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WHERE TO INSTALL THE I224 DETECTOR

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Abstract:

Recently M.Ambrosio et al have submitted a Letter of Intent to the SPSC, in which they propose to expose a neutrino detector (much smaller but of a type similar to Monolith) to the neutrinos that accompany the M2 muon beam in the CERN North Area. In fact a significant neutrino flux (almost $2\ 10^9$ ν per SPS cycle) is produced during the muon running of COMPASS at full intensity, out of which some $5\ 10^8$ would traverse a detector with a section of 2 meters diameter. These neutrinos pass well below the COMPASS experiment, located in experimental hall EHN2. The neutrino detector will be housed in a new experimental hall, with a floor level, depending on the site chosen, several meters underground. On their way towards the detector, the neutrinos would traverse one or several RF cavities, recuperated from LEP, which may induce neutrino oscillations. Another part of the proposal addresses the question of speed of flight of the neutrinos by measuring the time difference between the neutrino interaction and the time of the muon from the same pion decay. This note compares and proposes suitable locations for the different detector components.

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Introduction

Recently M.Ambrosio et al have submitted a Letter of Intent[1] to the SPSC, in which they propose to expose a neutrino detector (much smaller but of a type similar to Monolith) to the neutrinos that accompany the M2 muon beam in the CERN North Area. In fact a significant neutrino flux (almost 2 10^9 ν per SPS cycle) is produced during the muon running of COMPASS at full intensity, out of which some 5 10^8 would traverse a detector with a section of 2 meters diameter. These neutrinos pass well below the COMPASS experiment, located in experimental hall EHN2. The neutrino detector will be housed in a new experimental hall, with a floor level, depending on the site chosen, several meters underground. On their way towards the detector, the neutrinos would traverse one or several RF cavities, recuperated from LEP, which may induce neutrino oscillations. The schematic layout is shown in Figure 1.

