Beam Experiments With AC Dipole

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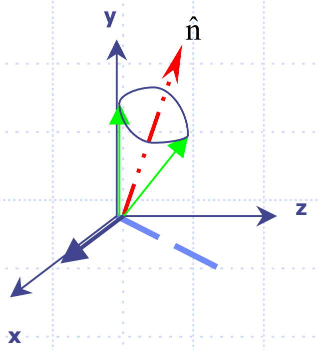
Outline

- Why
- what are the experiments
- hardware readiness
- experiments' necessities
- plan for the coming run
- conclusion

What can an ac dipole do?

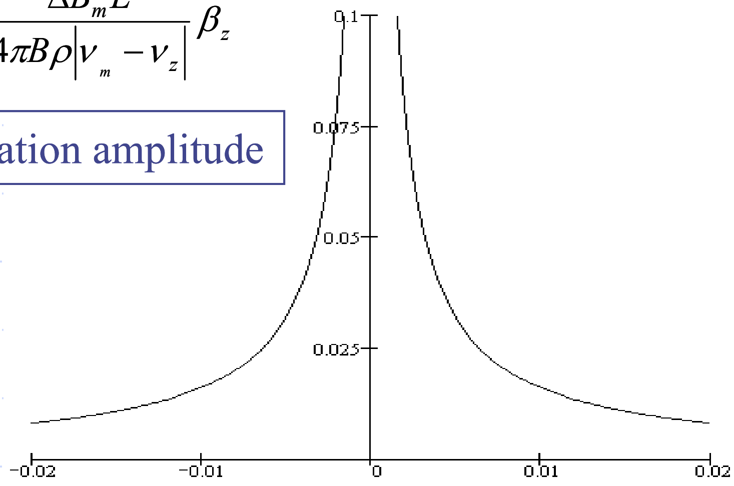
- can excite a long sustain coherent betatron oscillation
- the adiabatic excited coherence preserves the beam emittance
- can launch the beam to a large amplitude to explore the nonlinear beam dynamics
- the vertical ac dipole can also resonate around the spin precession frequency can be used to manipulate the spin motion



$$\varepsilon = \frac{1}{4\pi}(1+G\gamma)\frac{B_m L}{B\rho}$$

$$z_{coh} = \frac{\Delta B_m L}{4\pi B\rho |\nu_m - \nu_z|}\beta_z$$

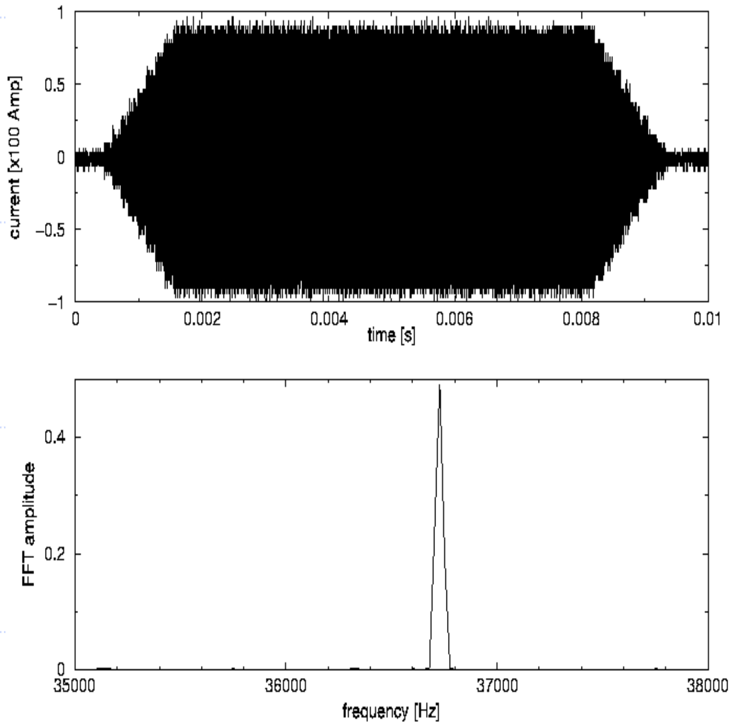
Coherent oscillation amplitude



Applications of the RHIC Ac Dipole(s)

