

# FAST EXTRACTED PROTON BEAMS AT LOW ENERGIES IN THE CPS EAST EXPERIMENTAL AREA

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To provide beams with characteristics required by the Energy Amplifier Test, the CERN PS had to deliver new beams, of low kinetic energy (0.6 - 2.7 GeV), low intensity ( $0.5\text{-}5 \times 10^9$  p) and short duration (<500 ns) via the existing slow extraction channel, the transfer line currently used for 24 GeV/c beams and a slightly modified secondary line. These beams were delivered without impairing other CPS operations and, despite large operational differences, the other three East area beam lines could alternatively be supplied with slow extracted beam, for half week periods, thanks to the short setting-up time of a few hours.

This paper describes how such beams were produced: by (i) acceleration or deceleration of the injected beam in the CPS, depending on the requested energy, (ii) fast extraction using the usual slow extraction channel, (iii) careful optics adjustments and reduction of multiple scattering in the transfer line. The range of beam characteristics achieved, as well as the limitations encountered are also reported.

## I. INTRODUCTION

An Energy Amplifier Test [1,2] was performed in the CPS East Experimental Area with a calorimeter housing a target hit by a low energy proton beam. For this test the south branch of the beam lines was used to transport a primary proton beam delivered by the PS via the usual slow extraction channel. The far end of the line, the T7 area, was covered and shielded to accept proton bunches of a few  $10^9$  particles per supercycle of 14.4 s.

## II. BEAM IN THE CPS

The basic CPS magnetic cycle used to deliver proton test beams at 2.7 GeV kinetic energy (3.5 GeV/c momentum) to the Antiproton Collector and Accumulator was adapted to this operation. Its flat-top was adjusted to the energy required by the experiment and consequently, the 1 GeV beam from the PS Booster was either accelerated or decelerated to energies ranging from 2.7 GeV down to 0.6 GeV. The usual fast extraction through straight section 16 was inactivated and replaced by a fast extraction via straight section 61 described later.

The relatively low intensity required was obtained by injecting in the CPS a single PSB ring of  $2.5 \times 10^{10}$  protons in five bunches. Although only one bunch was to be extracted, the five bunches were kept in the machine up to the firing of the extraction kicker in order to provide a better intensity signal to the RF beam control.

For each new magnetic cycle the transverse tunes were measured throughout the cycle of the bare machine

and adjusted by tuning of the low energy quadrupoles, to provide the proper phase advance for the fast extraction and to avoid resonances.

## III. EXTRACTION

Extraction towards the East Experimental Area used the existing elements of the 24 GeV/c slow extraction process with the exception of the electrostatic septum. It included two magnetic septa and a set of 4 local orbit bumpers pushing the beam first near the thin septum SMH57 placed towards the inside of the machine, then near the extractor septum SMH61 located towards the outside as shown in fig. 1. The thin septum having an unfavourable betatron phase advance of  $5 \times 2\pi + 3\pi/4$  with respect to the fast extraction kicker KFA71-79, instead of the ideal value multiple of  $\pi/2$ , a tune adjustment was applied with the low energy quadrupoles to bring the horizontal tune from 6.25 down to 6.1. This provided the required  $\pi/4$  phase lag to obtain a maximum horizontal deviation at the thin septum location. The kick duration was adjusted to extract a single bunch, the remaining ones being lost either on a pulsed beam dump or against the vacuum chamber wall during the decreasing part of the magnetic cycle.

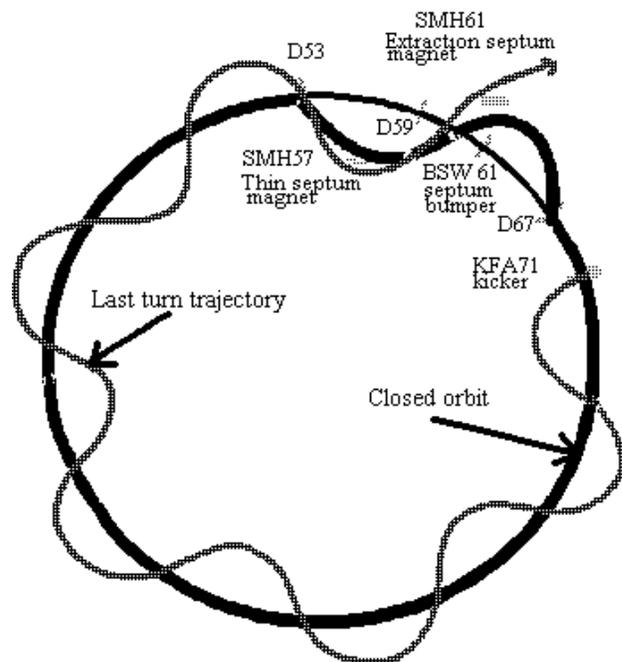


Figure 1. Schematic of the fast extraction scheme, using of 4 horizontal closed orbit bumpers, a fast kicker and 2 magnetic septa.

