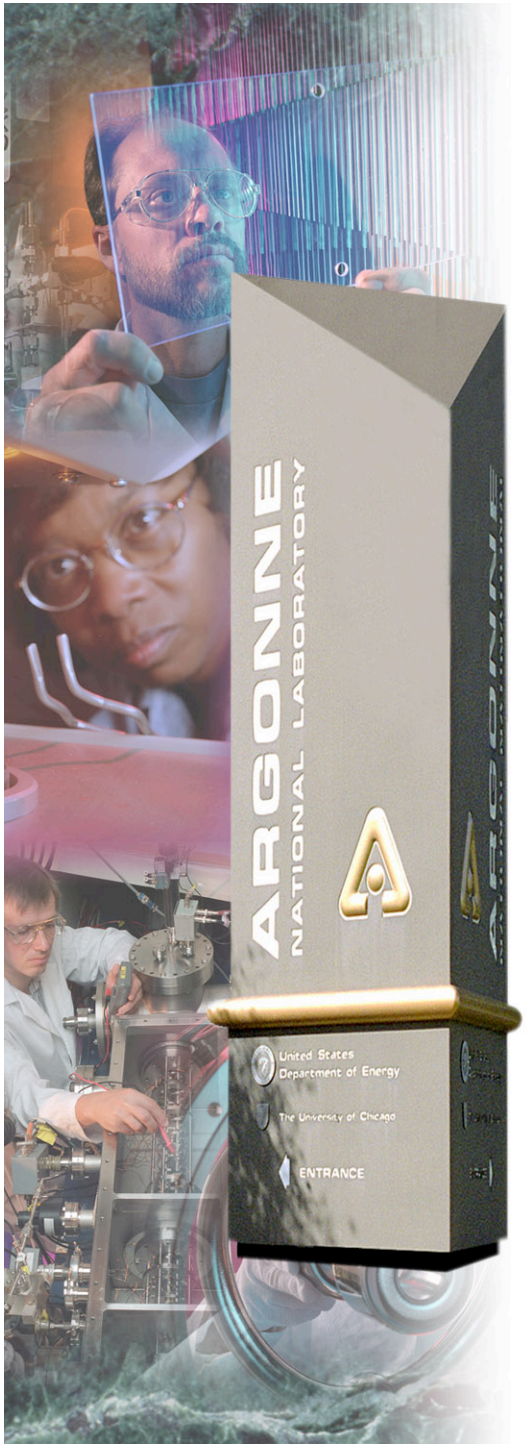

Radiation Damage to Undulators at the APS

Liz Moog

International Workshop on Undulator Systems for Free Electron Lasers (WUS)
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Argonne National Laboratory

Office of Science
U.S. Department of Energy

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Office of Science Laboratory
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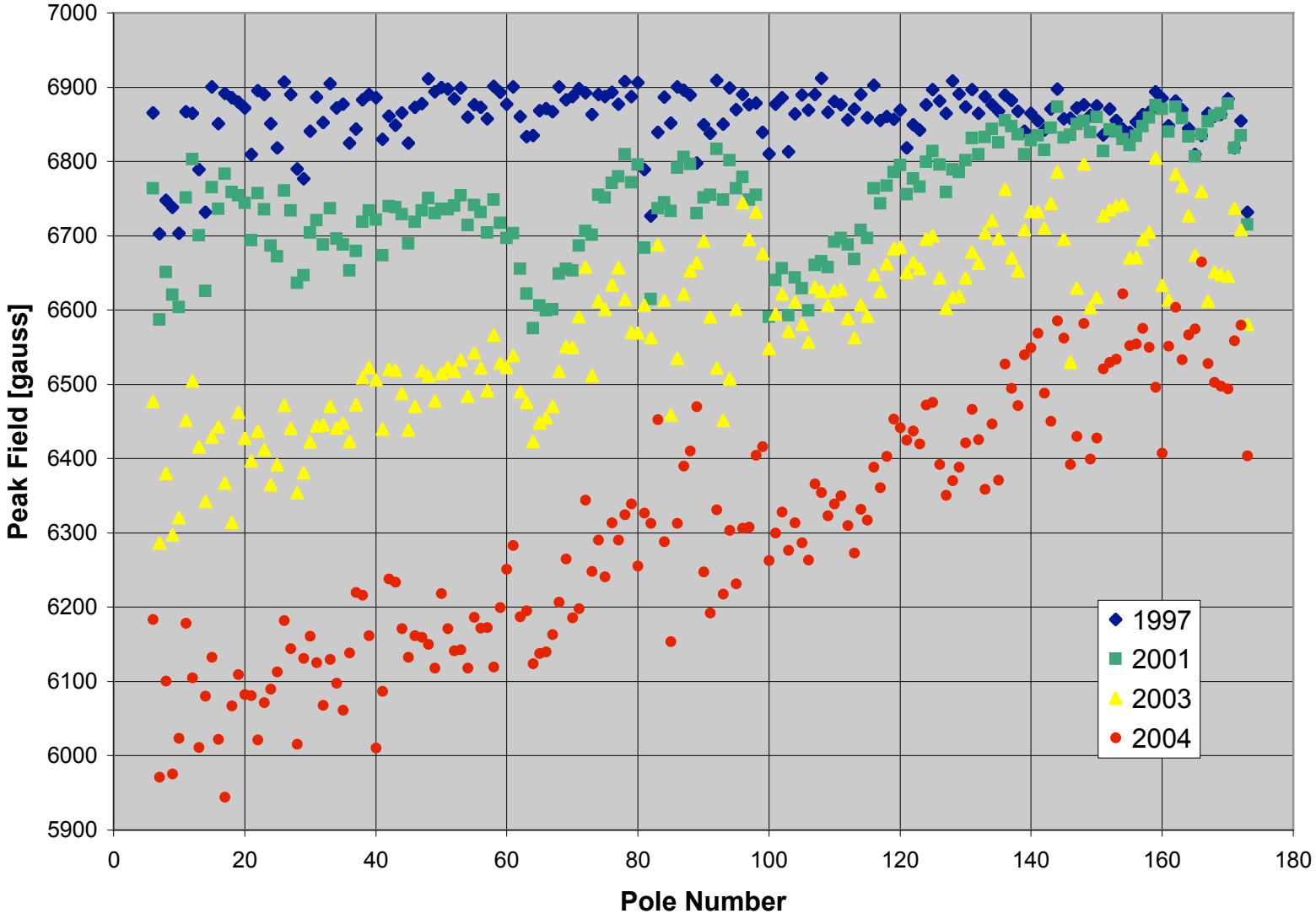
Introduction

- **Two sectors (Sectors 3 and 4) have 5 mm vertical aperture vacuum chambers. (Usual is 8 mm.)**
- **Since top-up began in 2001, undulators in those sectors have been suffering significant radiation damage.**
- **M. Borland and L. Emery determined, through simulations and experiments, that the limiting horizontal inboard aperture in the ring for the topup lattice is in those sectors.**

I will discuss the damage observed, the characterizations of it that we have done, and how we are dealing with the damage.

Damage sequence in downstream ID, Sector 3

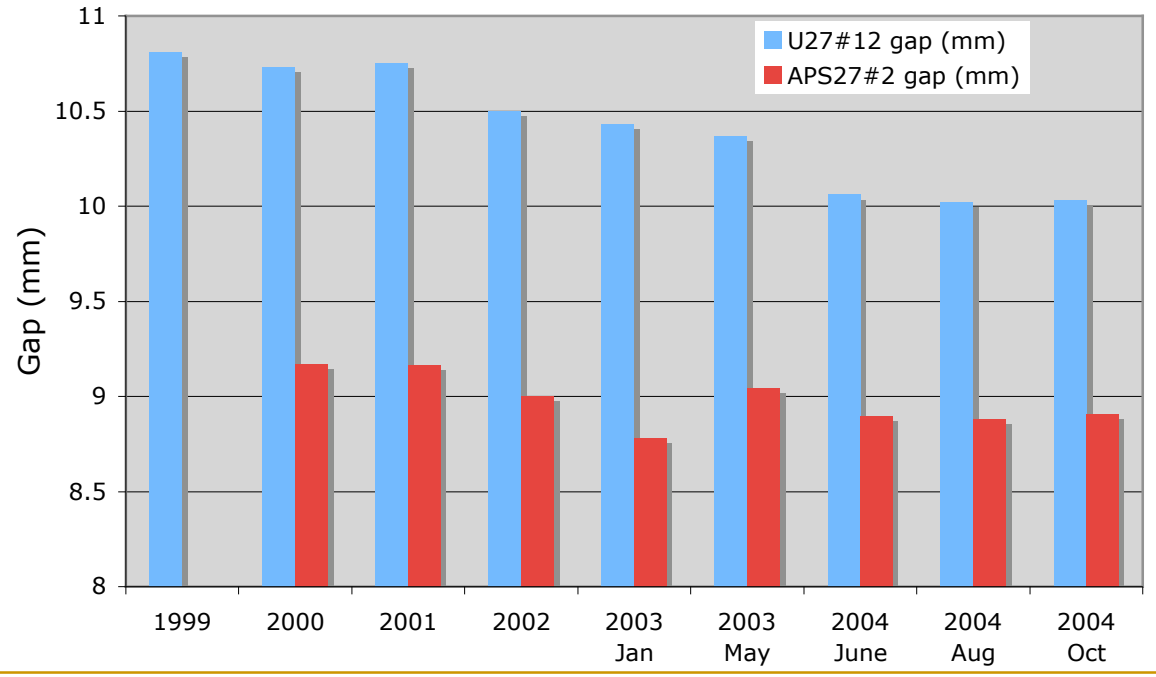


Keeping the users in business

- **A large part of the damage can be compensated by introducing a mechanical taper into the undulator.**
- **As the damage increases during a run, the users adjust the mechanical taper to restore the beam intensity.**
- **During shutdowns, I. Vasserman and S. Sasaki have performed additional tuning.**

