Status and Operational experience of the SuperKEKB positron source

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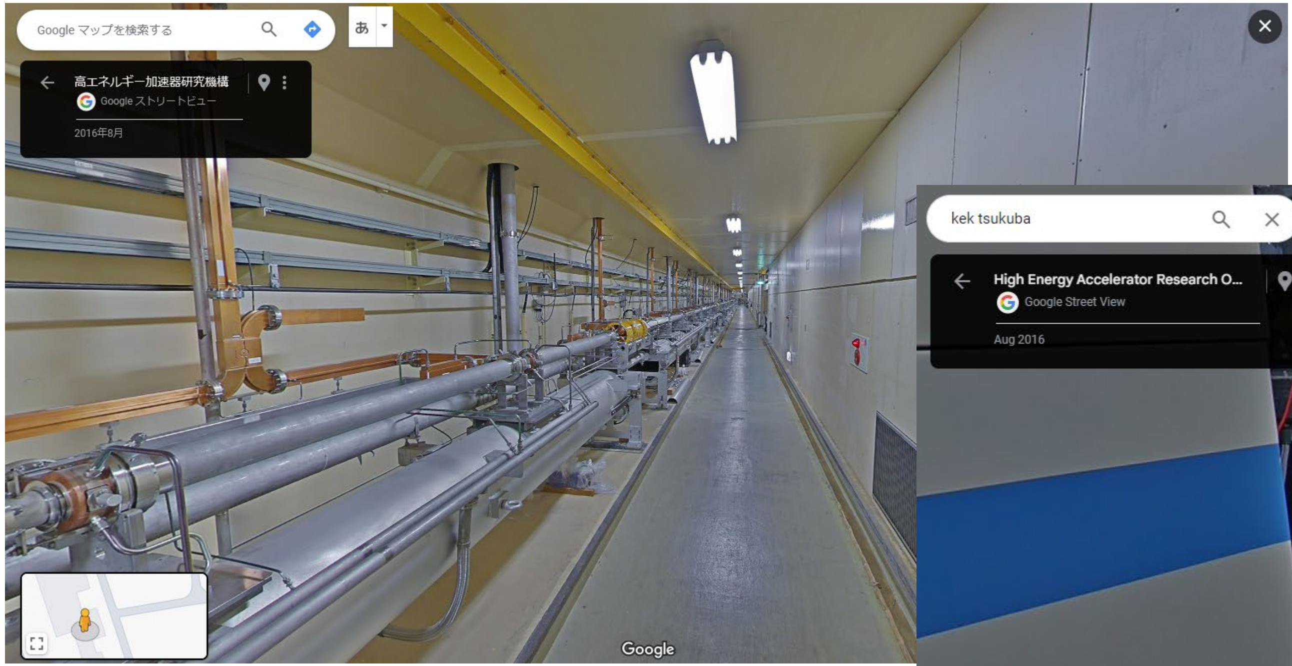
Overview of KEK e+e-Linac and Positron Production

Google Street View@KEK

Zoom and click around here

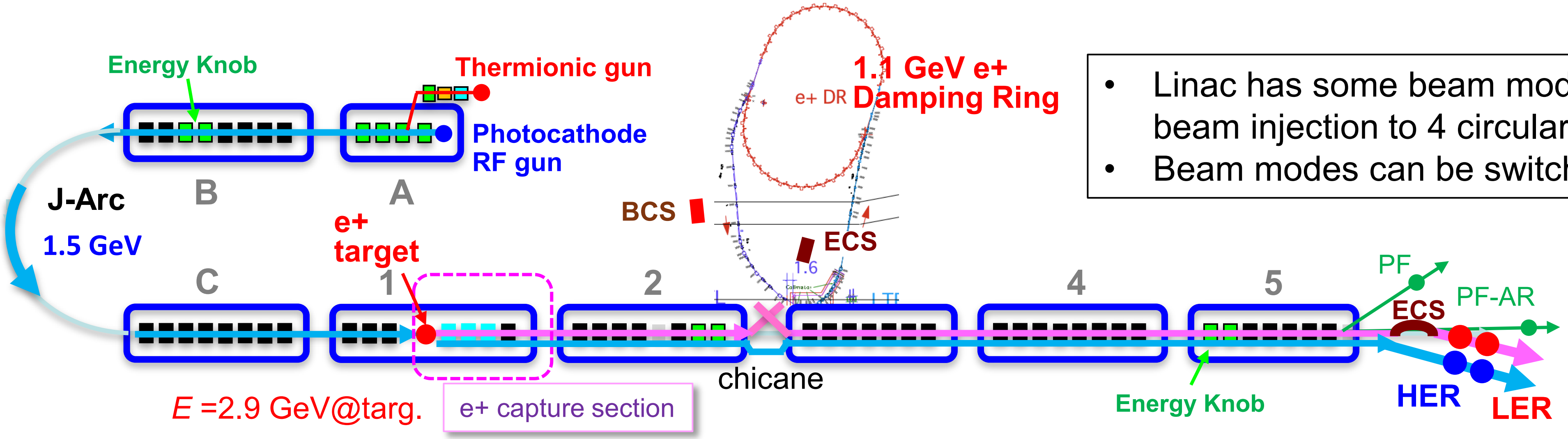
Linac Tunnel

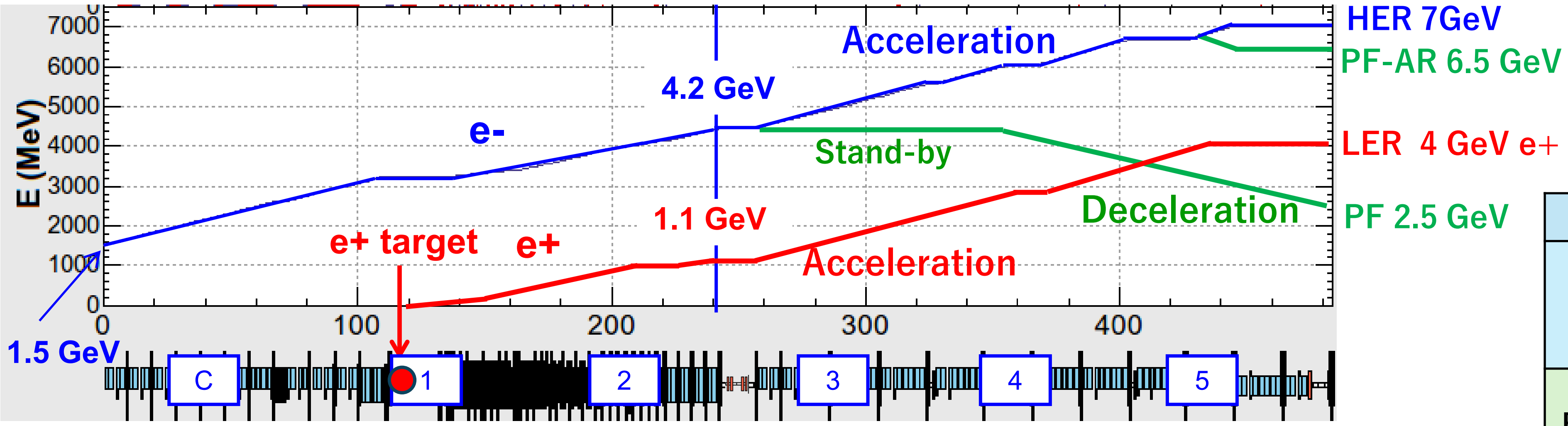


You can see the inside of the tunnel and Klystron Gallery

KEK Linac

- Linac has some beam modes matched beam injection to 4 circular accelerators
- Beam modes can be switched at 50 Hz



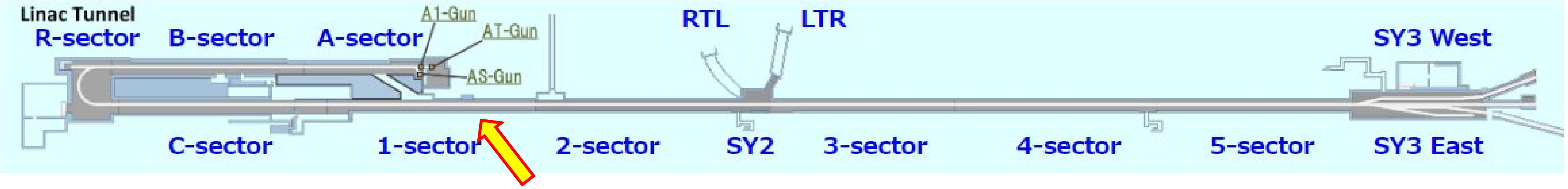


Beam energy for each beam mode along the beam line after the J-Arc.

