Boron Isotopes in the PAMELA Experiment

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ISCRA-2019. MEPhI, 28.06.2019, Moscow

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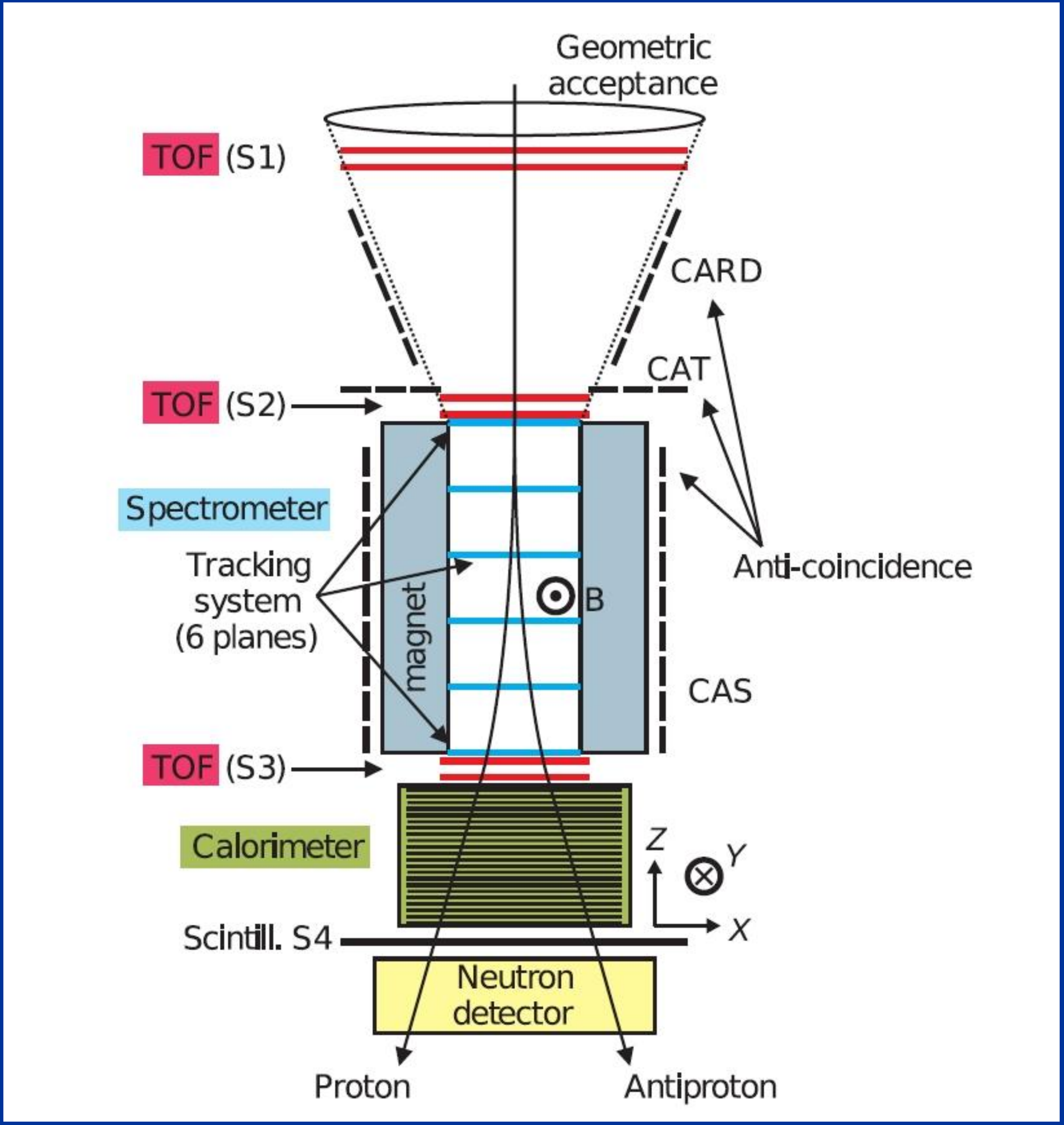
Introduction

Analysis of the isotopic composition of nuclei in galactic cosmic rays (GCR) in the PAMELA orbital international experiment allows to study the problems of cosmic ray origin and propagation in our Galaxy. PAMELA magnetic spectrometer data provided the significant progress in the study of the light nuclei isotopic composition of GCR from H to Be in the energy range ~ 0.1–1 GeV/nucl. This makes it possible to estimate the contribution of local (~ 100 pc) young (~ 10^6 years) interstellar sources (LIS) from supernova explosions into GCR fluxes. The analysis of boron (B) isotope fluxes in the GCR has so far been carried out only in the energy range ~ 0.08–0.17 GeV/nucl. in the space experiments Voyager, Ulysses, ACE. In present contribution the attempt was done to determine the $^{11}B/^{10}B$ ratio in the energy range ~ 0.1–1.0 GeV/nucl. for the first time on the base of 2006-2014 PAMELA data using the measurements of the detected nuclei rigidities, velocities and ionization losses in a multilayer calorimeter. The new PAMELA results are consistent with existing as experimental data and those expected from simulations. However the statistical and systematic measurement accuracies do not allow us to separate the local boron source contributions into GCR fluxes. The results of the boron isotope flux analysis in GCR (^{10}B, ^{11}B spectra and $^{11}B/^{10}B$ ratio dependences on the rigidity and energy) are presented as well as the existing measurement data and simulation results.

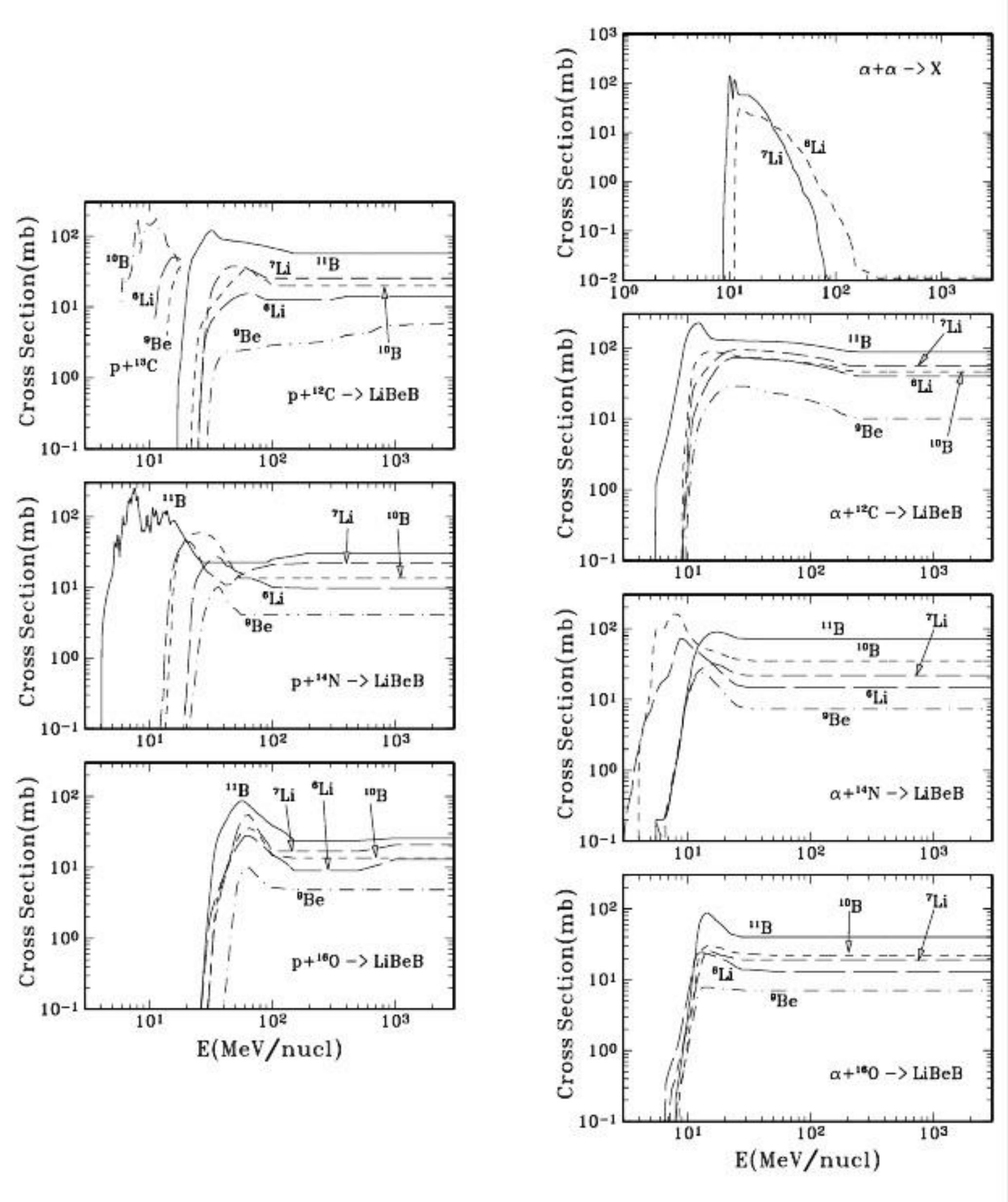
PAMELA Magnetic Spectrometer



Mass: $Mc^2=RZ/(\beta^{-2}-1)^{1/2}$

1. Z from S1, S2, S3
2. β=v/c from TOF
   Time resolution:
   Z=1 ~ 250 ps
   Z=2 ~ 100 ps
   Z=3 ~ 85 ps
   Z=4 ~ 80 ps
   Z=5 ~ 80 ps
3. R from Tracker
   MDR ~ 1 TV
4. Up to S3 - X~5 g/cm^2
5. Orbit inclination 70^0

