Insertion Device Workshop

Current APS Insertion Devices

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December 5, 2002

Outline

- Overview of IDs installed at the APS
- On-axis brilliance for APS devices (choice of undulators)
- Total power and on-axis power densities (limitations)
- Radiation-induced demagnitization of permanent magnets (is this an issue?)
- Small-gap undulators

IDs as Installed in December 2002

- 29 IDs installed today
  - 27 planar permanent magnet hybrid devices
    - 23 Undulator As
    - 2 27-mm period devices
    - 1 55-mm period device
    - 1 18-mm period "
  - 2 special devices
    - 1 circularly polarized undulator—CPU (electromagnets)
    - 1 elliptical multipole wiggler—EMW (electromagnet + permanent magnet)

Type	Number	Length (periods)	K_{eff}
33-mm undulator (UA)	23	72	2.74
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
85-mm wiggler (WA) (removed to SLAC)	1	28	9.50[*]
Elliptical wiggler (16 cm)	1	18	K_y=14.7[†] $K_x \leq 1.4$
Circularly polarized undulator (12.8 cm)	1	16[**]	$K_y \leq 2.86$ $K_x \leq 2.75$

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 15.5 mm gap. Output power would be too high at smaller gap.
† at 24 mm gap (the device minimum). Values are for peak K, not K_{eff}
¥ at 8.5 mm gap.
** In addition to this, there are separate correctors at both ends.

APS Low-Emittance Lattice (Center of ID Straight Sections)

Storage ring energy, E	7.0 GeV
Storage ring current, I	100 mA
Beam energy spread, $\delta E/E$	0.096%
Horizontal emittance, ε_x	3.5×10^{-9} m-rad
Vertical remittance, ε_y	3.5×10^{-11} m-rad
Coupling constant	1%
Horizontal beta function, β_x	14.4 m
Vertical beta function, β_y	4.0 m
Dispersion function, η_x	0.124 m
Horizontal beam size, σ_x	254 μm
Vertical beam size, σ_y	12 μm
Horizontal beam divergence, σ_x'	15.6 μrad
Vertical beam divergence, σ_y'	3.0 μrad

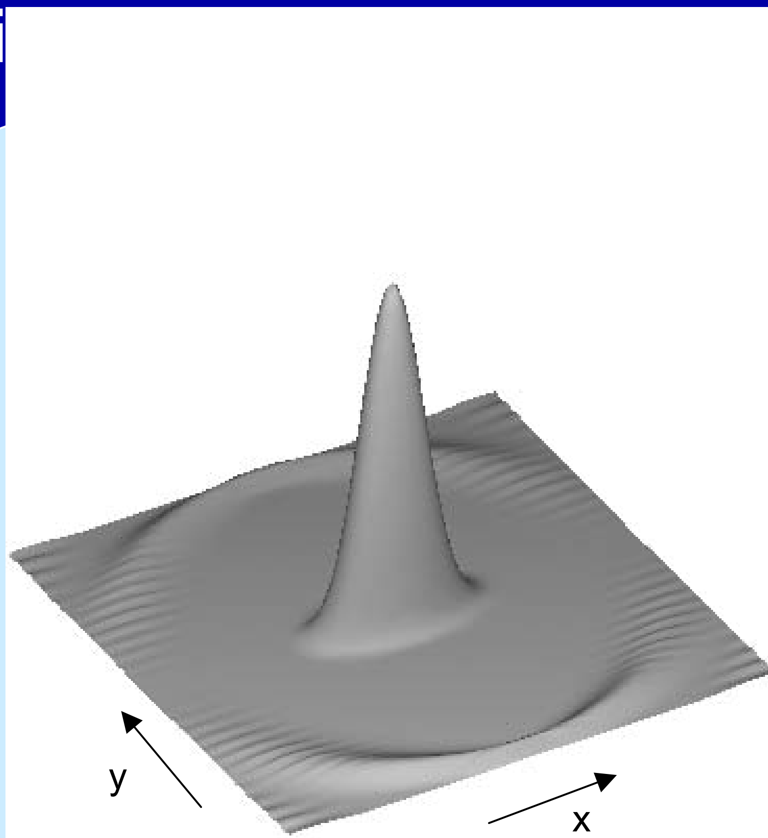
Undulator A In the Magnetic Measurement Laboratory

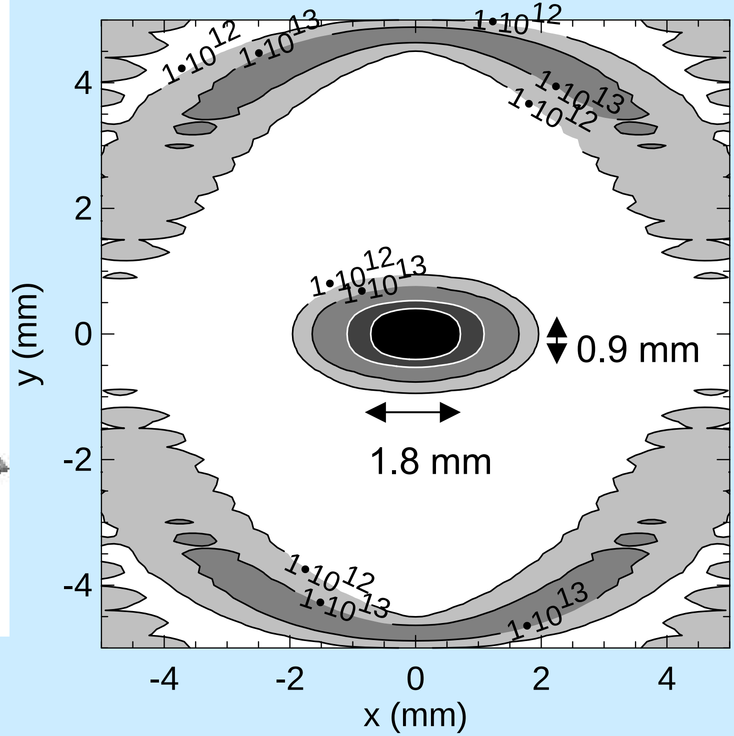
Magnetic Tuning

- All IDs are measured at the APS before installed in the ring
- Initial devices had been tuned by the manufacturer so we just tweaked …
- Today devices are assembled by vendor and shipped unmeasured. We do all tuning.
- Tuning of planar devices has become routine

