

# Ecole « techniques de base du détecteur » Oléron

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Université Pierre et Marie Curie

Introduction  
Les systèmes expérimentaux  
Les interactions des particules chargées  
Les interactions des particules neutres  
Les détecteurs de particules  
**Visite d'une expérience**

# Visite d'un détecteur

2005 : Astro-particules

2007 : ATLAS

2009 : Neutrinos

2011 : CMS

2013 : absent

**2015 : AMS-02**

# AMS-02



# Objectifs scientifiques

- Origine et accélération des rayonnements cosmiques
- Transport et interaction des rayonnements
- Nature de la matière noire
- Recherche de l'antimatière



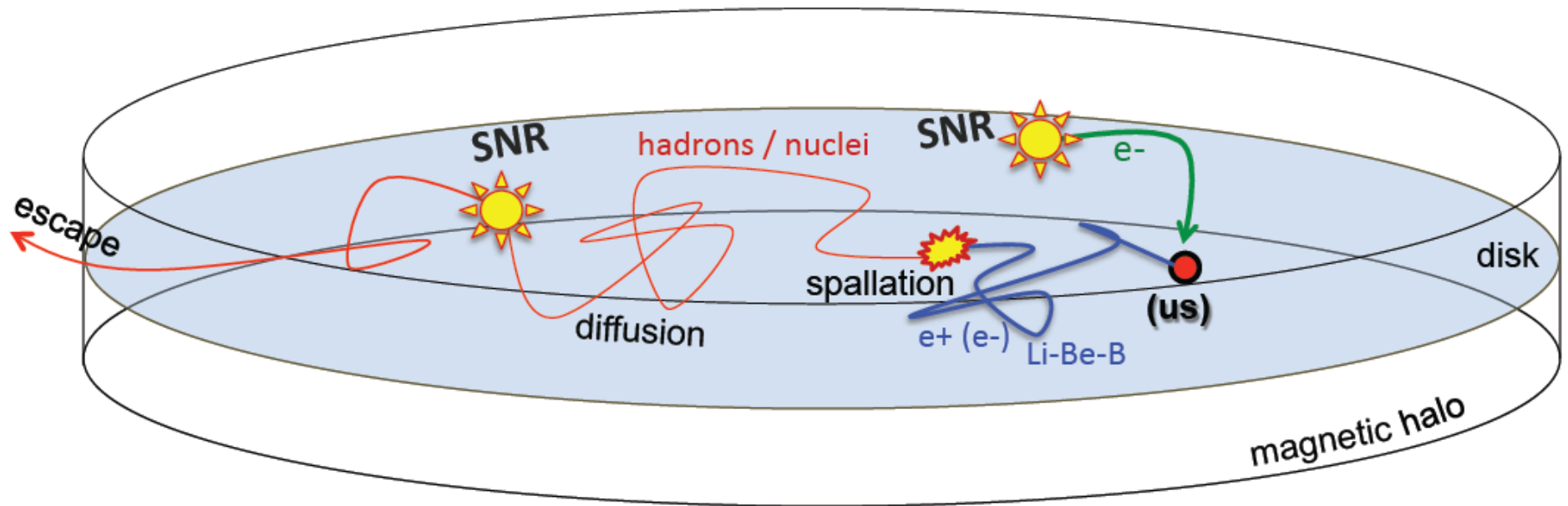
- Caractérisation des particules chargées
- Rayonnement gamma des hautes énergies
- Caractérisation des anti-particules



AMS-02

# TRANSPORT ET INTERACTION DES RAYONNEMENTS COSMIQUES

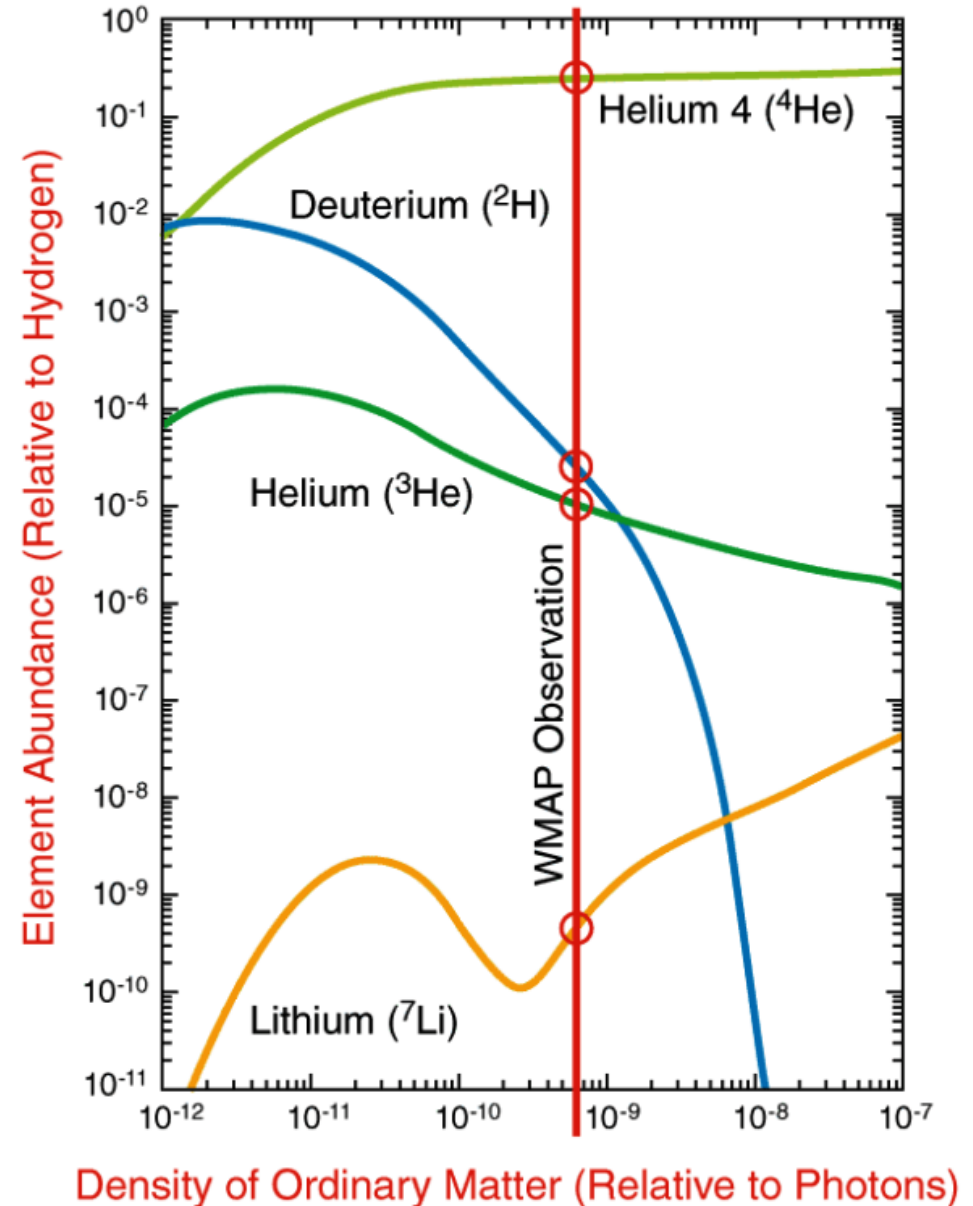
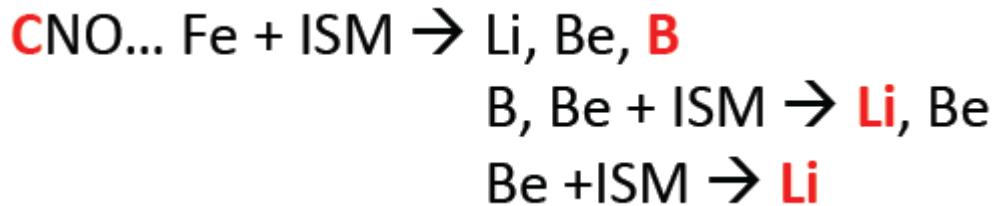
# Origine et accélération , transport et interaction des rayonnements cosmiques



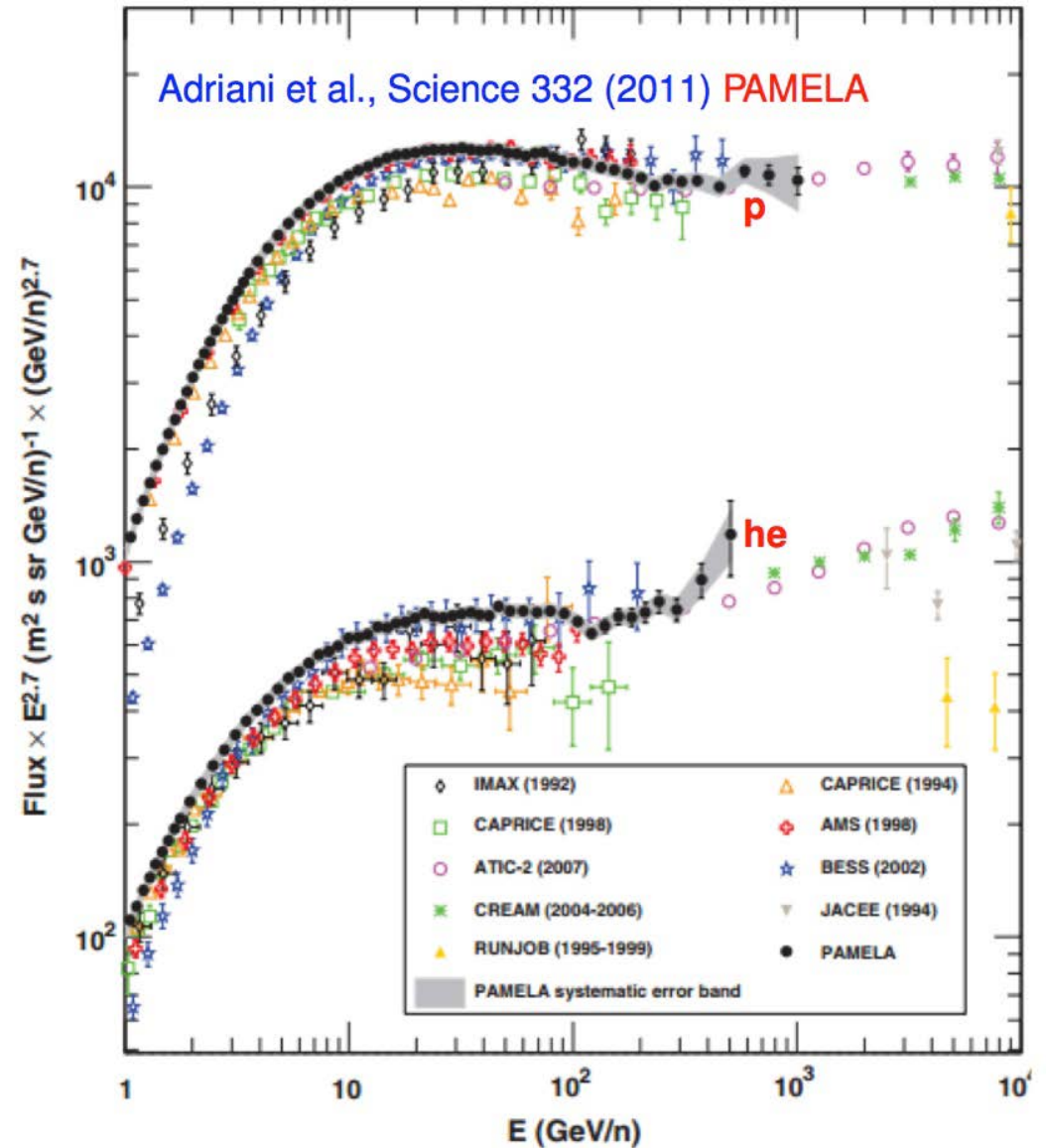
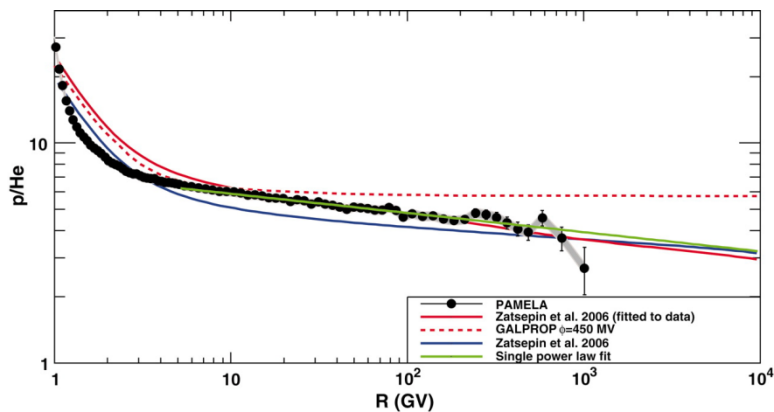
# Composition des rayons cosmiques

Etude de la composition des noyaux légers dans l'univers

Etude de l'époque de formation des structures



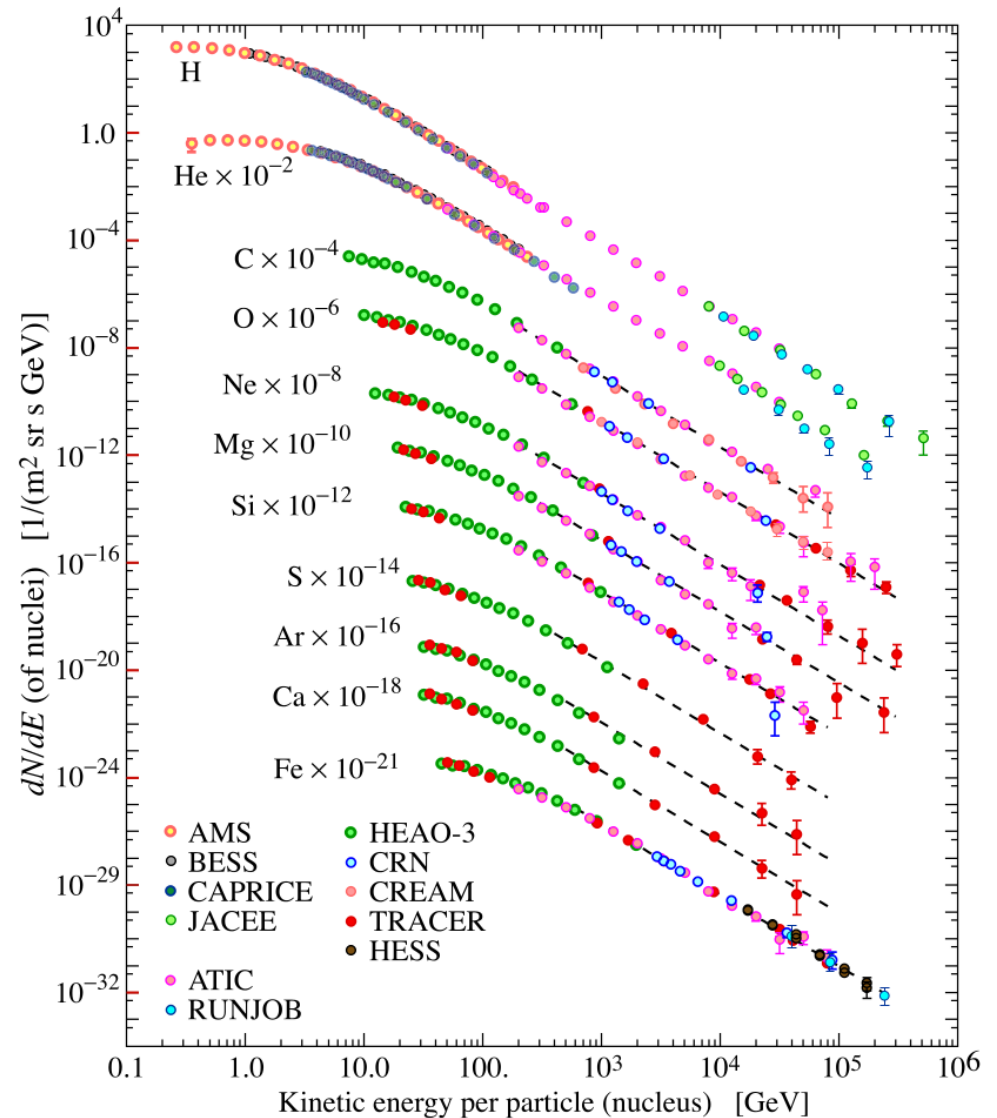
# Composition des rayons cosmiques





# Composition des rayons cosmiques

Et les autres ...



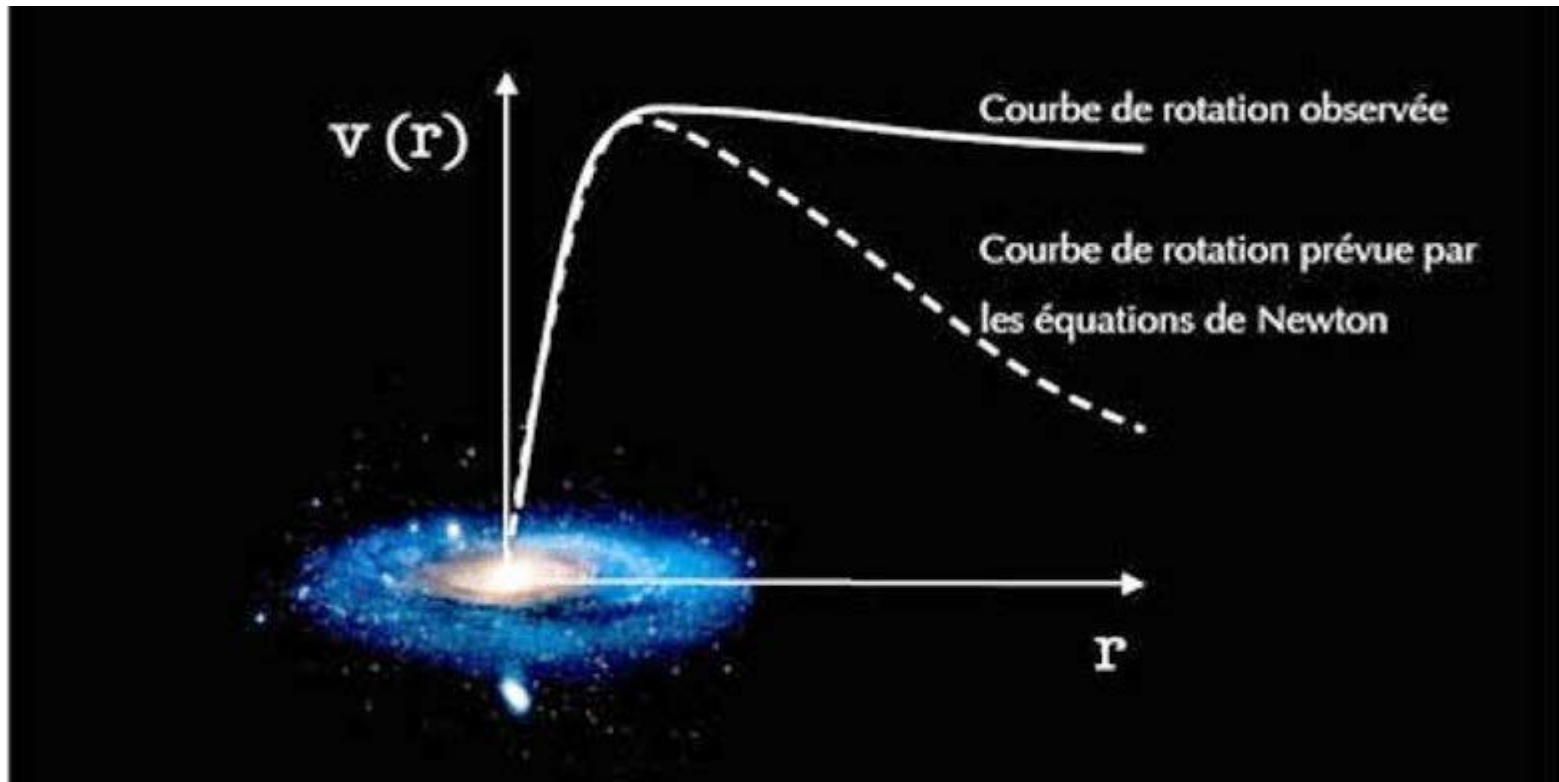


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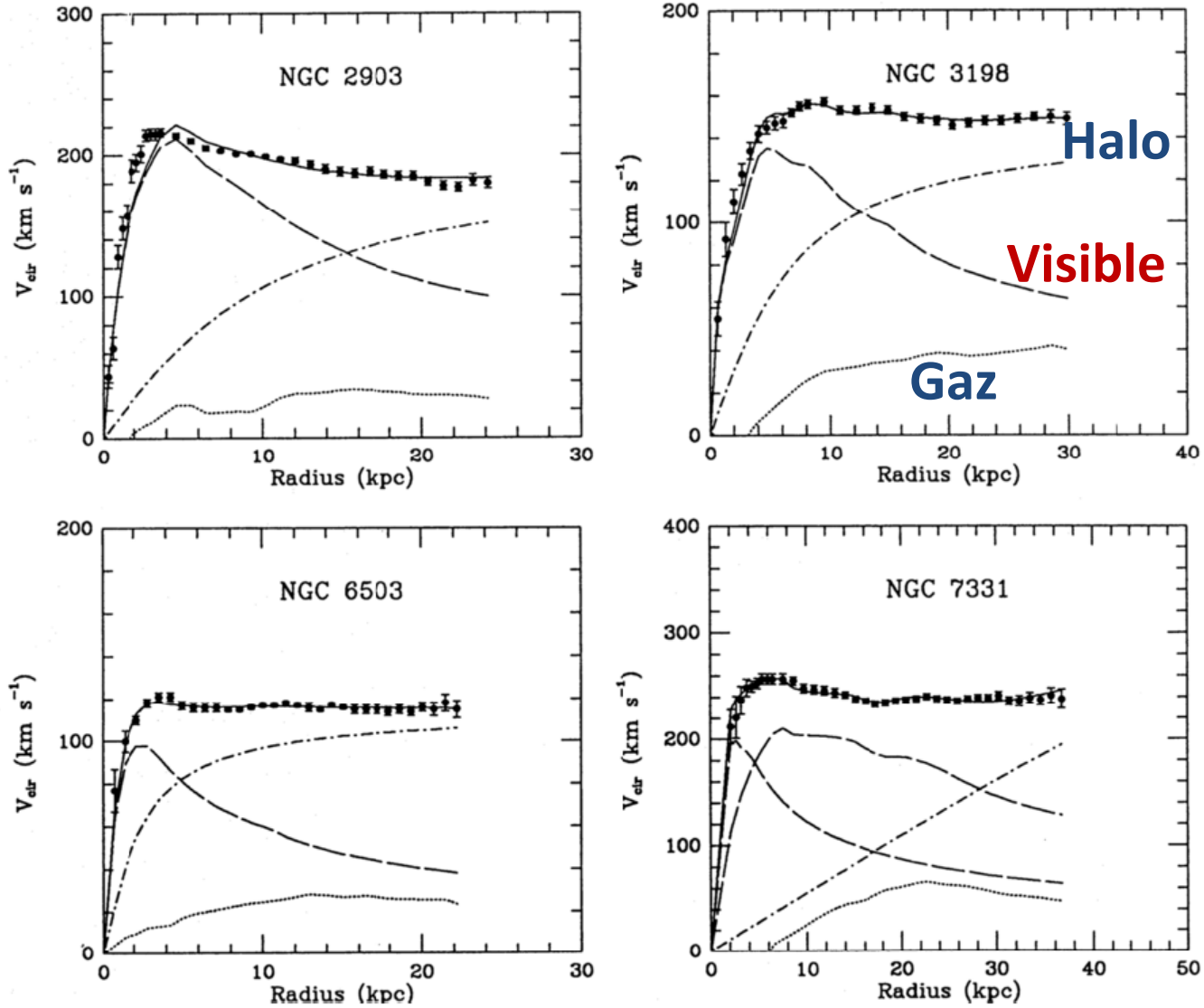
# LA NATURE DE LA MATIÈRE NOIRE

# AMS-02

La distribution des vitesses dans les galaxies s'écarte des prédictions de la théorie de la gravitation à grande distance du centre des galaxies.



