Status of Cryogenic Permanent Magnet Undulator Development

T. Tanaka, T. Hara, T. Bizen, T. Seike and H. Kitamura
SPring-8 Insertion Device Group

CONTENTS

- What is Cryogenic Permanent Magnet Undulator (CPMU)?
- History of Development
- Cold Magnetic Measurement
- Key Issues toward Realization

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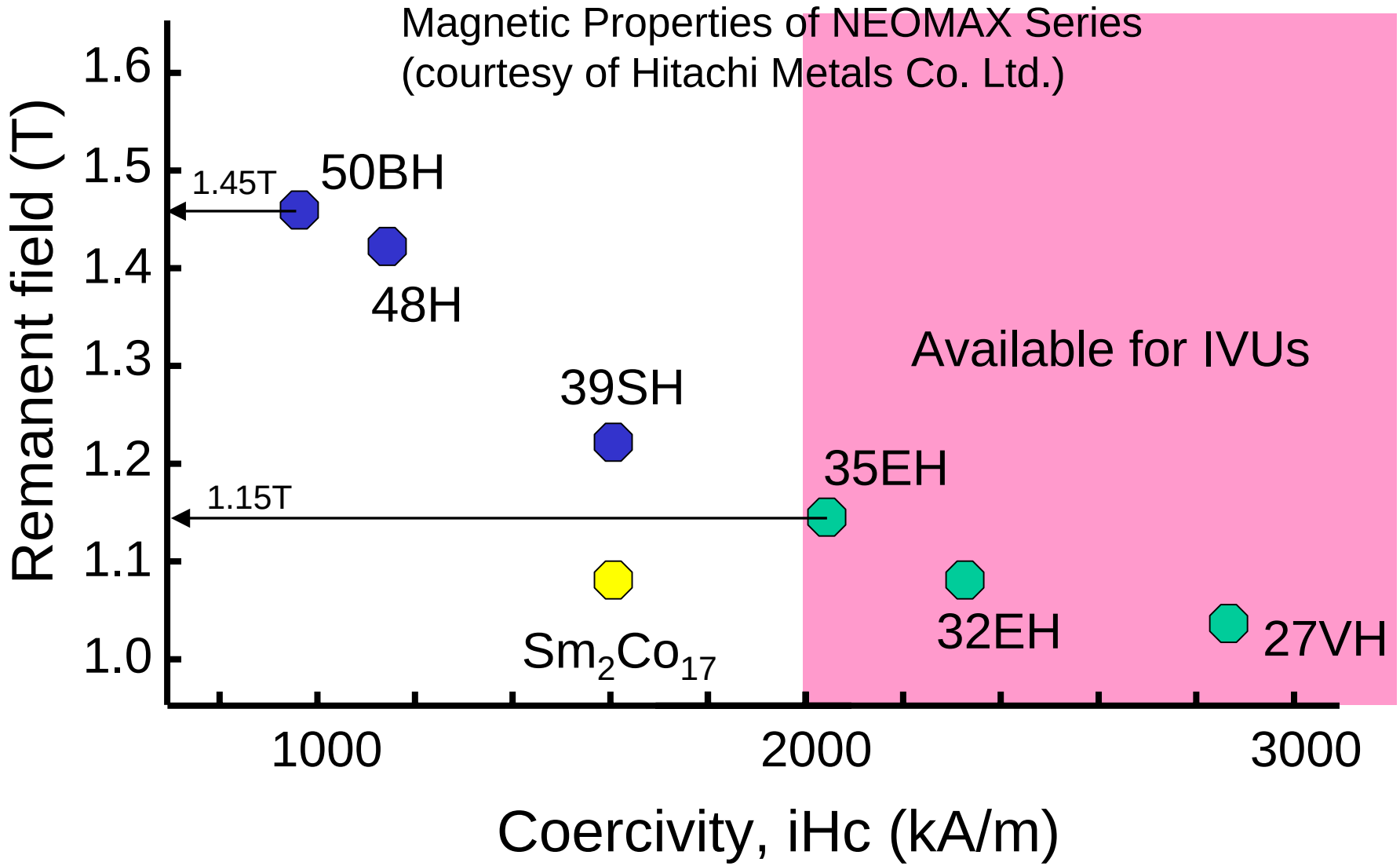
PM Material for Undulators



What is CPMU?: Concept

- PMs for Undulators Should Have:
  - high remanence: magnetic field
  - high coercivity: resistance against demagnetization

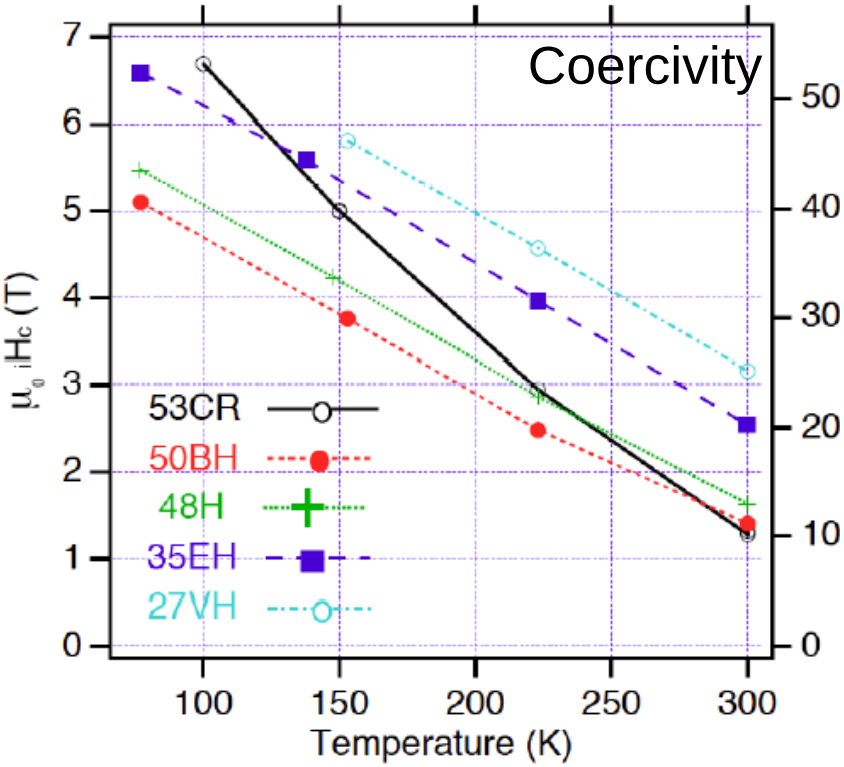
    However, Br x iHc ~ constant: low Br and high iHc
- Temperature Coefficient of PM Material
  - remanence: -0.1%/K@300K
  - coercivity: -0.6%/K@300K

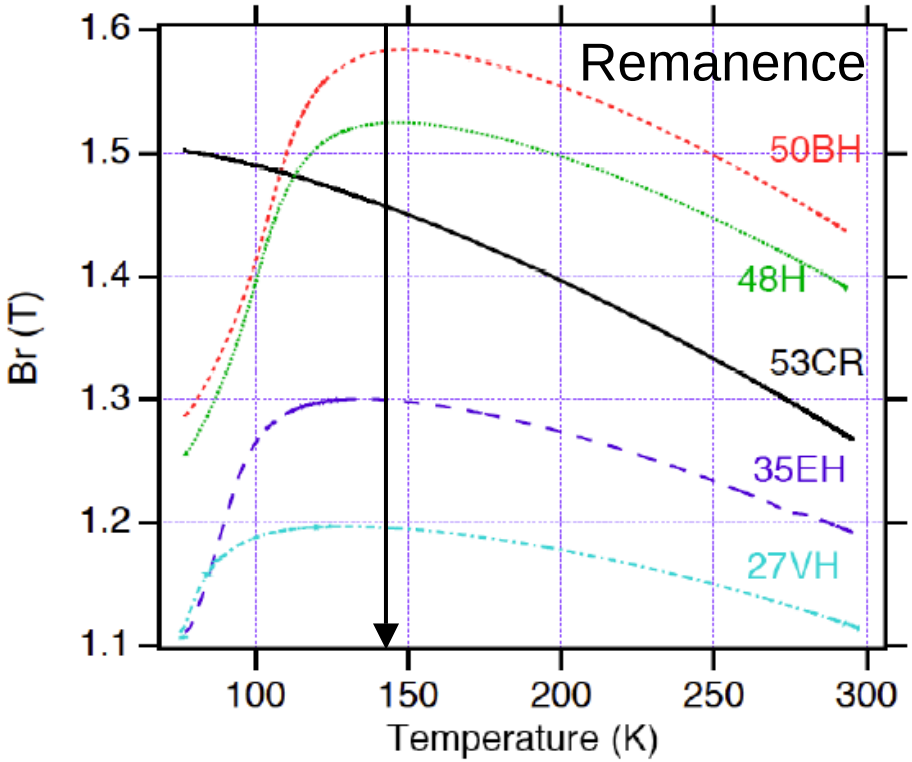
PMs at Cryogenic Temperature for Better Magnetic Performance

