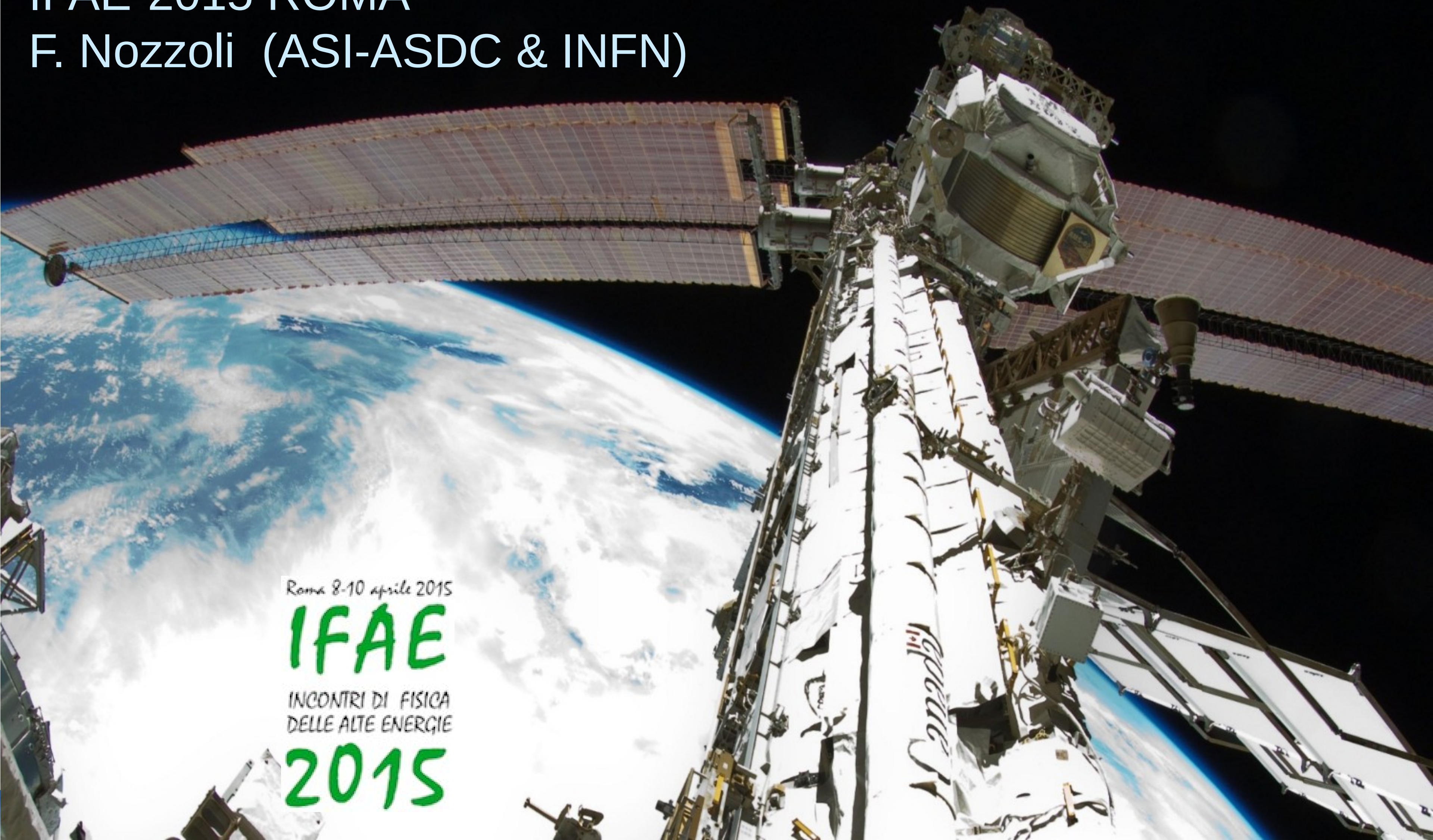
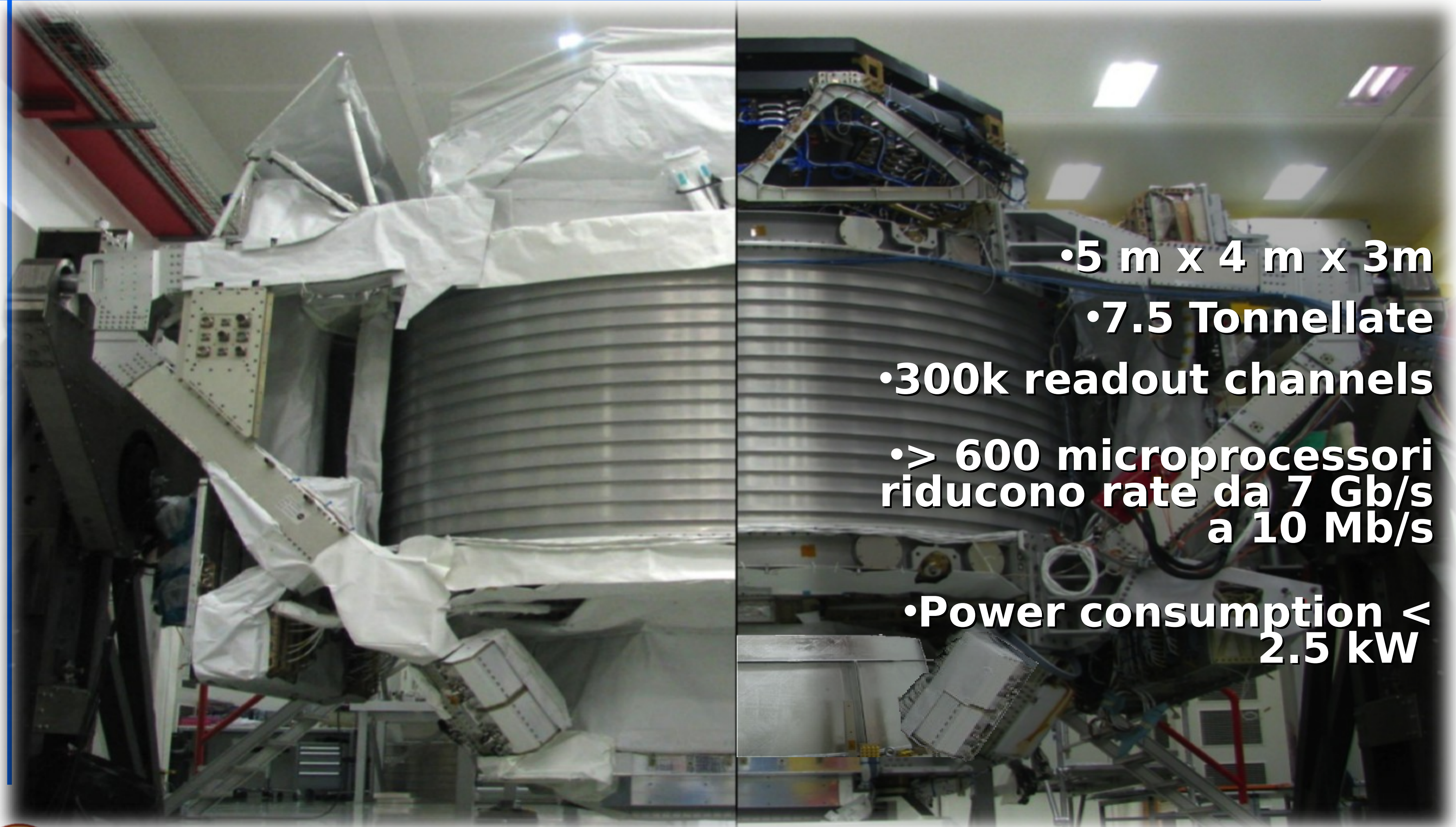
Alpha Magnetic Spectrometer sulla Stazione Spaziale Internazionale: stato e risultati dopo 4 anni di missione.

IFAE-2015 ROMA

F. Nozzoli (ASI-ASDC & INFN)



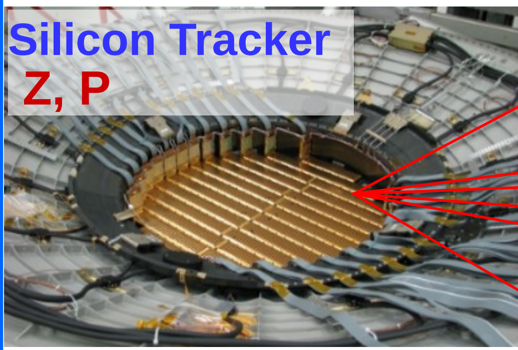
AMS02: alcuni numeri

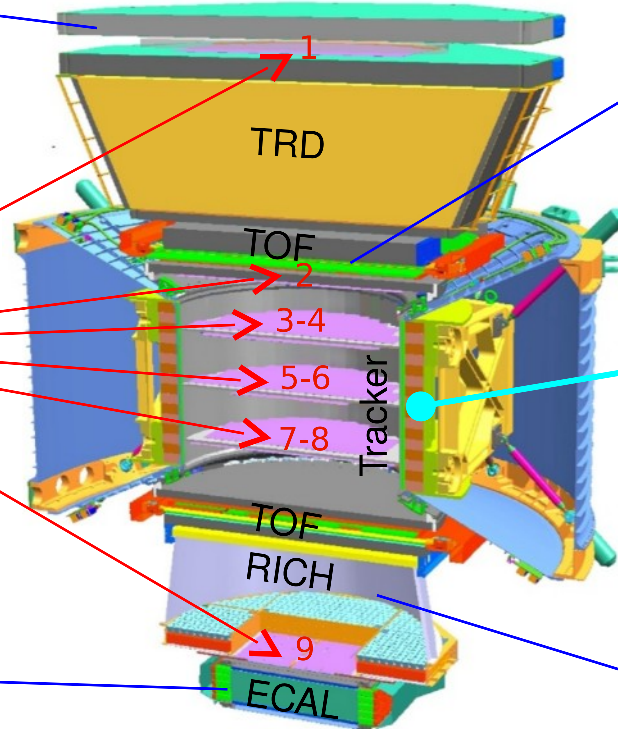


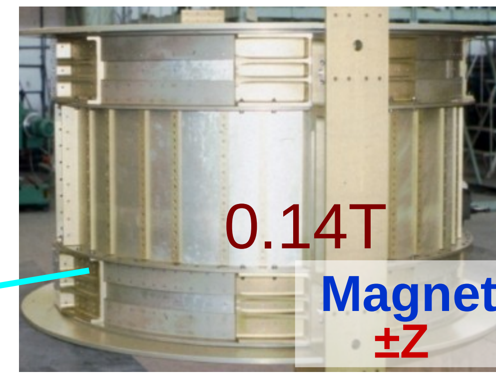
- 5 m x 4 m x 3m
- 7.5 Tonnellate
- 300k readout channels
- > 600 microprocessori riducono rate da 7 Gb/s a 10 Mb/s
- Power consumption < 2.5 kW

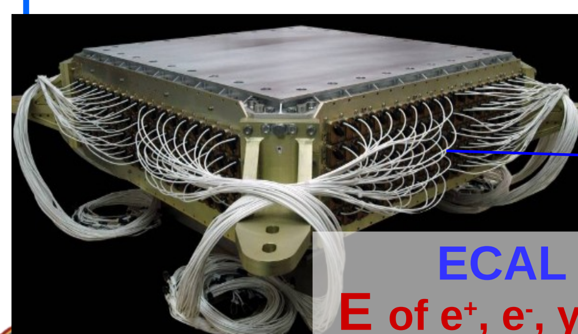
Spettrometro multipurpose, GeV->TeV

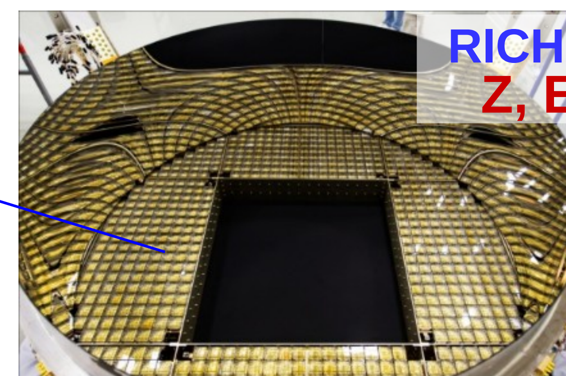
Z, P *misurate indipendentemente da*
Tracker, RICH, TOF, ECAL



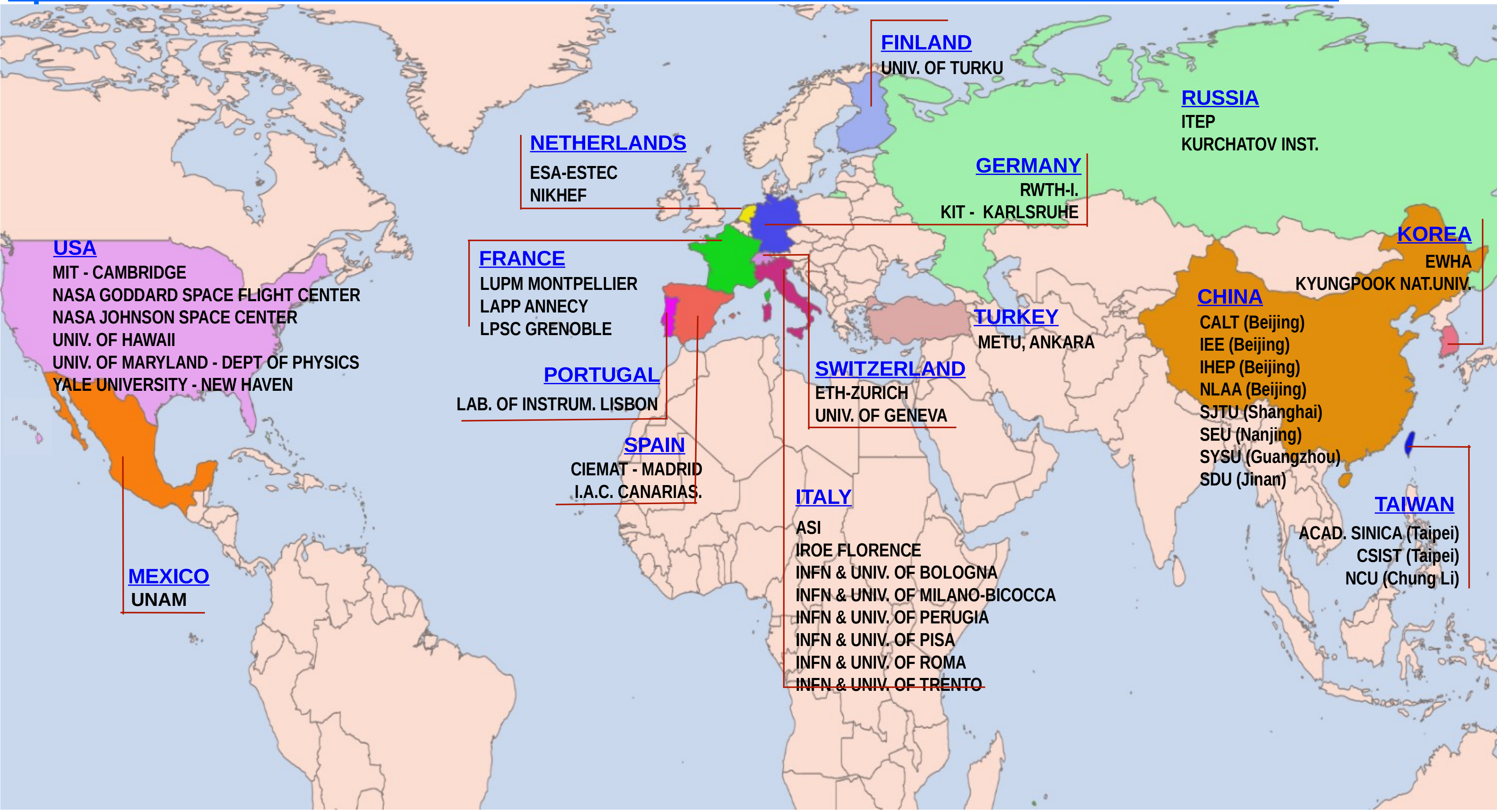








AMS02 nel mondo / in Italia



16 Maggio 2011: STS-134

19 Maggio 2011 AMS02 sulla ISS

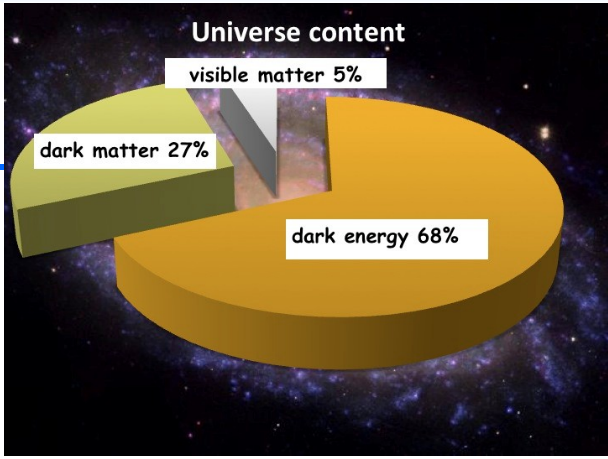
PARTE 1 : Obiettivi scientifici

Primordial origin (Signal: anti-nuclei)

Dirac's Nobel speech

"We must regard it rather as an accident that the Earth [...] contains a preponderance of negative electrons and positive protons. It is quite possible that for some stars it is the other way about."

Materia Oscura



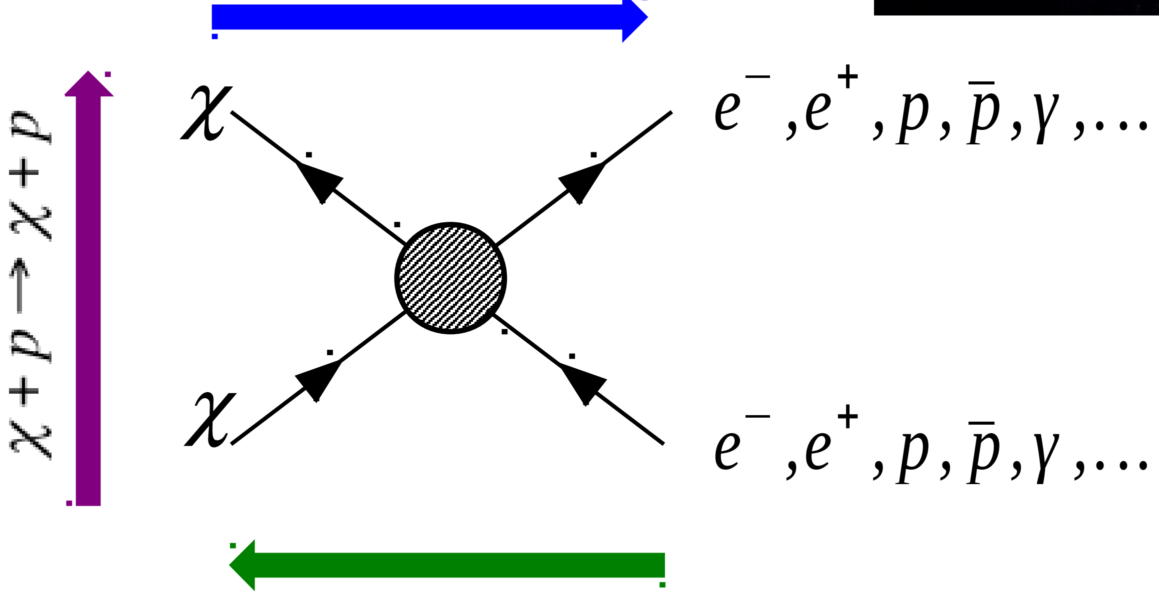
AMS

Annihilation (in Space)

$$\chi + \chi \rightarrow e^{+}, \bar{p}, \gamma, \ldots$$

Scattering (Underground)

LUX
DARKSIDE
XENON 100
CDMS II
DAMA
…



$$\chi + \chi \leftarrow p + p$$

Production (in Accelerators)

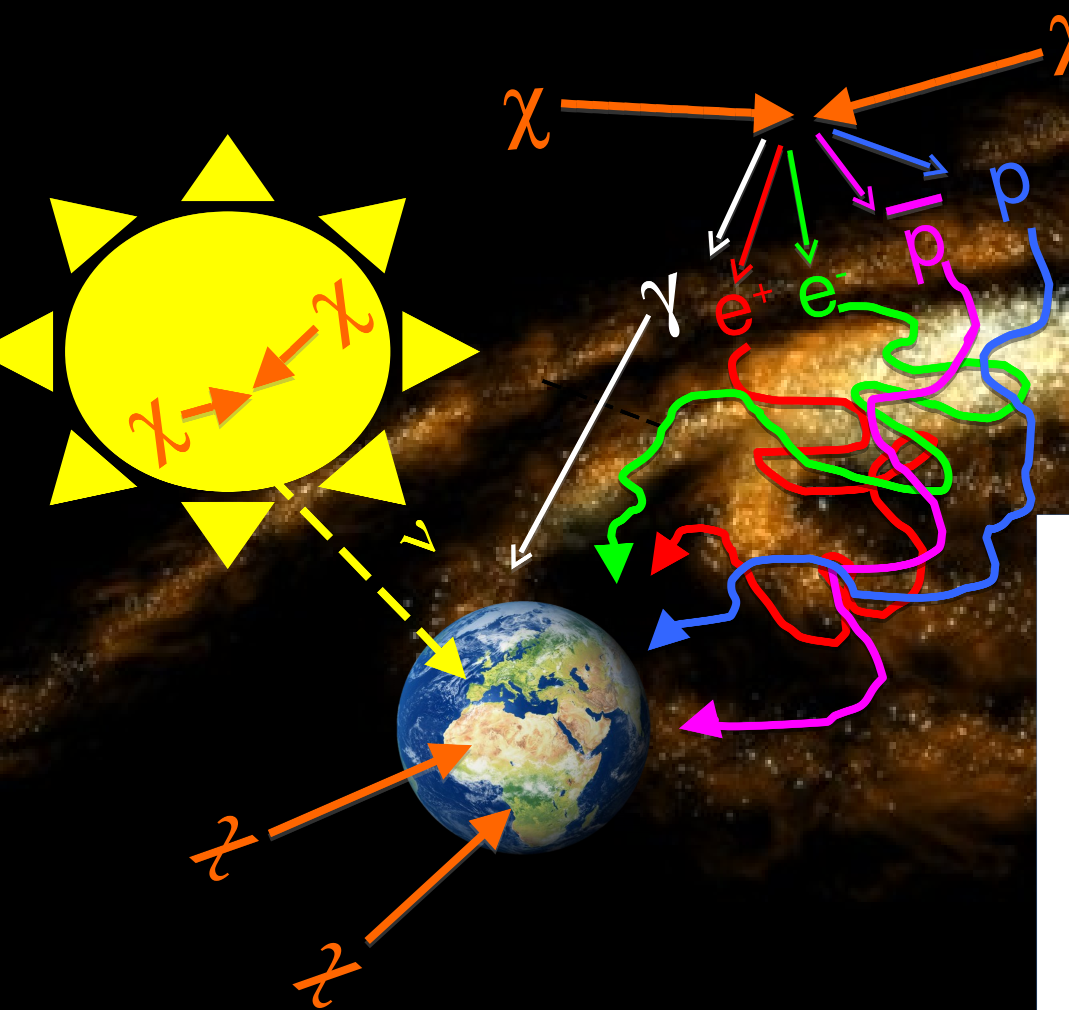
LHC

ANTI-MATTER & DARK MATTER

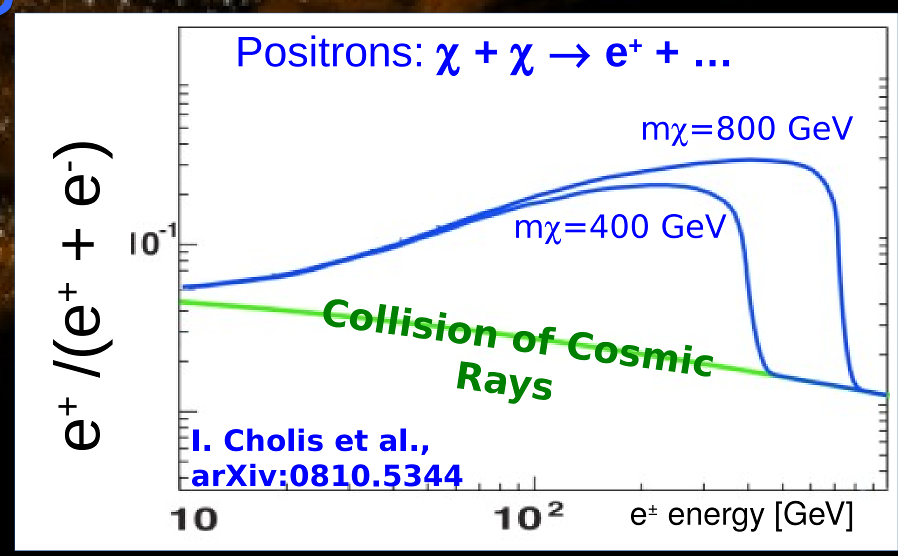
ANTI-MATTER & DARK MATTER

WIMP as the responsible of Dark Matter (?)

Indirect DM search → search for (RARE IN CR) products from their annhilation….



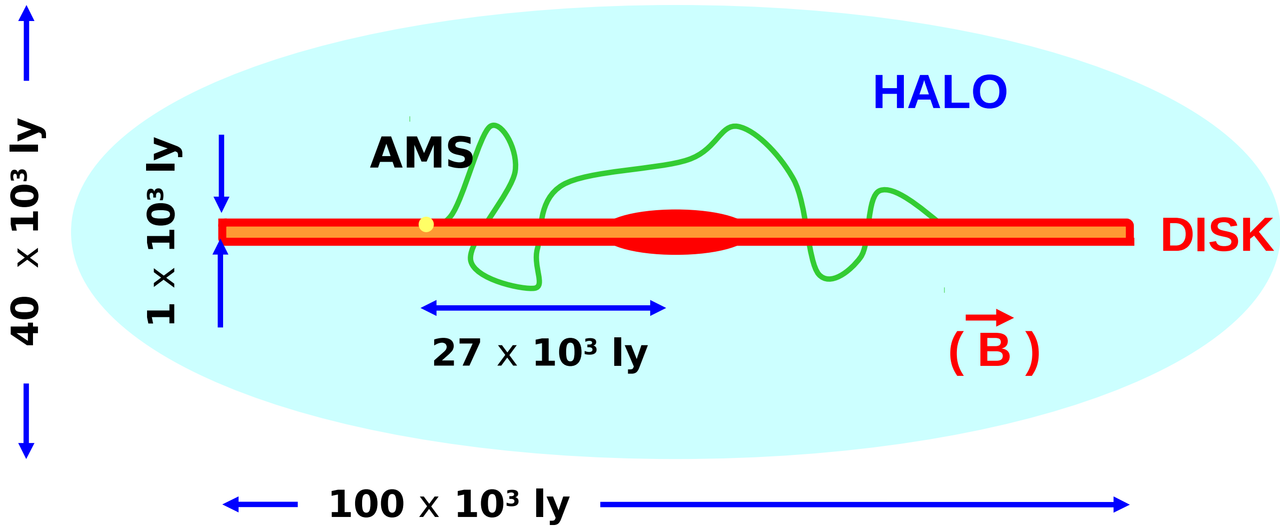
But you should know what you expect in the ISM !!



