Small-gap Undulator Development at the NSLS*

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Abstract

Improvements in the NSLS X-ray Ring lattice over the past decade have stimulated development of undulators with ever-smaller gaps. The first such device was the Prototype Small-Gap Undulator (PSGU), which featured a variable-gap vacuum chamber and a short magnetic structure outside the vacuum vessel, with separate gap-tuning drive. It was used to study beam lifetime as a function of aperture at the center of the X13 Straight. The second is an In-Vacuum UNdulator (IVUN), with the magnet array itself defining the beam aperture. Both devices show that the beam aperture can be safely reduced to nearly 3 mm in a low-beta straight before beam lifetime is affected. A reduced magnet gap permits a reduction in undulator period, while maintaining a high peak field, a K value close to unity, and strong photon output in the fundamental and at the third harmonic. Two short, IVUN-type devices are now planned for installation between the two pairs of RF cavities, creating new undulator beamlines at previously unused straights. The next in-vacuum R&D device will push the gap still lower, towards 2 mm.

Past and Future

PSGU — installed 1994; removed 1997

BNL designed and built the vacuum and support structure.
Rocketdyne designed and built the magnetic arrays under contract.

IVUN — Installed 1997

BNL designed and built the vacuum and support structure.
SPring-8 designed and built the magnetic arrays.

"Microundulator" — Under development

IVUN's for RF Straights — Planned for 2001 - 2002

References

P.M. Stefan *et al.*, "Small-gap undulator research at the NSLS: concepts and results", Nucl. Instr. & Meth. A412 (1998) 161-173.

P.M. Stefan *et al.*, "NSLS Prototype Small-Gap Undulator", Proc. 1991 PAC, 1096-1098.

G. Rakowsky *et al.*, Magnetic Performance of the Prototupe Small-Gap Undulator", PAC93

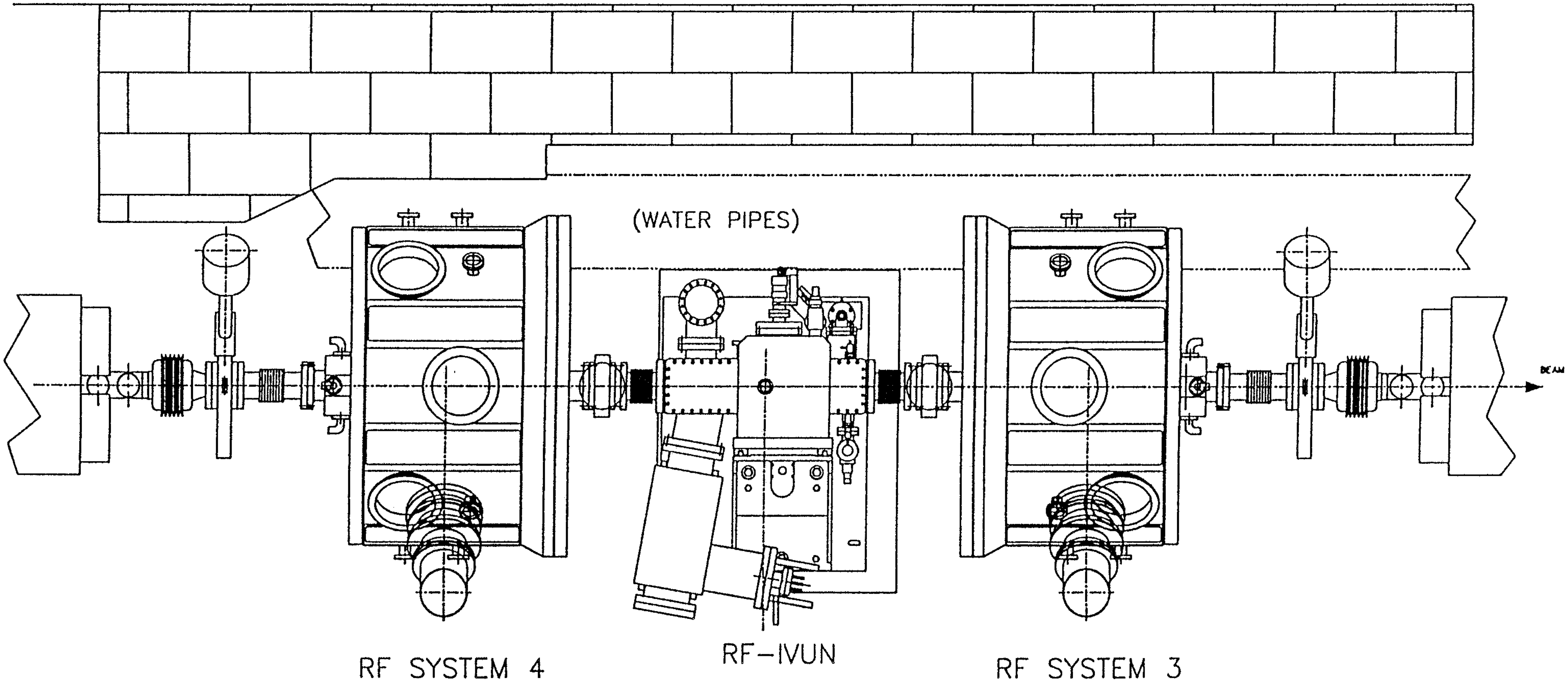
T. Tanabe *et al.*, "Development of an In-Vacuum Minipole Undulator", PAC97.

