Optics Design for the Commissioning of the Compact ERL Recirculation Loop

ERL 2013

The 53th ICFA Advanced Beam Dynamics Workshop on Energy Recovery linac

Miho Shimada*, Norio Nakamura, Yukinori Kobayashi, Tsukasa Miyajima, and Kentaro Harada

High Energy Accelerator Research Organization, KEK

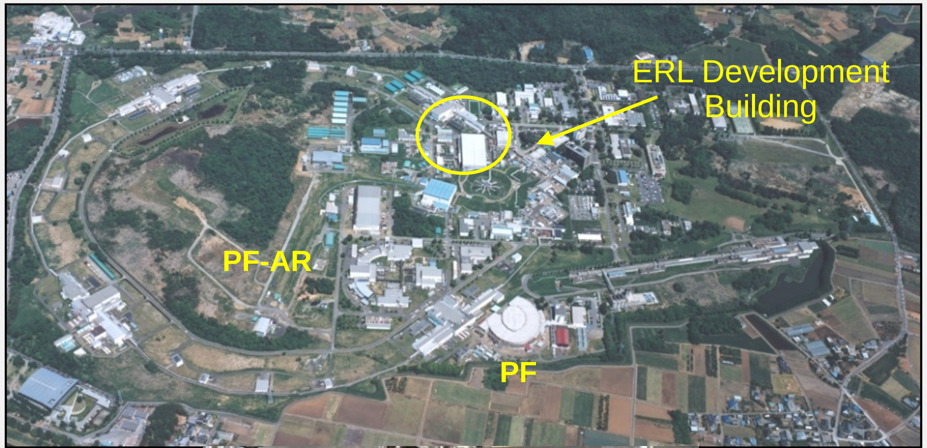
Ryoichi Hajima

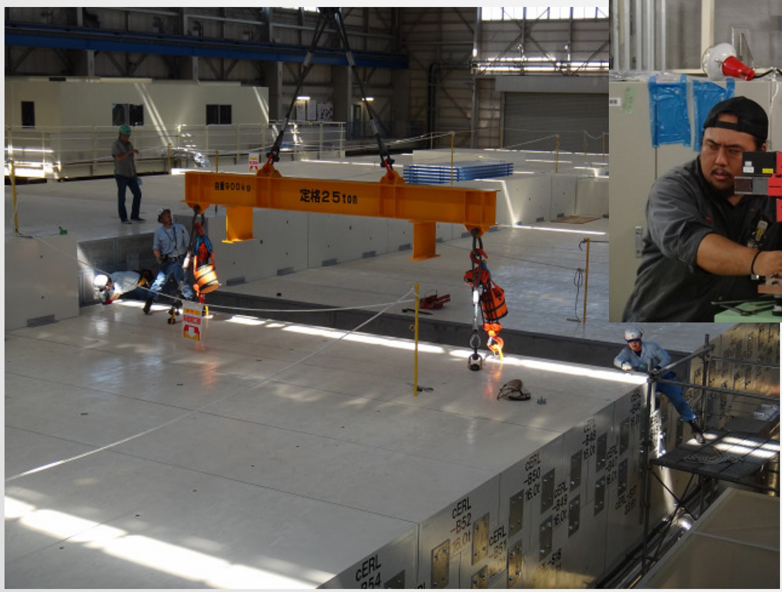
Japan Atomic Energy Agency, JAEA

Outline

- Introduction of Compact ERL
- Start-to-end (S2E) simulation for the Compact ERL (cERL)
  - Optimization of injector and recirculating loop
  - Particle tracking simulation including space charge or CSR wake effects
- Applications
  - Laser inverse Compton scattering
  - THz-CSR and bunch compression
- Beam loss and field-emission
- Summary

Site and construction of cERL



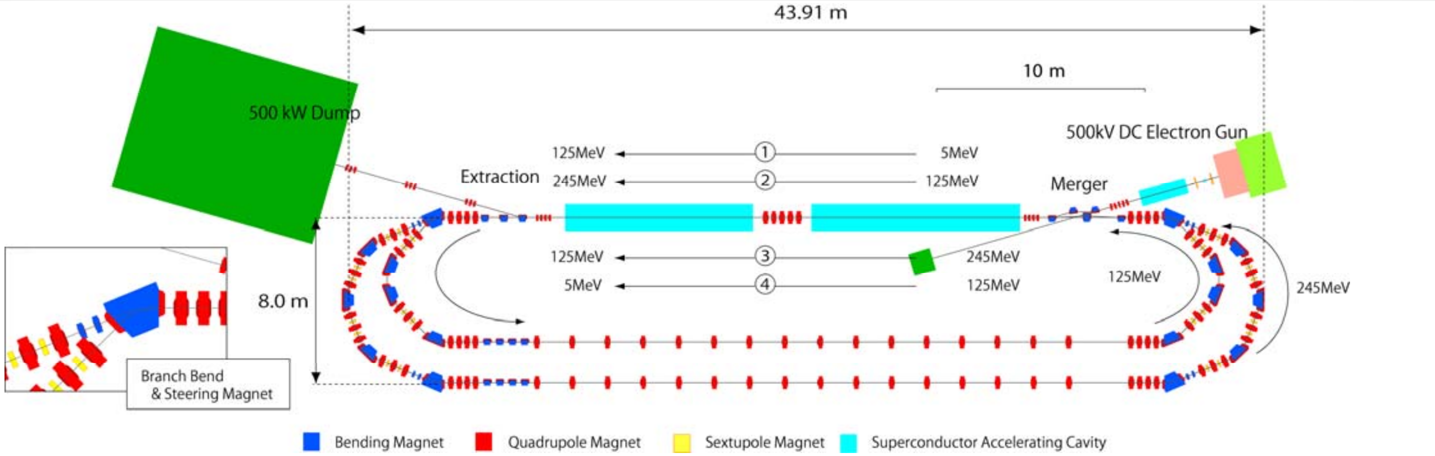


Final Goal of cERL, double Loop

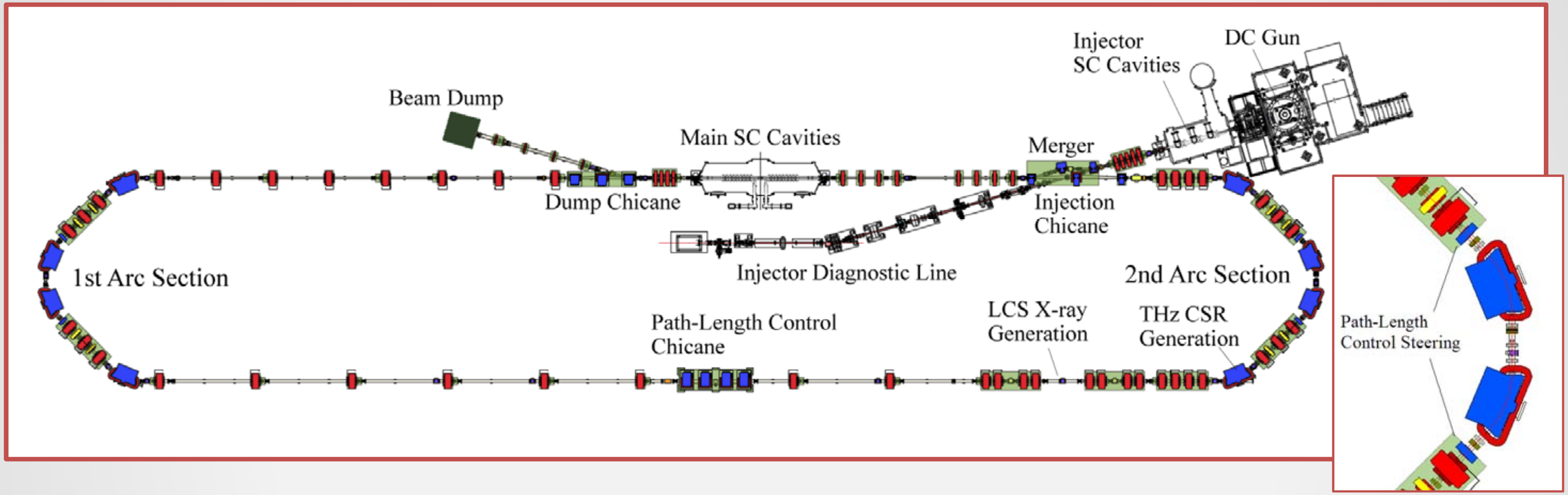
- **Why did we choose a double loop circulator?**

