P. Emma, N. Holtkamp, H.-D. Nuhn, ***SLAC***
C. Doose, J. Fuerst, Q. Hasse, Y. Ivanyushenkov, M. Kasa, G. Pile, E. Trakhtenberg, E. Gluskin, ***ANL***
D. Arbelaez, J. Corlett, S. Myers, S. Prestemon, R. Schlueter, ***LBNL***

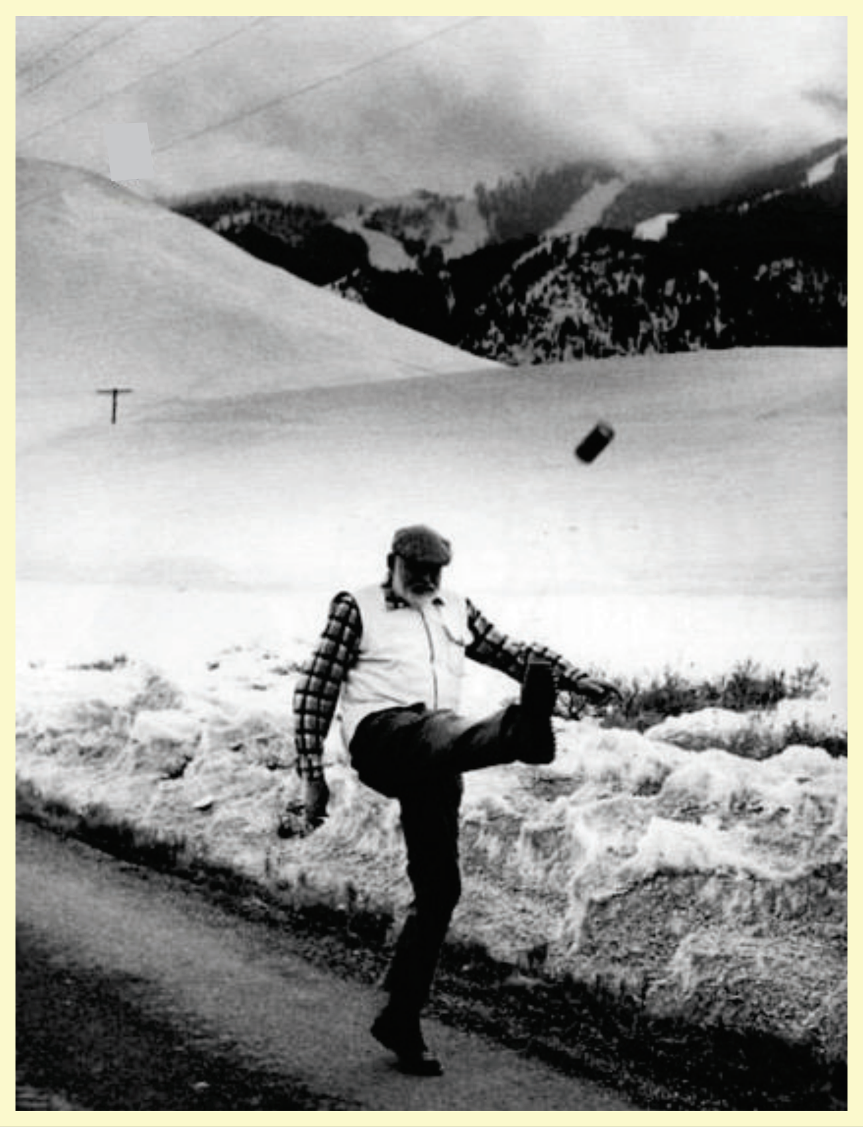
A Plan for the Development of Superconducting Undulator Prototypes for LCLS-II and Future FELS

P. Emma,

…for the SCU R&D (funded) collaboration: *ANL, LBNL, SLAC*

August 28, 2014

Kicking the Can Down the Road (SCU's)…



- Proposed by E. Gluskin & N. Vinokurov in 1999 for ***LCLS-I*** ⇒ ***"not ready for SCU"*** (**15** yrs ago!)
- Propose to re-design ***LCLS-II*** undulator and greatly improve performance (1 TW & 7 keV)?
- SCU's operating in ***ANKA*** (2005) & ***APS*** (2013) right now
- **Greatest** un-tapped potential available for FEL performance

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Superconducting Undulator Motivation

Advantages of an SCU:

- Higher magnetic fields allow superior FEL performance.
- No permanent-magnetic material to be damaged by radiation → longer life & smaller gaps.
- Reduced (?) resistive wakefield with cold bore (*preliminary*).
- Much lower vacuum pressure, which limits gas scattering.
- Smaller footprint and simpler *K*-control than typical, massive adjustable-gap PMU.
- Easily oriented for vertical polarization*.

SCU's need practical development…

* Vertical polarization allows efficient x-ray transport in horizontal deflections

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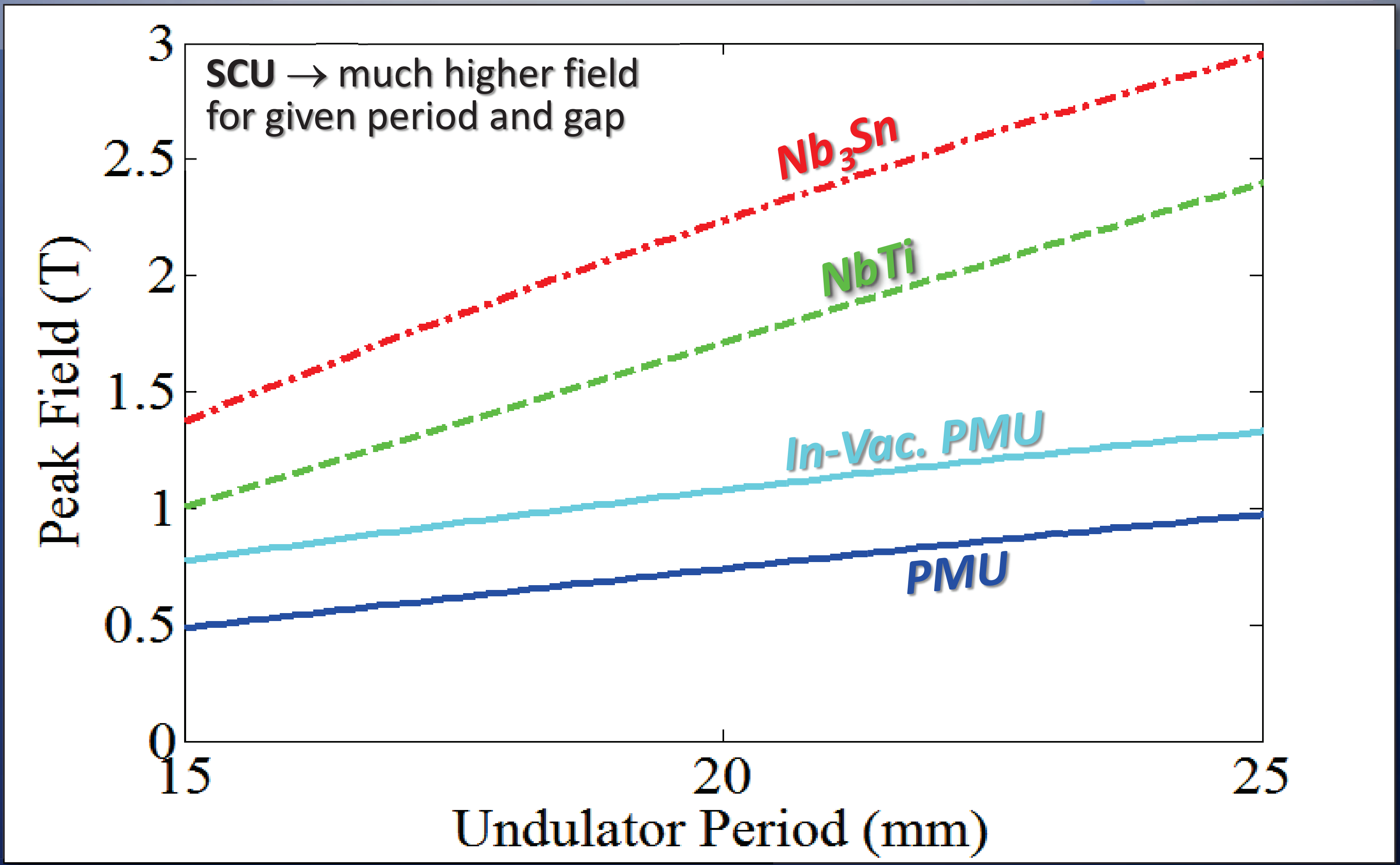
SCU's Provide Much Higher Fields than PMUs



- 5-mm vac. gap for all (7.3-mm mag. gap)
- *In-Vac* → same vac. gap (5.3-mm mag. gap)

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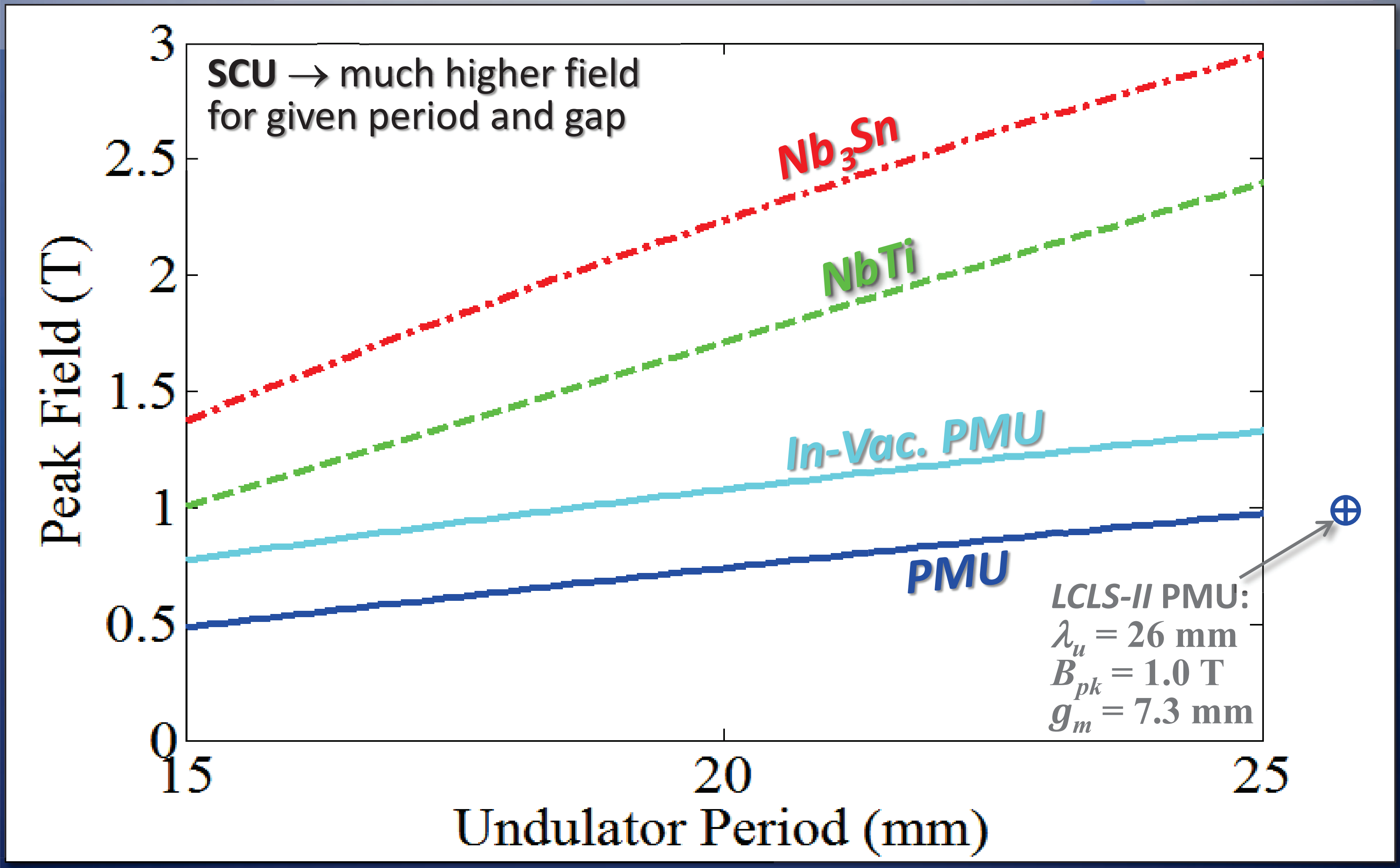

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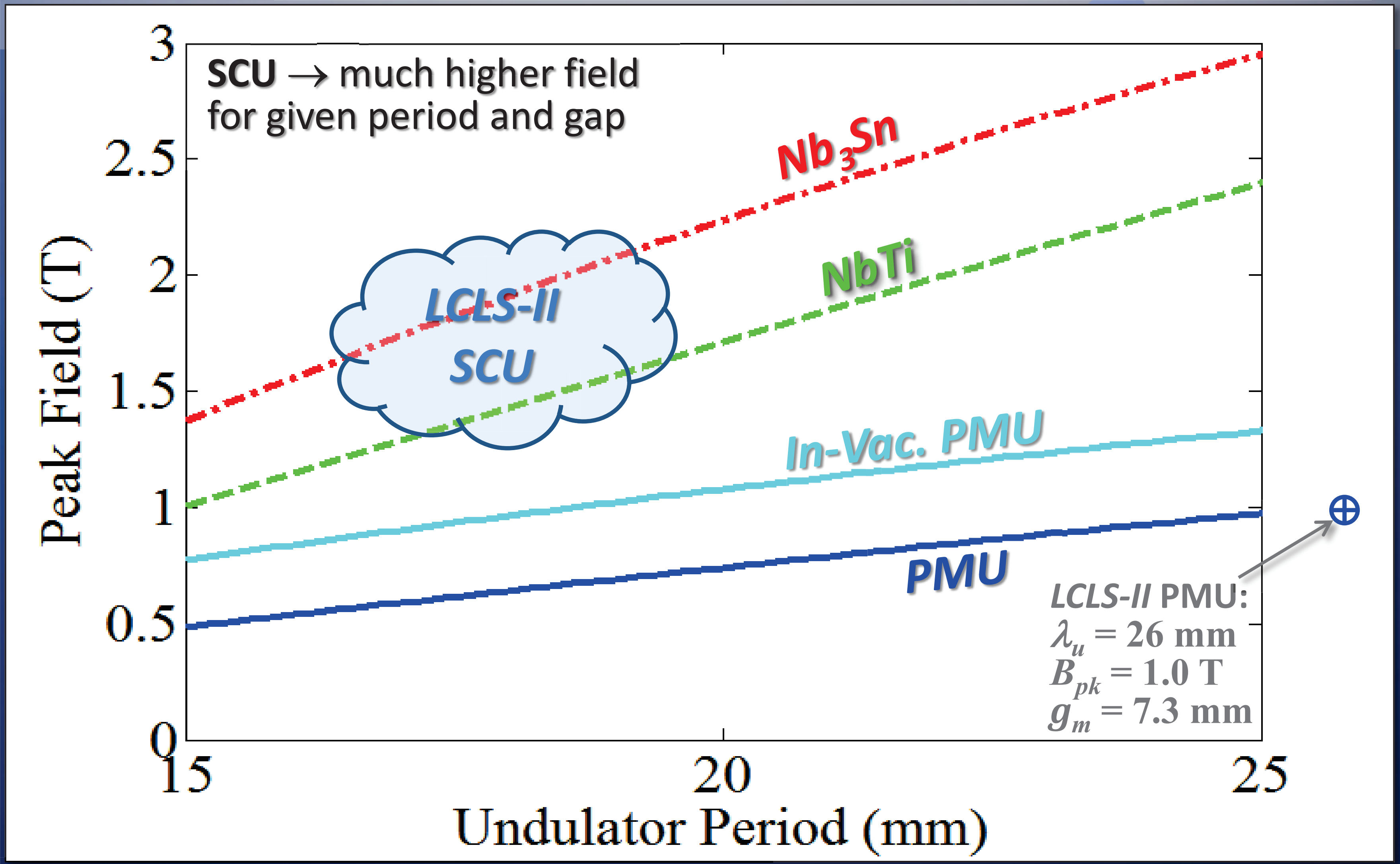

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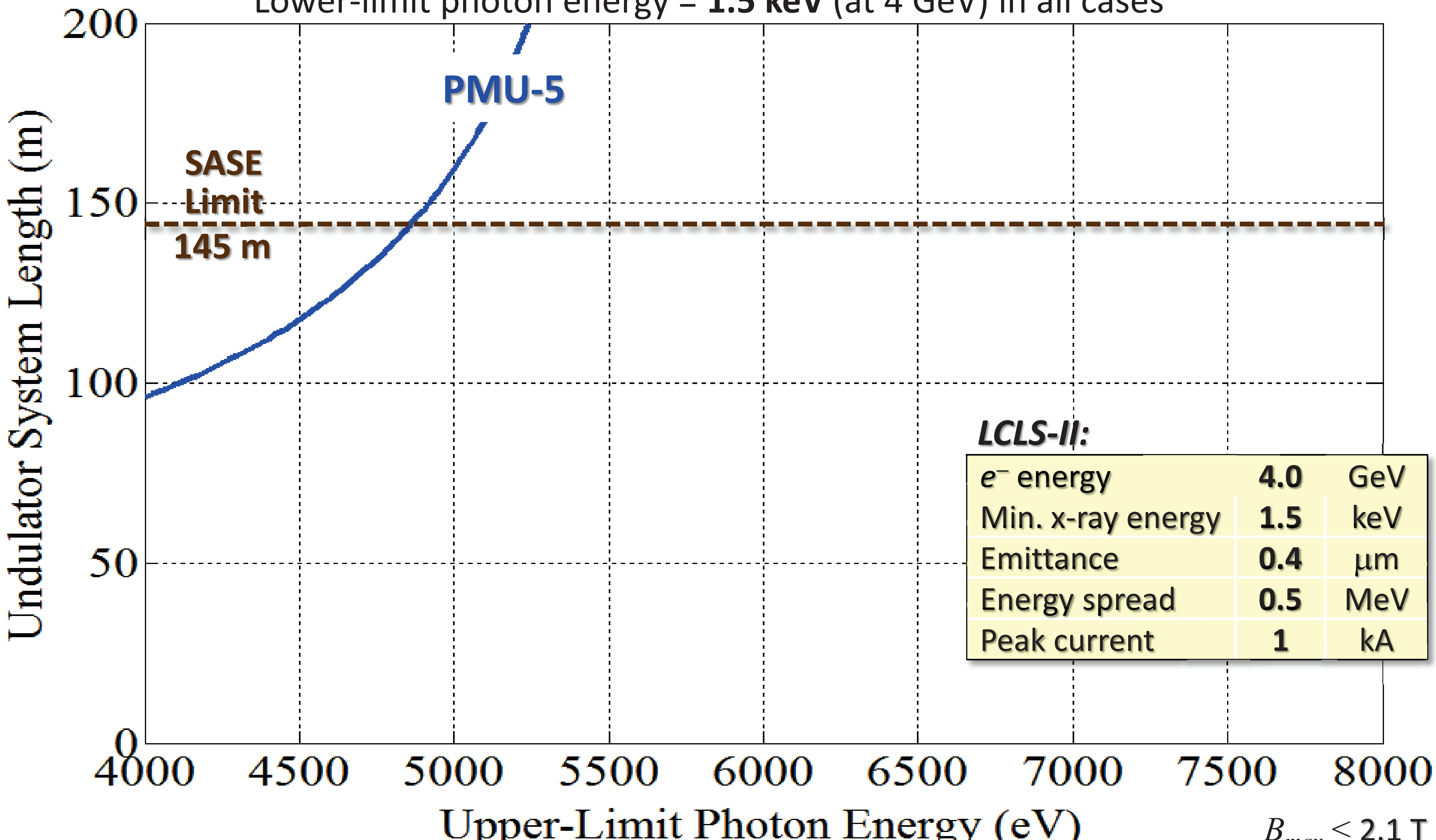
Und. Length vs Upper-limit Photon Energy (LCLS-II)

2-m segments & 0.7-m breaks

Lower-limit photon energy = **1.5 keV** (at 4 GeV) in all cases



LCLS-II:

e⁻ energy	**4.0**	GeV
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Emittance	**0.4**	µm
Energy spread	**0.5**	MeV
Peak current	**1**	kA

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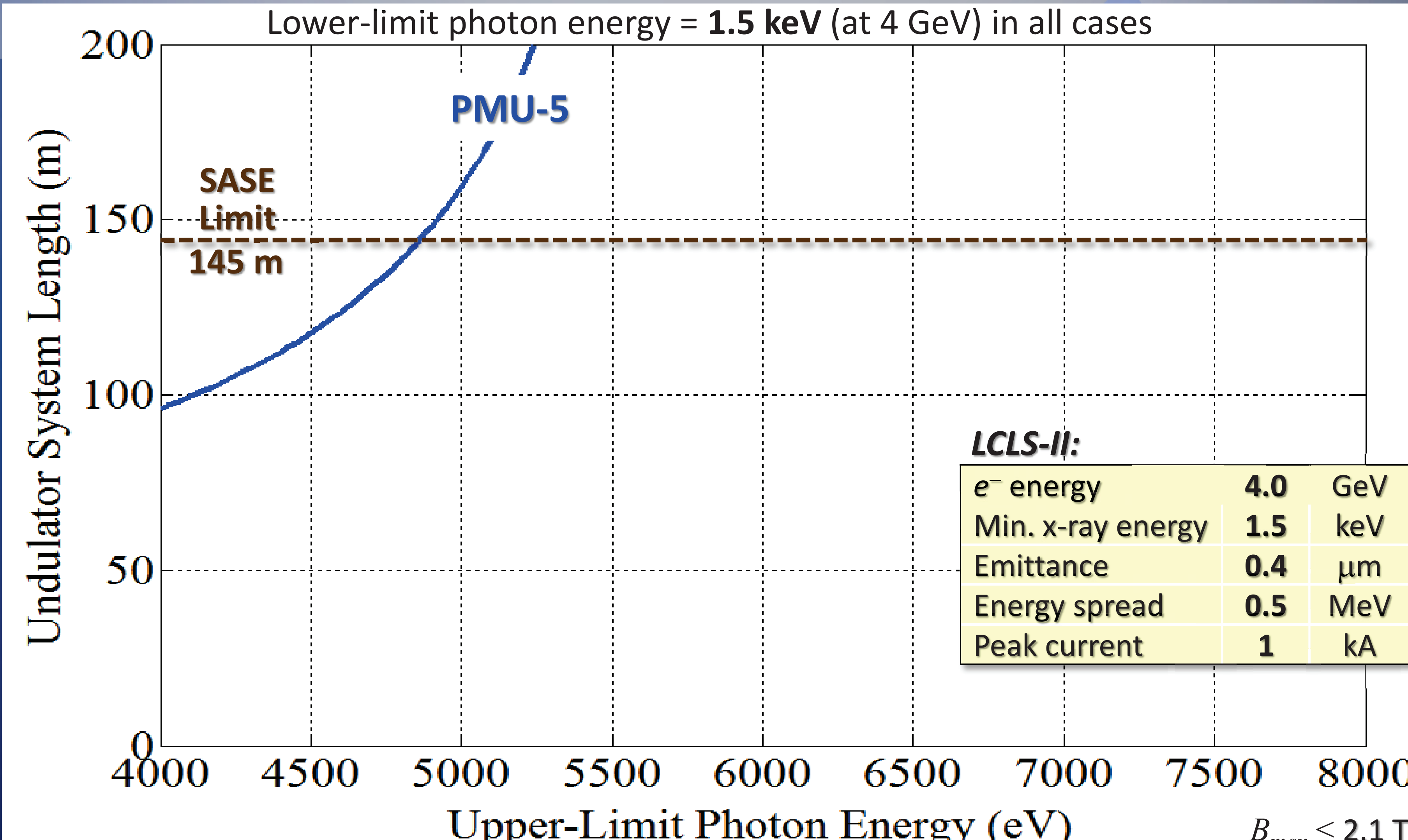

