KTH VETENSKAP OCH KONST

PaMeLa — a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics

Oskar Klein centre

PAMELA measurements of high energy cosmic ray positrons

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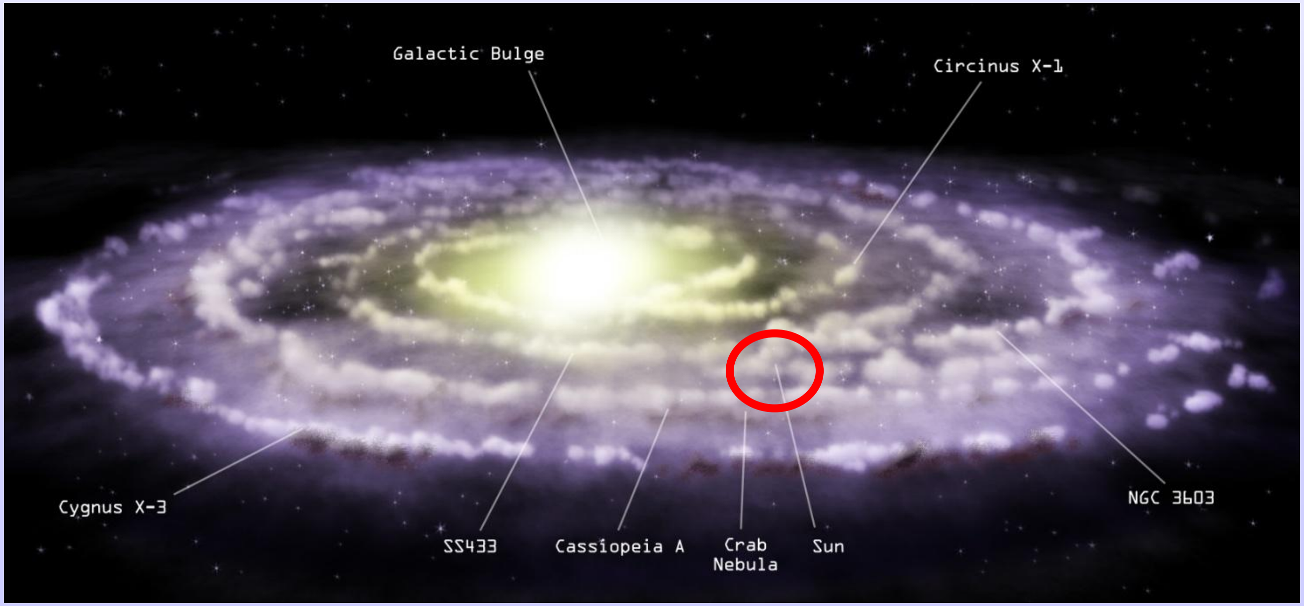
PhD defence, June 11th 2012, Stockholm

Cosmic ray positrons

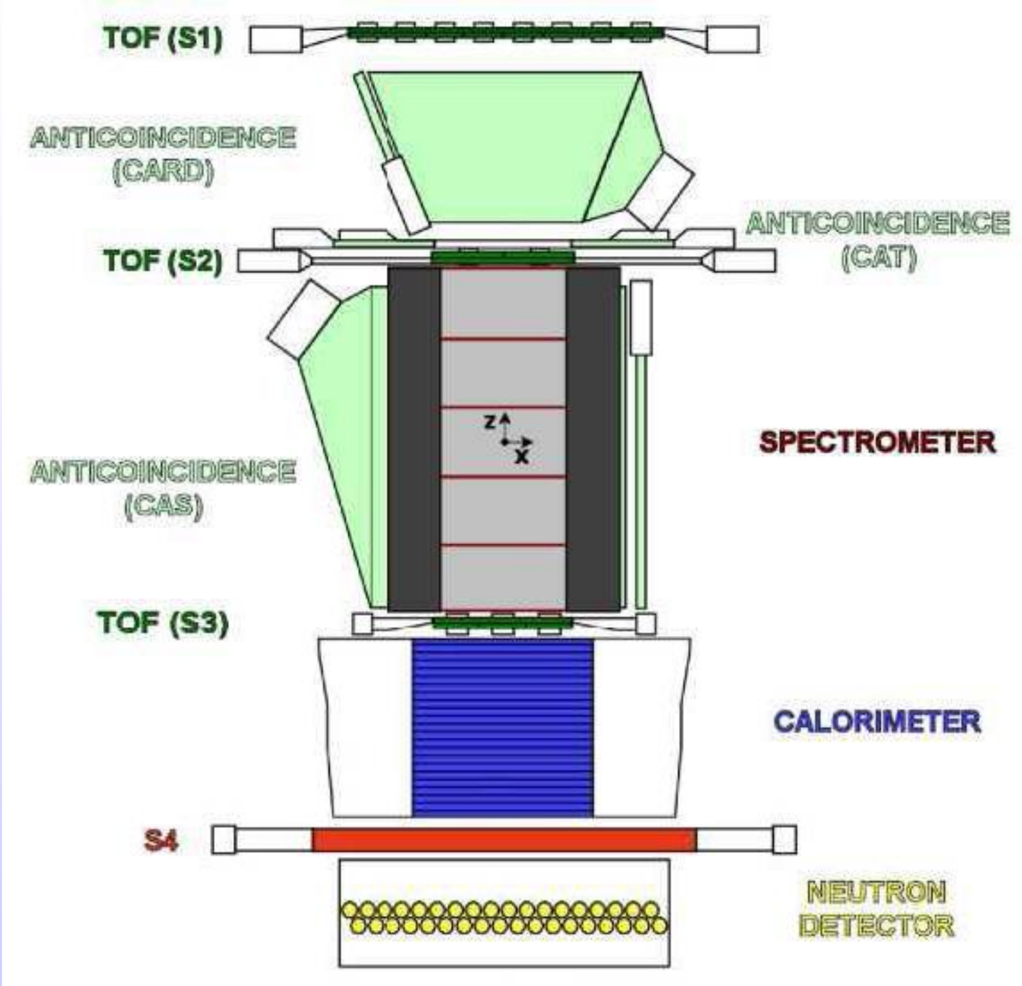
- Electrons account for ~ 2% of the cosmic ray particles
  → electrons and positrons lose energy very efficiently as they propagate
  → they can probe acceleration and propagation mechanisms in a galactic region of ~ 1 kpc

- positrons are believed to be mainly secondary particles: $p + p \rightarrow \pi^{\pm}, K^{\pm}$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} \rightarrow e^{\pm} + \nu_{e}$$
$$K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}\,,\ \pi^{0} + \pi^{\pm}$$



The PAMELA experiment



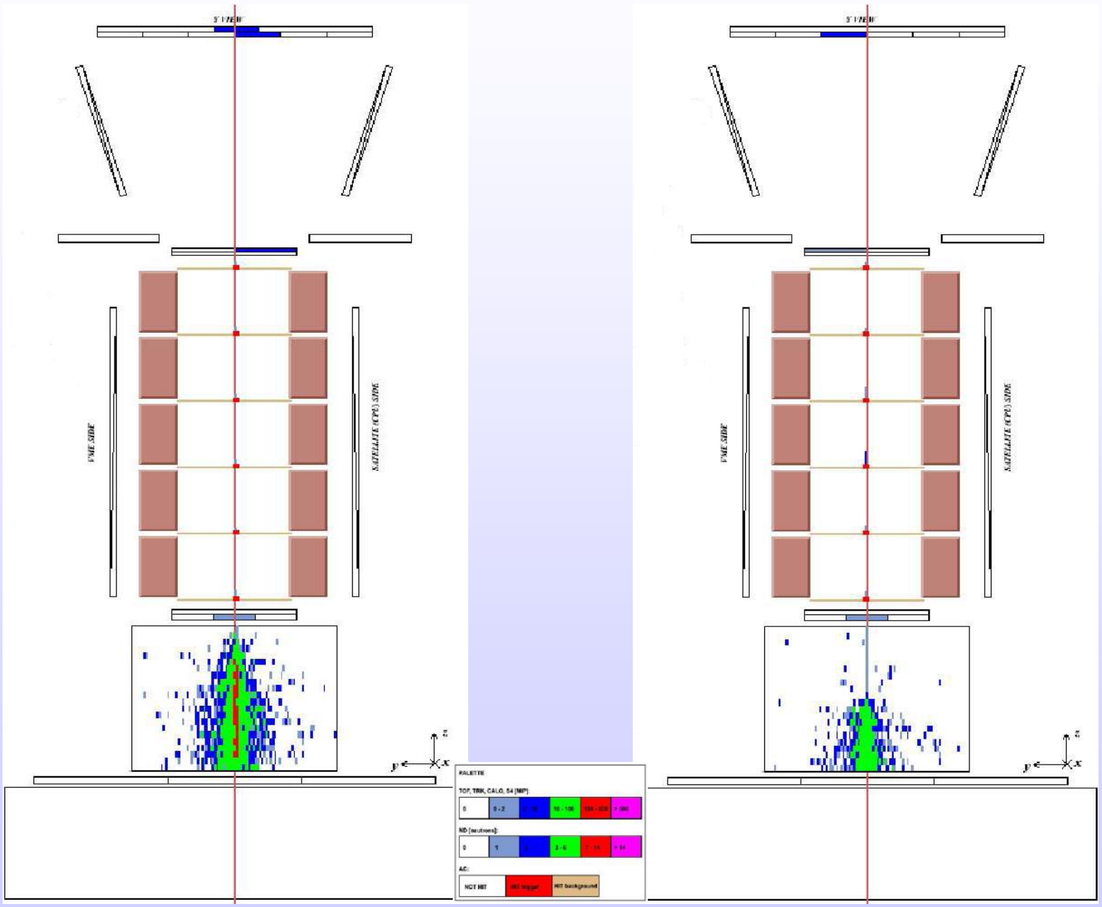
P. Picozza et al., 2007, Astrop. Phys., 27

