January 25, 2000

Study of the Vacuum Veto System (VVS) for CKM

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I) Introduction

The CKM Veto system has 3 components, the Vacuum Veto System (VVS) which surrounds the Fiducial Volume of the kaon decay studied, the Forward Veto System (FVS) at the very front of the apparatus, and the Hole Veto System (HVS) which covers the non-interacting beam hole as described in the proposal [1]. They constitute a major part of our detector in the detection of the background which is critical in our study. In this note we address the VVS.

II) Study of Cracks between modules of Vacuum Veto System VVS

1) Geometry used to study the cracks of the VVS

A toy VVS rotated by 90deg comparativly to its position in the VVS has been used. This was done in order to shoot the background particle directly at the VVS.

For that study we have used only 2 sectors of the VVS the sectors A and B . Each sector has a 40cm depth through which the particle travels and should be vetoed, with a surface of entry of dimension Dx=Dy=200cm. It is made of 331 Sc/Pb sandwiches 5mm Sc +1mm Pb) They are hanging in a containing Frame of Steel with a top wall 12mm thick carrying the weight), a bottom wall 3mm thick, and side walls 6mm thick. Those separating walls

between 2 adjacent sectors are piling up 2*6mm=12mm of steel constituting the cracks encountered by the particle, namely regions without active detecting material.

The parameters involved in the detection efficiency will be studied extensively at and around the cracks. Once the parameters understood and fixed we will extend our study to the whole region covered by the modules.

2) The Parameters

We are measuring the total energy left in the active material of two adjacent modules A and B by an icident γ. This was done for different incident energies of the γ. The energy range investigated extends between 15MeV and 1GeV. The particle studied are leptons, mostly γ's but also e$\pm$, they are found in the most dangerous Background we could think of. In that study the region lighted by the incoming particles was centered on the crack and extended in each side of the crack to xvertex=0 $\pm$ 5cm.

The parameters considered were:

- 1) The θ angle of the γ in various energy ranges, the actual angles are discussed here (whereas, it is their complement to 90 deg which will be used in the simulations, as should be in such a rotated modules
- 2) The thickness of the module container facing the incoming particle
- 3) The material used for the module container facing the particle, a plastic being an alternative to the original steel
- 4) The importance, for low energy γ's, of energy cutoff used in the simulation program.
- 5) The Energy Threshold for the signal, namely the minimum value of the energy that can be detected by the apparatus

Points 1), 2) and 3) being different ways to vary the number of radiation length seen by the incoming γ, 4) dealing with the best tuning of the MonteCarlo to the data in order to represent the physics and 5) dealing with the actual measurement apparatus. Different angle ranges were considered

depending on the incident energy considered. The angle ranges at the various energies was given by the kinematics of one of the main Background, the

decay $K \to \pi^+\pi^0$; $\pi^0 \to \gamma\gamma$. This background is particularly dangeourous since if undetected the two γ can fake the $\nu\bar{\nu}$ of the rare decay under study namely, $K \to \pi^+\nu\bar{\nu}$, and he too has a π^+ in the decay, furthermore its branching ratio is BR=21% versus $\simeq 10^{-11}$ for the rare decay under study. Its kinematic is slightly different being a set of 2 two-body decays instead of a three body decay, but it can also inform on many backgrounds which often do contain γ's or $e\pm$. The ranges of angular distributions of the photons at

different energies were obtained from Peter's fast MonteCarlo EXP, running 1M events at a time. The cuts applied in Exp being, a π^+ of energy above 12GeV, (required by RICH) and the vertex within the range z=[20m:40m] (the fiducial volume. They are given in the Figure 1