- high-precision linear optics measurements
- fast global decoupling
- measurement of nonlinear & linear driving term
- nonlinear phase space distortion measurement
- spin flipping and other spin diagnostics

Application	BmL [Gm]	Field Orientation	Center frequency [kHz]	Tunnin range [kHz]	Duty time
Spin flipping	≥ 100	Hori	37.5	±1.0	24s
Linear optics Measurement	78	Vert Hori	64.0	_	40ms
Non-linearity Measurement	380	Vert hori	64.0	±1.0	≥ 80ms



The current readback of RHIC vertical ac dipole and its spectrum. The ac dipole was configured to resonate at 36.6 kHz for the spin flipping.

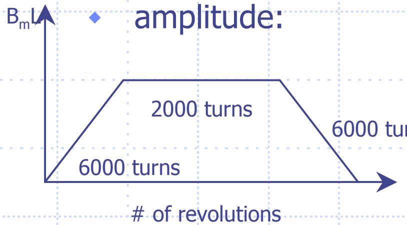
High-precision linear optics measurements

- objective

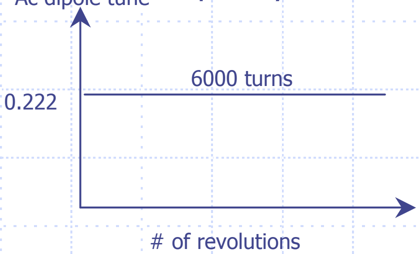
    Measure beta function and phase advance around the ring

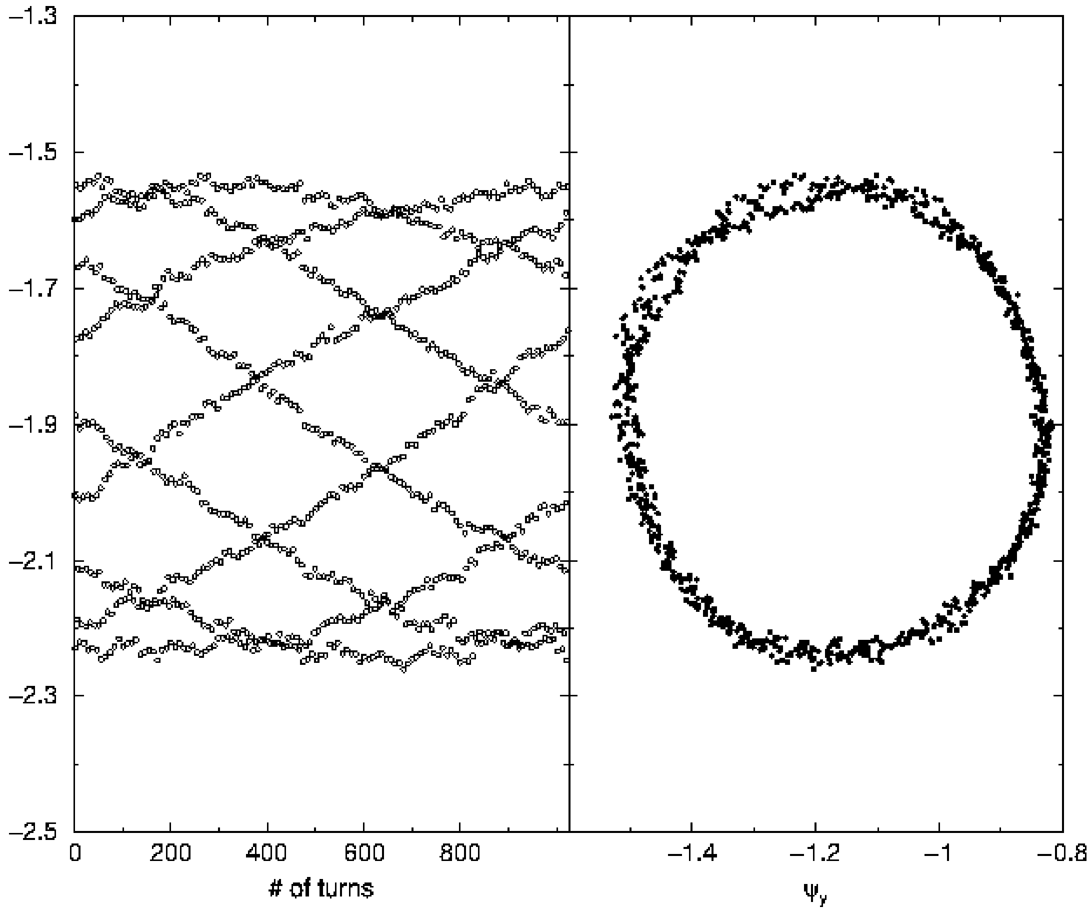
- observable(s)
    - 1k turn-by-turn bpm data.
    - about 1σ coherence amplitude

