PAMELA measurements of the boron and carbon spectra

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on behalf of the PAMELA collaboration

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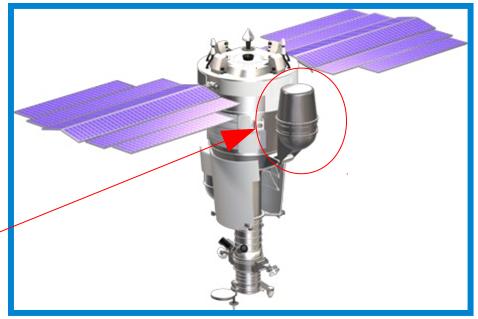
The PAMELA experiment

Resurs DK1 satellite



Satellite-borne experiment

↓

No atmospheric effects

Mission details

Orbit and altitude:

- elliptical, 360 – 600 km (up to 2010)
- circular, 600 km (since 2010)

Orbit inclination: 70°

Planned duration: 3 years

Launch: 15th June 2006

Technical data

Mass ~ 470 kg

Height ~ 1.3 m

Power cons. ~ 355 W

Downlink rate ~ 10 GB/day

Current status

8 years in orbit

Data taking LT ~ 75%

~ 50 TB of raw data

The PAMELA collaboration

Italy

INFN Istituto Nazionale di Fisica Nucleare

Bari

Naples

Florence

Tor Vergata

Rome

Trieste

Russia

Физический Институт

МИФИ

Moscow

Ioffe Physico-Technical Institute

St. Petersburg

Sweden

Kungl Tekniska Högskolan

Stockholm

Germany

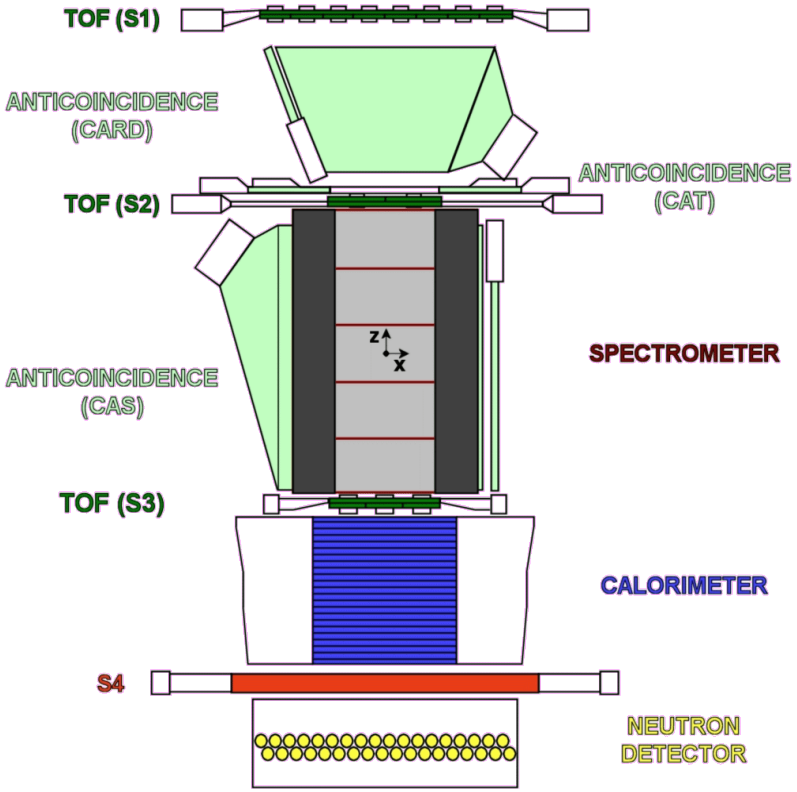
Universität Gesamthochschule Siegen

Siegen

Aimed at light particles (up to oxygen)

Main focus on **antiparticles**

The PAMELA detector



Time-Of-Flight (TOF)
Plastic scintillators + PMT
- Trigger
- Albedo rejection
- Mass identification up to 1 GeV
- Charge identification from dE/dX

Anticoincidence
Plastic scintillators + PMT
- Multi-particle and interacting event rejection

Electromagnetic calorimeter
W/Si sampling (16.3 X_0, 0.6 λ_I)
- e^+/p, $e^-/\bar{p}$ discrimination (shower topology)
- Direct energy measurement for $e^\pm$

Spectrometer
Microstrip silicon tracking system + perm. magnet
- magnetic rigidity R = pc/Ze
  - sign of charge
  - charge value from dE/dx

Neutron detector
36 ^{3}He counters
- High-energy e/h discrimination

Optimized for |Z|~1 particles

Tracking performance: σ_x = 3 μm, σ_y = 11 μm, MDR = 1.2 TV

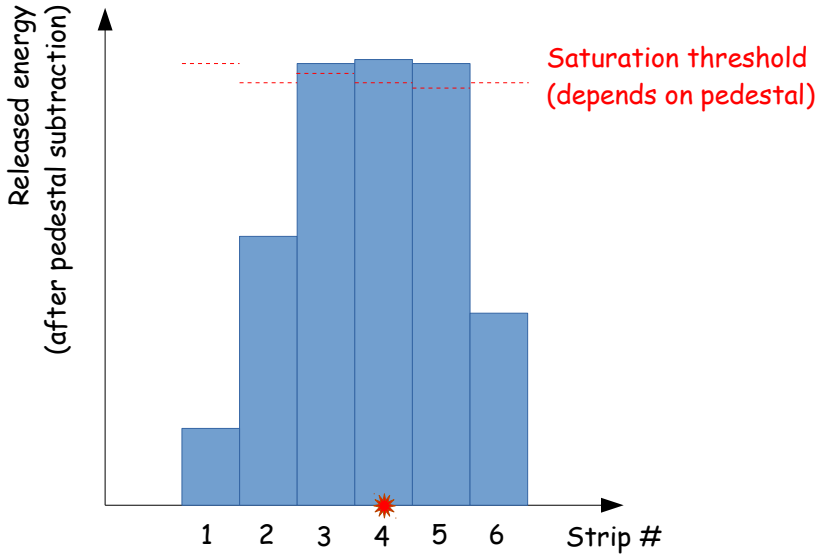
Performance with light nuclei

- ToF can identify particles up to Z~8
- ToF resolution: 70 ps (vs. 250 ps for |Z|~1)
- Single strips of tracking system saturate at ~ 9 MIP
  - Charge ID only up to Li and Be
  - Saturation regime for B and C

