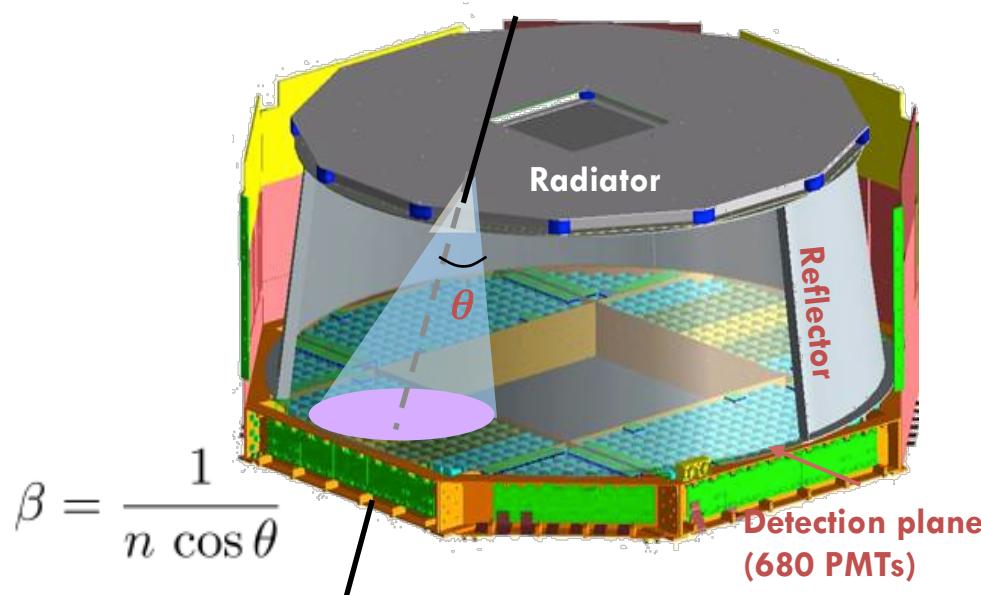


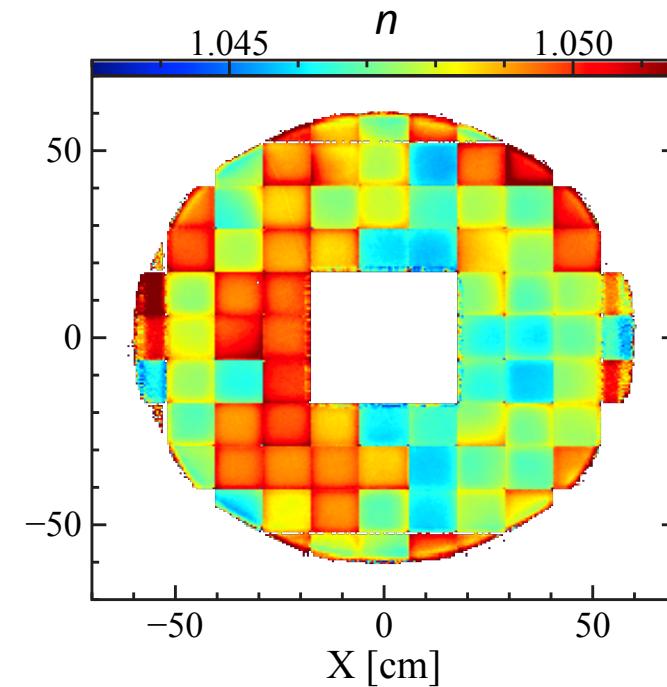
# Caractérisation des détecteurs: RICH

Reconstruction de la vitesse (taille de l'anneau) et de la charge nombre de photon dans l'anneau.



Reconstruction de l'angle cherenkov pour des protons  $R > 50\text{GV}$  ( $\beta=1$ ) → Carte de l'indice de refraction du radiateur.

→ Indice de réfraction reconstruit en chaque point de l'aérogel ( $0.5 \times 0.5 \text{ cm}^2$ )



# Analyses

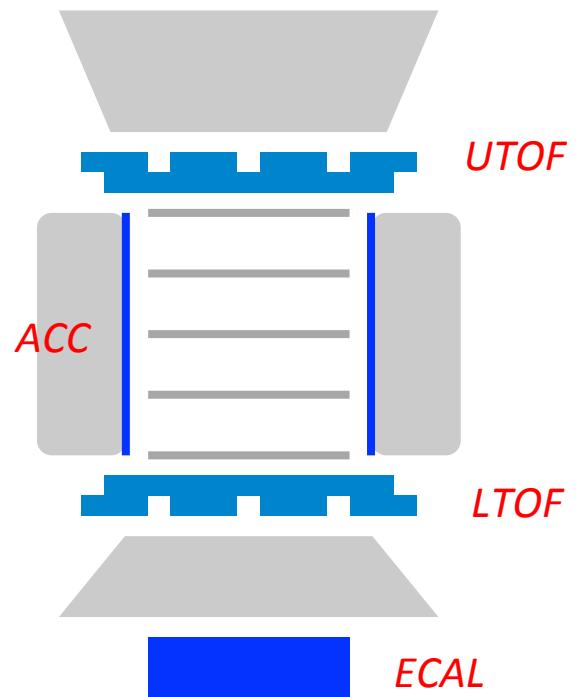
- Combinaisons des mesures associées aux sous-détecteurs pour sélectionner les différentes composantes
- Redondance des mesures dans AMS :
  - Estimation des efficacités
  - Construction de spectres de référence (templates)
  - Contrôle des systématiques
- Chaque analyse est spécifique:
  - Observable: Flux / rapport de flux
    - Ex: Flux  $e^+$ ,  $e^-$  --  $e^+/(e^++e^-)$  -- Flux  $(e^+ + e^-)$
  - Fonds dans le rayonnement cosmique
  - Fonds venant des interactions dans le détecteur
  - Mesure de l'énergie / Rigidité

# Analyses

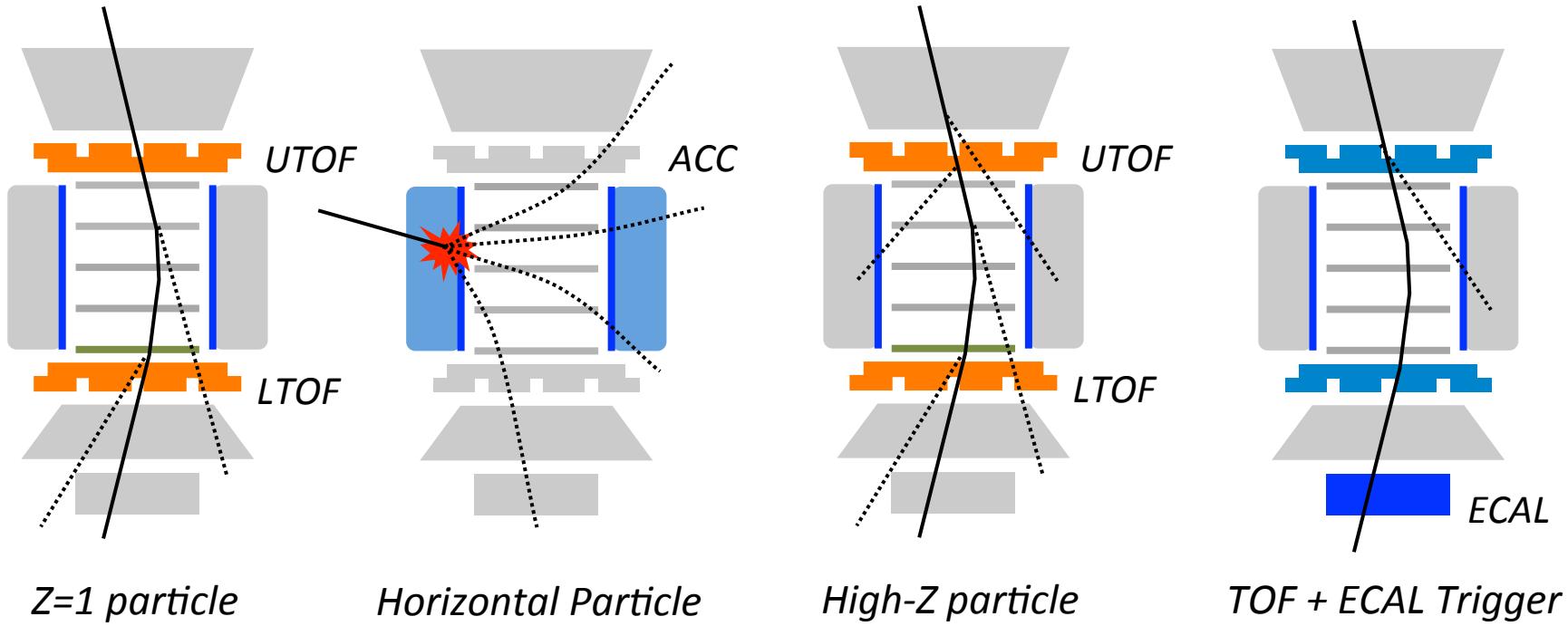
- Quelques exemples « illustratifs »:
  1. Fraction de positrons.
  2. Flux de protons.
  3. B/C
- Mais avant, important de comprendre comment est déclenché l'acquisition d'un événement...

# Trigger AMS

- Condition de déclenchement de l'acquisition
- Doit avoir la plus grande efficacité possible tout en gardant un taux < 2 kHz.
- Combinaison de l'information venant du **TOF**, de l'**ACC** et du **ECAL**.
- Trigger global = OU entre les triggers suivants :
  - « unbias » : TOF 3/4 HT, réduit d'un facteur 100  
→ efficacité proche de 100%, sans dépendance en énergie : va permettre d'estimer l'efficacité des autres triggers.
  - « proton » : TOF 4/4 HT,  $N_{acc} = 0$
  - « ion » : TOF 4/4 SHT,  $N_{acc} < 3$
  - « electron » : TOF 3/4 HT, ECAL shower
  - ...



# Trigger



**Accepted**

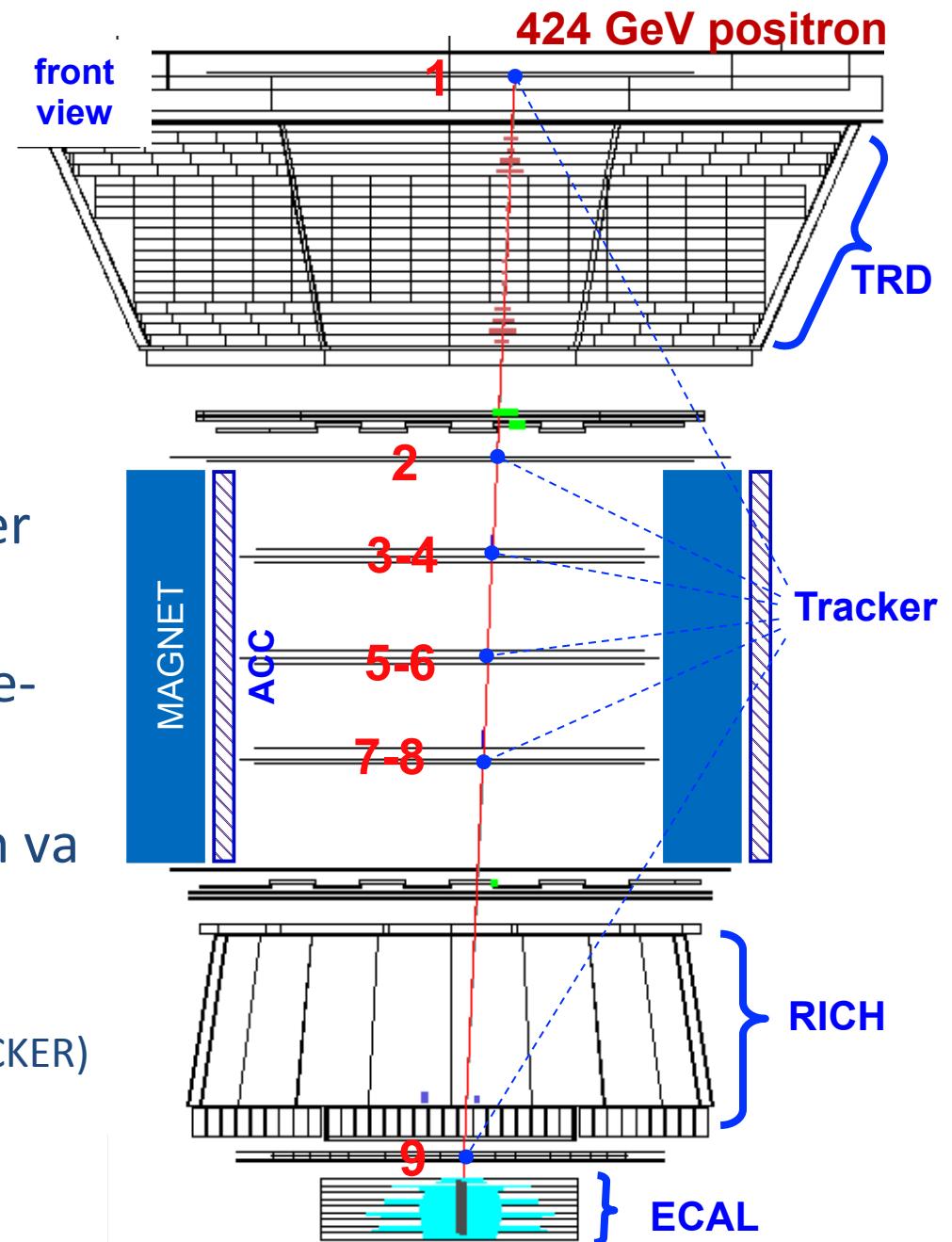
**Rejected**

**Accepted**

**Accepted**

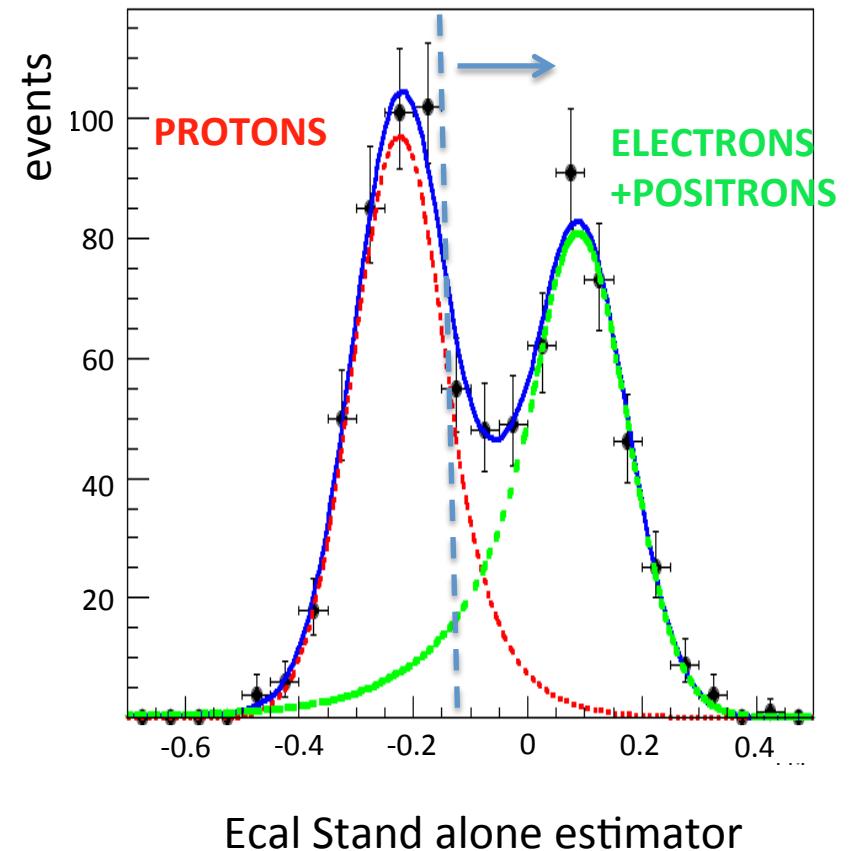
# Fraction de positron

- Mesure de l'énergie avec le calorimètre
- Mesure du signe avec le tracker sens de la courbure.
- Contamination principales: p, e- ( « spill-over », interaction)
- 3 principales variables que l'on va utiliser:
  - TRD: Likelihood (e/p)
  - E/P: Energie (ECAL)/Impulsion (TRACKER)
  - ECAL: Forme de la gerbe



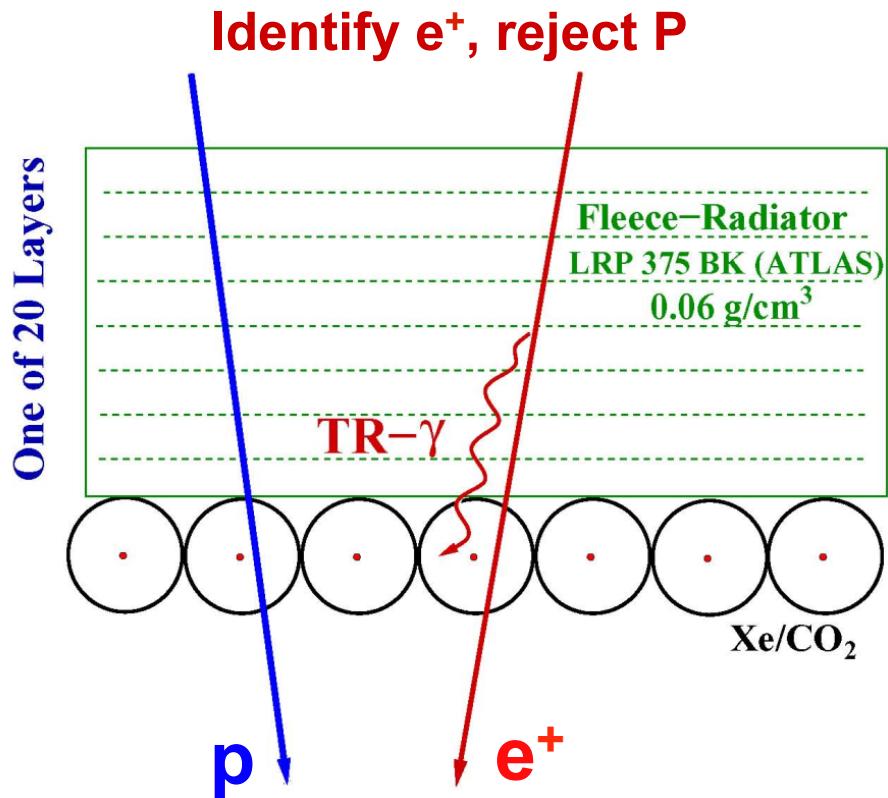
# Analyse Fraction de positron

- Méthode de comptage des  $e^-$  et  $e^+$  dans chaque bin en énergie :
  - Coupure (1D, 2D)
  - Fit de spectres de référence (1D, 2D)
- Mesure limitée statistiquement: optimisation de la méthode critique.
- 3 variables : beaucoup de combinaisons possibles
  - Présélection avec ECAL et E/P, fit 1D de TRD.
  - Présélection avec TRD et E/P, fit 1D de ECAL.
  - Présélection avec ECAL, fit 2D TRD E/P.
  - ...



