Magnet Development for SPring-8 Upgrade

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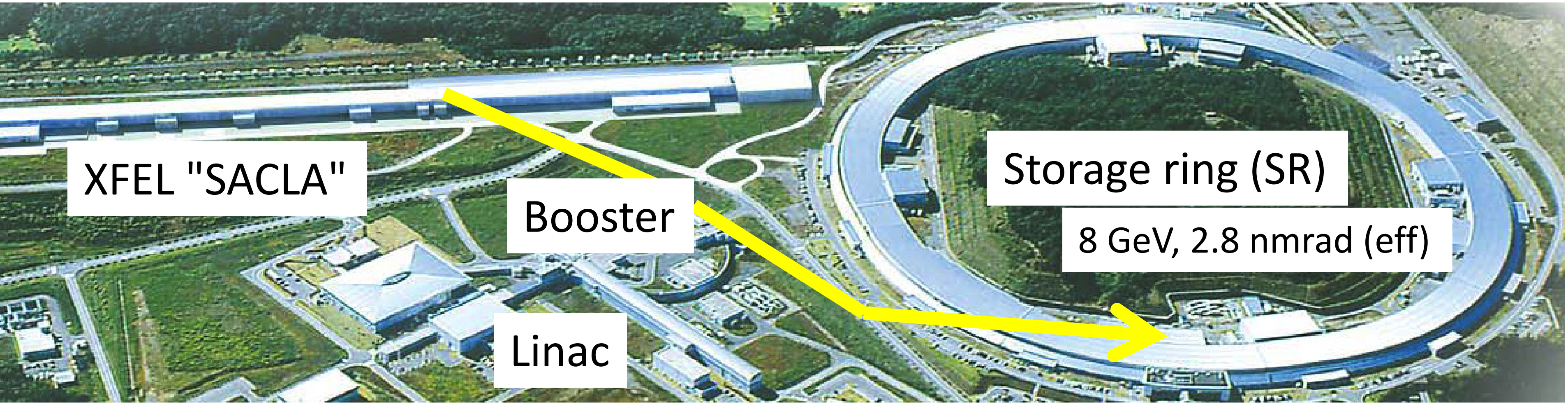
1) Brief overview of SPring-8-II project
2) Magnet developments:
    - permanent dipole magnet
    - multipole electromagnets
    - precise alignment
3) Summary

SPring-8 major upgrade, "SPring-8-II"



CDR, September 2014

SPring-8-II

Conceptual Design Report

RIKEN SPring-8 Center

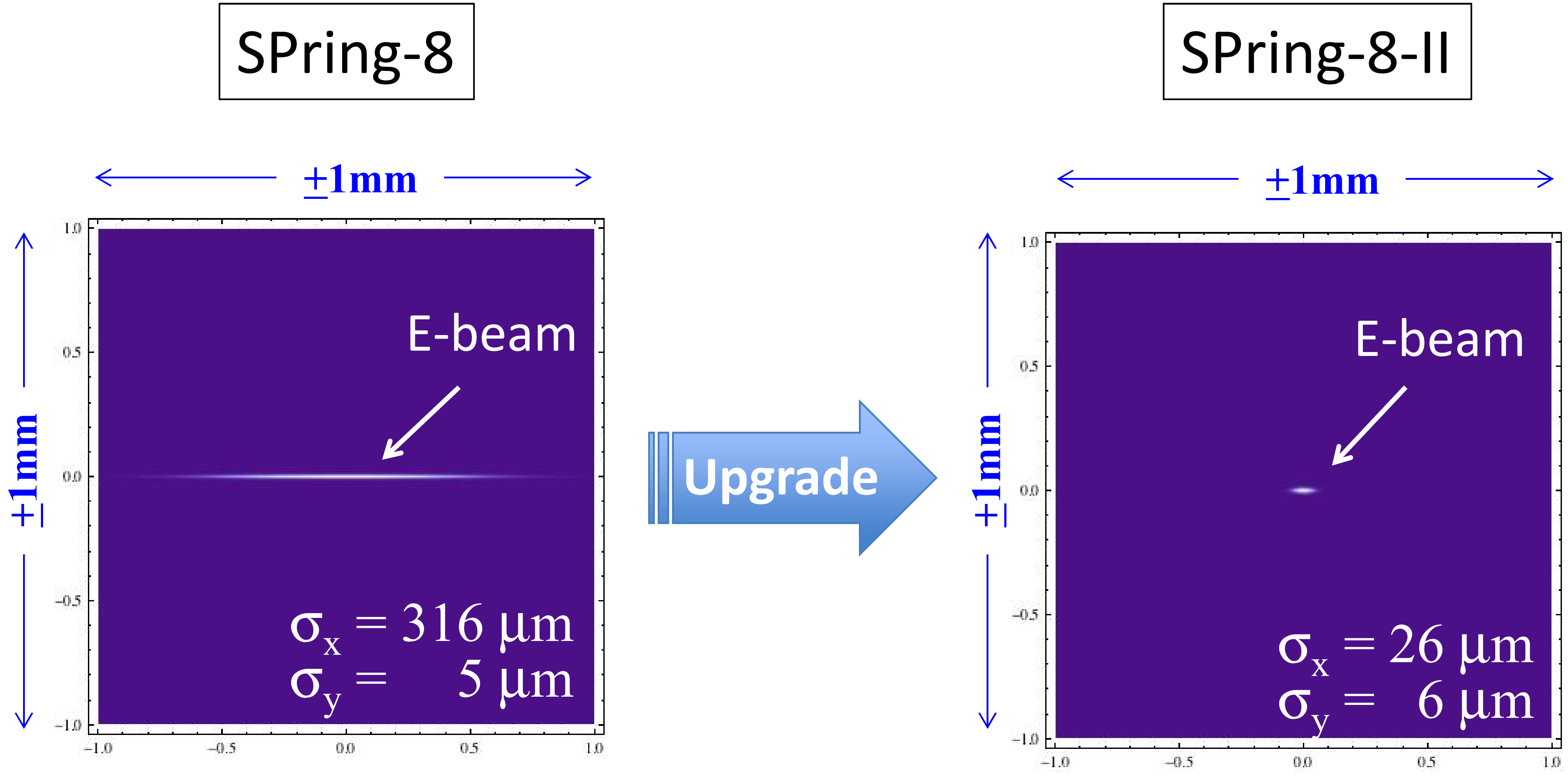
September, 2014

http://rsc.riken.jp

Project (not yet funded)

1) ~100 pmrad emittance for 20+ times brighter light
2) Advance in undulator technology
3) Less power consumption
   -> Dipoles to be replaced with permanent mags
4) Take advantage of SACLA linac
5) One year shutdown in early 2020's

Reduction of e-beam size@ID center



SPring-8: $\sigma_x = 316\ \mu m$, $\sigma_y = 5\ \mu m$

SPring-8-II: $\sigma_x = 26\ \mu m$, $\sigma_y = 6\ \mu m$

*ID = Insertion devices such as undulators

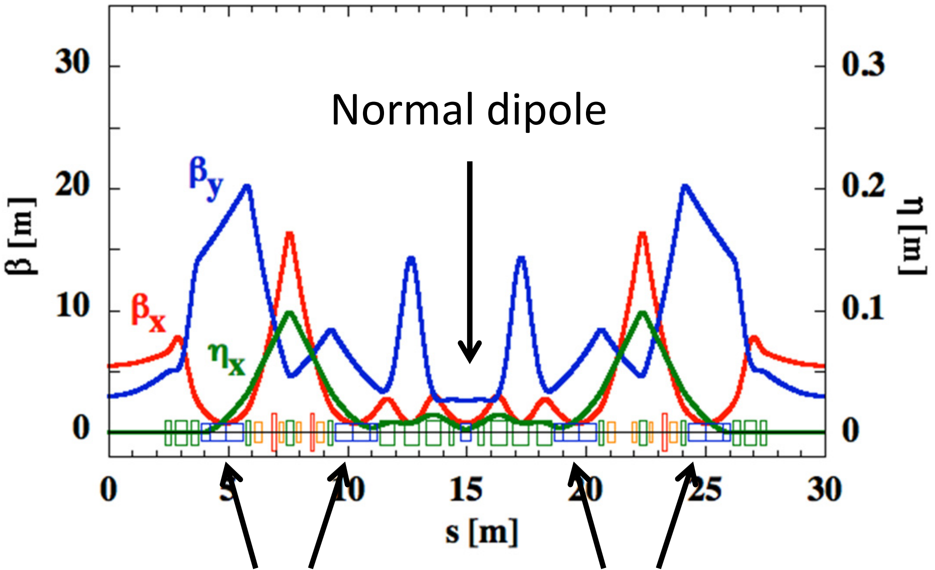
How to approach a smaller emittance ring

$$\varepsilon_{natural} = C_q \frac{\gamma^2 \langle H/\rho^3 \rangle}{J_x \langle 1/\rho^2 \rangle} \propto \frac{\gamma^2}{N_{bend}^3}$$

γ : Normalized electron energy

N_{bend}: Number of bending magnets

5 bend achromat lattice (interim)



LGB: Longitudinal gradient bend

Dispersion: Small -> Bend: Large
Dispersion: Large -> Bend: Small

	SPring-8-II	SPring-8
Energy (GeV)	6	8
# bends/cell	5	2
Stored current (mA)	100	100
Circumference (m)	1435.45	1435.95
Effective emittance (nmrad)	0.14 w/o ID	2.8 w/o ID
Energy spread (%)	0.093	0.109
Betatron tune	(109.135, 42.340)	(41.14, 19.35)
Straight section (m)	4.6	6.6
Dispersion @ ID (m)	0	0.146

Based on interim lattice. May change later.