PaMeLa

Light nuclei tracking optimizations

- Systematic displacement of tracking residuals when using |Z| ~ 1 PFA (COG-like) due to saturation
  - Digital PFA:



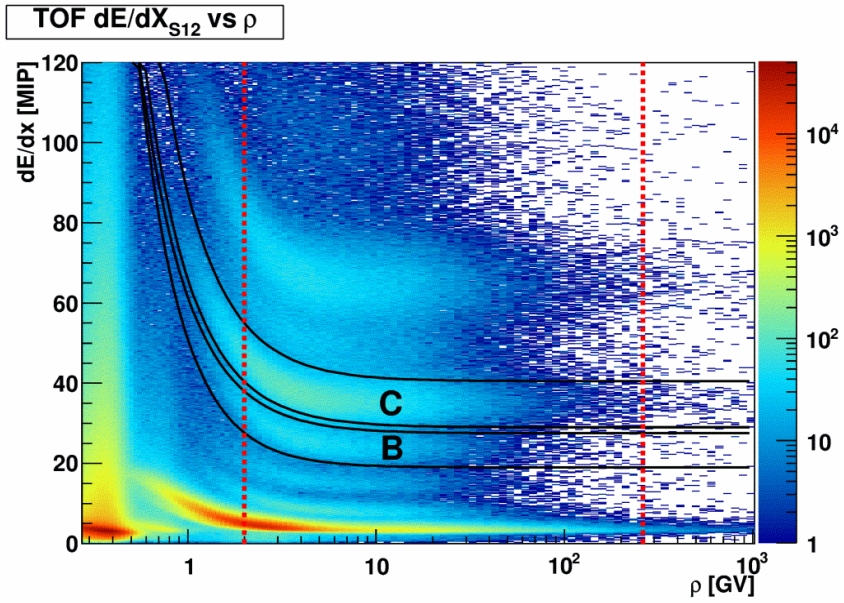
- Impact point is reconstructed as the middle point of the saturated plateau
  - e.g. middle point of strips 3, 4 and 5
- Energy release is ignored
- Spatial resolution: pitch/sqrt(12)
  - σ_x = 14 μm, σ_y = 18 μm
- MDR ~ 250 GV

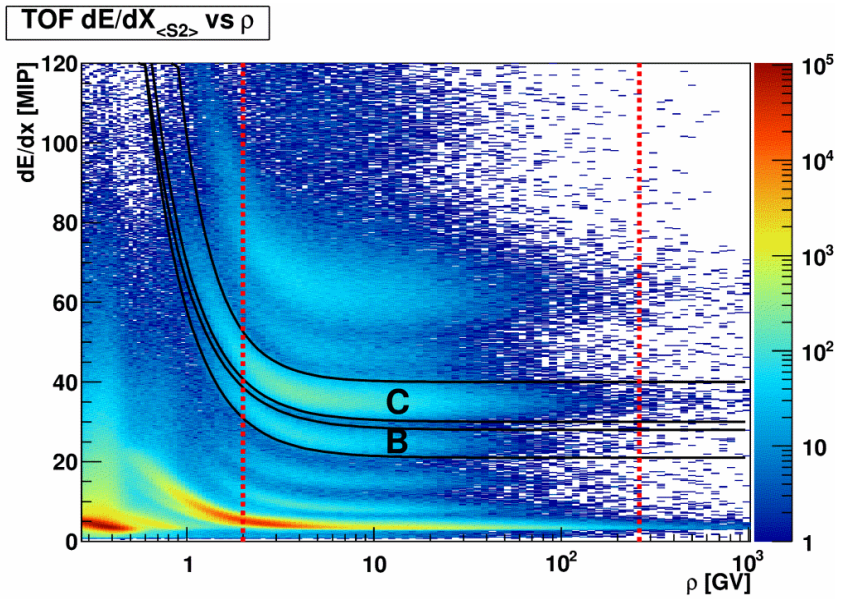
- Many spurious hits (delta rays, backscattering from CALO)
  - Rejection of light particles: $(dE/dx)_{cluster}$ > 5 MIP

