Development of focusing lens for high-density positron beam

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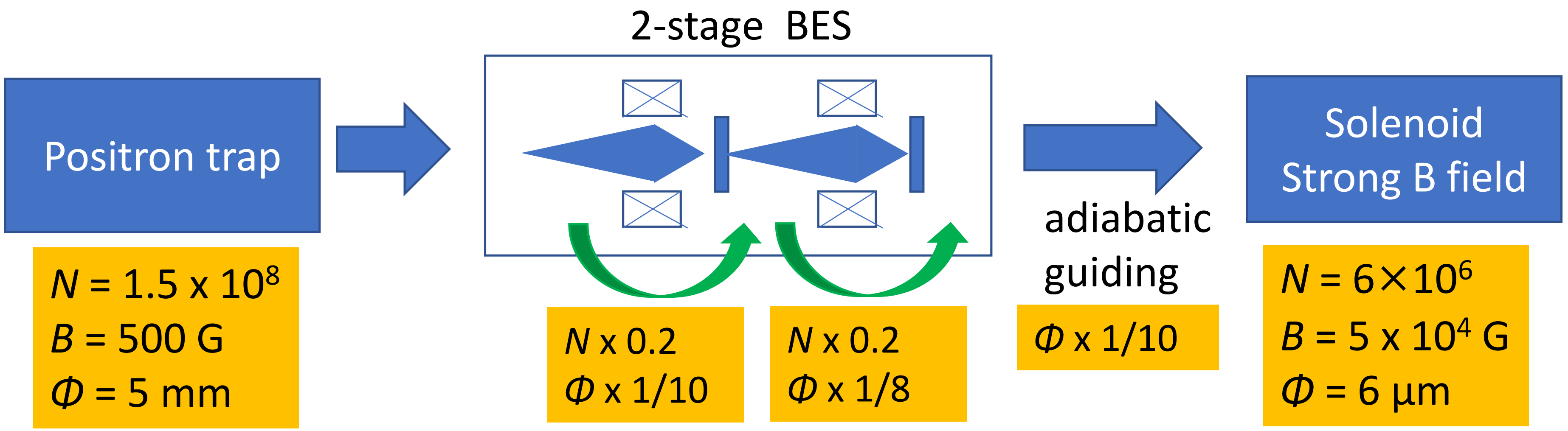
Introduction

- One of the challenges to realize positronium Bose-Einstein condensation (Ps-BEC) is to create dense Ps atoms (~10^{17} cm^{-3}).
- We achieve high-density Ps by increasing the brightness of the incident positron beam (1.5×10^8 e^+/ 50 ns bunch, 5 keV, ϕ5 mm, polarized).
- As a first step to design a dedicated positron focusing lens for Brightness Enhancement System (BES), we started with focusing positron beams using a magnetic lens prototyped by AIST.
- We conducted a positron focusing test experiment at KEK Slow Positron Facility (SPF).
- We tried to reproduce the results by simulations for future improvements of BES.

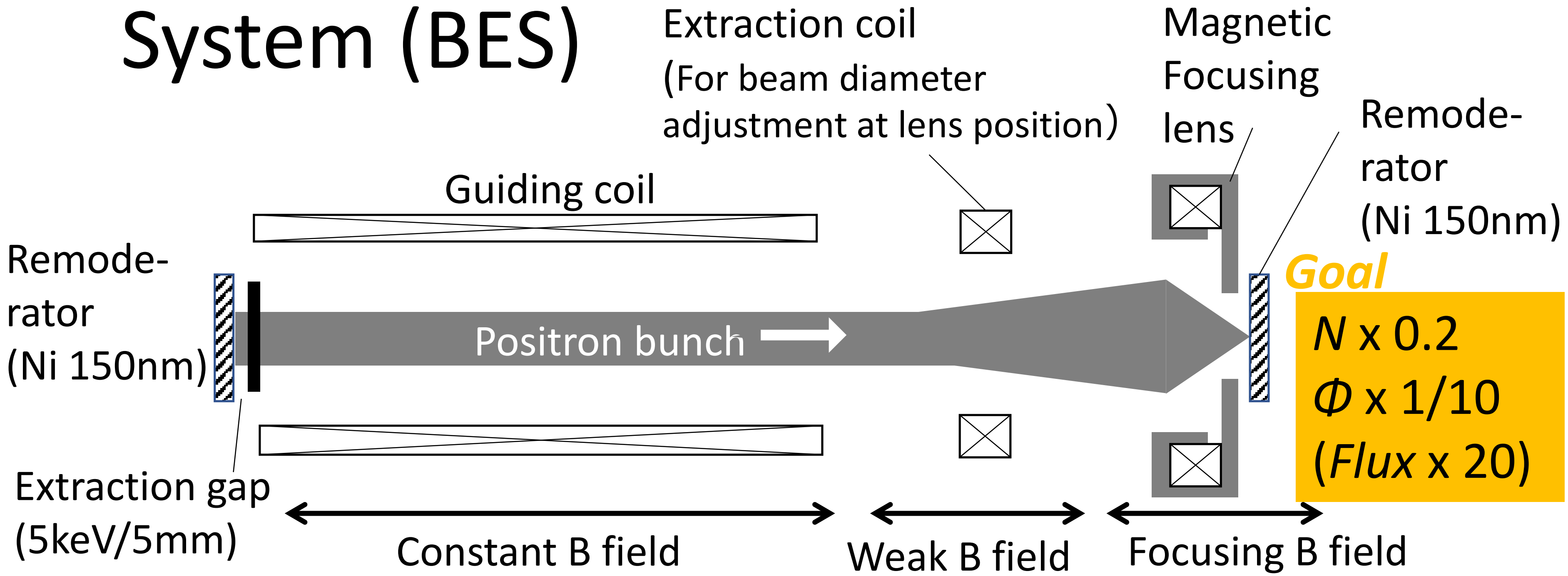
Our method to achieve dense enough e^+ bunch for Ps-BEC

Trap → 2-Stage Brightness enhancement system (BES) → Solenoid (strong B fields)