It is for saving
construction area
number of accelerator cavities
running cost of the refrigerators

Injection energy	5- 10 MeV
Full energy	245 MeV
Electron charge	77 pC
Average current	10-100 mA
Normalized emittance	< 1 mm-mrad
Bunch length	1-3 ps
Momentum spread	< 1e-3

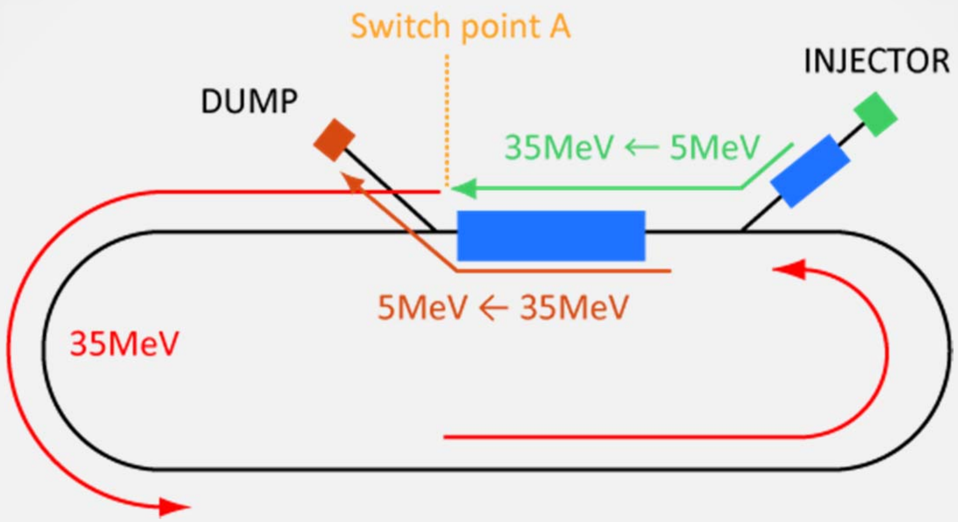


First commissioning of recirculation Loop



- **Only two superconducting cavities are installed.**
- **Circulating energy is 20 – 35 MeV with injection energy of 3.4 - 5 MeV**
  - Revolution time depends on the circulating energy.
- **Tunable range of the circumference is ±25 mm.**
  - Couples of steering magnets in the arcs (±20mm) , Chicane in the straight line (±5mm)
- **Applications**
  - X and gamma-ray source by Laser inverse Compton scattering (LCS)
  - THz source of CSR from short electron bunch

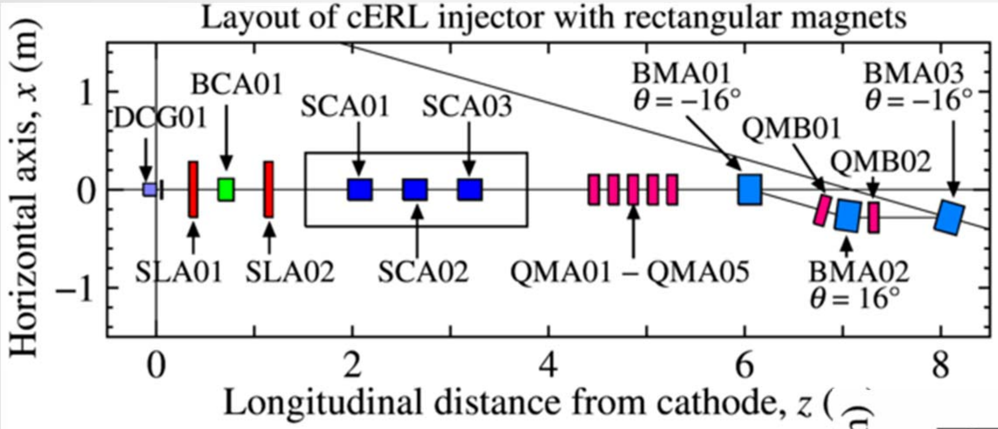
Start-to-end simulation

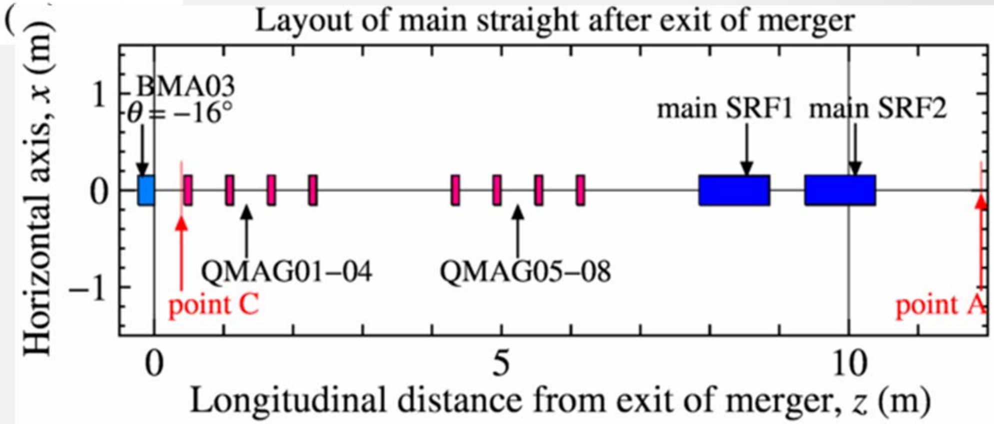


- **General Particle Tracer, GPT**
  - 6D tracking code with mesh based 3D space charge effect
  - CSR wake effects can be calculated but it costs huge calculation time…
- **"elegant"**
  - Matching of the linear optics is based on the transport matrix.
  - 1D CSR wake with transient effect and over a drift
  - lacking space charge effects
- **Injector → Switch point A**
  - Optics is optimized by GPT
- **Switch point A → Dump**
  - Optics is optimized by elegant
  - Particle Tracking
    - ✓ "elegant" to simulate CSR wake effect
    - ✓ GPT to simulate space charge effect

