EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

SPS/ABT/Int. 79-1
27 April 1979

# CALIBRATION OF THE SECONDARY EMISSION MONITORS TBIU AND TBID OF THE NORTH AREA TARGETS STATIONS T2, T4, AND T6 IN TCC2 FOR SLOW EXTRACTED PROTONS OF 400 GeV

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## 1. INTRODUCTION

An experiment[1] to measure the pion and kaon yields from collisions of 400 GeV protons in a beryllium target required an absolute measurement of proton intensity. For practical reasons this experiment could only take place in the North Area (NA) of the SPS, using the T2 target station in the target hall TCC2 and the H2 secondary beam line to measure the yields.

A primary proton beam of 400 GeV is extracted from the CERN SPS in LSS2 and sent to TCC2 via the TT20 transfer line (see Fig. 1). Two splitter stations distribute the proton beam over three branches, which feed the targets T2, T4, and T6.

For this yield experiment, an absolute calibration of the standard secondary emission monitor TBIU 23 09 49 (see Fig. 2), which measures the proton intensity incident on the target T2, was carried out. The target monitors of the stations T4 and T6 (see Figs. 3 and 4) were included into the calibration program, because this is of general interest for the users of the secondary beam lines. Furthermore, only the calibration of all three TBIU monitors in TCC2 permits a survey of their long-term stability under varying splitting ratios.

Usually such intensity calibrations are carried out using a fast extracted beam and the reading of a beam current transformer (BCT). However, such a BCT does not exist in the TT20 beam line, and in any case fast extraction to the North Area is not possible so far. Thus an auxiliary experiment was proposed[2] in which a stack of thin aluminium plus copper foils were to be exposed to the fast extracted proton beam in TT60. In this way, the ratio of a specific radioactivity of the foils, as measured with a gamma spectrometer, per incident proton intensity, as recorded with the BCT in TT60, could be determined. Identical foil stacks were to be irradiated in the beams incident on T2, T4, and T6, and from the radioactivity produced in these foils the incoming proton intensity could be evaluated. The target beam monitors in TCC2 could thereafter be calibrated from the measured proton intensity.

This note describes the results obtained in this calibration experiment, a corollary of which was the measurement of the cross-sections of the reactions used (Al, $^{24}$Na; Al, $^{18}$F; Cu, $^{24}$Na). Furthermore, the results of the long-term surveillance of the TBIU monitors in TCC2 are given.

## 2. THE IRRADIATION

Foil stacks consisting of 6 foils each (three of aluminium, 0.04 mm thickness, plus three of copper, 0.05 mm thickness) were prepared. Those destined for irradiation in the North Target Area were 10 cm × 10 cm in size; that for the TT60 irradiations was 18 cm × 10 cm since a motorized arm could be used to move the foil into a new position for each different irradiation. The aluminium foils were placed upstream in each case. The foil stacks were supported in light stainless-steel frames which could be placed quickly on the jigs prepared in front of the target stations and the TT60 irradiation position.

For the irradiation in TCC2 the splitting ratio was changed so that the proton intensity in each of the three branches was approximately equal. The proton beam to the North was then stopped and access granted to TCC2 to allow the foil stacks to be placed upstream of the targets. Extraction of protons was restarted and irradiation of the foils continued for 113 machine pulses. At the end of this irradiation the foils were removed and normal physics operation for the North Areas was resumed.

The extracted beam to the West Area (WA) was then interrupted by inserting the TED beam stopper in TT60 and the slow extraction at 210 GeV was stopped. After verification of the extracted intensities the SPS was stopped to allow access to the irradiation area of TT60 for the insertion of the foils. Vacuum window protectors just upstream of the foils were removed to avoid stray radiation problems.

Three different foil irradiations were made in TT60, the first one at 400 GeV with coherent half-integer (FFS) extraction and the two subsequent ones with 195 GeV fast extraction (FE).

The first foil spot was irradiated at 400 GeV FFS extraction with $7 \times 10^{12}$ protons per pulse (ppp) for 33 pulses, and the second one at 195 GeV FE with $5.8 \times 10^{12}$ ppp for 11 pulses. The intensity of the FE beam was thereafter reduced and a second 195 GeV irradiation started, this time for 99 pulses. Details of the TCC2 and TT60 irradiations are given in Appendix I. The standard extractions were then set up again, and normal physics operation in the West Area was resumed.

After irradiation the beam positions in the stacks were determined from contact radiographs made using polaroid films. Disks of 40 mm diameter were punched out of the foils using the beam position as centre. Additional disks were punched out away from the beam position to check for background and halo effects.

## 3. ASSAY TECHNIQUES

The centre disks from each stack, and the off-centre disks, were placed in turn at a distance of 10 cm from the upper surface of the NaI gamma spectrometer of the SPS-RP section. Perspex sheets of 6 mm thickness were placed above and below the disks to ensure that all positrons emitted were converted close to them, and that therefore the source of the 0.511 MeV annihilation gammas could be considered as punctual. $^{24}$Na activities in aluminium and copper were estimated from the counts in the 2.75 MeV full energy peak in the gamma spectrum; $^{18}$F activity in the aluminium disks was estimated from the annihilation gamma peak using a least squares analysis to remove the $^{24}Na$ contribution.

The aluminium and copper disks were also counted for $^{24}Na$ by the RP-Site section using their GeLi gamma spectrometer system.

The results given in Table 1 are the effective counts per second (SPS) or disintegrations per second (Site) of the irradiated disks corrected for decay to the end of each irradiation and for decay during each irradiation. The error is that derived from the weighted means of all measurements on the same disk taken with the statistical counting accuracy of each measurement. The error in the assumed efficiency for the "Site" measurements is not included.

The so-called 195 GeV* irradiation of Table 1 is in fact the short 195 GeV irradiation at high intensity.

The activities of the off-centre disks are given in Table 2. The activities of the off-centre copper disks were insignificant, whereas the activity of $^{24}Na$ in the aluminium disks was about 1% of the activity of the corresponding centre disk. Because off-centre activities are not available for the $^{18}F$ activity, the correction has not been included in the subsequent analysis.

## 4. BEAM CURRENT TRANSFORMER CALIBRATION AND MEASUREMENTS

The calibration of the NA target monitors TBIU and TBID described here depends essentially on the accuracy of the intensity measurement of the protons incident on the foil stack in TT60. The flux of the proton beam in TT60 was recorded with the beam current transformer BCT 61 03 07 situated about 10 m upstream of the foil stack. Because of the short distance, any substantial loss of protons between the two locations can be excluded.

During our experiment we have checked carefully, in different ways, whether the absolute calibration of this BCT was correct.

Firstly, the calibrator a precision current source ($< 3 \times 10^{-4}$), which can be switched into a one-turn winding, was used to provide an absolute calibration of the BCTs.

The transfer line BCTs have about 60 dB of feedback and should read accurately to $10^{-3}$ without correction (see Table 3). However, the calibrator reading for the extraction BCT 61 03 07 was $502.2 \times 10^{10}$ ppp (average of 10 pulses). Checking this transformer after the experiment showed that the calibrator current was set equivalent to $502.0 \times 10^{10}$ ppp. Therefore no correction is needed for the extraction BCT 61 03 07.

