# PAMELA Electrons and Positrons

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**(INFN - Trieste)**

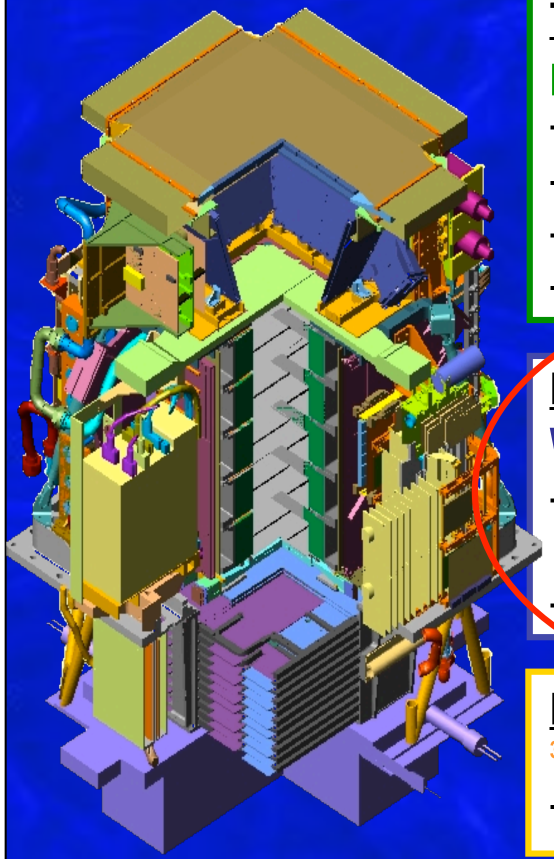
**on behalf of the *PAMELA collaboration***

# Presentation outline

- The PAMELA experiment
- Electron flux measurement
- Positron fraction measurement
- Summary

# PAMELA

# PAMELA apparatus



**Time-Of-Flight**

**plastic scintillators + PMT:**

- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX

**Electromagnetic calorimeter**

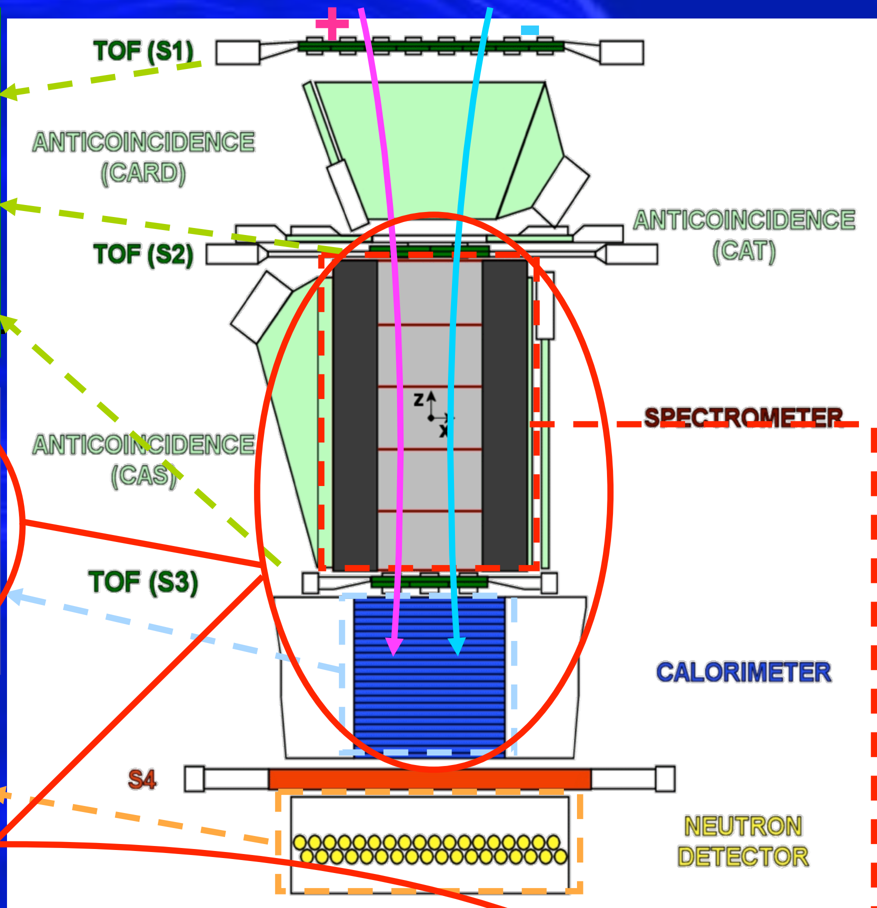
**W/Si sampling (16.3 X0, 0.6 λI)**

- Discrimination e+ / p, anti-p / $e^-$ (shower topology)
- Direct E measurement for $e^-$

**Neutron detector**

**$^3$He tubes + polyethylene moderator:**

- High-energy e/h discrimination



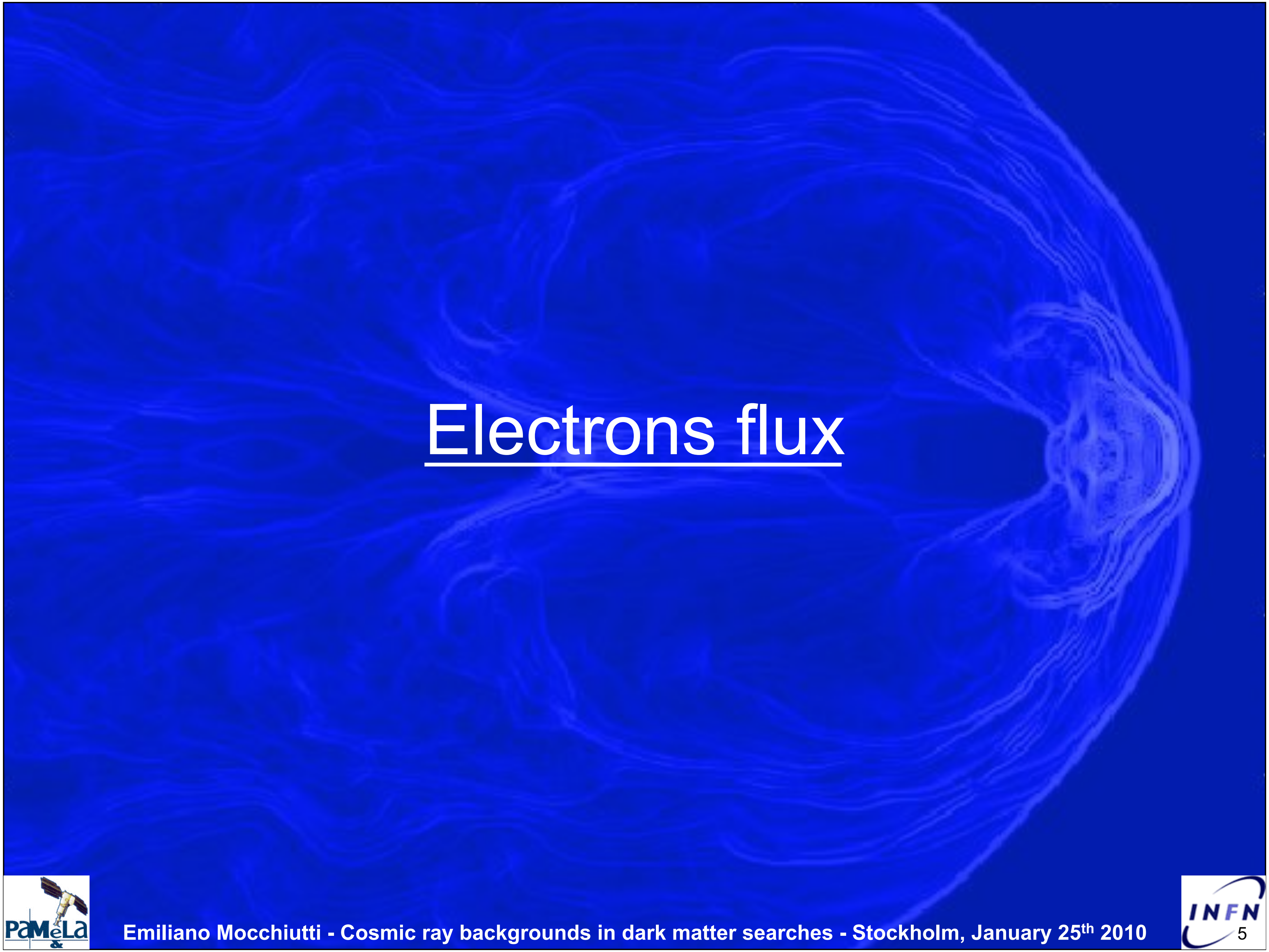

**GF: 21.5 cm² sr**
**Mass: 470 kg**
**Size: 130x70x70 cm³**
**Power Budget: 360W**

**Spectrometer**

**microstrip silicon tracking system + permanent magnet**

It provides:

- Magnetic rigidity → R = pc/Ze
- Charge sign
- Charge value from dE/dx



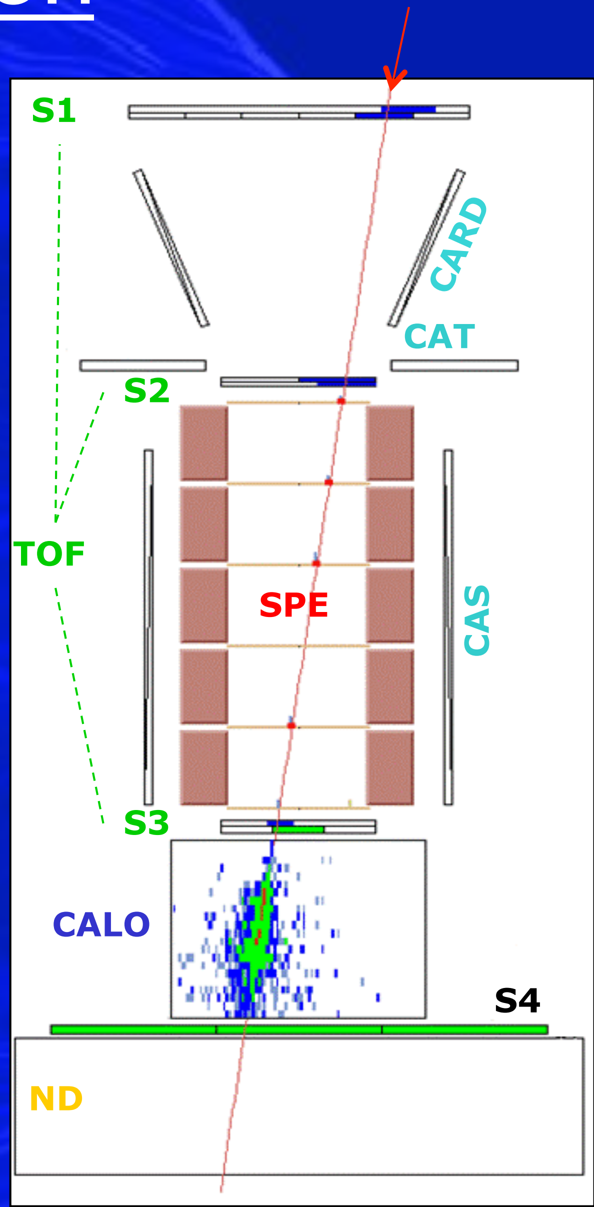
# Electrons flux

# Electron identification

- Analyzed data July 2006 – December 2008 (~850 days)
- Collected triggers >$10^9$
- Identified ~ 5.5 $10^5$ electrons between 1 and 200 GeV

Electron/positron identification:
- rigidity (R) → SPE
- |Z|=1 (dE/dx=MIP) → SPE&ToF
- $\beta$=1 → ToF
- *e-/e+ separation (charge sign) → SPE*
- *(e-/p-bar separation → CALO)*

- *~ no background, issues:*
  - spillover protons at high energy
  - spectrometer resolution
  - selection efficiencies



# Electron ($e^-$) flux, energy measurement

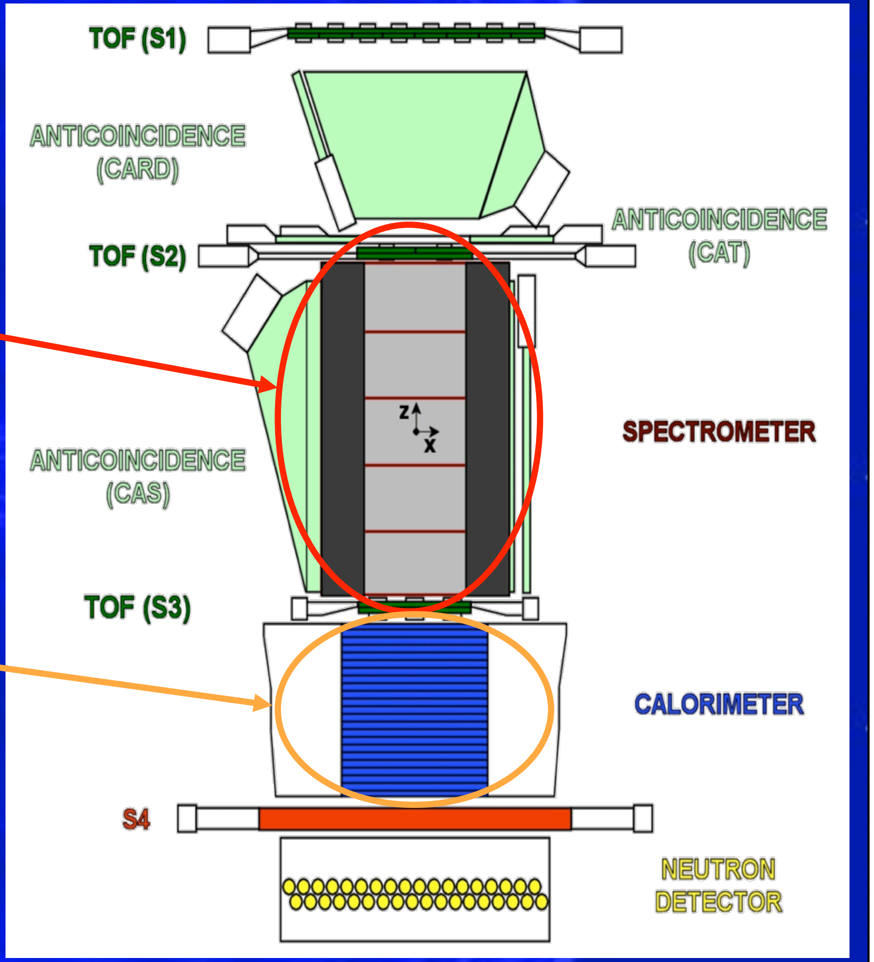
**Two independent energy measurements:**

**Rigidity from Tracker**

- bremsstrahlung above tracker
- decreasing energy resolution

**Energy from Calorimeter**

- **sampling calorimeter + dead areas**
- **increasing energy resolution**




**⟹ possibility to cross-check the energy measurement**

# Electron flux, methods

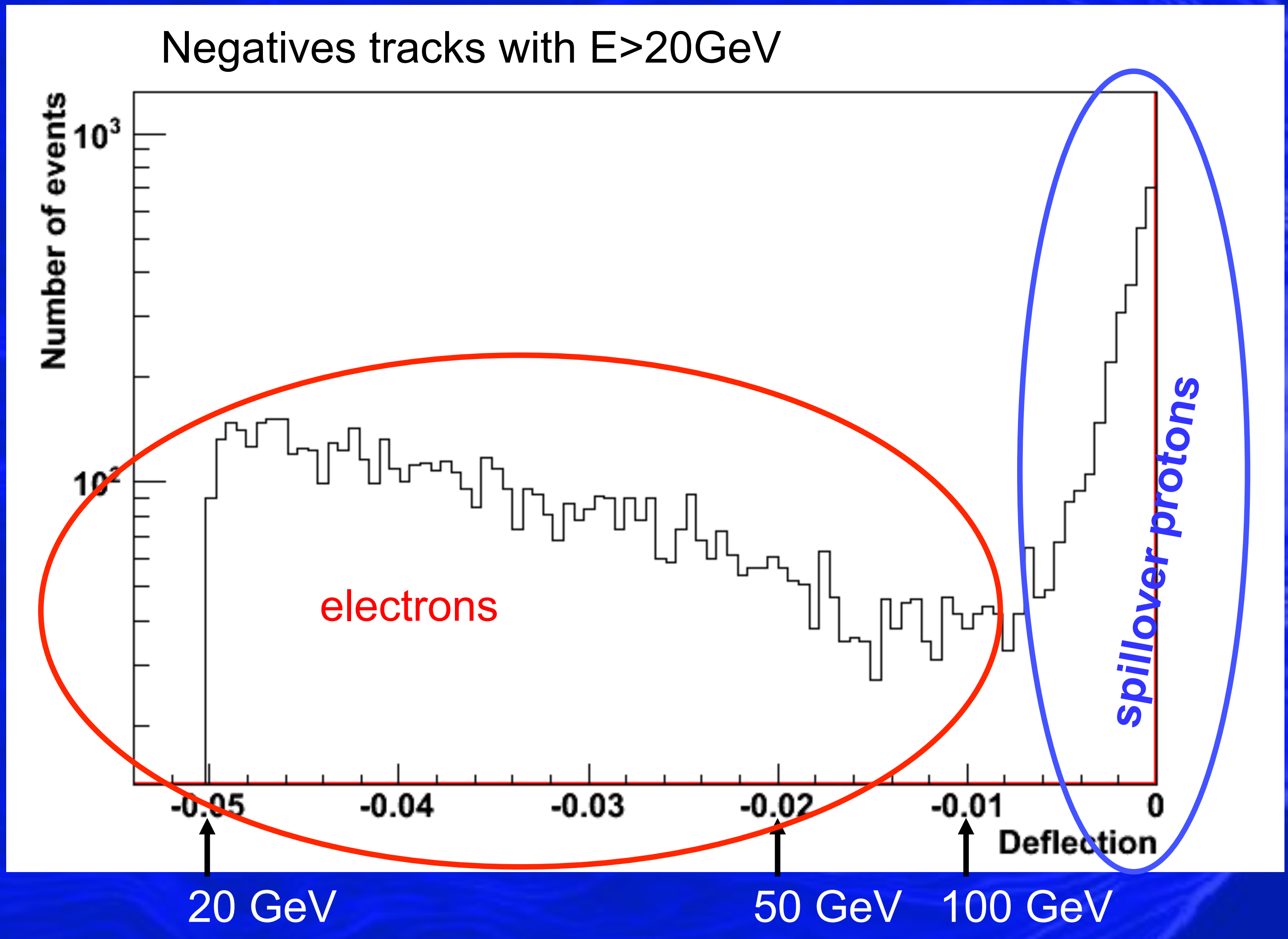
**Three different approaches:**

1) **Tracker-based selection (strong track quality requirements, loose calorimeter selection, energy measured by the tracker)**

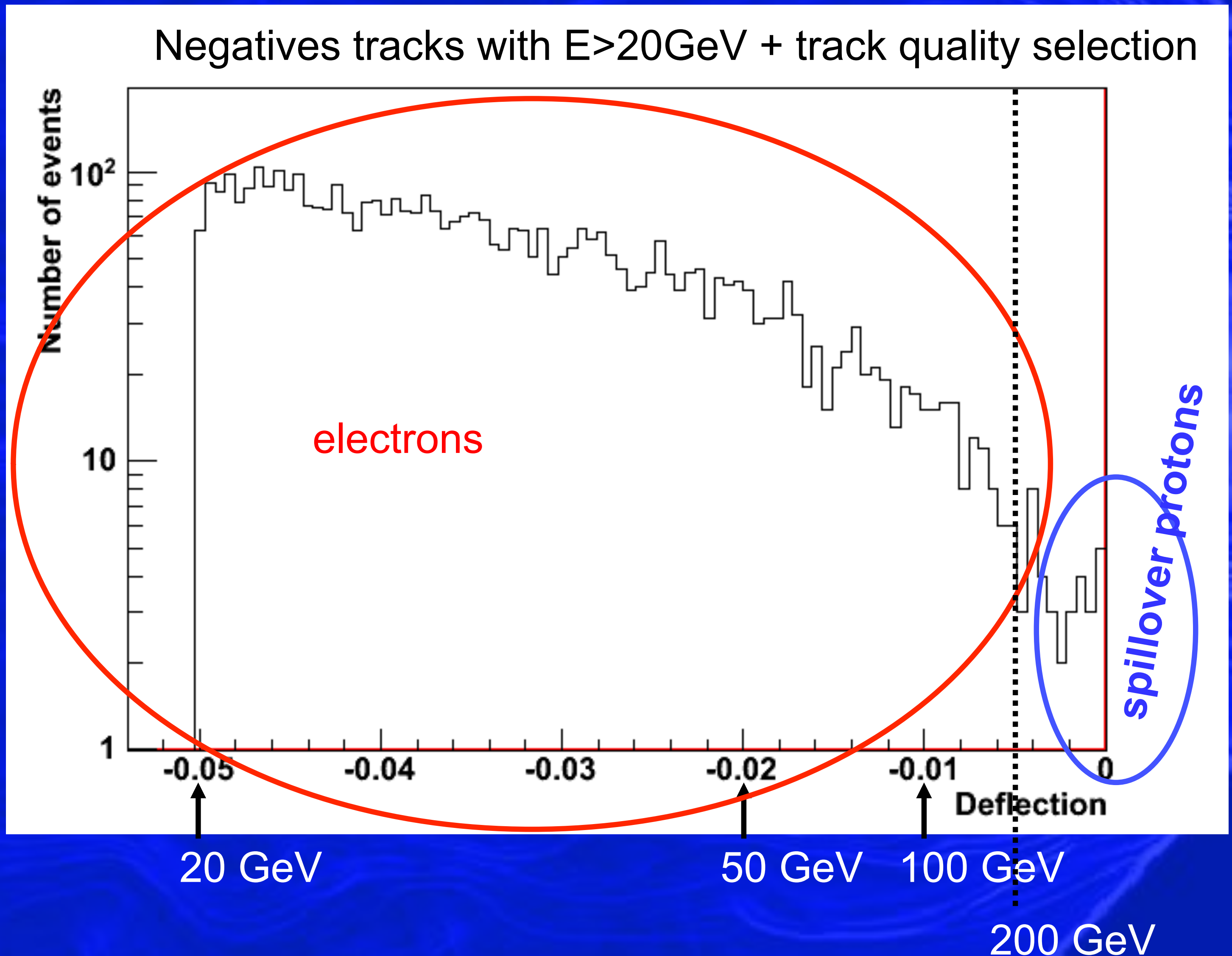
2) **Calorimeter-based selection (loose track quality requirements - negative charged particle, strong calorimeter selection, energy measured by the calorimeter)**

