Isotope solar modulation with the PAMELA experiment

25 July 2019

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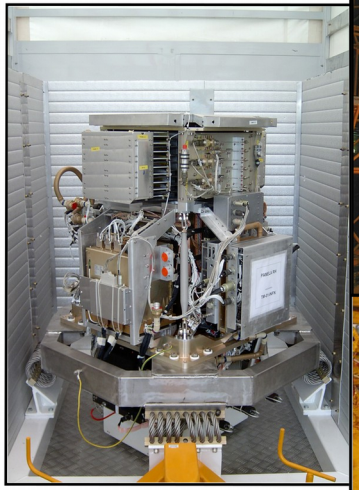
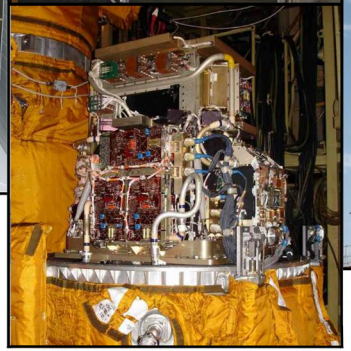
INFN Trieste

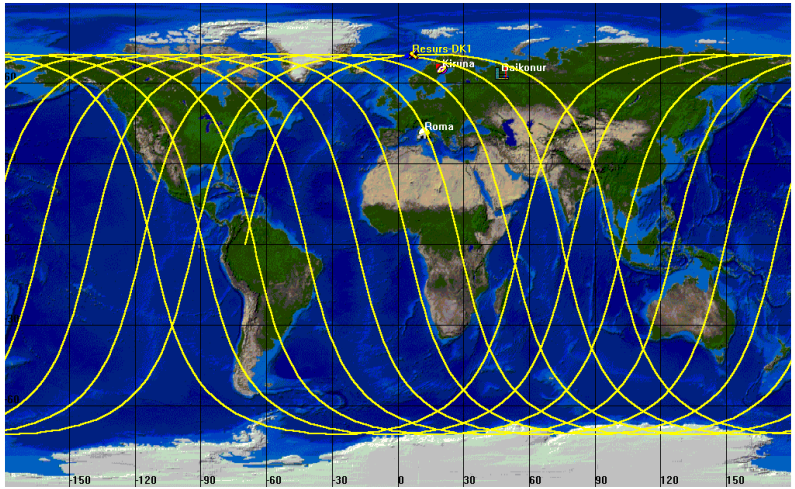




PAMELA: Cosmic Rays deeply inside Heliosphere

Ideal detector for CR solar modulation:

- 1 AU from the Sun
- Quasi polar orbit
- 50 MeV – 1 TeV
- Multi-particle measurement
- Particle-antiparticle measurement

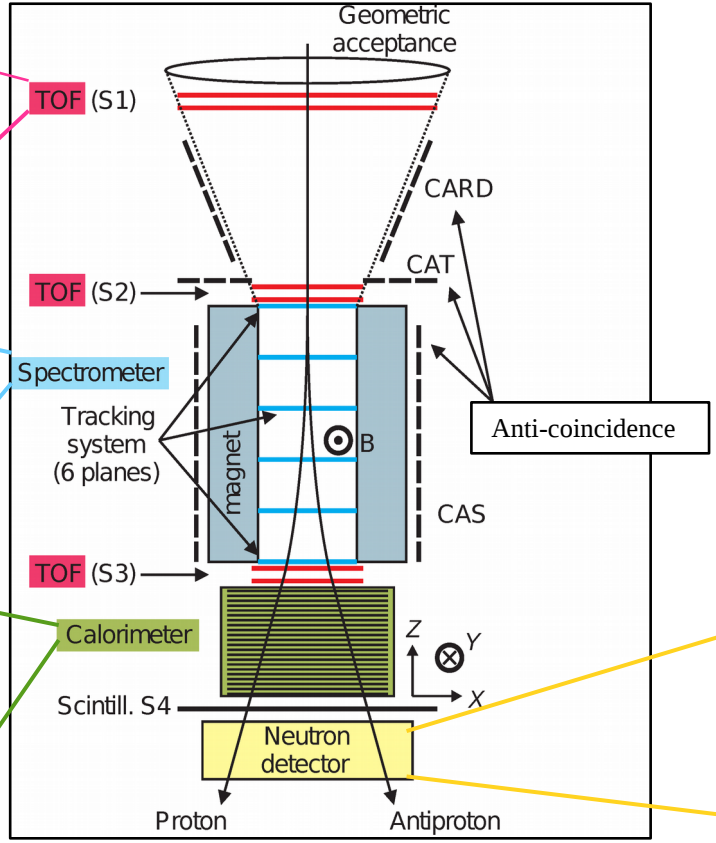


The PAMELA instrument

24 bars of plastic scintillator disposed on six plane, S11, S12, S21, S22, S31, S32: velocity, absolute charge Z<8.

Six plane of double side microstrip silicon detector inside a magnetic cavity: rigidity, absolute charge Z<6, charge sign.

44 planes of Si detector interleaved with 22 tungsten planes, 16.3 radiation length: hadron lepton separation.