Layout and optimization of injector

1. Minimization of emittance at the switching point A
2. Matching with circulator loops



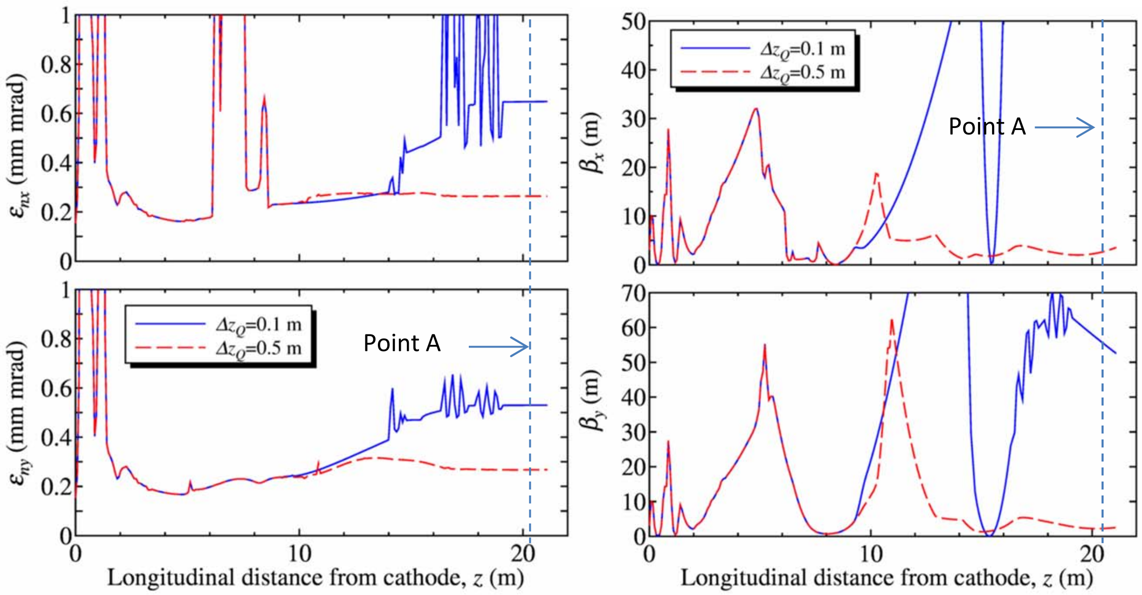


Point A : Switching point, 35MeV

Target of Twiss parameters

$-2 < \alpha_x < -0.36$, $2.63 < \beta_x < 8$ m, $-0.33 < \alpha_y < 0$, $10.2 < \beta_y < 24.4$ m

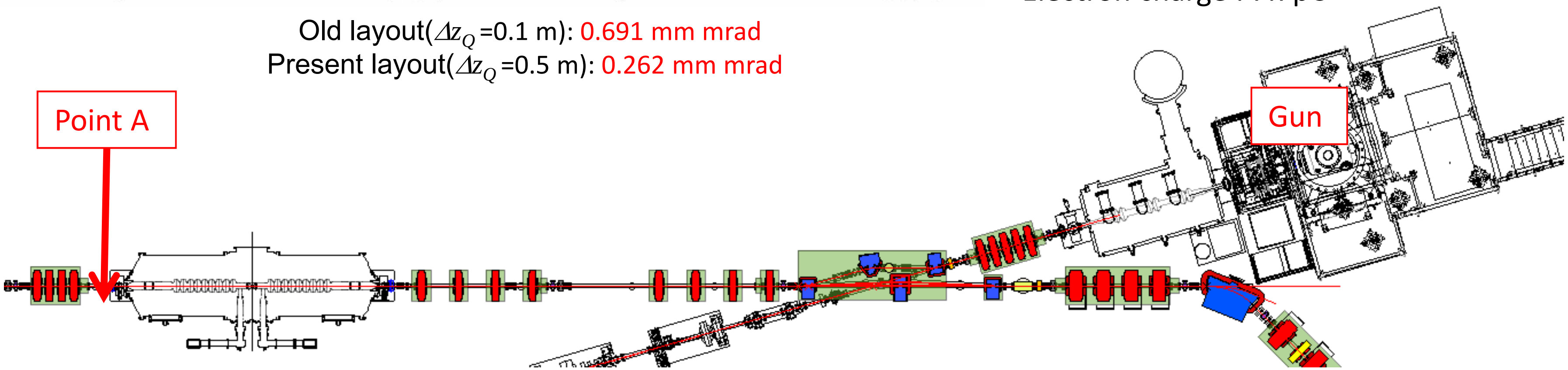
Results of optimization of injector



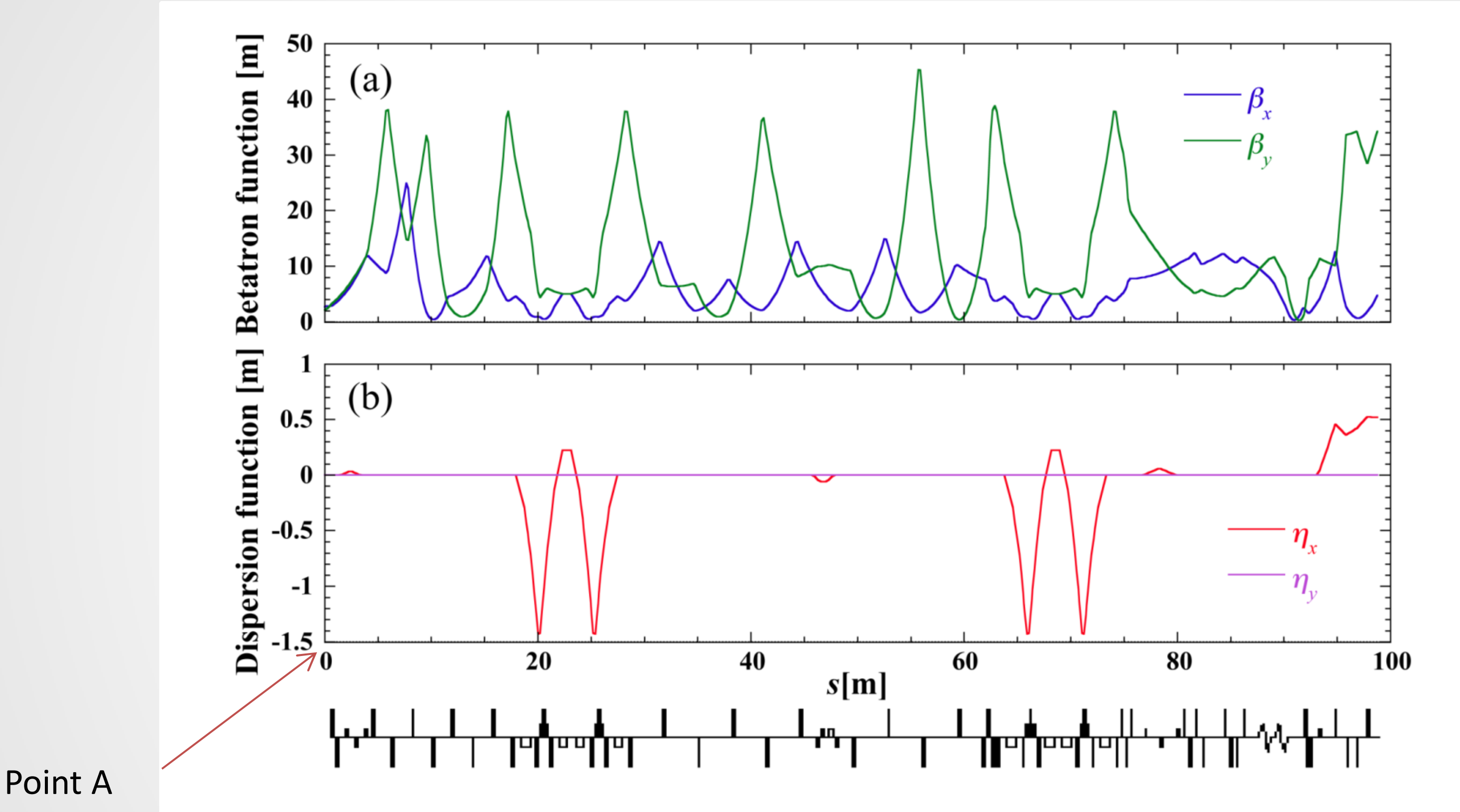
parameter	2 k particles	100 k particles
ϵ_{nx} (mm·mrad)	0.262	0.307
ϵ_{ny} (mm·mrad)	0.261	0.361
σ_z (mm)	0.846	0.873
γ	69.5014	69.497
σ_γ	0.0290783	0.0192432
β_x (m)	2.67319	2.59521
β_y (m)	2.11744	2.03121
α_x	-0.601	-0.945
α_x	-0.179	0.305