G Rakowsky *et al.*, "Magnetic Measurements on an In-Vacuum Undulator for the NSLS X-ray Ring", PAC97.

Parameter Comparison

	PSGU	IVUN	"Microundulator"
Magnet Type	Pure-PM In-air	Pure-PM In-vacuum	PM-Hybrid In-vacuum
Magnet length (m)	0.32	0.32	0.35
Period (mm)	16	11	12.5
Nom. magnet gap (mm)	6.0	3.3	2.0
Min beam aperture (mm)	3.0	3.0	2.0
No. periods	18.5	30.5	28
Peak field @ min. gap(T)	0.63	0.70	1.66
K	0.94	0.72	1.86
Magnet material	NdFeB	NdFeB	NdFeB
No.blocks/period	6	4	2
Pole material	n/a	n/a	Permendur
Sorting	Sim.Ann.	Sim.Ann.	t.b.d.
Cost Function	ϕ, B_y, B_x	dB/B	t.b.d.
Shimming	none	trim mag.	t.b.d.

RF-IVUN CONCEPT LAYOUT
SUPER-PERIOD 7
PLAN VIEW



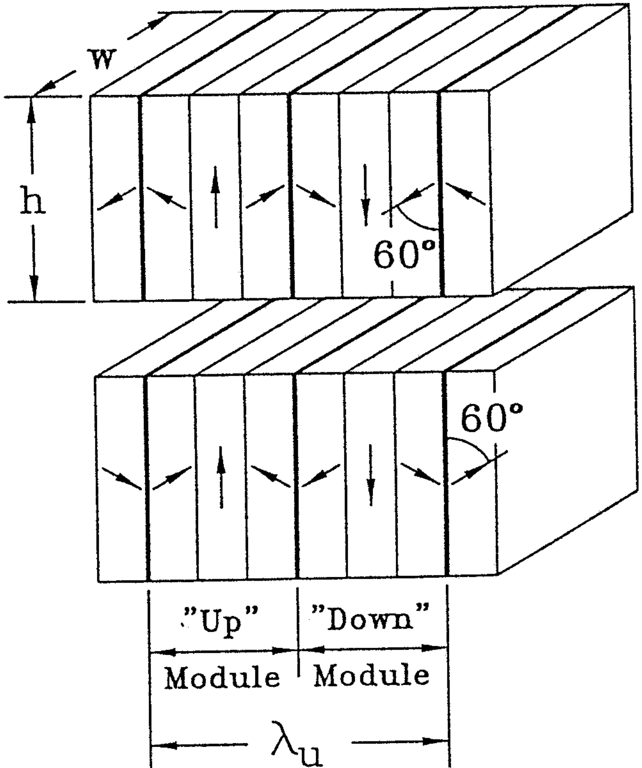


Figure 9 Schematic of the six-block/period pure-permanent-magnet structure used in the PSGU undulator.