Propagazione/Interazione

e^+, $\bar{p}$ are produced in the CR interactions with the ISM

$$P+H_{ISM} \, / \, P+He_{ISM}$$
$$He+H_{ISM} \, / \, He+He_{ISM} \longrightarrow \bar{P} + \ldots, e^+ \ldots..$$



Diffusion
Convection
Reacceleration

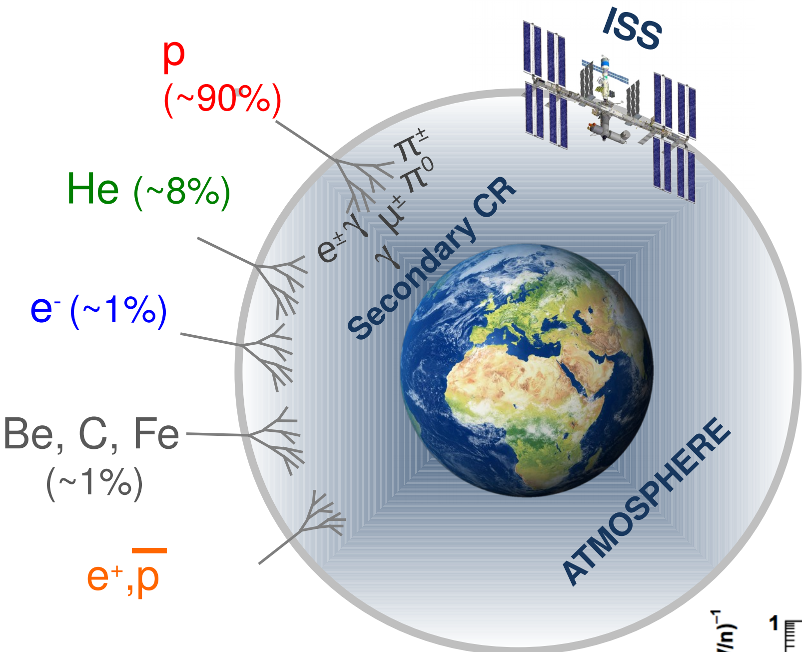
Interactions with the Interstellar Medium (ISM):

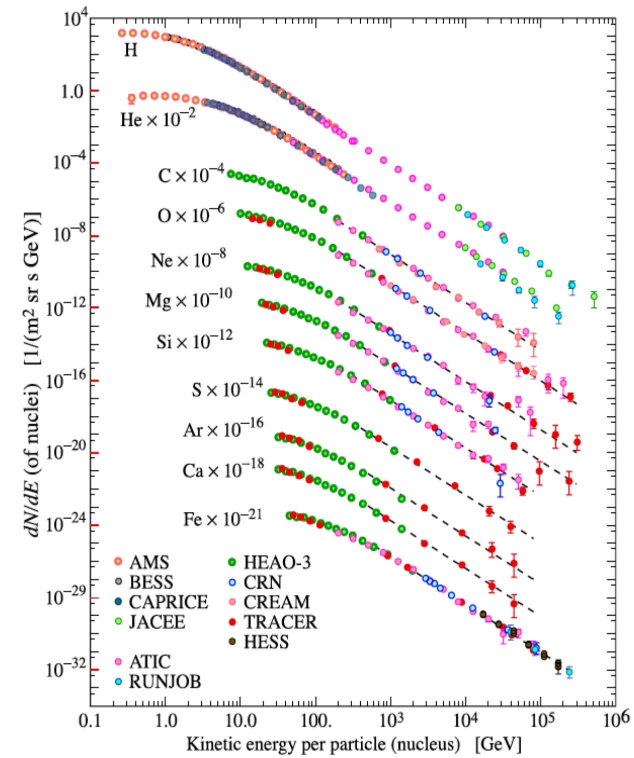
- Fragmentation
- Secondaries
- Energy loss

Information on Cosmic Ray Interactions and Propagation can be provided by the accurate measurement of nuclear species e.g. B/C

$$C + (p,He) \rightarrow B + \ldots$$

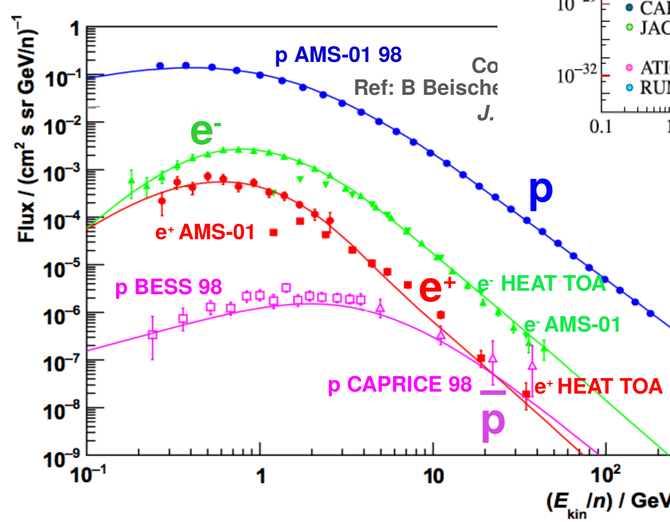
Fisica dei raggi cosmici



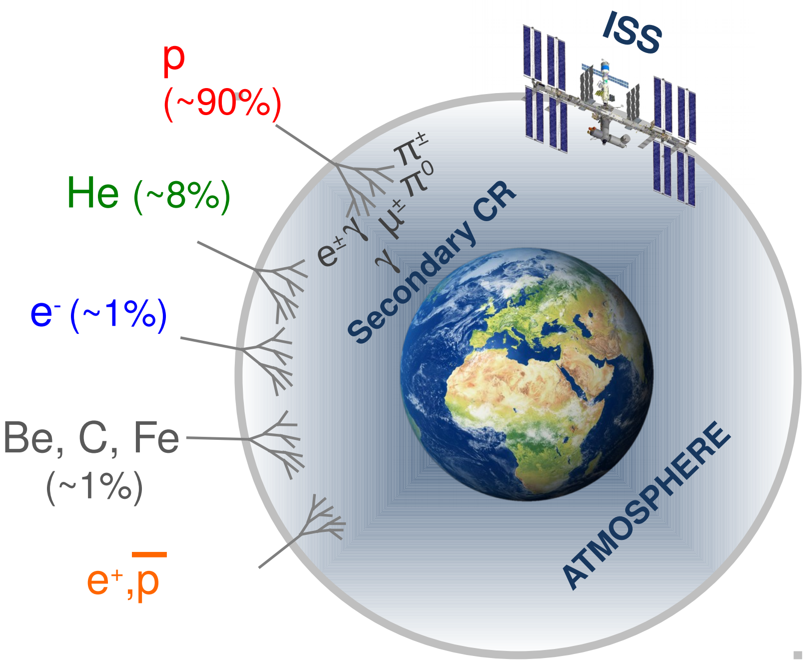


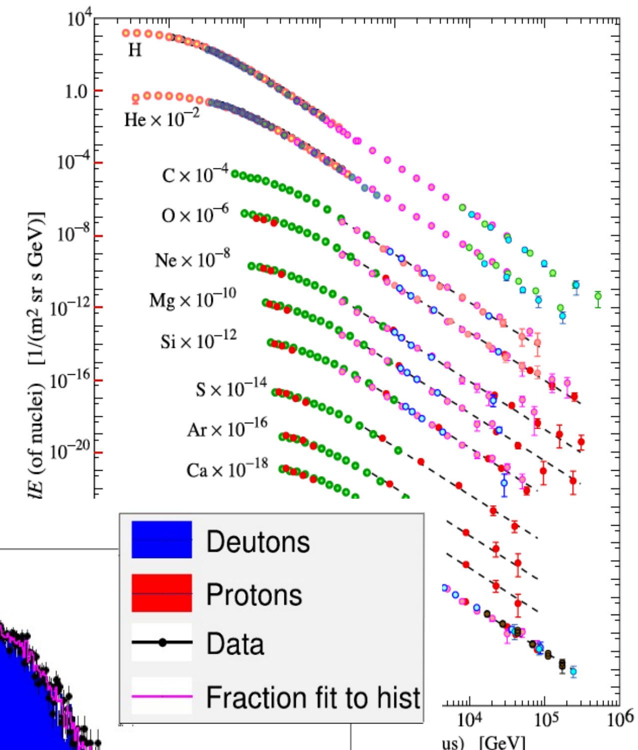
charged cosmic rays (GV-TV)

Gamma rays (E>1GeV)

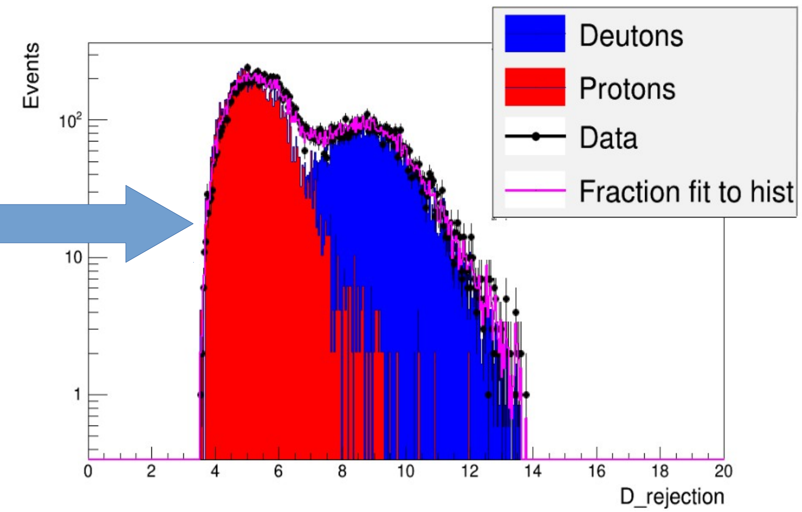


Fisica dei raggi cosmici



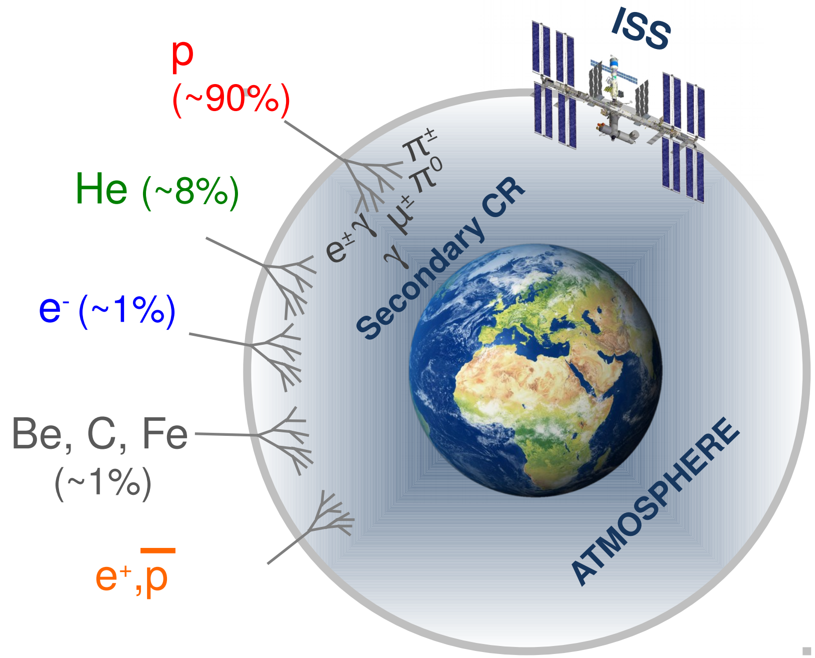


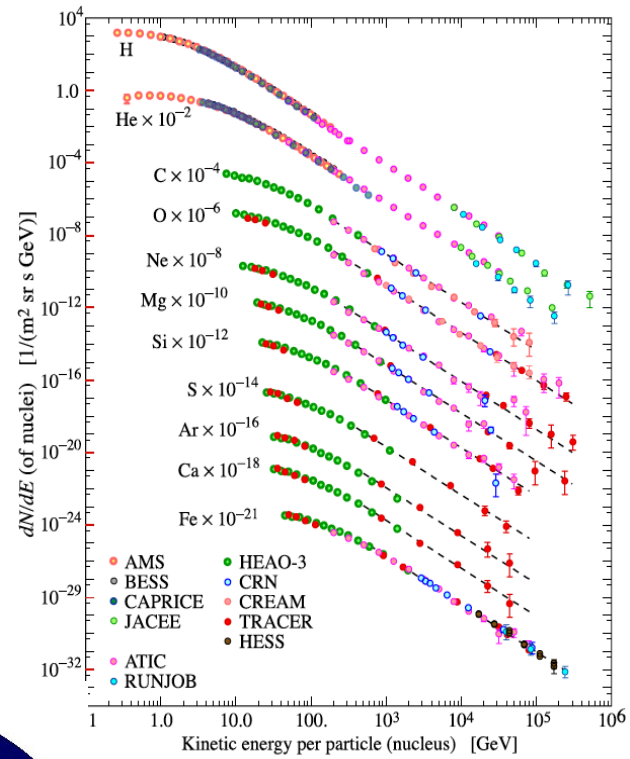
Charged cosmic rays (GV-TV)



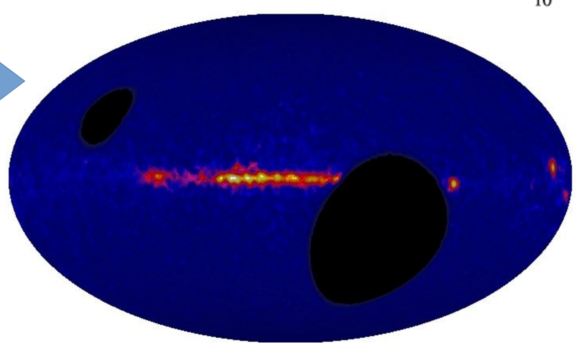
POSTER F. Dimiccoli
"Ricerca di Deutoni e AntiDeutoni cosmici con AMS-02"

Fisica dei raggi cosmici





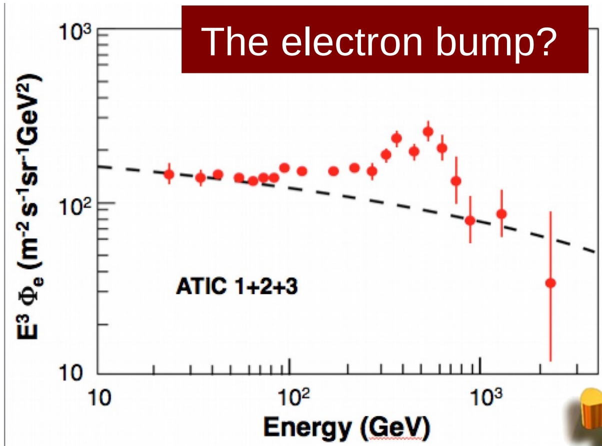
Gamma rays (E>1GeV)



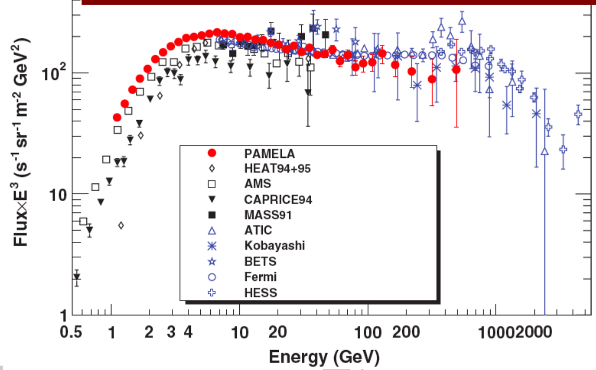
POSTER: I. Guerri
"Identificazione di sorgenti gamma con il calorimetro di AMS-02"

quadro sperimentale pre-AMS

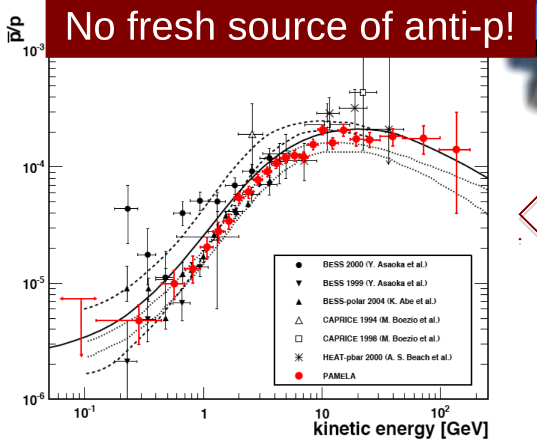
The electron bump?



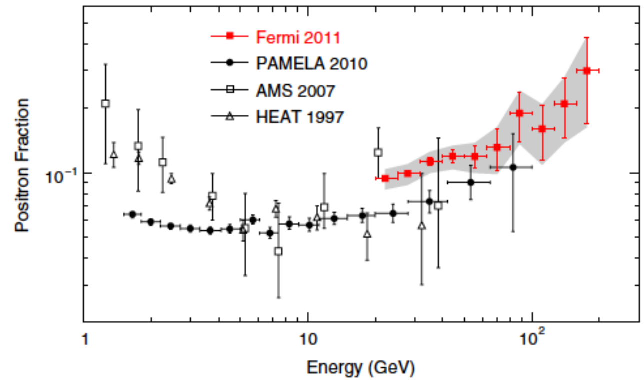
No bump in Fermi / PAMELA data



No fresh source of anti-p!

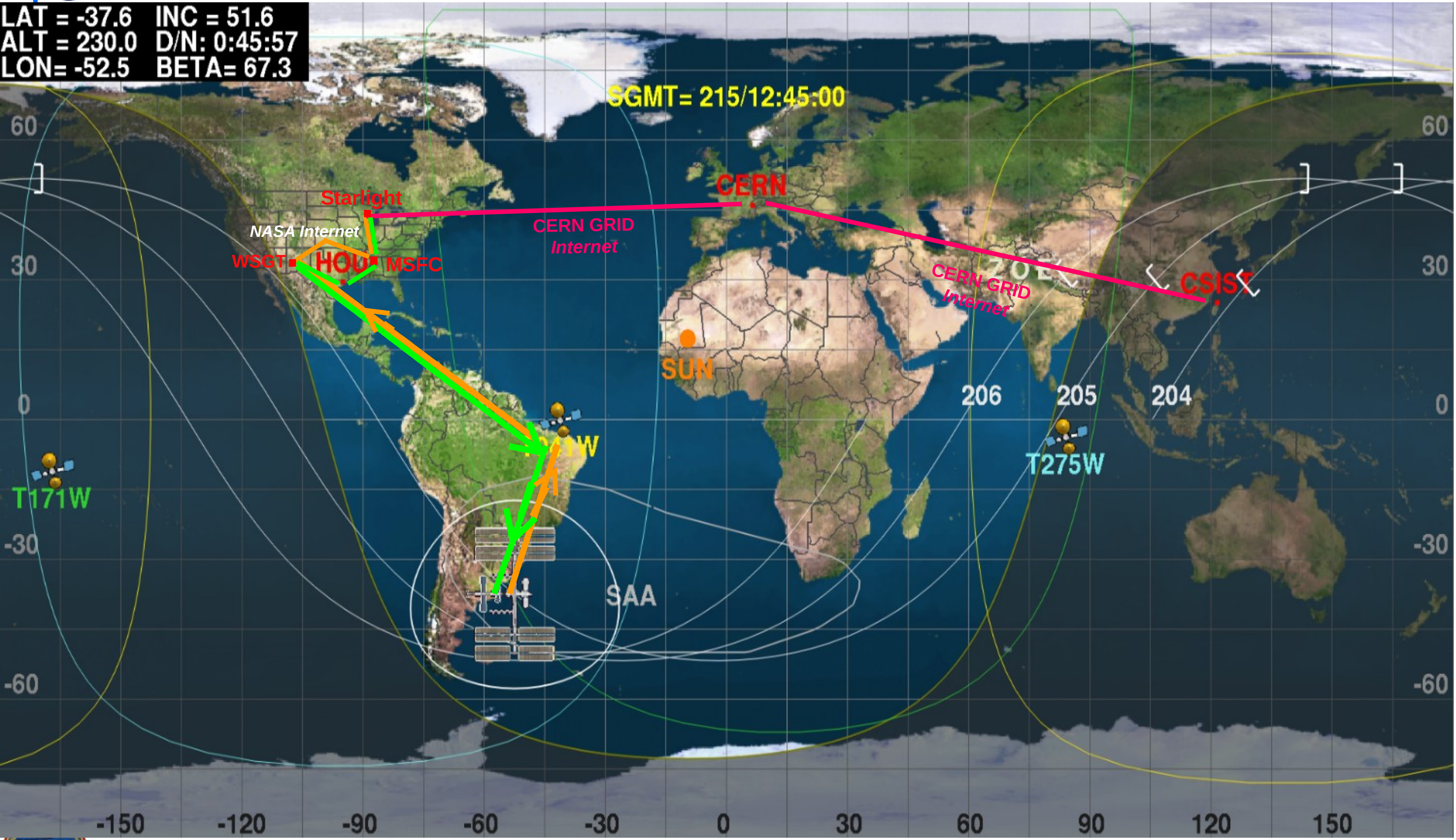


A confirmed positron "excess"



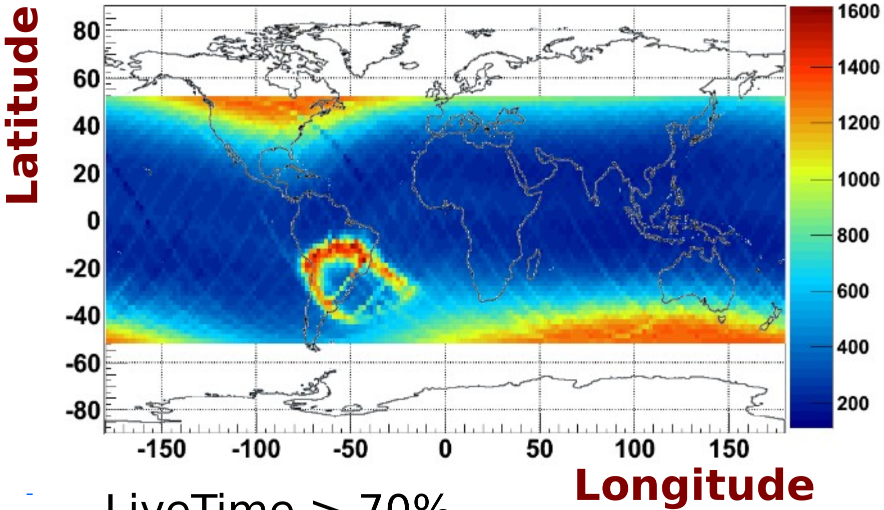
- **PARTE 2:**
  Detector & Presa dati

orbita @ 400 km T=90min

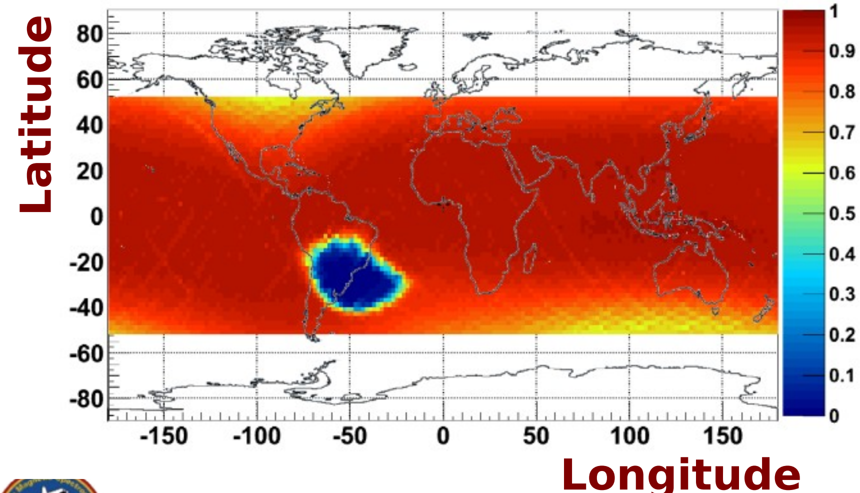


presa dati monitorata h24

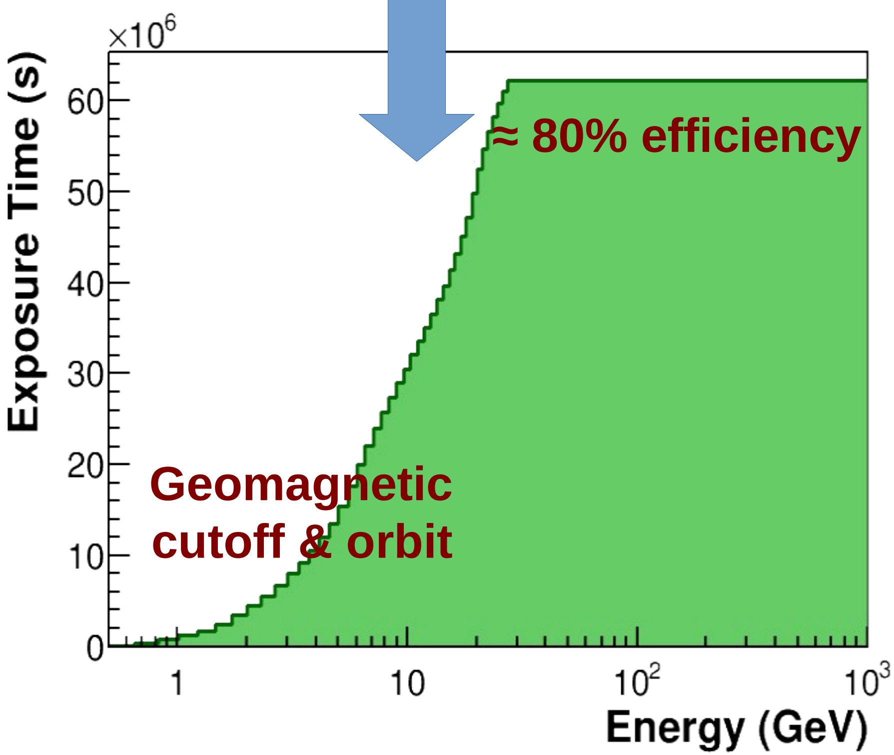
<Acquisition rate> ≈ 500 Hz



LiveTime > 70%

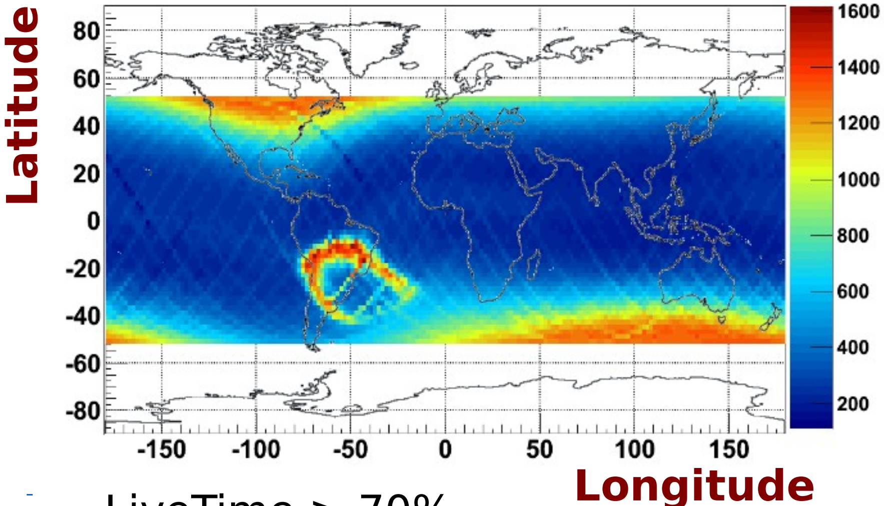


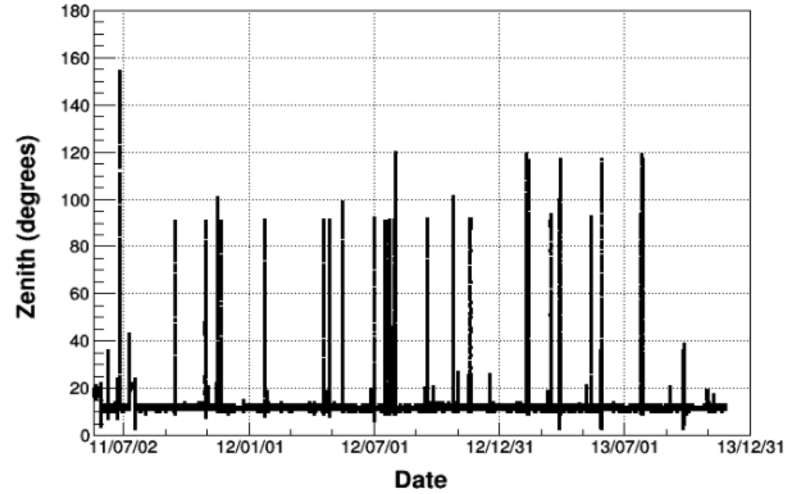
POSTER: F. Donnini
"Tecniche di calcolo del cutoff geomagnetico per esperimenti nello spazio"



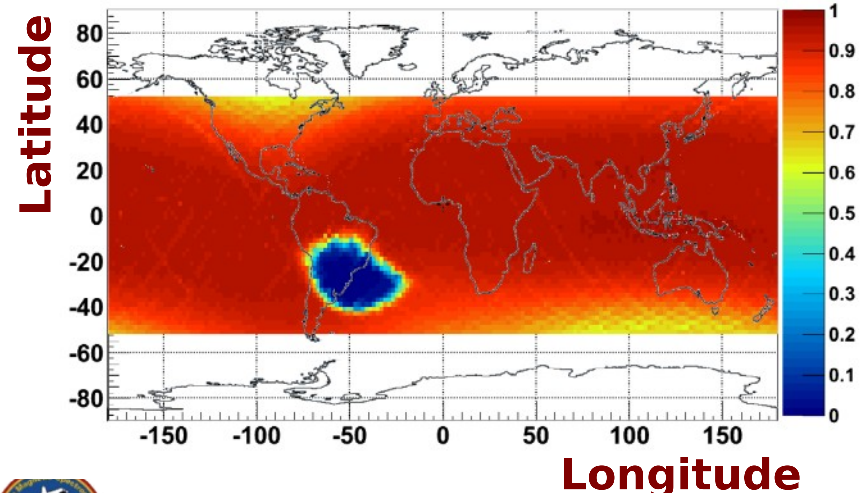
presa dati monitorata h24

<Acquisition rate> ≈ 500 Hz





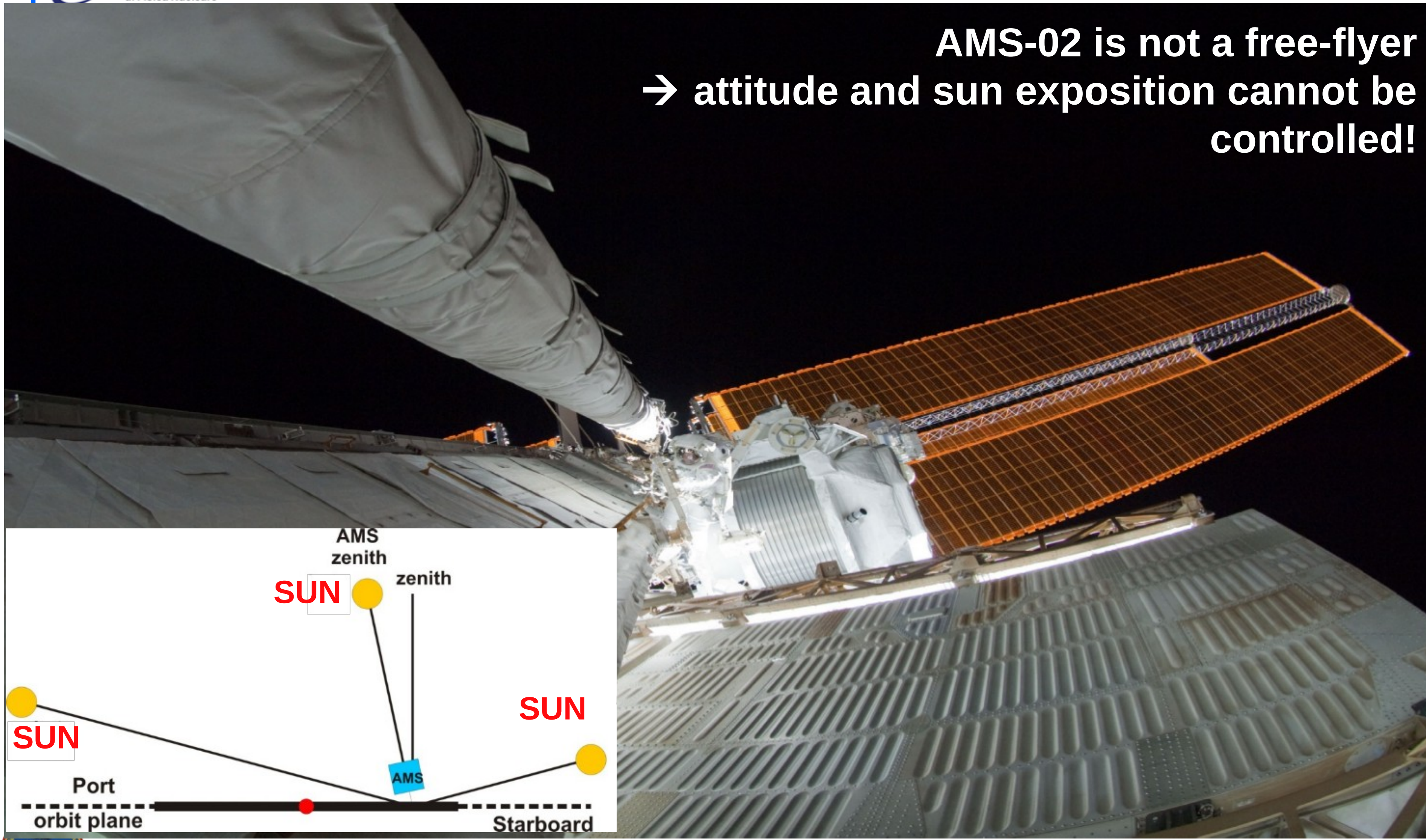
LiveTime > 70%



Payload Operation Control Center (POCC) @ CERN

variazioni termiche orbitali

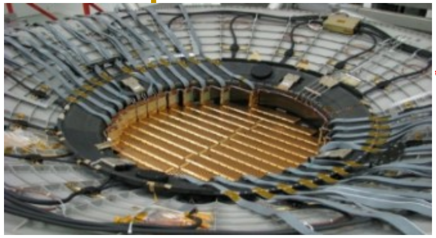
AMS-02 is not a free-flyer
→ attitude and sun exposition cannot be controlled!



