OPERA note 07-85

First results on the VETO commissioning

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Abstract

This note gives some preliminary results obtained during the VETO commissioning performed in Fall 2007.

Contents

1 VETO hardware setup

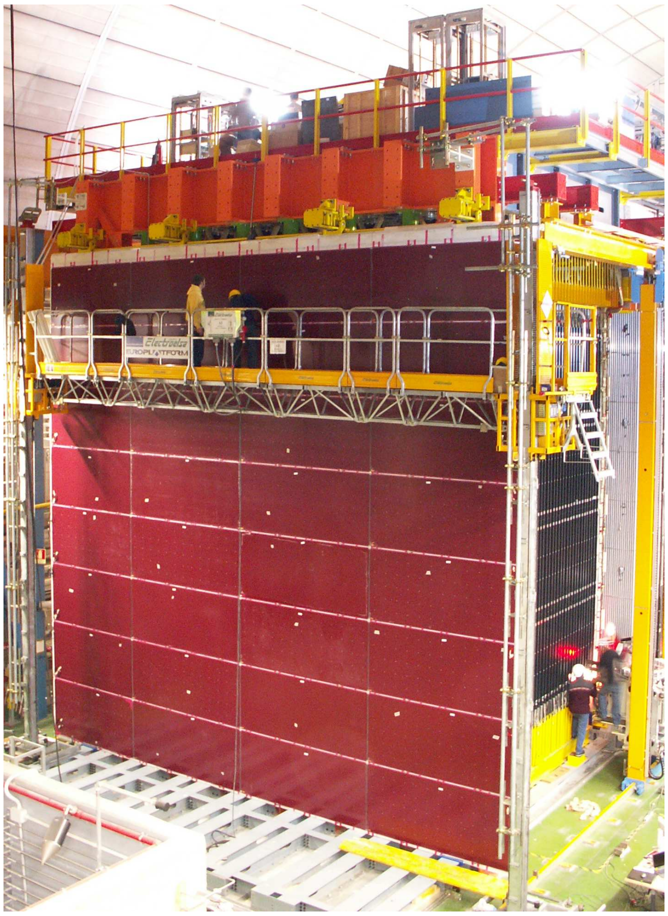

Figure 1: A phase of the VETO system installation in front of the OPERA detector. In total 64 glass Resistive Plate Chambers have been employed.

The VETO system, shown in fig. 1, is composed of two walls of glass Resistive Plate Chambers (GRPC). Each layer is made of 32 chambers organized in 8 rows. Each row is composed of four detectors: three of them are 2.60 m long and 1.14 m height, while the fourth is $2.20 \times 1.14\ m^2$. The overall sensitive area is close to 200 m^2: the VETO is the largest underground apparatus based on GRPC ever built.

1.1 High voltage

The main HV system of the experiment has been developed taking into account the requirements of the RPC planes of the spectrometer. For this reason, due to the different layout of the VETO, a custom HV system has been setup. As in the spectrometer case, the main HV supply frame is based on the use of a *CAEN SY* 127 equipped with 32 positive polarity and 8 negative polarity channels, respectively. Each positive channel is further divided into 2 subchannels to supply consecutive GRPCs in the same column. The negative polarity is supplied using two I-Meter devices, allowing current measurements with nanoamperometric precision. Each output channel provides the high voltage on 2 consecutive GRPCs in the same row. This "grid" configuration allows to monitor each GRPC of the apparatus. The high voltage system of the VETO will be integrated in Spring 2008 in the slow control system of the OPERA experiment.

1.2 Readout

Due to the different geometrical dimension with to respect the RPC planes in the spectrometer a different cabling strategy has been used. Each VETO plane is equipped with horizontal and vertical (2.2 cm wide) copper strips. The vertical and horizontal views have 416 and 384 strips, respectively. In total 1600 electronic channels collect the signal generated by the detectors. The signals are carried out from the strips to the Front End Board (FEB) by means of 38 16–pins flat cables. For the two vertical and horizontal views 14 and 16 FEBs are being used, respectively. The data are read out from the FEB by the so called mezzanine boards, each housed in a Controller Board (CB). Taking into account the maximum data load on each mezzanine, the VETO system requires 16 CBs, eight per readout plane. This is the substantial difference with respect to the spectrometer where each RPC plane can be redout by only one CB because the rate is a factor ten lower than the one of a VETO plane.

1.3 Gas system

One of the most important parameters to take into account when operating GRPC is the gas inside the detector. For this reason great care has been devoted to the gas system development considering uniform gas flow, flow rate check and humidity contamination check of the gas mixture. The gas system is based on a distribution with 8 parallel channels for each VETO plane. Each channel is equalized by using a flow resistor (needle) inserted in each line. A scheme of a four GRPCs line is reported in fig. 2. The flow resistor has been chosen taking into account that the "impedance" of

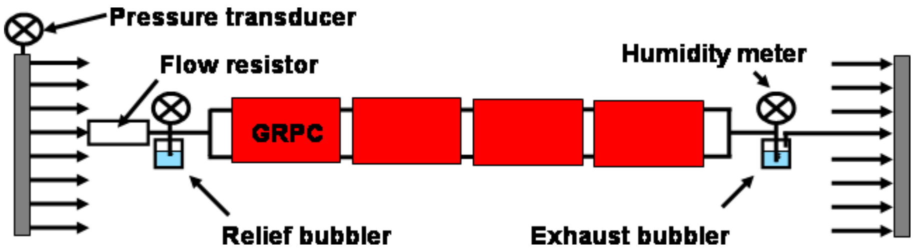

Figure 2: Gas distribution line in the VETO system. Each plane has 8 lines flushed in parallel. The flow rate, monitored by a pressure transducer, is equalized by means of flow resistor (needle) upstream of each string. A relief bubbler is used to protect the detectors from overpressure while an exhaust bubbler is placed downstream the line to monitor the flow inside the chambers. Humidity meters, placed in corrispondence of the gas input and output, are used to evaluate the water vapour contamination in the gas mixture.

the string should be as low as possible with respect to the needle. The "impedance" of the $G23$ needle, chosen for the VETO system, is about 60 times grater than the one of the detectors string. The gas system is provided with a pressure transducer to monitor the pressure of the main input gas line. Fig. 3 shows the flow rate since the beginning