Sector 3: Gap vs. time for 21.657 keV light

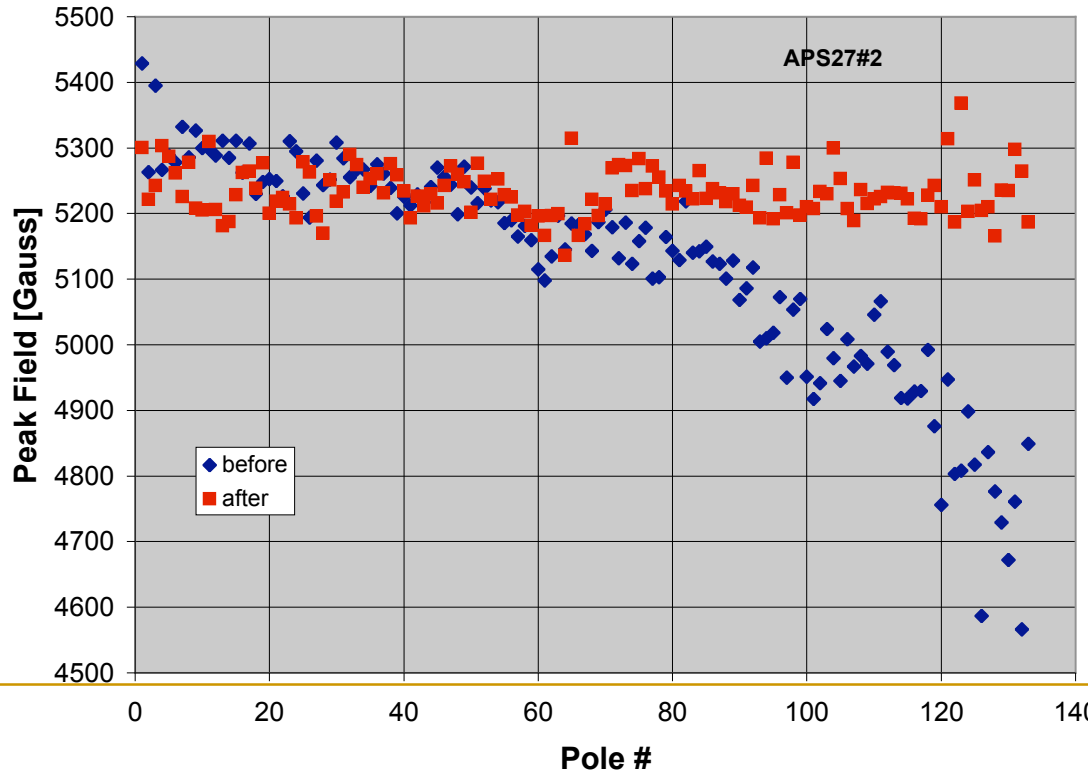
Year	U27#12 gap (mm)	APS27#2 gap (mm)	flux (arb.units)
1999	10.81		1.3
2000	10.73	9.173	1.3
2001	10.75	9.164	1.2
2002	10.5	9	1.1
2003 Jan	10.43	8.78	1
2003 May	10.37	9.045	1.3
2004 June	10.06	8.896	1.2
2004 Aug	10.025	8.88	1.2
2004 Oct	10.035	8.91	1.2



First major repair to undulator

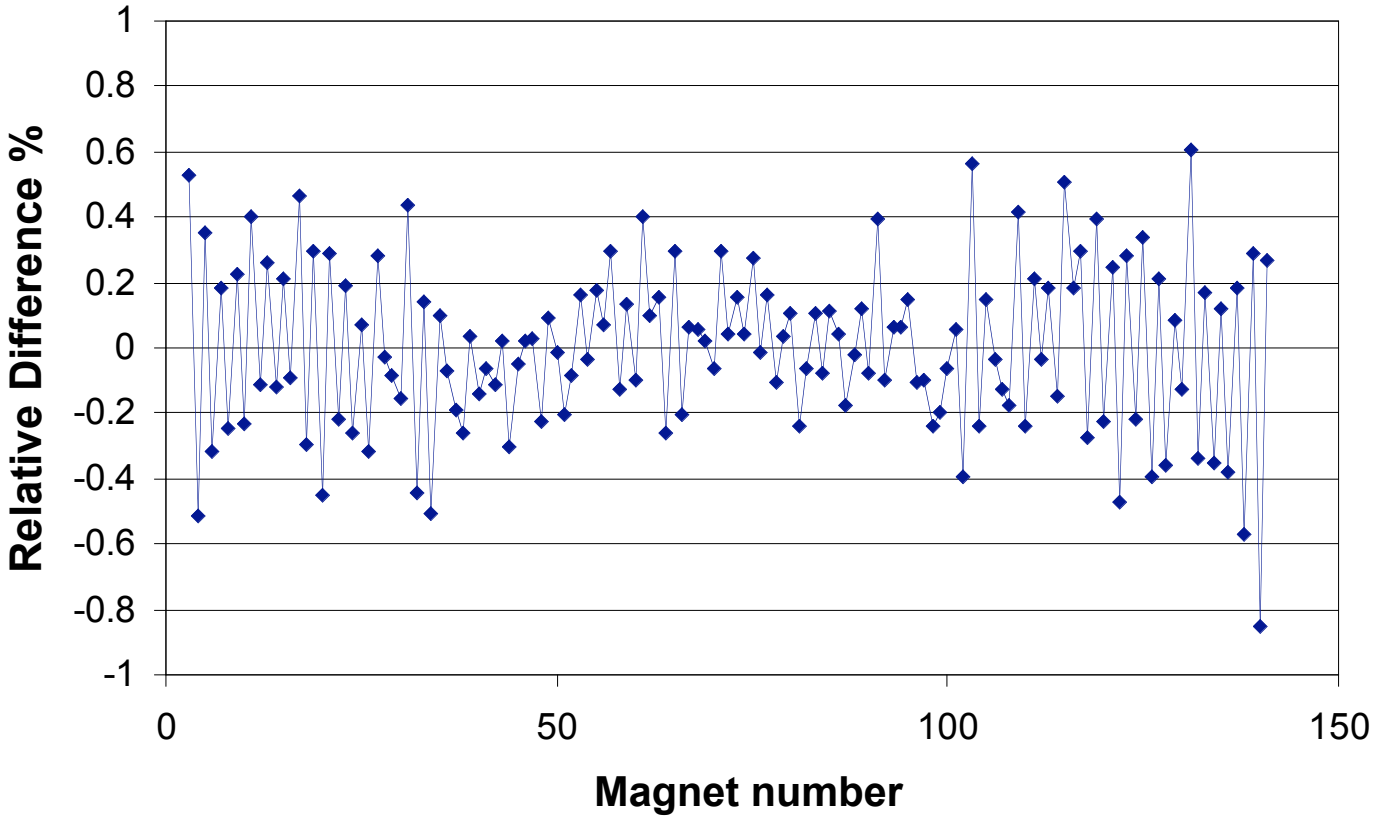
Damage to the upstream Sector 3 undulator reached the point where users could no longer close the gap enough to reach the desired photon energy. The undulator was restored to full operation by:

- Replacing some of the worst magnets with unused spares
- Rotating other magnets to turn the damaged side away from beam
- Standard tuning techniques



