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A TEST BEAM FROM THE BOOSTER SYNCHROTRON

by

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1. INTRODUCTION

The possibility has been raised of using the booster synchrotron as a source of photons or electrons for a High Energy Physics (HEP) test beam.

Although electrons will be extracted from the booster to fill the storage ring, there will be periods of several hours when the booster is merely "standing-by". However during this time the use of this extracted beam will be of little interest to prospective HEP users since the fast extraction process will produce an unacceptably short beam spill of about 300 ns. On the other hand the construction of a resonant slow-extraction system to produce a long beam spill would require additional equipment to be built into the booster synchrotron and space for this could not be allocated without a fundamental redesign of the booster. This would certainly increase its cost significantly.

A more easily implemented scheme, which is the subject of this note, would be to generate a bremsstrahlung beam from an internal target in the booster and at a convenient point away from the booster convert the photons in a secondary target into electron-positron pairs. A simple beam transport system would then select either electrons or positrons of a given energy and focus them into a test area. This scheme would have several advantages, which include its low cost, its simplicity of operation and the fact that it essentially produces a low intensity beam which is both suited to test beam usage and avoids difficulties with shielding and personnel access.

2. THE BREMSSTRAHLUNG BEAM

A bremsstrahlung beam with a spill time of several milliseconds could easily be generated by using a beam bump to engage the accelerated electrons with an internal target near the edge of the vacuum chamber. In this case the beam bump would be produced by a number of backleg windings on the booster synchrotron magnets. The basic hardware required would be an internal target and its drive mechanism and a pulsed power supply capable of delivering pulses of 200 A (peak) at 10 Hz into the backleg windings which would consist of 4 turns on 4 of the magnets.

Redundant NINA components could be suitable for this.

The direction of the bremsstrahlung beam from the internal target is primarily determined by its location around the azimuth of the booster. Once this has been fixed small changes for beam steering can be affected by adjusting the displacement of the target from the central orbit.

The location of the target has been chosen to lie 127.5 mm from the downstream end of an F type magnet. This specific position directs the beam into the narrow angular region between the inside of the F chamber flange at the upstream end of the next straight section and the outside of the D chamber flange at the downstream end of the same straight section and enables the beam to exit from the booster via a thin window (as shown in fig. 1). Any other azimuthal location will cause the beam to pass through the side of the corrugated, stainless-steel, vacuum chamber since it is not proposed, and may not be possible, to fabricate this structure with tangential side spouts or windows.

The angle of the beam with respect to the straight section will be 40 mrad, with a displacement of the internal target from the central orbit of approximately 40 mm. By adjusting this displacement the beam direction will change by 0.25 mrad for each millimetre of target movement and all beam directions from the target will pass through a pivot point 4 metres downstream from the target itself. If the target thickness is 0.01 radiation lengths and the incident electron energy is 600 MeV then the full divergence of the photon beam will be 15 mrad, so clearly the beam will be several centimetres wide a few metres along the beam line. The alignment of the beam onto the secondary target is therefore not likely to be critical.

3. THE SECONDARY BEAM

The general features of a secondary beam are shown in fig. 2. The primary bremsstrahlung beam is directed into a conversion target which would typically be a metal plate of a thickness 0.1 radiation length. Here photons would convert to electron-positron pairs which are then bent through an angle of 15^{o} by a large aperture magnet. It is suggested that this could be a type H10 magnet, the polarity of the magnet determining whether electrons or positrons are selected. A collimator downstream of the magnet transmits only particles of the desired momentum into a pair of quadrupoles which focus them into a test area.

The beam size and divergence in the test beam area will be largely determined by the apertures of the collimators, as also will be the range of momenta selected and to some extent the intensity of the test beam. Detailed design of the collimators has not been undertaken as these would need to be closely matched to the specific requirements of a given test beam user. Similarly the beam size, divergence and intensity are influenced by the thicknesses of the internal target and the conversion target, which also should be matched to a specific experimental requirement.

