Magnet Performance & RHIC Commissioning

Facility Overview
Magnet Acceptance/Ring performance
Pulsed Magnets/Helical Dipoles
Machine Optics
Dynamic Effects
Operating experience
Conclusions

The Relativistic Heavy Ion Collider Facility Overview

RHIC:
Two Independent superconducting rings, 4 km each. 6 collision points

Arc/Matching Sections
Dipoles, 8 cm (288) 3.5T,
CQS Assemblies, 8 cm (420) 72T/m
produced in industry

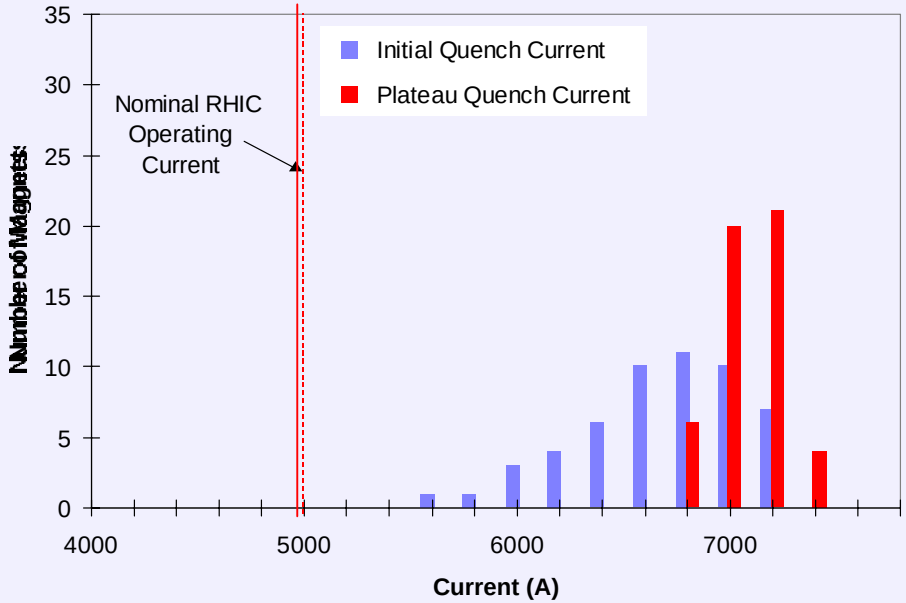
Interaction Regions
IP Quads, 13 cm (96)
IR Dipoles, 10 cm (24)
IR Dipoles, 18 cm (12)
produced at BNL

Engineering run 99 (beams circulate),
Commissioning run 00 (beams collide),
Physics run in progress 01/02 (35% design luminosity)

RHIC Arcs & IP's

RHIC - Magnet Testing/Ring Performance

- Arc magnet performance established by cold testing only a subset of the magnets (first 10% + 1-in-10)
- All IR magnets cold tested
- Field quality from warm measurements good enough for qualification (few tens of a unit)



Commissioning experience was essentially as expected from the cold testing:

- No arc magnet quenching.
- Training from the IP 18cm dipoles only

All magnets operated successfully to design energy !

RHIC - Magnet Acceptance

Given the cost of an accelerator magnet, magnet acceptance is generally a delicate dance between project management <-> accelerator physics with magnet builders caught in the middle.

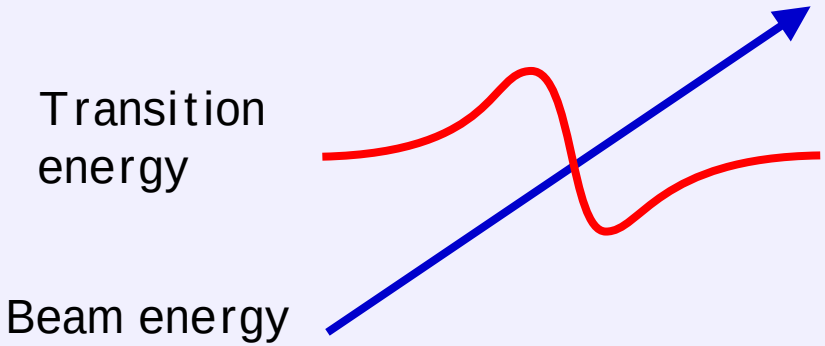
RHIC magnet field quality 'very good' - systematics rather than randoms dominated:

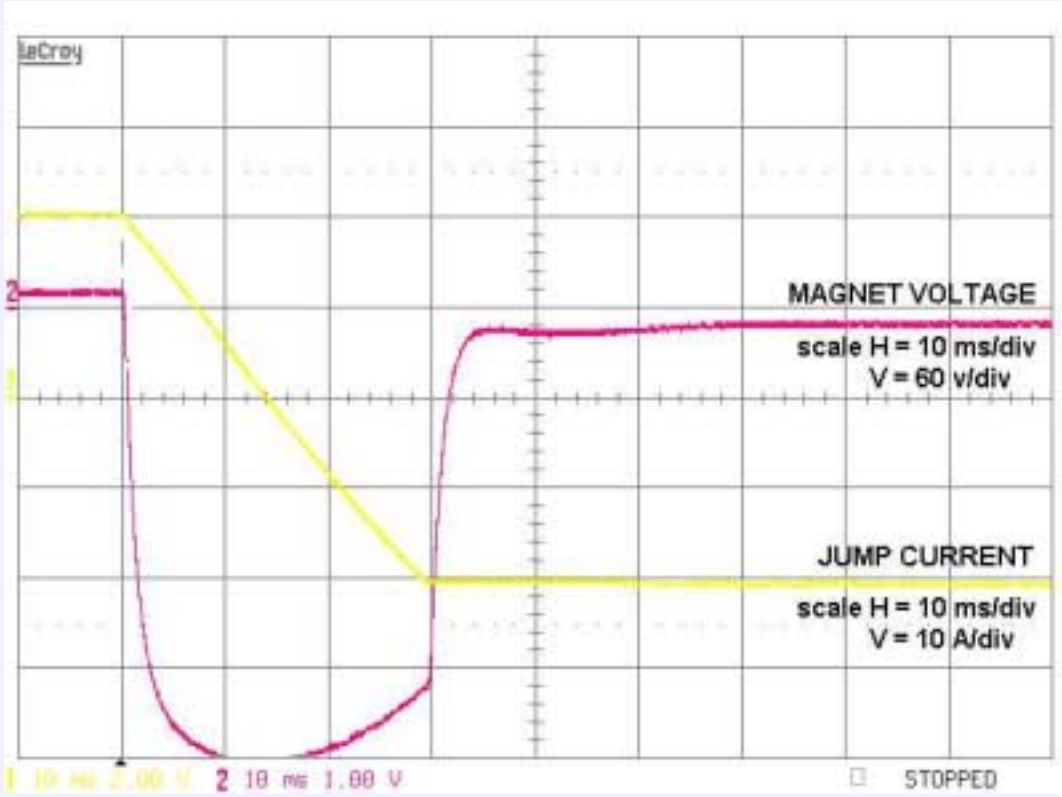
- some dipole sorting on transfer function
- sextupole quench current determined focusing location
- complex field quality assessment made to determine the best IP quadrupoles for the highest luminosity IR's
- some simple sorting on dipole field quality (-ve b_3 next to a +ve b_3)

No magnets were rejected at all. Occasionally elements were assigned as spares.

RHIC - fast pulsed quadrupole magnets

Pulsing the machine optics; a transition jump to rapidly cross an unstable region caused by the loss of RF phase focusing.
Standard RHIC (superconducting) correction quadrupoles