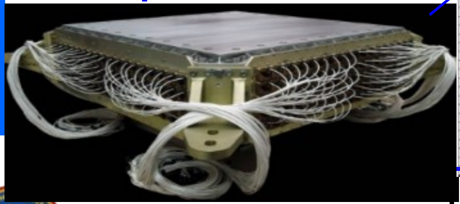
Elettronica dedicata al controllo termico

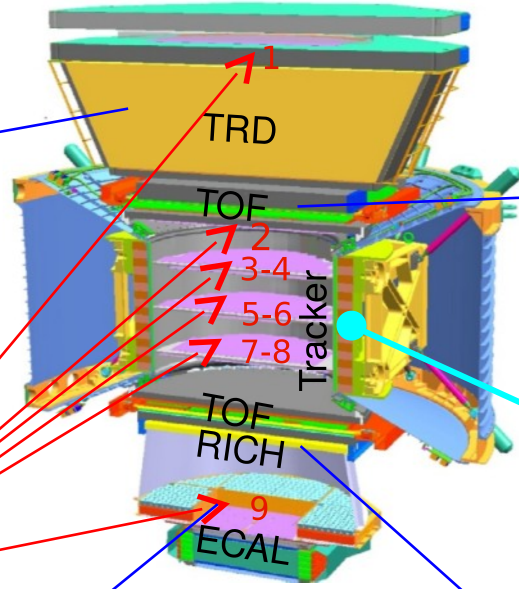
TRD
24 Heaters
8 Pressure Sensors
482 Temperature Sensors

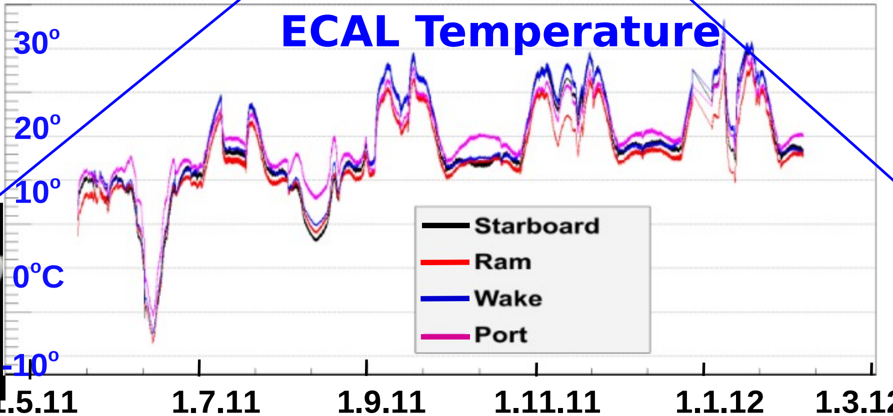
Silicon Tracker
4 Pressure Sensors
32 Heaters
142 Temperature Sensors



ECAL
80 Temperature Sensors

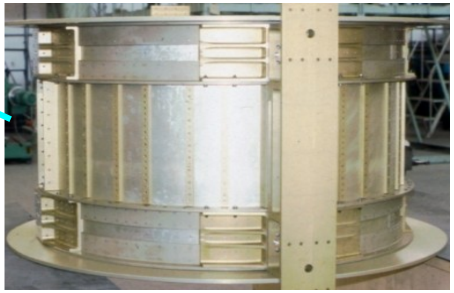




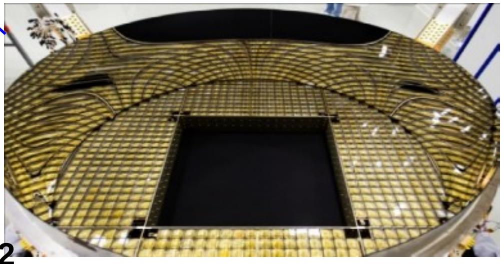


TOF & ACC
64 Temperature Sensors

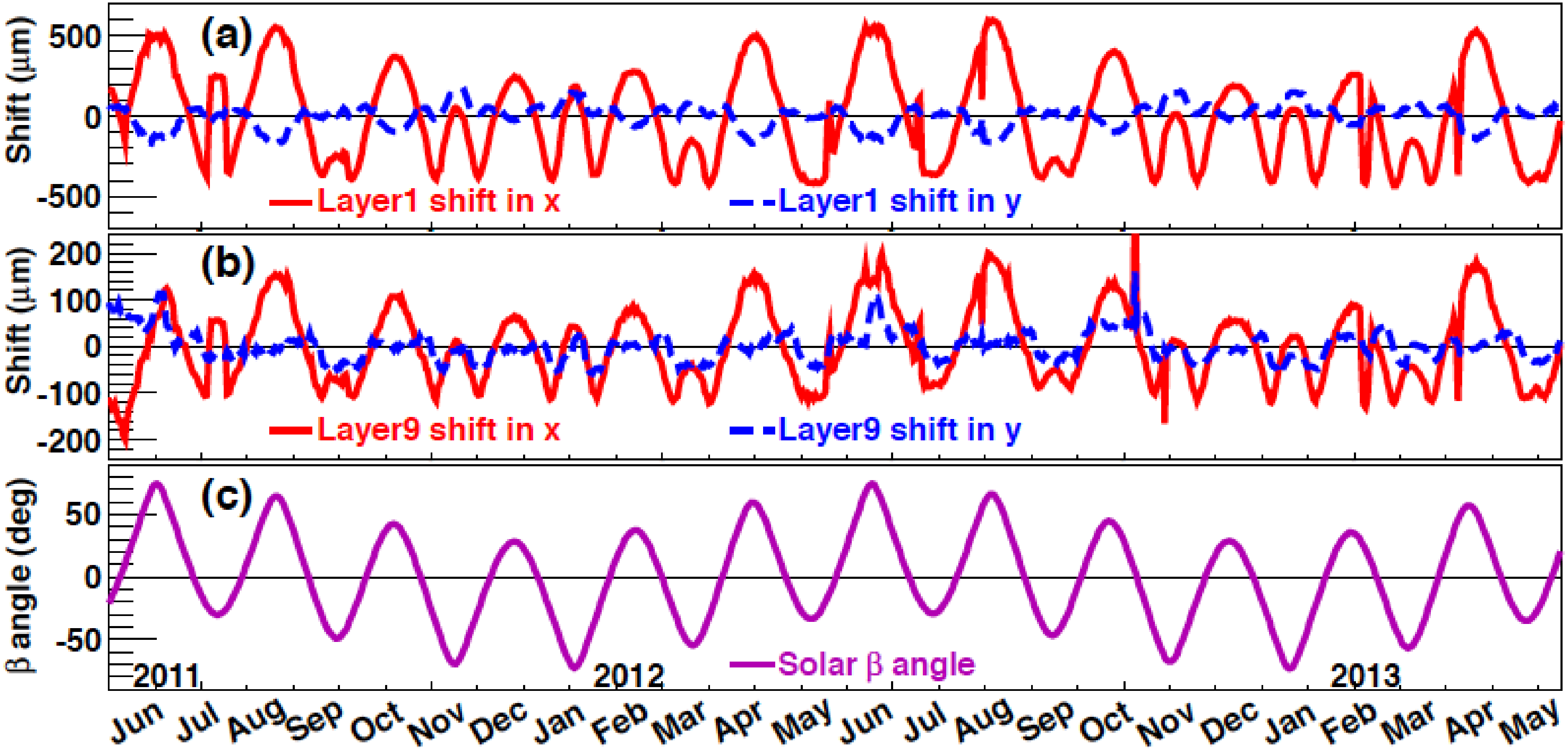
Magnet
68 Temperature Sensors



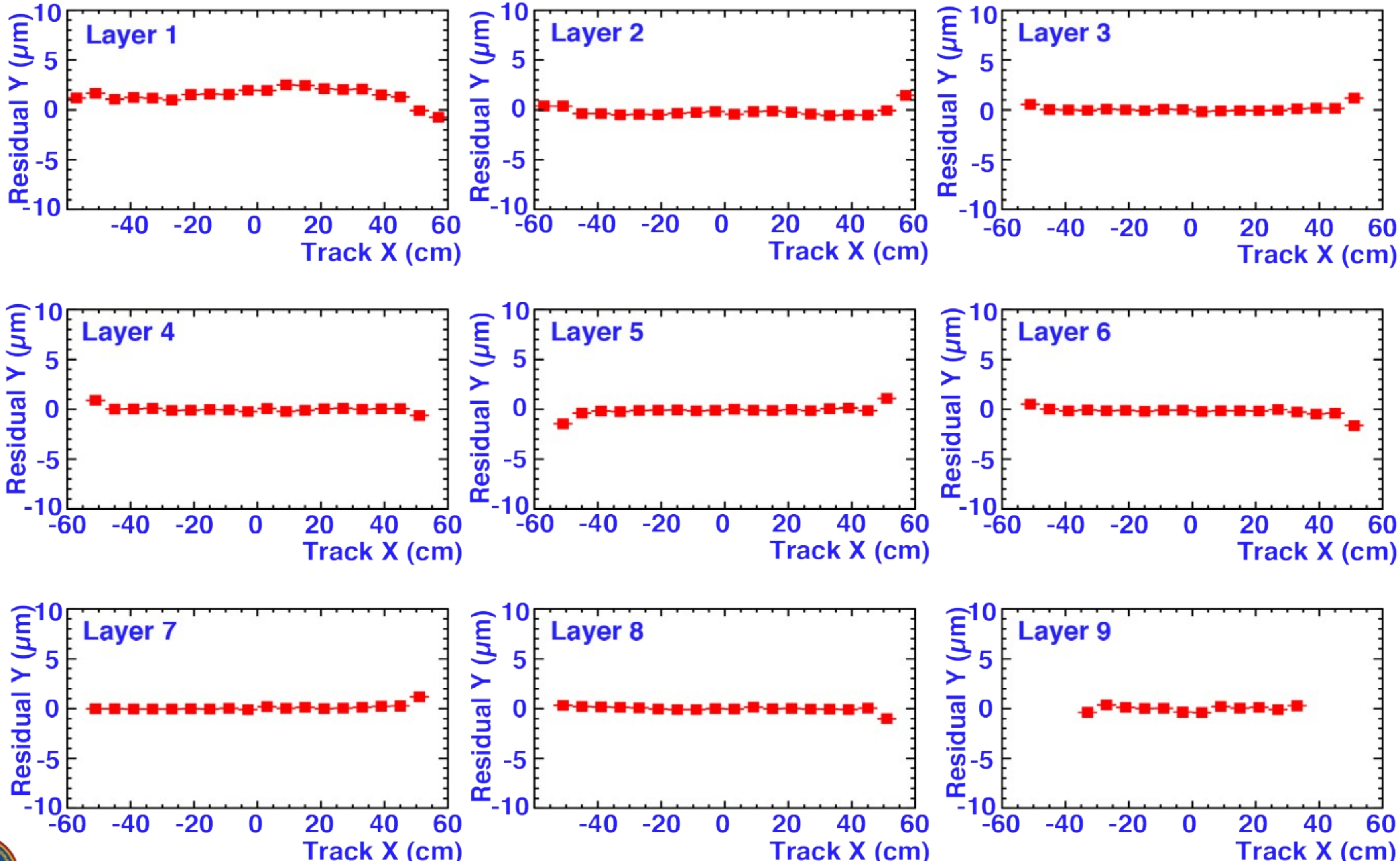
RICH
96 Temperature Sensors



Esempio: effetti termici sul Tracker



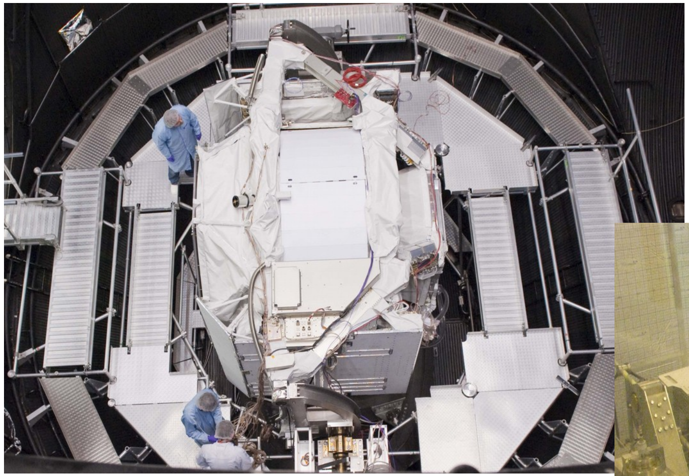
dopo il ri-allineamento del Tracker

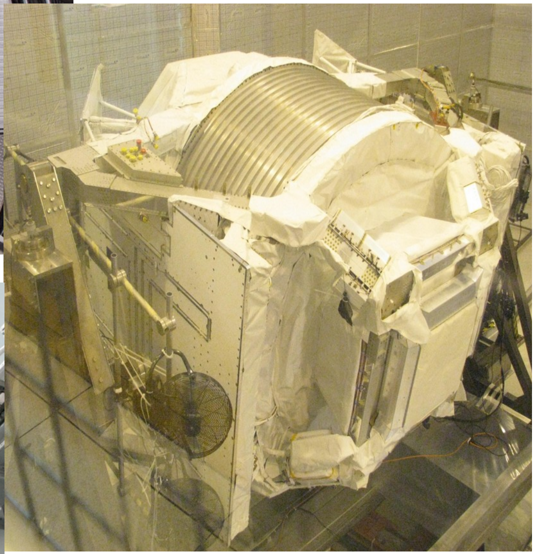


AMS: un detector HEP in ambiente ostile

Tutti i sotto-rivelatori estensivamente testati a terra

Before assembly :
Beam test,
Thermal,
Vibration,
TVT, EMI





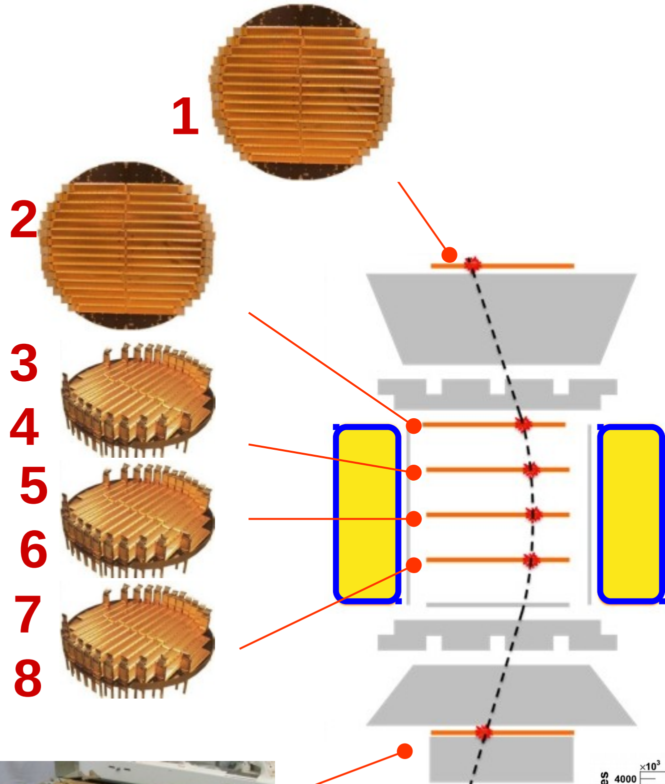
After assembly :
EMI, TVT,
Beam Test

Tracciatore al silicio

Coordinate resolution 10 μm (for Z=1)

→20–UV Lasers to monitor inner tracker alignment

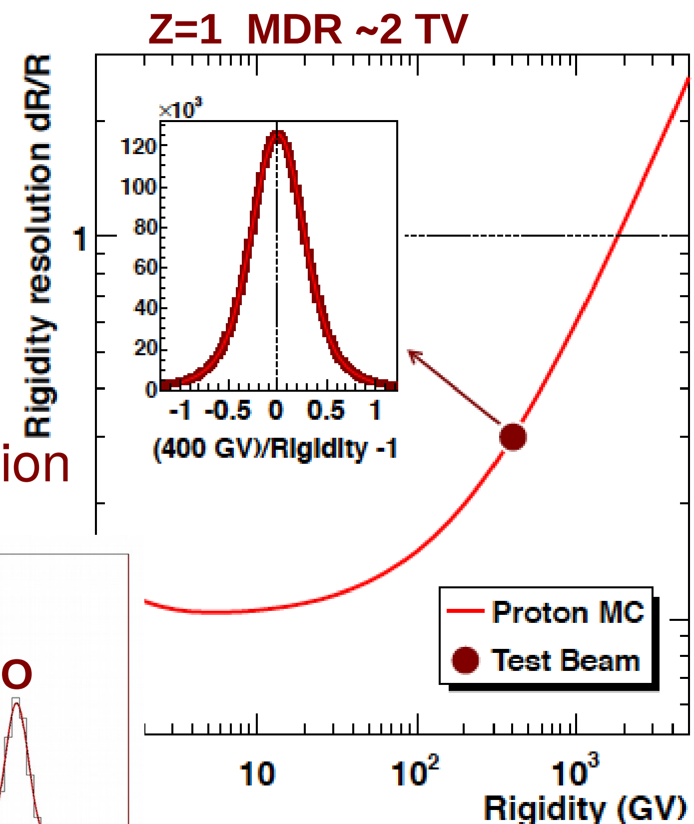
→Cosmic rays to monitor outer tracker alignment



192 ladders

2598 sensors

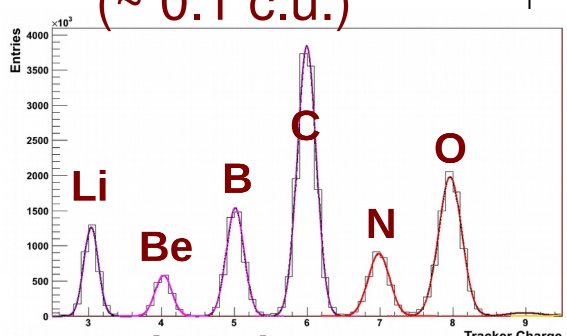
200k rd.ch.



9

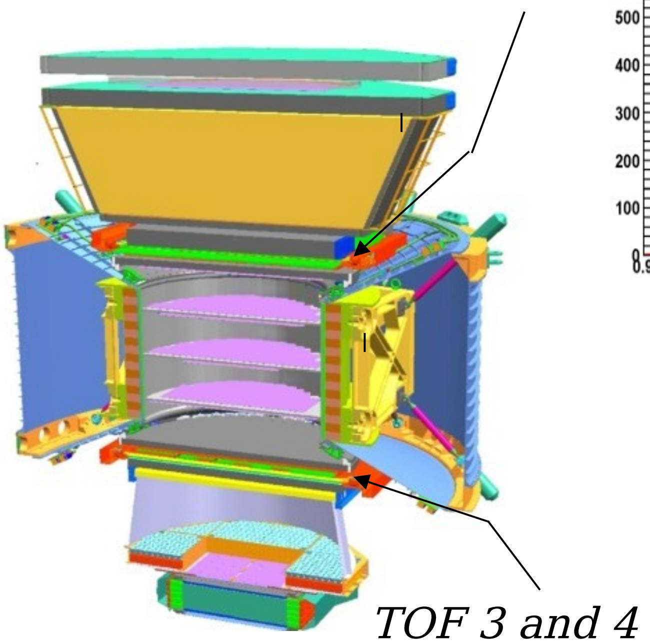
9 layers of double sided silicon microstrip detectors

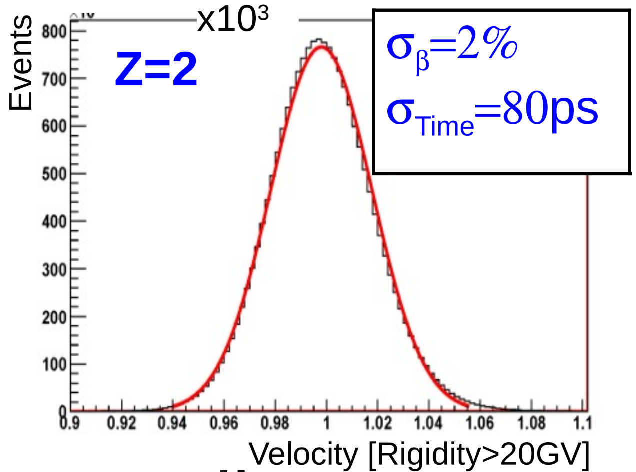
charge resolution (~ 0.1 c.u.)

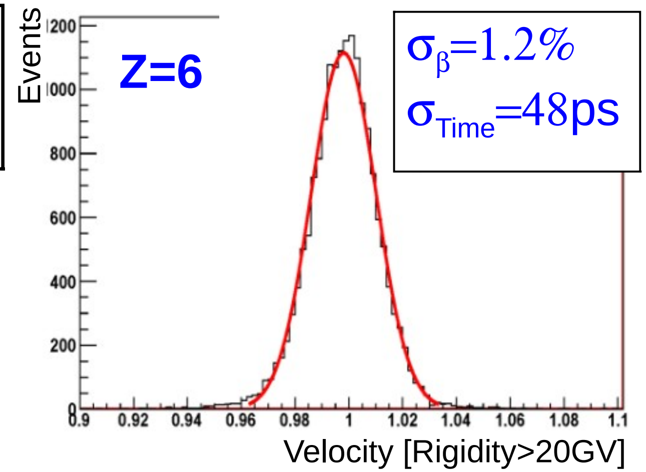


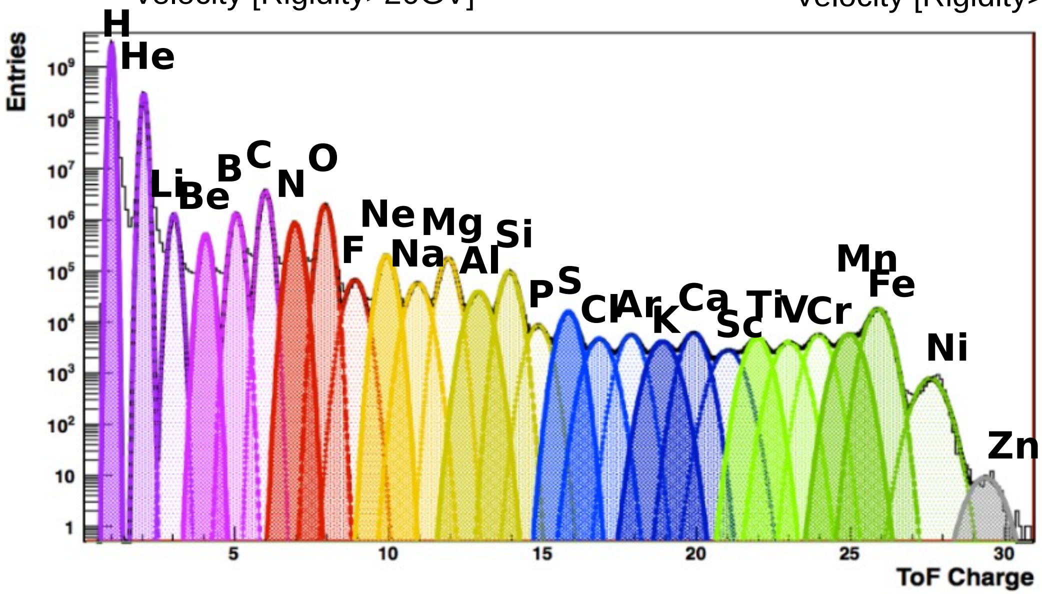
Tracker Charge

Time of Flight (TOF)



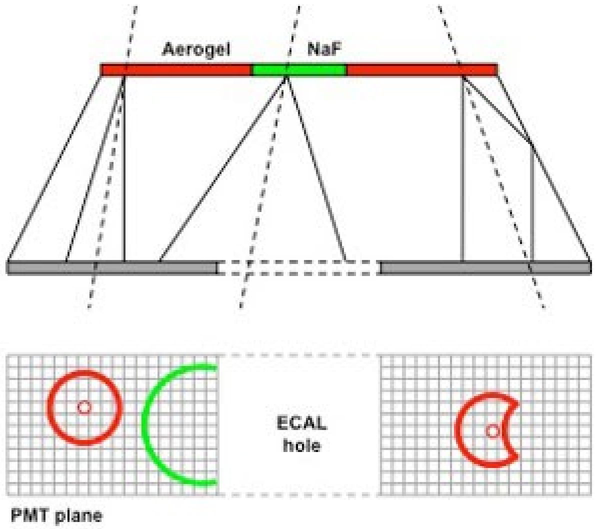




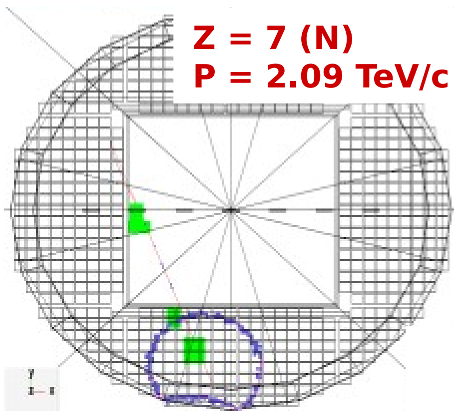


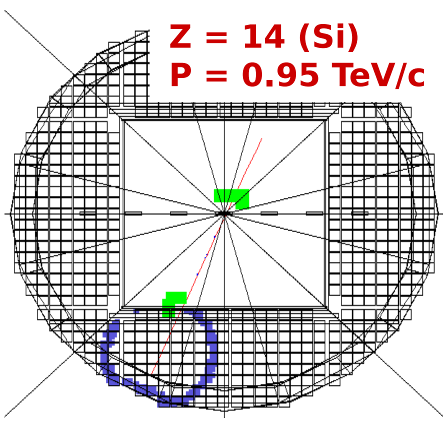
Up-going particles (fake anti-matter!) rejection up to 10^9

Rivelatore Cherenkov (RICH)