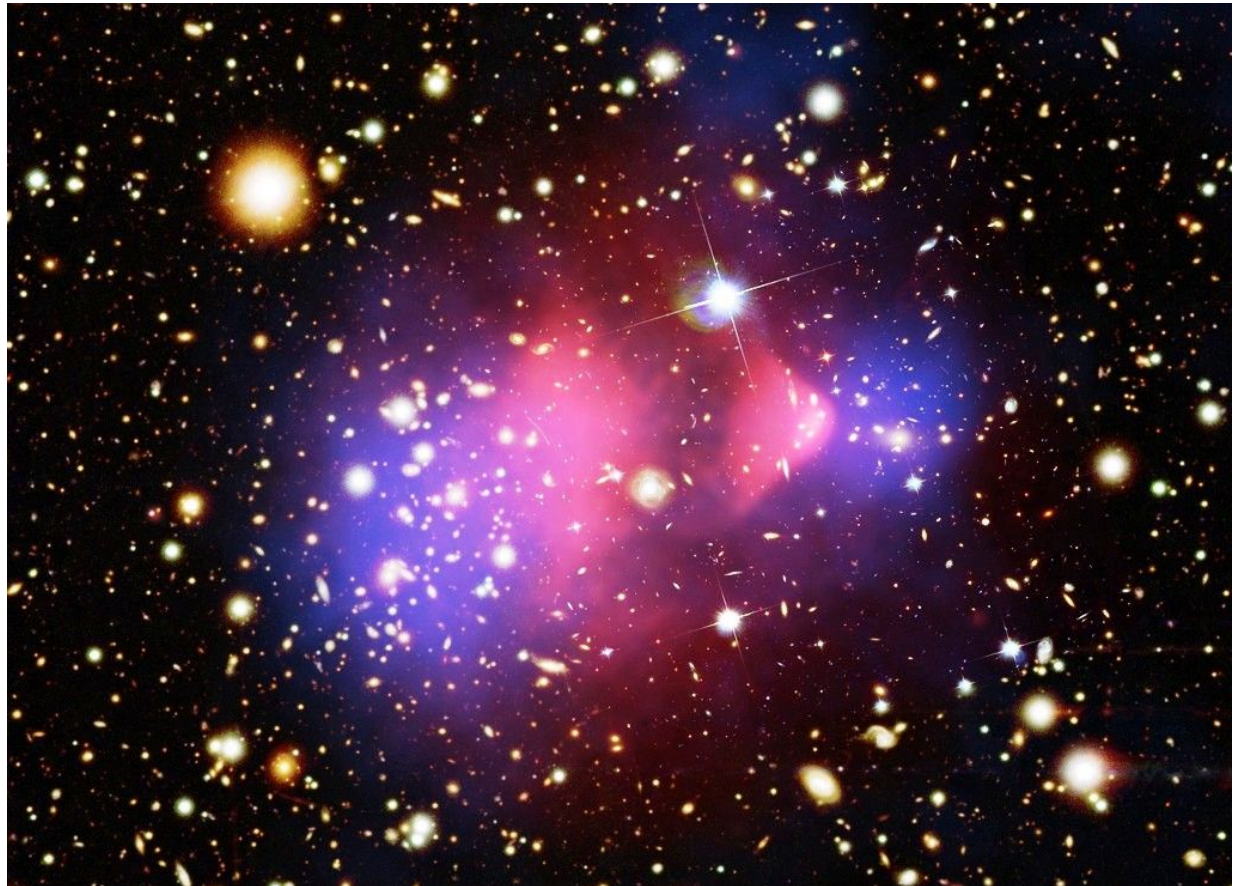
# AMS-02



# Indices de matière noire

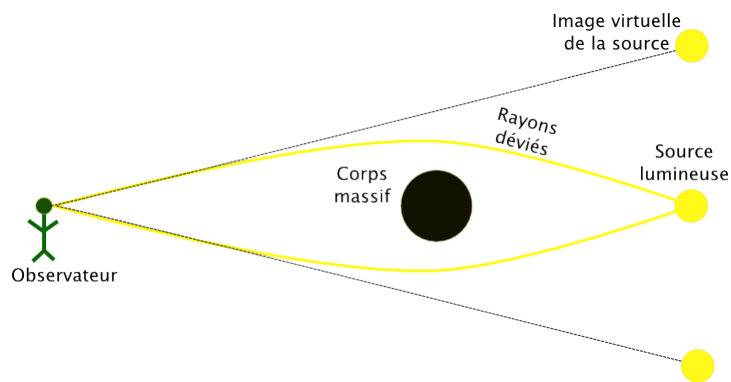
La collision de deux amas (le bullet cluster) :

- Les halos (en bleu) s'interpénètrent sans interagir,
- Le gaz de matière normal (en rouge) interagit et donc se retrouve décalé.



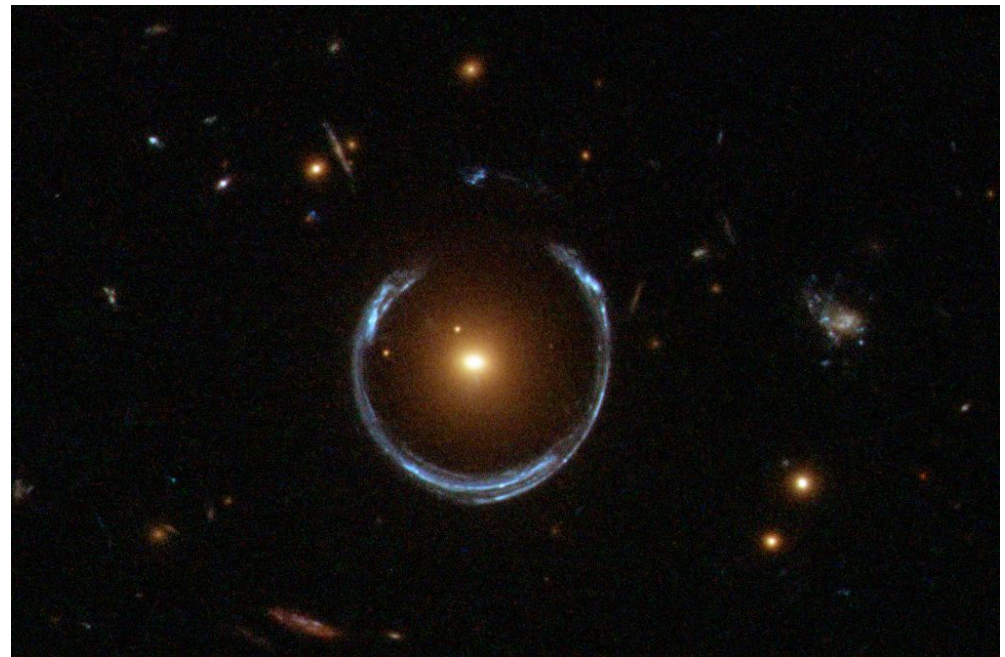
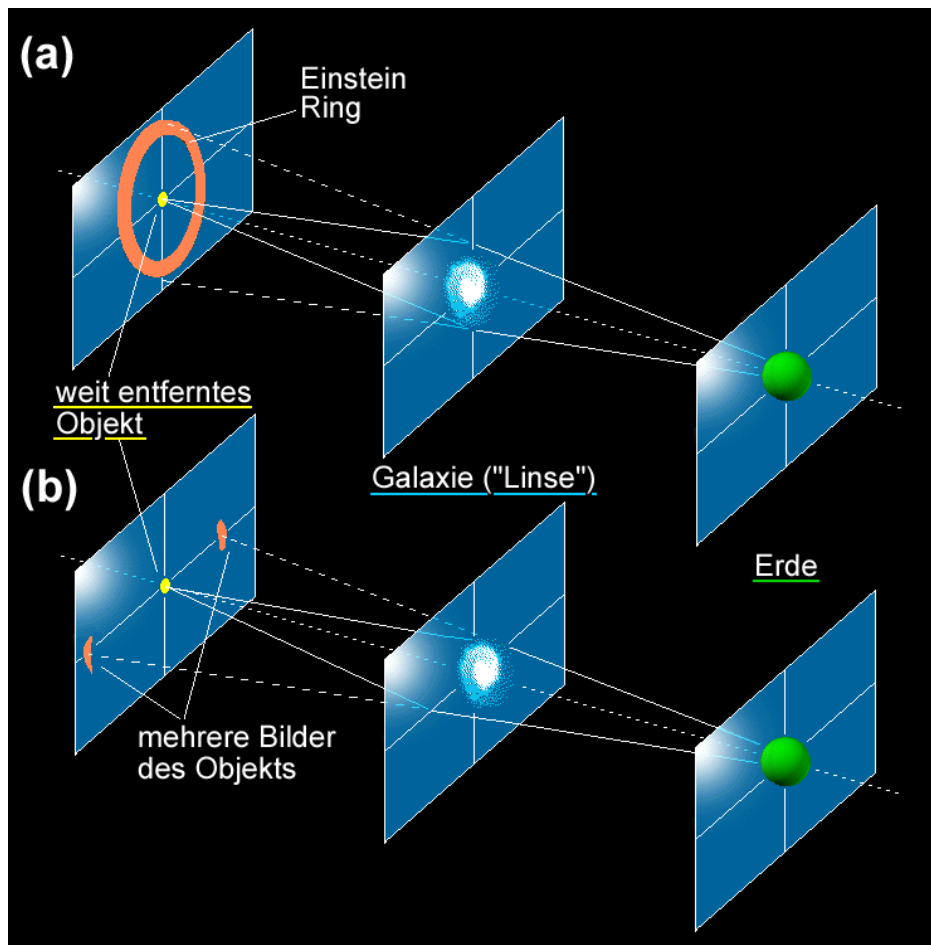
# Indices de matière noire

## Effet de lentille gravitationnel



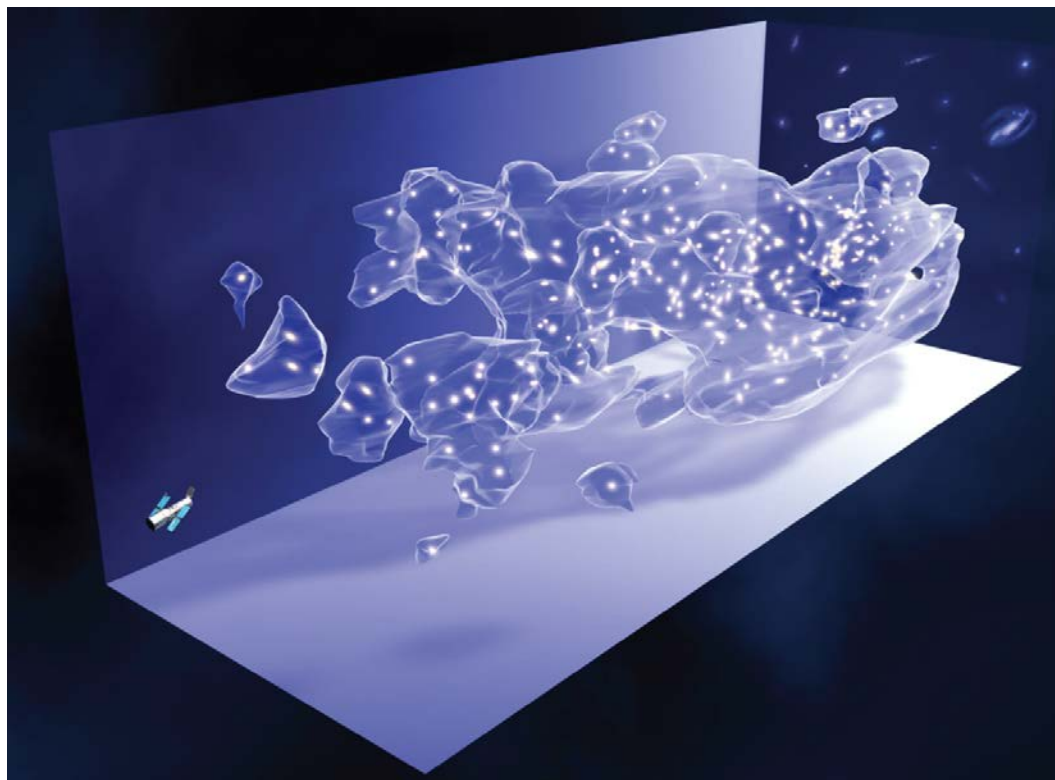
# Indices de matière noire

Effet de lentille gravitationnel : anneaux d'Einstein



# Indices de matière noire

En observant un champ de galaxies avec le télescope spatial Hubble, on établit pour une carte en trois dimensions de la matière noire dans une région de l'univers.



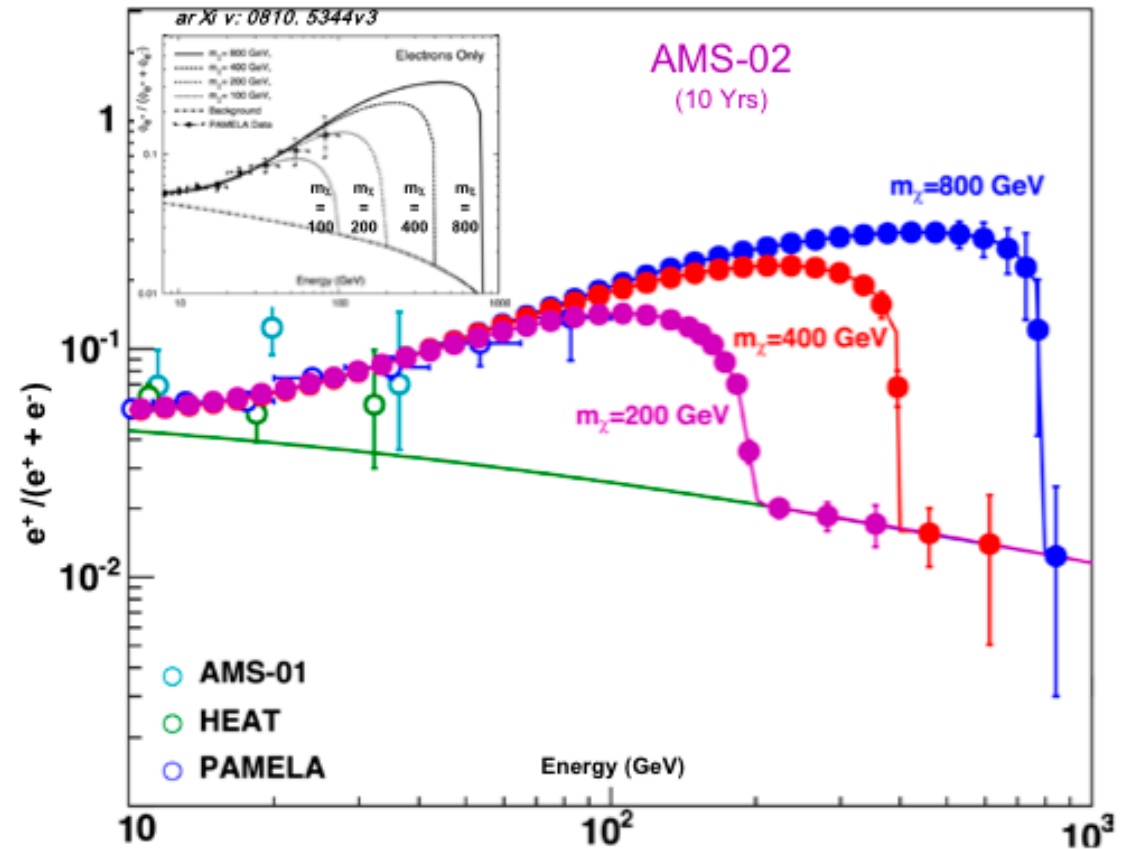


# Halo de matière noire



*N. Regn*

# AMS-02



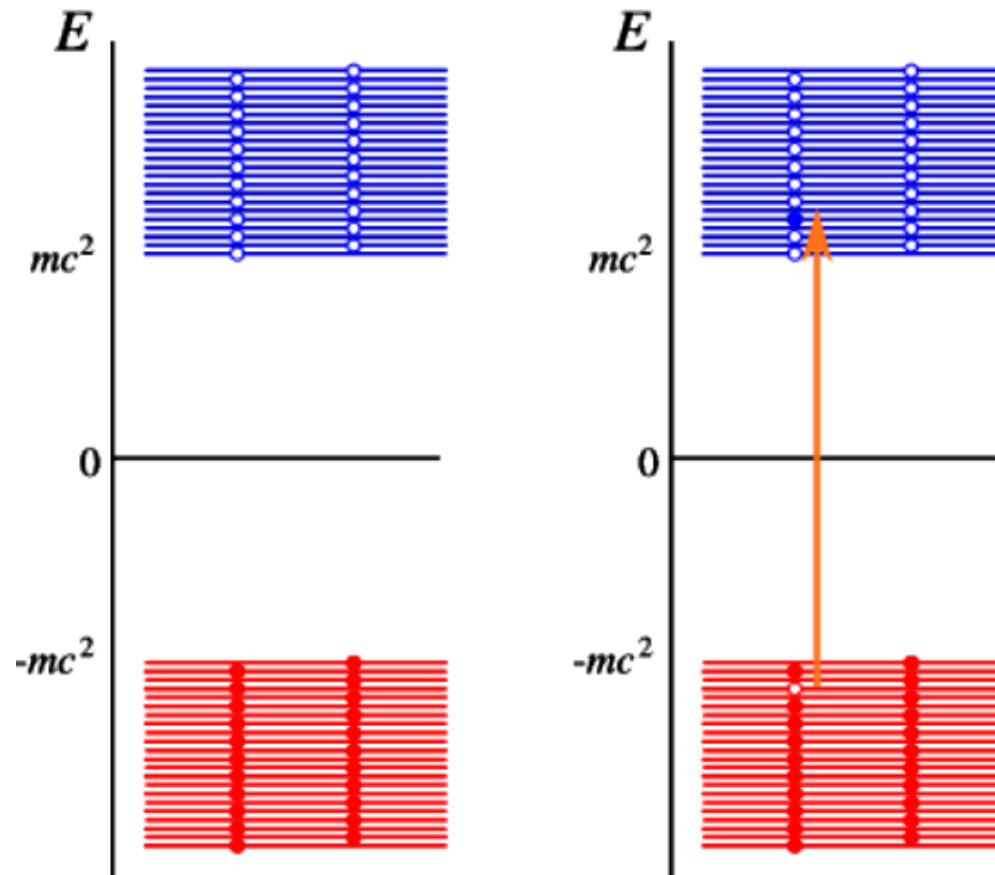


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# OÙ SE SITUE L'ANTIMATIÈRE ?

