Study of the solar modulation for the cosmic ray isotopes with the PAMELA experiment

Alex Lenni[123]

on behalf of the PAMELA collaboration

[1]University of Trieste, Department of Physics, Trieste (Italy)

[2]Istituto Nazionale di Fisica Nucleare (INFN), Section of Trieste, Trieste (Italy)

[3]Institute for Fundamental Physics of the Universe (IFPU), Trieste (Italy)

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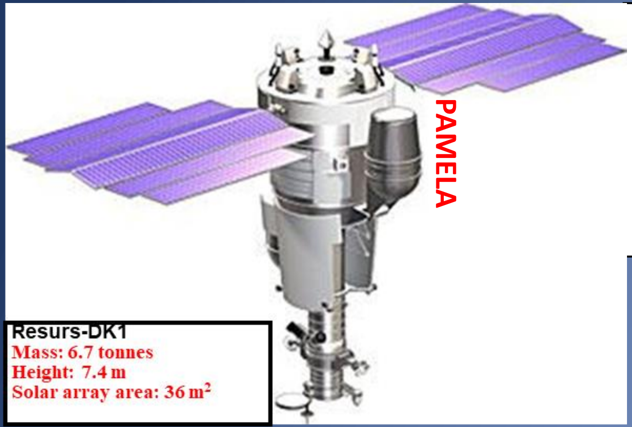
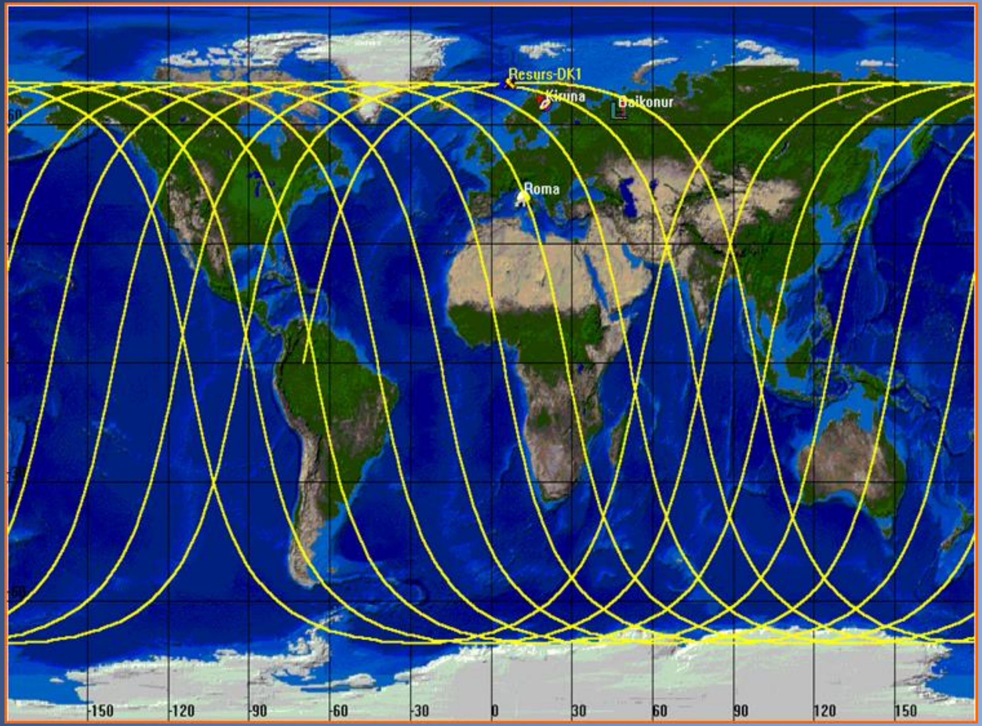
The PAMELA experiment



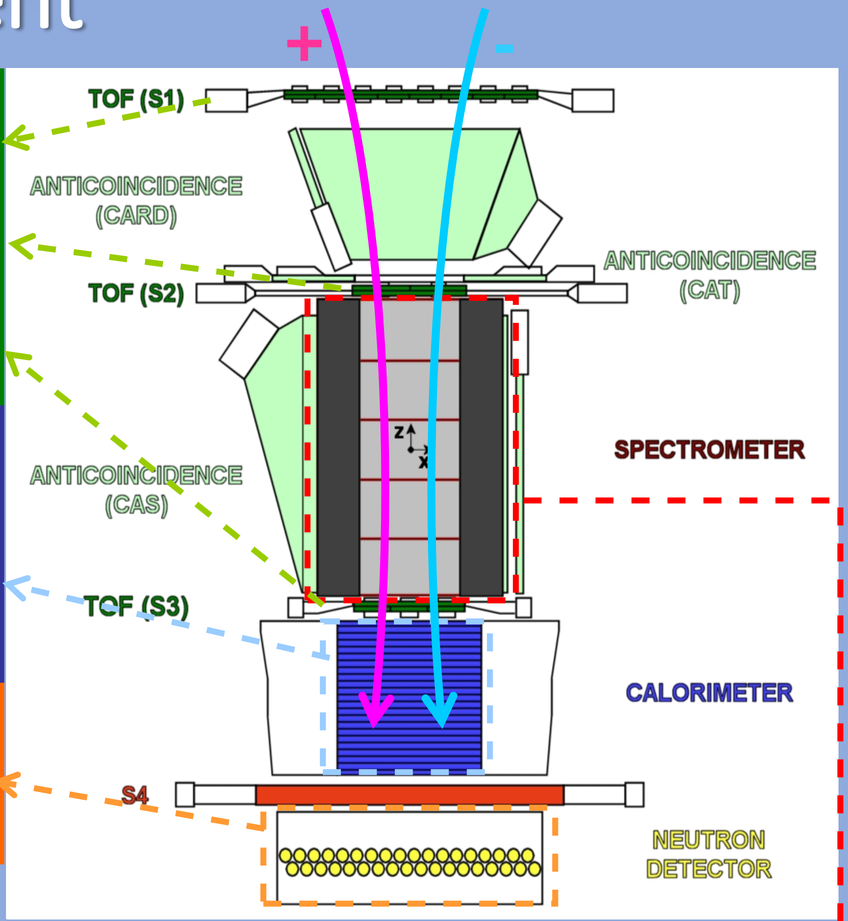
GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W



Time-Of-Flight
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX.