Cryogenic Permanent Magnet Undulator

T. Hara T. Tanaka H. Kitamura T. Bizen T. Seike T. Kohda & Y. Matsuura Phys. Rev. ST-AB, 7 (2004) 050702.

Temperature Dependence of PMs

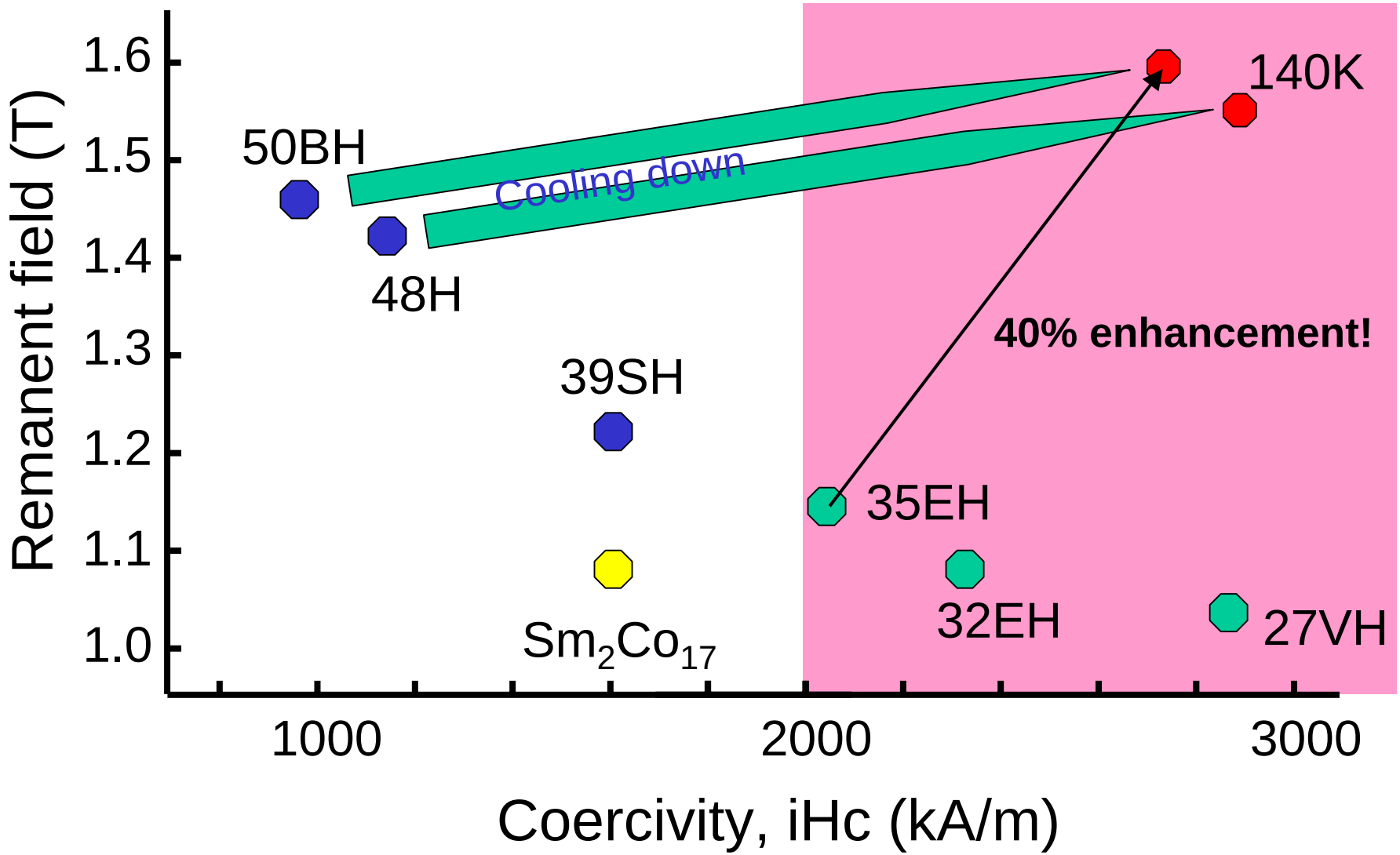




Operation of NEOMAX50BH around 140K is reasonable

- Maximum remanence
- Low sensitivity to temperature variation

Performance of CPMU



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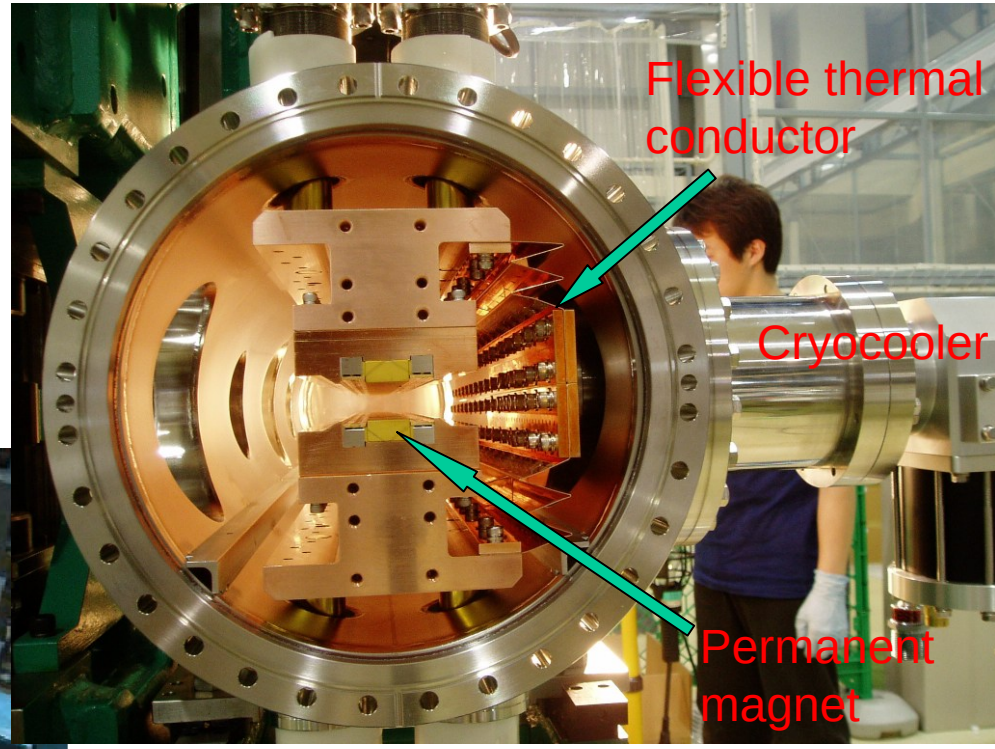
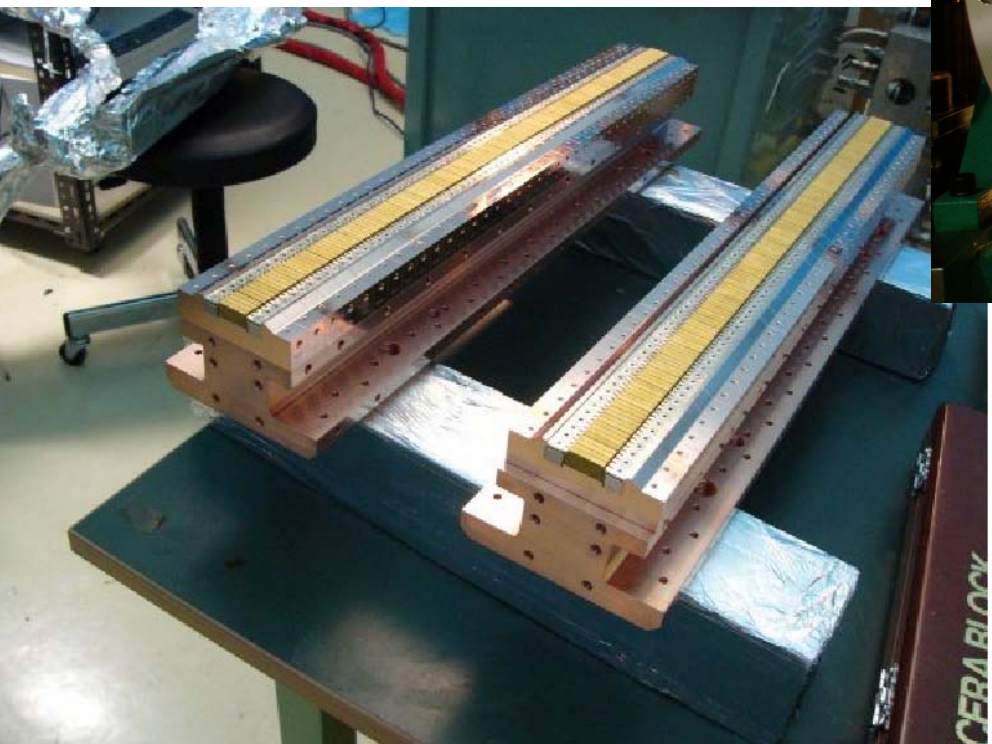
CPMU Prototype@SP-8 (2005)