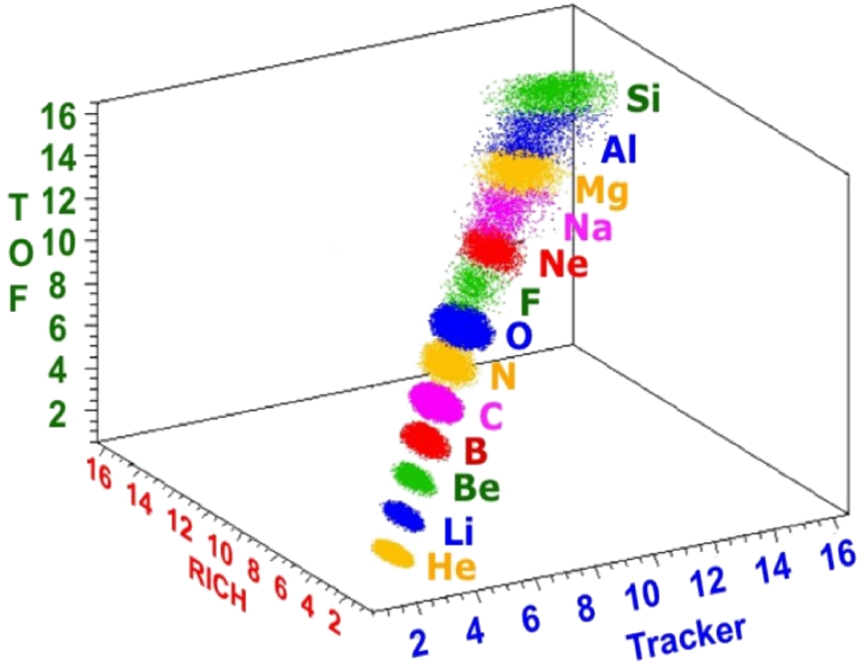


beta resolution 0.1% for Z=1 particles
0.01% for ions

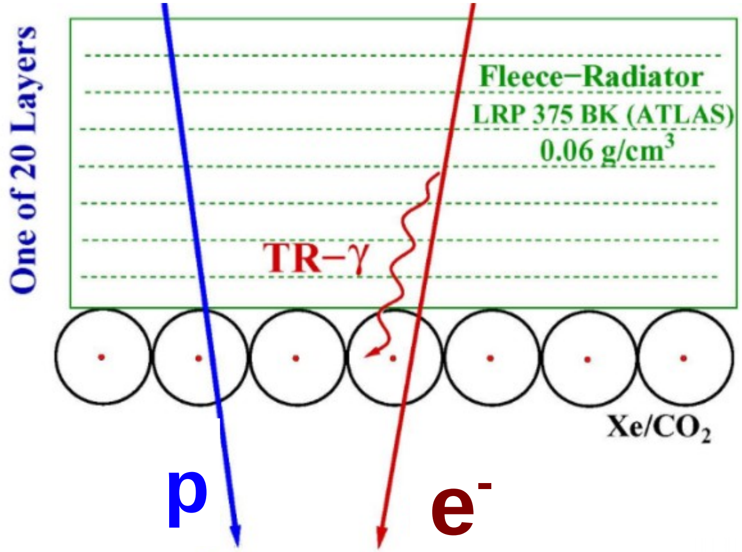


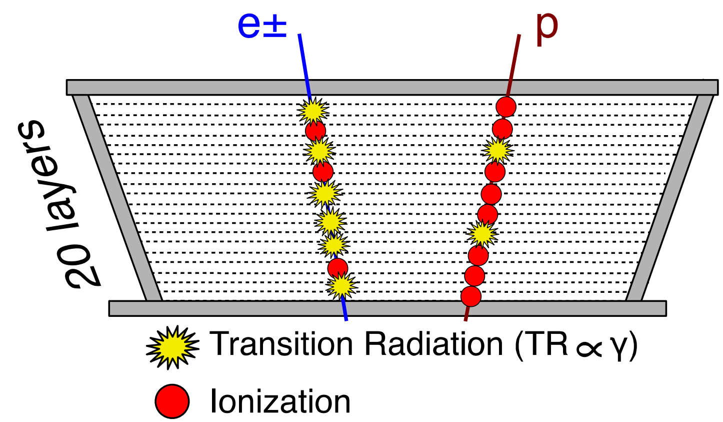


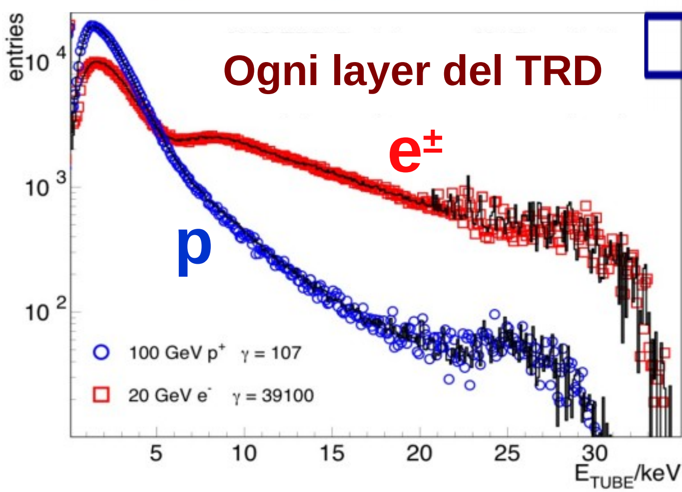
Redundant measurement of Z



Transition Radiation Detector (TRD)





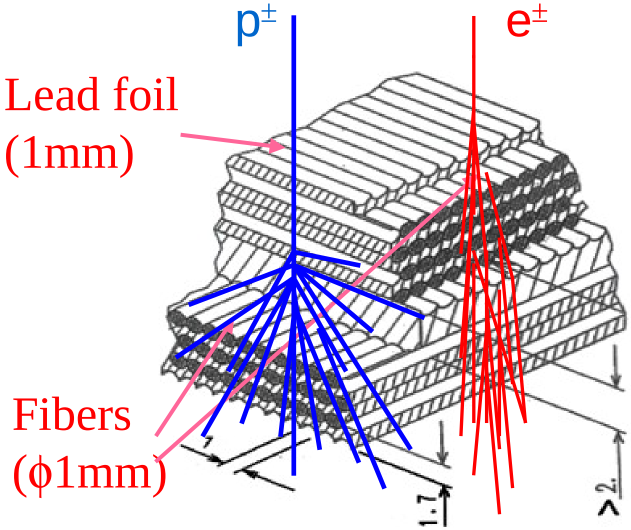


$$P_e = \sqrt[n]{\prod_i^n P_e^{(i)}(A)} \qquad P_p = \sqrt[n]{\prod_i^n P_p^{(i)}(A)}$$

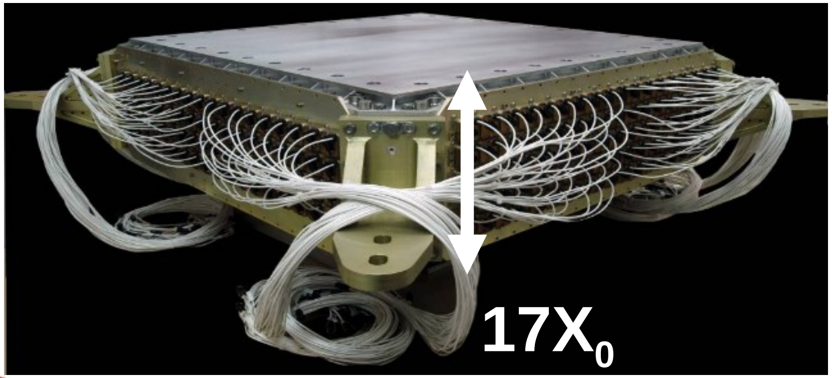
TRD Estimator = -ln(P_e/(P_e+P_p))

TRD Classifier = Log$_{10}$(P_e)

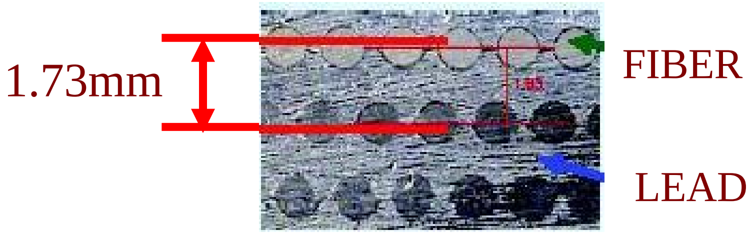
Calorimetro Elettromagnetico (ECAL)

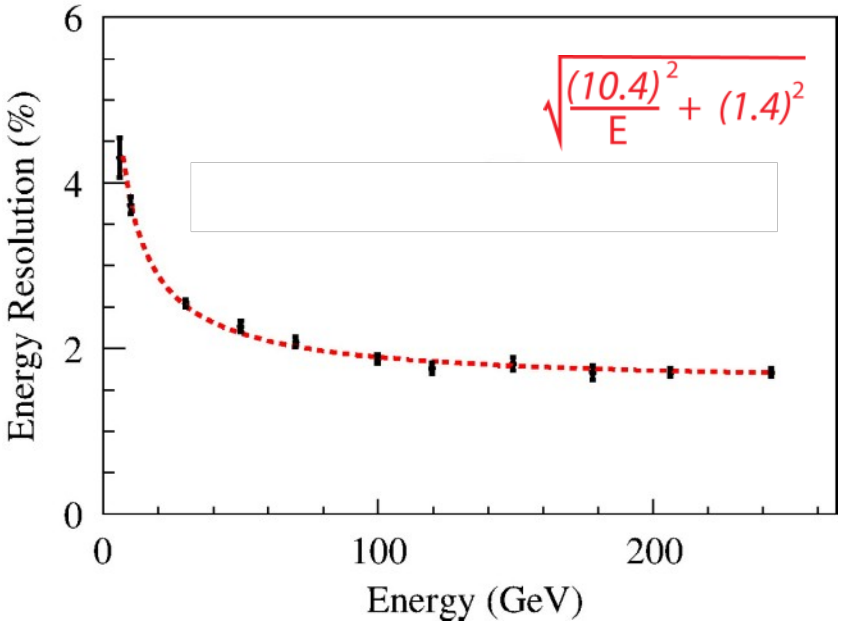


50,000 fibre, ϕ = 1 mm
distributed uniformly Inside 600 kg of lead

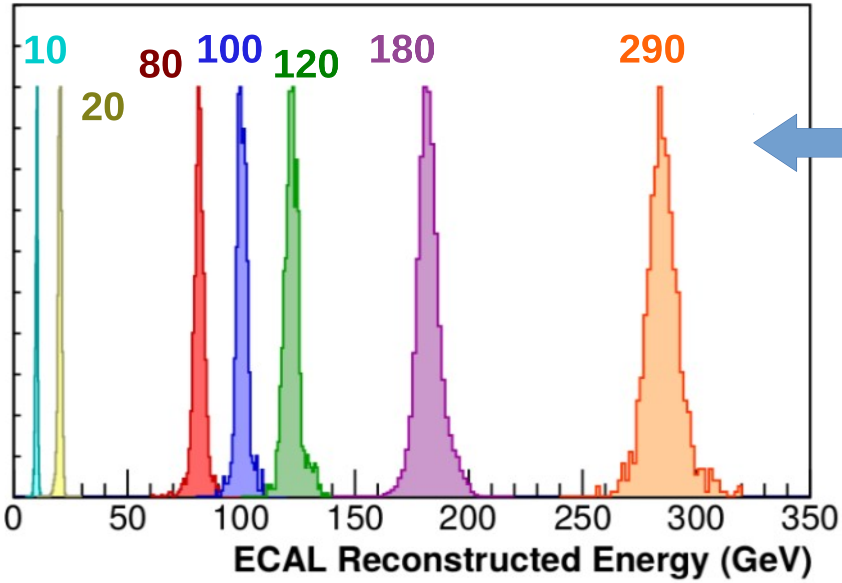


A precision, 3-D measurement of the directions and energies of gammas and electrons up to 1 TeV





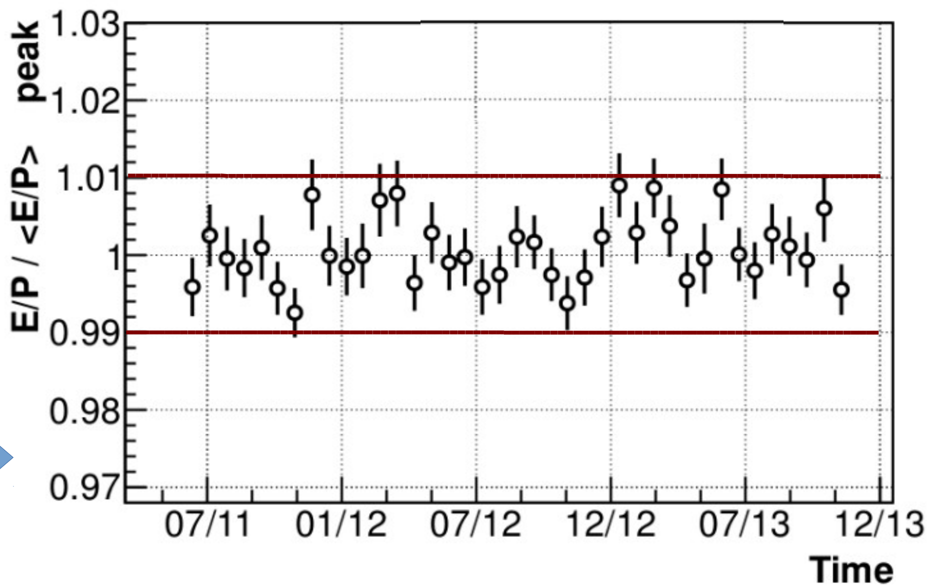
Scala energetica:



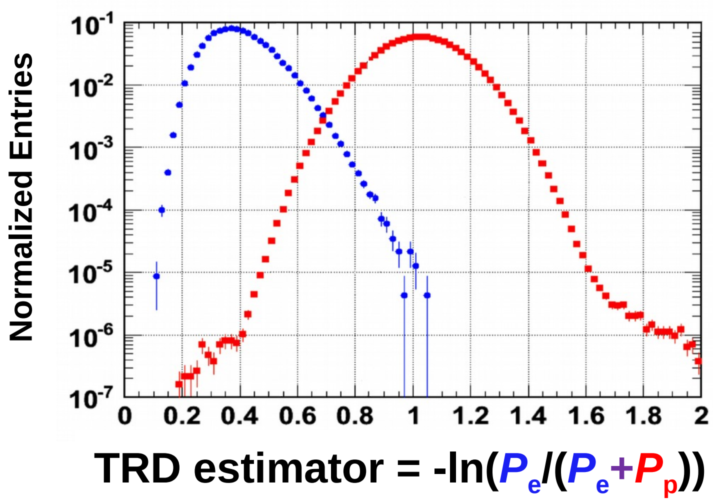
- **ECAL energy resolution ~2% at HE**
- **ECAL energy absolute scale** tested during test beams on ground

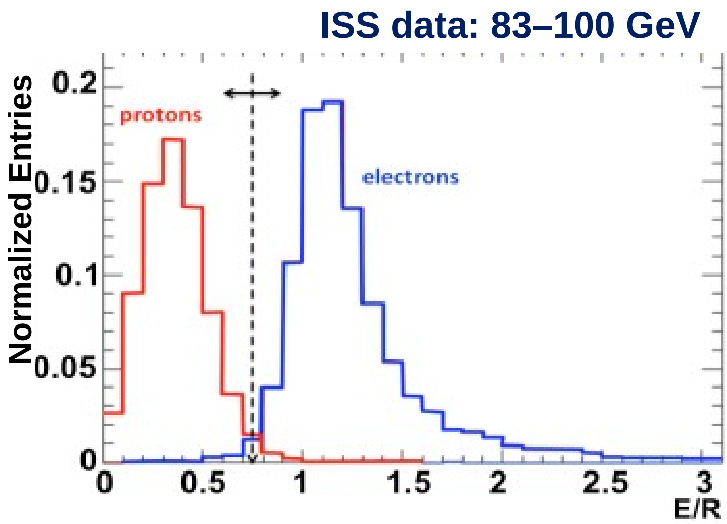
MIP ionization used to cross-calibrate the energy scale in flight

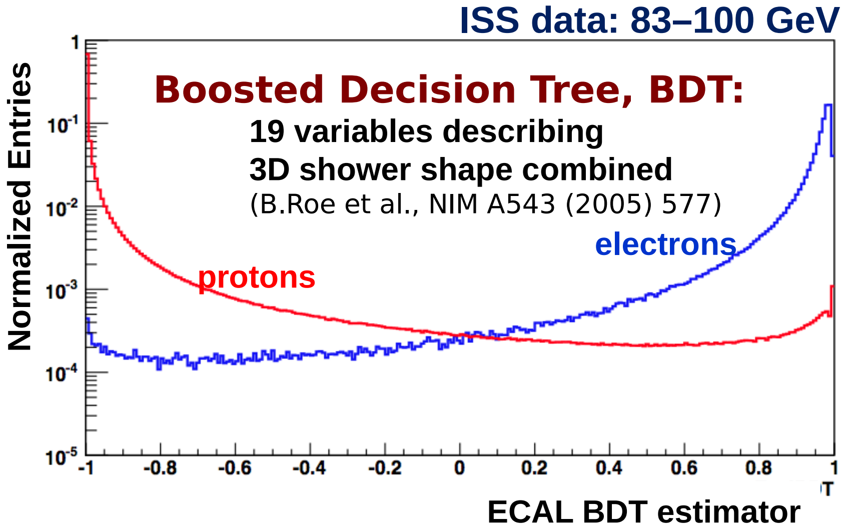
ECAL energy comparison with Tracker rigidity used to check the stability of the scale over time

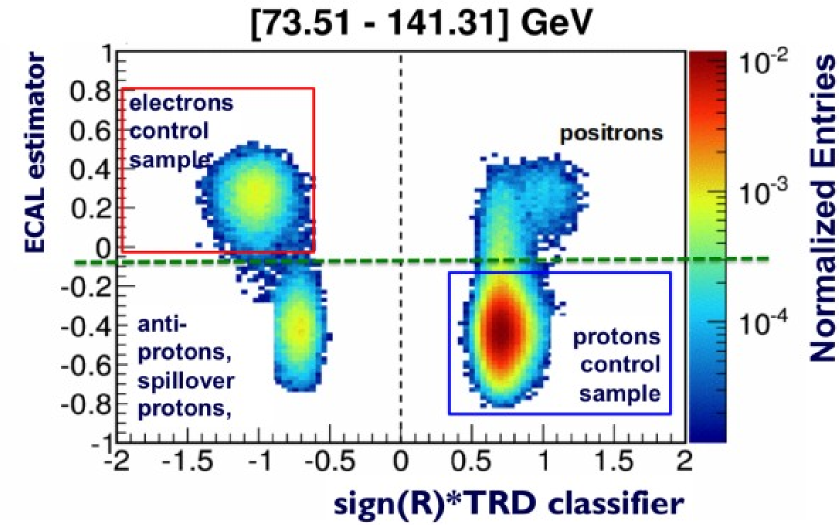


detector ridondanti e/o complementari









AMS-02 PID

	e^-	P	He,Li,Be,..Fe	γ	e^+	$\bar{P}$	$\bar{He}$, $\bar{C}$
TRD							
TOF							
Tracker							
RICH							
ECAL							
Physics example	Cosmic Ray Physics				Dark matter		Antimatter

PARTE 3: risultati

Published:

1. **Positron Fraction** (0.5–350 [2013] 0.5-500 GeV [2014])
2. **Electron** (0.5–700 GeV) and **Positron Fluxes** (0.5–500 GeV)
3. **All electrons Flux** (0.5 GeV – 1 TeV)

in 2015:

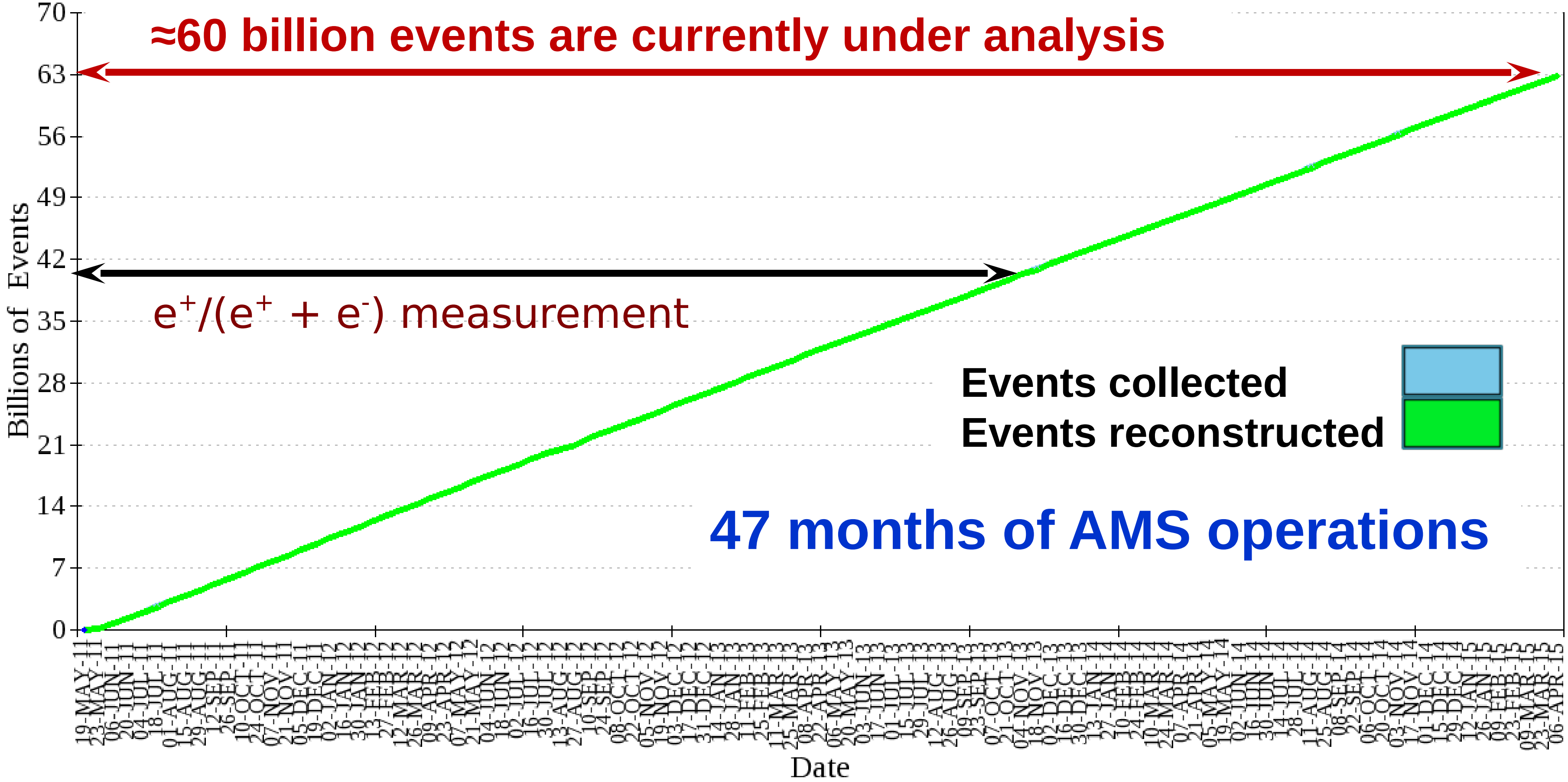
1.….**.proton, he fluxes**

2.….anti-proton

3.….B, C, Li, O …ratio / fluxes

Alta statistica accumulata

To date AMS collected > 60 billion events



Esempio identificazione e^+/e^-

-TRD:

- identify the particle as e^+/e^- rejecting the hadronic hypothesis

-TOF:

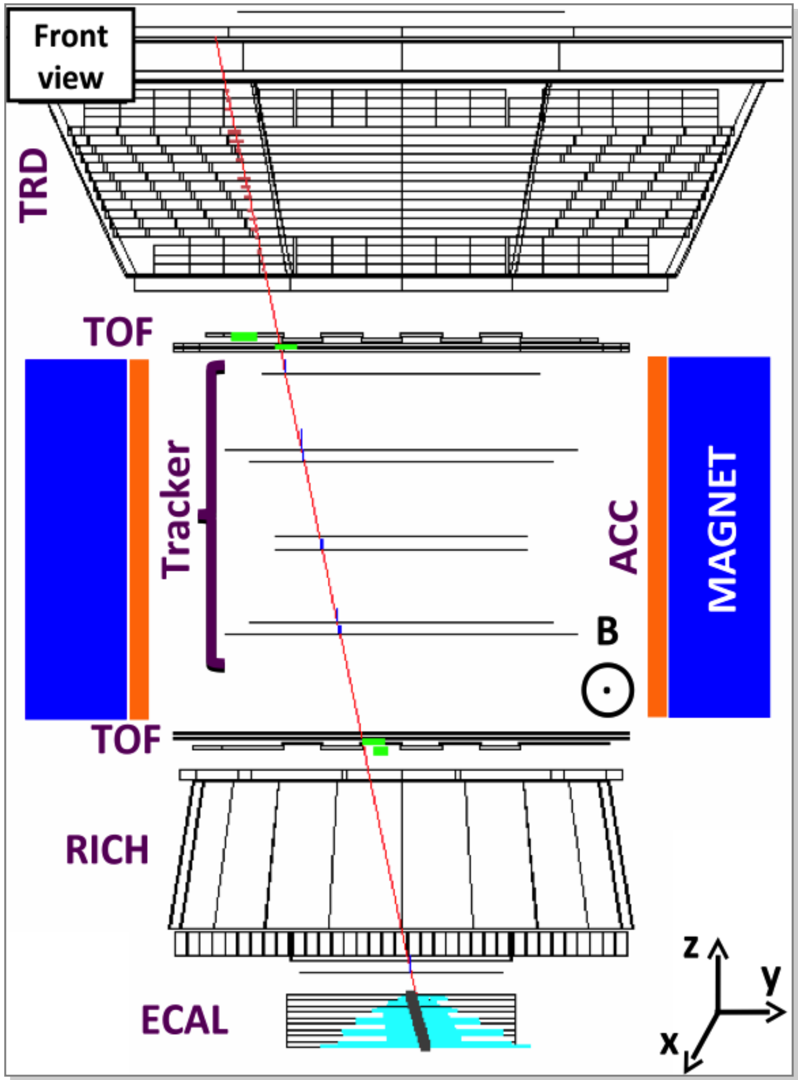
- main trigger
- down going relativistic particle
- Z=1

-TRACKER:

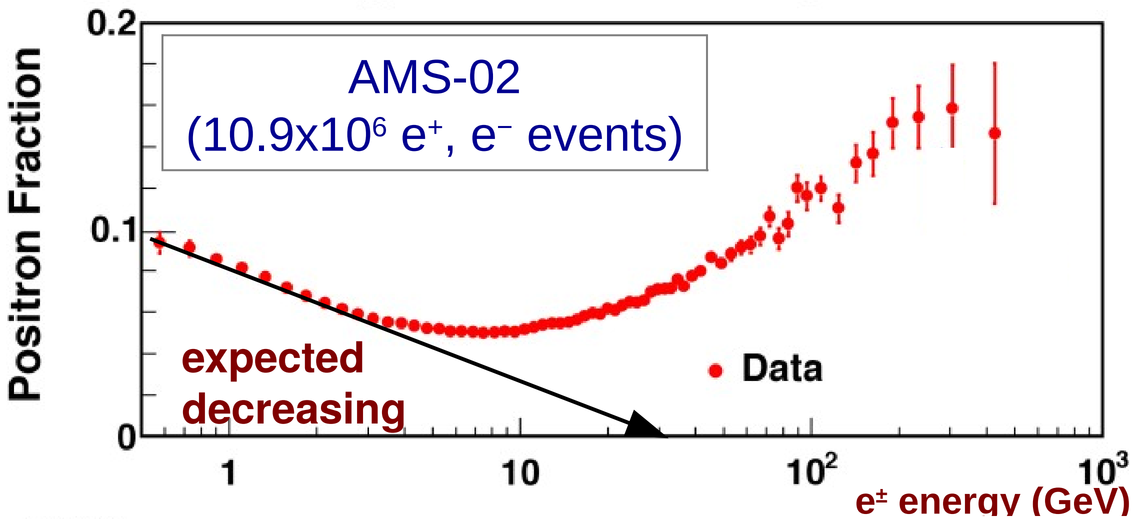
- Identify charge sign (e^-/e^+)
- Z=1
- Measure P

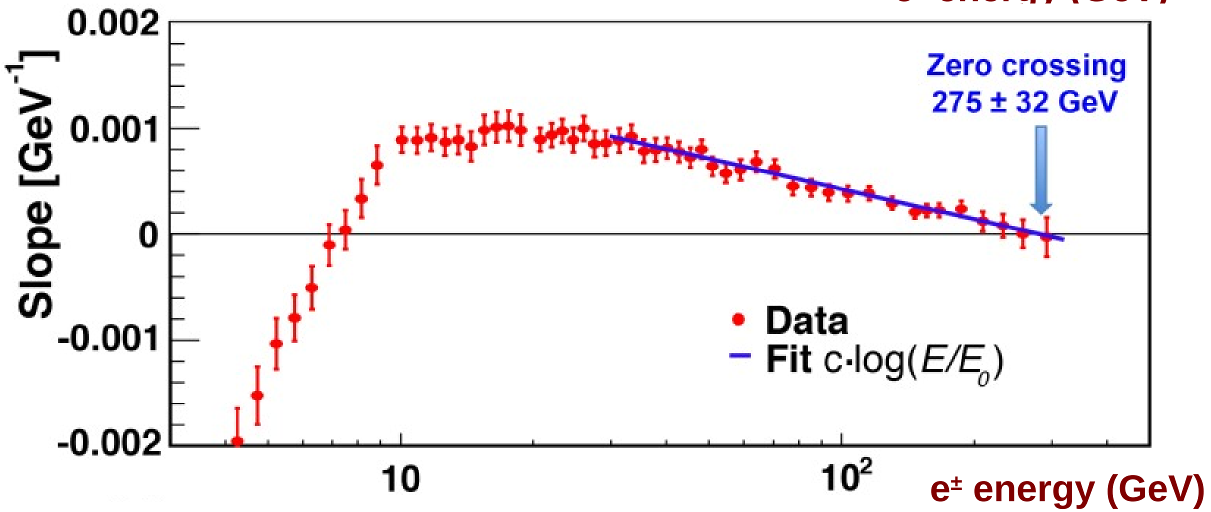
-ECAL:

- identify the particle as $e^+/e^-/\gamma$ rejecting the hadronic hypothesis (BDT,E/P)
- measurement of energy



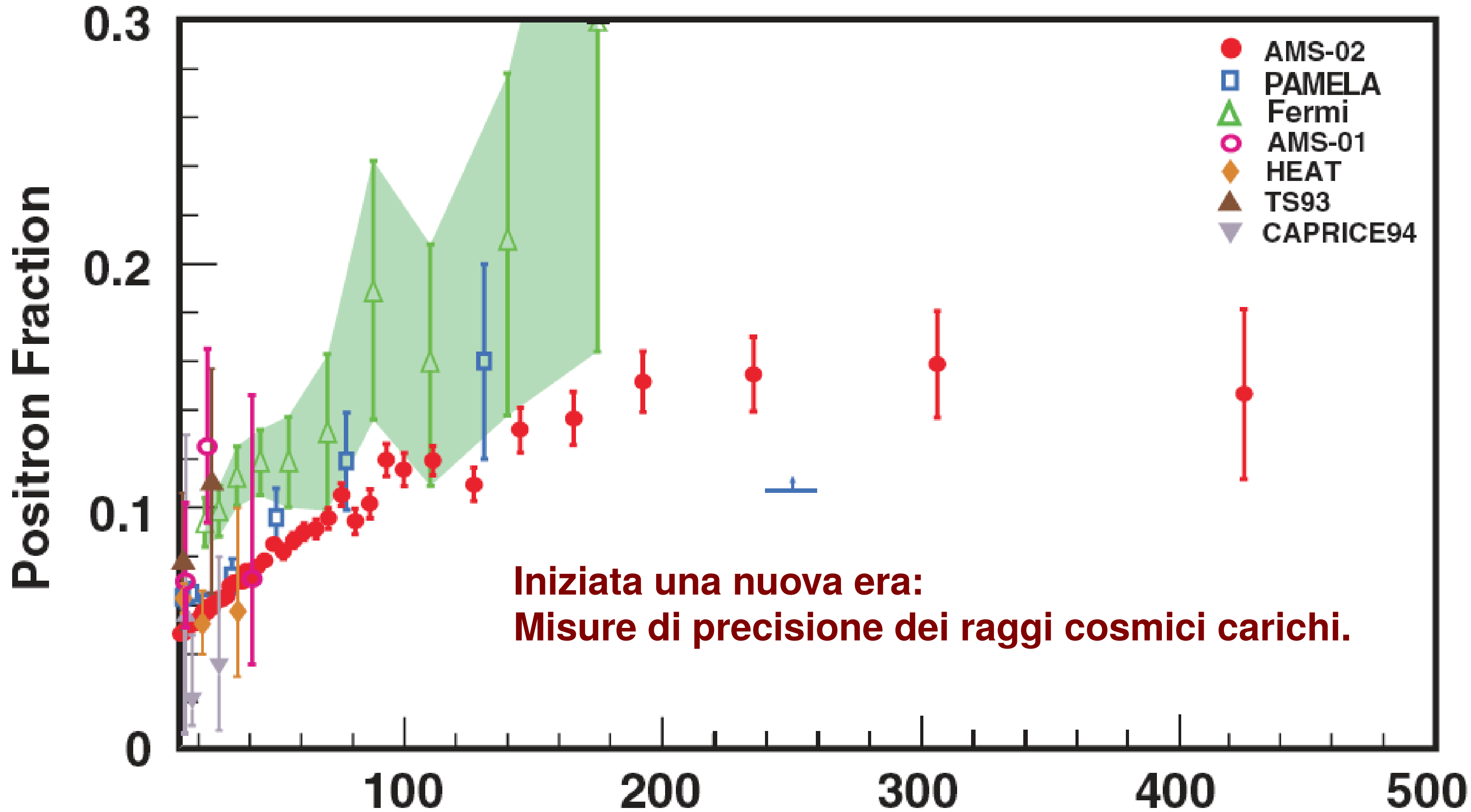
Frazione di Positroni : $e^+/(e^+ + e^-)$





No fine structures are observed, no anisotropies, slope suggests a maximum?

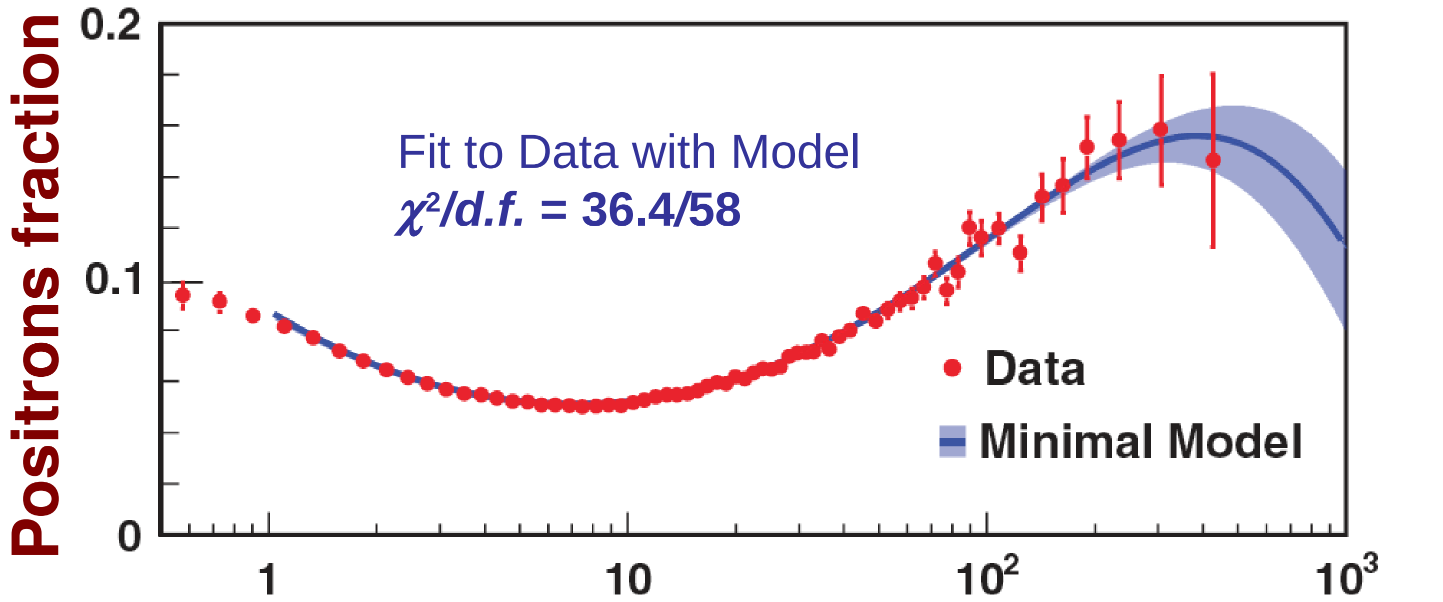
Frazione di Positroni ad alta energia



Iniziata una nuova era:
Misure di precisione dei raggi cosmici carichi.

$e^{\pm}$ energy (GeV)

Modello empirico minimale



Describe electron and positron fluxes as a sum of a **diffuse component** and a **common source** with a cutoff energy :

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$\gamma_{e-} - \gamma_{e+} = -0.56 \pm 0.03$

$\gamma_{e-} - \gamma_{S} = 0.72 \pm 0.04$

$C_{e+}/C_{e-} = 0.091 \pm 0.001$

$C_S/C_{e-} = 0.0061 \pm 0.0009$

$1/E_s = 1.84 \pm 0.58\ \text{TeV}^{-1}$

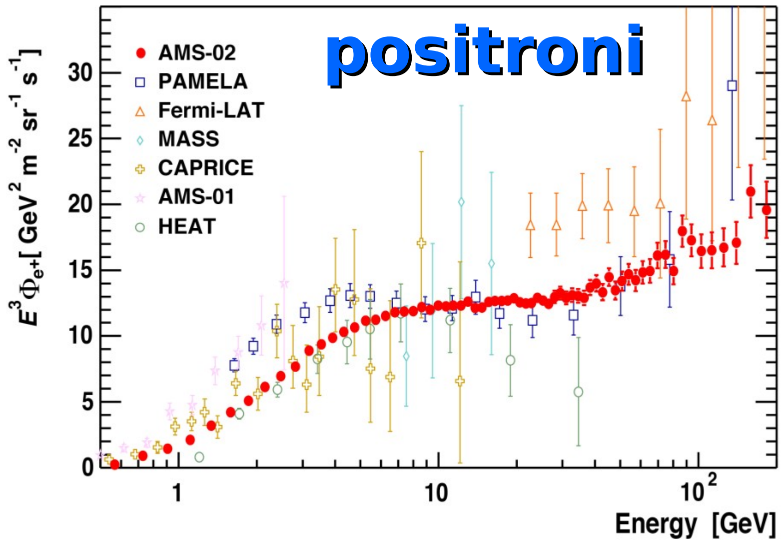
Origine fisica del termine di sorgente?

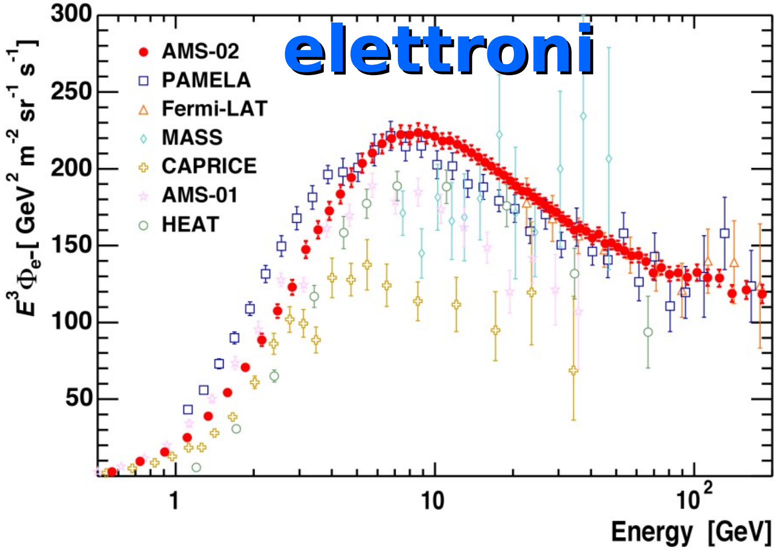
1) **Particle origin: Dark Matter**
2) **Astrophysics origin: Pulsars, SNRs**
3) **Secondaries: peculiarities of propagation**

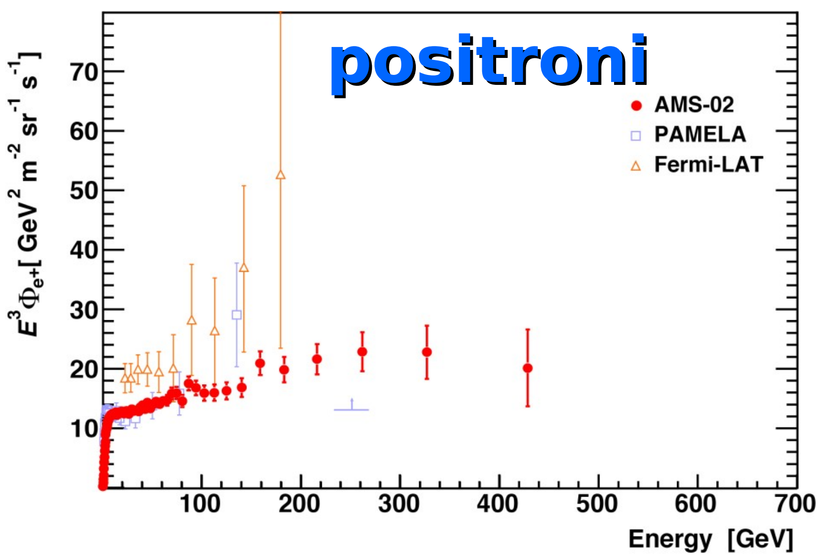
>300 references to the first AMS publication in 22 months..

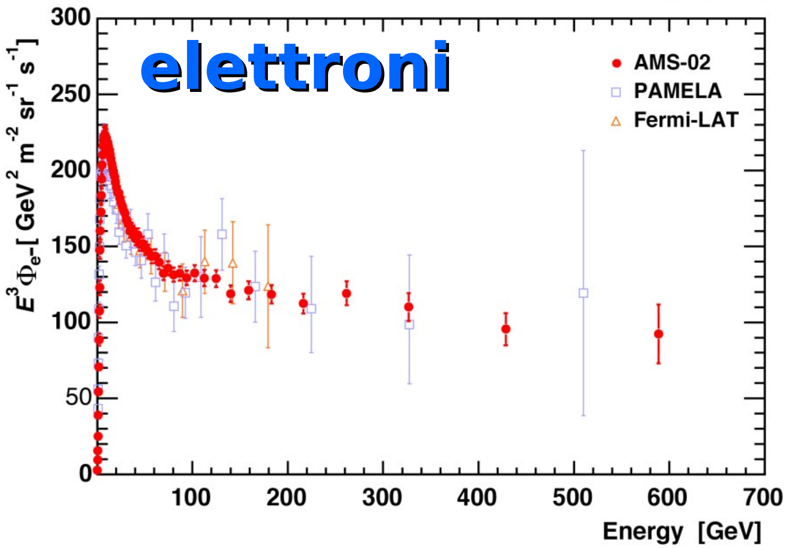
Presentazione: N. Masi @ IFAE2015
"*Interpretazione dei dati leptonici e nucleari di AMS-02: implicazioni e prospettive per la ricerca di materia oscura*"

Flussi di elettroni e positroni

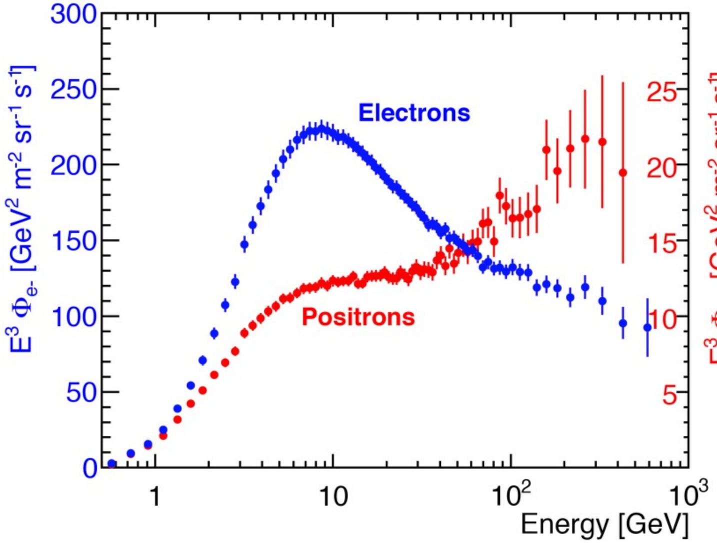


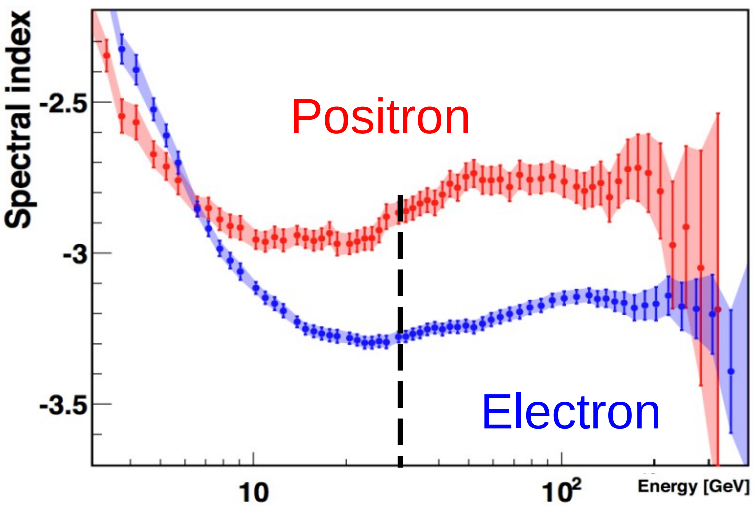






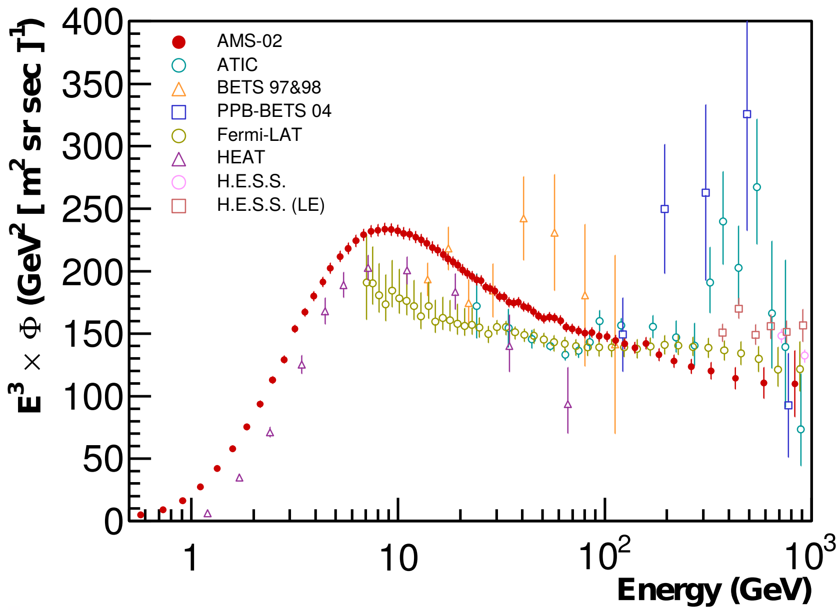
Flussi di elettroni e positroni

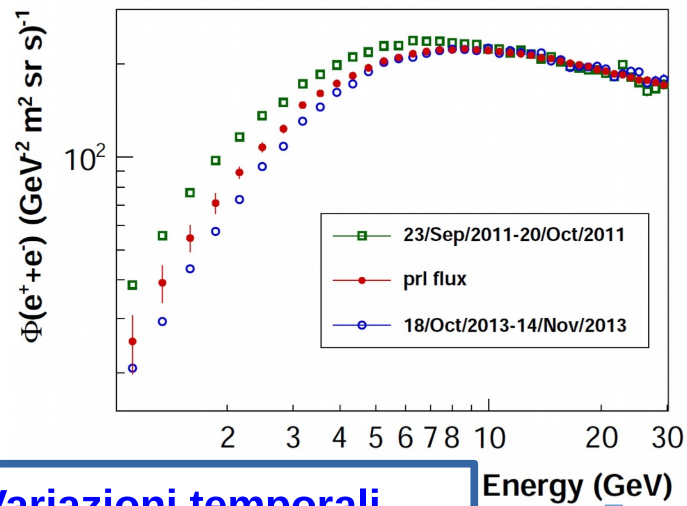




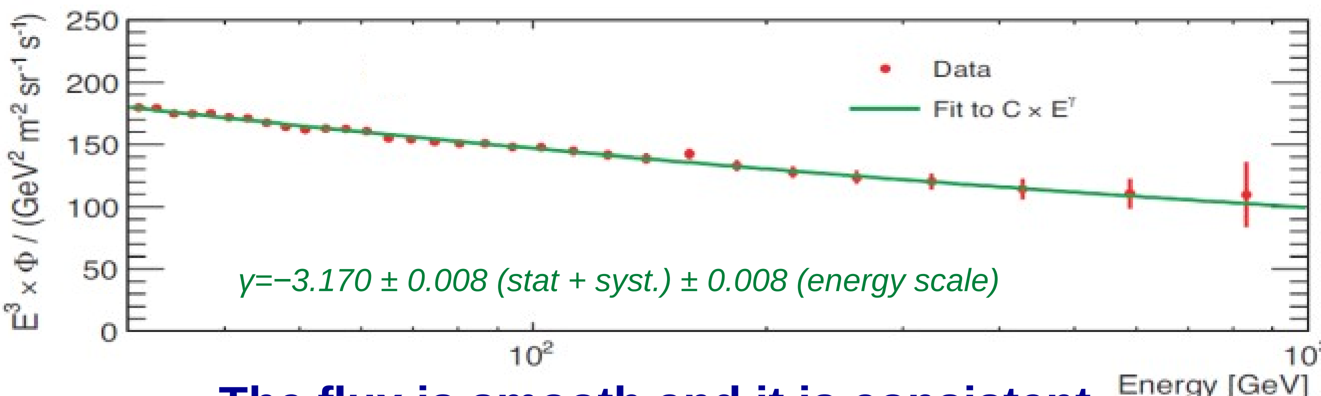
1. Both the electron flux and the positron flux **are significantly different in their magnitude and energy dependence**.
2. Both spectra **cannot be described by single power laws**.
3. The **spectral indices** of electrons and positrons **are different**.
4. Both change their behavior at ~**30GeV**.
5. The **rise in the positron fraction** from 20 GeV **is due to an excess of positrons**, not the loss of electrons (the positron flux is harder).

Il flusso somma ($e^+ + e^-$)





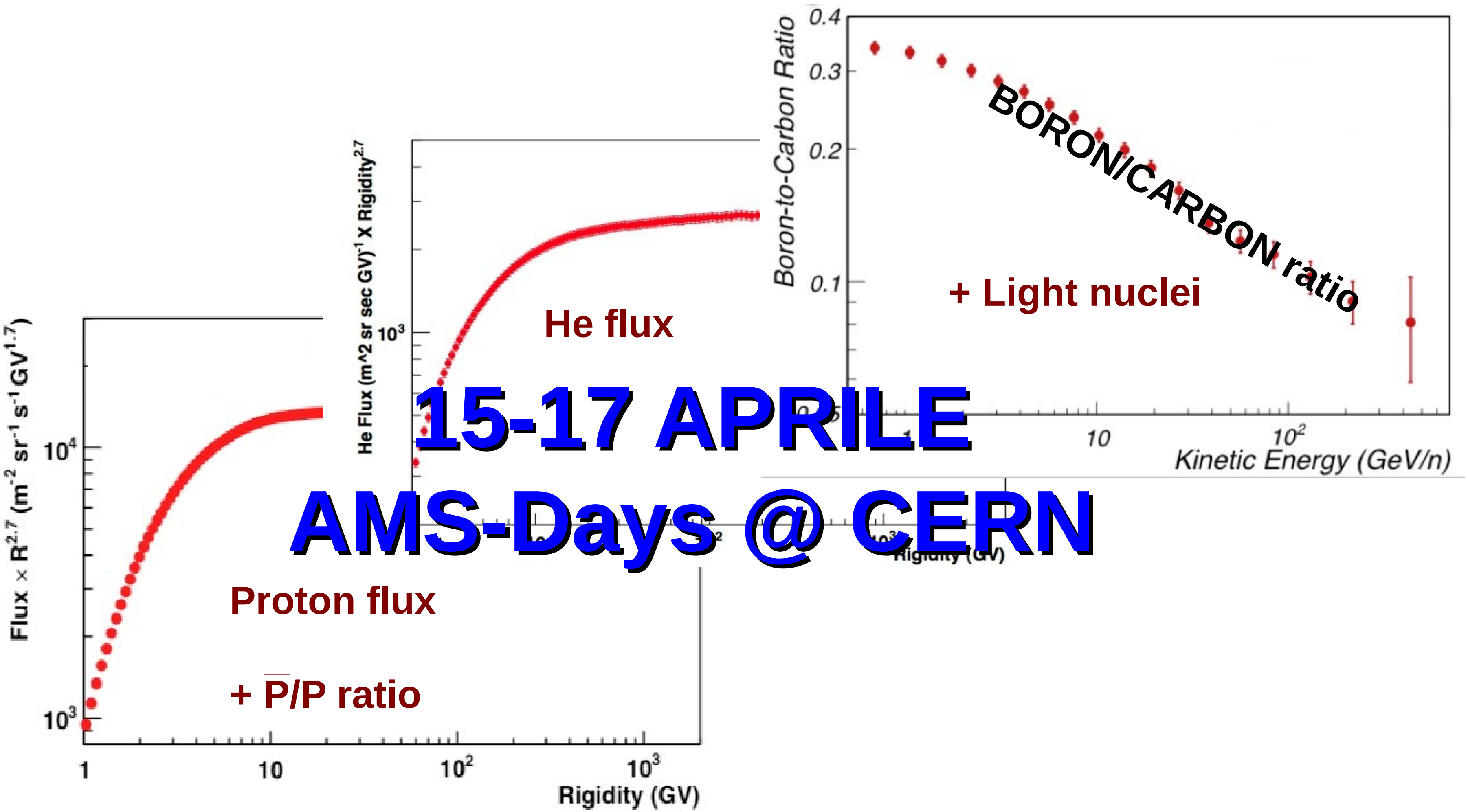
Variazioni temporali
→ Modulazione Solare



Sessione POSTER
M. Crispoltoni:
"Tecniche di analisi sviluppate per la misura della variazione del flusso di e+,e- nel tempo con AMS-02"

The flux is smooth and it is consistent with a single power law above 30 GeV.

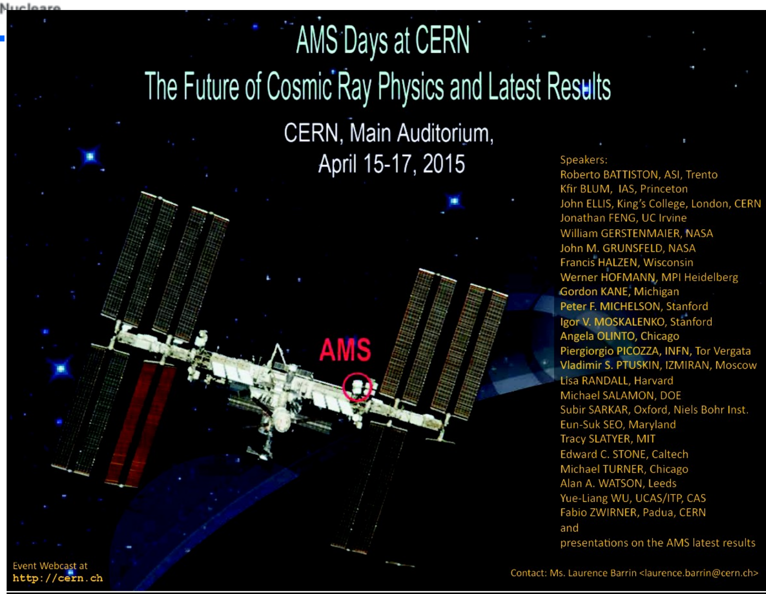
Stay tuned!