Electromagnetic calorimeter
W/Si sampling (16.3 X_0, 0.6 λ_I)
- Discrimination e^+ / p, p-bar / e^- (shower topology)
- Direct E measurement for e^-

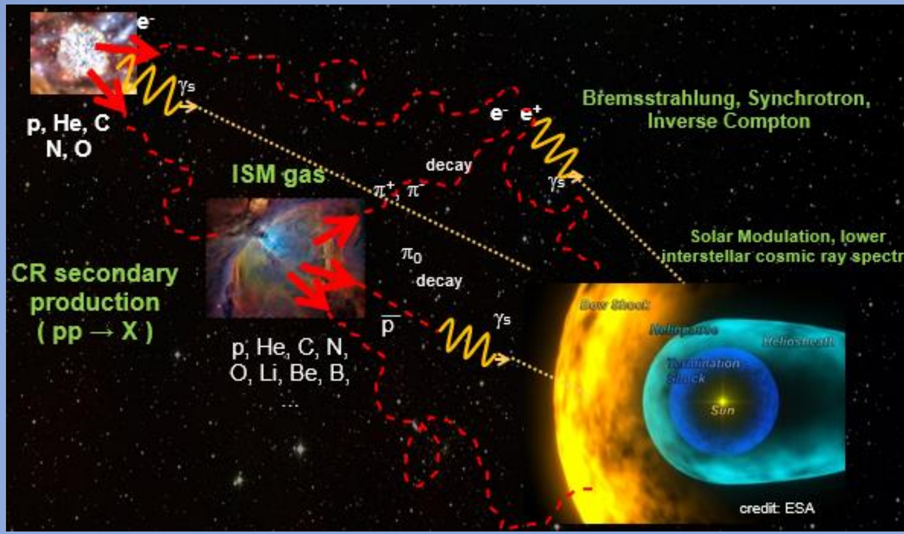
Neutron detector
^{3}He tubes + polyethylene moderator:
- High-energy e/h discrimination



Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- Magnetic rigidity R = pc/Ze
- Charge sign
- Charge value from dE/dx

Solar modulation of cosmic rays

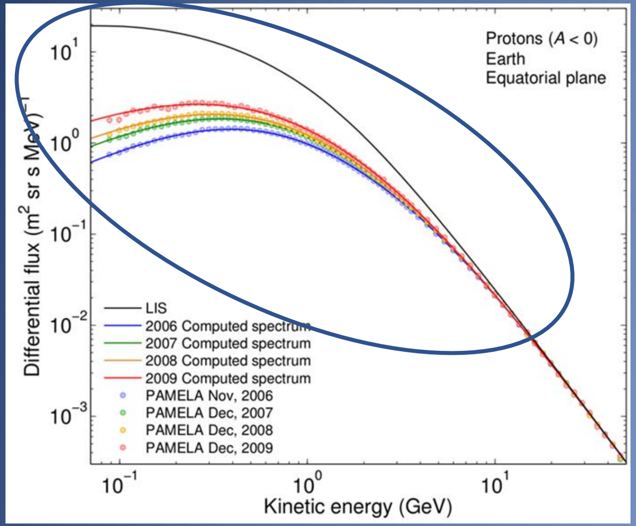
Interaction of cosmic rays with the solar wind and the heliospheric magnetic field

