OPERATING EXPERIENCE WITH

THE R.F. SEPARATED BEAM TO OMEGA

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Prévessin, September 20, 1979
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1. INTRODUCTION

In December 1977 the S1 beam in the SPS West Area was operated for the first time as a separated beam using its newly installed superconducting R.F. cavities. The R.F. separator was developed and built at KfK Karlsruhe. A 48 hour run was scheduled to test beam and cavity performance and indeed excellent separation conditions were observed at three momenta, namely 16, 26 and 37 GeV/c\(^1\,2\). From March to July and from October to December 1978, the beam and R.F. separators have been operated in a routine way under the control of different counter experiments using the beam. During this period no major breakdowns occurred of the cryogenic system, the separators and the beam line.

We present data obtained on the beam and cavity performance during the first year of operation and describe modes of separation, beam optics and tuning, controls, particle identification and the beam spectrometer for the benefit of potential users of this beam.

2. THE SUPERCONDUCTING R.F. SEPARATOR

A description of the separator can be found in references 2 and 3. By September 1979 the R.F. separator had been operated for a total of more than 4500 h of which 4200 h were during physics runs. Since the first assembly of the two deflectors eleven cooling cycles from 300\(^0\)K to 1.8\(^0\)K have been performed. During this time the separator has shown a remarkably stable and reliable behaviour; in particular the two s.c. deflectors RF1, RF2 have shown no decrease of quality factors and peak field-levels. They worked normally at a field level of 1.0 MV/m which is 20 % below the break down level of RF2 (1.2 MV/m). For periods of several days, operation fields > 1.1 MV/m were also achieved. During normal operation, breakdowns were observed only in RF2 (the breakdown field of RF1 being 1.4 MV/m) with a rate decreasing from an initial one breakdown/h to one breakdown/week.
Thermal breakdown have occasionally been observed in RF1 and RF2 at field levels below normal, particularly towards the end of a 10 days operation period. These thermal effects, which presumably are caused by adsorption of molecules on the cold cavity walls, can be largely avoided by pulsing the R.F.-power, i.e. by reducing the R.F. power level to about 10 % inbetween the beam-spills. This operation mode which was thought to lead to multipactor instabilities at low field levels turned out to provide extremely stable operation conditions. The requirements for amplitude and phase stability could be easily satisfied ($\Delta A/A = 1 \%$ ; $\Delta \phi < 2^\circ$). The long-term stability of the R.F. regulation systems can be checked during operation by measuring the beam enrichment.

The cooling time for the refrigerator, He-distribution system and cryostats from room temperature to $1.8^\circ$K, with a subsequent filling of both cryostats with He II, is about 40 h. About the same time has to be foreseen for warming up to room temperature.

3. SEPARATION MODES

Three ways of separation minority particles from pions have been used. They are schematically illustrated in Fig. 1. They all depend on the time of flight difference, over a length $L$, between momentum analyzed particles of different mass. Expressed in terms of the cavity frequency, the phase shift between wanted and unwanted particles (of masses $m_w$ and $m_u$) turns out to be

$$\tau = 2\pi \Delta t \ f = \frac{\pi L}{\lambda p^3} \ (m_w^2 - m_u^2) \ \text{rads} \quad (1)$$

where $\lambda$ is the cavity wavelength in m

and $p$ is the beam momentum in GeV/c.

3.1 Normal two cavity separation

Enrichment is normally accomplished by this method, illustrated in Fig. 1a), when the phase of the second RF cavity is adjusted to cancel the deflection of the unwanted particles which are absorbed
by a central beam stopper. The term $L$ in the equation 1 is the intercavity distance (83 m) and the deflection amplitude $\theta$ of the wanted particles is

$$\theta = 2\theta_1 \sin \left( \frac{\tau}{2} \right) \text{ mrad}$$  \hspace{1cm} (2)

where $\theta_1$ is the amplitude of the deflection due to one cavity. If there is no appreciable phase slip between the particles and the deflecting wave, then

$$\theta_1 = \frac{p_1}{P}$$  \hspace{1cm} (3)

where $p_1$ is the transverse momentum, in MeV/c, given by each cavity to the particles ($\gtrsim 2.7$ MeV/c). About 50% of the wanted particles are absorbed by the beam stopper.