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



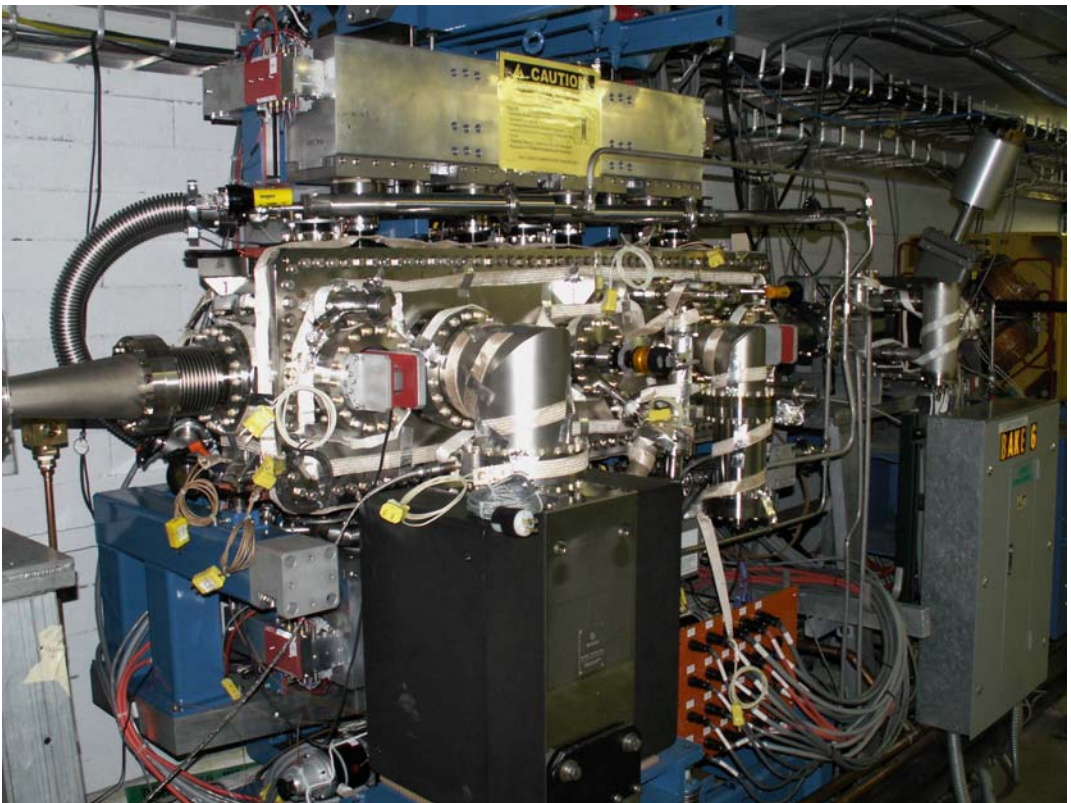


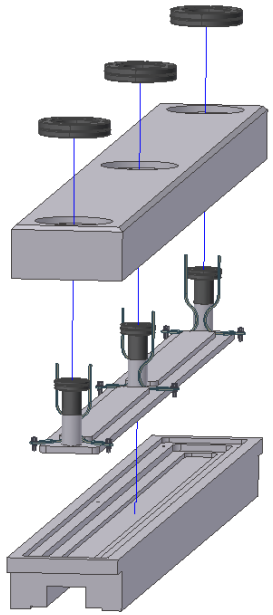
Temperature Control
GM-cycle Cryocooler &
Sheath Heater

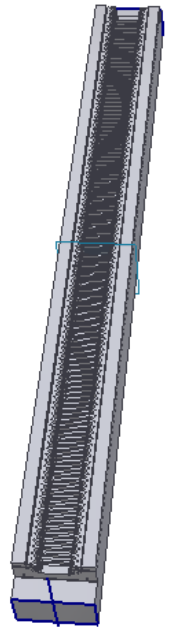
courtesy of T. Tanabe (BNL)

Cryo-ready IVU (2006)

- X25-MGU IVU λ_u=18mm, Minimum Gap=5.6mm, 1m Long
- integrally machined cooling passageways in arrays
- Low-temperature “friction stir welding” technique was used for the first time for Al alloys in a UHV accelerator device
- Cold test was conducted with boiled off LN gas

