Impact of Mini-Gap Undulators on Beam Dynamics and Operations at NSLS

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Abstract

The NSLS has been developing in-vacuum mini-gap undulators (MGUs) for well over a decade [1], and, at 3.3 mm, still holds the record for the smallest ID gap of any operating facility. Presently the NSLS X-ray ring has two MGU devices installed at beamlines X13 and X29, respectively; the installation of a 3rd MGU (possibly superconducting) at X9 is planned in the future. So far the impact of the MGUs on the machine has been small and predictible: twice a day the gap has to be opened to 10 mm for injection; after ramping to the operating energy of 2.8 GeV, closing the gap to 3.3 mm reduces the beam lifetime by <10 %. Recent installation of the X29 MGU seems to have slightly increased the tune shift with current, however no collective effect limitations are observed so far. Single bunch currents of up to 125 mA are still possible, with the (administrative) limit set due to heat in vacuum chamber components unrelated to MGUs.

The NSLS is vigorously pursuing the design of NSLS-II – a new ultra-low emittance 3 GeV 3rd generation storage ring with a top-off injector to eventually replace the existing facility [2]. To achieve the 1000-fold increase in undulator brightness NSLS-II will rely heavily on superconducting MGUs. Unlike the present X-ray ring, the MGUs will have a major impact on NSLS-II, affecting the beam dynamics and the overall design of the machine. A first look at beam dynamics reveals the need for further studies of collective effects due to MGUs, as well as optimization of transitions to the mini-gap chamber.

[1] SMALL-GAP UNDULATOR RESEARCH AT THE NSLS: CONCEPTS AND RESULTS
P. Stefan, S. Krinsky, G. Rakowsky, L. Solomon, D. Lynch, T. Tanabe, H. Kitamura,
Nucl. Instr. and Meth. A, Volume: 412, Issue: 1 July 21, 1998, pp. 161-173

[2] NSLS UPGRADE CONCEPT
B. Podobedov, J. Ablett, L. Berman, R. Biscardi, G.L. Carr, B. Casey, S. Dierker, A. Doyuran, R. Heese, S. Hulbert, E. Johnson, C.C. Kao, S.L. Kramer, H. Loos, J.B. Murphy, R. Pindak, S. Pjerov, J.Rose, T.Shaftan, B. Sheehy, P. Siddons, N. Towne, J.M. Wang, X.J. Wang, L.H. Yu, Proceedings PAC03, 2003

Outline and People

1) History and present status of mini-gap devices at NSLS
2) Mini-gap ID impact on NSLS X-ring
3) NSLS-II at a glance
4) Mini-gap ID impact on NSLS-II
5) Concluding remarks

Early MGU efforts at NSLS

P.M. Stefan, S. Krinsky, G. Rakowsky, L.Solomon, D. Lynch (present/former NSLS)