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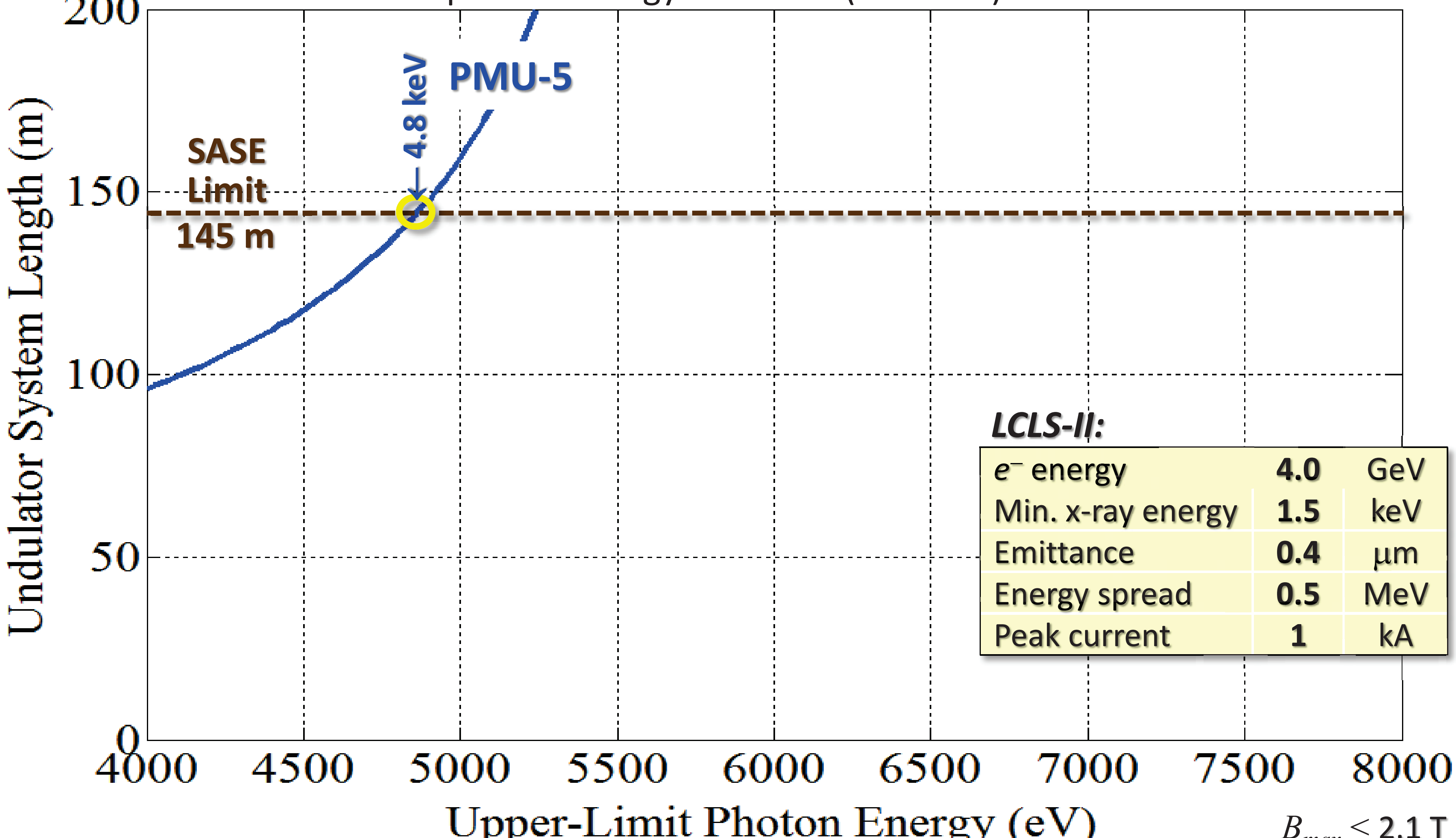

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B_{max} < 2.1 T

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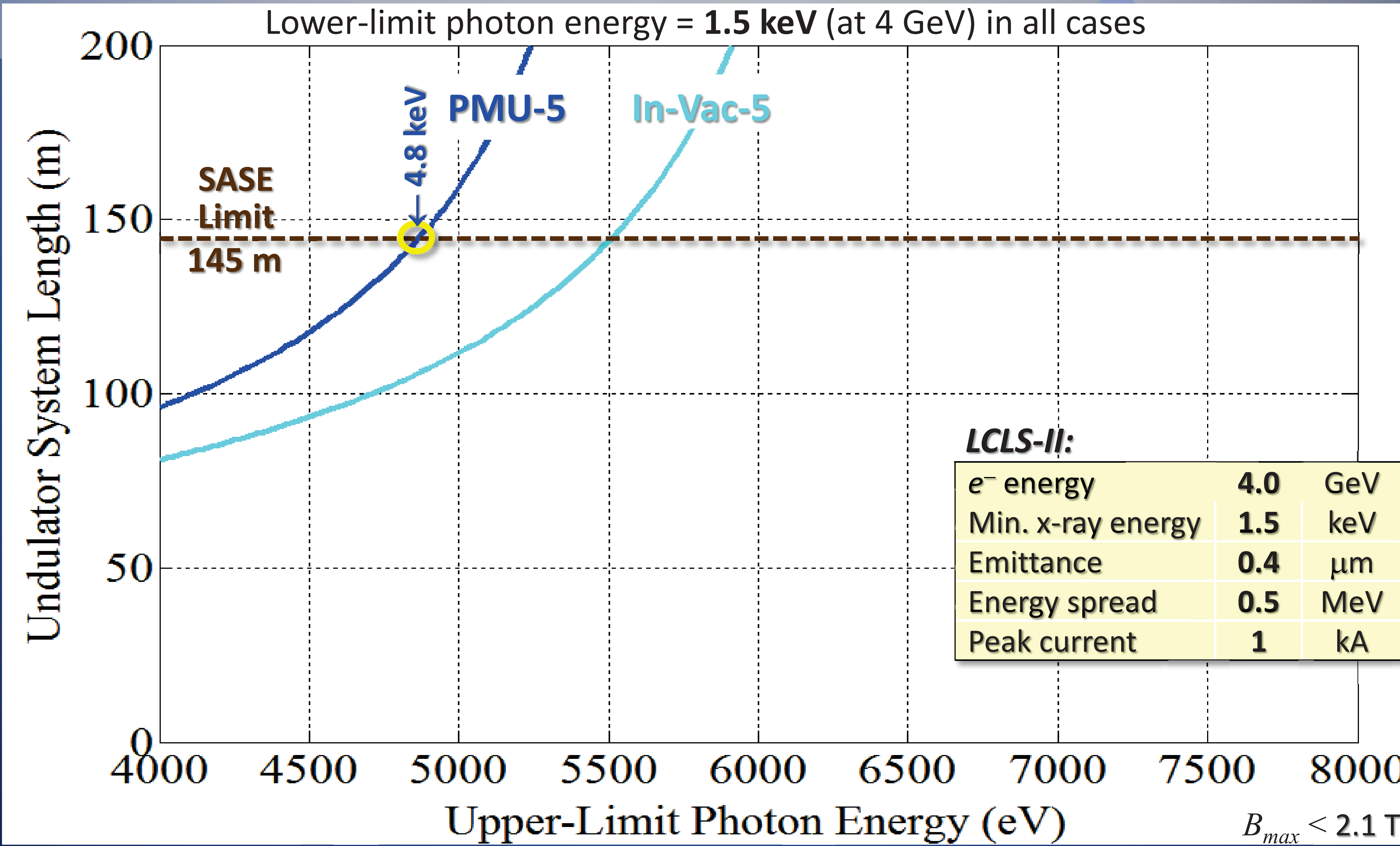

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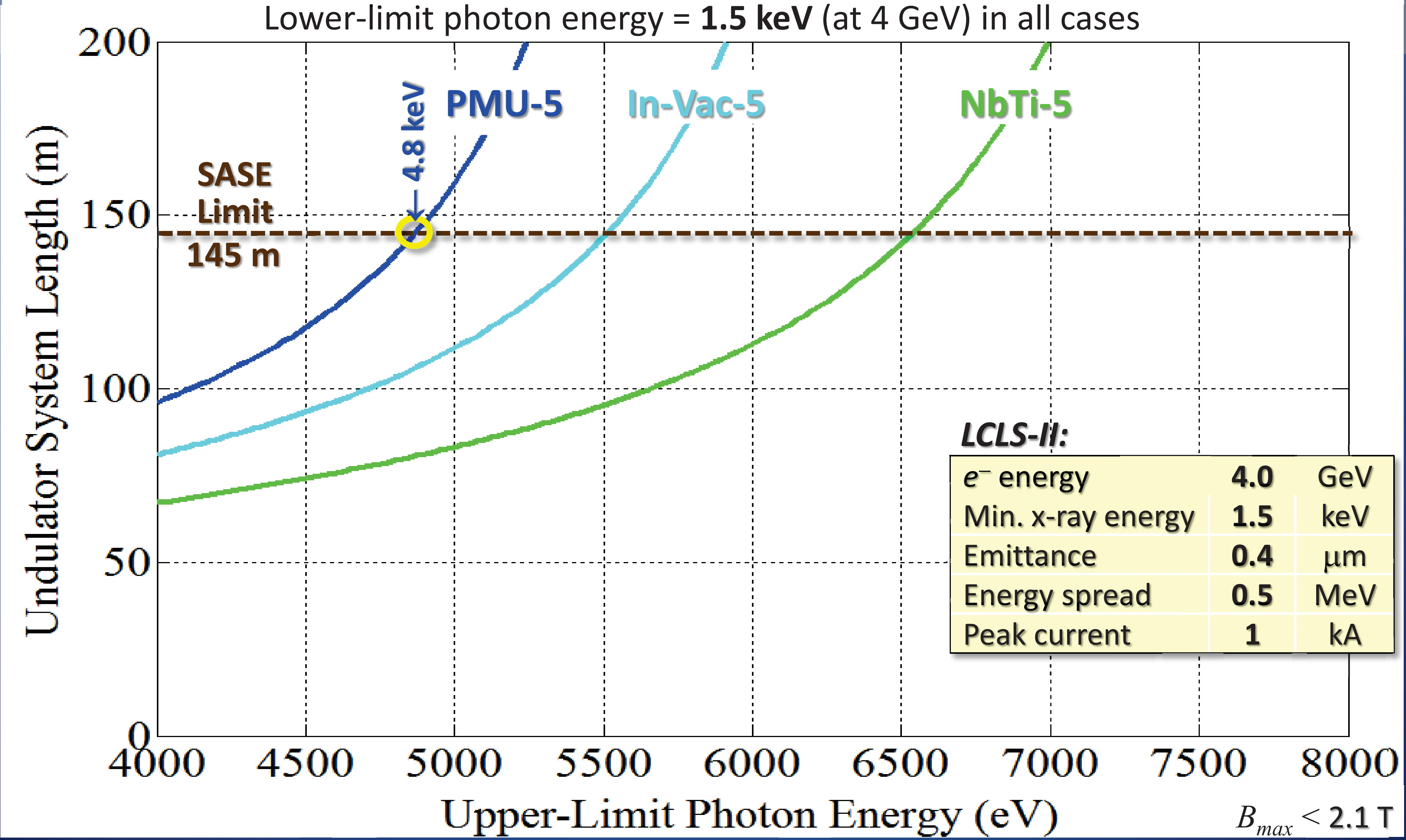

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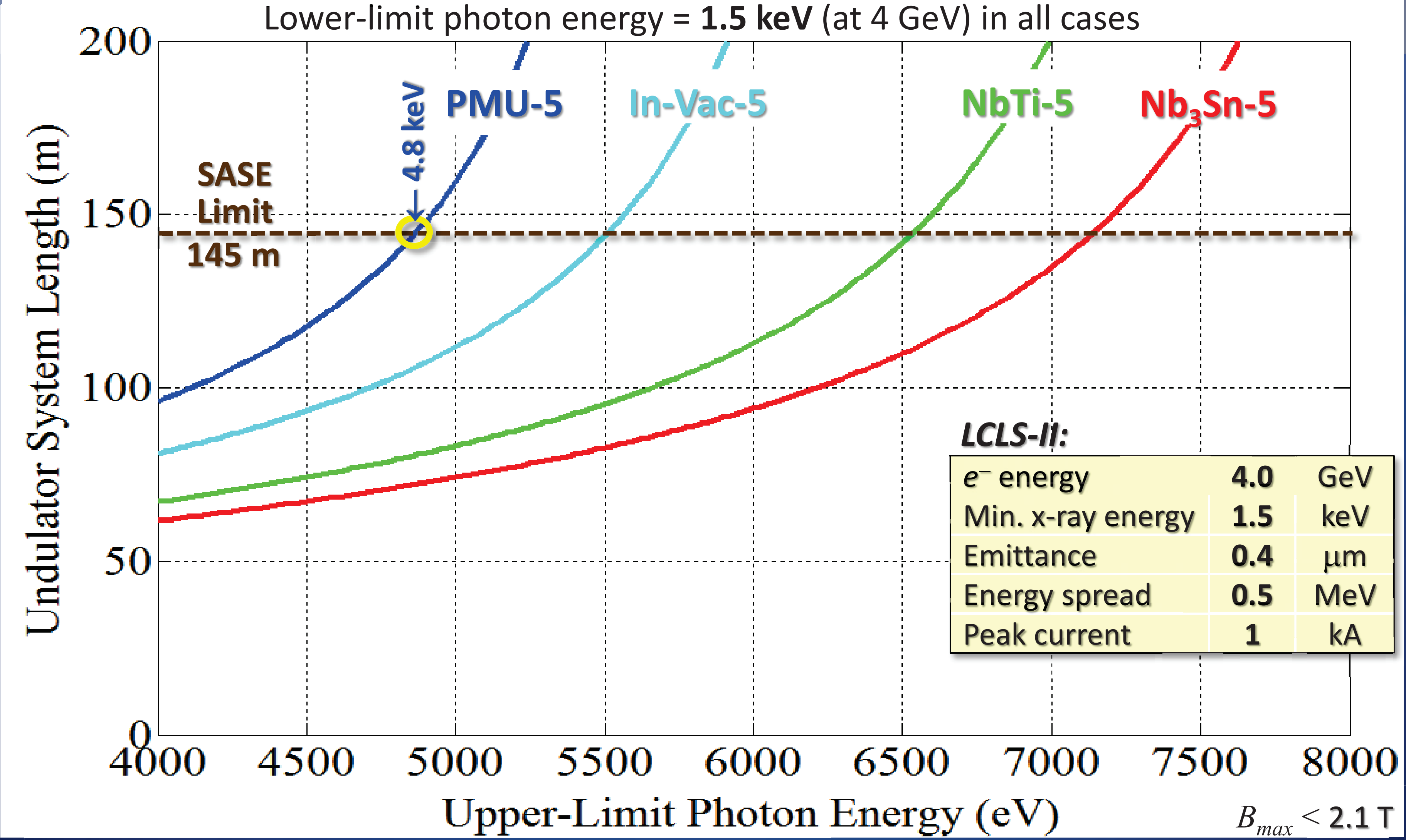

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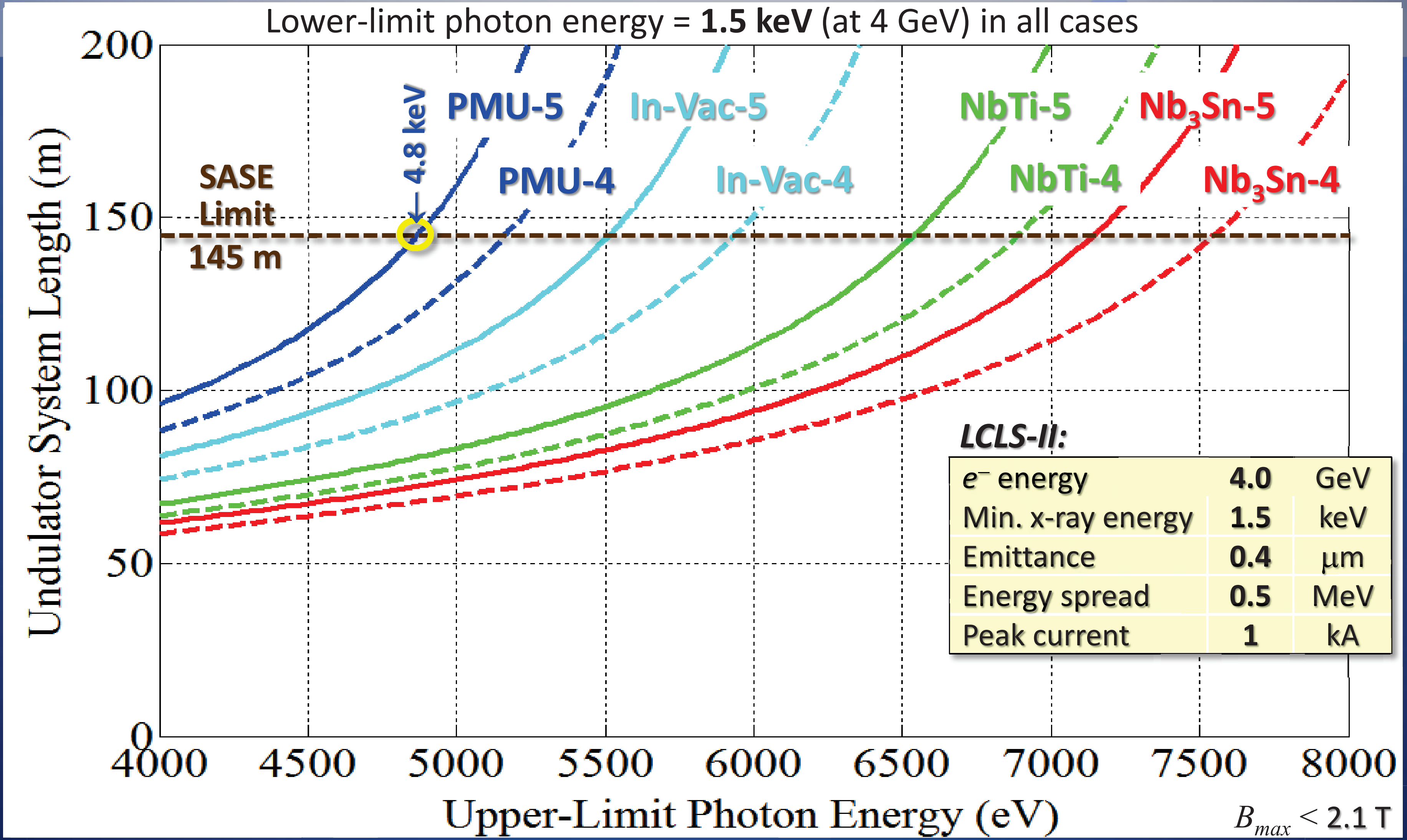

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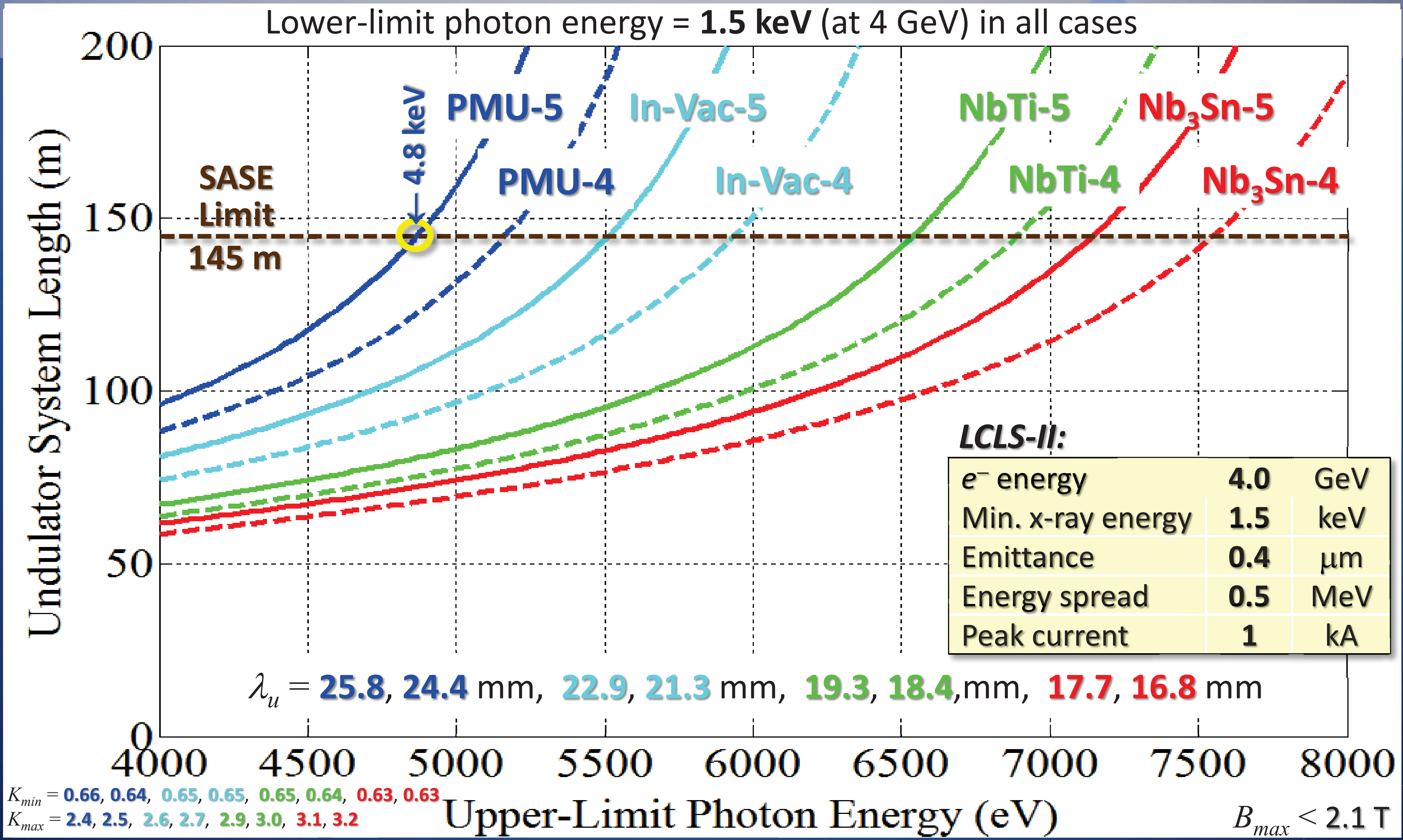