Uniformity of remagnetized magnets

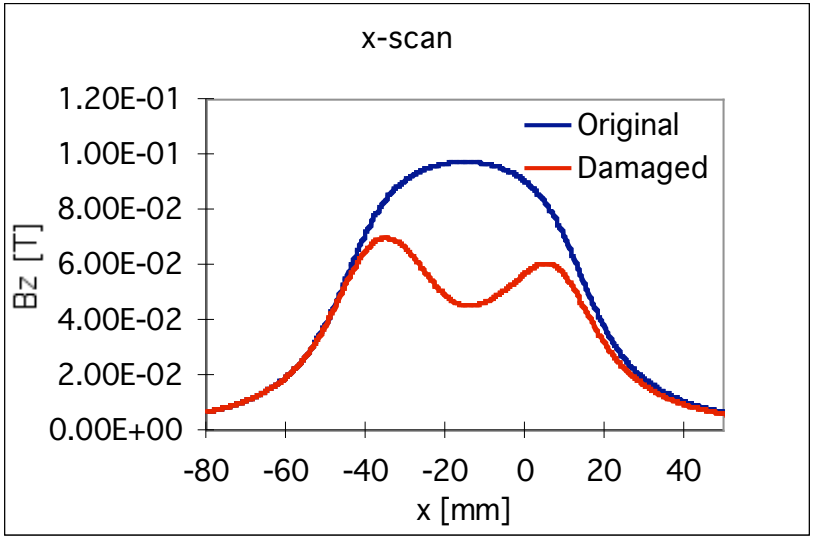
Magnets damaged in Sector 4 undulator were remagnetized. Uniformity of magnetic moment after remagnetization to saturation was very good

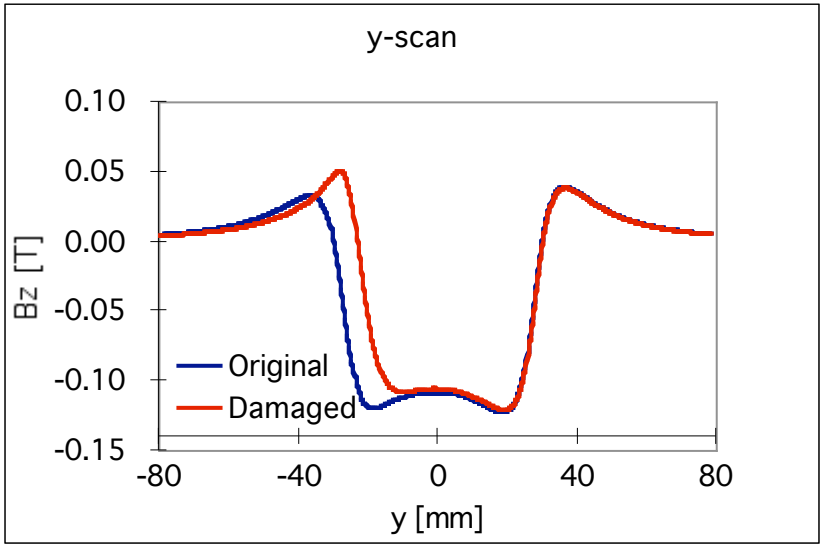


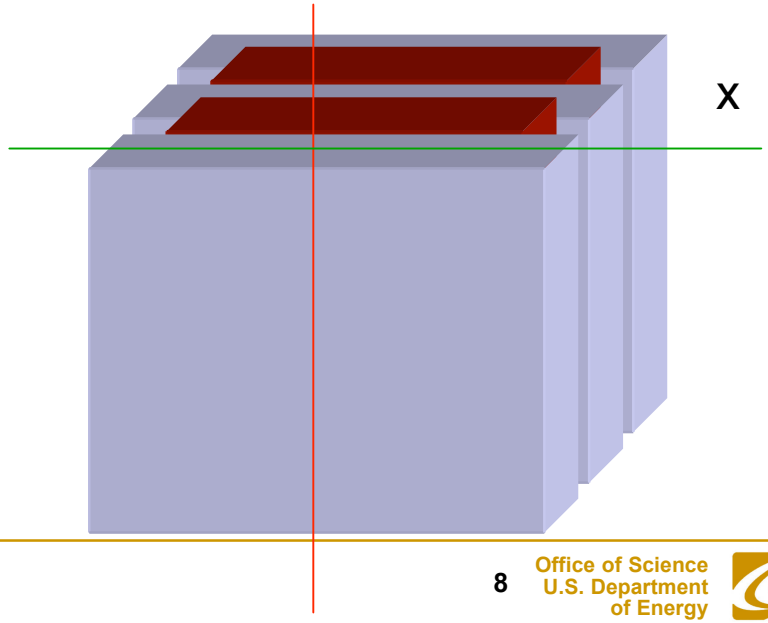
Damage distribution in magnet block

Hall probe scans were made along the surface of the magnet in x and y directions.

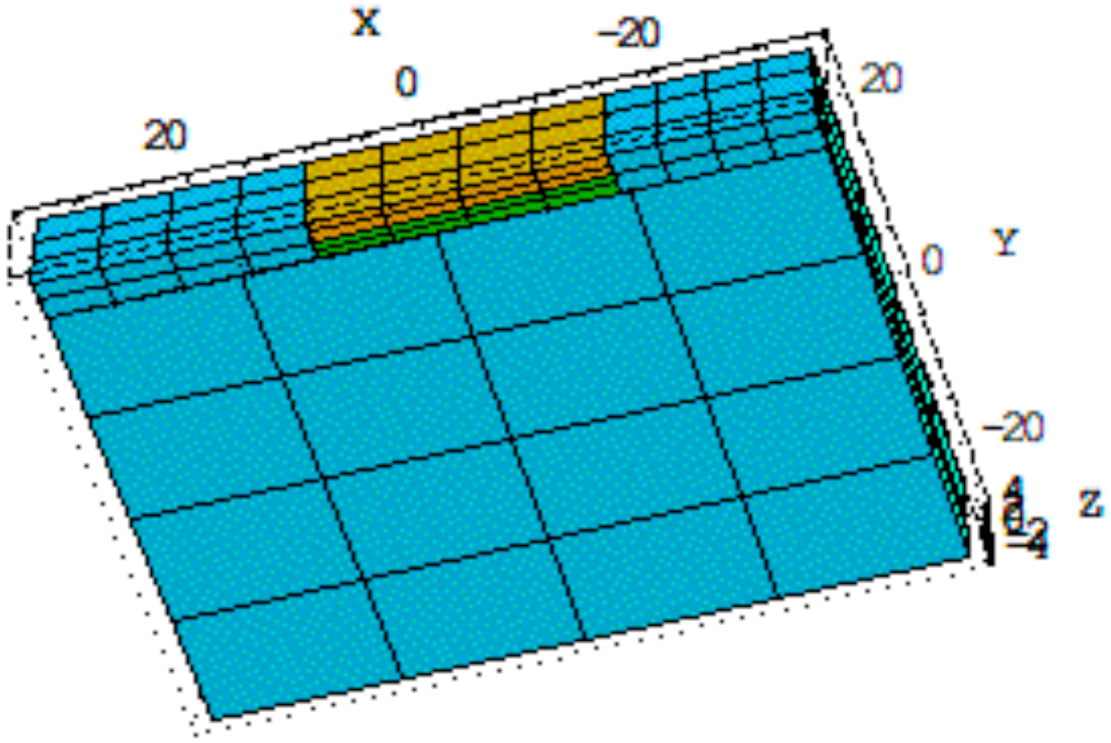
Magnet #6 from upstream end of upstream Sector 3 undulator