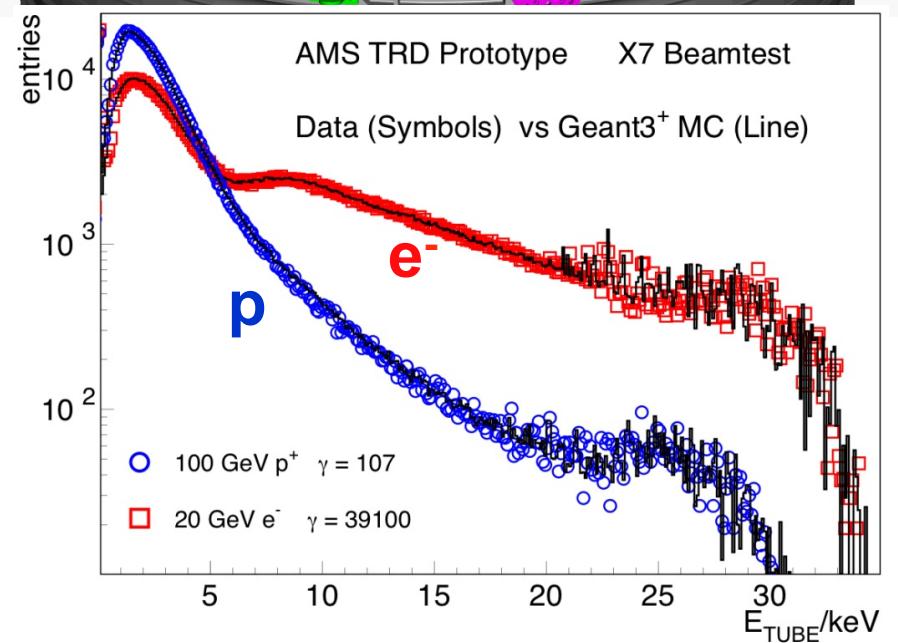
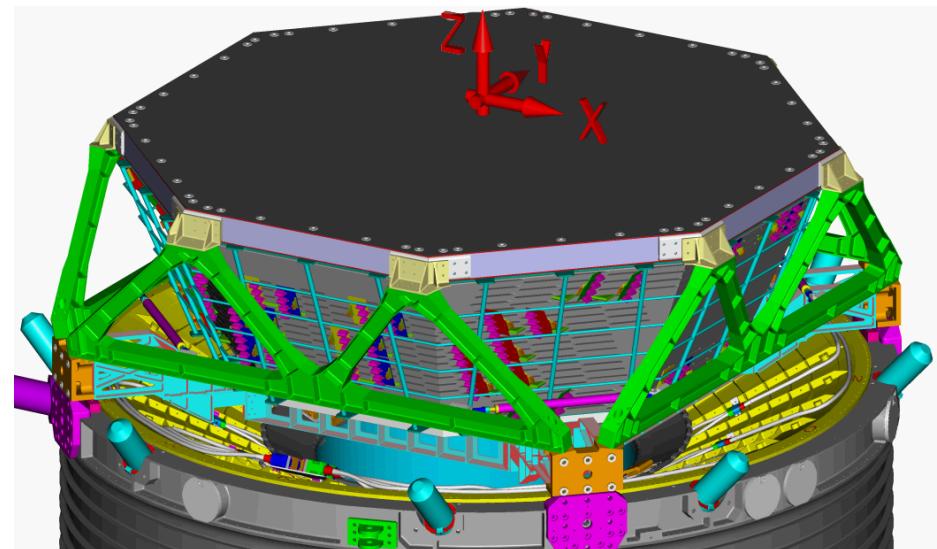


# Transition Radiation Detector.



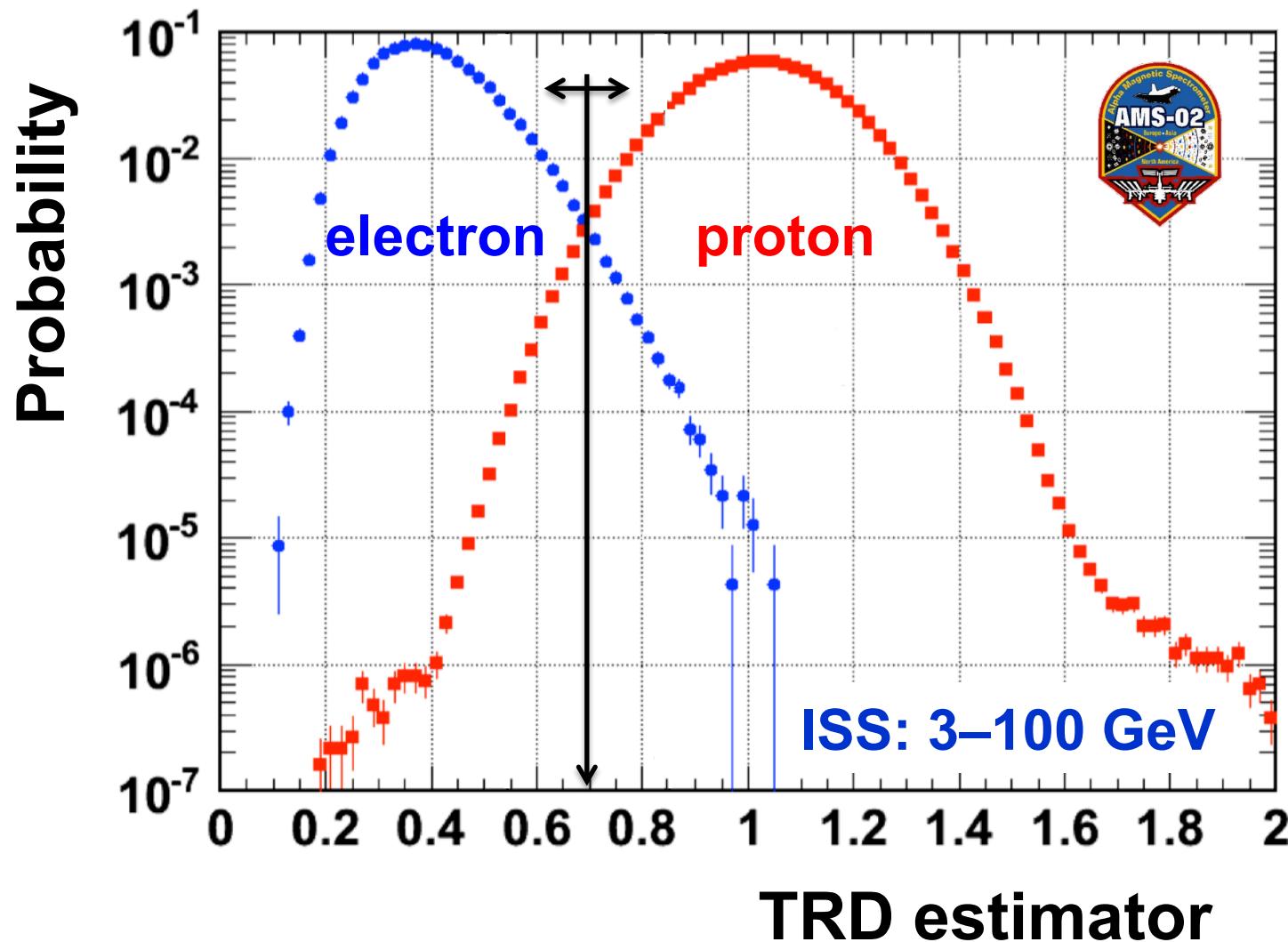
Leak rate:  $\text{CO}_2 \approx 5 \mu\text{g/s}$

Storage: 5 kg, >20 years lifetime



# TRD performance on ISS

$$\text{TRD estimator} = -\ln(P_e/(P_e+P_p))$$



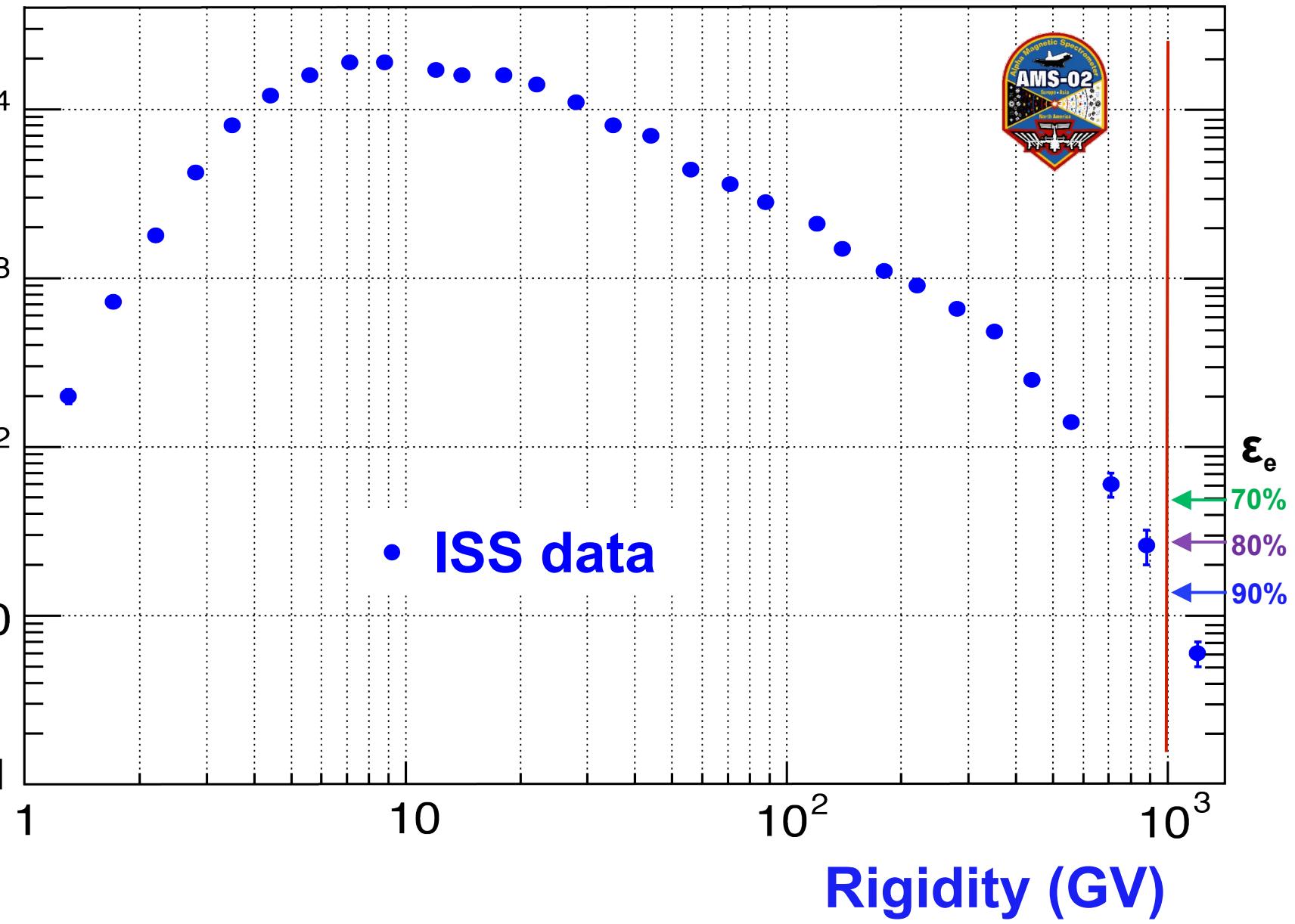
Normalized probabilities  $P_e$  and  $P_p$

$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)}$$

$$P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

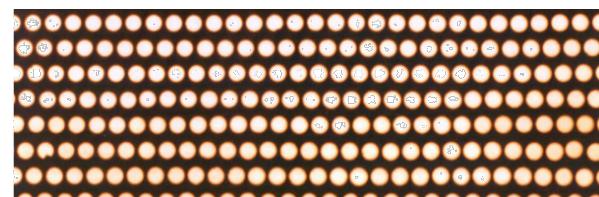
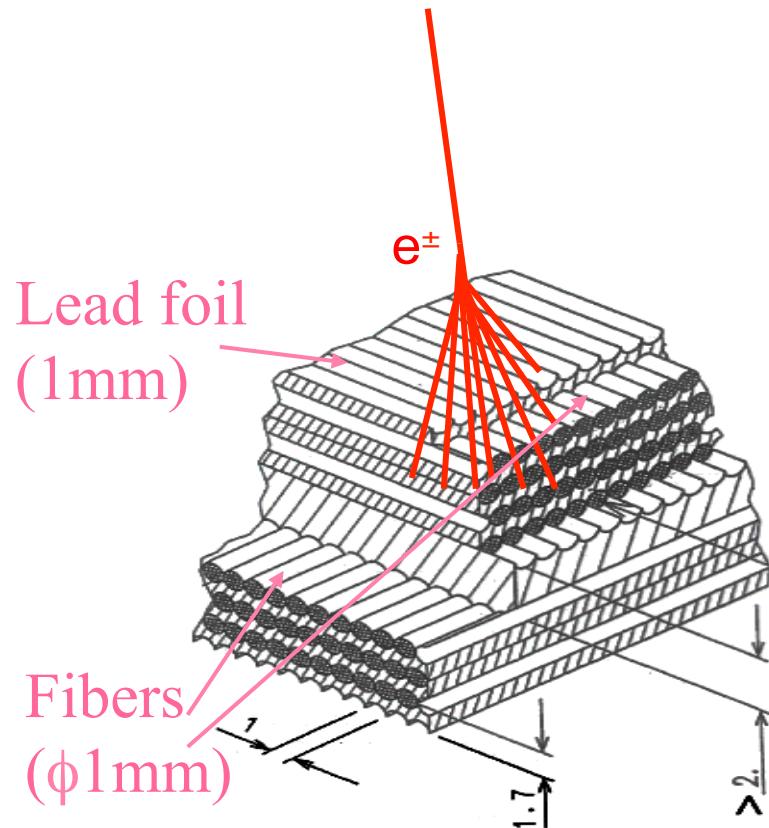
# Proton rejection at 90% $e^+$ efficiency

## TRD performance on ISS

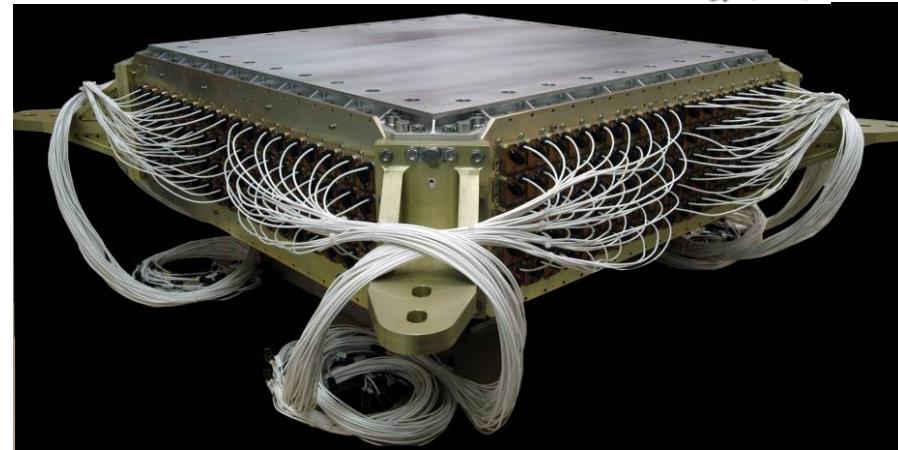
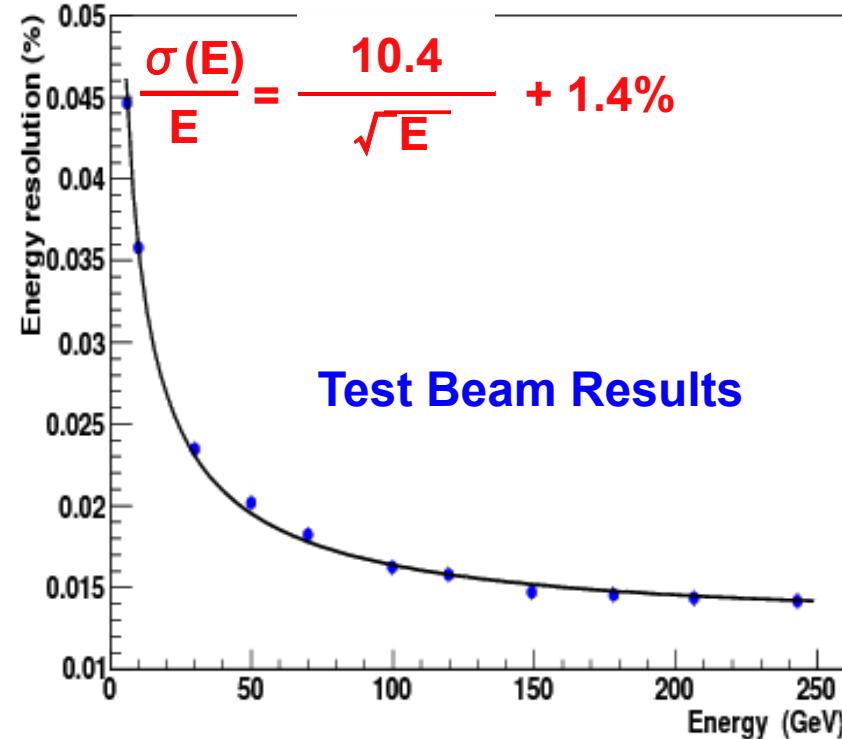


# Electromagnetic Calorimeter

A precision,  $17 X_0$ , TeV, 3D measurement of the directions and energies of light rays and electrons



50 000 fibers,  $\phi = 1\text{ mm}$   
distributed uniformly  
Inside 1,200 lb of lead



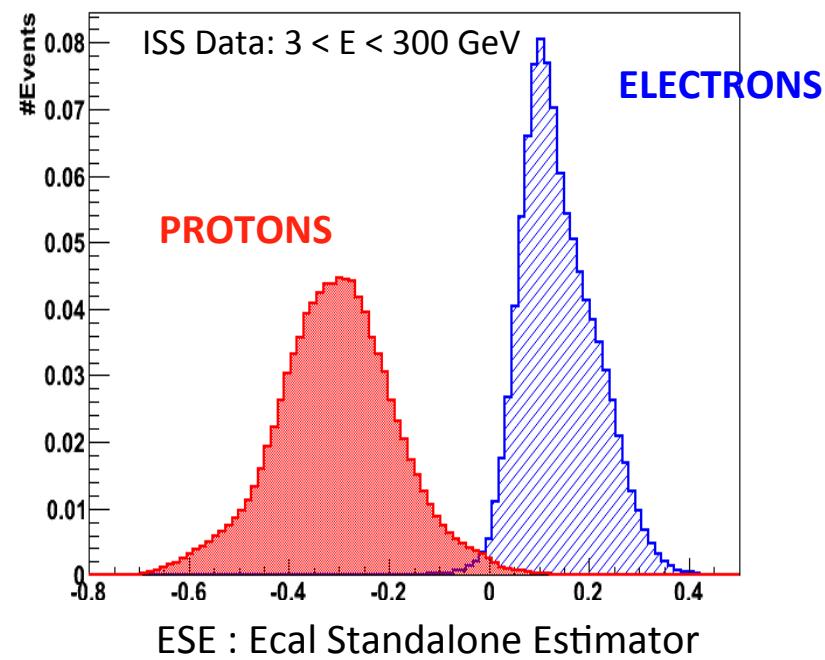
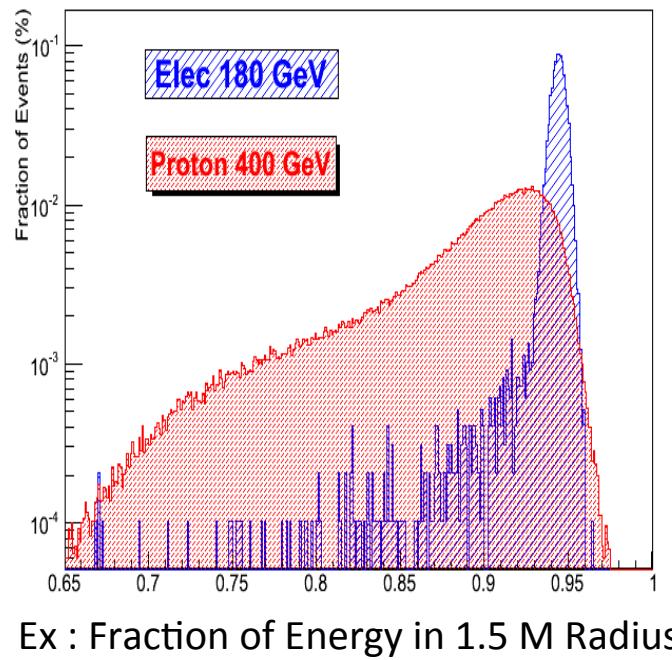
# Tool development: ECAL estimator

→ Use fine granularity of ECAL to discriminate e/p showers.

