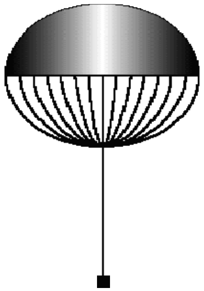
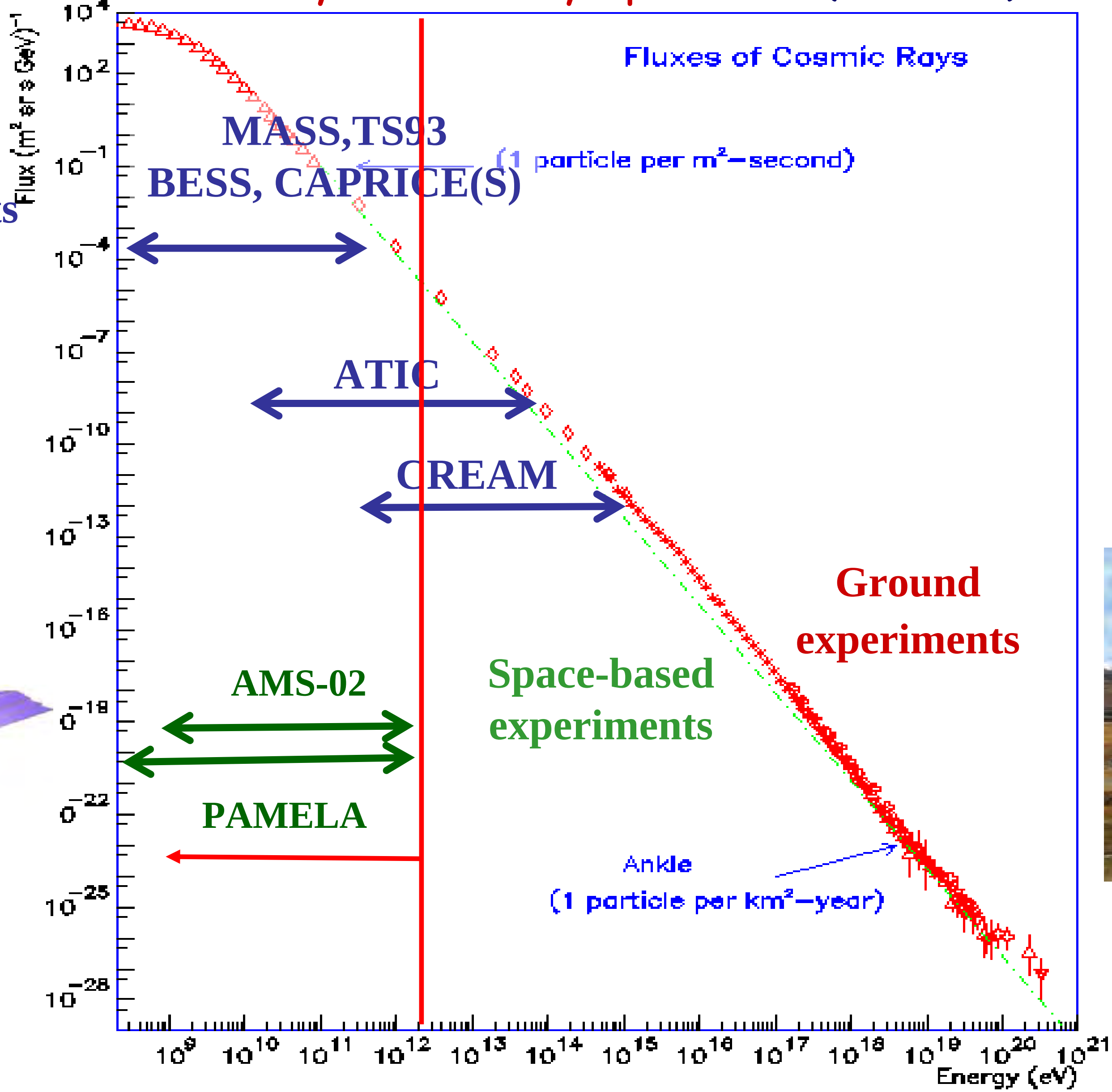
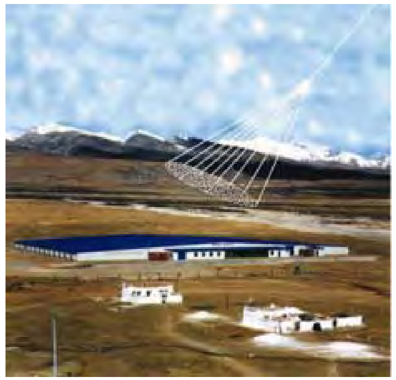
Tecniche di analisi e di identificazione di particelle nell'esperimento PAMELA.

F.S. Cafagna, INFN Bari

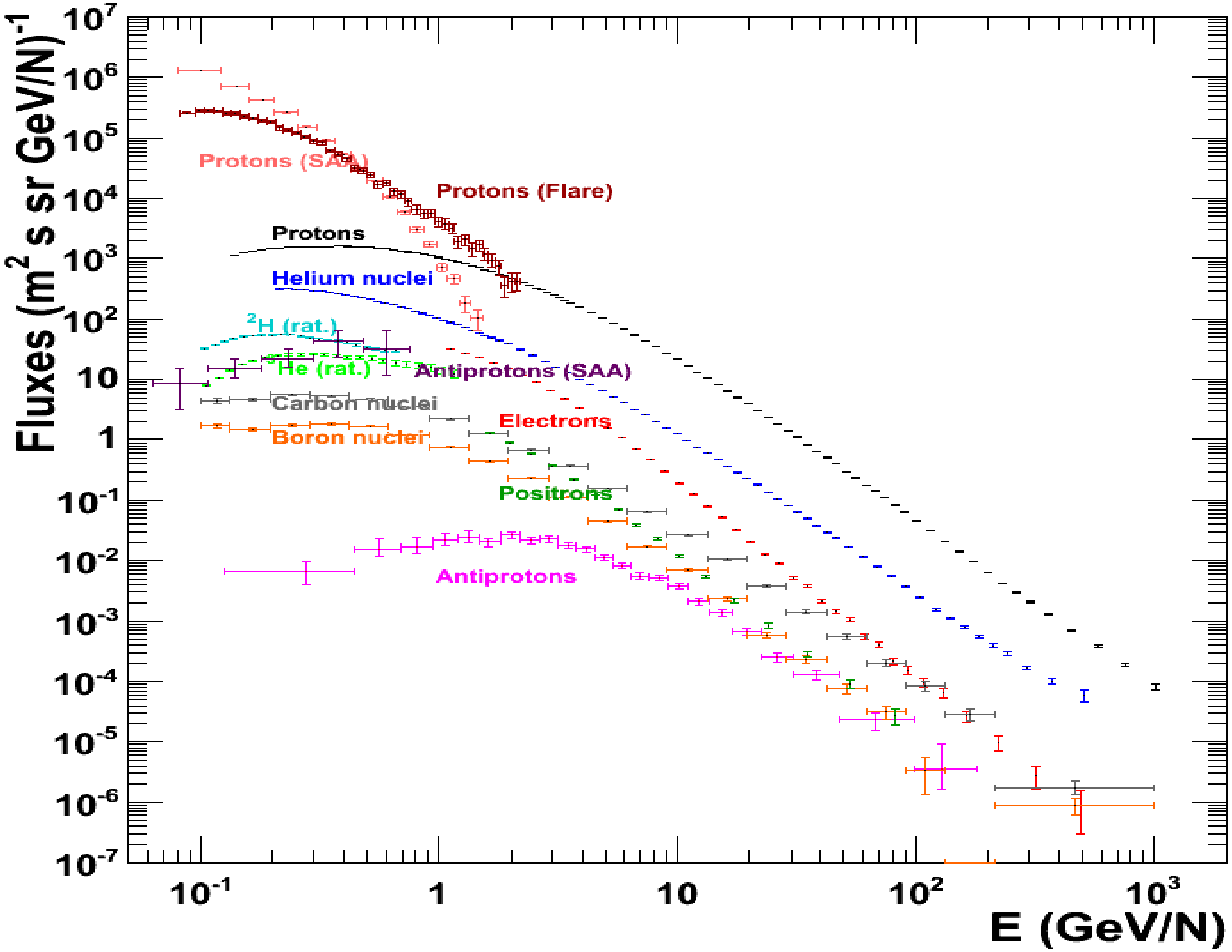
Primary cosmic ray spectrum (inclusive)







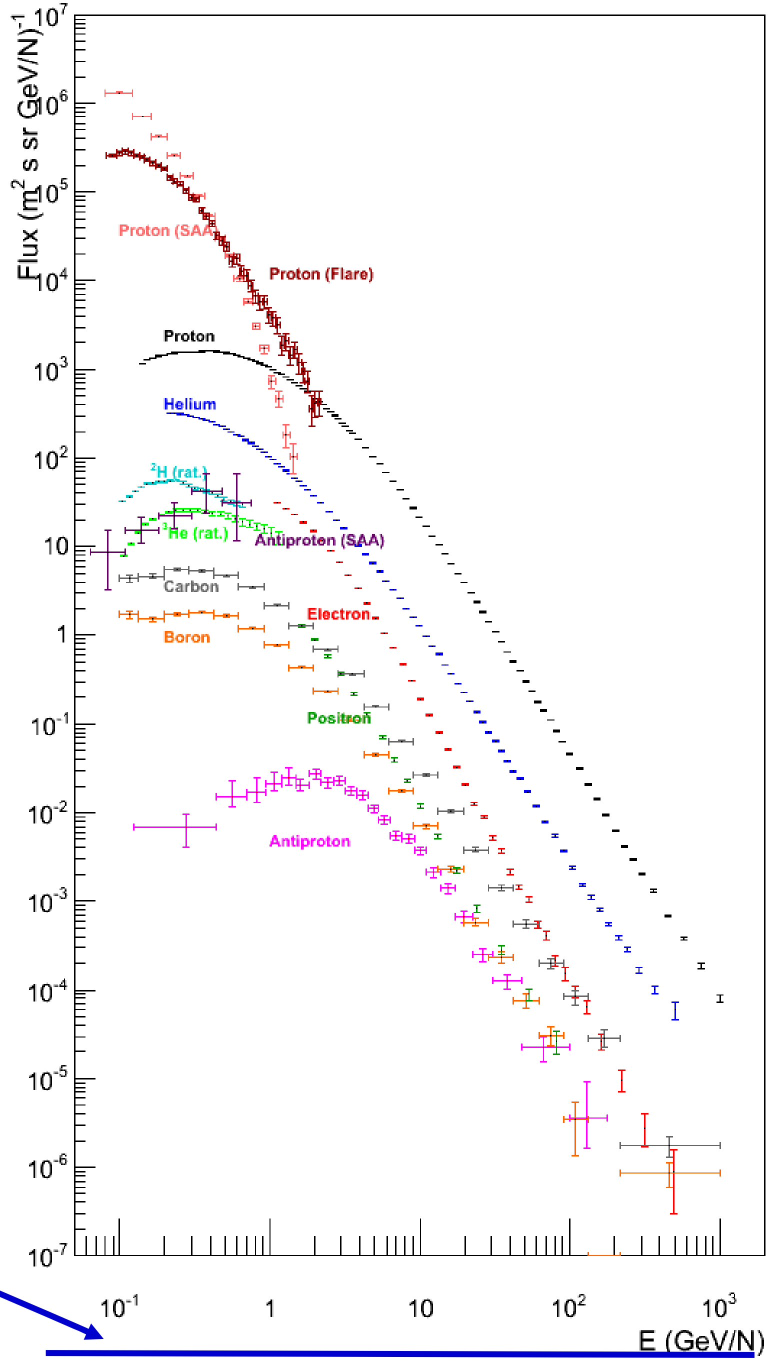
The PAMELA view



F.S. Cafagna, MAPSES, Lecce, Nov. 2011

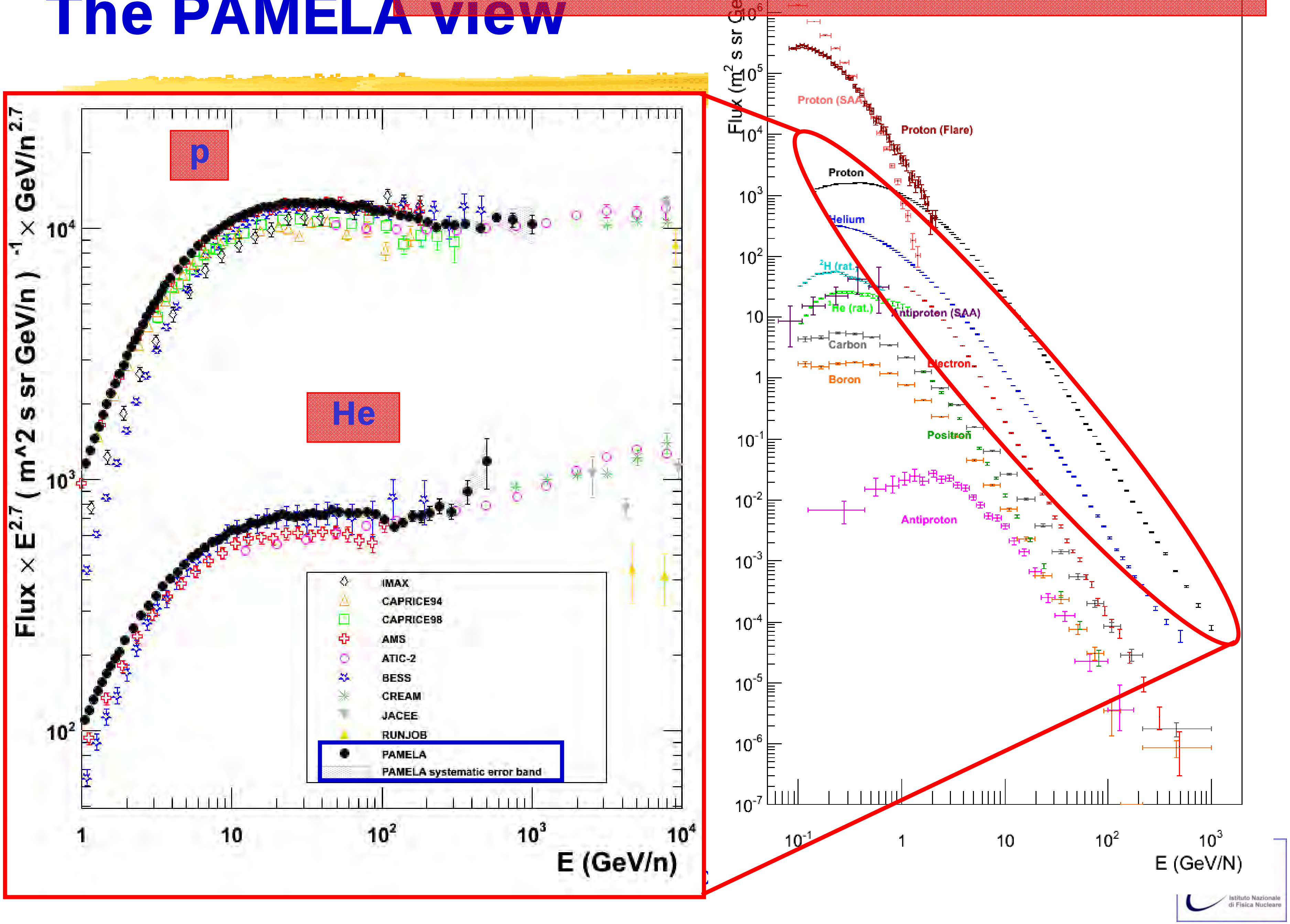
The PAMELA view

- Large flux range, from 10^{-7} to 10^{7} $(m^2\ s\ sr\ GeV)^{-1}$
- "Large" energy range, from .5 to 1000 TeV.
- Several measurements with the same detector, i.e. same systematic.



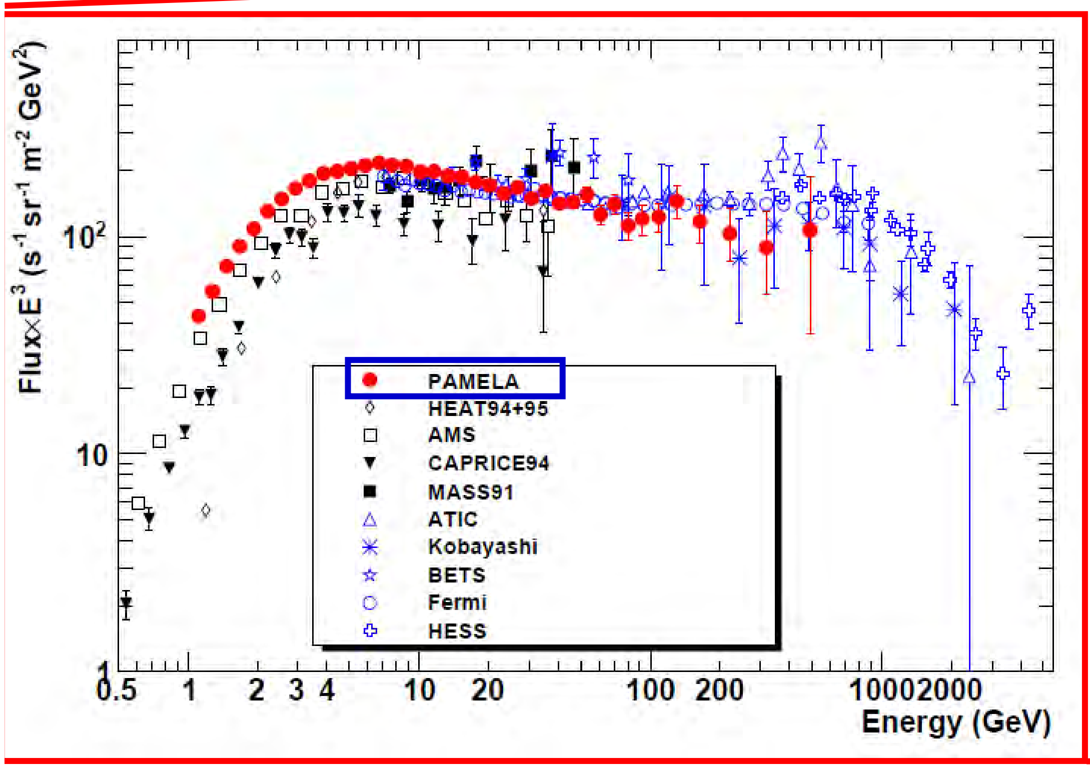
The PAMELA view

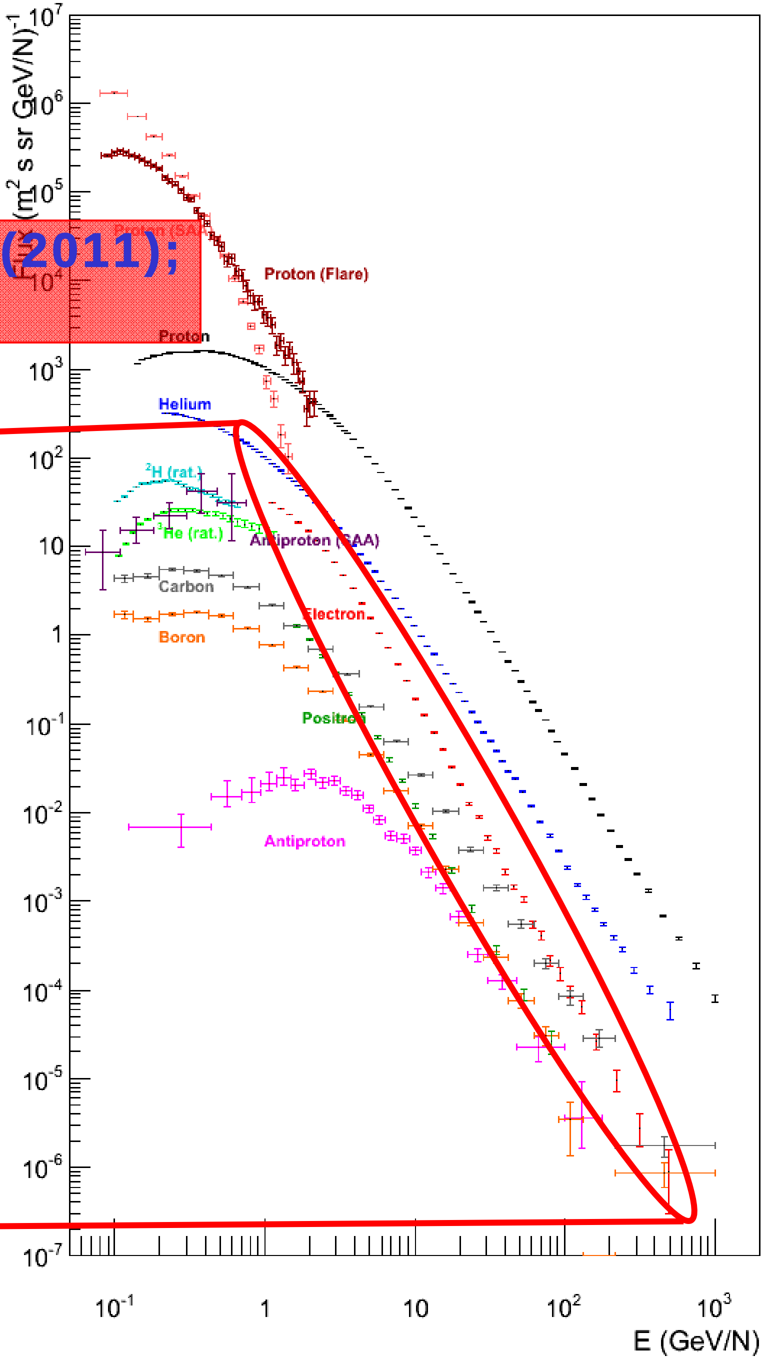
Adriani et al., Science, vol. 332 no. 6025 (2011); arXiv: 1103.4055



The PAMELA view

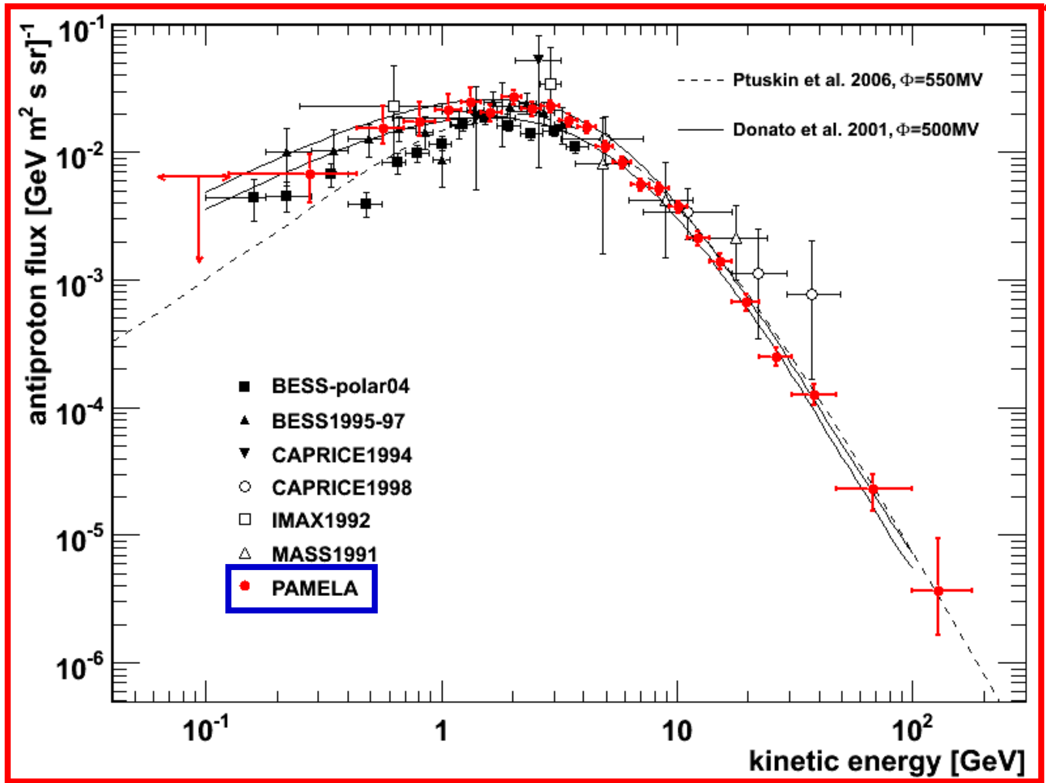
Adriani et al., Phys. Rev. Lett. 106, 201101 (2011); arXiv: 1103.2880

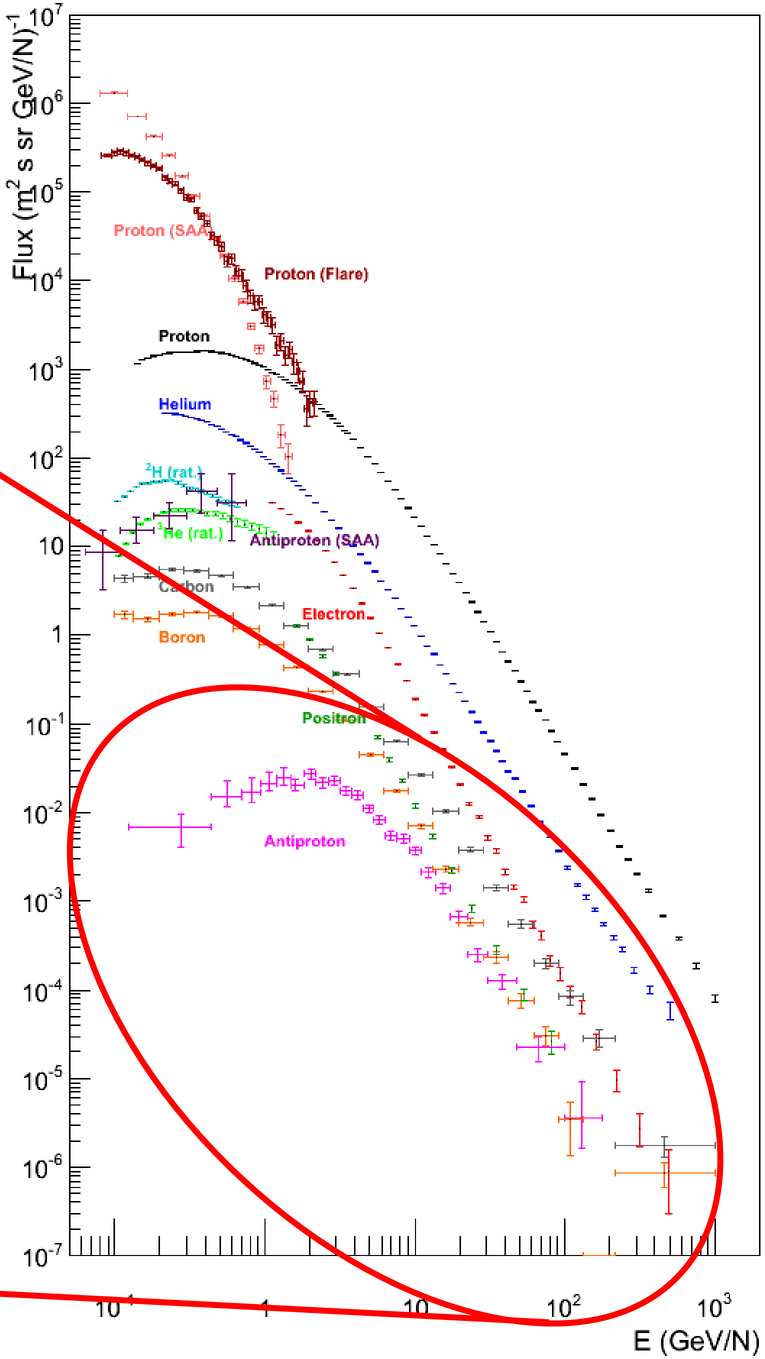




The PAMELA view

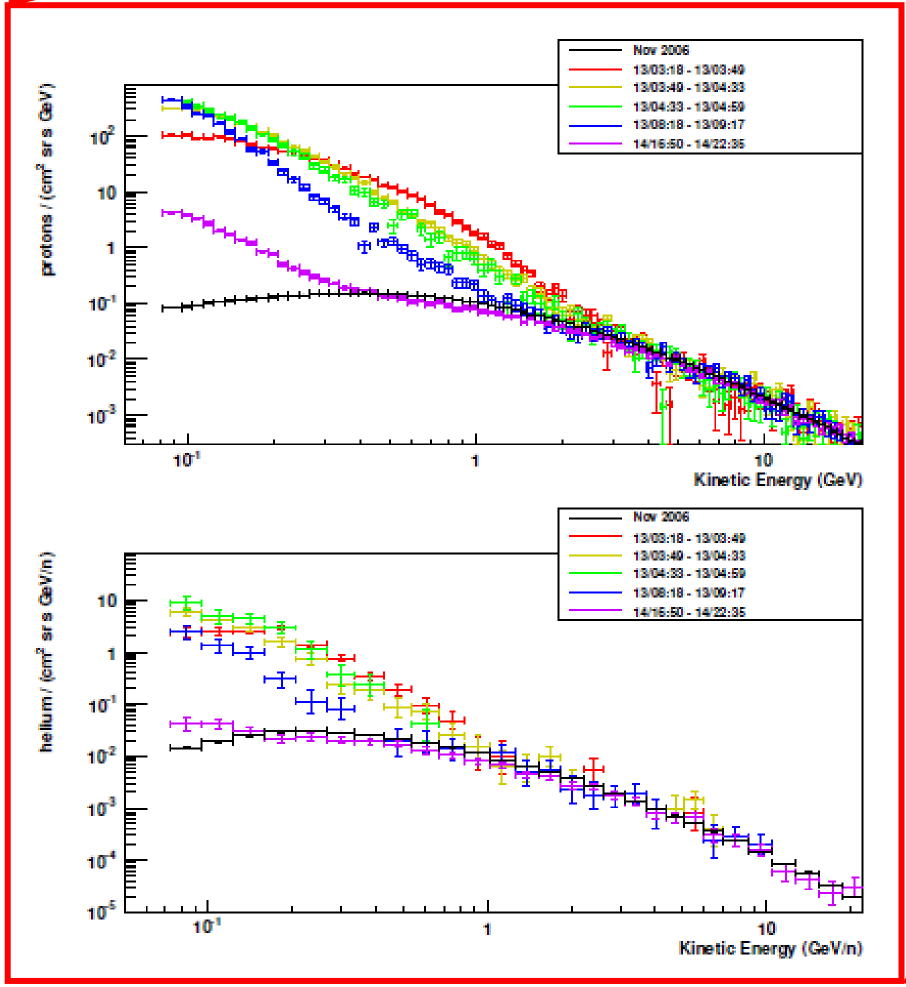
Adriani et al., Phys. Rev. Lett. 105:121101, 2010

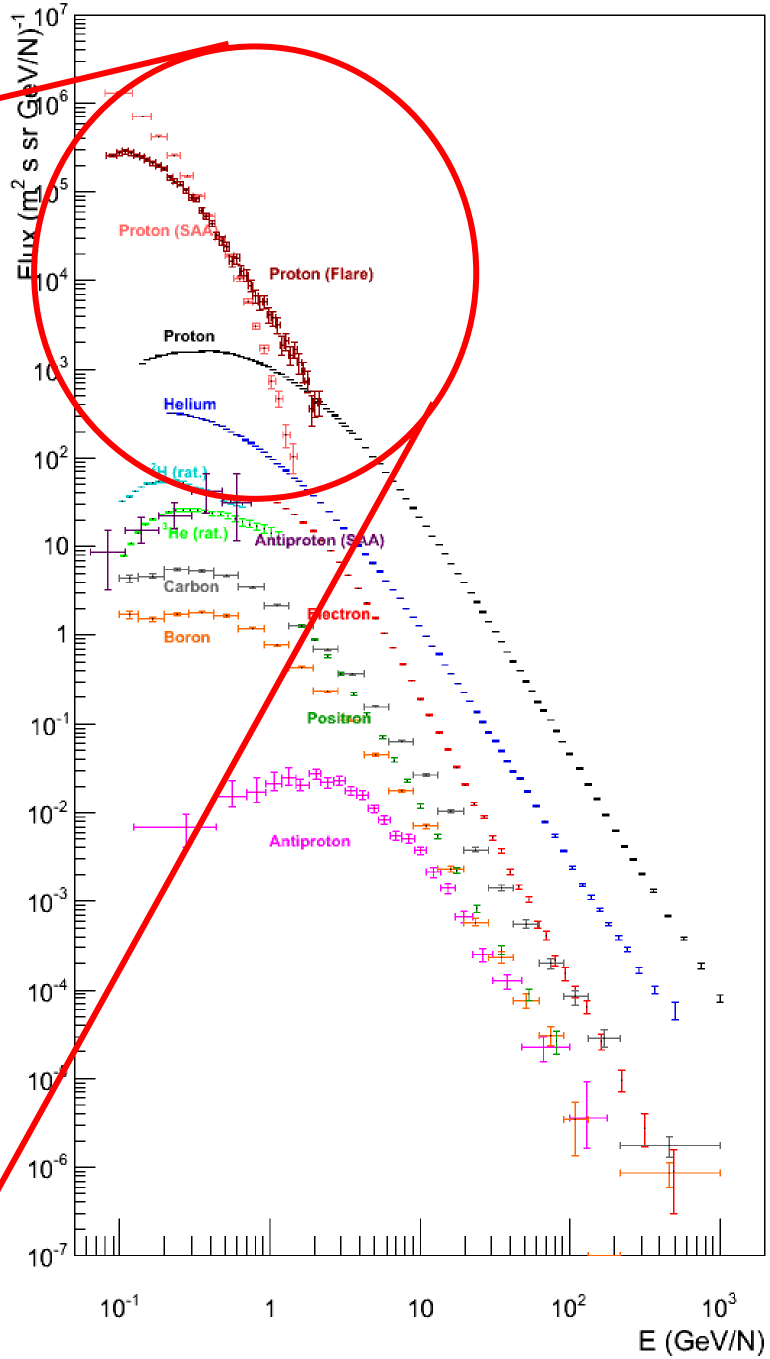




The PAMELA view

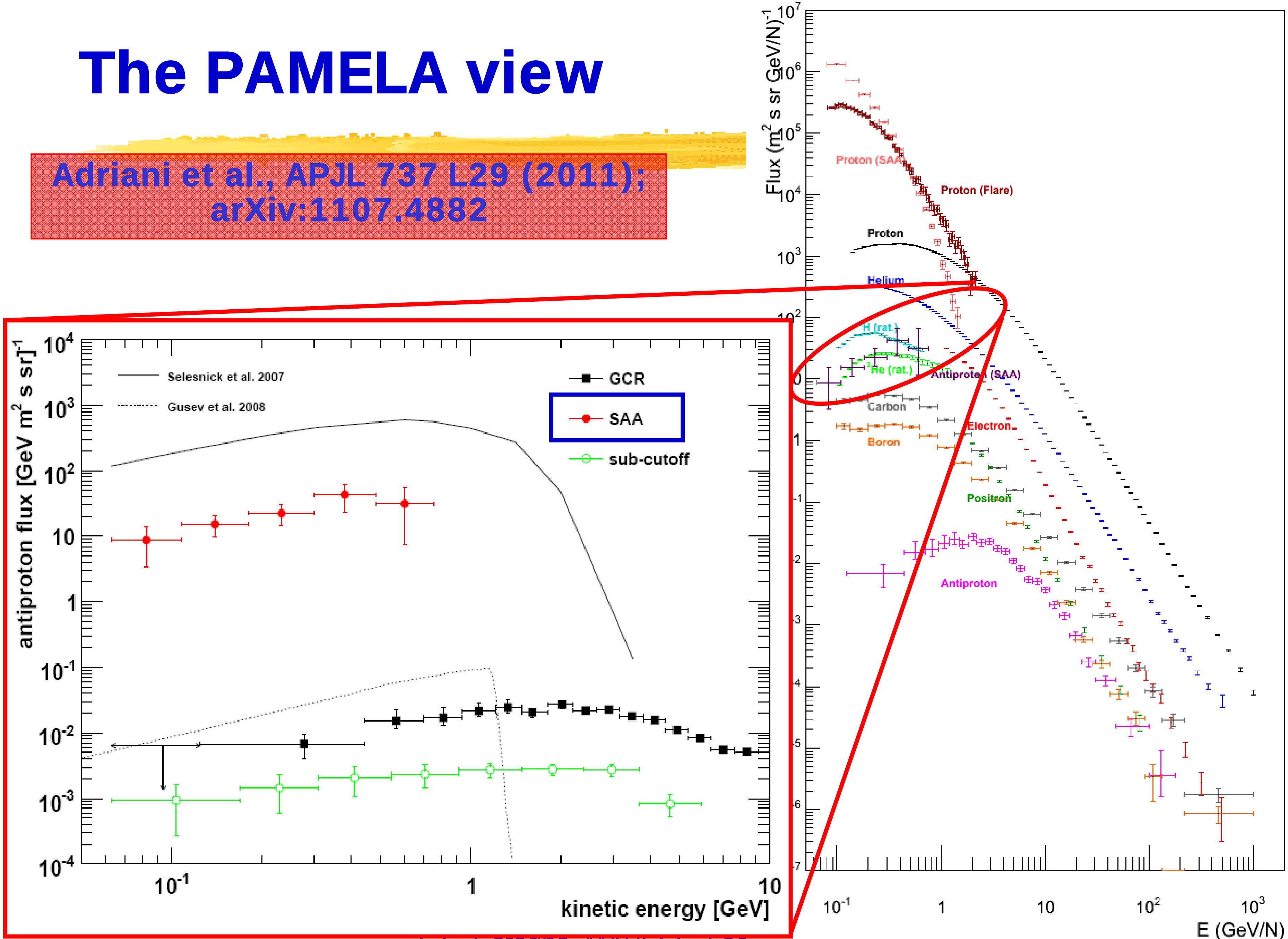
Accepted for publication on ApJ, arXiv:1107.4519