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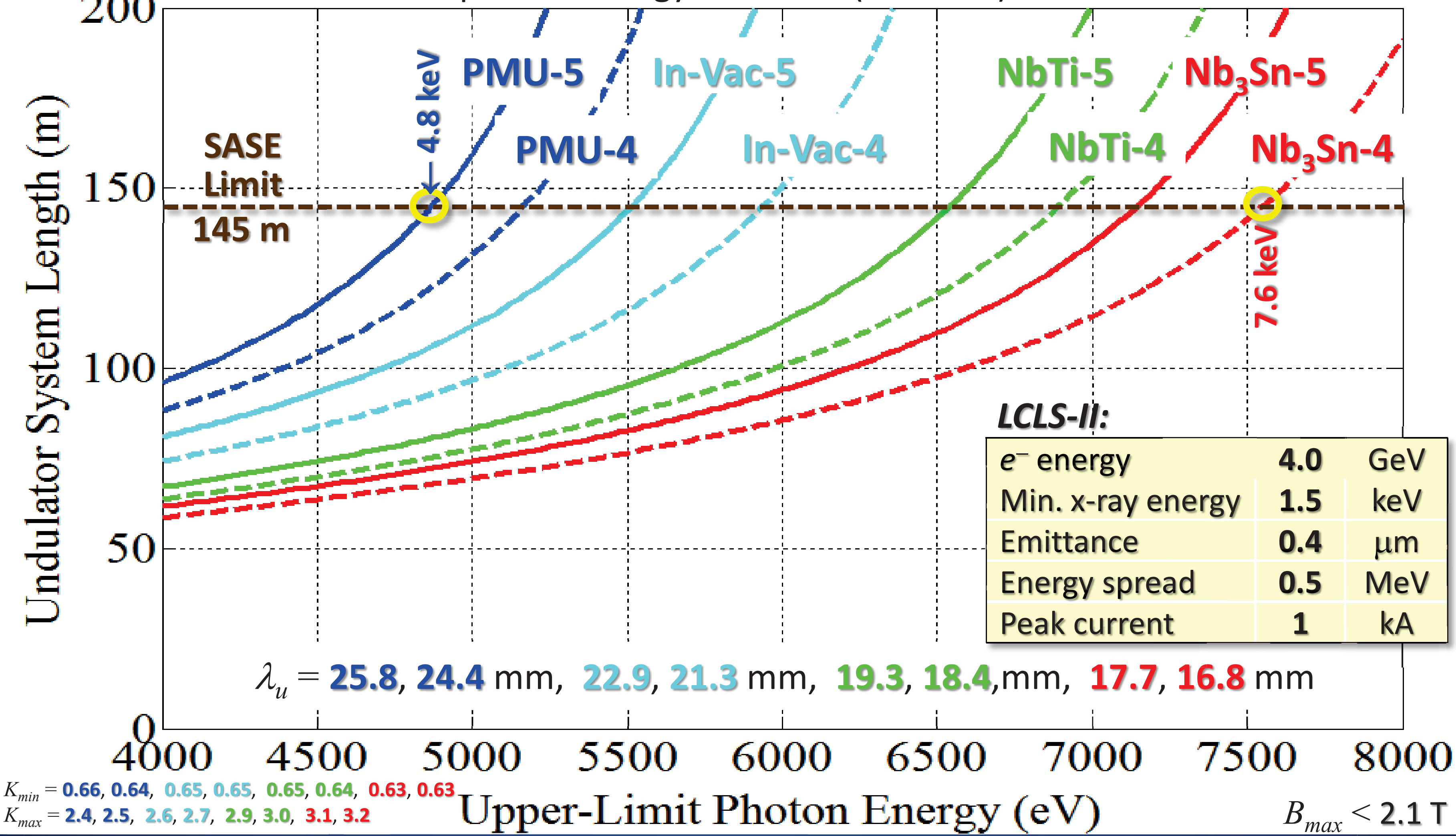

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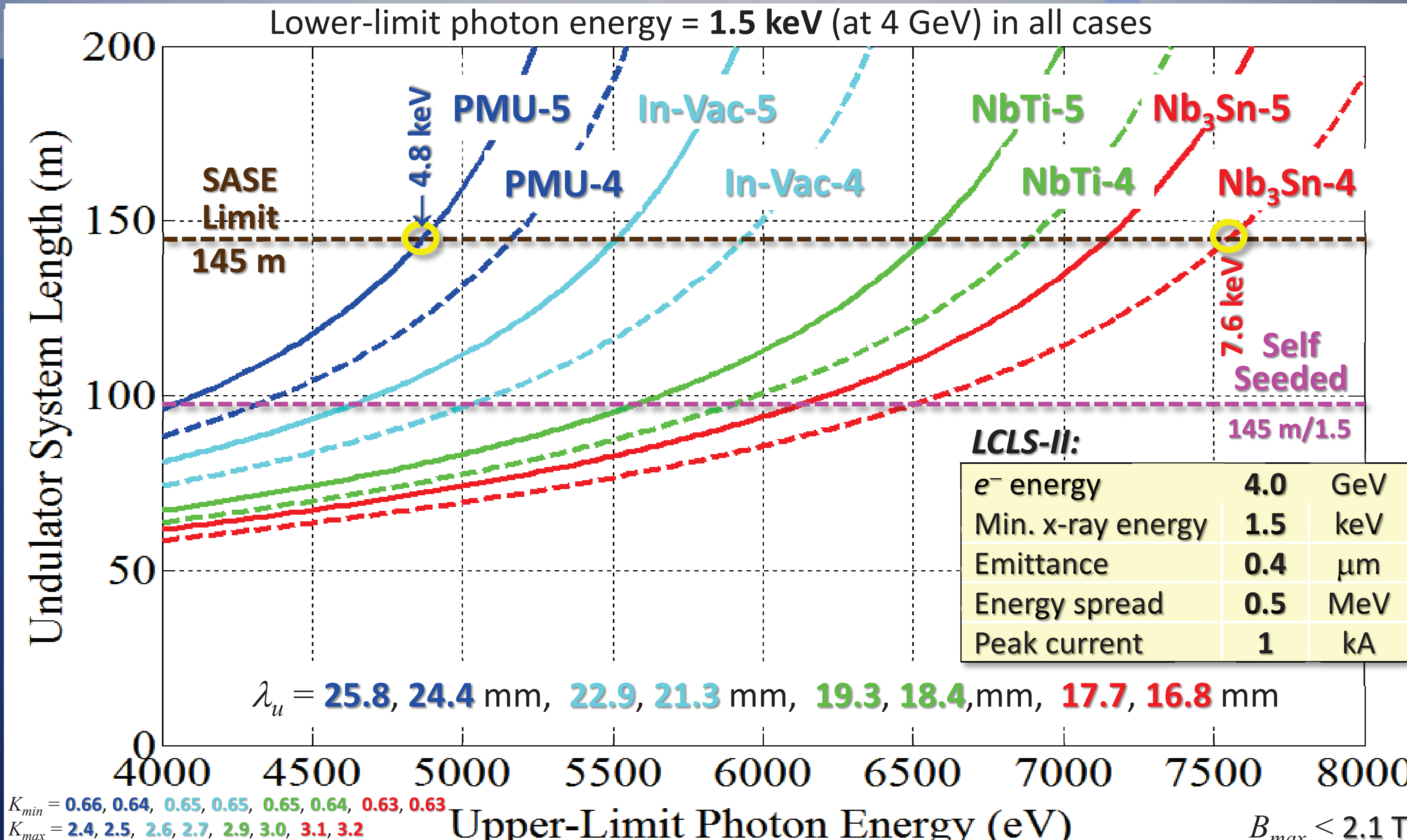

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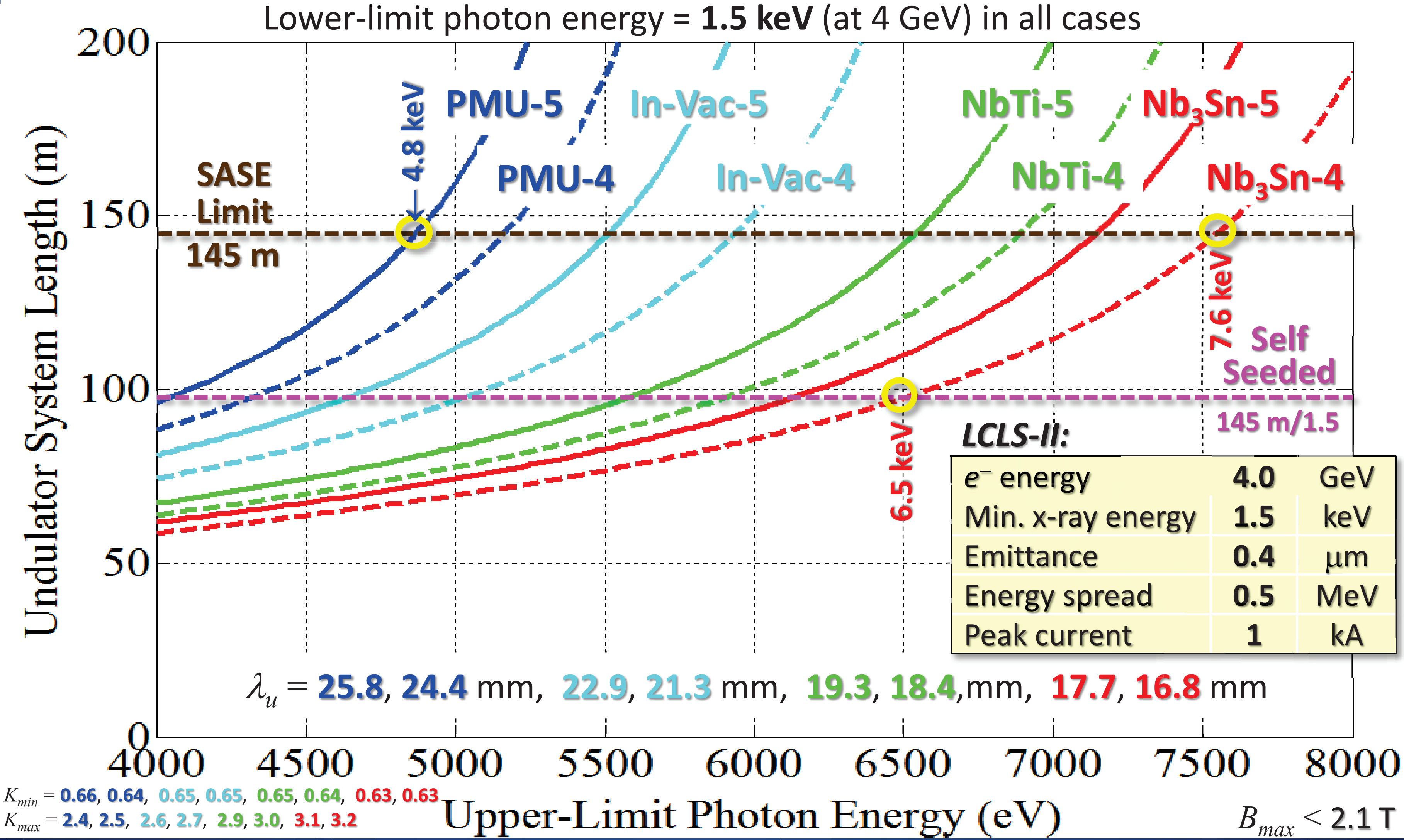

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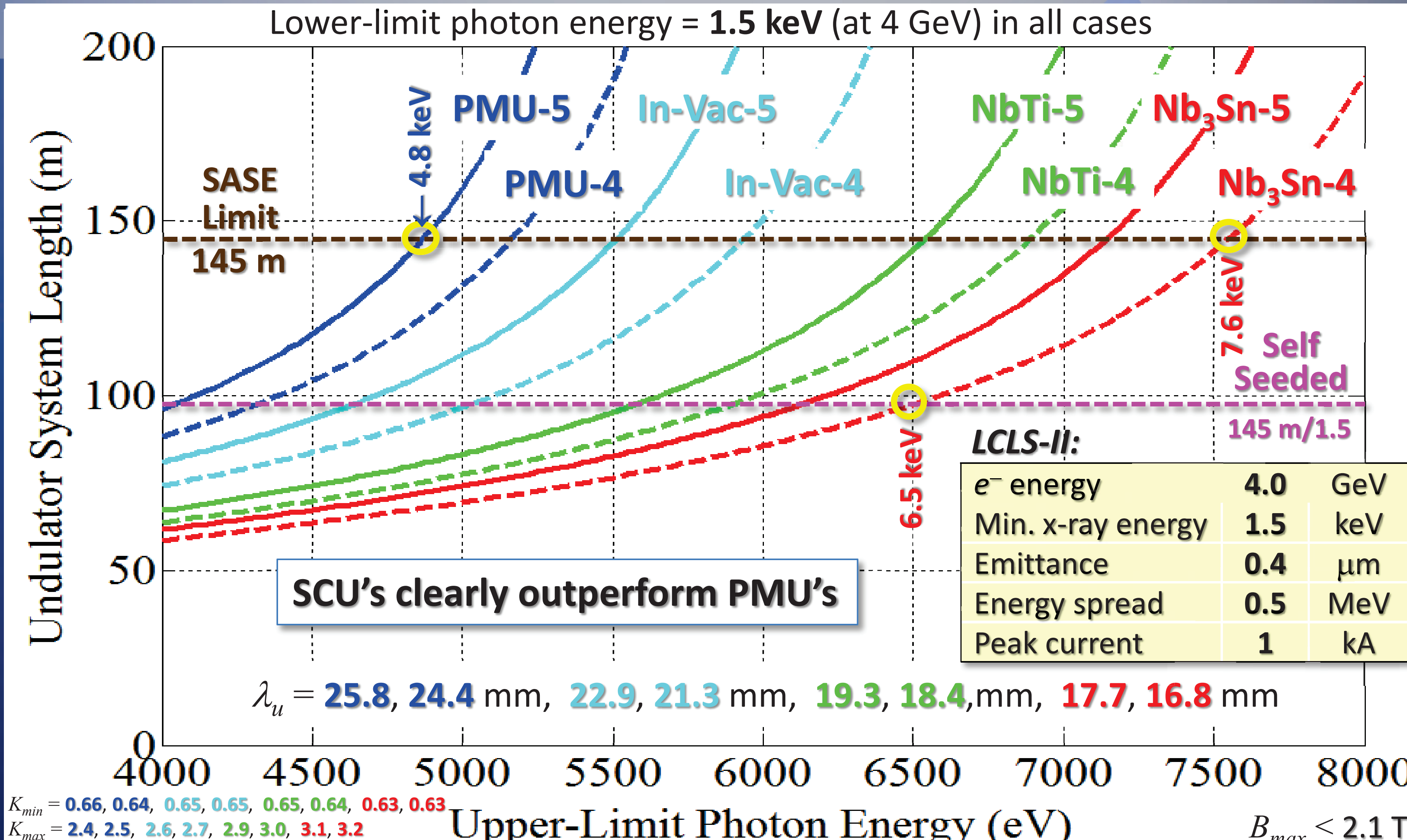

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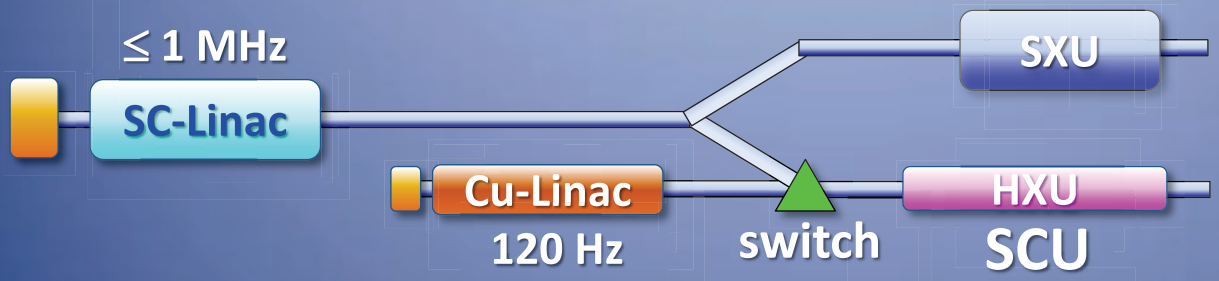
“TW-FEL” with SCU & Cu-Linac (LCLS-II)



C. Emma, C. Pellegrini, Z. Huang

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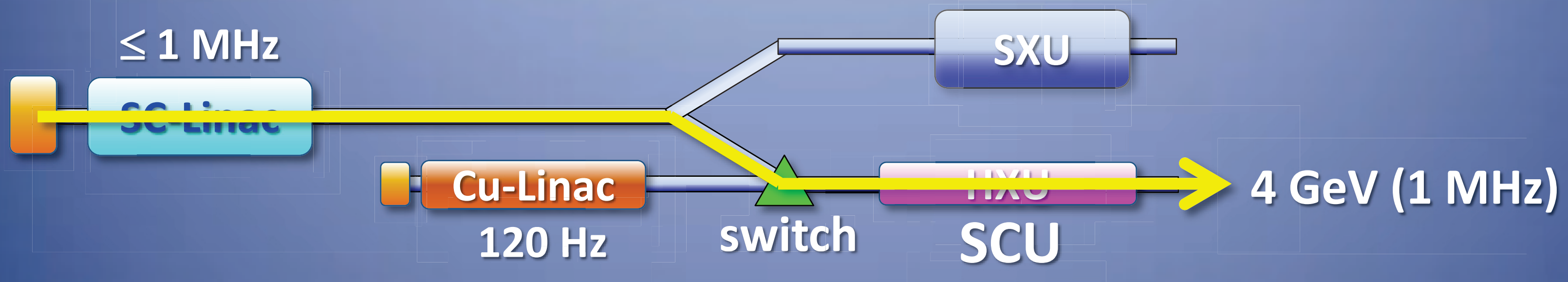

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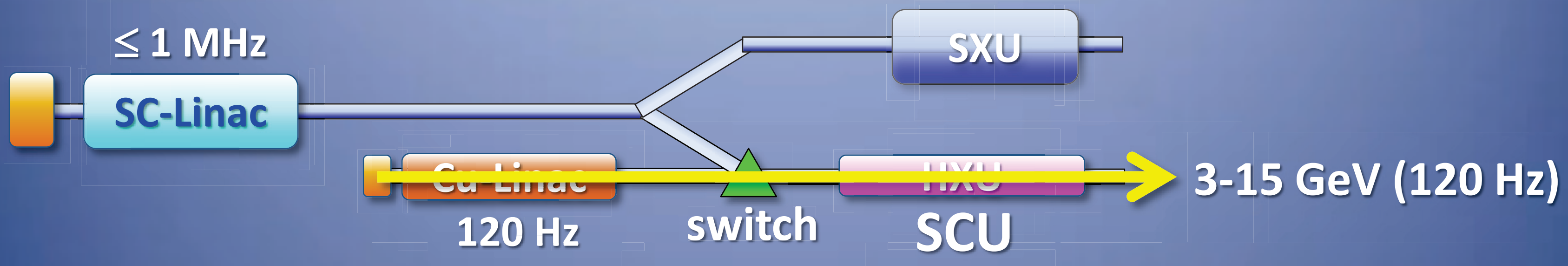

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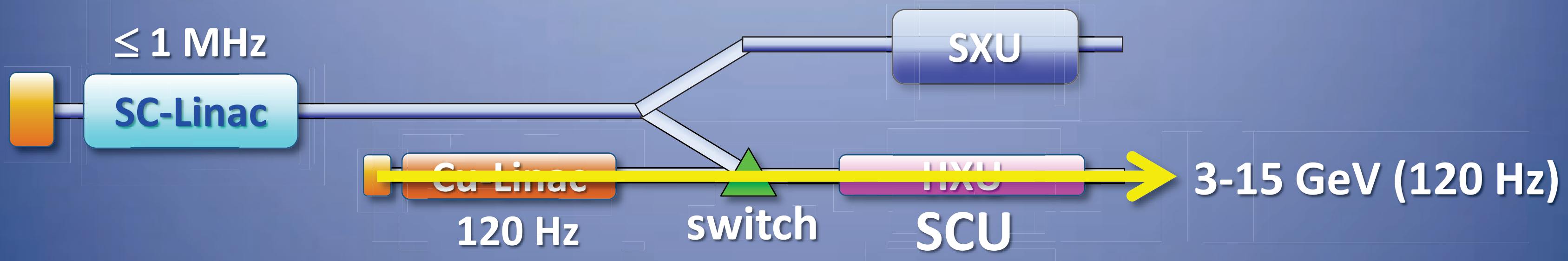

Und. tech.	Nb_3Sn	-
Vac. full gap	4	mm
Photon energy	4	keV
e^- Energy	6.6	GeV
Emittance	0.4	µm
Peak current	4	kA

C. Emma, C. Pellegrini, Z. Huang

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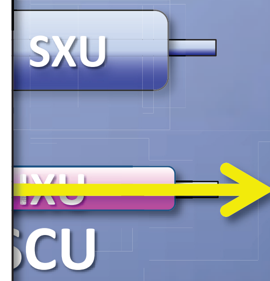