2k particles is used for optics optimization
100k is the final data
Electron charge : 7.7pC

Old layout(Δz_Q=0.1 m): 0.691 mm mrad
Present layout(Δz_Q=0.5 m): 0.262 mm mrad



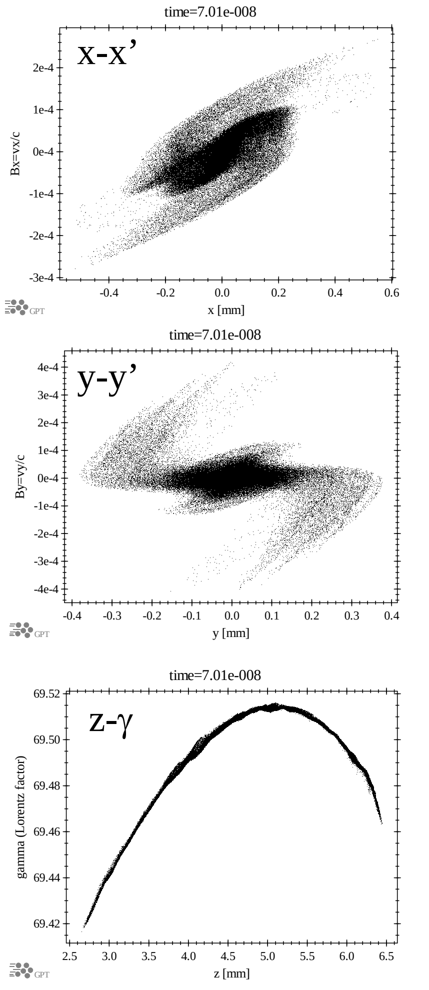
Optical functions of circulating loop

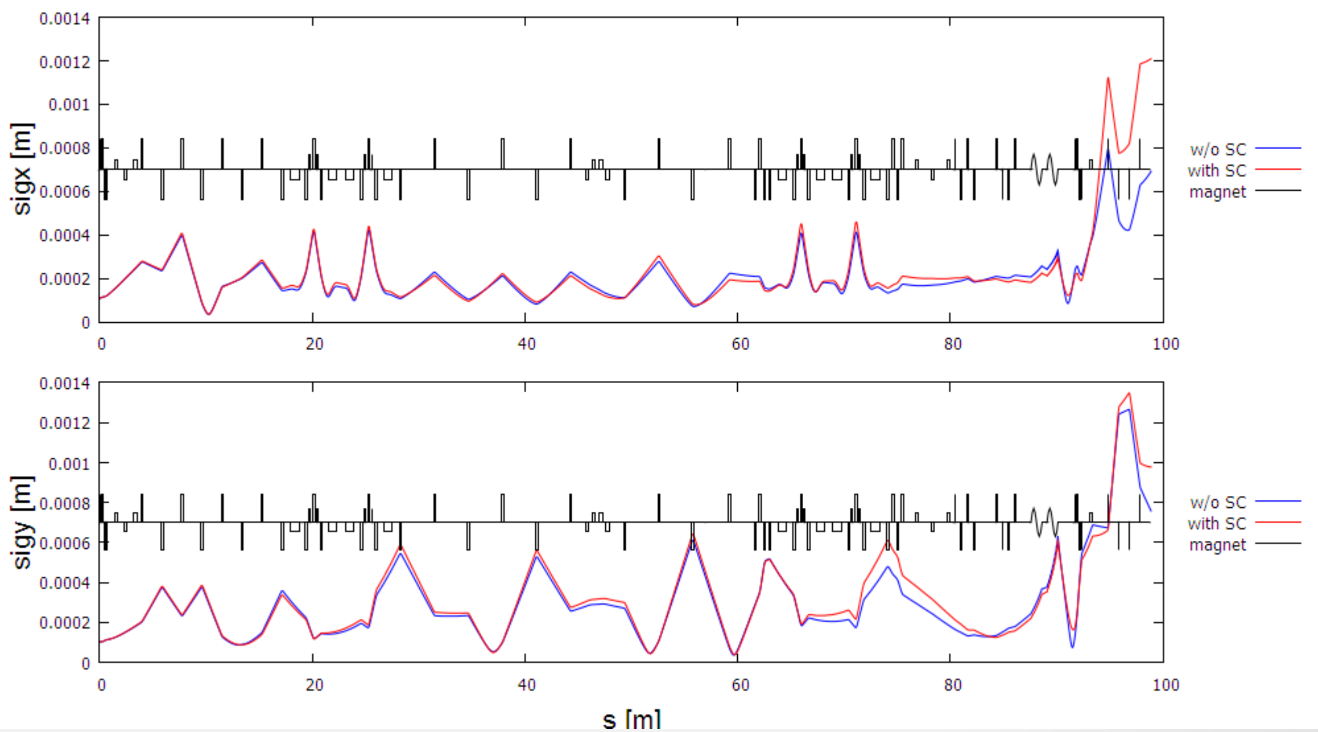


- Just after acceleration up to 35 MeV to dump.
- 5 MeV and 35 MeV pass through the same transport line.
  - Optics is optimized for the lower energy beam.
- Arc section is based on TBA with isochronous condition.
  - Triplet between the bending magnets is DFD to make it easy to match the optical functions.