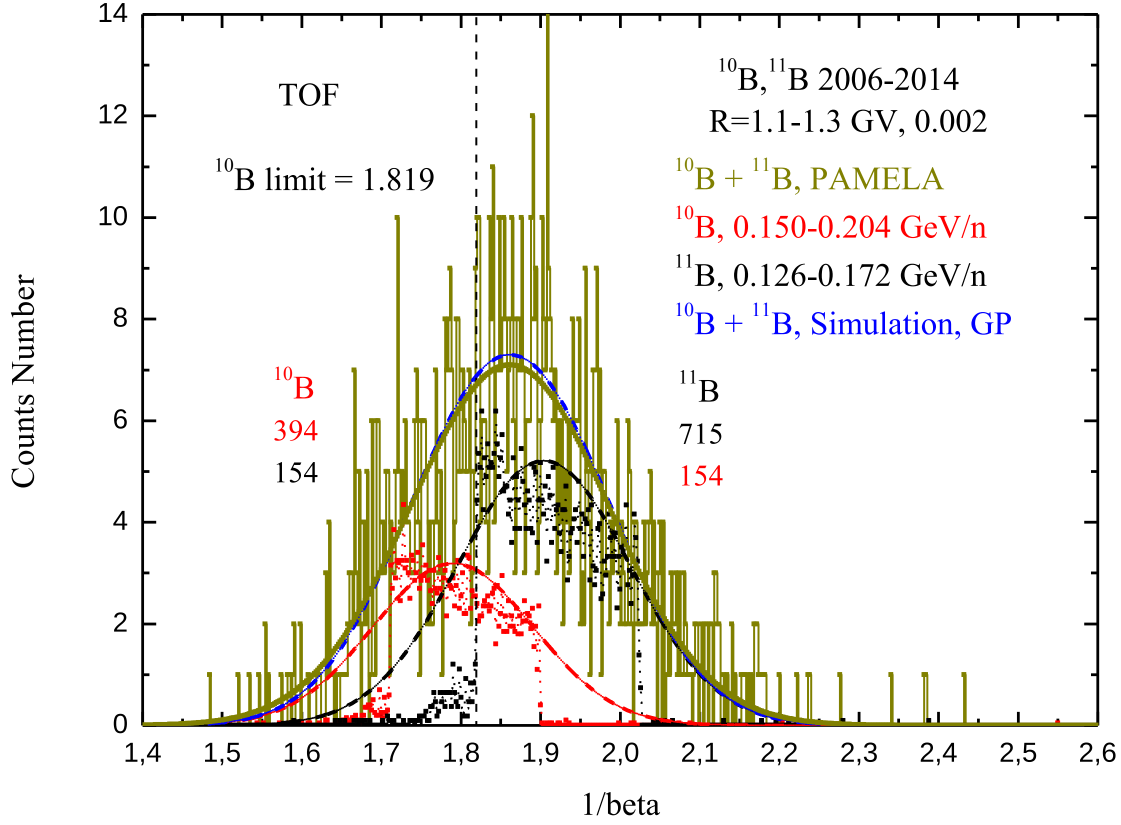
Origin of Li, Be and B Isotopes –
GCR 1H and 4He interactions on He, C, N, O



E. Vangioni-Flam et al.
astro-ph 990717

NB. 6Li, 7Li from He+He by
E = 10-100 MeV/nucl.

Method of limits for isotopes selection (example), TOF

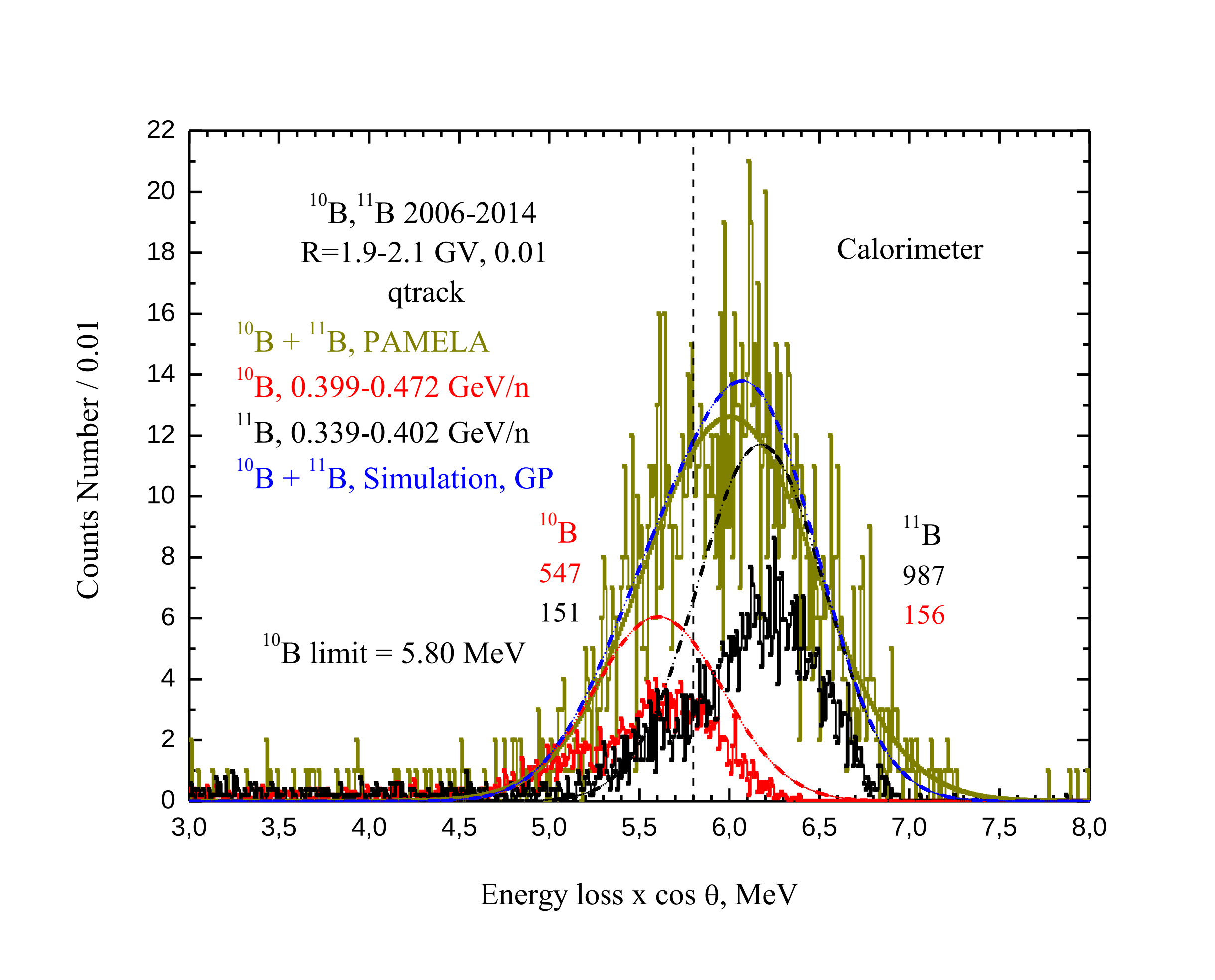


Advantages:

1. Simple
2. Stable to 1/beta distributions and isotope ratio in reasonable limits
3. Precision of data for 1/beta limits ~ 0.002-0.004
4. Good agreement with usual methods by GCR H and He isotopes analysis.

NB. Events in crossing area include in errors of ratio data.

Method of limits for isotopes selection (example), Calorimeter

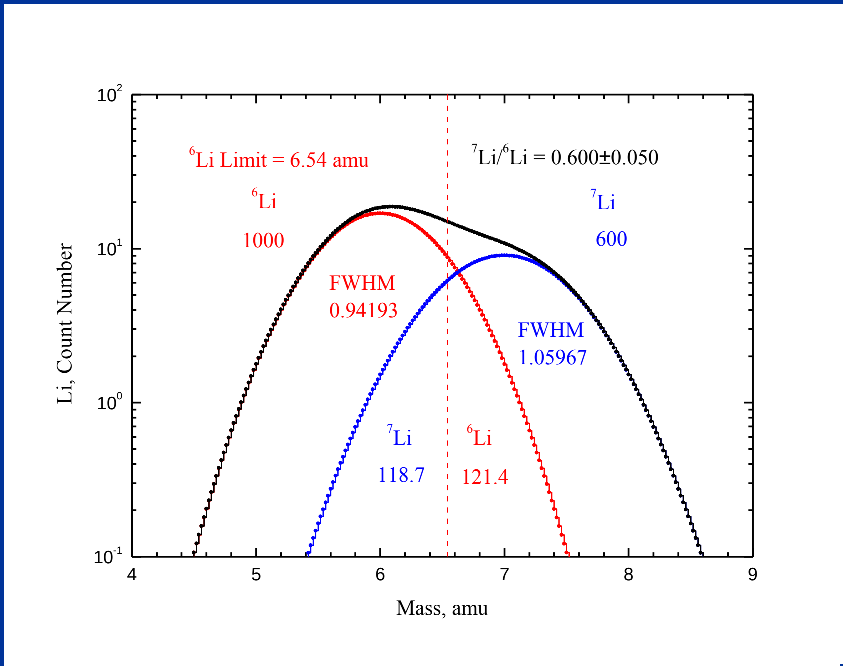


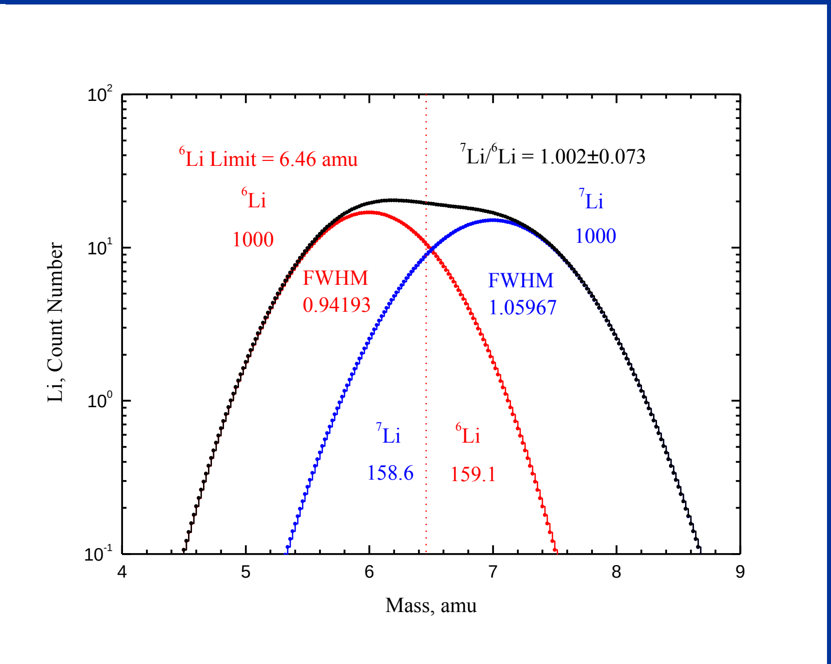
Advantages:

1. Simple
2. Stable to dE/dx distributions and isotope ratio in reasonable limits
3. Precision of data for 10B limits ~ 0.01 MeV
4. Good agreement with usual methods by GCR H and He isotopes analysis.