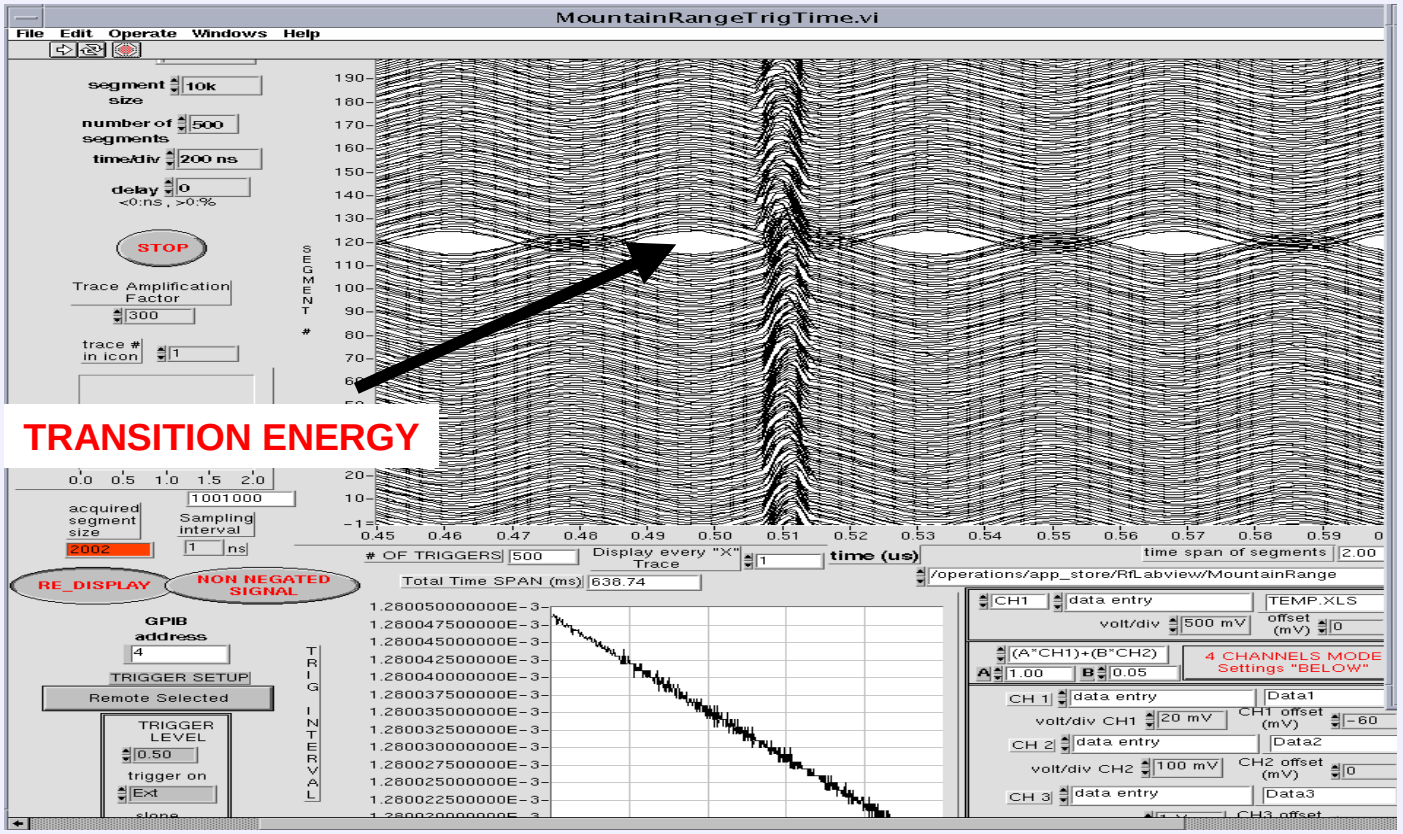




±40A in 30ms.

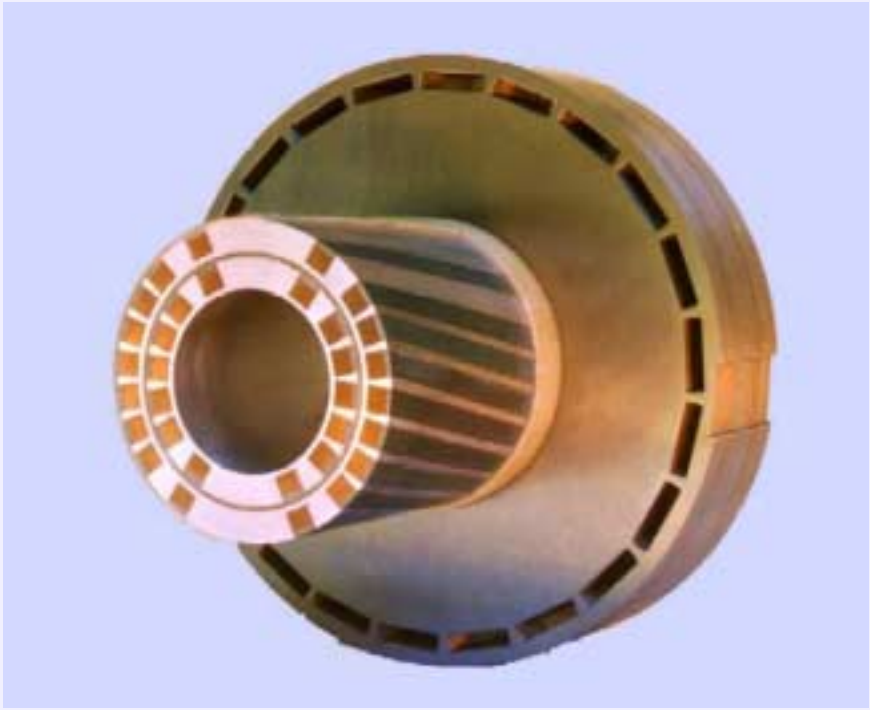
dI/dt up to 4 kA/s in a low field environment

RHIC - fast pulsed quadrupole magnets



Transition crossing 'mountain range' plot - turn by turn longitudinal profile

RHIC - Polarized Protons/Helical Dipoles



Four Helical dipoles, 4T, 2 m long, & 360° Twist in each Siberian Snake/Spin Rotator

The Siberian Snakes have been operated but no significant polarised proton running yet