3) **Pure calorimetric measurement, strong calorimeter selection and energy measured by the calorimeter (à la ATIC/Fermi), $e^{-}+e^{+}$ flux**

# Electron flux - tracker-based



# Electron flux - tracker-based

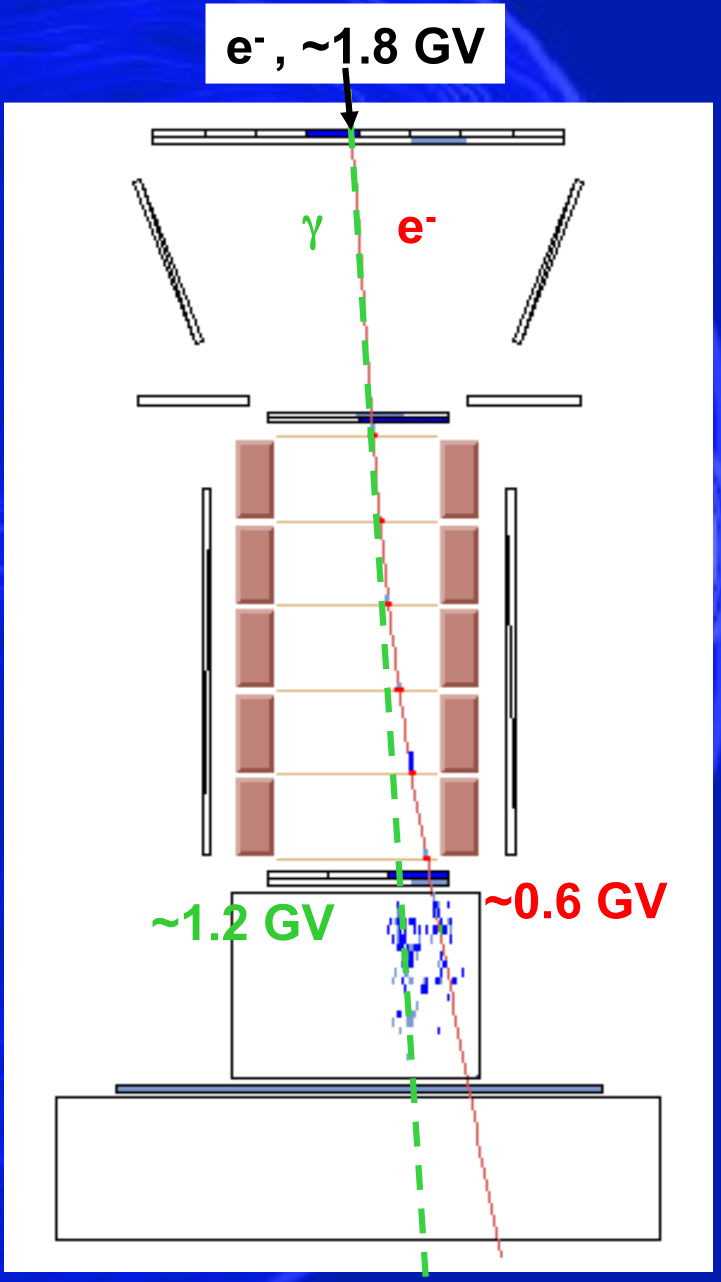


# Electron flux - tracker-based

Efficiency determination with simulations and real data (energy from calorimeter)

Bayesian unfolding procedure (D'Agostini method) accounts for:

- energy loss above the spectrometer

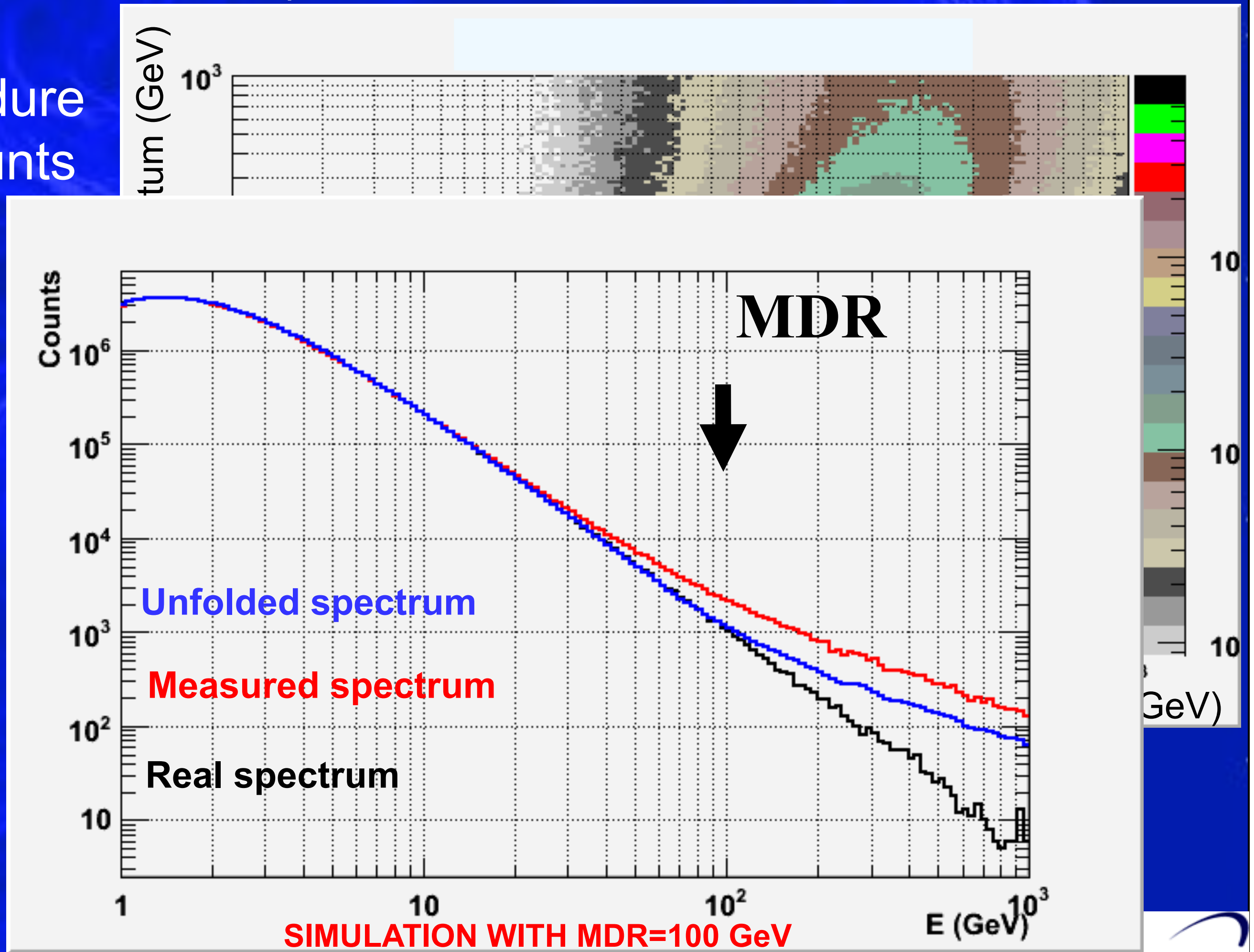


# Electron flux - tracker-based

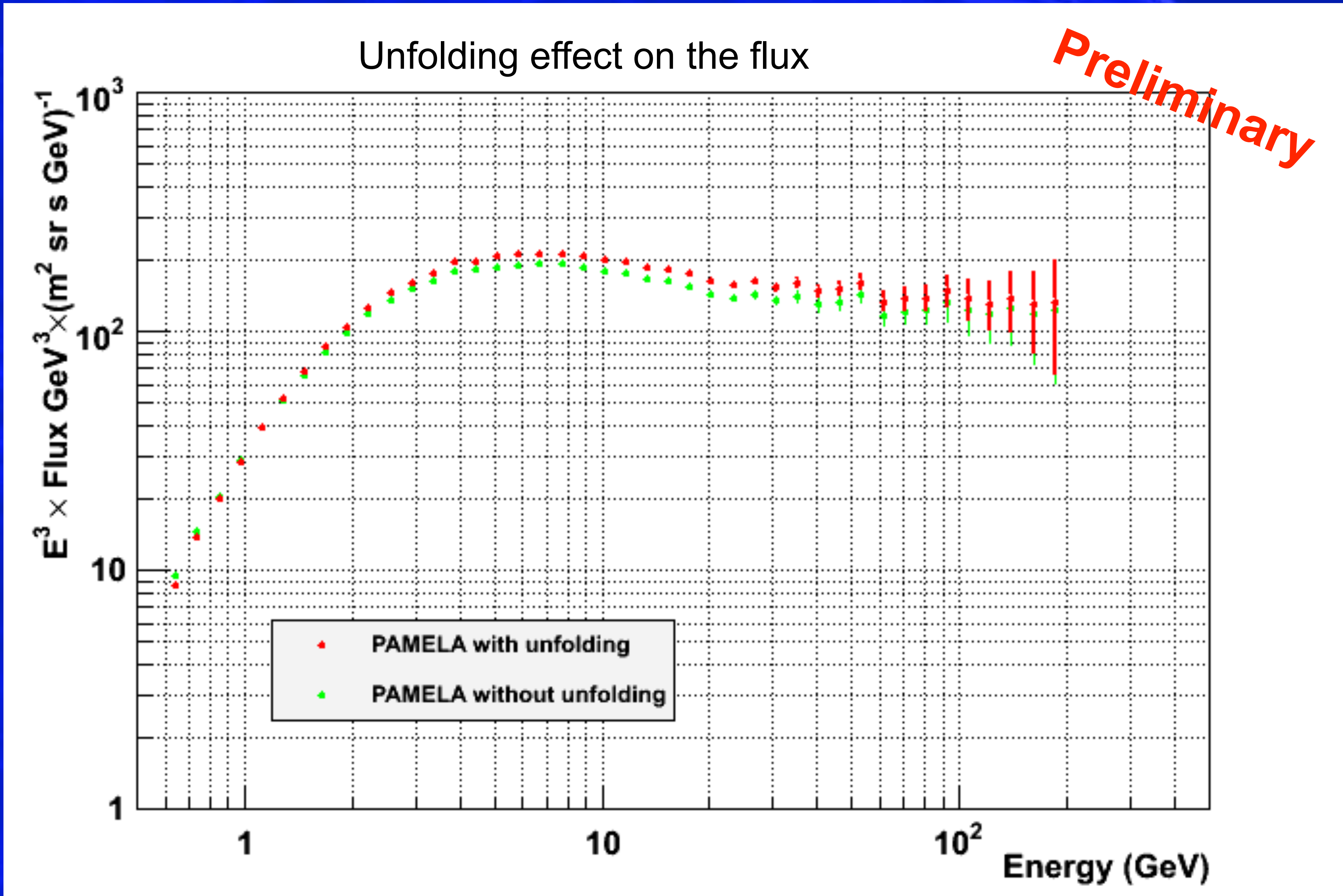
Efficiency determination with simulations and real data (energy from calorimeter)

Bayesian unfolding procedure (D'Agostini method) accounts for:

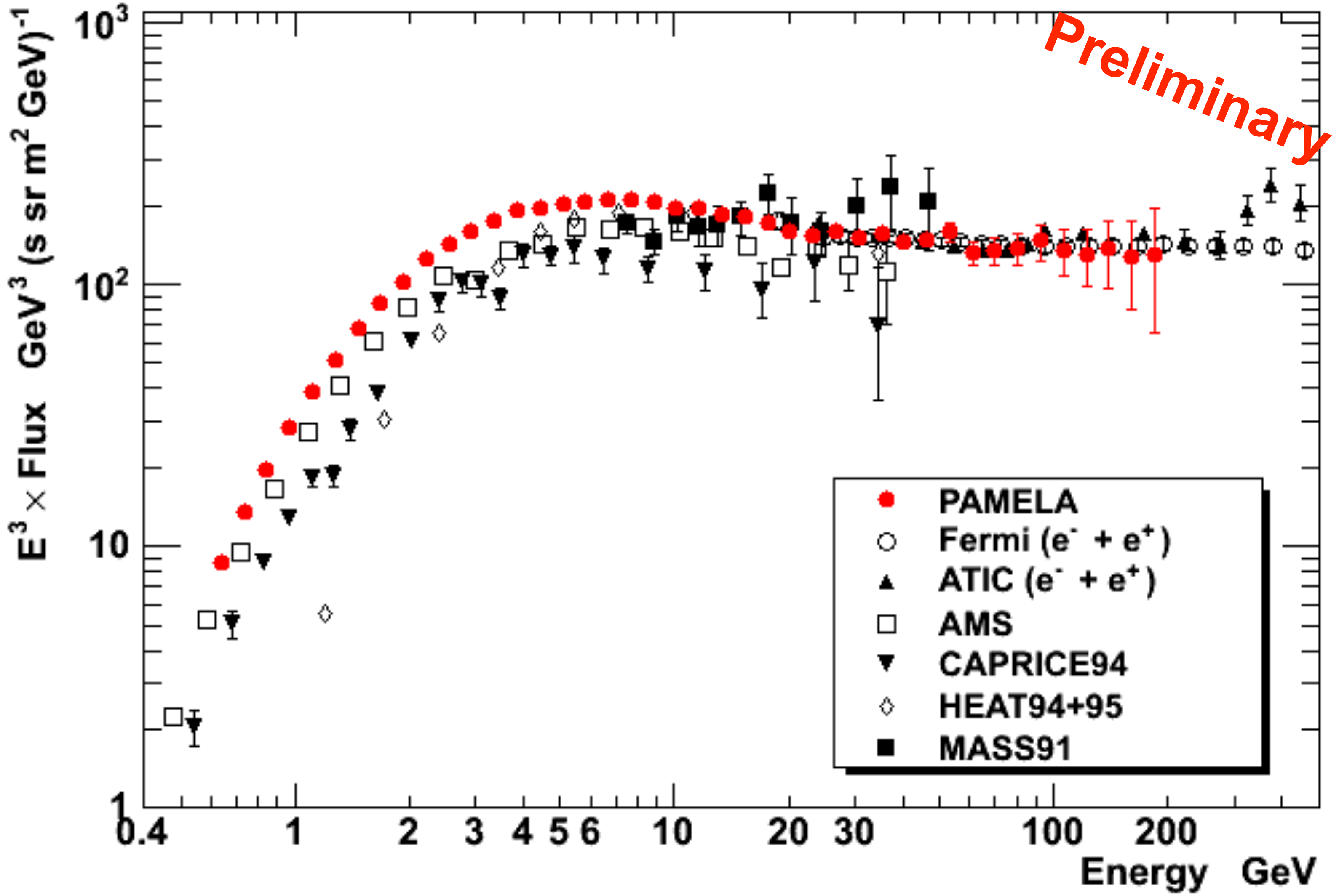
- energy loss above the spectrometer
- spectrometer resolution



# Electron flux - tracker-based



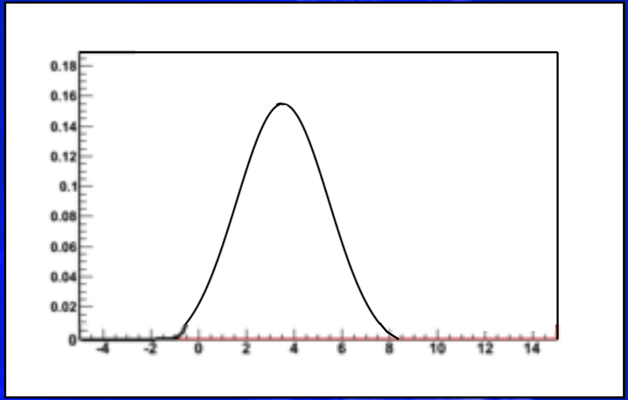
# Electron flux - tracker-based



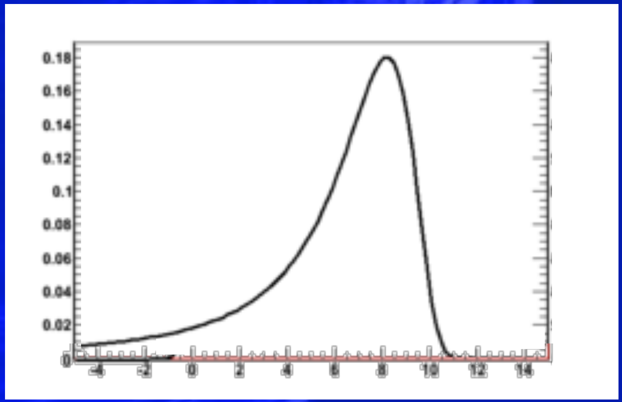
# Electron flux - calorimeter-based

**Energy measurement:**

I. gaussian energy distribution, small/ no unfolding effect at high energy




II. non-gaussian energy distribution, need for flux unfolding (as it is done for tracker)



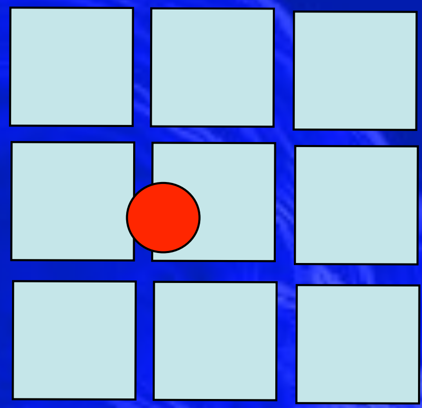
# Electron flux - calorimeter-based I.

