Salim Ogur

First Injection to the Damping Ring

CERN, 26 July 2017

Acknowledgements: K. Oide, N. Iida, F. Zimmermann

Outline

0. Review of Accelerators
1. Review of KEK e+ Data & DR Parameters
2. e+ Beam Transfer Line to the DR for Injection
3. Energy Compressor with Double Bend Achromat
4. Conclusion

0. Motivation

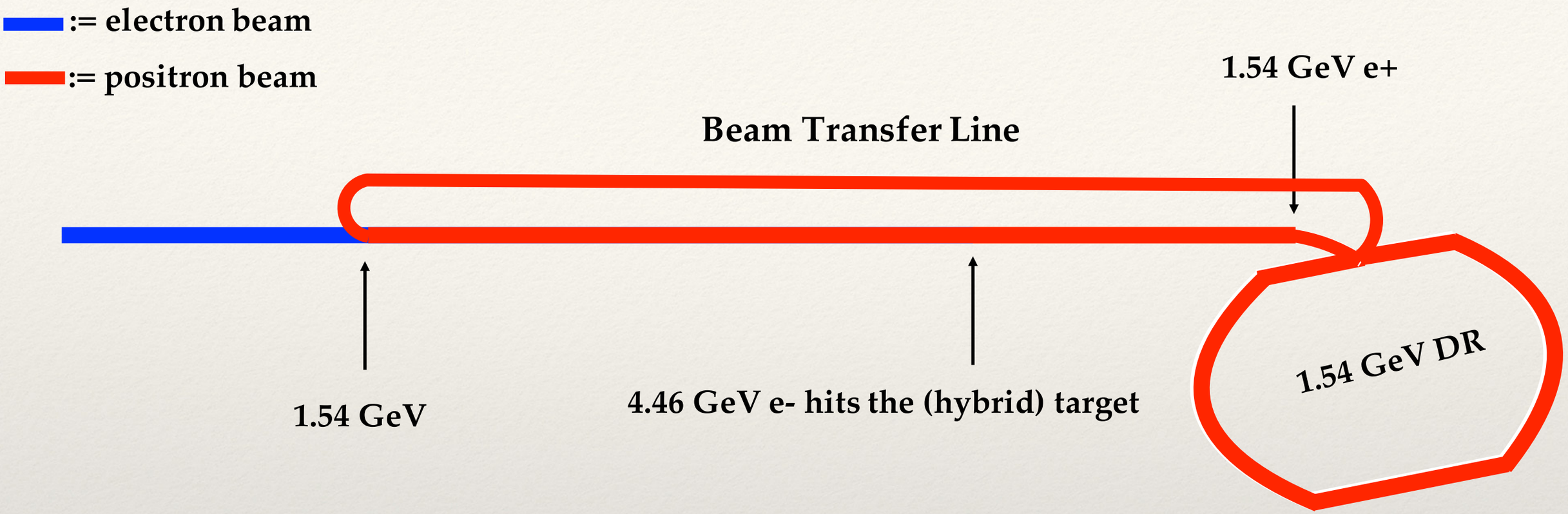
★ The energy compressor with 180 degree turn needs to be avoided due to the emittance dilution.

★ Referring ***N. Iida*** (KEK)'s presentation, we conclude that the **ECS MAY NOT BE NEEDED** within the current baseline and with e+ data available.

★ A beam transfer line has been designed to match e+ data to the DR injection point. The DR aperture size hasn't been set, yet 15 mm "aperture" has been assumed in the injection point, and in all turns (magnetic field of the quadrupoles were also calculated for the radius of 15 mm, all were below 0.6 T).

★ Therefore, the flow schemes of beams have been revised such that the e+ beam is NOT bended noticeably, as ***K. Oide*** suggests. On the other side, we have such a degree of freedom to meander the e- beam since we can damp the e- emittance 2 order of magnitude.