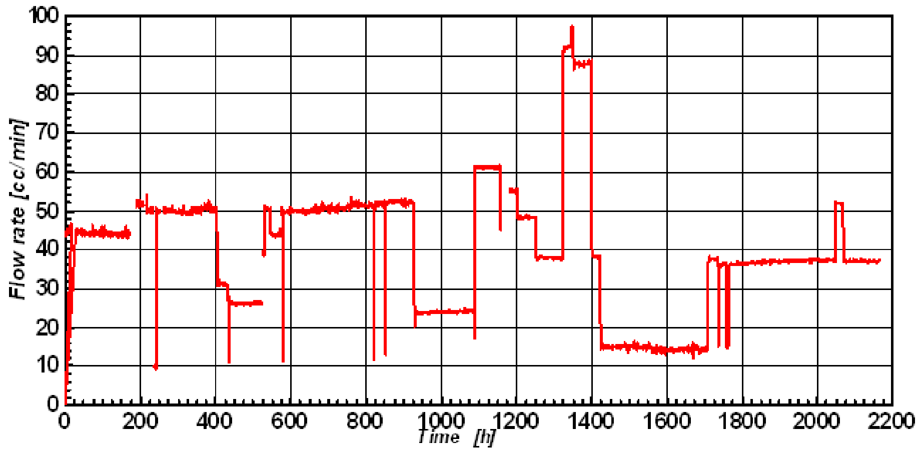

Figure 3: Flow rate as a function of time. The monitor started with the first VETO operations.

of the VETO operations. As glass RPCs are affected by ageing when water vapour contamination occurs in the gas mixture only stainless steel and unhygroscopic plastic pipelines have been used. It is worth to point out that the drying process is quite slow hence before operations can start it is important to flux the detectors with dry gas to remove the water vapour inside the volume. To complete the gas system, humidity transducers have been placed upstream and downstream each string to evaluate the remaining water percentage in the gas mixture. A detailed description of these devices is reported in the next section.

1.4 Humidity monitoring system

In order to prevent disastrous ageing effects, due to water contamination of the gas compounds, a humidity monitoring system has been developed. This system consists of 32 humidity meters (Honeywell HiH-4602-C), placed as shown in fig. 2, readout by a National Instruments Field Point System. All the sensors have been calibrated by using the MTS5(GE Panametrics) humidity meter as a reference. In fig. 4 the monitored water concentration is reported for one of the input and output lines. In

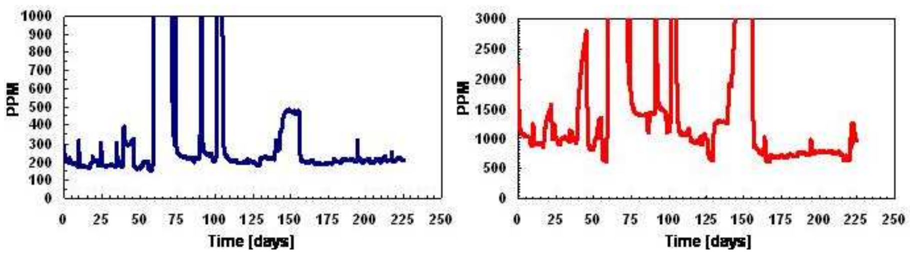

Figure 4: Monitor of the water vapour concentration (ppm) in corrispondence of one of the input and output lines. It is apparent that the input is drier than the output.

working conditions, with a flow rate of at least 70 cc/min, all the gas input lines show a contamination level lower than 200 ppm while the output lines are at about 1000 ppm. This gap is due to the fact that for the input lines only stainless steel piping is used while in corrispondence of the output the water concentration increases because of the polycarbonate frame of the detectors and the plastic material used for the connections. In any case GRPCs should be operated only when the contamination level is below of

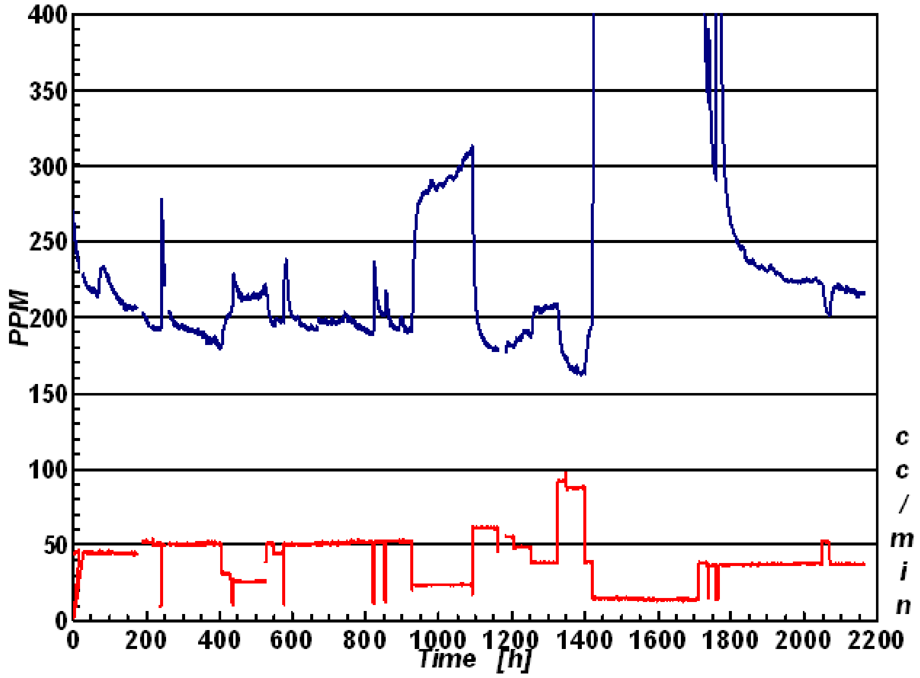

Figure 5: Water vapour concentration and flow rate as a function of time.

2000 *ppm*. As shown in figure 5, the water concentration strongly depends on the flow rate: when the flow decreases the humidity increases.

2 VETO hits

In Fall 07 the VETO readout was performed with a set of 4 controllers for the x and the y coordinate of each plane, respectively. Hence the total number of controllers in the VETO readout was 16. In order to:

- maximize the efficiency of the VETO;
- keep the number of words each controller has to readout, at the level of 10–15 k words / cycle (in order to avoid dead time in the data trasfer at the controller level);

the following setup was used:

- time coincidence between the $FAST\_OR$ signals of the x and y views of each VETO plane;
- events with at least a coincidence, as defined above, either in the interal or the external VETO plane.

So the two VETO planes are in OR and the two views of each plane are in AND. The events fulfilling these conditions are further transmitted to the OPERA Manager.

Hence VETO events are expected to have x and y hits either in a single plane or in both planes. The observed VETO hits multiplicity in extractions 430–431 is shown in fig. 6: the expected peaks at 2 hits and 4 hits can be clearly seen. There are also events with 1 hit and 3 hits, see also fig. 7, in this case the x or y hit in one of the two VETO planes is missing. This behaviour is currently under investigation.

