# Experience in Tuning the Magnetic Structure of Circular Accelerators at BINP

R. Z. Mamutov, G. N. Baranov, V. V. Balakin, F. A. Emanov, D. A. Lipovyy, P. A. Piminov, S. V. Sinyatkin

Budker Institute of Nuclear Physics

Sarantsev seminar, September 2024

BUDKER INSTITUTE OF NUCLEAR PHYSICS
SIBERIAN BRANCH OF RUSSIAN ACADEMY OF SCIENCE

# Table of Contents

# Overview of the accelerators at BINP

Two colliders operation

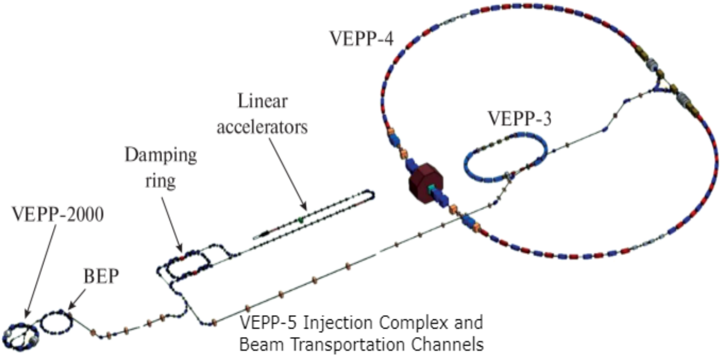



Figure: BINP accelerators layout.

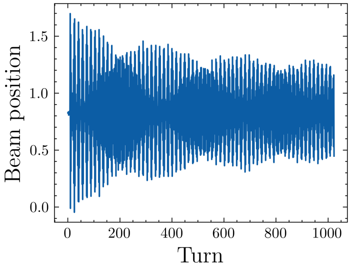
# Instrumentation and techniques

## Observables:

- Orbit responses to dipole correctors
- Orbit responses to quadrupole correctors
- Dispersion responses to skew-quadrupole correctors
- Turn-by-Turn orbit and tunes
- Orbit and Dispersion

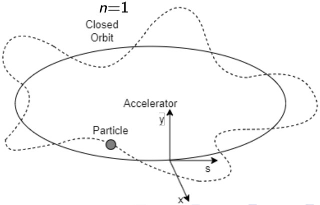
$$\frac{\Delta r_i}{\Delta \theta_j} = \frac{\sqrt{\beta_i \beta_j}}{2 \sin \pi\nu} \cos\left(|\phi_i - \phi_j| - \pi\nu\right) - \frac{\eta_i \eta_j}{\alpha_c L} \quad (1)$$

$$M = \begin{pmatrix} M_{xx} & M_{xy} \\ M_{yx} & M_{yy} \end{pmatrix} \quad (2)$$




$$C_i = \sum_{n=1}^{N} x_i(n) \cos\left(2\pi\nu n\right) \quad (3)$$

$$S_i = \sum_{n=1}^{N} x_i(n) \sin\left(2\pi\nu n\right) \quad (4)$$



# Instrumentation and techniques

## Accelerator control via:

EPICS (VEPP-4)
CXv4 (VEPP-5)