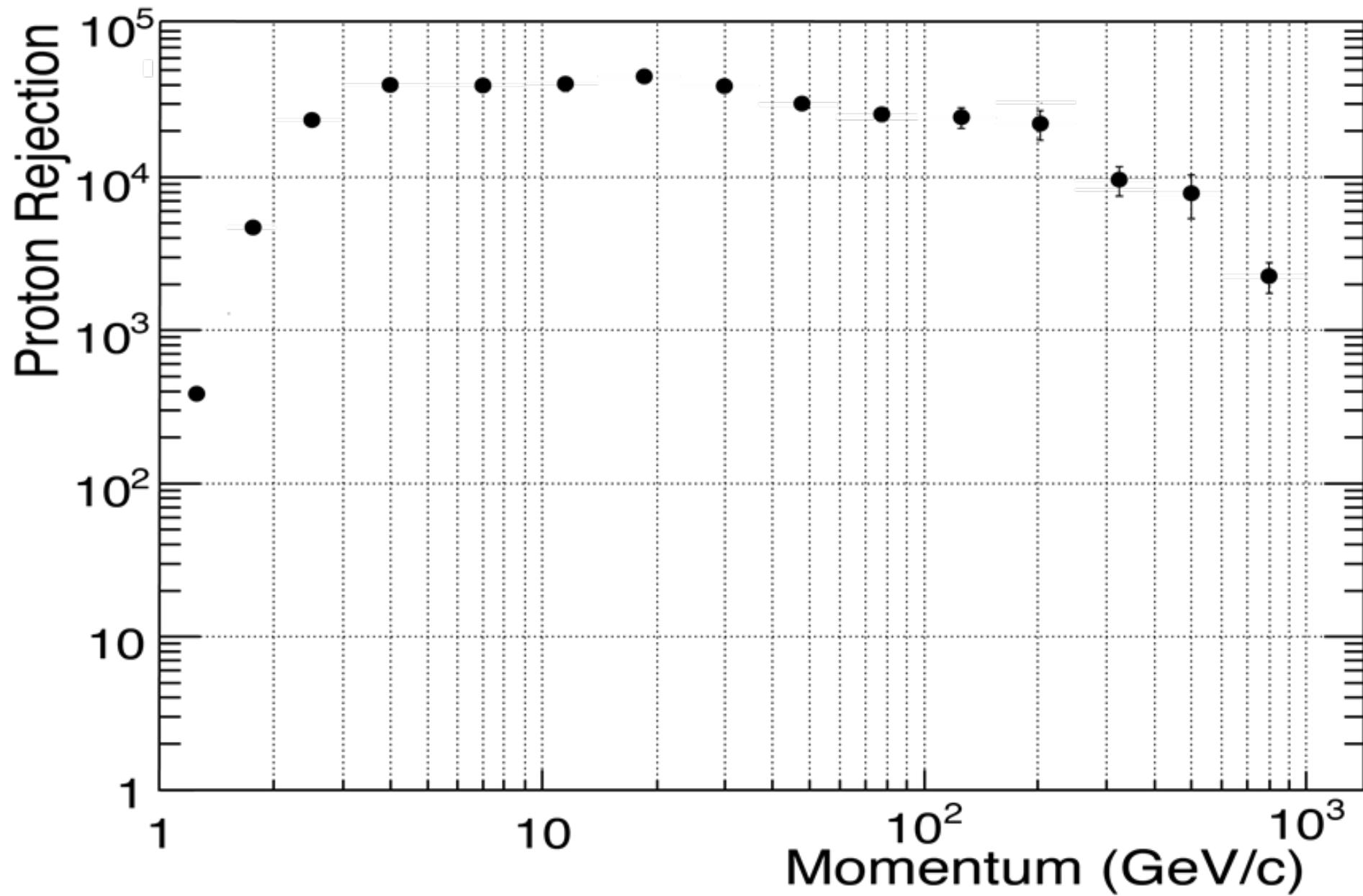
Identification of discriminant variables  
based on the shower 3D shape properties



- Combination of discriminant variables with a multivariate tool (BDT) → Ecal Standalone Estimator
- Training based on ISS data  $e^-$  and p tagged with TRD to achieve best separation



# Data from ISS: Proton rejection using the ECAL



## Tracker

A track in the Tracker containing at least one hit in planes 1 or 2 or 9 and hits in planes (3 or 4), (5 or 6) and (7 or 8). In addition, the projected track must pass within 3 cm in x and 10 cm in y of the center of gravity of the ECAL shower.

Primary particles, above  $1.2 \times \text{geomag. cutoff}$

The relative error on the curvature (inverse of the rigidity) value from the track fit is less than 50 %, which ensures that tracks have rigidities well below their Maximum Detectable Rigidity.

## DAQ

The detector livetime exceeded 50 %, which excludes, for example, the South Atlantic Anomaly.

## TOF

The particle velocity measured by TOF  $\beta > 0.8$ .

The value of the absolute charge is required to be between 0.8 and 1.4.

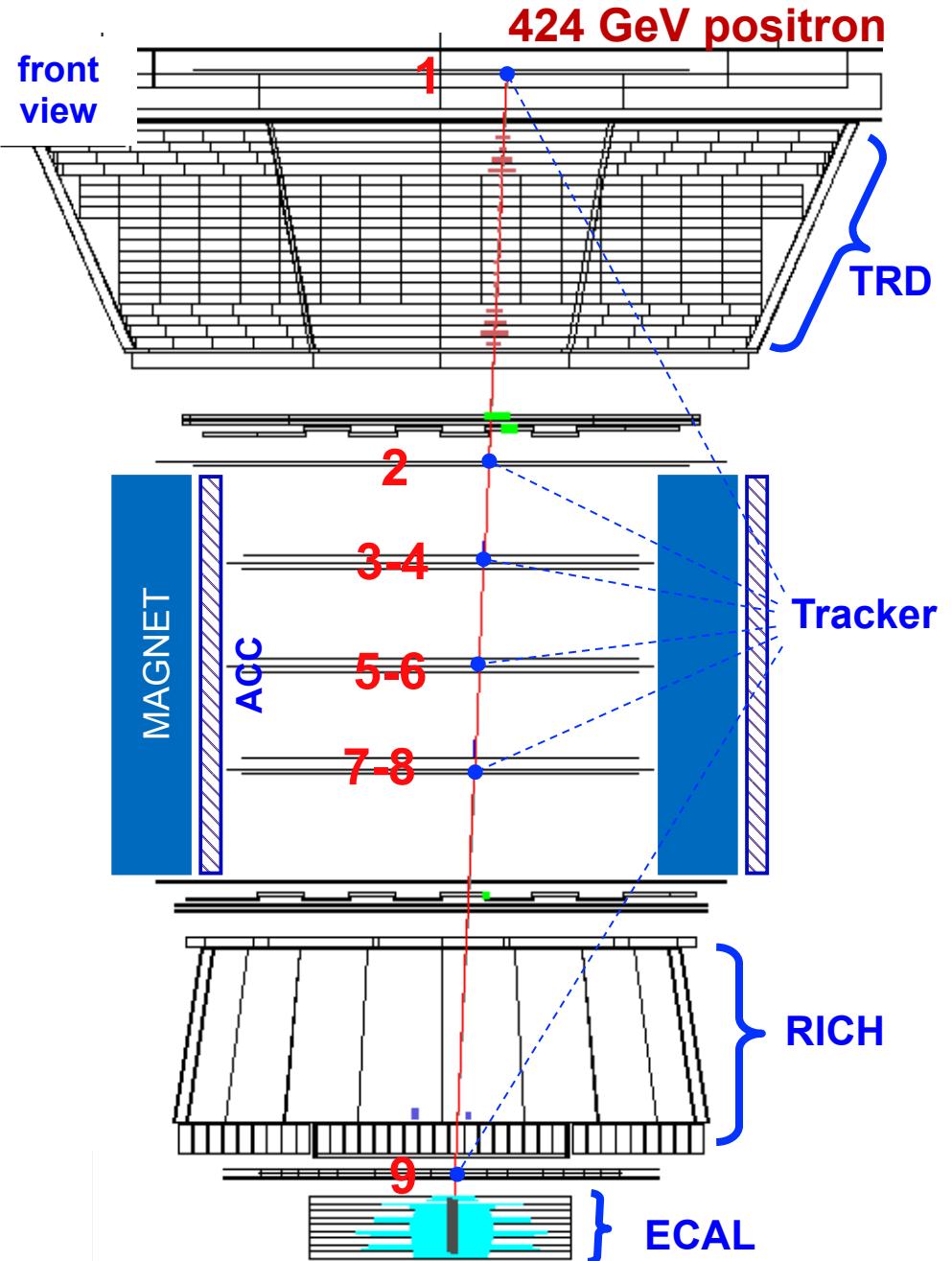
## TRD

At least 15 TRD hits on the Tracker track traced through the TRD.

## ECAL

A shower axis within the ECAL fiducial volume.  
The ECAL shower has electromagnetic shape

## Event selection.

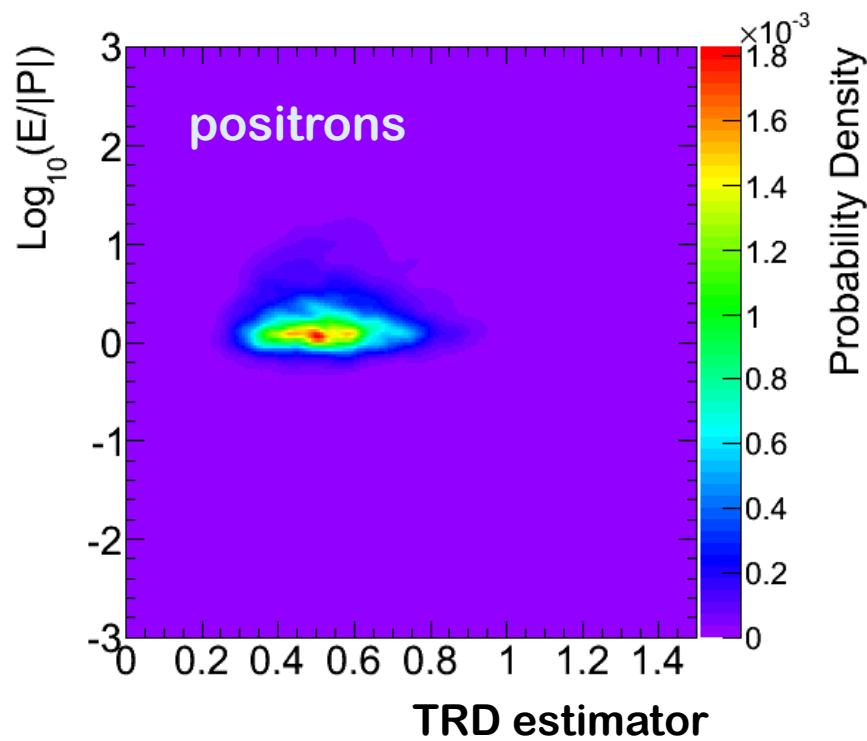
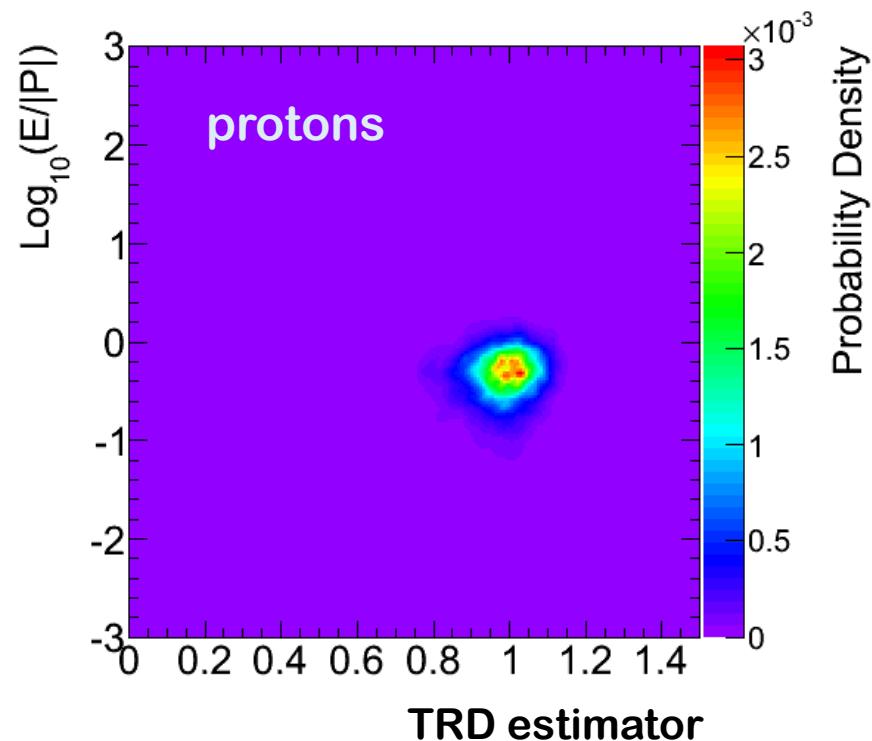


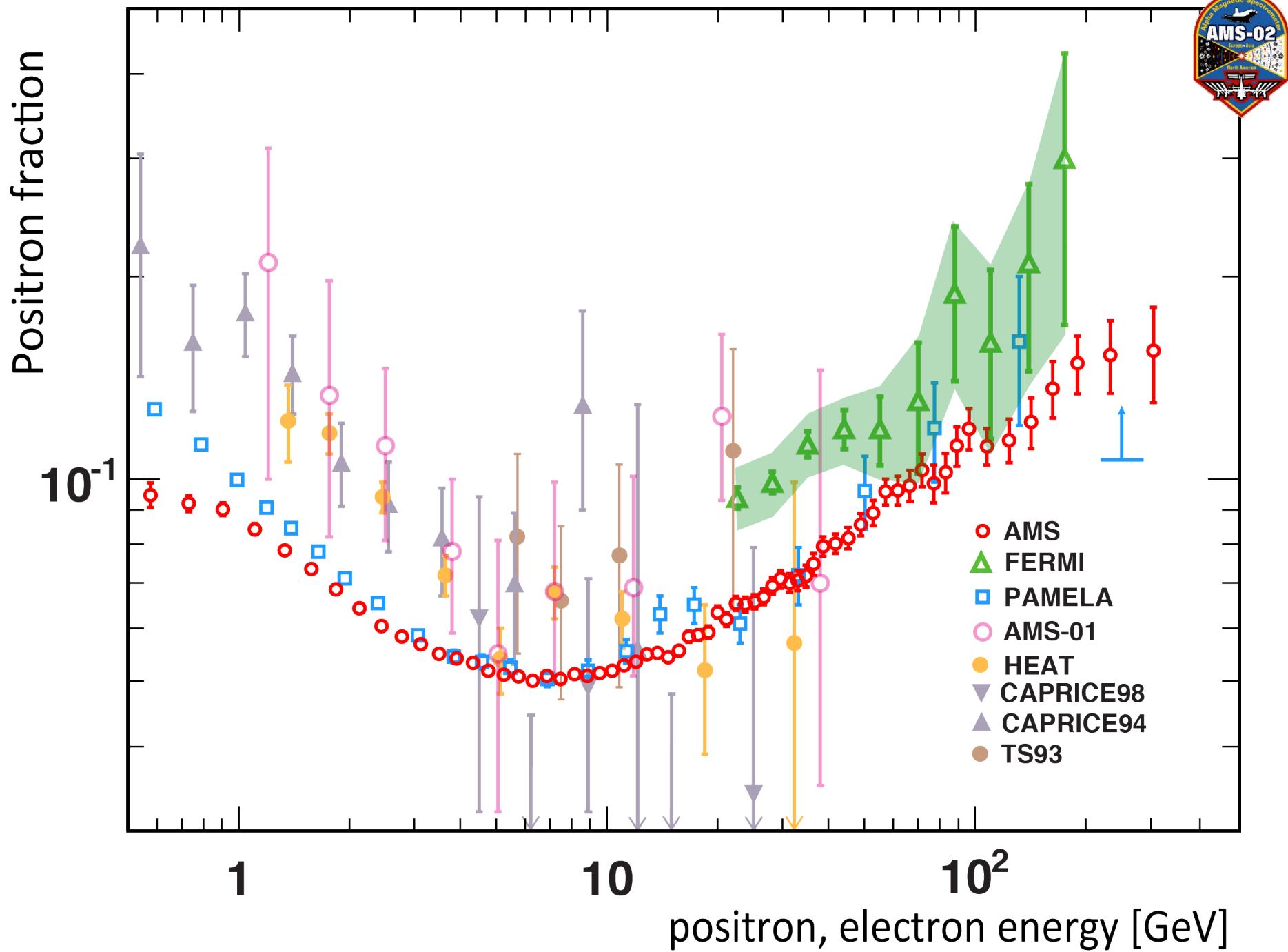


# Analysis: 2D fit to measure $\text{Ne}^+$ and $\text{Np}$

2D reference spectra for the signal and the background are fitted to data in the [TRD estimator-  $\log(\text{E}/|\text{P}|)$ ] plane.

The method combines redundant information from TRD, ECAL, and Tracker; and provides much better statistical accuracy compared to cut-based analysis.





