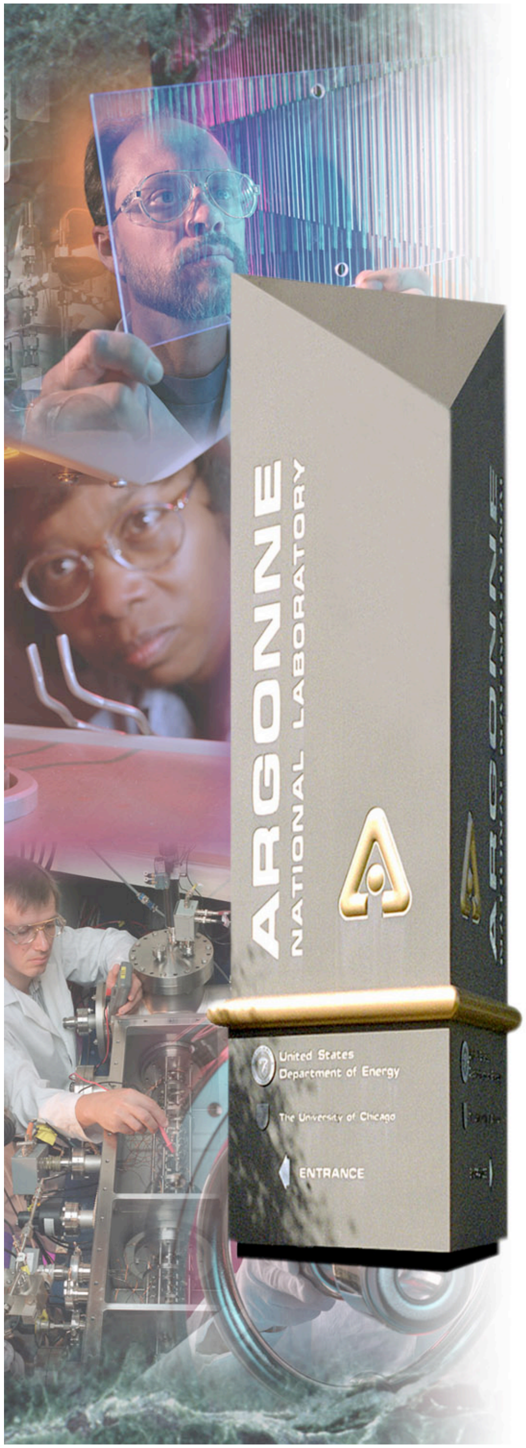

APS Experience with Elliptical Insertion Devices

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EPUs: Integration and Operation on 3rd Generation Synchrotron Machines

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Argonne National Laboratory

Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

IDs installed as of Feb 2005

Type	Number	Length (periods)	K_{eff}
33-mm undulator	24	72	2.75
33-mm undulator	5	62	2.75
55-mm undulator	1	43	6.57
27-mm undulator	1	88	1.70; 2.18¥
27-mm undulator	1	72.5	1.36; 1.80¥
18-mm undulator	1	198	0.455
Elliptical wiggler (16 cm)	1	18	K_y=14.7† $K_x \le 1.4$
Circularly polarized undulator (12.8 cm)	1	16	$K_y \le 2.86$ $K_x \le 2.75$

Device length includes the ends - approx. one period at each end is less than full field strength.

K value is at 10.5 mm gap unless stated otherwise. (CPU and horizontal elliptical wiggler field are electromagnetic, with different fixed gaps.)

