

# The magnetic spectrometer of the **PAMELA** satellite experiment



- INTRODUCTION
- DESCRIPTION OF THE MAGNETIC SPECTROMETER
  - Silicon Sensors
  - Mechanics
  - Electronics
- TESTS RESULTS
- CONCLUSIONS

Oscar Adriani

INFN Sezione di Firenze / Dipartimento di Fisica dell'Universita' di Firenze  
The PAMELA collaboration

# The **PAMELA** experiment

## MAIN TOPICS:

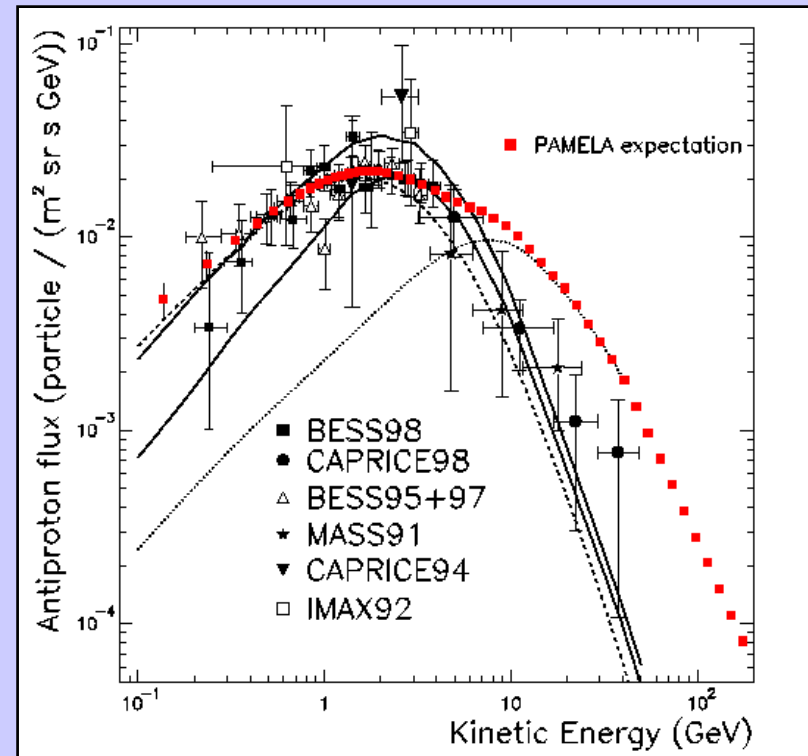
- $e^+ / \bar{p}$  fluxes measurement
- Search for light Antinuclei

## SECONDARY TOPICS:

- Modulation of GCR's in the Heliosphere
- Solar Energetic Particles (SEP)
- Earth Magnetosphere
- ...

$\bar{p}$  spectra → 80 MeV/c ... 190 GeV/c  
 $e^+$  spectra → 50 MeV/c ... 270 GeV/c

## Antiproton flux



# The **PAMELA** experiment

## MAIN TOPICS:

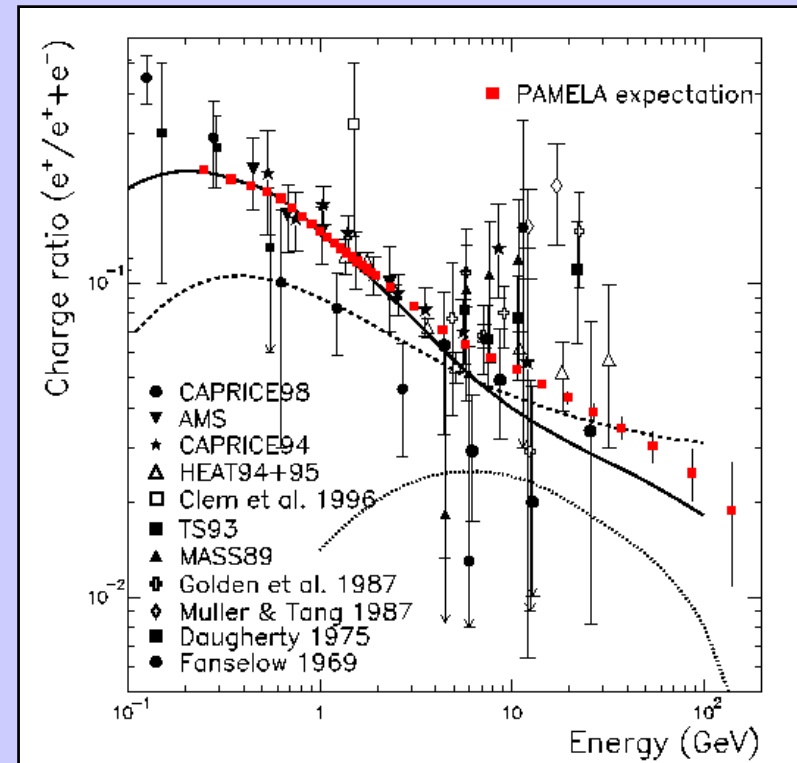
- $e^+ / \bar{p}$  fluxes measurement
- Search for light Antinuclei

## SECONDARY TOPICS:

- Modulation of GCR's in the Heliosphere
- Solar Energetic Particles (SEP)
- Earth Magnetosphere
- ...

$\bar{p}$  spectra → 80 MeV/c ... 190 GeV/c  
 $e^+$  spectra → 50 MeV/c ... 270 GeV/c

## Positron charge ratio



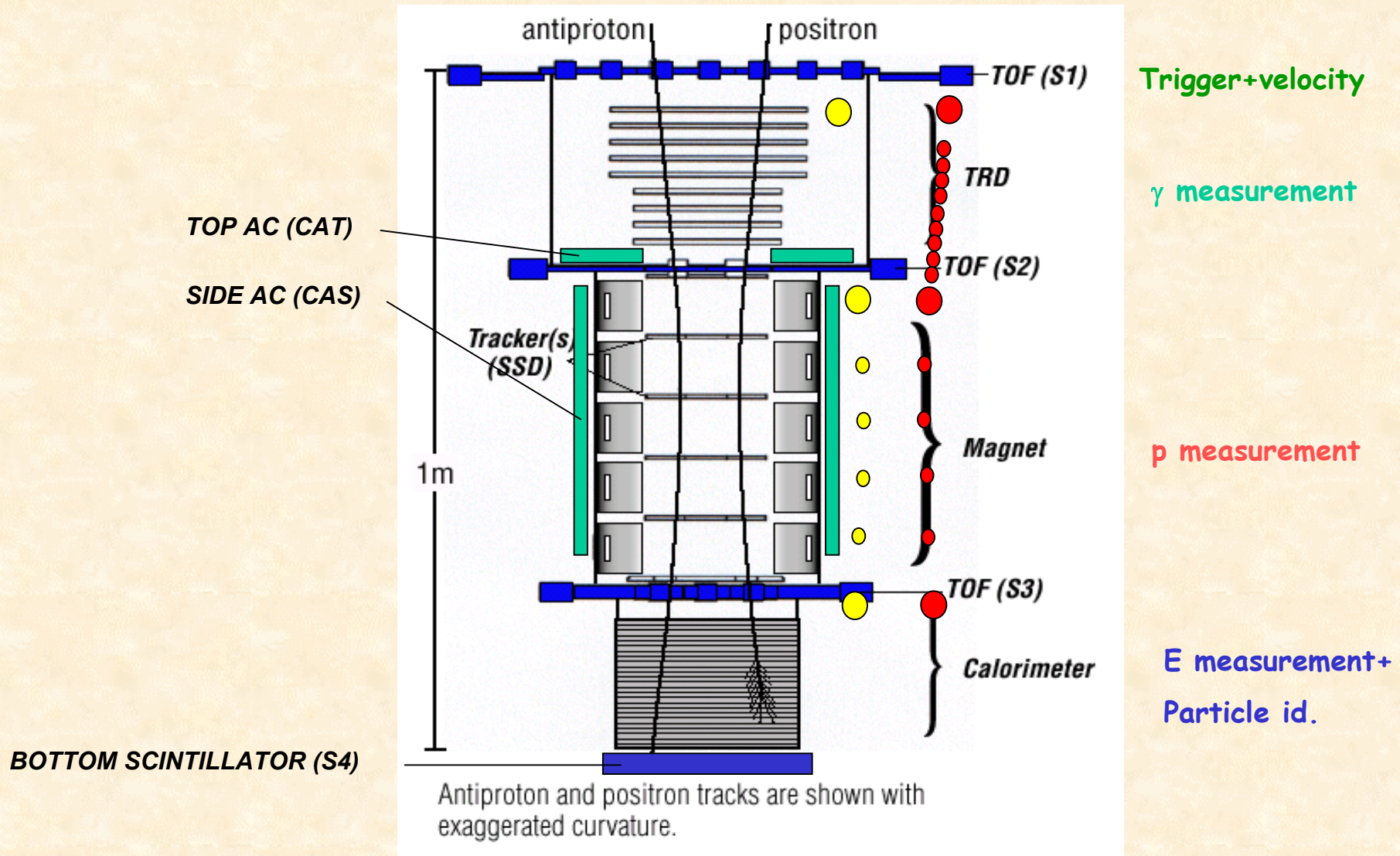
## Expected Fluxes in 3 Years

Particle	Number (3 yrs)	Energy Range
Protons	$3 \cdot 10^8$	80 MeV - 700 GeV
Antiprotons	$>3 \cdot 10^4$	80 MeV - 190 GeV
Electrons	$6 \cdot 10^6$	50 MeV - 2 TeV
Positrons	$>3 \cdot 10^5$	50 MeV - 270 GeV
He	$4 \cdot 10^7$	80 MeV/n - 700 GeV/n
Be	$4 \cdot 10^4$	80 MeV/n - 700 GeV/n
C	$4 \cdot 10^5$	80 MeV/n - 700 GeV/n
Antihelium Limit	$7 \cdot 10^{-8}$	80 MeV/n - 30 GeV/n

- 'Semi-Polar' orbit ( $70^\circ$ )  $\Rightarrow$  Low energy particles
- Wide energy range + 3 years mission  $\Rightarrow$  Reliable measurements



# Principle of Operation



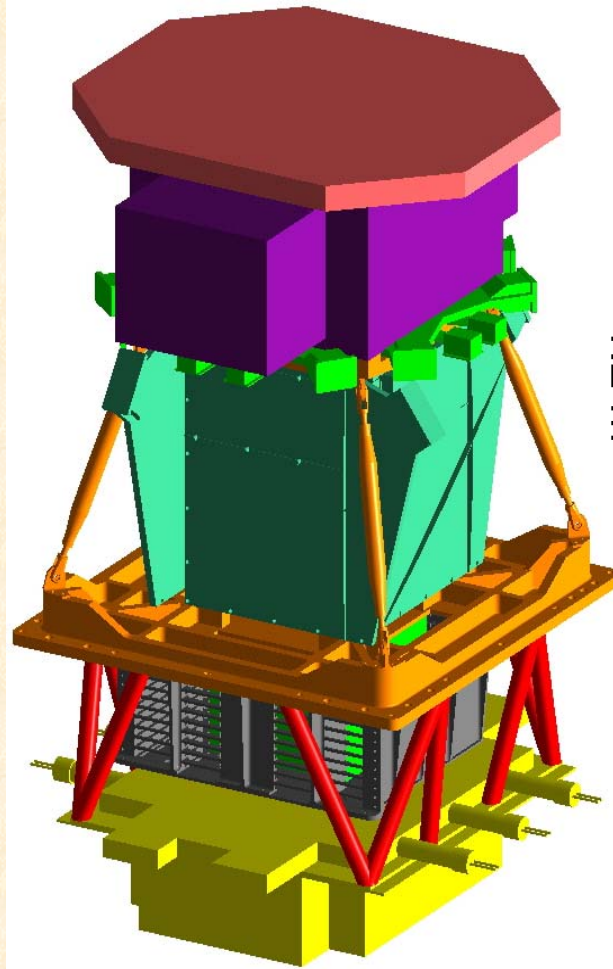
# Pamela Subdetectors

## TRD

- Threshold device. Signal from  $e^\pm$ , no signal from  $p$ ,  $\bar{p}$
- 9 planes of Xe/Co<sub>2</sub> filled straws (4mm diameter). Interspersed with carbon fibre radiators  $\Rightarrow$  crude tracking.
- Aim: factor 20 rejection  $e/p$  (above 1GeV/c) ( $2 \cdot 10^5$  with calorimeter)

