Silicon μstrip tracker for Crystal Collimation experiments at the SPS

INFN Perugia / l'Université de Genève

- AMS-02 silicon sensors
- AMS-02 silicon tracker
- Test beam operation / performance
- Considerations for present application

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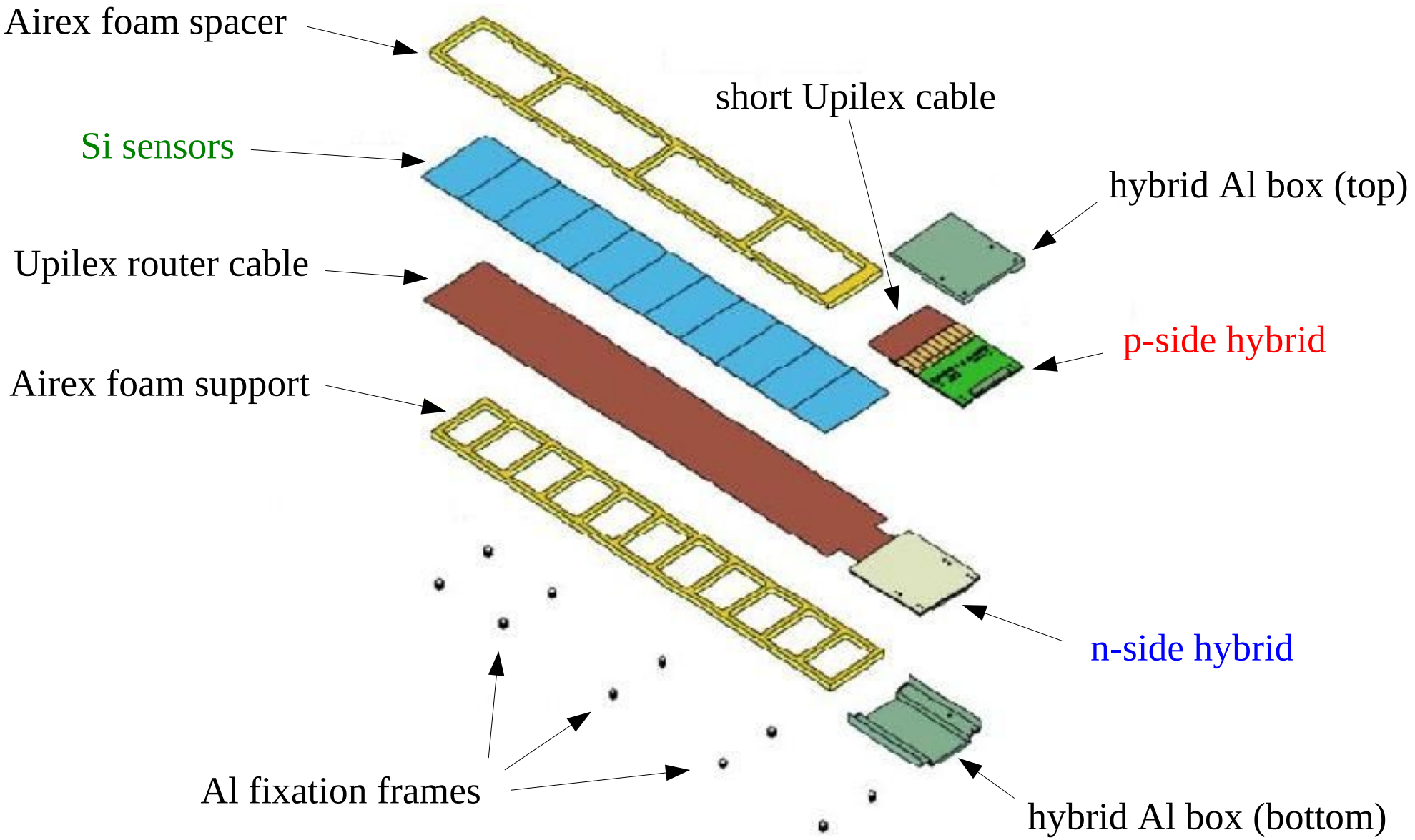
Silicon Detectors

- sensor dimensions: 4.136 x 7.205 x 0.03 cm^3
- n-type silicon with implantation/readout strip pitches
  p-side: 27.5/110 microns, type p^+
  n-side: 52.0/208 microns, types n^+ and p^+ blocking
- capacitive charge coupling
  p-side: 3 floating strips (holes collected)
  n-side: 1 floating strip (e^- collected)
- average measurement resolutions
  for singly-charged minimum ionizing particles:
  15 and 30 μm @ normal incidence

AMS-02 Silicon Tracker (1)

- Sensors are organized in functional units *(biasing, readout and mechanical precision)* called ladders.
- The tracker contains 192 ladders of variable length (7 to 15 sensors).
- Each ladder contains two hybrids operating at the bias potential difference (80 V).
- The hybrids contain the frontend readout chips: the 64 channel VA_hdr, a charge sensitive amplifier (CR-RC semi-Gaussian shaper)
  p-side hybrids contain 10 VAs (640 channels)
  n-side hybrids contain 6 VAs (384 channels)