**Transversal and dead areas leakage:**

**- strong containment conditions**

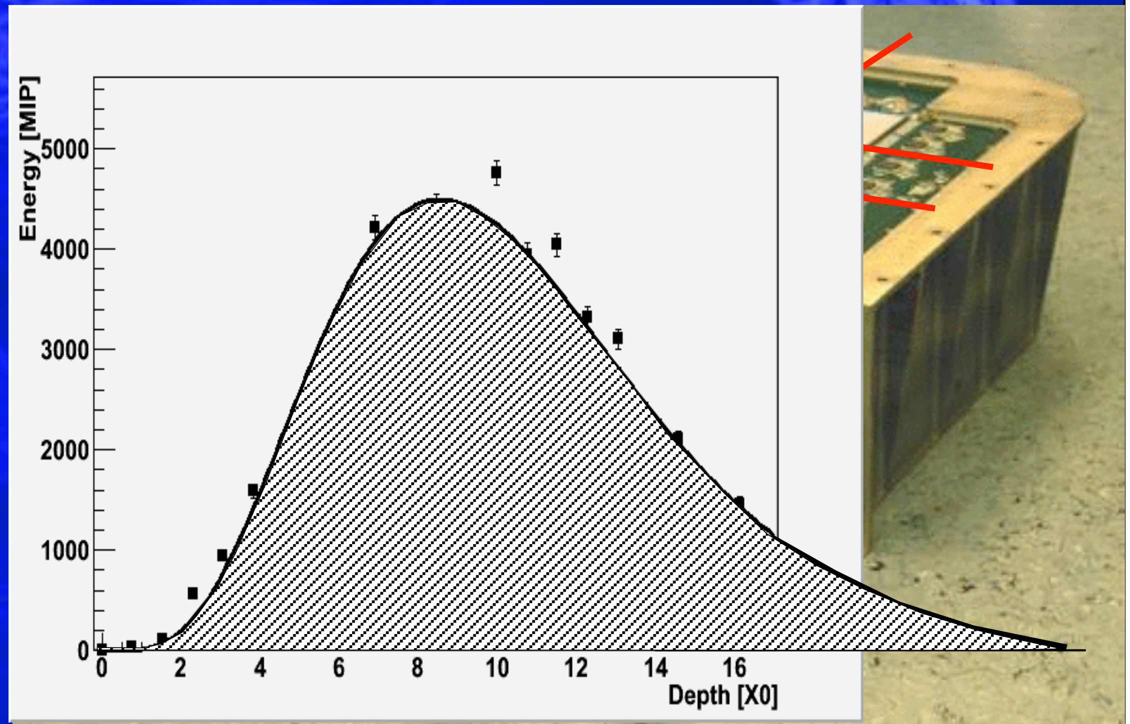
**Other possible solution:**

**- energy recovered from a transversal fit (depends on energy) or from geometrical assumptions**



**Longitudinal leakage:**

**- Integrate a longitudinal fit of the shower**

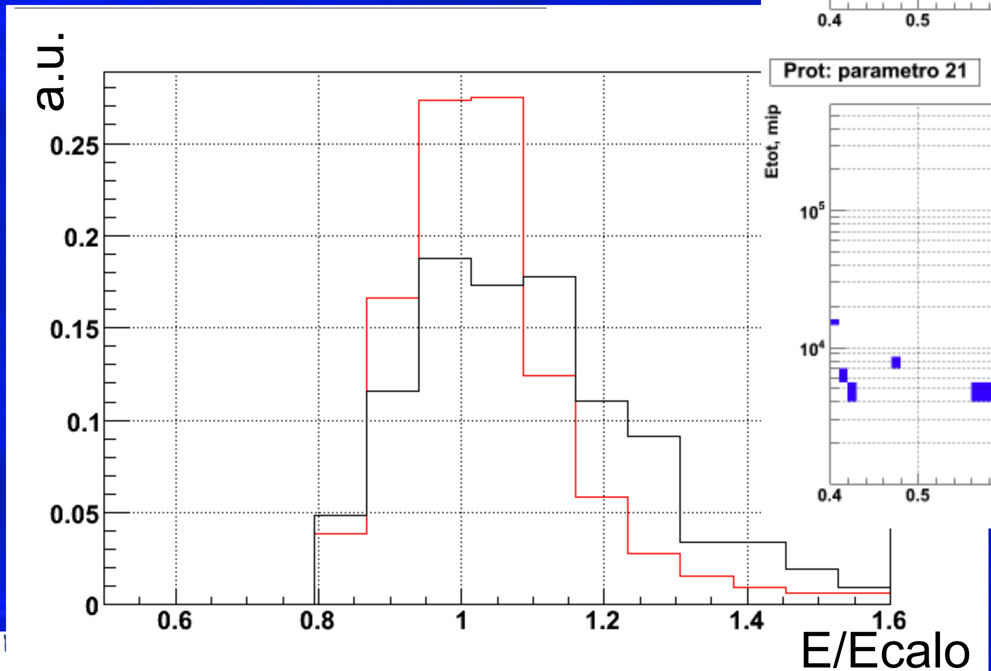


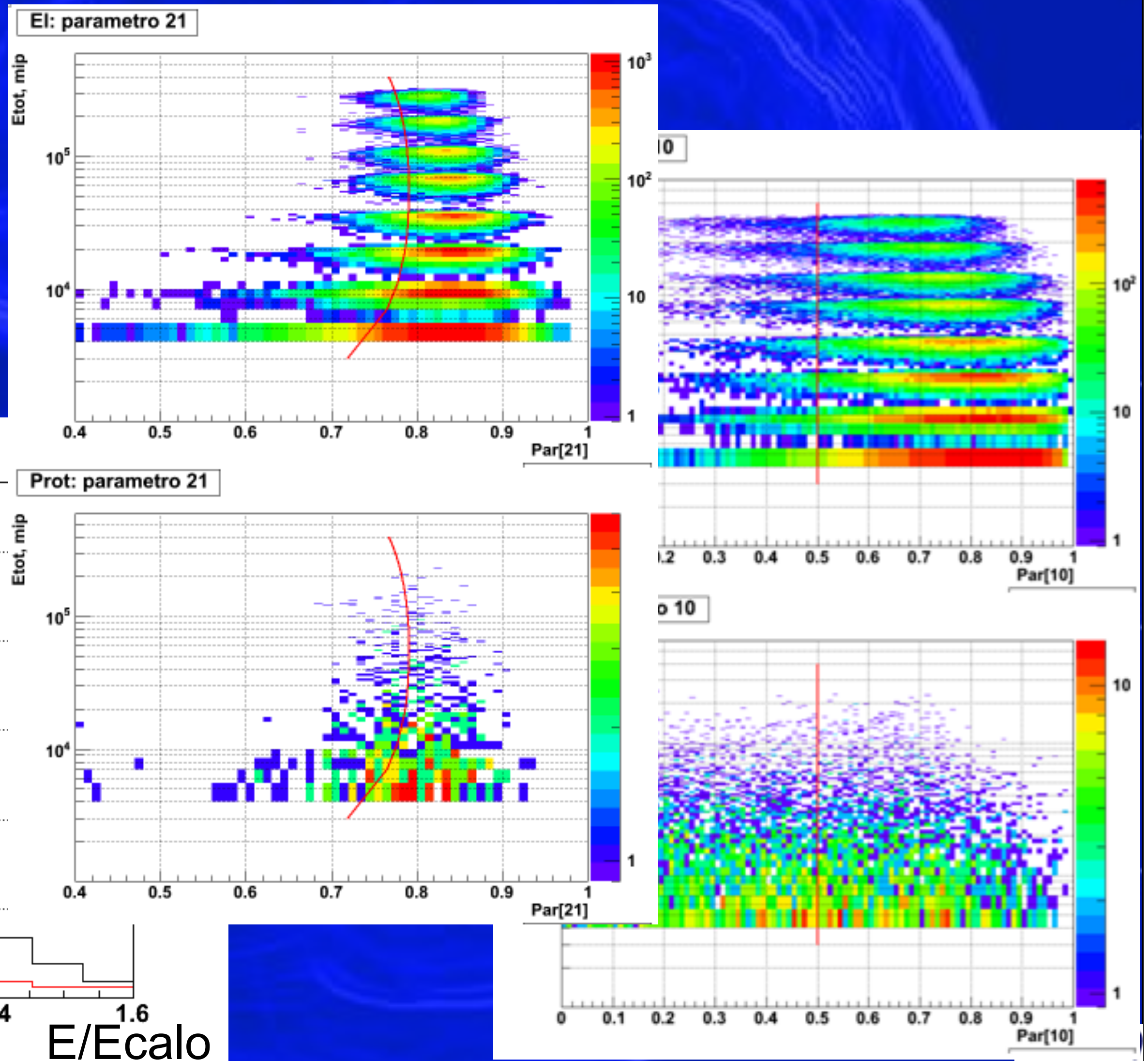
# Electron flux - calorimeter-based I.

- ● Tracker-based
- ■ Calorimeter-based

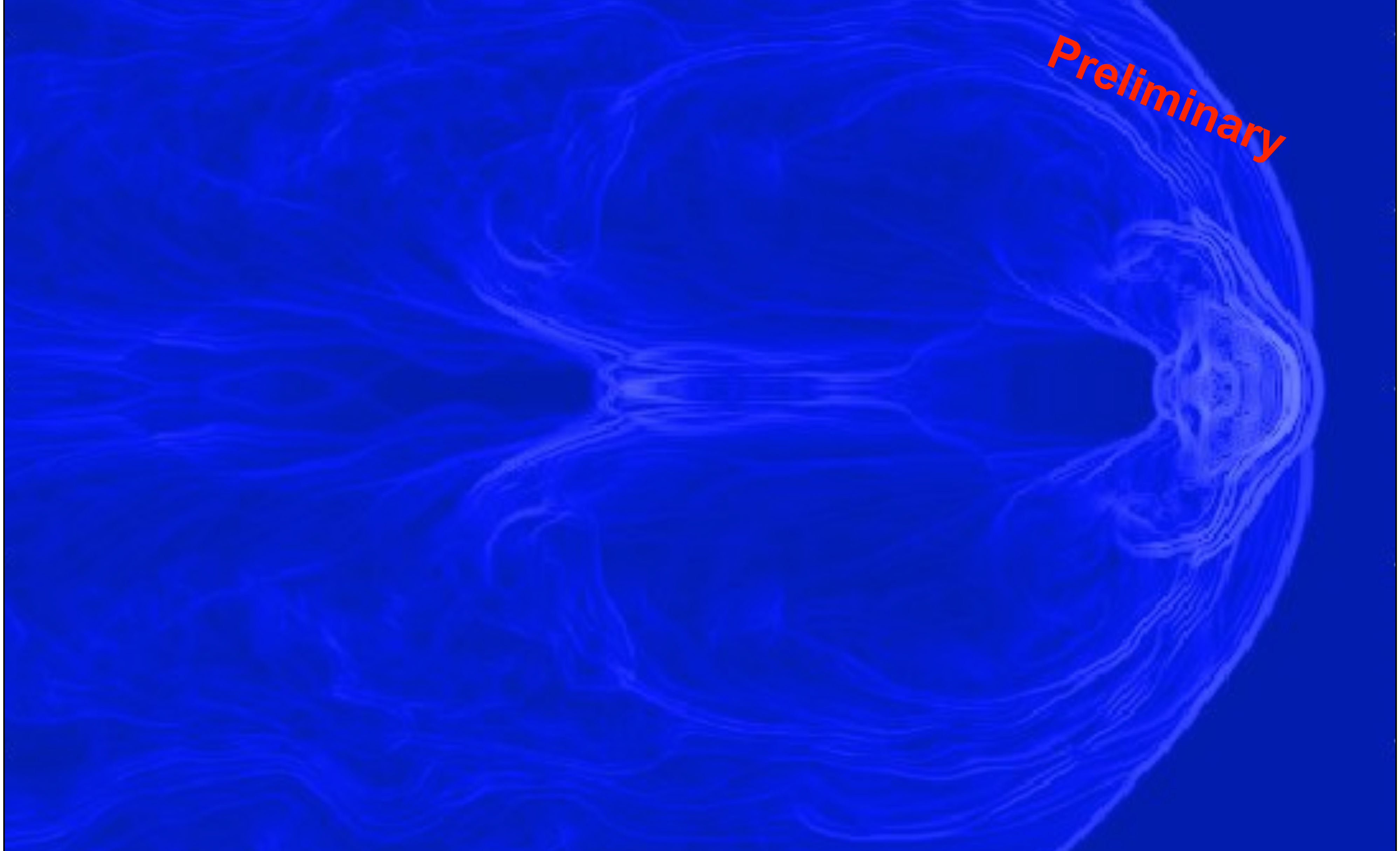
# Electron flux - calorimeter-based II.

- Set of strong calorimeter selections
- Energy with calorimeter
- Tracker acceptance
- Unfolding

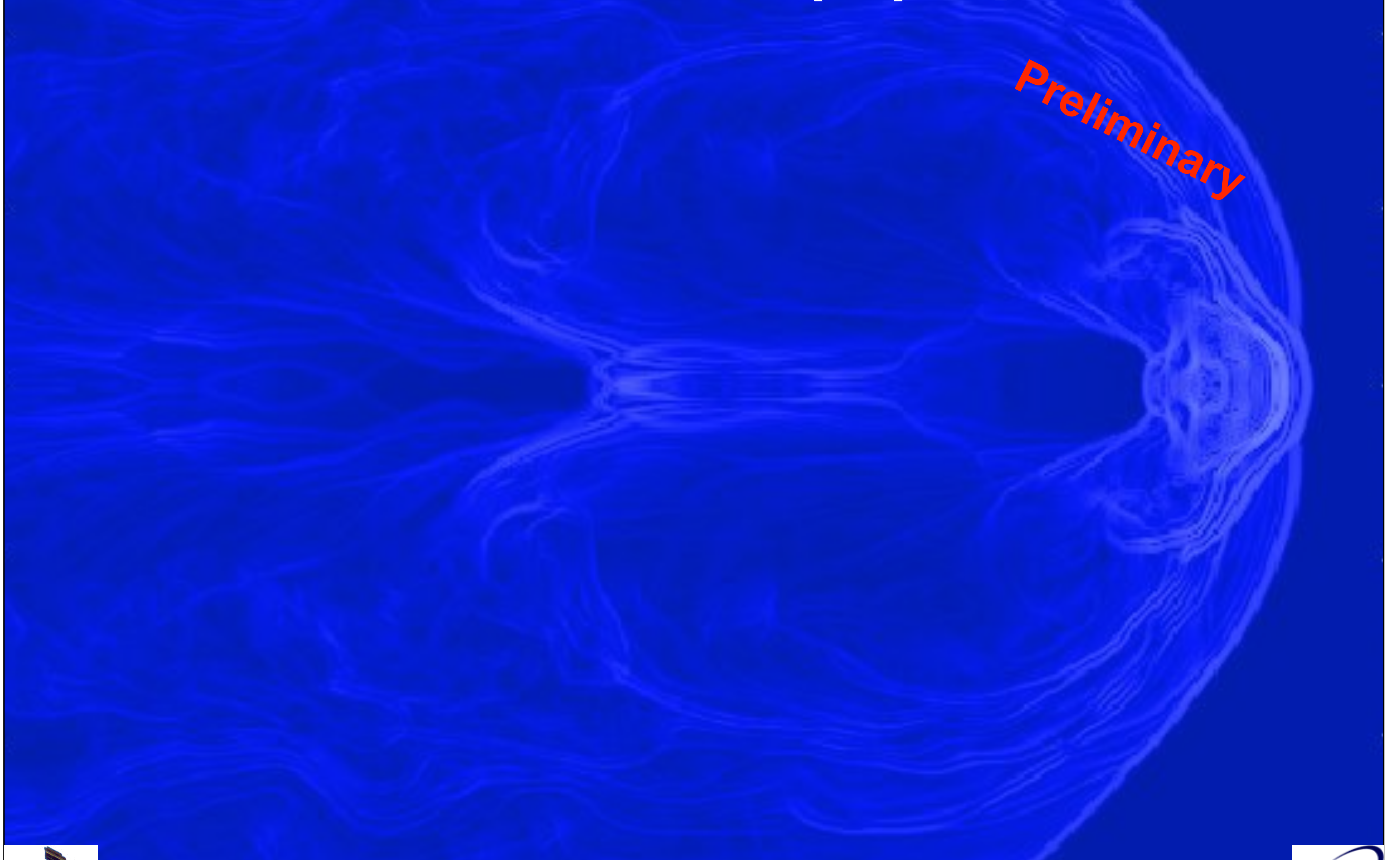


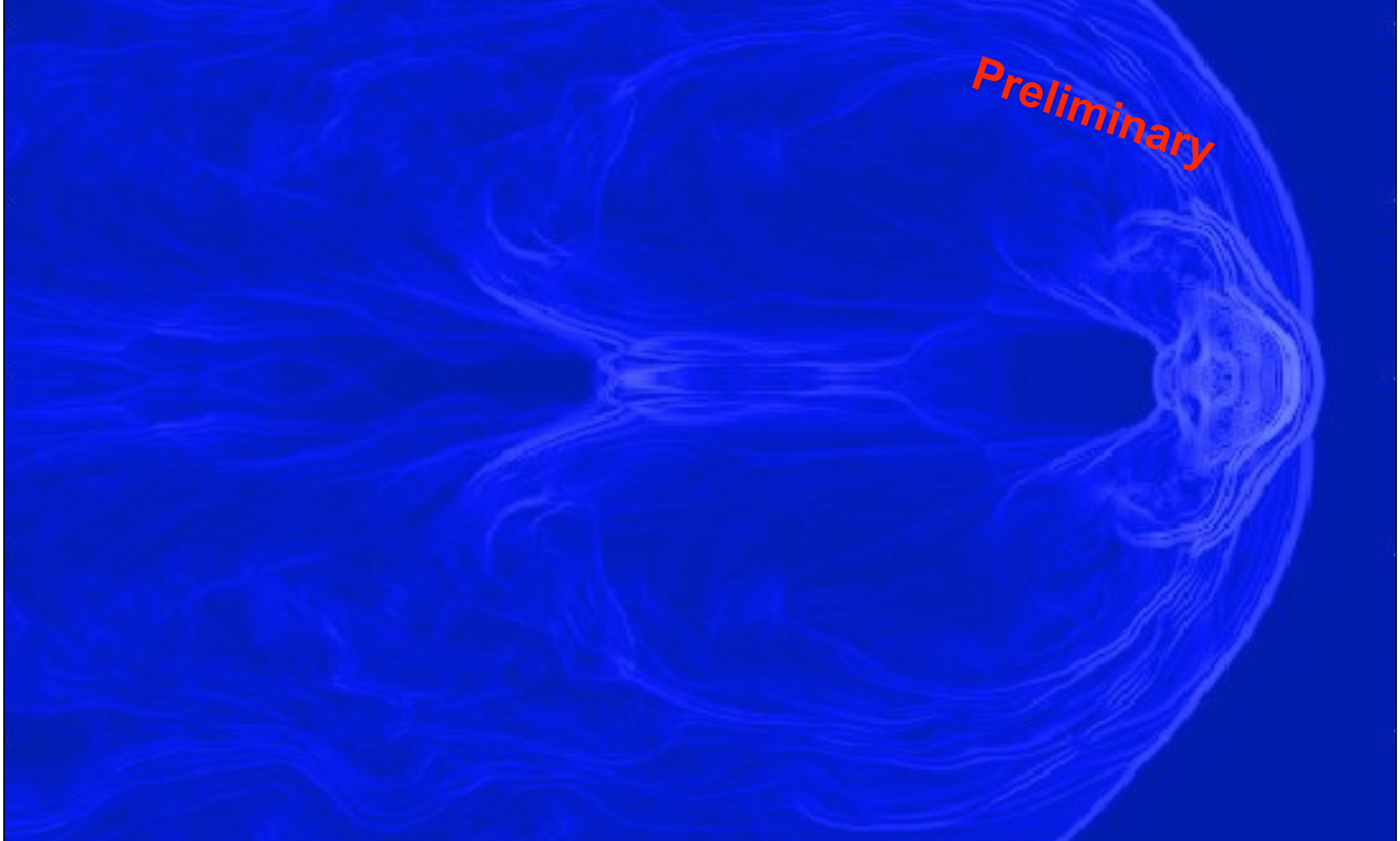
# Electron flux - calorimeter-based II.