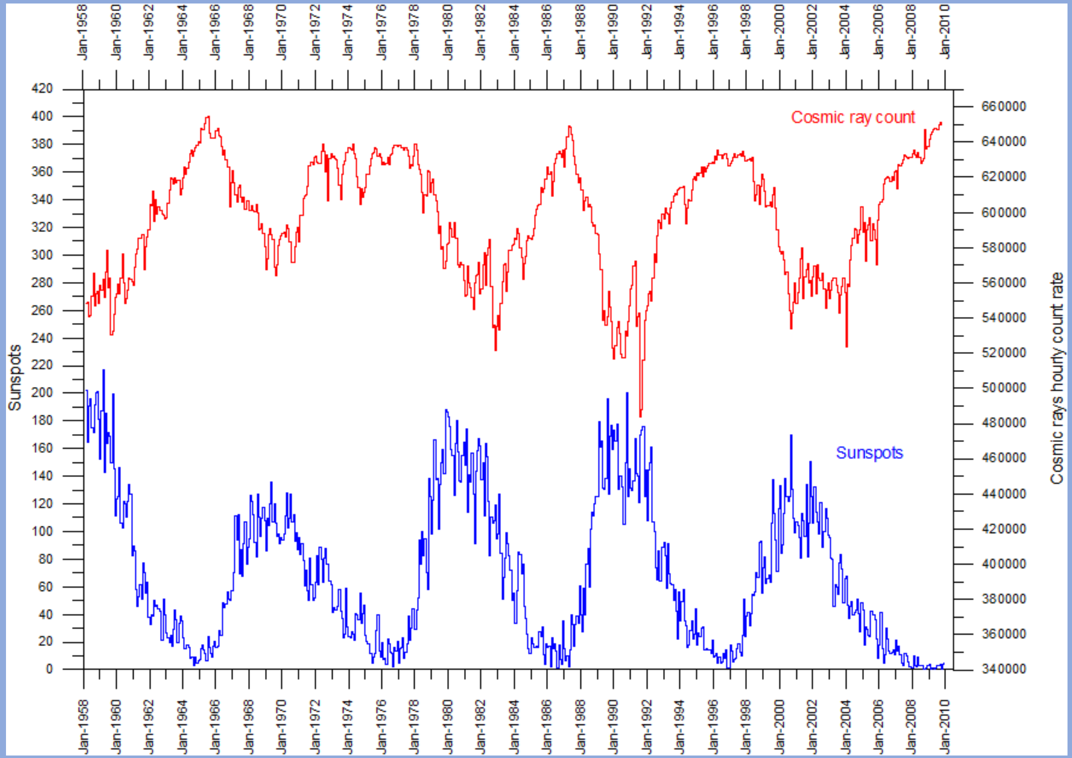


Solar Modulation effects

Decrease of the cosmic ray intensity below few tens of GeVs

Time dependence of cosmic ray fluxes as a function of the solar activity





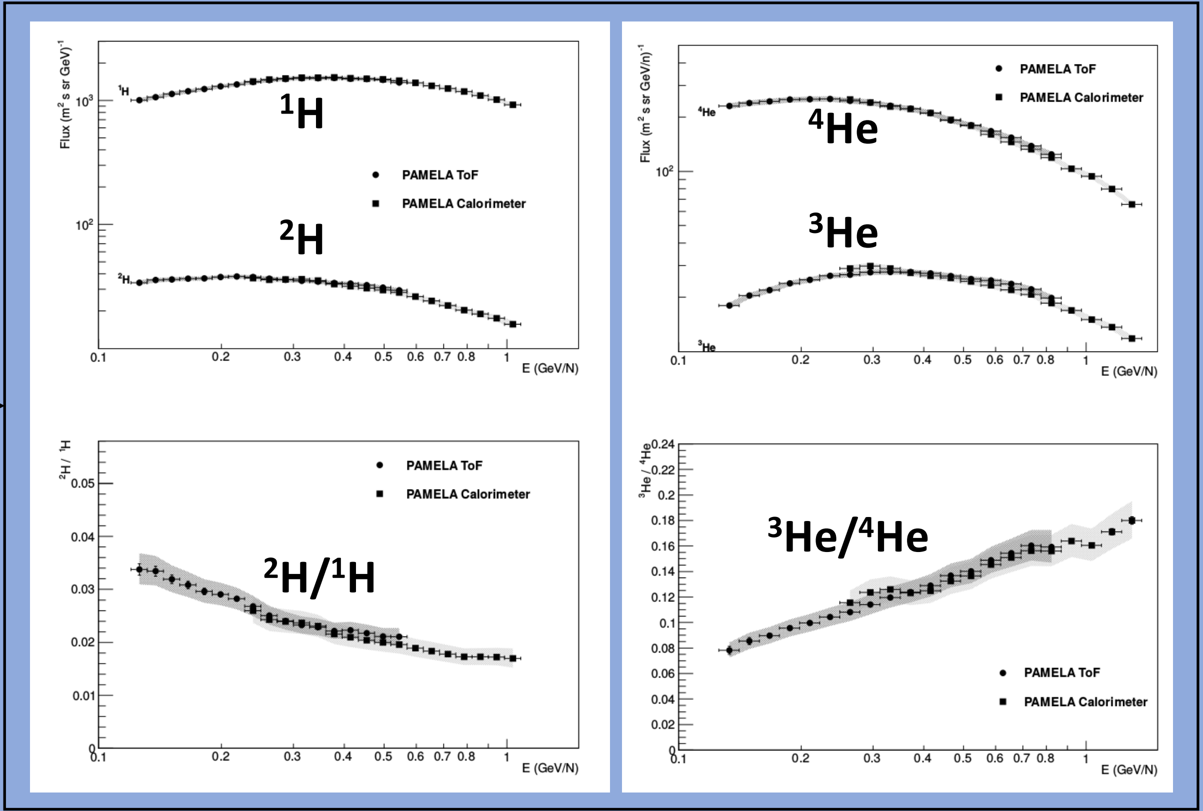
Sophisticated numerical models have been introduced in the recent years → **Modulation of the Local Interstellar Spectrum of the cosmic rays** to reproduce the measurements inside the Heliosphere

Solar modulation of the H and He isotopes

- ^{2}H and ^{3}He isotopes are generated by the interaction of the primary ^{1}H and ^{4}He with the interstellar medium. Their spectrum is determined by the primary one and the propagation mechanisms.
- Below few tens of GeVs the fluxes are affected by the solar modulation. Measurements of the time dependence of the low energy fluxes provide important information about the propagation mechanisms in the Heliosphere.

- Published fluxes for the time period July 2006 – December 2007:

^{1}H-^{2}H:	0.12 – 0.57 GeV/n (ToF)
	0.22 – 1.08 GeV/n (Calo)
^{3}He-^{4}He:	0.12 – 0.87 GeV/n (ToF)
	0.25 – 1.37 GeV/n (Calo)