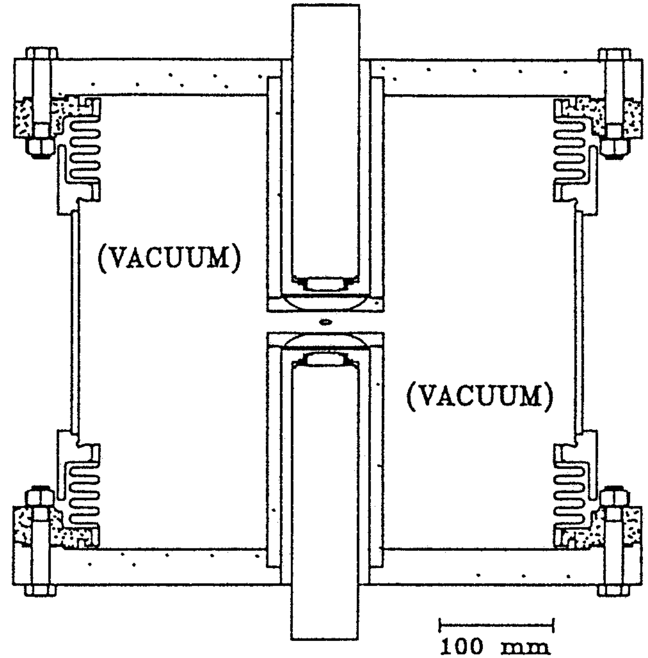
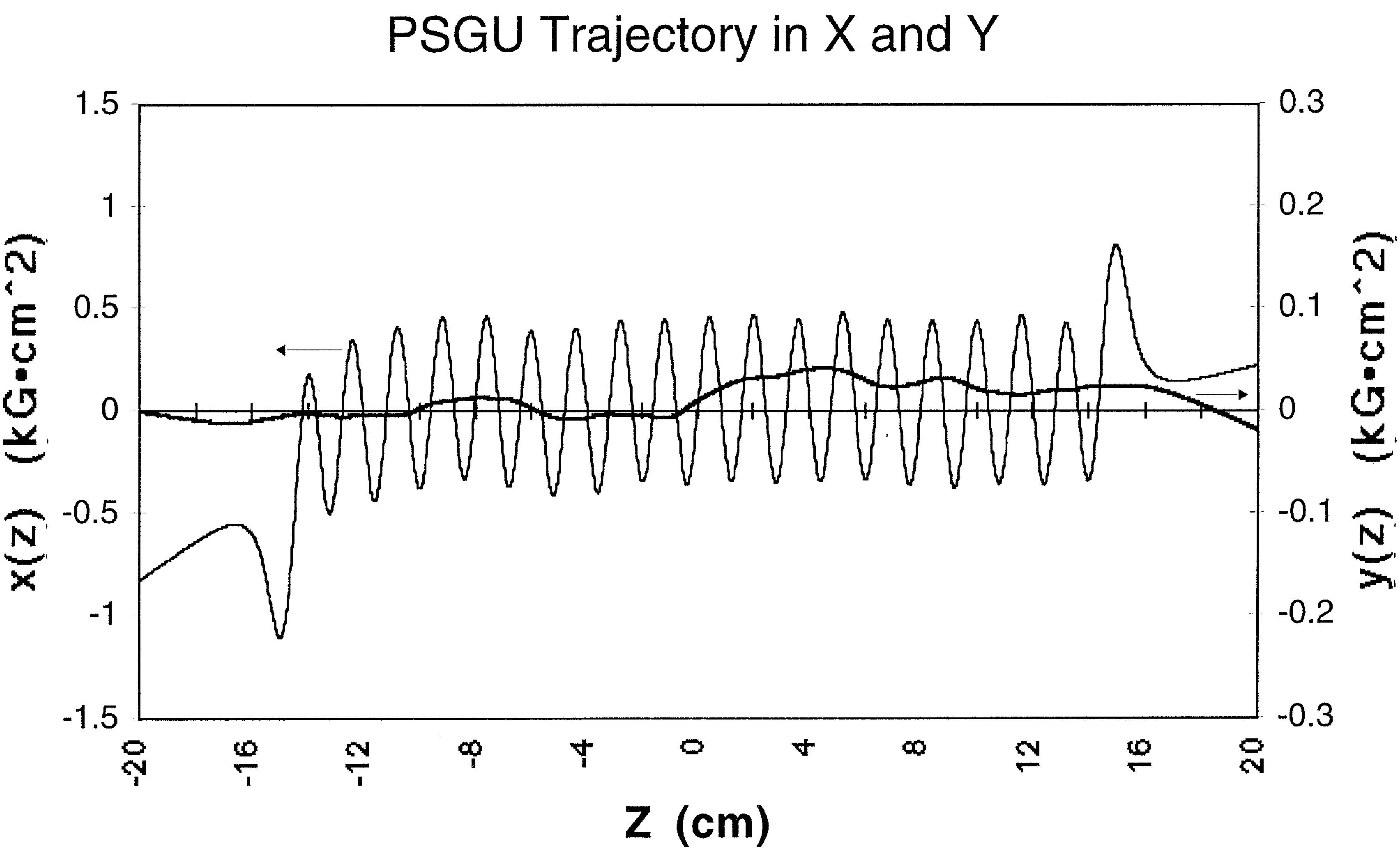
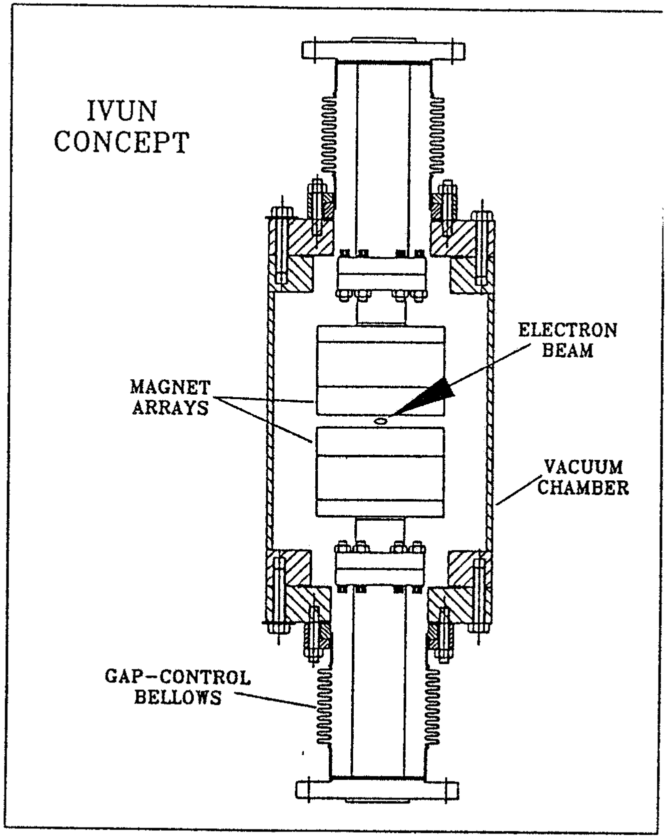


Figure 1 Cross section of the NSLS Prototype Small-Gap Undulator (PSGU) vacuum chamber, as seen along the stored beam direction. The stored beam is centered in the vacuum space between the two deep wells. The regions of the wells nearest the electron beam are thinned to 1 mm and the undulator magnet arrays are inserted into the wells, up to the thinned region.