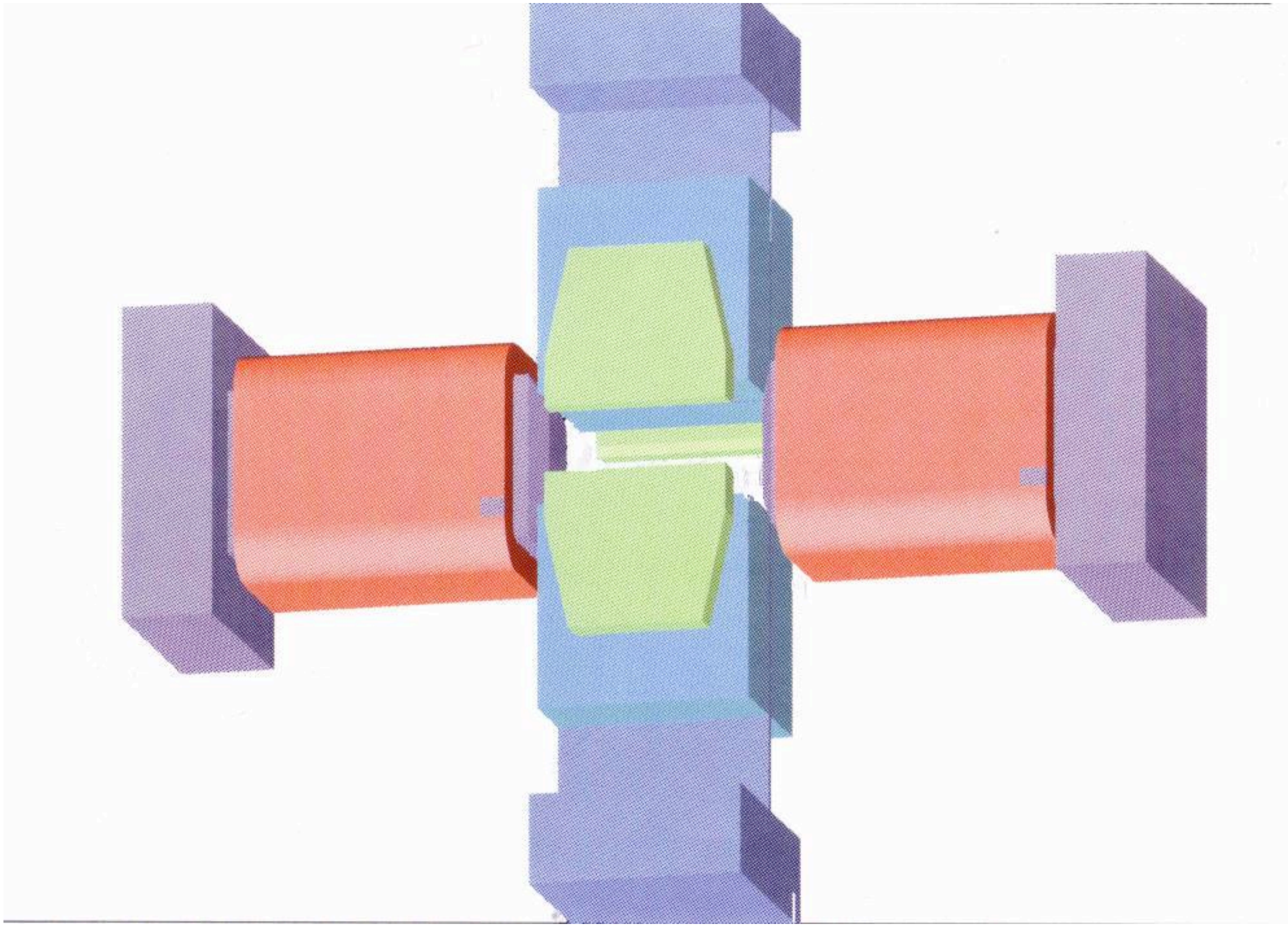
† at 24 mm gap (the device minimum). Values are for peak K, not K_{eff}

¥ at 8.5 mm gap.

New IDs now in production

Type	Length (m)	Scheduled date for installation
New 2.7-cm period	2.4	April/May 2005
3.0-cm period: Two of them	2.4	April/May 2005
3.5-cm period using SmCo magnets	2.4	Sept 2005
3.0-cm period	2.1	Dec 2005 ?

Model of Elliptical Motion Wiggler




CAUTION
PERMANENT MAGNET
STRONG FIELD
ALWAYS ON
CAUTION
CAUTION
HIGH MAGNETIC FIELD IN AREA
PERMANENT MAGNET
FIELD ALWAYS ON

APS Elliptical Wiggler

Period is 16 cm

Overall length ~ 3 m

<u>Horizontal Field Component is from Electromagnet</u>

- 36 poles, of which 32 are full field
- 2 end poles (at each end) are at magnetic scalar potentials of nominally 1/4 and 3/4 of the full-field poles
- Peak field of 0.0997 Tesla (K_x=1.5) at a current of 1 kA
- Up to 10 Hz

APS Elliptical Wiggler - 2

<u>Vertical Field Component is from Hybrid Permanent Magnet Structure</u>

- 37 poles, of which 32 are full field
- 2 poles at the upstream end and 1 pole at the downstream end have no adjacent magnet to power them
- The 3rd pole at the upstream end and the next-to-last at the downstream end are at magnetic scalar potentials of nominally half that of the full-field poles
- Peak field of 0.9826 Tesla (Ky=14.6)
- Minimum gap 24 mm

Electromagnetic correction coils are at both ends of the device for vertical and horizontal correction

EMW Use

Users have the possibility of supplying beam to 3 experiments simultaneously:

- Linearly polarized x-rays are produced in two intense beams above and below the axis
- Circular polarization on axis

Handedness of circular polarization can be switched at up to 10 Hz; 1 Hz or 1/2 Hz is more typically used.

The EMW has been in operation since it was installed in late 1996. It has been reliable, but there have been occasions when users complained of beam instability, prompting retuning.