- species: polarized proton
- energy: 100 GeV/c
- beam tune measured with RHIC tune meter:
    - horizontal tune=0.209
    - vertical tune=0.212
- ac dipole setting
    - amplitude:



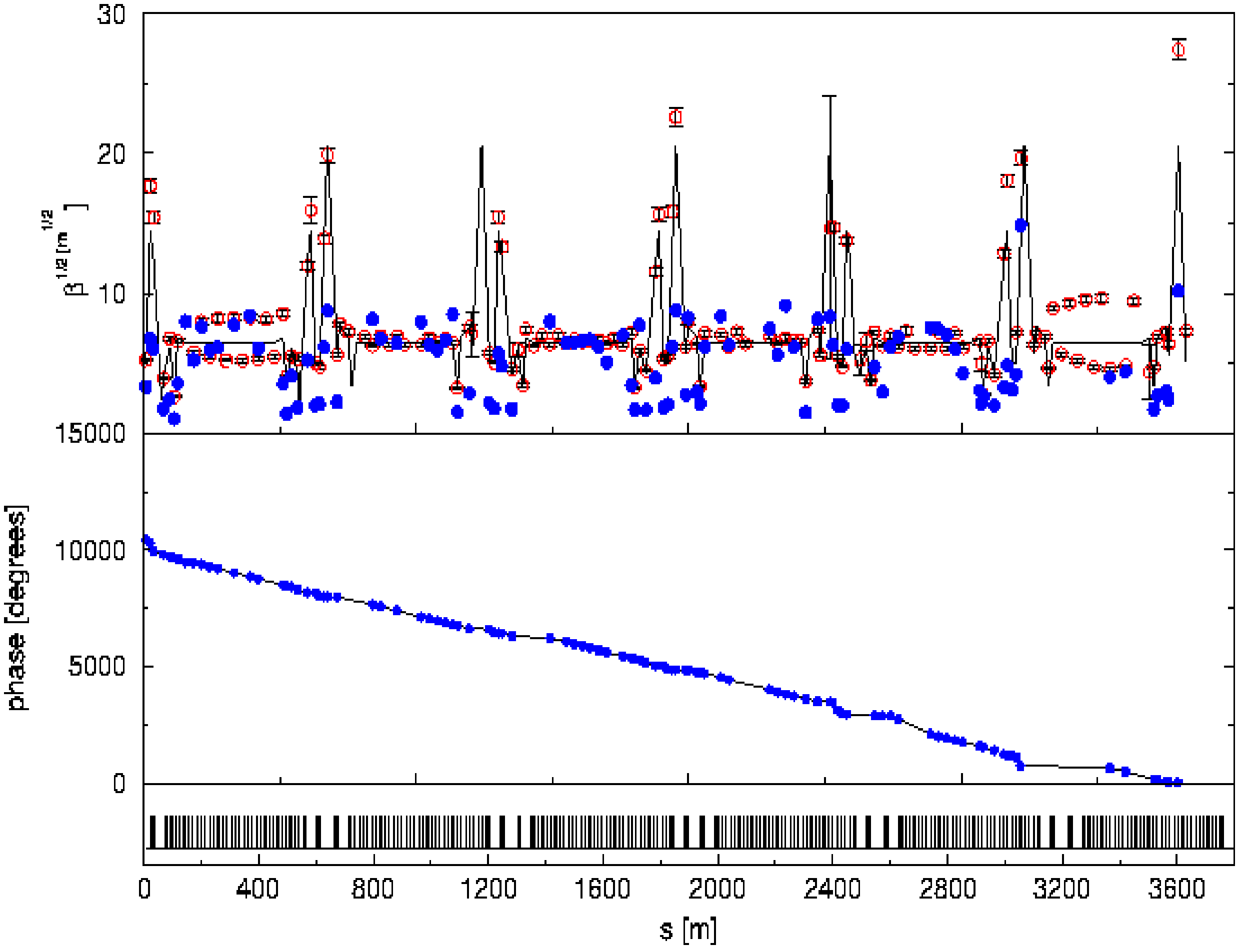
    - frequency





Betatron amplitude functions in the Yellow ring at storage.

- Polarized proton setup:
  - injection
    - energy = 24.3 GeV/c
    - lattice: β*=3 m at all IPs
  - storage energy
    - energy = 100.7 GeV/c
    - lattice: β*=3 m at all IPs |
- The betatron functions in the arcs me by the ac dipole agree well with the model prediction. However, the turn by turn data in the interaction regions are rather noisy and the agreement between the measurement and model is poor.

