CREAM: fragmentation in the residual atmosphere

L. Derome[1] , B. Coste[1] , A. Putze[1,2]

[1]LPSC, Grenoble

[2]RWTH, Aachen

December 3, 2012
Nuclear physics for Galactic Cosmic Rays in the AMS-02 era

CREAM Experiment

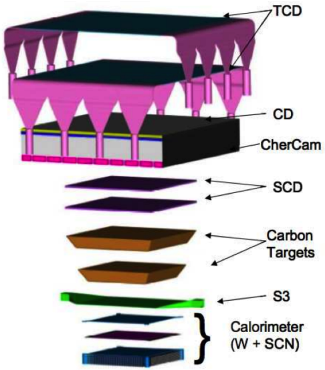
- Balloon borne experiment to measure CRs in the energy range $10^{11} - 10^{15}$ eV, launched from Antarctica (Mc Murdo)
- 6 flights from 2004 to 2010, 164 days in total

Energy measurement

- Hadronic calorimeter (Carbon targets + Tungsten plates + Scintillating fibers)

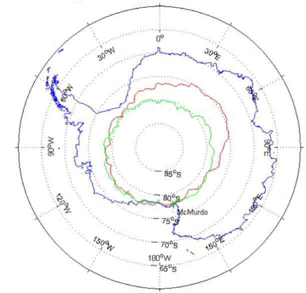
Charge measurement

- Pixelized Silicon sensors (SCD)
- Ring Imaging Cerenkov detector (CherCam)

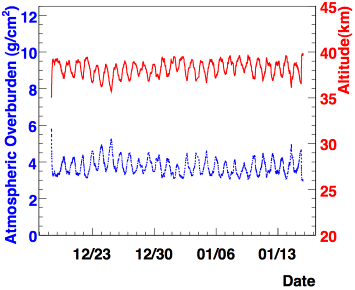


CREAM III Flight

- Balloon trajectory 19 December 2007 to 17 January 2008



- Altitude of the balloon and the corresponding atmospheric depth.



- Mean atmospheric depth above the instrument: $\sim 4\ \mathrm{g/cm^2}$
- Not negligible compared to the amount of matter seen by CRs in the Galaxy

$\Rightarrow$ Need to back propagate fluxes to the Top of Atmosphere (TOA)

Propagation of CRs in the Atmosphere

Straight ahead approximation:

$$\frac{\mathrm{d}N_i(x,E_k)}{\mathrm{d}x} = \sum_T \frac{R_T(x)}{m_T}\left(-\sigma_{iT}(E_k)N_i(x,E_k) + \sum_{j>i}\sigma^j_{iT}(E_k)N_j(x,E_k)\right)$$

- $N_i(x, E_k)$ represents the flux of element i at the atmospheric depth x and for the kinetic energy per nucleon E_k.

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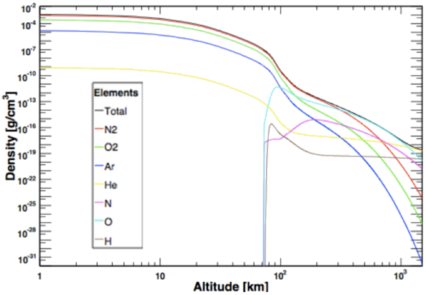
- $R_T(x) = \frac{\rho_T(x)}{\rho_{\mathrm{tot}(x)}}$ is the relative density for the target T.
- can be obtained with the MSISE-90 model (provided by NASA)



Propagation of CRs in the Atmosphere

Straight ahead approximation:

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Absorption

$\sigma_{iT}(E_k)$ total inelastic cross section for the nucleus i on the target T. Computed from Tripathi & al.

Production

$\sigma^j_{iT}(E_k)$ fragmentation cross section of the nucleus j producing a nucleus i on the target T. Extrapolated from the empirical formula of Webber & al.

