Nuclear Inst. and Methods in Physics Research, A 901 (2018) 62–68

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

The polarized proton and antiproton beam project at U-70 accelerator

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ARTICLE INFO

Keywords:
Beam
Spin
Polarization
Proton
Antiproton
Hyperon
Decay
Target

ABSTRACT

The design and parameters of the polarized-beam facility at U-70 proton synchrotron of NRC "Kurchatov Institute" — IHEP are presented. The new beamline 24A will provide the polarized proton and antiproton beams for carrying out the rich physics program of the SPASCHARM experiment for comprehensive studies of spin phenomena in a wide spectrum of hadronic reactions in the energy range of 10–45 GeV.

1. Introduction

The planned upgrade of the U-70 accelerator [1] to a higher intensity of up to 3×10^{13} protons per (9–10) s cycle opens new horizons for comprehensive studies in high energy physics at the accelerator complex of NRC "Kurchatov Institute" — IHEP. This requires, in turn, building the next-generation beamlines for delivering to the experiments the full spectrum of particles in the beams of the best quality. The higher proton beam intensity brings new challenges to the design of beamlines and requires a significant layout rearrangement in the existing U-70 experimental area. As a pilot project, two new beamlines, 24A & 24B, for the SPASCHARM [2] and VES [3] experiments are to be built at the areas currently occupied by some running experiments after their completion. These two beams will operate from a single external production target exposed to the slowly-extracted 50–60 GeV proton beam at the intensity of $\geq 10^{13}$ protons per cycle. Relying on an external target rather than currently used internal targets would essentially reduce the radiation load to the equipment in the U-70 ring. This also provides more flexibility for designing the higher intensity and better quality beams and significantly improve an utilization efficiency of protons accelerated in U-70.

This paper is focused on the design and properties of the beamline 24A which will deliver a whole spectrum of charged-particle beams to the SPASCHARM experiment. The SPASCHARM's physics program requires hadronic beams of various species as well as electrons and/or positrons for detector calibrations. But predominantly it concentrates on systematic and comprehensive studies of spin phenomena in exclusive and inclusive hadronic reactions in the U-70 energy range. Therefore, the core SPASCHARM program [2] relies, first of all, on the study of interactions of high energy polarized protons and antiprotons selected and transported to the experiment by the beamline 24A, as well as on the use of polarized target.

The polarized proton and antiproton beams for the SPASCHARM experiment are to be created by the method suggested by O. Overseth and J. Sandweiss [4]. So far, this method has been twice successfully realized in practice. First, the 185 GeV/c proton and antiproton polarized beam facility has been built and operated at an 800 GeV accelerator of Fermilab for the E704 experiment [5]. Later on, the existing multipurpose beamline at U-70 accelerator has been modified in order to form the 40 GeV/c polarized proton beam for the FODS experiment [6].

While the main subject of this paper is the discussion specifically of the beamline 24A, it is preceded by the description of the target area, where the slowly extracted proton beam from U-70 is steered onto the external target, and then the secondary particle flux is split and directed toward the simultaneously operated beamlines 24A & 24B.

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https://doi.org/10.1016/j.nima.2018.05.050
Received 1 April 2018; Received in revised form 20 May 2018; Accepted 23 May 2018
Available online 26 May 2018
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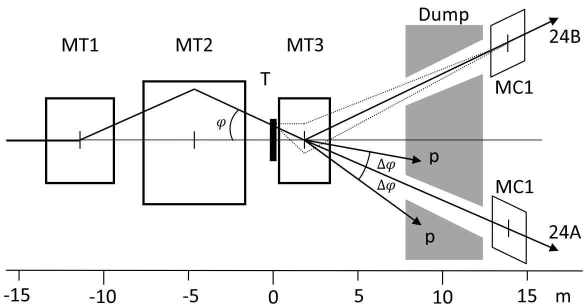

Fig. 1. Schematic top view of the target area for the beamlines 24A & 24B. T is for production target; MT is for dipole magnets; MC1 is for magnet-correctors; Dump is the 5 m thick steel beam absorber. In the shown configuration, neutral secondaries go straight toward the 24A beamline, while charged particles of a desirable sign are deflected toward beamline 24B. The dashed lines show some trajectories of charged particles emitted from the target at nonzero angles.

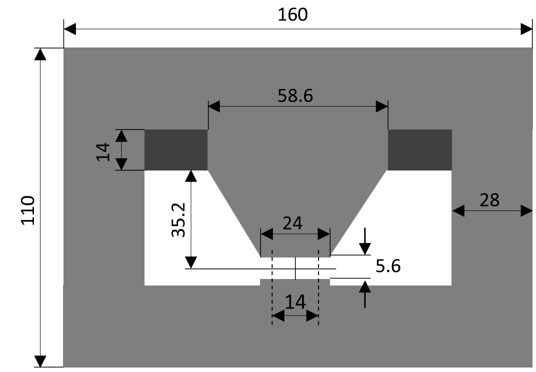

Fig. 2. Cross section of the MT3 magnet. All dimensions are in cm.