- Launch: 15th June 2006
- height of ~ 1.3 m
- mass of 470 kg

- time-of-flight system
- magnetic spectrometer
- electromagnetic calorimeter
- neutron detector
- anticoincidence system

- **electromagnetic calorimeter**
  → 44 silicon sensor planes (x-y) interleaved with 22 tungsten planes
  → total depth = 16.3 X_0 ~ 0.6 λ
  → lepton – hadron separation

Electromagnetic and hadronic showers



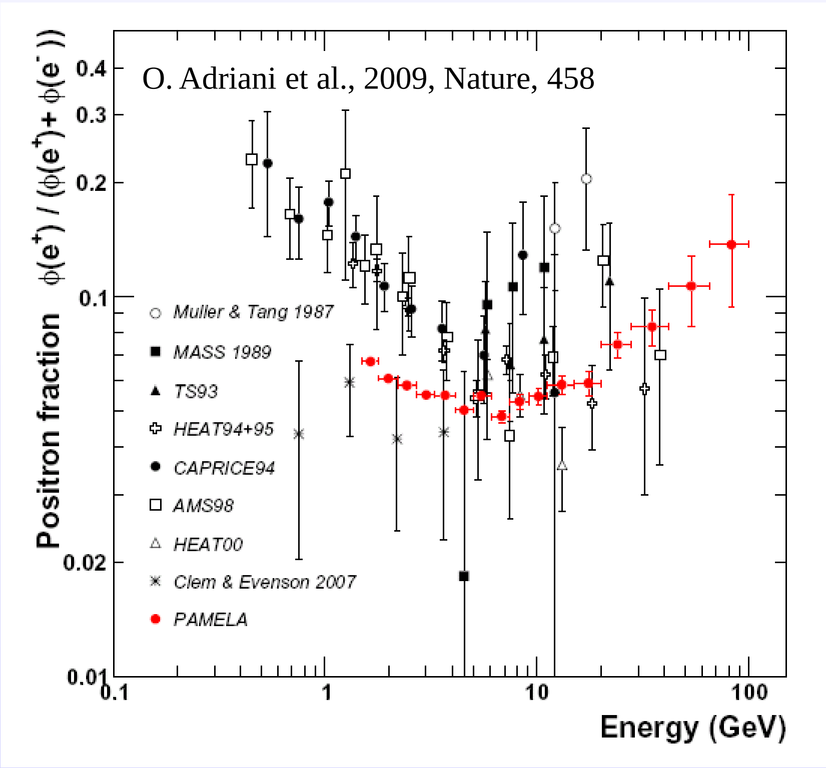
100 GeV positron

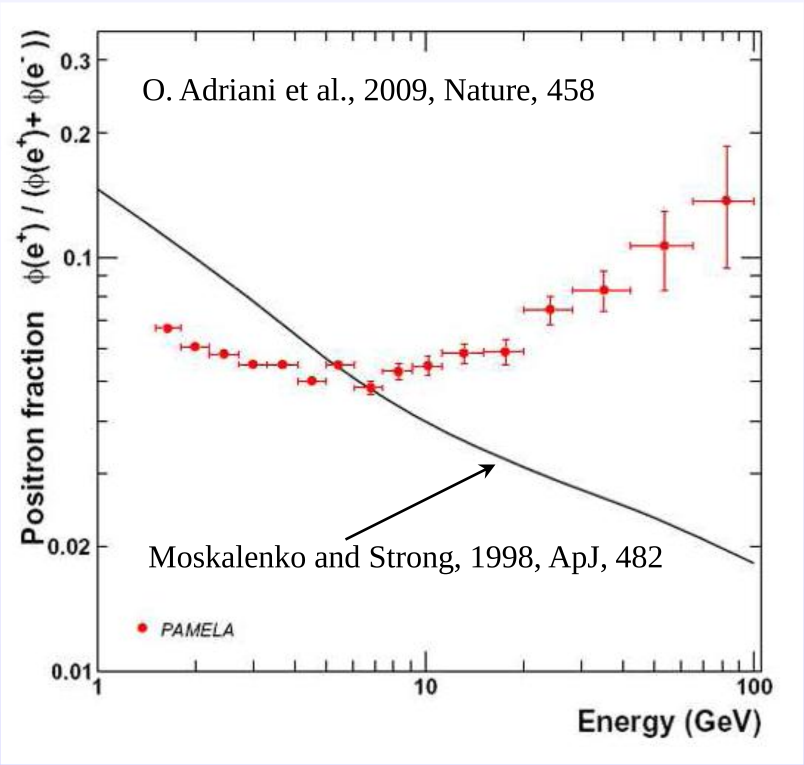
100 GeV proton

- **electromagnetic showers**
  → characterised by a pronounced central core surrounded by a halo
- **hadronic showers**
  → broader
  → any maximum lies deeper in the calorimeter for a given incident energy
  → **electromagnetic component induced by π^0**

PAMELA positron fraction

- Positron fraction measured between **1.5 GeV** and **100 GeV**
- result based on the data collected between July 2006 and February 2008 (total acquisition time of ~ 500 days)

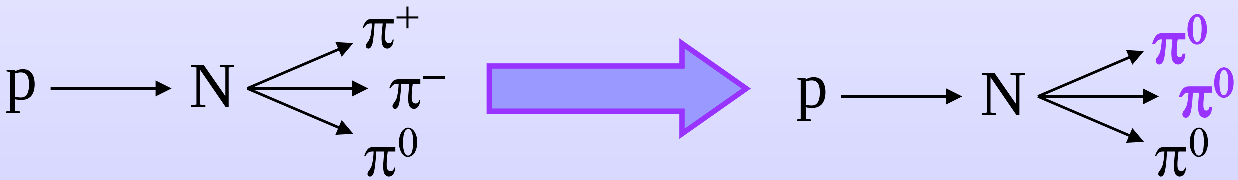




Simulation studies of π^0 contamination

- Study the π^0 produced in hadronic showers within the context of the positron analysis

- the study has been performed using Geant3 simulations
  → the number of π^0 has been artificially increased by changing **every $\pi^\pm$** produced into **π^0**
  (without modifying the cross section of protons!!)



proton
normal case

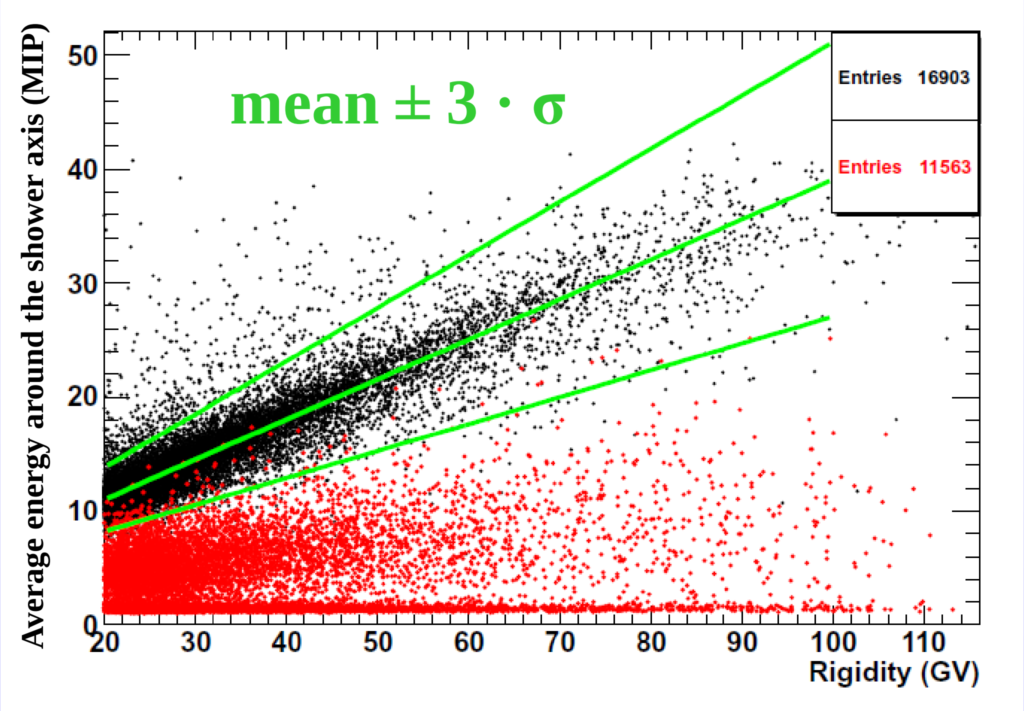
proton
only–π^0 case

- simulations in the range **20 – 100 GeV** and **100 – 300 GeV**

A new approach for positron identification

- Study distributions of shower profile variables as function of the rigidity

  → identify what variables permit an efficient discrimination between positrons and protons



