Data acquisition system of PAMELA silicon tracker

Snowmass Village
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Summary

Introduction

- The PAMELA experiment.
- The magnetic spectrometer and its tracking system, developed by Florence group.

Tracker data acquisition system

- Main requirements and problems.
- Adopted solutions.
- Structure and characteristics.

a Payload for Antimatter Matter Exploration and Light–nuclei Astrophysics

ITALY

- **INFN Section and Physics Department of Bari University**
- **INFN Section and Physics Department of Florence University**
- **INFN Section Roma II and Physics Department of Rome "Tor Vergata" University**
- **INFN Section and Physics Department of Trieste University**
- **INFN Section and Physics Department of Naples University**
- **INFN National Laboratories of Frascati**
- **IFAC - CNR Florence**

RUSSIA

- **Cosmic Rays Laboratory, Moscow Engineering and Physics Institute, Moscow**
- **Laboratory of Solar and Cosmic Ray Physics, P.N. Lebedev Physical Institute Academy of Sciences of Russia**
- **Ioffe Institute, St Peterburger**

USA

- **NASA Goddard Space Flight Center**
- **Particle Astrophysics Laboratory, New Mexico State University, Las Cruces**

GERMANY

- **Physics Department of Siegen University**

SWEDEN

- **Royal Institute of Technology, Stockholm**

INDIA

- **Tata Institute of Fundamental Research, Bombay**

The PAMELA experiment

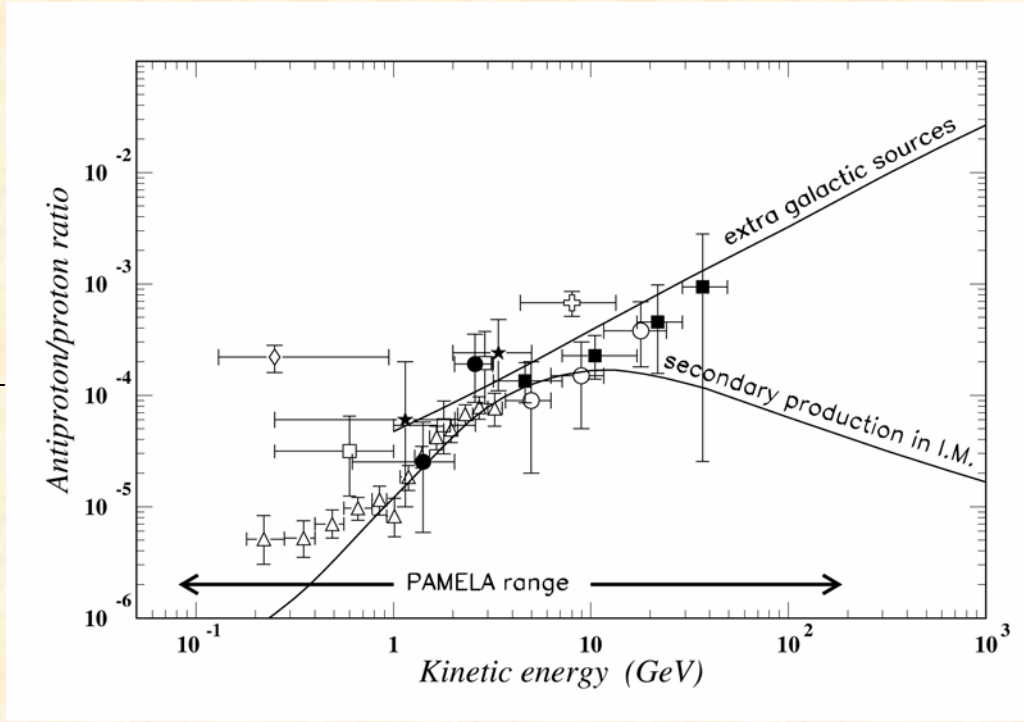
Aims to extend the known energy spectrum of light antiparticles in cosmic rays.

- Satellite-borne: Resurs-DK1 (Russia), 3 years flight from 2004.
- Semi-polar orbit: 70.4°, 350 - 600 km.
  - ➢ High statistics, low atmospheric background.

	kinetic energy
antiprotons	80 MeV - 190 GeV
positrons	50 MeV - 270 GeV
antinuclei	up to 30 GeV/n

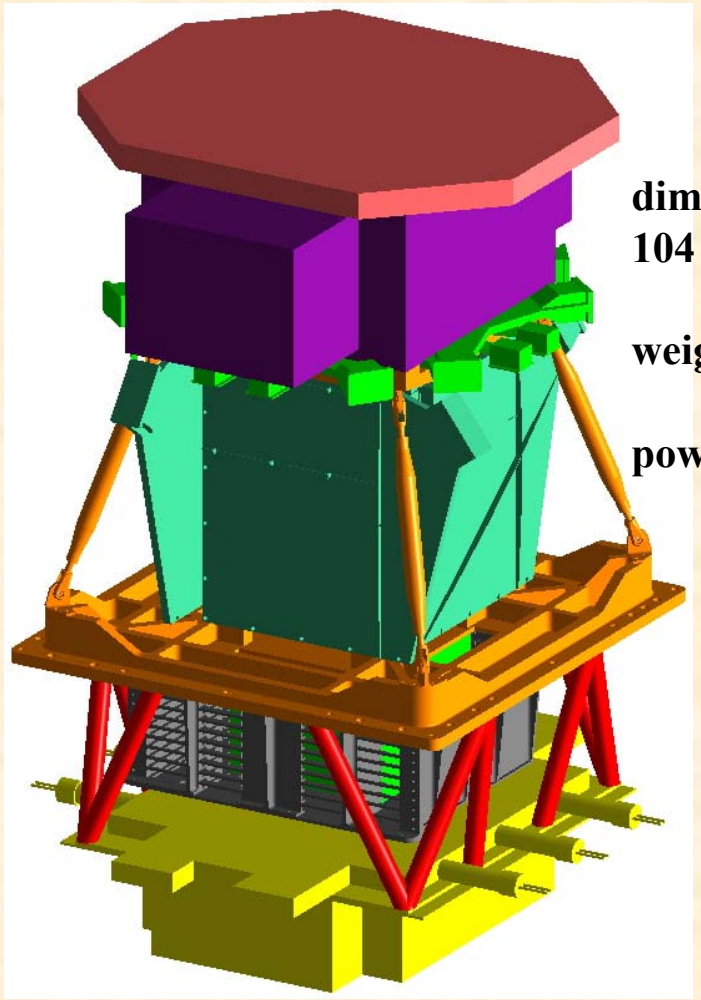
- expected : $2 \cdot 10^4$ $\bar{p}$ and $2 \cdot 10^5$ e^+
- $\overline{He}/He$ sensitivity $< 10^{-7}$

No antiparticles above 40 GeV detected till now.



