Measurements as a Tool to Monitor Magnet Production

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Introduction

- The primary goal of magnetic measurements is to provide the data necessary for smooth operation of accelerators, or for accurate analysis of data from detectors. (***Need based measurements***)
- Field quality is very sensitive to small changes in conductor placement and material properties. This makes magnetic measurements an excellent tool to monitor magnet production.
- Warm measurements, carried out in the early stages of production, can be particularly beneficial in providing a timely feedback.

Examples

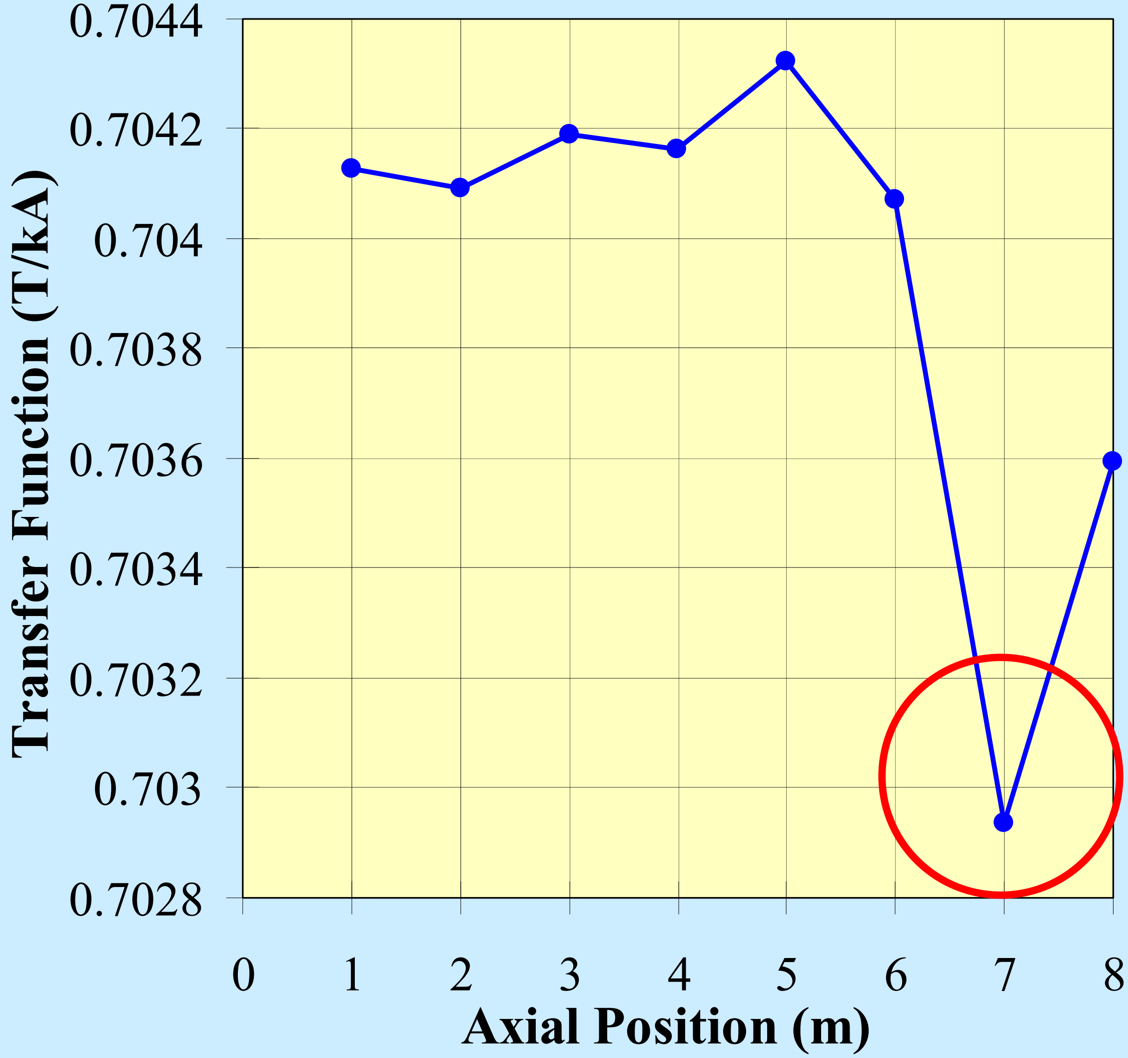
- Nearly all large scale magnet productions have several instances where magnetic measurements have indicated a problem with the production.
- The problems could vary over a wide range, e.g.
  - ***Parts that are slightly out of tolerance***
  - ***Material with undesirable magnetic properties***
  - ***Incorrect or missing parts***
  - ***Electrical shorts***
- With a timely feedback, one can prevent use of defective magnets in complex assemblies, or minimize affected magnets in a large production.

Role of Data Analysis

- Some problems cause a drastic change in field quality, and are hard to miss.
- Some problems may be more subtle (e.g. a slow trend in the dimension of parts) and may require attention to detail.
- Some localized problems in a long magnet, even if drastic, may not show up in the integral field quality. Local variations must be studied.
- In all cases, once a problem is confirmed, it is important to provide useful clues as to what may possibly be wrong. This is not always easy.