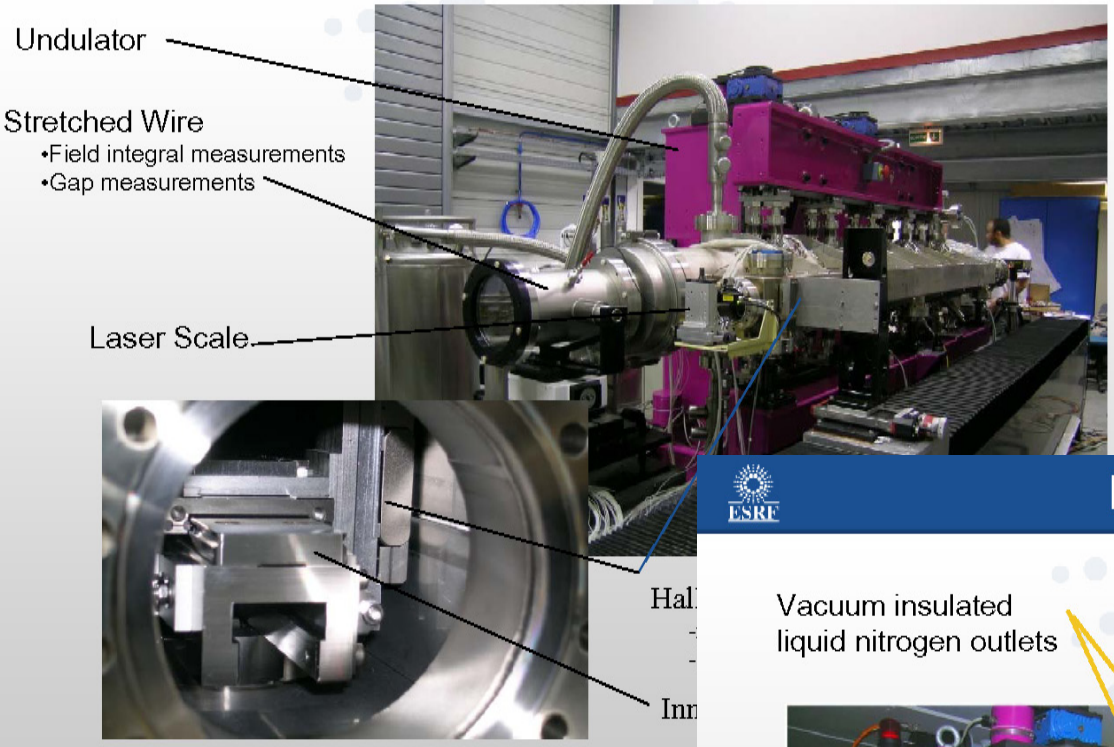






Development of measuring systems

A Light for Science



European Synchrotron Radiation Facility

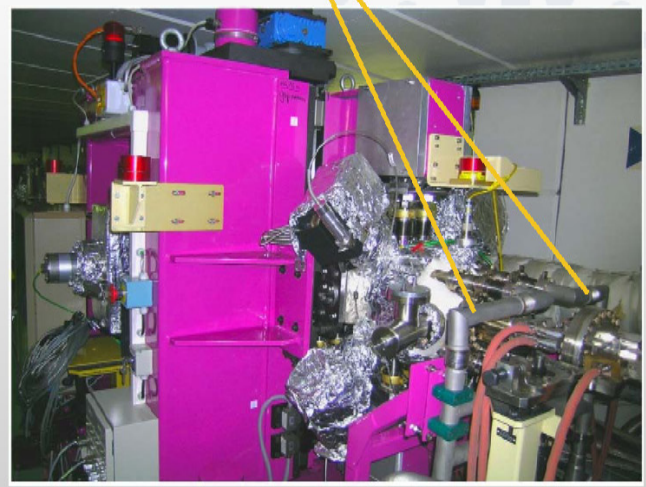
CPMU for ESRF (2008)
L=2m, λ_u=18mm

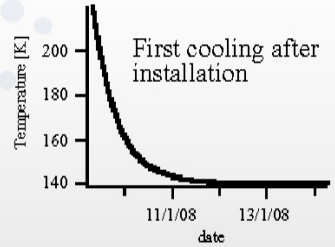
courtesy of J. Chavanne (ESRF)

The device is now under routine operation at CT and characterization is being carried out.

Installed CPMU

A Light for Science





See
" First operational experience with a Cryogenic Permanent Magnet undulator at ESRF"

J. Chavanne, G. Lebec, C.Penel, F.Revol, ESRF, Grenoble France
C. Kitegi, SOLEIL, Gif sur Yvette France.

PAC09

CPMU installed in ID6 straight section (January 2008)

CPMU for SLS (2009)

- Under construction in collaboration between PSI and SPring-8.
- To be replaced with the wiggler installed in an existing beamline to increase the brilliance up to 30 keV.
- Field measurement & correction at RT has been finished (phase error < 2^{o}).
- Cooling test will be carried out in June followed by field measurement at CT.

CPMU at Diamond Light Source

- The CPMU will be used for beam line I07
- Period: 17.7mm, K= 1.7 at 5mm, L = 2 m
- Working temperature 120K – 150K
- Ordered from Danfysik
- FDR completed
- Delivery October 2009

courtesy of J. Schouten (DIAMOND)

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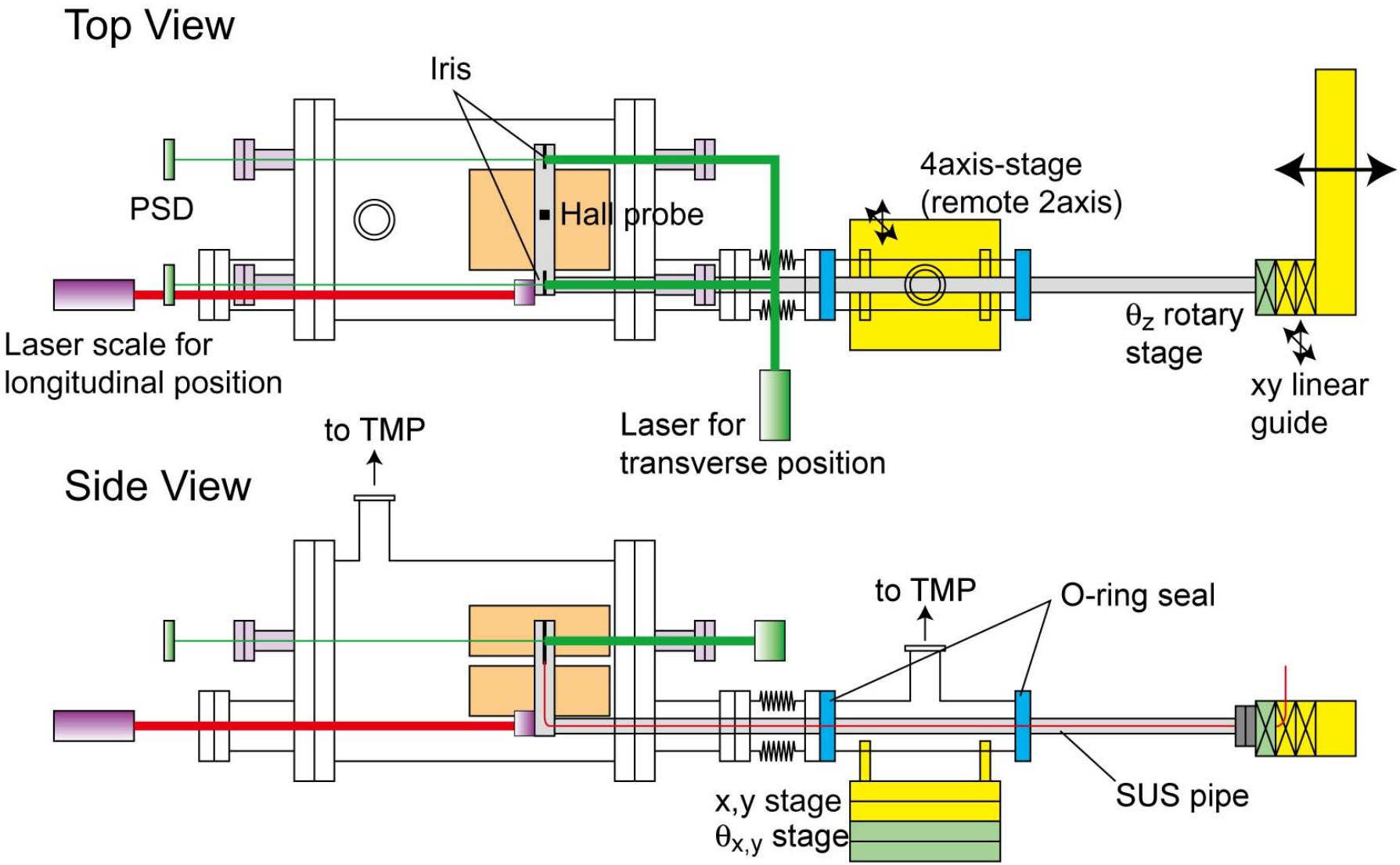
Cold Magnetic Measurement