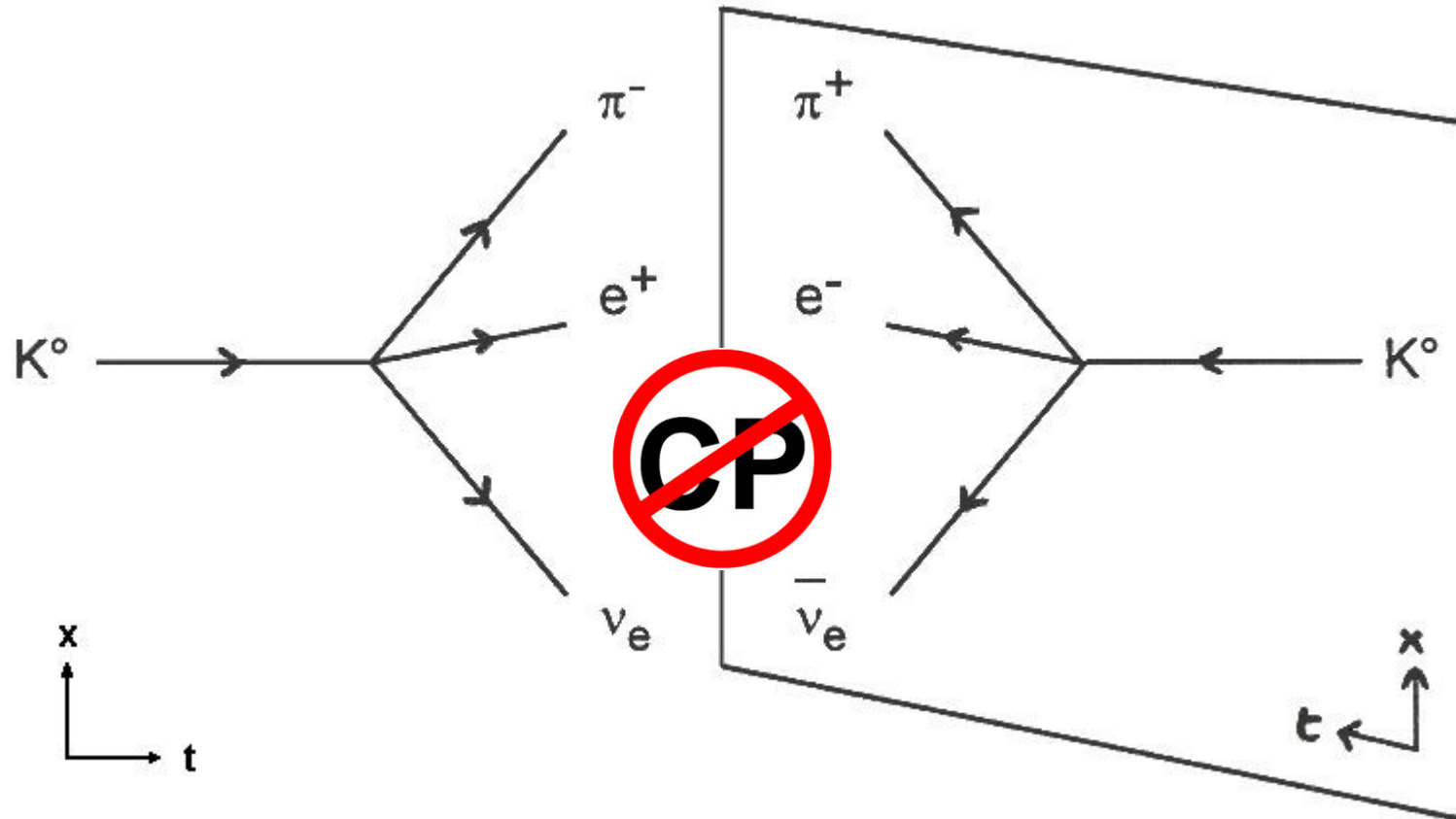
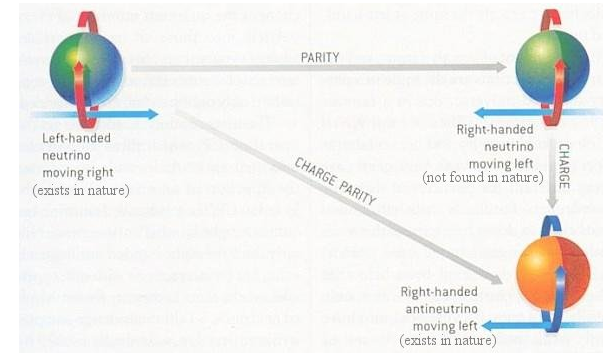
# L'antimatière

Hypothèse de Dirac, le champ d'antimatière est saturé et la production d'antimatière correspond à la libération d'un état dans le champ d'antimatière



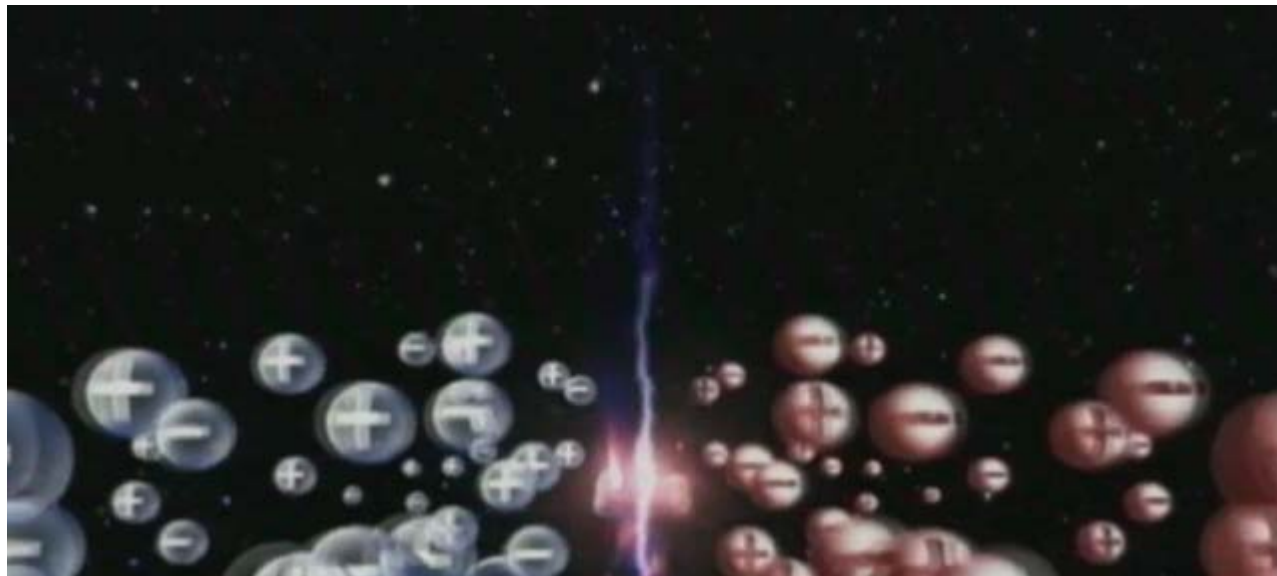
# L'antimatière

Disparue à travers s'asymétrie de CP ?



# L'antimatière

Au-delà de la matière dans un univers d'antimatière exerçant une antigravitation responsable de l'accélération de notre univers ?



# L'antimatière

$\overline{\text{He}}$  ?



AMS-02

# L'INSTRUMENT



# AMS-02

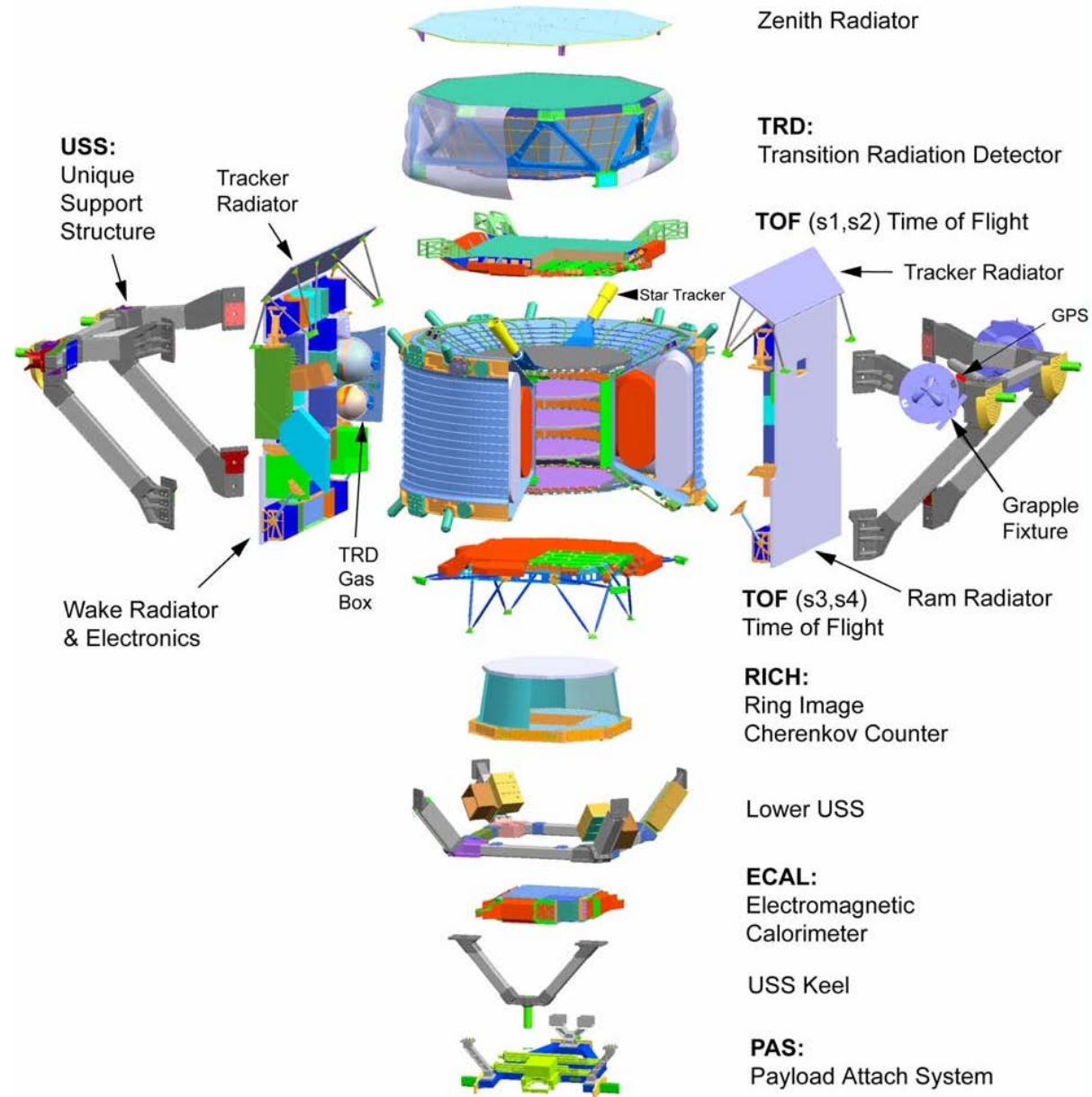
## Instrument

- Mesure de la **charge** :  $Z = 1 - 28$
- **Energy** : GeV – TeV
- séparation **lepton/hadron**
- Distinction **matière-antimatière**
- Mesure de la **masse** des nucléides
- Détection et reconstruction des  $\gamma$



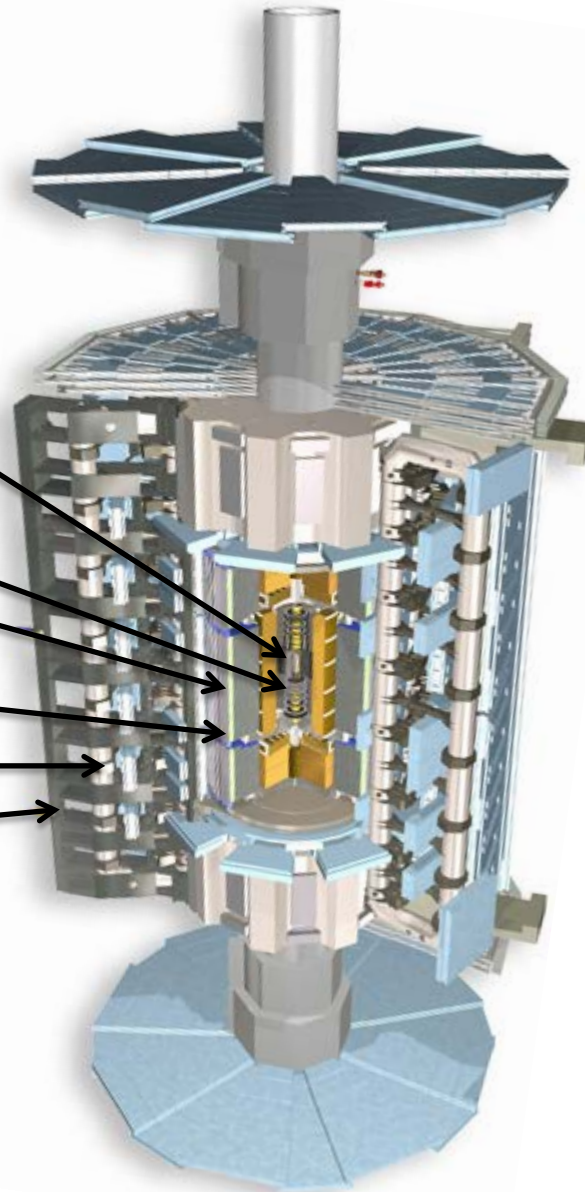
# AMS-02

- Silicon tracker
- TRD
- TOF
- RICH
- ECAL
- MAGNET
- ACC



# ATLAS-02 ?

- Silicon tracker
- TRD
- TOF
- RICH
- ECAL
- MAGNET
- ACC



# AMS-02

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Parameter	Value
Dimensions	3 m × 4 m × 5 m
Weight	8500 kg
Acceptance	0.5 m <sup>2</sup> sr
Power (delivered through the solar panels of the ISS)	2500 W
Altitude on the ISS	400 km
Particle rate near the equator	200 Hz
Particle rate near the magnetic pole	2000 Hz
Data acquisition efficiency on average	85%
Data acquisition efficiency near the equator	96%
Data acquisition efficiency near the poles	65%
Average data acquisition rate [KC12]	10 Mbits/sec
Average event acquisition rate	700 Hz ( $17 \times 10^9$ /year)

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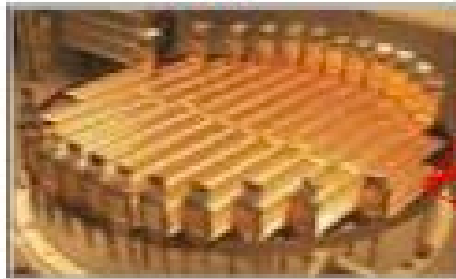
# Rôle des sous-détecteurs

$\pm Z, P, E$  et  $Id$

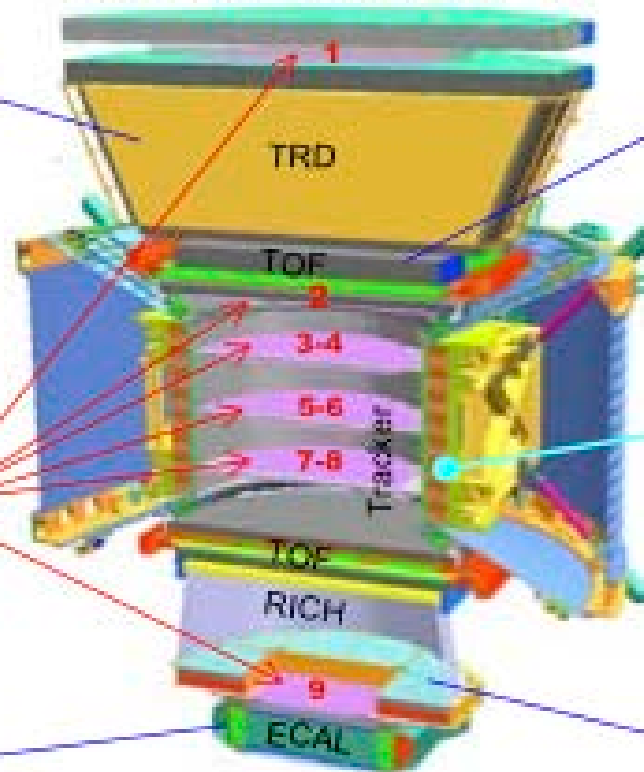
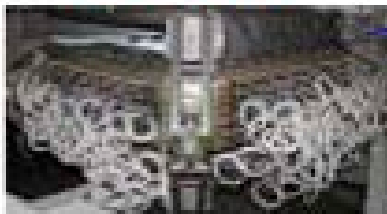
TRD  
Identify  $e^+, e^-$



Silicon Tracker  
 $Z, P$



ECAL  
 $E$  of  $e^+, e^-, \gamma$



TOF  
 $Z, E$



Magnet  
 $\pm Z$



RICH  
 $Z, E$



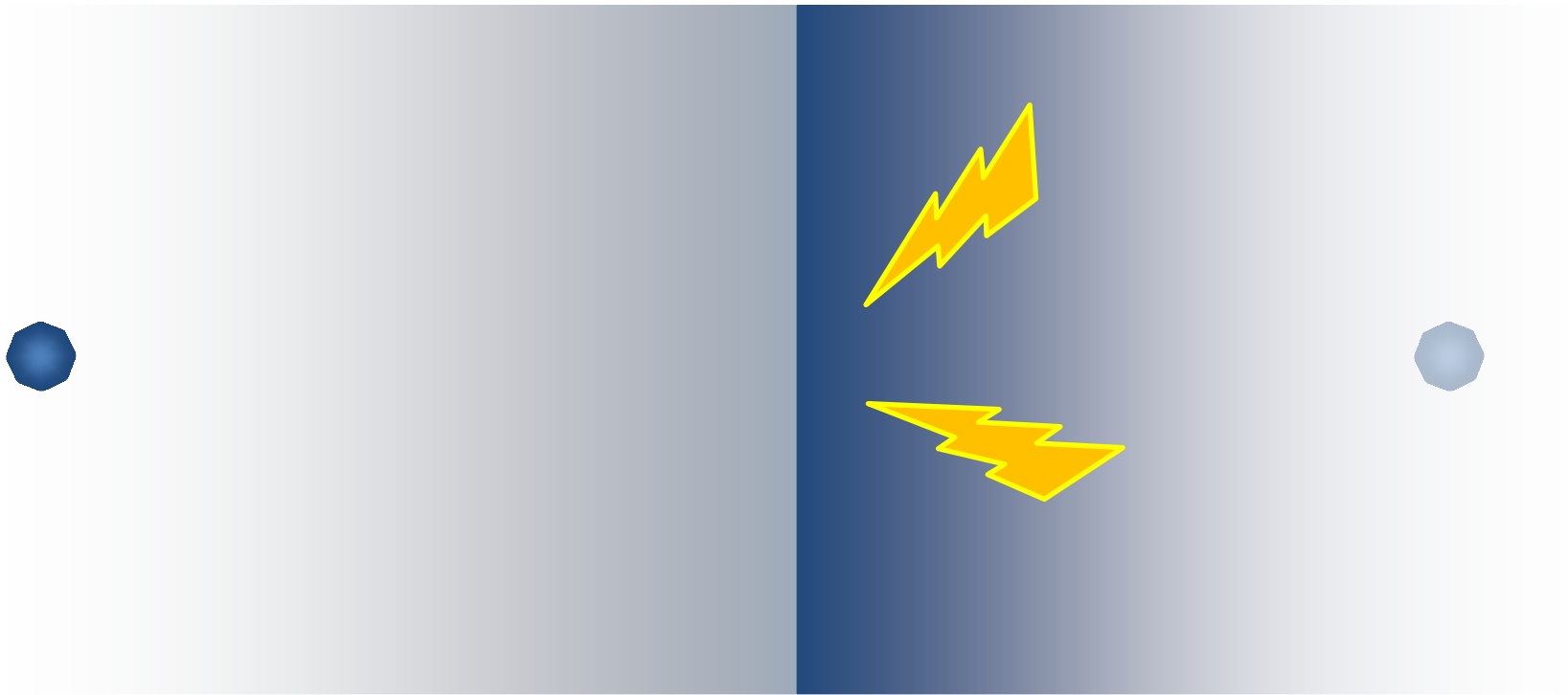


AMS-02

# TRD : LE DETECTEUR À RAYONNEMENT DE TRANSITION

# Le rayonnement de transition

une particule chargée qui traverse une interface entre deux milieux de constantes diélectriques différentes émet un rayonnement au passage de la discontinuité



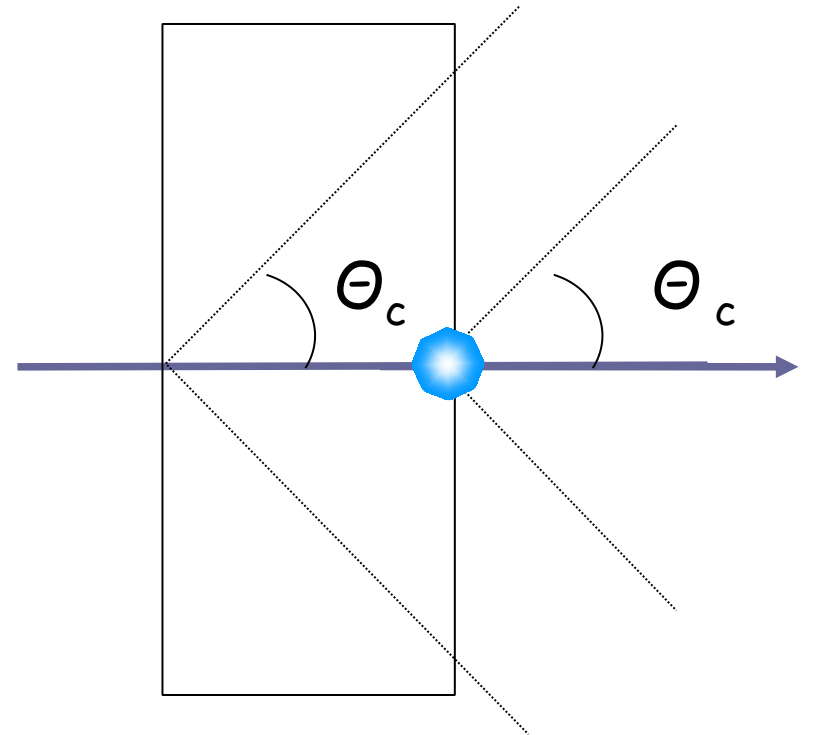
# Le rayonnement de transition

L'énergie rayonnée par une particule de charge  $ze$  traversant une frontière entre deux milieux de fréquence plasma  $\omega_p$  différentes s'écrit :

$$W = \frac{2}{3} \alpha \hbar z^2 \gamma \omega_p$$

L'angle d'émission est :

$$\Theta_c \approx \frac{1}{\gamma}$$





# Le rayonnement de transition

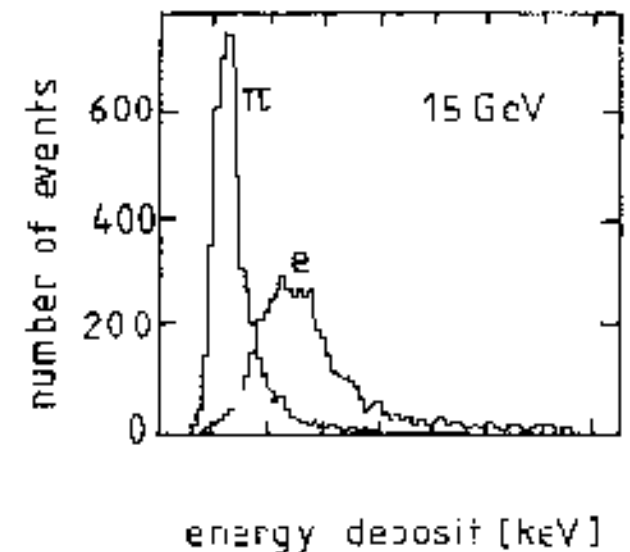
Des particules de même énergie possèdent des  $\gamma$  de valeur différente. Pour des pions et des électrons de 15 GeV :

$$\text{Pion : } \gamma = \frac{E}{m} = \frac{15 \text{ GeV}}{0.140} = 110$$

$$\text{Electrons : } \gamma = \frac{E}{m} = \frac{15 \text{ GeV}}{0.000511} = 30\,000$$

La radiation de transition permet de distinguer ces deux types de particules :

$$W \propto \gamma \omega_p$$

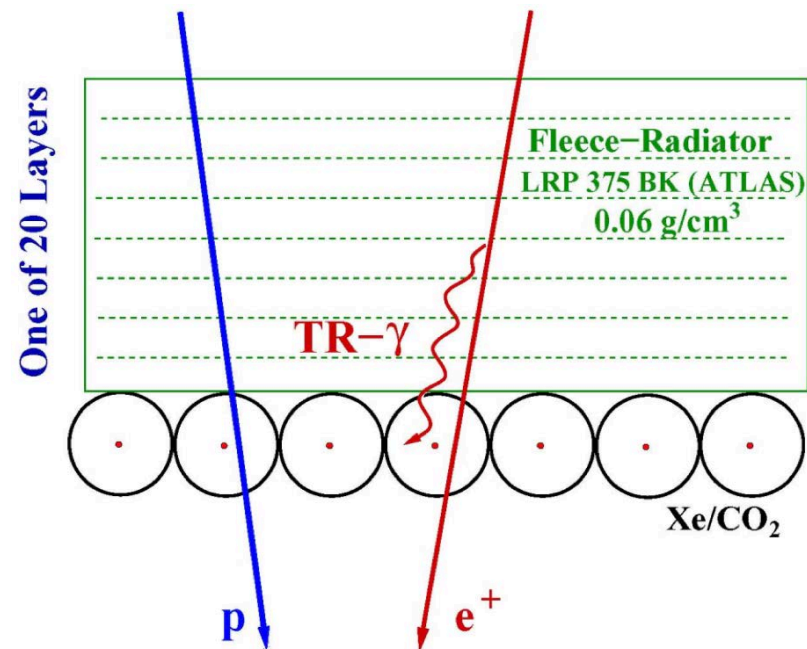


# Le rayonnement de transition

Le nombre moyen de photons rayonnés est proportionnel au produit  $\alpha\gamma$

$$\langle N \rangle \approx \alpha \gamma \hbar \frac{\omega_p}{\omega}$$

Le spectre en énergie des photons émis correspond à la bande des X (entre typiquement 10 a 30 keV).