Fig. 2–5 show the deflections of various particles versus beam momentum. The minima correspond to phase slips over the intercavity distance of even multiples of $\pi$. The maxima are near to momenta where phase slips are odd multiples of $\pi$. At low momenta, the variation with momentum of phase slip for $\bar{p}$ or $\bar{D}$ particles becomes rapid giving rise to narrow peaks. The very low energy and $D$ deflection curves are included more for academic interest than for practical use; they illustrate an interesting phenomenon however. As the momentum decreases, the heavy particles acquire a time lag relative to the deflecting wave which reduces the single cavity deflection amplitude to

$$\theta_1 = \frac{p_1}{P} \frac{\sin \left( \frac{\tau_{1c}}{2} \right)}{\left( \frac{\tau_{1c}}{2} \right)}$$  \hspace{1cm} (3a)

$\tau_{1c}$ is the phase slip between the particle and deflecting wave over the length of one R.F. cavity. The reduction in the envelope of peak deflections is due to this effect.

Fig. 6 presents a measured phase scan for unwanted particles. A phase stability of a few degrees is ample for this kind of separation. At
low momenta, the electron intensity produced from a long production
target exceeds the charged pion intensity. A similar curve can be
measured for the electrons with a minimum transmission occurring at
a different phase angle. A compromise phase setting might be chosen
which minimizes the $e + \pi$ transmission.

3.2 Two cavities, two collimator separation

This method is illustrated in Fig. 1b). It is relevant for $P$
in the neighbourhood of 3.3 GeV/c where it has been successfully
applied. The $P$ acquire a phase slip over the cavity length of about
360° relative to the deflecting fields and are thus no longer deflected.
We came across this effect above when discussing Fig. 4, where a clear
envelope minimum can be seen at about 3.3 GeV/c. The $P$ therefore pass
through both collimator openings. The phase slip between the light
particles ($\pi + e$) and the deflecting field remains negligible however
and they are deflected as usual. The phasing between RF1 and RF2 is
chosen as indicated in Fig. 1b), so that pions and electrons passing
through the first collimator experience maximum field in the second
and are thrown into the jaws of the second collimator. Note that no
loss of wanted particles occurs.

3.3 One cavity separation

This method is applicable at low energies when there is a large
phase slip through a single R.F. cavity between the wanted and un-
wanted particles.

In the normal $\pi/2$ working mode the phase velocity of the deflec-
tion field ($v_\phi$) is equal to the speed of light and is therefore well
matched to deflecting $\pi^-$ and $e^-$ down to momenta below 3 GeV/c. By
changing the working mode (frequency) $v_\phi$ can be reduced and chosen
so that $e^-$ and $\pi^-$ slip in phase by 360° relative to the deflecting
field over the cavity length. Thus the $e^-$ and $\pi^-$ are no longer de-
flexed and are stopped by a central beam stopper. The wanted heavier
particles acquire a smaller phase slip and are deflected by:

$$\Theta_1 = \frac{p_1}{p} \sin \left( \frac{2\pi - \frac{\tau_1 c}{2}}{2\pi - \frac{\tau_1 c}{2}} \right)$$  (4)
This separation mode is very simple because it involves only one cavity and no phase or amplitude regulation. Fig. 7 shows the $\bar{P}$ deflection versus momentum for this technique.

We have successfully operated this mode of separation for $\bar{P}$ at 5 GeV/c, when the phase slip between the antiprotons and the deflecting wave is about 160° over the 2.74 m cavity length.

4. **THE S1 BEAM**

The most important parameters of the S1 beam are summarized in Table 1.