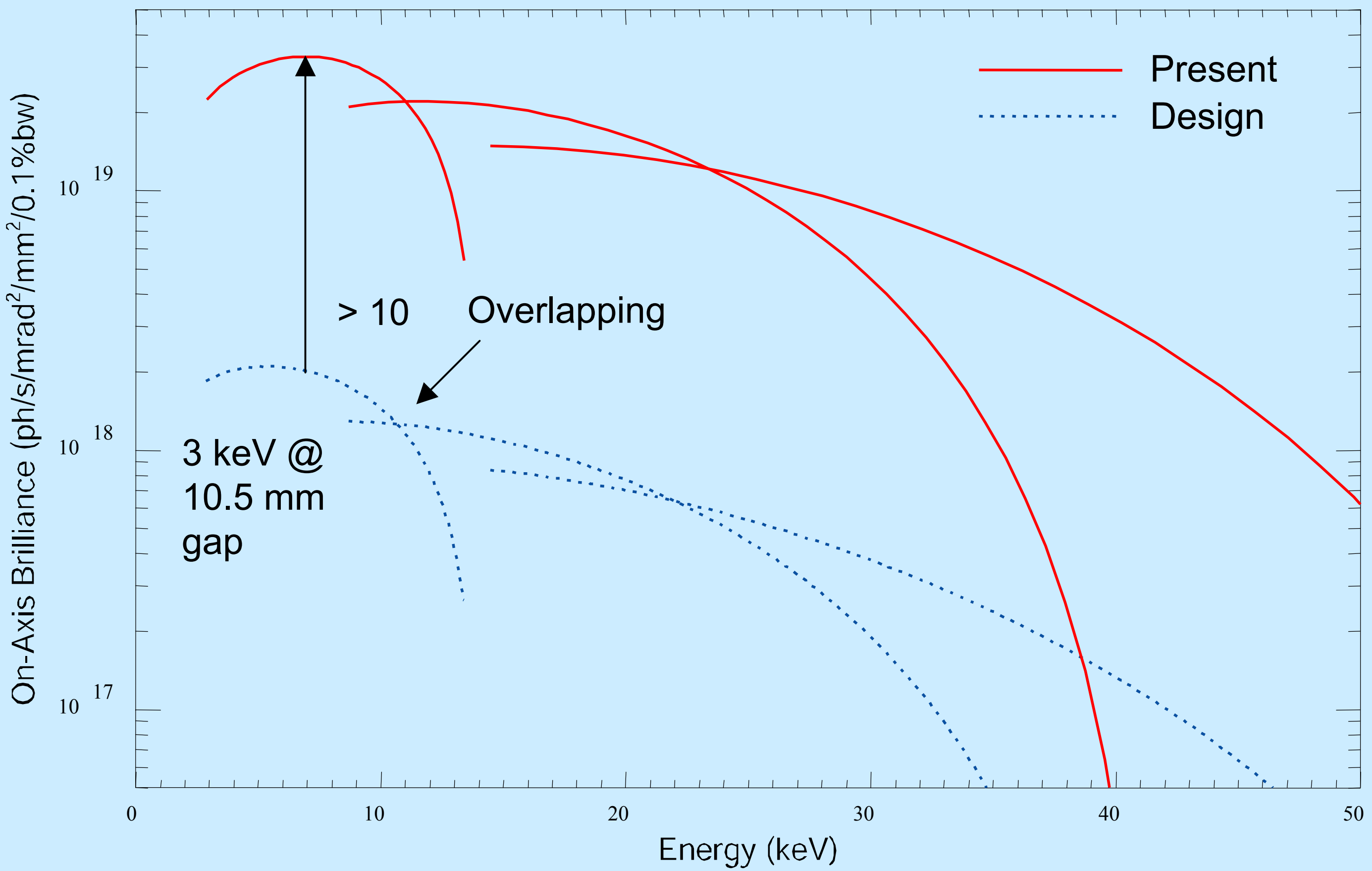
UA: Photon Distribution at 30 m (undulator at closed gap 10.5 mm)

- First harmonic at 3 keV
- Tracing peak intensity vs. gap (energy) -> on-axis bri