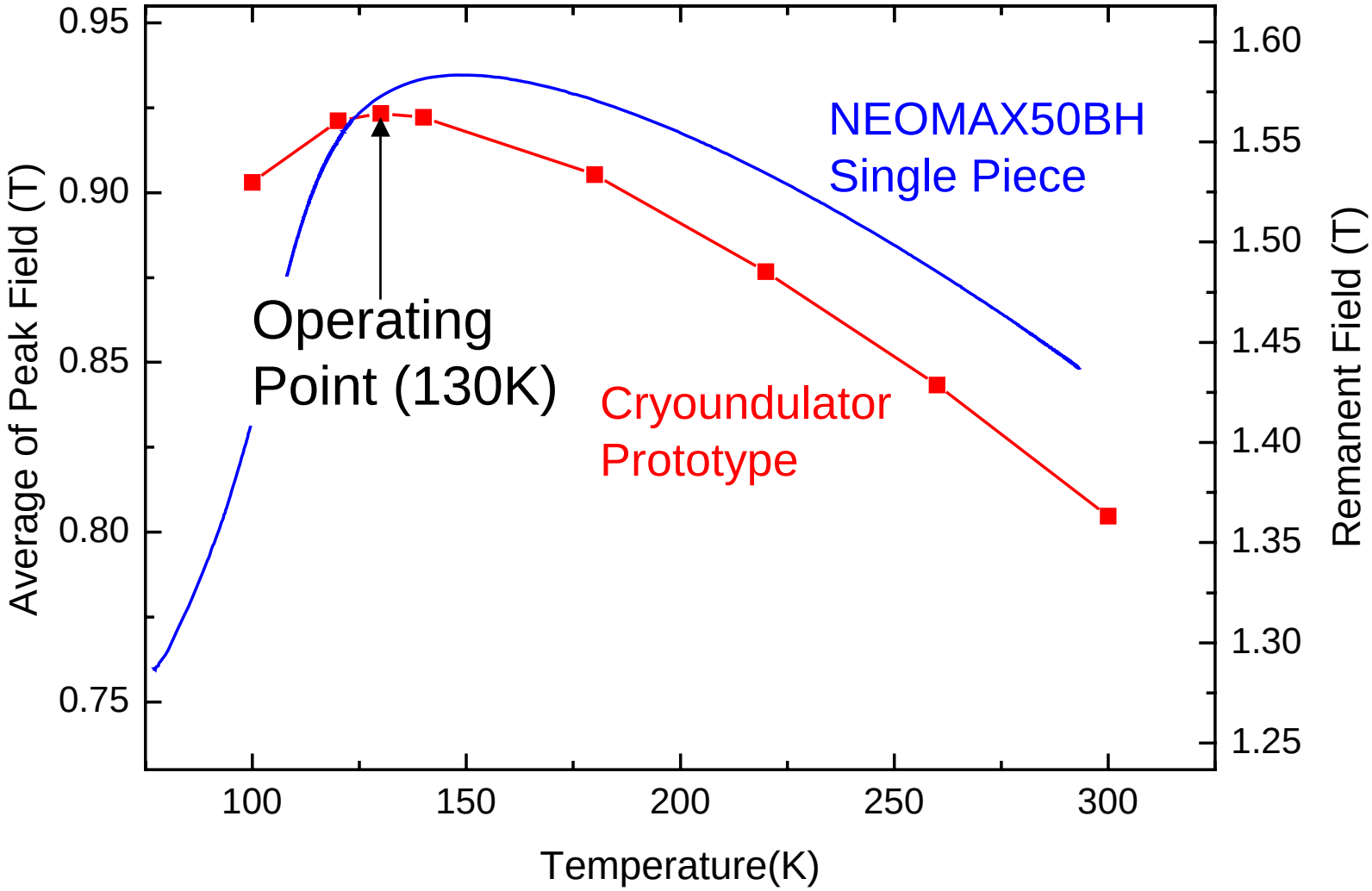
- Magnetic measurement of PM array at a cryogenic temperature, in order to check
  - field enhancement (optimum temperature)
  - variation of the undulator performance
- Requirements on measurement
  - actuation of a Hall probe in vacuum
  - positional fluctuation due to pitching, rolling and yawing of the actuator should be low enough
- Possible Solution
  - install a rigid linear guide with high mechanical precision in vacuum
  - measure the Hall-probe position and feedback

Meas. System for CPMU Prototype

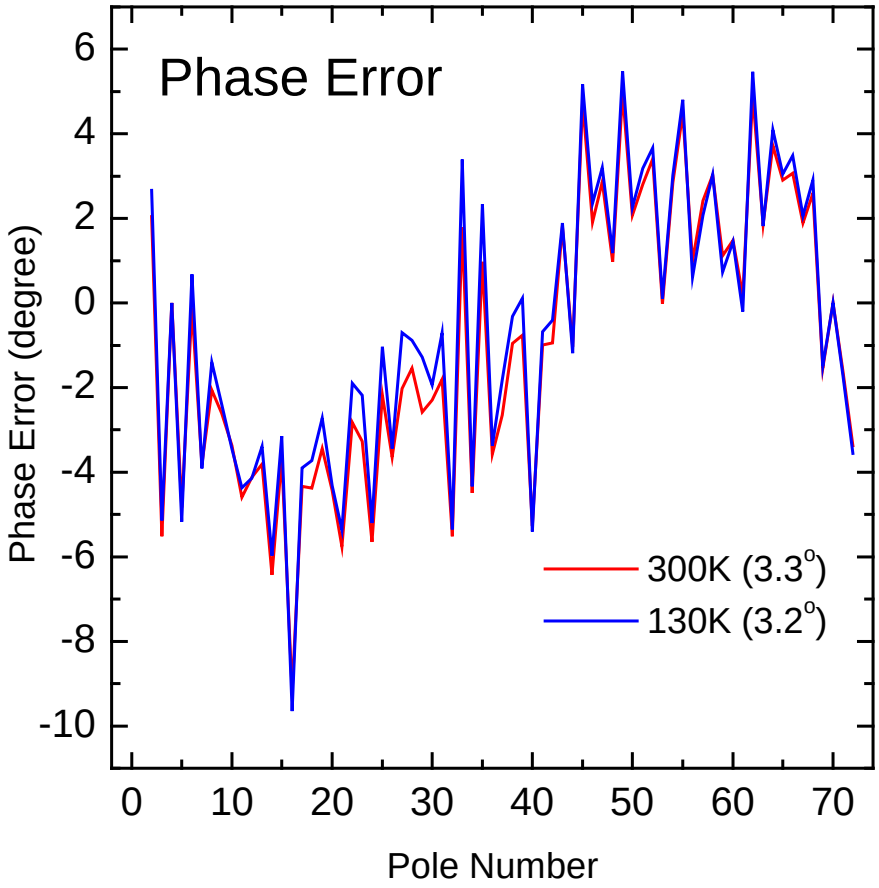


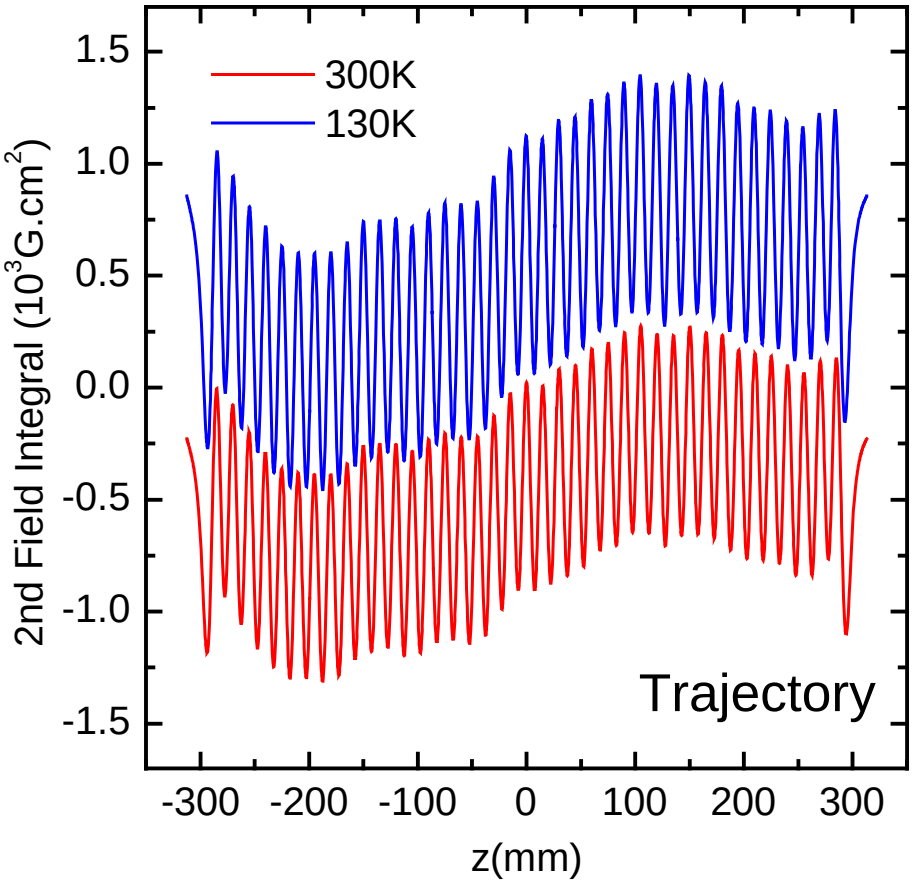

o-ring seal
laser diode
mirror
beam splitter
4-axis stage

Peak Field vs. Temperature



Variation of Und. Performance





The difference between RT and CT is negligibly small!

