

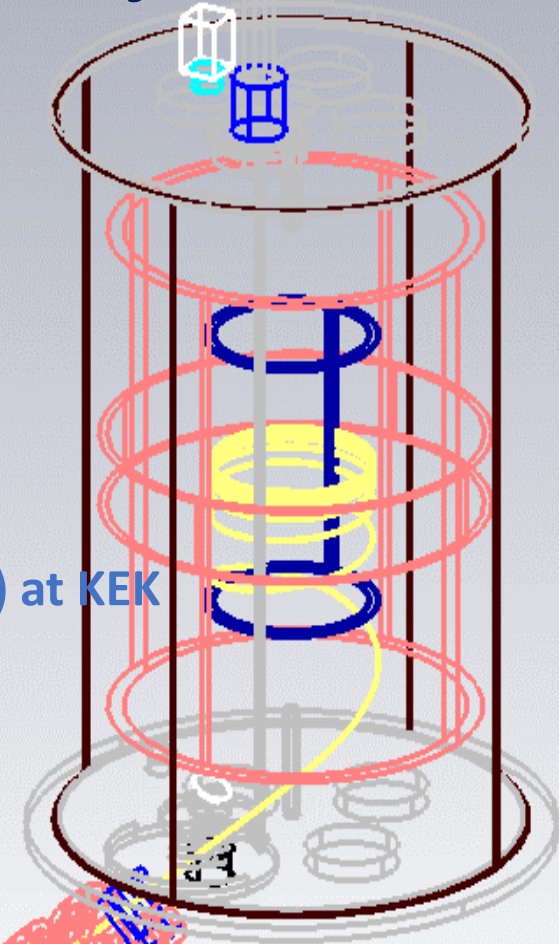
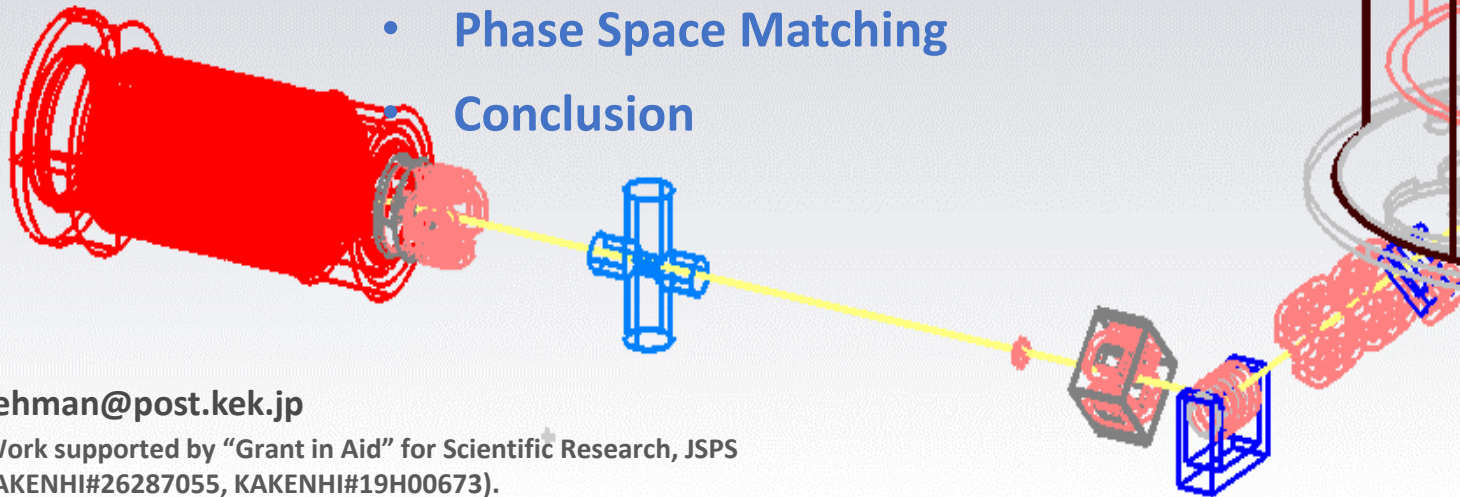
# The First trial of XY-coupled Beam Phase Space Matching for Three-dimensional Spiral Injection\*

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## Content

- Introduction
- Spiral Injection Test Experiment (SITE) at KEK
- Phase Space Matching
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**MOPAB162**

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# Muon g-2/EDM Experiment at J-PARC

