DESIGN CRITERIA AND TECHNOLOGY CHALLENGES FOR THE UNDULATOR OF THE FUTURE

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Undulator

Magnetic period

$$\lambda = \frac{\lambda_u}{2n\gamma^2}\left(1 + K^2/2\right)$$

Lorentz factor

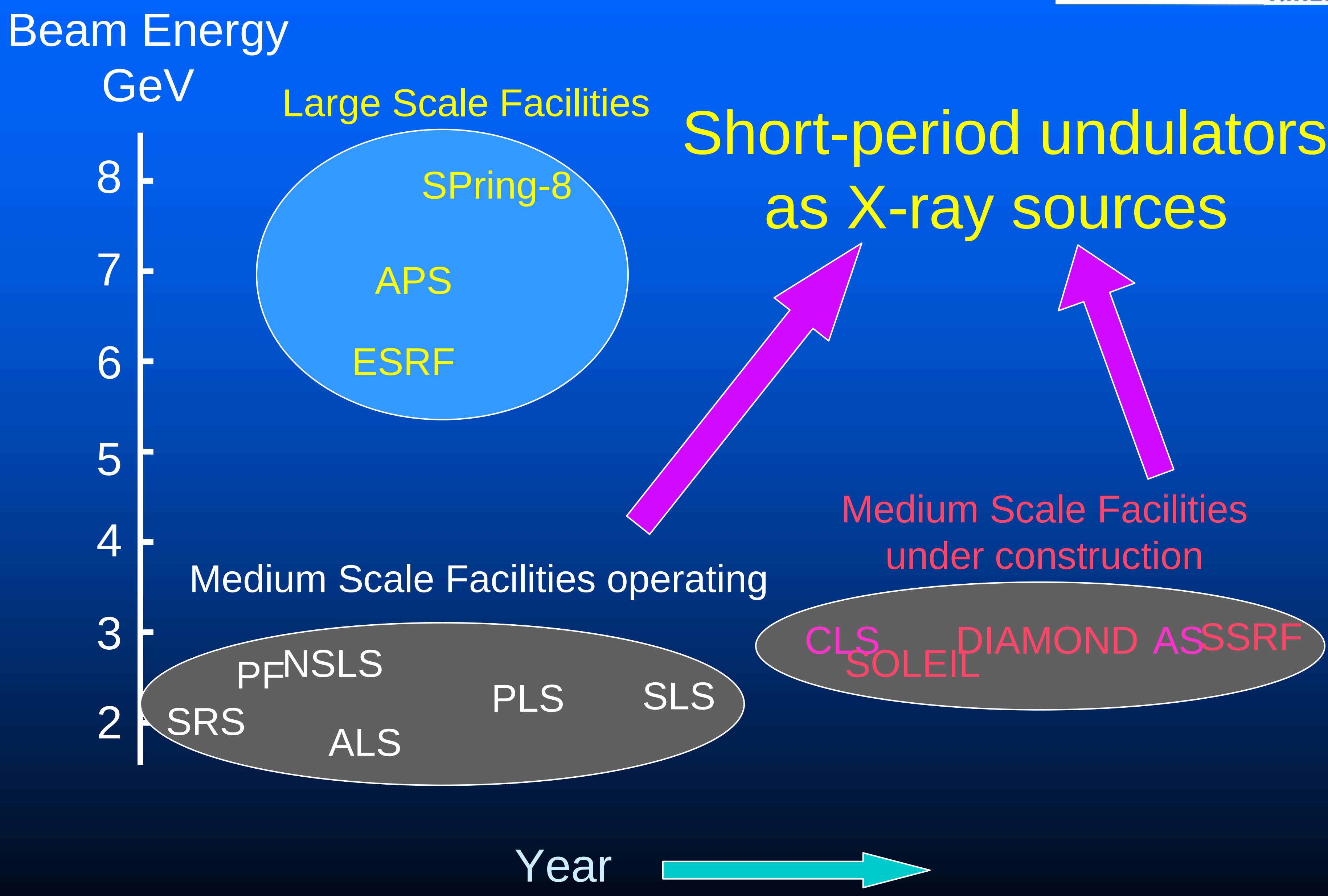
$$K = 93.4 B_0 \lambda_u \text{ (SI unit)}$$

Quasi-monochromatic radiation

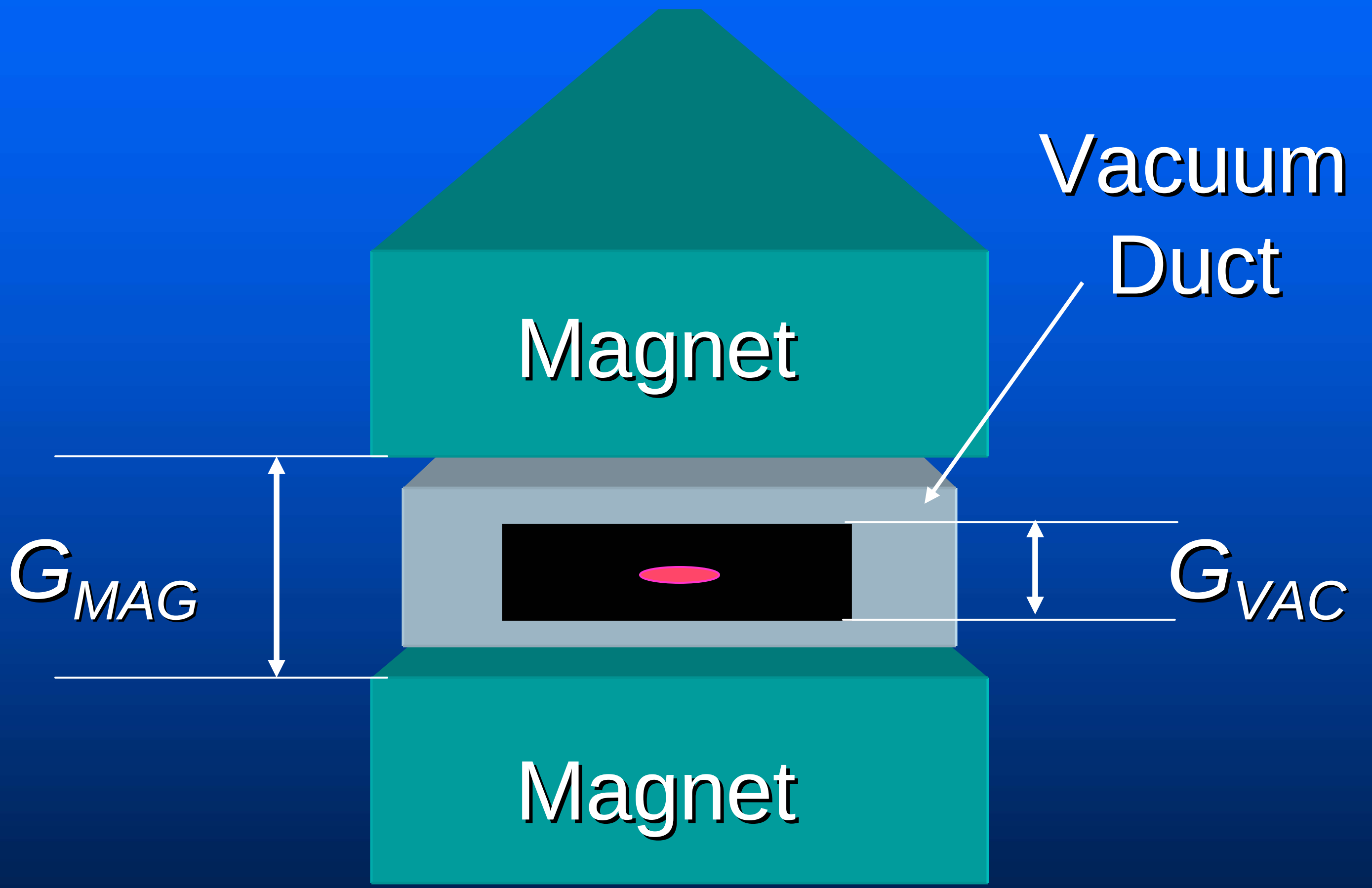
Highly collimated radiation

High brightness !!

X-ray SR Facilities

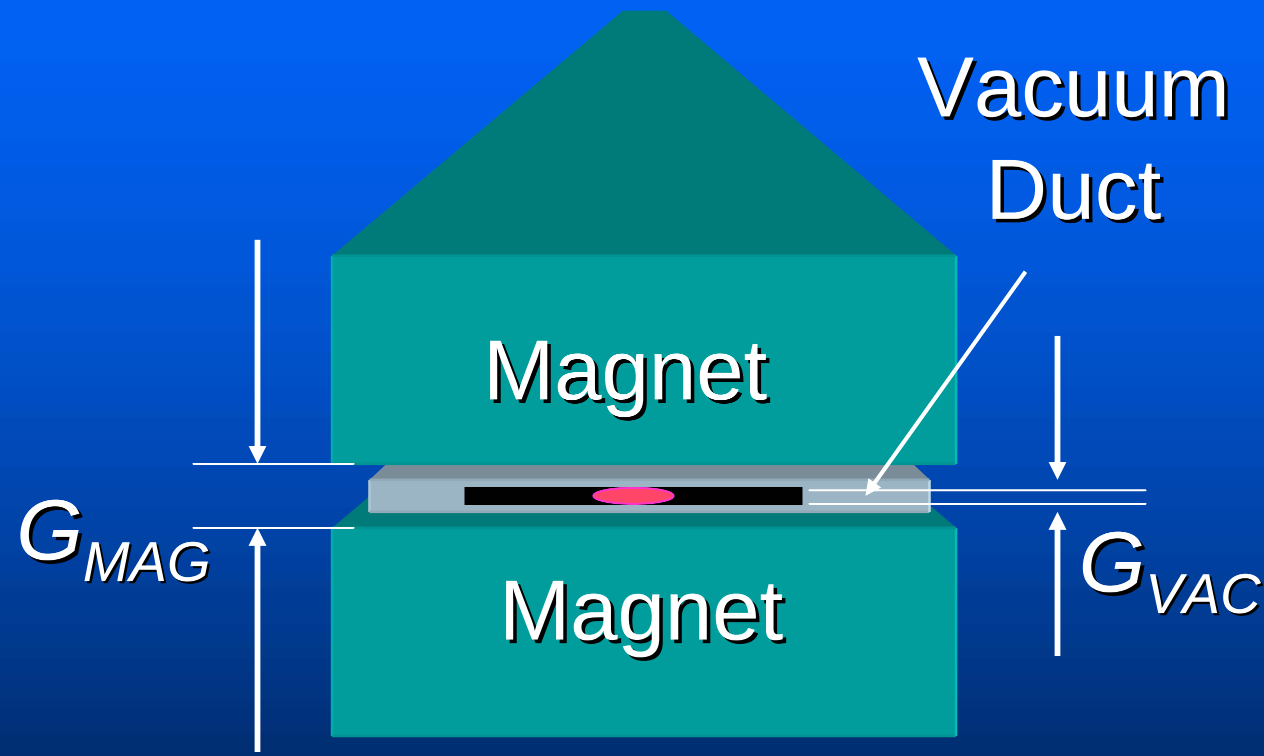


Ordinary Undulators
(Out-of-Vacuum)