RHIC - machine optics/orbits

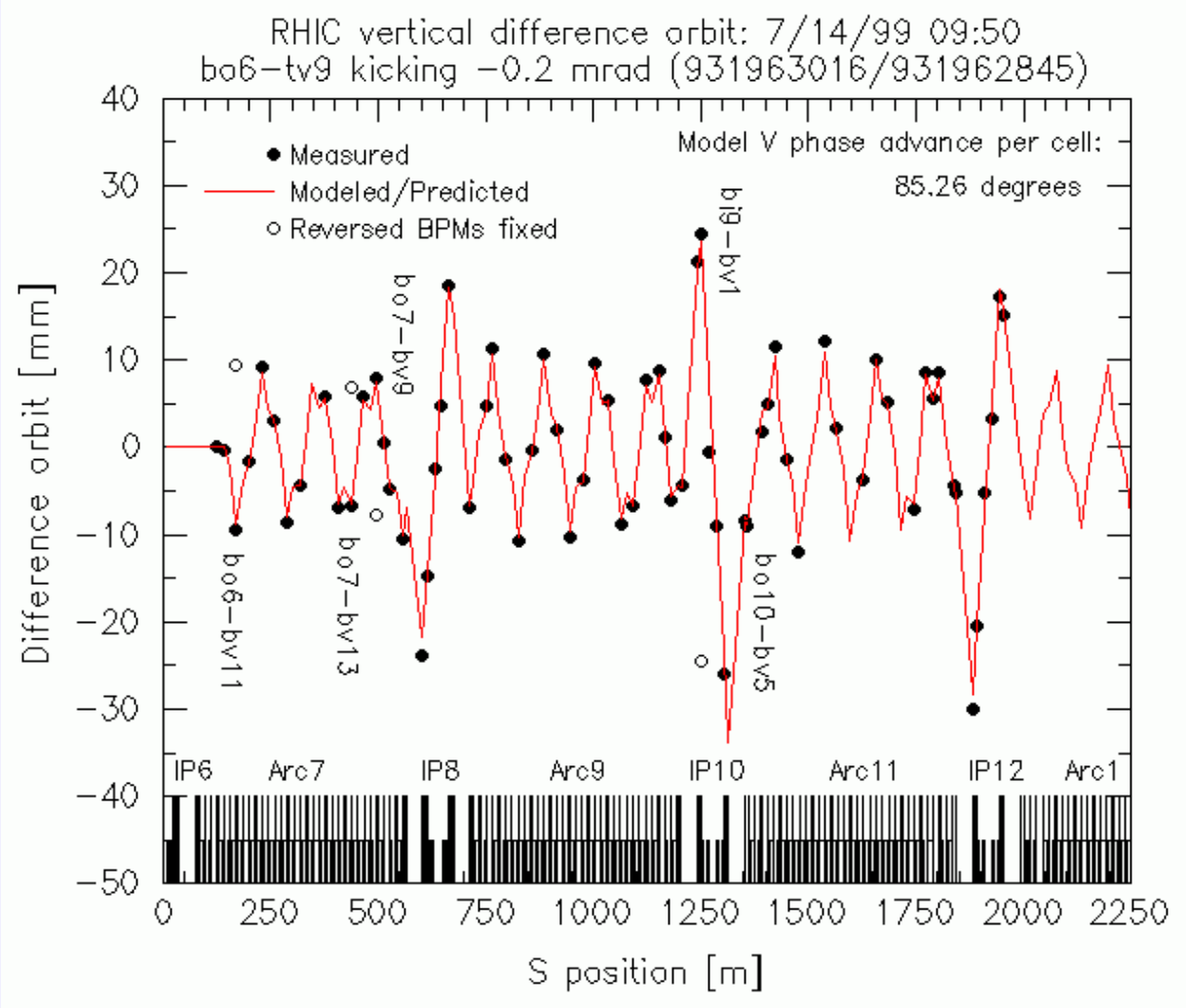
Comparison of

Measured Orbit Deviation from a Small Vertical Kick

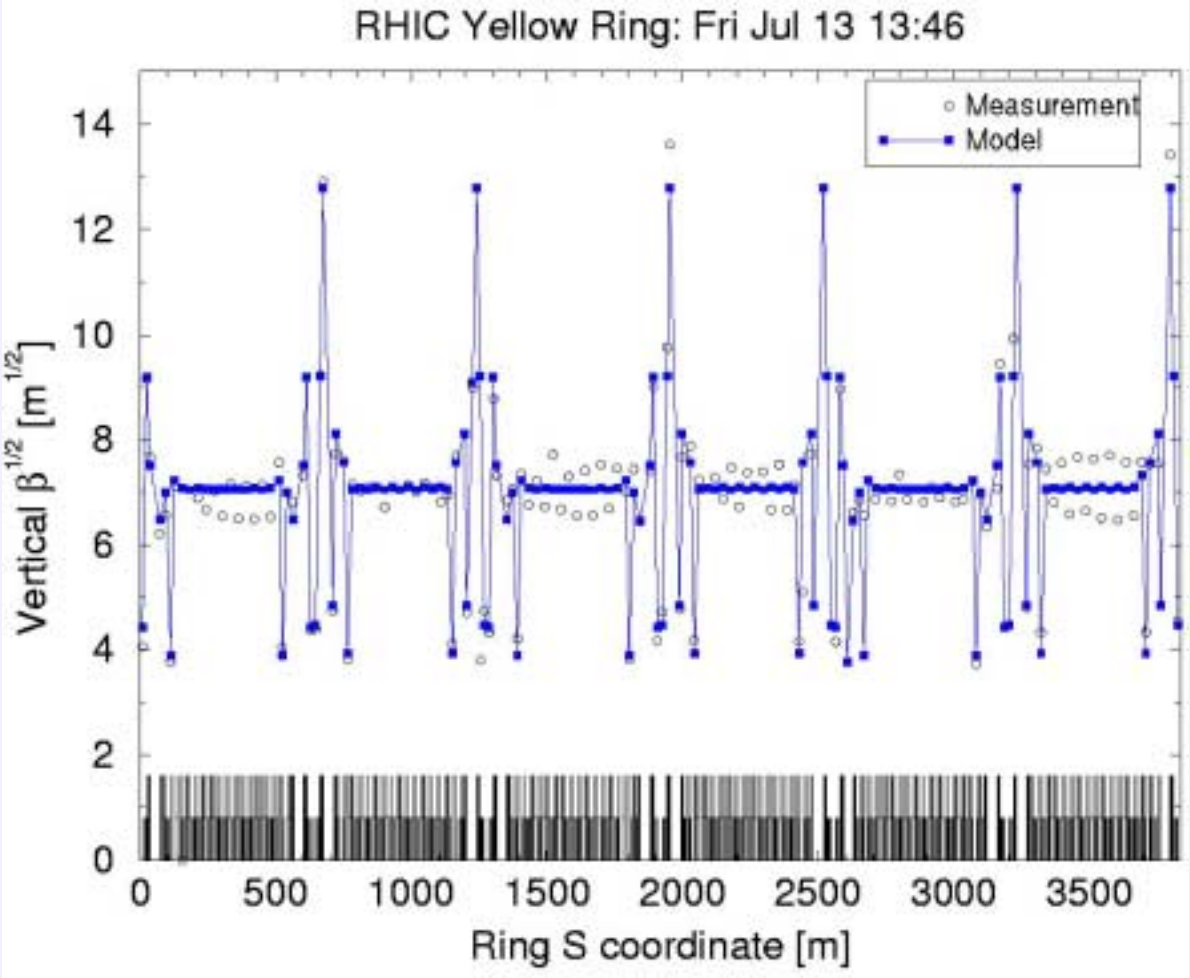
vs.,

Predicted Deviation Based on the Design Optics

Excellent agreement



RHIC - machine optics/beta functions



