Latest Developments on Insertion Devices

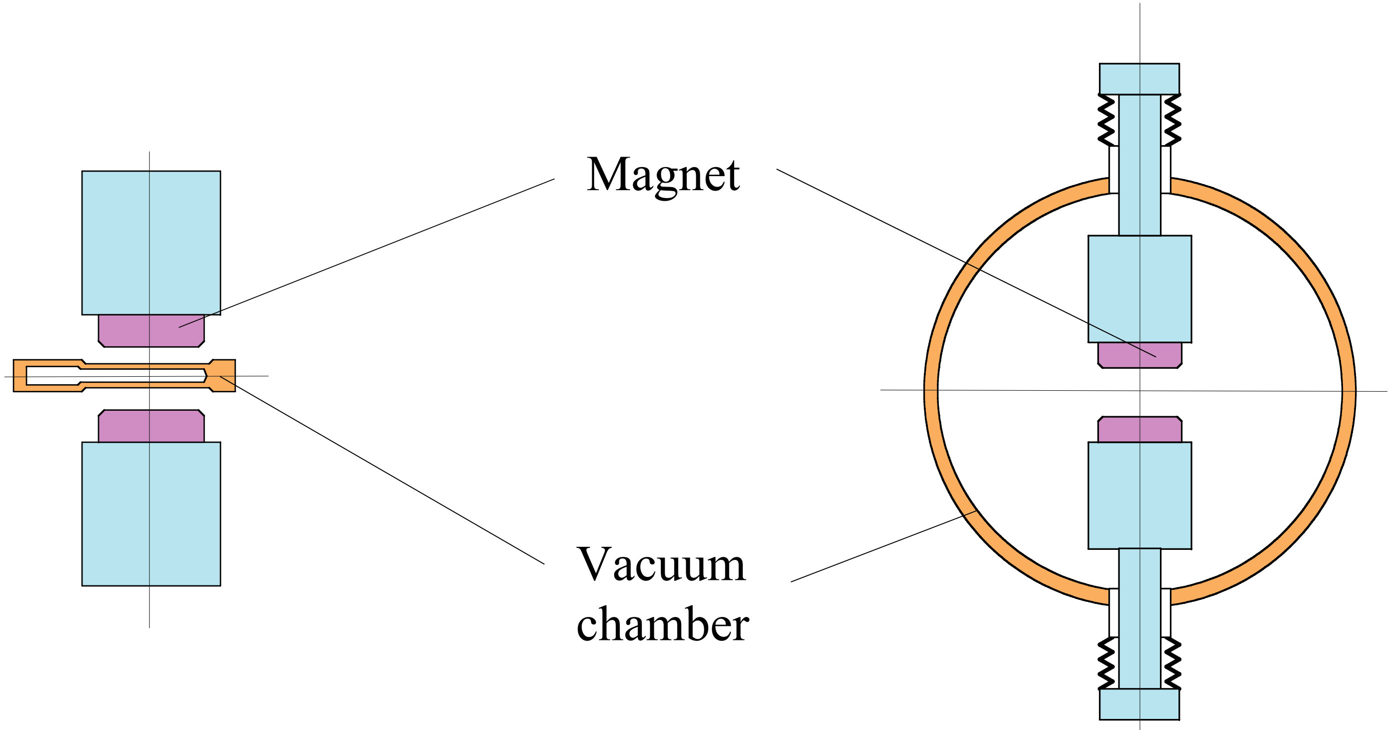
J. Chavanne, P. Elleaume

ESRF, Grenoble, France

Content

- Generalities
- Permanent Magnet Undulators
- Superconducting Undulators and Wigglers
- Circular Polarization
- SASE Undulators
- Miscellaneous

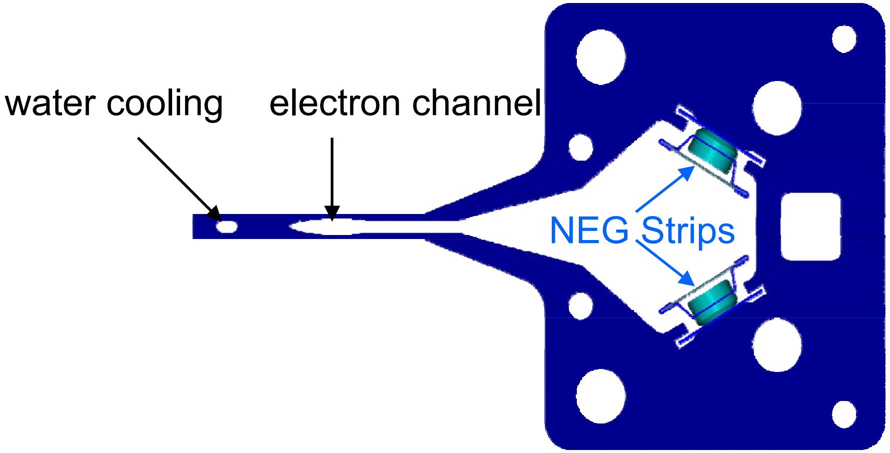
Permanent Magnet Undulators
$\Delta B/B \sim 20\%$ / mm gap for a 20 mm period



Min gap = beam stay clear
+ Material thickness
+ alignment tolerances
≈ 10 mm

Min gap= beam stay clear + NiCu sheet
≈ 5 - 6 mm
Large International development
following success at Spring8

Narrow Aperture Undulator Vacuum Chambers



Applied to **APS**, BESSY, SLS, ...

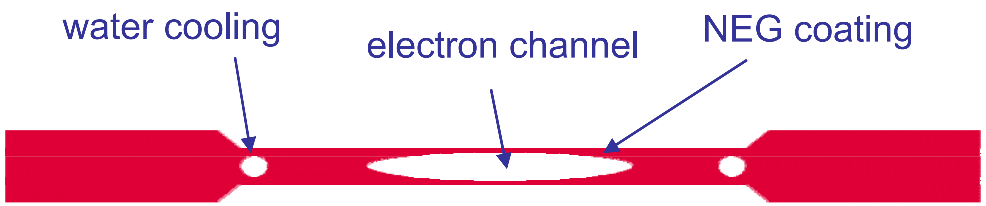
APS type Chamber

Int/ext gap = 5-7 mm, L =2.5 m

ST707 NEG strips

Strip Activation @ 350-450°C

Restrict Undulator Space



Applied to **ESRF**, ELETTRA, MAXLAB, SLS, SOLEIL (10 m) , DIAMOND,…

ESRF type Chamber

Int/ext gap = 8-10 mm , L=5 m

NEG Coating, Ti-Zr-V, 1 µm

Chamber Activation @ 200 °C.