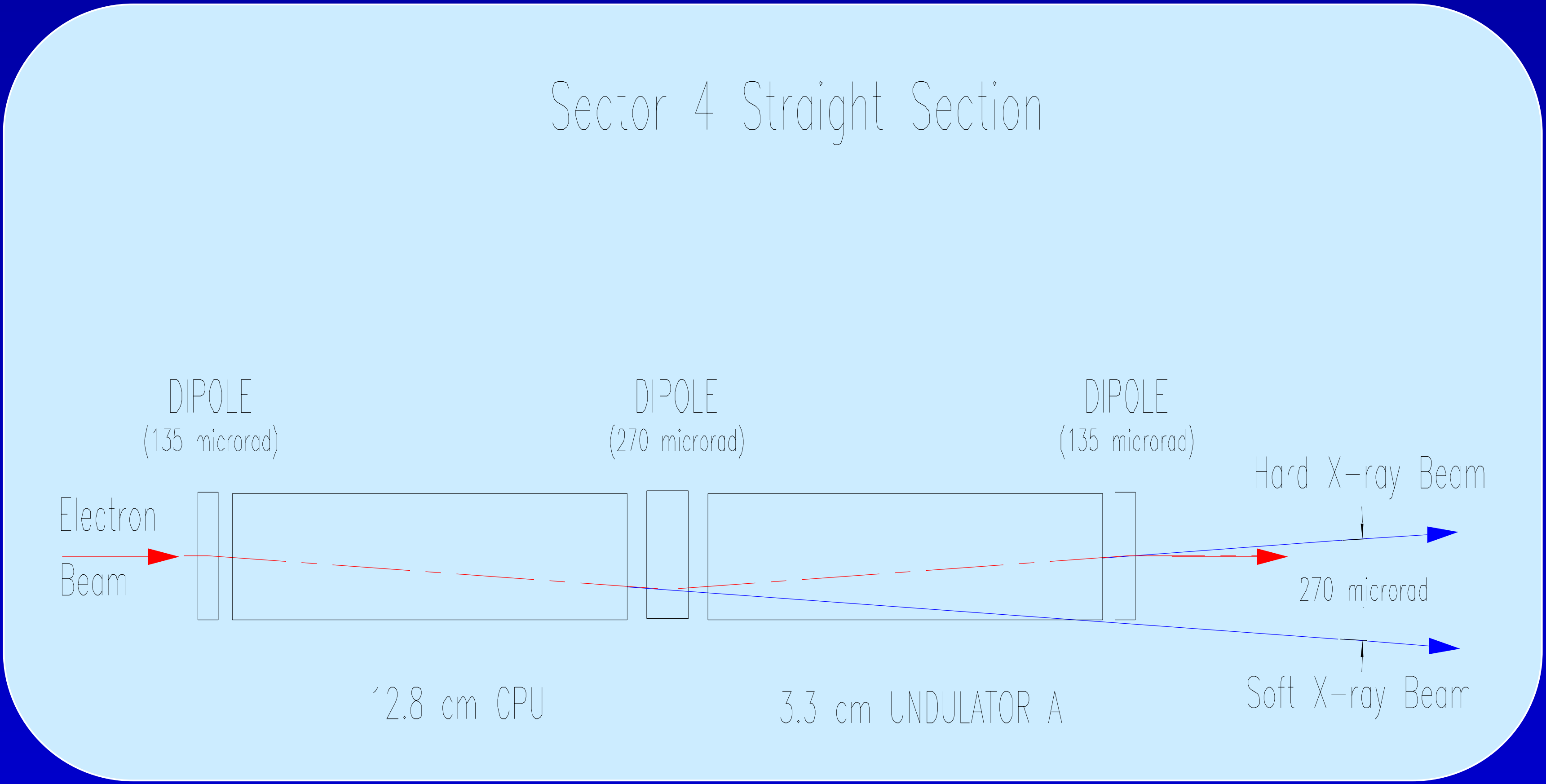


Undulator A On-axis Brilliance Tuning Curves—Past and Present



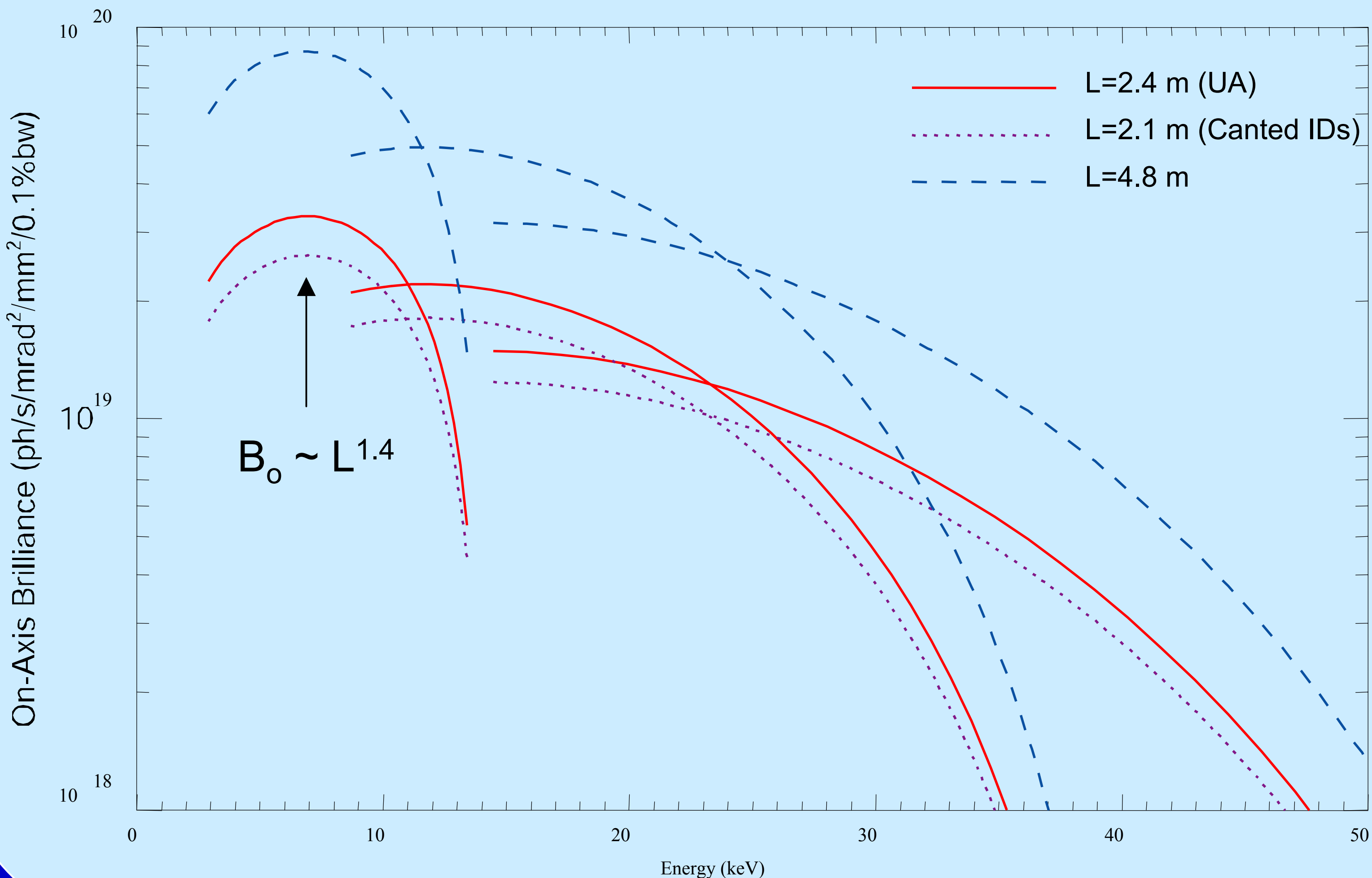
Two IDs in Tandem

"Dogleg" in sector 4
Same Idea for New 2.1-m-long "Canted IDs"
(but with larger separation angle 1 mrad)

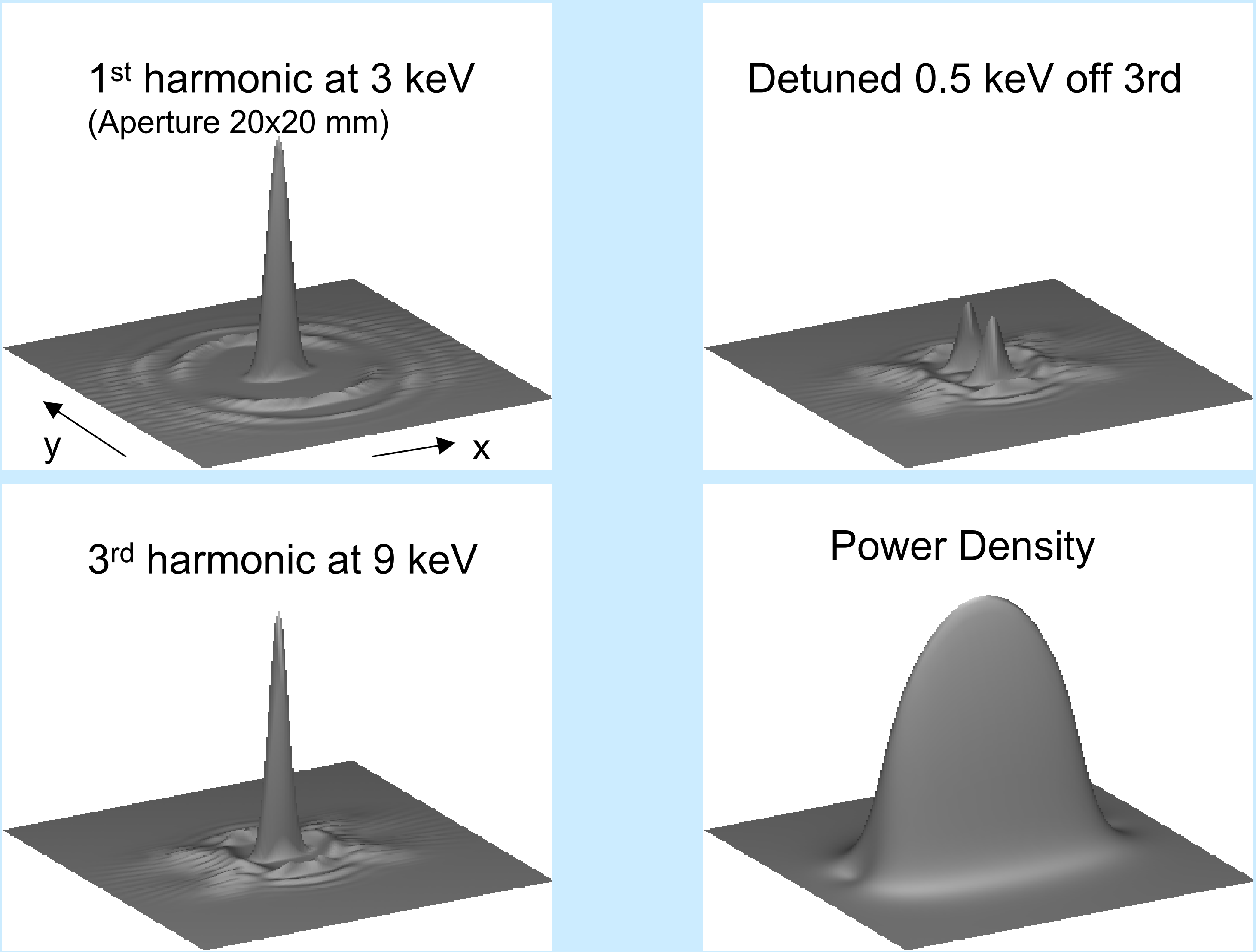


On-axis Brilliance vs. Undulator Length (3.3-cm period)

Photon Source



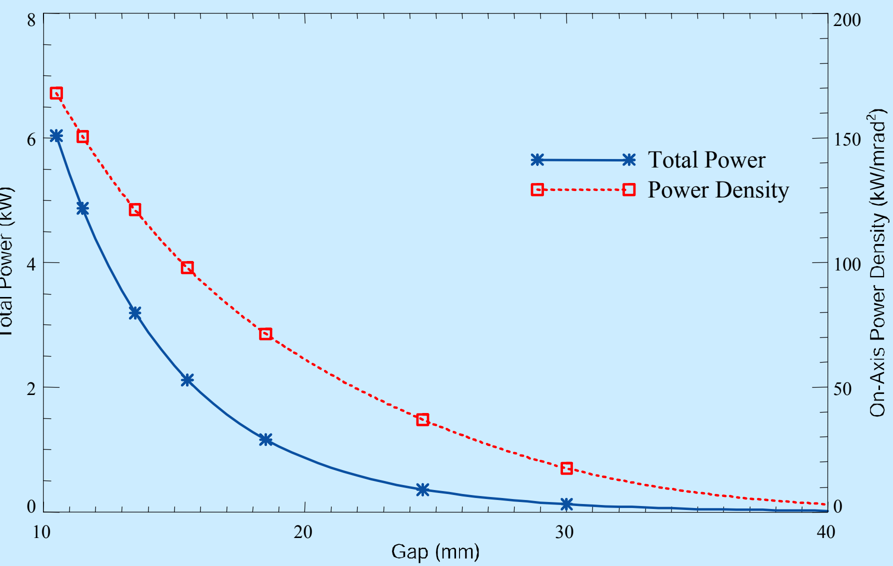
UA: Spectral Power and Power Density (closed gap; @ 30 m)