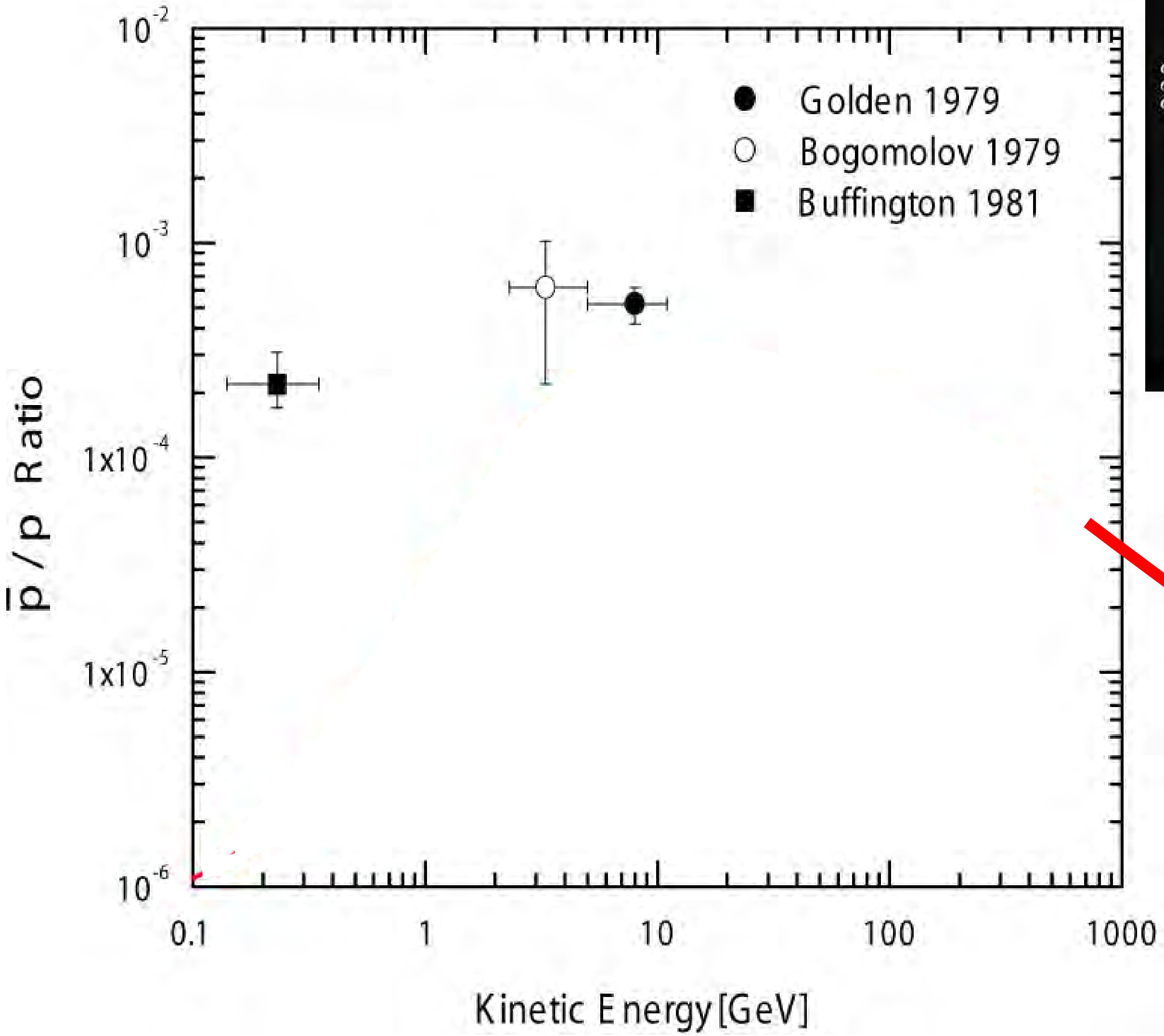
The PAMELA view

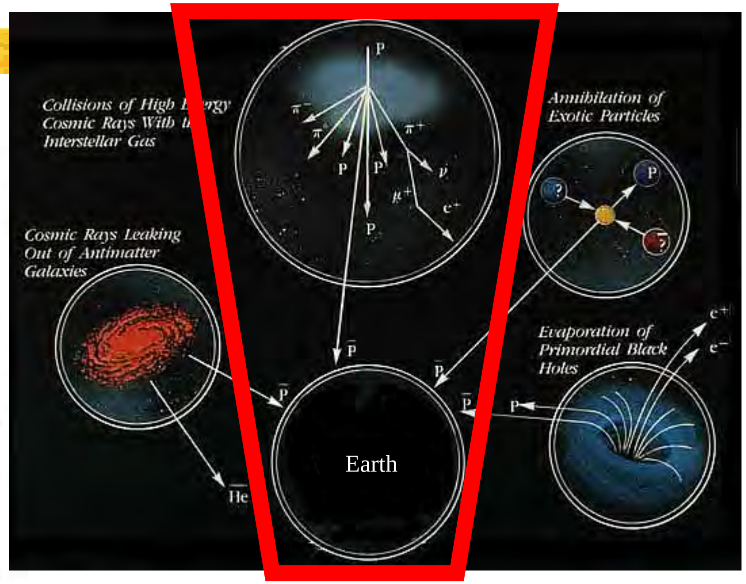
Adriani et al., APJL 737 L29 (2011); arXiv:1107.4882

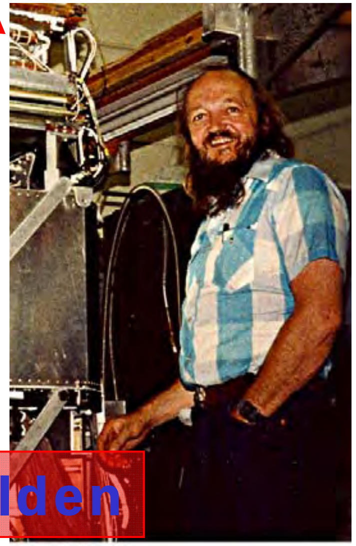


Why Anti(particle)matter matters?

Why Anti(particle)matter matters?

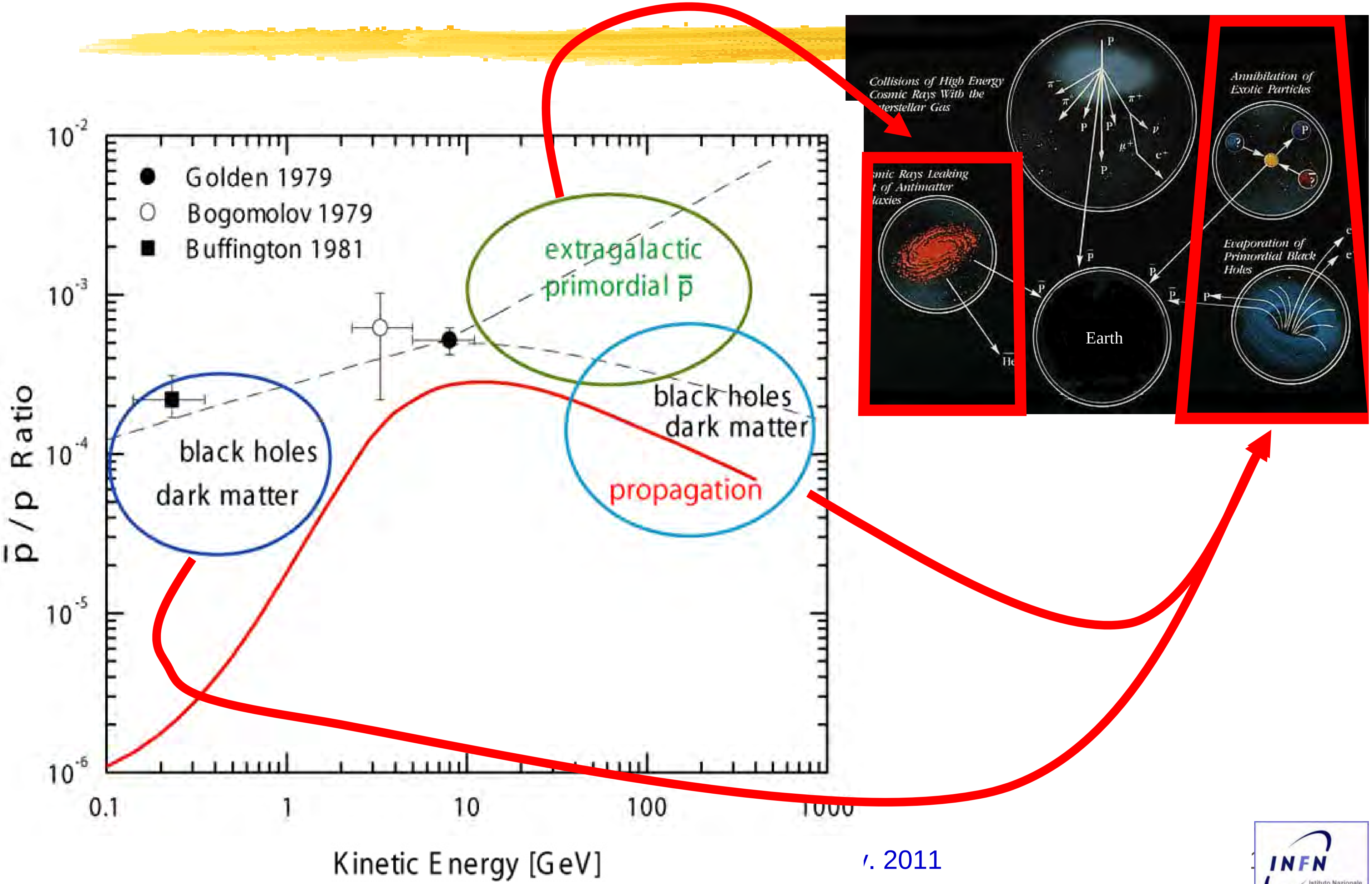




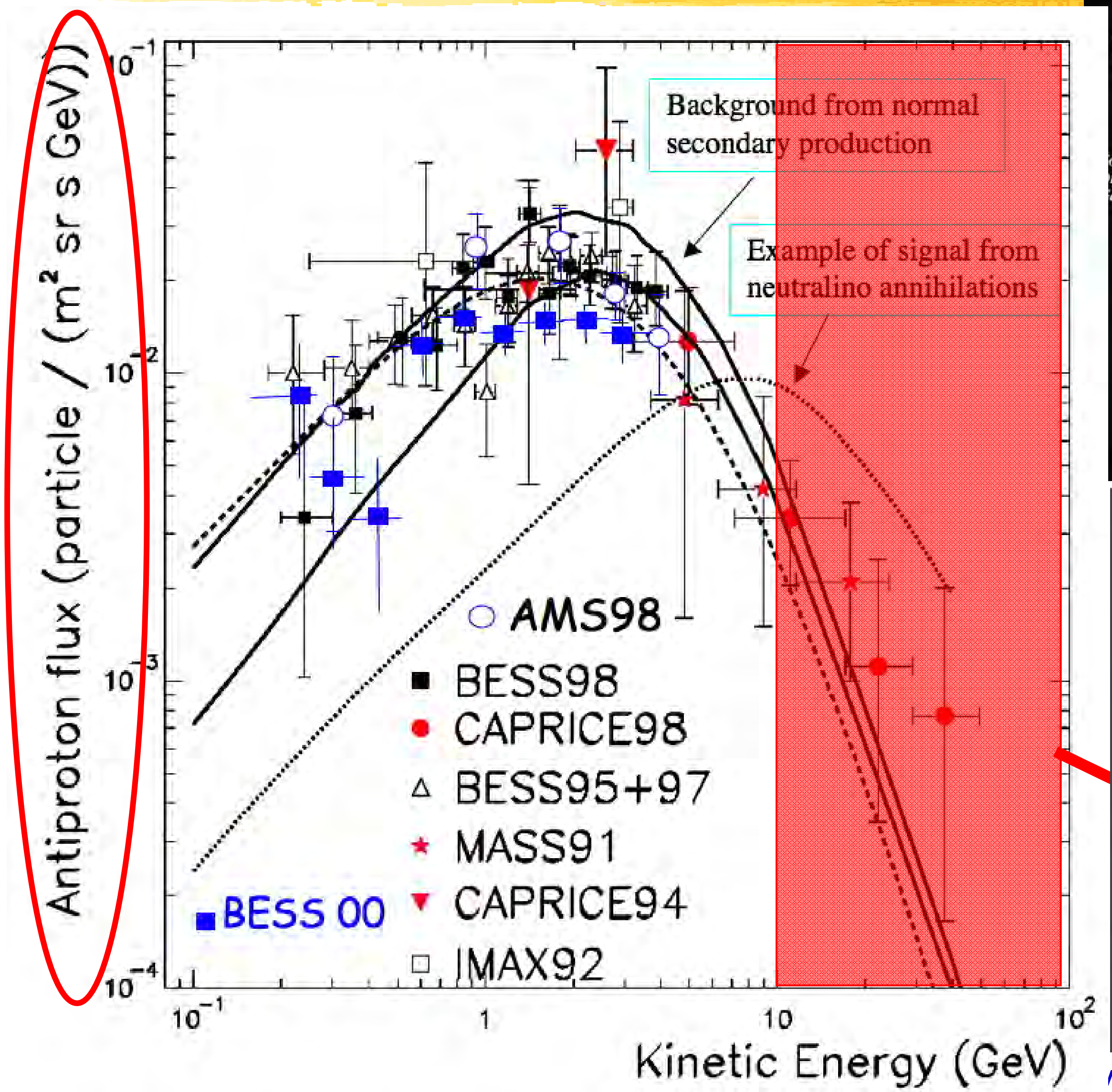


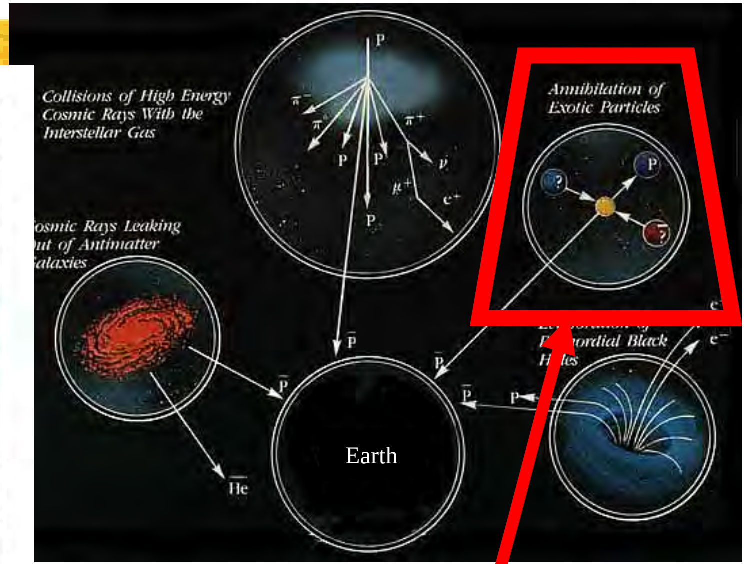
R.L. Golden

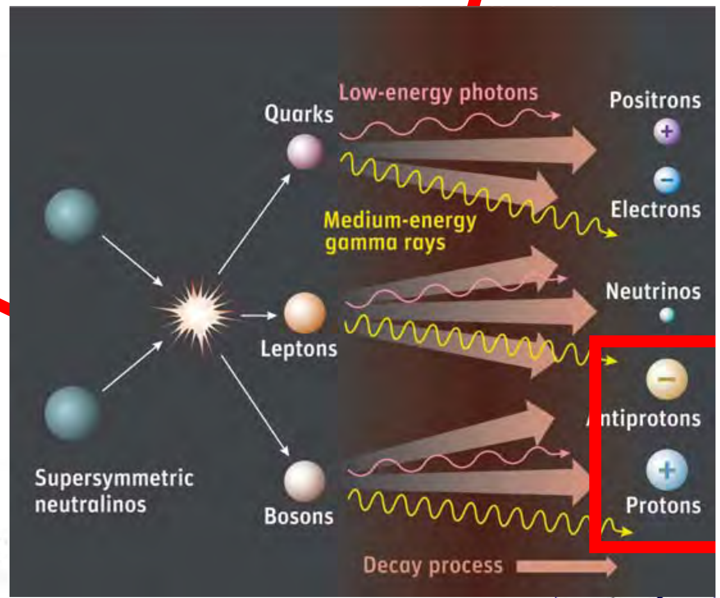
Why Anti(particle)matter matters?



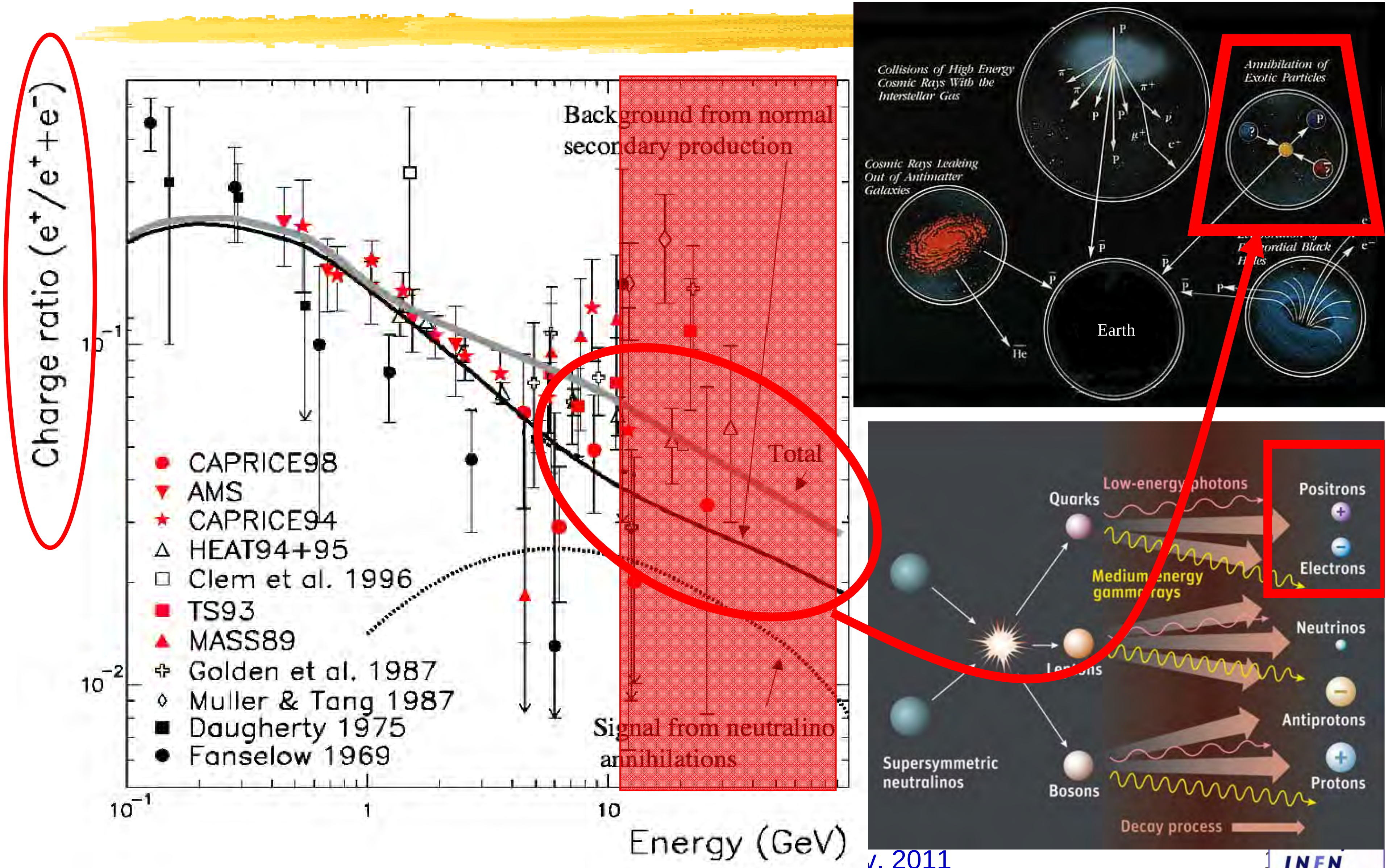
Why Anti(particle)matter matters?







Why Anti(particle)matter matters?



CR antimatter detector cookbook

- Charge identification
- Good (≥1TV) Maximum Detectable Rigidity (MDR) to defeat particle spillover (pbar)

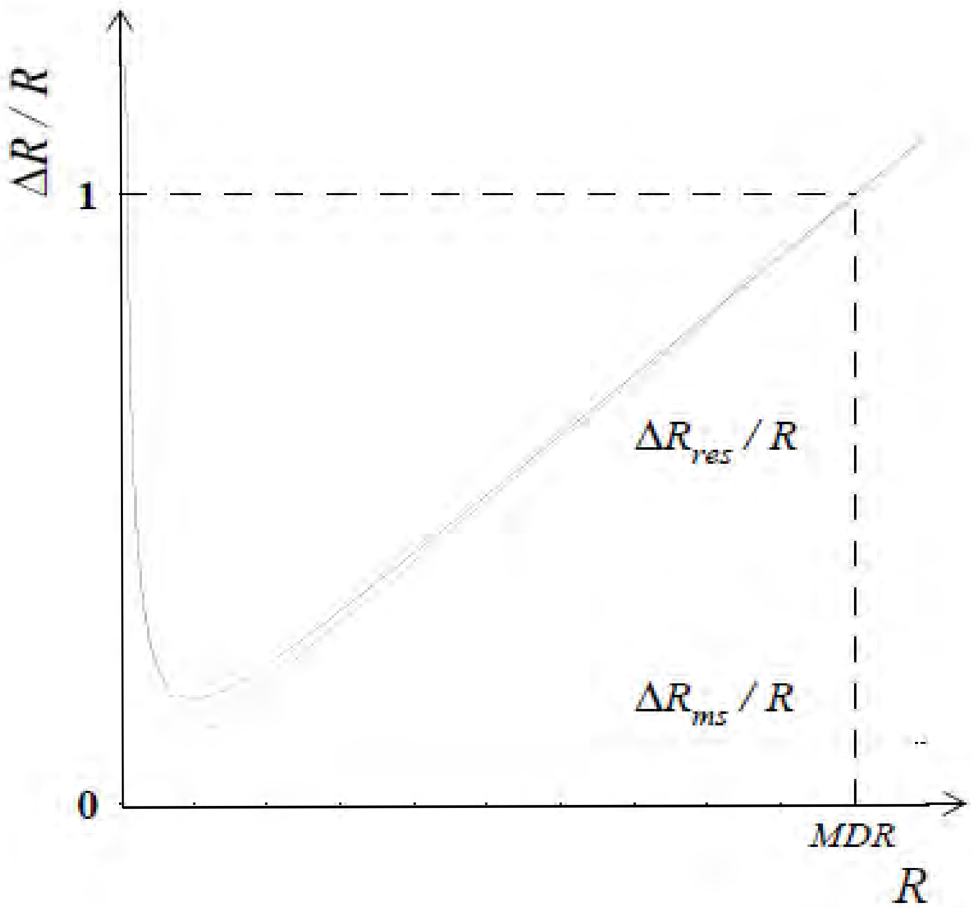
The CR toolkit: the jargon

- Rigidity or magnetic rigidity, R: gyroradius multiplied by the magnetic field strength:

$$R = p\, c/(ze) = rB$$

- What MDR means?
  - The reconstructed rigidity for which the error is 100%

The CR toolkit: the jargon



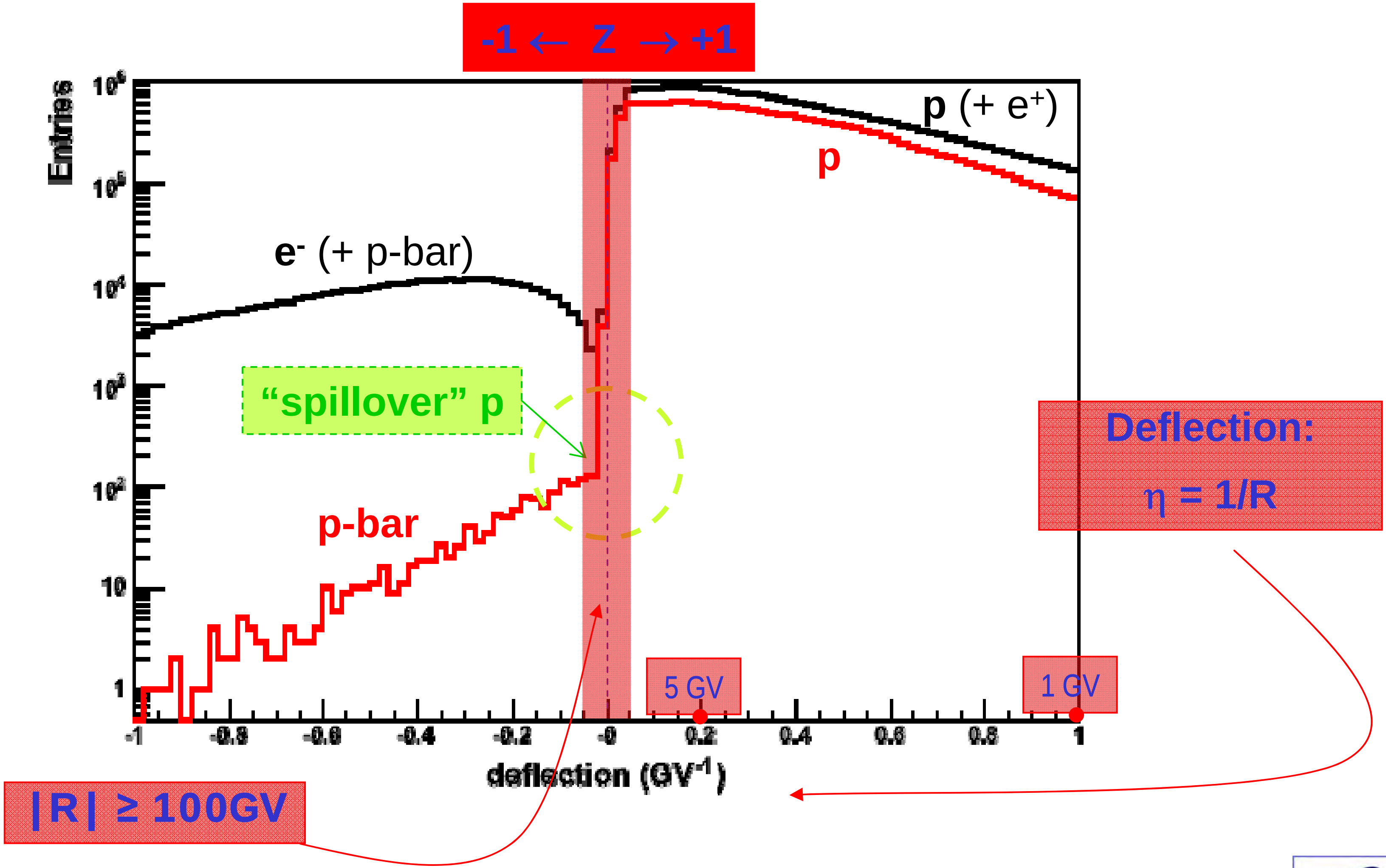
The CR toolkit: the jargon

- Rigidity or magnetic rigidity, R: gyroradius multiplied by the magnetic field strength:

$$R = p\,c/(ze) = rB$$

- What does MDR means?
  - The reconstructed rigidity for which the error is 100%
- What does Spillover means?
  - At high rigidity particle charge can be confused do the finite spectrometer precision.
  - Protons can mimic antiprotons, “spilling” into the antiprotons spectra.

CR antimatter detector cookbook



The CR toolkit: the jargon

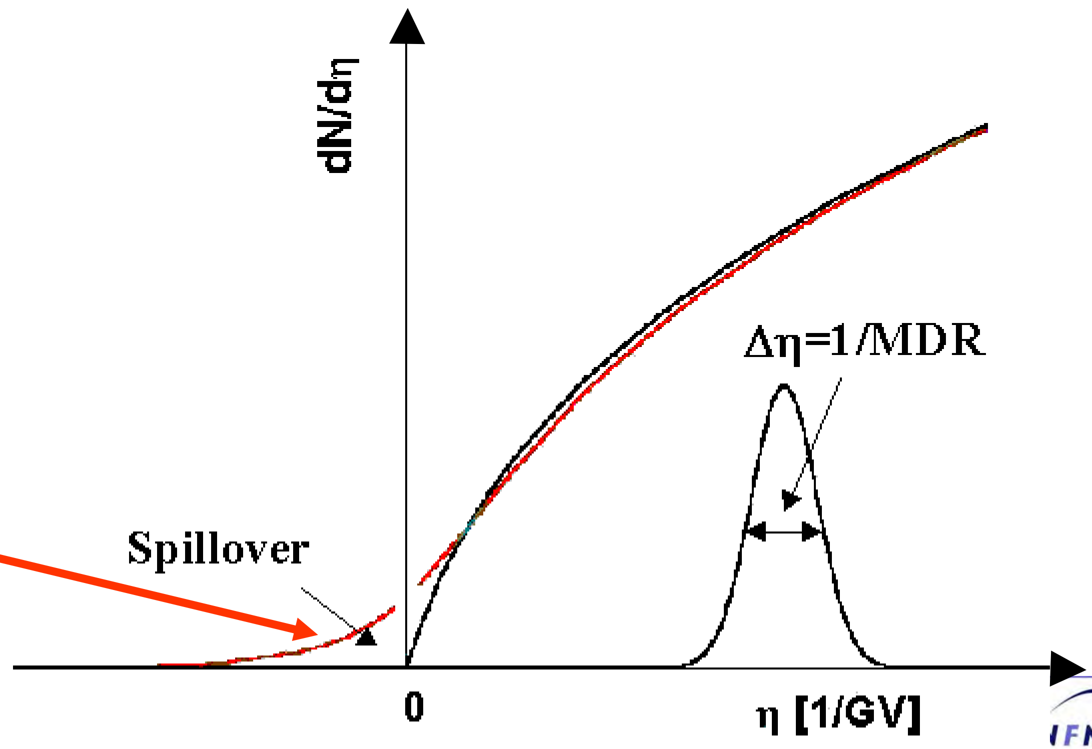
- We actually measure deflection: $\eta = 1/R$
- Measuring this quantity the error is gaussian.
- Moreover:

$$\left|\frac{\sigma_R}{R}\right| = \left|\frac{\sigma_\eta}{\eta}\right| = \left|\sigma_\eta \times R\right| \xrightarrow{\frac{\sigma_R}{R}=1} MDR = \frac{1}{\sigma_\eta}$$

The CR toolkit: the jargon

- Spillover is calculate convolving spectra with spectrometer resolution

Convoluted spectra



Exercise: spillover estimation

- Let's try to estimate the spillover for a generic MDR and a rigidity spectra with spectral index α.
- This means:

$$\frac{d\mathrm{N}}{d\mathrm{R}} \approx R^{-\alpha} \longrightarrow \frac{d\mathrm{N}}{d\eta} \approx \eta^{\alpha-2}$$

Exercise: spillover estimation

- Let's build a random number generator according to a normal (gaussian) distribution.
- For this let's use an enough precise and simple methods: the Box-Muller one. See for example Numerical Receipies in Fortran, C or C++, chapter 7.2: www.nrbook.com

Exercise: spillover estimation

- Almost all programming languages do offer a random number generator according to a flat distribution, that is an uniform probability of generate a random number between *x* and *x+dx:*

$$p(x)dx = \begin{cases} dx & 0 < x < 1 \\ 0 & \text{for any other value} \end{cases}$$

- Being the probability distribution normalized:

$$\int_{-\infty}^{\infty} p(x)dx = 1$$

Exercise: spillover estimation

- In C and C++ a generator is supplied generating random numbers up to a RAND_MAX (a preprocessor variable) value: *rand()*
- So, to uniformly generate in the range [0,1[, usually the user define:

  #define DRAND(PAR) rand()/(double)RAND_MAX
- It is also possible to define a starting seed using the function: *sran(int)*

Exercise: spillover estimation

- Let's suppose we know hot to uniformly generate *x*, and consider the function:

$$y(x)$$

its probability distribution will be:

$$p(y)dy$$

that is:

$$|p(y)dy| = |p(x)dx|$$

$$p(y) = p(x)\left|\frac{dx}{dy}\right|$$

Exercise: spillover estimation

- So if the probability distribution of an arbitrary distribution is a positive function, invertible and normalized to 1, we will have:

$$p(y) = f(y)$$

$$\int_{-\infty}^{\infty} f(y) = 1$$

$$\frac{dx}{dy} = f(y)$$

- Solution to the latest differential equation:

$$x = F(y) = \int_0^y f(y)dy = \int_0^y p(y)dy$$

Exercise: spillover estimation

- So the transformation to obtain, from an uniform one, a distribution $f(y)$ is:

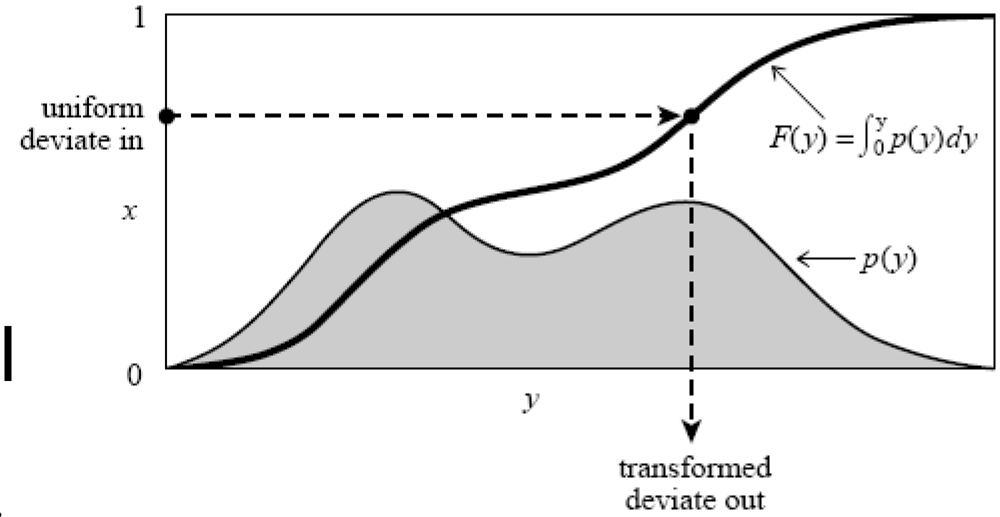
$$y(x) = F^{-1}(x)$$

being F^{-1} the inverse function of $f(y)$.