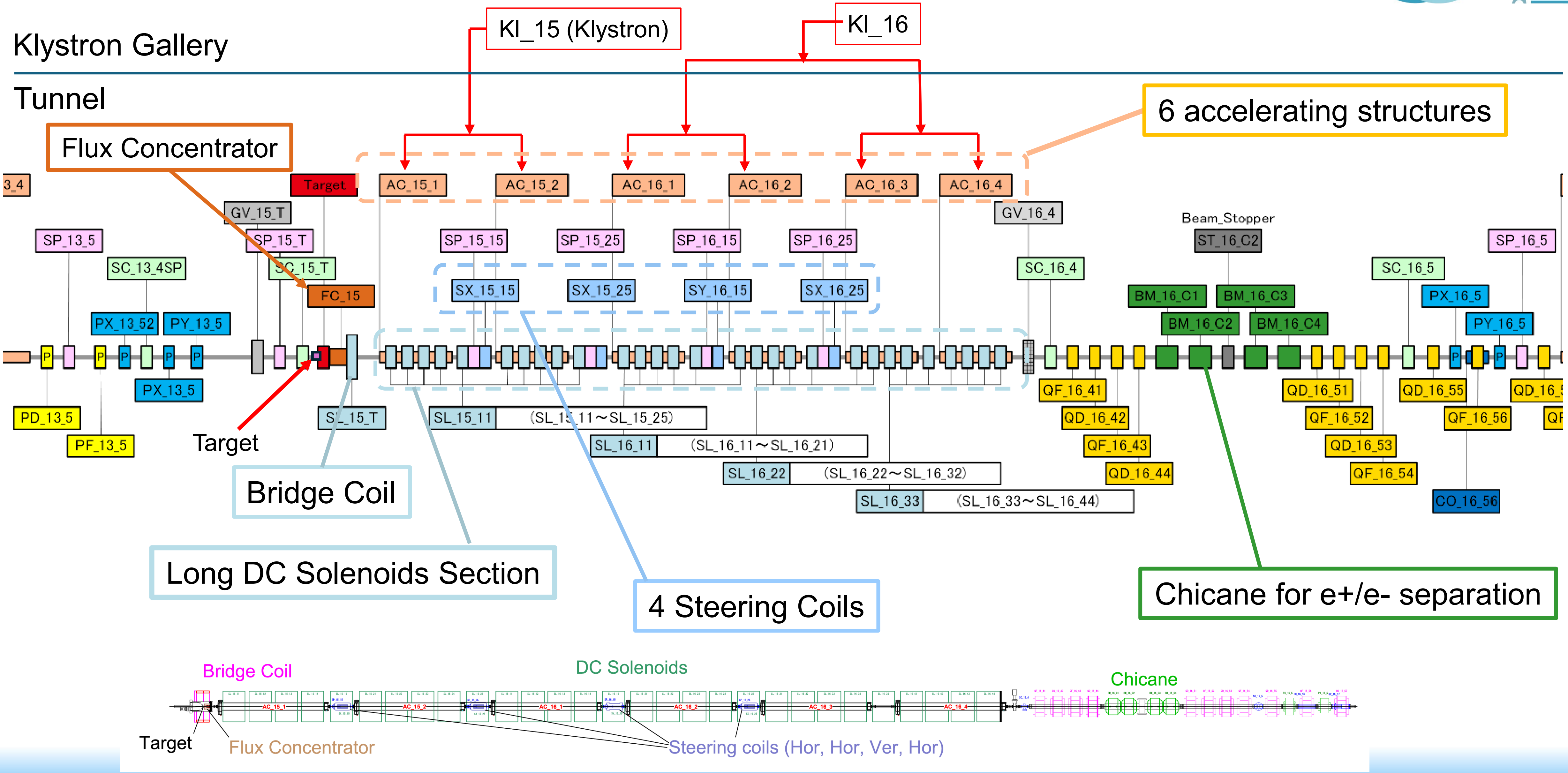
Bunch charge [nC]

