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Bulk High-T_c Superconductor Staggered Array Undulator

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- Motivation
- Concept
- Experiment
  - Magnetization
  - Controlling K value by solenoid field
- Summary

Short Period Undulators

- Short wavelength FEL
  with low energy electron beam.
- Compact FEL

However,
To obtain same K value as large period,
we must generate stronger undulator field.

$$K = 93.36 B_0 \lambda_u .$$

B_0 : Undulator Field, λ_u : Undulator Period.

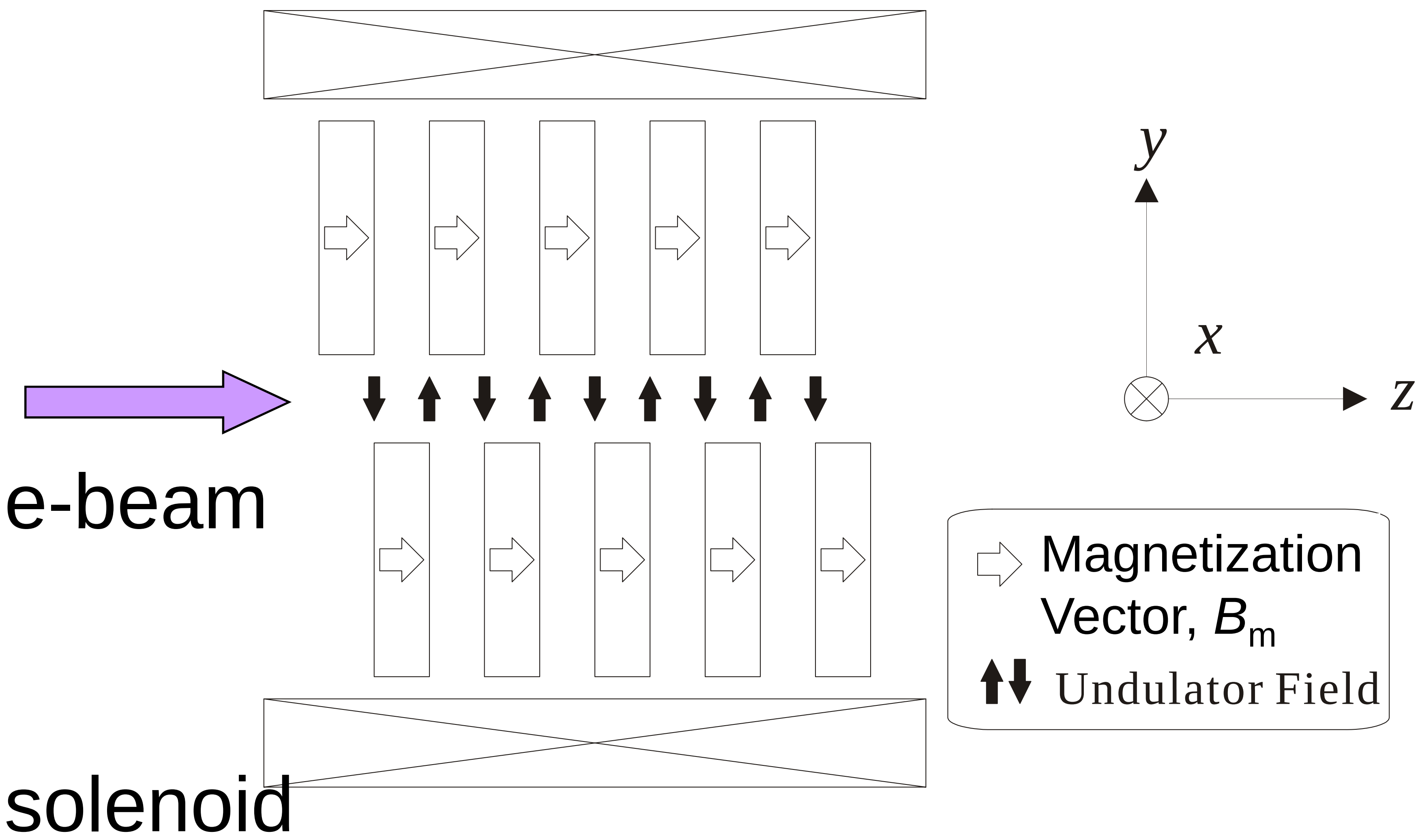
Bulk High-T_c Superconductor (Bulk HTSC)

- T_c of Bulk HTSC is over 77K.
- Bulk HTSC can generate
  - Over 17 T @ 29K*
  - Several T @ 77K

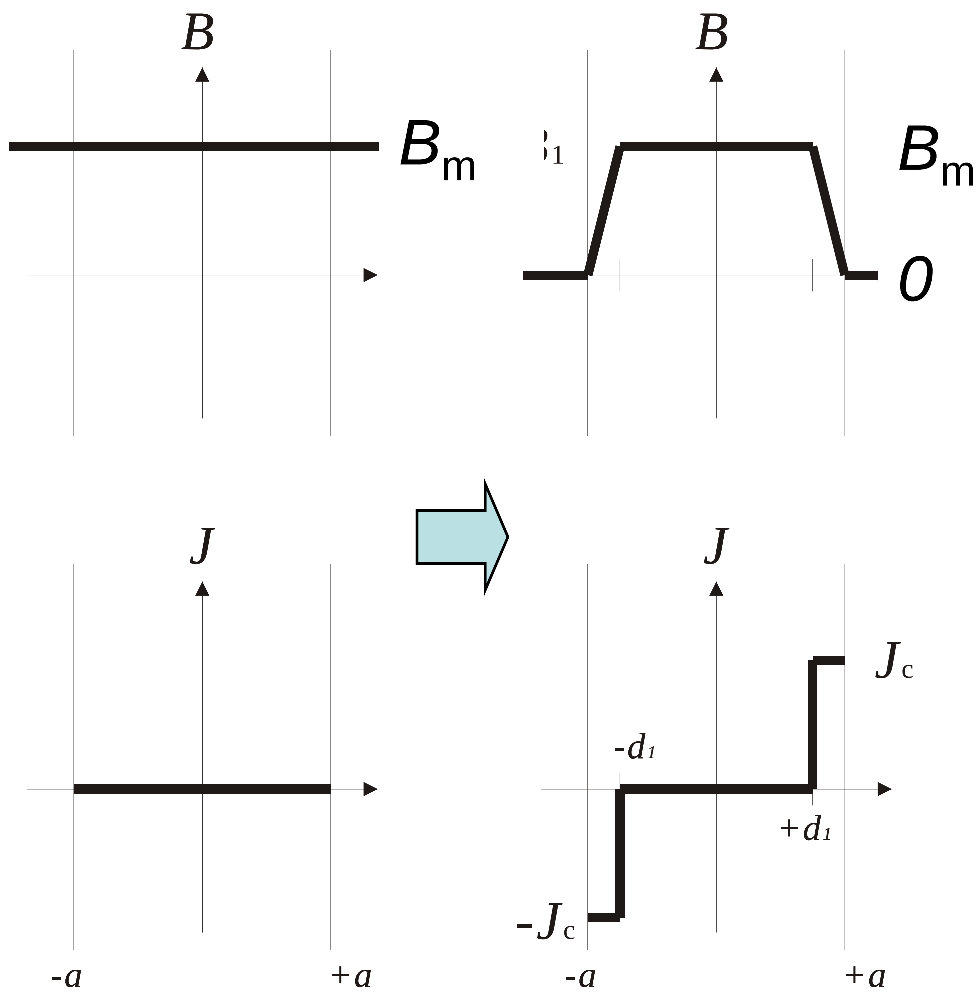
However,
How can we realize periodic transverse field?
How can we control K value?