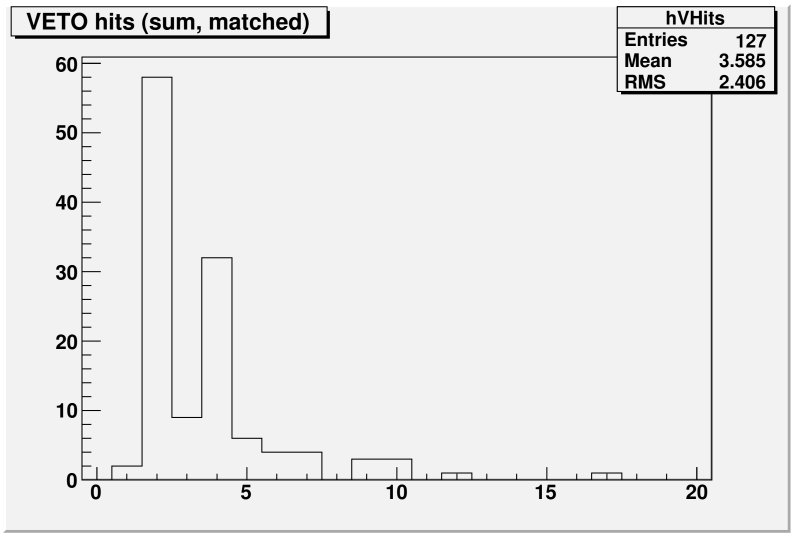

Figure 6: Hits multiplicity.

Fig. 8 compares the VETO hits multiplicity observed in extractions 414–417 and 430–431. In extractions 414–417, as well as in most of the Fall 07 data taking period, the trigger logic was performed with a set of NIM modules. In the last two extractions of the Fall 07 data taking period, extractions 430–431, a custom trigger board was used to

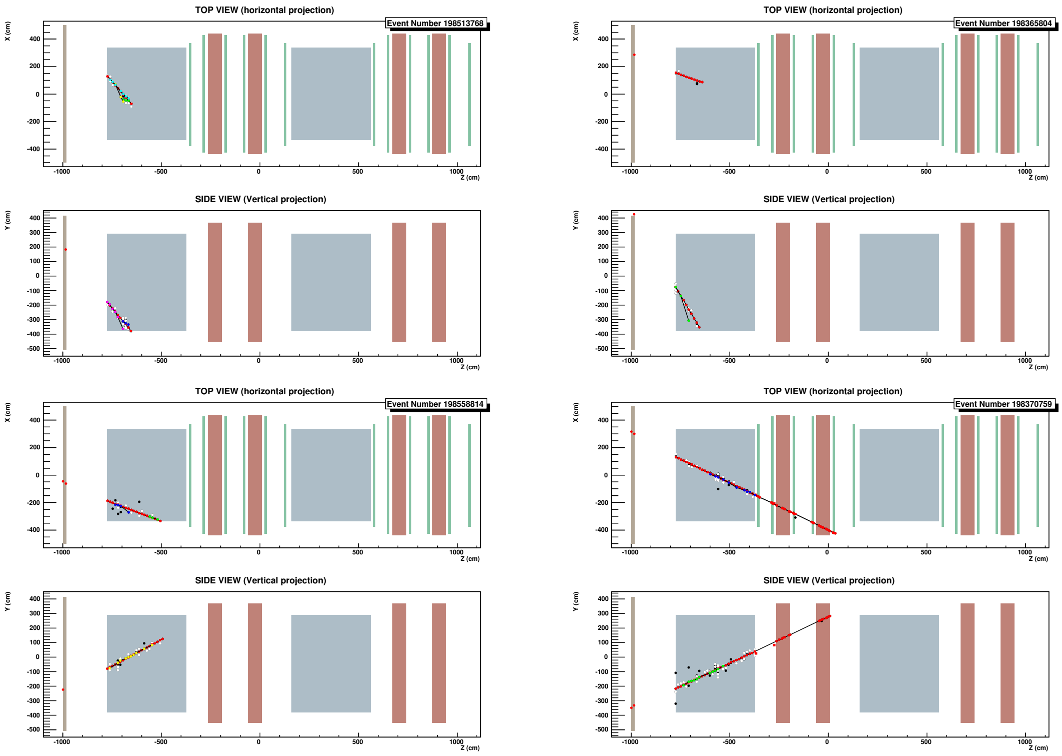

Figure 7: Cosmic events with 1, 2, 3 or 4 hits in the VETO.

compute the trigger decision. Fig. 8 suggests a decrease of the unexpected 1 and 3 hits configurations in extractions 430–431 and hence seems to indicate better performances of the custom trigger board with respect to the previous hardware configuration.

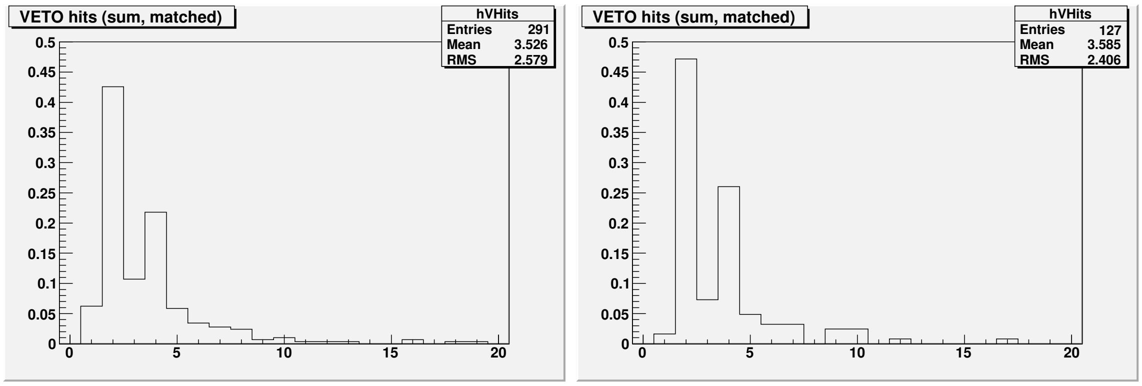

Figure 8: Hits multiplicity in extractions 414–417, left, and 430–431, right, respectively.

3 VETO alignment

The VETO aligment was studied using cosmic ray tracks. The official OPERA reconstruction package, OpRec, is providing the parameters of the cosmic tracks crossing the OPERA detector in 3 dimensions, shown by the black continous lines in fig. 7.

Cosmic ray tracks usually have large momenta and hence the extrapolation of the OpRec track to the surface of the inner (outer) VETO plane is performed assuming a straight line path. If the track crosses the surface within the sensitive volume of the glass RPC detector the predicted position can be compare with the position measured by the VETO itself. We can then compute the difference between the x (y) predicted and measured position, the residuals in the x (y) coordinate. We can also study the distribution of the x residual vs the y residual.

Using as input tracks a "small angle" MC sample, muon tracks from neutrino interactions in front of OPERA with almost perpendicular incidence, we obtain the plots shown in fig. 9 and 10 for the external and internal VETO planes, respectively. These plots show the expected behaviour: small residuals centred on 0 for both coordinates. The rms are consistent with the VETO strip pitch.