The main ring BCT No. 3, which was also used for the cross-calibration of this extraction BCT, gave a calibrator value of $497.8 \times 10^{10}$ ppp (average of

## Table 1

### Decay corrected activities

Aluminium-Sodium 24

| | SPS | | Site | |
|---|---|---|---|---|
| | cps | Error | dps | Error |
| 400GeV | 21.81 | 0.10 | 7078 | 127 |
| 195GeV | 13.26 | 0.08 | 4309 | 129 |
| 195GeV* | 5.53 | 0.04 | 1757 | 62 |
| T2 | 12.25 | 0.07 | 4002 | 96 |
| T4 | 19.82 | 0.11 | 6578 | 164 |
| T6 | 26.31 | 0.16 | 8561 | 188 |

Copper-Sodium 24

| | SPS | | Site | |
|---|---|---|---|---|
| | cps | Error | dps | Error |
| 400GeV | 15.43 | 0.40 | 4949 | 138 |
| 195GeV | 9.23 | 0.16 | 3100 | 112 |
| 195GeV* | 3.89 | 0.07 | 1206 | 52 |
| T2 | 8.23 | 0.12 | 2633 | 79 |
| T4 | 13.90 | 0.20 | 4538 | 141 |
| T6 | 18.63 | 0.20 | 6107 | 165 |

Aluminium-Fluorine 18

| | SPS | |
|---|---|---|
| | cps | Error |
| 400GeV | 1012 | 3 |
| 195GeV | 648 | 14 |
| 195GeV* | 264 | 3 |
| T2 | 601 | 7 |
| T4 | 934 | 6 |
| T6 | 1283 | 14 |

PROTON INTENSITIES FROM BCT

| | |
|---|---|
| 400GeV | 2.431E+14 protons |
| 195GeV | 1.528E+14 protons |
| 195GeV* | 6.375E+13 protons |

IRRADIATION TIMES

| | | |
|---|---|---|
| 400GeV | 5.13 | mins |
| 195GeV | 15.68 | mins |
| 195GeV* | 1.60 | mins |
| T2 | 17.92 | mins |
| T4 | 17.92 | mins |
| T6 | 17.92 | mins |

HALF-LIVES

| | | |
|---|---|---|
| Na-24 | 900.0 | mins |
| F-18 | 109.8 | mins |

## Table 2

### Activities of off-centre disks

| Foil | Aluminium-Sodium 24 (SPS) | | Copper-Sodium 24 (SPS) | |
|---|---|---|---|---|
| | cps | Error | cps | Error |
| 195*-400GeV †) | 0.20 | 0.04 | 0.02 | 0.03 |
| 195-195*GeV †) | 0.14 | 0.05 | <0.01 | 0.03 |
| T2 | 0.03 | 0.03 | <0.01 | 0.03 |
| T4 | 0.04 | 0.04 | <0.01 | 0.03 |
| T6 | 0.12 | 0.04 | <0.01 | 0.03 |

†) From disks punched out of the TT60 foil in the area situated in between the 195* and 400 GeV respectively the 195 and 195* GeV beam positions.

10 pulses) instead of 500 × $10^{10}$ ppp. This error is compatible with the finite closed-loop gain (about 40 dB) of the magnetic amplifier. Therefore the readings of the main ring BCT No. 3 were multiplied by 1.0044 to give the correct value of the circulating proton beam.

Table 3

The principal specifications for the SPS BCTs

| | Main Ring | Transfer lines |
|---|---|---|
| LF cut-off | d.c. | 10 Hz |
| HF cut-off | 1 MHz | 1 MHz |
| Precision | $10^{-2}$ | $10^{-3}$ |
| Resolution | 1 × $10^{10}$ ppp | 1 × $10^{10}$ ppp |
| Calibrator | 5 × $10^{12}$ ppp | 5 × $10^{12}$ ppp |

(ppp = protons per pulse)

Secondly, we compared the readings of the extraction BCT 61 03 07 and the main ring BCT No. 3 for fast (FE) extraction at 195 GeV and for fast-fast-slow (FFS) or coherent half-integer extraction at 400 GeV as set up during our experiment.

Fast extraction at the SPS is normally made by synchronizing the rise of the magnetic field of the kicker system with the gap of 2.1 μs in the circulating proton beam. During the rise-time of the kickers, which is only 1.2 μs, practically no protons are lost on the extraction septa. Hence the efficiency for fast extraction of all circulating protons should be 100%, which provides a means to cross-calibrate a BCT in the TT60 via a main ring BCT.

The extraction efficiency for FE was measured by comparing the loss of circulating beam as read by the main ring BCT No. 3 with the intensity of the extracted beam as read by the extraction BCT 61 03 07.

At 195 GeV FE we measured the following extraction efficiencies of (99.89 ± 0.37)% (average over 11 pulses of 6 × $10^{12}$ ppp) and (100.57 ± 0.86)% (average of 99 pulses of 1.5 × $10^{12}$ ppp). Only statistical errors are quoted corresponding to one standard deviation.

Since, furthermore, a comparison of the other two BCTs in the West transfer lines with the extraction BCT showed identical readings, we conclude that our reference BCT 61 01 07 is perfectly calibrated within < 1%, at least for measuring the intensity of a fast extracted proton beam.

However, for the direct comparison of the NA and WA foil activities an irradiation of the TT60 foil with 400 GeV protons was required. Only in this way did the absolute calibration of the TCC2 target monitors become independent of any energy-dependent variation of the implied production cross-sections.

At present, a fast extraction at 400 GeV is not employed because of risks for the extraction channel*). Therefore, a FFS extraction was used to irradiate the foils in TT60 with 400 GeV protons.

Again the extraction BCT was used to normalize the measured specific activities (see Section 3) per proton incident on the foil stack.

However, this type of extraction is less "clean" than fast extraction, and because of the losses no simple cross-calibration of extraction versus main ring BCTs is feasible. Apart from the extracted protons, circulating beam will be lost owing to

a) beam lost on the septum wires ($\lesssim$ 3%);

b) dumping of non-extracted beam;

c) beam lost in an uncontrolled way in the main ring during extraction.

With the present BCT acquisition system a proper discrimination between the different processes (a) to (c) is virtually impossible.

We first measured the extraction efficiency with the machine set-up for a two-turn extraction. This gave an extraction efficiency of 90.7% (averaged over 20 pulses). We then delayed the early dump to see how much beam was being lost by dumping the circulating beam already after a two-turn extraction. This gave an extraction efficiency of 93.1% (averaged over 33 pulses of about $7 \times 10^{12}$ ppp).

The measured efficiency for 400 GeV FFS seems rather low if one takes into account only the calculated 3% of proton losses due to the electrostatic septum wires[3]).

Therefore, we used the results of the foil irradiation in TT60 in order to obtain an independent cross-check for the accuracy of the extraction BCT readings at 400 GeV FFS extraction. A detailed description of this method is given in Appendix II. From the arguments presented there, we conclude that the readings of the extraction BCT are correct also for the 400 GeV FFS extraction. The measured difference of about 2.7% in the foil activity per incident proton, when comparing the 195 and 400 GeV irradiations, is attributed to a small increase of the implied nuclear cross-sections with higher proton energies.

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*) In the meantime, a fast extracted beam of 400 GeV has been used for the WA neutrino beam dump experiment. On this occasion we have verified that the readings of the extraction BCT and of the main ring ΔBCT agree within <1%.

## 5. ESTIMATES OF THE TCC2 PROTON INTENSITIES AND SECONDARY EMISSION EFFICIENCIES

The TCC2 proton intensity estimated from the formula: ("TT60 BCT protons" × "TCC2 target foil activity")/"TT60 foil activity", is given in Table 4 for each target station and each monitor reaction normalized to each TT60 exposure. Foil activities were normalized for the slight variations in foil thicknesses. Tests for systematic errors were made by taking the weighted means of different sub-groups, e.g. all 400 GeV normalized data, respectively all (Al, $^{24}$Na) data. Two estimates of error on these weighted means are given: the first is calculated from the errors of the quantities in the activation measurement making up the mean; the second (the scatter) is the estimate of the standard error on the mean calculated from the scatter of the data around that mean. When these two estimates of error are equal this implies that all errors are mainly due to counting statistics; a larger scatter estimate would imply the existence of other effects, such as local variations in foil thickness, or random BCT errors. As mentioned in Section 4 and discussed in detail in Appendix II, there is a difference of about 2.7% between the 400 GeV and the two 195 GeV normalizations. There is, however, no systematic difference between the data for different gamma spectrometers nor between those data from the different monitor reactions. In all cases the error on the means is smaller than 1%.