Beta functions are the closed solutions to the ensemble of quadrupole focussing strengths (effectively the relative beam sizes at the various locations)

Blue lines are the model, open circles are the measurements

1000 point turn by turn at each position monitor

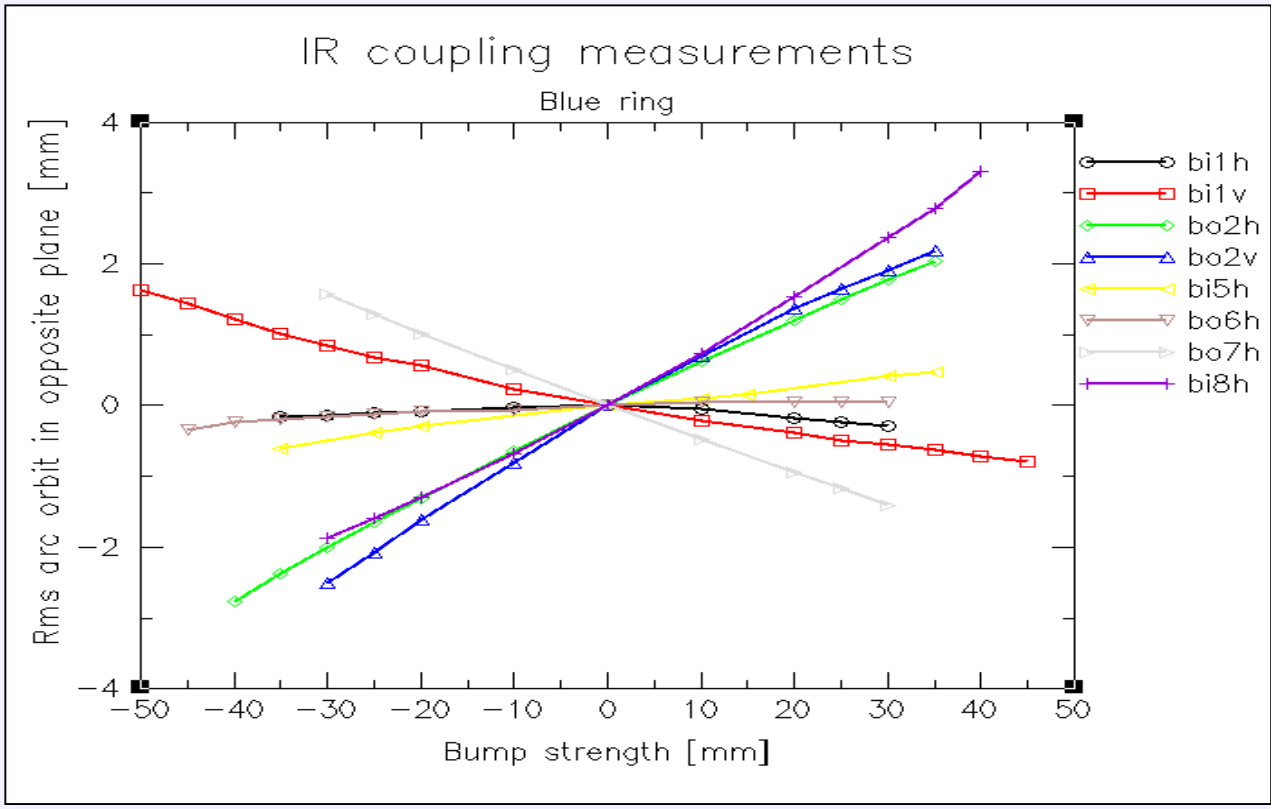
Machine model and RHIC agree very well. (~ 5%)

