The Time of Flight detector of the AMS-02

Lecture 1

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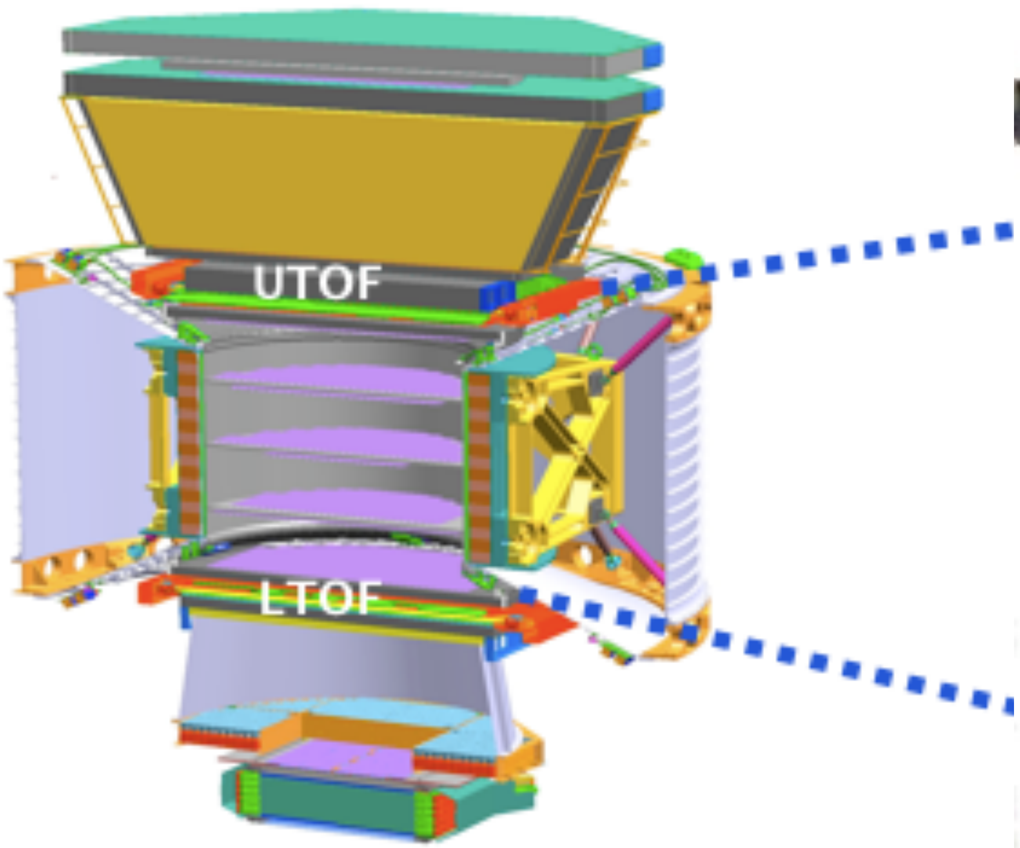
for TOF collaboration

Outline

- The TOF goals
- The design philosophy
- The main constituents of the TOF detector, their assembly and test
- The TOF detector assembly
- The TOF space qualification tests
- The AMS-02 calibration and Space qualification
- The TOF optimization and tuning
- The TOF performance in Space

The Time of Flight (TOF)



TOF acceptance 0.4 m^2 sr

The AMS-02 TOF system is based on previous experience (AMS-01) and well-established techniques.
It has been completely designed and built at the INFN Laboratories in Bologna (Italy), to provide:

- the fast trigger to AMS;
- the measurement of the time of flight (Δt) for the determination of the particle velocity (β);
- the distinction from upward and downward going particles at a level of 10^{-9} necessary to distinguish between matter and antimatter;
- the measurement of the absolute particle charge;
- distinguish at the trigger level protons from high charge nuclei.

The main parameters for the TOF

(a) Total sensitive area
AMS-02 has been designed to have a large acceptance for cosmic ray tracks.
The magnet aperture is about 0.4 m^2sr, in order to reach a 10^9 sensitivity for the flux of anti-Helium/Helium nuclei. To match the full acceptance of the magnet, each layer of the TOF system has to cover a circular area of about 1.6 m^2.

(b) Trigger selection
The TOF-ACC system provides an efficient background rejection allowing, for trigger purposes, a TOF granularity of about 12X12 cm^2 and a lateral cylindrical segmentation of 22.5^o of the 16 anti-coincidence scintillator counters (ACC).

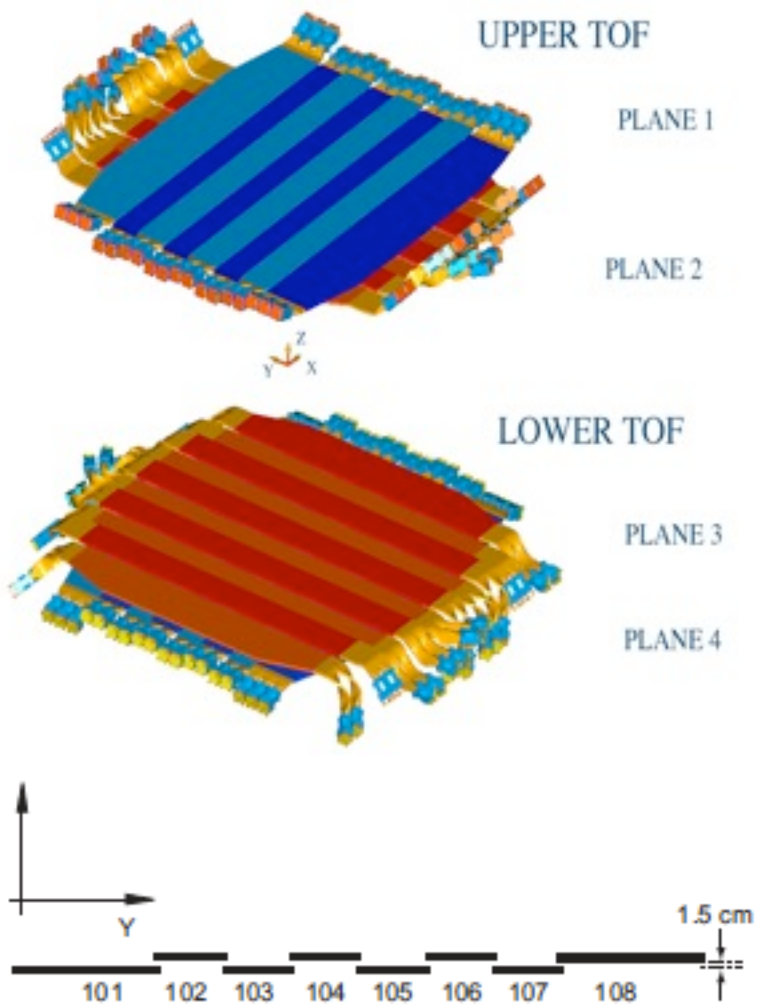
(c) Weight
Given the strong limitations in the total weight of the AMS detector, the TOF system was allotted 268 kg to accommodate for the detector itself and for the support structure.

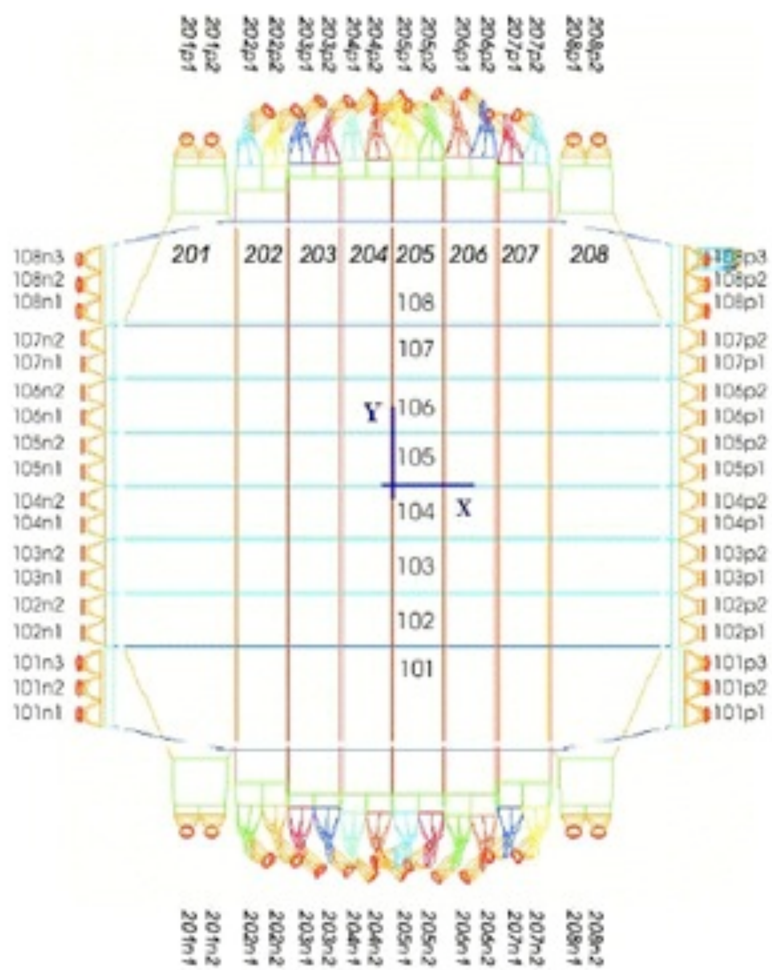
(d) Power consumption
The TOF system was allowed to use about 150W for photomultiplier tube operation and signal read-out, out of the 2 kW electric power given by NASA to the AMS experiment on the ISS.

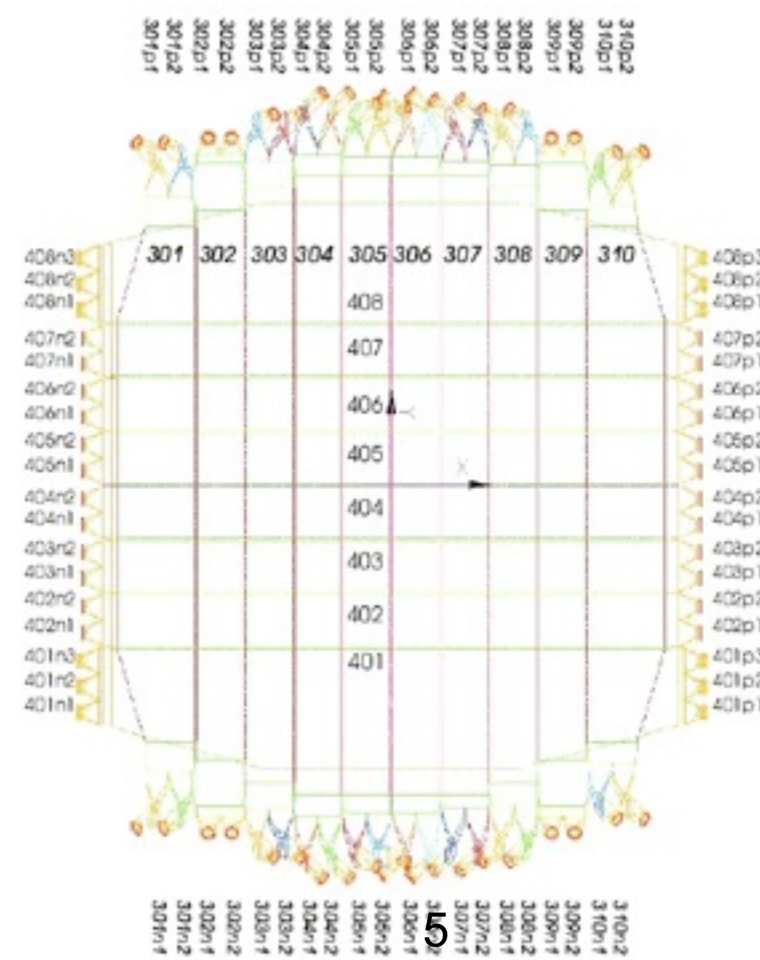
(e) Time-of-flight resolution
A resolution in the TOF better than 180 ps is needed to satisfy the physics requirements. The choice was one centimeter thick scintillator, as a compromise between the minimum thickness and the light output needed to reach this resolution.

The TOF system

The TOF system consists of planes of scintillator paddles mounted inside AMS-02.
Upper TOF (UTOF - layer 1 and 2) contains two layers of counters, in x and y directions, and it is situated at the entrance of the magnetic volume. Lower TOF planes (LTOF - layer 3 and 4) is below the magnet, at a distance of 626 mm in the z direction, as defined in the reference frame of the experiment.
The total number of scintillation counters is 34, namely 8 counters in layers 1, 2 and 4, and 10 counters in layer 3. Each layer is made scintillator paddles of different lengths, staggered by 1.5 cm in z and overlapped by 0.5 cm to avoid geometrical inefficiencies.
Mechanical constraints due to the magnet vacuum case and to the support structures of the other AMS-02 detectors required a different design for the UTOF, mechanically connected to the TRD, and for the LTOF mechanically connected to the Unique Support Structure (USS).



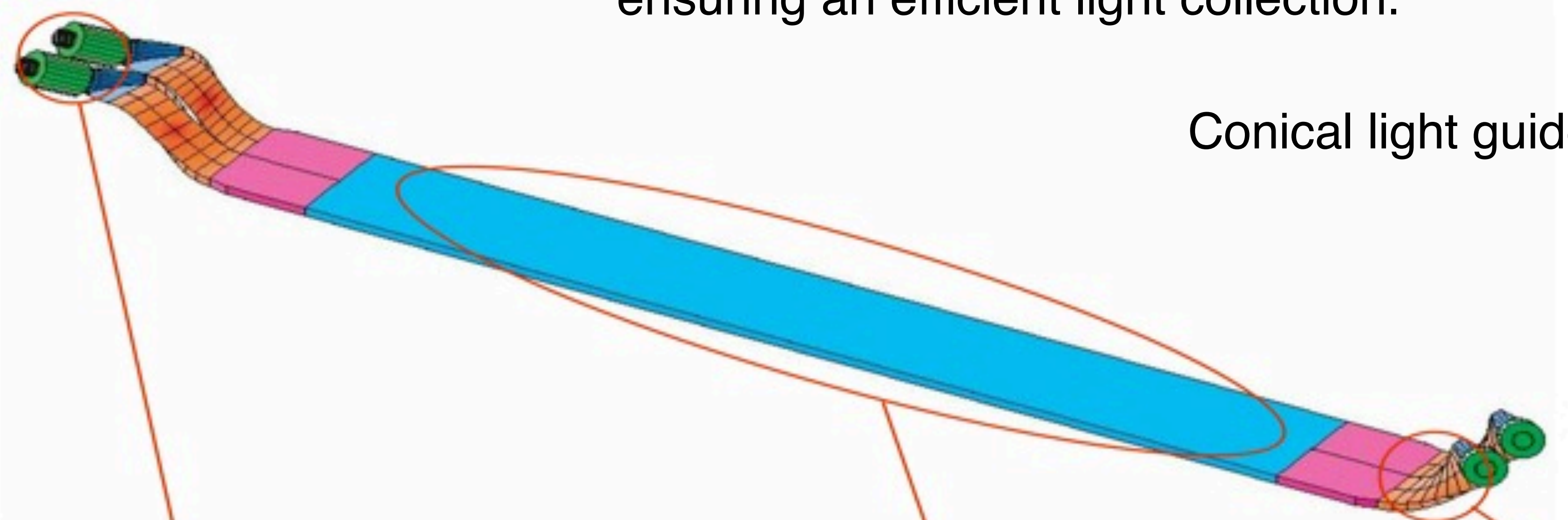




The main constituents of the TOF

Each counter of the TOF detector is made of a 1 cm thick scintillator paddle optically coupled at both ends with PMTs in order to have a time resolution nearly independent from the position of the impact point of the measured particle.

Each paddle is read-out by two PMTs (2 x 5.7 cm^2 cathode area) at each end, almost matching the area of the scintillator cross-section (12 cm^2), thus ensuring an efficient light collection.



Conical light guides couple each counter to the PMTs.

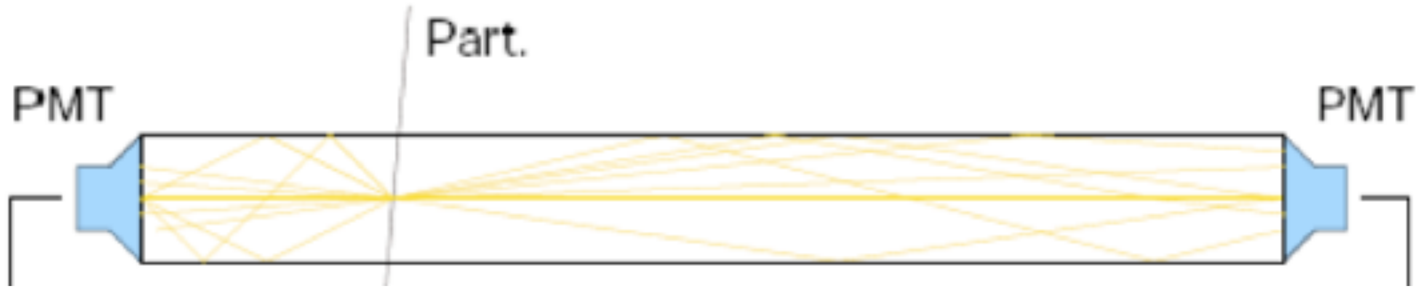
Light detectors

Scintillator

Light guides

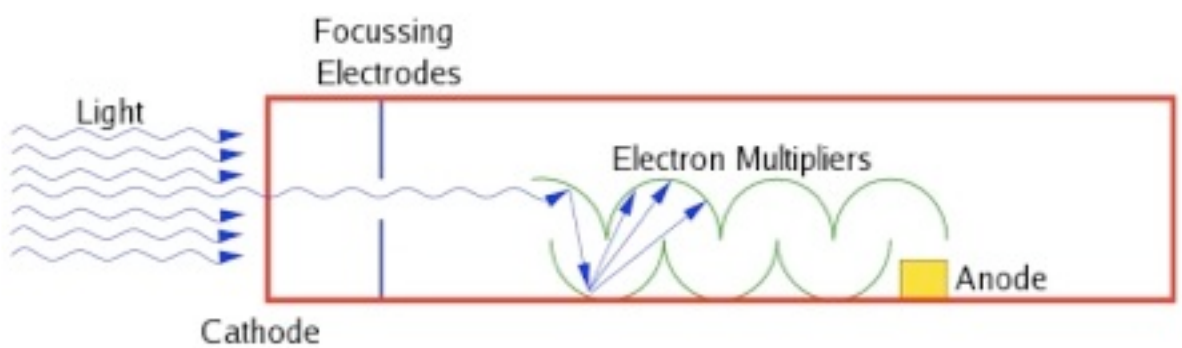
The main constituents of the TOF

When a particle crosses a scintillator, the absorbed energy is reemitted by the scintillator in form of light, that traversing all the counter through the light guide, reach the PMTs.



The photomultipliers are constructed from a glass envelope with a high vacuum inside, which houses a photocathode, several dynodes, and an anode.

Incident photons strike the photocathode material, with electrons being produced as a consequence of the photoelectric effect. These electrons are directed toward the electron multiplier, where electrons are multiplied by the process of secondary emission.

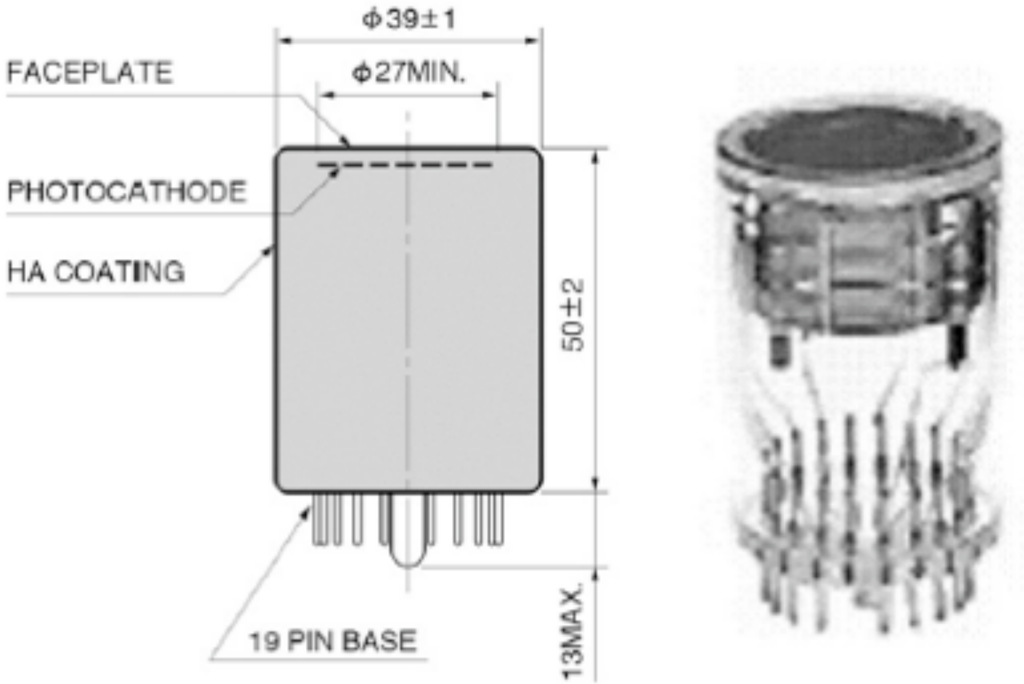


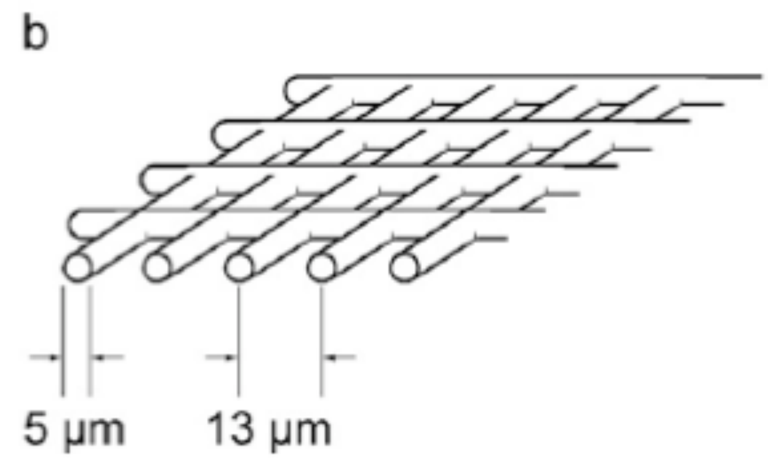
The electron multiplier consists of a number dynodes. Each dynode is held at a more positive voltage than the previous one, so electrons are accelerated by the electric field and arrive with much greater energy. The geometry of the dynode chain is such that a cascade occurs with an ever-increasing number of electrons being produced at each stage.

Finally, the electrons reach the anode, where the accumulation of charge results in a sharp current pulse that is measured by the front-end electronics.

The TOF photomultipliers

Hamamatsu fine-mesh R5946





The choice was fine-mesh PMTs, R5946 W/FL Hamamatsu, for their capability of working in high magnetic fields, while keeping good timing characteristics.

This PMT has a 16 mesh dynode chain, its nominal gain is 10^6 at 2000 V, the rise time 1.9 ns, the transit time 7.7 ns and the single electron time jitter 0.35 ns at zero magnetic field.

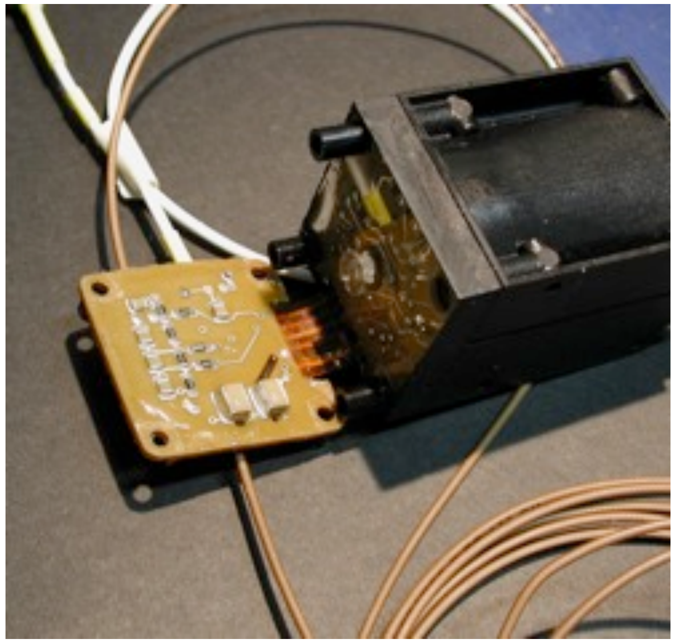
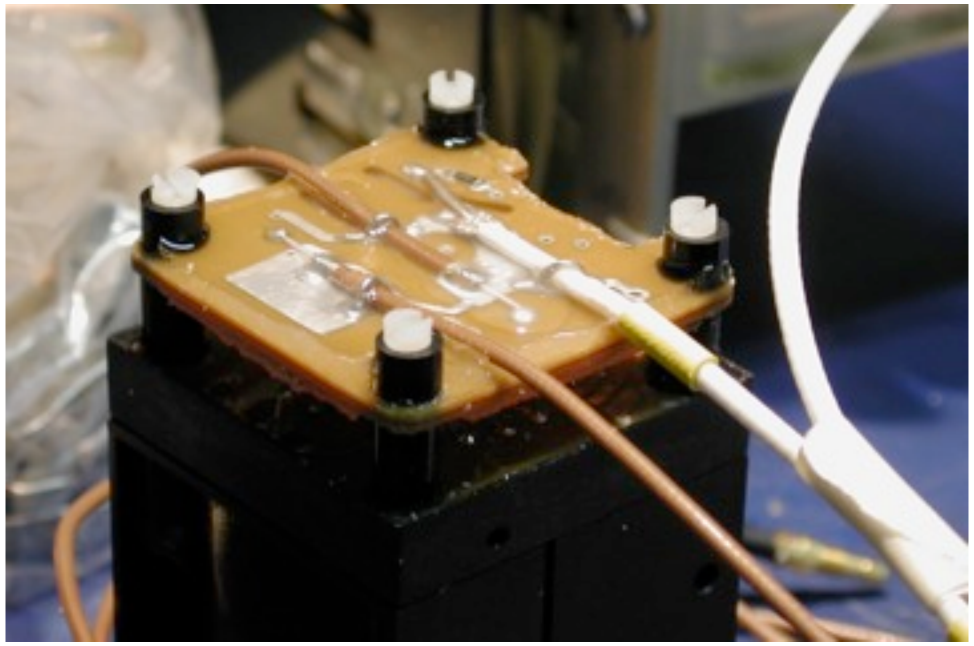
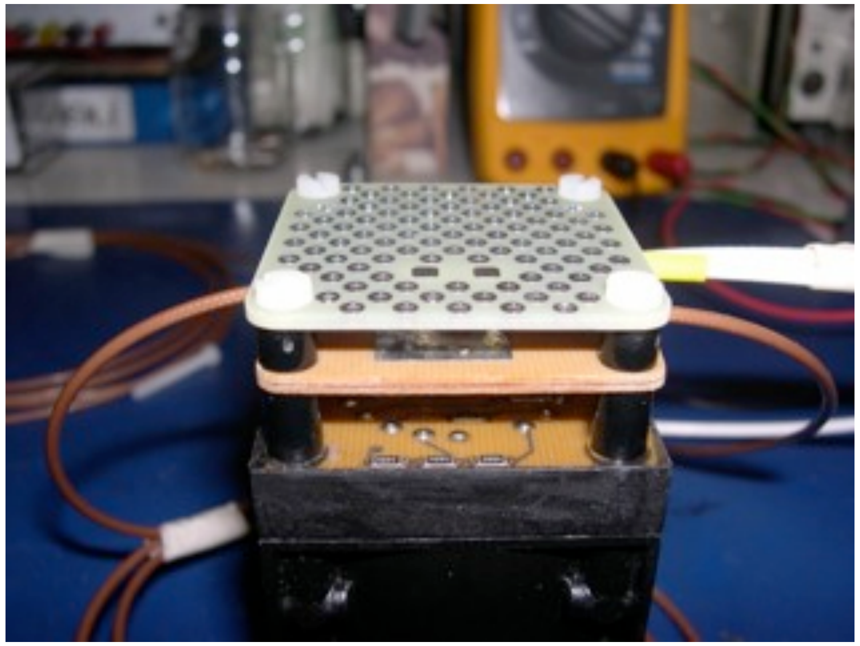
The spectral response ranges from 300 to 600 nm with a maximum response at ~ 420 nm.

Fringing magnetic field (400 G) in the TOF system region

The Photomultiplier assembly

In addition to the anode signal, the signal of the last third dynode is read out independently to measure particle with higher charges.

The assembly of the PMT electronics is shown in these pictures.

The PMT flying leads for the anode, the dynode and the PMT HV are soldered to the first card of the base.
The first card is connected to a second card holding the HV divider resistor and the capacitors to connect the cables. On the top of the second card the HV, the anode and dynode cables are suitably coated to ensure electrical insulation.
A grounding card which mechanically protects the whole base is finally added.

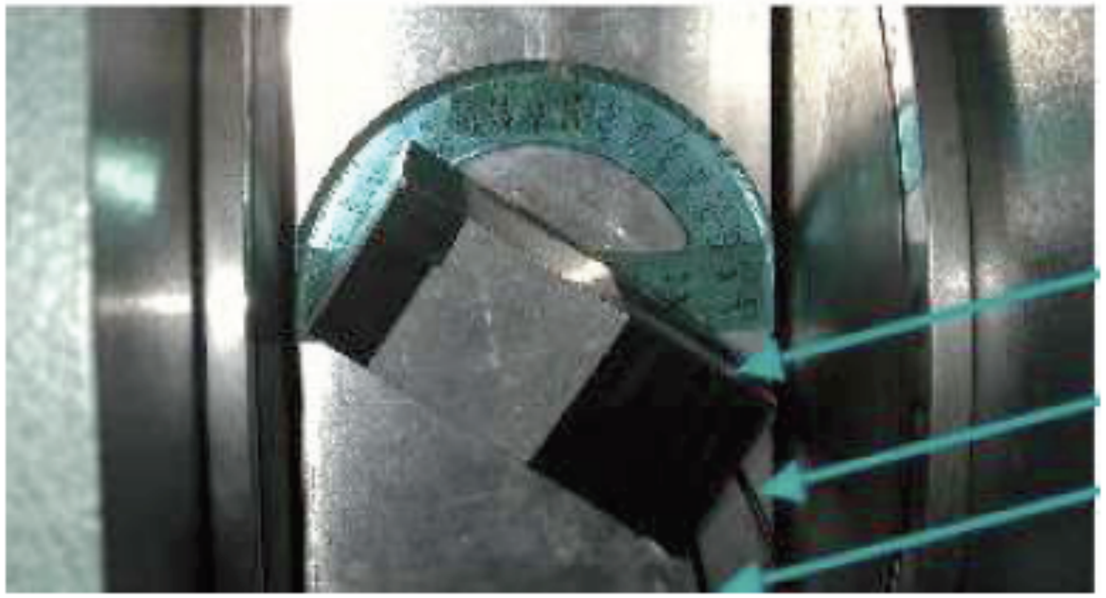
Photomultiplier calibration

In the Bologna laboratory the PMTs behavior in magnetic field has been extensively studied, both in pulse height response and in time resolution.