T. Tanabe, H. Kitamura (SPRING-8)

Present MGUs for NSLS & NSLS-II design/engineering/beam physics

D. Lynch, S.L. Kramer, J.B.Murphy, B.Podobedov, G.Rakowsky, J.Skaritka, J.M. Wang

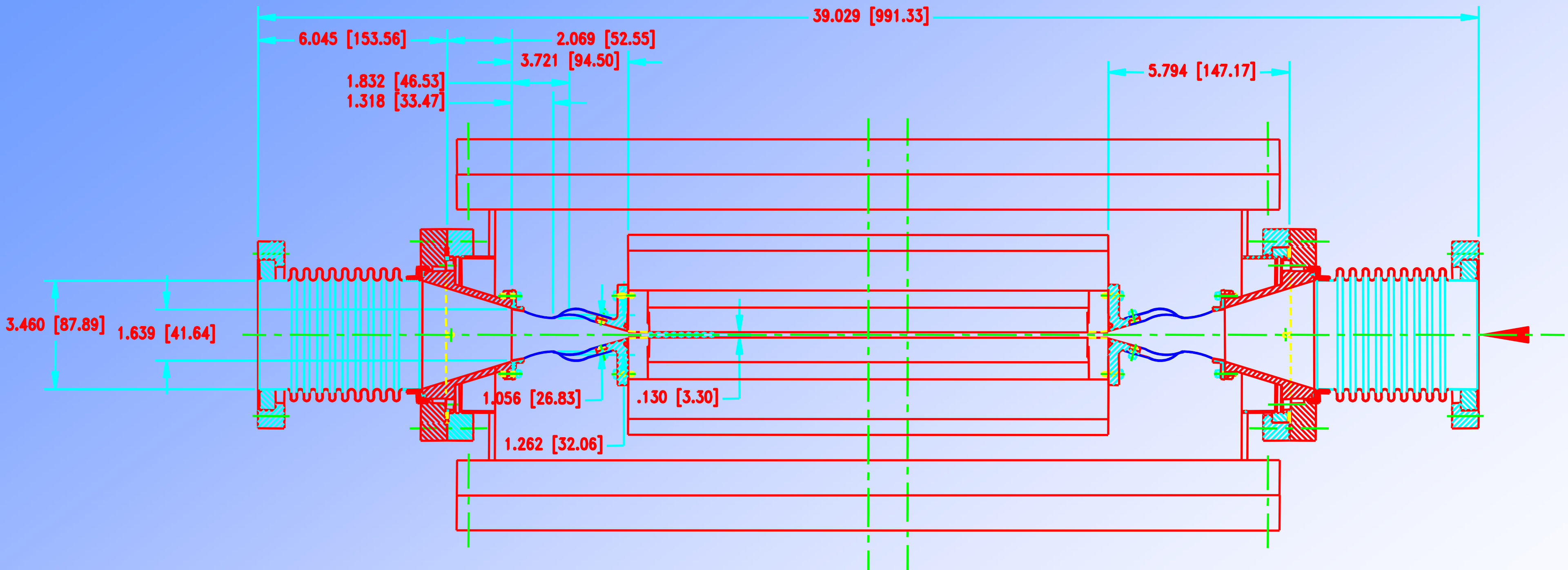
NSLS Mini-Gap Undulator Program

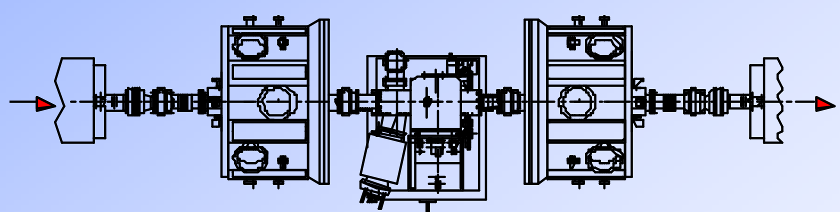
Device / Parameter	PSGU (1993)	IVUN (1997)	MGU (2002)	MGU (2003)
Beamline	X13	X13	X13	X29
Type	Pure PM	Pure PM In-Vacuum	Hybrid PM In-Vacuum	Hybrid PM In-Vacuum
Period λ_u	16 mm	11 mm	12.5 mm	12.5 mm
No. of Periods	18	30.5	27	27
Nom.Mag.Gap	6.0 mm	3.3 mm	3.3 mm	3.3 mm
Peak Field B_u	0.62 T	0.68 T	0.95 T	0.95 T
K_{max}	0.93	0.7	1.1	1.1
Fund. Energy @ 2.8 GeV	3.2 keV	5.4 keV	3.7 keV	3.7 keV

X9

Superconducting MGU?