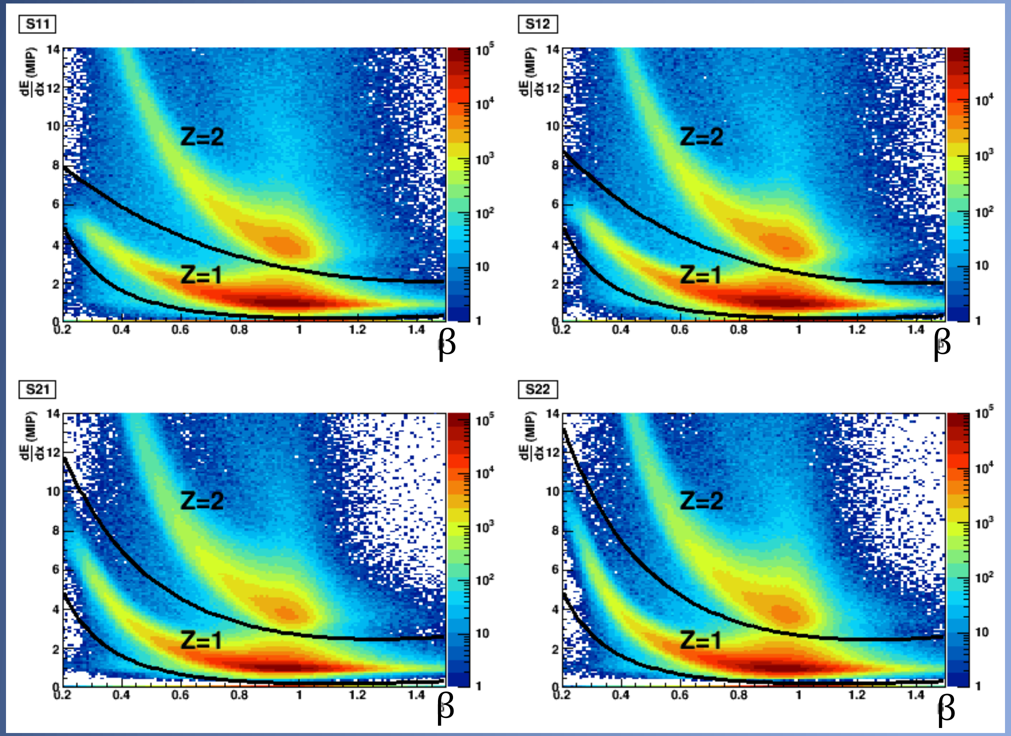


- Work to extend these measurements up to September 2014

Selection of the isotopes ^{1}H and ^{2}H

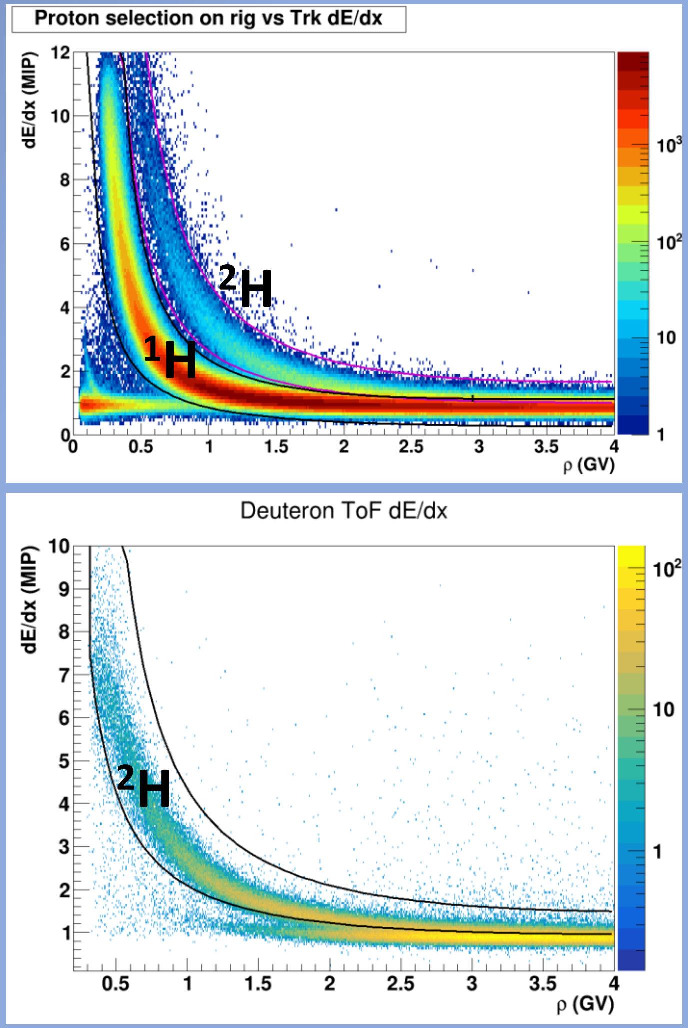
1) Selection of **a sample of events with a single track** reconstructed with good quality inside the Tracker.

2) **Charge selection:** dE/dX measurements in the first four ToF layers as a function of the velocity $\beta = v/c$.



3) **Isotopic separation**:

Truncated mean of the dE/dX measurements in Tracker and ToF



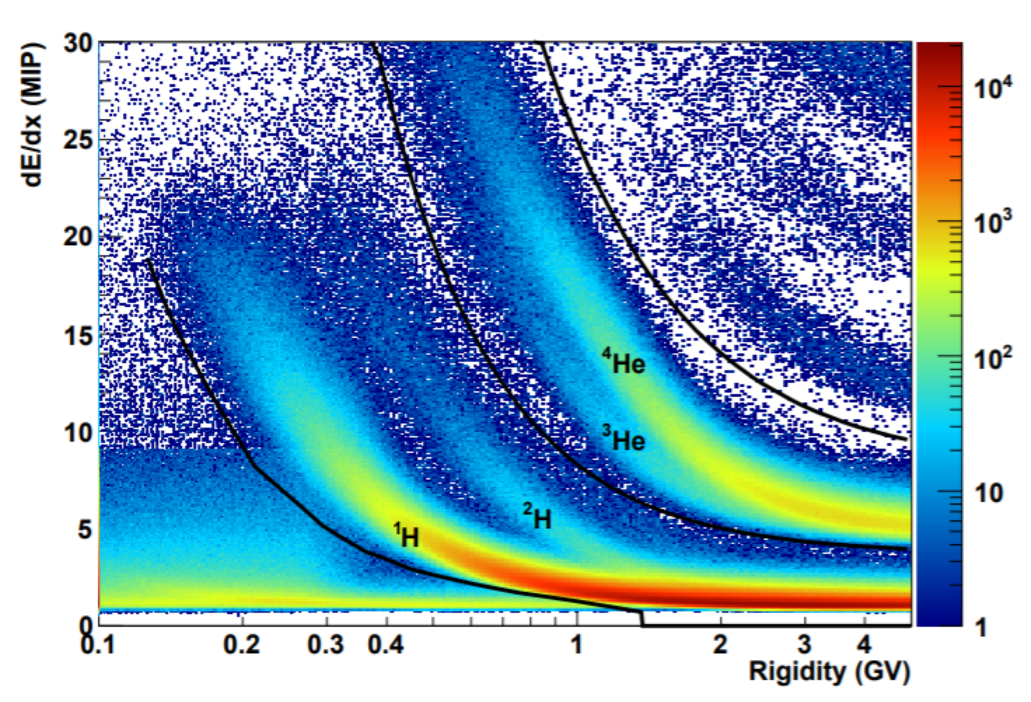
Protons and deuterons dE/dX distributions in Tracker as a function of rigidity

Additional selection of deuterons on the ToF dE/dX distribution as a function of rigidity

Selection of the isotopes ^{3}He and ^{4}He

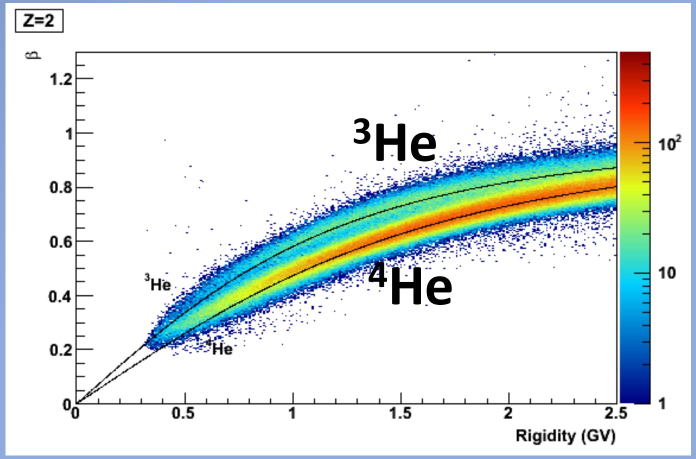
1) Selection of **a sample of events with a single track** reconstructed with good quality inside the Tracker.

2) **Charge selection:** dE/dX measurements in the Tracker as a function of the rigidity.

