EXPECTED SIGNAL FOR THE TBID AND THE IONIZATION CHAMBERS DOWNSTREAM OF THE CNGS TARGET STATION

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Abstract

Downstream of the carbon graphite target of the CNGS (CERN Neutrinos to Gran Sasso) facility at CERN a secondary emission monitor called TBID (Target Beam Instrumentation Downstream) is installed to measure the multiplicities and the left/right as well as up/down asymmetries of secondary particles from the target. Calculations show that the titanium windows used to close off the TBID vacuum tank might not withstand the highest beam intensities with small spot sizes expected at CNGS, in case the proton beam accidentally misses the 4-5 mm diameter target rods. Therefore it has been suggested to place two ionisation chambers as a backup for the TBID, located left and right of the TBID monitor. Monte Carlo simulations with the particle transport code FLUKA were performed firstly to obtain the fluence of charged particles in the region of interest and secondly to estimate the induced radioactivity (background signal) in this area. This allows to assess the actual signal/noise situation and thus to determine the optimal position of the ionisation chambers. This paper presents the results of these calculations.

THE CNGS MONITORING SYSTEM

Diagnostics for targeting and secondary beam is a crucial part of the CNGS project. For this purpose the T40 target station has been equipped with a TBID (Target Beam Instrumentation Downstream) placed downstream of the target, and two ionization chambers outside the shielding close to the target station [3].

In case of accidental beam displacements in position or angle, many important CNGS components have to be protected, first of all the neck of the horn inner conductor (diameter 18 mm). For this purpose a 1 m long collimator made of boron nitride with a 14 mm diameter opening has been added in the layout, upstream the T40 target.

The TBID is placed 70 cm downstream of the last target rod. The beam profile monitor consists of circular titanium foils of 7.25 cm radius and 12 μm thickness. The foils are perpendicular to the beam axis and when they are crossed by high energetic particles they emit electrons, which are collected on the electrodes, see fig. 1. The purpose of this monitor is to measure the multiplicity (i.e. ratio of number of secondary beam charged particles to number of protons hitting the target), the asymmetry of the secondary hadron beam (i.e. differences in multiplicity between right and left half planes in the horizontal direction, and upper and lower half planes in the vertical direction) and the halo of the secondary hadron beam (i.e. population of the tails of the beam distribution). The vacuum box containing the instrumentation is closed by two titanium windows (250 μm thick), which might not withstand the beam intensity in case of accidental mis-steering of the beam.

The idea, proposed by the CNGS project team, is to put additional ionization chambers as back up instrumentation. Even if the information will be less accurate than the one of the main monitor, the instruments will still remain sensitive to eventual beam misalignments [4].

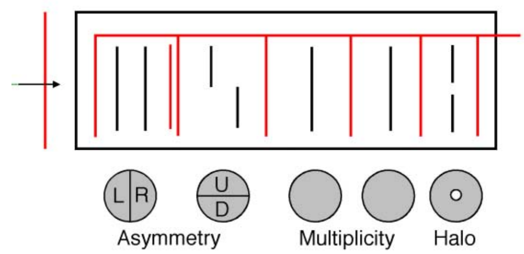

Figure 1: Schematic representation of the TBID: the disks (black) represent secondary emission titanium foil, the red lines represent electrodes.

SIMULATION METHODOLOGY

For the calculations the version 2004 of the FLUKA Monte-Carlo code has been used [1, 2].

As beam parameters a proton energy of 400 GeV and a gaussian beam profile ($\sigma_x = \sigma_y = 530$ μm) have been used in the simulations. In the geometry input the secondary emission titanium foils have been shaped as a compact cylinder of 7.25 cm radius and 144 μm thickness (corresponding to 12 foils). The cylinder itself has been divided in different regions: two half disks have been used to check the horizontal asymmetry of the secondary beam, for nominal beam position (Δx=0 mm) and in case of horizontal displacement (Δx=1 mm, 2 mm, 3 mm, 5 mm, 7 mm, 10 mm). The fluence of particles in the left and right half disks has been compared moving the beam injection point to the positive side.

RESULTS FOR THE TBID

In table 1 the values of charged particles fluence are shown: when the beam is centered in the nominal position or 1 mm displaced, no difference appears between the spectra on the left and right foils; the asymmetry can be noticed when the beam is displaced by 2 mm or more from the nominal position. In this case the proton beam is half-hitting the target rods with 2 mm radius (11 rods out of 13), and fully hitting rods with 2.5 mm radius (2 rods out of 13).

When the beam is missing the target - i.e. Δx=3 mm, 5 mm - a sharp peak appears at 400 GeV in the spectrum

Table 1: Charged particles fluences on left and right TBID foils normalized to 1 proton.