0. Positron Flow Scheme



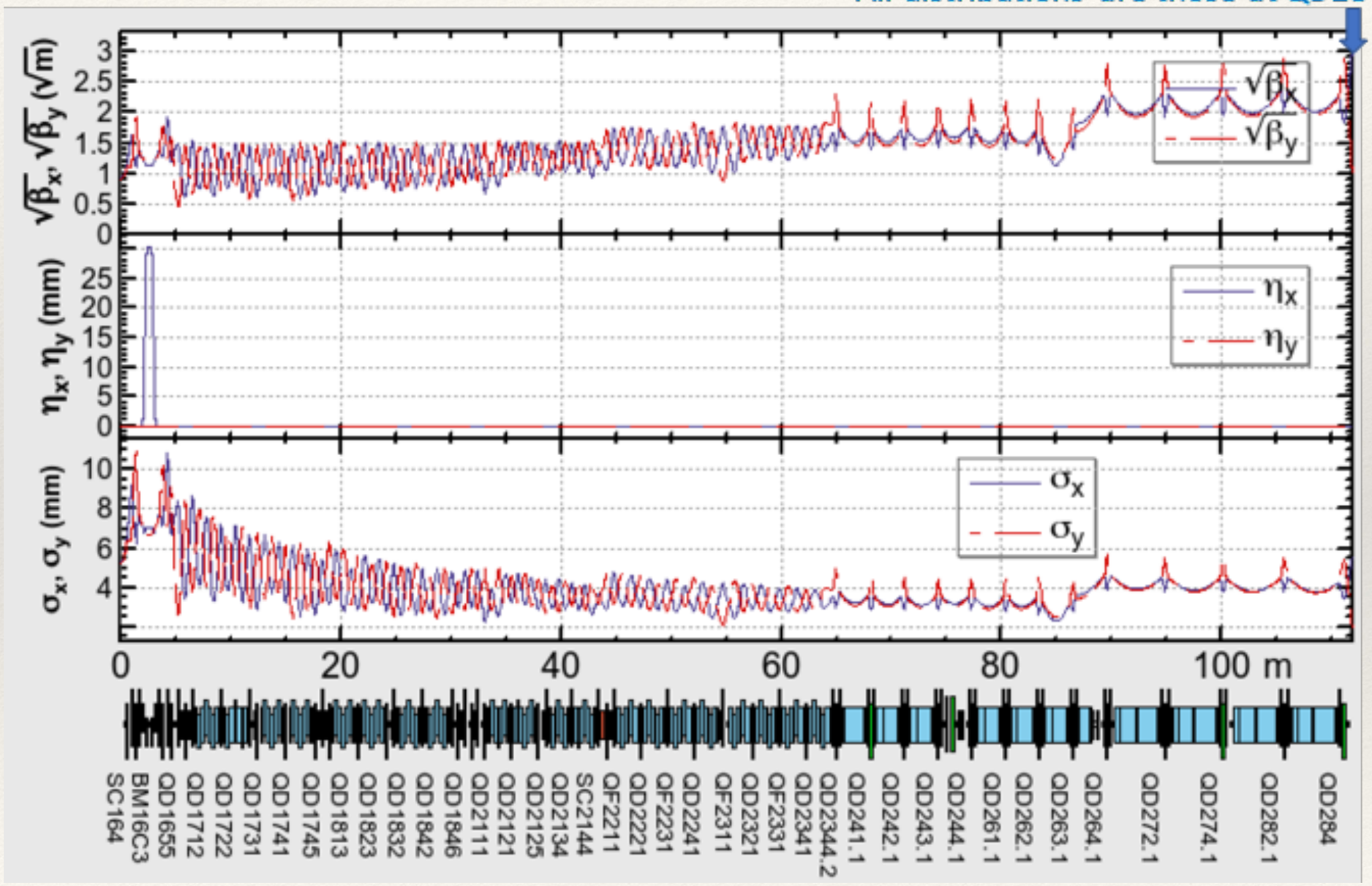
not to scale!

- We may tilt the DR just by a small angle (i.e. a septum kick) in order to keep e+ emittance intact. However, we have such an enormous safety margin for e- damping. Also this way, the BTL can share the same tunnel as the main linac.

1. KEK e+ Data

Optics from the exit of the capture section of e+ to the entrance of LTR

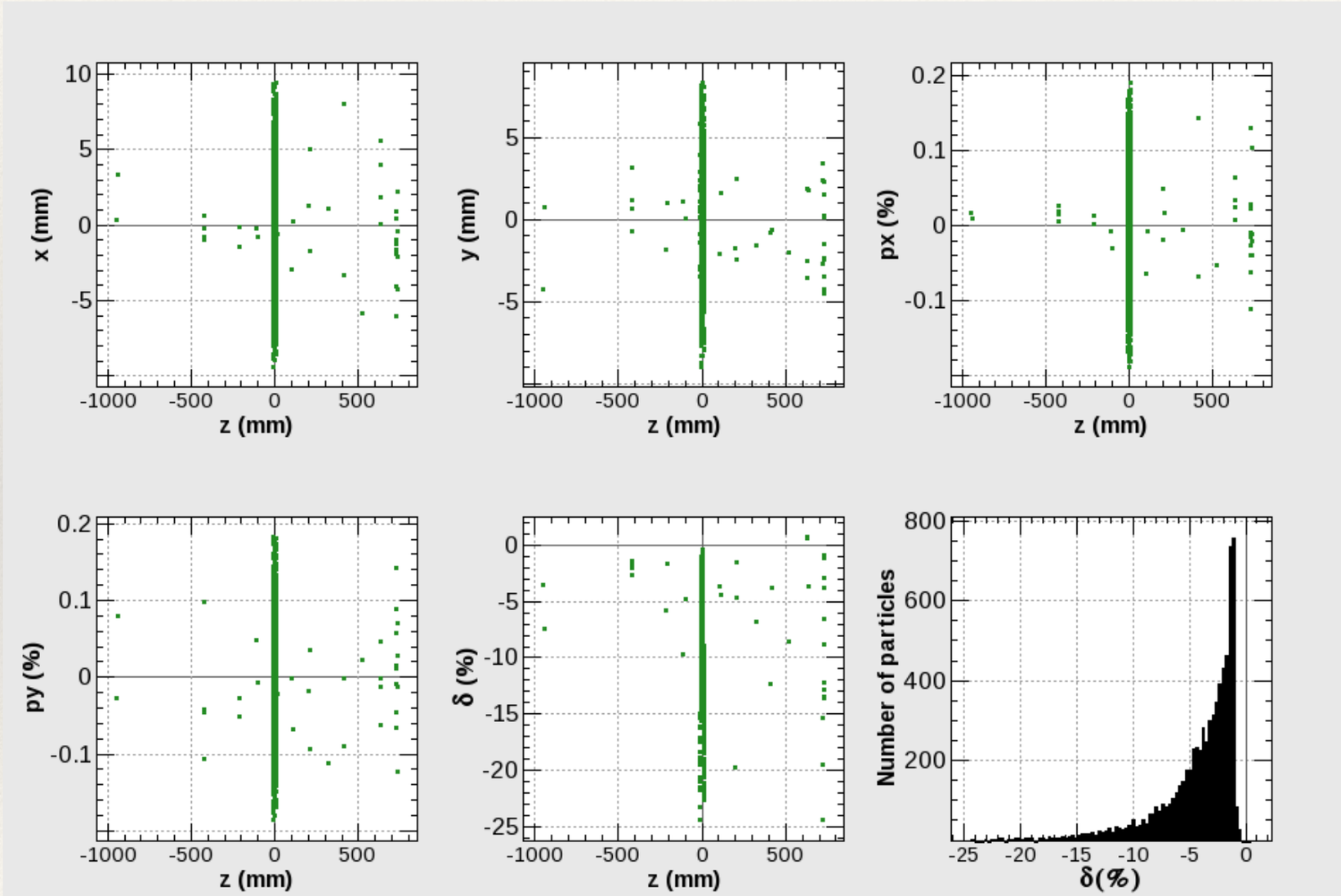
All distributions are those at QD284.