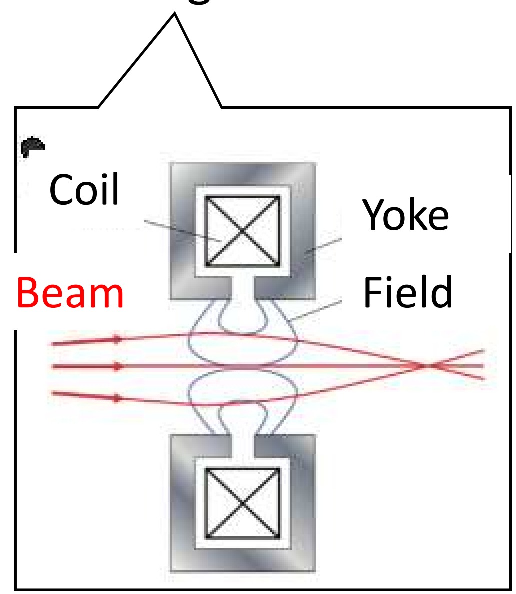
We have shown that a high-enough density for Ps-BEC could be reached by the model.
We have considered (1) space charge limited current density (Child-Langmuir law), (2) Brillouin flow, and (3) the beam envelope equation including space charge effect. (N. Oshima, ICPA-18)

Positron Brightness Enhancement System (BES)

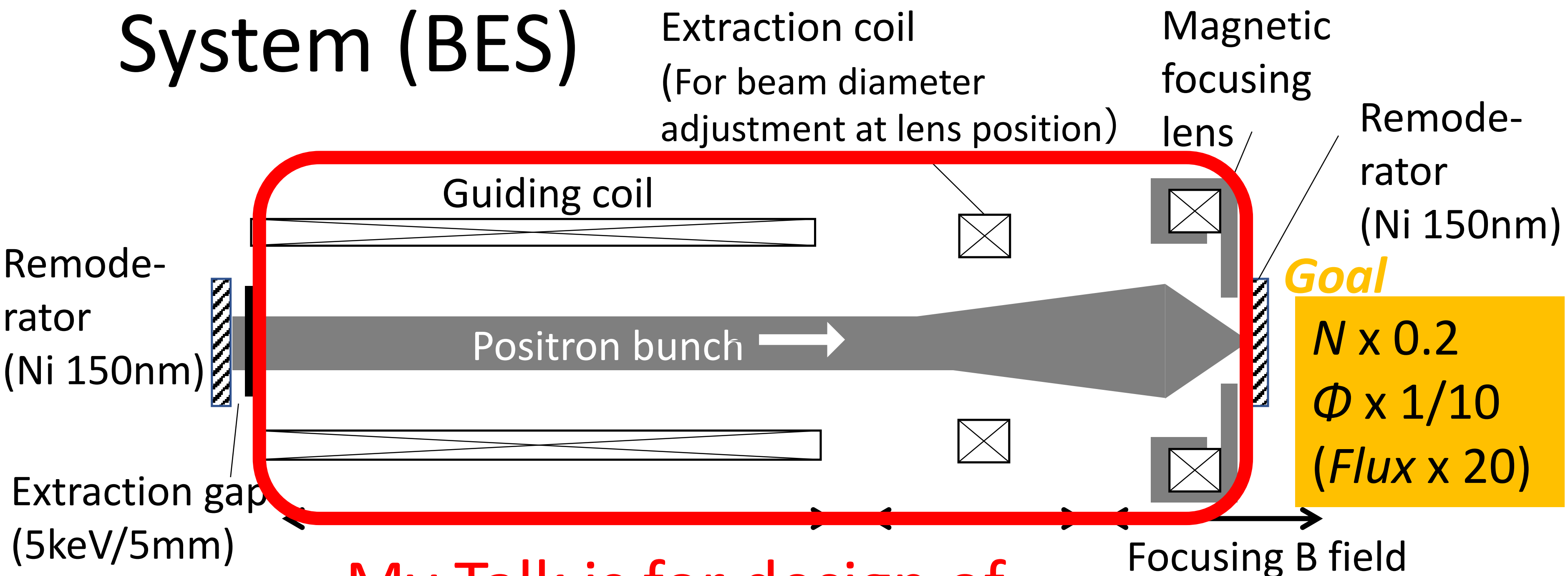


- This system consists of solenoids and a magnetic focusing lens

1. slow positron beam is magnetically guided with solenoids.
2. The beam is extracted from the constant B field to the weak B field
3. The beam is focused by the magnetic focusing lens

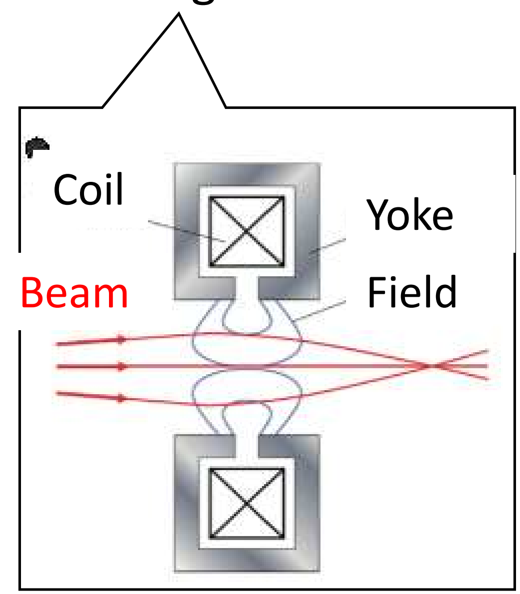


Positron Brightness Enhancement System (BES)