# PAMELA electron ($e^-$) spectrum



# Electron flux - break in the spectrum?



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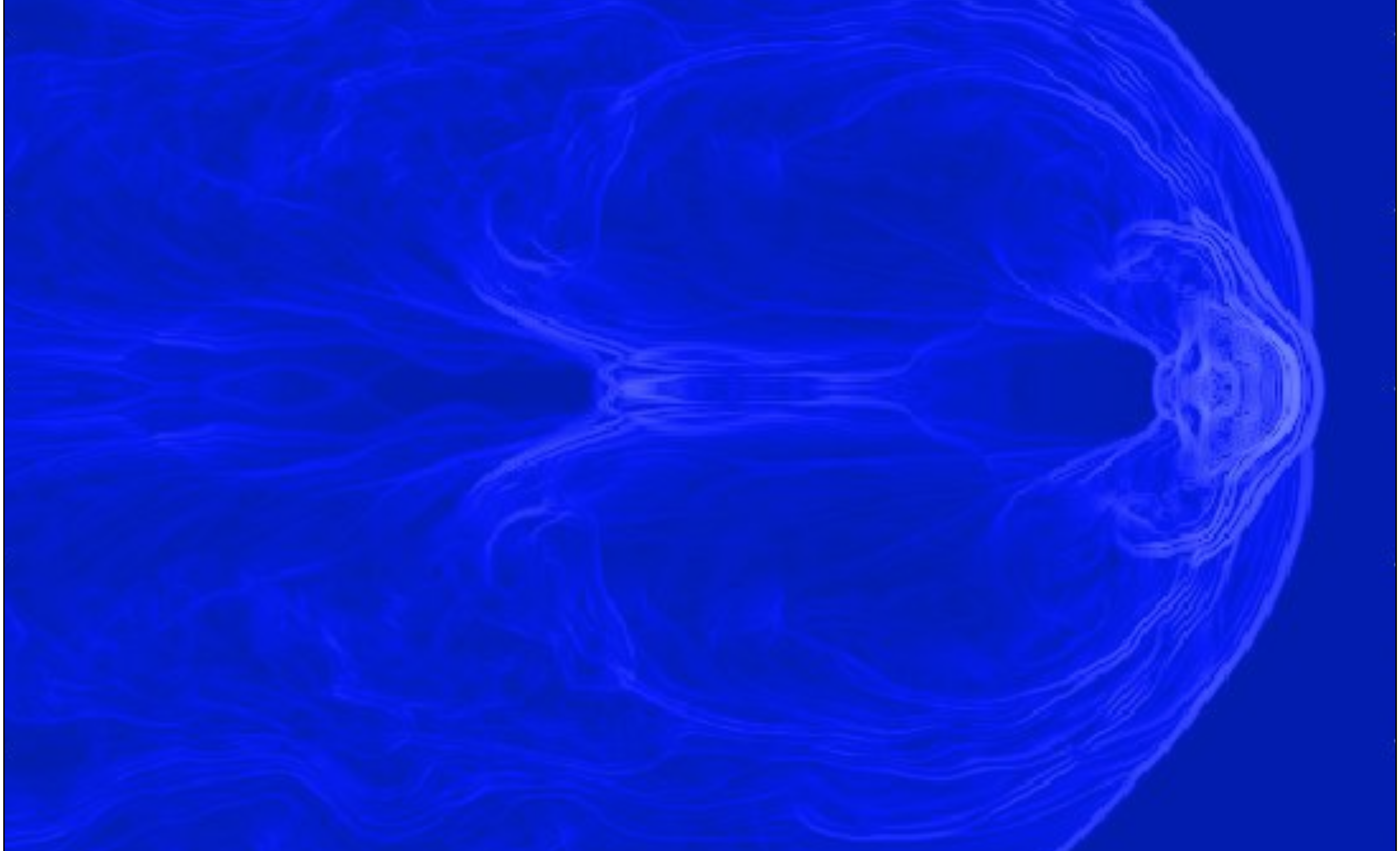
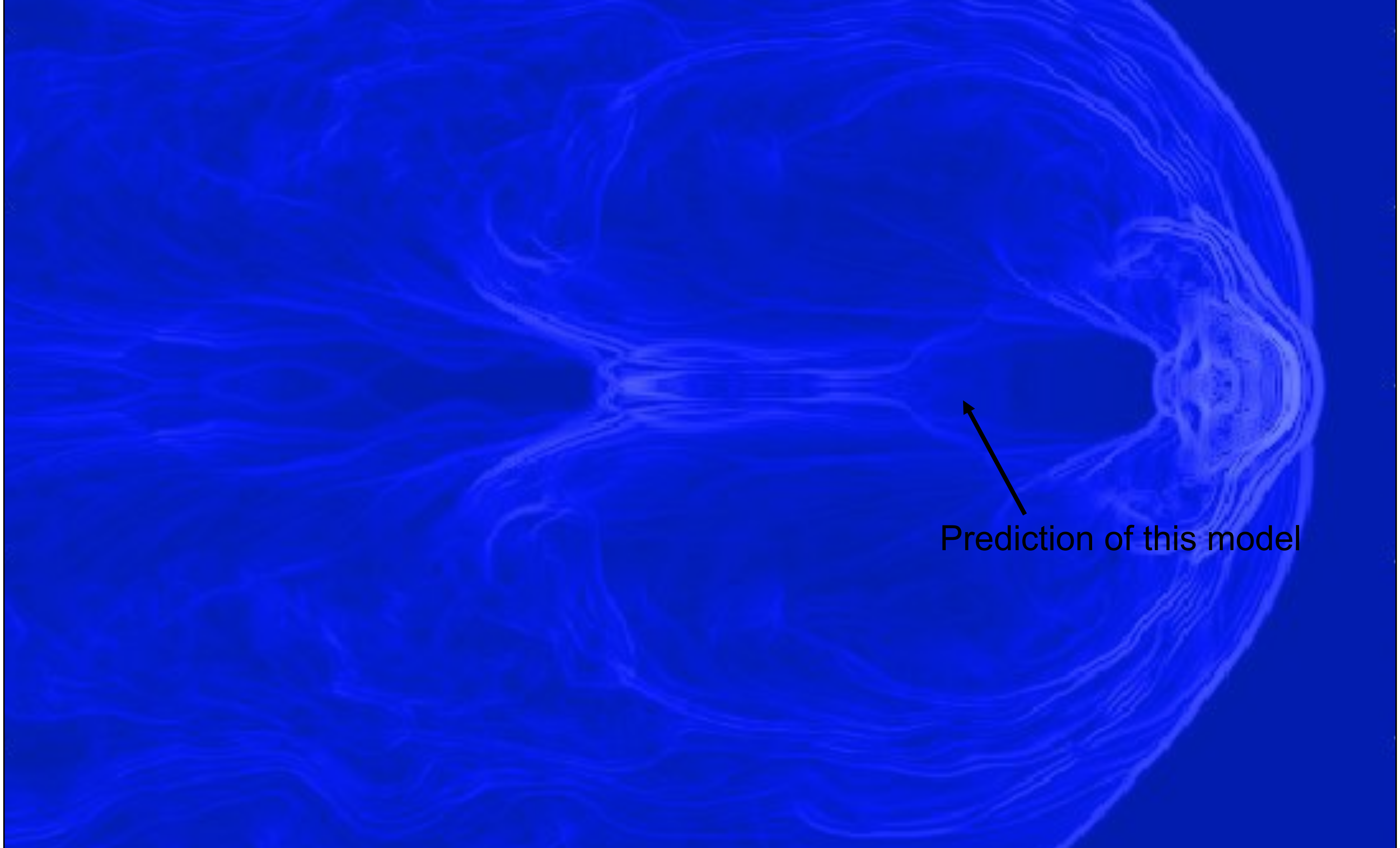


# Electron flux - break in the spectrum?



# Positrons fraction

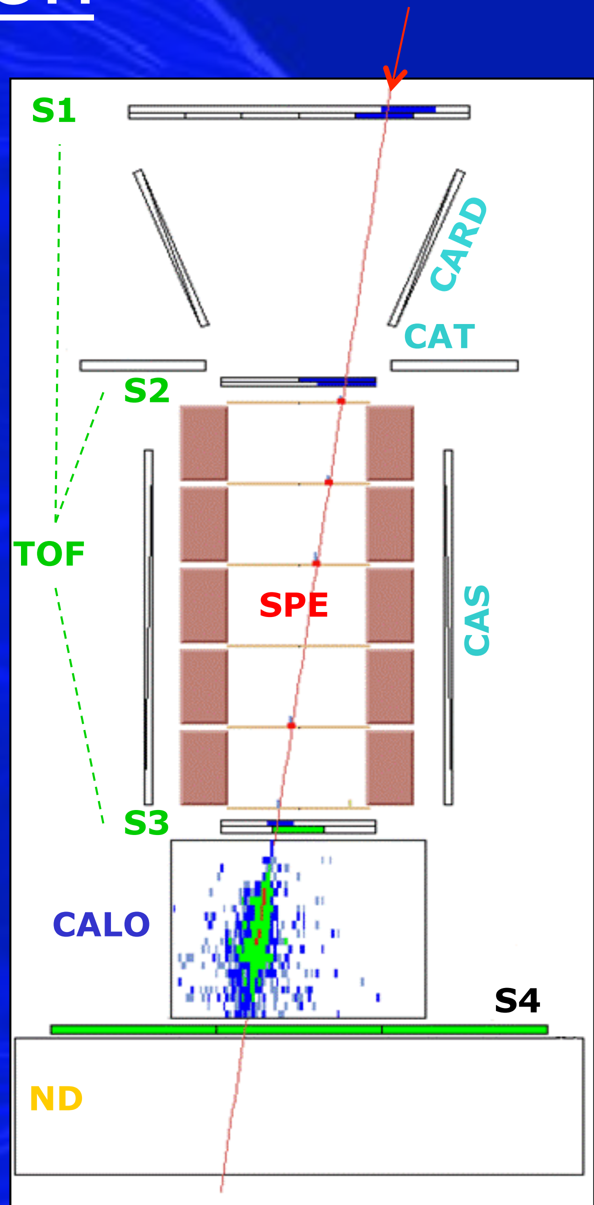
# Positron identification

- Analyzed data July 2006 – December 2008 (~850 days)
- Collected triggers >$10^9$
- Identified ~ 9 $10^3$ positrons between 1.5 and 100 GeV - *180 positrons above 20 GeV*

Electron/positron identification:
- rigidity (R) → SPE
- |Z|=1 (dE/dx=MIP) → SPE&ToF
- $\beta$=1 → ToF
- *e-/e+ separation (charge sign) → SPE*
- *e+/p separation → CALO*

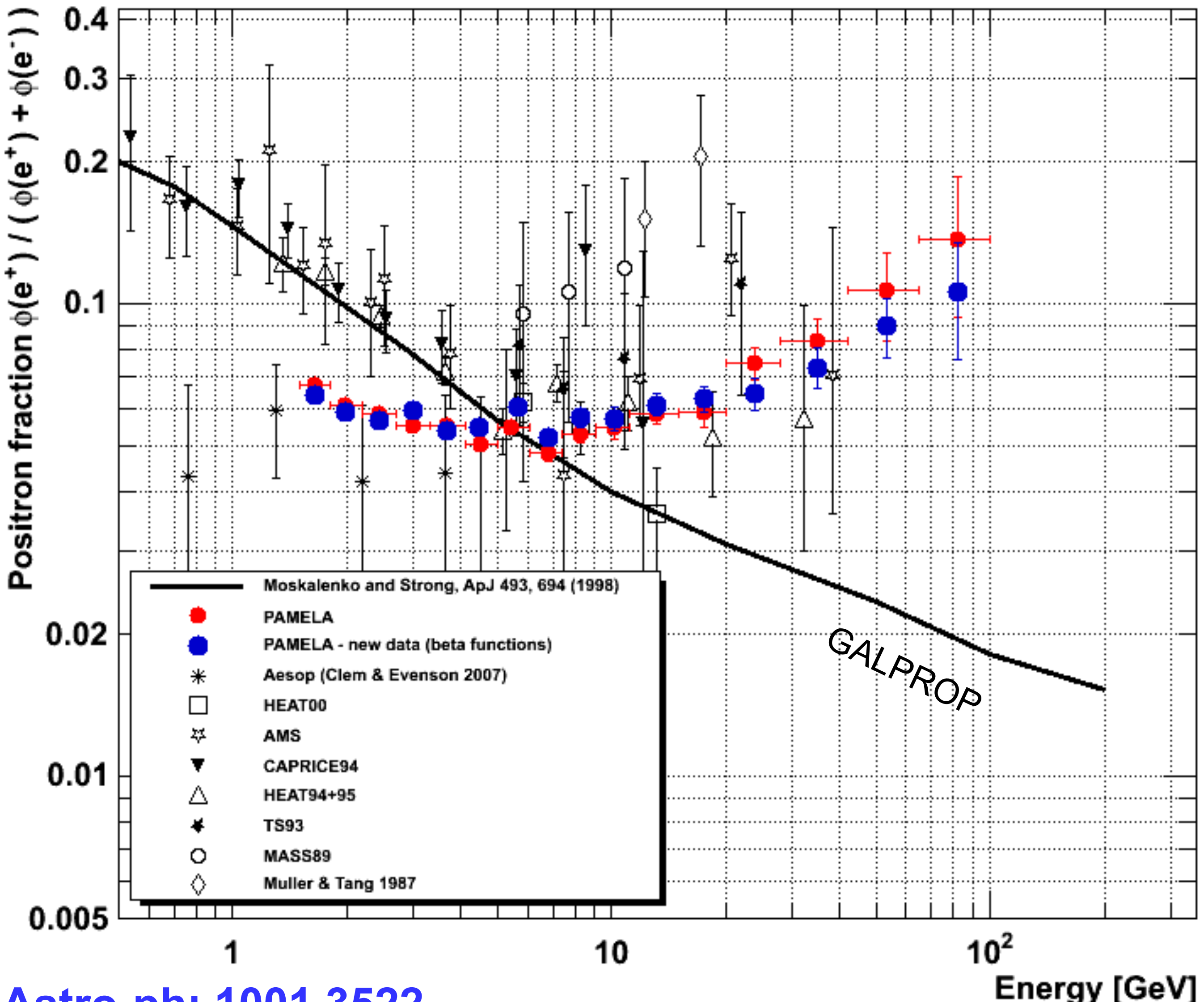
- *Dominant background → **interacting protons**:*
  proton spectrum harder than positron
  ⇒ p/e+ increase for increasing energy ($10^3$ @1GV $10^4$ @100GV)

***→ Strong CALO selection required***



# Positron to Electron Fraction

**New data, up to end 2008 (+1 year // + ~30% statistics)** **NEW!**



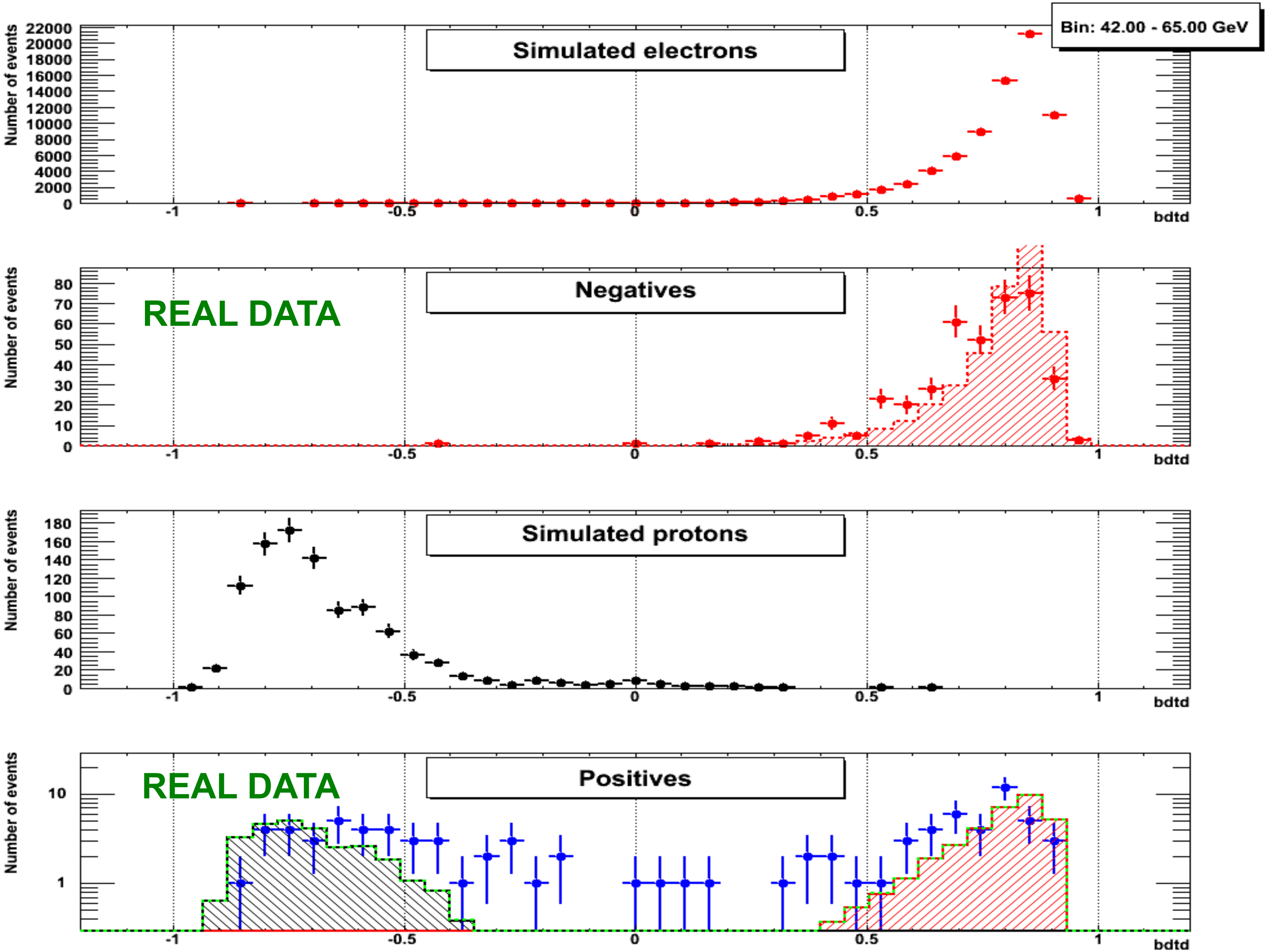

**Astro-ph: 1001.3522**

# Extending the positron fraction measurement

- New data, +1 year of data

- Background suppression method, full calorimeter:
  - No proton sample from flight data
  - Simulations & Test beam data needed
  - Strong selections to reject protons using TMVA (Toolkit for MultiVariate data Analysis)
  
  " TMVA host large variety of multivariate classification algorithms - cut optimization with genetic algorithm, linear and non-linear discriminant and neural networks, support vector machine, boosted decision trees, ..."

# Boosted decision tree output 42-65 GeV



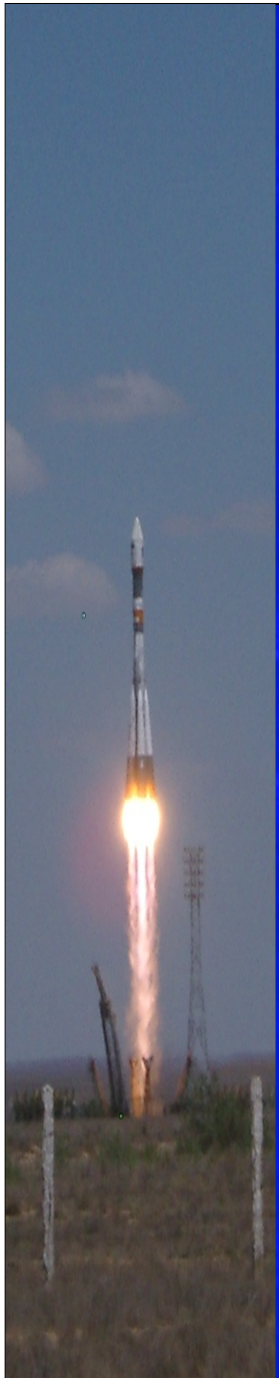
# Positron to Electron Fraction

**Statistics improved by ~2.5 times, 3 times in the last point** NEW!

Preliminary

GALPROP

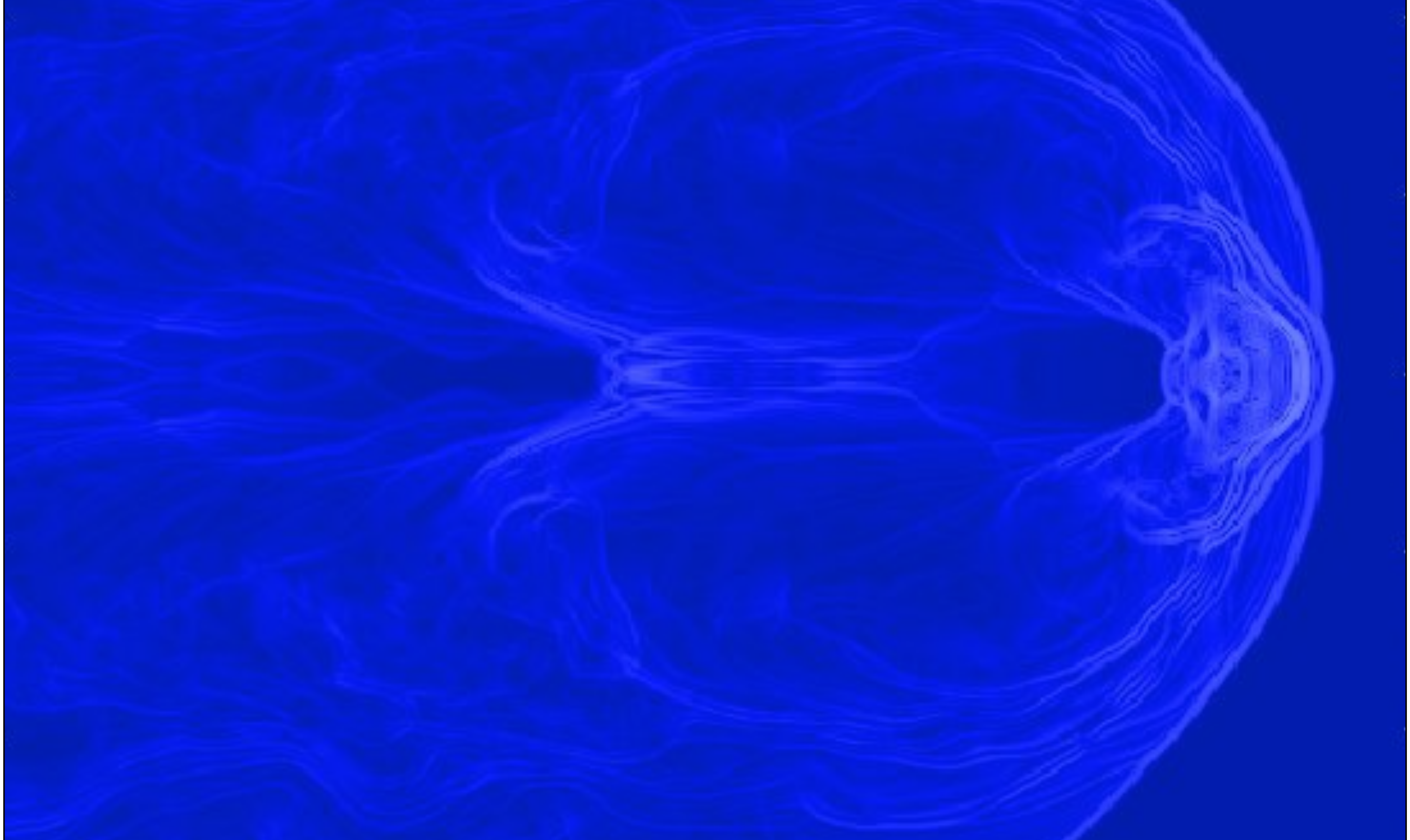
**TMVA analysis for data with E>20 GeV**