The PAMELA apparatus

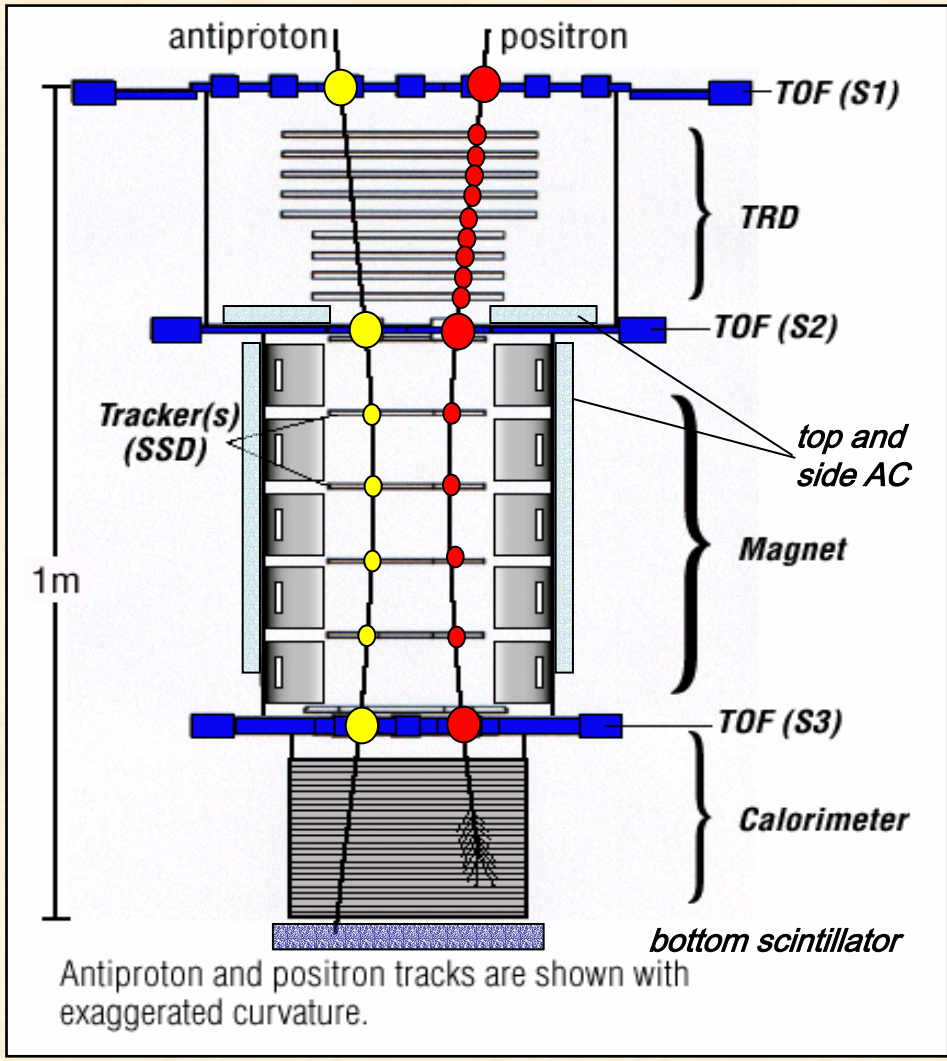
- measure of momentum and charge (with sign);
- $\bar{p}/e^-$ and e^+/p discrimination.



