МФТИ
Лаборатория Физики Ускорителей

NICA
NUCLOTRON BASED ION COLLIDER FACILITY

ОИЯИ

Preservation of the proton polarization up to 3.5 GeV/c in the Nuclotron at JINR using correcting dipoles and a weak solenoid

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The XXVth International Baldin Seminar on High Energy Physics Problems "Relativistic Nuclear Physics and Quantum Chromodynamics“, September 18–23, 2023, JINR, Dubna

Outline

1. Spin resonances in the Nuclotron.
2. Preservation of the proton polarization in the Nuclotron by a weak solenoid.
3. Preservation of the proton polarization in the Nuclotron by orbit-steerer dipoles.
4. Summary.

Spin resonances of linear approximation

Type of a resonance	*Condition of a resonance*	*Number of resonances*
Intrinsic resonances	$\nu = kN \pm \nu_y$	0
Integer resonances	$\nu = k$	6
Non-superperiod resonances	$\nu = m \pm \nu_y, m \neq kN$	10
Coupling resonances	$\nu = k \pm \nu_x$	10

In the Nuclotron lattice with the number of superperiods N=8, when choosing betatron tunes in the range from

$$7 < \nu_x < 8, \qquad 7 < \nu_y < 8$$

the first intrinsic resonance is $\gamma G = \nu_y$, which corresponds to the minimum energy $E_{min} = 7mc^2/G \approx 3.6$ GeV or to the momentum $p_{min} = 3.54$ GeV/c.

The others resonances are associated with misalignments and manufacture errors of the Nuclotron magnetic elements (imperfection resonances).

Spin resonance crossing

The spin-tune offset-from-resonance (resonance-detune): $\varepsilon = \gamma G - \nu_k$

The normalized resonance-detune rate: $\varepsilon' = R\frac{d\varepsilon}{dz} = \frac{eGR\rho}{mc^3}\left(\frac{dB}{dt}\right),$

In the Nuclotron at $R \approx 40$ m, $\rho \approx 22$ m $\varepsilon' \approx 1.75 \cdot 10^{-6}\frac{dB\,[\mathrm{T}]}{dt\,[\mathrm{s}]}$

The vertical spin component after the crossing changes according to the Froissart-Stora equation

$$S_y^{\mathrm{after}} = \left(-1 + 2\exp\left(-\frac{\pi\,\omega^2}{2\varepsilon'}\right)\right)S_y^{\mathrm{befor}}$$

ω is a resonance strength

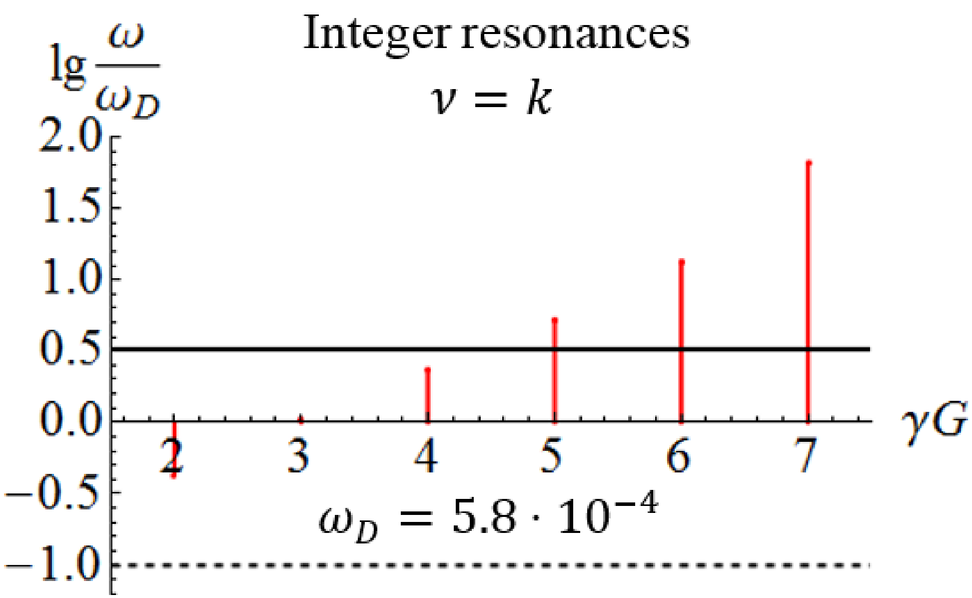
$\omega_D = \sqrt{\varepsilon'/\pi}$ is a characteristic resonance strength

