Wiggler Design Possibility Based on a Cryogenic Permanent Magnet Insertion Device

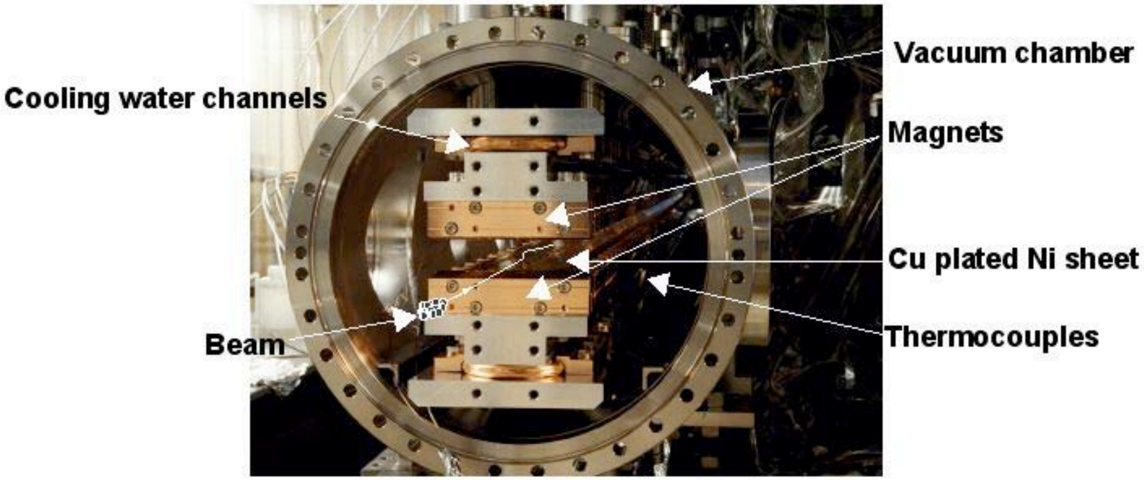
SPring-8 insertion device group
presented by Toru HARA

- Characteristics of permanent magnets at cryogenic temperatures (> 77 K)
- Cryogenic prototype insertion device
- Expected performance of cryowiggler
- Summary

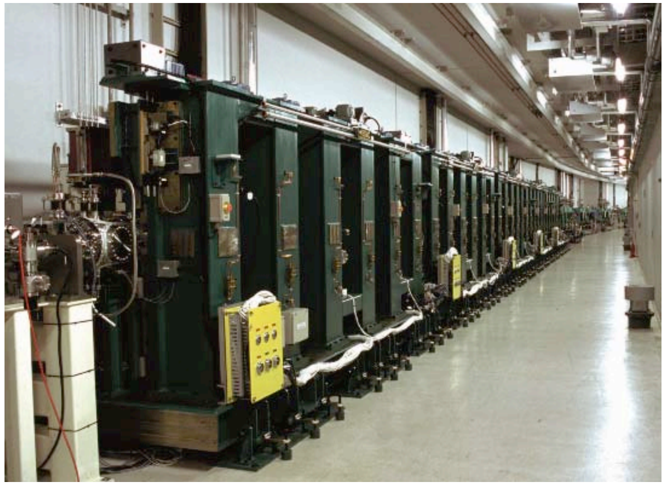
SPring-8 insertion devices

- **5 soft X-ray undulators** with large undulator periodic length (> 10 cm). SPring-8 type helical, figure-8, asymmetric figure-8, APPLE II, revolver.
- **1 elliptical wiggler** with λ_u = 12 cm, B_y = 0.88 T and B_x = 0.88 T.
- **1 superconducting wiggler** B_y > 10 T (tentative use, by Soutome).
- **20 in-vacuum undulators** with λ_u = 2.4 ~ 4 cm.

  Planar pure magnet, planar hybrid, helical, figure-8.
- **3 other in-vacuum devices** including 11 mm period undulator (BNL) and in-vacuum revolver with λ_{u_min} = 6 mm (PAL).



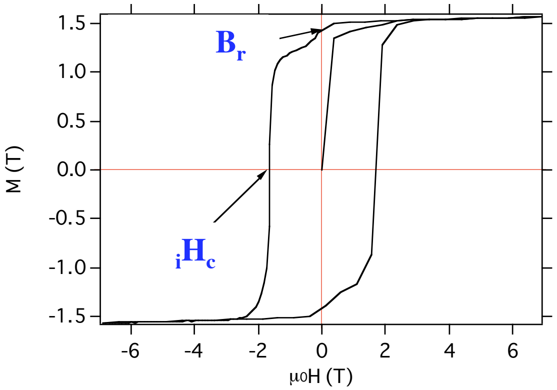
Cross section of in-vacuum device



25 m in-vacuum undulator

The design of the cryogenic insertion devices are based on current in-vacuum undulator and requires small modification.

