# PAMELA satellite:
## fragmentation in the instrument

**Alessandro Bruno**
**INFN, Bari (Italy)**

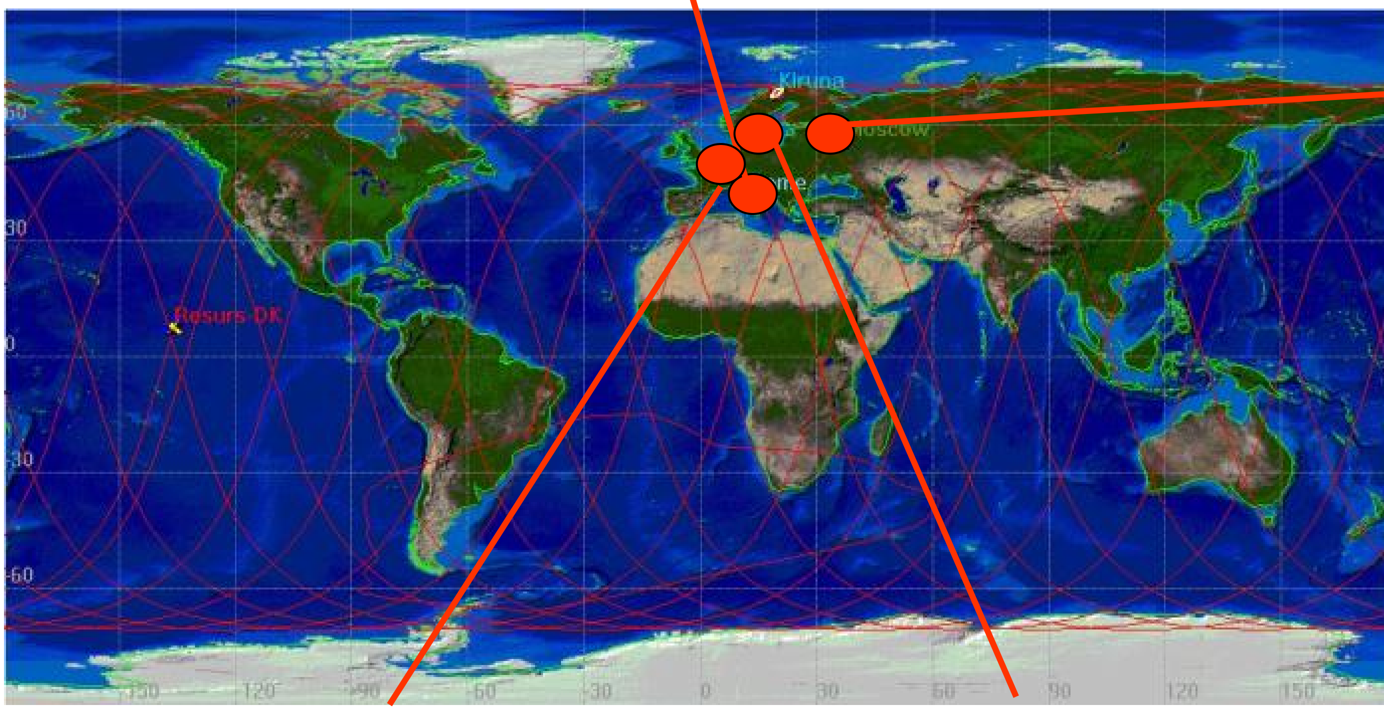
**for the PAMELA collaboration**

**Nuclear Physics for Galactic CRs in the AMS-02 era**
**3-4 Dec 2012 LPSC, Grenoble**

# The PAMELA collaboration

Italy: Bari Florence Frascati Naples Rome Trieste CNR, Florence

Russia: Moscow St. Petersburg

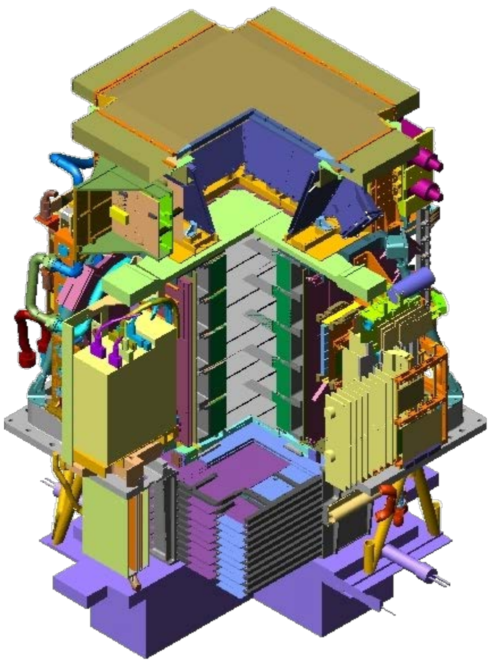



Germany: Siegen

Sweden: KTH, Stockholm

# The PAMELA apparatus

**Main requirements** → high-sensitivity particle identification and precise momentum measure



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

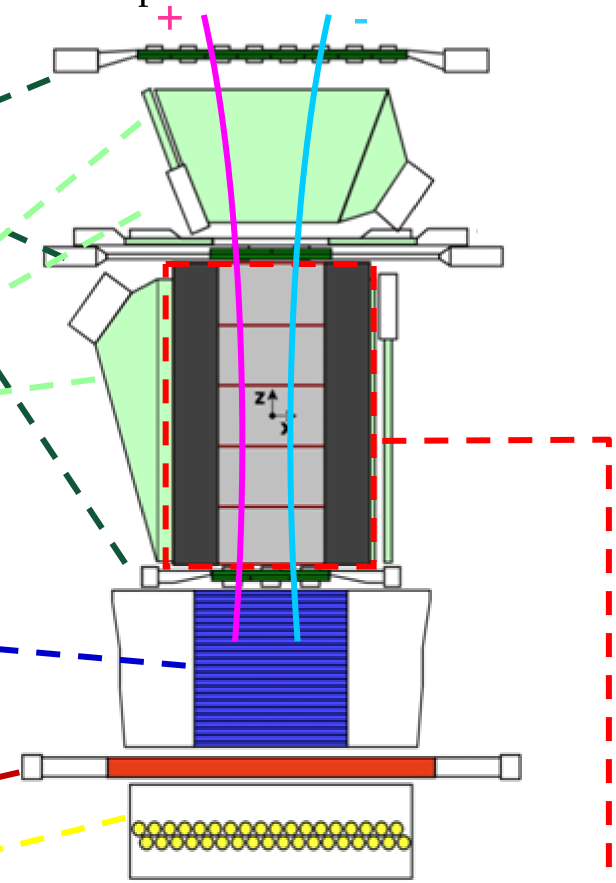
**Time-Of-Flight**
plastic scintillators + PMT
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX.

**Anticoincidence shield**
plastic scintillators + PMT

**Electromagnetic calorimeter**
W/Si sampling (16.3 $X_0$, 0.6 $\lambda I$)
- Discrimination e+ / p, anti-p / $e^-$ (shower topology)
- Direct E measurement for $e^-$

**Bottom scintillator** (+PMT)

**Neutron detector**
$^3$He counters
- High-energy e/h discrimination




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

# Introduction:
## reconstructing spectra

- Flux at the top-of-apparatus in each energy bin *E:*

$$\Phi(E) = \frac{N(E)}{\varepsilon(E)\cdot A_{cce}(E)\cdot \Delta E \cdot \Delta T} \qquad \left[\mathrm{GeV}\cdot \mathrm{m}^2 \cdot \mathrm{sr}\cdot \mathrm{s}\right]^{-1}$$

where $N(E)$ is the number of detected particles, $\varepsilon(E)$ is the total selection efficiency, $A_{cce}(E)$ is the apparatus acceptance and $T$ is the livetime

- Selection efficiencies were derived using flight data (combined information from different subdetectors) and account for the time-dependecy of the instrument performances
- Simulations (and Beam Tests data) used to cross-check results, and to evaluated the apparatus acceptance and the background in the measured samples

