EXTERNAL INJECTION INTO PHASOTRON
(COMPUTER SIMULATION)

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Abstract

The paper summarizes the computer simulation data of the beam capture in acceleration at the external injection into the JINR Phasotron (Fig.1) for the injection energies 1.5, 3.0 and 5.0 MeV. The simulation takes into account the particle starting phase and injection time, the horizontal and axial beam emittances and the influence of the particle scattering by foil on the increase in the axial emittance. Simulation is fullfilled for the experimental magnetic field and RF program. Calculation shows the 15% capture efficiency for the injection energy 1.5 MeV and 24% for 5.0 MeV (the particle injection time of 80 μs).

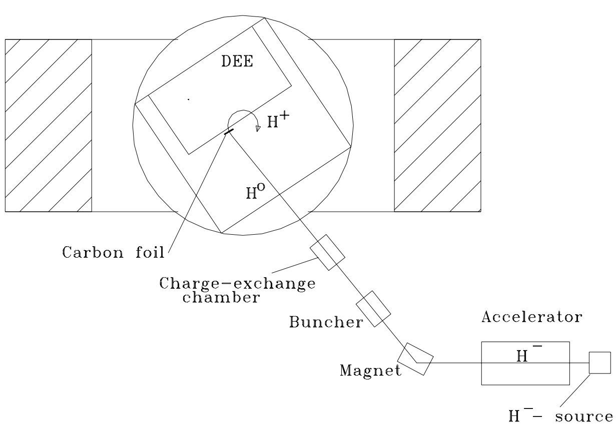

Figure 1: External injection scheme into Phasotron

COMPUTER SIMULATION

The program used for the calculations integrates the equations of the longitudinal (phase) and transverse (radial and axial) motion by the Runge-Coutte method. The Phasotron magnetic field is shown in Fig.2.

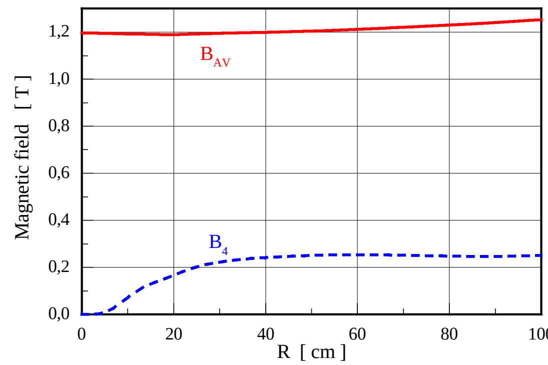

Figure 2 : Phasotron magnetic field (average B_{av} and main harmonic B_4)

Taking into account the preliminary considerations [1] we chose the injection energy to be W_1= 1.5 MeV and the injection orbit radius to be R_i=14.95 cm. The axial oscillation frequency at this radius is near ν_z=0.1.

As a first step, the phase stability region was investigated. The central particle (the particle with R=14.95 cm, P_r=-8 mrad, Z=0 cm; P_z=0 mrad) was injected with different initial phases and times. For t=0 the accelerating frequency is F_{rf}=18.175 MHz and varies linearly with $dF_{rf}/dt=-1.0 \cdot 10^3$ MHz/s.

At the time t=60 μs the accelerating frequency is equal to the particle orbit frequency. The dee accelerating voltage is 40 kV, i.e. the maximum energy gain is 80 kV. All particles were accelerated 200 μs. If the particle energy decreased to 0.1 MeV this particle was lost due to returning to the center of the accelerator.

At the next step the capture efficiency was estimated for 1000 particles arbitrarily distributed in the six dimensional phase space (R, P_r, Z, P_z, φ_{st}, T_{st}).

The transverse particle distributions in the R and Z phase spaces and at φ_{st}÷T_{st} surface are shown in Fig.3. The acceleration was going on for 150 μs.

[1] O.N.Borisov, L.M.Onischenko External Injection into JINR Phasotron, EPAC 1998, Stokholm, p.2097