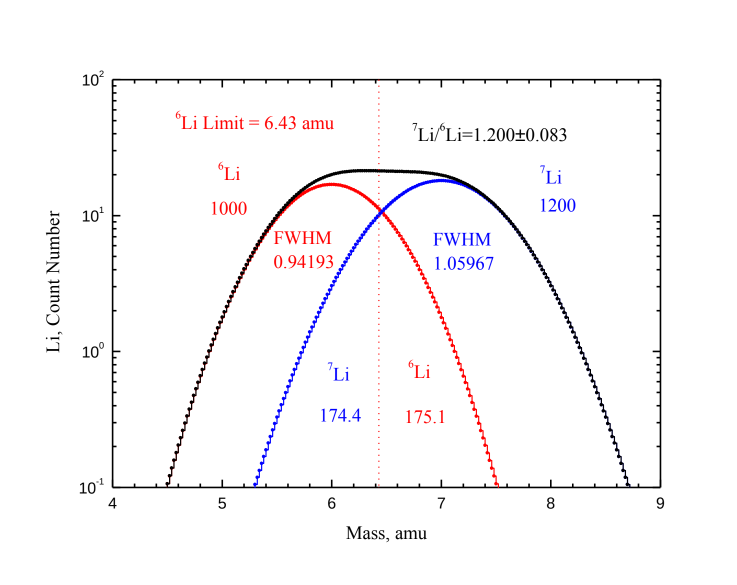
NB. Events in crossing area include in errors of ratio data.

Method of limits for isotopes selection and Gaussians (example)



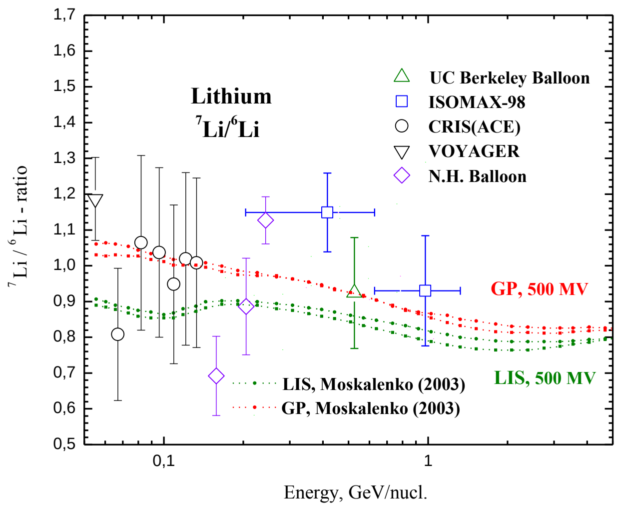


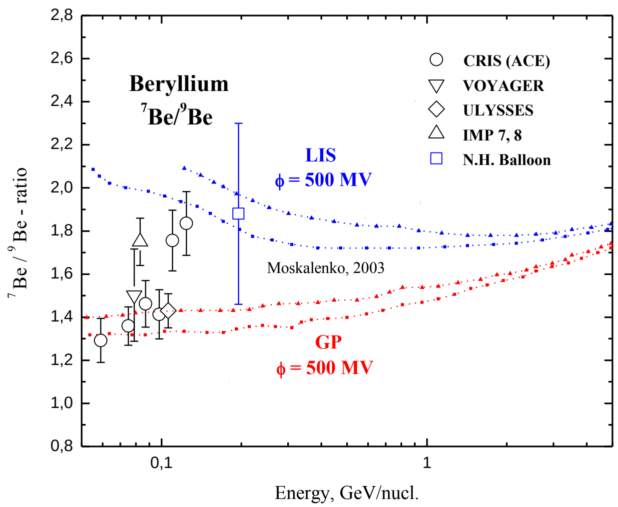
Accuracy ~ 7-8%

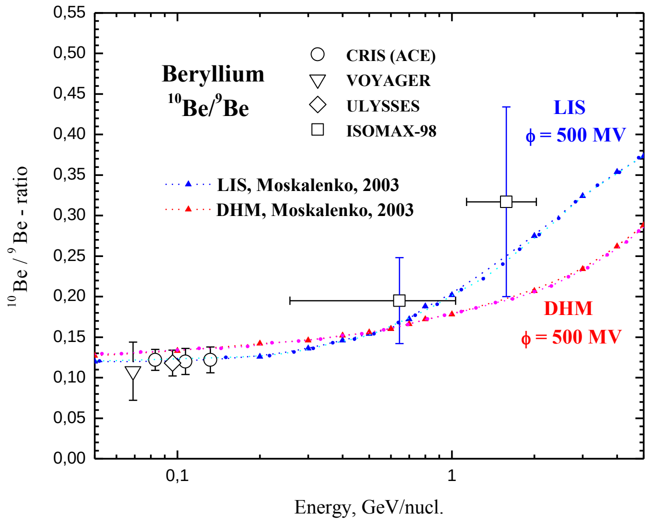


After it can use
ITERATION METHOD

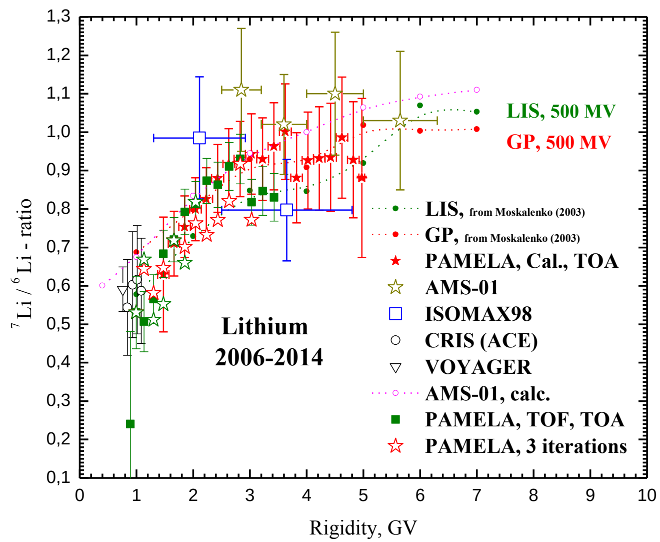
7Li/6Li, 7Be/9Be, 10B/9Be E-Ratio before PAMELA

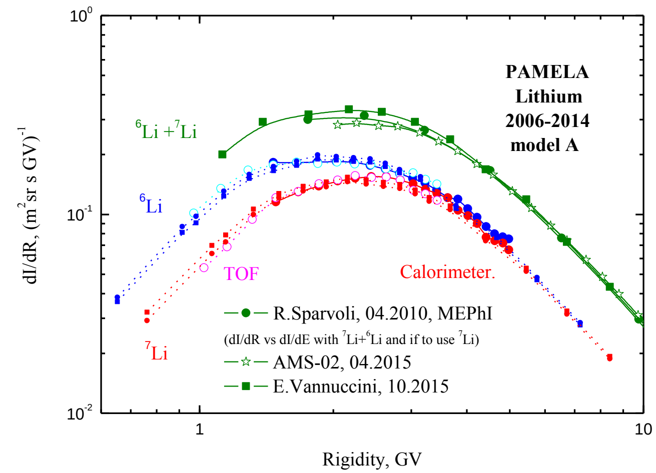


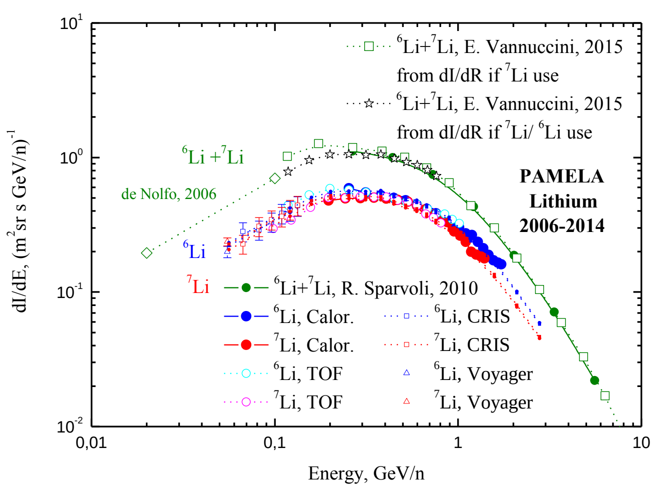


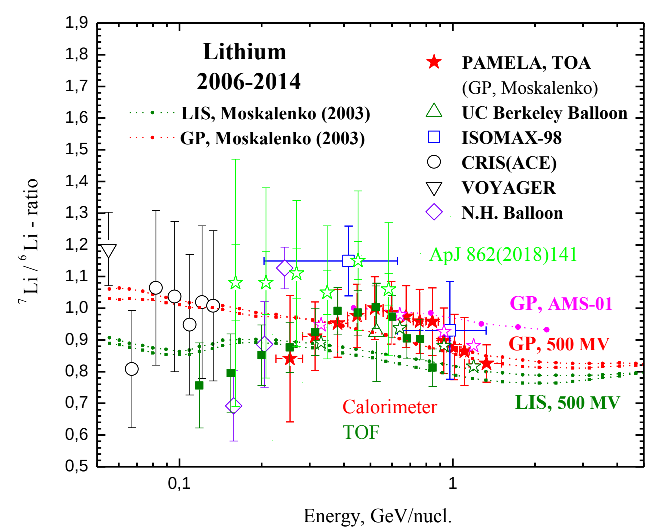


PAMELA, 7Li/6Li-Ratio, R and E-Spectra, 2006-2014 and Local Interstellar Sources (Preliminary data)