Magnet performance at cryogenic temperatures



High B_r

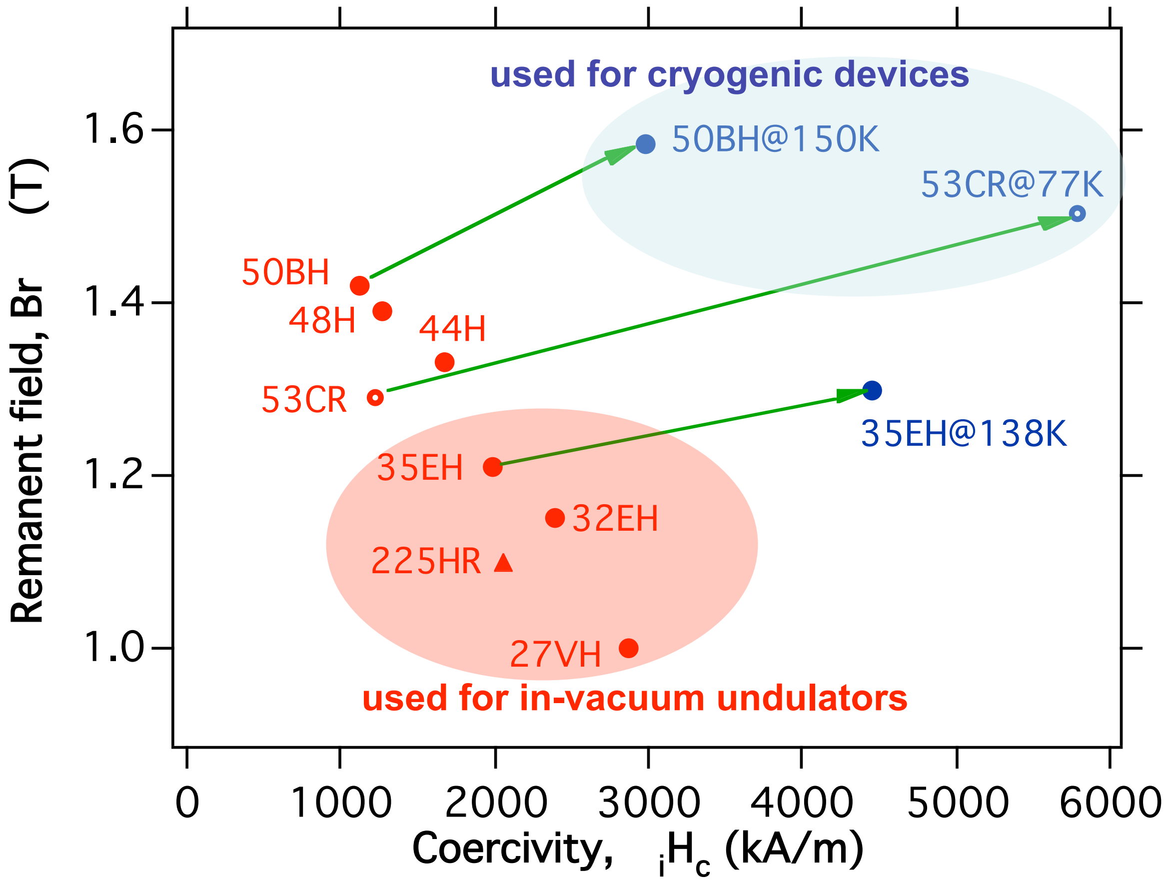
↓

High magnetic performance

Large $_iH_c$

↓

High stability against demagnetization



NdFeB magnets achieve highest magnetic performance among permanent magnet materials. But high B_r NdFeB magnets show small $_iH_c$.

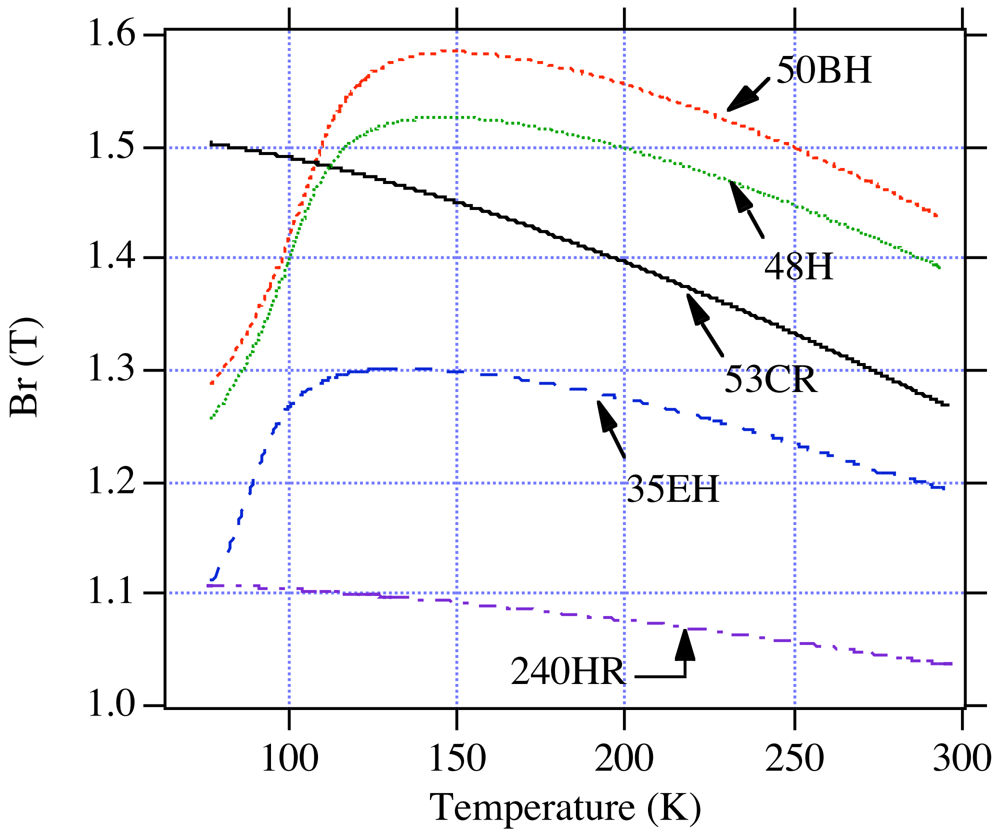
Concept of cryogenic insertion devices

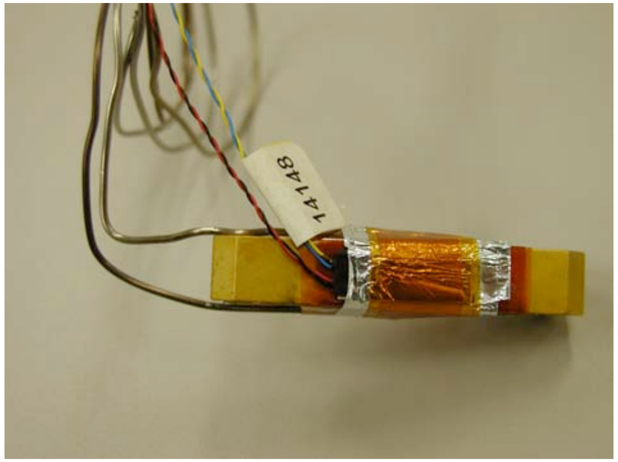
- Increased coercivity at cryogenic temperatures (> 77K) => choice of high B_r material, high resistance against demegnetization.
- Increased remanent field (B_r) by ~ 10 %.

Short period undulators and short period wigglers.