# Reconstruction du flux de Proton

- Composante dominante du RC :
  - Pas de contamination
  - Pas limité par la statistique
    - Mesure de grande précision
    - Contrôle des systématiques grâce à la redondance des détecteurs
- Mesure de la Rigidité à l'aide du tracker  MC
- Reconstruction d'un flux :
  - Temps d'exposition / Lifetime
  - Acceptance du détecteur / efficacité des coupures  MC
  - Efficacité du Trigger

# Notion d'acceptance

Flux de particules  $[(\text{m}^2\text{sr s GeV})^{-1}]$ :

$$\phi(E) = \frac{dN}{d\Omega dS dt dE}$$

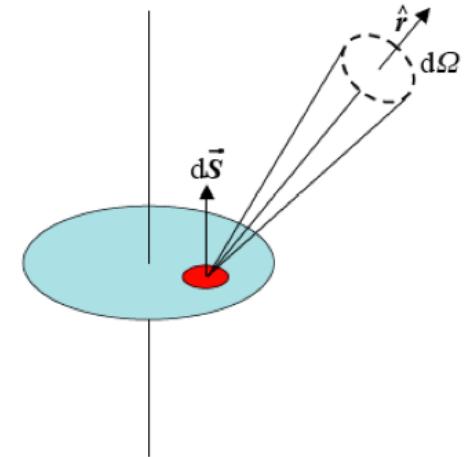
En pratique, dans un bin en énergie, on détecte :

$$N(E) = \int_S \int_\Omega \int_t \int_{E - \frac{\Delta E}{2}}^{E + \frac{\Delta E}{2}} \phi(E') \epsilon(E', x, y, \theta, \phi) d\vec{\Omega} \cdot d\vec{S} dt dE'$$

Flux stable, isotrope :

$$N(E) = T \phi(E) \Delta E \int_S \int_\Omega \epsilon(E, x, y, \theta, \phi) d\vec{\Omega} \cdot d\vec{S}$$

$\text{Acc}(E)$  : Acceptance  $[\text{m}^2\text{sr}]$



# Notion d'acceptance

Pour un télescope simple avec  $\varepsilon = 1$ :

$$Acc(E) = \int_{S_2} \int_{\Omega_2} d\vec{\Omega}.d\vec{S}$$

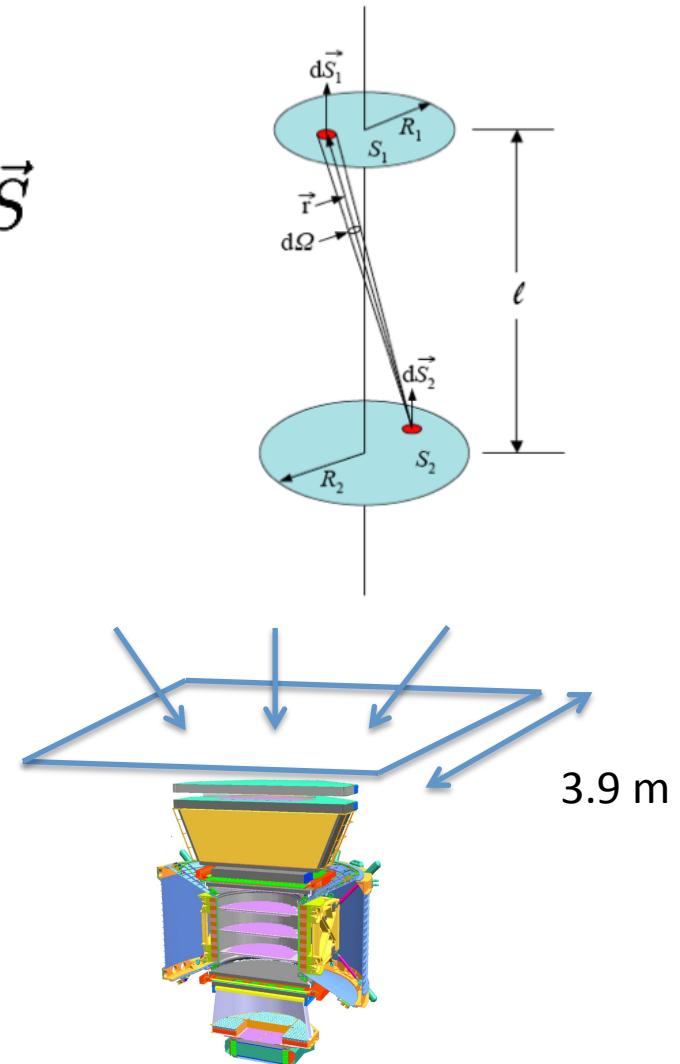
$$Acc(E) \approx \frac{S_1 S_2}{l^2}$$

En pratique, estimation MC (GEANT4) :

$$Acc(E) = Acc_{gen} \frac{N_{sel}}{N_{gen}}$$

Où:

$$Acc_{gen} = \pi \cdot 3.9^2 \text{ m}^2 \text{sr}$$



# Proton flux analysis in AMS-02

$$F(R) = \frac{N_{\text{obs.}}(R)}{T_{\text{exp.}}(R) A_{\text{eff.}}(R) \varepsilon_{\text{trig.}}(R) dR} \quad (\text{For isotropic flux with } \theta_{\text{zen}} < 20^\circ)$$

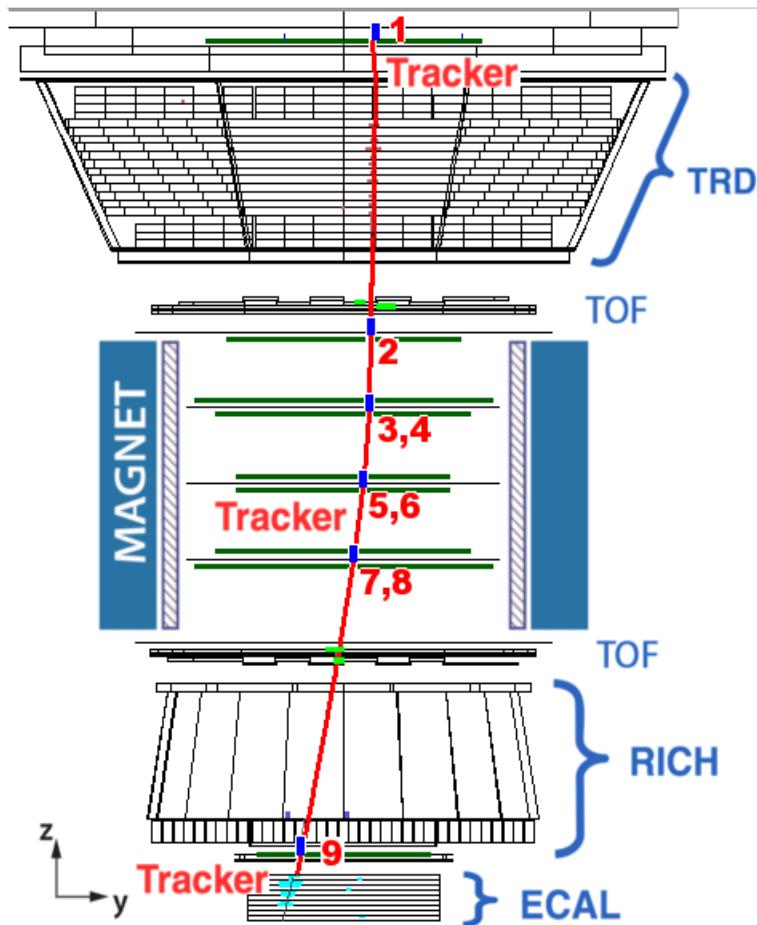
- $F$  : Absolute differential flux ( $\text{m}^{-2}\text{sr}^{-1}\text{s}^{-1}\text{GV}^{-1}$ )
- $R$  : Measured rigidity (GV)
- $N_{\text{obs.}}$  : Number of events after proton selection
- $T_{\text{exp.}}$  : Exposure life time (s)
- $A_{\text{eff.}}$  : Effective acceptance ( $\text{m}^2 \text{ sr}$ )
- $\varepsilon_{\text{trig.}}$  : Trigger efficiency
- $dR$  : Rigidity bin (GV)

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# Rigidity measurement

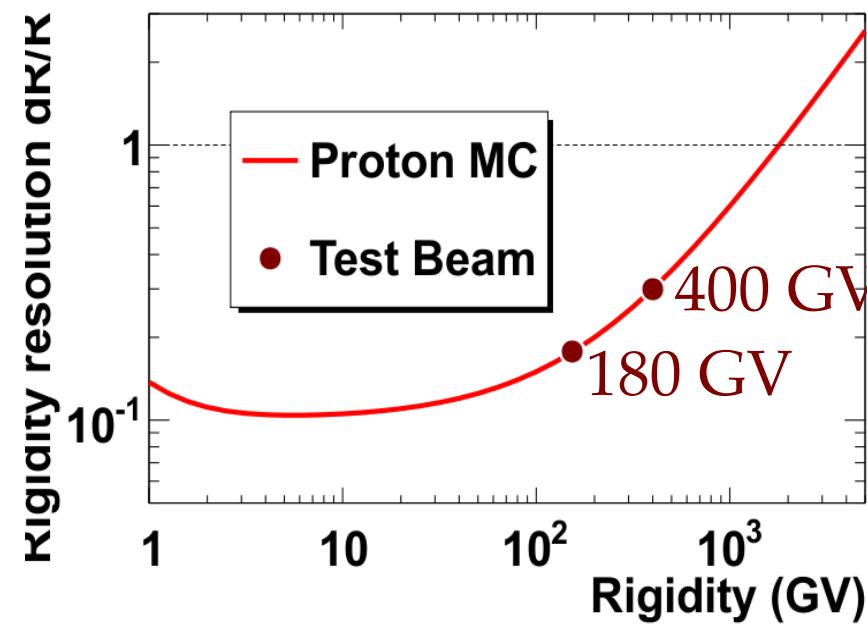


$$B_x = \sim 0.14 \text{ T}$$

$$L = \sim 3\text{m}$$

$$\sigma_y = \sim 10\mu\text{m}$$

MDR :  $\sim 2\text{TV}$



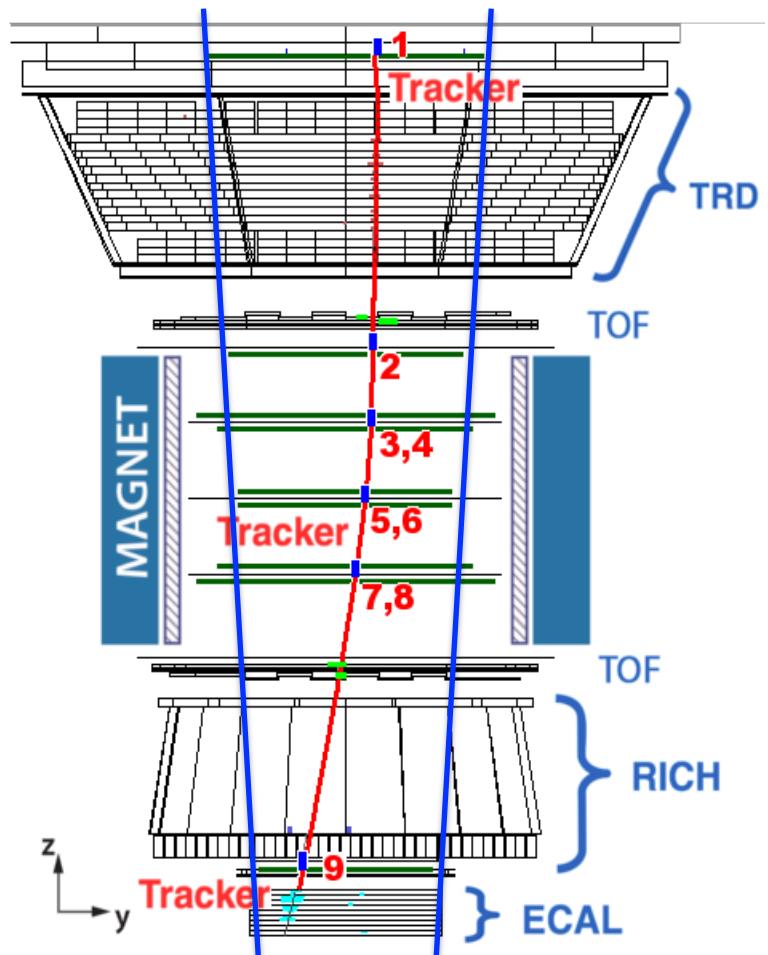
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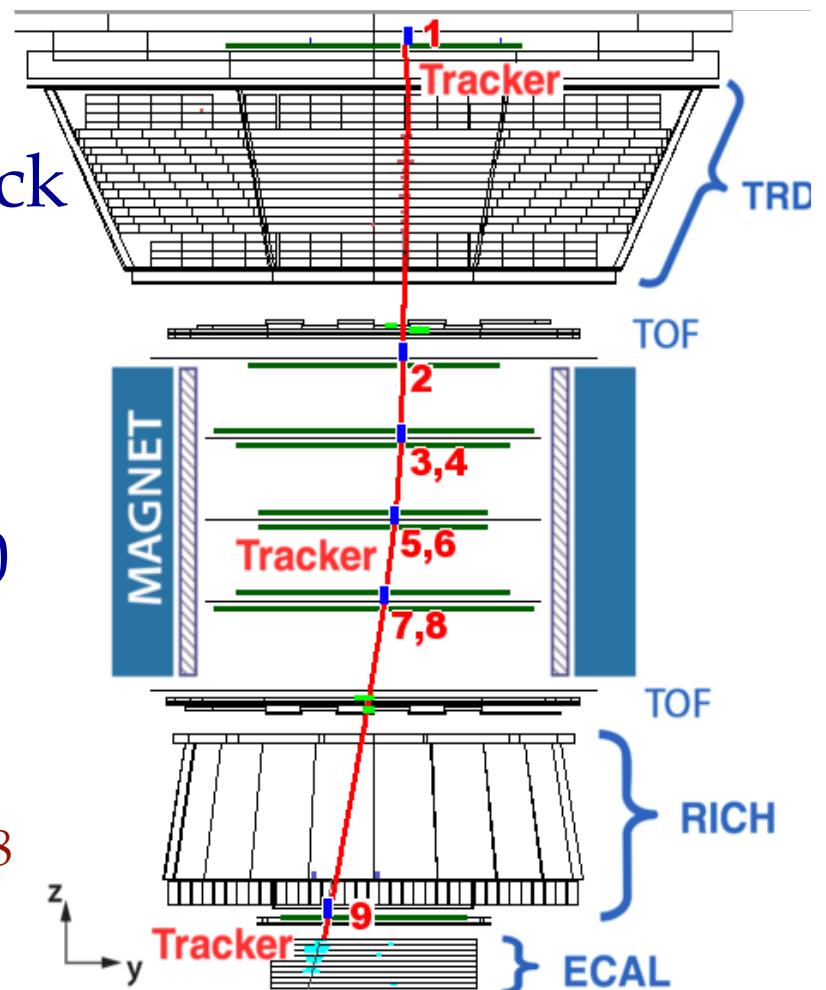
# Pre selection

- Velocity measured by at least 3 TOF counters (out of 4)
- TOF track pass both Tracker L1 and L9



# Full span track selection

- Events with at least one track with measured hit points both in Layer 1 and 9
- Normalized  $\chi^2$  of the track fitting :  $\chi^2 < 10$
- Final selected events :  
 $N_{\text{obs.}}(R > 1 \text{ GV}) = 3.03 \times 10^8$



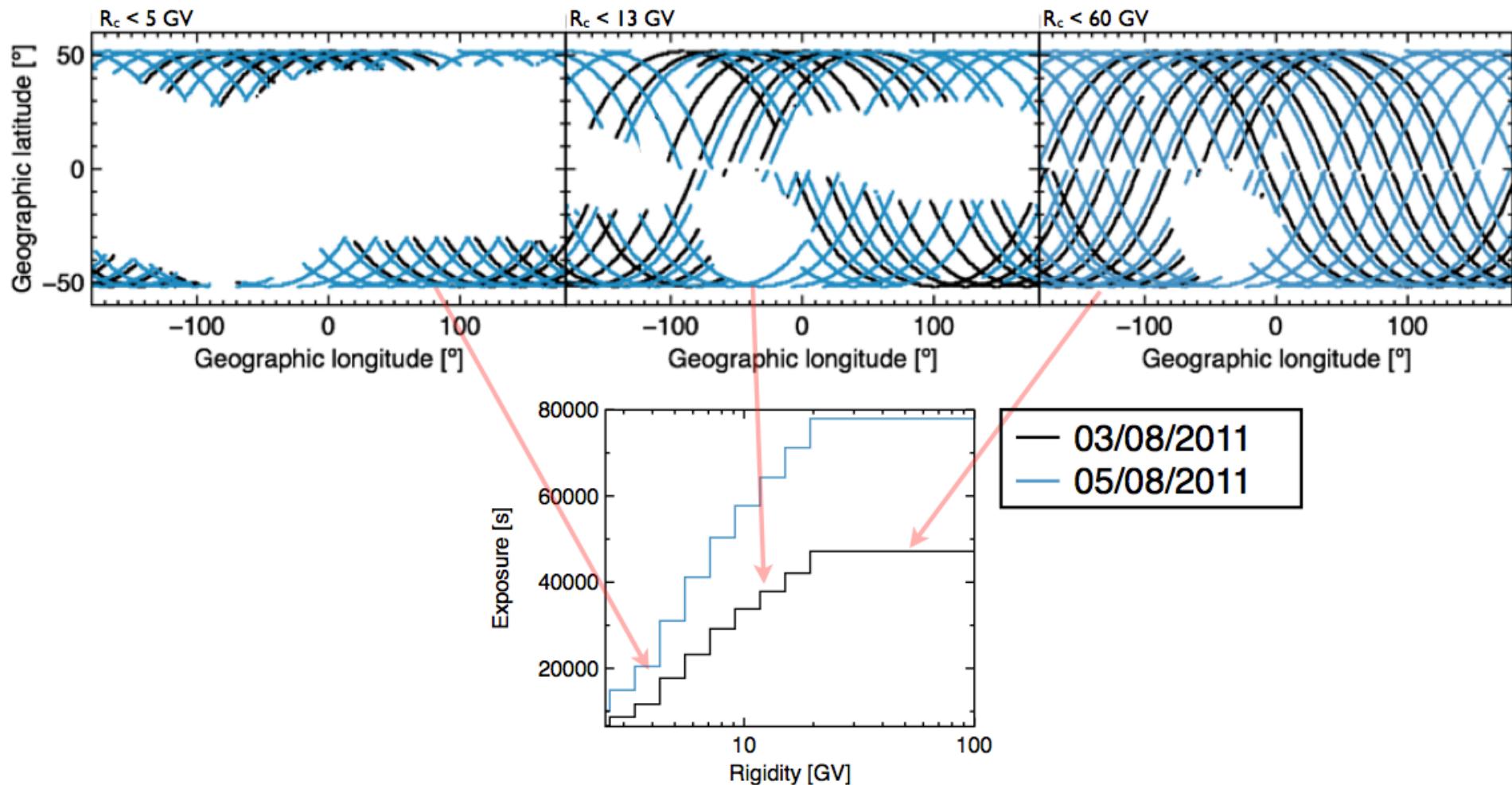
# Proton flux analysis in AMS-02

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- $\varepsilon_{\text{trig.}}$  : Trigger efficiency
- $dR$  : Rigidity bin (GV)

# Temps d'exposition

Rigidité dépendant : le temps d'exposition pour une rigidité  $R$  correspond au temps pendant lequel le détecteur est en une position où la rigidité de coupure géomagnétique est  $< R$ :



## Data period

Data taken from : 19 May 2011  
to : 19 May 2013 (2 years)

- Total exposure time :

$$T_{\text{exp.}} (R > 25 \text{ GV}) = 51.2 \times 10^6 \text{ sec}$$

- Average live time fraction :

$$T_{\text{exp.}} / 2 \text{ years} = 81.6 \%$$

# Proton flux analysis in AMS-02

$$F(R) = \frac{N_{\text{obs.}}(R)}{T_{\text{exp.}}(R) A_{\text{eff.}}(R) \varepsilon_{\text{trig.}}(R) dR}$$

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- $\varepsilon_{\text{trig.}}$  : Trigger efficiency
- $dR$  : Rigidity bin (GV)

