Isotope separation with the RICH detector of the AMS experiment

Rui Pereira

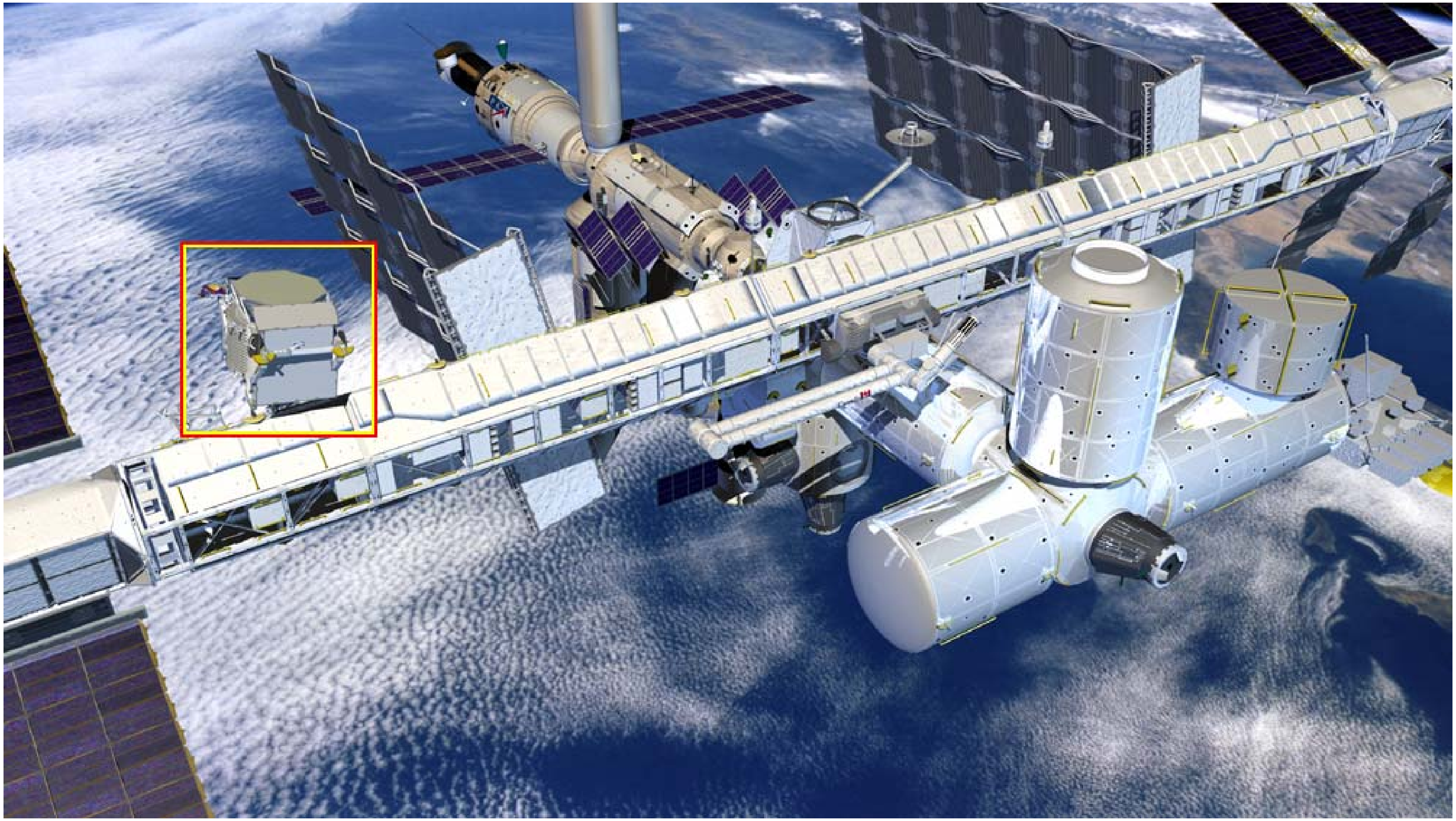
(LIP - Lisbon)

e-mail address: pereira@lip.pt

5th NWAP, Faro, 8-10 January 2005

The AMS experiment

- Broad international collaboration for the detection of primary cosmic rays in space

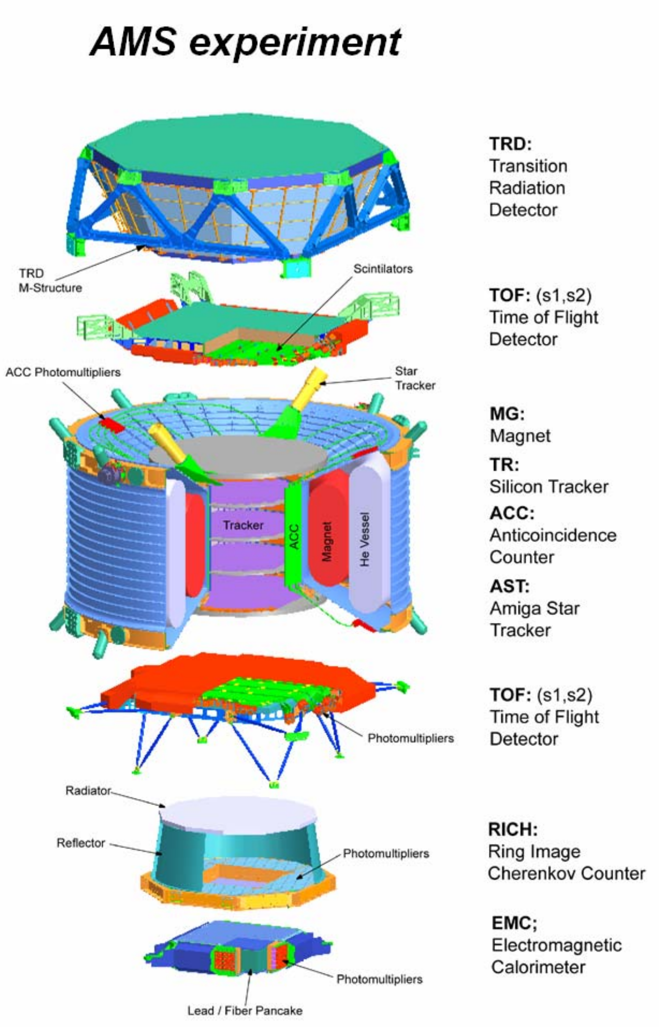


The AMS experiment

- Delivery to ISS scheduled for 2007
  - *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