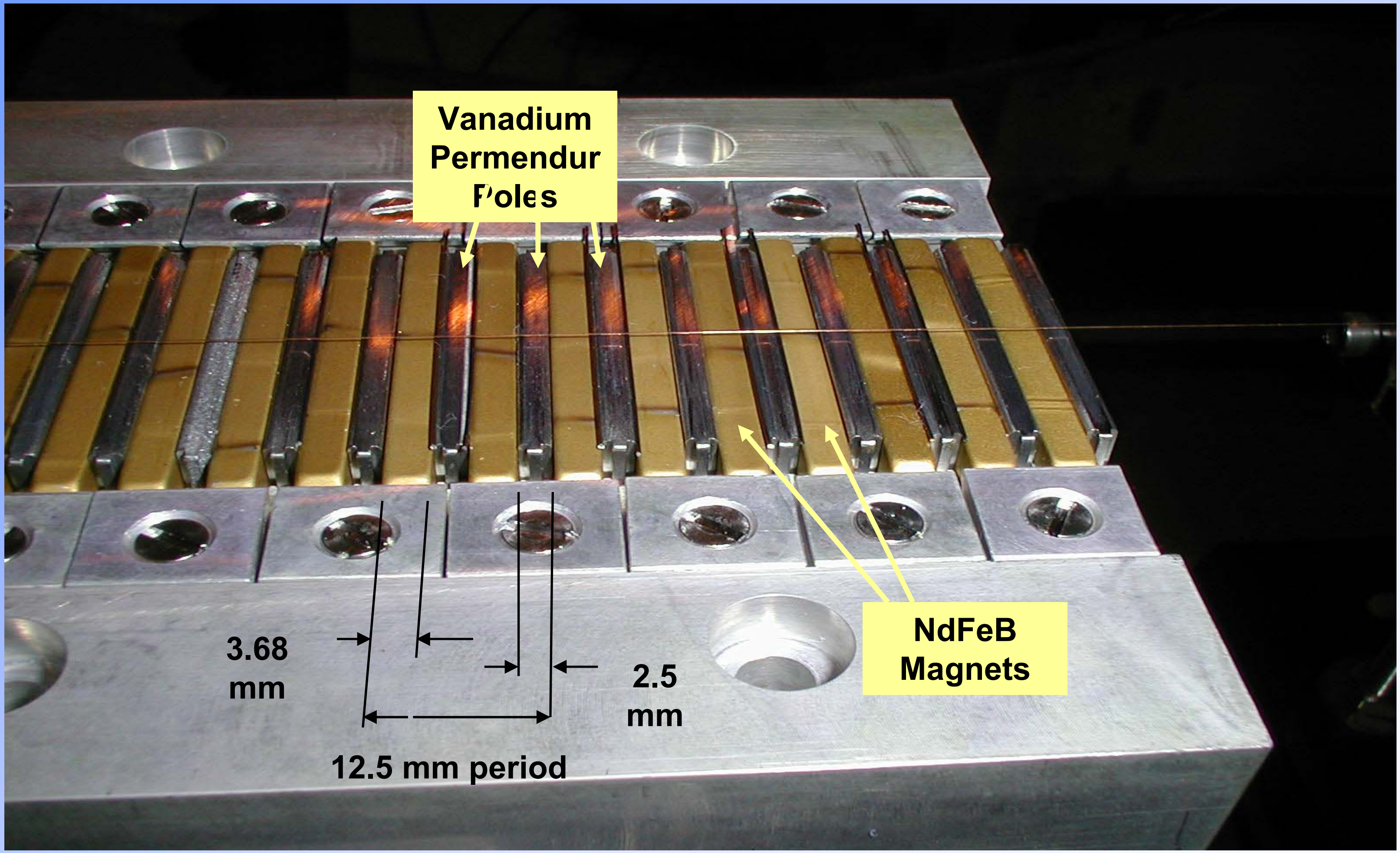
X29 MGU: Dimensions and Location





- Dimensions in inches [mm]
- Variable gap 3-10 mm (3.3 mm nominal)
- Length ~34 cm
- Gap has a small effect on geometric Z(ω)
- "New" undulator straight

