CONTAMINATION OF NUCLEAR FRAGMENTS IN A 200 GEV PER NUCLEON OXYGEN ION BEAM AT CERN

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Abstract

200 GeV-per-nucleon oxygen ions have been transported in secondary beam lines at CERN. The contamination of nuclear fragments in one of the beams has been measured with thin-filament scintillator scanners. The spatial distribution of the fragments in the transverse plane is presented and the effect of collimation on the fragment distributions is discussed.

1. Introduction

In Autumn 1986 the CERN complex of accelerators accelerated and extracted fully-stripped oxygen ions up to an energy of 200 GeV per nucleon [1]. The beam lines that normally transport secondary particles from the proton target stations to the experiments were used, with small modifications, to transport the extracted oxygen ions to the different experiments.

Intensities greater than 10^8 ions per burst were accelerated in the SPS as this was a minimum requirement from the point of view of beam observation and control in this accelerator. Due to the large cross-section and the high multiplicities in nucleus-nucleus collisions, several experiments could only stand 10^4-10^5 ions per burst and thus a reduction of the intensity by a factor 1000 to 10000 was necessary. This reduction was achieved in three different steps :

1. By splitting the extracted ion beam by means of steel-septum magnets [2]. The beam was divided twice, with the first splitting having a ratio of 1:10 (the major part of the beam being given to a high intensity experiment) and the second splitting, with a ratio of 1:1, providing lower intensities into two other beam lines. Splitting ratios much below 1:10 are difficult to obtain if, at the same time, reasonable stability for the low-intensity part of the split beam is to be maintained. As a result of splitting, the intensity was thus reduced by roughly a factor of 20.
2. By using a 3.2 m long collimator with a circular hole of 12 mm diameter, situated at the beginning of the secondary beam transport system. The beam was blown up at the collimator in such a way that roughly 1/10 of the intensity passed through the hole.
3. By using the various collimators integrated in the normal secondary beam transport system, these being either horizontal or vertical iron-jaw collimators with tungsten faces. Typical collimator settings used during the data-taking reduced the flux by another factor of 25.

Clearly, in each of the above-mentioned steps, there will be edge effects where some of the oxygen ions interact with the material of the splitters or collimators. A nucleus-nucleus collision frequently results in a break-up of the beam nucleus into lighter nuclear fragments which keep the velocity of the beam particles and have the same Z/A ratio as the parent; hence, if they are not absorbed, they will be transported to the end of the beam as a contamination to the oxygen ions. Thus beam splitters and collimators are potential sources of nuclear fragments.

The same is true for any other material in the beam line, and hence great care was taken to eliminate such sources as far as possible. Much of the beam monitoring equipment was removed and only retractable detectors, installed in vacuum, were kept. However, approximately 2 g/cm^2 of material remained in the region of the target station, consisting essentially of vacuum windows and air. The cross-section to create fragments with Z/A = 0.5 in a typical oxygen collision with such matter is approximately 1 barn, thus giving an interaction probability of ~ 10 % in the residual material [3].

The purpose of the measurements presented here was to study the contamination of nuclear fragments in the oxygen beams transported to experiments and to investigate how the purity of the beams was affected by the strong collimation needed.

2. The beam and the collimators

The investigation was made in the H2 high-energy, high-resolution beam [4] of the North experimental area of the SPS, the basic layout and optics of the beam being shown in Fig. 1. The first vertical bend provides the momentum analysis and the second vertical bend is used for the momentum recombination. The longitudinal collimator positions are indicated in the figure and the reduction of intensity was achieved with the horizontal and vertical acceptance collimators C2 and C6, respectively.

The angular dispersion of the fragments will be slightly larger than that of the oxygen beam. With the purpose of removing fragments in the tails of the beam distribution, collimators C5 and C9, located at a horizontal and vertical focus, respectively, were closed as far as possible, but with the requirement of not touching the oxygen beam.

Collimator C3 defines the momentum bite of the beam when used to transport secondary particles. The momentum spread of the oxygen beam is quite small (~ ± 1 per mille), about five times the intrinsic momentum resolution of the beam line. The fragments, on the other hand, due to Fermi motion in the parent nucleus, will have a momentum spread at the percent level and hence can be removed if the C3 opening is set just large enough to transmit the oxygen beam.

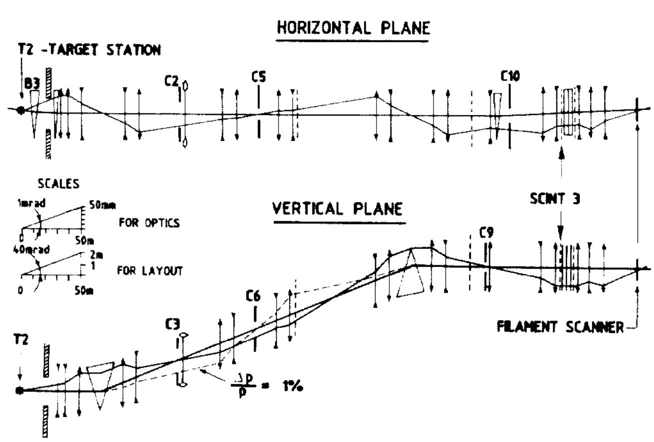

Fig. 1 Layout and optics of the H2 beam line.