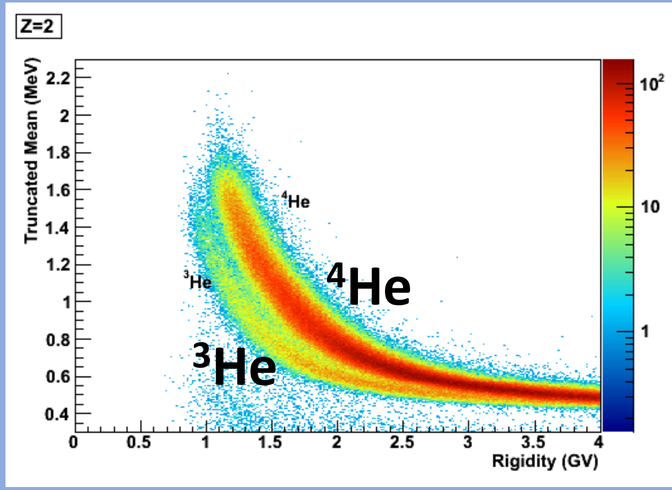


3) **Isotopic separation**:

β measurements by ToF e dE/dX measurements by Calorimeter



ToF: $\beta - \rho$ distributions

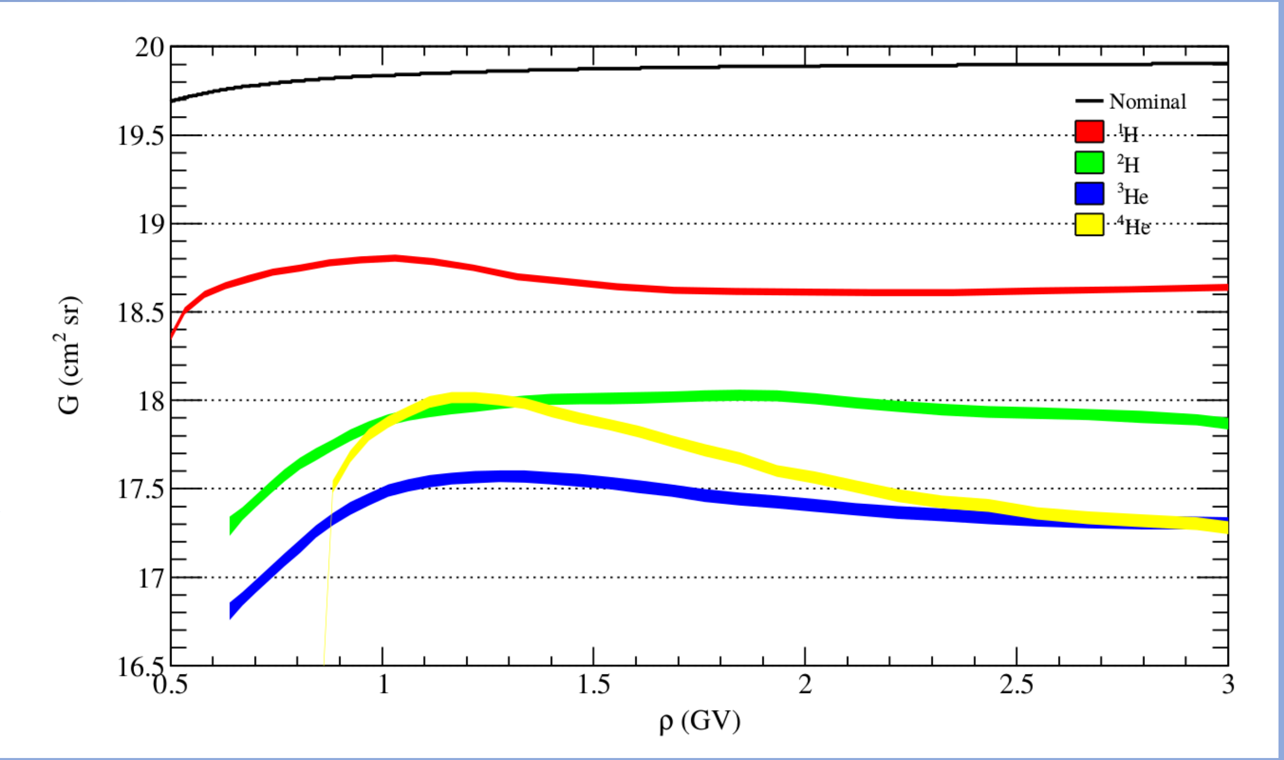


Calorimeter: truncated mean of the dE/dX for no interacting events

Flux calculation:

$$\Phi(\rho) = \frac{n(\rho)}{\Delta\rho \cdot \varepsilon(\rho) \cdot G(\rho) \cdot T(\rho)}$$

- $n(\rho)$ number of events per rigidity bin
- $\Delta\rho$ width of the rigidity bin
- $\varepsilon(\rho)$ efficiency of the total selection
- $G(\rho)$ geometric factor



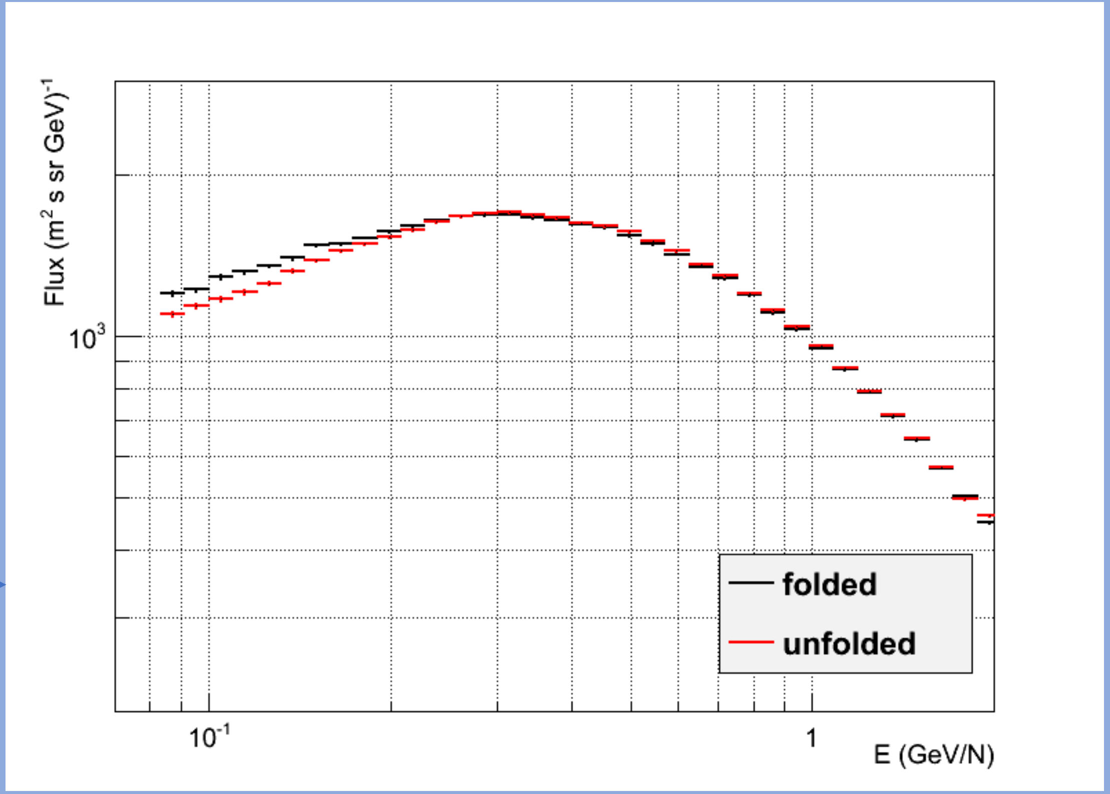
Reduced values with respect to the nominal values accounting for the effects of scattering and fragmentation in the materials above the Tracker.