HER	2
LER	11 e- for e+ @gun exit
	3.5 nC @end
PF/ PF-AR	0.3

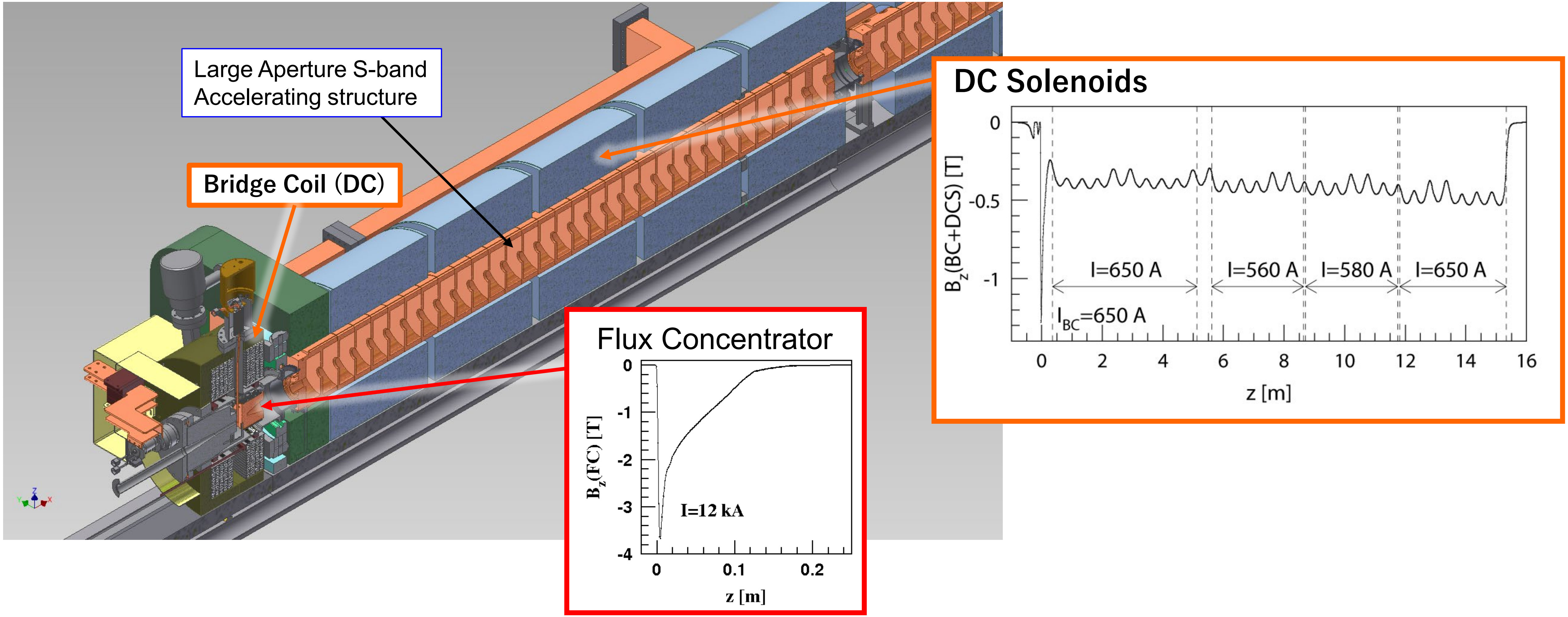
Positron Capture Section



Capture Section Layout



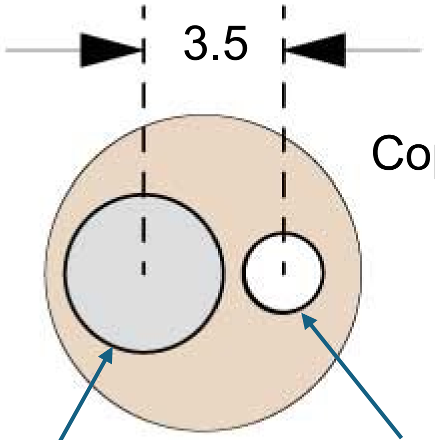
Head of e+ Capture Section



Cross-section view of the capture section

Target

Y. Enomoto



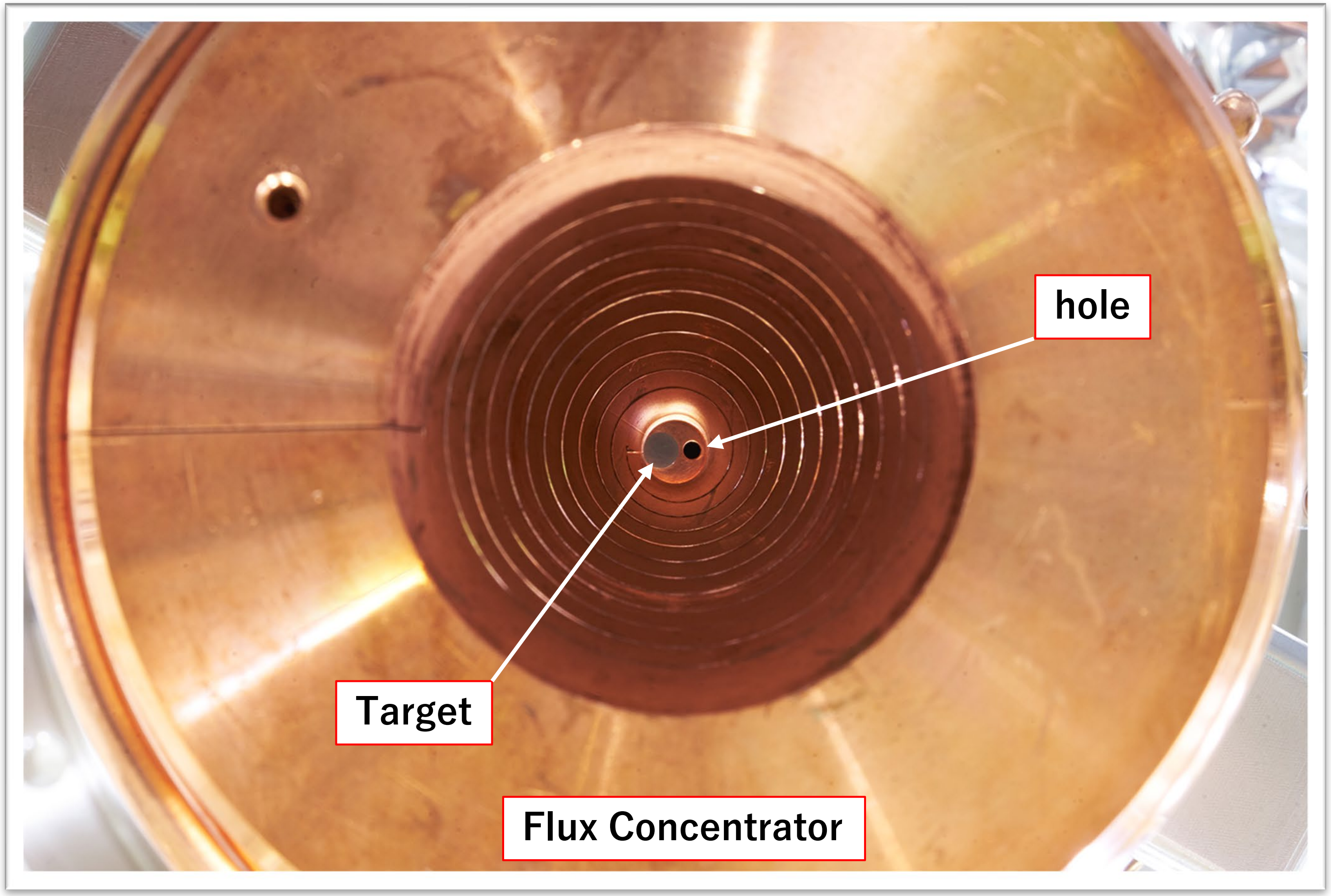
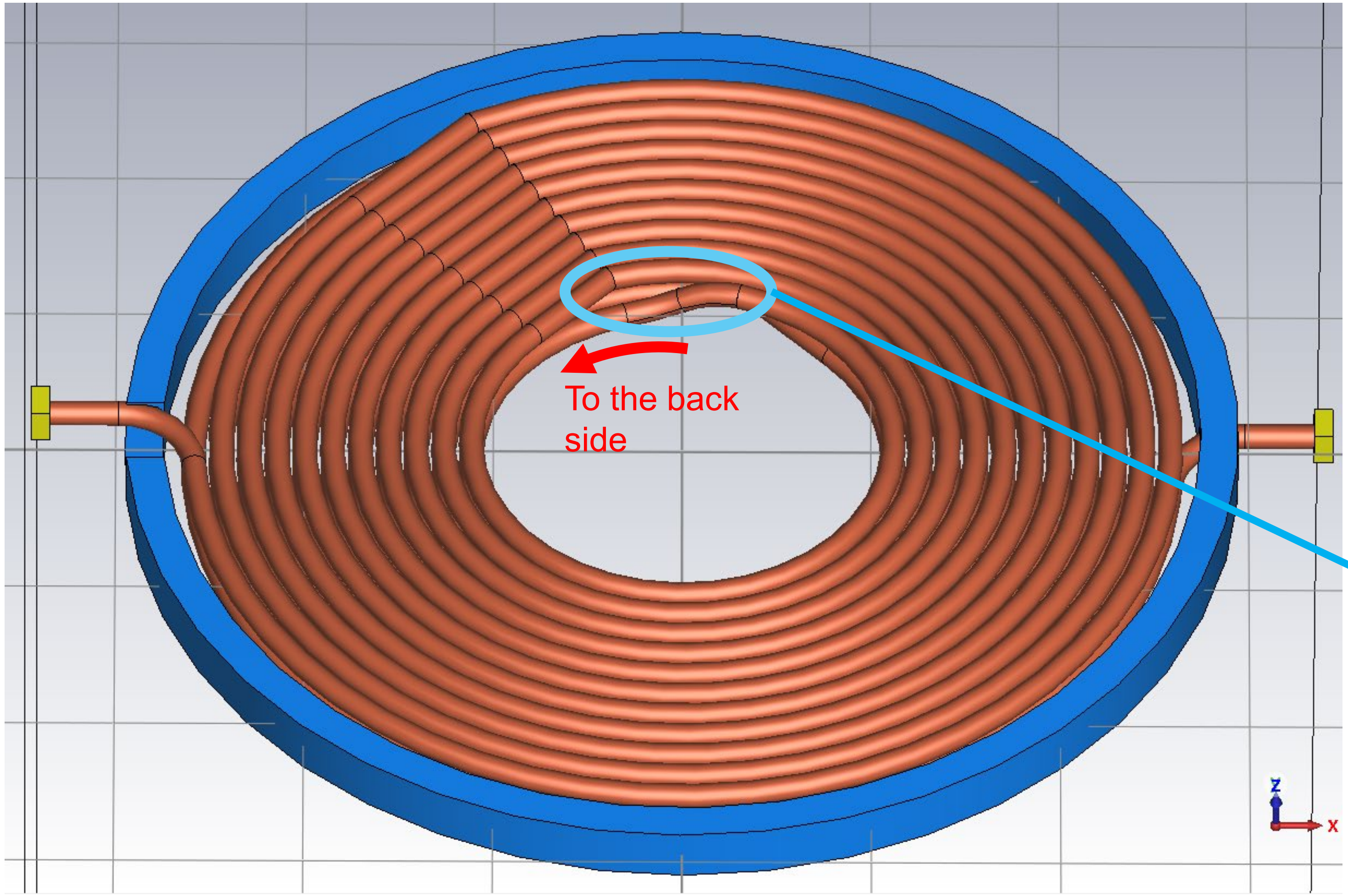