## Muon's g-2

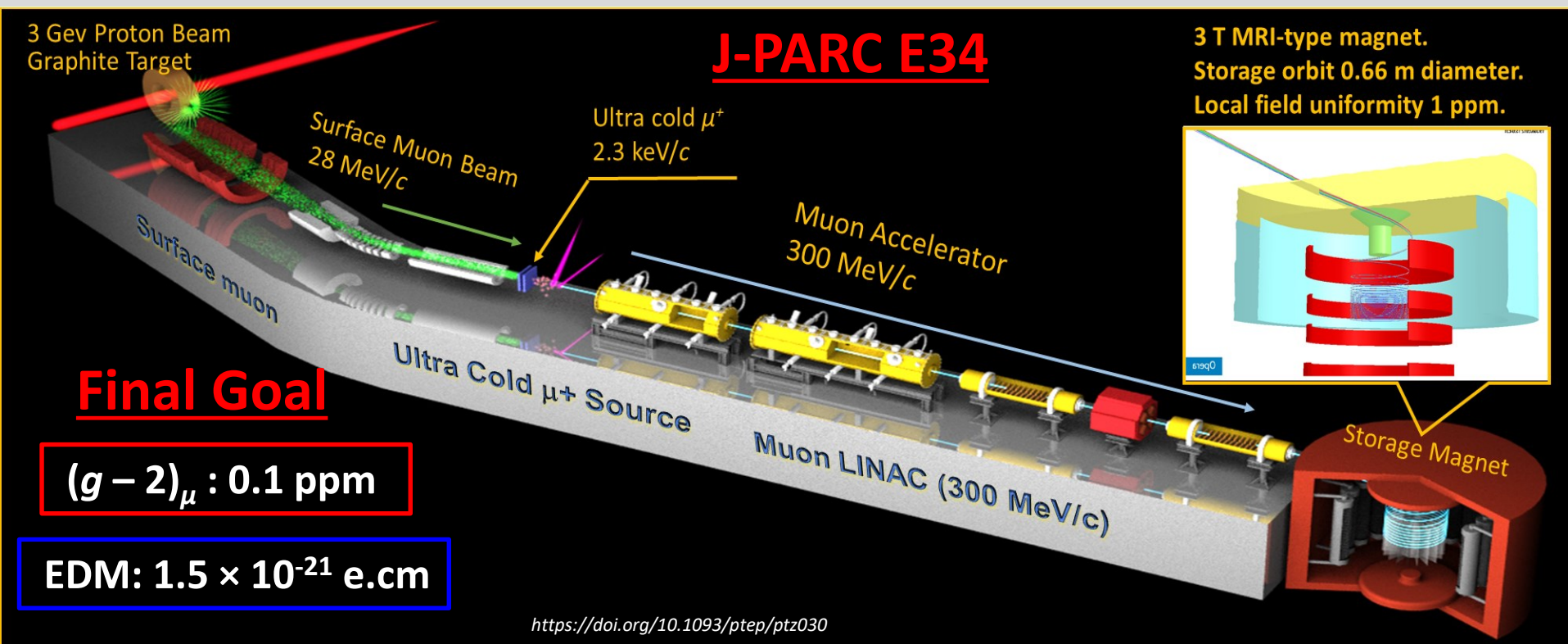
- 3.8σ discrepancy exist between Experiment and Standard Model
- Excellent Probe for New Physics(NP)

$$\vec{\mu} = g \left( \frac{q}{2m} \right) \vec{s} \quad a_{\mu} = \frac{g - 2}{2}$$

## Muon's EDM

- Upper Limit;  $0.9 \times 10^{-19}$  e.cm
- No finite EDM found Yet
- Any Finite value of EDM → NP

