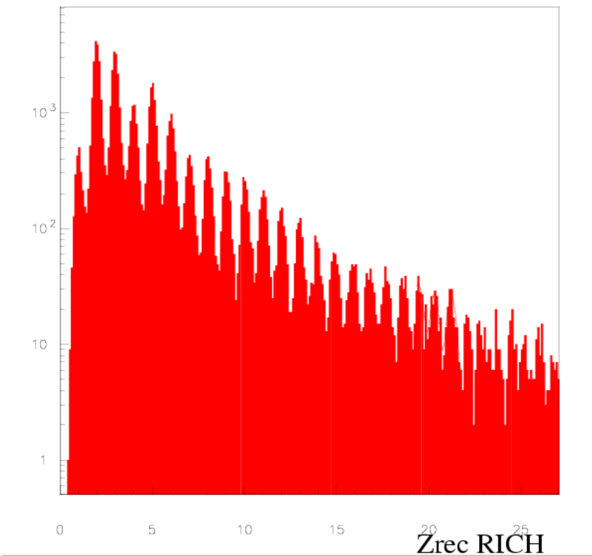
RICH detector

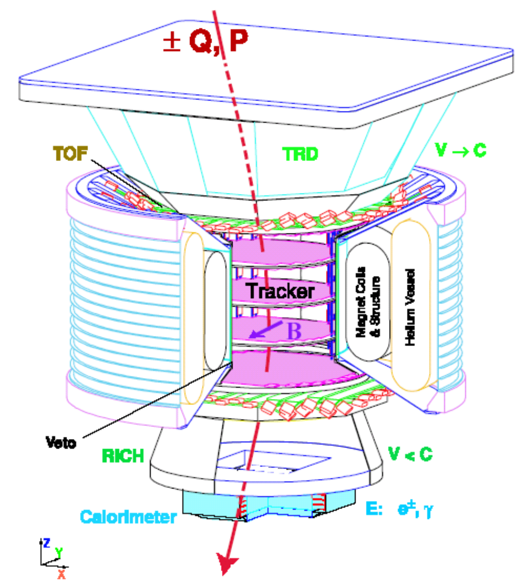
Charge measurement

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

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

  - *Ring acceptance and other effects (e. g. mirror reflectivity) must be taken into account*
  - *Cross-check with measurements from Tracker, TOF*



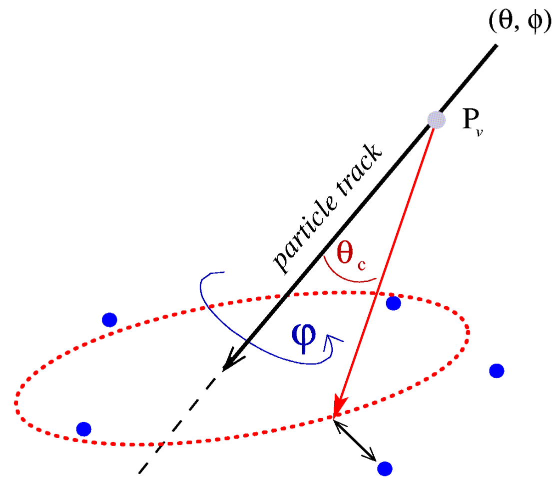


- Charge signal
  - *Particle bending information from Tracker*
  - *Albedo rejection from TOF, RICH (no ring if particle comes from bottom!)*

Velocity measurement

- Opening of Cherenkov cone is function of velocity:

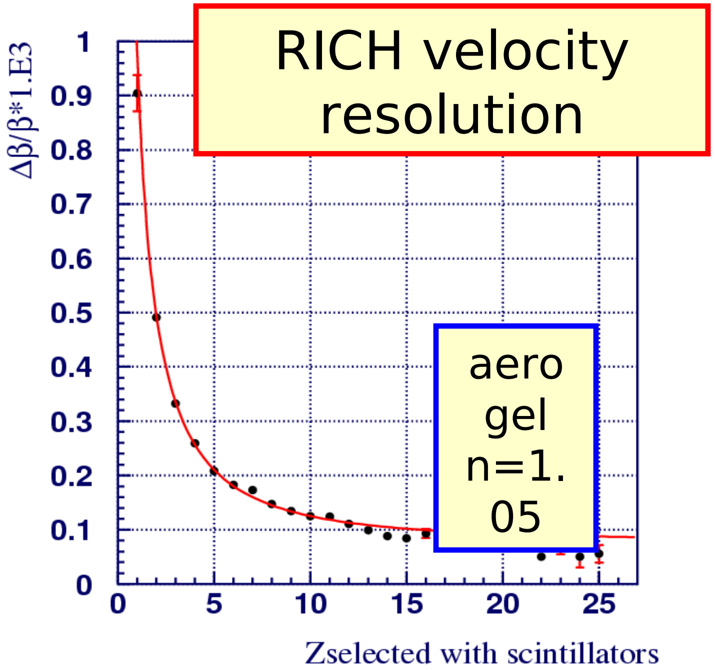
$$\cos\ \theta_c = \frac{1}{\beta\ n}$$



<u>RICH velocity resolution</u>

(aerogel)