# Acceptance

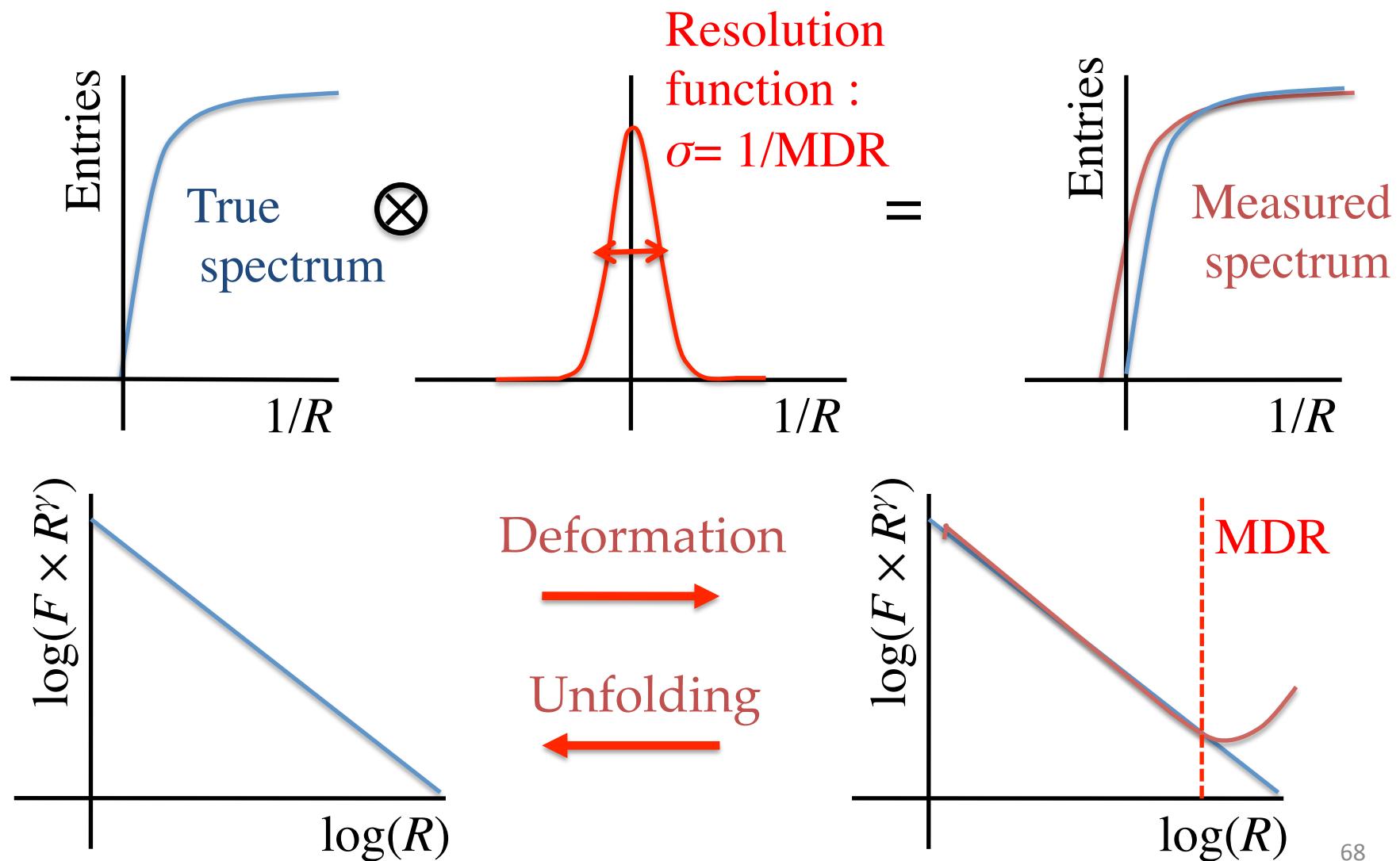
- Estimated with MC (Geant 4)

$$A_{\text{eff.}}(R) = A_{\text{generated}} \times \frac{N_{\text{passed-preselection}}(R)}{N_{\text{generated}}(R)}$$

where  $A_{\text{generated}} = \pi \times 3.9 \times 3.9 \text{ m}^2\text{sr}$

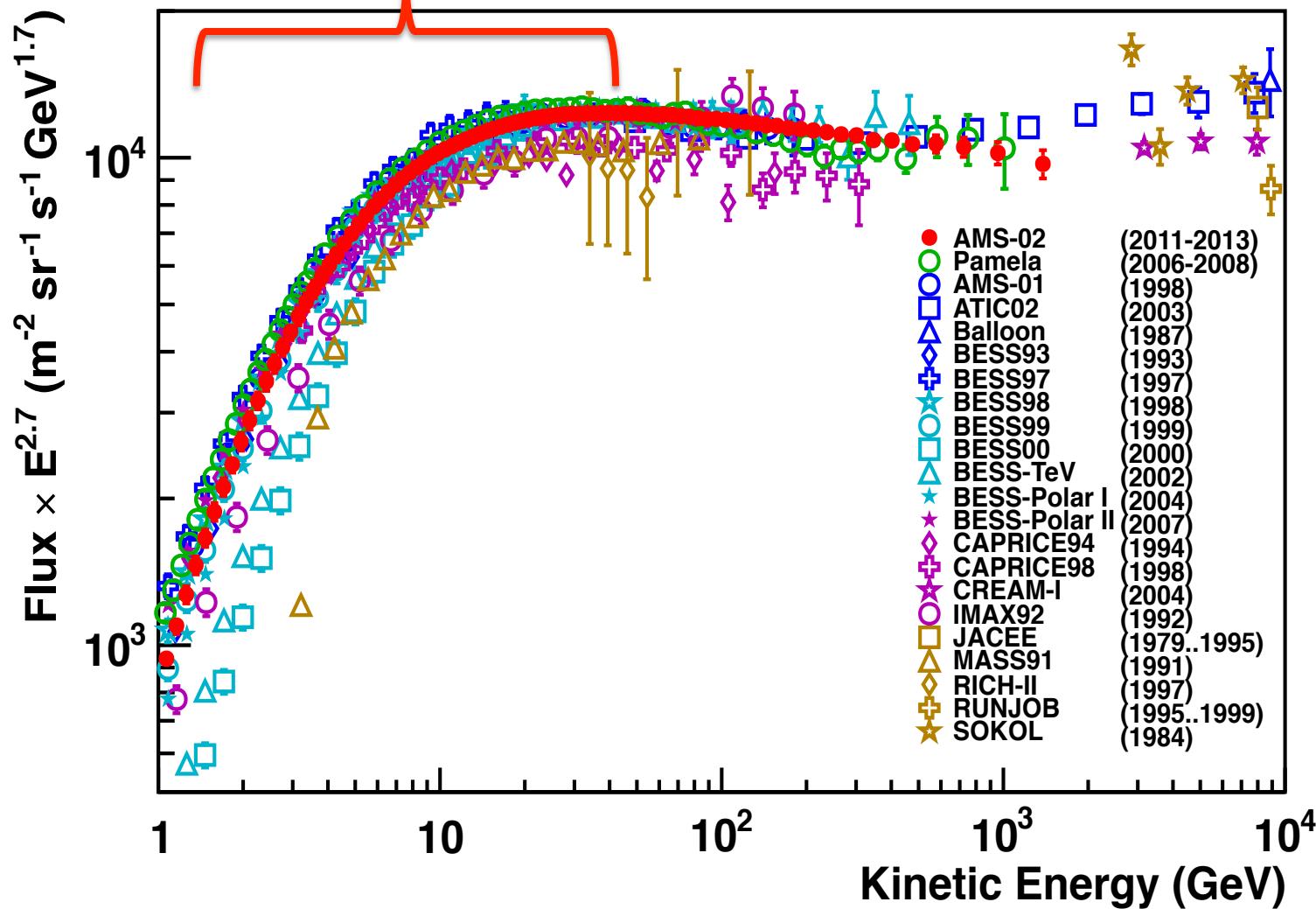
- Constant for  $R > 10 \text{ GV}$
- Systematic error :  $\pm 2.8 \%$   
due to the uncertainty of energy dependence of  
the hadronic interaction probability

# Spectrum unfolding



# Features (1)

$R < 20$  GV : Daily variation by solar activity



# Cosmic ray modulation

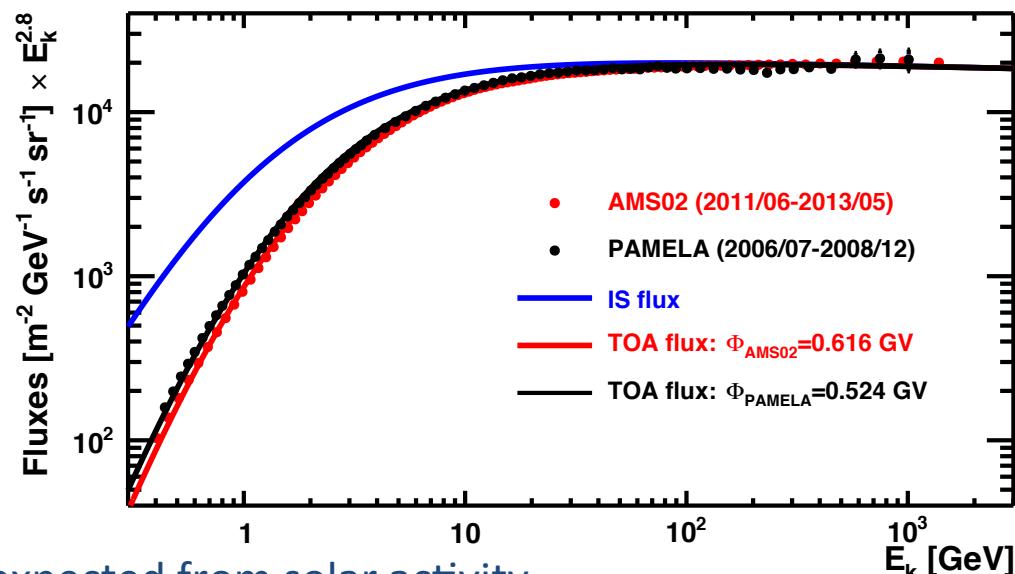
- Simplest model for Solar Modulation: Force-Field

$$J(E, t) = \frac{E^2 - M^2}{(E + \Phi(t))^2 - M^2} J^{IS}(E + \Phi(t))$$

Where  $\Phi(t)$  is the modulation parameter  
→ all time dependence contained in  $\Phi(t)$

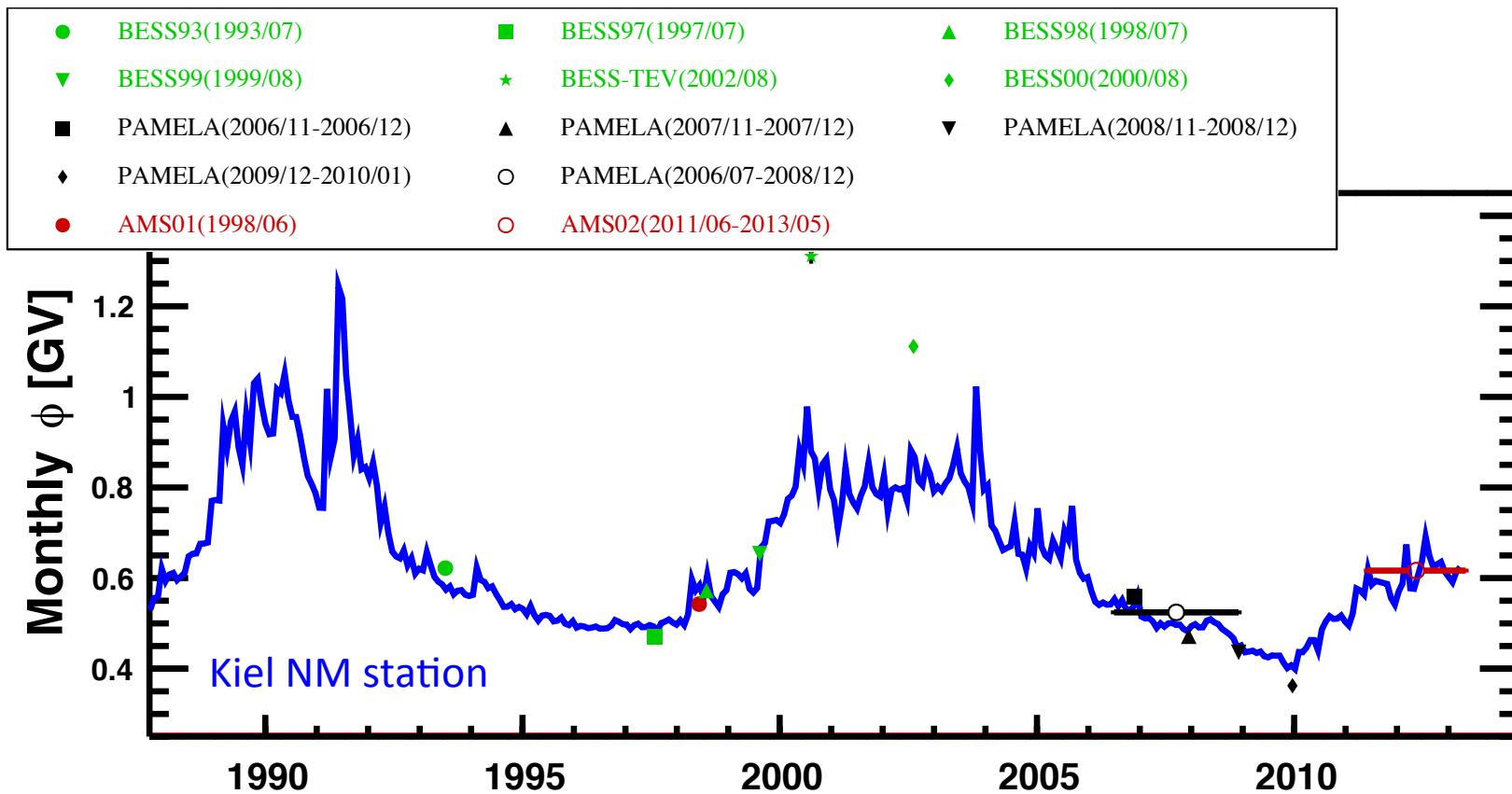
- Flux fitted on data:

$$J^{IS}(E) = a_0 \beta^{a_1} R^{-a_2}$$



- Stronger Solar modulation as expected from solar activity
- High statistics of AMS: possibility to reconstruct a flux for each day and then to study the time fluctuation.

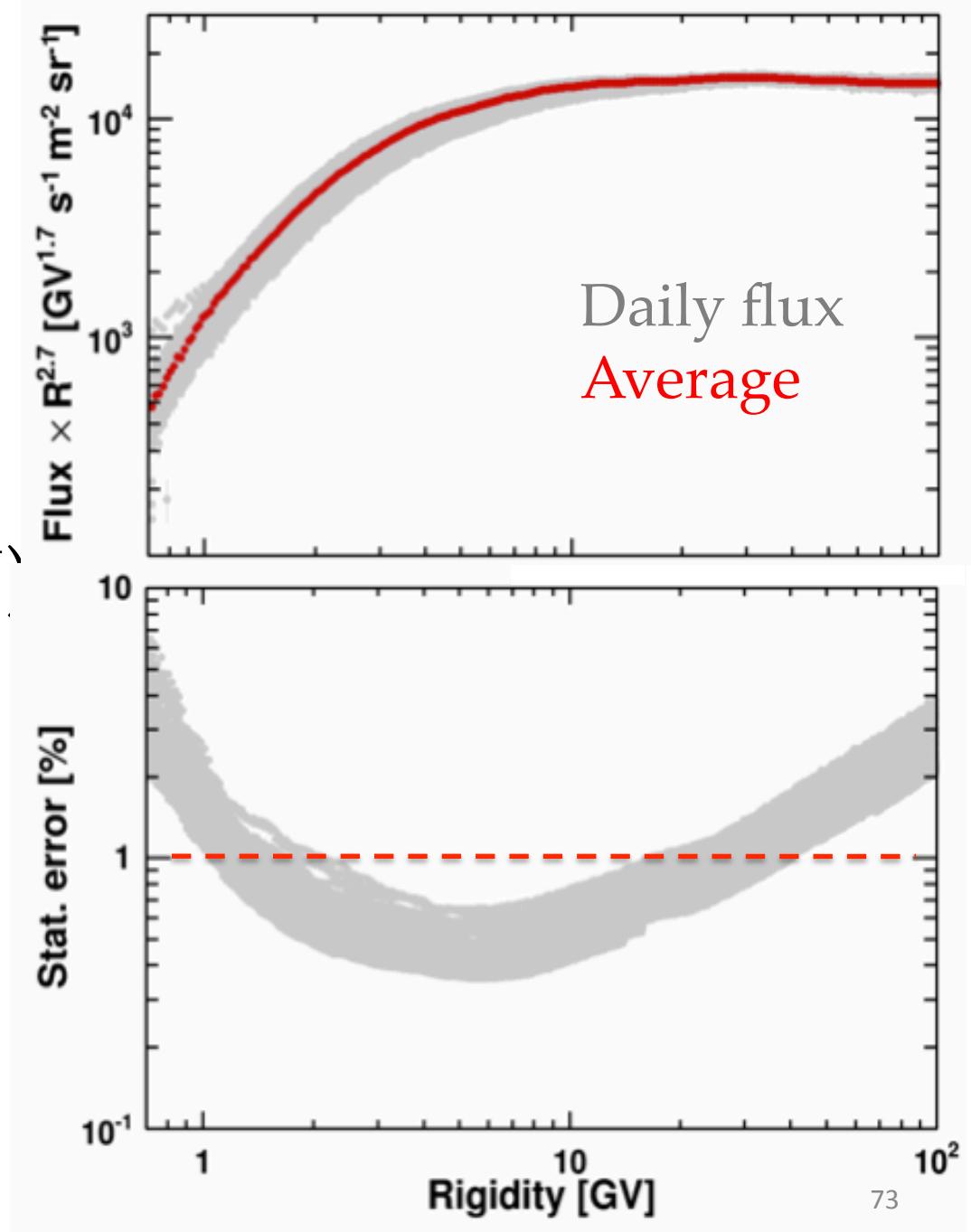
# Comparison with Neutron Monitor



- Good agreement but for BESS-TeV and BESS-2000 experiments (Large solar activity)
- Modulation measured on proton spectrum by AMS correspond to what is expected from Solar activity.