N. Iida *et al.*

1. KEK e+ Data

- KEK simulated e+ data up to linac exit at 1.1 GeV has a dispersion of ~25% in total. The *main bunch* is followed and preceded by a very small head and tail.



$$\sigma_z = 4.01\ mm$$

$$\varepsilon_x = 1.29\ \mu m$$

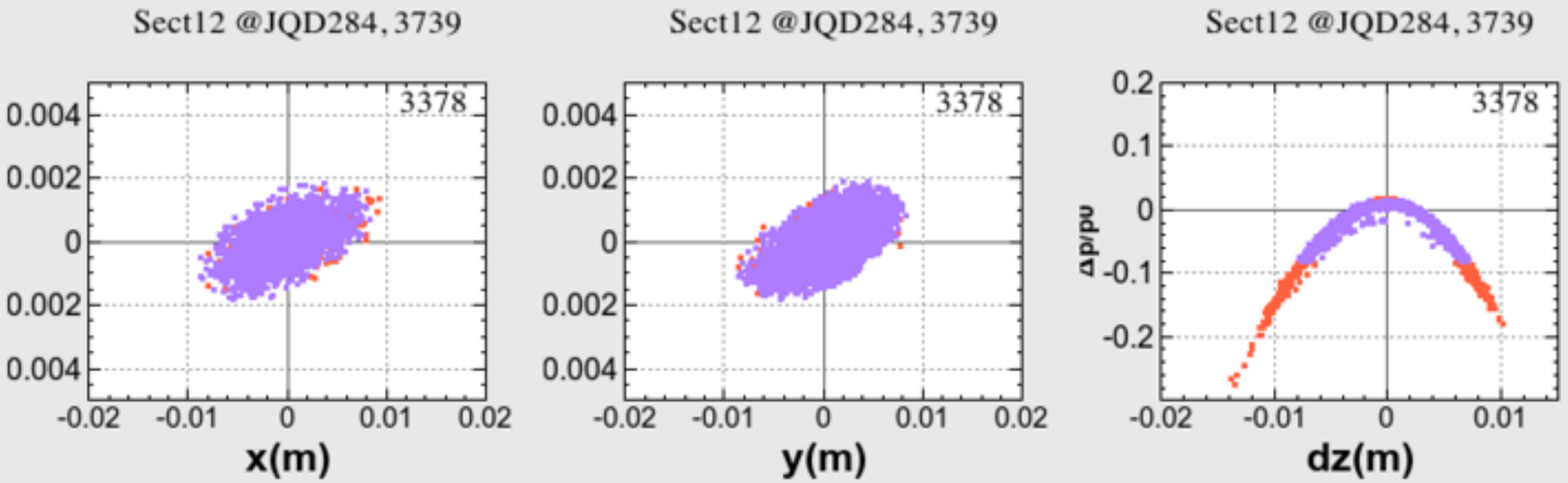
$$\varepsilon_y = 1.22\ \mu m$$

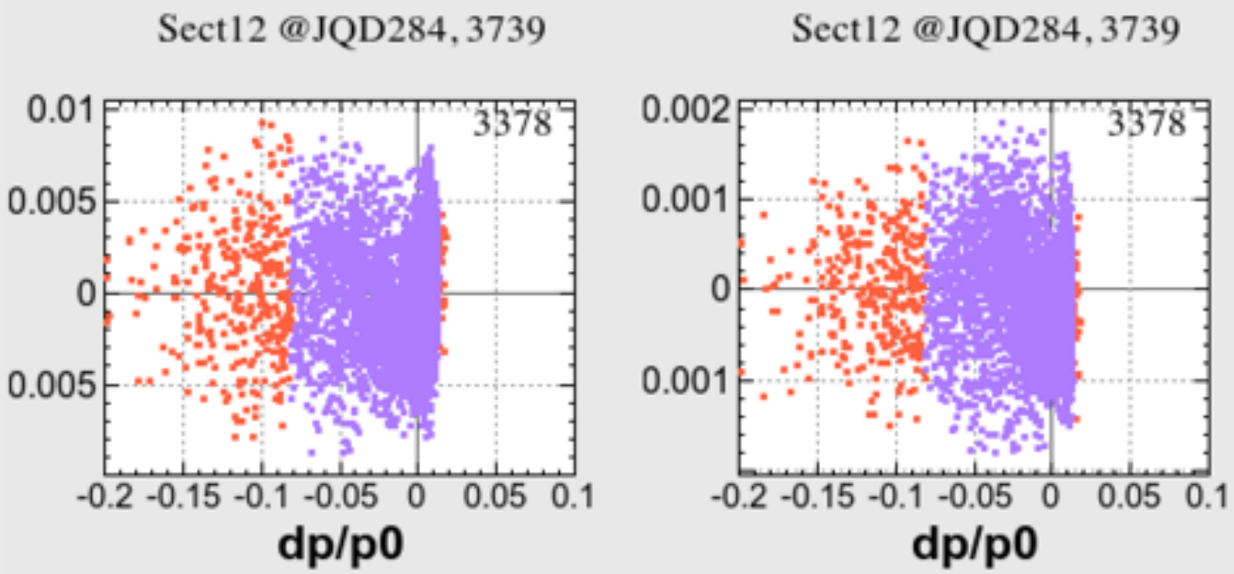
$$\varepsilon_z = 1.36\ mm$$

N. Iida *et al.*

1. KEK e+ Data