4.1 **Optics** (see Figs 8 and 9)

It is conventional to consider a beam to be composed of several stages. In this framework the most upstream part of the beam (stage 1) defines the angular and momentum acceptances. The acceptance quadrupoles (Q1, Q2) are placed as near to the production target as is compatible with 40 GeV/c operation, thus maximizing geometrical angular acceptance (i.e. intensity). Since the cavities deflect in the vertical plane, the first quadrupole focusses horizontally, thereby increasing mass resolution at the expense of momentum resolution.

A collimator placed at the first vertical focus redefines the vertical target size and indeed this is found necessary for achieving high enrichments. The beam is vertically parallel at the first RF cavity, which is imaged onto the second RF cavity with a $-1$ matrix transformation.

A central beam stopper of variable thickness placed at a vertical focus downstream of the separators should eliminate most of the unwanted particles and absorb less than half of the wanted particles. This is followed by a collimator redefining the target horizontally and by a second dispersion section used to eliminate unwanted background generated at the beam stopper and to measure individual particle momenta to high precision. A threshold Cerenkov counter is also installed in this section.
Finally the beam passes through a further threshold Cerenkov or a "CEDAR" (differential Cerenkov with achromatic ring focus) for particle identification and is focussed onto the Omega target.

4.2 Beam diagnostics

A variety of beam monitors are installed to assess beam quality. They are described in the "SPS Experimenters' Handbook 1978", edited by E.J.N. Wilson, on pages 73 and 74. They may be interrogated through standard tree programmes.

4.3 Momentum measurement

A focussing spectrometer for measurement of individual particle momenta is provided by the SPS Experimental Areas Group. It is equipped with a scintillator hodoscope just upstream of the beam stopper and two digital wire chambers. Momentum resolution can be calculated by a Monte-Carlo programme "RESORT" (RESORT - Resolution of Spectrometers by Ray Tracing)\(^4\), table 2 gives a partial RESORT output for a 12 GeV/c beam.

4.4 Particle identification

The SPS Experimental Areas Group equip the beam with threshold Cerenkov counters and/or a CEDAR. CEDAR users are provided with shaped pulses of the 6, 7 and 8 fold coincidences fast enough to be incorporated in their trigger. Efficiency and rejection power can be traded off according to physics needs.

4.5 Computer control

Control of the S1 beam and monitoring equipment (and indeed all SPS secondary beams except BEBC beams) is provided via a NORD 10 computer. Beam and detector operation and setting up is done by the user through a set of computer programmes activated from his interactive terminal.
5. **PERFORMANCE OF THE SEPARATED BEAM**

This section gives information on beam performance, with some comparison with predictions. The predictions are from a Hagedorn-Ranft model which is not expected to be reliable at low momenta.

### 5.1 Beam setting up

Lists of currents (beam data files) have been established at many momenta. In general very little or no optical tuning has to be done (i.e. no focussing), but fine adjustments have to be made to the steering. The steering procedure is well understood and is described in the S1 Handbook.

If a change in S1 momentum is required, an existing tuned data file can be extrapolated to a new momentum. This is done by a programme available on the control tree. The characteristic curves of all magnets, quadrupoles and sextupoles are known, in a parameterized form, to this programme, which is thus able to convert the reference currents to magnet strengths, linearly extrapolate the bending or focussing strengths and convert the result back into currents. Thanks to this procedure, we were able to set up and run the beam at 3 momenta during the 48 hours given to us in December 1977 for first operation as an RF separated beam.

Experiments which require very frequent changes of momentum should bear in mind the following point. After the proton beam has produced secondary particles for S1, it is recuperated for a test beam and the West Hall hyperon beam. The two beams, S1 and the proton beam, share a bending magnet so that a change in S1 momentum necessitates a re-steering of the proton beam. For this reason S1 momentum changes have to be agreed to by all the users concerned and should be announced in advance at the weekly SPS schedule meeting.