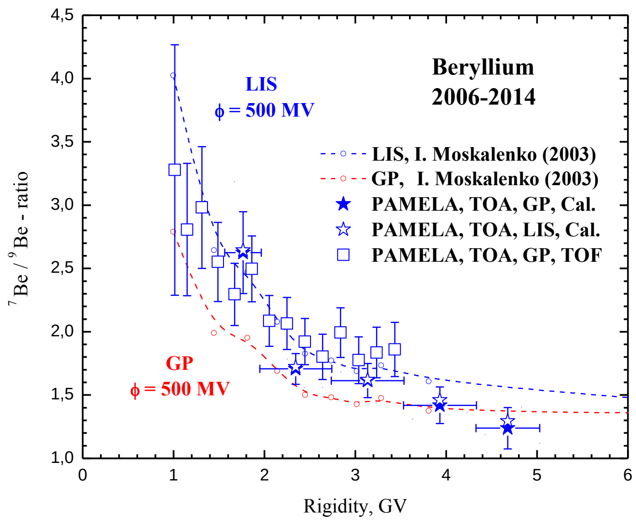


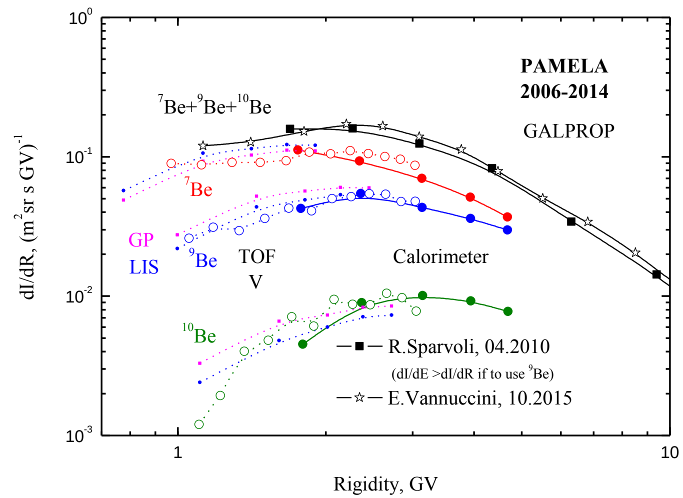


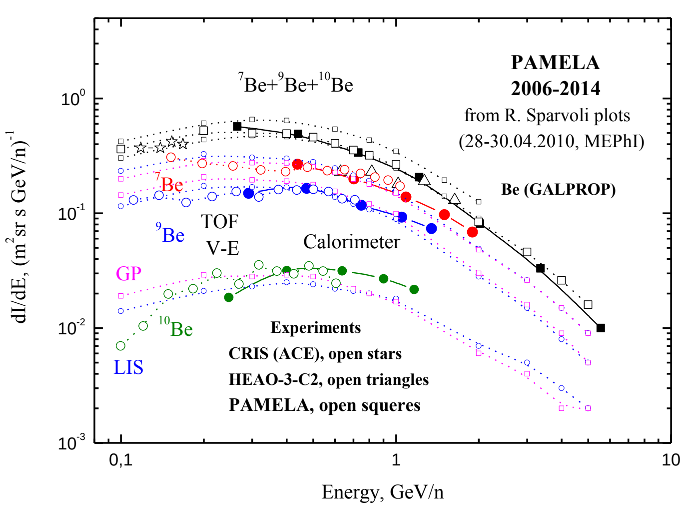


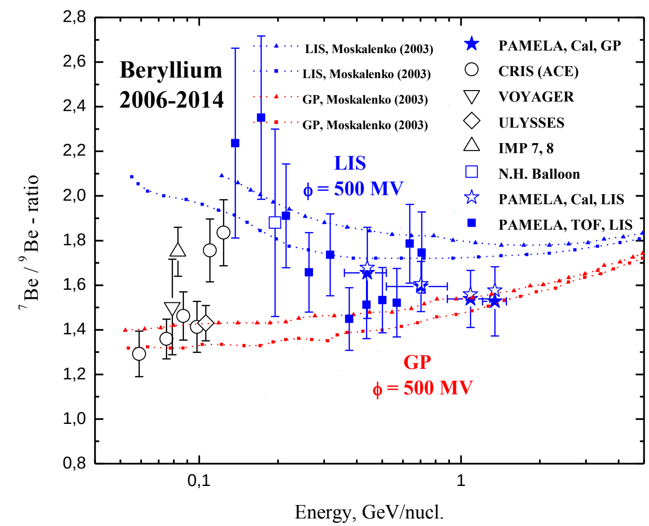


PAMELA, 7Be/9Be-Ratio, R and E-Spectra, 2006-2014 and Local Interstellar Sources (Preliminary data)

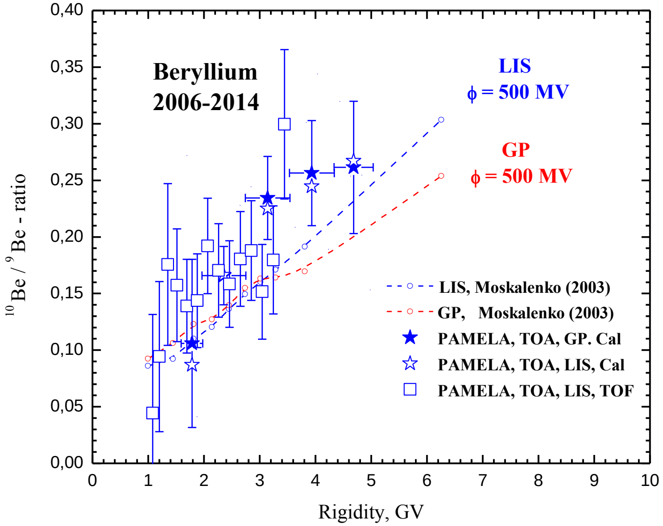


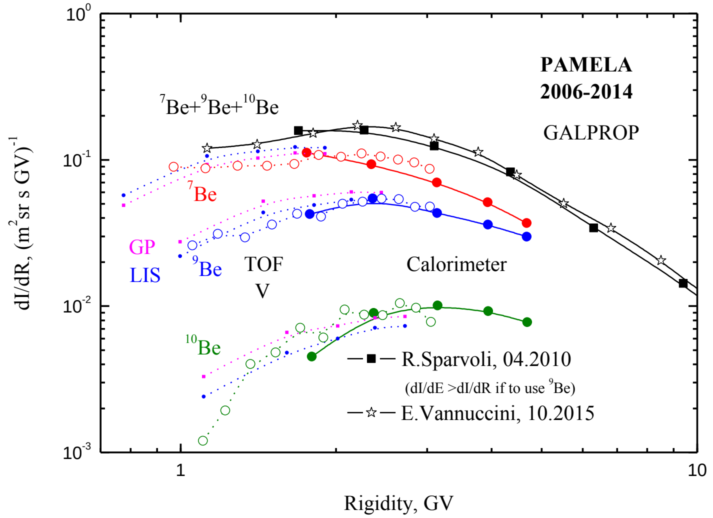


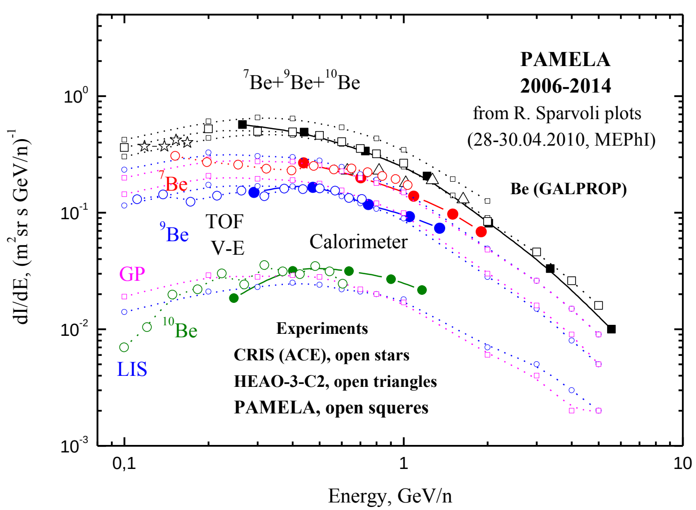


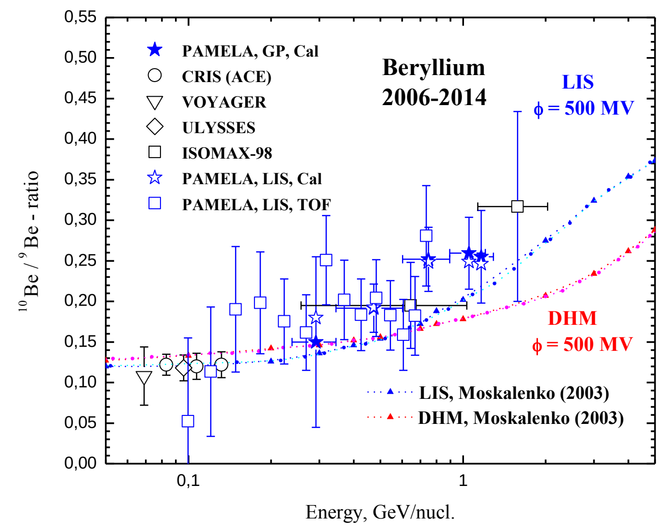


PAMELA, 10Be/9Be-Ratio, R and E-Spectra, 2006-2014 and Local Interstellar Sources (Preliminary data)