$$\vec{d} = \eta \left( \frac{q}{2mc} \right) \vec{s}$$

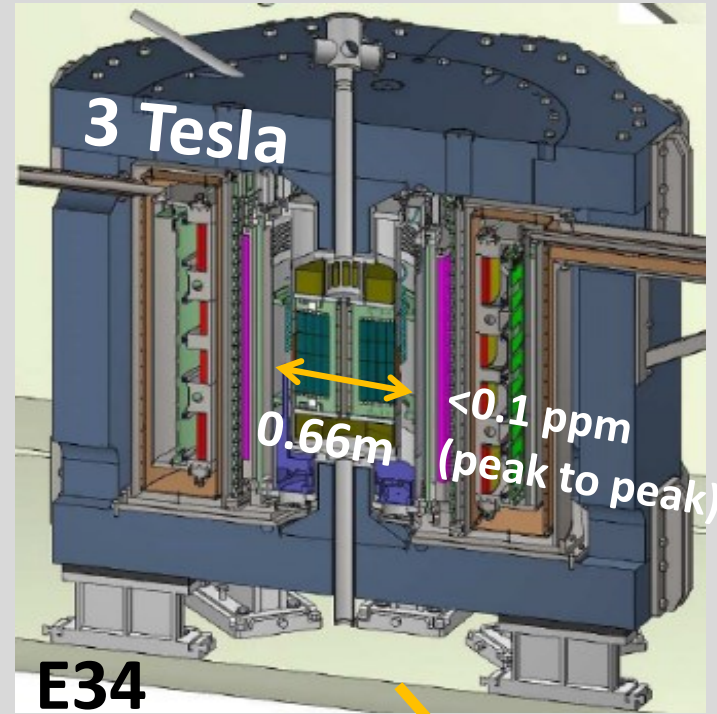
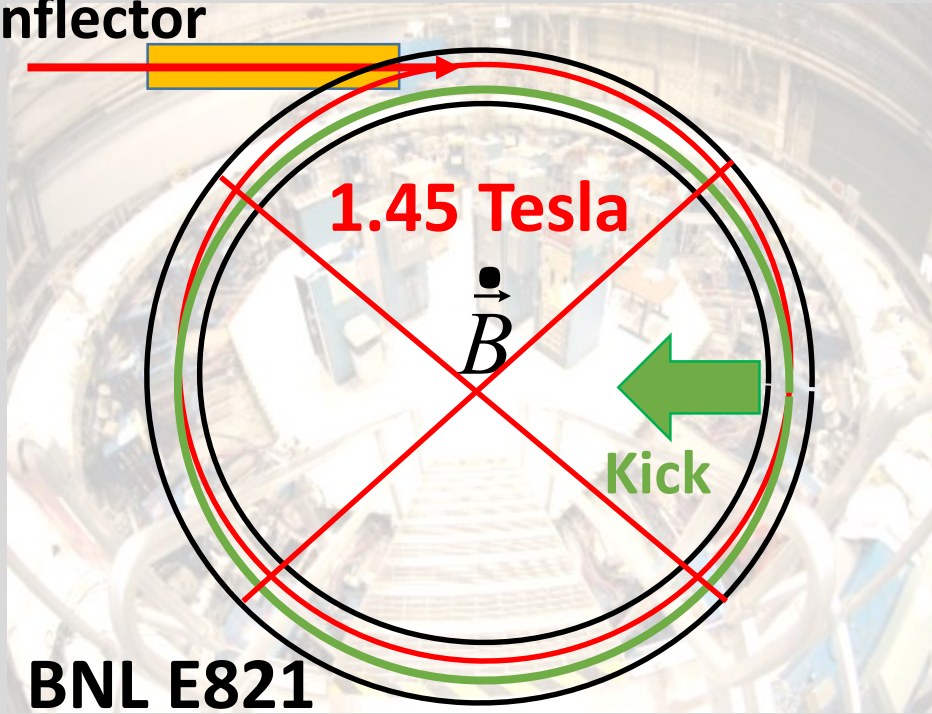


# Why inject beam spirally?

Conventional 2D injection (BNL)

E34 3T MRI type storage magnet

Inflector

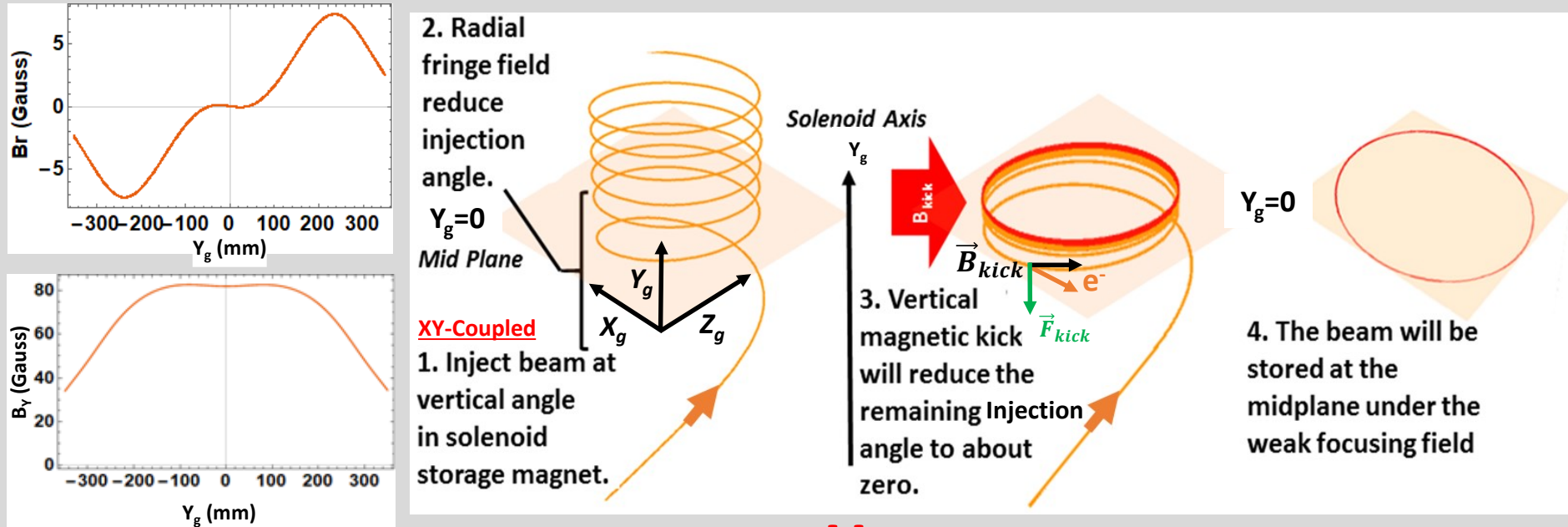


14 m orbit, To avoid beam hit at inflector (77 mm), kick angle become 10.8 mrad within 149 ns.