EMW Challenge

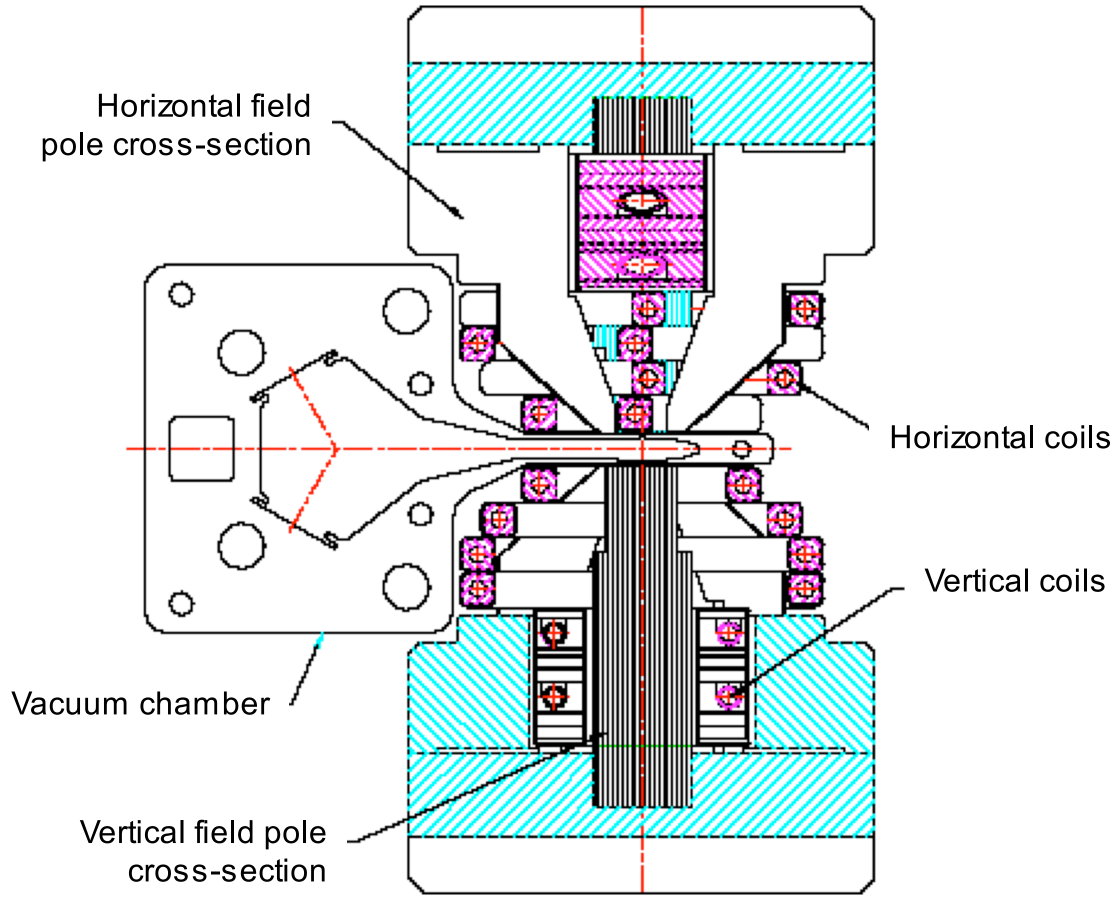
Not all the issues involving beam stability are solved yet

- **Beam position monitors upstream and downstream are used to hold electron beam stable**
- **Compensation elsewhere in the ring is done**
- **However, trajectory inside undulator is what's important for x-ray beam**
- **A recent experimenter complained that degree of polarization was not the same for left- and right-handed polarizations, and that this adversely impacted the desired experiment**
- **Measuring x-ray beam characteristics to tune device requires collaboration with users**