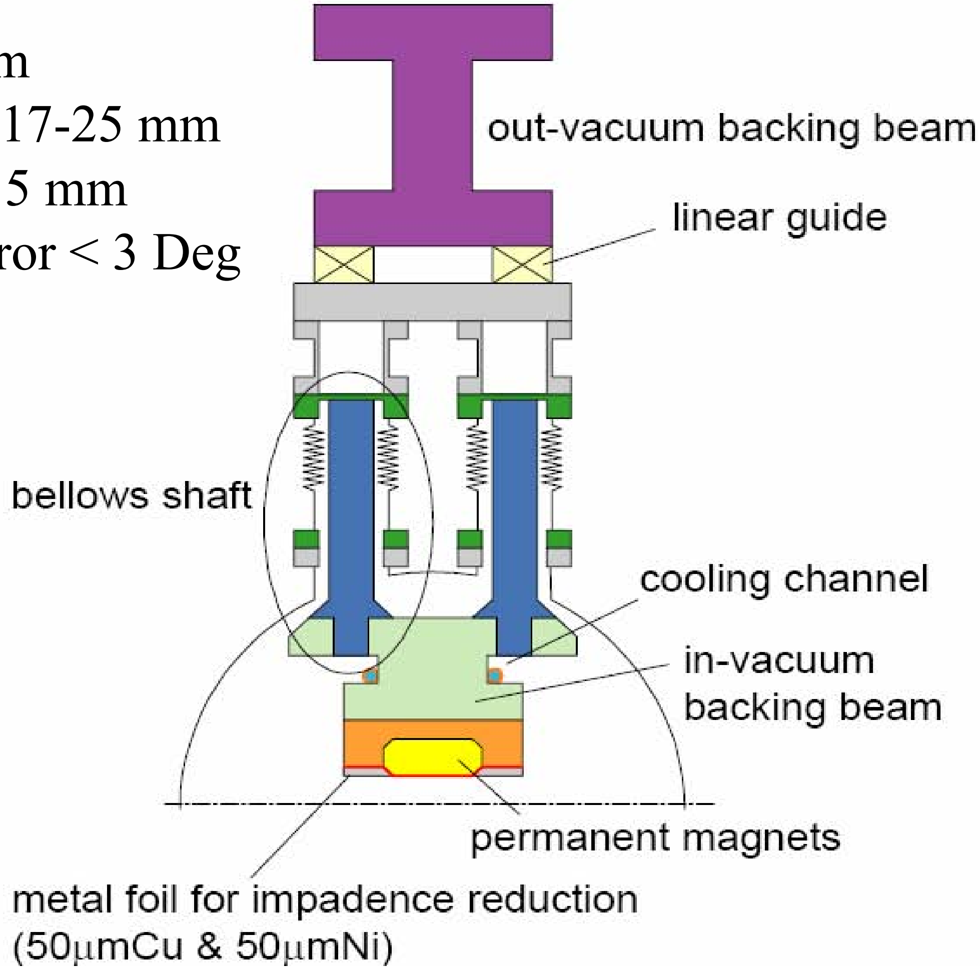
Low Photon Induced Desorption

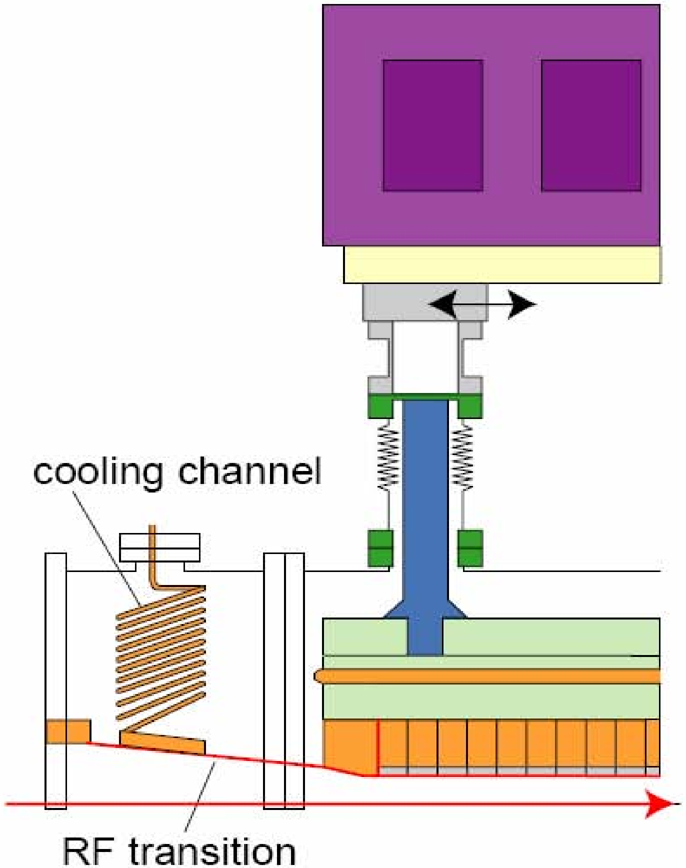
Rapid Conditioning

Less Constraints on Undulators

Technologies: Overall Structure

L ~ 2 m
Per ~ 17-25 mm
Gap ~ 5 mm
Ph. Error < 3 Deg





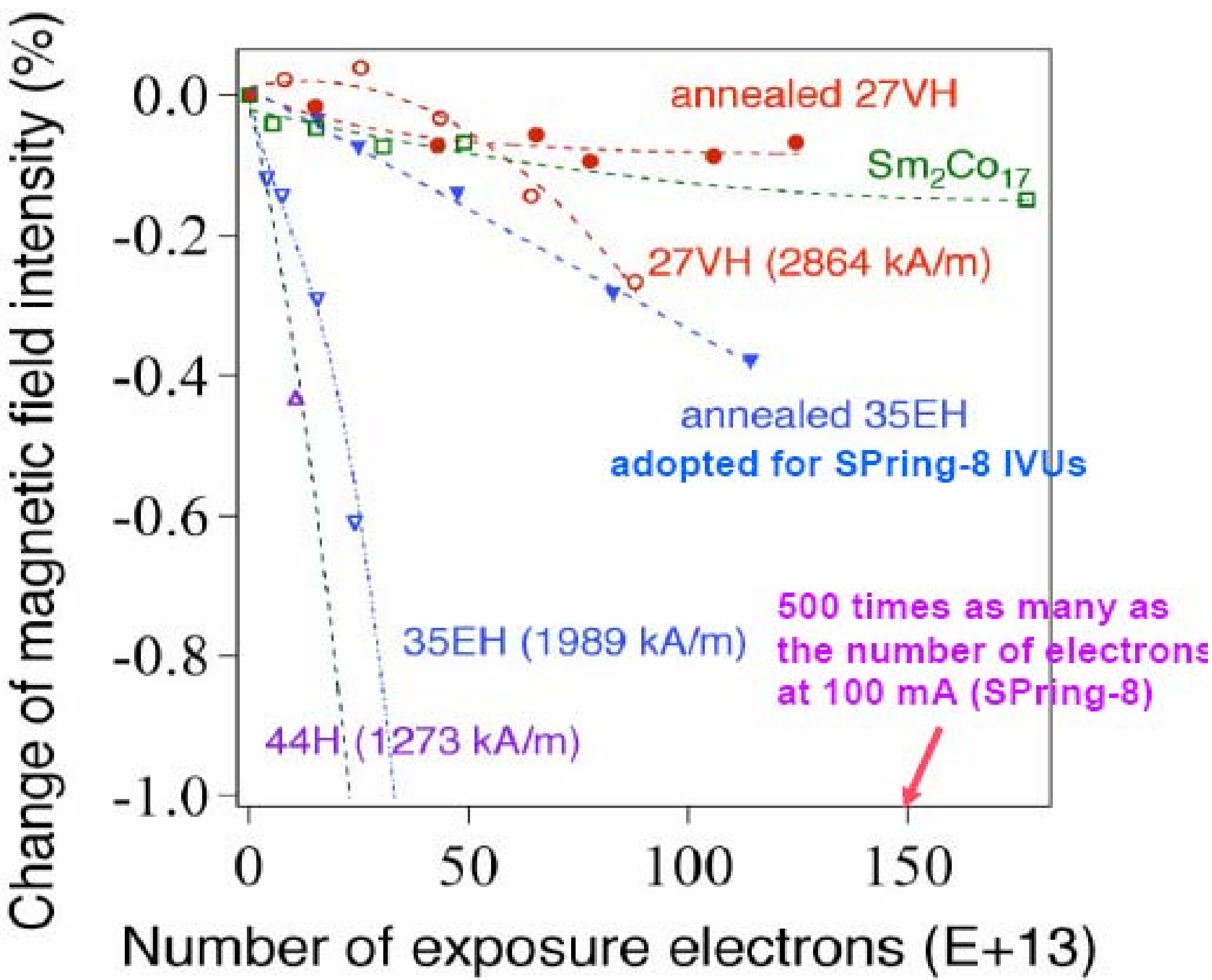
Courtesy of T. Tanaka, Spring8

NdFeB Demagnetization by e-beam

Serious Issue :
- Observed at ESRF,APS,…
On low gap undulators
- Critical with high current and short lifetime
- Detailed Experimental study by Spring8 team at PLS

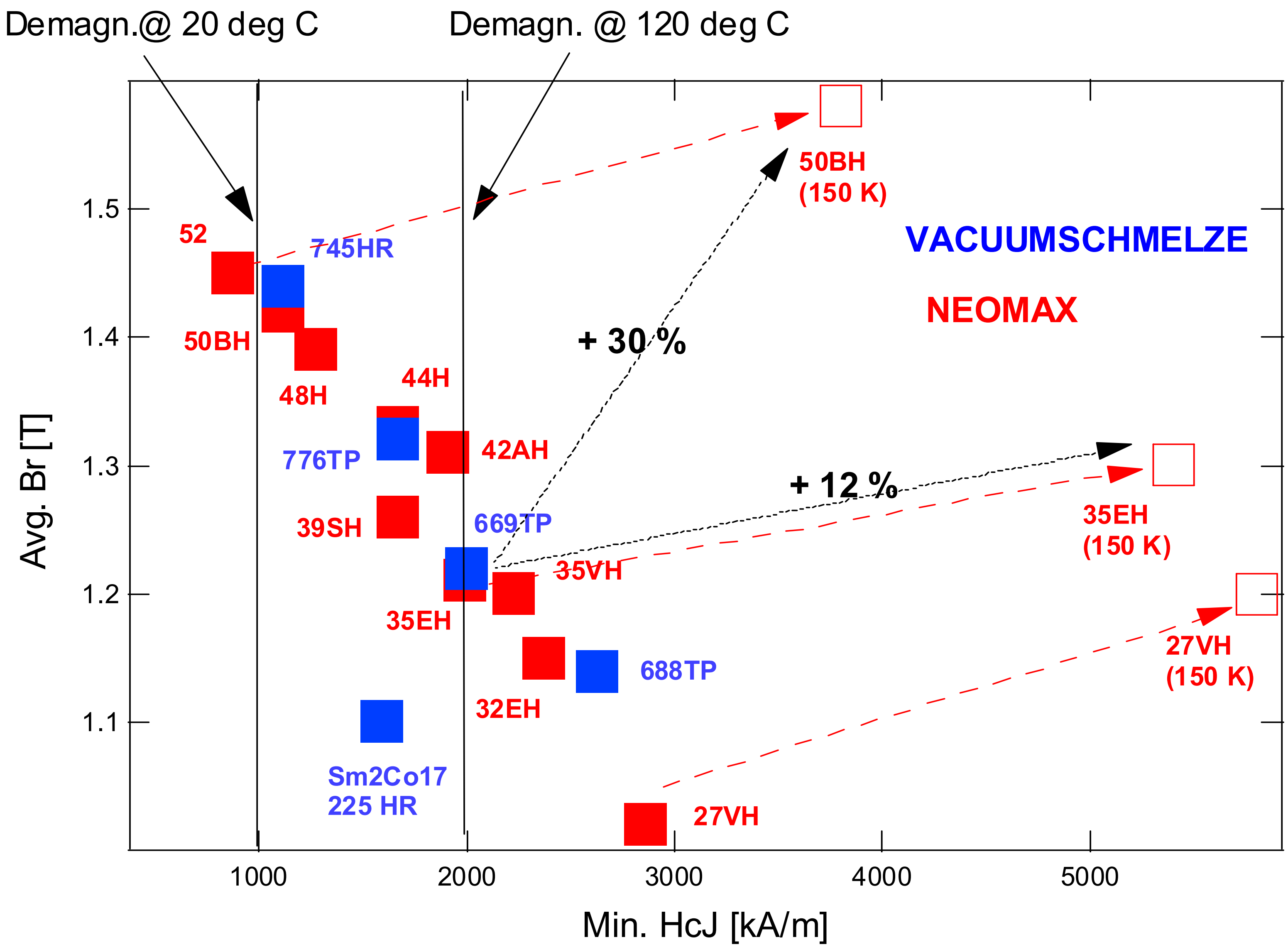
Remedies :
- Use Sm_2Co_{17}
- Use NdFeB with Hc > 2700 kA/m (2000 kA/m with Temp Annealing)