$\boldsymbol{\omega \ll \omega_D}$ fast crossing, $\boldsymbol{\omega \gg \omega_D}$ adiabatic crossing,

$\boldsymbol{\omega \sim \omega_D}$ intermediate crossing (depolarization occur)

At the field ramp rate $dB/dt = 0.6$ T/s $\varepsilon' \approx 10^{-6}$, $\boldsymbol{\omega_D = 5.6 \cdot 10^{-4}}$

Integer spin resonances



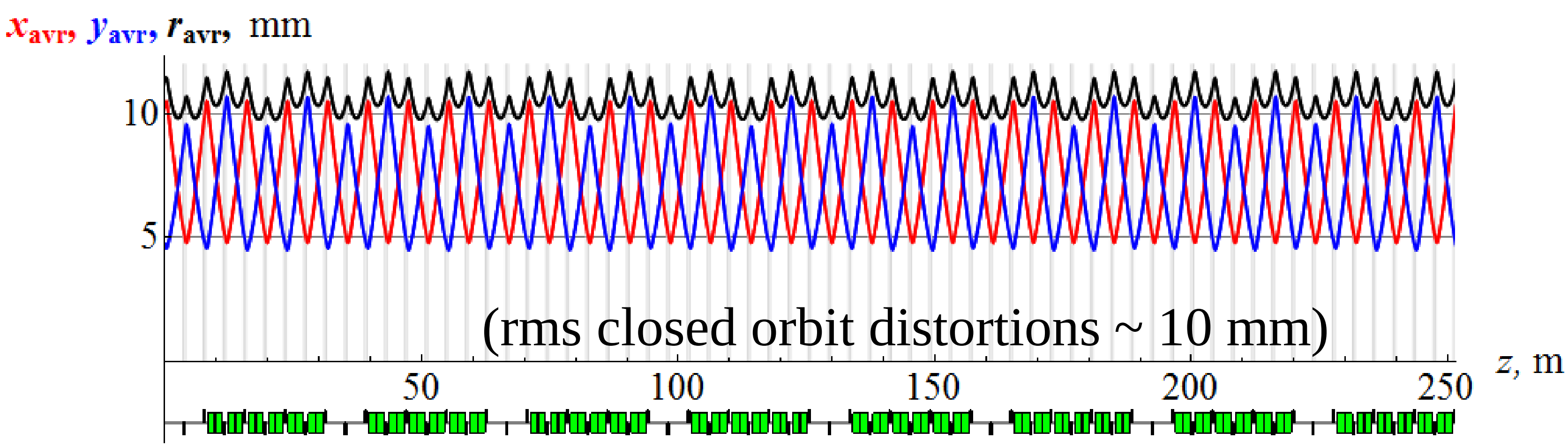
$$\omega_{rms}^2 = \sum_{\text{elem}} \frac{\langle \Delta B_x^2 \rangle F^2 L_{el}^2}{4\pi^2 (B\rho)^2}.$$

$$\Delta B_x = \alpha_z B_y, \qquad \Delta B_x = \frac{\partial B_x}{\partial y} \Delta y_q.$$

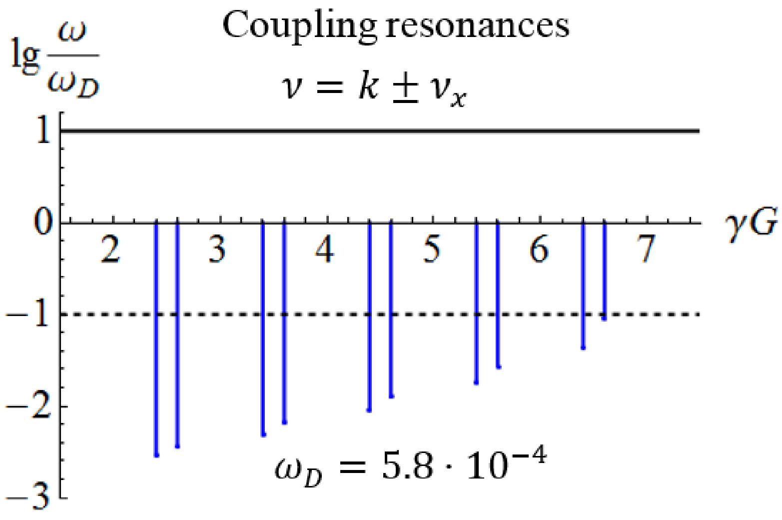
Error of dipole rolls : $\sigma_{\alpha_z} = 1\text{mrad}$