⇒ Field correction at RT is still effective.

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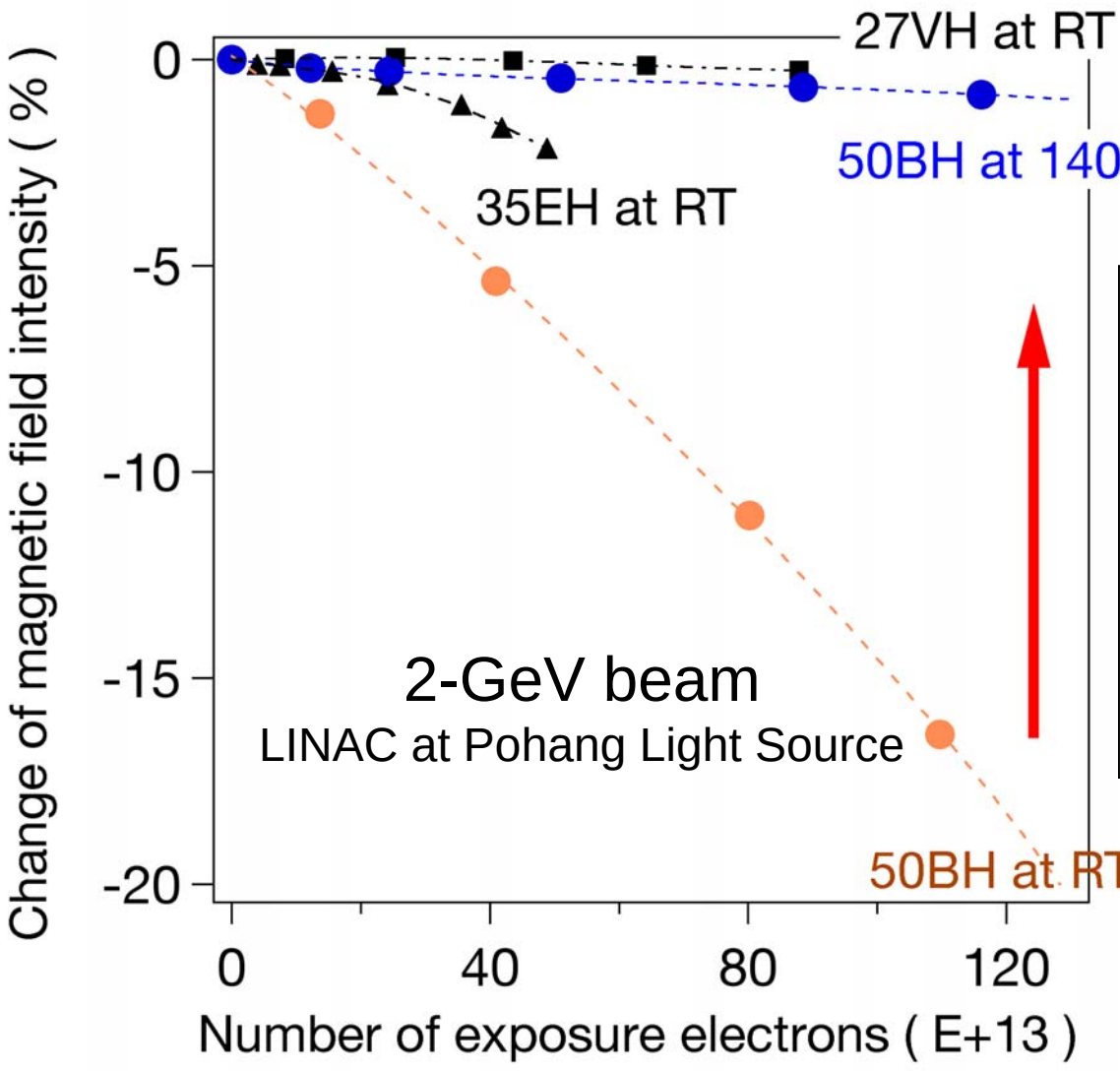
Resistance against Radiation Damage



Resistance to Radiation Damage:

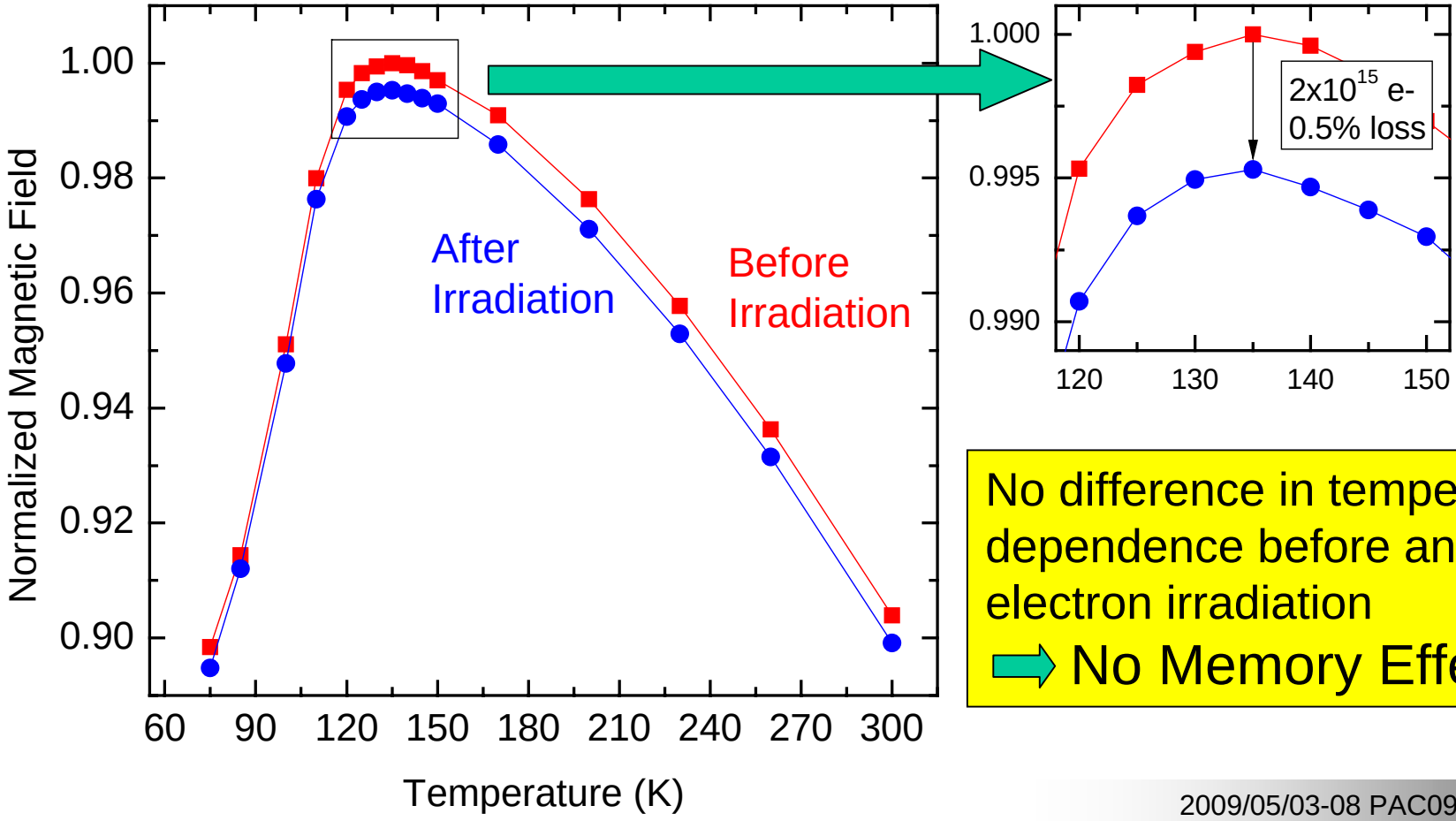
NEOMAX50BH@140K

~ NEOMAX27VH@RT

> NEOMAX35EH@RT

Demagnetization by “Memory Effect”