* M. Tomita, Nature Vol. 421 30 January 2003, pp. 517-520 , 2003

Bulk HTSC
Staggered Array Undulator



Principle 1 : How to magnetize



Faraday's law:

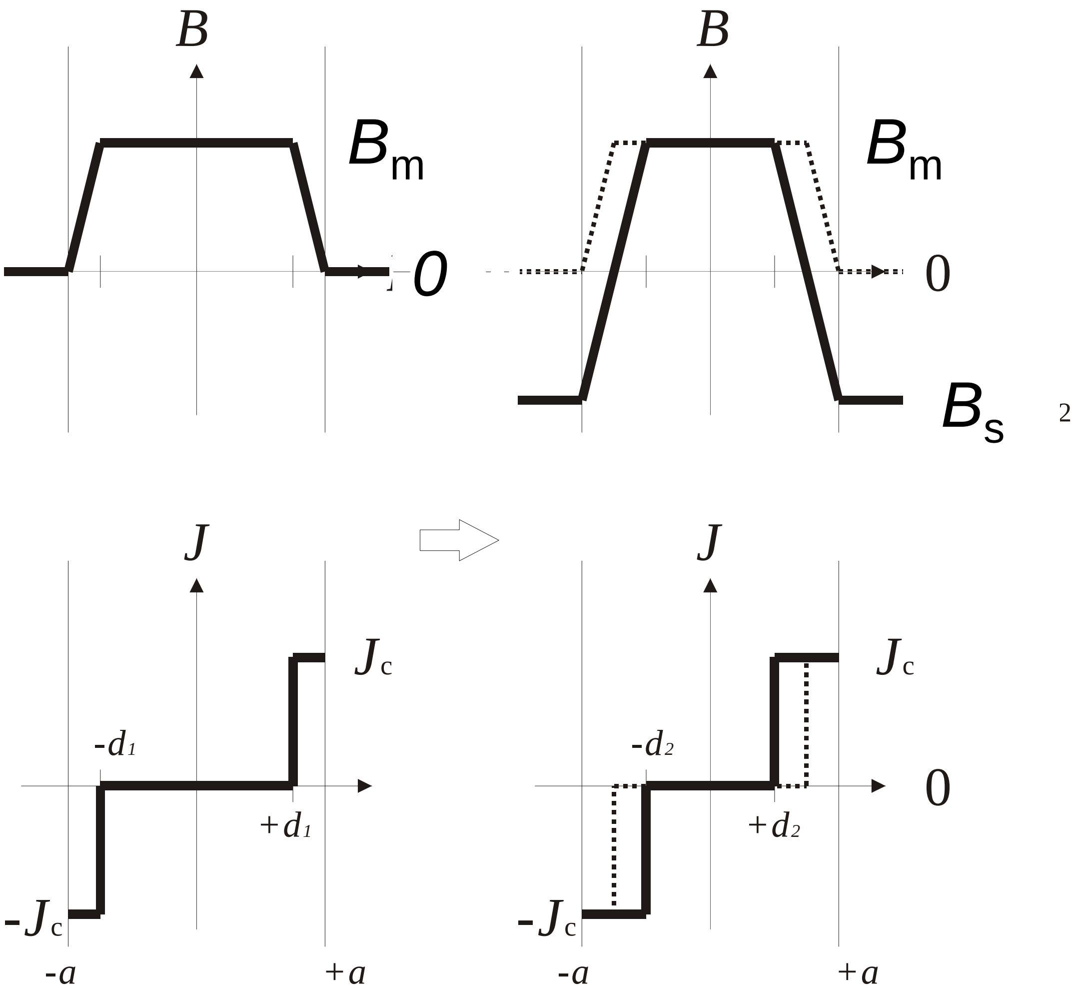
$$\nabla \times E = -\frac{\partial B}{\partial t}.$$

solenoid field, B_s,
decreases from B_m to zero.

Superconducting current flows in Bulk HTSC and will not decay.

Bulk HTSC works as magnet.

Principle 2 : How to control K value



Faraday's law:

$$\nabla \times E = -\frac{\partial B}{\partial t}.$$

Reverse solenoidal field is applied ($B_s < 0$)

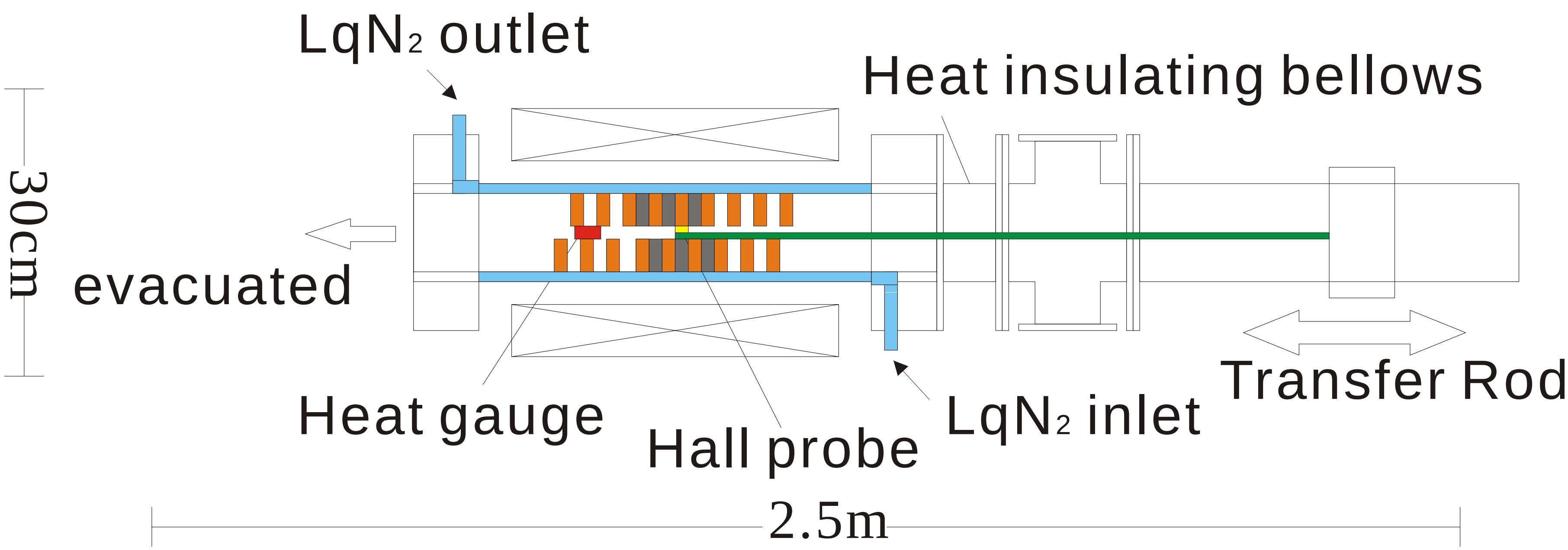
Additional current flows in HTSC and will not decay.

Total current in HTSC increase.