Transverse emittances of the circulating beam were (at  $2\sigma$ )  $5 \mu\text{m}$  in the horizontal plane and  $2.5 \mu\text{m}$  in the vertical one. However, as the corresponding extraction channel acceptances are respectively  $2 \mu\text{m}$  and  $6.6 \mu\text{m}$ , transmission efficiency was limited to 30 %. Table 1 shows the main parameters of this extraction scheme.

Horizontal tune, $Q_x$	6.10
Orbit bump in Straight Section 57	-61 mm
Orbit bump in Straight Section 61	43 mm
Kicker KFA71-79 deflection	-1.5 mrad
Septum SMH57 deflection	3.1 mrad
Septum SMH61 deflection	2.2 mrad

Table 1. CPS beam tune, displacement and deflections in the fast extraction process using a fast kicker and elements of the slow extraction.

#### IV. BEAM TRANSPORT

The extracted beam was transferred to the experiment along the existing primary line FT61S and one of the secondary test line T7, target removed. Modifications of the two lines had to be kept to a minimum owing to time, budget and reusability constraints. However, it was necessary to adapt the primary line designed for slow 24 GeV/c extraction to the low momentum fast extraction scheme used. Moreover, at low energy (1 GeV and below) as some correctors were out of their control range, they had to be turned off, leading to an unavoidable slight trajectory error compensated downstream.

The beam splitter was used to deflect the beam to the south branch but also to control the delivered intensity by adjustment of its gap.

Additional beam instrumentation was installed in the last part of the T7 line, shown in fig. 2:

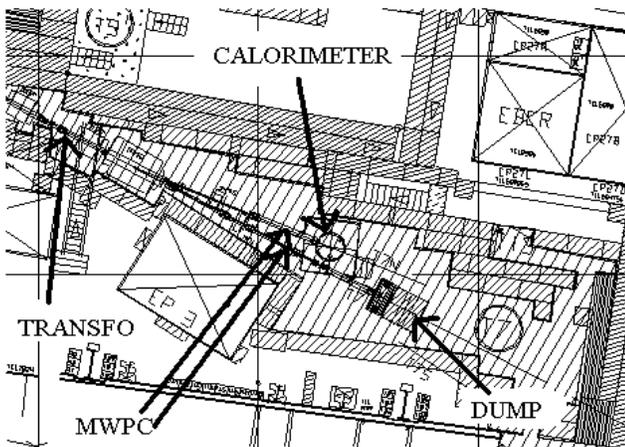


Figure 2. The test area (T7) with the monitoring devices. Beam goes either to a dump, if undeflected, or to the calorimeter, if deflected by the last bending magnet.

- a second beam transformer close to the target, to monitor the beam intensity,
- two scintillator counters close to each of the lines, to provide triggers to the experiment,
- two Multiwire Proportional Chambers (MWPCs) on the dump and target line, to focus and centre the beam, and to estimate its profiles. These MWPCs were used as first ionisation chambers, with a voltage limited to about 100 V, due to the high beam density.

On various occasions films were exposed to the beam, to provide a qualitative assessment of its size and position and aluminum foils were irradiated in order to give a further calibration of the beam intensity, a fundamental parameter in evaluation of the Energy Amplifier gain.

The optics functions of the secondary line were completely changed in order to accommodate a primary beam with very low losses, particularly beyond the beam transformer. Simulations performed with the computer code TURTLE (see Table 2) and a preliminary test showed an excessive contribution of multiple scattering in the target area. Therefore a 4.6 m air drift space was replaced with a helium bag and some  $200 \mu\text{m}$  Al windows changed to  $150 \mu\text{m}$  Mylar ones in order to bring this effect down to an acceptable level.

Transfer Line	H (mm)	V (mm)
'Standard' optics	20.8 mm	6.3 mm
- with He bag	13.8 mm	4.9 mm
- with Mylar window	10.0 mm	4.3 mm
'Round beam' optics	6.1 mm	5.9 mm

Table 2. Beam sizes (FWHM) at 2.7 GeV estimated by TURTLE. Multiple scattering was reduced by replacing free air space and Al window with He bag and Mylar windows

The 'round beam' optics, giving a better matching to the experiment target, was chosen. It was achieved with a triplet at energies higher than 1 GeV and with a quadruplet at 1 GeV and below. For each energy, matching was adjusted to minimize losses in the beam transformer and beyond. Figure 3 shows the beam optics for energies higher than 1 GeV.