The AMS experiment

- 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*



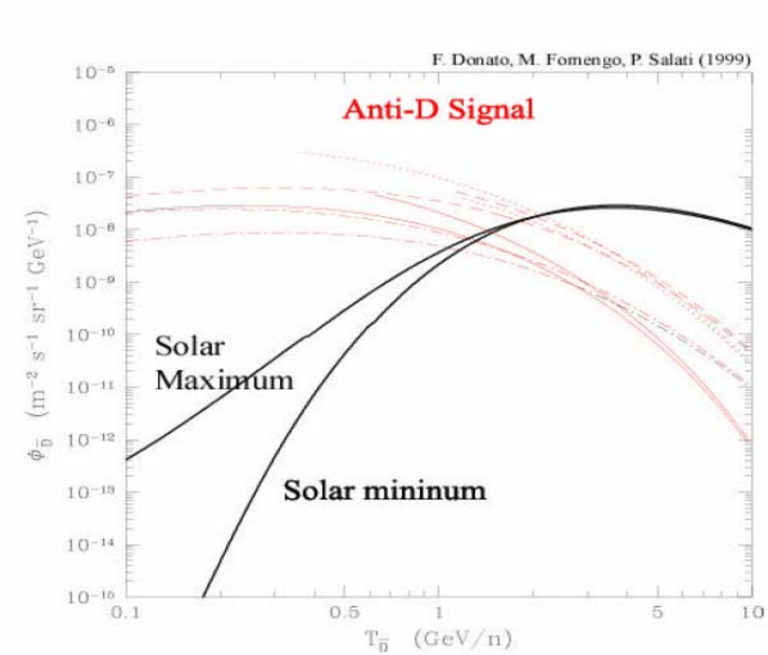
Physics issues

- Confinement times & propagation
  - *Relative abundances of stable and unstable isotopes (e.g., ^{9}Be and ^{10}Be) provide a cosmic ray «clock» $\Rightarrow$ information on cosmic ray origin, propagation*
  - *Abundances of secondary cosmic rays (e.g., ^{2}H, ^{3}He), produced as spallation products, give information on the amount of matter crossed by cosmic rays before their detection*

- Antinuclei
  - *Production of antinuclei with $Z>1$ from ordinary matter is extremely unlikely $\Rightarrow$ detection of $\bar{H}e$ should mean there is some other source*
  - *Detection of heavier antinuclei like $\bar{C}$ would clearly indicate antimatter domains exist in the Universe*

Physics issues

- Dark matter
  - *Neutralino (χ) is the lightest SUSY particle*
  - *Strong candidate for cold dark matter: abundant, massive, neutral particle*
  - *Neutralino annihilation ($\chi + \chi \rightarrow ...$) expected to take place in galactic halo, reaction products include e^+, $\bar{p}$, $\bar{d}$, ... $\Rightarrow$ several particle spectra might show neutralino contribution*
  - *Production of low energy $\bar{d}$ (GeV region) expected, no other physical processes in this energy region $\Rightarrow$ very clear neutralino signature*
    - *Drawback: $\bar{d}$ / $\bar{p}$ ~ 10^{-5}*



Black: non-SUSY flux

Red: flux for 4 SUSY models

Isotope ratios: previous experiments

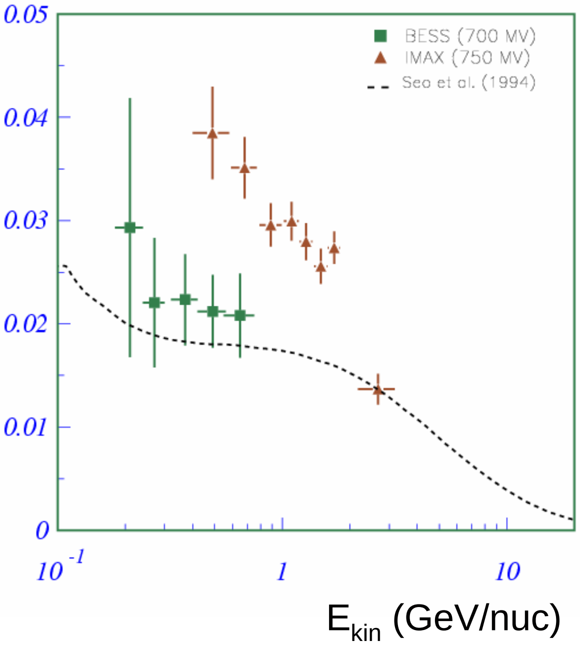
- Balloon experiments
  - *IMAX, ISOMAX, SMILI, BESS...*

- Space experiments
  - *Voyager, Ulysses, ISEE...*

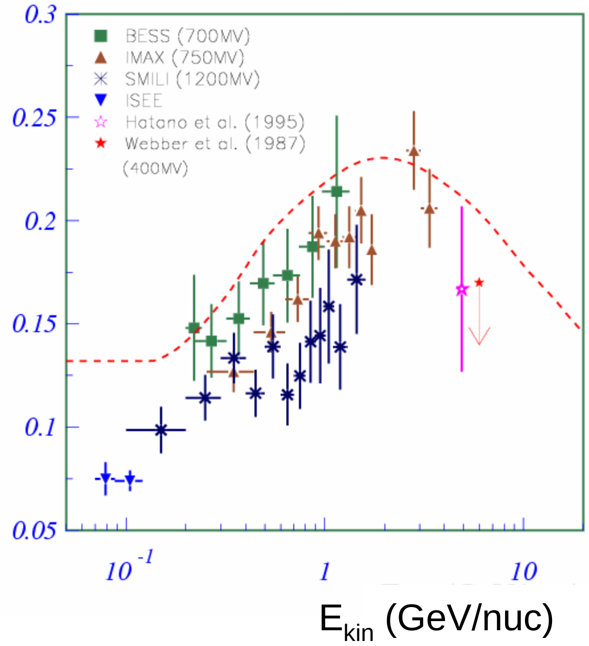
Isotope ratios: current data

- Some existing results on isotope ratios:
  - *Limited statistics and energy ranges*
  - *Dashed lines show models used for this simulation*