- The method depends on whether the inverse function of F exist and on its computation feasibility (either numerical or analytical).

Exercise: spillover estimation

- There is a simple geometrical interpretation. $F(y)$ is the area below the probability curve before y .
- So we have to:
  - Choose a random x
  - Find the value, y, into which the integral of the probability function is equal to x



Exercise: spillover estimation

- For the Box-Muller method, we can start from:

$$p(y)dy = \frac{1}{\sqrt{2\pi}} e^{-y^2/2} dy$$

- And consider the multidimensional extension of the previous method:

$$p(y_1, y_2, \ldots)dy_1 dy_2 \ldots =$$

$$p(x_1, x_2, \ldots)\left|\frac{\partial(x_1, x_2, \ldots)}{\partial(y_1, y_2, \ldots)}\right| dy_1 dy_2 \ldots$$

Exercise: spillover estimation

- Using the functions:

$$y_1 = \sqrt{-2\ln x_1}\cos(2\pi x_2)$$

$$y_2 = \sqrt{-2\ln x_1}\sin(2\pi x_2)$$

- These can be inverted into:

$$x_1 = \exp\left[-\frac{1}{2}(y_1^2 + y_2^2)\right]$$

$$x_2 = \frac{1}{2\pi}\arctan\left(\frac{y_2}{y_1}\right)$$

Exercise: spillover estimation

- The jacobian determinant is:

$$\frac{\partial(x_1, x_2)}{\partial(y_1, y_2)} = \begin{vmatrix} \frac{\partial x_1}{\partial y_1} & \frac{\partial x_1}{\partial y_2} \\ \frac{\partial x_2}{\partial y_1} & \frac{\partial x_2}{\partial y_2} \end{vmatrix} =$$

$$-\left[\frac{1}{\sqrt{2\pi}} e^{-\frac{y_1^2}{2}}\right]\left[\frac{1}{\sqrt{2\pi}} e^{-\frac{y_2^2}{2}}\right]$$

Exercise: spillover estimation

- We can independently generate x_1 and x_2 to obtain the two y_1 and y_2
- If we use trigonometric coordinates:

$$R^2 \equiv v_1^2 + v_2^2 \rightarrow x_1$$

$$angle\ (v_1, v_2) \rightarrow 2\pi x_2$$

- It is simpler to write:

$$y_1 = \sqrt{-2 \ln x_1}\left(v_1 / \sqrt{R^2}\right)$$
$$y_2 = \sqrt{-2 \ln x_1}\left(v_2 / \sqrt{R^2}\right)$$

Exercise: spillover estimation

- To summarize:
  - We generate v_1 and v_2 in the square having sides [-1,1]
  - We check that we are on the unitary circle
  - We calculate y_1 and y_2 using the Box-Muller transformation:

$$y_1 = \sqrt{-2\ln x_1}\left(v_1 / \sqrt{R^2}\right)$$
$$y_2 = \sqrt{-2\ln x_1}\left(v_2 / \sqrt{R^2}\right)$$

  - We return one calculated value and store the other to be use for the next call.

Exercise: spillover estimation

```
#ifndef GAUSSRND_H
#define GAUSSRND_H

#include <iostream>
#include <cstdlib>
#include <cmath>

#define DRAND(PAR) rand()/(double)RAND_MAX
#define SRAND(PAR) srand(PAR)
#define RANGEN

// To generate a normal distributed Gaussian rand number
// distribution using the Box-Muller method. See Numerical Receipies
// in Fortran, chapter 7.2

class gaussrnd{

private:

  int _flag;
  int _seed;
  double _g1,_g2;

public:

  // Init the rand48 random number generator
  gaussrnd(const int &seed=0 ): _flag(0) {NewSeq(seed);}

  // Inizialize a new random sequence
  void NewSeq(const int &seed) {_seed=seed; SRAND(_seed);}

  double Grnd();
  void Print();

};


#endif //GAUSSRND_H
```

Exercise: spillover estimation

```
#include "gaussrnd.h"

double gaussrnd::Grnd(){
  double v1,v2,rsq,fac,g;
  switch(_flag){

  case 0:
    // Generate two new random number
    rsq=2.;
    while( (rsq>=1.) || (rsq==0.) ){
      v1=2.*DRAND()-1.;
      v2=2.*DRAND()-1.;
      rsq=pow(v1,2.)+pow(v2,2.);
    }
    fac=sqrt(-2.*log(rsq)/rsq);
    _g1=v1*fac;
    _g2=v2*fac;
    _flag=1;
    g=_g1;
    break;
  case 1:
    g=_g2;
    _flag=0;
    break;
  default:
    std::cout << " gaussrnd::Grnd flag error ! _flag= "
              << _flag << std::endl;
    break;
  }
  return g;
}

void gaussrnd::Print() {
  std::cout << " gaussrnd::Print max random number: " << RAND_MAX << '\n'
           << "               Seed : " << _seed << std::endl;
}
```

Exercise: spillover estimation

- Now that we have a shiny gaussian random number generator, we just need to apply the transformation methods to the power law:

$$x = F(y) = \int_0^y \eta^{\alpha-2} d\eta = \frac{y^{\alpha-1}}{\alpha - 1}$$

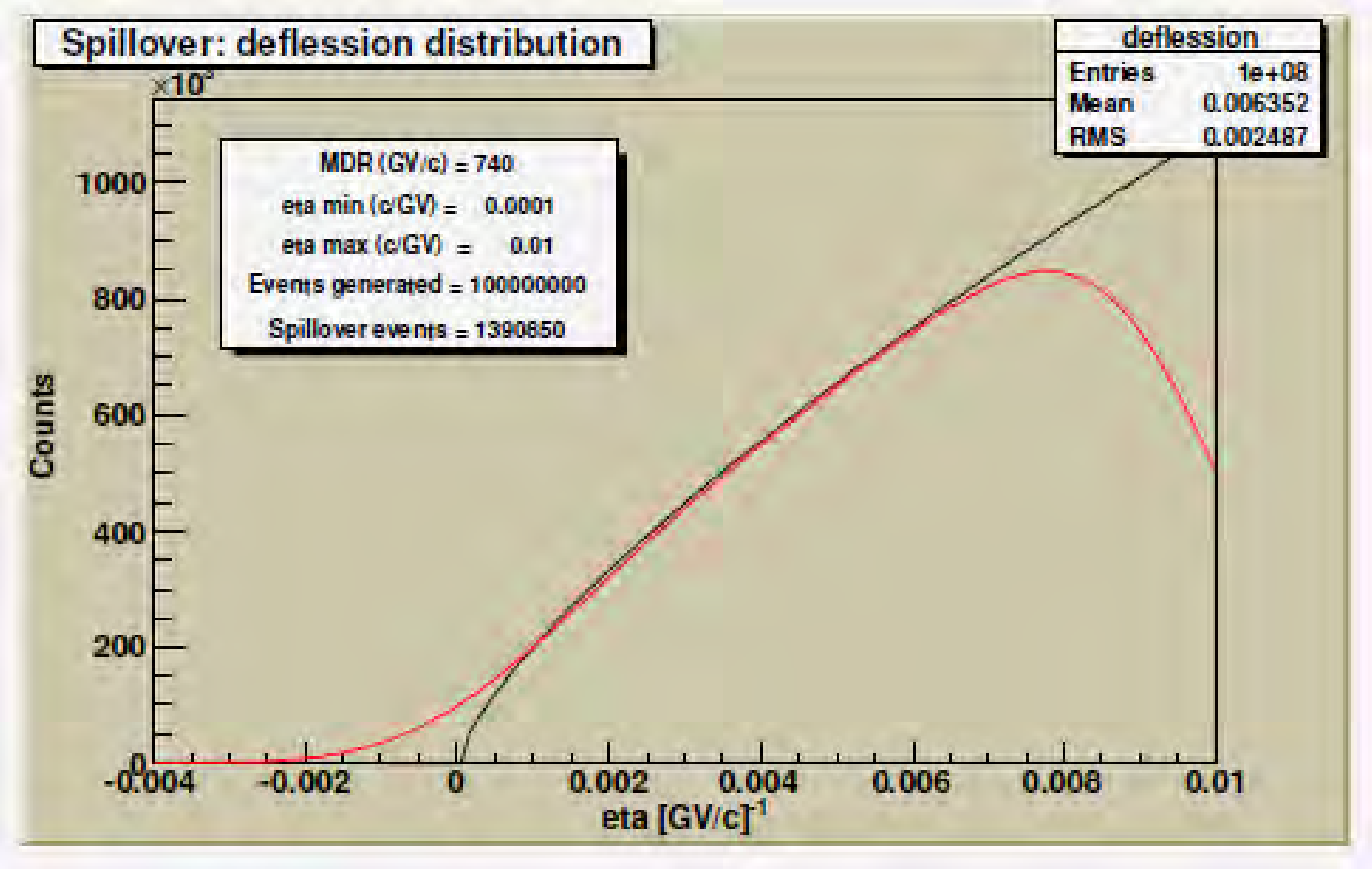
Exercise: spillover estimation

```
#include <cmath>

class flux{
private:
  double alfa_;
public:
  flux(double a=2.7): alfa_(a){};
  void SetIndex(double a) { alfa_=a; }

  double Y(double x) { return pow(((alfa_-1)*x), 1./(alfa_-1));}
};
```

Exercise: spillover estimation



CR antimatter detector cookbook

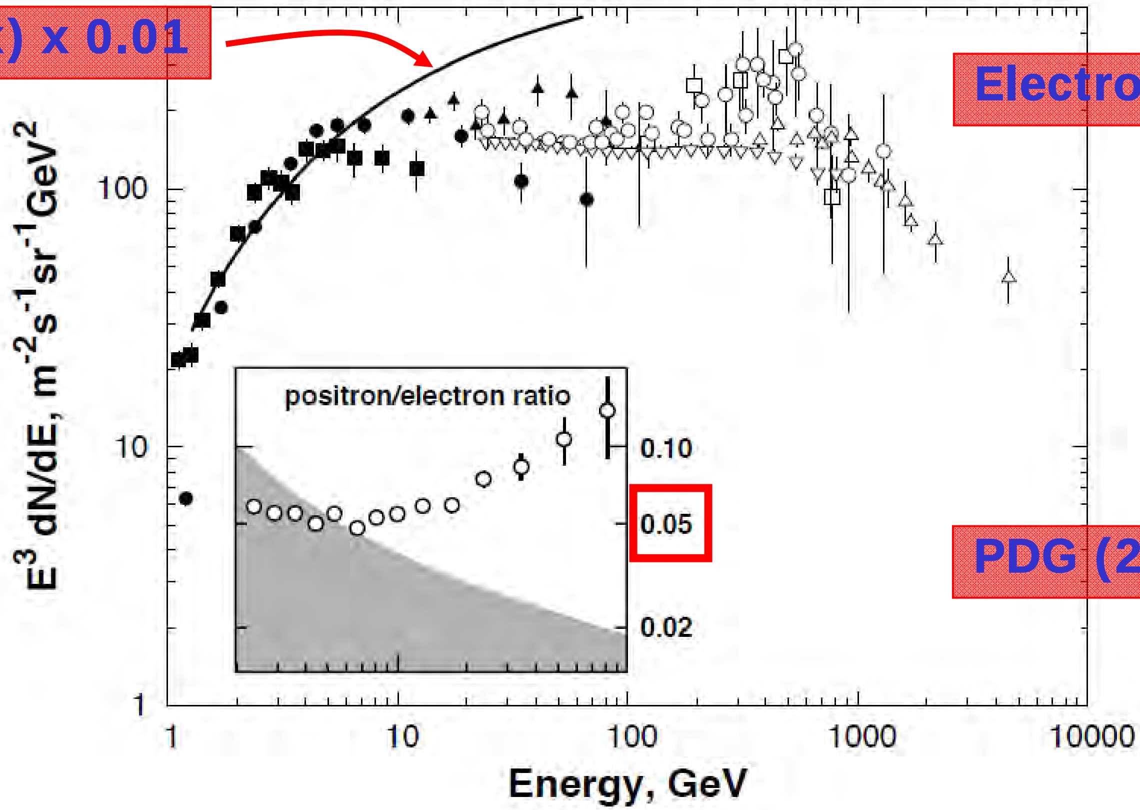
- Charge identification
- Good (≥1TV) Maximum Detectable Rigidity (MDR) to defeat particle spillover (pbar)
- Good (*e/h* > 10^{-5}) particle identification (positron)

CR antimatter detector cookbook

(Proton flux) x 0.01

Electron flux

PDG (2010)



Positron/Proton rejection factor > 10^{-5}

CR antimatter detector cookbook

- Charge identification
- Good (≥1TV) Maximum Detectable Rigidity (MDR) to defeat particle spillover (pbar)
- Good ($e/h > 10^{-5}$) particle identification (positron)
- Redundancy to calculate efficiencies and systematic in flight (absolute fluxes)
- All other useful detectors ...
- Very low secondary background -> SPACE

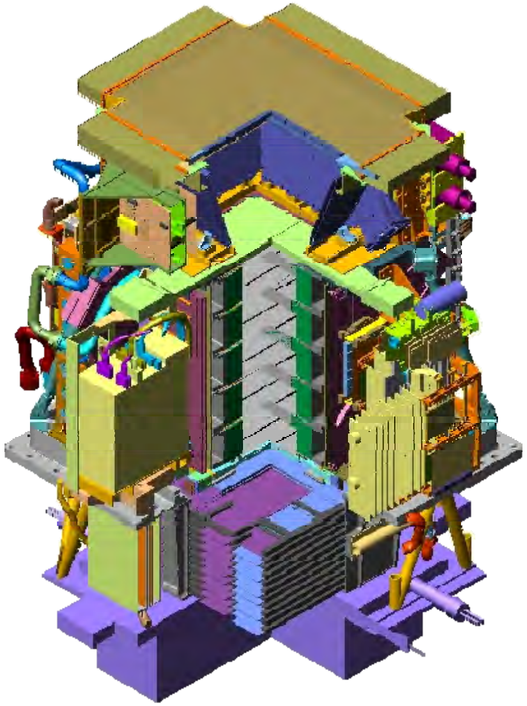
CR antimatter detector cookbook

- Charge identification
- Good (≥1TV) Maximum Detectable Rigidity (MDR) to defeat particle spillover (pbar)
- Good ($e/h > 10^{-5}$) particle identification (positron)
- Redundancy to calculate efficiencies and systematic in flight (absolute fluxes)
- All other useful detectors ...
- Very low secondary background -> SPACE


PAMELA Collaboration
Italy
INFN
Bari
Florence
Frascati
Naples
Tor Vergata
Rome
Trieste
IFAC
CNR, Florence
4
Germany:
Universität Gesamthochschule Siegen
Siegen
Sweden:
Kungl Tekniska Högskolan
KTH, Stockholm
Russia:
Физический Институт
Ioffe Physico-Technical Institute
Moscow / St. Petersburg

PAMELA detectors

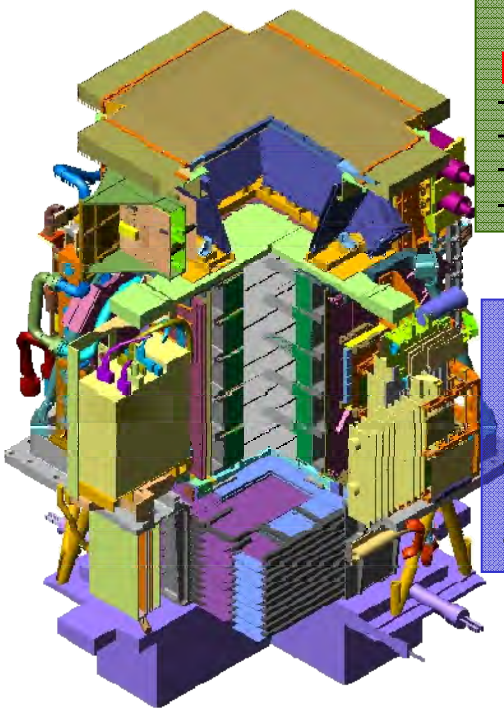
Main requirements → high-sensitivity antiparticle identification and precise momentum measure

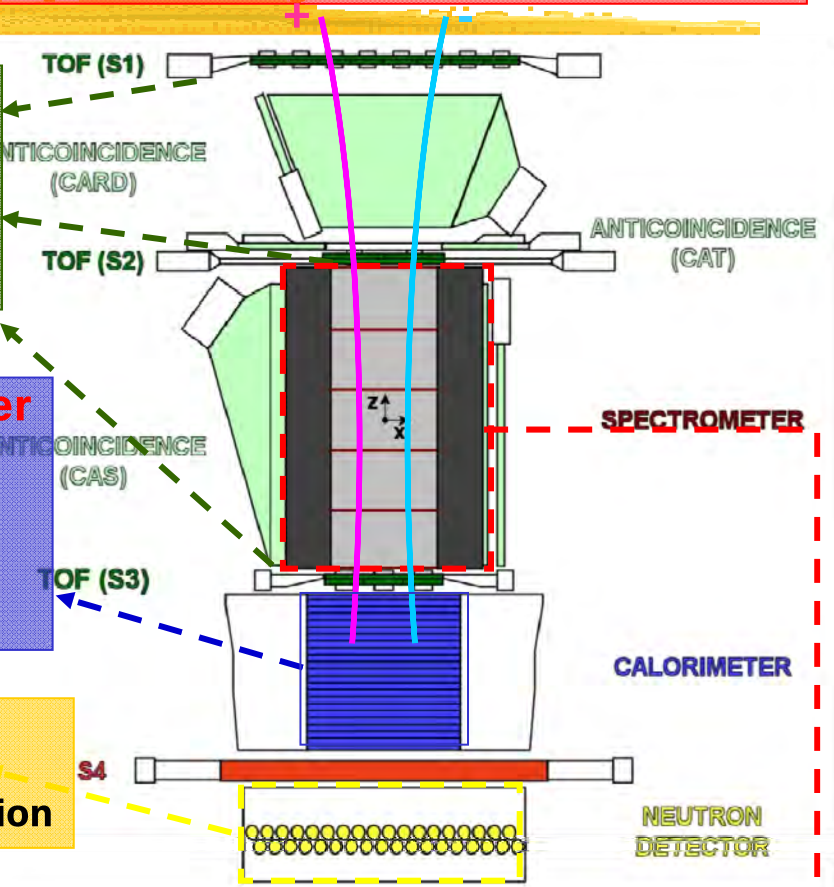


GF:	**21.5 cm^2 sr**
Mass:	**470 kg**
Size:	**130x70x70 cm^3**
Power Budget:	**360W**

PAMELA detectors

Main requirements → high-sensitivity antiparticle identification and precise momentum measure





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
($16.3\ X_0$, $0.6\ \lambda_I$)
- Discrimination e^+ / p, pbar / e^- (shower topology)
- Direct E measurement for e^-

Neutron detector &
Shower-tail catcher (S4):
- -High-energy e/h discrimination

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

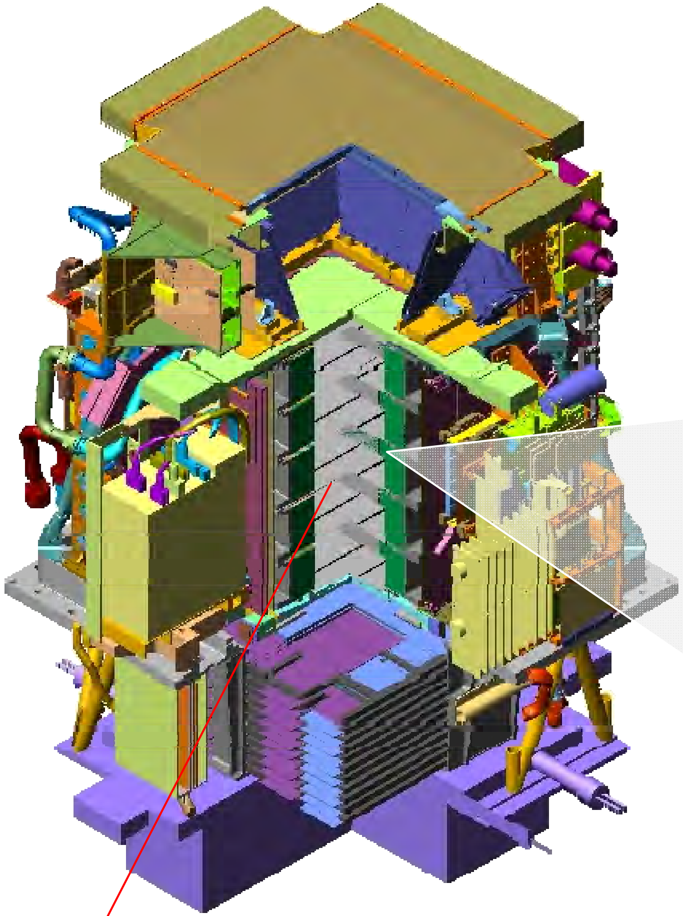
Spectrometer microstrip silicon tracking system+permanent magnet
- Magnetic rigidity (R = pc/Ze)
- Charge sign
- Charge value from dE/dx

Design Performance

• Antiprotons	80 MeV - 150 GeV
• Positrons	50 MeV – 270 GeV
• Electrons	up to 400 GeV
• Protons	up to 700 GeV
• Electrons+positrons	up to 2 TeV (calorimeter alone)
• Light Nuclei (He/Be/C)	up to 200 GeV/n
• AntiNuclei search	sensitivity of 3×10^{-8} in $\overline{He}/He$

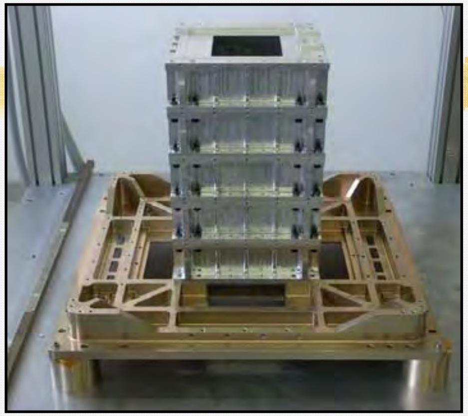
→ Simultaneous measurement of many cosmic-ray species
→ New energy range
→ Unprecedented statistics

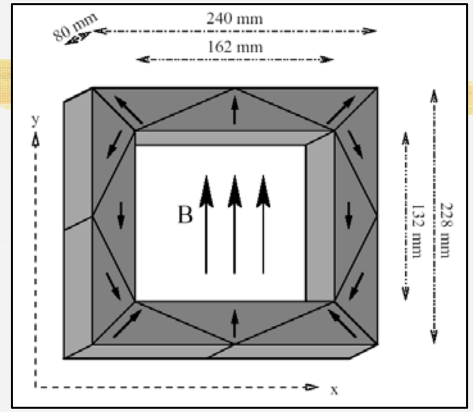
PAMELA



SPECTROMETER

The magnet

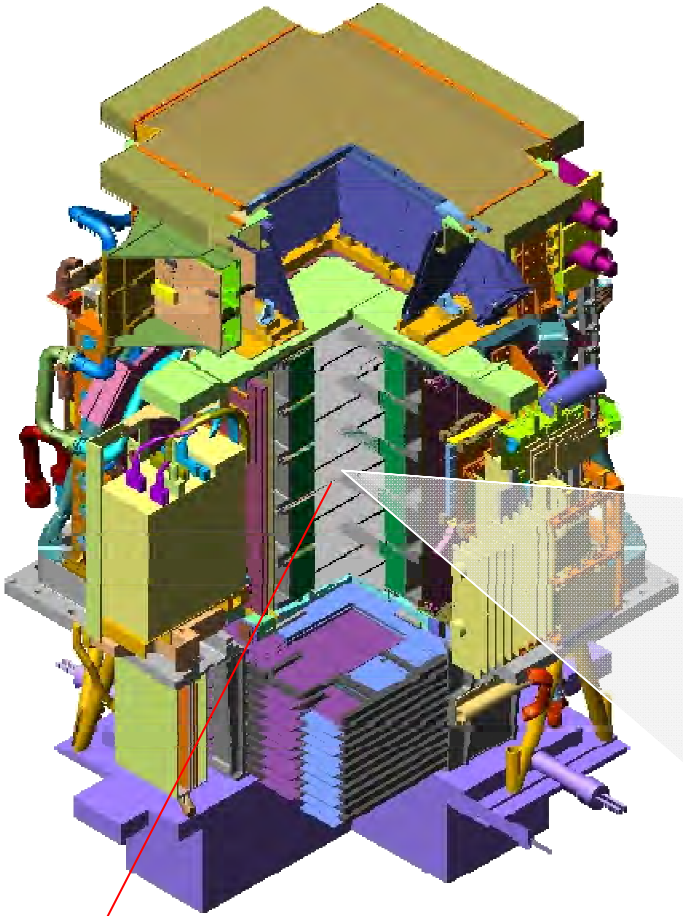




Characteristics:

- 5 modules of permanent magnet (Nd-B-Fe alloy) in aluminum mechanics
- Cavity dimensions 162x132x445 cm^3
  → GF 21.5 cm^2sr
- Magnetic shields
- 5mm-step field-map
- B=0.43 T (average along axis), B=0.48 T (@center)

PAMELA



The tracking system

Main tasks:

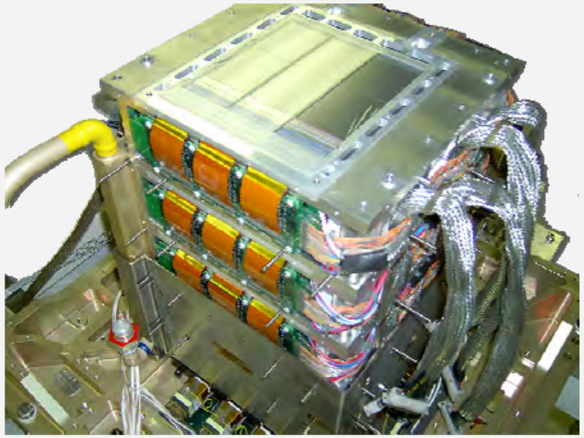
- Rigidity measurement
- Sign of electric charge
- dE/dx

Characteristics:

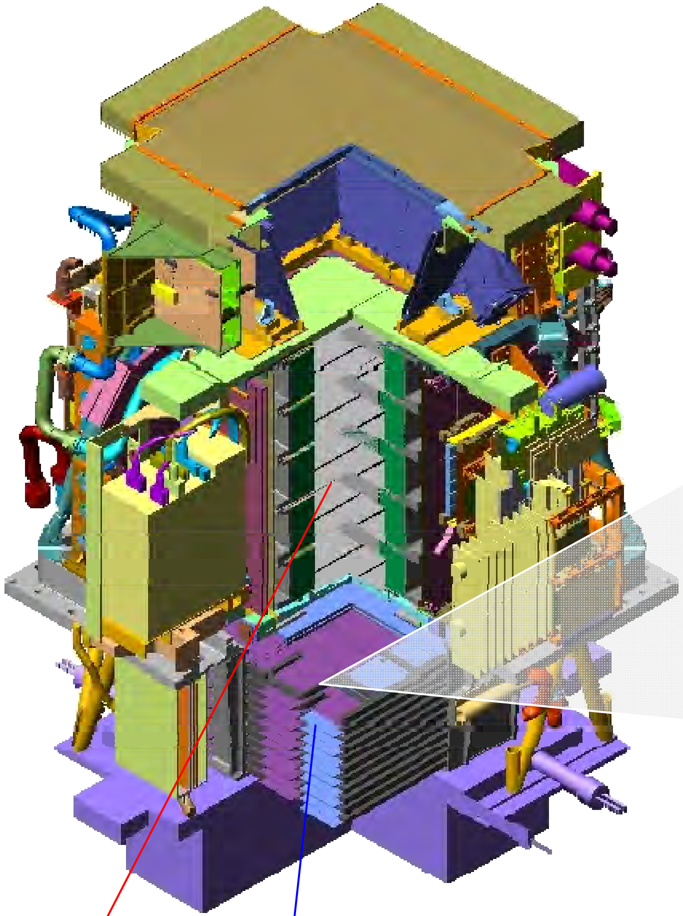
- 6 planes double-side (x&y view) microstrip Si sensors
- 36864 channels
- Dynamic range 10 MIP

Performances:

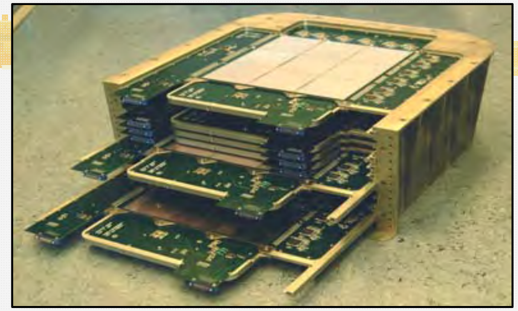
- Spatial resolution: 3-4μm
- MDR ~1T (from test beam data)



PAMELA



The electromagnetic calorimeter



Main tasks:

- e/h discrimination
- $e^{+/-}$ energy measurement

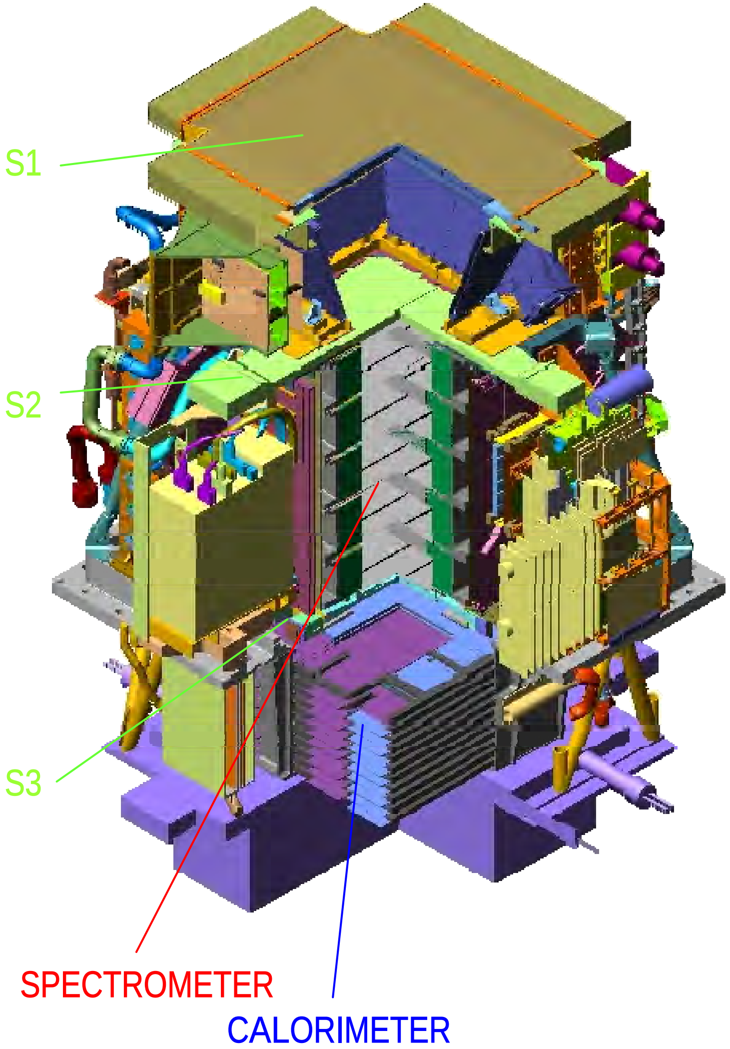
Characteristics:

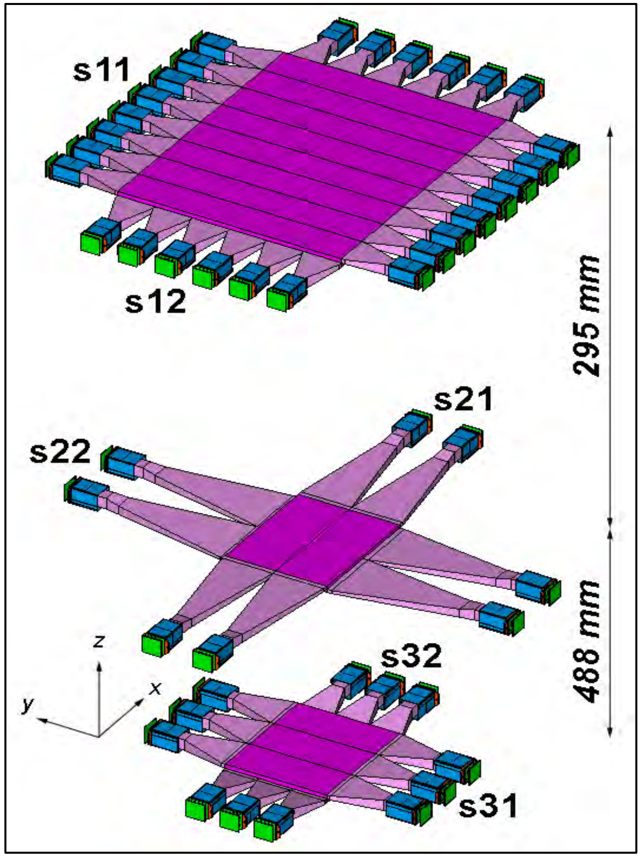
- 44 Si layers (X/Y) +22 W planes
- 16.3 X_o / 0.6 l_0
- 4224 channels
- Dynamic range 1400 mip
- Self-trigger mode (> 300 GeV GF~600 cm^2 sr)

Performances:

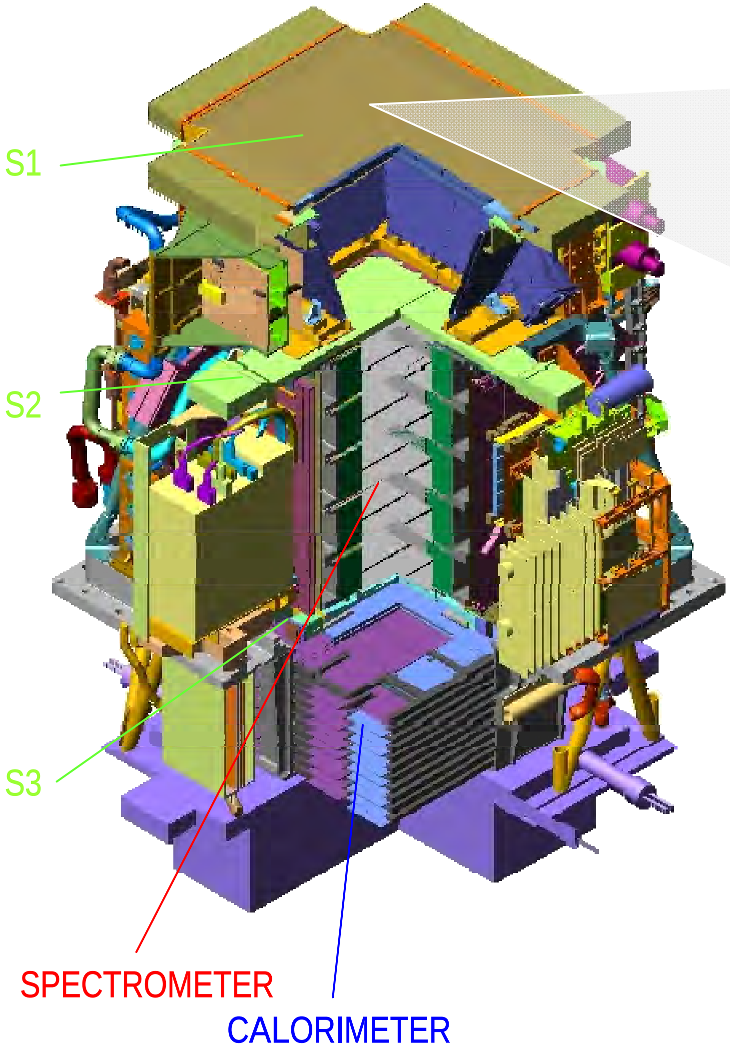
- p-bar and e^+ selection efficienecy ~ 90%
- p rejection factor >10^5
- e^- rejection factor > 10^4
- Energy resolution ~5% @200GeV