dimensions:
$104 \cdot 40 \cdot 45$ cm^3

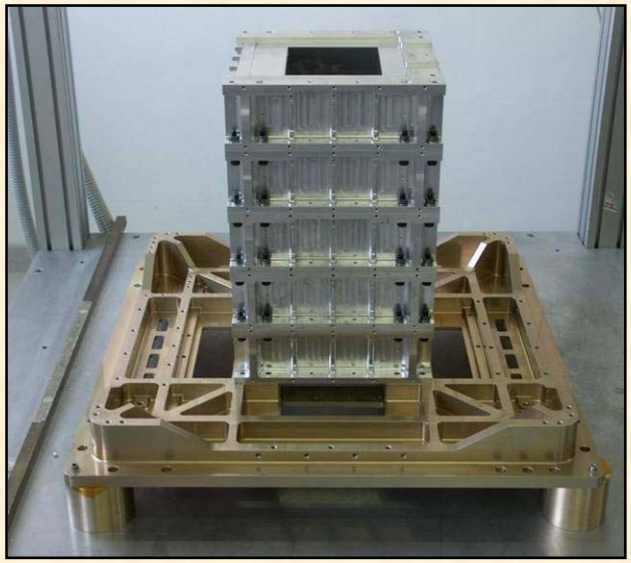
weight: 440 kg

power: 345 W



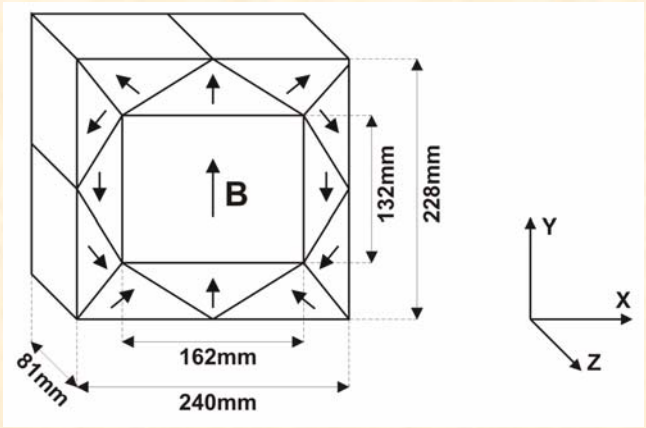
The magnetic spectrometer

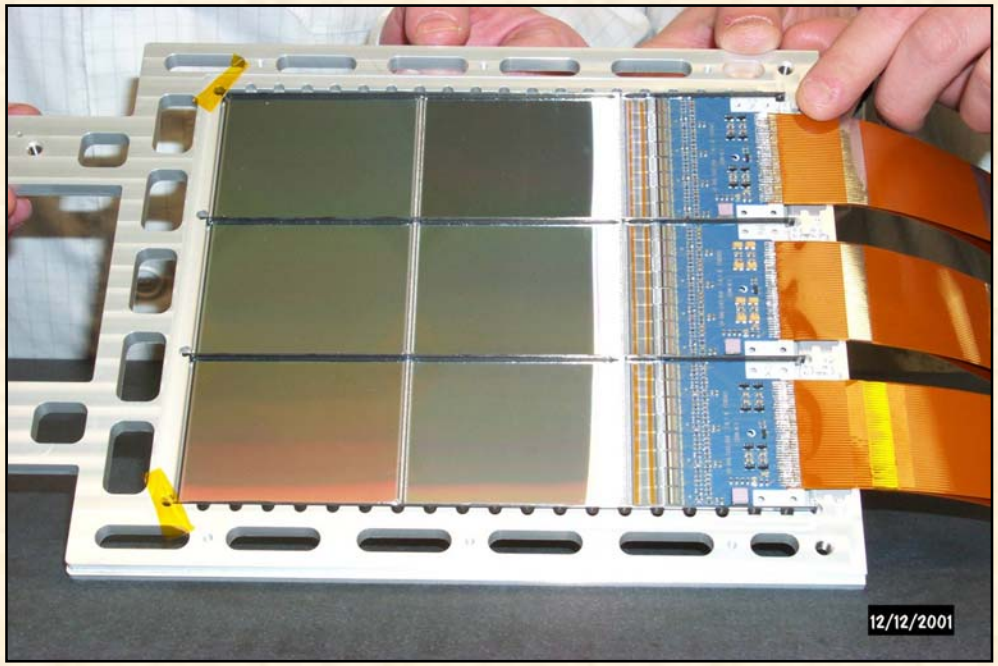
acceptance: 20.5 $cm^2 \cdot sr$



5 modules, Nd-Fe-B alloy;

B = 0.48 T at tracker centre.



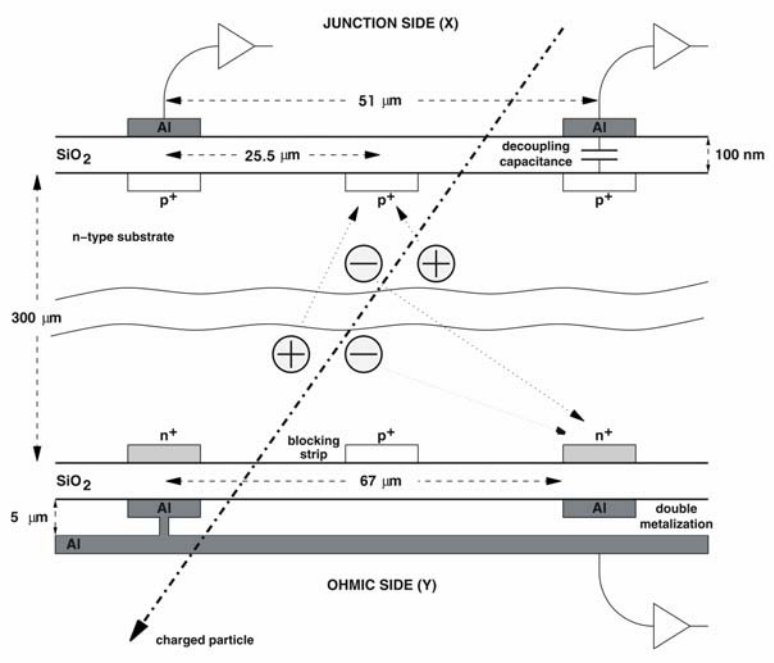


6 planes of silicon microstrip detectors:

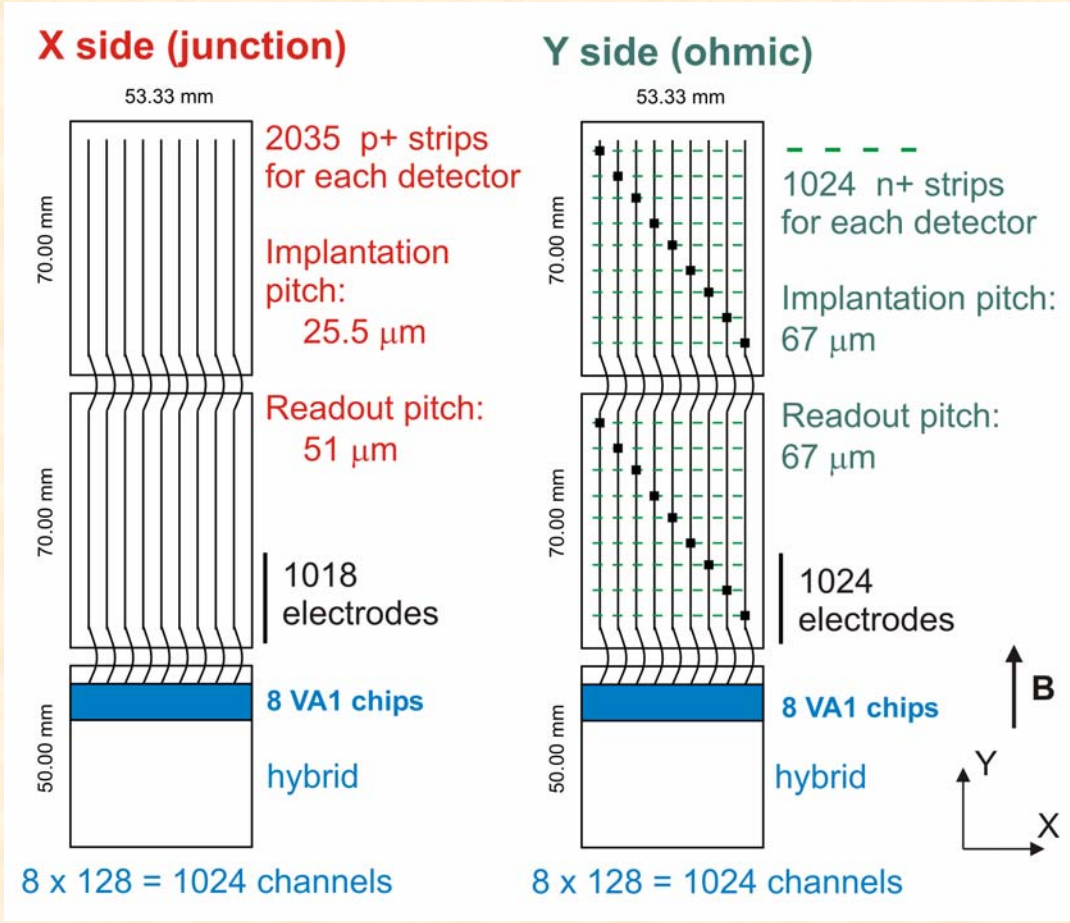
- double-sided (junction and ohmic strips implanted orthogonally);
- double metallization on ohmic side;
- integrated capacitive decoupling;

3 independent “ladders” for each plane.