The number of protons passing through the TCC2 foils on different bases (all data, 400 GeV data only, and 195 GeV data only) is given in Table 5. In addition, these numbers are compared with the number of protons calculated from the BSI-1 signal of the TBIU monitors (see Figs. 2 to 4) for the nominal calibration of $1.36 \times 10^{12}$ protons per volts-bit (see Appendix III) as used up to now at the SPS for the targets T2, T4, and T6. The error quoted in Table 5 includes the error of the activation measurements (see Table 4) and a 1% error in the TT60 proton intensity as measured with the extraction BCT.

Table 6 shows the final results of our calibration experiment for the target monitors TBIU and TBID of the stations T2, T4, and T6 in TCC2. The "foil protons" are based on the 400 GeV data only in order to avoid that the calibration could be influenced by an energy-dependent variation in the implied nuclear cross-sections. In addition to the secondary emission efficiency, the measured calibration coefficient (protons/volts-bit) is given (see also Appendix III).

## 6. LONG-TERM STABILITY OF THE BSI-1 DETECTORS ON THE TBIU TARGET MONITORS IN TCC2

The absolute calibration of the secondary emission monitors TBIU and TBID of the targets T2, T4, and T6 (see Figs. 2, 3, 4) has been described in the preceding sections. The experiment was performed during physics operation of the SPS under

## Table 4

### Proton intensities

### T2 Target Exposures

| Normalized to | 400GeV | | 195GeV | | 195GeV* | |
|---|---|---|---|---|---|---|
| Reaction | Protons | Error | Protons | Error | Protons | Error |
| Al Na-24 SPS | 1.357 | 0.010 | 1.419 | 0.012 | 1.400 | 0.013 |
| Al Na-24 Site | 1.365 | 0.041 | 1.426 | 0.055 | 1.440 | 0.061 |
| Cu Na-24 SPS | 1.351 | 0.040 | 1.420 | 0.029 | 1.405 | 0.033 |
| Cu Na-24 Site | 1.352 | 0.056 | 1.351 | 0.064 | 1.450 | 0.076 |
| Al F-18 SPS | 1.435 | 0.016 | 1.424 | 0.035 | 1.439 | 0.021 |

| Weighted Means | Mean | Error | Scatter |
|---|---|---|---|
| All 400GeV | 1.378 | 0.008 | 0.017 |
| All 195GeV | 1.418 | 0.010 | 0.005 |
| All 195GeV* | 1.412 | 0.010 | 0.009 |
| All Al Na-24 | 1.388 | 0.007 | 0.013 |
| All Cu Na-24 | 1.395 | 0.017 | 0.014 |
| All Al F-18 | 1.435 | 0.012 | 0.003 |
| All data | 1.399 | 0.005 | 0.008 x 1.0E+14 |

### T4 Target Exposures

| Normalized to | 400GeV | | 195GeV | | 195GeV* | |
|---|---|---|---|---|---|---|
| Reaction | Protons | Error | Protons | Error | Protons | Error |
| Al Na-24 SPS | 2.254 | 0.016 | 2.357 | 0.019 | 2.327 | 0.021 |
| Al Na-24 Site | 2.305 | 0.071 | 2.408 | 0.094 | 2.431 | 0.105 |
| Cu Na-24 SPS | 2.250 | 0.066 | 2.363 | 0.048 | 2.339 | 0.054 |
| Cu Na-24 Site | 2.297 | 0.096 | 2.296 | 0.109 | 2.464 | 0.130 |
| Al F-18 SPS | 2.291 | 0.016 | 2.273 | 0.052 | 2.296 | 0.028 |

| Weighted Means | Mean | Error | Scatter |
|---|---|---|---|
| All 400GeV | 2.273 | 0.011 | 0.009 |
| All 195GeV | 2.350 | 0.017 | 0.014 |
| All 195GeV* | 2.323 | 0.016 | 0.015 |
| All Al Na-24 | 2.307 | 0.011 | 0.021 |
| All Cu Na-24 | 2.333 | 0.023 | 0.023 |
| All Al F-18 | 2.291 | 0.013 | 0.004 |
| All data | 2.304 | 0.008 | 0.011 x 1.0E+14 |

### T6 Target Exposures

| Normalized to | 400GeV | | 195GeV | | 195GeV* | |
|---|---|---|---|---|---|---|
| Reaction | Protons | Error | Protons | Error | Protons | Error |
| Al Na-24 SPS | 2.980 | 0.023 | 3.116 | 0.027 | 3.076 | 0.029 |
| Al Na-24 Site | 2.938 | 0.085 | 3.122 | 0.116 | 3.151 | 0.130 |
| Cu Na-24 SPS | 2.973 | 0.083 | 3.123 | 0.056 | 3.091 | 0.066 |
| Cu Na-24 Site | 3.048 | 0.119 | 3.047 | 0.138 | 3.270 | 0.166 |
| Al F-18 SPS | 3.134 | 0.037 | 3.110 | 0.077 | 3.142 | 0.049 |

| Weighted Means | Mean | Error | Scatter |
|---|---|---|---|
| All 400GeV | 3.022 | 0.013 | 0.034 |
| All 195GeV | 3.115 | 0.022 | 0.006 |
| All 195GeV* | 3.099 | 0.023 | 0.019 |
| All Al Na-24 | 3.048 | 0.015 | 0.027 |
| All Cu Na-24 | 3.088 | 0.034 | 0.029 |
| All Al F-18 | 3.134 | 0.027 | 0.007 |
| All data | 3.071 | 0.012 | 0.017 x 1.0E+14 |

Table 5

Target proton intensities

| | T2 | T4 | T6 |
|---|---|---|---|
| BSI-1 protons | $1.798 \times 10^{14}$ | $2.187 \times 10^{14}$ | $2.905 \times 10^{14}$ |
| All data | | | |
| Foil protons | $1.399 \times 10^{14}$ | $2.304 \times 10^{14}$ | $3.071 \times 10^{14}$ |
| Error | 1.4% | 1.2% | 1.2% |
| Foil protons/BSI-1 protons | 0.778 | 1.053 | 1.057 |
| 400 GeV data only | | | |
| Foil protons | $1.378 \times 10^{14}$ | $2.273 \times 10^{14}$ | $3.022 \times 10^{14}$ |
| Error | 1.8% | 1.1% | 1.5% |
| Foil protons/BSI-1 protons | 0.766 | 1.039 | 1.040 |
| 195 GeV data only | | | |
| Foil protons | $1.415 \times 10^{14}$ | $2.337 \times 10^{14}$ | $3.107 \times 10^{14}$ |
| Error | 1.8% | 1.1% | 1.5% |
| Foil protons/BSI-1 protons | 0.787 | 1.069 | 1.070 |

The foil protons are calculated from:

$$\frac{\text{"TT60 BCT protons"} \times \text{"TCC2 Target foil activity"}}{\text{"TT60 foil activity"}}$$

The BSI-1 protons are determined from the BSI-1 signal of the TBIU monitors for the nominal calibration of $1.36 \times 10^{12}$ protons/volts-bit as used up to now at the SPS for T2, T4, and T6.