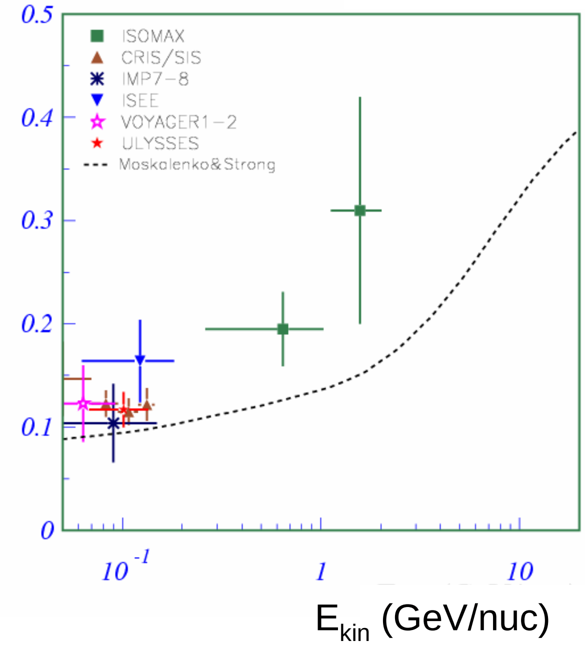
d/p



$^{3}He/^{4}He$



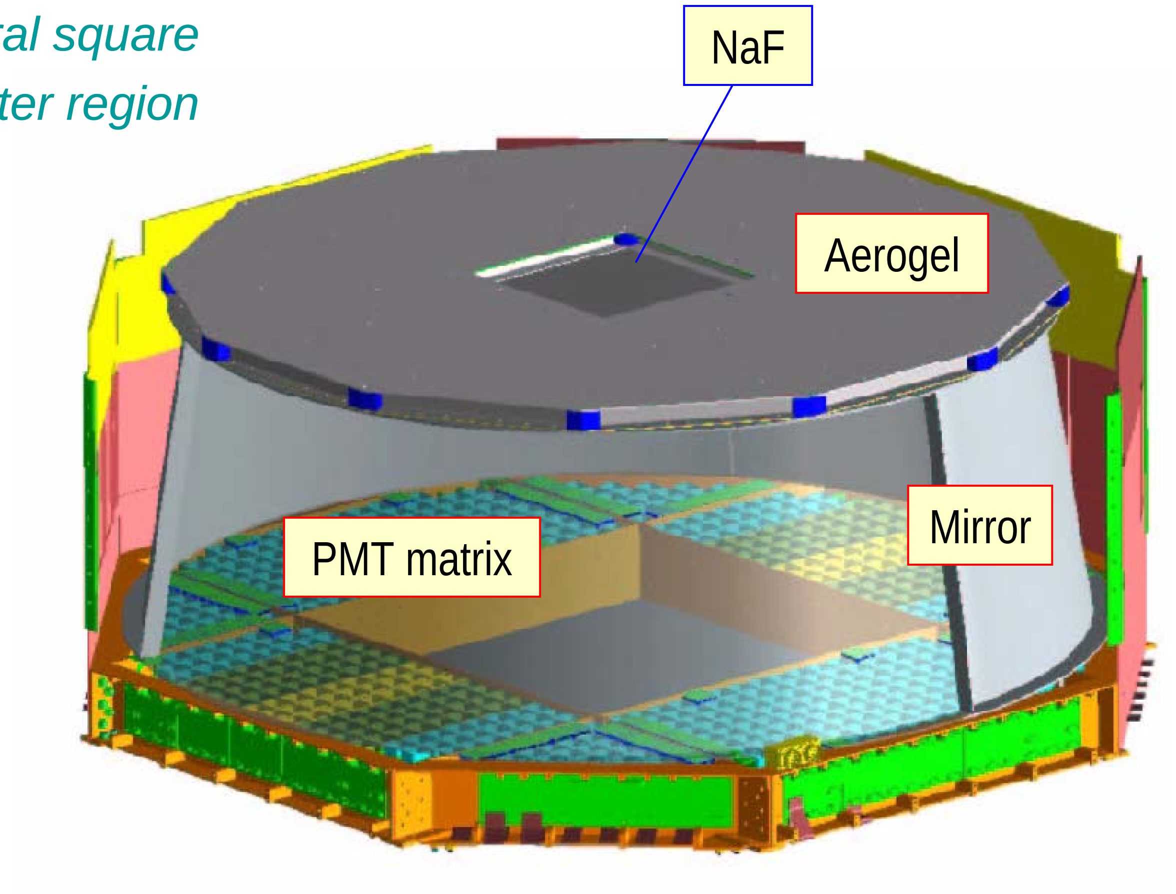
$^{10}Be/^{9}Be$



RICH detector

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

(see Luísa Arruda's talk)



RICH simulation data samples

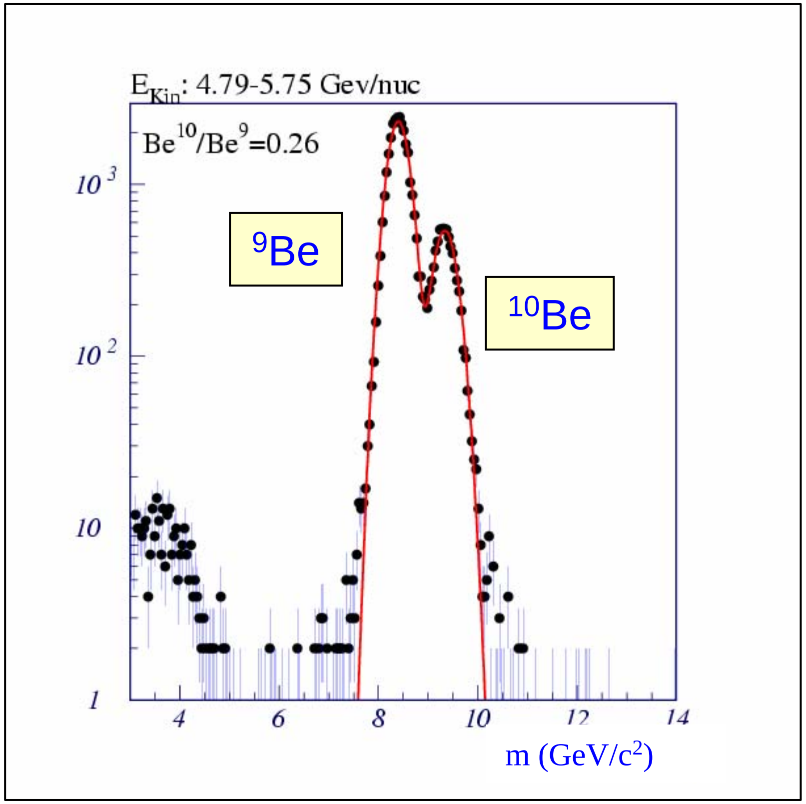
- A large statistics was fully simulated on the RICH:

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	^{3}He, ^{4}He	2.0×10^6		≈ 1 day
4	^{9}Be, ^{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)

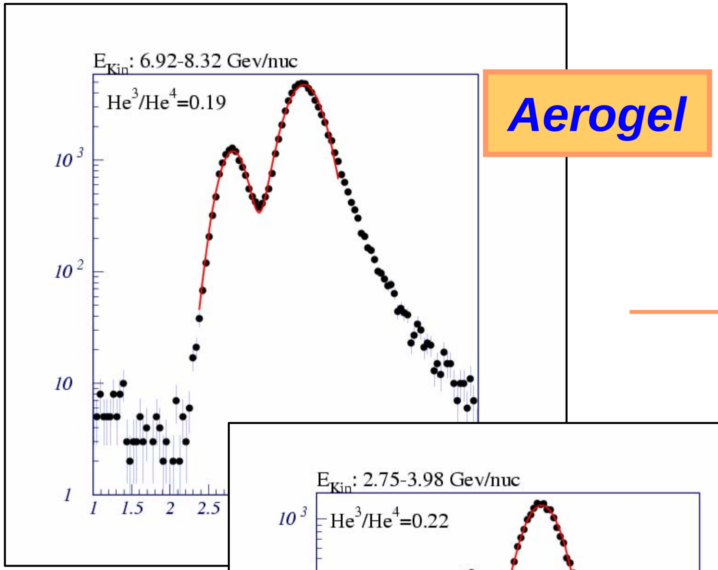
- Simulated ratios ~ 0.1-0.4
- Mass reconstructed from p & β data
  - Mass resolution depends on energy
- Relative isotopic abundances determined for He, Be:
  - Separate mass fits for Aerogel & NaF populations, one fit for each energy channel
  - Overall mass region fit to 2 gaussians, width ratio assumed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