RHIC - machine optics/coupling

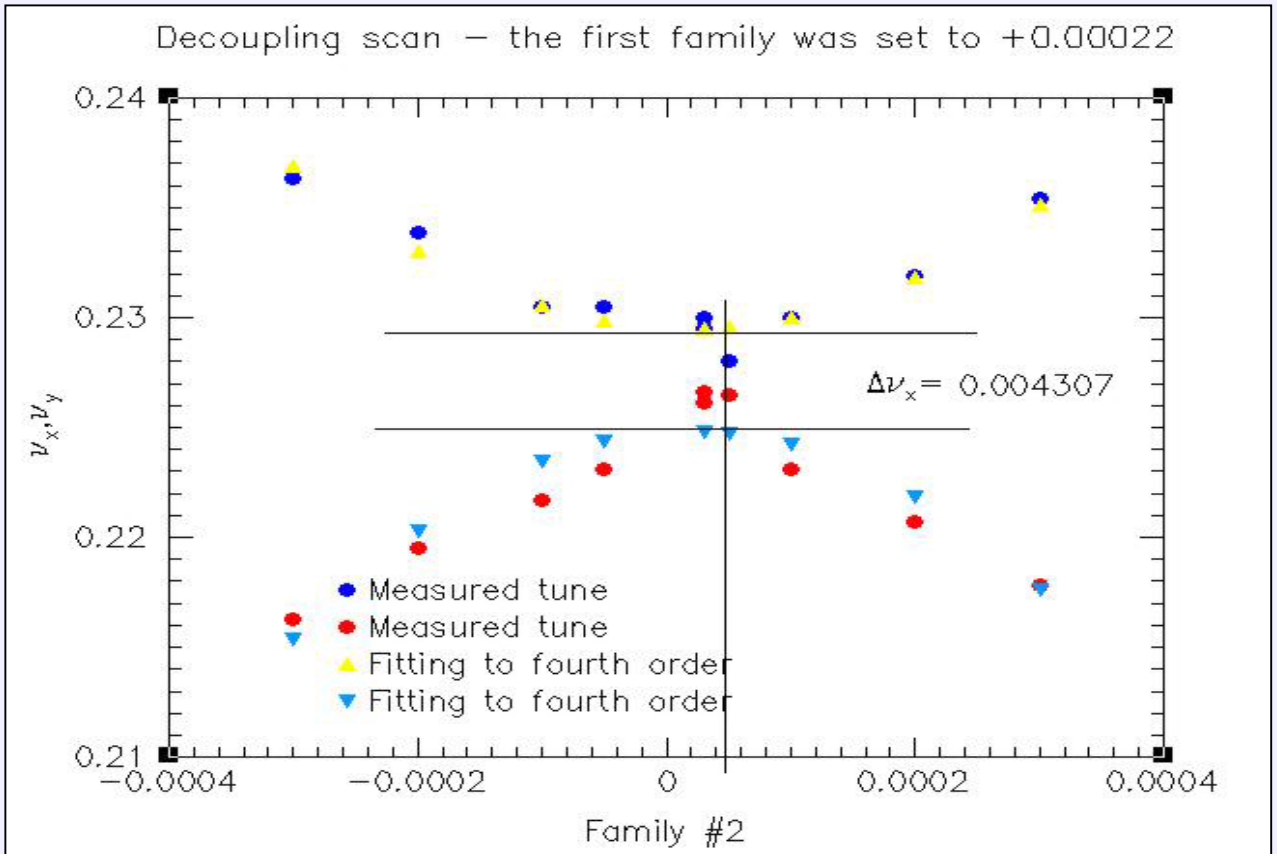
- Coupling is the 'mixing' of horizontal and vertical planes inside the machine and is determined primarily by the orientation of the quadrupole field.