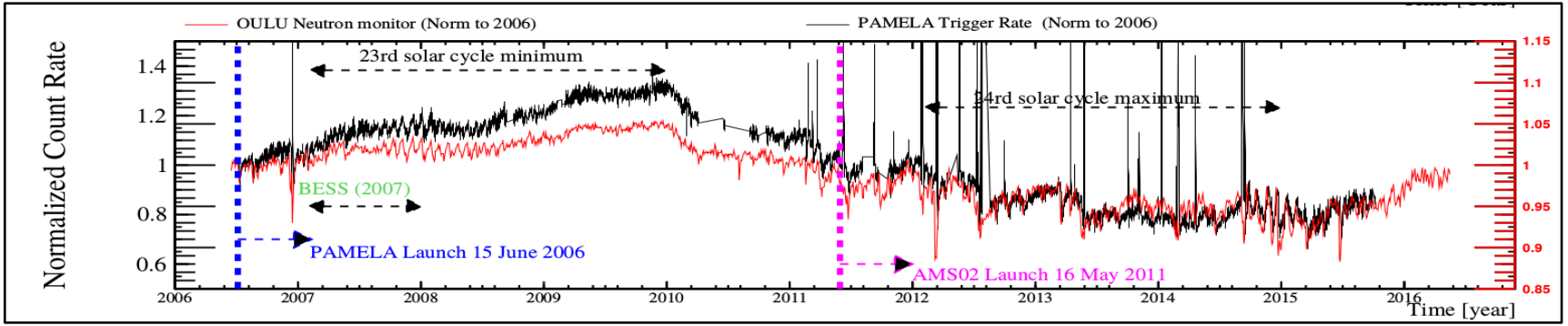


GF: 21.5 cm2 sr
Mass: 470 kg
Size: 130x70x70 cm
Power budget: 360 W

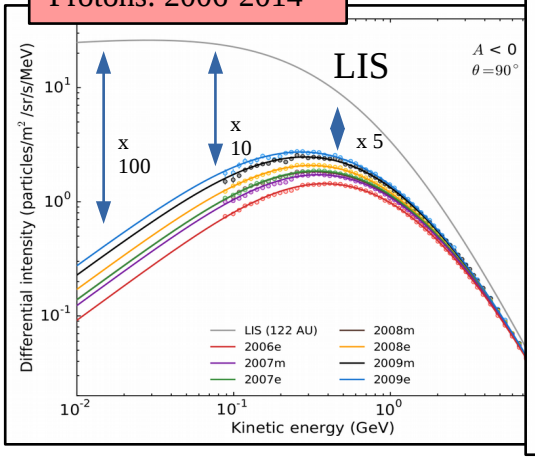
(CAS, CARD e CAT) nine plane of plastic scintillator around the apparatus: reject false trigger or multi-particle events.

36 proportional counter filled with 3He: improve hadron rejection.