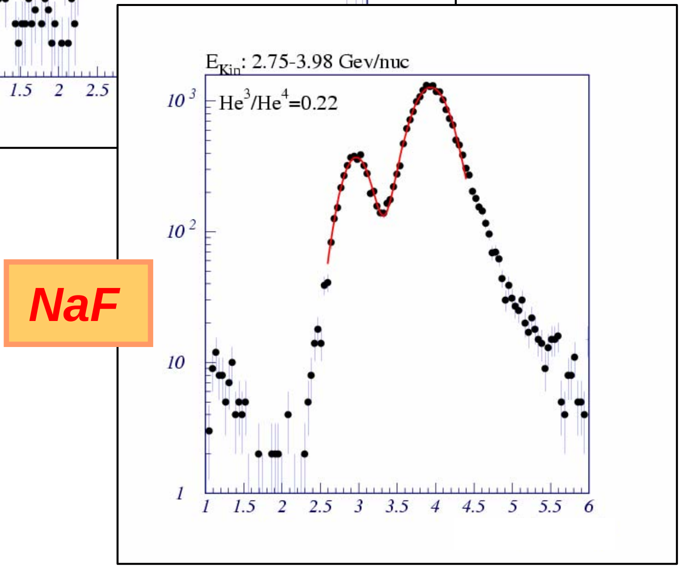


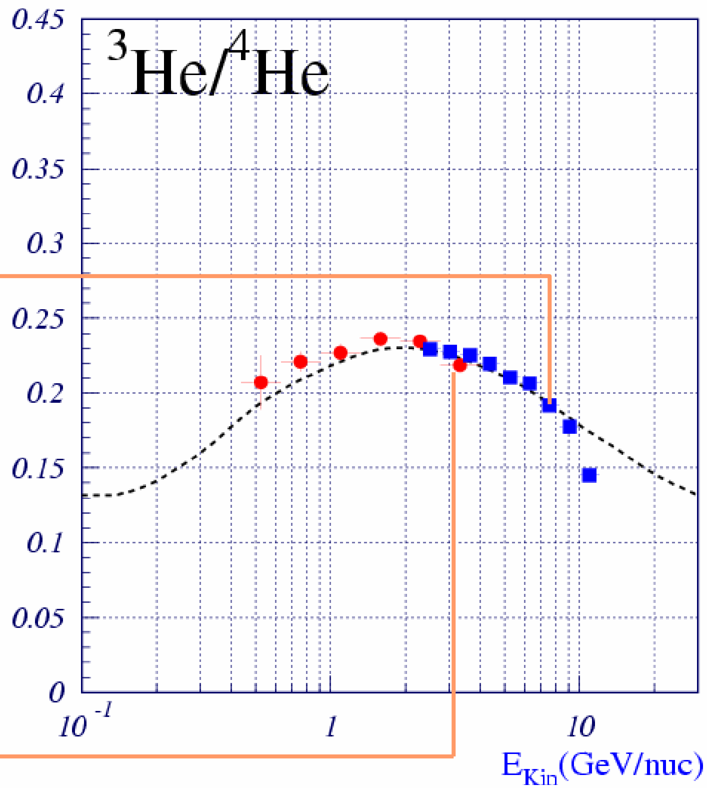
Reconstruction results: ^{3}He, ^{4}He

Mass distributions

Isotope ratios



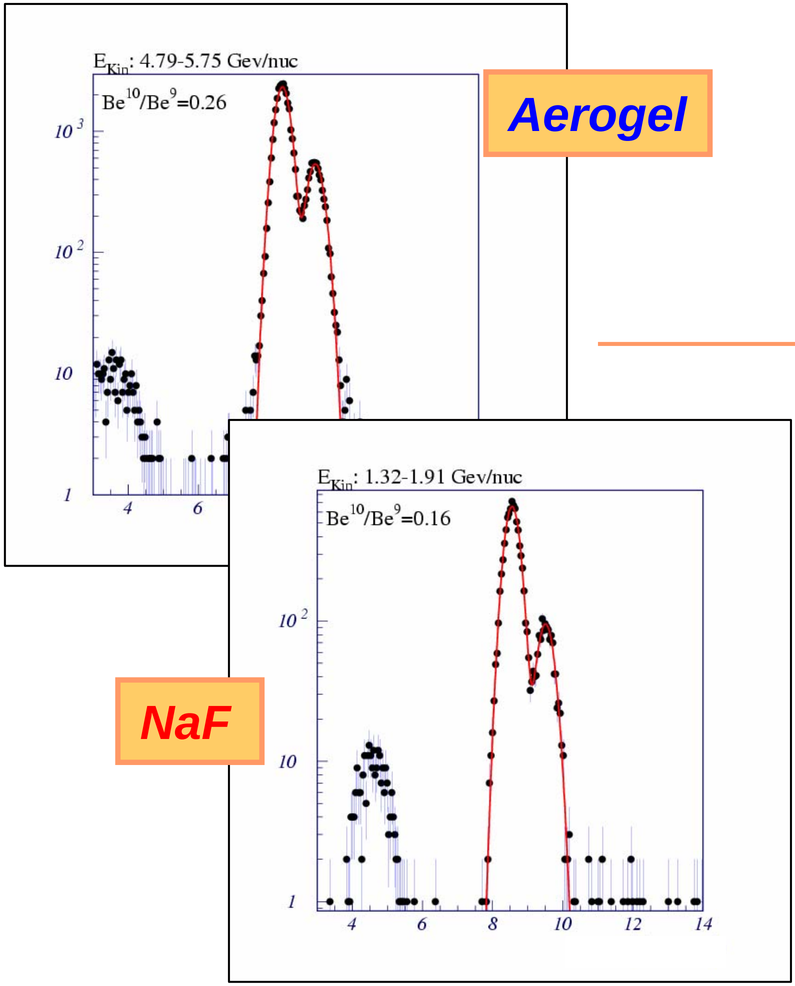




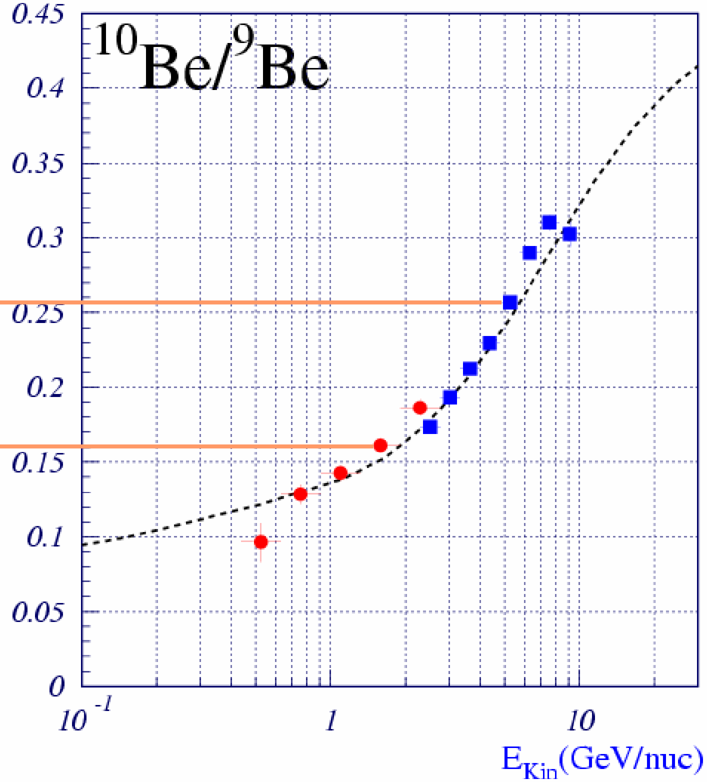
Simulated curve from Seo et al. (1994)

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

Mass distributions



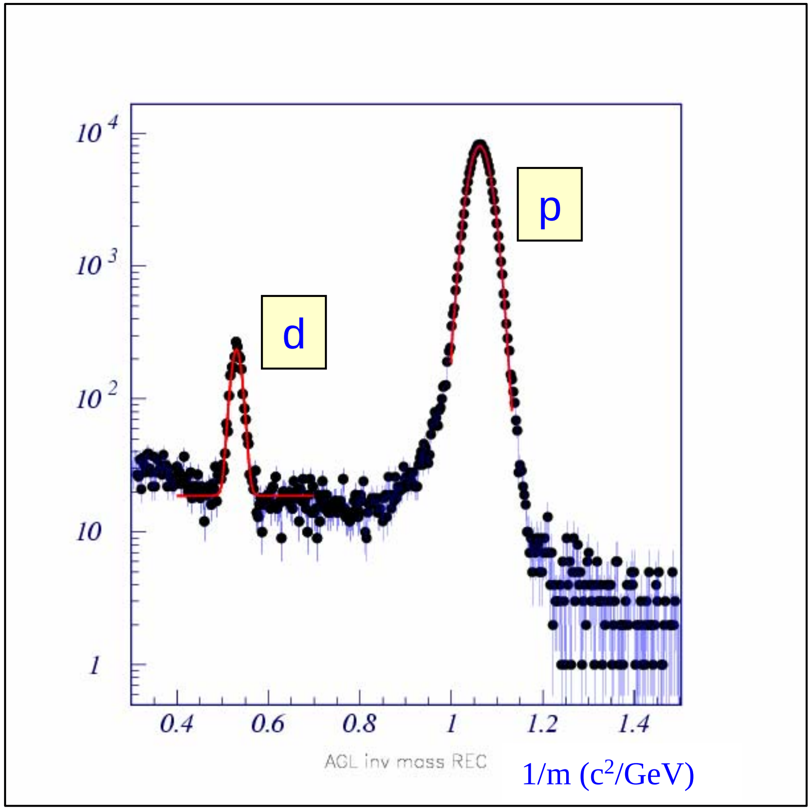
Isotope ratios



Simulated curve from Strong & Moskalenko (2001)