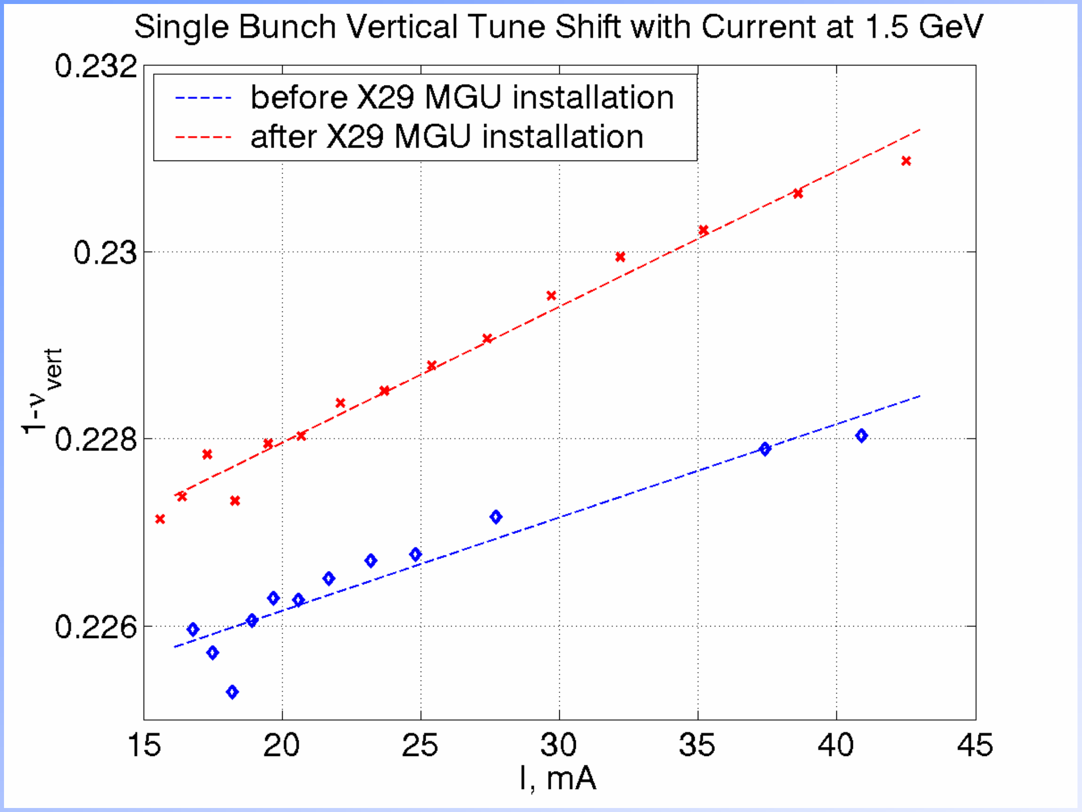
MGU Lower Magnet Array on Pulsed-Wire Bench



MGU Impact on the Machine

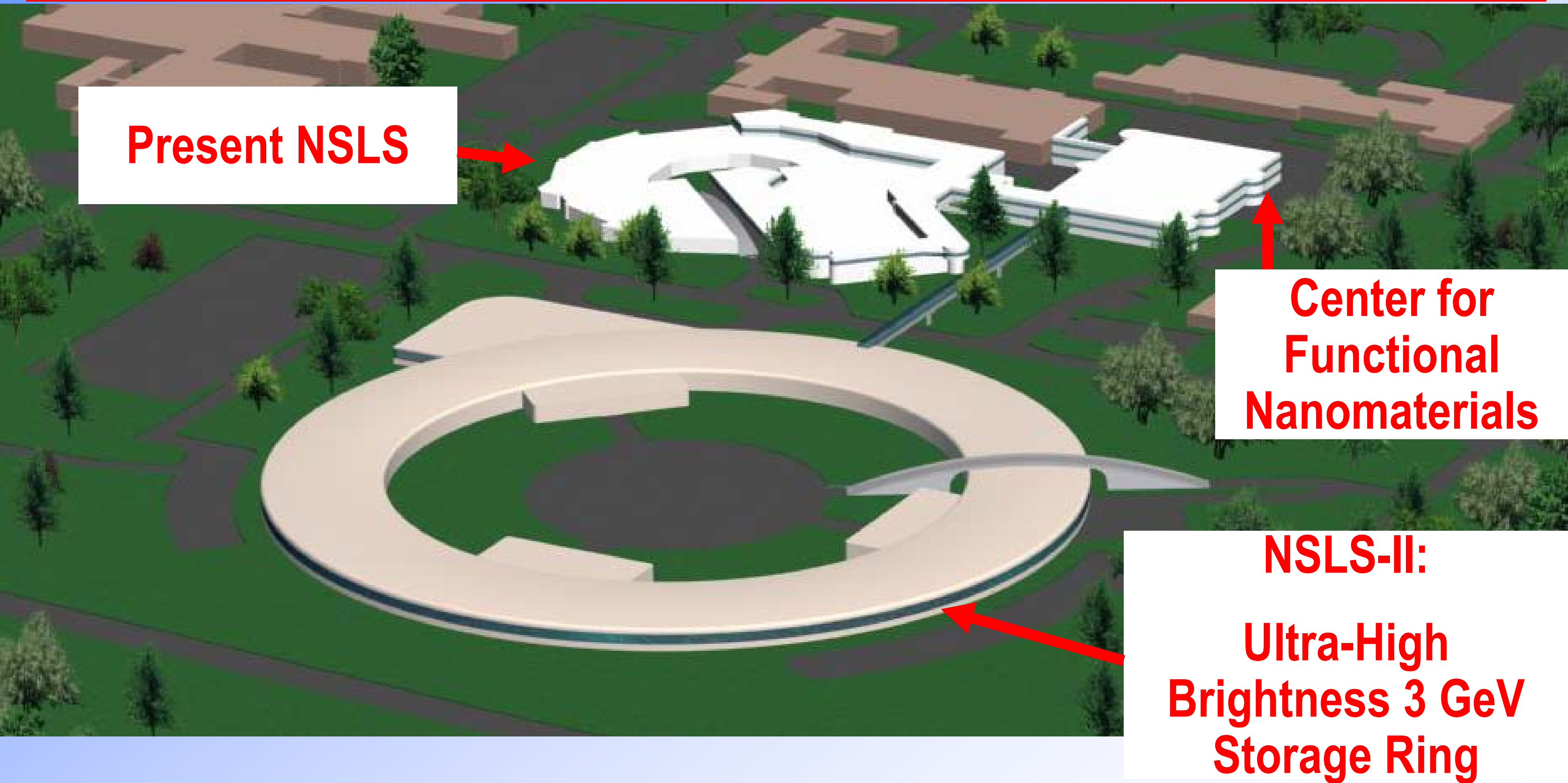
- Gap is open for injections to 10 mm
- Injection with closed gap is slow but possible, some radiation occurs
- At full energy closed gap (3.3 mm) causes ~10% reduction in lifetime
- No collective effect limitations. We can inject and store up to 125 mA single bunch current (administrative limit due to heat elsewhere)
- Gap opening/closure causes:
  - ✓No (measurable) effect on beam trajectory
  - ✓No effect on tunes, beam sizes, etc.
  - ✓No change in the amount of tune shift with current