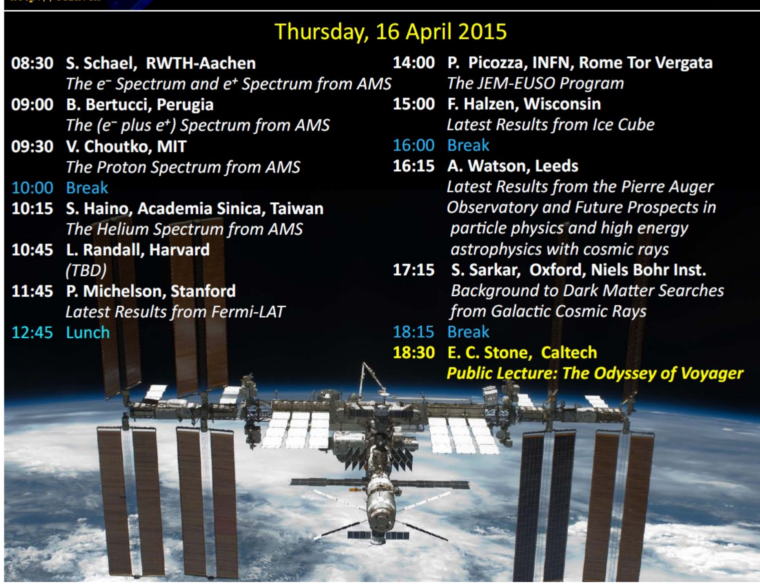


15-17 APRILE

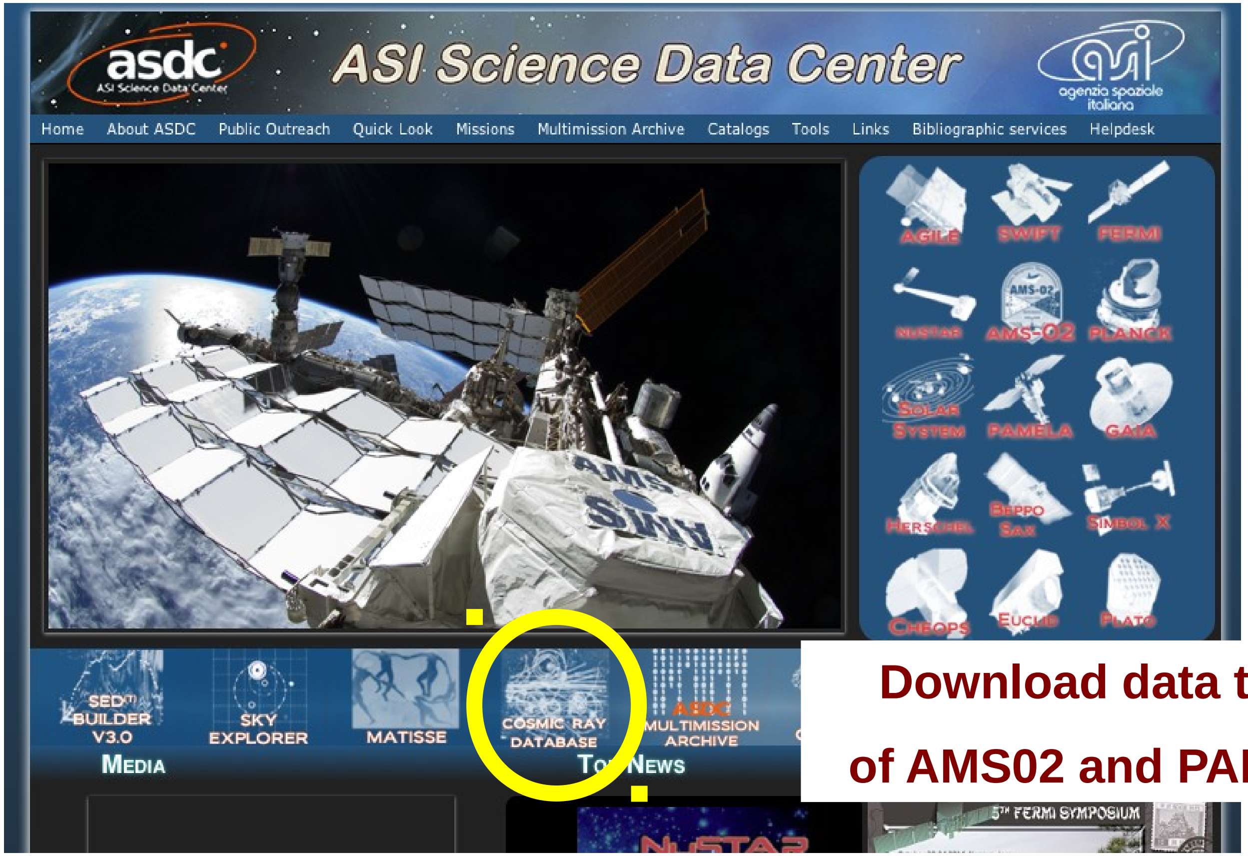
AMS-Days @ CERN

15-17 aprile AMS-Days @ CERN



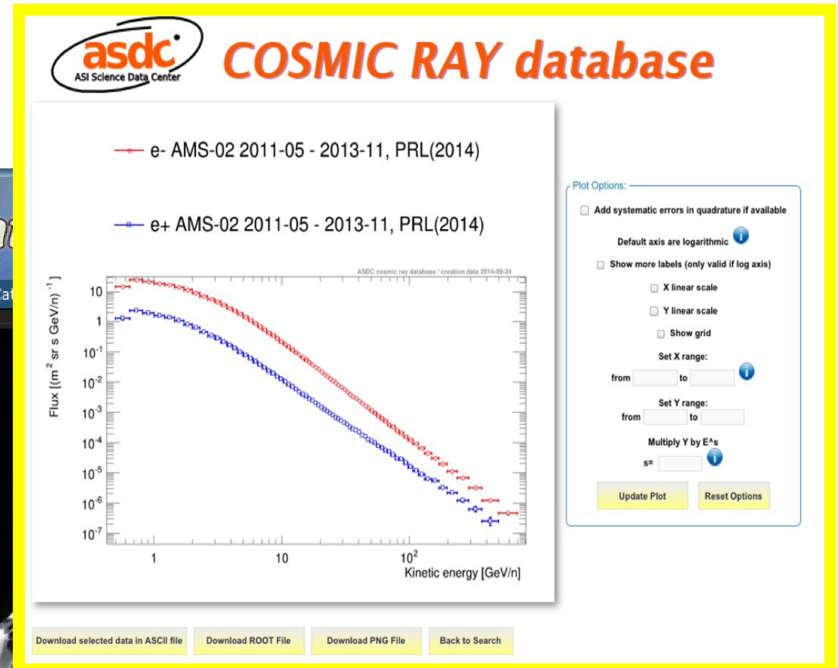


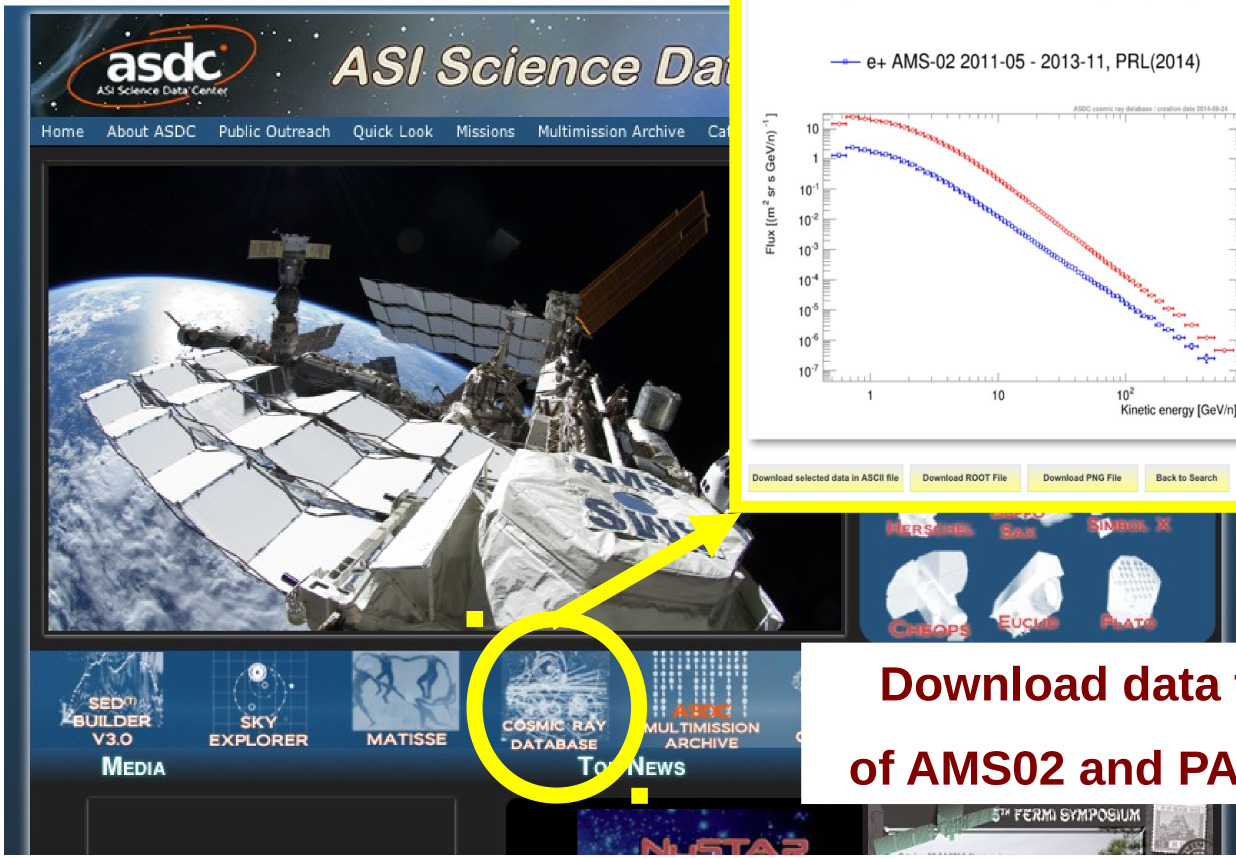
www.asdc.asi.it



Download data tables & ROOT files of AMS02 and PAMELA published data

www.asdc.asi.it



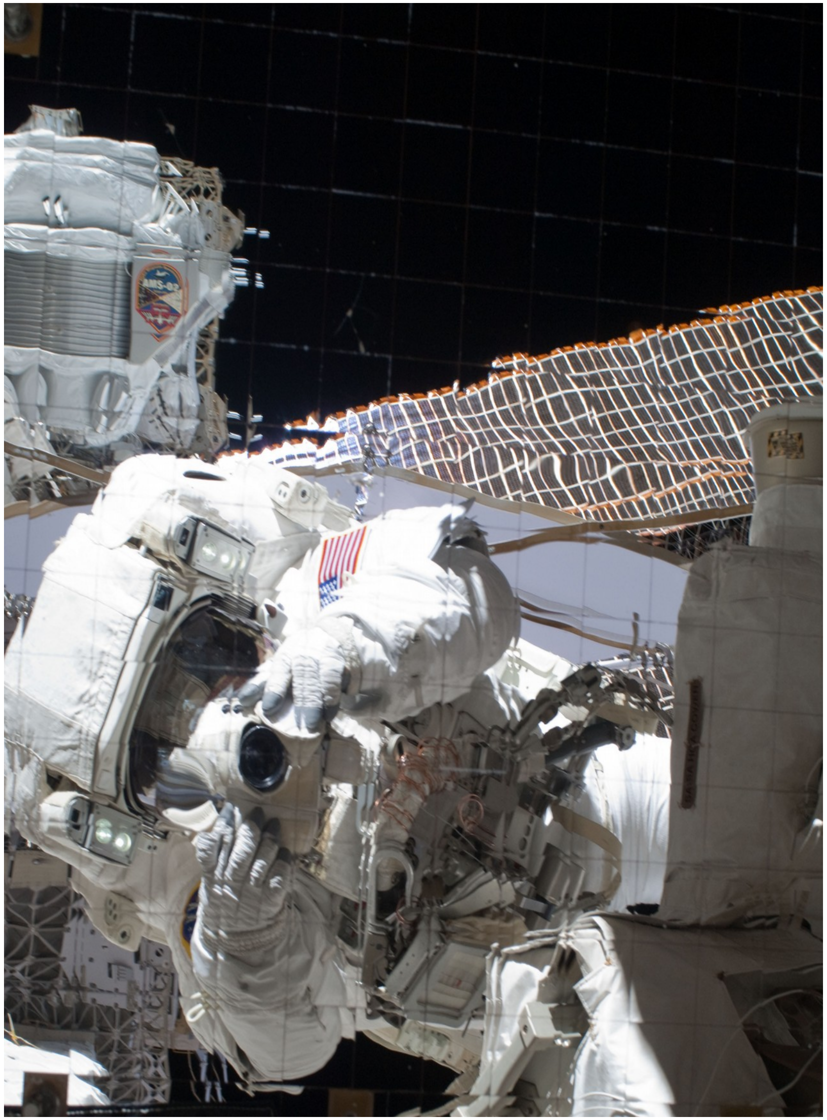


Download data tables & ROOT files

of AMS02 and PAMELA published data

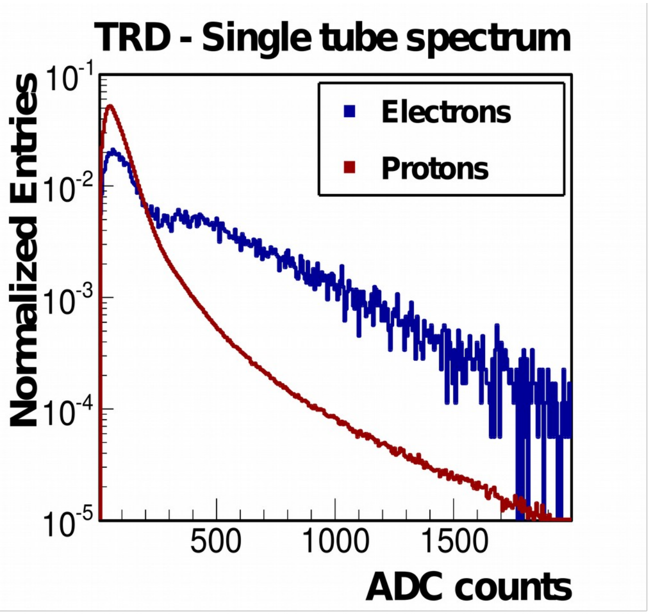
Conclusioni

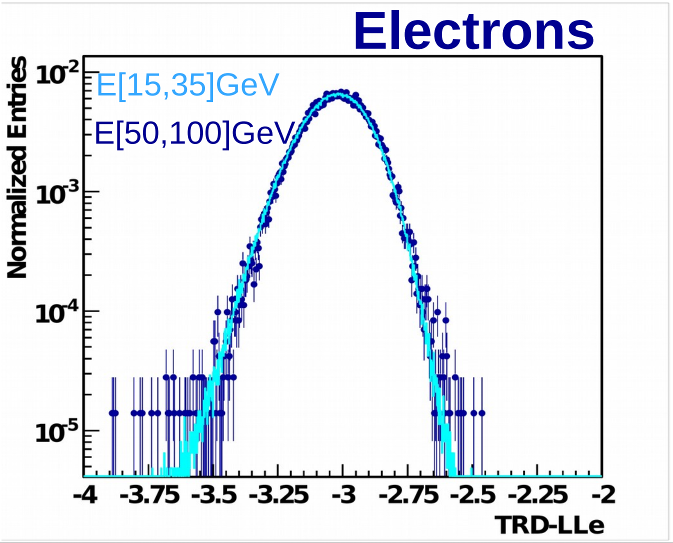
- **AMS02 è il più grande spettrometro che opera nello spazio**
- **Progettato per raccogliere dati per l'intera vita della ISS**
- **4 anni di presa dati: 60 Miliardi di eventi raccolti**
- **Misure di precisione fino alla scala dei TeV**
- **Evidenza di una sorgente esotica nel flusso dei positroni le cui caratteristiche sono misurate per la prima volta con precisione**
- **Sorgente astrofisica o evidenza di materia oscura?**
- **Nuovi risultati stanno arrivando!**

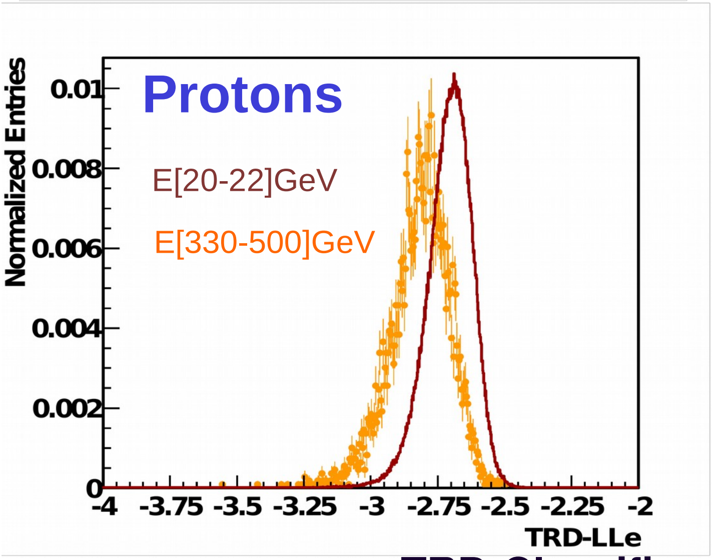


Stay tuned!

distribuzione TRD indipendente da E







TRD-Classifier

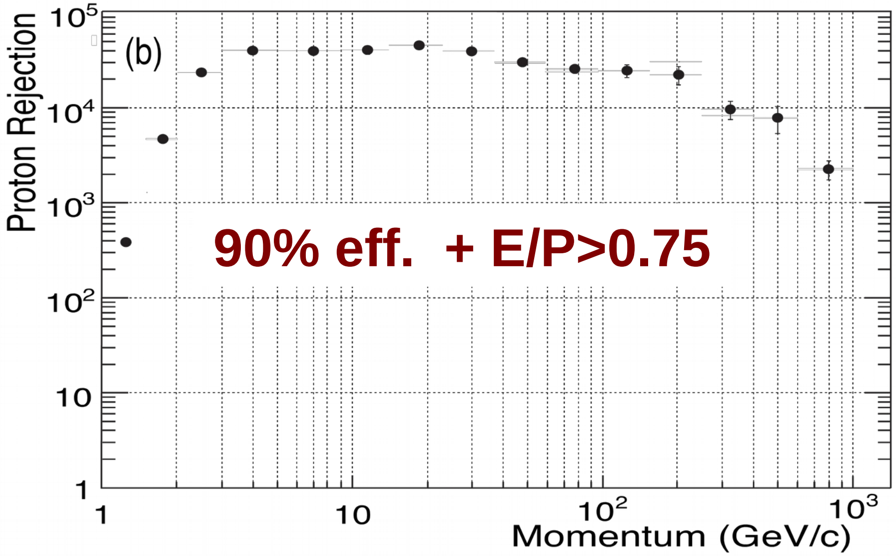
Combined Probability to be electron :

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

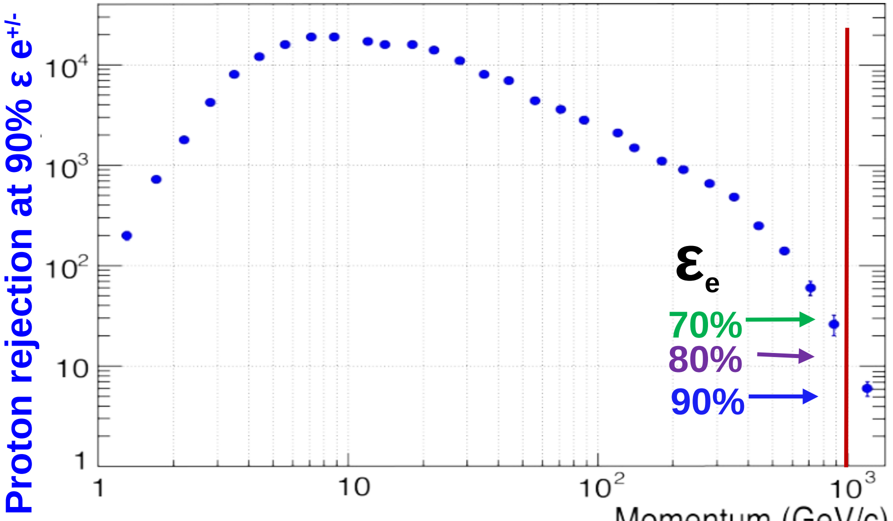
TRD-Classifier = $Log_{10}(P_e)$

P rejection

Ecal BDT Classifier

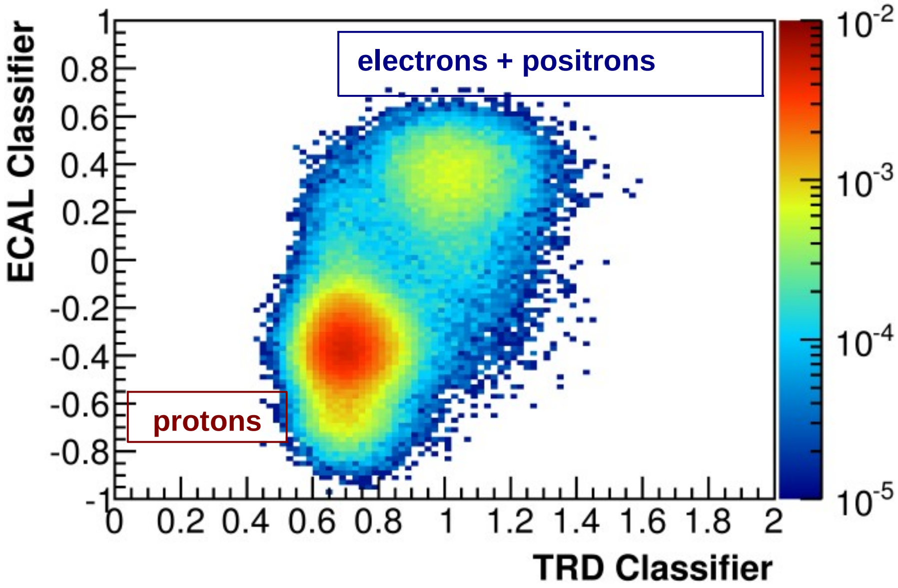


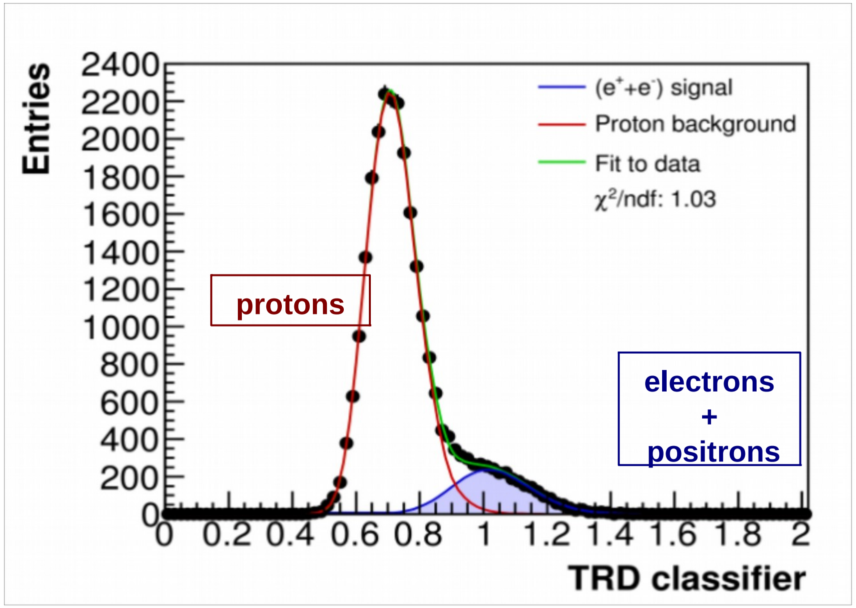
TRD Classifier



1D fit to measure N_e and N_p

Reference spectra for the signal and the background are fitted to data as a function of the TRD classifier for different cuts on the ECAL BDT estimator

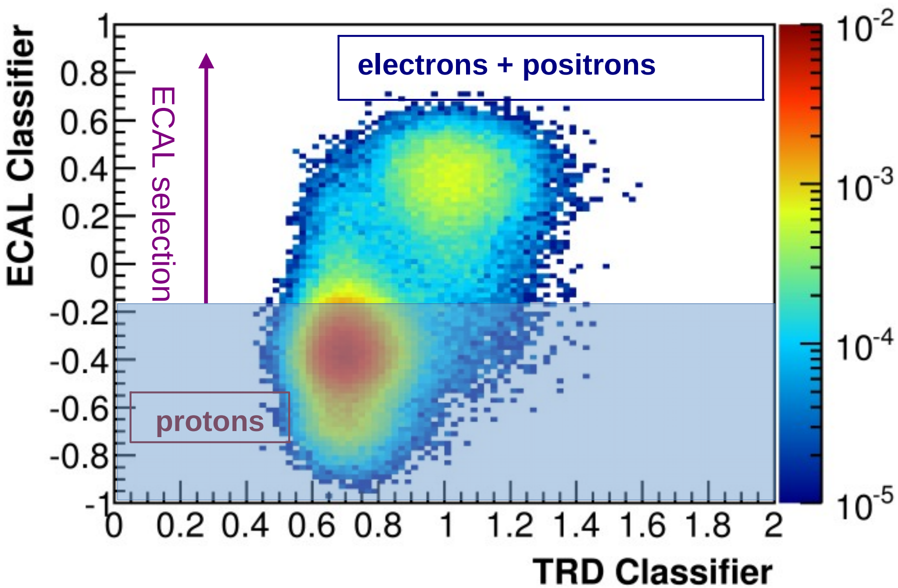


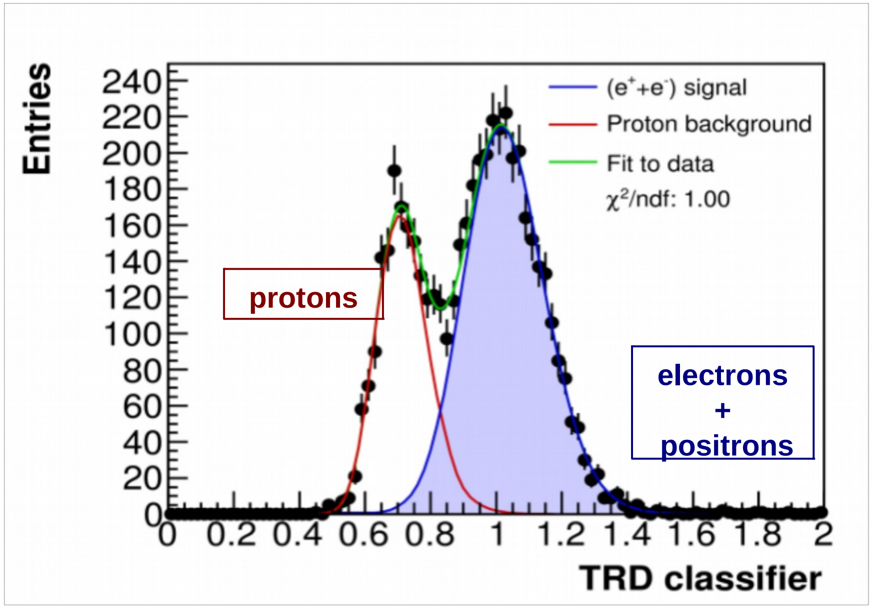


Measurement is performed for the BDT cut that minimizes the overall statistical + systematic uncertainty (→ ε_{BDT})

1D fit to measure N_e and N_p

Reference spectra for the signal and the background are fitted to data as a function of the TRD classifier for different cuts on the ECAL BDT estimator



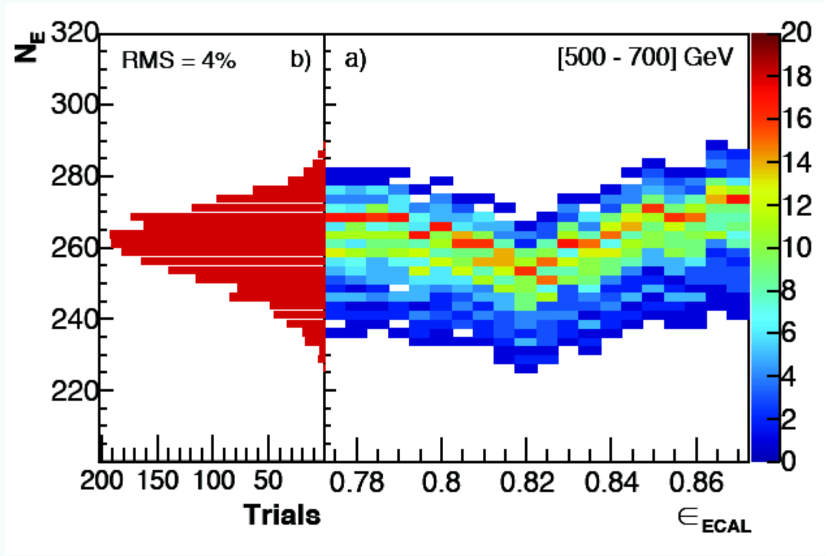


Measurement is performed for the BDT cut that minimizes the overall statistical + systematic uncertainty (→ ε_{BDT})

Stabilità del segnale

Dominating systematic uncertainties on $N_{e^{+}+e^{-}}$

- **Knowledge of the TRD reference distributions**
- **Stability of the fit result for different background levels, e.g. ECAL classifier cuts**



The analysis was repeated 2000 times in each energy bin varying the ECAL estimator cut and different values of selection cuts used to construct the templates and the stability of the results verified within a 5% window in ECAL estimator cut efficiency

Data Analysis

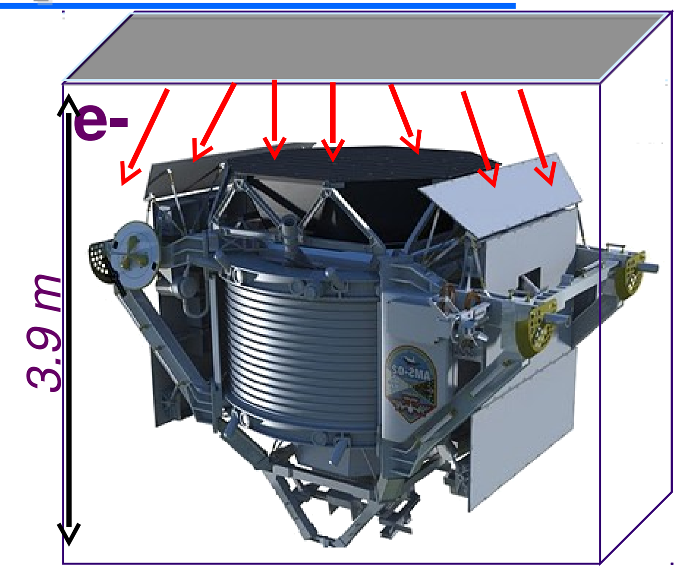
$$\mathbf{\Phi}(E, E+\Delta E) = \frac{\mathbf{N}(E, E+\Delta E)}{\mathbf{\Delta E}\,\mathbf{A}(E)\,\epsilon_{\mathbf{trig}}\,\mathbf{\Delta T}}$$

- ✓ Event Selection
- ✓ Energy measurement
- ✓ Exposure Time
- → Detector acceptance
- → Trigger efficiency