- Memory Effect
  - PMs irradiated at CT can be demagnetized due to accumulated radiation damage once heated up to RT.

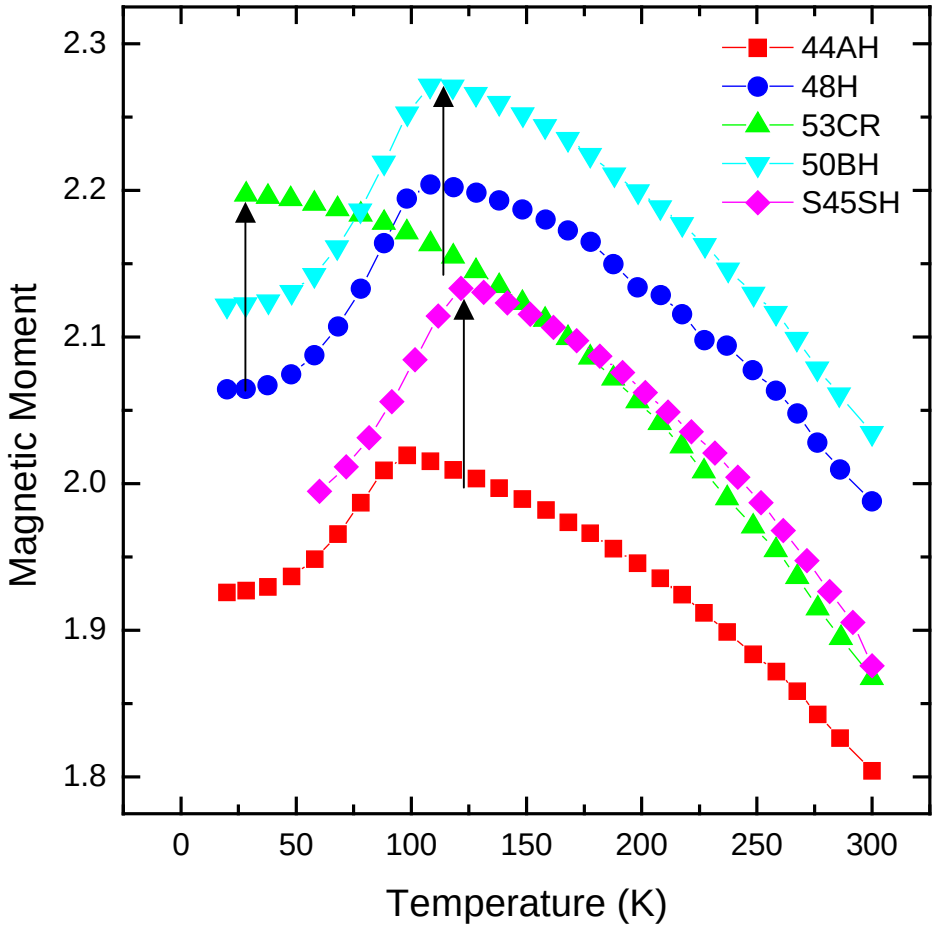


No difference in temperature dependence before and after electron irradiation

⇨ No Memory Effect!

Temperature Gradient (1)

- Cooling to CT may bring nonnegligible temperature gradient over the magnet array.



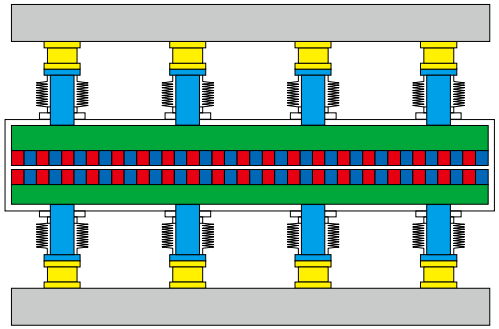
B_r is much less sensitive to *T* at the operation point.

⇒ Temperature gradient may not be a problem.

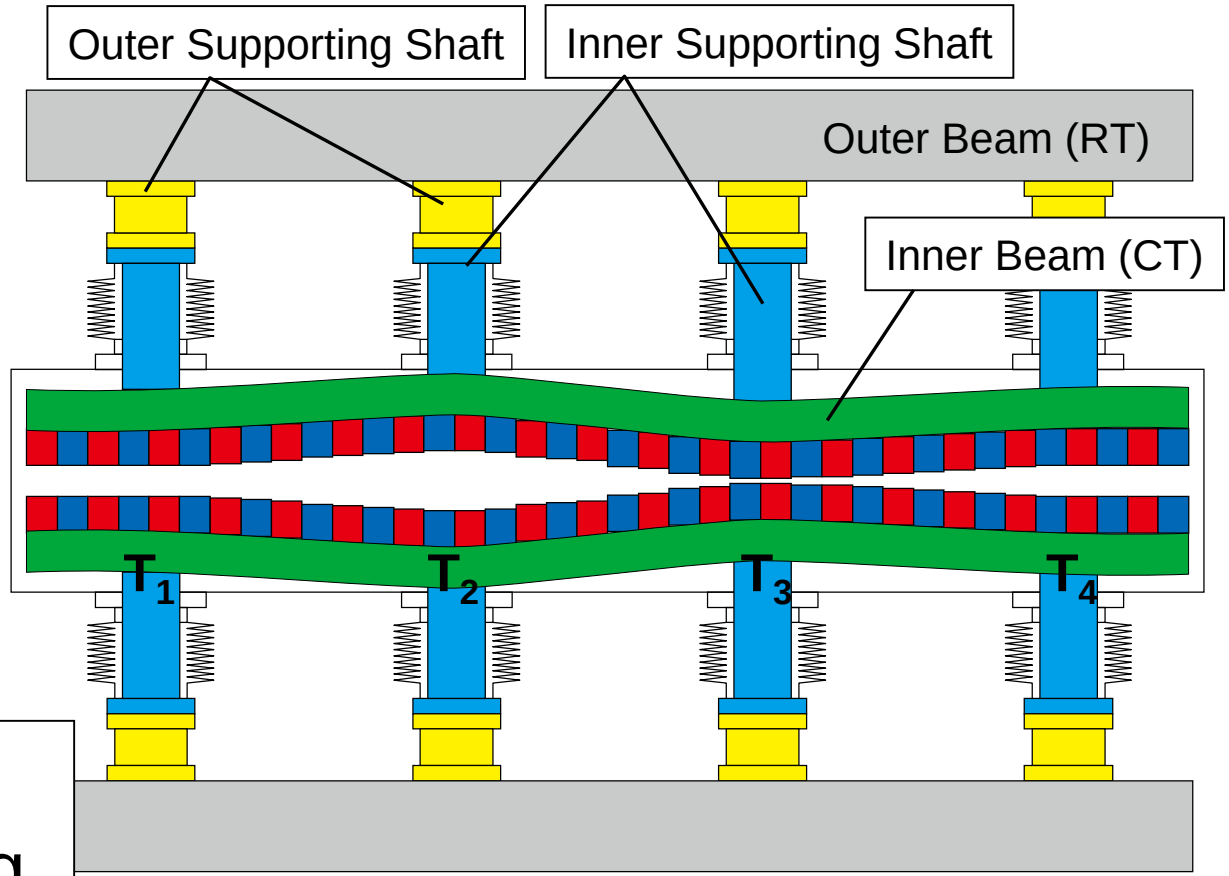
Another Concern: Deformation of the Inner Beam.