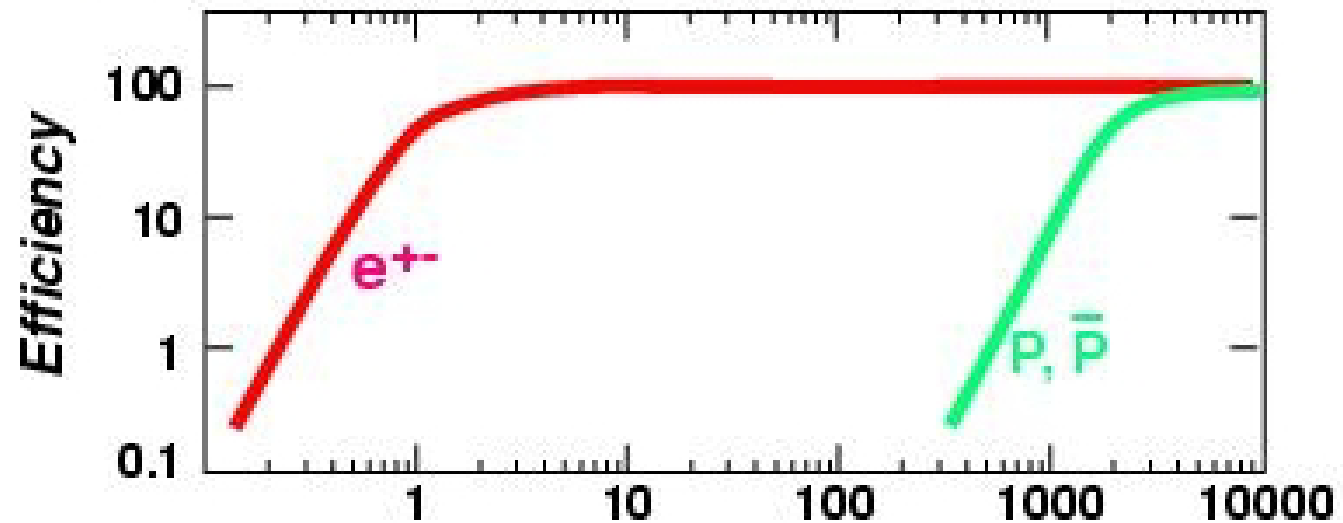


# TRD

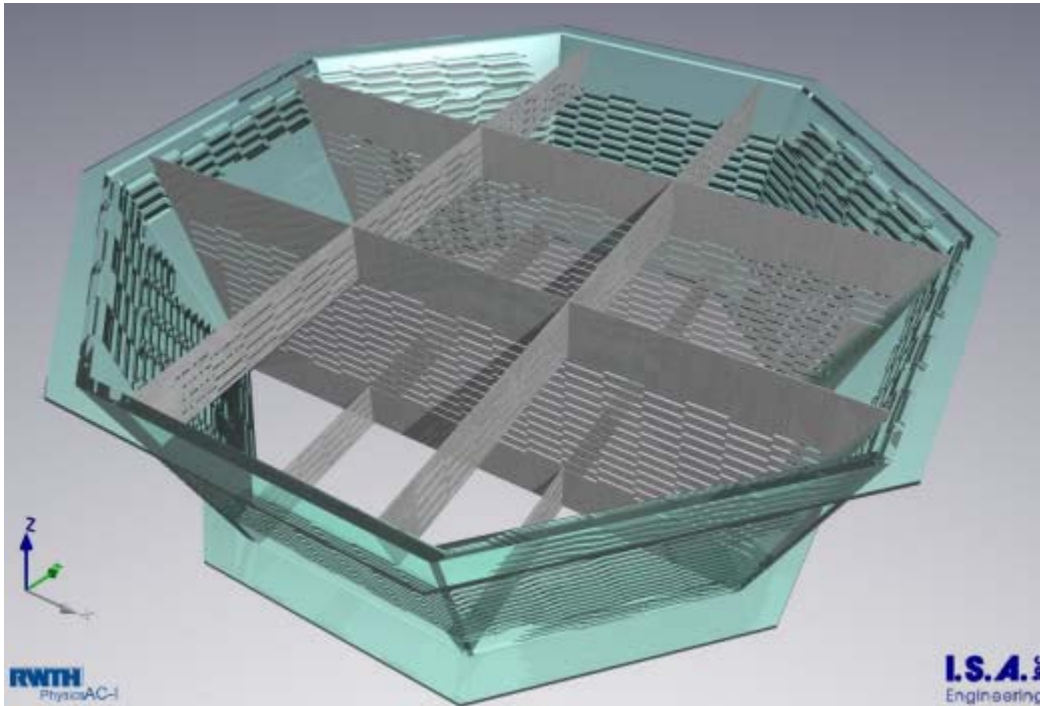
TRD module



TRD:  $e^{\pm}$  / hadron rejection  $> 10^3$



# TRD



**Required mechanical accuracy < 0.1 mm**  
**Expected weight: 53 kg measured: 52 kg**

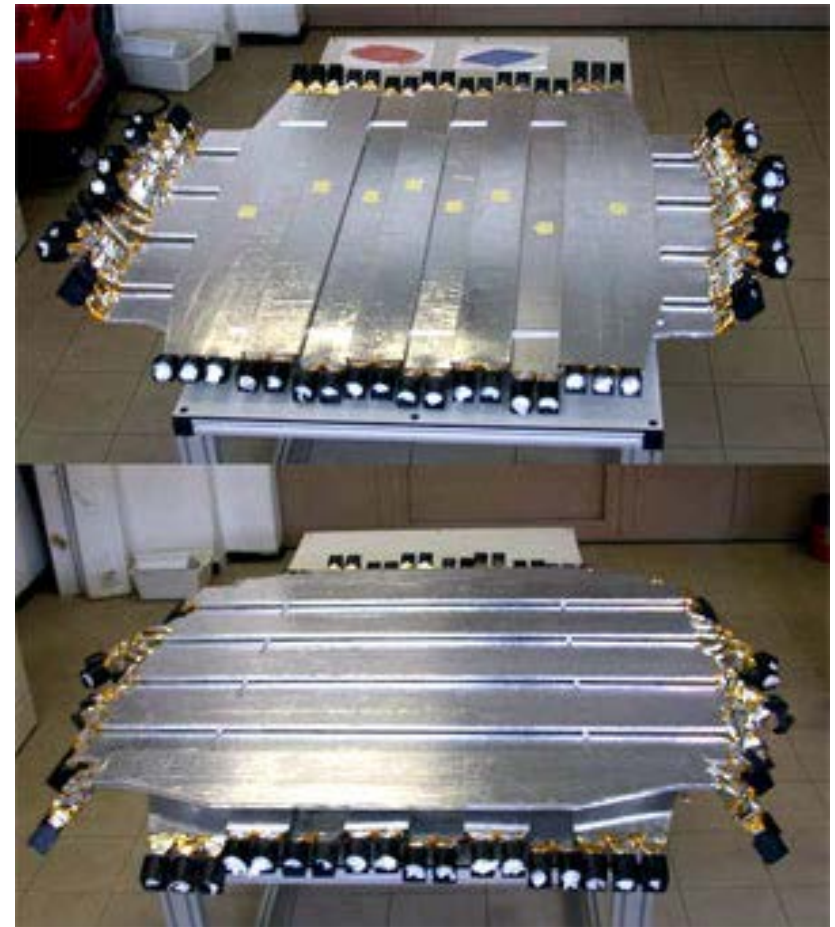


AMS-02

# TOF : TEMPS DE VOL DES PARTICULES

# Time-of-flight

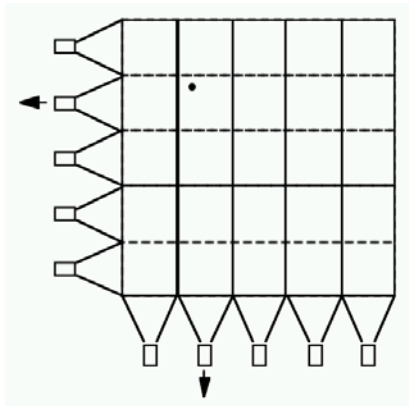
- Premier niveau de déclenchement pour les particules chargées
- Direction des particules (montantes/descendantes)
- Séparation entre  $e^+/e^-$  et  $p/\bar{p}$  jusqu'à 2 GeV
- Mesure de la charge absolue des particules incidentes



# Time-of-flight

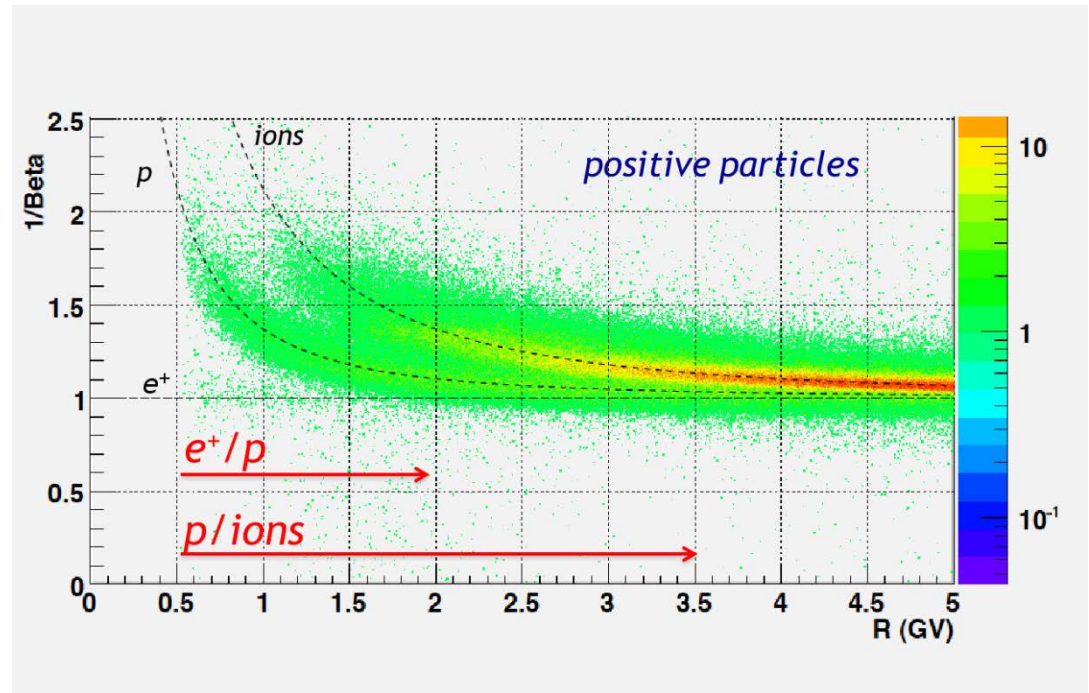
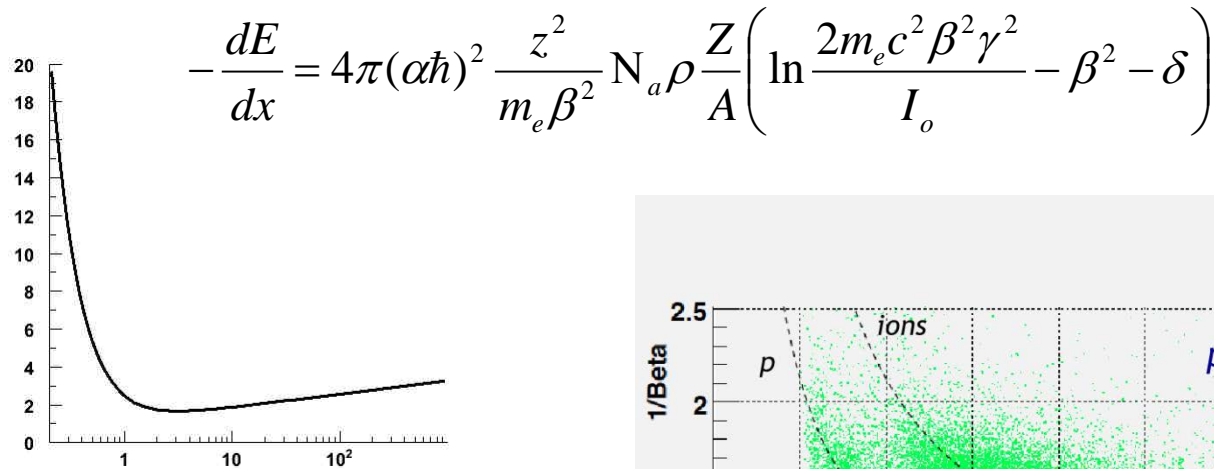
The subdetector is made of polyvinyltoluene **scintillator paddles** of rectangular or trapezoidal shape having approximate dimensions of 1x12x120 cm<sup>3</sup>.

Plaques de scintillateurs couplés à des **photomultiplicateurs**



# AMS-02

TOF allows to distinguish positrons from protons in the rigidity range 0.5 to 2GV and protons from ions up to R 3,5 GV.





# AMS-02

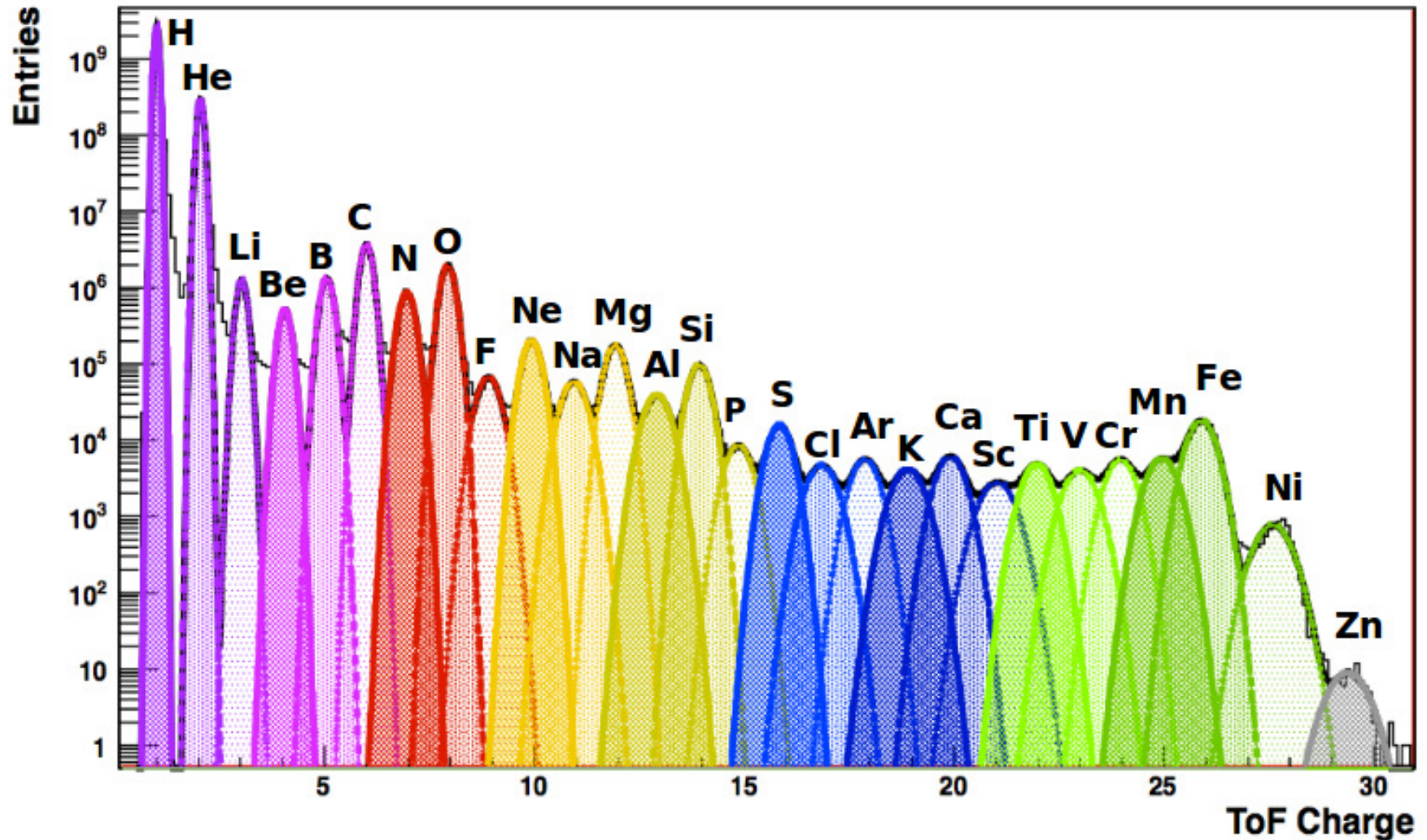
L'ionisation est proportionnelle au carré de la charge des particules.