Structure of a ladder



bias (V_Y - V_X) : + 80 V
biasing resistance X side: > 50 MΩ, punch-through Y side: > 10 MΩ, polysilicon
leakage current: < 1 μA/detector



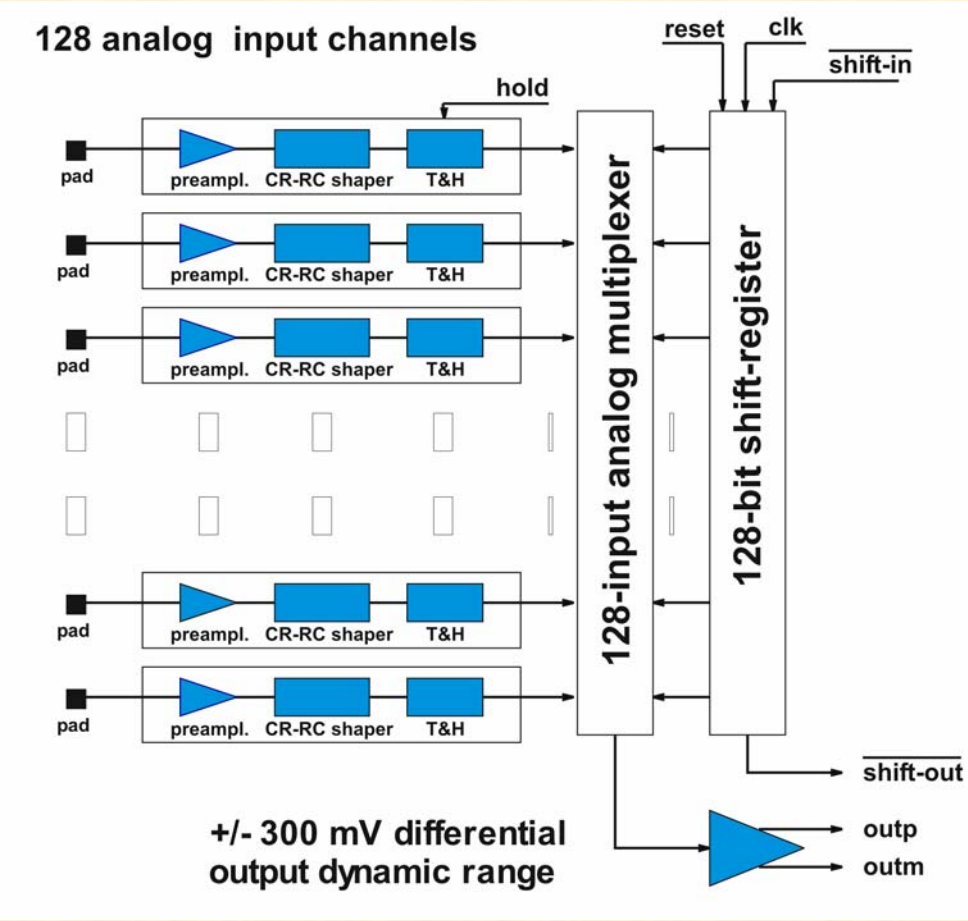
- junction side strips measure X coordinate (normal to B);
- bias fed through guard ring surrounding the strips.

The VA1 chip

- 1.2 μm CMOS (6.2 · 4.5 mm^2 chip area);
- ±2 V power rails;
- low-noise charge preamplifier;
- operating point set for optimal compromise:

	"typical"	adopted
shaping time	1 μs	1 μs
dissipation/ channel	1.3 mW	1.0 mW
voltage gain	12.5 mV/fC	7.0 mV/fC

- total VA1 dissipation: 37 W;
- output saturation at ~ 10 MIP (MIP release 4.6 fC in 300 μm Si).



Tracker data acquisition system

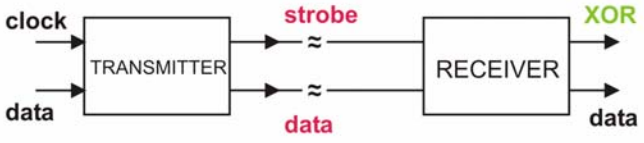
- Requirements for high precision position measurement:
  - high number (36864) of channels: complexity;
  - low noise electronics;
  - high reliability for whole apparatus.

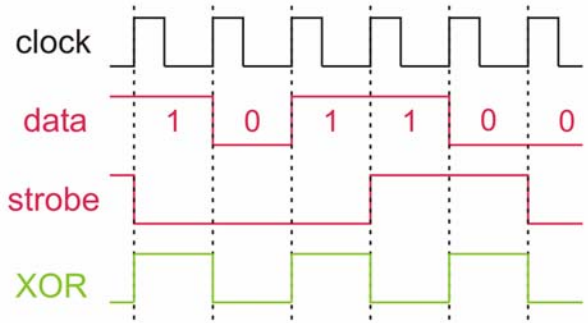
- Problems for satellite-borne apparatus:
  - high radiation damage risk in space (TID, SEL, SEU);
  - strong mechanical stresses at launch require compactness;
  - limited power available: ~ 45 W for tracker;
  - restricted bandwidth for data transmission to earth: 4 Gbyte/day.

- Last but not least:
  - cost.