### 5.2 Particle ratios

Particle ratios in S1 have been measured and published by the WA33 collaboration\(^5\). Figs 10 and 11 show their measurements compared to the predictions of the Hagedorn-Ranft model used by EA Group. The plotted data points give the ratios at Omega and are just the WA33 measurements, which are quoted at the production target, corrected for decays.
5.3 Intensities

Intensities have not been measured systematically; in general they have been recorded during setting up or during an experiment. Systematic errors have not been evaluated so the data points are given without errors. The data therefore give only a rough idea of how the beam performs and how it compares with predictions. The predictions use Hagedorn-Ranft and a Monte-Carlo Programme for the beam acceptance.

Table 3 gives some measurements made in the separated beam. Clearly some inconsistencies exist among the measurements, at $-12$ GeV/c in particular, which can be partially explained by different target heights and acceptance conditions at Omega.

5.4 Enrichment

By enrichment we mean the ratio "wanted particle intensity/total intensity" in the separated beam to the same quantity in the unseparated beam. Enrichment depends on many factors, in particular the RF deflection, the beam stopper thickness and the image size at the beam stopper. The dependance on beam stopper thickness of measured particle intensity at $-16$ GeV/c is shown in Fig. 12. Enrichments can be derived from this graph. Table 4 lists some enrichments.

In general the enrichments were high for a counter beam, due to the fact that limited total intensities of only about $10^6$ particle/burst, were required. With the advent of $\Omega$' with its faster detectors, higher rates can be tolerated and might have been achieved at the expense of enrichment.

5.5 Electron content

At low energies the electron content can be very high if a long production target is used. Fig. 13 shows some measurements reported by WA13 and WA60. Lead foils placed near the beam stopper help to eliminate the electrons as shown in Fig. 14.

5.6 Calibration of mean beam momentum

The mean beam momentum can be determined using the RF separators. Phase scans, in the normal two cavity mode, were made on two kinds of
particles. The difference in phase between the two minima are related through equation (1) to the mean beam momentum, since all the other parameters in that equation are known with high precision, the cavity frequency in particular.

Application of this method has given the following results:

WA33 : for five momenta between 10 and 27 GeV/c, they find the measured beam momentum is higher than the expected momentum by 0.4 to 2 %.

WA13 : for momenta between 3 and 12 GeV/c, the measured momenta are higher than data files momenta by 0.8 %.

WA48 : at 13.05 GeV/c, a momentum difference of 0.5 % has been found, the measured momentum being again higher than the files reference momentum.

6. ACKNOWLEDGEMENTS

We acknowledge the help of many people from inside and outside of CERN.

The operation of the separator would not have been possible without the competence and effort of many people. We thank in particular the operating crew of the refrigerator under G. Winkler as well as C. Dalmas and A. Scharling from the separator groups. We acknowledge the support of the Karlsruhe separator crew during the initial stages of operation.

The SPS Experimental Areas Group provided monitoring equipment for tuning and operating the beam, in addition to the particle identification apparatus used for standard Omega operation. We would like to thank many users for having provided data for the report. L. Moscoso, A. Muller and P. Sonderegger have taken a special interest in the separated beam, above the needs of their own experiment. The experiment WA33 contributed largely to our knowledge of the beam performance and provided special detectors for particle identification.
REFERENCES

1. "First results from the S1 RF superconducting cavities", CERN, GfK Karlsruhe, WA33 (Bologna, SACLAY), SPS/EBP/Note 78-3.


5. "Production of $\pi^\pm$, $K^\pm$, p and $\bar{p}$ by 200 GeV/c protons", W. Bozzoli et al., Nucl. Phys. B 140 (1978) 271.
FIGURE CAPTIONS

Fig. 1  Separation methods:

a) Normal two cavity separation with central beam stopper. The phase relation of wanted (w) and unwanted particles (u) with respect to the deflection fields is indicated. The phase slip between particles and fields over the deflector length is supposed to be negligible.

b) Separation at low momentum with two cavities and two collimators and with the normal cavity excitation mode. The heavy wanted particles (p) get a phase slip with respect to the deflection fields over the cavity length of about 360° and are no longer deflected. The unwanted particles are eliminated at the two collimators by using the phase relations indicated.

c) Separation with one cavity and a different working mode with v_φ < c. The light unwanted particles (π⁻ and e⁻), which acquire a phase slip of 360° over the cavity length, are not deflected and are eliminated by the central beam stopper. The heavy particles are deflected.