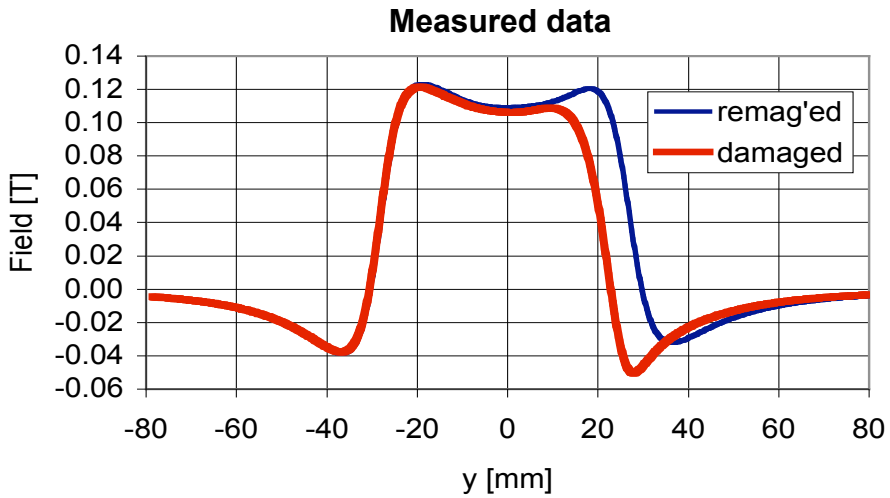


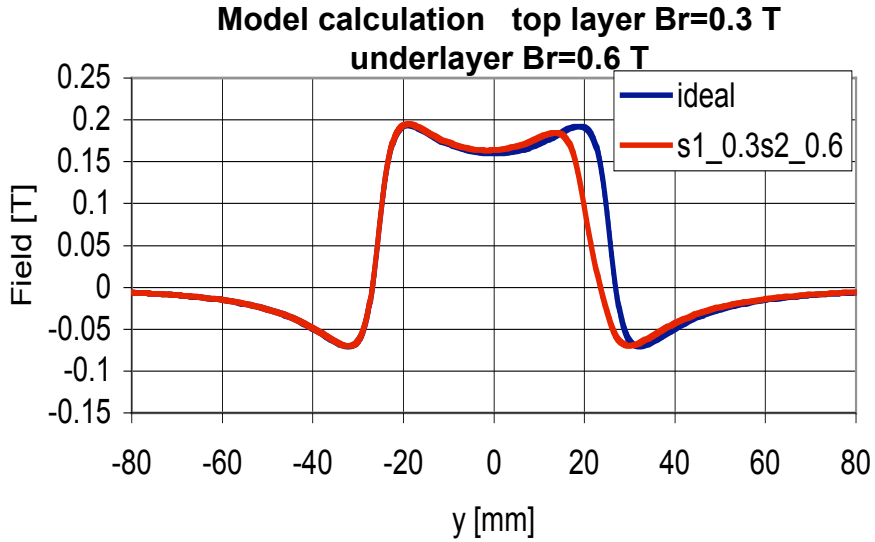
Model for magnet damage calculations

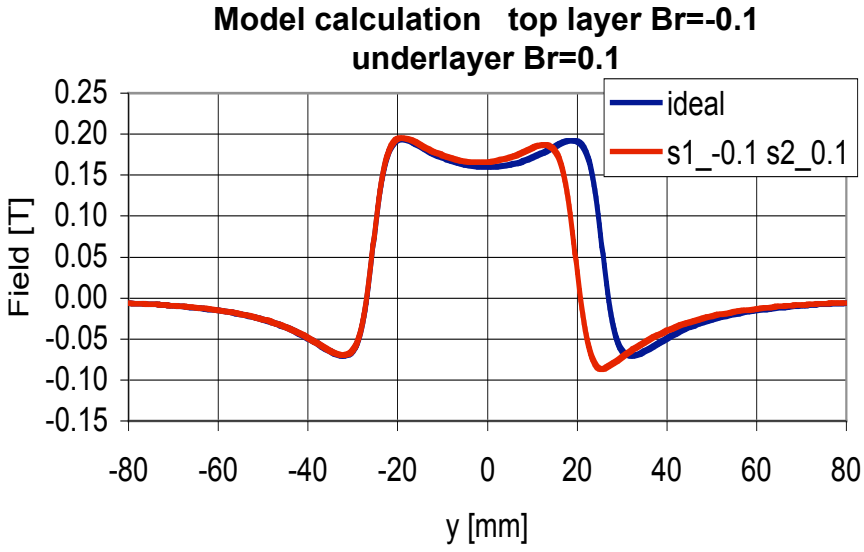


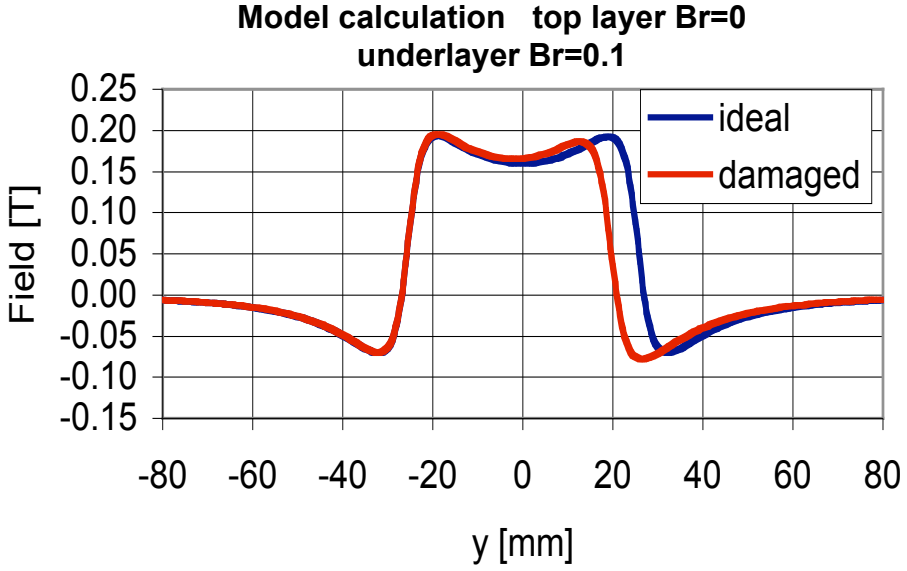
Two regions in the magnet can be set to have a magnetic field strength different than in the body of the magnet, to simulate damage profiles. Each region is 3 mm thick.