Dipole Example from RHIC

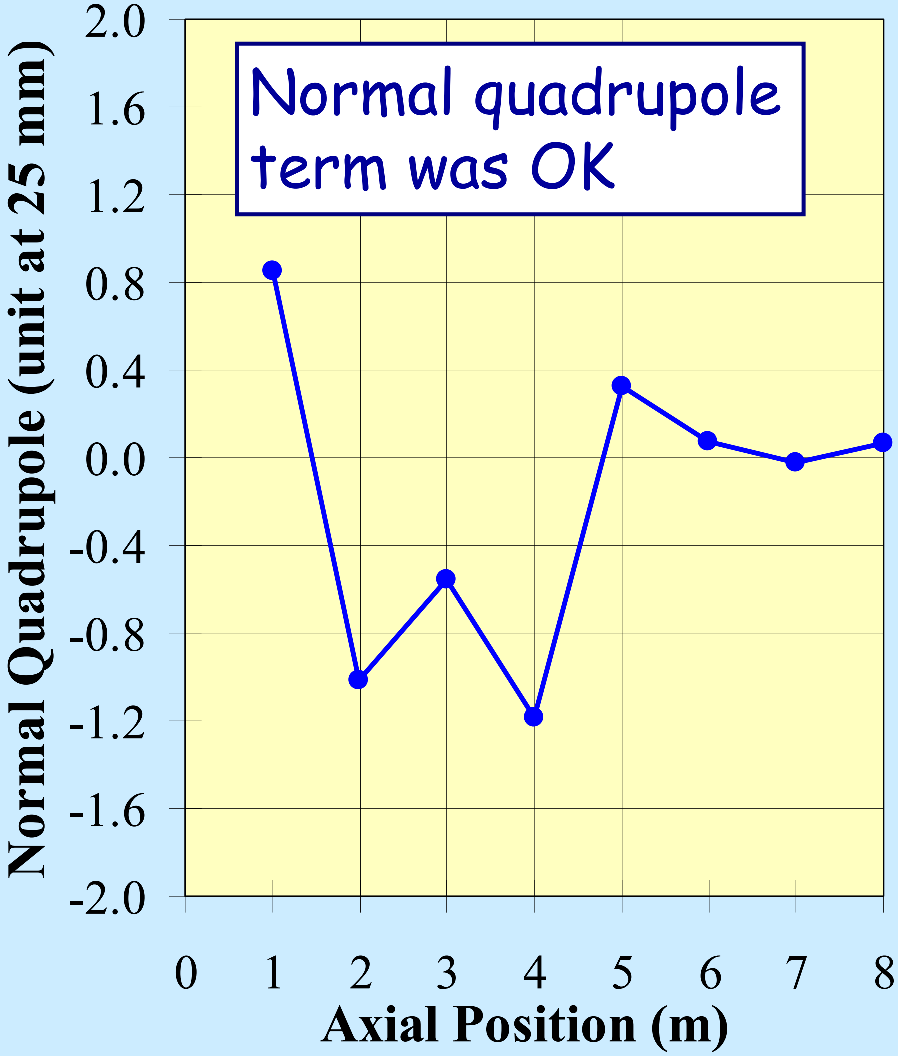
Dipole No. 149 (DRG189): Axial scan with 1 m long mole in 1 m steps

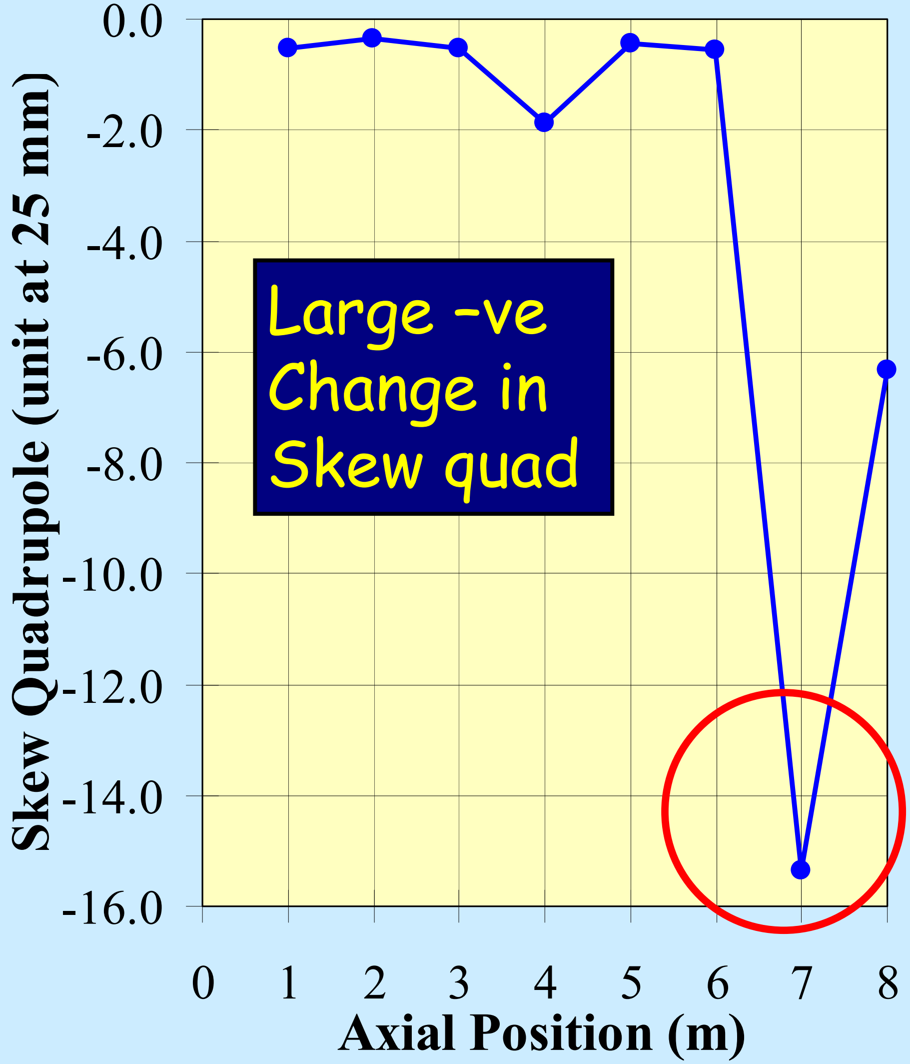


Warm meas. at the vendor's site showed an unusual drop in