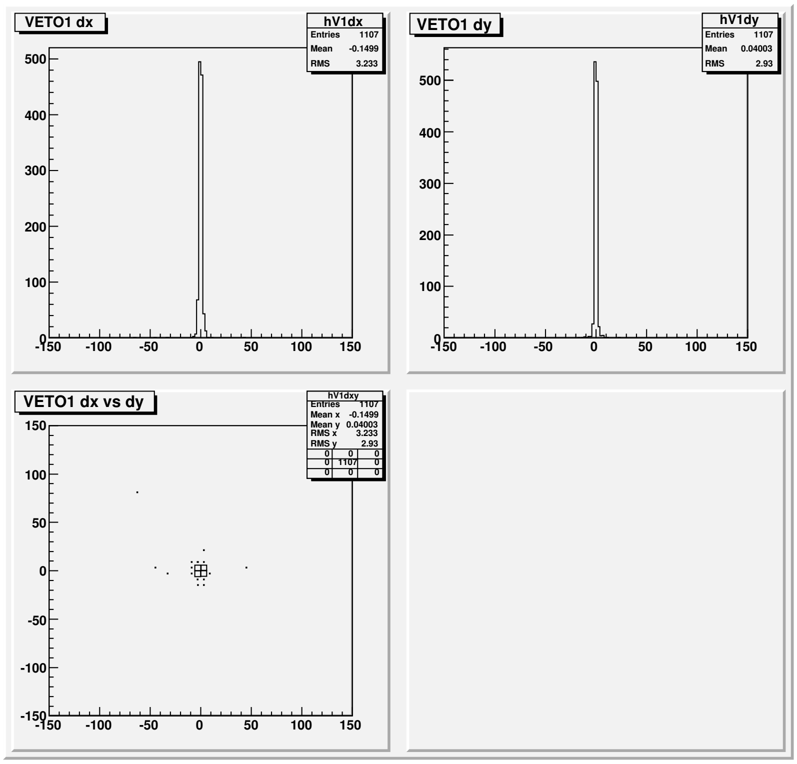

Figure 9: Residual between the OpRec track prediction and the VETO measurement for the outer plane with the "small angle" MC sample.

Using as input MC tracks coming from the lateral shielding of the OPERA experiment, hence tracks with not so large momemtum and large incidence angle, "large angle" MC sample, we obtain the plots of fig. 11 and 12. The residuals are still centred on 0, as expected, but the rms are substantially bigger with respect to fig. 9 or 10. Hence the rms of the residuals depends rather strongly on the kinematic of the incoming particle in terms of momemutm and incidence angle.

Fig. 13 and 14 show the result obtained using as input tracks a cosmic ray data sample recorded in Fall 07. The distributions have a gaussian–like shape, the rms is similar to what observed for MC tracks with a large incident angle (see figs. 11 and 12)

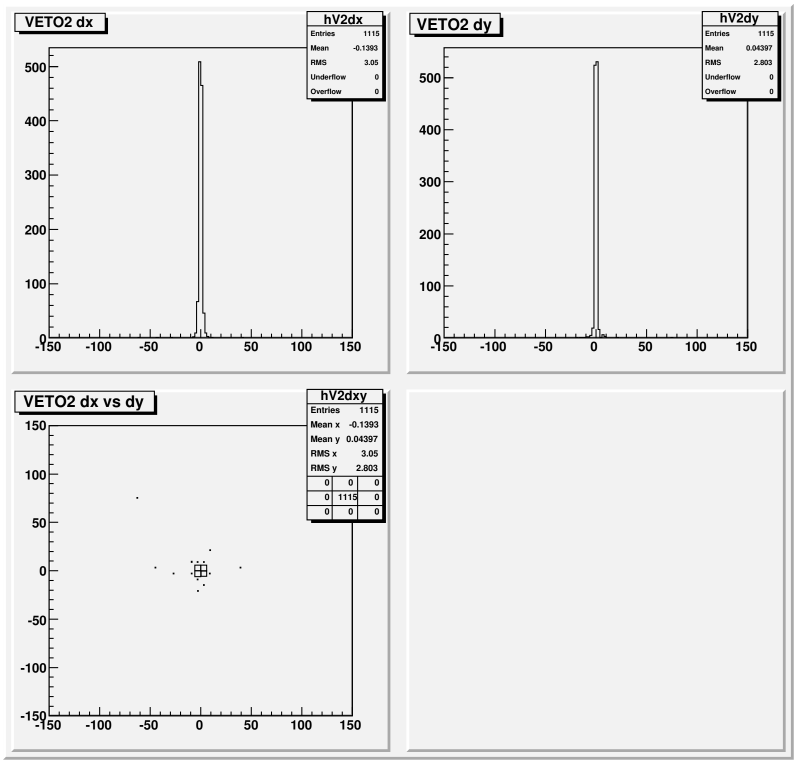

Figure 10: Residual between the OpRec track prediction and the VETO measurement for the inner plane with the “small angle” MC sample.

but the residuals are not centred on 0. This clearly indicates that the VETO planes are not properly aligned in the data.

To further investigate this point we studied the correlation between the predicted x (y) coordinate at the VETO surface and the measured x (y) coordinate, as seen by the VETO itself. The results are shown in fig. 15. In case of perfect aligment all the data points should lie along the main diagonal of the plane, the straight line with equation $y = x$. In case of a misaligment of the VETO planes the equation becomes $y = x + a$ where the constant parameter a can be extracted from the shift from 0 seen in the residual distribution. The continous lines shown in fig. 15 are precisely obtained taking the non 0 value of the parameter a from the residual distributions.

4 VETO mistag probability

A detailed description of the OPERA DAQ during the Fall 07 data taking period can be found at [1]. For this study we are interested in the time distribution of the VETO signal with respect to the signals from the others OPERA electronic detectors.

Assuming t_0 to be the time at which a charged track crosses the OPERA sub–detectors, the hits of the TT are expected to be recorded with only a small delay with respect to t_0 because of the very fast time responce of scintillating detectors.
Also the time responce of the RPC, XPC and VETO detectors is expected to be very short because RPC, XPC and VETO are based on the same resistive plate chambers technology.

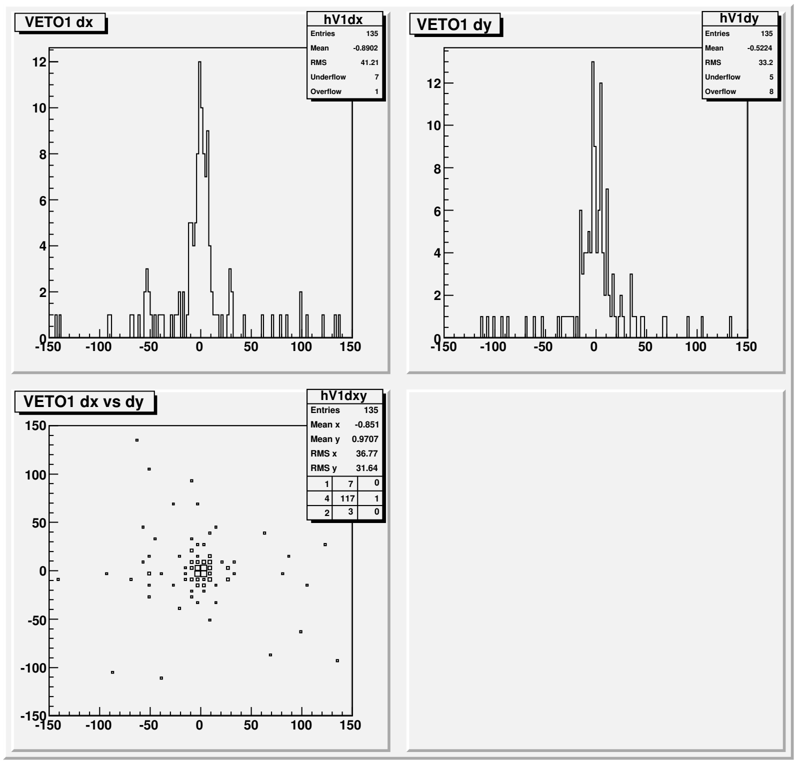

Figure 11: Residual between the OpRec track prediction and the VETO measurement for the outer plane with the "large angle" MC sample.