The PMT response to a red light emitting diode (LED) was measured inside the poles of an electromagnet on a movable stand which could be rotated at a maximum angle of 90°.

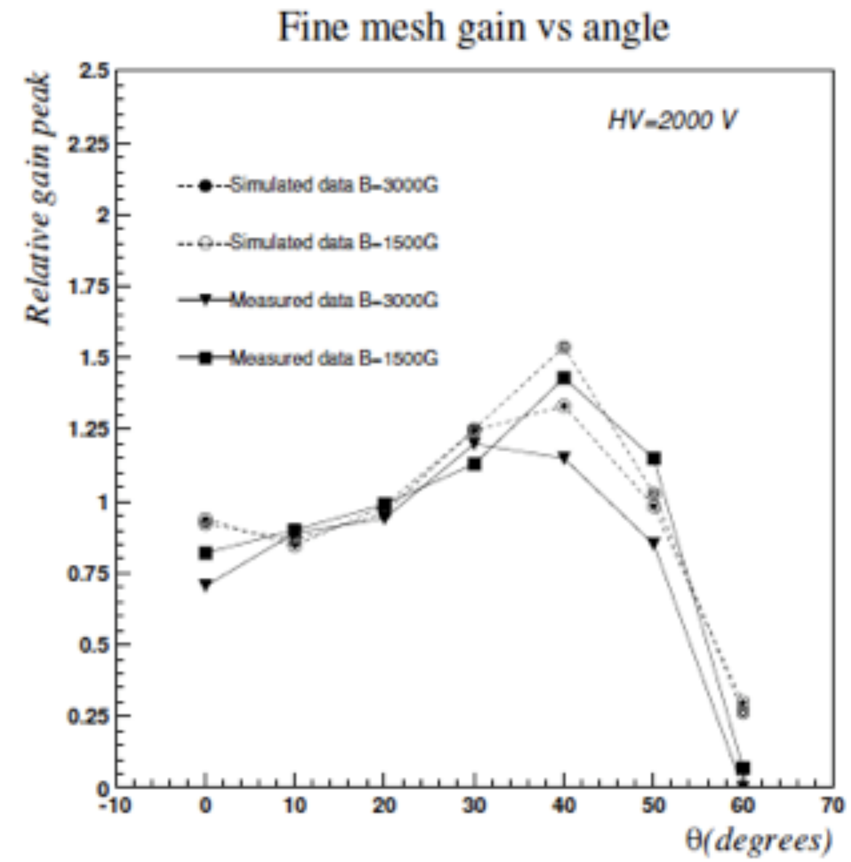
The photomultiplier response was measured for different values of the magnetic field B and of the angle between the tube axis and the field direction.

To understand and validate the results of the measurements, a model simulation was also implemented that reproduces the single photoelectron spectrum and the amplitude and time response as a function of the intensity of the magnetic field and of its angle with respect to the PMT axis.



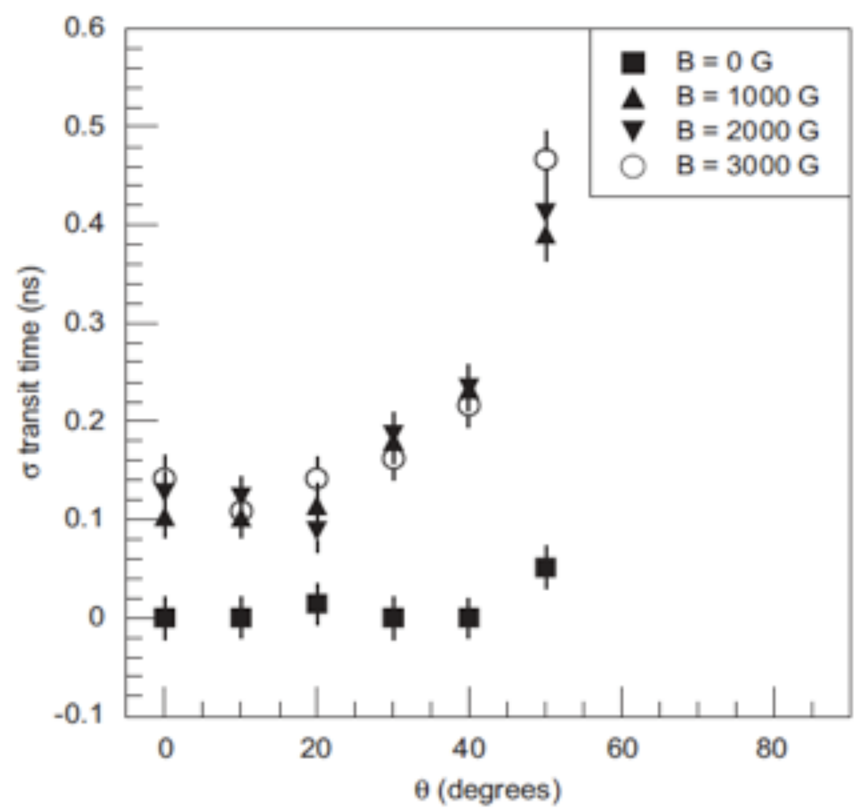
Photomultiplier calibration

The PMT pulse hight response in a magnetic field depends on the probability that an electron hits the first dynode mesh. This probability increases at angles between the PMT axis and the magnetic field greater than 0° and below 40°, resulting in a larger PMT response. Above about 50° the electrons do not reach the first dynode and the PMT response decreases dramatically.



In the figure in the right (top), the measured (solid lines, squares) and simulated (dotted lines, points) relative gain vs the angle between the PMT axis and the magnetic field are shown, at two values of magnetic field: 1500G (open points and squares) and 3000G (black points and triangles). The simulation results agree well with data.

The time response of the phototube in the magnetic field as been also studied. Due to the increase in flight path length of the electrons spiraling around the magnetic field lines, the transit time of the electrons from the photocathode to the first dynode increases with increasing angles between the PMT axis and the magnetic field and with increasing magnetic field. In fact for $\theta \geq 35^\circ$ the transit time and the transit time resolution worsen badly as shown in the figure in the right (bottom).



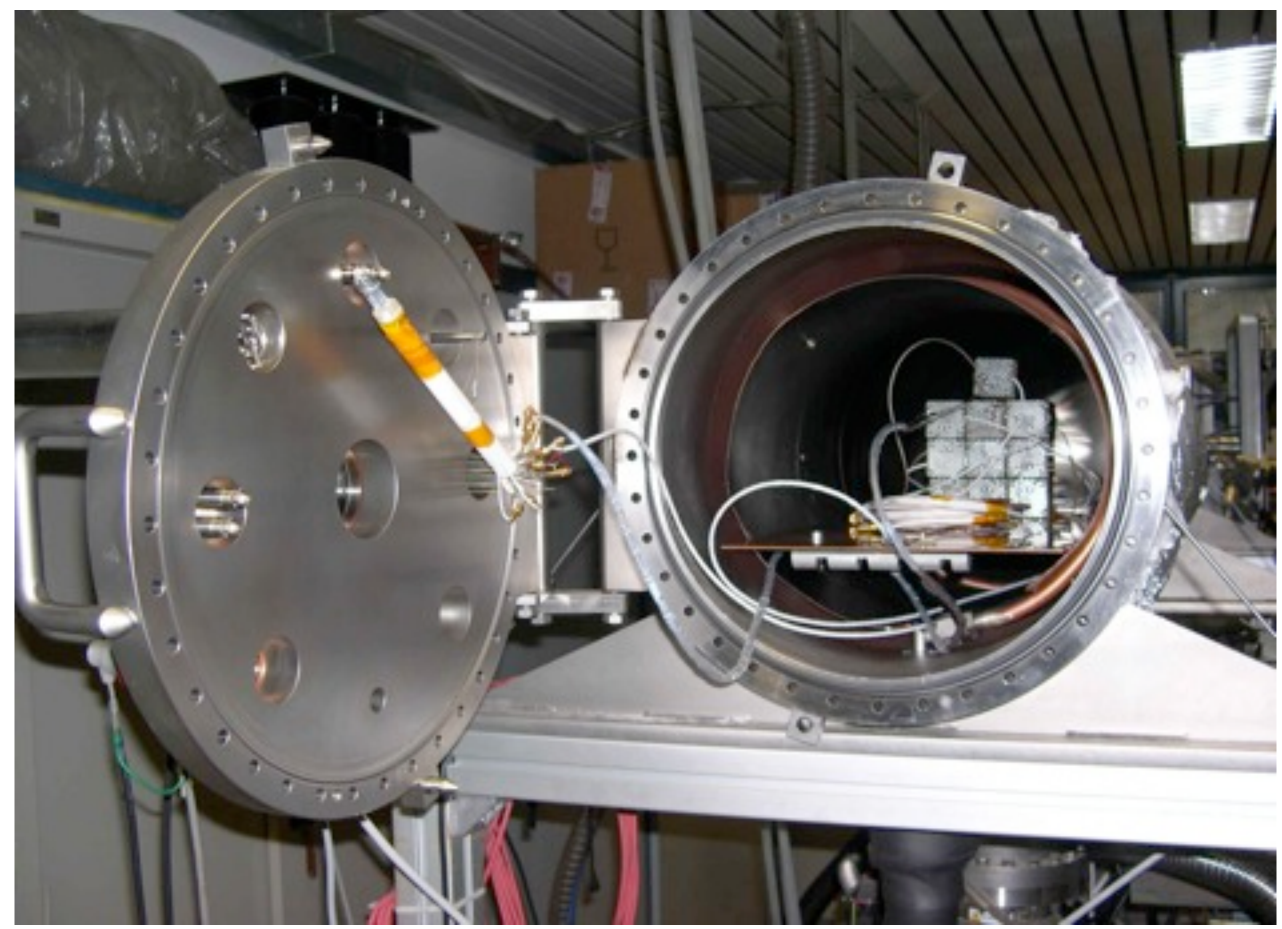
The Hamamatsu fine-mesh R5946 photomultipliers are able to operate in strong magnetic field environment. The curved light guides keep the angles of the TOF PMTs below this critical value.

Photomultiplier thermal vacuum test

The PMTs must withstand the severe Space environmental conditions of the Space Station.

Extensive tests have been made in a thermal vacuum chamber built in Bologna.

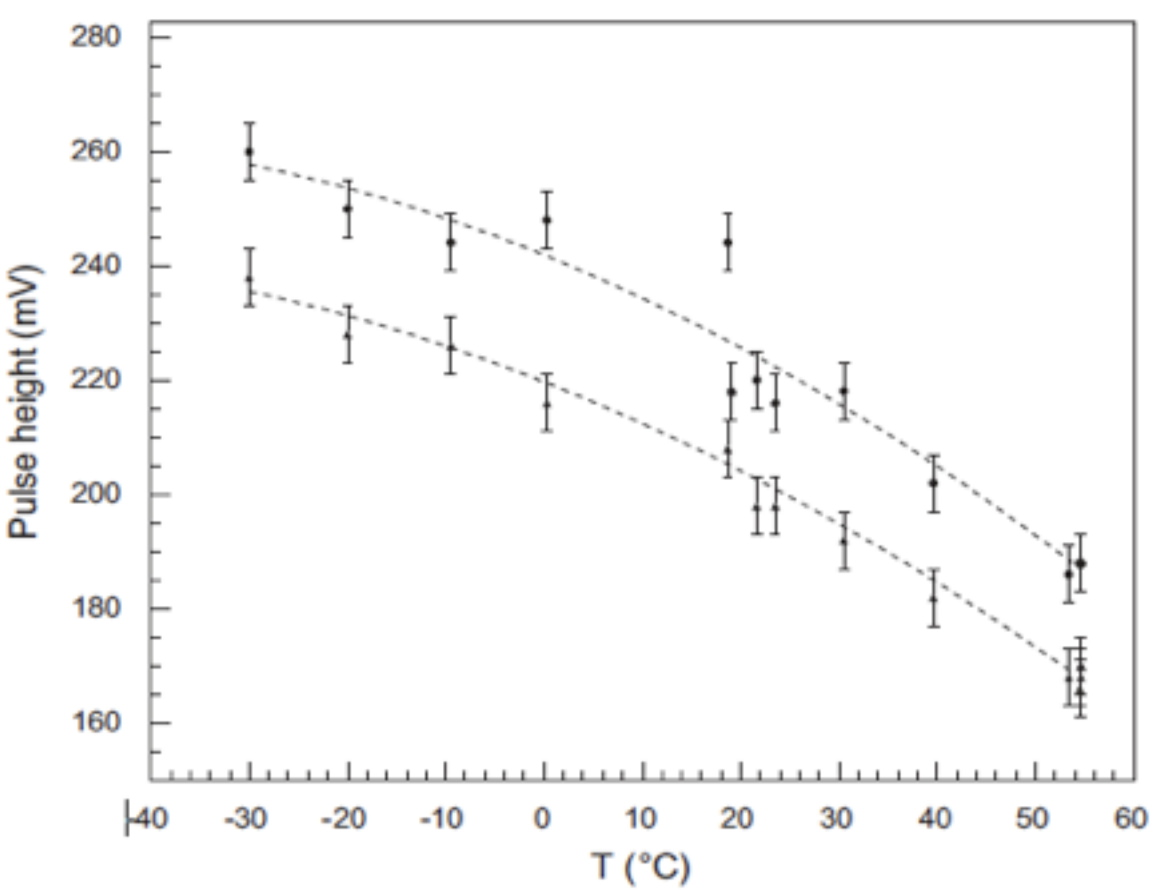
The photomultipliers were tested at a pressure of about 10^6 mbar with temperature varying between -30 and +55 C.



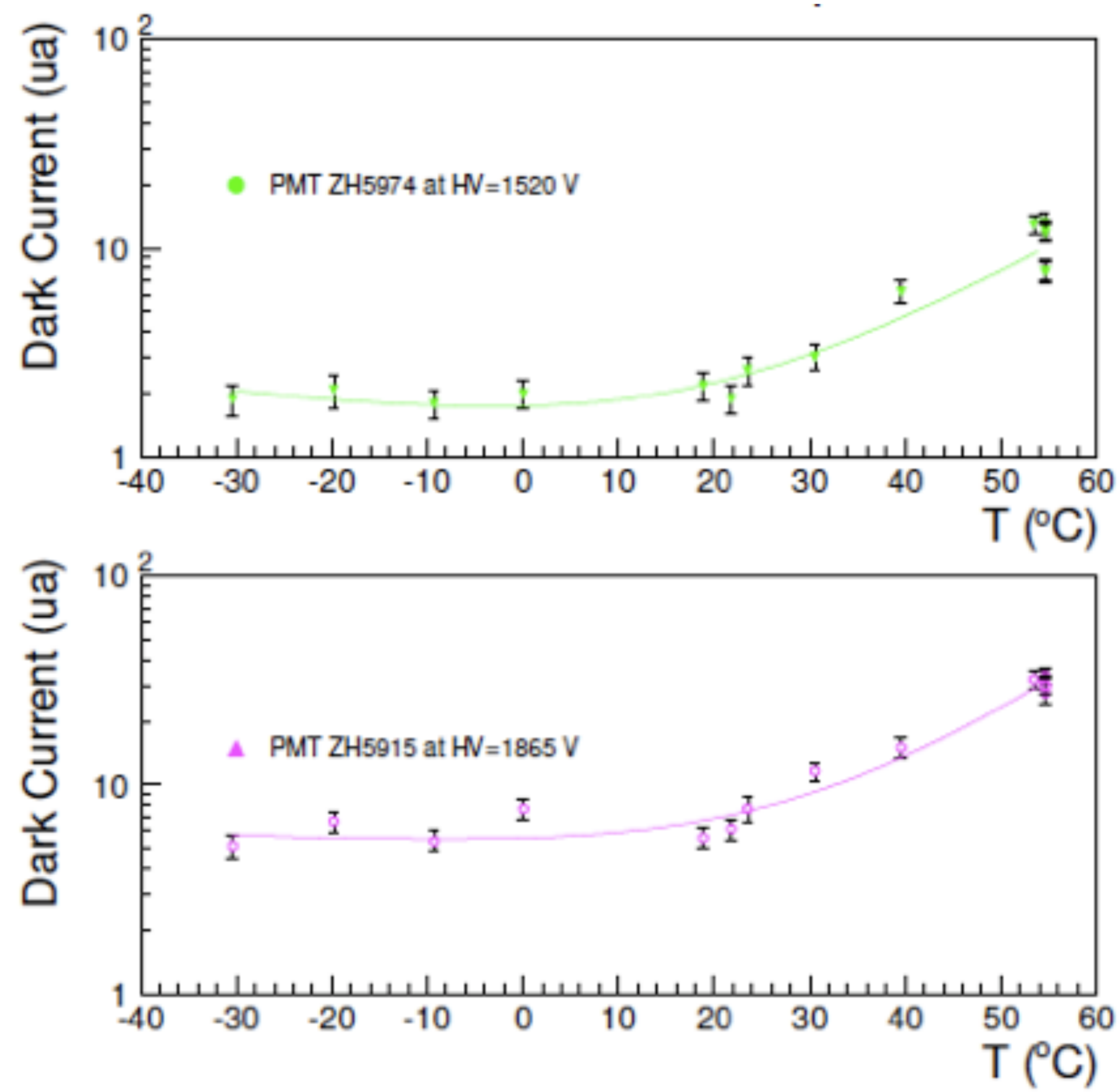
Photomultiplier thermal vacuum test

Four PMTs were equipped with a radioactive source and a small scintillator, used as a reference to measure the variation of the pulse height as a function of the temperature (figure in the left).

All the other PMTs were monitored for dark current at the same pressure and temperature range (in the figure in the right, the dark current for two PMTs is shown). Even if an increase is clearly measured at high temperature, the dark current is always negligible.



The variation of the pulse height as a function of temperature for two PMTs.

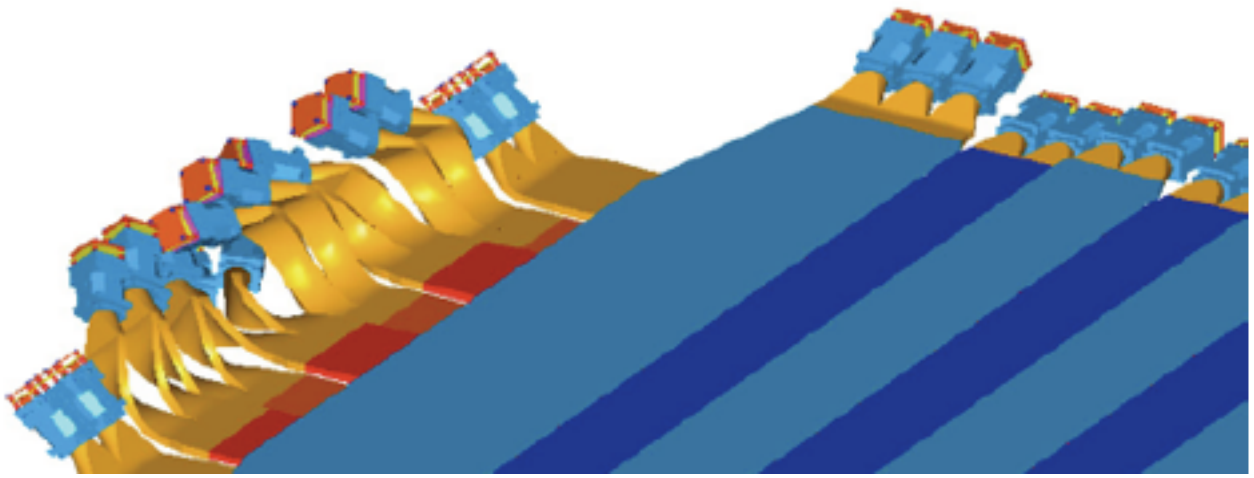


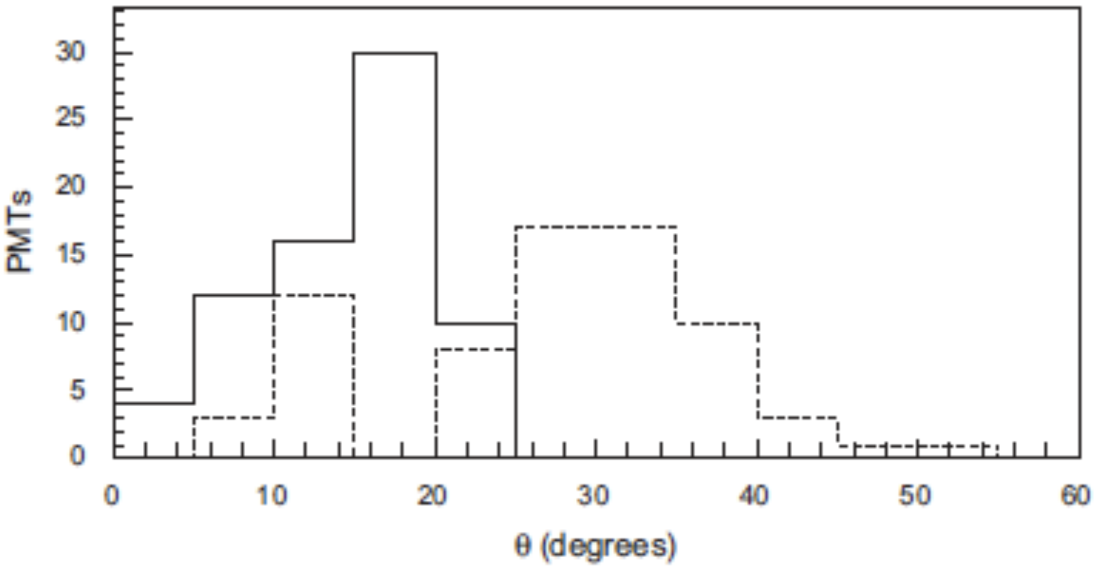
The variation of the dark current versus temperature for two PMTs.

The light guides

To minimize the angle between the direction of the field with respect to the photomultiplier axis three kinds of plexiglass light guides have been designed and built: straight, tilted and twisted.

The best orientation of each PMT, compatible with all the mechanical constraints, was therefore chosen for each PMT.





The resulting angle distribution with respect to the magnetic field for all PMTs. Full lines: layers 1 and 4. Dotted lines: layers 2 and 3.

The TOF plastic scintillators

The scintillator material used for the TOF counters is Eljen Technology (type EJ-200) widely used in large dimension detectors for the low attenuation of light, fast time response and emission spectrum well matched to the PMT.

Physical and Scintillation Constants:

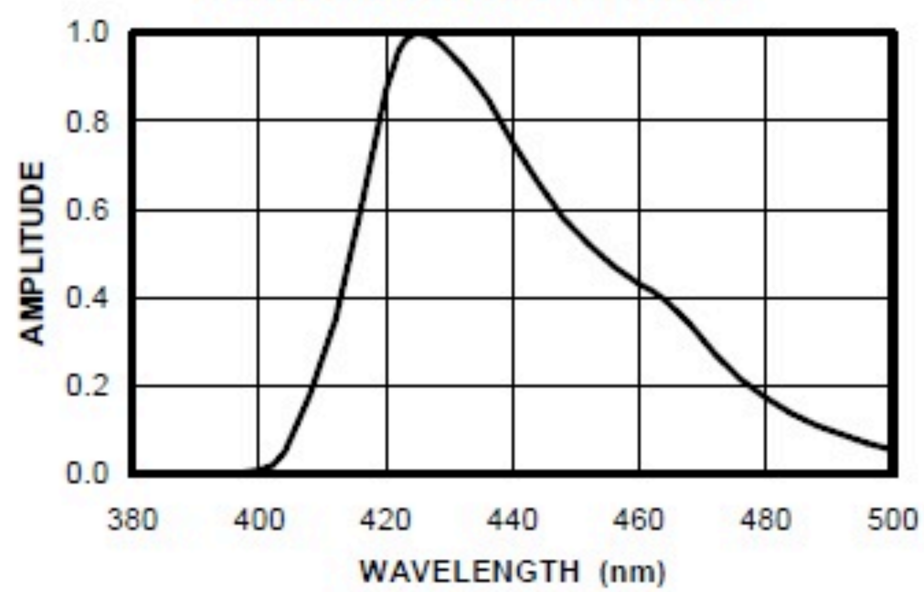
Light Output, % Anthracene	64
Scintillation Efficiency, photons/1 MeV e^-	10,000
Wavelength of Max. Emission, nm	425
Rise Time, ns	0.9
Decay Time, ns	2.1
Pulse Width, FWHM, ns	~2.5
No. of H Atoms per cm^3, x 10^{22}	5.17
No. of C Atoms per cm^3, x 10^{22}	4.69
No. of Electrons per cm^3, x 10^{23}	3.33
Density, g/cc:	1.023

Polymer Base: .... Polyvinyltoluene
Refractive Index: 1.58
Vapor Pressure: .... Is vacuum-compatible
Coefficient of Linear Expansion: .... 7.8 x 10^{-5} below +67°C

Light Output vs. Temperature:
At +60°C, L.O. = 95% of that at +20°C
No change from +20°C to -60°C

Chemical Compatibility: Is attacked by aromatic solvents, chlorinated solvents, ketones, solvent bonding cements, etc. It is stable in water, dilute acids and alkalis, lower alcohols and silicone greases. It is safe to use most epoxies and "super glues" with EJ-200.

EJ-200 EMISSION SPECTRUM



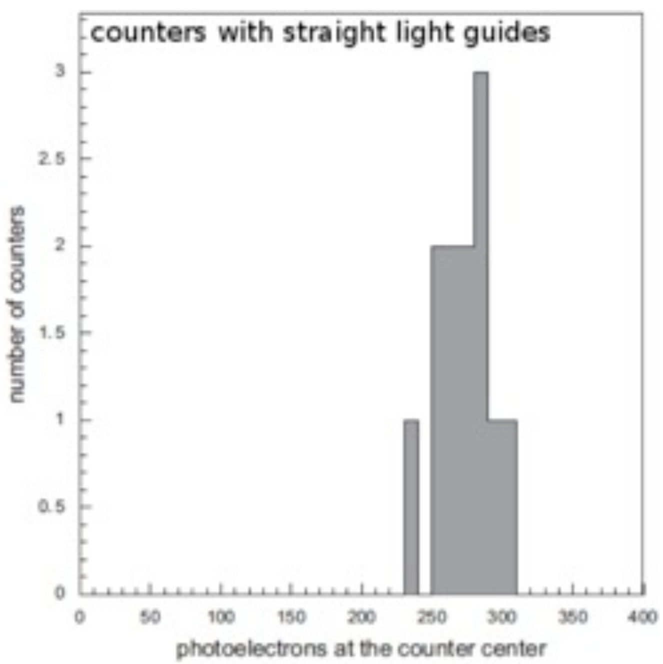
The TOF plastic scintillators test

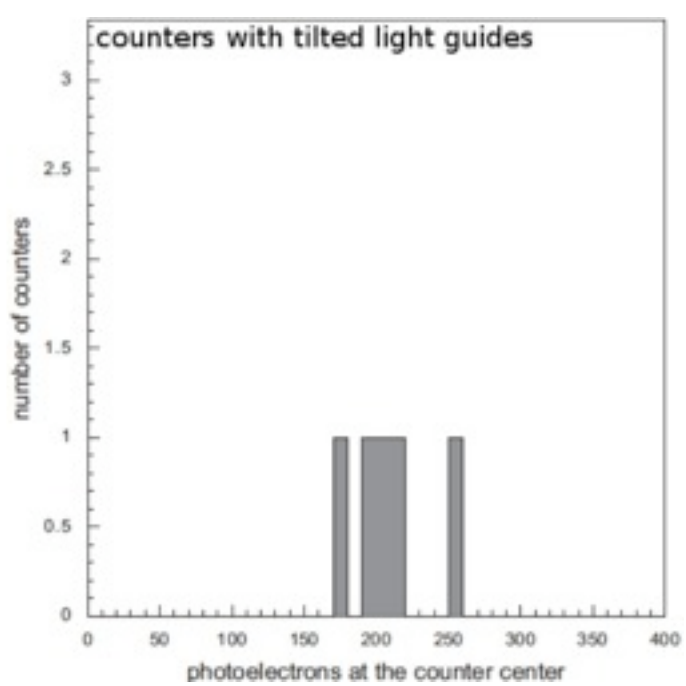
All counters have been tested in a cosmic ray test telescope, using the same photomultipliers and the same electronics for all of them. From the pulse height spectrum of particles hitting the center ± 5 cm of the counter, the total number of photoelectrons collected at both sides of the counter was evaluated as:

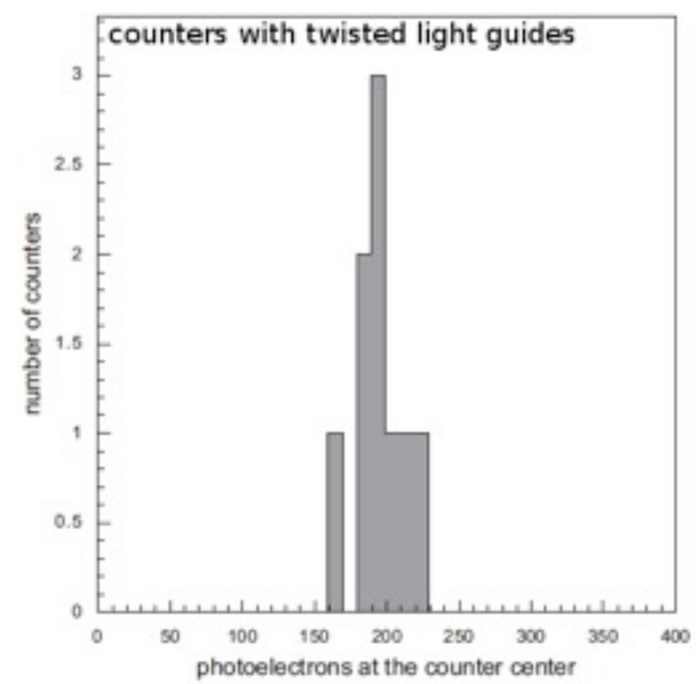
$$N_{\text{phe}} = \frac{1}{\sigma_R^2} \quad \text{with} \quad R = \frac{Q_n - Q_p}{Q_n + Q_p}$$

where Qn and Qp are the signal amplitudes seen at side n for negative AMS x or y coordinate, and at side p for positive AMS coordinate of the counter respectively, and σ_R is the variance of the R distribution.