# Introduction:
## reconstructing spectra

- The factor of proportionality between counting rates (corrected by selection efficiencies) and incident fluxes is by definition the apparatus **gathering power** $\Gamma_F$ :

$$\Gamma_F = \int_\Omega d\omega F(\omega) \int_S d\sigma \cdot \hat{r} = \int_\Omega d\omega F(\omega) A(\omega) \quad [\mathrm{cm^2 sr}] \qquad \textit{(Sullivan 1971)}$$

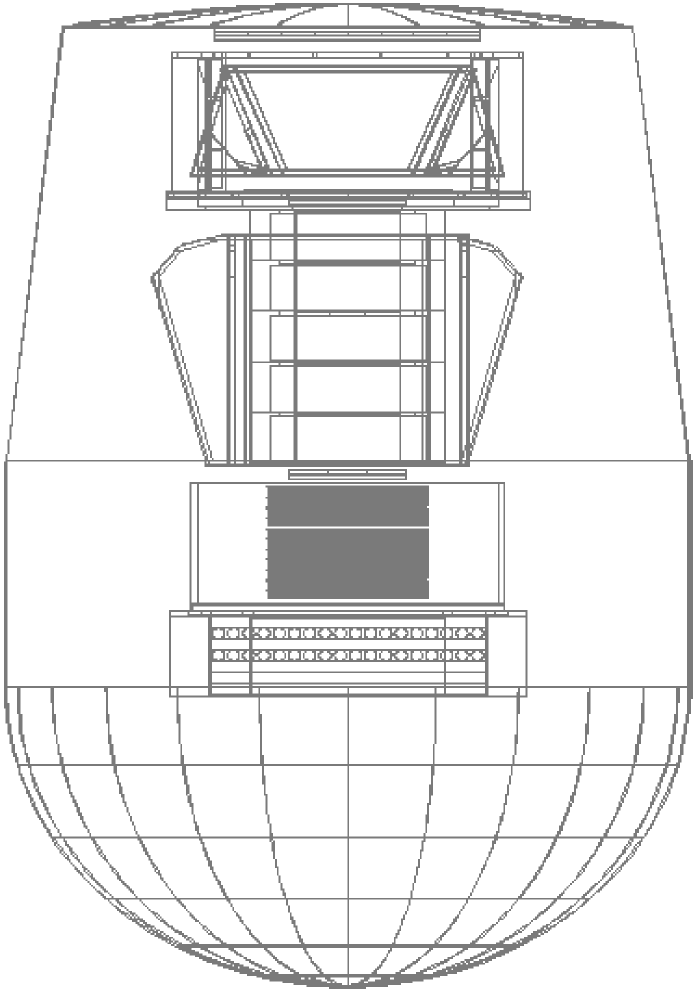
- where F(ω) represents the angular dependence of the incident flux and A(ω) is the detector response function

- For isotropic exposition F(ω)=1, and $\Gamma_F$ is called the **geometric factor** $G_F$

- The effective apparatus **acceptance** $A_{cce}$ is given by a convolution of the geometric factor with the losses in the instrument
  - inelastic reactions, multiple scattering, etc.

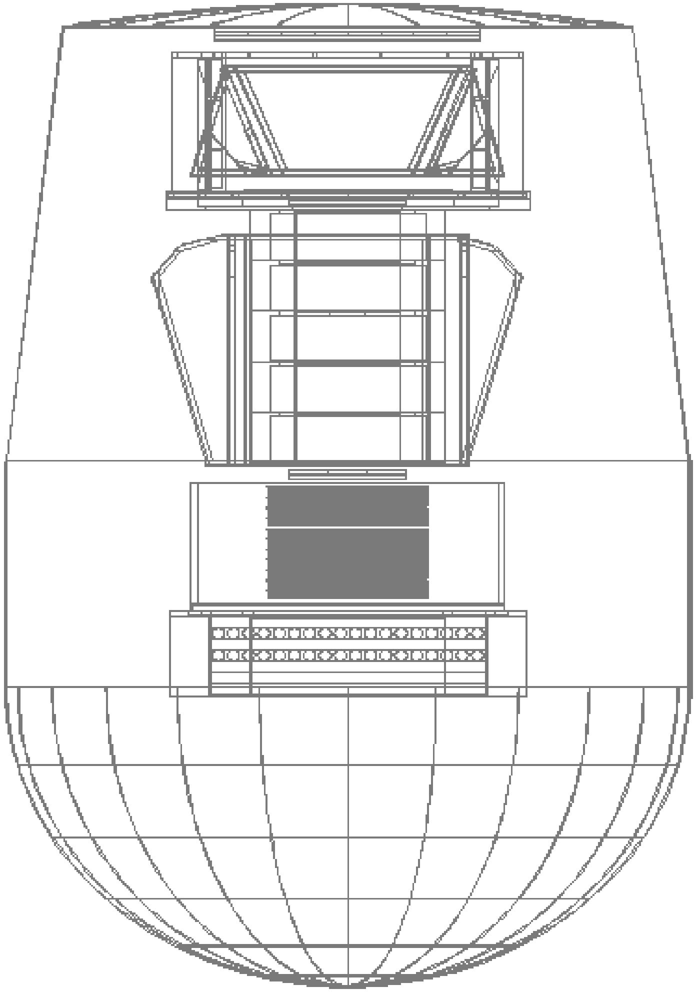
$$A_{cce}(E) = G_F(E) \otimes K_{loss}(E)$$

# PAMELA simulation: GPamela



- Full simulation of the PAMELA apparatus
  - accurate detector description, including the aluminium container, mechanical supports, etc.
  - detector response (spatial residuals, etc.) tuned to reproduce flight data performances
- Based on GEANT 3.21
  - Cross sections updated using PDG data

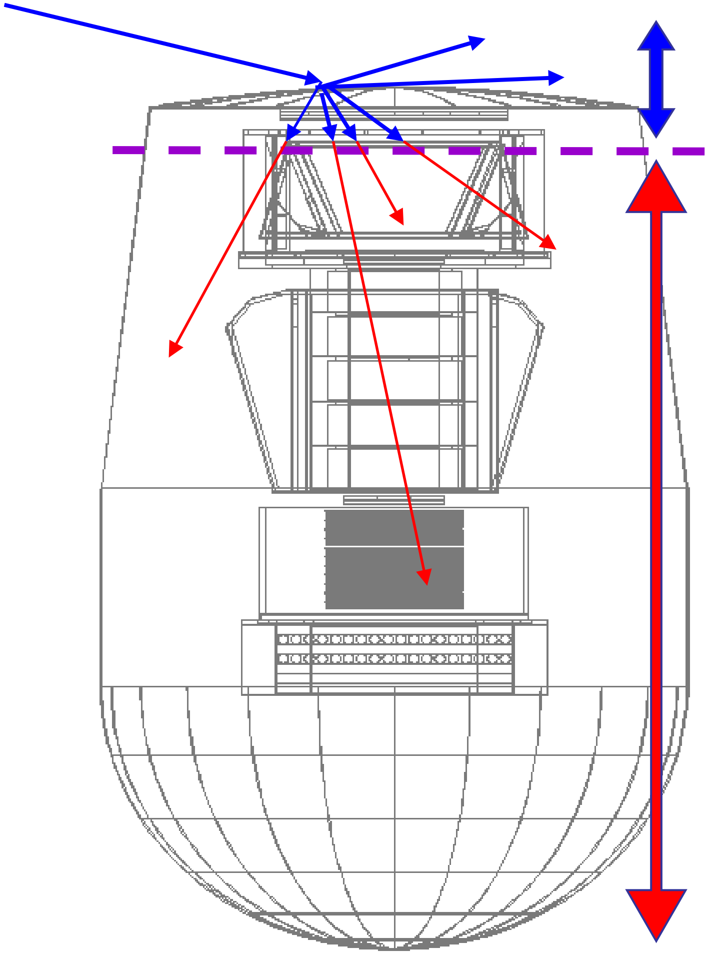
# PAMELA simulation: FLUKA



PAMELA geometry has been esported from GEANT3 to **FLUKA** (standalone)

- very accurate description of hadronic interactions
- N/N interactions:
  - modified RQMD (<5 GeV/n)
  - DJMJET 3 (>5 GeV/n)