Courtesy of Bizen, Spring8

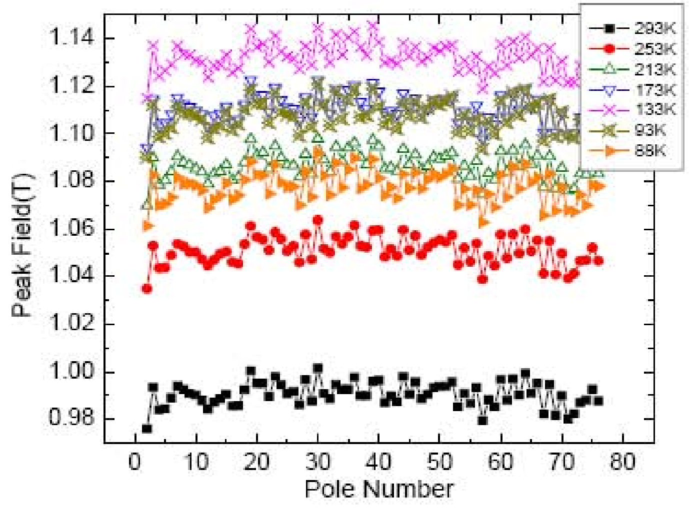


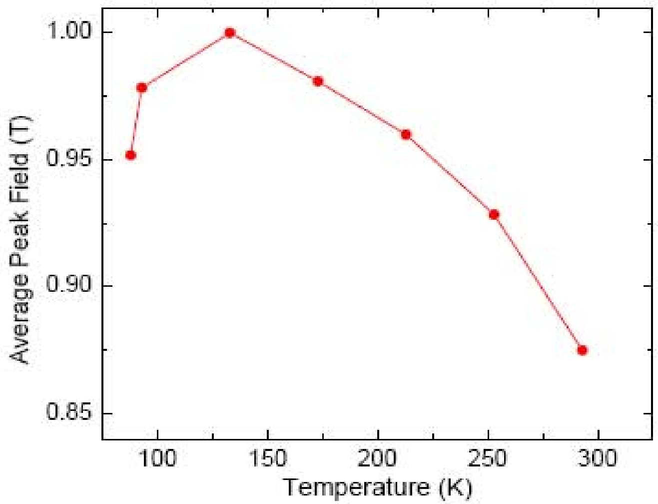
Courtesy of H. Kitamura, Spring8

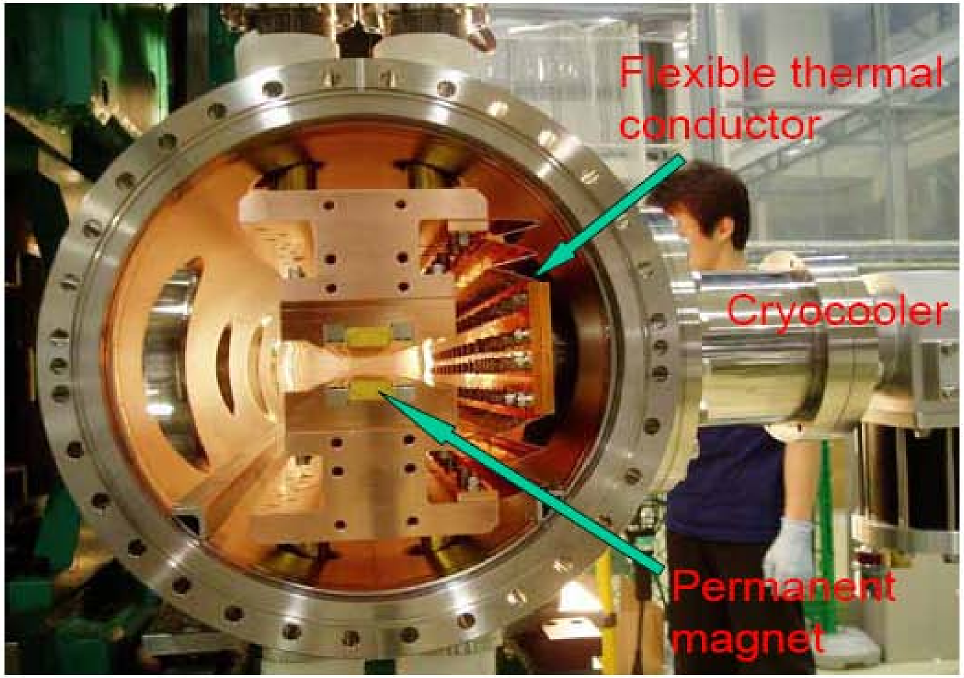
Permanent magnet materials



Spring8 Cryoundulator Prototype







Cryoundulator Prototype
PM Material: NEOMAX50BH
λ_u=15mm,L=0.6m

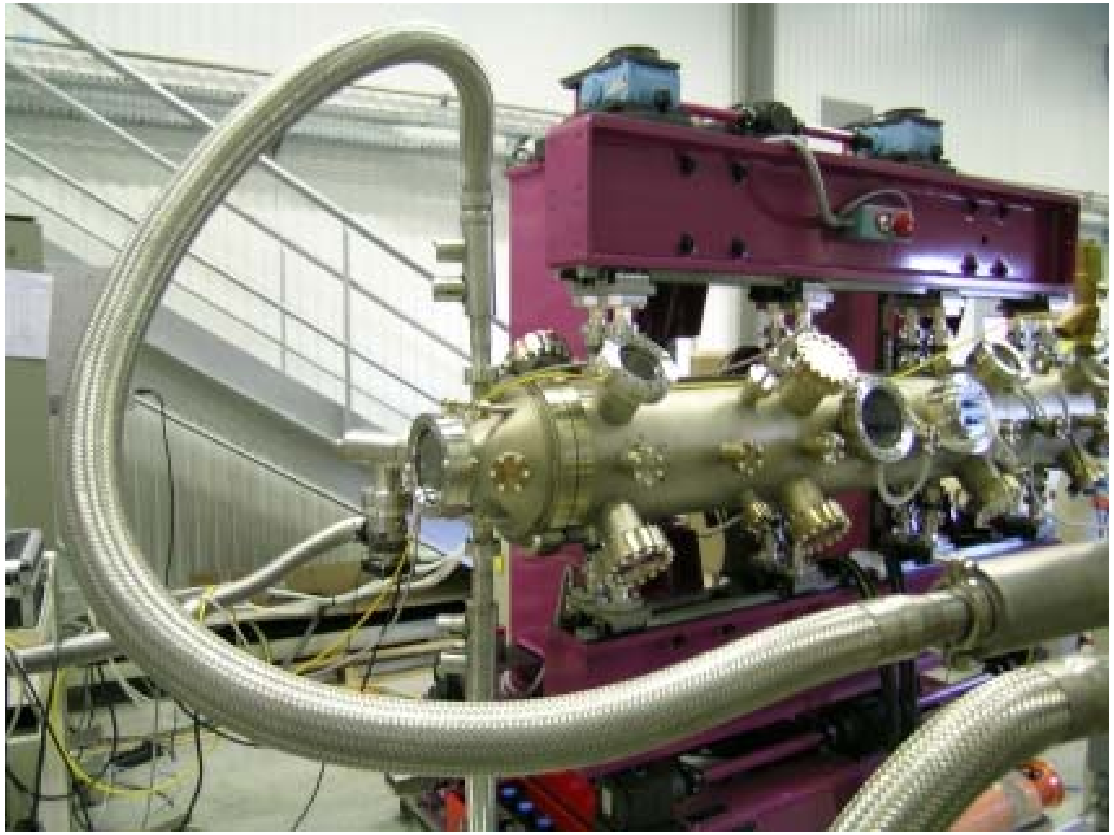
Courtesy of T. Tanaka, Spring8

Cryogenic Undulator At ESRF

- Extensive tests on Sample and Modelization of NdFeB material with Radia

- Tested cooling and temperature uniformity on a full 2m length undulator using liquid Nitrogen < 10 deg K on Stainless Steel and a gap variation < 10 microns

Measured Heat budget ≈ 150 W



Magnetic measurements of Cryogenic Undulator

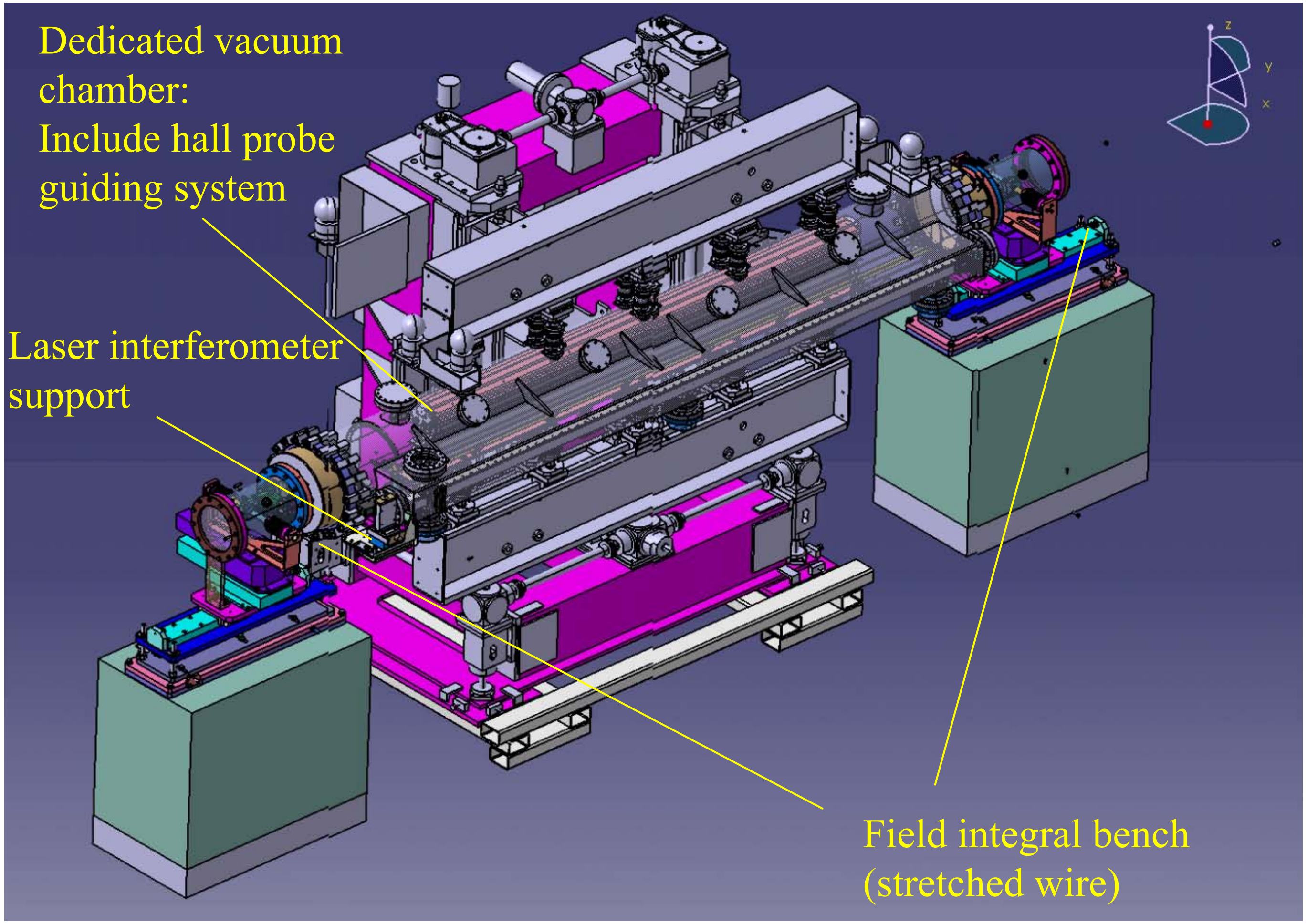
Hybrid Undulator

Period 18 mm
L= 2m
NdFeB material
Br 1.17 T
Hc=2400 kA/m

-Full Mag. Field measurement at 150 K under preparation. Fall 2006

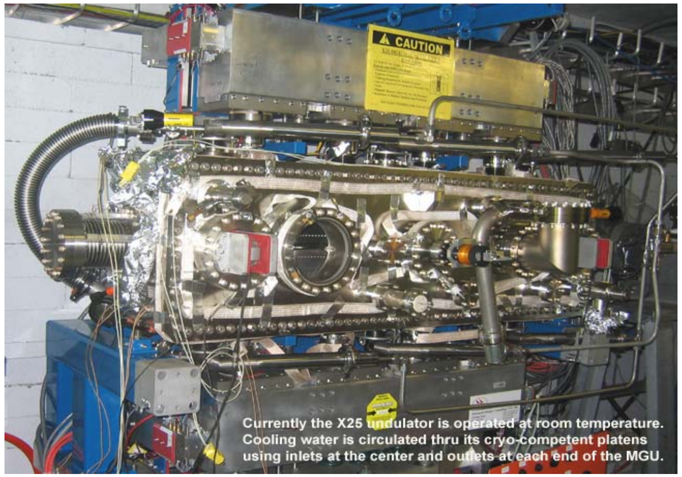
-To be tested on ID6 beamline of ESRF in 2007