Quadrupole shifts : $\Delta y_q = 0.1\text{mm}$

F is a spin response function



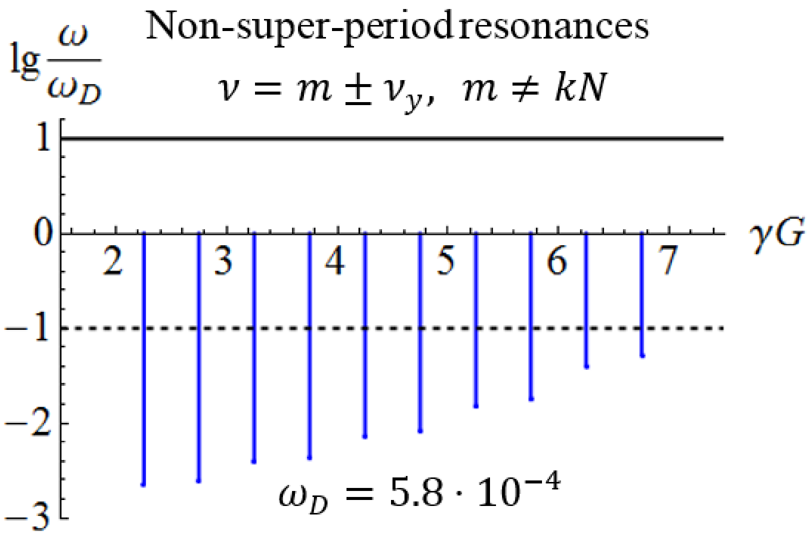
Weak spin resonances



$$\omega_{rms}^2 = \langle \alpha_z^2 \rangle \frac{\epsilon_x}{4\pi^2} \sum_{quad} \left(\frac{\partial B_x}{\partial y}\right)^2 \frac{F^2 \beta_x L_{el}^2}{(B\rho)^2}$$

Error of quadrupole rolls : $\sigma_{\alpha_z} = 1$mrad

Normalized betatron emittances
$\epsilon_{x,y} = 4\pi$ mm·mrad



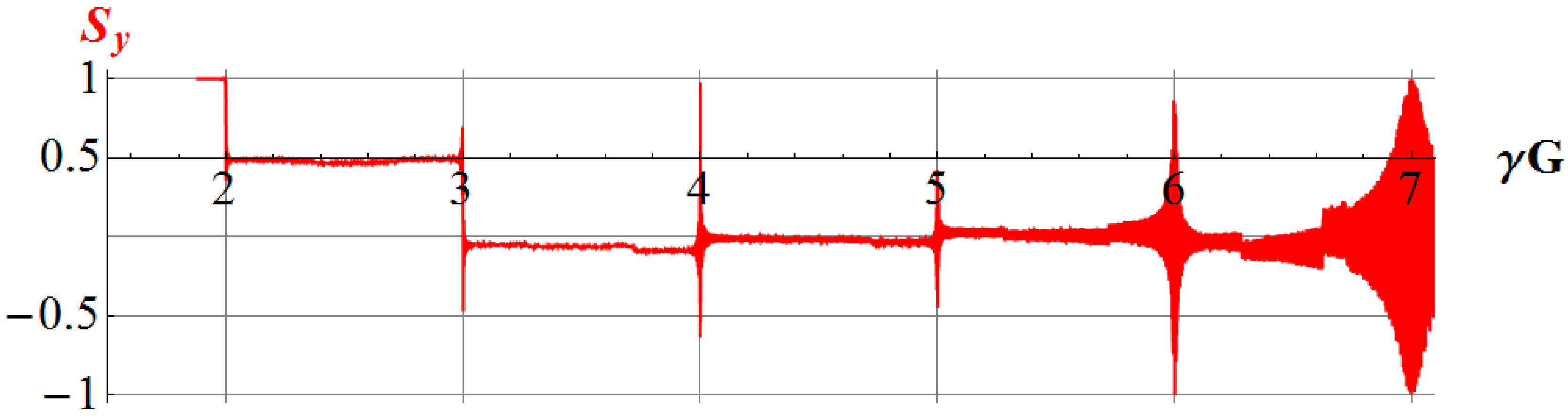
$$\omega_{rms}^2 = \left\langle \left(\frac{\Delta g}{g}\right)^2 \right\rangle \frac{\epsilon_y}{16\pi^2} \sum_{quad} \left(\frac{\partial B_x}{\partial y}\right)^2 \frac{F^2 \beta_y L_{el}^2}{(B\rho)^2}$$