Models with different parameters



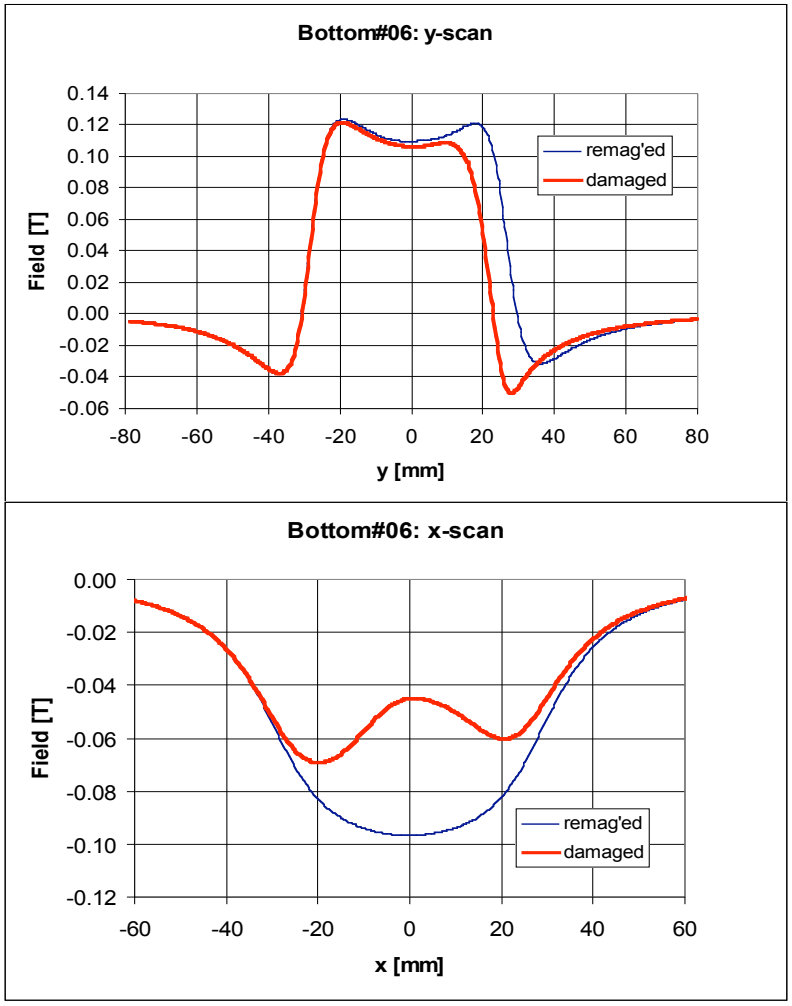




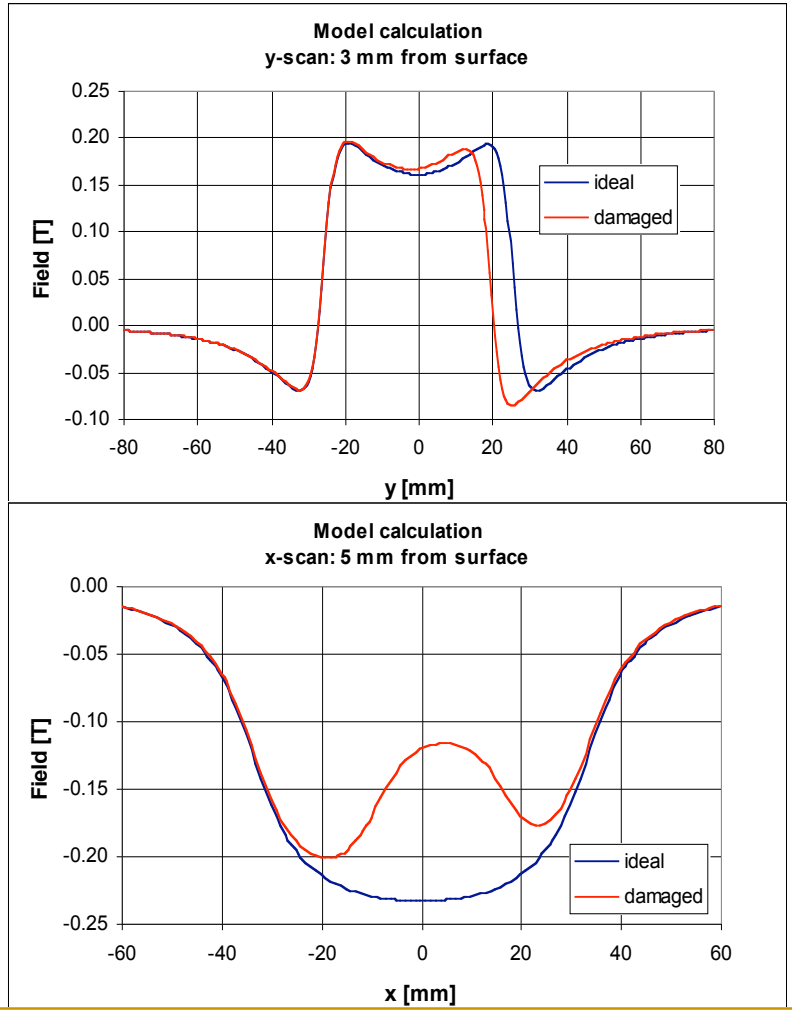


Measured and fitted profiles of one magnet

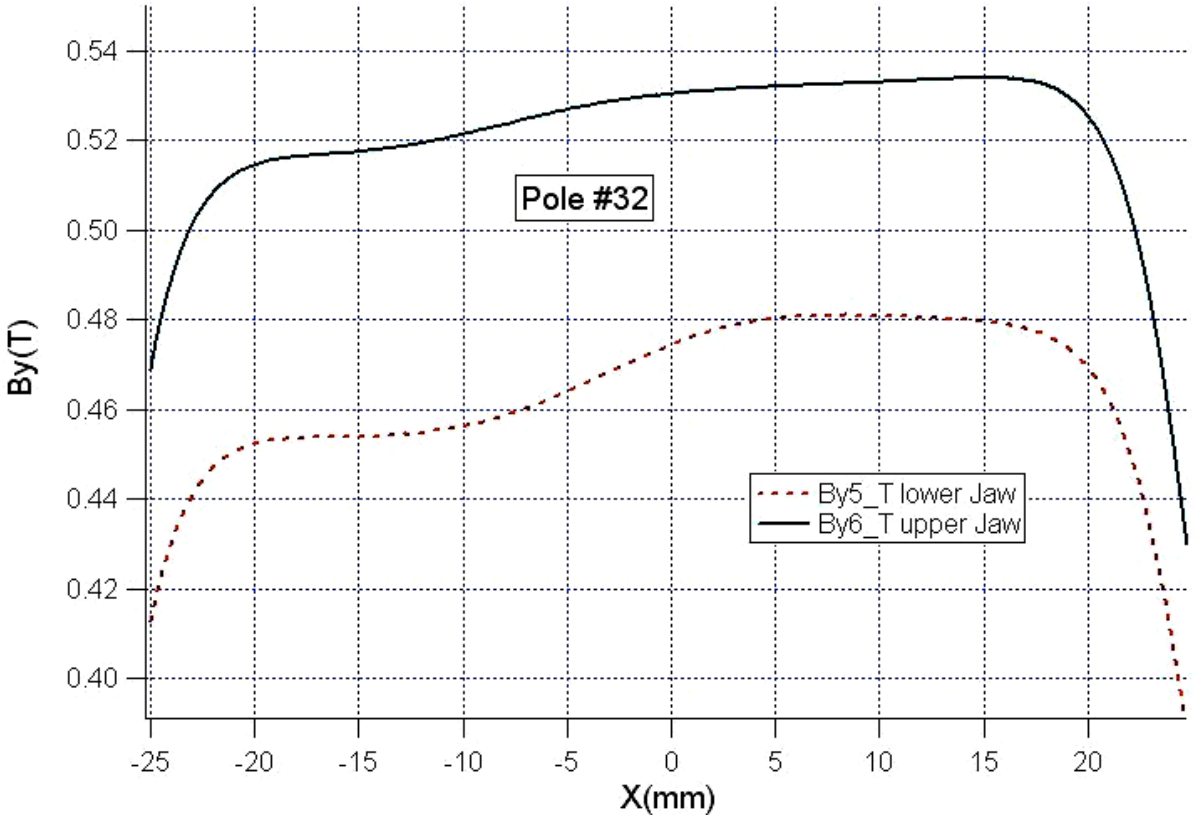
Measured



Model calculation. Surface Br=-0.1 T, underlayer Br=0.1 T



Sector 4 demagnetization vs. x: is the damage inboard or outboard?



In May 2004, the demagnetization was worse on the outboard side.

However, in Dec 2004 (above), demagnetization was worse on the inboard side.

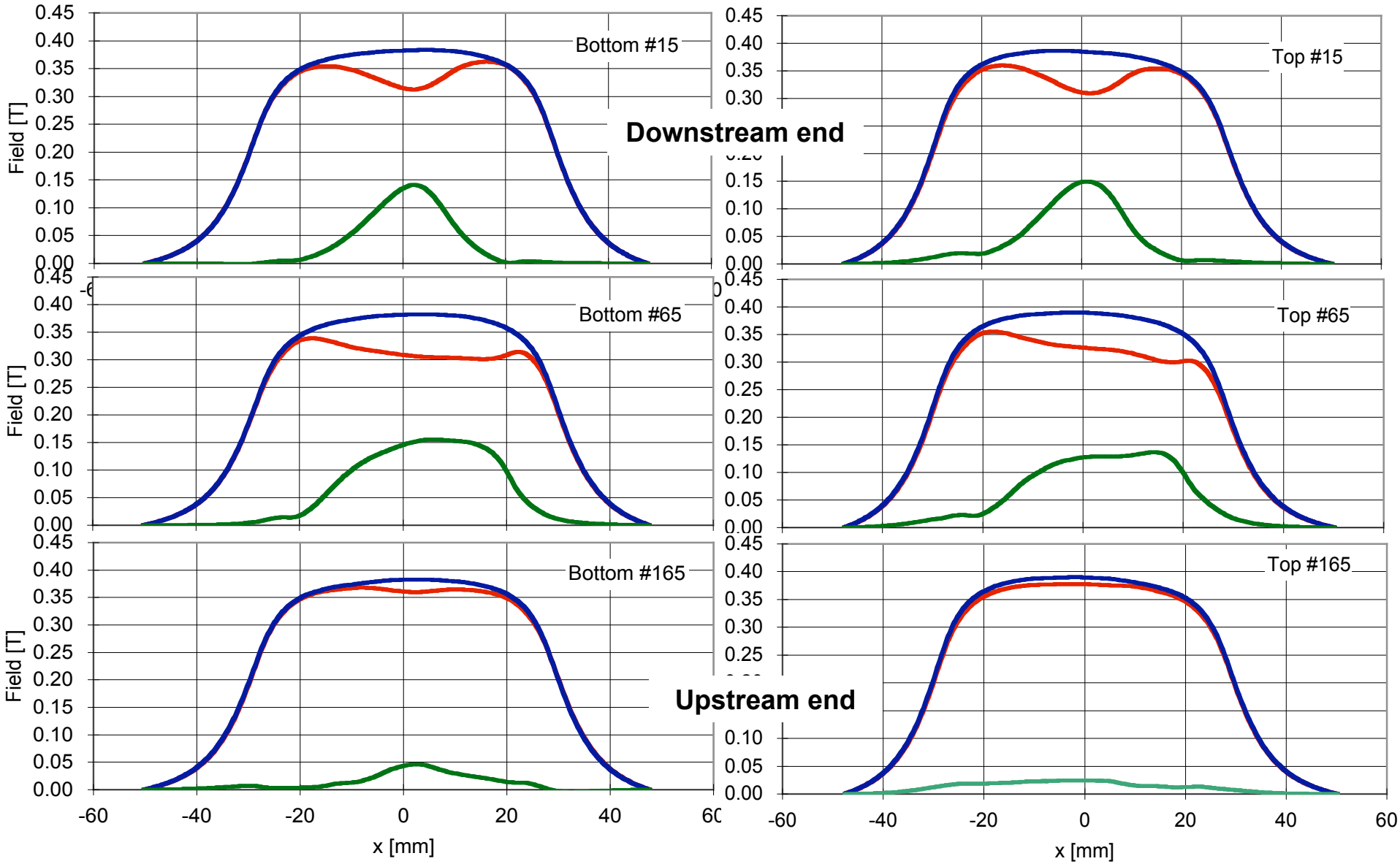
In the most recent data, inboard damage is worse, consistent with scraping low-energy particles on the inboard side.