Effects of space charge on beam size

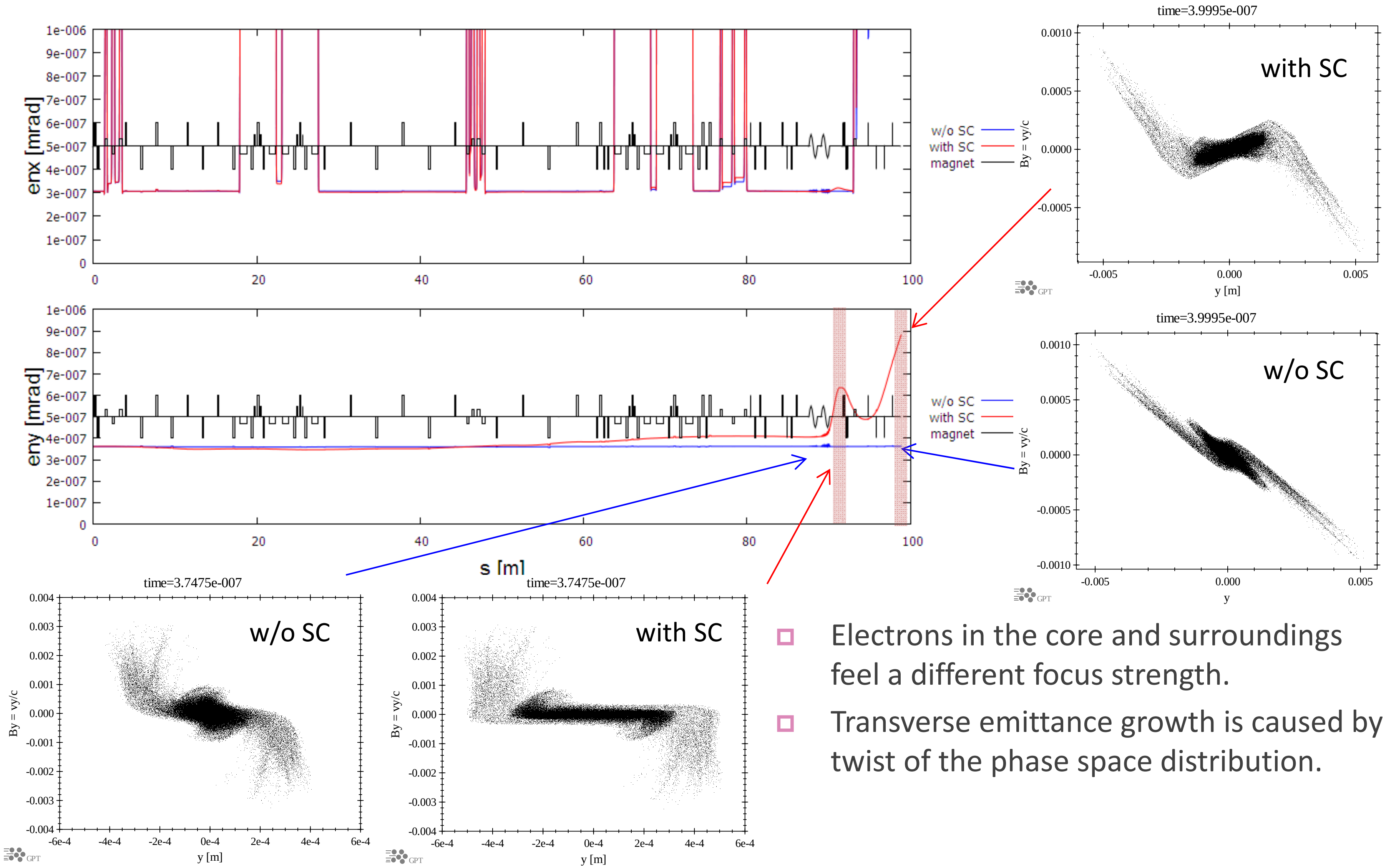
Data at switching point A





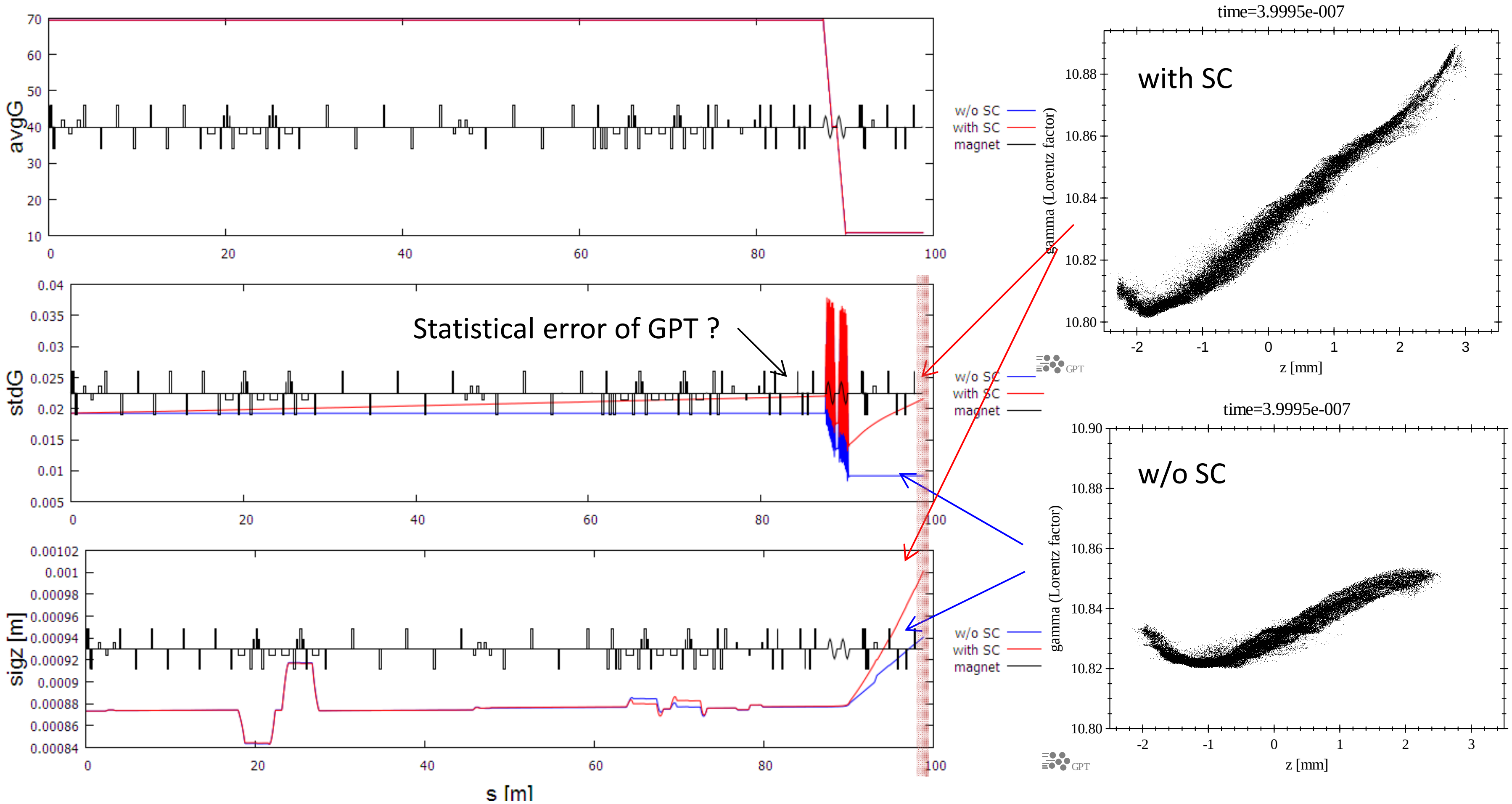
- Particle tracking is performed with GPT.
- Horizontal beam size increase at the dumpline.
- There are no significant effects of space charge before energy recovery.