Shorter period → Narrower G_{MAG}

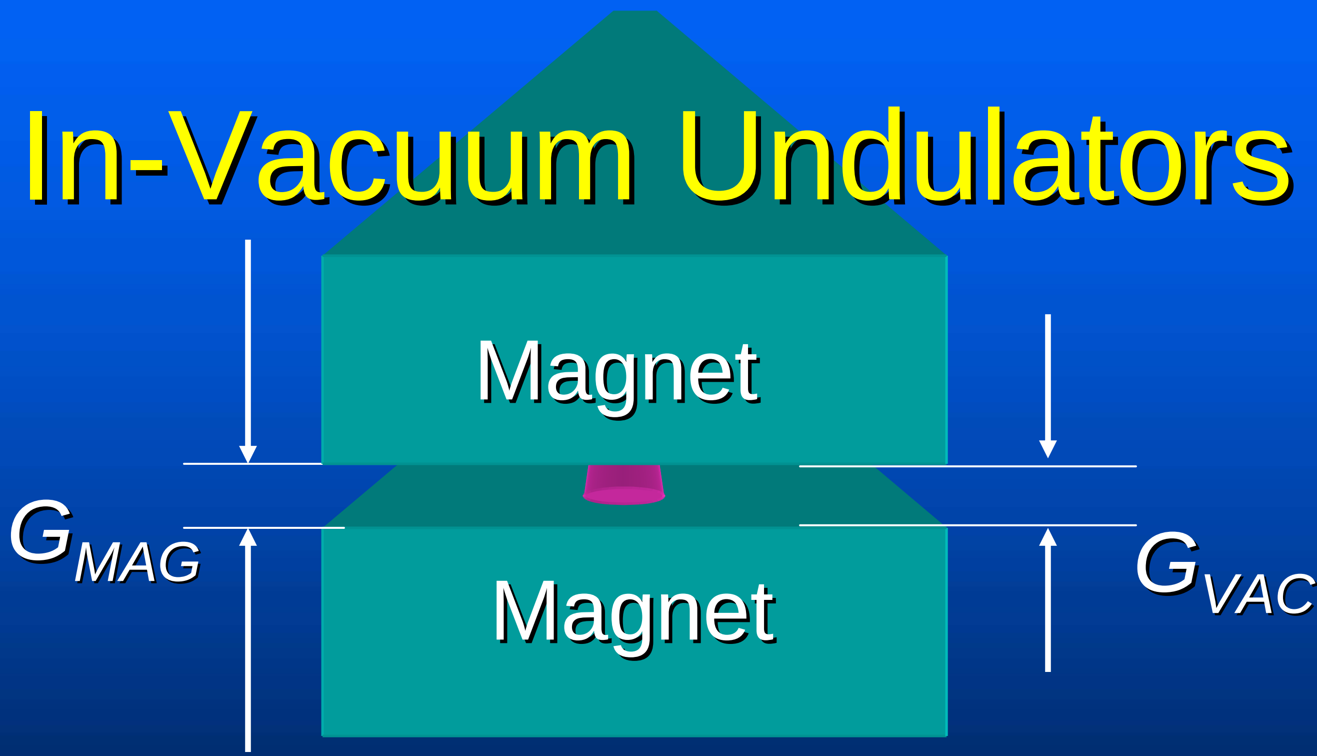
Short-period Undulators
(Out-of-Vacuum)



$G_{MAG} >> G_{VAC}$

Short-period Undulators

In-Vacuum Undulators



$$G_{MAG} = G_{VAC}$$

Three Different Types for In-Vacuum Undulators

In-vacuum undulators (IVUs)

based on permanent magnet technology.

Since 1990.

Superconducting undulators (SCUs) of in-vacuum type

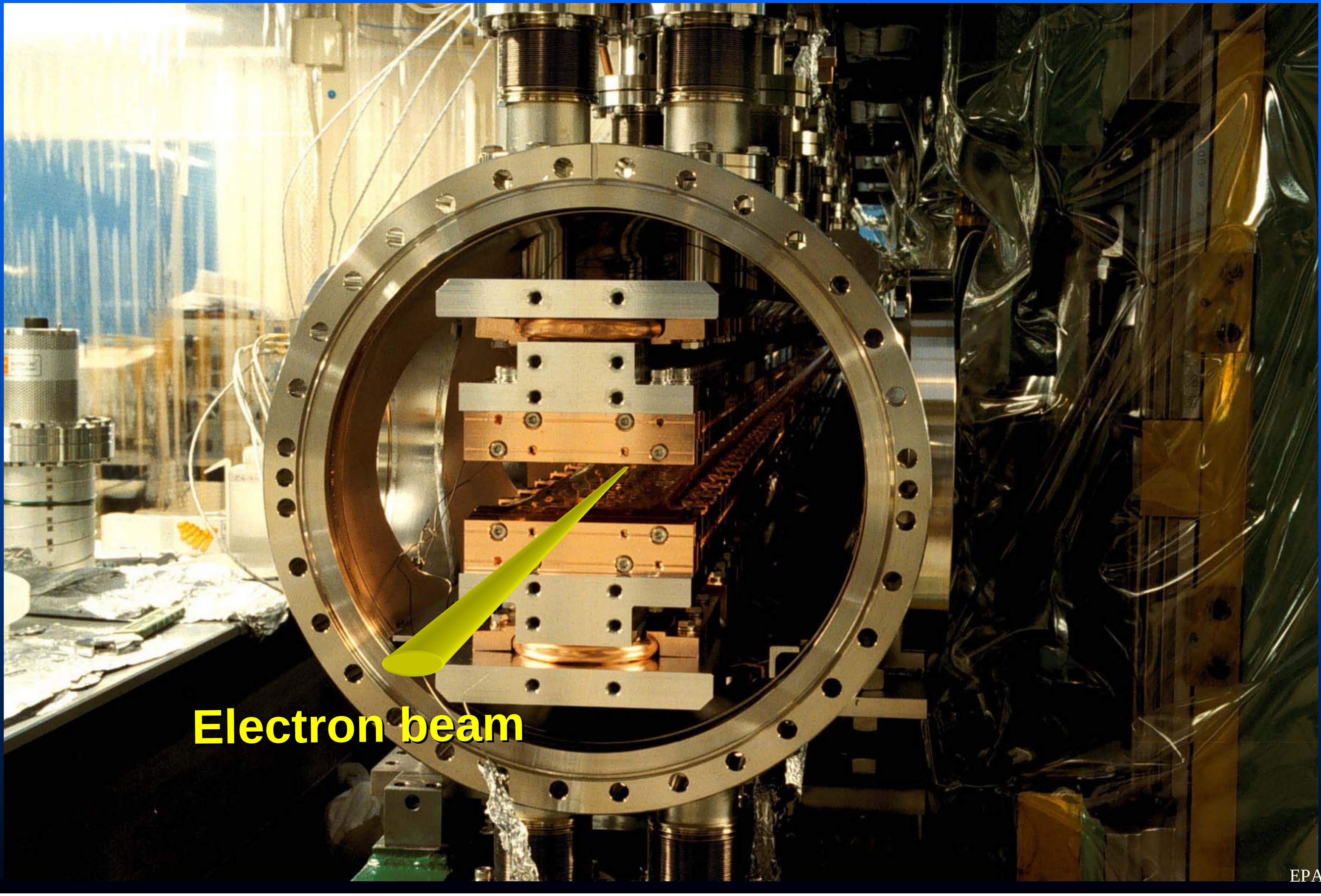
Since 1999.