The PSGU undulator magnet is 320 mm long,


PSGU Trajectory in X and Y
x(z) (kG•cm^2)
y(z) (kG•cm^2)
1.5
1
0.5
0
-0.5
-1
-1.5
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-20
-16
-12
-8
-4
0
4
8
12
16
20
Z (cm)



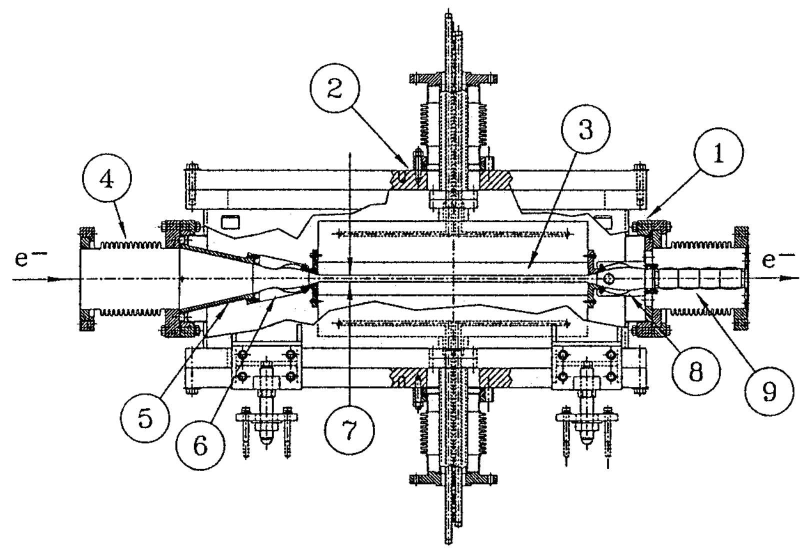
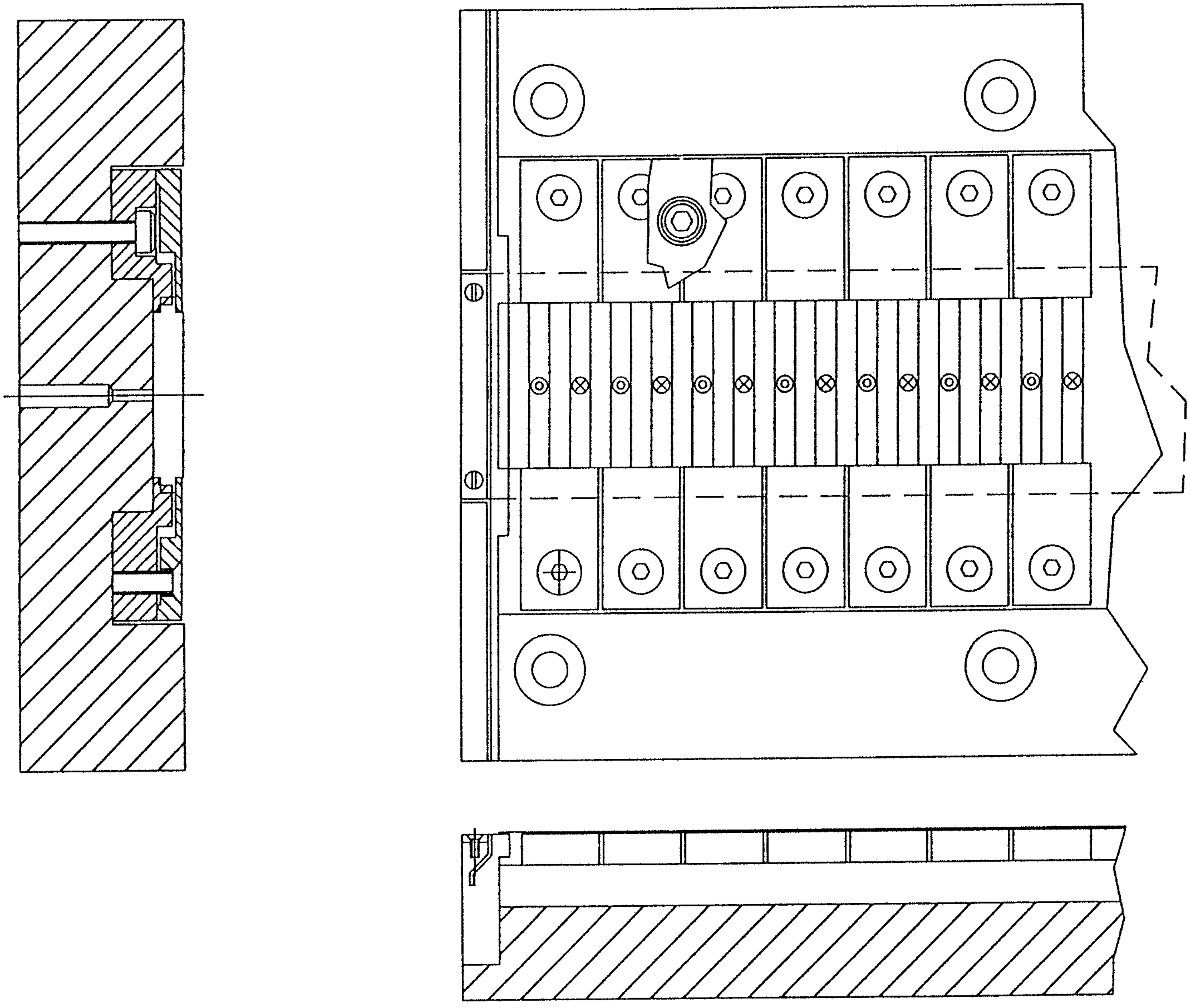
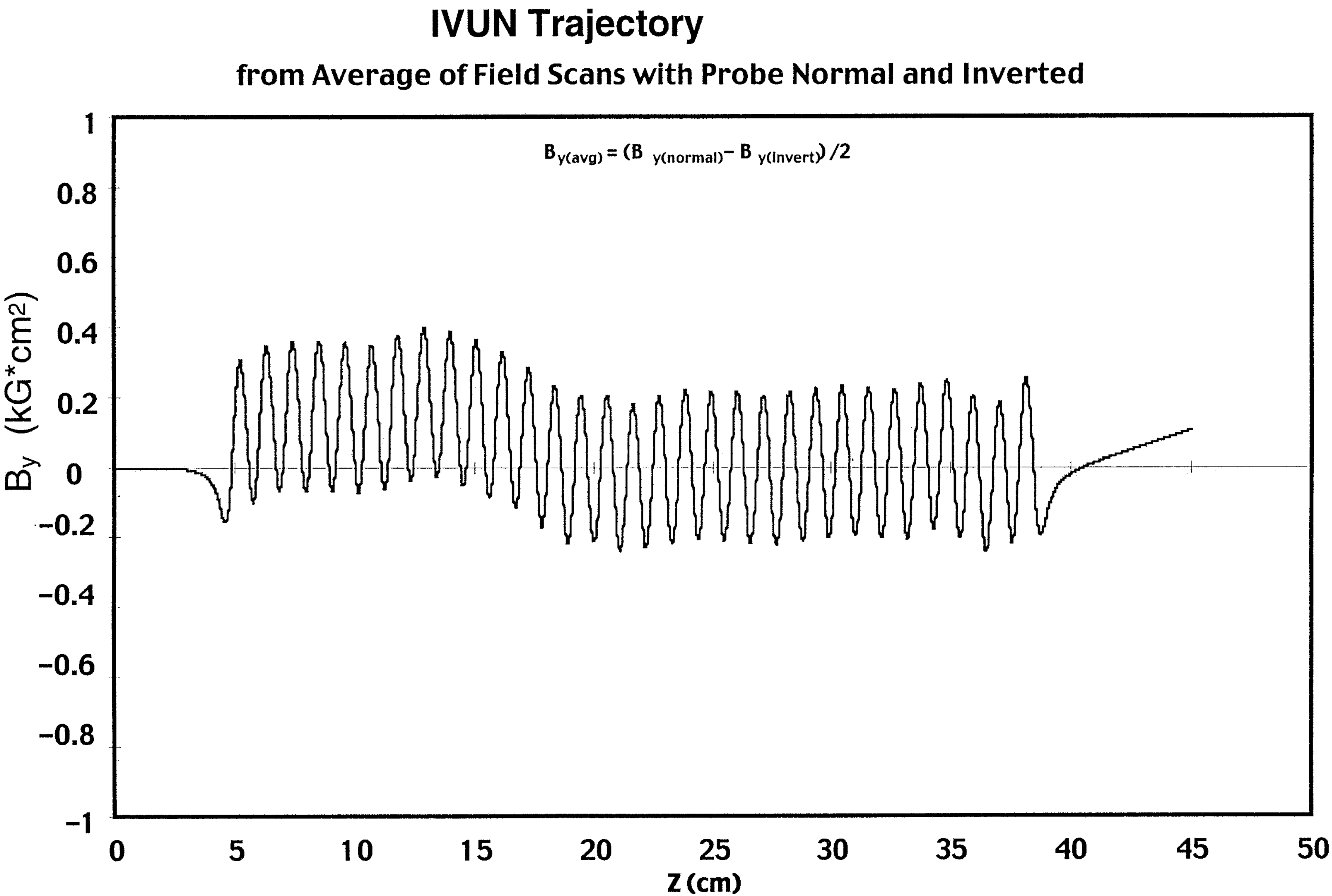


Fig. 6. Elevation view of the IVUN vacuum chamber, with the stored electron beam in the plane on the page. ① central vacuum chamber, which is supported from below by the elevator base stage. ② main flange, drive bellows, and water-cooled magnet-mounting block assembly. ③ the upper undulator magnet array. ④ upstream bellows. Along with its downstream counterpart, these bellows allow the vacuum chamber to be vertically centered with respect to the stored beam. ⑤ solid round-to-rectangular transition. ⑥ upstream flexible-sheet transition structure. ⑦ the minimum aperture region. ⑧ downstream flexible-sheet transition structure. ⑨ flexible bellows liner/transition.