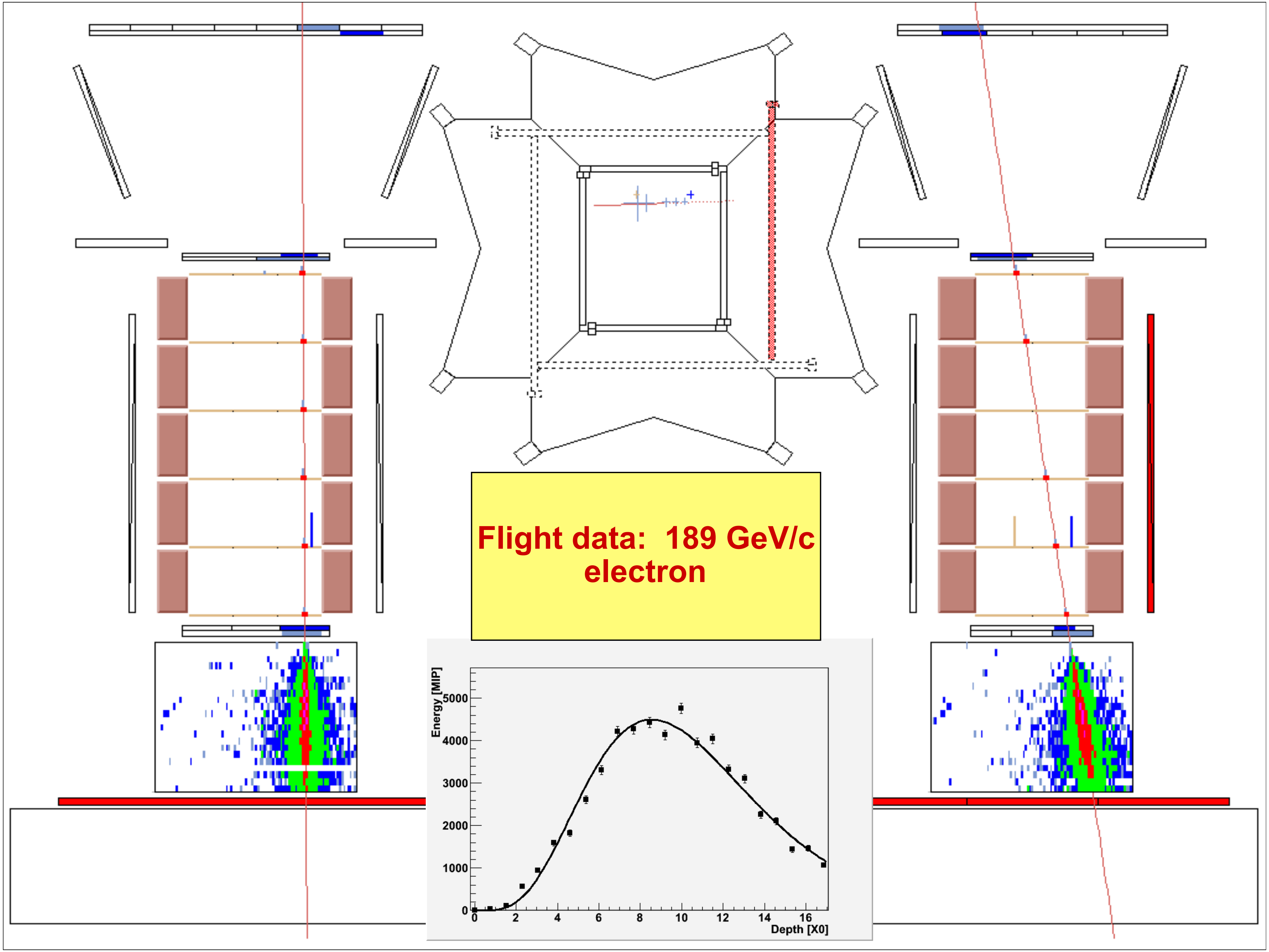


# Summary

- PAMELA has been in orbit and studying cosmic rays for ~1400 days. >$10^9$ triggers registered, and >18 TB of data has been down-linked.
- Electron flux analyses based on different approaches with different systematics are in agreement
- High energy positron fraction (>10 GeV) increases significantly (and unexpectedly!) with energy, electron flux shows a possible break in the spectrum. Primary source?
- Analysis ongoing to extend the electrons and positrons measurements and to increase the statistics.

# Backup slides





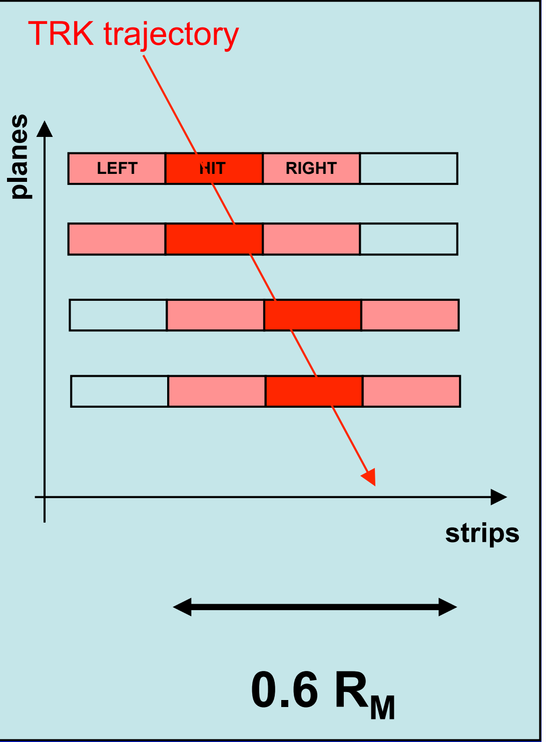
Flight data: 189 GeV/c electron
Energy [MIP]
Depth [X0]
0
1000
2000
3000
4000
5000
0
2
4
6
8
10
12
14
16

# Positron selection

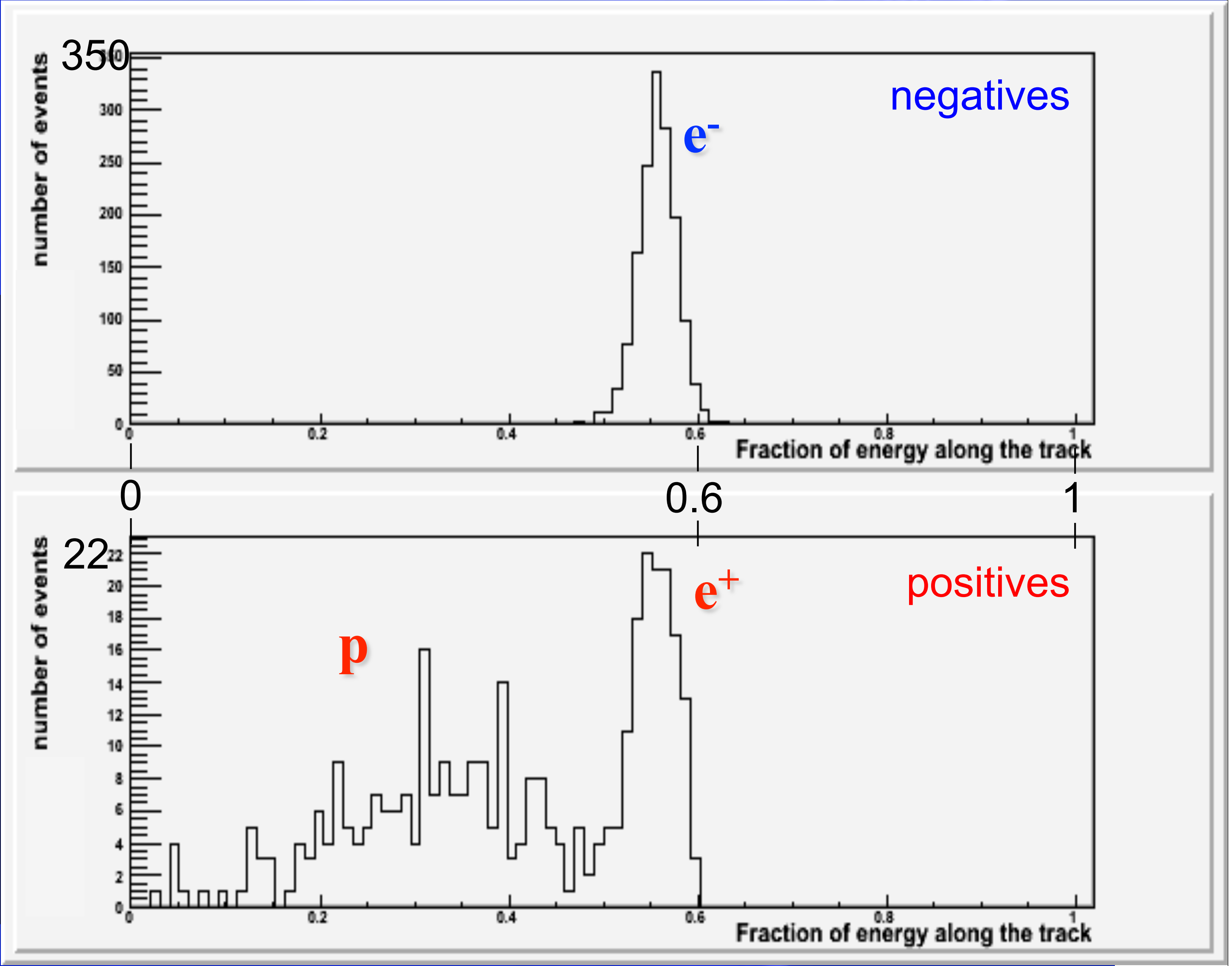
**Pre-selections:**

- **Energy-momentum match**
- **Starting point of shower**

**Rigidity: 20-30 GV**




**Fraction of energy released along the track (left, hit, right) in the calorimeter**



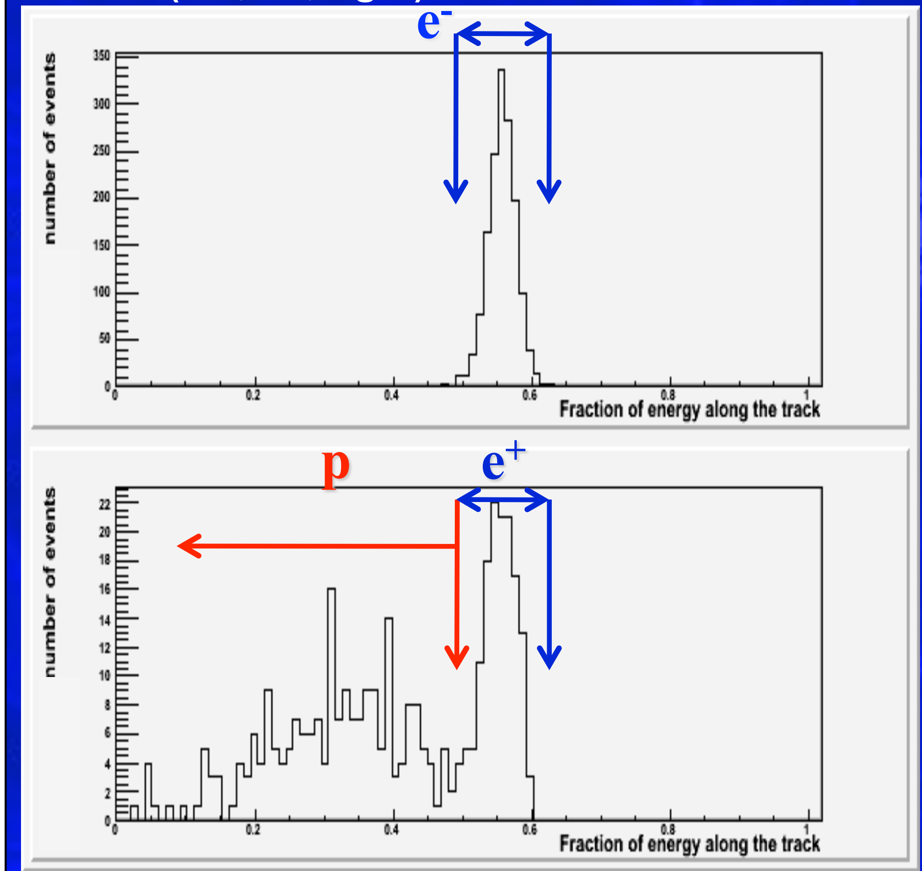
# Positron selection

**Pre-selections:**

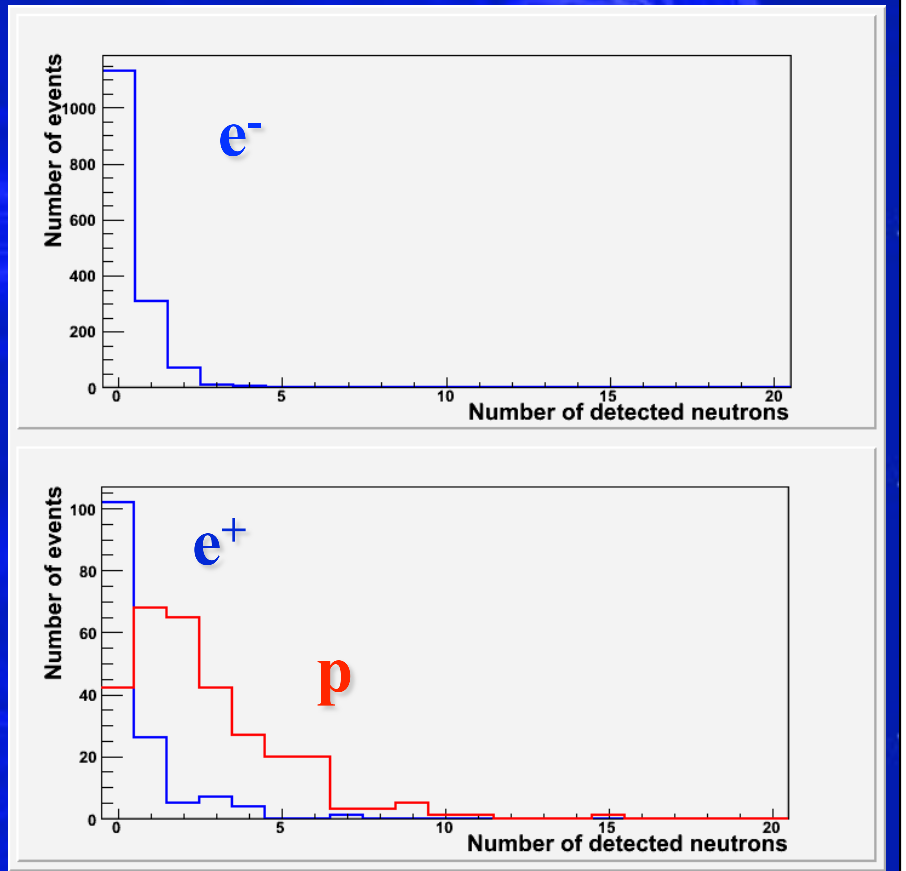
- Energy-momentum match
- Starting point of shower

**Rigidity: 20-30 GV**

**Fraction of charge released along the track (left, hit, right) in the calorimeter**




**Neutrons detected by ND**

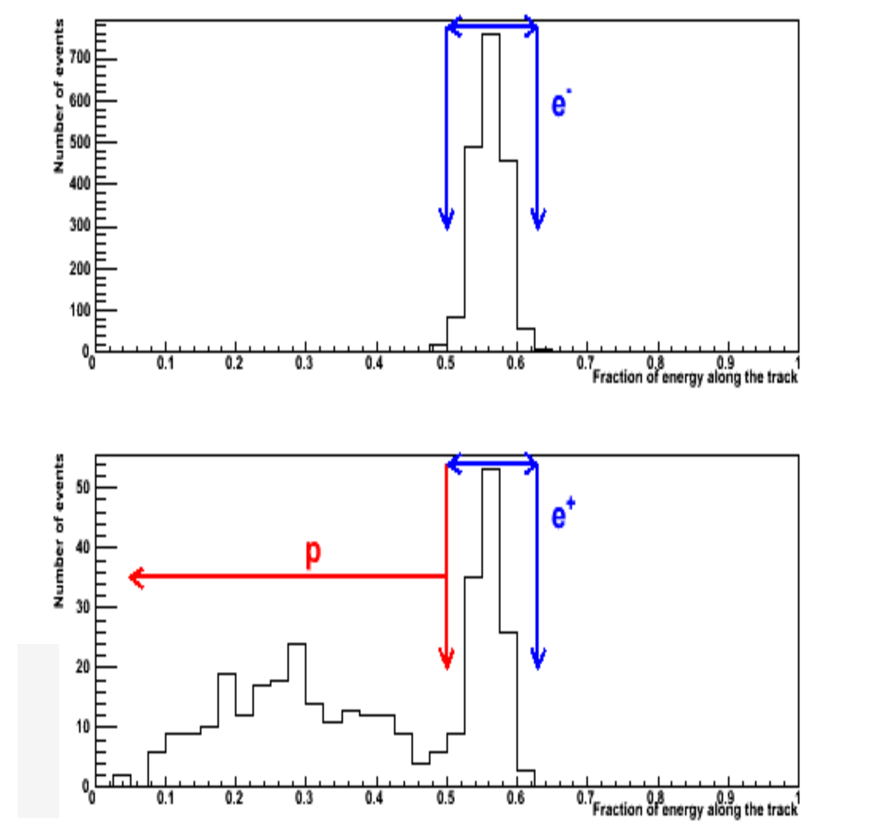


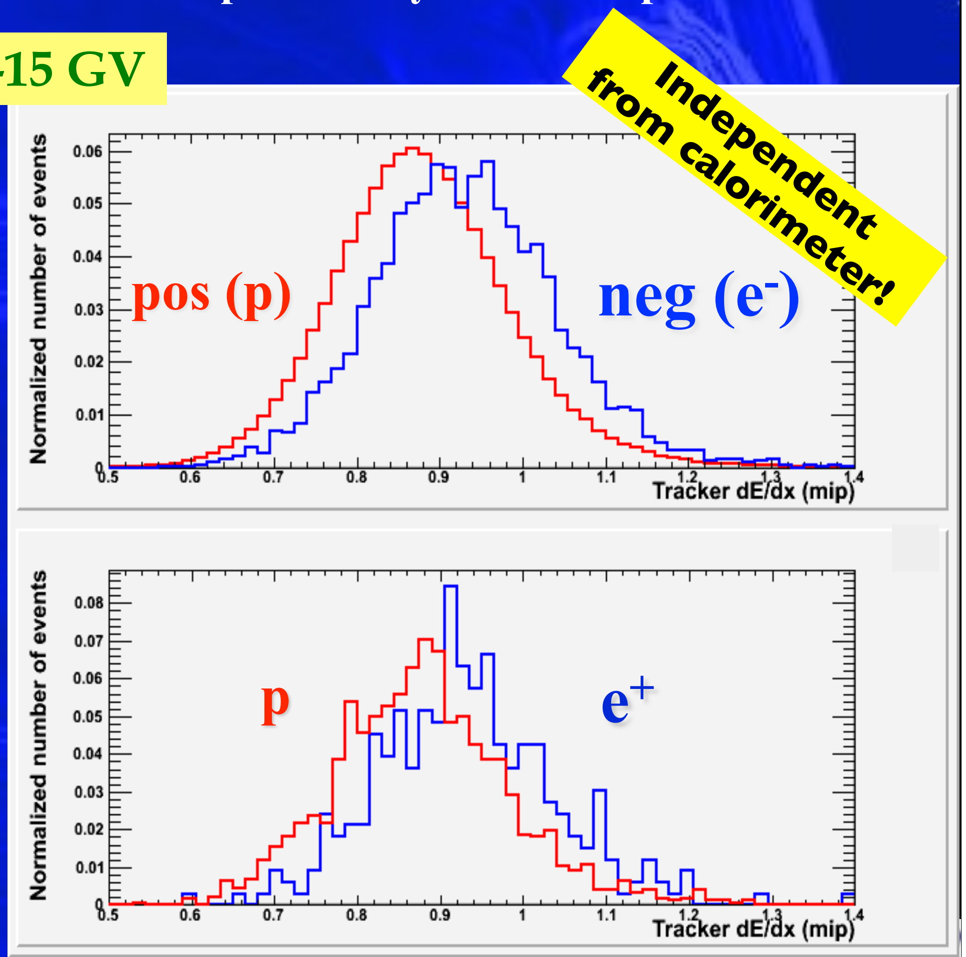
# Positron selection

$$-\frac{dE}{dx} = K z^2 \frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_e c^2\beta^2\gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$

**Energy loss in silicon tracker detectors:**
- **Top: positive (mostly p) and negative events (mostly $e^-$)**
- **Bottom: positive events identified as p and $e^+$ by trasversal profile method**