transfer function (0.18%) at one location.

Dipole Example from RHIC

Dipole No. 149 (DRG189): Axial scan with 1 m long mole in 1 m steps





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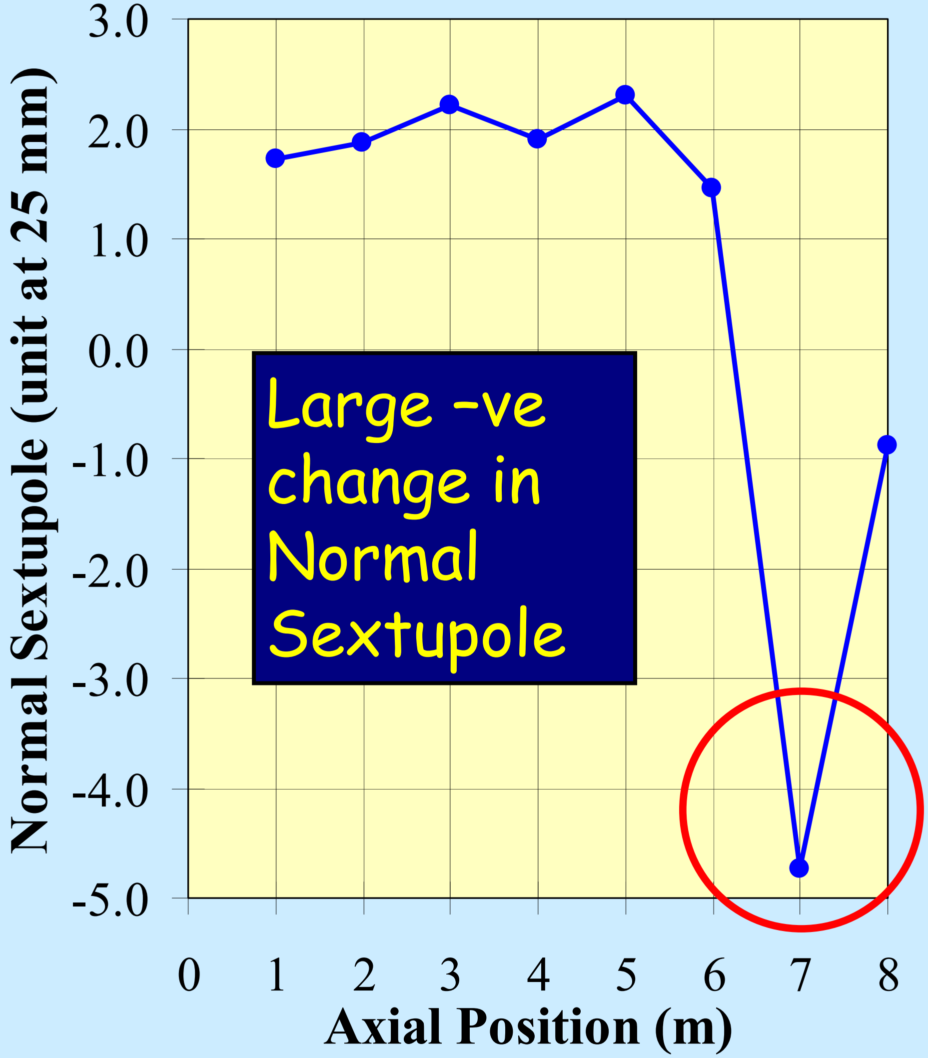