Objective of Experiment

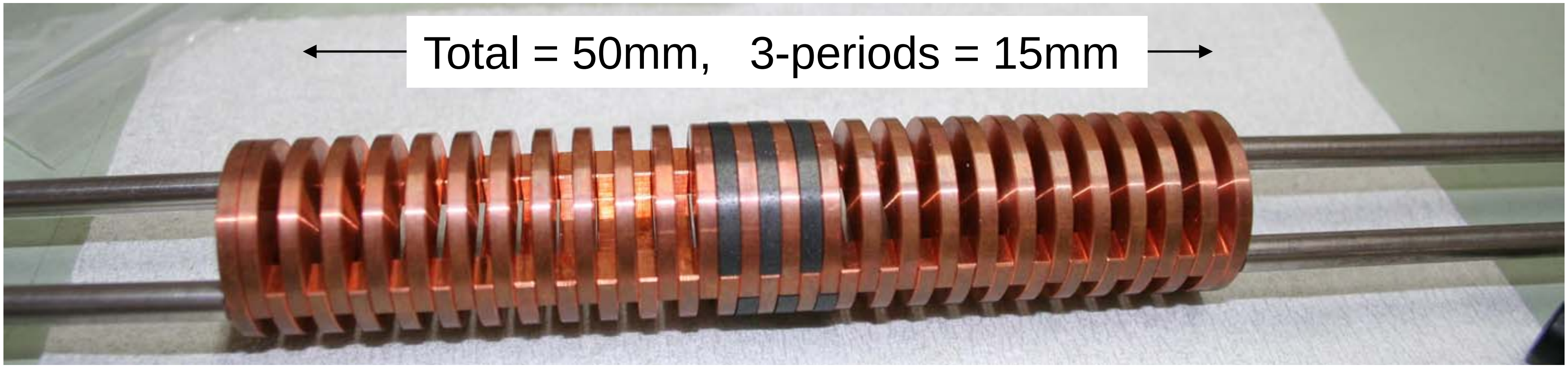
- Proof of principle experiment
  - Can we **magnetize** the Bulk HTSC?
  - Can we **generate** the periodic B_y?
  - Can we **control** B_y by B_s?
  - How is the amplitude of B_y?

Experimental Setup of 3-period Prototype

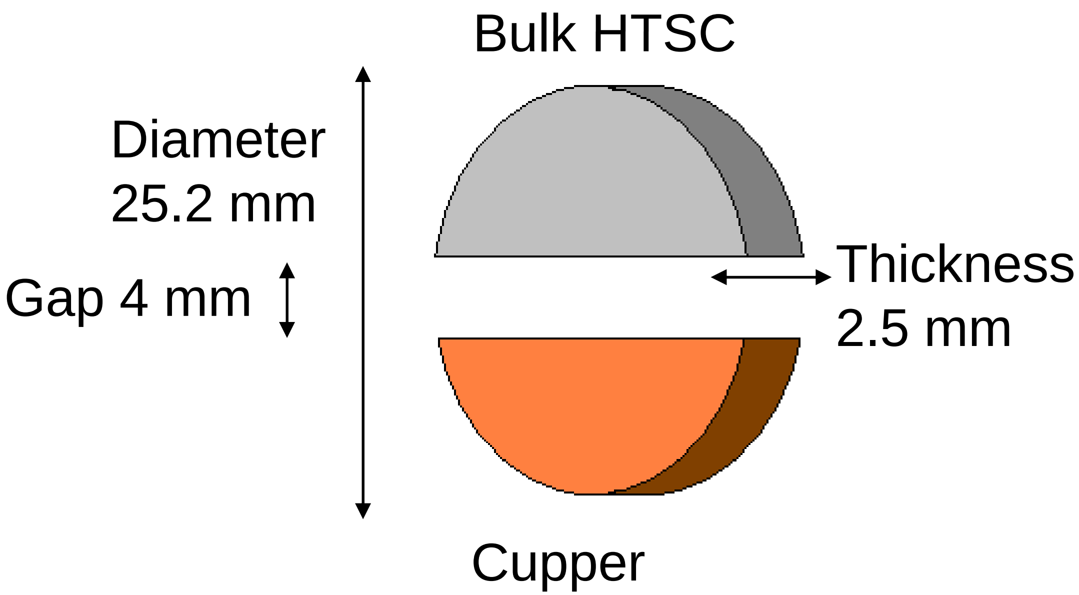


Solenoid Field, B_s, 0 – 350 gauss (0.035 T)

Specification of 3-period prototype



HTSC
DyBaCuO (Tc = 91 K, Jc ~ 1×10^9 A/m^2 at 77 K, 0 T)



Experiment 1

Can we **magnetize** the Bulk HTSC ?

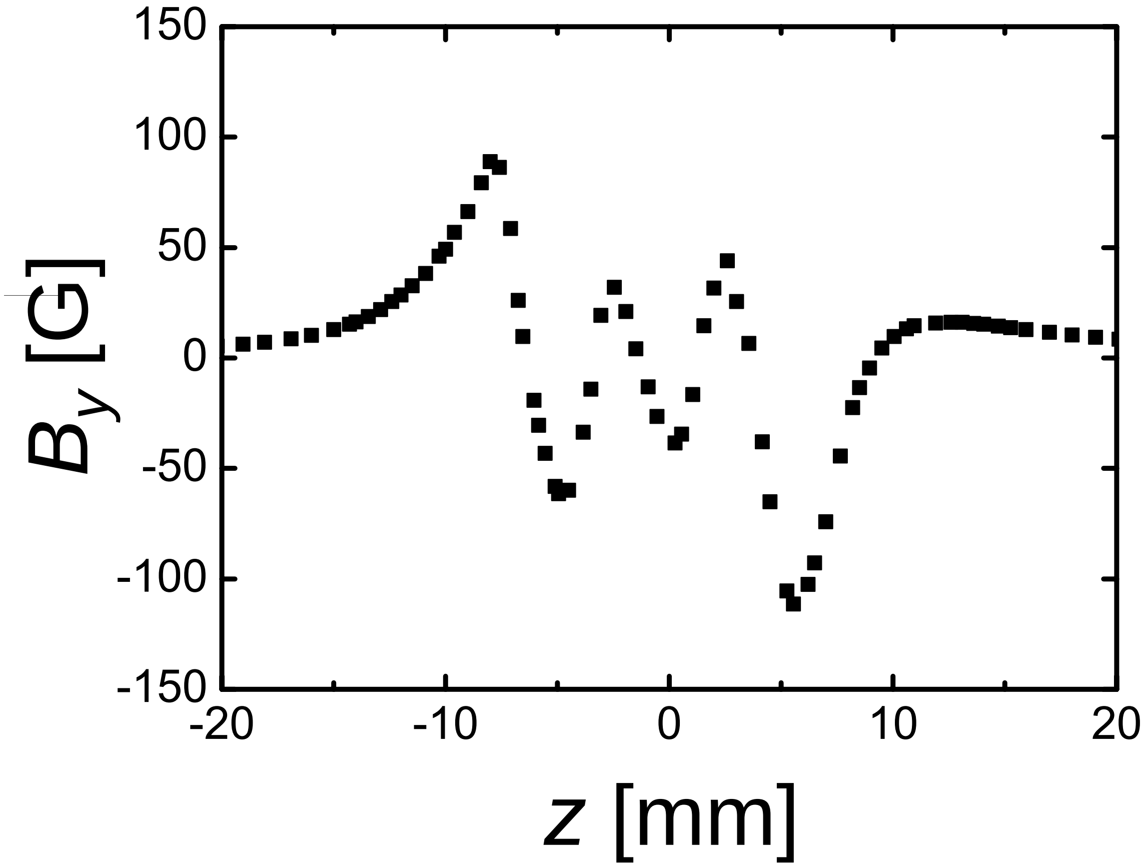
Can we **generate** periodic B_y?