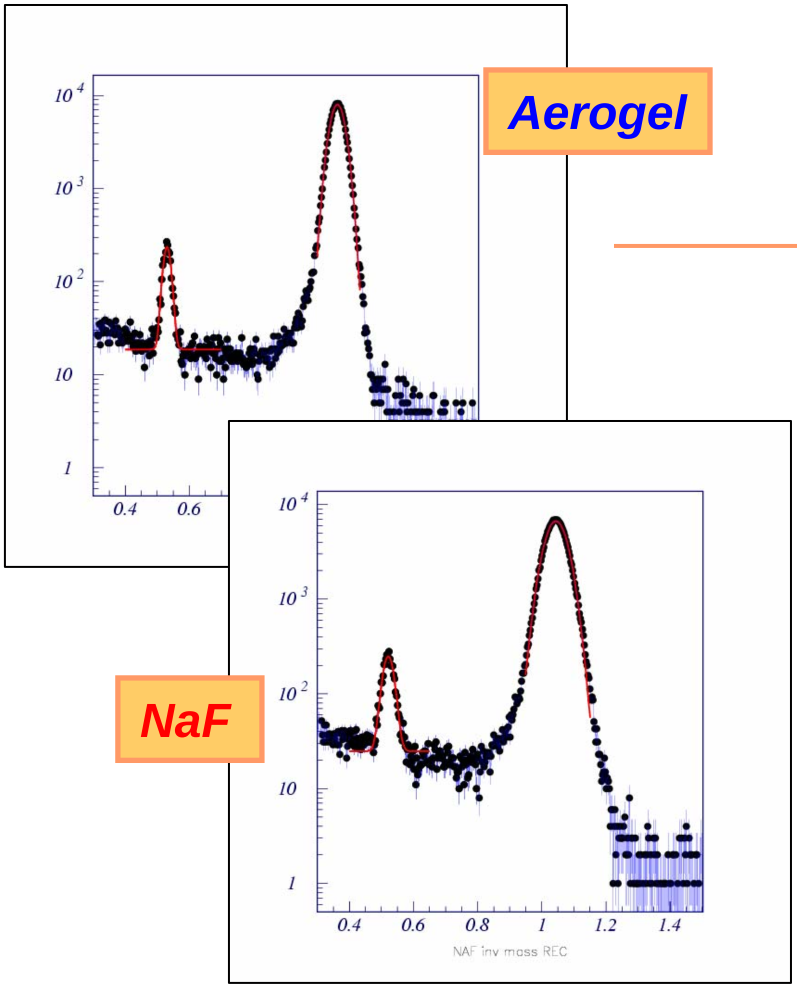
Isotope separation procedure (H)

- 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 (assumed constant in peak region) used for deuteron peak