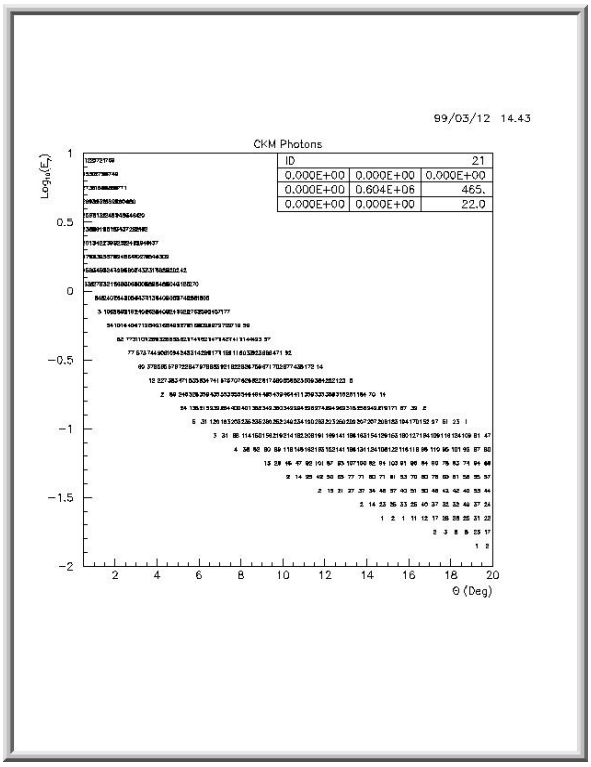

Figure 1: The energy versus angle ranges distribution for the γ in the reaction $K \to \pi^+\pi^0$; $\pi^0 \to \gamma\gamma$ as obtained from EXP MonteCarlo, the Energy is shown in a logarithmic scale.

Geant was the simulation program used, with a cutoff energy of 1MeV for hadrons and 0.5 MeV for leptons.

A set of γ's were sent on our toy detector made of 2 modules, at three different θ angles. The angles covered being energy dependant and dictated by the Exp results. The inefficiencies obtained were checked against the SPEC given in the proposal [1].

The angles were θ_{min}, θ_{max} and θ_{med}, where Θ_{med} is about the central value in the angle range for that energy. For some energy ranges it was enough to run at two angles as mentionned in those cases, the depth of the sector crossed by the particle, being angle dependant.

The depth of the sectors has also been changed directly, 2 depth 40cm and 80cm were studied. Depending on the θ angle, and on the position of the vertex, the resulting energy left in the scintillator of one sector could be bigger than the energy left in the other sector, but we got an overall sum of energies left in the module which stayed almost constant, except for those events starting at the crack, with a θ=0deg angle showing that the photon produced at the center of the crack and perpendicular to it, showers and is absorbed by the steel of the crack. It was leaving too little energy in the scintillator of the sectors A and B located in both side of the crack to be detected, therefore the x distribution was depleted around x=0cm.

At lower energies, $\leq$ 50 MeV and depending on the θ angle, the main Backgrounds came from two sources

1)Whenever the photon interacted in the frame and the products of interaction were back-scattered to death either in the steel of the frame or in the lead of the sandwich and never got a chance to enter the Scintillator of the Detector, see Figure 2

This was occuring mainly at lower energies and smaller angles. We should be able to decrease the occuraance of the events starting by the bottom face of the container directly crossed by the particle by decreasing the thickness of the steel and/or choosing a material with a bigger radiation length. Both solutions have been studied below.

2) punch through events , 1 such event has been found the probability of such an event at that energy being ,8.*10*−5).