- No quench and stable operation.
- Magnetic field alignment technique of conventional insertion devices can be applied, such as sorting or shimming methods.
- Sufficiently large cooling capacity of a cryocooler (a few hundreds watts) at the temperatures > 77 K.
- Only a slight modification required on in-vacuum devices.
- No bake-out necessary.

Remanent field (B_r) measured at cryogenic temperatures



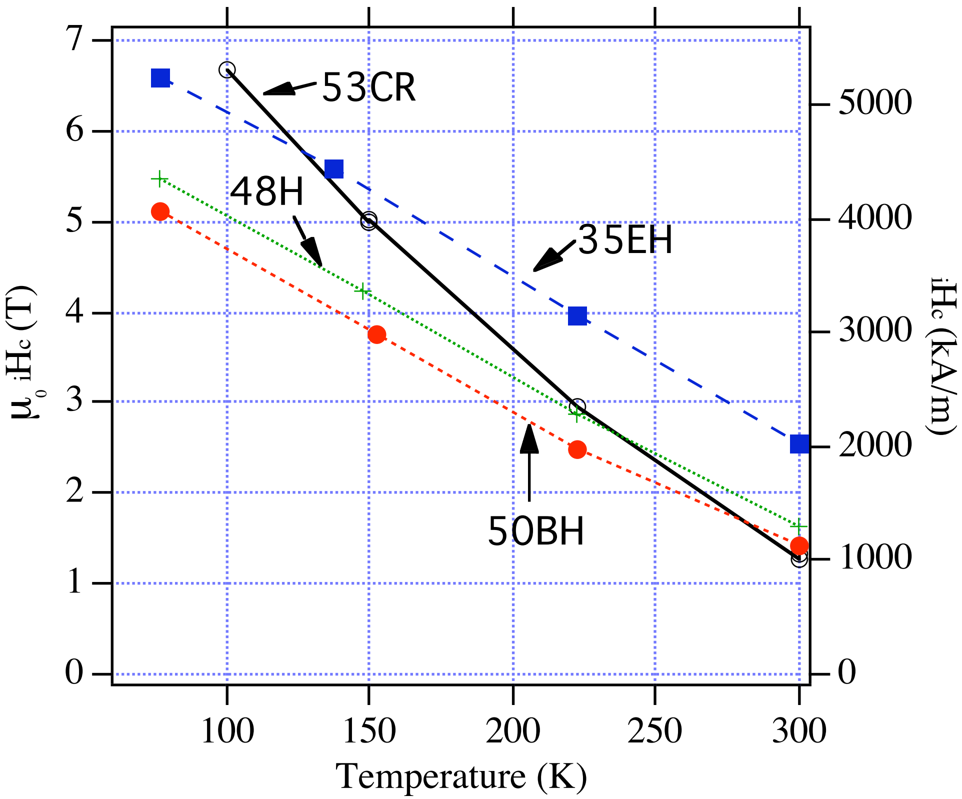


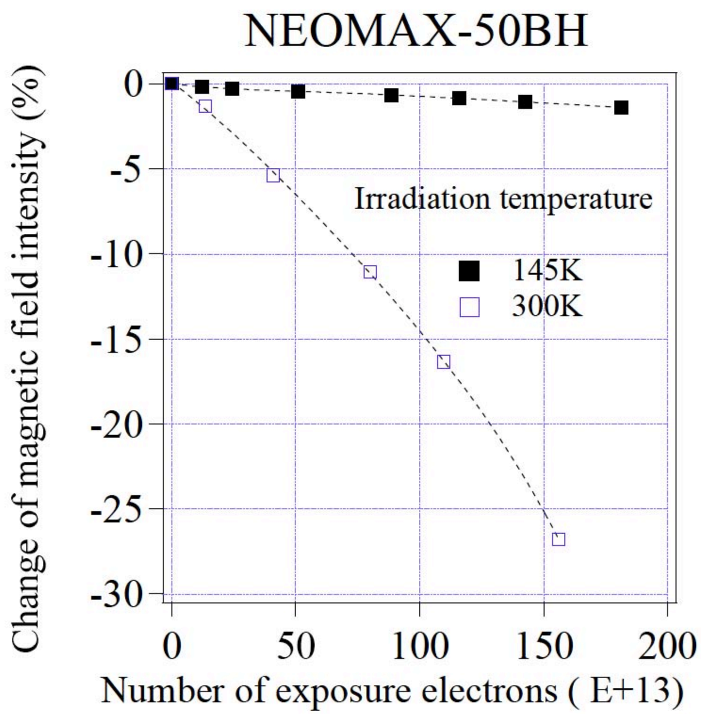
35EH is a standard material for the conventional in-vacuum undulators of SPring-8.

Field change is completely reversible with respect to the temperature.

VACOMAX 240HR	Sm_2Co_{17} magnet
NEOMAX 50BH, 48H, 35EH	NdFeB magnet
NEOMAX 53CR	PrFeB magnet