Succeeded in Magnetization by **Field Cooling**

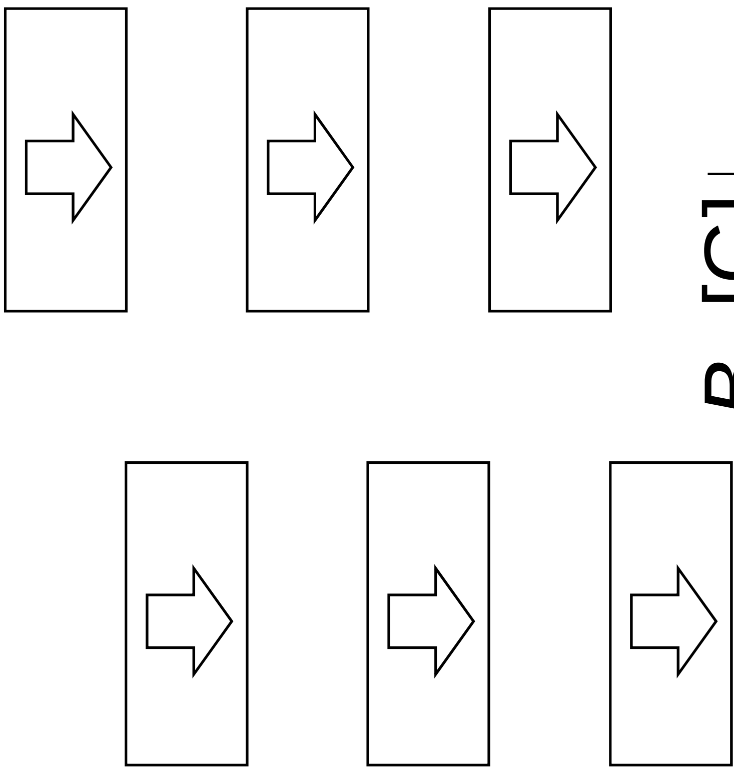
- Solenoid ON (250 gauss) @ T > Tc

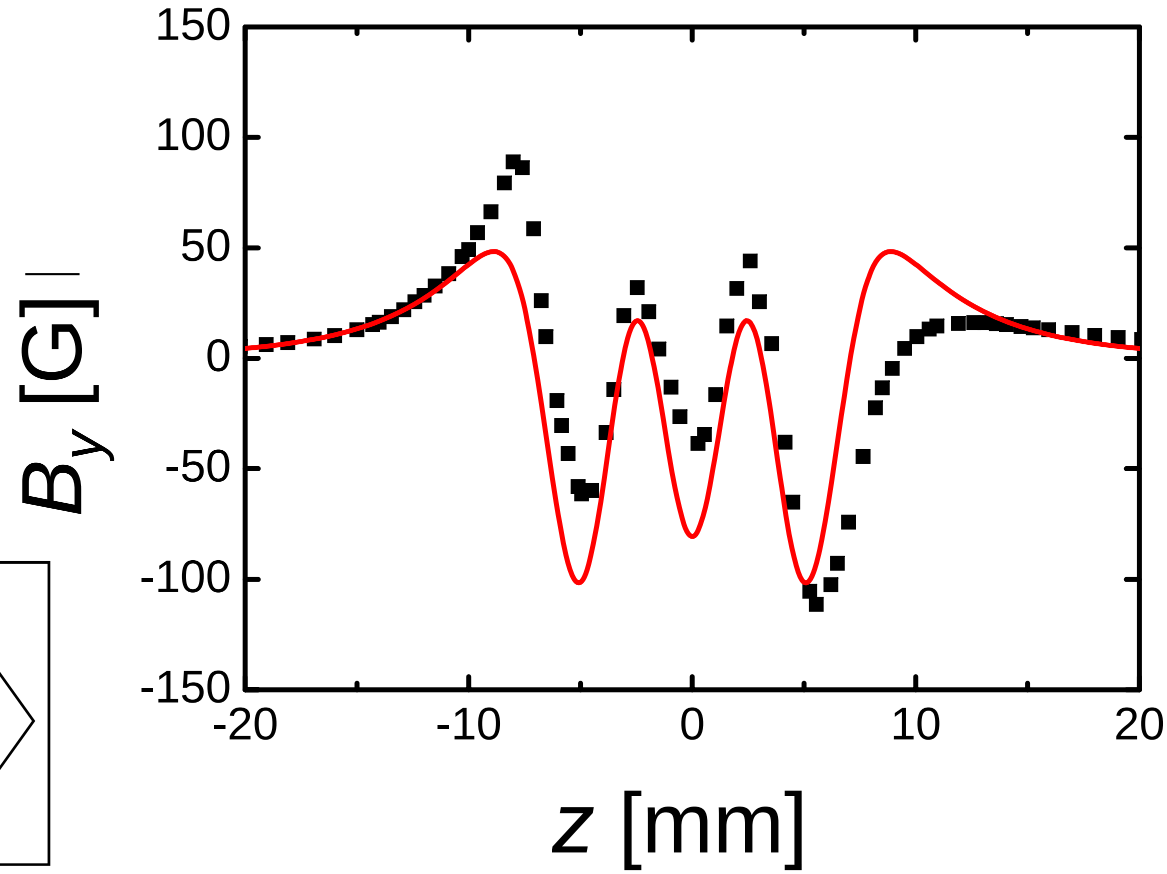
- **Field Cooling**

- Solenoid OFF @ T < Tc

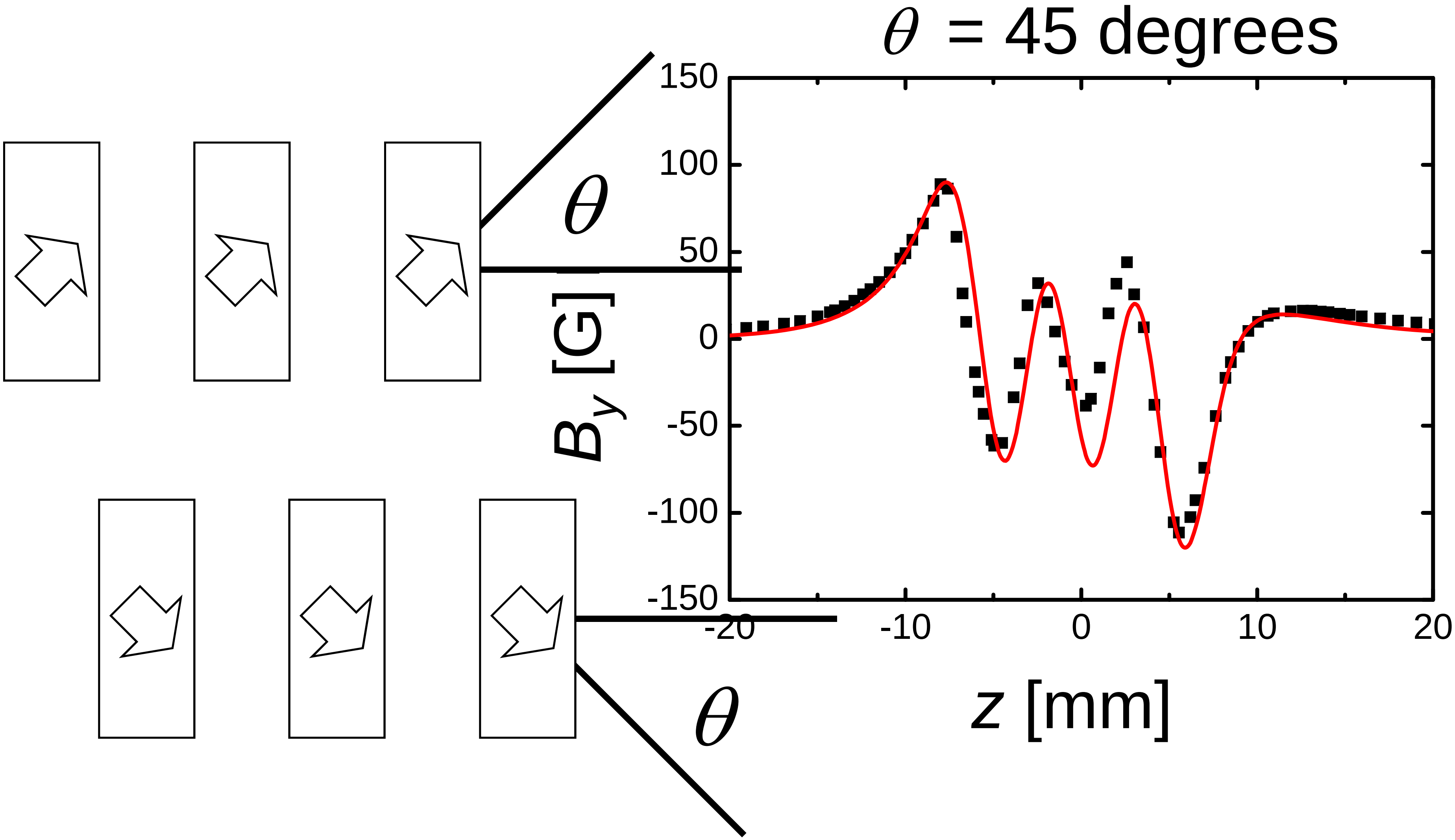


Calculation and Experiment