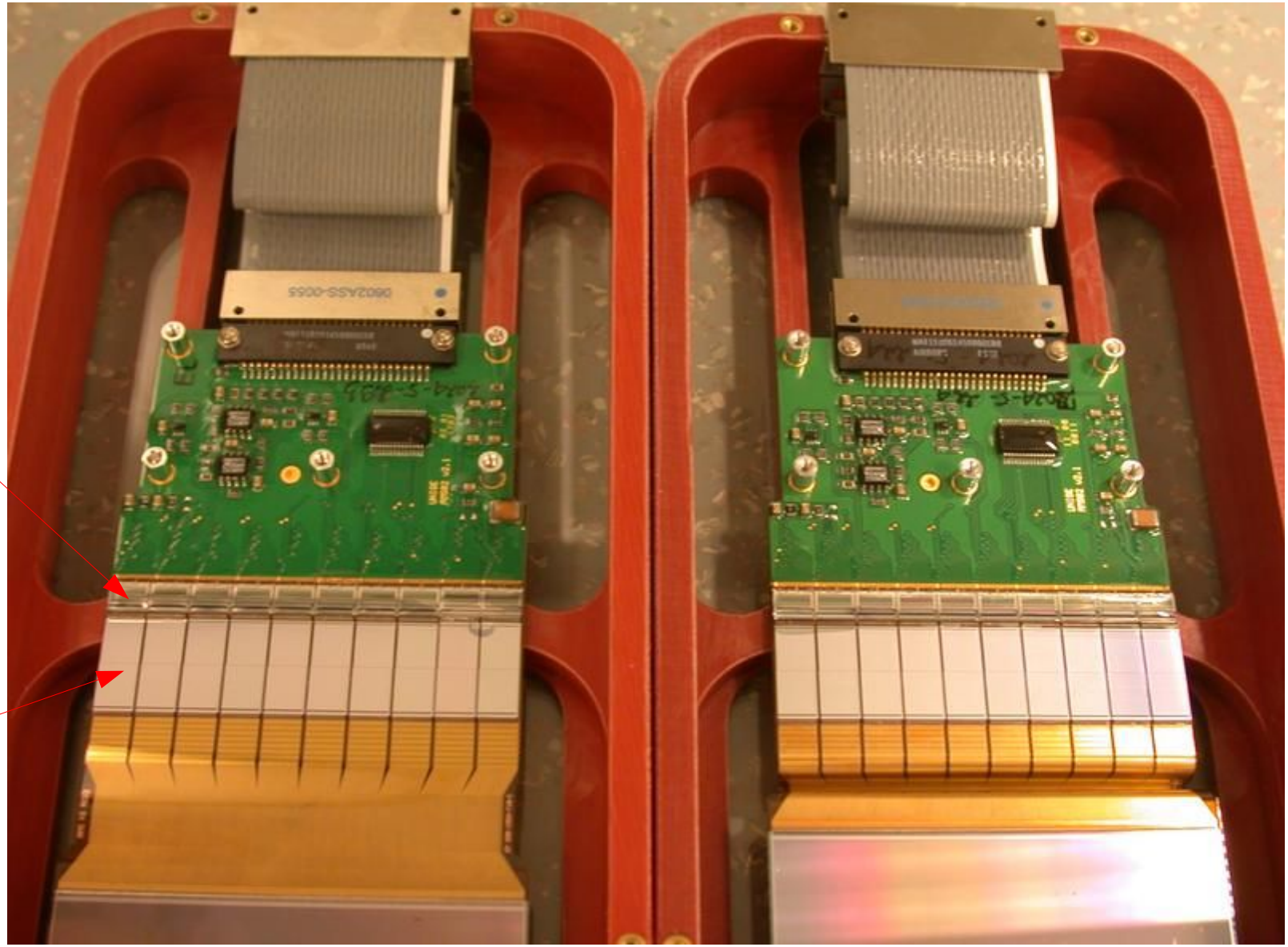
AMS Silicon Ladder



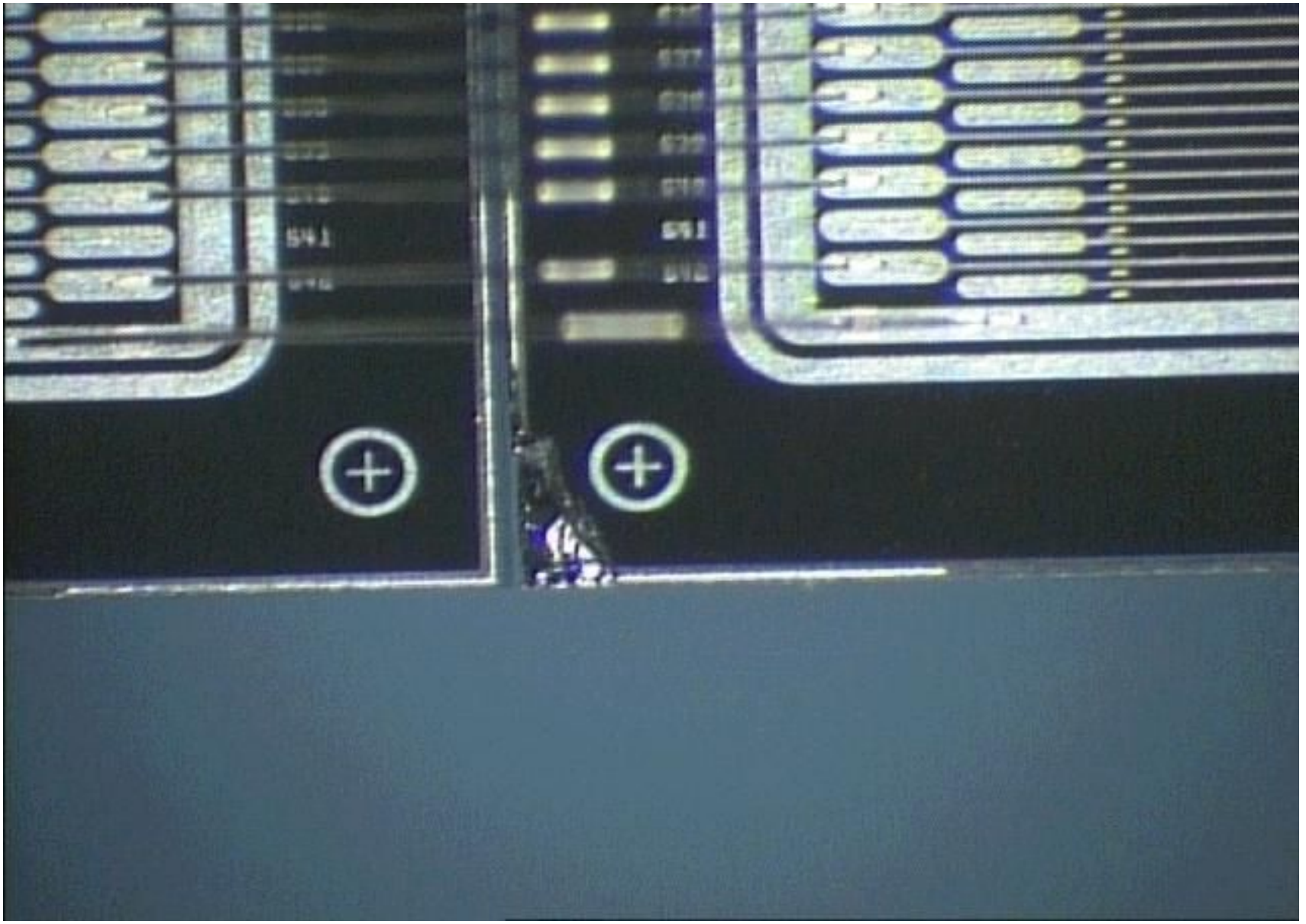
AMS Silicon Ladder
n-side

AMS Silicon Ladder
p-side

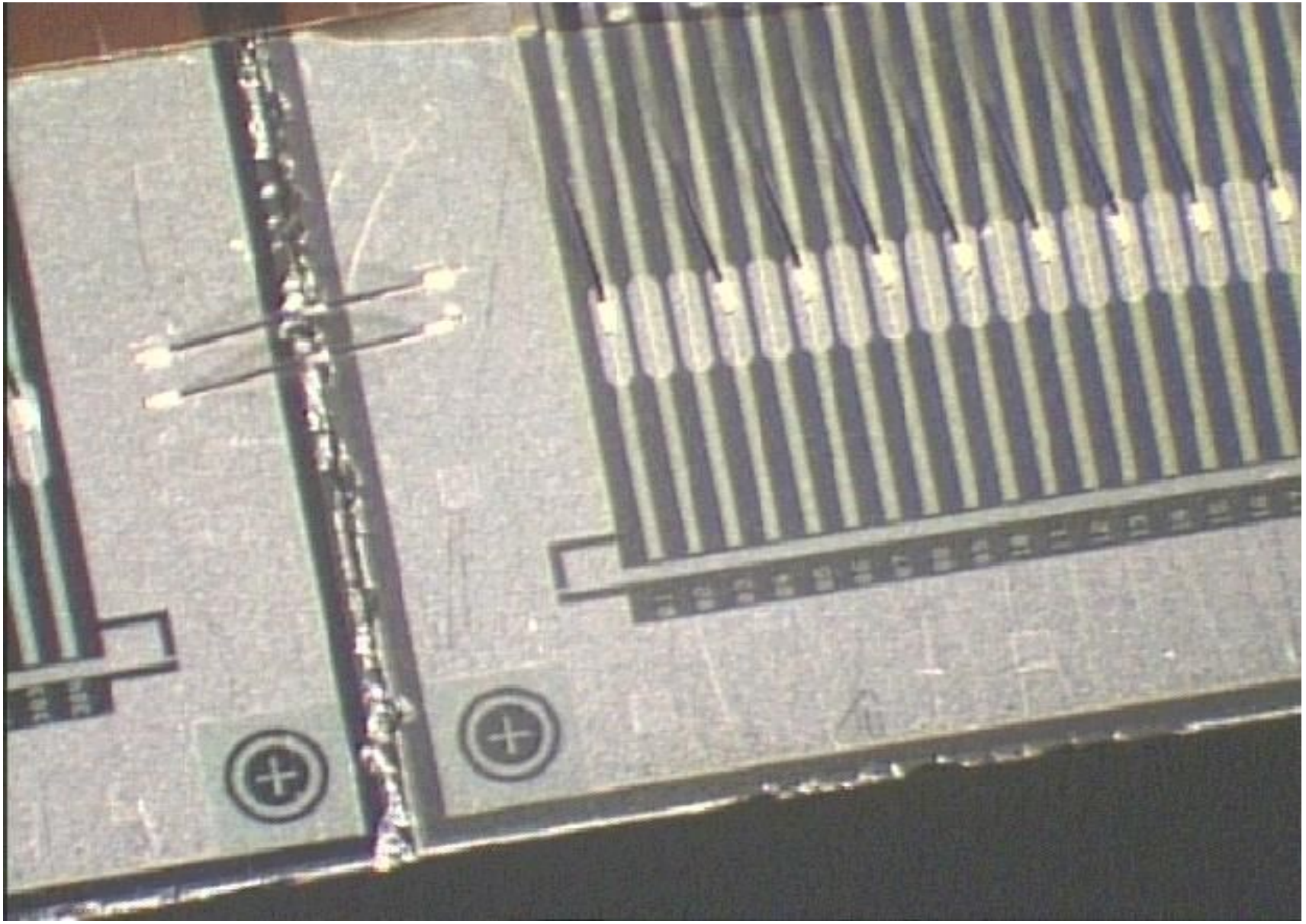
P-Side Hybrids



Silicon Sensors
p-side



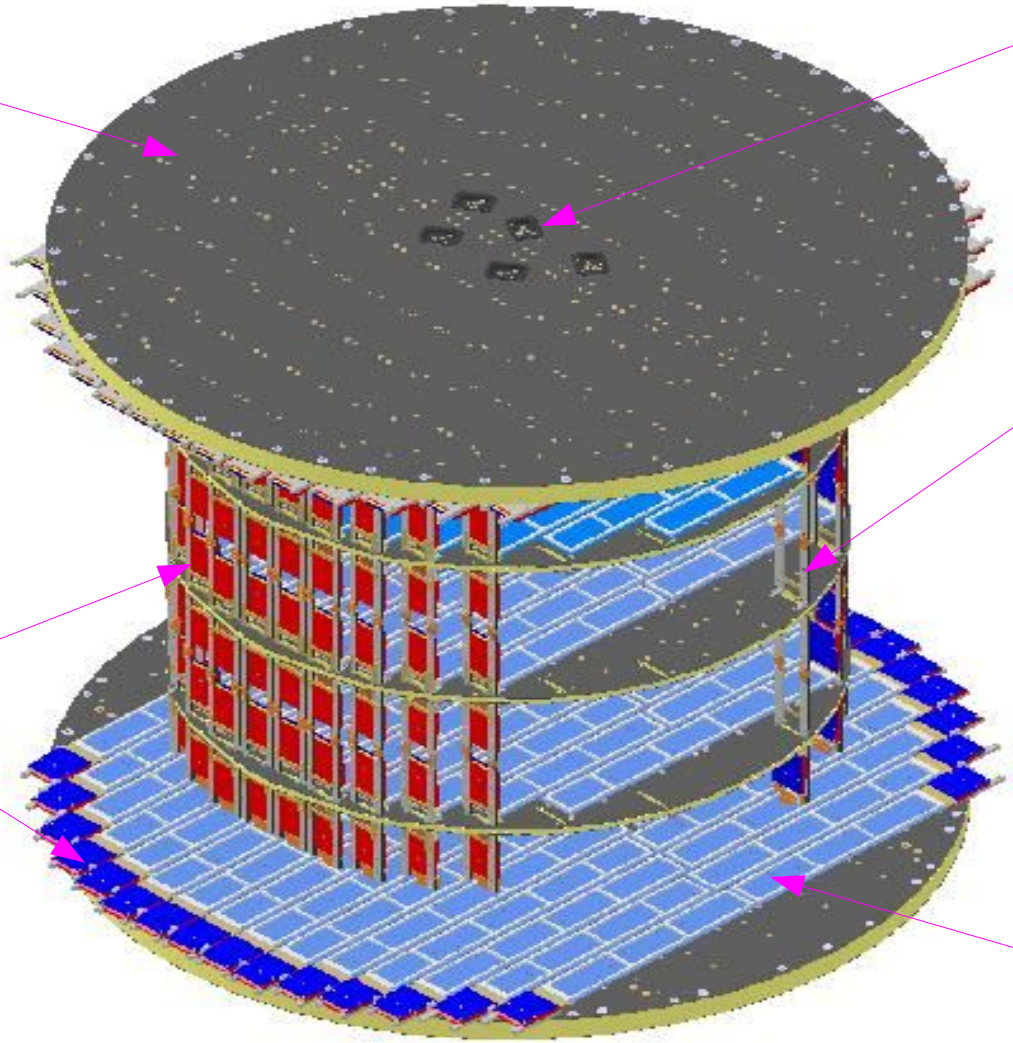
Silicon Sensors
n-side



AMS-02 Silicon Tracker (2)

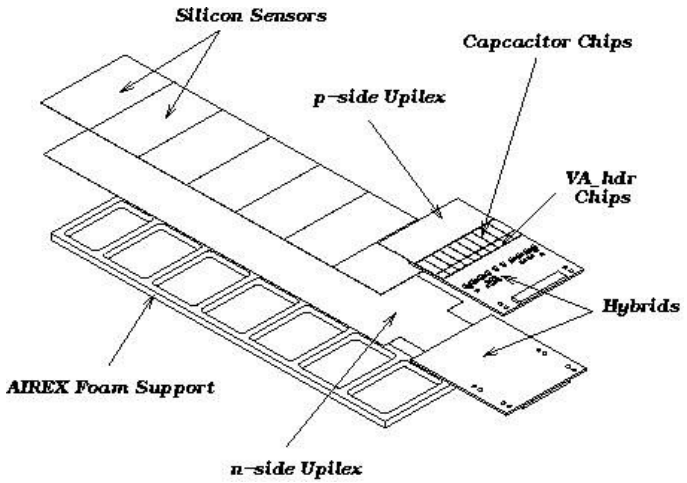
- Signal digitisation, calibration and data reduction and performed with 12-bit ADCs and DSPs located on the Tracker Data Reduction cards (TDR)
- 1-3 m long cables connect the hybrids to TDRs
- 2 ladders per TDR, 12 TDRs per crate
- The tracker contains 8 layers of silicon sensors mounted on 5 Al honeycomb / carbon fiber support planes
  external: 1.43 m dia., 4 cm thick, ρ = 0.032 g/cm^3
  internal: 1.07 m dia., 1.2 cm thick, ρ = 0.016 g/cm^3
- Tracker structure completed by two carbon fiber flanges which support the external planes, and carbon fiber cylindrical shells which surround the internal planes.

AMS-02 Tracker Support Structure



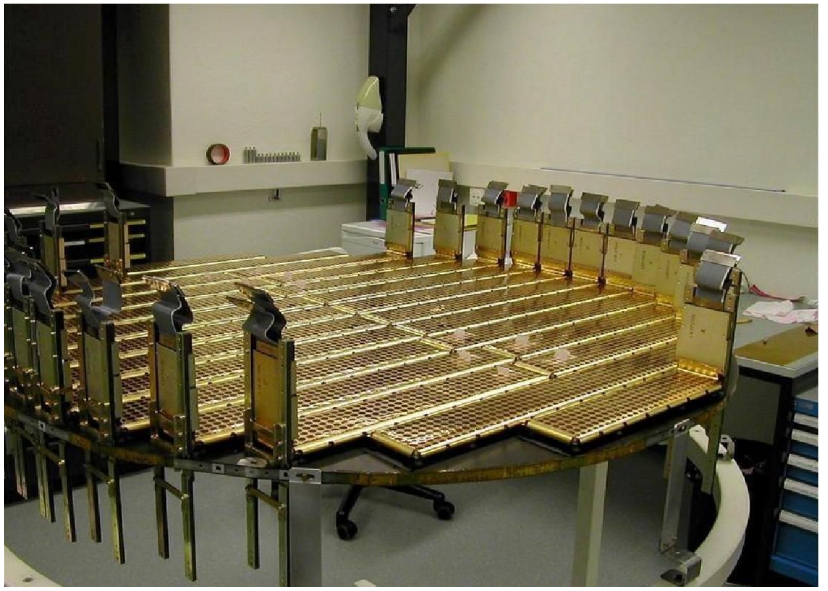
Démontage du tracker AMS-01

AMS-02 Silicon Tracker



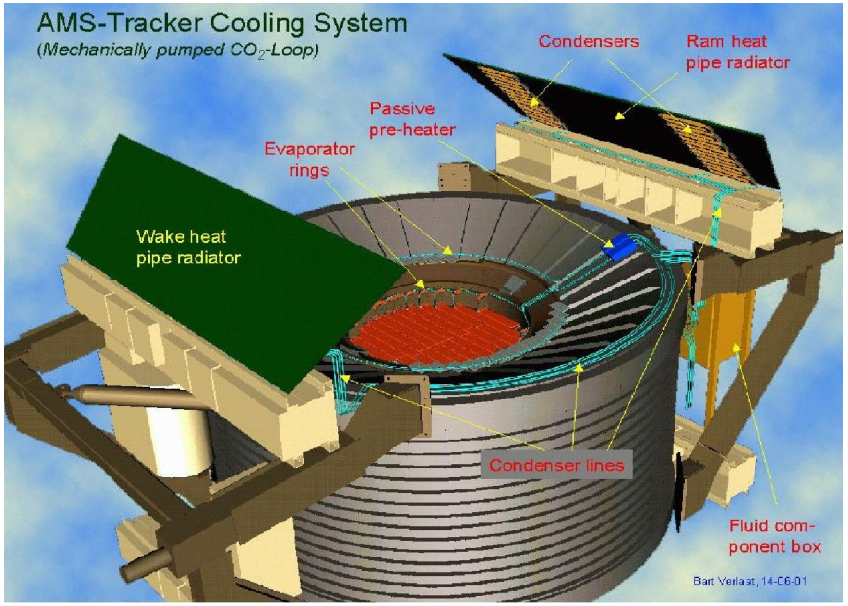
Ladder: implantation strip pitch n-side 26 → 52 microns

Plane: 6 → 5, layers of silicon 6 → 8

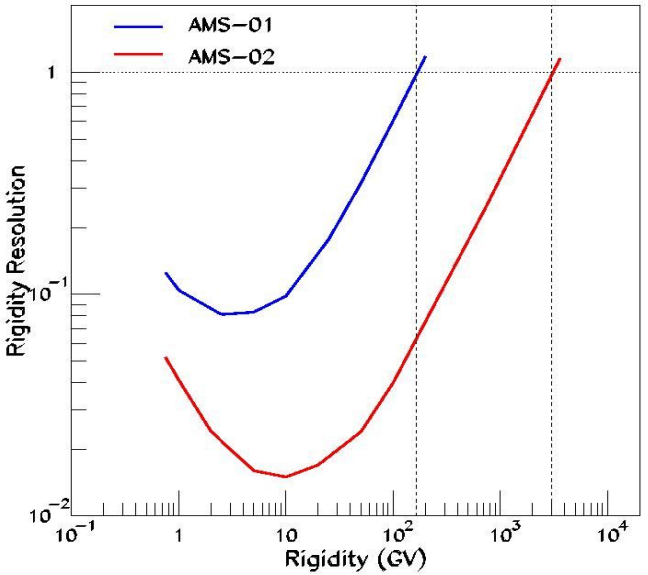


Tracker Thermal Control System (TTCS)

Liquid CO_2 used to remove heat generated by the front-end electronics in the interior of the magnet.