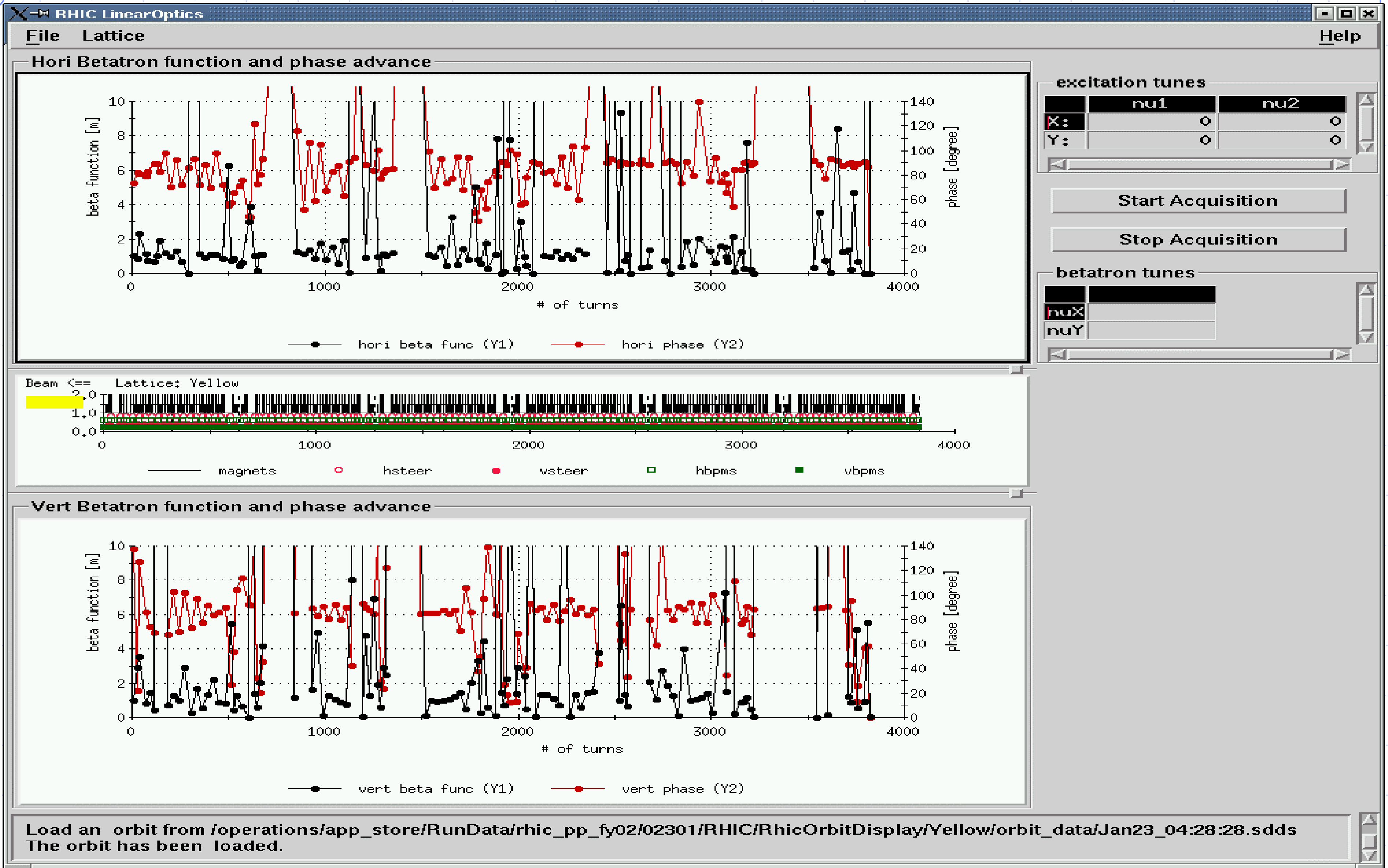


—— model

o Measured with injection oscillation

● Measured with ac dipole at storage

RHIC LinearOptics online application



Fast global decoupling

- objective

  online decoupling

- observable(s)
  - 1k turn-by-turn bpm data from both planes
  - about 1σ coherence amplitude
- Data analysis
  - input: TBT bpm data around the ring

    ac dipole parameter
  - output: coupling strength

measure coupling matrix R

$$\begin{pmatrix} A & 0 \\ 0 & B \end{pmatrix} = \Re^{-1} \begin{pmatrix} M & m \\ n & N \end{pmatrix} \Re \qquad \Re = \begin{pmatrix} I & \bar{R} \\ -R & I \end{pmatrix}$$

$$R = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix} \qquad \begin{pmatrix} x \\ x' \\ y \\ y' \end{pmatrix} = \begin{pmatrix} I & \bar{R} \\ -R & I \end{pmatrix} \begin{pmatrix} u \\ u' \\ v \\ v' \end{pmatrix}$$

for (v, v')=0,

$$x = A_x \sqrt{\beta_x} \cos(\nu_x \theta) \quad x' = -A_x \sqrt{\beta_x} \sin(\nu_x \theta)$$

$$y = -A_x \sqrt{\beta_x} \left(R_{11} \cos(\nu_x \theta) + R_{12} \sin(\nu_x \theta) \right)$$

for (u,u')=0,

$$y = A_y\sqrt{\beta_y}\cos(\nu_y\theta) \qquad y' = -A_y\sqrt{\beta_y}\sin(\nu_y\theta)$$

$$x = A_y\sqrt{\beta_y}\left(R_{22}\cos(\nu_y\theta) - R_{12}\sin(\nu_y\theta)\right)$$

for a vertical coherent excitation, we expect to measure R_{22} and R_{12} by fitting the turn-by turn dual plane bpm data.

$$y = a\cos(\nu_m\theta + \chi_y)$$
$$x = b_1\cos(\nu_m\theta + \chi_y) + b_2\sin(\nu_m\theta + \chi_y)$$

and

$$b_1 \propto R_{22}; \qquad b_2 \propto R_{12}$$

Measurement of nonlinear and linear driving term

- objective

  measure nonlinear resonance driving term from the Fourier spectrum

- observable(s)
  - > 1k turn-by-turn bpm data from both planes
  - prefers large oscillation amplitude
- Data analysis
  - SUSSIX
  - input: TBT bpm data around the ring
  - output: driving terms