The situation is radically different for the HPT detectors because of the slow drift of the ionisation in the HPT tubes and hence the large delays of the signals with respect to t_0, of the order of 1000–2000 ns. Hence the OPERA DAQ in Fall 07 was using a rather large time window to record electronic signals and all signals falling inside this window were put together to build an OPERA event.

Fig. 16 shows the delay between each VETO hit and the average time of all the hits of the TT, RPC and XPC detectors, the detectors with a fast time responce, for extraction 388: clearly the OPERA DAQ was using a $\pm$ 3000 ns "effective" time window to cluster the electronic detectors signals while the delay of the VETO hits was significantly smaller, of the order of 500 ns. The VETO hits of the peak close to a 0 ns delay are correlated in time with hits in others OPERA electronic detectors while the rest are not and represent a source of "noise" to the OPERA events (as can be seen in the upper part of fig. 4).

Fig. 17 shows that the delay was further increased to $\pm$ 6000 ns in extraction 412. The width of this time window is strongly correlated with the fraction of OPERA events having at least one hit in the VETO. At the beginning of the Fall 07 data taking period, while the HPT were not yet fully embedded in the OPERA readout, the DAQ time window was set to 500 ns and in this case the fraction of OPERA events with at least one hit in the VETO was ~ 5 %. Later on this fraction increased at the ~ 15 % level and then again at the ~ 30 % level, changes likely correlated with the increase of the time window first to 3000 ns and then to 6000 ns.

In the rush time of the data taking period we decided to keep only VETO hits

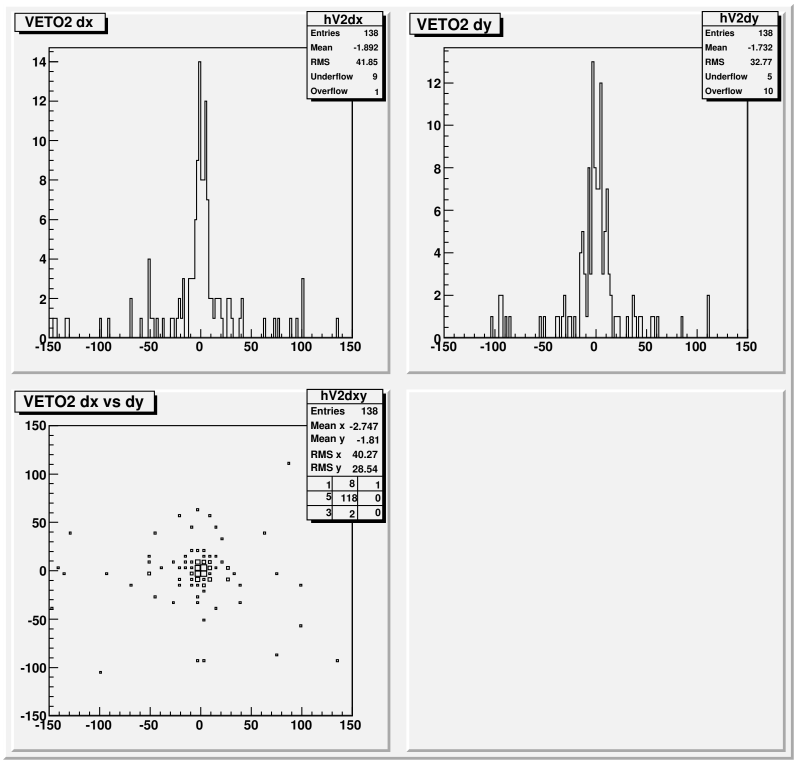

Figure 12: Residual between the OpRec track prediction and the VETO measurement for the inner plane with the “large angle” MC sample.

within a ± 500 ns time window from the average time of the hits of the TT, RPC and XPC detectors. This “time filtering” was applied at the offline level. In this way any loss of efficiency due to an improperly shaped time window can be recovered performing a new reconstruction of the already recorded data. After this filtering the fraction of OPERA events with at least a hit in the VETO dropped again below the 5 % level i.e. the “noise” level in the VETO was largely reduced without any significan loss of efficiency.

Fig. 18 shows in more detail the time structure of the delay between the VETO hits and the average time of the hits of the TT, RPC and XPC detectors. Clearly the distribution is not centred on 0 and it looks like some hits can arrive with more that 500 ns of delay. The shift away from 0 can be attributed to the following main factors:

- the delay needed to process the External Trigger signal which is then sent to the VETO controllers (this delay is absent for the TT, RPC and XPC controllers because they are not using an External Trigger signal)

- the delay introduced by the cables bringing the clock signal to the VETO controllers (this delay is corrected for in the case of the TT, RPC and XPC controllers)

Hence for the reprocessing of the Fall 07 data we decided to use an asymmetic time window set from + 0 ns up to + 700 ns. The delay of the VETO hits after this cut is shown in the left part of fig. 19 for extractions 414–417, where the External Trigger

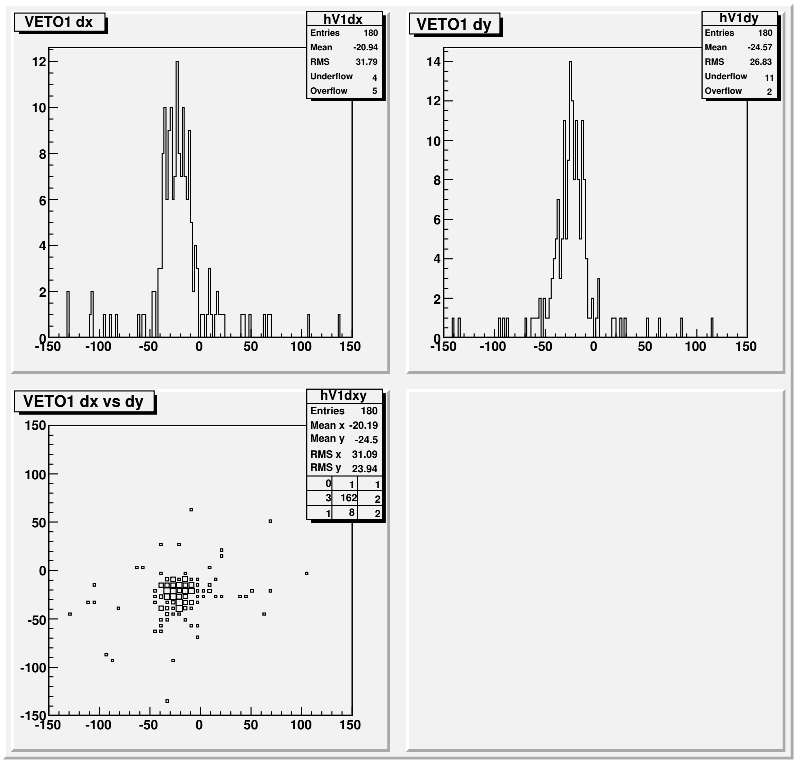

Figure 13: Residual between the OpRec track prediction and the VETO measurement for the outer plane with a cosmic data sample.