The results of this first calibration show that the average number of photoelectrons decreases for the more complex light guides.







The scintillation counters assembly

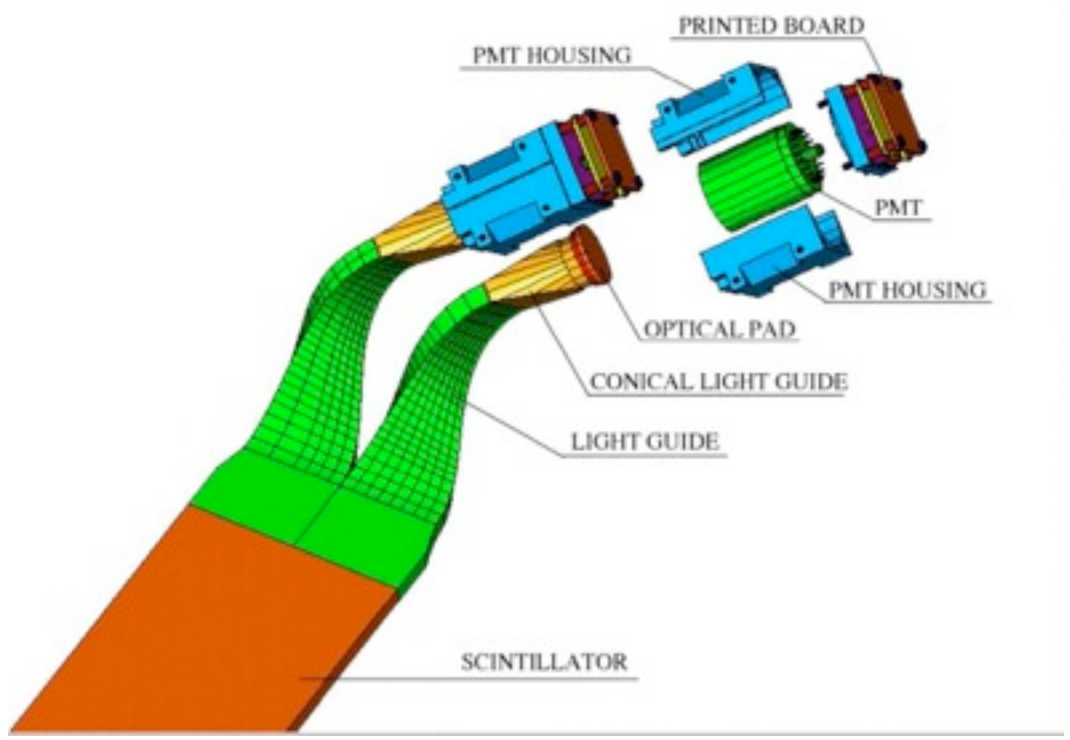
The scintillator counter were assembled with the light guides and the PMTS.

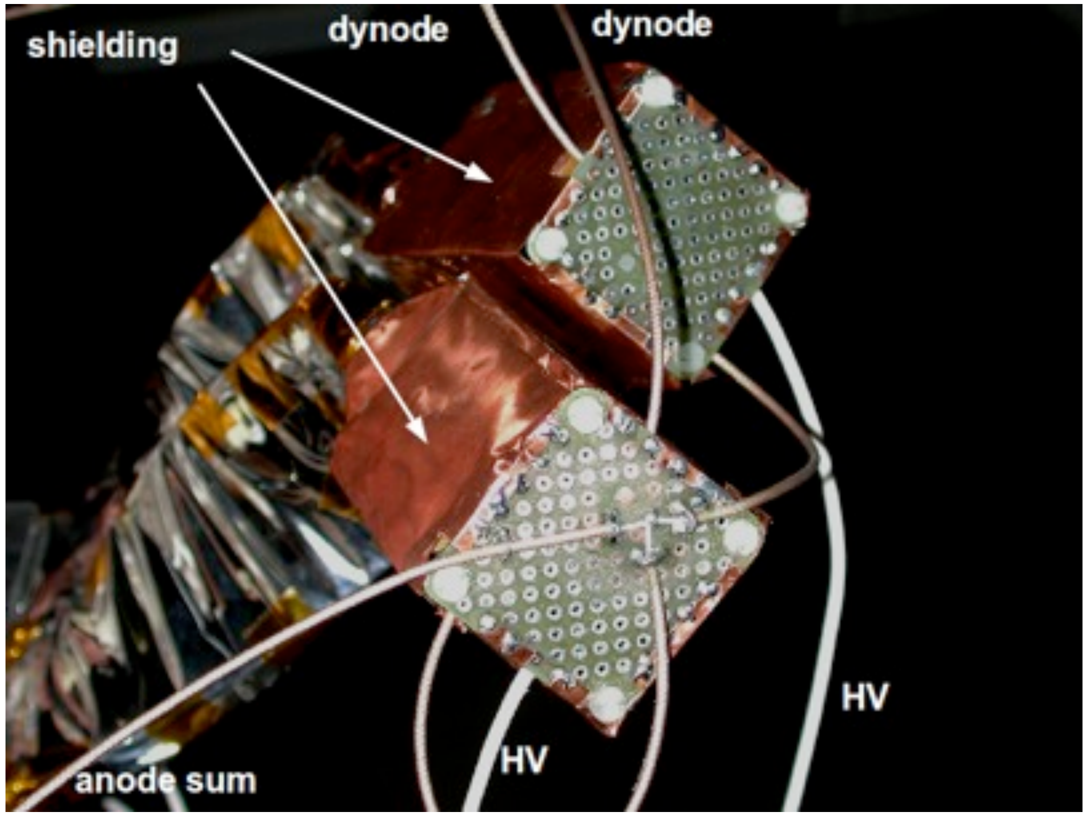
The light guides of different shapes were glued to the conical light guides to couple each counter to the PMTs. Round optical silicon (Dow Corning 93–500) rubber disks are used as optical contacts and mechanical pairing between the light guide and the PMT photocathode window.

Each counter is read at each side by two or three photomultipliers for redundancy. On each side of the counter the anode signals from the PMTs are passively summed to be used at the trigger level and to measure low charged particles, while the dynode signals are read independently to measure high charged cosmic rays.

PMTs should in principle be operated independently from each other. However, due to weight and power limitations, each high voltage (HV) channel was set to power two PMTs. To increase the fault tolerance of each side of the counter, the two PMTs on the same side are powered by different HV channels.

The best combination of PMTs was determined with a ‘‘simulated annealing’’ algorithm (checked with a genetic algorithm) in order to have equal responses from both PMTs in the same side.





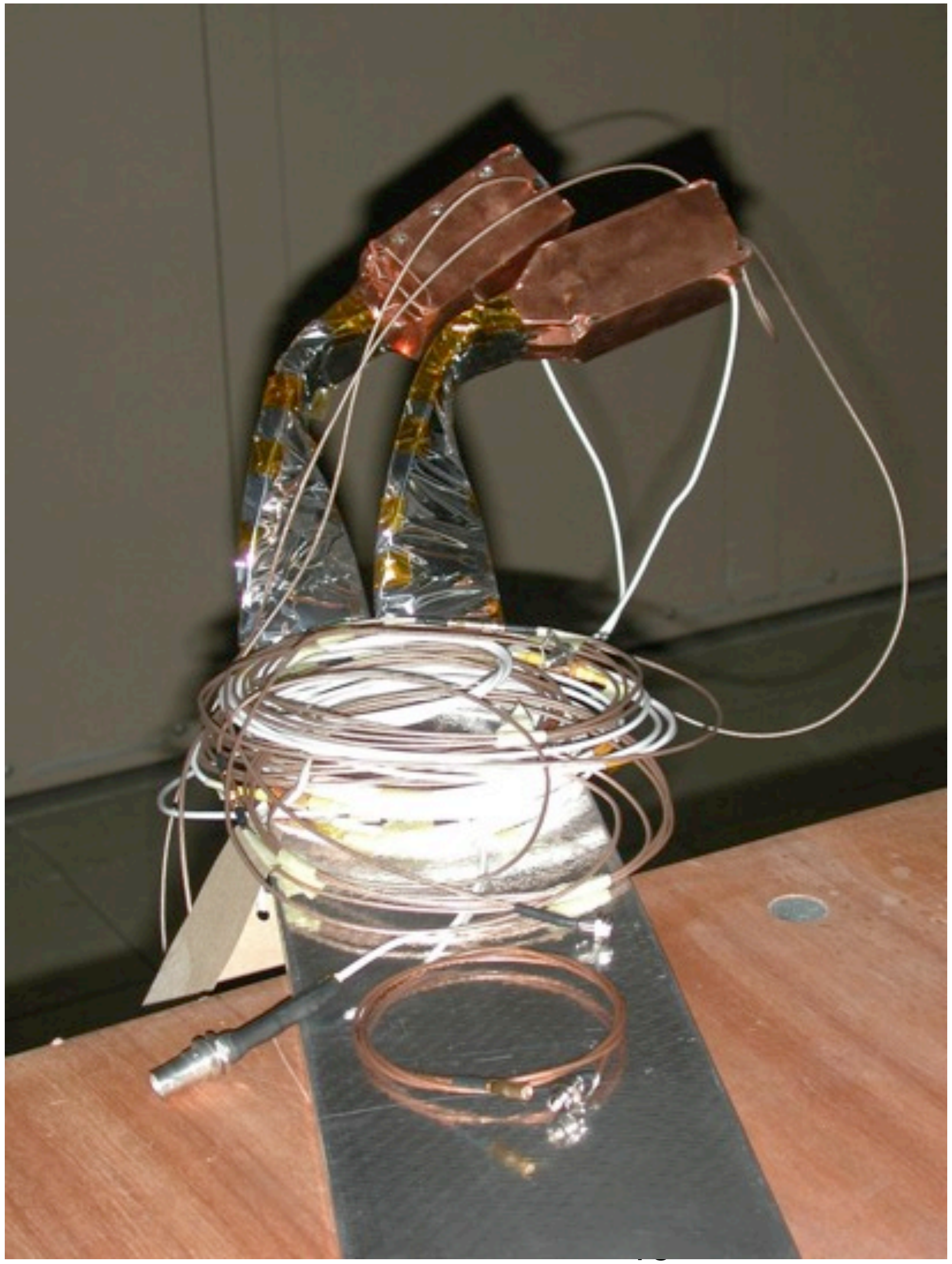
The scintillation counters of the TOF detector

All counters, once assembled with the light guides and the PMTs, were wrapped with aluminized mylar and enclosed in a rigid carbon fiber box, while the PMTs were enclosed in an electromagnetic shielding.

The assembled counters were then tested in vacuum for proper high voltage insulation of the PMT base and of the flight cables.

Maximum effort was done to minimize the number of different types of counter and to provide for each type at least one spare.

Counter(s)	Light guide	Shape	Length (cm)	PMTs
102–107	Straight	Rectangular	130.5	2
402–407	Straight	Rectangular	134.0	2
202,303	Tilted	Rectangular	127.0	2
204,305	Tilted	Rectangular	132.2	2
302,309	Tilted	Rectangular	117.2	2
203,304	Tilted and twisted	Rectangular	132.2	2
206,307	Tilted and twisted	Rectangular	132.2	2
205,306	Tilted and twisted	Rectangular	132.2	2
207,308	Tilted and twisted	Rectangular	127.0	2
101,108	Tilted	Trapezoidal	126.5	3
401,408	Tilted	Trapezoidal	130.0	3
201,208	Tilted	Trapezoidal	117.2	2
301	Tilted and twisted	Trapezoidal	110.0	2
310	Tilted and twisted	Trapezoidal	110.0	2



The TOF counters calibration

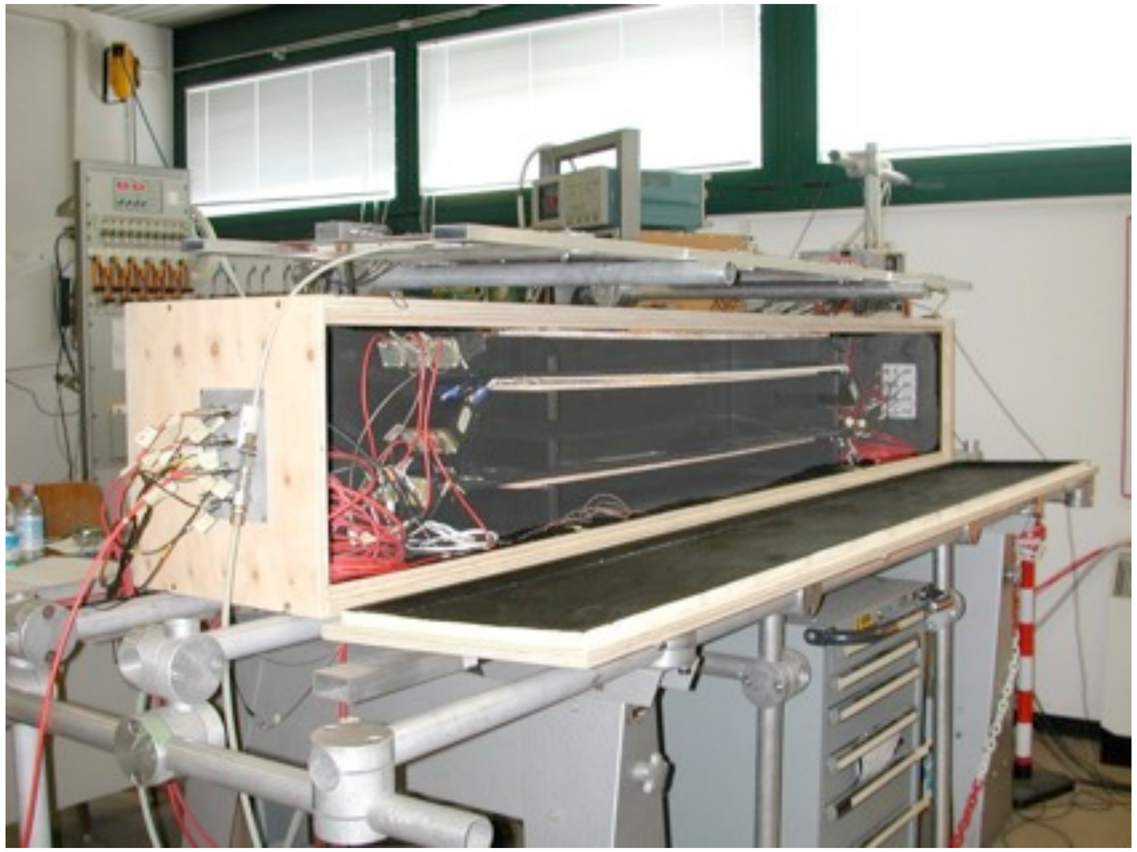
Each counter has been calibrated using the cosmic ray telescope.
The following characteristics of each counter were measured using cosmic muons:

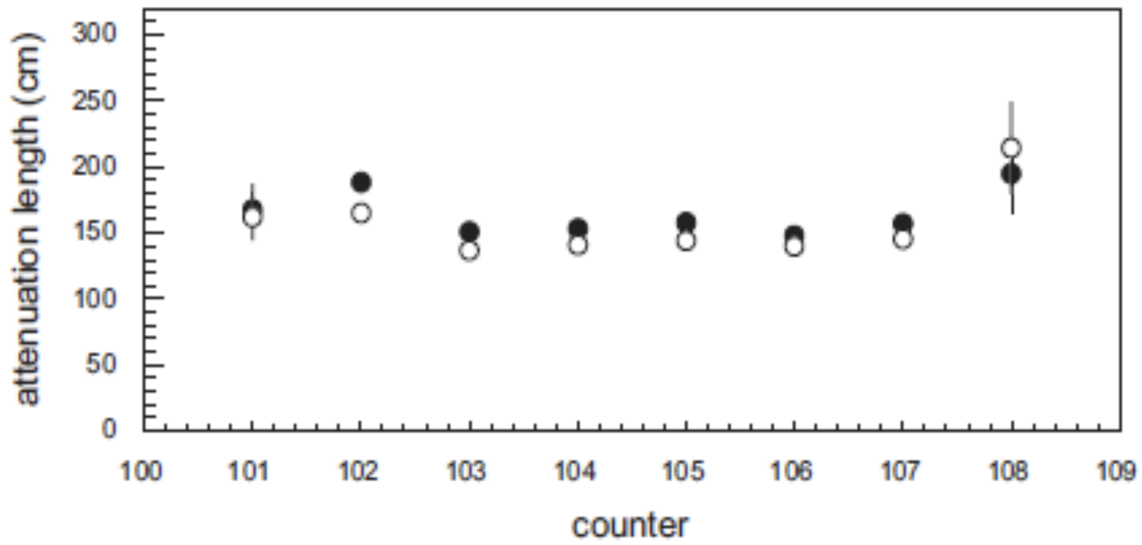
• **Attenuation lengths measured at both ends**

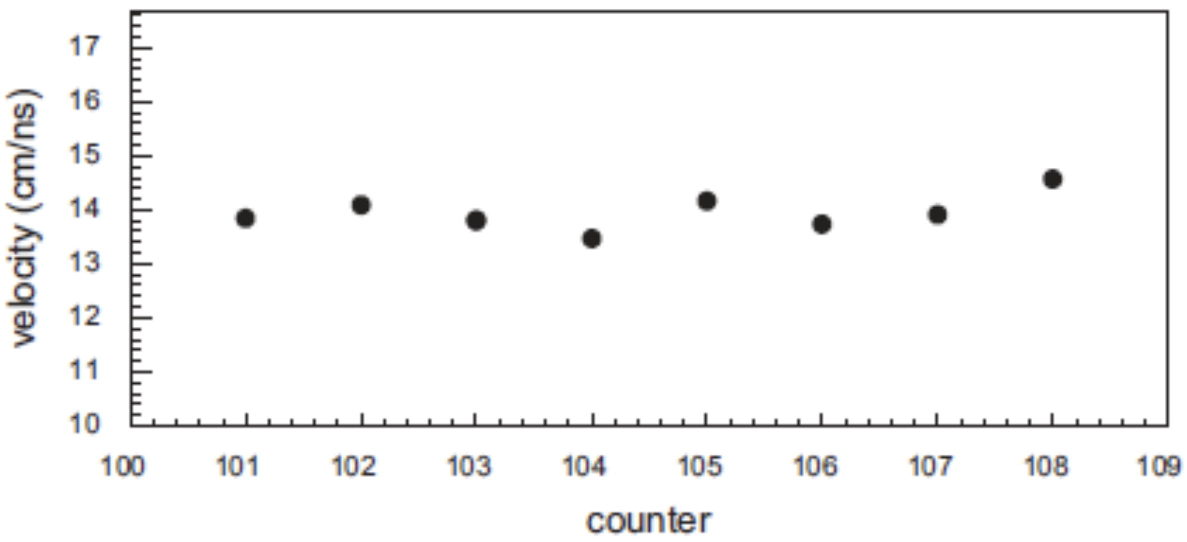
A typical attenuation length is about 150 cm.

• **Light velocity in the scintillator**

The effective velocity of light propagation along the scintillator is about 14 cm/ns.







The TOF counters calibration

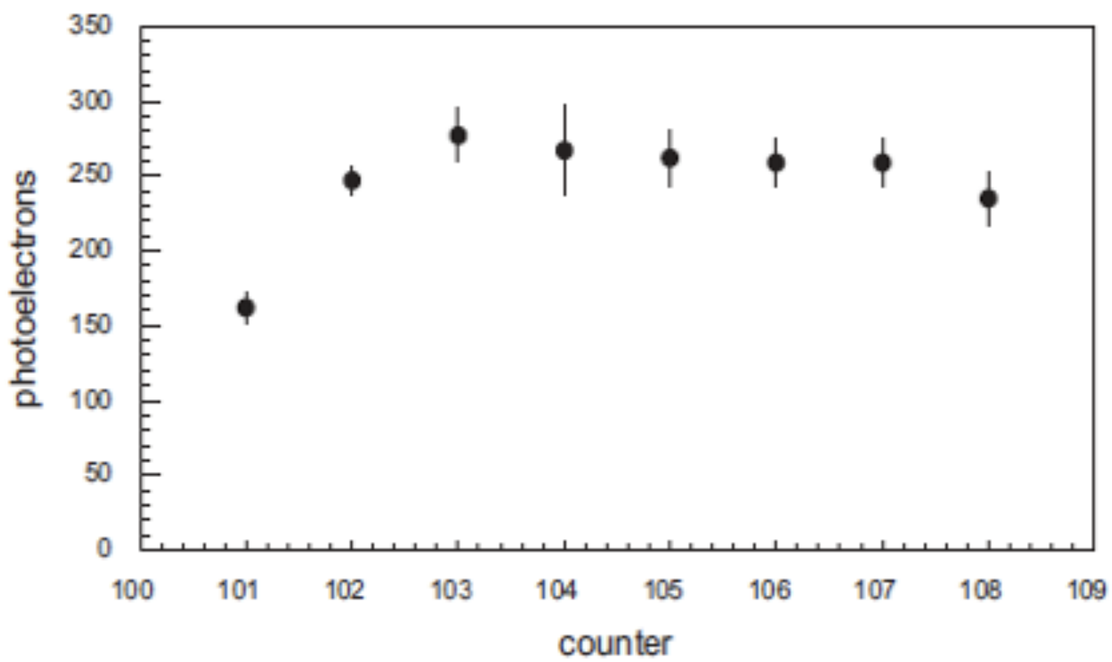
• **Number of photons at the counter center**

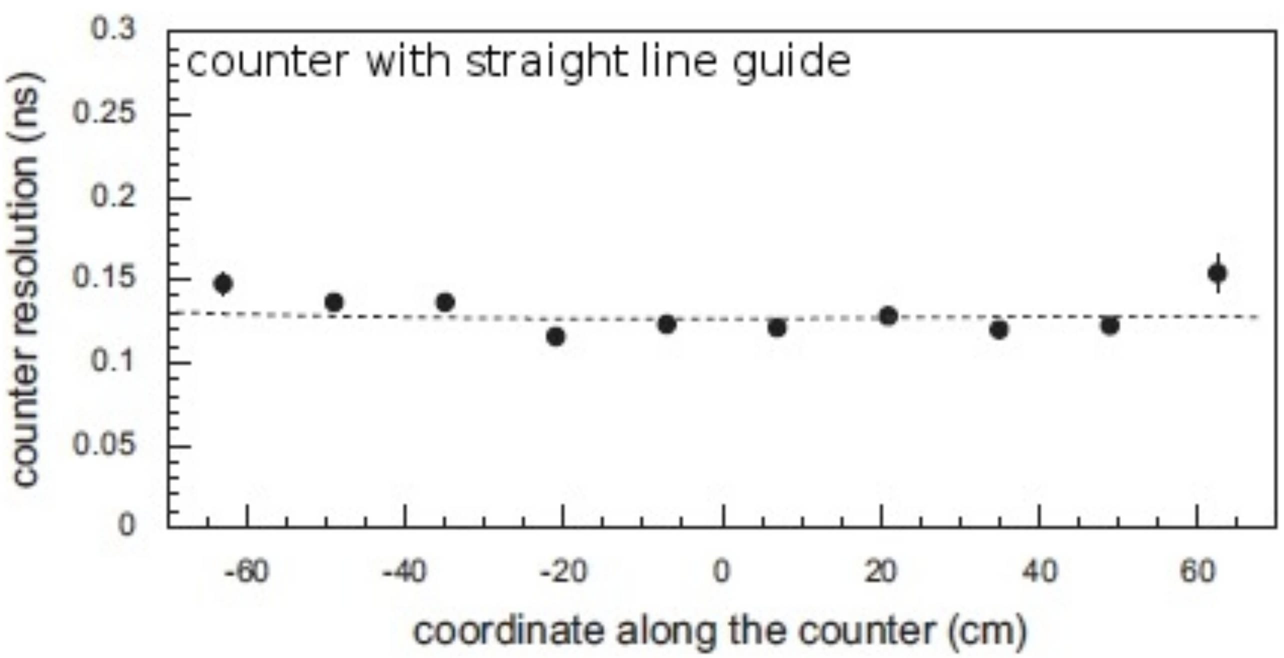
The number of photoelectrons for straight light guides is about 260;

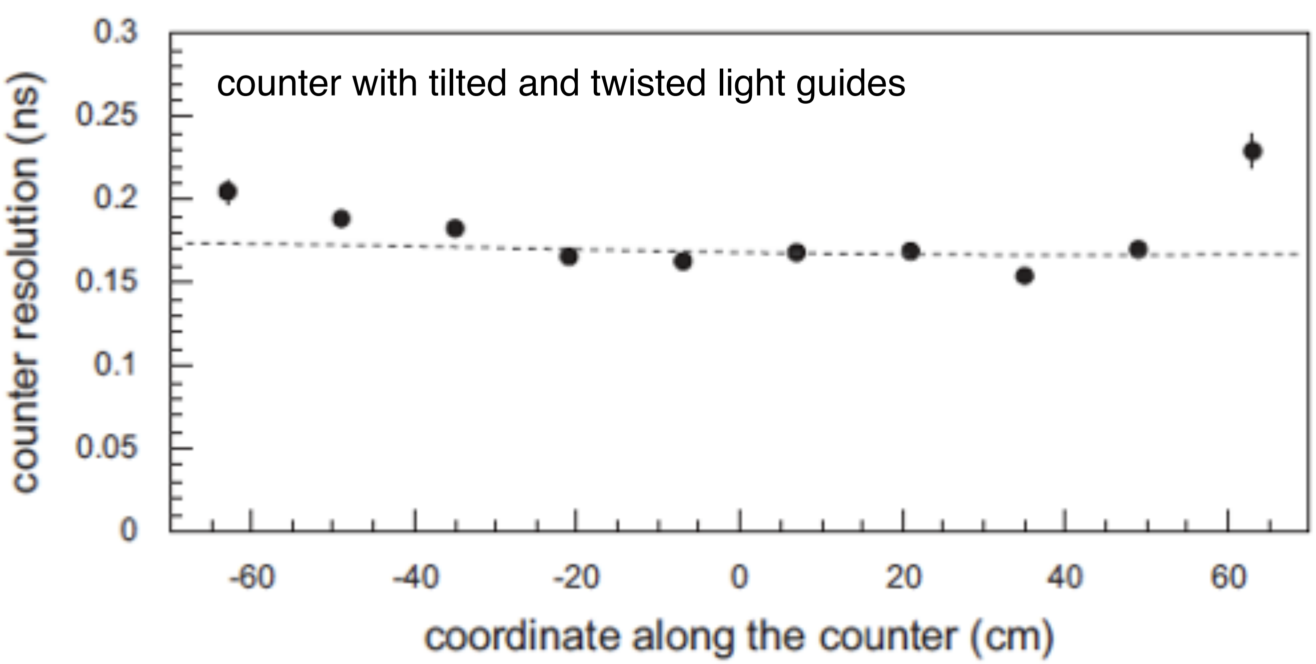
• **Intrinsic time resolution (half difference of times from the two sides)**

The time resolution for a counter with straight light guides varies from 120 to 150 ps depending on the particle impact point.
The time resolution with tilted and twisted light guides varies from 150 to 200 ps.

The lower number of collected photoelectrons determines a larger time resolution.



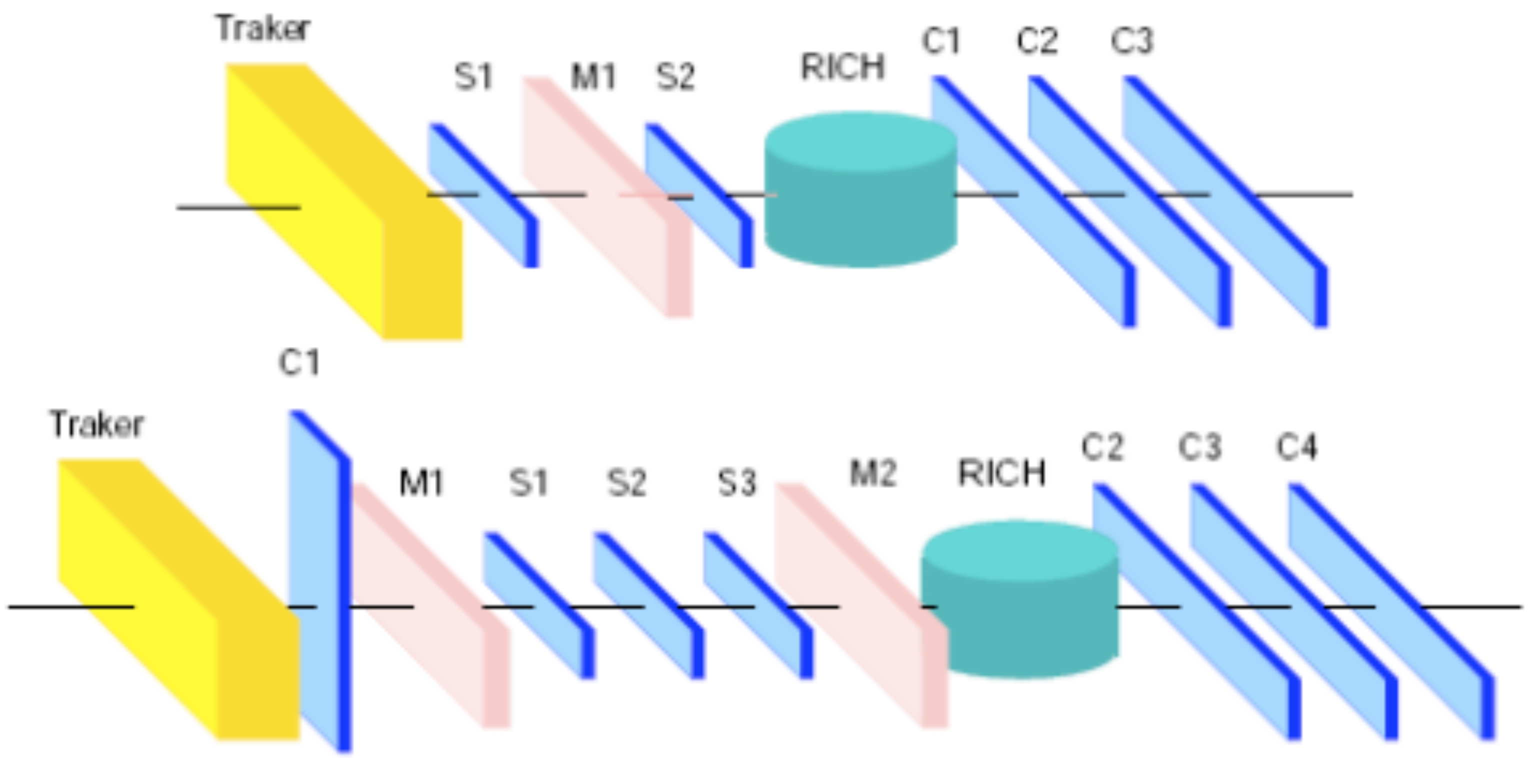




The test beam of the counters

TOF counters, together with the AMS-01 counters used as reference, a RICH prototype and some Tracker strips have been tested with a Lead (Pb) beams at 20 GeV/c/amu, accelerated by the Super Proton Synchrotron (SPS) at CERN and colliding with a Be target.

