THE PROTON BEAMS FOR THE TIME-OF-FLIGHT NEUTRON FACILITY AT THE CERN-PS

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Abstract

The experimental determination of neutron cross sections in fission and capture reactions as a function of the neutron energy is of primary importance in nuclear physics. Recent developments at CERN and elsewhere have shown that many fields of research and development, such as the design of Accelerator-Driven Systems (ADS) for nuclear waste incineration, nuclear astrophysics, fundamental nuclear physics, and dosimetry for radiological protection and therapy, would benefit from a better knowledge of neutron cross sections. A neutron Time-of-Flight facility (n-ToF) at the CERN-PS has been built with the aim of carrying out a systematic and high-resolution study of neutron cross sections. Time-of-Flight is used to determine the neutron energy. The facility requires a high-intensity proton beam (about 0.7×10^{13} particles/bunch) in a single bunch of about 25 ns total length ($\approx$ 7 ns r.m.s.) to produce the neutrons by means of spallation in a lead target. To achieve these characteristics, a number of complex beam gymnastics have to be performed. They are presented in this paper as well as some beam dynamics issues encountered during the setting-up. The details of the new transfer line used to deliver the beam to the target are also described.

1 THE n-TOF FACILITY

As a result of the studies reported in Ref. [1], a neutron Time-of-Flight facility at the CERN-PS has been proposed [2], which delivers an average intensity of 2×10^{16} neutrons/pulse. This allows to study, systematically and with excellent resolution, neutron cross sections of almost any element using targets of very modest mass, in the interval from 1 eV to 250 MeV.

The principle consists of extracting, at 20 GeV/c, proton bunches onto a lead target ($N_\mathrm{b} \approx 0.7 \times 10^{13}$ particles/bunch, r.m.s. length $\approx$ 7 ns). The neutrons produced by spallation are transported to an experimental area located 200 m downstream through a vacuum pipe, making use of an existing tunnel about 7 m below the former ISR tunnel (see Fig. 1).

2 THE PROTON BEAM

2.1 General Considerations

The PS proton beam requirements are the following:

- The nominal momentum is 20 GeV/c, which is the maximum attainable for a 1.2 s repetition rate of the PS magnetic cycle.

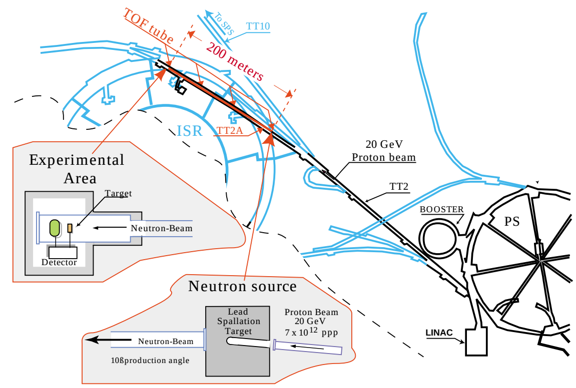

Figure 1: Schematic view of the n-ToF facility.

- The single proton bunch each machine cycle contains 0.7×10^{13} protons and has a r.m.s. length $\leq$ 7 ns.
- The number of cycles per super-cycle of 14.4 s varies from 1 to 4, depending on the sharing with other PS users. The maximum number 4 is related to the maximum beam loss which can be accepted in the PS machine, to the maximum power dissipation on the lead target, and to the radiation level in the target area.
- The beam is fast extracted to bombard the lead target using the present fast extraction FE16; there are no modifications in the PS ring.

Two modes of operation are foreseen: the 'dedicated mode' and the 'parasitic mode'. In the 'dedicated mode', one or more 20 GeV/c 1.2 s cycles are dedicated to the n-ToF experiment with the highest bunch intensity. The 'parasitic mode' allows an easier scheduling as the beam is shared with the users of the PS East Hall Experimental Area [3], but has a lower intensity.

2.2 The Proton Beam in 'Dedicated Mode'

To achieve the required beam parameters, a dedicated magnetic cycle has been programmed (see Fig. 2). To carry out the complex beam gymnastics, it has been necessary to suppress the intermediate plateau at 3.5 GeV/c, normally used to apply a longitudinal blow-up to stabilise the beam before transition crossing.

A single bunch in a single PS Booster ring is accelerated and injected into the PS at 1.4 GeV kinetic energy. This higher injection energy (recently modified for the LHC beam requirements) allows the self-field space charge tune shift to be kept to a value smaller than 0.3 during the 20 ms injection flat bottom. The bunch is then accelerated using harmonic number $h = 8$.

The horizontal and vertical tunes $Q_{\rm H}, Q_{\rm V}$ have been carefully adjusted to avoid, as much as possible, resonance crossings during the acceleration. Head-tail transverse instabilities at low-energy are cured using linear coupling with skew quadrupoles [4]. Furthermore, both horizontal and vertical chromaticities $\xi_{\rm H}, \xi_{\rm V}$ have their natural value of about -1 below transition energy ($\gamma_{\rm tr} \approx 6.1$) and to $+0.1$ above transition, to avoid head-tail instabilities. The RF voltage is adjusted during the acceleration to optimise the longitudinal acceptance so as to improve Landau damping and minimise longitudinal instabilities.