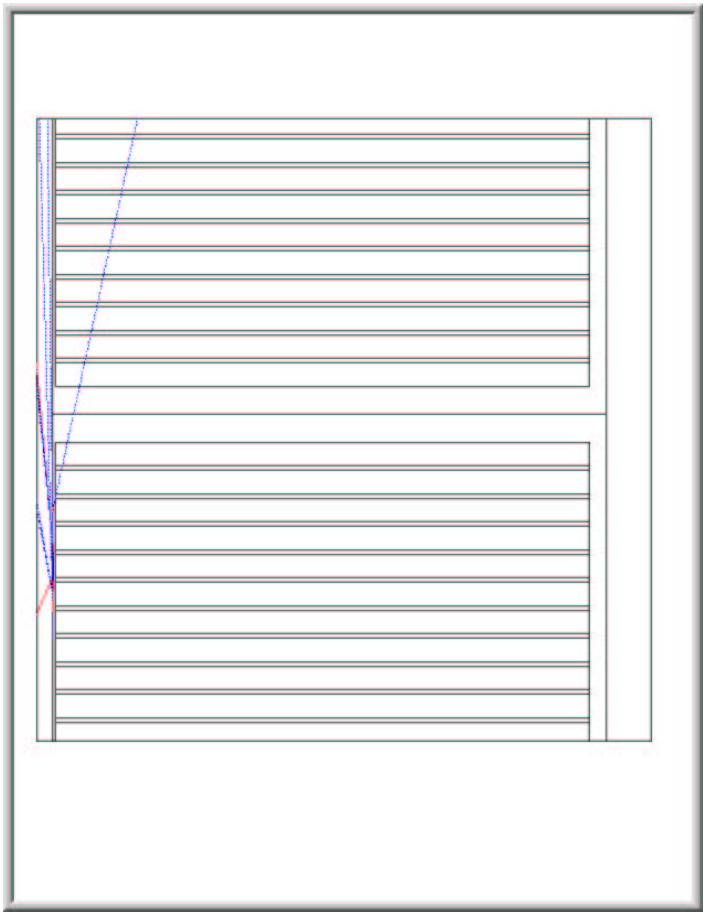

Figure 2: γ Back-Scattered by the Steel of the VVS module container

Below, in Table 1 we show the values obtained for the VVS inefficiencies at various energies, as compared to the SPECS of [1] This has been done for different angles spanning the angle ranges at each energy and for two different thickness of the module container directly facing the γ 3mm and 1mm. This is refered to as the bottom of the container. It appears clearly that the inefficiency is strongly dependant on the θ angle of the photon. Different angles providing different path length into the detecting material and is also dependant on the thickness of the bottom of the container on which the incident particle may back-scattered without leaving any energy in the calorimeter or interact in the steel.

For real low energy γup to 20 MeV, our SPEC =4 10^{-1} is rather low and easy to meet, but for low energy above $\simeq$ 20 MeV our SPEC gets higher and the particles interacting in the steel, the componants of the interaction might not make their way to the scintillator. The 1mm bootom allow to improve significantly the efficiency for γ's below 1 GeV, allowing to meet the SPEC at angles where the 3mm case did not, see the Table 1. At higher energy, however, and as expected, the improvment is not as significant.

The 1mm case has mostly been tried, at the angles which did not meet the SPEC for the 3mm bottom thickness for that γ energy.

The study of the sensitivness the γ energy cutoff used in Geant has been checked for 0.5 MeV, 1MeV and 5MeV energy cutoff at various θ angles and for the 1mm steel thickness of the bottom of the module container. The result obtained corresponds to a decrease in efficiency, smaller than a factor 2 between the 0.5 MeV and 1MeV cutoff and by up to an order of magnitude for the 5MeV cutoff. Therefore an energy cutoff of 1MeV, more realistic than the 0.5 MeV one coupled with a faster simulation, was adopted from now on, for both Hadrons and Leptons.

This has been done for incoming energy γ's of up to 200MeV, at and above that energy the inefficiency becomes stable. The 1MeV cutoff will be used from now on.

3) The Detection inefficiency at the cracks of the VVS

In Table 2 is reported against the SPEC, the VVS efficiency for 2 different energy thresholds, 1MeV and 5 MeV. We use a 1MeV cutoff in Geant compare the detection inefficiencies for various θ angles of the γ both with 1mm steel facing the particle and with 1mm plastic instead.

In the table one can see that although for the E_{th}=1MeV one meets the SPEC and are even better by often as much as an order of magnitude, at all energies, and for all the angles with the dz=1mm plastic and for part of the angles, even for dz=1mm steel, whereas for the E_{th}=5MeV,à la KTeV, we