# PAMELA simulation: FLUKA/G3



## 2 STEPS SIMULATION:

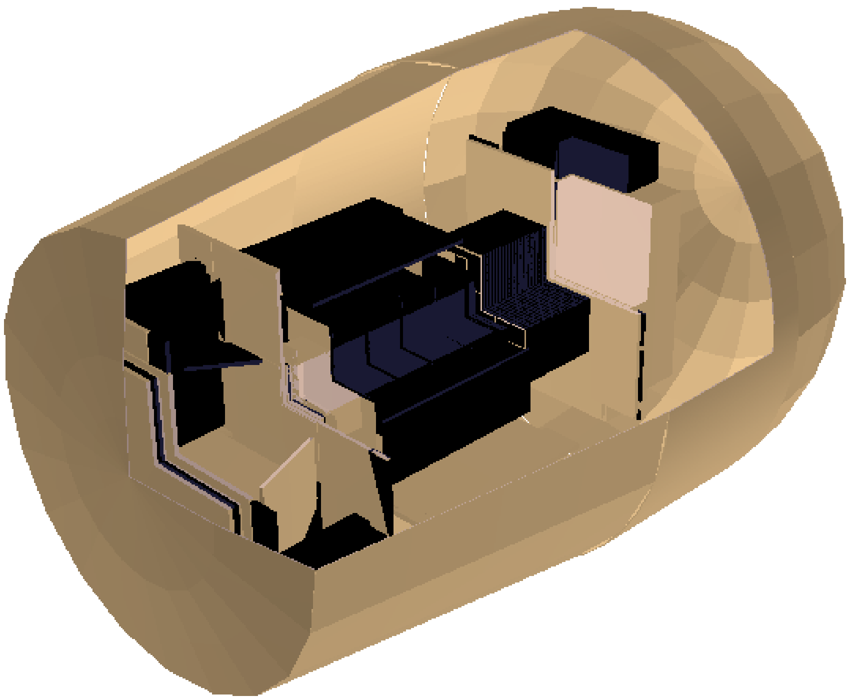
**STEP1:**

- **FLUKA standalone**
- Simplified geometry
  - only top parts of the apparatus simulated
- Possibility of selecting events of interest, to be propagated in the rest of the apparatus

**STEP2:**

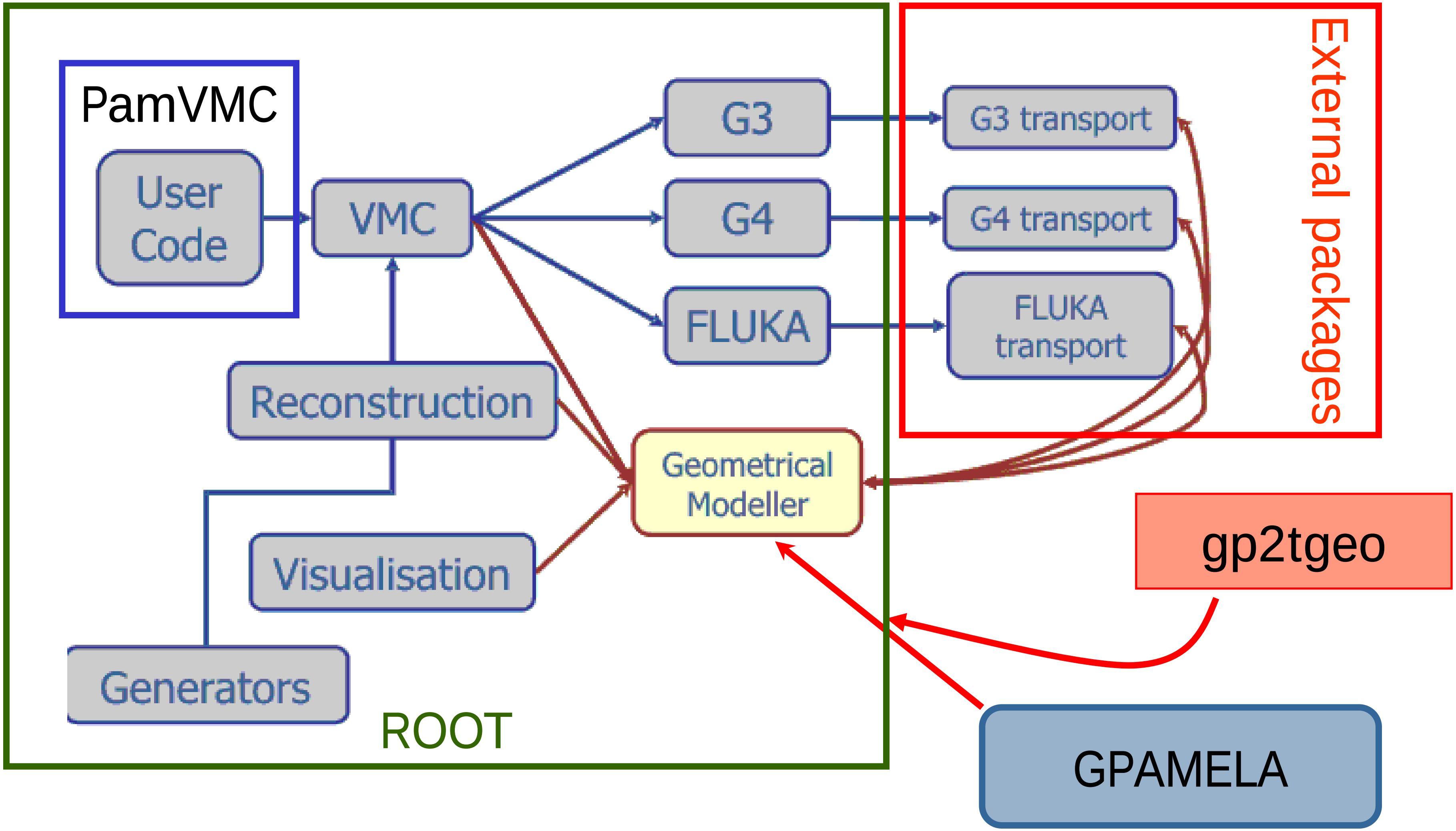
- **GPAMELA**
- reads output from STEP1
- performs simulation in the rest of the apparatus

# PAMELA simulation: the Virtual MC



- The Virtual Monte Carlo (VMC) has been developed by the ALICE Offline project in the close collaboration with the ROOT team
- The VMC allows to run different simulation Monte Carlo without changing the user code and therefore the input and output format as well as the geometry and detector response definition
  - GEANT3
  - **GEANT4** ←
  - FLUKA (discontinued by the FLUKA team in 2010)
- PAMELA VMC
  - Materials and Volumes migrated from GEANT3
  - The GPAMELA HIT structure has been migrated to a ROOT tree (no limitation on number of hits)
  - GEANT4 physics list introduced

# PAMELA simulation: the Virtual MC



# Antiproton measurements

# Antiproton analysis

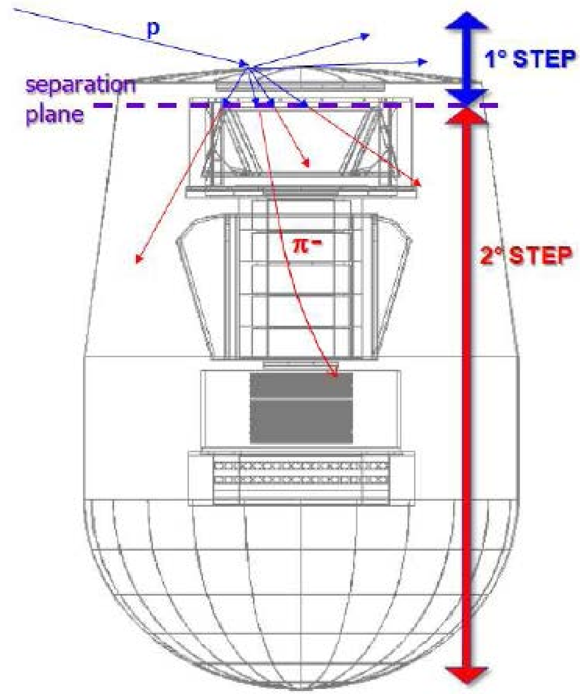
- Background evaluation
  - secondaries (mostly $\pi$-) produced in the top parts of the apparatus
- Correction for losses inside the apparatus
  - inelastic reactions, events scattered out of the apparatus, etc

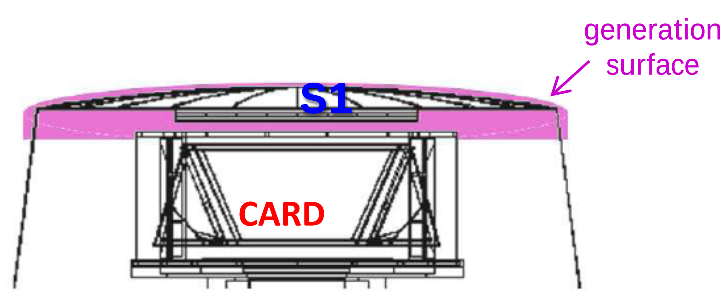
# Antiprotons: pion contamination

- Above 1 GV the combined ToF+Trk info are not enough to provide unambiguos pbar/pion discrimination
- ✓ Simulation study
  - Very large statistics required!