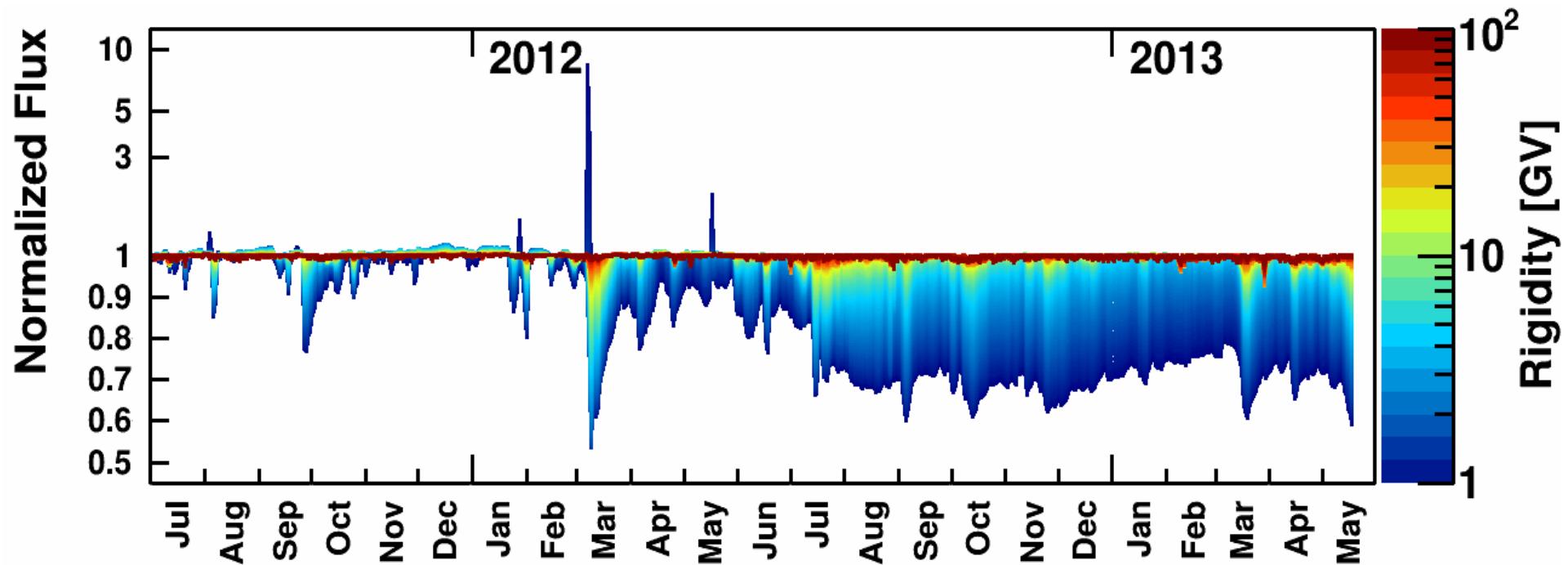
# Daily flux

Stat. Error <  $\sim 1\%$   
 $(1 < R < \sim 20 \text{ GV})$



# Daily normalized flux

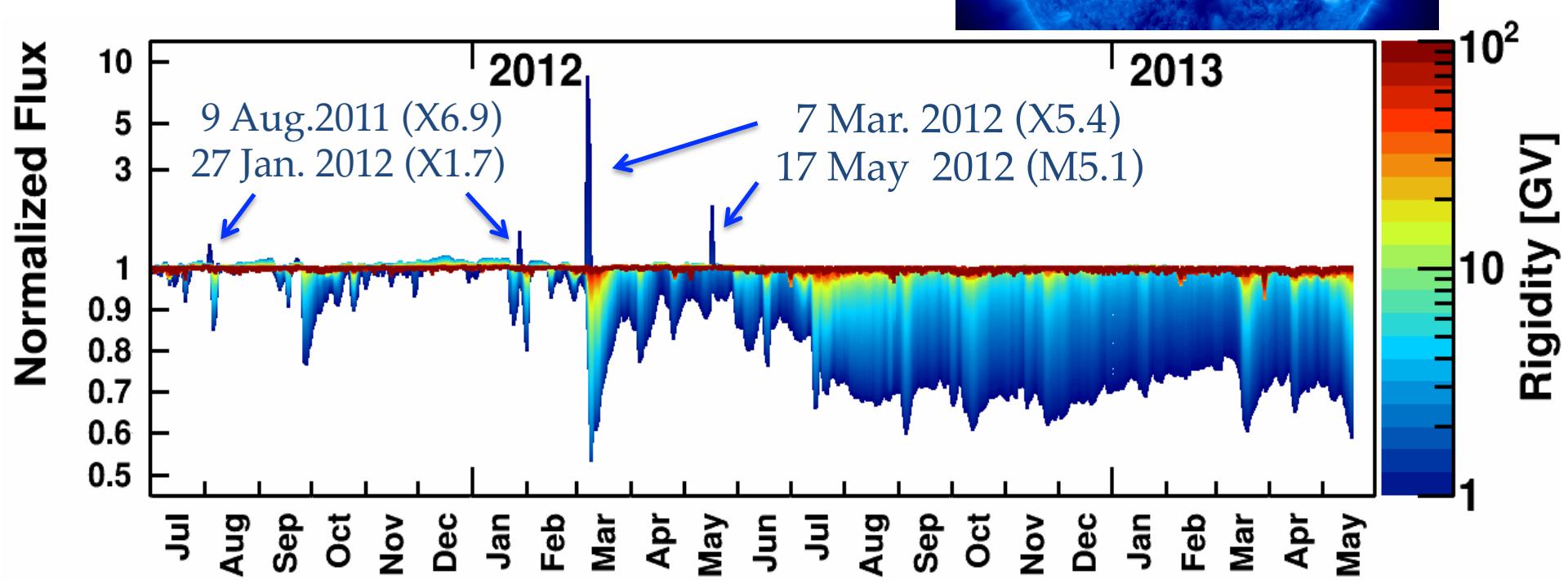
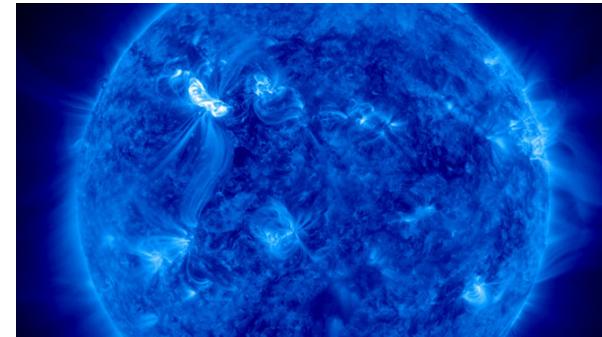
Time fluctuation of proton rate for different rigidities from AMS02 data:



→ AMS proton daily fluxes represent a unique set of data for the Solar physics community, and to understand Solar modulation

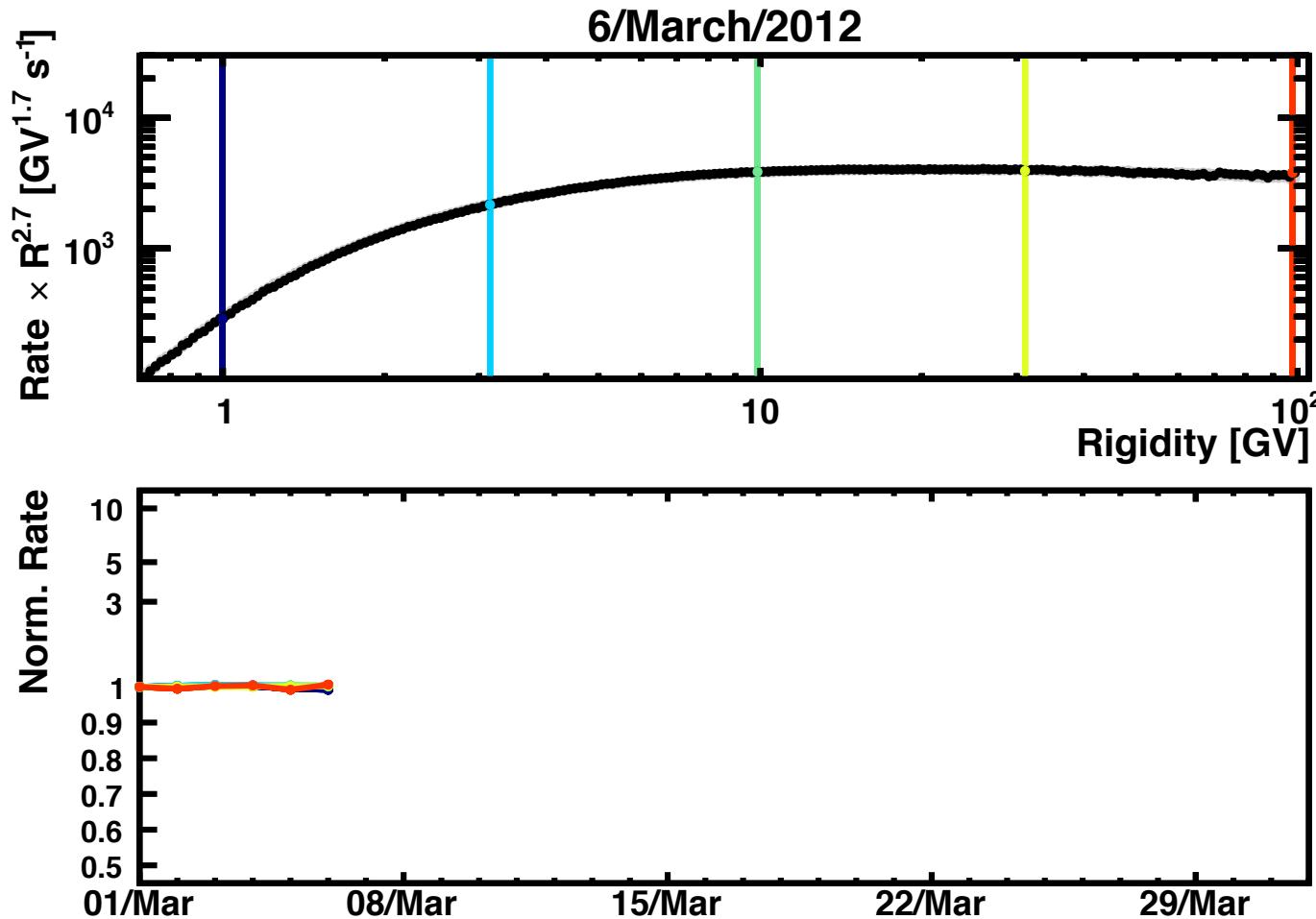
# Daily normalized flux

$R < \sim 3$  GV : Peaks associated with  
Solar flares (SEP)



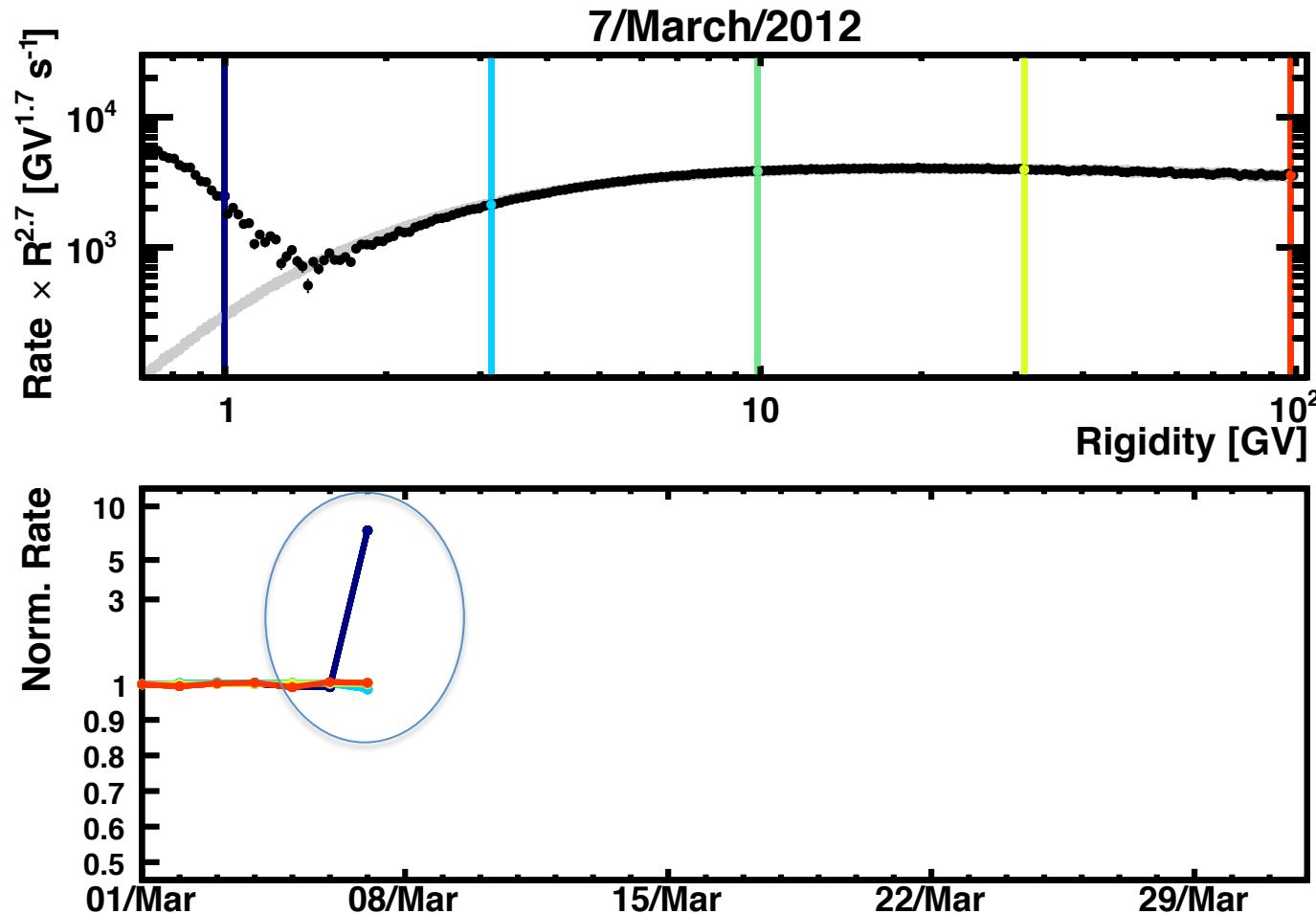
# March 2012 solar event

Daily proton rate reconstructed from AMS02 data:



# March 2012 solar event

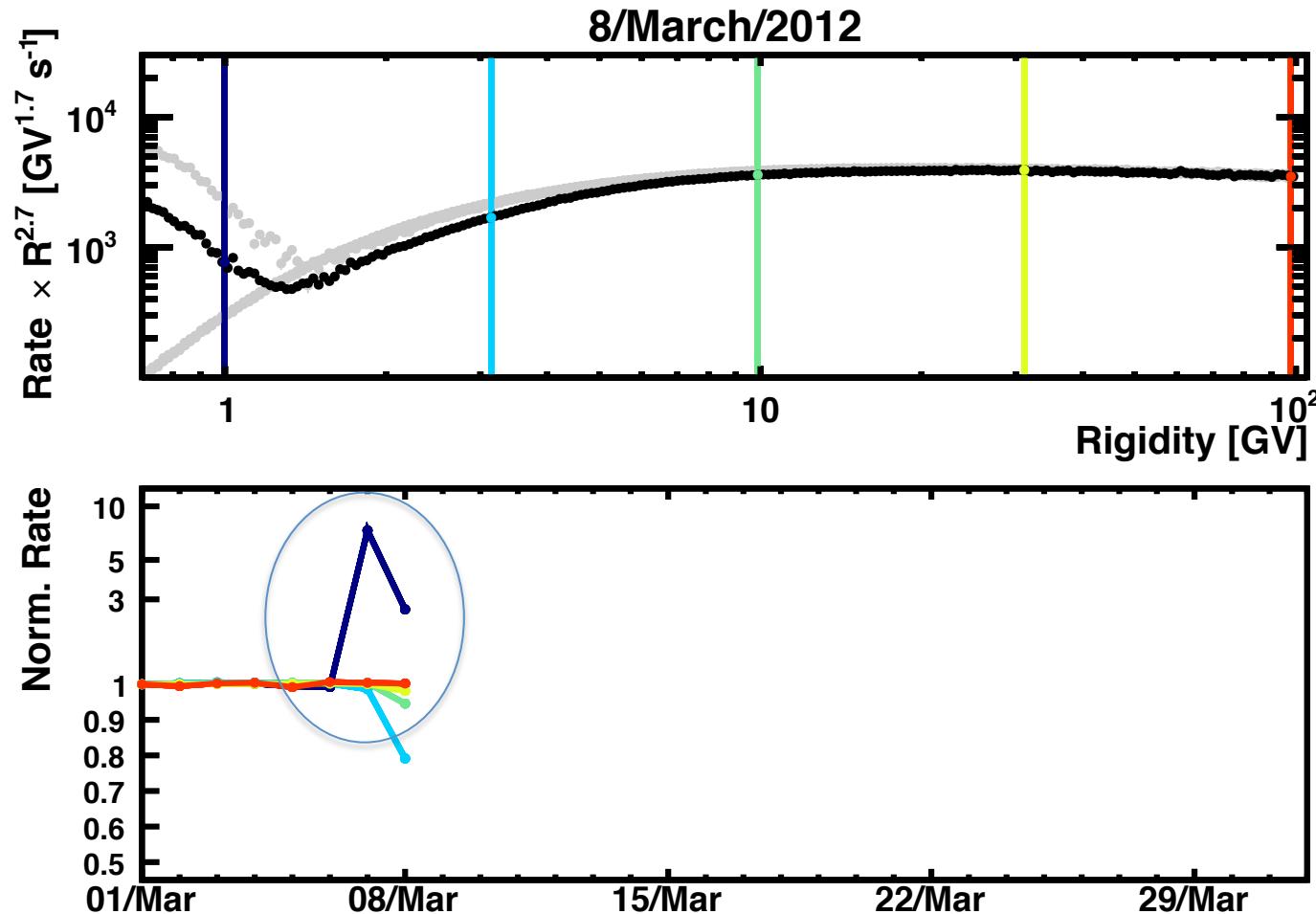
Daily proton rate reconstructed from AMS02 data:



Bunch of low energy particle produced by the flare

# March 2012 solar event

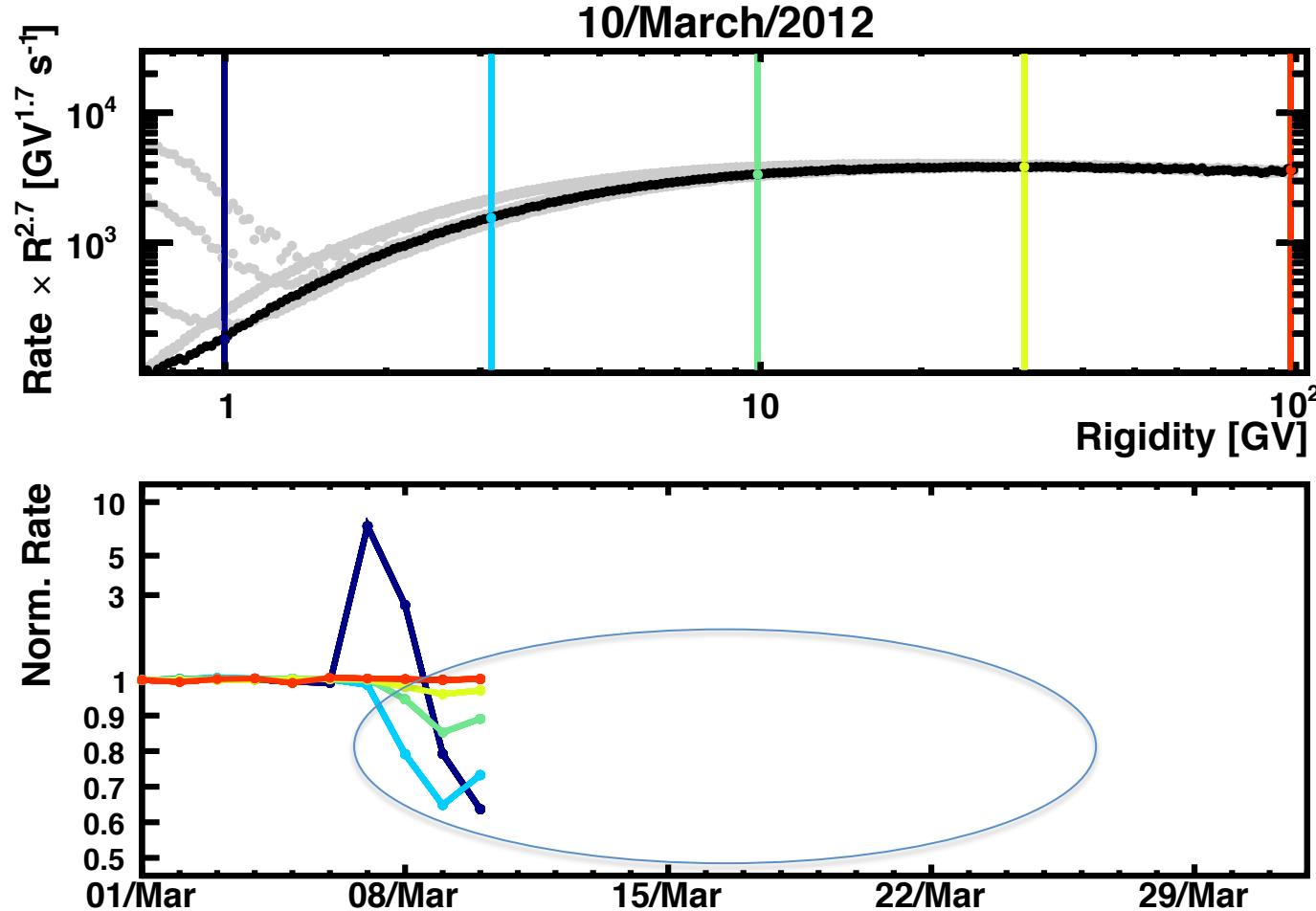
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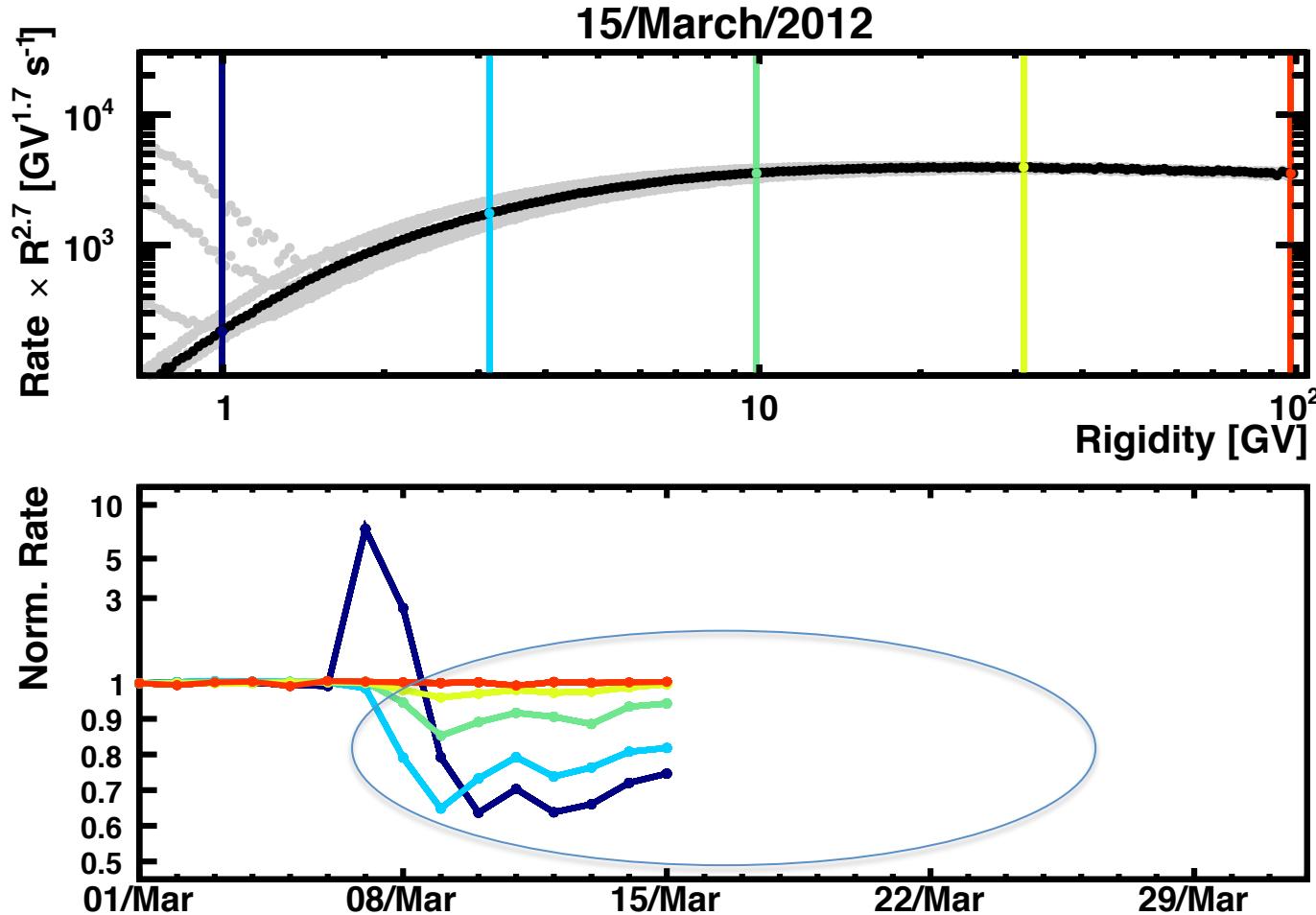
Daily proton rate reconstructed from AMS02 data:



Forbush decrease (due to the large magnetic disturbance) lasting ~20 days

# March 2012 solar event

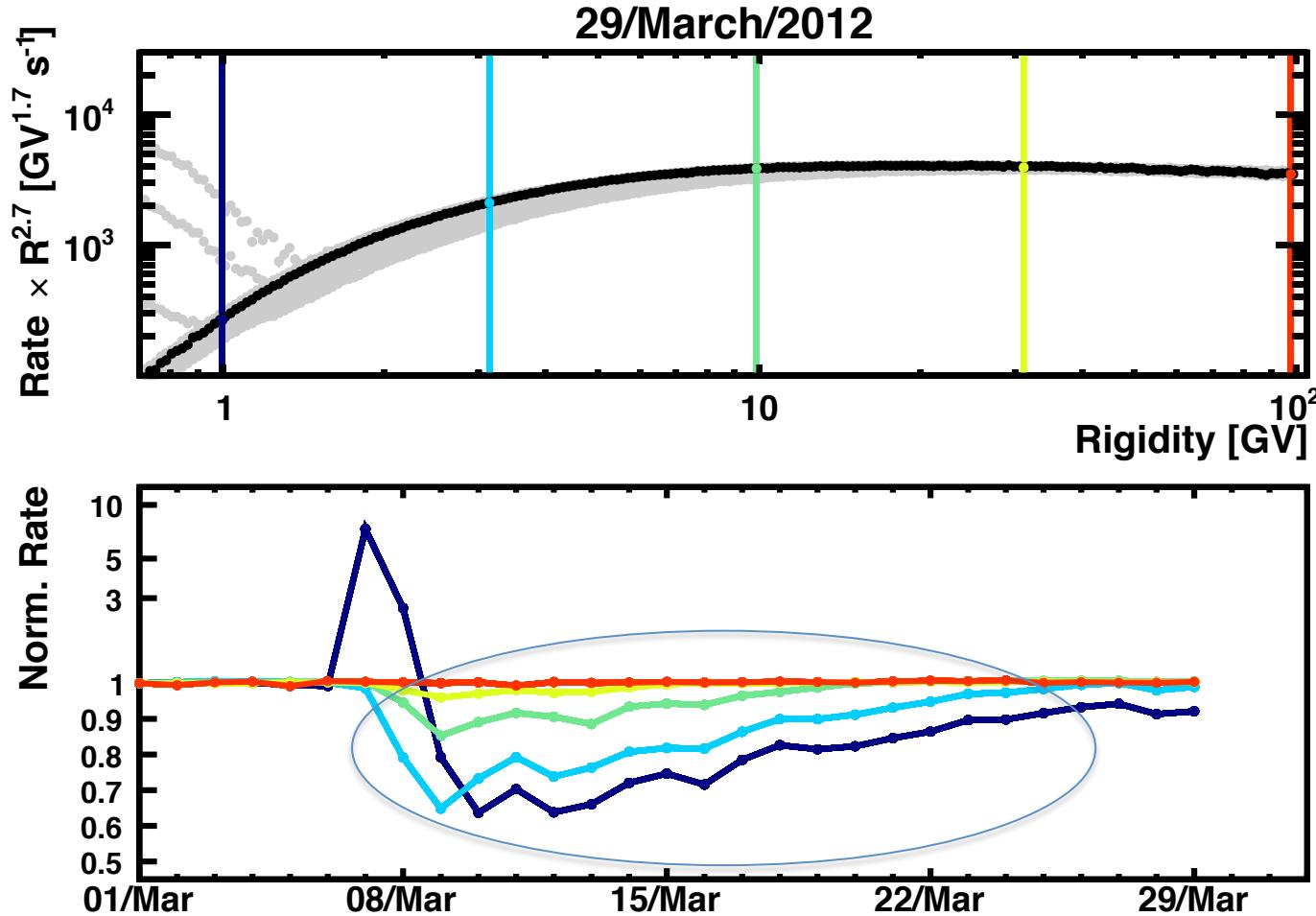
Daily proton rate reconstructed from AMS02 data:



Forbush decrease (due to the large magnetic disturbance) lasting  $\sim$ 20 days

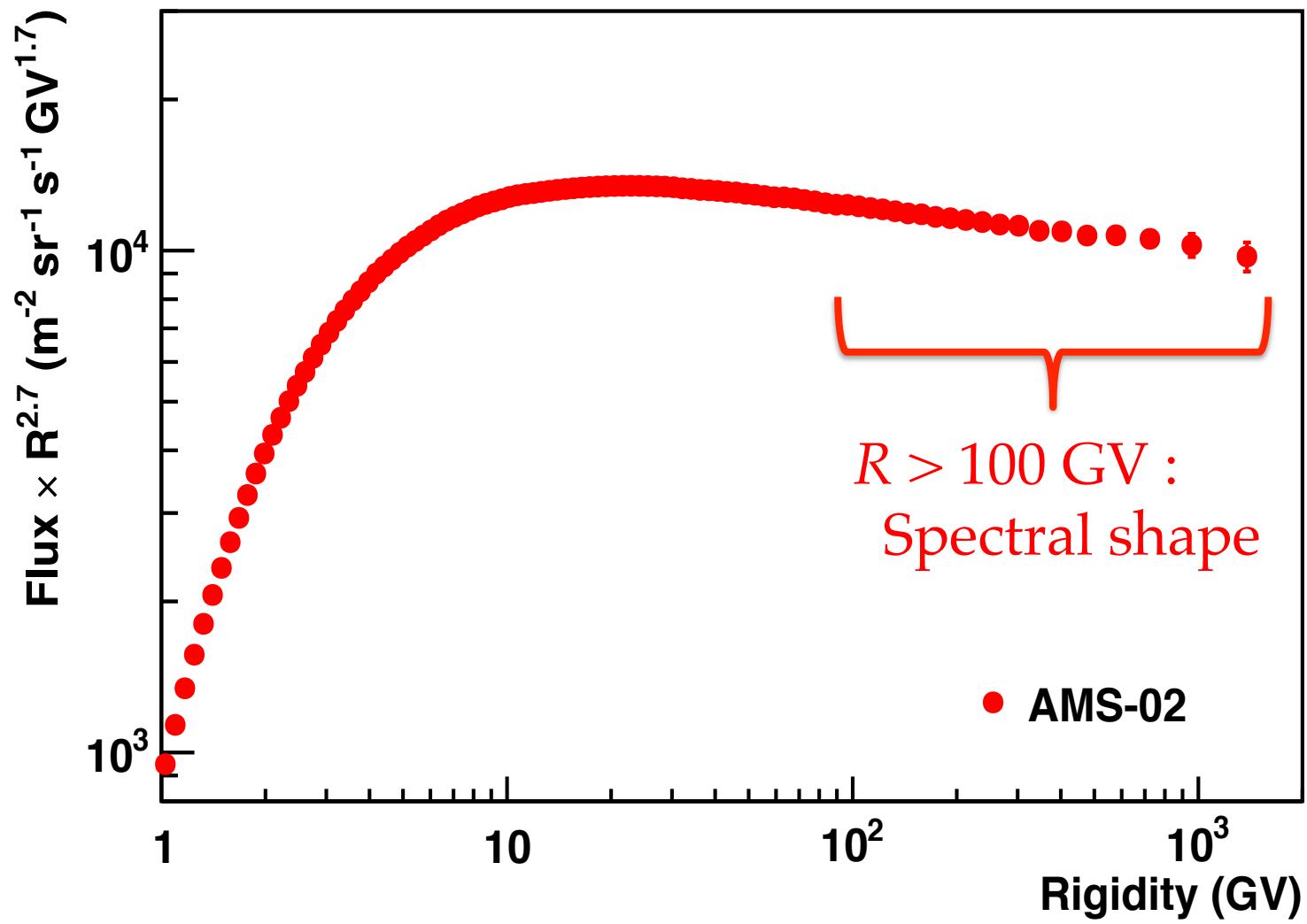
# March 2012 solar event

Daily proton rate reconstructed from AMS02 data:

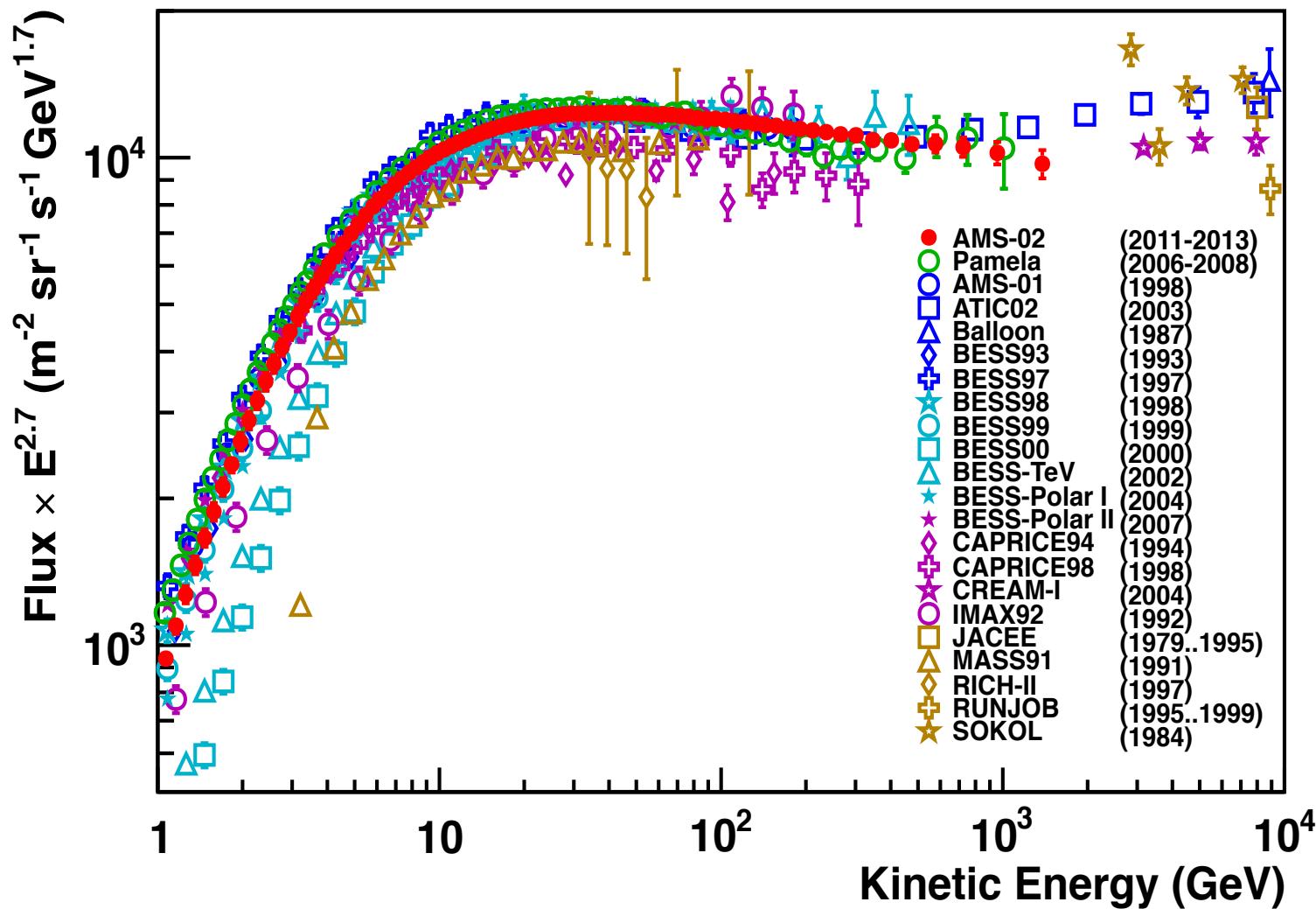


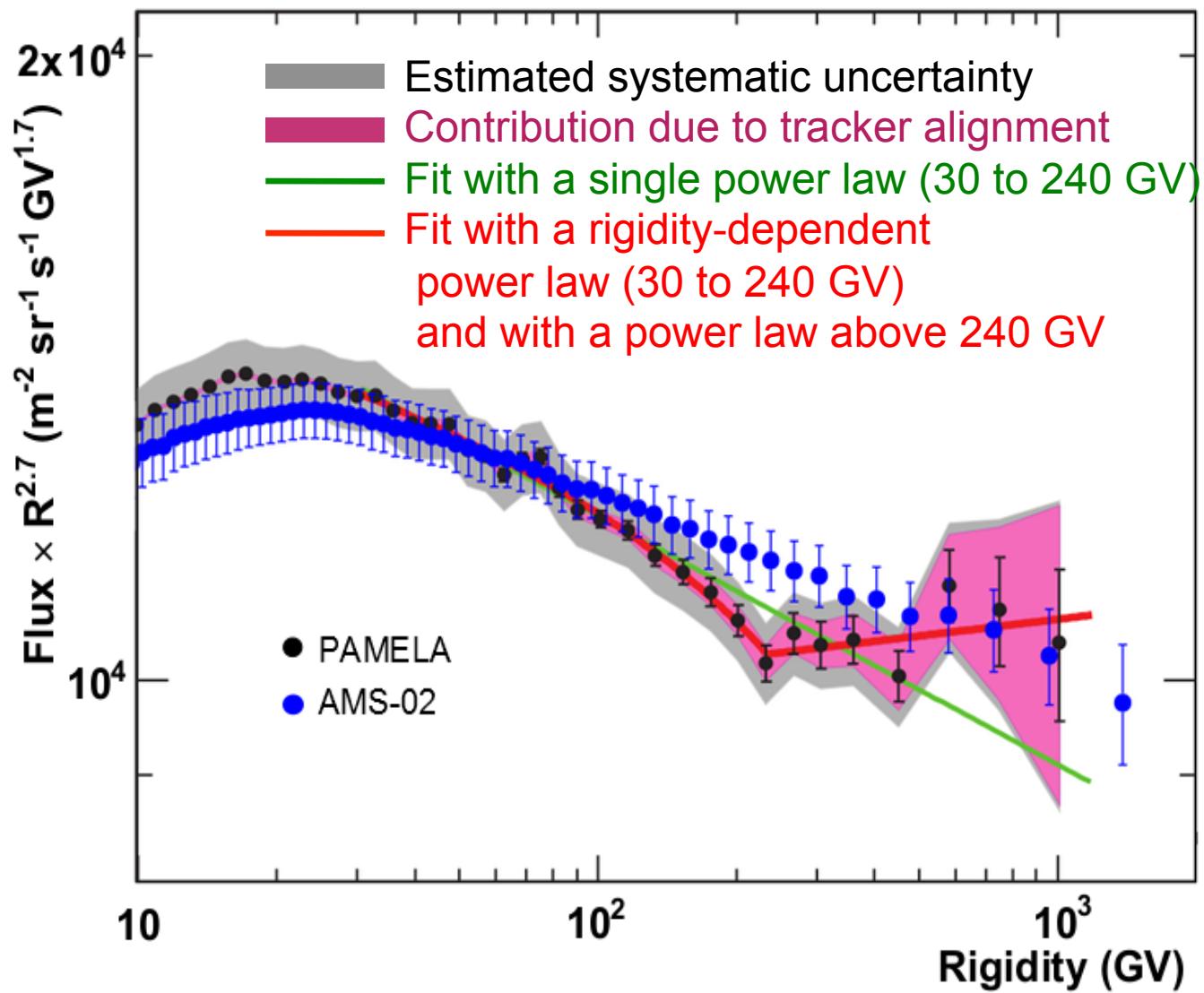
Forbush decrease (due to the large magnetic disturbance) lasting  $\sim$ 20 days