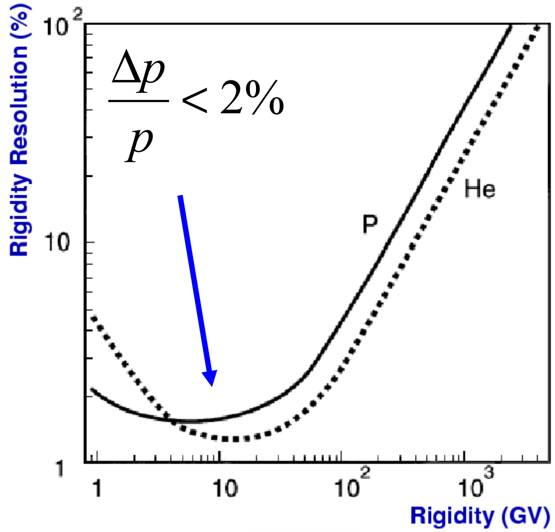
- ***Test beam, cosmic ray data:***
  - *Δβ/β = 0.09% for Z=1*
- ***Expected in AMS-02:***
  - *Δβ/β ~ 0.13% for Z=1*
  - *Δβ/β ~ 10^{-4} for Z>10*



Mass identification

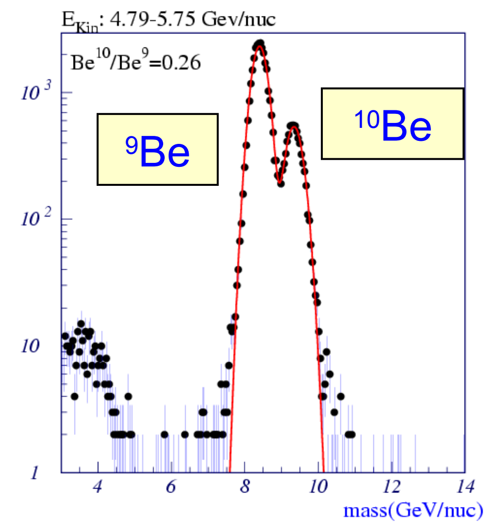
- Rigidity (R) measurement from Tracker
  - *Signal in tracker planes indicates particle bending in magnetic field*
- Charge + rigidity ⇒ momentum:

$$p = RZ$$



- Momentum + velocity ⇒ mass:

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



- Isotopic separation relies on accurate mass identification

RICH simulation data samples

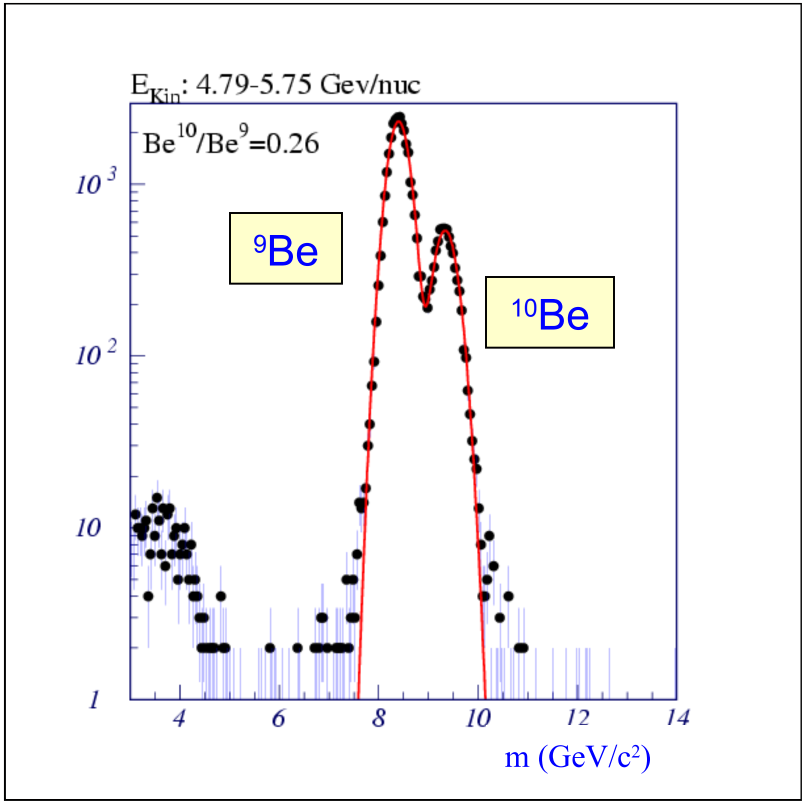
- A large statistics was fully simulated on the RICH:

Z	Isotopes	No. events		Time
1	p, d	AGL+NaF events	1.6×10^7	≈ 1 day
		NaF only events	1.5×10^7	≈ 1 week
2	^3He, ^4He	2.0×10^6		≈ 1 day
4	^9Be, ^{10}Be	8.5×10^5		≈ 1 year

- Setup tested: Aerogel (n=1.05) + NaF
  - *Realistic radiator properties (from beam tests, etc.) were used*
- Only events above geomagnetic cutoff were considered
  - *Simulation takes this into account*
  - *Cutoff is higher at equator, lower at magnetic poles*

Isotope separation procedure (He, Be)

- Simulated ratios ~ 0.1-0.4
- Mass reconstructed from p & β data
  - *Mass resolution depends on energy*
- Relative isotopic abundances determined for He, Be:
  - *Separate mass fits for Aerogel & NaF populations, one fit for each energy channel*
  - *Overall mass region fit to 2 gaussians, width ratio assumed constant:*
    - $\sigma_1/\sigma_2 = m_1/m_2$