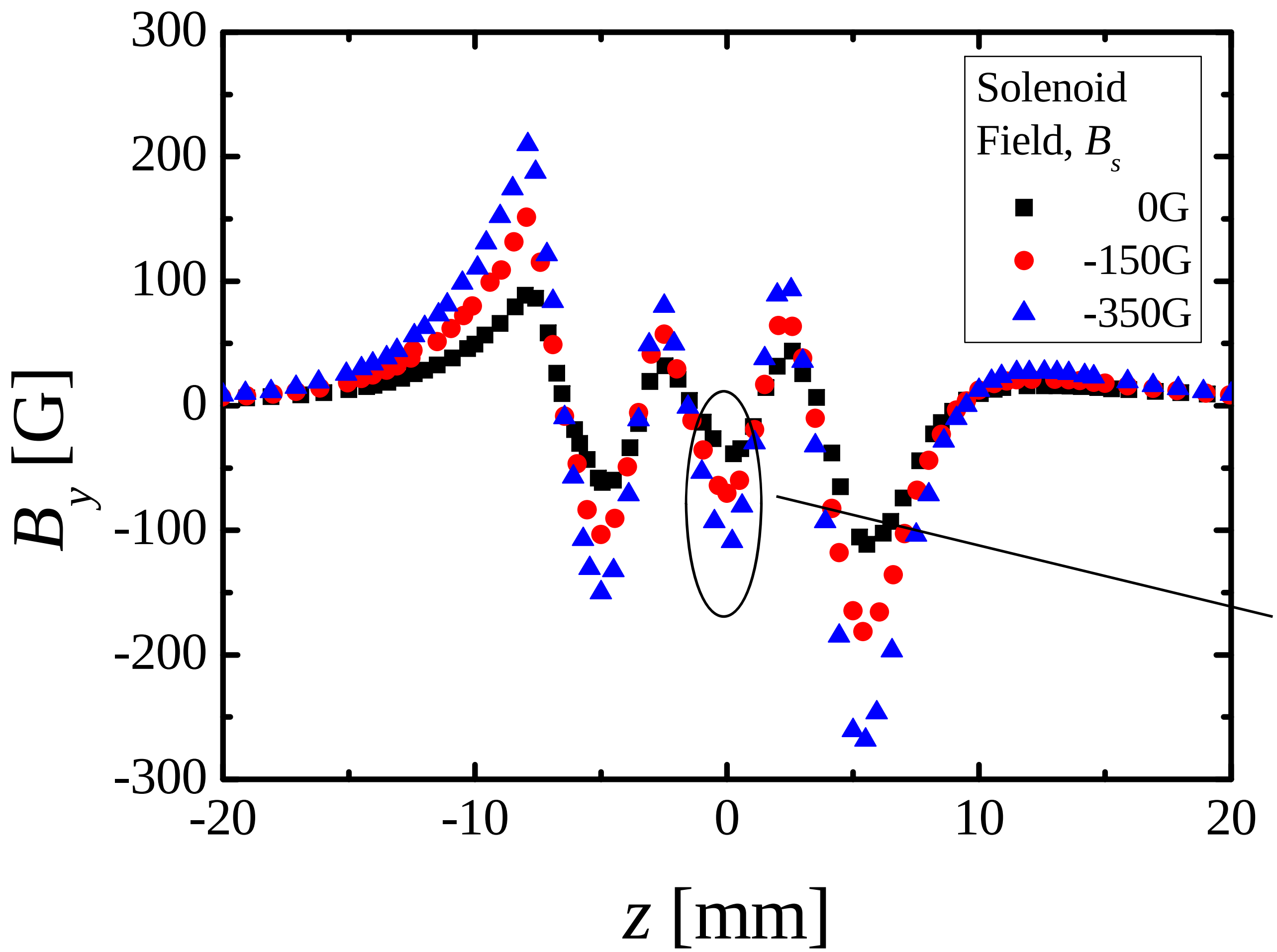
Calculation and Experiment



Experiment 2

Can we **control** B_y by B_s?

Reverse Solenoid Field is applied (B_s < 0)



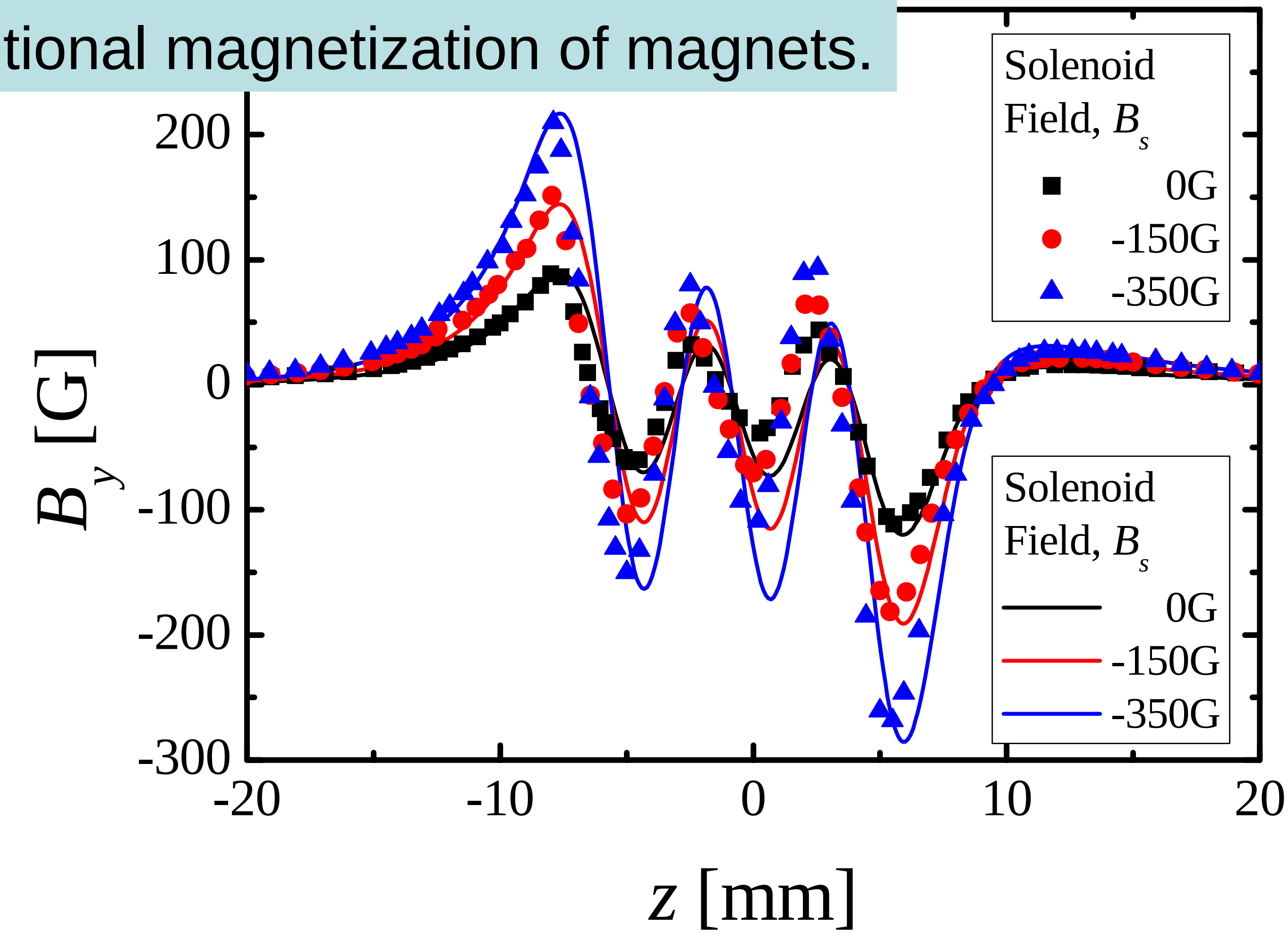
B_m : magnetization
B_s : solenoid field
B_0 : B_y @ center