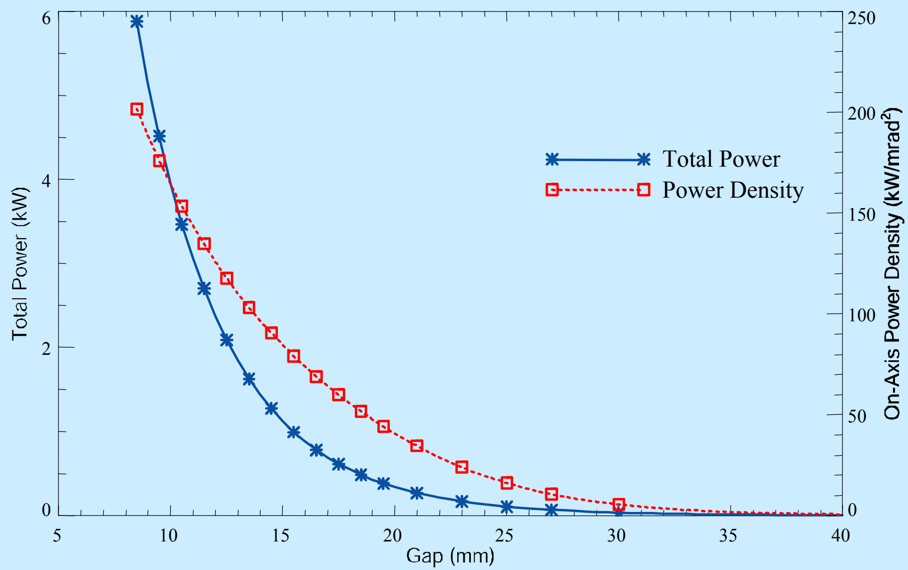
Total Power and On-Axis Power Density

- Limits today: ~7 kW, ~200 kW/mrad^2

Undulator A (2.4 m)

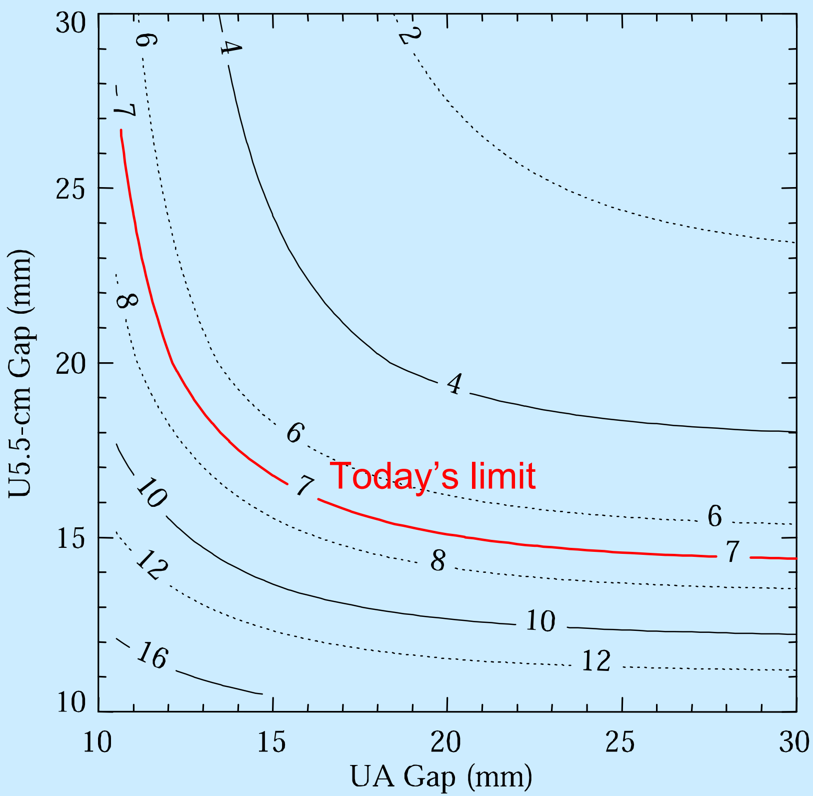


U2.7 cm

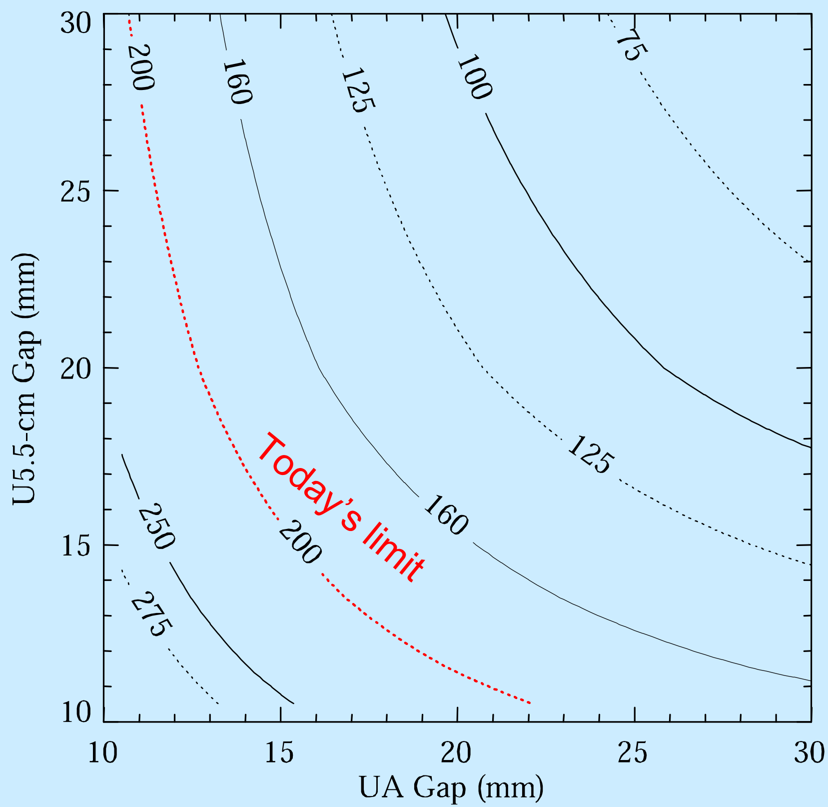


Total Power and On-axis Power Density vs. Gap for two Undulators combined (sector 2)

Power (kW)



On-axis power density (kW/mrad^2)