Fig. 2  Angular deflection of K⁺ in the normal two cavity separation mode. π⁻ deflection cancelled. (pₜ = 2.74 MeV/c)

Fig. 3  Angular deflection of p in the normal two cavity separation mode. π⁻ deflection cancelled

Fig. 4  Angular deflection of d in the normal two cavity separation mode. π⁻ deflection cancelled.

Fig. 5  Angular deflection of e in the normal two cavity separation mode. π⁻ deflection cancelled.

Fig. 6 a) Measured phase scan (transmission curve) for normal two cavity separation with a central beam stopper. The momentum was -37.7 GeV/c and the beam stopper thickness was 5 mm. The peak intensity was about 10⁶ π⁻/burst. Optimum phase for p enrichment is 114°.
b) Measured phase scan (transmission curve) for separation with two cavities and two collimators at -3.3 GeV/c. It can be shown that the two maxima for a given particle must have different heights. For convenience the curve has been extended to 540°.

Fig. 7  \(p\) angular deflection in the one cavity separation mode.

Fig. 8  S1 beam optical mode: Horizontal plane. Trajectories are shown for a ray starting from the production target T1 with 8 mrad divergence and no displacement, and for an axial ray with \(\Delta p/p = 5\%\).

Fig. 9  S1 beam optical mode: Vertical plane. A trajectory is shown for a ray produced at T1 with 2 mrad divergence and zero displacement. The dashed trajectory illustrates the effect of an angular kick at the second RF cavity.

Fig. 10  Particle ratios for negative particles at Omega. The measured points are from WA33 (4). The continuous lines are the Hagedorn-Ranft prescription used by the SPS/EA Group.

Fig. 11  Particle ratios for positive particles at Omega. The measured points are from WA33 (4). The continuous lines are the Hagedorn-Ranft prescription used by the SPS/EA Group.

Fig. 12  \(\pi^-, K^-\) and \(\bar{p}\) intensity at -16 GeV/c versus beam stopper thickness.

Fig. 13  The \(e/\pi\) ratio from a 30 cm Be production target.

Fig. 14  The relative ratios \(e/\bar{p}\) and \(\bar{p}\) incident protons versus the thickness of lead foils placed near the beam stopper.
K⁺ DEFLECTION
NORMAL 2 CAVITY MODE
NORMAL 2 CAVITY MODE

\( \bar{p} \) DEFLECTION

DEFLECTION (mrad)

BEAM MOMENTUM (GeV/c)

Fig. 3
\[ \tilde{D} \] DEFLECTION

NORMAL 2 CAVITY MODE

DEFLECTION (mrad)

BEAM MOMENTUM (GeV/c)

Fig. 4
ELECTRON DEFLECTION
NORMAL 2 CAVITY MODE

DEFLECTION (mrad)

BEAM MOMENTUM (GeV/c)

Fig. 5
NORMAL 2 CAVITY MODE

RELATIVE PHASE RF1 - RF2

Fig. 6 (a)

Y - INTENSITY
2 CAVITY - 2 COLLIMATOR MODE

Fig. 6 (b)
$\bar{p}$ DEFLECTION

1 CAVITY MODE

DEFLECTION (mrad)

BEAM MOMENTUM (GeV/c)