First Hints for MGU Taper Contribution to the Impedance



- X29 MGU was installed during May 03 shutdown
- Cannot close the gap yet but all the tapers are in
- Now measure higher tune slopes vs. current at low E
- Slopes are still small and are unlikely to cause future problems. (I_{max} <12mA per bunch for regular ops @ 2.8 GeV)

Possible Site Layout for NSLS-II



NSLS-II Motivation and Goals

Background:

- The two rings at the NSLS are entering their 3rd decade of dedicated operation for 2500 users!
- Brighter sources exist in the USA and abroad; in fact with the SPEAR3 upgrade will have the lowest brightness in USA
- Bulk of the light source users reside in 5-20 keV
- Brightness is the driver but average current / flux users are important as well

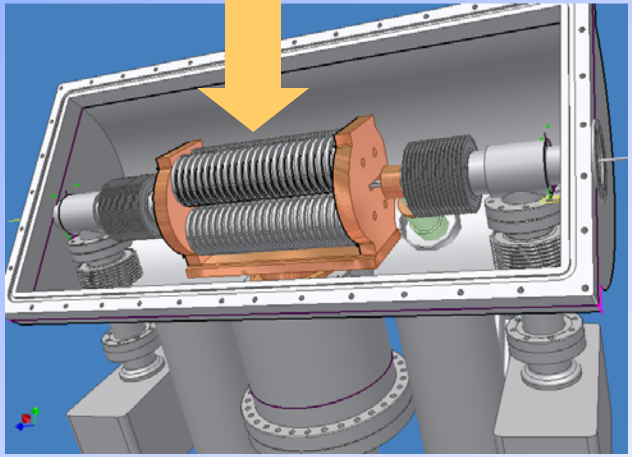
Goals:

- 10^3 increase in undulator brightness in the 5-20 keV range
- without a significant reduction in flux
- increase the insertion device capacity from 5 to ~20,
- all done for a reasonable cost -> circumference & energy

Superconducting Mini Gap Undulators

Why SC MGU?

