Optimization of the HADES secondary pion beam spectrometer*

B. Ramstein[†1], *E. Atomssa*[1], *T. Hennino*[1], *L. Hijazi*[1], *W. Koenig*[2], *J. Biernat*[3], *and P. Salabura*[3]
[1]IPNO, Orsay, France; [2]GSI, Darmstadt, Germany; [3]Jagiellonian University, Crakow, Poland

The GSI pion beam

To maximize the pion yield in the momentum range around 1 GeV/c, the secondary pion beam is obtained by the interaction of a fully stripped 2 GeV/nucleon ^{14}N ion beam with an intensity close to the SIS18 space charge limit of 0.8-1.0 10^{11} ions/spill impinging on a 10 cm thick Be target. In these conditions, the pion flux at the HADES target is about 5 10^5 π/spill at 1 GeV/c and decreases by a factor 2 at 0.7 GeV/c and 1.3 GeV/c. The pions are then transported to the HADES target, located 33 m downstream of the production point by a beam line composed of a lattice of 7 quadrupole and 2 dipole magnets, as shown in Fig.1 of [1].

Optimization of the spectrometric pion line

While the pion flux at the entrance of the spectrometric beam line is determined by the primary beam characteristics and the target nature and geometry, the setting of the beam line needs to be adjusted to maximize the transmission and reduce the size of the beam spot on the HADES target. This optimization is particularly important in studies of the production of rare probes, like dielectrons and strange particles and in the use of the HADES liquid hydrogen target with its diameter of 12 mm. In addition, to reject background events and select exclusive channels in the π-nucleon reaction, an event-by-event reconstruction of the pion momentum and positions by means of position measurements in two newly-built in-beam Si-strip detectors [1] has been introduced.

For these studies, a Monte Carlo simulation was carried out. In a first step, a TRANSPORT [2] program code based on a given geometrical configuration of the spectrometric beam line and detectors is used to fit the quadrupole strengths to fulfill general constraints (focus in horizontal and vertical planes at the intermediate and final images, where the detectors will be placed and achromaticity in both vertical and horizontal directions at the HADES target point). In the usual beam optics formalism, a particle with momentum p and horizontal and vertical positions (angles), x (θ) and y (ϕ), respectively in the plane transverse to the optical axis are described by an array of five coordinates, ($x(1)$, θ(2), y(3), ϕ(4), δ(6)). The number in brackets is the index of the corresponding coordinate and $\delta = (p - p_{ref})/p_{ref}$ is the momentum offset with respect to the reference momentum p_{ref} corresponding to particles on the optical axis. The TRANSPORT program allows to calculate the first and second order transport coefficients T_{ij} and T_{ijk} relating the coordinate array at any position in the beam line to the one at the production target. In a second step, these coefficients are used in a MonteCarlo simulation to trace the particles all along the spectrometer within the geometrical acceptance of the magnets, detectors and HADES target. In this way, the transmission and the envelope of the beam is followed step by step. Due to the tilt angle (21.75°) of the two dipoles, horizontal and vertical planes are coupled. In particular, the dispersion terms in the vertical plane associated to the coefficients T_{36}, T_{336} and T_{366} and the coupling terms associated to the coefficients T_{14} , T_{146} and T_{32} cannot be neglected.

The first part of the spectrometric line is fixed, but the positions of the last three quadrupoles (two 1 m long and one 0.4 m long) and of the two detectors have been adjusted to minimize both the global transmission loss and the size of the beam envelope at the HADES target. The global transmission, measured with respect to the entrance of the spectrometer is about 56% for δ=0 and decreases gradually as a function of $|\delta|$, reaching zero for $\delta = \pm 6\%$. Most of the losses are due to the apertures of the magnets, especially the second dipole and the following quadrupoles. In the presence of the LH2 target, with a 12 mm diameter, additional losses of about 35% are expected. In addition, some background is expected from interactions with the inner tube, 48 mm in diameter placed upstream of the target. Due to second order terms, the transmission is larger for positive values of δ. As a result, the δ distribution can be represented to first order by a Gaussian distribution centered at +0.5% and a variance of 1.5%. While a possible shift of the primary beam in the horizontal direction would just shift the momentum distribution, with no significant change of the global transmission, the sensitivity to a vertical shift is much larger. This is due to the large value of the magnification coefficients T_{33} which reaches values as large as -70 at the second detector position. As an example, a shift of 1 mm would induce a decrease of the acceptance by 50%. The vertical alignement of the primary beam has therefore to be adjusted very carefully. In the first experiment performed in 2014 with the pion beam, the transmission pattern was found to be in very good agreement with the calculations [1]. The measured rates allow to confirm a pion flux of 5 $10^5\pi$/spill on target at 1.0 GeV/c.

* Work supported by .
† ramstein@ipno.in2p3.fr

DOI:10.15120/GR-2015-1-MU-NQM-HADES-18

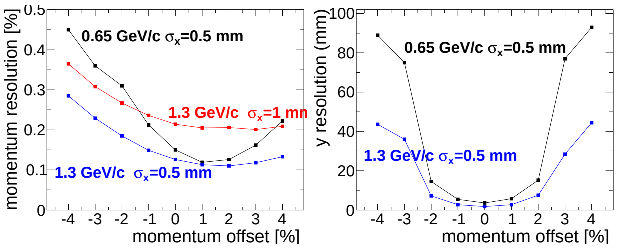

Figure 1: Left: Pion momentum resolution as a function of the momentum offset δ for different values of reference momenta and primary beam transversal sizes. Right: Same for the vertical position resolution at the HADES target.