- See C. Kitegi et Al., this conf.



Cryo-ready In-vacuum Undulator at the NSLS

- Period : 18 mm
- Length : 1 m
- Min Gap : 5.6 mm
- Techno : Hybrid
- NEOMAX 42 AH
- Installed on X25
- Gaseous Helium Cooling



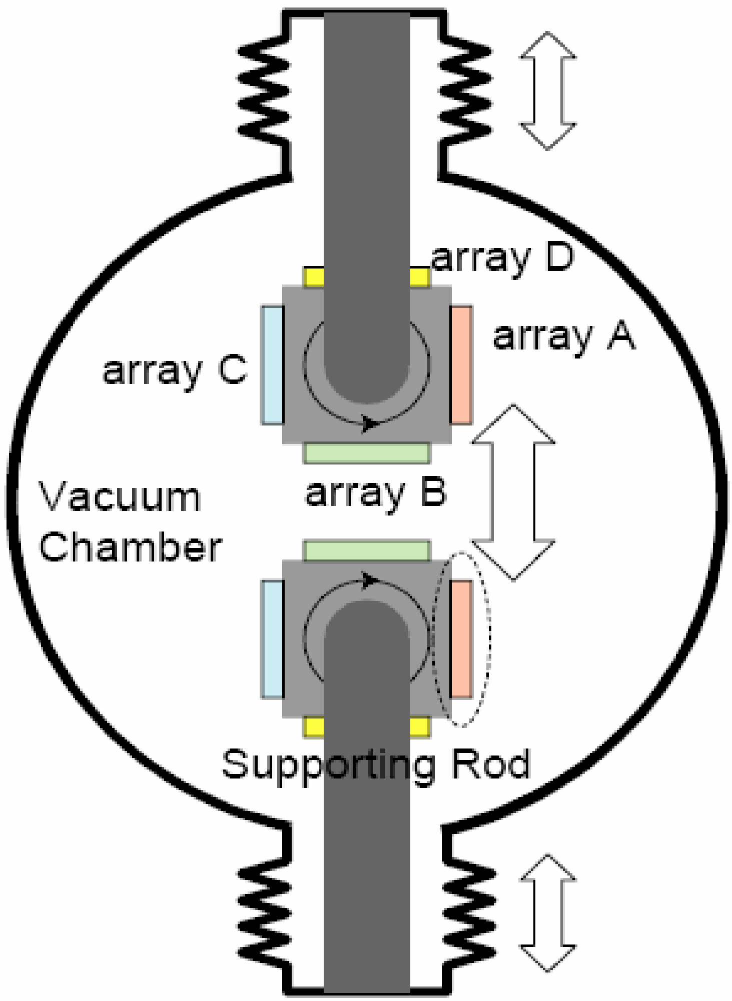
Courtesy of T. Tanabe, NSLS

Where are we ?

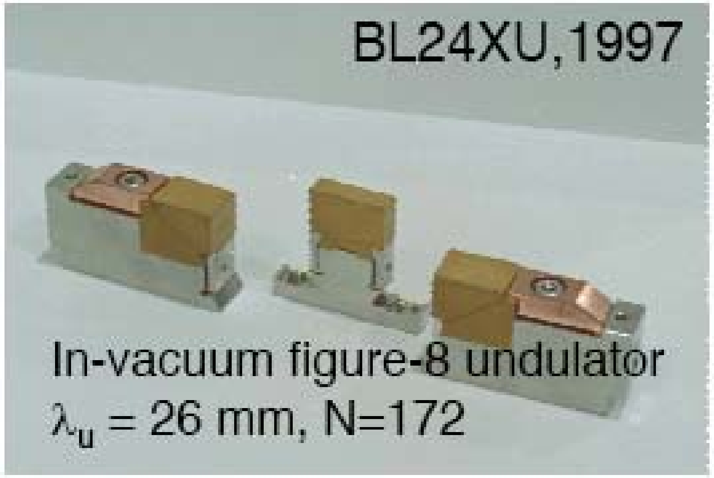
- Development work carried out at Spring8, ESRF, NSLS,..but not in operation yet.
- Mechanical deformation induced by thermal gradient along the beam
  - Liquid Nitrogen or Gaseous Helium appears preferable than cryocooler
  - Use Aluminium girder in vacuum
- Goal
  - Increase the peak field by 25% without risk of demagnetization of the magnet array.

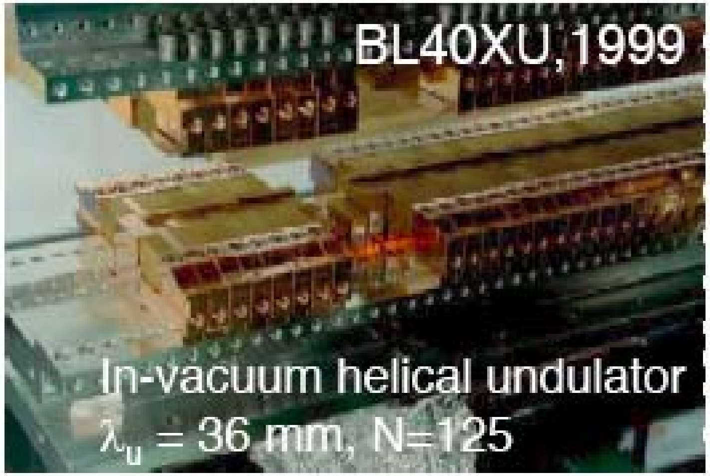
In-Vacuum Revolver

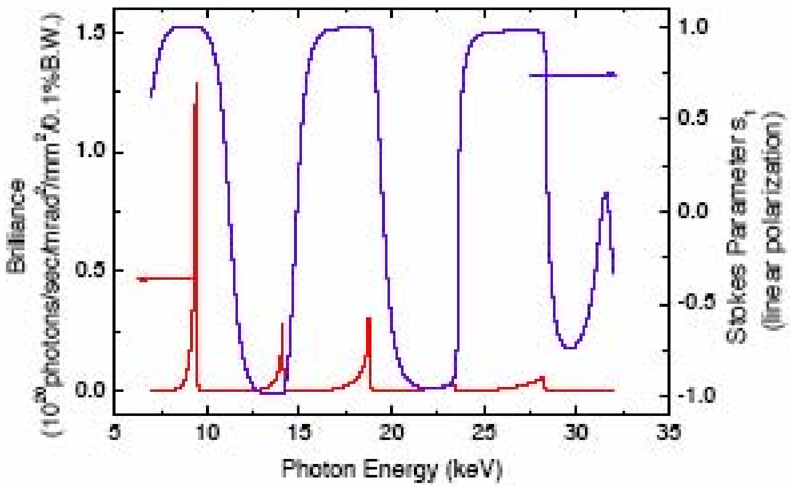
- Built at Spring8 in 1999
- Installed on PLS in 2003
- Period 10,15,20, 24 mm
- L=1 m

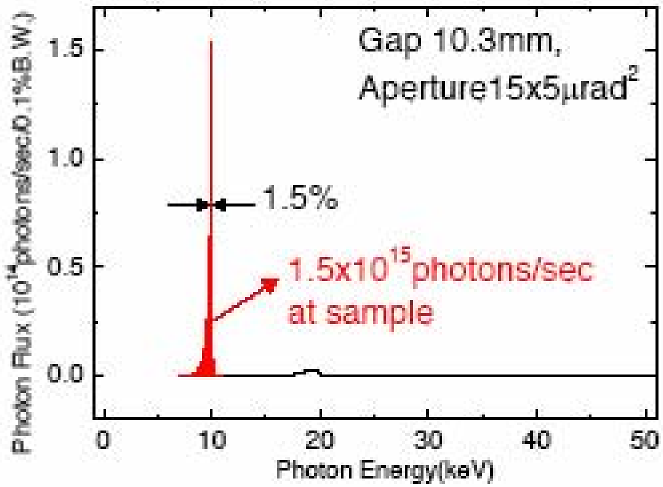


In-vacuum Figure 8 Undulator (SPRING 8)