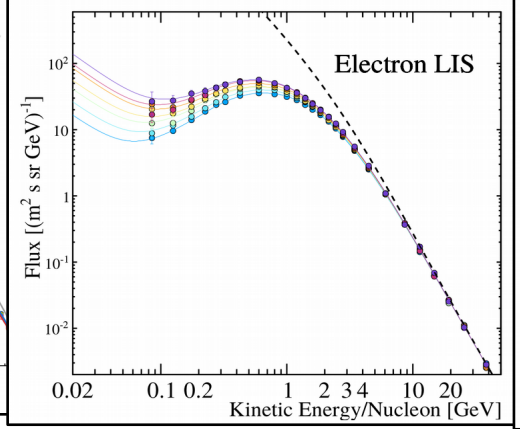
PAMELA results on solar modulation



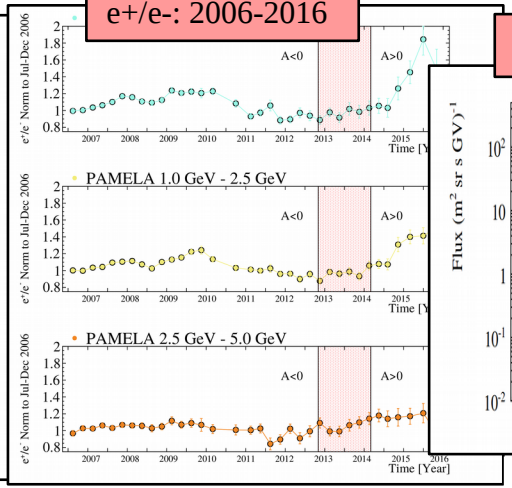
Protons: 2006-2014



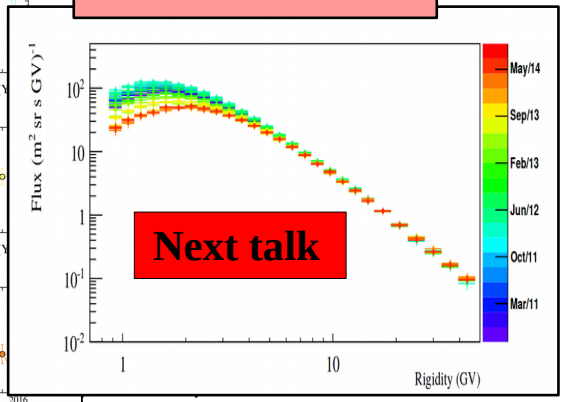
Electrons: 2006-2009



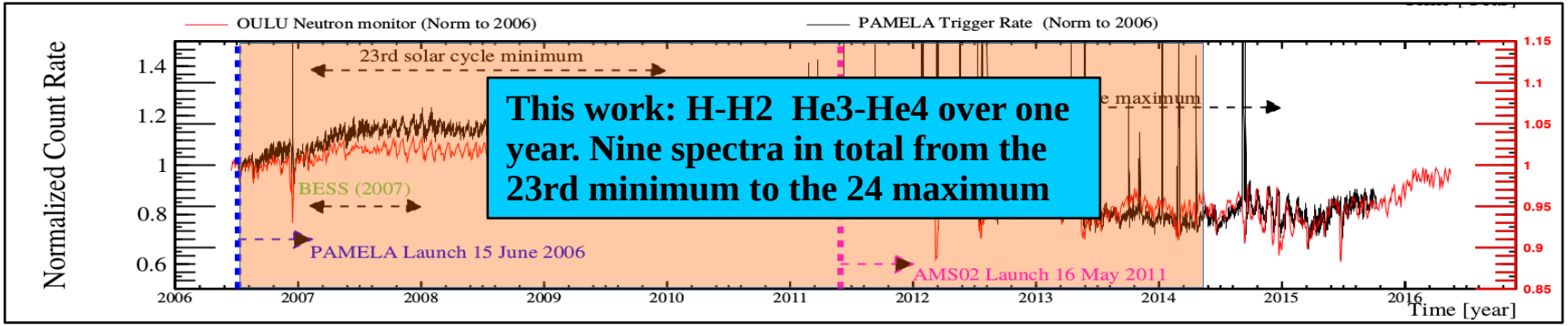
e+/e-: 2006-2016



Helium: 2006-2014

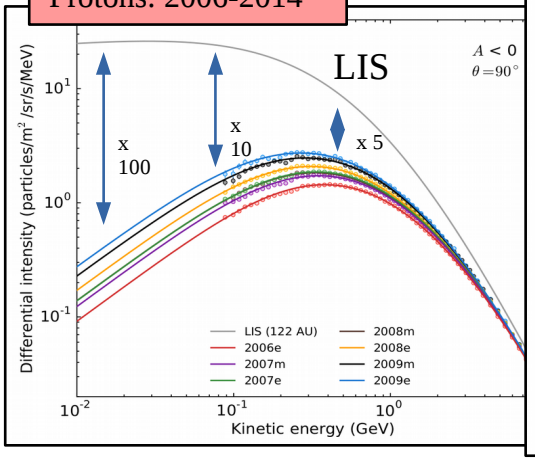


PAMELA results on solar modulation

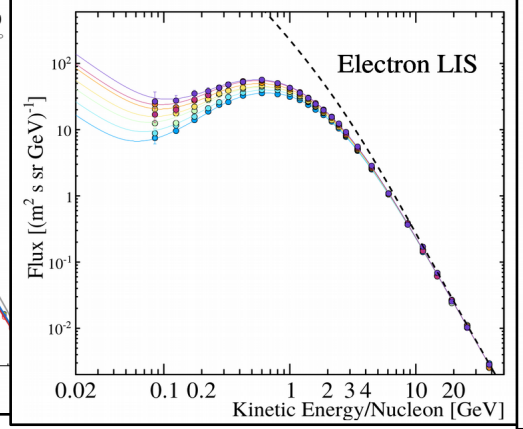


This work: H-H2 He3-He4 over one year. Nine spectra in total from the 23rd minimum to the 24 maximum