Energy (GeV)	VVS SPECS	θ	Geant Inefficiency	dz steel
0.0-0.02	$4\ 10^{-1}$	70 deg	$4.8\ 10^{-2}$	3mm
		19.25deg	$5.0\ 10^{-2}$	3mm
		70 deg	$2.62\ 10^{-2}$	1mm
		19.25deg	$2.83\ 10^{-2}$	1mm
0.04-0.06	$3\ 10^{-3}$	40 deg	$3.0\ 10^{-4}$	3mm
		15.5deg	$4.6\ 10^{-3}$	3mm
		9.0 deg	$2.2\ 10^{-2}$	3mm
		15.5deg	$8.0\ 10^{-4}$	1mm
		9.0 deg	$3.0\ 10^{-3}$	1mm
0.1-0.2	$4\ 10^{-4}$	30 deg	$3.0\ 10^{-5}$	3mm
		10 deg	$1.49\ 10^{-3}$	3mm
		5.5 deg	$1.36\ 10^{-2}$	3mm
		10 deg	$1.50\ 10^{-4}$	1mm
		5.5 deg	$3.50\ 10^{-3}$	1mm
0.2-0.4	$1\ 10^{-4}$	14 deg	$7.0\ 10^{-5}$	3mm
		8 deg	$2.0\ 10^{-4}$	3mm
		3.5 deg	$5.22\ 10^{-3}$	3mm
		8 deg	$1.43\ 10^{-5}$	1mm
		3.5 deg	$1.43\ 10^{-3}$	1mm
0.4-1.0	$1\ 10^{-4}$	10 deg	$1.0\ 10^{-5}$	3mm
		4.5 deg	$6.0\ 10^{-5}$	3mm
		2.1 deg	$1.64\ 10^{-3}$	3mm
		2.1 deg	$6.80\ 10^{-4}$	1mm
1.0-3.0	$3\ 10^{-5}$	6. deg	$< 1.0\ 10^{-5}$	3mm
		0.5 deg	$6.37\ 10^{-3}$	3mm
		0.5 deg	$6.8\ 10^{-4}$	1mm

Table 1: VVS inefficiency at various energies, for various θ angles and for a thickness of steel of 3mm and 1mm of module container bottom. The γ energy cutoff adopted in Geant being 0.5 MeV

Energy (GeV)	VVS SPECS	Geant inefficiencies dz=1mm steel vs dz=1mm plastic			
		E_{Thres} Detected	θ deg	Ineff. in dz=1mm steel	Ineff. in dz=1mm plastic
0.0-0.02	$4\ 10^{-1}$	E_{th}=1MeV	70 deg	$1.0\ 10^{-1}$	$3.02\ 10^{-2}$
			30 deg	$1.1\ 10^{-1}$	$3.27\ 10^{-2}$
			19.25 deg	$1.4\ 10^{-1}$	$5.0\ 10^{-2}$
		E_{th}=5MeV	70 deg	$7.2\ 10^{-1}$	$6.68\ 10^{-1}$
			30.0 deg	$7.3\ 10^{-1}$	$6.8\ 10^{-1}$
			19.25deg	$7.4\ 10^{-1}$	$6.8\ 10^{-1}$
0.04-0.06	$3\ 10^{-3}$	E_{th}=1MeV	40 deg	$2.3\ 10^{-3}$	$2.5\ 10^{-5}$
			15.5 deg	$1.71\ 10^{-2}$	$5.7\ 10^{-4}$
			9.0 deg	$1.72\ 10^{-2}$	$< 10^{-}3$
		E_{th}=5MeV	40 deg	$5.1\ 10^{-2}$	$5.6\ 10^{-3}$
			15.5 deg	$3.6\ 10^{-2}$	$2.2\ 10^{-2}$
			9.0 deg	$1.06\ 10^{-1}$	
0.1-0.2	$4\ 10^{-4}$	E_{th}=1MeV	30 deg	$4.8\ 10^{-4}$	$2.0\ 10^{-5}$
			10 deg	$5.0\ 10^{-4}$	$2.4\ 10^{-4}$
			5.5 deg	$9.8\ 10^{-3}$	$< 10^{-4}$
		E_{th}=5MeV	30 deg	$4.9\ 10^{-4}$	$2.4\ 10^{-4}$
			10 deg	$7.3\ 10^{-3}$	$6.8\ 10^{-3}$
			5.5 deg	$7.3\ 10^{-2}$	

Table 2: VVS γ Detection Inefficiency at different energies, for 2 threshold values of the threshold on the detected energy E_{th} as obtained for the usual values of the γ θ angles at those energies and for steel and plastic of a thickness of 1mm of the module container facing the beam. The γ energy cutoff adopted in Geant is 1MeV for all hadrons and leptons, including gammas.

are often short to make it for the medium angles and below even for dz=1mm plastic. In Figure 3, below, we have plotted the results shown in Table 2 for 1mm plastic and E_{th}-1MeV