3. The filament scanner

Oxygen ions were distinguished from nuclear fragments by measuring the energy loss in a thin scintillator, using the fact that, for relativistic particles the energy loss is proportional to Z^2. The scintillator is a filament of dimensions 1 mm by 100 mm perpendicular to, and 4 mm along, the beam direction, its longitudinal positon in the beam being indicated in Fig. 1. Fig. 2 shows these dimensions as

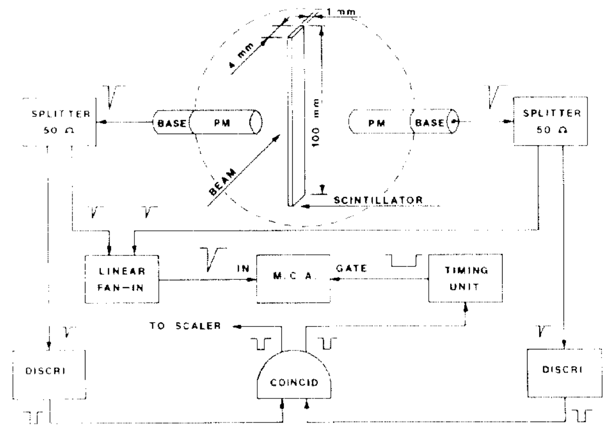

Fig. 2 The filament scanner with associated electronics.

well as a schematic layout of the electronic chain leading to the multi-channel-analyser used to measure the pulse-height. The filament is installed in a vacuum tank; it can be moved perpendicular to the beam and is viewed by two photomultipliers. A horizontal and a vertical scanner were used.

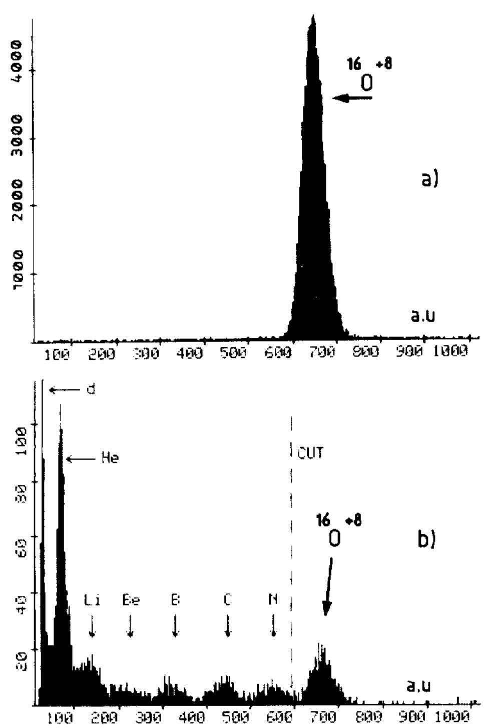

Fig. 3 Pulse-height spectrum (a) with the filament in the centre of the oxygen beam and (b) with the filament 2 mm off centre.

4. Results

Figure 3 shows two pulse-height spectra from the horizontal filament. The upper plot corresponds to the filament being positioned in the middle of the beam and the lower one to the filament being 2 mm out from the centre. This latter spectrum nicely shows all the fragments with Z < 8 as well-separated peaks. In the subsequent analysis, the percentages of oxygen and fragments have been calculated using a raw cut in the pulse-height spectrum between the nitrogen and oxygen peaks as shown in Fig. 3.

Figure 4 shows the result of filament scans. Oxygen ions and fragments are separated at each position by the cut on pulse-height explained above. Corrections have been applied to compensate for deadtime effects in the multi-channel-analyser. Burst-to-burst incident intensity variations were eliminated by normalising to the rate measured with a secondary emission monitor (SEM) situated at the beginning of the beam line.

Further, the horizontal and vertical oxygen distributions have been divided by factors of 59 and 35, respectively, in order to make their maxima coincide with the fragment distributions. The striking features are the width and tails of the fragment distributions as compared to those of oxygen. Table 1 summarizes how the purity of the beam deteriorates in moving out from the centre both horizontally and vertically. The values in the table have been obtained by integrating the curves of Fig. 4.

It should be remembered that the filament is 100 mm long in the direction perpendicular to the scanning direction and thus the core of the beam is even purer than indicated by the numbers in the table. A theoretical estimate [3], based on the flux of fragments produced in material traversed and at the surface of septa and collimators and on

TABLE 1

Fraction of fragments in percent of the oxygen beam

	Horizontal scan	Vertical scan
At the centre	1.7	2.8
Within $\pm 2\sigma_{ox}$	2.1	3.4
Within $\pm 5\sigma_{ox}$	2.7	4.1

No attempt is made to give an error on these values.

their momentum spread due to Fermi motion in the parent nucleus, gives an expected contamination of 1.1 %. This is of the same order as found in the measurements.