B_m = 250G

B_m - B_s	B_0
250G	50G
400G	70G
600G	110G

Comparison between Calculation and Experimental Result

Model: Reverse Solenoid Field is treated as additional magnetization of magnets.



Conclusion

- The periodic B_y was observed.
- B_y was controlled by B_s.
- B_y @ center was about 110G with B_m = 250 G and B_s = -350 G

⇨ We showed proof of principle of Bulk HTSC Staggered Array Undulator.

Next Step

We plan to install

- stronger solenoid

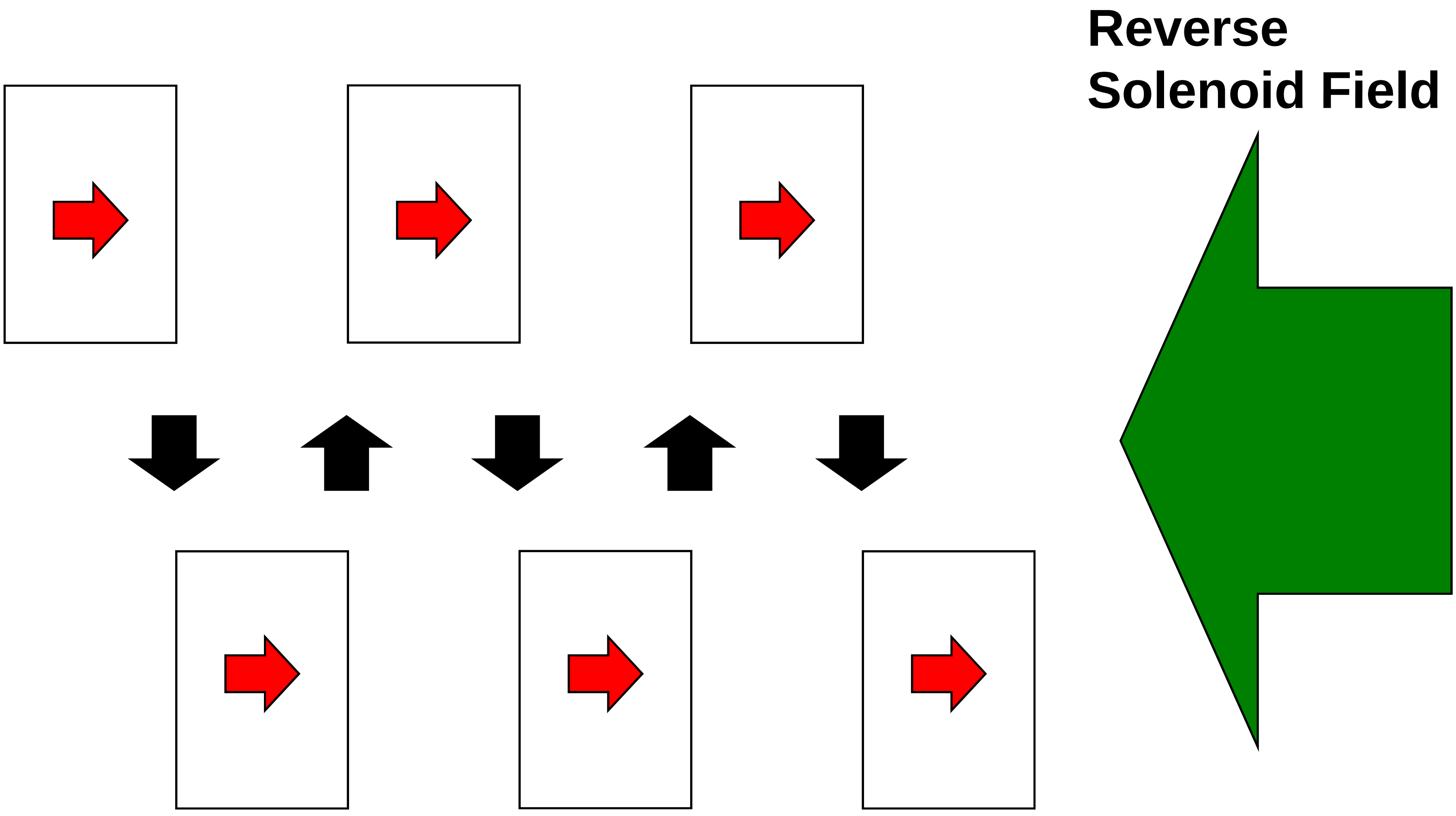
    to estimate the performance as

    the undulator

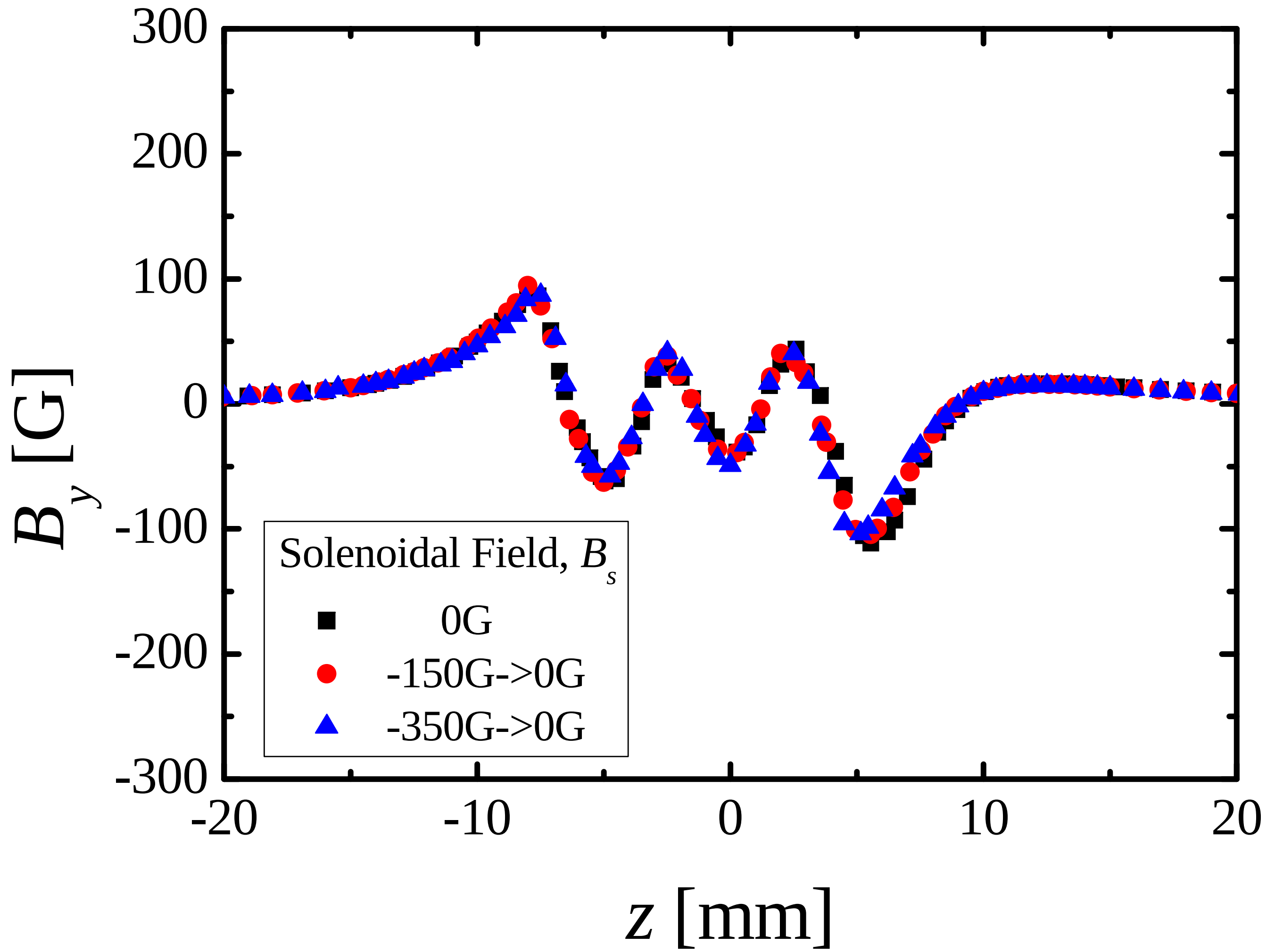
- more periods

    to check the effect of the small number of periods