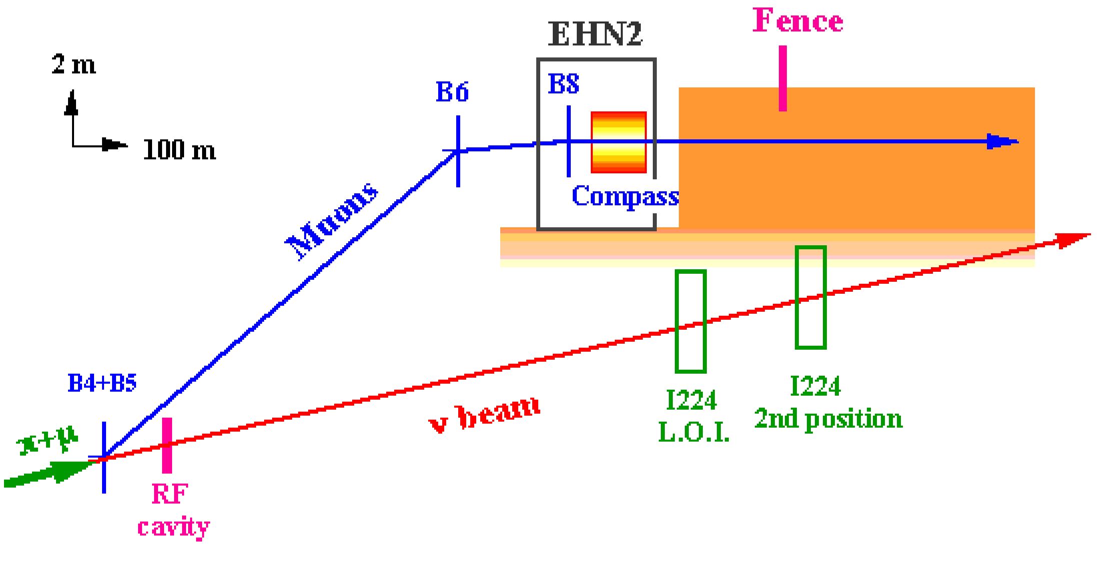

Figure 1: *Schematic layout of the M2 beam with COMPASS and the I224 detector.*

In the figure, the originally proposed location for the new experiment is indicated ('I224 L.O.I.'), just downstream of EHN2. At this point the maximum neutrino flux can be recuperated within a given detector section. However, simulations[2] show that there is a significant muon background, almost 2 10^6 muons per SPS cycle when COMPASS runs at its nominal intensity of 2 10^8 muons per SPS cycle. Also the detector would be quite deep underground. In fact the neutrinos follow a straight line with an upward slope of 9.69 mrad, which is a straight prolongation of the pion decay section in the muon beam. Therefore the new experimental hall floor would be less deep underground if the detector would be located further downstream. In Figure 2 we show the vertical separation between the muon beam leaving the COMPASS experiment and the neutrino axis.

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[1] M.Ambrosio et al., A neutrino experiment at the CERN North Area, CERN/SPSC 2001-019, SPSC/I224

[2] Ch.Iselin, HALO, a computer program to calculate muon halo, CERN 74-17, 29 August 1974.

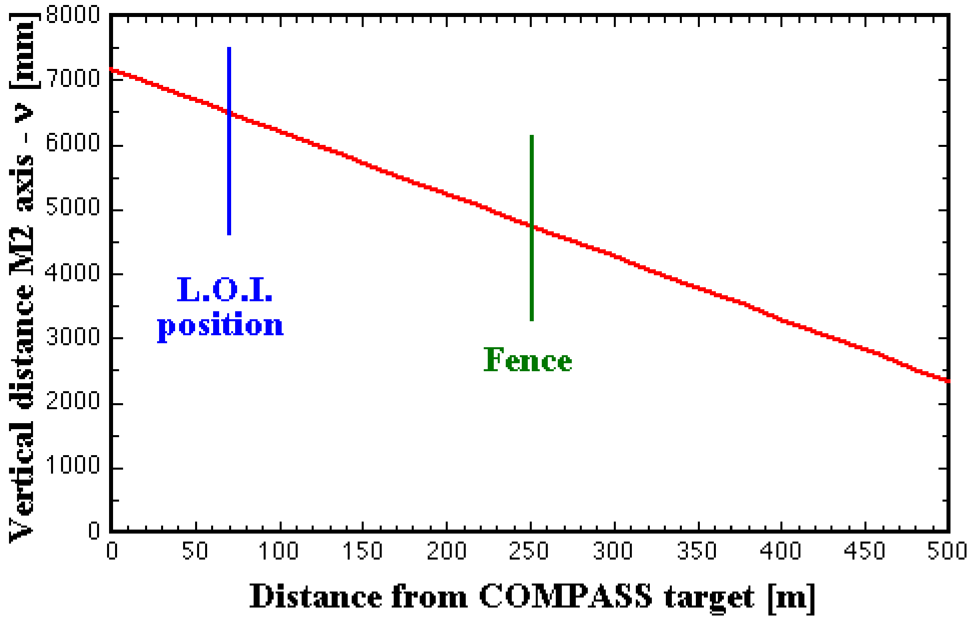

Figure 2: *The vertical separation between the M2 line and the neutrino axis versus Z position*

The green vertical line indicates the fence which limits the **beam area**, i.e**. only downstream of that fence one has access with beam on**[3].

In this note we look for an optimal location of the I224 apparatus as a compromise between various parameters:

1. Neutrino flux,
2. Muon background,
3. Level below ground of new experimental hall,
4. Possibility to construct the hall and install the apparatus during COMPASS runs,
5. Cost. However, no detailed cost estimate will be presented in this document.

Separate chapters address the locations for the main neutrino detector, the RF cavity and the muon tagging detector, respectively.

[3] Please note that in general this applies only above ground level.

1. Optimum place for neutrino detector.

In Figure 3 we show the neutrino flux into the detector as a function of its longitudinal distance from the COMPASS target. The detector section is defined as a circle with 1 meter radius.