PAMELA

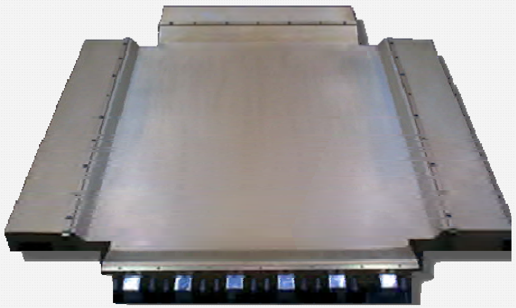

S1
S2
S3
SPECTROMETER
CALORIMETER


s11
s12
s21
s22
s32
s31
295 mm
488 mm
z
y
x

PAMELA



The time-of-flight system

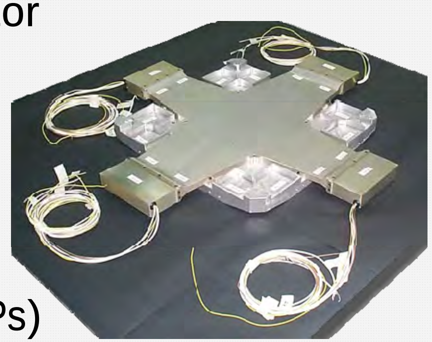


Main tasks:

- First-level trigger
- Albedo rejection
- dE/dx
- Particle identification (<1GeV/c)

Characteristics:

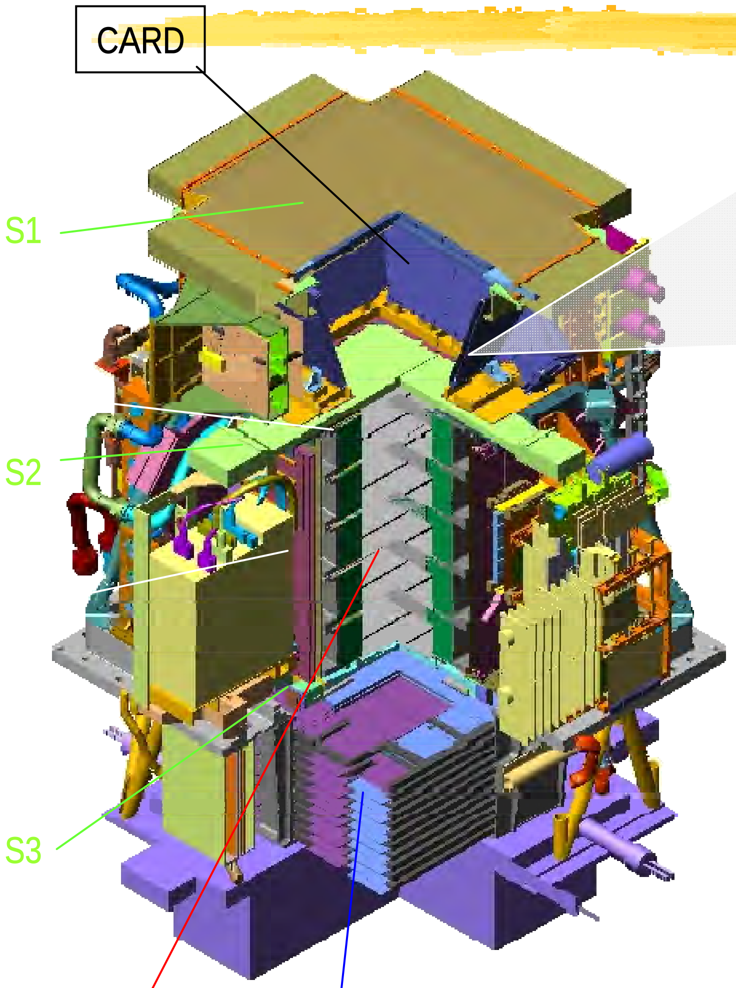
- 3 double-layer scintillator paddles
- X/Y segmentation
- Total: 48 Channels



Performances:

- σpaddle ~ 110ps
- σTOF ~ 330ps (for MIPs)

PAMELA



The anticounter shields

Main tasks:

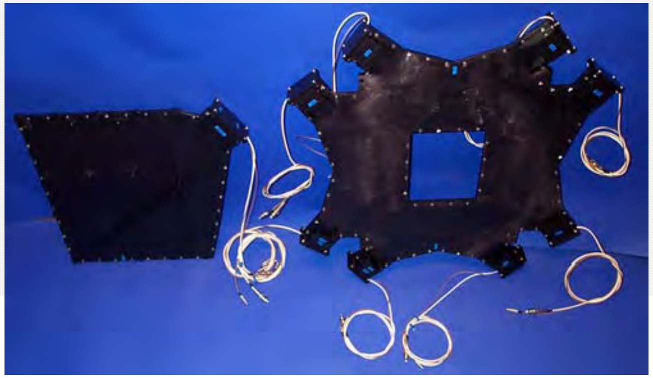
- Rejection of events with particles interacting with the apparatus (off-line and second-level trigger)

Characteristics:

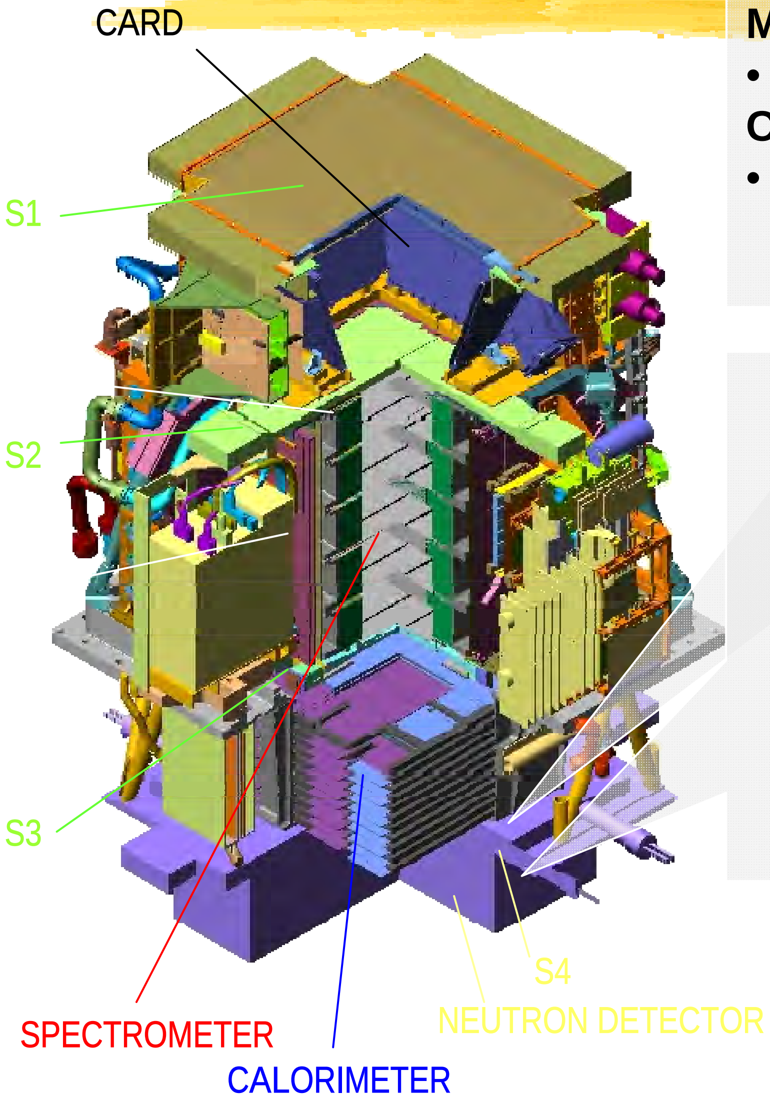
- scintillator paddles 10mm thick
- 4 up (CARD), 1 top (CAT), 4 side (CAS)

Performances:

- Efficiency > 99.9%



PAMELA



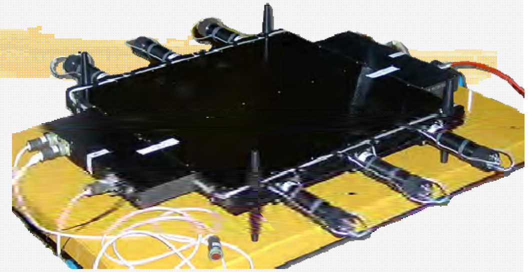
Shower-tail catcher (S4)

Main tasks:

- ND trigger

Characteristics:

- 1 scintillator paddle 10mm thick



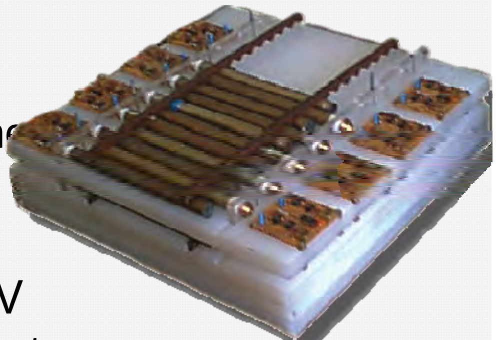
Neutron detector

Main tasks:

- e/h discrimination @high-ene

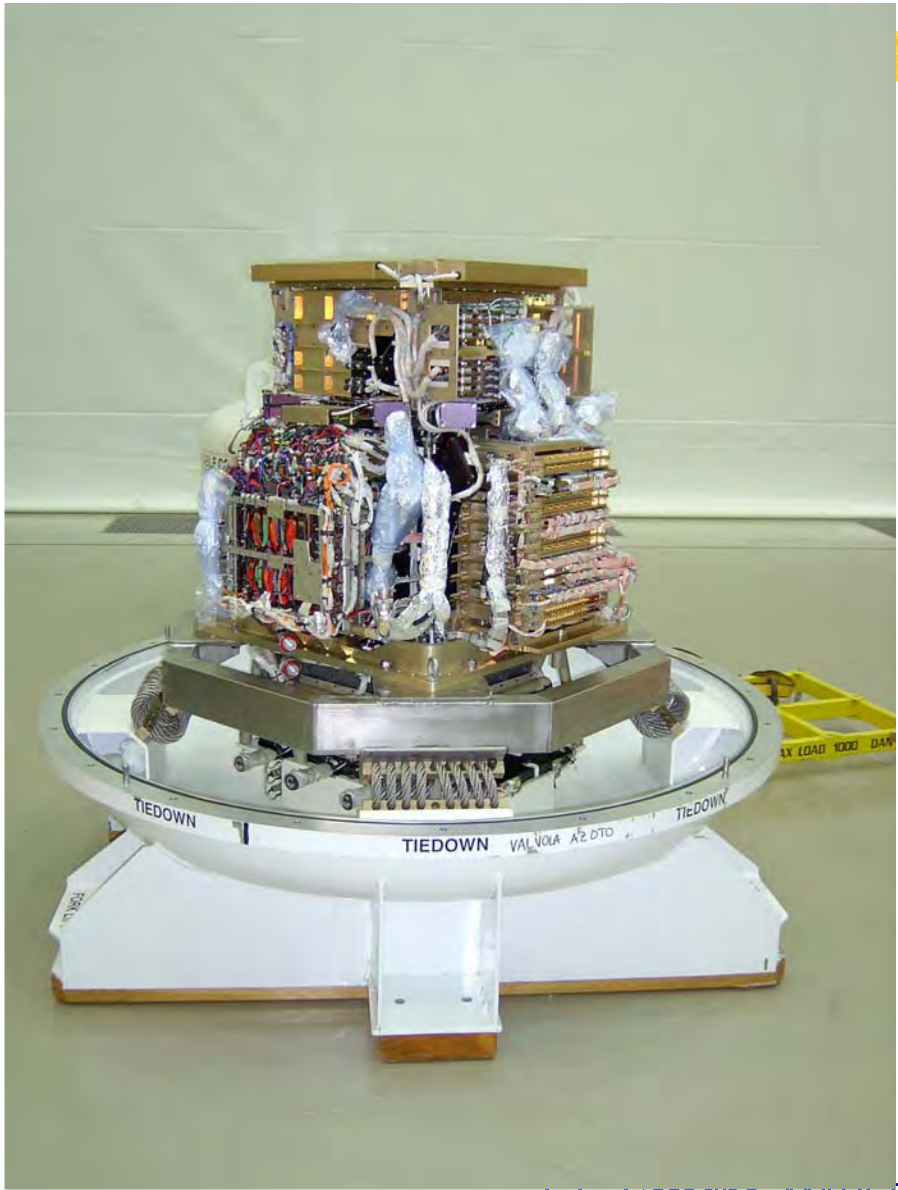
Characteristics:

- 36 ^{3}He counters: ^{3}He(n,p)T → Ep=780 keV
- 1cm thick polyetilene moderators
- n collected within 200 μs time-window

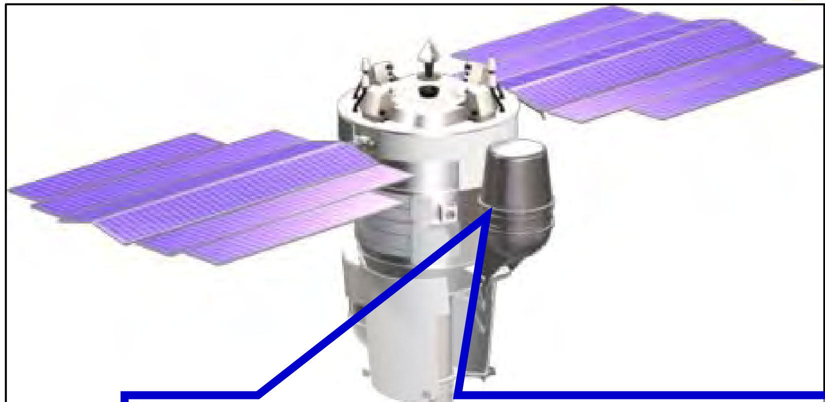


e$^+$ background estimation from dataThe "pre-sampler" method

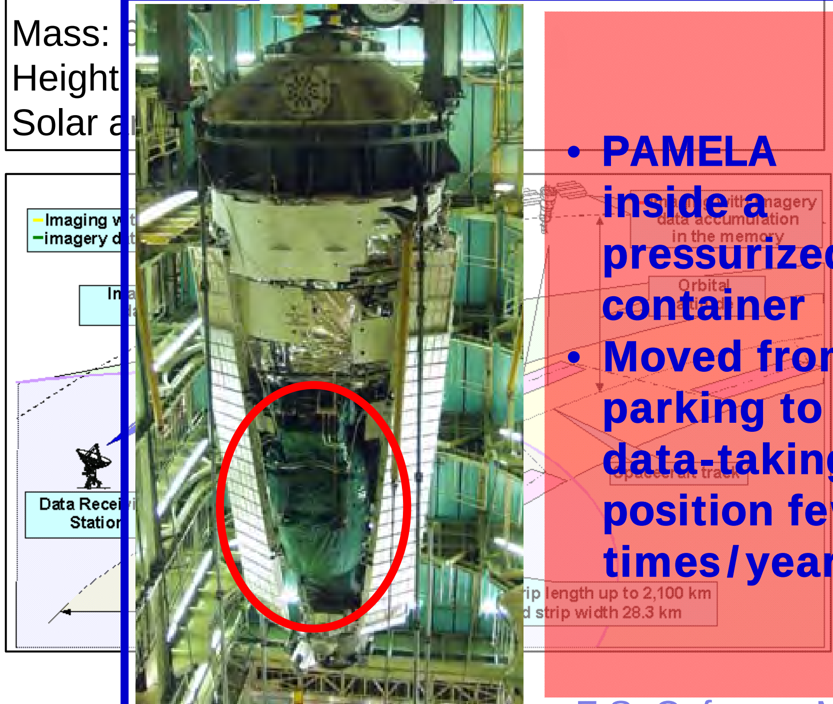
PAMELA: the integration



The Resurs DK-1 spacecraft



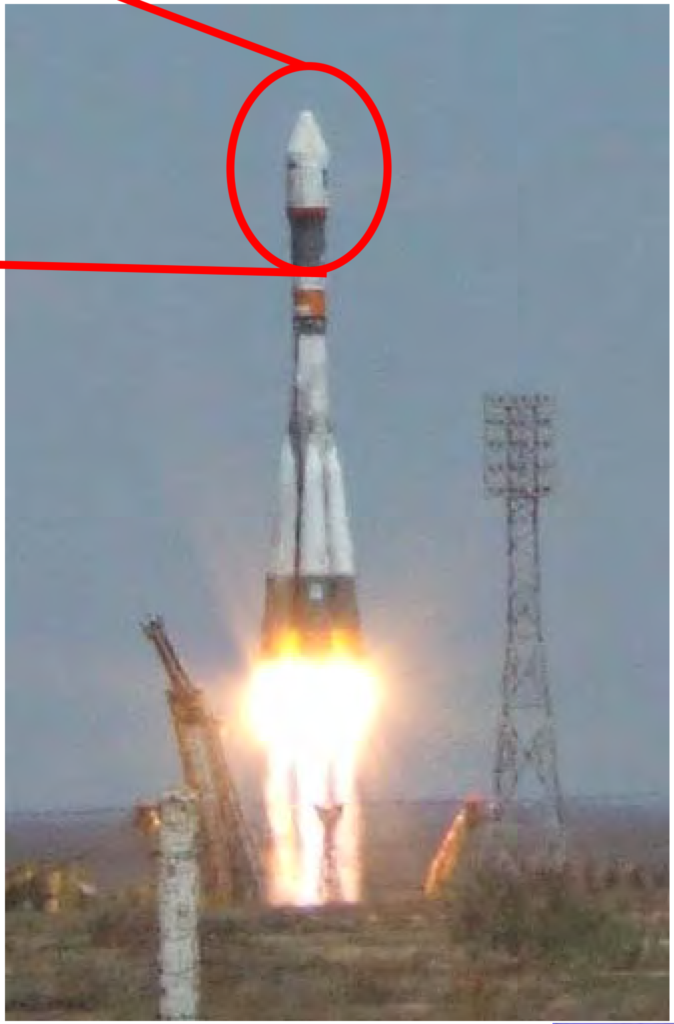
Mass:
Height
Solar a



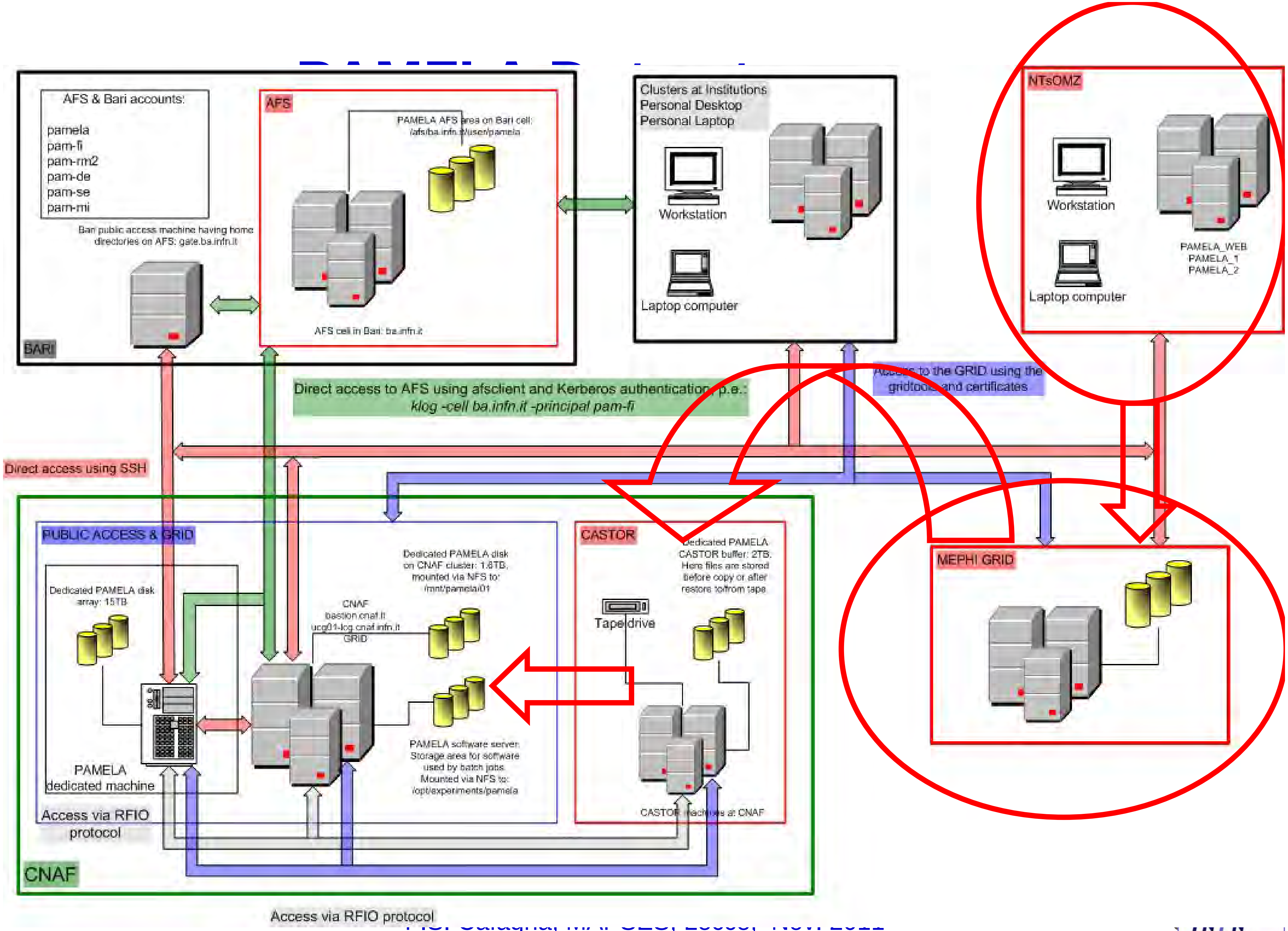
- **PAMELA inside a pressurized container**
- **Moved from parking to data-taking position few times/year**

- Multi-spectral remote sensing of earth's surface
  → near-real-time high-quality images
- Built by the Space factory TsSKB Progress in Samara (Russia)
- Operational orbit parameters:
  - inclination ~70º
  - altitude ~ 360-600 km (elliptical)
- Active life >3 years
- Data transmitted via Very high-speed Radio Link (VRL)

the satellite & launch



- Launch from Baikonur:
  June 15th 2006, 0800 UTC.
  Power On: June 21st 2006, 0300 UTC.
  Detectors operated as expected after launch
- PAMELA in continuous data-taking mode since commissioning phase ended on July 11th 2006
  - ~1500 days of data taking (~73% live-time)
  - ~19 TByte of raw data downlinked
  - >2.2x10^{9} triggers recorded and under analysis



AFS & Bari accounts:
pamela
pam-fi
pam-rm2
pam-de
pam-se
pam-mi
Bari public access machine having home directories on AFS: gate.ba.infn.it
BARI
AFS
PAMELA AFS area on Bari cell: /afs/ba.infn.it/user/pamela
AFS cell in Bari: ba.infn.it
Clusters at Institutions
Personal Desktop
Personal Laptop
Workstation
Laptop computer
NTsOMZ
Workstation
Laptop computer
PAMELA_WEB
PAMELA_1
PAMELA_2
Direct access to AFS using afsclient and Kerberos authentication, p.e.:
klog -cell ba.infn.it -principal pam-fi
Access to the GRID using the gridtools and certificates
Direct access using SSH
PUBLIC ACCESS & GRID
Dedicated PAMELA disk array: 15TB
PAMELA dedicated machine
Dedicated PAMELA disk on CNAF cluster: 1.6TB, mounted via NFS to: /mnt/pamela/01
CNAF bastion.cnaf.it ucg01-lcg.cnaf.infn.it GRID
PAMELA software server: Storage area for software used by batch jobs. Mounted via NFS to: /opt/experiments/pamela
Access via RFIO protocol
CASTOR
Dedicated PAMELA CASTOR buffer: 2TB. Here files are stored before copy or after restore to/from tape
Tape drive
CASTOR machines at CNAF
MEPHI GRID
CNAF
Access via RFIO protocol

The CR toolkit: the jargon

- We want to measure spectra, i.e. differential fluxes for several energy values:

$$\Phi(E) = \frac{N_{cand}}{\Gamma T \varepsilon \Delta E}$$

- Where: Γ is the geometrical factor (better: the gathering power), T the livetime, ε the overall efficiency

The CR toolkit: bin mean value

Nuclear Instruments and Methods in Physics Research A 355 (1995) 541–547

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

N·H ELSEVIER

Where to stick your data points:
The treatment of measurements within wide bins

G.D. Lafferty [a,*], T.R. Wyatt [b,1]

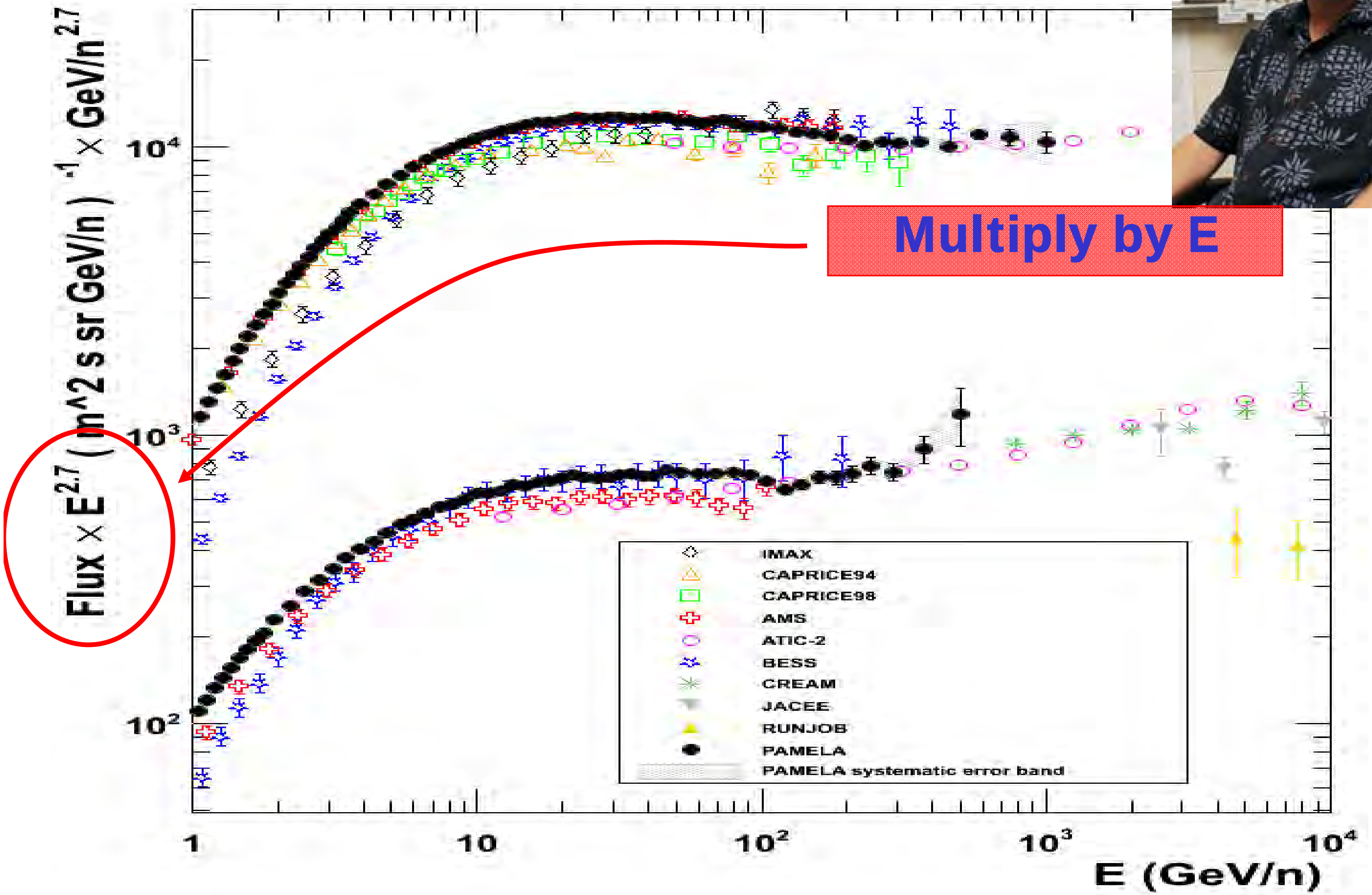
[a] Department of Physics and Astronomy, The University of Manchester, Manchester M13 9PL, UK
[b] PPE Division, CERN, CH-1211 Geneva 23, Switzerland

Received 17 June 1994; revised form received 29 August 1994

- Given a bin: (E_1,E_2), the correct mean value, E_c, is the value at which the measured spectrum is equal to the expectation value of the "true" spectrum:

$$\Phi(E_c) = \frac{1}{E_2 - E_1}\int_{E_1}^{E_2} \Phi(E)\,dE$$

The CR toolkit: bin mean valu



The CR toolkit: gathering power

NUCLEAR INSTRUMENTS AND METHODS 95 (1971) 5–11; © NORTH-HOLLAND PUBLISHING CO.

GEOMETRICAL FACTOR AND DIRECTIONAL RESPONSE OF SINGLE AND MULTI-ELEMENT PARTICLE TELESCOPES*

J. D. SULLIVAN†

Enrico Fermi Institute and Dept. of Physics, The University of Chicago, Chicago, Illinois 60637, U.S.A.

Received 26 February 1971

The CR toolkit: gathering power

The expression in square brackets in eq. (2) is the gathering power of the telescope when the intensity has an angular dependence given by $F(\omega)$. That is

$$\Gamma_F = \int_\Omega \mathrm{d}\omega \int_S \mathrm{d}\boldsymbol{\sigma} \cdot \hat{\boldsymbol{r}} F(\omega) = \int_\Omega \mathrm{d}\omega\, F(\omega) \int_S \mathrm{d}\boldsymbol{\sigma} \cdot \hat{\boldsymbol{r}} . \qquad (3)$$

We can define the directional response function of a telescope, $A(\omega)$, as

$$A(\omega) = \int_S \mathrm{d}\boldsymbol{\sigma} \cdot \hat{\boldsymbol{r}} . \qquad (4)$$

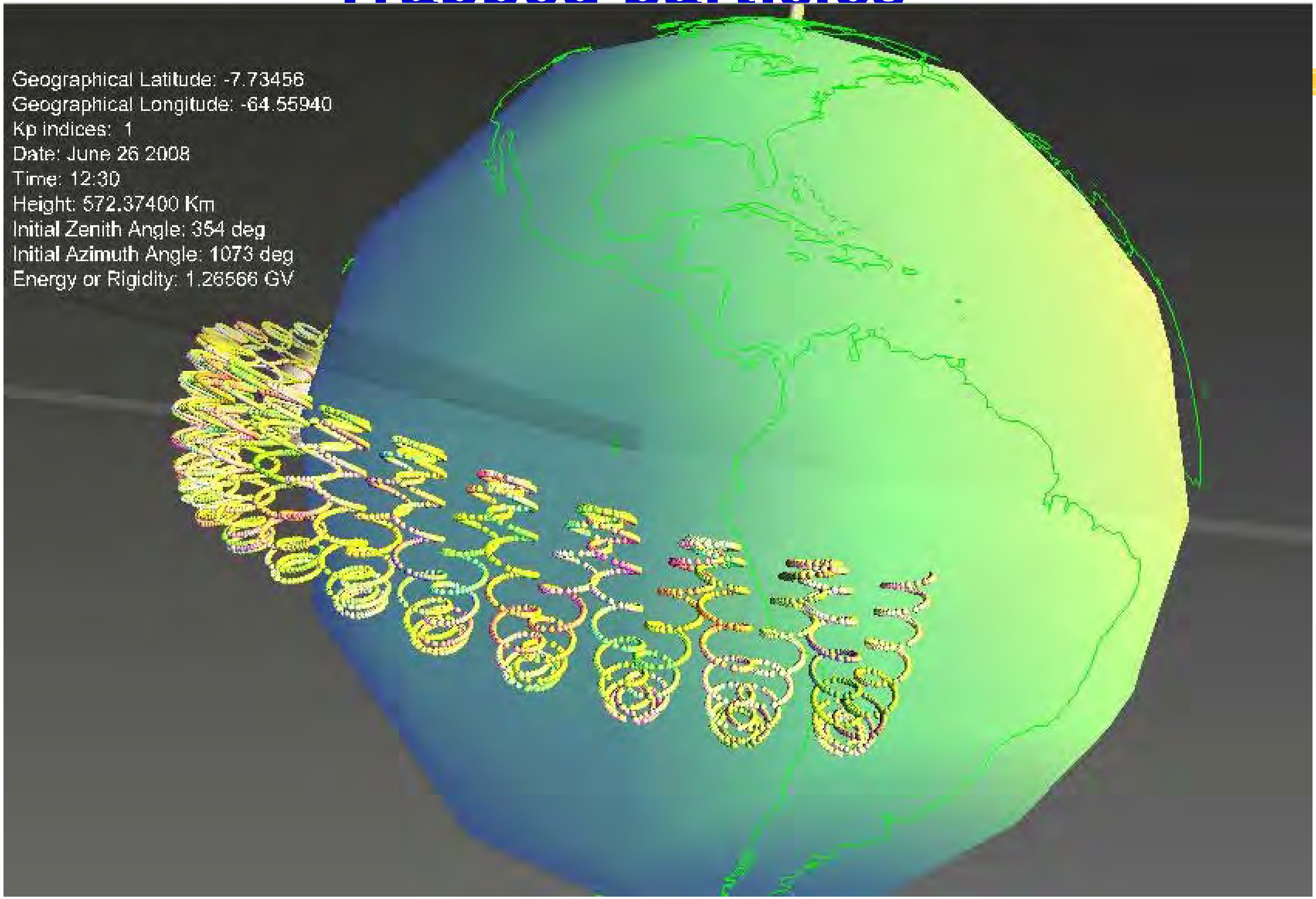
Thus, eq. (3) may be rewritten as $\Gamma_F = \int_\Omega \mathrm{d}\omega\, F(\omega) A(\omega)$ and the directional response function can be used to facilitate the computation of the gathering power. This is especially useful for numerical calculations.