The secondary fragments (all nuclei up to Pb, mostly with the same momentum per nucleon as the primary beam) were filtered obtaining a 3 cm^2 ion beam with given A/Z ratio (i.e. defined rigidity). The selection line was set at values A/Z=2, A/Z=3/2, A/Z=7/4 and 1 to have similar rates for all ions.

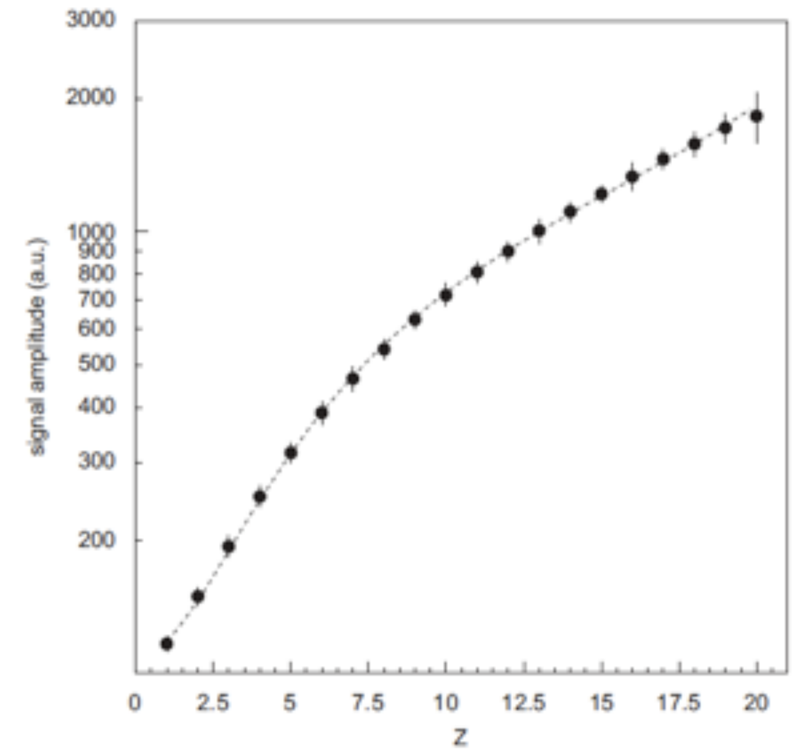


The test beam of the counters

The scintillator response is not a simple linear function of the ionization energy density, but it is well modeled by the Birks-Chou law:

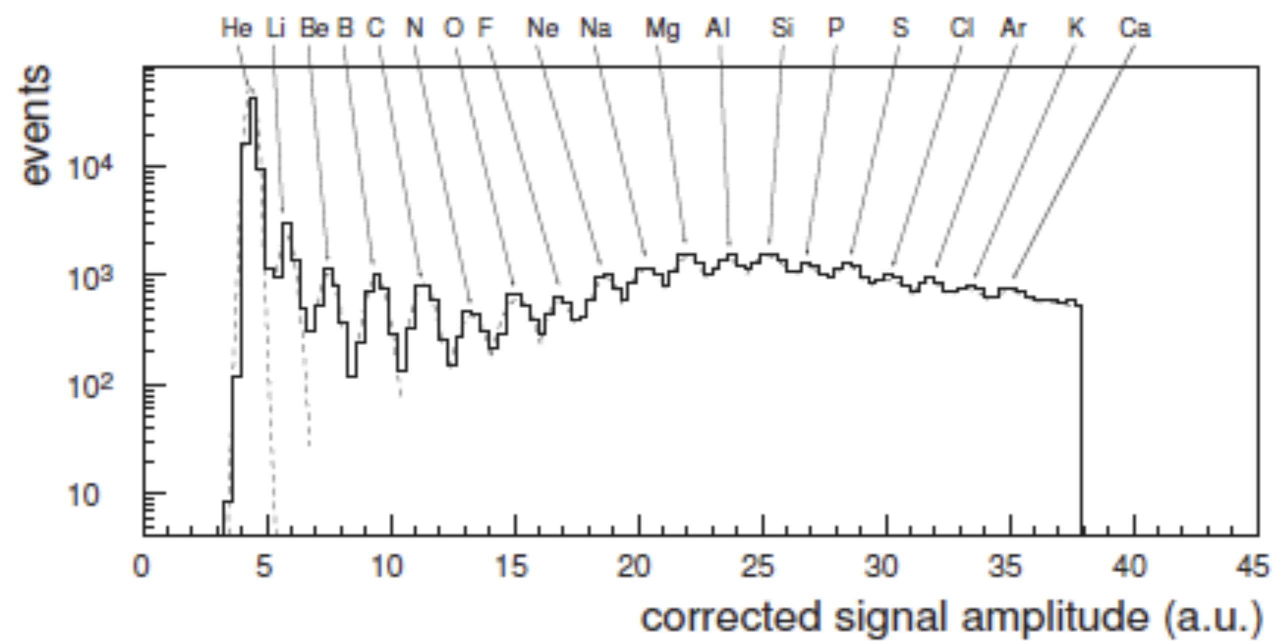
$$\frac{d\mathcal{L}}{dx} = \frac{A(\frac{dE}{dx})}{1 + kB(\frac{dE}{dx}) + C(\frac{dE}{dx})^2}$$

where $\mathcal{L}$ is the scintillator luminescence, *A* is the luminescence at low specific ionization density, *kB* is the Birks' constant different for each scintillator, *C* is a small correction parameter due to saturation and dE/dx is the energy loss in the scintillator described by the Bethe-Block function. For particle crossing the same material and with the same β, the mean energy loss is a function only of their atomic number.



The charge measured to various ions

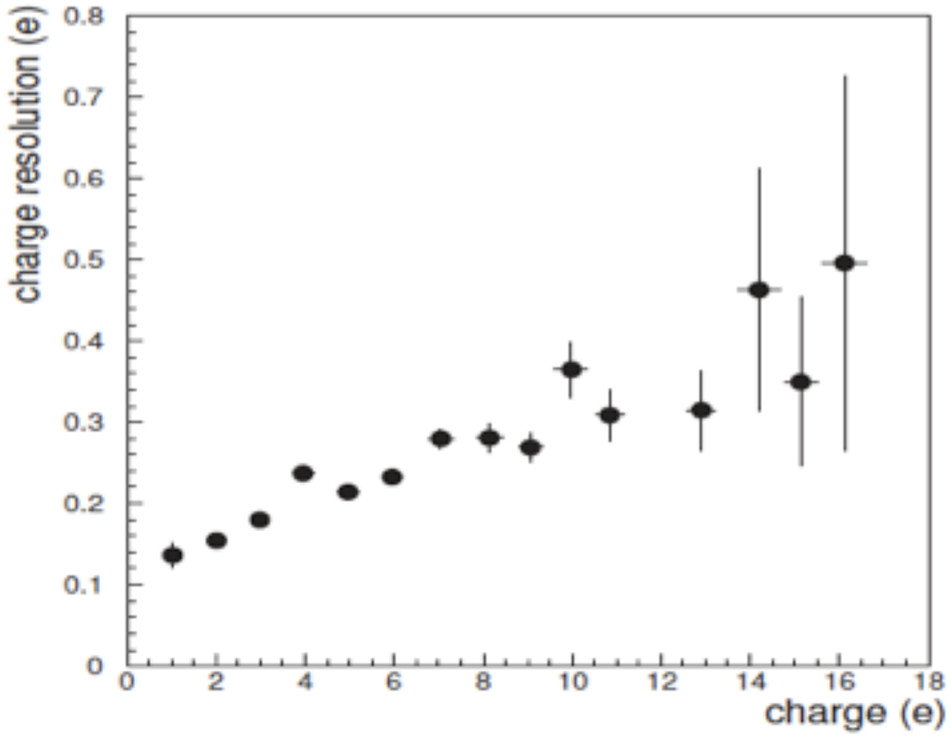
The energy loss dE/dx by a particle with atomic number Z is proportional to Z^2, but the emitted scintillation light is proportional to dE/dx only for small values of the energy loss. In general, the amplitude Q of the signal is the time integral of the PMT current pulse, i.e. it is proportional to the emitted scintillation light, and can be written according to Birks' formula.



The amplitude spectra for different ions have then been corrected for the scintillator response.

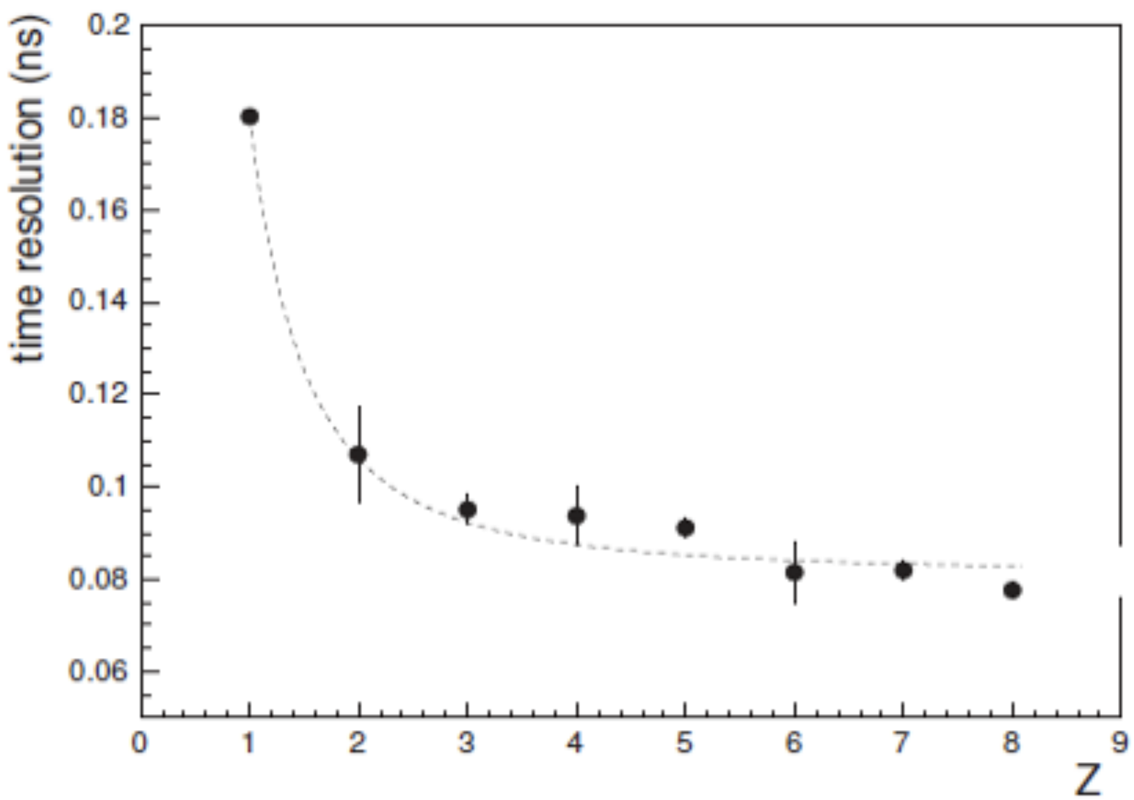
The test beam of the counters

The charge resolution of a single counter, shown degrades with an increasing charge, as expected given the saturation of the emitted light. The complete TOF detector should allow ion identification up to charge Z=15.



The time-of-flight resolution, measured between the two AMS-02 counters, decreases with increasing Z following the formula:

$$\sigma_t = \sqrt{\left(\frac{P_1}{Z}\right)^2 + P_2^2}$$



The first term in the resolution is inversely proportional to Z and hence to the square root of the number of photoelectrons produced by the particle; the second term is a constant representing the overall time resolution of the electronics chain (including cables).

LTOF and UTOF detectors assembly

The mechanical supports for TOF planes were designed to be accommodated into the general mechanical structure of AMS-02.

They have been calculated through structural and modal analysis, to sustain the acceleration and vibration stresses induced during the early stage of the Space Shuttle take-off.

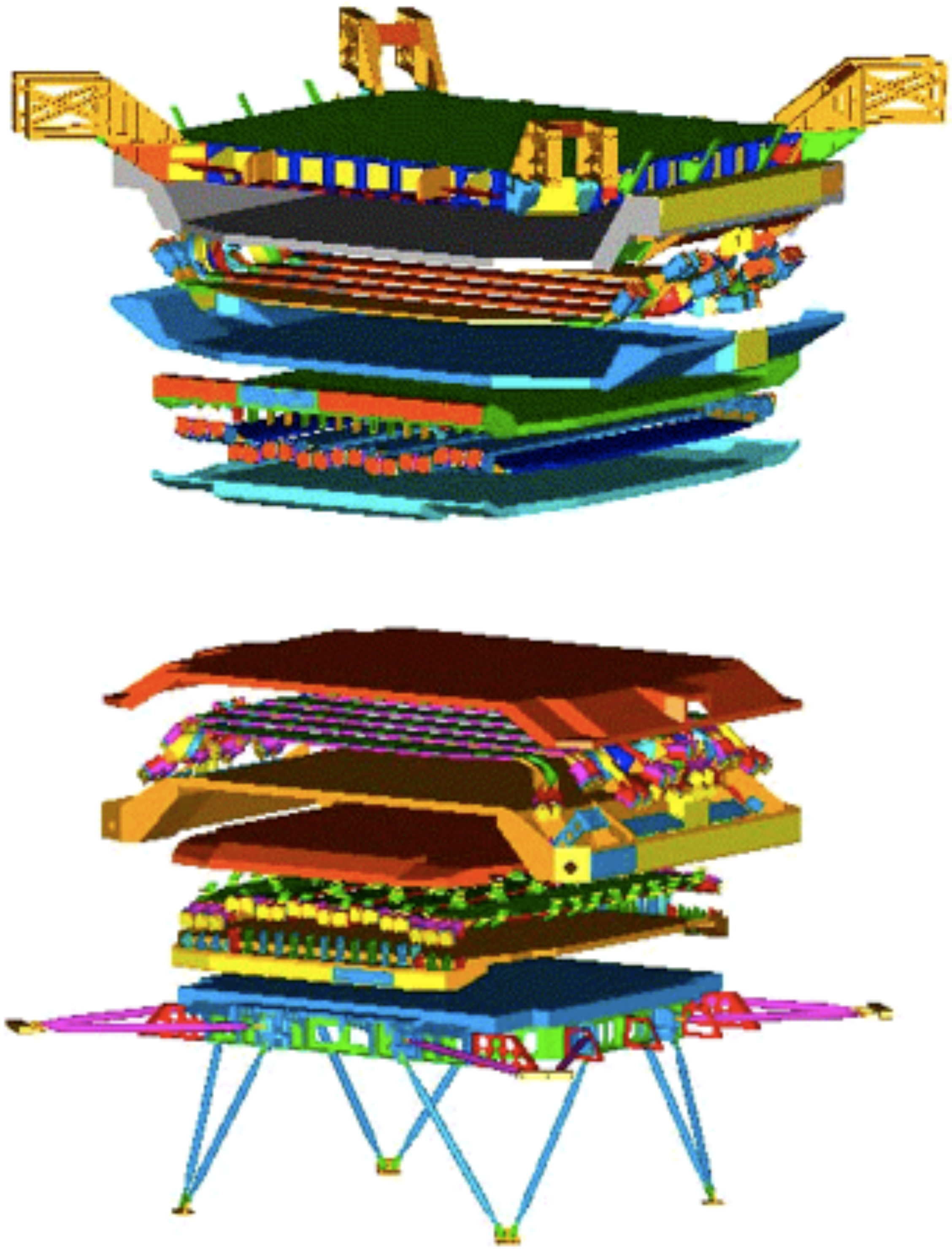
Vibrational and TVT tests on prototypes of single sub-assembly or parts were performed at an early phase of the design to validate it.

A rigid aluminum honeycomb plate is used as a general support structure attached to the USS (Unique Support Structure). Light aluminized carbon fiber covers enclose each layer, ensuring the necessary light tightness and providing an electromagnetic shielding.

Each counter and PMTs inside the box is in turn fixed to the covers and to the honeycomb plate by means of special carbon fiber brackets.

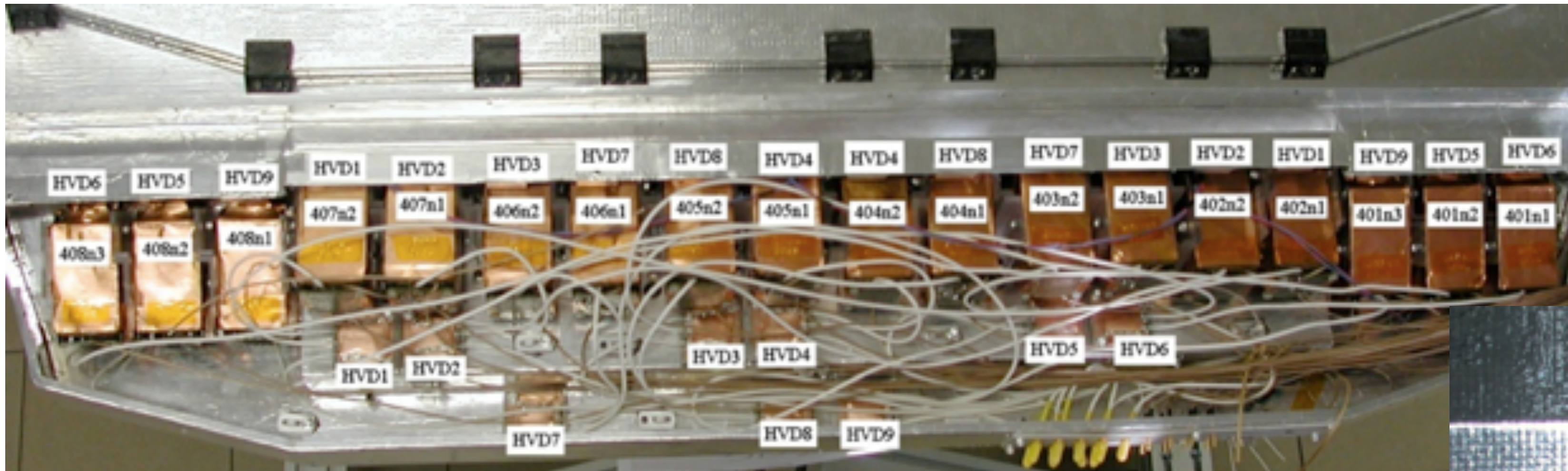
A special soft open cell rubber foam is placed between the counters to dump the effect of vibrational modes.

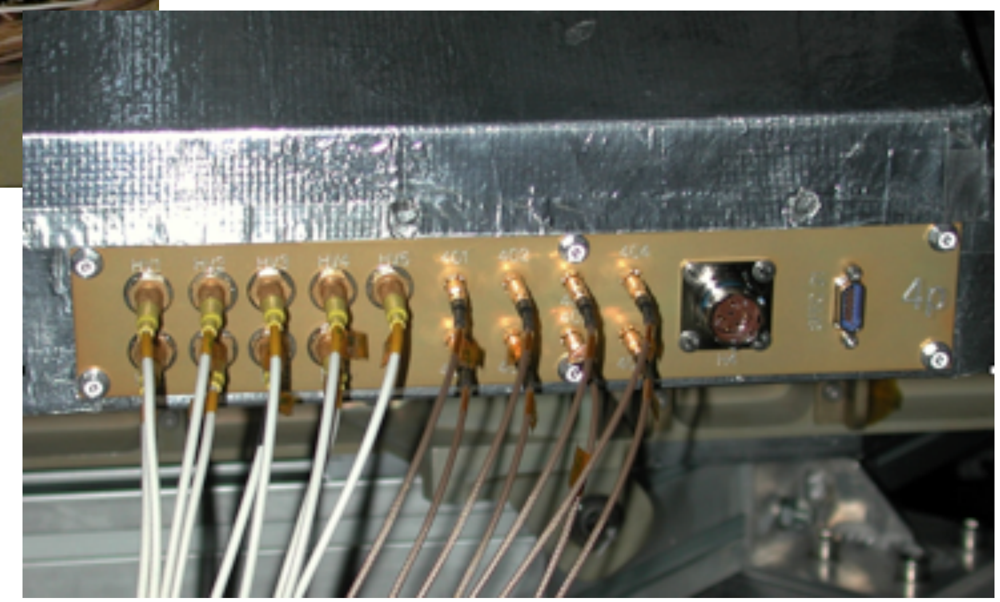
The honeycomb support of UTOF is 10 cm thick, reinforced by aluminum beams around the perimeter and rigidly connected to the TRD support structure. The honeycomb support of LTOF is 5 cm thick and reinforced by an octagonal aluminum structure connected to it. It is fixed vertically by 16 tension rods to the USS.



The exploded view of the mechanical structure of the upper and lower TOF

The cables routing to the panels

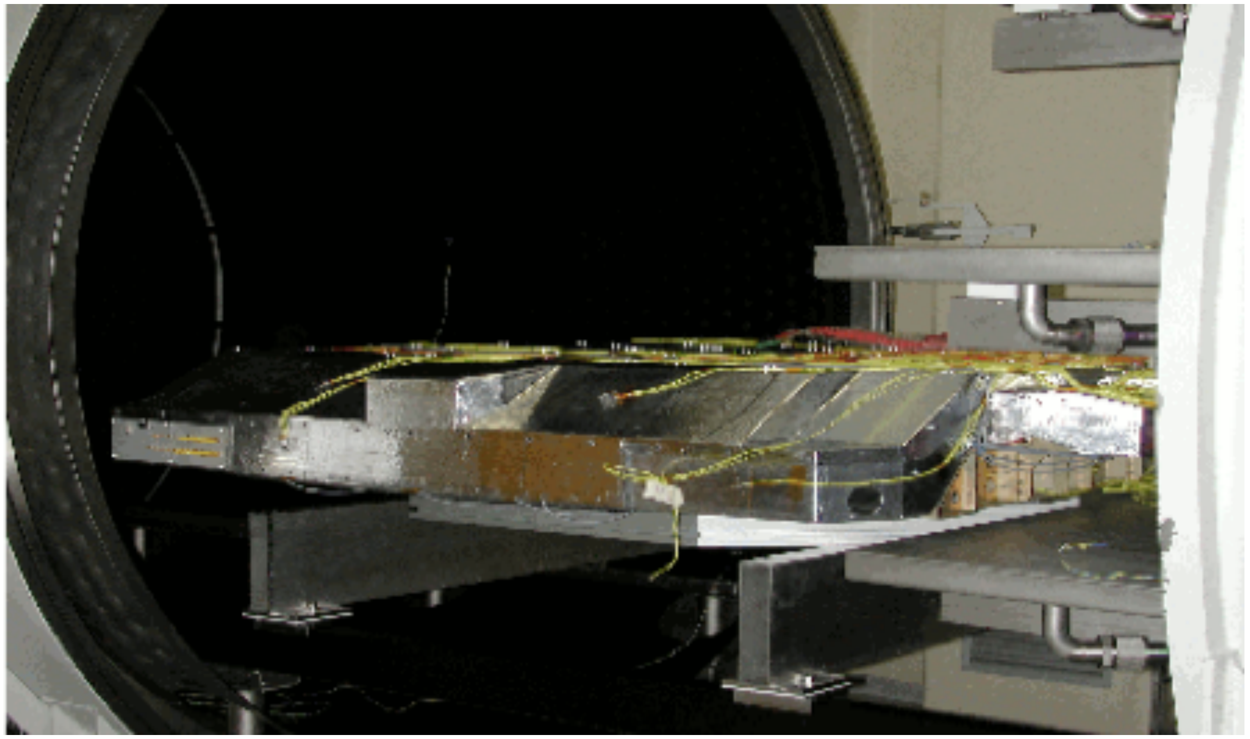




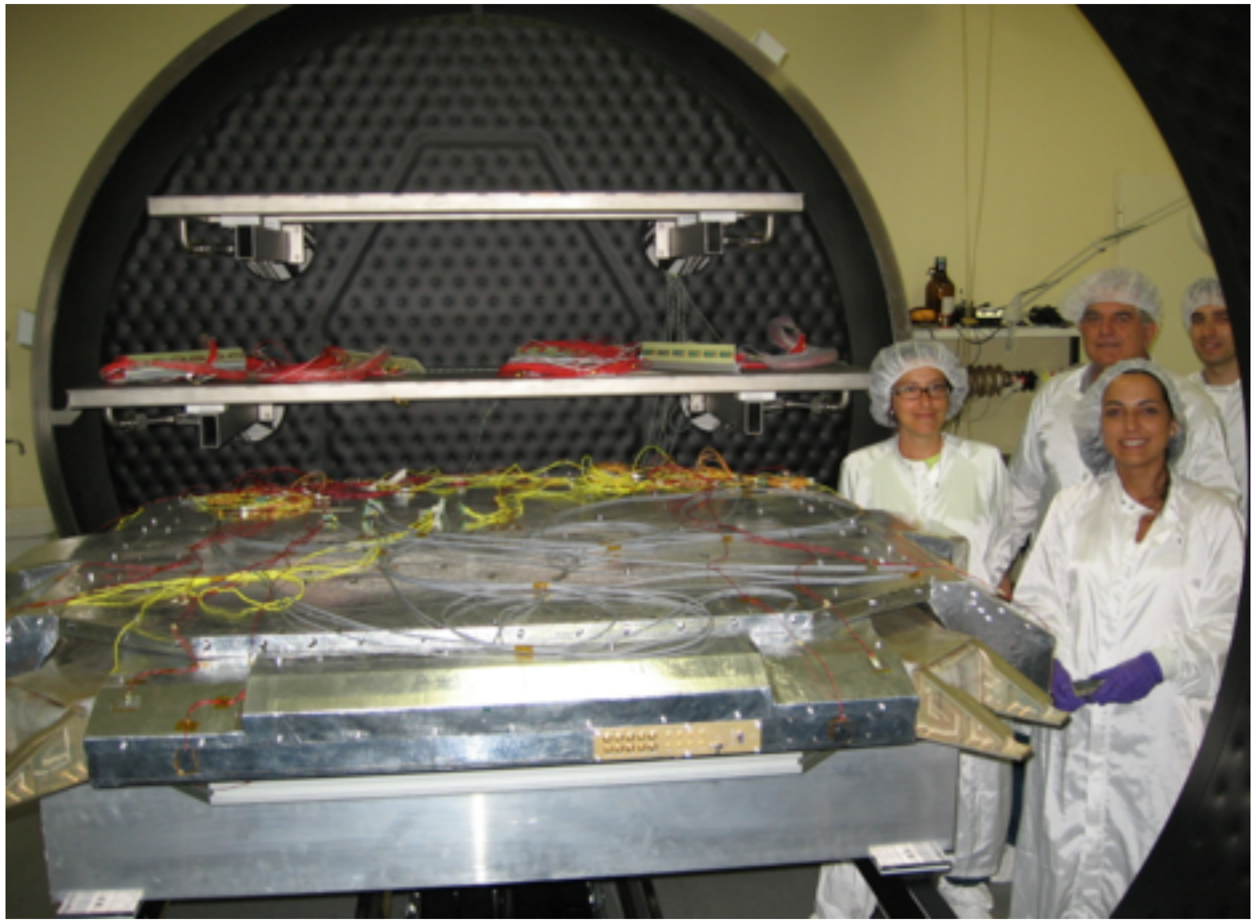
The Space qualification tests

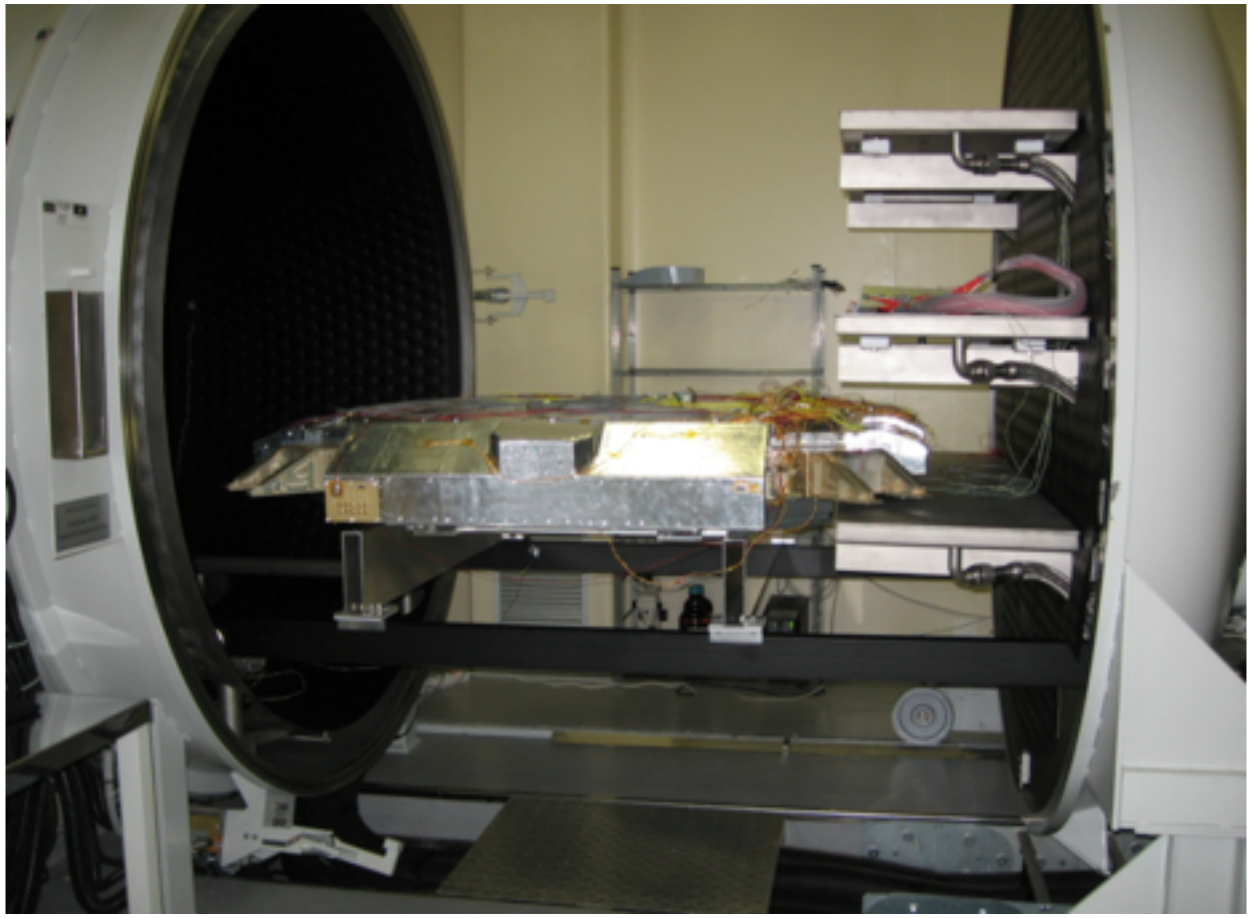
Space qualification of the detector was required by NASA in order to satisfy the safety conditions for payloads using the Space Shuttle (Vibration Tests – VTs), and to verify its functioning in Space conditions (Thermal Vacuum Test – TVT).