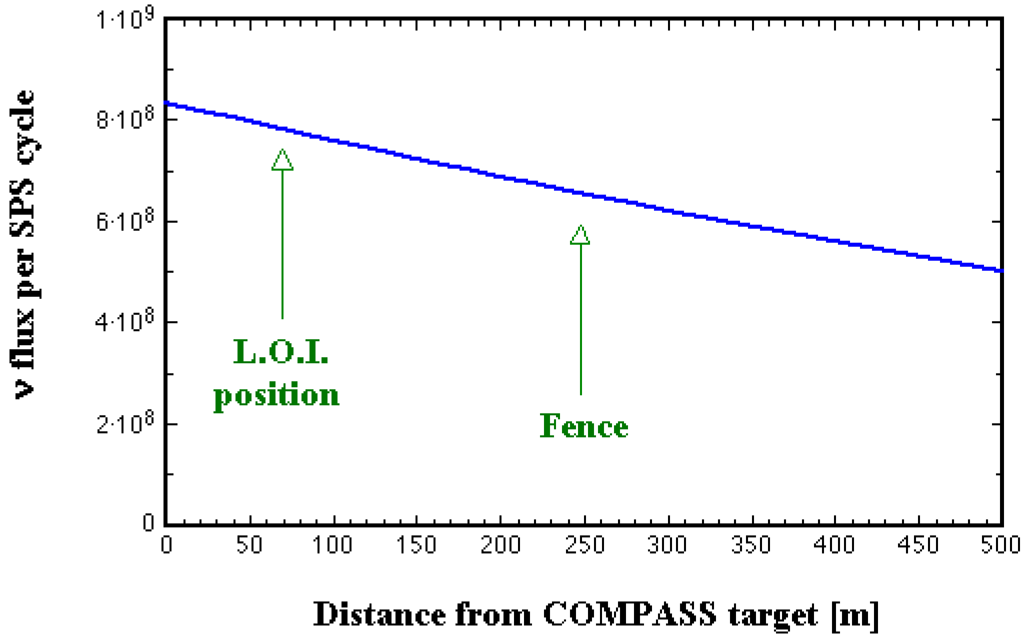

Figure 3 : *Neutrino flux into the I224 detector versus its distance from the COMPASS target.*

The COMPASS target position is defined as 0 meters, the upstream end of the proposed location (in L.O.I I224) at the end of EHN2 is at 70 meters and the first location downstream of the beam area fence is at about 250 meters. At that point the **decrease of neutrino flux** w.r.t. the L.O.I. position is **17%**.

In the L.O.I. the authors mention the significant muon background of about 2 10^6 muons per SPS cycle. Their typical momentum is about 50 GeV/c, according to the simulation, with a maximum close to 90 GeV/c. They come from the pion decay tube and have not yet ranged out. The authors propose to install an iron shield of 25 meters long. This would be difficult to install and be quite costly (at least 1 Meuro). An alternative solution would be to use the ground shield which is already present downstream of EHN2. Using the HALO program we calculated the muon flux as a function of longitudinal position. The result is shown in Figure 4. There is **no background** beyond 450 m.

The flux at the L.O.I. position is almost exclusively muons originating from the pion decay tube (the muons ‘miss’ the vertical bends B4+B5). As their remaining energy is low, they should essentially range out before the location of the fence. However, with increasing distance, the vertical separation between the muons from the COMPASS beam and the neutrino line decreases and some beam muons scatter into the I224 detectors. A minimum is observed in the region around the fence, at a level **below 10^5 muons per SPS cycle**. This **without the need of an iron shield**. In reality the situation may be further optimized by deflecting the muons sideways after the COMPASS target.