MDR ~2 TV



AMS-02

w.r.t AMS-01

Modified:

magnet (0.8 T)
tracker
TOF
ACC

Replaced:

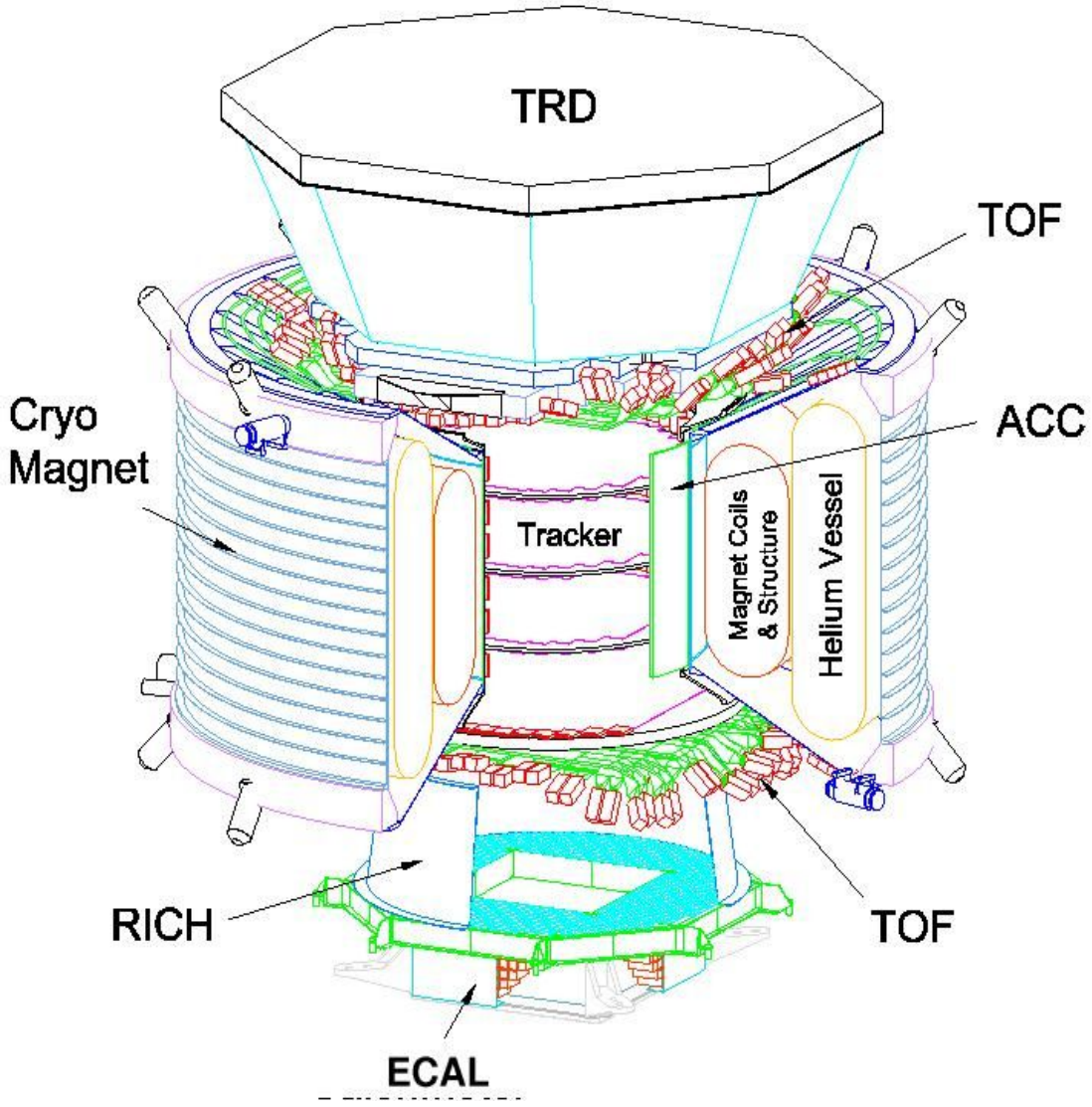
Cherenkov ⇒ RICH

Added:

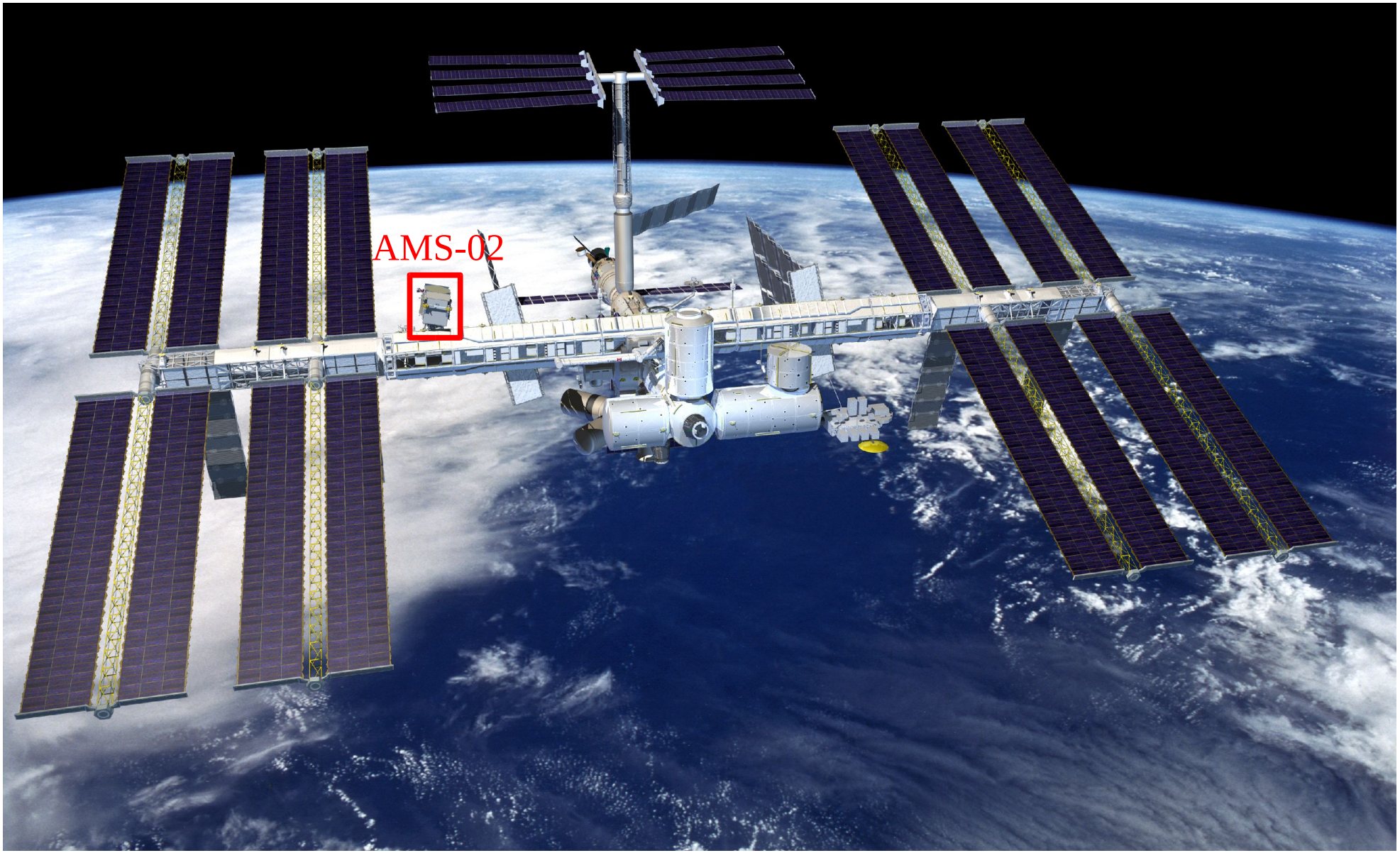
TRD
ECAL

Resources:

mass 3.2 → 7.0 t
power 1.0 → 2.0 kW
2 Mbit/s downlink



AMS-02 on the ISS



Tracker Test Beams (1)

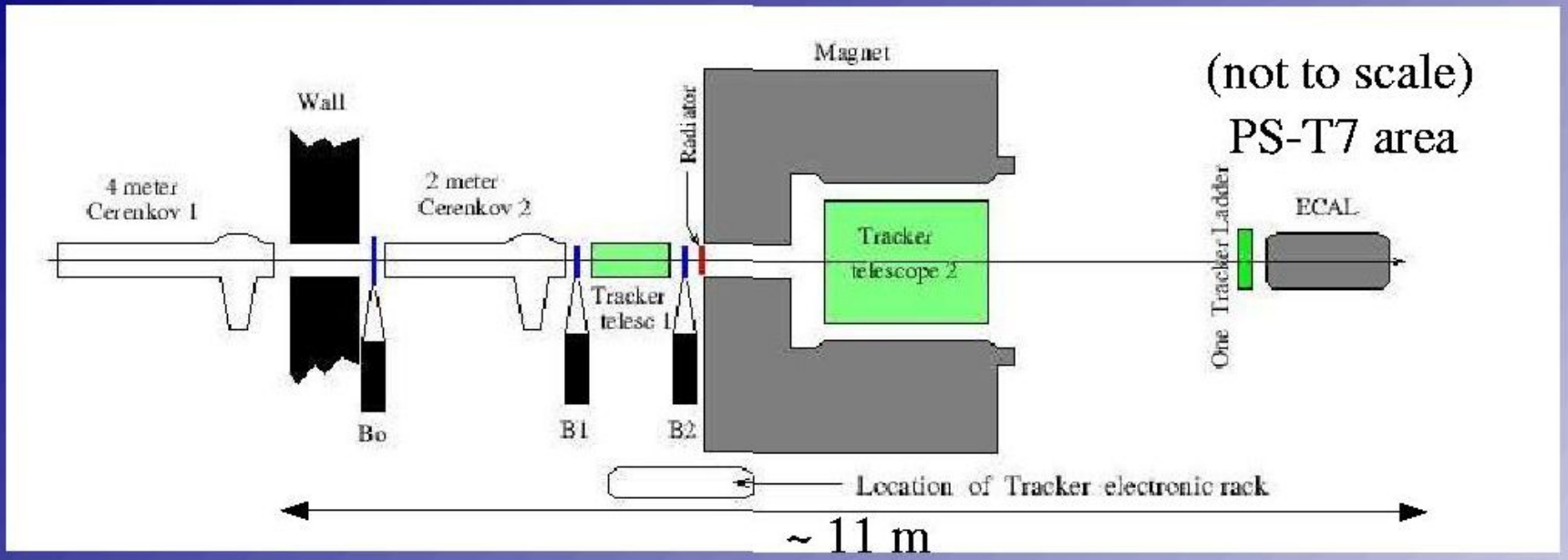
- Oct. 2002 at CERN SPS *(with RICH and TOF)*
  relativistic ions and protons
  6 flight ladders with inclined ladder
  "engineering model" TDR, raw data, offline calibration
- June 2003 at CERN PS
  10 GeV/c protons
  4 flight ladders, VA shaping time study
  "engineering model" TDR, raw data, offline calibration
- Oct. 2003 at CERN SPS *(with RICH and TOF)*
  relativistic ions and protons
  6 flight ladders
  "qualification model" TDR, raw data, offline calibration

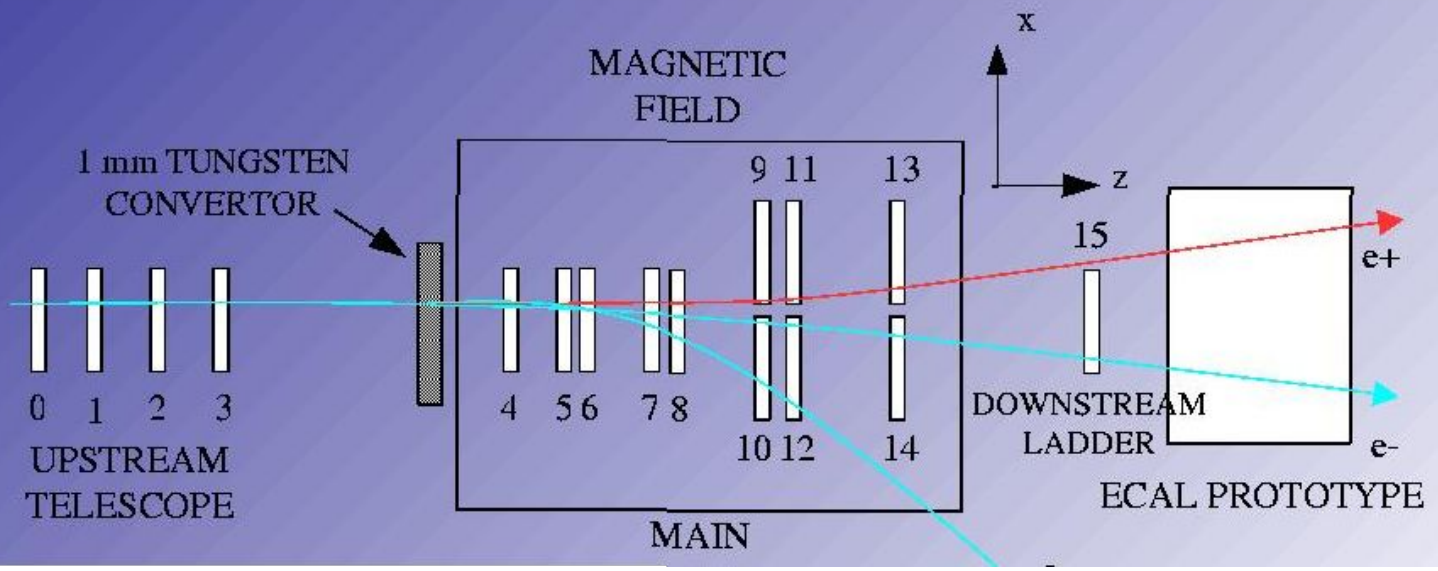
Tracker Test Beams (2)

- Oct. 2003 at GSI
  0.8 GeV/A boron and carbon beams
  same 6 flight ladders from CERN SPS test beam
  “qualification model” TDR, raw data, offline calibration
- Sept. 2004 at CERN PS
  3, 5 and 7 GeV/c electrons, pions and radiative photons
  16 flight ladders
  “flight model” TDR and power supplies
  online data reduction and calibration