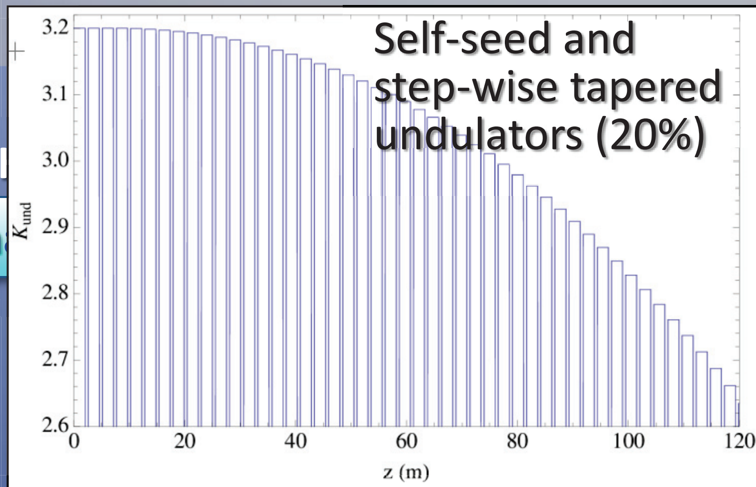

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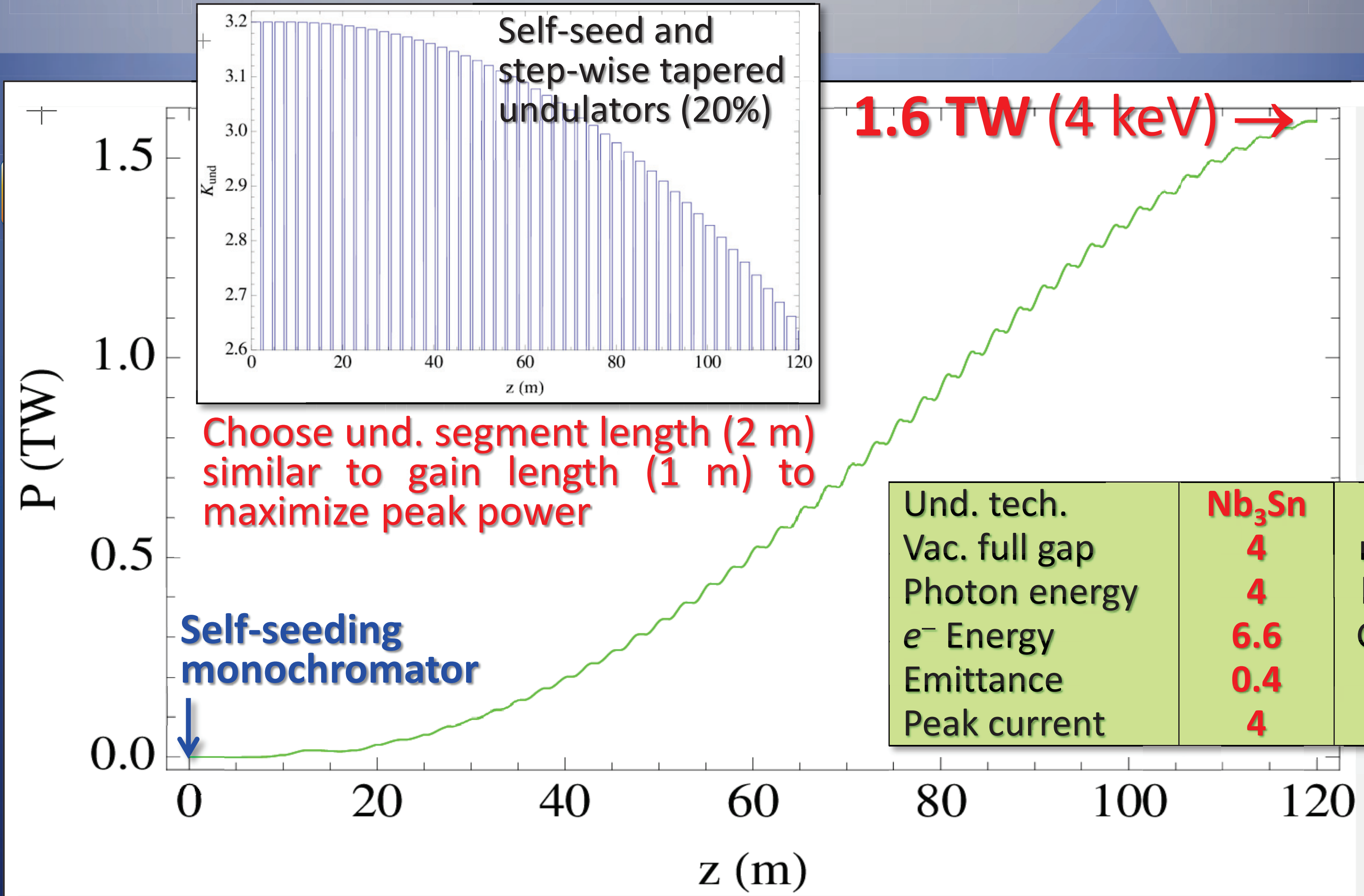

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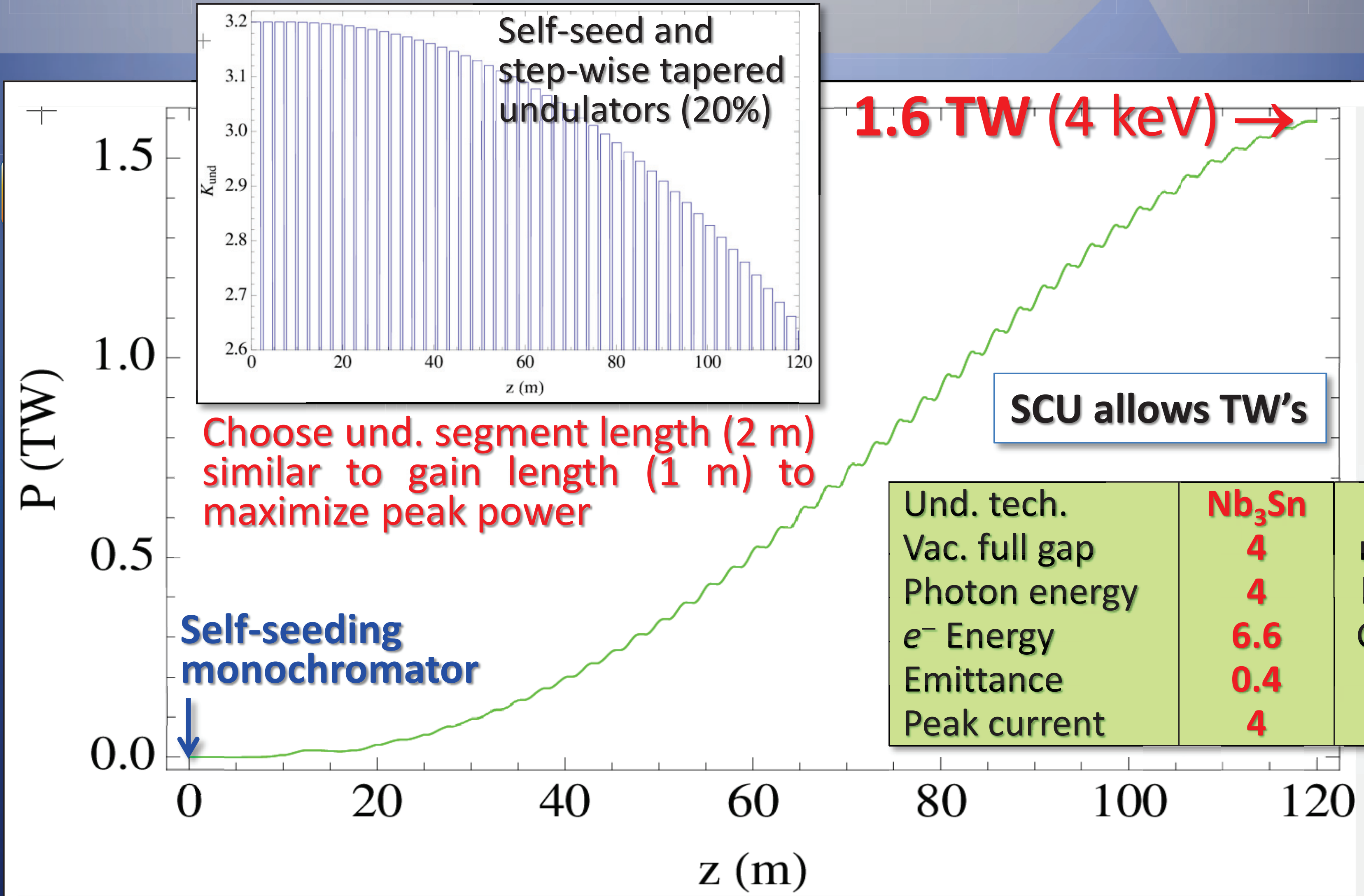

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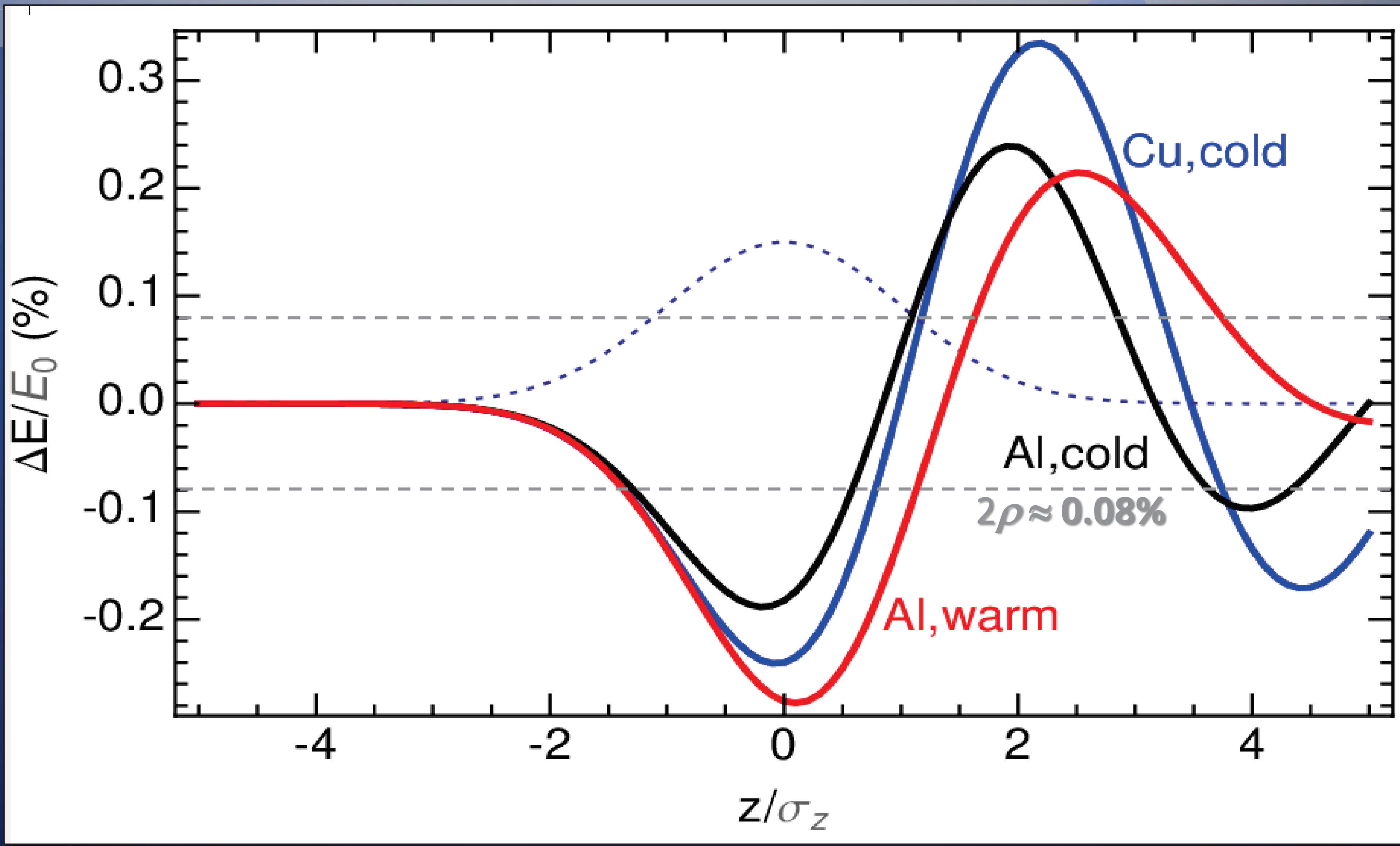
Resistive-wall Wake of Cold-bore Undulator



Based on work by **B. Podobedov**, PRSTAB, **12**, 044401 (2009), and new **G. Stupakov, K. Bane** model (*preliminary*)

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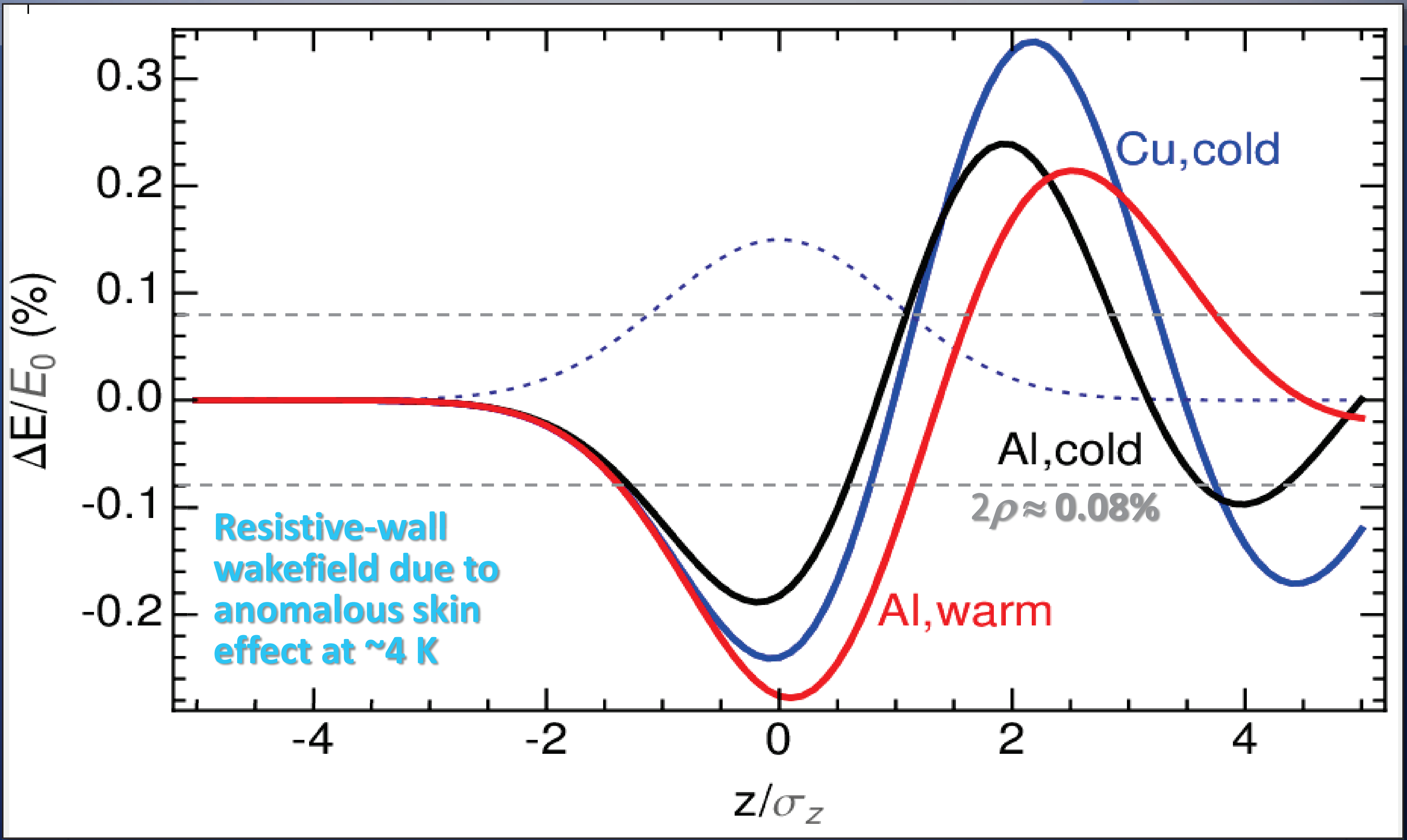

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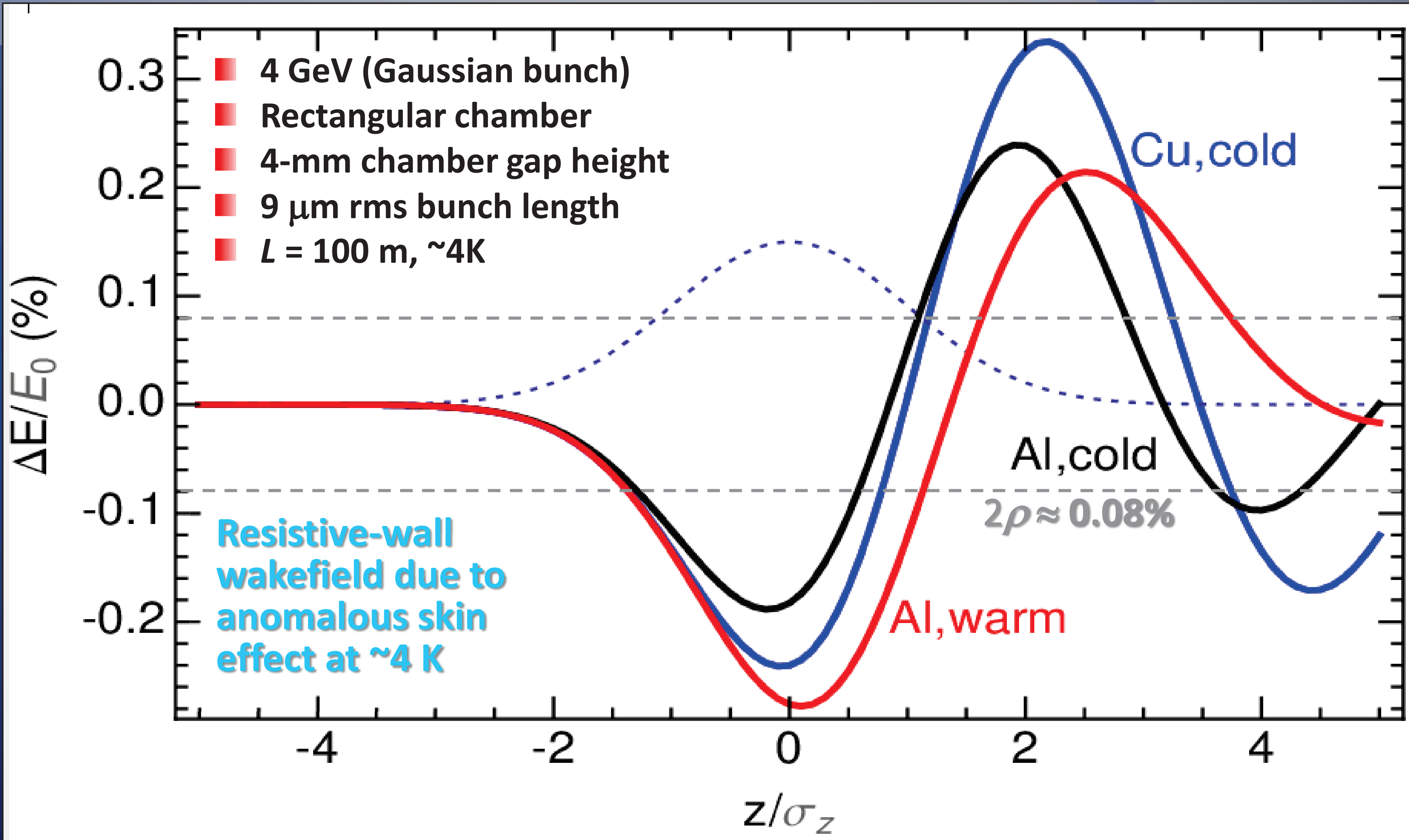

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SCU R&D Plan

- *ANL…*
  - Build a 2-m test cryostat (existing design)
  - Build & test 1.5-m long *NbTi* prototype und. ($\lambda_u \approx 21$ mm)
- *LBNL…*
  - Build & test 1.5-m long *Nb_3Sn* prototype und. ($\lambda_u \approx 19$ mm)
  - Develop meas. & tuning schemes (small tuning cryostat)
- Together…
  - Develop field measurement and correction techniques
  - Demonstrate predicted field, field quality, end corrections, and cold-mass integration into cryostat
  - Develop conceptual design for full-length SCU in *LCLS-II*
- Goal: By July 2015, deliver 2 fully functional, 1.5-m long, SCU prototypes meeting *LCLS-II* HXU spec's

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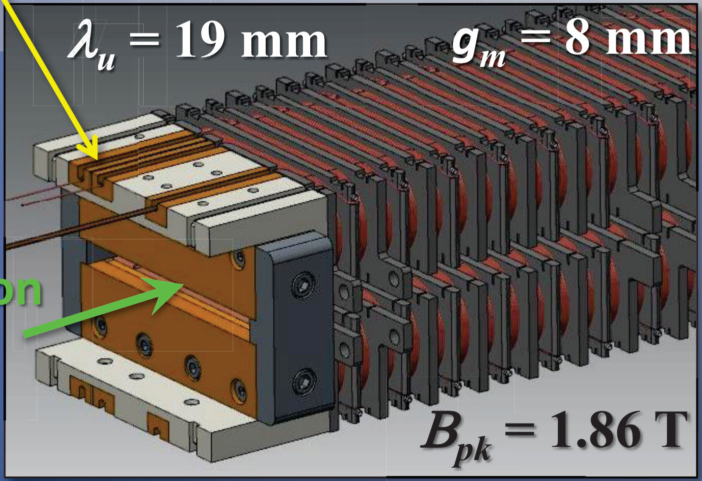
Prototype Magnet - *LBNL* (Nb_3Sn)



Nb_3Sn

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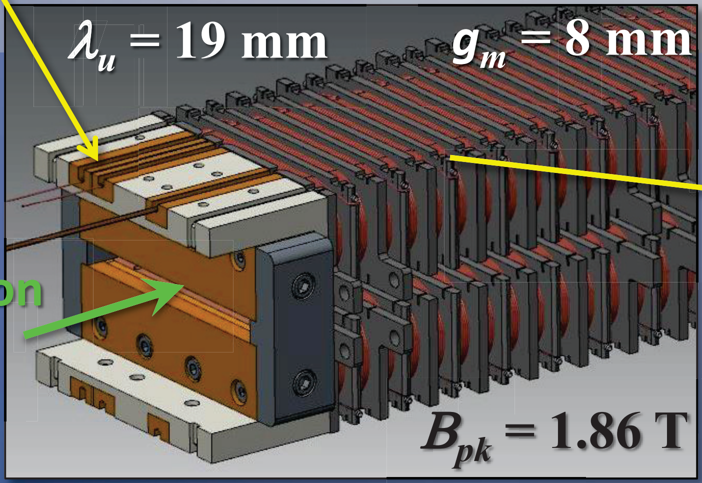
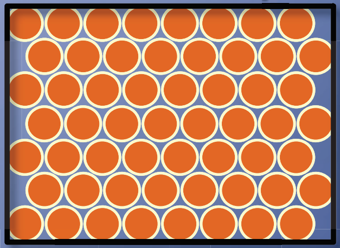