Cryoundulators (CryoUs)

Cryogenic permanent magnet undulators

just proposed at SPring-8 in May,2004

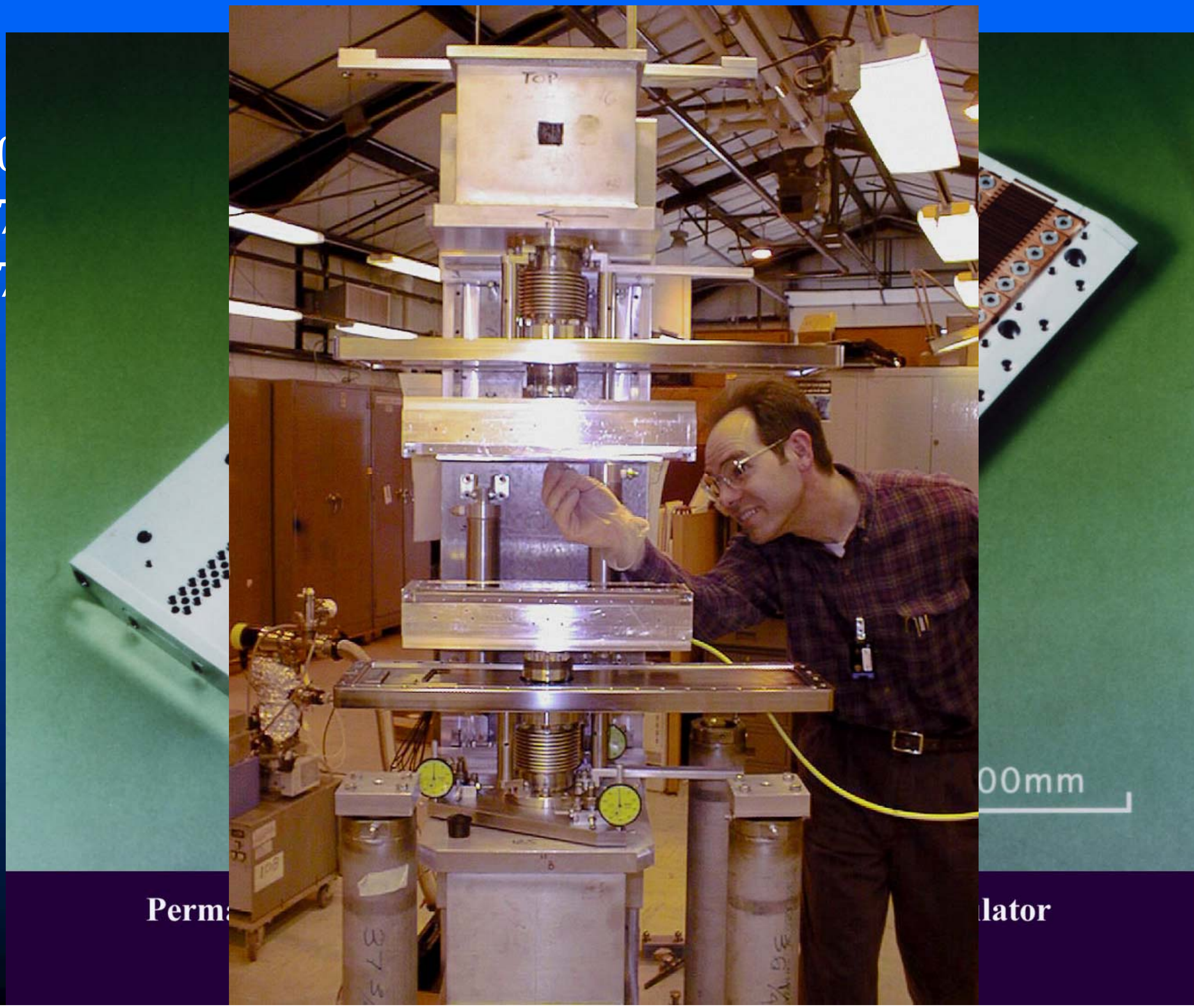
In-vacuum undulator (SPring-8)



Brief History of In-vacuum Undulator Development

1990
1997
1997

Pring-8)



Brief History of In-vacuum Undulator Development

1990 First IVU was operated at KEK

1997 Four IVUs were operated at SPring-8

1997 IVU of mini-gap type was operated at NSLS

λ_u=11mm, N = 27, G_{min}= 3.2 mm (collaboration with SPring-8)

1999 IVU was operated at ESRF

2001 IVU was operated at SLS

2004 34 IVUs are operated in the world.

SPring-8:20, ESRF:4, SLS:3, KEK:2, UVSOR:2, NSLS:2, PLS:1

Important Technological Points in IVU Developments

1. Ultrahigh vacuum → Baking

   Permanent magnet (PM) with high coercivity
   Thermal treatment for PMs
   Coating on PMs

2. Flexible transition

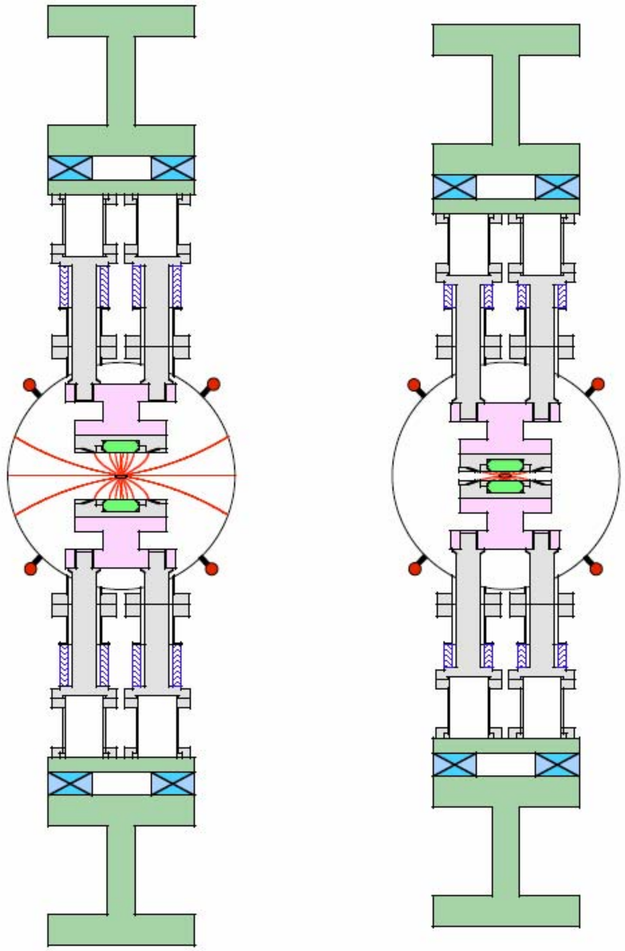
   Smooth and flexible transition necessary between PM array and vacuum chamber

3. Image current heating

4. Radiation damage in permanent magnets

Important Technological Point-3

Image Current Heating



$$P = MI_b^2\left(\frac{L_u}{\pi G}\right)\frac{\Gamma(3/4)}{\omega_0\sigma_t^{3/2}}\sqrt{\frac{\mu_0\rho}{2}}$$

K. Bane

SPring-8 case

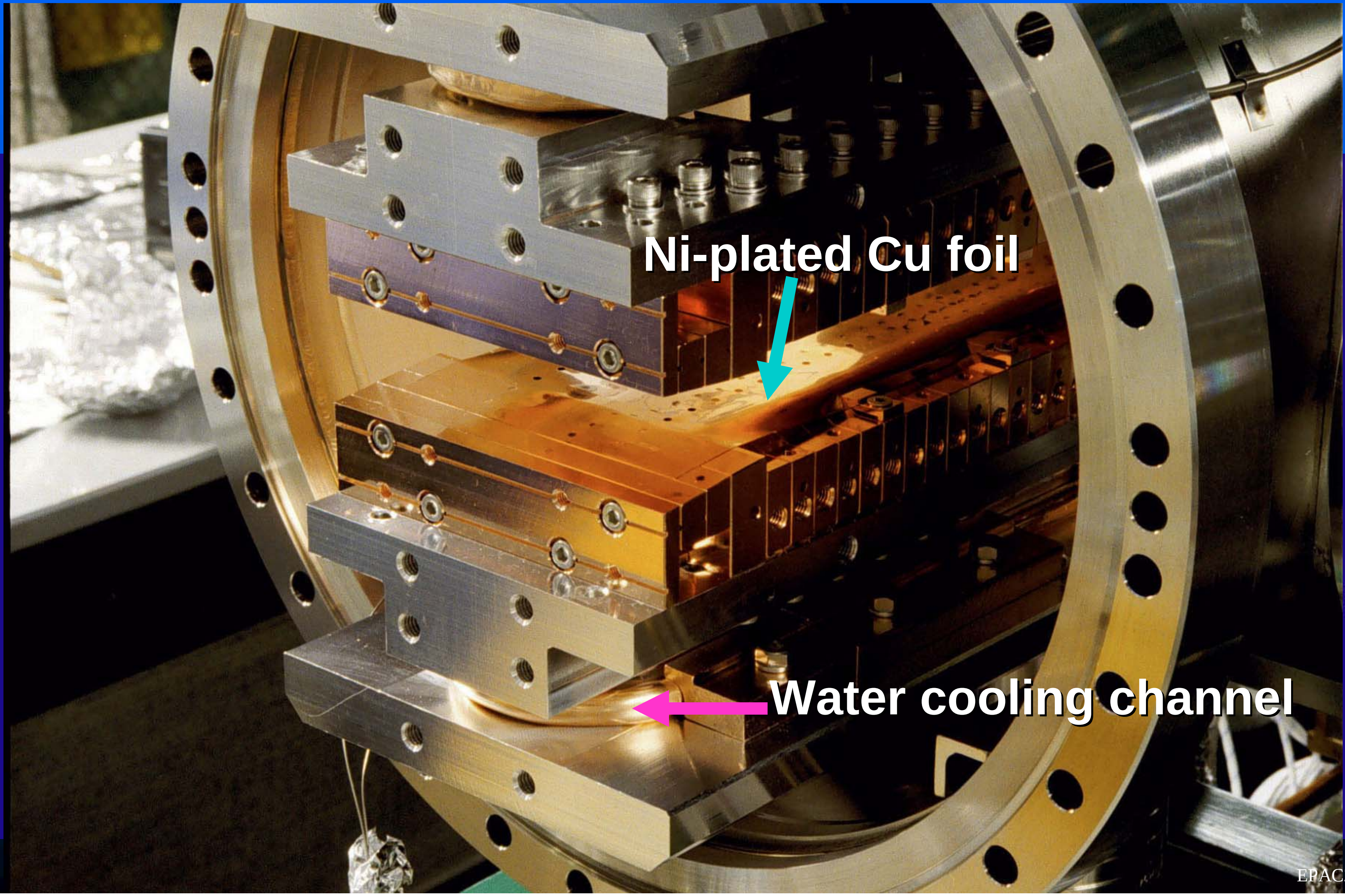
I_b = 6 mA, M=16, σ_t = 30 psec,
ω_0 = 1.3 MHz
G = 8 mm,
ρ = 8E10-7 ohm.m (SS)

P = 50 W/m !!