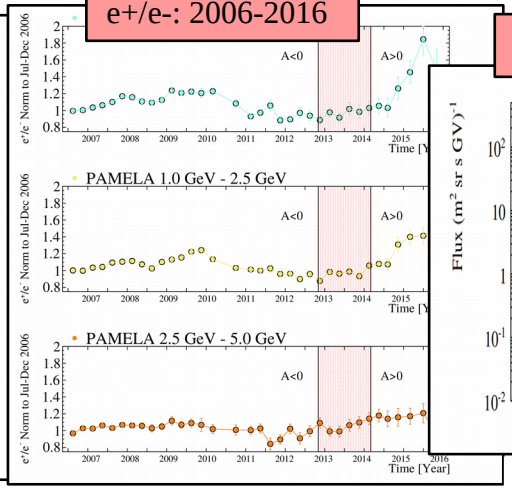
Protons: 2006-2014



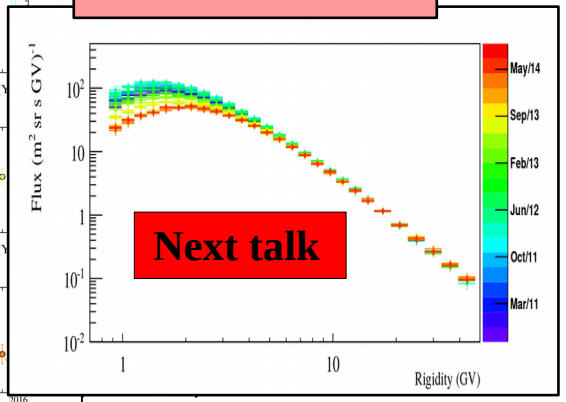
Electrons: 2006-2009



e+/e-: 2006-2016



Helium: 2006-2014

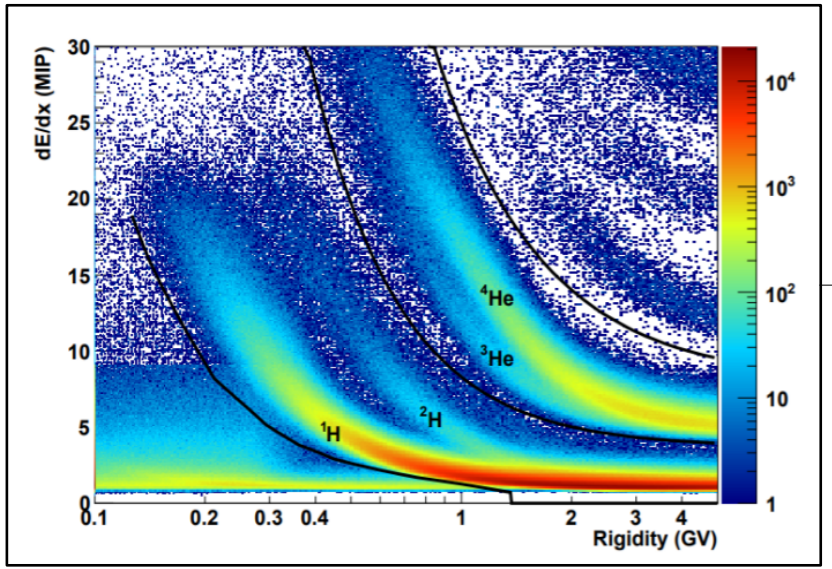


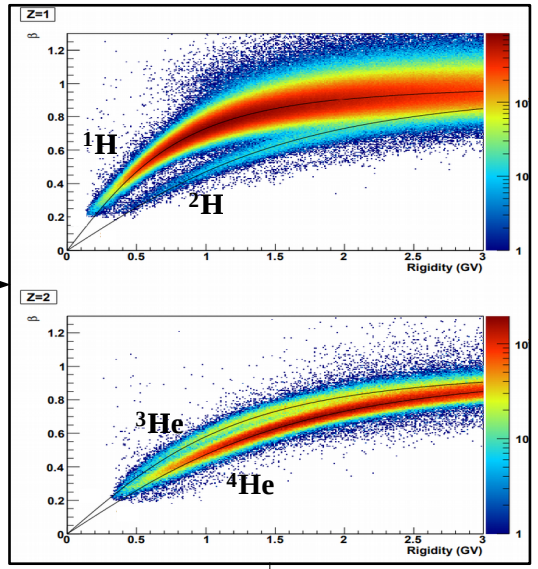
Next talk

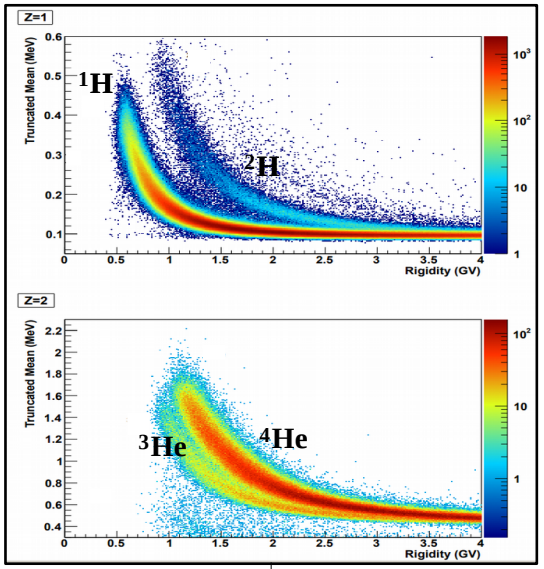
Isotope selection: H-H2 He3-He4

Charge selection: dEdx measurements (tracker)

Isotopes selection based on ionization energy losses and velocity





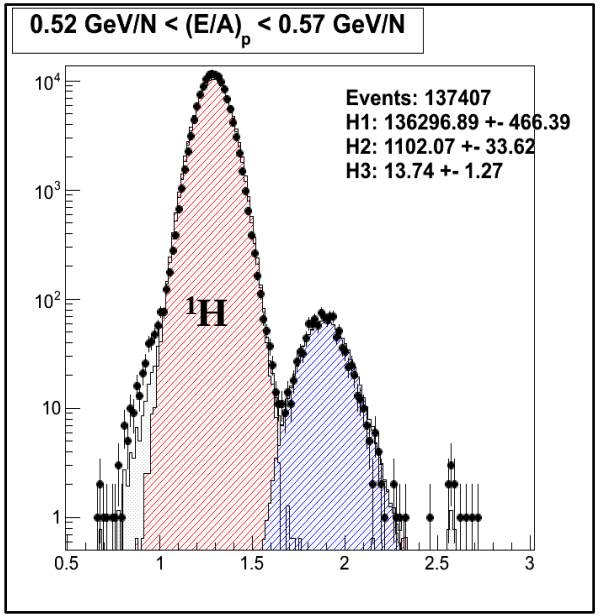


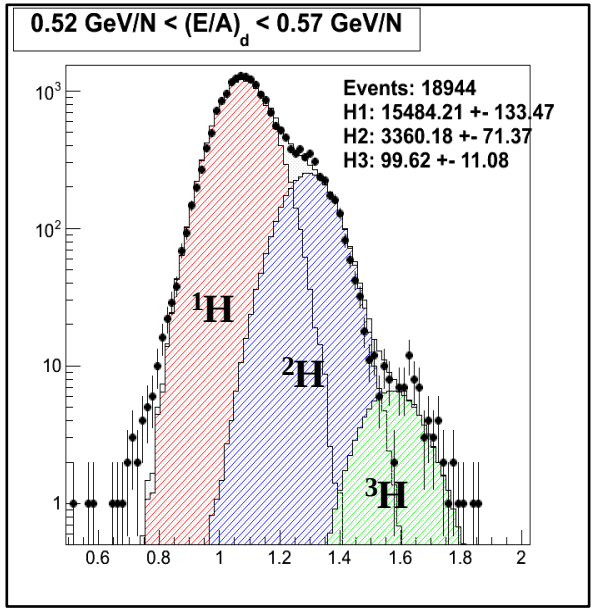
Clean track based on number of point used for track reconstruction and fit Chi2

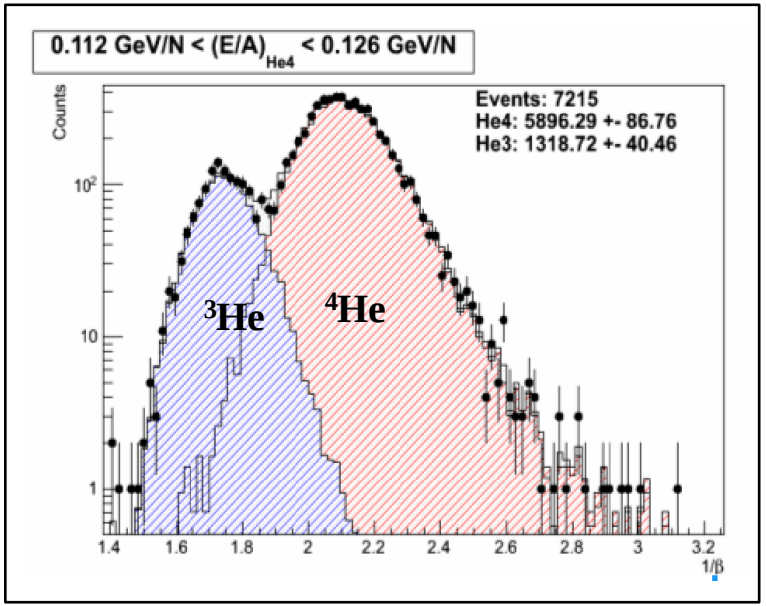
Time of flight: 1/beta distribution expected to have Gaussian behaviour

Calorimeter dEdX: truncated mean with non interacting events to cut Landau tails.