Considering eq. (3) again we see that if the intensity is isotropic then $F(\omega)$ is unity and the geometrical factor (the gathering power for isotropic flux) depends only on the geometry of the telescope. In other words:

$$G = \int_\Omega \mathrm{d}\omega \int_S \mathrm{d}\boldsymbol{\sigma} \cdot \hat{\boldsymbol{r}} = \int_\Omega \mathrm{d}\omega\, A(\omega) . \qquad (5)$$

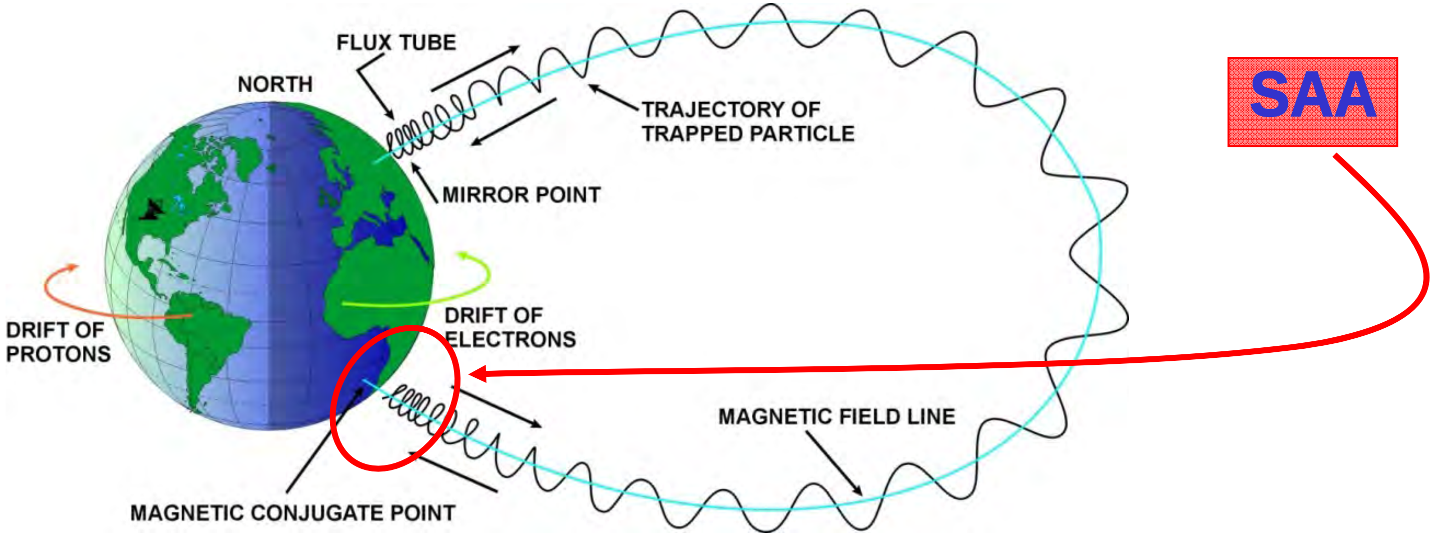
This is not always true!!!

Trapped particles



Trapped particles

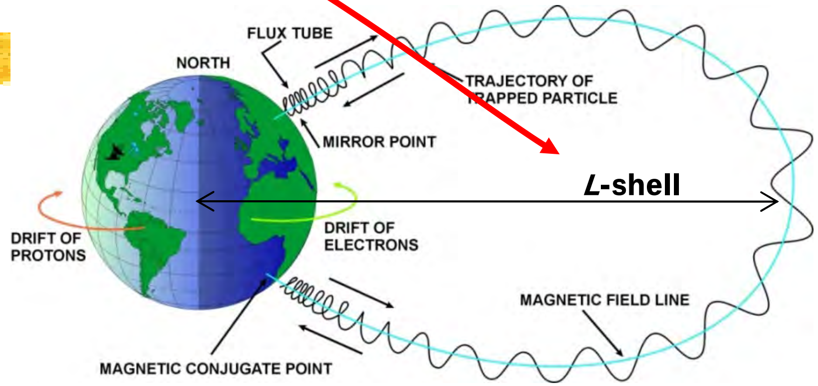
- Charged particles trapped in the Earth's Magnetosphere:
  - Gyrate around and travel along the geomagnetic field lines.
  - Are trapped in a magnetic mirror, bouncing from North to South and back.
  - Experience gradient and curvature drifts to the West for protons and to the East for electrons (drift due to gravitational force is present, but it is of significantly smaller magnitude).



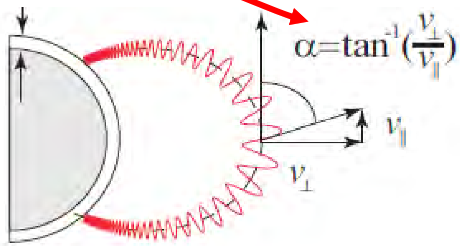
Thanks to A. Bruno: alssandro.bruno@ba.infn.it

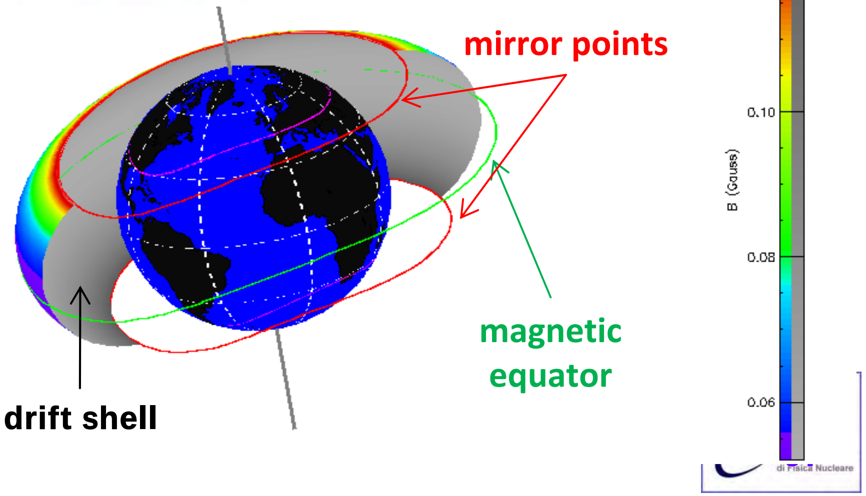
Trapped Radiation

- L-shell parameter:
  - it is the distance of the field line from the center of the dipole, at magnetic equator
  - During the longitudinal drift around the Earth, particles move in the same L-shell
  - A drift shell is the convolution of the field lines belonging to the same L-shell.

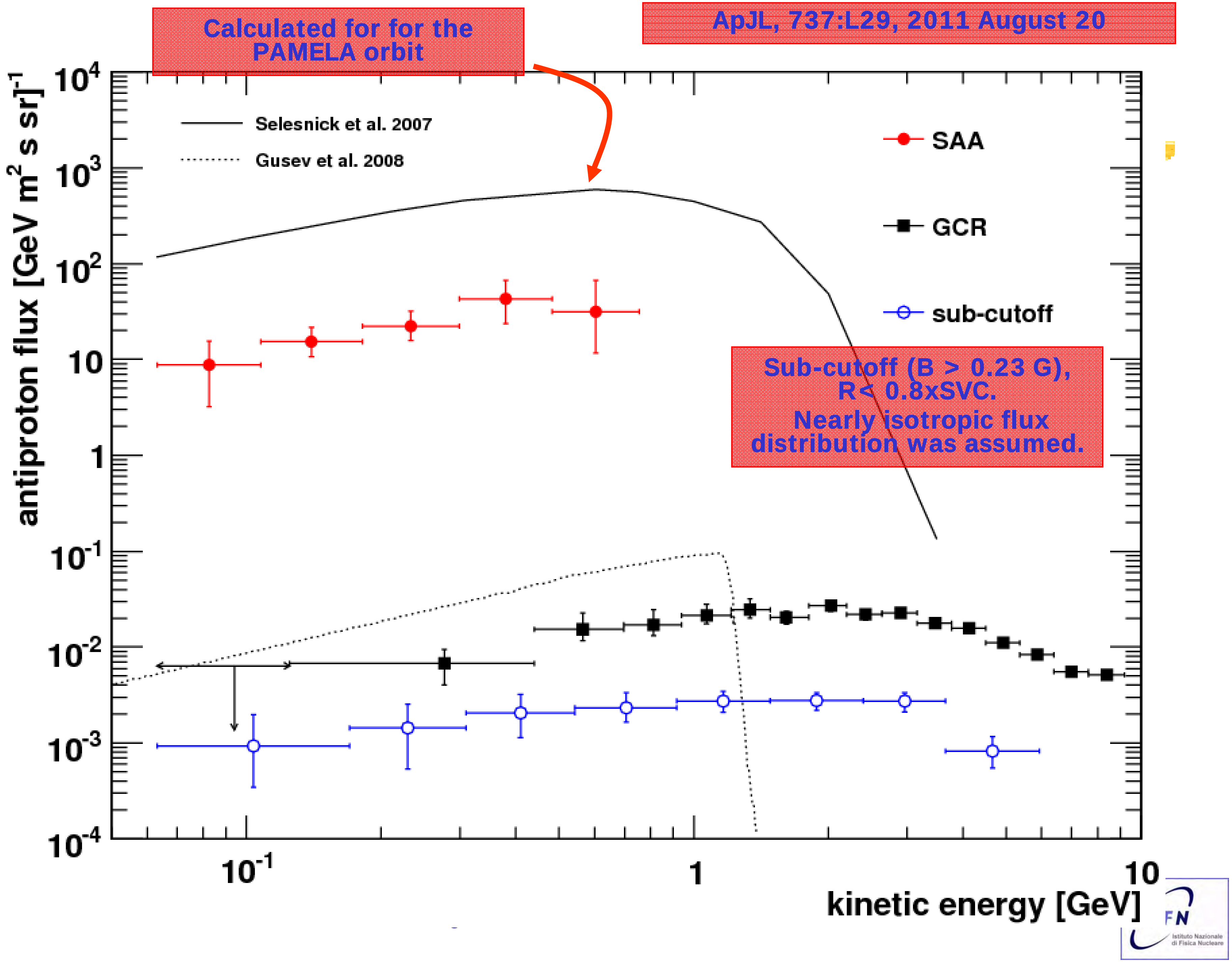


- Pitch angle:
  - The pitch angle α is the angle between particle velocity and magnetic field directions
  - The particle's pitch angle is constantly changing as it travels along the non-uniform magnetic field lines
  - The equatorial pitch angle α_{eq} is a convenient reference point.





Thanks to A. Bruno: alssandro.bruno@ba.infn.it



Calculated for for the PAMELA orbit
ApJL, 737:L29, 2011 August 20
Selesnick et al. 2007
Gusev et al. 2008
SAA
GCR
sub-cutoff
Sub-cutoff (B > 0.23 G), R< 0.8xSVC.
Nearly isotropic flux distribution was assumed.
antiproton flux [GeV m^2 s sr]^-1
kinetic energy [GeV]
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-1
1
10

Tracking in non uniform field

- A recursive method to track particle and derive deflection, along with the MDR on event by event basis.

366

Nuclear Instruments and Methods in Physics Research A306 (1991) 366–377
North-Holland

Performance of a balloon-borne magnet spectrometer for cosmic ray studies

R.L. Golden, C. Grimani, R. Hull, B.L. Kimbell, R. Park, S.A. Stephens, S. Stochaj and W.R. Webber
New Mexico State University, Particle Astrophysics Laboratory, Las Cruces, NM 88003-0001, USA

G. Basini, E. Bonaviri, F. Massimo Brancaccio and M. Ricci
Laboratori Nazionali INFN, Italy

J.F. Ormes, E.S. Seo and R.E. Streitmatter
NASA/Goddard Space Flight Center, USA

F. Celletti and P. Spillantini
Università di Firenze, Firenze, Italy

A. Codino, M. Menichelli and I. Salvatori
Università di Perugia, Perugia, Italy

F. Bongiorno
Università di Roma I (La Sapienza), Roma, Italy

V. Bidoli, A. Buccheri, M.P. De Pascale, A. Morselli and P. Picozza
Università Tor Vergata, Italy

Received 2 January 1991

$$\alpha = (x^*, y^*, \sin\theta^*, \varphi^*, \eta)$$

Tracking in non uniform field

- Start from a state vector on a given plane:

$$\boldsymbol{\alpha} = (x^*, y^*, \sin\theta^*, \varphi^*, \eta)$$

- Minimize chi-square back propagating the particle:

$$\chi^2(\boldsymbol{\alpha}) = \sum_i^N \left[\left(\frac{x_i - \tilde{x}_i(\boldsymbol{\alpha})}{\sigma_{x_i}} \right)^2 + \left(\frac{y_i - \tilde{y}_i(\boldsymbol{\alpha})}{\sigma_{y_i}} \right)^2 \right]$$

- MDR will be equal to: $\frac{1}{\sigma_\eta} = \left(\frac{\partial \chi^2}{\partial \eta^2} \right)^{1/2}$

Ionization losses at lower rigidity

Nuclear Instruments and Methods in Physics Research A 362 (1995) 487–498

ELSEVIER

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

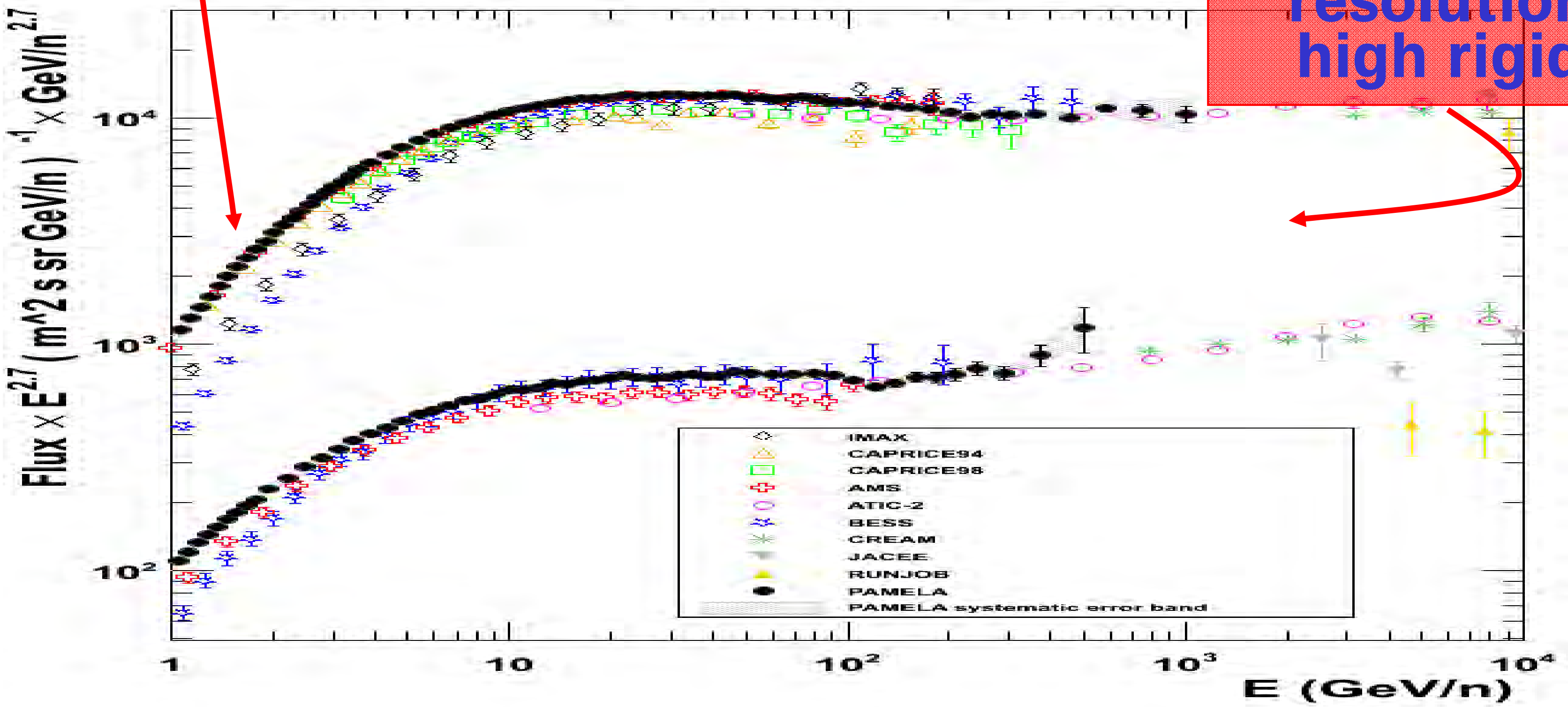
A multidimensional unfolding method based on Bayes' theorem

G. D'Agostini *

Università "La Sapienza" and INFN, Roma, Italy

Received 5 August 1994; revised form received 2 March 1995

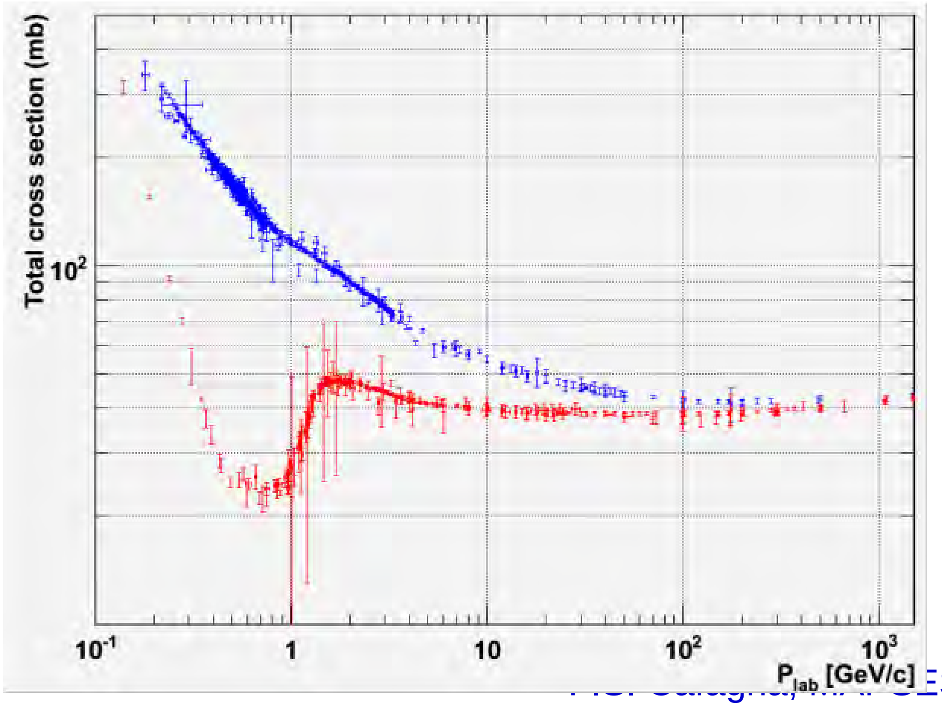
Spectrometer resolution at high rigidity

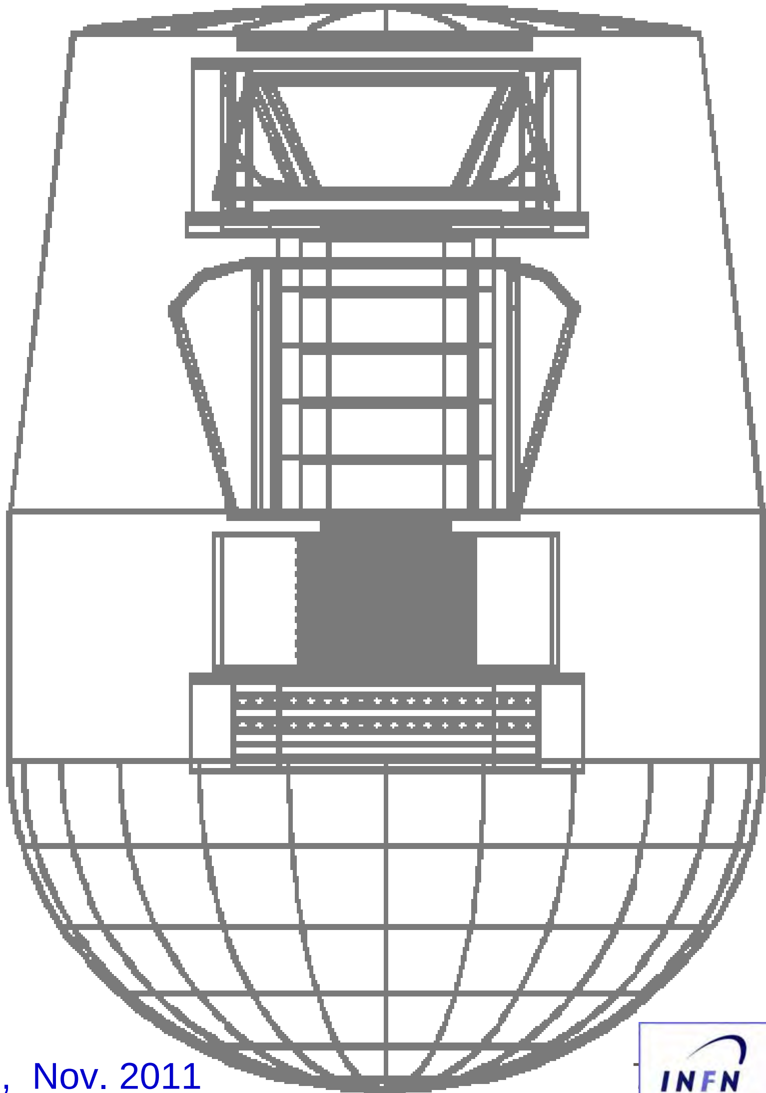


INFN Istituto Nazionale di Fisica Nucleare

Montecarlo

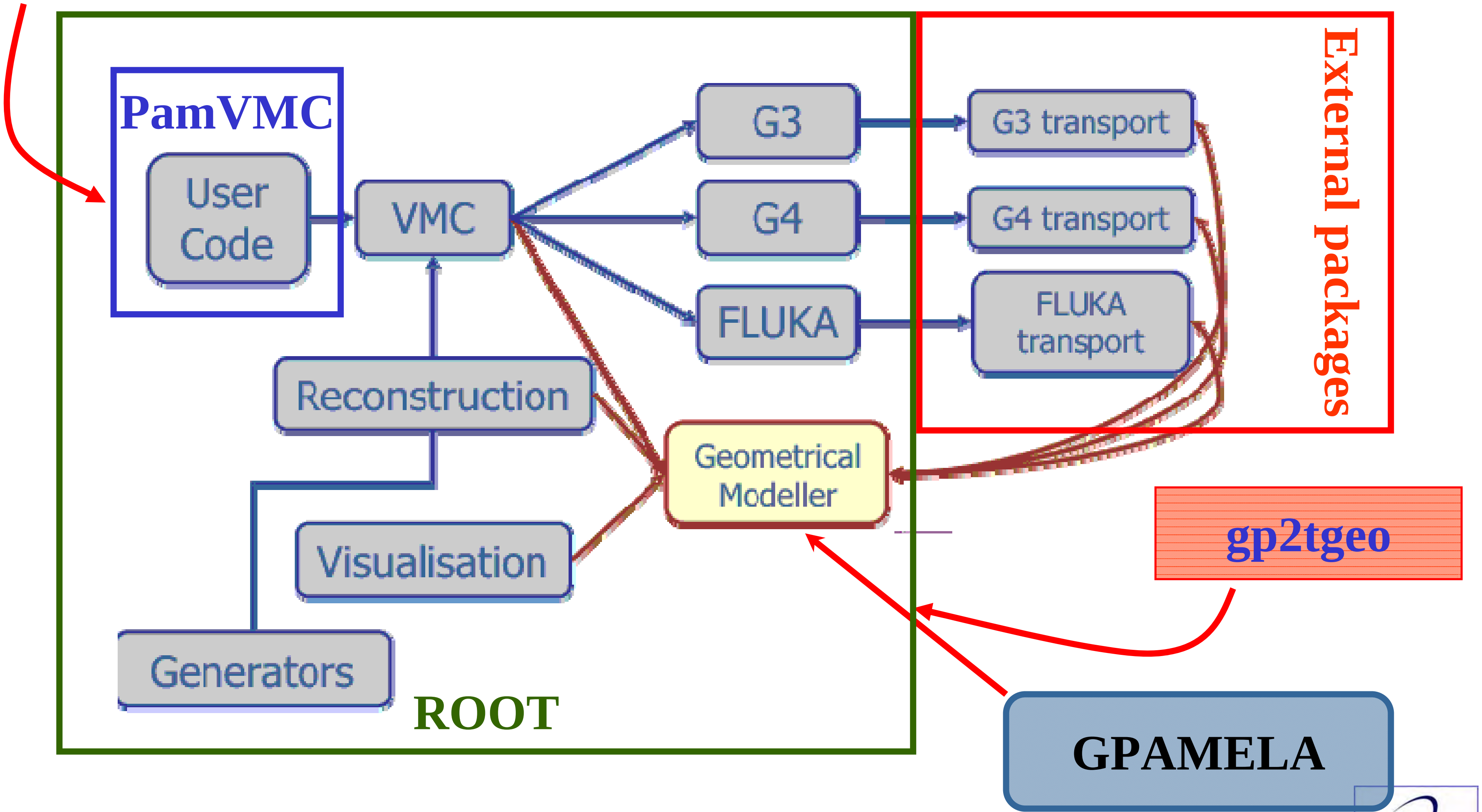
- Geant3 with modified antiproton cross section.
- Geant4 via VMC (ALICE coll.)





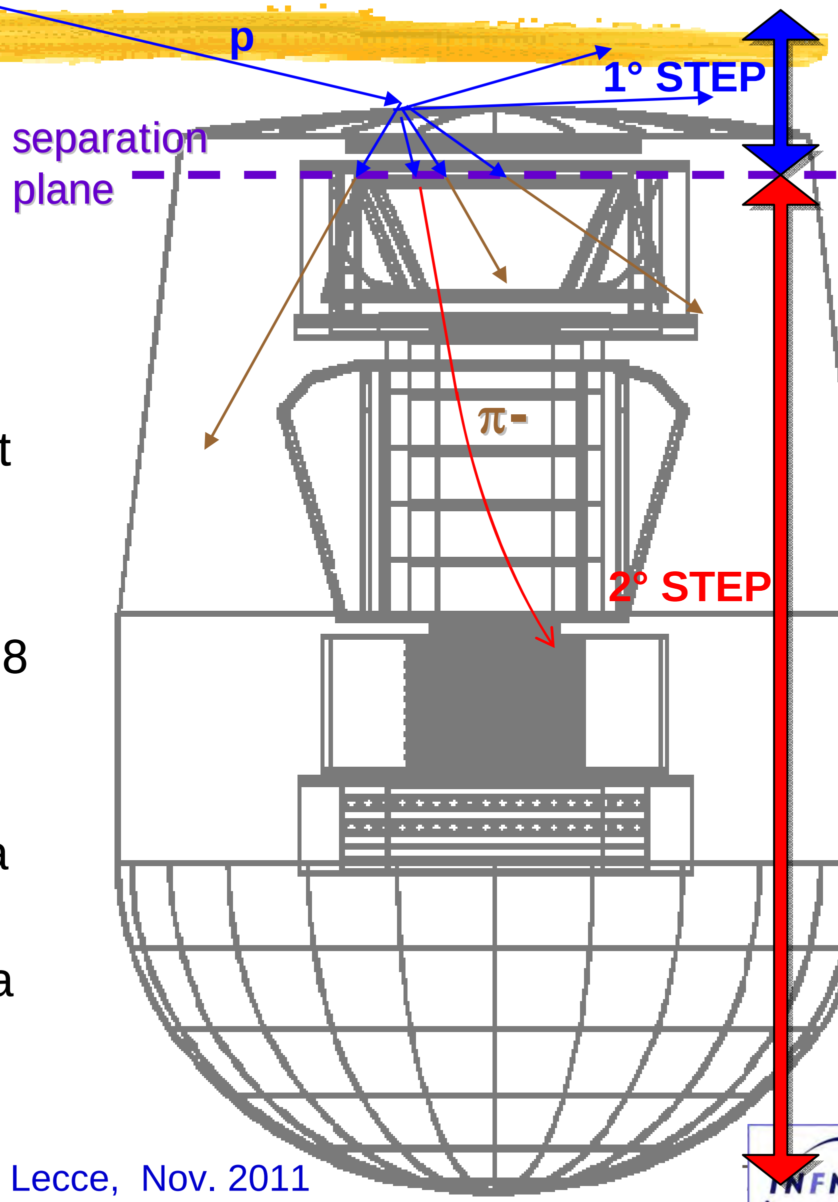
From GEANT3 to VMC (G4)

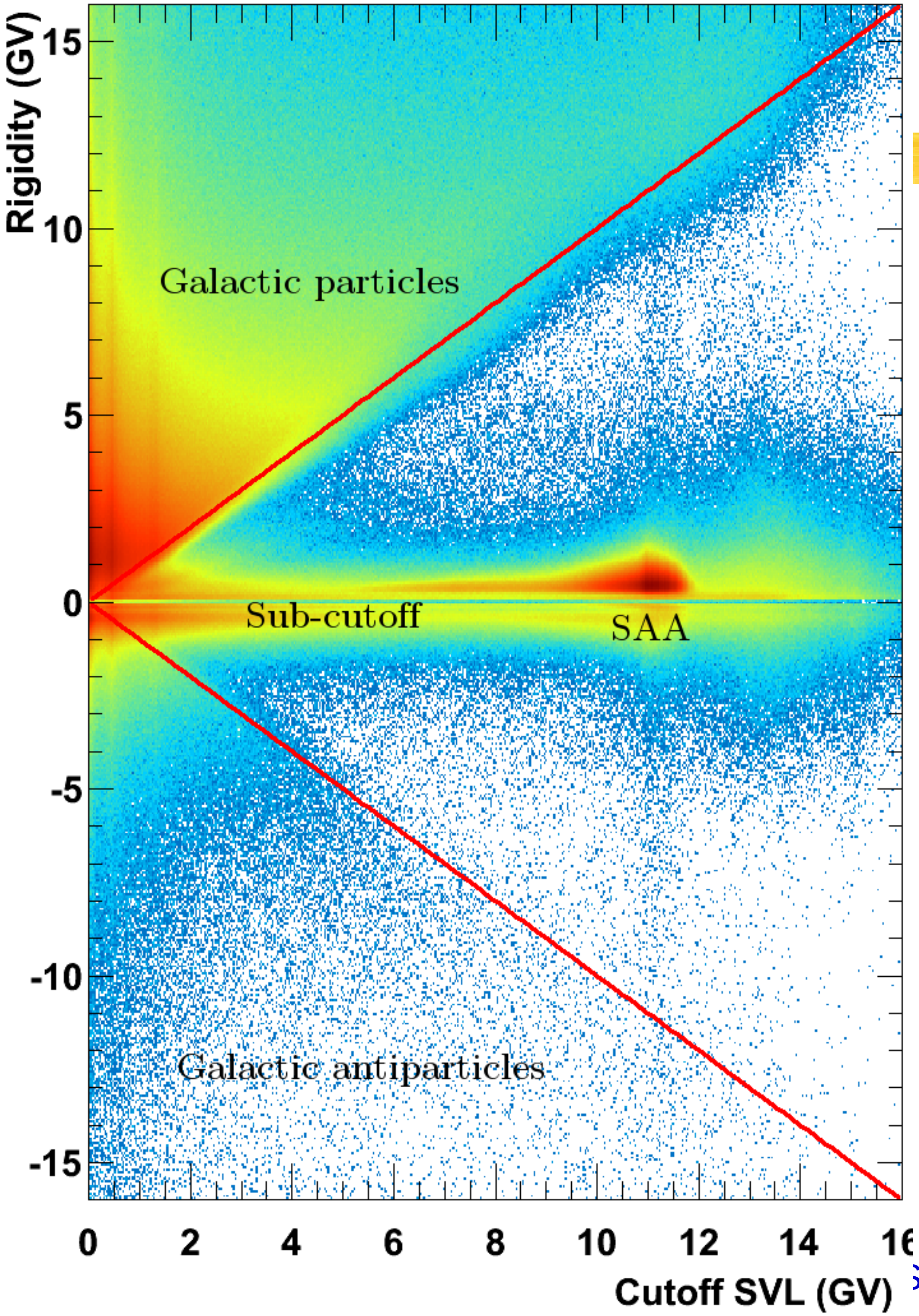
User code is the same for each transport



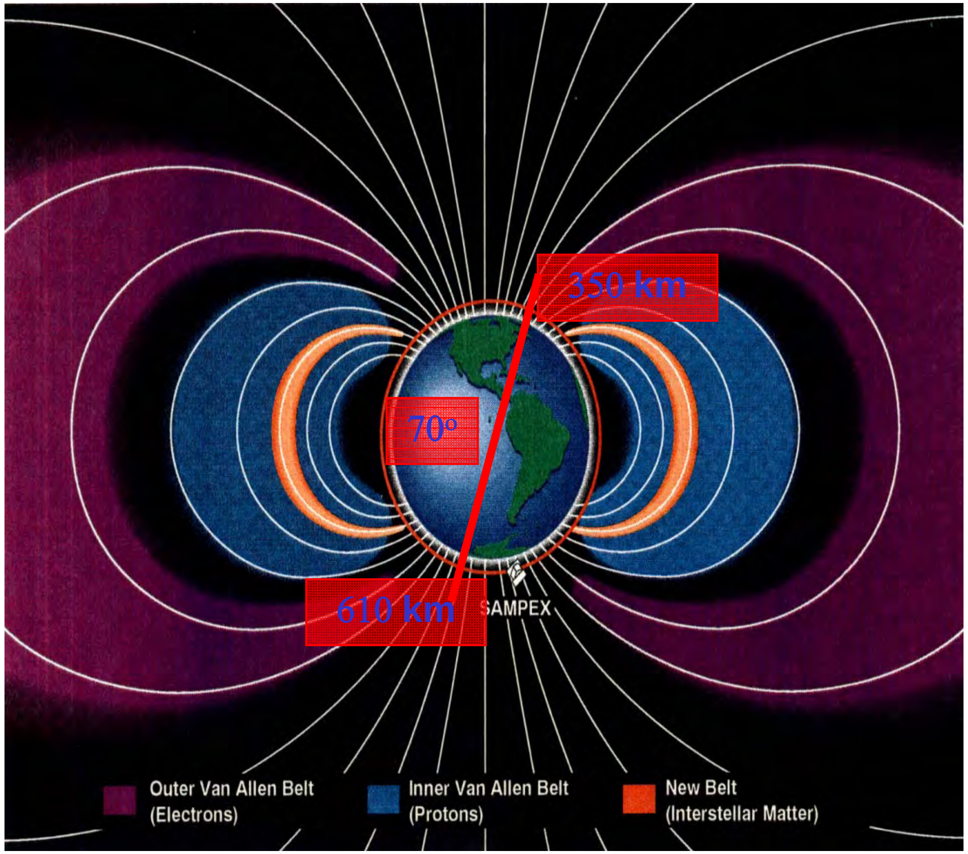
Background study with FLUKA

- π-: the main uncertainty up to a few GeV
- Dedicated application developed:
  - 2 steps (FLUKA+GPAMELA) simulation chain
- PAMELA proton spectrum used as input
  - geomagnetic cutoff included
- Contribution from nuclei
  - α particles (DPMJET-III, CAPRICE98 spectrum)
- Very high statistics produced:
  - ~3.5·10^{11} protons (~7 years of data taking)
  - ~3.6·10^{10} alpha (~3 years of data taking)