Emittance growth caused by space charge



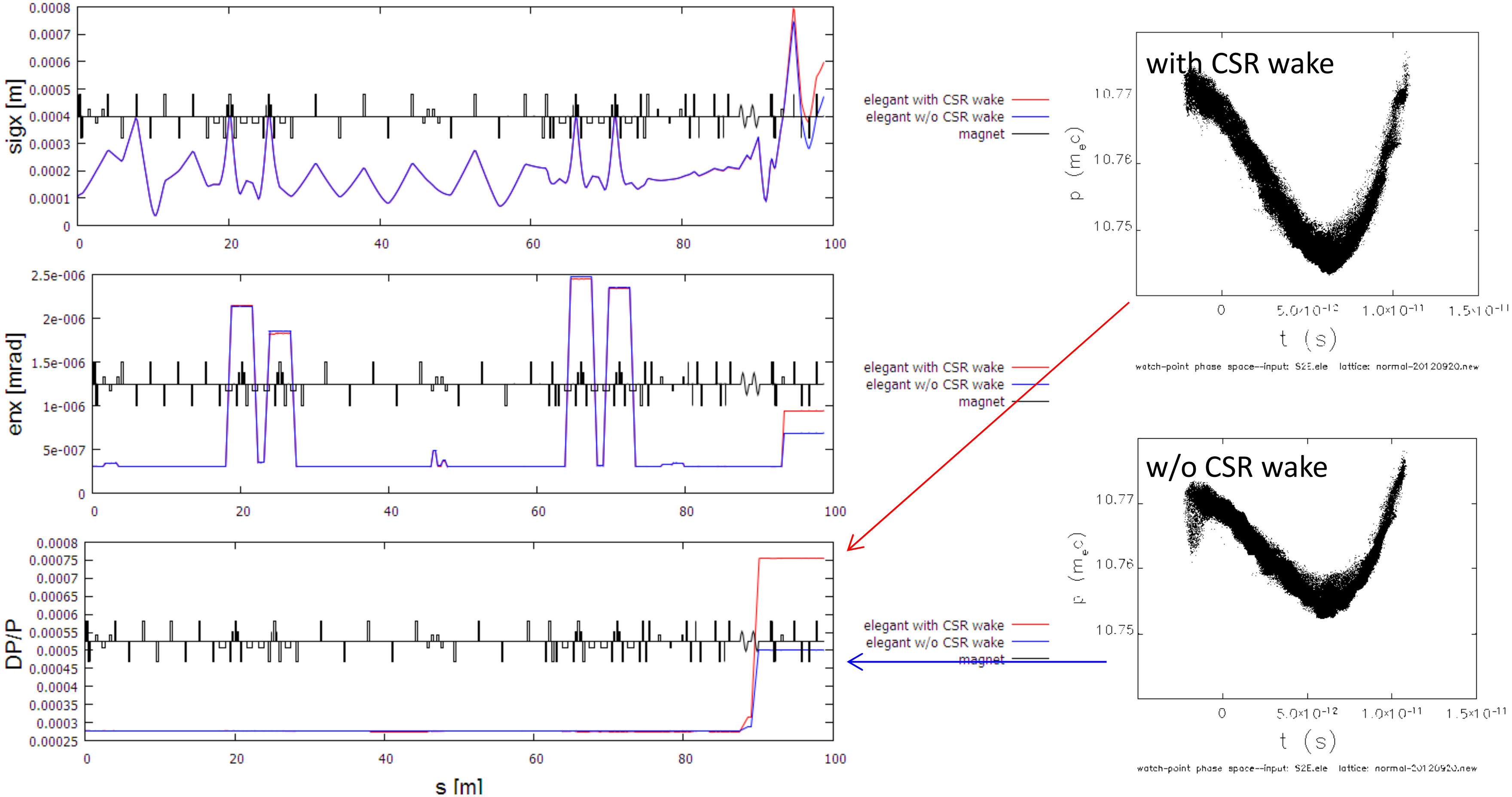
- Electrons in the core and surroundings feel a different focus strength.
- Transverse emittance growth is caused by twist of the phase space distribution.

Energy and bunch length



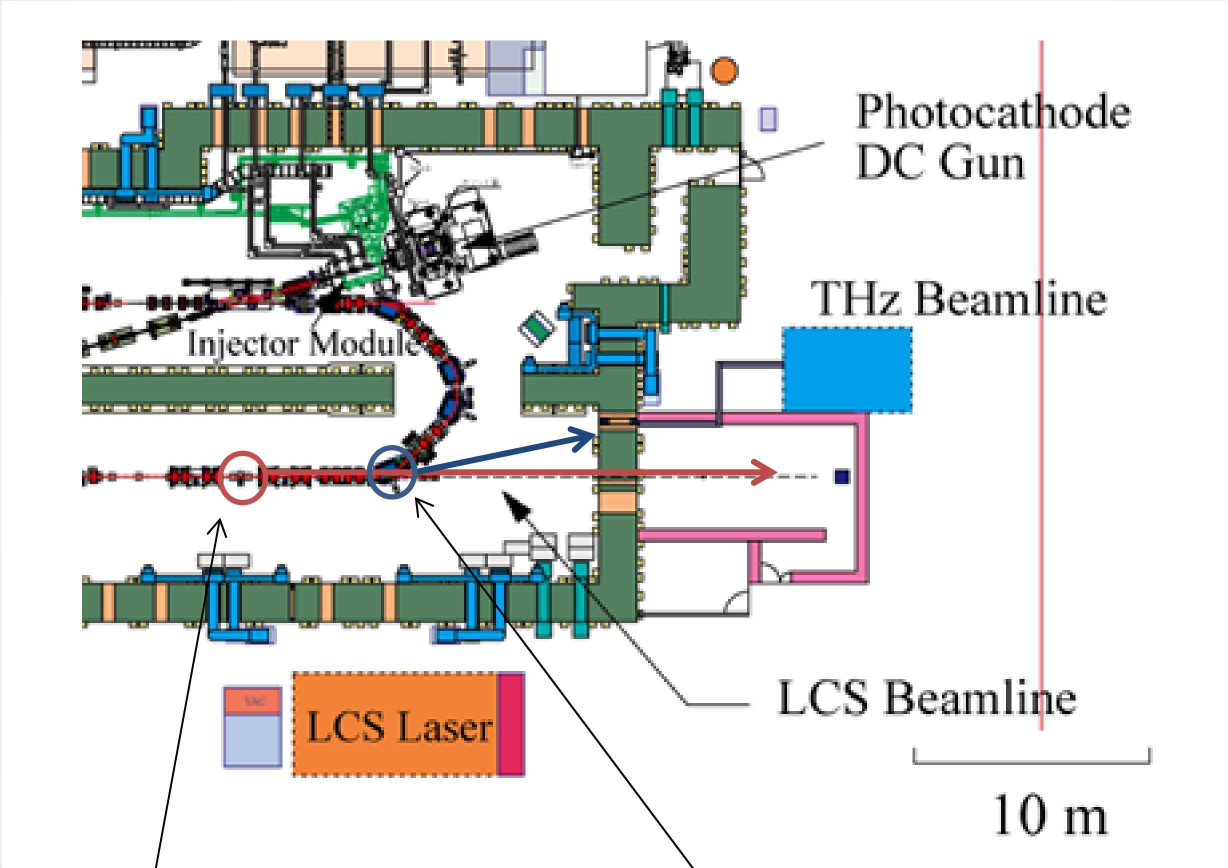
- Space charge effect increase the energy spread and bunch length

Effects of CSR wake on horizontal beam size and emittance



- Energy spread almost doubles after energy recovery but it still less than 0.001.
- There are no significant effects of CSR wake in the recirculating loop.