Coercivity ($_iH_c$) measured at cryogenic temperatures

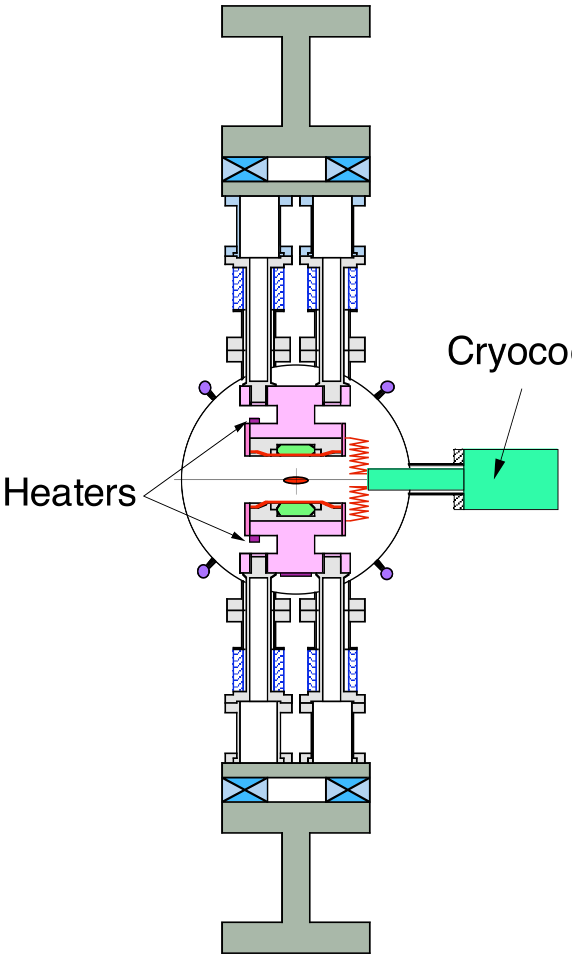




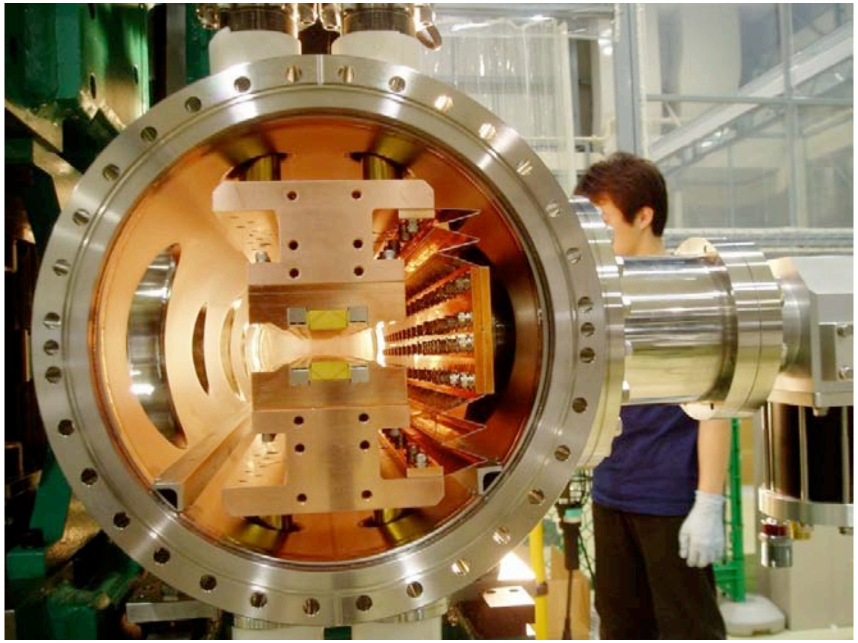
Beam energy 2 GeV

- Coercivity increased inversely proportional to the temperature.
- High resistance against demagnetization due to beam irradiation at cryogenic temperatures.

Prototype of Cryoundulator

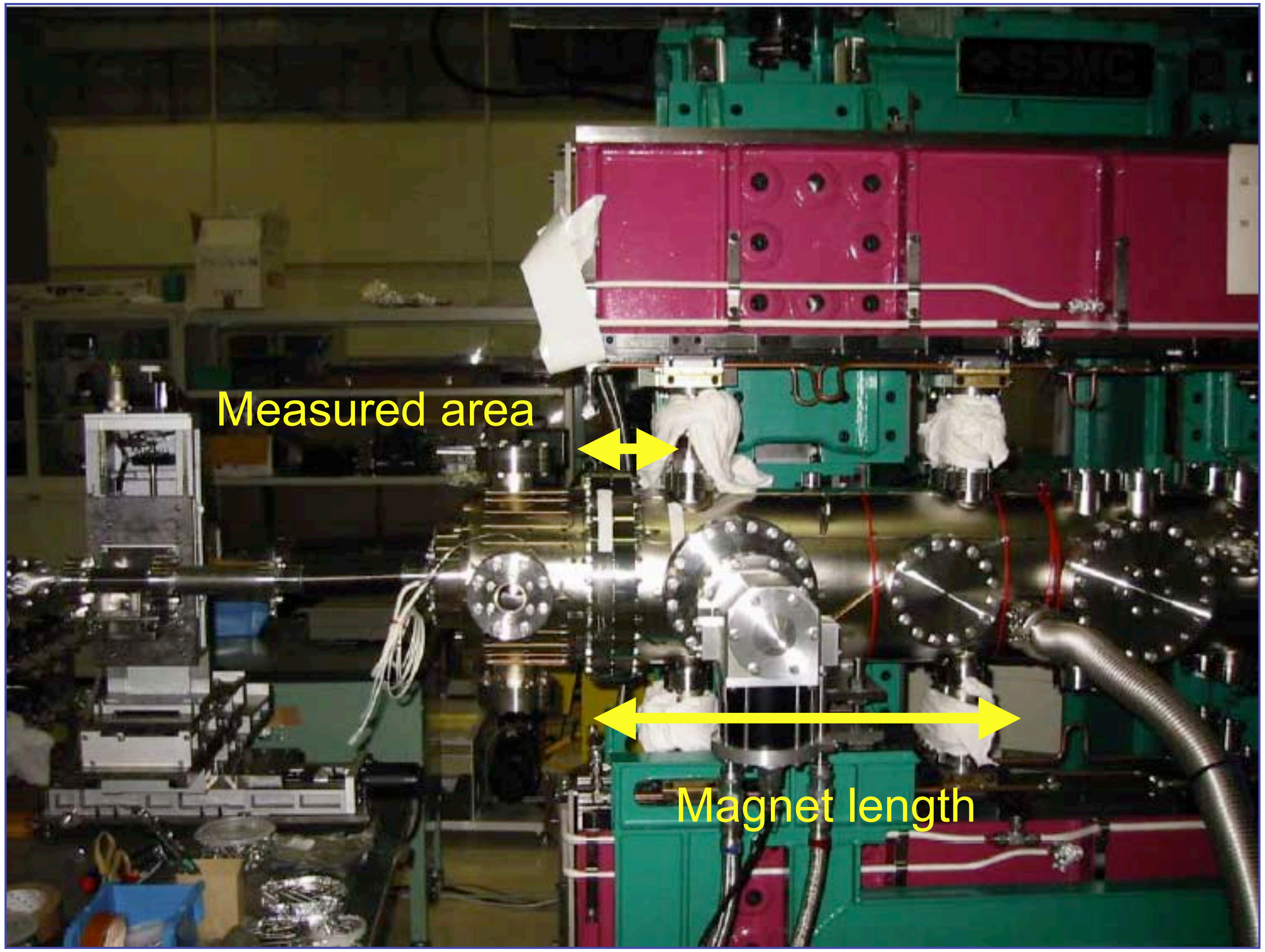


Undulator period	15 mm
Type	halbach ppm
Legnth	~ 0.6 m
Material	NdFeB 50BH
Temperature control by heaters	