**Rigidity: 10-15 GV**



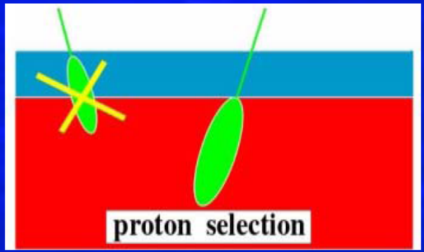



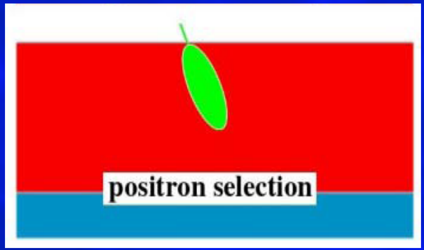
# Background estimation from data

**Pre-selections:**

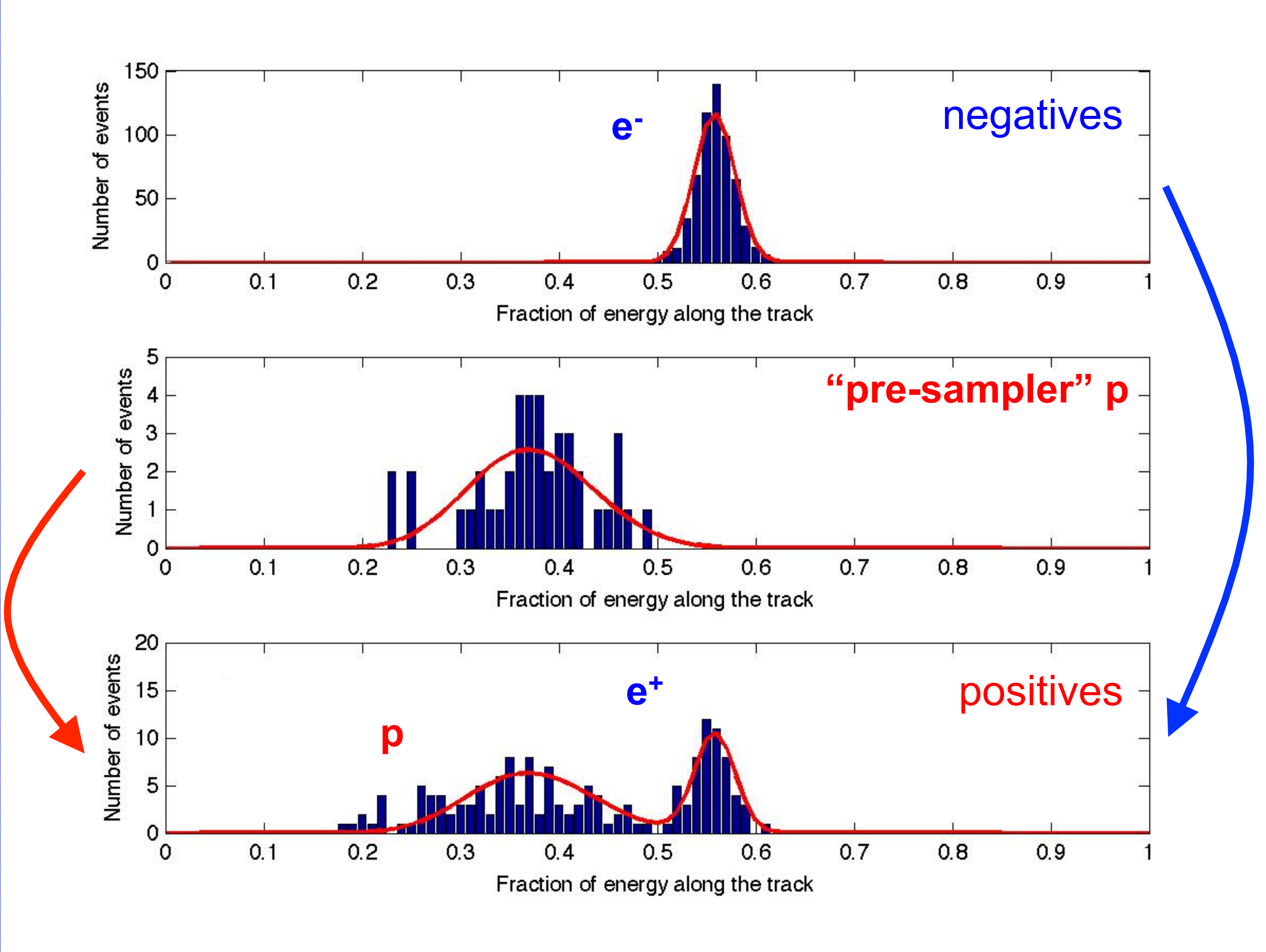
- **Energy-momentum match**
- **Starting point of shower**