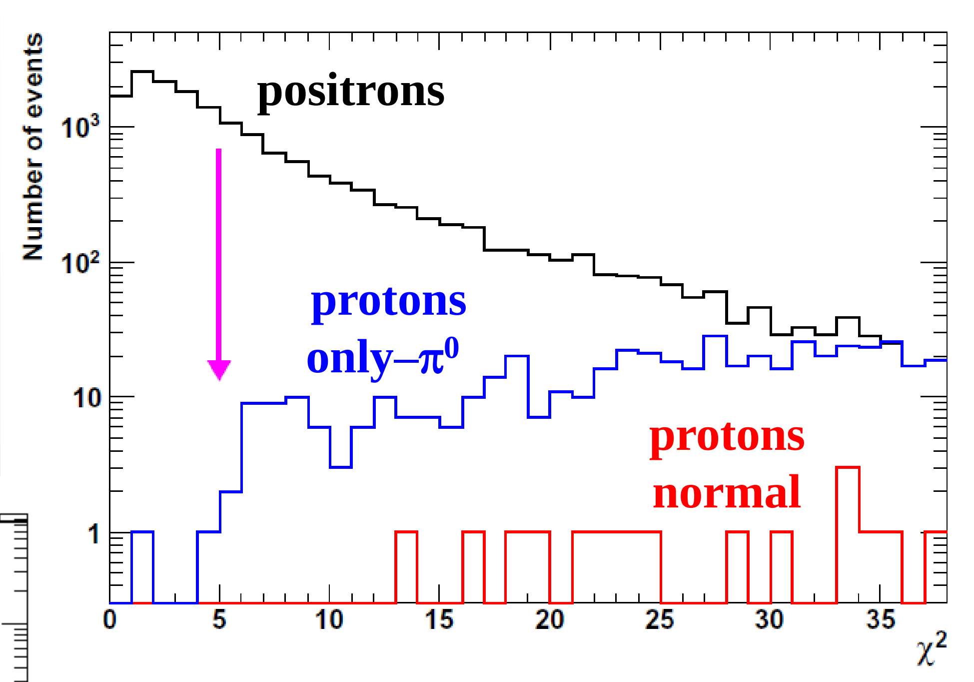
simulated positrons

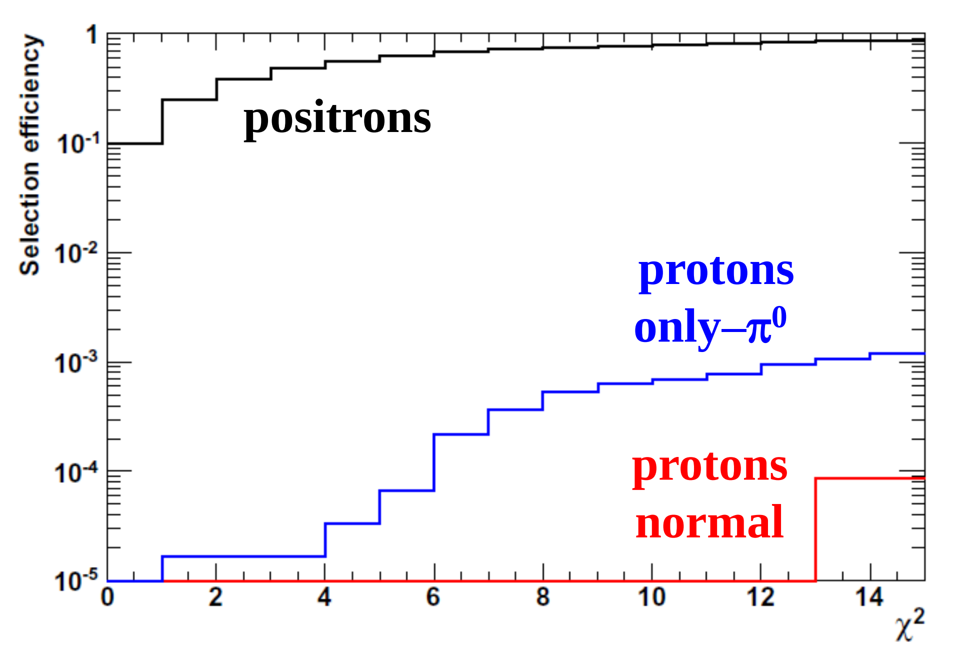
simulated protons

→ **χ^2 method**

Analysis in the energy range 20 – 100 GeV

χ^2 constructed using 6 shower profile variables





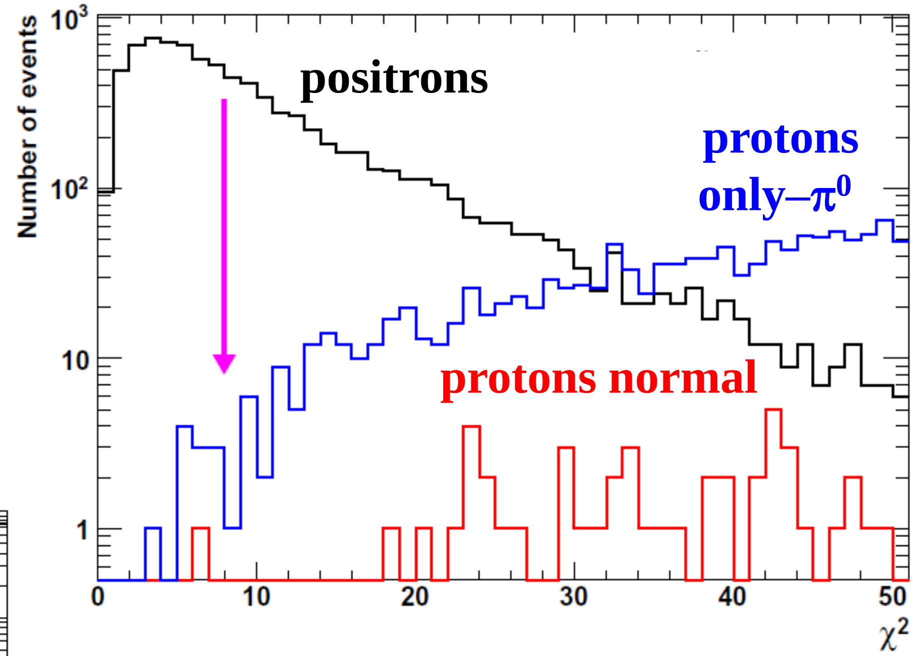
$\chi^2 < 5$

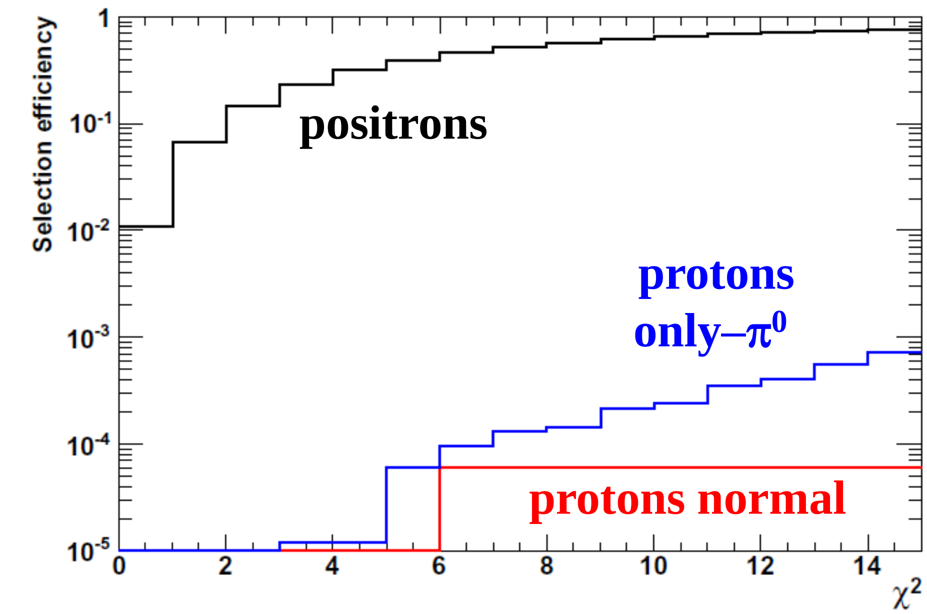
→ positron selection efficiency ~ **57%**

→ proton contamination of order of **10^{-5}**

Analysis in the energy range 100 – 300 GeV

χ^2 constructed using 8 shower profile variables





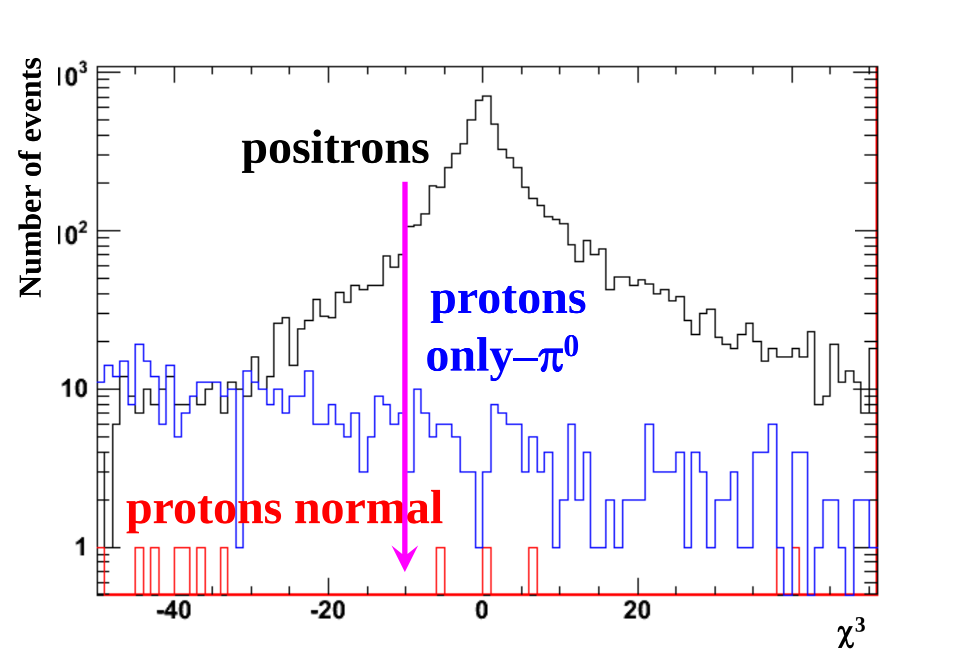
$\chi^2 < 8$

→ positron selection efficiency ~ **52%**

→ proton contamination of order of **10^{-4}**

Analysis in the energy range 100 – 300 GeV

$$\chi^3 = \sum_{i=1}^{n} \chi^3_{\text{variable}[i]} = \sum_{i=1}^{n} \frac{\left(\text{variable}[i] - \overline{\text{variable}[i]}\right)^3}{\sigma^3_{\text{variable}[i]}}$$