If the effects of collimation are ignored then the number of electrons per second, n, in the secondary beam in an energy band δE centred on an energy E is given

$$n = \frac{7}{9} t_1 t_2 \, \delta E \left(\frac{1}{E} - \frac{1}{Em} \right) N$$

where t_1 is the internal target thickness in radiation lengths

t_2 is the conversion target thickness in radiation lengths

Em is the peak energy of the accelerated electrons

N is the number of electrons in the booster accelerated per second

t_1, t_2 << 1.0 and $E + \frac{\delta E}{2} < Em$

As a typical example consider

$t_1 = 0.01$ r.l.

$t_2 = 0.1$ r.l.

$\delta E = 50$ MeV

$E = 550$ MeV

$Em = 600$ MeV

It is expected that the booster will accelerate an electron current of 20 mA (instantaneous) at a repetition rate of 10 Hz, which leads to

$$N = 10^{11} \text{ electrons/s}$$

Then applying the formula above we have

$$n \gtrsim 6 \times 10^5 \text{ electrons/s.}$$

Collimation can be expected to reduce this by between at least one or two orders of magnitude.

Other necessary features of the beam line include a well shielded beam dump for the primary bremsstrahlung beam, a beam shutter and an evacuated beam pipe. If access to the test beam area is required when the shutter is open then some form of radiation protection interlock will be required between the shutter and an ion chamber in the beam, to ensure that radiation levels are suitably low.

4. BEAM LAYOUT WITH RESPECT TO THE BOOSTER

Figure 3 shows two possible HEP test beams with the primary bremsstrahlung beams originating in booster magnets F4 and F5. For reasons given presently, only one other origin is possible, and that is from magnet F1. Unfortunately this would locate the test beam area in the main access route to the SRS experimental area, and this is considered to be unacceptable.

As was explained in section 2 and is demonstrated in fig. 1, in order for the bremsstrahlung beam to emerge through a thin window it must be directed at a quite specific angle and location with respect to the long straight section. Furthermore, the equipment located in the long straights must have sufficient aperture to clear both the bremsstrahlung beam and the circulating electron beam aperture.

In order to locate the test beam area into a position which affords adequate space for its exploitation it is clear that only those beams originating from magnets F4 and F5 are of interest. There must then be adequate aperture in both of the following straight sections. The one following F4 contains an extraction kicker at its upstream end and to clear the bremsstrahlung beam the horizontal aperture must be increased from 120 mm to 150 mm. As the technical and economic consequences of this increase are modest if incorporated at an early stage it has already been decided to build this kicker, and all the booster kickers, with this aperture. There are considerable advantages, both from the viewpoint of cost and beam dynamics, in having identical apertures in all the kickers.

The straight following F5 is the only one which is not so far occupied by a major item of booster equipment. If it is necessary in the future to install equipment in this straight then the test beam from this straight will only remain possible if the plant item can be provided with the required aperture (150 mm at the upstream end, 175 mm at the downstream end).

The side spout on the corrugated vacuum chamber for the internal target has not been designed and will not be provided initially, nor will the backleg windings for the beam bump.

5. CONCLUSION

The present design and layout of the booster will permit the future addition of an internal target in either or both of two different locations, each of which would produce a bremsstrahlung beam. This could then be used to generate a secondary beam of electrons or positrons for use as a test beam. The beam spills would be about 5 ms long with a repetition frequency of 10 Hz. With an electron current in the booster of 20 mA the particle flux in the secondary beam would be of the order of 10^4/s in an energy bandwidth of 10% up to a maximum energy of 600 MeV.

In order that the bremsstrahlung beam may emergy from the booster via a thin window, the kicker magnets will be constructed, from the outset, with a horizontal aperture of 150 mm. Later, at the time of installing the internal target, modifications will be necessary to the corrugated vacuum vessel to accommodate a flange for the target shaft.

Much of the necessary equipment, such as collimators, shutters, target mechanisms, etc. could be redundant items from the NINA programme.