## Preparation for the experiment:

Correctors cycling procedure
Beam current threshold

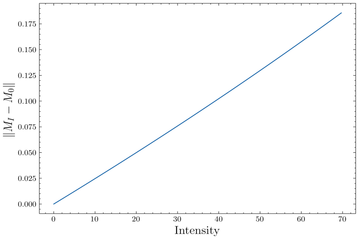



Figure: Response matrix vs Intensity

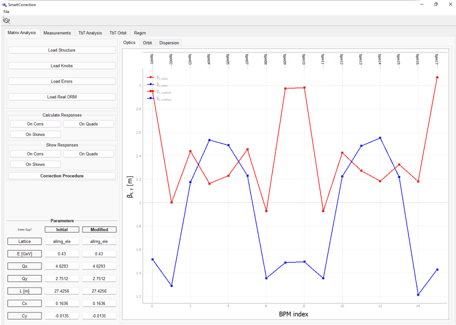



Figure: Software interface

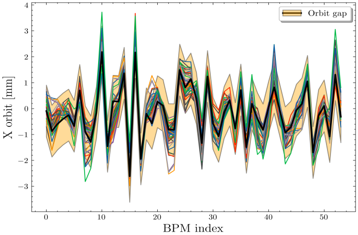



Figure: Correctors cycling procedure

# VEPP-5: Main Parameters

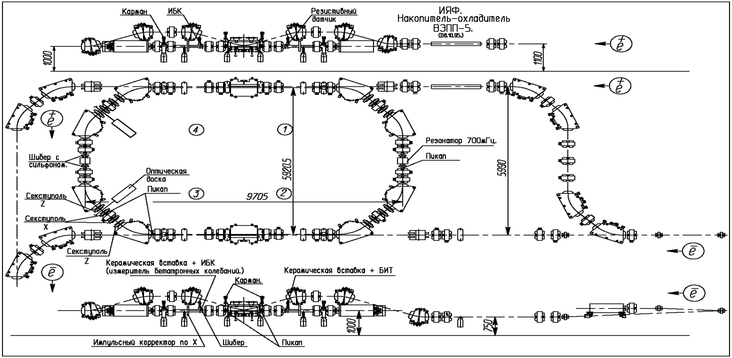



Figure: Damping ring layout

Table: Main Parameters

| | |
|---|---|
| Max. Energy | 510 MeV |
| Circumference | 27.4 m |
| Qx/Qy | 4.63/2.75 |
| RF frequency | 11.94 MHz |
| Design beam current | 30 mA |
| Damping times, h/v/l | 11/18/12 ms |
| Hor./vert. emittance | 2.3/0.5 · 10–6 rad · cm |

- 16 BPMs
- 6 power supplies for quadrupole families
- 28 quadrupole correction windings
- 36 dipole correction windings

# VEPP-5: Damping Ring Optics

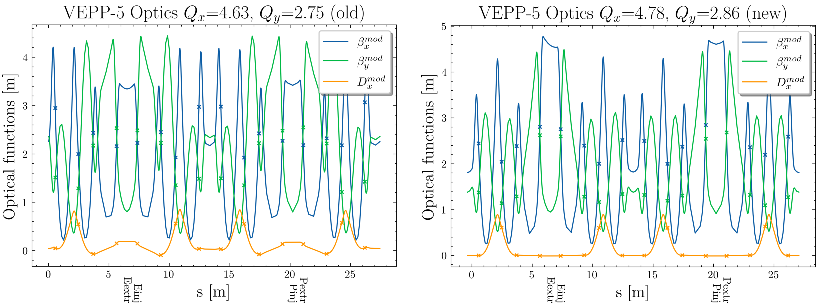
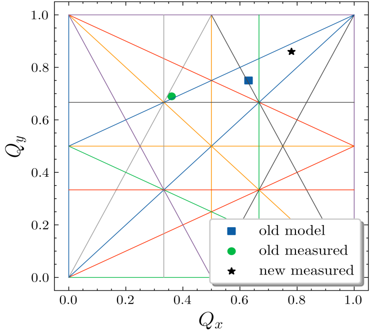



Figure: Optical functions for two structures

# VEPP-5: Tune Working Points

With the help of 6 power supplies:

$$\begin{pmatrix} \Delta Q_x \\ \Delta Q_y \end{pmatrix} = \begin{pmatrix} -0.00186 & -0.00102 & -0.00089 & 0.00595 & 0.00242 & 0.00326 \\ 0.00221 & 0.00244 & 0.00301 & -0.00261 & -0.00105 & -0.00002 \end{pmatrix} \cdot \begin{pmatrix} \Delta I_{d1} \\ \Delta I_{d2} \\ \Delta I_{d3} \\ \Delta I_{f1} \\ \Delta I_{f3} \\ \Delta I_{f4} \end{pmatrix} \quad (5)$$




| | $Q_x$ | $Q_y$ |
|---|---|---|
| Old model | 4.63 | 2.75 |
| Old measured | 4.36 | 2.69 |
| New measured | 4.78 | 2.86 |