Fig. 7
$y^* = 2 \text{ mrad}$

Fig. 9 - S1 OPTICAL MODE: VERTICAL PLANE
Fig. 11. PARTICLE RATIOS AT OMEGA
Figure 12
WA 60 & WA 13 MEASUREMENTS

THE ELECTRON/PION RATIO FROM A 30 cm Be TARGET

Fig 13
Fig. 14
**TABLE 1**

**Characteristics of the separator and the S1 beam**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production angle</td>
<td>$0^\circ$</td>
</tr>
<tr>
<td>Proton beam momentum</td>
<td>200-240 GeV/c</td>
</tr>
<tr>
<td>Maximum momentum</td>
<td>40 GeV/c</td>
</tr>
<tr>
<td>Beam length</td>
<td>234 m</td>
</tr>
<tr>
<td>Maximum geometrical acceptance</td>
<td>horizontally $\pm 8$ mrad</td>
</tr>
<tr>
<td></td>
<td>vertically $\pm 2$ mrad</td>
</tr>
<tr>
<td></td>
<td>$\Delta \Omega = 50 \mu$ SR</td>
</tr>
<tr>
<td>Dispersion at momentum slit</td>
<td>5.2 mm/%</td>
</tr>
<tr>
<td>Intrinsic momentum resolution</td>
<td>0.8 %</td>
</tr>
<tr>
<td>Intercavity distance</td>
<td>83 m</td>
</tr>
<tr>
<td>R.F. Frequency</td>
<td>2865.9 MHz</td>
</tr>
<tr>
<td>R.F. Wavelength</td>
<td>10.46 cm</td>
</tr>
<tr>
<td>Effective cavity length</td>
<td>2.74 m</td>
</tr>
<tr>
<td>Typical deflecting field</td>
<td>1 MeV/m</td>
</tr>
<tr>
<td>Diameter of the deflector opening</td>
<td>40 mm</td>
</tr>
<tr>
<td>Maximum useful collimator openings:</td>
<td></td>
</tr>
<tr>
<td>Collimator 1 (horizontal)</td>
<td>$\pm 24$ mm (3 mm/mrad)</td>
</tr>
<tr>
<td>Collimator 2 (vertical)</td>
<td>$\pm 18$ mm (9 mm/mrad)</td>
</tr>
</tbody>
</table>
Table 2

Partial "Resort" output for the S1 beam spectrometer. The coefficients R11-R166 relate measured positions in planes 1, 2 and 4 to the momentum dispersion as follows:

\[ x_1 = R_{11} x_2 + R_{12} x_4 + R_{16} \Delta + R_{116} x_2 \Delta + R_{126} x_4 \Delta + R_{166} \Delta^2 \]

The resolution at 12 GeV/c has \( \sigma = 9.9 \) MeV/c. The effects of "Systematic uncertainties on the resolution are given in complete "REASORT" runs.

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Simulation of particles through spectrometer (Resort), Date 05/09/79

Standard S1 spectrometer, with split hodoscope, October 1978.

<table>
<thead>
<tr>
<th>Central Momentum</th>
<th>P0 = 12,000</th>
<th>+ Centroid Shift = 0.000 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Particles</td>
<td>N = 1000</td>
<td>+ Centroid Shift = 0.000 mm</td>
</tr>
<tr>
<td>Half Maximum Width at Focus</td>
<td>X0 = 3.500</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
<tr>
<td>Half Max. Angular Divergence at Focus</td>
<td>TL0 = 3.000</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
<tr>
<td>Half Max. Beam Spread</td>
<td>PL0 = 2.240</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
<tr>
<td>First Plane Location</td>
<td>L1 = 3.837</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
<tr>
<td>Spacing at First Plane</td>
<td>D1 = 1.000</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
<tr>
<td>Second Plane Location</td>
<td>L2 = 2.868</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
<tr>
<td>Spacing at Second Plane</td>
<td>D2 = 1.000</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
<tr>
<td>NC Third Plane</td>
<td>L3 = 2.780</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
<tr>
<td>Spacing at 4th Plane</td>
<td>D4 = 1.000</td>
<td>+ Centroid Shift = 0.000 mrad</td>
</tr>
</tbody>
</table>

\[ x_0 = \frac{1}{12.5000} x_0 + \frac{1}{0.0000} x_0 + \frac{1}{12.1800} \]

\[ x_1 = R_{11} x_2 + R_{12} x_4 + R_{16} \Delta + R_{116} x_2 \Delta + R_{126} x_4 \Delta + R_{166} \Delta^2 \]