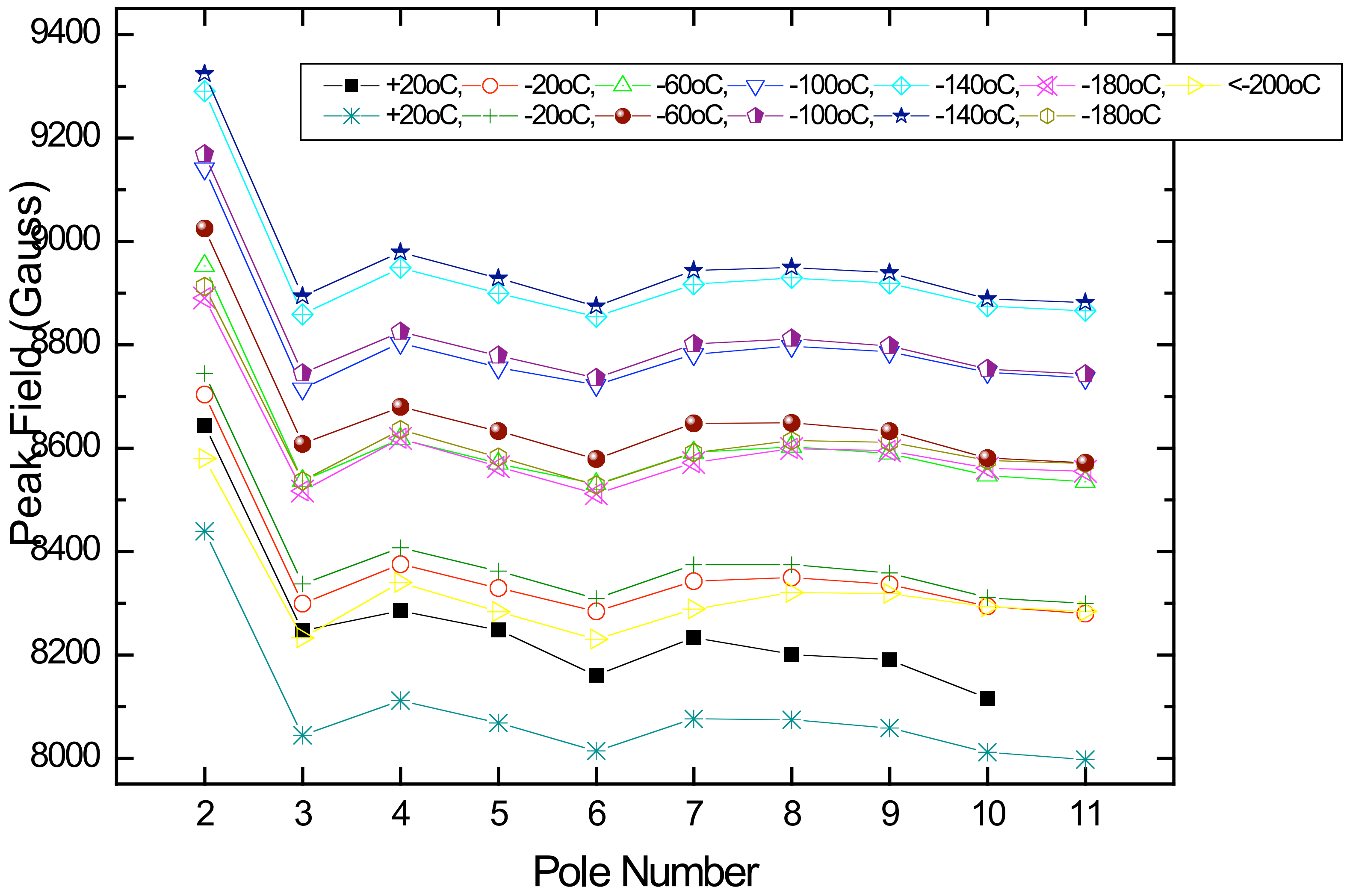
- Cryocooler installation with flexible Cu plate.
- Enforcement of thermal isolation at magnet beam supports.

Field measurement using a hall probe



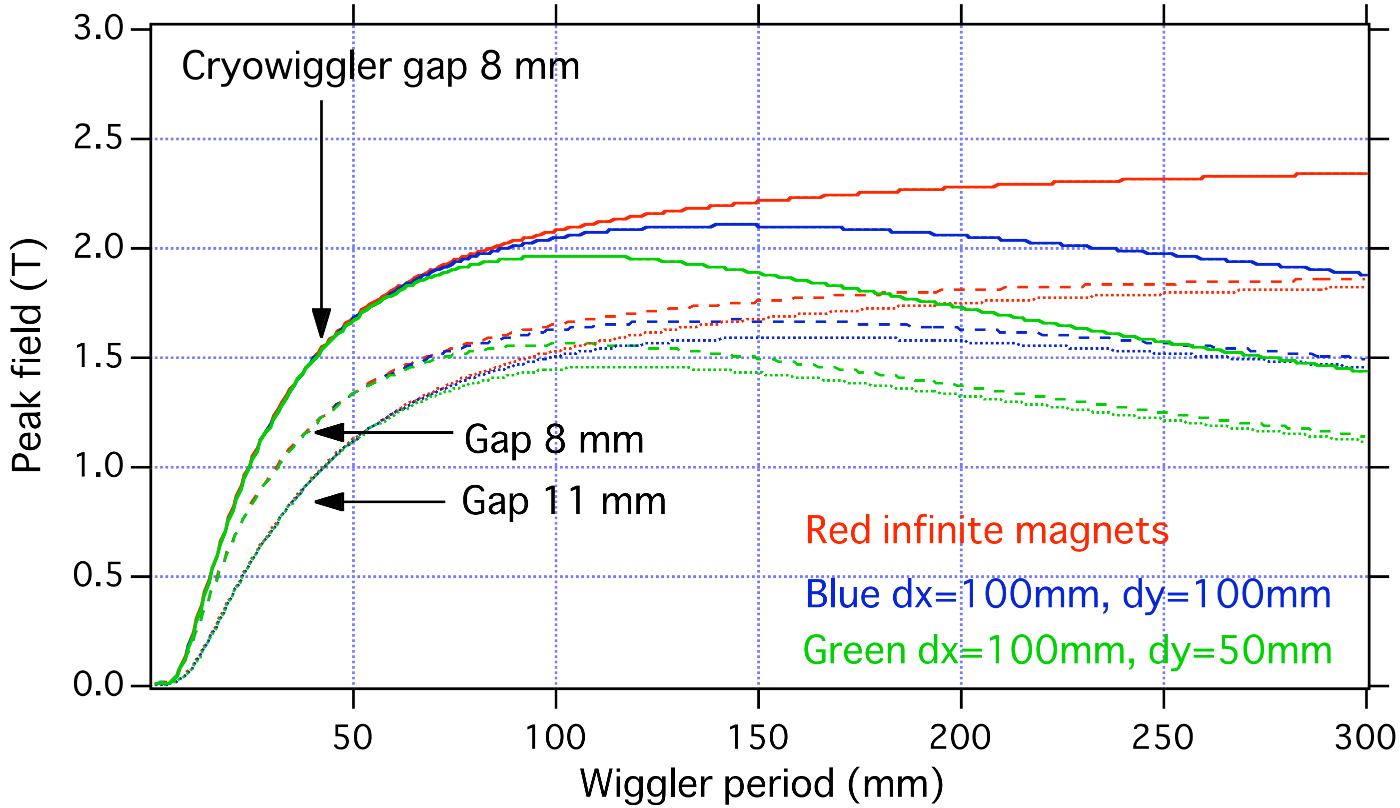
Field measurement using a hall probe in vacuum at 5 mm gap.