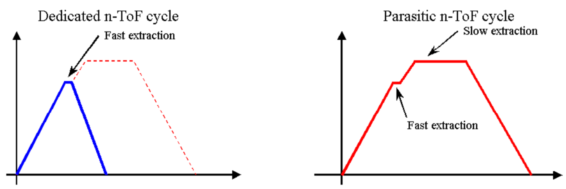

Figure 2: Magnetic cycles for the n-ToF proton beam in 'dedicated mode' (left) and in 'parasitic mode' (right).

To prevent beam break-up instabilities at transition [5], which could lead to the loss of 50% of the beam, the longitudinal emittance needs to be increased from 2 to 2.5 eVs, using the standard longitudinal blow-up and a 200 MHz cavity on the injection flat bottom. On the 20 GeV/c flat top, a phase jump RF gymnastic is used to compress the bunch just before extraction, thus reducing its length from 13 to 6 ns r.m.s. (see Fig. 3).

It is worth mentioning that the n-ToF beam represents a PS record in terms of peak current. Assuming a parabolic longitudinal distribution,

$$I_{\rm peak} = \frac{3eN_{\rm b}}{2\tau_{\rm b}}, \tag{1}$$

where $\tau_{\rm b}$ represents the total bunch length, this gives $I_{\rm peak} \approx 60$ A. This is not only a challenge as far as the beam dynamics is concerned, but also for the beam instrumentation.

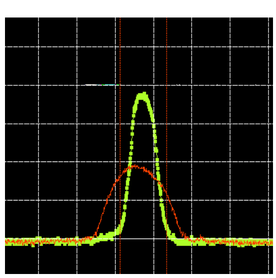

Figure 3: Longitudinal bunch profile before compression (thin line) and after compression (thick line). The horizontal scale is 20 ns/div, the vertical one is 50 V/div.

The normalised transverse r.m.s. emittances are 40 and 30 μm in the horizontal and vertical plane respectively. The total transmission efficiency is better than 90% (see Fig. 4).

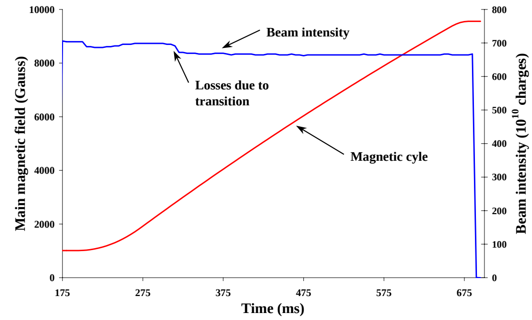

Figure 4: Beam intensity vs time along the magnetic cycle for the n-ToF proton beam in 'dedicated mode'.

2.3 *The Proton Beam in 'Parasitic Mode'*

In the 'parasitic mode', the proton bunch is accelerated together with a much lower-intensity bunch (about $1/20$ of the n-ToF bunch intensity) which is slow-extracted at 24 GeV/c to the PS East Hall Experimental Area [3].

The high-intensity n-ToF bunch is fast-extracted at an intermediate flat top at 20 GeV/c. The small bunch goes through a bunch compression as well, and has to be decompressed, with a reverse RF gymnastic to recover its normal size well-suited for the slow extraction (see Fig. 6).

In 'parasitic mode', the r.m.s. bunch length is the same as in the 'dedicated mode' (i.e. 7 ns), but the maximum intensity is only 0.4×10^{13} particles/bunch (see Fig. 5). The advantage of running in 'parasitic mode' is an easier n-ToF scheduling as the slow extraction cycles are present almost all of the time in the PS super-cycle.

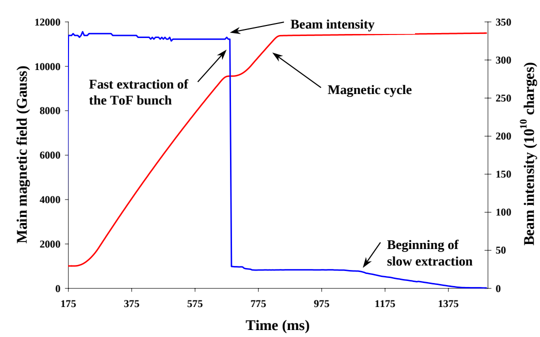

Figure 5: Beam intensity vs time along the magnetic cycle for the n-ToF proton beam in 'parasitic mode'.

3 THE PROTON BEAM LINE LAYOUT

The new proton transfer line branches off the existing TT2 line joining the PS and the SPS machines. The length of the new proton transfer line is about 80 m (see Fig. 7). The total length of the transport channel from the PS extraction point to the lead target is about 400 m.