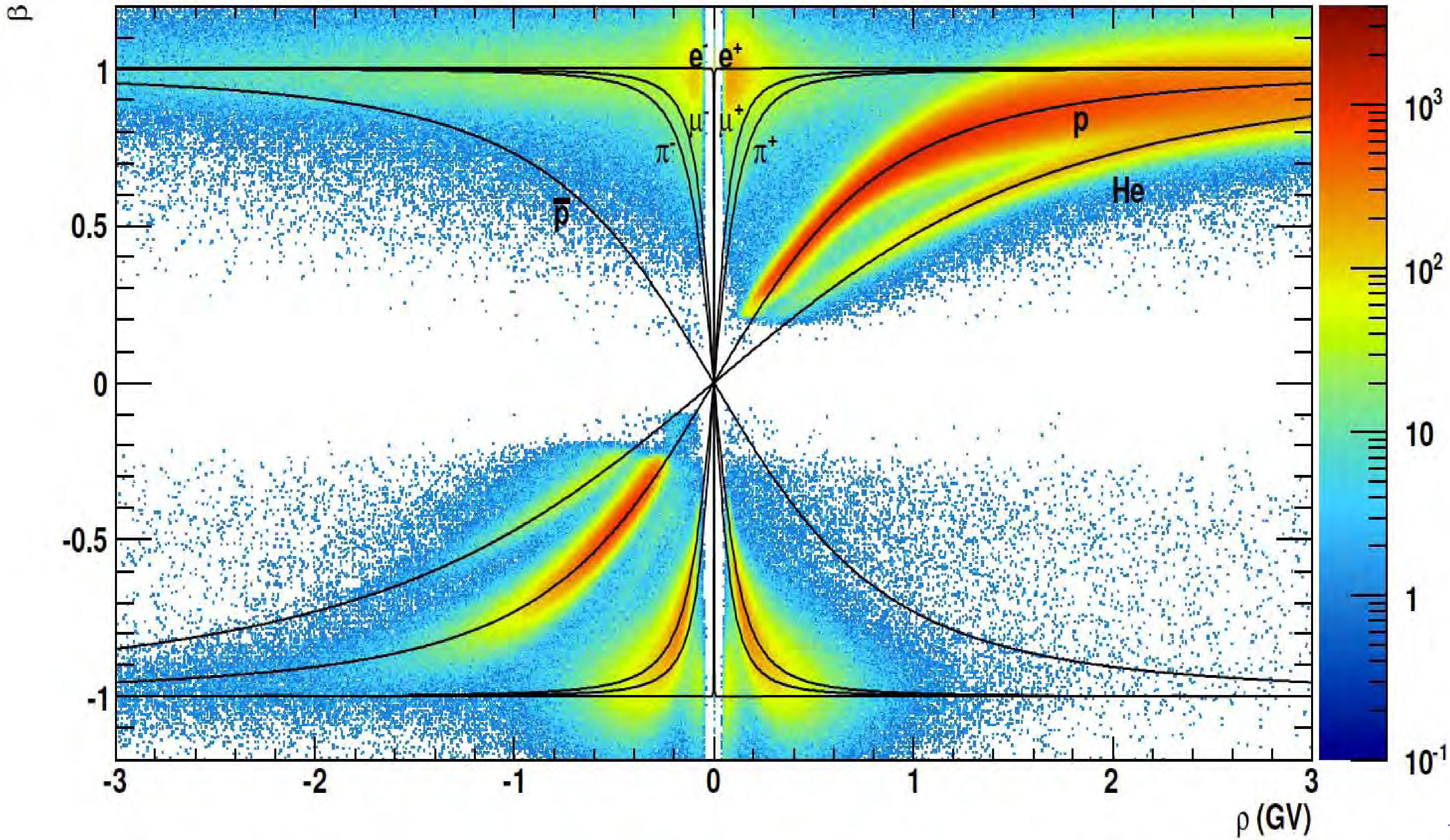




Characteristics

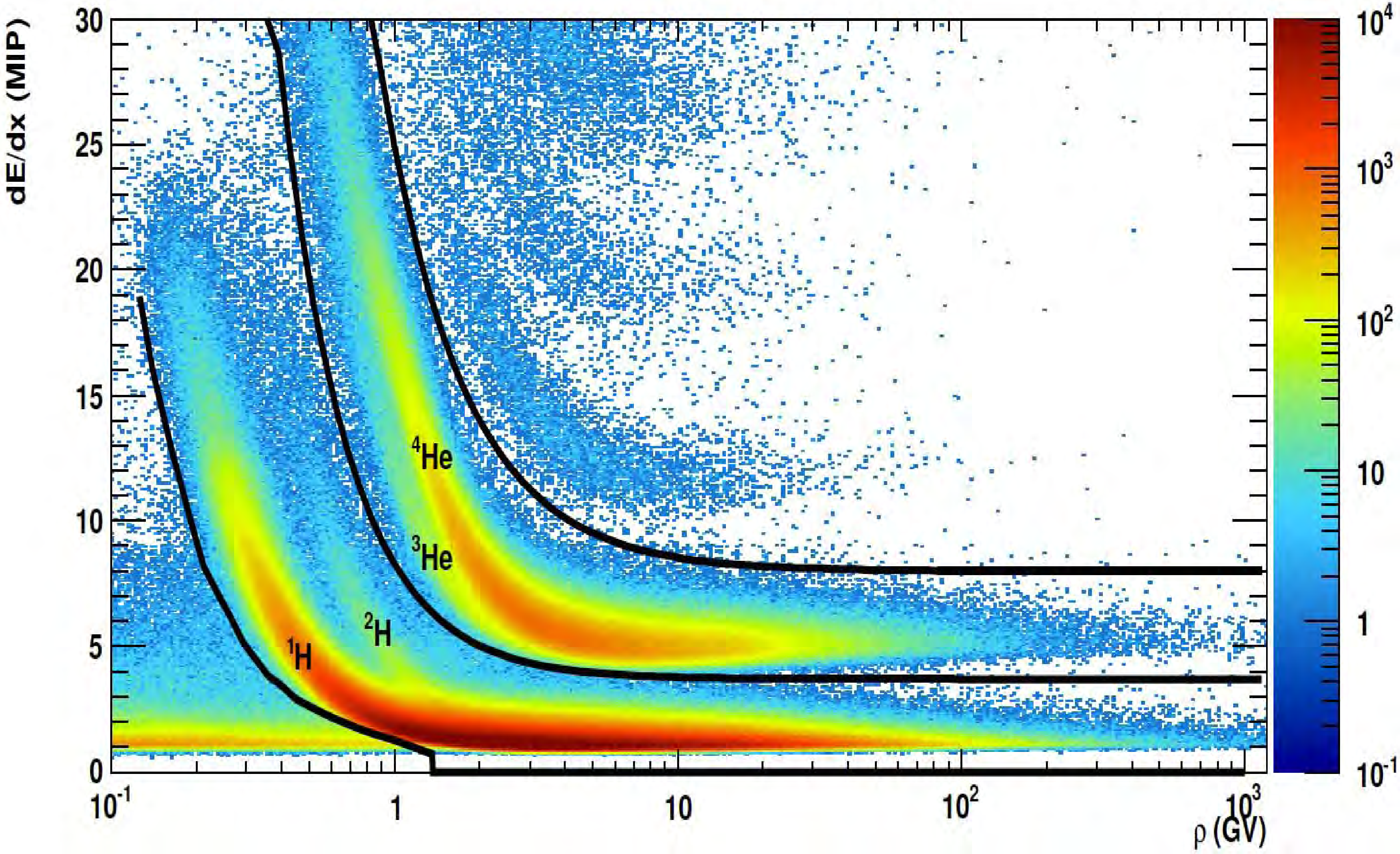


Particle selection: TOF

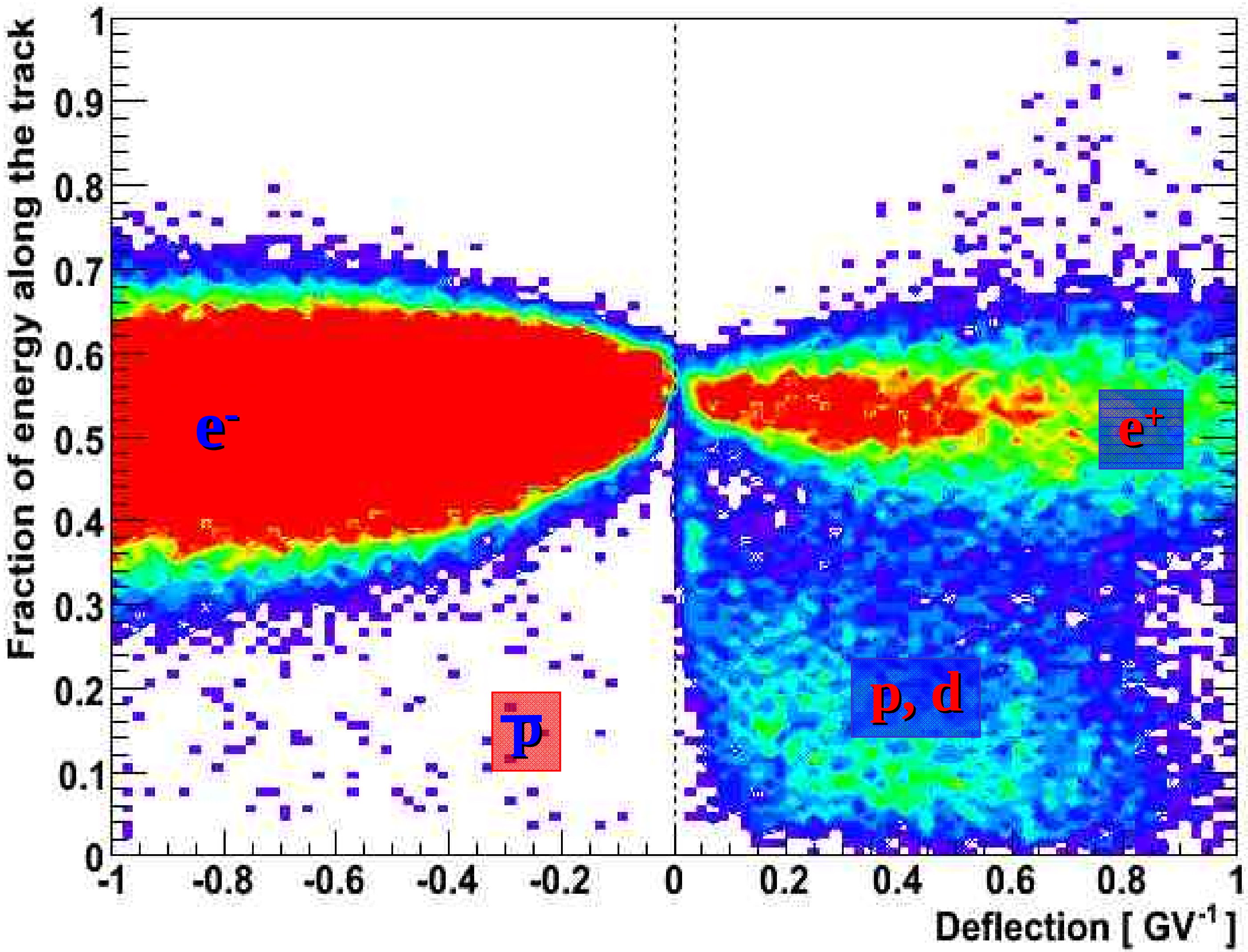


INFN Istituto Nazionale di Fisica Nucleare

Particle selection: Tracker



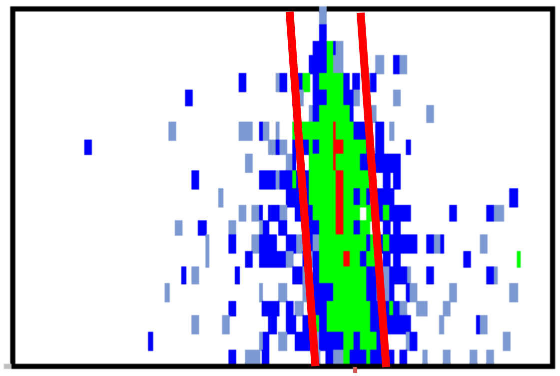
Particle selection: calorimeter

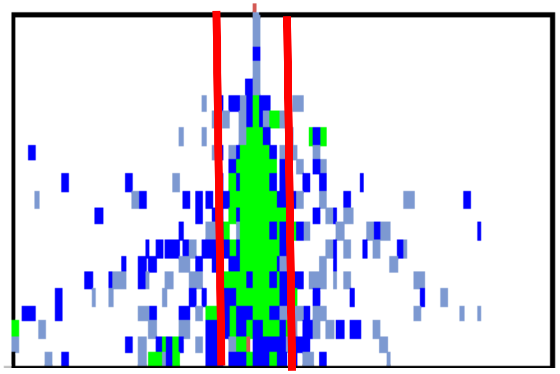


Positron selection with calorimeter

51 GV Positron

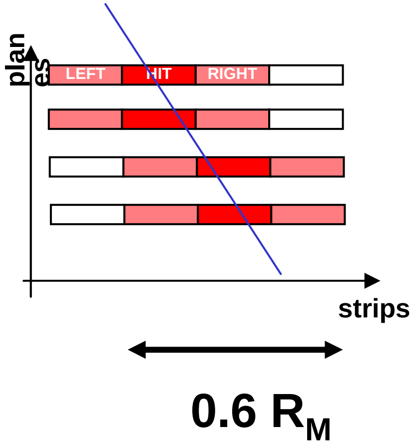
80GV Proton

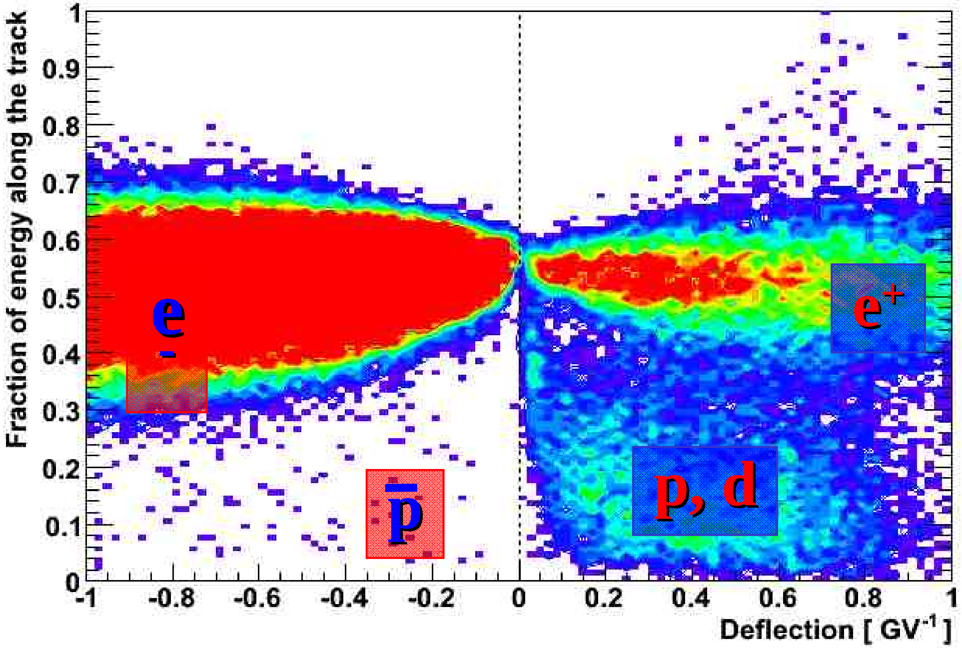




Fraction of charge released along the calorimeter track

Energy (calo) – Momentum (spectrometer) match

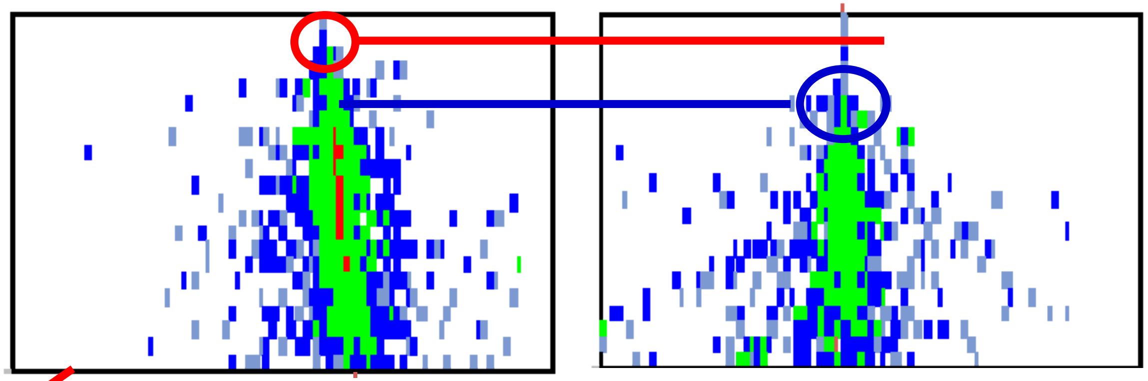


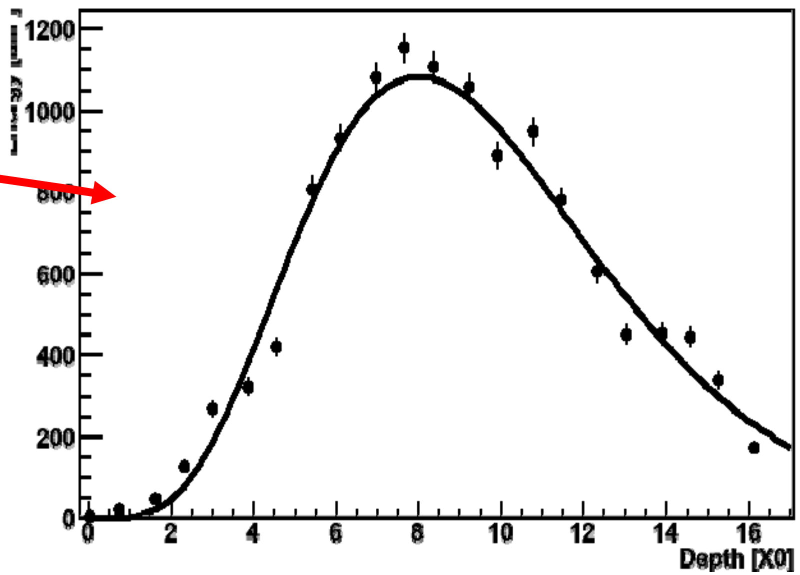


Positron selection with calorimeter

51 GV Positron

80GV Proton





Fraction of charge released along the calorimeter track

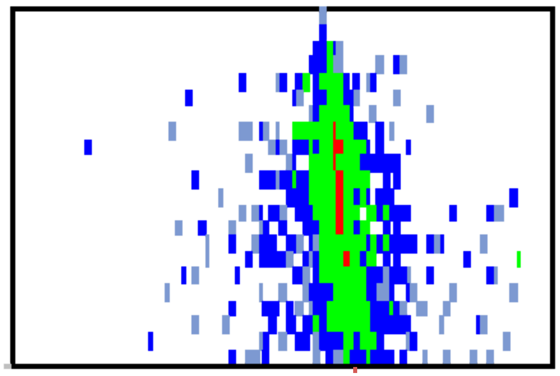
Energy (calo) – **Momentum (spectrometer)** match

Shower starting point

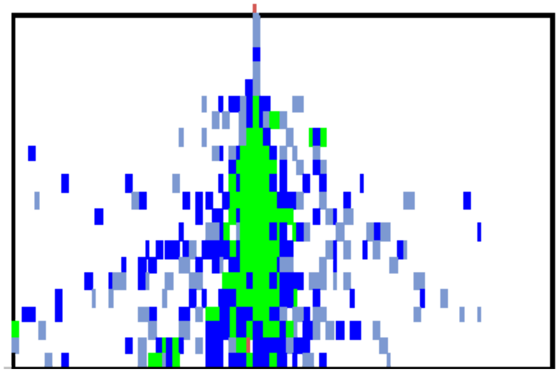
Longitudinal profile

Positron selection with calorimeter

51 GV Positron



80GV Proton



Fraction of charge released along the calorimeter track

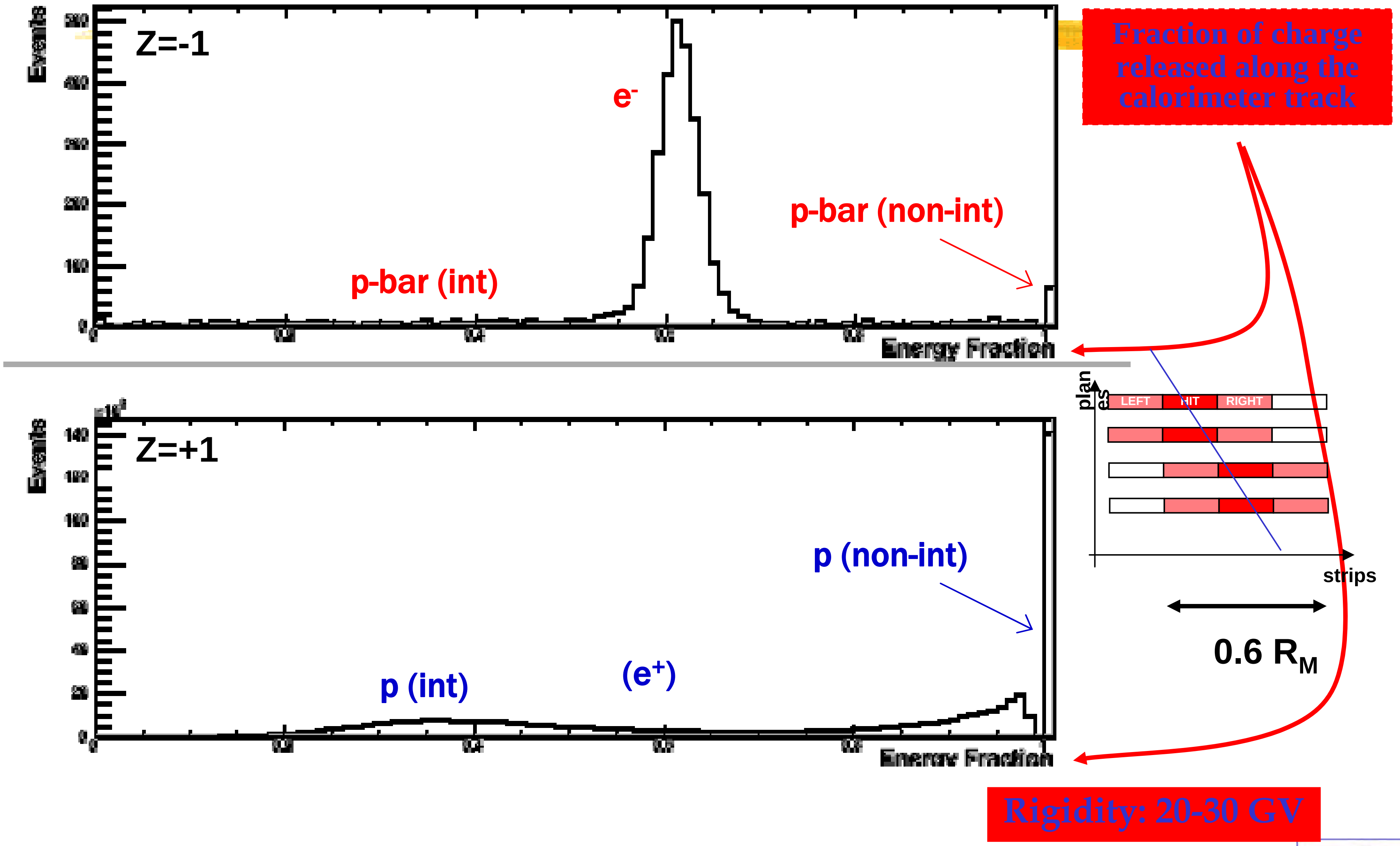
Energy (calo) – Momentum (spectrometer) match

Shower starting point

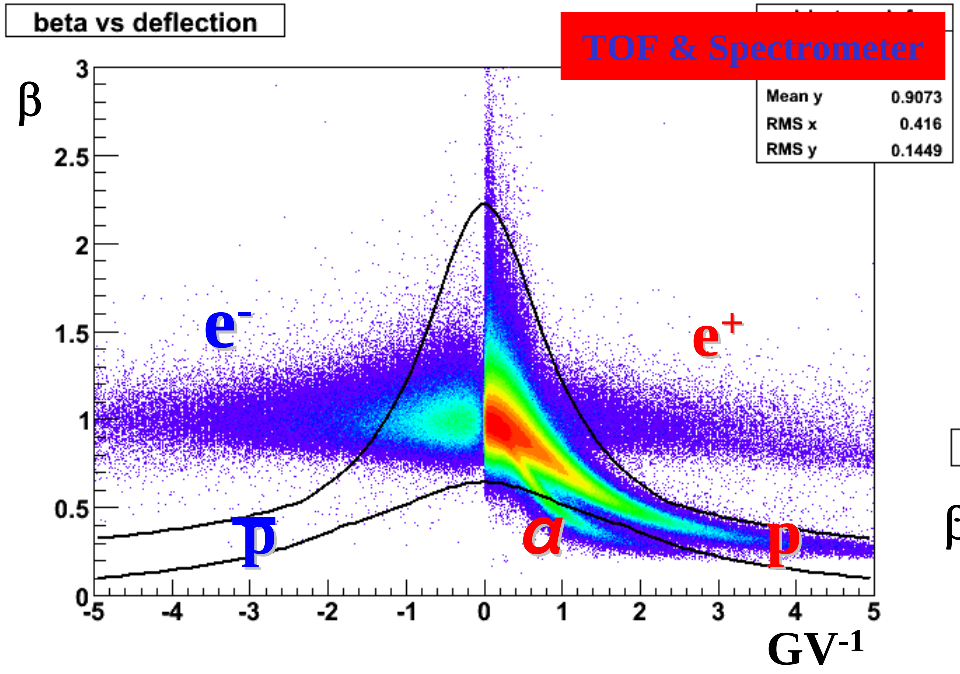
Longitudinal profile

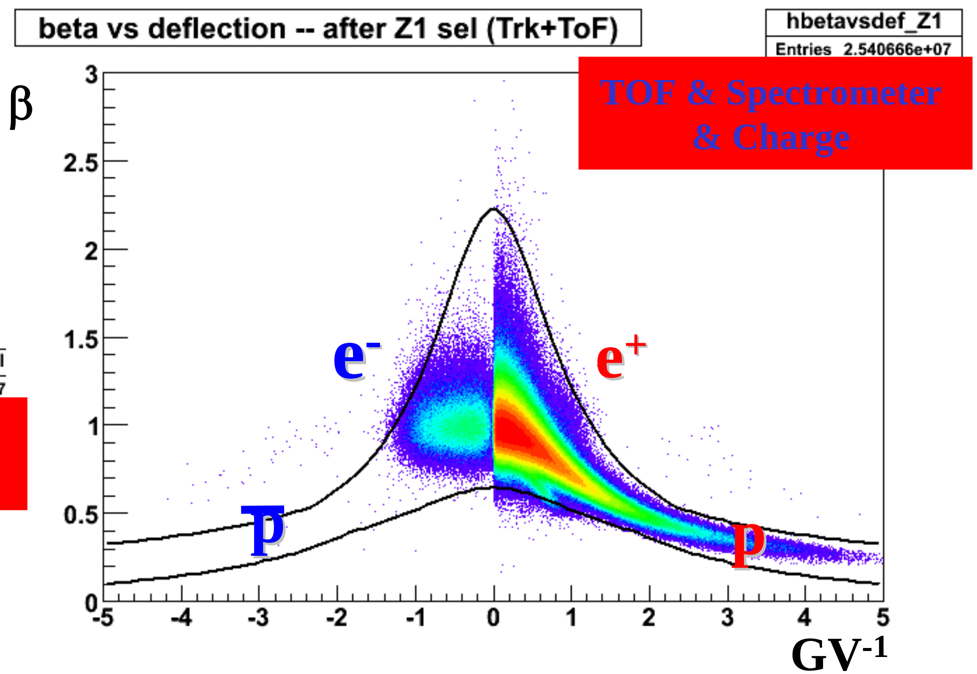
- Tuning/check of selection criteria using:
  - test-beam data
  - simulation
  - flight data: *dE/ dx* from spectrometer & neutron yield from ND
- Selection of pure proton sample from flight data ("pre-sampler" method):
  - Background-suppression method
  - Background-estimation method
- Final results DON'T MAKE USE of test-beam and/or simulation calibrations.

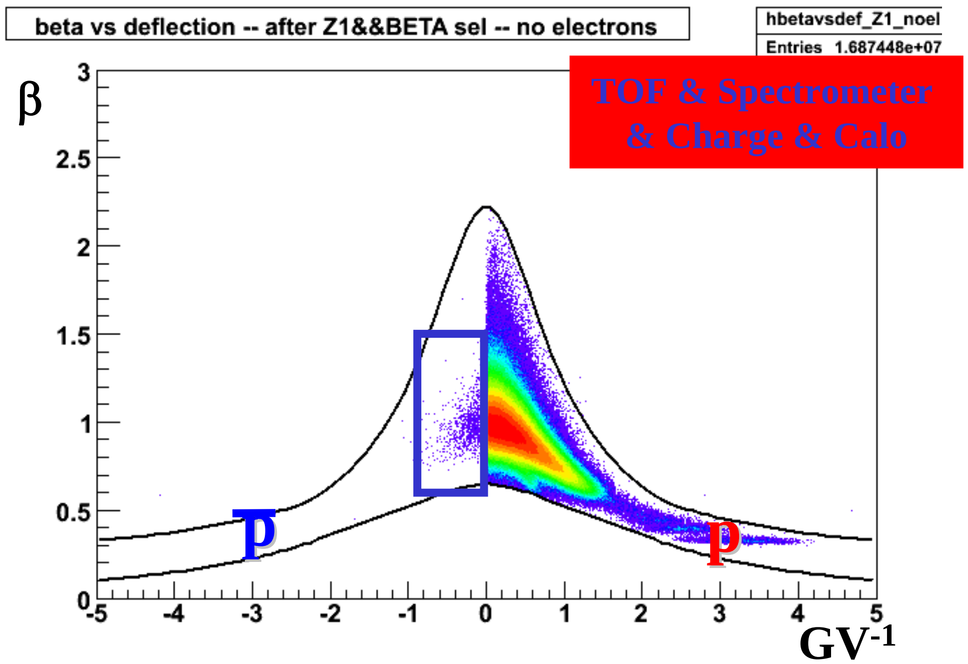
Positron selection with calorimeter



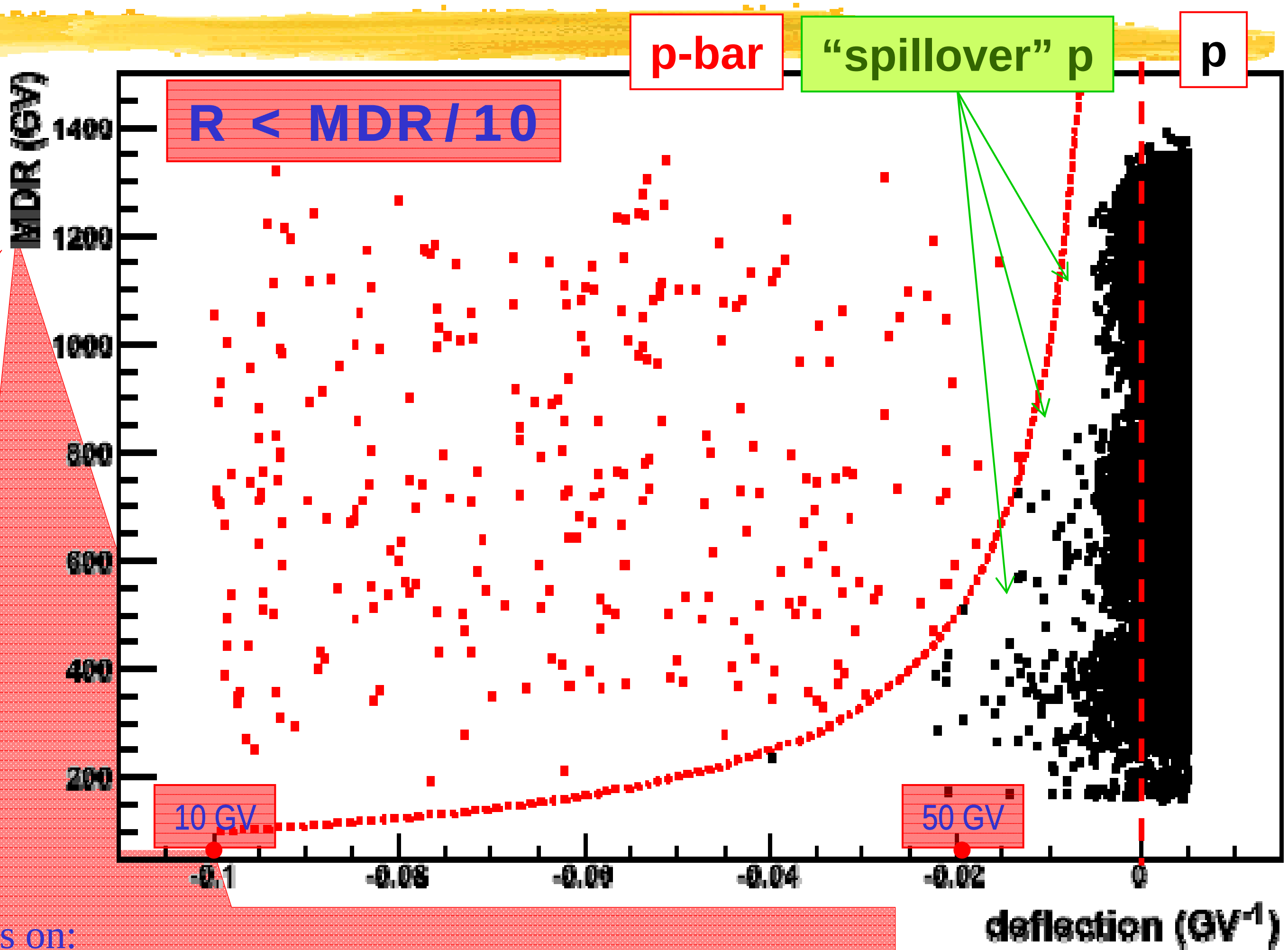
Antiproton Selection







Spillover cut

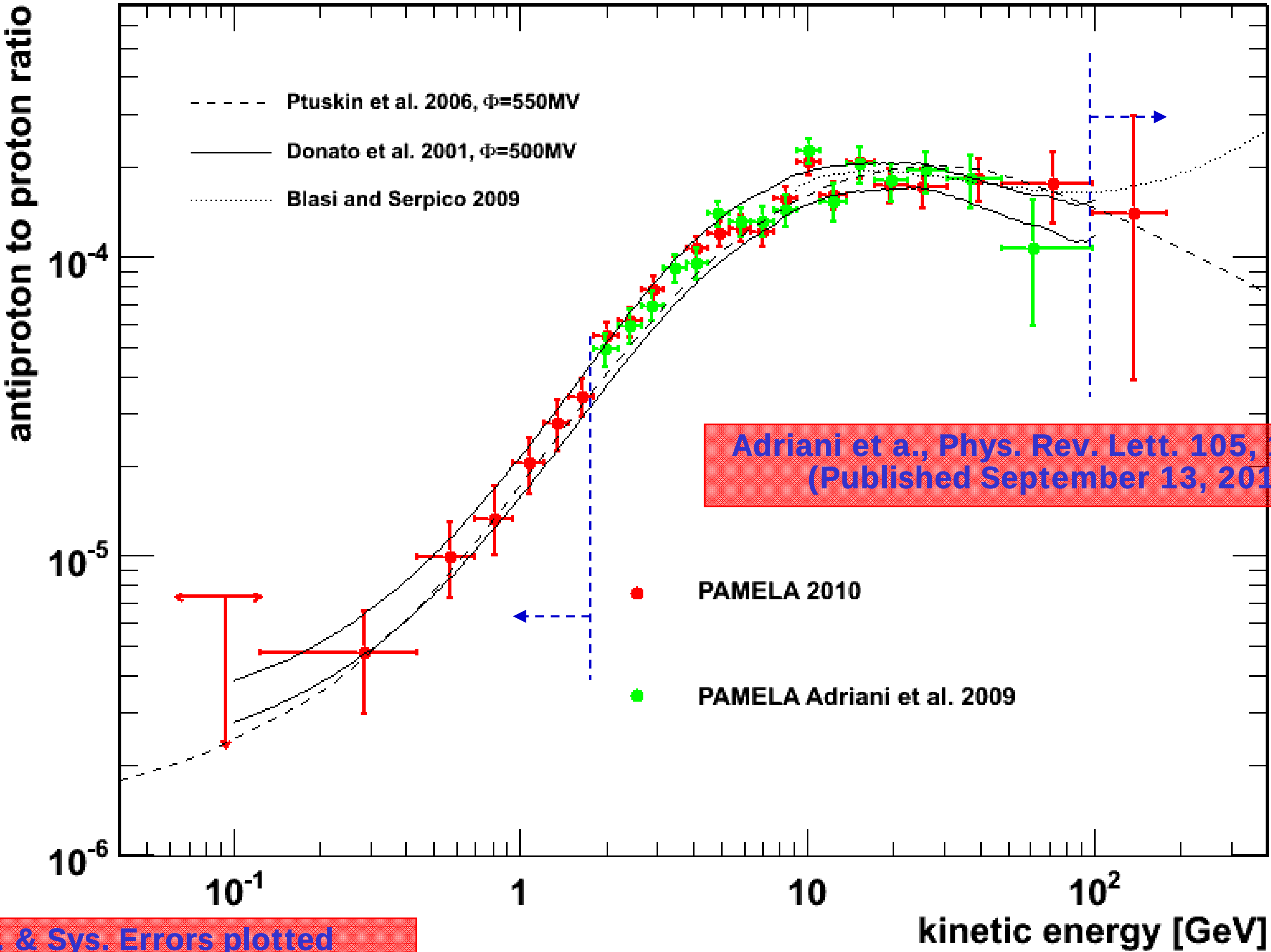


MDR = $1/s_h$ (evaluated event-by-event by the fitting routine)