Hardware challenges

> Permanent dipole magnets

> Compact, high gradient electromagnets

> High precision magnet alignment (~ 25 micron)

Today's talk

> Small aperture vacuum components → THPMY001

> Highly stable, precise e-beam/photon monitors → MOPMB028

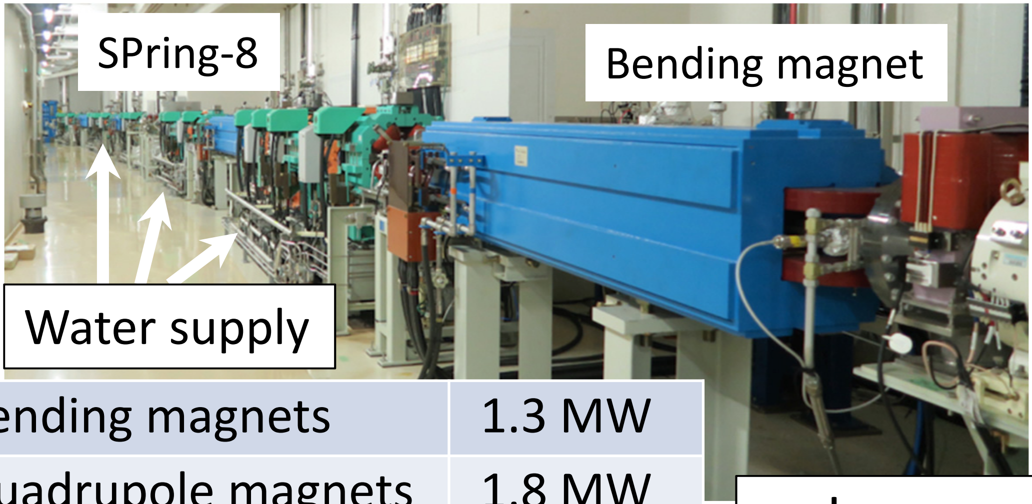
and more... (RF: MOPMW009, ID: THPOW040)

Magnet	Max. field	#/ring		cf. SPring-8
Normal bend (NB)	0.95 T	44	220	88
Longitudinal gradient bend (LGB)	0.86 T	176		
Quadrupole	56 T/m	924		470
Sextupole	2,700 T/m^2	352		288

Based on interim lattice. May change later.

(1) Permanent dipole magnet

Pros and cons of permanent magnet



Bending magnets	1.3 MW
Quadrupole magnets	1.8 MW
Sextupole magnets	0.5 MW
RF	5.0 MW

incl. power supply efficiencies

Lower energy consumption
Less power/water supply failure
Less noise

There are reasons why permanent magnet has NOT been chosen;

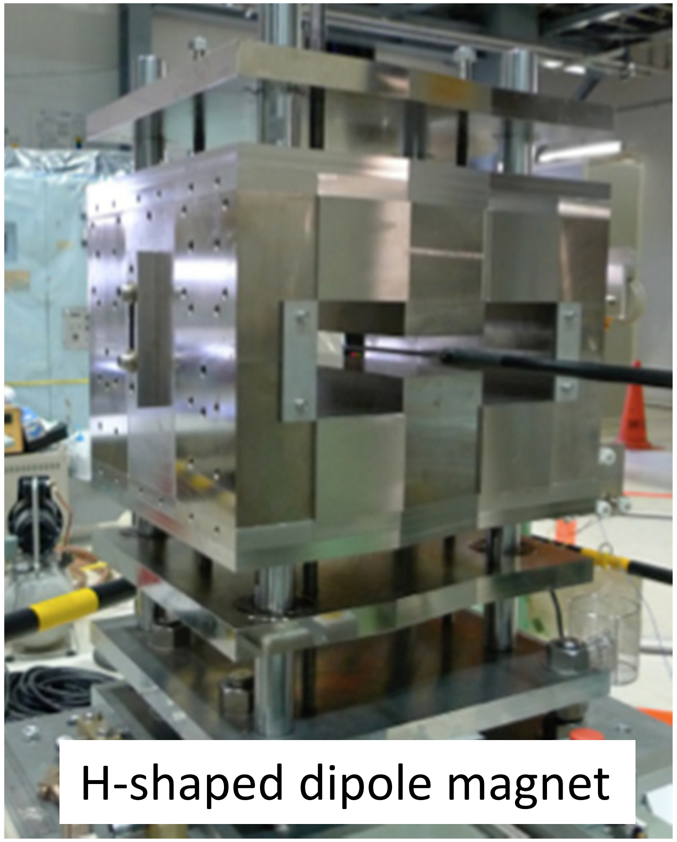
1. Magnetic field adjustability
2. Temperature dependence
3. Demagnetization
4. Initial cost (manufacturing etc.)

and more (field quality, edge field, longitudinal gradient field, etc.)

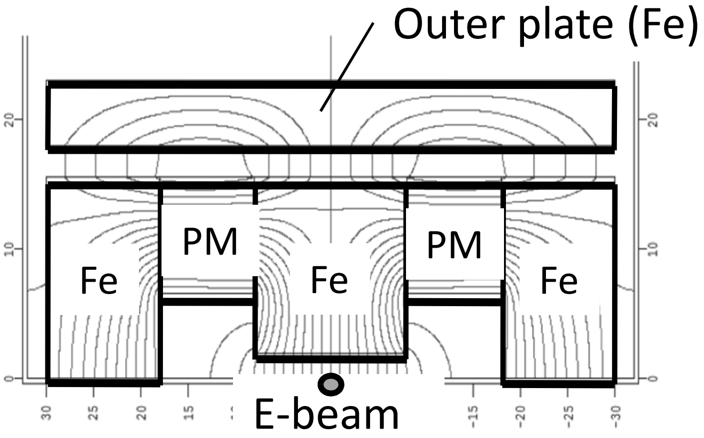
cf. J. Chavanne,Talk at IPAC2014

1. Magnetic field adjustability

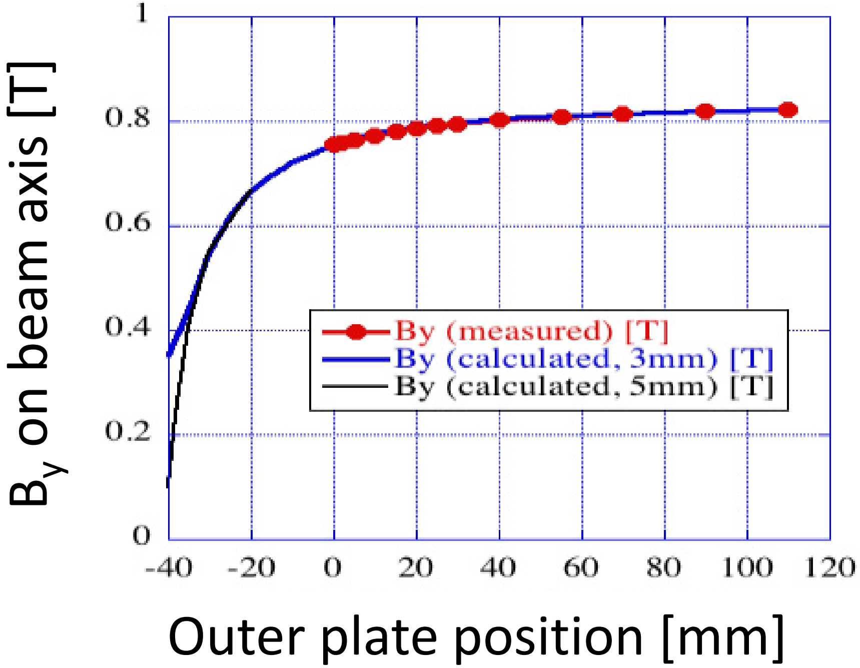
Good for
- low cost production
- compensation for demagnetization



H-shaped dipole magnet

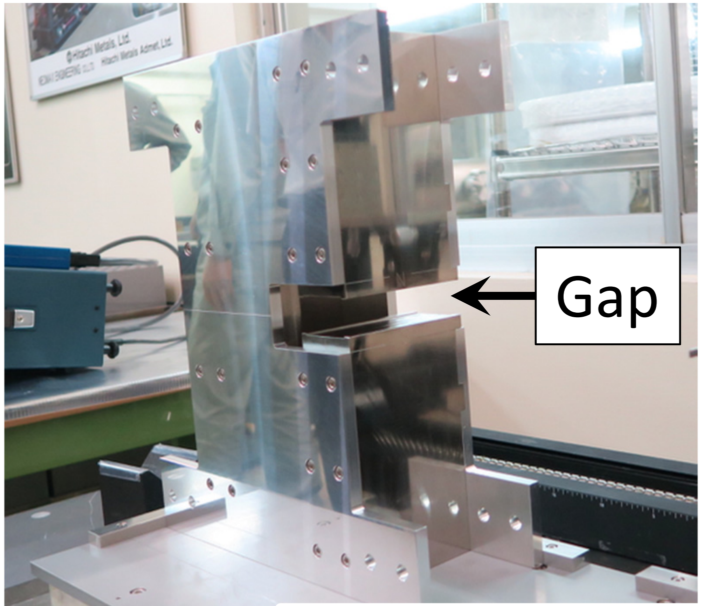


B-field on beam can be adjusted by moving outer plates.