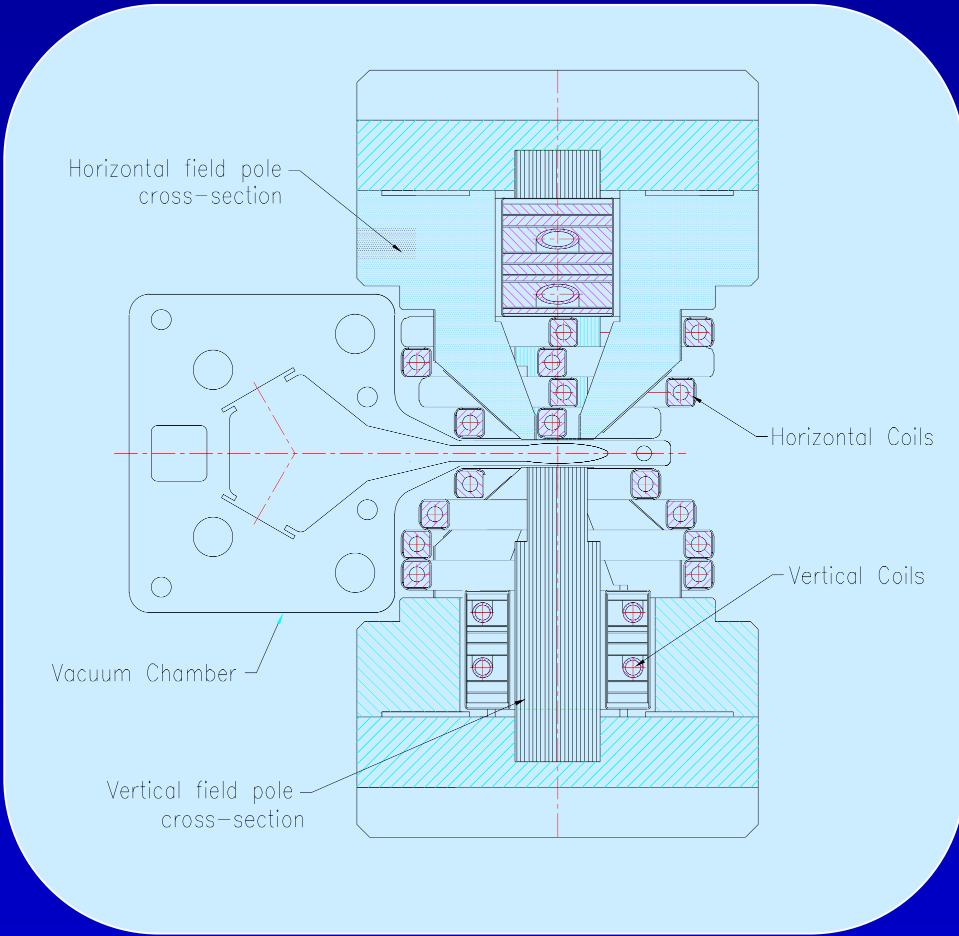


New Front-End Design for Increased Power Loads

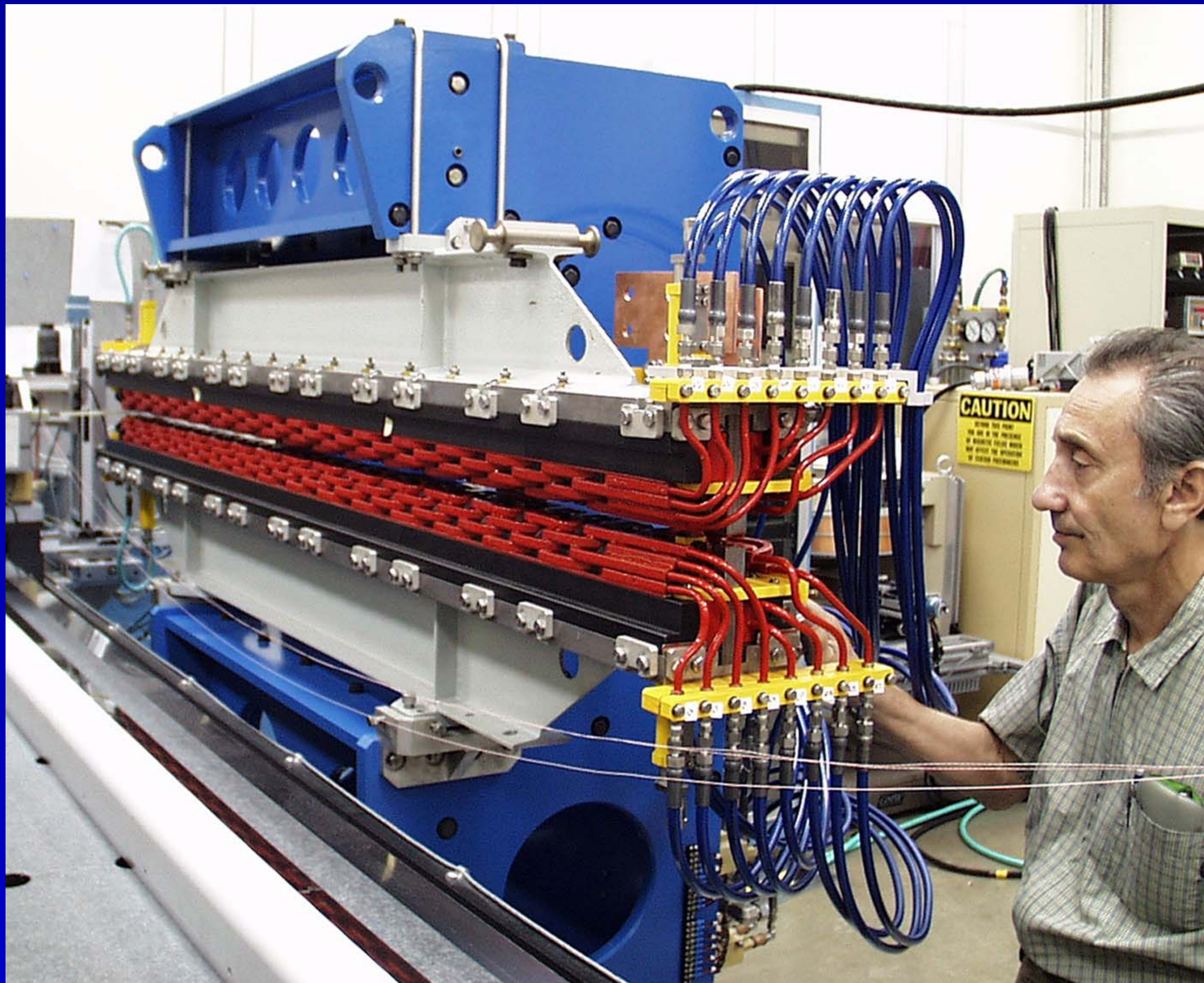
- New front-end design for Nano-CAT and IXS-CAT underway
- Total power ~ 20 kW, on-axis power density ~ 600 kW/mrad^2 (~ 3x above today's limits)
- New shutters and masks capable to withstand power from two tandem Undulator As at closed gap (10.5 mm) at 180 mA beam current

Circularly Polarized Undulator (shown in cross-section)