To obtain an idea of how the strong collimation affected the contamination of the beam, a comparison scan with all collimators open was also made. In this case the data were normalized to the counts in a 10 cm x 10 cm scintillator downstream of the last collimator (SCINT 3 in Fig. 1) in order to measure composition as a fraction of the total beam. The resulting fragment distributions are shown in Fig. 5 and we conclude that the strong collimation of the oxygen beam, followed by "cleaning" collimators, did not deteriorate the purity of the beam but on the contrary improved the conditions somewhat.

The figure also demonstrates what happens to the fragment distribution when the 2 mm thick normalization scintillator is removed (curve marked "collimation + scint 3 out"). For this curve, the SEM count was used instead in the normalization. This shows the importance of having a minimum of material in the beam; this is especially true in the downstream end of the beam line, where fragments can no longer be removed by collimation or the effect of magnets.

In Figure 6, the curve marked "coll 10 cutting" shows what happens when the intensity is reduced with a downstream collimator close to the experiment (for the position of collimator 10 see Fig. 1). Clearly more off-centre fragments are generated than are absorbed by this collimator.

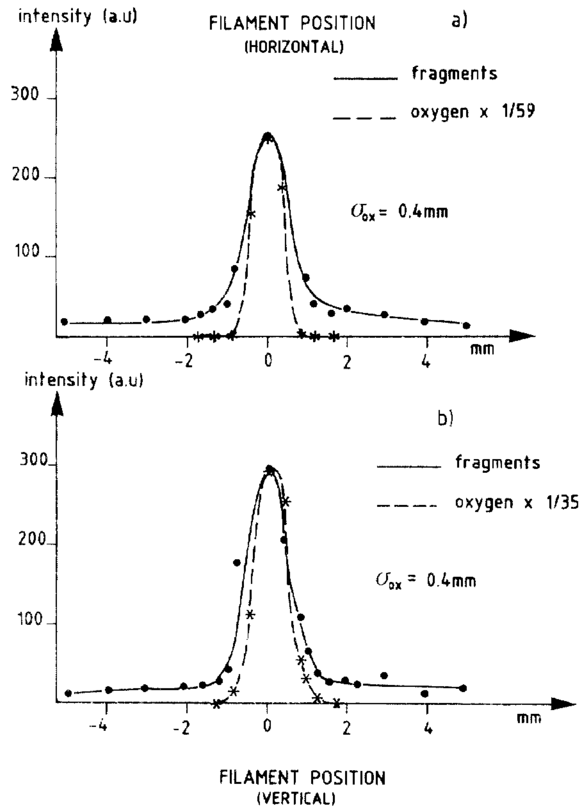

Fig. 4 Intensity of oxygen and fragments as a function of filament position (a) horizontal, (b) vertical.

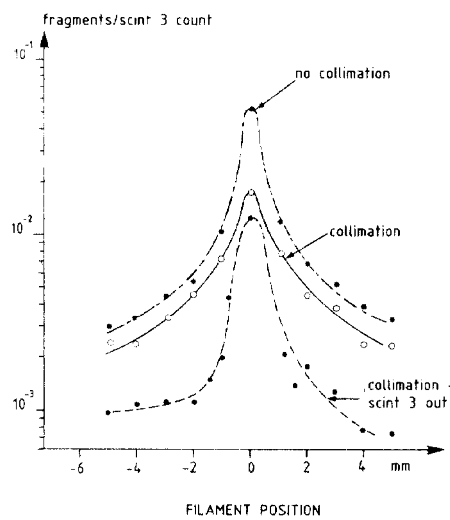

Fig. 5 Relative intensities of fragments as a function of filament position, showing effects of collimation and material in the beam.

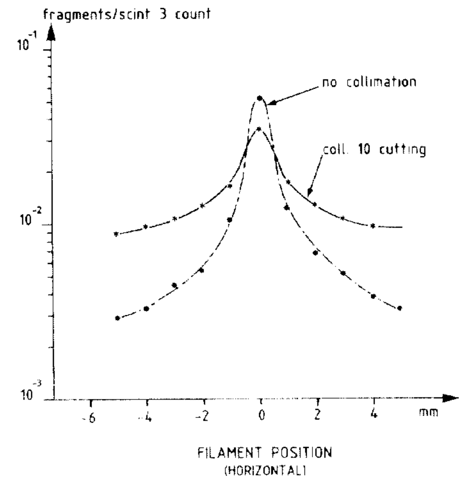

Fig.6 Relative intensities of fragments as a function of filament position, showing effect of cutting with a collimator near the end of the beam.

5. Conclusions

It has been shown that the high-energy, high-resolution secondary beams of the CERN-SPS are well suited, with little modification, to transport oxygen ions to experiments. In particular, the adjustable collimators and filament scintillator scanners provided in such a beam can be used respectively to reduce the intensity by large factors and to measure the subsequent beam properties. The unavoidable material traversed by the ions and the judicious use of collimators early in the beam line do not lead to an appreciable background of lighter fragments being transported to the experiments. The remaining contamination of such fragments, measured to be at the percent level in the core of the beam, is consistent with predictions made on the basis of cross-sections and kinematics of the fragmentation process.

References

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