Nb_3Sn

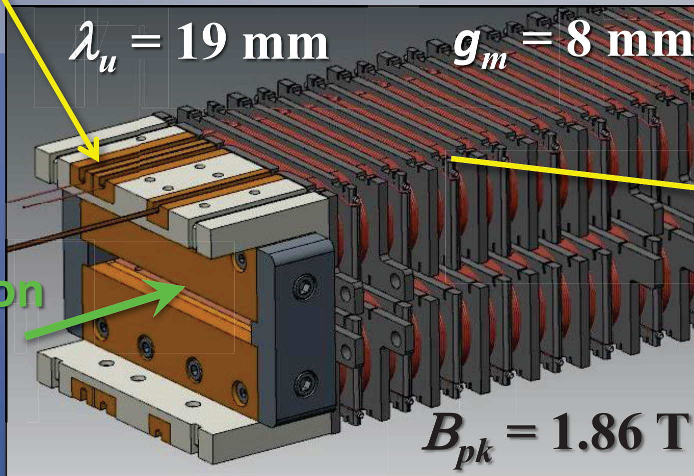
Wire Pocket (8×7)



0.6-mm diam. wire,
60-μm braid insulation

Prototype Magnet - *LBNL* (Nb_3Sn)

Nb_3Sn to NbTi joints at end of undulator



Electron Beam

Nb_3Sn

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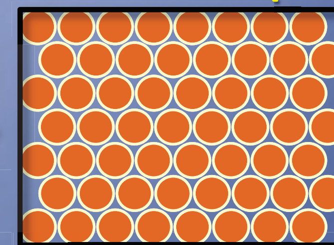

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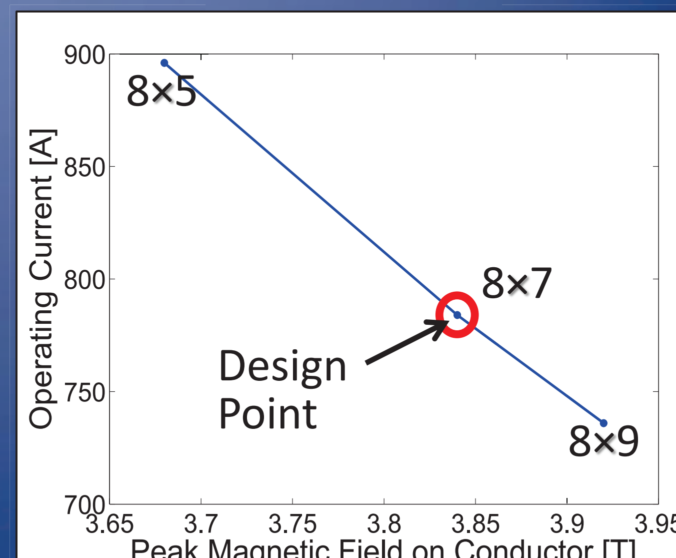

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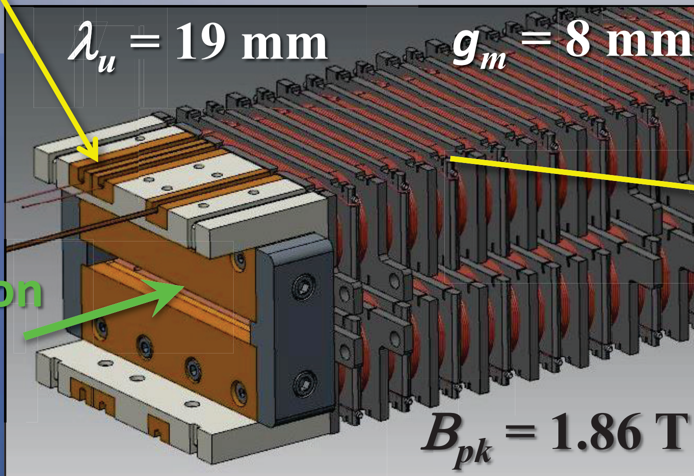

Nb_3Sn

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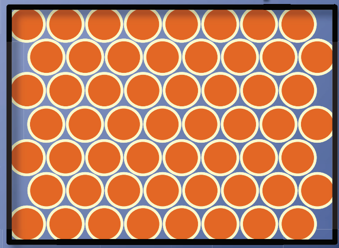

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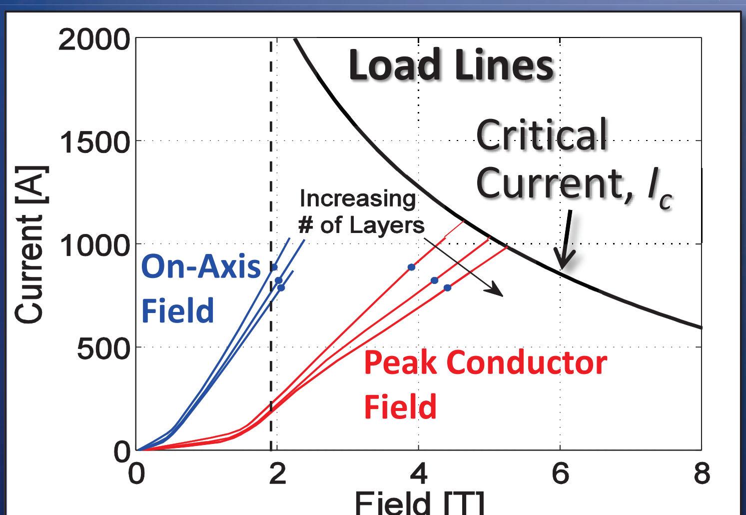

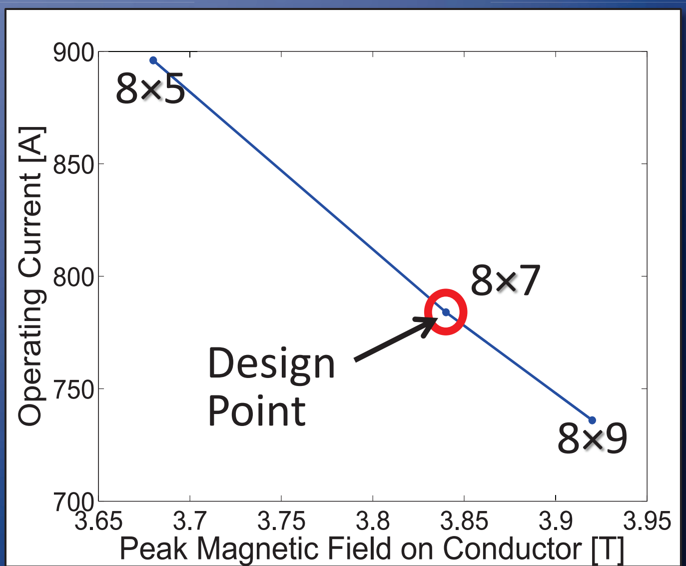

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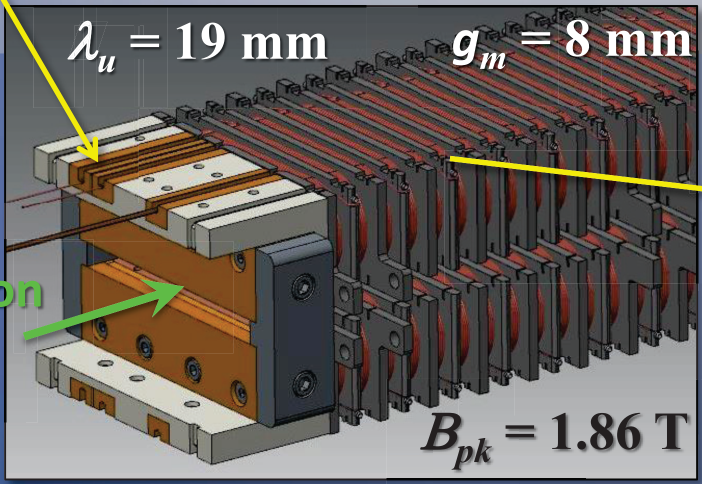

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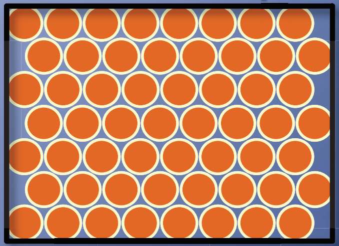
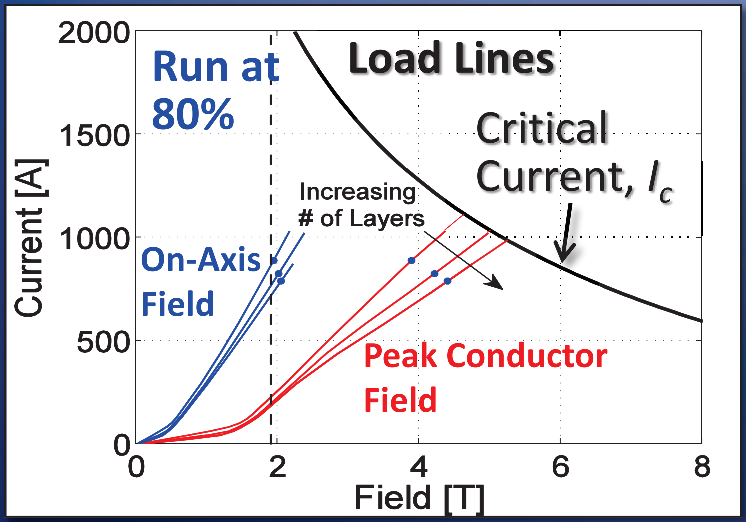
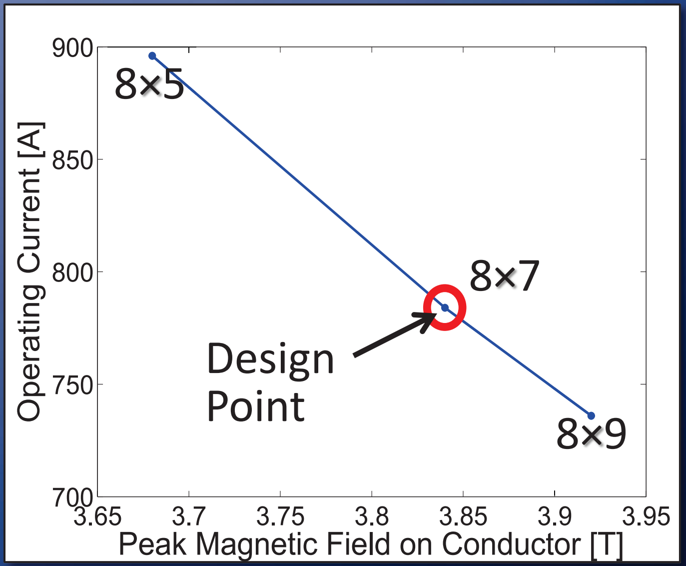


0.6-mm diam. wire, 60-μm braid insulation





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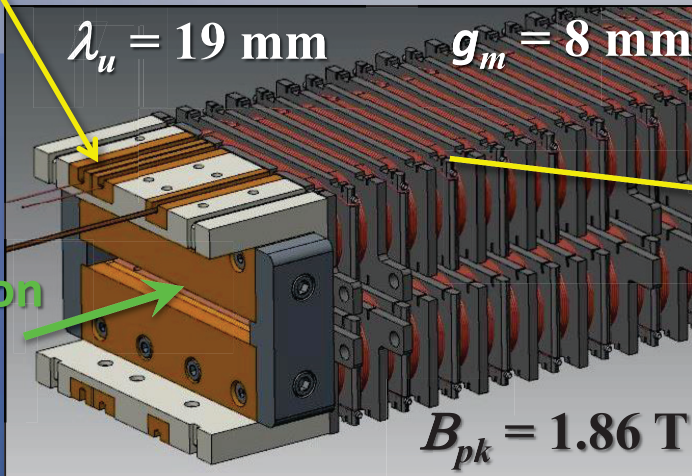
BERKELEY LAB

Prototype Magnet - *LBNL* (Nb_3Sn)

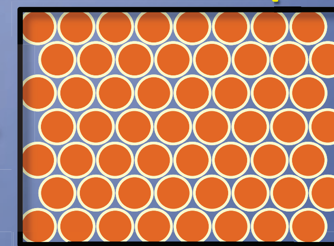
Nb_3Sn to NbTi joints at end of undulator



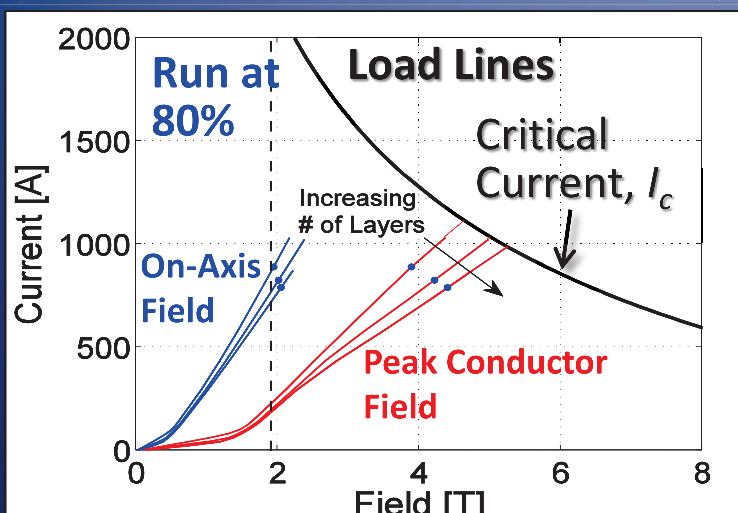
Electron Beam

Nb_3Sn

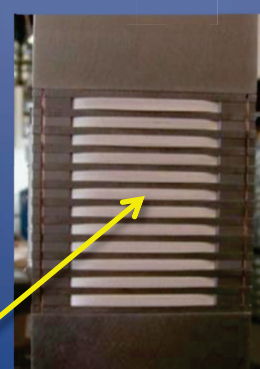
Wire Pocket (8×7)

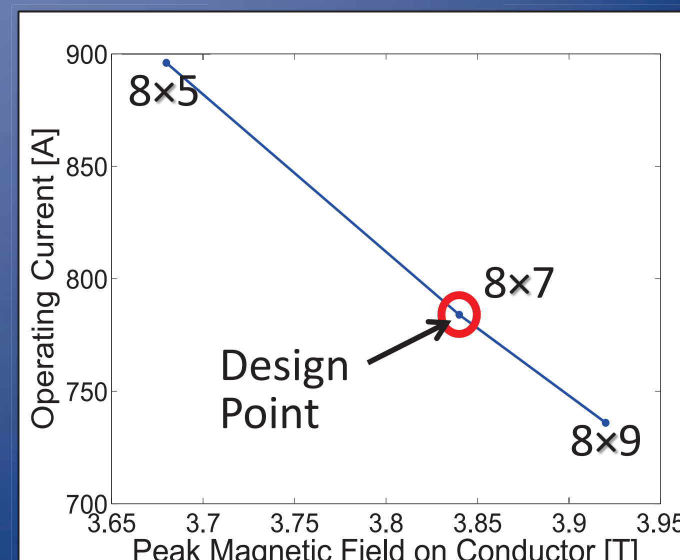


0.6-mm diam. wire,
60-μm braid insulation



IEEE Trans. on App. Supercon., Vol. 17, No. 2, June 2007 , pp. 1243-1246.





6-period prototype (Nb_3Sn) built at LBNL in 2006 - reached 97% of current (λ_u = 14.5 mm).

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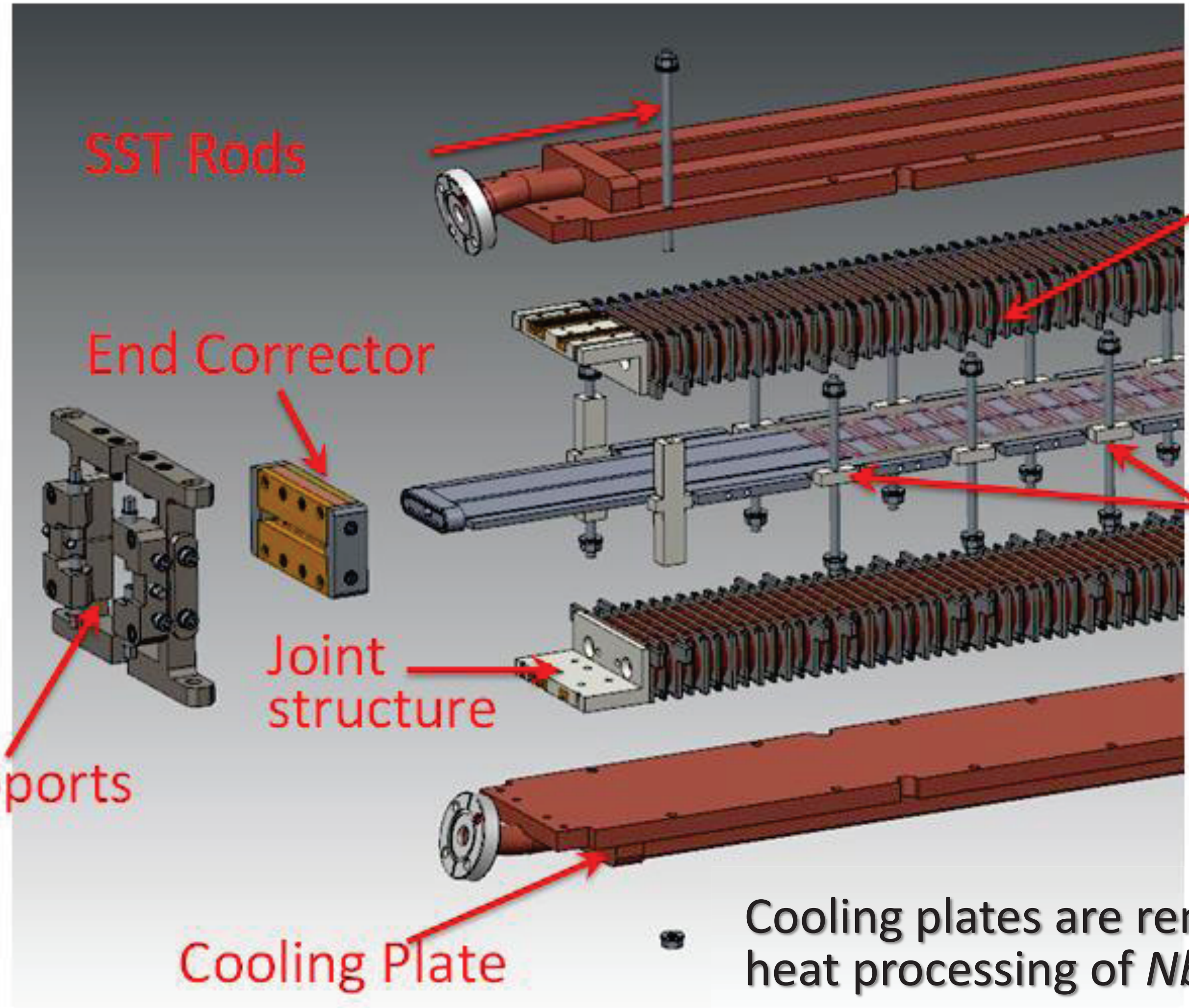
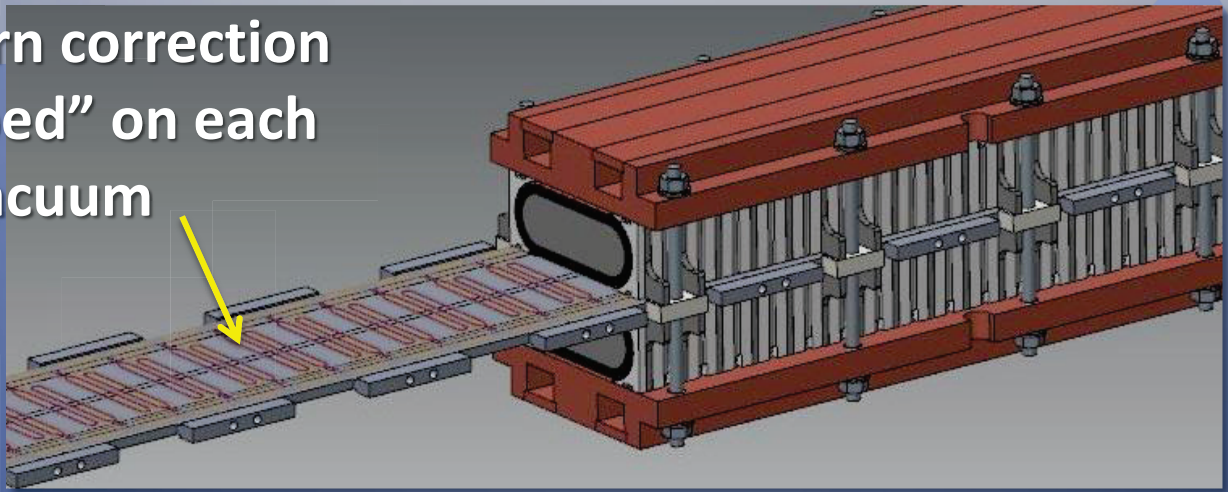
Undulator Assembly Components - *LBNL*



Cooling plates are removable to allow heat processing of *Nb_3Sn* (~635 C)

SCU Phase Correction Scheme - *LBNL*

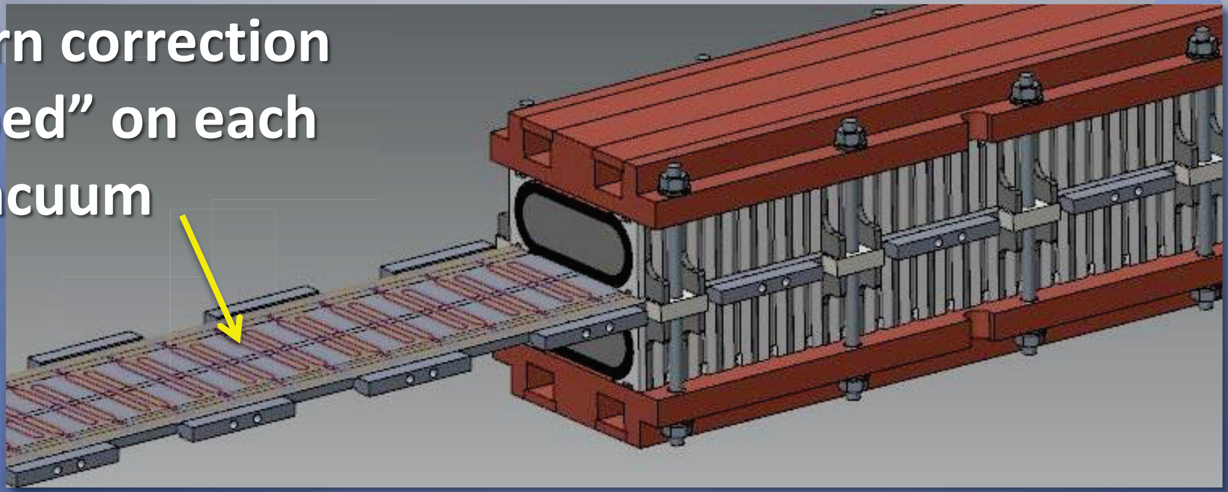
Single-turn correction coils "taped" on each side of vacuum chamber