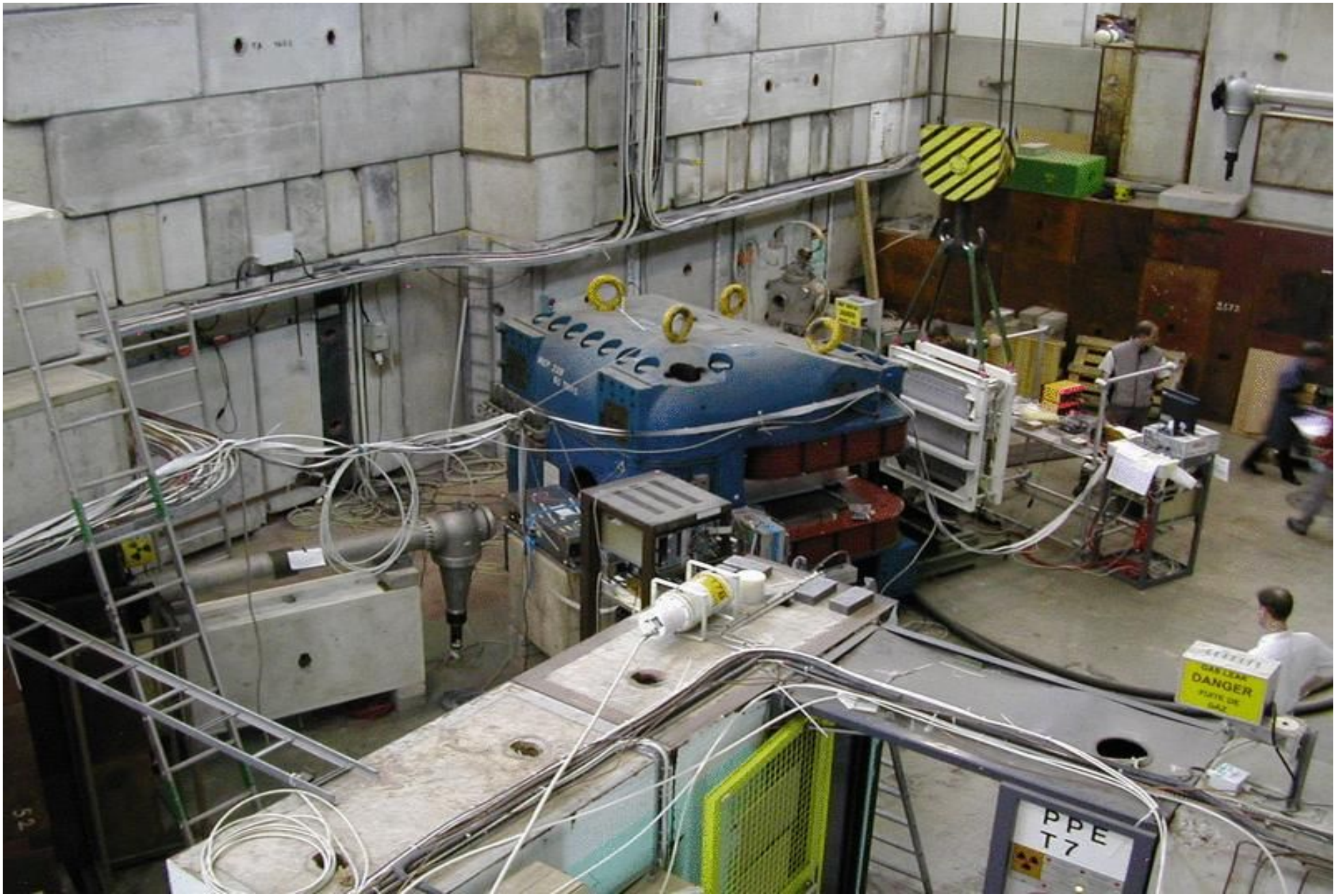
CERN PS 2004 Test Beam

Setup

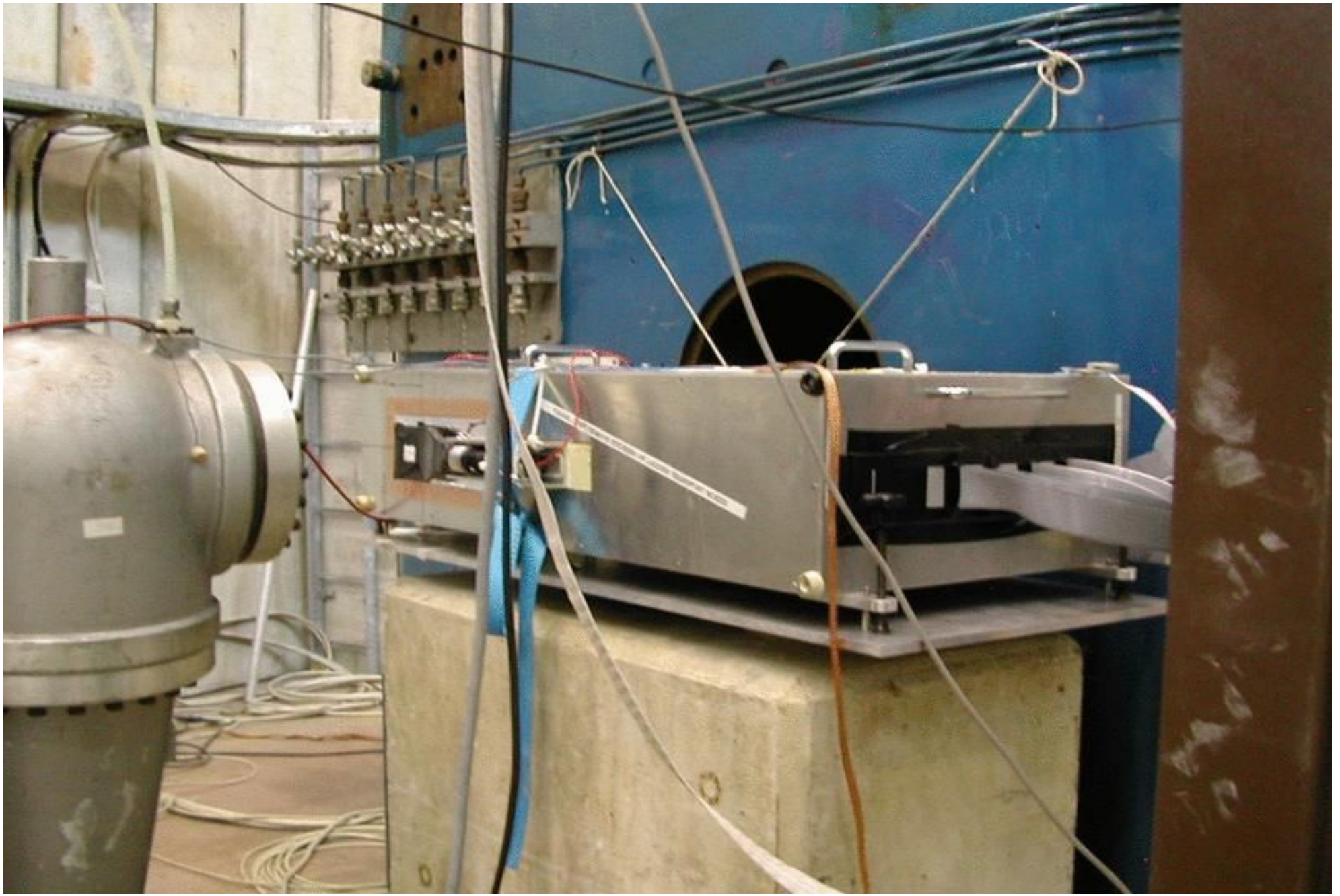




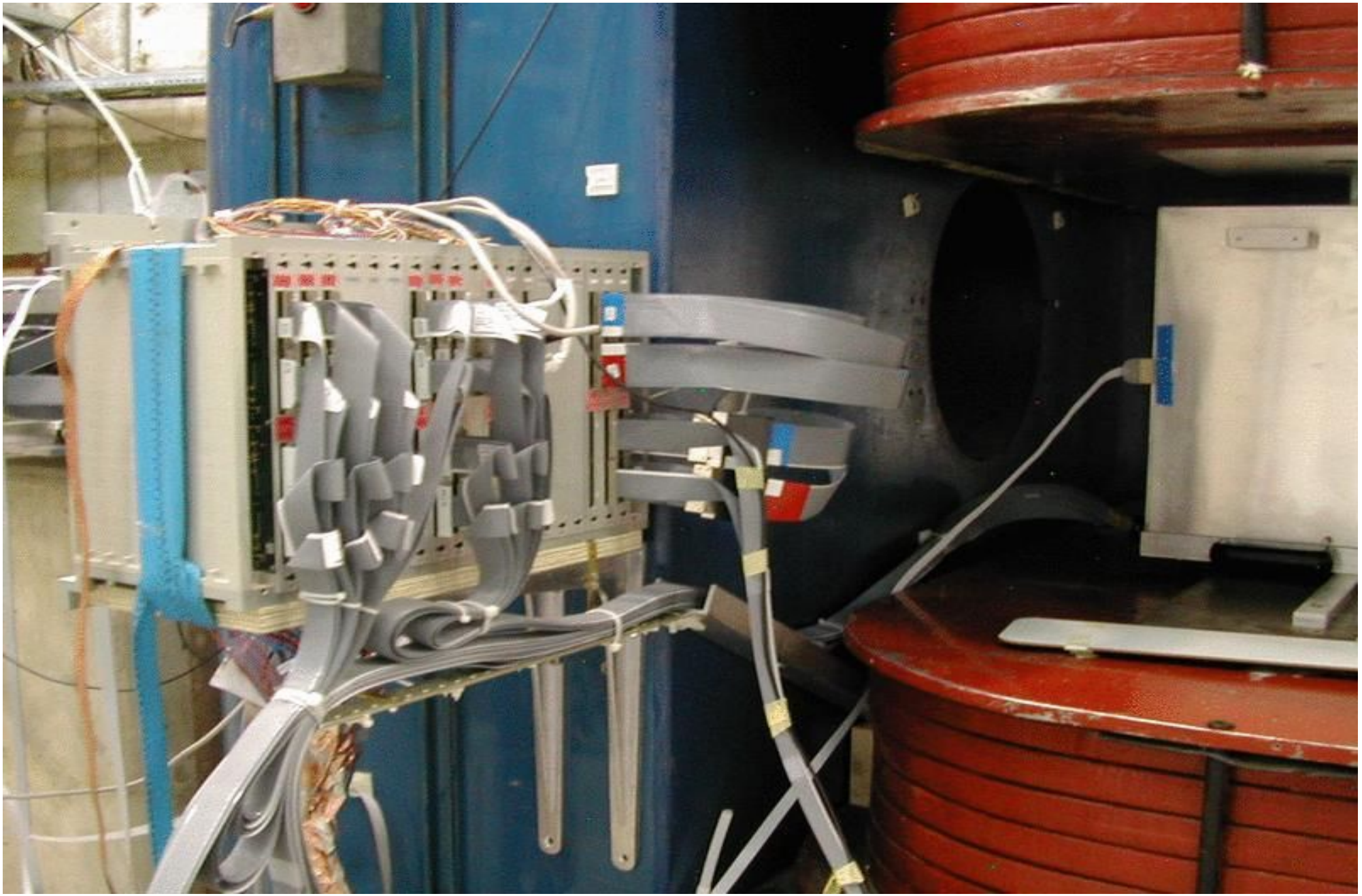
CERN PS 2004 Test Beam



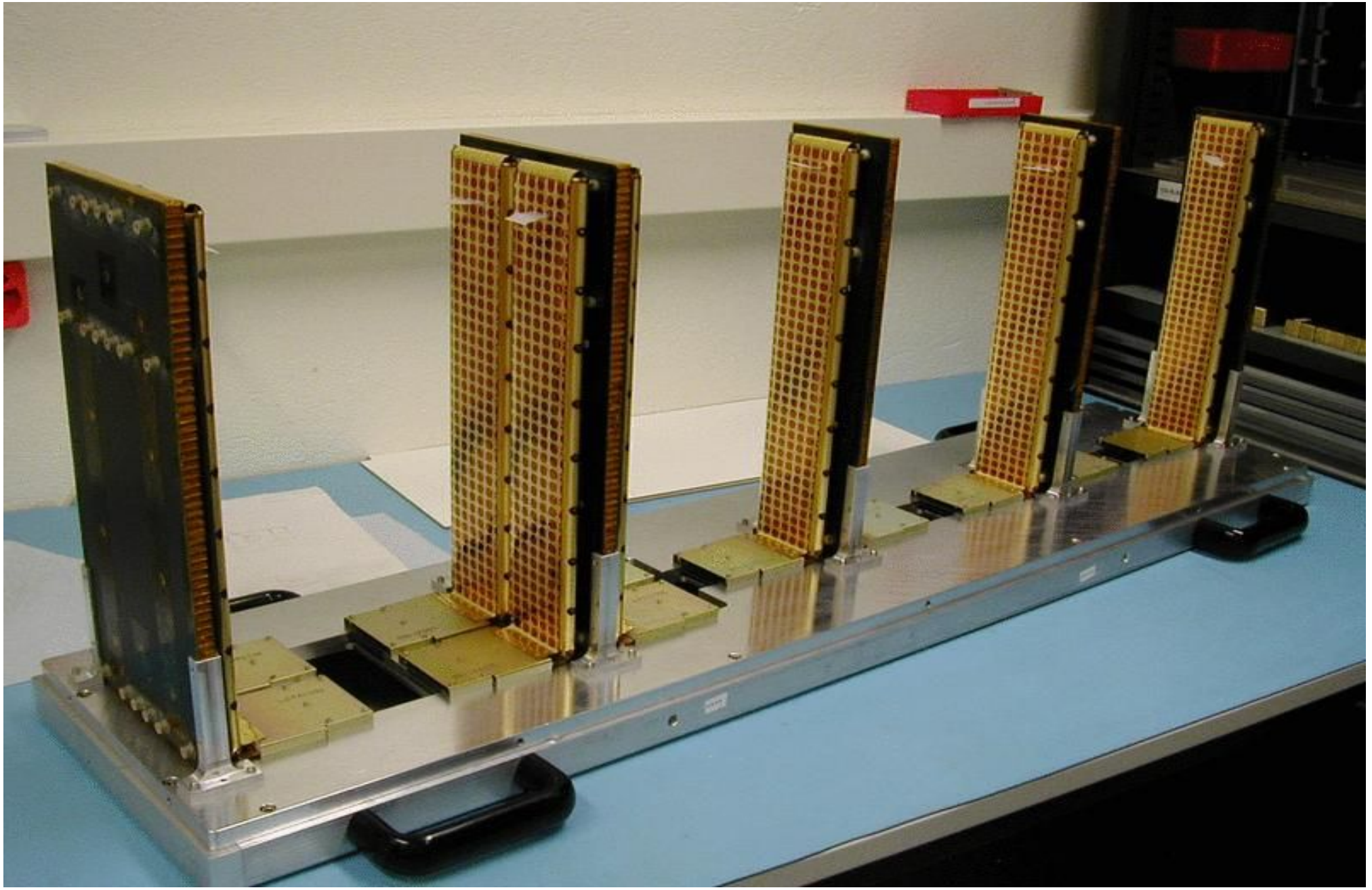
4 Ladder Telescope



Tracker Readout Crate



2004 Test Beam Tracker



Data Reduction and Track Selection

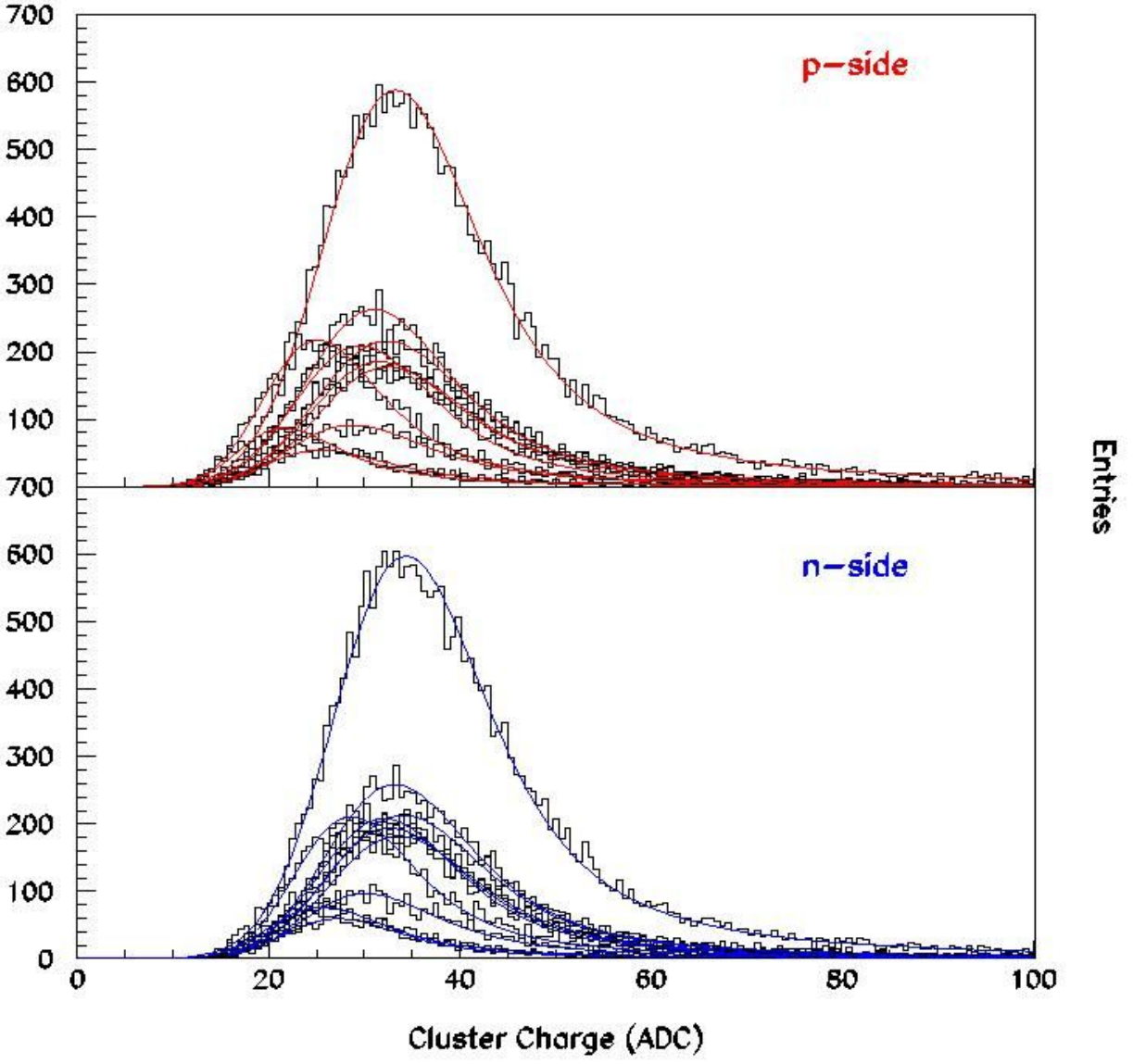
two approaches

- subtract channel pedestal and VA common noise level
- identify "seed" strip(s) by applying a 4 / 3 σ_{ped} threshold
- neighboring strips added if above σ_{ped} , if no second strip found add the strip with the highest, positive signal level
- demand single np cluster pair in each ladder /