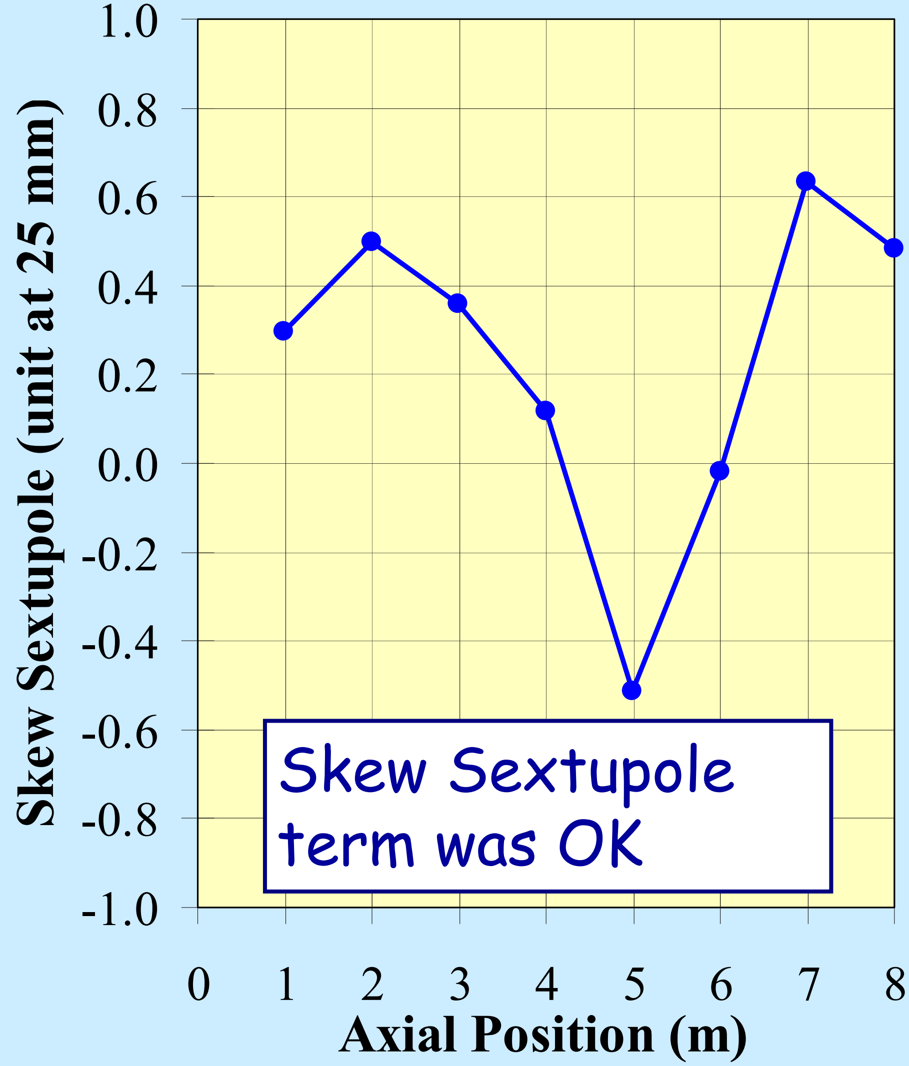

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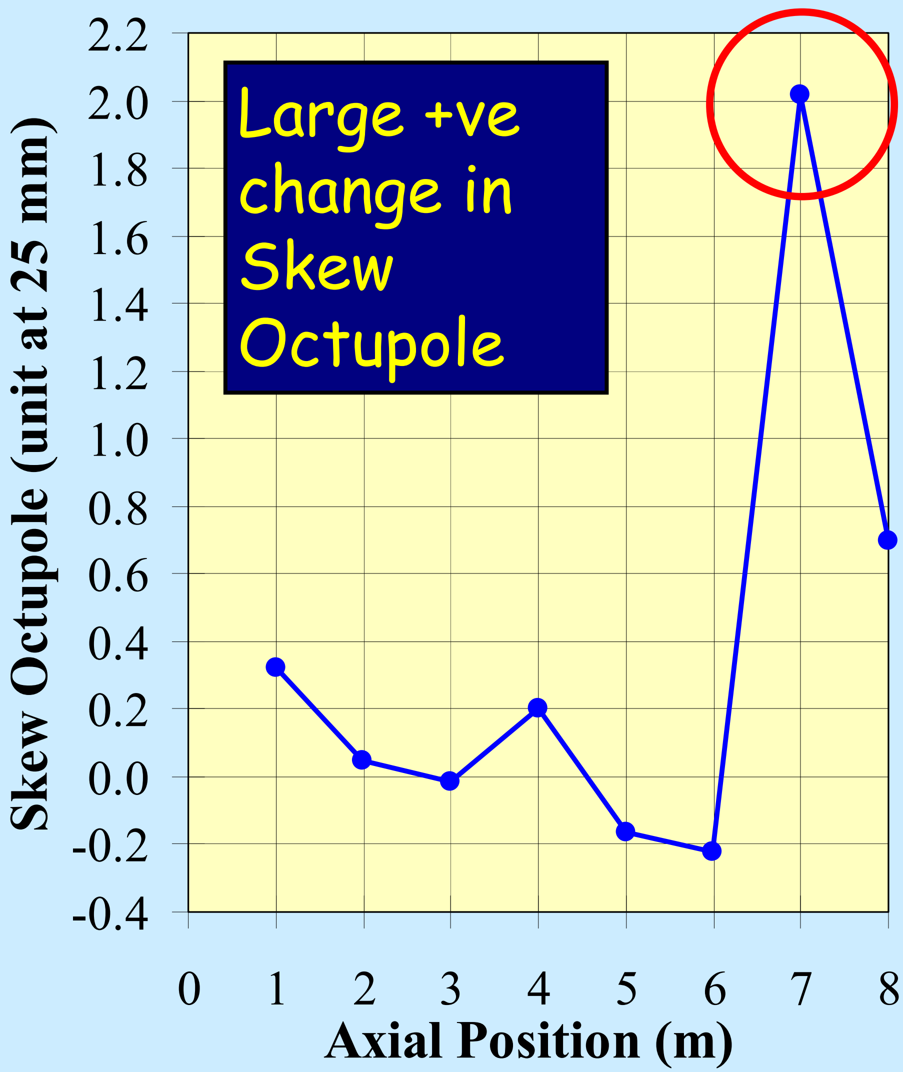
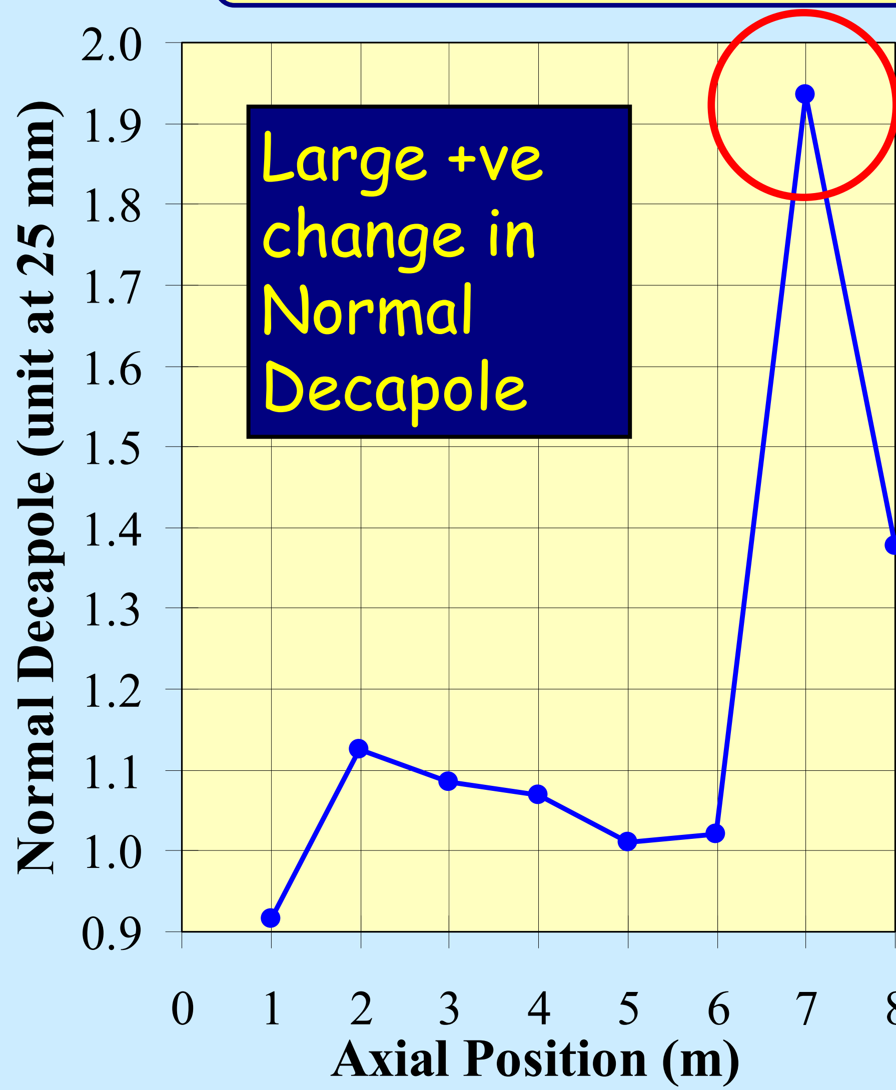