Table 6

Efficiencies of TCC2 target monitors (based on 400 GeV data only)

| Target | Beam Monitor | Monitor foil | Integrator capacitance (nF) | Monitor signal (volts-bit) | Foil protons | Secondary emission efficiency (%) | Calibration coefficient (protons/volts-bit) |
|---|---|---|---|---|---|---|---|
| T2 | BSI 23 07 05 | Al | 10 | 146.597 | $1.378 \times 10^{14}$ | 6.50 | $0.940 \times 10^{12}$ |
| | TBIU BSI-2 | Ni | 10 | 142.380 | " | 6.32 | $0.968 \times 10^{12}$ |
| | TBIU BSI-1 | Al | 10 | 132.200 | " | 5.86 | $1.042 \times 10^{12}$ |
| | TBID $\sum$BSP-H | Al | 10 | 127.418 | " | 5.65 | $1.081 \times 10^{12}$ |
| | ERROR | | 1% | $\sim$ 0.1% | 1.8% | 2.1% | 1.8% |
| T4 | TBIU BSI-1 | Al | 10 | 160.793 | $2.273 \times 10^{14}$ | 4.32 | $1.414 \times 10^{12}$ |
| | TBID BSI-2 | Al | 100 | 16.324 | " | 4.39 | $1.392 \times 10^{13}$ |
| | ERROR | | 1% | $\sim$ 0.1% | 1.1% | 1.5% | 1.1% |
| T6 | TBIU BSI-1 | Al | 10 | 213.601 | $3.022 \times 10^{14}$ | 4.32 | $1.415 \times 10^{12}$ |
| | TBID BSI-2 | Al | 10 | 160.239 | " | 3.24 | $1.886 \times 10^{12}$ |
| | ERROR | | 1% | $\sim$ 0.1% | 1.5% | 1.8% | 1.5% |

The measured monitor signals for the calibrated secondary emission monitors in TCC2 are given together with the foil protons as obtained from the measured foil activities. The measured signal of the T4 TBID is smaller by a factor of 10, because of the larger capacitance for the BSI-2. The last two columns contain the measured secondary efficiency and the calibration coefficient (see Appendix III). As long as the integrator capacitors are not exchanged, the 1% tolerance in the capacitances must only be taken into account for the systematic error in the secondary emission efficiency.

stable machine conditions. The period of time needed for the irradiation of the foils exposed in TCC2 was 18 minutes only; therefore it has to be considered as one single data sample during a run of several weeks.

Earlier measurements[4-7] have shown that the sensitivity of secondary emission monitors varies with time, with the size of the beam spot, and with the integral dose of traversing protons. In order to estimate the validity of the calibration experiment an investigation of the long-term stability of the TCC2 target monitors during two physics runs was carried out.

The <u>only</u> precise method of doing this is by repeating, at regular intervals, the described activation measurements at the location of the target monitors. However, this would cause loss of time for physics of at least one hour per measurement because of the necessary time for access to the TCC2 target zone. A less accurate but nevertheless reliable indirect method was therefore used to estimate the unknown variation in sensitivity of the secondary emission monitors of TCC2.

### 6.1 Method

Almost once every day during the physics runs, the signals of the concerned target TBIU BSIs of T2, T4, T6 and of two other secondary emission monitors in TT20 have been measured and normalized to the ΔBCT reading of one of the main ring current transformers. Each measurement was averaged over ten consecutive stable machine cycles. The data obtained are thus independent of beam intensity, but contain variations due to changes in extraction efficiency, splitting ratio, splitter losses, and detector sensitivities.

Variations in the splitting ratio can be eliminated by summing up the BSI-1 detector signals for the targets T2, T4, and T6, termed $\sum$BSI-1, for each cycle during the measurements. Changes in the extraction efficiency can be removed by normalizing the $\sum$BSI-1 signal to a common detector in TT20, assuming that the variation in sensitivity of this latter monitor could be neglected during the period of interest. The variations of the thus normalized $\sum$BSI-1 signal can then be due only to changes in splitter losses and in detector sensitivity.

The TBID monitors downstream from the T2, T4, and T6 targets were not included in the long-term surveillance, because the required target removal from the beam would have disturbed the physics runs.

### 6.2 Results

Table 7 shows the average values and the standard deviations of the rough data for the periods 8A and 8B and for the calibration experiment made on 20 November 1978. The detector signals are already normalized on the ΔBCT reading. The $\sum$BSI-1 has been calculated directly from the BSI-1 signals of T2, T4, and T6 without taking into account the observed differences in the individual secondary emission efficiencies.

Table 8 shows the results of Table 7, but corrected for the individual efficiencies. In order to facilitate the comparison of both tables, the secondary emission efficiency of the BSI-1 of T6, called $\varepsilon_6$, is taken as reference. Therefore, only the BSI-1 signals of T2 and T4 are corrected by the corresponding efficiency ratios $\varepsilon_6/\varepsilon_2$ respectively $\varepsilon_6/\varepsilon_4$.

Table 9 shows the results of Table 7, but normalized to the common detector BSI 21 02 79 in TT20. The figures given are therefore independent of changes in the extraction efficiency.

Table 10 is obtained from Table 9 after a correction for the individual secondary emission efficiencies. Again, $\varepsilon_6$ is taken as reference as explained for Table 8.

The last column gives the standard deviation of the $\sum$BSI-1 signals in percent.

For the T2 TBIU monitor, Table 11 shows the ratio of the signals from the BSI-2 with the Ni detector foil, and the BSI-1 with the Al detector foil.

6.3 Conclusion

A study of the results shown in Tables 7 to 10 gives the surprising result that the $\sum$BSI-1 signals, when the experimental data are compared with the data of both physics runs 8A and 8B, differ only by about 2% provided that a correction for the individual secondary emission efficiency is not yet applied (Table 7); whereas after this correction the difference increases to about 7% (Table 8). A comparison of the $\sum$BSI-1 signal between 8A and 8B yields only a difference of about 1%, which is well within the standard deviations (2% for 8A and 4% for 8B) of these measurements.

The surprising result of the reduced $\sum$BSI-1 signal as recorded during our irradiation experiment (see Table 8) is mainly explained by the fact that for our irradiation experiment we had to modify the splitting ratio in such a way that the doses received by the irradiated foils were roughly equal. Unfortunately, there was not sufficient time for careful optimization of the beam position on the splitters, and therefore the splitter losses during the calibration experiment were much higher than for normal physics runs.

A detailed study of all individual measurements during the irradiation experiment and the two physics runs shows that $\gtrsim$ 4% of the 7% difference quoted above are due to beam loss on the splitters, the remaining $\lesssim$ 3% being due either to other losses in the beam line downstream of the splitters or to modified sensitivity of the target beam monitors.

Hence the following conclusions:

1) During the physics runs a stability of $\sim$ 4% for the $\sum$BSI-1 signal of the upstream target monitors TBIU of T2, T4, and T6 has been measured.

| Table | Period | BSI 210279 | BSPV 210280 | $\frac{\text{BSPV 210280}}{\text{BSI 210279}}$ | TBIU T2 BSI-1 | TBIU T4 BSI-1 | TBIU T6 BSI-1 | TBIU T2+T4+T6 ∑BSI-1 | Standard deviation (in %) |
|---|---|---|---|---|---|---|---|---|---|
| 7 | 8A except Exp. | 784 ± 8.2 | 816 ± 7.2 | 1.039 ± 0.006 | 58.2 ± 28.3 | 137.9 ± 10.4 | 462.8 ± 21.4 | 658.9 ± 11.8 | 1.79 |
| | Experiment | 770 ± 1.4 | 801 ± 1.1 | 1.040 ± 0.001 | 166.3 ± 3.8 | 201.7 ± 3.2 | 270.2 ± 2.5 | 638.2 ± 0.9 | 0.14 |
| | 8B | 762 ± 9 | 797 ± 8 | 1.045 ± 0.003 | 46.4 ± 19.7 | 225.9 ± 23.7 | 373.6 ± 39.7 | 645.9 ± 26.0 | 4.03 |
| 8 | 8A except Exp. | | | | 42.8 ± 20.8 | 137.8 ± 10.4 | 462.8 ± 21.4 | 643.4 ± 13.1 | 2.04 |
| | Experiment | | | | 122.4 ± 2.8 | 201.5 ± 3.2 | 270.2 ± 2.5 | 594.1 ± 1.0 | 0.17 |
| | 8B | | | | 34.2 ± 14.5 | 225.7 ± 23.6 | 373.6 ± 39.7 | 633.4 ± 25.4 | 4.01 |
| 9 | 8A except Exp. | 100 ± 1.1 | 104 ± 0.9 | | 7.4 ± 3.6 | 17.5 ± 1.3 | 59.0 ± 2.7 | 84.0 ± 1.5 | 1.78 |
| | Experiment | 100 ± 0.2 | 104 ± 0.14 | | 21.6 ± 0.5 | 26.2 ± 0.4 | 35.1 ± 0.3 | 82.9 ± 0.1 | 0.12 |
| | 8B | 100 ± 1.2 | 104 ± 1.05 | | 6.1 ± 2.6 | 29.6 ± 3.1 | 49.0 ± 5.2 | 84.8 ± 3.4 | 4.01 |
| 10 | 8A except Exp. | | | | 5.5 ± 2.7 | 17.6 ± 1.3 | 59.0 ± 2.7 | 82.1 ± 1.7 | 2.07 |
| | Experiment | | | | 15.9 ± 0.4 | 27.3 ± 0.4 | 35.1 ± 0.3 | 77.2 ± 0.1 | 0.13 |
| | 8B | | | | 4.5 ± 1.9 | 29.6 ± 3.1 | 49.0 ± 5.2 | 83.1 ± 3.3 | 3.97 |
| 11 | 8A except Exp. | 1.077 ± 0.02 } $\frac{\text{BSI-2 (Ni detector foil)}}{\text{BSI-1 (Al detector foil)}}$ of T2 TBIU | | | | | | | |
| | Experiment | 1.076 ± 0.01 | | | | | | | |
| | 8B | 1.083 ± 0.01 | | | | | | | |