Event count: H-H2 He3-He4





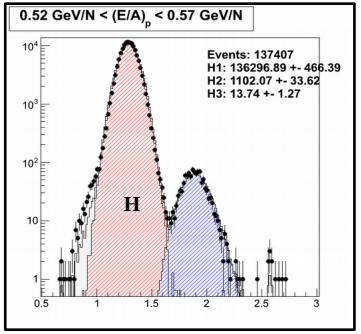


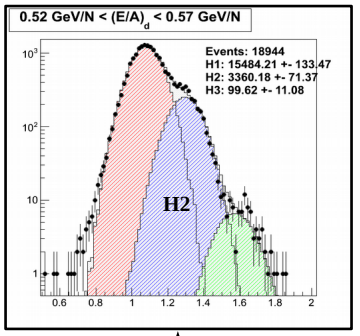
Likelihood Method TFractionFitter: Model distribution built on tuned simulation

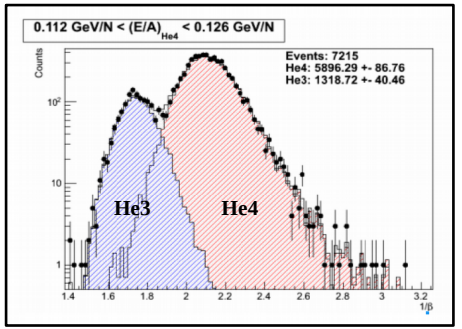
Flux calculation

$$\phi(E) = \frac{N(E,E+\Delta E)}{\epsilon \times G \times T \times \Delta E}$$

- N(E,E+ΔE): event number





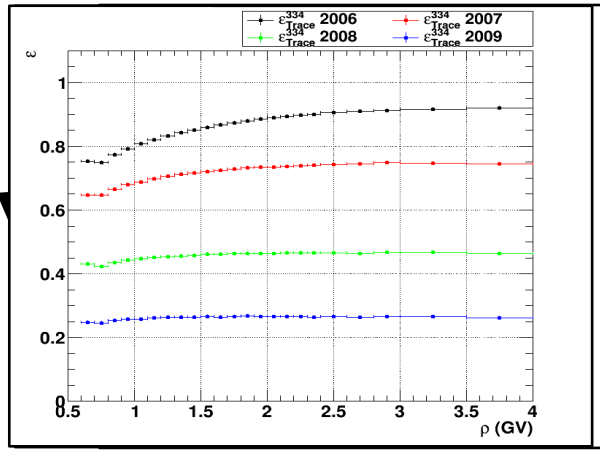


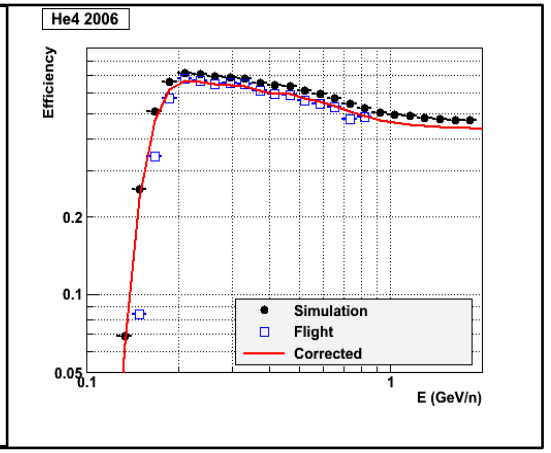
Flux calculation

$$\phi(E) = \frac{N(E,E+\Delta E)}{\epsilon \times G \times T \times \Delta E}$$

Evaluated with flight data and Monte Carlo. Time dependent to account change in reconstruction performances.

- N(E,E+ΔE): event number
- ε: total efficiency selection



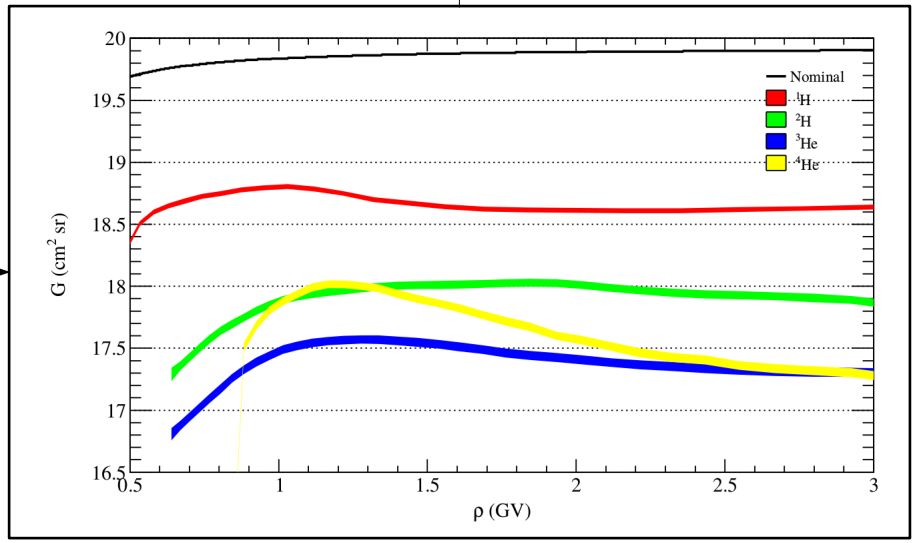


Flux calculation

$$\phi(E) = \frac{N(E,E+\Delta E)}{\epsilon \times G \times T \times \Delta E}$$

Geometrical factor: lower than the nominal due to scattering and fragmentation on the material above tracker

- N(E,E+ΔE): event number
- ε: total efficiency selection
- G: geometrical factor