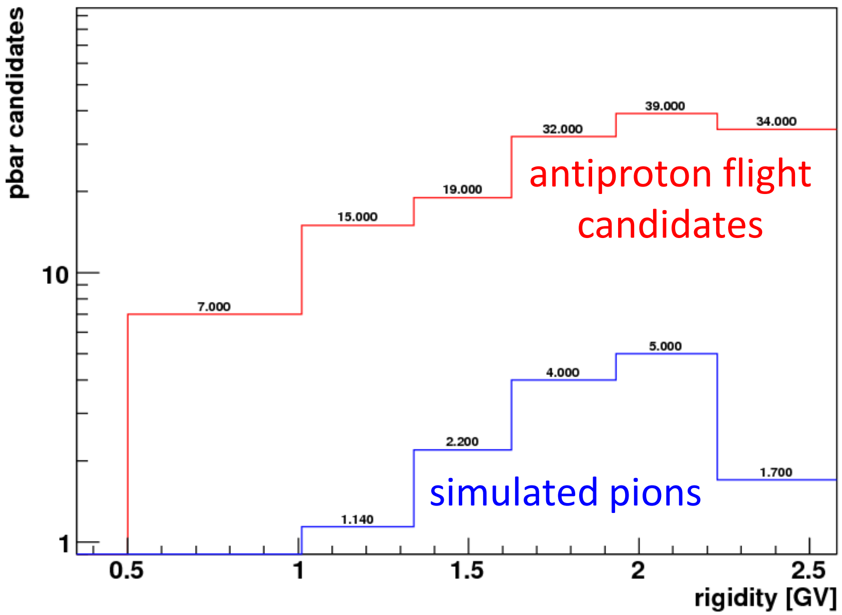
**2-step simulation chain** (FLUKA+GPAMELA)

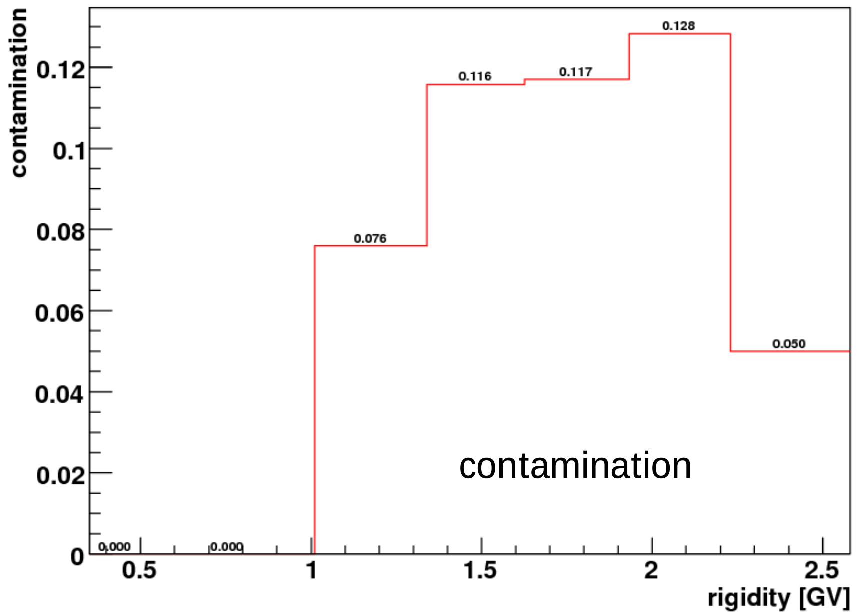
- $2\pi$ isotropic generation
- Rigidity range: 0.4-1500 GV
- Input spectra:
  - Proton and He nuclei fluxes as measured by PAMELA
  - geomagnetic modulation accounted for
- Step1 pre-selection (FLUKA):
  - all events interacting in the top parts of the apparatus, with production of secondary charged particles inside acceptance
- Step2 pre-selection (GPAMELA):
  - different trigger configurations



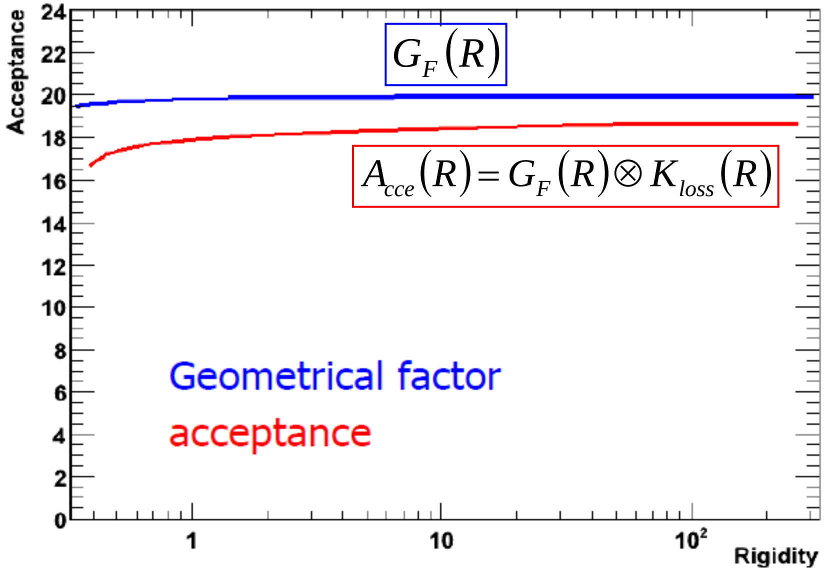
# Antiprotons: pion contamination

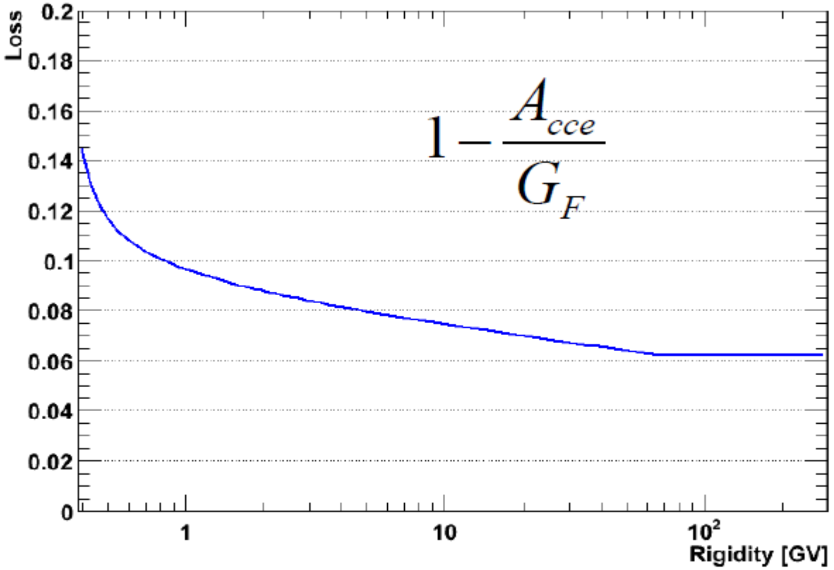


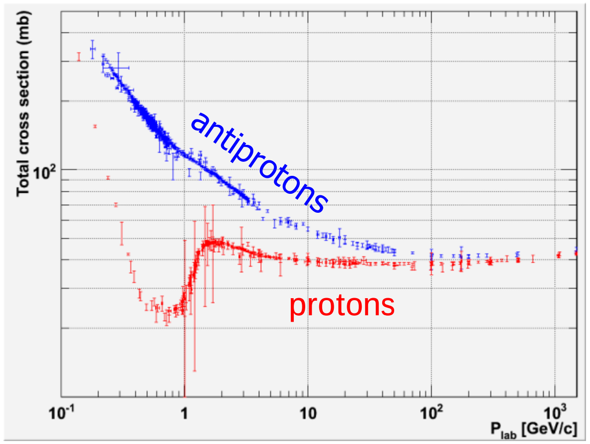



# Antiprotons: acceptance

NB - **fiducial acceptance**: trajectories required to be at least 1.5mm apart from the spectrometer cavity walls