Table 7 $\quad \dfrac{\text{BSI (x)} \ [10^{-3} \text{ volts-bit}]}{\Delta\text{BCT} \ [10^{12} \text{ protons}]}$

Table 8 $\quad \dfrac{\text{BSI-1}(T_x) \ [10^{-3} \text{ volts-bit}]}{\Delta\text{BCT} \ [10^{12} \text{ protons}]} \cdot \dfrac{\text{EFFICIENCY BSI-1 OF } T_6 : \varepsilon_6}{\text{EFFICIENCY BSI-1 OF TARGET } T_x : \varepsilon_x}$

Efficiency of BSI-1 of T2: $\varepsilon_2 = 5.866\%$
" " " " T4: $\varepsilon_4 = 4.323\%$
" " " " T6: $\varepsilon_6 = 4.320\%$

Table 9 $\quad \dfrac{\text{BSI (x)} \ [\text{volts-bit}]}{\text{BSI 210279} \ [\text{volts-bit}]}$

Table 10 $\quad \dfrac{\text{BSI-1}(T_x) \ [\text{volts-bit}]}{\text{BSI 210279} \ [\text{volts-bit}]} \cdot \dfrac{\text{EFFICIENCY BSI-1 OF } T_6 : \varepsilon_6}{\text{EFFICIENCY BSI-1 OF TARGET } T_x : \varepsilon_x}$

2) A sensitivity change of 3% for these monitors may have occurred owing to modified beam optics.

3) Therefore, in addition to the error on the absolute calibration as given in Table 6, we quote a global error of about 7% for the stability of the BSI-1 of T4 and T6 during the periods 8A and 8B. However, only about 10% of the total beam was sent to T2; consequently, because of its correspondingly small contribution to the $\sum$BSI-1 signal, this error could be larger for the T2 BSI-1 detector. An additional estimate of the T2 BSI-1 stability is derived from the ratio of the signals from the BSI-2 (Ni detector foil) and the BSI-1 (Al detector foil). The measured variation of this ratio of ±2% does not indicate a much larger instability for this monitor than observed for the BSI-1 of T4 and T6.

4) Although during period 8B the average beam intensity to the NA was about 40% higher than in period 8A, this had virtually no influence on the normalized beam monitor signals. It can therefore be assumed that the sensitivity of the target monitors was independent of the beam intensity to within a precision of $\lesssim$ 2%.

## 7. MEASUREMENT OF CROSS-SECTIONS

From the known efficiencies of the SPS NaI gamma spectrometer[8-9] it was possible to estimate the activity of $^{24}$Na and $^{18}$F in the exposed foils. The efficiencies are known to within a standard deviation of 3%. The calculated activities are compared with those measured by the Site section in Table 12, which shows that any difference is within the errors quoted. From these data and the measured foil thicknesses the cross-sections for the monitor reactions were determined.

There is very little data available giving these cross-sections at 400 GeV. Some measurements have been made by the Argonne group[10] at Fermilab. These and other measurements are summarized in the Fermilab Radiation Guide[11], but these values are quoted without errors.

The values determined for the Cu-$^{24}$Na and the Al-$^{24}$Na cross-sections are in good agreement with the other data, but that for the Al-$^{18}$F reaction is somewhat higher. Back-scatter and build-up of activity in the foil stack could give rise to higher activities, but one would expect the discrepancy to be largest for the reaction with the lowest threshold energy, i.e. Al-$^{24}$Na. We propose to investigate these effects in future exposures. The systematic difference between the 400 GeV data and the 195 GeV data is also noticeable.

Table 12

Cross-sections of monitor reactions

| Irradiation (GeV) | SPS | | Site | | Mean | | Cross-section (mb) | Error |
|---|---|---|---|---|---|---|---|---|
| | dps | Error | dps | Error | dps | Error | | |
| Al-$^{24}$Na | | | | | | | | |
| 400 | 6920 | 210 | 7080 | 200 | 7000 | 140 | 8.82 | 0.18 |
| 195 | 4210 | 130 | 4310 | 160 | 4260 | 100 | 8.44 | 0.20 |
| 195* | 1760 | 50 | 1760 | 80 | 1760 | 40 | 8.48 | 0.21 |
| FNAL 400 | | | | | | | 8.4 | |
| Cu-$^{24}$Na | | | | | | | | |
| 400 | 4900 | 190 | 4950 | 170 | 4920 | 130 | 3.96 | 0.10 |
| 195 | 2930 | 100 | 3100 | 130 | 3020 | 80 | 3.89 | 0.10 |
| 195* | 1235 | 40 | 1206 | 60 | 1220 | 35 | 3.76 | 0.11 |
| FNAL 400 | | | | | | | 3.8 | |
| Al-$^{18}$F | | | | | | | | |
| 400 | 45000 | 1400 | | | | | 6.92 | 0.20 |
| 195 | 28800 | 1100 | | | | | 6.96 | 0.27 |
| 195* | 11700 | 400 | | | | | 6.88 | 0.22 |
| FNAL 400 | | | | | | | 5.8 | |
| 300 (Ref. 10)$^{+)}$ | | | | | | | 5.9 | 0.2 |

+) Based on an 8.0 mb cross-section for Al-$^{24}$Na

## 8. CONCLUSION

The secondary emission monitors TBIU and TBID of the NA target stations T2, T4, and T6 have been calibrated by measuring the induced activity of thin Al and Cu foils irradiated in TCC2 just upstream of the targets by a 400 GeV slow extracted proton beam. In an auxiliary experiment in TT60 the ratio of induced activity per incident proton intensity -- the latter measured with the BCT in the TT60 proton beam line -- was determined for 195 GeV fast extraction and 400 GeV FFS extraction. The proton intensity on the TCC2 foils is then equal to the ratio of the "TCC2 foil activity" over "TT60 foil activity" multiplied by the "TT60 proton intensity".

Since the TCC2 and the TT60 foil activities have been measured in parallel and at similar counting rates with the same detectors, any influence of detector efficiencies and dead-time on the results are cancelled.

The error of the absolute calibration of the secondary emission monitors as measured during our experiment on 20 November 1979 is estimated to be $\lesssim$ 3%.

The long-term stability of the secondary emission monitors is more difficult to evaluate. From the measured variation of the target TBIU BSI-1 signals when normalized on the corresponding main ring $\Delta$BCT reading, we estimate that during the periods 8A and 8B the sensitivity of these monitors could have varied by about 7%.

The over-all error in the proton intensities as measured with the secondary emission monitor BSI-1 of the T2 TBIU, taking into account the error in the absolute calibration and a possible long-term variation in sensitivity during the period 8, is estimated to be about 10%.