- Reduction of heat load
- Utilization of both polarizations

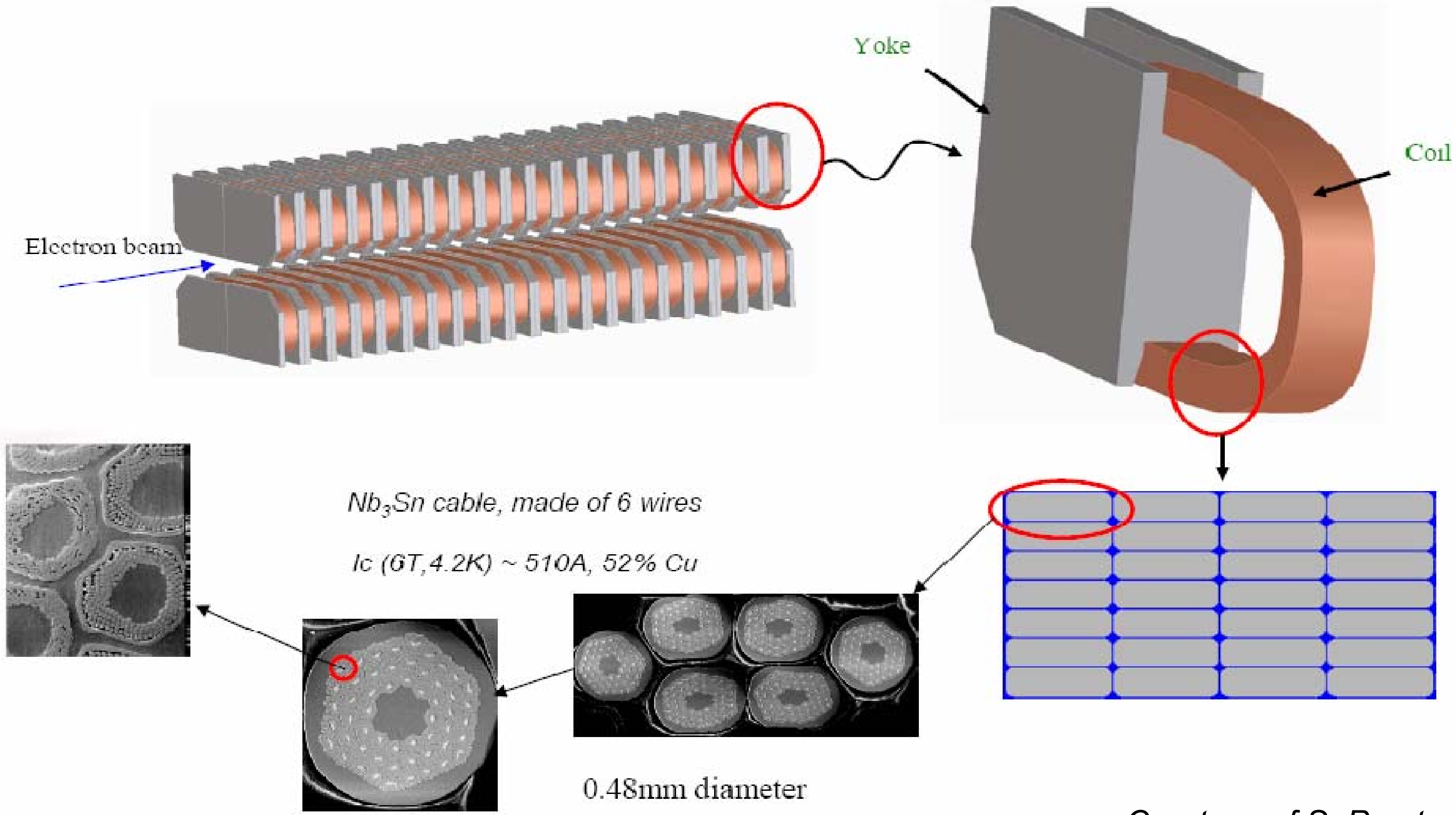
- High flux without monochromator
- Special magnet configuration

Superconducting Undulators

Brief History of Superconducting Undulator

- FEL HEPL (1975), FEL ACO (1979), NSLS,…, Renewed Interest (R. Rossmanith et al…EPAC2002)
- World Wide Interest : Anka, Max-Lab, ELLETRA, ESRF, ALS, APS, NSLS, ACCEL, Budker Institute …
- Workshop on Superconducting Insertion Devices at ESRF : http://www.esrf.fr/Accelerators/Conferences/ID_Workshop
- First operation of a superconducting undulator built by ACCEL on a storage ring at Anka in March 2005.
  - No difficulties with respect to the ring operation.
  - Some technical defects of the undulator :
    - Early quench at 660 A
    - Large phase error (mechanical problem identified)
    - Smaller beam aperture than expected (mechanical problem identified)

Superconducting undulators – general approach



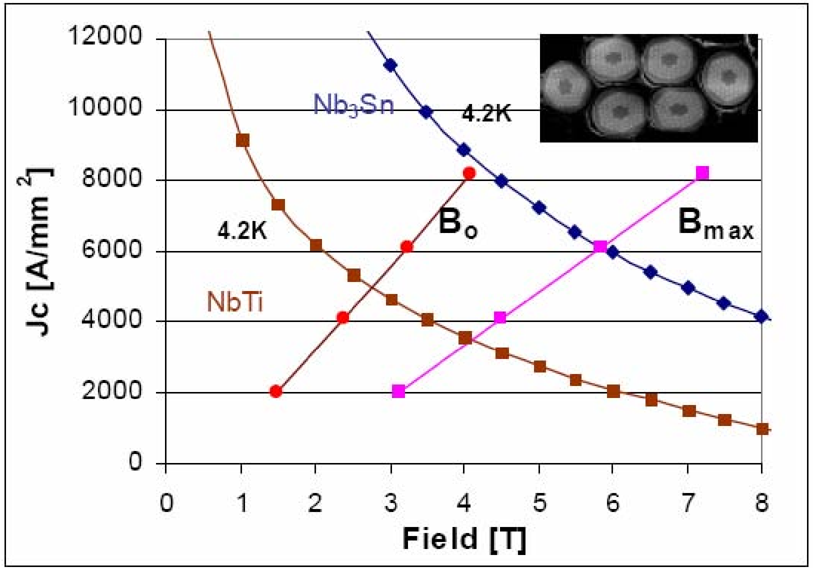
Courtesy of S. Prestemon, LBNL

Nb_3Sn Superconducting Undulators (LBNL)

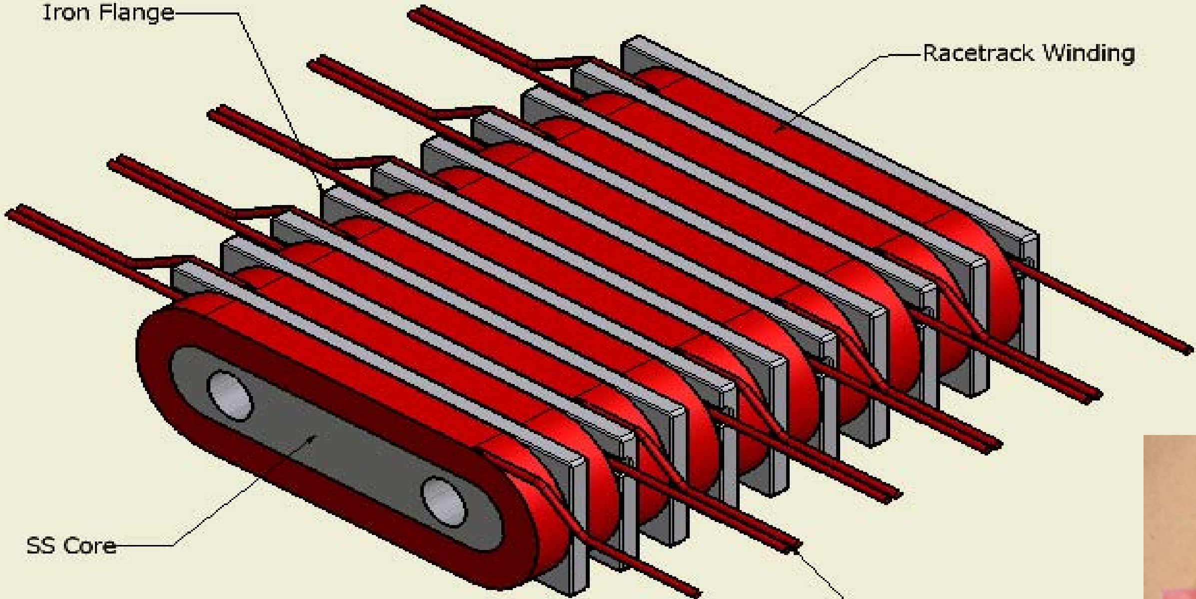
-Expect twice more field than NbTi (At same T.)

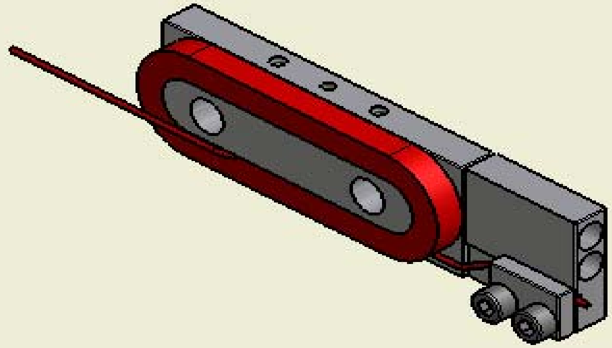
- Heat Treatment Required

Courtesy of S. Prestemon, ALS



Nb_3Sn Superconducting Undulators (NHMFL)





Partially Assembled Winding & Heat Treatment Assembly

Undulator Modular Coil Assembly

Courtesy of H. Weijers, NHMFL

Beam Heating

	Return Current (2/3 Filling)	Bending Magnet Radiation	Total
ESRF 300 mA	2.2 W	2.6 W	4.8 W
DIAMOND 500 mA	9.4 W	6.7 W	16.1 W

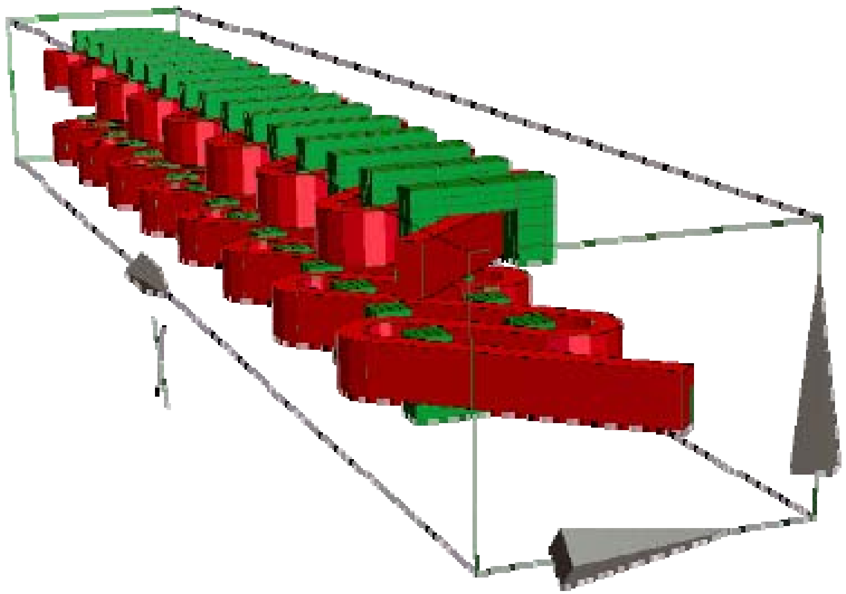
Assume L = 2m Gap = 5 mm

Technical Challenges

- Beam Induced Heatload
  - Cooling (cryocoolers, bath helium …)
  - Screening
- Narrow thickness ultra flat UHV chamber walls to insulate beam vacuum from cryogenic vacuum
- High tolerance of yoke machining and coil assembly
- Phase Error corrections and Field shimming
- Precise magnetic field measurement at 4 deg K