Principle 2: How to control K value



Reverse Solenoid Field is removed ($B_s = 0$)



Performance Estimation

- The ratio, Σ, of B_y, to $B_m - B_s$ at center point is over 1/5.
- $J_c = 1 \times 10^9$ A/m^2, $d = 5 \times 10^{-3}$,
  $B_m - B_s = 4\pi \times 1 \times 10^9 \times 5 \times 10^{-3} \sim 6.3$T.
- $B_0 = 1.2$T, 4mm gap, 5mm period.
  K ~ 0.56

(But it's over estimated.
For larger B_m, Σ will be smaller.)

Strong Undulator Field

- Superconducting wires
  < 30K(-243C) required.
  thermal input from harmonics of image current (> 20W)

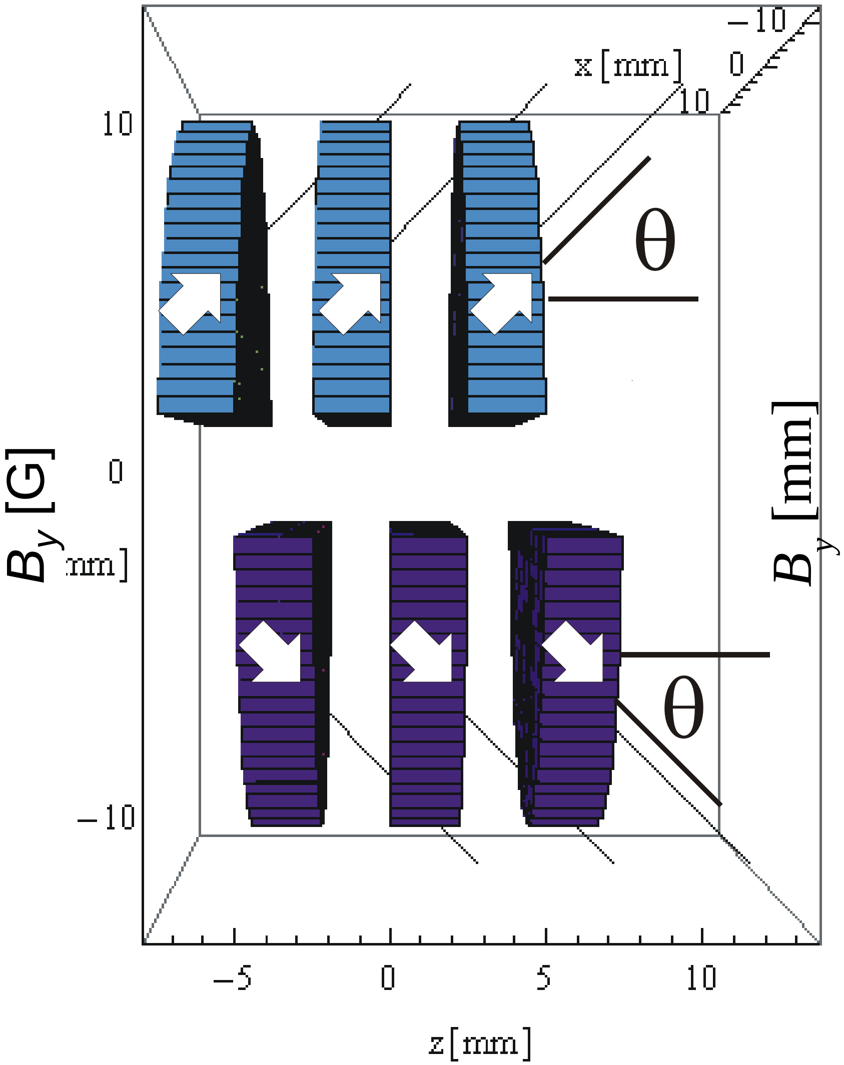
- CPMU (Cryogenic Permanent Magnet Undulator)
  limited by permanent magnet performance (B_r = 1.? *)