signal was processed by a set of NIM modules, and in the right part of fig. 19 for extractions 430–431, where the External Trigger signal was processed by a suitably developped trigger board. The double peak structure, with a "satellite" peak centered at $\sim$ 600 ns, obtained using the NIM modules is unexpected. This "satellite" peak is not present in the data recorded with the devoted trigger board.

Just to have a few numbers in hand let us consider the specific case of extration 430:

- 14486 is the total number of recorded events for this particular extraction
- 496 events have at least one hit in the VETO after the asymmetic time filtering described just above
- 65 of these 496 events are clean cosmic events seen both by the VETO and the TT
- so the fraction of events with activity in the VETO not correlated with the rest of the OPERA electronic detectors is at most 496-65/14486 i.e. 3 %

so at most 3 % of the OPERA events may have at least one uncorrelated hit ANYWHERE in the VETO which has an active surface of at least 900 $\times$ 900 cm^2. If, as suggested by the rms of fig. 13 and 14, we consider only a 30 $\times$ 30 cm^2 area to look for hits correlated in space with the track crossing the VETO volume we should have a further reduction of a factor of 1 / 30 on the fraction of events with accidental hit(s)

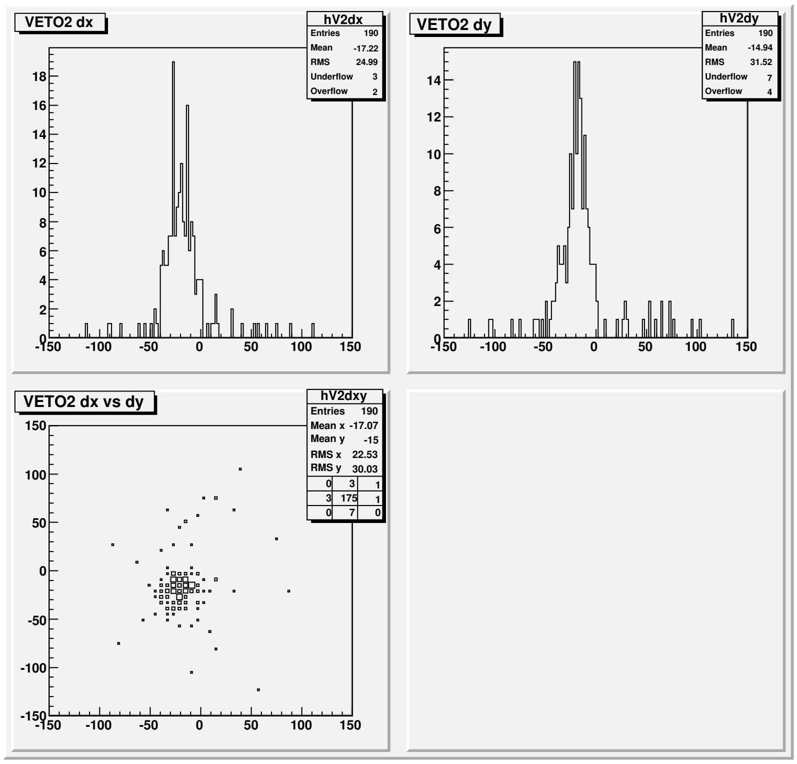

Figure 14: Residual between the OpRec track prediction and the VETO measurement for the inner plane with a cosmic data sample.

in the VETO.
So the overall fraction of OPERA events with accidental hit(s) in the VETO is at the 0.1 % level.

We can also illustrate graphycally the effect of the "time filtering" algorithm. The upper plot of fig. 4 shows the first interaction inside the OPERA target observed in Fall 07 (extraction 385, event 173520769), the reconstruction was performed with the "standard" OPERA reconstruction code available at the time extraction 385 was recorded. Some "noise" is obvious on the VETO detector. The lower plot of fig. 4 shows the same event reconstructed with an "intermediate" version of the OPERA reconstruction code implementing the "time filtering" of the VETO hits. It is apparent that all the "noisy" hits are removed by the time filtering hence these hits where not correlated in time with the other hits seen in the TT, RPC and XPC detectors.

5 VETO efficiency

The overall VETO efficiency is computed as the fraction of OpRec 3D tracks crossing the VETO active volume leaving at least one hit in the VETO. Similarly the efficiency of the inner (outer) plane is defined as the fraction of OpRec 3D tracks crossing the inner (outer) plane active volume leaving at least one hit in the inner (outer) plane. In this note the efficiency has been estimated using cosmic ray tracks. The efficiency is computed for each extraction i.e. using all the OpRec tracks recorded in one extraction. Theoretically one extraction should correspond to 12 hours of data taking but

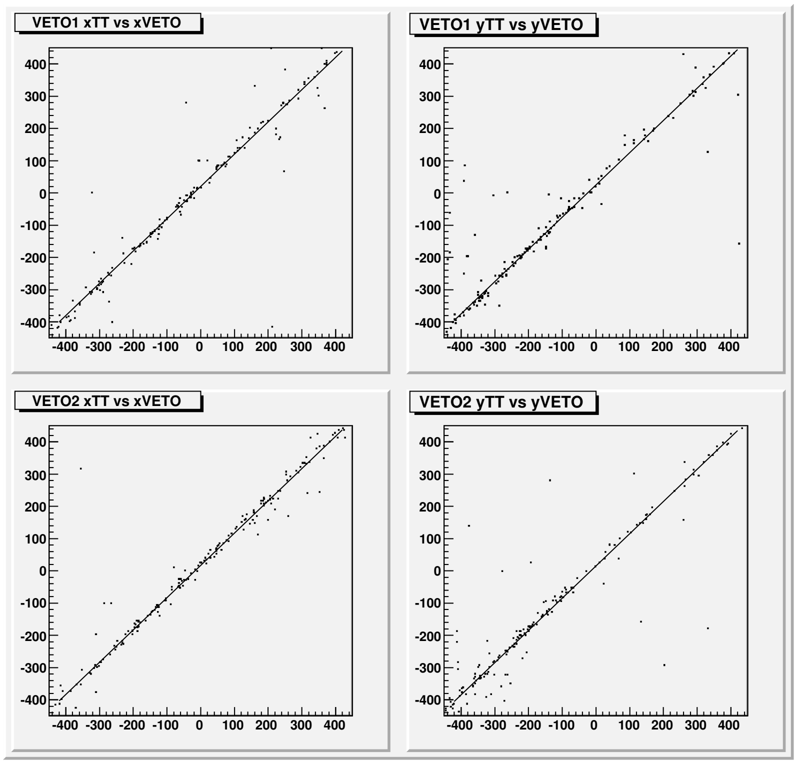

Figure 15: Correlation between the OpRec track prediction and the VETO measurement for the outer and inner plane with a cosmic data sample.