Le TOF détermine la charge des particules jusqu'à  $Z = 30$ ,

$$-\frac{dE}{dx} = 4\pi(\alpha\hbar)^2 \frac{z^2}{m_e\beta^2} N_a \rho \frac{Z}{A} \left( \ln \frac{2m_e c^2 \beta^2 \gamma^2}{I_o} - \beta^2 - \delta \right)$$

# AMS-02

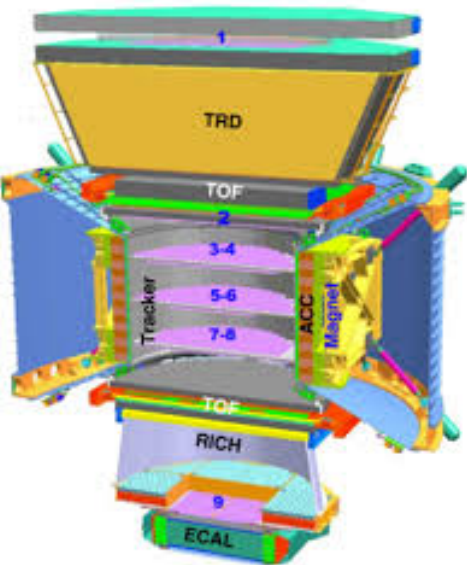
2 années d'opération sur l'ISS





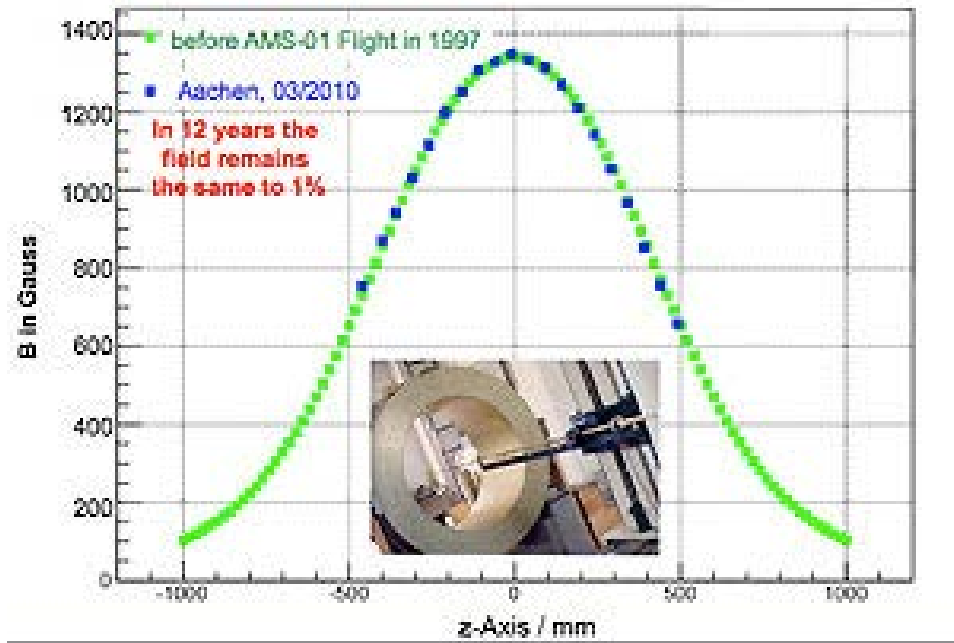
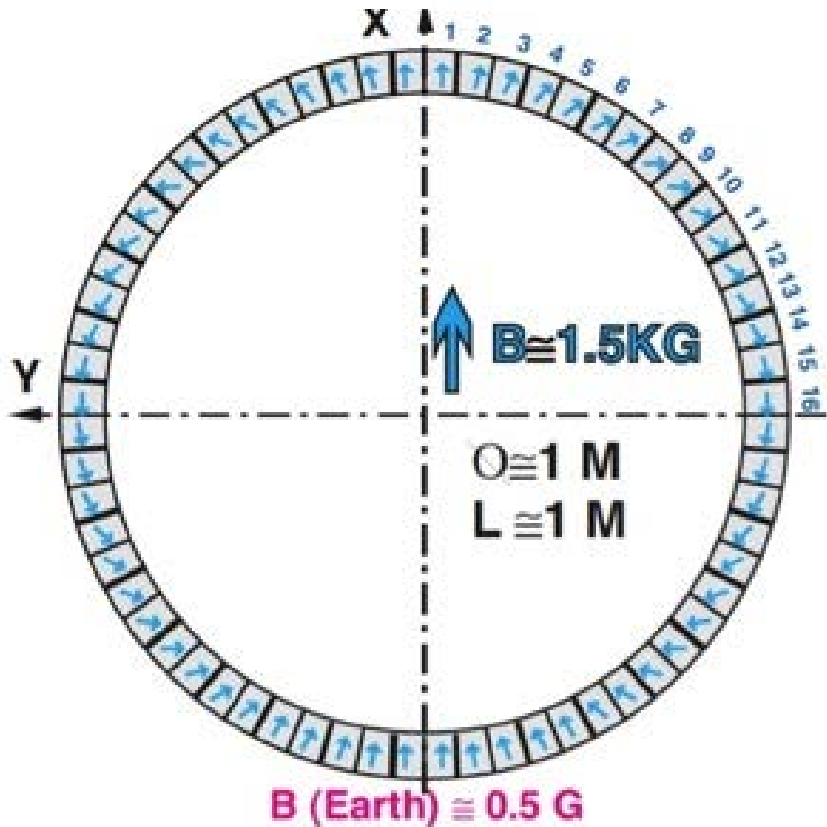
AMS-02

# L'AIMANT

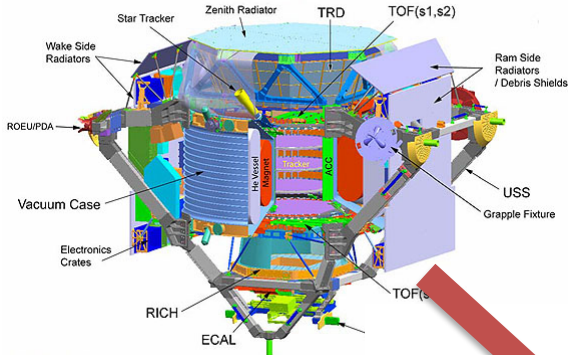


# AMS-02

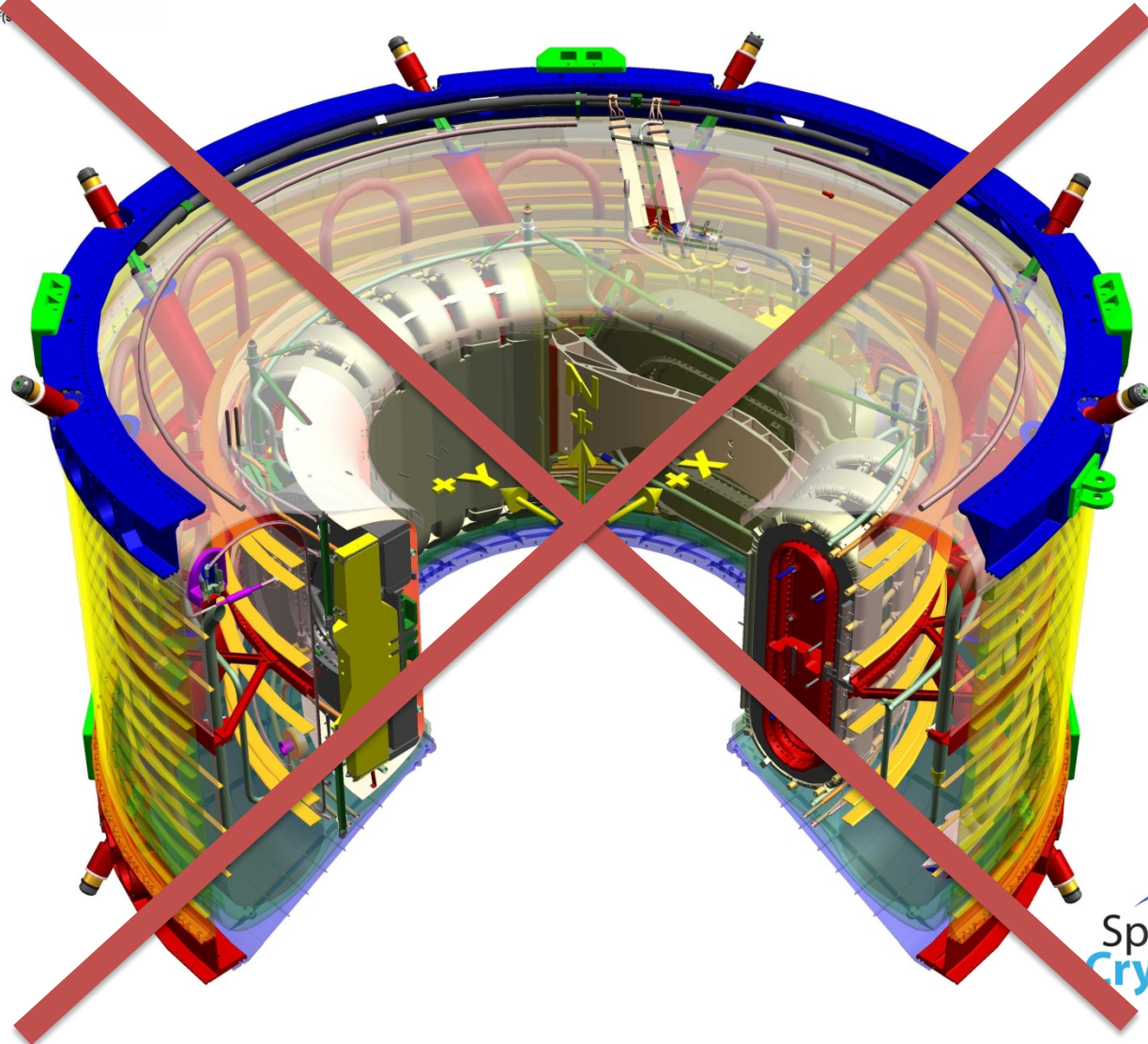
The permanent magnet is a cylinder of 1m in diameter and height. It consists of over 6000 Neodinium-Iron-Boron blocks of dimensions 2x2x1 inches<sup>3</sup> glued together with epoxy. It develops a uniform magnetic field of 0,15T



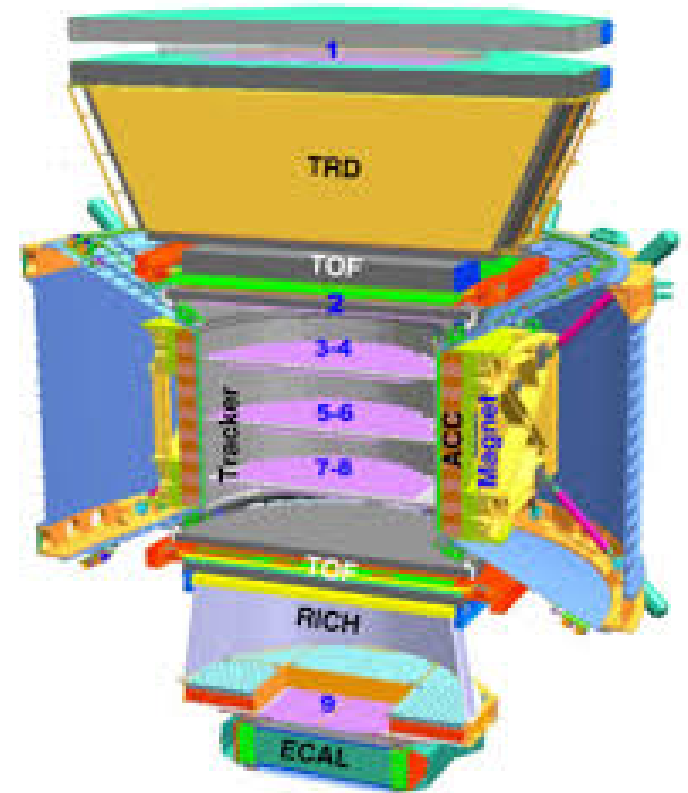
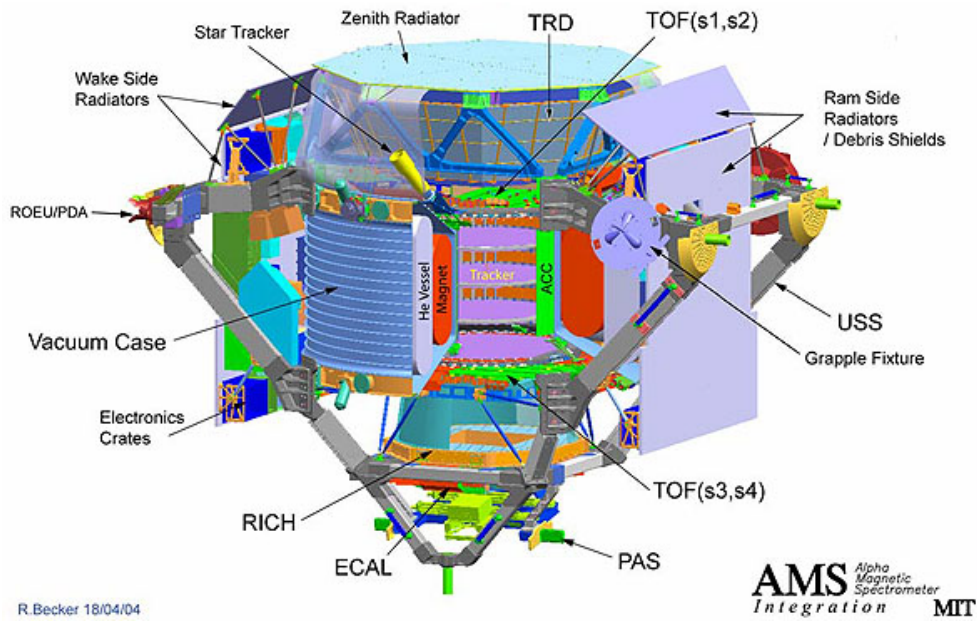
# AMS 02



# AMS-02



# AMS-02





AMS-02

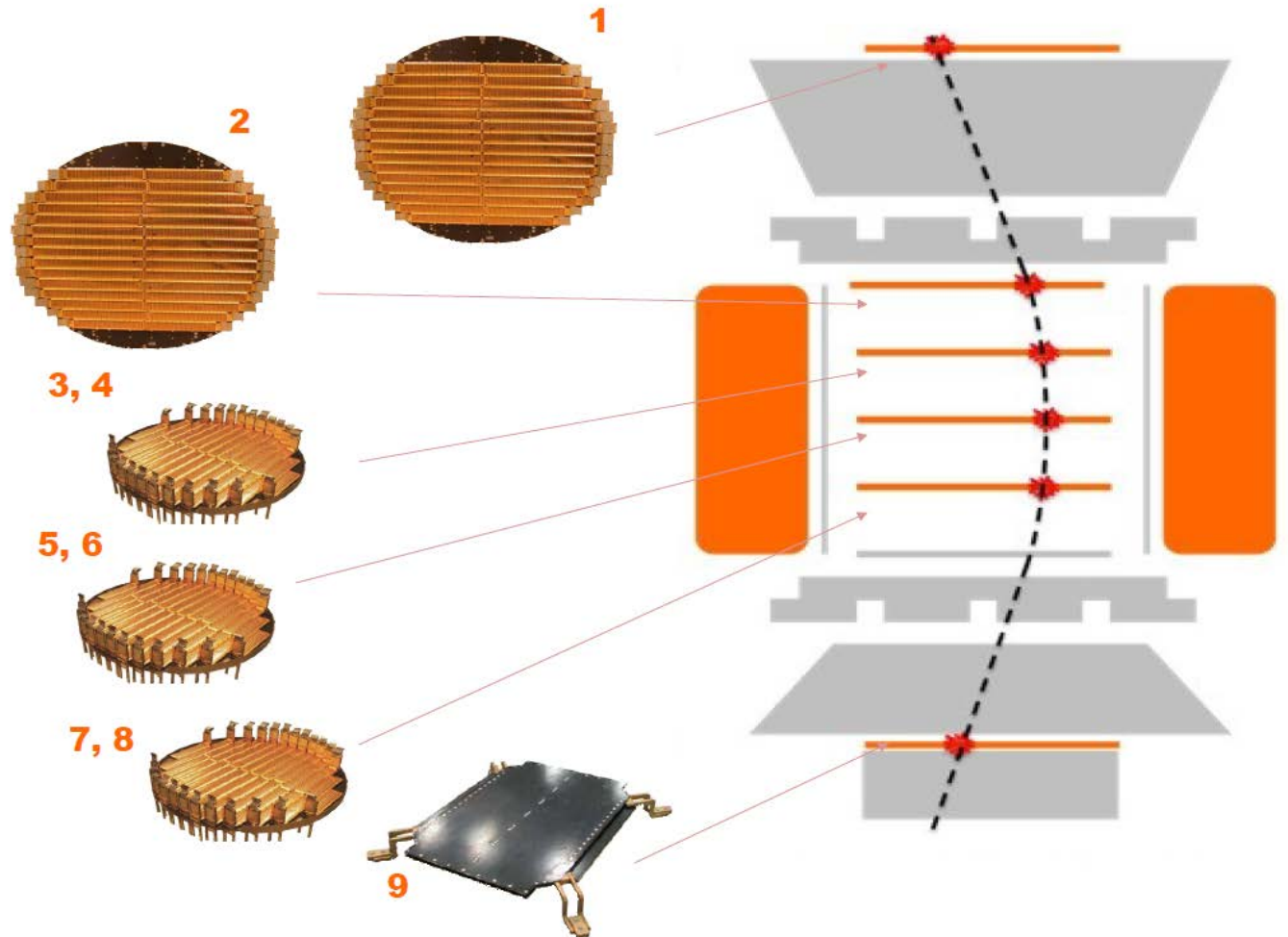
# LE TRACKER AU SILICIUM

# Silicon tracker

2264 sensors assembled  
in 192 read-out units, the  
ladders

Finally assembled in **9  
planes** or layers in the  
final setup, **7 of them  
inside the permanent  
magnet,**

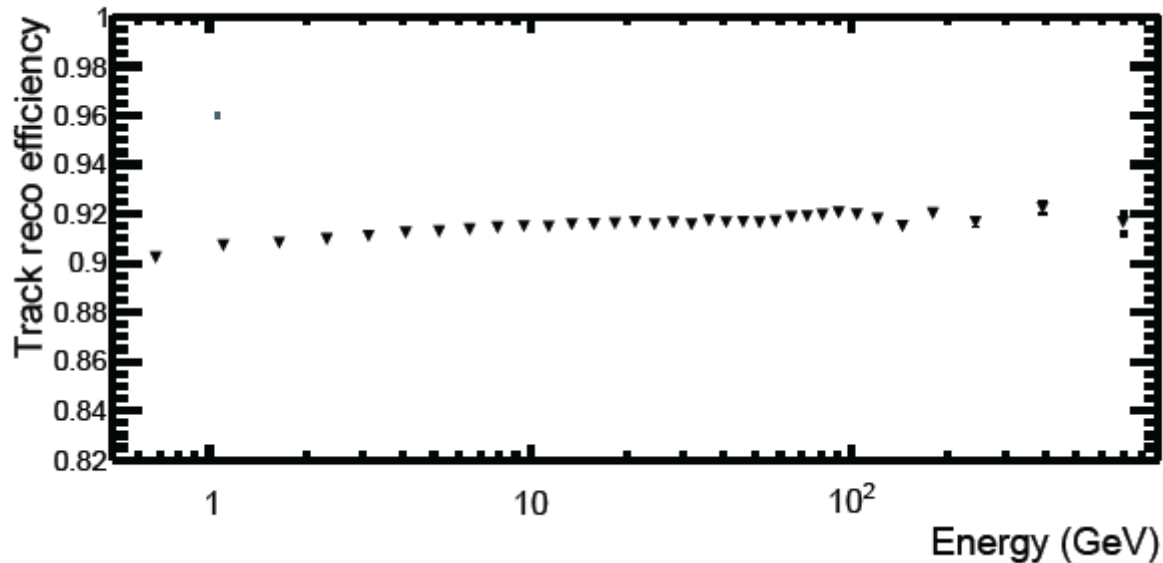
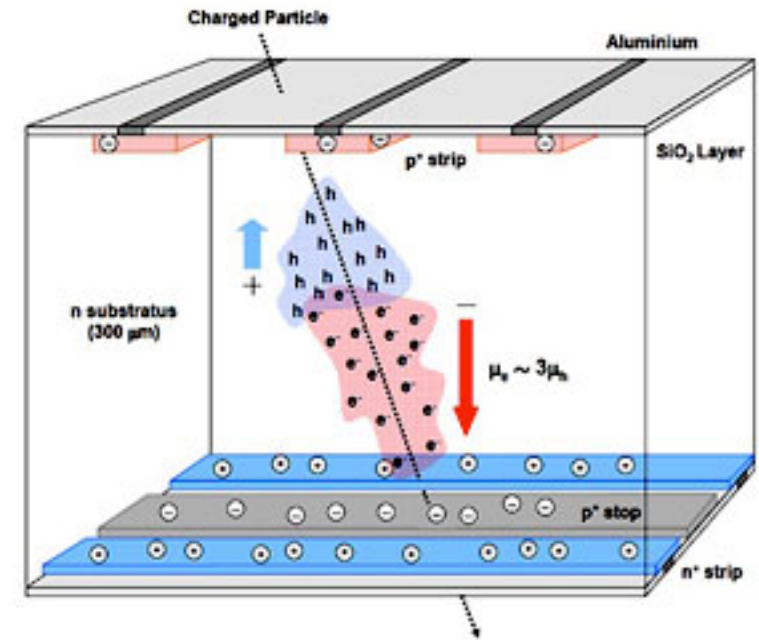
2 others outside





# Silicon tracker

The basic element of the tracker are **double-sided micro-strip sensors** consisting on a substrate of high-purity doped silicon (72 41mm<sup>2</sup>, 300  $\mu\text{m}$  thick) surrounded by aluminum strips running in orthogonal directions, with interstrips distance of 50  $\mu\text{m}$

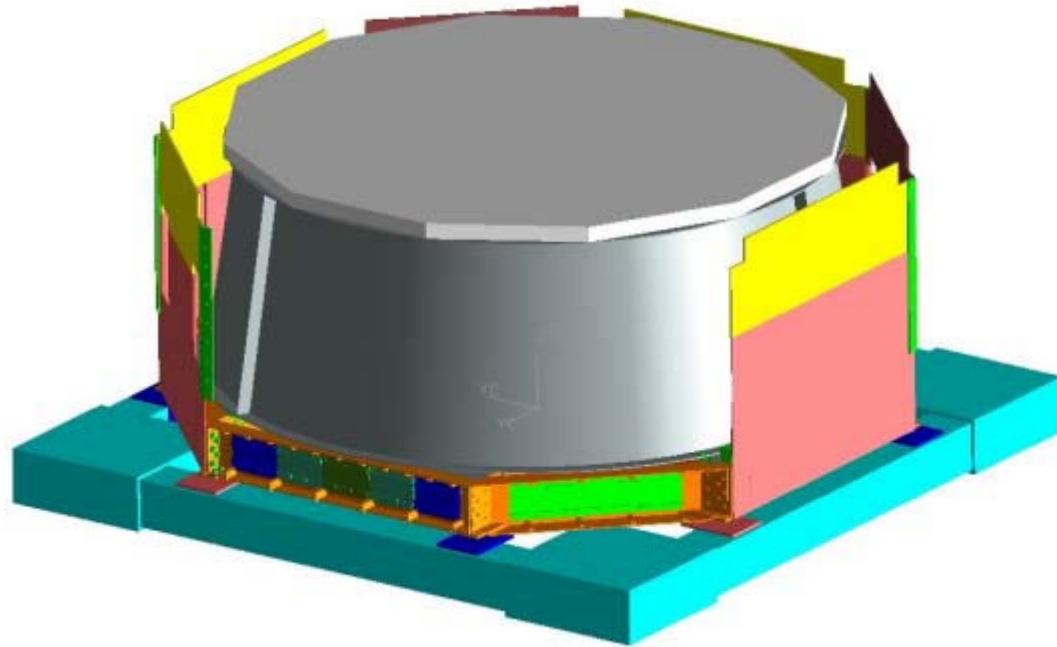




AMS-02

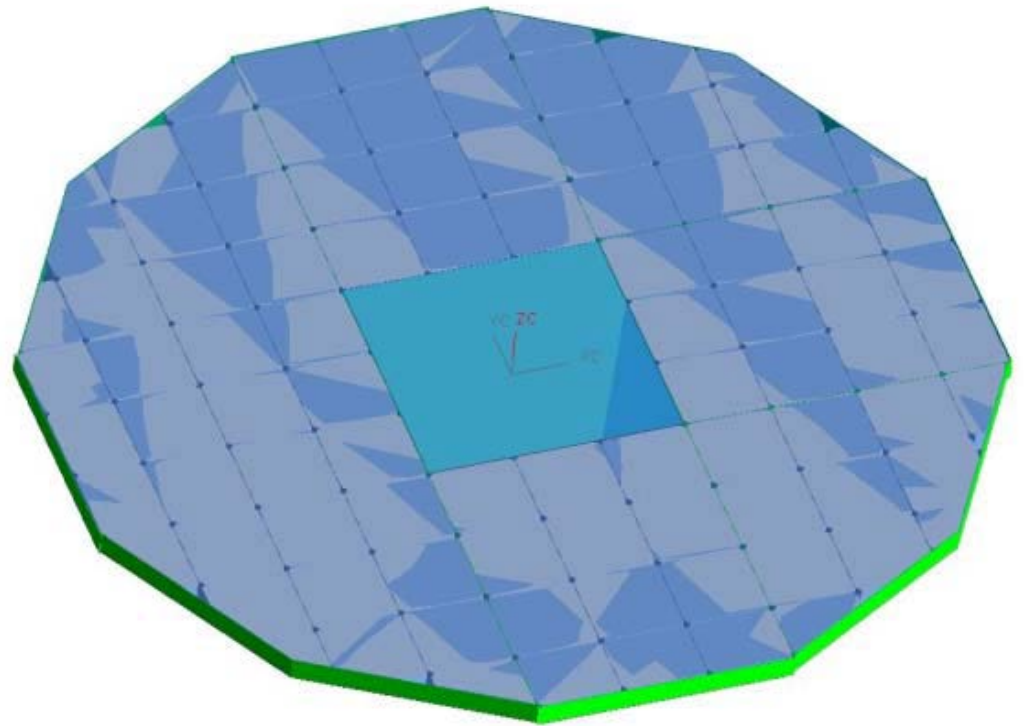
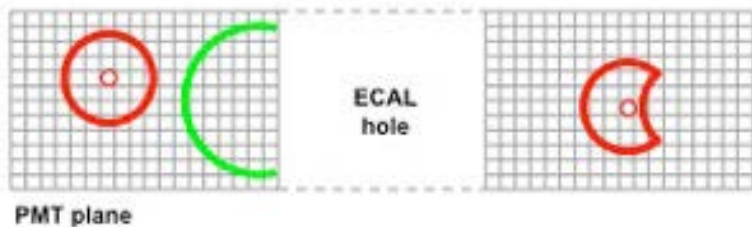
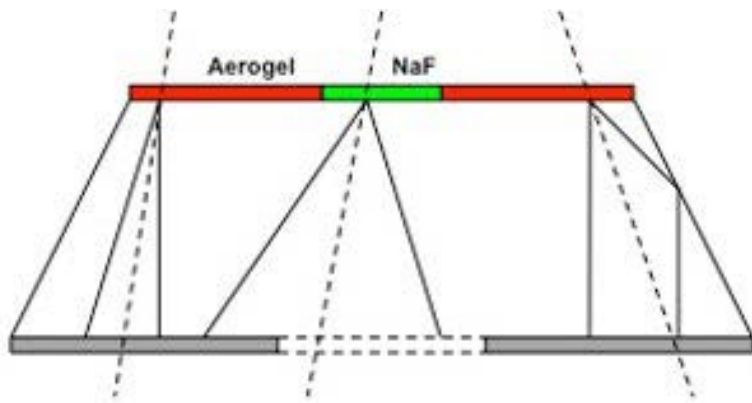
# **RICH : DÉTECTEUR CHERENKOV**

