$^3\text{He}/^4\text{He}$ ratio in Cosmic Rays with AMS-02

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EPS Conference on High Energy Physics
Venice, Italy 5-12 July 2017
Motivation

- Element abundances in Cosmic rays, is different form the one observed in the solar system. Spallation reactions of CR nuclei on the ISM are responsible for these differences.

- The isotopic composition of each element is also strongly biased by spallation interactions.

- Both the element and the isotopic abundances in the CR at the Earth offer a mean to investigate the propagation of CR in our galaxy.

- As most of the B in CR is produced by C spallation, most of the $^3$He is produced by $^4$He spallation.

- $^4$He/$^3$He and $^3$He/$^4$He are probing different propagation distances, accounting for the the smaller $^4$He spallation cross section, when compared to the Carbon one.
Available measurements

![Graph showing 
AMS and the $^3$He/$^4$He measurement

- AMS-02 is a precision Multipurpose spectrometer installed on ISS operating since May 2011.
- It is made of several sub-detectors for a redundant Particle Identification.
- Mass is determined through the simultaneous measurement of Charge, Ridity and Velocity.

Redundant Z measurement allows for a clean selection of He (Z=2) events.
Measuring Isotopic composition with AMS

AMS measure the mass using a simultaneous determination of Rigidity, Charge and Velocity:

\[ m = \frac{Z R}{\gamma \beta} \]

We measure the velocity \( \beta \) with the RICH

- RICH NaF
  \[ \frac{\sigma_\beta}{\beta} \approx 0.3\% \]
  effective range \( 0.75 < \beta < 0.98 \)
  \[ 0.7 < E_{\text{kin}} < 3 \text{ GeV/n} \]

- RICH AGL
  \[ \frac{\sigma_\beta}{\beta} \approx 0.1\% \]
  effective range \( 0.96 < \beta < 0.996 \)
  \[ 2.6 < E_{\text{kin}} < 10 \text{ GeV/n} \]

- Tracker rigidity resolution is \( \approx 8\% \), for \( E_{\text{kn}} \) \([0.8 – 10]\) GeV/n
- This prevents an efficient event by event identification of \(^3\text{He}\) and \(^4\text{He}\).
- The identification of the abundance of \(^3\text{He}\) and \(^4\text{He}\) must come from a template fitting to the mass distribution.
AMS He Data: mass vs Kinetic E

RICH NaF

RICH Aerogel

Mass (a.m.u.) vs Kinetic Energy/n (GeV/n)
AMS He Data: mass vs Kinetic E

RICH NaF

RICH Aerogel

Mass (a.m.u.) vs Kinetic Energy/n (GeV/n)
Measurement Strategy

• Select a narrow bins in beta
• For those event calculate $1/m$ using,

$$\frac{1}{m} = \frac{\gamma \beta}{Z} \frac{1}{R}$$

where $1/R$ and $\beta$ have Gaussian like errors

• The resulting $1/m$ distribution is expected to be the convolution of $1/R$ and $\beta$ distributions.

• At first order $1/m$ has gaussian like distribution with sigma

$$\frac{\sigma_{1/m}}{1/m} = \sqrt{(\frac{\sigma_{1/R}}{1/R})^2 + \left(\frac{\gamma^2 \sigma_{\beta}}{\beta}\right)^2}$$

$E_k = 3 \text{ GeV} / n \approx 9\% \approx 0.1\%$

$E_k = 10 \text{ GeV} / n \approx 12\% \approx 13\%$
Rigidity and beta resolution in AMS

1/R resolution from MC

We build a 1/mass template using an analytic function derived from the 1/R distribution.
AMS data: He isotopes fit

- Two templates sharing the same analytical expression: one for $^4\text{He}$ and one for $^3\text{He}$
- $^3\text{He}$ template shape is fixed from $^4\text{He}$ template shape and the isotope masses ratio
  - $^3\text{He}$ template peak fixed to be $m_4/m_3 \times ^4\text{He}$ template peak
  - $^3\text{He}$ template sigma fixed to be $m_4/m_3 \times ^4\text{He}$ template sigma (constant relative error)

\[ \chi^2/\text{df}= \]

- 3 GeV/n
  \[ \chi^2/\text{df}=90/73 \]
  \[ \text{Ratio: } 18.51 \pm 0.06 \% \]

- 4 GeV/n
  \[ \chi^2/\text{df}=98/78 \]
  \[ \text{Ratio: } 18.11 \pm 0.07 \% \]

- 6 GeV/n
  \[ \chi^2/\text{df}=110/86 \]
  \[ \text{Ratio: } 17.57 \pm 0.08 \% \]

- 9.5 GeV/n
  \[ \chi^2/\text{df}=117/109 \]
  \[ \text{Ratio: } 16.1 \pm 0.16 \% \]

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Test of the accuracy of the fitting procedure

- AMS MC Simulation + use the measured He ($^3$He+$^4$He) spectrum and a realistic isotope fraction
- use MC information to predict $^3$He/$^4$He that should be measured
- compare prediction with result from the Fitting Procedure.