SCAT1 = 115.9  SCAT2 = 115.9  SCAT3 = 0.0  SCAT4 = 115.9

| 22.0 -22.0 16.0 -15.0 0.0 0.0 16.0 -15.0 |
| Planes 1, 2, 4, Average = 0.0 Sigma = 8.9 (MeV/c) |
**Table 3**

Measured intensities compared to predicted intensities

<table>
<thead>
<tr>
<th>Momentum (GeV/c)</th>
<th>Collimators C1, C2, C3 (mm)</th>
<th>Target Length (mm)</th>
<th>$K^+/10^{12}$ incident protons</th>
<th>$p^+/10^{12}$ incident protons</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.1</td>
<td>±24, ±16, ±16</td>
<td>300</td>
<td>-</td>
<td>-</td>
<td>WA 13</td>
</tr>
<tr>
<td>-5.0</td>
<td>20, 16, 16</td>
<td>100</td>
<td>-</td>
<td>-</td>
<td>WA 13</td>
</tr>
<tr>
<td>-8.0</td>
<td>24, 16, 16</td>
<td>300</td>
<td>1.8 $10^4$</td>
<td>7.7 $10^4$</td>
<td>WA 13</td>
</tr>
<tr>
<td>-10.1</td>
<td>20, 6, 8</td>
<td>100</td>
<td>1.4 $10^4$</td>
<td>5.0 $10^4$</td>
<td>WA 33</td>
</tr>
<tr>
<td>-12</td>
<td>25, 20, 12</td>
<td>300</td>
<td>0.9 $10^5$</td>
<td>8.6 $10^5$</td>
<td>WA 13</td>
</tr>
<tr>
<td>-12</td>
<td>20, 16, 16</td>
<td>300</td>
<td>1.3 $10^5$</td>
<td>6.7 $10^5$</td>
<td>WA 13</td>
</tr>
<tr>
<td>-12</td>
<td>8, 8, 12</td>
<td>300</td>
<td>0.6 $10^5$</td>
<td>0.97 $10^5$</td>
<td>WA 49</td>
</tr>
<tr>
<td>-18.5</td>
<td>25, 7, 19</td>
<td>300</td>
<td>7.5 $10^5$</td>
<td>1.5 $10^6$</td>
<td>WA 60</td>
</tr>
<tr>
<td>-18.5</td>
<td>25, 10, 6</td>
<td>300</td>
<td>2.7 $10^5$</td>
<td>5.5 $10^5$</td>
<td>WA 60</td>
</tr>
<tr>
<td>-25.6</td>
<td>10, 7.5, 16</td>
<td>100</td>
<td>-</td>
<td>4.9 $10^5$</td>
<td>WA 33</td>
</tr>
<tr>
<td>-26.4</td>
<td>8.5, 7.5, 18</td>
<td>100</td>
<td>-</td>
<td>5.1 $10^5$</td>
<td>WA 33</td>
</tr>
<tr>
<td>+13</td>
<td>25, 10, 8</td>
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<td>-</td>
<td>0.5 $10^6$</td>
<td>WA 33</td>
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*) The smaller bracketed number was measured with an Omega Beam Telescope.
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<tr>
<th>Momentum</th>
<th>Target Length (mm)</th>
<th>Total intensity /$10^{12}$ incident protons</th>
<th>$\bar{P}$/total</th>
<th>$\bar{P}$ Enrichment</th>
<th>$K^+$/total</th>
<th>$K^+$ Enrichment</th>
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<tbody>
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<td>7.5</td>
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<td>-5.0**</td>
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</tbody>
</table>

** 1 cavity type separation

* 2 collimators, 2 cavity separation