With the help of our accurately measured cross-sections a future calibration of secondary emission monitors in slow extracted beams can be performed without recurring to the auxiliary experiment in TT60.

Although the time necessary for such a calibration experiment and its analysis can be cut down, we feel that this procedure still requires a considerable amount of time and co-operation between different groups. Therefore, this calibration method is almost excluded for current applications and must be reserved for special physics requirements.

To circumvent the above-mentioned limitations, different methods can be envisaged which would avoid frequent recalibration of the upstream target monitors TBIU in TCC2 by the described activation procedure, but which would nevertheless permit a surveillance of the long-term stability of these detectors.

It has been shown[6,7] that the reduction in efficiency of secondary emission detectors, called ageing, depends on the integrated proton flux per $cm^2$.

Since the secondary emission is a pure surface effect, a possible solution could be the development of specially coated and cleaned detector foils[6,7], which provide a stable secondary emission coefficient. However, this would require an important amount of development work and the construction and installation of new TBIU monitors. In addition, we have already reached the limit, at least for the target monitors of T6, where beam-induced changes in the crystalline structure of detector foils due to nuclear interactions might be expected (about $10^{20}$ protons/$cm^2$) [7].

Therefore, a different solution is proposed here, which uses the installed TBIU monitors without any modification and which takes advantage of the fact that these monitors can be displaced horizontally, with high position accuracy, in a remotely controlled way. Thus in order to avoid the ageing effect a detector could be calibrated by using a foil area which is normally not irradiated by the proton beam.

The BSI-1 detector of a TBIU which is used to measure the proton flux, is made of a 25 μm aluminium foil with a sensitive area of 145 mm in diameter. In the case of the upstream monitor TBIU, only the central part (< 10 mm diameter) of this foil is exposed to a high-intensity proton flux. During its calibration via the activation method, the TBIU monitor should therefore be displaced horizontally by, for example, 20 mm so that the proton beam hits a detector area which is normally not irradiated. Thereafter, the monitor is removed to its standard position with the beam well centred on the split foils. When the absolute proton flux incident on a target must be measured again, the TBIU is moved, for a couple of machine pulses, back into the calibration position. In this way the integrated proton flux per $cm^2$ on the calibrated detector area can be kept low, and hence it is expected that the ageing effect will become negligible.

Furthermore, it has been suggested[12] that, during the activation run, the secondary beam lines should be operated in a simple and reproducible mode so that a correlation between a "reference" secondary particle flux and the incident proton intensity could be established. This correlation could thereafter be used for the recalibration of the TBIU monitors, provided that the same beam optics for the primary proton beam, as selected for the activation run, are used again.

As a future development we could envisage a combination of both solutions described here, by adding to the existing miniscanner BBST of the TBIU monitor, a special foil flag for beam intensity measurements, which would normally be far out of the beam. This flag could be coated and cleaned in an appropriate way in order to give a stable secondary emission coefficient. Once calibrated by the activation method, it could be displaced for a couple of machine pulses by the miniscanner movement into the proton beam, in order to provide a cross-calibration of the standard BSI-1 detector of the TBIU monitor.

Acknowledgements

We would like to thank P. Gerdil and W. del Torre who fabricated and installed the foil holders and their supports, and S. Livesley, Ø. Olsen and B. Zihler for the TV-controlled displacement of the TT60 foil assembly.

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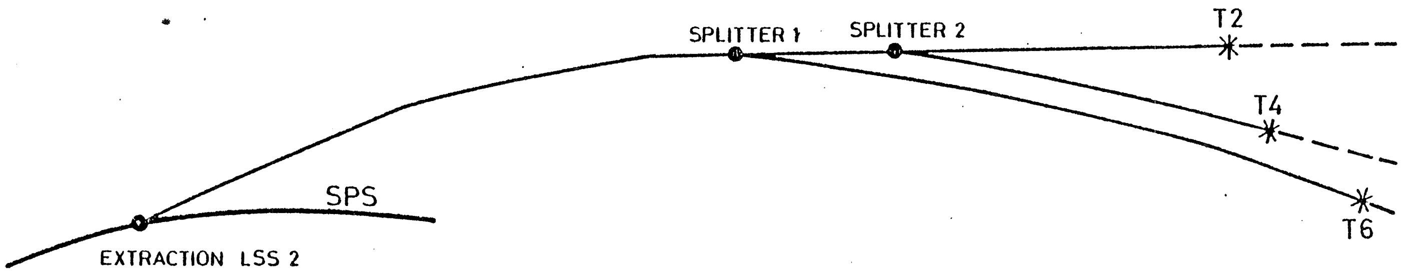
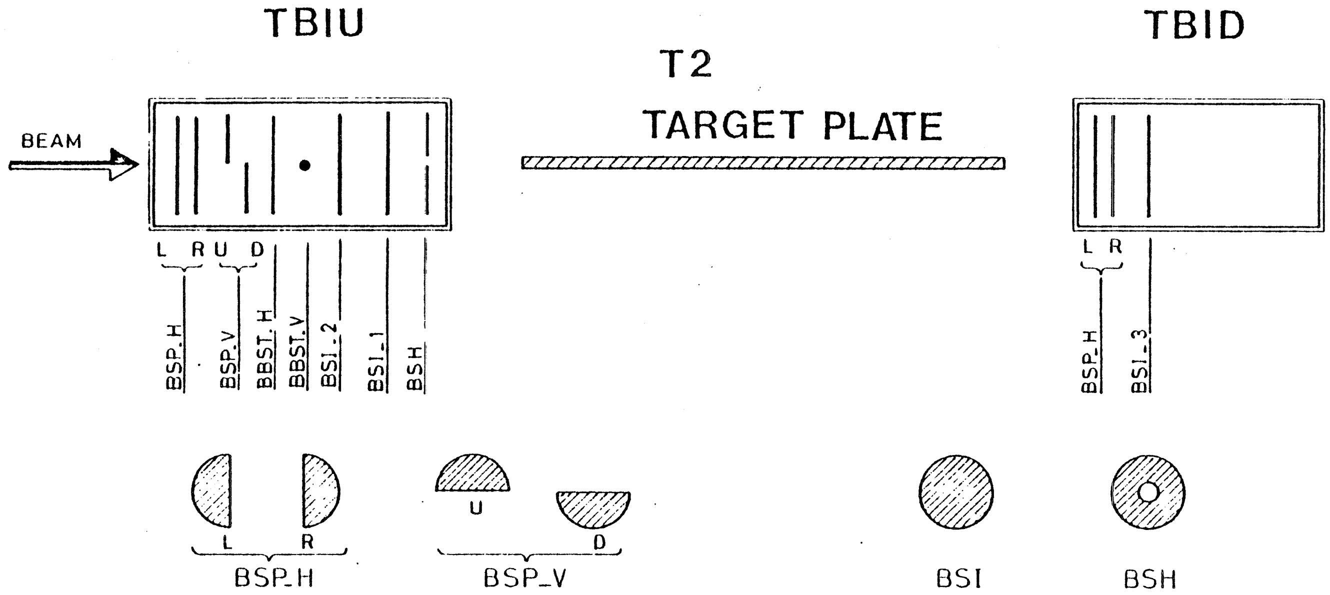



Fig. 1 Schematic layout of the external proton beam lines to the North Area of the SPS.