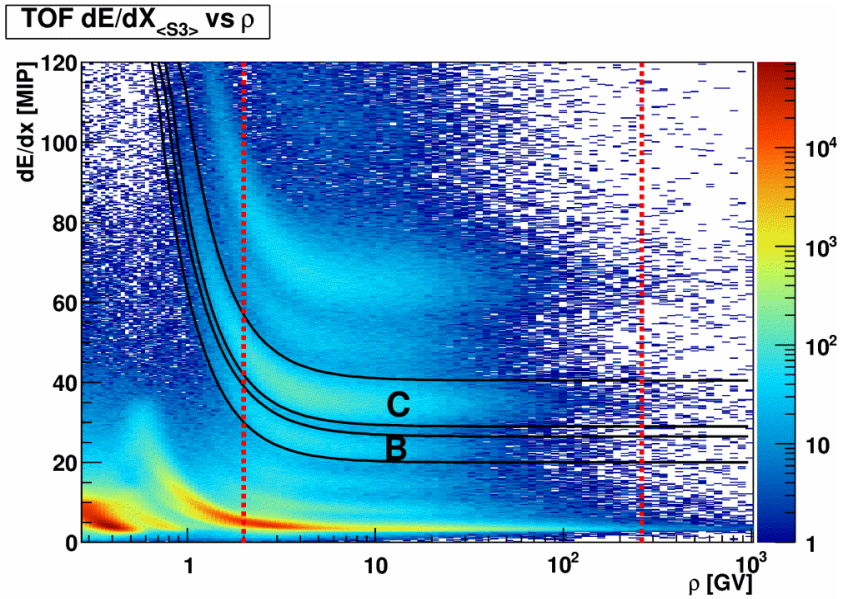
Event selection

- Single track with at least 4 hits on X view and 3 on Y view, good χ^2 (constant 90% eff.)
- Down-going particle
- Galactic particle ($\rho > 1.3 * \rho_{SVC}$)
- Fiducial acceptance (track within 1.5 mm from magnet walls)
- Charge consistency between S12, <S2> and <S3>

Event selection

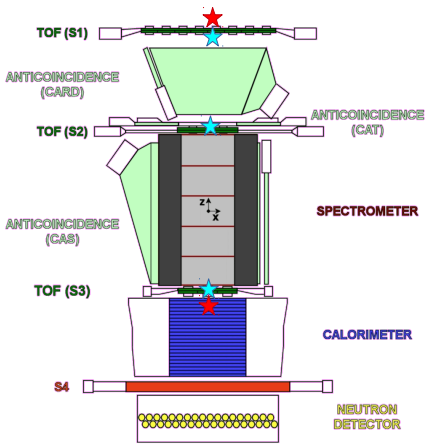






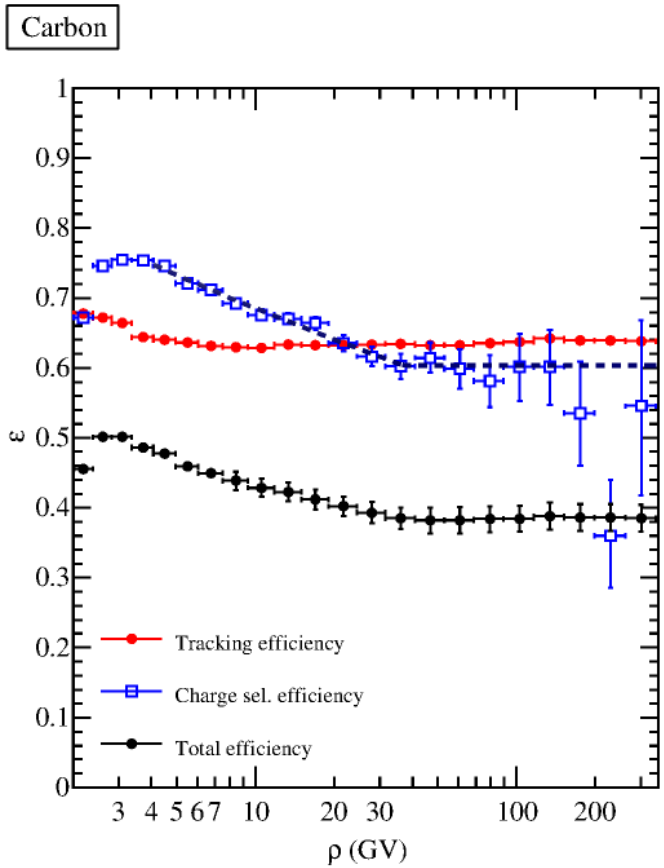
Selection efficiencies

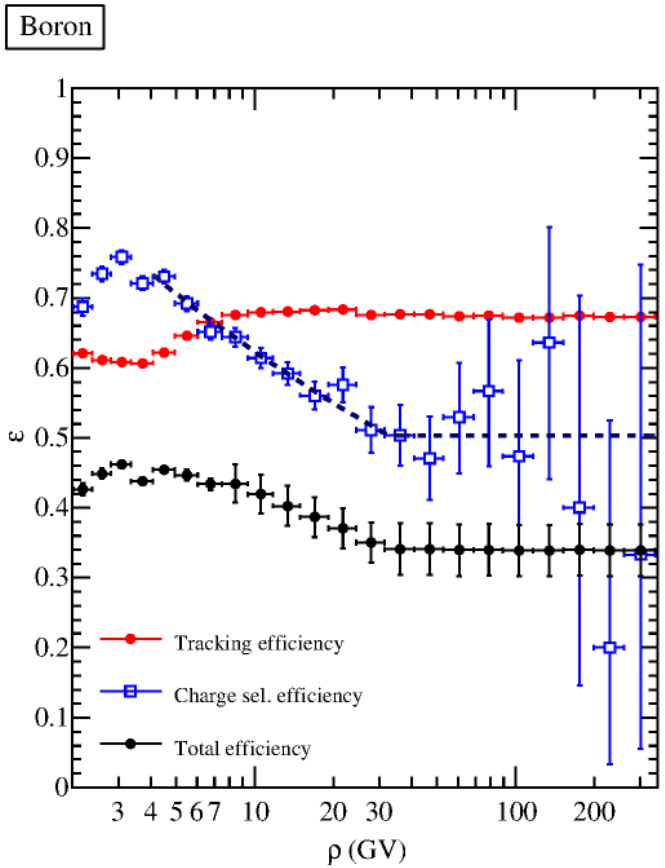
- Tracking: flight data + Monte Carlo
- Charge selection: flight data (tag with S11 + CALO)