ρ = 2E10-8 ohm.m (copper)

P = 8 W/m !!

Metal cover for magnet arrays



Radiation Damage in NdFeB PMs

Neutrons produced by electron beam irradiation

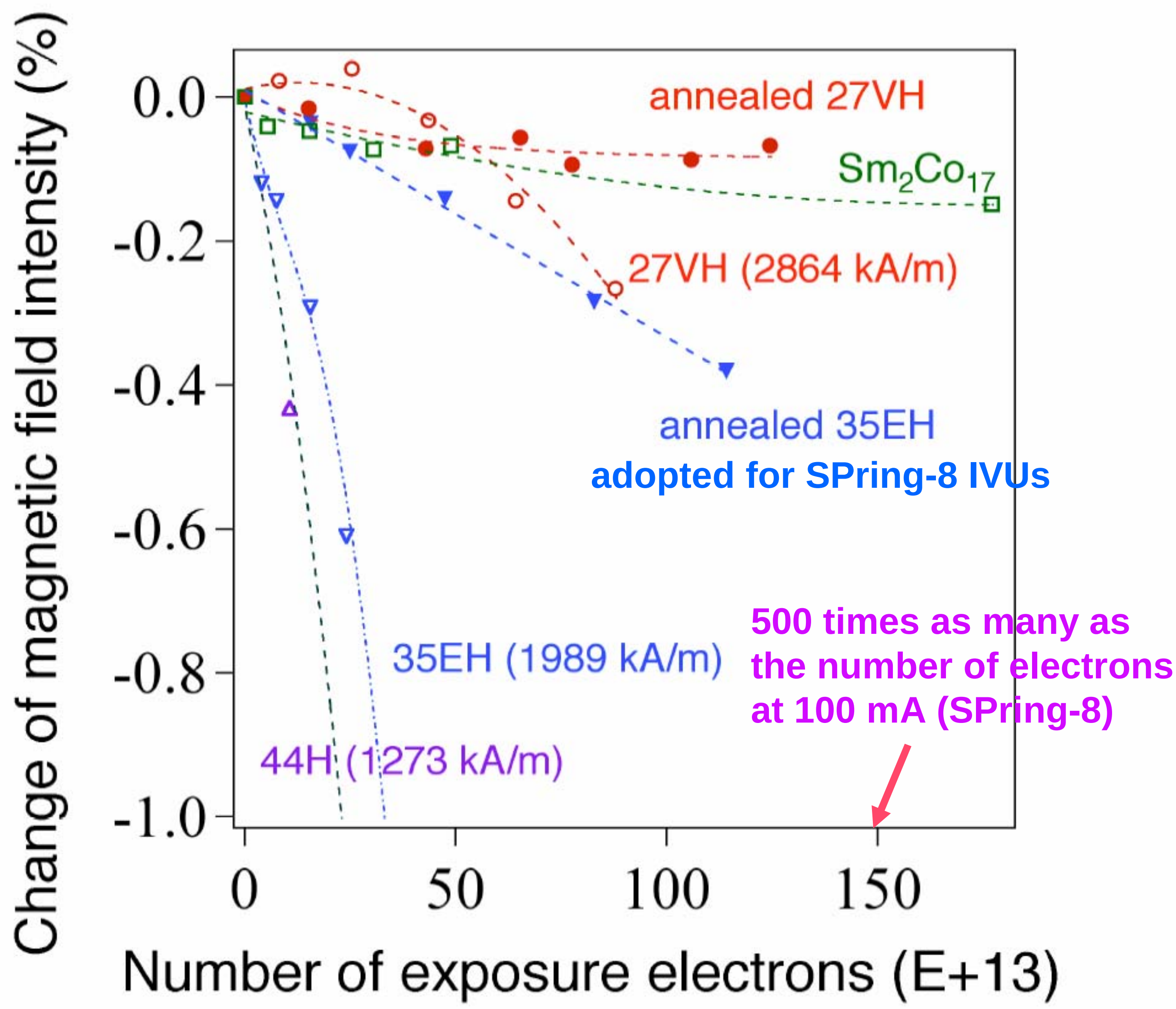
Observed in out-of-vacuum undulators at ESRF/APS

However,

Not observed in IVUs at SPring-8

Radiation Damage Test for NEOMAX-XX

2-GeV LINAC at PLS



Summary of Radiation Damage Test

Radiation resistance higher for NdFeB PMs with higher coercivity

Resistance improved drastically by thermal treatment for NdFeB PMs

Choice/treatment of PMs against radiation damage is the same for IVUs as UHV systems

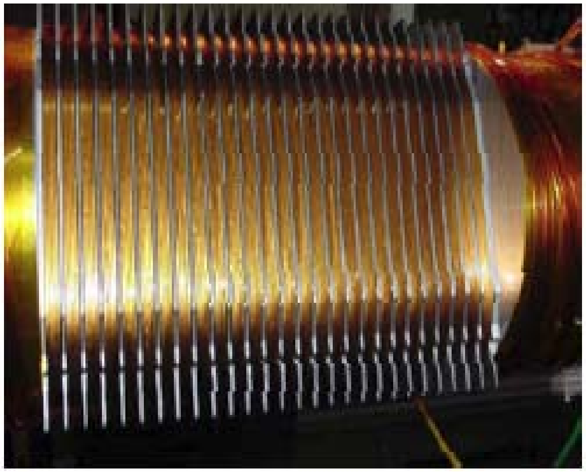
SCU of In-Vacuum Type

Proposed by Forschung Karlsruhe Anka & ACCEL

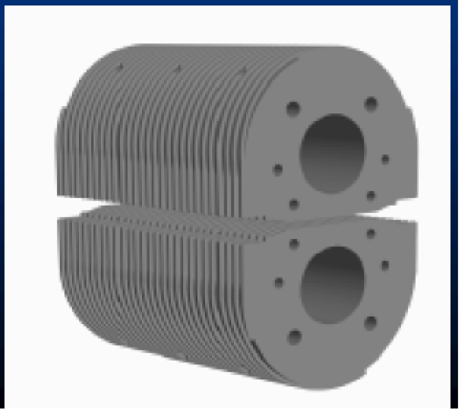
R. Rossmanith, H. O. Moser, A. Geisler, A. Hobl, D. Krischel, M. Schillo

Prototype, λ_u =14 mm

B = 1.3 T at G_{MAG} =5 mm

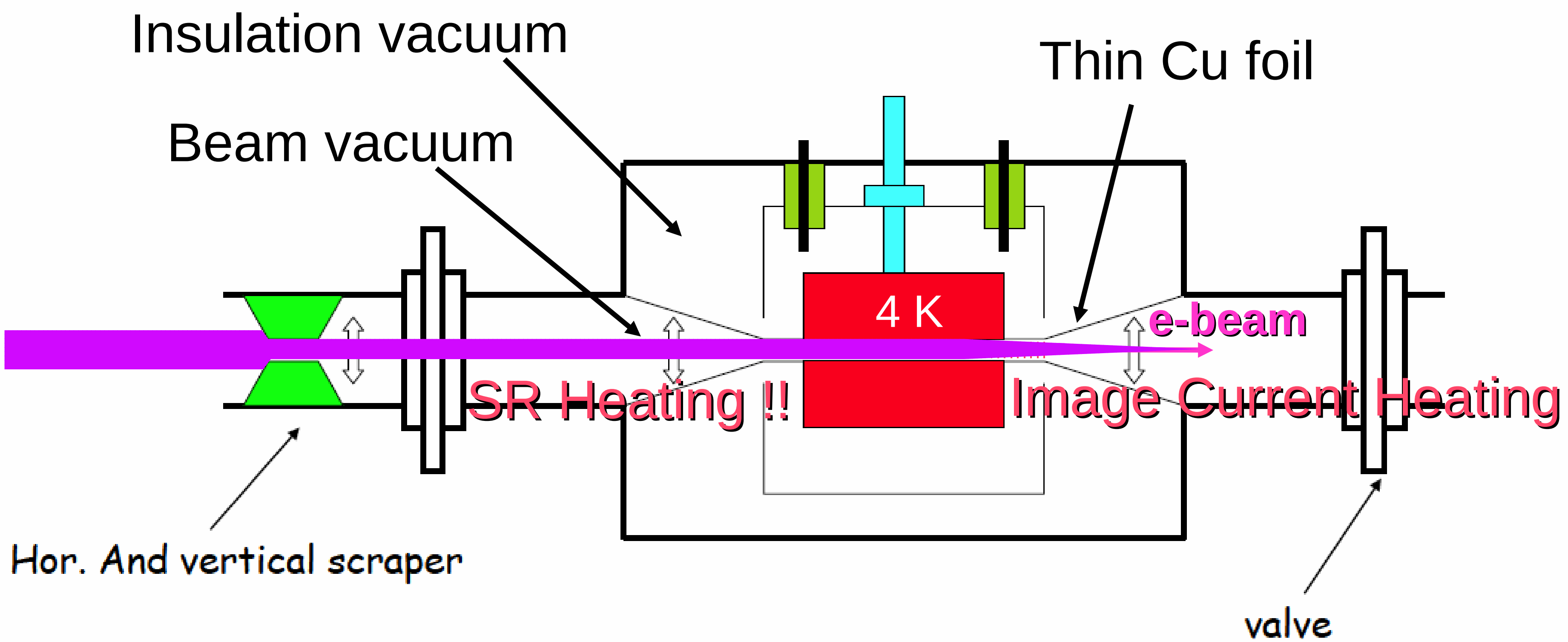


In-vacuum PM undulator
B = 0.7 T



Proposed Scheme for In-Vacuum SCUs

How to realize $G_{MAG}=G_{VAC}$



Rossmanith et al. Forschung Karlsruhe Anka

Possibility of Reduction of Image Current Heating

If *RRR* = 60 (copper),
Heating power can be reduced to 1/8 compared to that at room temp.