## Features (2)



# Comparison with past measurements



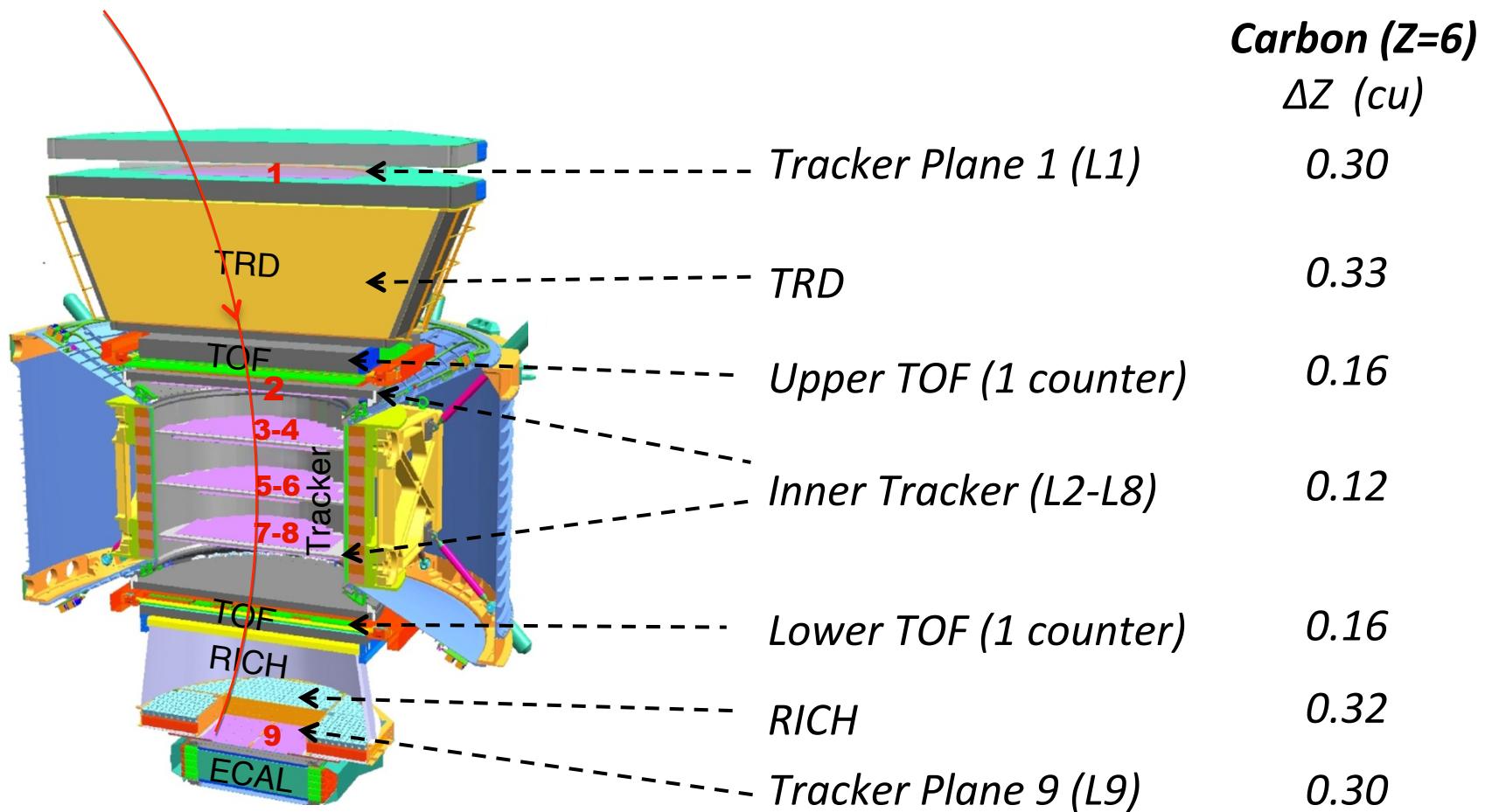


# Reconstruction du rapport B/C

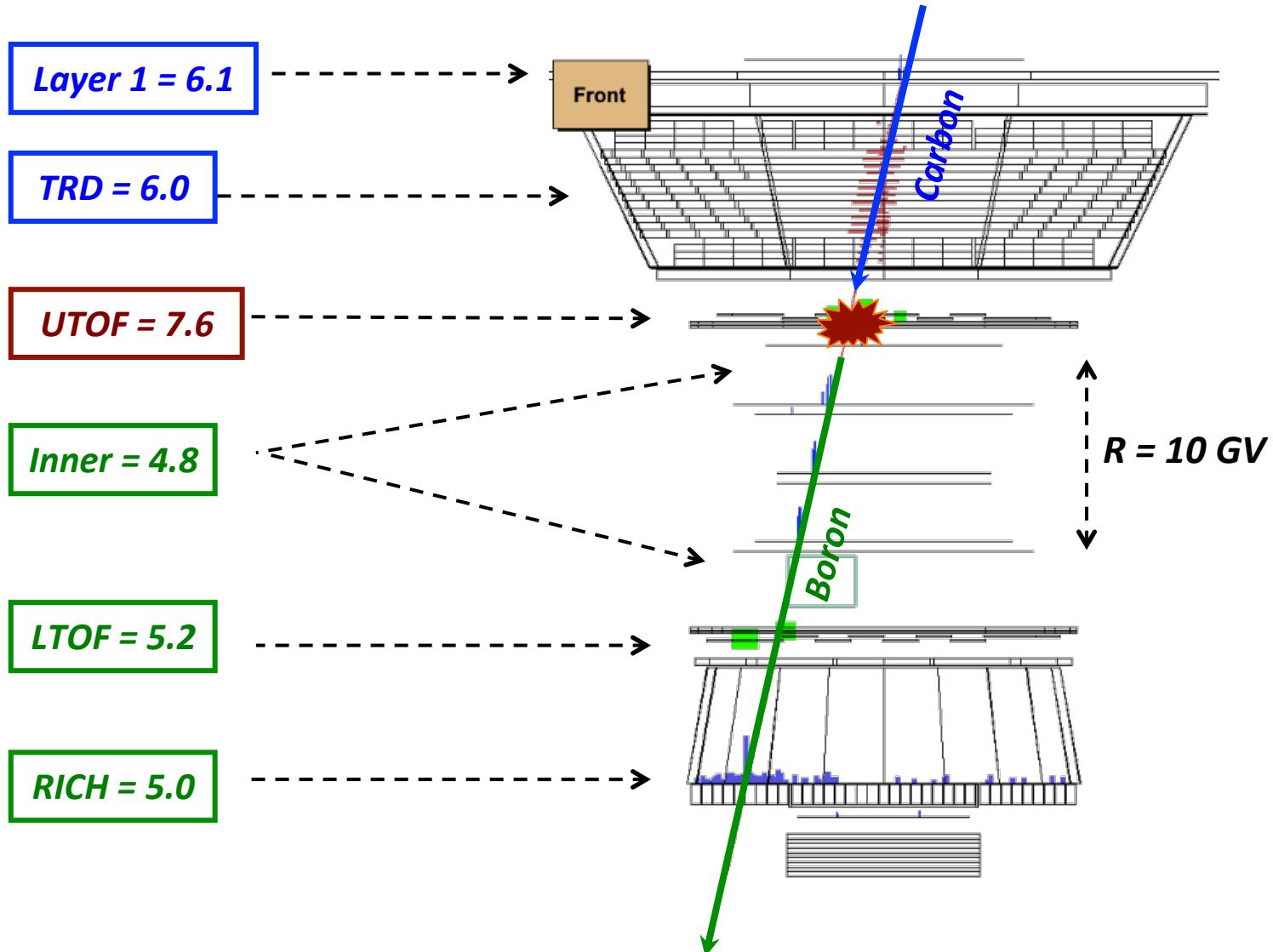
Points importants:

- Identification simple ( $Z=5)/(Z=6)$  et grande redondance de la mesure de charge.
- Rapport → Pas besoin des efficacités, juste des rapports des efficacités.
- *Mesure de la rigidité dans le tracker: pour estimer l'énergie on doit faire une hypothèse sur les abondances isotopiques.*
- Fond principal: fragmentation ( $C \rightarrow B$ ) dans le détecteur

# *Multiple Measurements of Charge*



# *Identification of Fragmentation Events*



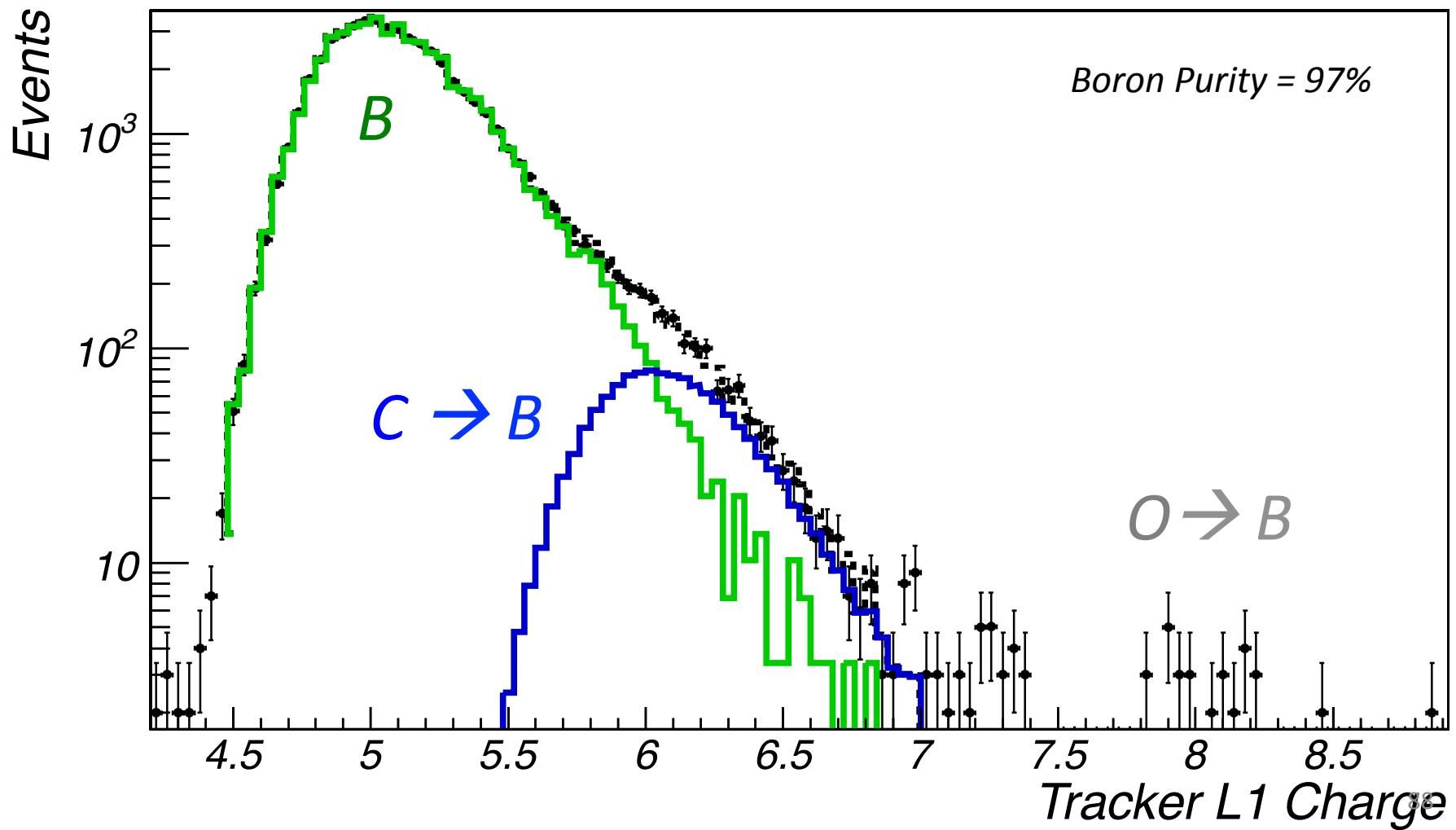


# Purity Estimation

Selection efficiency is >70% for both Boron and Carbon, ratio is  $\approx 1$ .

Boron selected with Inner Tracker and TOF.

Background estimated down to accuracy of 0.1%.



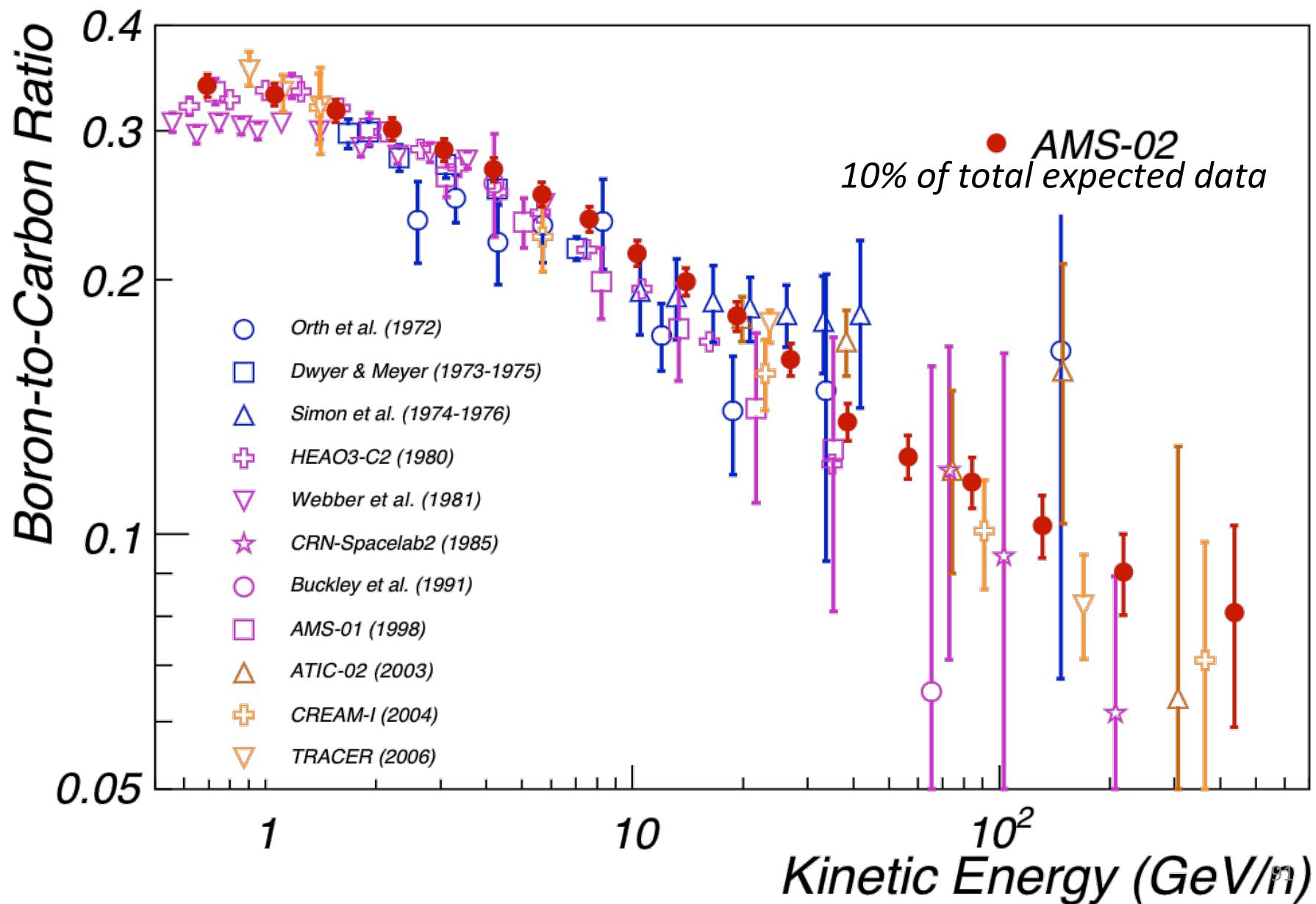
## *Top-of-the-Instrument Correction*

*Carbon to Boron conversion on materials above L1.*

$$\left(\frac{B}{C}\right)_{L1} = \frac{B + C \cdot \epsilon_{C \rightarrow B}}{C} = \left(\frac{B}{C}\right)_{TOI} + \epsilon_{C \rightarrow B}$$

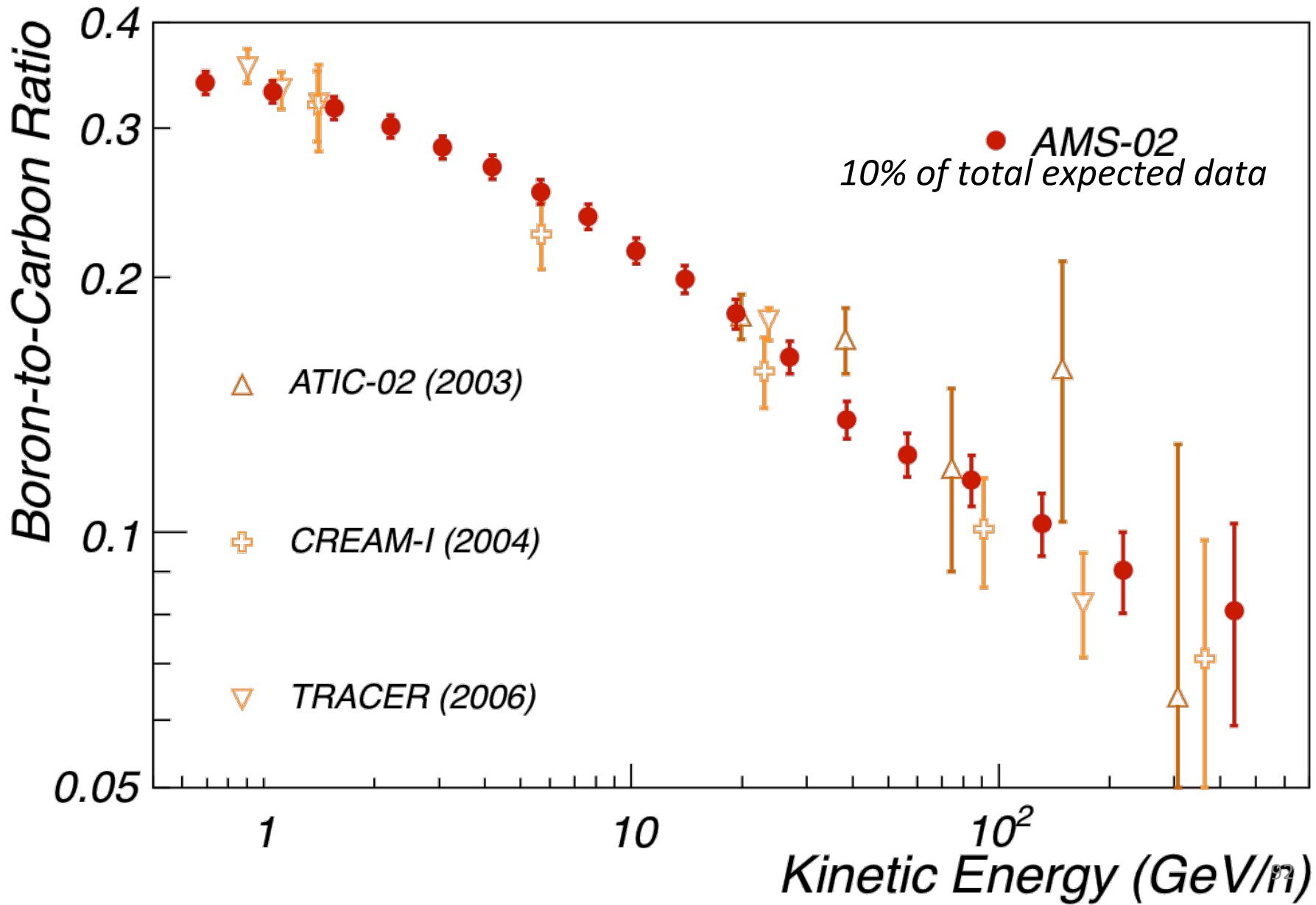
*Correction to the ratio has been estimated with MC:  $\epsilon_{C \rightarrow B} = 0.005 \pm 0.002$ .*

# $B/C$ Ratio





## *B/C Ratio (year > 2000)*



# Conclusions

- Mesure directe du rayonnement cosmique depuis un siècle depuis la haute atmosphère ou l'espace :
  - Sources du RC, accélération du RC, recherche de sources locales.
  - Processus de propagation, propriétés de la Galaxie (taille du halo...)
  - Activité solaire, modulation du RC
  - Origine de l'antimatière dans le rayonnement cosmique, recherche de matière noire
- Combinaisons des mesures associées aux sous-détecteurs pour mesurer les différentes composantes du RC : chaque analyse est spécifique.
- Situation particulière en ce moment : AMS sur l'ISS au moins jusqu'en 2020. Juste au début de l'exploitation des résultats de l'expérience.
  - Autres analyses en cours : He --  $e^-, e^+$ ,  $(e^- + e^+)$  -- B,C -- pbar, pbar/p
  - Et d'autres futures : Isotopes – Dbar – Hebar -- LiBBe (rapports secondaire/primaire)
- Expériences futures (Calorimétrique) CALET -- ISSCREAM (2014-2015)