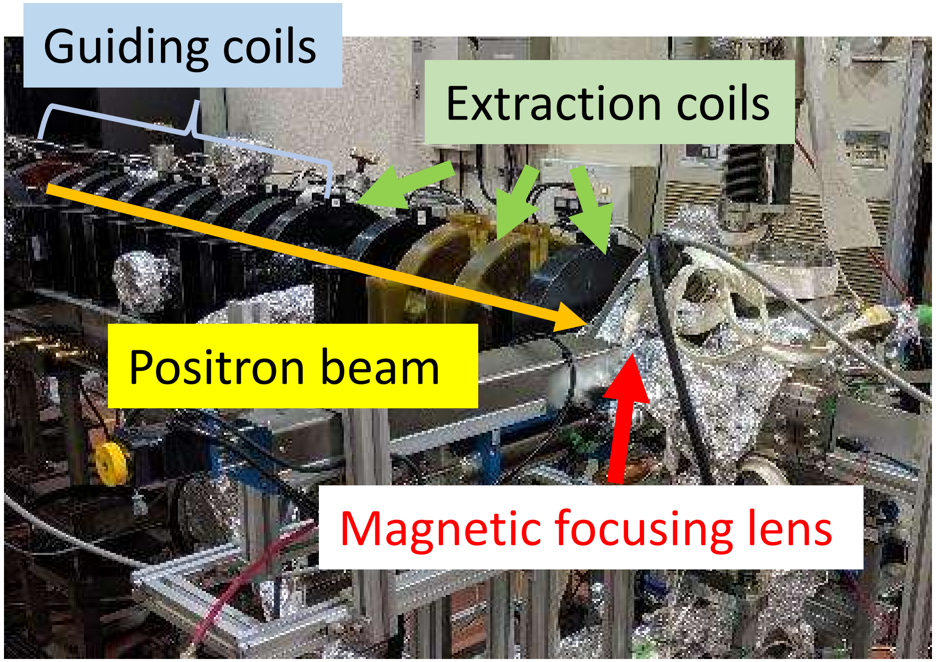


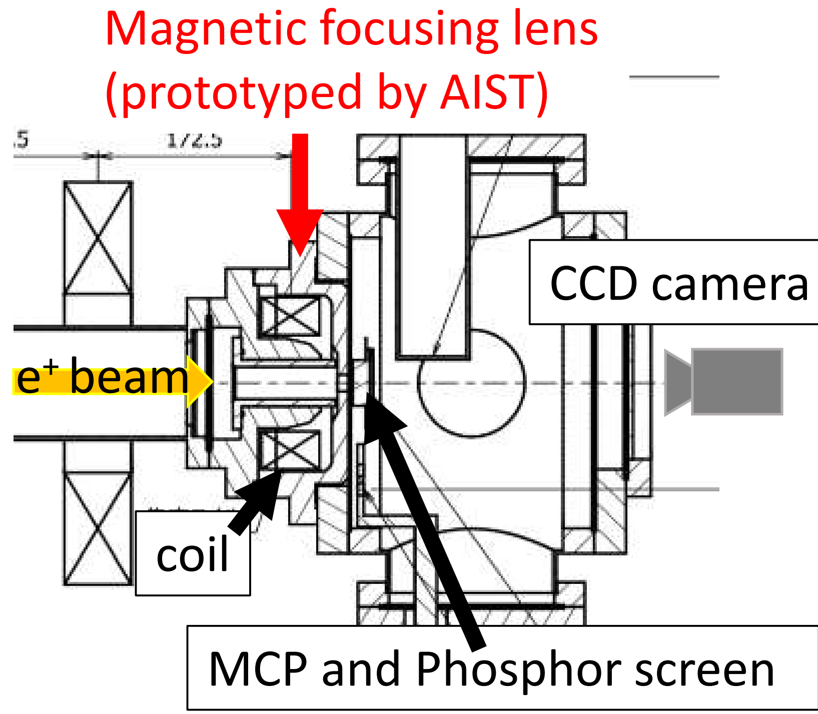
My Talk is for design of magnetic focusing lens.

1. Positron focusing test experiment at KEK-SPF.
2. Comparison of experimental data with simulation.



Positron focusing test experiment at KEK Slow Positron Facility (SPF)