Nonlinear phase space distortion

- objective

  test the idea of assessing the nonlinearity by using SUSSIX

- observable(s)
  - 1million turn-by-turn bpm data from both planes
  - prefers large amplitude oscillation
- Data analysis
  - reconstruct phase space
  - input: TBT bpm data around the ring
  - output: distortion of the phase space

Spin flipping and diagnostics

- objective

  achieve 99.9% spin flip

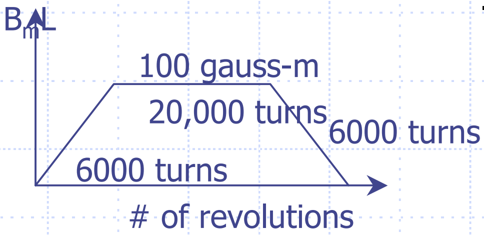
  measure spin tune to calibrate the snake settings
- observable(s)
  - asymmetry of the beam
- Data analysis
  - input: beam asymmetry before and after the spin flipping
  - output: spin flipping efficiency

Spin flipper commissioning

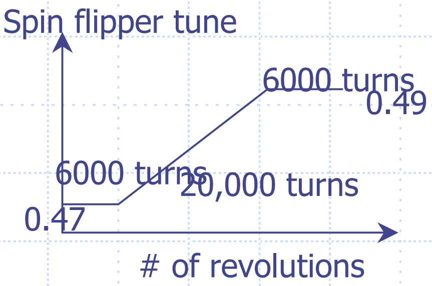
------- Blue Ring

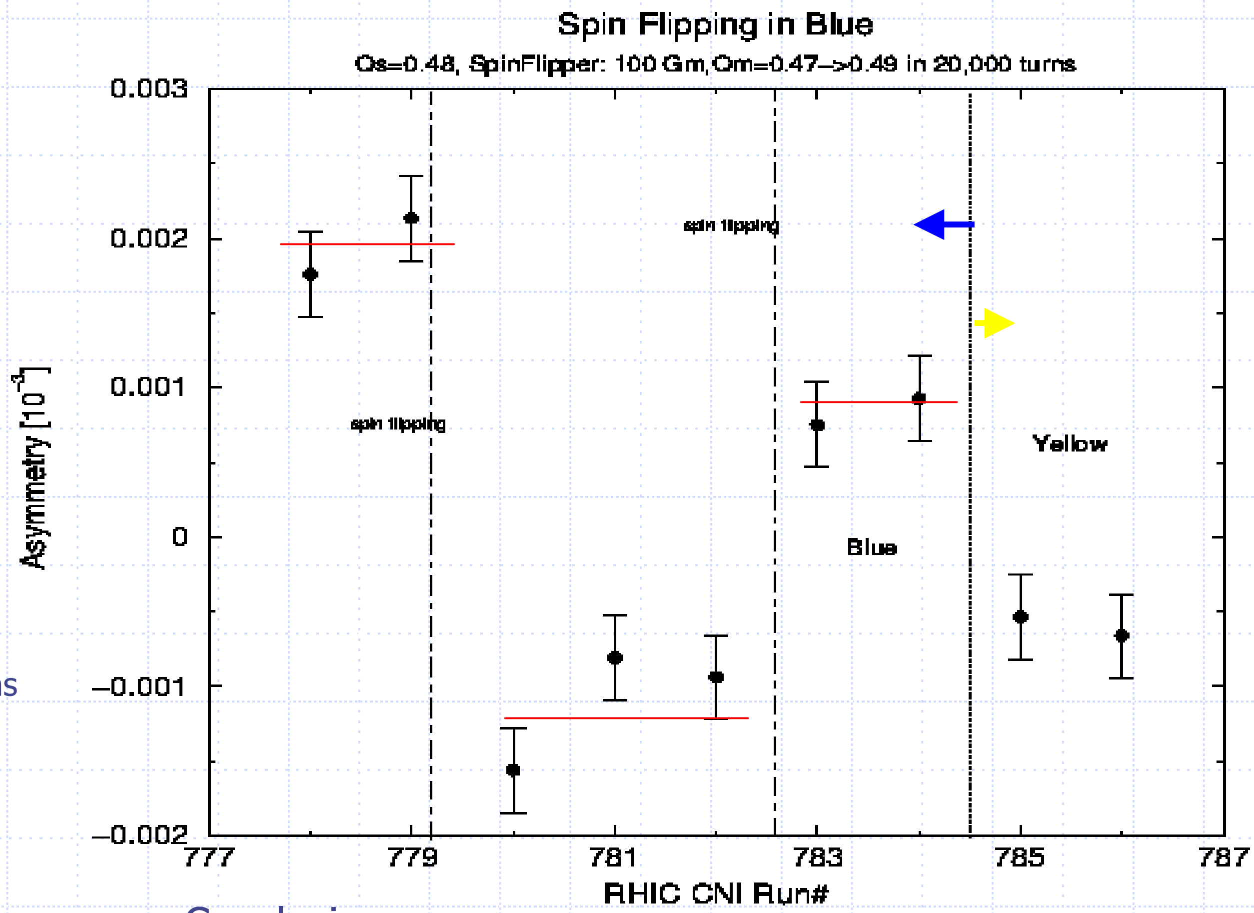
- Setup:
  - snake:
    - inner current=325.06A
    - outer current=106.11A