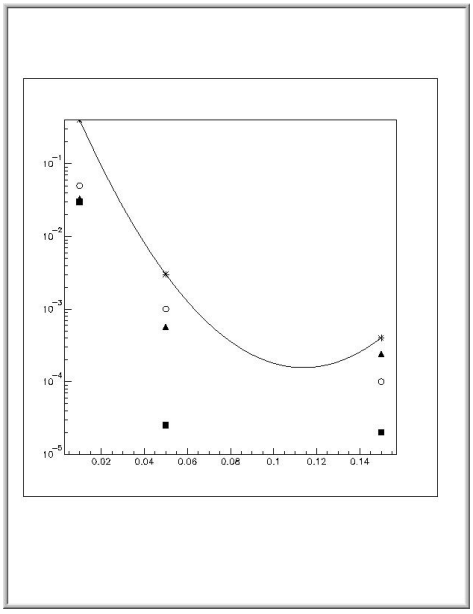

Figure 3: The inefficiency as function of the γ energy for dz=1mm plastic, and at different angles, the stars represent the SPECS at those energy, the full squares the SPECS for the maximum angle at various energy, the full triangles the medium angle and the empty circles the minimum angle. One can see that those inefficiencies are better than the SPECS everywhere, being below the curve joining the SPECS

To summarize, we have first studied at length the most sensitive regions of the VVS, namely, the cracks with a region of ±5cm around them, there are about 10 of those regions which in the calorimeter 20meters length corresponds to the most sensitive 5of the whole detector surface. We have defined the parameters of interest during that study and found that the θ angle plays an important role, especially at medium energy where the SPEC requirements are high comparatively to the requirements at low energy (see Table 1 and Table 2). Particles coming with a small angle on passive material having a bigger probability to be missed, we will tilt our apparatus to avoid

those limiting angles. The thickness and material of the module container at the particle incidence plays also an important role. It defines the number of radiation length on which the particle looses its energy before reaching the active material of the detector. In fact 1mm steel does contains > 22times the number of radiation length than 1mm of plastic. The energy threshold of the detection is also an important parameter, at a 1MeV threshold we reach detection efficiencies better than the SPEC everywhere, whereas with the 5 MeV detection threshold adopted by KTeV, part of the medium angles and below do not reach the SPEC at energies in the region above 100 MeV and below 1 GeV. However, in KTeV, the detected energy span was reaching values higher by an order of magnitude than in CKM. Those considerations will be taken into account in the next part of the study involving the body of the modules as well.

III)Study of the VVS Modules Inefficiency

1) Geometry adopted for the Modules

This study will be done using again a toy detector, but this time the face of the module 2 modules will be half the size the other half between them will be void.

Here too we will rotate the modules by 90 deg. with respect with their position in VVS in order to shoot directly the background γ at them. The set of 2 modules separated by a void is shown in Figure 4 together with a detected event.

The part of the modules facing the particle will therefore, be DX*DY=100cm*100cm and the void 100cm*100cm between them. The Z dimension will be kept 40cm. The void would be seen by γ incoming at an angle θ with tg(θ)=40cm/100cm$\leq$1/2, namely of $\simeq$45deg, first proposed by Erik Ramberg. [1]. As can be seen in Figure 1 and in Table 1 and Table 2 the angle span by the γ of energies $\geq$50MeV from the main background, namely $K \to \pi^+\pi^0; \pi^0 \to \gamma\gamma$ is [>0.5deg:40deg]. For γs with energy below 50 MeV, the requirements being rather low, are easily met but will be studied in detail as well.

[1]here again we are addressing the angle and simulating the complement to 90deg to the angle, which correponds to rotating the geometry used

If that indeed appears to be true, this will allow to use half the modules in VVS and therefore half the material, half the electronics and will cut in cost as well as in weight.

But for angles below 45 deg, the detector has a lower detection efficiency for particles coming at a small angle, those particles just do not have a chance to leave energy in the active material. In order to avoid those small angles the detector shown in Figure 4 is tilted by 17 mrad.

Therefore we are studying the inefficiencies using a set of 2 modules of dimension Dx*Dy=100cm*100cm and DZ=40cm tilted by 17mrd. Those two modules are embedded in a Frame, the back of the frame being 12mm thick and tilted by 17mrd as well as the front of the frame made of 1mm plastic.