- Short-period (~ 1 cm) is a must to generate tunable, multi-keV photons in medium-energy rings
- Higher fields, higher K (>2.2), full tuning range (3:1) attainable only with SC technology



NSLS SCU cryo-cooler design, J. Skaritka

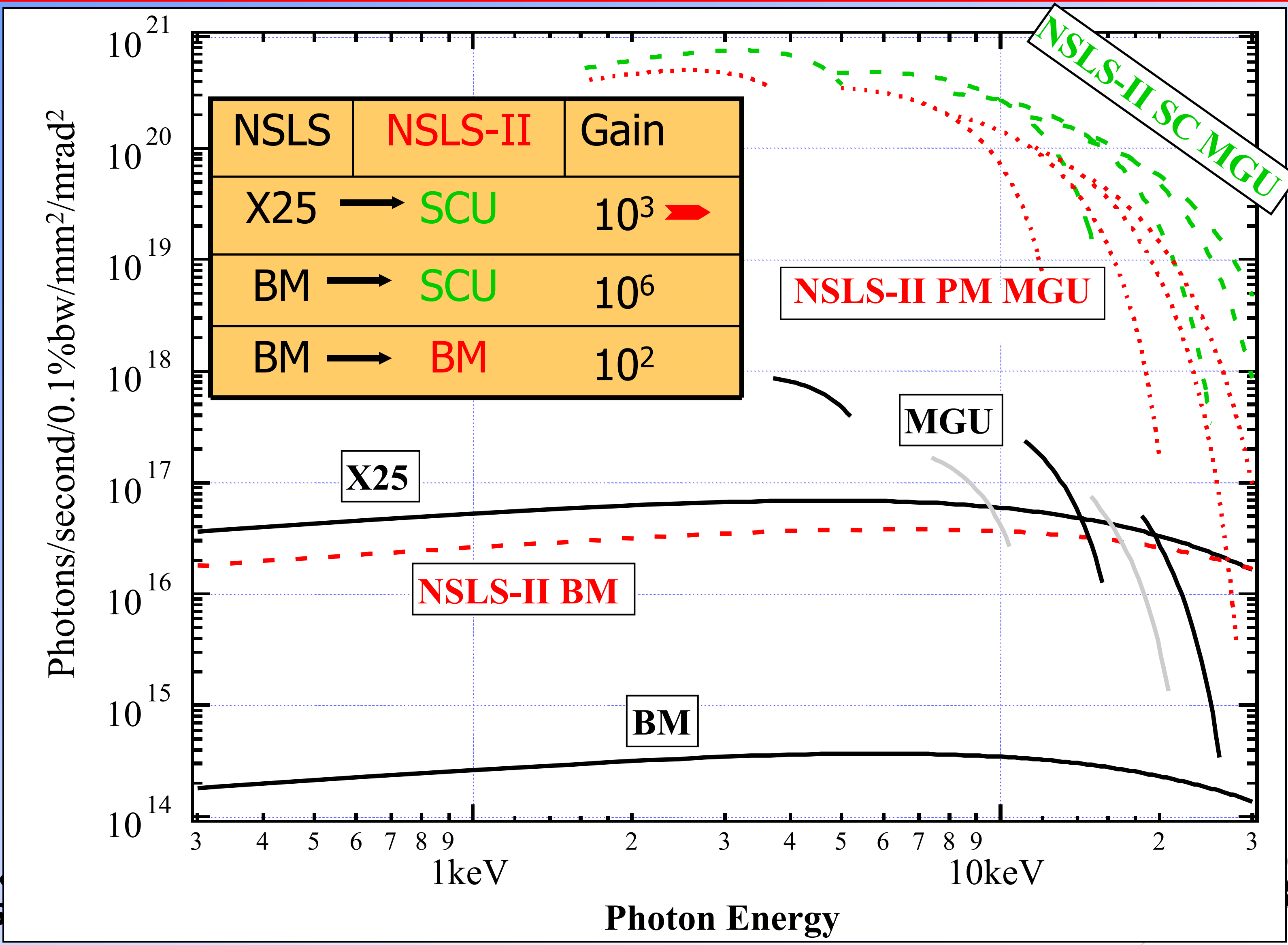
Will it be there?