Pion momentum and position reconstruction

The principle of pion momentum, angle and position reconstruction is based on the relation between the measured positions (X_1, Y_1) and (X_2, Y_2) in two detectors placed in the spectrometric line and the beam particle coordinates at the production target $(x_0, \theta_0, y_0, \phi_0, \delta)$, which can be written using the first and second order transport coefficients, as discussed above. To solve this set of 4 equations with five unknowns, x_0 is set to 0 and the corresponding neglected terms will then contribute to the resolution on the coordinate reconstruction. In addition, terms with negligible contributions are not taken into account, leading to the following relations:

$$X_i = T^i_{12}\theta_0 + T^i_{14}\phi_0 + T^i_{16}\delta + T^i_{126}\theta_0\delta + T^i_{146}\phi_0\delta + T^i_{166}\delta^2 \quad (1)$$

$$Y_i = T^i_{32}\theta_0 + T^i_{33}y_0 + T^i_{34}\phi_0 + T^i_{36}\delta \; T^i_{336}y_0\delta + T^i_{346}\phi_0\delta + T^i_{366}\delta^2 \quad (2)$$

where $i = 1, 2$ is the detector index. These equations are solved iteratively, determining in a first step θ_0 and δ by neglecting the coupling to the vertical plane. Fig.1 (left) shows the pion momentum resolution for reference momenta of 0.65 GeV/c (black curve) and 1.3 GeV/c (blue curve) as a function of the momentum offset δ. These results have been obtained in a simulation with realistic beam conditions (x_0 and y_0 distributed following gaussians with variances of 0.05 cm and θ_0 and ϕ_0 uniformly distributed with intervals of half-width respectively 10 and 50 mrad) and taking into account the design geometry of the in-beam Si strip detector [1], with a position resolution of 800 μm and a thickness of 300 μm. For pions travelling along the optical axis, the resolution is about 0.1%. This value grows linearly with the beam spot size, as demonstrated by the red line corresponding to a variance in x_0 of 0.1 cm. The dependence on $|\delta|$ of the resolution is due to the effect of multiple scattering in the first detector, which affects the momentum determination only for trajectories away from the optical axis and decreases with increasing pion momentum. In the range $|\delta| < 3\%$, where the transmission is significant, the resolution stays better than 0.4%, even at the lowest momenta. It has been checked that the impact on the selection of exclusive channels ($\pi^- p \to n e^+ e^-$ or $\pi^- p \to n\pi^+\pi^-$) of the pion momentum resolution is a factor 3 lower than the impact of the momentum resolution of particles detected in HADES.

By using the reconstructed values θ_0, y_0, ϕ_0 and δ of the pions, an estimate of their positions at the HADES target can be deduced by using the appropriate transport coefficients. The resolution on the position measurements is dominated by the effect of the multiple scattering. Its dependence on the primary beam transverse position is therefore very weak. The resolution on the horizontal position is almost independent on δ, with values of the order of 9.6 mm at 0.65 GeV/c and 4.6 mm at 1.3 GeV/c. The resolution on the vertical position at the target depends both on the reference momentum and on the offset, as displayed in Fig.1 (right).

To check the validity of the beam line description, a proton beam of known momentum (2.7 GeV/c) has been used [1]. Its incident angle and position could be varied up to $\pm$1.4 mm in x_0, $\pm$2.2 mrad in θ_0, $\pm$0.7 mm in y_0 and $\pm$7 mrad in ϕ_0. The spectrometric beam line was used with different settings, corresponding to values of δ for the proton beam ranging from -4.3% to 4.7%. The impact positions on the Si detectors were used to deduce, when possible, experimental values of the transport coefficients. The most important dispersion term T^1_{16} is found only 3% lower than the value calculated with the TRANSPORT code. Taking into account the observed deviations for measured coefficients and potential deviations for unmeasured ones, the resolution stays below 0.3% for a reference momentum of 1.3 GeV/c.

Purity and future perspectives

The purity of the negative pion beam is not an issue. Even if a sizeable fraction of electrons from the π^0 Dalitz decay and of muons from in-flight pion decays might reach the target, a negligible contribution to the measured events is expected due to their low interaction rates. At larger momenta, kaons can be produced, but most of them will decay before reaching the HADES target. In the future, the possibility to use a positive pion beam will be studied. This will require the separation of protons using time-of-flight information and possibly the use of a proton beam at the maximum energy to reduce the relative yield of protons. The use of a primary proton beam can also be preferable to increase the pion flux at momenta above 1.5 GeV/c.

References

[1] J. Wirth et al., "Tracking Pions with CERBEROS at the HADES spectrometer", contribution to this report.

[2] PSI Graphic Transport Framework by U. Rohrer based on a CERNSLAC- FERMILAB version by K.L. Brown et al, 2007. URL http://aea.web.psi.ch/Urs_Rohrer/MyWeb/trans.htm.