Preliminary results of field measurement



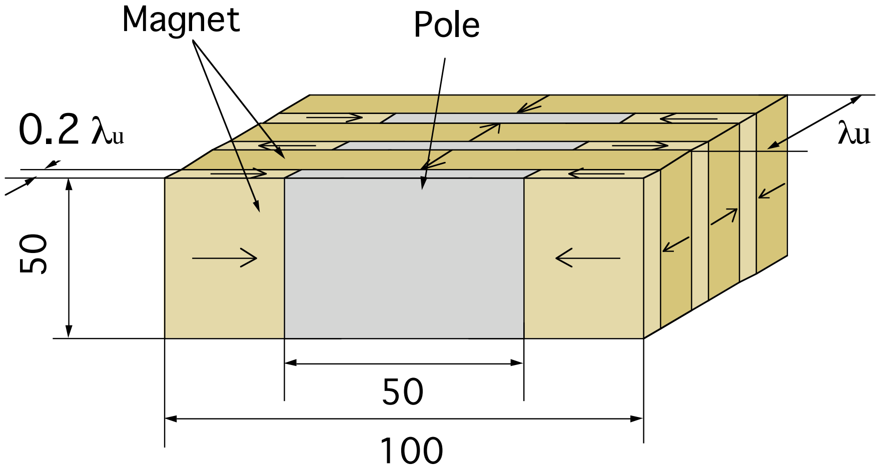
Expected performance of ppm cryowiggler

- Magnet assumption
  For room temperature device, B_r = 1.25 T, $_iH_c$ ~ 2000 kA/m,
  For cryogenic device, B_r = 1.58 T, $_iH_c$ ~ 3000 kA/m@150 K,



Peak fields of **pure magnet type wigglers**, cryogenic wiggler (solid lines), in-vacuum wiggler (dashed lines) and out of vacuum wiggler (dotted lines).