## Si Tracker + magnet

- Measures rigidity
- 5 Nd-B-Fe magnet segments (0.4T)
- 6 planes of 300 $\mu$ m thick Si detectors
- $\sim 3\mu$ m resolution in bending view demonstrated, ie: MDR = 740GV/c
- $\pm 10$  MIP dynamic range



Mass  $\sim 450$  kg

Acceptance  $\sim 20.5$  cm<sup>2</sup>sr

## Anticoincidence system

- Defines acceptance for tracker
- Plastic scintillator + PMT

## Time-of-flight

- Trigger / detects albedos / particle identification (up to 1 GeV/c) /  $dE/dx$
- Plastic scintillator + PMT
- Timing resolution = 120ps

## Si-W Calorimeter

- Measures energies of  $e^\pm$ .  
 $\Delta E/E = 15\% / E^{1/2} + 5\%$
- Si-X / W / Si-Y structure.
- 22 Si / 21 W  $\Rightarrow 16X_0 / 0.9\lambda_0$
- Imaging: EM - vs- hadronic discrimination, longitudinal and transverse shower profile

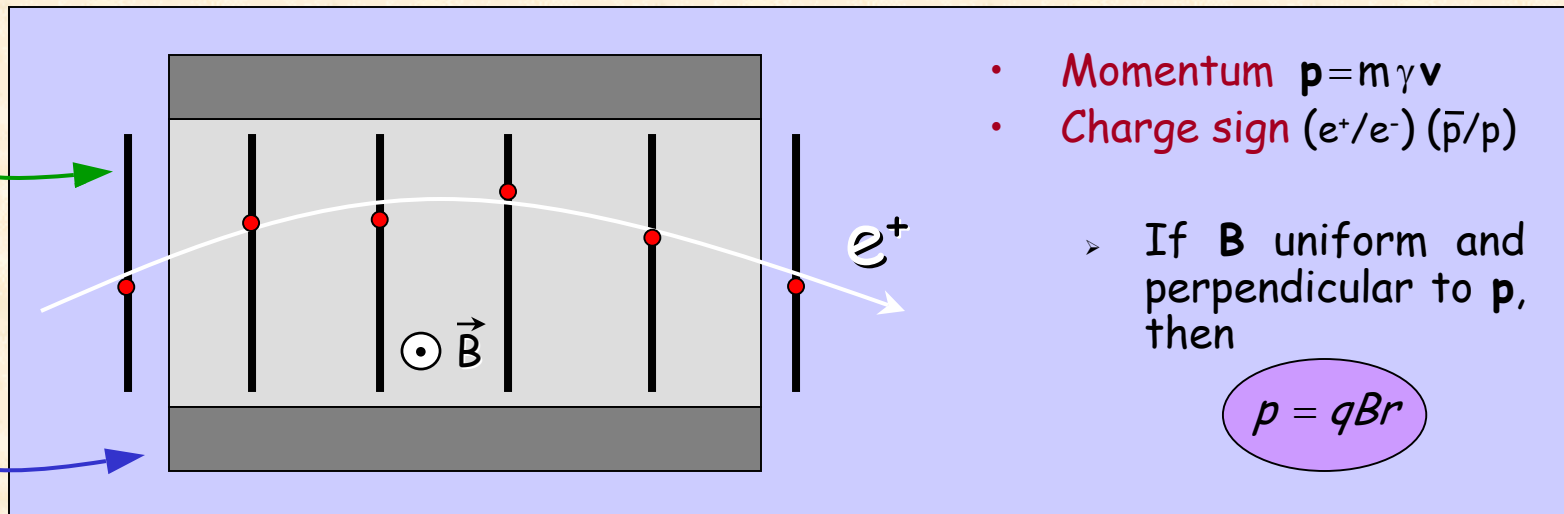
# The PAMELA Magnetic Spectrometer

- **Magnetic System**

- It produces an intense magnetic field region where charged particles follow curved trajectories

- **Tracking System**

- It allows to determine six points in the high field region to reconstruct the particle trajectory and so its momentum and charge sign

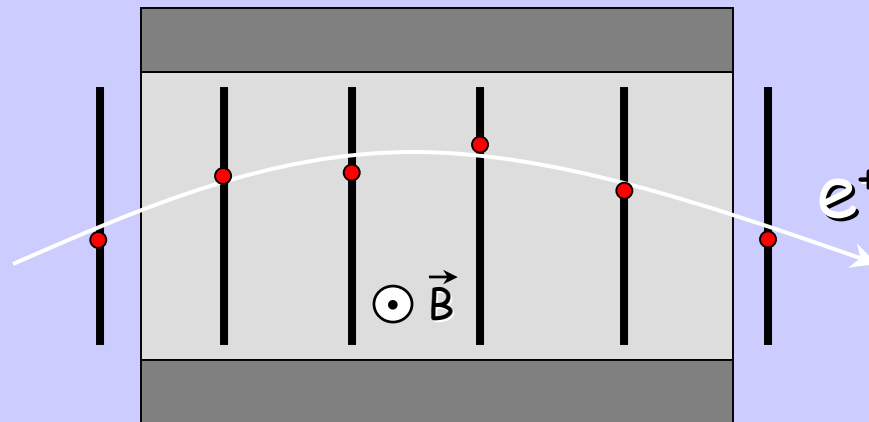


# A glossary of magnetic spectrometers for cosmic rays studies

- **Momentum**  $p = qBr$  ( $r$ =radius of curvature)
- **Rigidity**  $R = p/q = Br$
- **Deflection**  $\eta = 1/R = q/p$
- $\Delta R/R = \Delta\eta/\eta = R \Delta\eta$  ( $\Delta\eta = \text{constant} \propto \text{point's measurement error}$ )

 spatial resolution

- **Maximum Detectable Rigidity (MDR) :**  $\left(\frac{\Delta R}{R}\right)_{R=MDR} = 1$

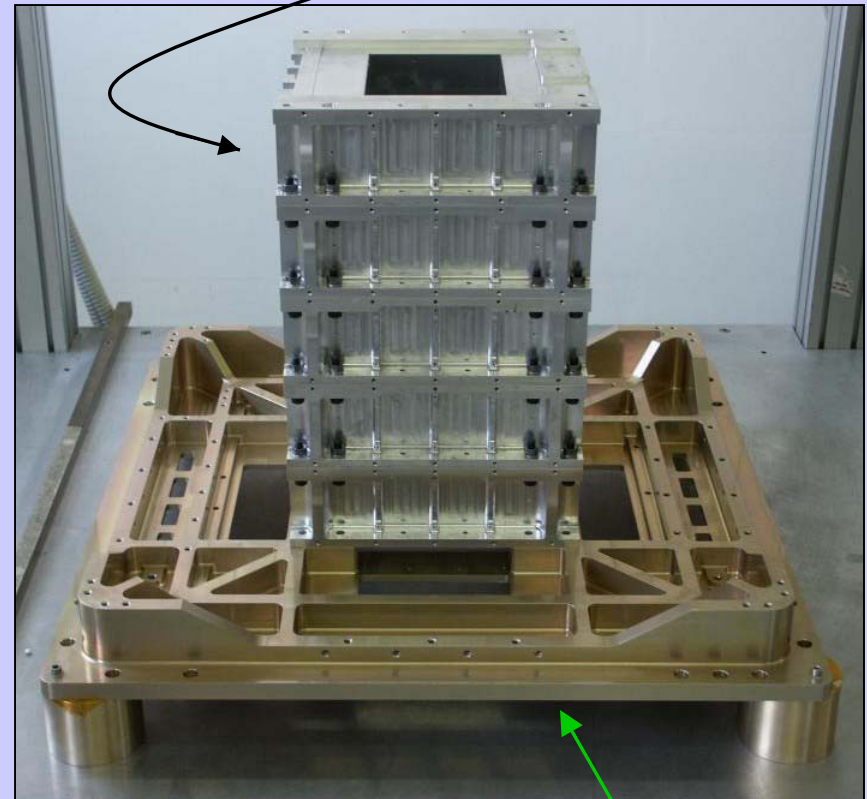


# The **PAMELA** Magnetic Spectrometer

## MAGNETIC SYSTEM

- 5 magnetic modules
- permanent magnet assembled in an aluminum mechanics
  - **Nd-Fe-B** alloy
- magnetic cavity sizes:
  - (132 x 162) mm<sup>2</sup> x 445 mm
- field inside the cavity:
  - **0.48 T** at the center
- places for detector planes and electronics boards lodging
- Geometric Factor: 20.5 cm<sup>2</sup>sr
- Black IR absorbing painting (not shown in the picture!)

The "Magnetic Tower"



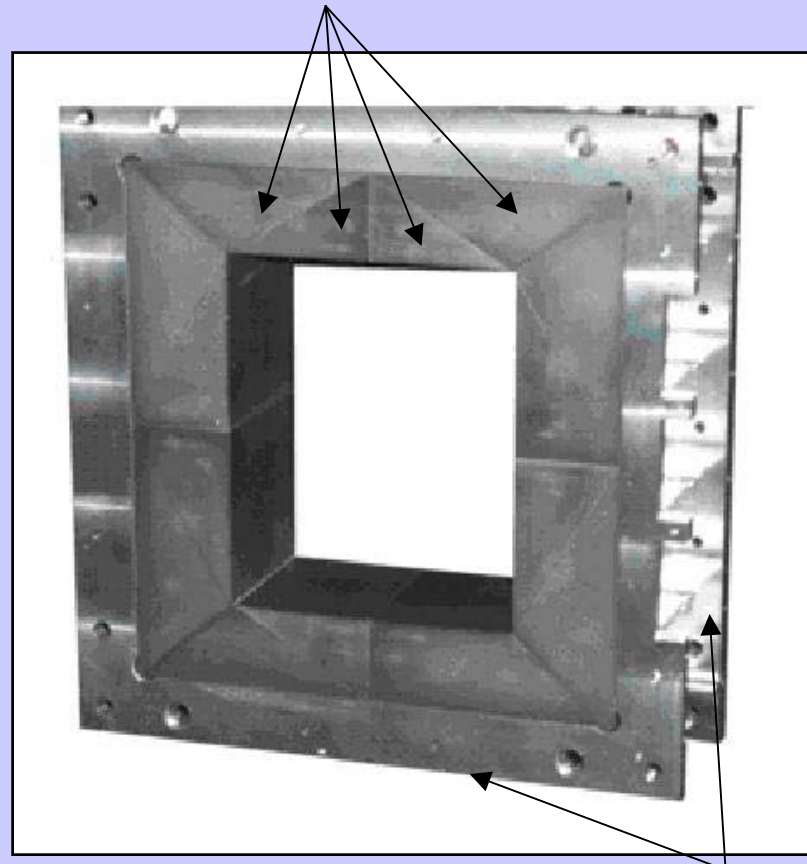
Base Plate prototype

# The **PAMELA** Magnetic Spectrometer

## MAGNETIC SYSTEM

- 5 magnetic modules
- permanent magnet assembled in an aluminum mechanics
  - **Nd-Fe-B** alloy
- magnetic cavity sizes:
  - $(132 \times 162) \text{ mm}^2 \times 445 \text{ mm}$
- field inside the cavity:
  - **0.48 T** at the center
- places for detector planes and electronics boards lodging
- Geometric Factor: **20.5 cm<sup>2</sup>sr**
- Black IR absorbing painting (not shown in the picture!)