# RICH



# RICH

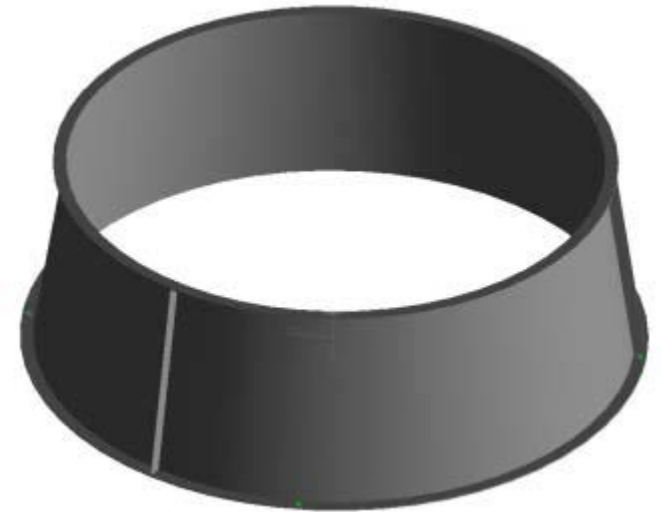
- Un pad central de fluor de sodium (3 mm)
- Entouré d'un damier d'aérogel (30 mm)



# RICH



- Guides de lumière et photomultiplicateurs

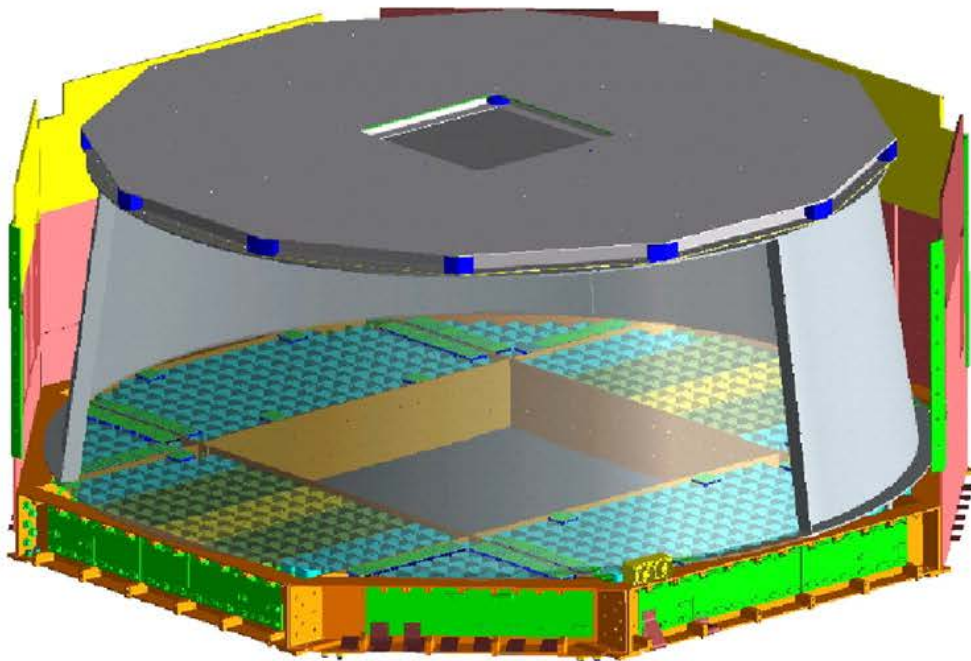


- Réflecteur en aluminium



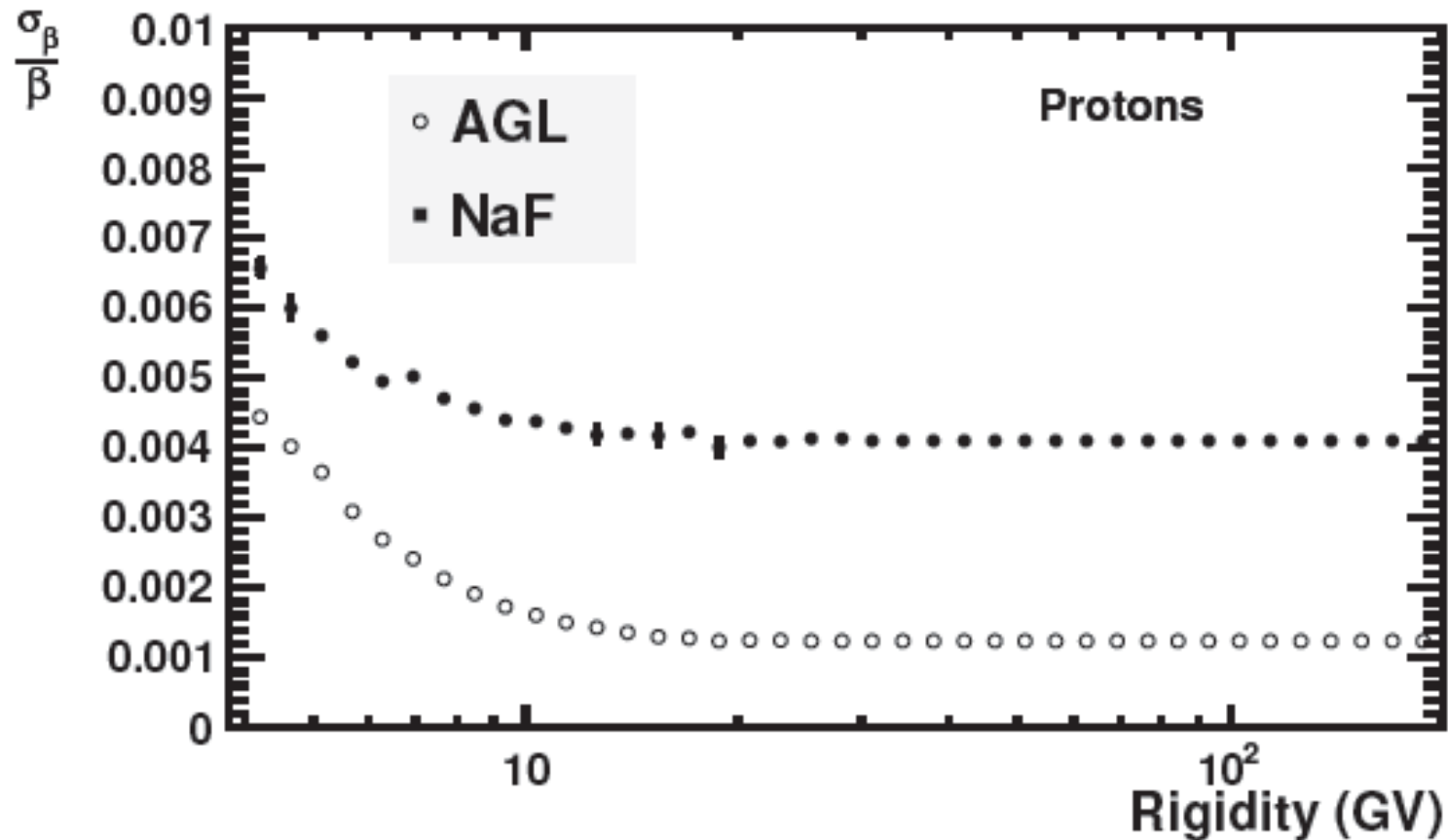
# RICH

- The RICH detector of AMS-02. The NaF square is visible at the centre of the radiator plane (left). View of the assembled RICH detector at CIEMAT (right).



# RICH

Relative resolution of velocity for proton events in aerogel (open circles) and NaF (full circles) as a function of rigidity



# Détermination de la masse

$$m = R.Z. \frac{\sqrt{1 - \beta^2}}{\beta}$$

**R** est donné par le tracker

**Z** : tracker, TOF et RICH

**$\beta$**  : RICH et TOF

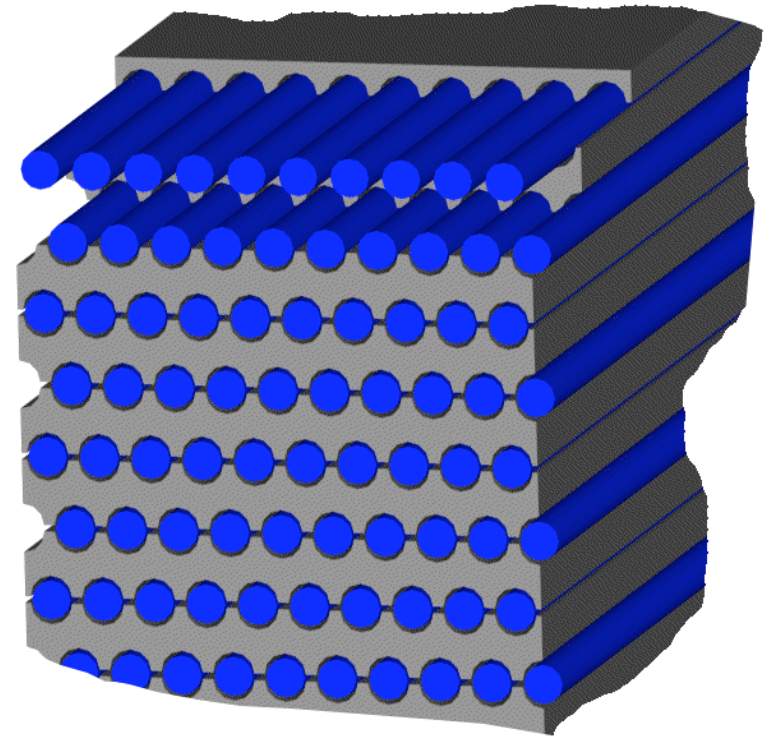
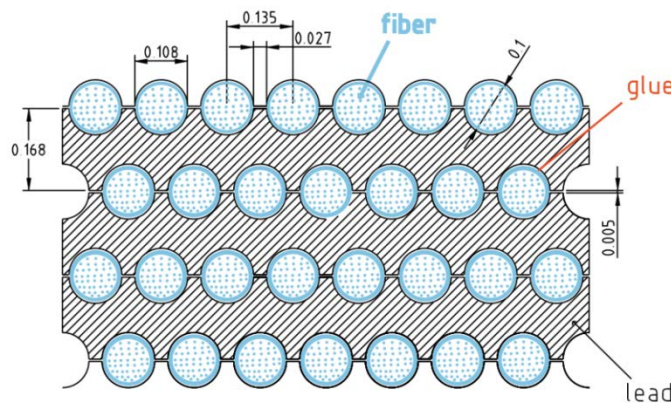




AMS-02

**ECAL**

# ECAL

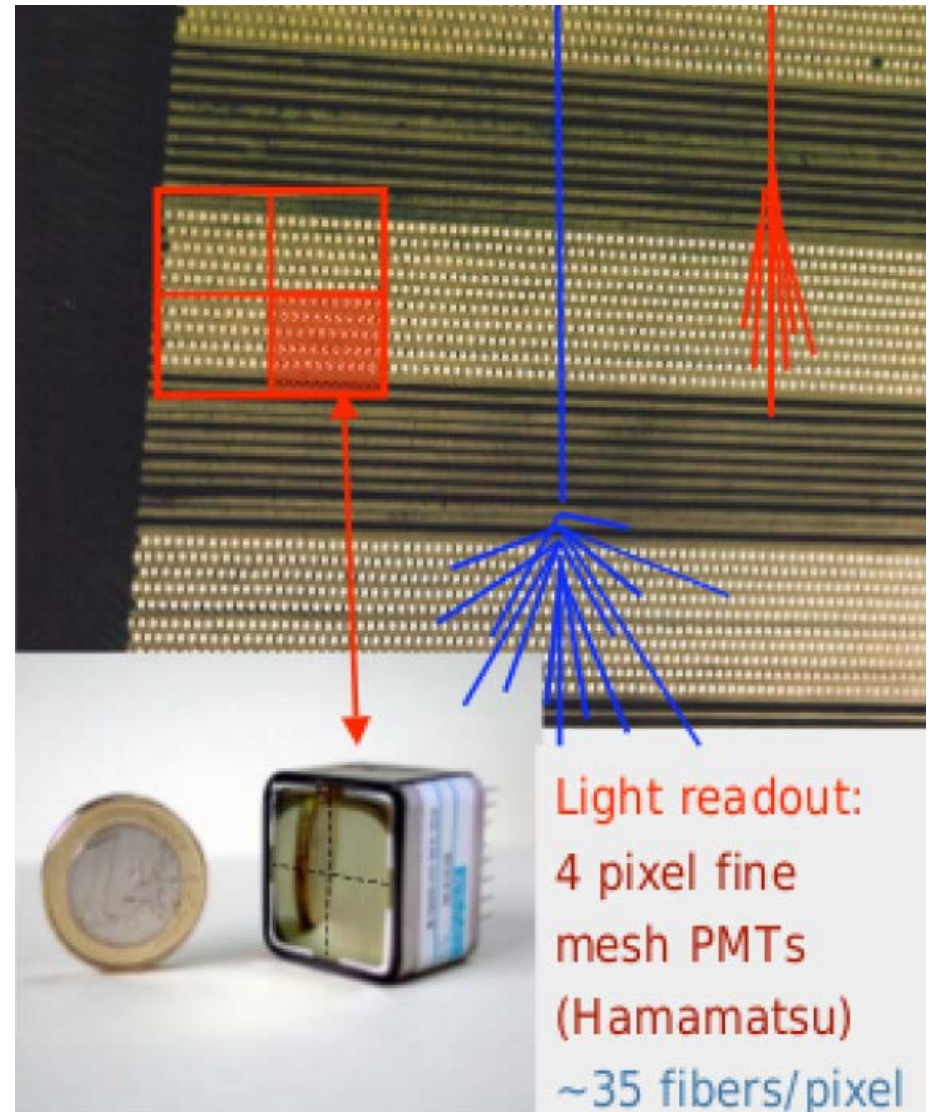


A 3-dimensional imaging calorimeter composed of a sandwich of **9 superlayers**. Each superlayer consists of scintillating silicium fibers with a diameter of 1mm inserted in 11 lead leaves with a thickness of 1:68mm. Each layer has a total thickness of 18:5 mm.

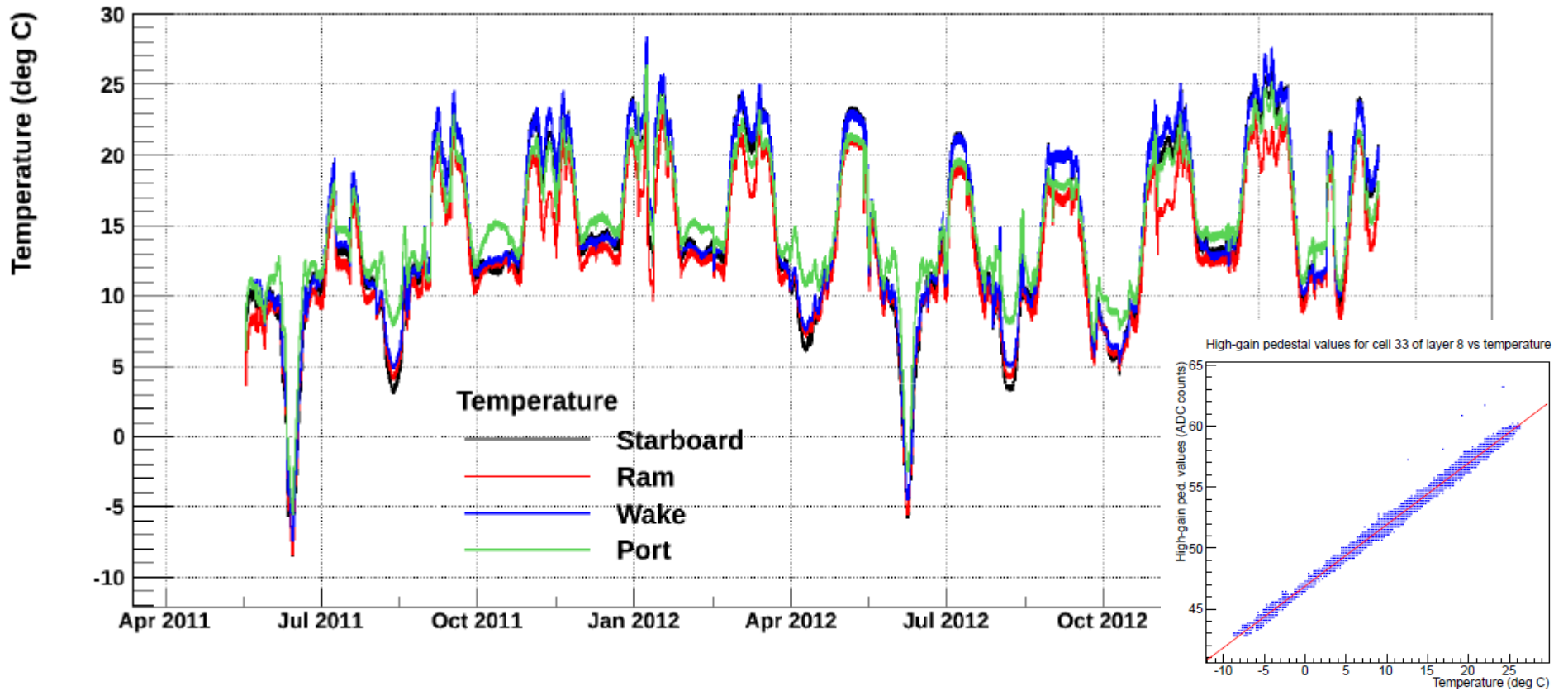
# ECAL

The light guided inside the fibers is collected at one end of them by 4-anode photomultipliers Hamamatsu R7600 00-M4.

Each PMT (dynode) consists of two pixels in height and two in width, for a total of 4 anodes.