★ Tag for charge sel. eff. measurement

☆ Charge selection





Corrections

- Secondaries produced in Al dome
  - Fluka simulation of C and O primaries
  - Contamination: ~ 10^{-3} for C, 5% → 20% for B
- Bayesian unfolding (D'Agostini)
  - Smearing matrix from Geant4 simulation
  - Accounts also for particle slow down in tracking system
- Particle loss due to interactions in Al dome
  - Fluka simulation
  - Correction factor: flat above 10 GV, 15% for C, 14% for B

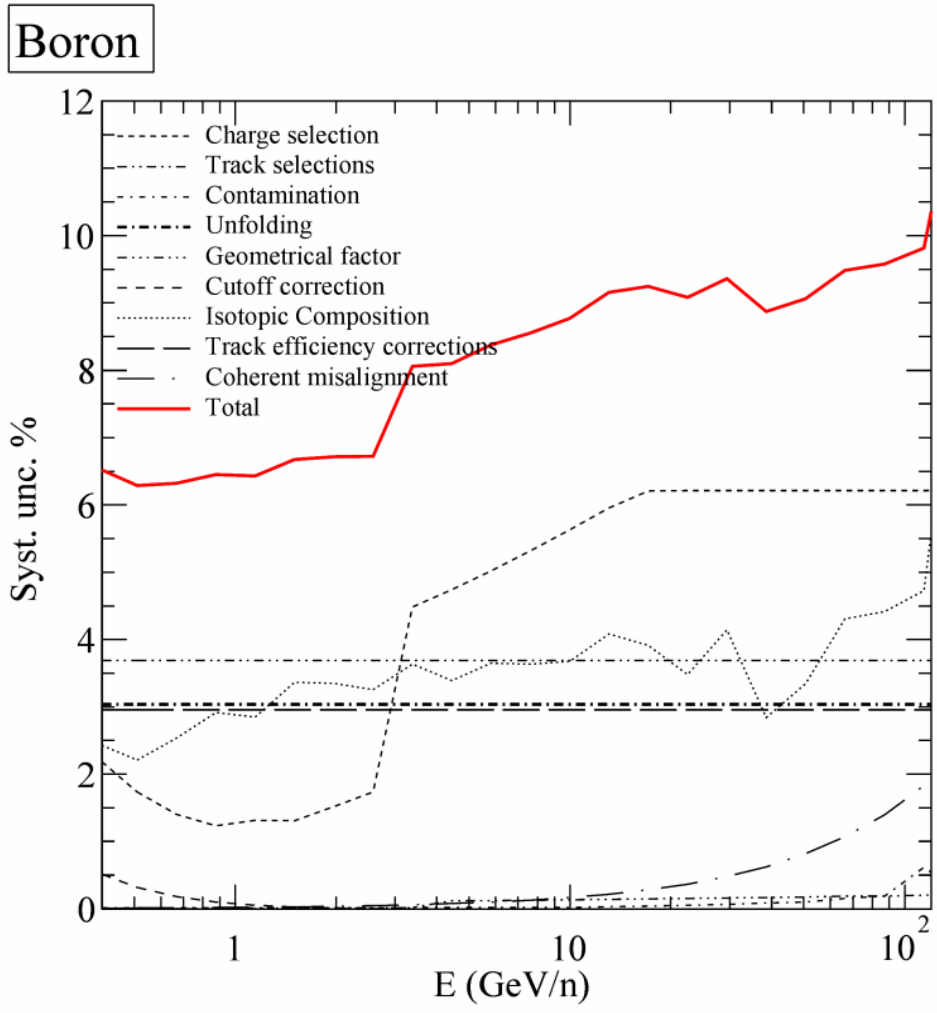
Corrections

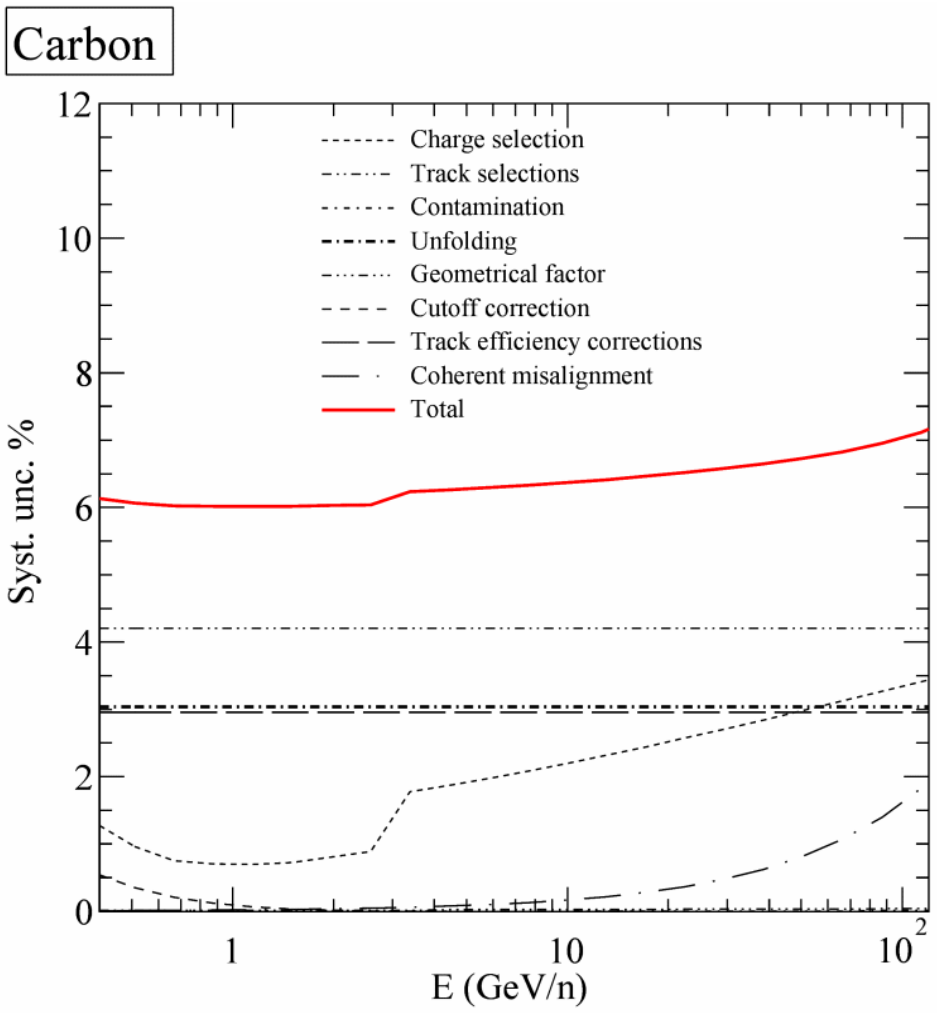
- Cutoff correction
  - Galactic selection ($\rho > 1.3*\rho_{SVC}$) is done before slow down correction (i.e. before unfolding)
  - Correction factor from Geant4 simulation: 0.97 at 2 GV, 1 at 3 GV and above
- Isotopic composition of B
  - ^{10}B fraction is almost constant in kinetic energy per nucleon
    - $\widetilde{F}_B = 0.35 \pm 0.15$
  - But our events are binned according to their rigidity
    - Each bin contains ^{10}B and ^{11}B events with different E_k/n
    - $F_B(\rho) \neq F_B(E_k/n)$