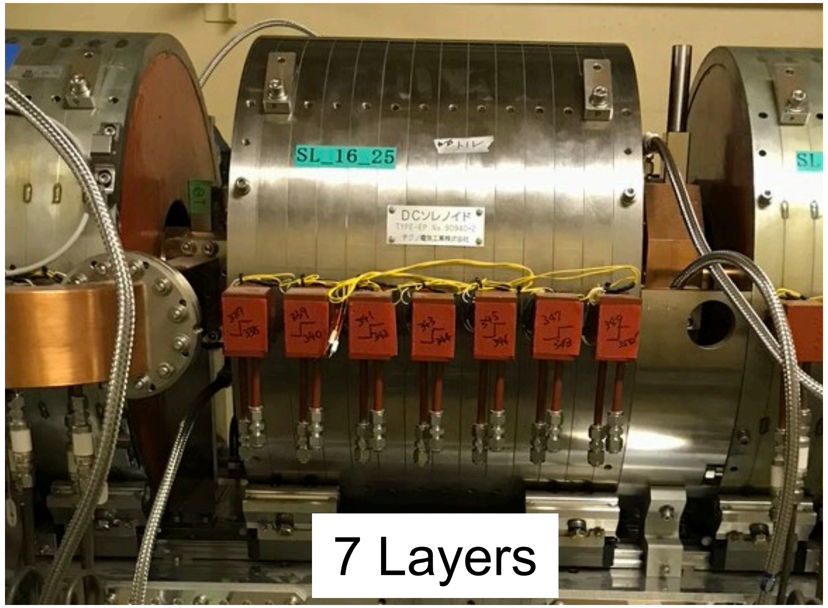
Photo looking at FC from beam exit

DC Solenoid

A. Enomoto



Two-layer structure of hollow-conductor

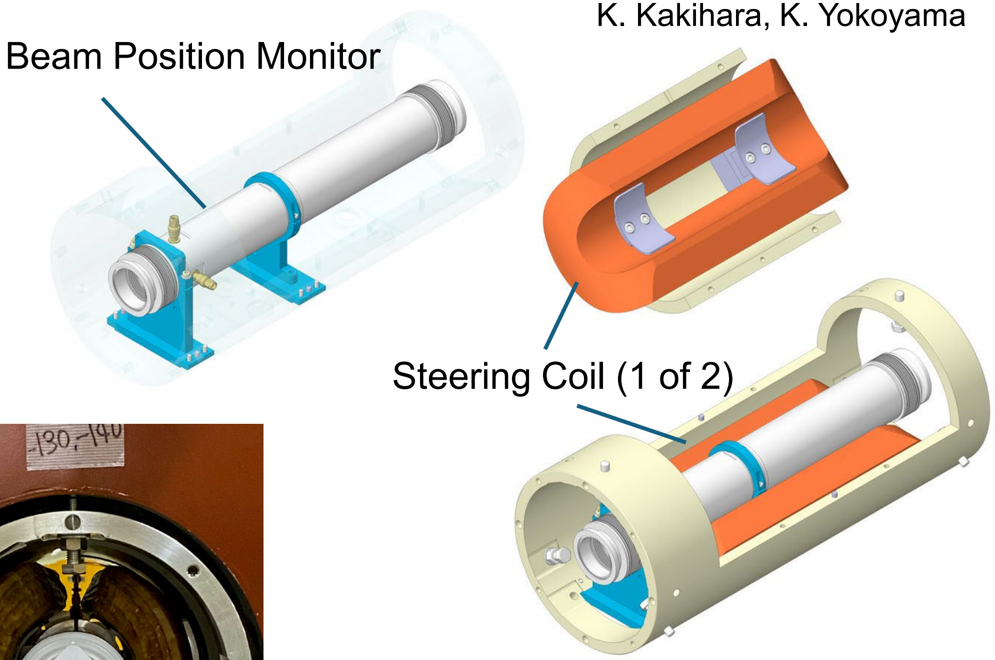


Axial symmetry of the magnetic field is broken due to this part

Steering Coils

4 Steering coils to compensate for kicks caused by non-axisymmetric magnetic fields

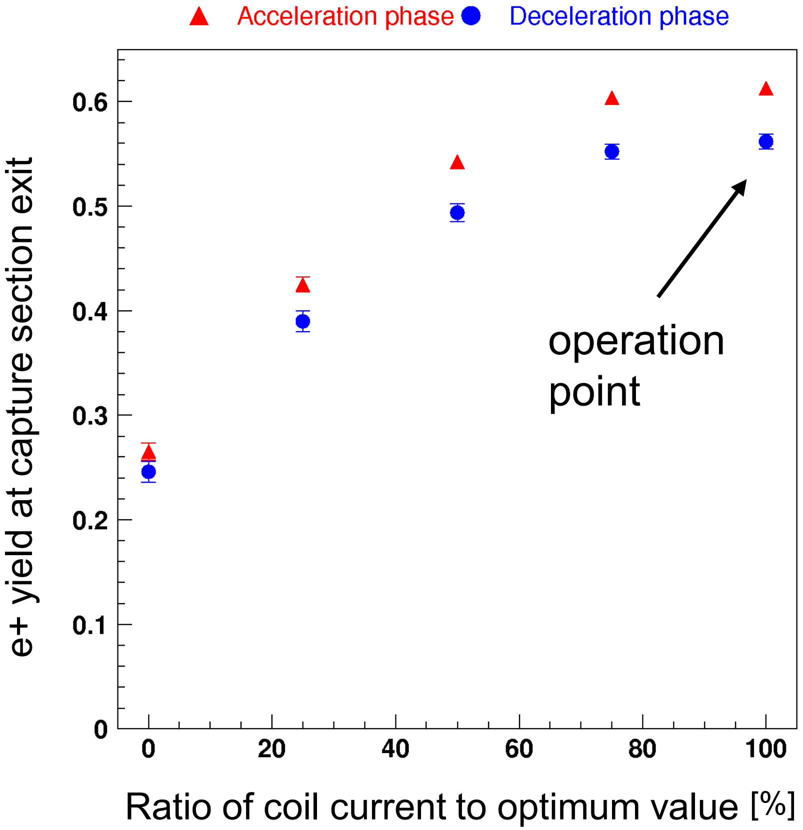
K. Kakihara, K. Yokoyama



The electron beam through the hole shifts by up to 3.8 mm compared to the solenoid OFF

⇩

Steering coils were installed in 2020.



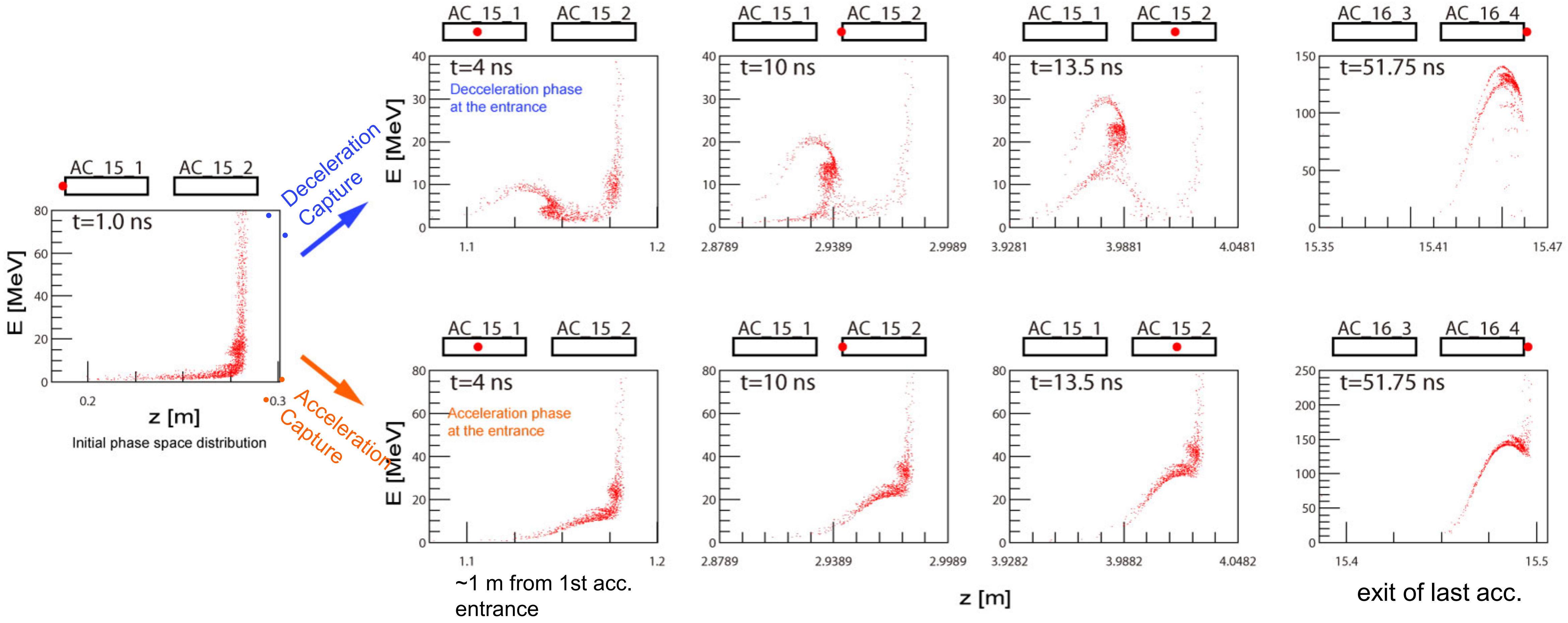
Steering coils are very important for positron capture section

Capture Section Particle Motion

1. e+ are captured in a deceleration phase of first accelerating structure
2. Decelerated e+ move to the acceleration phase

Deceleration @1st Acc. Capture

Longitudinal Phase Space



Acceleration capture has a large energy spread ⇨

- Difficult to transport beam up to DR with small beam loss.
- Beam transport line to the DR has only a 10% energy aperture

Beam line after the Cap. Sec.

Chicane for e+/e- separation
(e- beam is stopped by beam stopper)

Many quadrupoles are installed at short intervals up to the Damping Ring

Positron Beam Tuning

Beam tuning procedure

Beam tuning procedures after long-term shutdown

1. **RF phase and beam orbit rough tuning**
   → Beam reaches up to DR and Linac End (Beam loss is OK)

2. **RF Phasing**
   Change the RF phase to find the crest phase from the position change at a Beam Position Monitor where the dispersion is large

3. **Manual beam tuning**
   Operator loads previously best parameters.
   → Energy and beam orbit tuning