Detector Acceptance

Estimated with MC (Geant 4)

$$A_{eff}(E) = A_{generated} \times \frac{N_{selected}(E)}{N_{generated}(E)}$$

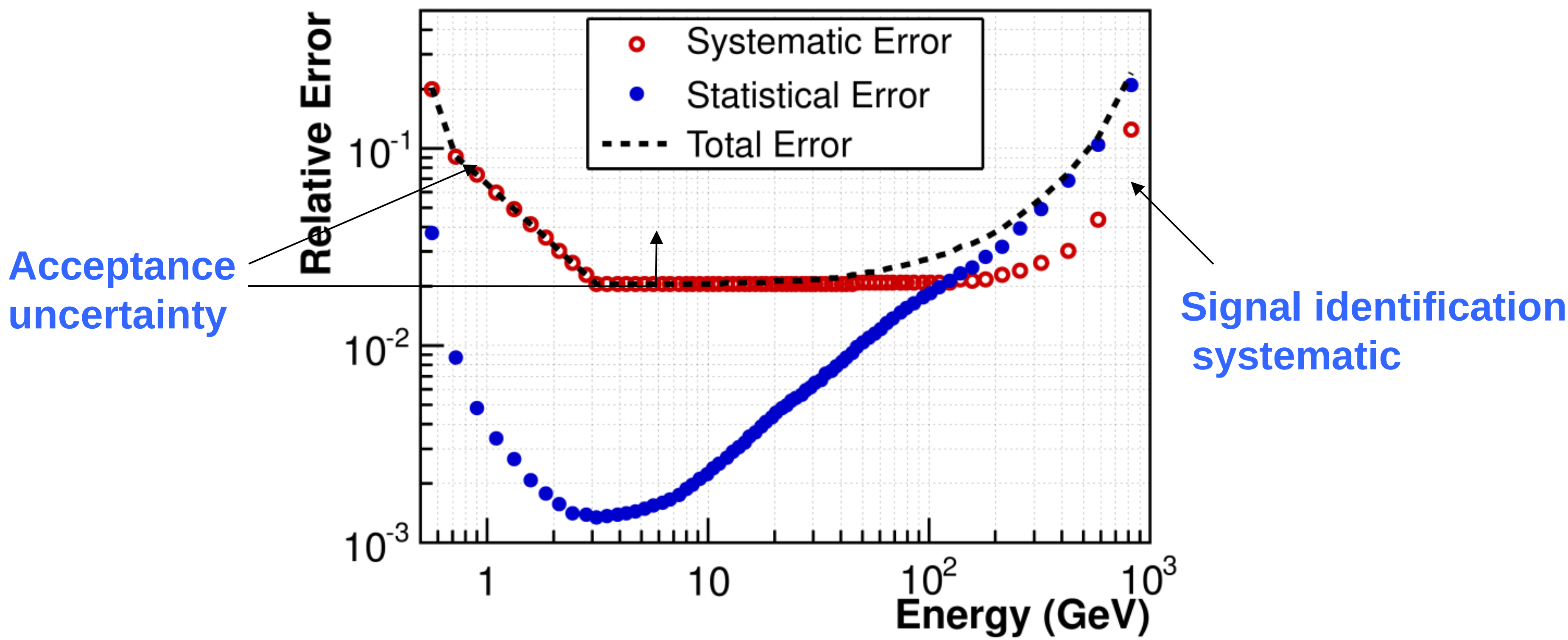


$A_{generated}$ = acceptance of the generation surface
$N_{selected}$ = events passing through active volume of TRD,TOF,TRK,ECAL ($A_{geom} \approx$ 550 $cm^2 sr$) and satisfying selection criteria ($\varepsilon_{sel} \approx$70-90%)

$$A_{\text{eff}} = A_{\text{geom}} \cdot \epsilon_{\text{sel}} \cdot (1 + \delta)$$

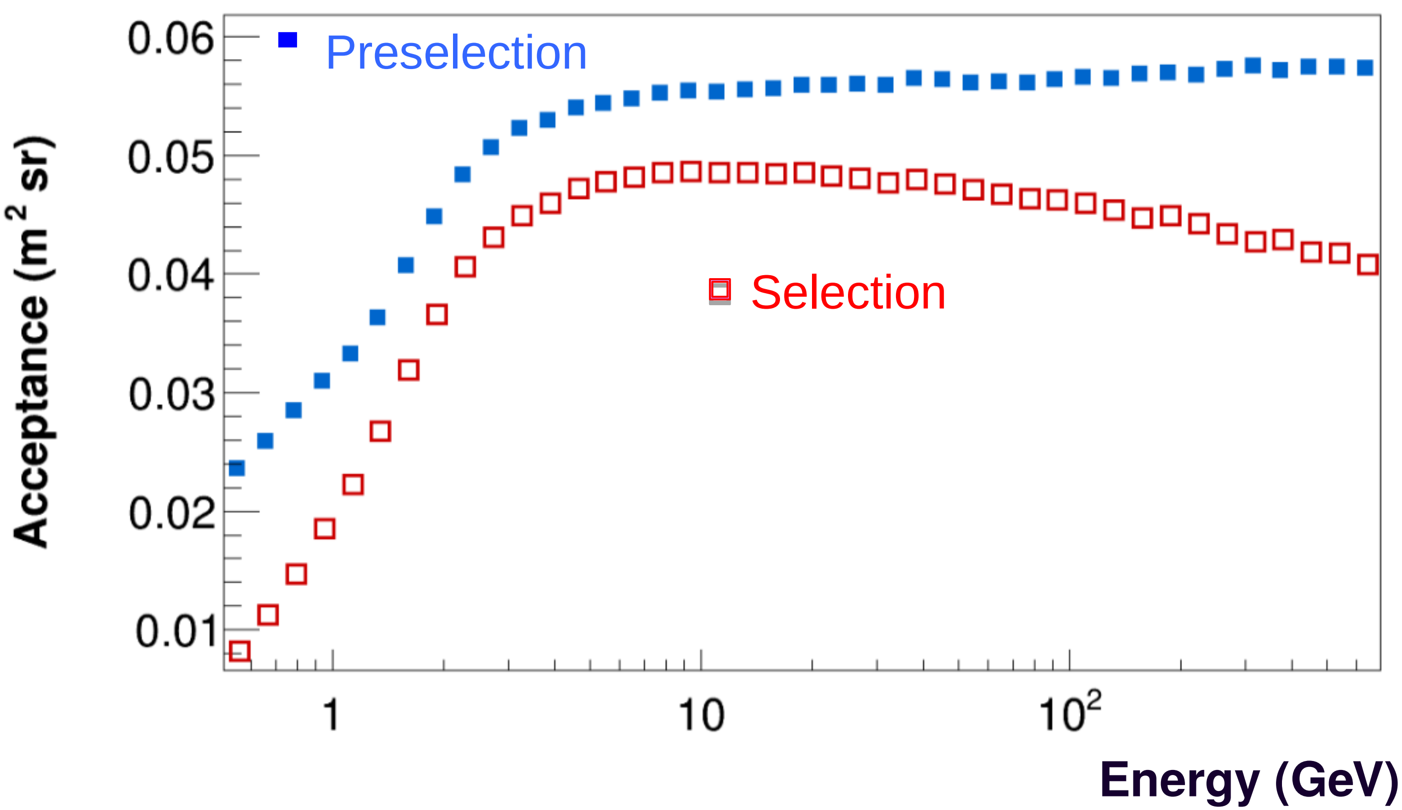
δ = data derived correction (-4%@2GeV, -3%@1TeV)

Measurement Error



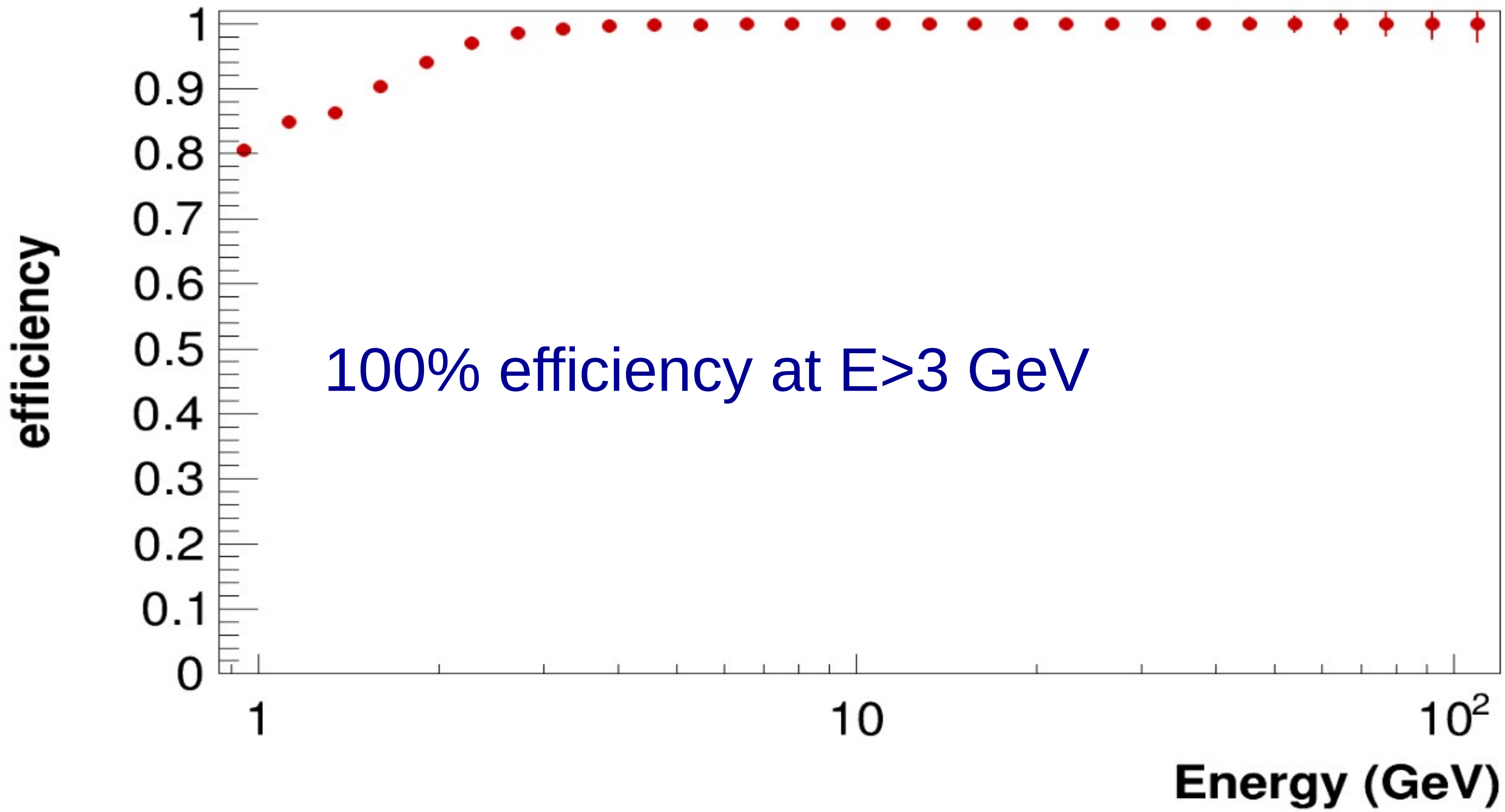
- Measurement error dominated by the acceptance systematic below 100 GeV
- Statistical fluctuation dominates the error above 200 GeV

The Acceptance



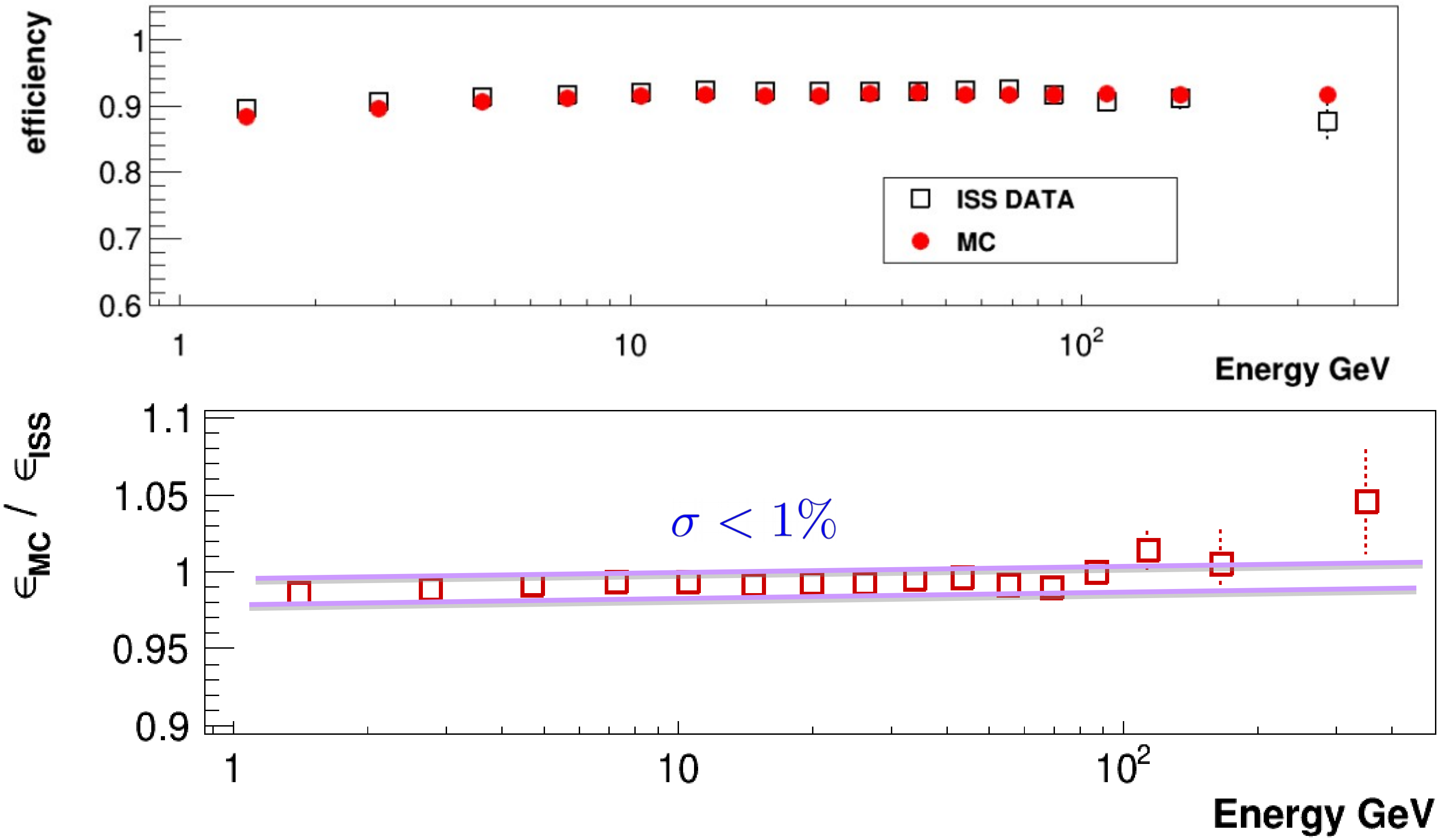
Trigger Efficiency

Determined with ISS data using with unbias trigger (pre-scaled by 1/100)



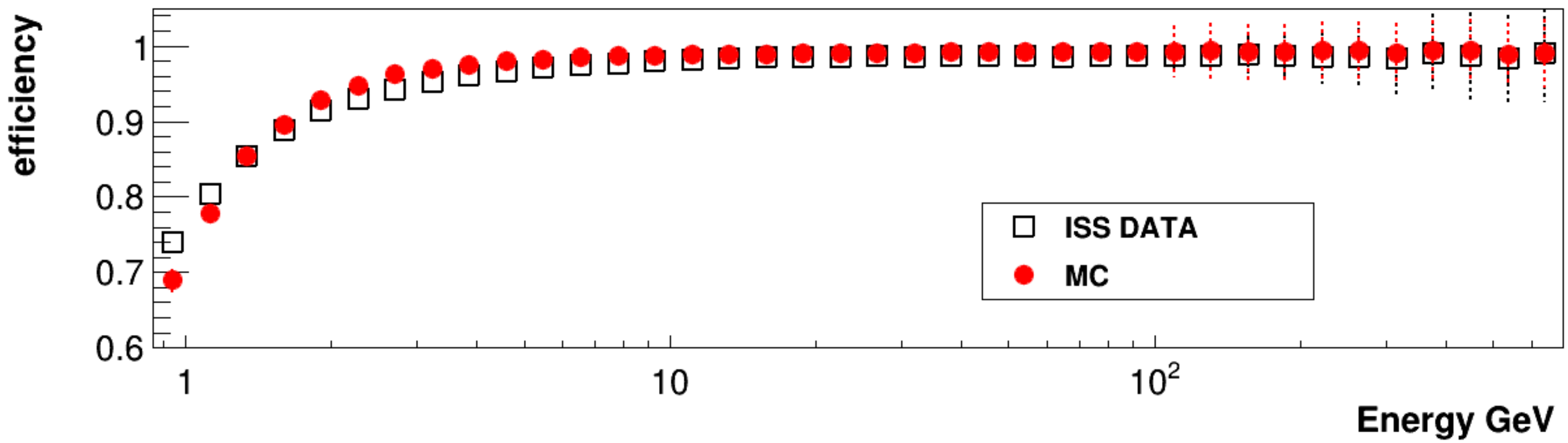
The Tracker Efficiency

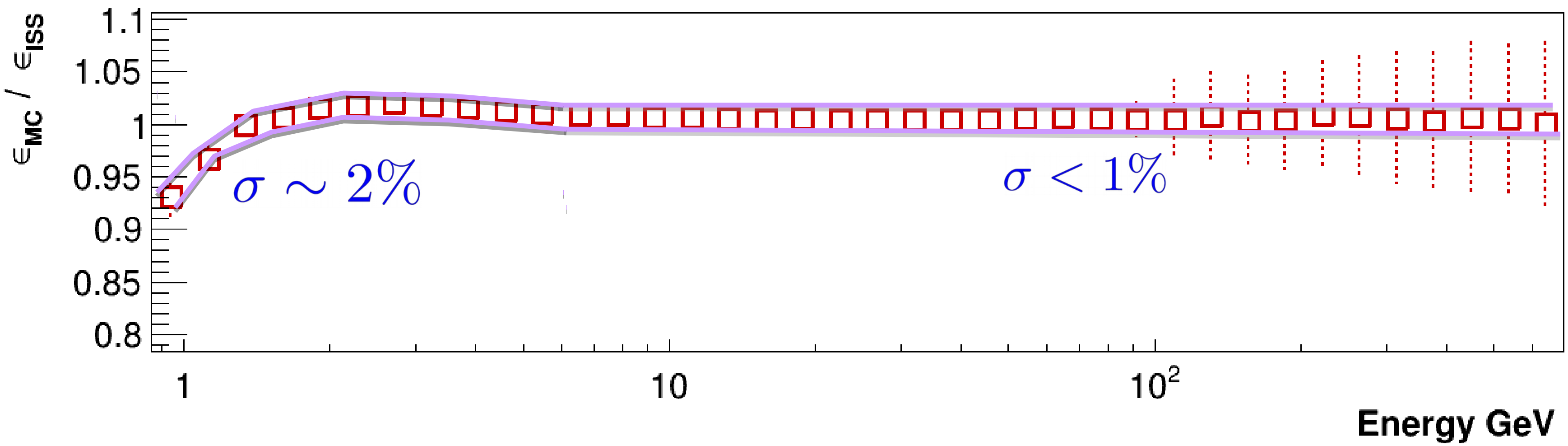
Track reconstruction: $\dfrac{\text{\# of electrons with a track}}{\text{\# of electrons passing through TRK acceptance}}$



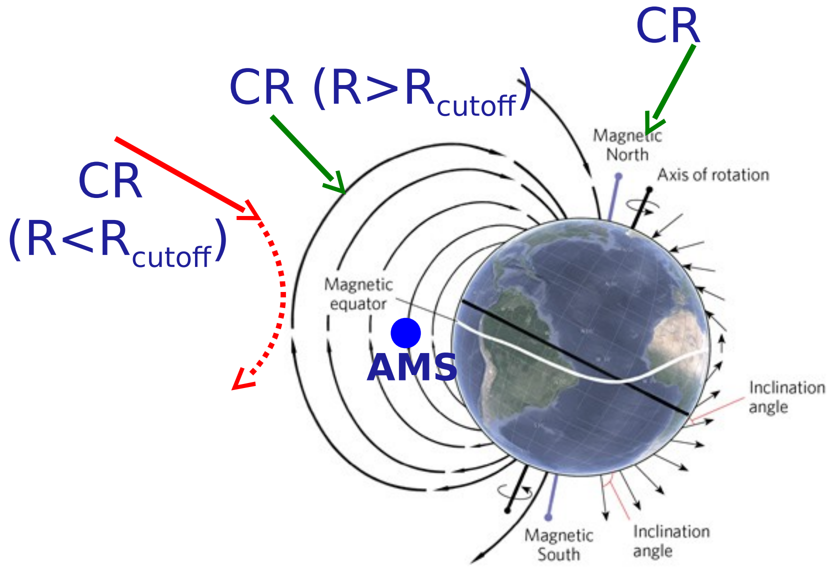
The TRD efficiency

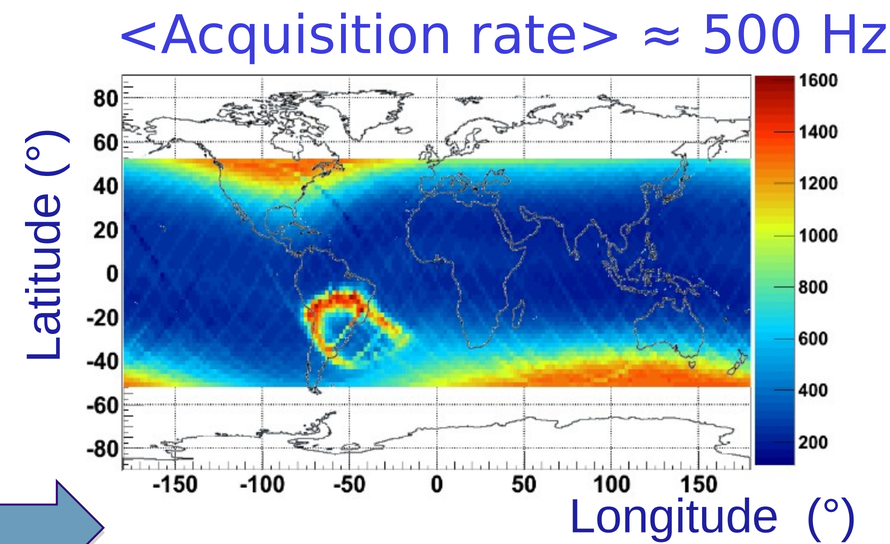
≥ 8 TRD hits used in the estimator

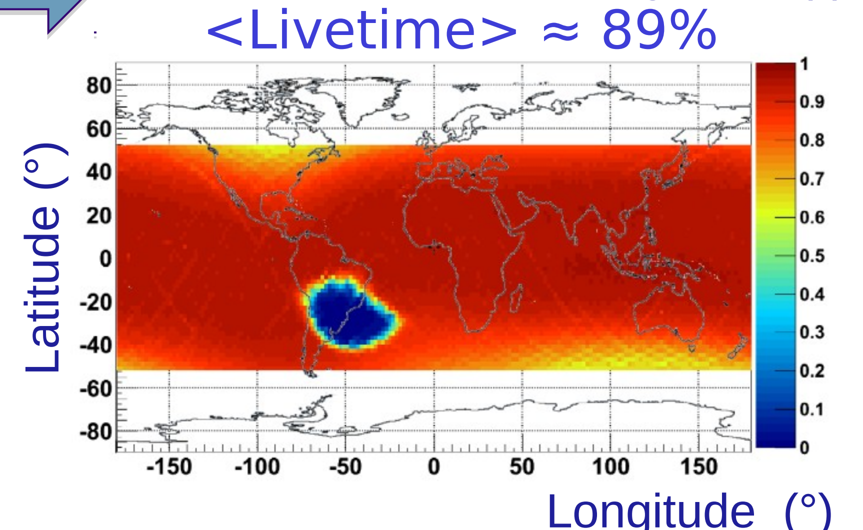




Exposure time: geomagnetic effects





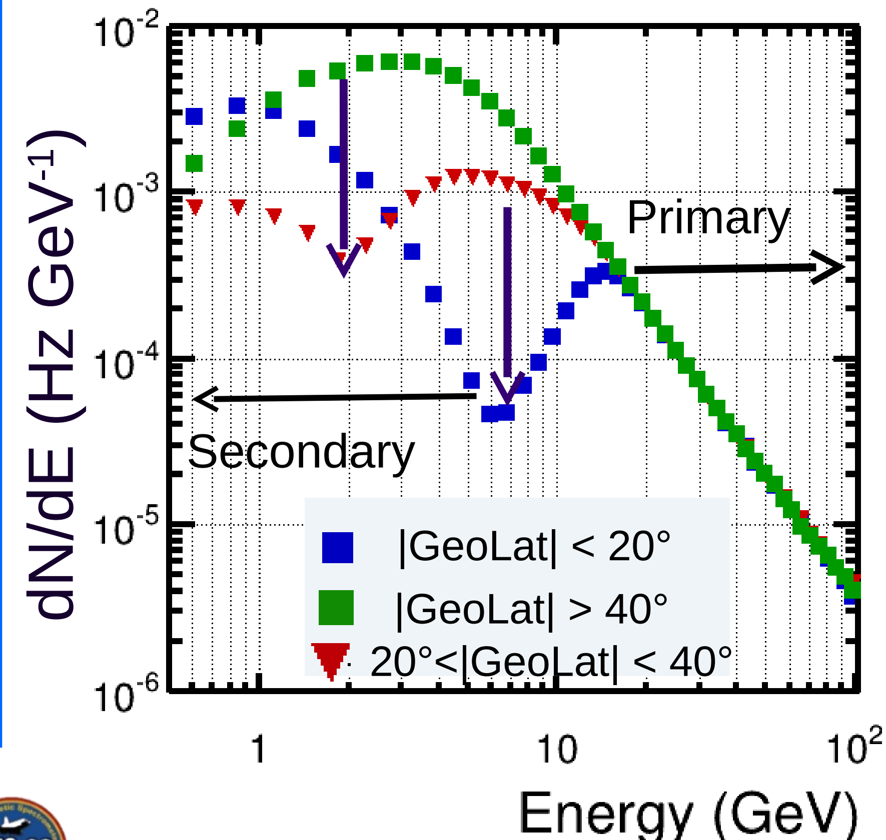


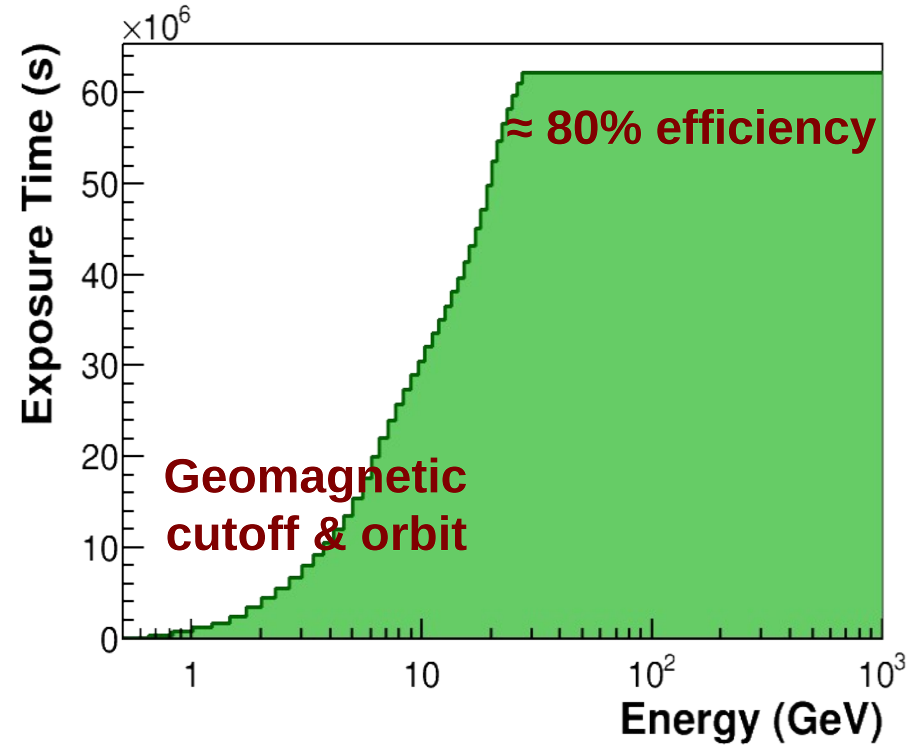
Effect on data taking:

-**Reduced livetime**: in South Atlantic Anomaly region and close to geomagnetic poles.