SS14SSSS_DCC-deg1-240_deg2-220_Capture-end_with-fc-targ-offset-Miyahara_20130520.dat
/users/takako/LINAC/newOptics/20130220SECT35FODO/Sect2_new.deck, JQD284





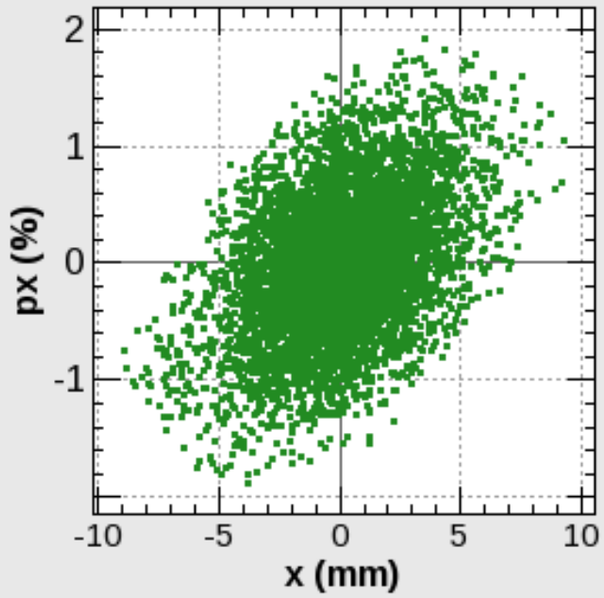
N. Iida *et al.*

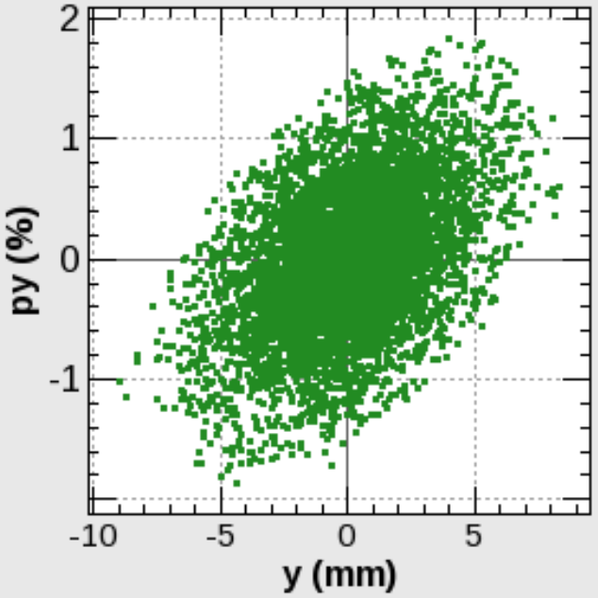
The purple particles are safely injected into the DR. The orange particles are cut by the collimators at LTR because they can not enter the separatrix of DR.