Flux calculation:

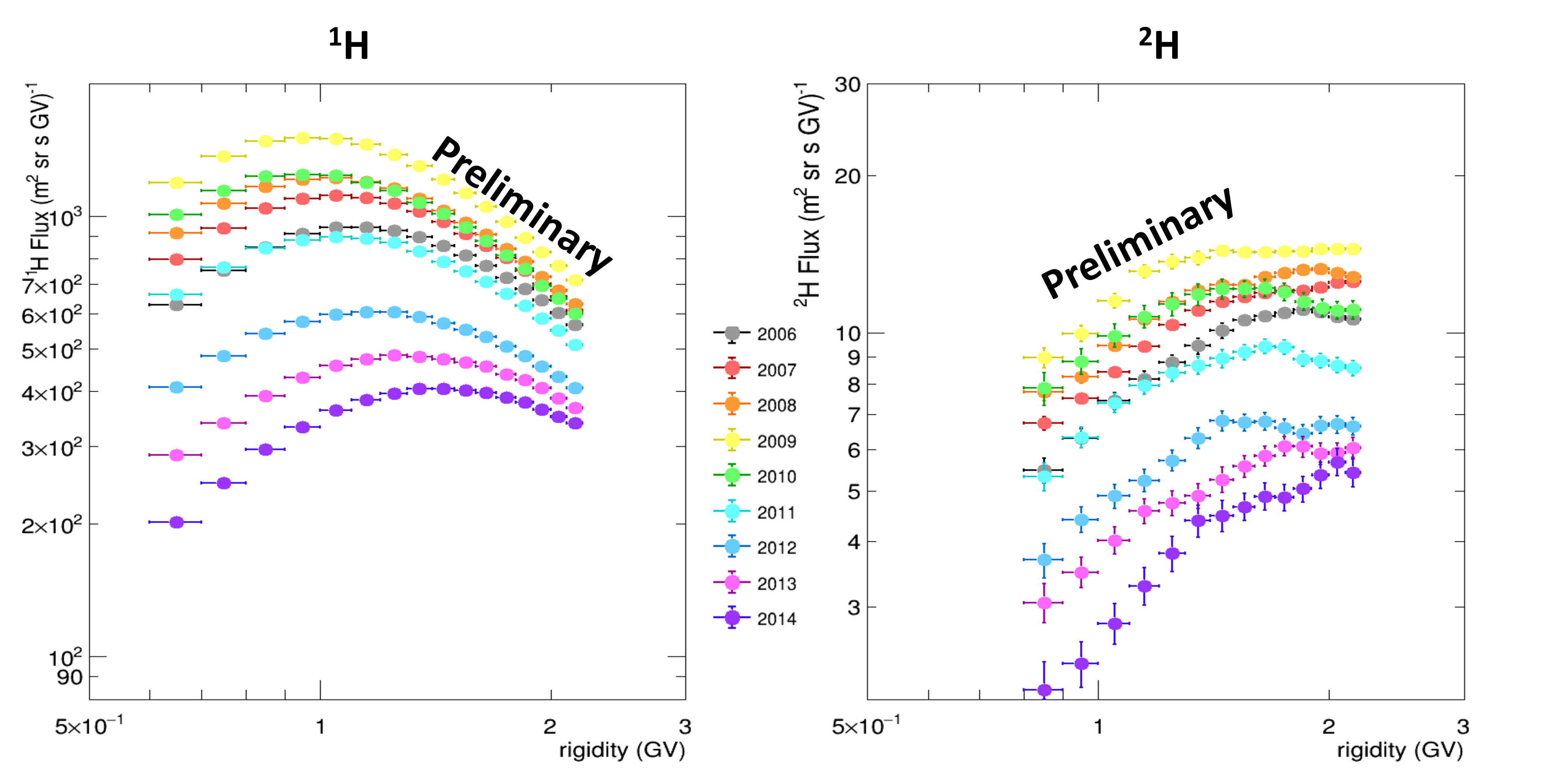
$$\Phi(\rho) = \frac{n(\rho)}{\Delta\rho \cdot \varepsilon(\rho) \cdot G(\rho) \cdot T(\rho)}$$

- $n(\rho)$ number of events per rigidity bin
- $\Delta\rho$ width of the rigidity bin
- $\varepsilon(\rho)$ efficiency of the total selection
- $G(\rho)$ geometric factor
- $T(\rho)$ live time
- Unfolding