Circularly Polarized Undulator

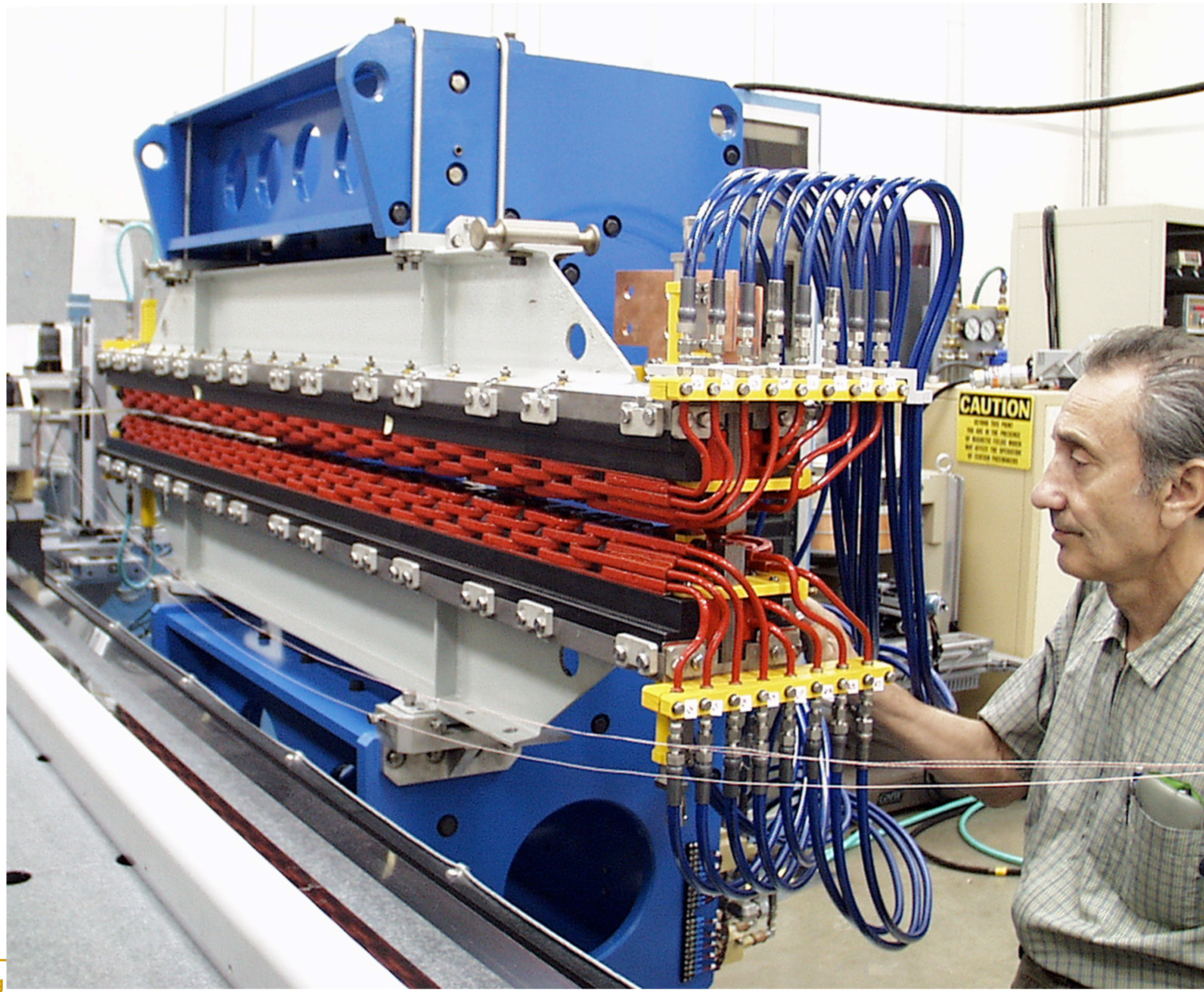
Advanced Photon Source

- All electromagnetic
- 500-3000 eV output
- circular polarization, both left and right
- linear polarization, both vertical and horizontal
- switchable polarization
- compatible with standard ID vacuum chamber, so it can share a straight section
- open along one side for access by magnetic measurement probes