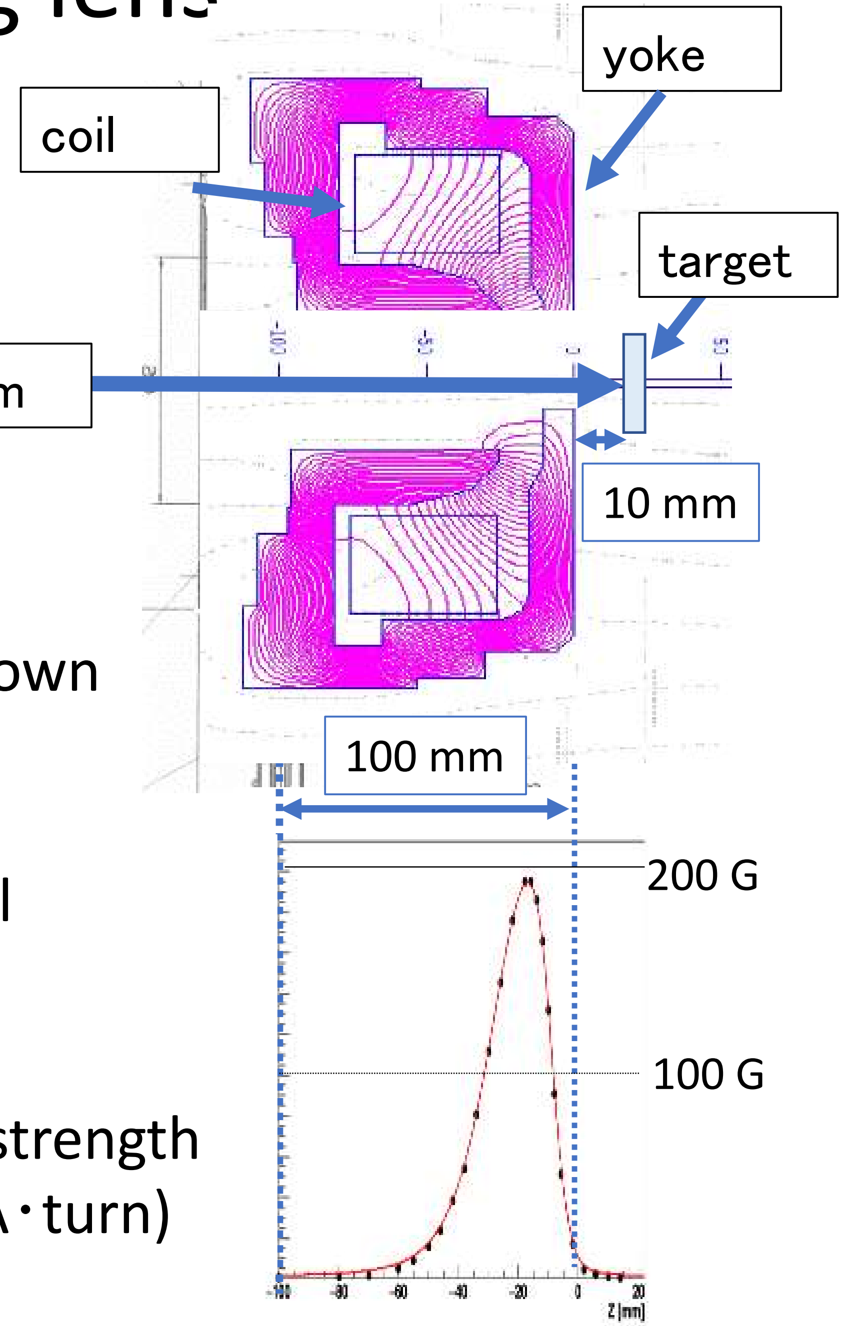


Beam profiles

- Energy : 5keV
- Intensity : $5 \times 10^5\ e^+/s$
- Pulse repetition : 50 Hz
- Pulse width : 16 ns

We observed the image of MCP / Phosphor screen recorded by a CCD camera.
This focusing lens will be used for Ps laser cooling experiment at the same beamline if it has a good enough performance.

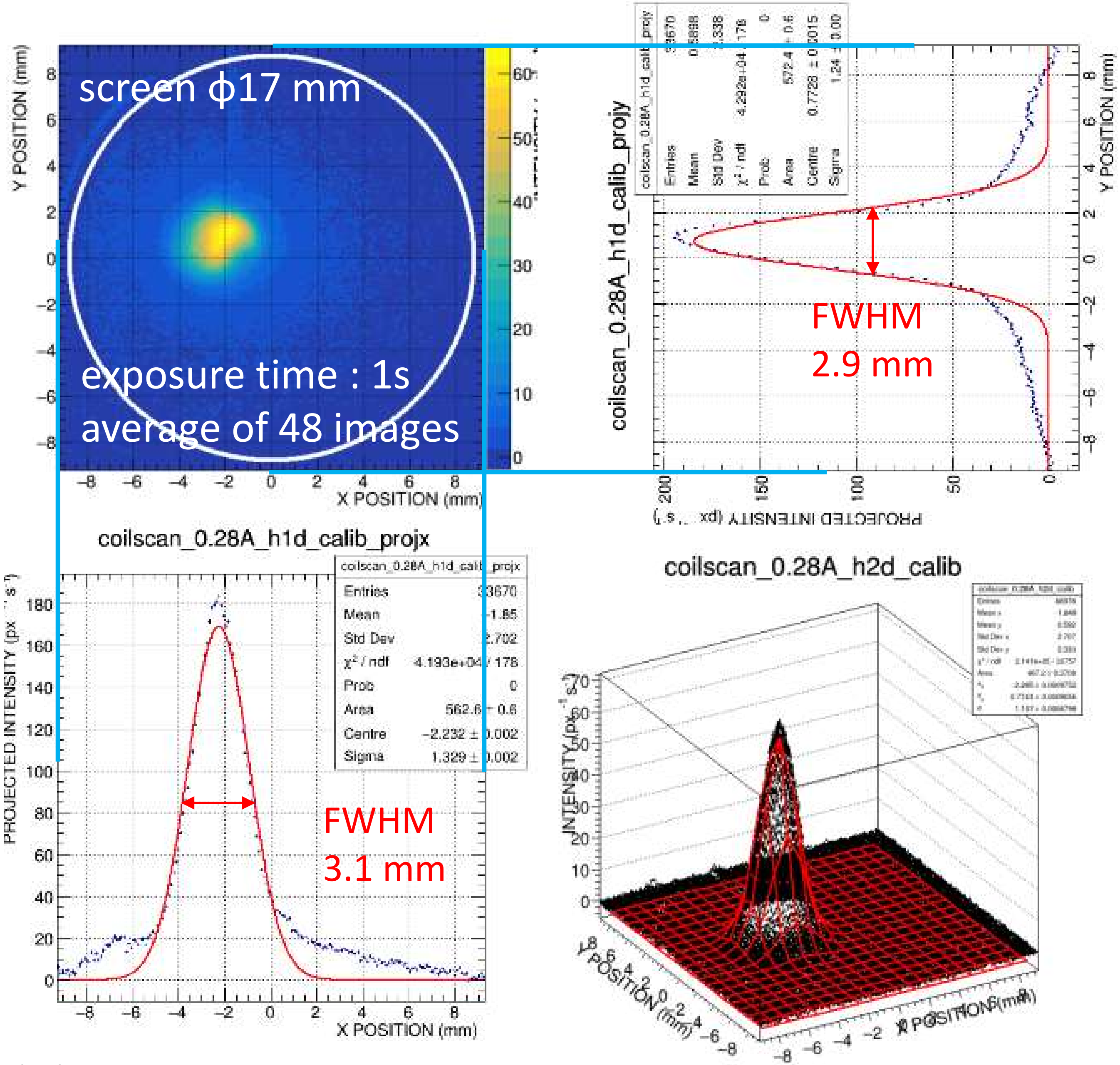
Magnetic Focusing lens profile



- A magnetic focusing lens consisting of a yoke and a coil creates a magnetic field as shown in the figures.
- By changing the current, we can change the beam focal points.