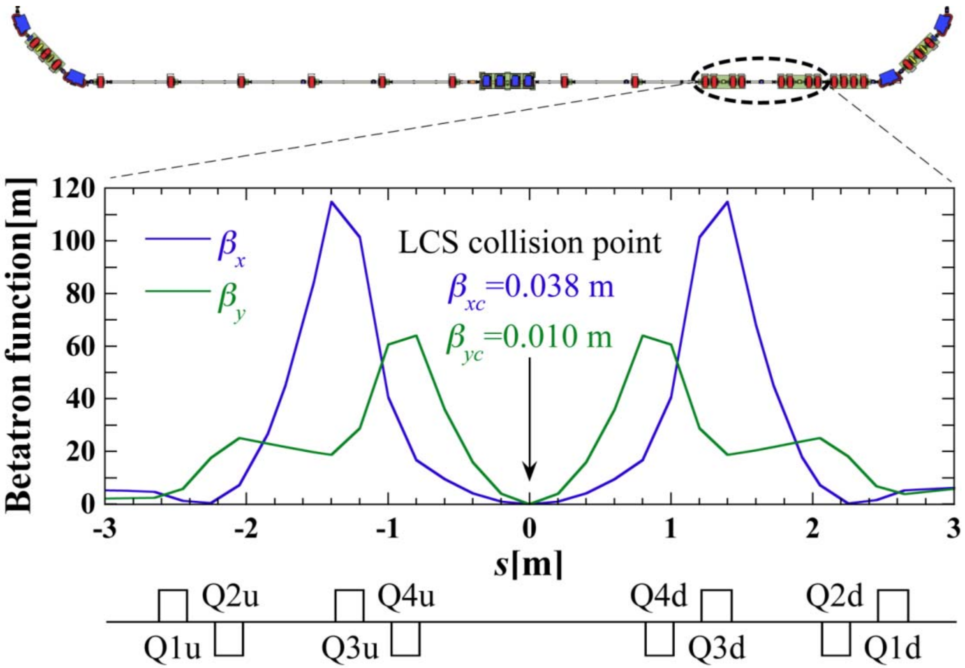
Applications of cERL

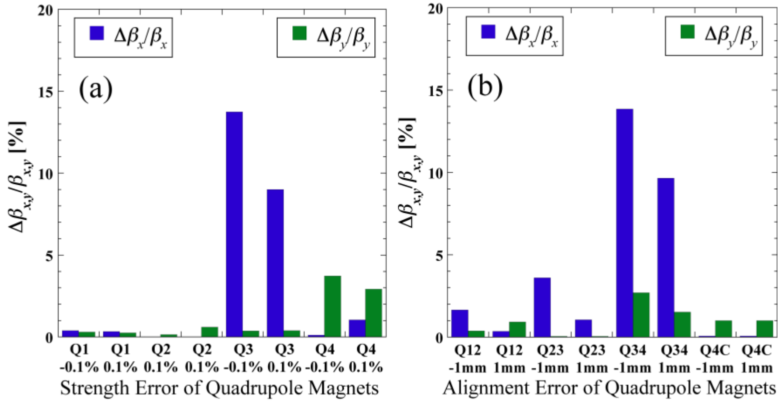


- Collision point of LCS
- Laser optical cavity

- THz-CSR from short electron bunch
- Bunch length is less than 150 fs

Laser inverse Compton scattering

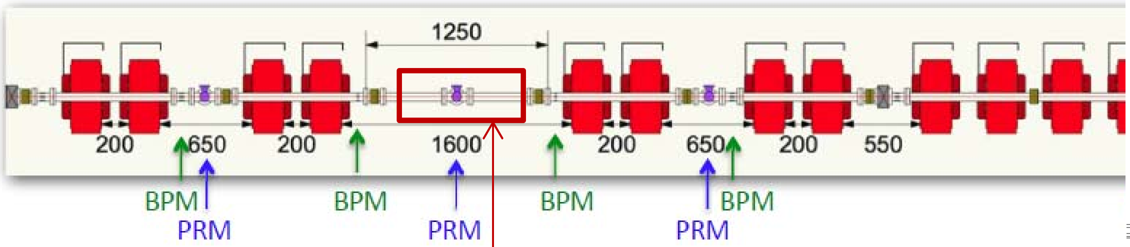




Nominal rms beam size @ collision point

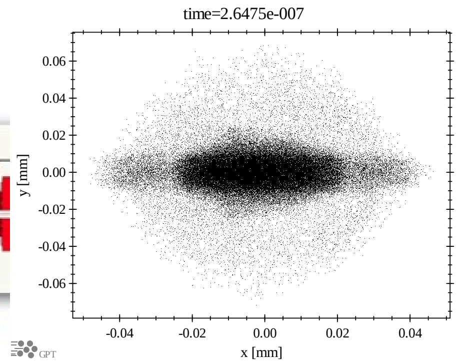
σ_x = 12.8 μm, σ_y = 6.6 μm

@ $\varepsilon_{nx}=\varepsilon_{ny}$=0.3mm mrad



Laser optical cavity

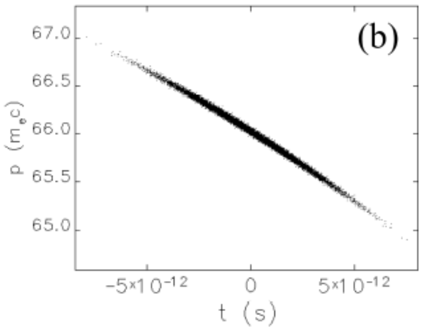
BPM : Beam Position Monitor, PRM : Profile Monitor