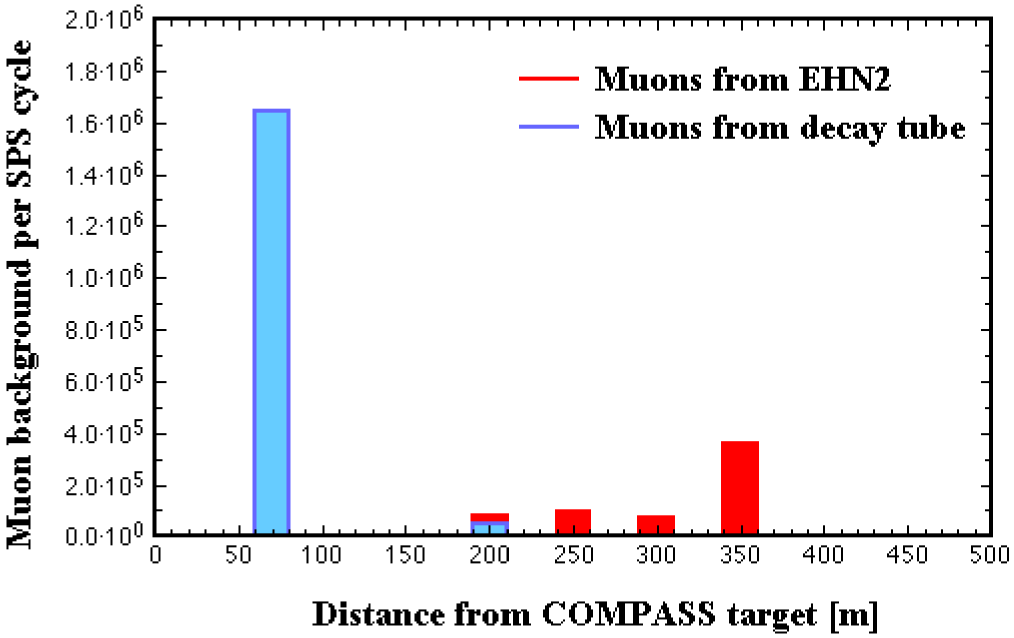

Figure 4 : *The muon background into the I224 detector as a function of its distance from the COMPASS target. The blue bars indicates muons from the decay volume, the red bars punch-through from muons traversing the COMPASS experiment.*

In Figure 5 we show the approximate height of the neutrino beam with respect to the ground level. It is clear that the cost of digging decreases the further downstream the hall is situated. However, there would be some additional cost in terms of road construction. A major advantage of installing the hall just behind the fence of the beam zone is that, with certain constraints, access to the pit is possible with beam on[4]. This location corresponds to the position 1375 to 1405 meters in Beatch beam length and is indicated as 'New position ?' in the figure. It is also the location referred to in the Addendum to the Letter of Intent[5]. The constraints are listed in a memo by TIS/RP[6]. In Figure 6 the momentum spectrum of the neutrinos hitting the detector in this new position is compared with the spectrum at the L.O.I. position.

[4] These constraints imply that the access to the underground cavern must be via a shaft that is displaced laterally by a substantial amount. Also the current in the last vertical bend must be limited by an interlock.

[5] M.Ambrosio et al., Addendum to the Letter of Intent I224, CERN/SPSC 2001-024, SPSC/I224 Add.1, 31 July 2001.

[6] S.Roesler et al., Memorandum, RP Considerations for the site selection of Experiment I224, copy available on the web at http://cern.ch/gatignon/i224rp.ps.