General outline

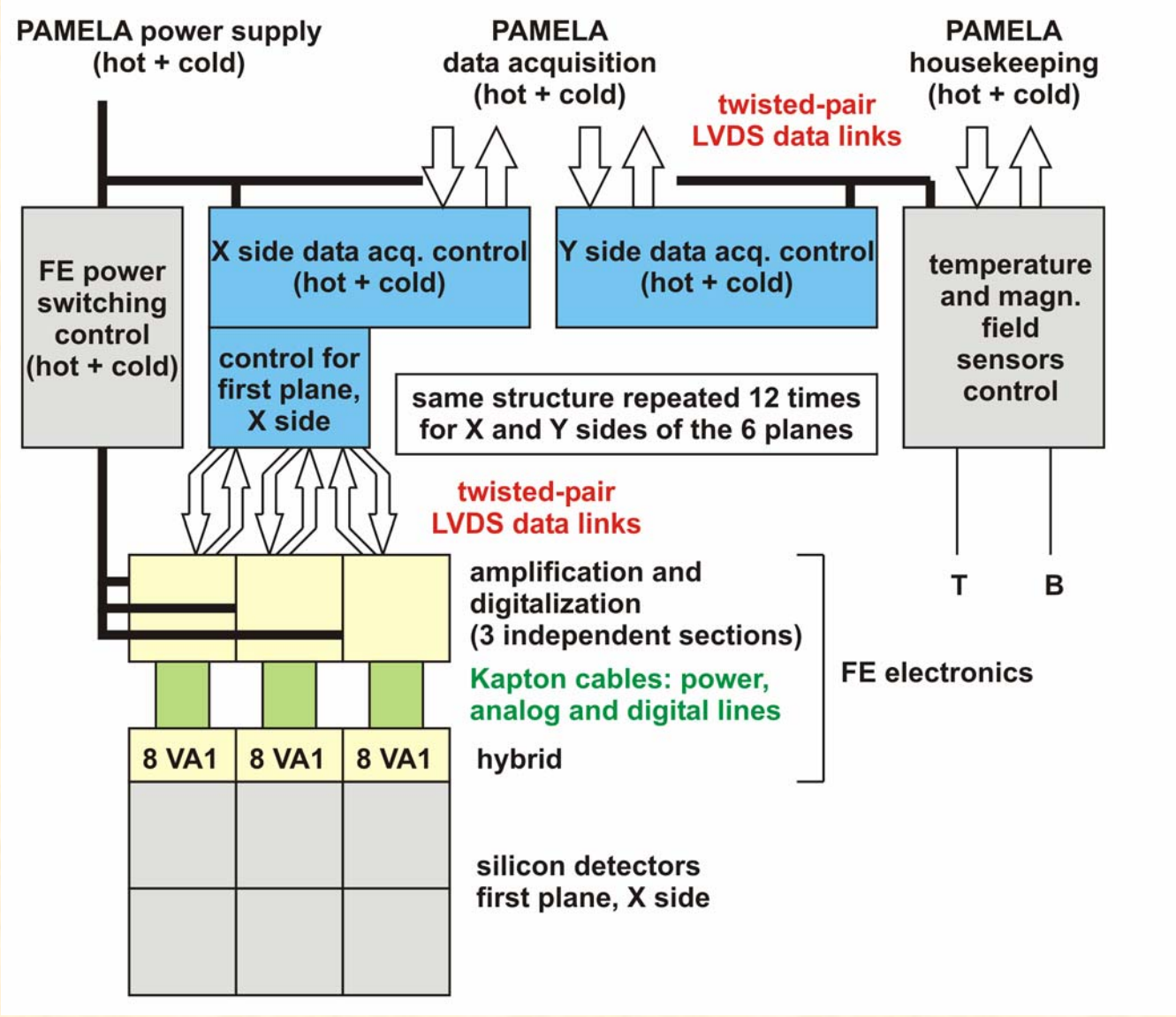
- Devices doubled (hot/cold) within power limits.
- Commercial components, tested up to 30 krad TID with γ-source at ENEA (Rome) (foreseen in 3 years: ~ 1 krad – CREME96).
- VLSI CMOS devices, LVTTL (3.3 V).
- SEL protection with current limiter; latch-up removed by switching-off power supply.
- Optimized digital interface:
  - **LVDS transmission protocol;**
  - **8-bit Cyclic Redundancy Check (CRC) of errors;**
  - **serial links with data/strobe encoding.**





Tracker electronics

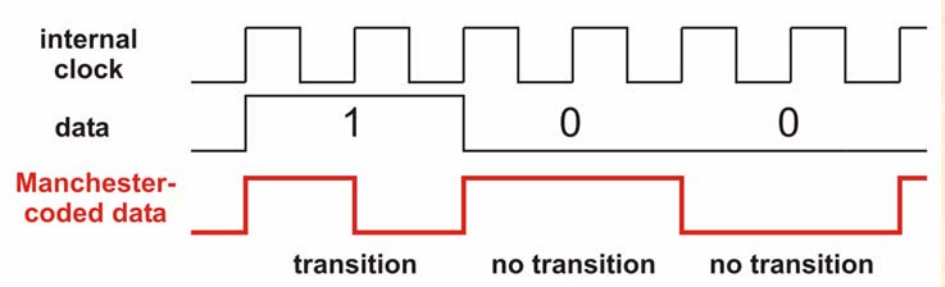
- separate power lines for X and Y side FE electronics.
- Y side ground is 80V above X side to avoid stressing SiO_2 integrated decoupling capacitances.



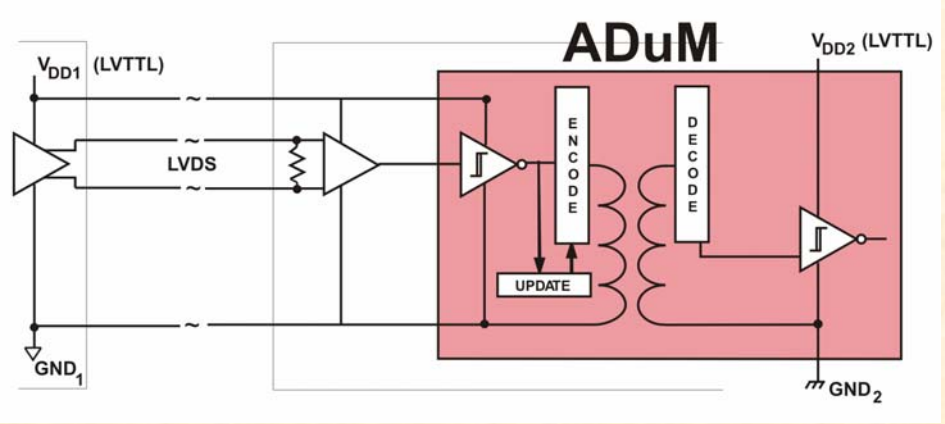
X-Y side decoupling

DC decoupling done on digital links between tracker FE and data acquisition control electronics:

- passive (e.g. CR filter) decoupling implies use of rapidly varying signals (e.g. "Manchester" encoding) with ½ transmission efficiency;



- we chose active inductive decoupling with ADuM1100 IC: transmission efficiency is 1; additional consumption introduced at 3.3 V, 20 Mbps: 2.6 mA/line (LVDS requires 7.5 mA/line).