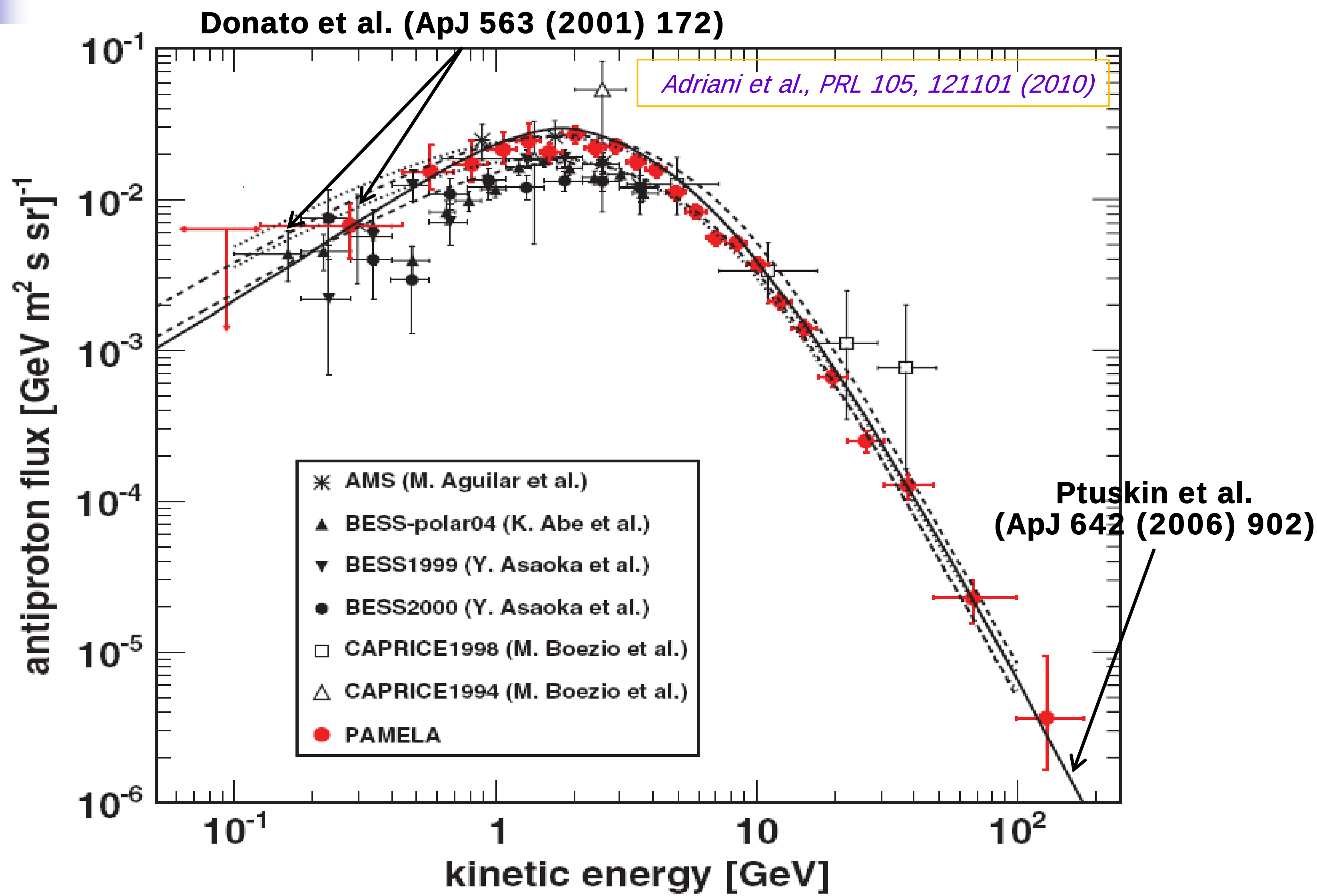



The acceptance accounts for the loss of events due to interactions with the apparatus (inelastic reactions, multiple scattering, ionization, deflection due to the spectrometer magnetic field, etc.)

# The antiproton spectrum



# Nuclei analysis

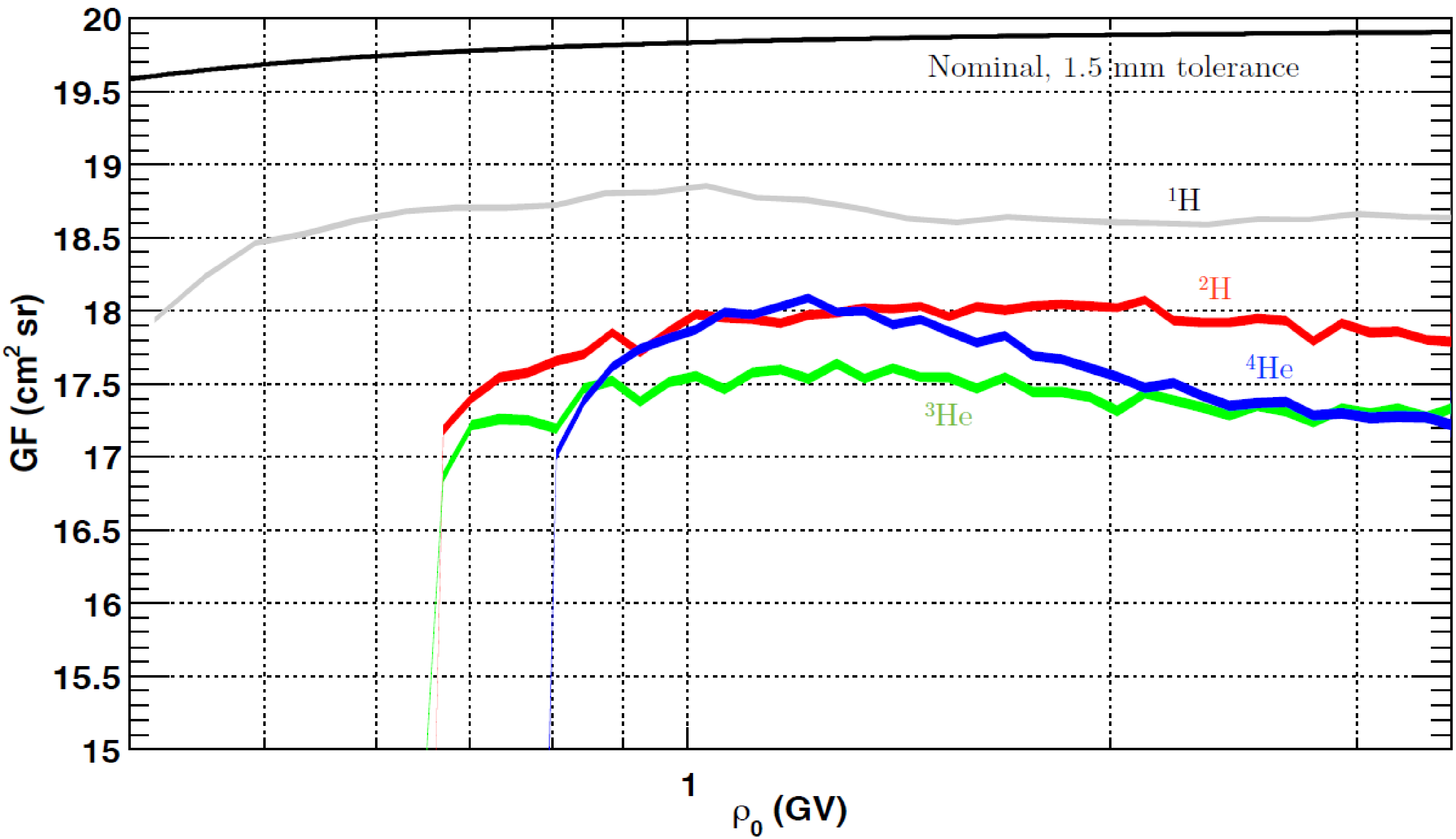
# Nuclei analysis

- Selection efficiencies
  - derived using flight data, cross-checked by full GEANT4 simulations
- Correction factors
  - contaminations from nuclear spallation in the apparatus (e.g. $^{12}C \rightarrow {}^{11}B$)
  - loss due to inelastic interactions in the apparatus
  - FLUKA simulations