Large closed horizontal offsets across the IP's and look at residual vertical offsets in the rest of the machine after calculated corrections

Coupling from the triplets agrees quantitatively with predictions (field quality & survey) but not in detail



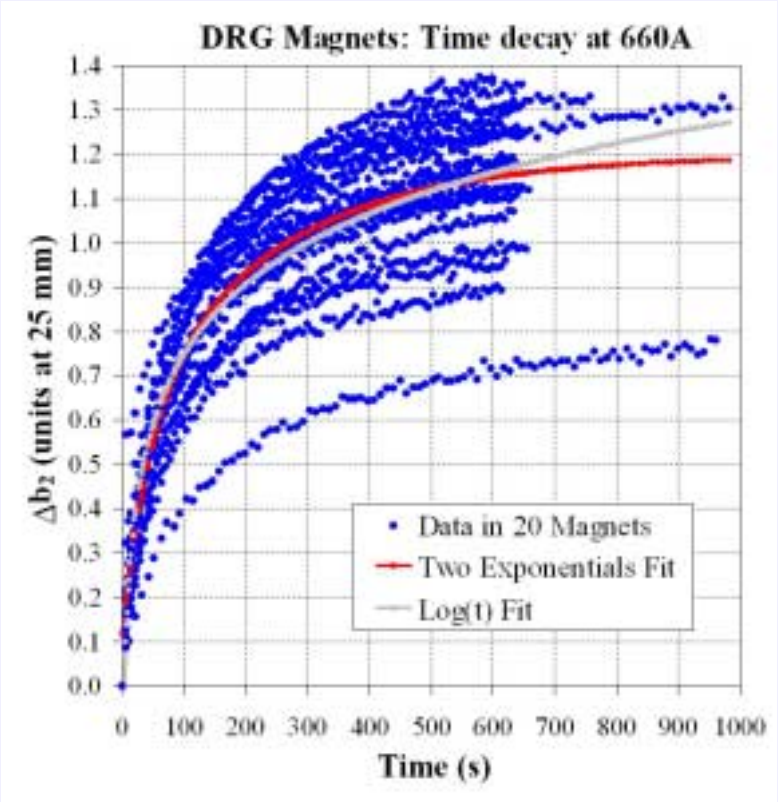
RHIC - machine optics/coupling

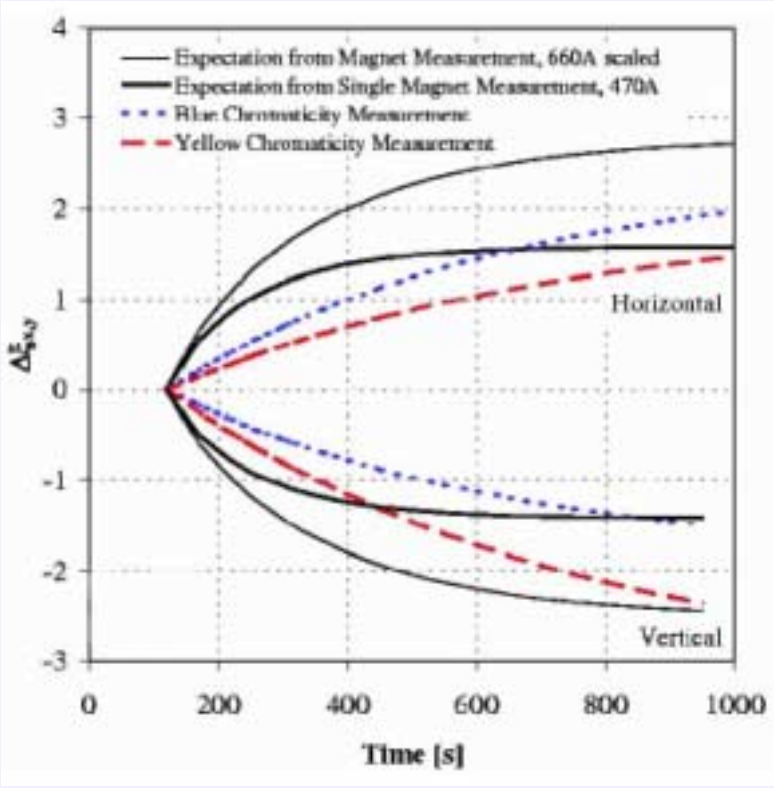


Coupling in the arc sections is measured by looking at minimum tune separation between planes after local compensation of the IP's.