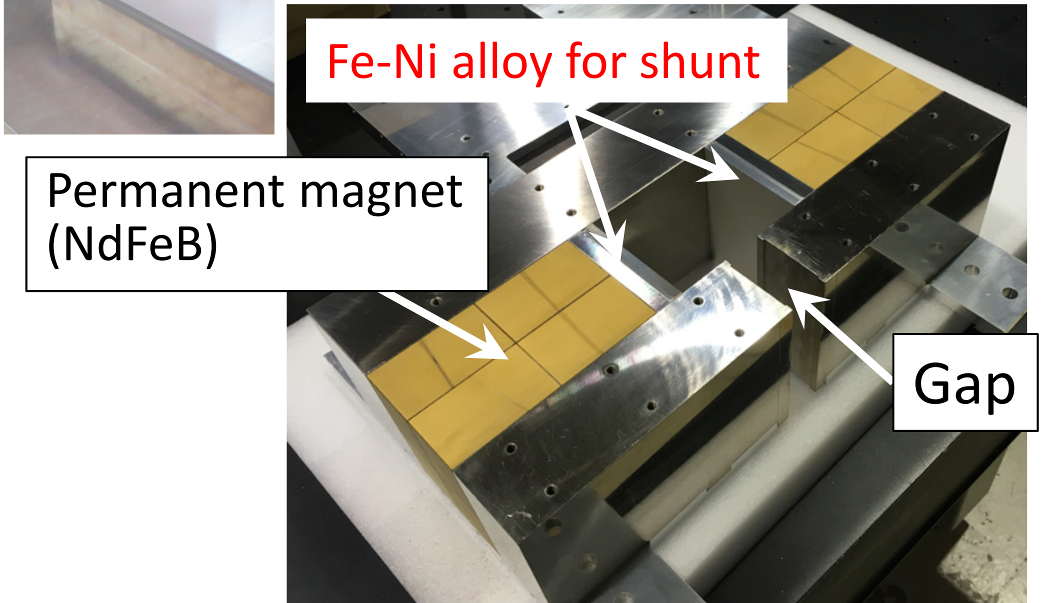


2. Temperature dependence

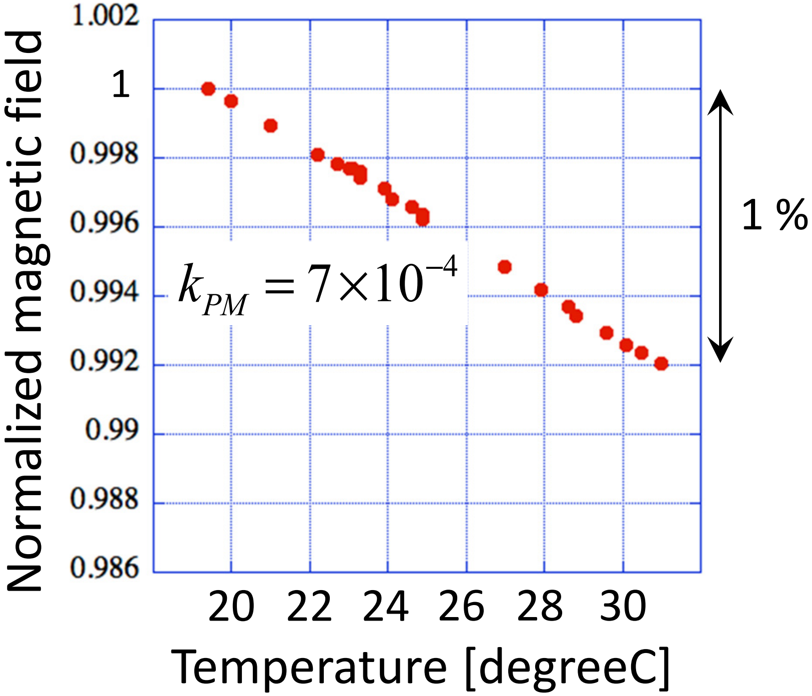
C-shaped dipole magnet



Hitachi
NEOMAX



$$\Phi_{gap} = \Phi_{PM}$$
$$= \left(1 + k_{PM}\Delta T\right)\Phi^{0}_{PM}$$



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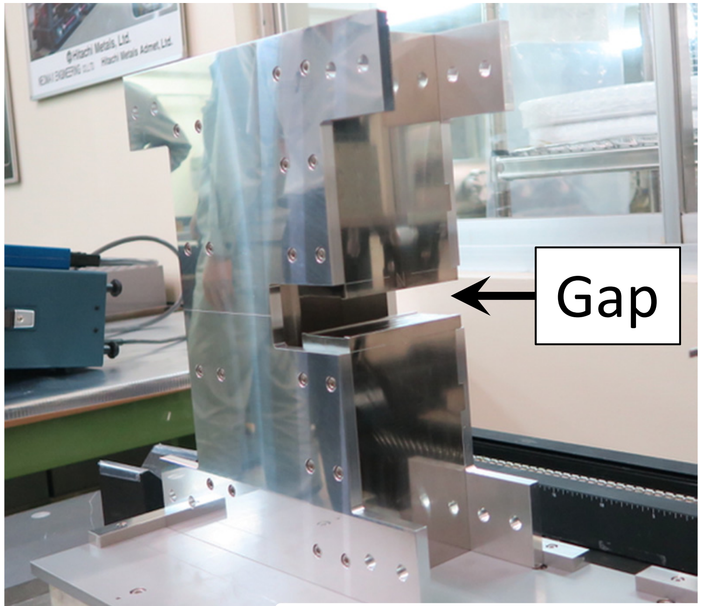

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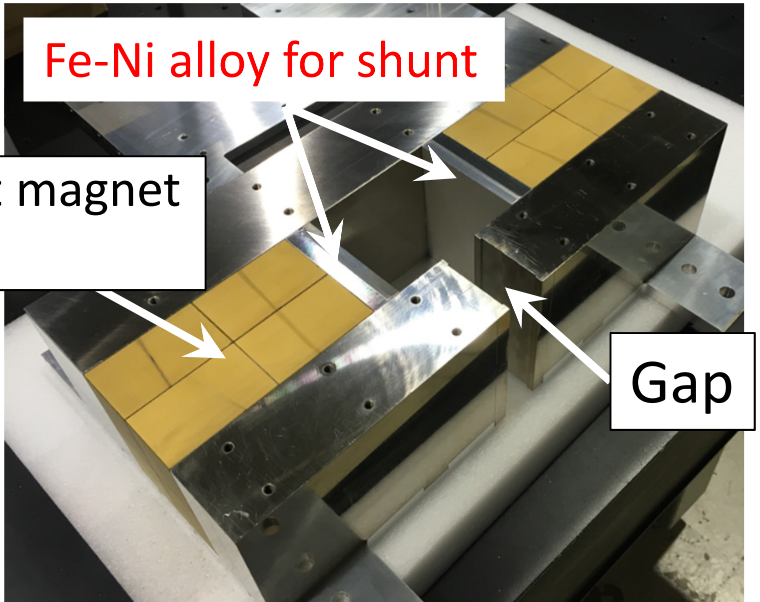
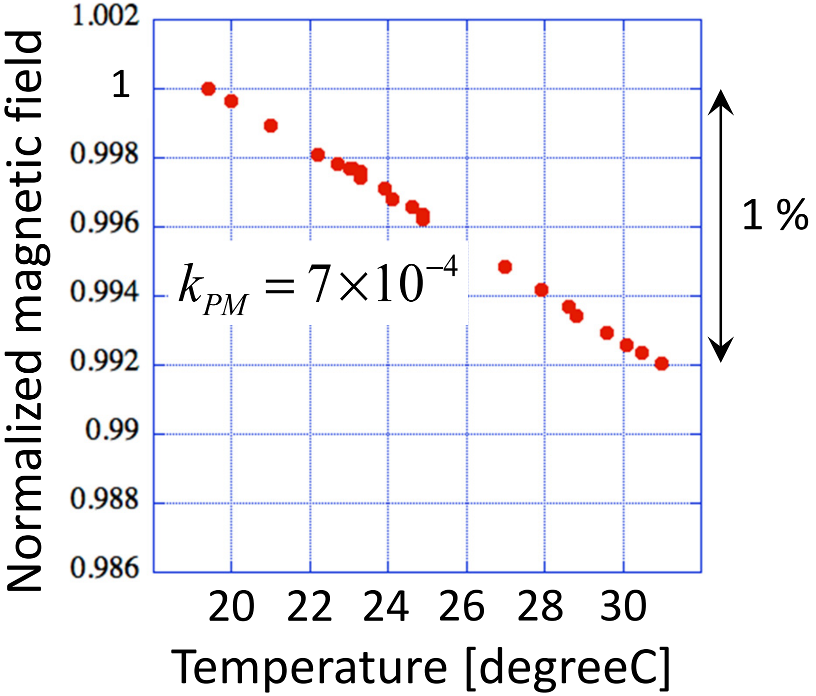