Temperature Gradient (2)

- Temperature gradient may cause discrepancy in the distance between supporting shafts.



cooling

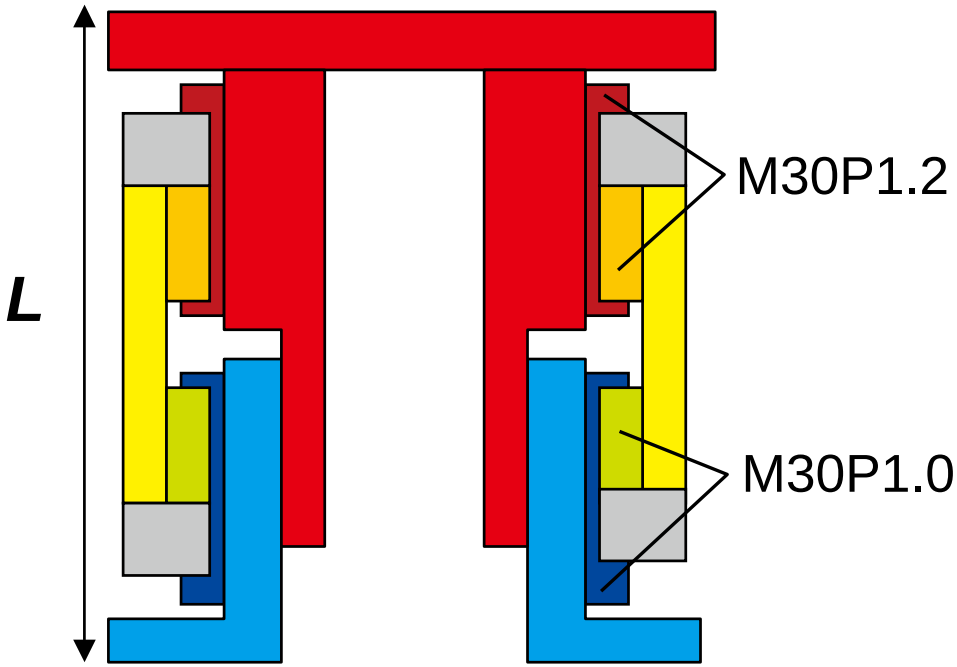


$T_3 > T_1 \sim T_4 > T_2$

$\Rightarrow g_3 < g_1 \sim g_4 < g_2$

Correction with Differential Adjuster

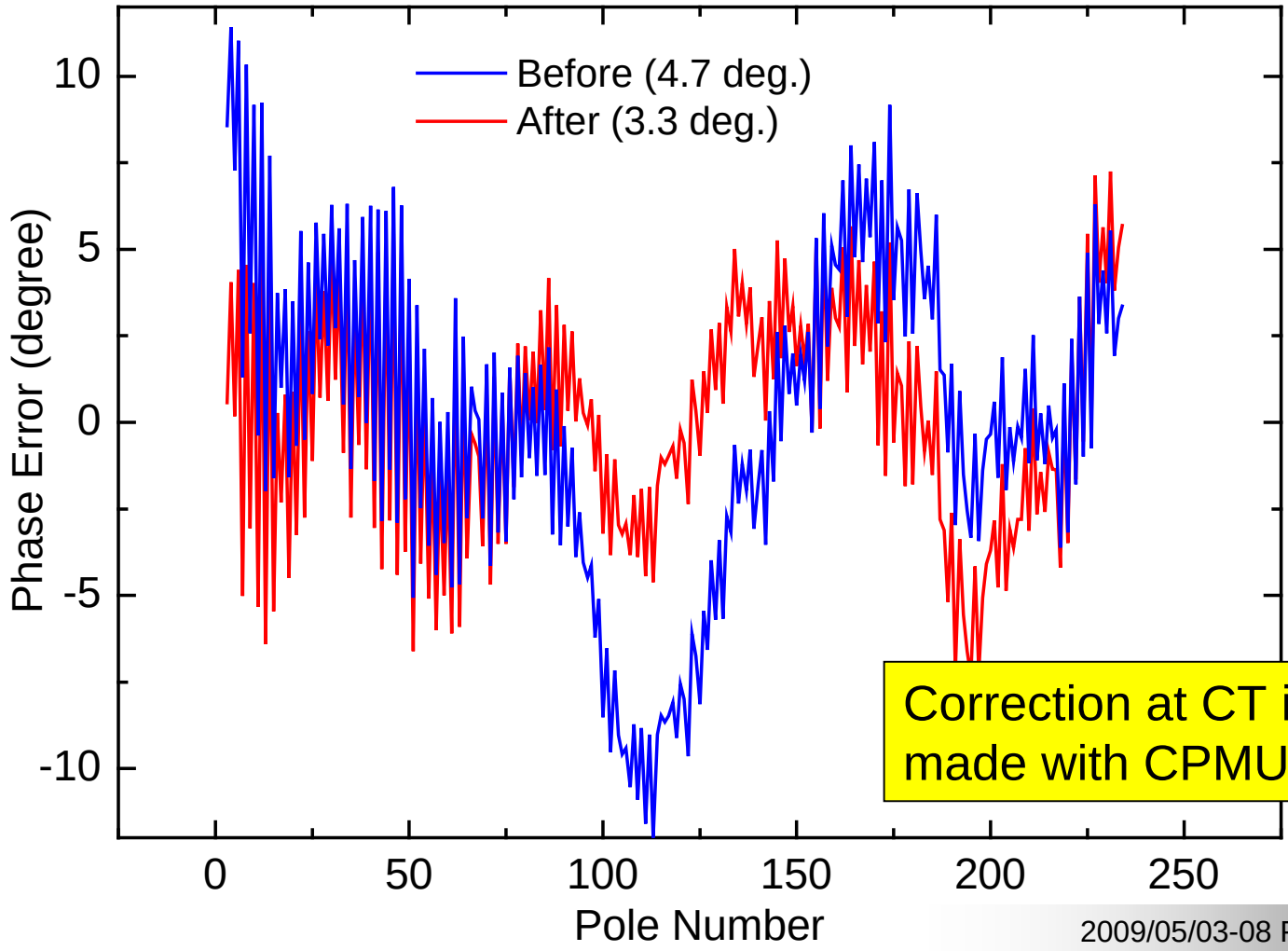
- If the length of supporting shaft is adjustable, then the distortion can be corrected.
- “Differential Adjuster” as the outer shaft has been developed and tested at SPring-8. The function is similar to a turnbuckle.



L can be adjusted by 0.2mm/rev.

Example of Correction

Result of phase error correction (at RT) by means of the differential-adjuster shaft.



Correction at CT is to be made with CPMU for SLS

Others Topics

- Cooling System
  - Three different methods have been tried:
    - Cryocooler (prototype@SP-8)
    - Gas Coolant (cryo-ready@NSLS)
    - LN Circulation (ESRF, PSI)
- Gap Monitoring
  - Gap variation due to thermal shrink of the supporting shafts
  - Optical Micrometer (KEYENCE LS-7000)
- Vacuum Test without Baking
  - Vacuum of SCSS IVU (1/2 pumping speed & no baking) operated at RT < 10^{-7}Pa
  - What is the achievable vacuum at CT?
- New PrFeB* as an alternative to NdFeB
  - Br=1.64T@77K

* T. Tanabe, private communication

Summary

- CPMU concept
  - Simple modification of IVU
  - Enhancement of magnetic properties of PMs by cooling to CT (>100K)
- Several prototypes constructed, two devices are under construction
- A variety of R&D activities carried out toward realization, now ready to start construction of practical devices.

Thank you for attention!