    the predicted spin tune equals to 0.48.
  - Spin flipper:
    - amplitude:



    - frequency





Conclusions:

- spin flip efficiency η

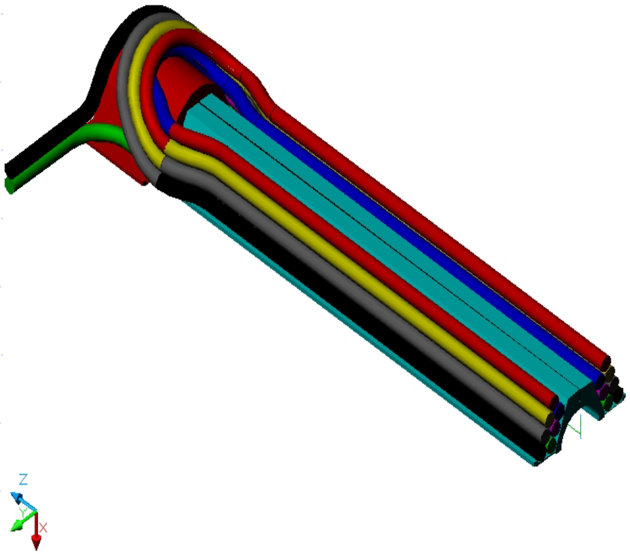
$$P_2 = P_1\eta = P_0\eta^2 \qquad \eta \approx 0.66$$