Magnetic field strength at 0.28 A (470 A・turn)

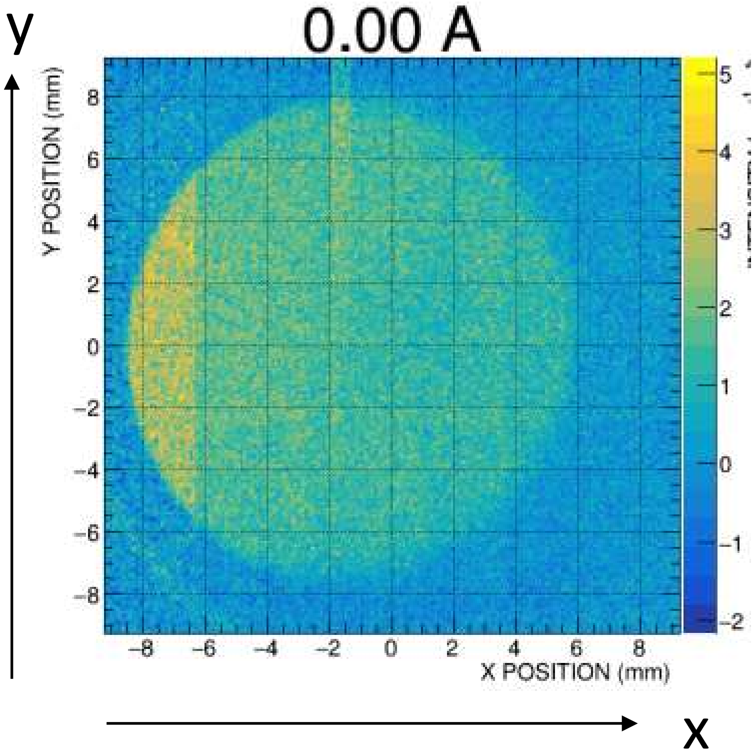
Obtained beam profile @0.28 A (470 A･turn)

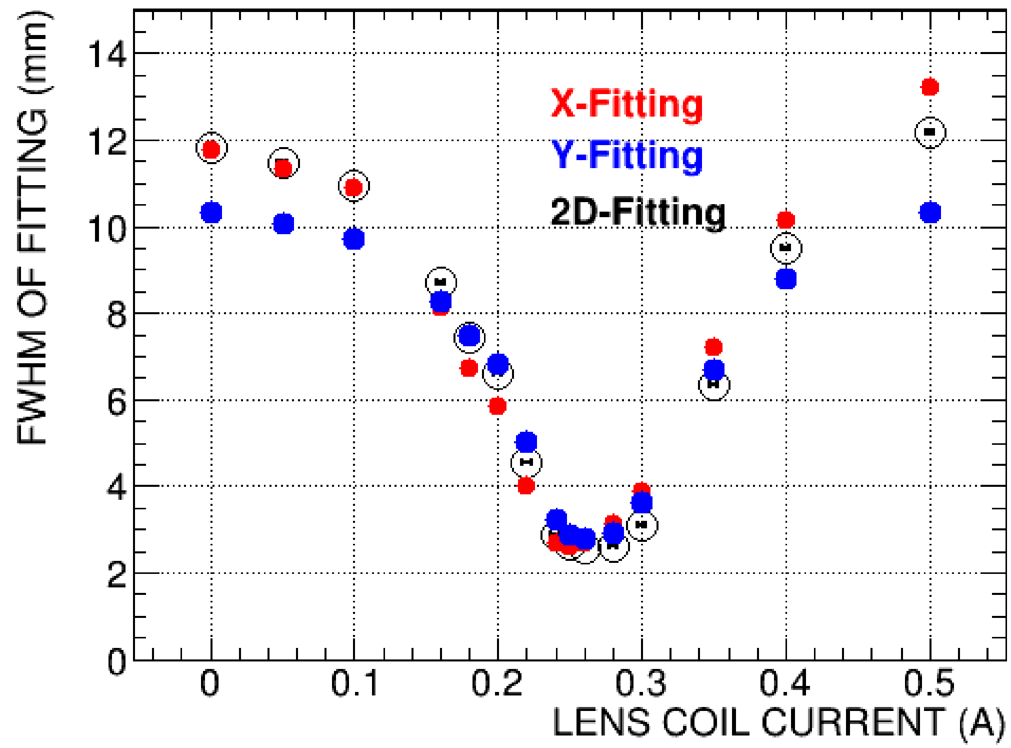


- The beam size was measured by fitting with a Gaussian to the X-projection, Y-projection and 2-D image of the focused beam profile.
- In the following, we use the full width at half maximum (FWHM) as the beam diameter and use the integral of the profile as the beam intensity.

The beam diameter was minimized to 2.6 mm.