Systematic errors

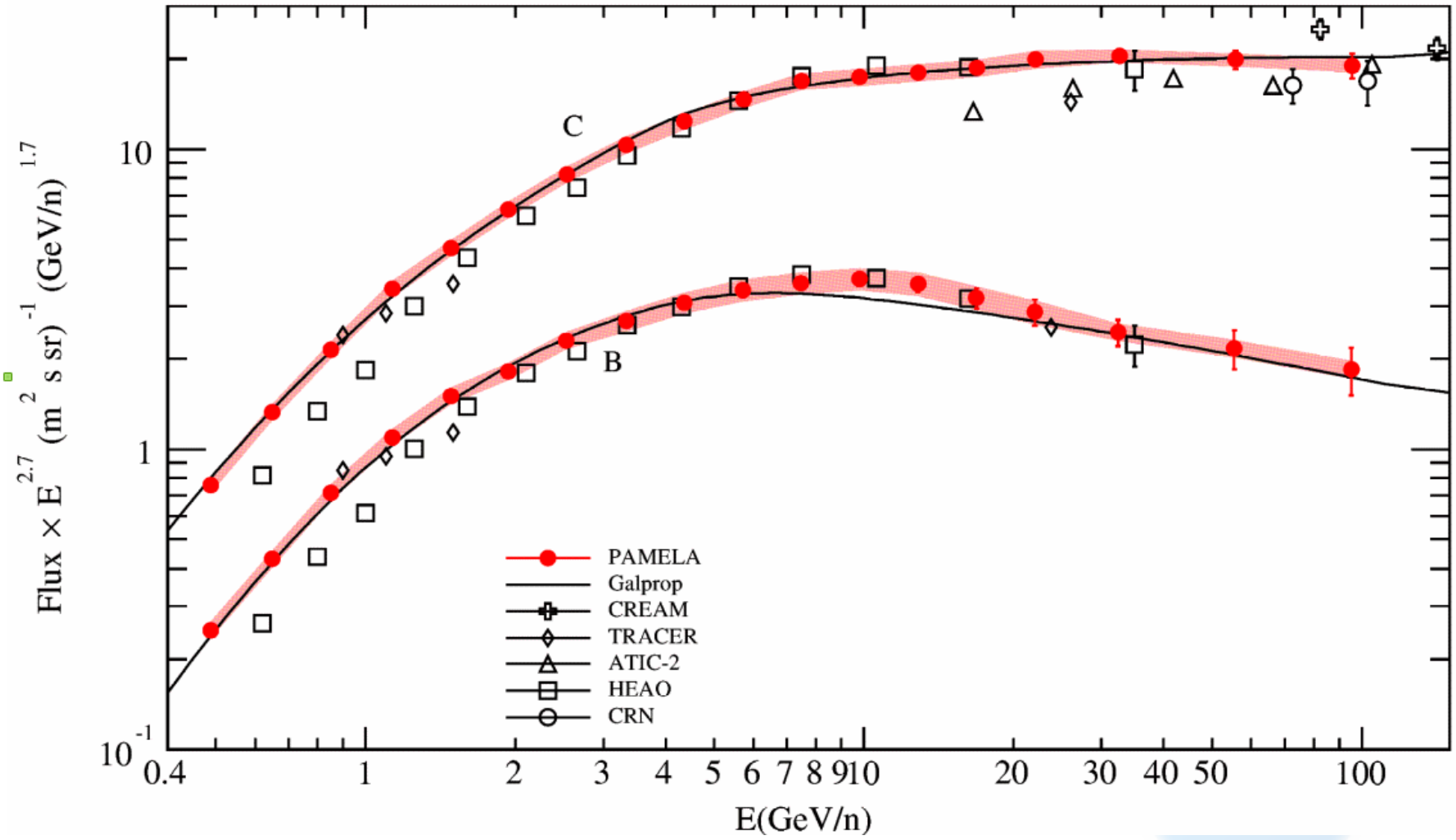
- Statistical errors on:
  - efficiency measurements
  - computation of correction factor
- Residual coherent misalignment of the spectrometer
- Fiducial containment
- Flight/MC disagreement for tracking efficiency
- Unfolding (fold/unfold test)
- Isotopic composition of B