2. Target area for the 24A & 24B beamlines

The schematic view of the target area is shown in Fig. 1. With the dipole magnets MT1 & MT2, the primary proton beam from U-70 is directed through the target T toward the center point of the magnet MT3 at certain angle φ in horizontal plane relative to the MT1–MT3's center line. Then, the third dipole magnet MT3 distributes the fractions of the secondary particle flux, produced in the target, between the beamlines 24A & 24B. Two parameters: the angle φ and the MT3 bending power are adjusted so as the particles of desirable charges and momenta are directed toward the beamlines 24A & 24B. Such "three-magnet systems" have been successfully used at CERN SPS experimental areas for operating two or three beams from a single production target [7].

The dipole magnets SP-129 & SP-7,[2] from the equipment pool of the U-70 experimental complex will be used for MT1 & MT2. The angle φ is limited to $|\varphi| \leq \varphi_{max} = 27$ mrad by the parameters of the dipole magnet SP-7. The initial sections of the beamlines 24A & 24B are aligned along the straight lines through the MT3 center at the angles $\pm\varphi_{max}$. On the one hand, the large angle between these directions, equal to $2\varphi_{max}$, gives more space for placing the first quadrupole lenses as close to the target as it possible. On the other hand, with such a layout, it is still possible to direct toward either beamline a flux of neutral particles produced in the target at zero angle relative to the direction of the incident primary protons.

As the basic element in the target area the MT3 dipole magnet operates as a distributor of charged particles, thereby defining the charges and momenta for the both beamlines. At the same time, it serves as a sweeping magnet for "neutral" beams, deflecting all charged particles out of the beamline, which is used to create the beams of polarized protons (antiprotons) from $\Lambda\left(\bar{\Lambda}\right)$-decays as well as of electron or positron beams from γ-conversions [8]. As a result, MT3 parameters have been chosen as a compromise between contradictory requirements to its length at the highest value of the magnetic field: $L = 2.6$ m, useful aperture $H \times V = 140 \times 56$ mm^2, $B_{max} = 1.9$ T.

The production target, which is located at the front end of the MT3 magnet, is an aluminum plate, 400 mm long, 3 mm high, and 100 mm wide. The extended horizontal width of the target makes it unnecessary to move the target when the angle φ varies within the limits $|\varphi| \leq \varphi_{max}$.

The target area layout is symmetric relative to the initial direction of the primary proton beam. This makes the beamlines 24A & 24B absolutely equivalent in terms of the capabilities for directing any available particle flux to the acceptance of either beamline. The relations between parameters of two beams are as follows:

- With the angle $\varphi = \pm\varphi_{max}$, the secondary neutral particles produced at zero angles go straight in the direction of one of the beamlines. At the same time, the beam of positive or negative particles with momentum in the range from 16 to 28 GeV/c is deflected toward the other beamline. The lower momentum limit is set by the requirement for non-interacted primary protons to be deflected by MT3 away from the angular range $\pm\left(\varphi_{max} \pm \Delta\varphi\right)$, and steered to the absorber. The highest available momentum is limited by the maximum deflection power of the magnet MT3.
- With the angle $|\varphi| < \varphi_{max}$, the secondary particles of opposite charges are selected for the beamlines 24A & 24B. In the most interesting case of utilizing secondary particles produced at zero angles, the momenta p_A and p_B are bound by the relation: $q_A p_A\left(\varphi_{max} + \varphi\right) + q_B p_B\left(\varphi_{max} - \varphi\right) = 0$ where $q_A = -q_B = \pm 1$ are the particle charges. As in the previous case, the requirement of correct absorption of non-interacted primary protons sets certain limitations on momenta for the available secondary particles produced at zero angles.

In both cases, the magnet-correctors MC1 with the deflection power of up to 0.3 T $\times$ m in the horizontal plane extend the beamline acceptances to charged secondary particles produced in the target at non-zero angles.

The MT3 magnet is located just downstream the target struck by a high intensity primary proton beam. Hence, it is irradiated by a high intensity flux of secondary particles emerging from the target. This sets strong requirements to its long term radiation hardness, resulting in certain limitations on the MT3 design and available technologies. The most vulnerable part of the magnet under high radiation is the insulation of the exciting coil. In order to reduce the radiation load, the MT3 coil was moved upward above the beamline plane by ~35 cm from the direct view of the target behind the upper pole steel, as shown in Fig. 2. Such a solution [9] allows to save on investment in the technologies for fabricating the coils with, e.g., asbestos-cement or MgO radiation-resistant insulations [10,11] but rely instead on a coil manufactured, using more conventional technology with vacuum impregnation by epoxide compound.

The simulations of radiation load, using the MARS computer code [12], have shown that, in the magnet design described above, the estimated life-time of the coil (the time required to accumulate a radiation dose of 10 MGy [10]) is about 300 days at the intensity of primary protons of 2×10^{13} per cycle. With the additional steel plates, protecting the protruding parts of the coil, and the concrete filling of the space between the upper pole and the yoke, the life-time would be extended to ~2600 days.

3. Optical scheme of the polarized proton (antiproton) beamline 24A

The method [4–6] for creating polarized proton or antiproton tertiary beams, which exploits the parity-violating decays of Λ-hyperons,

[2] SP-129 parameters: length $L = 4$ m, useful aperture $H \times V = 330 \times 100$ mm^2 maximum field $B_{max} = 1.8$ T; SP-7 parameters: $L = 6$ m, $H \times V = 500 \times 200$ mm^2; $B_{max} = 1.8$ T.