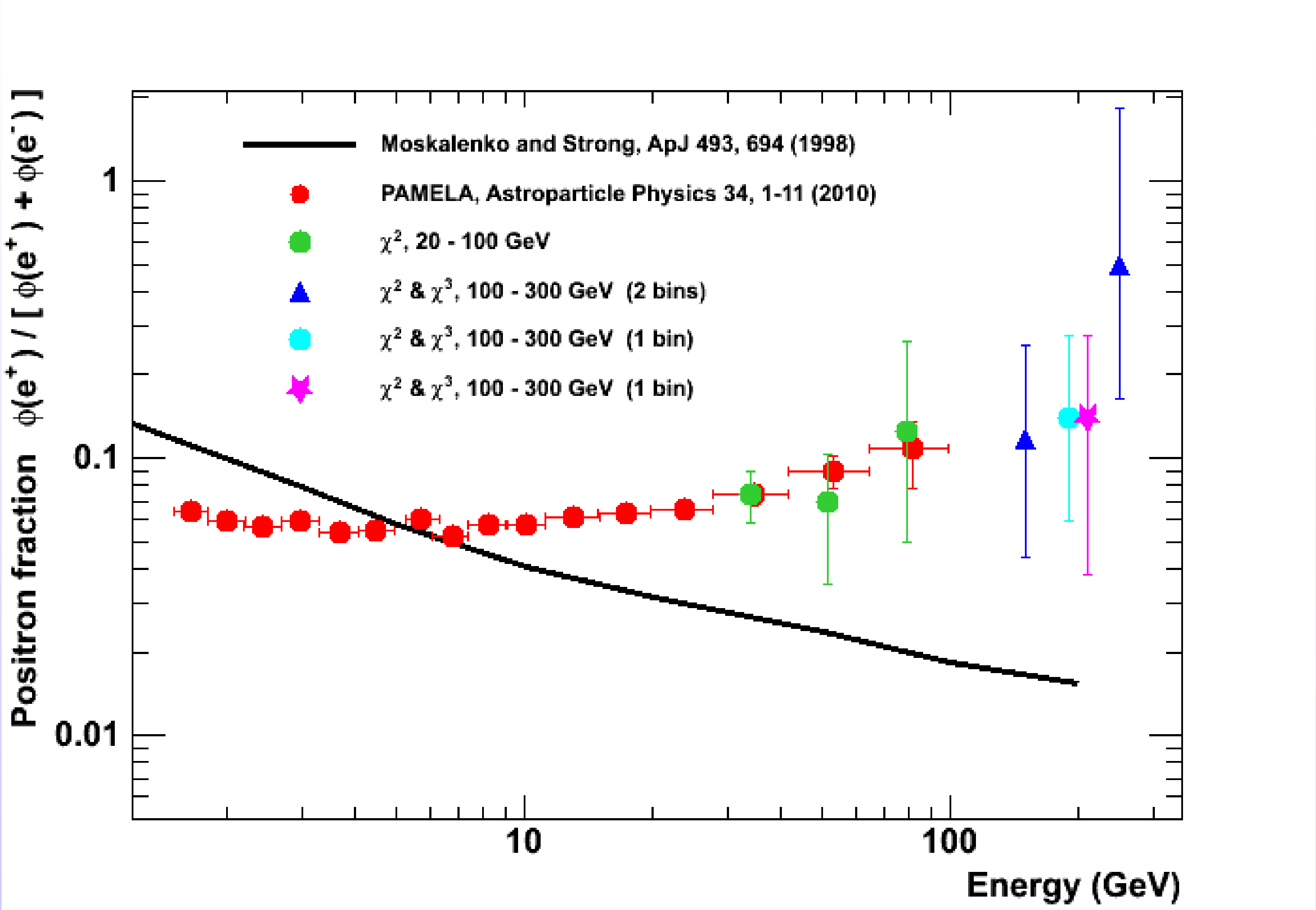
χ^3 constructed using 3 shower profile variables

$\chi^3 > -10$

→ positron selection efficiency **~ 50%**

→ proton contamination of order of **10^{-4}**

Positron fraction



Multivariate analysis approach

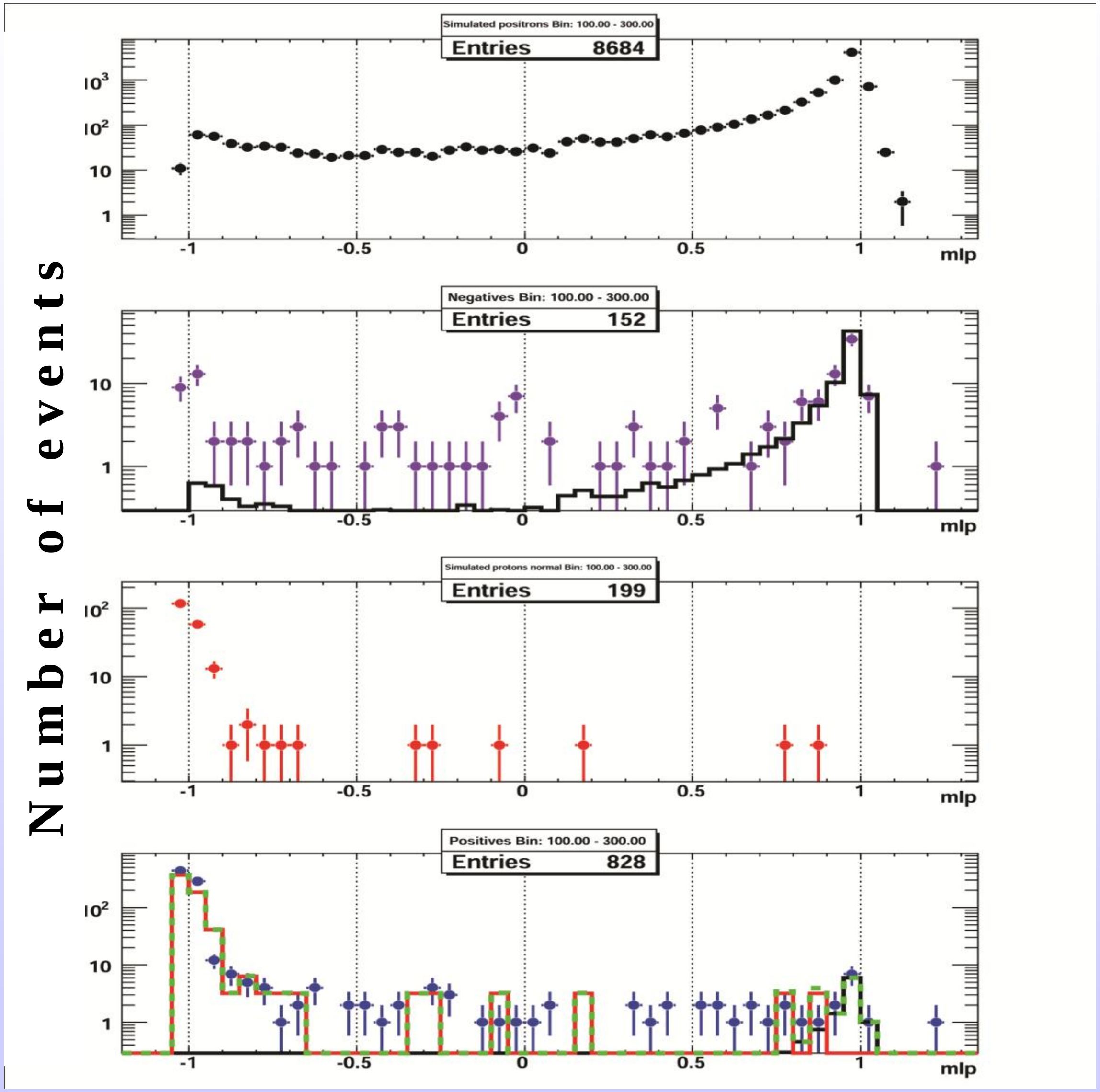
- As a cross–check to the results obtained with the χ^2 method, a multivariate approach has also been applied to flight data in the energy range **100 – 300 GeV**

- the MultiLayers Perceptron (MLP) neural network has been used

  → the training process has been applied to the **signal** sample (**simulated positrons**) and to the **background** sample (**simulated protons** in the **only–π^0 case**)