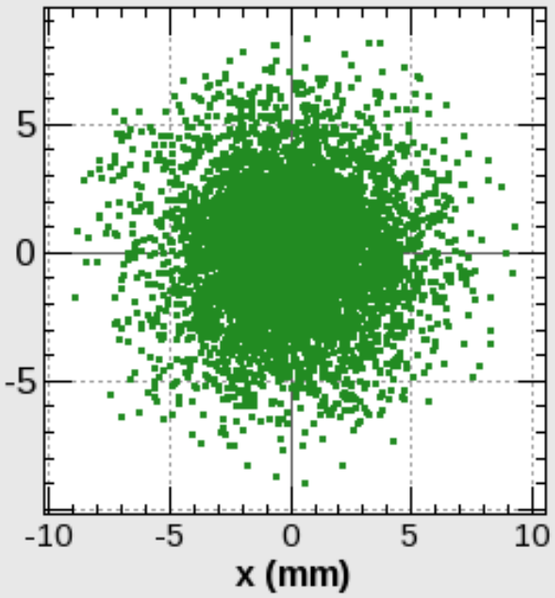
KEK collimates data to ±5%, then transfer through ECS.

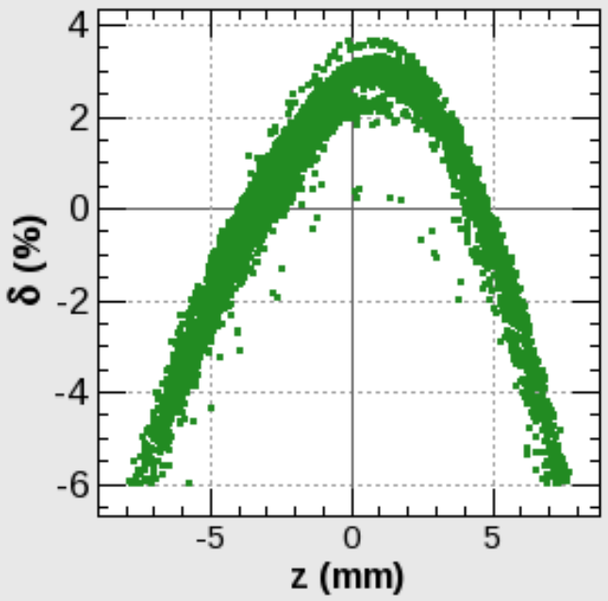
1. Collimated Beam

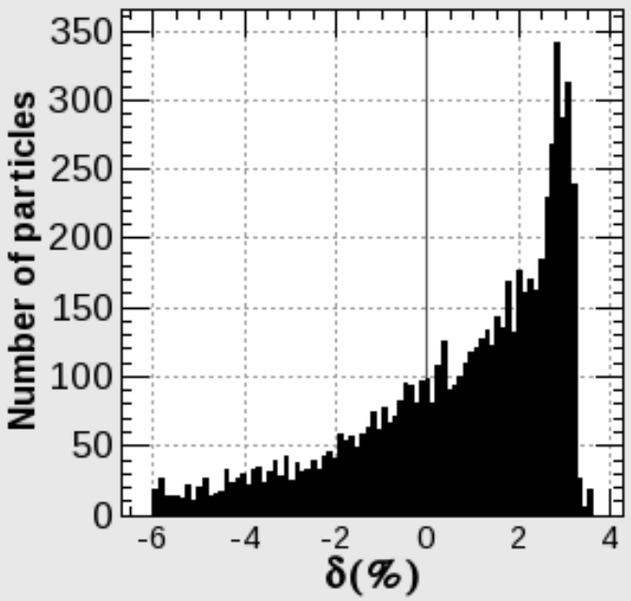
- Collimated data to fit in the our DR acceptance. Notice that, we still have 93% of the raw data.