Figure: Tune working points for two structures

# VEPP-5: Optics Correction

With the help of 28 quadrupole correction windings:

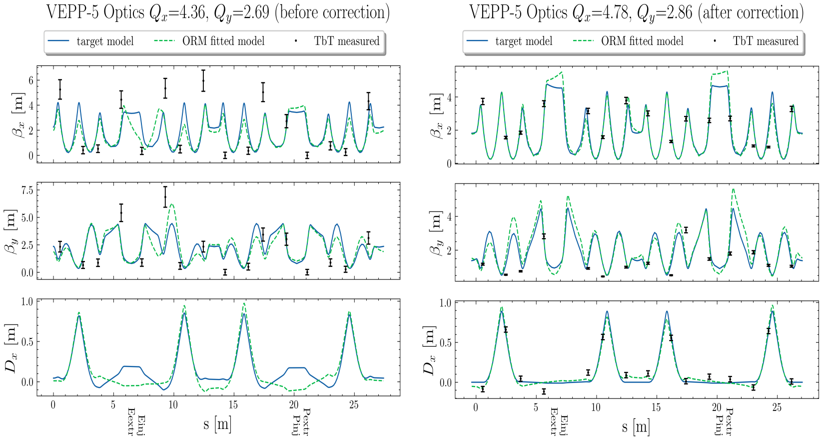



Figure: Optics functions before (left) and after (right) correction

# VEPP-5: Orbit Correction

With the help of 32 dipole correction windings:

$\Delta CorrectorKicks = M^{-1} \cdot \Delta Orbit$

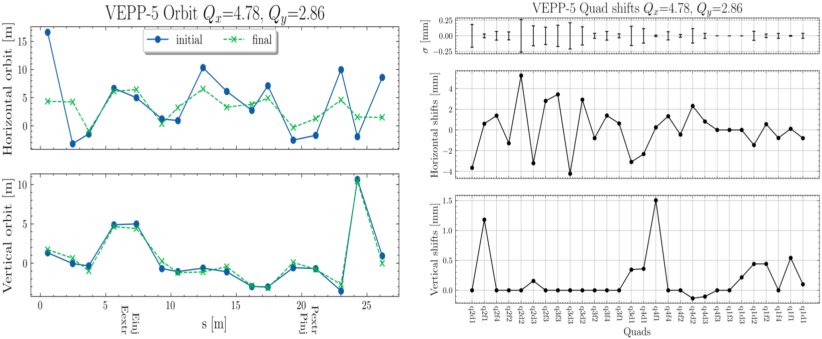
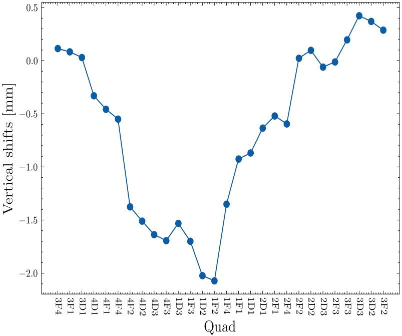



Figure: Beam orbit (left) and quadrupole shifts (right)

# VEPP-5: Geodetic displacements



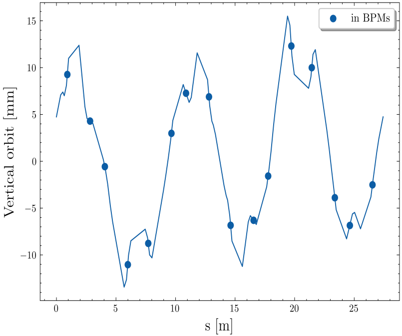




Figure: Vertical geodetic displacements of quads (left) and the resulting vertical orbit (right)