Relative error of the quadrupole gradients: $\sigma_g / g = 10^{-3}$

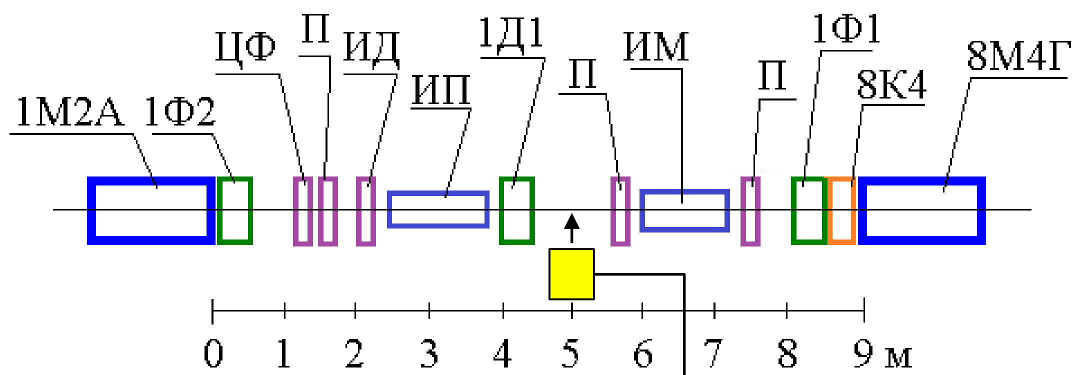
Integer Resonances Crossing (c.o. distortion 10 mm)

Table gathers integer resonance strengths ω and the corresponding depolarization degrees *D*, assuming a 100%-polarized incoming beam. RMS closed orbit distortion due to lattice imperfections is of **10 mm**, field ramp rate is of 0.7 T/s.

k	2	3	4	5	6	7
ω/ω_D	0.43	1.05	2.34	5.25	13.4	65.6
D, %	18	85	13	0	0	0



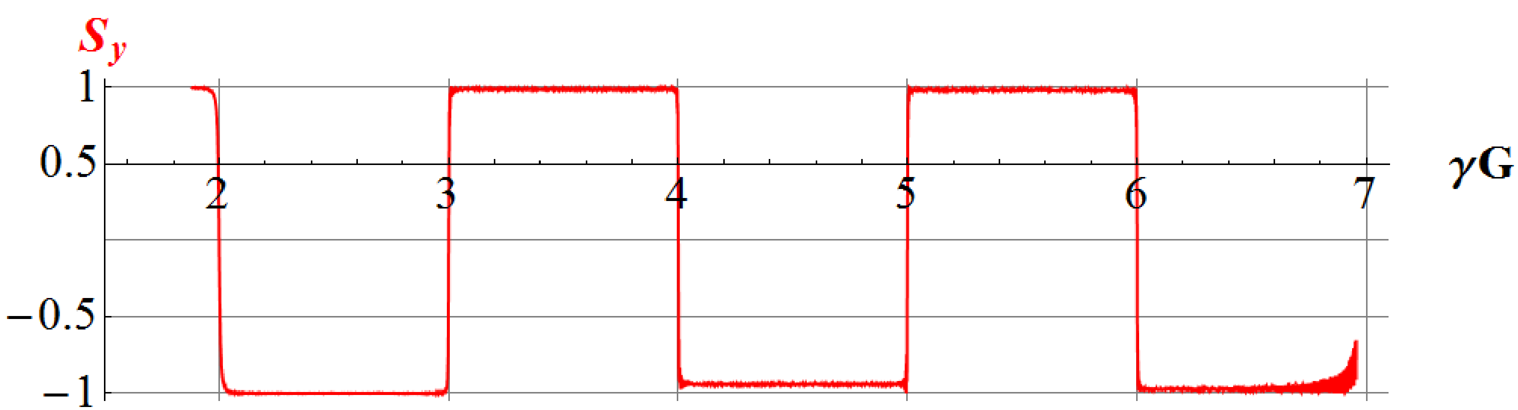
Preservation of the proton polarization in the Nuclotron by a weak solenoid



Прямолинейный промежуток 1:
корректор (8К4),
три профилометра (П),
цилиндр Фарадея (ЦФ),
ионизационный датчик (ИД),
импульсный магнит (ИМ),
инфлекторные пластины (ИП).

a weak solenoid ($B_s = 50$ mT, $L_s = 0.5$m)

The solenoid integral field $B_s L_s$=**25 mT·m** does not change during acceleration