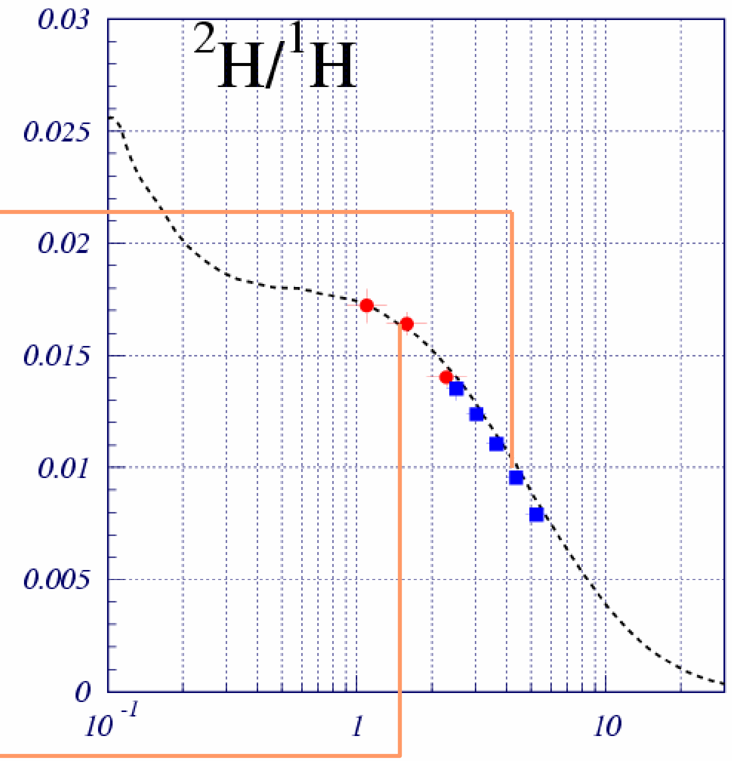


Reconstruction results: p, d

Inverse mass distributions

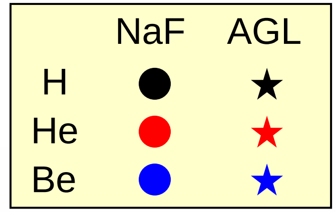


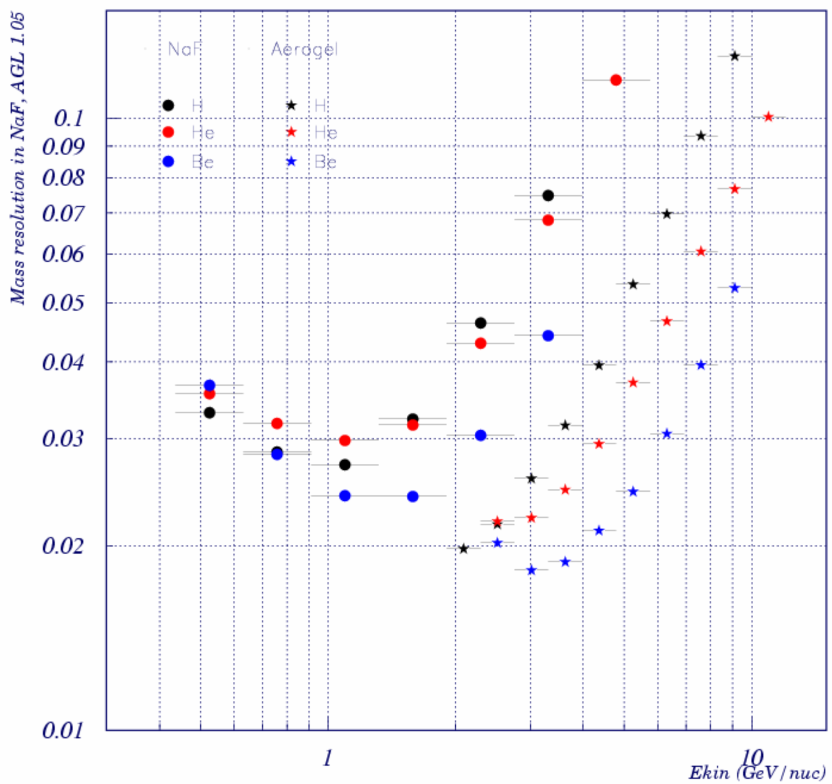
Isotope ratios



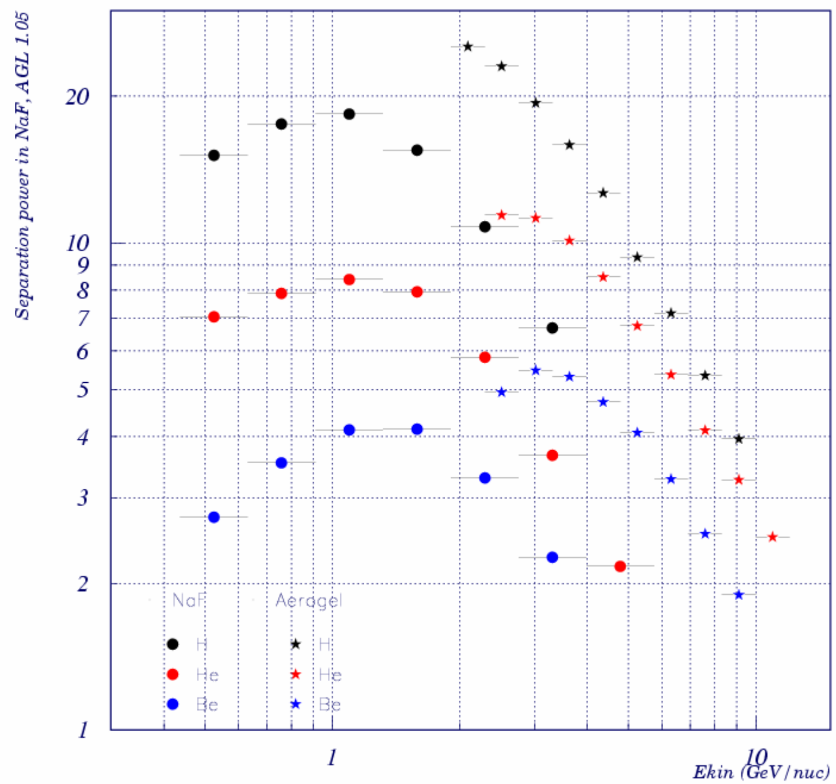
Simulated curve from
Seo et al. (1994)

Mass resolution & separation power





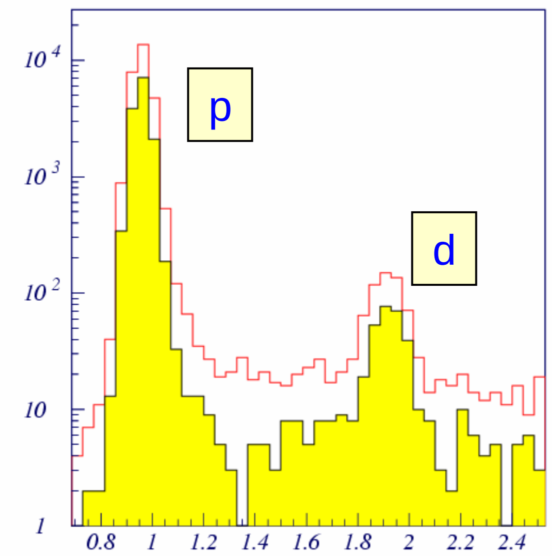
Mass resolution



Separation power = $\Delta m/\sigma_m$

Reconstruction efficiencies

- Average number of hits $\propto Z^2$
- Strong dependence on event geometry
- Minimum no. hits (~3-4) needed for good reconstruction (cut at 3 hits in this analysis)
  - ⇒ *critical issue for H, but not as important for He & Be*
- Reconstruction efficiencies for high E_{kin} (%):



H peaks (p & d)
- Red: cut at 3 hits
- Blue: cut at 4 hits

Isotope	Cut	Aerogel*	NaF
p	3 hits	80.0	23.7
	4 hits	68.9	11.2
^4He	3 hits	96.2	84.1
	4 hits	95.7	76.3
^9Be	3 hits	96.0	92.9
	4 hits	96.0	92.9

* n = 1.05; Outer events (particle impact < 2 cm from border) excluded

Energy cuts for table

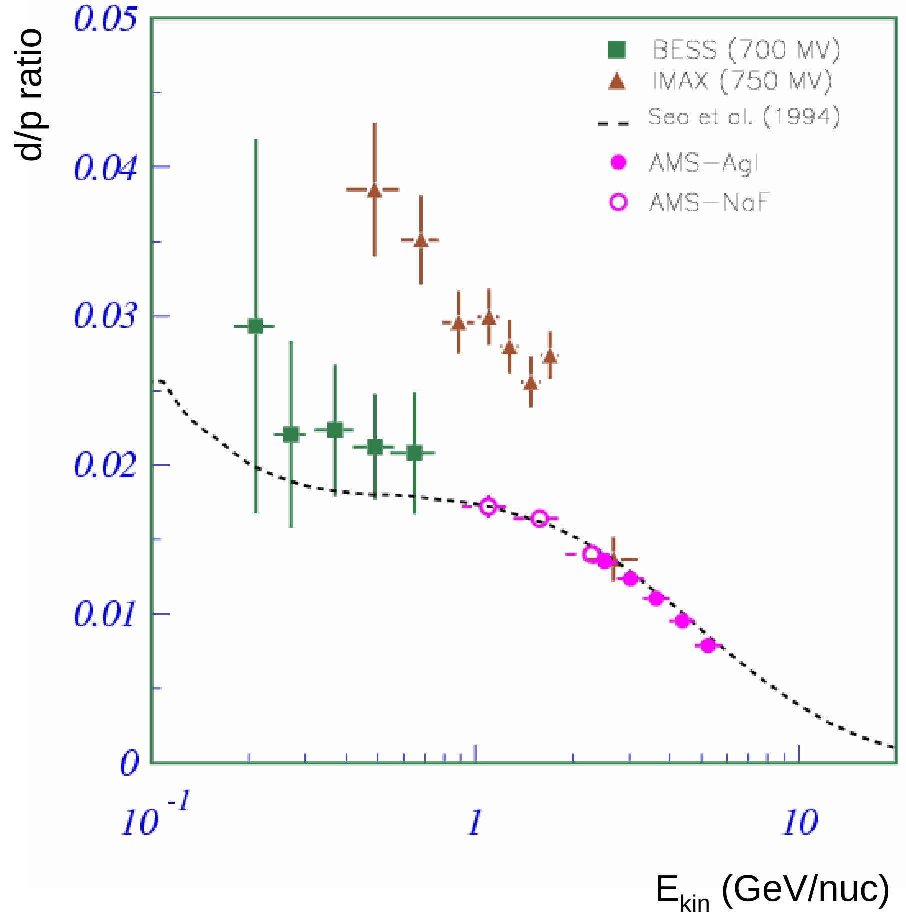
E_{kin} > 10 GeV/n (AGL)