# Summary

## Remarks

- New optics with a new working point
- Corrected orbit to reduce beam losses
- Improved injection, storing and stability
- Modern and easy to exploit machine (control and magnetic systems)

## Plans

- More iterations to fine-tune beta beatings and orbit
- Future beam-based alignment to realign quads and correct the orbit
- Unified optics for both electrons and positrons
- Transportation channels to colliders tunning

# VEPP-3

## Uses:

- Booster for VEPP-4M
- For Deuteron experiment
- For SR research

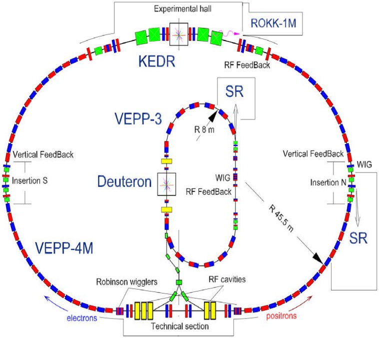



Figure: VEPP-4 acceleratring-storage complex layout

# VEPP-3: Main Parameters

Table: Main Parameters

| | |
|---|---|
| Energy range | 0.4-2 GeV |
| Circumference | 74.4 m |
| Compaction factor | 0.071 |
| Qx/Qy | 5.17/5.22 |
| RF frequency | 8.06/72.54 MHz |
| Revolution frequency | 4.03 MHz |
| Damping decrements, h/v/l | 0.93/1/2.07 |
| Beam lifetime | 0.5-6 hours |

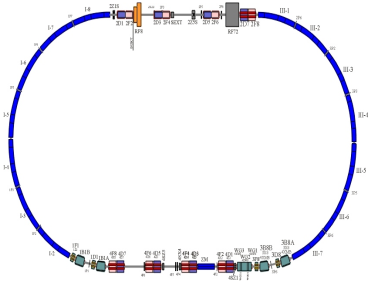


Figure: VEPP-3 ring layout

- 19 BPMs
- 4 power supplies for quadrupole families
- 53 dipole correction windings