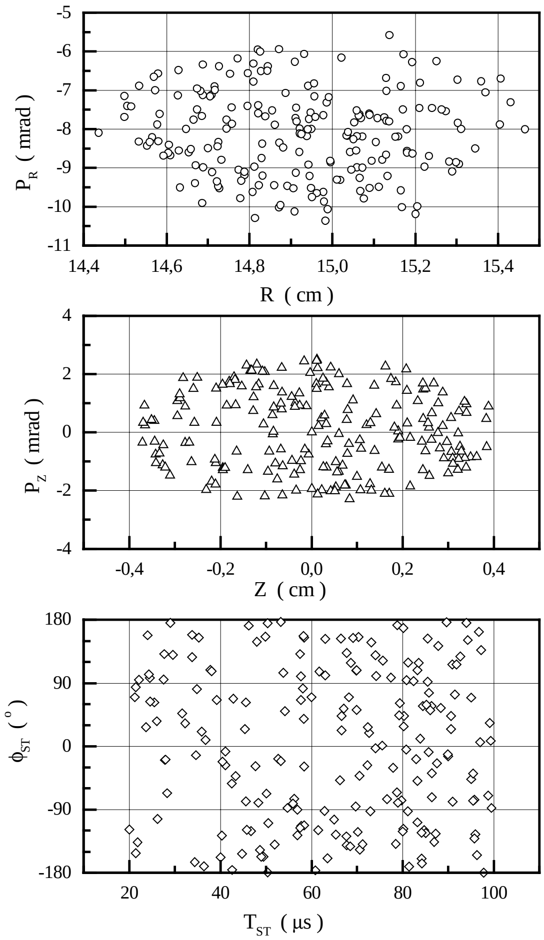

Figure 3: Initial radial, axial and $\varphi_{st} \div T_{st}$ distributions of 1000 particles, arbitrarily distributed inside the ellipses representing the beam with emittances $\varepsilon_R = \varepsilon_Z = 10$ $\pi \cdot$mm$\cdot$mrad and with φ_{st} inside ±180° at W=1.5 MeV

The particle parameters at the acceleration process were restricted to the following limits:
$W_{final} < 10$ MeV – phase losses;
R < 5 cm – losses due to returning to the center;
Z > 2 cm – axial losses.

The accelerated particles are marked in Fig.4 (top) by solid circles and their distribution on (W÷φ) surface is shown in Fig.4 (bottom).

The capture time is about 80 µs and the capture efficiency is about 32%. Fig.5 shows the radial and axial beam phase portraits. The beam axial size increased from 8 mm to 14 mm but there were no axial beam losses.