Polarization of target scan

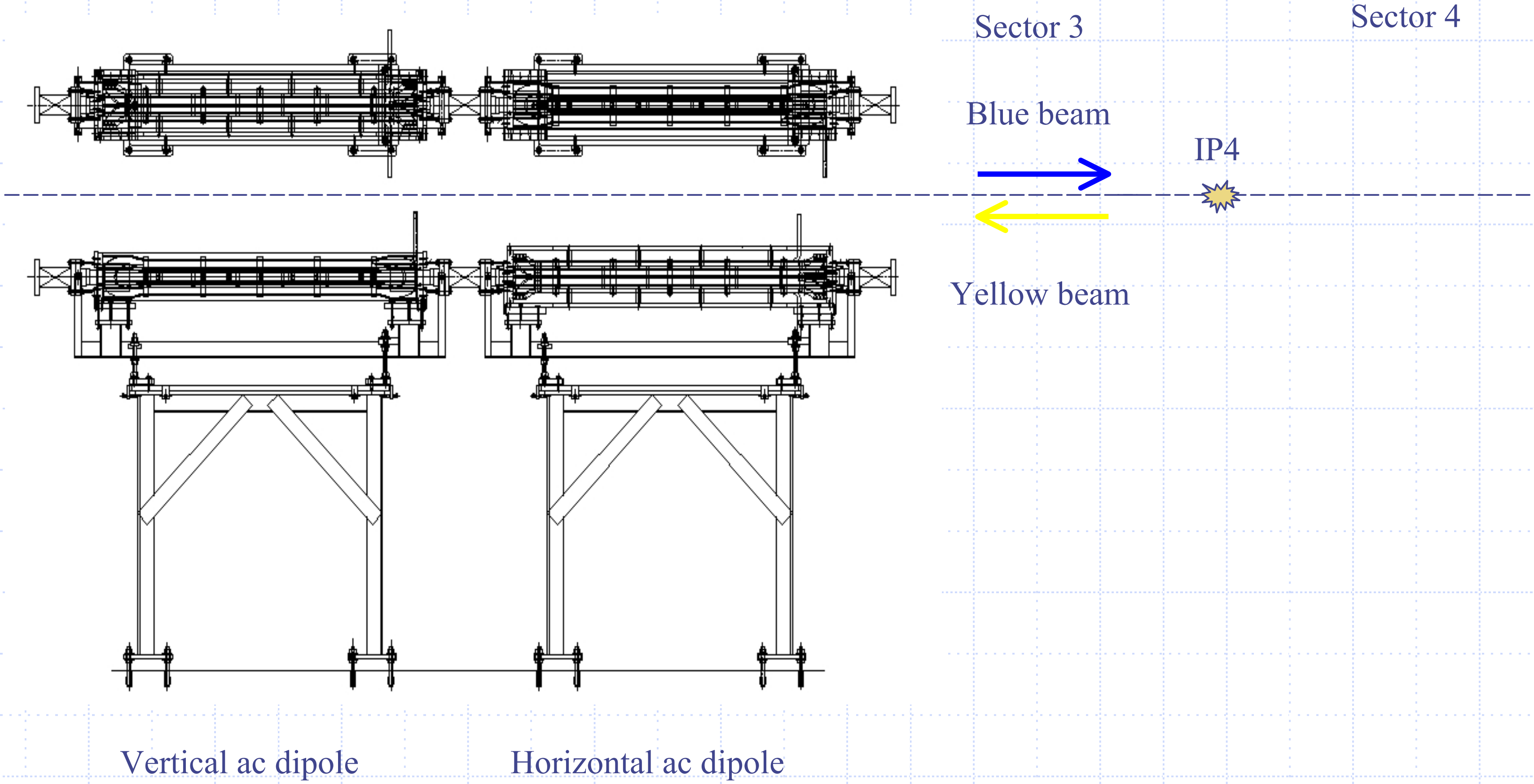
At the end of the last pp run, a scan of measured asymmetries as a function of the target horizontal position was measured. Instead of a flat line as we expected, the data shows a smaller asymmetry in the core of the beam than the asymmetries of the beam on the edges. We would like to revisit this during the coming pp run to have a full undertanding.

The RHIC ac dipole

- air-core magnet
- each magnet consists of two coils with seven turn windings
- each magnet is 1.19 m long
- ceramic beam pipe with dimensions: 53''(L) x 1.625''(ID) x 1.875''(OD)
- coil winding is made of Litz wire which consists of more than 4000 individually insulated strands
- the connections of the two coils can be switched between in parallel and in series to allow the ac dipole to be resonated either at 64 kHz or 37.5 kHz.



Location of the RHIC ac dipole



Necessities of the Experiment

Essentially, all these ac dipole beam experiments will be beneficial to improve the machine performance. The measurement of the betatron amplitude functions and the phase advances will tell us whether the linear optics is correct. The global decoupling is desired for decoupling the machine along the ramp. The non-linear driving term measurements are essential for the non-linear corrections. And the spin flipping is highly desired by the RHIC spin experiments

Plan for the coming run

For the coming run, we plan to comission the following applications

linear optics measurement
global decoupling
spin flipping

We also need dedicated beam study time for the nonlinear measurements.

Conclusions

Both horizontal and vertical ac dipoles will be available for the coming run. The applications of using these devices have been studied and planned to be carried out.