$$\Phi_{gap} = \Phi_{PM} - \Phi_{shunt}$$

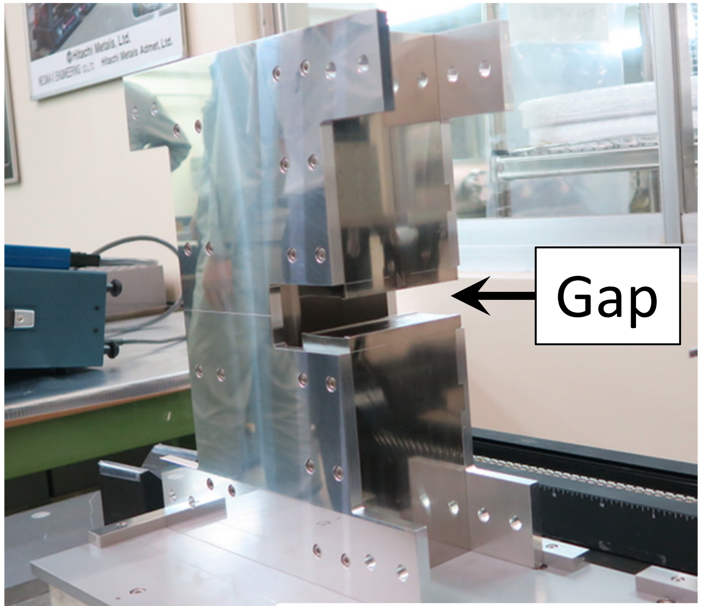
$$= \left(1 + \underbrace{k_{PM}\Delta T}\right)\Phi^{0}_{PM} - \left(1 + \underbrace{k_{shunt}\Delta T}\right)\Phi^{0}_{shunt}$$

Temperature dependence can be compensated.

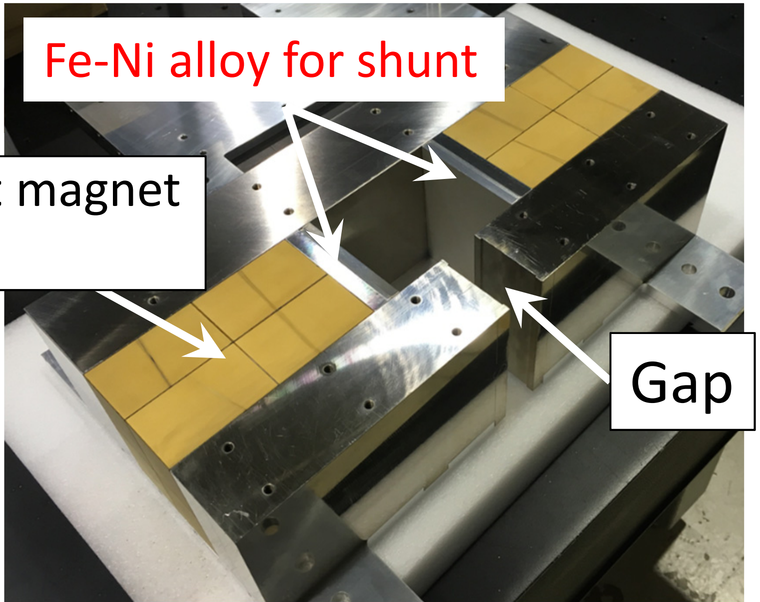


2. Temperature dependence

C-shaped dipole magnet


Gap

Hitachi
NEOMAX


Fe-Ni alloy for shunt

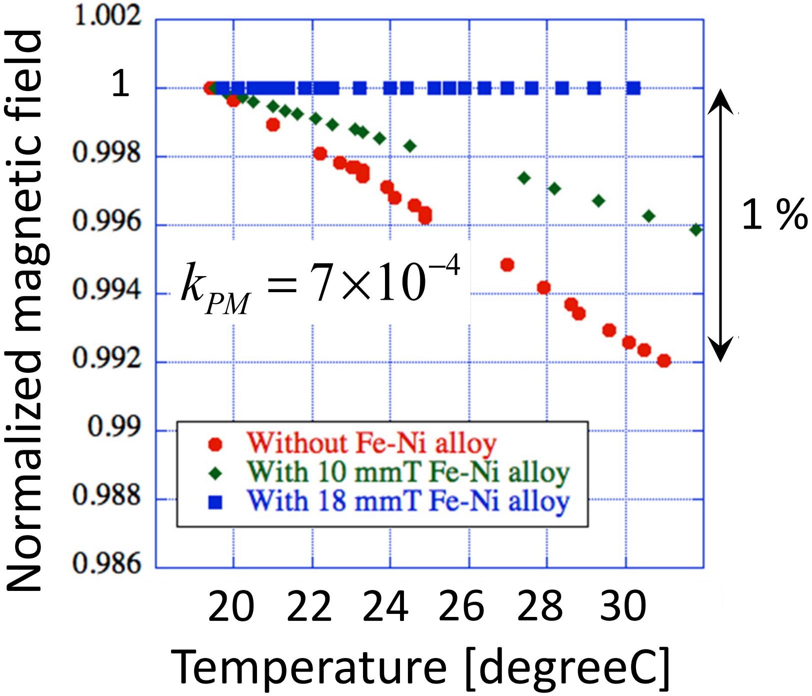
Permanent magnet
(NdFeB)

Gap

$$\Phi_{gap} = \Phi_{PM} - \Phi_{shunt}$$

$$= \underbrace{(1 + k_{PM}\Delta T)}\Phi^0_{PM} - \underbrace{(1 + k_{shunt}\Delta T)}\Phi^0_{shunt}$$

Temperature dependence can be compensated.



3. Demagnetization due to radiation

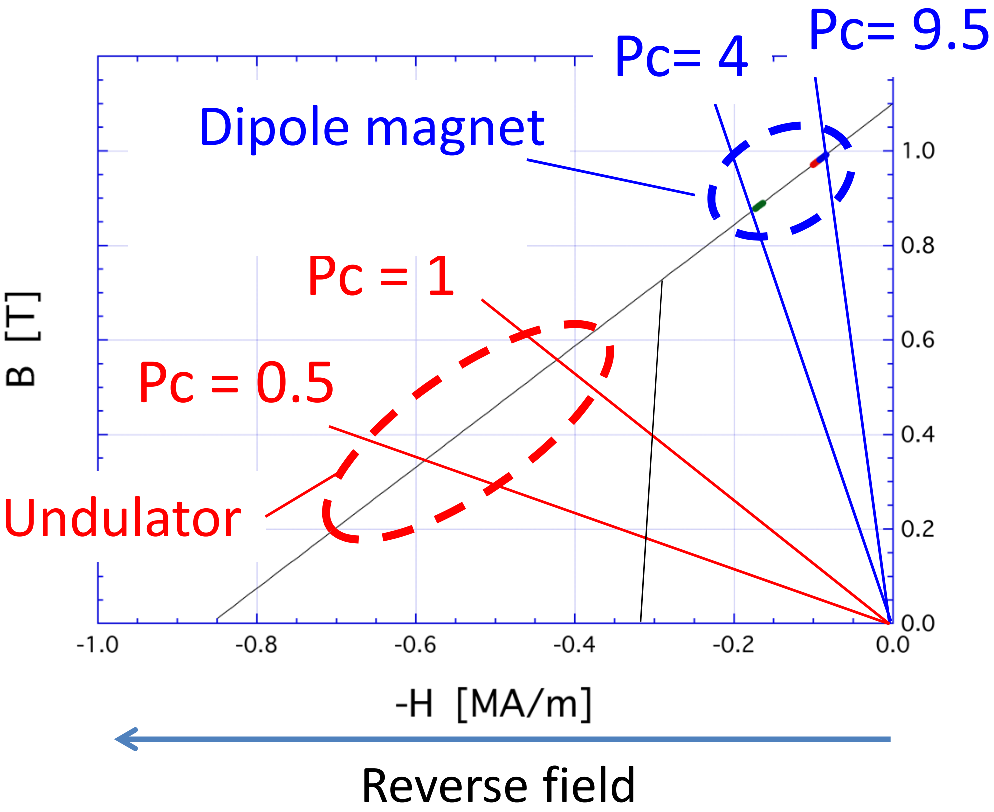
Demagnetization of undulators have been observed, but...