  if more than one cluster found on the ladder side, take highest s/n cluster, require cluster on each side of ladder
- consistency checks: χ^2, compare reconstructed beam slopes of the different two ladder combinations.

No significant difference seen in the resolutions obtained with the two selections. The seed threshold of the second is varied to study the detection efficiency.

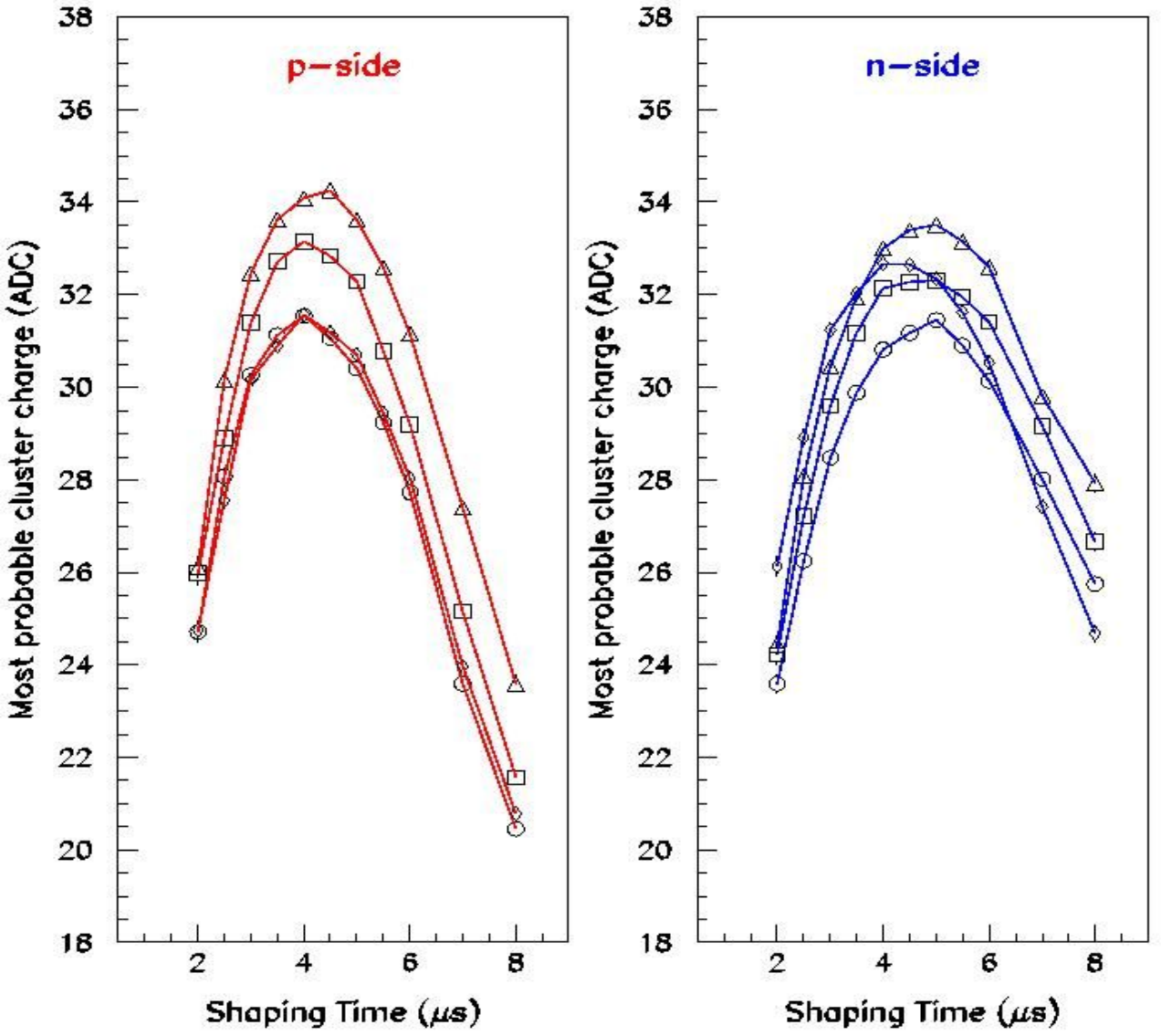
Performance and VA shaping time (June 2003)

specific energy loss distributions for different delay times (1-8 μs)



Signal level and VA shaping time

optimal values 4 and 4-5 μs

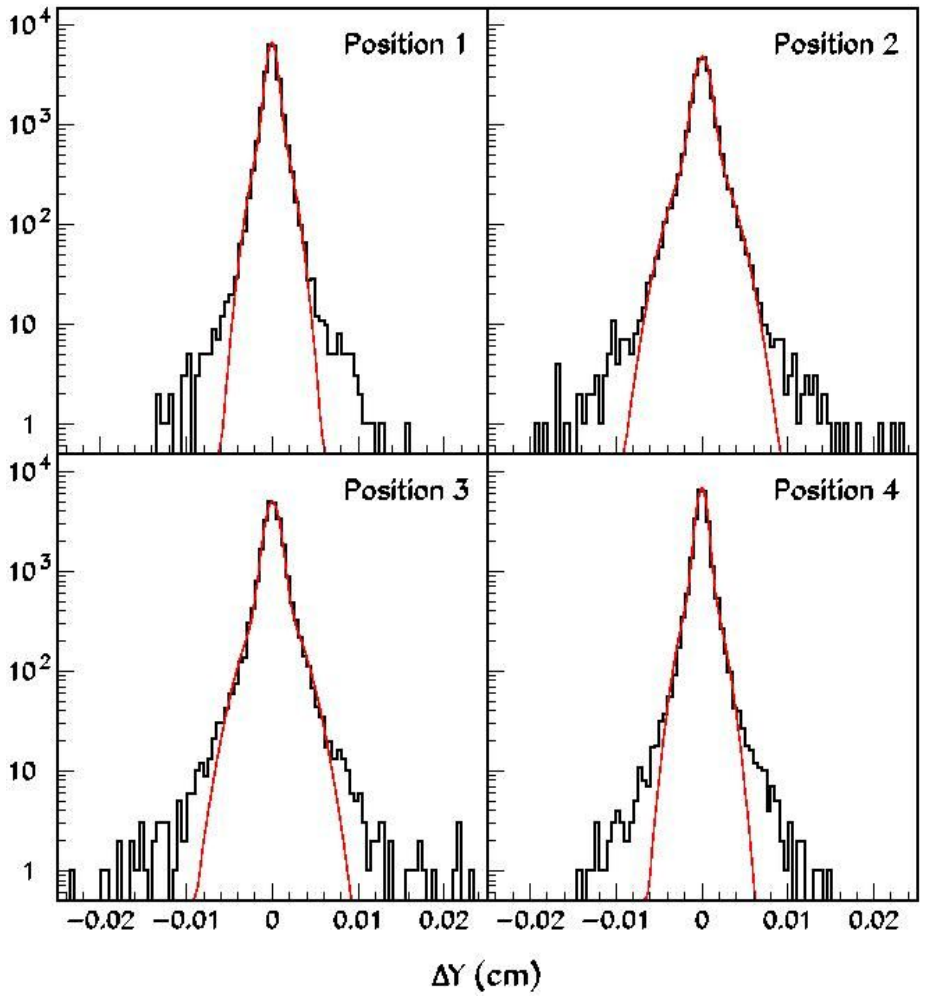


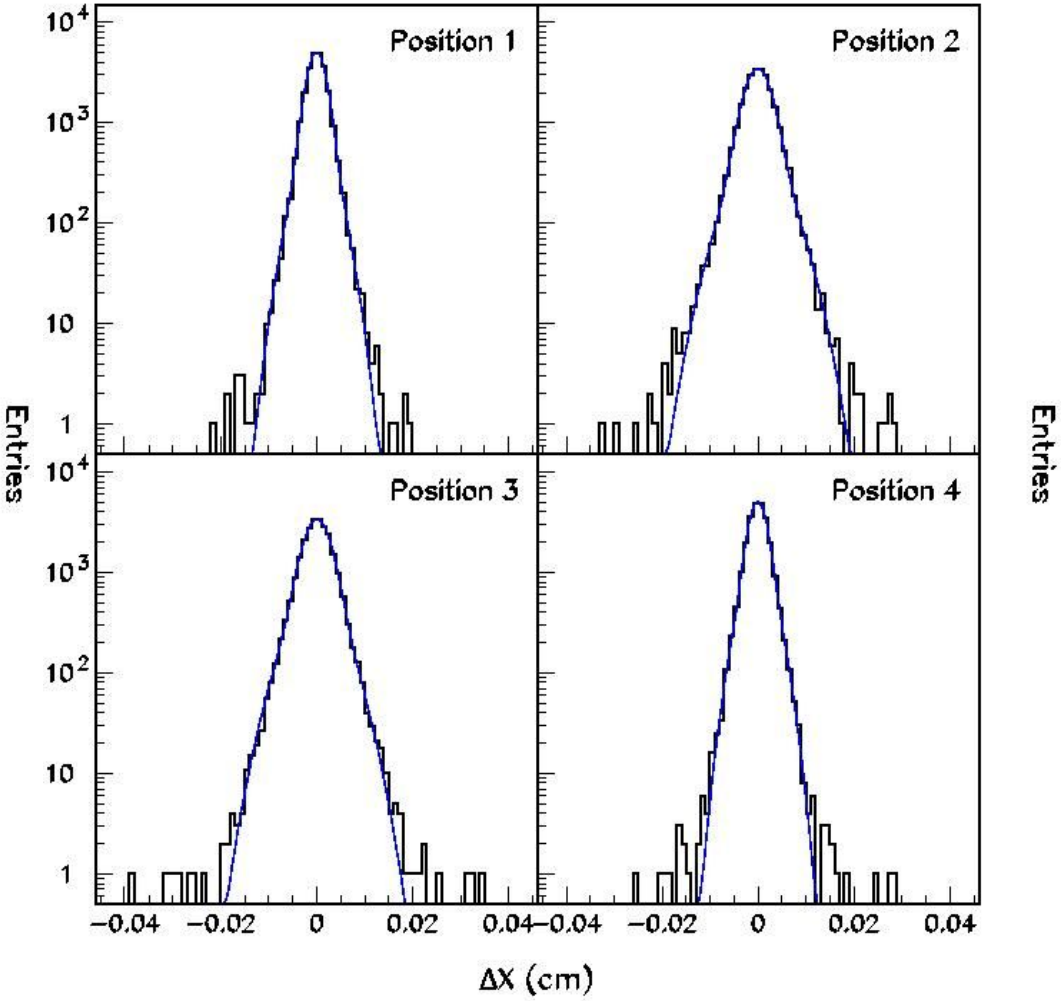
Residual Distributions in June 2003 Test Beam