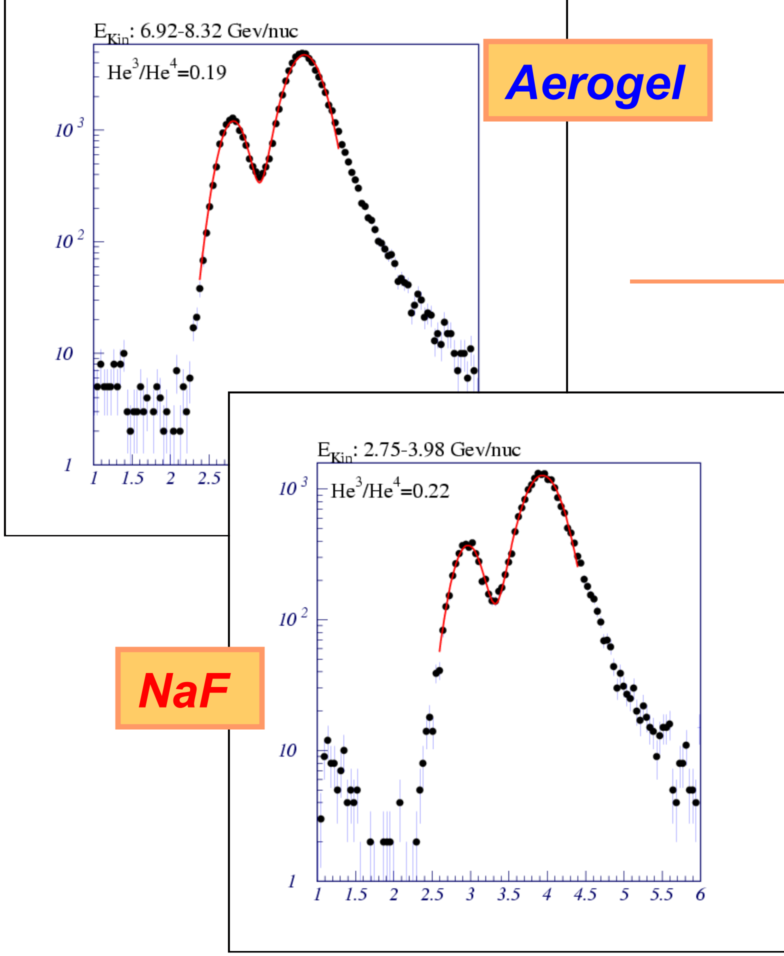


Reconstruction results: ^3He, ^4He

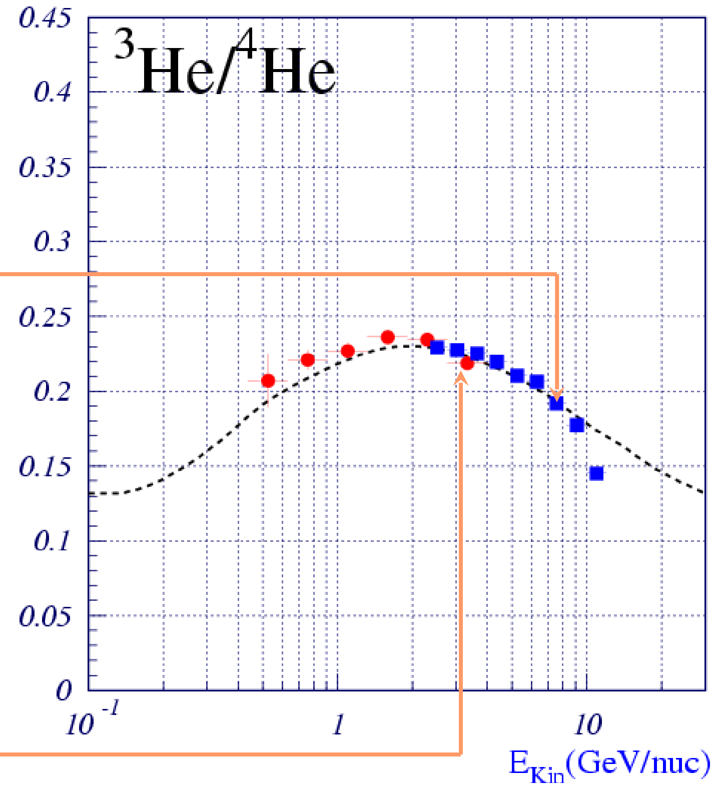
Mass distributions

Aerogel

NaF



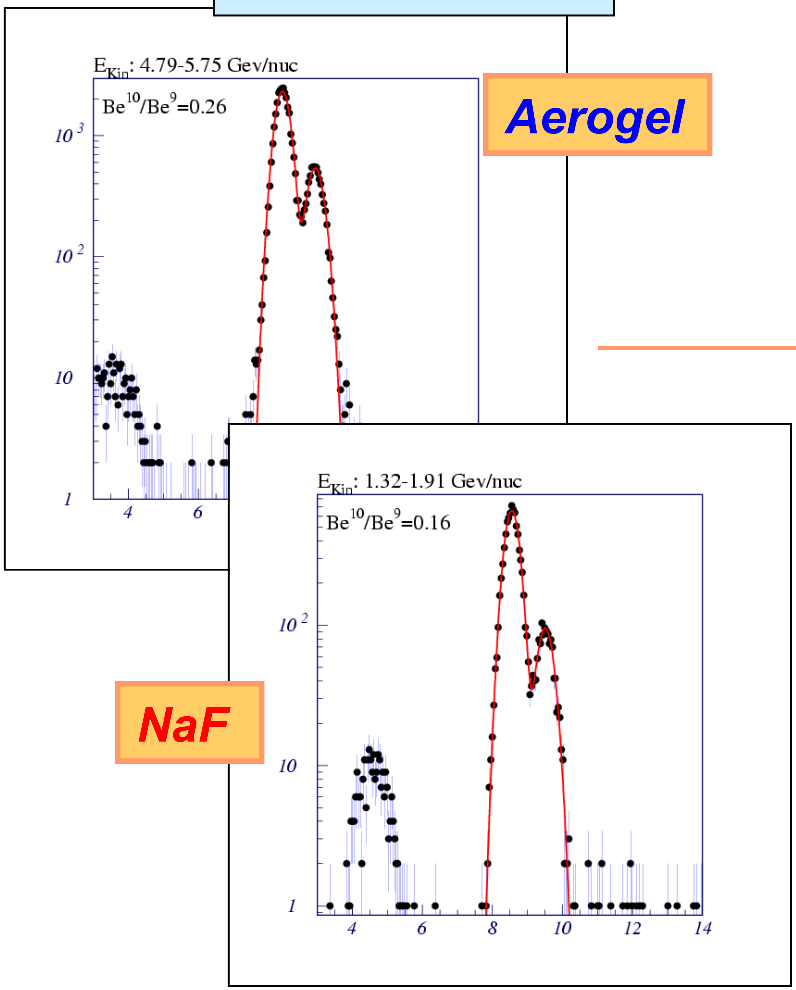
Isotope ratios