Permeance coefficient:

$$P_c = -\frac{1}{\mu_0}\frac{B}{H}$$

indicates how much reverse field magnet is exposed.

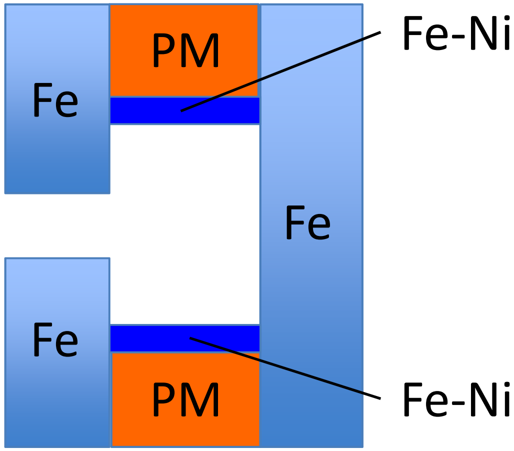
2nd quadrant of magnetization curve



Permeance coef. for dipole magnets are higher compare with undulators.
Plus, (i) Out-of-vac, (ii) Do not directly see e-beam, (iii) Sm_2Co_{17} possibility.
-> Demagnetization for dipole magnets should be less.
Radiation tests are underway.

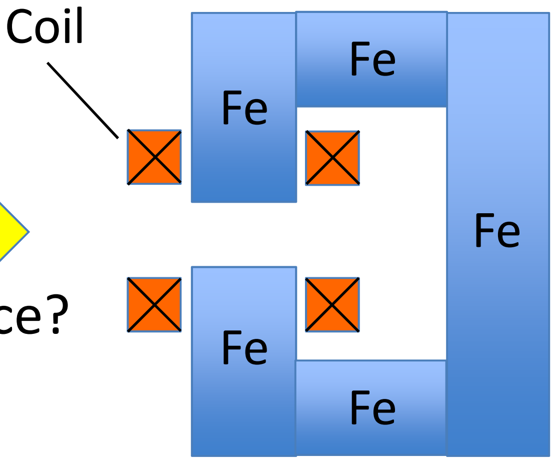
4. Initial cost (manufacturing cost)

Permanent magnet



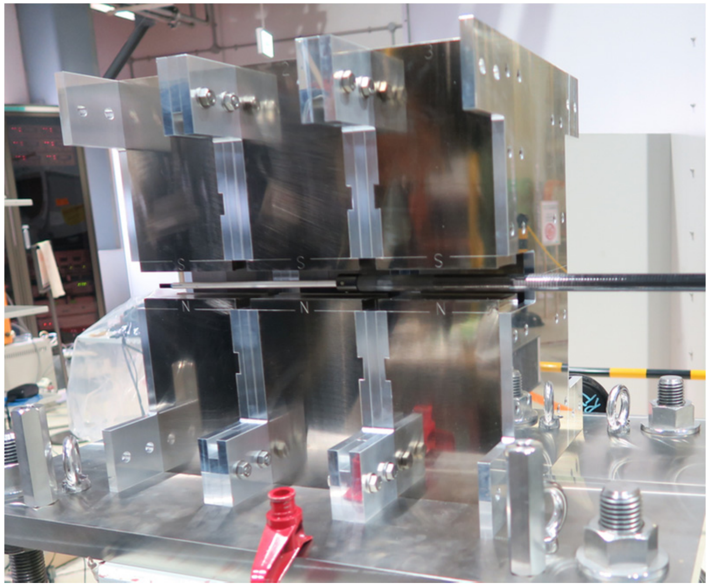
Big difference?

Electromagnet



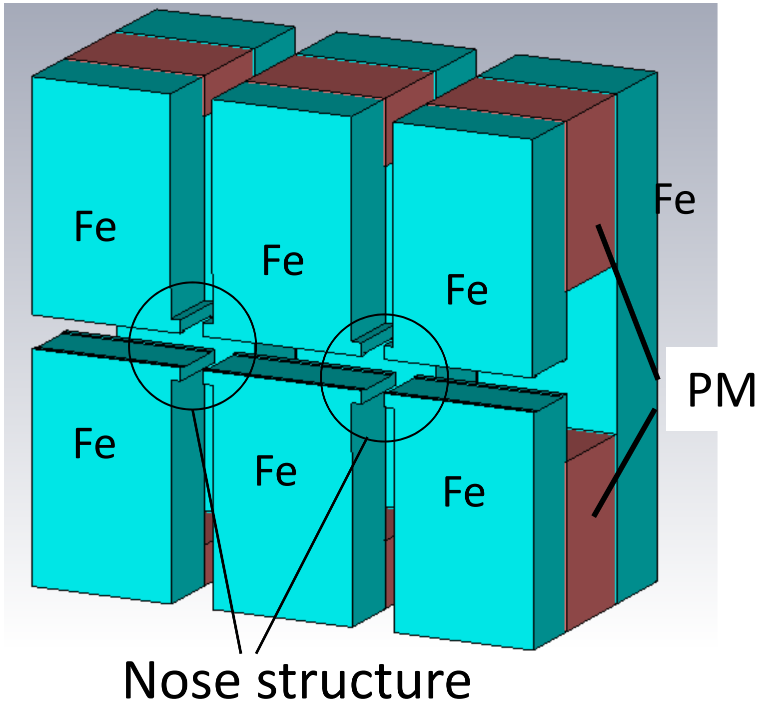
Power supply

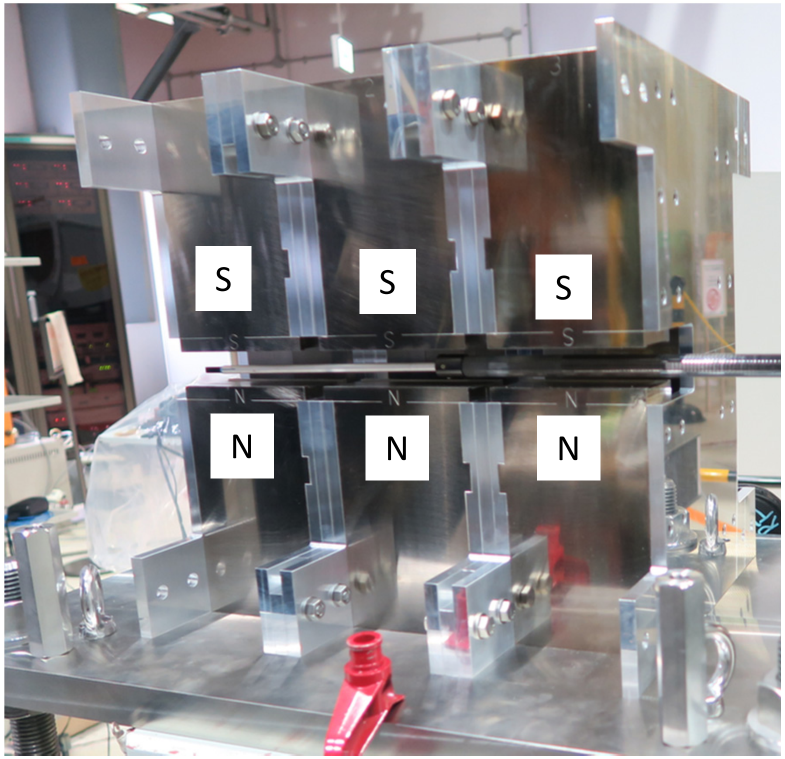
Test dipole magnet array: total length ~ 350 mm