S. Prestemon, D. Arbelaez, *LBNL*

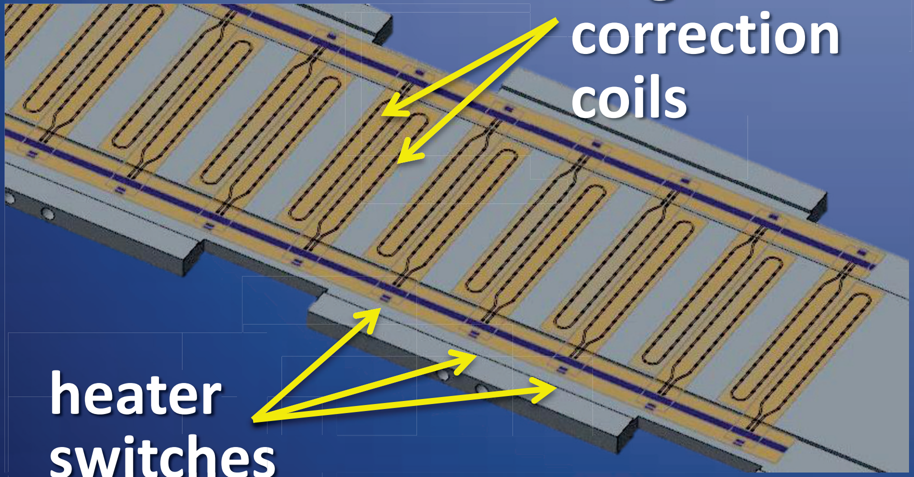
SCU Phase Correction Scheme - *LBNL*

Single-turn correction coils "taped" on each side of vacuum chamber



single turn correction coils

heater switches



S. Prestemon, D. Arbelaez, *LBNL*

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SCU Phase Correction Scheme - *LBNL*

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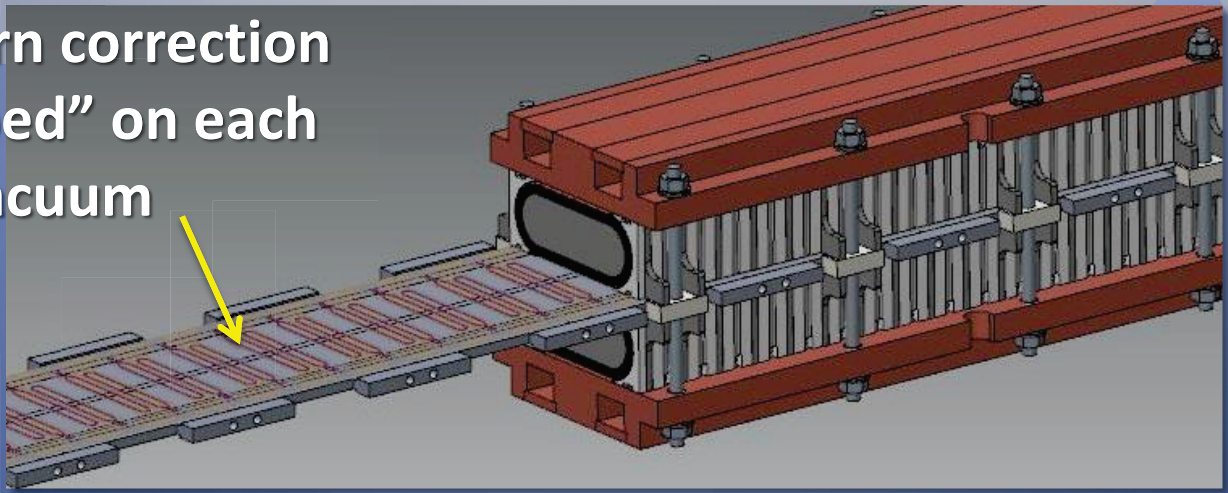

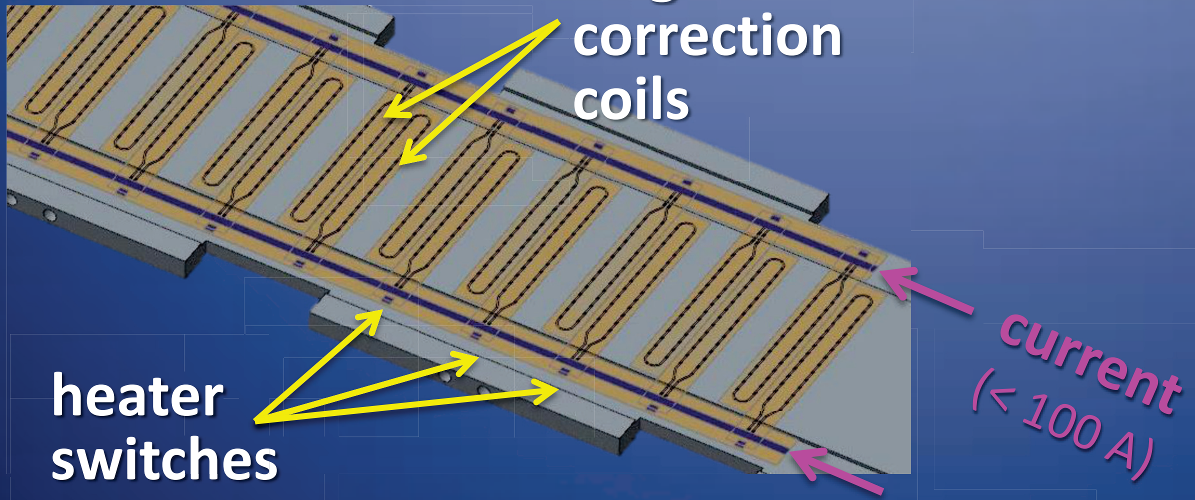

S. Prestemon, D. Arbelaez, *LBNL*

SCU Phase Correction Scheme - *LBNL*

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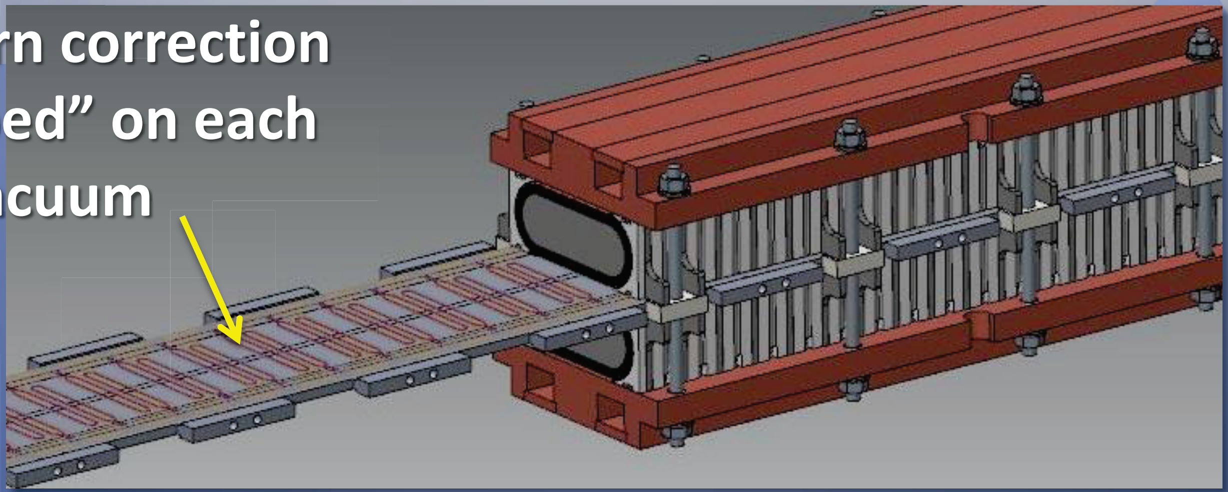
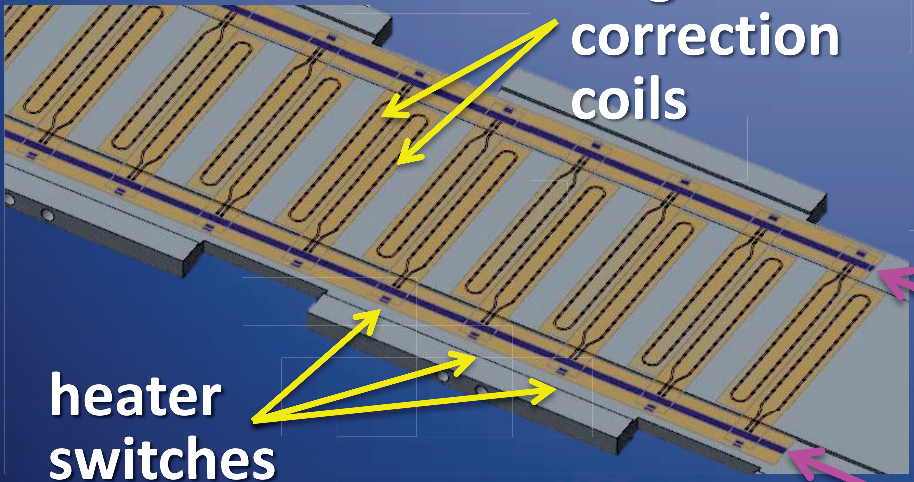
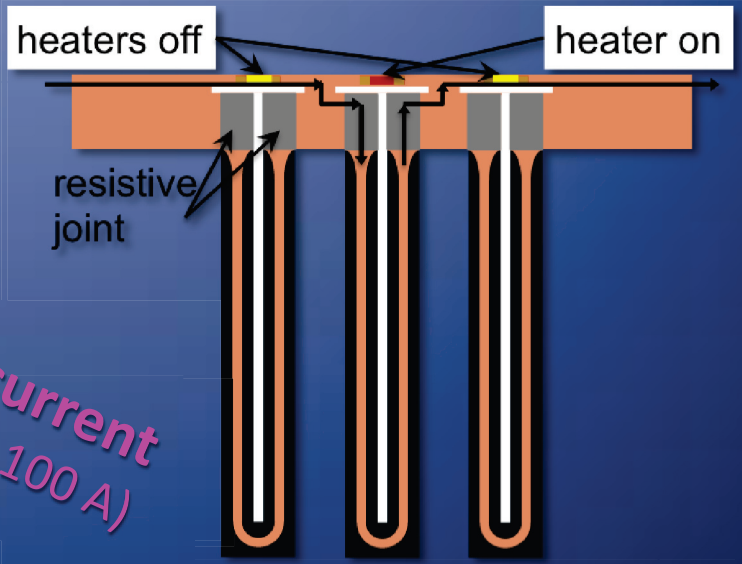


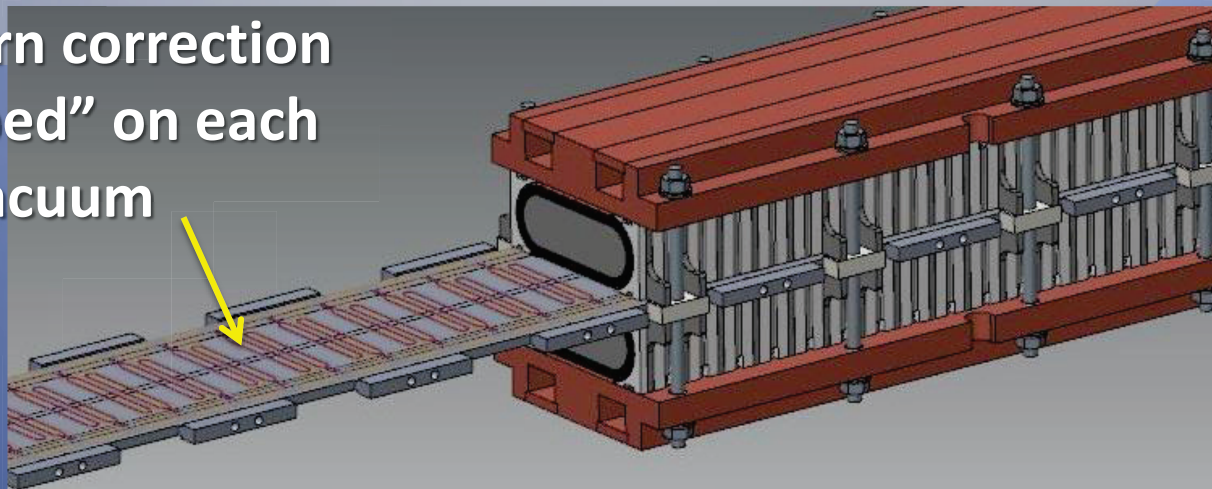


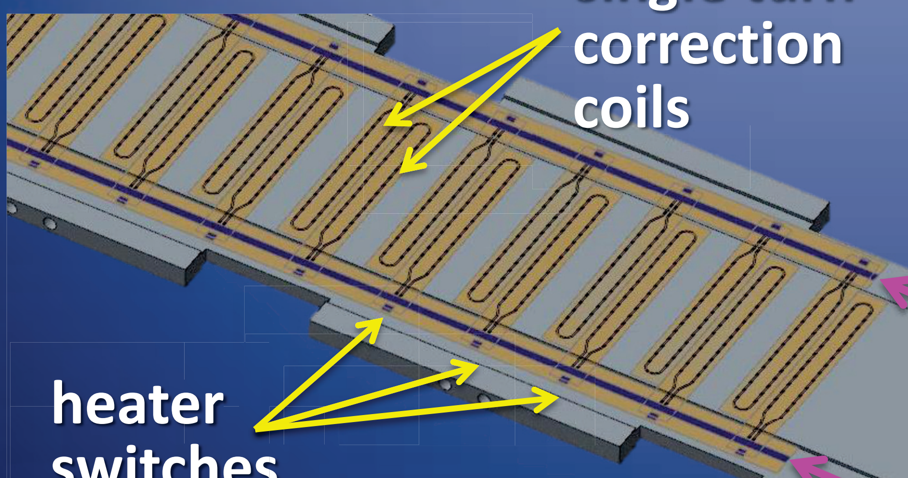


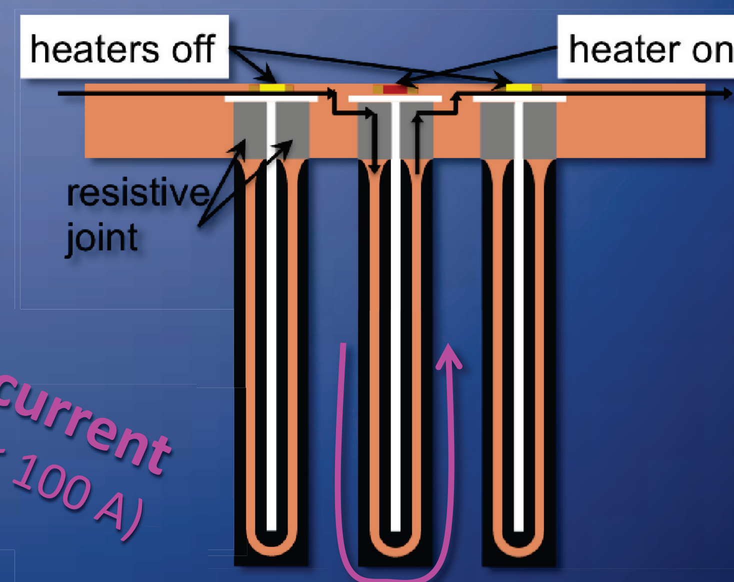
S. Prestemon, D. Arbelaez, *LBNL*

SCU Phase Correction Scheme - *LBNL*

Single-turn correction coils “taped” on each side of vacuum chamber



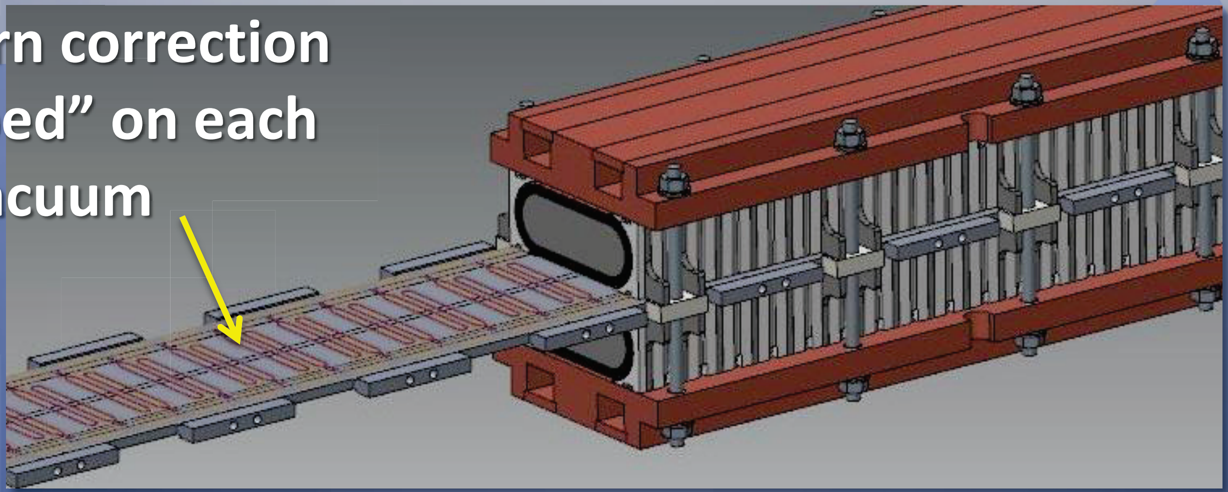




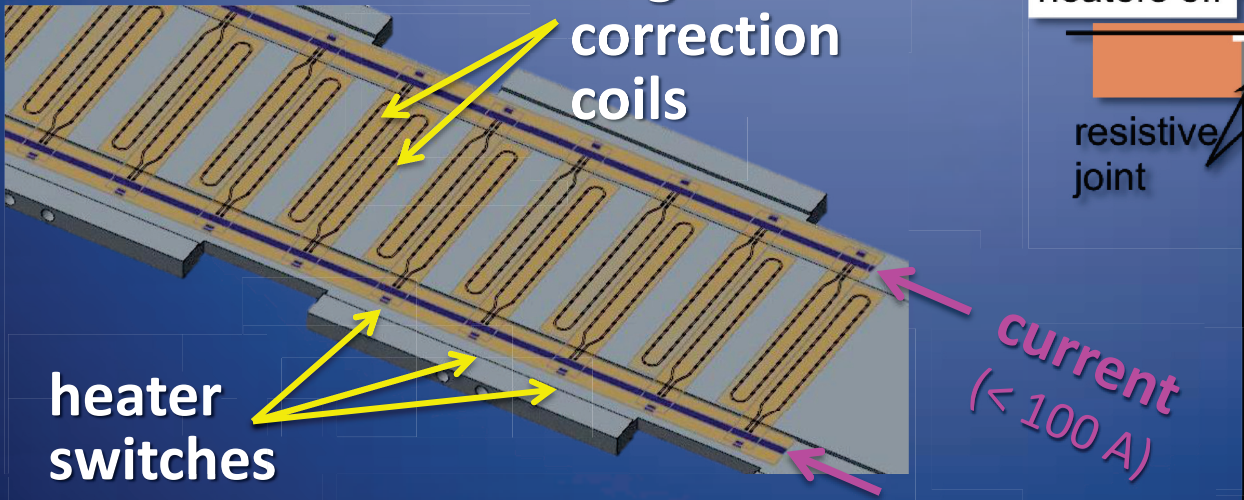
S. Prestemon, D. Arbelaez, *LBNL*

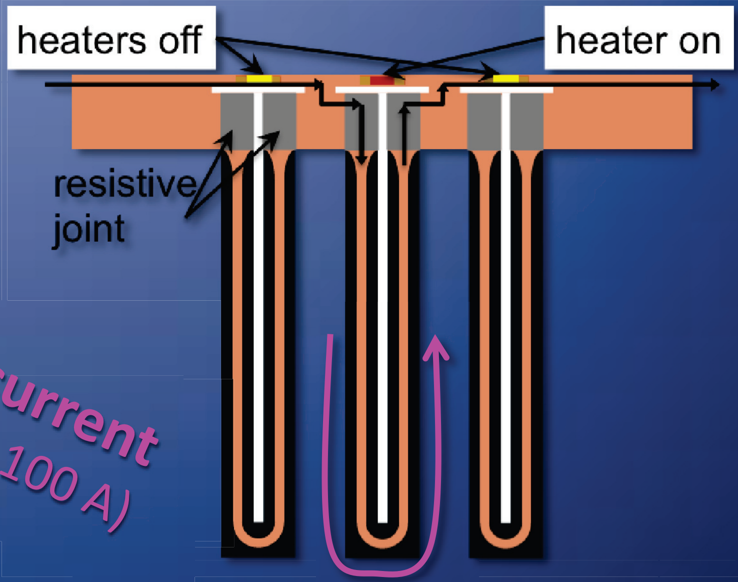
SCU Phase Correction Scheme - *LBNL*

Single-turn correction coils "taped" on each side of vacuum chamber



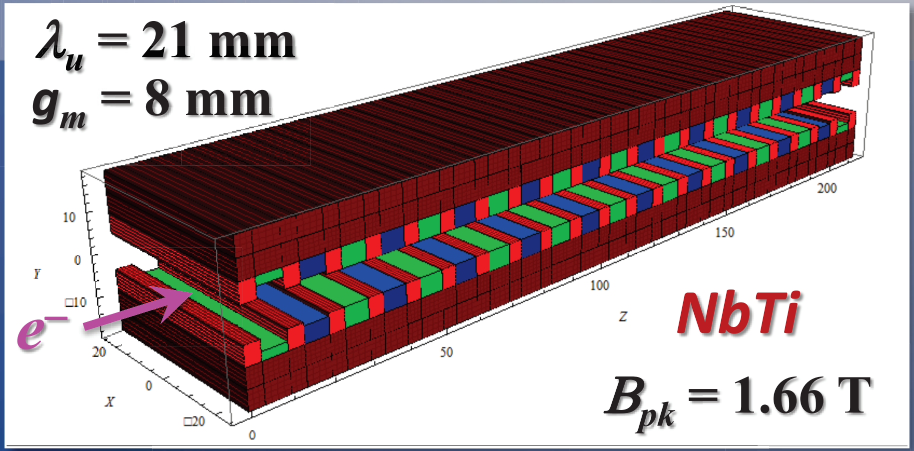
- Needs demo
- May not be necessary?