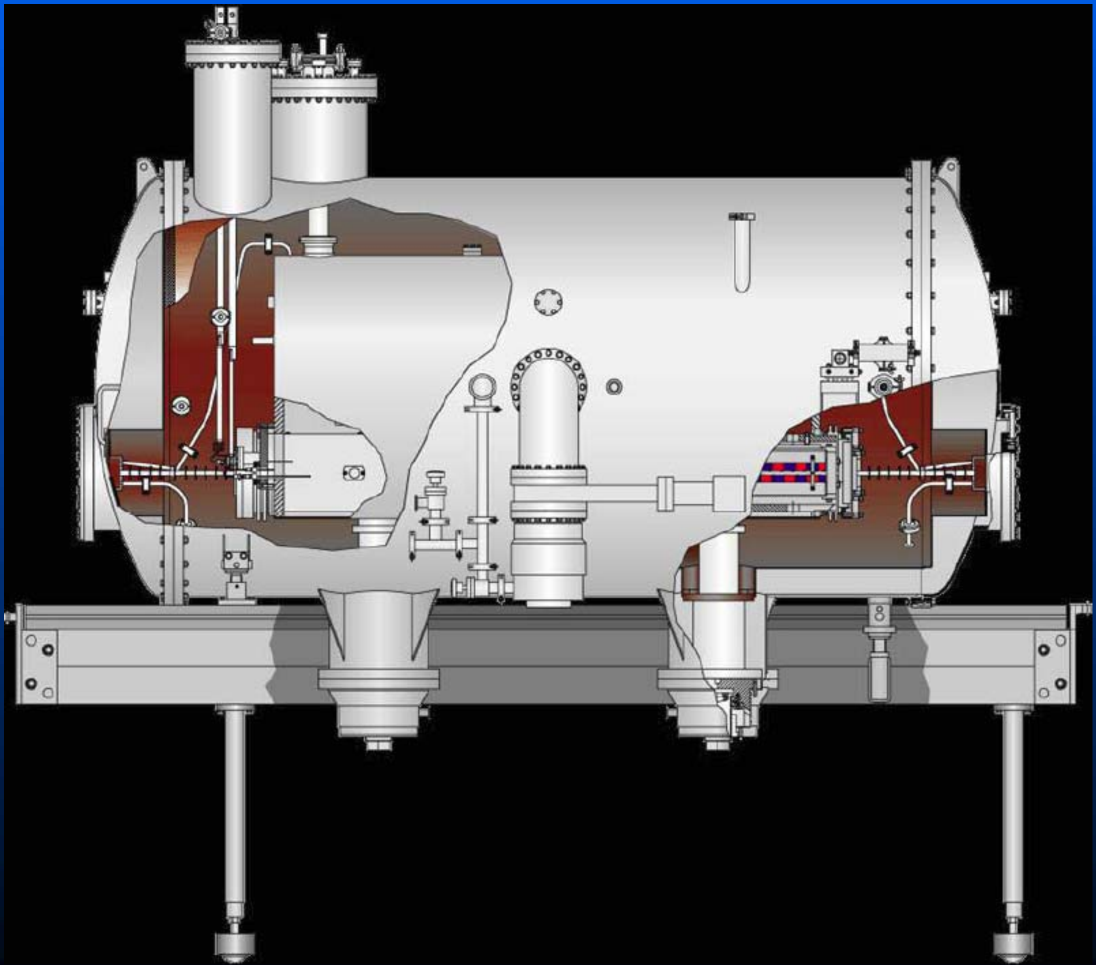
$$RRR = \frac{\rho\,(T = 300\mathrm{K})}{\rho\,(T = 4\mathrm{K})}$$

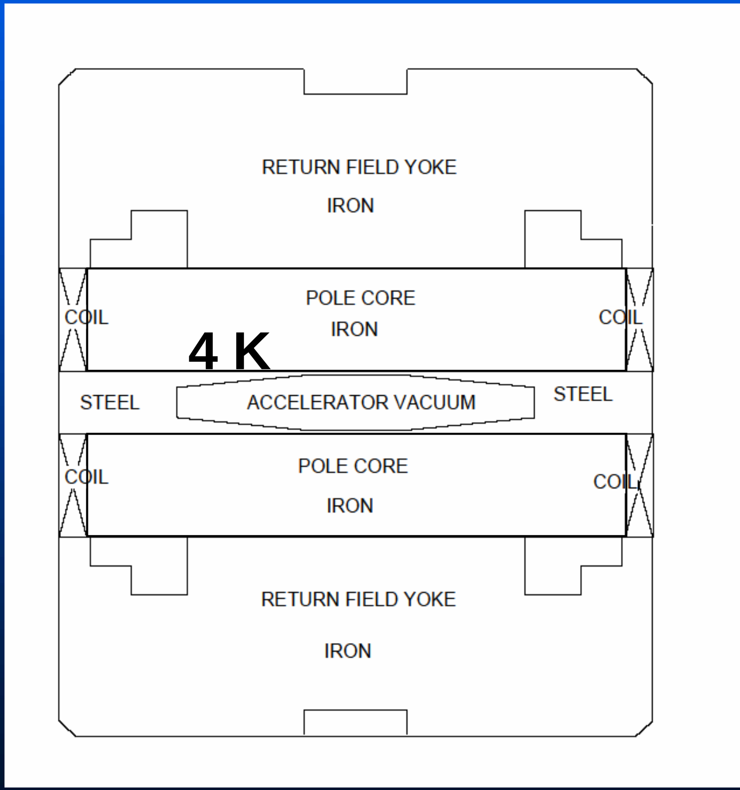
Cooling capacity at 4K : several watts !

3.5-T SC wiggler
Cold-bore type (not in-vacuum)

E. Wallén and G. LeBlanc, MAX Lab.

Operating !!





3.5-T SC wiggler
Cold-bore type (not in-vacuum)

E. Wallén and G. LeBlanc, MAX Lab.

Operating !!

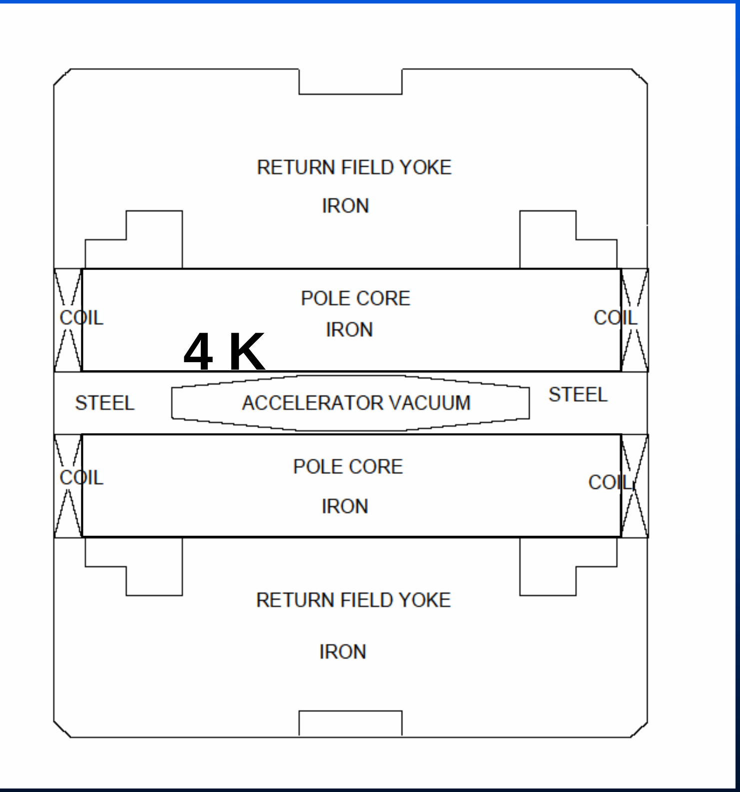
λ_u = 61 mm, N=23, L=1.47m
G_{VAC}=10.2 mm, B = 3.5 T

I= 200 mA, σ= 25 psec,

P_{image} = 1.37 W
P_{SR} = 0. 26W

Scaling to SPring-8 case
100 mA, 16-bunch operation

P_{image} = 40 W !



Cryoundulators
(Cryogenic PM Undulators)