Permanent magnet elements



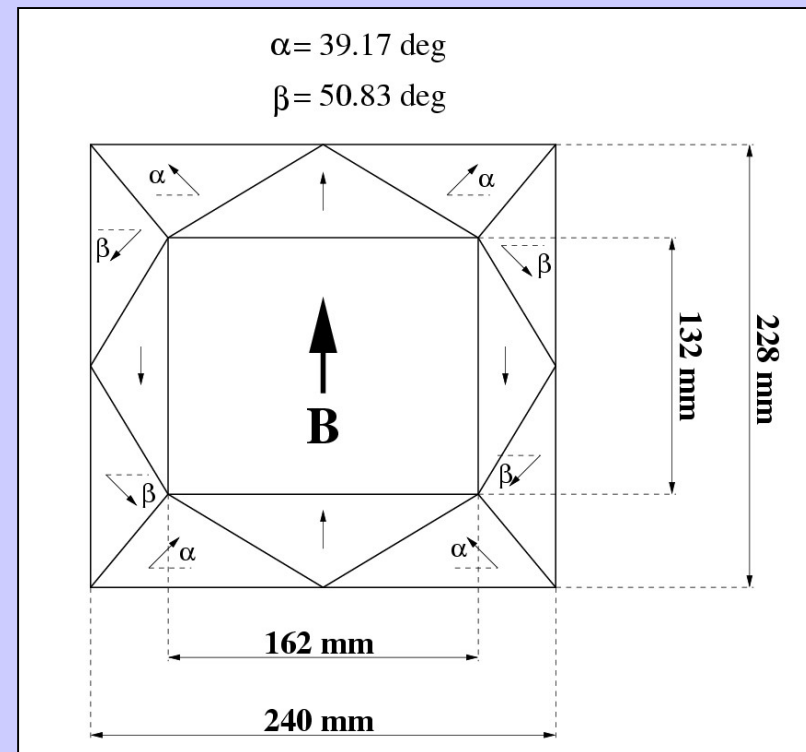
Aluminum frame

# The **PAMELA** Magnetic Spectrometer

## MAGNETIC SYSTEM

- 5 magnetic modules
- permanent magnet assembled in an aluminum mechanics
  - **Nd-Fe-B** alloy
- magnetic cavity sizes:
  - $(132 \times 162) \text{ mm}^2 \times 445 \text{ mm}$
- field inside the cavity:
  - **0.48 T** at the center
- places for detector planes and electronics boards lodging
- Geometric Factor: **20.5 cm<sup>2</sup>sr**
- Black IR absorbing painting (not shown in the picture!)

## Geometry of a magnetic block

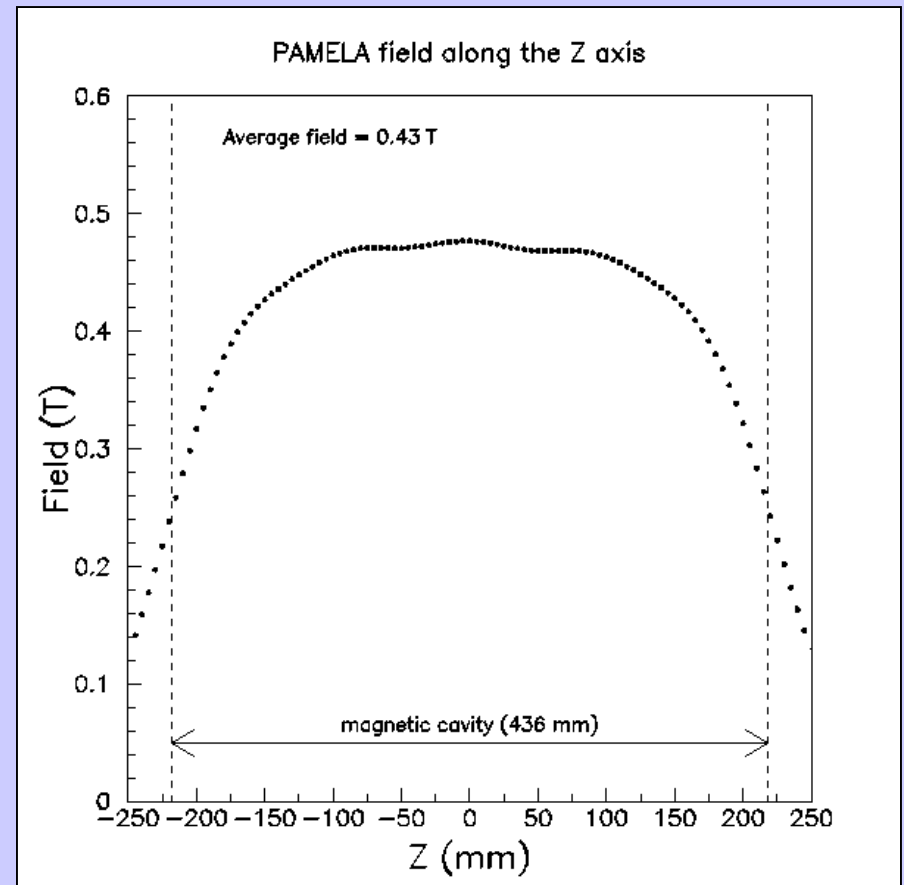


# The PAMELA Magnetic System

## Magnetic field measurement

- Gaussmeter F.W. Bell equipped with 3-axis probe mounted on a motorized positioning device (0.1mm precision)
- Measurement of the three components in **67367** points 5mm apart from each other
- Average field along the central axis of the magnetic cavity: **0.43 T**
- Good uniformity !

## Main field component along the cavity axis

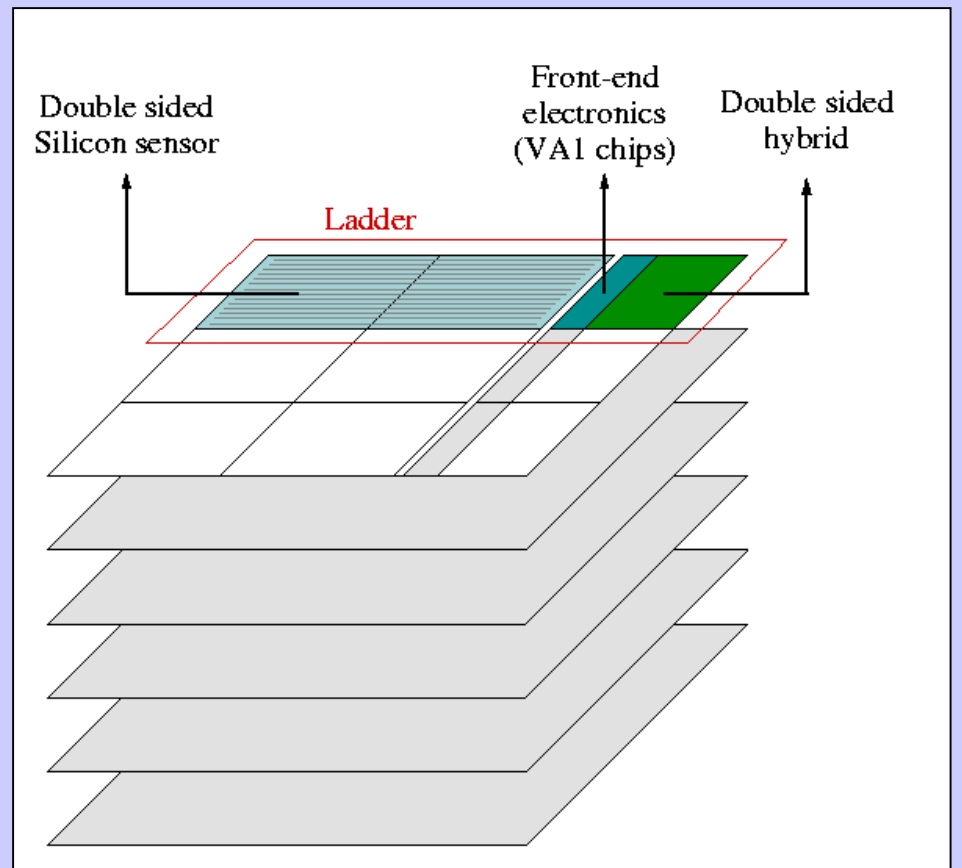


# The PAMELA Tracking System

## The TRACKER

- 6 detector planes
- each plane: composed by 3 "ladders"
- the "ladder": 2 microstrip silicon sensors + 1 hybrid circuit with front-end electronics (VA1 chip)
- silicon sensors: double sided; double metalization; integrated decoupling capacitance
- resolutions:  $\sigma_x \approx 3\mu\text{m}$ ,  $\sigma_y \approx 13\mu\text{m}$
- MDR > 740 (GV/c)

## The detector planes



# SILICON SENSORS

- Double Sided (x & y view)
- Double Metal (No Kapton Fanout)
- AC Coupled (No external chips)
- Produced by Hamamatsu

Geometrical Dimensions	70.0 x 53.3 mm <sup>2</sup>
Thickness	300 μm
Leakage Current	< 3 μA
Decoupling Capacitance	> 20 pF/cm
Total Defects	< 2%

## p side

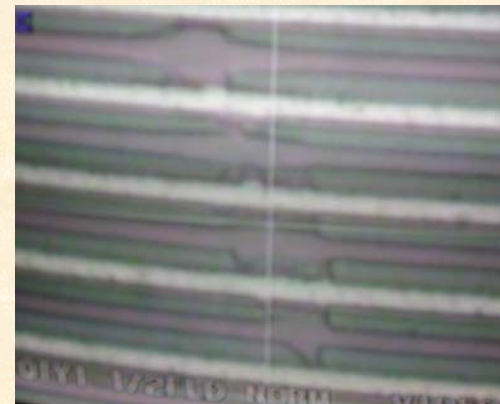
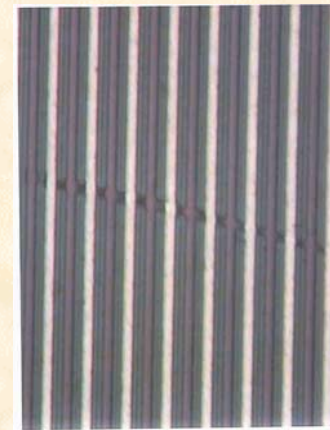
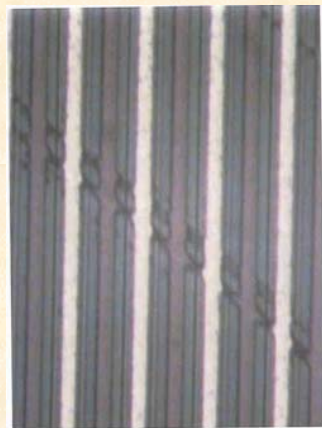
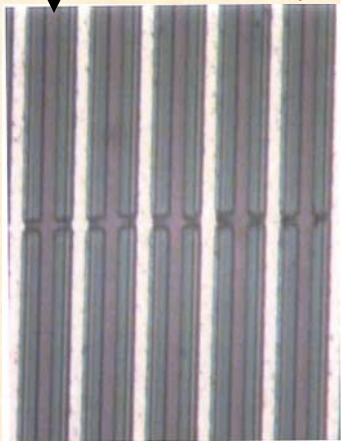
Implant Pitch	25 μm
Readout Pitch	50 μm
Biasing Resistance (FOX FET)	> 50 MΩ
Interstrip Capacitance	< 10 pF

## n side

Implant Pitch	67 μm
Readout Pitch	50 μm
Biasing Resistance (PolySilicon)	> 10 MΩ
Interstrip Capacitance	< 20 pF

Implanted strip

Implanted strip



# The **mechanical** assembly

## Requirements:

- 1 plane made by 3 ladders
- no material above/below the plane (1 plane = 0.3%  $X_0$ !!!)
- survive to the launch phase (7.4  $g_{rms}$ , 50 g shocks!!!)
- good alignment precision
- thermal stresses (5-35 °C)