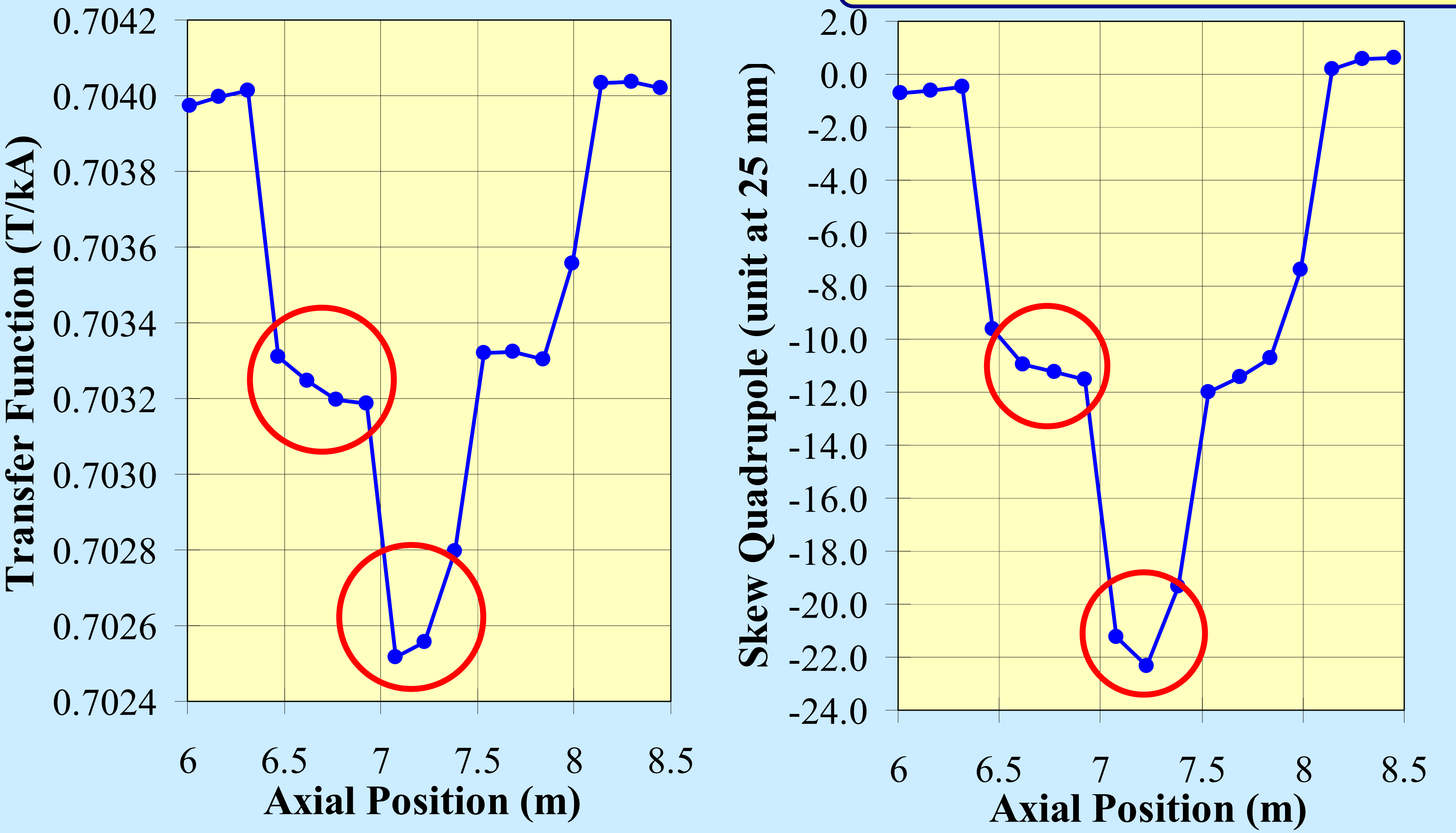


Dipole Example from RHIC

- The unusual changes in transfer function, and several harmonics, indicated a definite problem with the construction of the magnet.
- Only even skew and odd normal harmonics were affected. Even normal and odd skew terms were unaffected.
- Left-right anti-symmetry was preserved, but top-bottom symmetry was not preserved.
- Changes in the signs of harmonics indicated that the problem is closer to the pole, than midplane.

Dipole Example from RHIC

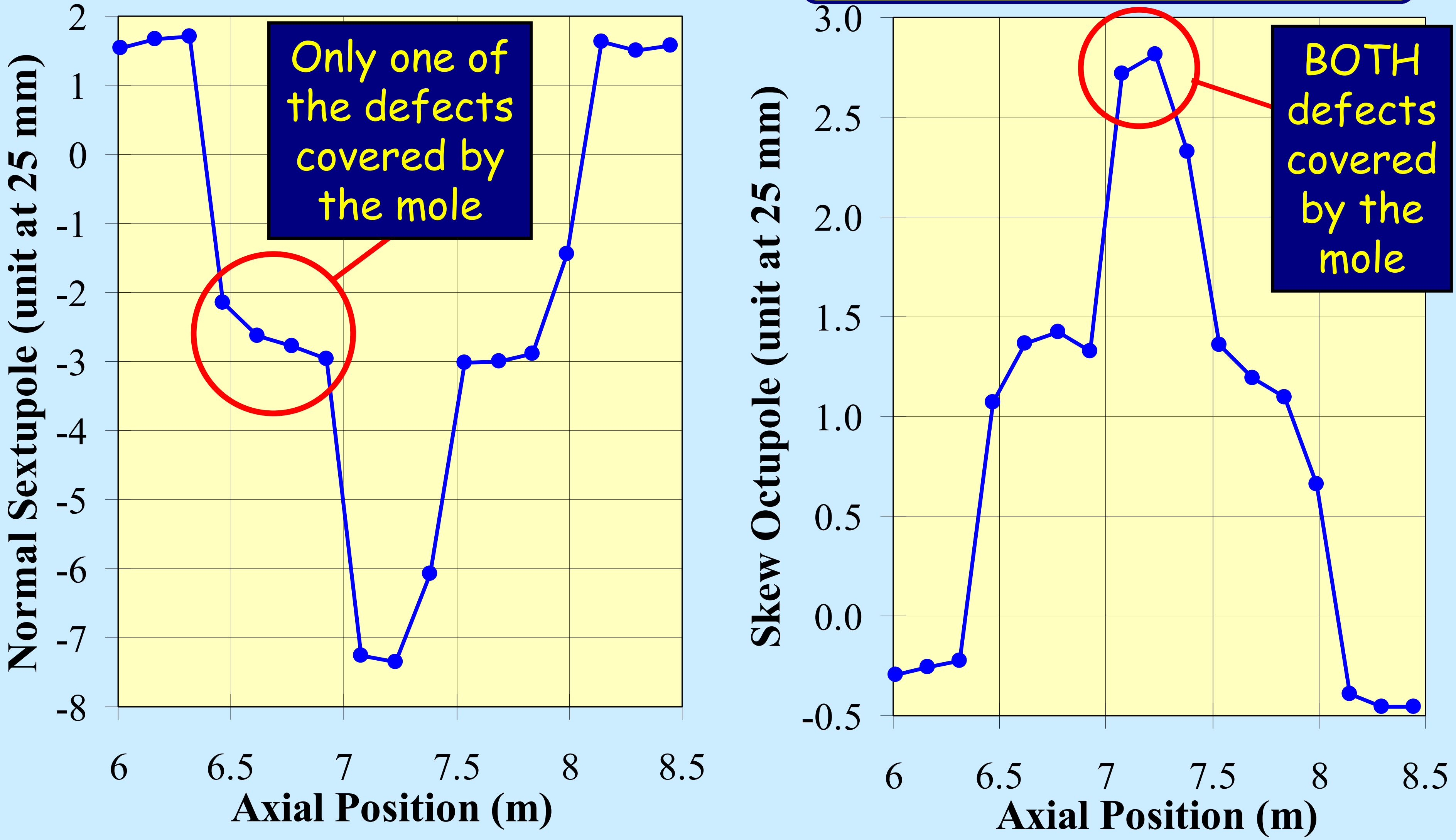
Dipole No. 149 (DRG189): Scan with 1 m long mole in 0.15 m steps



A finer scan indicated TWO similar defects !