MDR depends on:

- number and distribution of fitted points along the trajectory
- spatial resolution of the single position measurements
- magnetic field intensity along the trajectory

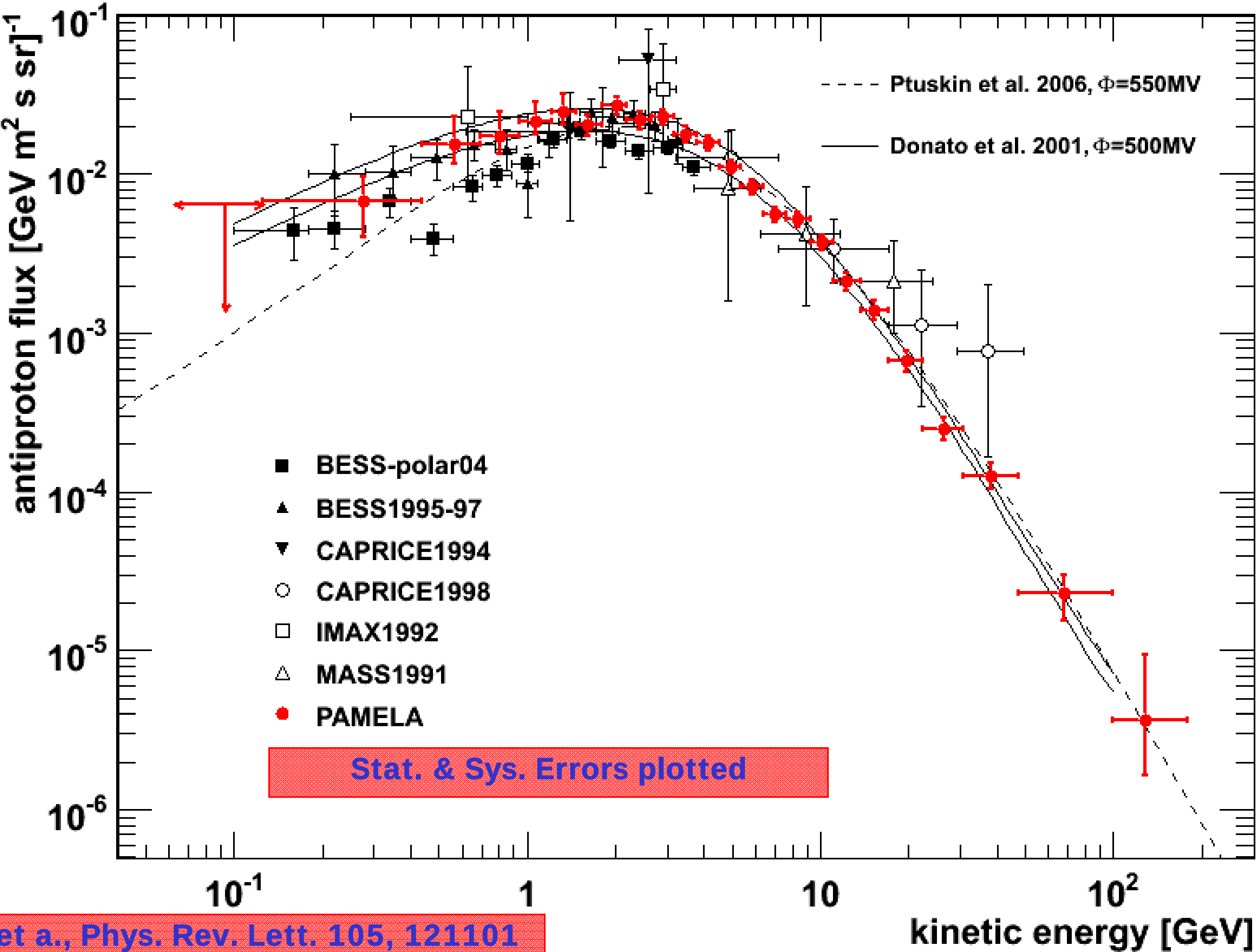
Antiproton to Proton Ratio



Adriani et a., Phys. Rev. Lett. 105, 121101
(Published September 13, 2010)

Stat. & Sys. Errors plotted

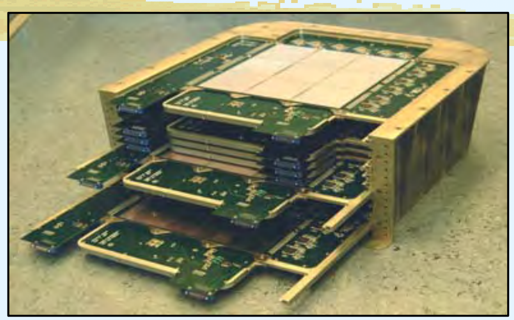
Antiproton Flux



Adriani et a., Phys. Rev. Lett. 105, 121101
(Published September 13, 2010)

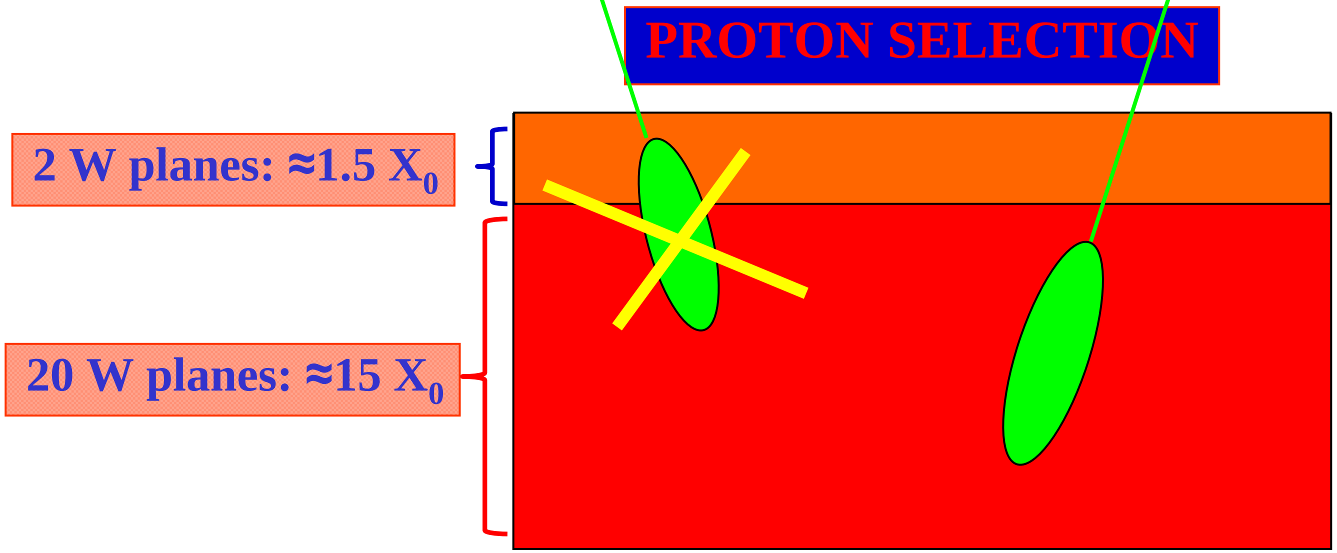
The “pre-sampler” method

The electromagnetic calorimeter



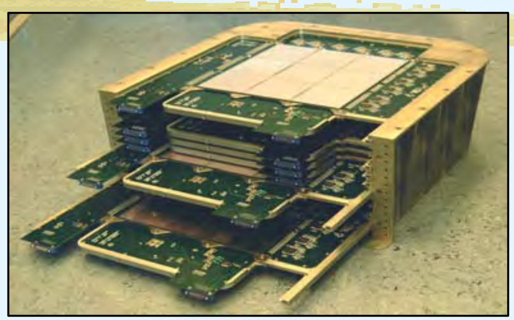
Characteristics:

- 44 Si layers (X/Y) +22 W planes
- 16.3 X_0 / 0.6 l_0
- 4224 channels
- Dynamic range 1400 mip
- Self-trigger mode (> 300 GeV GF~600 cm^2 sr)



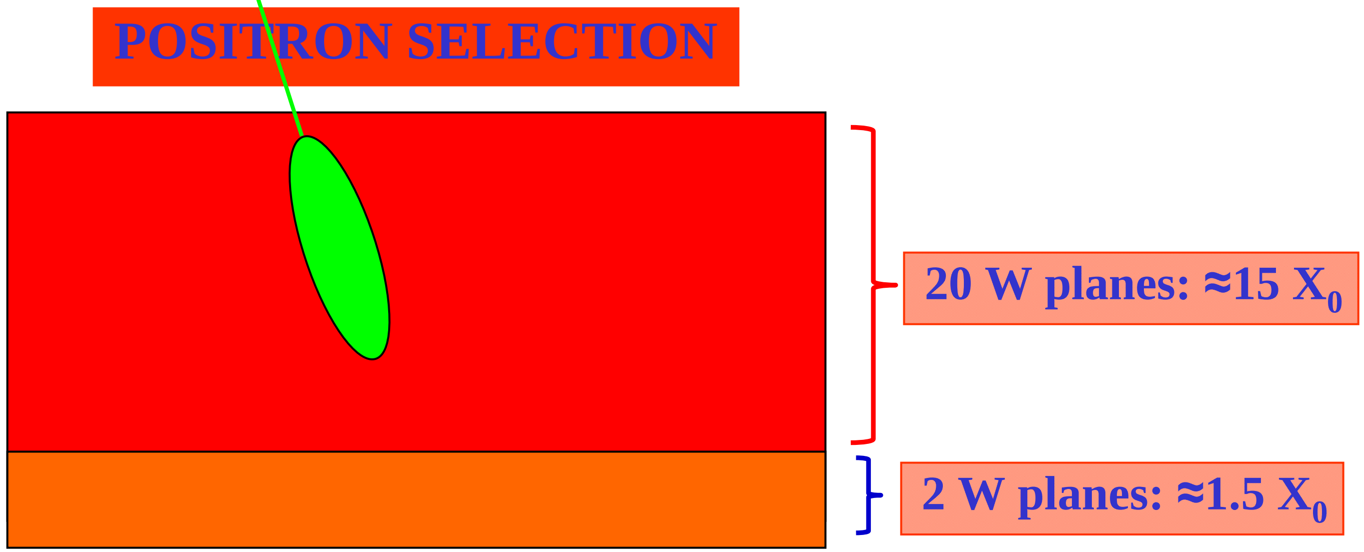
The “pre-sampler” method

The electromagnetic calorimeter



Characteristics:

- 44 Si layers (X/Y) +22 W planes
- 16.3 X_o / 0.6 l_0
- 4224 channels
- Dynamic range 1400 mip
- Self-trigger mode (> 300 GeV GF~600 cm^2 sr)

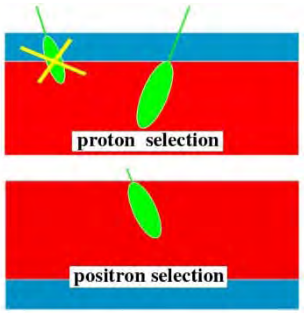


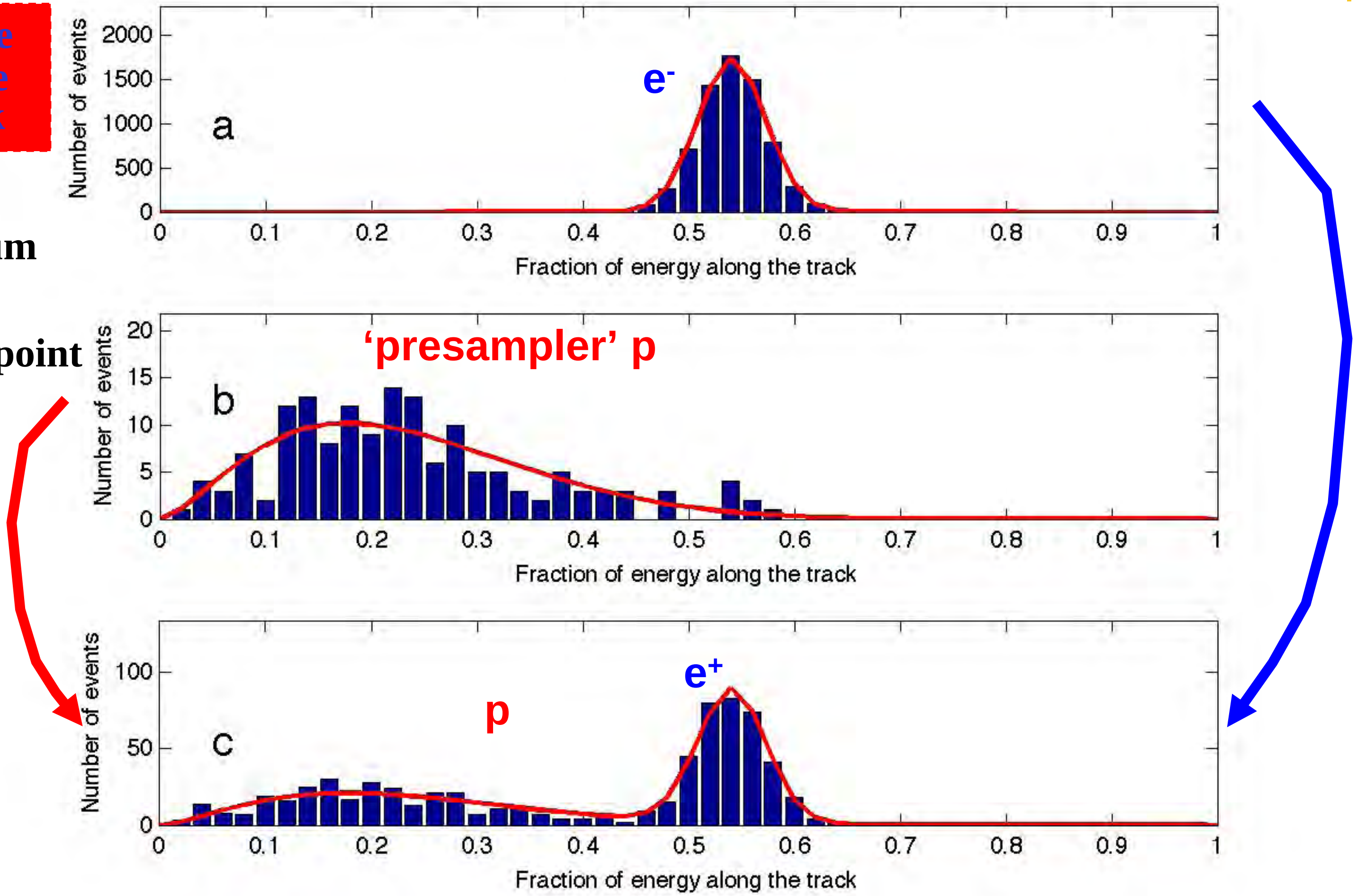
e^+ background estimation from data

Fraction of charge released along the calorimeter track

Constrains on:

- **Energy momentum match**
- **Shower starting-point**

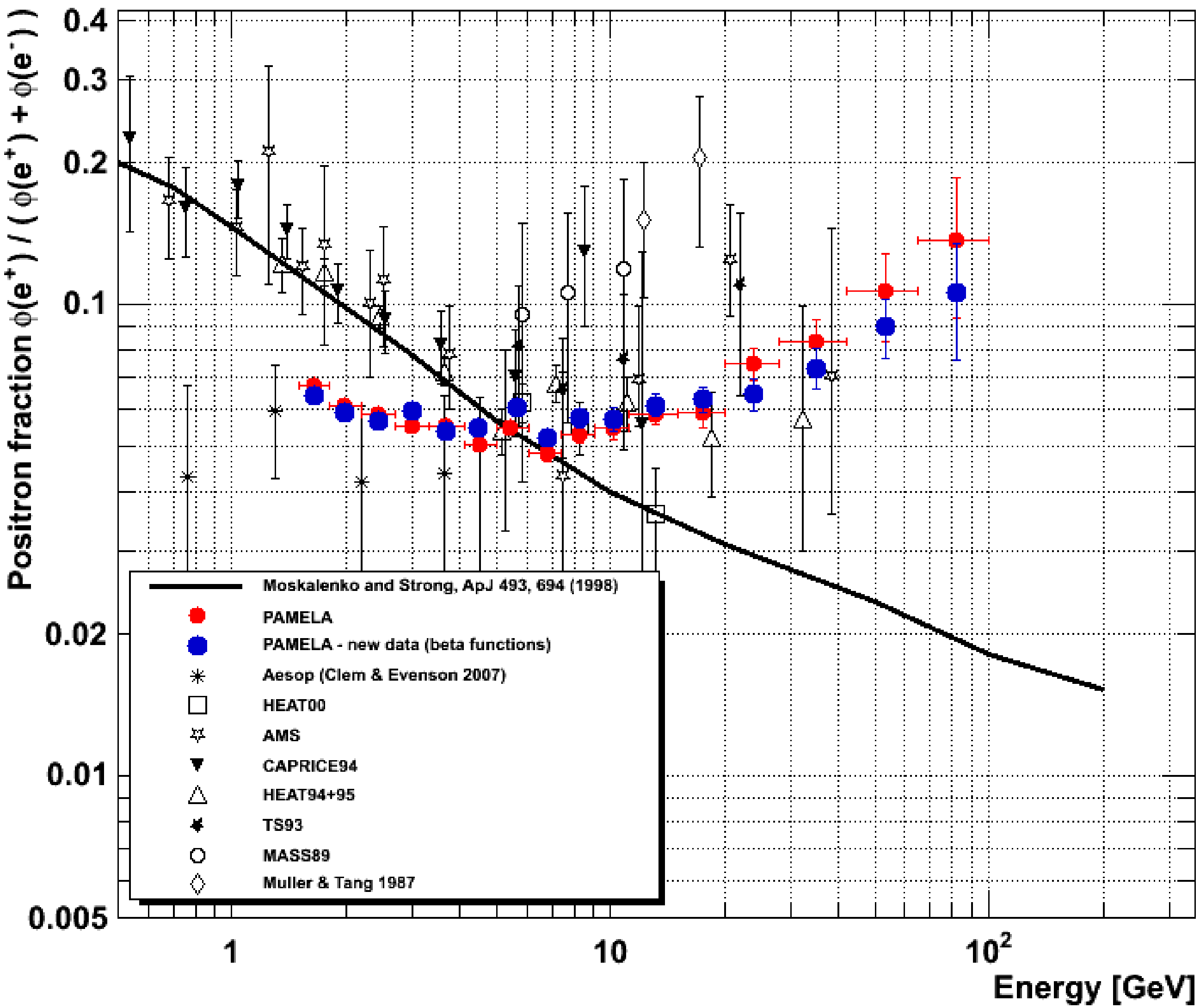




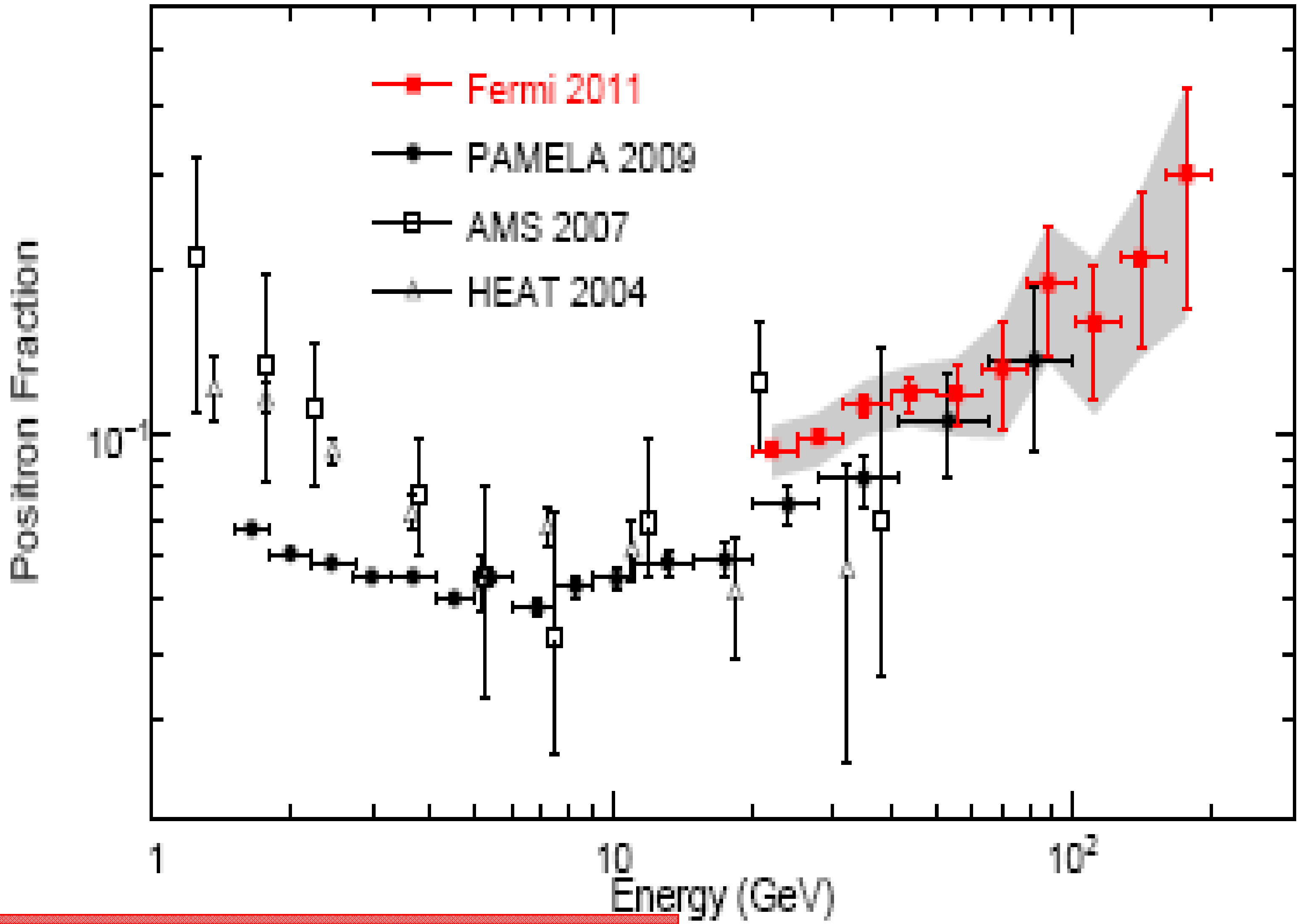
Rigidity: 20-28 GV

Positron to All Electron Fraction

Adriani et al., Astropart. Phys. 34 (2010) 1 - arXiv:1001.3522

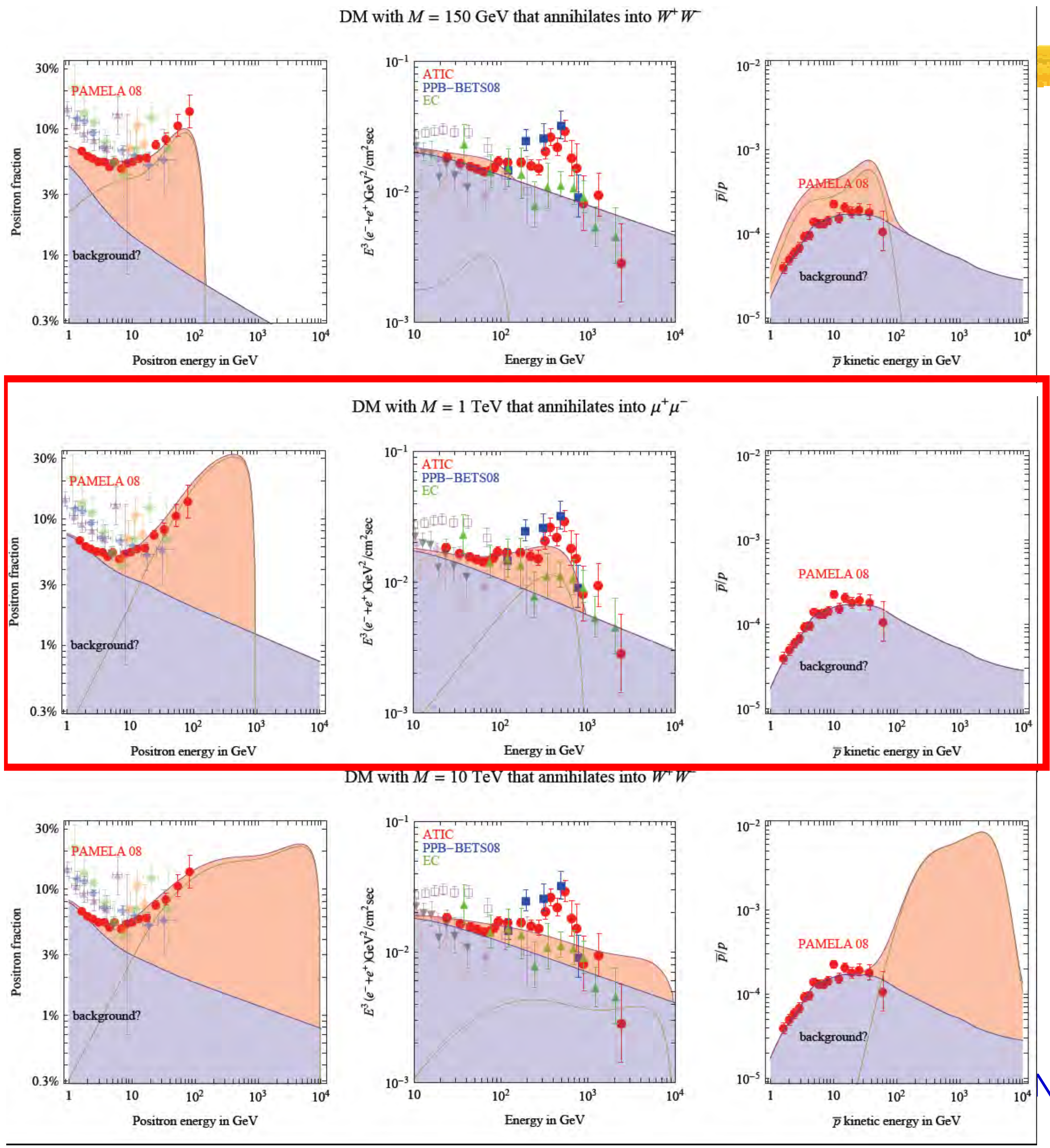


Positron fraction



M. Ackermann, astro-ph: 1109.0521

DM ?



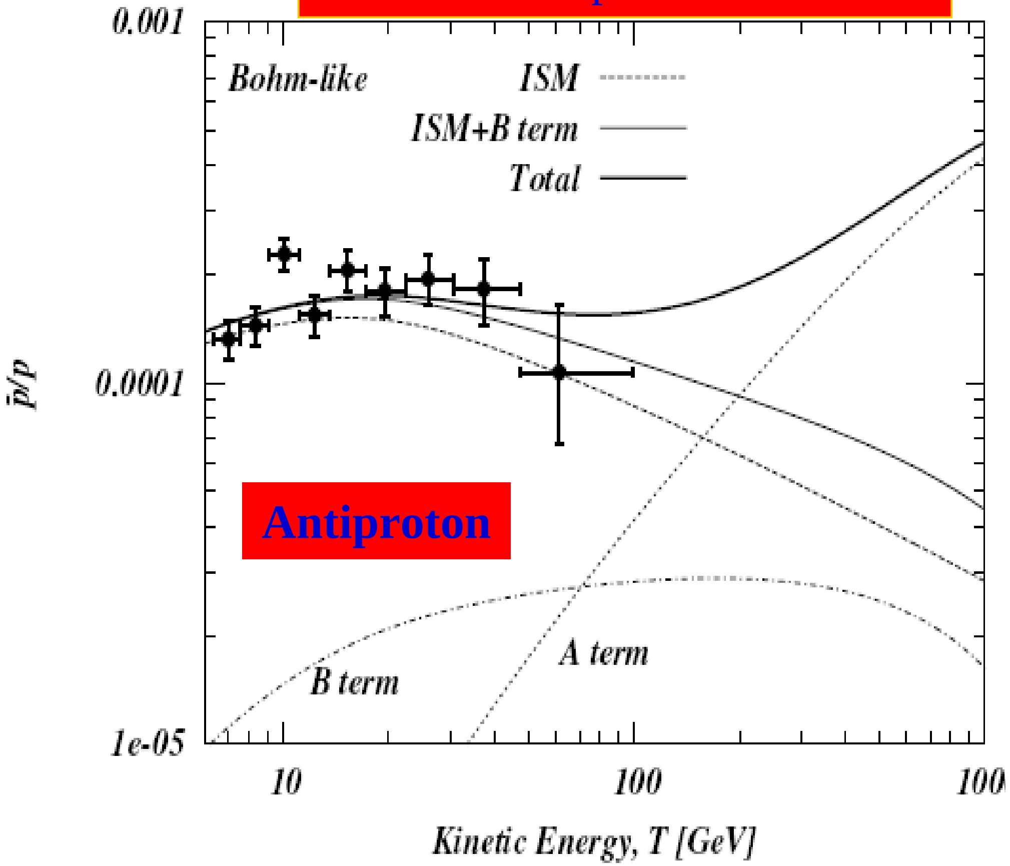
- PAMELA ability of measuring both proton and electron charge ration, make it possible to put several constrains to the models

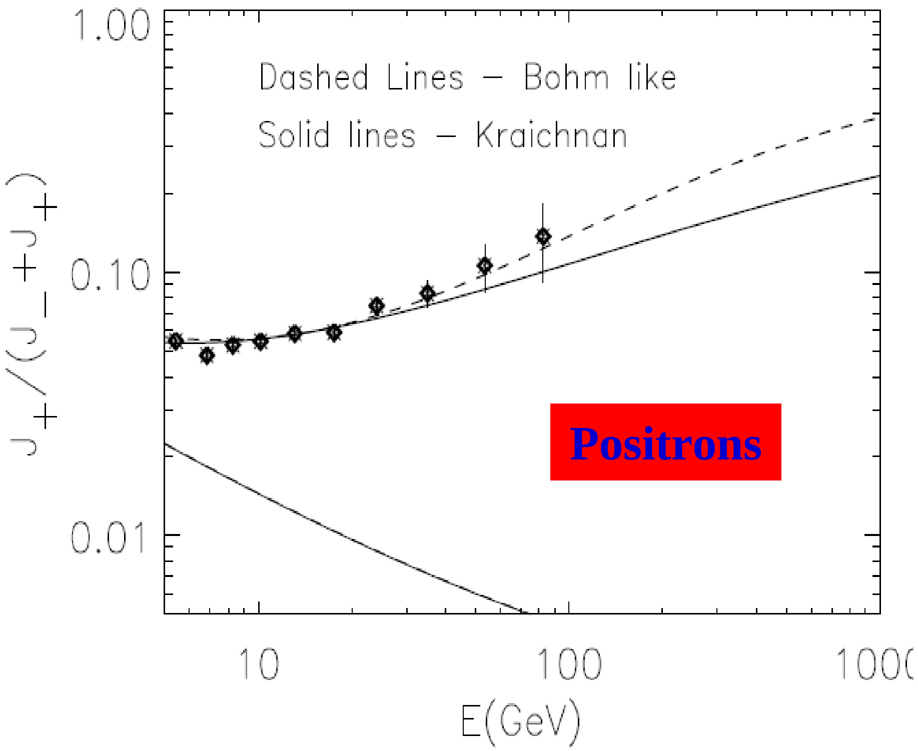
M. Cirelli, M. Kadastik, M. Raidal, A. Strumia
arXiv:0809.2409v3