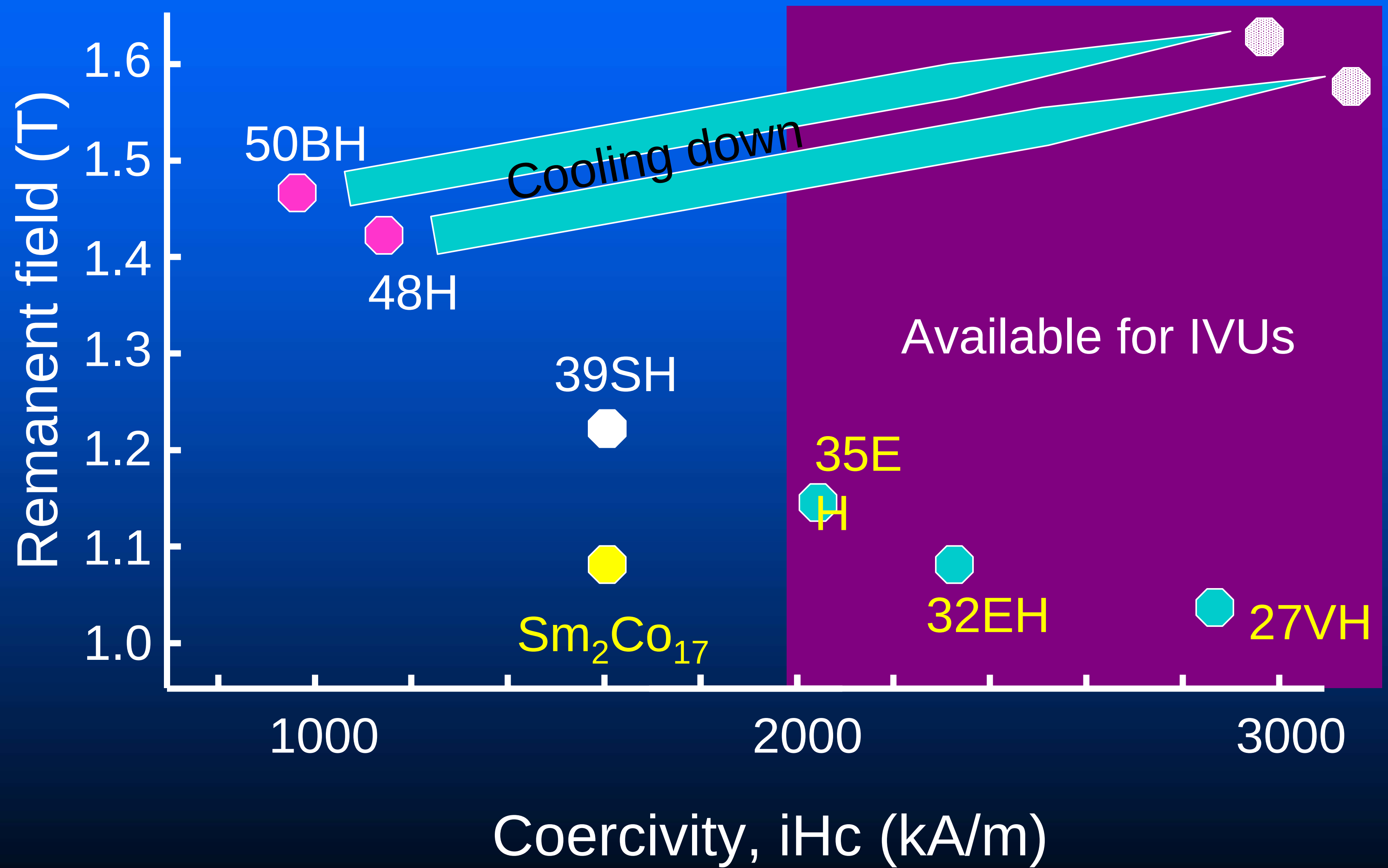
Motivation:

NdFeB PMs

Remanent field : - 0.1 %/K

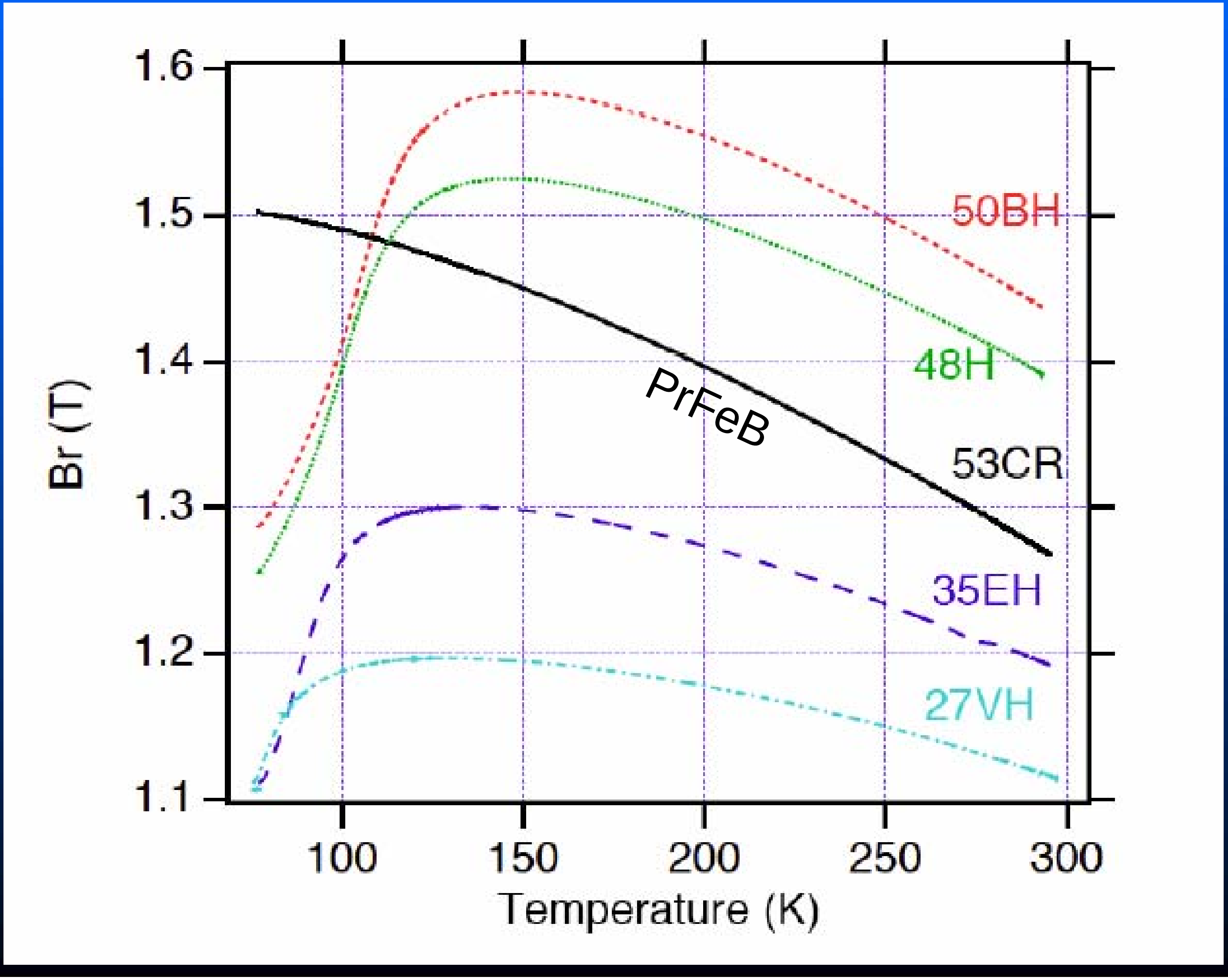
Coercivity : - 0.6%/K

Magnetic Performance of Various PMs at 300K



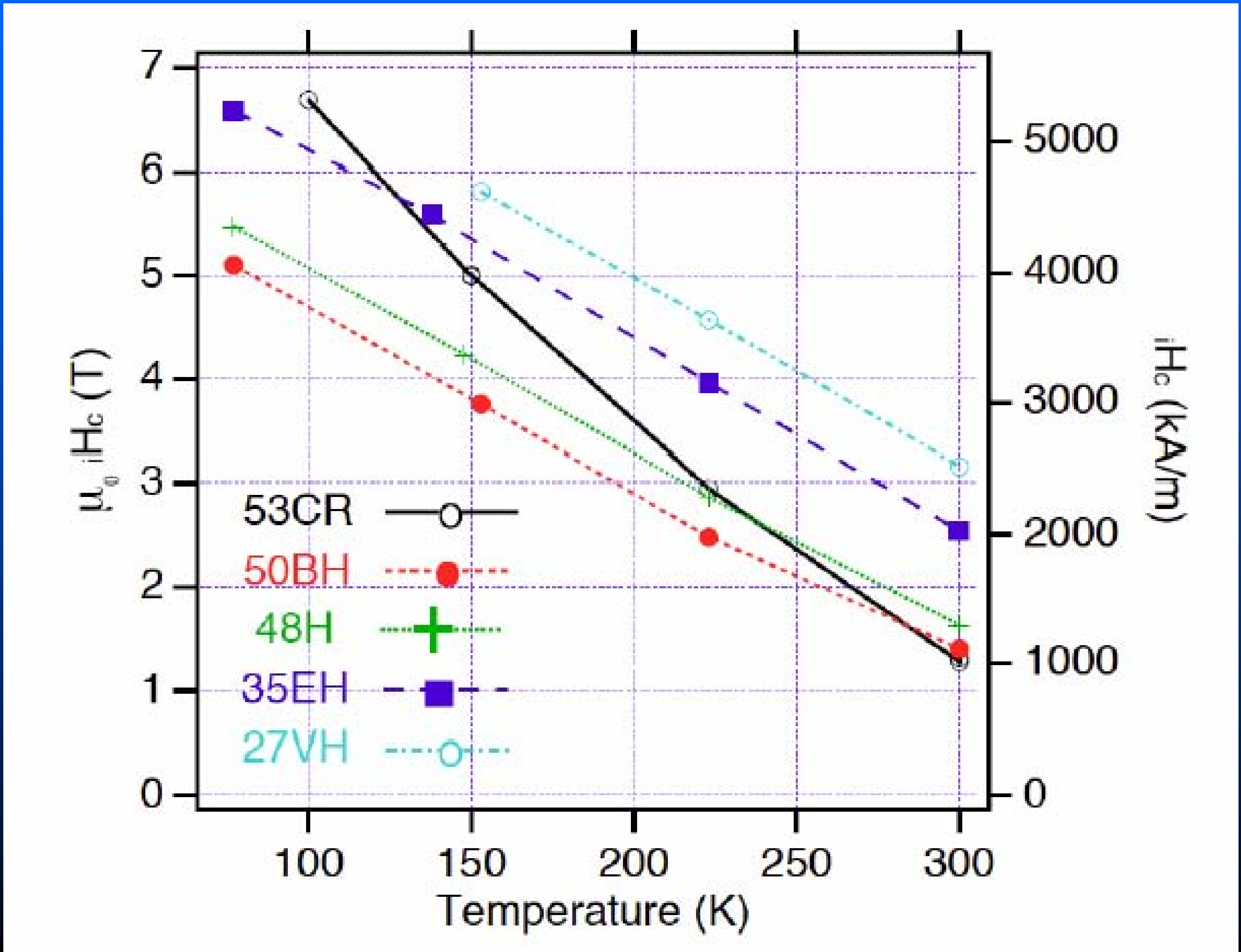
Temperature Dependence of Remanent Field