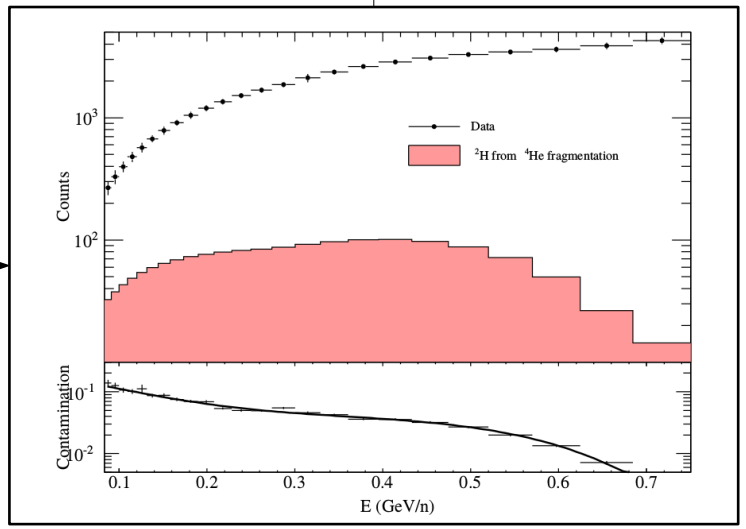


Flux calculation

$$\phi(E) = \frac{N(E,E+\Delta E)}{\epsilon \times G \times T \times \Delta E}$$

2H fraction due to 4He fragmentation

- N(E,E+ΔE): event number
- ε: total efficiency selection
- G: geometrical factor

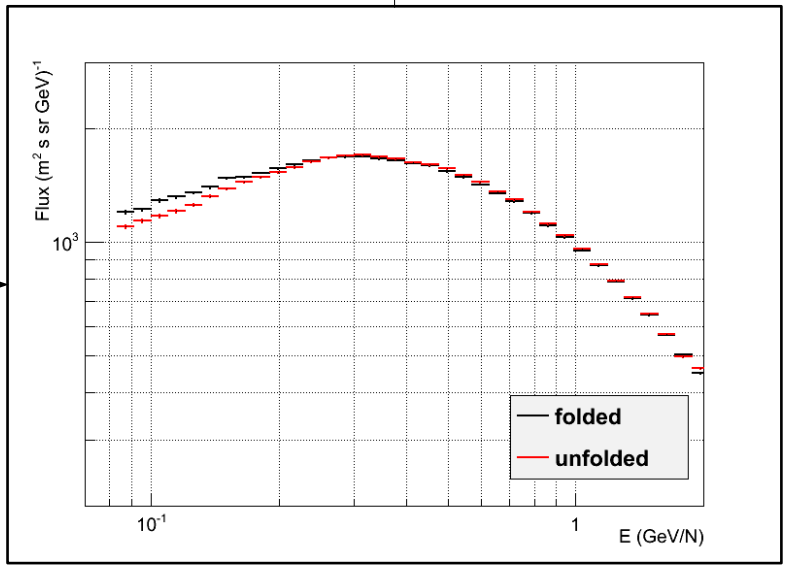


Flux calculation

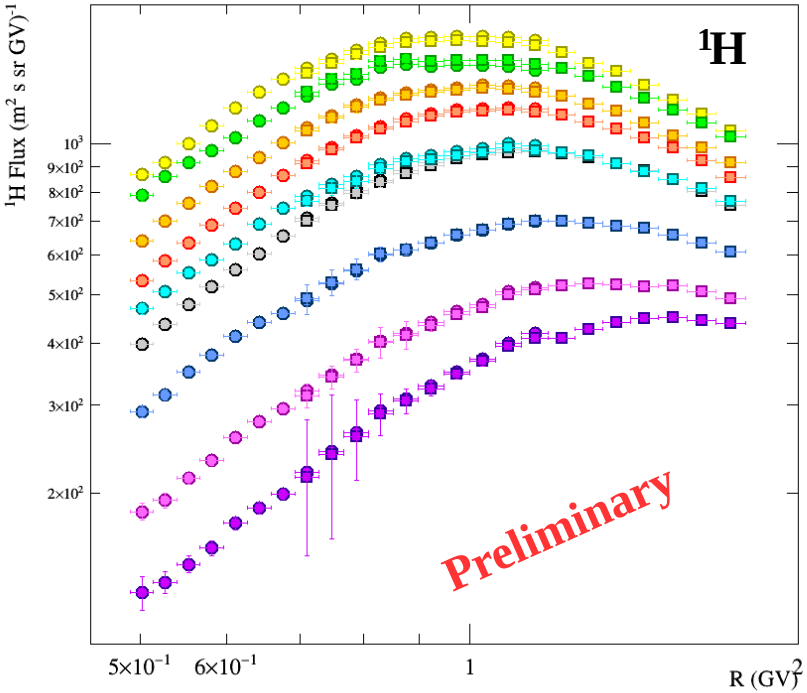
$$\phi(E) = \frac{N(E,E+\Delta E)}{\epsilon \times G \times T \times \Delta E}$$

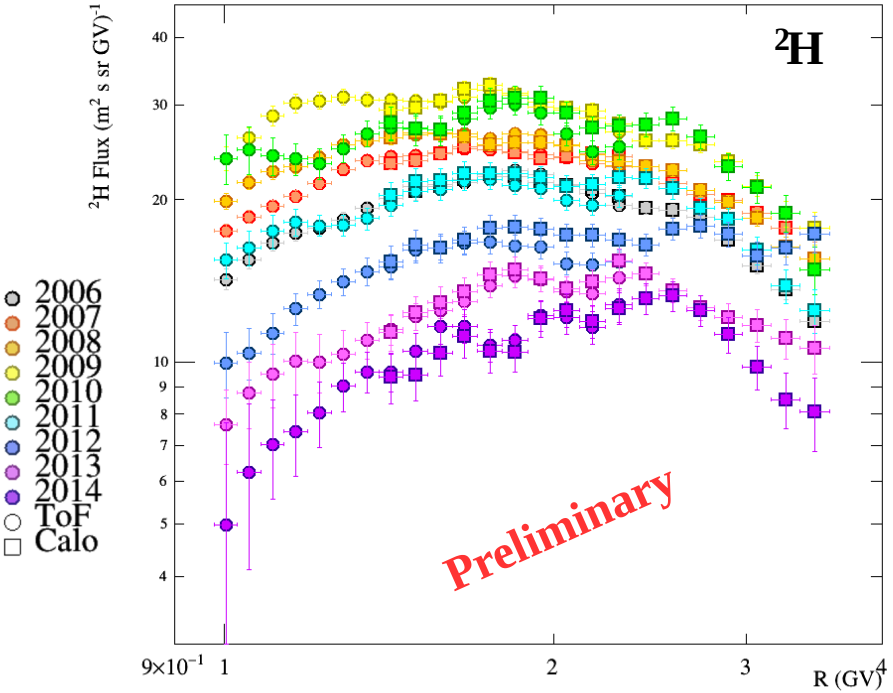
Reconstruct the spectrum at the top of the payload