  → the resulting weights have been applied to simulations and to flight data

Multivariate analysis approach



100 – 300 GeV

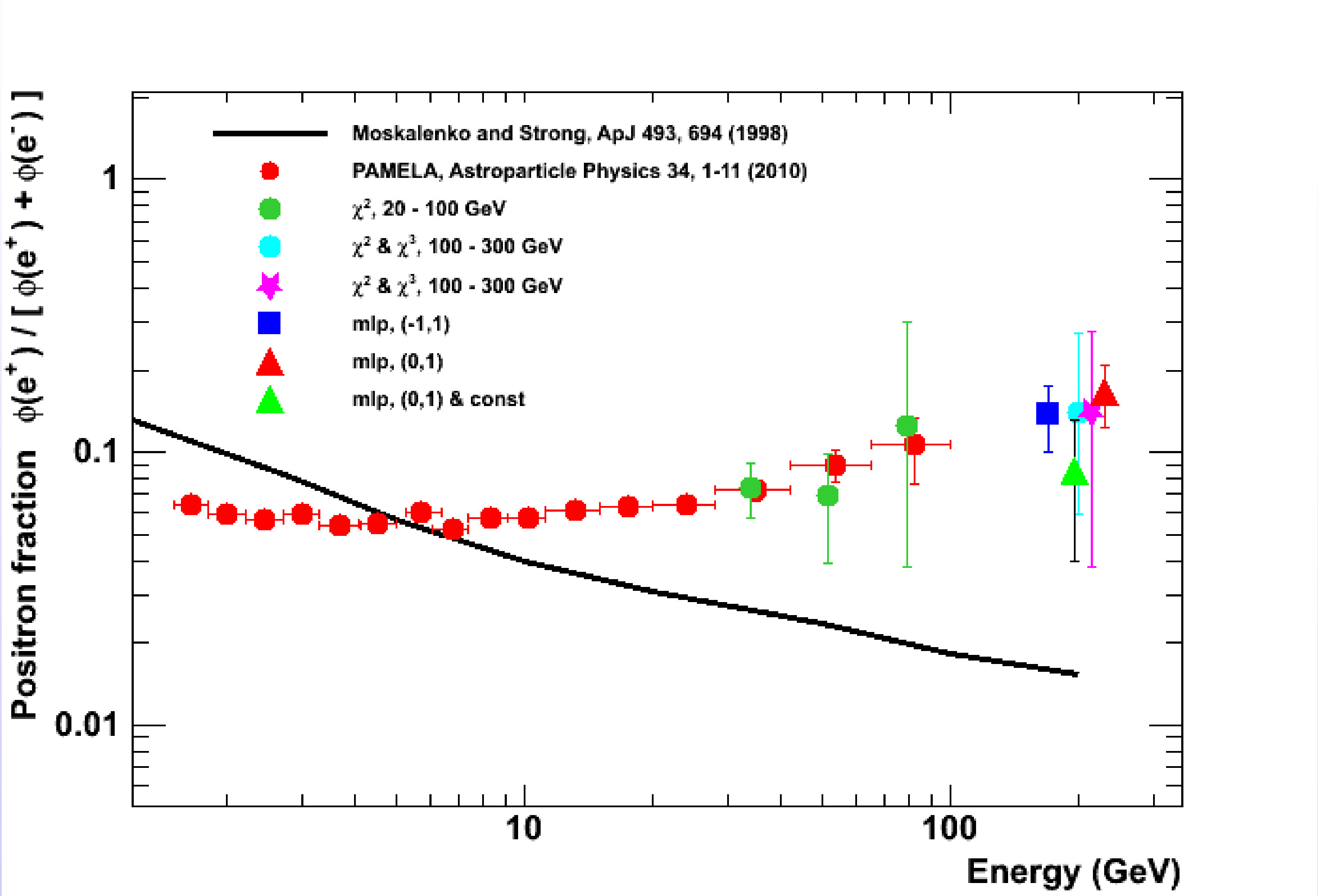
simulated positrons

negatively charged particles in flight data

simulated protons

positively charged particles in flight data

Positron fraction



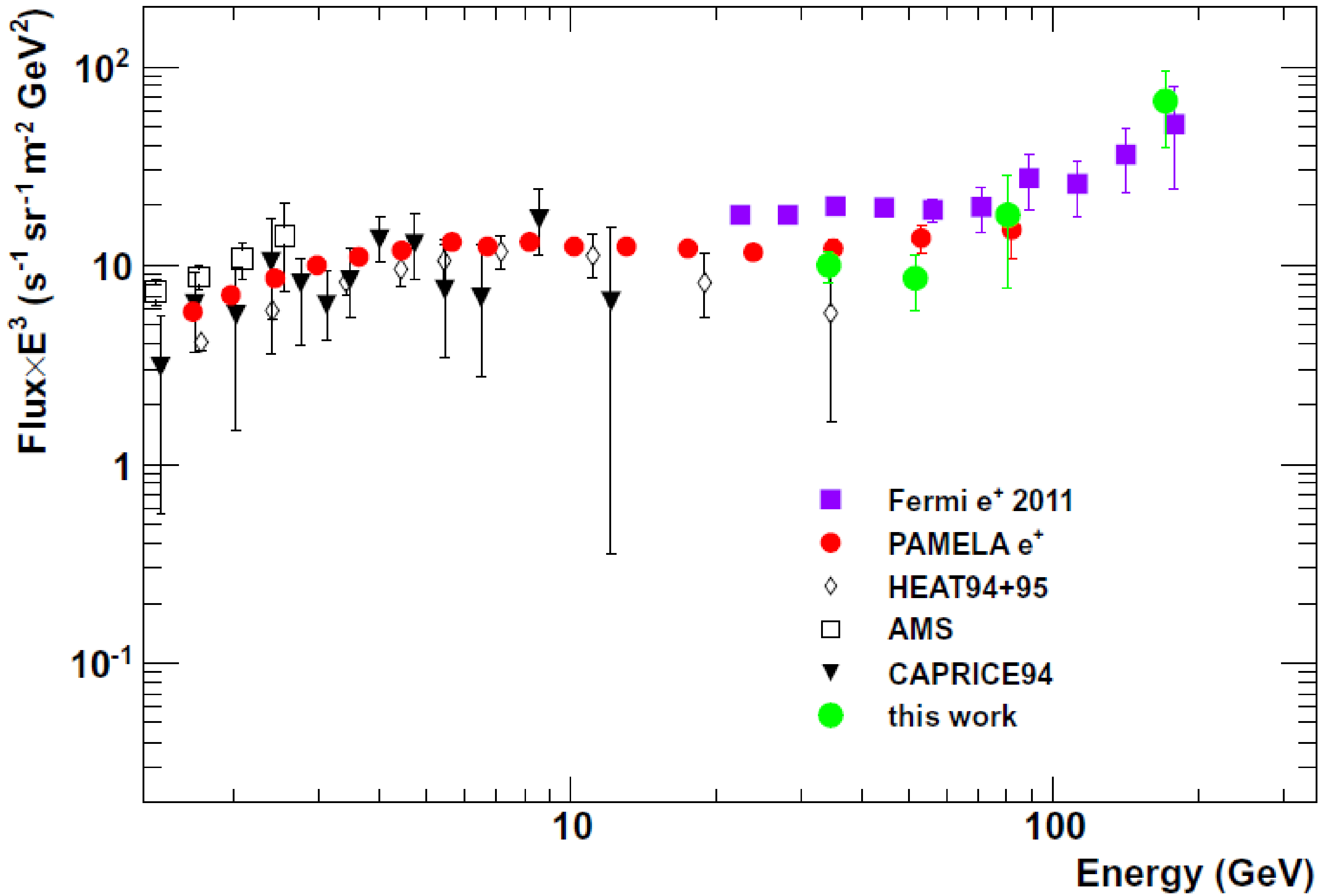
Positron flux

- The number of positron events selected using the **χ^2 method** have been also used to evaluate the **positron flux**

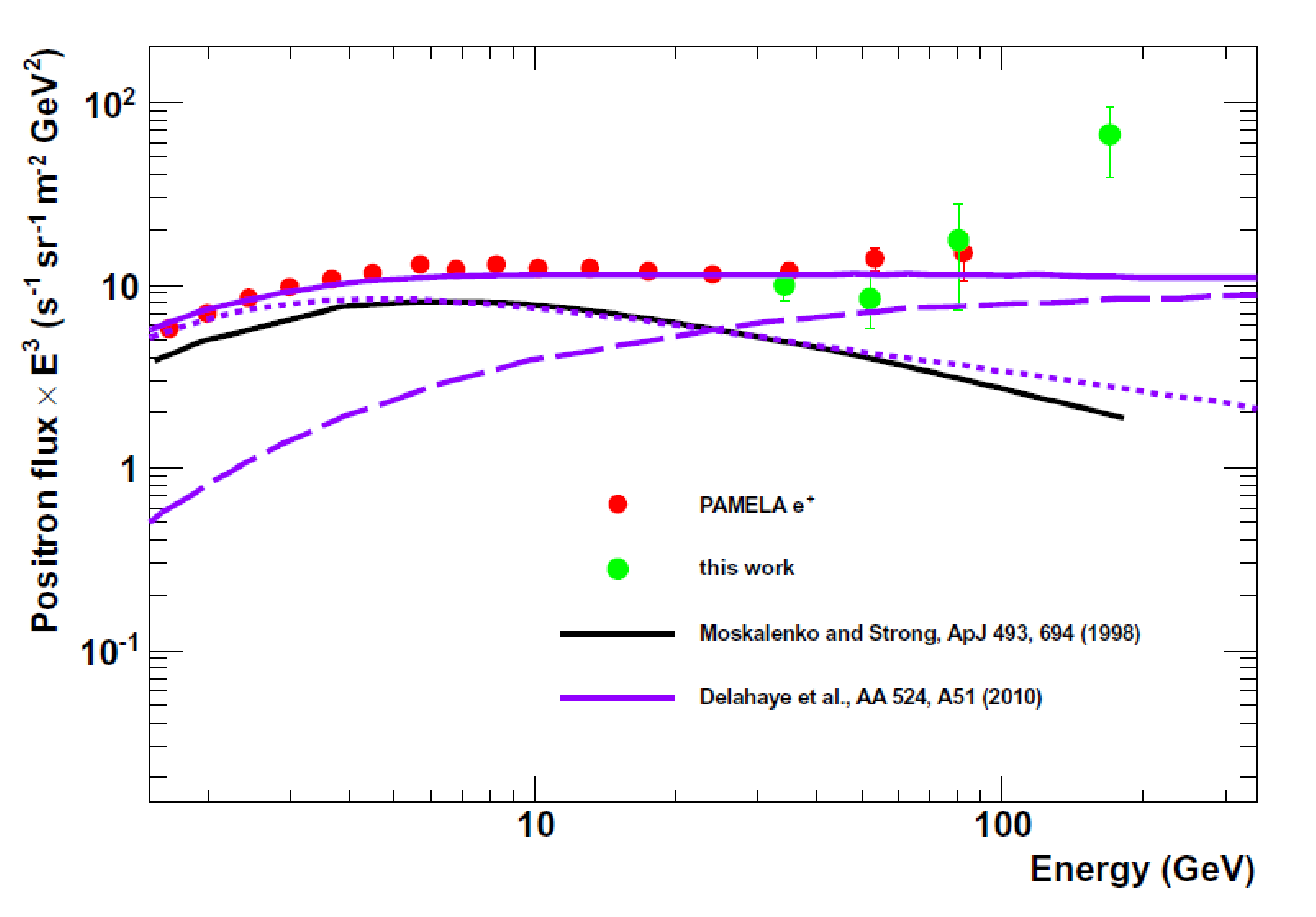
$$\Phi(E) = \frac{N(E)}{\varepsilon(E)} \cdot \frac{1}{T_{live} \cdot G(E) \cdot \Delta(E)}$$

$N(E)$ → number of particles
$\varepsilon(E)$ → total efficiency
T_{live} → live time
$G(E)$ → geometrical factor
$\Delta(E)$ → width of the energy bin

Positron flux



Positron flux



Conclusions

- A method which uses shower profile variables in the calorimeter has been tested on simulations in two energy ranges (**20 – 100 GeV** and **100 – 300 GeV**)

- a possible neutral pion contamination of hadronic showers has also been studied

- this method has been then applied to flight data

→ the rise of the positron fraction has been confirmed

→ the **positron fraction** and the **positron flux** have been evaluated up to **~ 300 GeV**

- new experimental data are needed (e.g. AMS–02)


Thank you!!!