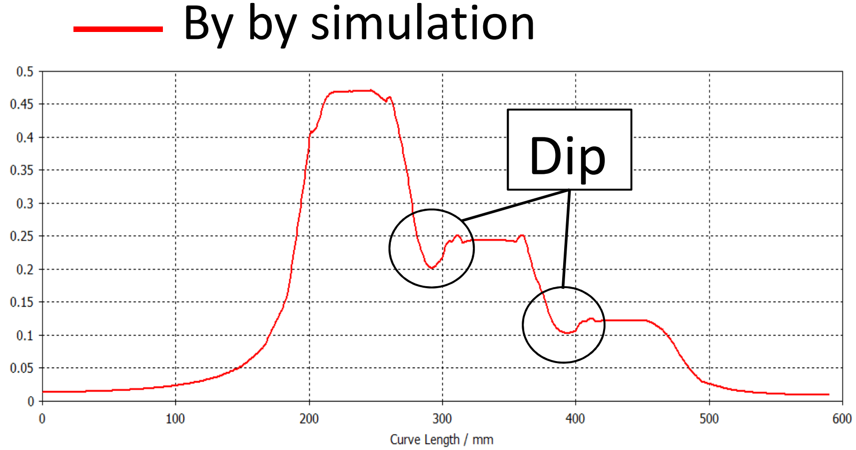
Less than $30k
incl. development cost

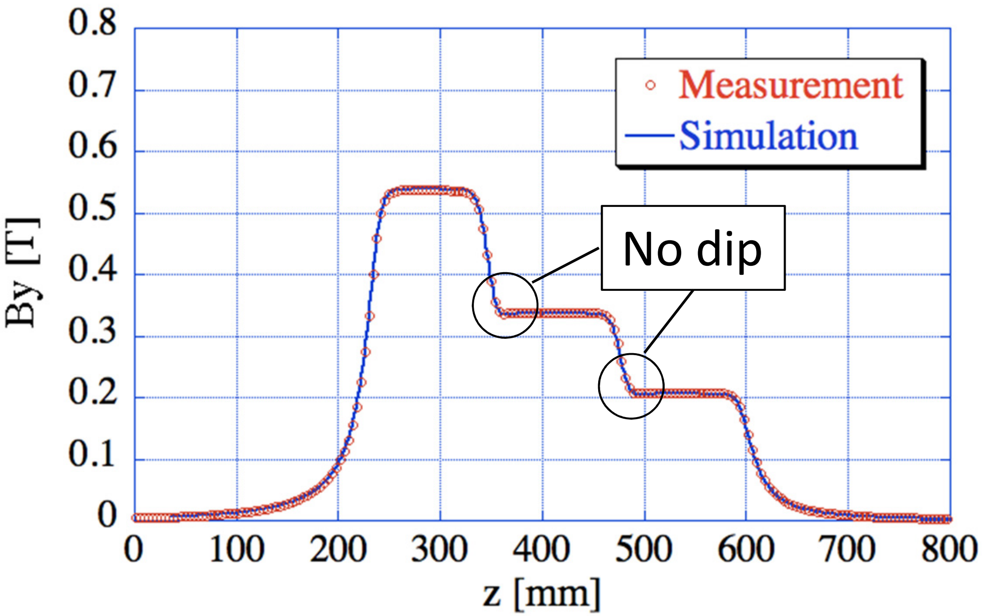
Longitudinal gradient field





Magnetic field w/o nose structure





Reasons why permanent magnet has NOT been chosen;

1. Magnetic field adjustability ✔
2. Temperature dependence ✔
3. Demagnetization ✔
4. Manufacturing cost ✔
5. Longitudinal gradient field ✔
6. Field quality ✔
7. Edge field ✔

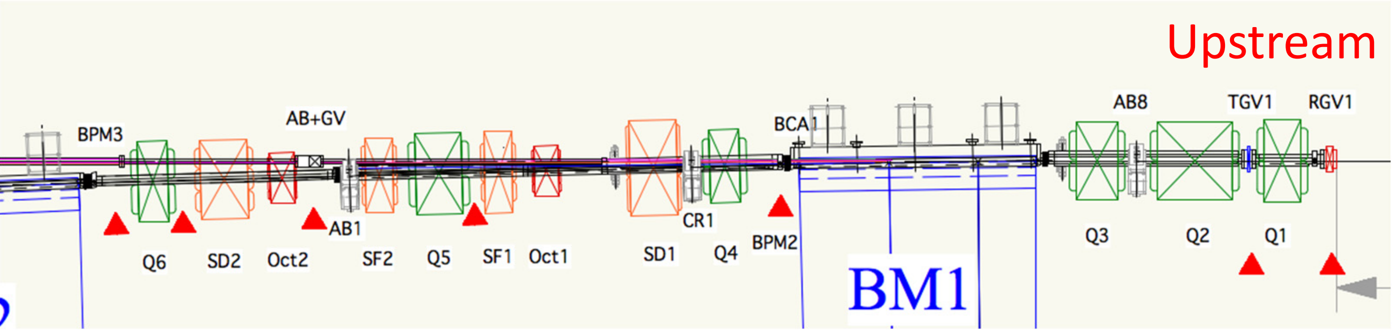
Proof-of-principle: so far so good.

Detailed design further needed for practical use.

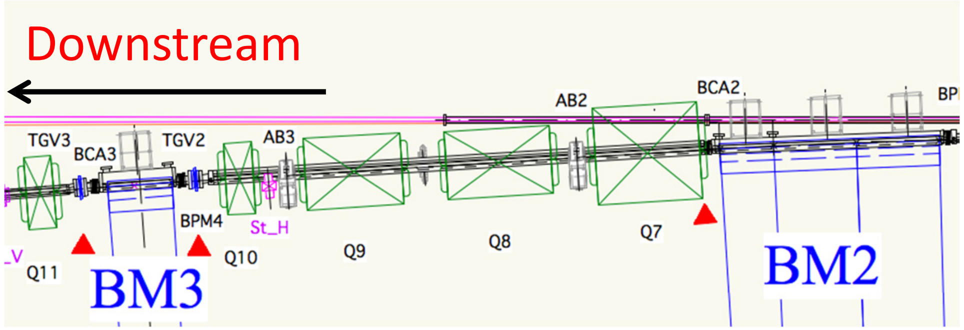
#6, 7 not presented today.

(2) Multipole electromagnets

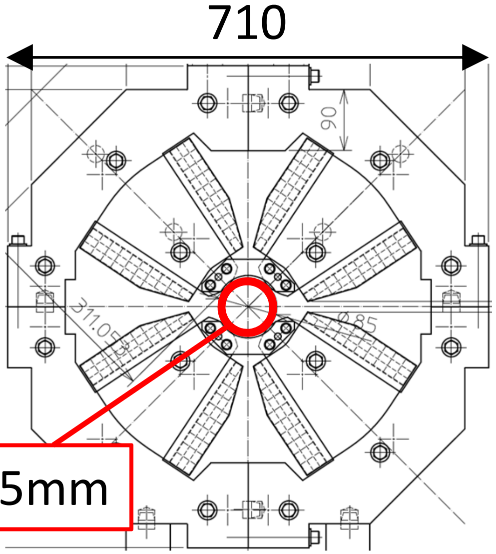
Multipole electromagnets: compact, high field



Half of a normal cell

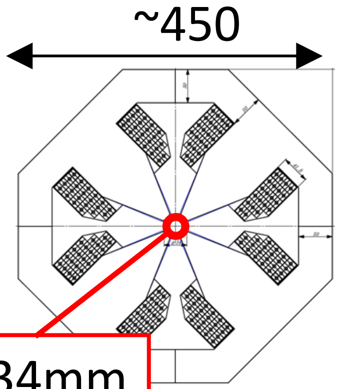


SPring-8



Bore dia. 85mm

SPring-8-II



Bore dia. 34mm

Multipole magnets for SPring-8-II

> Two times more magnets than SPring-8

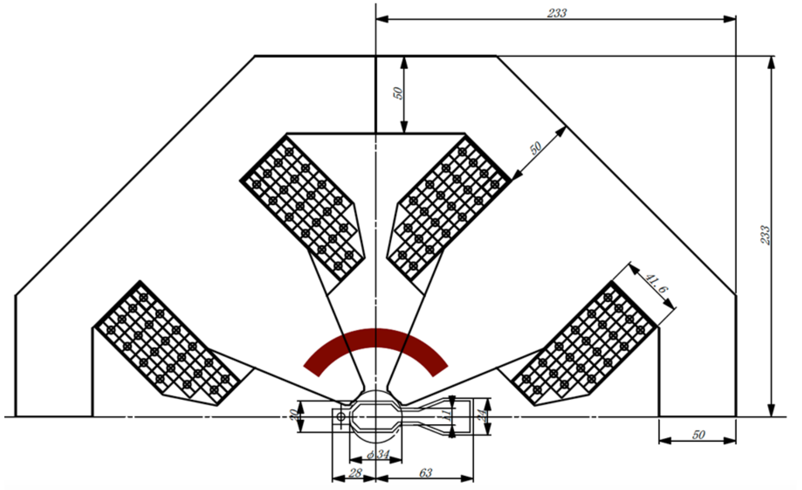
> Field gradient: <56 T/m for quadrupoles, <2,700 T/m^2 for sextupoles

> Bore diameter: 34 mm for quads, 36 mm for sexts.

> Good field region: <10^{-3}@±8 mm for quads, <10^{-3}@±6 mm for sexts.

> Sextupoles combined with steering (horiz. and vert.)