Optical parameters have been carefully matched to minimize losses using all available instrumentation. Special care was taken for the T7 line due to limited diagnostics and the necessity to guarantee the precision of the beam transformer.

The final focus was made on a beam dump location using MWPCs. Switching to the experiment target required one single dipole and no further adjustments. The power supply driving the last switching magnet provided interlocks to the beam request in order to ensure that beam was

delivered to the dump or to the calorimeter only when the appropriate current was settled.

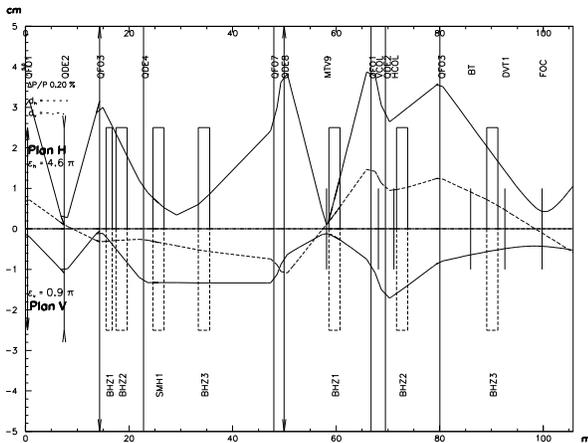


Figure 3. Beam optics for energies higher than 1 GeV.

## V. RESULTS

Eight different beam energies were set-up, from 2.7 GeV down to 0.6 GeV, the lowest energy the beam line could properly transport, to allow an estimation of the Energy Amplifier gain as a function of the energy of the beam hitting the target. Transverse beam dimensions measured at target position as in fig. 5, are plotted in fig. 4 as a function of beam energy. The relative mean energy variation had an rms value of  $2 \times 10^{-4}$  at high energy and  $7 \times 10^{-4}$  at low energy. The beam longitudinal emittance was 0.5 eVs and the RF voltage at extraction was adjusted to match the bunch length (70 ns) to the beam transformer bandwidth.

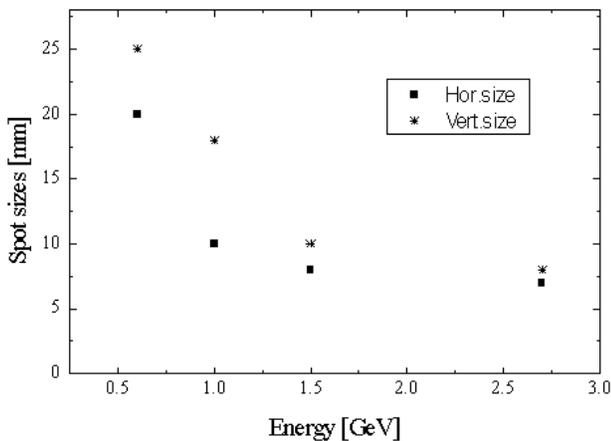


Figure 4. Spot sizes measured on MWPCs (FWHM), for the various beam energies achieved.

At the lowest energies transmission efficiency dropped to 10 % because beam dimensions naturally increase and multiple scattering induces transverse beam blow-up.

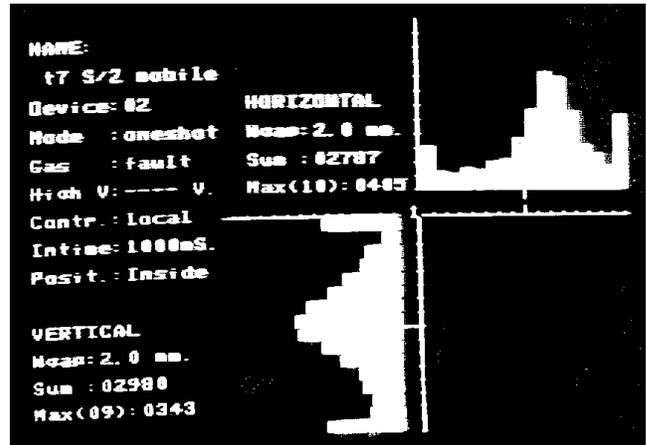


Figure 5. Beam shape on Multiwire Proportional Chambers (MWPCs), at 2.7 GeV. Extreme wires show the sum signal of all other undisplayed wires.

## VI. CONCLUSION

Additional new beams were delivered by the CPS to the East area, in fast extraction and in parallel with other operations. The limitations were given by the radiation level allowed by the shielding of the area, the power supply regulation at very low currents and beam dimensions and multiple scattering at low energy. However, these beams could satisfactorily cover the intensity, dimensions and energy range required by the Energy Amplifier Test.

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## VIII. REFERENCES

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