- 400-3000 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

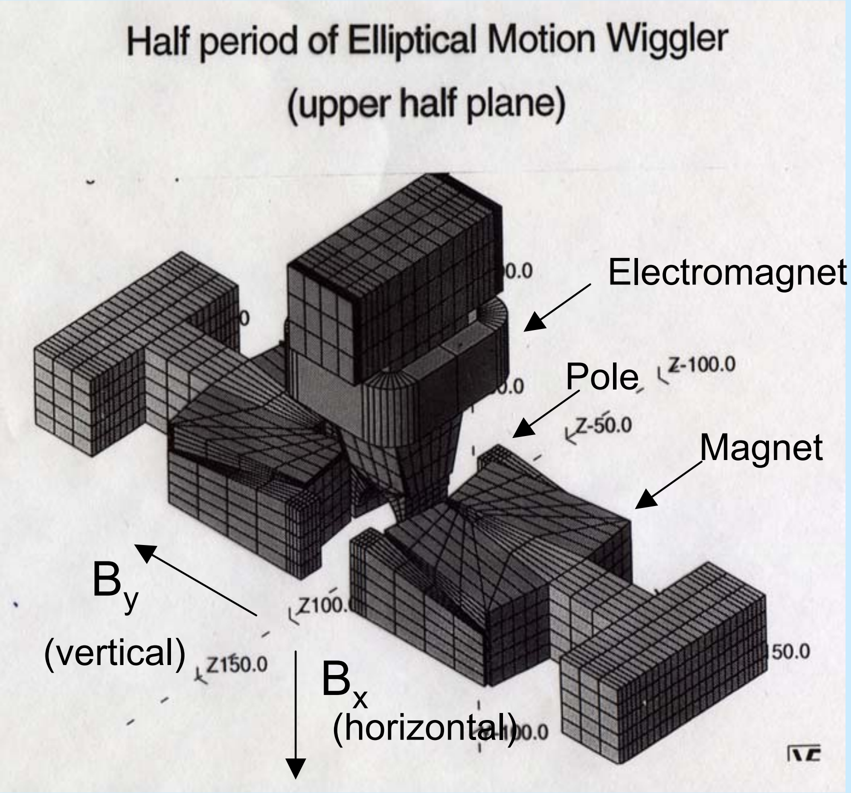


Circularly Polarized Undulator in Magnetic Measurement Laboratory



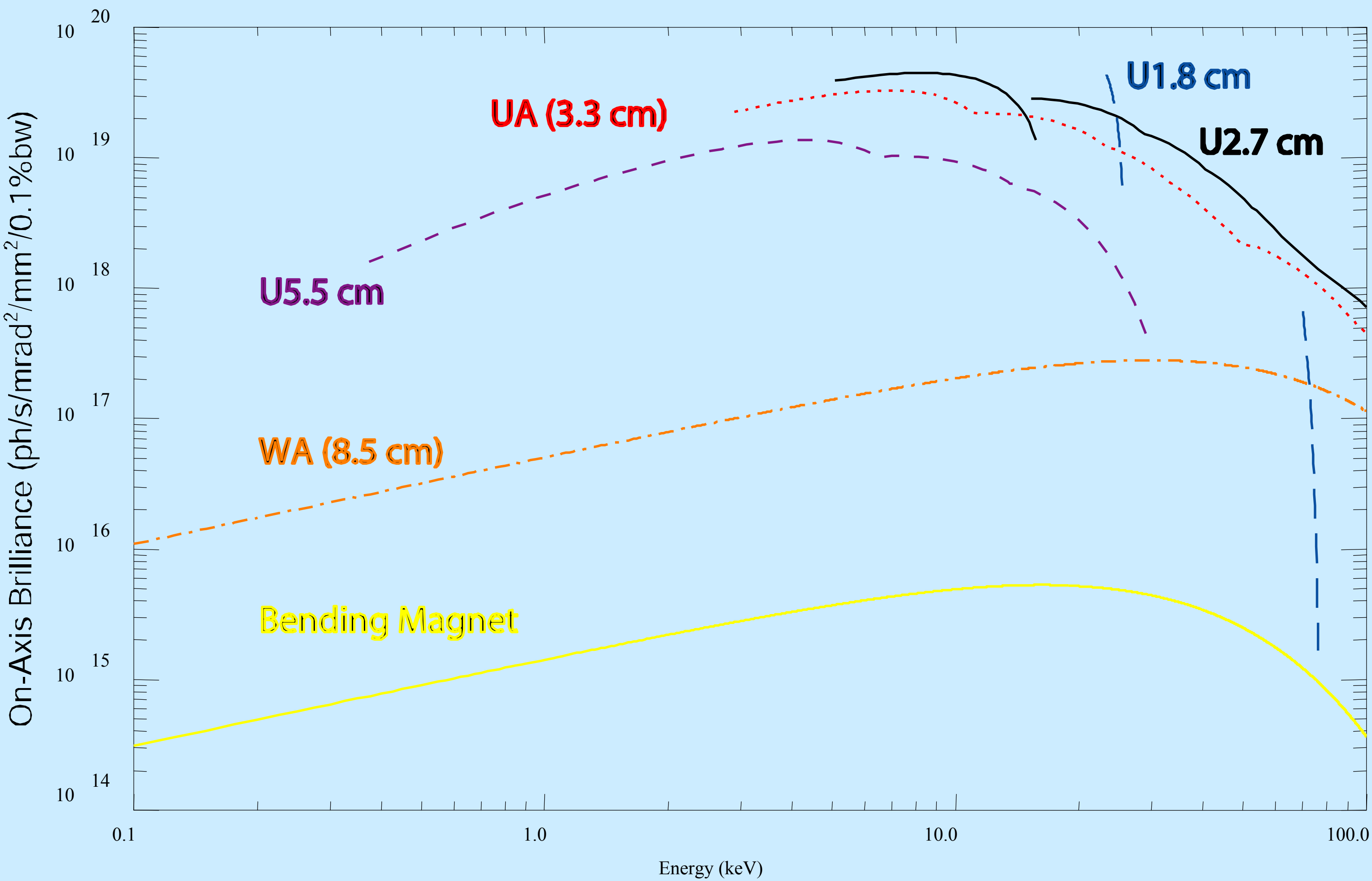
Half Period of EMW

- Critical energy ~ 32 keV -> high photon flux 10 – 100 keV
- Elliptical polarized light on-axis with Pc (degree of circular polarization) ~ 90%
- Linear horizontal polarized light off-axis (in the vertical plane ~ ± 1/γ)