The TVT consists in several thermal cycles in a vacuum chamber reproducing the temperature range and the pressure of AMS when operated on the ISS.

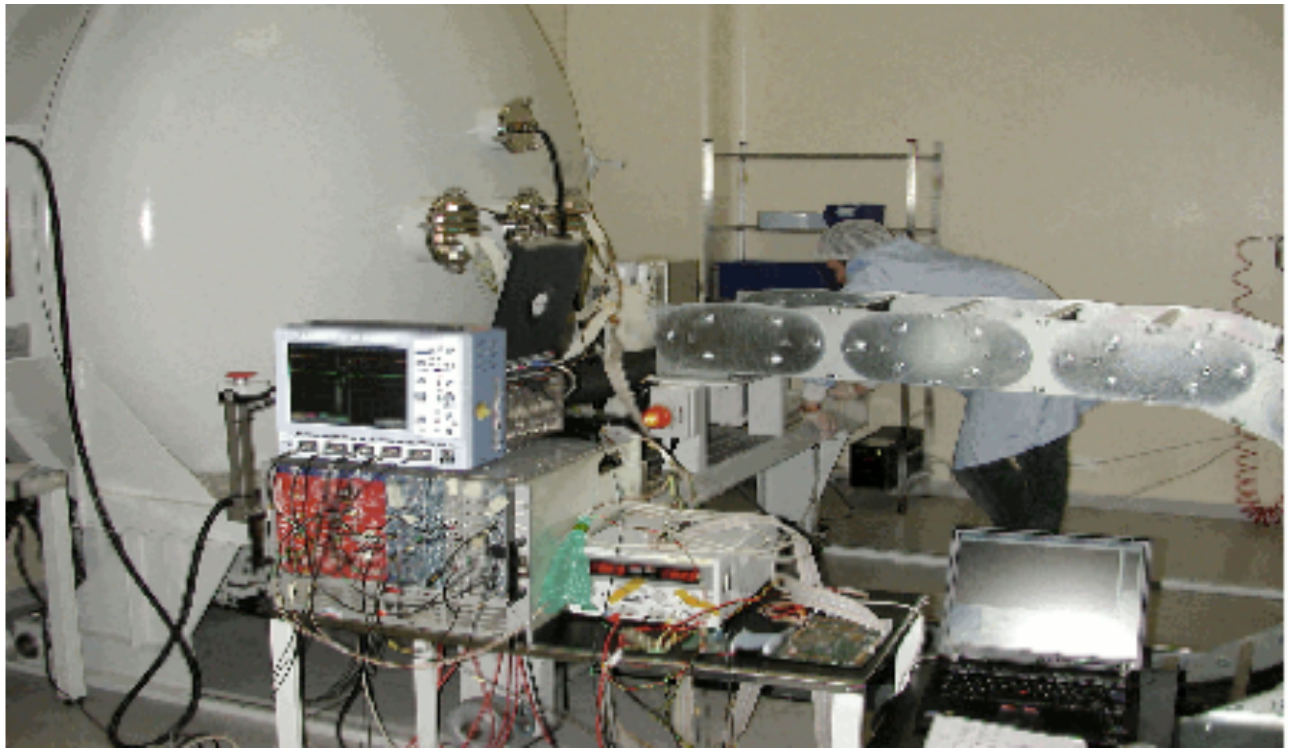


SERMS – Terni, May 2006





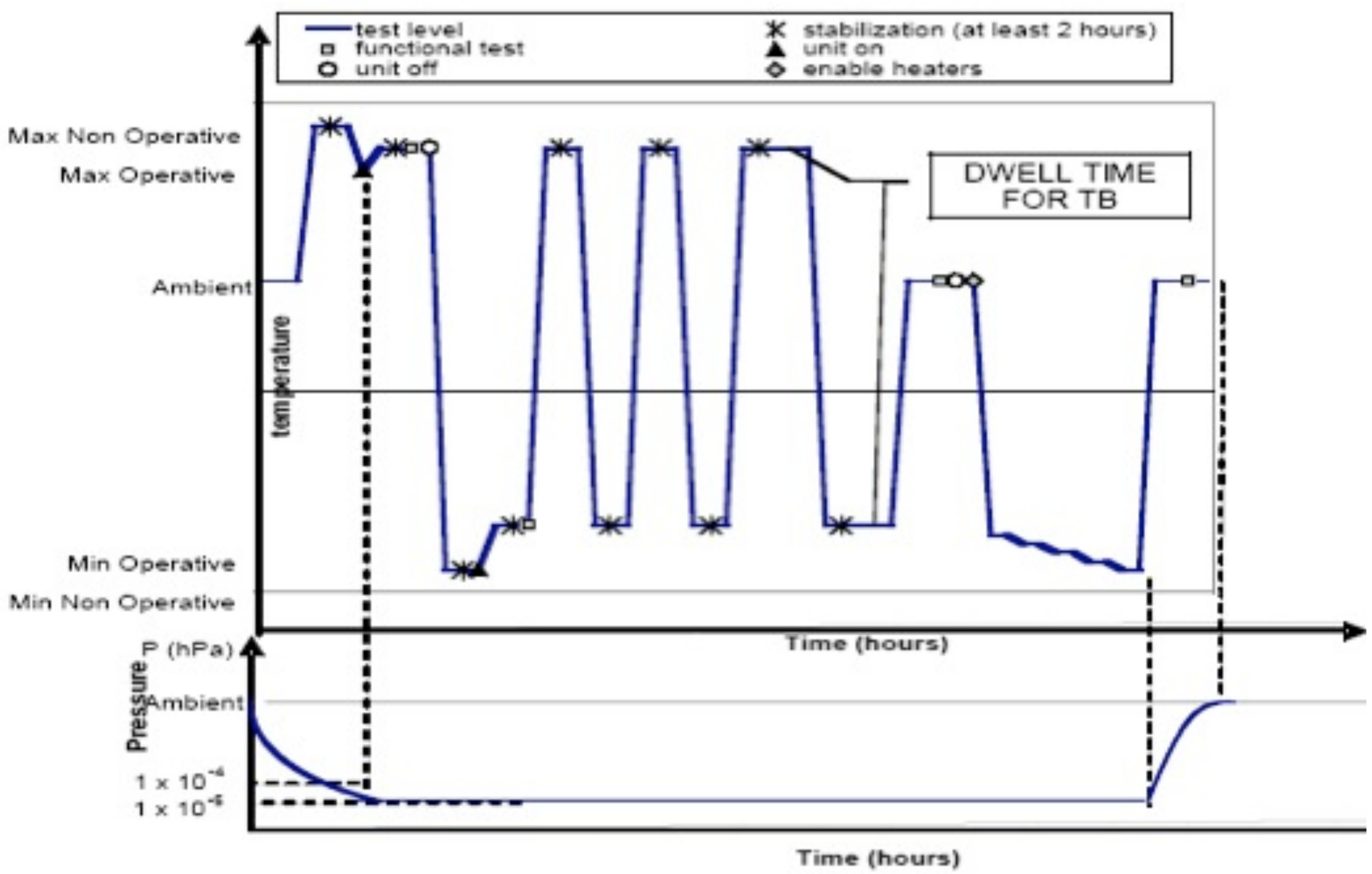
TOF Thermal vacuum test

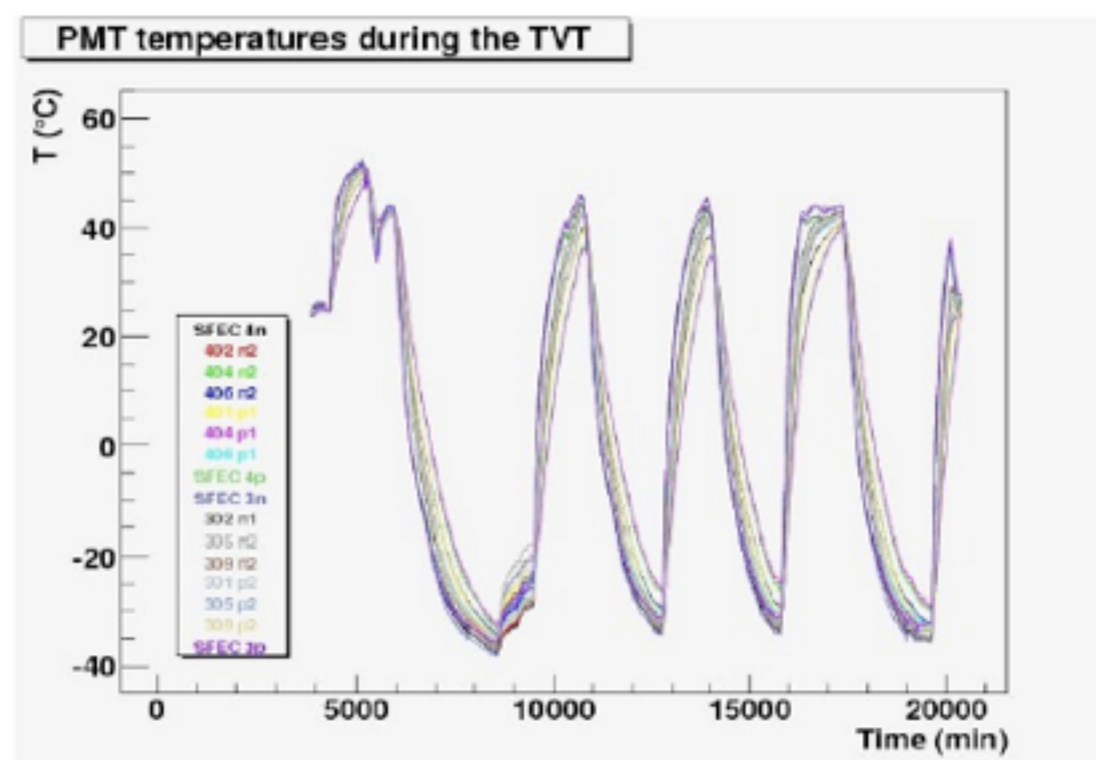


During the test, the pressure of the thermal vacuum chamber was about 3x10[5] mbar.

The maximum and the minimum non-operative temperatures were +50° C and -35°C with the detector off. The maximum and the minimum operative temperatures were +43°C and -32°C with the detector on.

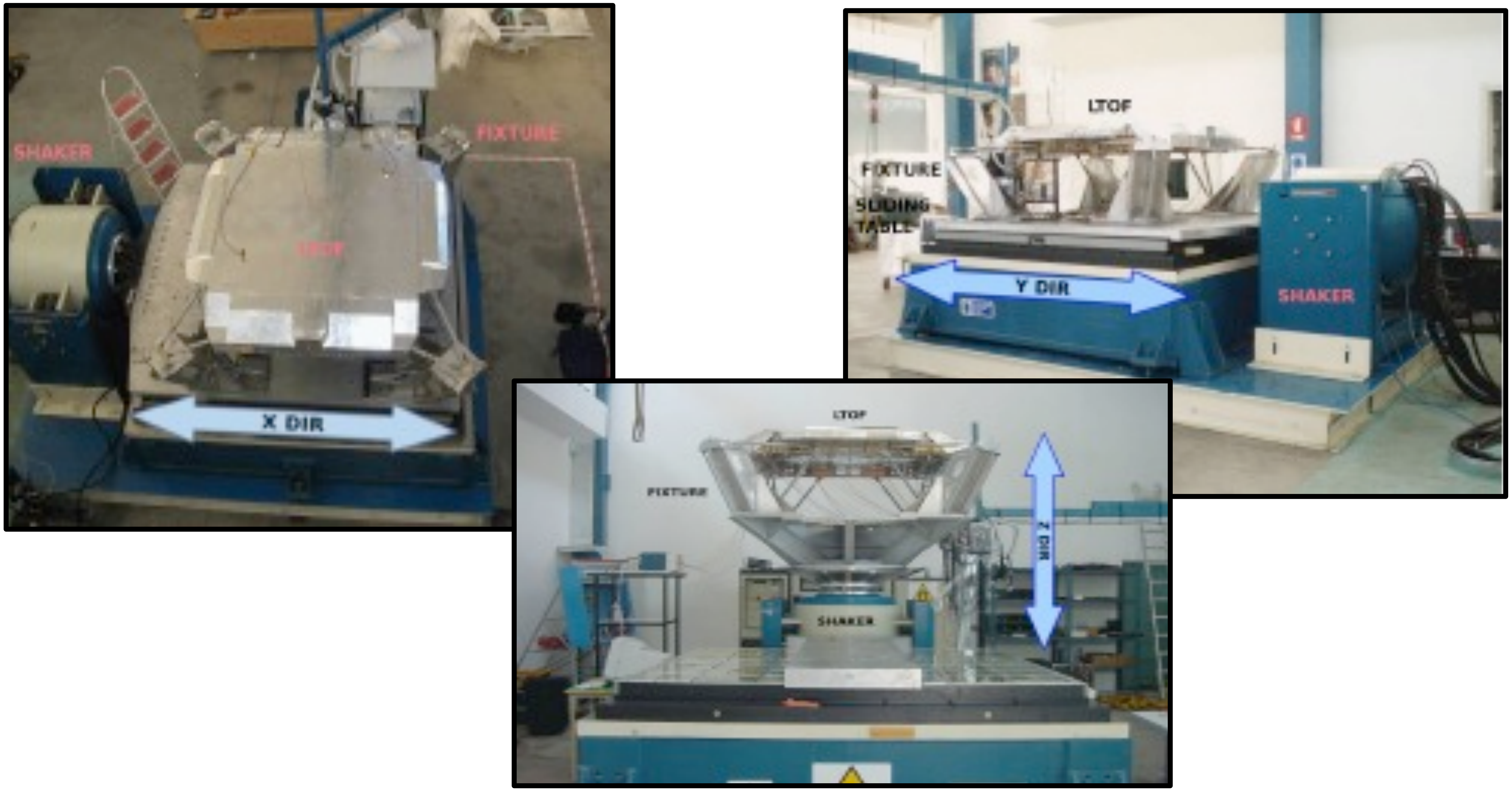
During the fourth cycle, the temperature was continuously monitored inside the detector by 32 Dallas sensors and on the outside by 44 PT100 sensors.





TOF vibration test

The vibration test consist in dynamic mechanical tests on vibrating tables.

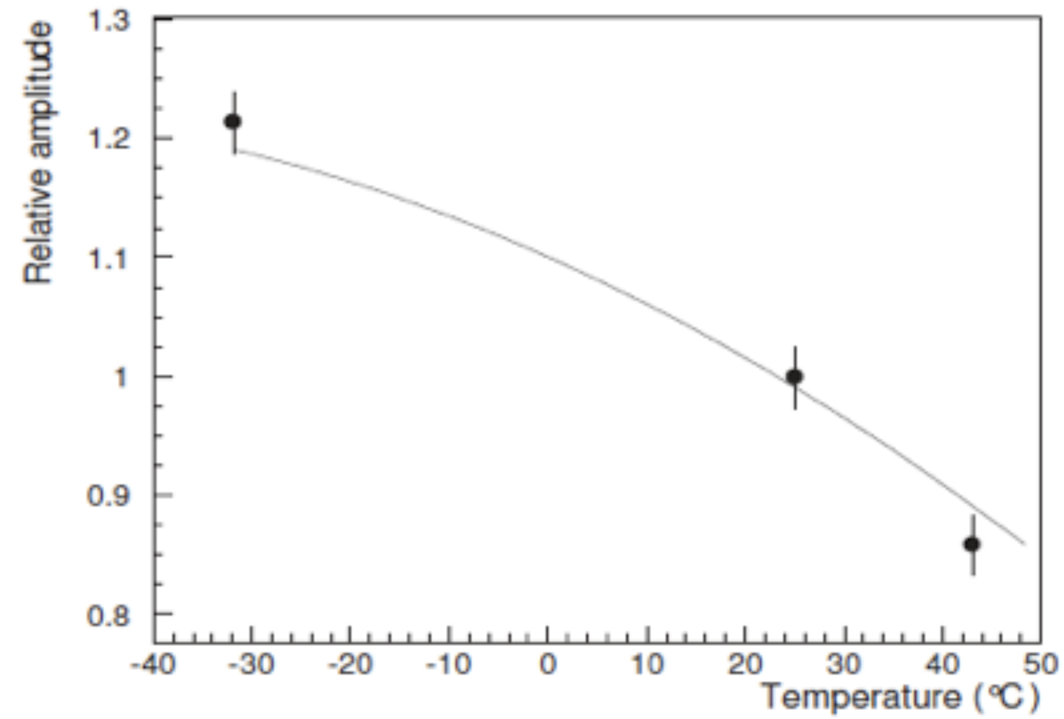


The vibration test has been performed along the three axes (X,Y,Z) with the Maximum Expected Flight Level specifications during shuttle take off and launch.

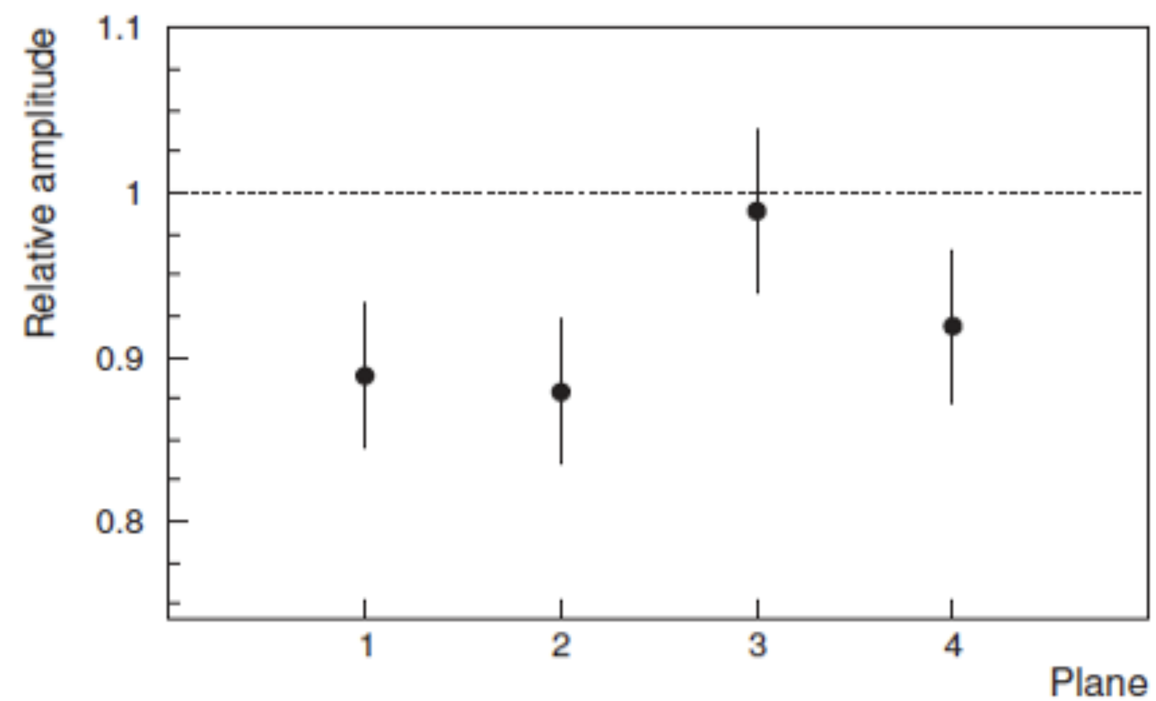
TOF TVT & VT results

Functional tests of the detectors were performed before and during TVT, and before and after VTs. The trigger to the data acquisition was given by the anode signals from the central counter of each layer.

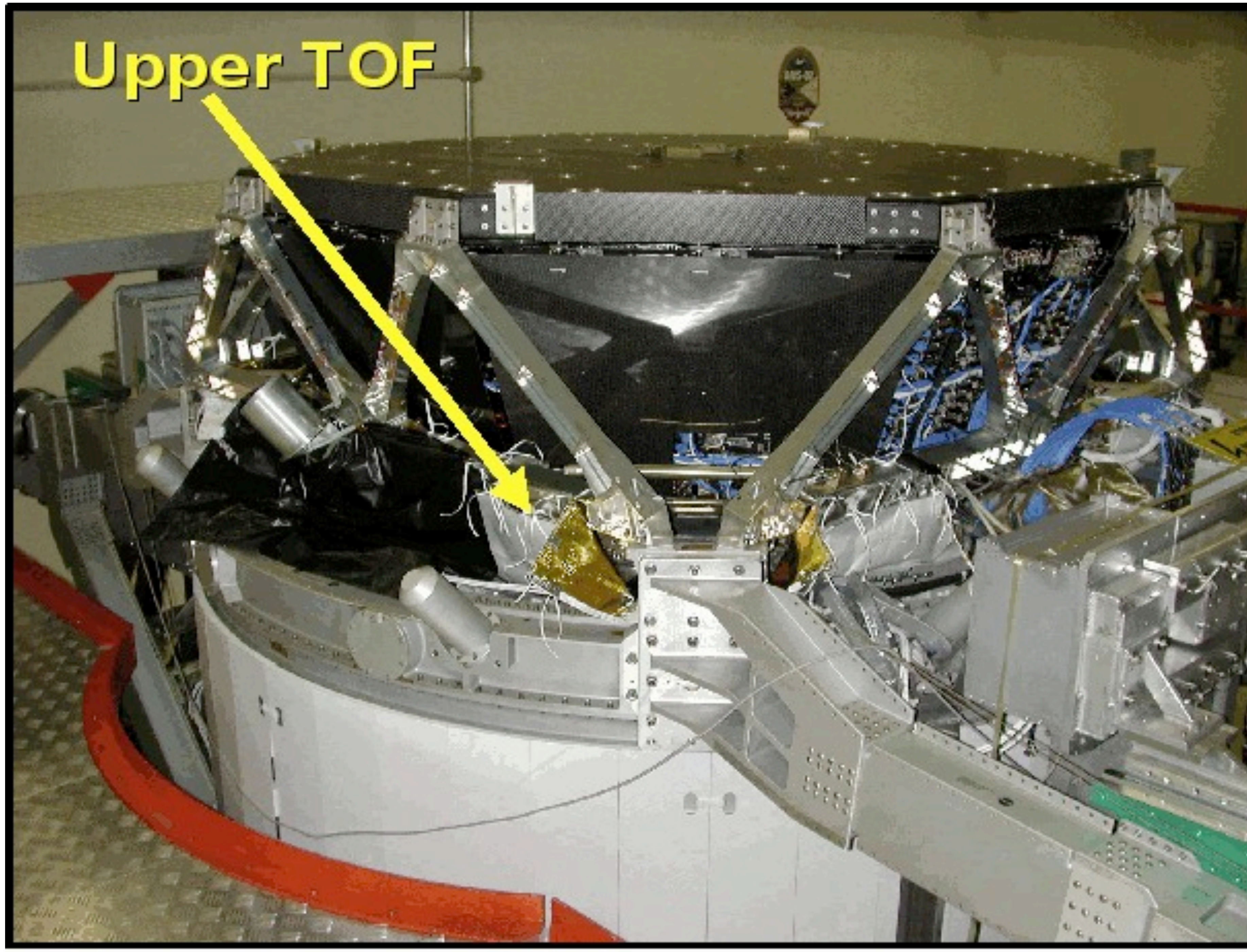
During the TVT, the amplitude of all the anode signals recorded at each minimum and maximum operative temperature shows the relative amplitude as a function of the temperature.



After vibration the mean anode amplitude in TOF layers 1, 2 and 4, relative to the amplitude before TVT, show a rather small decrease (about 10%) of the response, compatible with the scintillator accelerated aging due to the thermal stresses of the TVT test and the vibration.