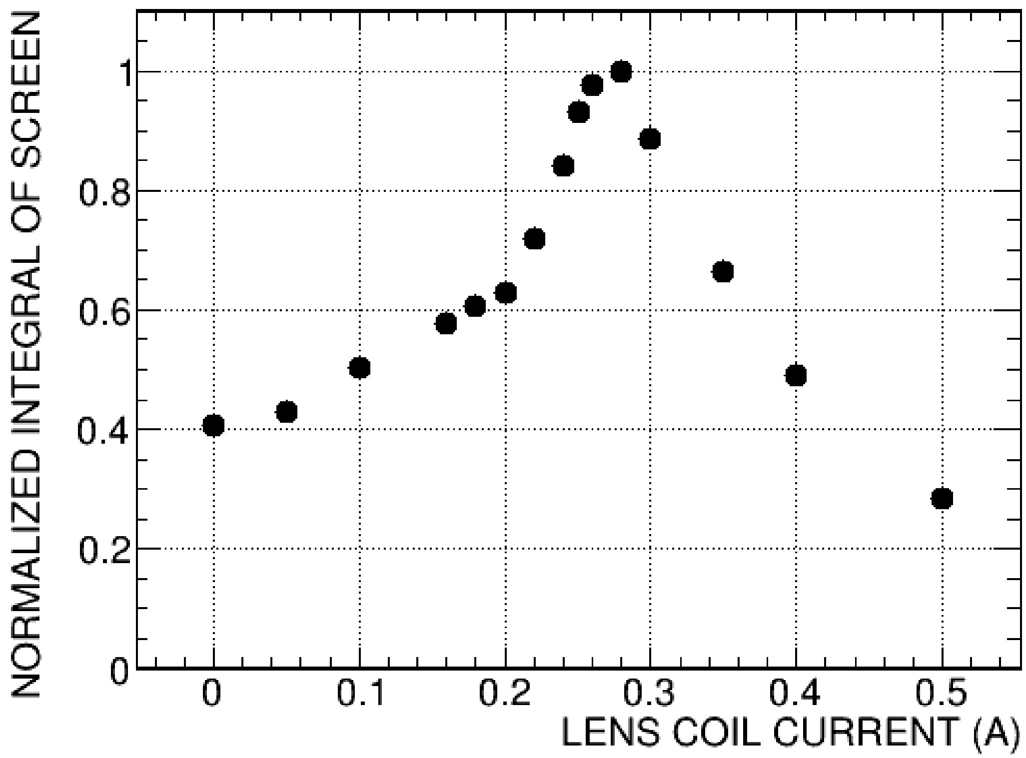
CCD image





- The obtained beam diameter is plotted for various currents.
- Minimum beam diameter: x direction: 2.6 mm (@0.25 A)
  y direction: 2.8 mm (@0.26 A)
  2D-fitting: 2.6 mm (@0.26 A)

Most positrons reached the MCP screen at 0.28 A lens coil current.



- The obtained normalized beam intensity is plotted for various currents.
- At 0.25—0.26 A the most focused beam was obtained, but at 0.28 A, the number of positrons reached on the screen was the largest.

Simulation

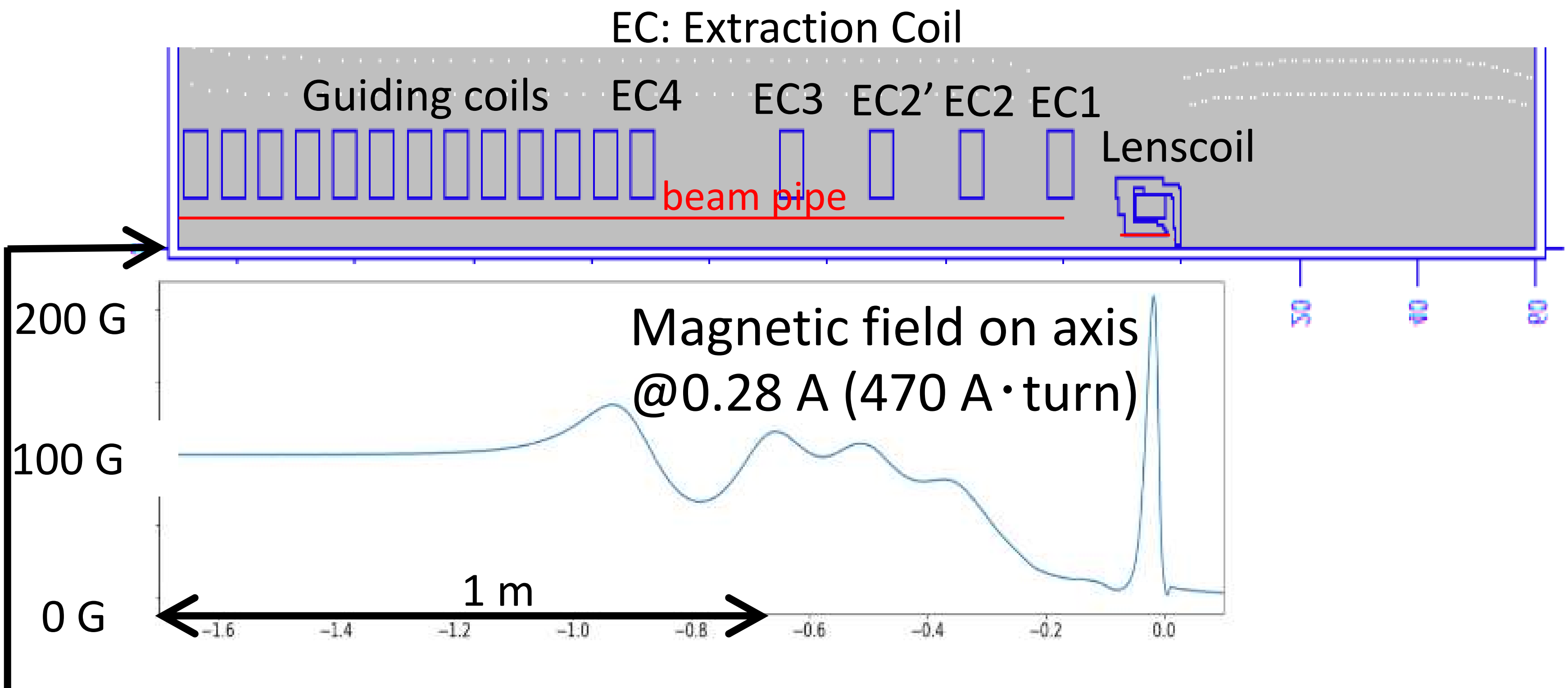
- We tried to reproduce these data (beam diameter, intensity) by simulations for validation of our simulation.
- We can also precisely understand the KEK-SPF beam profile for future Ps laser-cooling experiment.
- This is our first step to design BES for Ps-BEC using simulations.

We performed simulations for reproduction using the following software.

- **Poisson Superfish**: collection of programs for calculating electromagnetic fields
- **General Particle Tracer (GPT)**: simulation package for designing accelerator and beamline by solving 3D charged particle motion in an electromagnetic field

Initial beam profile and transverse momentum spread were treated as free parameters and tuned to reproduce the experimental result.