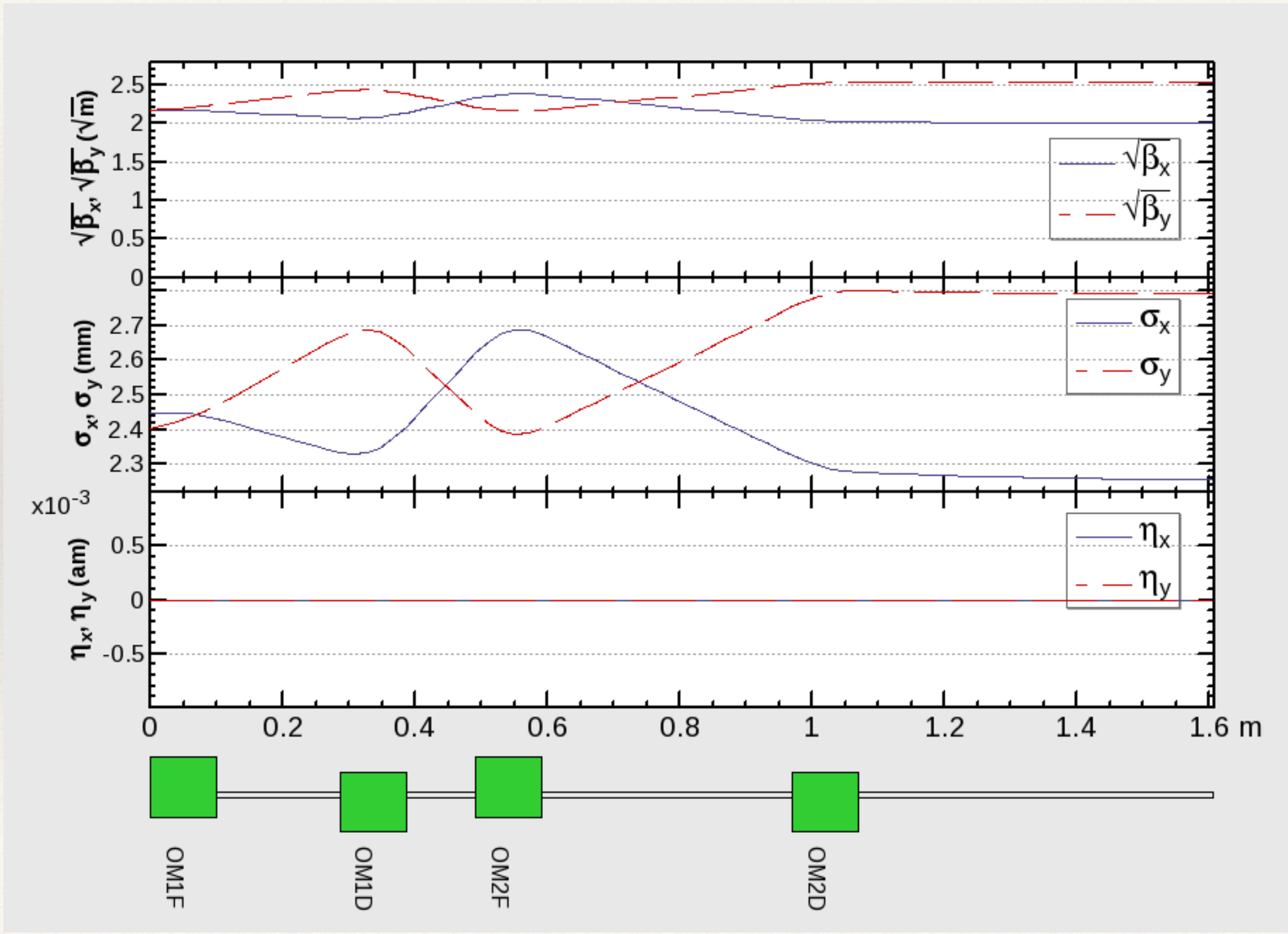




$$\varepsilon_x = 1.26\ \mu m$$
$$\varepsilon_y = 1.21\ \mu m$$
$$\varepsilon_z = 75.5\ \mu m$$
$$\alpha_x = -0.47$$
$$\alpha_y = -0.51$$
$$\alpha_z = -0.15$$
$$\beta_x = 4.71\ m$$
$$\beta_y = 4.74\ m$$
$$\beta_z = 0.15\ m$$

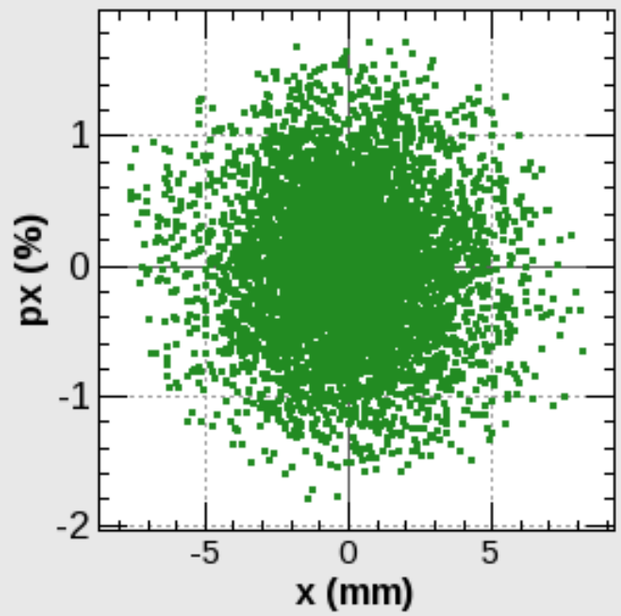
2. Linac to DR

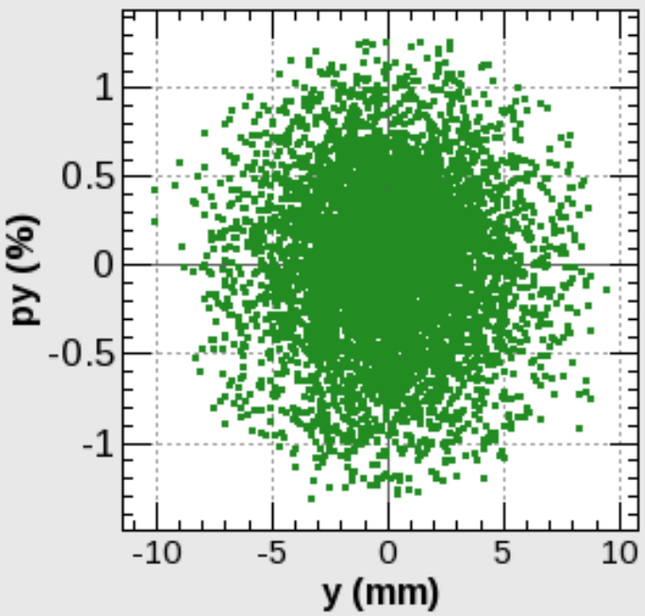
- A beam transfer line has been designed to match e+ to DR transversely.