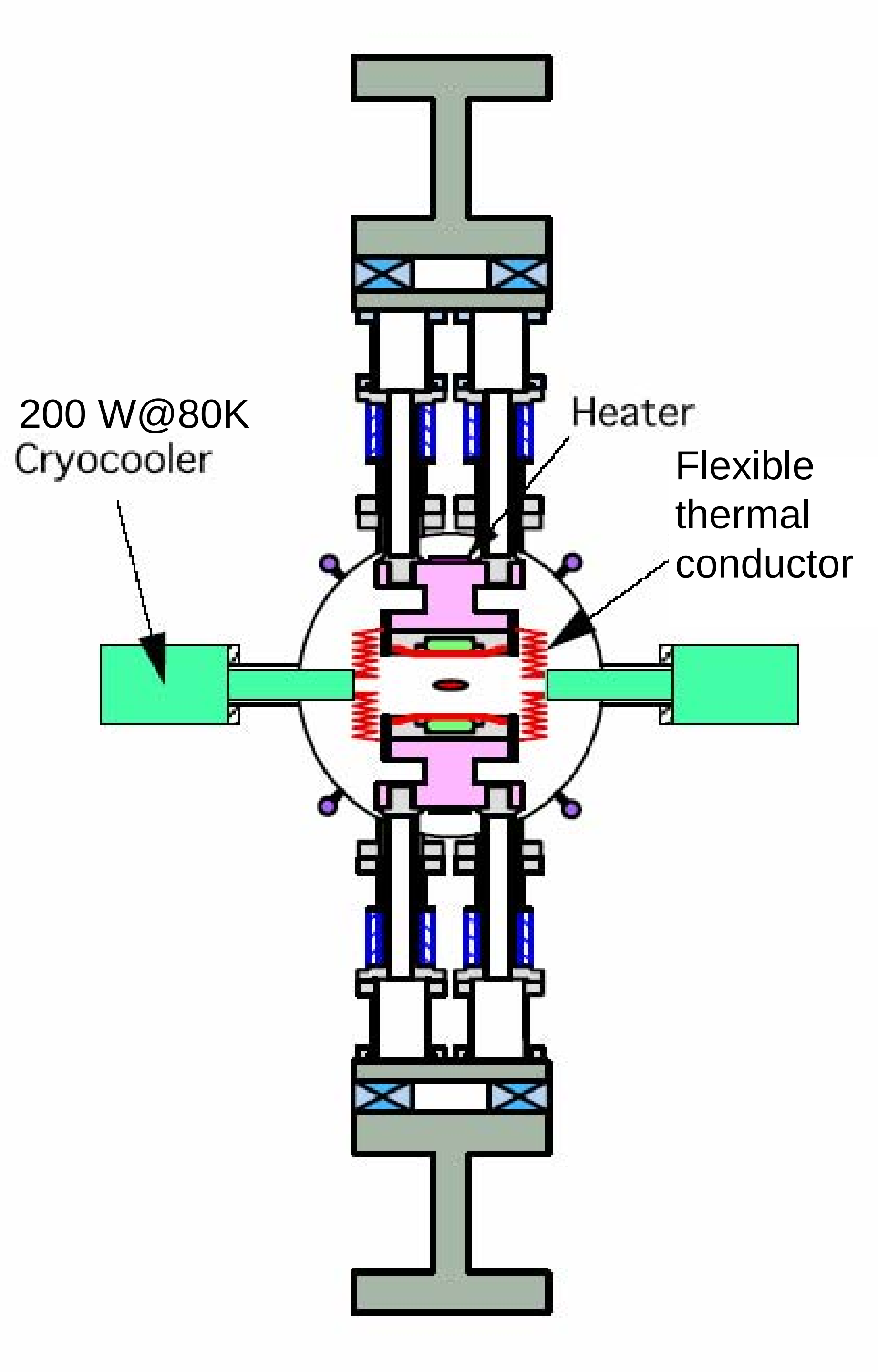
NEOMAX-XX (NdFeB, PrFeB)



Temperature Dependence of Coercivity

NEOMAX-XX (NdFeB, PrFeB)



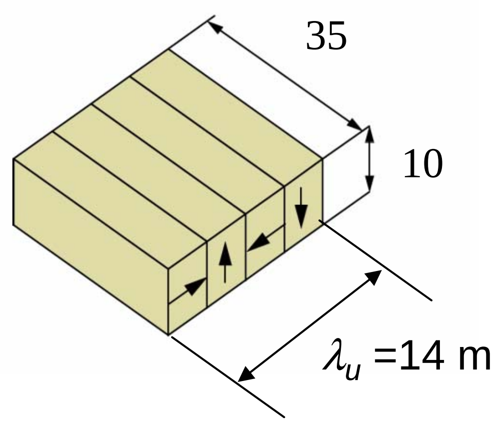


Characteristics of CryoU

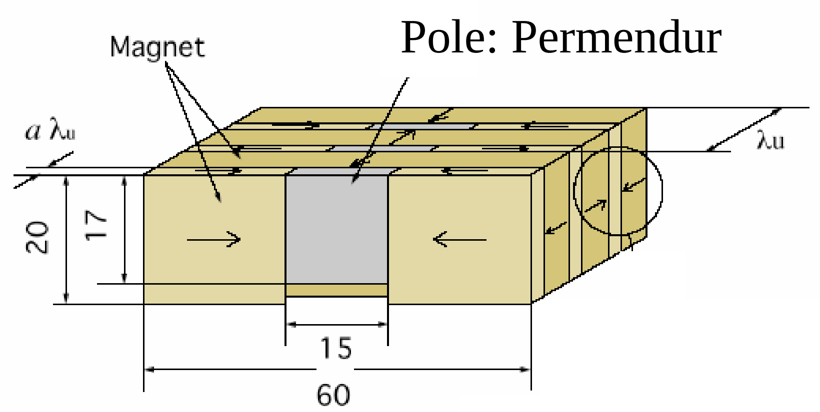
1. Extension from ordinary IVU design
2. Compact cryocooler
   with 200 W at 80 K available
3. High resistance
   against large thermal budget
4. High resistance
   against radiation damage
5. 30 - 50 % higher field
   compared to ordinary IVU

Evaluation of Magnetic Performance of Cryoundulator (λ_u =14 mm)