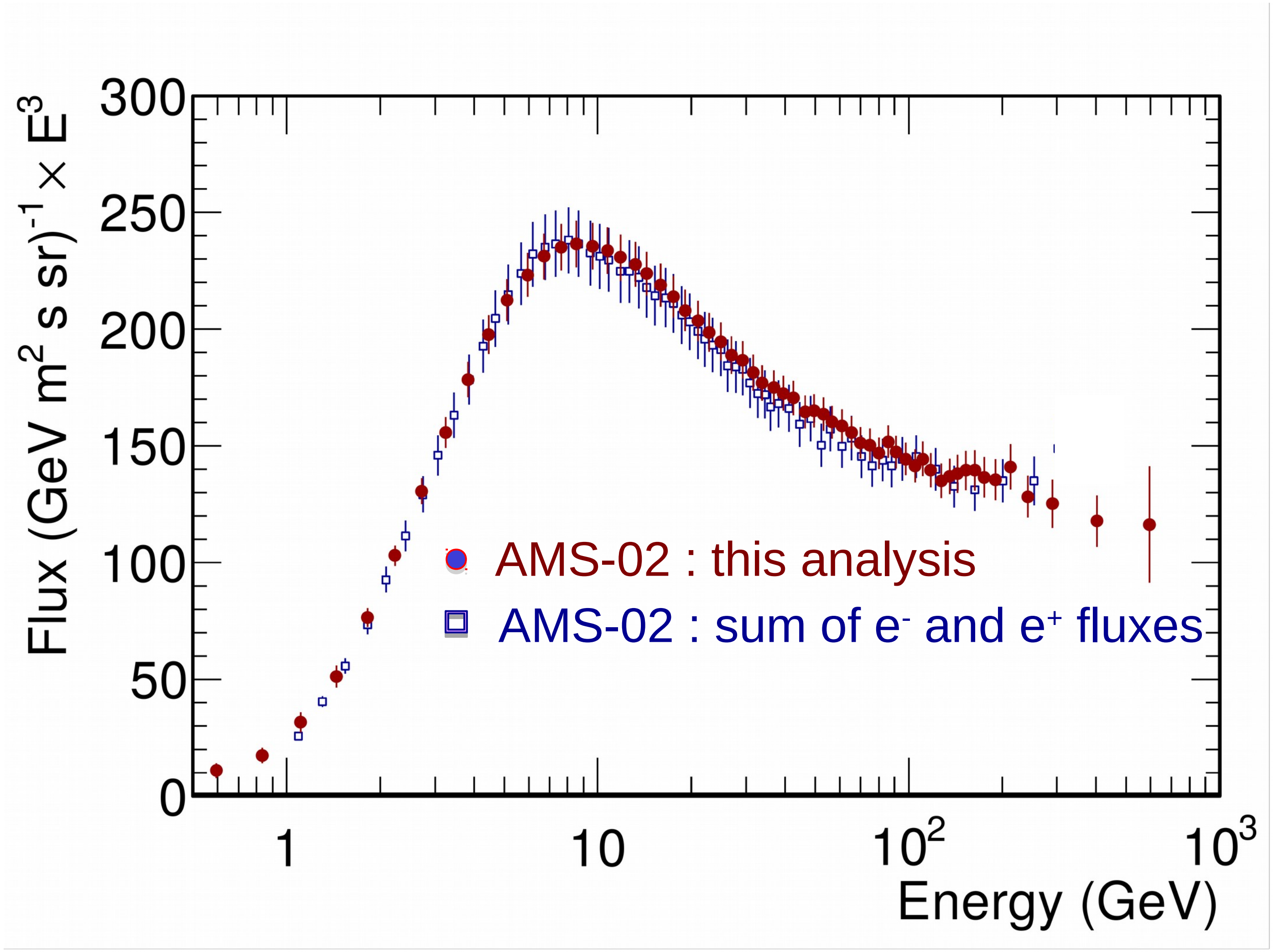
Exposure time

The exposure time to a given energy along the orbit is performed only considering the time spent in the regions where the rigidity cutoff used in the event selection is lower than the energy.



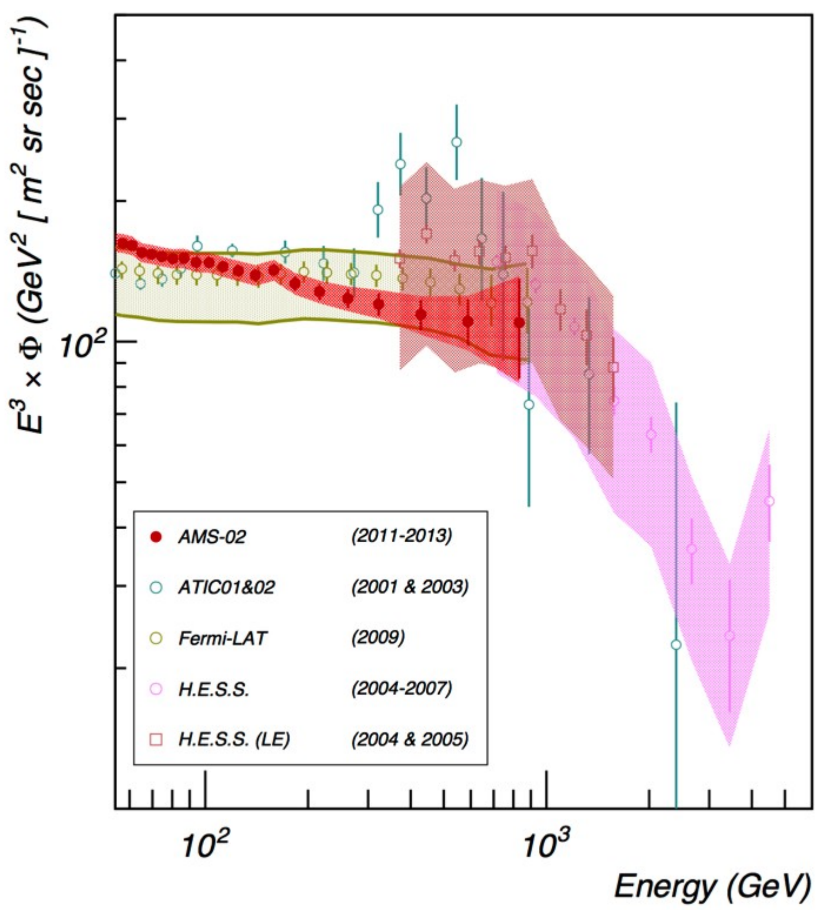


The (e^- +e^+) flux : AMS independent measurements



$e^+ + e^-$ flux measurements with AMS

..Taking into account also the knowledge of the energy scale….



EXAMPLE:

Minimal Model Fit to the data

Diffuse Flux — Source Flux

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Simultaneous fit to

- **a) Positron Fraction from 2GeV**
- **b) Electron + Positron from 2GeV**

- **$(\gamma_{e-} - \gamma_{e+})$, $(\gamma_{e-} - \gamma_s)$, C_{e+}, C_{e-}, C_s, E_s are constant**
- **γ_{e-} is energy dependent below ~15 GeV.**

Minimal Model:

Diffuse Flux | Source Flux

$$\Phi_{e+} = C_{e+}E^{-\gamma_{e+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e-} = C_{e-}E^{-\gamma_{e-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Fit to a) Positron Fraction from 2 GeV determines the relations:

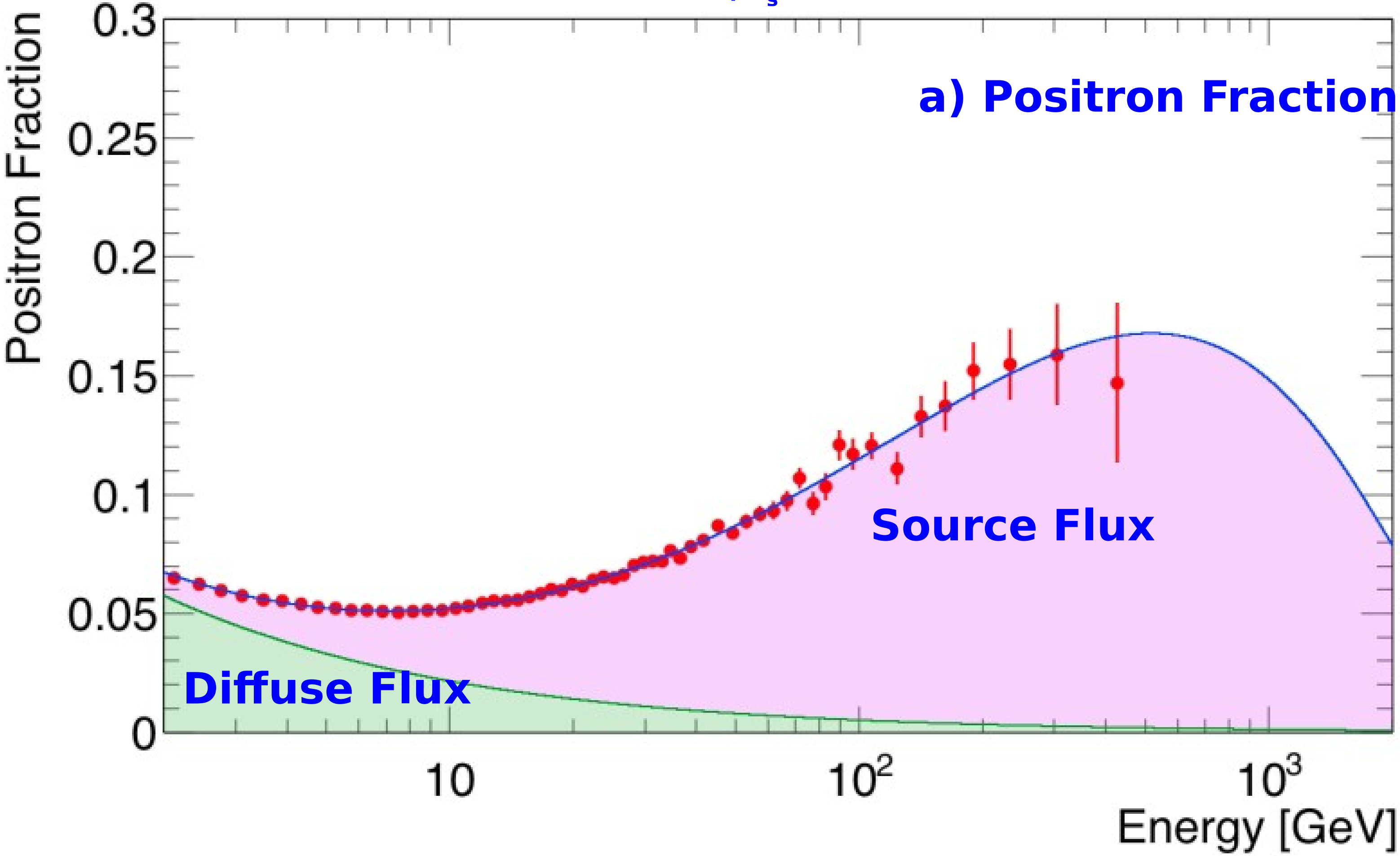
$\gamma_{e-} - \gamma_{e+} = -0.63 \pm 0.06$,

$\gamma_{e-} - \gamma_s = 0.66 \pm 0.05$,

$C_{e+} / C_{e-} = 0.095 \pm 0.003$,

$C_s / C_{e-} = 0.008 \pm 0.001$

$1/E_s = 1.3 \pm 0.6$ TeV^{-1}



Minimal Model:

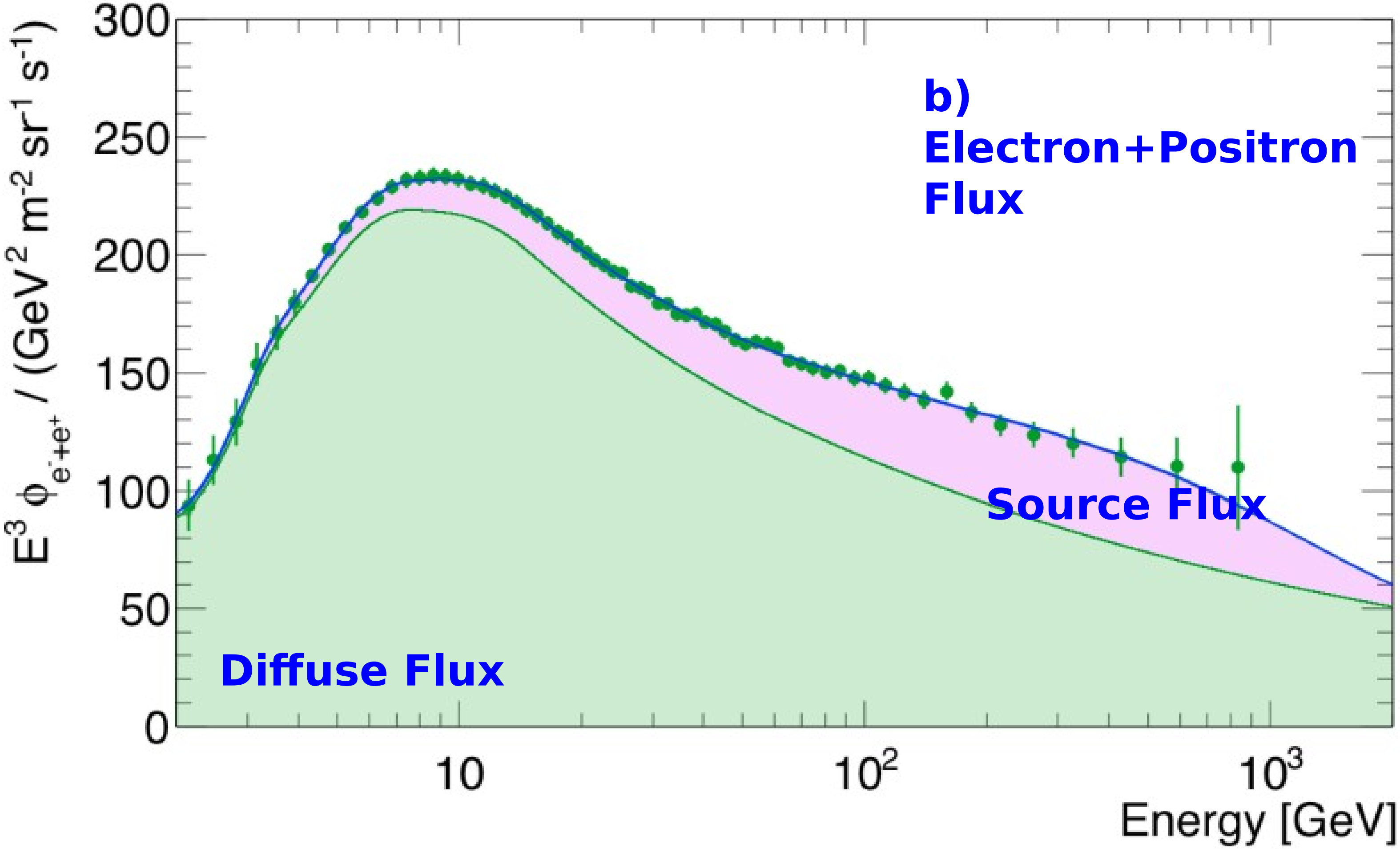
Diffuse Flux | Source Flux

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Fit to b) Electron + Positron Flux from 2 GeV determines γ_{e-} and C_{e-}

γ_{e-} is energy dependent below ~15 GeV



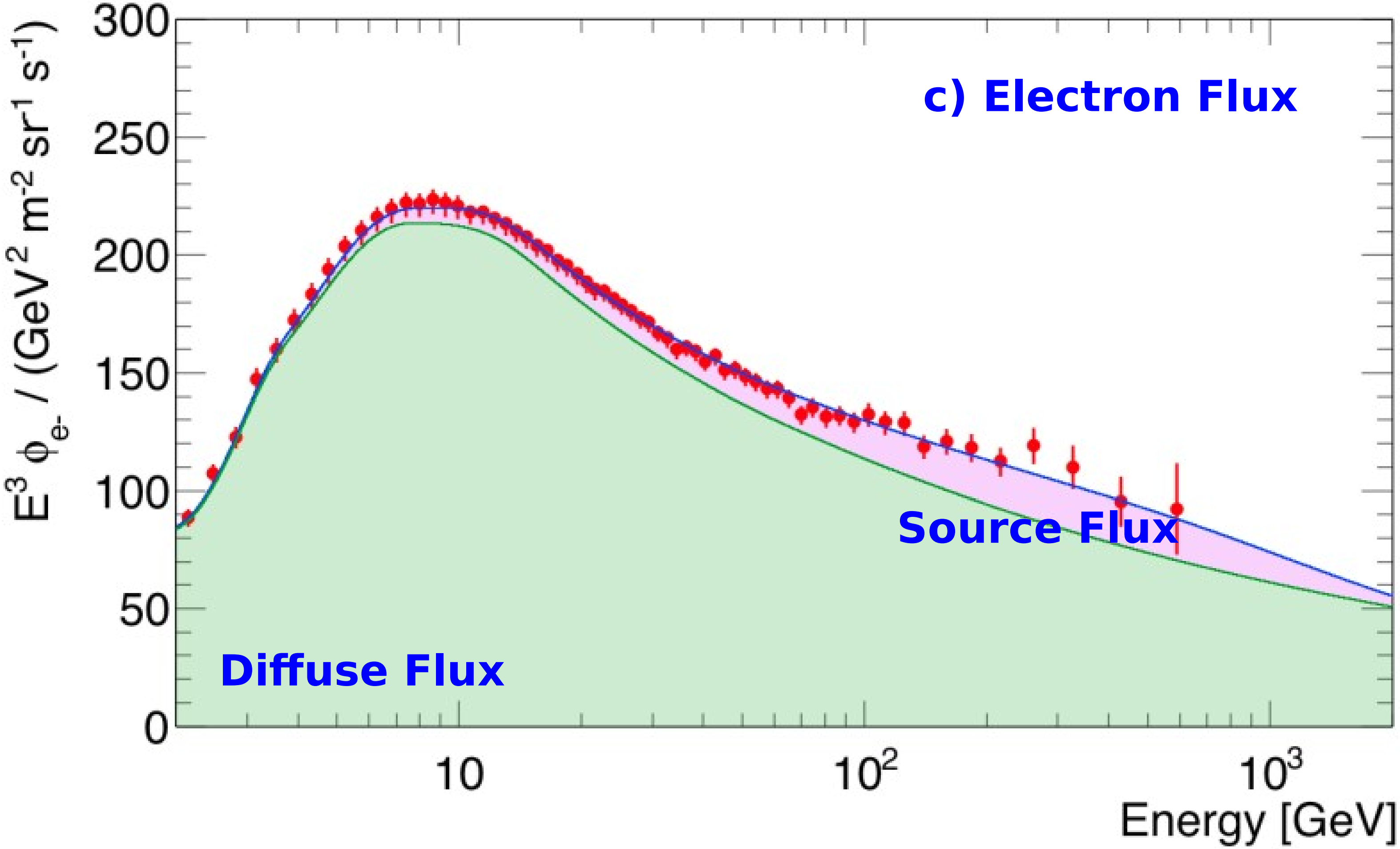
Minimal Model:

Diffuse Flux — Source Flux

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Prediction from fit it to a) Positron Fraction and b) Electron + Positron Flux



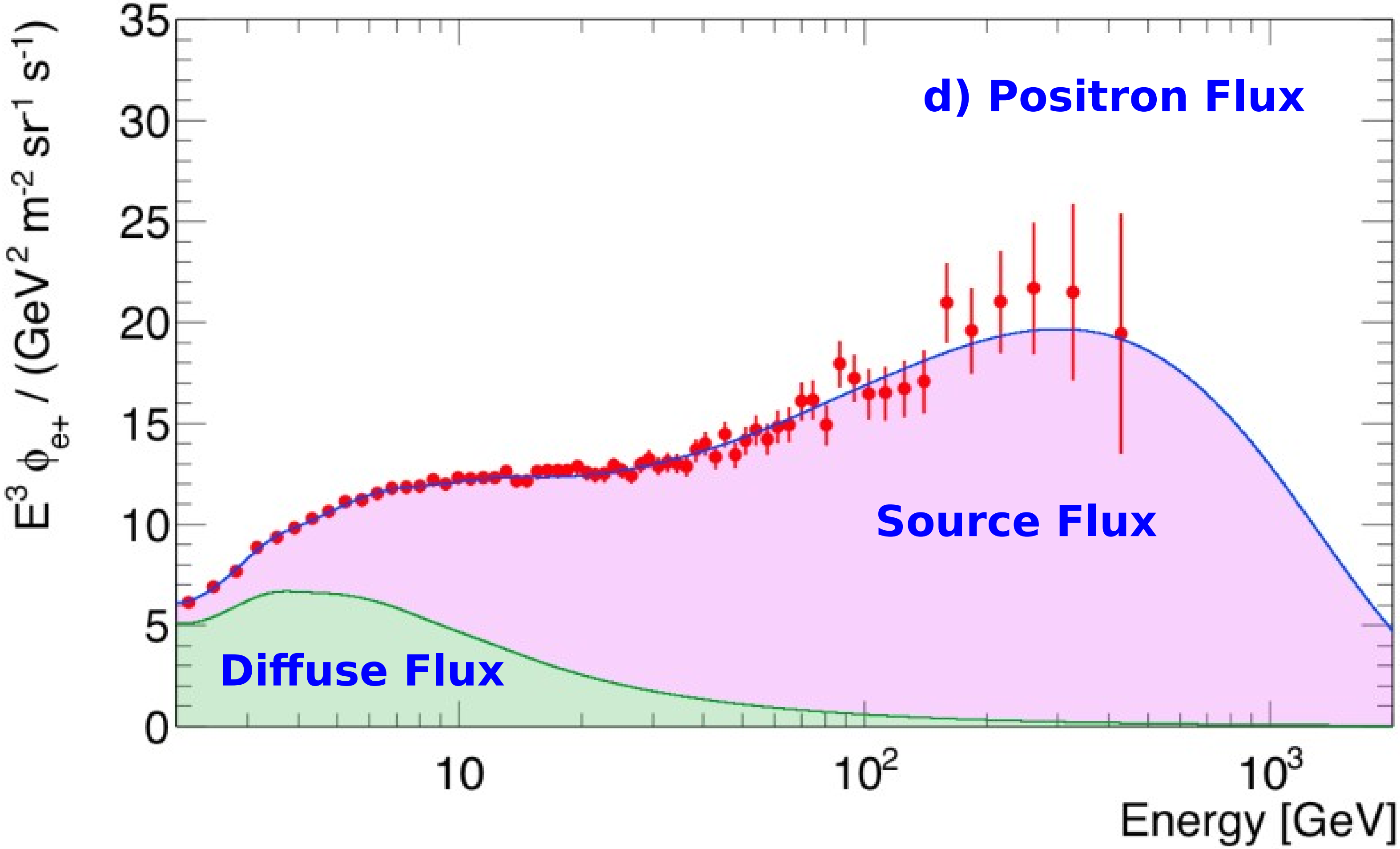
Minimal Model:

Diffuse Flux / Source Flux

$$\Phi_{e+} = C_{e+} E^{-\gamma_{e+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e-} = C_{e-} E^{-\gamma_{e-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Prediction from fit it to a) Positron Fraction and b) Electron + Positron Flux



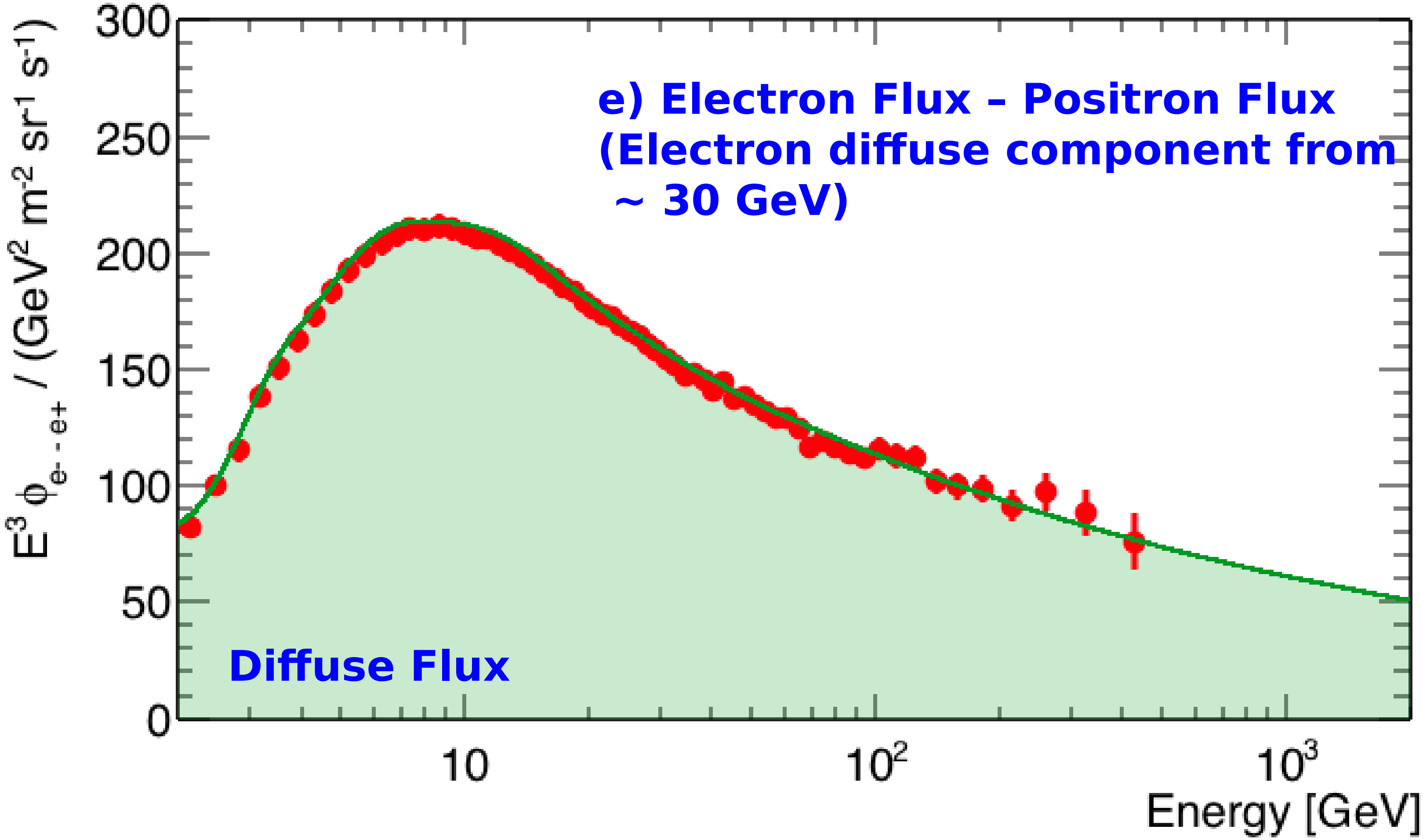
Minimal Model:

Diffuse Flux / Source Flux

$$\Phi_{e^+} = C_{e^+} E^{-\gamma_{e^+}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

$$\Phi_{e^-} = C_{e^-} E^{-\gamma_{e^-}} + C_s E^{-\gamma_s} e^{-E/E_s}$$

Prediction from fit it to a) Positron Fraction and b) Electron + Positron Flux

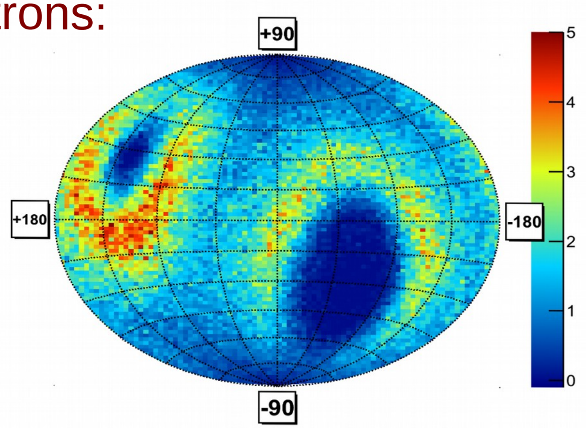


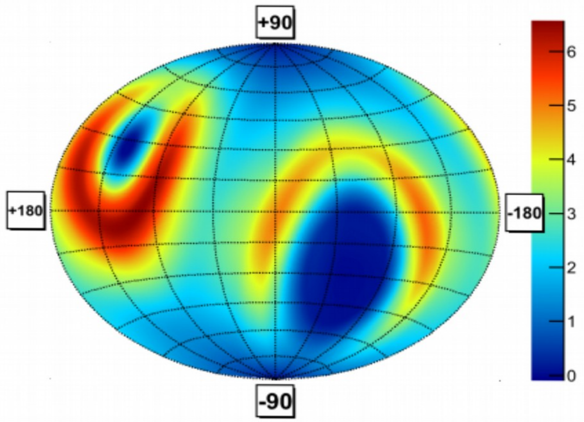
Flux anisotropy

Measured Distribution

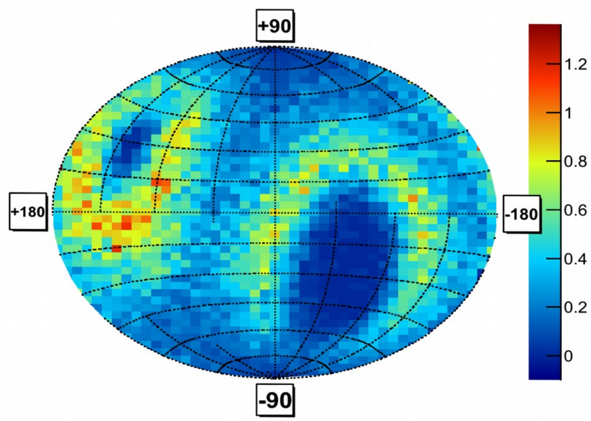
Expected Isotropic Distribution

Electrons:





Positrons:



The incoming direction of electrons above 16 GeV in galactic coordinates yields **$\delta \leq 0.01$ at the 95% confidence level**

The incoming direction of positrons above 16 GeV in galactic coordinates yields **$\delta \leq 0.03$ at the 95% confidence level**