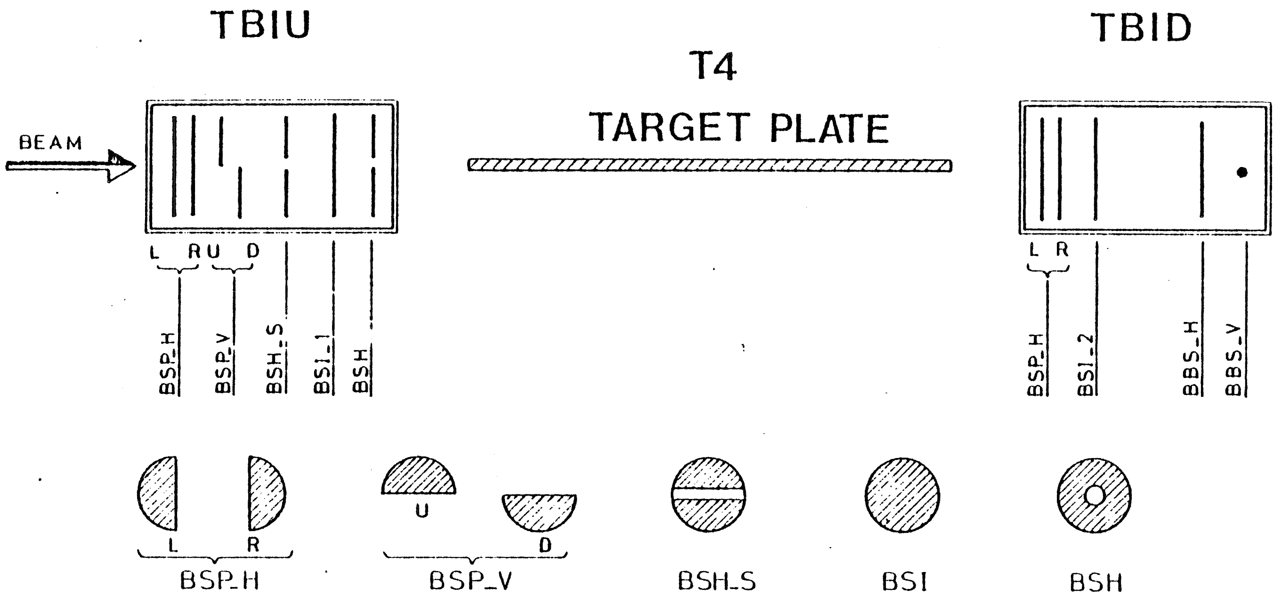

| Detector | Measures |
|---|---|
| BSP_H | HORIZONTAL BEAM POSITION |
| BSP_V | VERTICAL BEAM POSITION |
| BSH | BEAM HALO |
| BSI | BEAM INTENSITY |
| BBST. H | HORIZONTAL BEAM PROFILE |
| BBST. V | VERTICAL BEAM PROFILE |

| HALO FOIL | Hole Dimensions hor | vert |
|---|---|---|
| BSH | φ 2mm | |

Fig. 2 Schematic layout of the T2 target monitors TBIU 23 09 49 and TBID 23 09 50 in TCC2.

TBIU: Target Beam Instrumentation Upstream

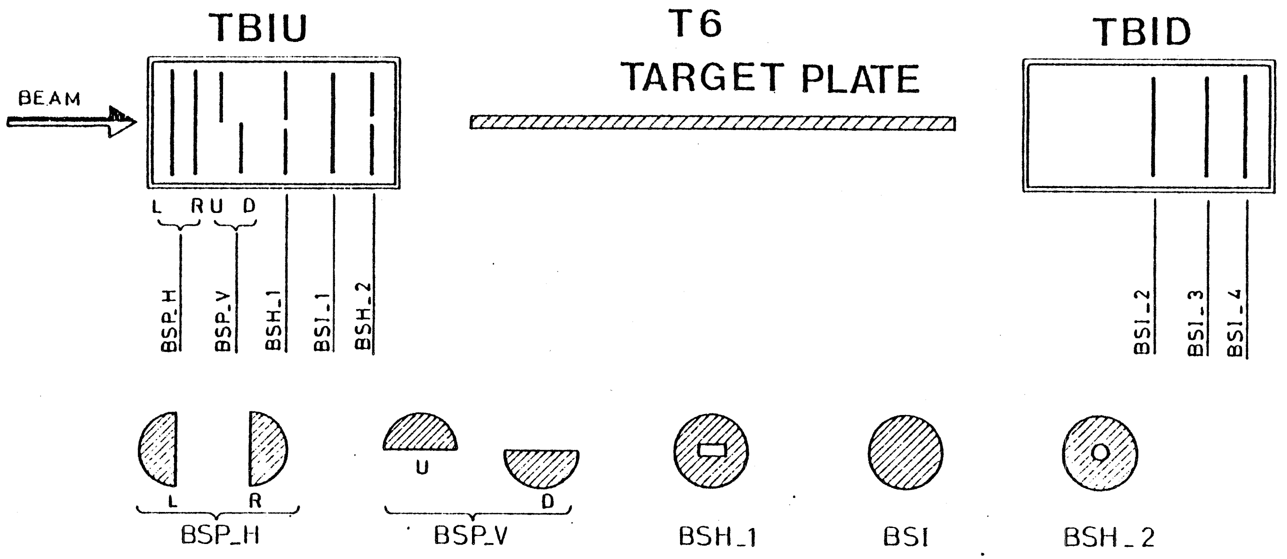
TBID: Target Beam Instrumentation Downstream




| Detector | Measures |
|---|---|
| BSP_H | HORIZONTAL BEAM POSITION |
| BSP_V | VERTICAL BEAM POSITION |
| BSH | BEAM HALO |
| BSI | BEAM INTENSITY |
| BBS_H | HORIZONTAL BEAM PROFILE |
| BBS_V | VERTICAL BEAM PROFILE |

| HALO FOIL | Hole Dimensions hor | vert |
|---|---|---|
| BSH_S | 145 mm | 2 mm |
| BSH | ϕ 2 mm | |

Fig. 3 Schematic layout of the T4 target monitors TBIU 24 11 49 and TBID 24 11 50 in TCC2.




| Detector | Measures |
|---|---|
| BSP_H | HORIZONTAL BEAM POSITION |
| BSP_V | VERTICAL BEAM POSITION |
| BSH | BEAM HALO |
| BSI | BEAM INTENSITY |

| HALO FOIL | Hole Dimensions | |
|---|---|---|
| | hor | vert |
| BSH_1 | 2mm | 2mm |
| BSH_2 | ϕ 2mm | |

Fig. 4 Schematic layout of the T6 target monitors TBIU 25 12 47 and TBID 25 12 48 in TCC2.