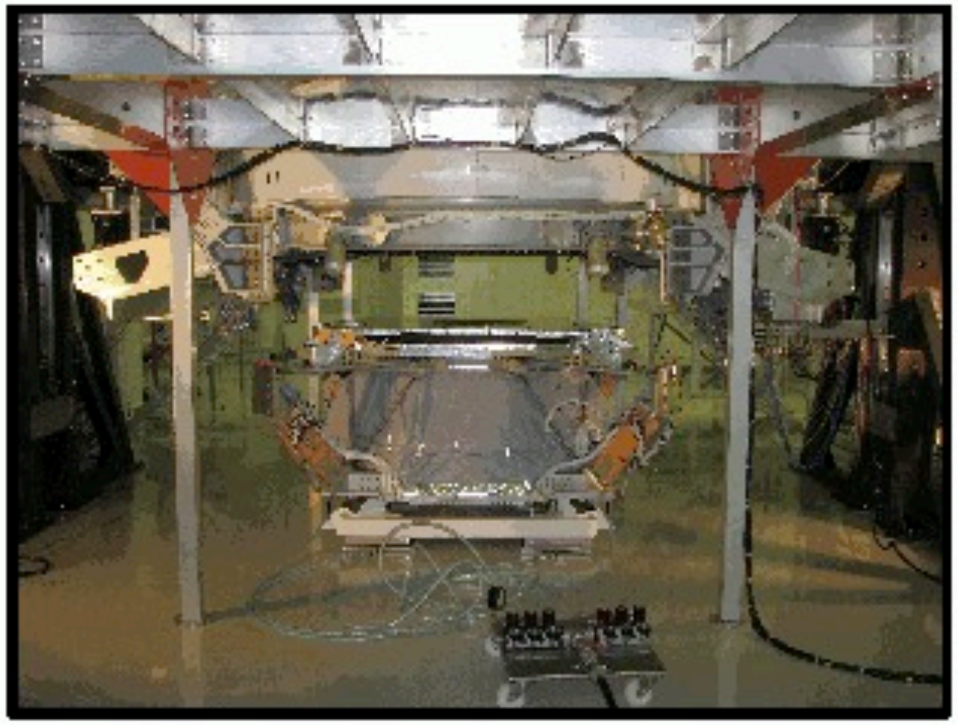


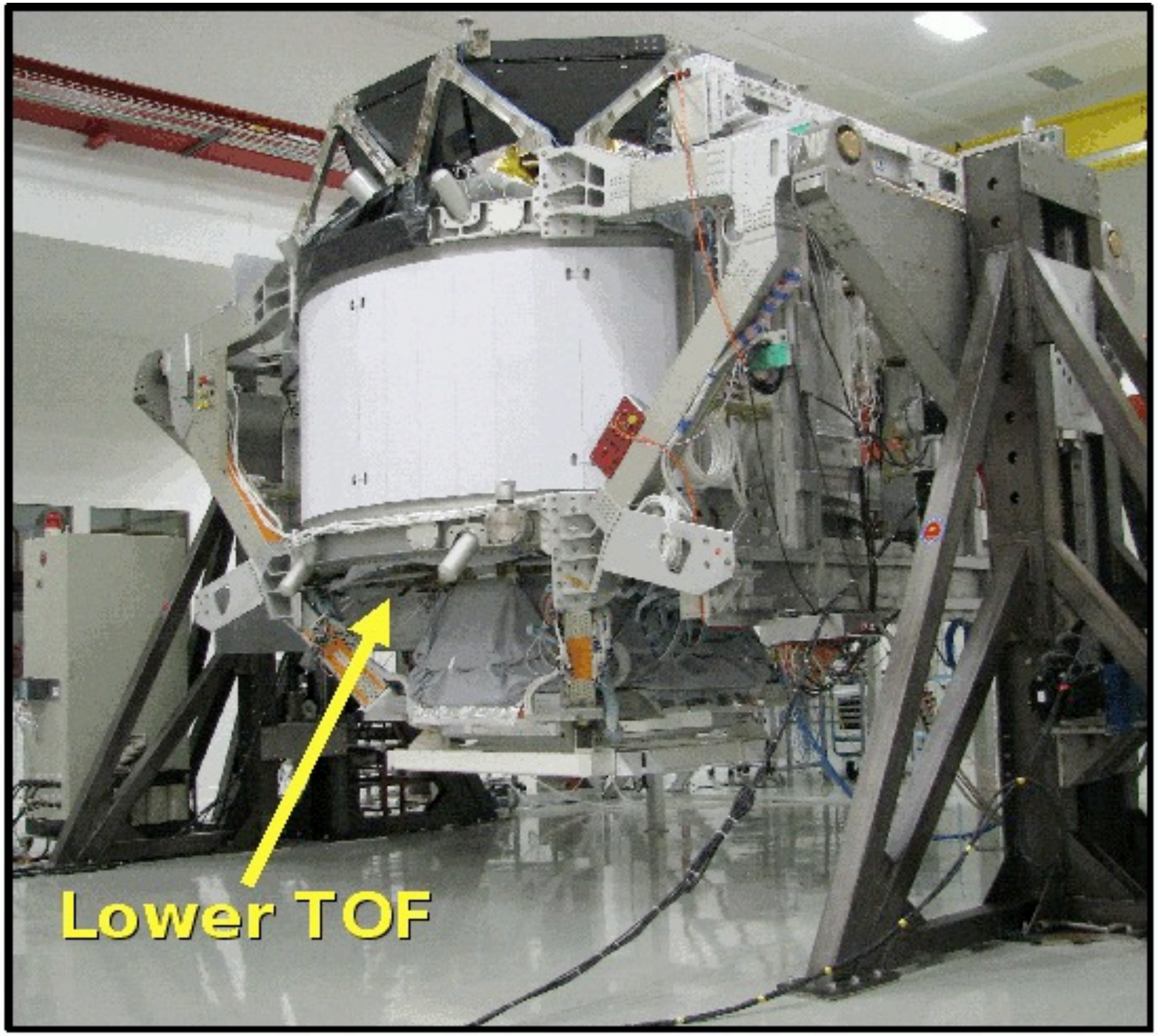
UTOF integration



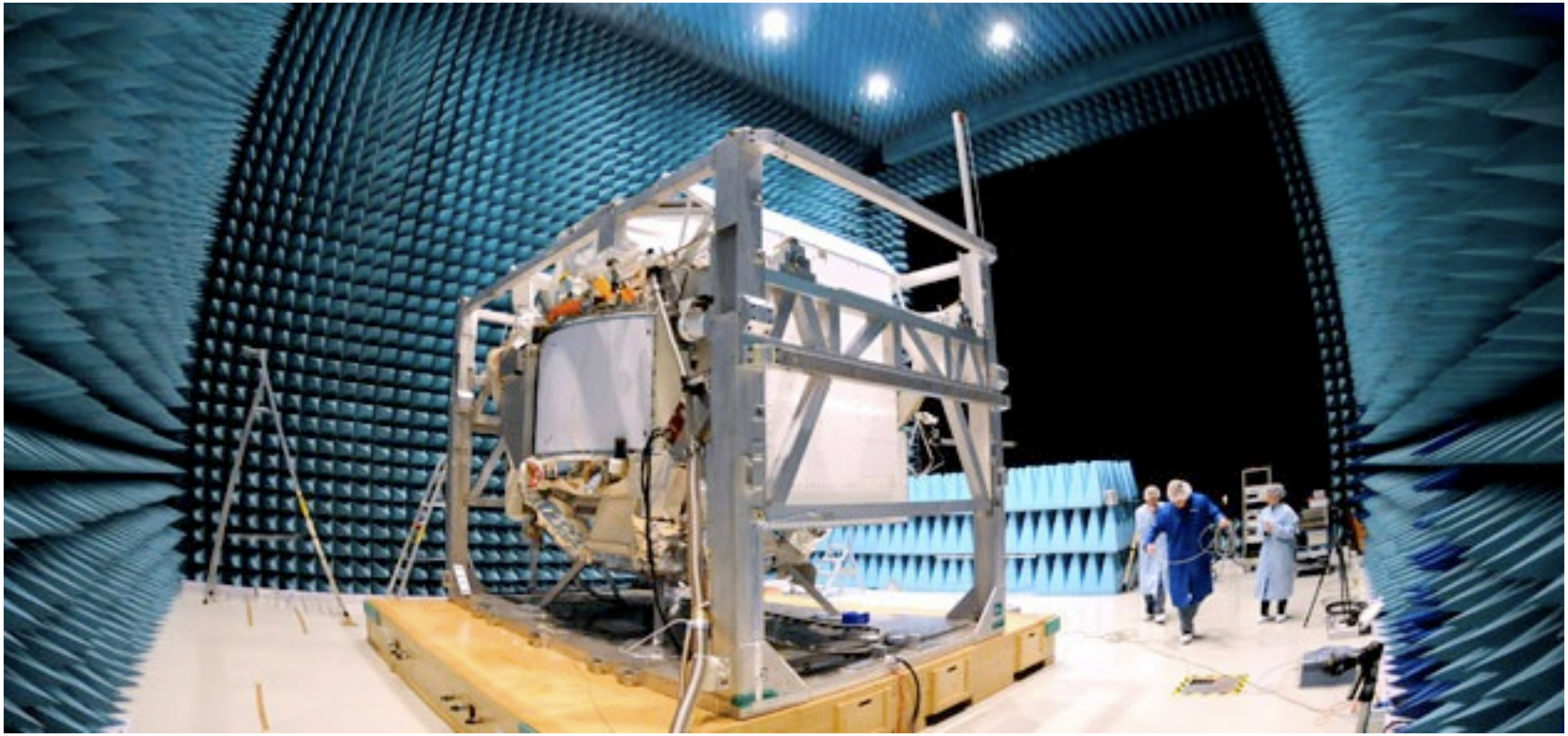
Upper TOF was integrated on AMS-02

LTOF integration



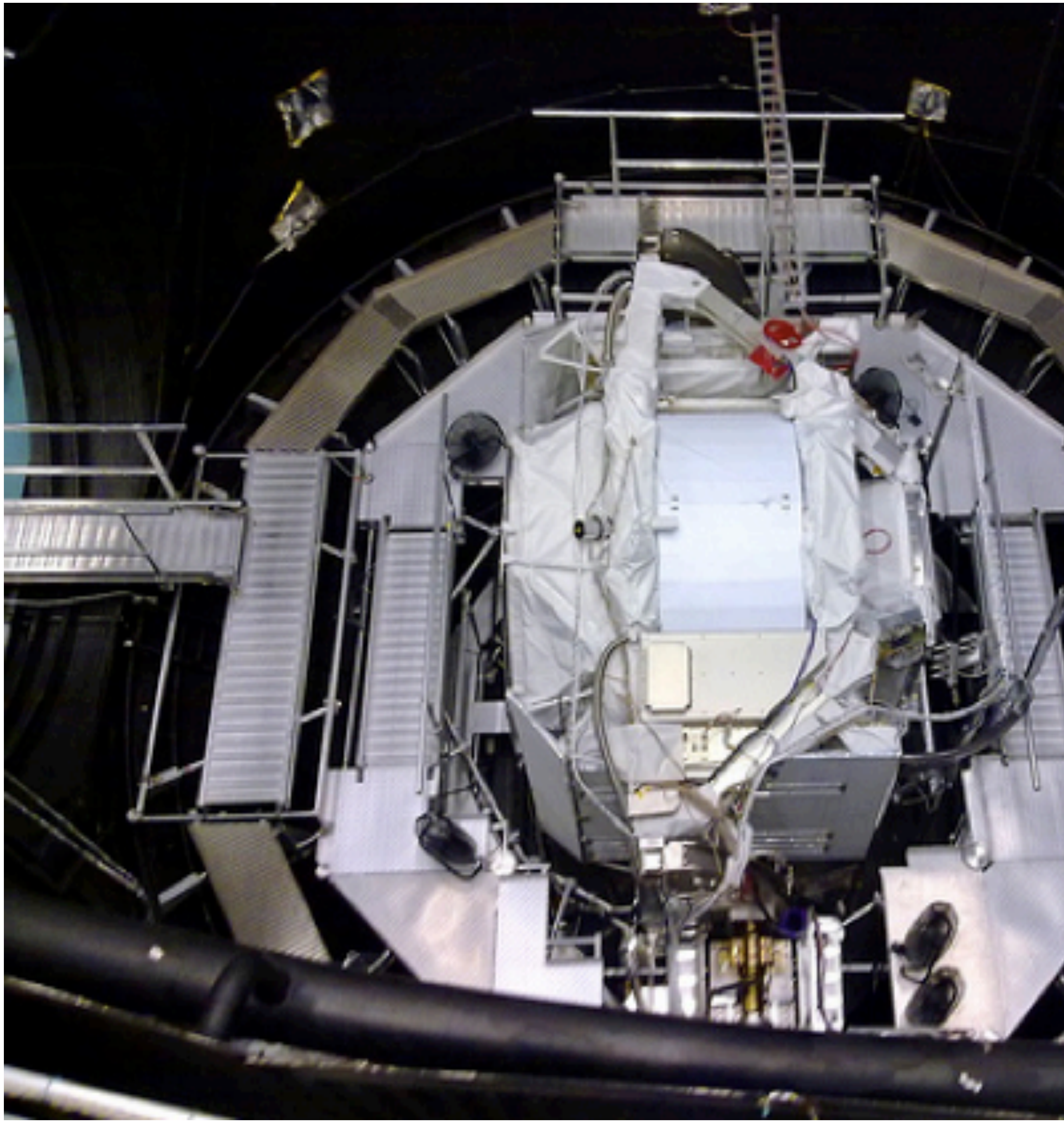


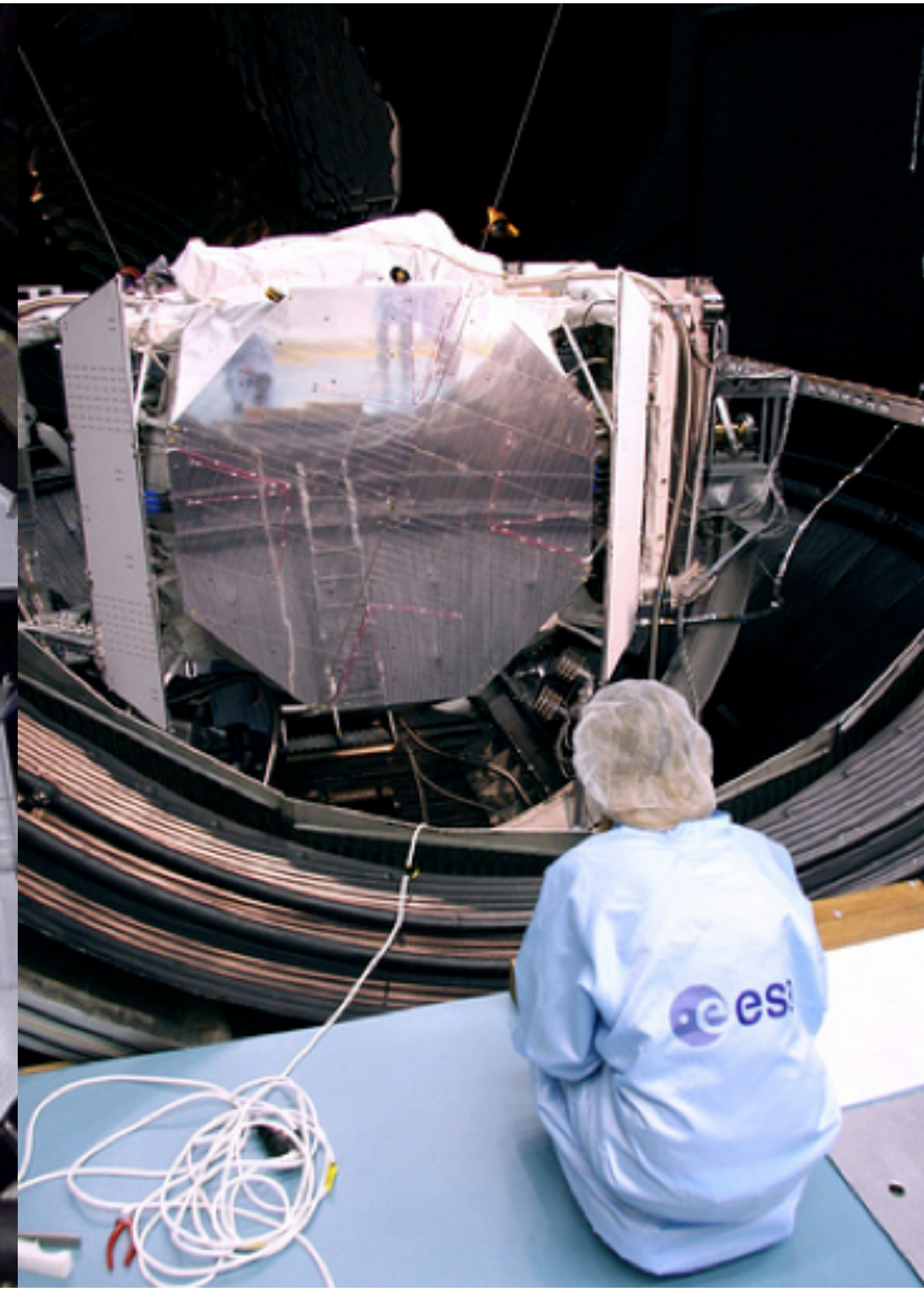
AMS-02 in ESTEC Maxwell EMI chamber



Electro Magnetic Interference test was needed to verify that TOF operations and performance were not adversely affected by the expected EMI environment of Shuttle and ISS and vice versa.

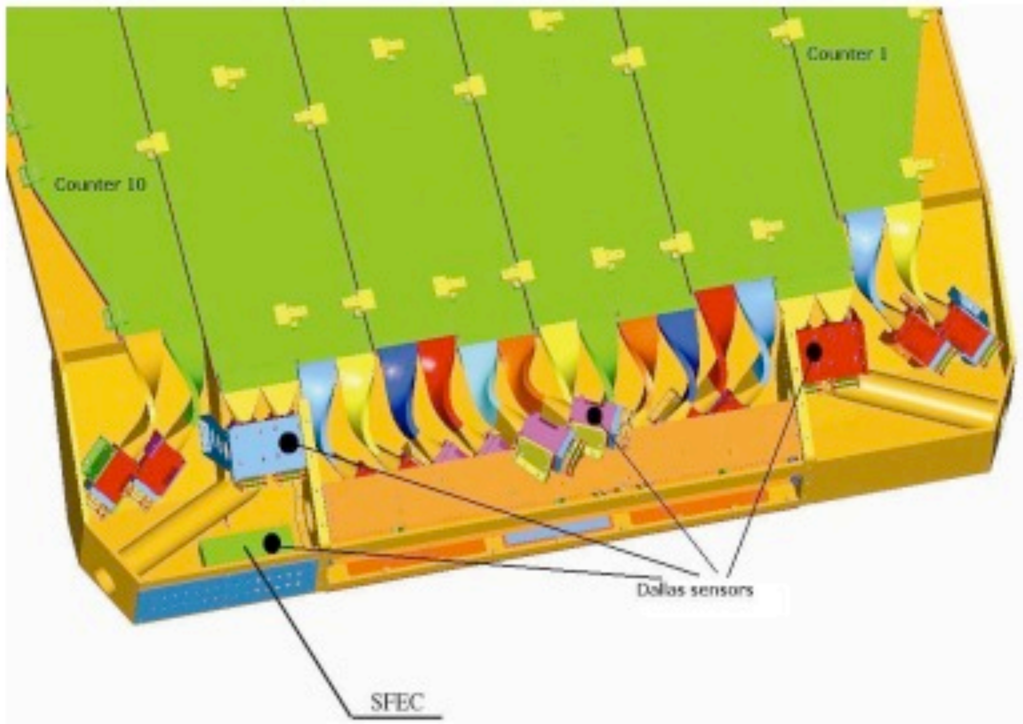
AMS-02 TVT test @ European Space Agency

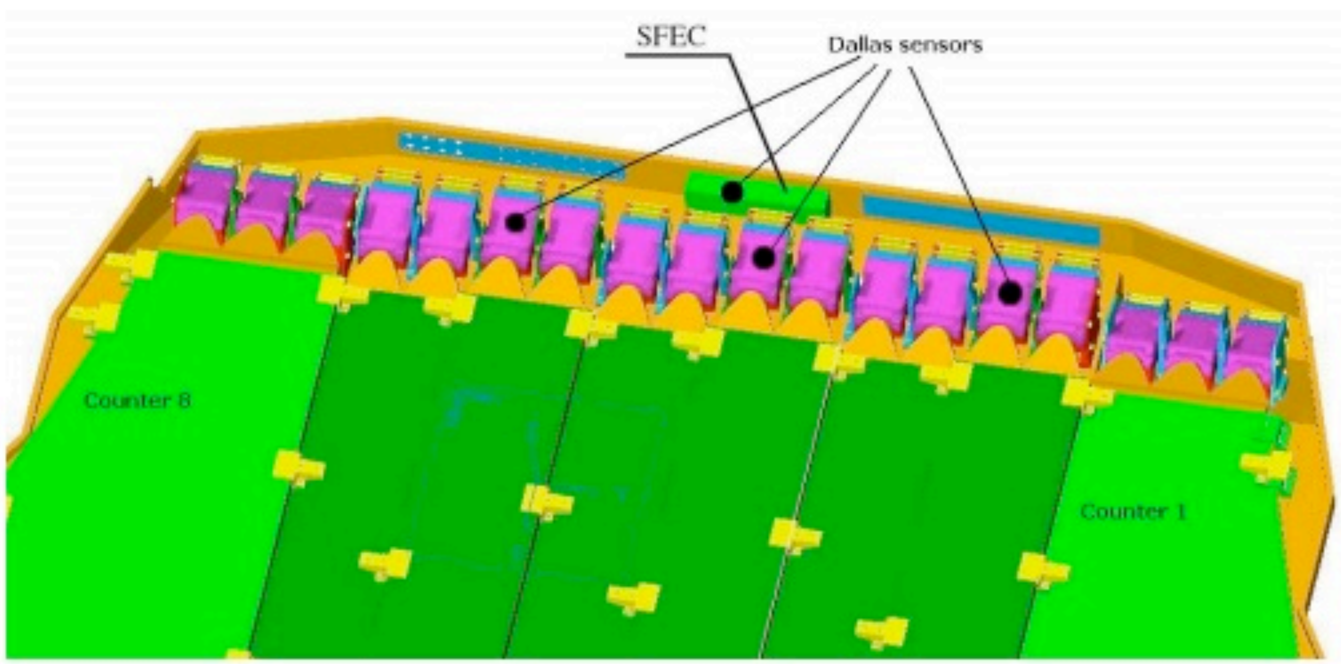




TOF Dallas sensors location

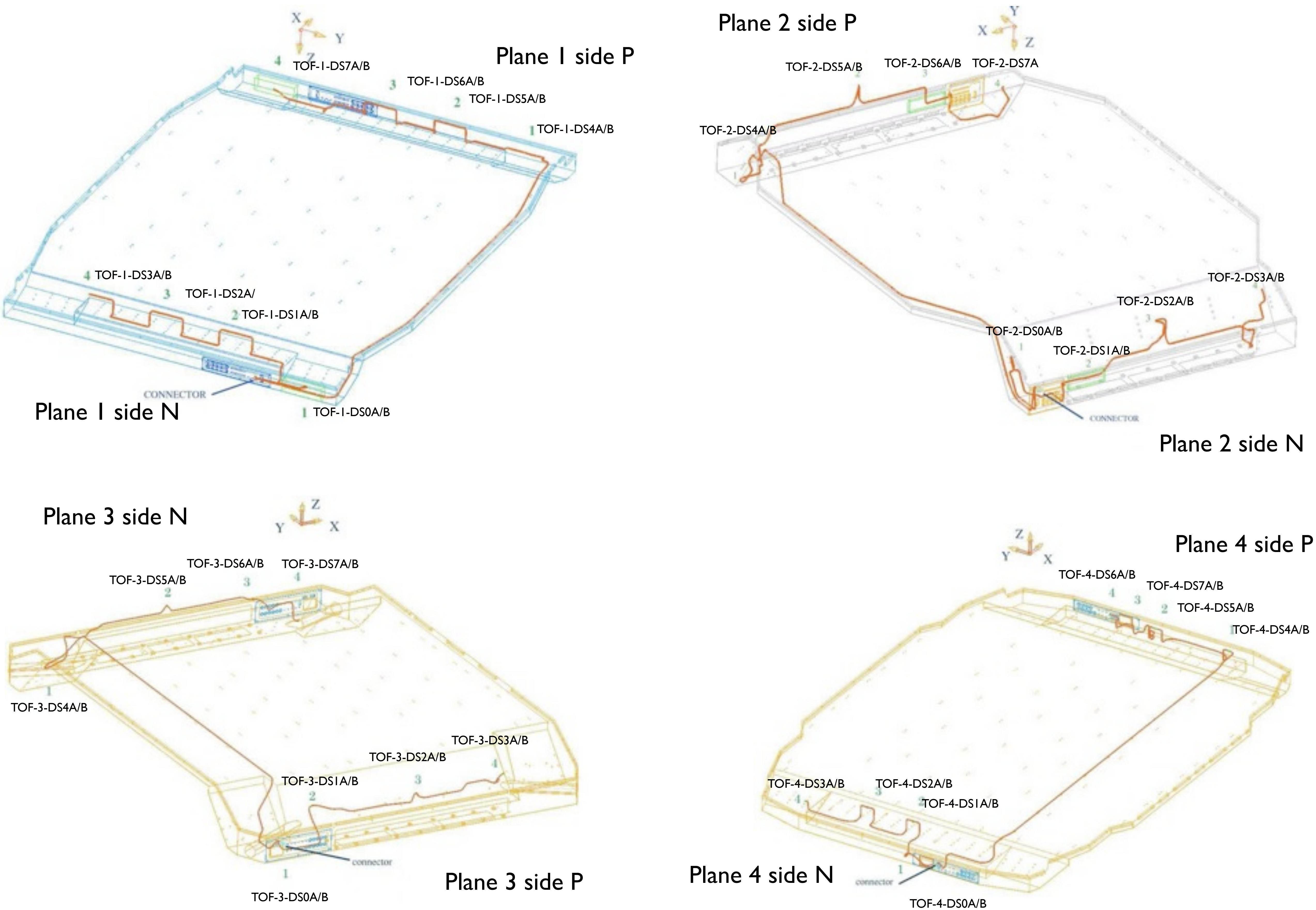
Temperature sensors location for PMT and SFEC temperature monitoring





Temperature sensors are also located on SFET TDCs

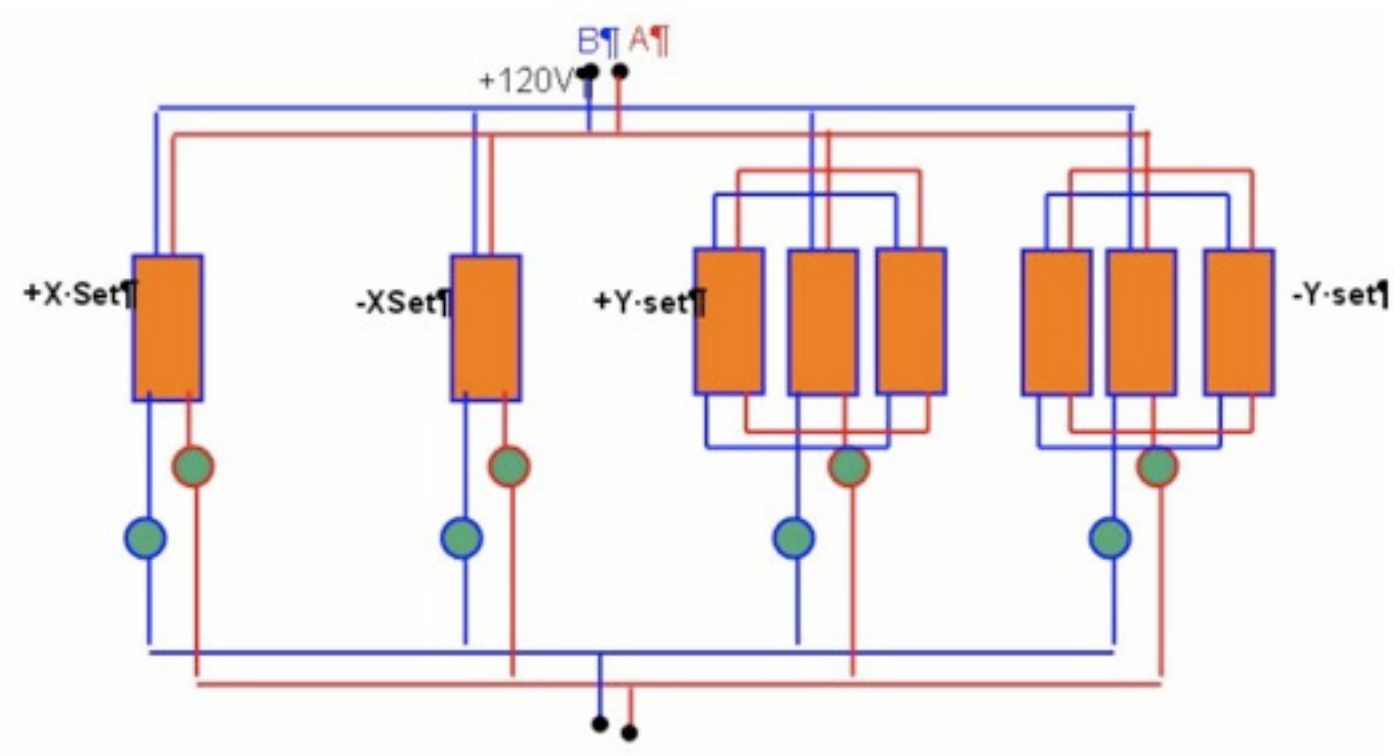
TOF Dallas sensors location

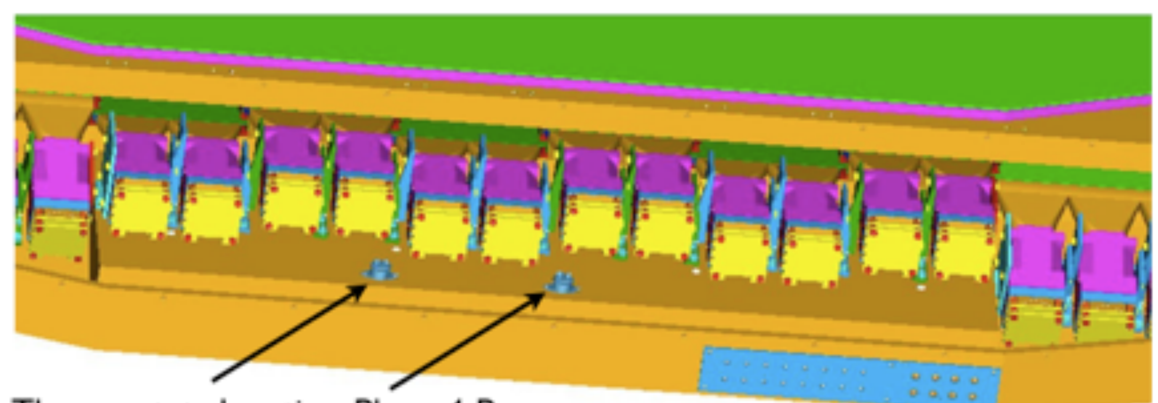


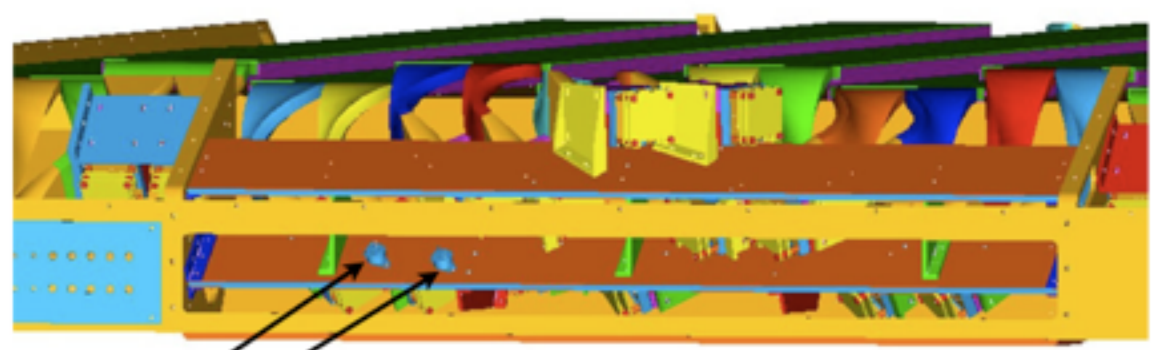
TOF temperature limits

Temperature Ranges	min. non operative	min. operative	Max. Operative	Max non operative
PMT´s	-35 (*)	-30	35	42
HVBricks	-35	-20	50	65
SFEC boards	-55	-40	80	80
TSPDs	-40	-20	50	80
SCrate		-20	50	

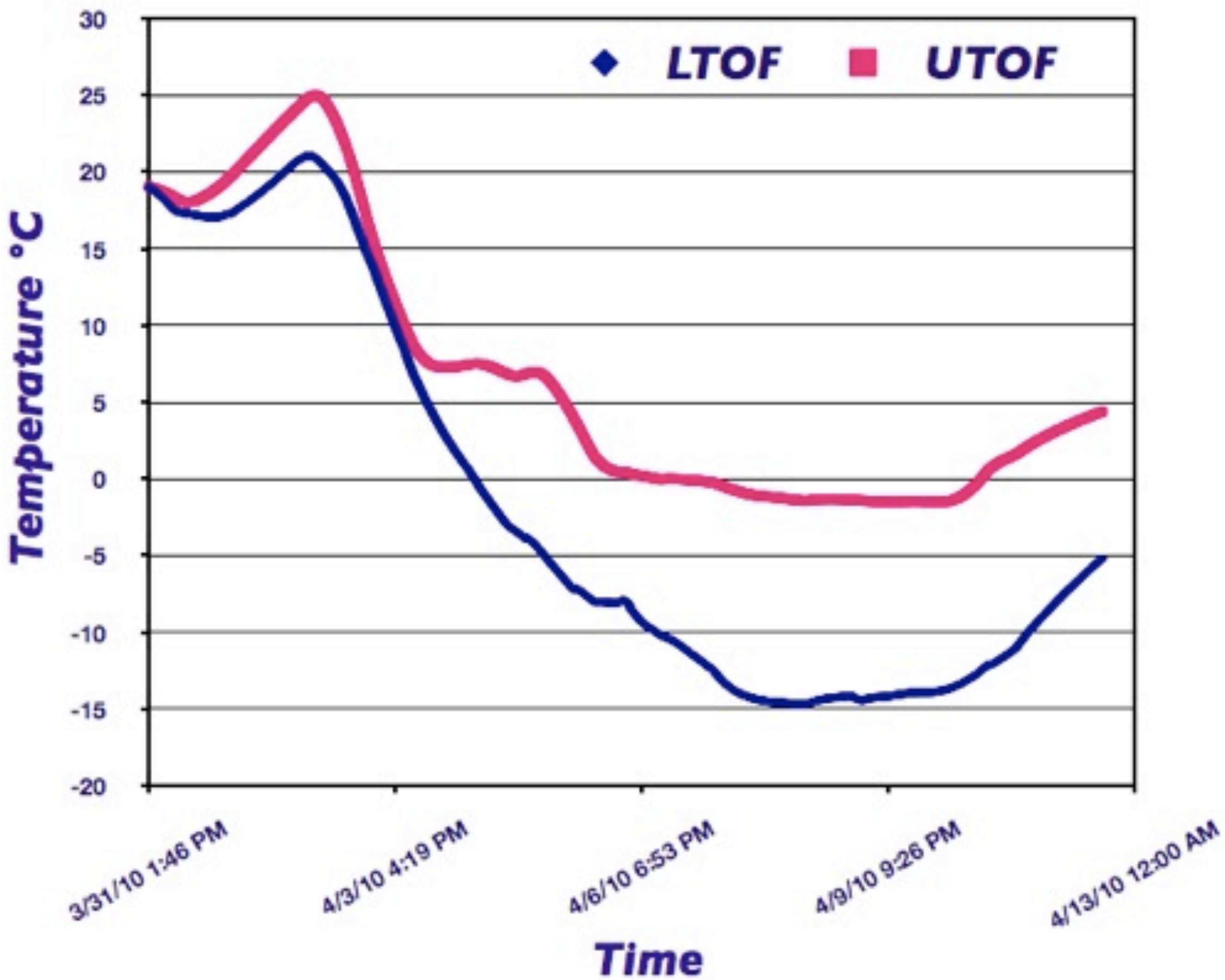
LTOF has heaters with thermostats set point at -22°C.