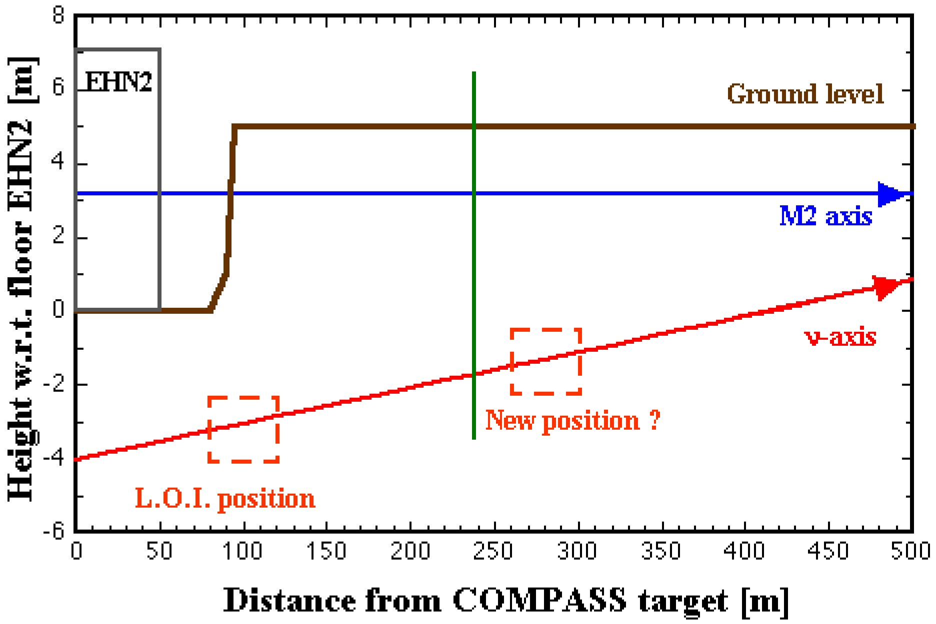

Figure 5: *The level of the neutrino beam w.r.t. the EHN2 experimental hall.*

However, the construction of the hall is still not possible with beam on, therefore it would be cumbersome and more costly[7].

These problems are avoided if the hall is located 600 meters downstream of the end of EHN2, i.e. just behind the CERN perimeter[8]. In that location no muons will reach the detector, even at the highest energies available at the SPS. Therefore no constraints are imposed on access or construction at any time[7]. Also the hall is less deep: the muons pass only 6 meters below ground level. However, there is again a price to pay in neutrino flux: about a factor 2 less than at the L.O.I. location.

There is a location, located some 1100 meters downstream of the end of EHN2, where the neutrinos reach the surface. At this location, still CERN property, a surface building could be installed. This location is also quite close to an existing road. However, at that point the neutrino is reduced to 1/3 of the flux at the L.O.I. location.

[7] Or the COMPASS schedule would have to be adjusted

[8] The land behind the fence is still CERN property over quite some length. Therefore it is not excluded to construct a building in this area, though some negotiation may be involved.

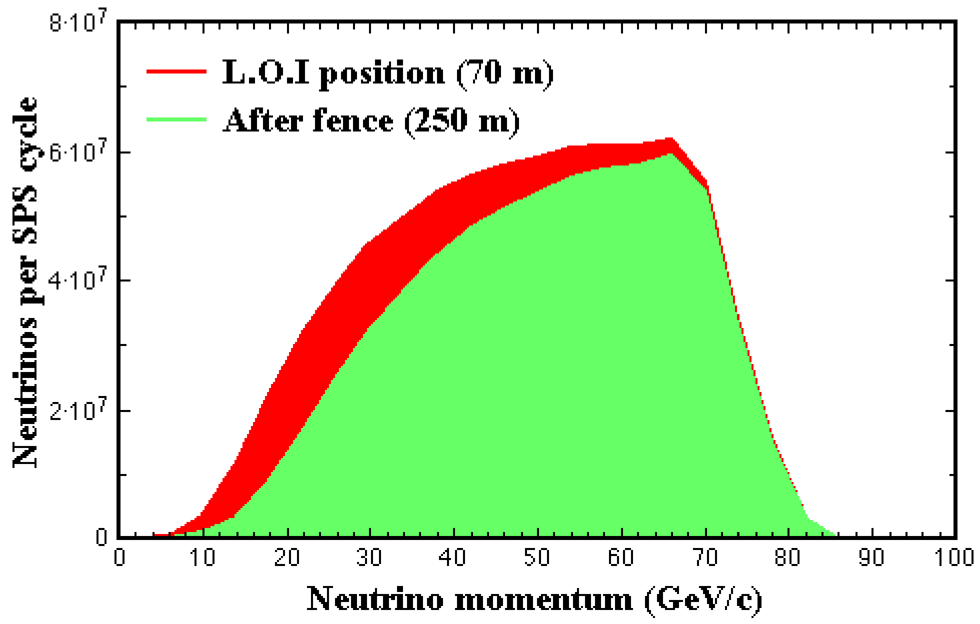

Figure 6: *The neutrino momentum spectrum at the suggested location (behind the fence) compared with the one at the L.O.I. position*

2. The RF cavity

The RF cavity should be located at a position sufficiently downstream of Bends 4 and 5 to have sufficient separation between the neutrino line and the M2 vacuum tube (at least 80 cm), but not so far away that the neutrino flux has disappeared into the floor of the tunnel. This position is just below the passage of the river Lion. After informal discussions with some members of the SL/CT group, it seems that the best location is at about 770 meters from the T6 target, more or less at the present location of MIB 1+2, which would have to be displaced slightly.