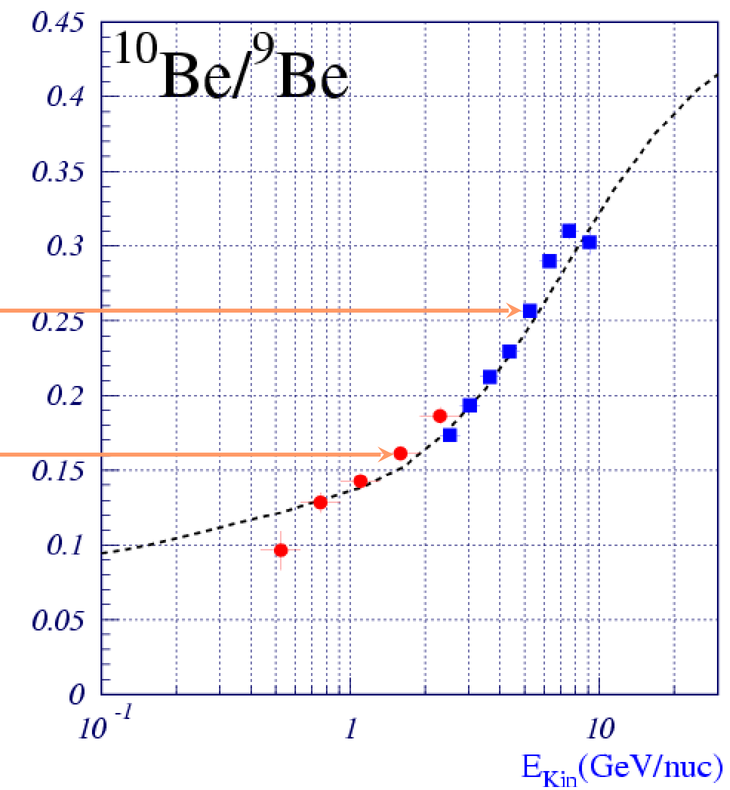
Simulated curve from Seo et al. (1994)

Reconstruction results: ^{9}Be, ^{10}Be

Mass distributions



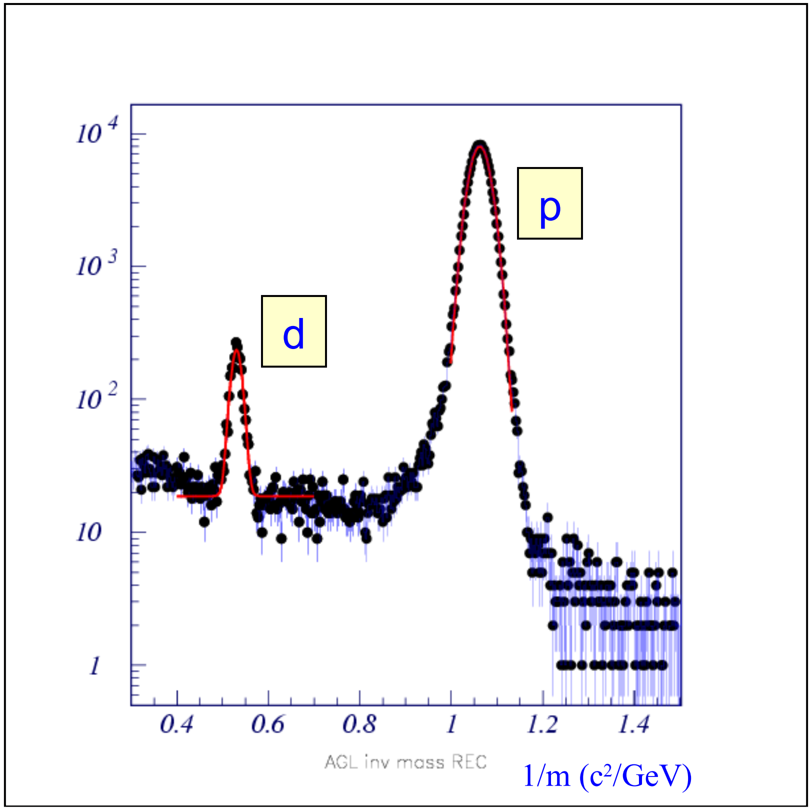
Isotope ratios



Simulated curve from Strong & Moskalenko (2001)