Each of the Sc/Pb sandwiches is shifted in order to follow the tilt, and they have the same composition as before, namely, 5mm(Sc)+1mm(Pb), now we have only 165 such sandwiches in each module half long.

There is an extra plate on each side of the module. On one side it is a 6mm steel plate and is part of the frame supporting the module. On the other side, the side facing the particle, it is an half way through plate, made of 6mm steel and supporting the sandwiches The second half being hollow (contains air) and is limited by 1mm of plastic scintillator since it has a chance to be hit by the photons. We will show a blown-up picture in Figure 5 of the half way through plate, seen by the incoming particle on module A, for the event shown in Figure 4.

In Figure 6 one can see the particle which exits the module A through the 6mm plate of steel.

The 100cm void between modules has been centered at 0cm, module A being on one side of the void (centered at +100cm), module B on the other side(centered at -100cm).

1) Study of the Inefficiency of the module

The γs will sent in a range of $\pm$100cm around the center at 0cm, this will allow to cover the hole and half of each modules A and B with their containing materials.

The parameters values are taken from the study on the crack in section

Energy (GeV)	VVS SPECS	θ	Geant Inefficiency
0.0-0.02	4 10^{-1}	19.25-70 deg	$0.09 - 4.4\ 10^{-1}$
0.04-0.06	3 10^{-3}	9-40 deg	$2\ 10^{-3} - 2.25\ 10^{-2}$
0.1-0.2	4 10^{-4}	5.5-30 deg	$3.4\ 10^{-4} - 4.10\ 10^{-3}$
0.2-0.4	1 10^{-4}	3.5-14 deg	$1.0\ 10^{-5} - 7.0\ 10^{-5}$
0.4-1.0	1 10^{-4}	2.1-10 deg	$\leq 3.\ 10^{-5}$
1.0-3.0	3. 10^{-5}	$\geq$0.5-6 deg	$< 1.0\ 10^{-5}$

Table 3: VVS inefficiency of the "Split" module Geometry at various energies, for various θ angles. The γ energy cutoff adopted in Geant being 1MeV for both Hadrons and Lepton, the E_{th}=1MeV

II, a cutoff at 1MeV for all the particles and an Energy threshold of 1MeV as well. A study as function of energy and angles is reported in the Table 3.

Errata: the lower limit of the Inefficiency in the energy range 100-200MeV has been corrected to 4.10 10^{-3} in the Table 3

In the energy range 40MeV-100MeV the inefficiency is now higher at maximum angle, we might have tilted the modules a little bit too much. For the other angles (θ_{med} to θ_{min} the inefficiency is better than the SPEC almost by one order of magnitude. This is true for all the higher higher energies, namely $\geq$200 MeV.

A x distribution of the detected events for the 15 MeV γ shows a deep which widens when going from θ_{min} to θ_{max}, following the increase in inefficiency. At 50 MeV the deep is present for θ_{max} and disappears totally for lower angles as can be seen in Figure 7 again following the efficiency.

At higher energy, the particles are hole-blind, since their θ angle is below 45deg, and no deep is shown at any angle.

V)Conclusion

We have studied the inefficiency of the Vacuum Veto System, using Geant on a couple of modules. We have used mostly γs at various energy in angular ranges dictated at each energy by the kinematics of the background

$K \to \pi^+\pi^0$ with $\pi^0 \to \gamma\gamma$, (Br=21requiring from the vertex to be in the decay volume. That study has been made against the SPECS, stating the inefficiencies we coul live with and summarized in [1]. Our results have been very encouraging as far as simulations are concerned we have now to check our results against "reality" using a prototype and a real beam.

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References

[1] FNAL Proposal, Charged Kaon at the Main Injector,April 15,98.