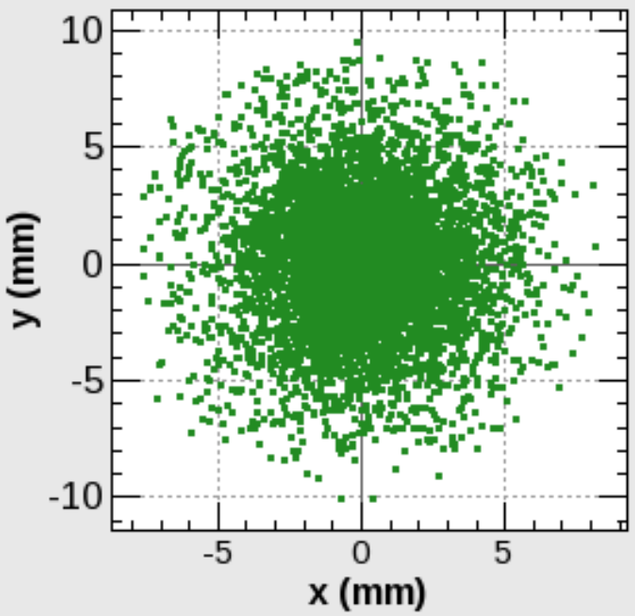


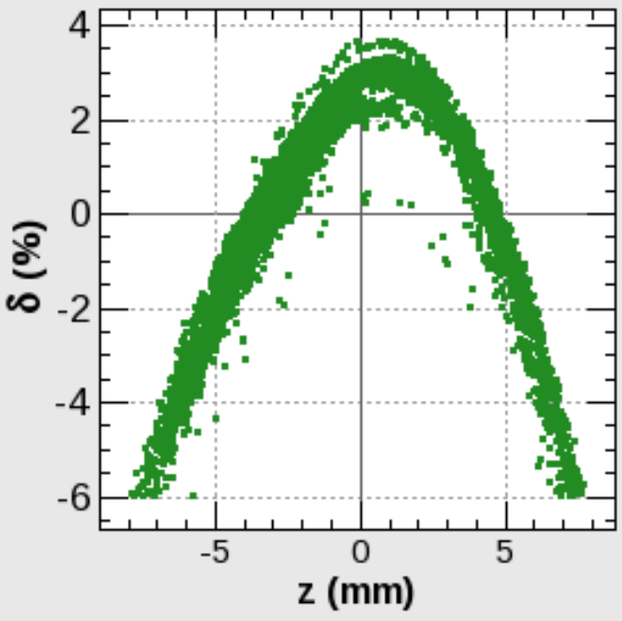
2. Beam Injected to the DR

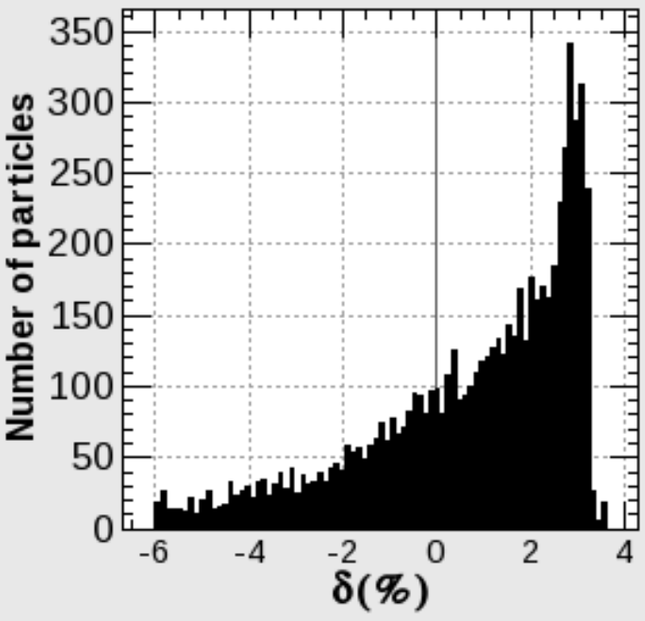
- The collimated beam is tracked through LitoDR, and matched to the DR.







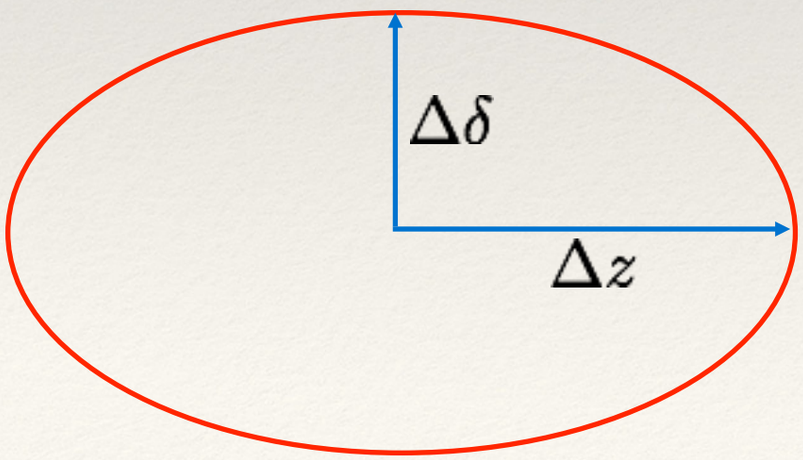




$$\varepsilon_x = 1.26\ \mu m$$
$$\varepsilon_y = 1.21\ \mu m$$
$$\varepsilon_z = 75.5\ \mu m$$
$$\alpha_x = 0.006$$
$$\alpha_y = 0.006$$
$$\alpha_z = -0.15$$
$$\beta_x = 4.00\ m$$
$$\beta_y = 6.38\ m$$
$$\beta_z = 0.15\ m$$