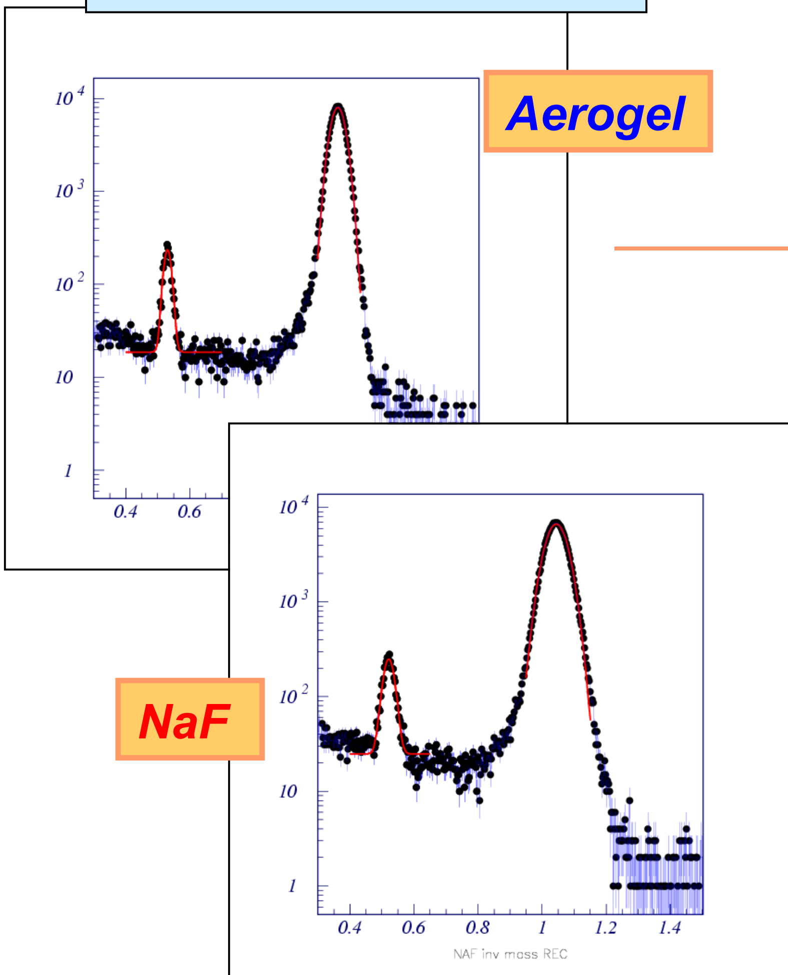
Isotope separation procedure (H)

- Simulated ratio: d / p ~ 10^{-2}
- Relative isotopic abundances determined for H (protons+deuterons):
  - Two kinds of spectrum tested:
    - *Mass distribution*
    - *Inverse mass distribution* → better
  - Fit to 2 gaussians not good for this case ($N_p >> N_d$, significant p tail in d region)
  - Gaussian fit performed on proton peak; fit to gaussian + noise used for deuteron peak