Δx	TBID positive	TBID negative
0 mm	$9.3 \cdot 10^{-2}$	$9.3 \cdot 10^{-2}$
1 mm	$8.8 \cdot 10^{-2}$	$8.7 \cdot 10^{-2}$
2 mm	$5.8 \cdot 10^{-2}$	$5.3 \cdot 10^{-2}$
3 mm	$2.4 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$
5 mm	$1.7 \cdot 10^{-2}$	$5.0 \cdot 10^{-3}$
7 mm	$6.1 \cdot 10^{-2}$	$4.9 \cdot 10^{-2}$
10 mm	$12.5 \cdot 10^{-2}$	$11.0 \cdot 10^{-2}$

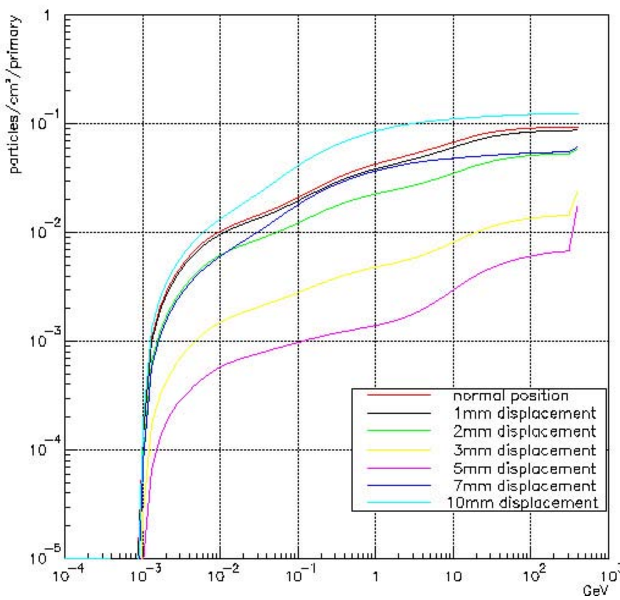

Figure 2: Fluence [part/cm^2/p.o.t.] of charged particles in the left half disk of the TBID.

of particles on the positive foil: this is due to the proton beam that is directly hitting the monitor; the peak is still evident, but weaker, when the proton beam grazes either the target (Δx=2 mm) or the inward surface of the upstream collimator (Δx=7 mm), see fig.2.

The multiplicity has been estimated by "counting" the number of particles crossing the entrance titanium window surface, since this is the first object seen by the secondary beam produced in the target. The expected number of charged particles per primary proton is 20.6 when the beam is in the nominal position. The energy of these particles is above 1 MeV. When the beam is displaced by 3 and 4 mm, the target is totally out of trajectory but still some charged hadrons can be detected: that is due to the graphite rods supports, see fig.3, that generate a detectable secondary beam.

The TBID is equipped with a disk with a hole to estimate the secondary beam halo. Simulations have been performed to optimize the diameter of the hole.

Fig.4 represents the ratio of the number of charged particles detected in the ring of radius 7.25-R cm to the number of charged particles in the 7.25 cm radius disk, as a function of R, radius of the aperture. It can be seen that when

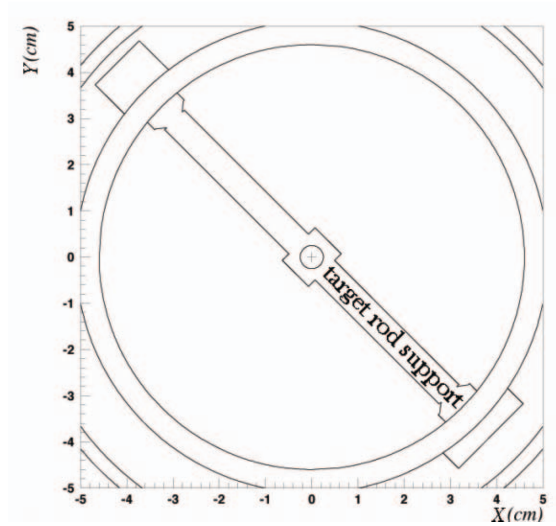

Figure 3: Transversal section of the target tube including the graphite supports of the target rods as described in FLUKA code

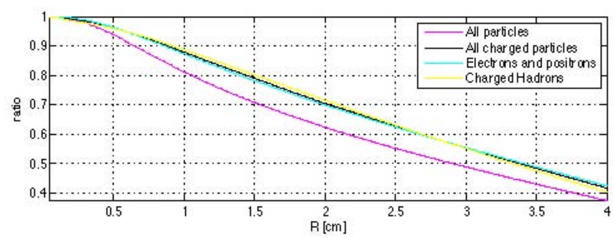

Figure 4: Ratio of number of charged particles in the ring of radius 7.25-R cm to the number of charged particles in the 7.25 cm radius disk, as a function of R.

the hole has a radius of 0.9 cm the ratio is 90%: therefore the optimal solution seems to be an aperture of 1 cm radius.