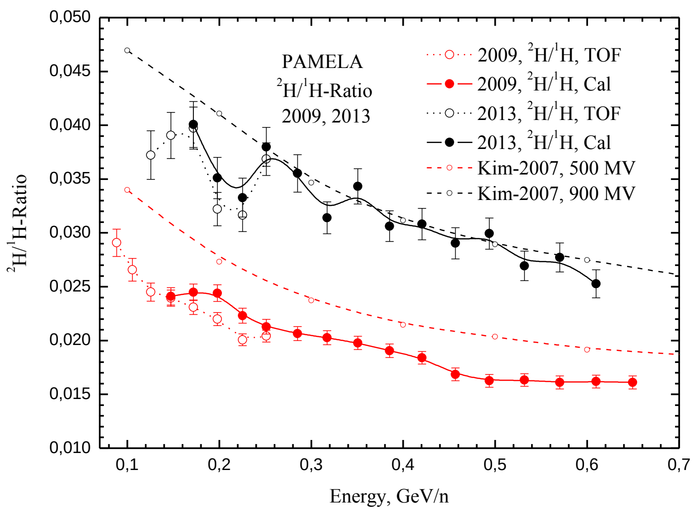


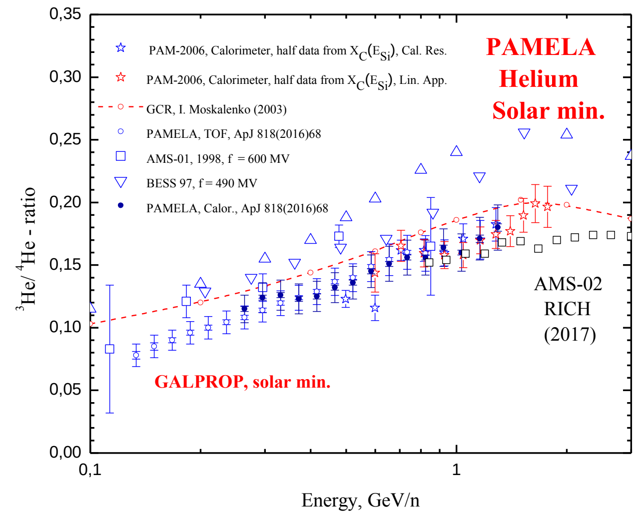


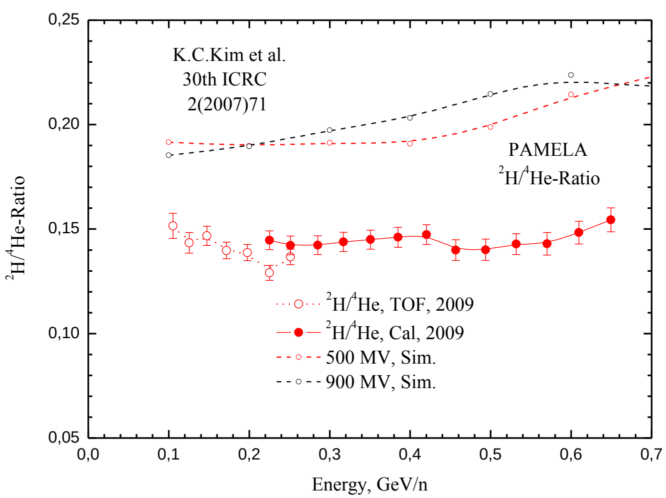




PAMELA, 2H/1H, 3He/4He, 2H/4He E-Ratio and Local Interstellar Sources







Measured decreasing of 3He/4He, 2H/1H , 2H/4He in comparison with GALPROP simulation can indicate on additional Local Interstellar Sources of 1H and 4He in Cosmic Rays…

7Be/9Be+10Be E-Ratio, PAMELA in ApJ 862(2018)141

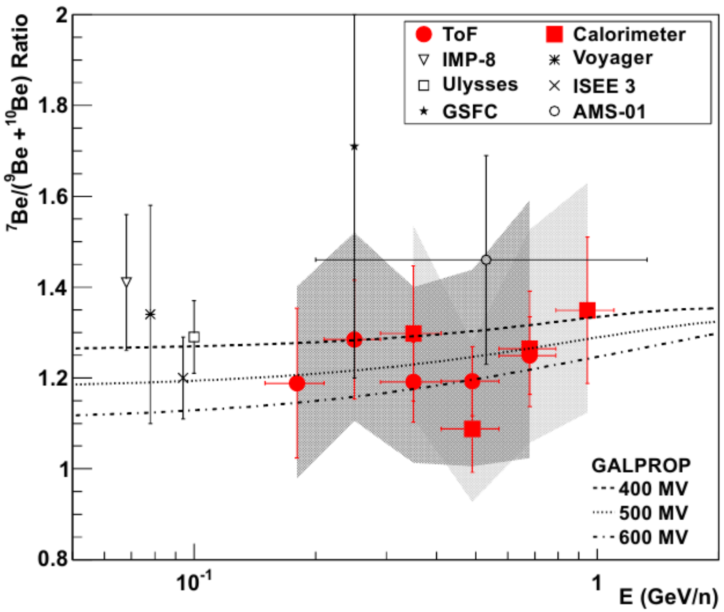
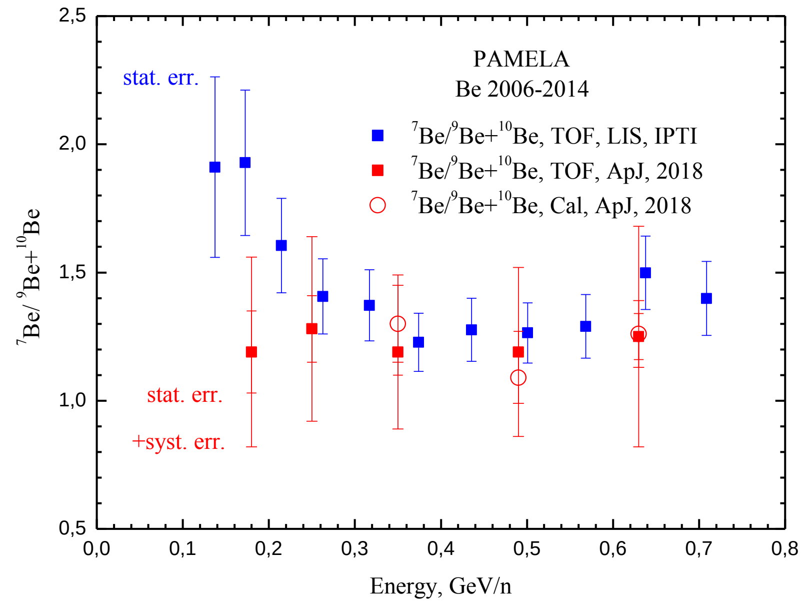
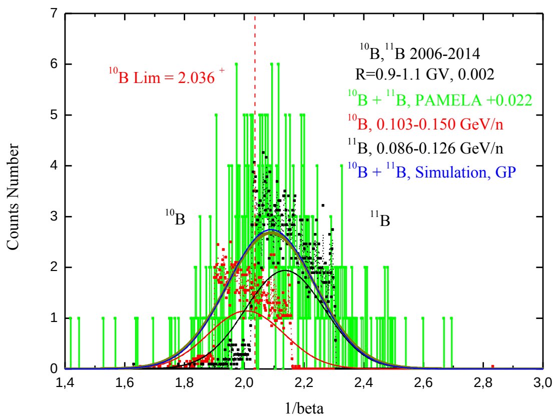


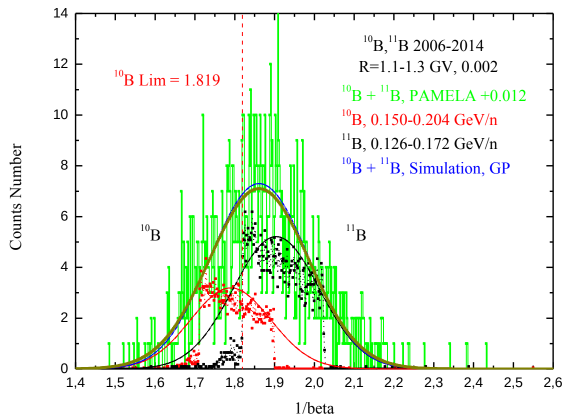
Fig. 11.— Ratio of $^{7}Be/(^{9}Be + ^{10}Be)$ derived with the PAMELA ToF (circles) or the calorimeter (squares). Error bars show the statistical uncertainty while shaded areas show the systematic uncertainty. Previous experiments are: Voyager (Webber *et al.* 2002), ULYSSES (Connell 1998), ISEE3 (Wiedenbeck & Greiner 1980), IMP7/8 (Garcia-Munoz *et al.* 1977), GSFC (Hagen *et al.* 1977), AMS-01 (Aguilar *et al.* 2011). Also shown are predictions of GALPROP webRun v54.1 (Vladimirov *et al.* 2011) using di†ferent solar modulation parameters.