# ECAL

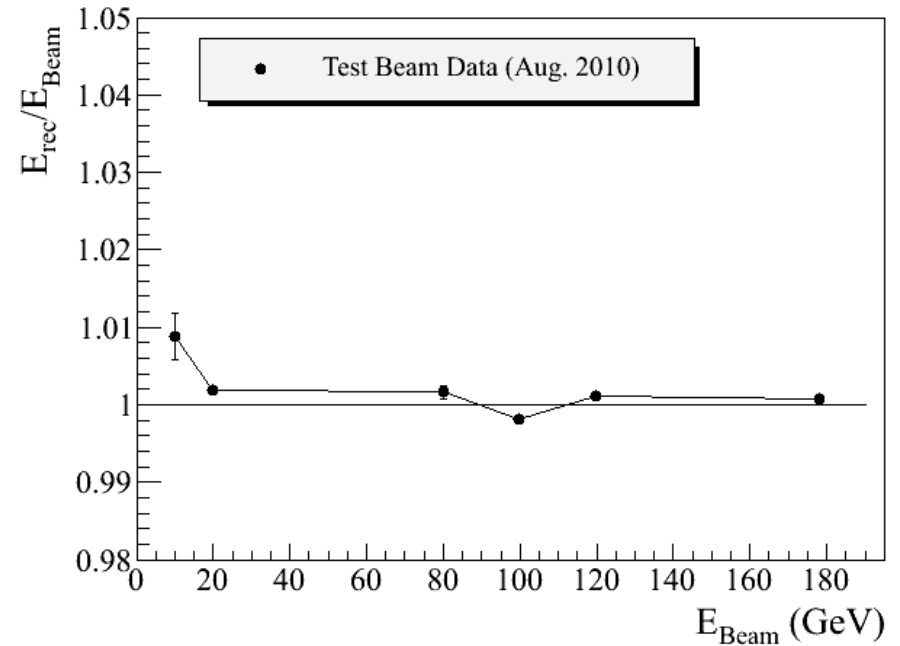


(a) HG values against temperature

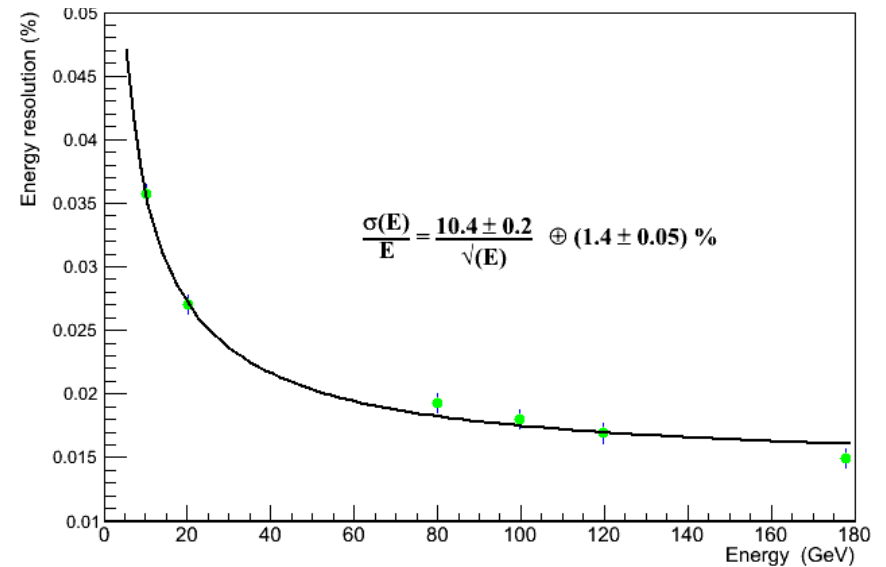
Evolution de la température sur les faces du détecteur (2 ans)

# ECAL

- Tests en faisceau de la réponse du ECAL

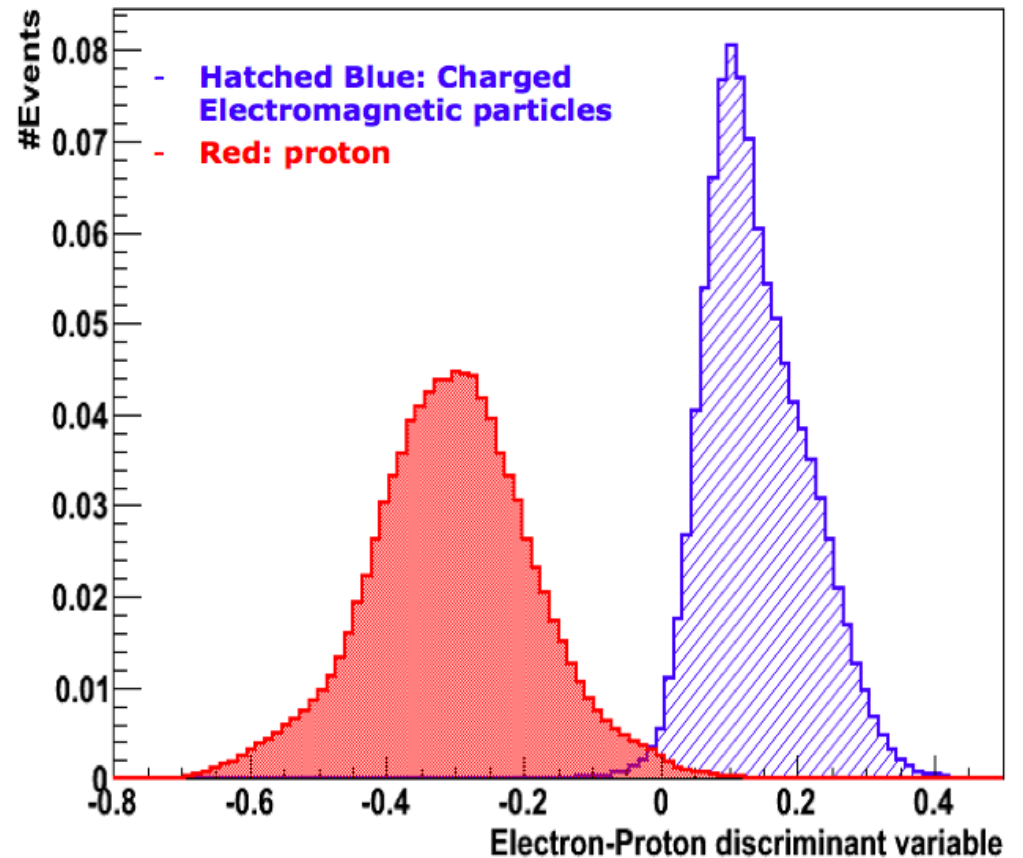


- Résolution en fonction de la rigidité



# ECAL

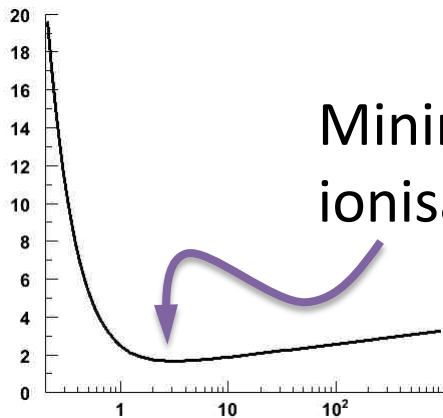
Séparation entre électrons/positrons et protons



Boosted Decision Tree distribution for electrons and positrons (blue distribution), as well as for protons (red distribution) for all energies.

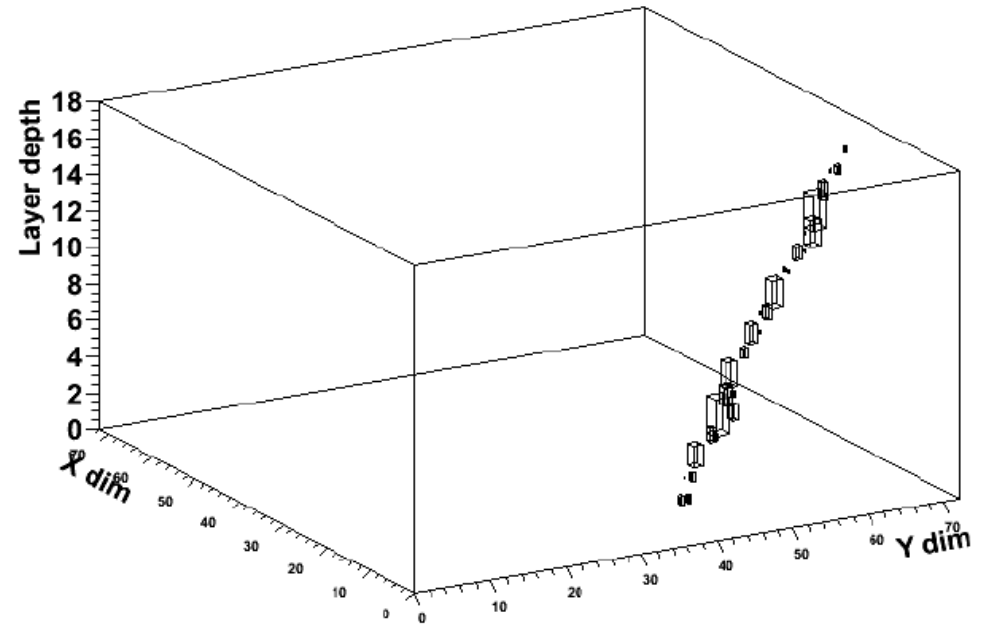
# ECAL@MIP

Le passage des autres  
particules que les électrons  
peut être identifié par leur  
traces au minimum  
d'ionisation



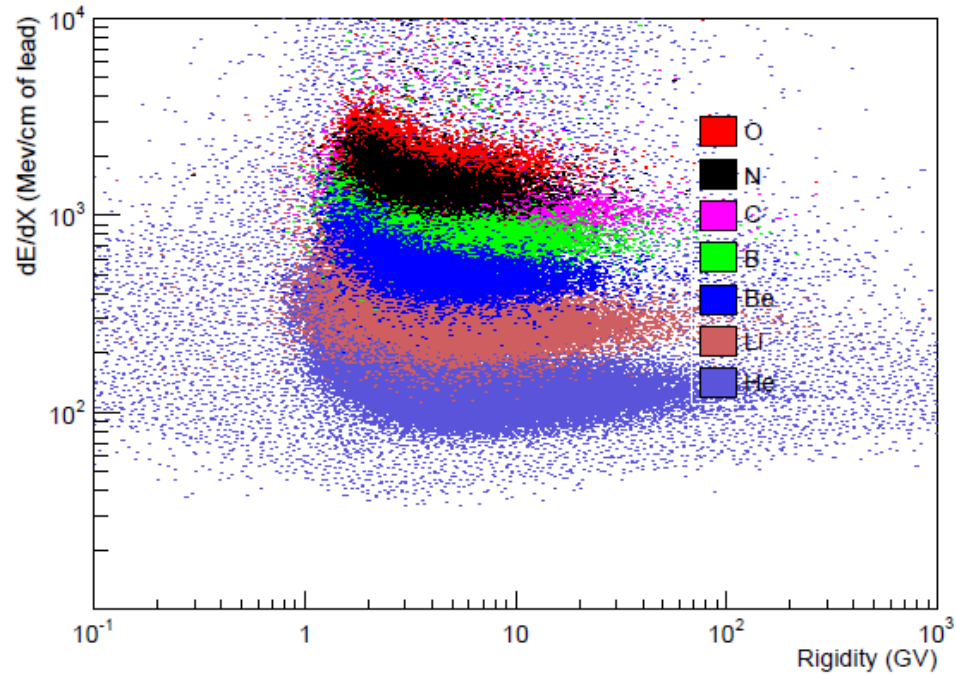
Minimum  
ionisant

$$-\frac{1}{\rho} \frac{dE}{dx} \Big|_{\min} \approx 2 \text{ MeV} \cdot \text{cm}^2 \cdot \text{g}^{-1}$$