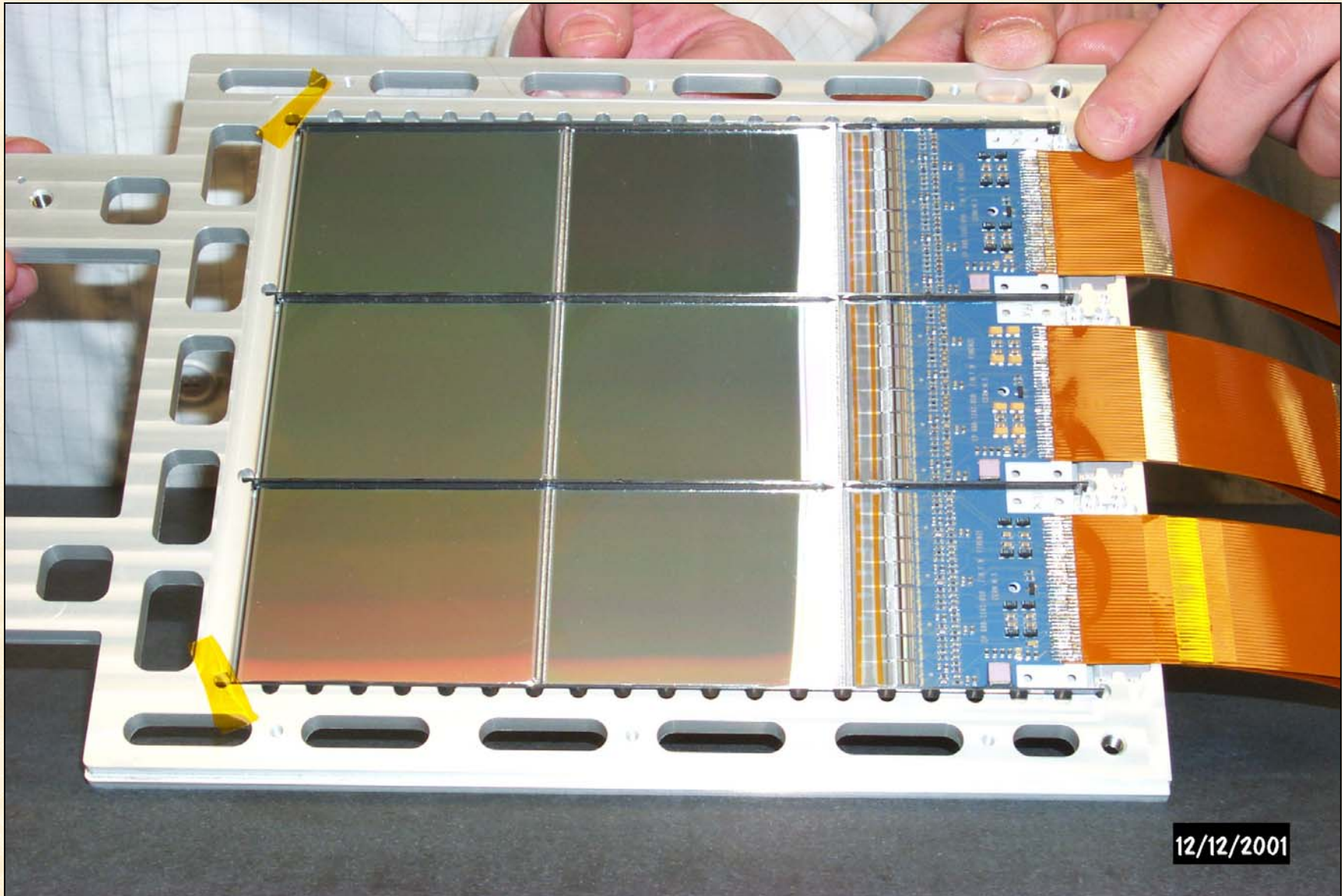
## Solution: carbon fibers stiffeners glued laterally to the sensors

- very high Young module carbon fiber (300 Gpa)
  - pultrusion technology
- Elastic + Rigid gluing

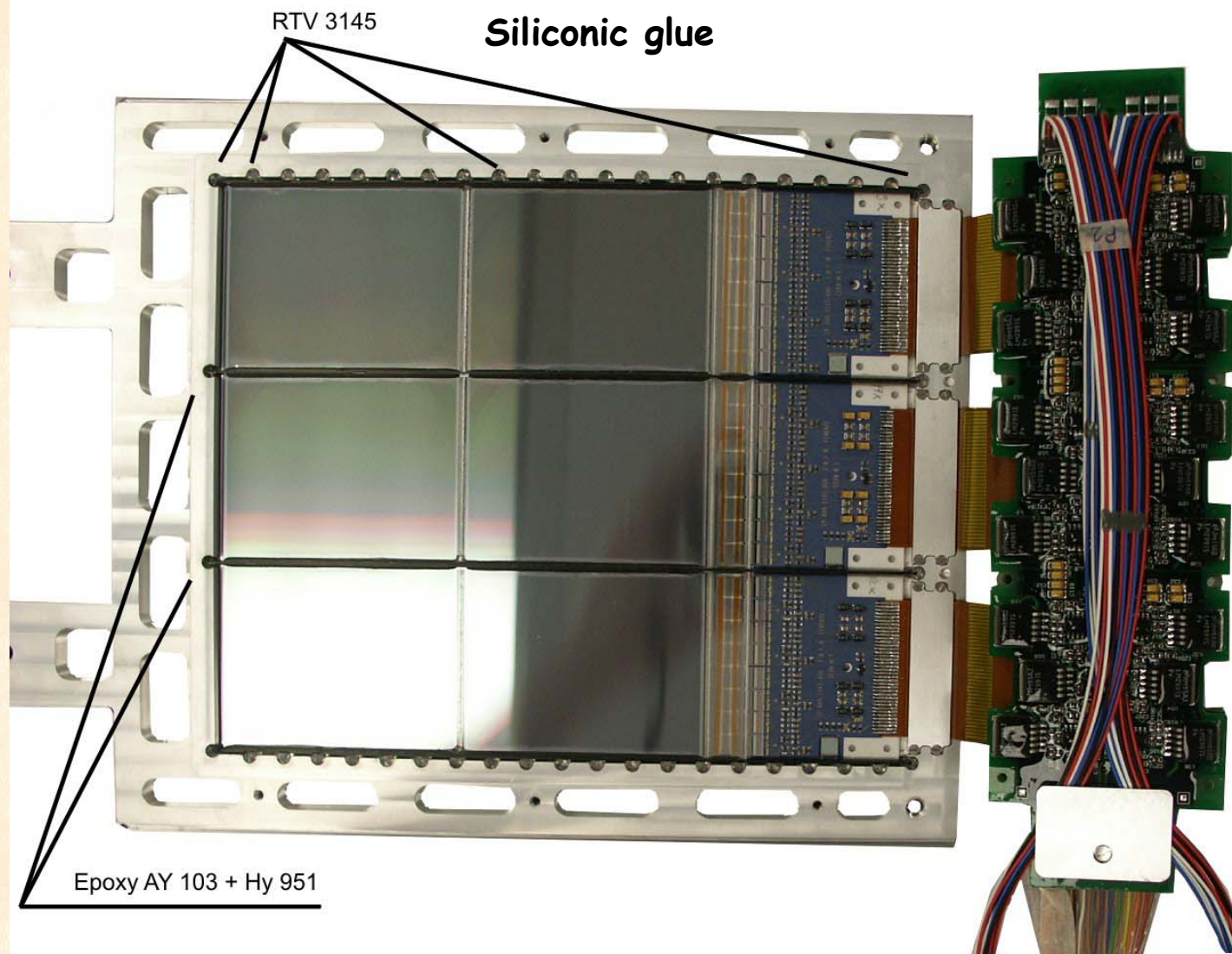
A very thin (2.5  $\mu m$ ) Mylar foil is glued on the plane to increase the safety of the whole spectrometer during integration and flight phases