Quadrupole magnet (example)



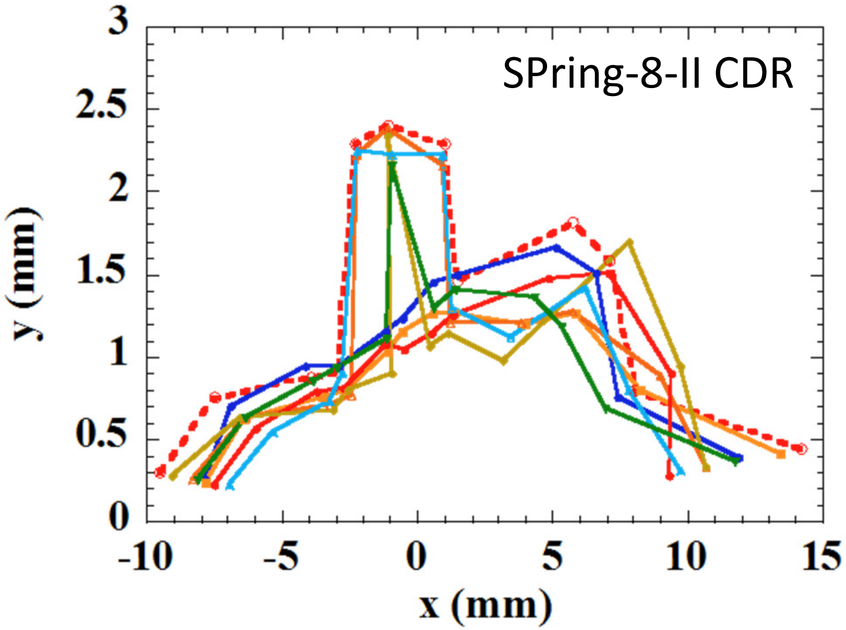
Feasible by existing technology.

Still need design works.

(3) Precise magnet alignment

Precise alignment of magnets

Dynamic aperture (example)



Dashed: DA without magnet alignment error
Solid : DA with σ=25 um Sx alignment error

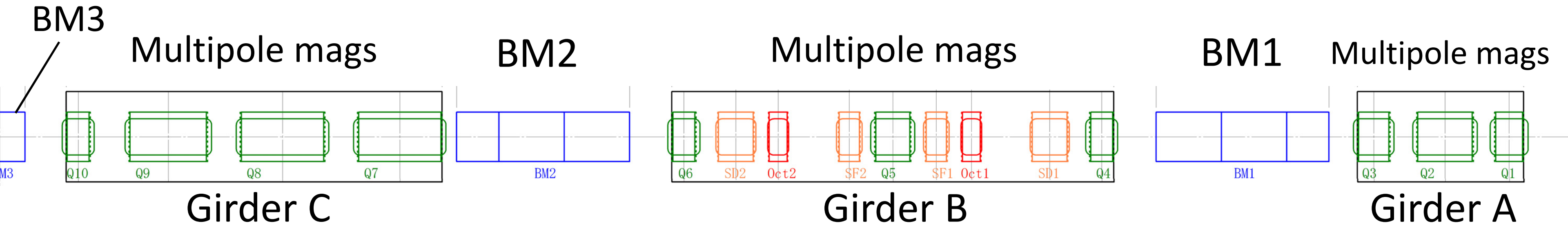
Two approaches for precise alignment

Rely on mechanical precision

Rely on precise measurement of magnetic field

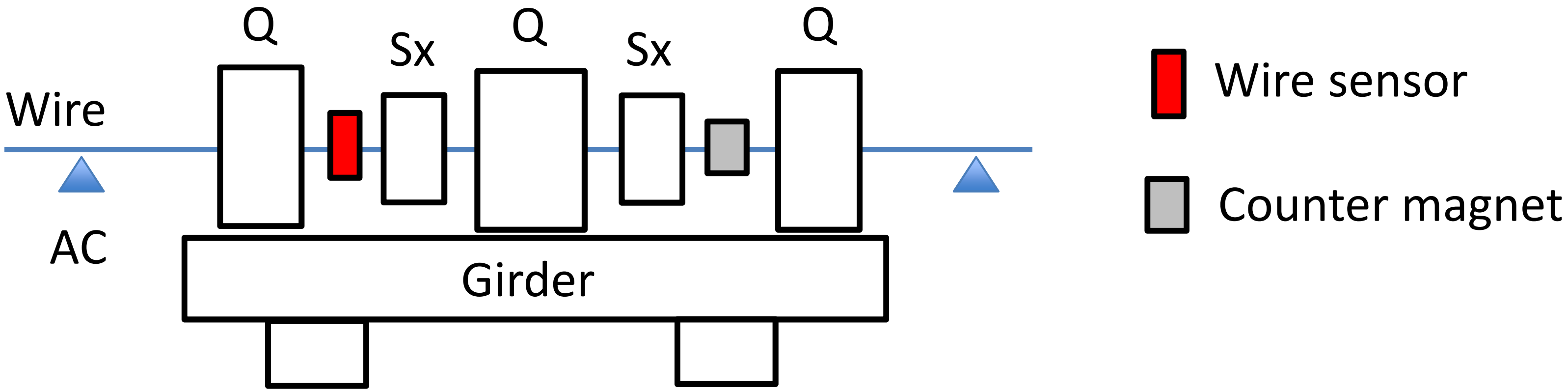
We take it.

Two step alignment procedure; 1) on a girder, 2) between girders



On-girder alignment by Vibrating Wire Method (VWM)*

*NSLS-II CDR etc.



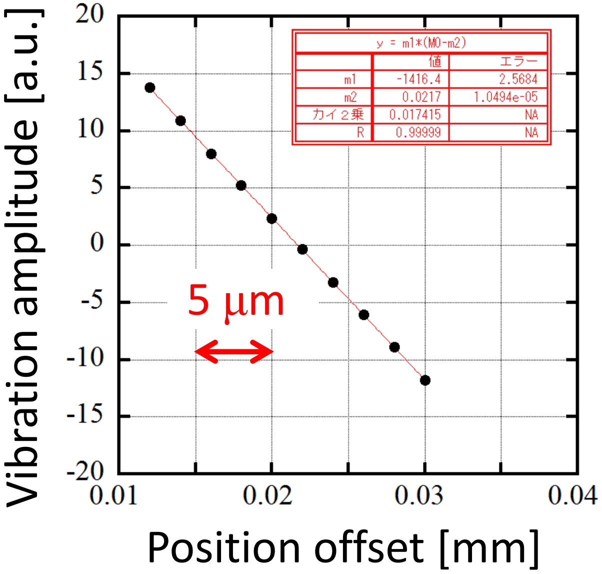
Magnet center: no vibration
Off-center : vibration

<u>Advantage over conventional schemes</u>

Magnets can be aligned while magnet center directly monitored.

Vibrating wire method for on-girder alignment

Quadrupole magnet

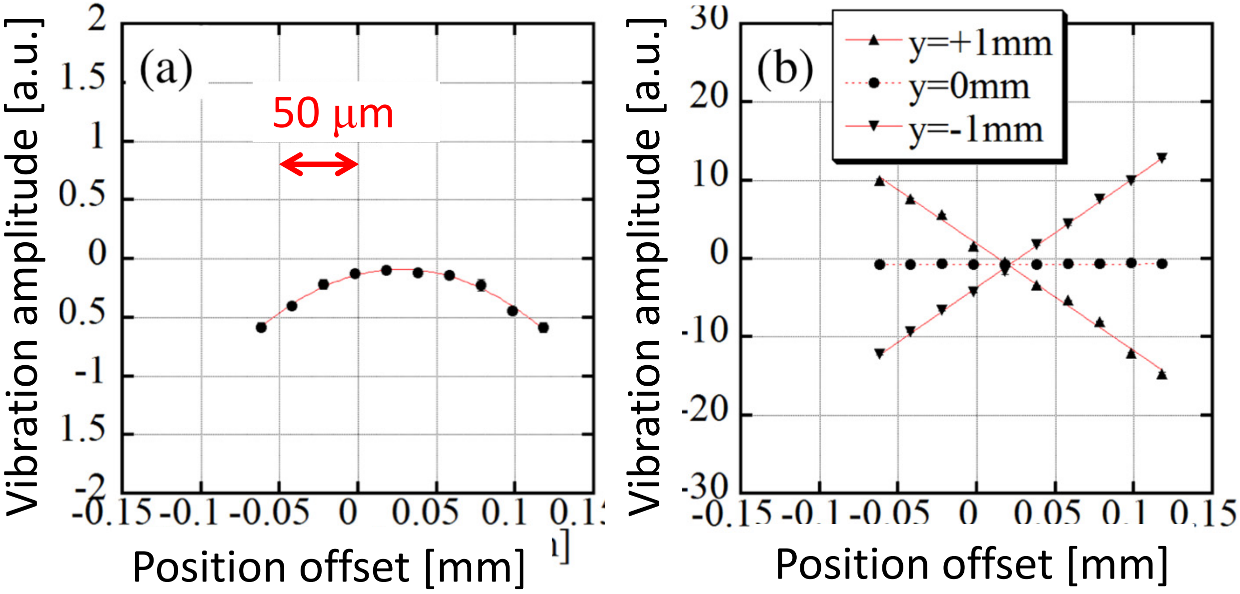


y = m1*(M0-m2)		
	値	エラー
m1	-1416.4	2.5684
m2	0.0217	1.0494e-05
カイ２乗	0.017415	NA
R	0.99999	NA

Sextupole magnet

(a) B_y vs x

(b) B_x vs x



Resolves sub-μm to μm position offset.