- NSLS pioneered PM MGUs.
- NSLS and BNL SC Magnet Division are setting up a SC MGU testing facility.
- NSLS joined SLAC, ALS & APS in collaboration in SC MGU R&D.
- Parallel R&D efforts in Europe (ANKA, ACCEL) may lead to commercial sources of SC MGUs.
- ⇒Confidence in availability of SC MGU in time for NSLS-II.

NSLS-II SC MGU

g=5 mm, λ_u=15 mm, K~2.2, n=1-11

Brightness Curves



NSLS		NSLS-II	Gain
X25	→	SCU	10^3
BM	→	SCU	10^6
BM	→	BM	10^2

Ring and MGU Parameters: NSLS X-ray vs. NSLS-II

Nominal Energy	2.8 GeV	3 GeV
Circumference (lattice)	170 m (8 fold DBA)	523 m (24 fold TBA)
Natural Emittance / Coupling	~60 nm / 0.2 %	1.5 nm / 0.5% (1 Å DL)
RF Frequency	53 MHz	500 MHz
Natural Bunch Length (rms)	150 ps	13 ps @ 3% rf bucket
Maximum Current	280 mA	500 mA
Injection	twice/day @ 0.74 GeV with MGUs open	top-off
Number & type of MGUs	2 perm. magnet	up to 18 supercond.
MGU length	34 cm	2 m
MGU magnetic params (gap, period, K, harmonics)	g=3.3 mm, λ_u=12.5 mm, K~1, n=1-5	g=5 mm, λ_u=15 mm, K~2.2, n=1-11

MGUs will have major impact on NSLS-II

Collective Effects & Lifetime

MGU Driven

- **Single Bunch Instabilities**
  - Longitudinal Microwave: O.K. for |Z/n|<0.1 Ω
  - Transverse (TMCI, MW): R&D Issue
- **Couple Bunch Instabilities**
  - Resistive Wall: O.K. for SCU, feedback for MGU?
  - From Cavity HOM: O.K. due to SCRF
- **Intra-Beam Scattering**: O.K., only few % ε blow-up
- **Gas Scattering Lifetime:** O.K., elastic/inelastic >10 hrs
- **Touschek Lifetime:** down to 2 hrs, O.K. with top-off?

MGU-driven Resistive Wall Instability

- Small gap drives the coupled-bunch resistive wall instability

  $Z_\perp \sim Z_{surface}/gap^3$

- Small β-functions in MGUs do help: growth-time $\gamma_{inst} \sim \langle \beta / Z_\perp \rangle_{ring}$

- Preliminary calculations (J.-M. Wang) give $\gamma_{inst} \approx \tau_d$ (radiation damping time) for 4.2 K cold bore IDs

⟶We could be OK.

- In contrast, for warm bore IDs $\gamma_{inst} \sim \tau_d/25$

⟶Bunch-by-bunch feedback may be needed

Assumptions

NSLS-II parameters from page 13 table, in addition ν_y=13.72, τ_d=12 ms (vertical), lattice from ref. [2], 20 MGUs, each is taken as a thick round Cu pipe 2 m long x 5mm diameter, extreme anomalous skin effect regime, rest of the ring is thick Al pipe 5 cm diameter , rigid-dipole mode only, formalism described in ZAP manual.

MGU-driven Transverse Single Bunch Instabilities

- TMCI and/or TMW instabilities are observed in many light sources and could limit single bunch current
- Usually described in terms of Broad-Band Impedance which includes both geometric and resistive contributions
- For typical warm MGU the geometric contribution due to transitions greatly exceeds the resistive wall contribution
(Bane & Krinsky PAC93, T. Günzel EPAC02, Y. Chae et al PAC03, + others)
- This should be even truer for cold bore devices
- Instability fix: higher chromaticity (R. Nagaoka et al, ESRF)
- Ultimate cure: optimal transition design (NSLS, others, work in progress)

Closing Remarks & Outlook

- **Mini-gap undulator program is very successful at present NSLS** 20 hr life-time @ 3.3 mm gap
- **So far the impact of MGUs on machine performance has been minimal** 125 mA single bunch
- **NSLS X-ray ring will get more MGUs, probably superconducting**
- **SC MGUs are going to be the workhorse for NSLS-II; they will have a major impact on the machine**
- **Studies of beam dynamics implications of multiple MGUs for NSLS-II are under way**