0.66 m orbit kick angle is **233 mrad** within **7.4 ns**. Impossible by any existent technology. 3 T is too high to be canceled by inflector.

# How to inject beam spirally?

To resolve technical challenges a [new 3D Spiral Injection](#) scheme has been invented



## The Elegance and Advantages

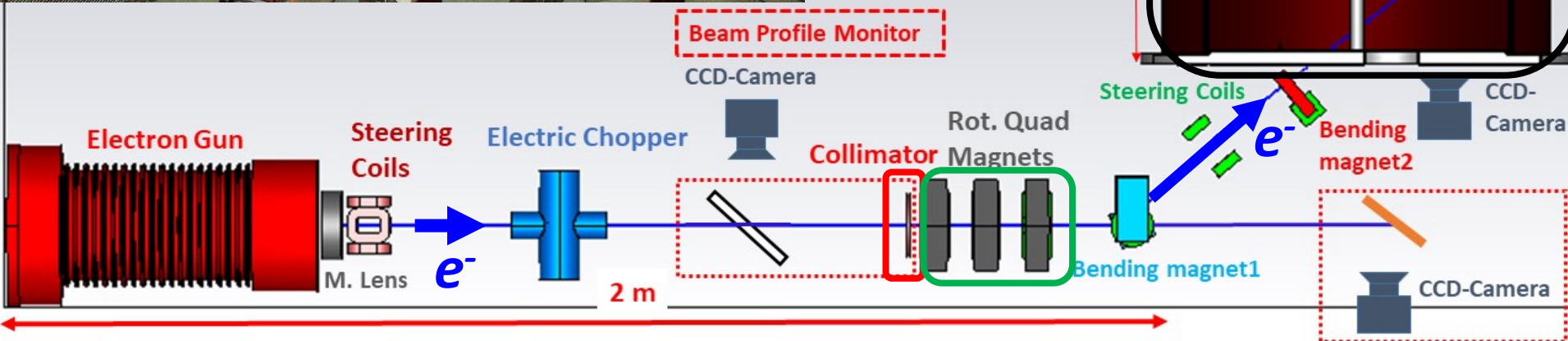
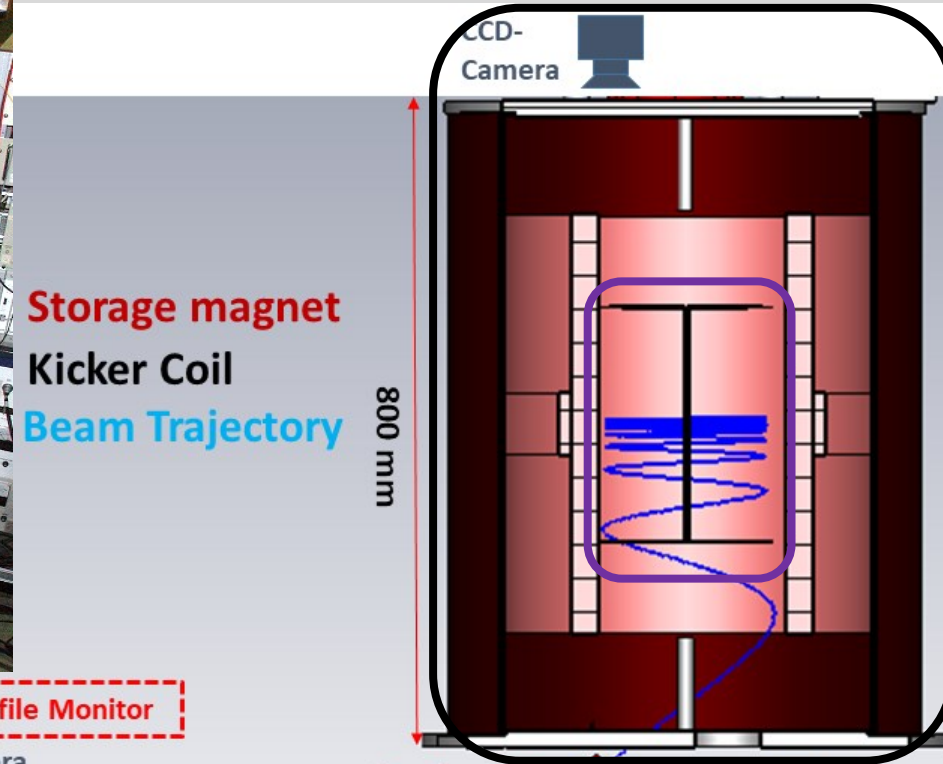
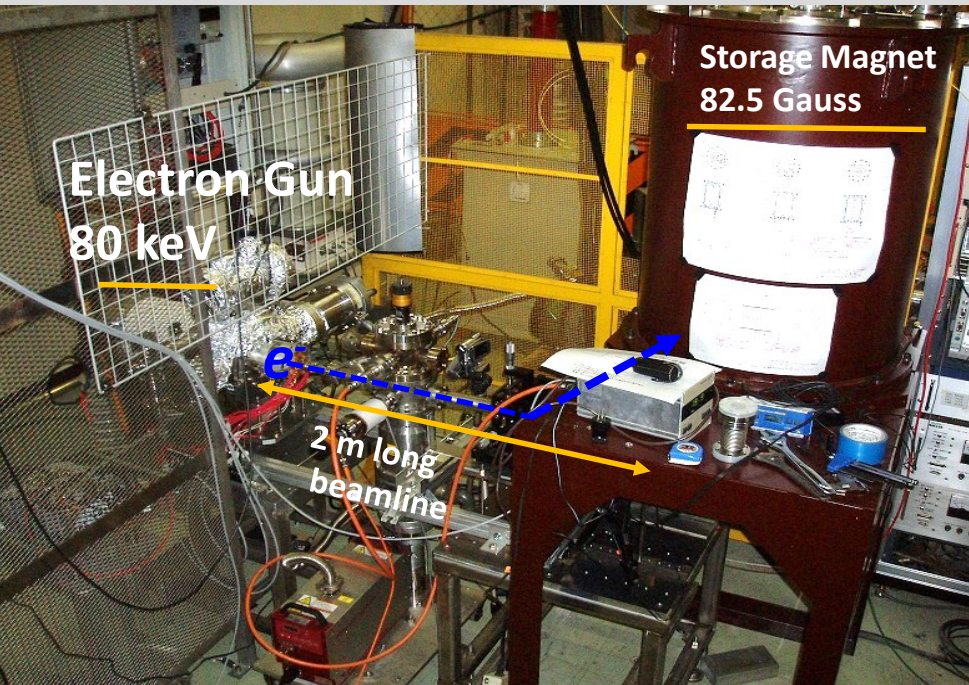
## However, Unprecedented