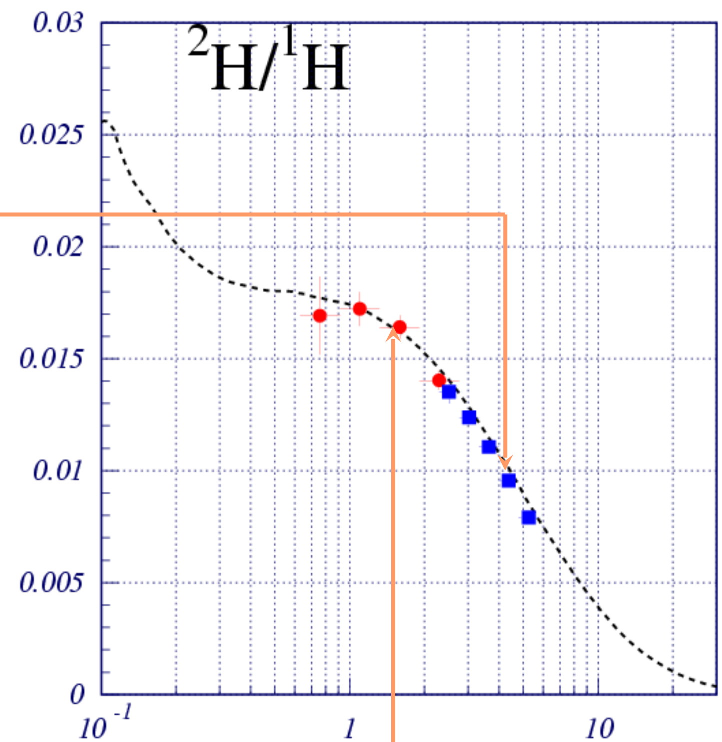


Reconstruction results: *p, d*

Inverse mass distributions

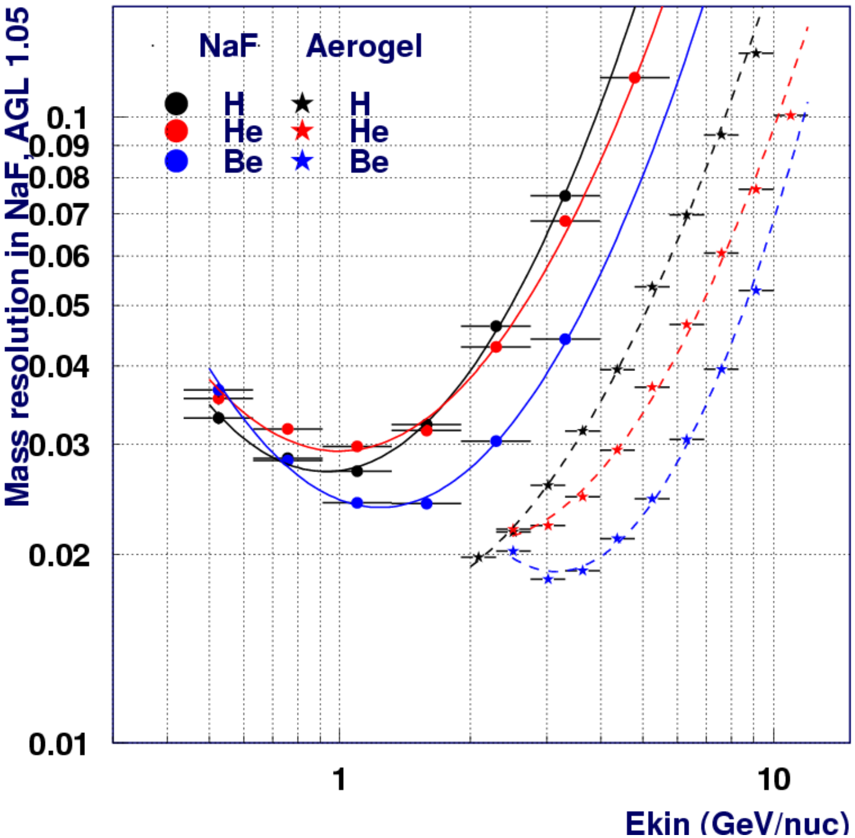


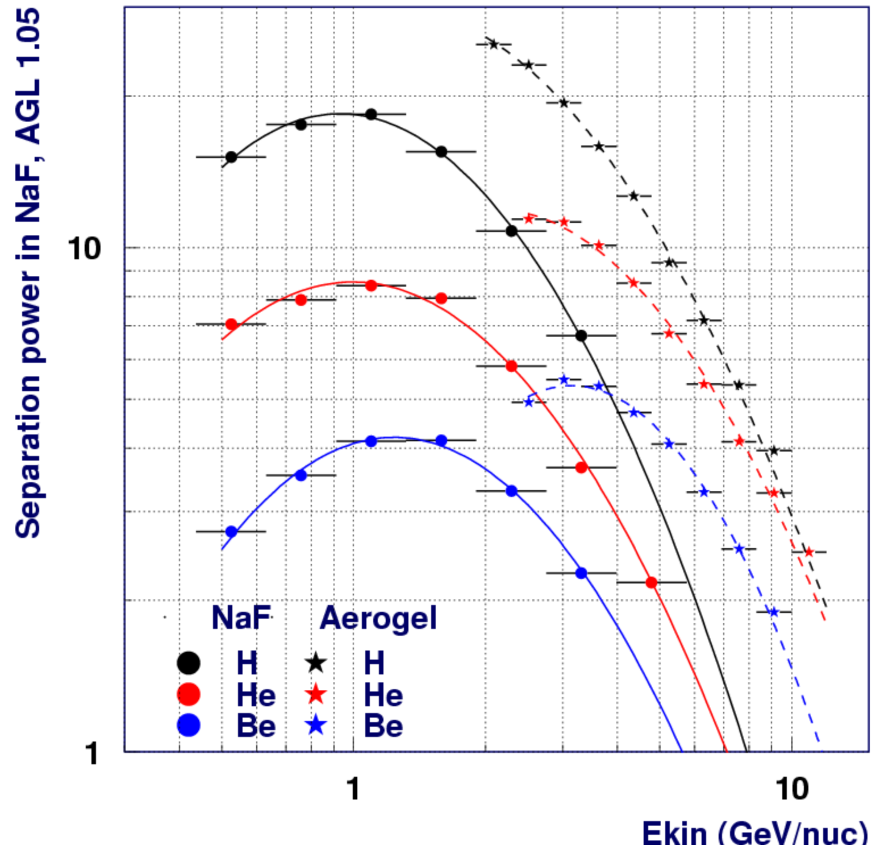
Isotope ratios



Simulated curve from Seo et al. (1994)