VA shaping time 4 μs, four point fit

p-side

n-side





Residual distributions described as the sum of two Gaussians

Parameters of two-Gaussian fits

June 2003 test beam,VA shaping time 4 μs, four point fit

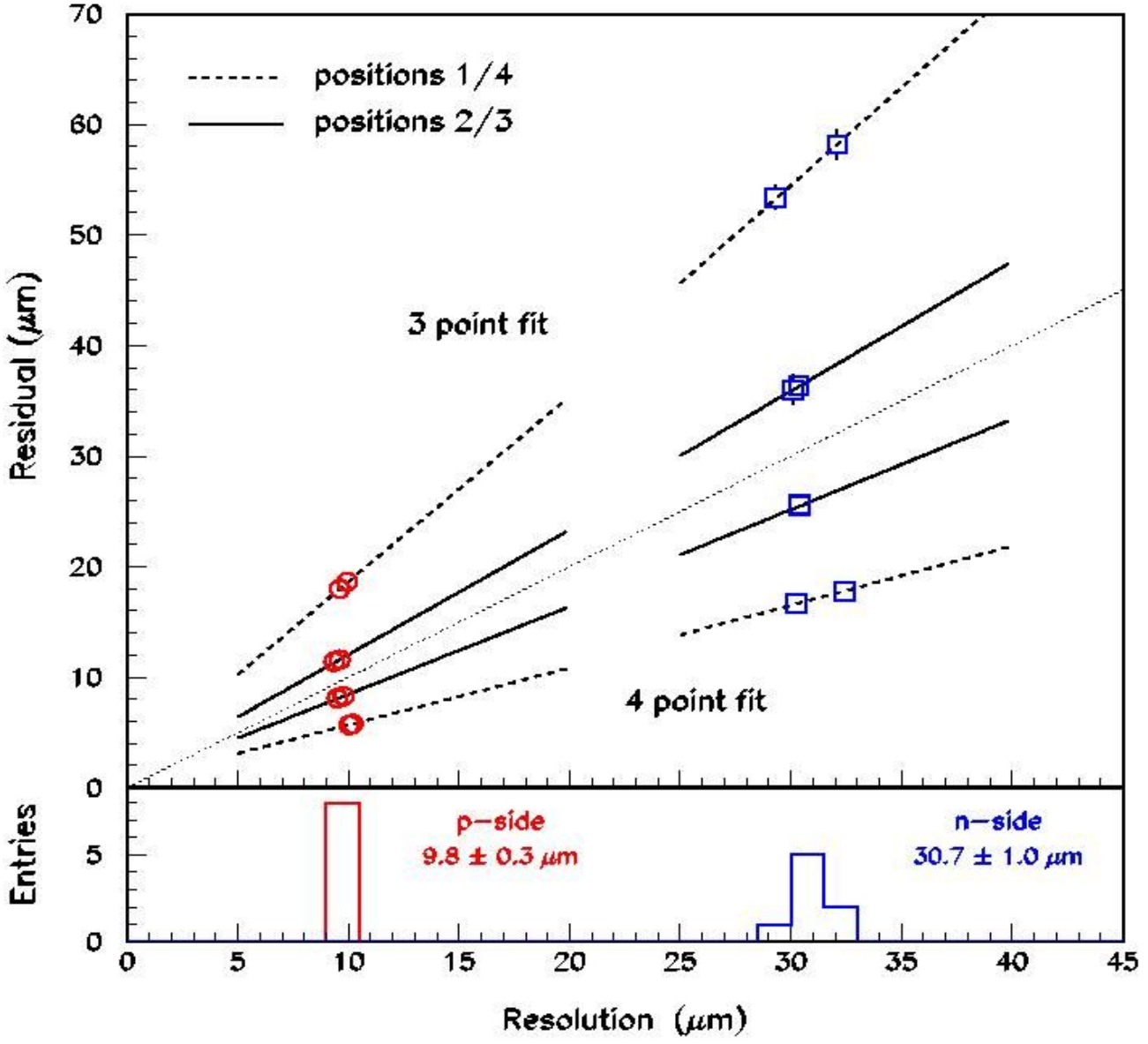
area-weighted average width

fraction represented by first Gaussian

	center(1)	σ_1	center(2)	σ_2	f_1	σ
position	(μm)	(μm)	(μm)	(μm)		(μm)
p-side						
1	-0.5 (0.1)	5.7 (0.1)	-0.2 (0.2)	15.3 (0.3)	0.67 (0.02)	8.9 (0.4)
2	0.4 (0.1)	8.3 (0.1)	0.2 (0.3)	24.3 (0.5)	0.74 (0.02)	12.6 (0.5)
3	0.2 (0.1)	8.1 (0.1)	1.6 (0.4)	24.5 (0.6)	0.76 (0.02)	12.1 (0.5)
4	-0.3 (0.1)	5.8 (0.1)	-0.7 (0.2)	16.4 (0.5)	0.74 (0.02)	8.6 (0.5)
n-side						
1	0.0 (0.2)	17.8 (0.3)	-0.8 (0.7)	35.4 (1.1)	0.82 (0.03)	21.0 (1.2)
2	-0.6 (0.2)	25.5 (0.5)	1.8 (0.9)	52.1 (2.2)	0.79 (0.04)	31.0 (2.5)
3	1.2 (0.3)	25.6 (0.5)	-1.7 (0.9)	50.6 (2.0)	0.76 (0.04)	31.5 (2.7)
4	-0.4 (0.2)	16.7 (0.4)	0.1 (0.5)	31.4 (1.2)	0.71 (0.05)	21.0 (2.1)

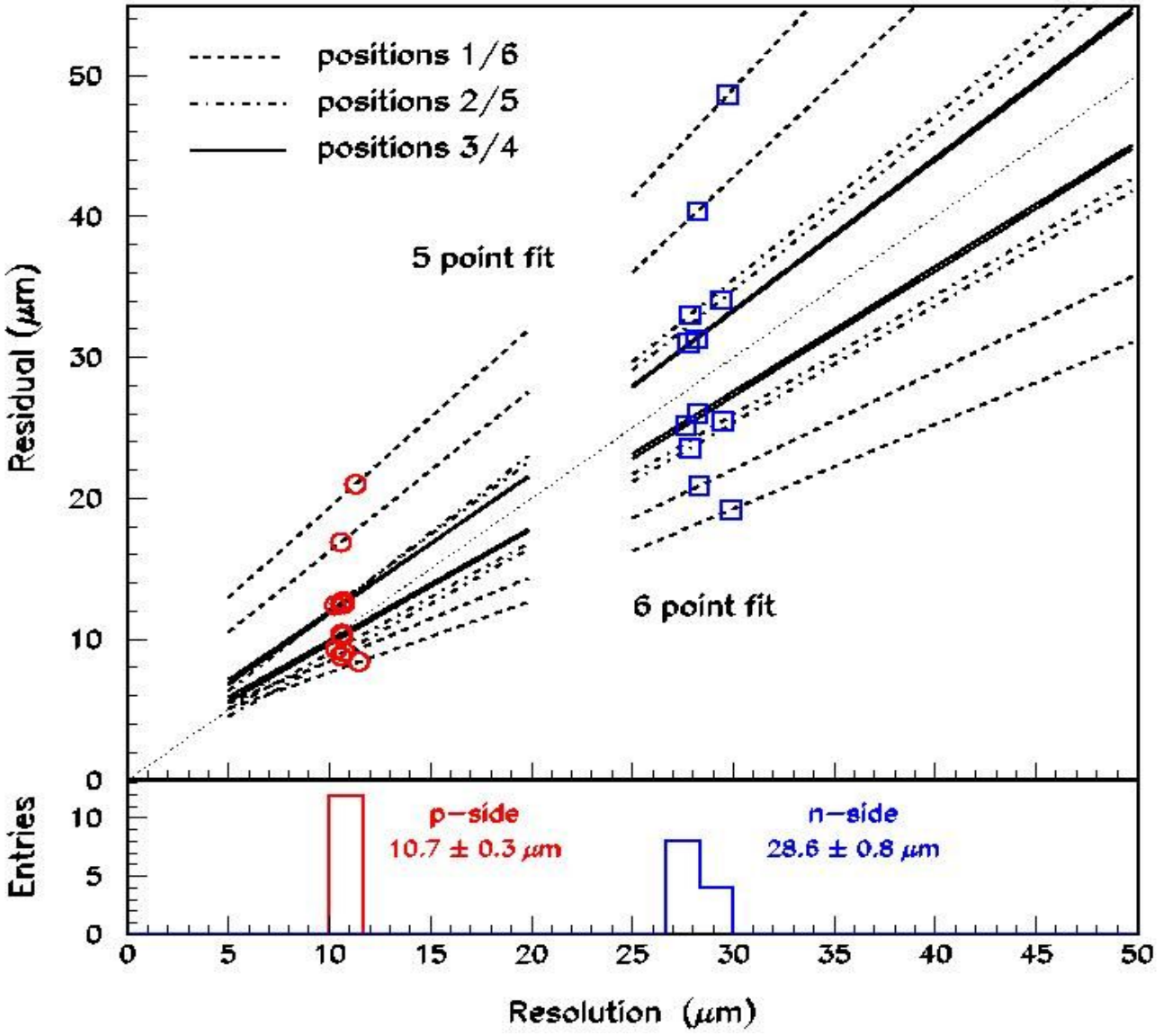
Residual *vs.* Resolution

June 2003 test beam, VA shaping time 4 μs



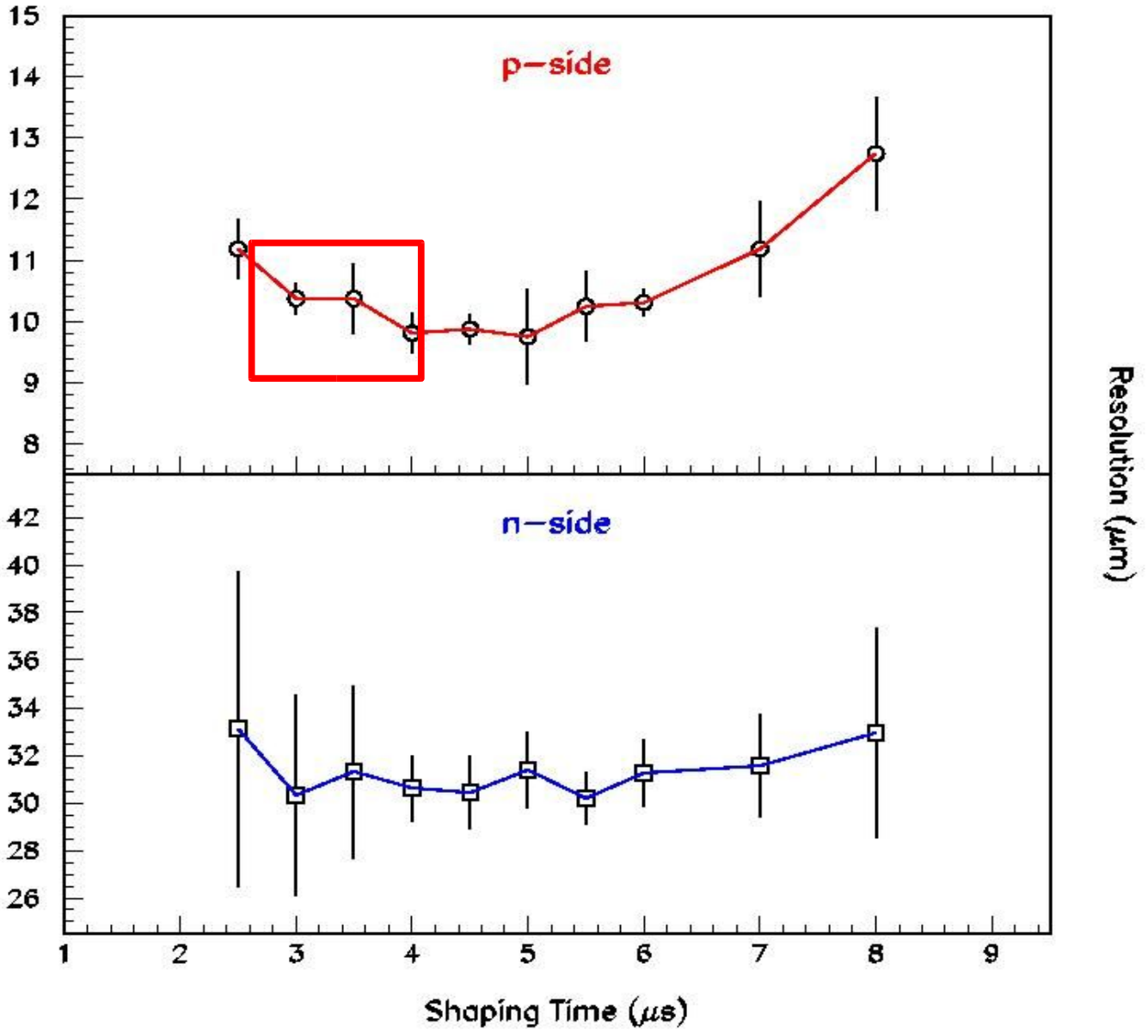
Residuals *vs.* Resolution

October 2003 test beam, VA shaping times 3 and 4 μs



Resolution *vs.* VA shaping time

June 2003 test beam



Position Resolutions

- for 7-15 GeV/c protons
  - p-side: 9.8 ± 0.3 μm (*71%*) / 15.3 ± 0.6 μm (*100%*)
  - n-side: 28.6 ± 0.8 μm (*90%*) / 31.7 ± 1.0 μm (*100%*)