**Rigidity: 28-42 GV**

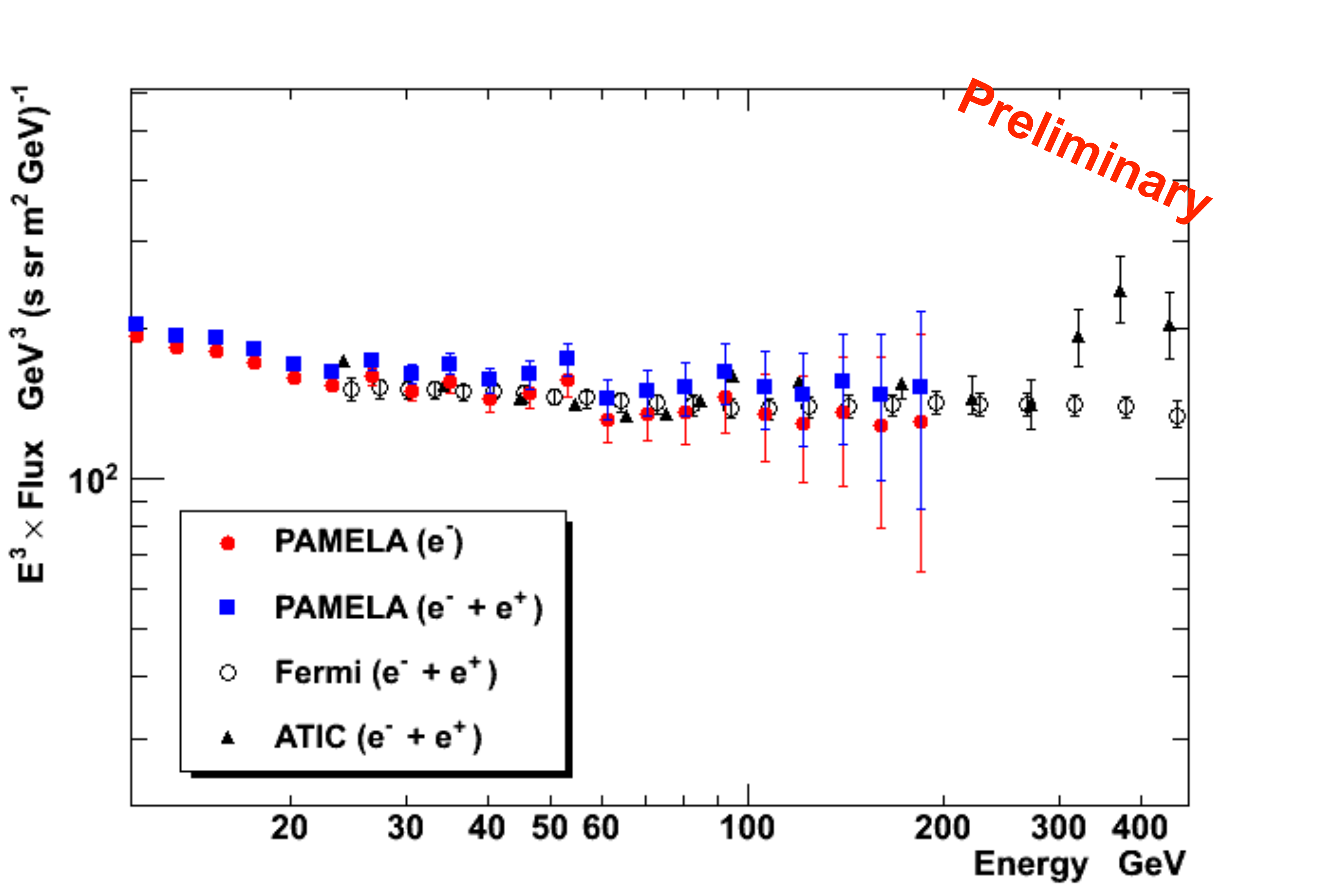



**Fraction of energy released along the track (left, hit, right) in the calorimeter**



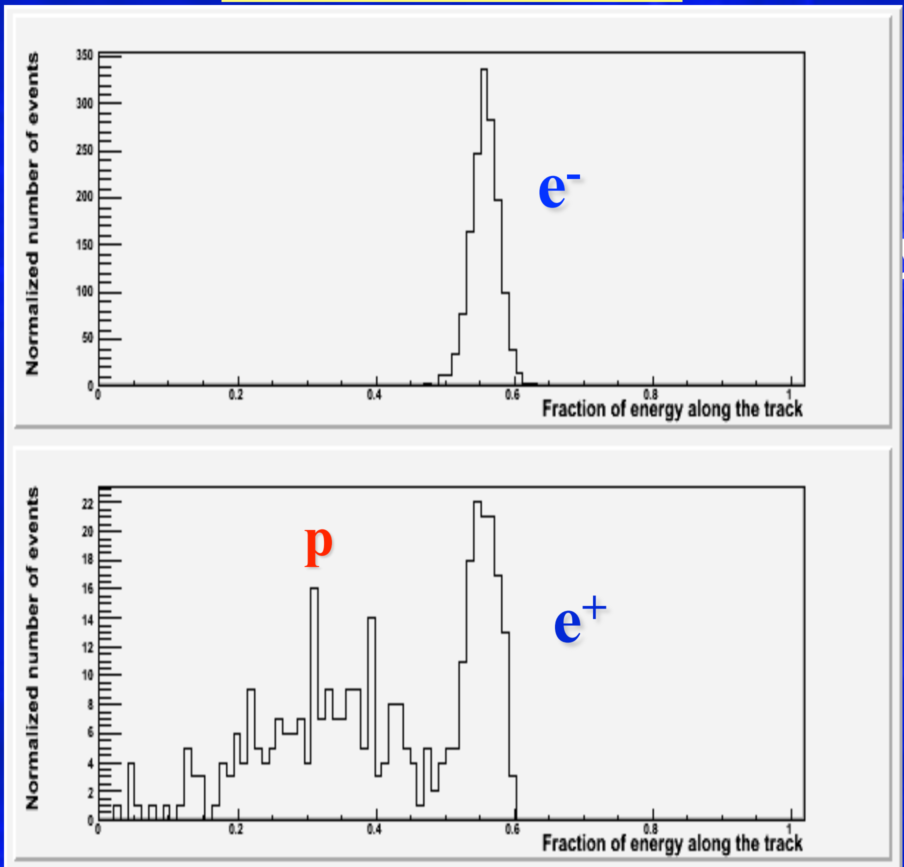
# All electron flux - tracker-based



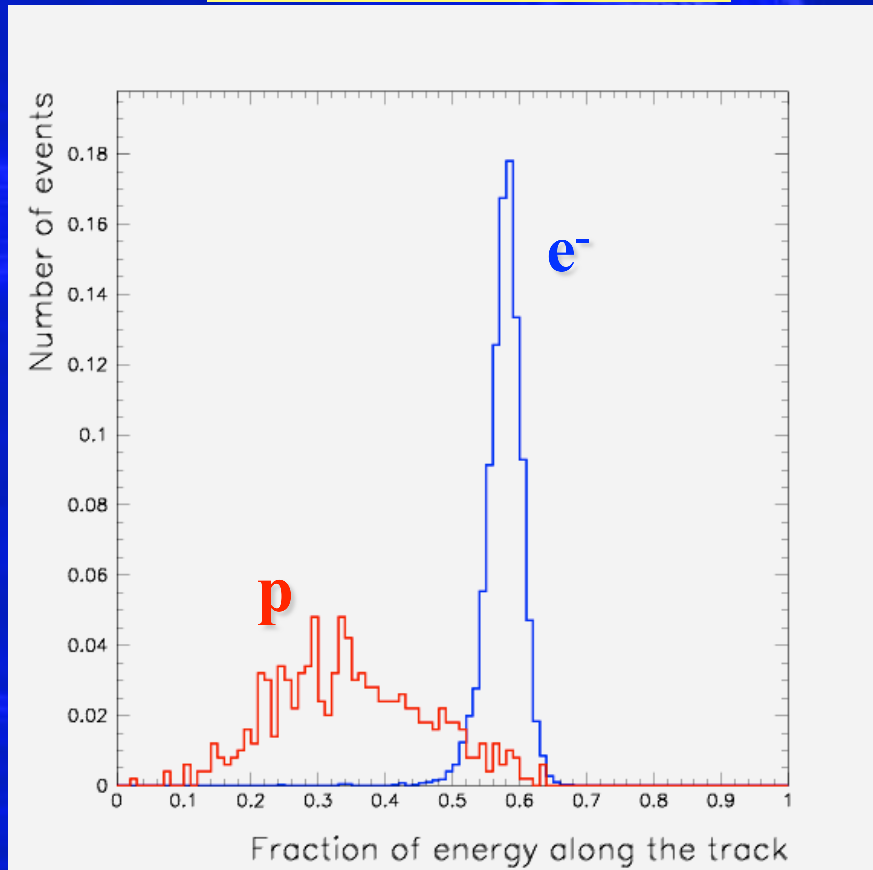
# Positron fraction, test beam data

**Fraction of energy released along the calorimeter track (left, hit, right)**

**Flight data:**
**rigidity: 20-30 GV**

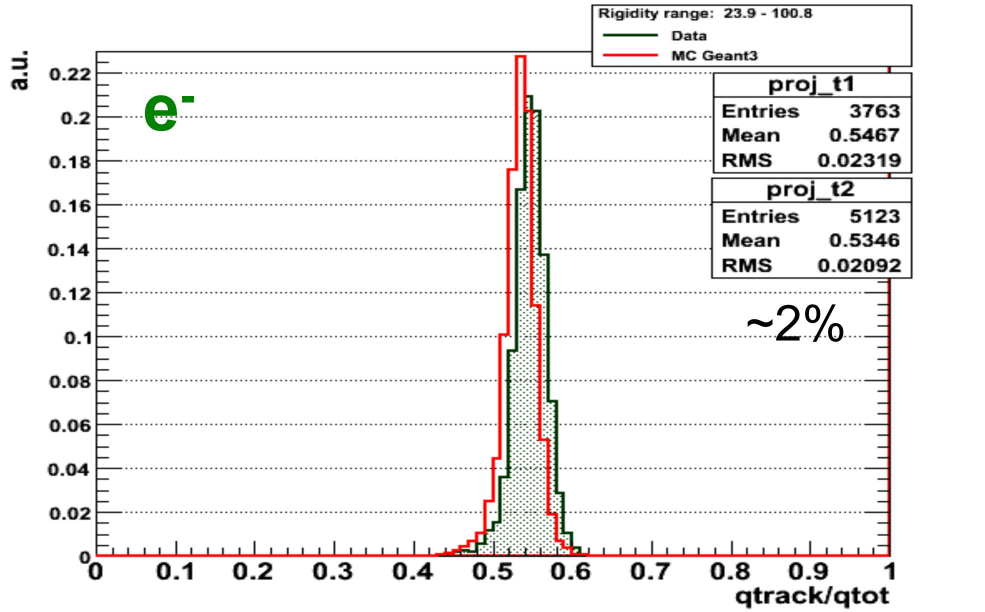


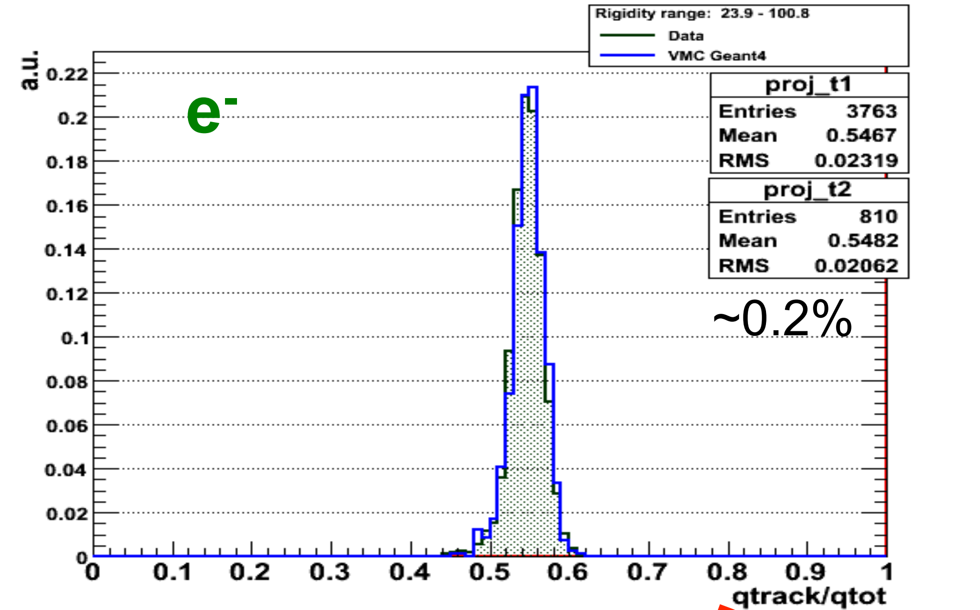

**Test beam data**
**Momentum: 50GeV/c**




**Energy-momentum match**
**Starting point of shower**

# Positron fraction, calorimeter simulation

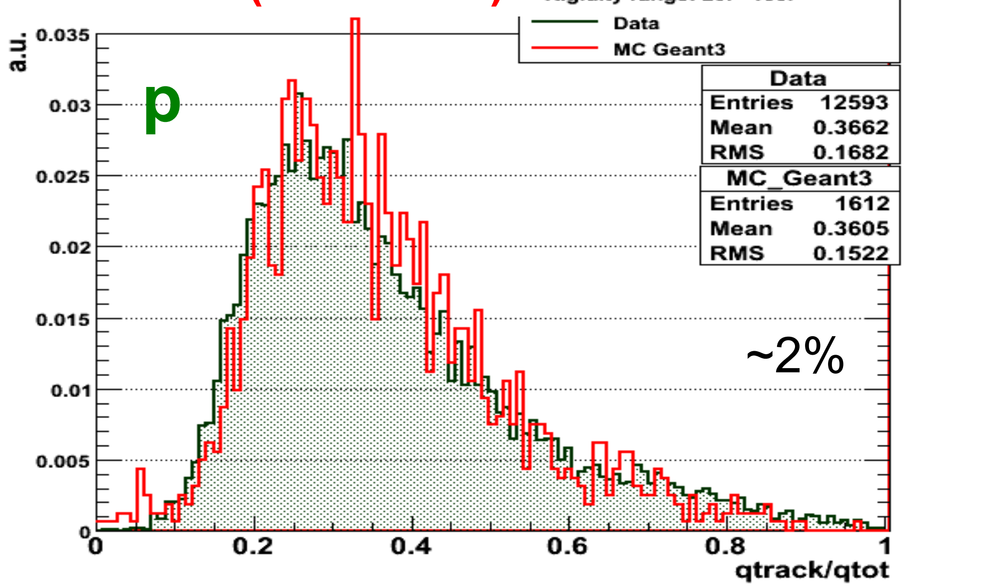


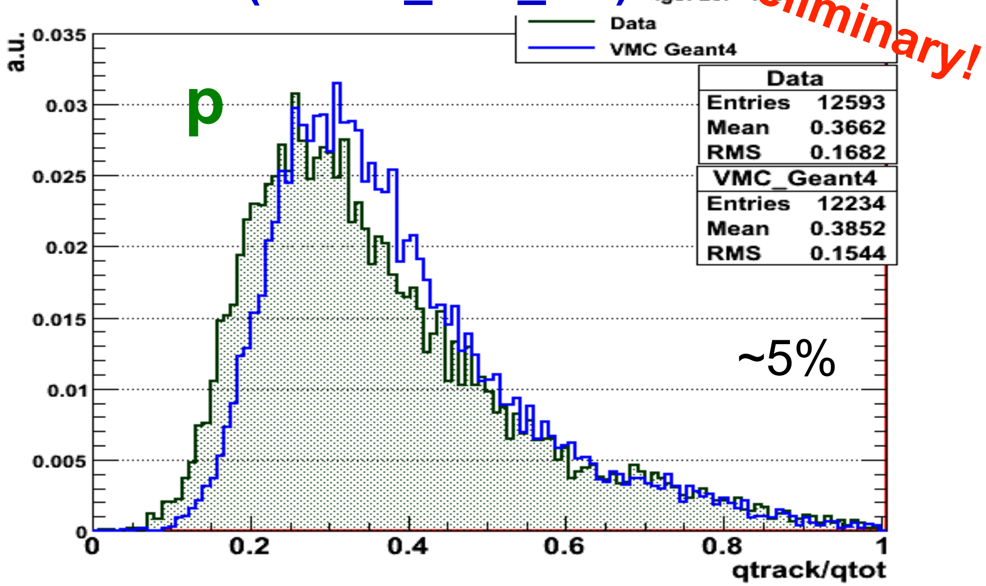




**GEANT 3 (GHEISHA)**

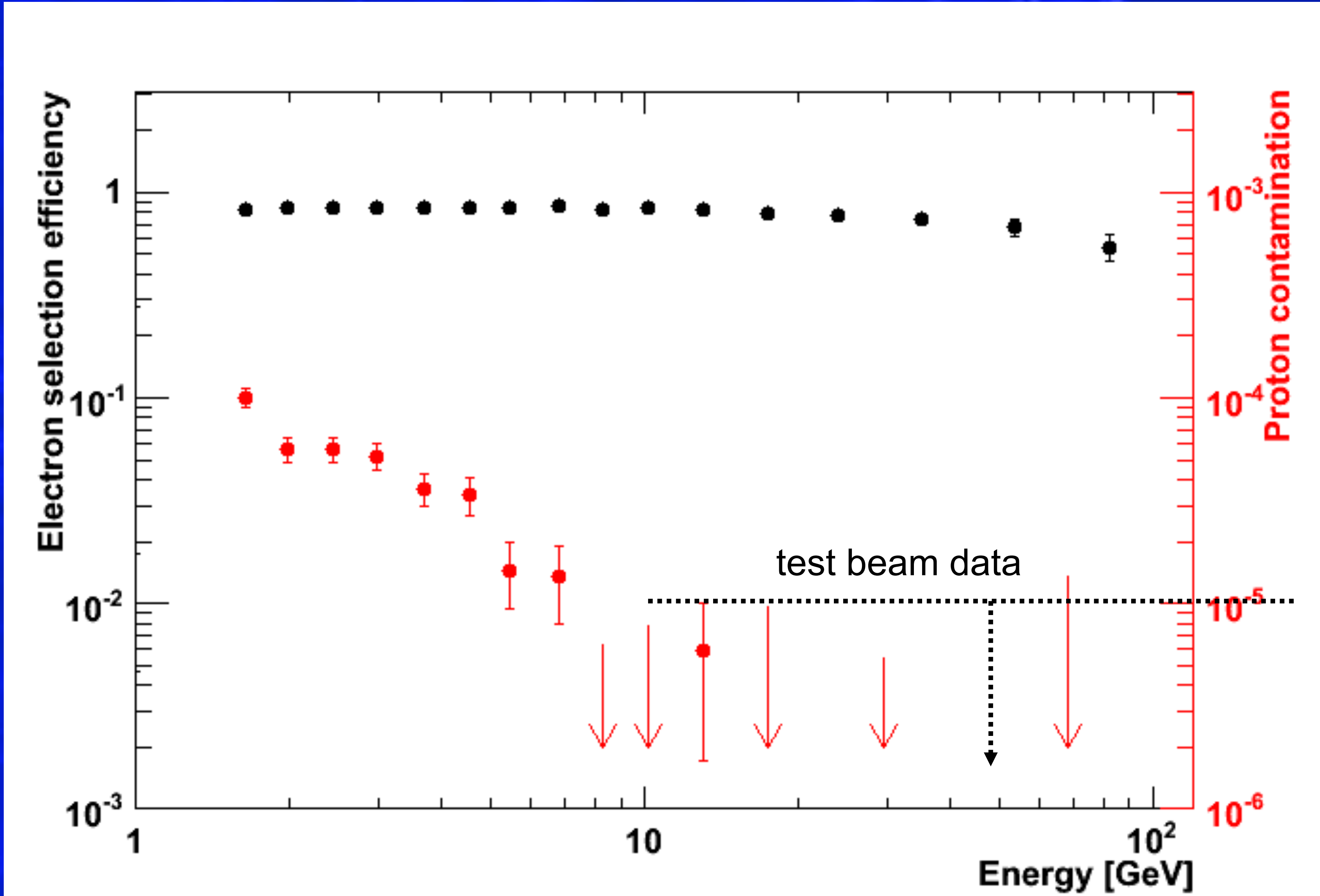
**GEANT 4 (QGSP_BIC_HP)**

**Preliminary!**

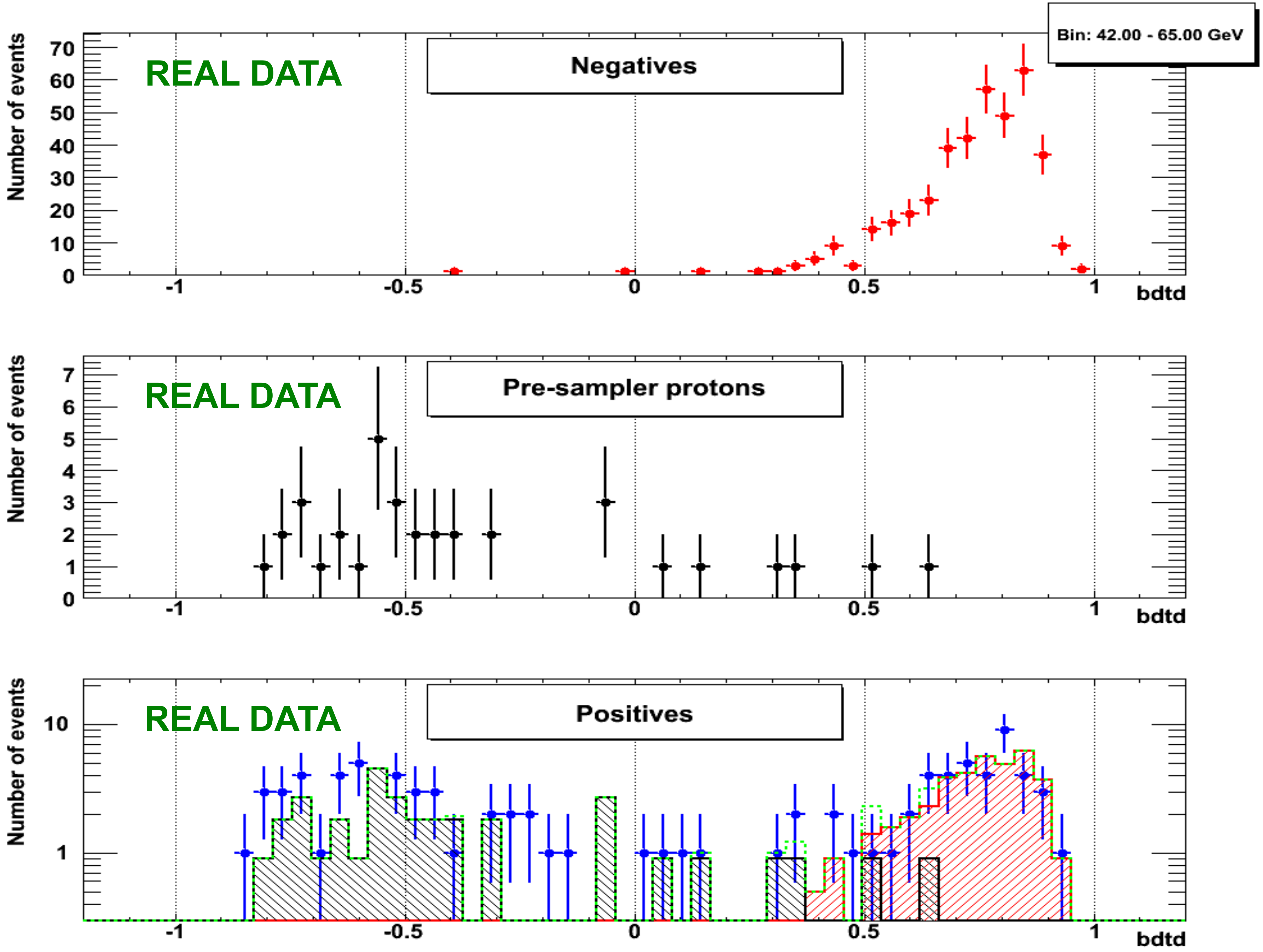


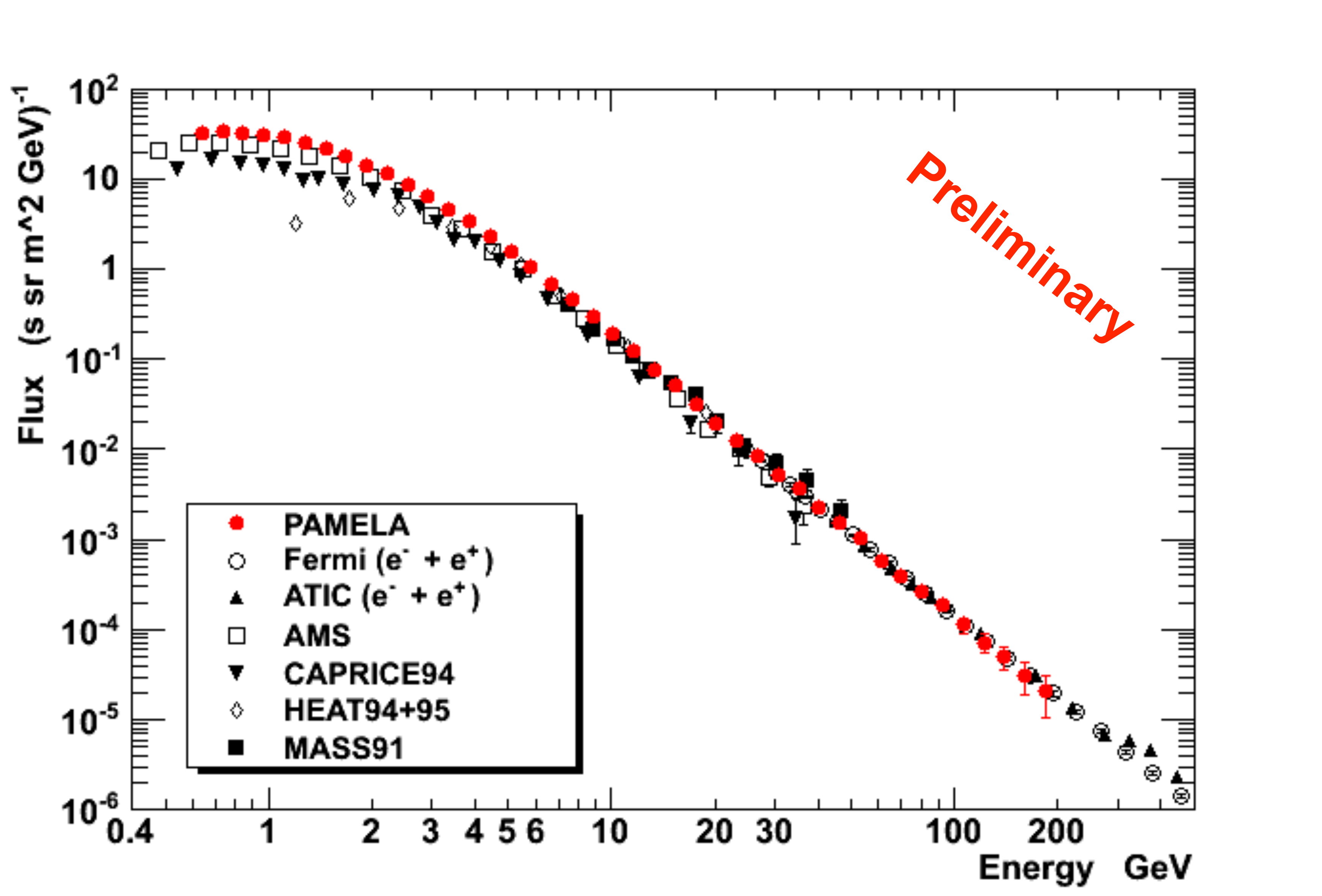
# Positron selection with calorimeter



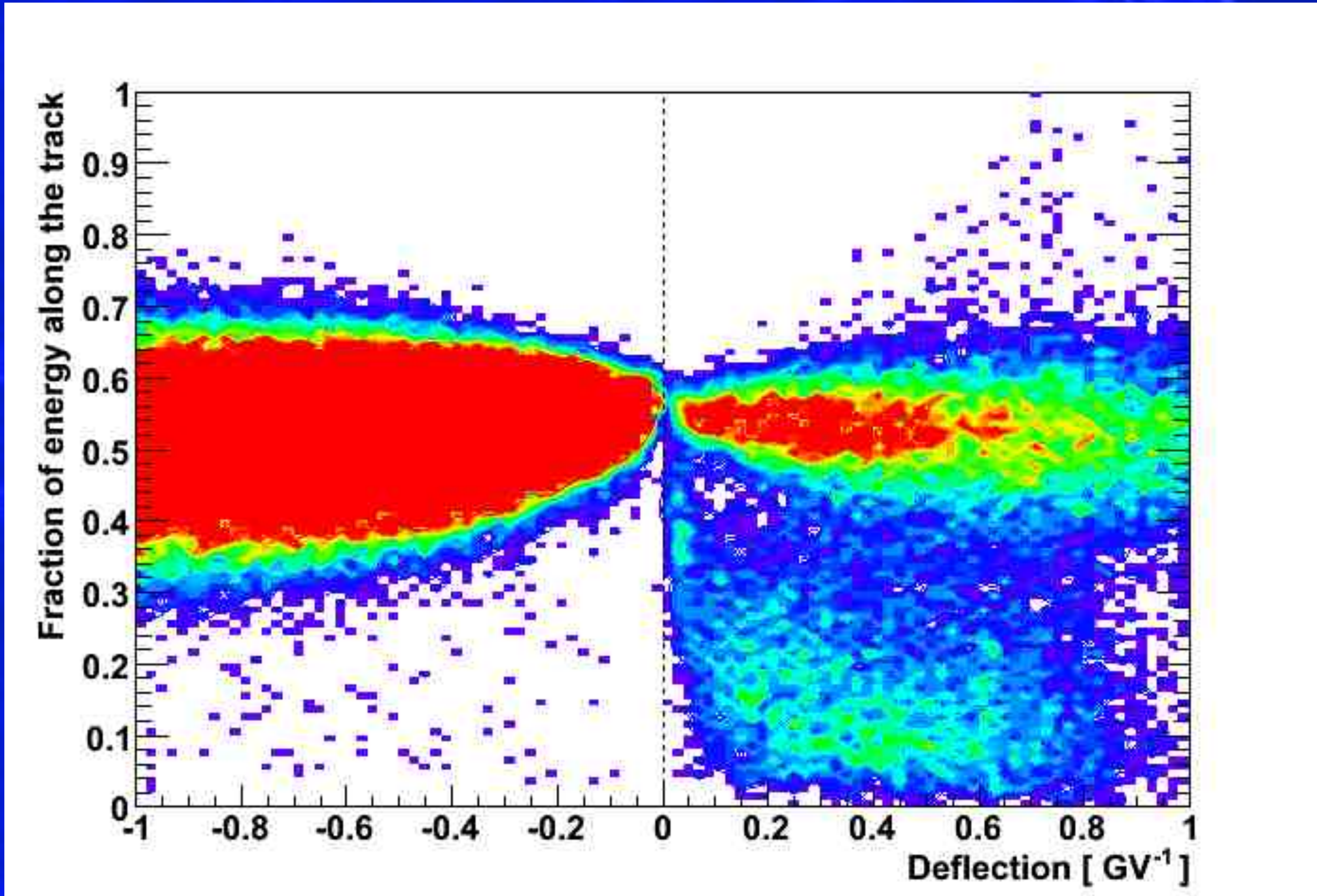
# Boosted decision tree output 42-65 GeV



# Electron flux - tracker-based



# Positron selection with calorimeter



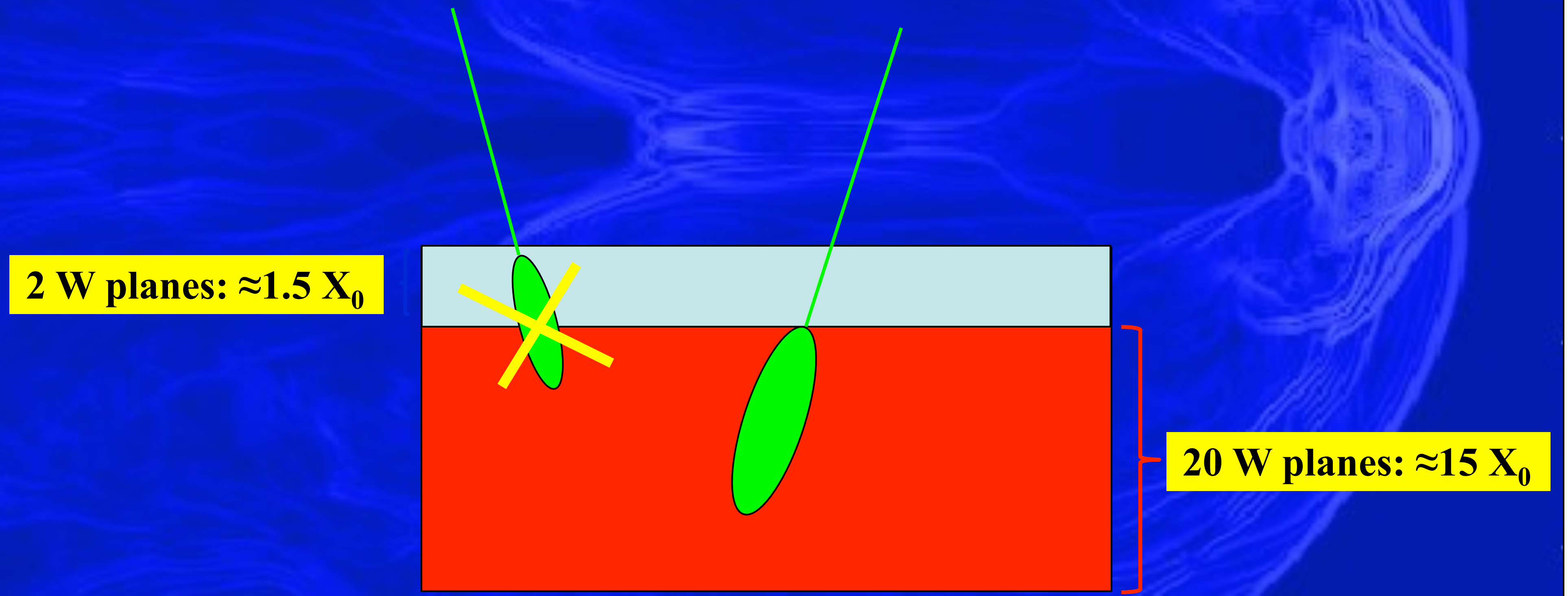

Fraction of charge released along the calorimeter track (left, hit, right)