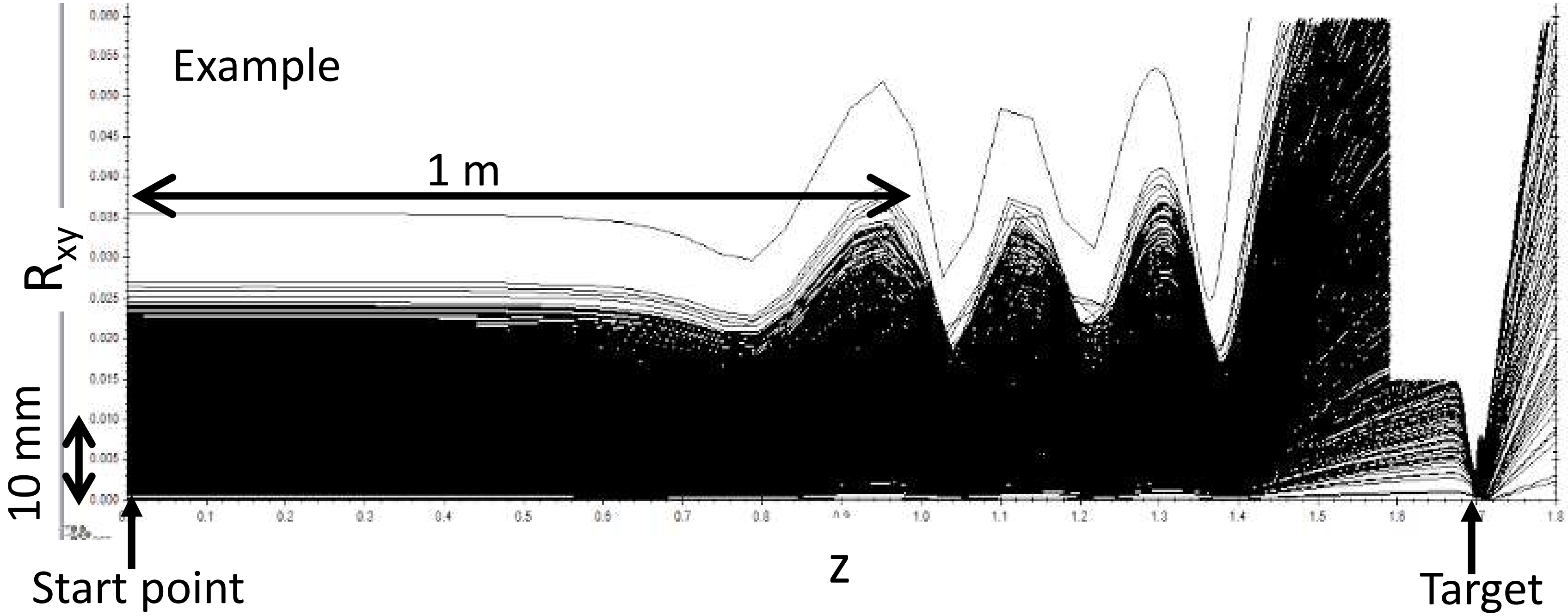
Geometry and magnetic field



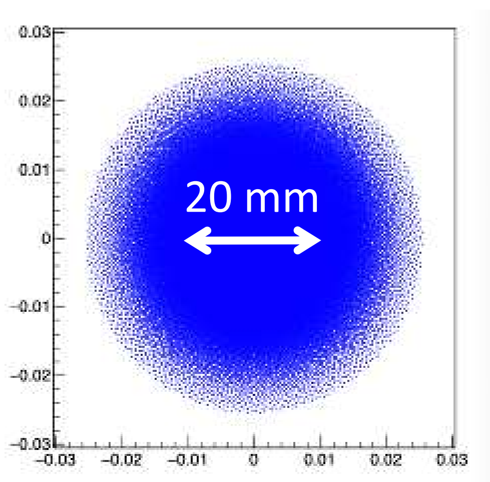
Free parameters (tuned values)

- Initial beam size (ϕ20 mm)
- Transverse momentum spread (120 eV)
- Average beam energy (4.9 keV)

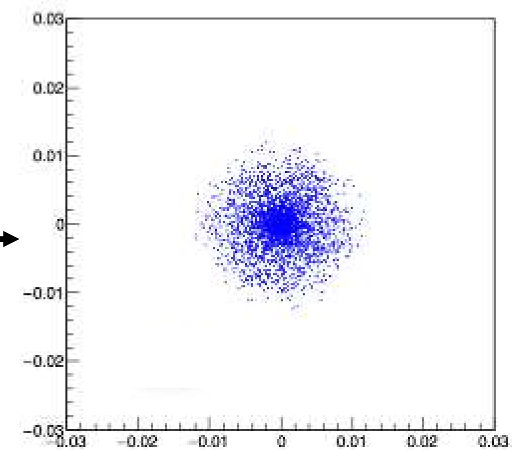
Obtained track and beam profile by GPT



We used Gaussian distribution (FWHM = 20 mm) for initial beam profile.