Dosimetry and damage

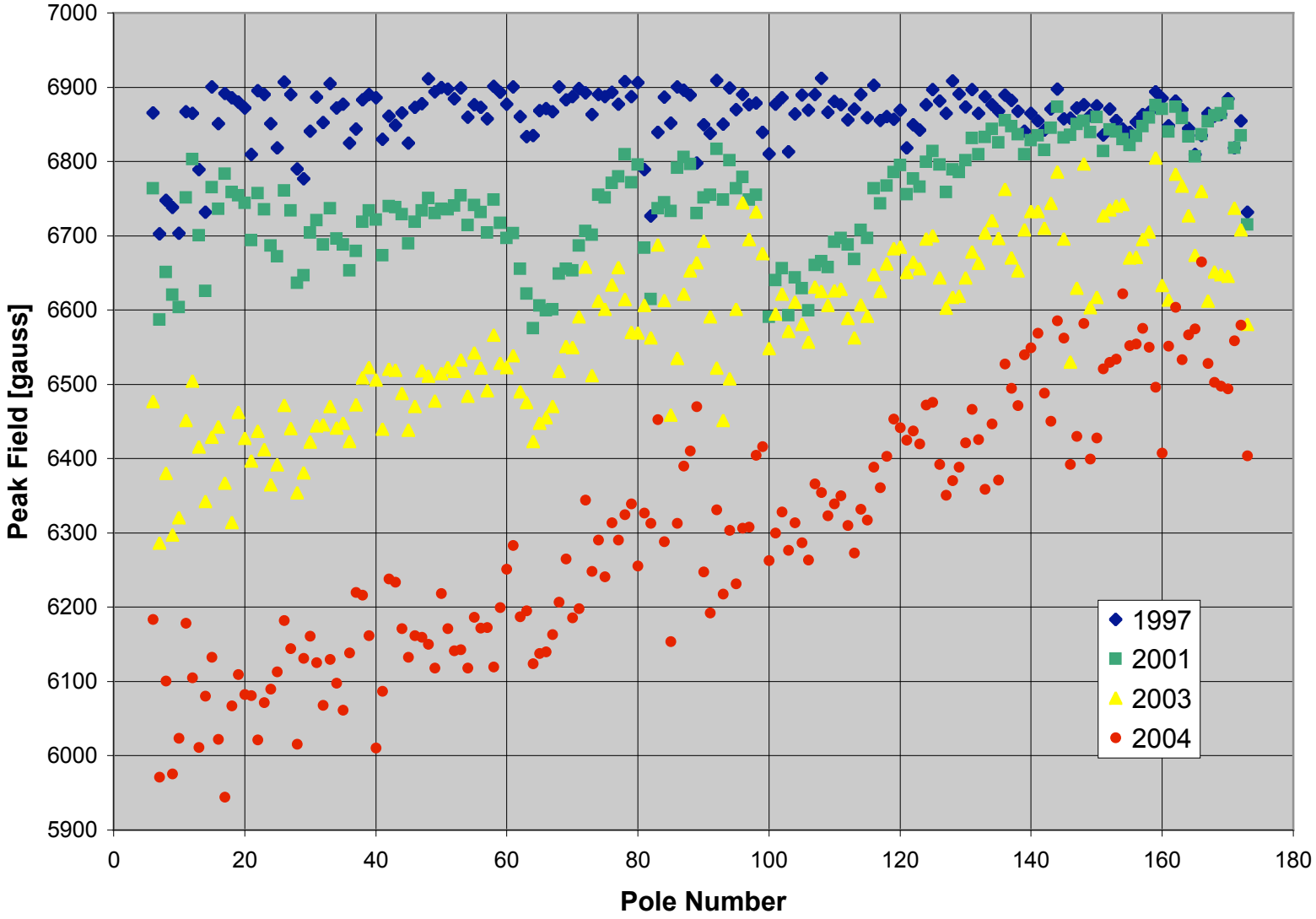
Attempts to correlate dose measurements to damage have not been as successful as we would have wished.

Sometimes there is some agreement but other times there is glaring disagreement.

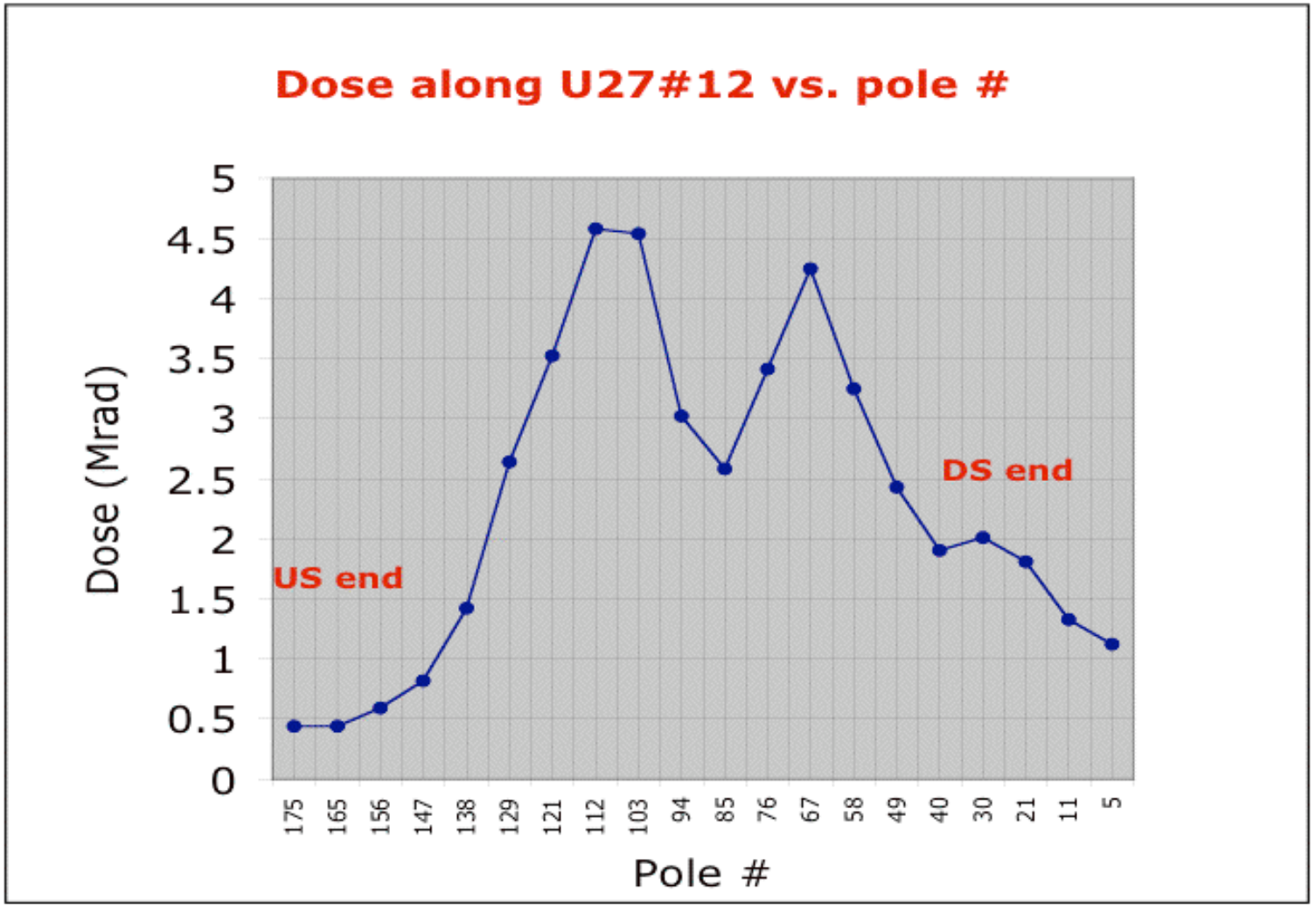
Demagnetization in Sector 3 downstream ID