SPARES!

Cosmic ray positrons

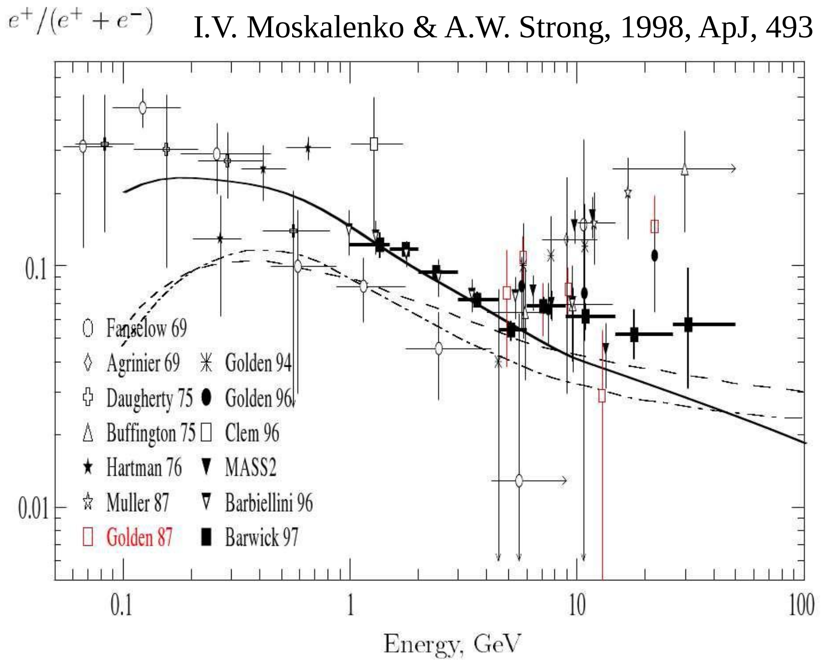
- Electrons account for ~ 2% of the cosmic ray particles
  → positrons can probe acceleration and propagation mechanisms in a galactic region of ~ 1 kpc (synchrotron radiation, inverse Compton scattering)

- positrons are believed to be mainly secondary particles: $p + p \rightarrow \pi^{\pm}, K^{\pm}$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} \rightarrow e^{\pm} + \nu_{e}$$

$$K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}, \pi^{0} + \pi^{\pm}$$

I.V. Moskalenko & A.W. Strong, 1998, ApJ, 493



—— pure secondary production without reacceleration

– · – leaky–box model

– – diffusion model

A new approach for positron identification

- Study distributions of shower profile variables as function of the rigidity

  → identify what variables permit an efficient discrimination between positrons and protons

- construct the χ^2 variable

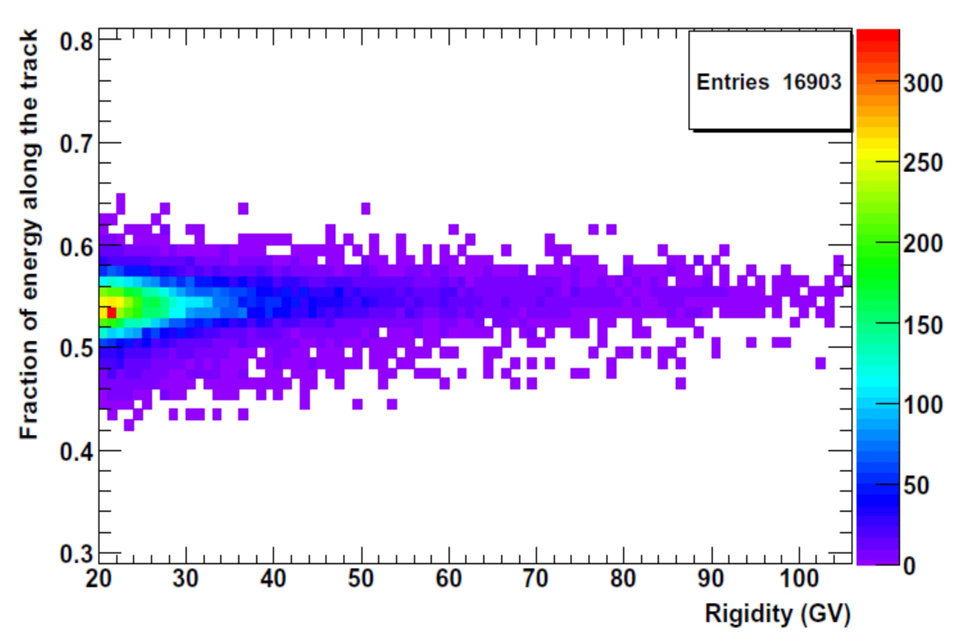
$$\chi^2 = \sum_{i=1}^{n} \chi^2_{\text{variable}[i]} = \sum_{i=1}^{n} \frac{\left(\text{variable}[i] - \overline{\text{variable}[i]}\right)^2}{\sigma^2_{\text{variable}[i]}}$$

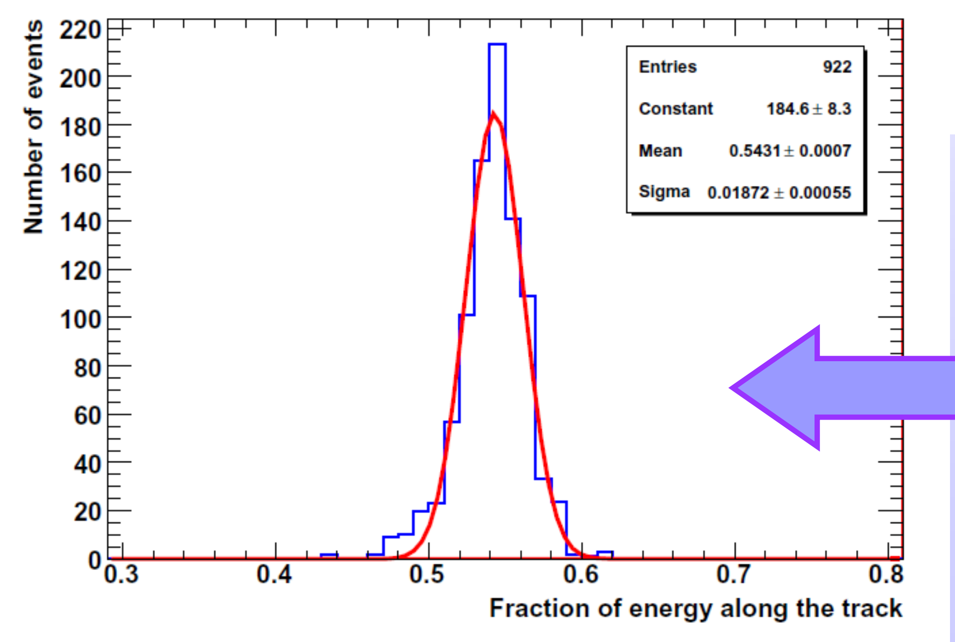
→ **mean** and **standard deviation** have been tuned on the **simulated positron sample**