Hybrid cryowiggler structure

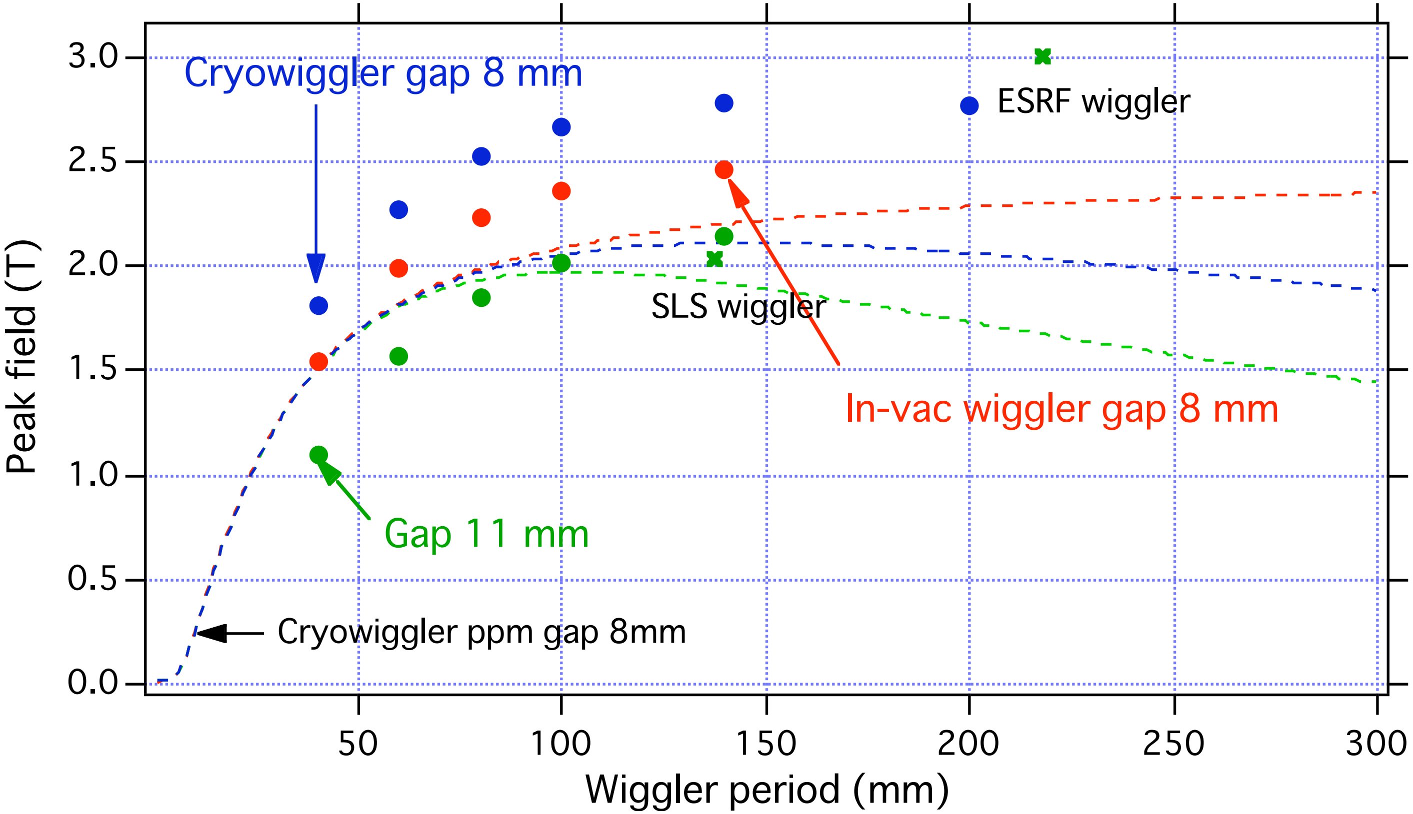


Hybrid structure for high field wiggler.
For room temperature device, B_r = 1.25 T, ${}_iH_c$ ~ 2000 kA/m.
For cryogenic device, B_r = 1.58 T, ${}_iH_c$ ~ 3000 kA/m@150 K.

Hybrid structure is not optimized for wiggler period.

SLS wiggler λ_u = 138 mm
B ~ 2.0 T @ 11 mm gap

Expected performance of hybrid cryowiggler

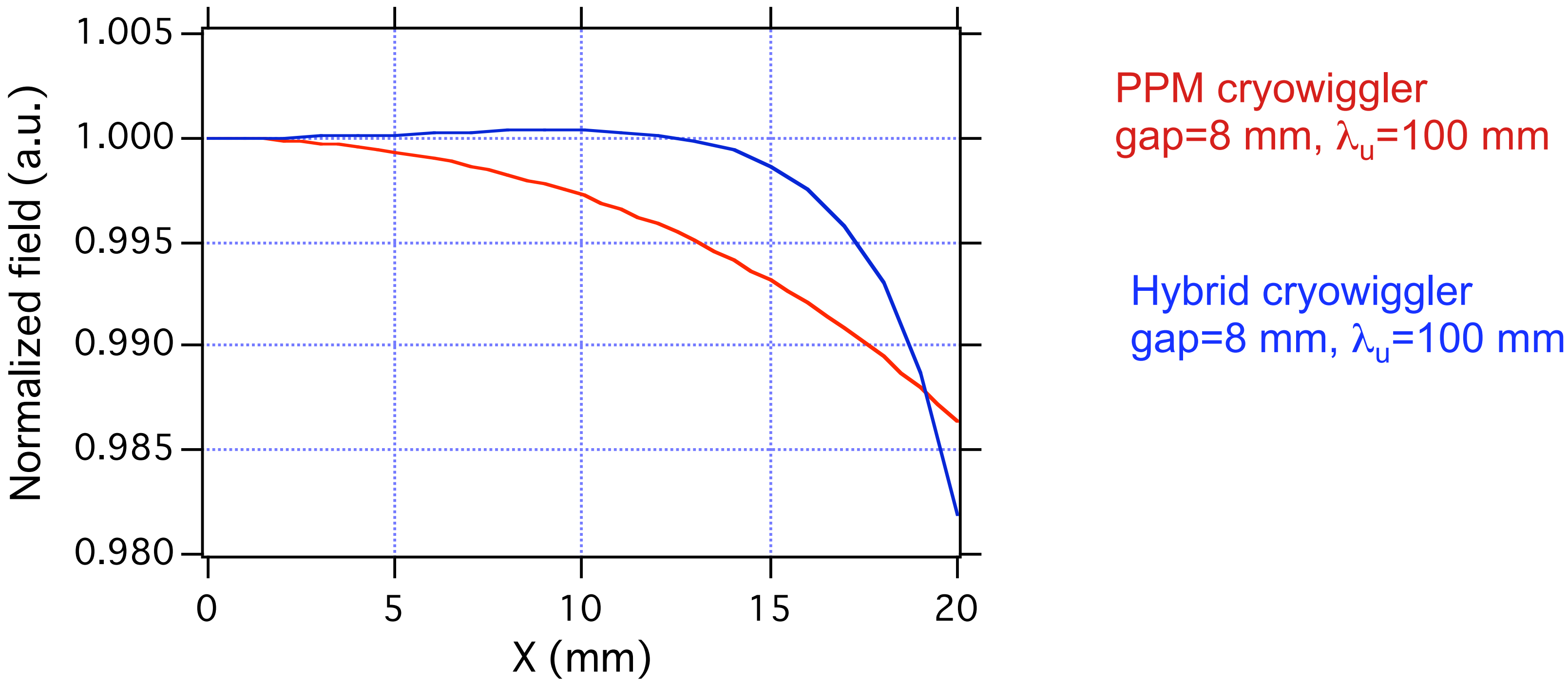


Peak fields of **hybrid type wigglers**, cryogenic wiggler (blue circles), in-vacuum wiggler (red circles) and out of vacuum wiggler (green circles), dashed lines are ppm cryowiggler for comparison.

Hybrid structure is not optimized for wiggler period.

ESRF wiggler is calculated and SLS wiggler is measured values.

Field uniformity

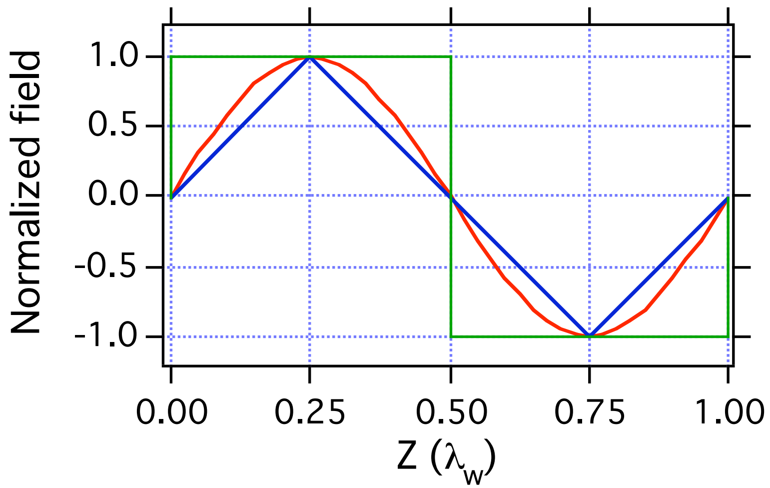


Field uniformity can be improved by increasing the magnet size.
100 mm width of the ppm magnets and 50 mm width of hybrid poles assumed.