Tracking results by GPT

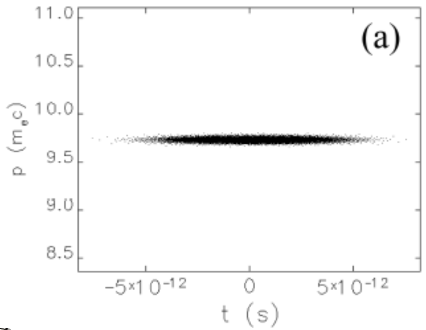
σ_x = 13.8 μm, σ_y = 10.7 μm

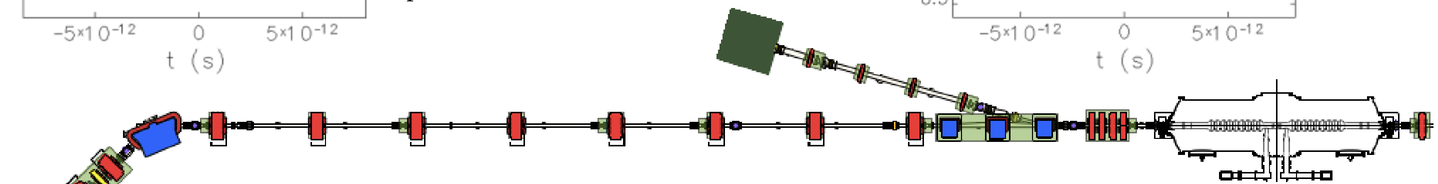
Bunch compression for THz light source

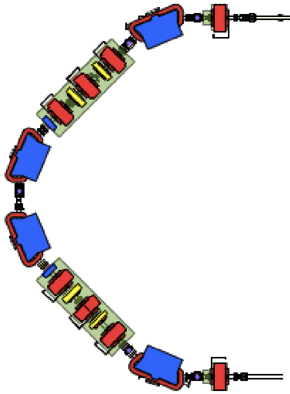


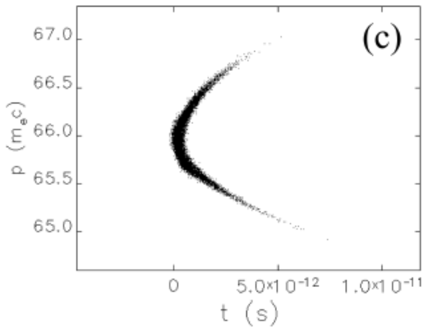
σ_z = 2.13 ps
σ_p/p = 0.00425

σ_z = 2 ps
σ_p/p = 0.002

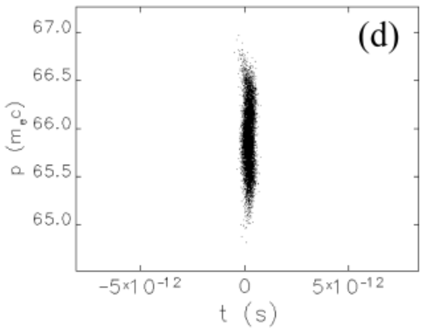








Sextupole OFF
σ_z = 686 fs
σ_p/p = 0.00425



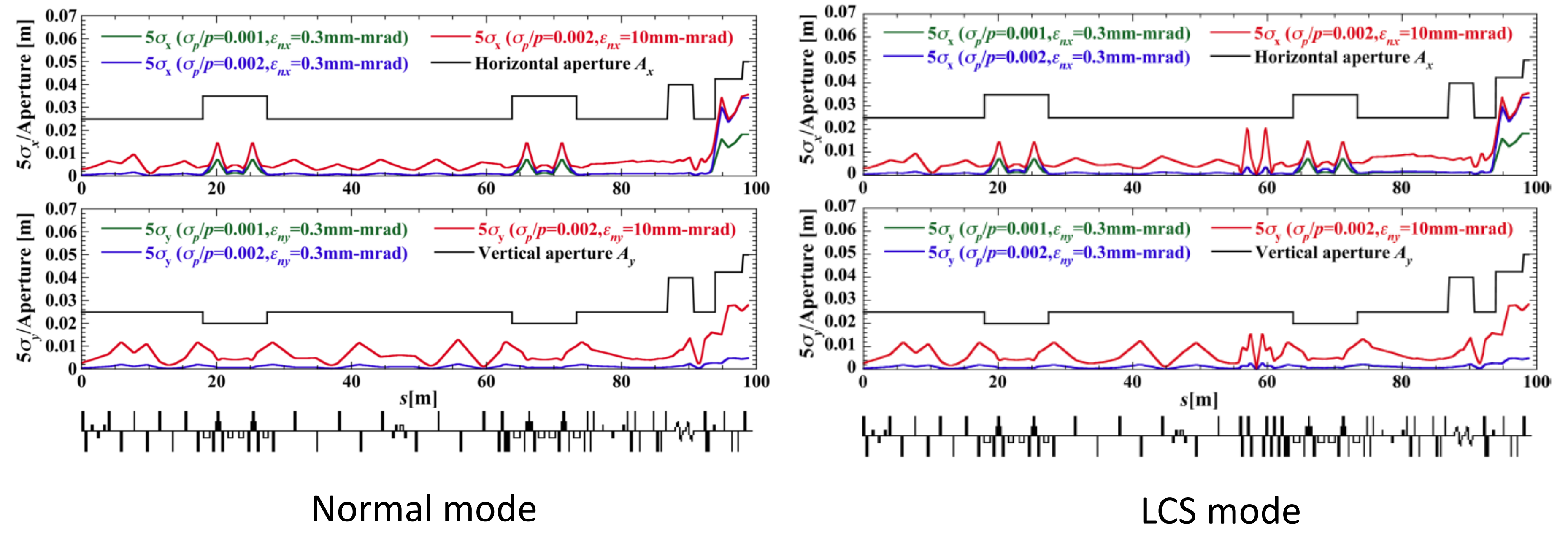
Sextupole ON
σ_z = 140 fs
σ_p/p = 0.00454

Initial Parameter
- Bunch charge : 77 pC
- Injection energy : 5.5 MeV
- σ_p/p : 0.002
- ε_{nx} and ε_{ny} : 1 mm mrad

Main SC cavities
- RF volt. 15 MV x 2 cav
- RF phase : 15.8 deg

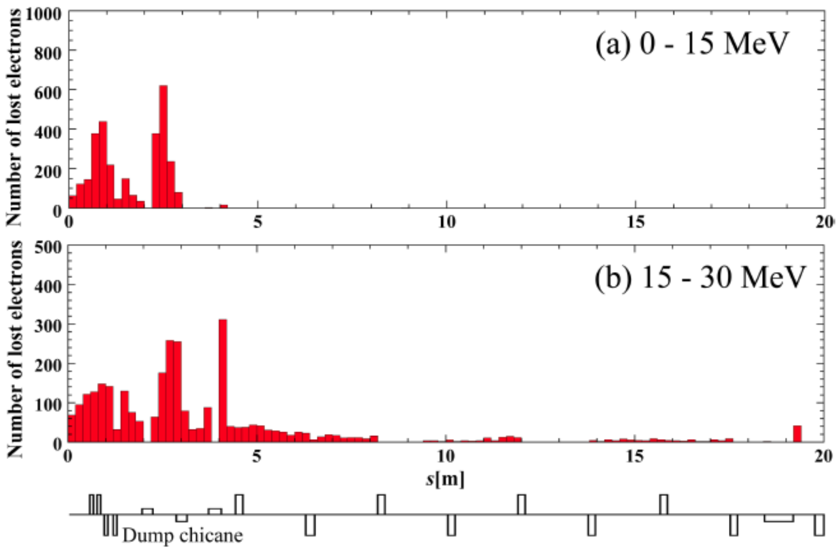
Tracking code : elegant
- 1D CSR wake, no Space Charge

Beam loss rate

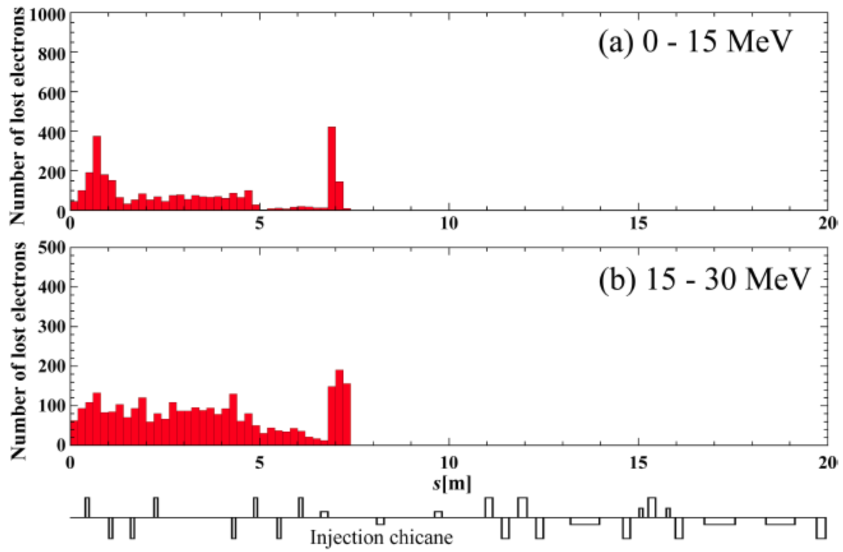


- Physical aperture larger than 5σ satisfies beam loss rate less than 1e-6.
- Thanks to the large apertures after energy recovery, there is no significant beam loss even a deteriorated electron beam (σ_p/p=0.002, $\varepsilon_{nx}=\varepsilon_{ny}$=10mm-mrad).

Loss of field emitted electrons



Downstream of the cavity



Upstream of the cavity

Distribution of lost field-emitted electrons (N=3000) with accl. field of 15MV/m

Additional radiation shields were installed
based on the results of a particle tracking simulation

Summary

- Start-to-end simulation
  - S2E simulation is performed to estimate the collective effect (space charge and CSR wake) on the commissioning energy of cERL.
  - Tracking results shows there is no significant effects on the beam.

- Applications
  - Effects of alignment of Q magnets and space charge effect on beam size are simulated at the collision point of LCS.
  - Rms bunch length can be compressed less than 150 fs for THz-CSR light source even the commissioning mode of 35 MeV.

- Beam loss
  - Beam loss due to physical aperture and loss of field-emitted electron are evaluated.
  - The simulation results is reflected in the design of radiation shielding.

Commissioning of recirculation loop will start this December !

Thank you for your attention