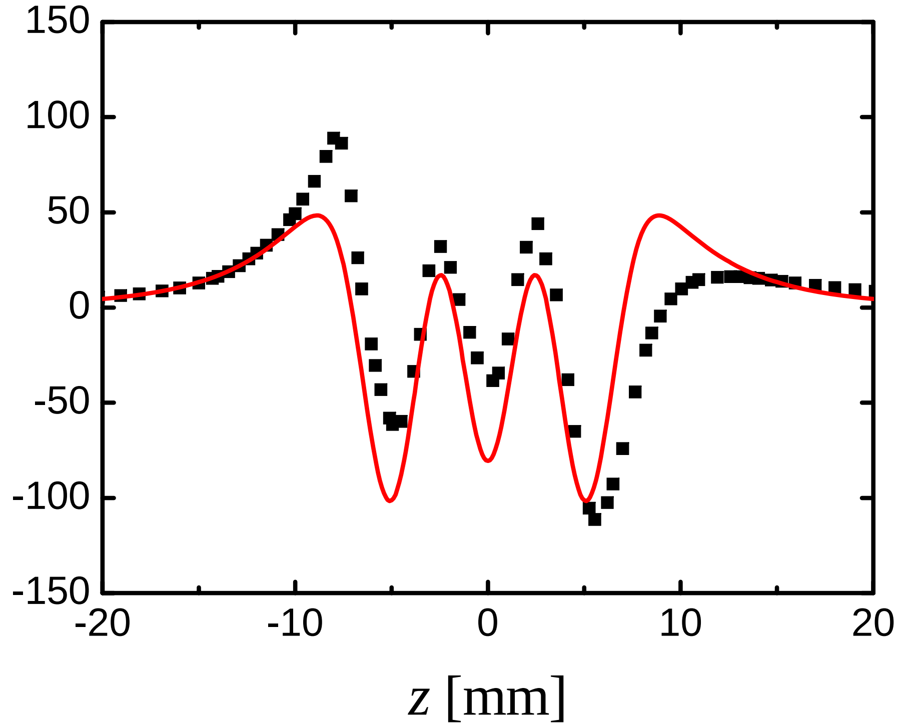
* T. Tanaka,

Hall probe position or direction

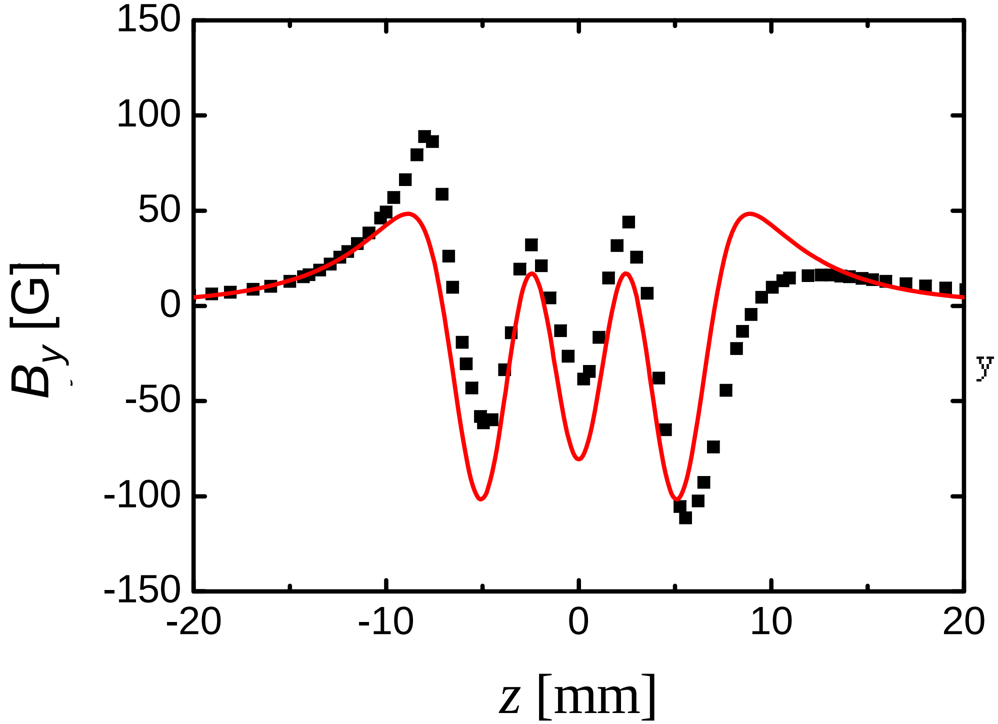
- If this result is caused by hall probe position error or direction error, position error or direction error must be too large.

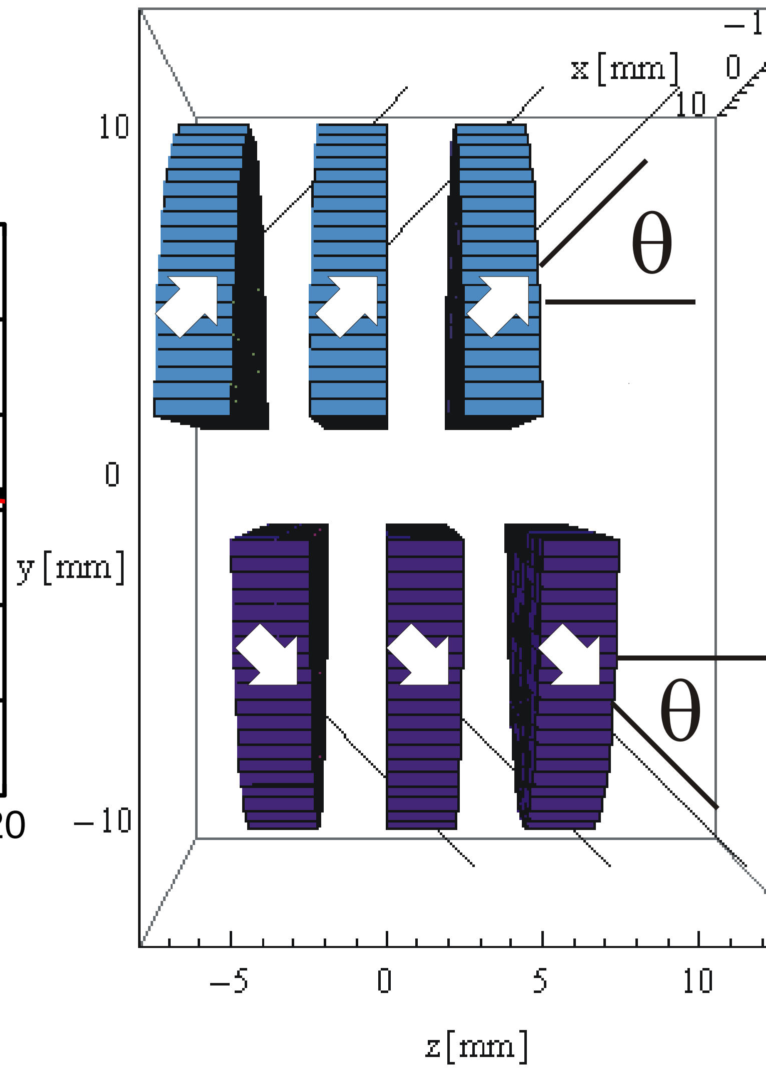
Calculation by Radia





Calculation by Radia



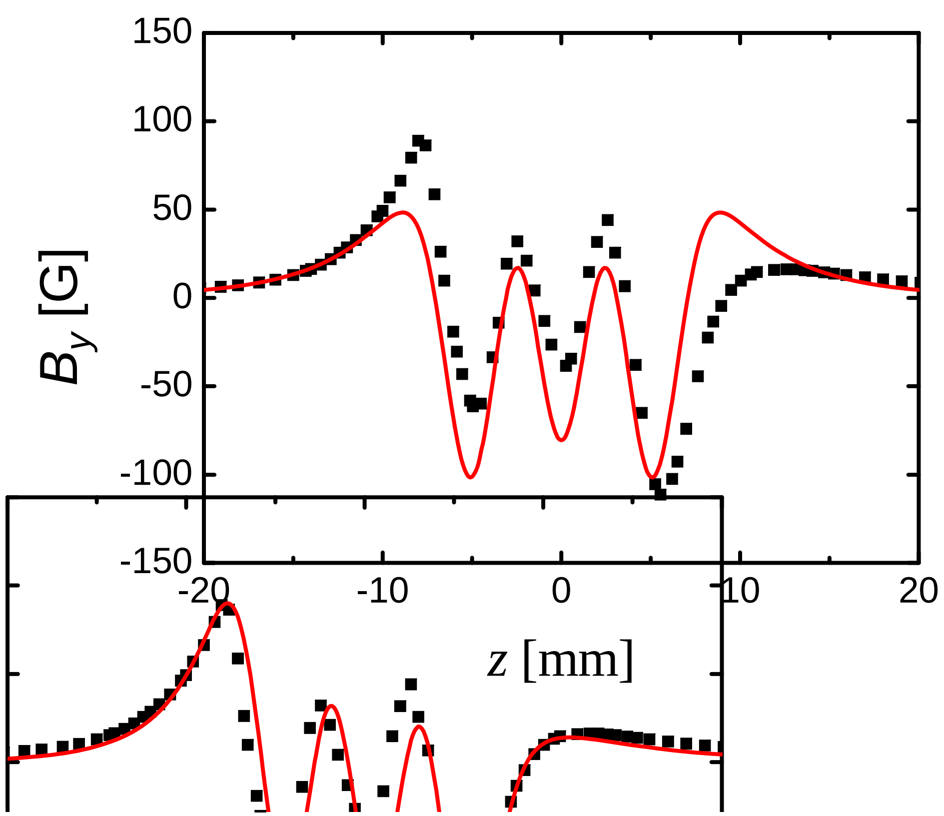


Comparison between Calculation and Experimental B_y

Model: The angle, θ, between magnetization vector and +*z* is …

θ = 0 degree

θ = 45 degrees



B_y [G]