Vibrating wire method for on-girder alignment

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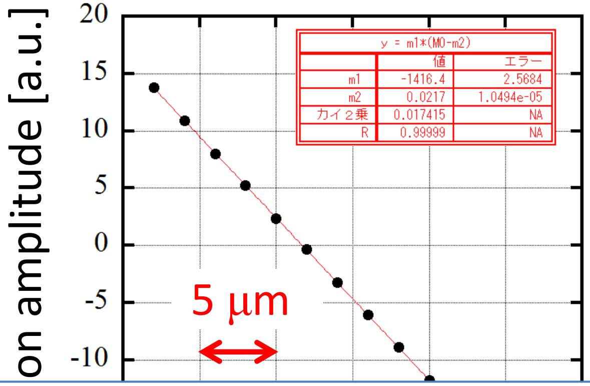
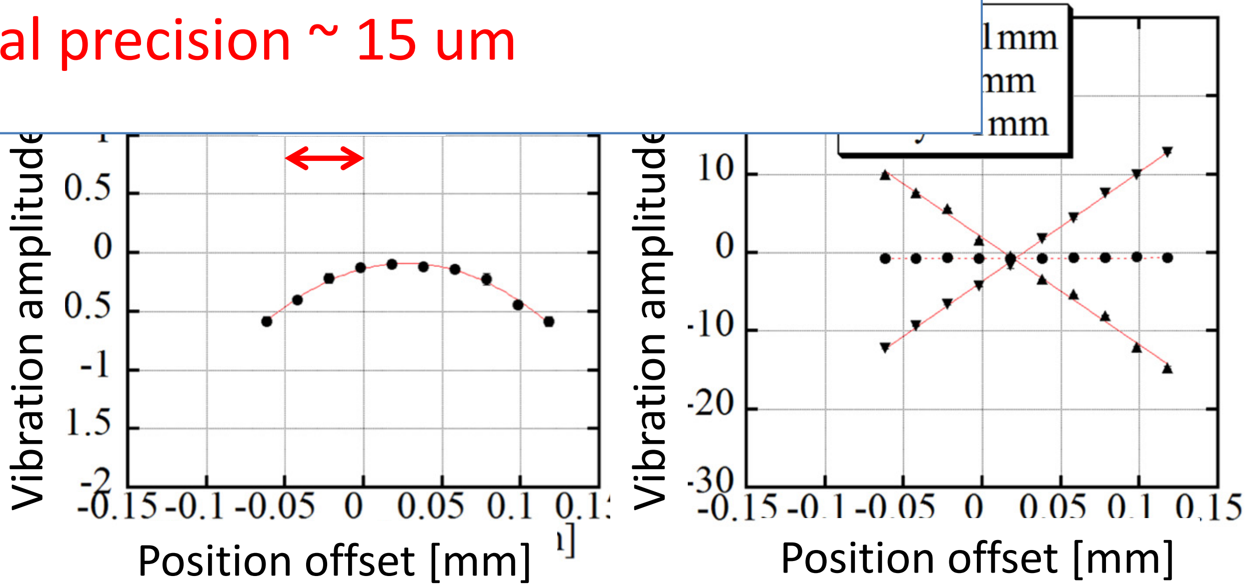


Wire sag, kink, temperature dependence,
Repeatability of magnet split,,,, etc.
-> Total precision ~ 15 um

Sextupole magnet

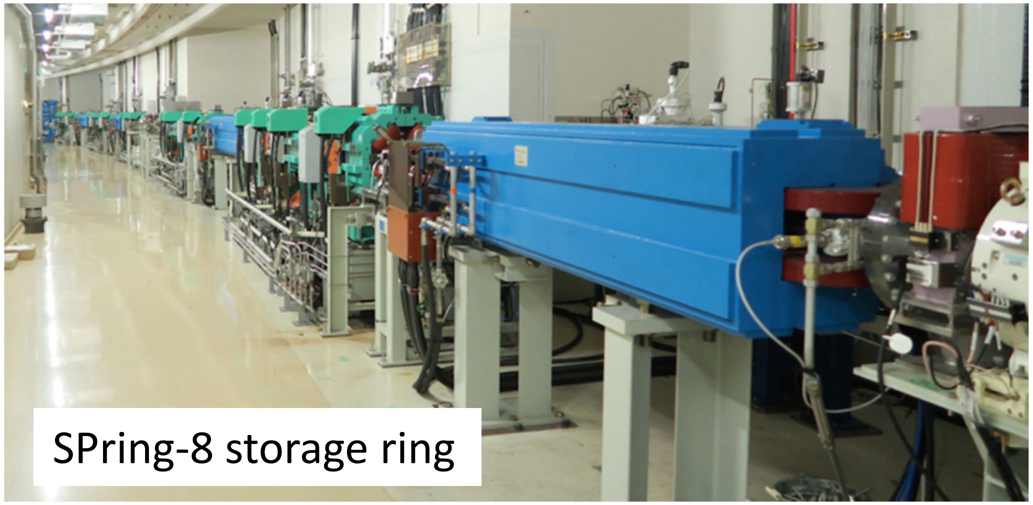
(a) B_y vs x
(b) B_x vs x



Resolves sub-µm to µm position offset.

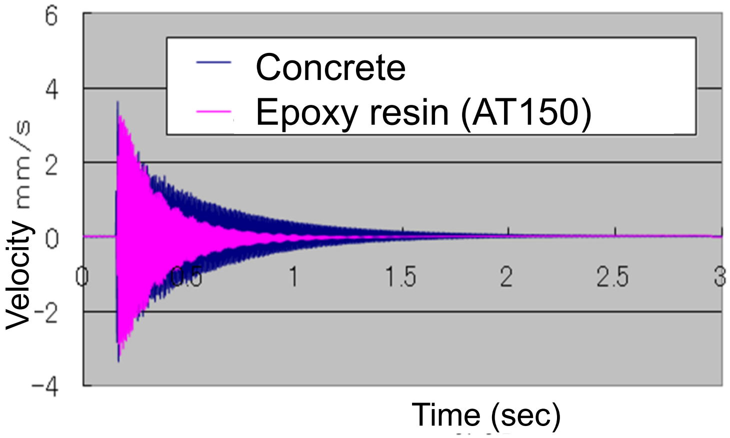
Impact of (approx.) 1 year shutdown

1) Remove
2) Re-install
3) Align + setup


SPring-8 storage ring

One of our solutions... epoxy resin for quick and solid baseplates

> Self-leveling: 50 micron/m
> Curing time: 1 week
> Little dust and debris during work
> Good mechanical properties
> Good bond to steel and concrete



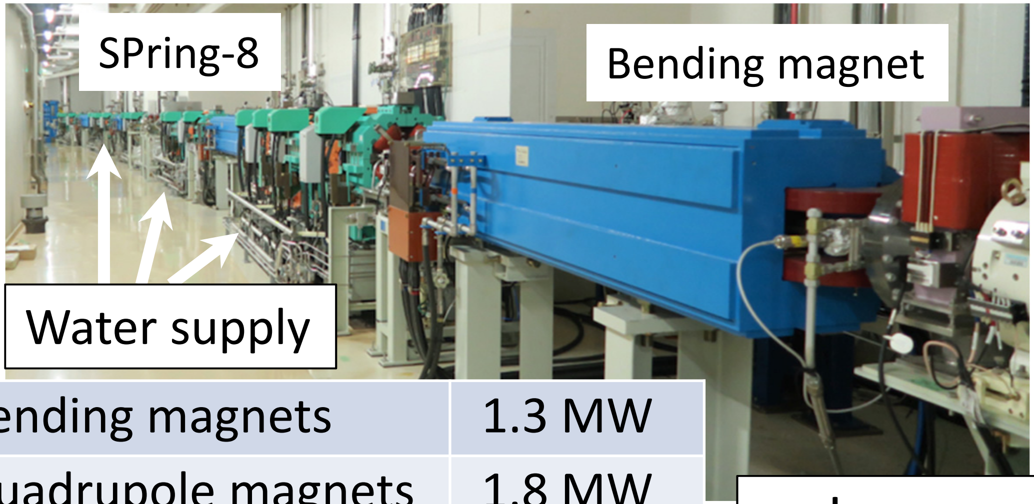
Summary

- SPring-8 has been working on major upgrade, SPring-8-II.
- Magnet development focuses on permanent dipole magnet,
  compact high gradient multipole magnets,
  precise alignment etc.
- Test one (or half) cell will be constructed in FY2017.
- Permanent magnet seems to be good so far. May be one of the steps towards quiet, PS related failure free light source...?

Presentations on SPring-8-II

Overview: H. Tanaka, WEPOW019
Lattice : K. Soutome, THPMR022
Vacuum : M. Oishi, THPMY001
RF : H. Ego, MOPMW009
Monitor : M. Maesaka, MOPMB028
ID : R. Kinjo, THPOW040

Pro and con of permanent magnet



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