A new approach for positron identification

Simulated positrons

20 – 100 GeV



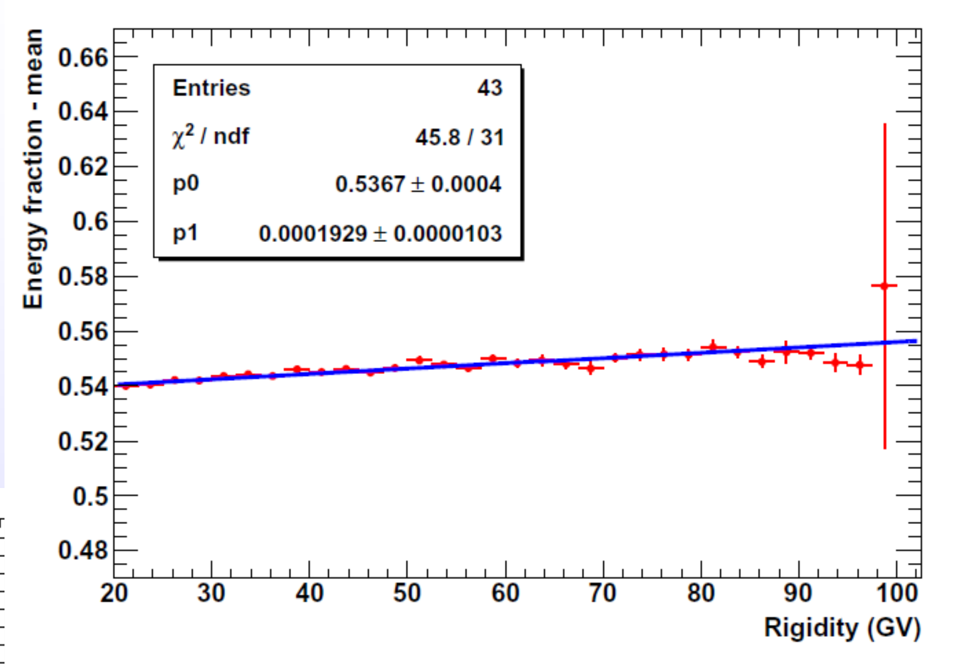


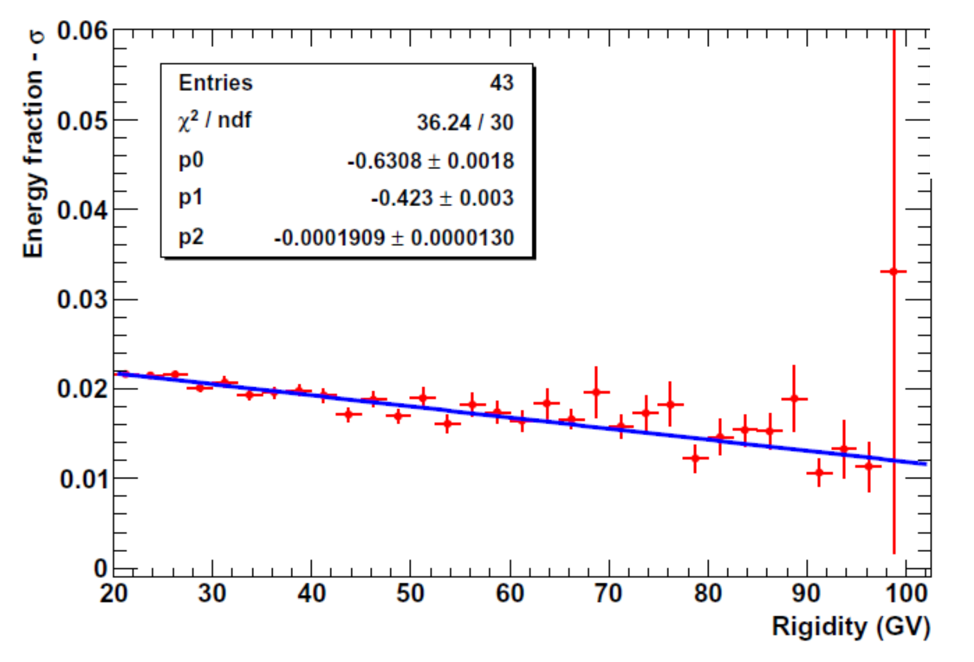
distribution in the rigidity interval (30 – 32) GV

A new approach for positron identification

Simulated positrons

20 – 100 GeV

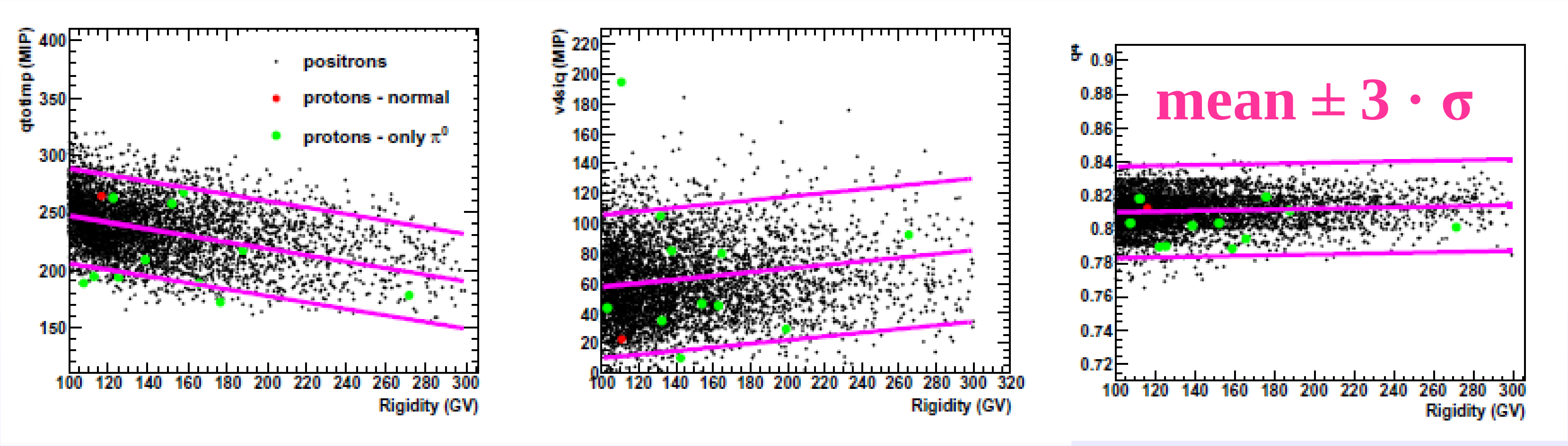


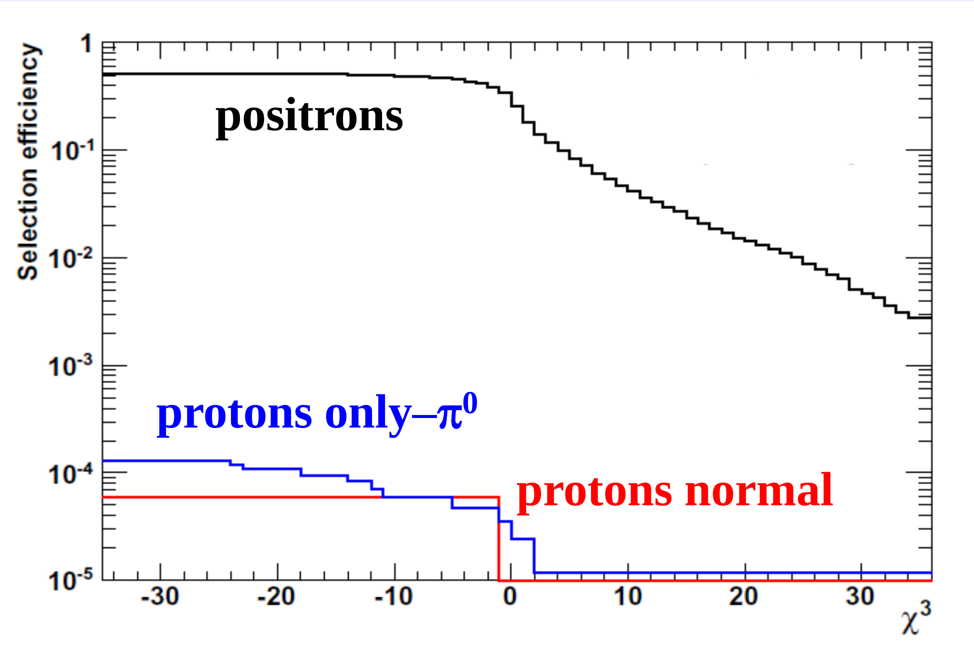


$$\text{mean} = 0.5367 + 0.0001929 \cdot R$$

$$\sigma = -0.6308 + e^{-0.423 - 0.0001909 \cdot R}$$

Analysis in the energy range 100 – 300 GeV





χ^3 constructed using 3 shower profile variables

$\chi^3 > -10$

→ positron selection efficiency **~ 50%**

→ proton contamination of order of **10^{-4}** (**normal** and **only–π^0 case**)

Positron fraction

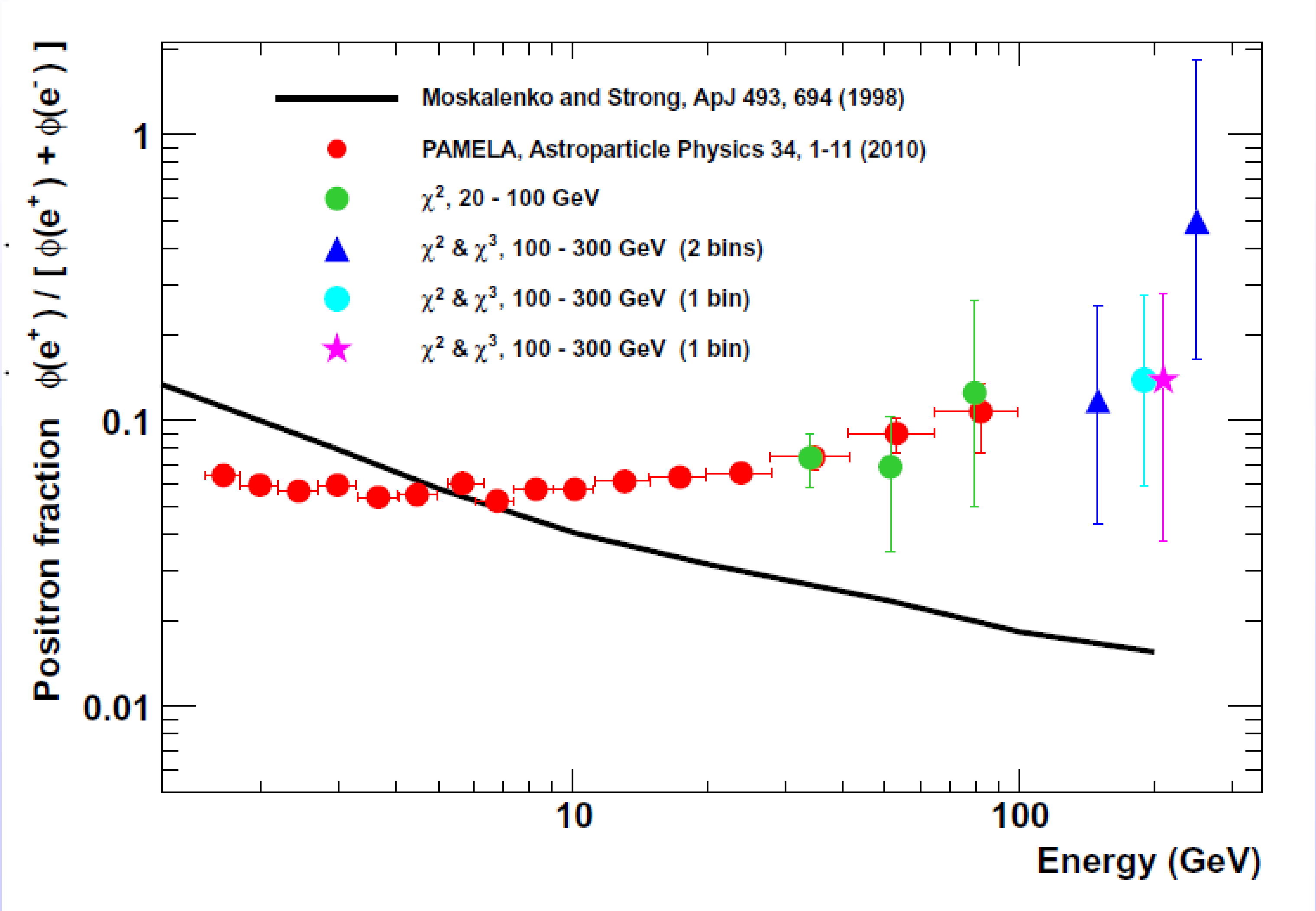
- Method tested on simulations in the energy ranges **20 – 100 GeV** and **100 – 300 GeV**