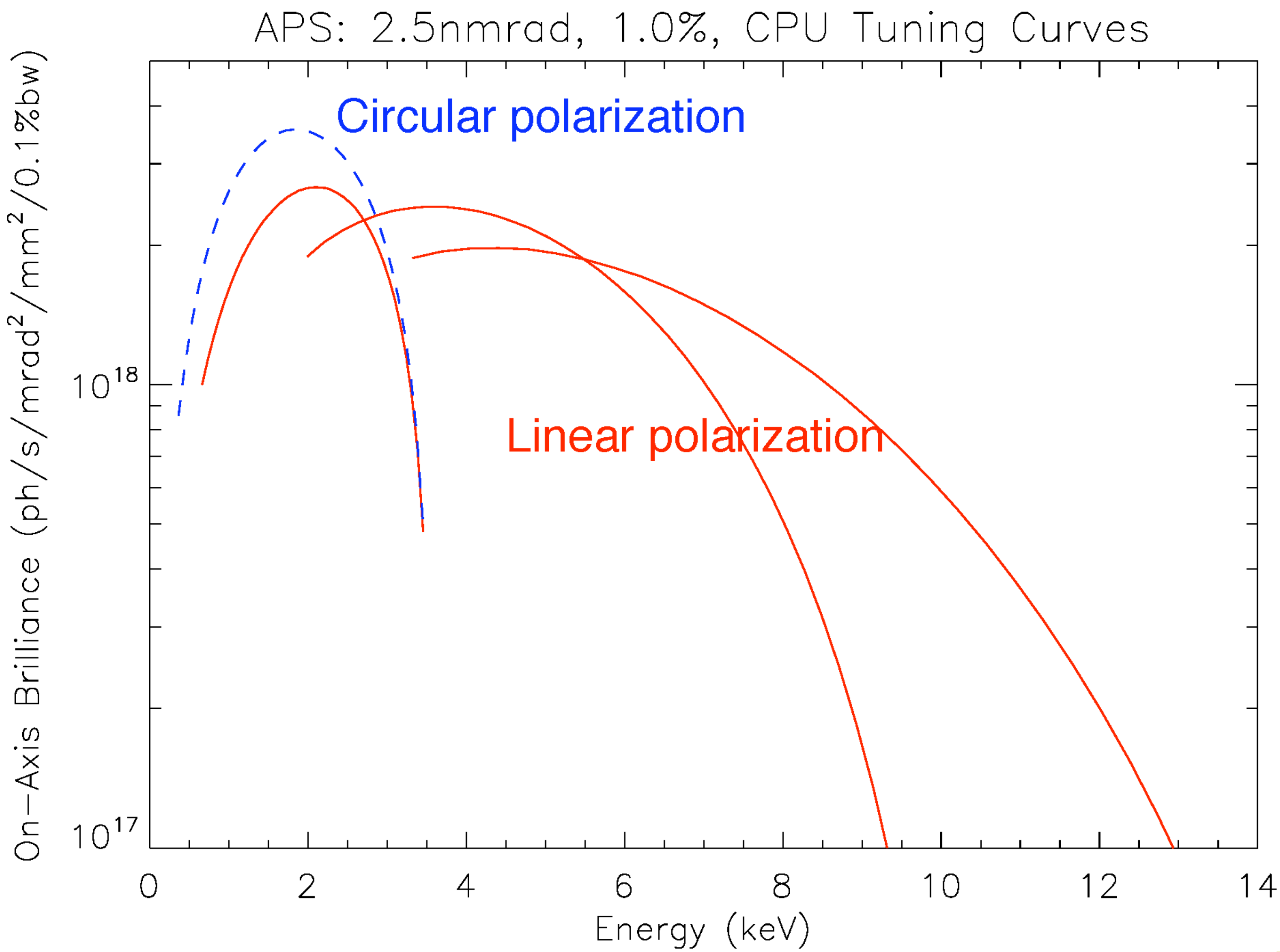


CPU in magnetic measurement room

Advanced Photon Source



CPU tuning curve



CPU Design Parameters

Parameter	Value	Units
Period	12.8	cm
Total number of horizontal-field poles	34	
Number of full-field horizontal poles	28	
Total number of vertical-field poles	34	
Number of full-field vertical poles	28	
Overall length	2.3	m
Vertical pole gap – vertical-field poles	11	mm
Vertical pole gap – horiz-field poles (nom.)	8.5	mm
Maximum peak magnetic field	0.28	Tesla
Horizontal peak field at 1370 amps	0.287	Tesla
Vertical peak field at 400 amps	0.31	Tesla
Maximum effective horizontal field	0.23	Tesla
corresp. 1^{st} harmonic energy (linear pol.)	752	eV
Maximum effective vertical field	0.24	Tesla
corresp. 1^{st} harmonic energy (linear pol.)	705	eV
1^{st} harmonic, circular polarization, for 0.23 T	425	eV
Switching frequency	0 – 10	Hz
Switching rise time (including overshoot)	<20	ms

CPU Saga

- Built by Budker Institute, Novosibirsk.
- No requirements on field quality or to measure / tune.
- Device was accompanied by a few scientists / engineers to help in the setup.
- User who had written the original specification left.
- New user didn't realize that achieving 500 eV photons with circular polarization didn't mean that it was possible with linear polarization.
- Minimum gap on poles had to be decreased, and the maximum current was increased.
- Field quality was atrocious.
- Originally, horizontal and vertical correction coils were installed at each end. They weren't enough.

CPU Saga - 2

- New power supplies were needed for stronger dipole corrections.
- The multipole moments needed correction too.
- New coils had to be added to correct normal quadrupole, skew quadrupole, and skew octupole moments.
- Transient fields needed to be measured and corrected.
- Programmable arbitrary function generators were added to help drive the correction coils.
- ~1.5 years between delivery and installation-readiness.

Device was installed in April 2001

CPU Saga - 3

- **A small interference between device and vacuum chamber support was discovered during installation, so device was installed with slight misalignment (250 microns).**
- **Pre-installation measurements no longer accurate.**
- **Beam-based adjustment of corrections was necessary.**
- **Different modes of operation:**
  - Left circular
  - Right circular
  - Vertical linear
  - Horizontal linear
  - A/C, with rapid switching between left and right circular