Variable Polarization

- Field not superior to that from an APPLE II permanent magnet undulator
- R &D
  - LBLN
  - ANKA
  - APS

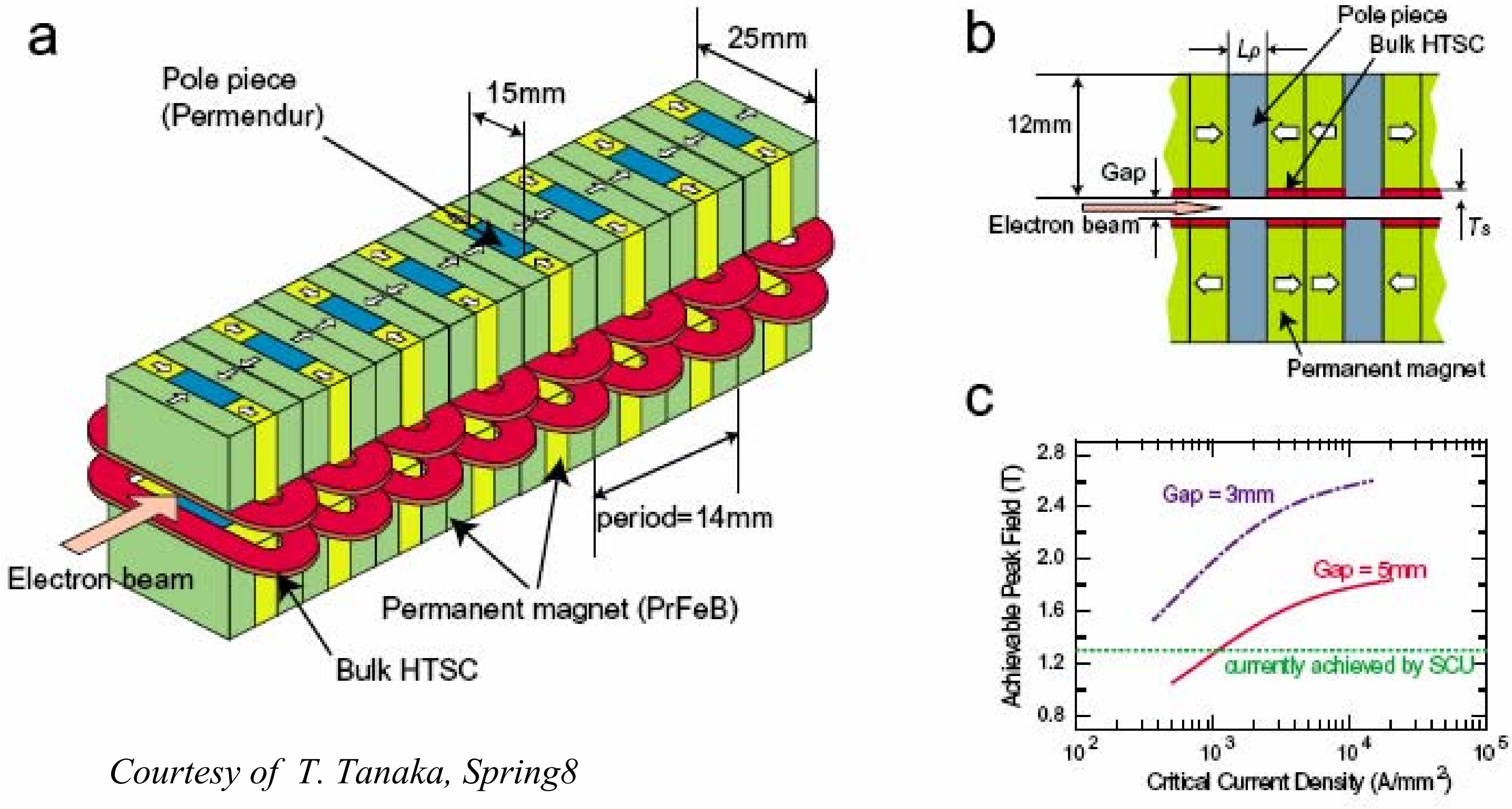


Shigemi Sasaki (workshop on Sc undulators @ ESRF)

On Going R&D

- ACCEL
  - NUS Undulator
  - ANKA Undulator
- ANKA
  - Shimming, Helical design,…
- LBNL
  - Build and quenched a 10 periods mock-up using Nb_3Sn
- ANL
  - Build a 10 periods mock-up using NbTi, cryogenic design, develop Nb_3Sn with HMFL & LBNL
- BNL
  - Cryogenic magnetic measurement facility
- Maxlab
- SRRC

High Tc superconductors in IVU (SPRING 8)



Courtesy of T. Tanaka, Spring8

Superconducting Multipole Wigglers

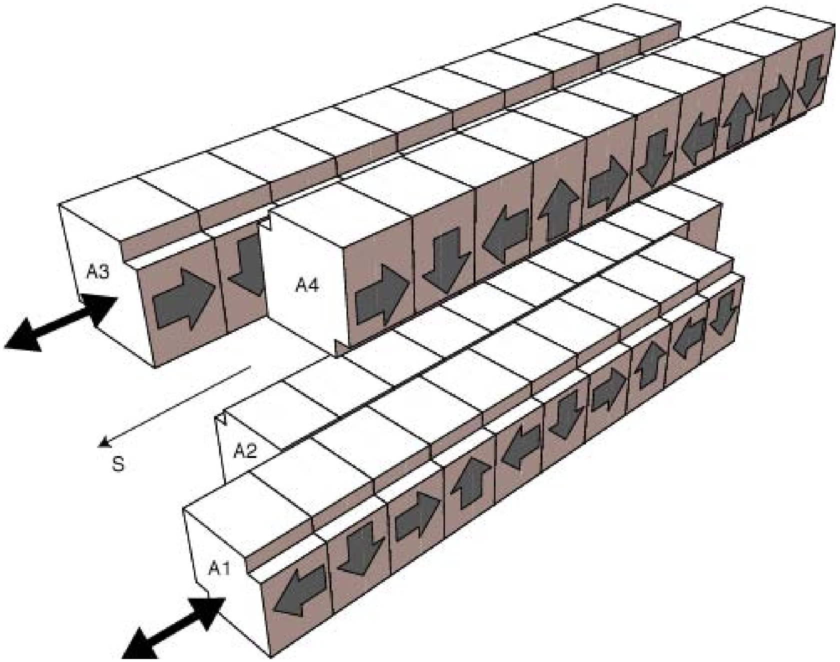
	Year	Field [T]	Period [mm]	N. of Poles	Beam Aperture [mm]
DELTA	1996	5.5 2.75	288 144	5 10	18
BESSY-HMI	2002	7	148	17	19
ELETTRA	2002	3.7	64	49	16.5
Max Lab	2002	3.5	61	48	12.2
CLS	2005	2.2	34	63	13.5
SRRC	2006	3.2	61	16	11
DIAMOND	2006	3.5	64	49	10
SOLEIL	2008	2.6	42	72	8.5

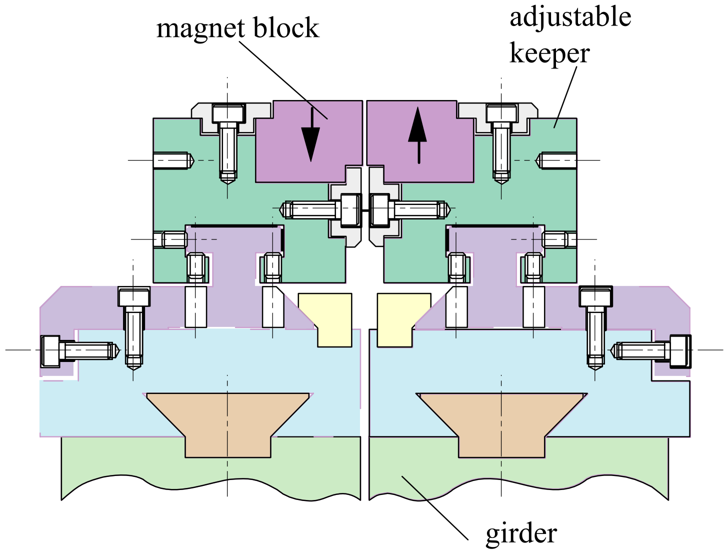
-Cryocoolers are reliable and frequently used.

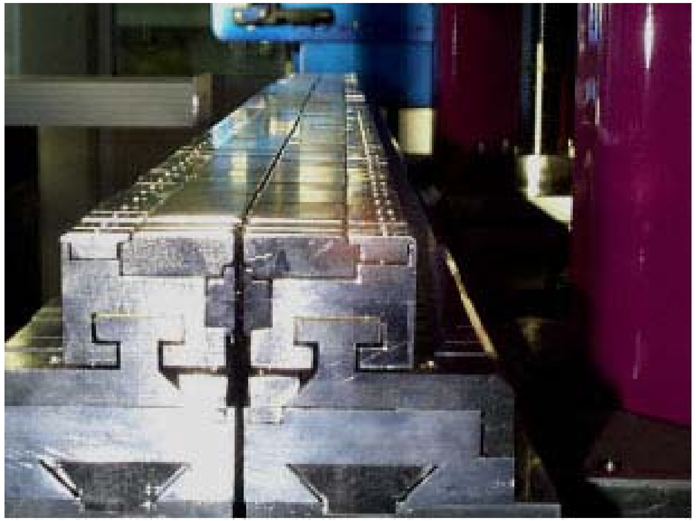
- A thermal screen insulate the cold box from the beam to limit heatload at 4.2 deg K (except for MaxLab Wiggler)