Two sets of three bending magnets each are used to deflect the beam. Each set generates a total bending angle of 6°, the first set to the left hand-side and the second one to the right hand-side. Three focusing and three defocus-

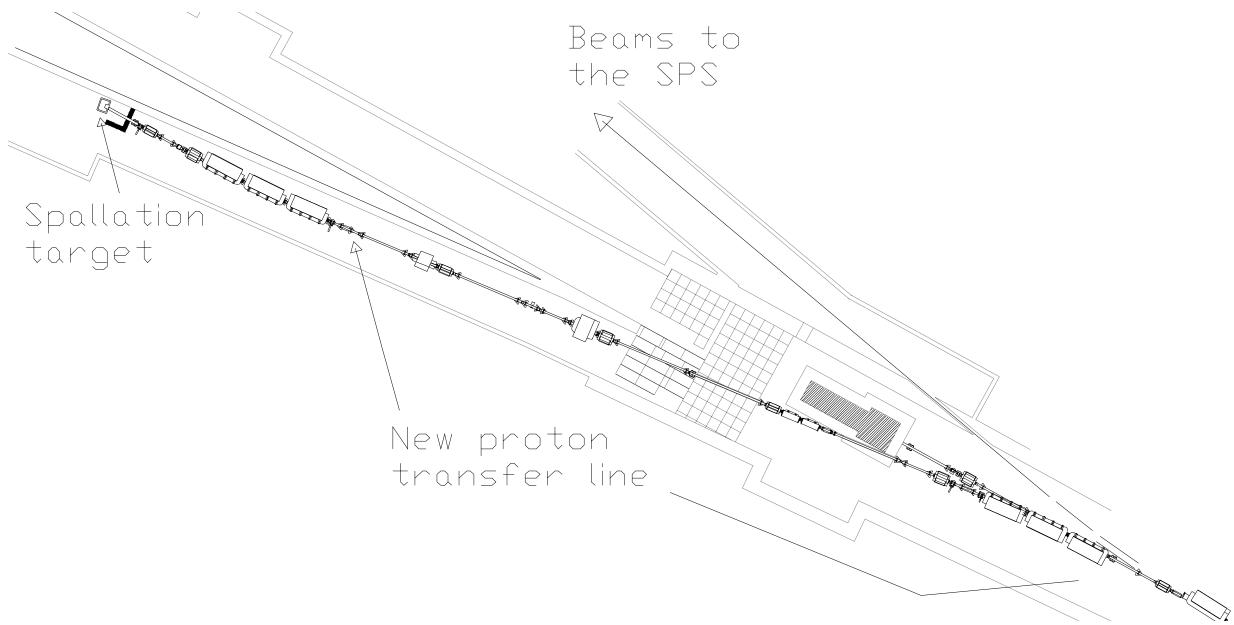

Figure 7: Layout of the new proton transfer line for the n-ToF facility.

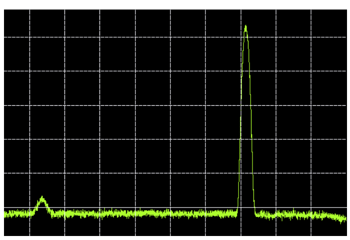

Figure 6: Longitudinal profile of low-intensity bunch (for slow-extraction) and high-intensity one (for n-ToF) after compression. The horizontal scale is 90 ns/div, the vertical one is 20 V/div.

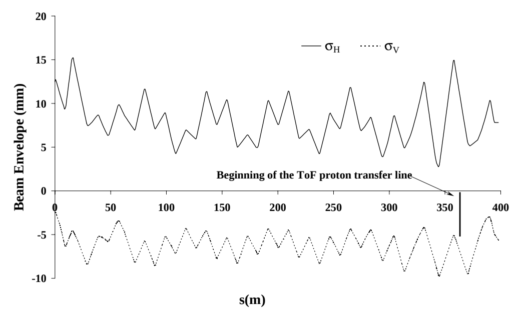

Figure 8: Beam envelope evolution along the whole transport channel from the PS extraction to the n-ToF target.

ing quadrupoles are used. They are equally spaced along the line. Two corrector magnets are installed for controlling the horizontal and vertical beam trajectory (measured by means of scintillator screens placed at three locations along the transfer line). With this choice of the geometry it was possible satisfy the constraint of having an angle of $10°$ between the proton beam and the neutron beam.

The optics of the new proton line matches that used in the TT2 transfer line used to deliver the fast extracted 26 GeV/c LHC proton beam to the SPS machine [6]. The optics was computed using the MAD program [7]. The beam envelope along the transport channel is shown in Fig. 8. The beam size at the target location is about 7.8 and 5.6 mm in the horizontal and vertical plane respectively.

4 SUMMARY AND CONCLUSION

The complex beam manipulations needed to meet the beam characteristics both in ‘dedicated mode’ and in ‘parasitic mode’ have been tested and the conditions for the nominal beam have been achieved.

The construction of the proton transfer line is completed and the hardware tests are being performed to allow the commissioning of the n-ToF Facility with beam in June 2000 in agreement with the physics schedule.

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