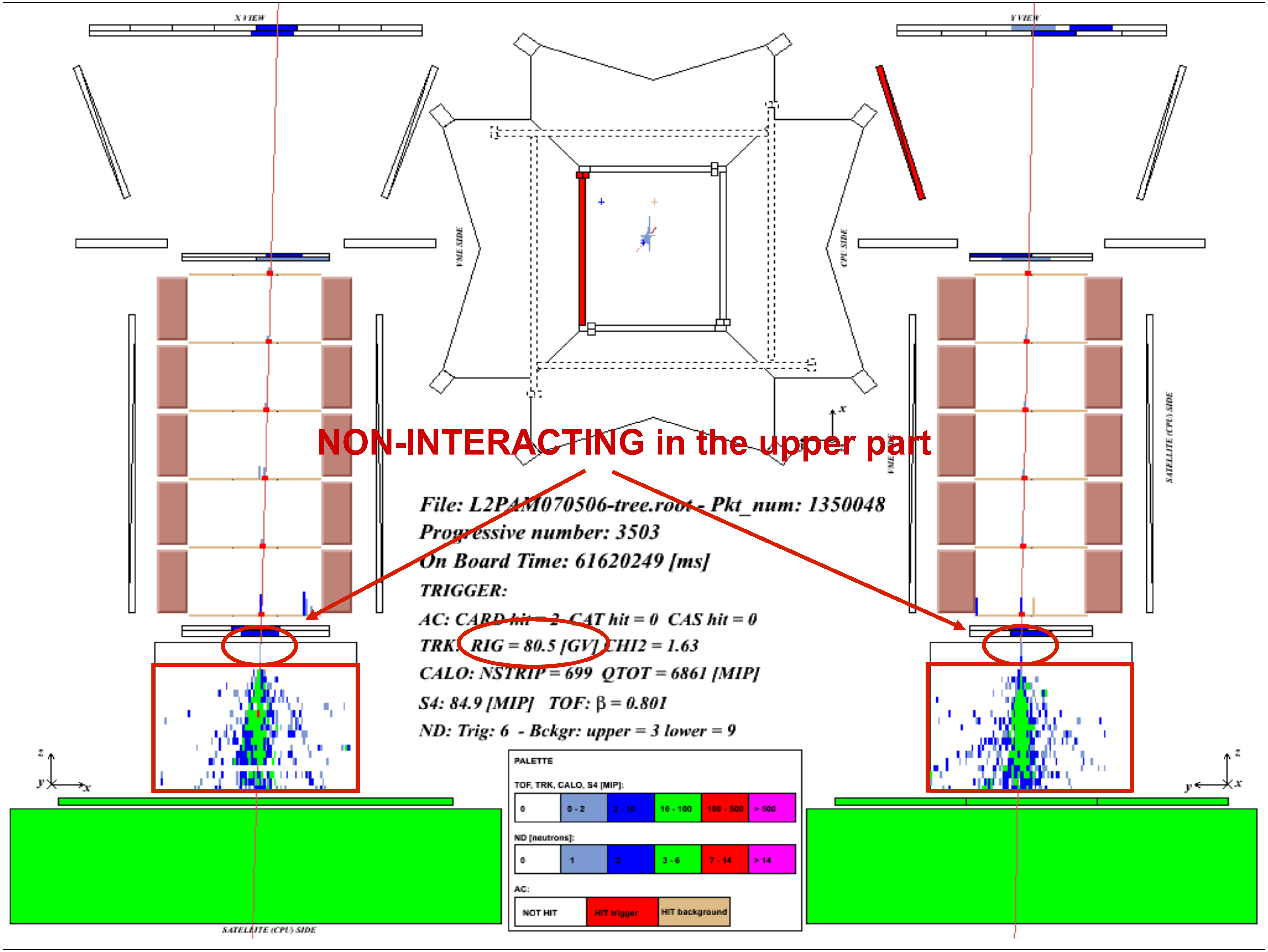
+

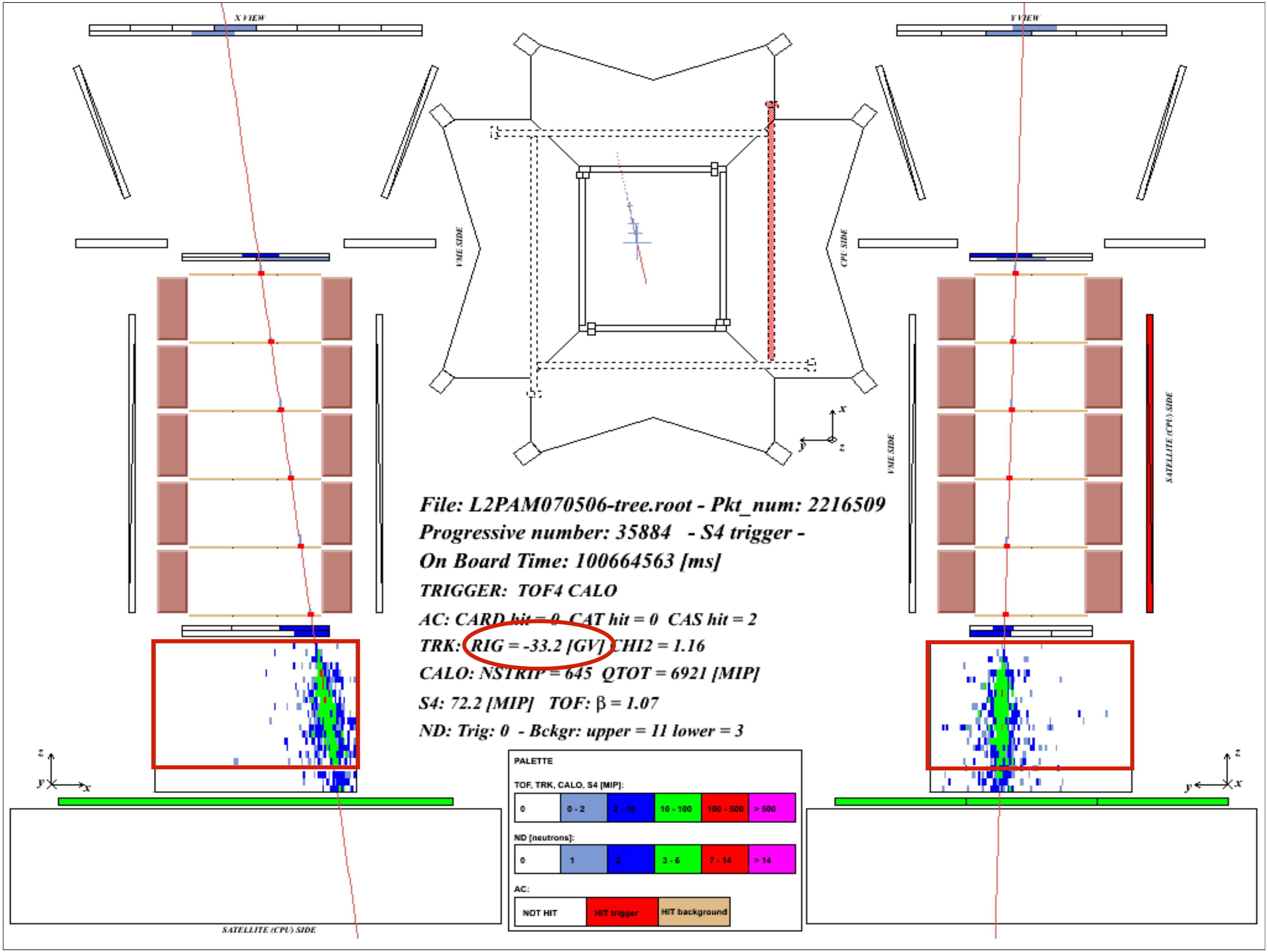
Energy-momentum match
Starting point of shower

# The "pre-sampler" method

**CALORIMETER: 22 W planes: 16.3 $X_0$**




X VIEW
Y VIEW
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
NON-INTERACTING in the upper part
File: L2PAM070506-tree.root - Pkt_num: 1350048
Progressive number: 3503
On Board Time: 61620249 [ms]
TRIGGER:
AC: CARD hit = 2 CAT hit = 0 CAS hit = 0
TRK: RIG = 80.5 [GV] CHI2 = 1.63
CALO: NSTRIP = 699 QTOT = 6861 [MIP]
S4: 84.9 [MIP] TOF: β = 0.801
ND: Trig: 6 - Bckgr: upper = 3 lower = 9
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background

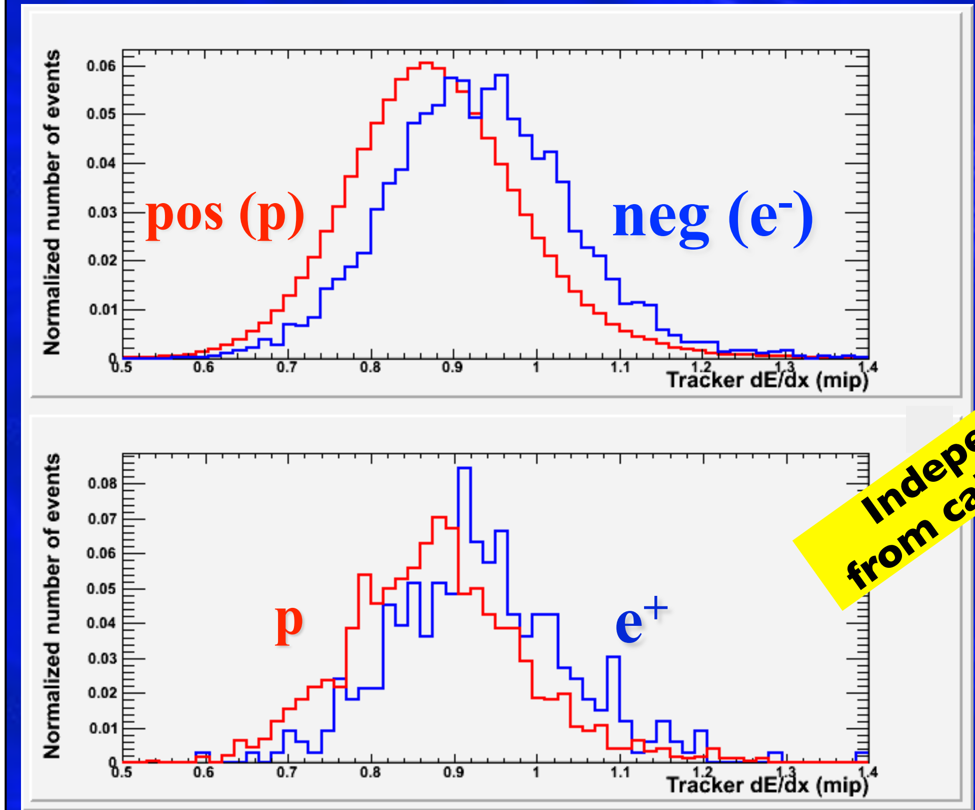

X VIEW
Y VIEW
VME SIDE
CPU SIDE
SATELLITE (CPU) SIDE
File: L2PAM070506-tree.root - Pkt_num: 2216509
Progressive number: 35884 - S4 trigger -
On Board Time: 100664563 [ms]
TRIGGER: TOF4 CALO
AC: CARD hit = 0 CAT hit = 0 CAS hit = 2
TRK: RIG = -33.2 [GV] CHI2 = 1.16
CALO: NSTRIP = 645 QTOT = 6921 [MIP]
S4: 72.2 [MIP] TOF: β = 1.07
ND: Trig: 0 - Bckgr: upper = 11 lower = 3
PALETTE
TOF, TRK, CALO, S4 [MIP]:
0
0 - 2
2 - 10
10 - 100
100 - 500
> 500
ND [neutrons]:
0
1
2
3 - 6
7 - 14
> 14
AC:
NOT HIT
HIT trigger
HIT background

# Positron selection

**Energy loss in silicon tracker detectors:**

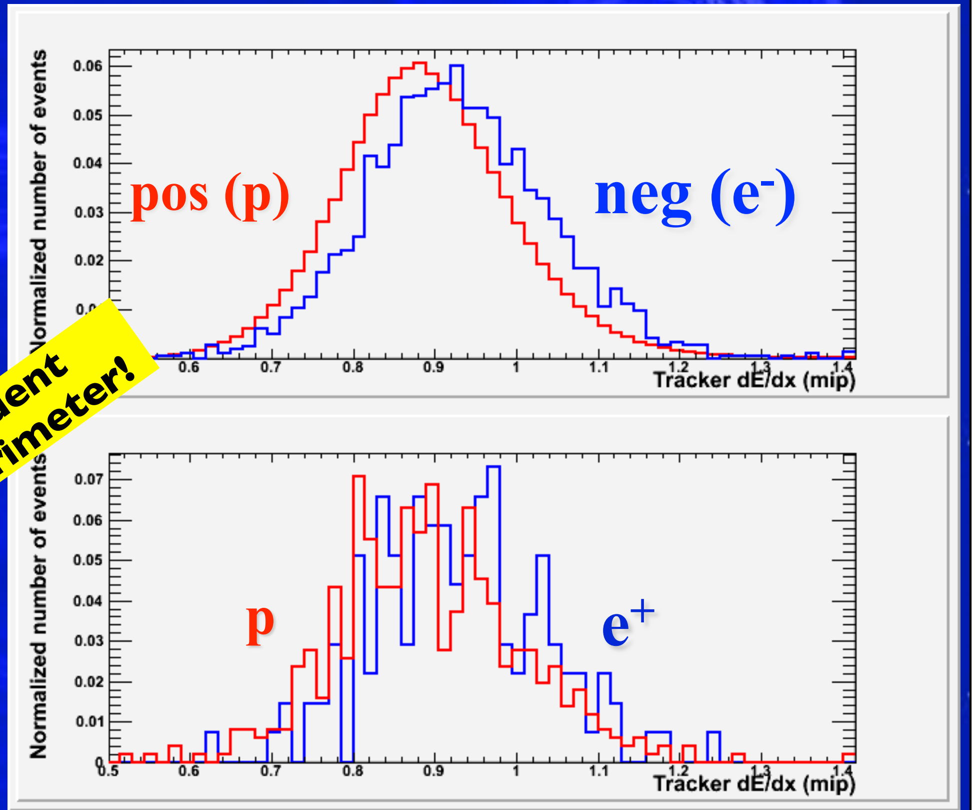
- **Top: positive (mostly p) and negative events (mostly e$^-$)**
- **Bottom: positive events identified as p and e$^+$ by trasversal profile method**

$$-\frac{dE}{dx} = Kz^2\frac{Z}{A}\frac{1}{\beta^2}\left[\frac{1}{2}\ln\frac{2m_ec^2\beta^2\gamma^2T_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2}\right]$$




**Rigidity: 10-15 GV**

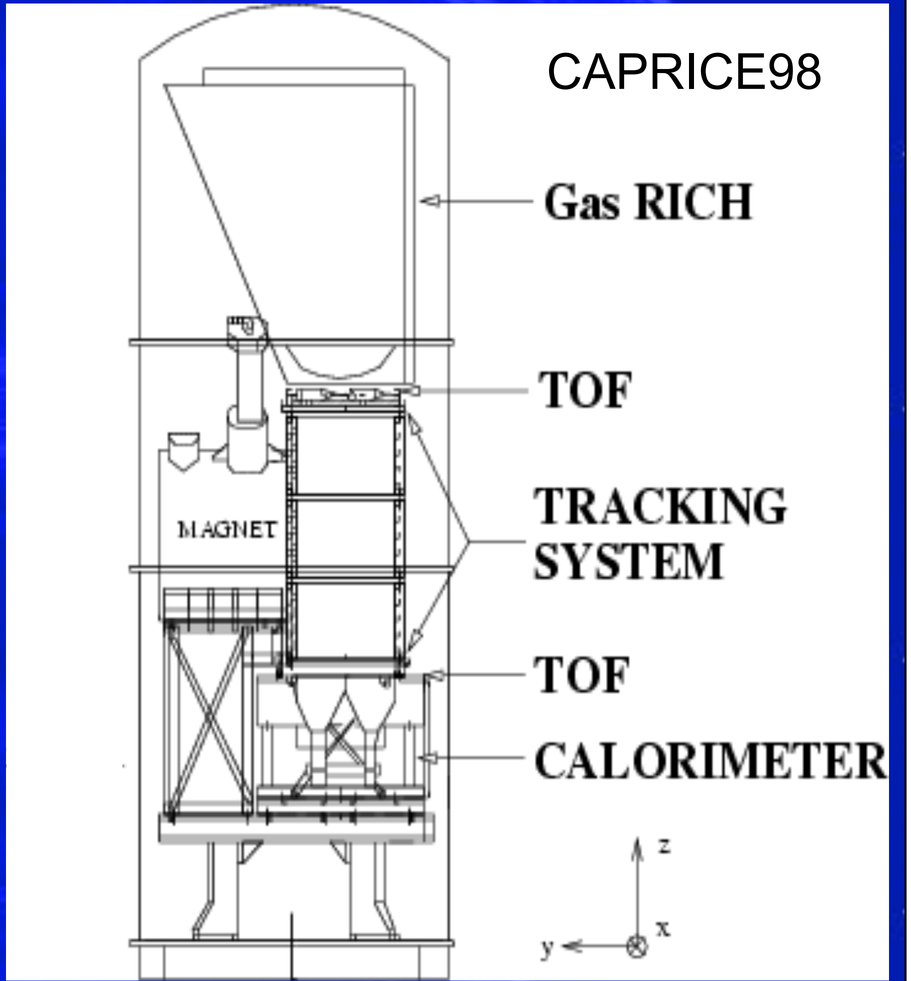
**Independent from calorimeter!**




**Rigidity: 15-20 GV**

# Proton rejection power: C98 vs PAMELA

| | CAPRICE98 | PAMELA |
|---|---|---|
| TRACKER MDR | ~350 GV | ~1000 GV |
| CALO DEPTH | 7.2 $X_0$ | 16.3 $X_0$ |
| LONGITUDINAL SAMPLING | 0.9 $X_0$ | 0.7 $X_0$ |
| TRANSVERSAL SAMPLING (strip width) | 0.3 $R_M$ (3.6 mm) | 0.2 $R_M$ (2.44 mm) |
| PROTON REJECTION | ~$10^5$ | >$10^5$ |



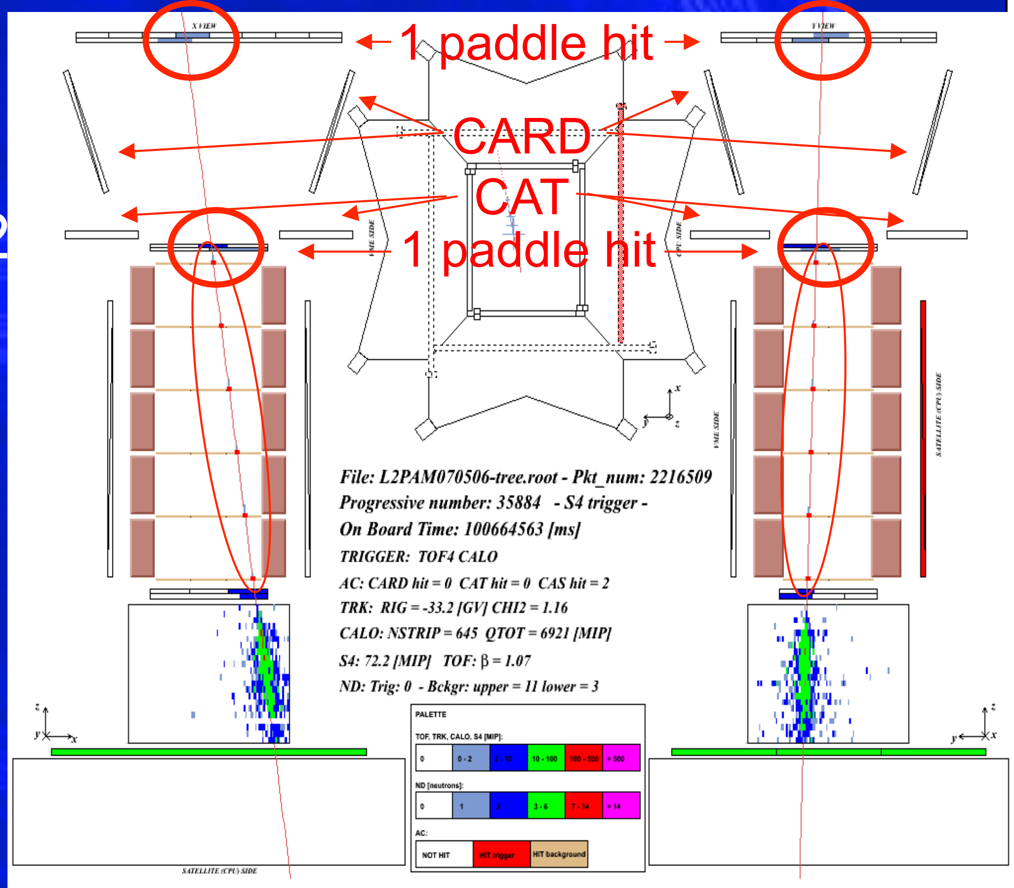

**tested with RICH up to 50 GV**

# Gamma-rays?

$\gamma/e^+$ : ~0.1 @ 10GeV
~0.2 @ 100GeV

Positron selection requires:

A. 1 MIP (>0.2MIP) signal on S1/S2
B. no multiple paddle hit on S1/S2
C. no hit on CARD and CAT
D. clean track in TRK
(no spurious hits, no clusters not used in track fitting)




From simulations:
$\gamma/e^+$ after cuts A-B-C:
< 4 x $10^{-3}$ @ 10GeV
< 2 x $10^{-3}$ @ 100GeV

# Unfolding (or deconvolution) problem

**Real energy particle spectrum**

↓

Instrumental effect
(energy loss, energy resolution, …)

↓

**Mesured energy particle spectrum**

**Statistical Unfolding Procedure**

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## A multidimensional unfolding method based on Bayes' theorem

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**Abstract**

Bayes' theorem offers a natural way to unfold experimental distributions in order to get the best estimates of the true ones. The weak point of the Bayes approach, namely the need of the knowledge of the initial distribution, can be overcome by an iterative procedure. Since the method proposed here does not make use of continuous variables, but simply of cells in the spaces of the true and of the measured quantities, it can be applied in multidimensional problems.

This paper presents a different approach, based on Bayes' theorem, recognized by statisticians as the most powerful tool for making statistical inferences. The main advantages with respect to other unfolding methods are:

— it is theoretically well grounded;

— it can be applied to multidimensional problems;

— it can use cells of different sizes for the distribution of the true and the experimental values;

— the domain of definition of the experimental values may differ from that of the true values;

— it can take into account any kind of smearing and migration from the true values to the observed ones;

— it gives the best results (in terms of its ability to reproduce the true distribution) if one makes a realistic guess about the distribution that the true values follow, but, in case of total ignorance, satisfactory results are obtained even starting from a uniform distribution;

— it can take different sources of background into account;

— it does not require matrix inversion;

— it provides the correlation matrix of the results;

— it can be implemented in a short, simple and fast program, which deals directly with distributions and not with individual events.

$C_i$ = ***causes*** (cosmic particle with real momentum in the bin number ***i=1,2…n$_c$***)

$E_i$ = ***effect*** (cosmic particle with measured momentum in the bin number ***i=1,2…n$_c$***)

$P_0(C_i)$ = ***probability of the causes*** (proportional to the cosmic ray spectrum)

$P(E_j|C_i)$ = ***matrix probability that the cause $C_i$ produces the effect $E_j$***
(from the simulation of the device)

$$P(C_i|E_j) = \frac{P(E_j|C_i)P_0(C_i)}{\sum_{l=1}^{n_C} P(E_j|C_l)P_0(C_l)}$$

**Bayes' theorem**

***$P(C_i|E_j)$ = smearing probability that the observed effect $E_j$ is produced by the cause $C_i$***

# Bayesian Unfoding Procedure

$P(E_j|C_i)$ = *matrix probability* ⇐ **From simulation**

$P_0(C_i)$ = *probability of the causes* ⇐ **Initial assumption**

$$P(C_i|E_j) = \frac{P(E_j|C_i)P_0(C_i)}{\sum_{l=1}^{n_C} P(E_j|C_l)P_0(C_l)}$$ ⇐ **Bayes' theorem**

If one observes $n(E)$ events with effect E, the expected number of events assignable to each of the causes is

$$\hat{n}(C_i) = n(E)P(C_i|E). \quad (2)$$

$P_{new}(C_i) \sim \hat{n}(C_i)$

**Iterative procedure**