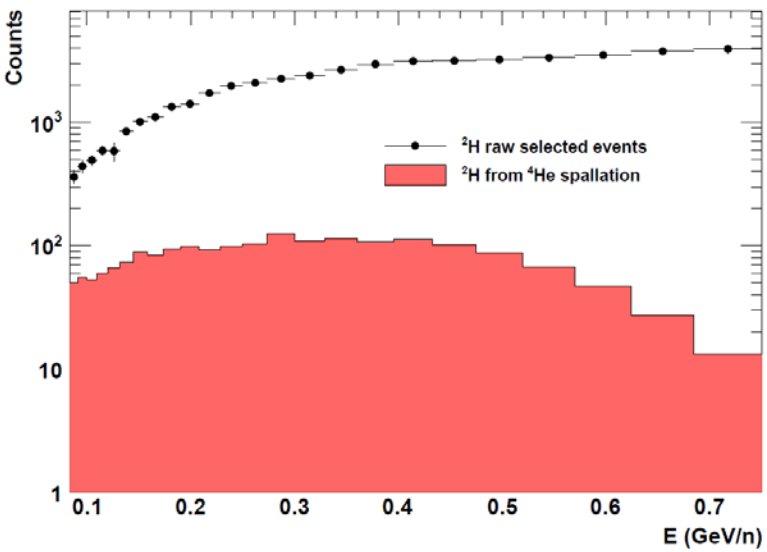
# H/He isotopes measurements

# H/He isotopes geometrical factor

Takes into account also particle losses due to fragmentation in the Aluminum dome



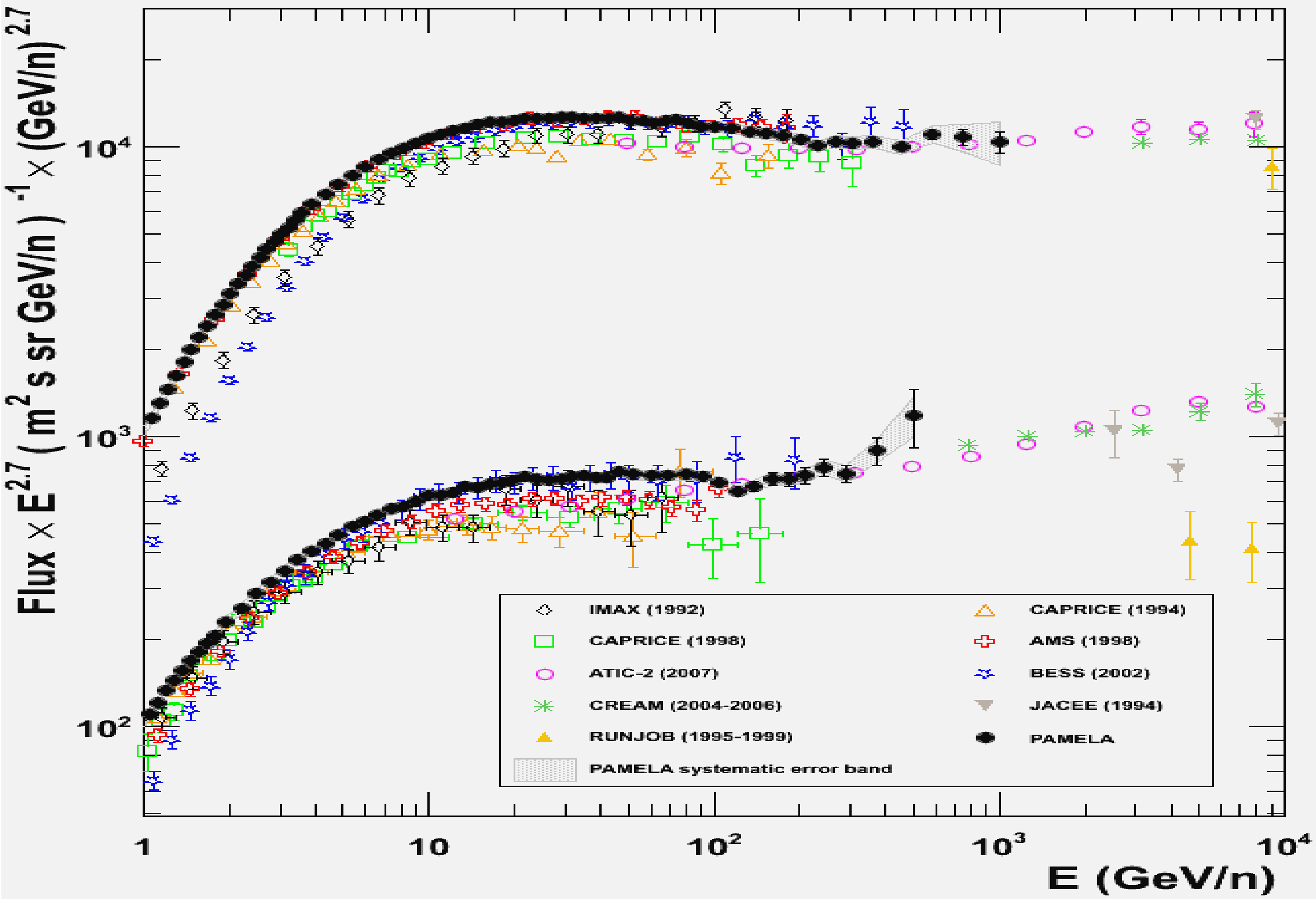
# H/He isotopes: contamination



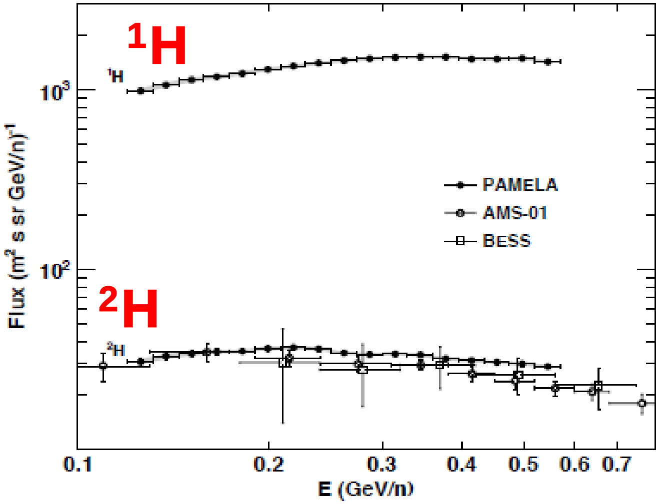

- The expected contamination in the $^2$H sample from $^4$He spallation is shown on the left
- contamination in the $^3$He sample from $^4$He is less than 1%.
- contamination by secondary He coming from heavier nuclei spallation was estimated to be negligible.