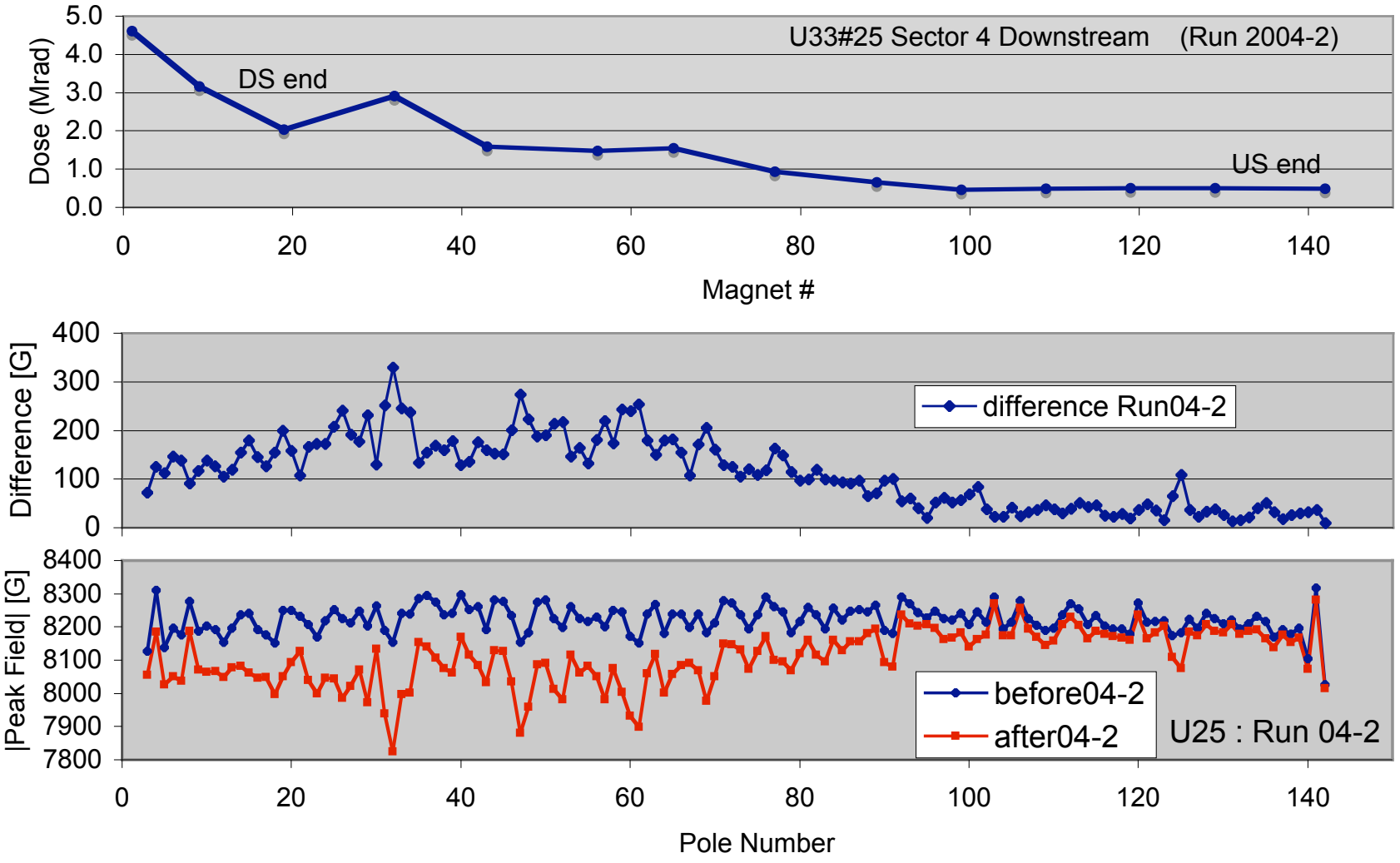
Damage sequence in downstream ID, Sector 3



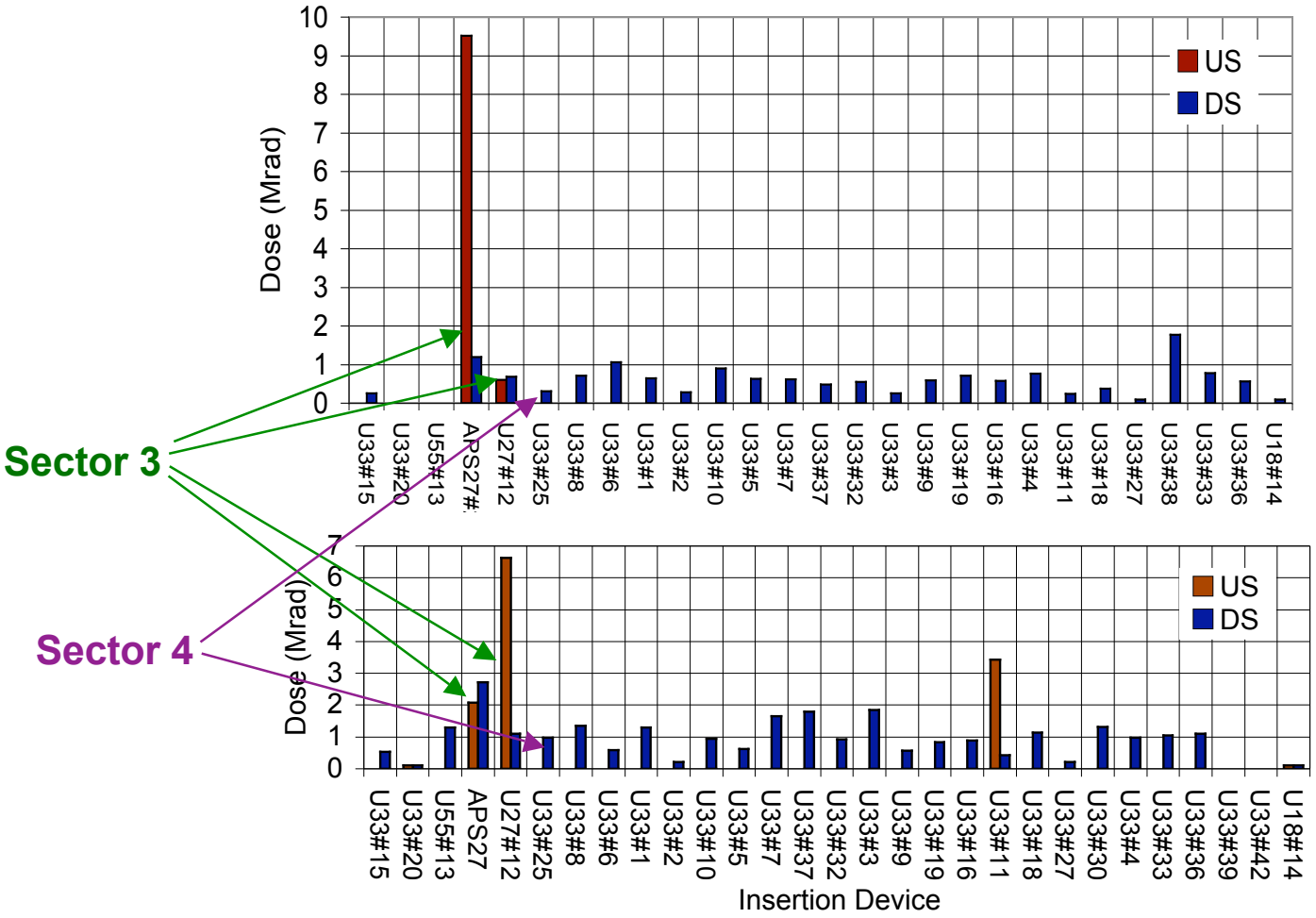
Dose profile along downstream Sector 3 ID



Comparison of dose and field loss



ID doses around the ring - alanine dosimetry



Run 2003-1

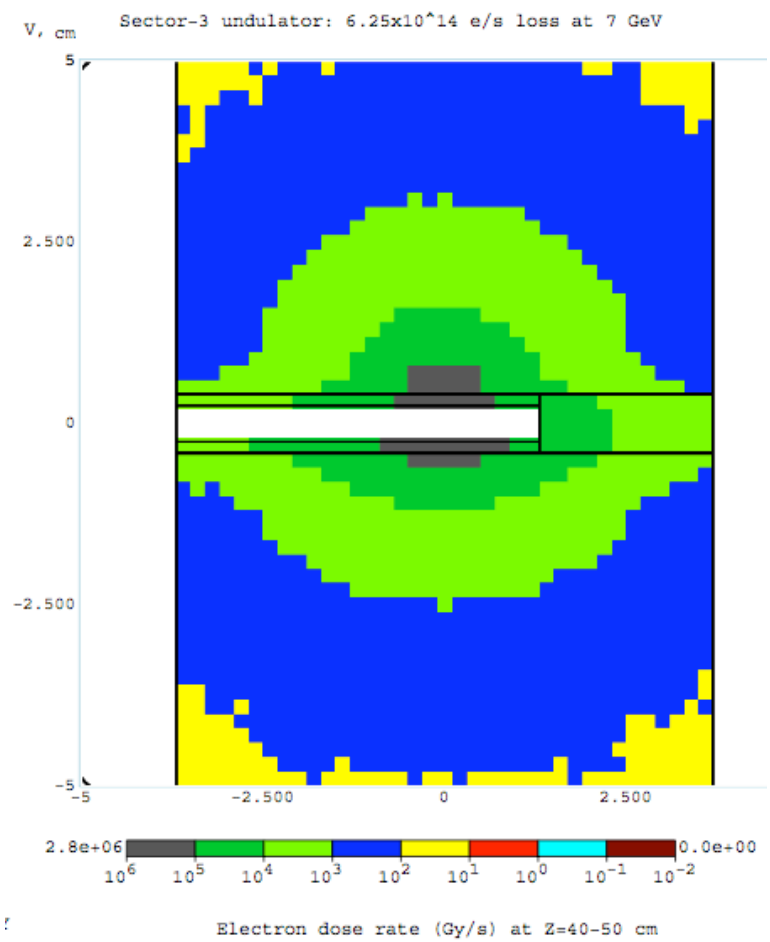
Run 2004-2

Doses in Sector 3 are typically very high. Doses in Sector 4 are low. Yet the damage rates are similar. Dosimetry is not measuring only what causes damage.