**Therefore, it is indispensable to prove the feasibility of this new scheme.**

- Smooth connection between injection and storage sections: No need of Inflector
- All in one storage magnet, reduce source of error fields: No Electric Quad
- No need to kick within a single turn: Simple kicker

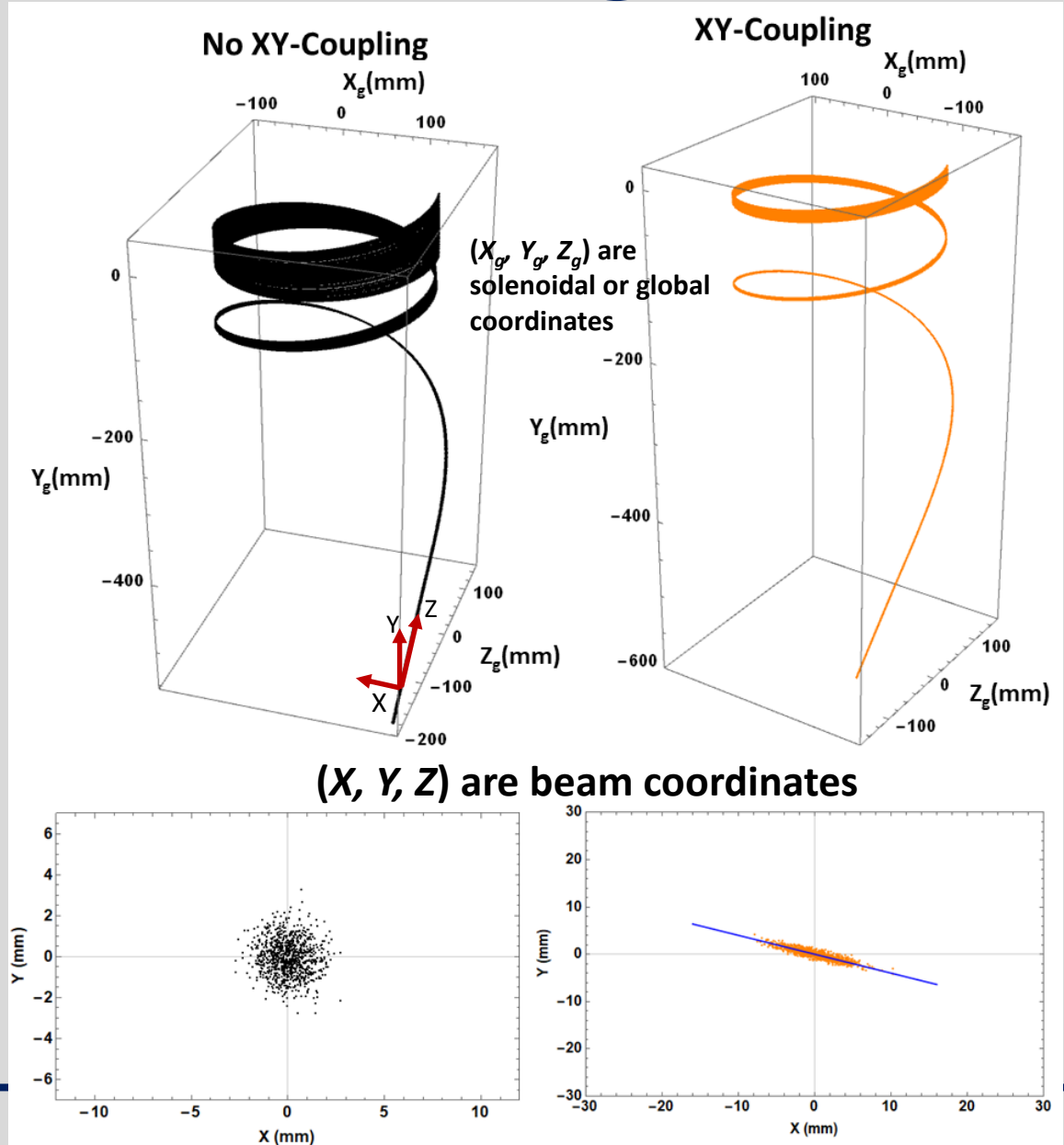
# Spiral Injection Test Experiment (SITE)