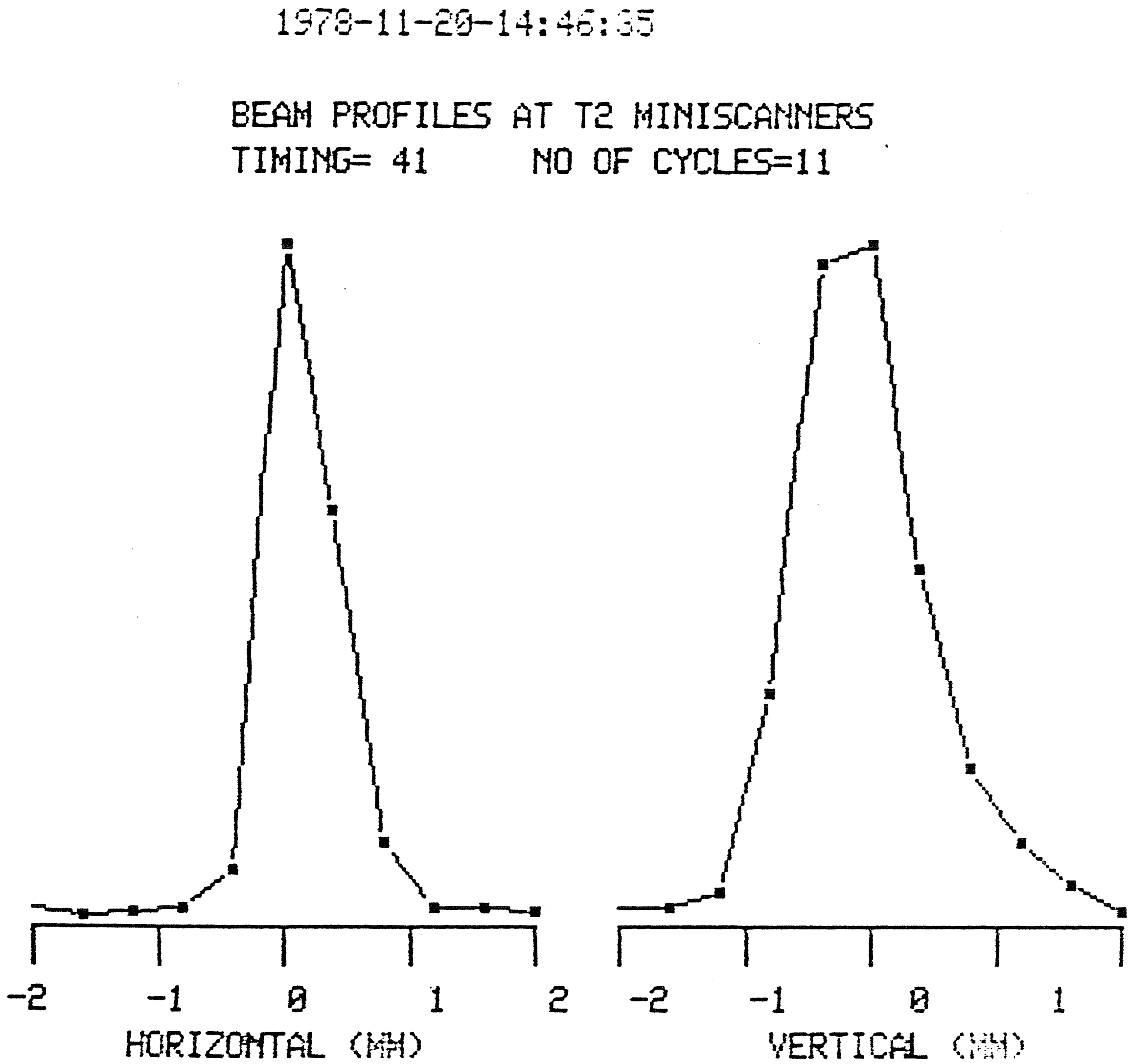



Fig. 5 The horizontal and vertical beam profiles of the proton beam on T2 as measured during the experiment on 20.11.78 with the target miniscanner BBST, which is incorporated in the TBIU monitor.

APPENDIX I

## DETAILS OF TCC2 AND TT60 IRRADIATION

### Table AI.1

Details of TCC2 irradiations and measured TBIU signals

| | |
|---|---|
| Start : | 15:11:09h |
| Finish : | 15:29:04h |
| Machine pulses : | 113 |
| T2 BSI-1 Al foil: | 132.20 volts-bit |
| T4 BSI-1 Al foil: | 160.79 volts-bit |
| T6 BSI-1 Al foil: | 213.60 volts-bit |

1 V ≙(1.0211 ± 0.0003) volts-bit
(see Appendix III)

### Table AI.2

Details of TT60 irradiations and measured proton intensity

| Irradn. (GeV) | Start | Finish | Pulses | Total BCT protons | BCT protons/pulse |
|---|---|---|---|---|---|
| 400 | 16:49:13h | 16:54:21h | 33 | $2.431 \times 10^{14}$ | $7.37 \times 10^{12}$ |
| 195* | 17:09:13h | 17:10:49h | 11 | $6.375 \times 10^{13}$ | $5.80 \times 10^{12}$ |
| 195 | 17:14:40h | 17:30:21h | 99 | $1.528 \times 10^{14}$ | $1.54 \times 10^{12}$ |

APPENDIX II

## BCT CROSS-CALIBRATION FOR 400 GeV FFS EXTRACTION

In order to obtain an independent cross-check for the accuracy of the extraction BCT readings for 400 GeV FFS extraction, we used the results of the foil irradiation in TT60. Provided that the relevant nuclear cross-sections remain constant for proton energies ranging from 200 to 400 GeV, the measured foil activities per incident proton should be the same for the 195 and 400 GeV irradiations. However, we found a difference of ∿ 2.7%, which can imply a small increase in the cross-sections of interest (see Section 7) with rising proton energy.

Systematic errors in the measured foil activity or proton intensity, which might have caused the same effect, were eliminated as follows:

a) Since all foils have been measured in parallel by the same detectors (Site and SPS) and for several reactions, the difference of ∿ 2.7% in the activity per incident proton cannot be due to systematic errors in the activity measurement.

b) During the foil irradiation with 400 GeV FFS extraction, we carefully checked whether the different extractions earlier in the SPS cycle were not completely stopped, so that protons were still leaking out of the machine. From the readings of the BSI monitors in the West extraction channel we can limit the number of protons which might have traversed the foil outside the BCT acquisition interval to < 1%.

c) Furthermore, we investigated whether the efficiency of the extraction BCT and the other West transfer line BCTs for multipulse measurements as made in the case of multiturn FFS extraction was not lower than the efficiency for single-pulse measurements as made in the case of fast extraction. This hypothesis was checked with a pulsed precision current source equivalent to $4 \times 10^{10}$ ppp. The ratio of double- to single-pulse readings averaged over 40 pulses was 2.0011 and, therefore, this effect can be neglected.

Hence, we conclude that the readings of the extraction BCT for 400 GeV FFS extracted protons are correct and that furthermore the difference of ∿ 2.7% in the measured activity per incoming proton could be due to an increase of the implied nuclear cross-sections with higher proton energies.

## APPENDIX III

### SECONDARY EMISSION EFFICIENCY AND CALIBRATION COEFFICIENT

The secondary emission efficiency $\varepsilon_{sem}$ is defined as follows:

$$\varepsilon_{sem} = \frac{\text{Number of electrons liberated from detector foil } (N_e)}{\text{Number of charged particles (protons) traversing detector foil } (N_p)}$$

Since $N_e$ is equivalent to the positive charge Q of the detector foil divided by the electron charge $e_0$, we can write:

$$\varepsilon_{sem} = \frac{Q}{e_0 \cdot N_p} = \frac{C \cdot U}{e_0 \cdot N_p}$$

$$\varepsilon_{sem} = 6.2415 \times 10^9 \times C\ (\text{nF}) \times U\ (\text{V}) \times \frac{1}{N_p} ,$$

where

$C$ = Capacitance of the integrator in units of (nF)

$U$ = Tension at integrator in (V)

$e_0 = 1.602189 \times 10^{-19}$ Coul.

At the SPS the tension at the integrator is correlated to the output signal of the ADC as follows:

$$10\ \text{V} \mathrel{\hat{=}} 1024\ \text{bits} .$$

A calibration of the ADC used in our experiment gave

$$10\ \text{V} \mathrel{\hat{=}} (1021.05 \pm 0.30)\ \text{bits} .$$

When the tension at the integrator of a secondary emission monitor is acquired via the corresponding data module (e.g. DET80), the bit reading is internally divided by 100, so that the value read corresponds directly to volts within an error of about 2%.

Hence, in order to avoid any ambiguity between volts and bits, we use in this report the following definition:

$$1\ \text{V} \mathrel{\hat{=}} 1.02105\ \text{volts-bit} .$$

For internal purposes it is more convenient to use instead of the secondary emission efficiency the calibration coefficient $C_{sem}$:

$$C_{sem} = \frac{\text{Number of charged particles (protons) traversing detector foil } (N_p)}{\text{Detector signal as read in volts-bit}}$$

or, shorter,

$$C_{sem} = \text{protons/volts-bit} .$$

Obviously, the value of this calibration coefficient (protons/volts-bit) depends on the value of the integrator capacitance. The number of protons $N_p$ traversing a detector foil is then

$$N_p = C_{sem} * U \text{ (volts-bit)} .$$

The secondary emission efficiency and the calibration coefficient respectively the reading in volts-bit are related as follows:

$$\varepsilon_{sem} = 6.1128 \times 10^9 \times \frac{C \text{ (nF)}}{C_{sem}}$$

$$\varepsilon_{sem} = 6.1128 \times 10^9 \times C \text{ (nF)} \times \frac{U \text{ (volts-bit)}}{N_p} .$$