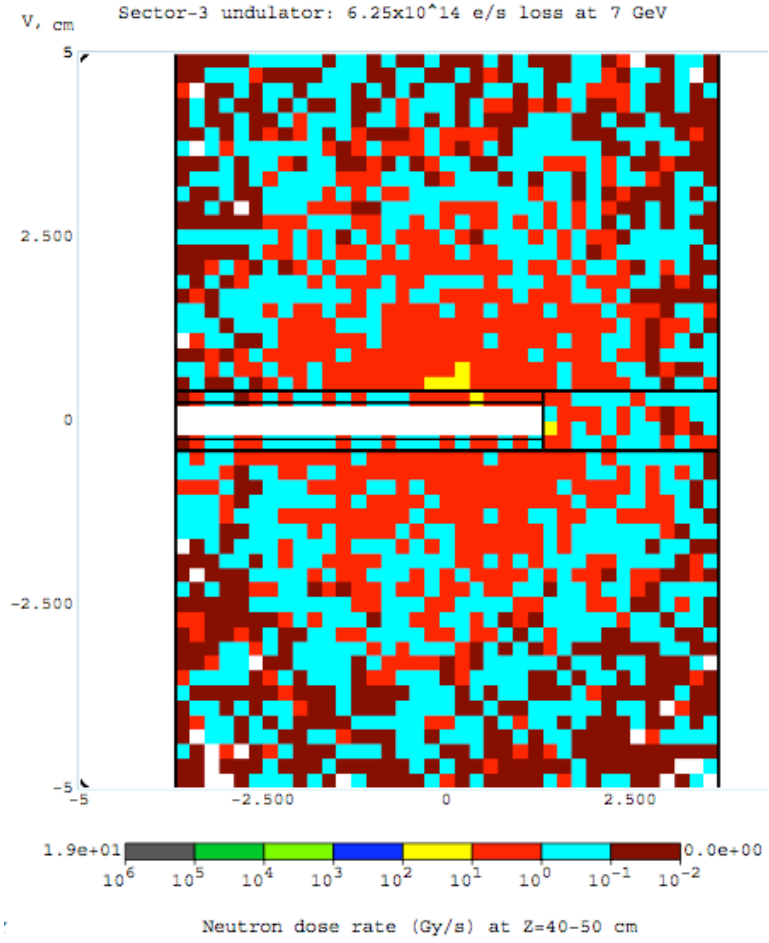
What component of the radiation causes damage?

- **Alanine dosimeters integrate dose over a wide photon/electron energy range.**
- **Not all those energies cause damage - synchrotron radiation doesn't, and ^{60}Co doesn't**
- **What about neutrons? Alanine not sensitive to them.**

Simulations of dose distributions



Electron dose



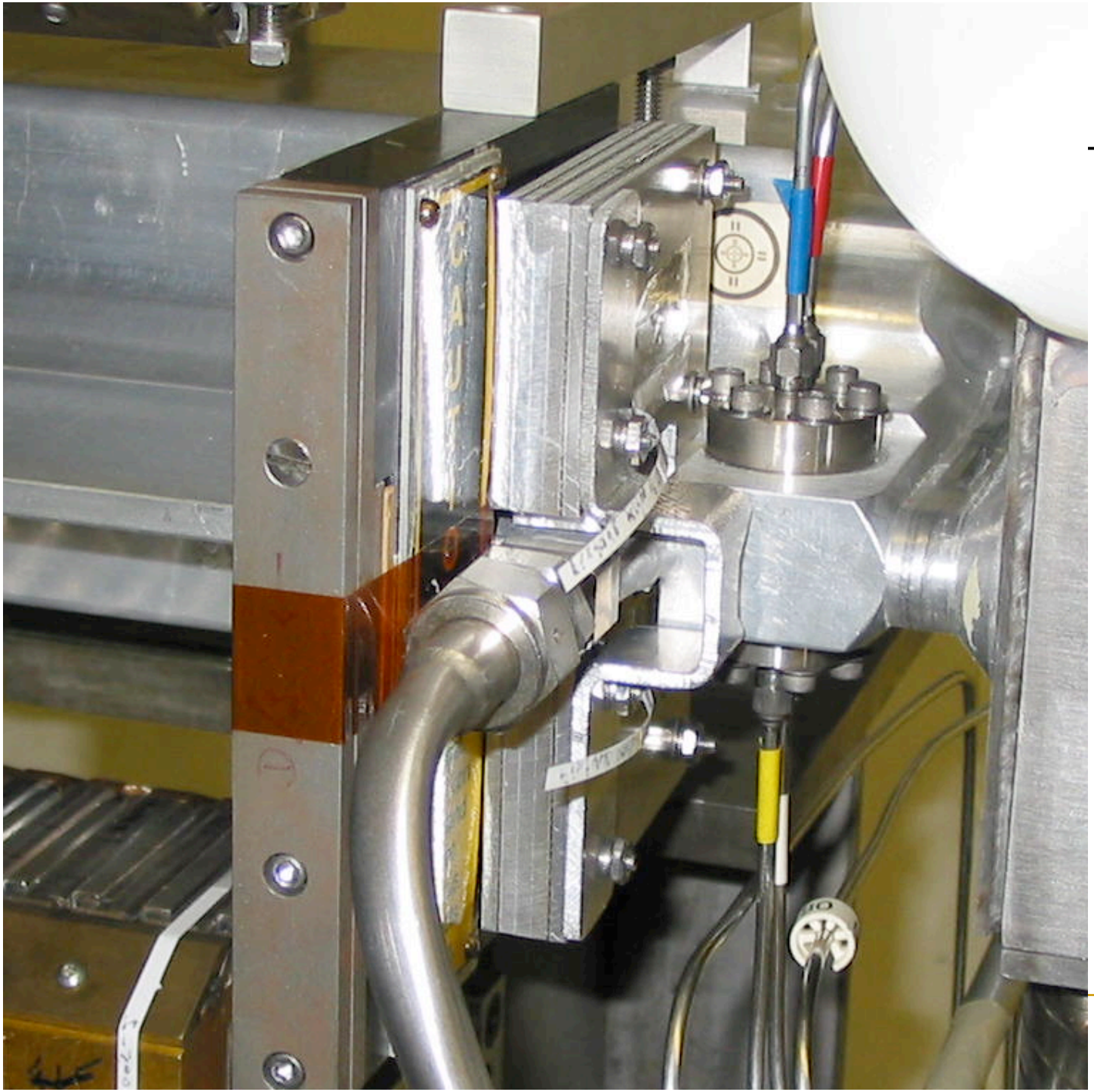
Neutron dose

Assuming 6.25x10^14 e/s loss at 7 GeV.

Mitigation plans

Retuning and remagnetizing of damaged undulators was consuming too much shutdown time.

- **Sector 3 has just had installed two new IDs with stronger field so they no longer need the small-gap vacuum chamber; it was removed in May 2005.**
- **A Sm-Co undulator is being built for Sector 4.**
- **A scraper for the ring is being designed and built. It will retract momentarily so as to not interfere with top-up injection, then reclose. Losses are expected to drop 5x.**
- **Radiation tests are being run on different grades of magnet.**



A three-pole "mini-undulator" has been installed. Radiation resistance of different magnet grades will be compared.

Contributors

Magnetic measurements and tuning:

- **Isaac Vasserman**
- **Shigemi Sasaki**

Magnetic modeling of damage:

- **Shigemi Sasaki**

Radiation dosimetry

- **Maria Petra**

Remagnetizing of magnet blocks

- **Chuck Doose**

Radiation dose modeling

- **Nikolai Mokhov (FNAL)**