- N(E,E+ΔE): event number
- ε: total efficiency selection
- G: geometrical factor
- T: live time
- ΔE: bin width
- Unfolding

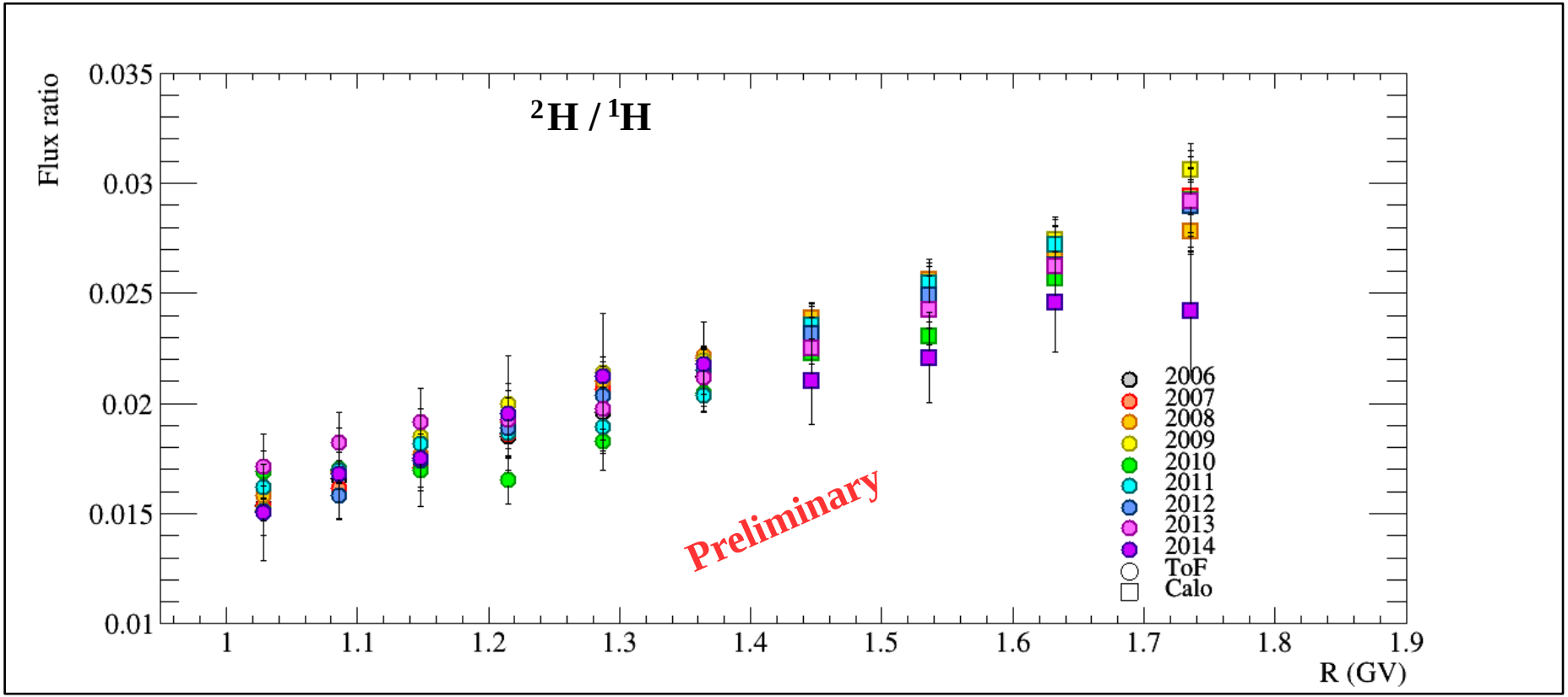


Results: 2H - 1H

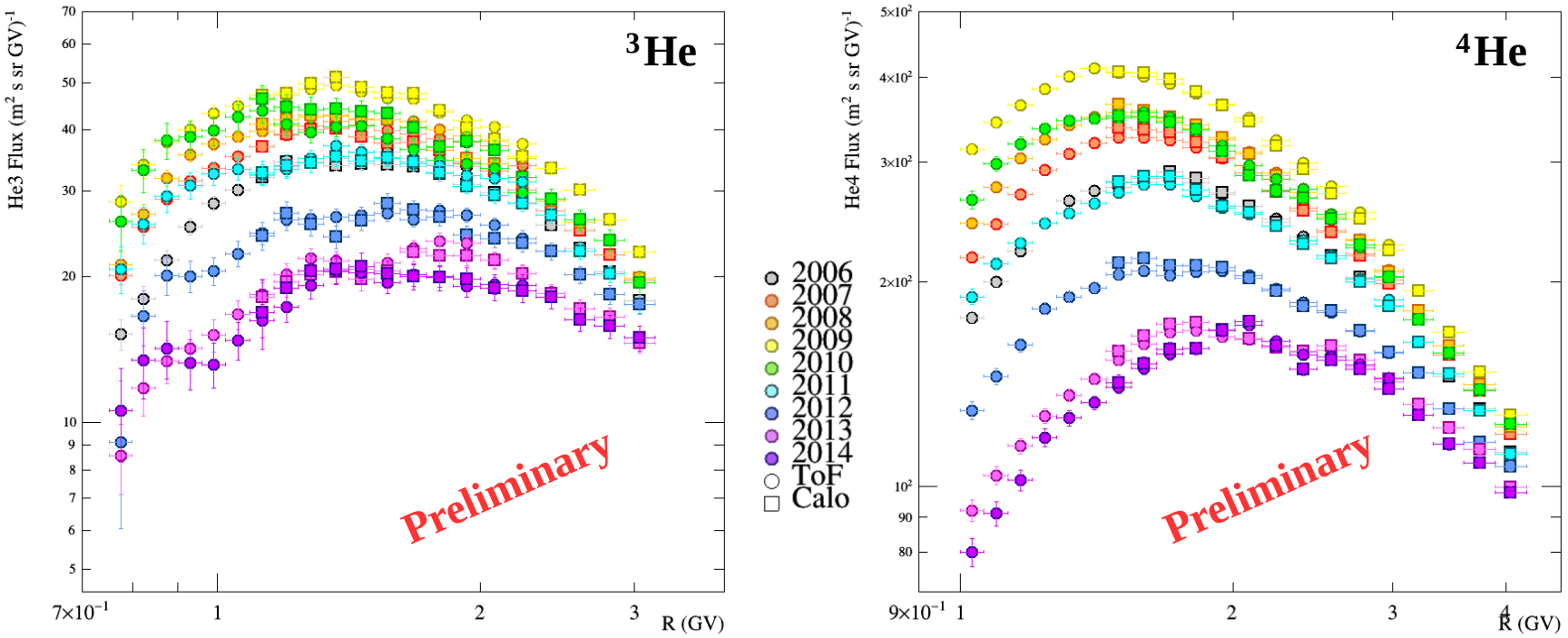




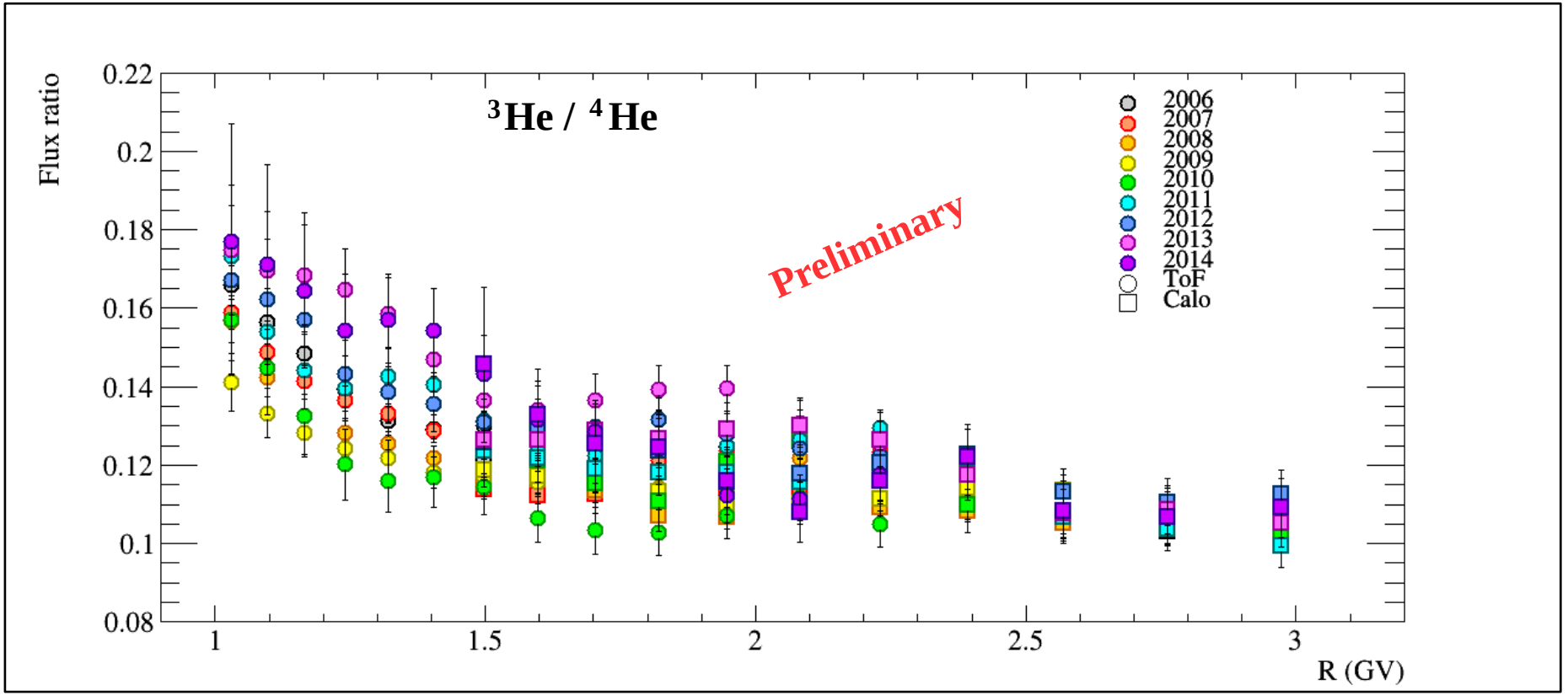
Results: 2H / 1H ratio



Results: 4He - 3He



Results: 3He / 4He ratio



Conclusion and perspective

- Yearly average fluxes measured with the PAMELA experiment were presented for 1H, 2H, 3He and 4He from 2006 to 2014.
- The isotope ratio 2H/1H shows not significant time variation.
- The isotope ratio 3He/4He shows a decrease over the solar minimum period and an increase as the solar maximum is approached.
- Possible explanation of a time-dependent ratio are difference in velocity which cause difference in the diffusion coefficient or different slope of the Local Interstellar Spectrum of the two different particle species.
- Numerical 3D model for CR propagation inside the heliopshere will be used to reproduce the data and improve the understanding of a time dependent ratio.
- Data up to 2016 will be used to extend the analysis.

Published data: H-H2 He3-He4

July 2006 – December 2007

H-H2: 0.12 – 0.57 GeV/n (ToF)
0.22 – 1.08 GeV/n (Calo)

He3-He4: 0.12 – 0.87 GeV/n (ToF)
0.25 – 1.37 GeV/n (Calo)

Solar modulation analysis:
July 2006 – September 2014

Statistics allow to study the time variation over one year. Nine spectra in total from the 23rd minimum to the 24 maximum