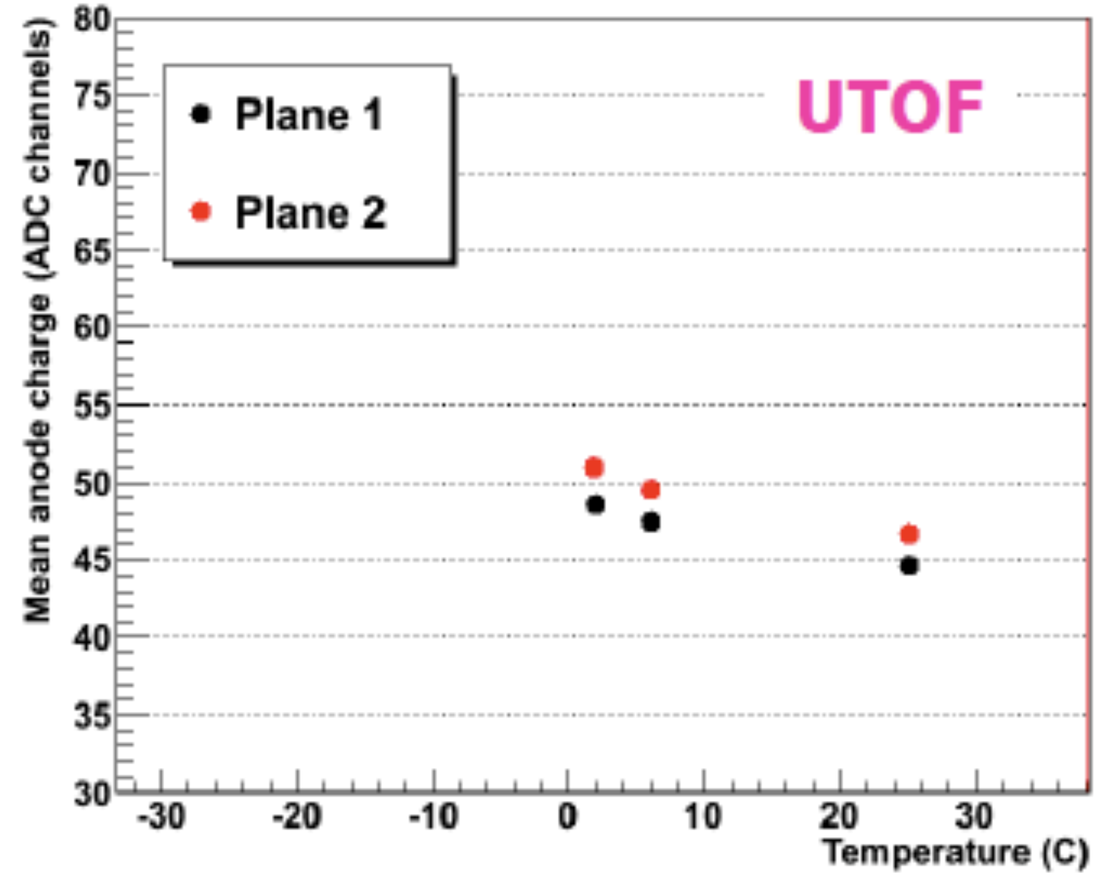


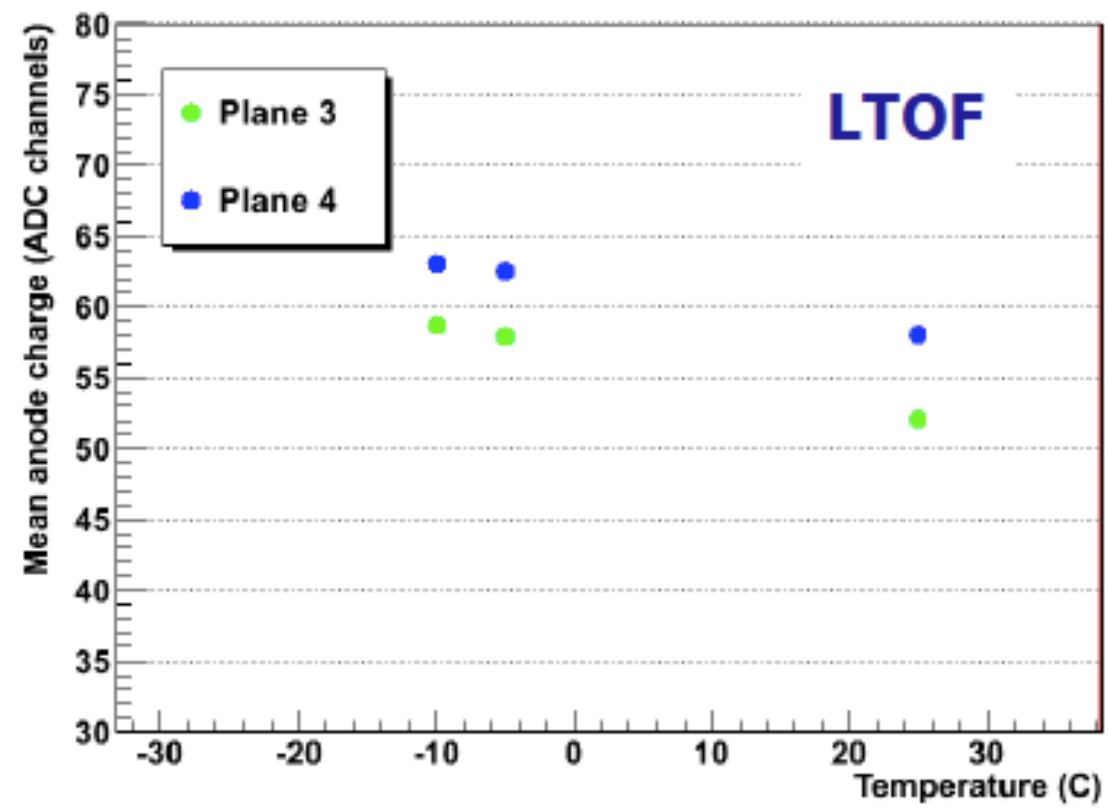

Thermostats location Plane 4 P


Thermostats location Plane 3 P

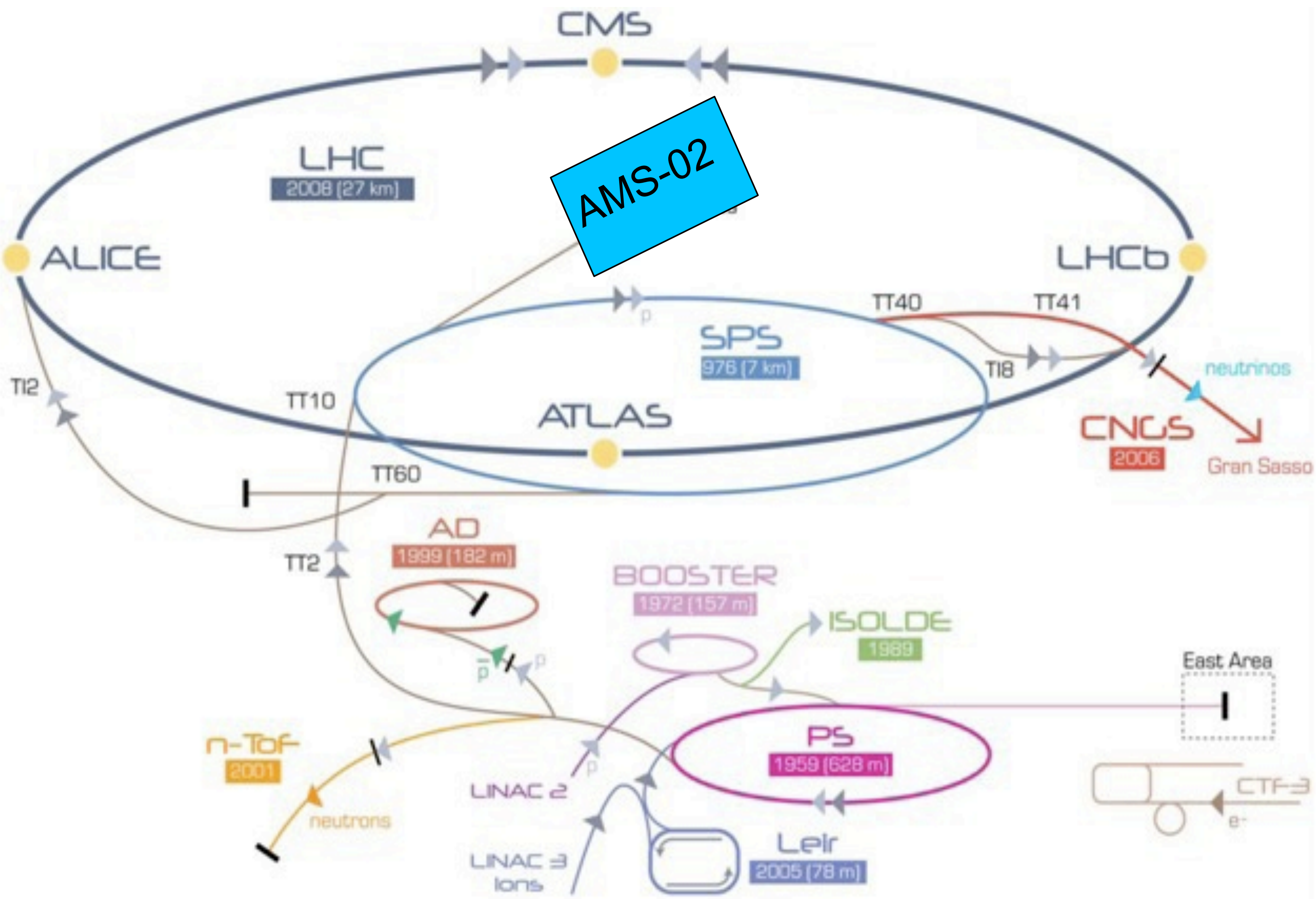
TOF temperatures during TVT







AMS-02 performance
test beam @ CERN (Switzerland)



OBJECTIVES

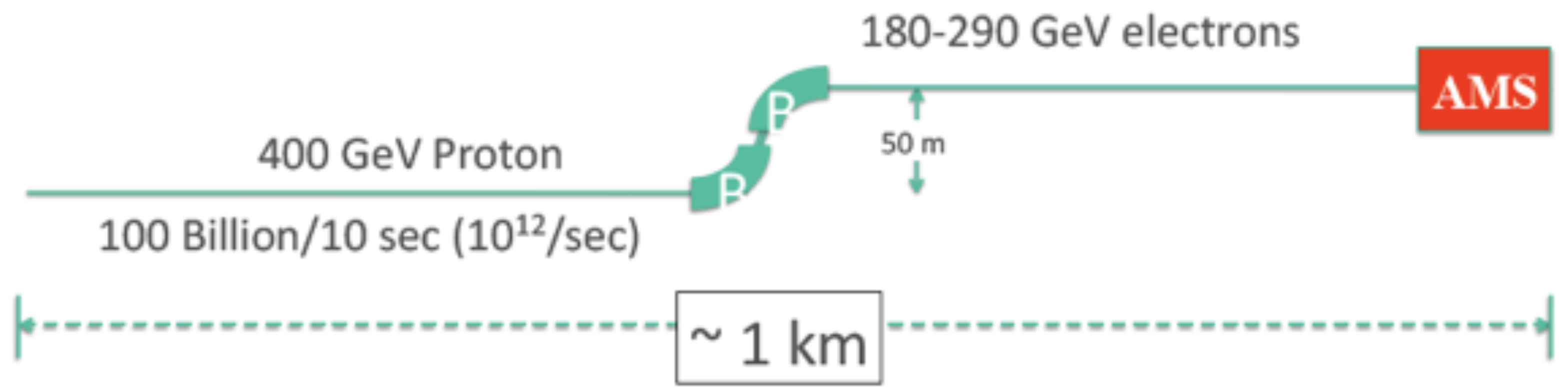
- ***e± signatures in TRD, ECAL & Tracker***
- ***e±/proton rejection***
- ***TRACKER alignment***
- ***RICH calibration***
- ***Trigger and Veto efficiency***

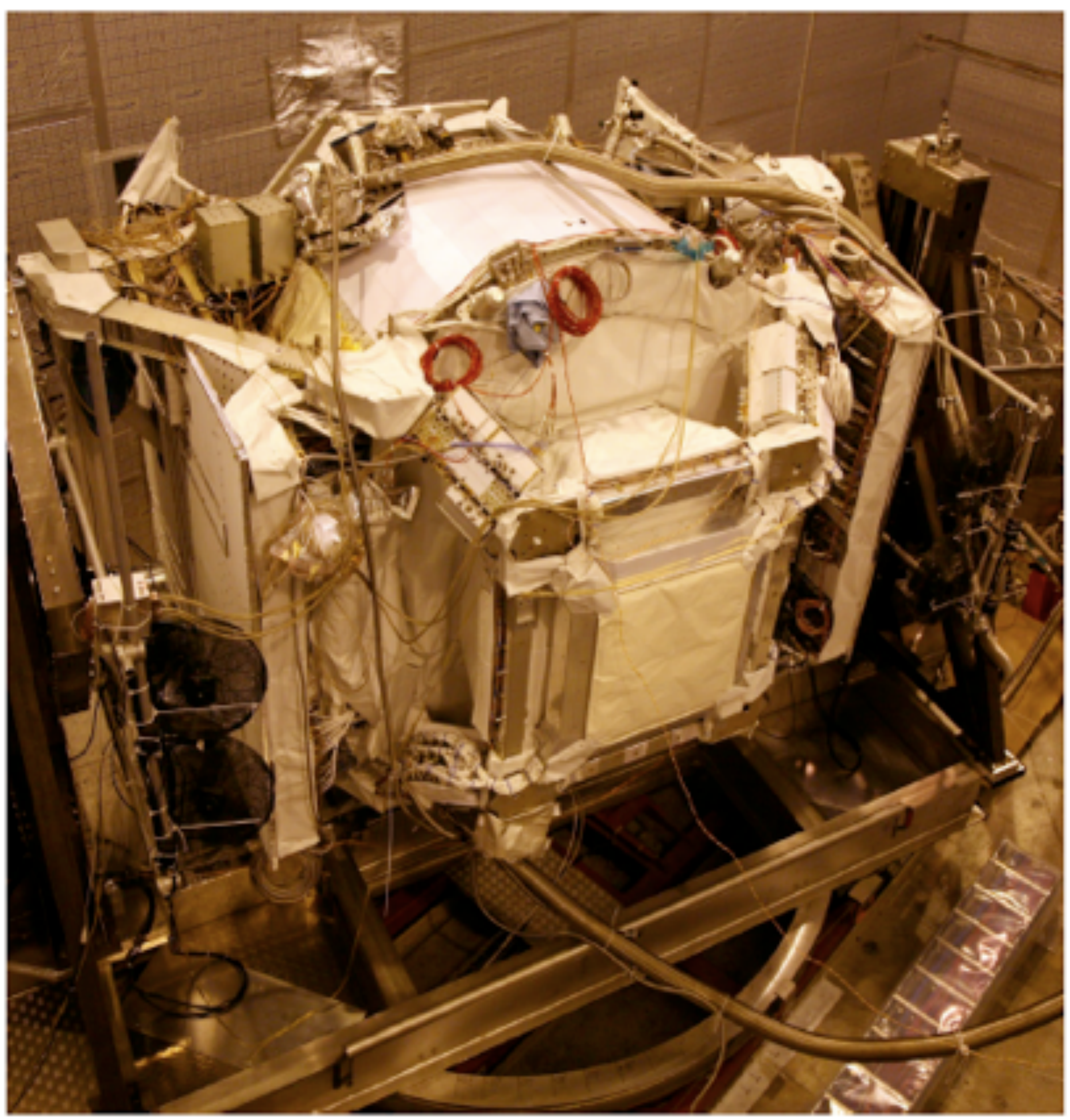
BEAM PARTICLES

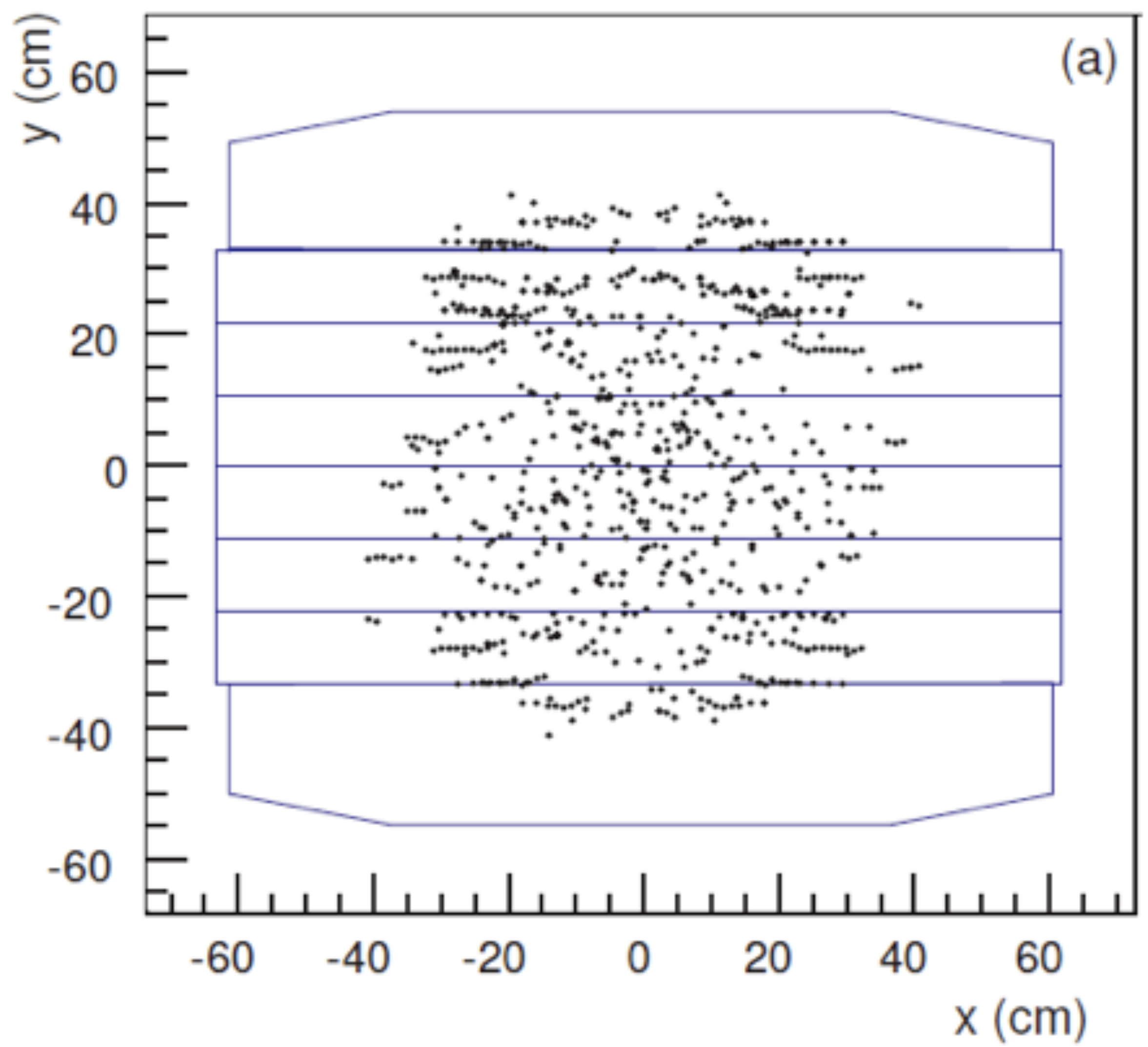
Particle	Momentum (GeV/c)
Protons	400
Positrons	290, 180, 120
Positrons	100, 80, 20, 10
Positrons/e^-	120

AMS in the test beam area

The high energy electron test beam was produced from an higher energy proton beam.





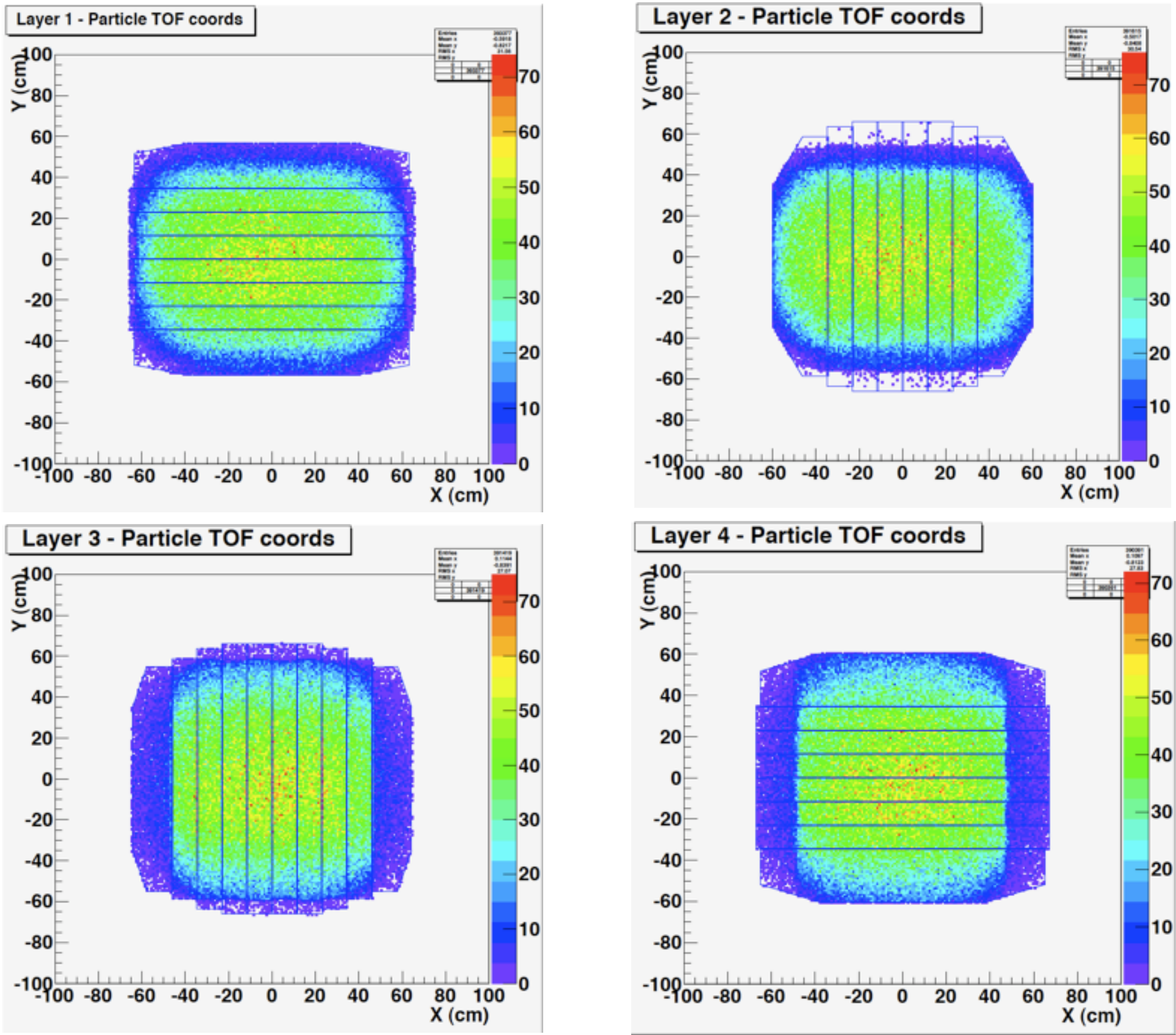


Beam impact points in the first TOF layer.

AMS-02 leaves to KSC 25 Aug 2010

May 19 2011: AMS installed on ISS Truss 5:15 CDT, start taking data 9:35 CDT

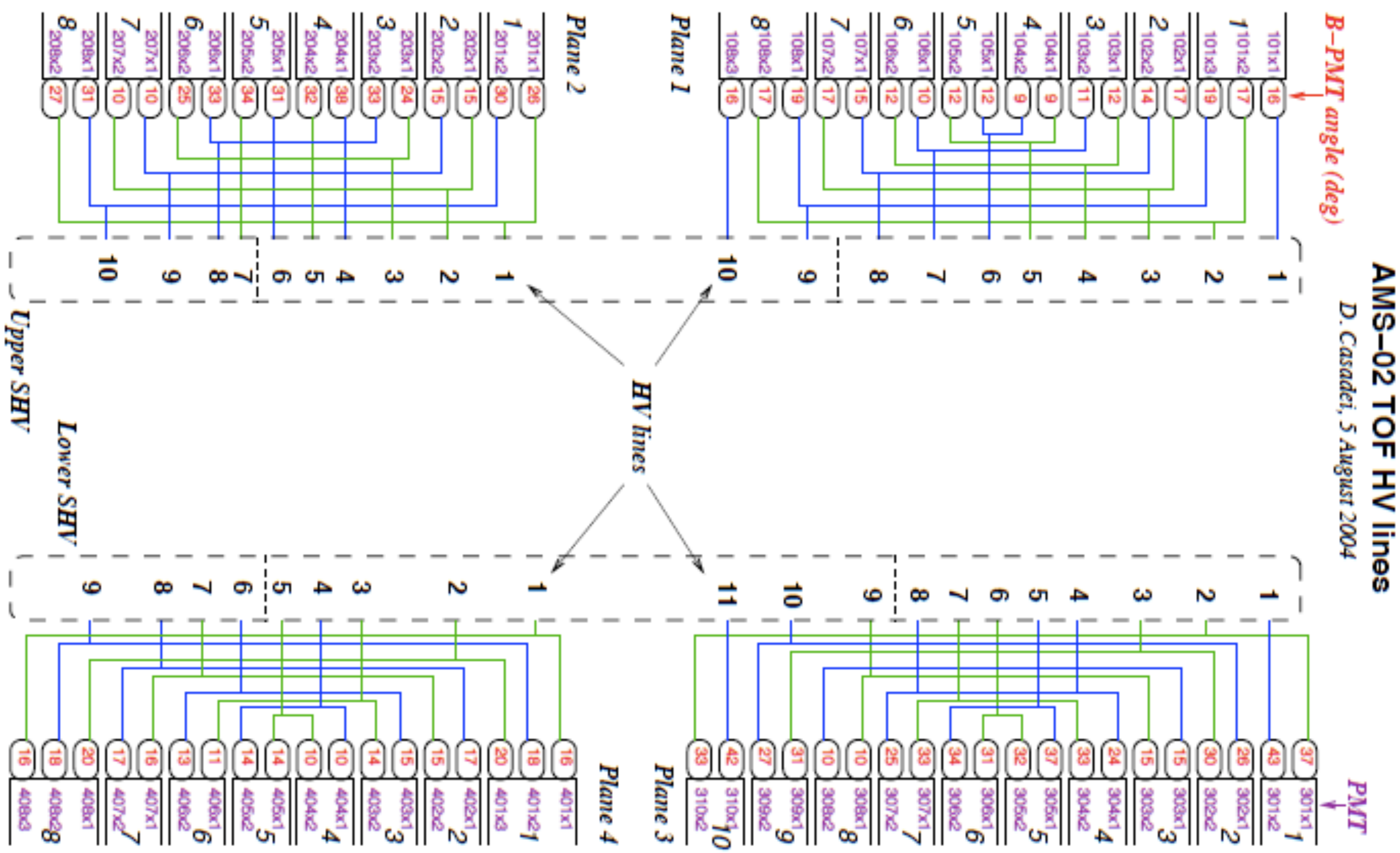
Cosmic rays impact point on the TOF layers



TOF optimization and tuning

The TOF detector has been characterized to set the PMT high voltages and the trigger thresholds in order to optimize the TOF response.

Constraints:
- Two PMTs in different counters are paired to the same HV channel.
- The anode signals of the PMTs connected to the same counter side are summed.
- Each counter must be able to operate with only one PMT powered in each side.



TOF optimization and tuning

The HV scan for the TOF was performed to determine the HV to apply at each PMT in order to:

- have a minimum ionizing particle signal passing a 60mV threshold at the counter center to improve the trigger efficiency;
- equalize the signals from the two sides of each the counters to increase the time resolution;

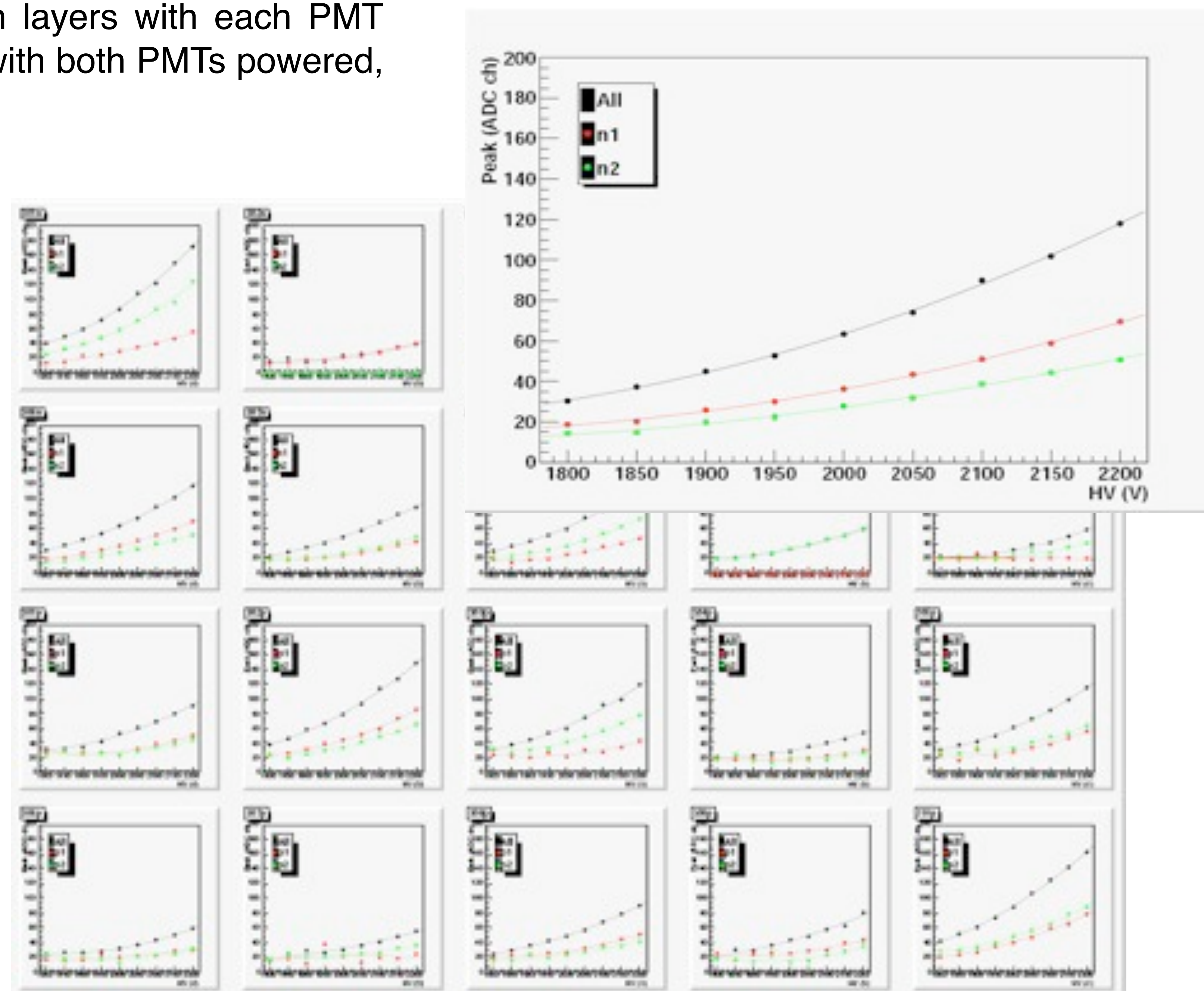
To set the HV of each PMT, cosmic ray data has been taken on ground by self triggering the scintillation layers with each PMT per counter side powered at a time and with both PMTs powered, with nine values of the HV:

1800, 1850, 1900, 1950, 2000, 2050, 2100, 2150 and 2200 V.