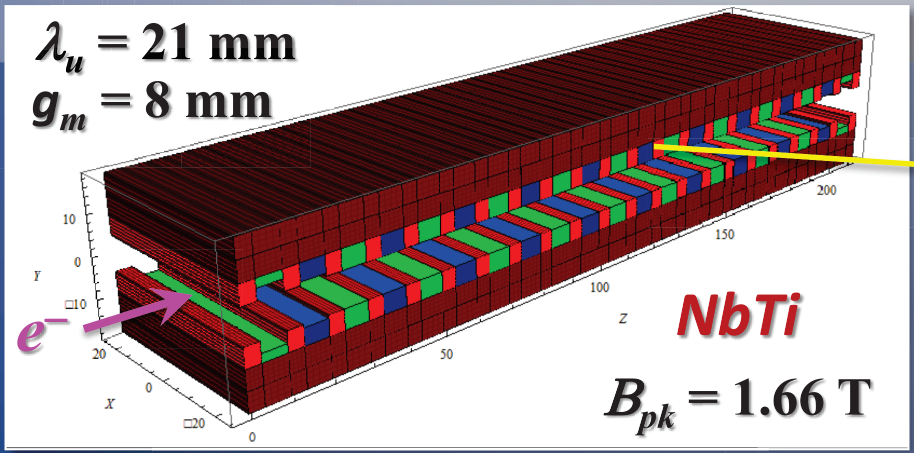
S. Prestemon, D. Arbelaez, *LBNL*

Prototype Magnet - *ANL* (NbTi)



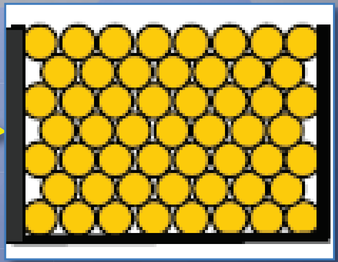
Lower risk, but less field

Prototype Magnet - *ANL* (NbTi)



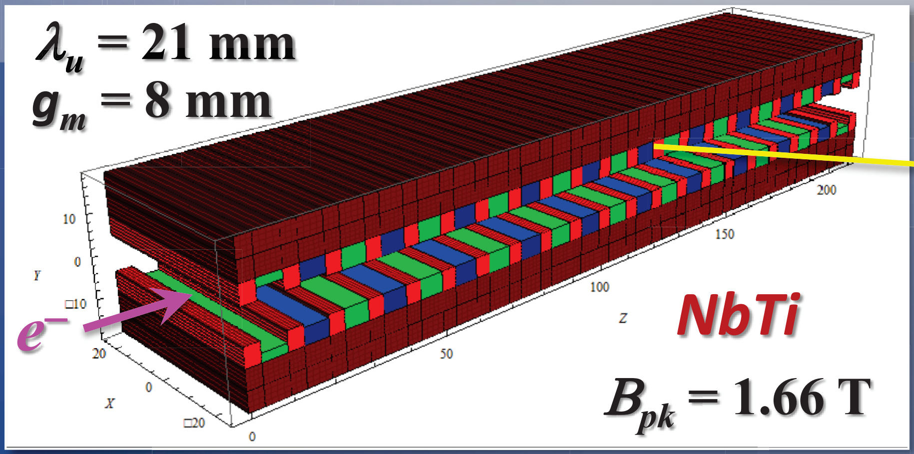
Lower risk, but less field

Wire pocket (53 turns)



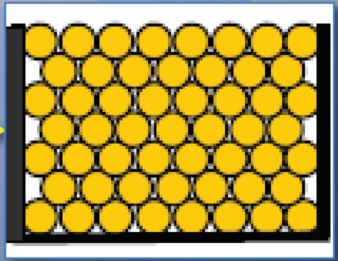
0.7-mm diam.
Supercon NbTi SC wire

Prototype Magnet - *ANL* (NbTi)



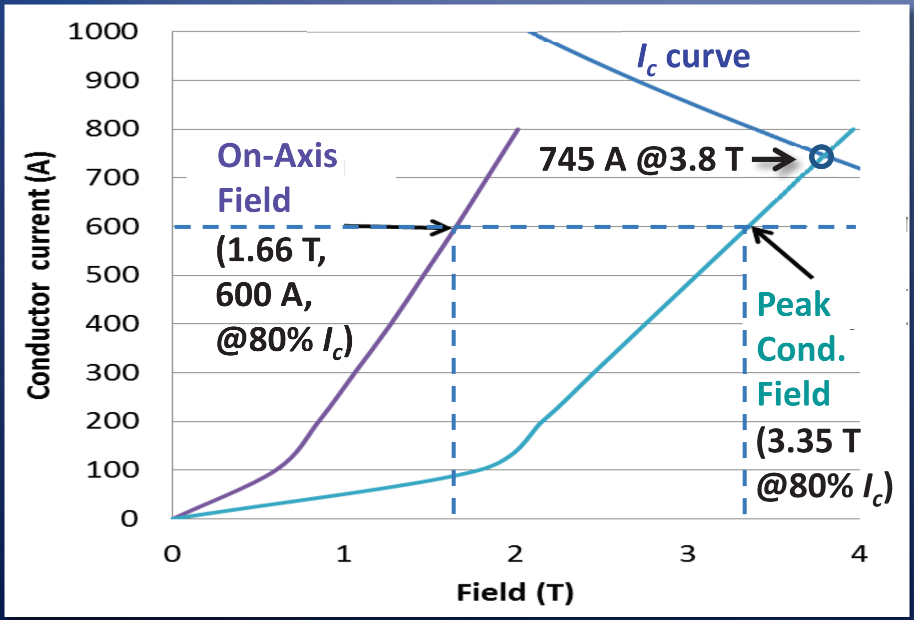
Lower risk, but less field

Wire pocket (53 turns)

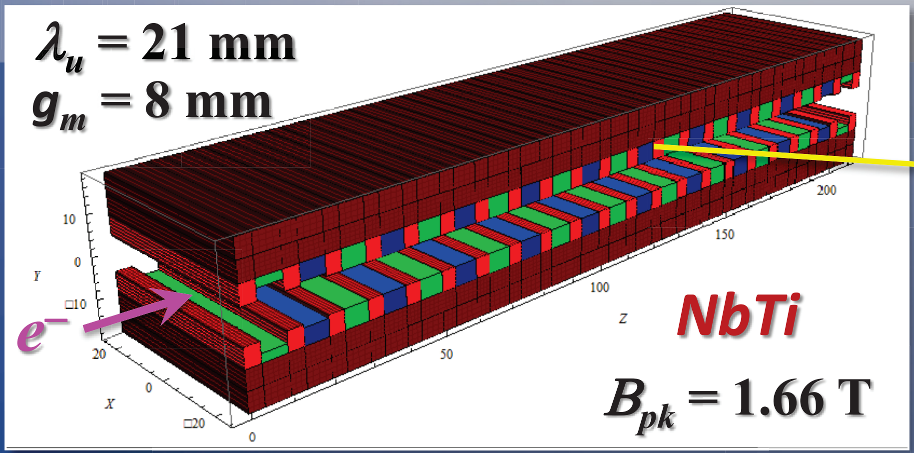


0.7-mm diam.
Supercon NbTi SC wire

Load Lines



Prototype Magnet - *ANL* (NbTi)



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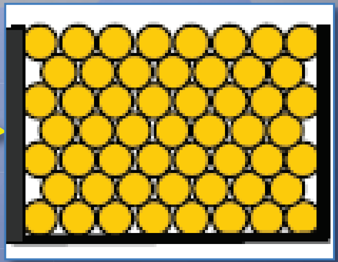

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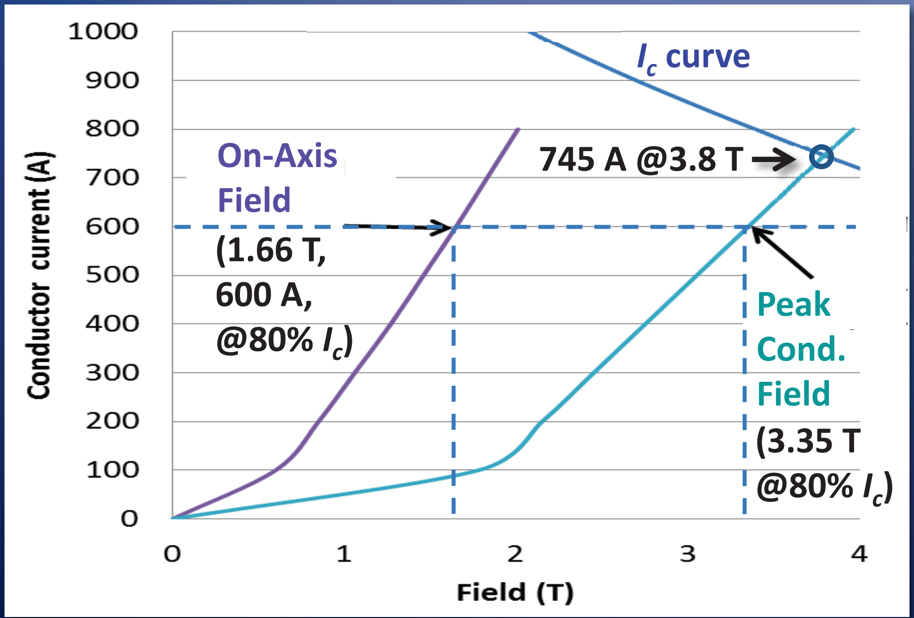
Load Lines



Short test cores to verify tolerances
and recent SCU1 (1.1-m) now powered

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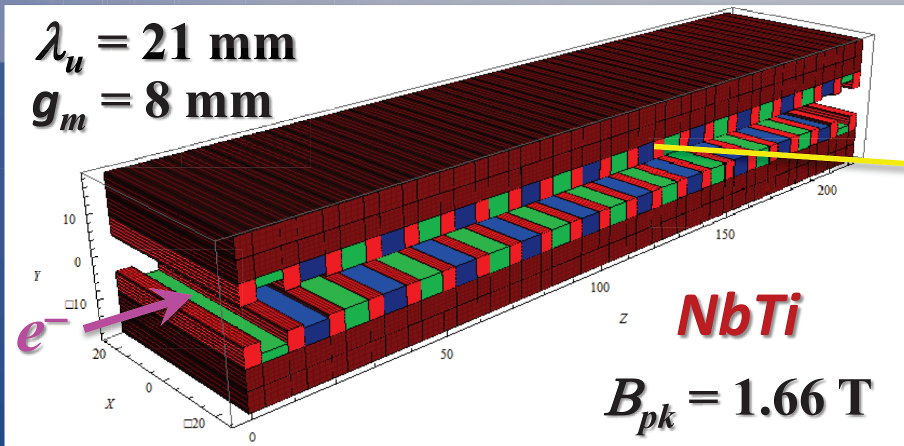
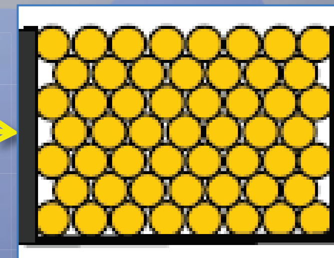
Prototype Magnet - *ANL* (NbTi)



Lower risk, but less field

Wire pocket (53 turns)



0.7-mm diam.
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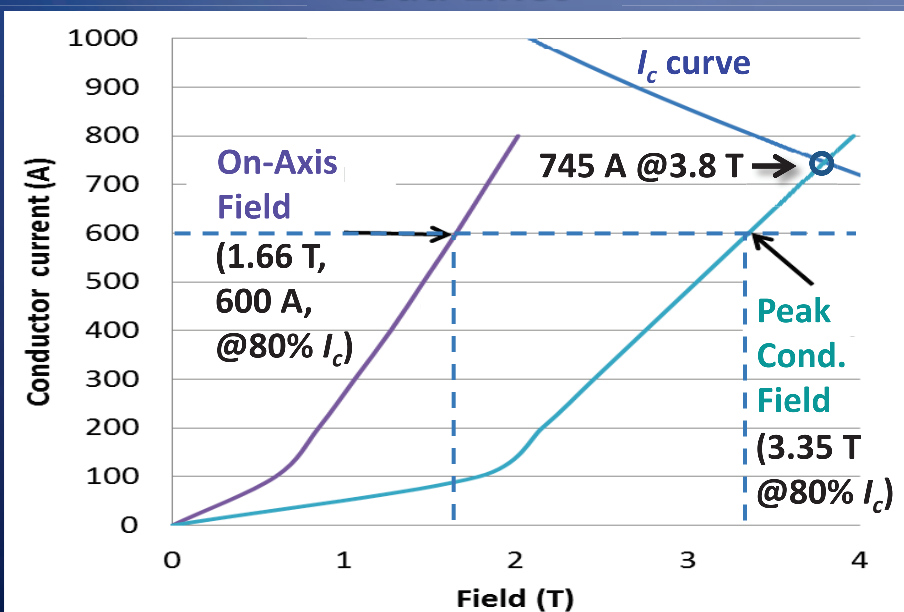
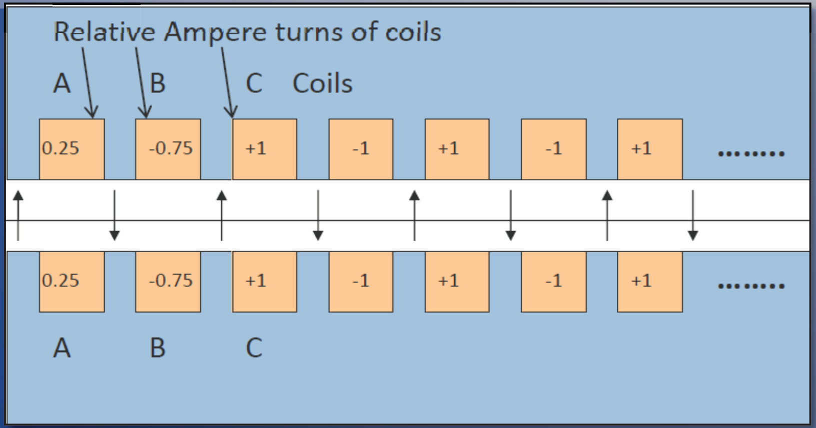
Load Lines



Short test cores to verify tolerances and recent SCU1 (1.1-m) now powered

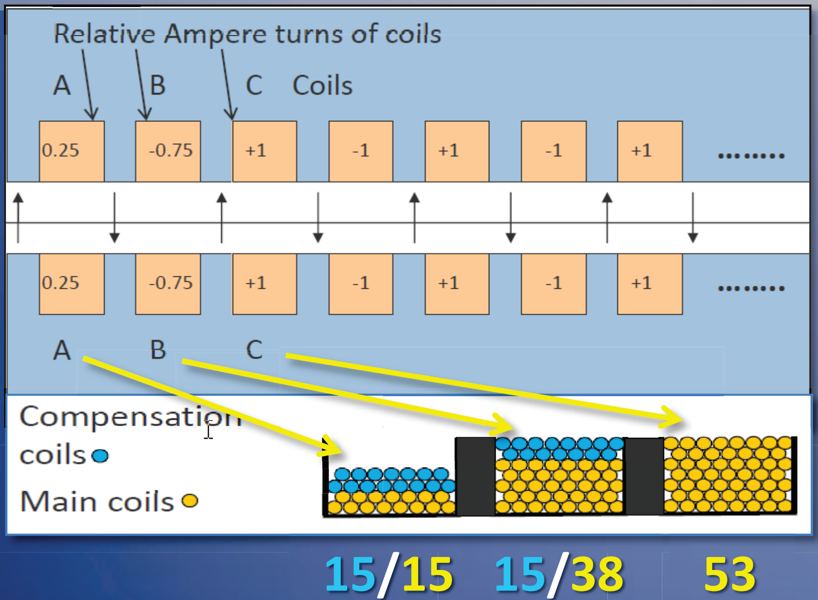
End-coil Winding Scheme - *ANL*

End-Terminations and Field Correctors



End-coil Winding Scheme - *ANL*

End-Terminations and Field Correctors



End-coil Winding Scheme - *ANL*

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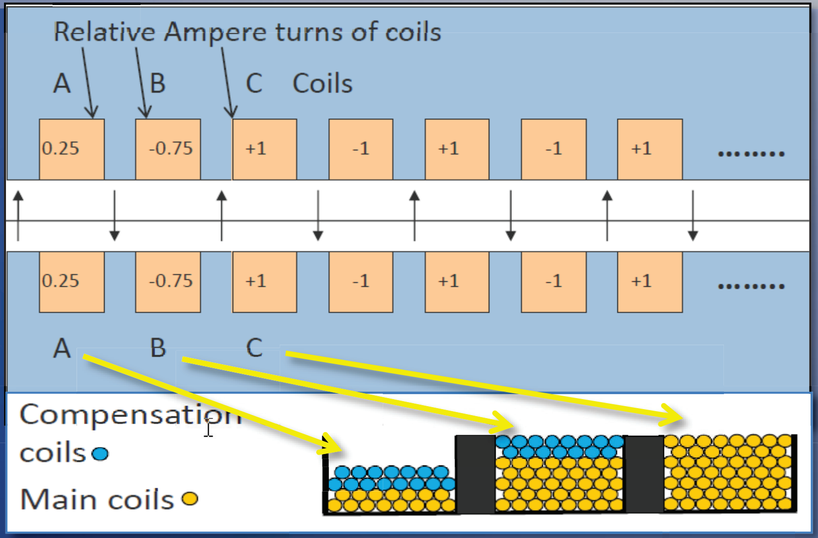
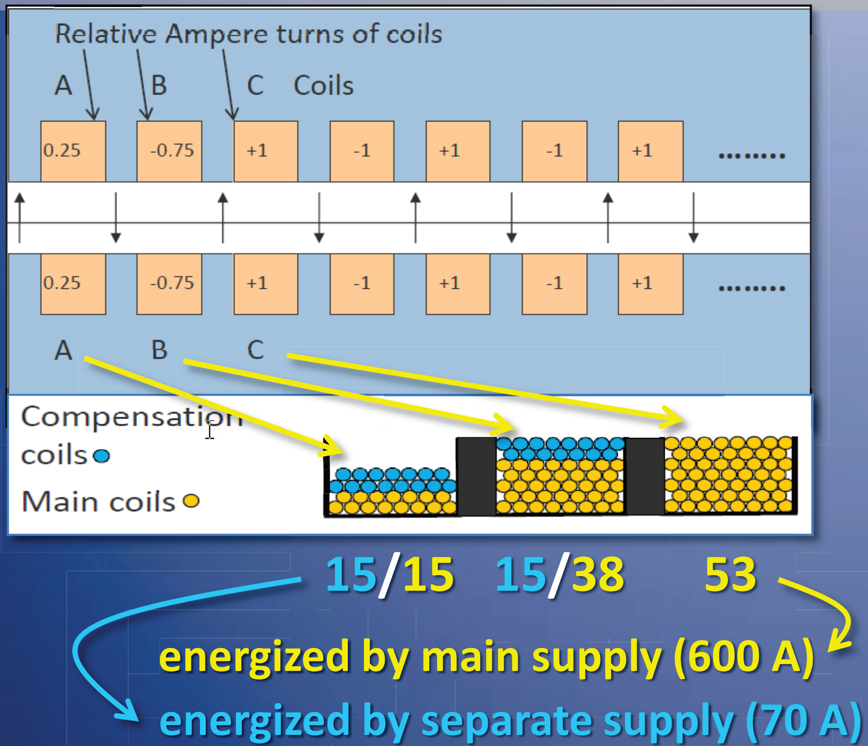


15/15 15/38 53

energized by main supply (600 A)

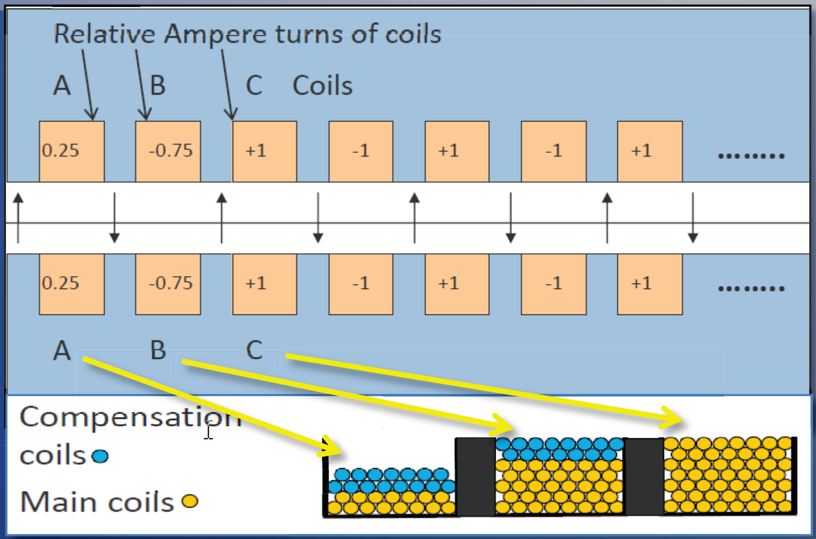
End-coil Winding Scheme - *ANL*

End-Terminations and Field Correctors



End-coil Winding Scheme - *ANL*

End-Terminations and Field Correctors

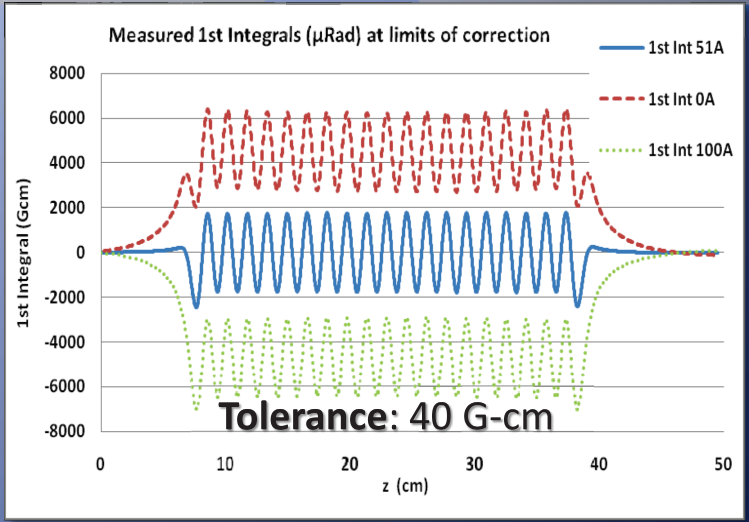


15/15 15/38 53

energized by main supply (600 A)