3. The muon tagging detector

For part of the physics program outlined in the Letter of Intent it is important to compare the time of the neutrino event with the time of the muon from the decay of the same pion. The HALO program allows to check where goes the muon partner to a neutrino that traverses the neutrino detector.

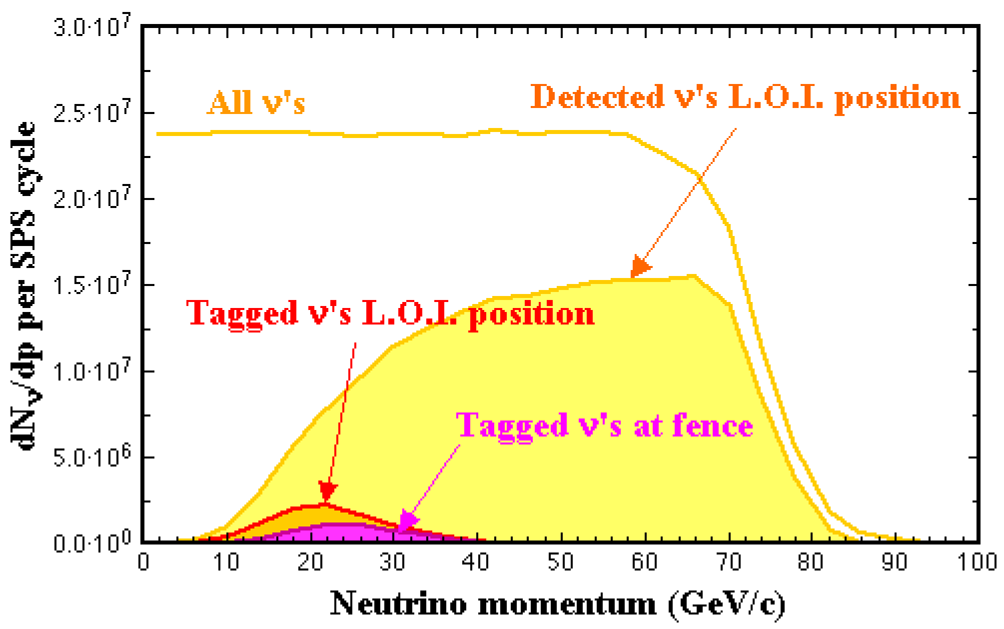

Figure 7: *The neutrino momentum spectra at the neutrino detector, tagged and untagged, at the L.O.I. position, compared with the tagged spectrum at the new proposed location as well as with the spectrum of all muons produced*

In Figure 7 we show the momentum of the neutrinos 'tagged' with a 'good' muon at the COMPASS experiment and compare this with the spectra of all neutrinos produced and of those traversing the neutrino detector. Only about 5% of the muons traversing the detector at the L.O.I. position are accompanied by a 'good' muon in the COMPASS apparatus. For the 2nd location, i.e. behind the fence, this fraction is only about 2.7% of the neutrinos traversing the detector and only 1% of all neutrinos produced. The fraction tagged will be even lower for a detector located behind the CERN fence.

For 'good' muons (i.e. those who never left the nominal aperture of the beam line), the neutrino momentum p_ν and the muon momentum p_μ are related to the parent pion momentum p_π by the relation

$$p_\nu = p_\pi - p_\mu - \Delta E/c$$

where ΔE is the energy loss of the muon in the Beryllium absorber (amounting to about 2.8 GeV). For halo muons (which have traversed material) this relation reduces to

$$p_\nu < p_\pi - p_\mu - \Delta E/c$$

This explains why the tagged neutrinos are concentrated at low momenta. As the neutrinos traversing the detector are rather forward ones, they tend to originate from the highest momentum pion decays (well above the average of 177 GeV/c) and therefore their typical momenta are of the order of 20 GeV/c as expected (177 + Δp_π – 162.8 GeV/c).
However, this disadvantage can probably be recuperated if a 'tagging hodoscope' would be installed in a suitable location, e.g. just downstream of SCRAPER 2, i.e. 719 meters from the center of the T6 primary target.
In Figure 8 we show the X and Y profiles of the muons correlated with a neutrino in the Monolith prototype at the new proposed location (1381 m, i.e. 180 meters from the L.O.I. position).