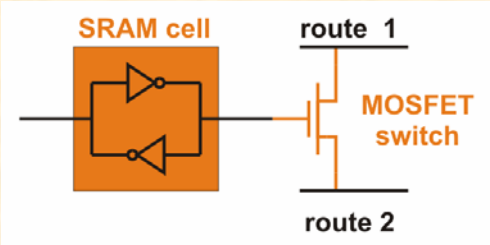


Tracker control logic

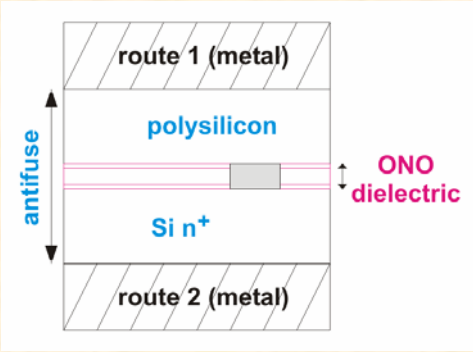
- Developed by Florence group on FPGA devices:
- synchronous logic machines as much as possible:
  - nearly independent from T, V;
  - induced noise on analog readout is reduced;
- clock oscillator set to 20 MHz (speed/power compromise);
- design takes care of possible metastable states (and upset) when sampling asynchronous data;
- asynchronous signals (e.g. resets) have no glitches.
- Performed complete functionality tests on whole recommended operating range: 0 - 70 ºC, 3.0 - 3.6 V.

Tracker control logic

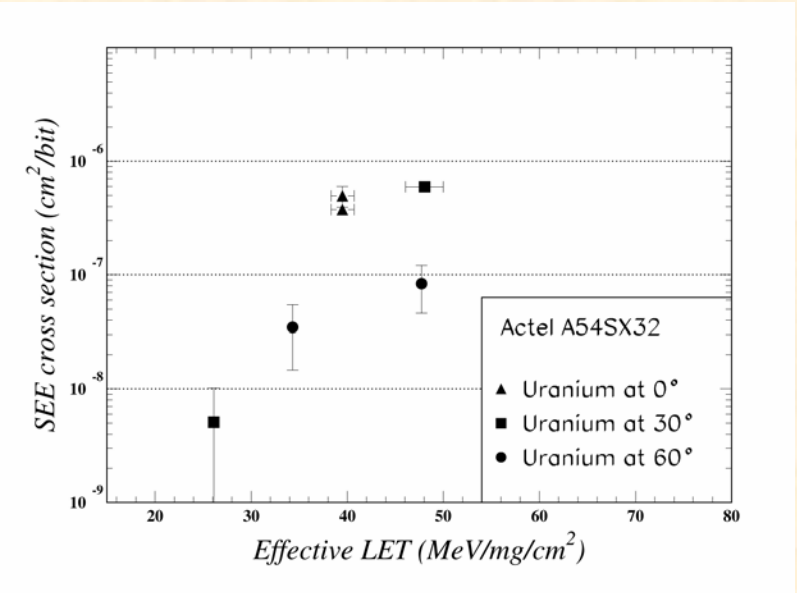
- For prototypes: used Altera SRAM-based FPGA.



- For flight-model: chosen Actel CMOS-antifuse A54SX/SXA FPGA families.



- Actel characterized for SEU and SEL at GSI (Darmstadt) together with AMS people:



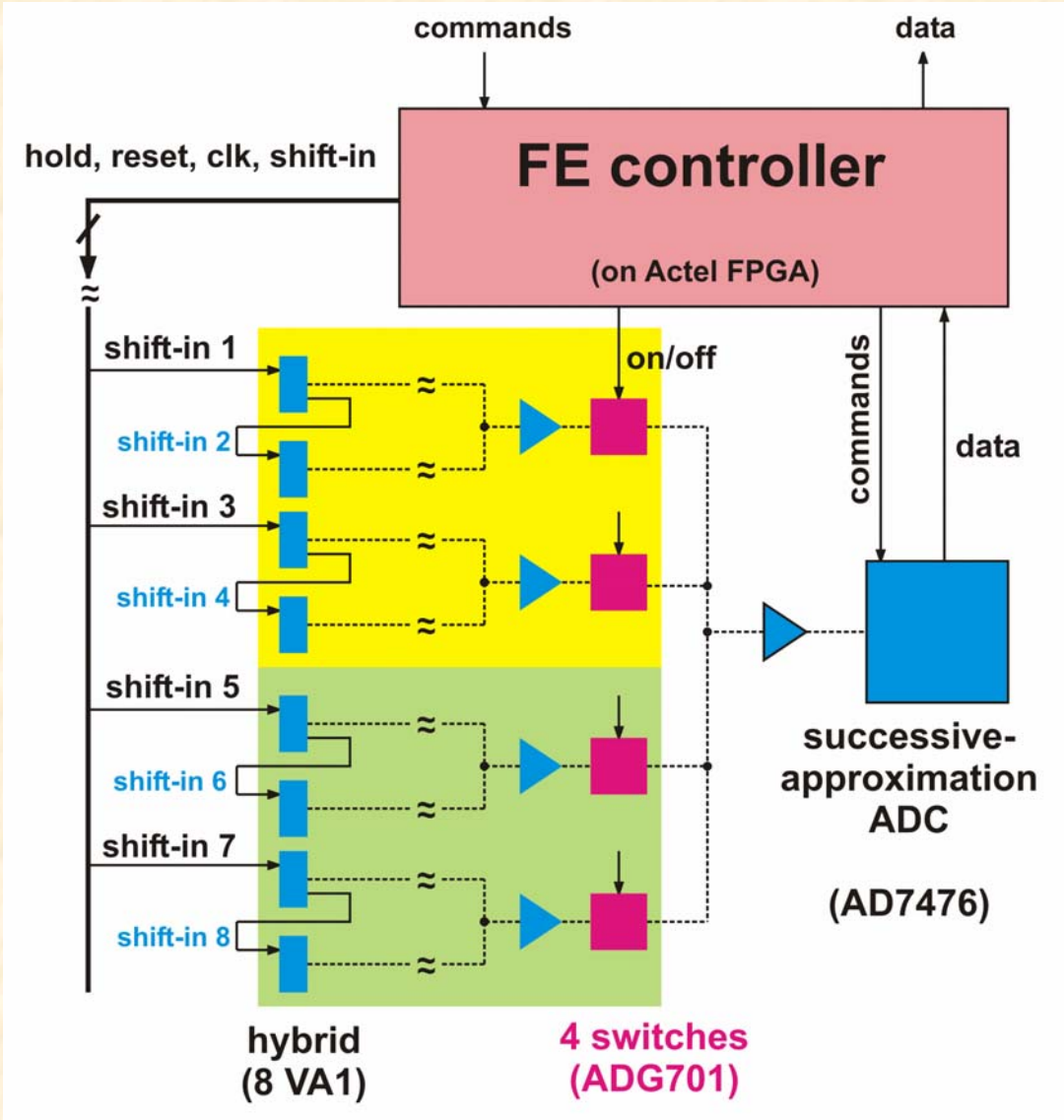
- no latch-up observed up to 50 MeV / (mg · cm^{-2}) LET;
- predicted SEE in 3 years flight with CREME96 software:

$1.6 \cdot 10^{-2}$ (galactic + trapped)

$6 \cdot 10^{-2}$ (10 days of solar maximum - 1989 data)

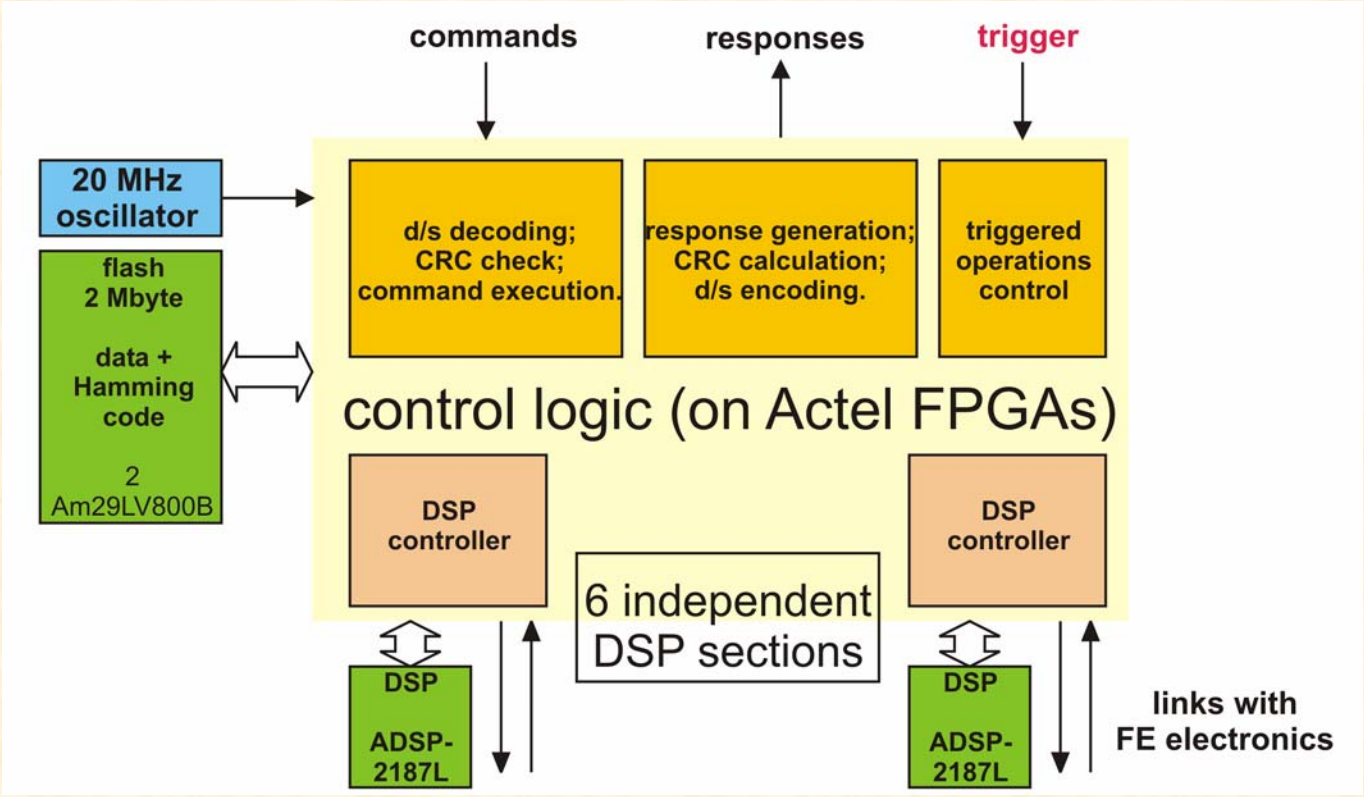
Front-end electronics for a ladder

- analog readout divided in 2 independent sections with separate voltage references;
- analog switches for safe insulation;
- VA1 paired to save resources;
- simple control logic performs fixed operations;
  - 20 MHz clock reconstructed from d/s;
  - 1024 · 2 μs cycles;
- ADC: 0.5 Msps, 12-bit serial data output.



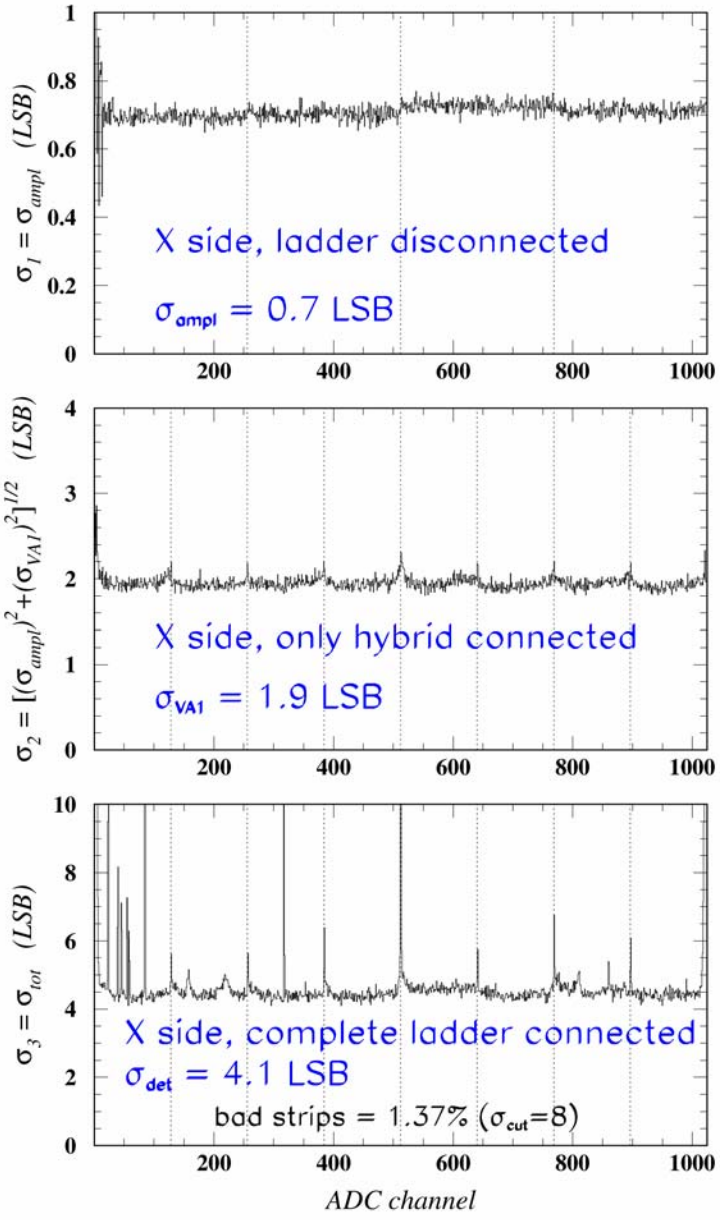
Data acquisition control for 6 sides

- 9 different commands;
- 9 possible error conditions with dedicated output alarm line;



- DSP used for data compression > 95% ;
- used IDMA port for fast access to DSP internal memory;
- flash store non-volatile copy of DSP program, Hamming-coded for automatic single upset detection and double upset detection.