## Spiral Injection Test Experiment Setup at KEK Tsukuba Campus



# Phase Space Matching for SITE

- Due to the axial symmetric field of the solenoid magnet an appropriate XY coupled beam is required
- Moreover, particles at different vertical positions face different radial field and eventually vertical blow-up
- Phase space matching is essential to avoid vertical blow-up



# Phase Space Matching for SITE

Apply transfer matrix consists of coupling parameters (R1,R2,R3,R4) and Twiss parameters to input phase space

$$X = M \cdot X_0 \quad M = U_{out}^{-1} \cdot D \cdot U_{in}^{-1}$$

Twiss Parameters

$$\begin{pmatrix} D_x & \mathbf{0} \\ \mathbf{0} & D_y \end{pmatrix}$$

Coupling Parameters

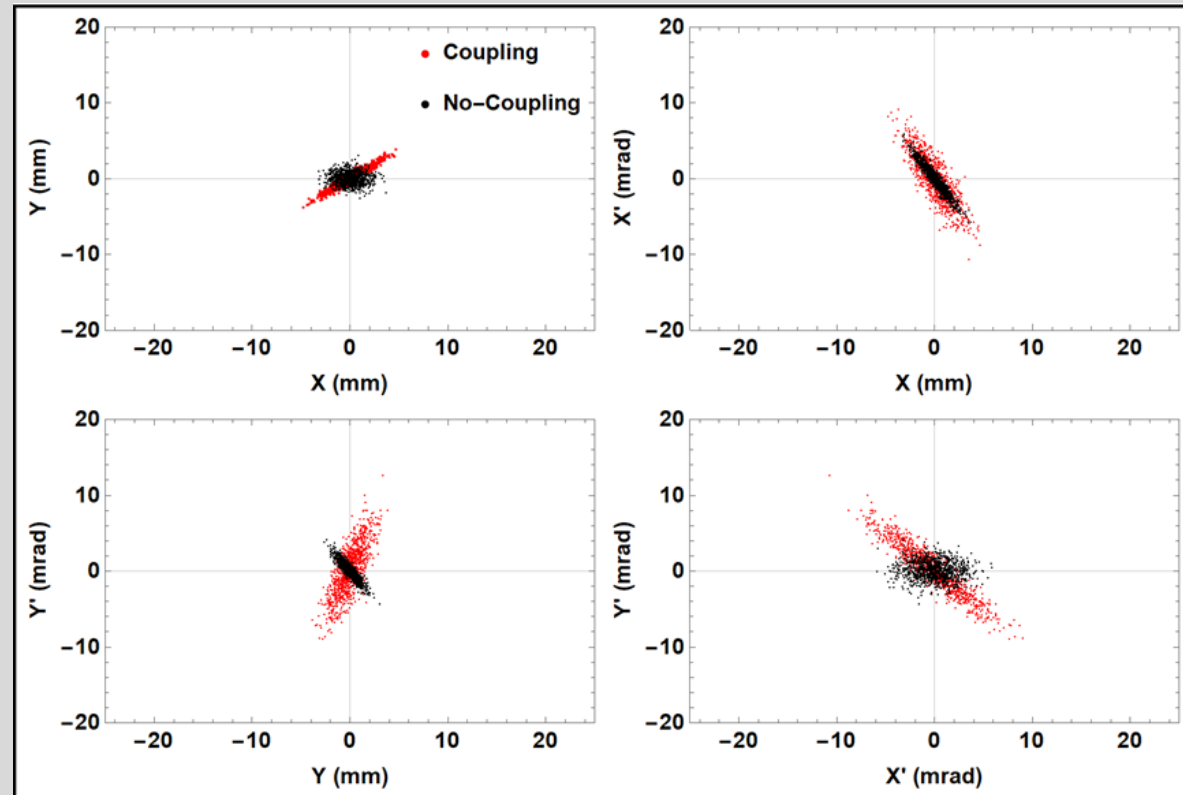
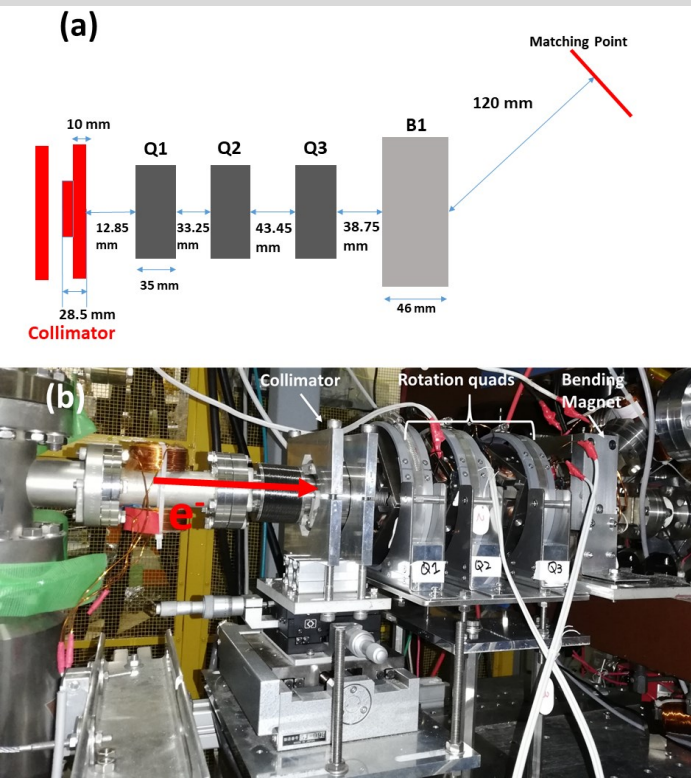
$$U_{out} = \begin{pmatrix} \mu & 0 & -R_4 & R_2 \\ 0 & \mu & R_3 & -R_1 \\ R_1 & R_2 & \mu & 0 \\ R_3 & R_4 & 0 & \mu \end{pmatrix}$$

$U_{in}^{-1} = Identity$  in our case,  
From Coupling Measurement.

$$M = U_{out}^{-1} D$$

Non-zero values of (R1, R2, R3, R4) shows coupling

# The matching beamline



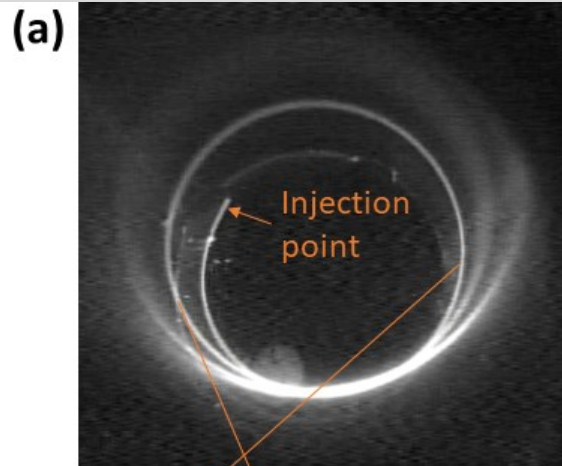
Iterate  $\theta$  and  $k$  to match slope