Reconstruction of the spectrum at the top of the payload



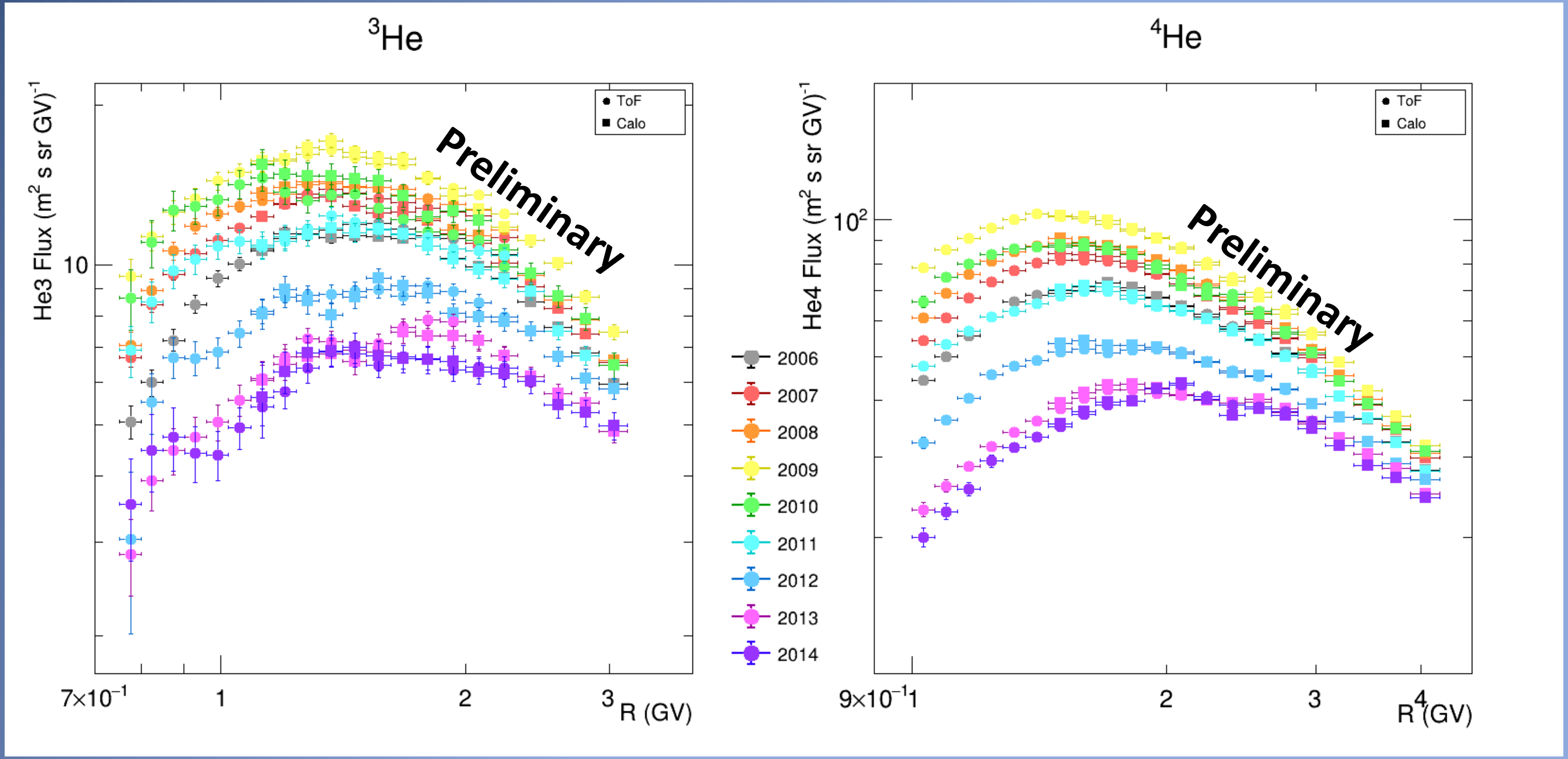
Results: ^{1}H and ^{2}H fluxes



Time dependence due to the solar modulation:

- increase of the fluxes from 2006 to 2009 (solar minimum phase),
- decrease of the fluxes from 2009 to 2014 (solar maximum phase).