On-axis Brilliance for APS Devices for Today's Low-Emittance Lattice

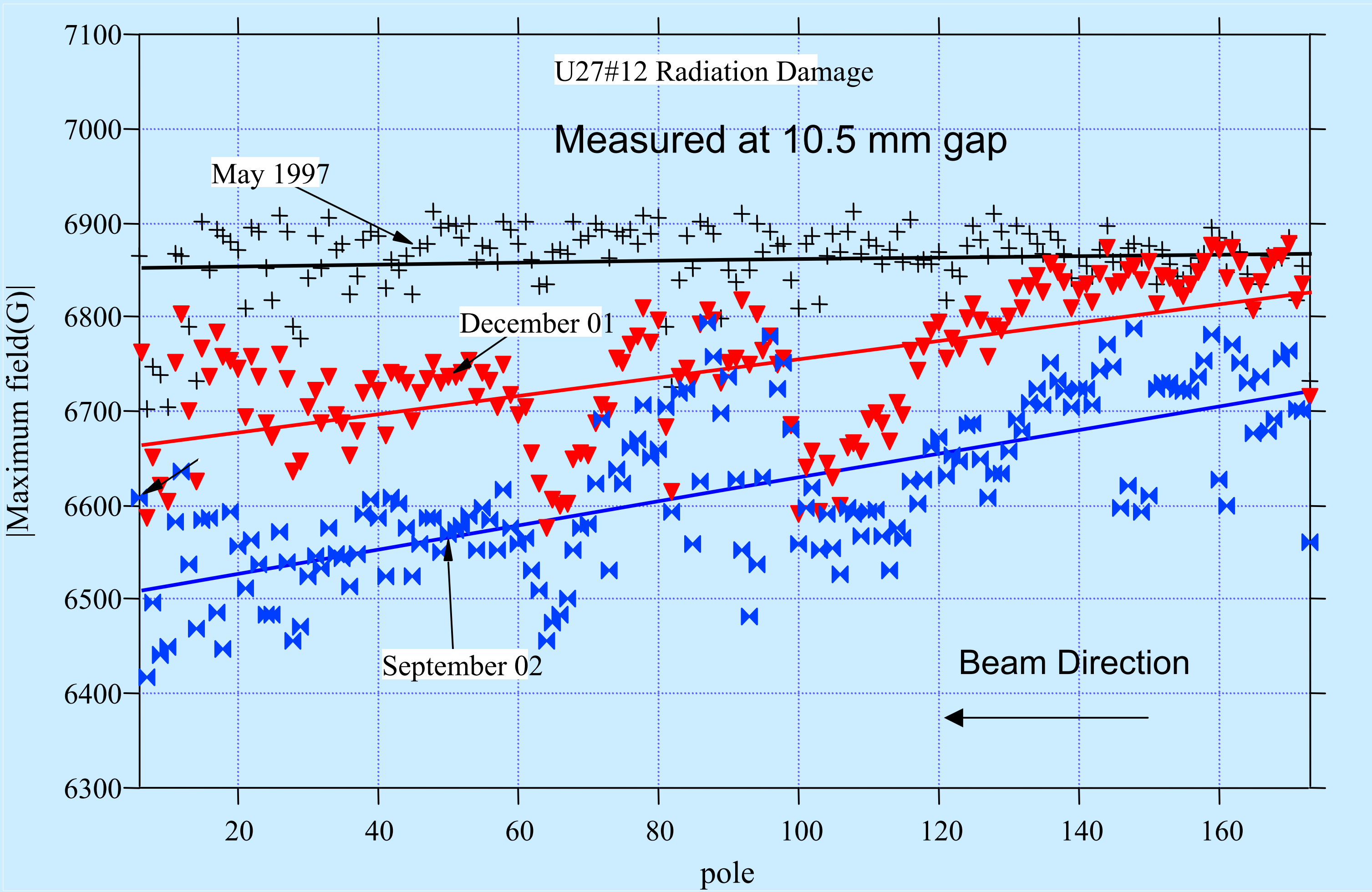
Photon Source



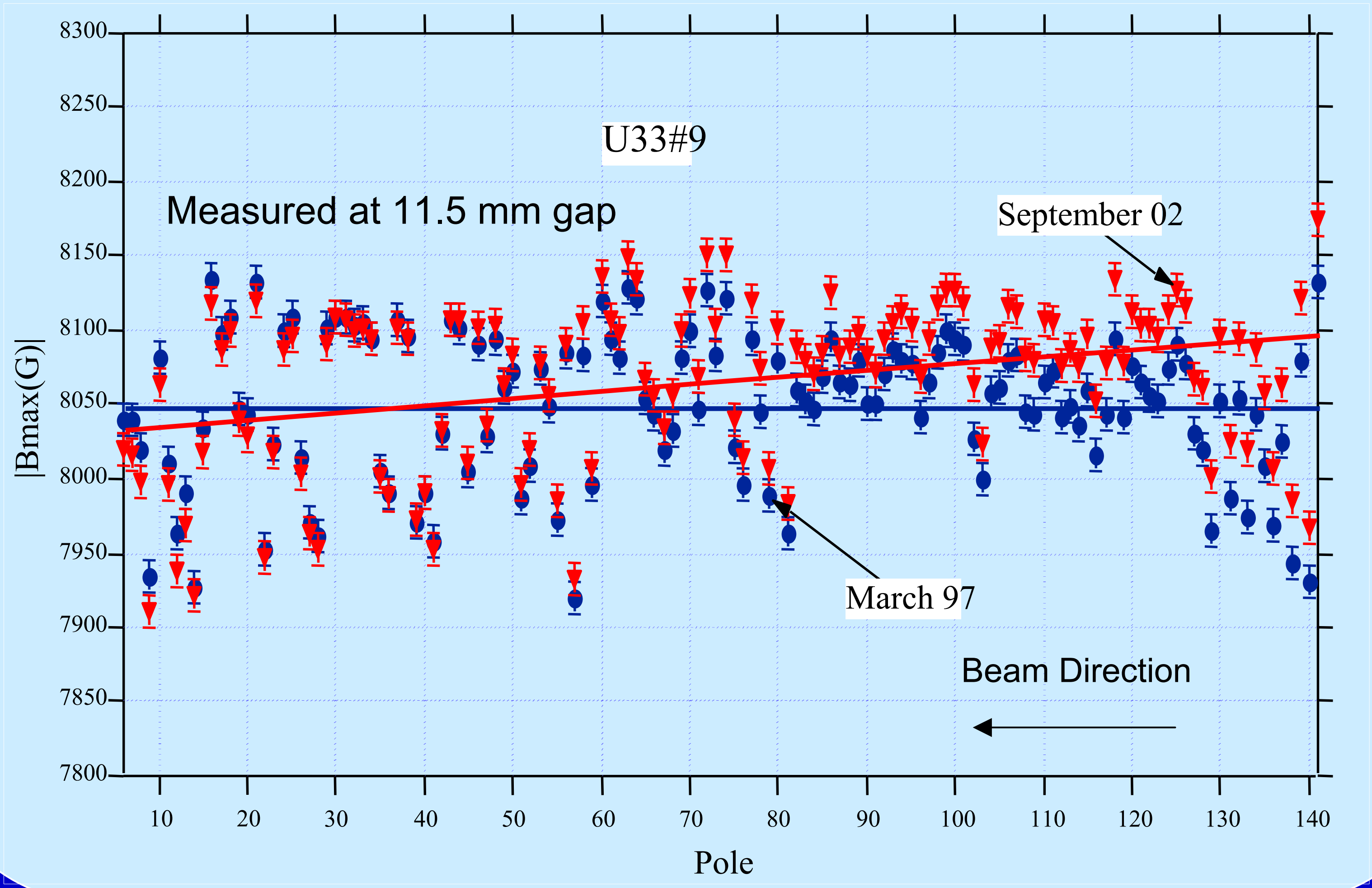
Radiation Damage and Radiation Monitoring

- Radiation damage has been seen; worst in sector 3
  - First small-gap vacuum chamber after injection
  - Damage began after top-up started
  - Decreases the intensity of the high harmonics
- Radiation monitoring
  - TLDs in the past
  - Alanine dosimeters today

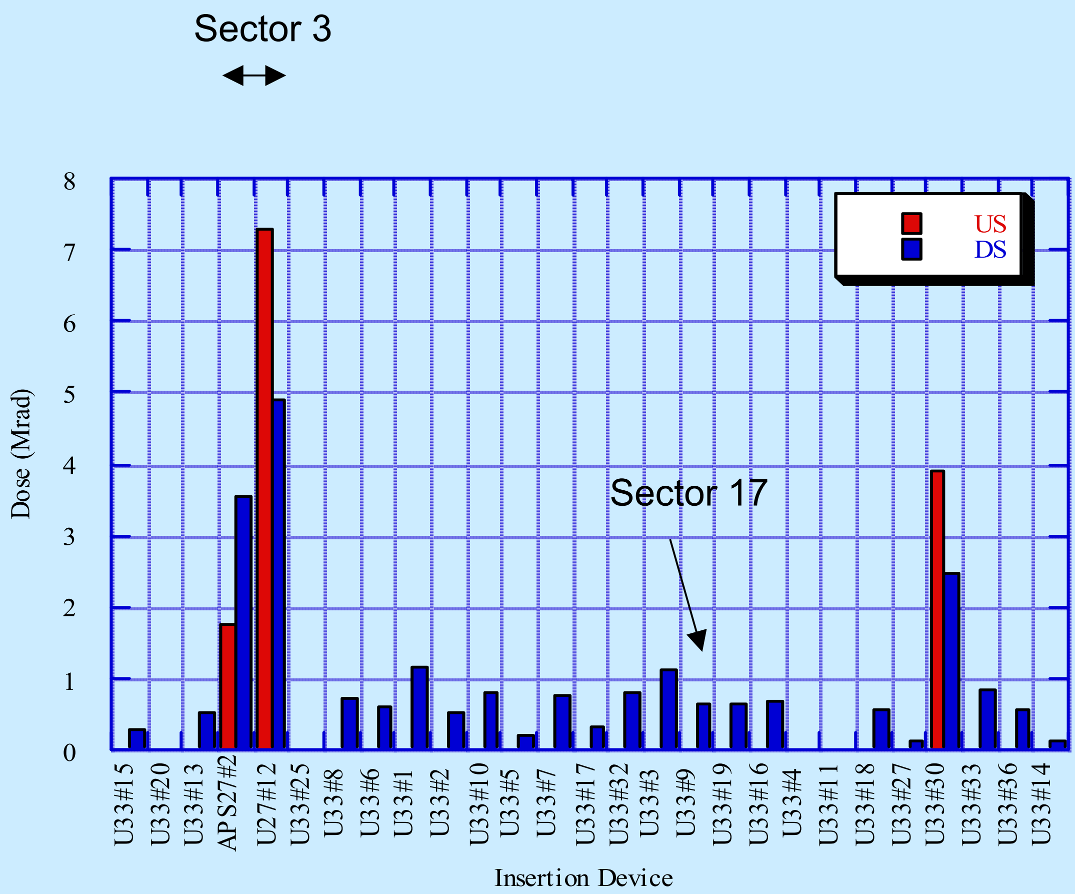
U27#12 Radiation Damage Seen (sector 3 DS): 1997, 2001, 2002



U33#9 Small Changes Seen (sector 17): 1997, 2002



Measured Absorbed Dose Using New Alanine Dosimeters for Run 2002-2 (range: up to 20 Mrad)



U27#12 **Gap 10.5mm** **Sector 3 DS**

Date	RMS Phase error	3rd harm., % of ideal	notes
1997 June 23	5.45	82.6	reference
2001 Dec. 31	36.5	35.2	damaged
2002 Jan. 3	9.29	69.0	tuned, taper 0.160mm
2002 May 6	14.14	52	more damage
2002 May 7	10.81	62.4	tuned, taper 0.025mm
2002 Sept 12	15.00	49.2	more damage
2002 Sept 13	6.9	75.2	tuned, add 0.05 mm taper

U33#15 **Gap 11.5mm** **Sector 1 DS**

1997 Sept. 9	2.88	89.8	reference
2002 May 2	5.91	82	some damage
2002 May 3	5.14	84	tuned, taper 0.040 mm

APS27#2 **Gap 11.5mm** **Sector 3 US**

2000 June 23	2.62	91.5	reference
2002 Jan. 8	10.79	64.2	damaged
2002 Jan. 8	3.67	86.1	tuned, taper -0.150 mm
2002 Sept 18	32.9	30.9	more damage
2002 Sept 18	5.90	74.1	tuned, add -0.4 mm taper