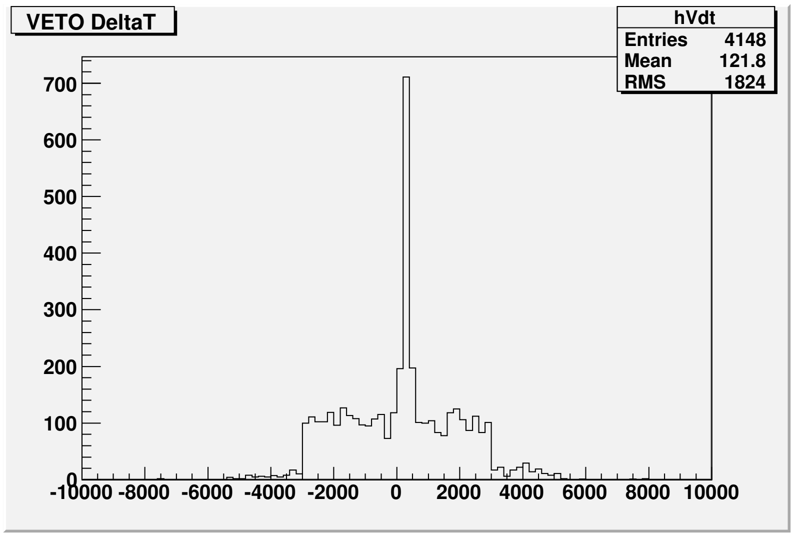

Figure 16: Delay of the VETO hits (w.r.t. the RPC, XPC and TT hits) for extraction 388.

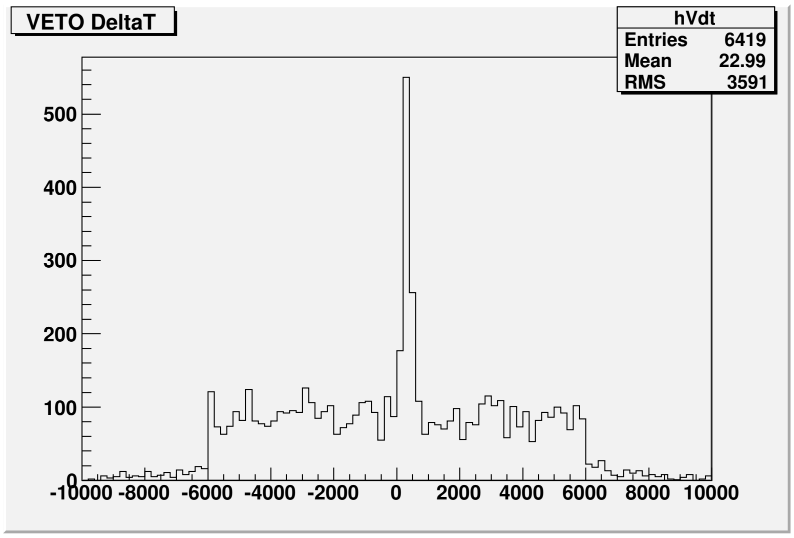

Figure 17: Delay of the VETO hits (w.r.t. the RPC, XPC and TT hits) for extraction 412.

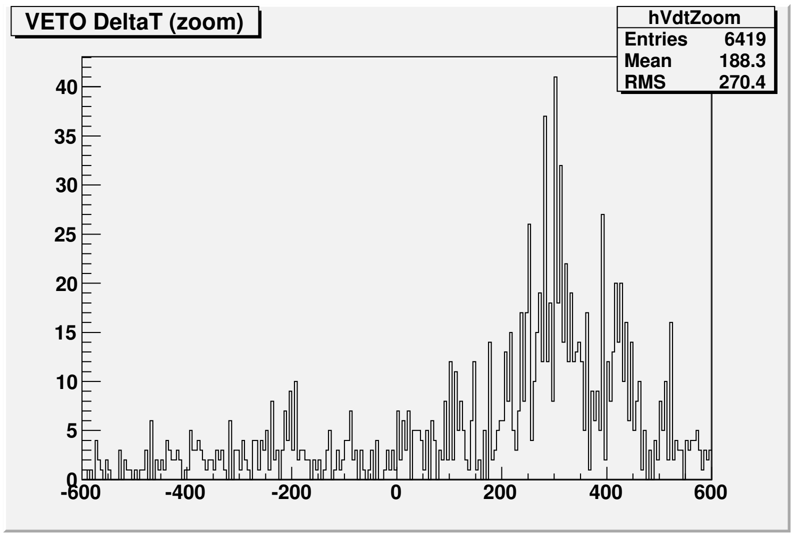

Figure 18: Delay of the VETO hits (w.r.t. the RPC, XPC and TT hits) for extraction 412 with an expanded time scale w.r.t. fig. 17.

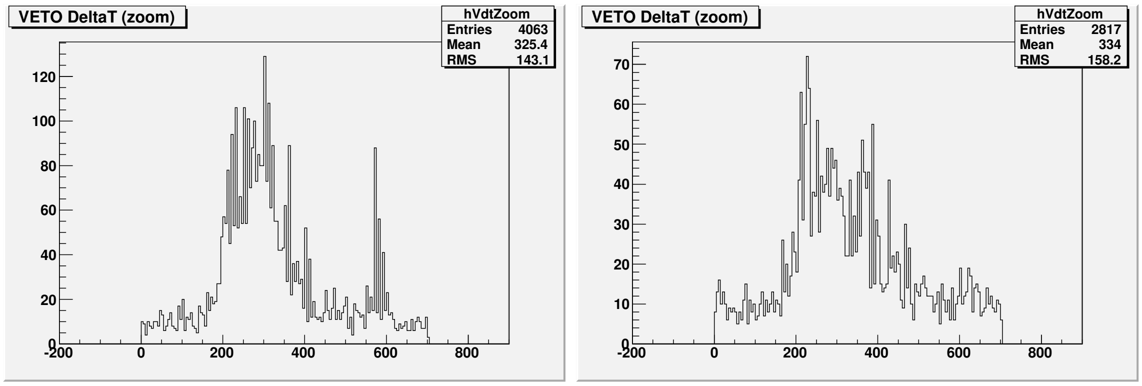

Figure 19: Delay of the VETO hits (w.r.t. the RPC, XPC and TT hits) for extractions 414–417, left, and 430–431, right, respectively.