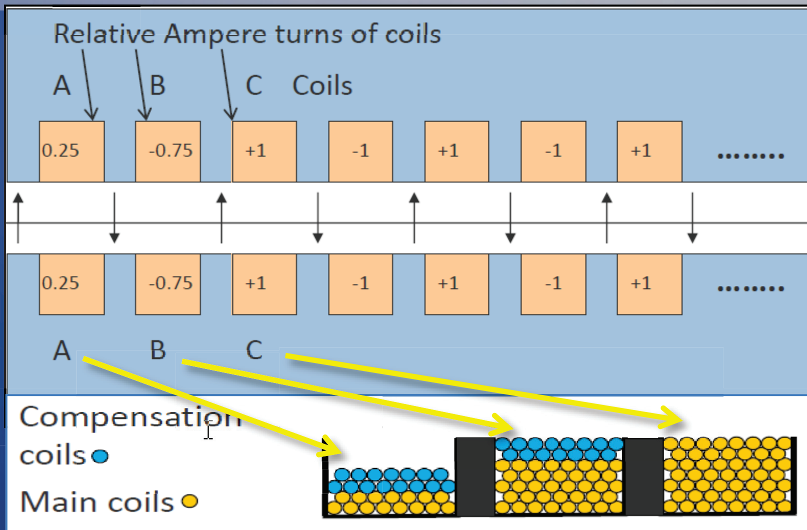
energized by separate supply (70 A)

0 , 51, 100 Amp (Measurements)



End-coil Winding Scheme - *ANL*

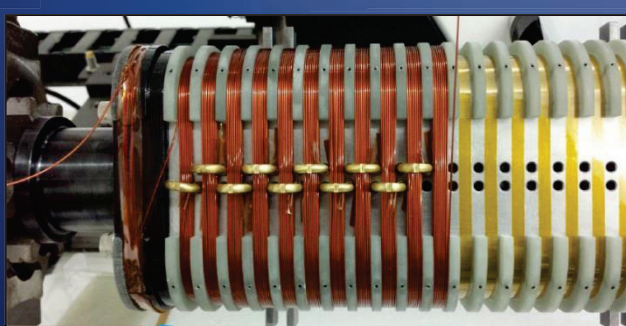
End-Terminations and Field Correctors



15/15 15/38 53

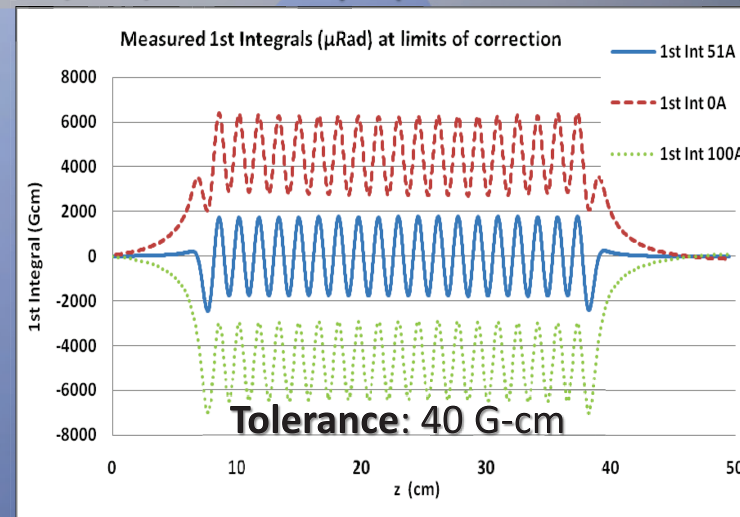
energized by main supply (600 A)

energized by separate supply (70 A)



shows 11 complete coil packages

0 , 51, 100 Amp (Measurements)



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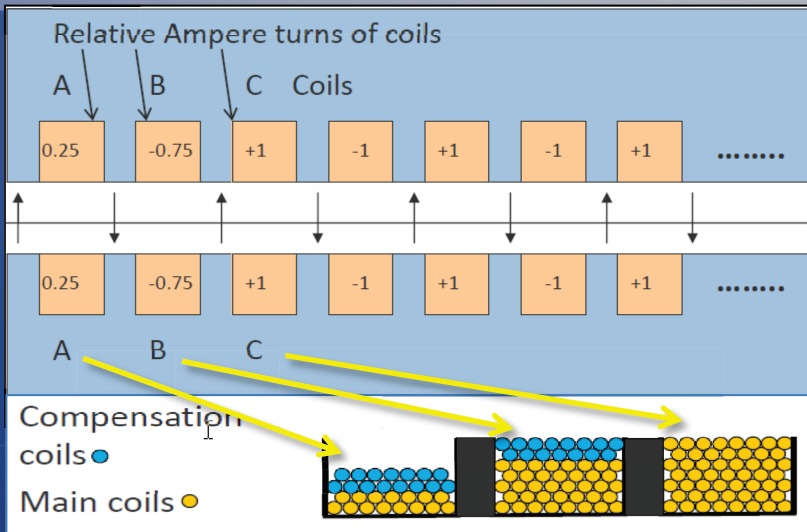
End-coil Winding Scheme - *ANL*

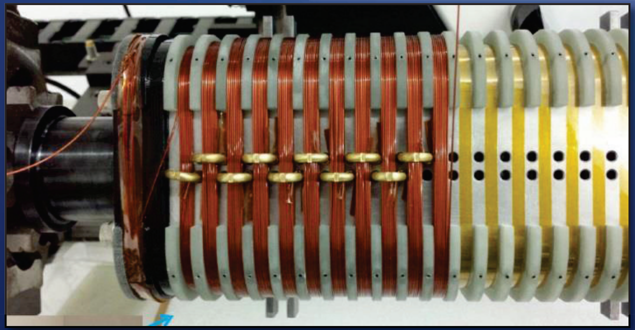
End-Terminations and Field Correctors



15/15 15/38 53

energized by main supply (600 A)

energized by separate supply (70 A)



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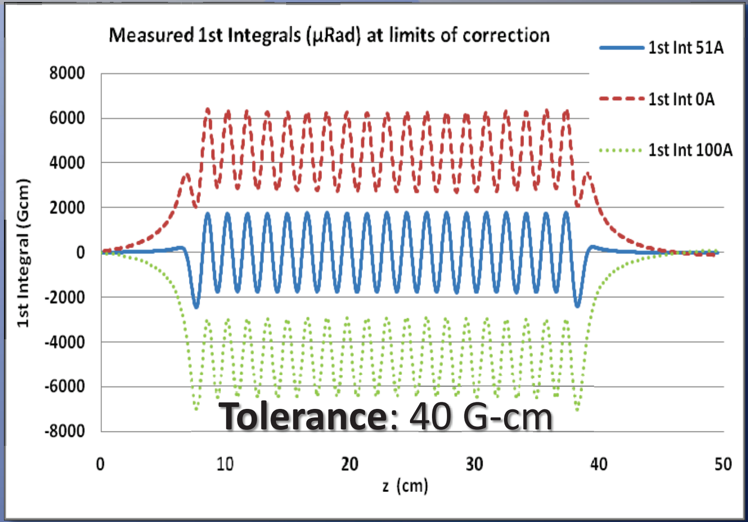
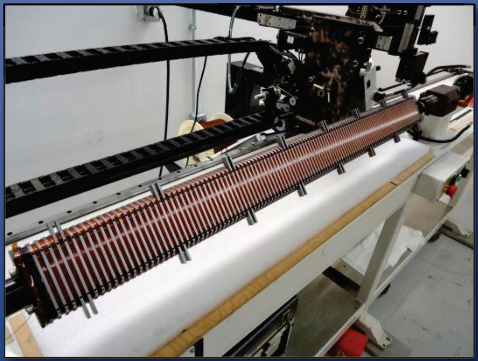
0 , 51, 100 Amp (Measurements)



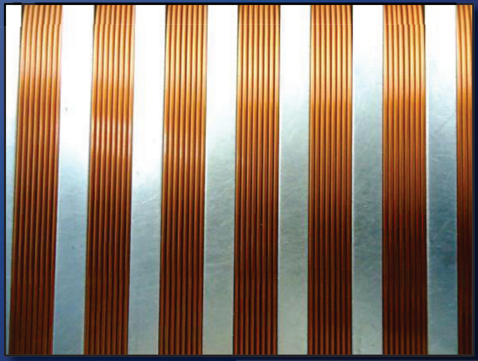
Precision cores & precision winding!

"SCU1" being wound on bench

Fully wound 1.1-m half-magnet



winding pack front face



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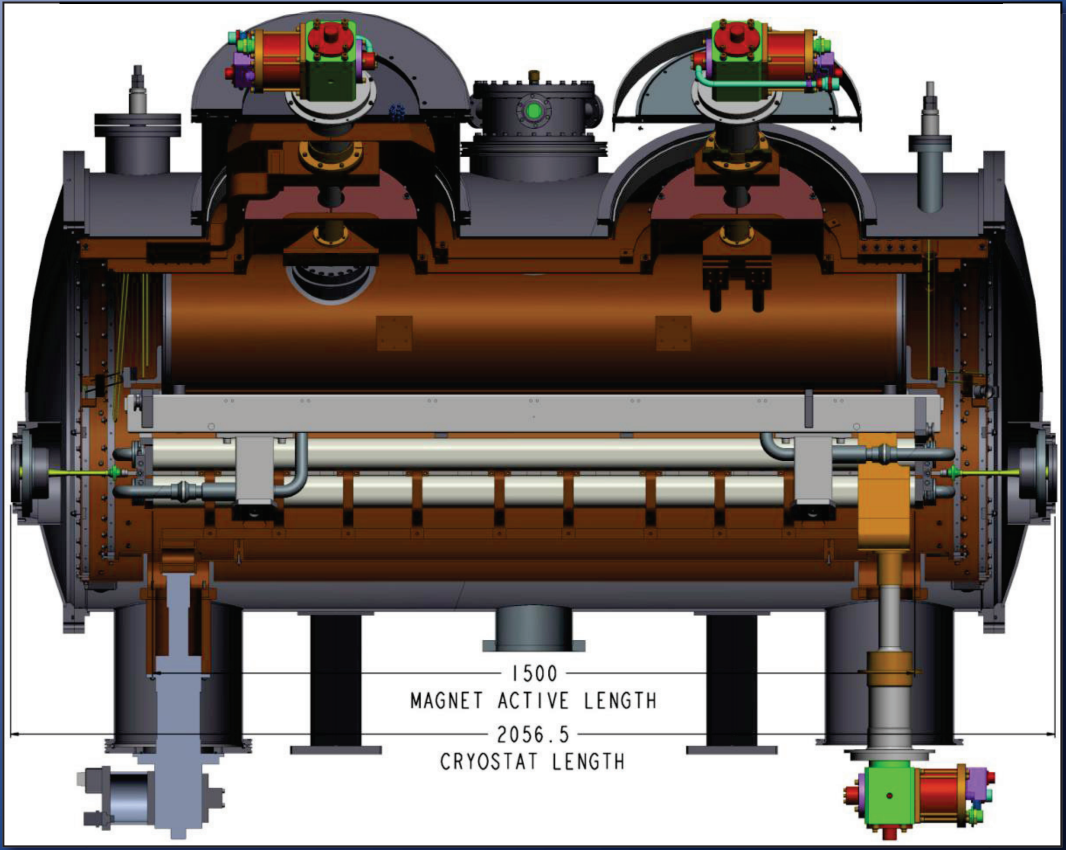
ANL 2-m Cryostat (to test both magnets)

Existing 2-m cryostat (4K) at APS

- Experience with SCU's at APS
- Each magnet to be tested in this cryostat



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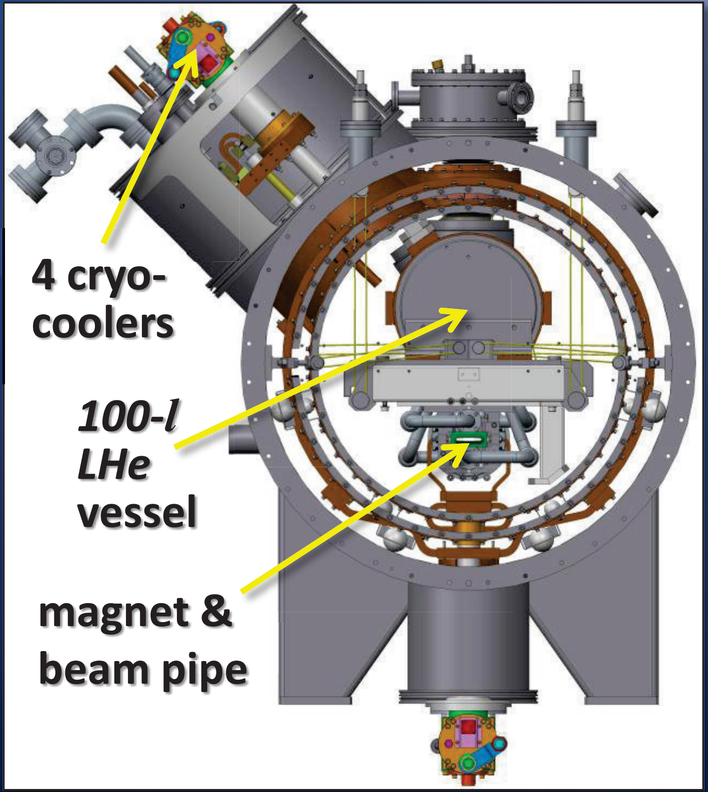

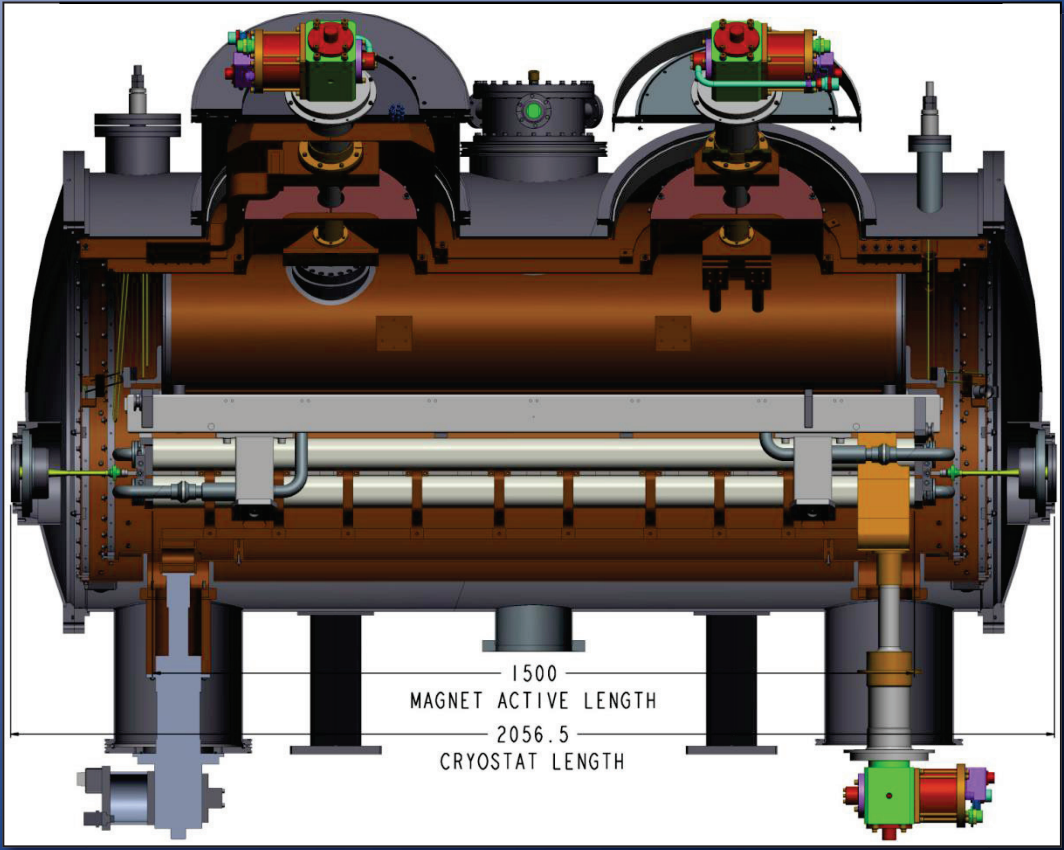

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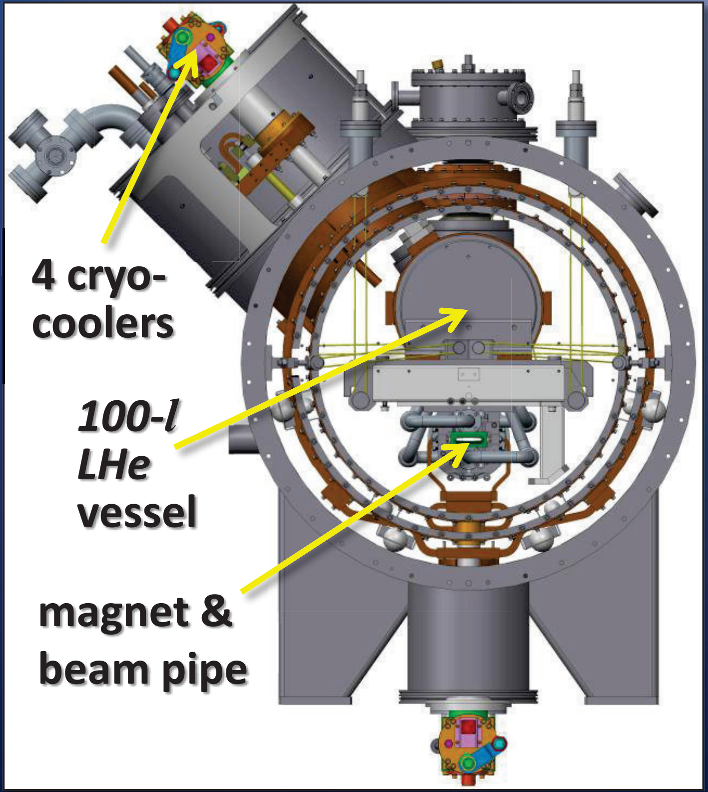
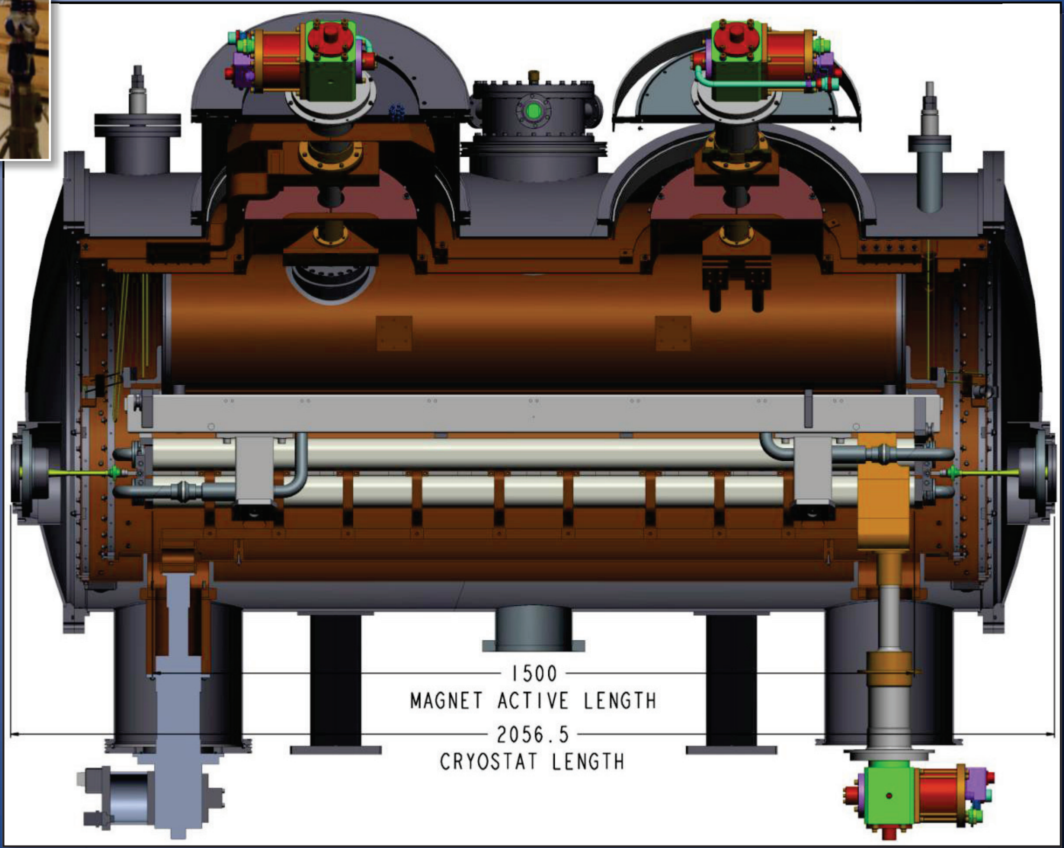
ANL 2-m Cryostat (to test both magnets)

2-m long cryostat; 4 cryo-coolers; Loss-free He system

Existing 2-m cryostat (4K) at APS

- Experience with SCU's at APS
- Each magnet to be tested in this cryostat





SCU System Concept for *LCLS-II* HXU

0.5-m cold breaks
2-m long segments (+quad+BPM+PS)
λ_u = 17-19 mm, Vacuum gap = 4-5 mm
5-m cryostats
500-W cryo-plant at 4 K

Joel Fuerst, *ANL*

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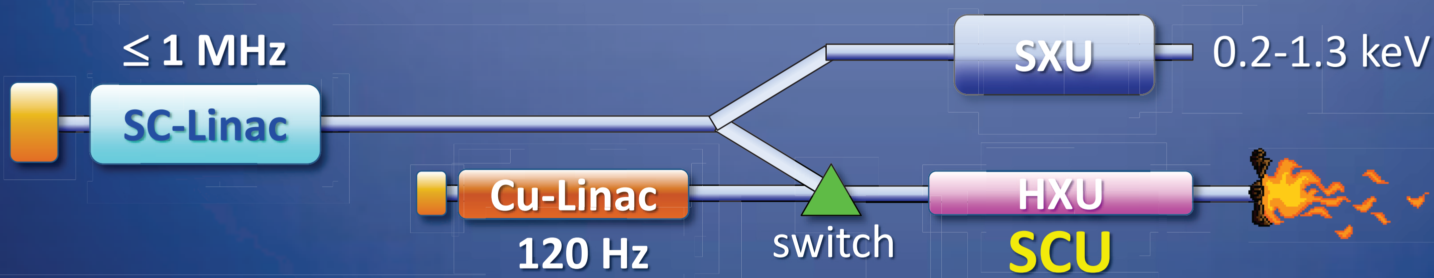
Summary

- **SCU technology promises a potential leap in FEL performance – needs development now**
- **LCLS-II HXU can be extended to 7+ keV (1 MHz) and 1 TW (120 Hz) using the same SCU**
- **R&D is underway – re-baseline of LCLS-II is possible, but depends on R&D and LCLS-II project schedule**



1 MHz,
1 - 7+ keV

or

120 Hz,
1 - 25 keV,
1 TW (4 keV)

Thanks to the SCU team:

P.E., N. Holtkamp, H.-D. Nuhn, ***SLAC;***
C. Doose, J. Fuerst, Q. Hasse, Y. Ivanyushenkov, M. Kasa, G. Pile, E. Trakhtenberg, E. Gluskin, ***ANL;***
D. Arbelaez, J. Corlett, S. Myers, S. Prestemon, R. Schlueter, ***LBNL***