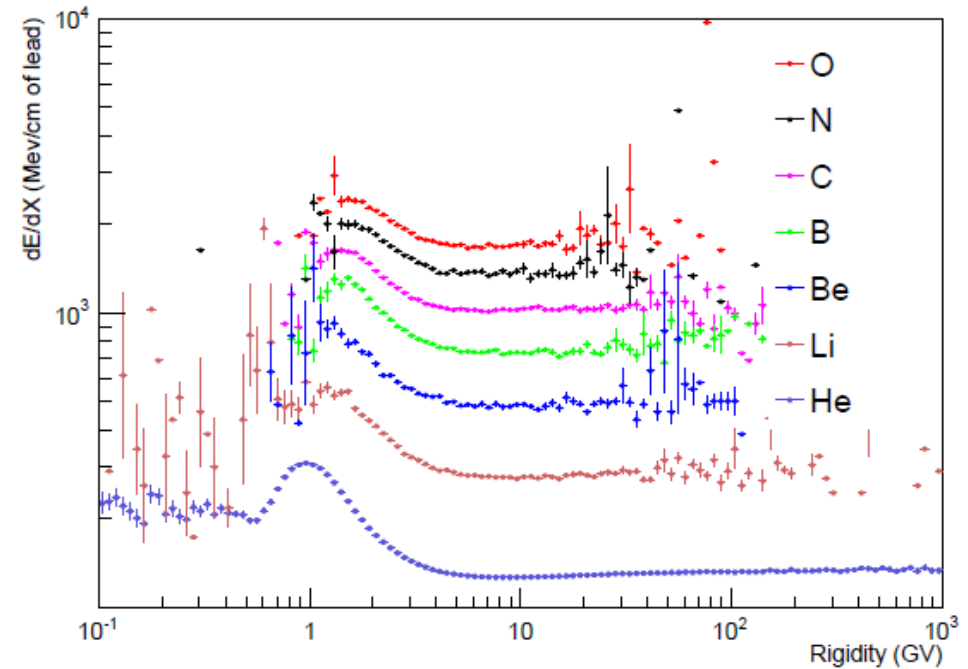
# ECAL

dE/dX vs rigidity until N = 8



(a)  $dE/dX$  vs Rigidity

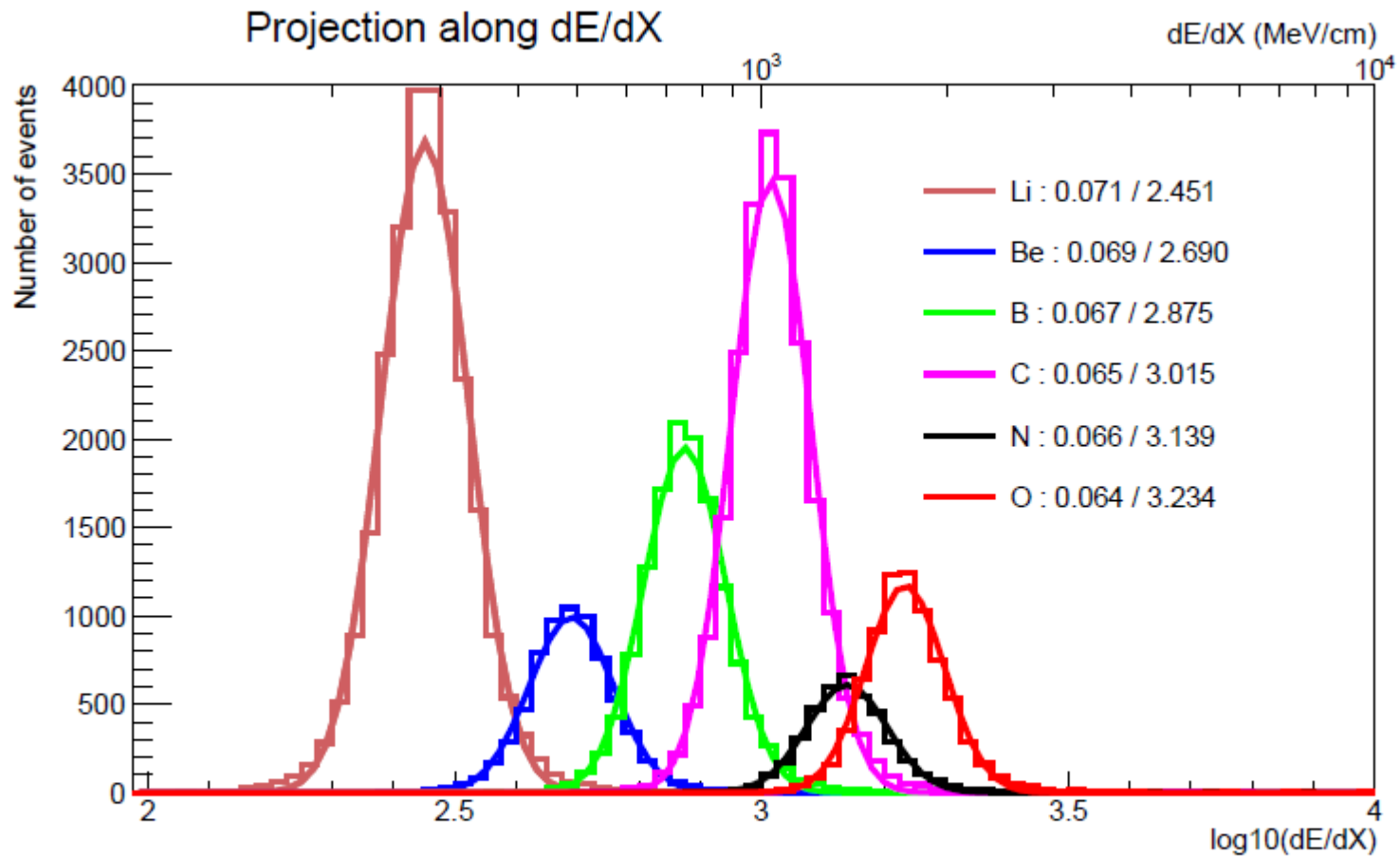
Bethe-Bloch curves until N = 8



(b) Profiles of the previous plot



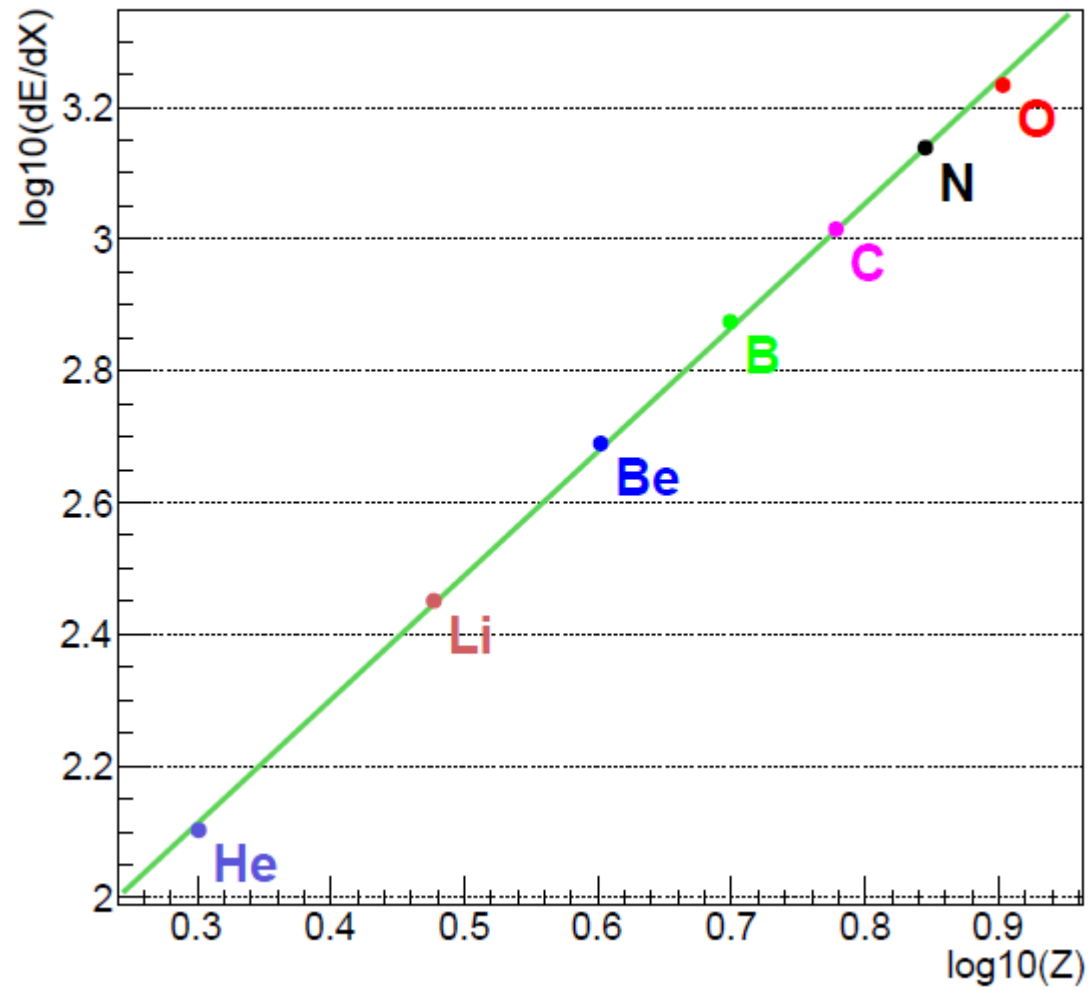
# ECAL



(c) Projection along  $dE/dX$

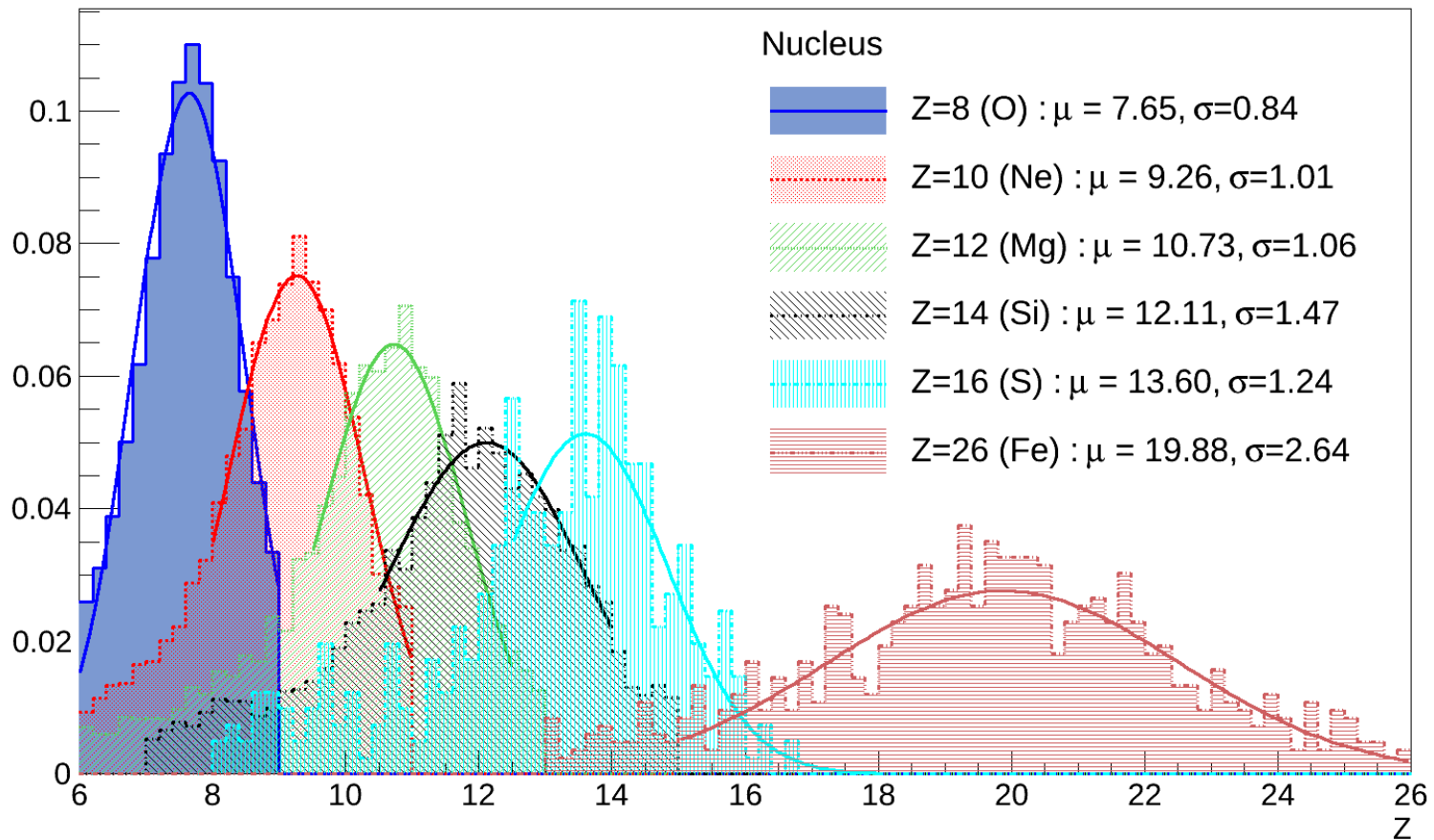
# ECAL

Linearity check until Z=8

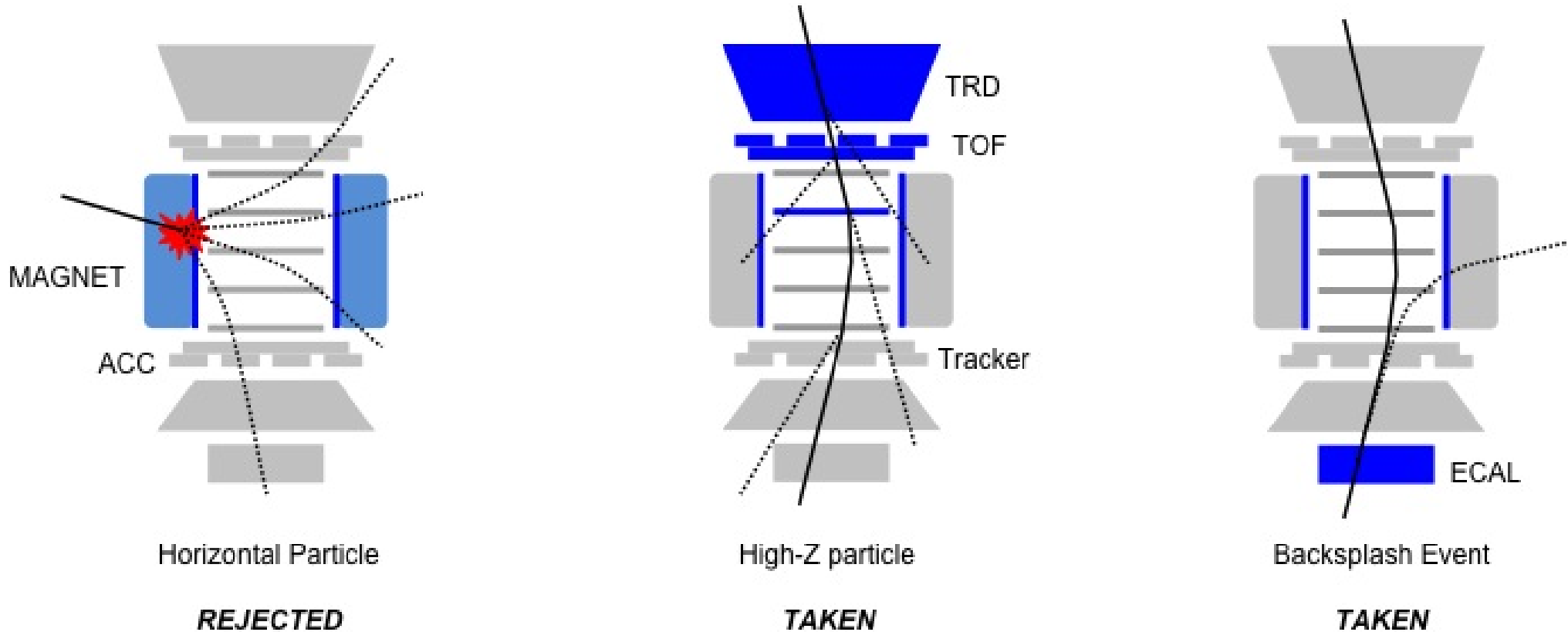


# ECAL

Normalized number of events and gaussian fit of selected nuclei

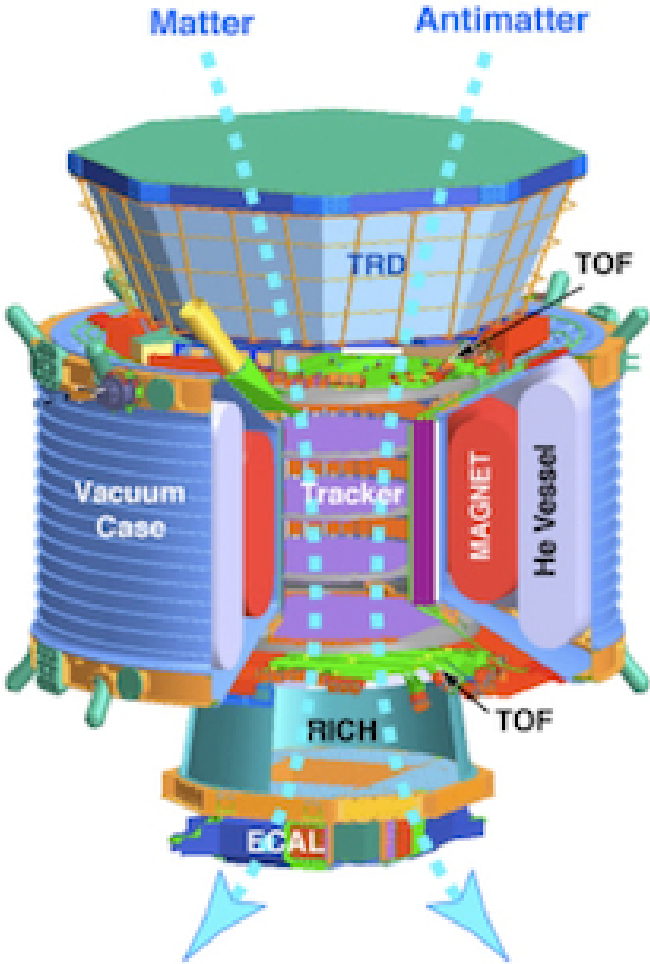


# ACC – Anti-Coincidence-Counter



The ACC is composed of **16 vertical scintillating paddles** of 10mm thickness located between the inner tracker and the permanent magnet. Photomultipliers read the light at both end of paddles

# Identification des composantes

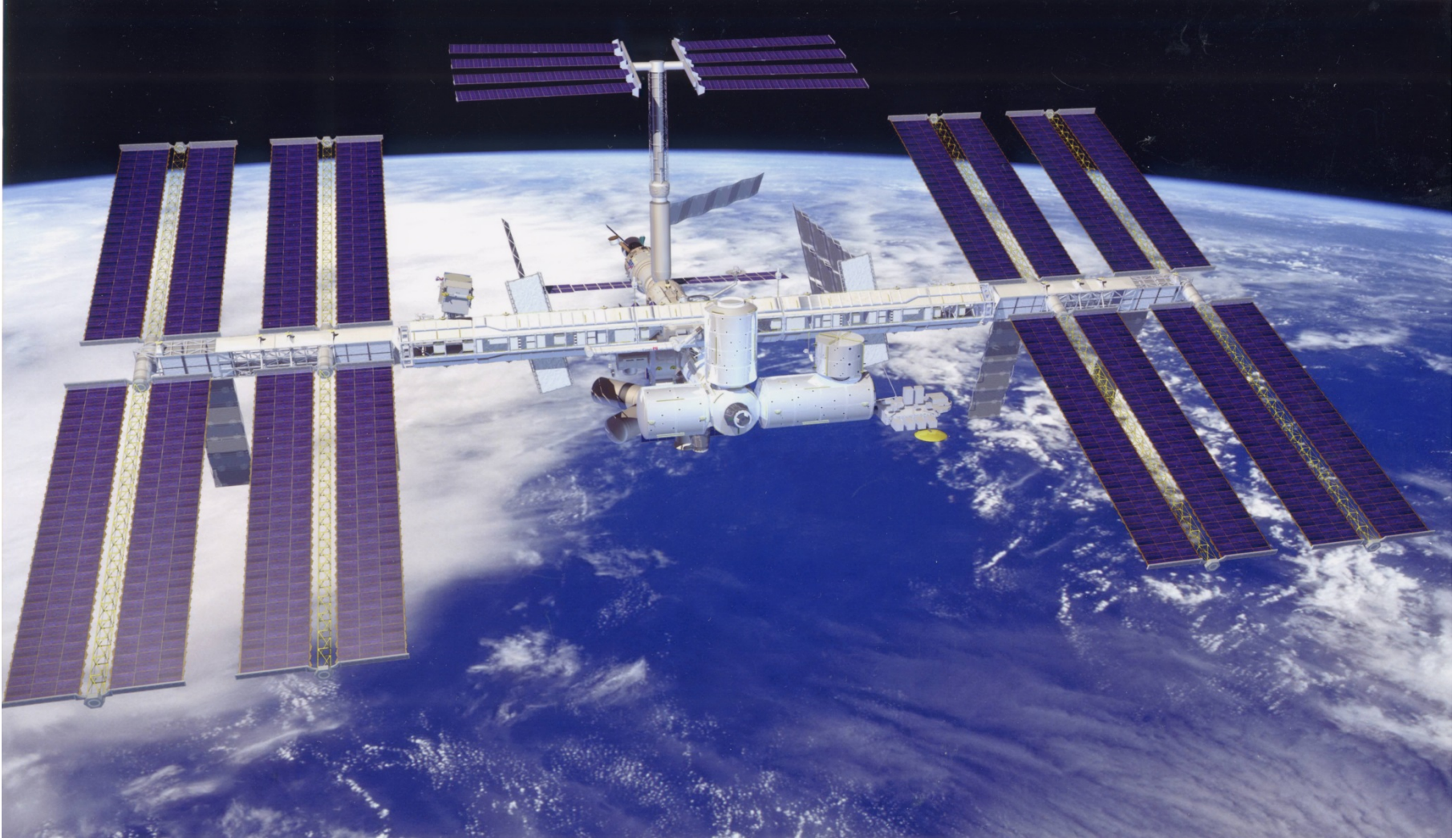


	$e^-$	P	Fe	$e^+$	$\bar{p}$	$\bar{He}$
TRD						
TOF						
Tracker + Magnet						
RICH						
ECAL						
exemples de Physique	Rayons cosmiques et étrangelets			Matière noire		Antimatière

# AMS-02



# AMS-02

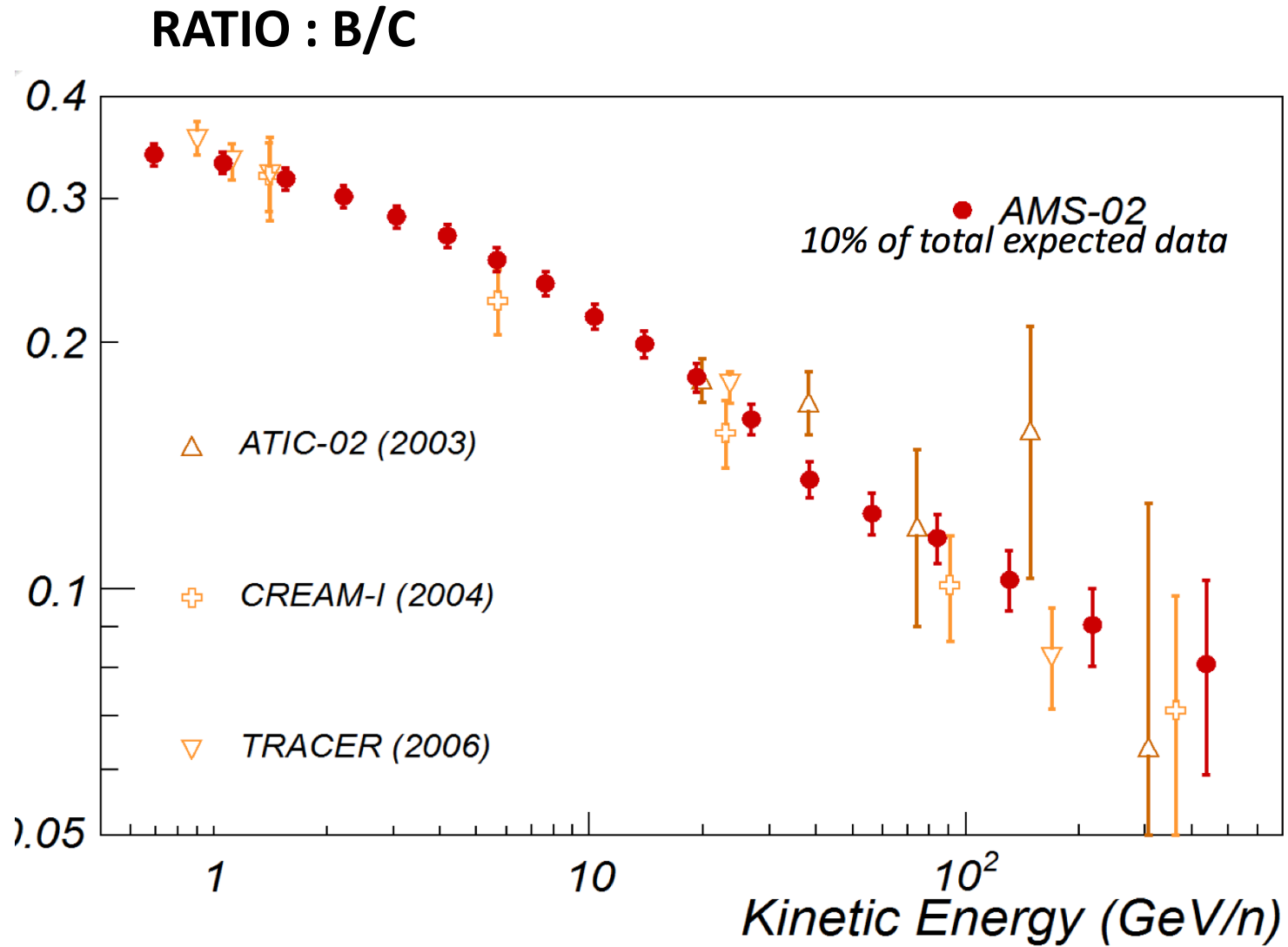


# AMS-02

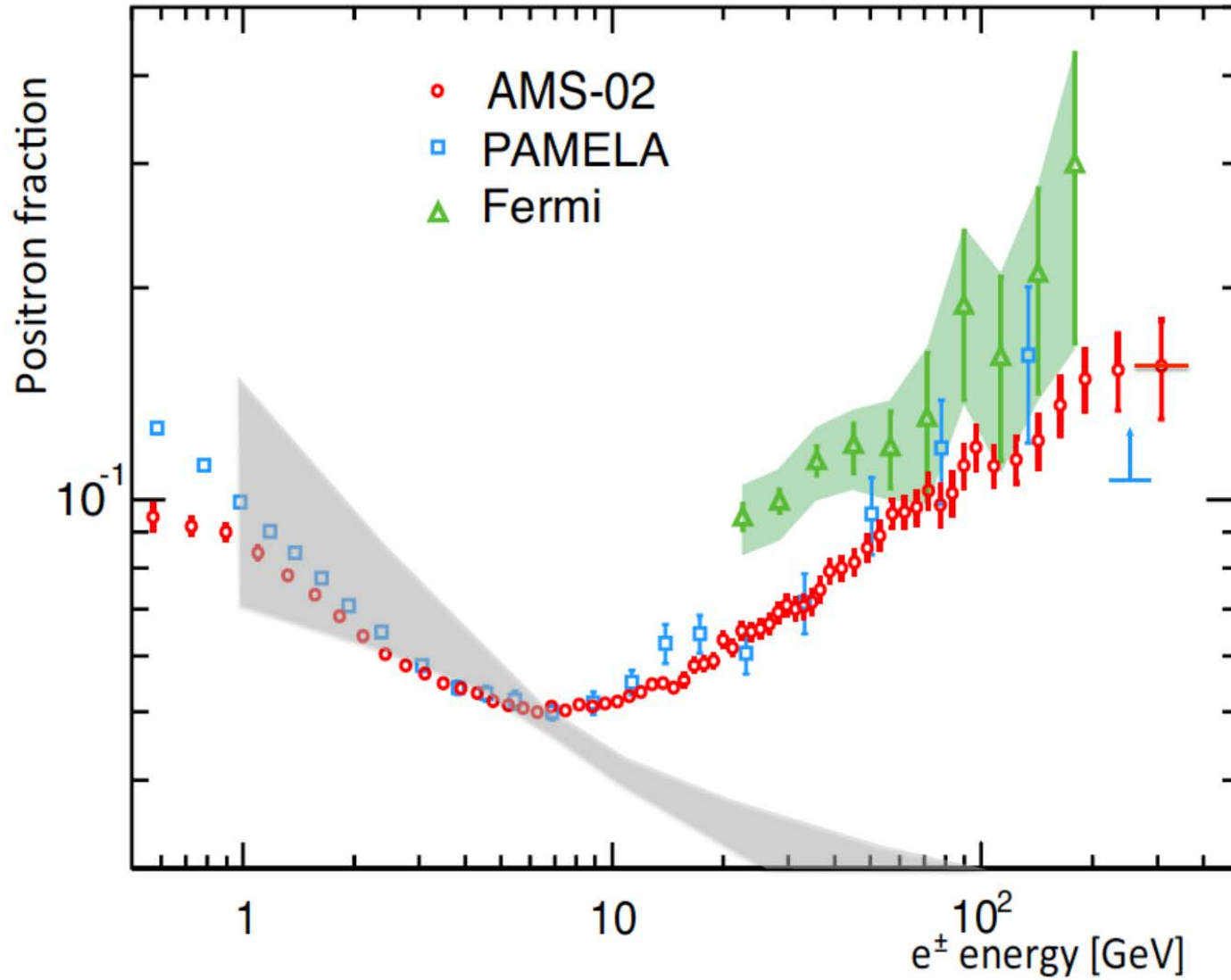




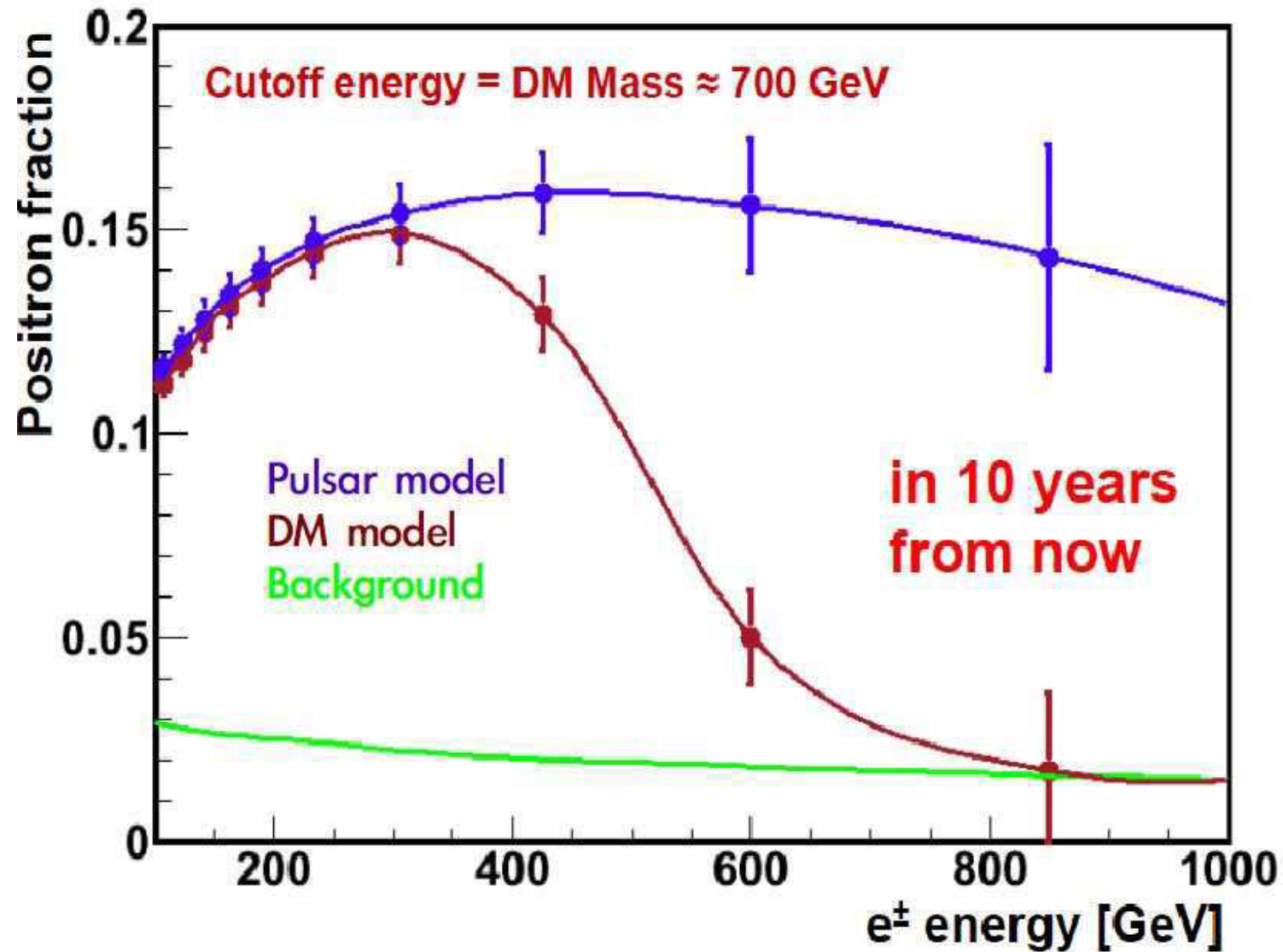
# AMS-02



# AMS-02



# AMS-02



**La fin.**

**SALUT !**