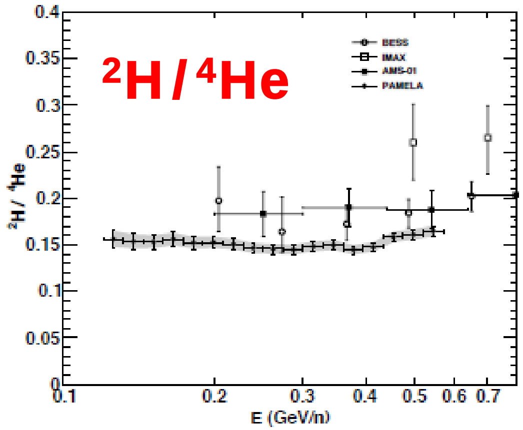
# H & He spectra

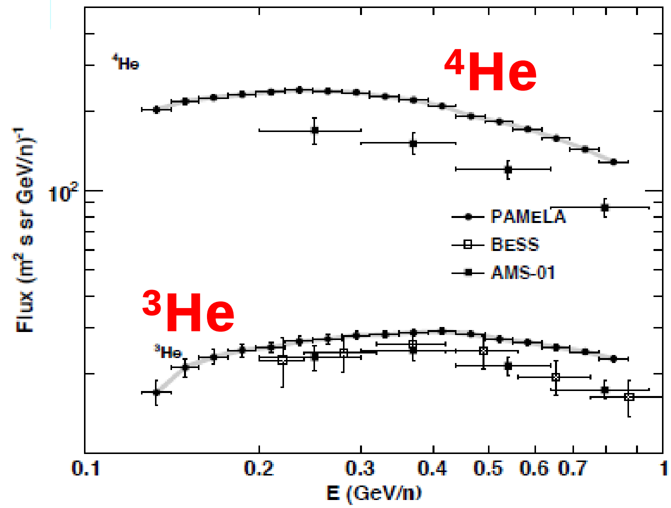
Adriani et al., Science, vol. 332 no. 6025 (2011), arXiv: 1103.4055

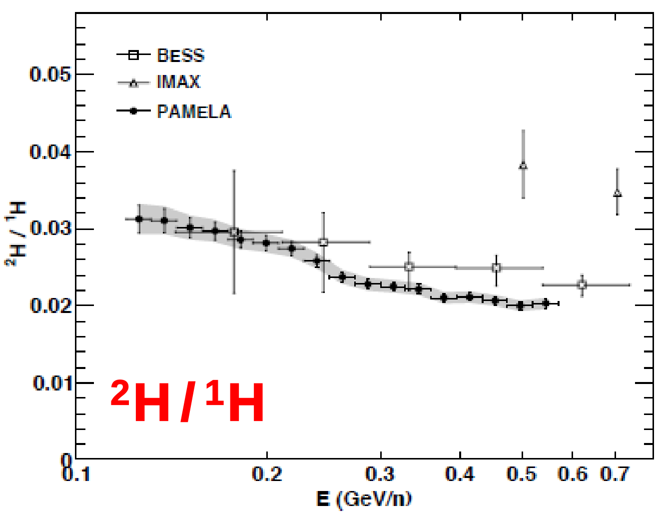


# H/He isotopes spectra & ratios

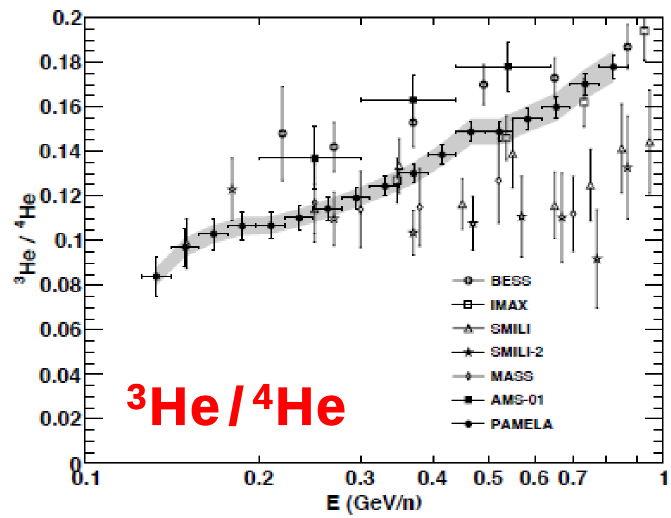


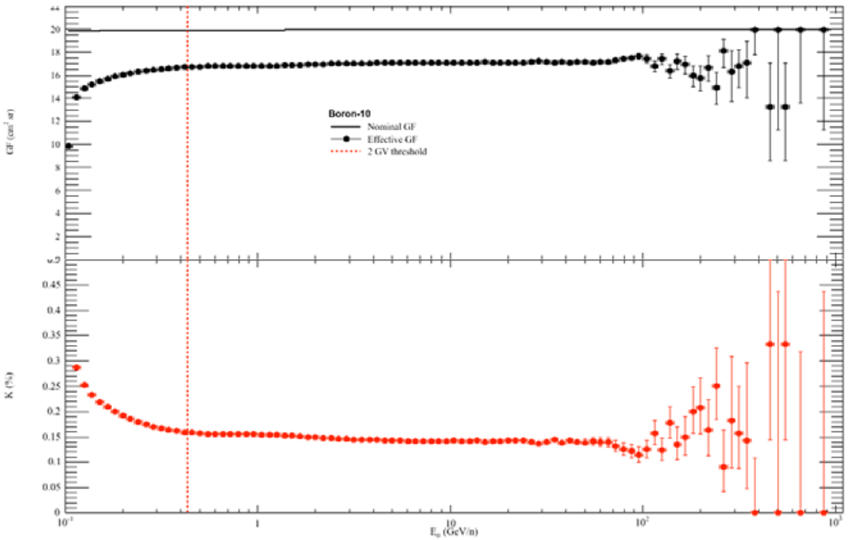

Submitted to ApJ

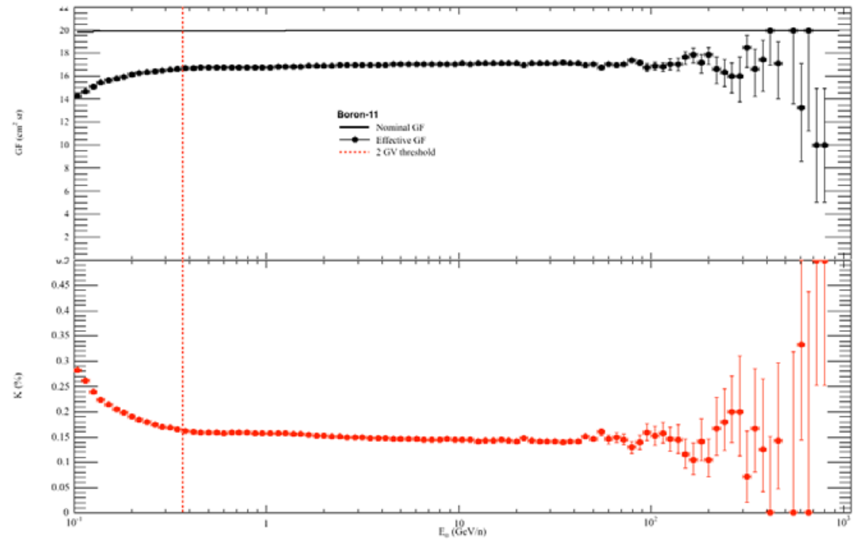


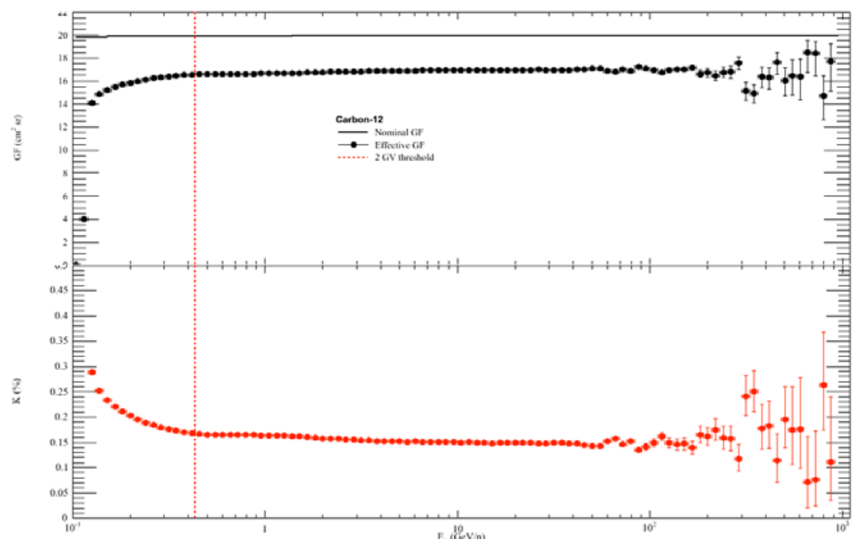
# Light nuclei measurements

(preliminary!)