IVUN UNDULATOR ARRAY
(ROUGH LAYOUT)




IVUN Trajectory
from Average of Field Scans with Probe Normal and Inverted
B y(avg) = (B y(normal) − B y(Invert)) /2
By (kG*cm2)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
5
10
15
20
25
30
35
40
45
50
Z (cm)

BEAM LIFETIME COMPARISON

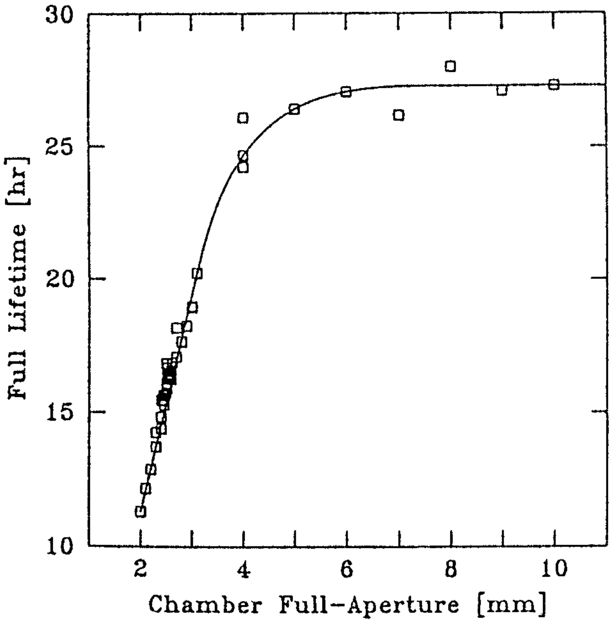


Fig. 7. Storage ring beam lifetime as a function of the PSGU vacuum chamber electron beam aperture, at 220 mA. The solid line is a guide to the eye.

PSGU

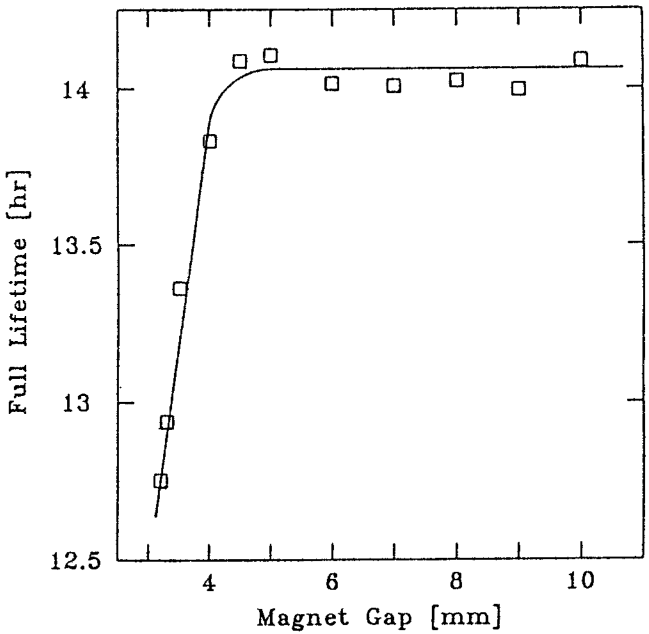


Fig. 8. The NSLS X-ray ring beam lifetime as a function of the IVUN magnet gap. Average stored current was 270 mA. The electron beam aperture is 0.3 mm less than the magnet gap.

IVUN

PHOTON FLUX COMPARISON

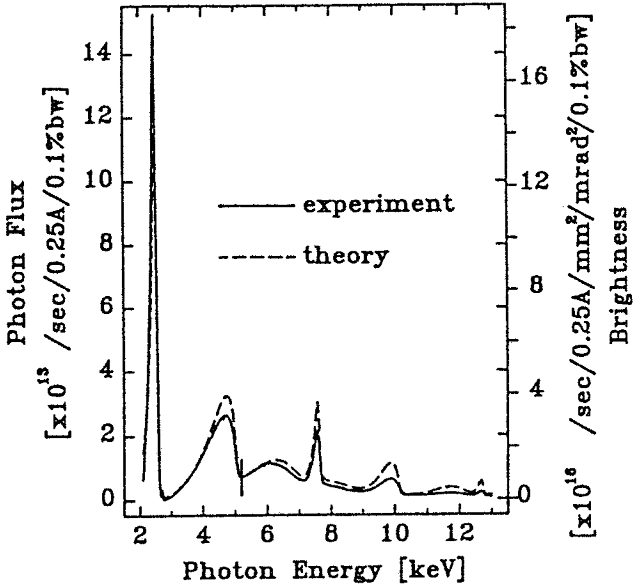
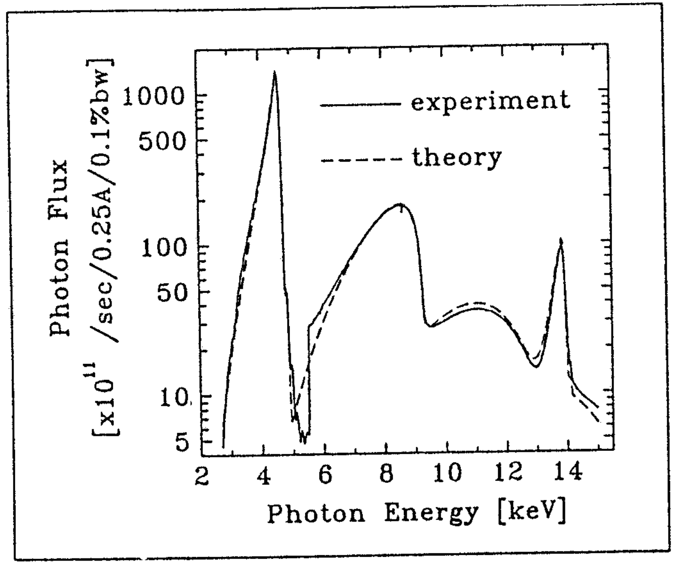