Variable Polarization Undulators

Apple II Variable Polarization Undulator







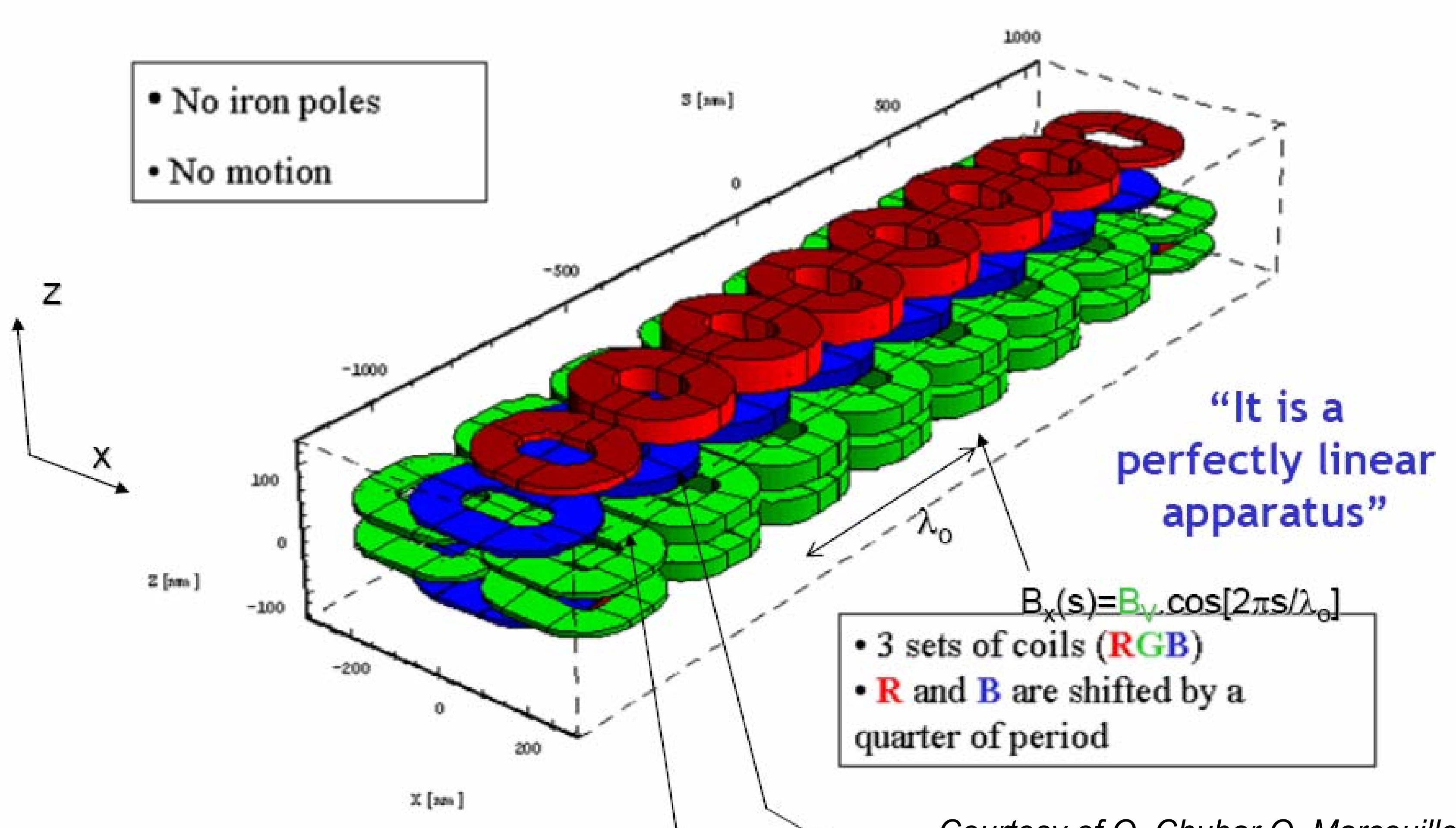
Why so popular ? :
- High linear/helical magnetic field
- Generating any polarization (linear,elliptical,..)

Several Devices in the last years
- Maxlab, Soleil, Diamond,…

Beam Disturbance

- Observation with Beam
  - Closed Orbit Distortion (vs 3 dof)
  - Vertical beam size variation
  - Dynamic Aperture (lifetime & Injection Efficiency)
- Explanation
  - Nominal Field
    - Effect (description, dynamic aperture)
    - Special shims for Correction (ESRF, BESSY)
  - Field Errors
    - Difficult to shim
    - ALS Skew Quadrupole (800 G) S.Marks et al. MT19

Soleil Helical/Planar Undulator



Courtesy of O. Chubar, O. Marcouille, Soleil

Radia code: http://www.esrf.fr $B_z(s)=B_B.\cos[2\pi s/\lambda_o]+B_R.\sin[2\pi s/\lambda_o]=B_{zo}.\cos[2\pi s/\lambda_o+\phi]$

Soleil Low Energy Undulator

Period = 640 mm

Peak Field = 0.11 T

Length = 10 m

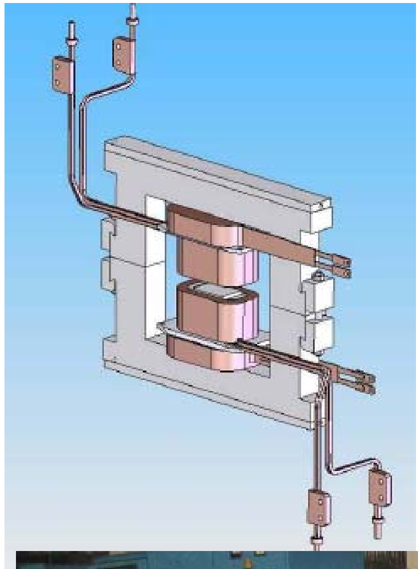
Photon Energy = 5-40 eV

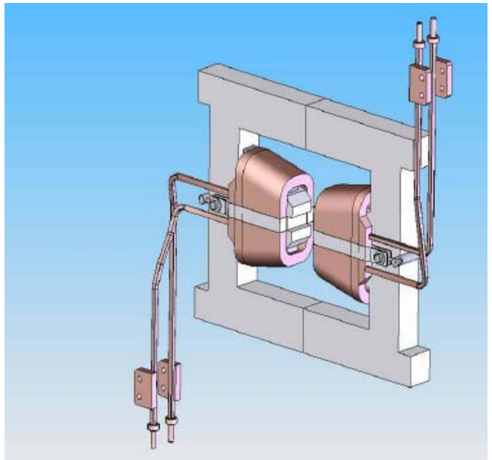
Min Gap = 19 mm

Polarization = Circular/Linear

Courtesy of O. Chubar, Soleil

HU256 of SOLEIL





Period = 256 mm

Peak Field = 0.28 / 0.4 T

Length = 3.5 m

Photon Energy = 7-1000 eV

Min Gap = 16 / 56 mm

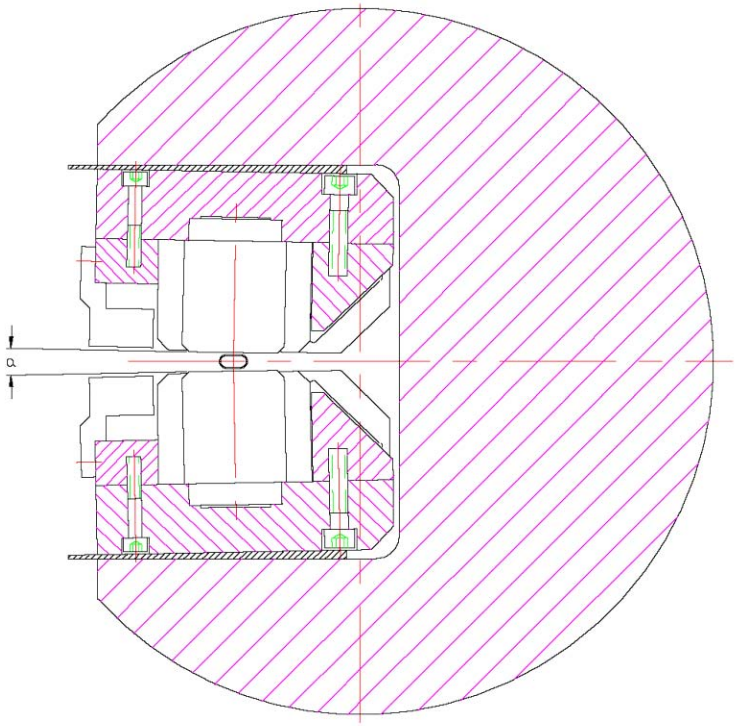
Polarization = Circular/Linear

Courtesy of O. Chubar, Soleil

SASE FEL Undulators

LCLS Undulator

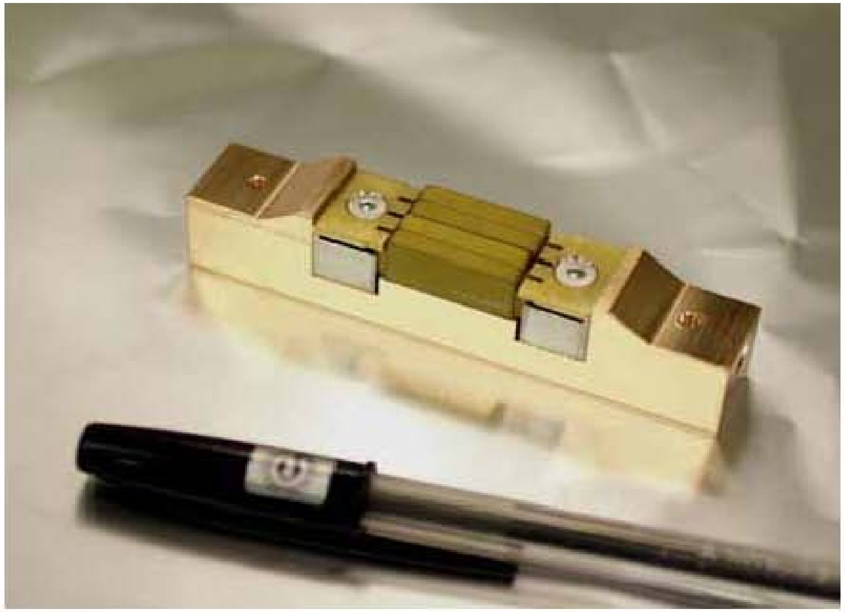
Courtesy of L. Moog, APS



LCLS UNDULATOR CROSS SECTION WITH THE WEDGED SHIMS
(angle a is exaggerated)

To be built by industry supervised by APS
To be measured and shimmed at SLAC
33 x 3.4 m segments
Hybrid NdFeB
Fixed gap ~ 6.8 mm
Field Adjustable by Canting