Systematic errors



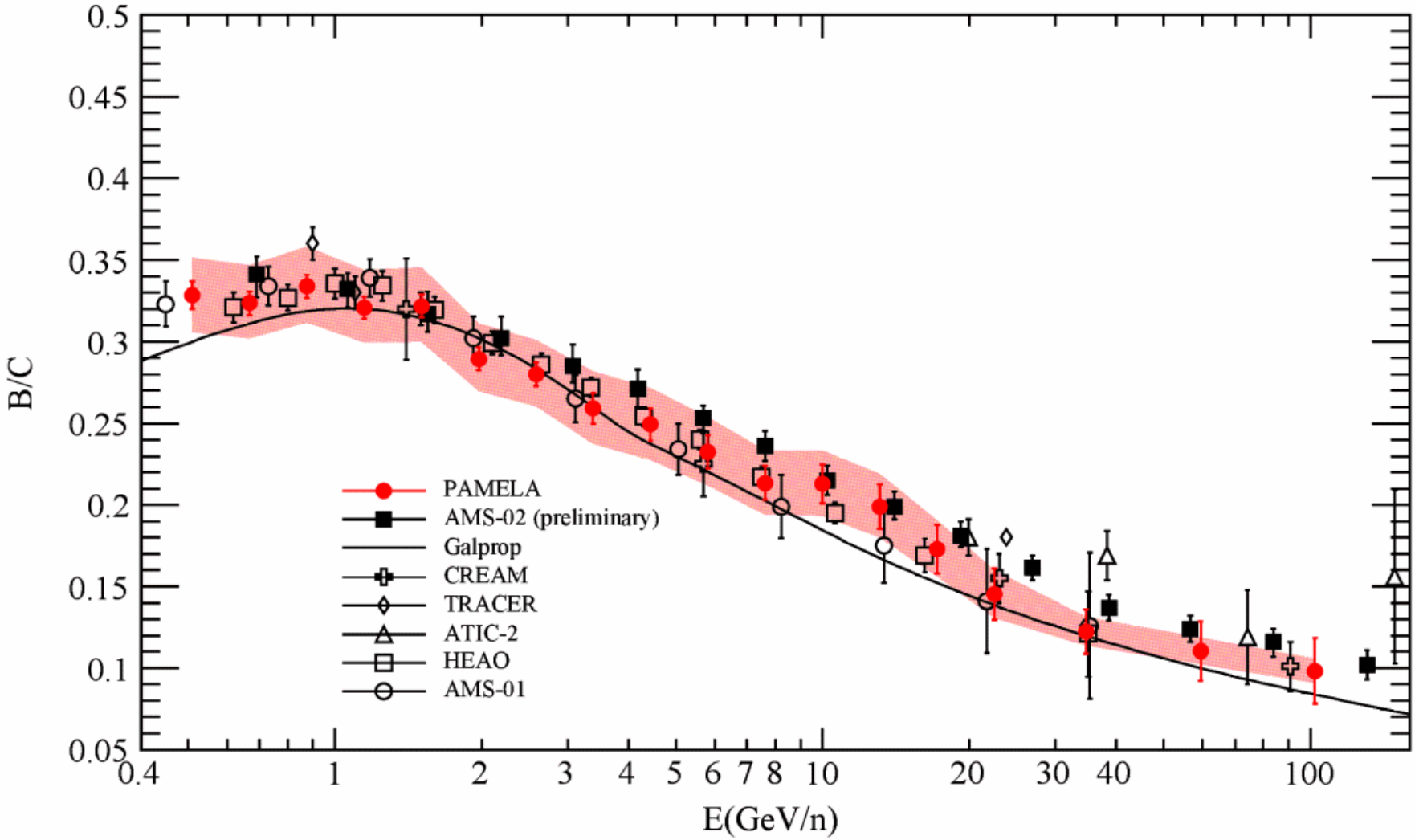


Results



Spectral indexes (fit above 20 GeV/n): γ_B=3.01±0.13, γ_C=2.72±0.06

Results

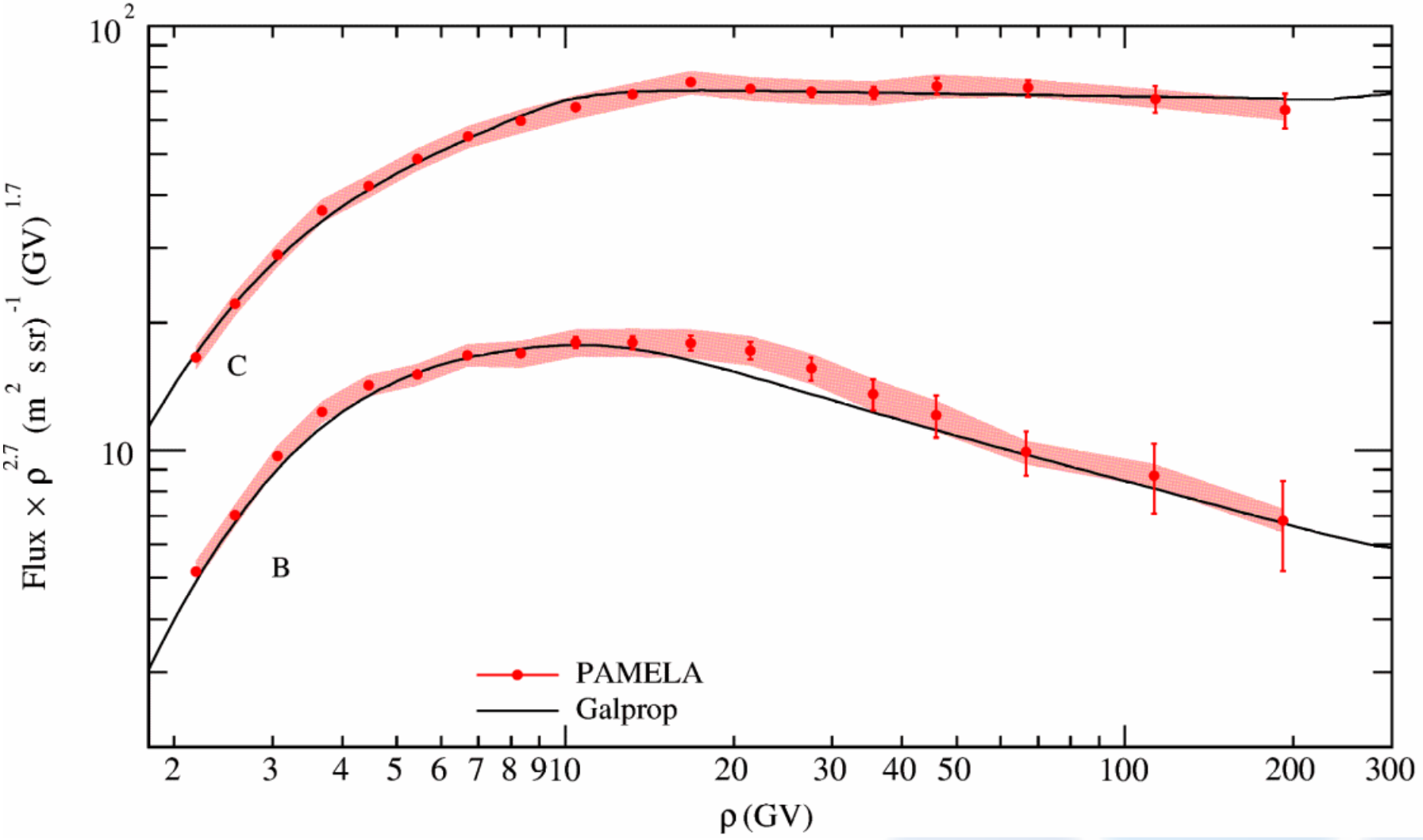