Figure 20 Spectrum measured from the PSGU undulator, for a magnet gap of 5.6 mm, K=1.056, at 2.584 GeV, 90 mA, with an electron beam full aperture of 2.5 mm. The fundamental is at 2.5 keV. The 4th and 5th harmonics, are also seen. The theory curve was obtained using the URGENT [7] code.

PSGU

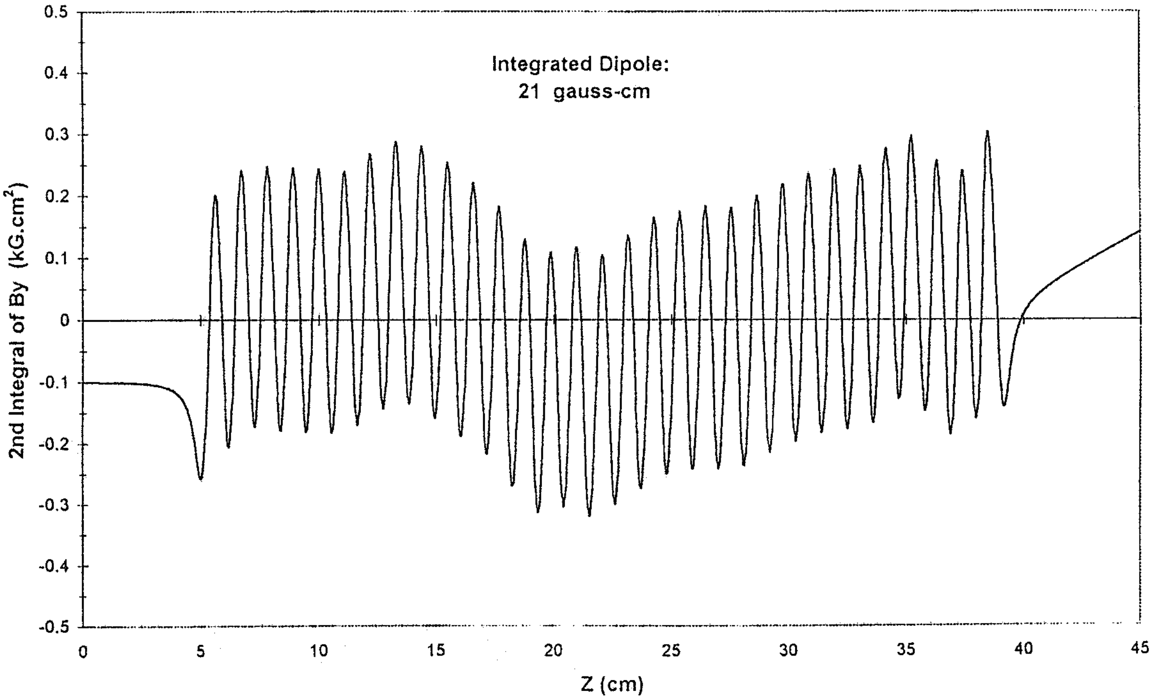


IVUN

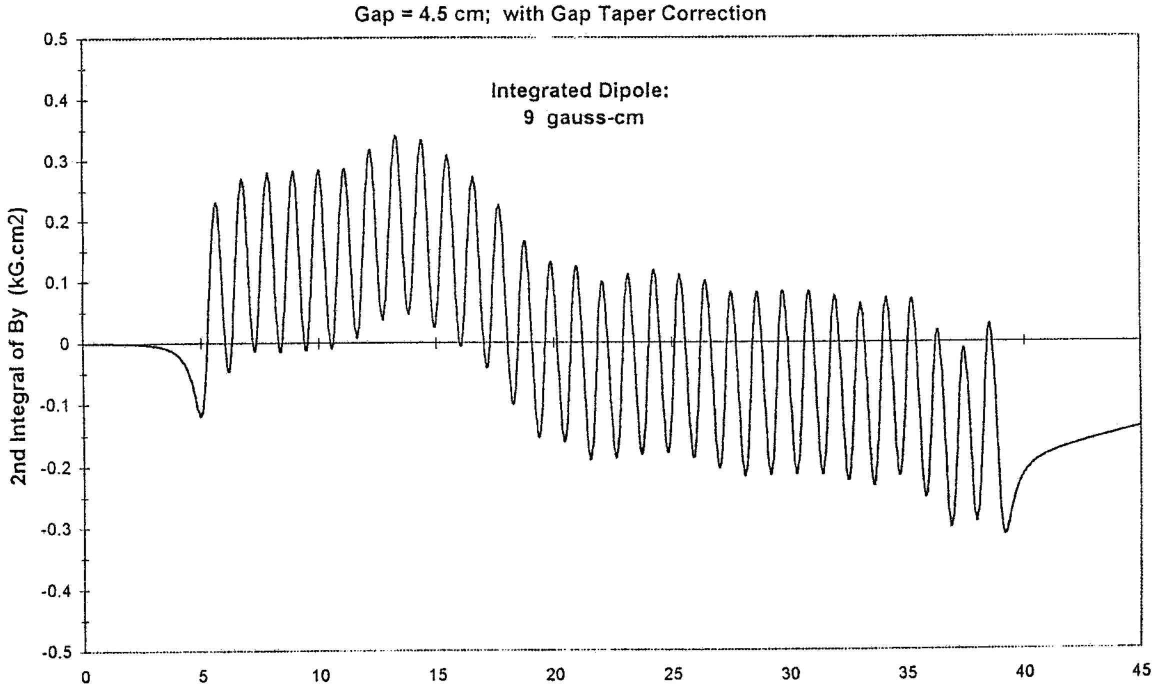
IVUN TRAJECTORY VS. GAP

"FEATURES" DON'T SCALE IF DUE TO SOURCES FAR FROM MIDPLANE

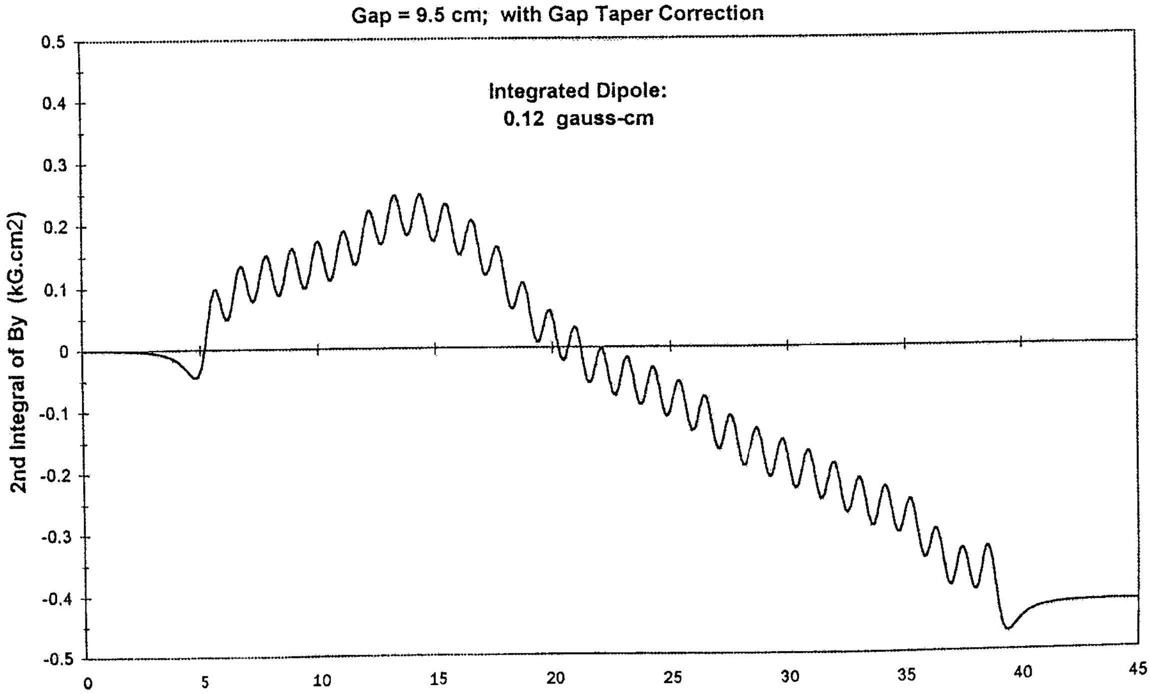
Gap = 3.3 cm; with Gap Taper Correction



Gap = 4.5 cm; with Gap Taper Correction



Gap = 9.5 cm; with Gap Taper Correction



CONCLUSIONS

Pure-PM undulators should be sorted to minimize **Optical Phase Error.**

For **gap-tuned** devices, shimming to correct trajectory or phase errors should be done at the magnet **surfaces facing the gap**.

Shims or trim magnets applied far from midplane should only be used in **fixed-gap** or **axially-phase-tuned,** pure-PM undulators.

Attention should be paid to non-exponential gap dependance of fields from end poles/magnets. (Quimby, PAC'99)

New high-temperature NdFeB materials with high Br and very high Hci withstand strong demagnetizing fields and **can be baked.**

Peak field and K are constrained by gap, period, remanence, saturation. Pushing to smaller gaps requires compromises.