DOWNSTREAM IONIZATION CHAMBERS SIGNAL

The TBID titanium vacuum windows might not withstand the beam intensity in case of accidental mis-steering of the beam; for this reason two ionization chambers, identical to the SPS beam loss monitors, have been added, as backup instrumentation, downstream the target station to detect eventual beam misalignments. The sensitivity range of the ionization chambers to the fluence of charged particles is between 10^2–10^8 particles per cm^2.

Based on these limits, simulations were performed to obtain values of fluence of charged particles in the region of interest and thus determine the optimal position (lateral displacement with respect to the beam line) of the instrumentation.

Results show that inside the horn-shielding box the values of the fluence per particle are in the range of 10^{-4}–10^{-2} particles per cm^2 per primary proton; with a nominal beam intensity of $2.4 \cdot 10^{13}$ particles per extraction the fluence detected stays within the interval $2.4 \cdot 10^9$–$2.4 \cdot 10^{11}$ particles per cm^2. These values are clearly outside of the

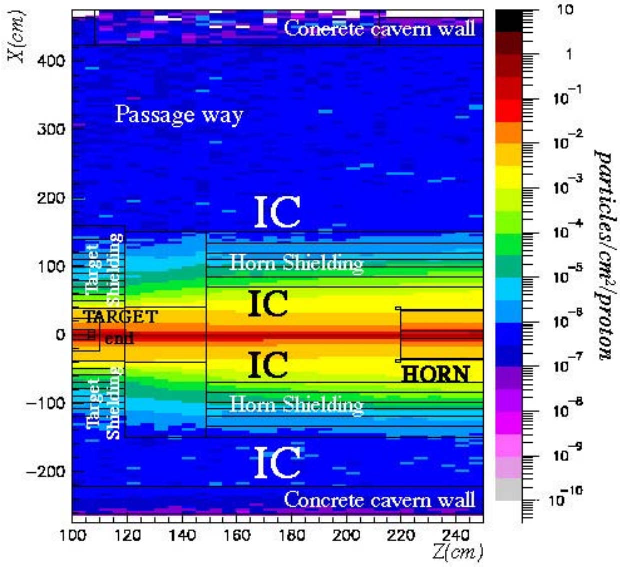

Figure 5: Fluence of all charged particles in the area intended for the ionization chambers location (IC).

monitor sensitivity range. Therefore, the option of locating the monitor inside the horn-shielding box had to be discarded.

Outside the shielding the values of fluence are in the range 10^{-7}–10^{-6} particles per cm^2 per proton, which translates into $2.4 \cdot 10^6$–$2.4 \cdot 10^7$ particles per cm^2 per nominal extraction. These values are within the range of the monitors, therefore it is decided to place the ionization chambers outside the horn shielding, see figure 5.

Since the purpose of these monitors is the detection of beam misalignments, simulations have been done displacing the beam position by 1, 2, 3, 5, 7 and 10 mm on the horizontal plane.

It has been seen that the difference between nominal and misguided beam fluences starts to be detectable above a displacement of 2 mm; when the beam injection point is 5 mm away from the nominal, the fluence is 400 times lower than the one in nominal position (the target is missed).

Taking the injection point 7 mm away, there is almost no difference with the fluence detected in the nominal case; increasing the displacement to 10 mm, the fluence appears even higher than the nominal: the collimator upstream of the target station works as a "target" producing a secondary beam giving the signal.

For all the cases analyzed, the fluence in the right region is slightly higher than in the left one. The asymmetry is mainly due to the target station layout: in addition to the iron target shielding, a marble block 0.4 m thick has been placed at the passage side (left side), this causes an asymmetrical shielding of the secondary beam; moreover, the target station is not centered in the cavern but is closer to the right concrete wall, thus the right monitor location sees the contribution of the cascade generated in concrete.

BACKGROUND SIGNAL

To calculate the values of fluence due to induced radioactivity close to the ionization chambers downstream of the target, an irradiation time of 200 days and a cooling time of 1 ms was considered. For the calculations the same method as explained in [5] has been used, except that the subroutine to transform fluence to dose equivalent rate was excluded. This method was also used in [6] to calculate remanent dose equivalent rates for some interventions in the CNGS facility.

In the region of the ionization chambers, outside the horn shielding, the values are in the range $10^4 - 3 \times 10^5$ part./cm^2/s. Considering an integration time of the detector of 20 ms, that results in an integrated fluence in the range of $2 \cdot 10^2$–$6 \cdot 10^3$ part./cm^2. That means that the background signal is about 10^4 times lower than the prompt signal for the ionization chambers downstream of the target, and hence negligible.

CONCLUSION

The secondary emission monitors of the CNGS monitoring system has been placed downstream the target, right before the focusing device: it provides a complete information in terms of multiplicity, asymmetry, and halo of the secondary beam. The two ionization chambers can be used as backup instrumentation: they will be placed outside the horn shielding, where the particles fluence stays in the sensitivity range of the instrument, and, even far form the nominal beam axis, they will detect a beam misalignment.

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