U33#9 **Gap 11.5mm** **Sector 17 DS**

1997 Sept.3	4.86	86.1	reference
2002 Sept 25	12.99	58.0	damaged
2002 Sept 25	5.78	82.8	tuned, taper 0.09 mm

U33#3 **Gap 11.5mm** **Sector 15 DS**

1997 Sept.	4.54	91	reference
2002 May	5.14	89	still OK

U33#4 **Gap 11.5mm** **Sector 20 DS**

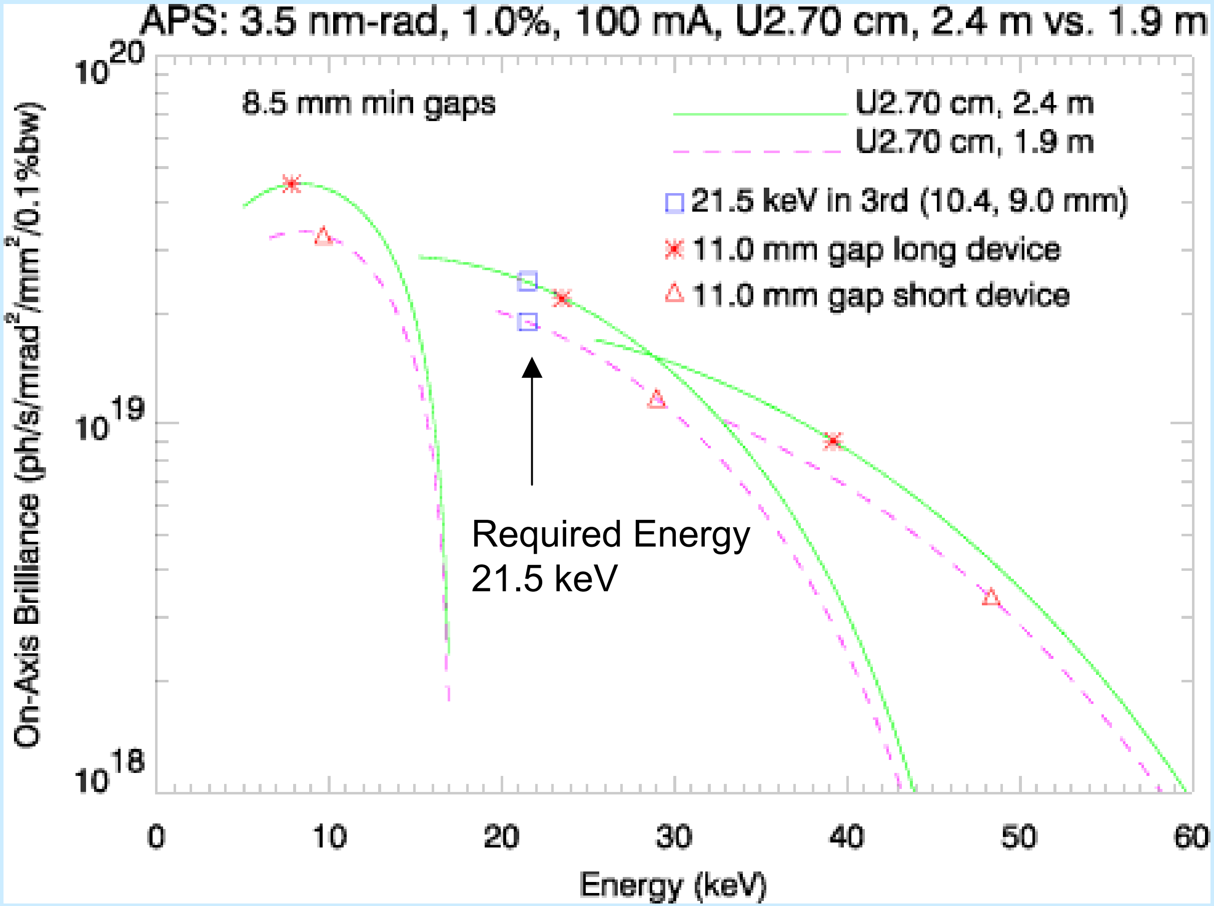
1996 Sept	3.44	91.6	reference
2002 Sept	3.37	92.6	still OK

Radiation Damage: Action Plan

- Level of damage
  - Unless you operate routinely at very small gaps (< 11 mm) there are only small or no damages seen to date
- IDs are checked/retuned routinely in MM laboratory
- A magnetizer is being purchased for remagnetizing magnets
  - IDs will be disassembled, remagnetized, reassembled and retuned; U27#12 is first
  - A replacement for U27#12 will be purchased
- Dosimetry measurements of the IDs (both US and DS ends) with new Alanine dosimeters are becoming routine—started in 2002 (in addition to TLDs)
- Future irradiation testing facility at the booster under investigation

Why Small Gaps?—Example Undulator 2.7 cm

Photon Source

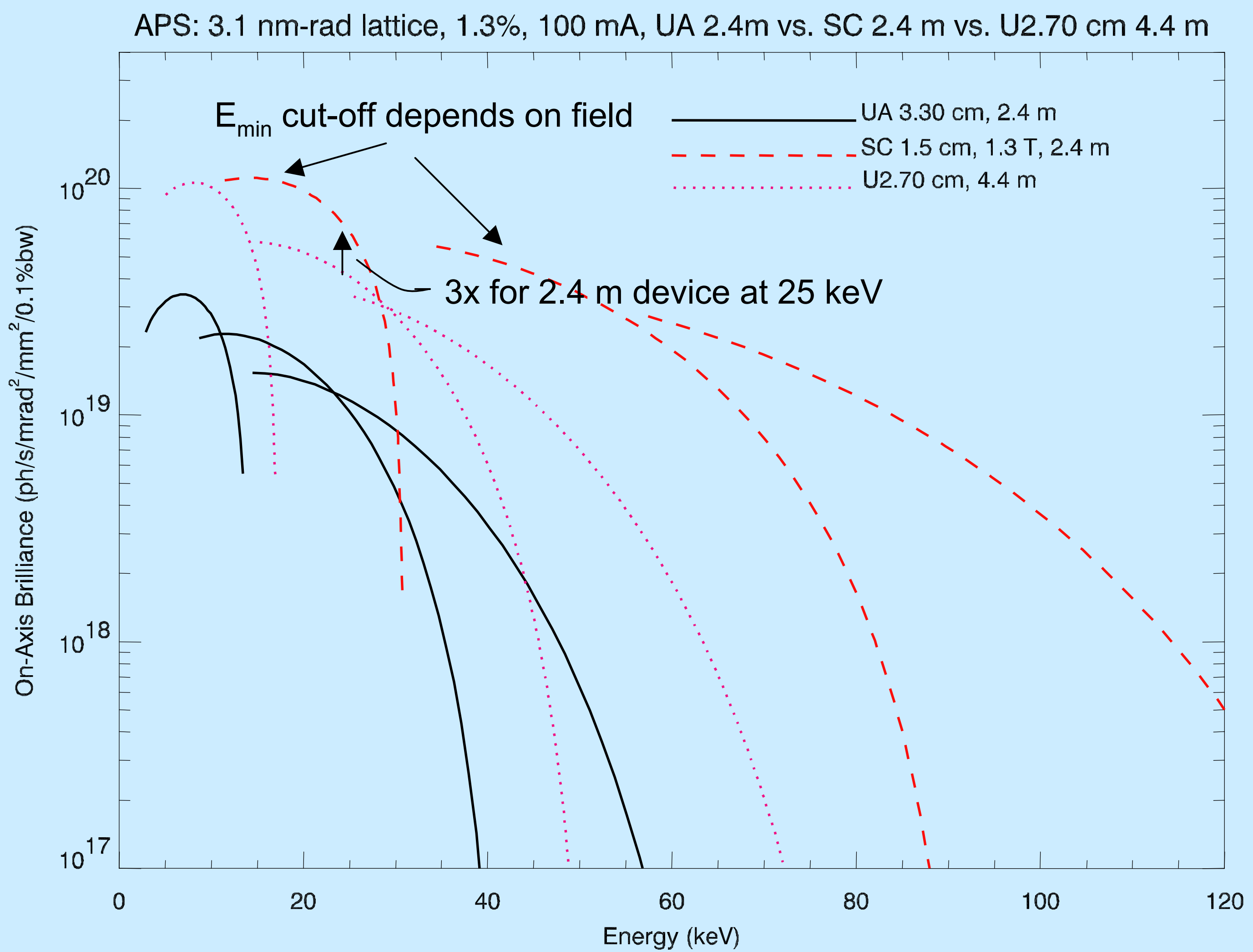


Alternatives to Small-Gap Vacuum Chambers

- In-vacuum undulators
  - Gain 2 mm in gap because of two 1-mm thick vacuum chamber walls are gone
  - But magnets need higher coercivity to survive additional radiation exposure
  - Higher coercivity magnets have weaker remanence fields (~90% for N32Z-NdFeB; ~82% for R26SH-SmCo) -> need smaller gap (~1.2 mm for NdFeB, 2.1 mm for SmCo—assuming 3.3-cm period)
- Superconducting undulators
  - 15 mm period; tunable ~15 – 25 keV in the first harmonic
  - Gap ~8 mm

Superconducting Undulator vs. UA (2.4 m) and U2.70 cm (4.4 m)

Photon Source



Undulator A Reference: TB-45

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ANL/APS/TB-45

Undulator A Magnetic Properties and Spectral Performance

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