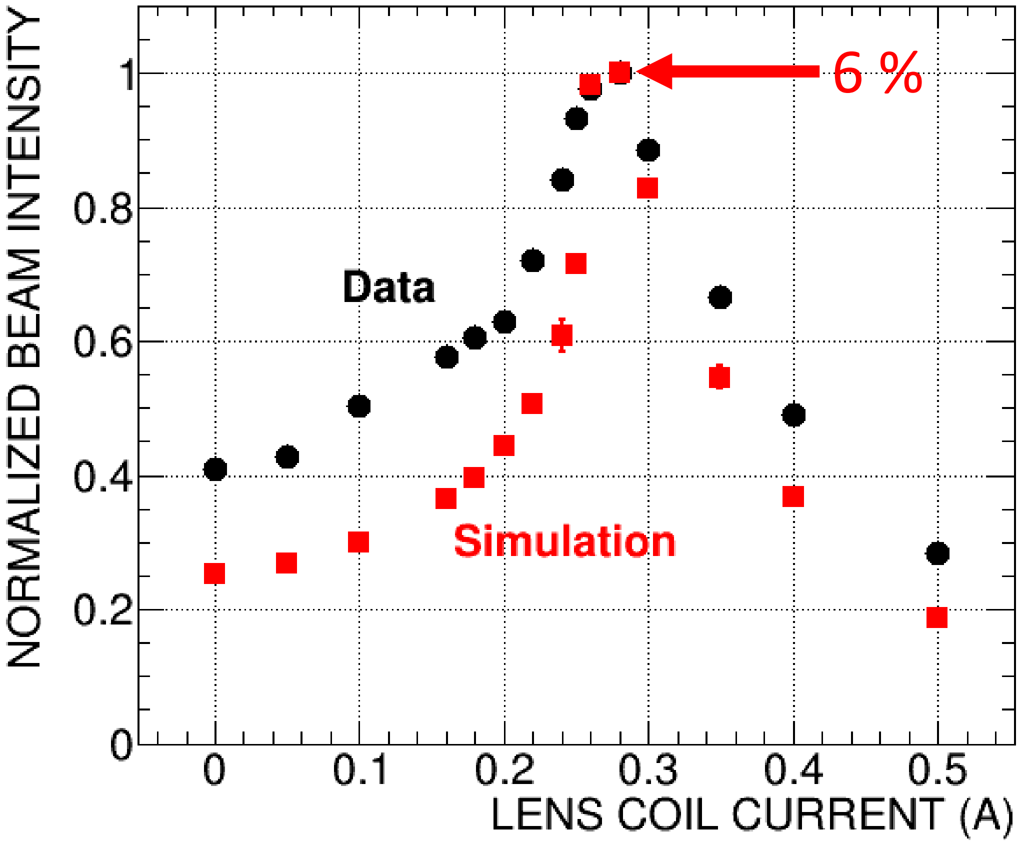


Beam profile @start



Beam profile @target

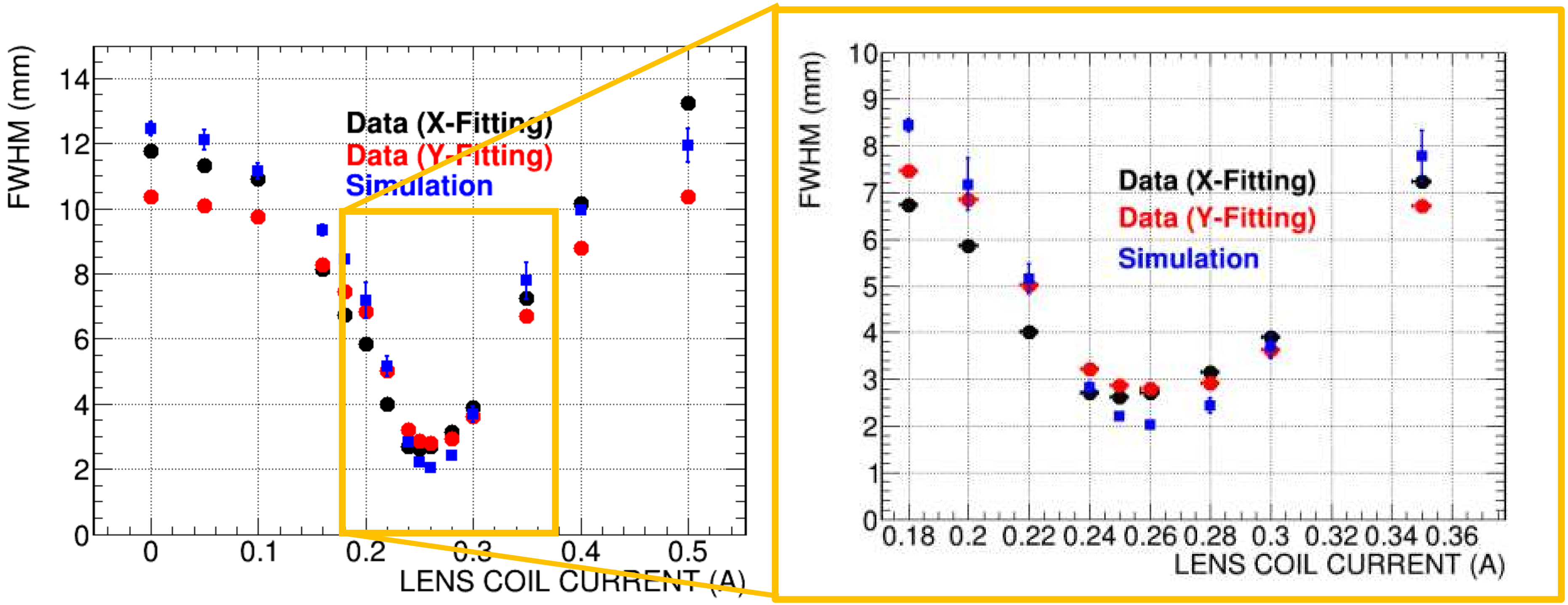
Normalized beam intensity vs. lens coil current



Plotted the beam intensity normalized by the value at 0.28 A.

- Around 0.28 A, the simulation can roughly reproduce the results.
- In the simulation, about 6% of the initial positrons are focused on the screen. This means the flux of the beam was increased by a factor 3.5 using focusing lens.

Beam diameter vs. lens coil current



- Plotted the beam diameters.
- The simulation can roughly reproduce the experimental results.
- Simulations were slightly more focused than data at around 0.26 A.

Current status of the simulation

- Our simulation can roughly reproduce the experimental result.
- There is some discrepancy on the beam intensity.
- The beam is more focused in the simulation than the data.

Possible future improvements of the simulation

- Further parameter tunings.
- Include the misalignment effect in the simulation.
- Include the space charge effect in the simulation.

Future prospects

1. For Ps laser cooling experiment which will be performed at KEK-SPF by next April
   - Improve the simulation in order to understand the property of the positron beam at KEK more accurately.
   - Optimize the experimental setup using the simulation and check if Ps laser cooling can be performed using the prototype focusing lens. If not, develop a dedicated focusing lens for Ps laser cooling.
2. For development of BES for Ps-BEC
   - Improve the design of the focusing lens for BES using the simulation.
   - Obtain the beam-quality requirements for Ps-BEC experiment.
   - Fabricate a prototype positron focusing lens within a year and test it using KEK or AIST positron beam.

Summary

- We will develop a positron Brightness Enhancement System (BES) to realize Ps-BEC.
- We conducted a positron focusing experiment with prototype magnetic focusing lens at KEK-SPF and confirmed the focusing of a slow positron beam.
- The beam flux was multiplied by 3.5, and the beam was focused to 2.6 mm FWHM.
- The simulation was able to reproduce the experiment roughly at average beam energy = 4.9 keV, transverse momentum spread = 120 eV, and initial beam diameter = 20 mm.

Future work

- Calculate the optimal parameters and the number of positrons expected to be obtained for the Ps laser cooling experiment.
- Design a lens with better performance for BES.