To increase radiation power

- Wiggler radiation power is proportional to $\int_0^{\lambda_w} B^2(z)dz$.

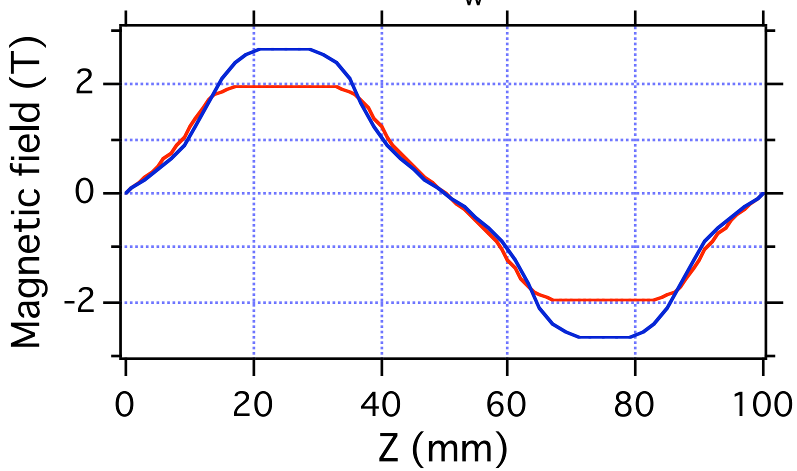
To increase the dumping effect, large B^2 average is required.



Sinusoidal $\int_0^{\lambda_w} B^2(z)dz = \frac{\lambda_w}{2} B_{peak}^2$

Square $\lambda_w B_{peak}^2$

Triangle $\frac{\lambda_w}{3} B_{peak}^2$



PPM cryowiggler gap=8 mm, λ_u=100 mm

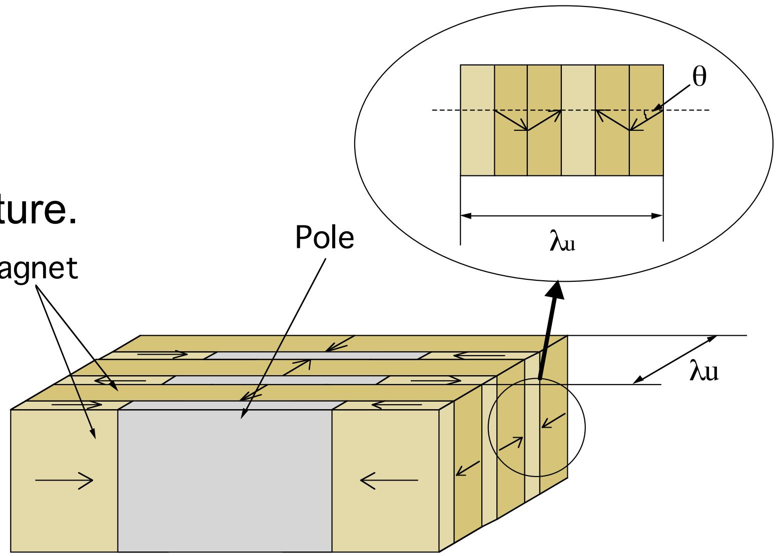
$0.57\lambda_w B_{peak}^2$

Hybrid cryowiggler gap=8 mm, λ_u=100 mm

$0.45\lambda_w B_{peak}^2$

For higher field

• Use of tilted magnetization in hybrid structure.

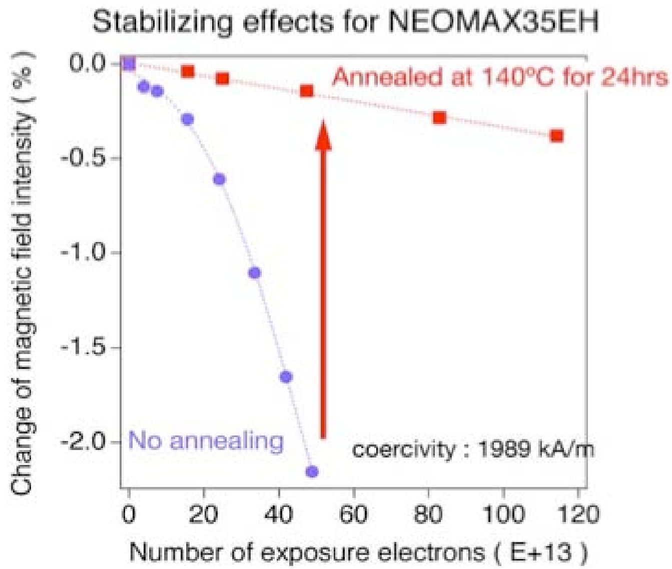


• In the cryowiggler, the field reduction due to the pole saturation can be avoided by using PrFeB (B_r ~ 1.5 T @ 77K) magnets and Dy poles (B_s ~ 3.2 T @ 77K) instead of permendure poles (B_s ~ 2.4 T).

Some concerns

• High B_r magnet may be demagnetized during the construction at room temperature.

• Better to pre-bake the magnets in order to make them more radiation resistant.



Beam energy 2 GeV

Summary

- Proof of principle experiment is carried out on the cryogenic insertion device. There still remains some engineering problems, but the expected field enhancement is confirmed.
- Cryogenic and in-vacuum devices show their advantages at small wiggler periods.
- For example,
  - 100 mm period
    out of vacuum ~ 2.0 T, in-vacuum ~ 2.3 T, cryogenic ~2.6 T,
  - 40 mm peirod
    out of vacuum ~ 1.1 T, in-vacuum ~ 1.5 T, cryogenic ~ 1.8 T,

  (assuming 11 mm gap for out of vacuum and 8 mm for in-vacuum and cryogenic devices).