**Graphs:**
- **NaF fit** versus **NaF MC prediction**
- **AGL fit** versus **AGL MC prediction**

**Tables:**
- **NAF**
  - $\chi^2 / \text{ndf}$: 13.95 / 15
  - Mean: $1.023 \pm 0.004$

- **AGL**
  - $\chi^2 / \text{ndf}$: 39.1 / 9
  - Mean: $1.013 \pm 0.001$
Corrections for He Isotope flux ratio

Energy Loss

- From MC get the average Energy loss $\langle \Delta E \rangle$
  Top of AMS $\leftarrow\rightarrow$ Inner Tracker
- Correct for the path length
- Calculate $E_k$ at the top of AMS

Average Energy Loss

Acceptance and Fragmentation

From MC we extract corrections for

A. $^4$He and $^3$He different acceptance
B. $^3$He production $^4$He-$^3$He

$$\frac{\Phi_3}{\Phi_4} = A \frac{N_3}{N_4} - B$$

Flux ratio

Measured ratio
Corrections from Monte Carlo simulation

NaF

$^4\text{He}/^3\text{He}$ Acceptance correction (A)

Aerogel

$^4\text{He} \rightarrow ^3\text{He}$ correction (B)

Acceptance and Fragmentation corrections reliability is being verified $\rightarrow$ Sys error
Final result and previous measurements

Preliminary Data. Please refer to the AMS forthcoming publication in PRL.

Error bars: stat + sys
Three independent $^3$He/$^4$He analyses

1. Resolution model template fitting *(just presented)*
2. Data driven Template Fitting
   - $^4$He mass distribution extracted from the data using geomagnetic cutoff selection of quasi-pure sample
   - $^3$He mass distribution template generated from the $^4$He one
   - Fit templates vs energy
3. Tracker resolution unfolding
   - Use the full tracker resolution matrix from MC
   - Unfold the mass distribution to extract $^3$He/$^4$He at the top of instrument

The three methods produce results which agree within 4%
Summary

• A new preliminary measurement of $^{3}\text{He}/^{4}\text{He}$ ratio in cosmic rays extending from $E_k$ 0.8 to 10 GeV/n has been presented.

• The measurement extends in an energy range where previous measurement are sparse and affected by large errors.

• The measurement is dominated by systematic uncertainty on the interactions within AMS. Further studies will reduce such uncertainty.

• Li and Be isotopic composition analysis is currently undergoing.
THANK YOU
Backup
AMS measurement compared to propagation models

Preliminary Data.
Please refer to the AMS forthcoming publication in PRL.


- **Model I**
  - fit to: \( B/C \) (pre-AMS) + PAMELA \( ^3\text{He}/^4\text{He} \)
  - Diffusion Coefficient \( D(E) \propto E^\delta \), \( \delta \approx 0.2 \)

- **Model II**
  - fit to: \( B/C \) (pre-AMS) + BESS and IMAX \( ^3\text{He}/^4\text{He} \)
  - Diffusion Coefficient \( D(E) \propto E^\delta \), \( \delta \approx 0.6 \)
AMS: A TeV precision, multipurpose spectrometer

Particles and nuclei are defined by their charge ($Z$) and energy ($E \sim P$)

- **TRD** Identify $e^+$, $e^-$, $Z$
- **Silicon Tracker** $Z$, $P$
- **ECAL** $E$ of $e^+$, $e^-$

- **MDR** ($Z=2$) $\sim 3.2$ TV
- **Z and P** are measured independently by the Tracker, RICH, TOF and ECAL

- **TOF** $Z$, $E$

- **RICH** $Z$, $E$

- **AMS**: A TeV precision, multipurpose spectrometer

- **Magnet** $\pm Z$ 20 m

- **µ** $\Delta [-40 -30 -20 -10 0 10 20 30 40 ]$

- **Events**

- **ISS He Data 55-65 GV**

- **He Simulation**

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- **$\sigma_{\beta}=2\%$**
- **$\sigma_{Time}=80$ ps**
Uncertainties

Tot err (Stat + Sys)
- Statistical Error
- Sys 1 (frag 4He->He3)
- Sys 2 (Accept. ratio)
- Sys 3 (Fitting)
Compatibility MIT/CIEMAT

![Graph showing the relationship between relative distance from average and E_kn (GeV/n). The graph includes data points for CIEMAT CD and MIT PZ.]
Fit results: width of the $^4$He peak

$$\sigma_{1/m} = \frac{1}{m} \sqrt{\left(\frac{\sigma_1}{1/R}\right)^2 + \gamma^4 \left(\frac{\sigma_\beta}{\beta}\right)^2} = \frac{1}{m} \sqrt{(p_0 + p_1 E_k + p_2 E_k^2)^2 + \gamma^4 (p_3)^2}$$

![Graph showing sigma of $^4$He 1/m peak as a function of $E_k/n$ (GeV/n)]

- $\sigma_{1/m} = 0.024 \approx 9\%$
- Expected from tracker resolution
- Fitted RICH beta resolution 0.073 %