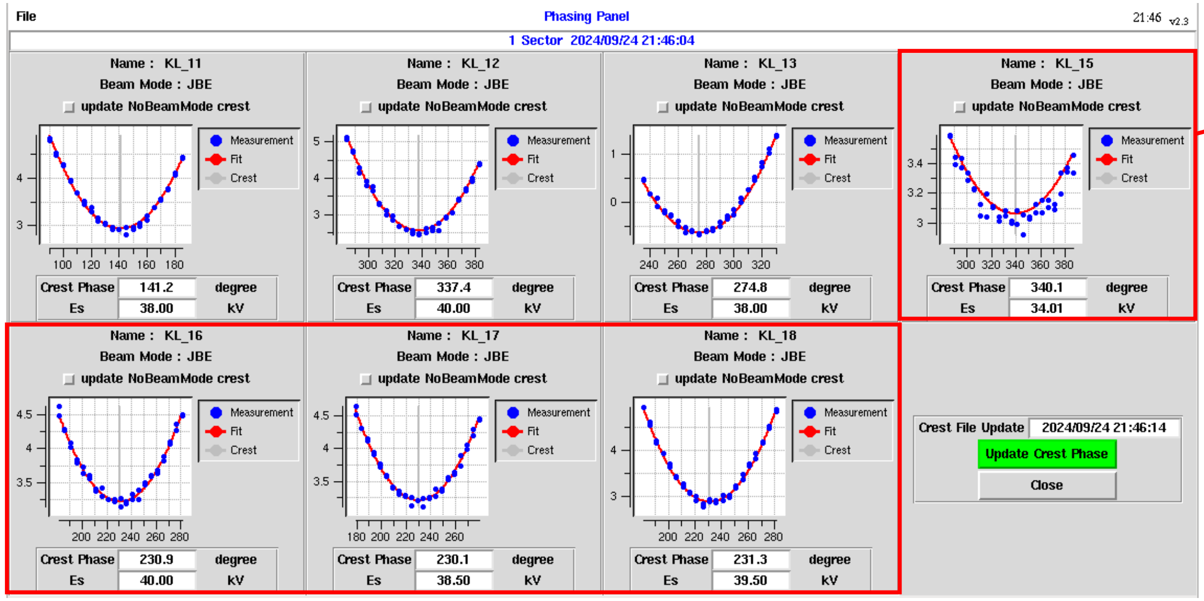
4. **Fine tuning with a machine learning (ML tuning)**

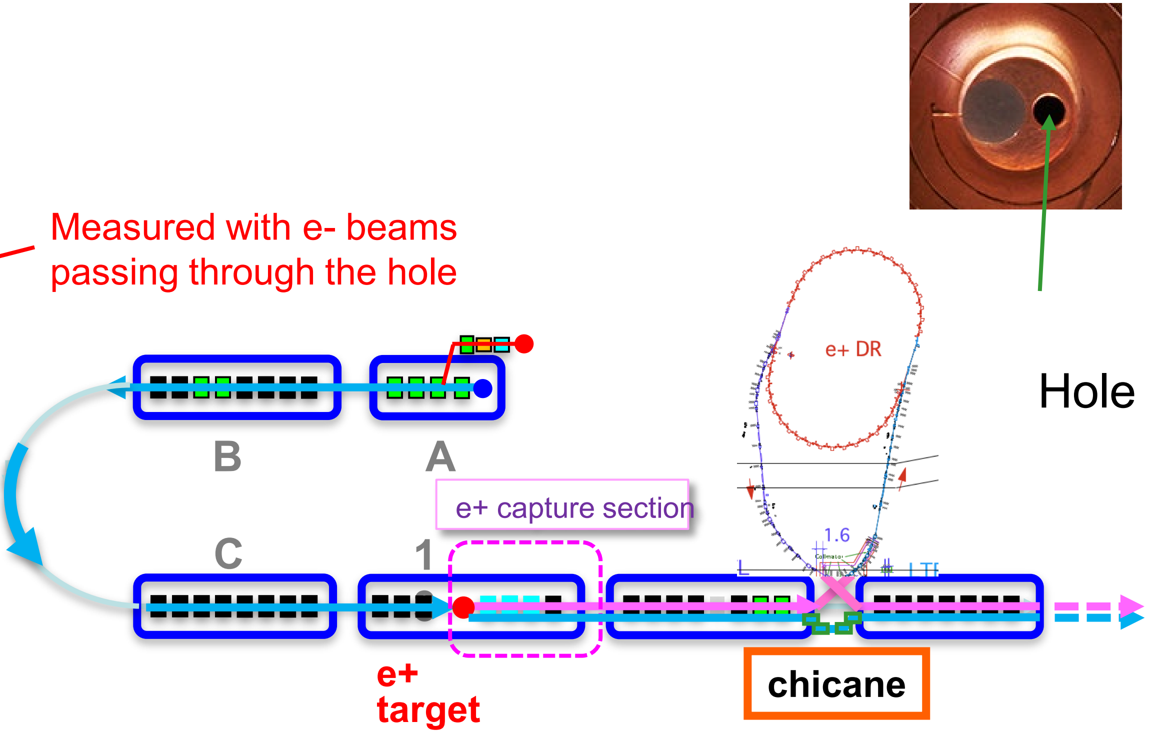
RF Phasing after the cap. section

The RF crest phase is found by varying the RF phase and measuring the beam position at location with a large dispersion function.

e+ beam in/after capture section has a large energy spread and it's difficult to transport

➔ Using low charge primary electron beams passing through the target hole
(e+ crest phase = e- crest phase + 180 deg.)



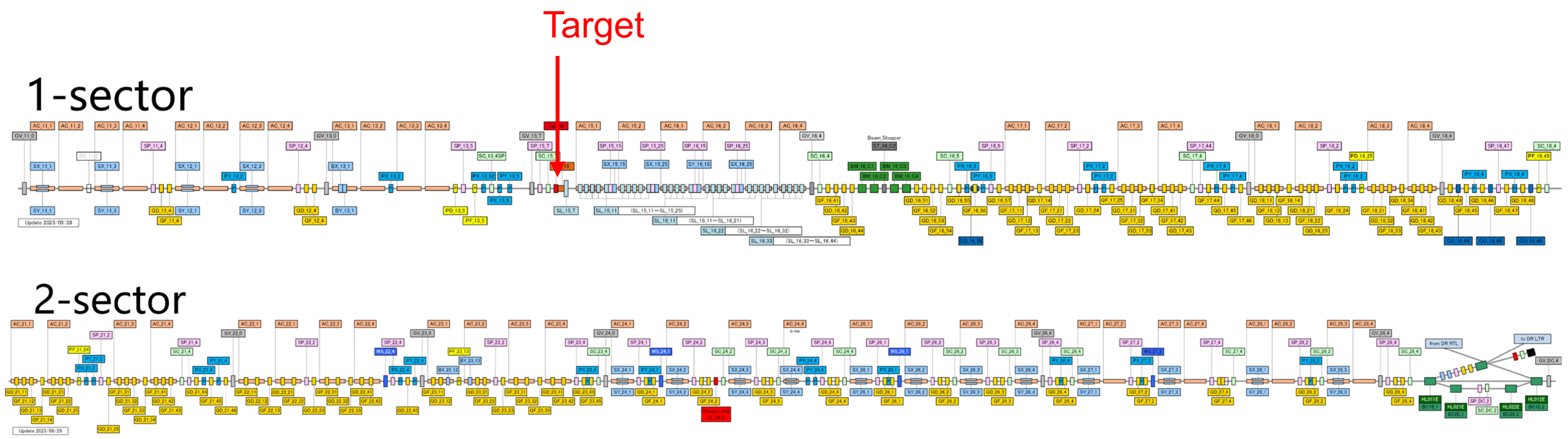


Klystron phase and e- beam position in the center of the chicane

Fine tuning with ML

Why use machine learning?

- After the capture section, energy spread, beam size and emittance are very large
  (Design optics are no longer relevant for fine tuning)
- ML tuning can be worked all the time
- ML tuning does not depend on the skill of the operator
- Too many parameters (← depends on the goal)



Linac layout from the target to switch yard to Damping Ring

Quadrupole

Dipole (streering)