  → applied to the flight data set collected between July 2006 – January 2010 (~ 1200 days)

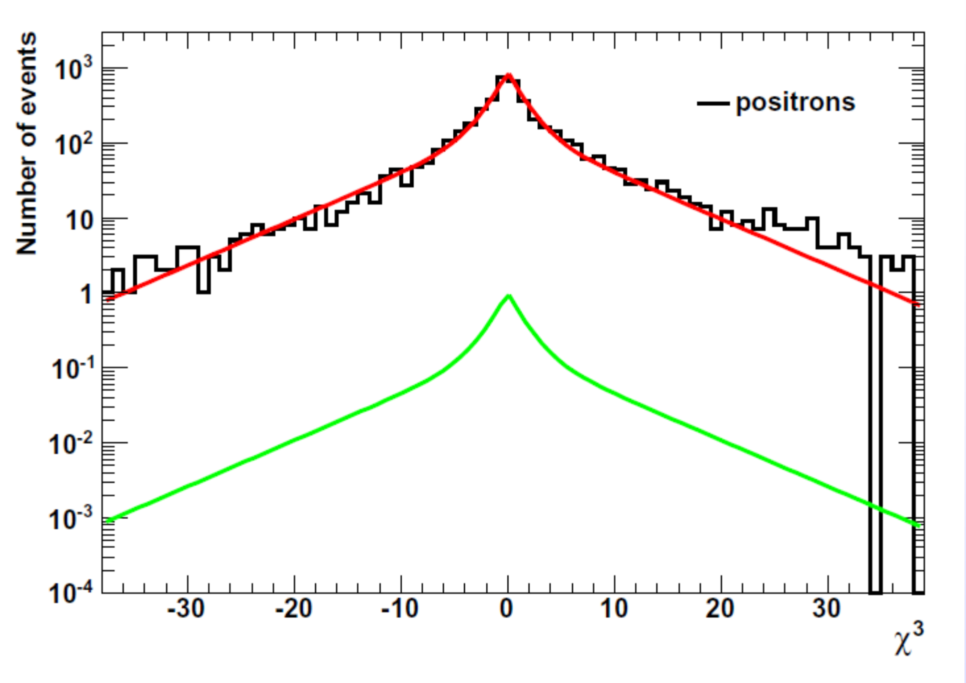
- in the energy range **100 – 300 GeV** the positron fraction is dependent on the selection on the χ^3 variable

  → a possible proton contamination needs to be estimated

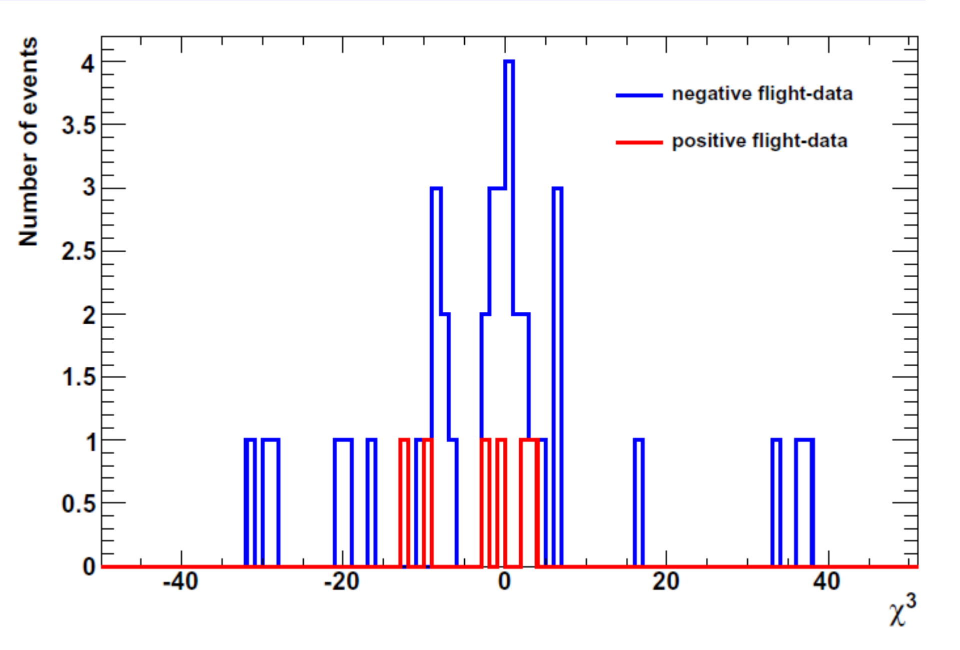
Positron fraction



Positron fraction



How is it possible to estimate the proton contamination?



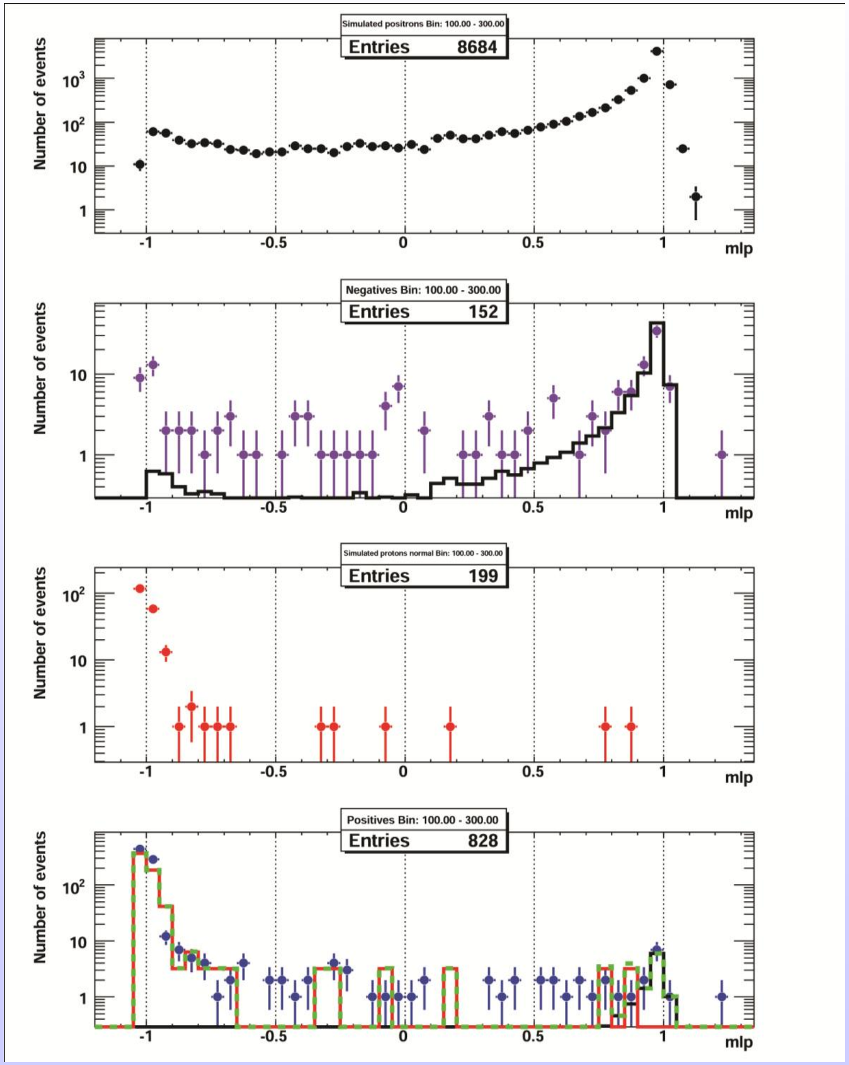
100 – 300 GeV

Positron fraction

Rigidity (GV)	N_{e^+}	N_{e^-}	e^- selection efficiency	N_{e^+} / (N_{e^+} + N_{e^-})
28 – 42	47	587	38.9 %	0.074 ± 0.017
42 – 65	11	148	23.1 %	0.069 ± 0.030
65 – 100	3	21	7.5 %	$0.125\ ^{+\,0.177}_{-\,0.087}$

Rigidity (GV)	N_{e^+}	N_{e^-}	e^- selection efficiency	N_{e^+} / (N_{e^+} + N_{e^-})
100 – 200	4	30	10.6 %	$0.118\ ^{+\,0.137}_{-\,0.074}$
200 – 300	1	1	0.5 %	$0.500\ ^{+\,1.322}_{-\,0.336}$
100 – 300	5	31	6.6 %	$0.139\ ^{+\,0.136}_{-\,0.080}$ (*stat.*)
100 – 300	5	31	6.6 %	$0.139\ ^{+\,0.136}_{-\,0.120}$ (*stat.+syst.*)
100 – 300	$6.1\ ^{+\,6.9}_{-\,4.9}$	38	8.1 %	$0.138\ ^{+\,0.138}_{-\,0.101}$

Multivariate analysis approach



Fit range	N_{e^+}	N_{e^-}	N_{e^+} / (N_{e^+} + N_{e^-})
[−1 , 1]	13.7 ± 4.1	85.8 ± 8.8	0.138 ± 0.037
[0 , 1]	16.2 ± 4.7	81.4 ± 8.5	0.166 ± 0.043
[0 , 0.7] with constant	6.3 ± 3.7	66.2 ± 6.2	0.087 ± 0.047
χ^2 and χ^3 method	5	31	$0.139\,^{+\,0.136}_{-\,0.080}$ (*stat.*)
χ^2 and χ^3 method	$6.1\,^{+\,6.9}_{-\,4.9}$	38	$0.138\,^{+\,0.138}_{-\,0.101}$

Positron fraction