Measured coupling in the arcs agrees well with the predictions

RHIC - Dynamic effects/persistent currents





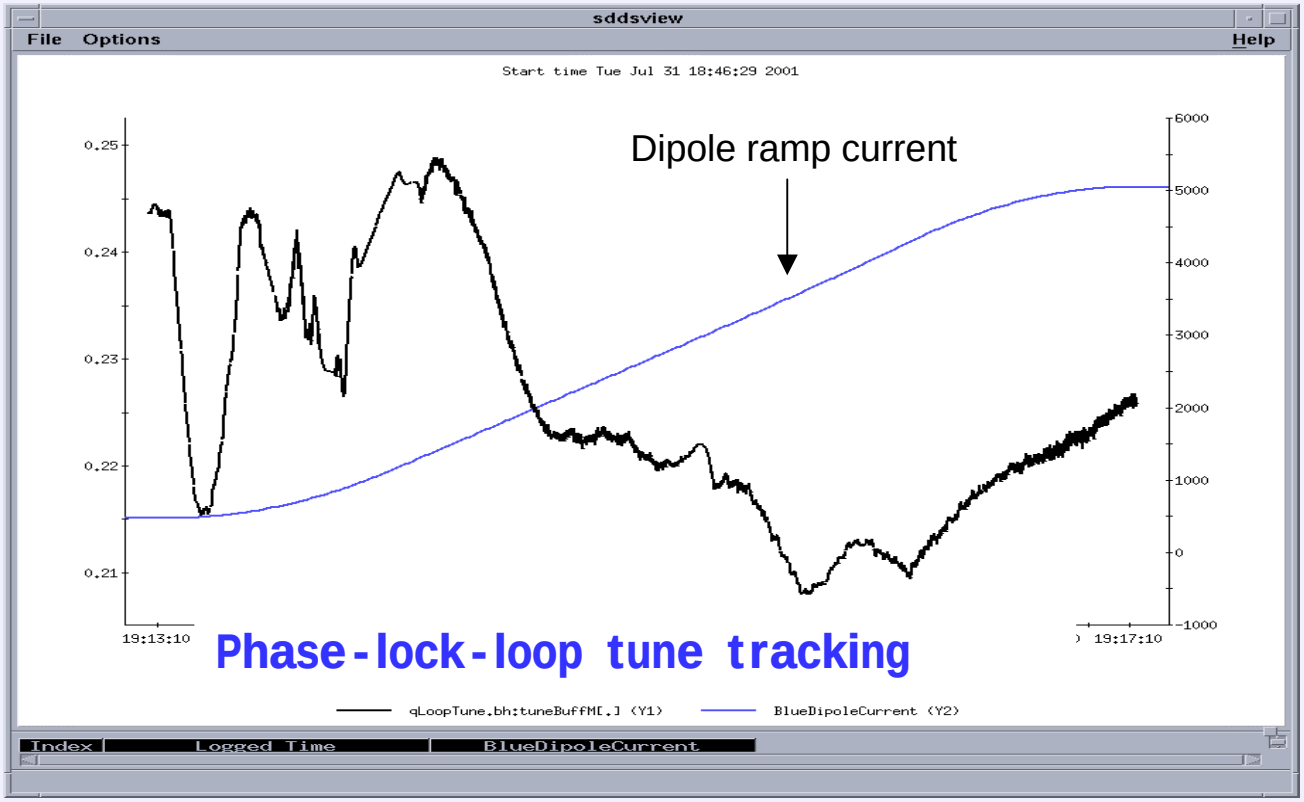
Measured and predicted time varying chromaticity.

Qualitative agreement but large magnet to magnet variations preclude accurate projection. Why is the shape different ?

LHC must do better than this

RHIC - Dynamic effects/quad focusing

Blue Horizontal Tune (effectively the ratio between integrated quad and dipole fields) stable to 1 in 10^4. Not good enough !



Maintaining ~60 quad circuits (single elements & strings) in synchronism during dynamic processes (acceleration or lo-beta squeeze) can be difficult. More of a power converter issue than a magnet one

RHIC - Operating Experience

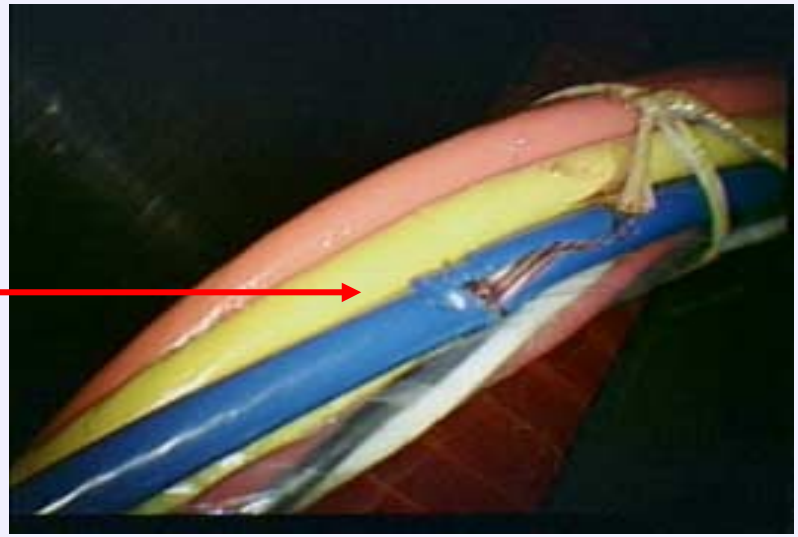
Operating experience with the magnet system to date has been good. After the initial engineering run shakedown there has been no major magnet failure (electrical or mechanical)

The magnets are essentially cryostable at injection energies but will (and have) quench at top energies. No damage during quenches.

There has been a small number of voltage taps opened up.

One shorted cable in a low current bundle.

One failed pulsed quadrupole which has been removed(with it's twin) from the circuit.



Magnet Performance & RHIC Commissioning - Conclusions

- 'Individual' magnet performance has been as expected e.g. quench.
- 'Ensemble' magnet performance as expected in the arcs but not as good agreement in the IP's (it would appear we understand magnets better than cryostats !).
- Complete cold testing did not prove necessary on the high volume elements
- Magnet reliability has been good to date