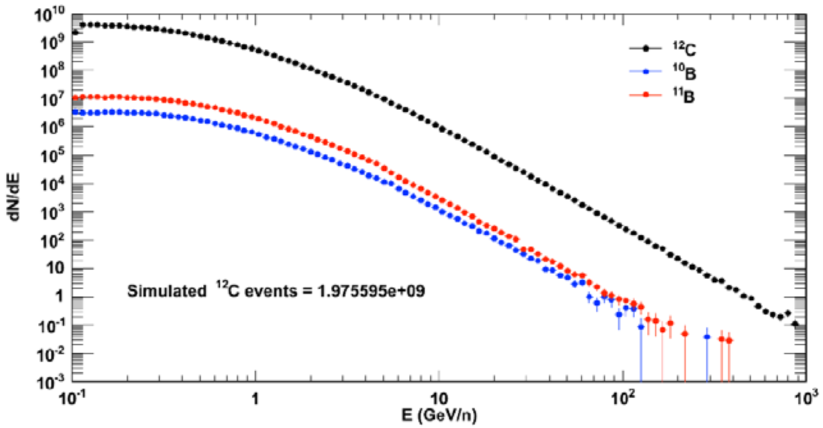
# B & C nuclei:
## geometrical factor & losses in the apparatus



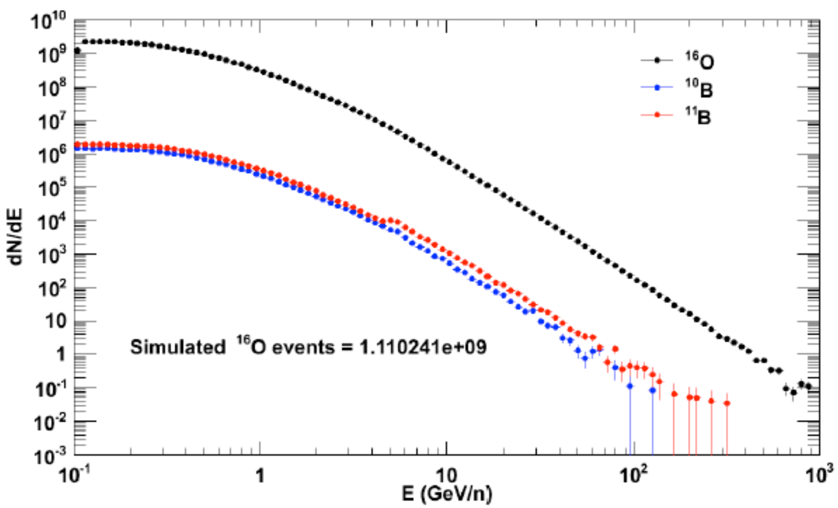



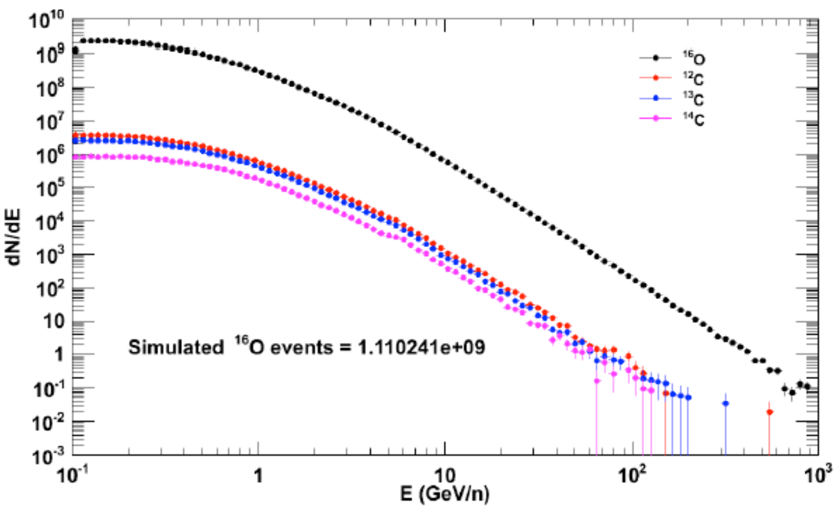



# B & C nuclei:
## contamination from C/O nuclei spallation

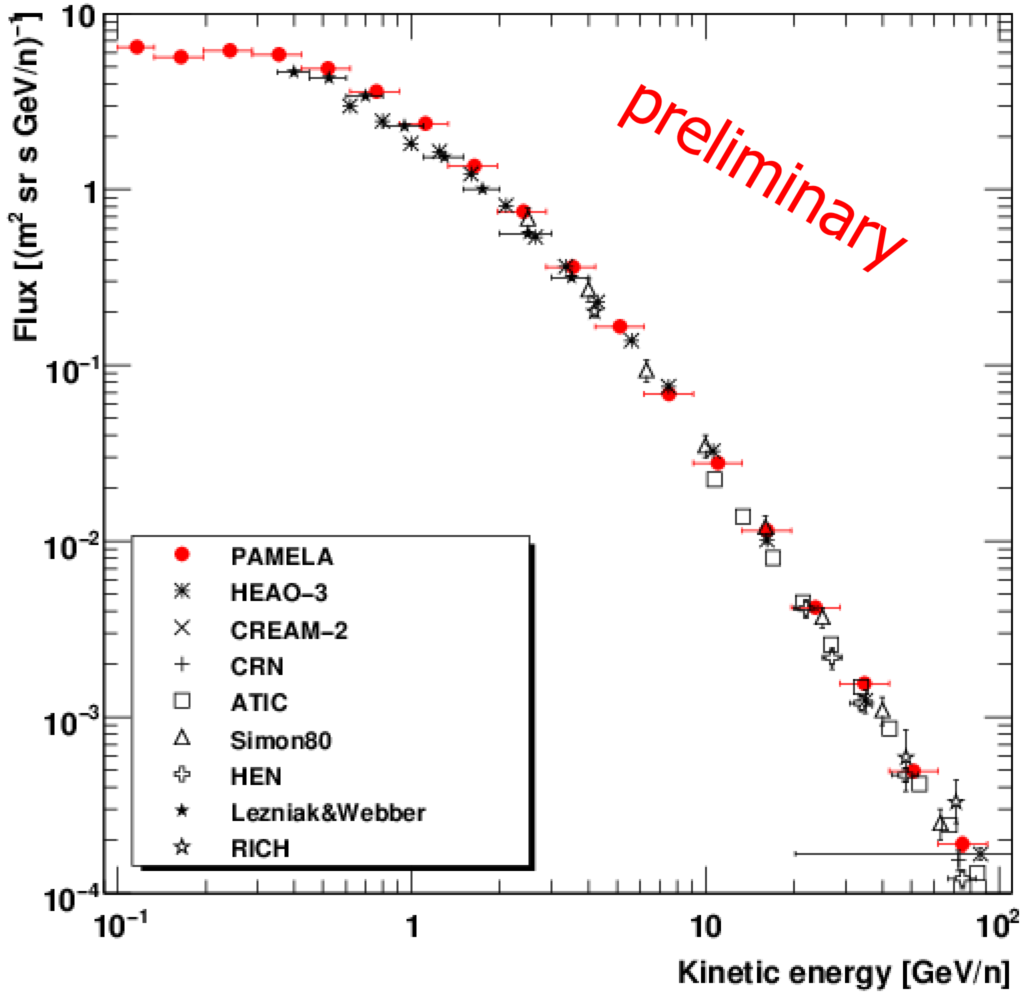



number of secondary B and C nuclei produced by incident C and O nuclei inside the apparatus



# The Carbon spectrum



# Conclusions

- PAMELA is in orbit since June 2006
  - >$10^9$ triggers registered and >25 TB of down-linked data
- Very important results in many fields of CR physics
  - indirect search for dark matter
  - search for cosmological antimatter
  - study of CR origin and propagation in the Galaxy
  - solar & magnetospheric physics
- The use of simulation tools in PAMELA analysis has been discussed
  - dedicated applications for the study of different items (interactions in the apparatus, background, ...)
  - different MC (cross-checking results)

# Thanks for your attention!