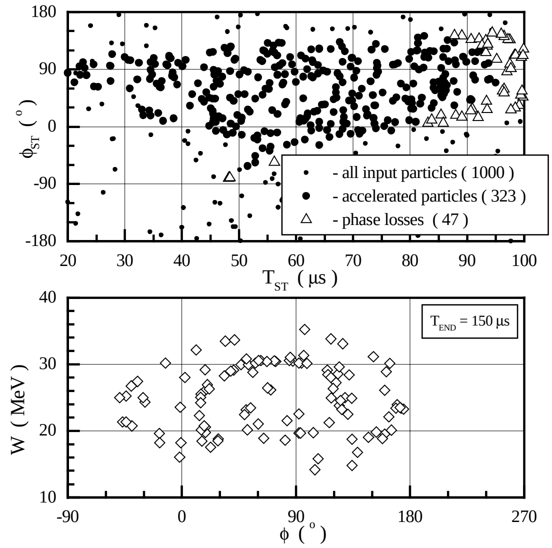

Figure 4: Accelerated particles and final distribution on W÷φ surface

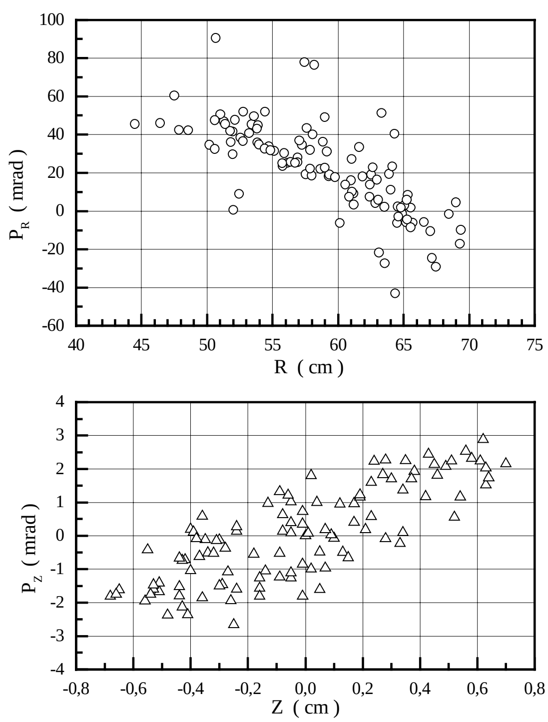

Figure 5: Radial and axial beam phase portraits for accelerated beam

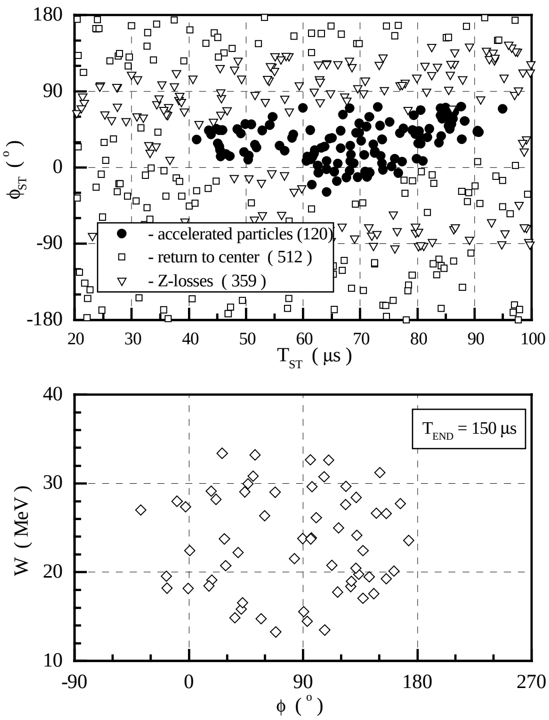

Figure 6: Same as in Fig.4 but with the scattering by the foil δ = 10^{18} atoms/cm^2 for W = 1.5 MeV

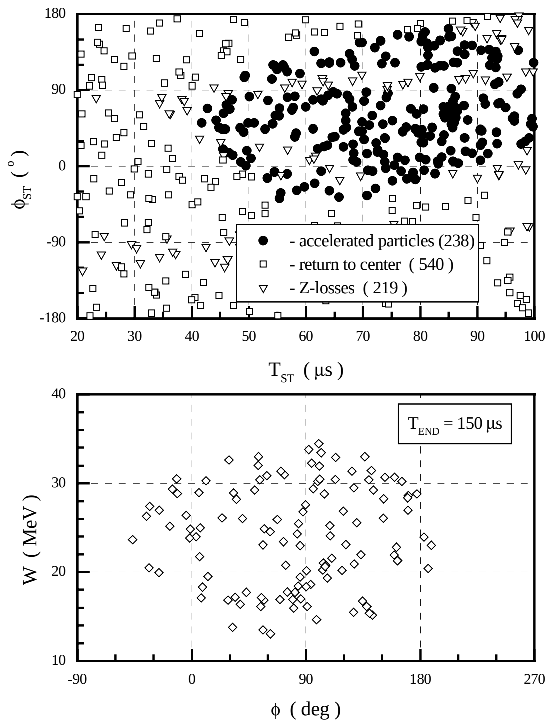

Figure 7: Same as in Fig.4 but with the scattering by the foil δ = 0.5×10^{18} atoms/cm^2 for W = 5.0 MeV

In previous calculations the particle scattering by the foil was not taken into consideration.

The cross section σ for scattering of the particle with energy W and charge ze by the foil with charge Ze at angles above Θ is determined by [2]

$$\sigma = \frac{\pi e^4 z^2 Z^2}{W^2 \Theta^2} = \frac{1.628 \cdot 10^{-26} z^2 Z^2}{W_{MeV}^2 \Theta_{mrad}^2} cm^2 \quad (1)$$

For the carbon foil (Z=6) of thickness δ the probability of proton scattering at angles exceeding Θ is given by

$$P = \sigma\delta = \frac{0.586}{W^2 \Theta^2} \quad (2)$$

From (2) it follows that for 1.5 MeV protons and δ=10^{18} atoms/cm^2 the scattering angle Θ is above 0.7 mrad with the probability P of 50%.

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Hence we suppose that after each passage through the foil of radial size 1 cm the proton increases its axial angle by 0.7 mrad. This rather rough approximation gives us estimate of the available injection energy (or foil thickness).

The results of this step of calculations are shown in Fig.6. It is obvious the unacceptable decreasing the capture efficiency to the 12%.

Fig.7 shows the results of calculations for the injection energy W_i=5.0 MeV and the foil thickness δ=0.5$\cdot 10^{18}$ atom/cm^2 (Θ is above 0.1 mrad with probability of 50%). The efficiency increases but not yet enough

CONCLUSION

We will continue our computer simulation of the external injection to estimate the capture efficiency more precisely. We also plan to take into account the space charge influence on the capture process.

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[2] E.Segre. Experimental Nuclear Physics (russian) Moscow, 1955, v.1, p.161