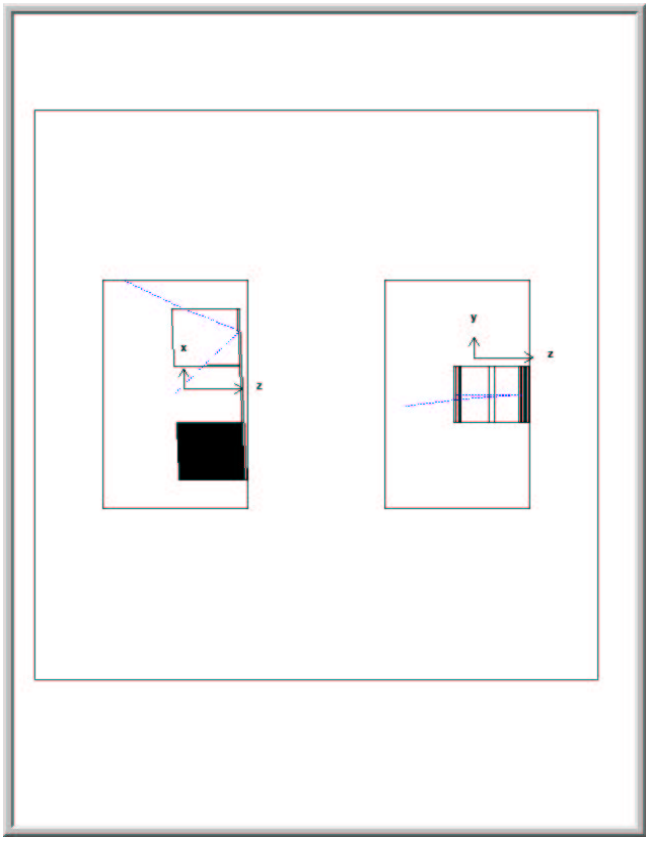

Figure 4: γ A detected event in the two 'split' modules of dimensions DXxDY=100cmx100cm and DZ=40cm of the VVS, separated by a void the size of the module. For this study we have rotated 90 deg to face the incoming particles in Geant

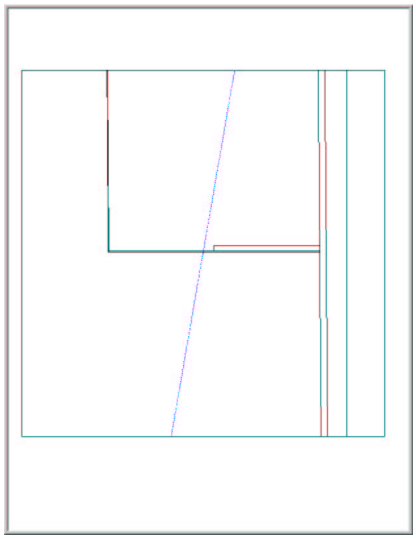

Figure 5: The incoming γ entering the module A through the half-way through plate

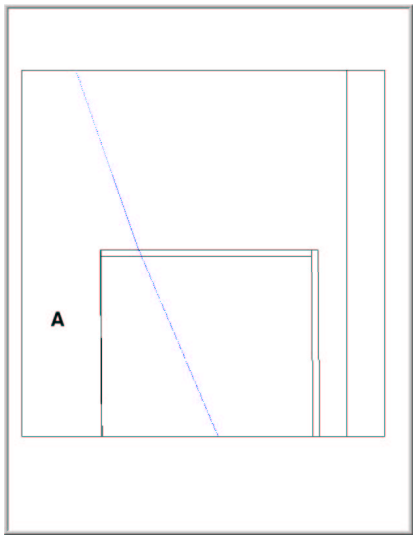

Figure 6: Particle which exits module A through the 6mm plate of steel

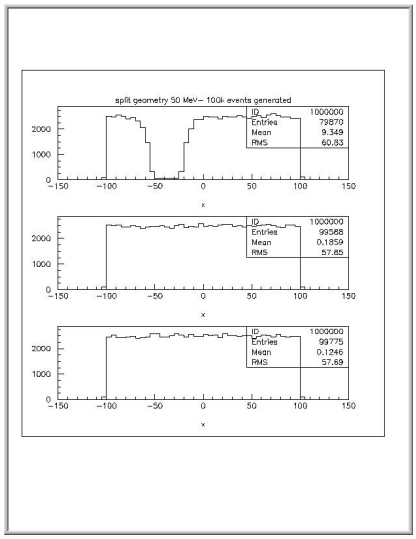

Figure 7: The x distribution of the incoming γ at the entrance of the VVS for the split Geometry