E_{kin} > 12 GeV/n (NaF)

AMS vs. previous experiments: H

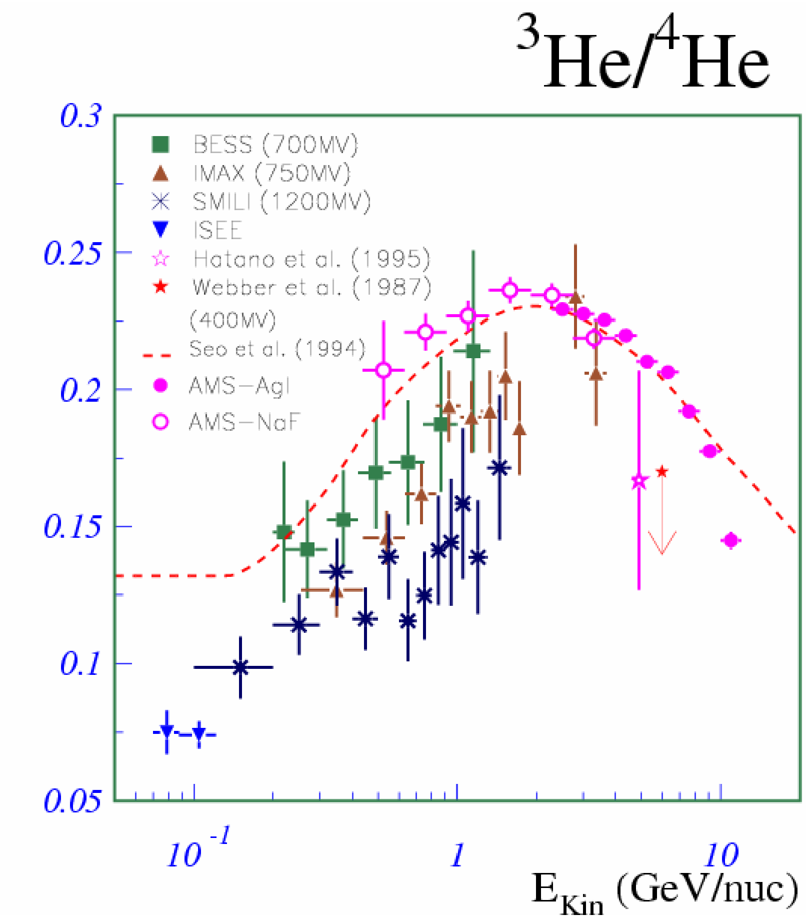
- NaF radiator: allows a clear improvement on existing data at ~ 1 GeV
- Aerogel radiator: allows an extension of energy region to ~ 5 GeV

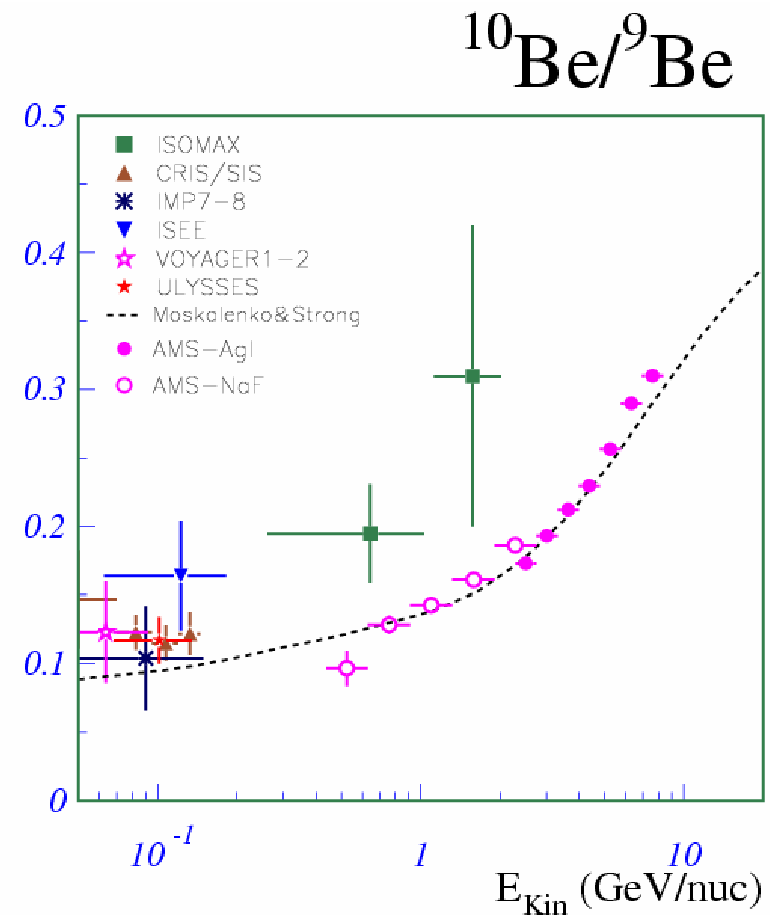
- Prospects from a single week (NaF) or day (Aerogel) of data
  - *AMS will work for 3 years*



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
- 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
  - Techniques presented here may also applied in the challenge of $\bar{d}$ / $\bar{p}$ separation
  - AMS results will provide a major improvement on existing data
- ***AMS may help answering some of today's most important issues in cosmology!***