No coating on the bonding

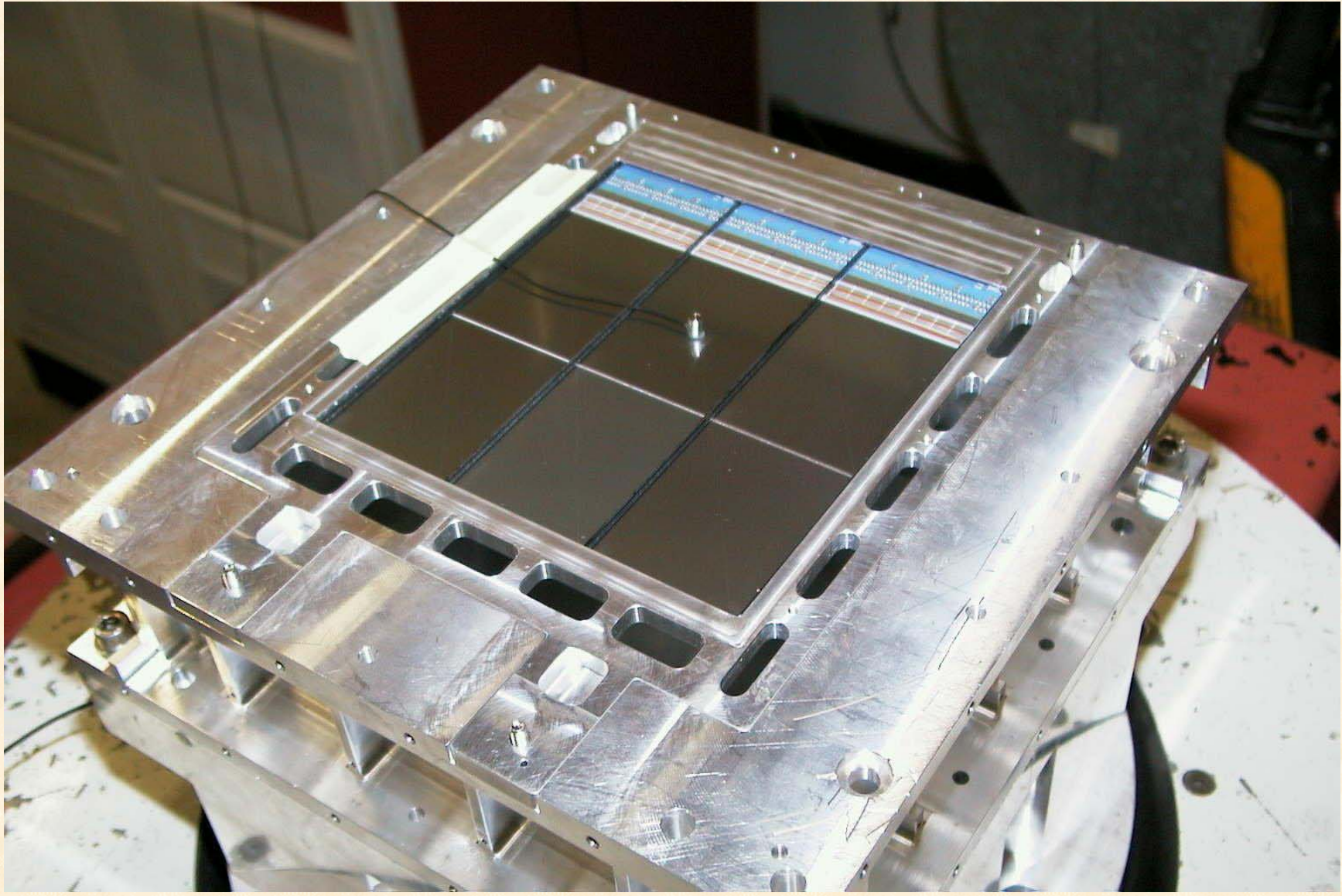
## The first detector plane







## Vibrations tests in Galileo (Florence)



# Vibrations tests in Galileo (Florence)

24 sep 2001

11:49:44

OFFICINE GALILEO

Laboratorio Prove Ambientali

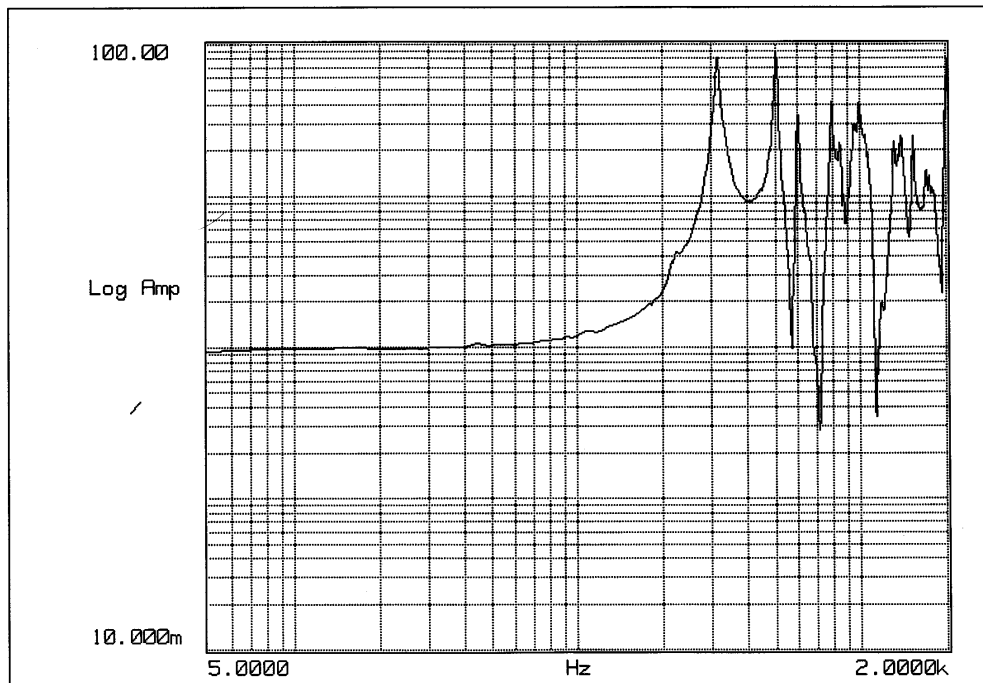


TEST REPORT 219-LPA-01 Annex. n. 9

Test Unit: INFN PAMELA pultruded silicon\_ardite

LMS CADA-X 2.8 HP35650

TEST ID.: Resonance



Z AXIS

Initial

Low Level Sine 0.5g

sweep rate : 2 oct/min

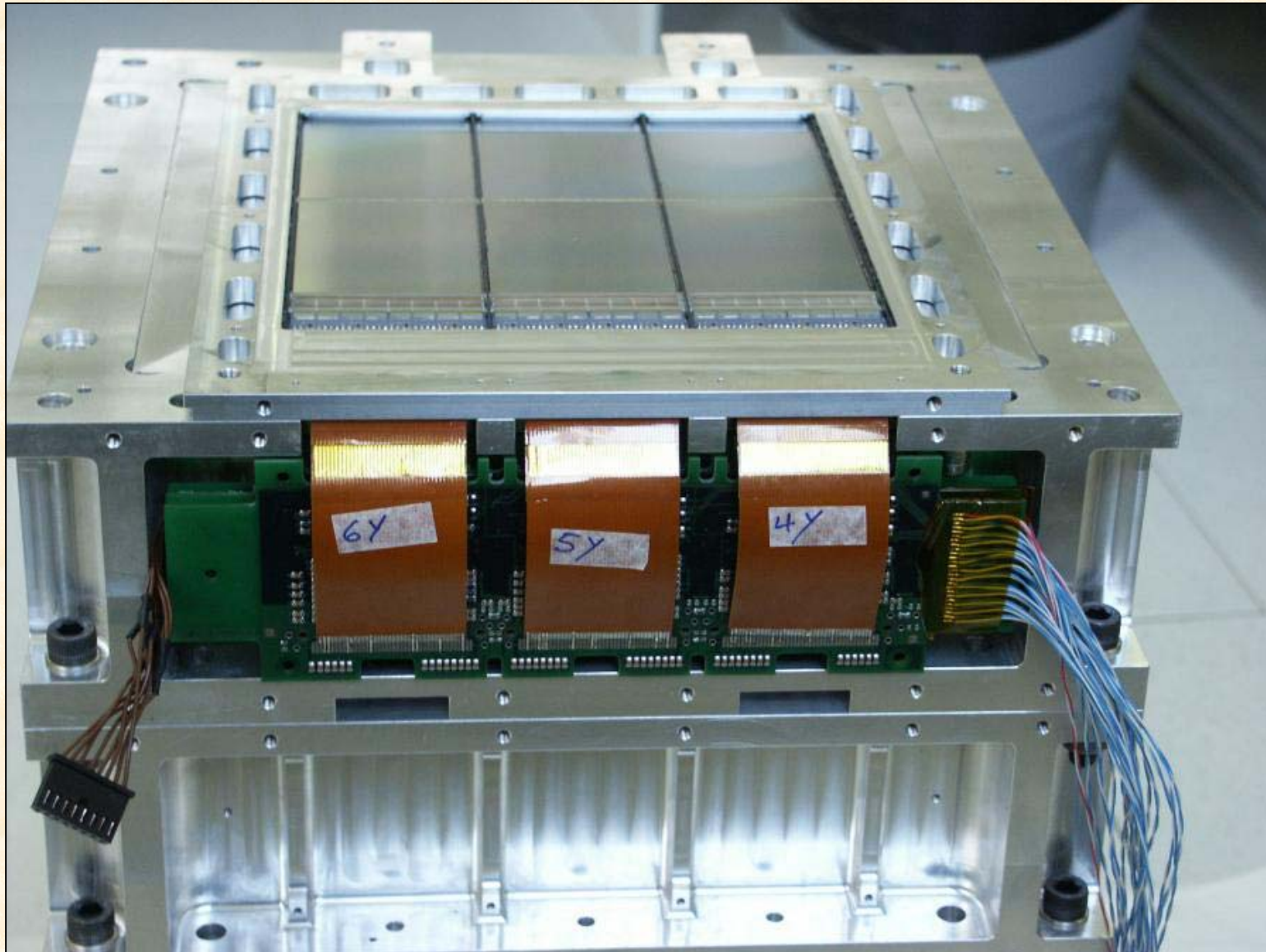
Rcc silicon / Control

0011

First resonance frequency: 340 Hz!!!!

Test plane survived to +6db spectrum (10.4 g rms)  
and repeated 50 g/5 ms + 40g/1 ms shocks

## The test plane electronics lodging on the magnetic system



# Few words on the electronics....

(a dedicated talk will be necessary!)

## Requirements:

- Very small power consumption  
(60 W all included for 36864 readout channels)
- Very low noise  
(3  $\mu\text{m}$  resolution required!!!!)
- Redundancy and safety  
(satellite experiment)
- Protection against highly ionizing cosmic rays  
(Mainly Single Event Effect tests)
- Very big data reduction  
(4 GB/day of telemetry, 5 Hz trigger rate, 30 GB/day of data, >90% reduction is mandatory)

## Solutions:

- CMOS low power analog and digital electronics
- VA1 chips ( $\text{ENC} = 185 e^- + 7.5 e^- \cdot C(\text{pF})$ )  
Small input Capacitance (<20pF)  
Decoupling between front-end and read-out
- Big modularity, hot/cold critical parts
- Selection of components (dedicated tests)  
Limiting circuits on the power lines  
Architectural 'tricks' (error correction codes, majority logic etc.)
- 12 dedicated DSP (ADSP2187) with highly efficient compression algorithm

# ZOP compression algorithm

No Zero Suppression (Losses of particles in case of bad strips or change in the pedestals!!!)

We use a *reversible* algorithm (Zero Order Predictor, ZOP)

$$\Delta_{\text{strip}}^{\text{event}} = \text{ADC}_{\text{strip}}^{\text{event}} - \text{PED}_{\text{strip}} - \text{CN}_{\text{event}}$$

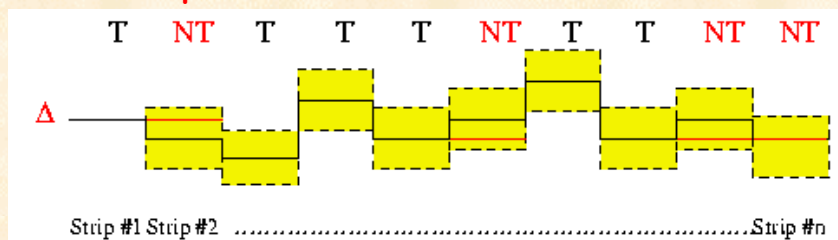
$\Delta_{\text{strip}}^{\text{event}}$  is distributed around 0

First word is transmitted

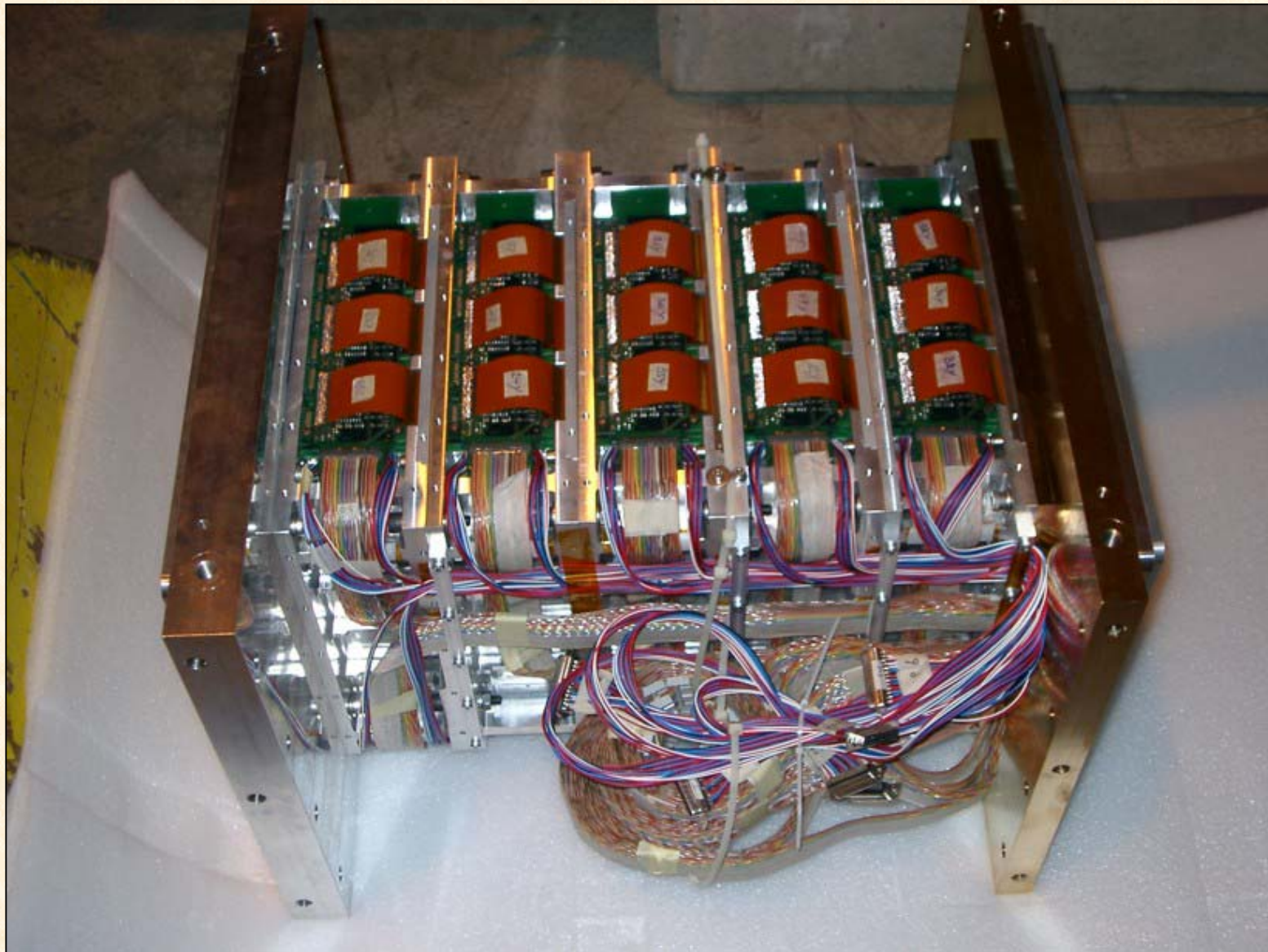
Following word is transmitted if above/below  $n \sigma$