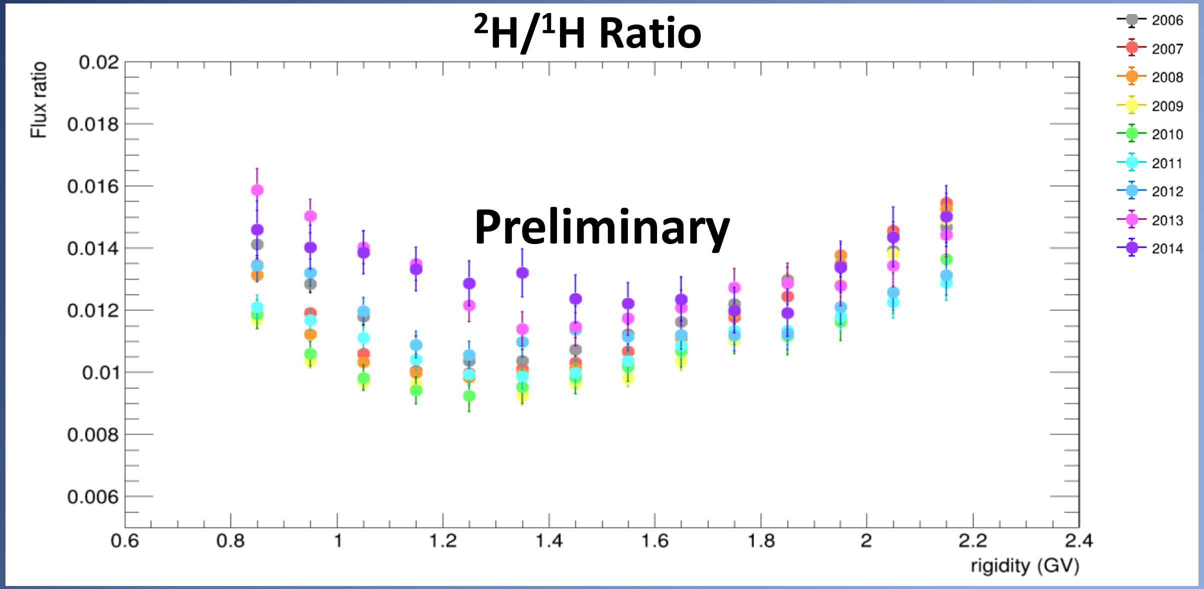
Results: ^{3}He and ^{4}He fluxes

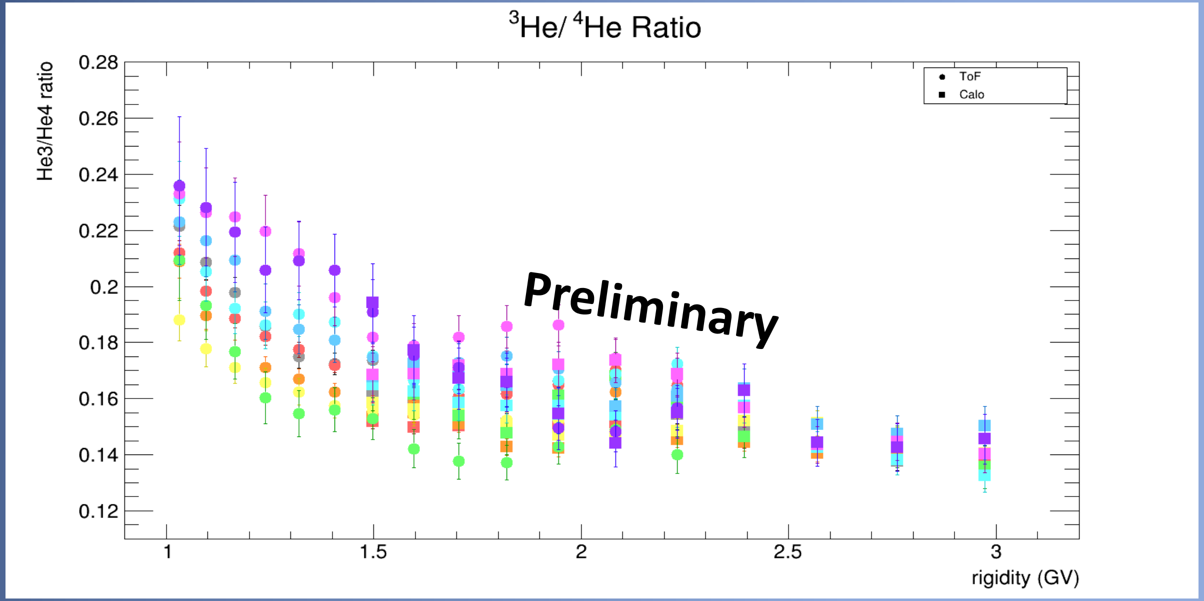


Time dependence due to the solar modulation:

- ➢ increase of the fluxes from 2006 to 2009 (solar minimum phase),
- ➢ decrease of the fluxes from 2009 to 2014 (solar maximum phase).

Results: ratio $^2H/^1H$ and $^3He/^4He$

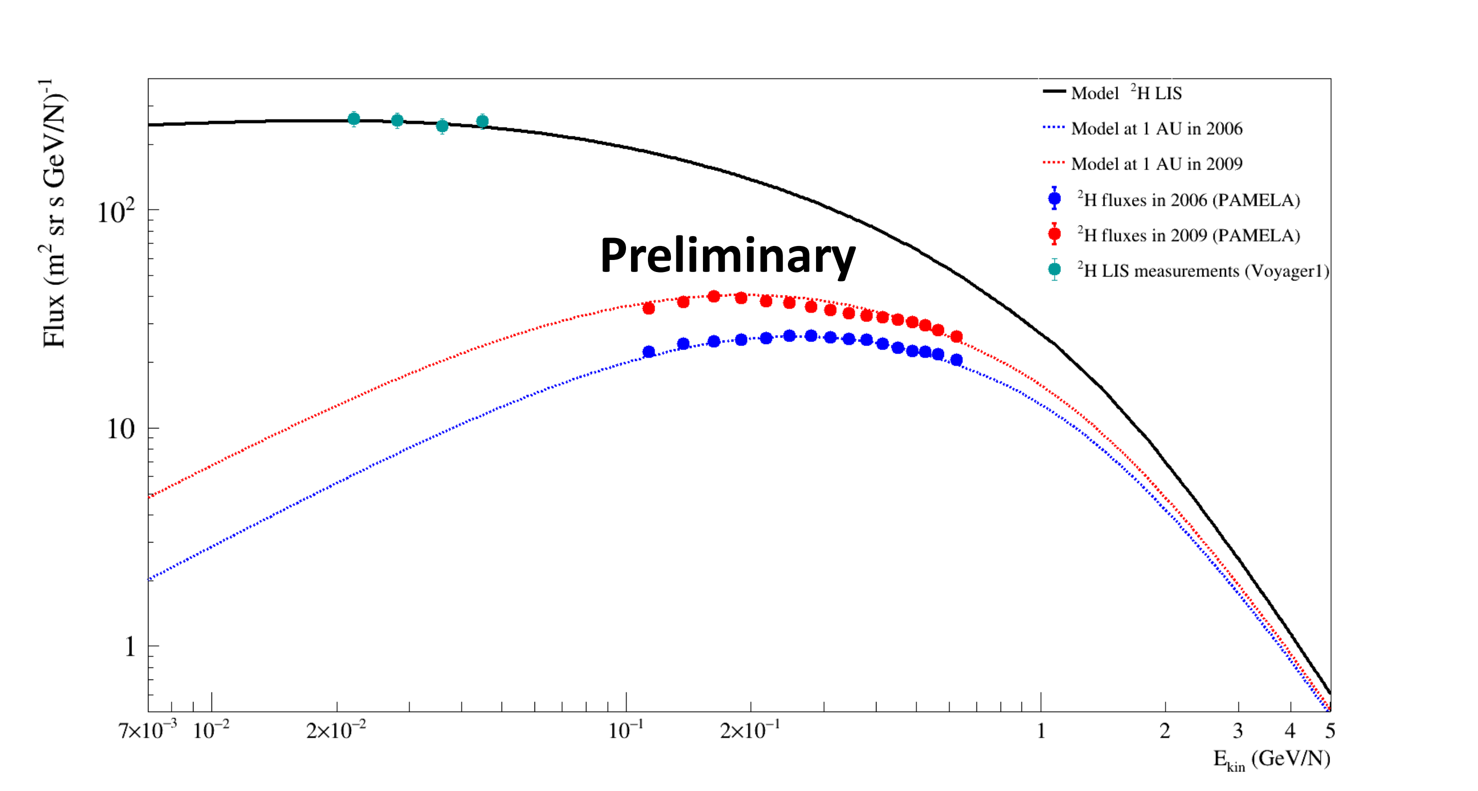




Time variation of the **$^2H/^1H$ and $^3He/^4He$** ratios due to the solar modulation:

- ➢ decrease of the ratios with the solar activity reduction (minimum in 2009),
- ➢ growth of the ratios with the increase of the solar activity (maximum in 2014).

Measured fluxes compared with expectations from a state-of-the-art model for CR propagation in the Heliosphere



Measured ^{2}H fluxes in 2006 and 2009 (solar minimum phase) compared with expected fluxes from a state-of-the-art model of CR solar modulation of a starting modelled LIS.

See also talks 262 and 264 presented by Dr. Ngobeni

Conclusions:

- Yearly fluxes of ^{1}H, ^{2}H, ^{3}He, ^{4}He in cosmic rays have been obtained for the time period from 2006 to 2014.
- The $^{2}H/^{1}H$ and $^{3}He/^{4}He$ ratios decrease during solar minimum phase and increase during solar maximum phase.
- The explanation of this time variation can be related to both **a velocity dependence of the diffusion coefficients** and by **the different spectral shape of the** LIS.
- Numerical models of propagation of cosmic rays in the Heliosphere are being used to understand time variation of the ratios.