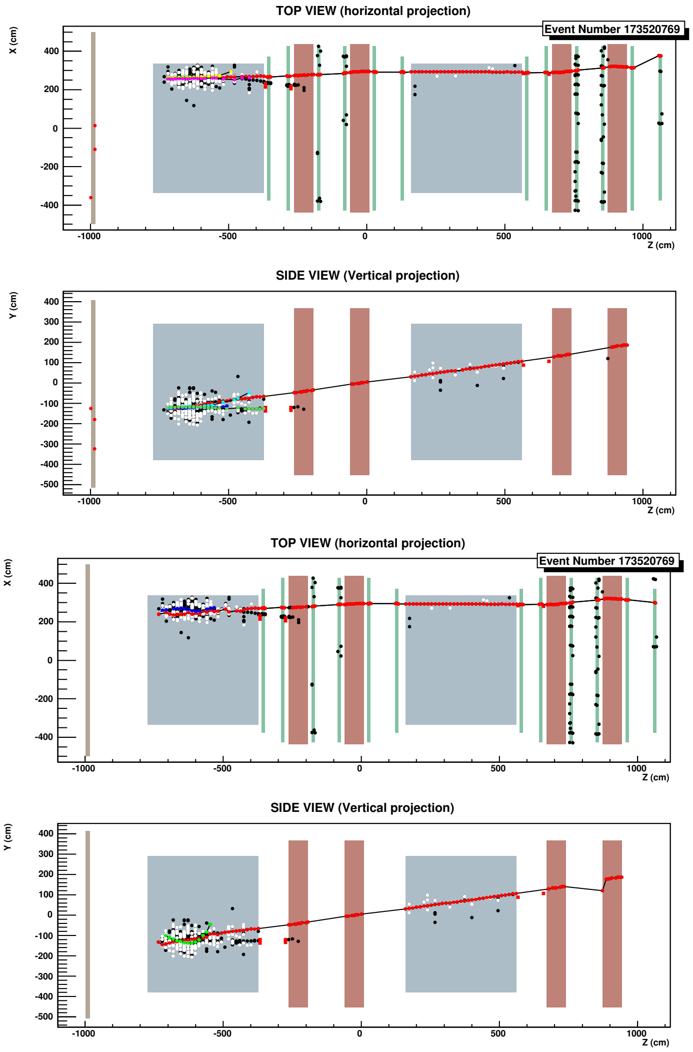

Figure 20: The upper plot shows the first interaction inside the OPERA target observed in Fall 07. No time filtering of the VETO hits was applied. The same event after time filtering of the VETO hits is shown in the lower plot.

in practice, due to frequents "hickup" of the extraction control software, this almost never happens. So each extraction has a different "statistical weight".

The active volume of each VETO plane is worked out knowing:

- the position of the corridor lower end of each plane;
- the number of strips of each plane;
- the strip pitch;

according to the aligment studies presented in this report there is a reasonable correlation between the x and y coordinates measured by VETO and TT and so the first point is under reasonable control. The second point is trivial. The third is known to a good accuracy but we should keep in mind that a 0.1 mm inaccuracy propagated over 100 strips result in a 1 cm shift.

During the Fall 07 data taking period the inner VETO plane was operated setting the high voltage at 5.7 kV and with a threshould for both vertical and horizontal strips set at $\pm$ 50 mV. In these conditions efficiencies ranging between 70 % and 45 % where observed and the reason of the rather large variation not understood.

The analysis of the efficiency as a function of the atmospheric preasure recorded during the extraction seems to provide some qualitative understanding about what is going on. The analysis was performed for the inner VETO plane selecting extractions where the plane worked in a satisfactory way (no controller disconnected from the DAQ during the extraction, as an example). A similar analysis could be performed also for the outer plane but the conditioning of the outer plane turned out to be more difficult and this makes the process of selecting extractions where the plane worked satisfactorily much more difficult.

The efficiency as a function of the atmospheric preasure shown in fig. 21: the error on the efficiency is due to the statistical error on the number of OpRec 3D tracks crossing the inner plane volume. The error on the atmosferic preasure is the rms of the distribution of the preasure measured once per hour over the full extraction time. Fig. 21 suggests that poor efficiency of the VETO inner plane seems to be related to high atmosferic preasure while low preasure is giving better efficiency. This can be understood by the different amount of ionization produced under the same electric field applied if the preasure of the gas being ionized is changed [2]. We could then define an effective HV value, V_{eff}, at a preasure P and at a temperature T, linked to the applied HV value V_0, at a preasure P_0 and at a temperature T_0, by the following formula:

$$V_{eff} = \frac{P_0}{P}\frac{T}{T_0}V_0, \tag{1}$$

from this formula we see that V_{eff} increases ad P decreases and hence the efficiency increases as the atmosferic preasure decrease.

6 Conclusions and future prospects

The readout setup used for the VETO commissioning in Fall 07 was described. The VETO aligment and mistag probability were studied using cosmic ray tracks.

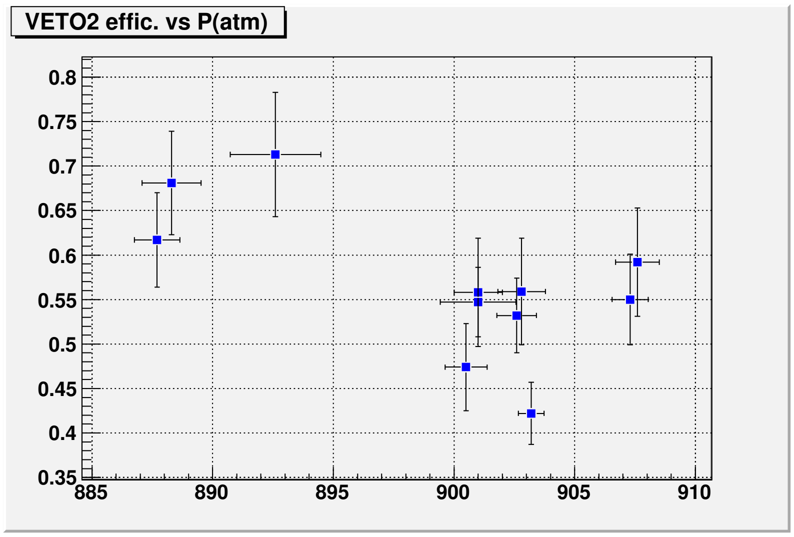

Figure 21: VETO inner plane efficiency vs atmospheric preassure.

A preliminary study of the VETO efficiency based on cosmic ray tracks was also performed. This study shows the relevance of an accurate control of the applied HV as a function of the atmospheric preasure in order to stabilize the VETO efficiency.
Under apropriate conditions ~ 70 % efficiency for the inner plane was reached with the current hardware and DAQ setup.
This would translate in an efficiency at the 90 % lever for the two VETO planes in OR. This expectation will be tested in a devoted data taking period early next year.

Acknowledgements

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List of Figures