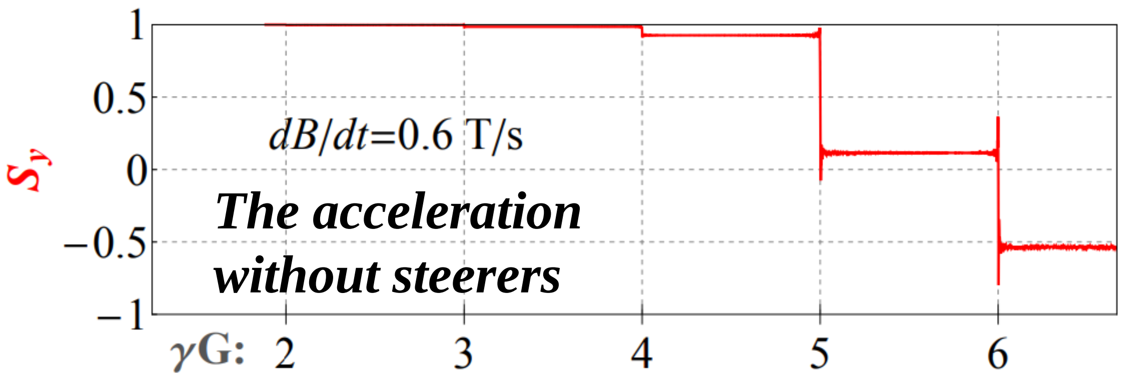


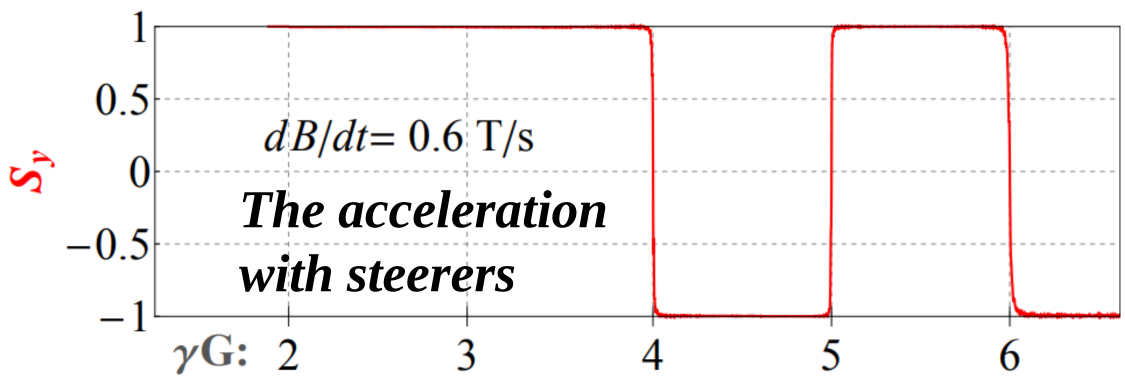
RMS closed orbit distortion is of **10 mm**, field ramp rate is of 0.7 T/s, $\frac{\Delta p}{p} = 10^{-3}$

Preservation of the proton polarization in the Nuclotron by orbit-steerer dipoles

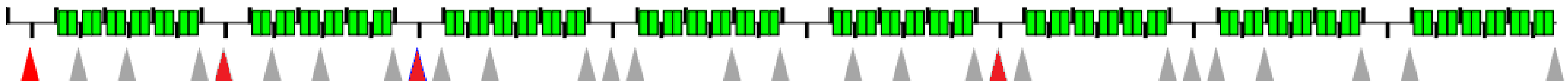
k	2	3	4	5	6
D, %	0.2	1.1	5.2	25	85

RMS c.o. distortion - **2 mm**, field ramp rate - 0.6 T/s.





The closed-orbit deviation is introduced in the γG range from 3.3 to 3.7 by a continuous inclusion of the 1, 5, 9, 20 steerers, after which the orbit is kept constant to enhance the strengths of integer resonances γG = 4, 5, 6. The maximum orbit deviation went up to 15 mm at the maximum steerer field values $b_1 = -b_5 = b_9 = -b_{20}$ = 0.2T at γG = 6.5



Summary

A successful preservation of polarization of protons with a momentum up to 3.5 GeV/c by a weak solenoid and/or orbit-steerers enables one to carry out experiments at external targets as well as to use the Nuclotron as a rapid-cycling injector of polarized protons into the NICA collider.

It will become possible to inject protons into the NICA collider directly at energies corresponding to the spin transparency regime at integer spin resonances (the NICA ST regime without two full solenoid snakes).

Thank you for your attention!