Galprop fit: $\delta = 0.397 \pm 0.007$ $D_0 = (4.12 \pm 0.04) \cdot 10^{28}$ cm^2/s

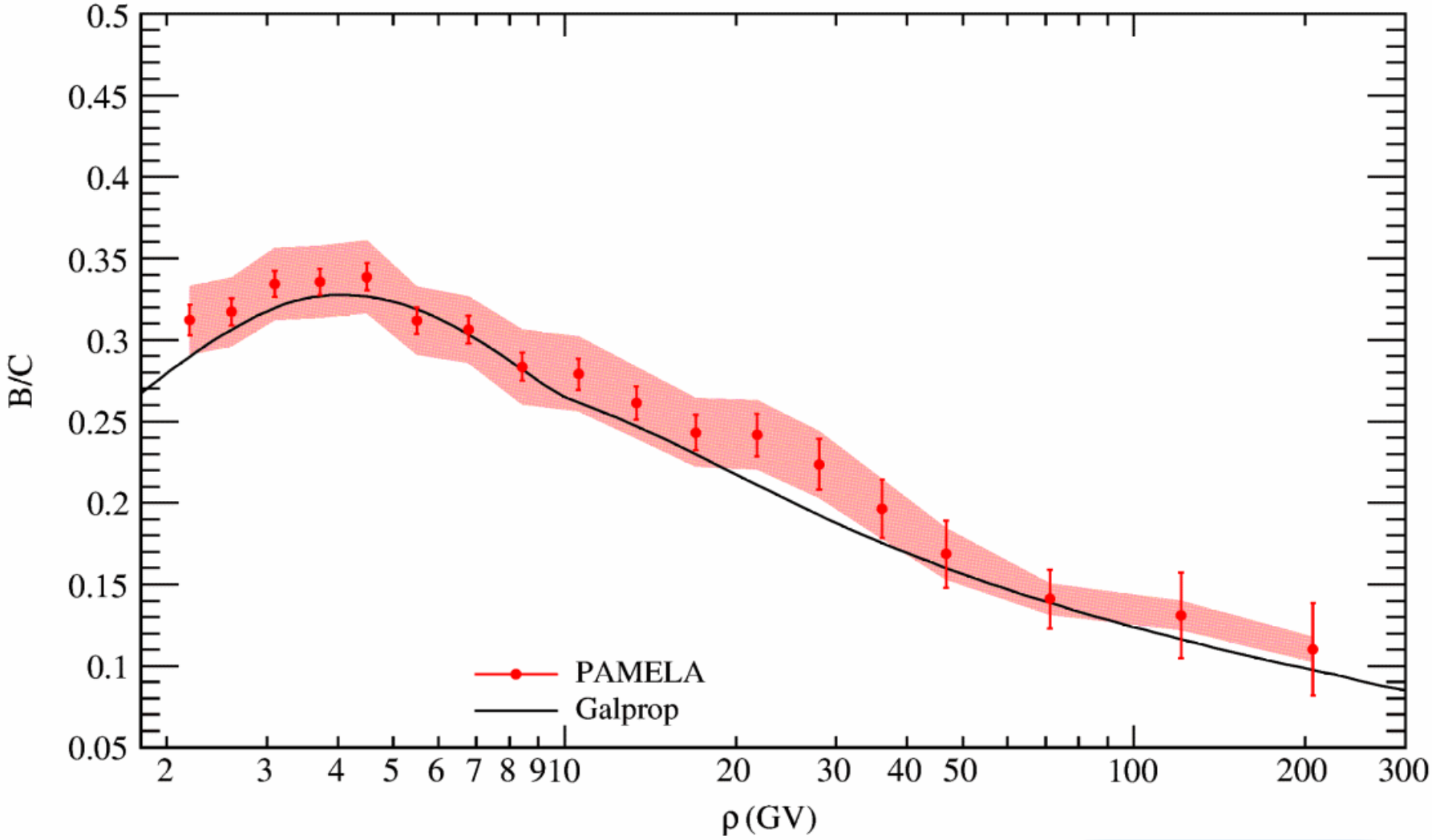
$\Phi = (0.40 \pm 0.01)$ GV $N = 1.04 \pm 0.03$