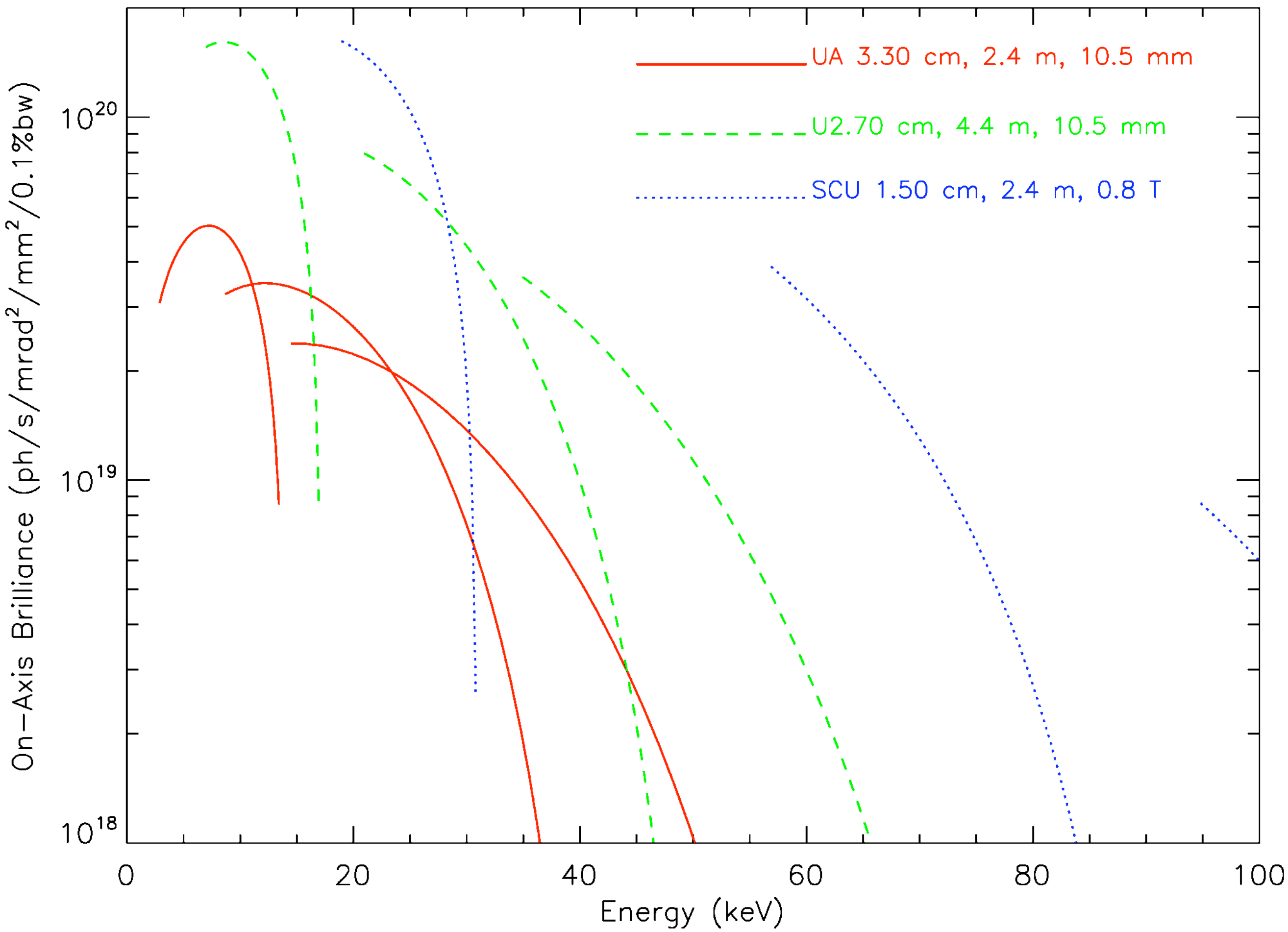
CPU Saga - 4

- **Key parts:**
  - How to measure effect on beam (real-time feedback signals are monitored) and how to determine transient profile
  - Software modification needed to aid changes
  - Triggering of switching in ac mode needed to be coordinated with triggering of position monitors
- **It is now over 30 studies shifts later.**
- **Feedforward corrections and waveforms for ac mode transients keep dipole perturbations outside the sector small.**
- **Switching transients last ~150 ms.**
- **Faster orbit correction (10 Hz rather than 1 Hz) allowed an increase in CPU ramp rate.**
- **Original magnetic measurements results are used for normal quadrupole corrections. They are also used for transient skew quad correction, because it's hard to measure.**

CPU quirks

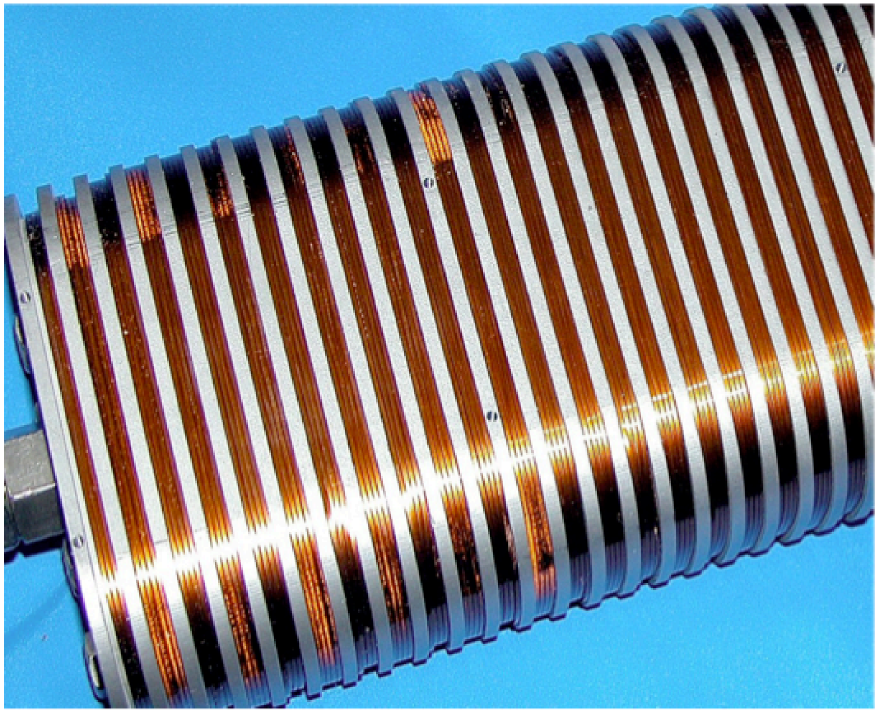
- There is cross-talk between horizontal and vertical fields
- Corrections determined for repeated ramping of field strength within one mode are not the same as for other modes, due to hysteresis in the iron.
- The correction needed for the first cycle in a particular mode depends on the recent history.
- User keeps switching modes.
- If we were to add different corrections for the first cycle in a new mode, it would require significant changes to the control system. Without doing it, the coupling variation in the beam is from 1% to 1.2%, i.e., small and of low priority.
- It takes time for the magnetic field to change so the correction determined at a static current is not the same when passing through.