- for 80 GeV/c He nuclei
  - p-side: 3.9 ± 0.2 μm (*64%*) / 6.5 ± 0.2 μm (*100%*)
  - n-side: digital response ⇒ 104 μm / $\sqrt{12}$ = 30 μm

COG and η

- Track position extracted using the signal-weighted mean of the positions of the two highest signal-to-noise strips in the cluster, i.e. center-of-gravity (COG) of the two strips
  ⇒supposes a linear correlation between the relative signal levels of the two strips (η) and the track position in the readout gap
- With $\eta = S_2 / (S_1 + S_2)$, S_1 and S_2 representing the signals of the 1st and 2nd strips (in readout order), the readout pitch p, and the position of the 1st strip X_1, the track position $X(\eta)$ is given by

$$X(\eta) = X_1 + p\,\eta$$

Eta function

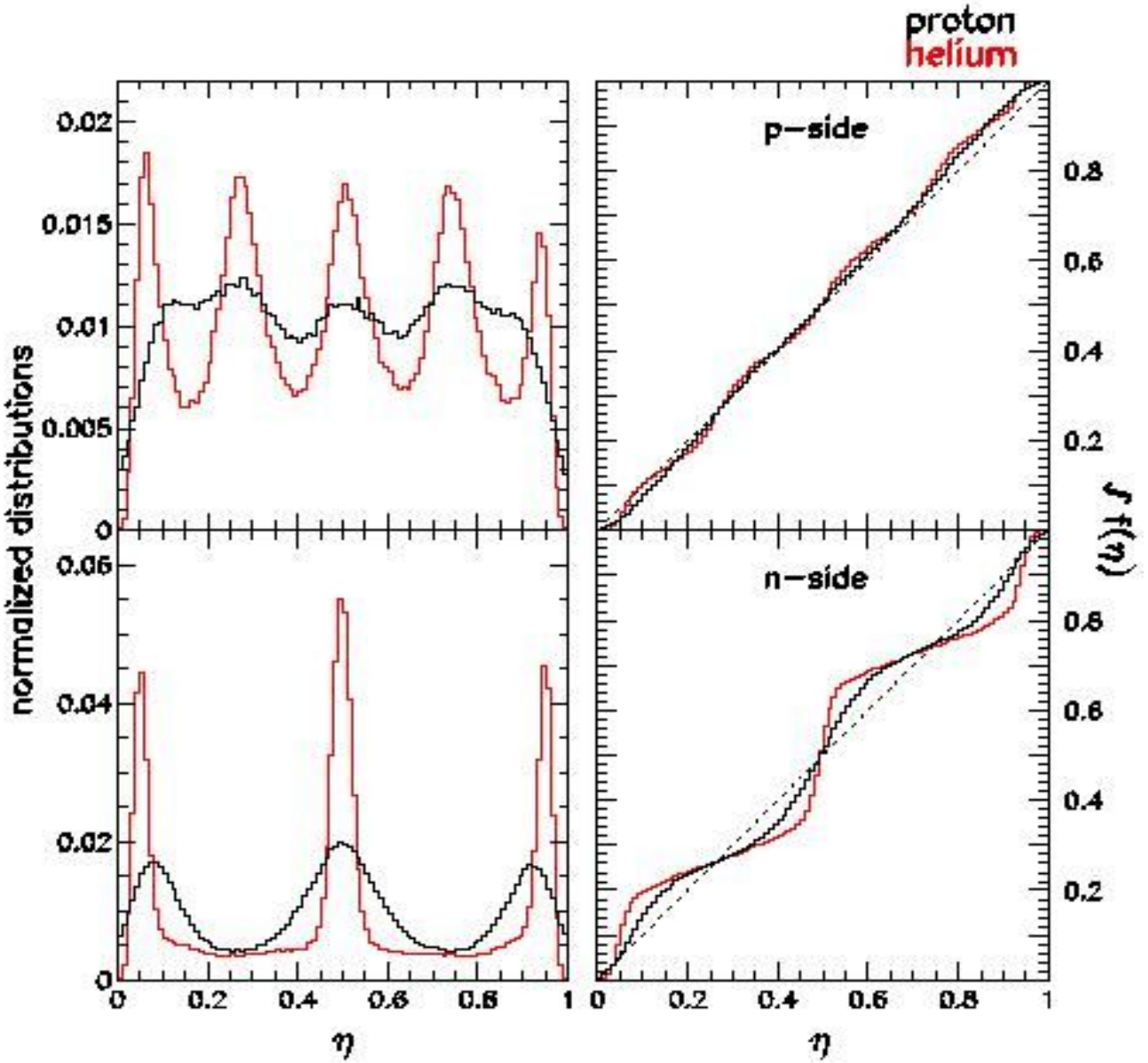
- The correlation between position and the strip signals is the result of the dispersion of charge in the volume of the silicon (inclined tracks) and the effects of the strip implantation scheme at the surface of the silicon.
  ⇒ capacitive charge coupling
  ⇒ p^+ blocking strips on n-side
- The track position may be calculated with normalized integral of the eta function $f(\eta) = dN/d\eta$

$$X(\eta) = X_1 + \frac{p}{N_t}\int_0^{\eta} \frac{dN}{d\eta'}\, d\eta'$$

$$\text{with} \quad N_t = \int_0^1 f(\eta)\, d\eta$$

Charge Collection for Protons and He

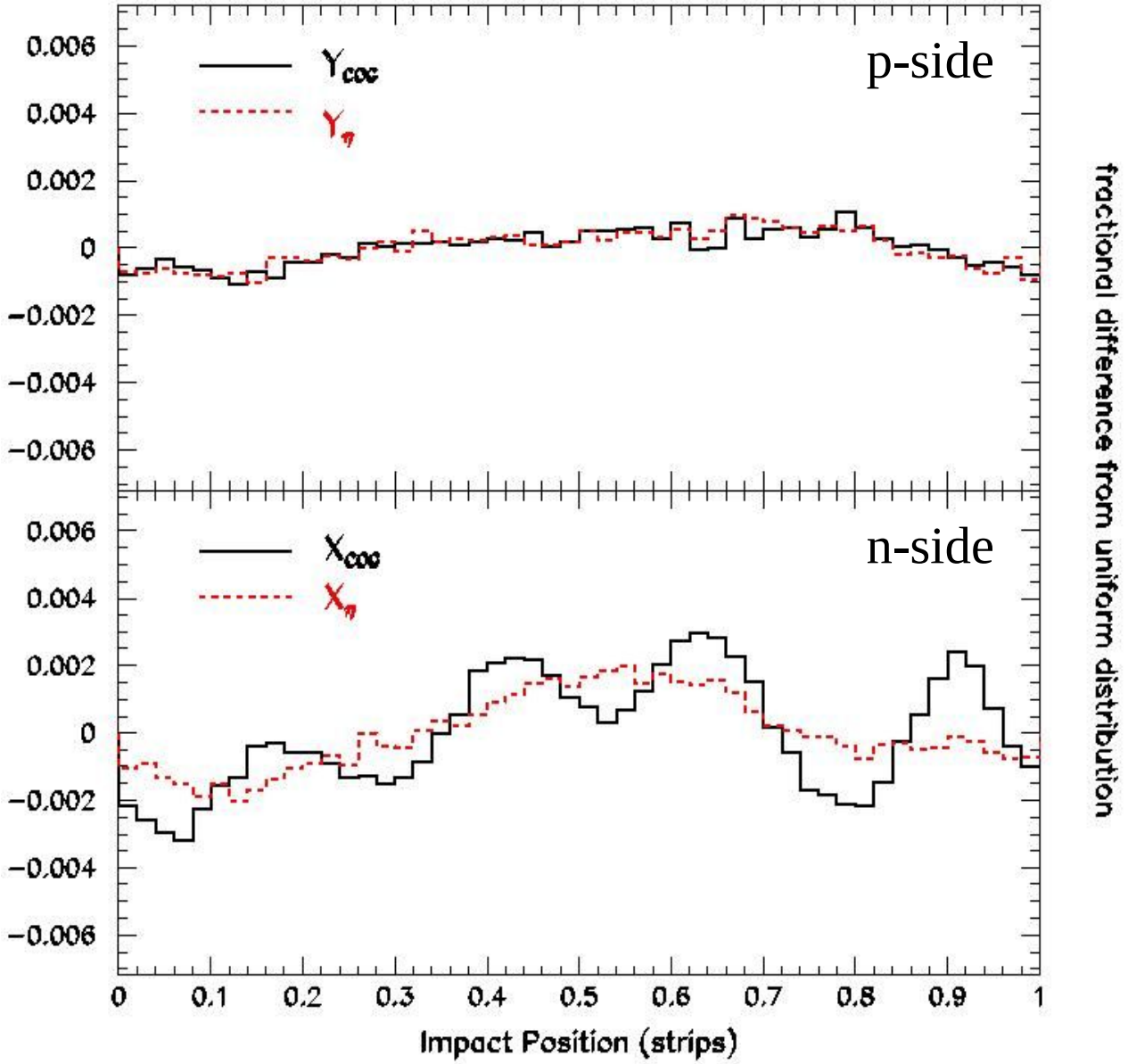
η and ∫f(η)dη distributions



Projected Impact Position and η correction

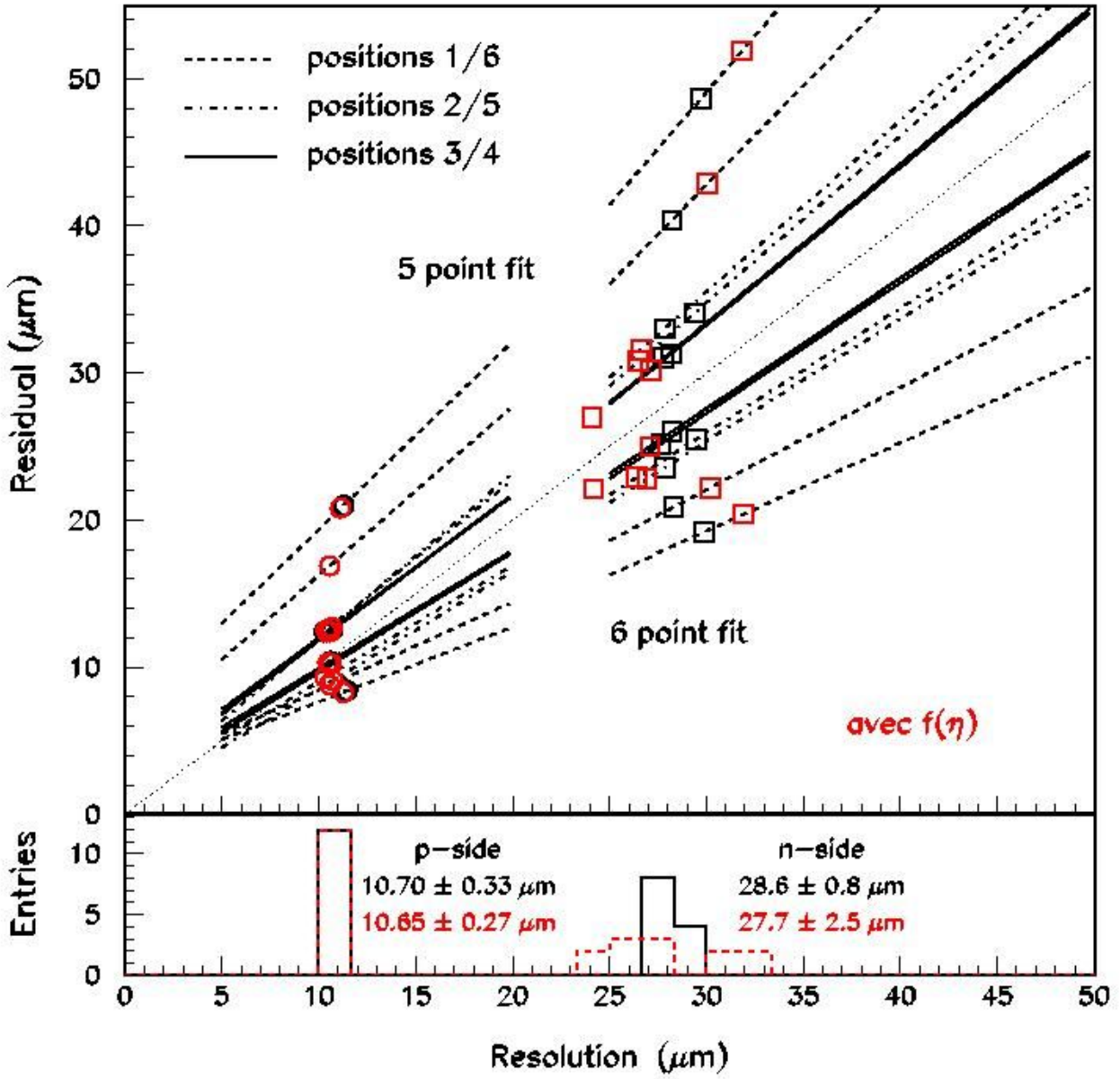
October 2003 test beam (protons)

Projected track positions in the interstrip gap of the ladder in position 2 from COG and f(η).