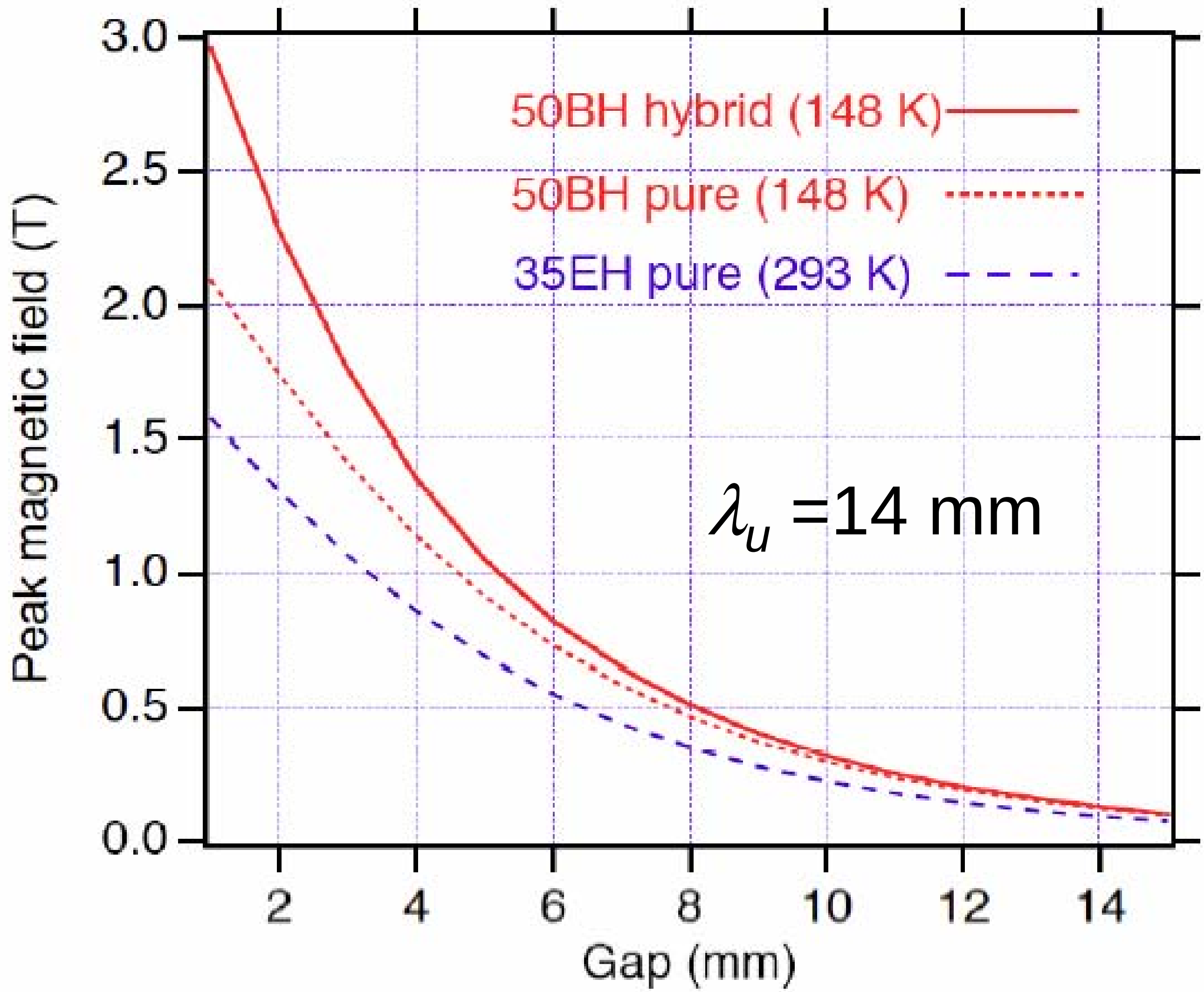
Pure (Halbach) type



Hybrid type

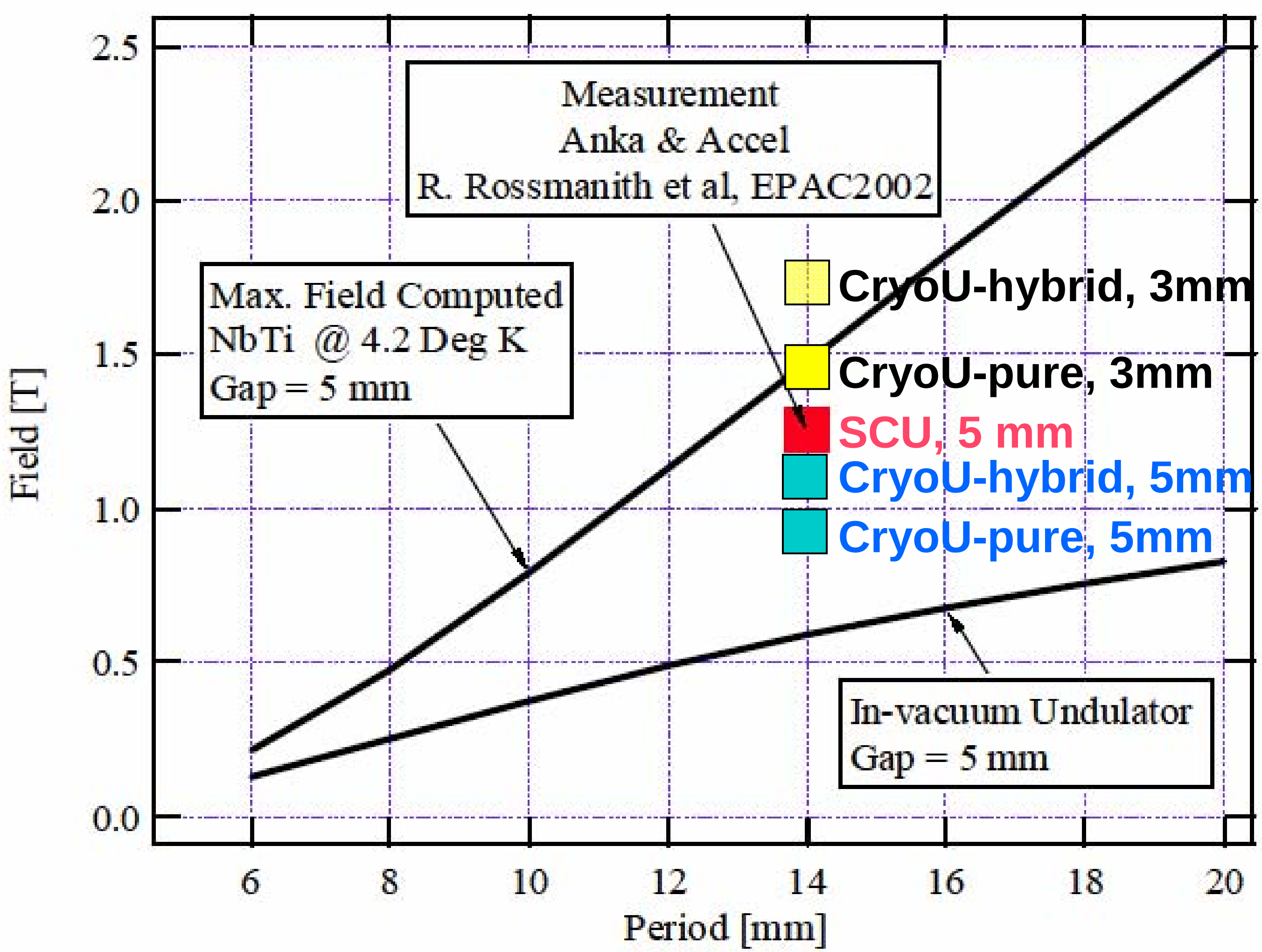


Calculated Magnetic Field in CryoU



RADIA (Chubar, Elleaume and Chavanne)

Comparison of IVU, SCU & CryoU at G_{MAG}=5 mm



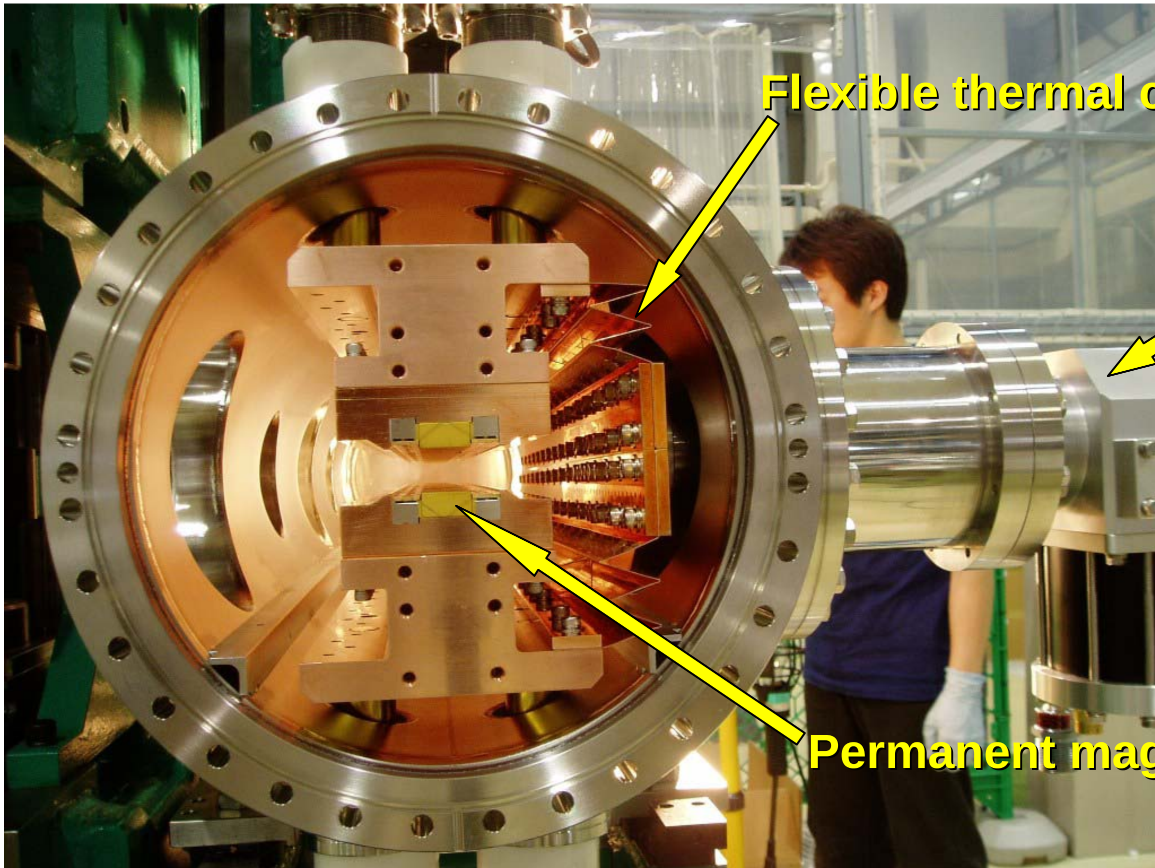
P. Elleaume

Summary

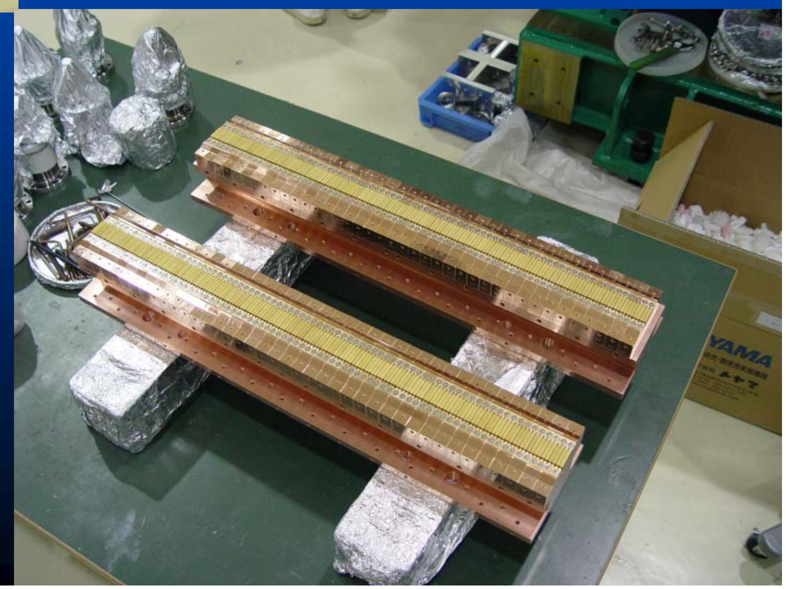
1. In-vacuum undulators
   - -Performance proven.
   - -Standard device as an X-ray source in a medium-scale facility.
   - -NdFeB with high coercivity or Sm_2Co_{17} should be adopted.
2. Superconducting undulators of in-vacuum type
   - -Generating highest field at the same magnetic gap.
   - -First operation in an electron storage ring is expected.
   - -Successful operation depends on the measure against thermal budget problem.
3. Cryoundulators
   - -Magnetic performance is much higher than that of IVU but somewhat lower than that of SCU.
   - -Extension from IVU design. An old IVU can be remodeled to CryoU.
   - -High resistance against thermal budget.
     - Very narrow gap may be allowed.
     - Practical performance may be higher than that of SCU.
   - -Principle should be verified as soon as possible.
4. Outlook

   Future undulator design?

   One of the candidates: Combination of CryoU and HTSC



Cryoundulator of prototype under construction



Magnet arrays for CryoU

Thank you for your attention!