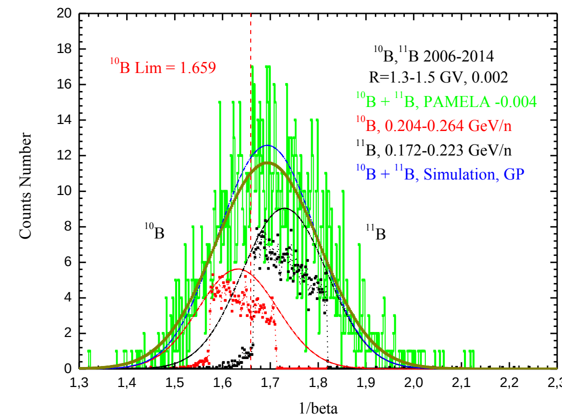


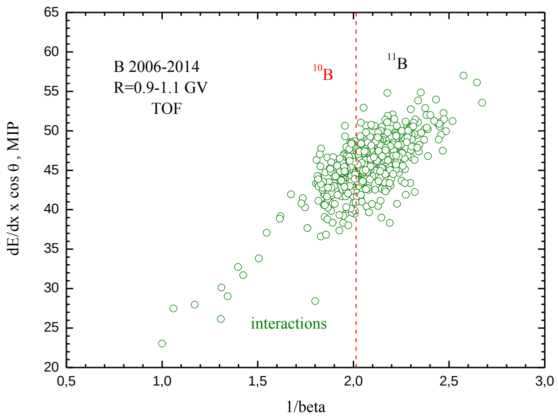
Boron Isotopes In Cosmic Rays

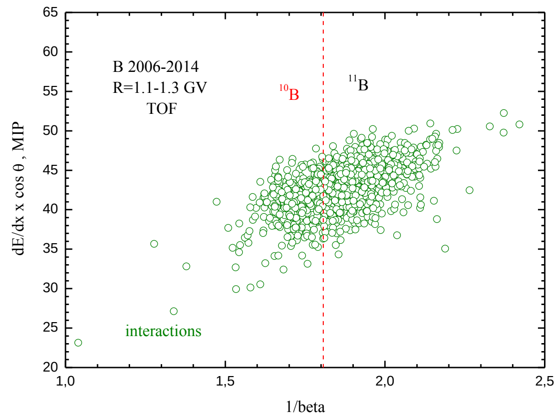
10B and 11B, 0.9-1.5 GV, 2006-2014, TOF

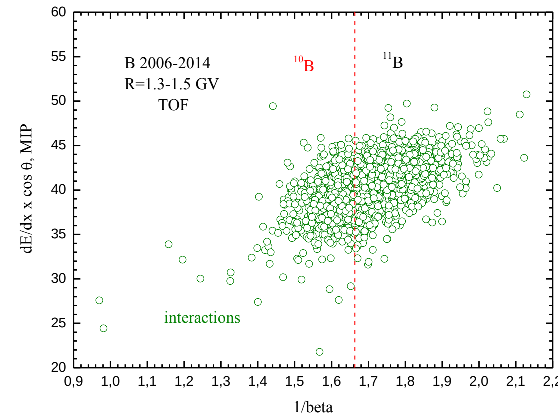






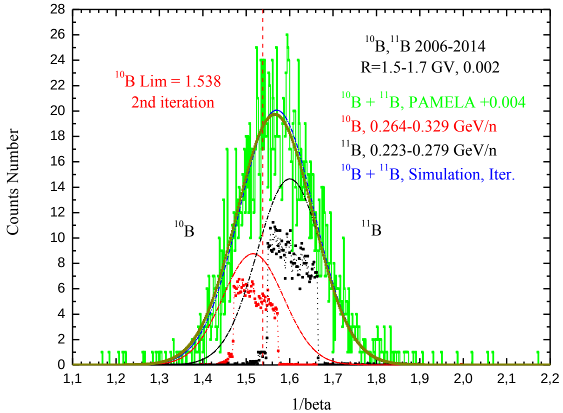


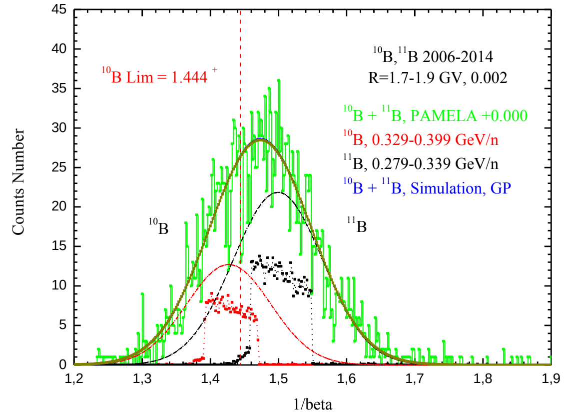


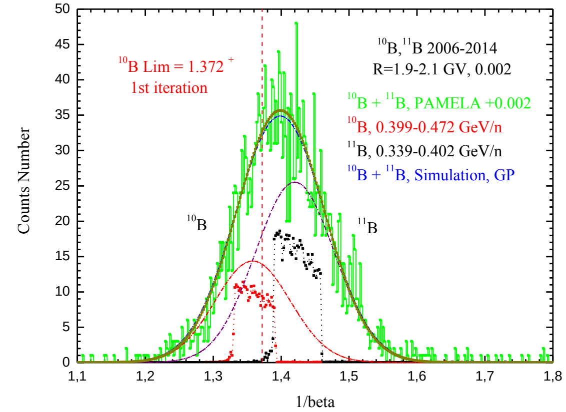


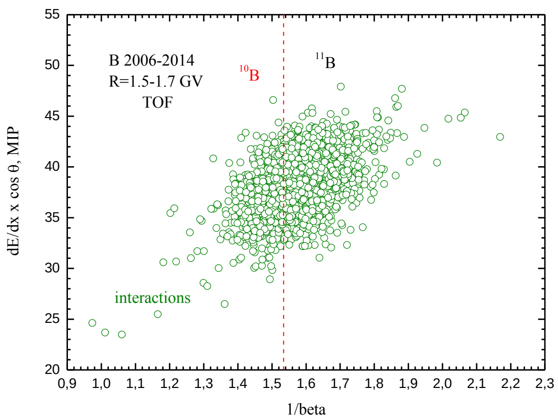
2D-analysis (dE/dx vs 1/beta) can use for background selection of nuclear interactions.

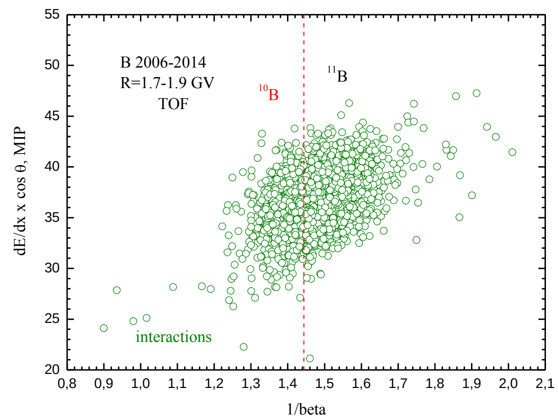
10B and 11B, 1.5-2.1 GV, 2006-2014, TOF

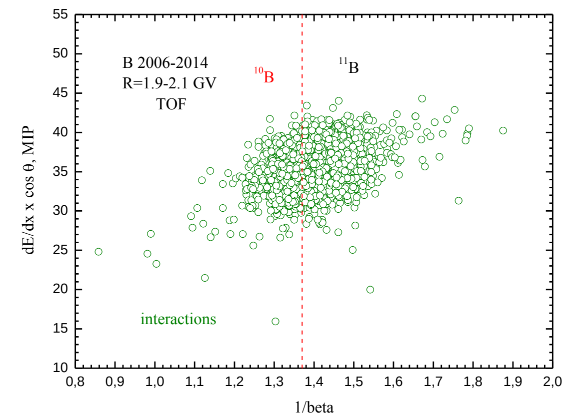






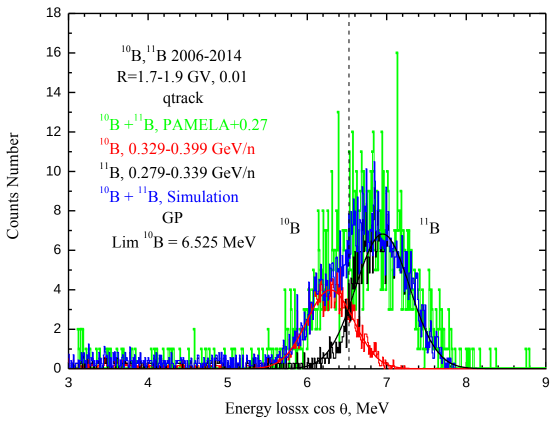


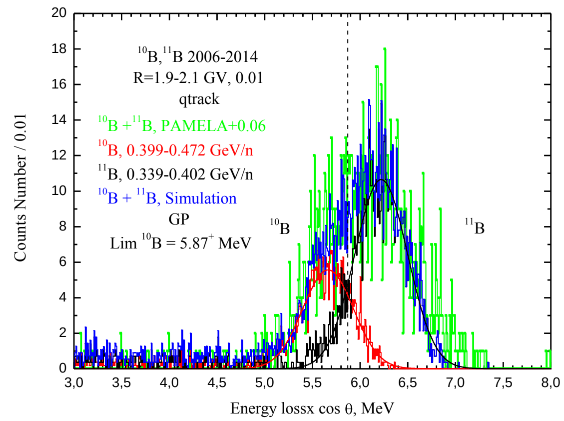


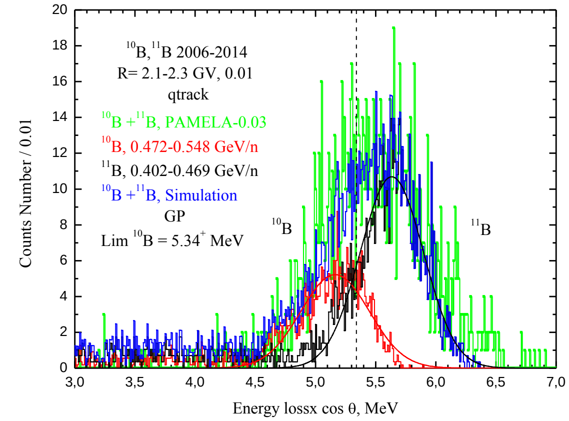


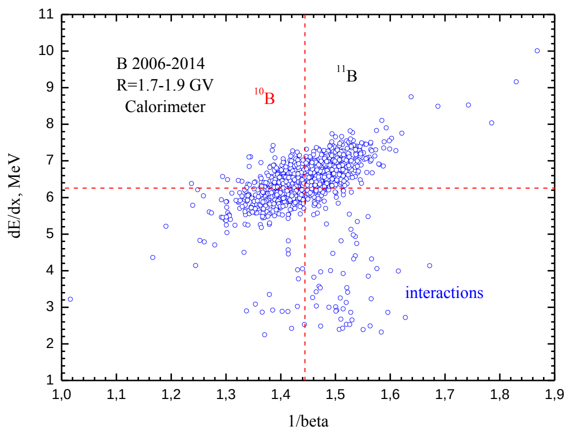
Background of nuclear interactions is not so big in the PAMELA TOF flight data.