$$M_{total} = L5. B1. L4. Q3_R. L3. Q2_R. L2. Q1_R. L1$$



# Results

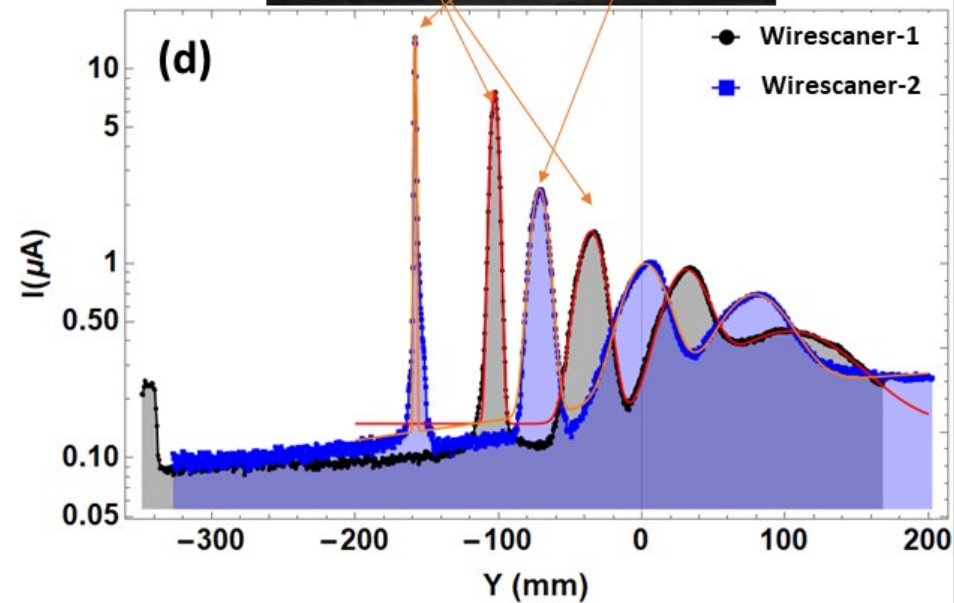
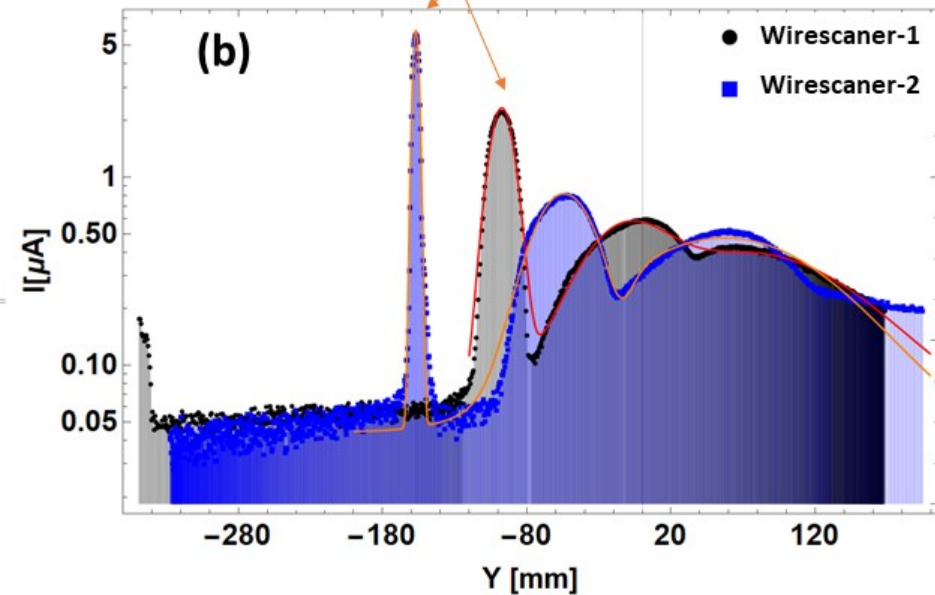
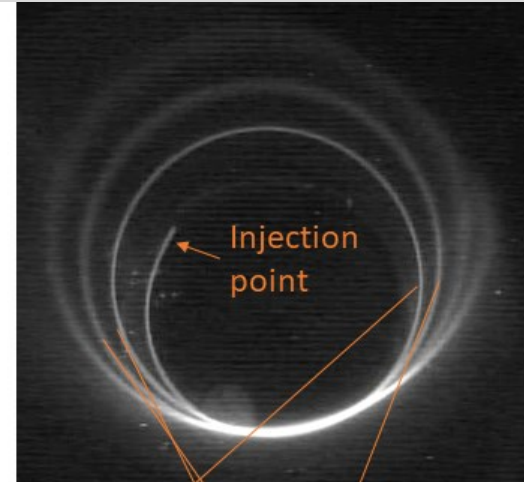
## Without XY-coupling



Gas Monitor

(c)

## With XY-coupling



# Conclusion

- To overcome the vertical beam blow-up in the solenoid-type storage magnet, a beam transport line consisting of three rotatable quadrupole magnets has been designed and built
- The dramatic reduction in the vertical beam size was observed with the appropriate setting of three rotatable quadrupole magnets
- Without any beam phase-space matching, the beam size grows to  $8.18 \pm 0.03$  mm ( $1\sigma$ ) at the kick point ( $Y \sim 100$  mm). The vertical beam blow-up was reduced to  $2.56 \pm 0.005$  mm ( $1\sigma$ ) at the kick point with the appropriate combination of the three rotation quadrupole magnets.