Dipole Example from RHIC

Dipole No. 149 (DRG189): Scan with 1 m long mole in 0.15 m steps



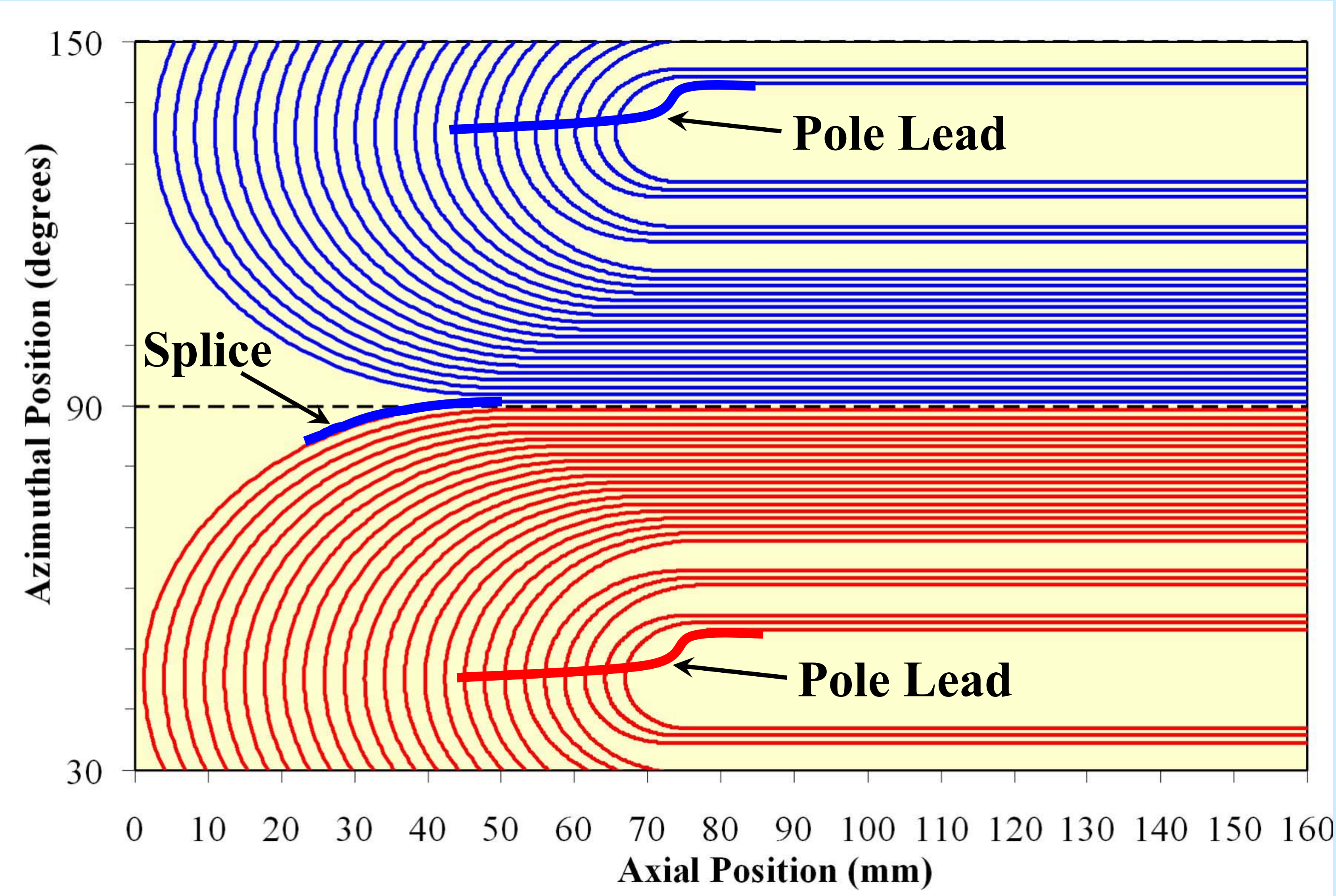
Dipole Example: Summary

- The nature of harmonics indicated that the coil turns near the upper pole have moved symmetrically towards the vertical axis.
- There were two defect regions, each about 0.15m long.
- RHIC dipoles use 0.15 m long RX630 pole spacers between coil and yoke. The end section spacers are different from the straight section.
- The end type of spacers were inadvertently used in the straight section. This was verified later.

Shorts in a Multilayer Magnet

- BNL has recently built several multilayer magnets for the HERA upgrade program at DESY, Hamburg.
- These magnets were fabricated by winding a 1 mm diameter superconducting cable using an automatic winding machine.
- The magnets had several layers of coils with different multipolarities.
- On two occasions, the coil curing process produced electrical shorts.

Splice Between "Sub-coils"



Electrical Short in QH0103

- Large changes in the harmonics were observed in the main quadrupole of the magnet QH0103 after all the layers were completed.
- Magnetic measurements were NOT carried out after each step. So, it was difficult to judge at what step the problem could have occurred.
- Warm measurements were carried out at 0.25A on individual layers using the voltage taps as current leads.
- The measurements indicated a problem with the 2nd quad layer, which was burried under 3 more layers.

Harmonic Changes in QH0103: Q2

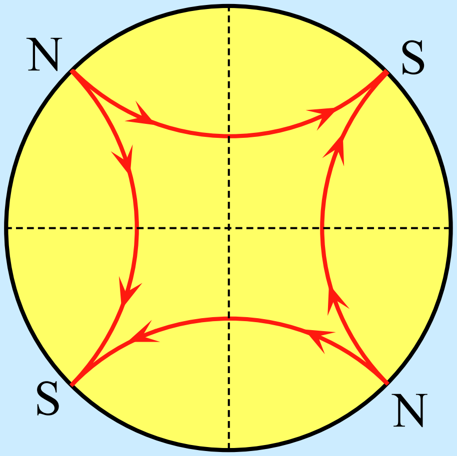
	as wound	final meas.	Change
T.F.(T/m/kA)	8.6534	8.6956	**0.49%**
b3	-2.91	16.47	**19.37**
b4	0.77	1.39	**0.62**
b5	-0.50	-7.82	**-7.32**
b6	-0.98	5.66	**6.64**
b7	-0.19	-2.81	**-2.62**
a3	-1.82	16.71	**18.52**
a4	-4.12	-21.69	**-17.57**
a5	-0.12	7.77	**7.89**
a7	-0.16	-2.64	**-2.47**

⇐ increase was as expected

Selected harmonics in "units" at 31 mm reference radius

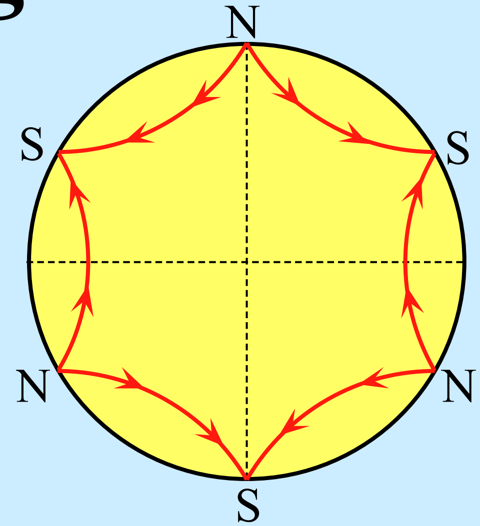
b3 = normal sextupole, and so on.