Transport Equation

Solution of the system of linear differential equations

$$\tilde{N}(x, E_k) = \exp\left(S(x, E_k)\right)\tilde{N}(0, E_k)$$

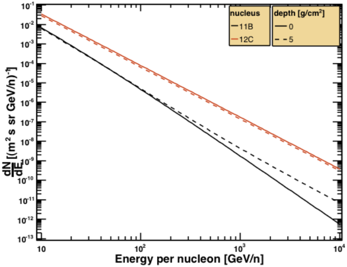
Where

$$\tilde{N}(x, E_k) = \begin{pmatrix} N_1(x, E_k) \\ \vdots \\ N_{n-1}(x, E_k) \\ N_n(x, E_k) \end{pmatrix}$$

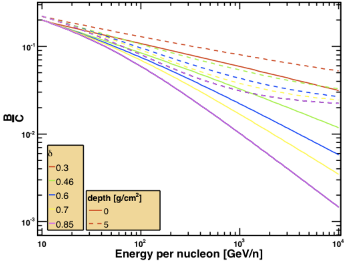
$$S(x, E_k) = \sum_T \int_0^x \frac{R_T(x')}{m_T} \mathrm{d}x' \begin{pmatrix} -\sigma_{1T} & \sigma_{2T}^1 & \cdots & \sigma_{nT}^1 \\ 0 & -\sigma_{2T} & \ddots & \vdots \\ 0 & 0 & \ddots & \sigma_{nT}^{n-1} \\ 0 & 0 & 0 & -\sigma_{nT} \end{pmatrix}$$

Transport Equation: Example

Fluxes



B/C



- No big change on the primary flux.
- At high energy, the propagated B/C ratio reaches a plateau at $\sim 2\ 10^{-2}$.

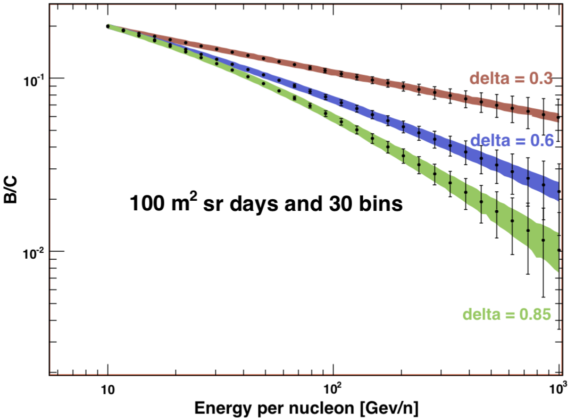
From TOI to TOA

Back propagation to the top of atmosphere

$$\tilde{N}(0, E_k) = \exp\left(-S(x, E_k)\right)\tilde{N}(x, E_k)$$

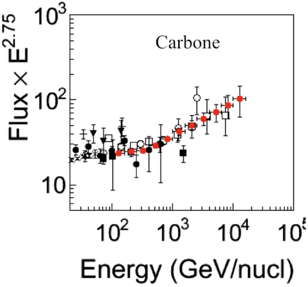
Systematics from uncertainties on cross sections

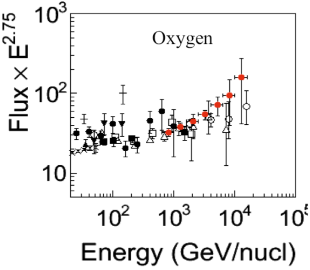
- 5% on total inelastic cross sections (Absorption)
- 10% on fragmentation cross sections



Practical case, CREAM III analysis

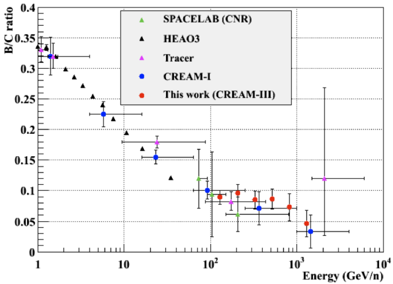
TOA fluxes





B/C

- Systematic errors dominated by the back propagation (20 % on frag. cross sections)
- $\simeq$ statistical errors.



Conclusion

- CR measurements of balloon borne detectors need to be corrected for production of secondaries in the atmosphere.
- Strong dependence on total and fragmentation cross sections.
- Fragmentation cross section extrapolated from model based on data on H and He targets.
- Important contribution to the systematics of the measurements.
- Next generation of balloon (Ultra Long Duration Balloon): more statistics and lower altitude $\Rightarrow$ bigger impact.

Needs

- Better model/data to estimate the fragmentation cross sections.
- Same projectiles, fragments and energy range as for galactic propagation but:
  - Not the same targets: N & O
  - Propagation time in the atmosphere $\ll$ confinement time in the Galaxy: no cumulative cross section.