Mass resolution & separation power





Mass resolution

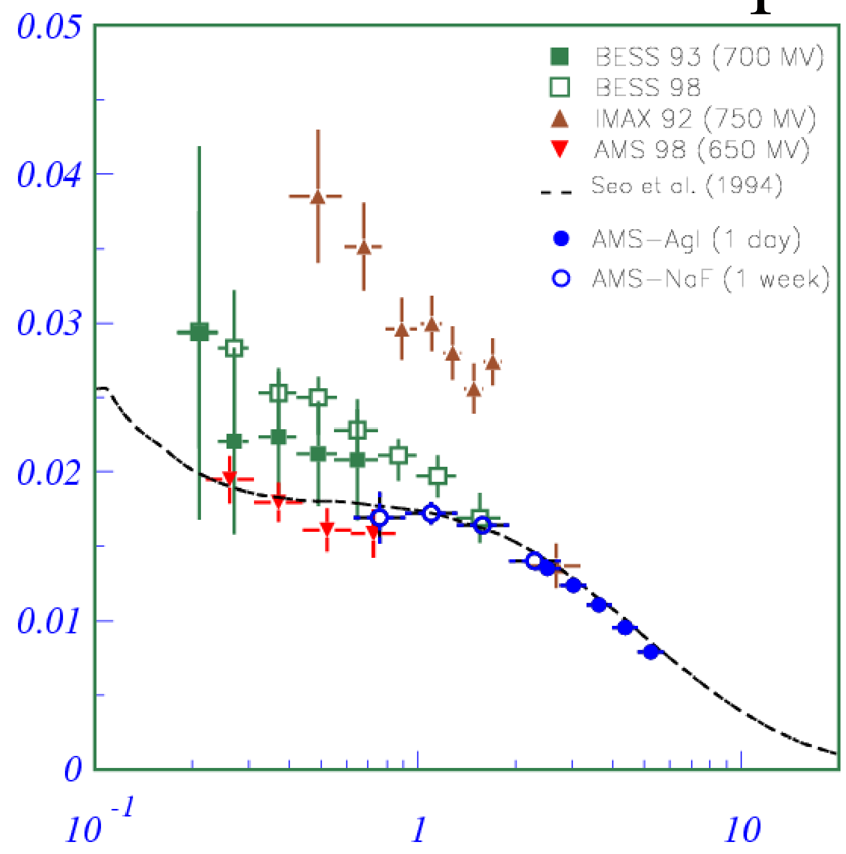
Separation power = $\Delta m/\sigma_m$

AMS vs. previous experiments: H

- NaF radiator: allows a clear improvement on existing data at ~ 1 GeV
- Aerogel radiator: allows an extension of energy region to ~ 5 GeV

- Prospects from a single week (NaF) or day (Aerogel) of data
  - *AMS will work for 3 years*