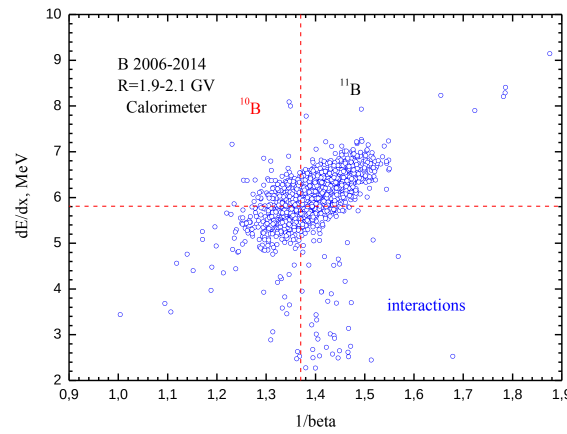
10B and 11B, 1.7-2.3 GV, 2006-2014, Calorimeter

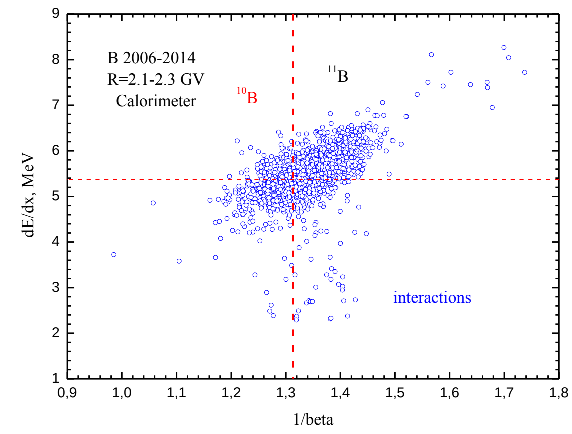






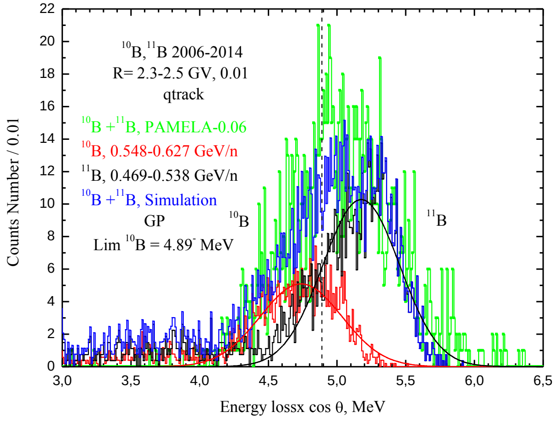


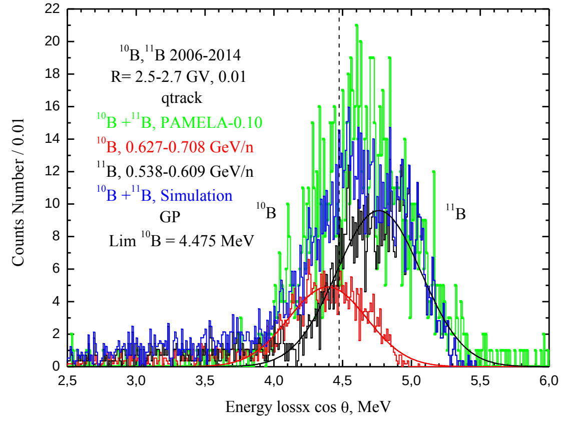


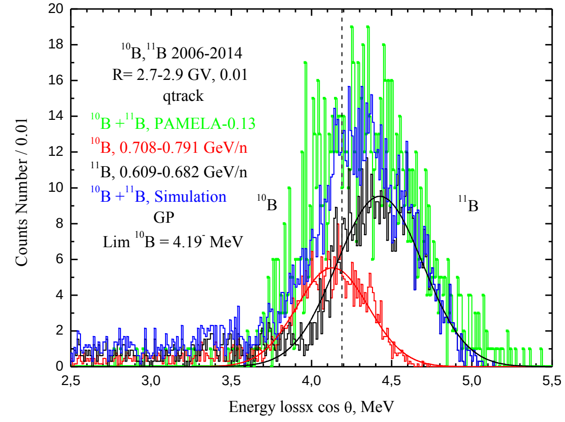


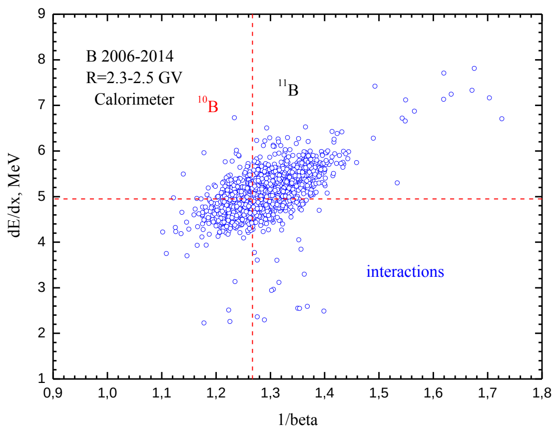
2D-analysis (dE/dx vs 1/beta) can use for background selection of nuclear interactions.

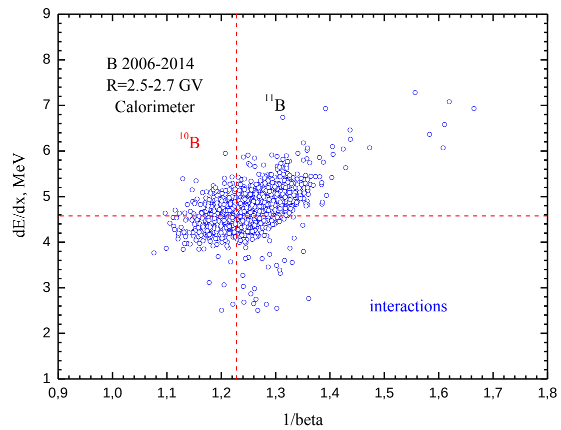
10B and 11B, 2.3-2.9 GV, 2006-2014, Calorimeter

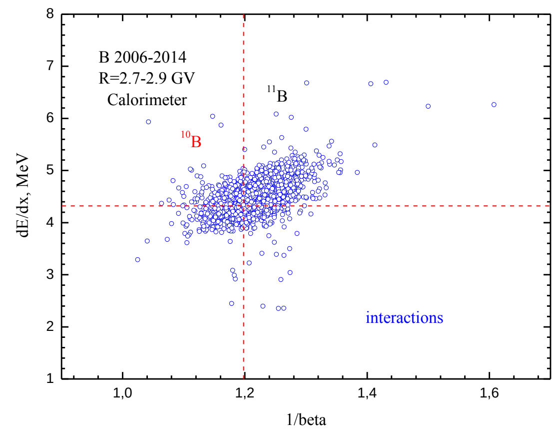




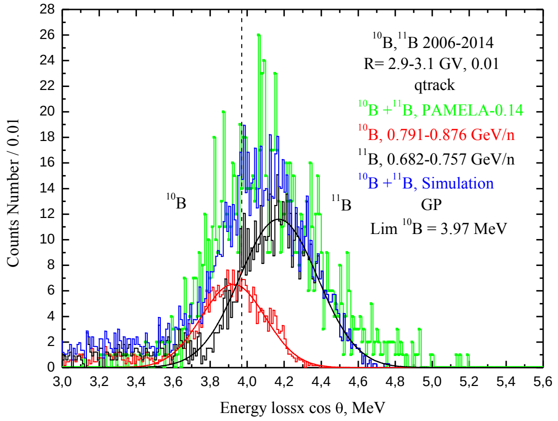


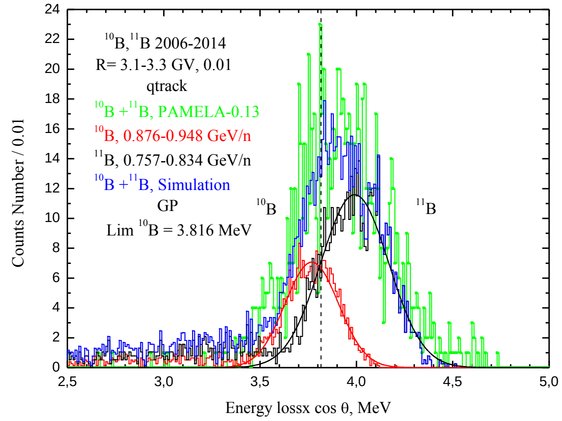


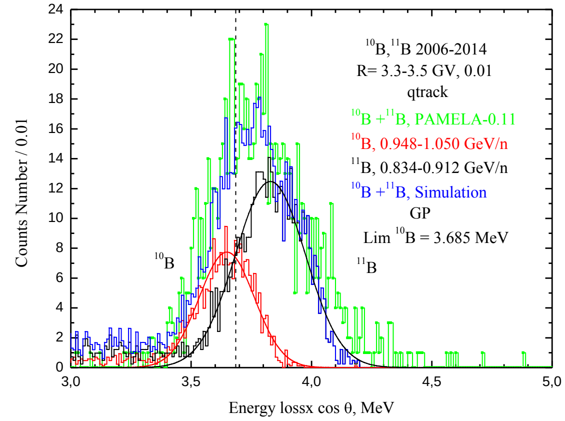


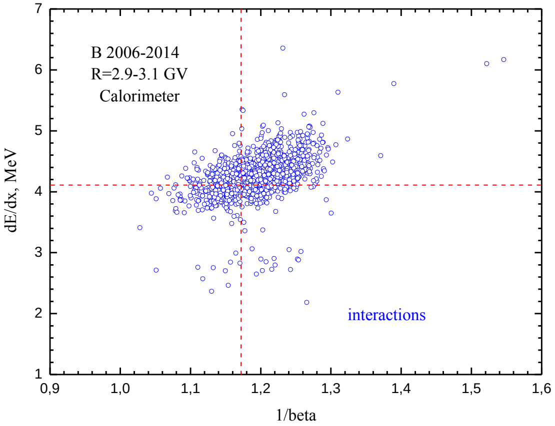


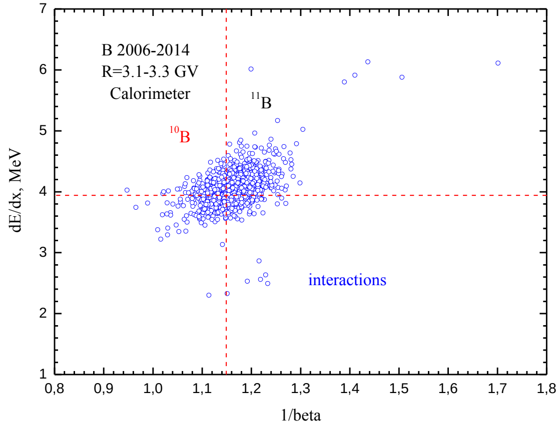
10B and 11B, 2.9-3.5 GV, 2006-2014, Calorimeter