Antiprotons & positrons from old SNR's

P.Blasi Astro-ph.HE 0904.0871

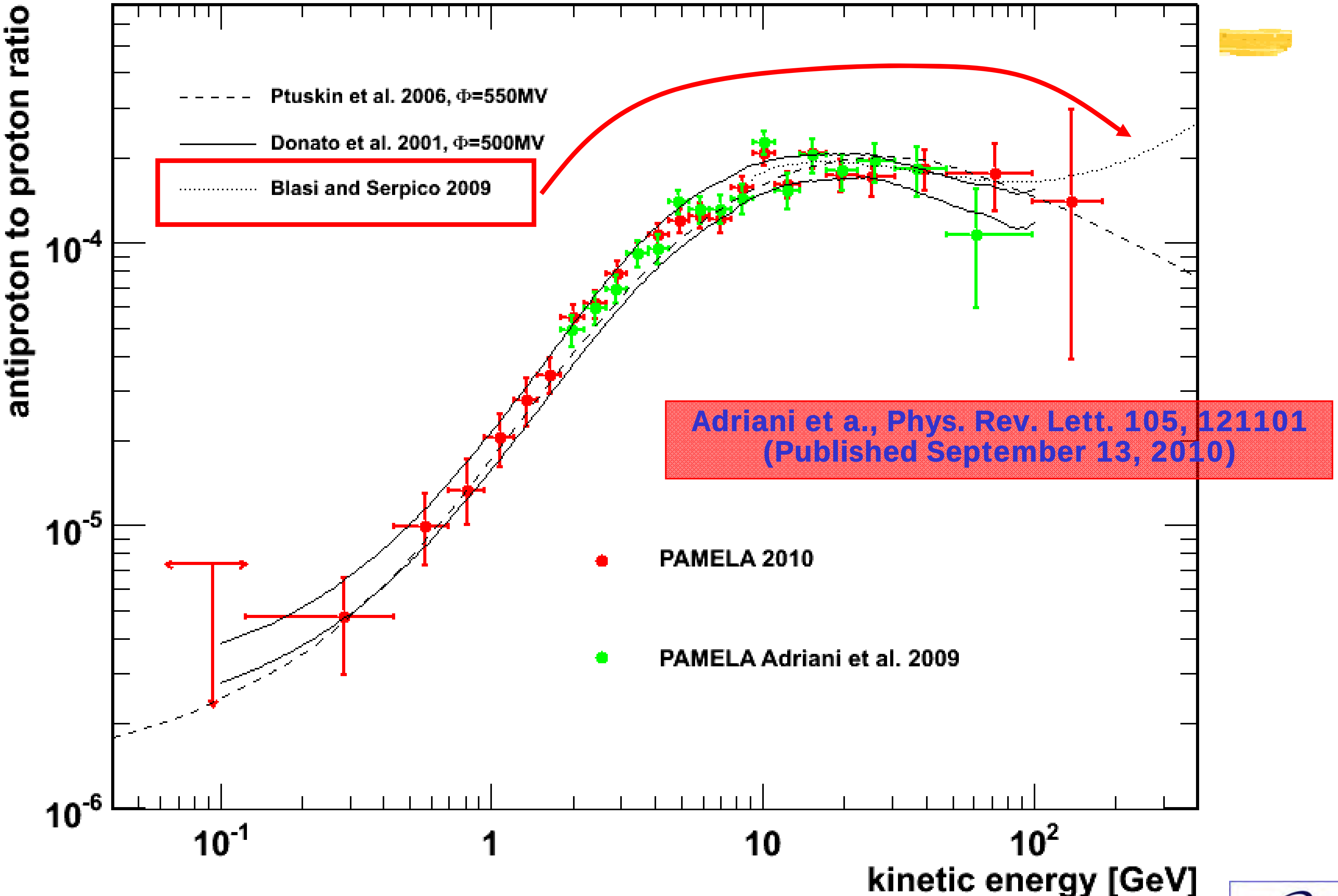
P. Blasi 0903.2794





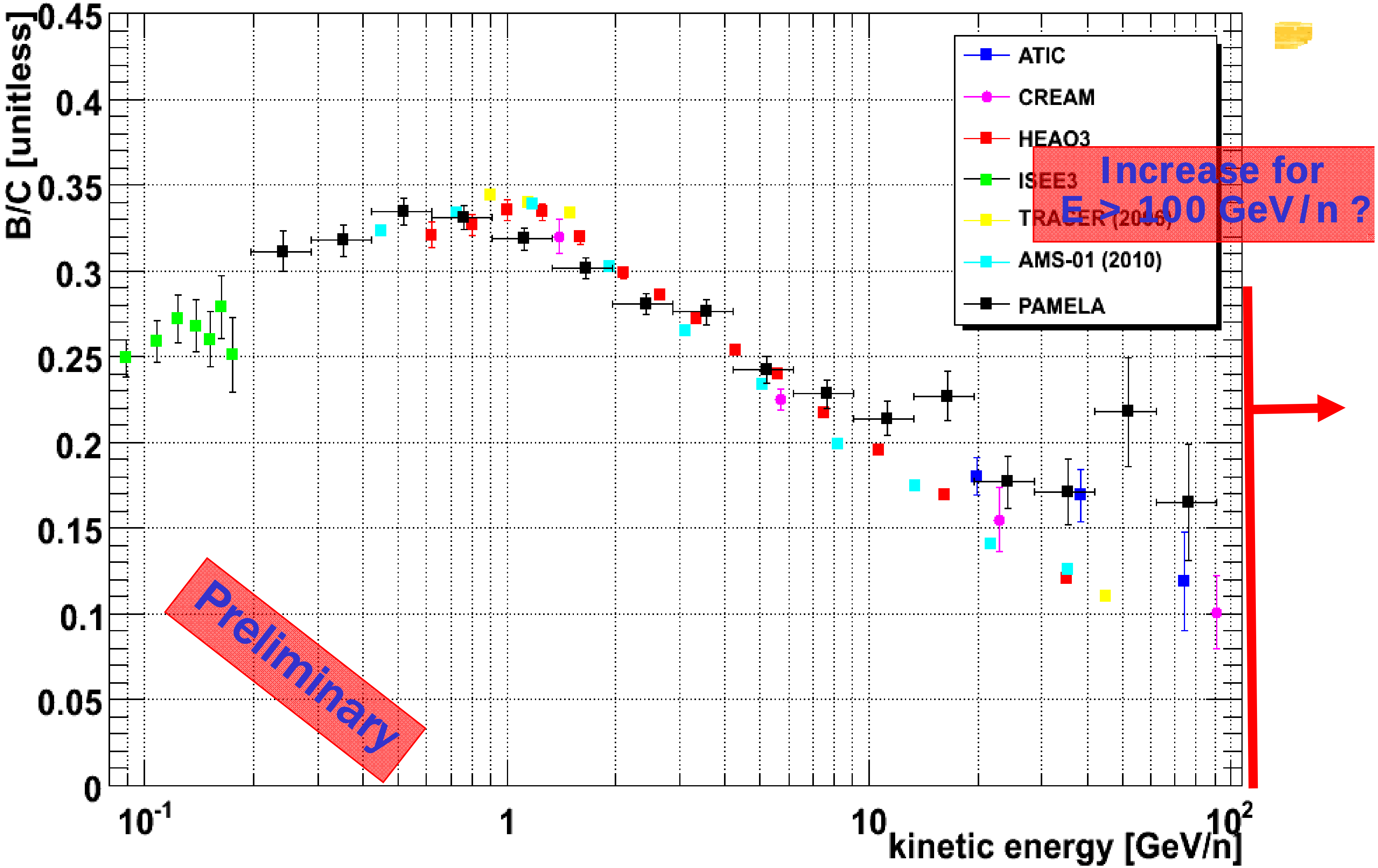
- positrons created as secondary products of hadronic interactions inside the sources
- secondary production takes place in the same region where cosmic rays are being accelerated
- Antiproton/proton and B/C increase for E> 100GeV

Antiprotons & positrons from old SNR's



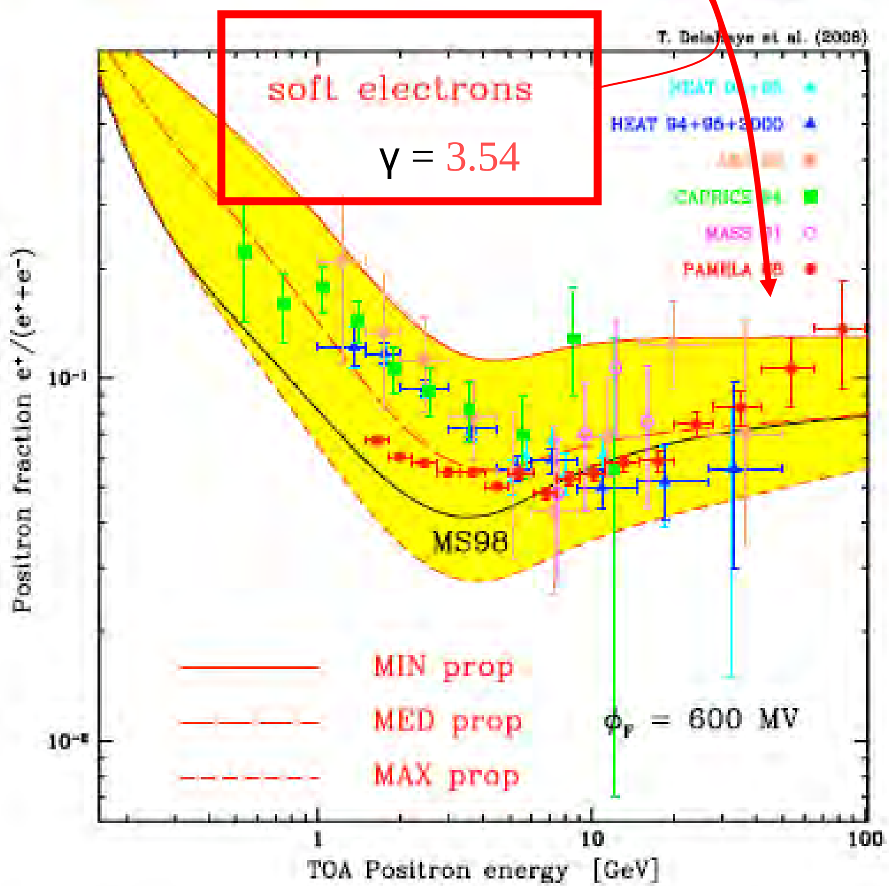
INFN Istituto Nazionale di Fisica Nucleare

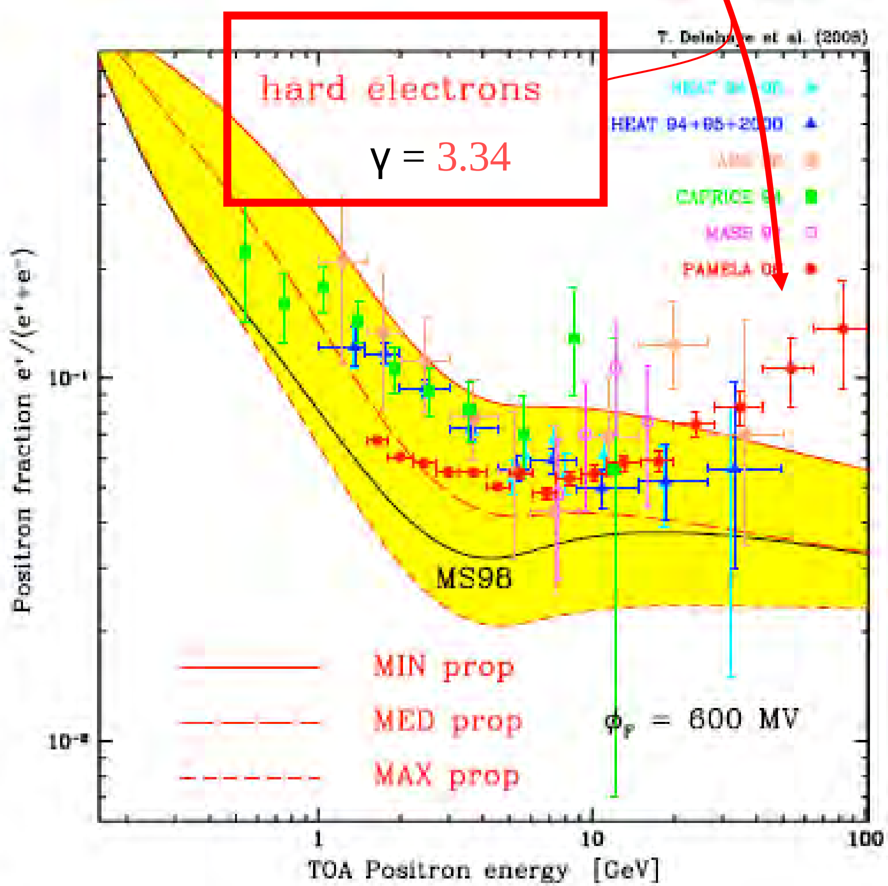
Antiprotons & positrons from old SNR's



Positron Fraction Theoretical Uncertainties

Less significant | **Most significant**

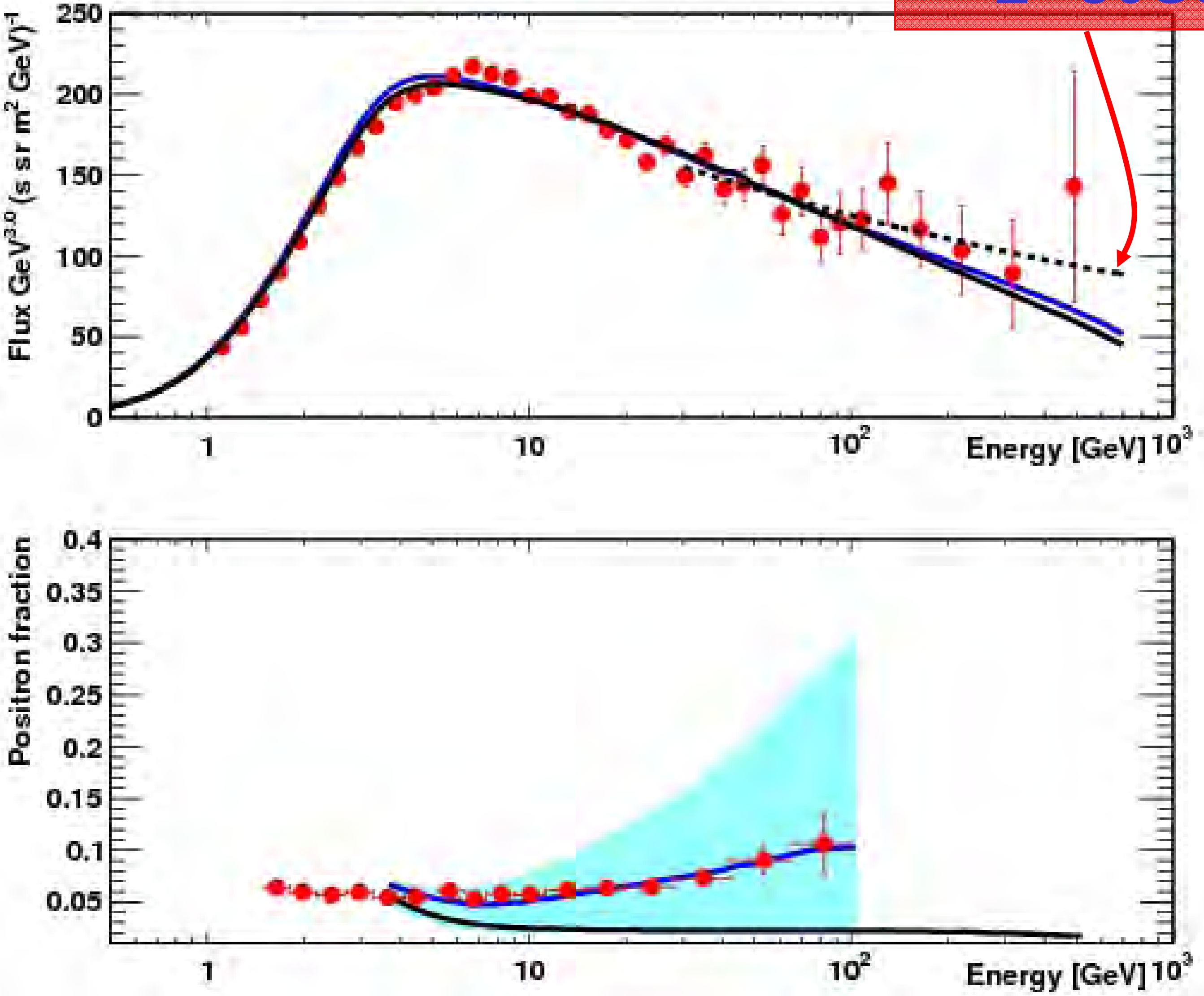




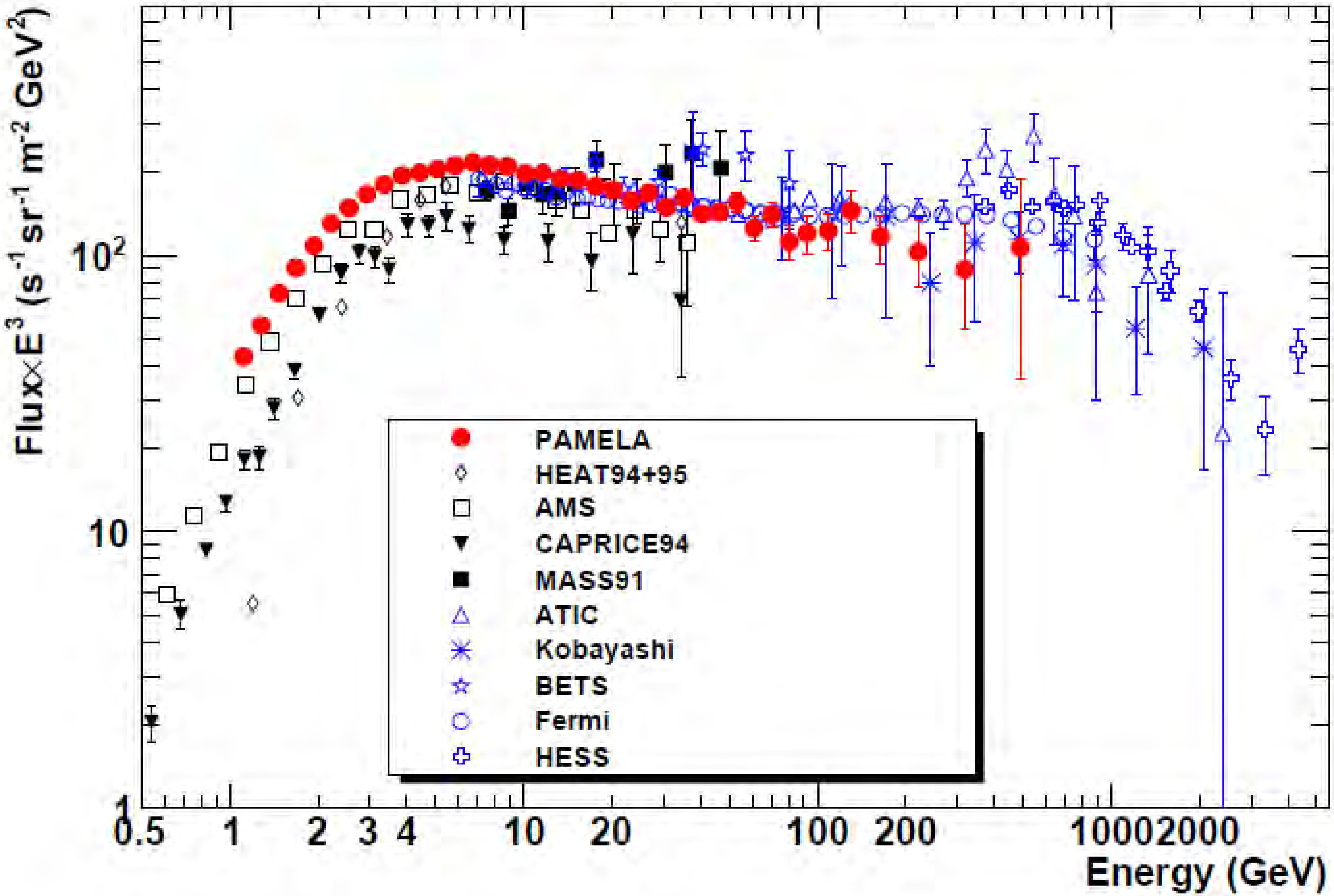
T. Delahaye et al., arXiv: 0809.5268v3

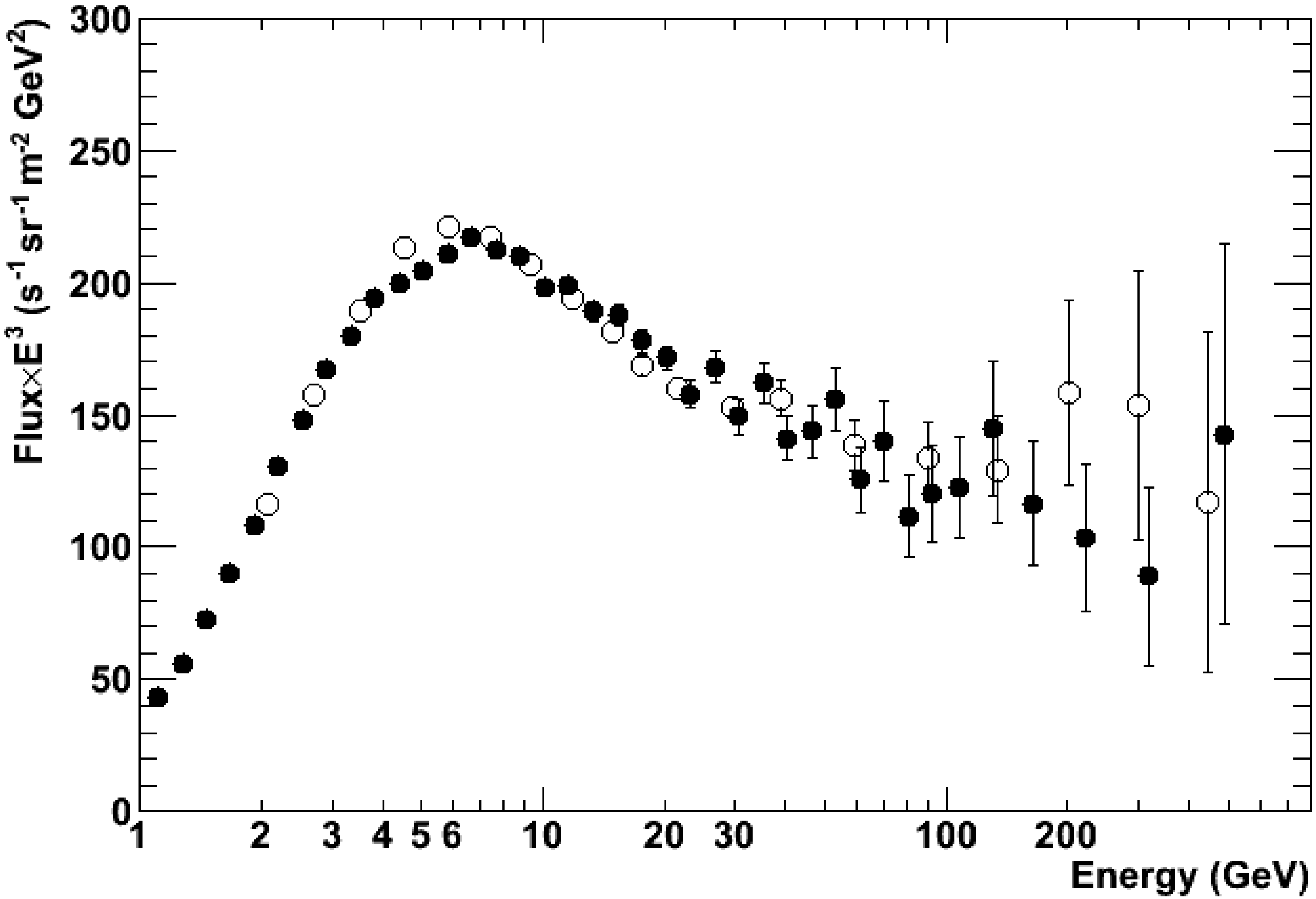
Electron flux

$\gamma = 3.17 \pm 0.07$
E>30GeV

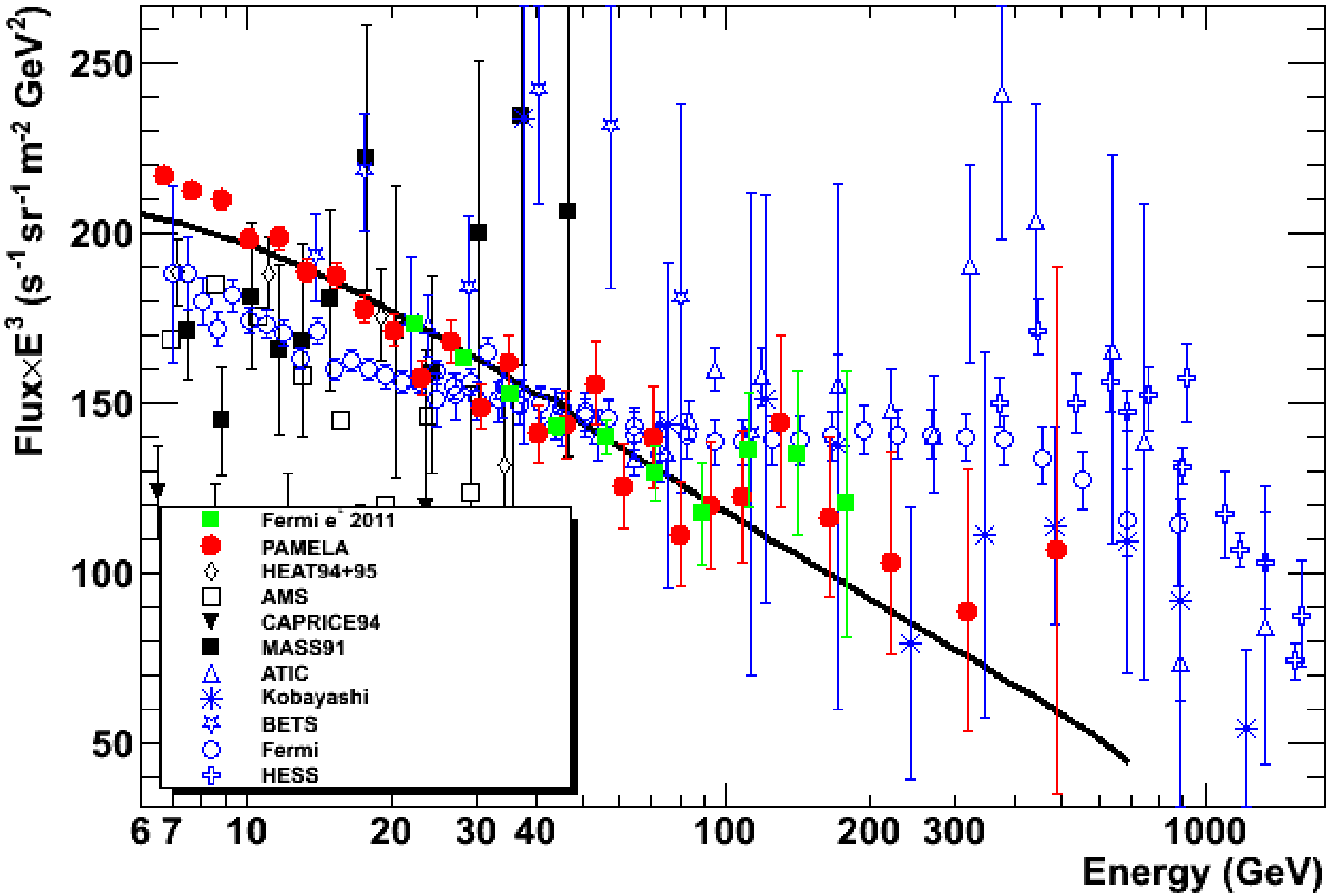


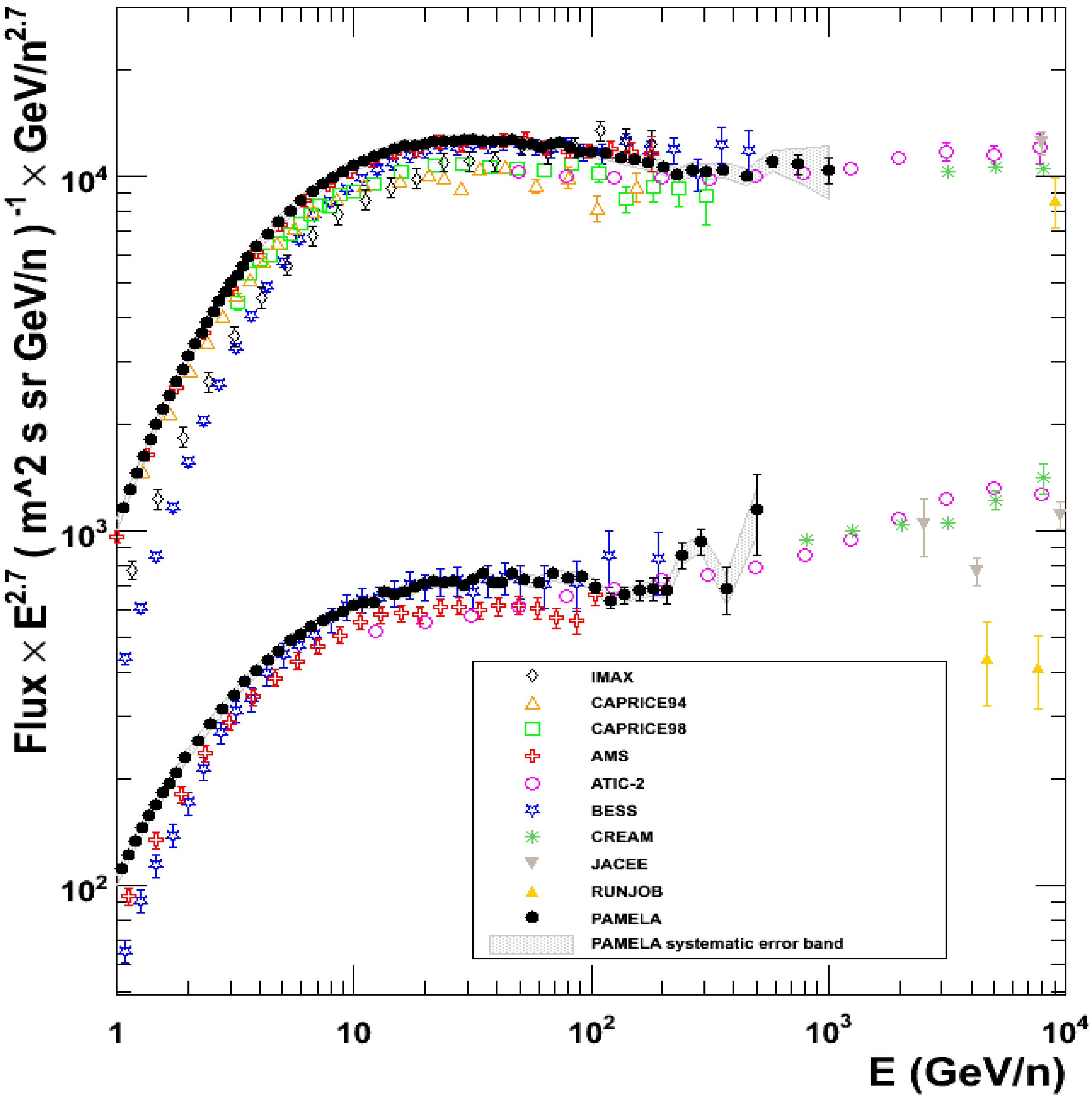
Electron flux




Flux×E^3 (s^-1 sr^-1 m^-2 GeV^2)
300
250
200
150
100
50
0
1
2
3
4
5
6
10
20
30
100
200
Energy (GeV)

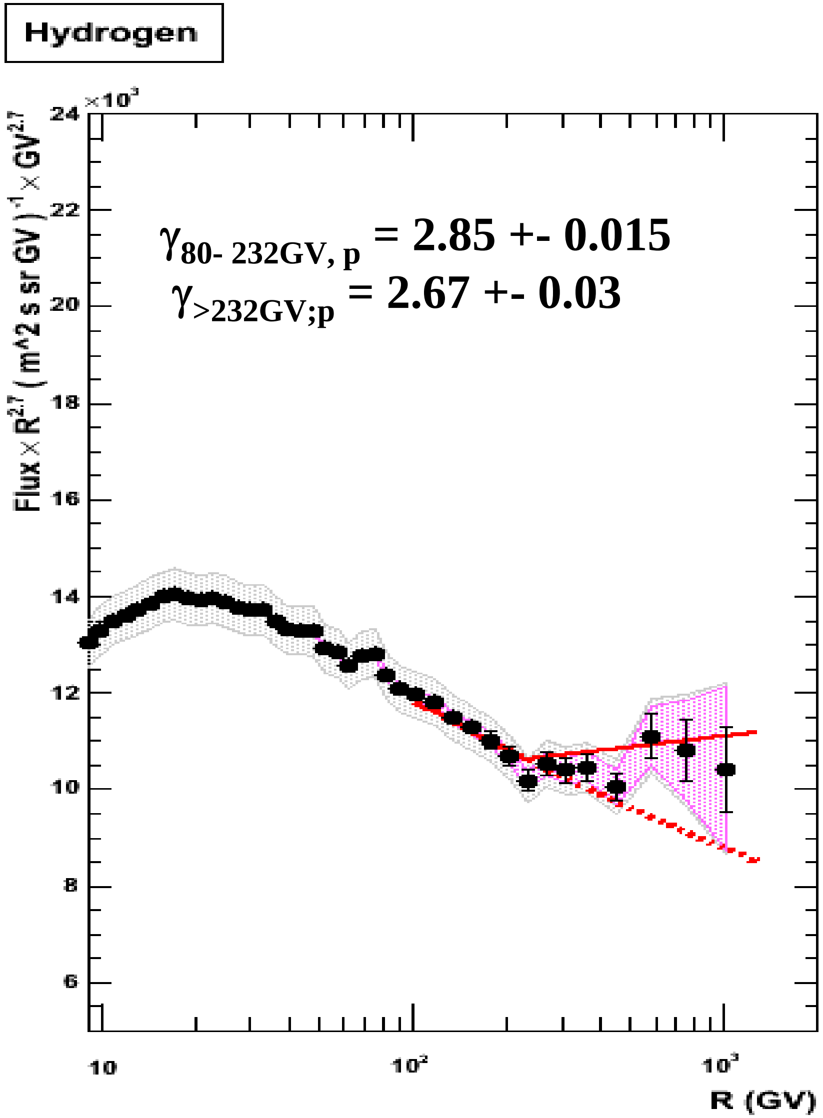
Electron flux

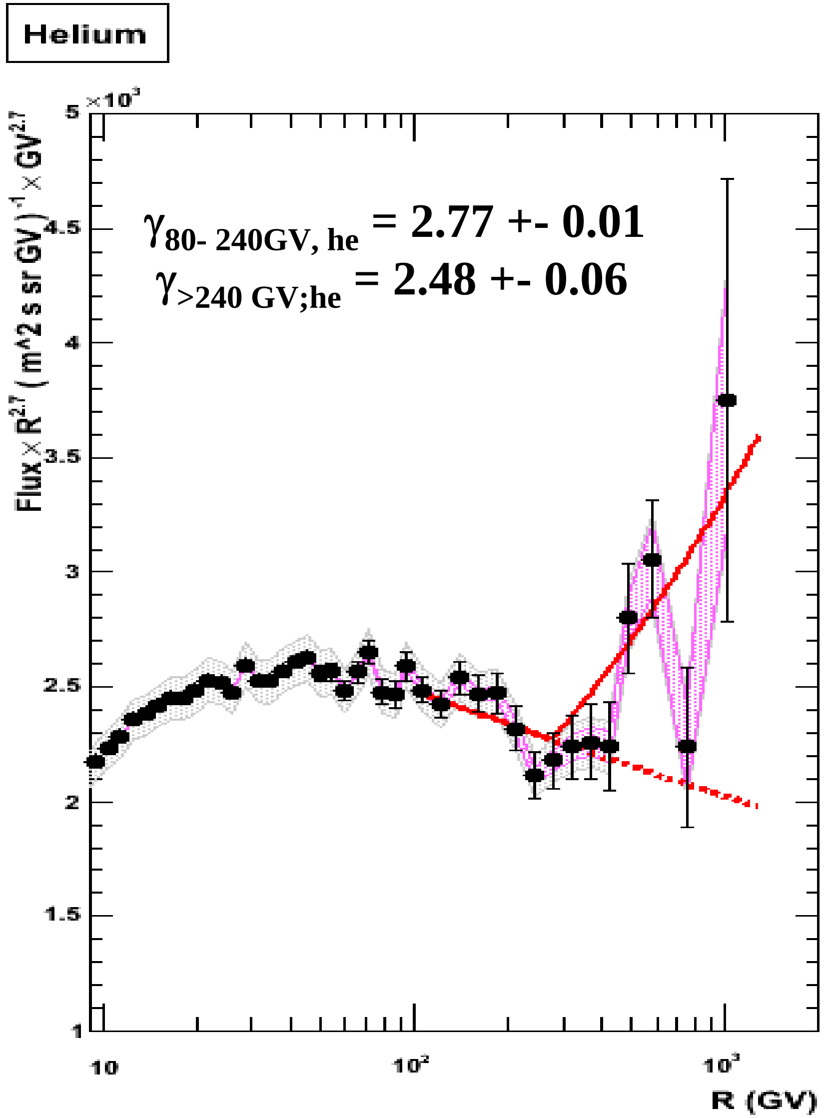




Flux × E^2.7 (m^2 s sr GeV/n)^-1 × GeV/n^2.7
10^4
10^3
10^2
1
10
10^2
10^3
10^4
E (GeV/n)
IMAX
CAPRICE94
CAPRICE98
AMS
ATIC-2
BESS
CREAM
JACEE
RUNJOB
PAMELA
PAMELA systematic error band

Galactic H & He





Conclusions

- We are entered in the new era of precision measurements of (anti)particle fluxes in CR.
- There is room for improvement in analysis techniques while increasing the statistic.
- The knowledge of background and particle fluxes must be improved.
- Waiting for AMS, stay tuned for new PAMELA data on $e^{\pm}$, p & He, B & C fluxes!

THANKS !!!!