Fig. 1 The position of the Bremsstrahlung beam with respect to a straight section.

Fig. 2 Elements of a typical secondary beam.

Fig. 3 The layout of two possible test beams.

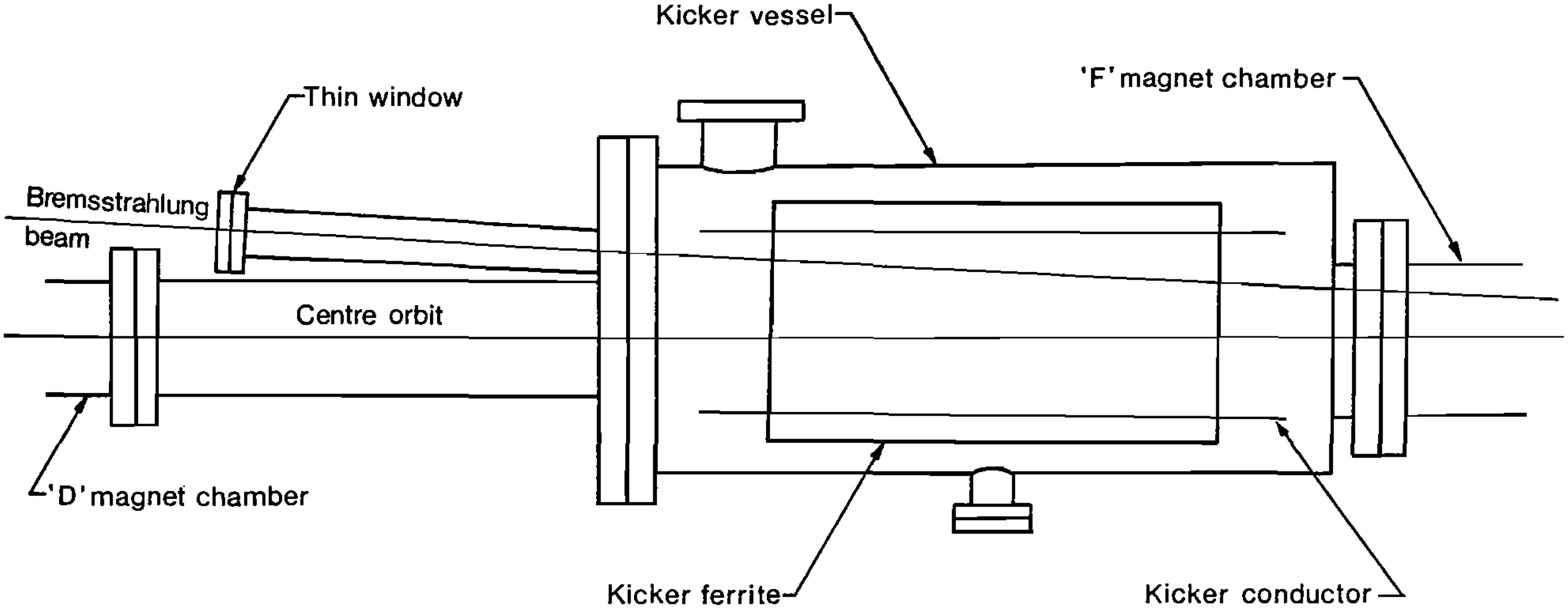
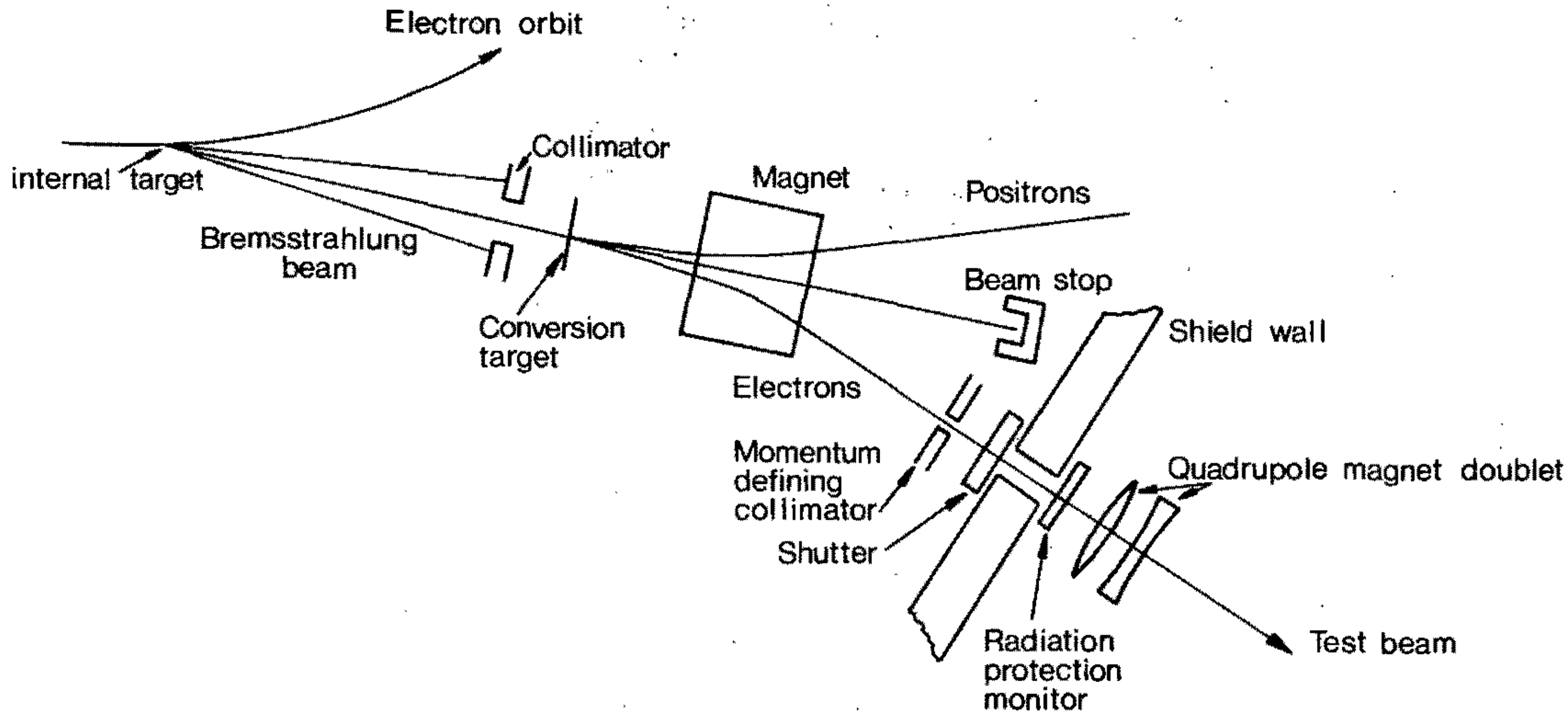
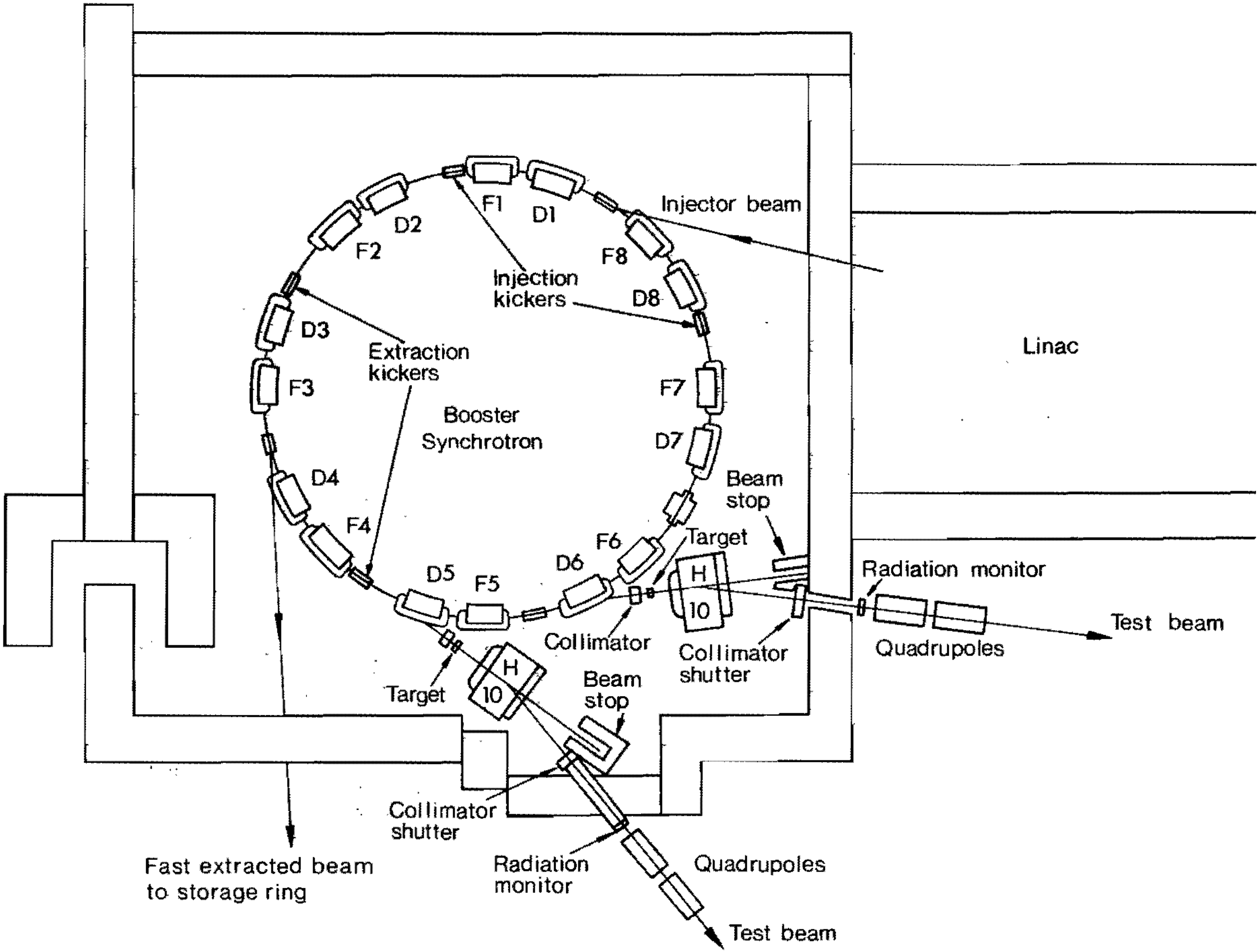

Kicker vessel
'F' magnet chamber
Thin window
Bremsstrahlung
beam
Centre orbit
'D' magnet chamber
Kicker ferrite
Kicker conductor

Fig. 1



Electron orbit
internal target
Collimator
Bremsstrahlung beam
Conversion target
Magnet
Positrons
Beam stop
Shield wall
Electrons
Momentum defining collimator
Shutter
Quadrupole magnet doublet
Radiation protection monitor
Test beam

Fig. 2



Injector beam
Linac
F1
D1
D2
F2
F8
Injection
kickers
D8
D3
Extraction
kickers
F3
F7
Booster
Synchrotron
D7
D4
Beam
stop
F4
F6
Target
D5
F5
D6
Radiation monitor
H
10
Test beam
Collimator
Collimator
shutter
Quadrupoles
H
10
Beam
stop
Target
Collimator
shutter
Fast extracted beam
to storage ring
Radiation
monitor
Quadrupoles
Test beam

Fig.3