A word is transmitted with the corresponding address if the preceding one was not transmitted

If a cluster is identified ( $\Delta_{\text{strip}}^{\text{event}} > N \sigma$ )  $\Rightarrow$  +/- 2 strips are transmitted



The magnetic spectrometer during the last beam test at CERN (July 2002)



# July 2000: CERN SPS

- FINAL LADDERS
- FINAL ELECTRONICS
- SMALLER MAGNETIC SYSTEM



## Spatial resolution

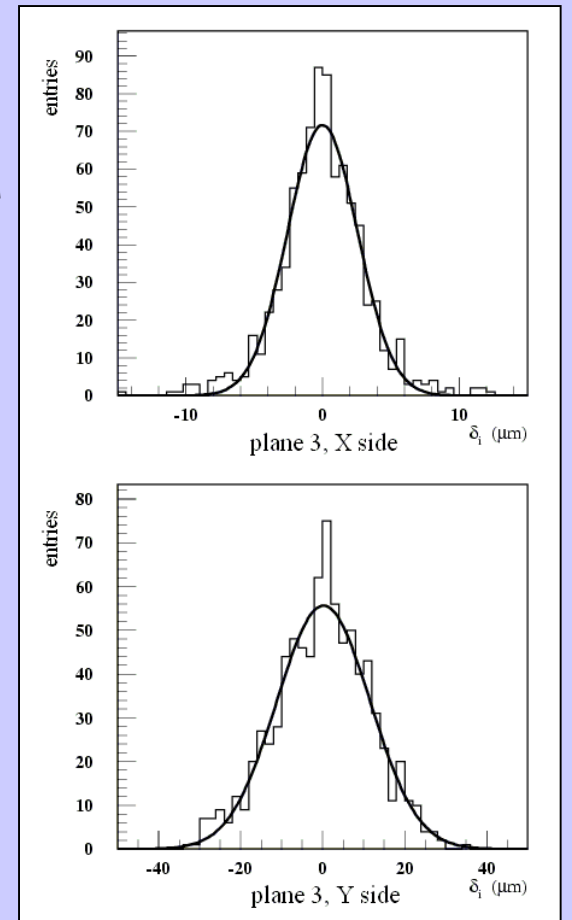
(July 2000 beam test with 5 ladder prototype MS)