SCSS Undulator at Spring8



SCSS Undulator Prototype

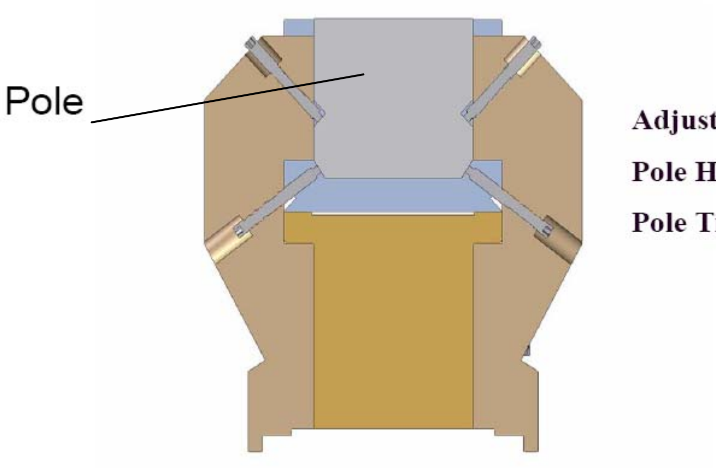
- λ_u=15mm
- G_{min}=2mm (nominal:3.5mm)
- L = 2 x 4.5 m @ λ = 50 nm
  L = 20 x 4.5 m @ λ = 0.1 nm

Courtesy of T. Tanaka, Spring8

XFEL Undulators at DESY

Name	Period [mm]	Gap [mm]	Peak Field [T]	Length [m]
SASE1	35.6	10	1.0	201
SASE2	48	10-19	1.37-0.63	256
SASE3	80	10-23	0.91-0.44	128
U1,U2	20.0	6-22	0.98-0.1	122

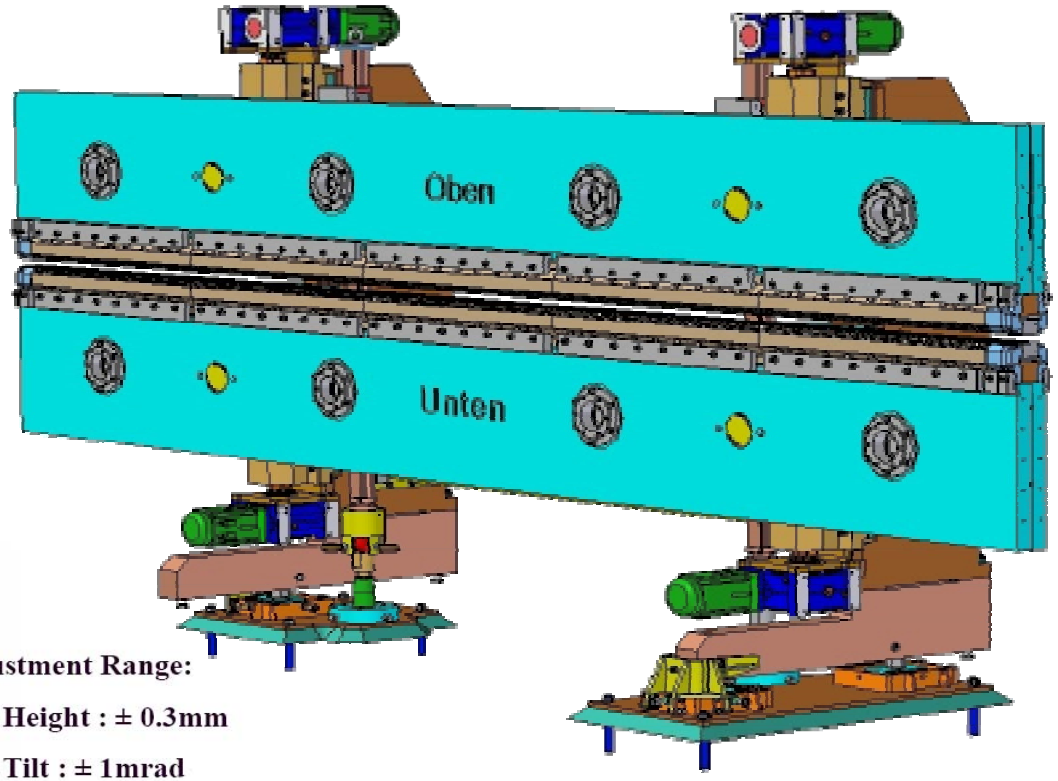
Prototype Segment



Adjustment Range:

Pole Height : ± 0.3mm

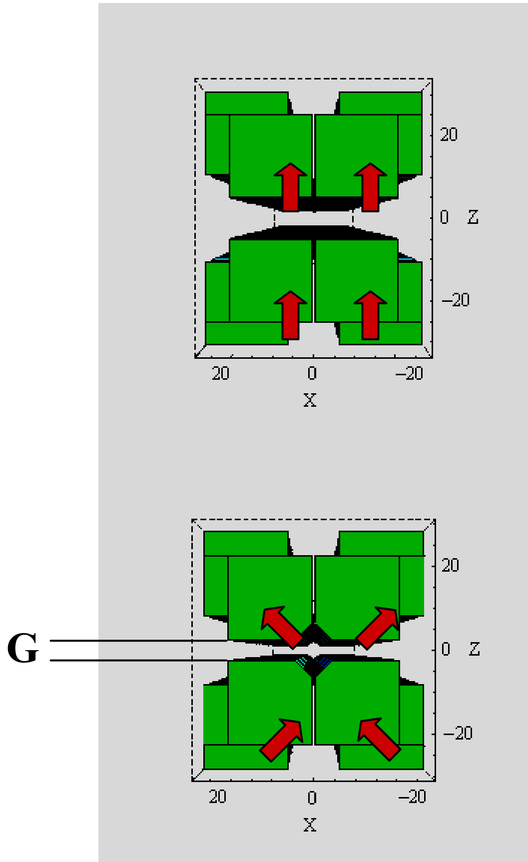
Pole Tilt : ± 1mrad



Courtesy of J. Pflueger, DESY

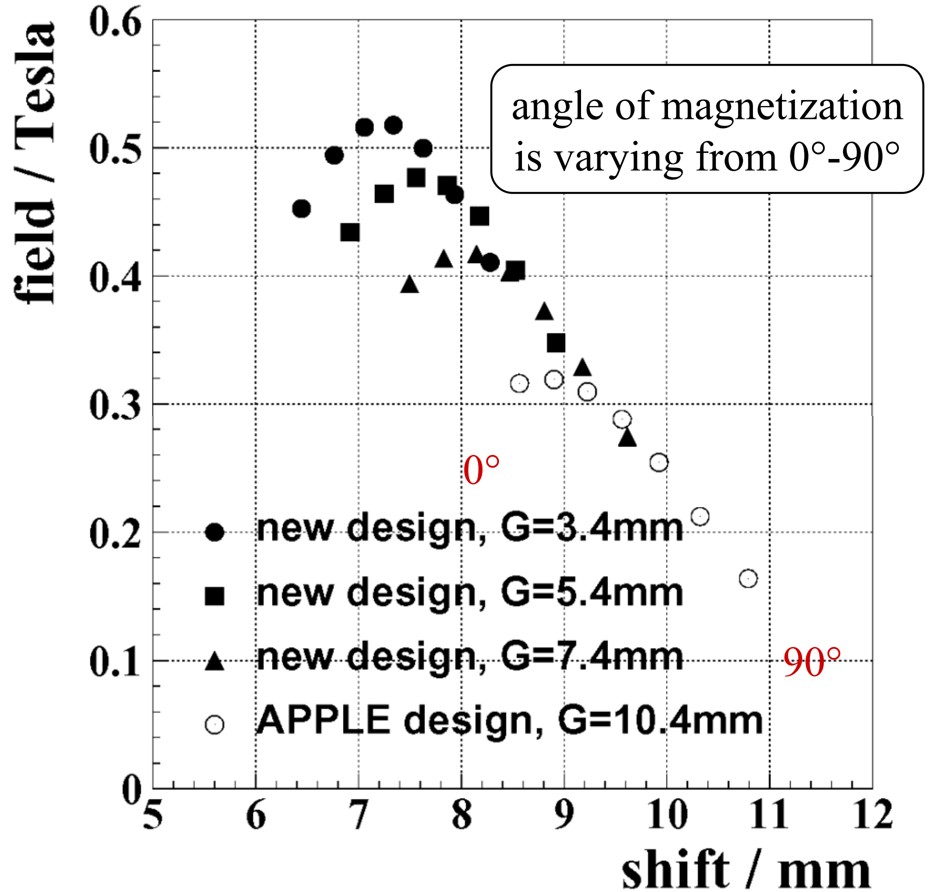
Helical Undulator for SASE

Helical Undulator provides higher growth rate
In FEL systems a circular vacuum chamber can be used
An APPLE III provides higher fie



APPLE II

APPLE III
factor 1.4
higher field



Courtesy of J. Bahrdt, BESSY

Miscellaneous

Industrials

- **Accel (Germany)**
  http://www.accel.de/
- **Advanced Design Consulting (USA)**
  http://www.adc9001.com/
- **Budker Institute (Russia)**
  http://ssrc.inp.nsk.su/english/
- **Danfysik (Denmark)**
  http://www.danfysik.com/
- **Neomax (Japan)**
  http://www.neomax.co.jp/english/sai_2e.htm
- **Wang NMR Inc**
  http://www.wangnmr.com/default_v1.shtm

3D Modeling and Tracking

- Several 3D Magnetostatic Codes are available allowing Design of extremities
  - Integral Volume : Radia (free and user friendly)
  - Finite Element : TOSCA, ANSYS, FLUX3D,…
- Tracking in storage ring with Undulators and wigglers is now possible :
  - Kick Map method
  - Undulator treated as a sequence of non linear thin lenses
  - Thin lens focusing is computed from 3D magnetic field data.
  - Numerically efficient
  - Initiated at ESRF and applied to IDs of Soleil and Diamond

Acknowledgements

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• BESSY	J. Bahrdt
• Budker Institute	N. Mezentsev
• Danfysik	F. Bodker
• Desy	J. Pflueger
• Diamond	J.C. Schouten
• Elettra	B. Diviacco
• LBLN	R. Schlueter, S. Prestemon
• Neomax	S. Okada
• NSLS	T. Tanabe
• MaxLab	E. Wallen
• Soleil	O. Chubar, M-E. Couprie
• Spring8	H. Kitamura, T. Tanaka, X. Marechal
• SRRC	Ching-Shiang Hwang

The End