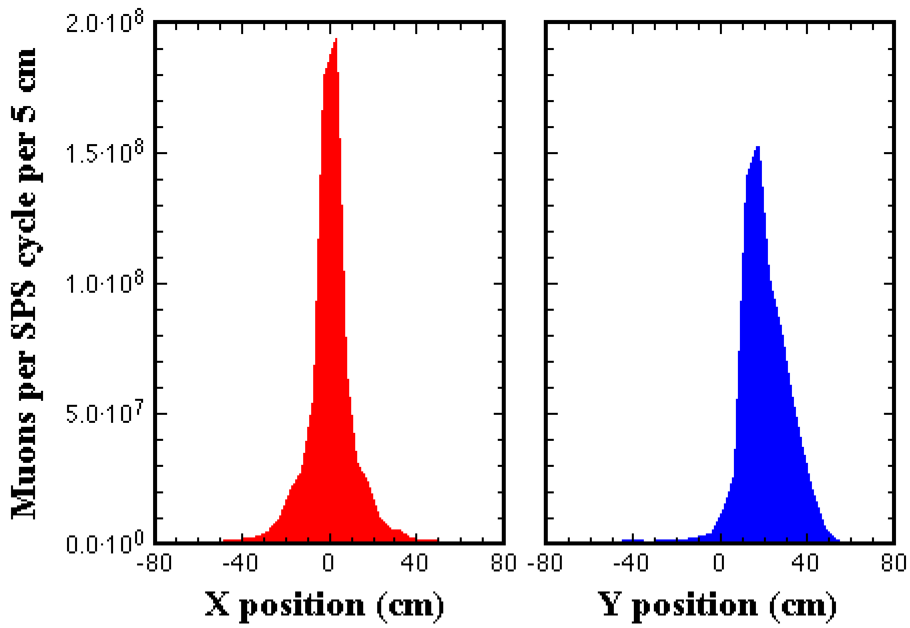

Figure 8: *The profiles in the plane just behind SCRAPER 2 of muons from the same pion decay as a neutrino in the Monolith prototype in the new location.*

A hodoscope covering 1 meter in X and 1 meter in Y would thus allow to tag some 99% of the muons accompanying the useful neutrinos. However, it should be pointed out that this detector should be a rather performant one. In fact the total rates are rather high at that location:

'Good' muons:	about $4 \cdot 10^8$ per spill	with RMS (X x Y) = 2.5 x 2.0 cm
'Halo' muons:	about 10^9 per spill	with RMS (X x Y) = 70 x 50 cm

Therefore at least the central strips of a hodoscope should be rather finely segmented. Please note that the centre of the flux is some 20 cm above the nominal beam axis in the vertical plane! One possible solution may be a Scintillating Fiber tracker (e.g. 1mm fibers), which also offers good time resolution: it seems that resolutions of the order of 300 to 500 psec can be achieved.

Conclusions

The best compromise in terms of neutrino flux and minimum background seems to be the location just behind the CERN fence, i.e. some 200 meters behind EHN2. However, practical considerations and cost lead to a preference for a more downstream location, behind the CERN fence. The fact that construction and installation work is no longer restricted to winter periods may make it more realistic to do the job in a limited time and budget. The neutrino flux just after the CERN fence, 600 meters behind EHN2, is about half the one at the location suggested in the Letter of Intent. This flux is reduced to about 1/3 of the L.O.I. values at the first location, 1100 metres downstream of EHN2, where a substantially cheaper hall at ground level can be considered. The land still belongs to CERN. The latter location is probably the most realistic as an overall compromise between physics performance, time schedules and cost.

Acknowledgements

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