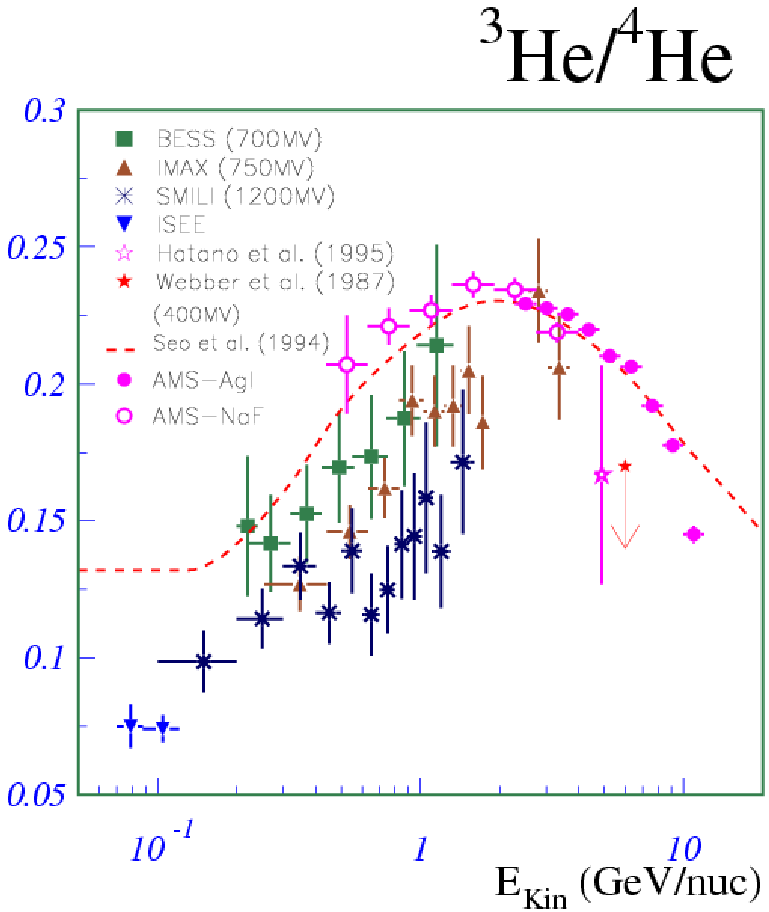
d/p

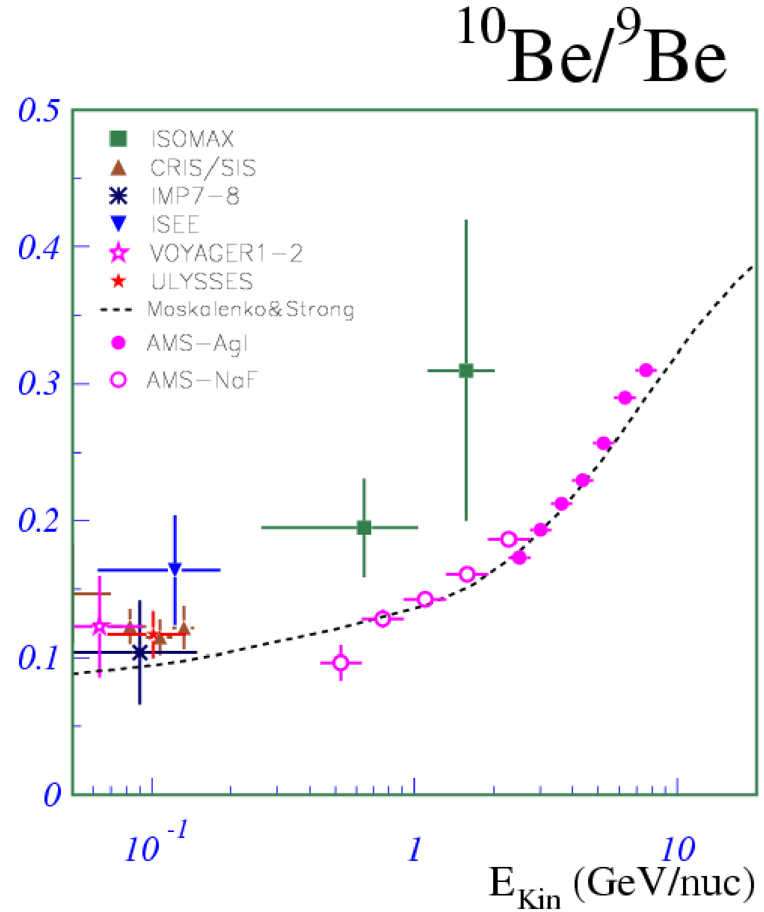


E_{Kin} (GeV/nuc)

AMS vs. previous experiments: He, Be

- Major improvements also expected for other elements:





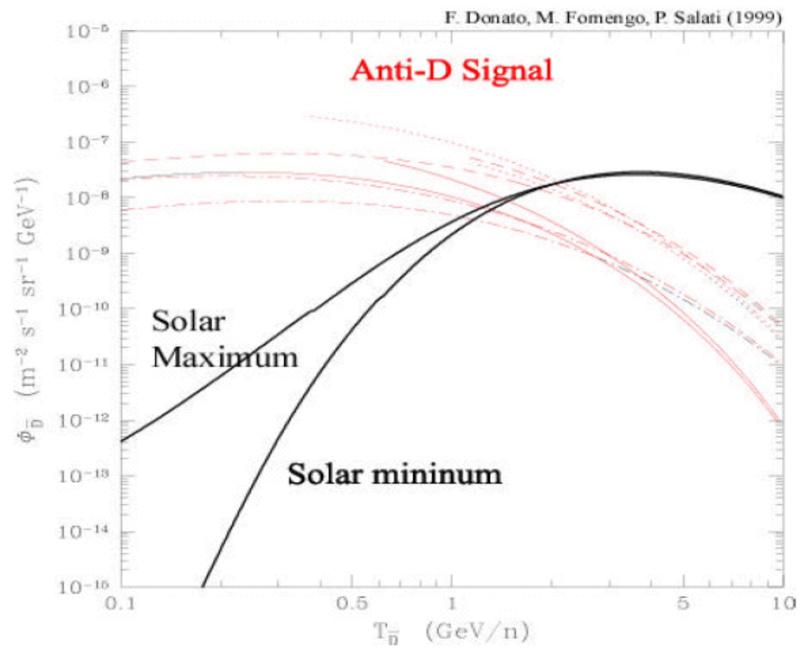
Conclusions

- Results of Monte Carlo simulation of H, He and Be events in the RICH detector of AMS were analysed
  - *Two independent methods for velocity and charge reconstruction developed at LIP and CIEMAT*
- Isotopic separation was performed
  - *Good results with «low» statistics (compared to AMS-02 total):*
    - ~ 1 day/week for H & He, ~ 1 year for Be
  - *Low isotopic ratio (~10^{-2}) and low mass posed a problem for hydrogen ⇒ overcome by specific tools (e. g. inverse mass fits)*
  - *Best mass resolutions ~ 2 % at 3 GeV/n (Aerogel), ~ 3 % at 1 GeV/n (NaF) for all elements tested*
  - *Isotopic ratios may be calculated for 0.5–10 GeV/nucleon*
  - *Good reconstruction efficiencies for high energy ⇒ tight cuts can always be applied to improve signal/background ratio*
  - *AMS results will provide a major improvement on existing data*

- Near future...

Future work

- The challenge of $\bar{d}$ / $\bar{p}$ separation
  - *Hardest channel*
  - *Use AMS full simulation to study this problem*
  - *Explore full capabilities of RICH*
- Evaluate AMS sensitivity to $\bar{d}$ channel
  - *$\bar{d}/\bar{p} \sim 10^{-5}$ reachable?*
  - *Tighten energy boundary?*
  - *Reduce strongly $\bar{p}$, p background?*



Black: non-SUSY flux

Red: flux for 4 SUSY models

- Can the exotic (dark matter) signal be enhanced? How?