~160 parameters

⇩

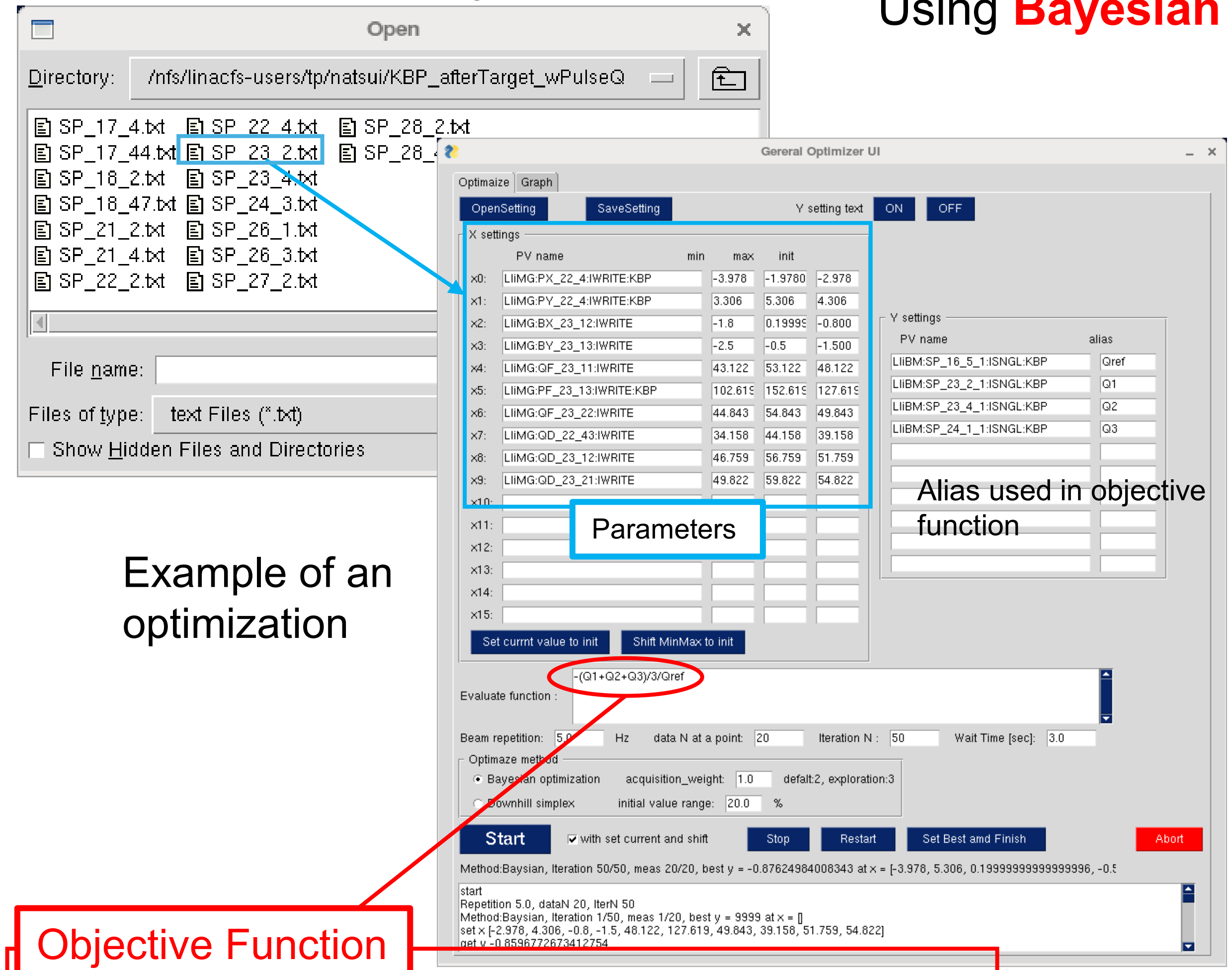
Manual tuning is almost impossible

Optimization Program

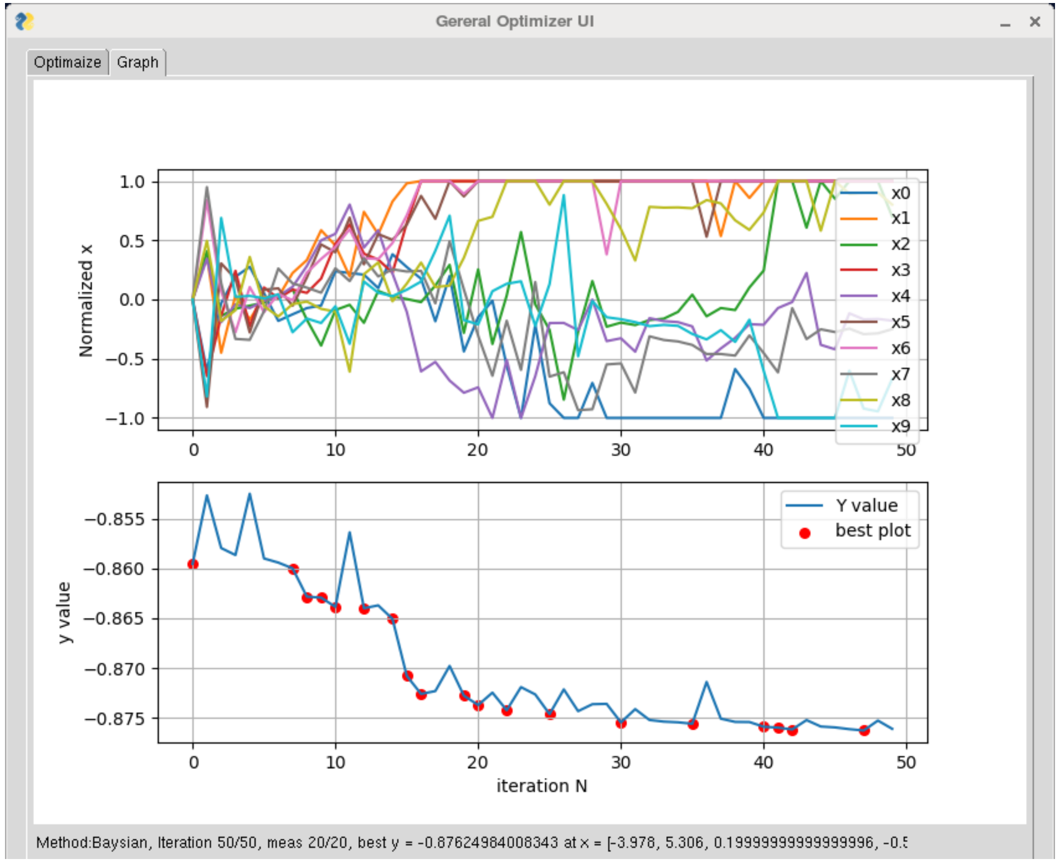
Using **Bayesian optimization**, or Downhill simplex

T. Natsui

Files with list of magnets



Example of an optimization



The process of the objective function decreasing during an optimization.

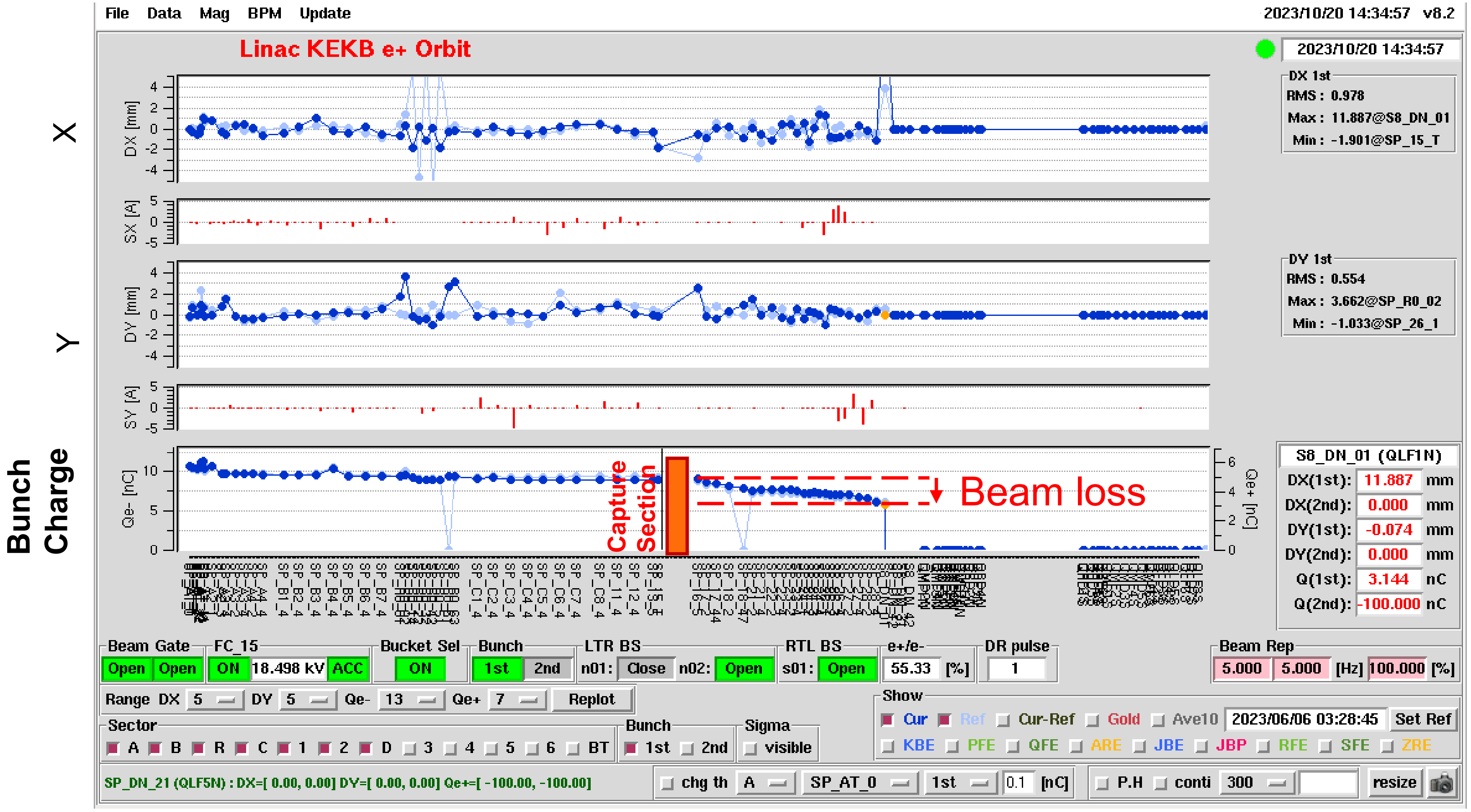
Objective Function

f = -(Q(BPM1)+Q(BPM2)+Q(BPM3))/Q(BPM0)