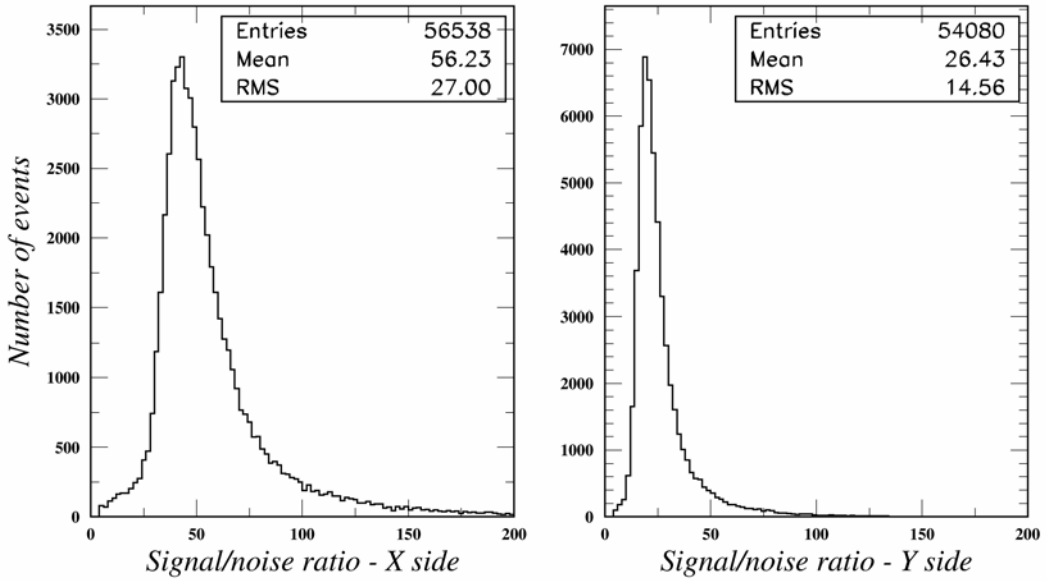
Noise characterization



- done in 3 different configurations to isolate single contributions:

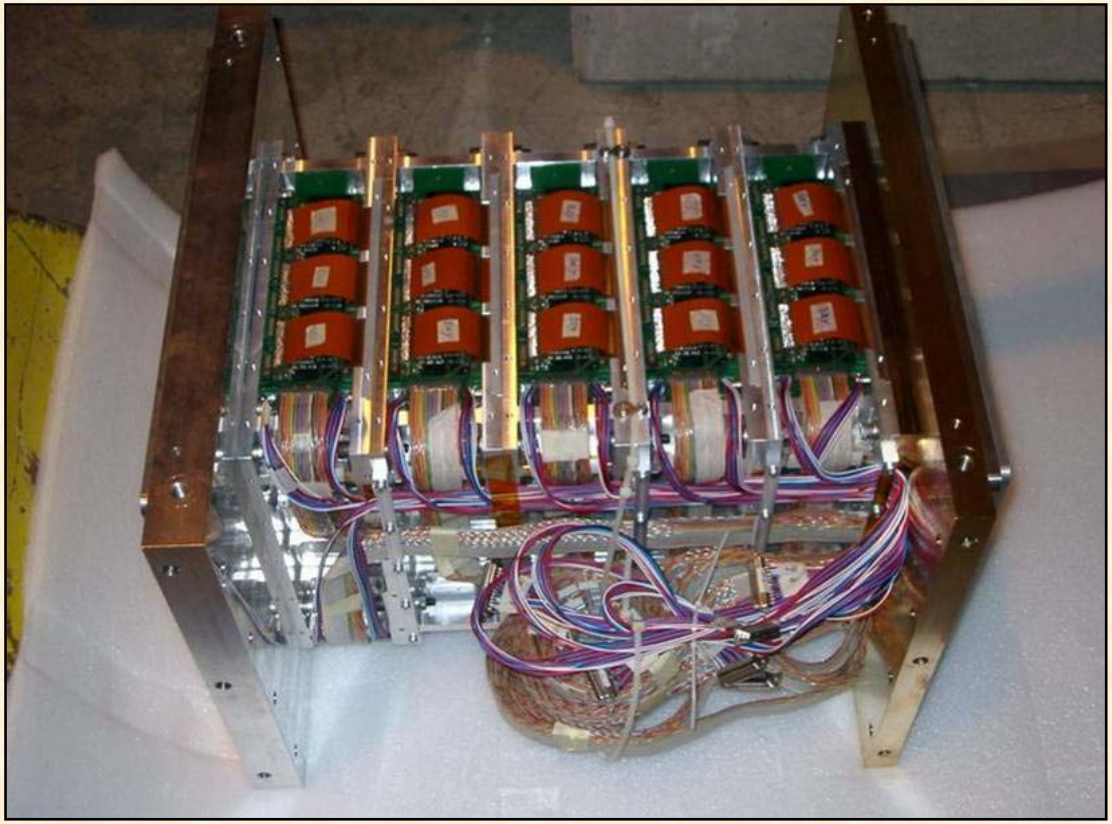
$$\sigma_{tot}^2 = \sigma_{ampl}^2 + \sigma_{VA1}^2 + \sigma_{det}^2$$

- almost all noise due to detector structure, as expected;
  for X side: $\sigma_{tot} \approx \sigma_{det} = 500\ e^-\ (ENC)$



Tracking system performances

- MIP signal/noise ratio: X side 55 Y side 27
- spatial resolution: X side 2.8 μm Y side 13 μm
- maximum detectable rigidity: 740 GV/*c*



Conclusions

- Magnetic system, tracker silicon detectors and front-end electronics: flight model assembled and extensively tested for required performances.
- Tracker data acquisition control electronics: already developed and under final tests.
- Magnetic spectrometer in advanced integration phase with other PAMELA sub-detectors.
- PAMELA ready for launch at end of 2003.