Other parameters from Vladimirov *et. al*, ApJ 752 (2012)

Results


10^2
10
Flux × ρ$^{2.7}$ (m^2 s sr)$^{-1}$ (GV)$^{1.7}$
C
B
PAMELA
Galprop
2 3 4 5 6 7 8 9 10 20 30 40 50 100 200 300
ρ (GV)

Results


B/C
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
2
3
4
5
6
7
8
9
10
20
30
40
50
100
200
300
ρ (GV)
PAMELA
Galprop

Conclusions

- The absolute fluxes of B and C and the B/C ratio have been measured by the PAMELA experiment in the 0.44 – 129 GeV/n range
- Results are in fair good agreement with previous experiment except at low energies (solar modulation)
- Published in ApJ (2014), 791, 93
  - doi:10.1088/0004-637X/791/2/93

Spare slides

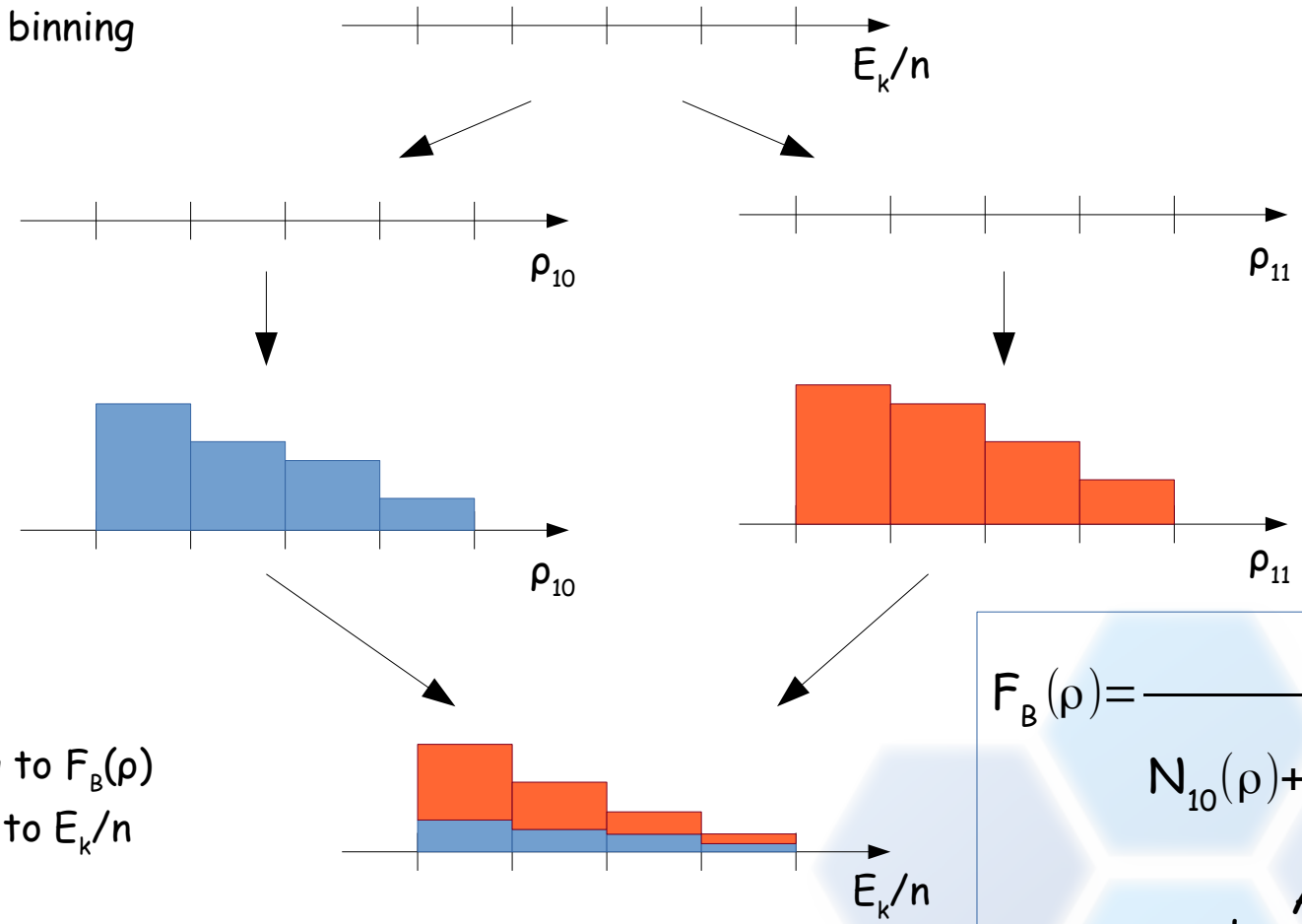
Isotopic composition of B

Start with a E_k/n binning

Convert to ρ assuming pure ^{10}B and pure ^{11}B

Fill event count histos

Weight according to $F_B(\rho)$ and convert back to E_k/n



$$F_B(\rho) = \frac{N_{10}(\rho)}{N_{10}(\rho) + \frac{1-\tilde{F}_B}{\tilde{F}_B} N_{10}(\rho')}$$

$$\rho' = \frac{A_{10}}{A_{11}}\rho$$

For each bin:

$$\Delta N = \Delta N_{10} F_B(\rho_{10}) + \Delta N_{11}(1-F_B(\rho_{11}))$$

For power law spectra: $F_B(\rho) \approx 0.29$