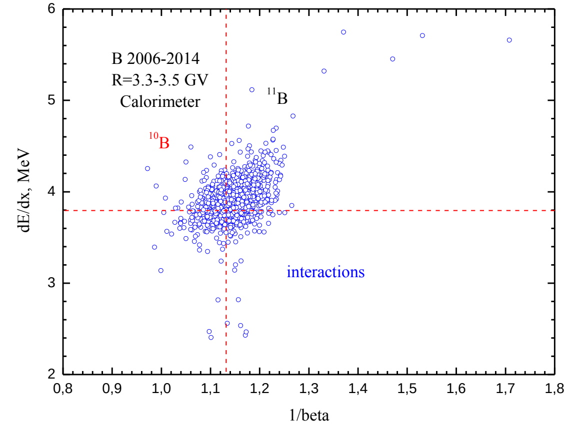




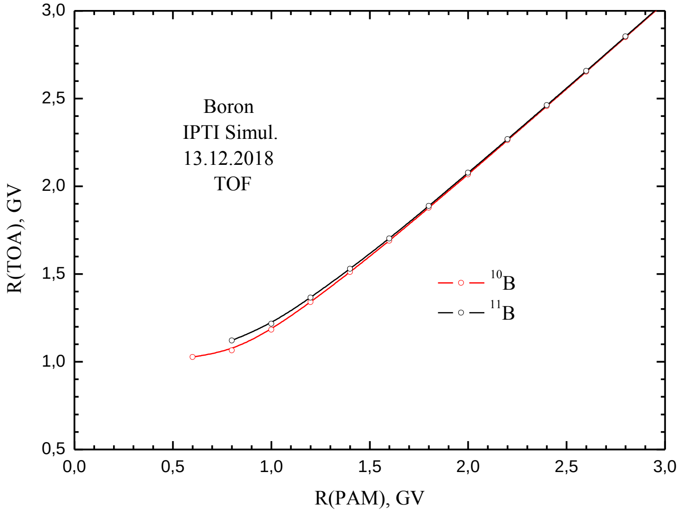


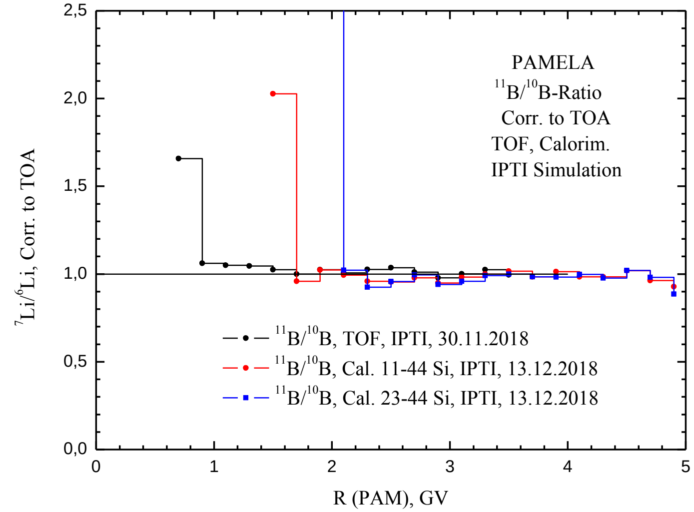


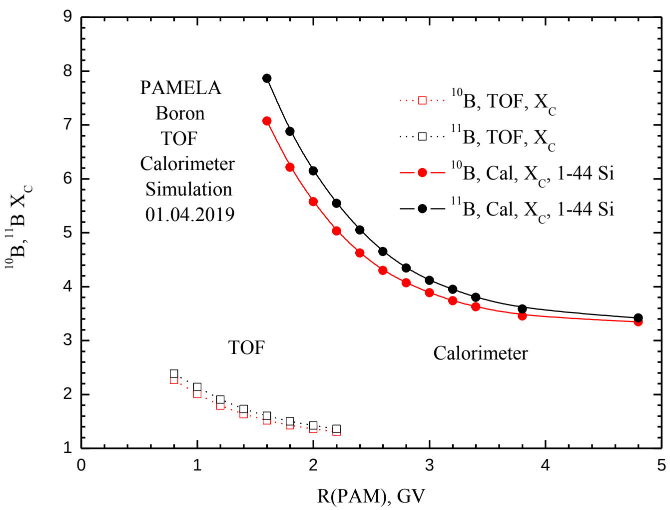


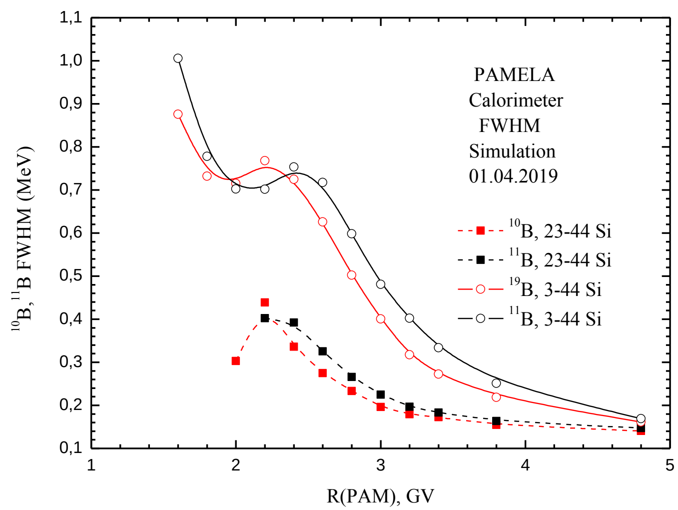


PAMELA. Correction of B data to TOA (Space), Xc, FWHM

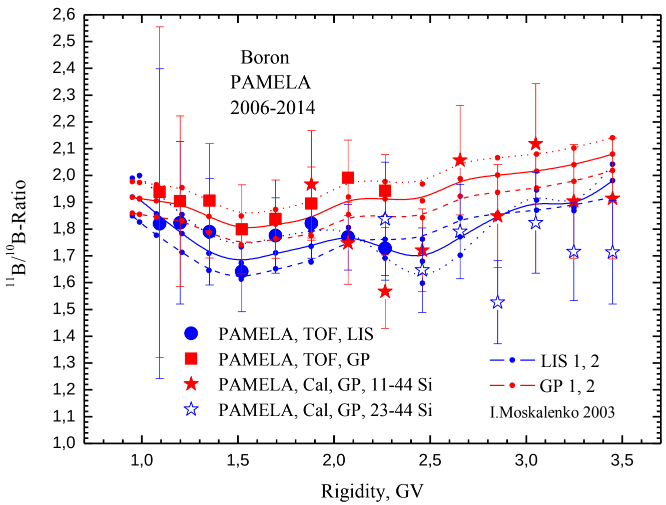


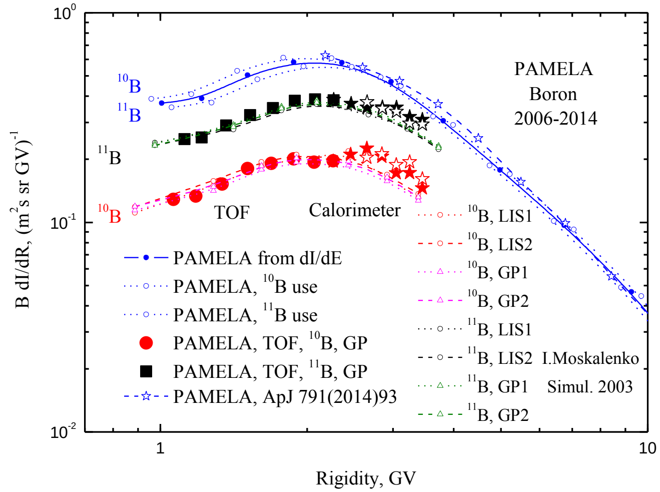


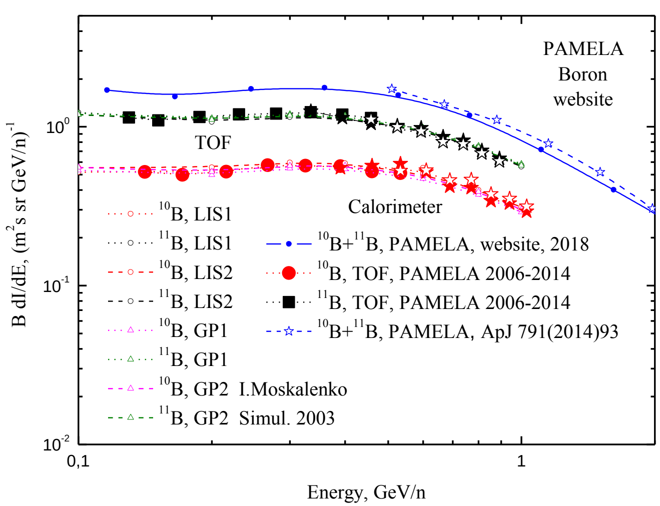


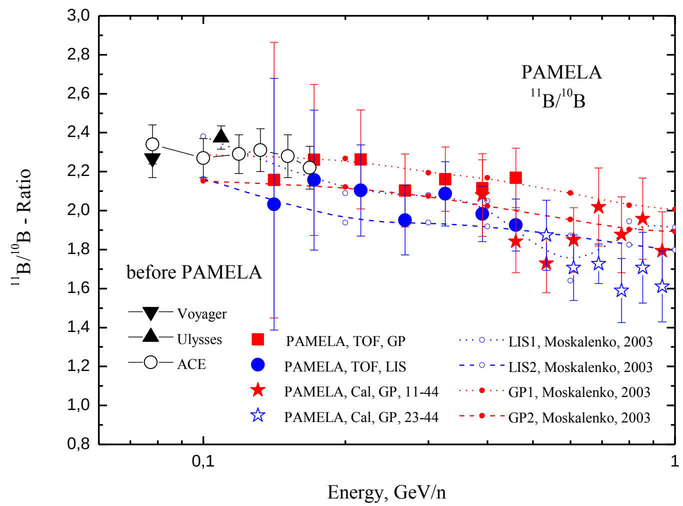


PAMELA, 11Be/10B-Ratio, R and E-Spectra, 2006-2014
GCR and Local Interstellar Sources (Preliminary data)









Conclusion.

Presented for the first time in this work, preliminary data on the analysis of the isotopic composition of boron nuclei in cosmic rays in the energy region of ~ 0.1–1.0 GeV/nucleon, obtained in the PAMELA experiment during measurements in 2006–2014, are consistent with the expected results of calculations and measurements on the spacecraft Voyager, Ulysses, ACE at energies ~ 0.1 GeV/nucl. Due to the statistical accuracy of the measurements, it is not possible to isolate the contribution of local interstellar sources (LIS) of boron isotopes in the GCR. Further progress in the study of the isotopic composition of boron nuclei in GCR is possible after additional modeling and optimization of the flight data sample. The co-authors of the work are naturally the members of the PAMELA Collaboration who obtained the initial flight information used in this analysis.

Best wishes from St. Petersburg :~)

Thanks