Determining the Problem Quadrant



Normal Quad

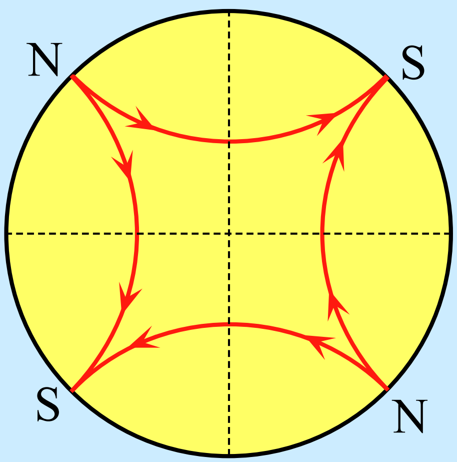
+



+ve Normal Sextupole

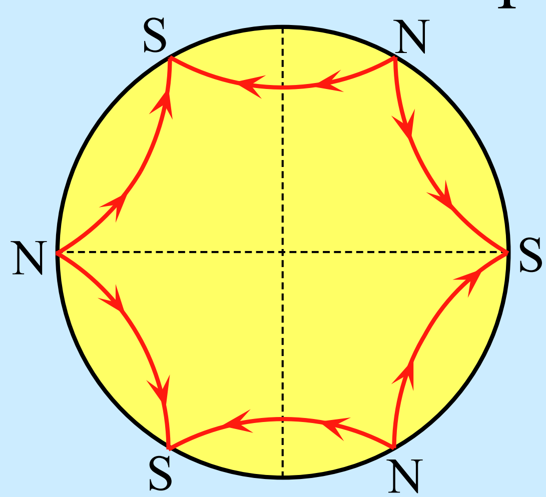
=

Weaker field on LEFT



Normal Quad

+



+ve Skew Sextupole

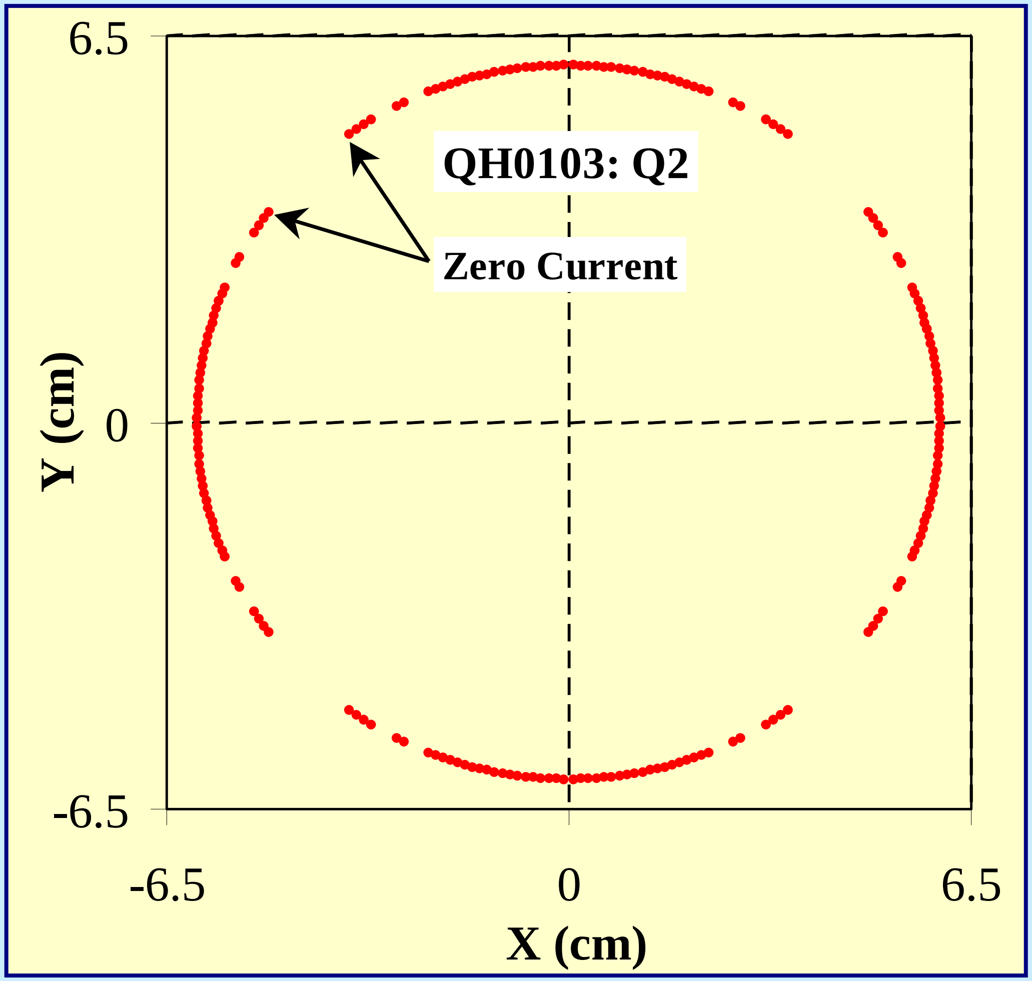
=

Weaker field on TOP

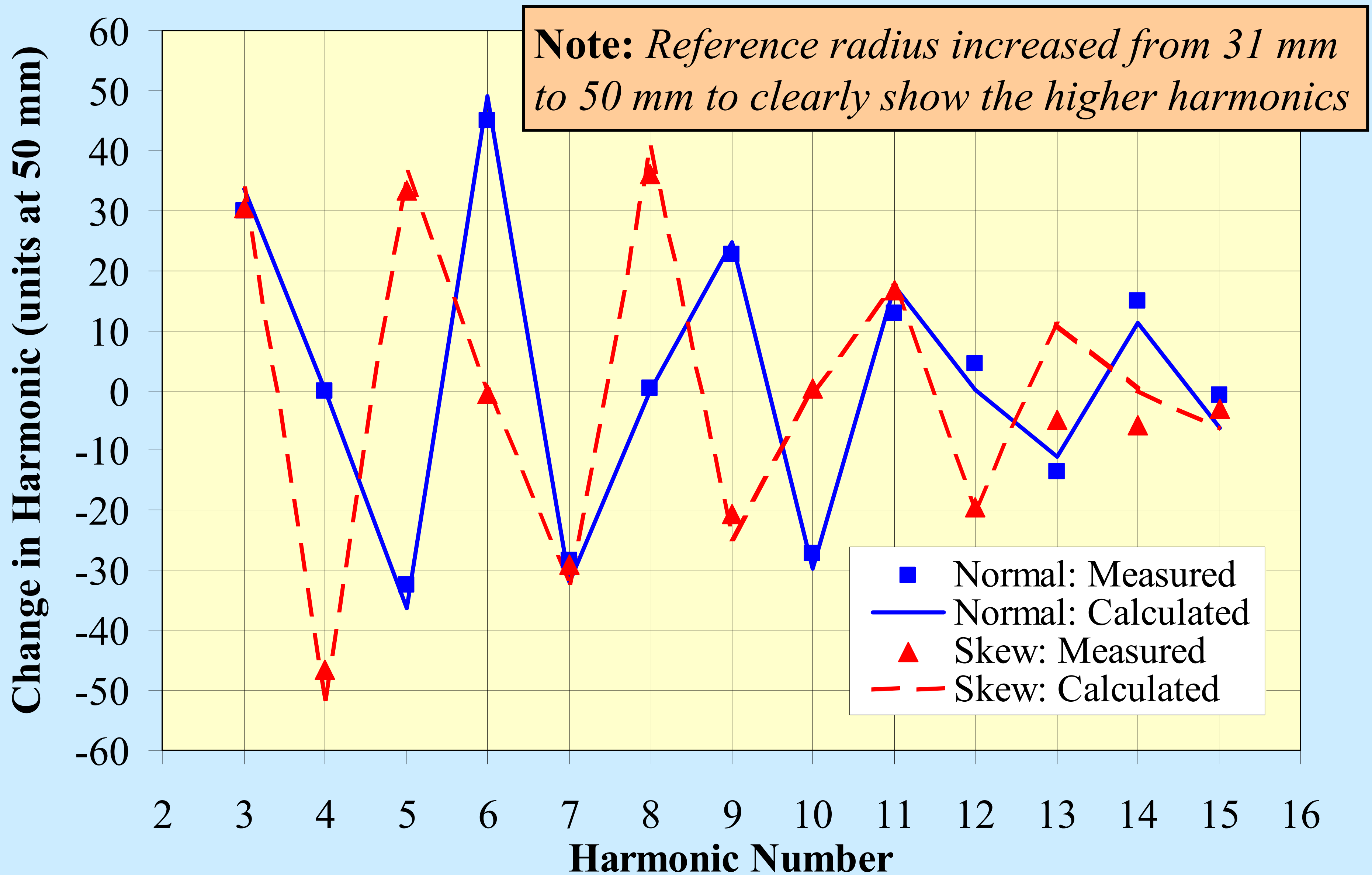
Missing Current in the 2nd Quadrant

Modeling Field Errors in QH0103

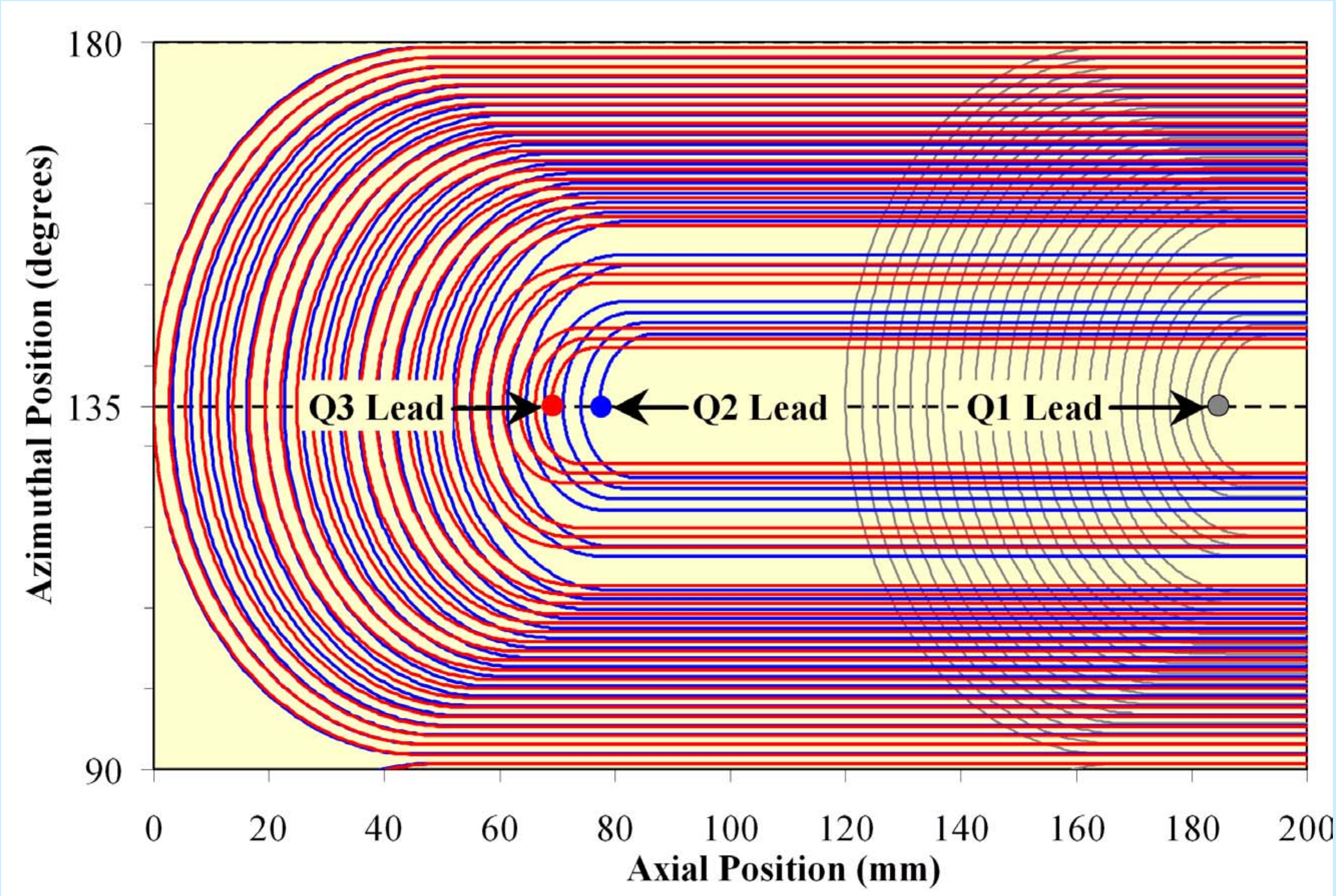
- Most likely area: pole lead in the 2nd quadrant.
- Would bypass current from the pole-most turn.



Computed Vs Measured Changes



QH0103: Q1, Q2, Q3 Layers



QH0103: Repair of Q2 Short

Fortunately, it was possible to carefully cut into the S-glass wrap to reach the pole lead of Q2, without affecting other layers. Thus, a repair could be performed without sacrificing any layer.

Conclusions

- Warm measurements have proved to be a very sensitive tool to monitor magnet production.
- Accurate harmonic information, coupled with a model analysis, can provide exact location of defects. This may allow for efficient repairs in some cases.
- Gross errors are often easy to detect and model. Subtle changes may be hard to model.
- One must be careful in interpreting data from long probes. A "deconvolution" of data may be needed to better characterize the defects.