# VEPP-3: Baseline Optics

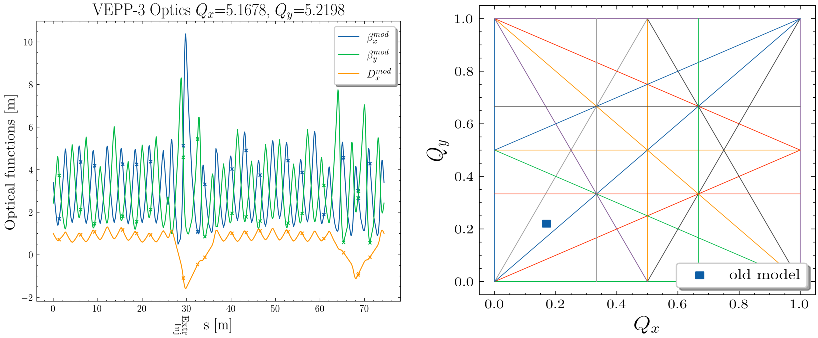



Figure: Optical functions and working point

# VEPP-3: Matrix Analysis

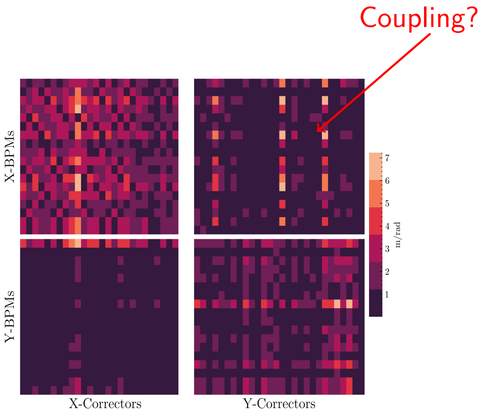



Figure: Heatmap of measured response matrix

# VEPP-3: Optics Correction

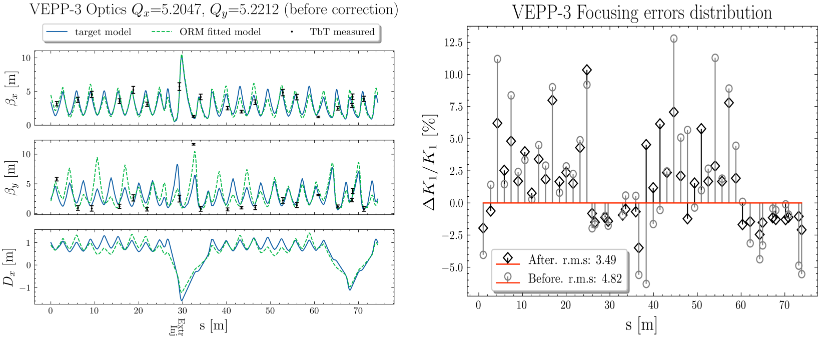



Figure: Optical functions and errors distribution

# Summary

## Remarks

- Optics measurements and the calibrated model for the first time at VEPP-3
- Amount of knobs is crucial for optics correction
- Boosters usually lack control knobs
- Calibrated model but not corrected optics
- It is optimal to use a tune-to-current knob in this case

## Plans

- Orbit bumps in non-linear elements to create necessary focusing
- Perhaps it's worth finding a new model structure to start with

# VEPP-4M

## Uses:

- For KEDR experiments
- For SR research
- For ROKK-1M experiments

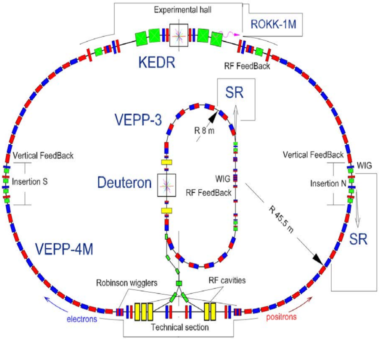



Figure: VEPP-4 complex layout

Table: Main Parameters

| | |
|---|---|
| Energy | 1.9-6 GeV |
| Circumference | 366.075 m |
| Rev. frequency | 818.924 KHz |
| RF frequency | 180 MHz |
| RF harmonic | 222 |
| Betatron tunes | 8.54/7.58 |
| Synchrotron tune | 0.006-0.03 |
| Comp. factor | $1.68 \cdot 10^{-2}$ |
| Hor. emit. | $24.6$ nm $\cdot$ rad |
| Energy spread | $3.7 \cdot 10^{-4}$ |
| Bunch current | 6 mA |

# VEPP-4M: Main Parameters

- main field **H** powered by 1 power supply
- gradient **F7**. 1 power supply
- gradient **D7**. 1 power supply
- sextupole corrections: **FS**, **DS**. 4 power supplies
- correction of the horizontal orbit **X**. 1 power supply per element
- correction of the vertical orbit **Y** and betatron coupling **SQ**. 2 power supplies per element

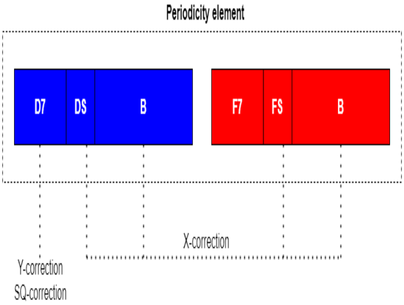
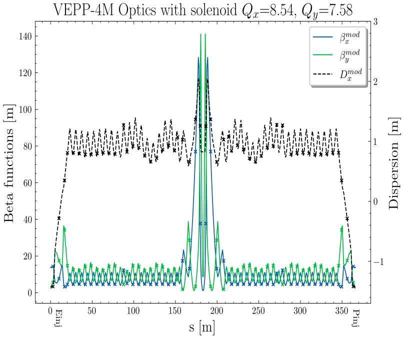