The resulting calibration curve was then fitted with the function:

$$Q = \left(\frac{\mathrm{HV}}{\mathrm{HV}_0}\right)^p$$

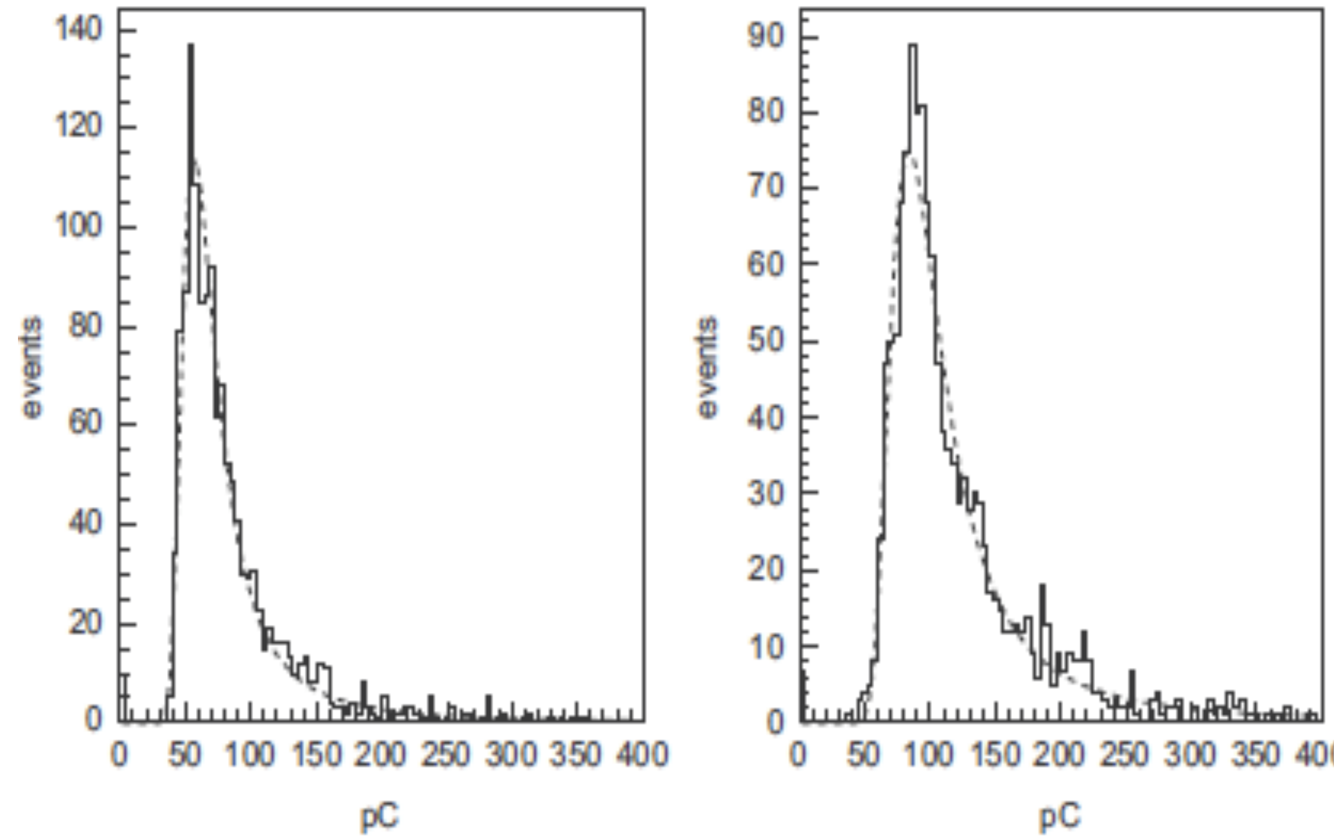
where Q is the charge peak in ADC channels, p is the gain factor of each PMT, HV is the applied voltage in Volts, and HV_0 is a parameter common to all PMTs.



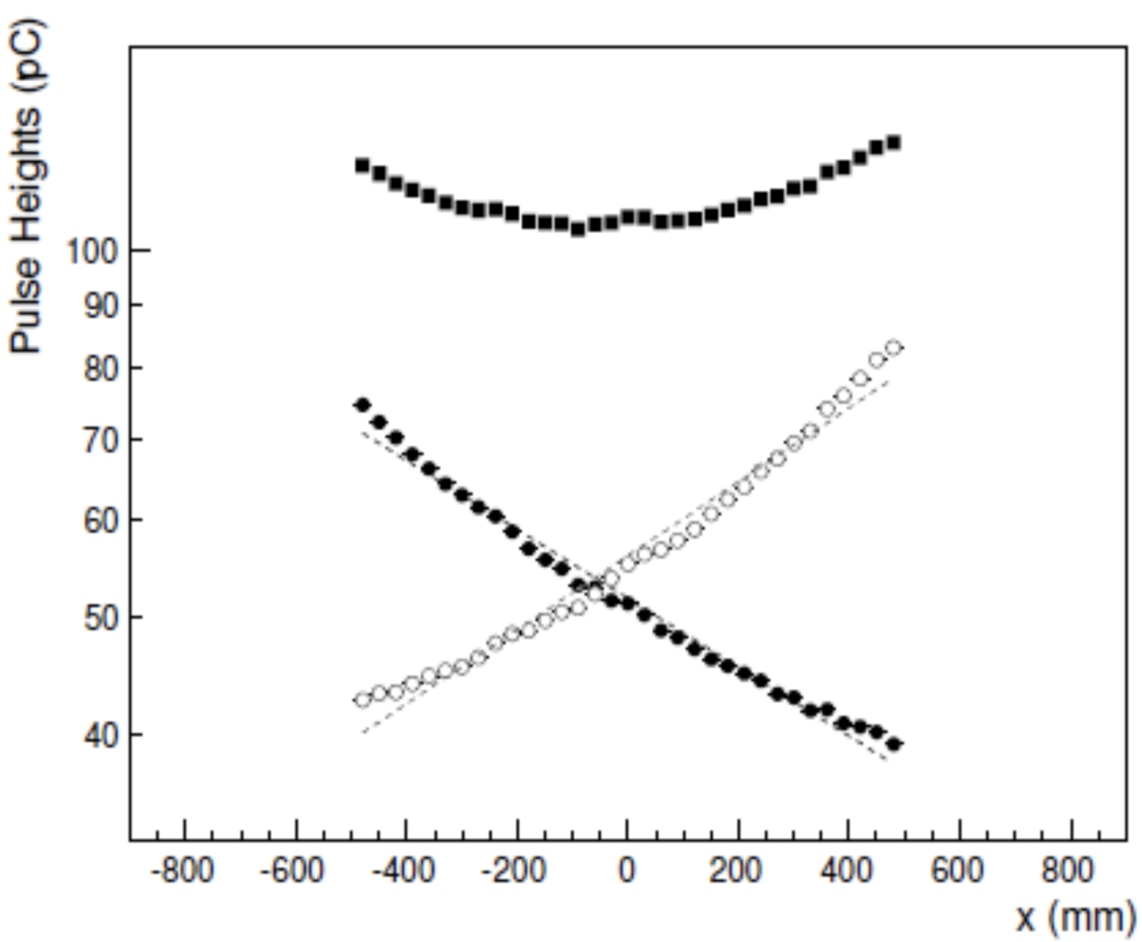
TOF optimization and tuning

Procedure:

1. The HV of each PMT was set to have a minimum ionizing particle signal passing a 60mV threshold at the counter center, thus ensuring a good trigger efficiency in case of a failure of the other PMT on the same counter side, or of the corresponding HV line.
2. HV was tuned to acceptable value for both PMTs connected to the same HV channel. In case a PMT required a HV higher then the paired one, both have been set to the higher HV value.
3. Measure the performances of the counters using the better HV set in for all channels.



The anode pulse eight spectra of sides n and p of counter 402 for events selected in a 10 cm central section, fitted with a Landau shaped function.

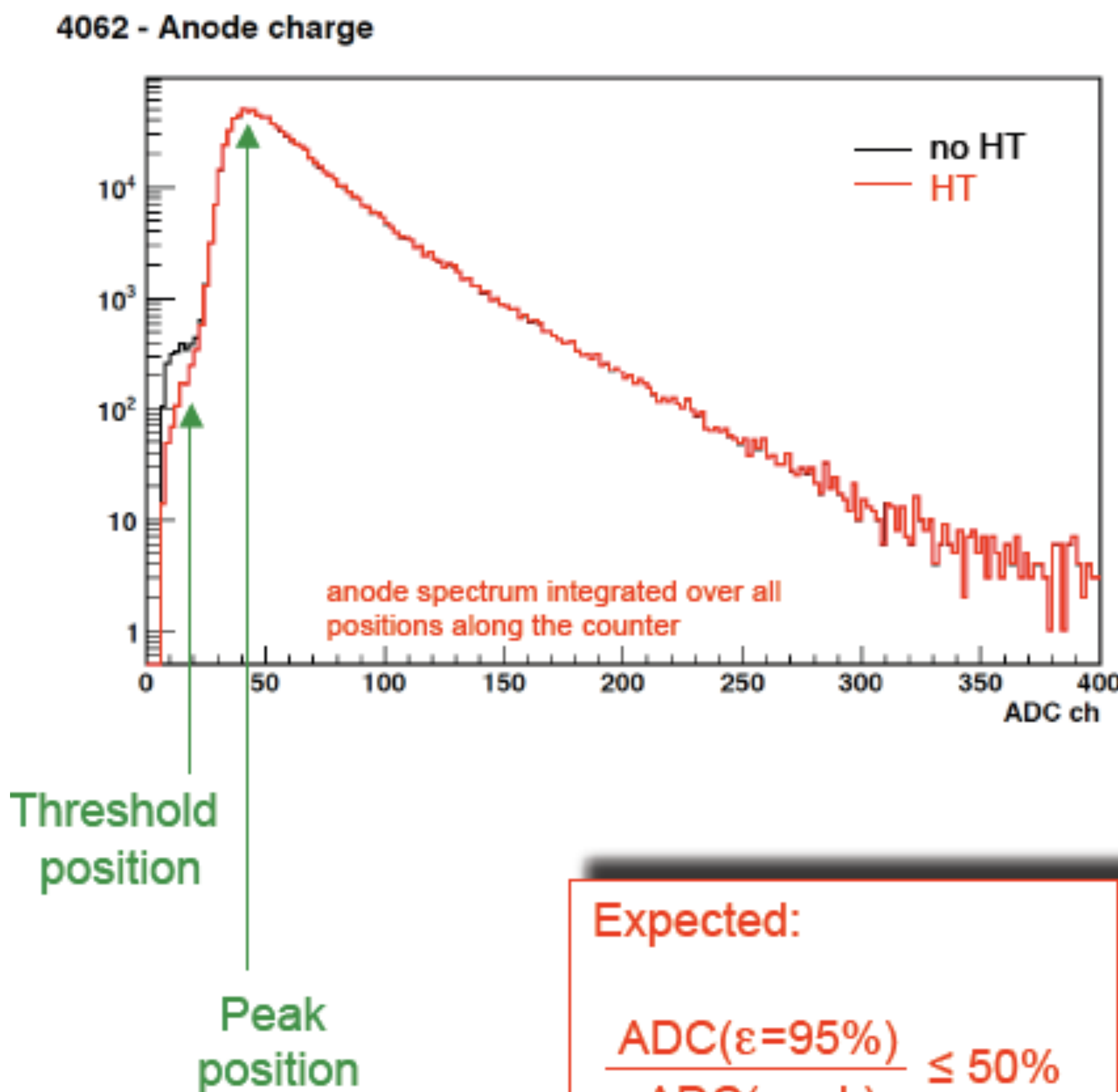


Pulse height for minimum ionizing particles as a function of the hit position along the counter; p side (white dots), n side (black dots) and sum of the two sides (black squares). The dashed lines are exponential fits to the data.

Threshold efficiency

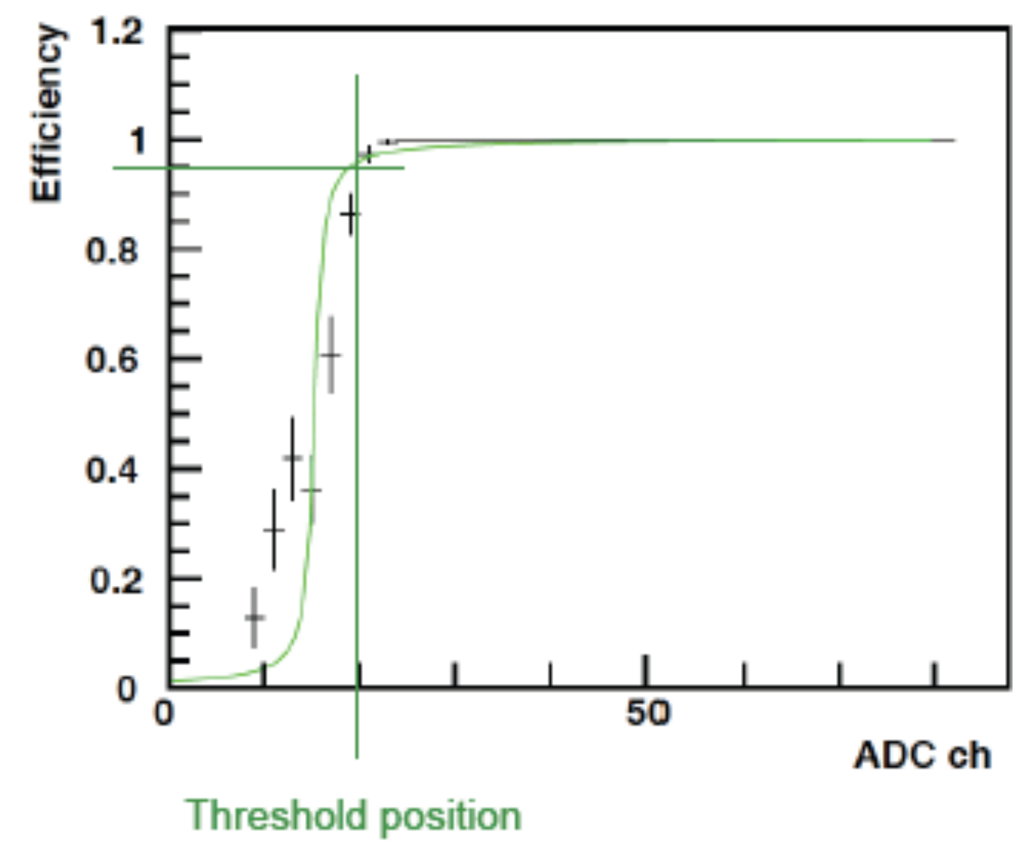
In order to have an efficiency of 95%, the threshold has to be set around the 50% of the anode peak position.

Constraints:
- the same threshold is used for more anode signals at the same time.



Expected:

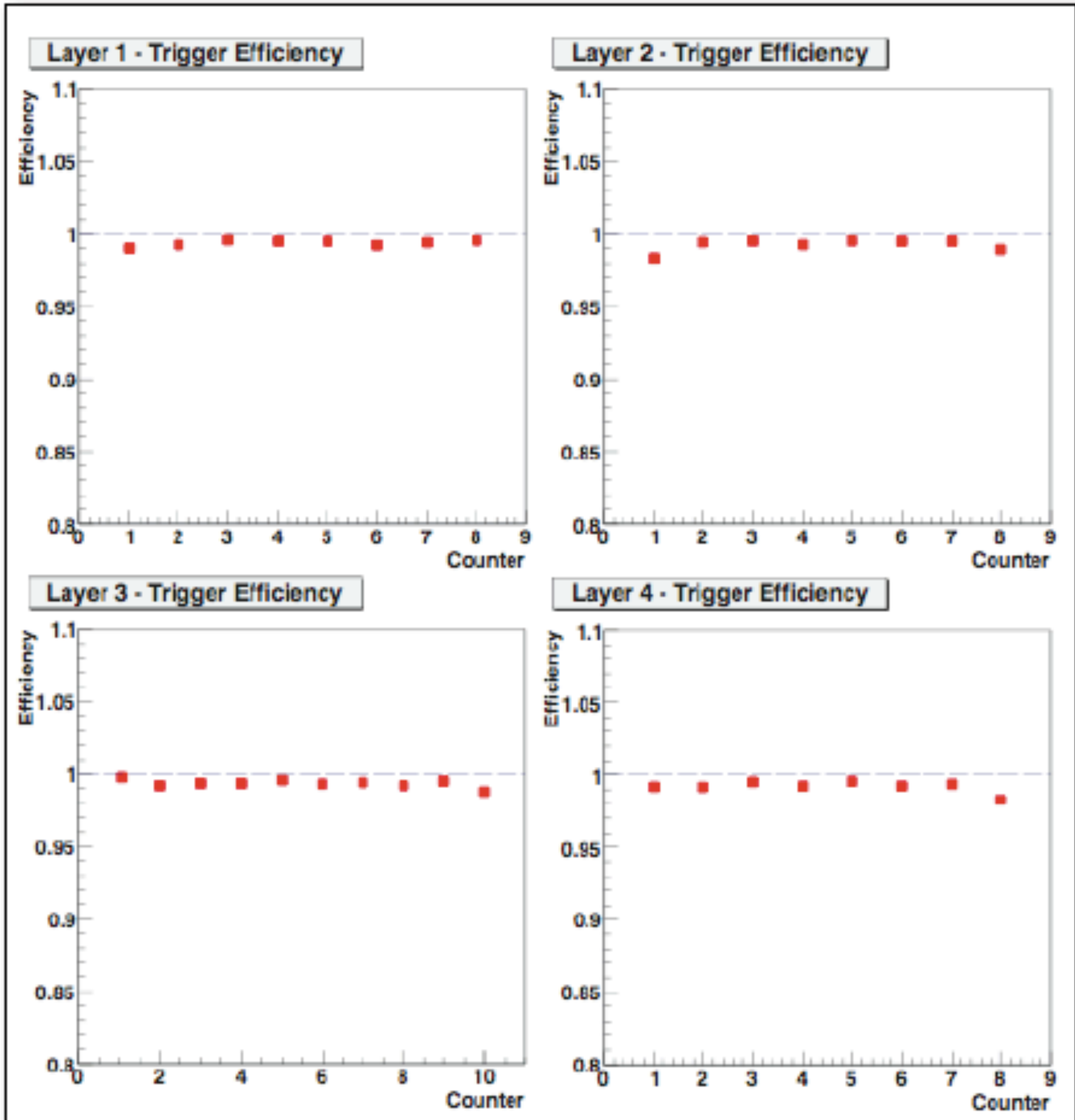
$$\frac{ADC(\varepsilon=95\%)}{ADC(peak)} \leq 50\%$$



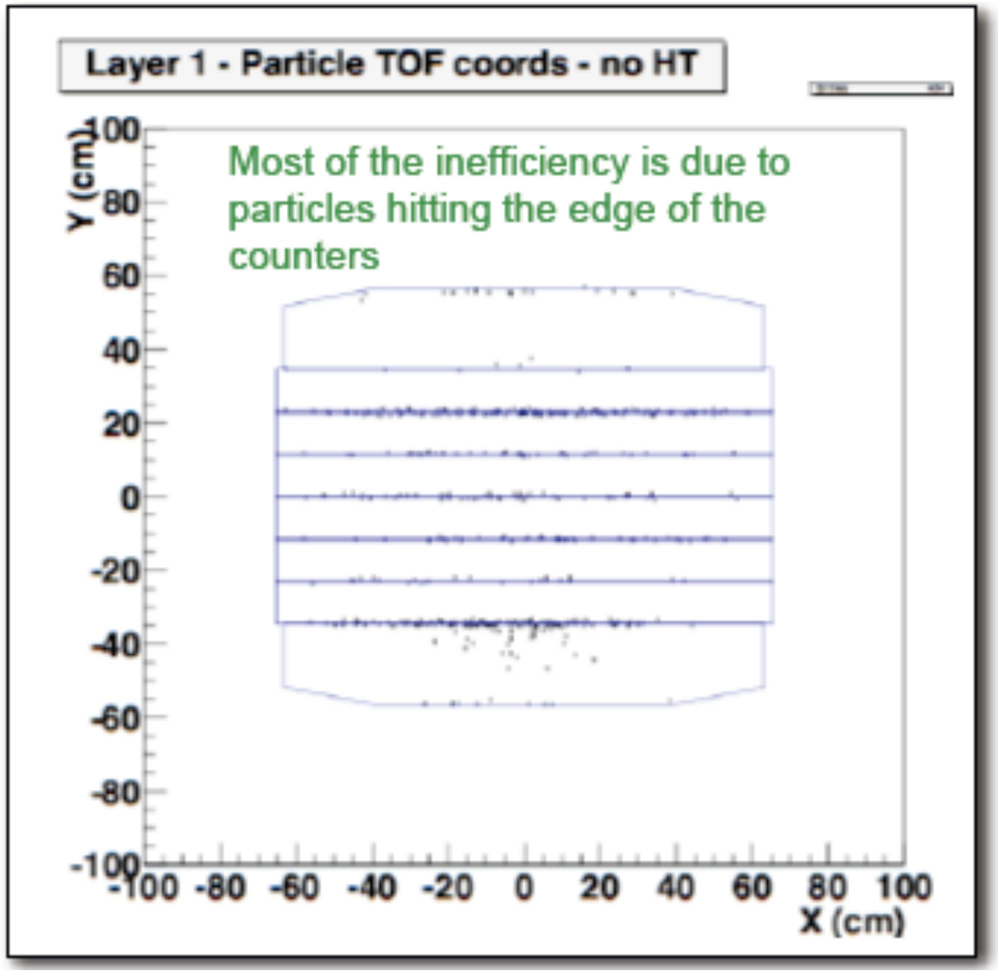
Ratio between threshold and peak positions.

Ratio between the raw spectra with and without High Threshold to determine threshold position.

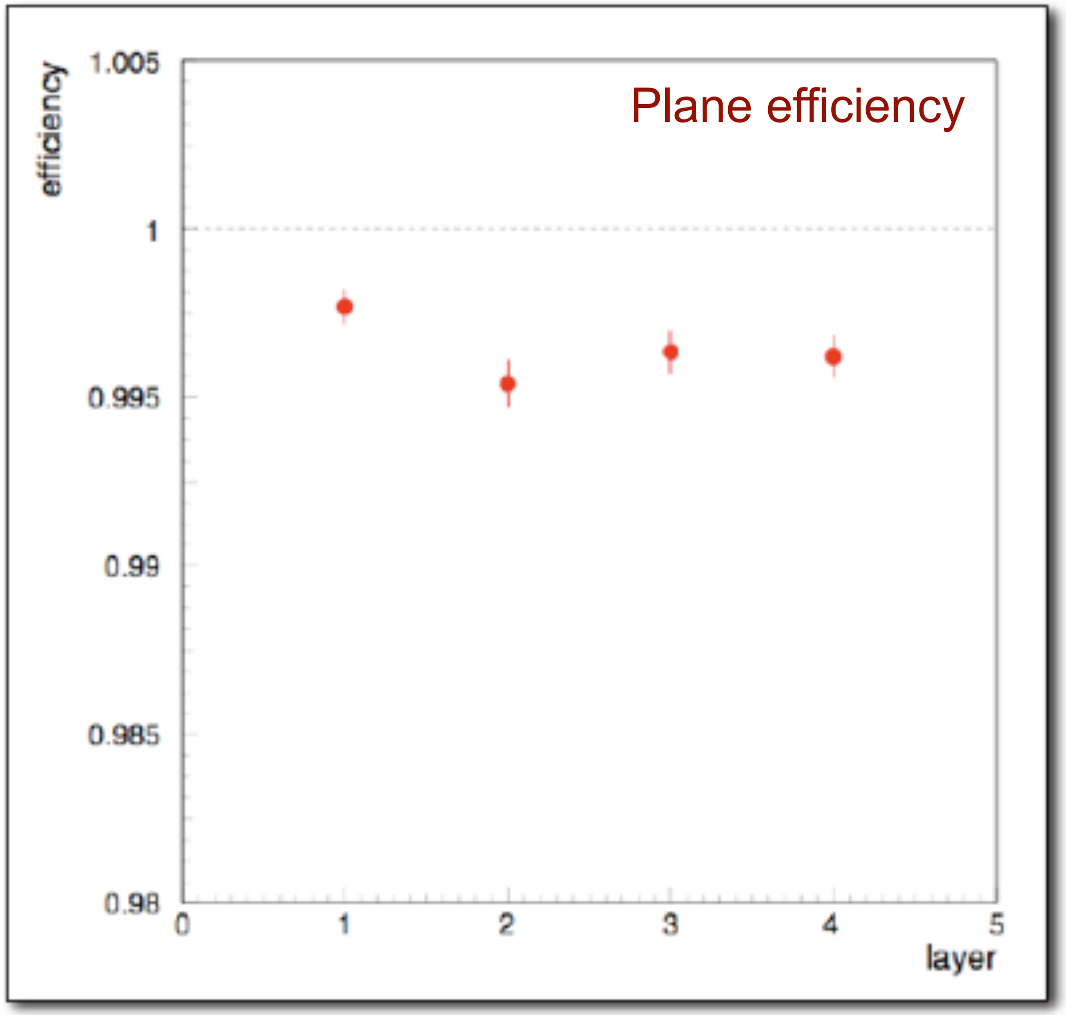
Single counter trigger efficiency



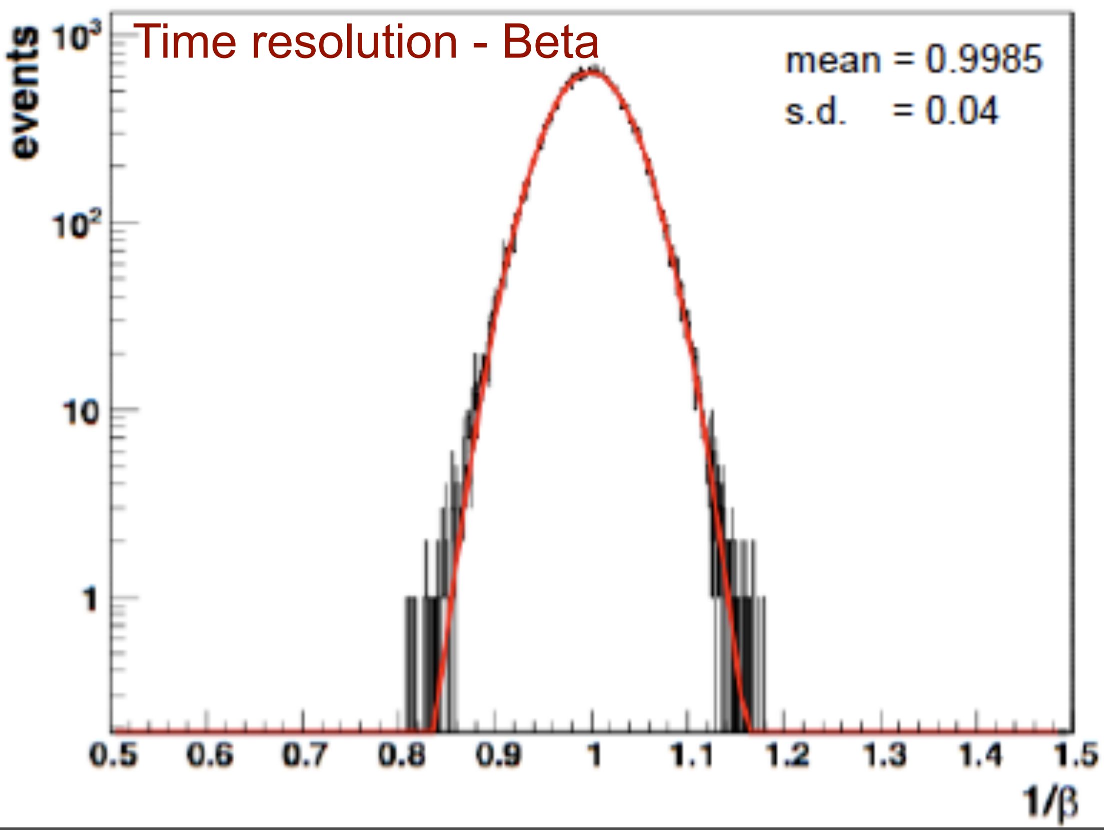
The efficiency of the counter is computed as the ratio between the number of events with any High Threshold in the counter and the total number of events with a particle hitting the counter.



TOF performances



The efficiency of the plane is computed as the ratio between the number of events with any High Threshold in the plane and the total number of events with a particle hitting the plane.
Inefficiency is better than 0.995% in each plane.



σ ~ on beta 4% that corresponds to 180 ps single counter resolution (average flight path ~140 cm)

These results are in complete agreement with the previous ones obtained with cosmic muon @CERN and @KSC and during the test beam.