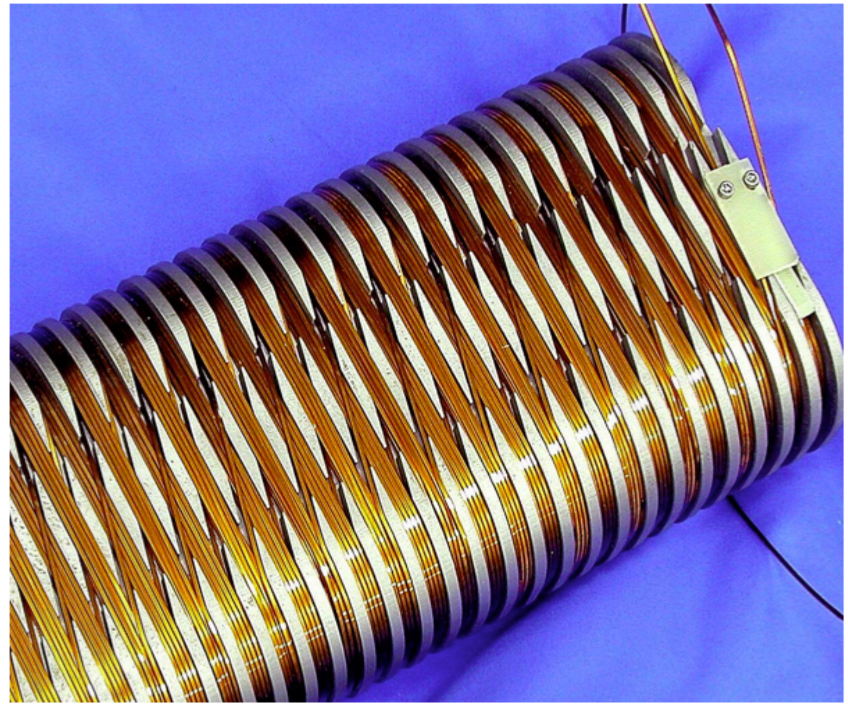
Superconducting und. at 20-25 keV



- **Superconducting undulator surpasses Undulator A ~ 10 times at 25 keV (when magnetic field errors are taken into account)**

Test coil built at APS

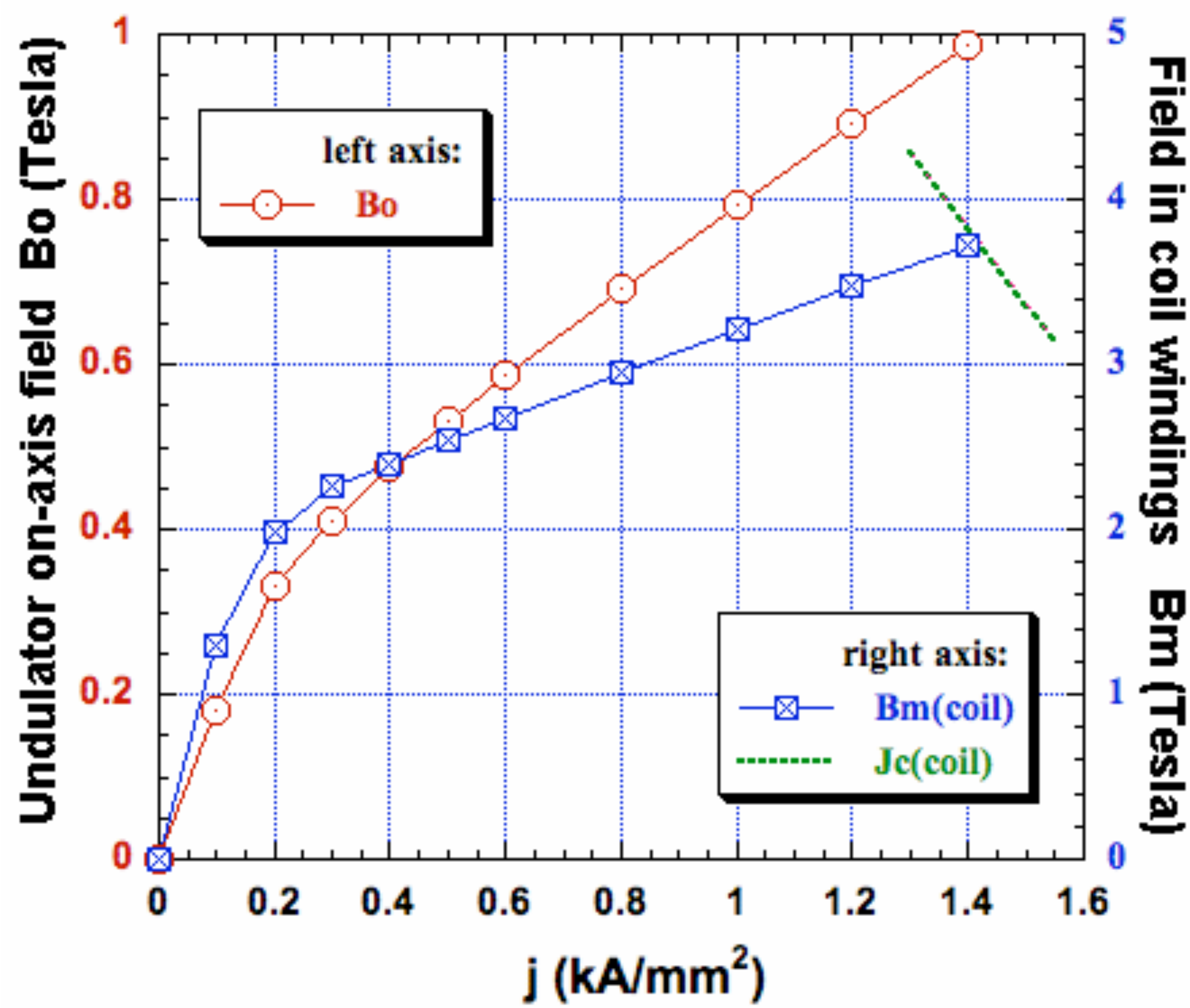




Goals for undulator:

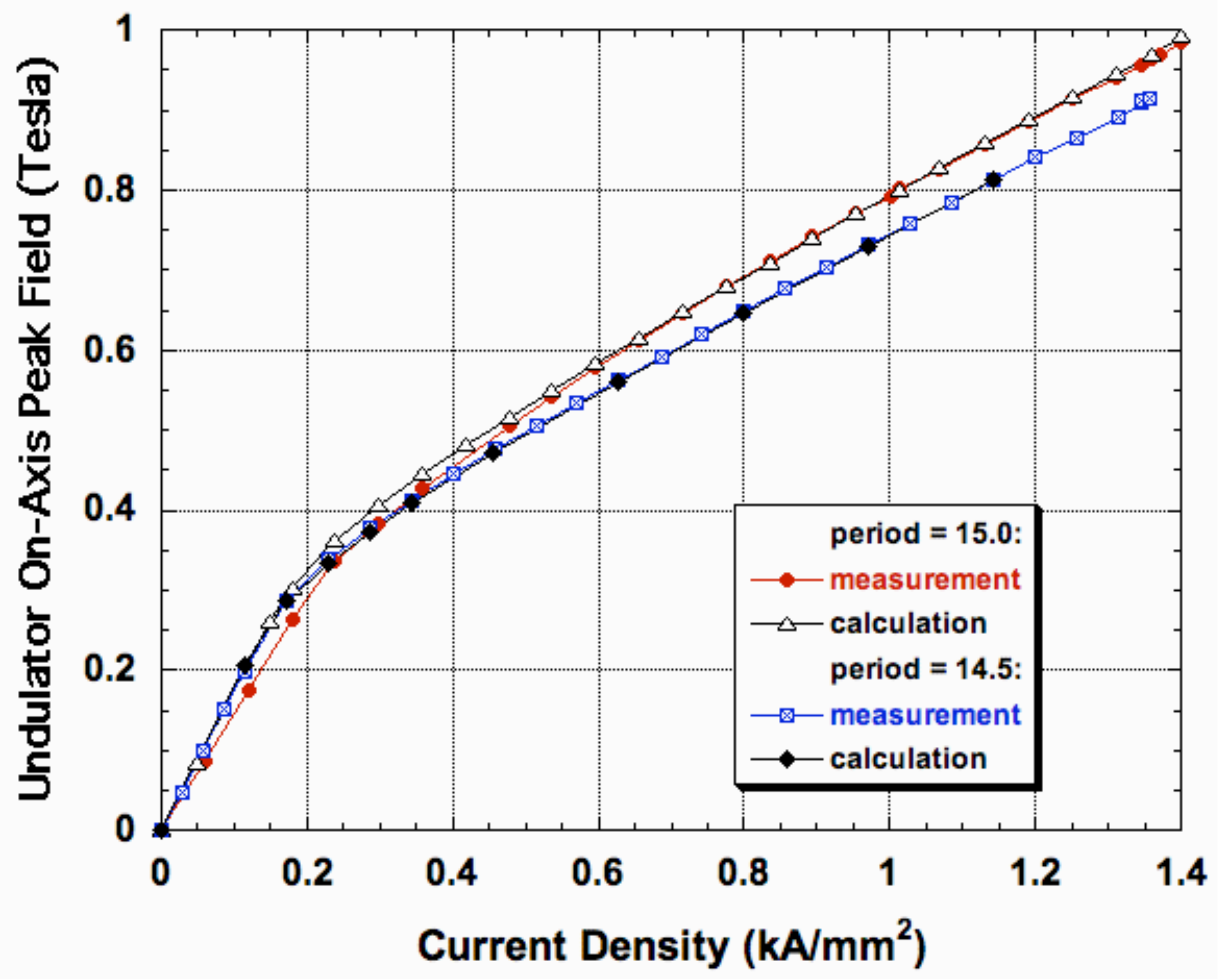
- 15-mm period (or shorter)
- 0.8 T field (or higher)
- 1st harmonic tunable down to 20 keV
- Field quality adequate for strong 3rd harmonic

Magnetic model calculations



8 mm
pole
gap

High current density tests



Next steps for R&D

1. Build a second NbTi coil so a short section of a full undulator can be measured
   - Field measurement, field quality, and magnetic tuning issues can be studied
2. Test sections using Nb_3Sn wire
   - Higher critical current
   - Must be wound in its non-superconducting state, then fired
   - After processing, wire is brittle

Options for acquiring an SCU

1) ACCEL:
   Design based on NbTi conductor
   Prototypes promising, approach looks feasible but not much margin
   Magnetic measurement & tuning not finalized

2) A collaboration with Nat'l High Magnetic Field Lab in Florida
   Design based on Nb_3Sn conductor (higher critical current)
   Proposed design has wider magnetic gap so beam chamber is at liq N_2 temp.
   No pressure bursts in ring even if superconductor quenches
   They know Nb_3Sn and know who can wind to their specs
   Collaborate on measurement & tuning
   Prototype first

3) Collaborating with Berkeley, who also are working on one