Figure: Periodicity element at the arcs

- 54 BPMs
- 26 quadrupole correction windings
- 6 quads have individual transistor shunts
- 105 dipole correction windings

# VEPP-4M: Optics for Experiments 4.7 GeV



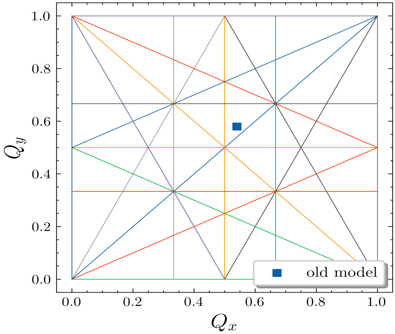




Figure: Optical functions and working point

$$\Delta k = C\Delta I. \tag{6}$$

## Quadrupole effectiveness

- Measure two matrices: $M(I)$, $M(I + \Delta I)$
- Fit a model to $M(I)$
- With the model, vary lens' $\Delta k$ to fit $M(I + \Delta I)$

## Skew-quadrupole effectiveness

- Measure one matrix: $M$
- Fit a model to $M$
- Measure disperson responses : $D_y/\Delta I$
- With the model, vary lens' $\Delta k$ to fit $D_y/\Delta I$

# VEPP-4M: Solenoid Compensation Checking

From the model calibration, error $\Delta I_{sol}/I_{sol} < 0.5\%$

$$M = \left(\Delta D_y/\Delta I\right) \tag{7}$$

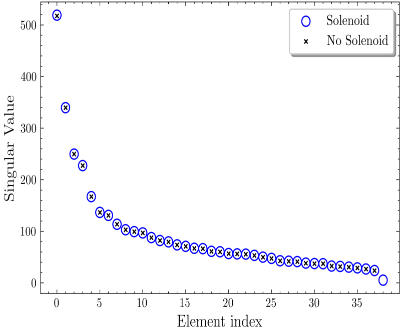



Figure: Singlular values of dispersion responses to skew-quads and solenoid matrix

# VEPP-4M: BetaY* and Dispersion Minimization

$\beta_y^*$: 6 cm $\rightarrow$ 4 cm

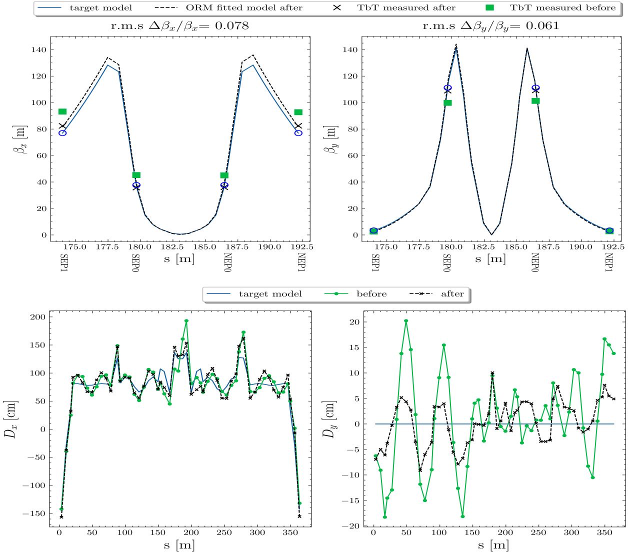



Figure: Beta function correction at the experimental area. Dispersion correction.

# Summary

## Remarks

- Amount of knobs is crucial for optics correction
- Don't limit yourself to one model, but try to find another one
- Hard to use non-isolated knobs that change not only focusing properties
- The trend in accelerator design is a higher structure fill-factor than it was for VEPP-4M: combined function magnets + correction windings

## Plans

- To validate the increase in luminosity as the season begins
- Orbit bumps in non-linear elements to create necessary focusing

**Thank you for your attention!**