$$\langle \sigma_x \rangle = (2.77 \pm 0.04) \mu\text{m}$$

$$\langle s/n \rangle \approx 50$$

$$\langle \sigma_y \rangle = (13.1 \pm 0.2) \mu\text{m}$$

$$\langle s/n \rangle \approx 20$$



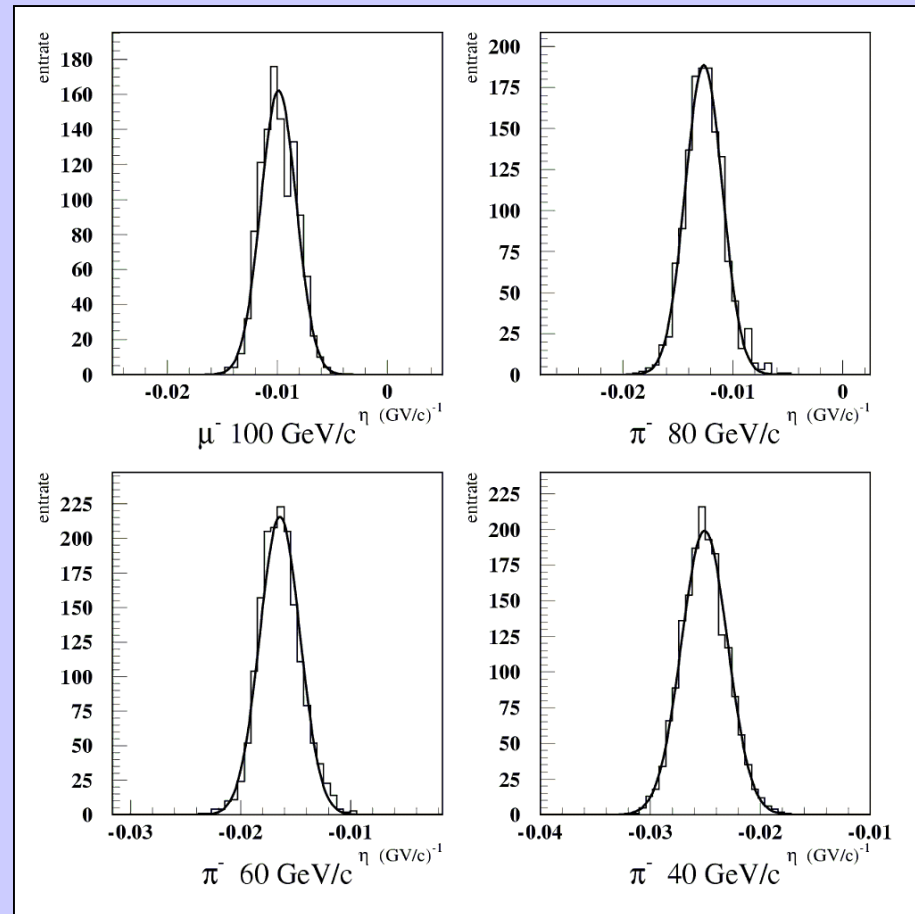
# July 2000: CERN SPS

- FINAL LADDERS
- FINAL ELECTRONICS
- SMALLER MAGNETIC SYSTEM



## $\eta$ DISTRIBUTION

$$\eta = 1/R = q/p$$

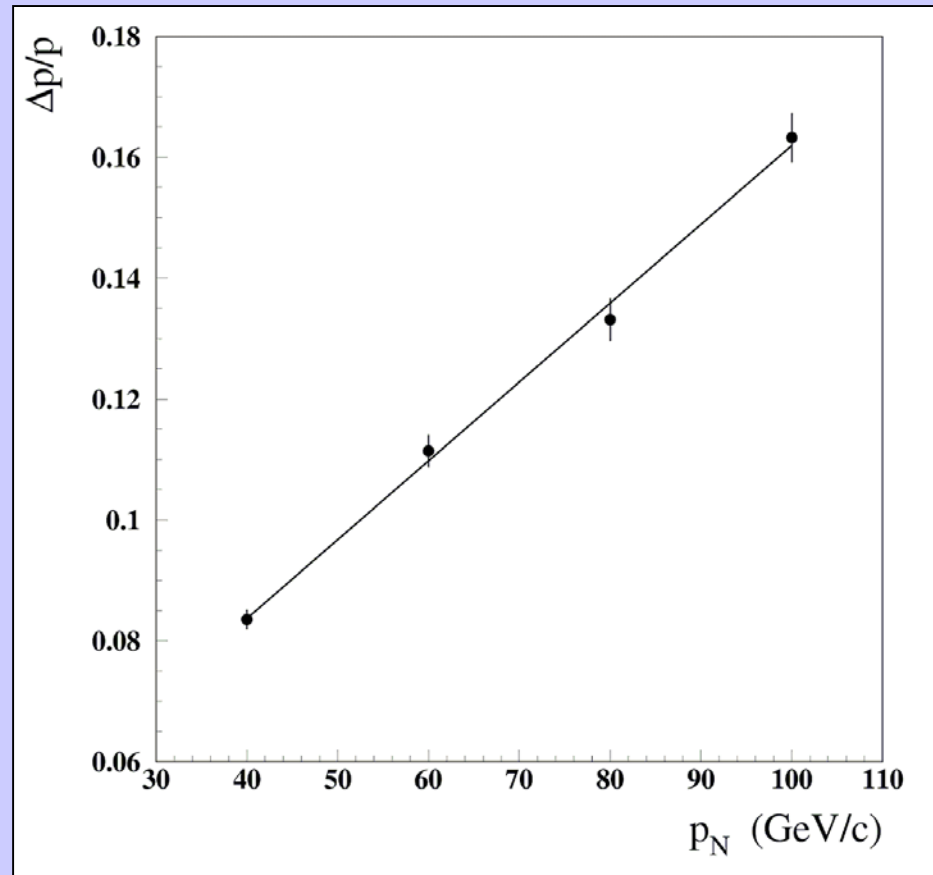


# July 2000: CERN SPS

- FINAL LADDERS
- FINAL ELECTRONICS
- SMALLER MAGNETIC SYSTEM

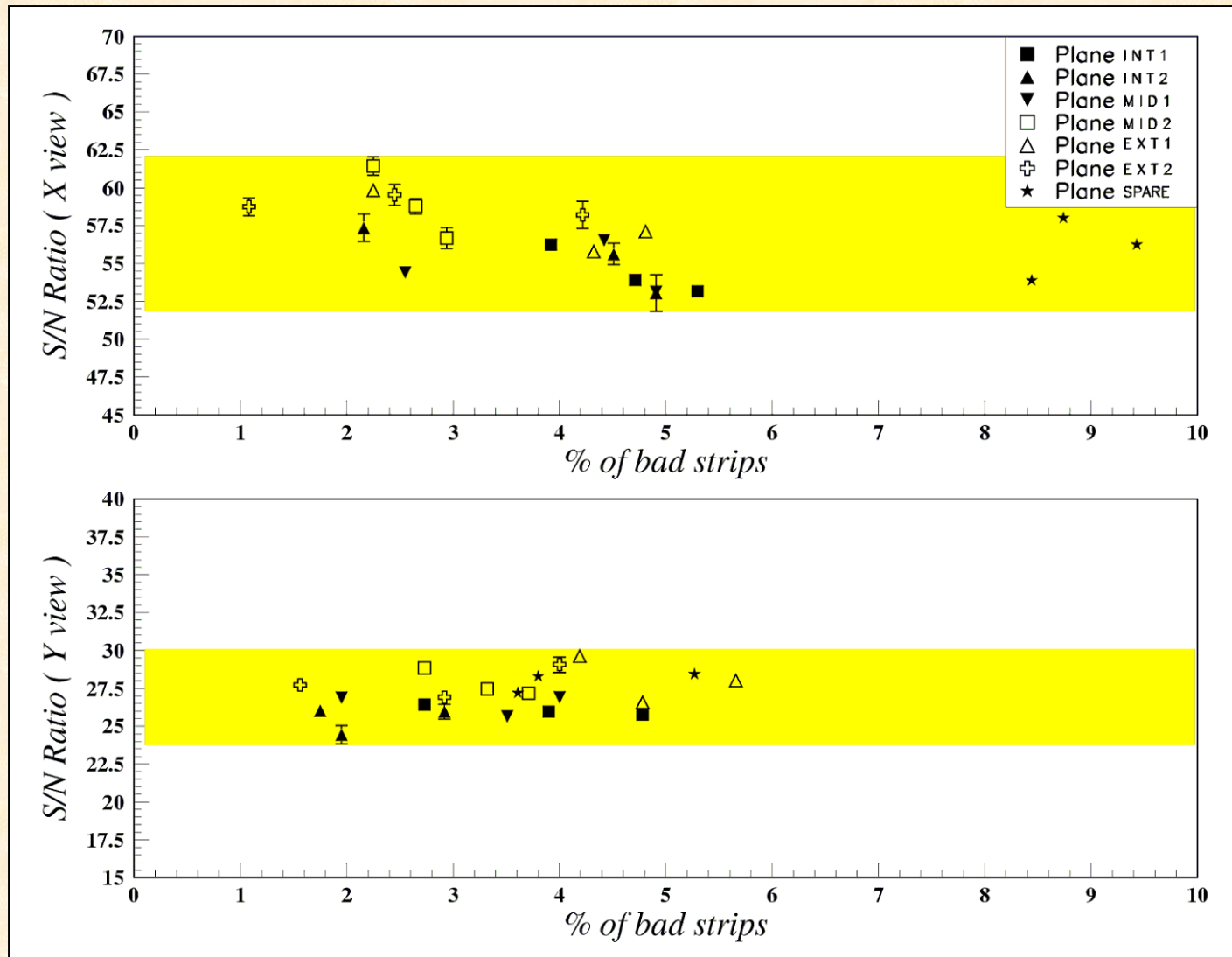


$\Delta p/p$  versus  $p$



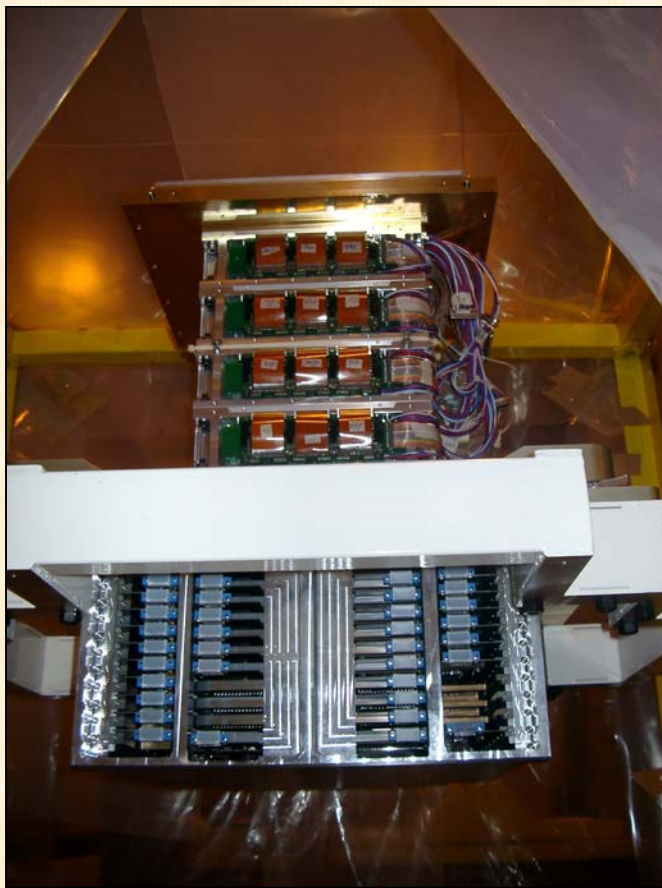
## 2002: production of flight model detector planes

Performances obtained with cosmic rays in Firenze : s/n for MIP



# July 2002: CERN SPS

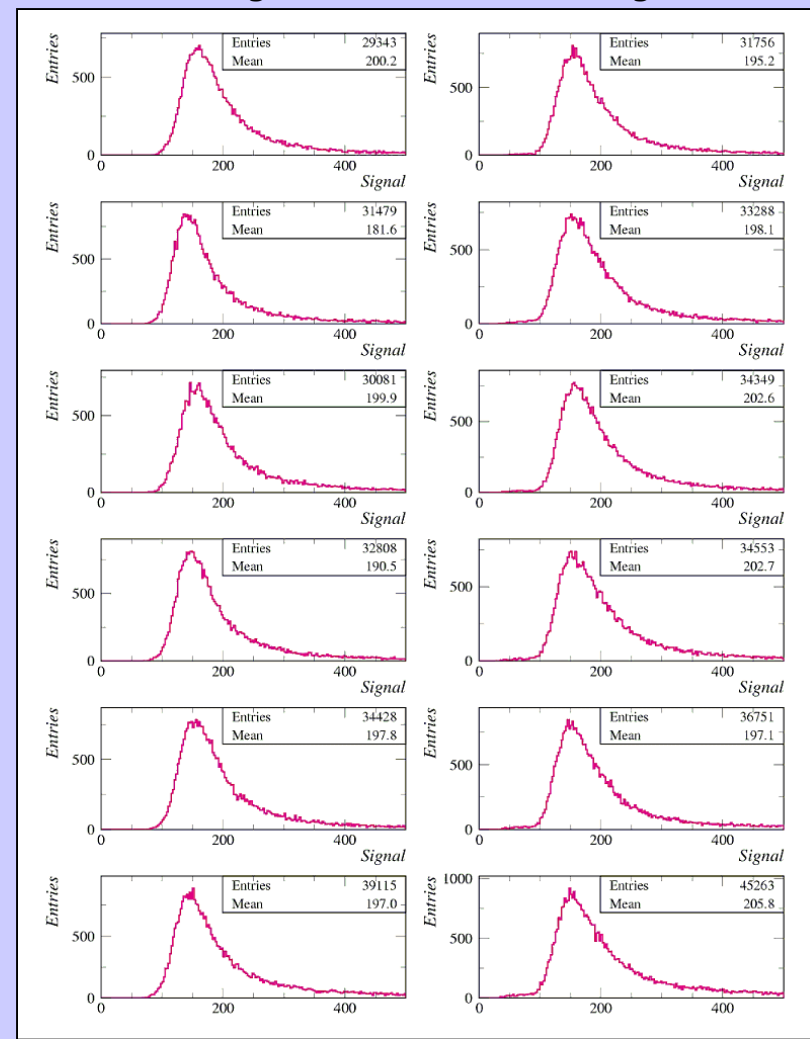
During the last test (June 2002) the spectrometer flight model has been tested to determine the performances



## Signal

non bending view

bending view



# July 2002: CERN SPS

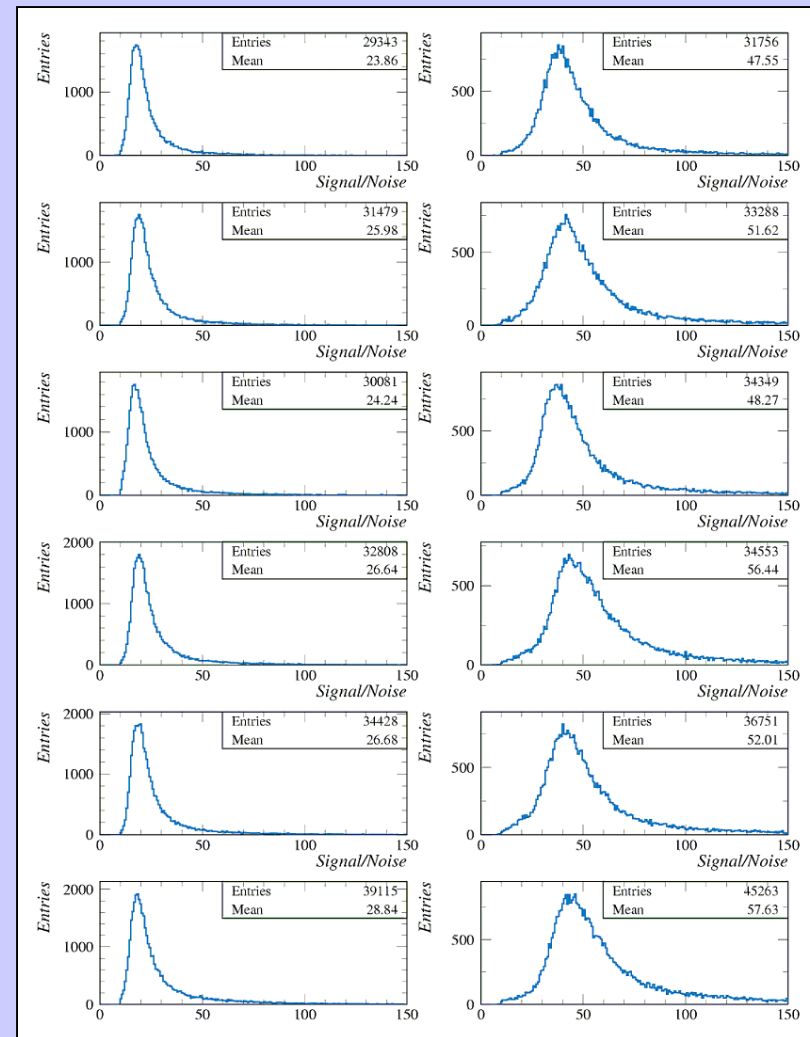
During the last test (June 2002) the spectrometer flight model has been tested to determine the performances