Minimizing this function is equivalent to maximizing beam transmission

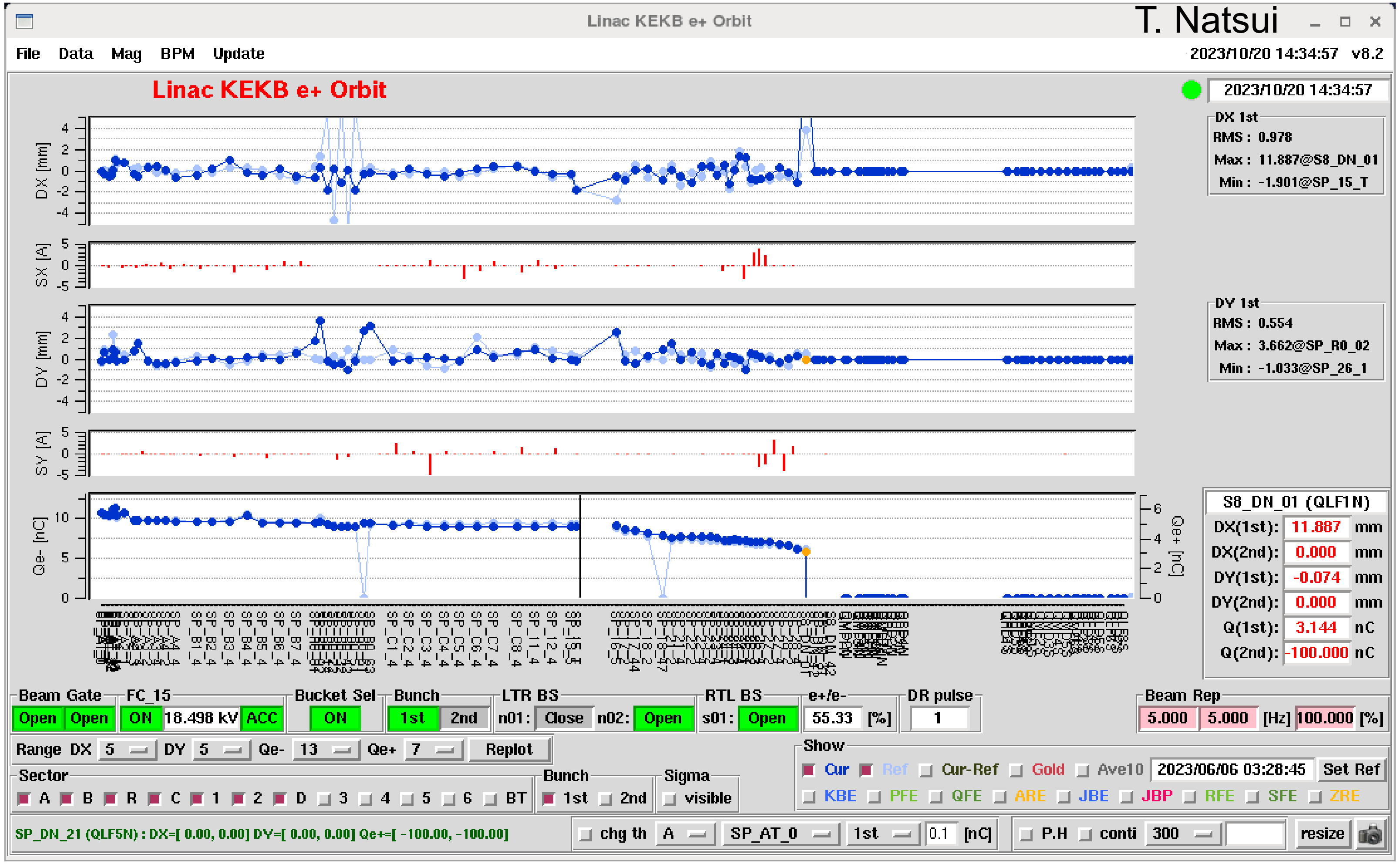
Tuning of Quadrupole, Steering Magnets

Goal: Minimize beam loss up to the DR beam transport line

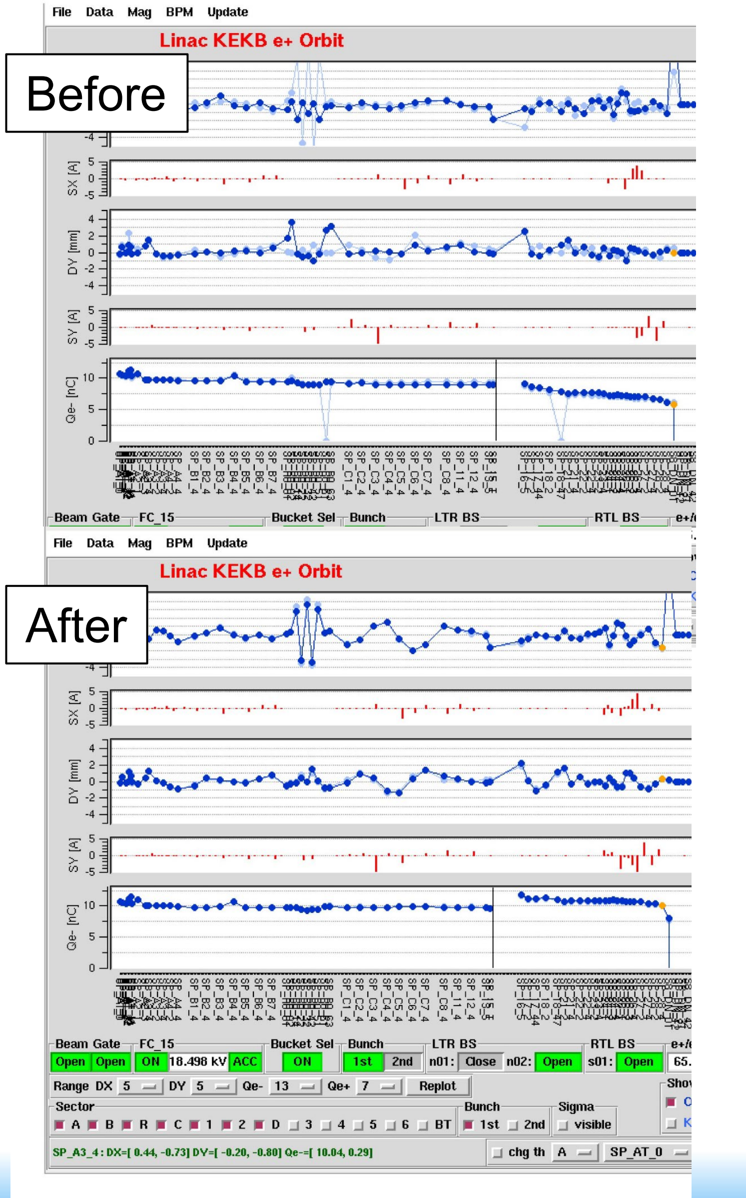


Beam orbit and charge before ML tuning

Improvement of transmission



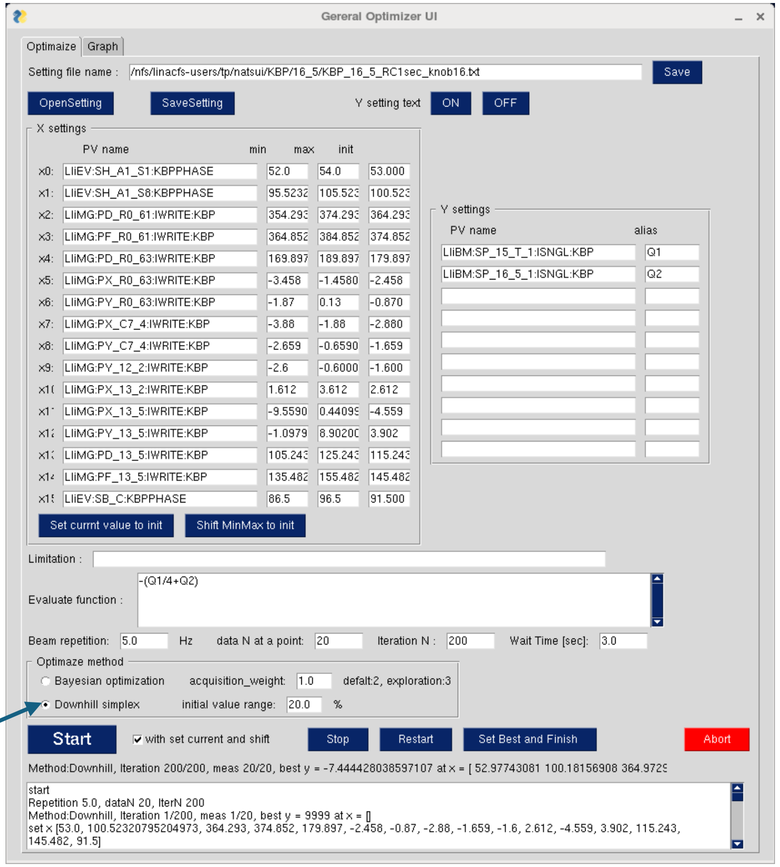
Progression of tuning process



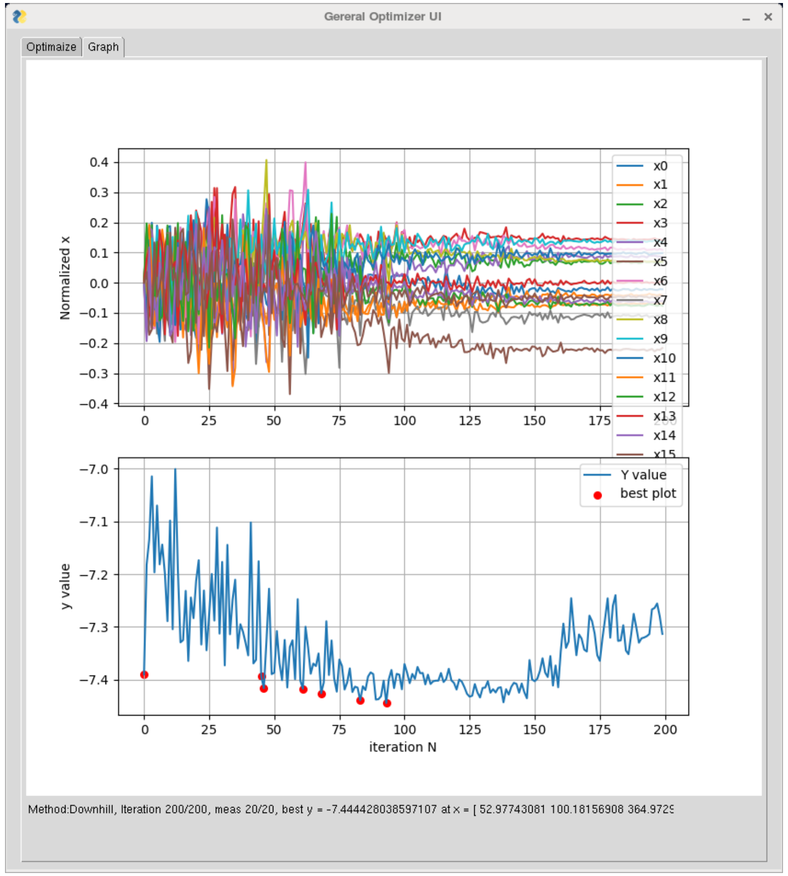
This tuning process (~160 parameters) takes a few days, so we have only done it once so far.

Optimization to keep the condition

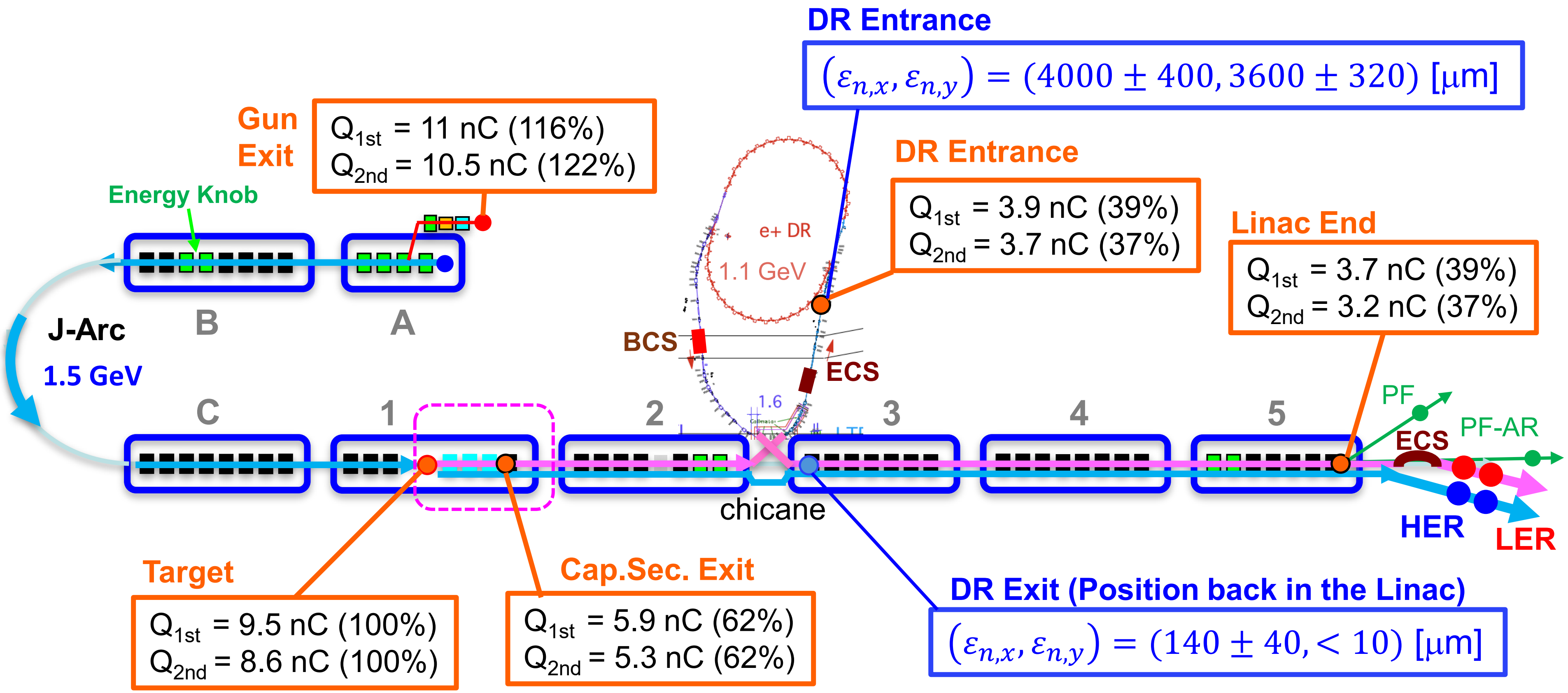
Bayesian optimization moves parameters significantly
➔ The downhill simplex method is used when condition deviates slightly from best ones



Downhill simplex



Current Status

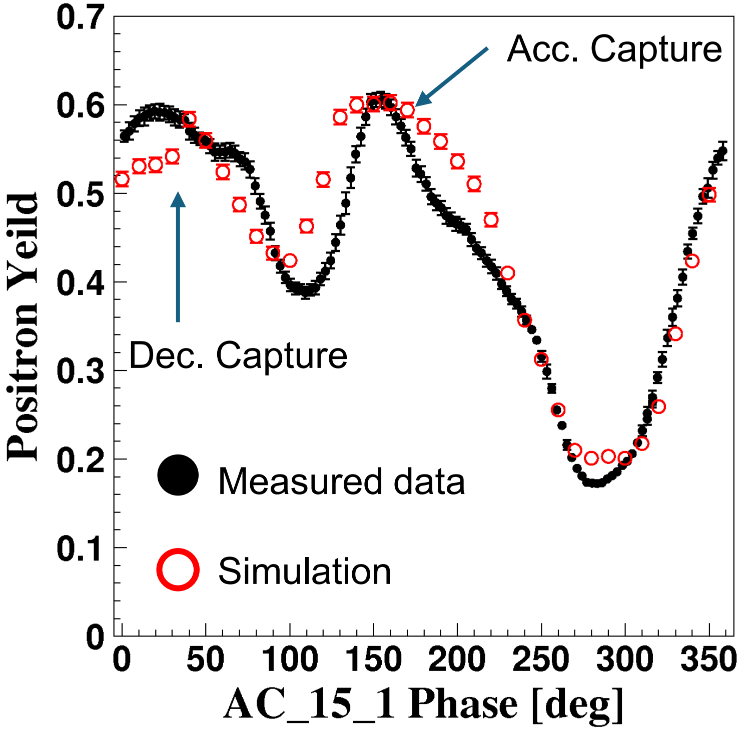


Bunch charge and normalized emittance

- Primary electron beam has large energy spread and emittance, so it loses about ~20% up to the target
- Conversion efficiency of primary electron beam to positron beam is ~60%
- 30% of the beam is lost in the Beam transport line (SY2 to DR) → Bunch charge decreases to ~40% at the end

Comparison of simulated and measured data

- Simulation (EGS5 and GPT) roughly reproduce experimental values for the phase dependence of yield
- Slightly different phase-dependent structure
  → Simulation studies are needed
  (Fahad will reports on this topic on Friday)



Klystron phase of 1st accelerating structure and positron yield

Summary

- KEK e+e- Linac and Positron Capture Section Overview
- Positron beam tuning : Manual and machine learning are used together
  - Bayesian optimization is very useful in improving position yield and beam transmission
  - If the parameters deviate slightly from the optimum, Downhill Simplex is effective
- Current Status of the positron beam
  - Bunch charge : 11 (Gun Exit) → 9.5 (Target) → 3.9 (DR) → 3.7 (Linac end) [nC]
  - Normalized Emittance (x,y) : (~4000, ~3600) @DR, (~140, ~10) @Linac end [μm]
- Measurements and Simulation
  - Simulation roughly reproduces experiment
  - However, differences also exist, and further investigation is needed