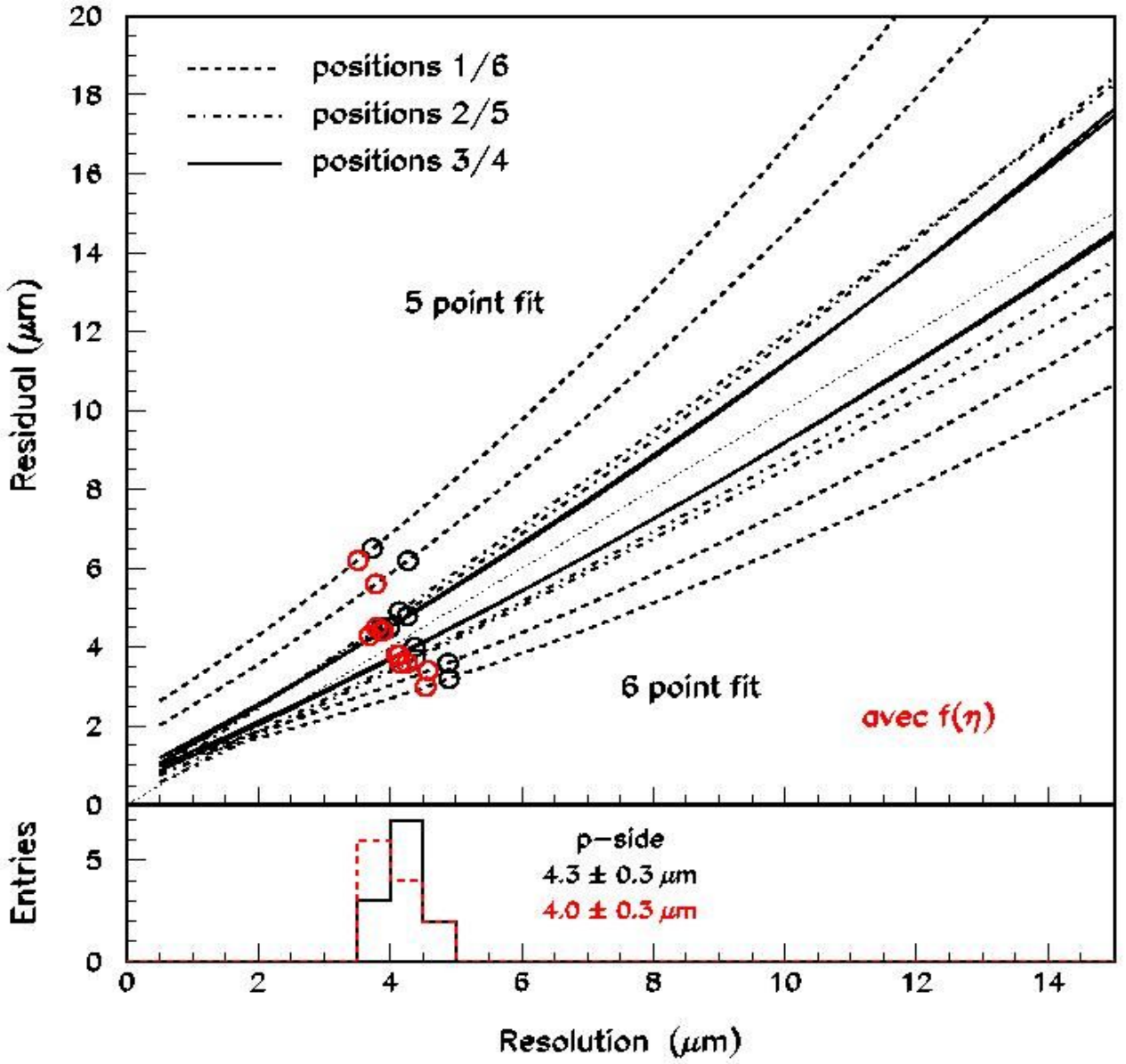
Proton resolutions (σ_1) and η correction

October 2003 test beam

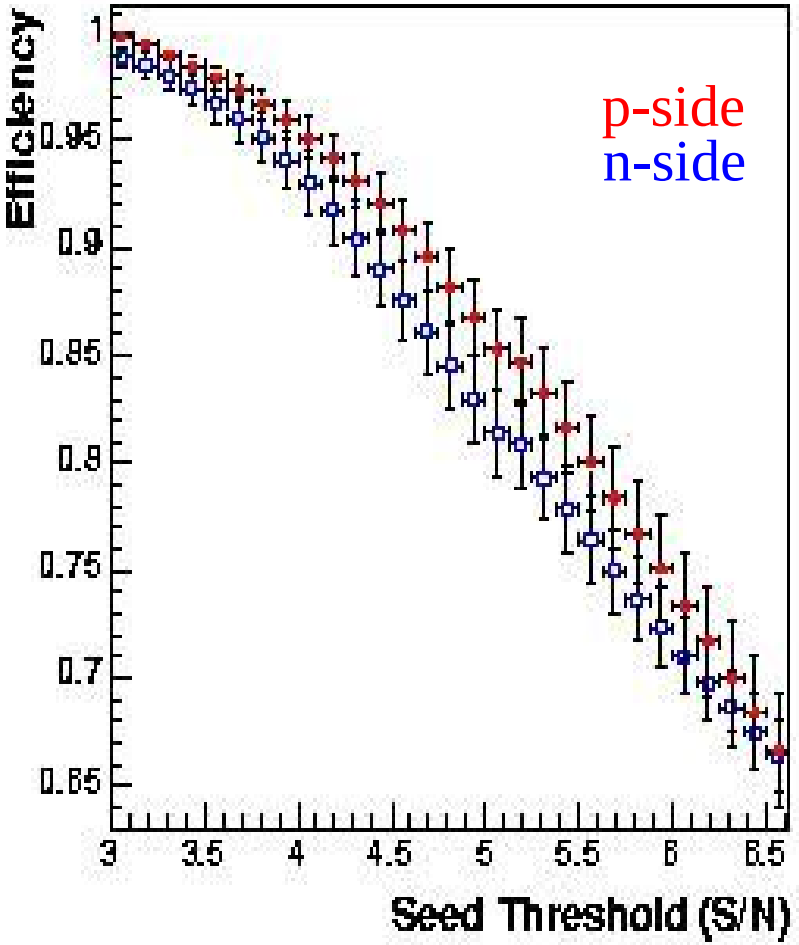


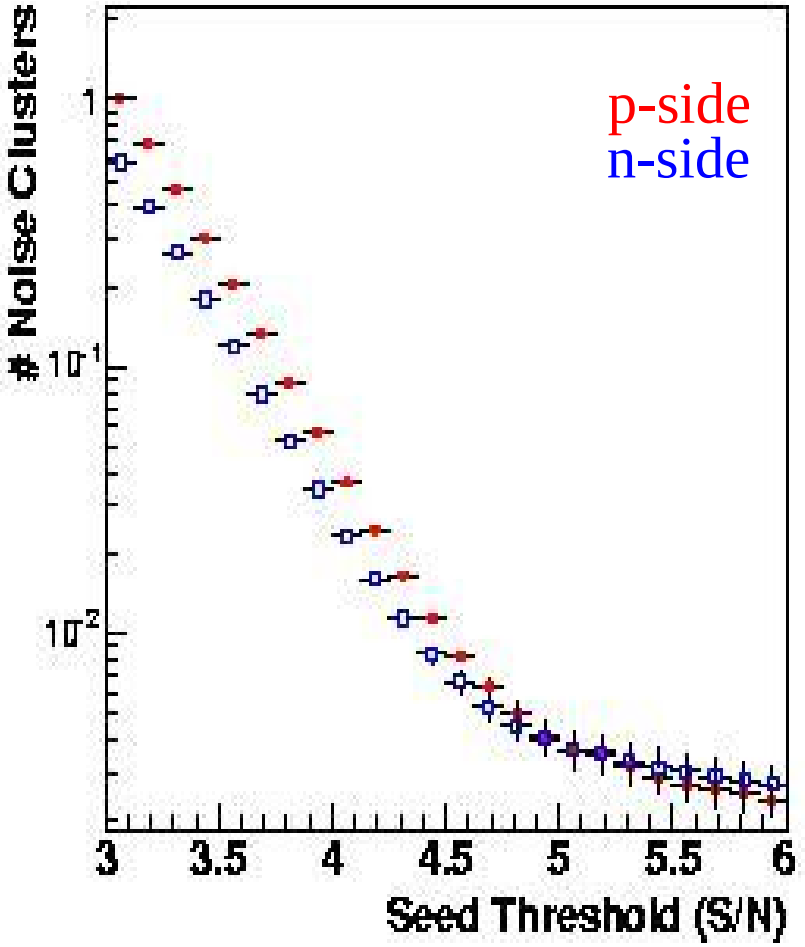
Helium p-side resolution (σ_1) and η correction

October 2003 test beam



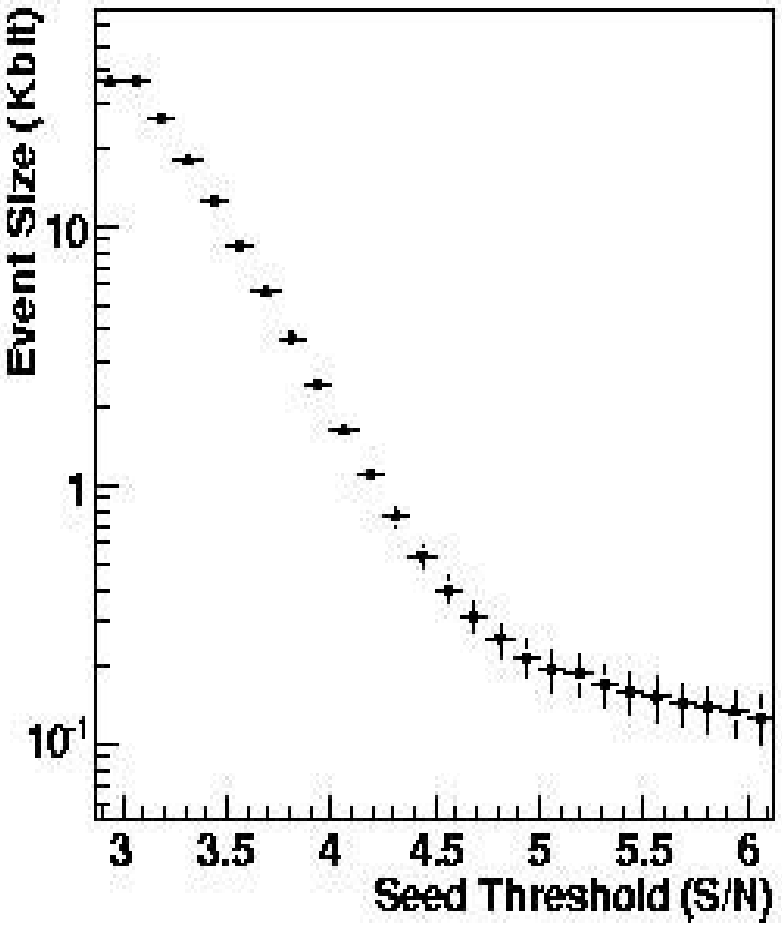
Detection Efficiency *vs.* Noise
ladder level

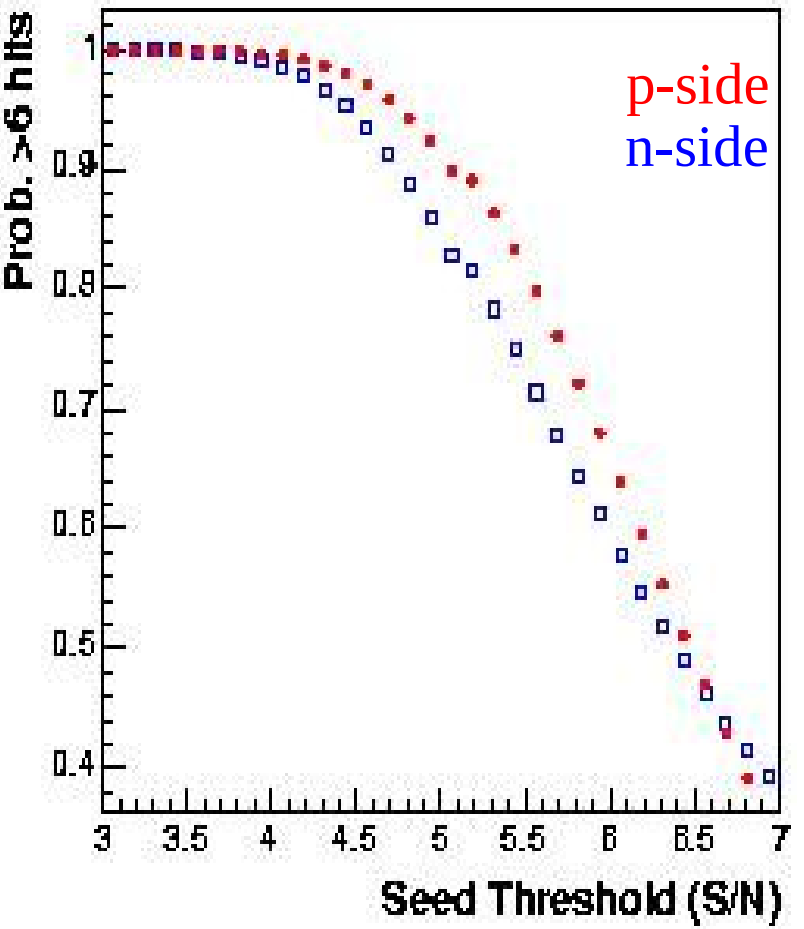




Detection efficiency ≥ 95% for S/N seed threshold ≤ 4

Detection Efficiency *vs.* Event Size
tracker level





Projected bandwidth 2 Mbit/s, with 1 kHz average trigger rate per orbit

⇒ maximum event size ~2 kbit

⇒ seed S/N threshold ~4

Crystal Collimation Silicon Tracker(s)

questions / propositions

- two trackers for incident and scattered beams ?
- incident: limited dimensions ?

  small detectors, not AMS-02 ladders
- scattered: dimensions and the “bending direction”, i.e. horizontal or vertical boxes ?

  if measurement range exceeds 8 cm in direction of the ladder length then sensitive to n-side ambiguity
- trigger rate > 2 kHz ?
- number of silicon detectors/ladders

  ⇒ raw mode or online data reduction ?

Crystal Collimation Silicon Tracker(s)

questions / propositions cont'd

- required online information, e.g. after alignment ?
- for alignment (ladder level) require a sufficient number of strait tracks over the full acceptance
- .....