## Signal/Noise

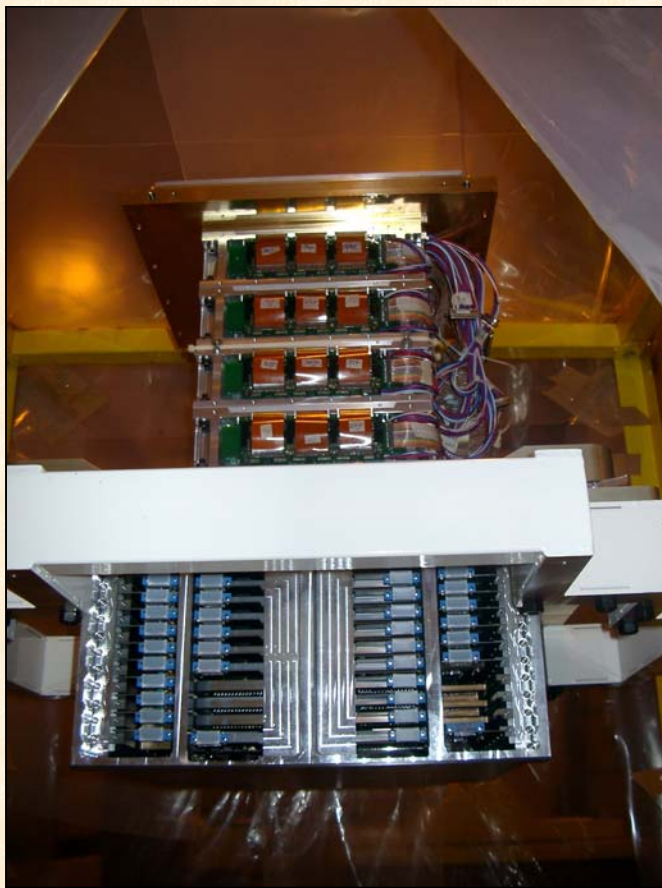
$s/n \approx 26$

$s/n \approx 52$



# July 2002: CERN SPS

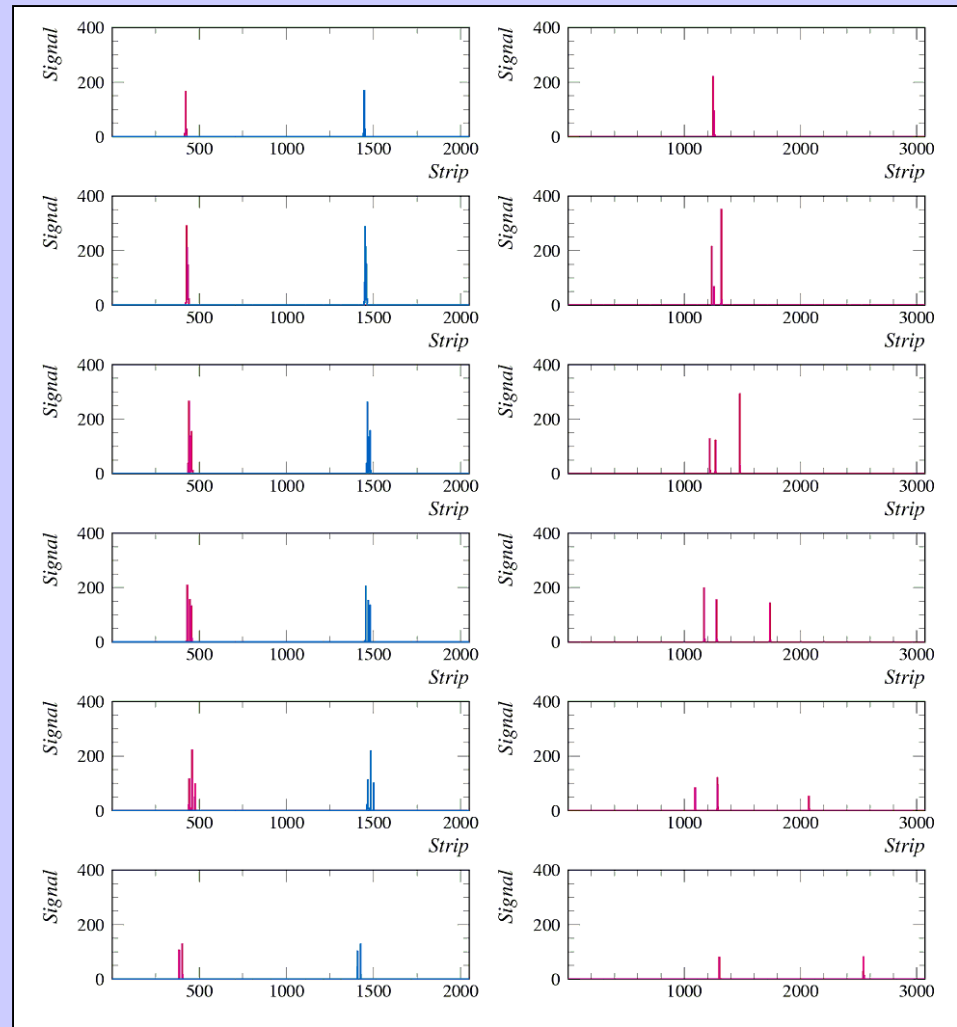
During the last test (June 2002) the spectrometer flight model has been tested to determine the performances



## 300 GeV/c Electron event

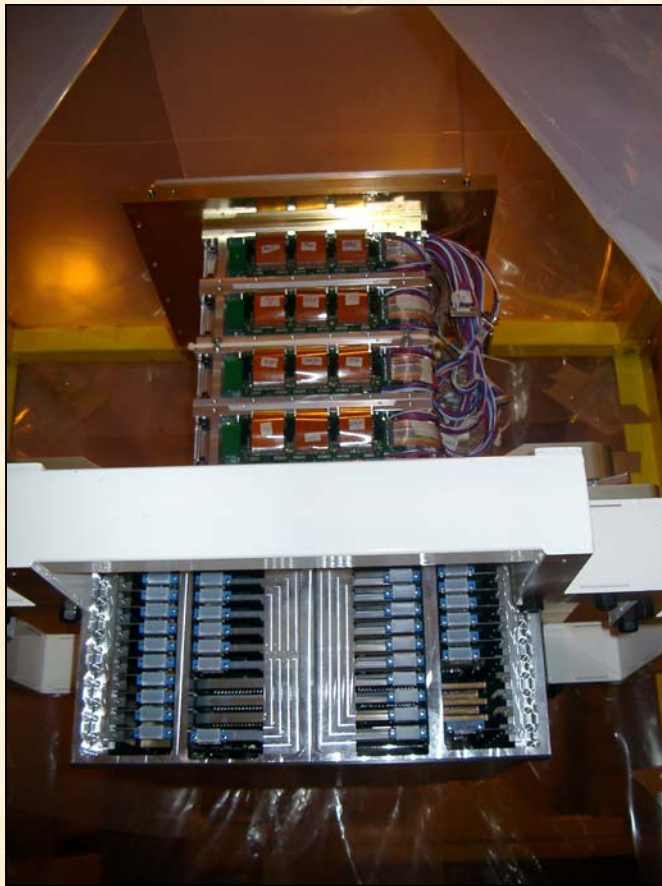
non bending view

bending view



# July 2002: CERN SPS

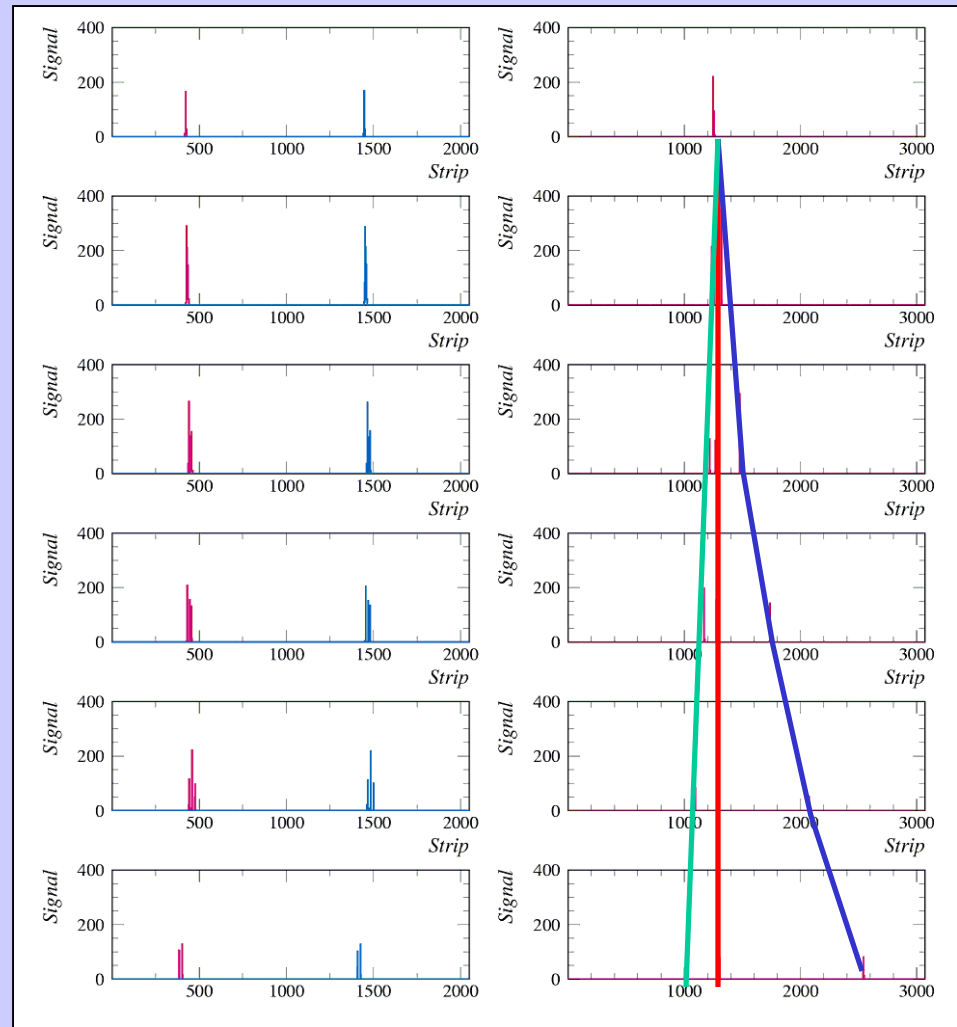
During the last test (June 2002) the spectrometer flight model has been tested to determine the performances



## 300 GeV/c Electron event

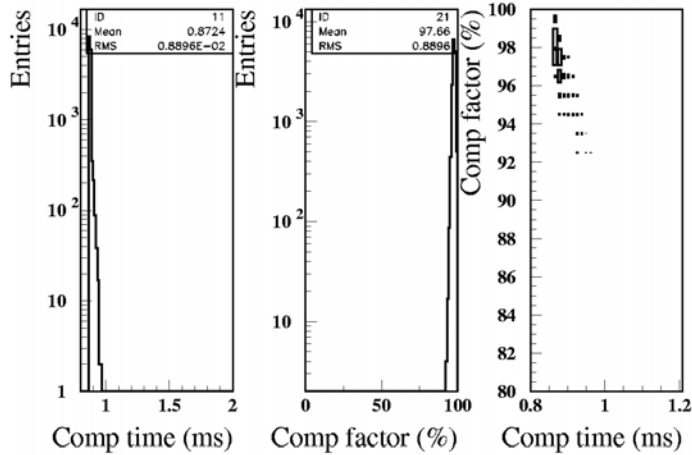
non bending view

bending view

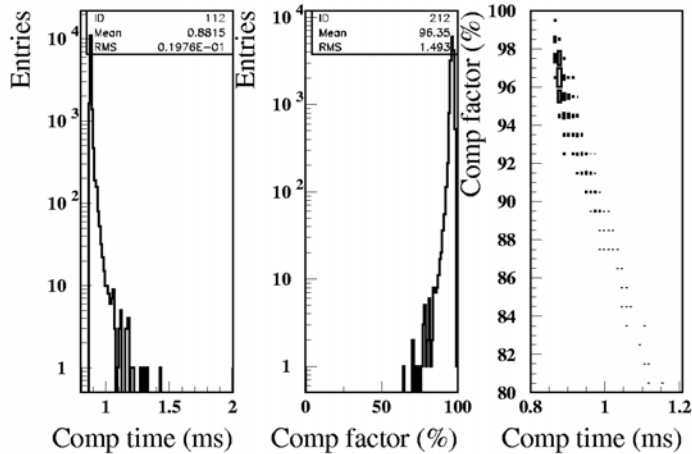


# Some results on the compression...

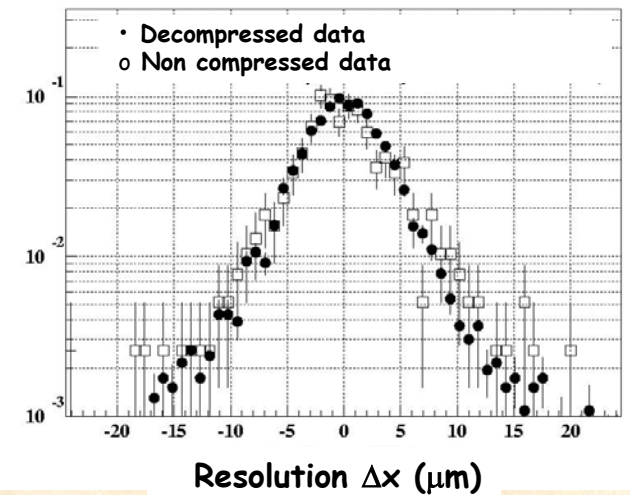
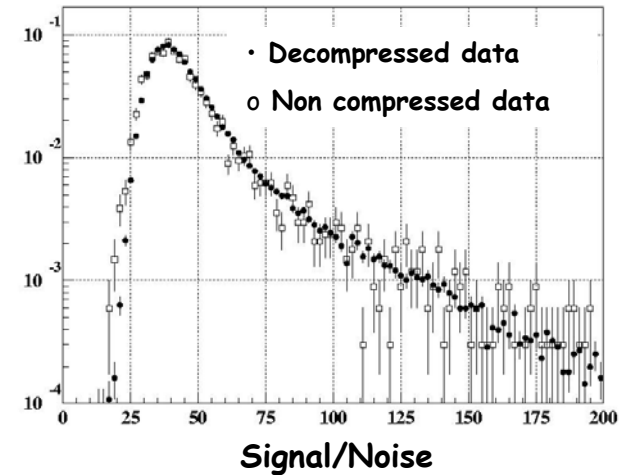
Compression time < 1ms  
Compression factor > 96%



First Plane



Last Plane



# CONCLUSIONS

- The PAMELA magnetic spectrometer is now ready for the final assembly phase
- The tracking capabilities have been accurately studied in several beam tests at CERN PS and SPS since 1998
  - $(s/n)_x \approx 52$  ,  $(s/n)_y \approx 26$  for MIP
  - spatial resolution :  $\sigma_x \approx 3\mu\text{m}$  ,  $\sigma_y \approx 13\mu\text{m}$
  - MDR > 740 (GV/c)
- The whole detector will be assembled starting from **next week** in the laboratory of Roma Tor Vergata