2. DR Acceptance vs Positron Data

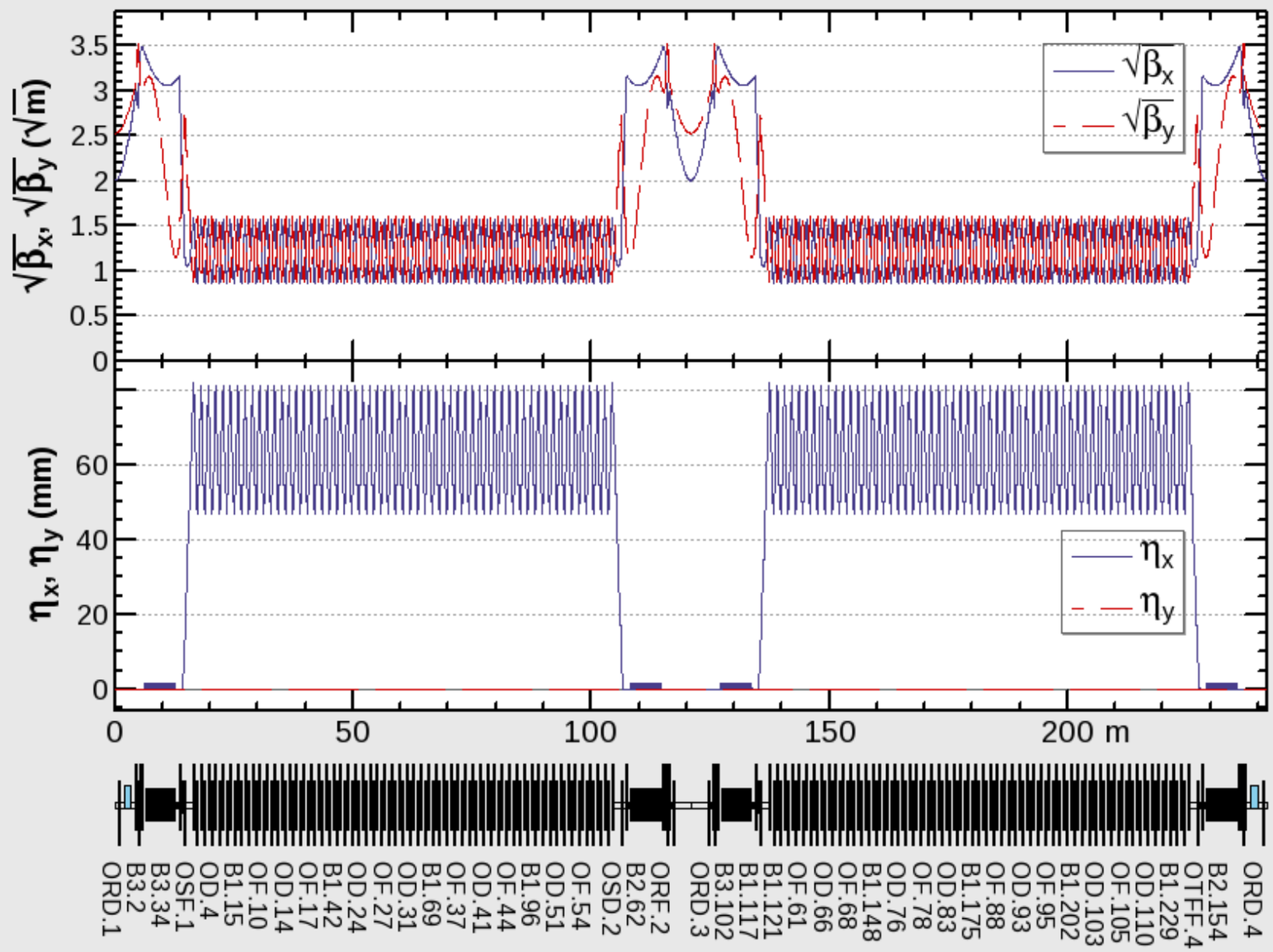
Parameter	KEK e+ data (raw i.e. 100%)	KEK e+ data (collimated i.e. 93%)	Damping Ring (acceptance)
Energy Spread (total)	±12%	±5 %	±7.9%
Bunch Length (total)	~ ± 12 mm	± 8 mm	±92.4 mm
β_z	1.19 m	0.15 m	2.96 m



$$DR_{acc.}^{long.} = (\pm 100)^2 \times 1.46\ \mu m = 14.6\ mm$$

$$\Delta z = \frac{7.3\ mm}{7.9\%} = 92.4\ mm$$

2. Damping Ring

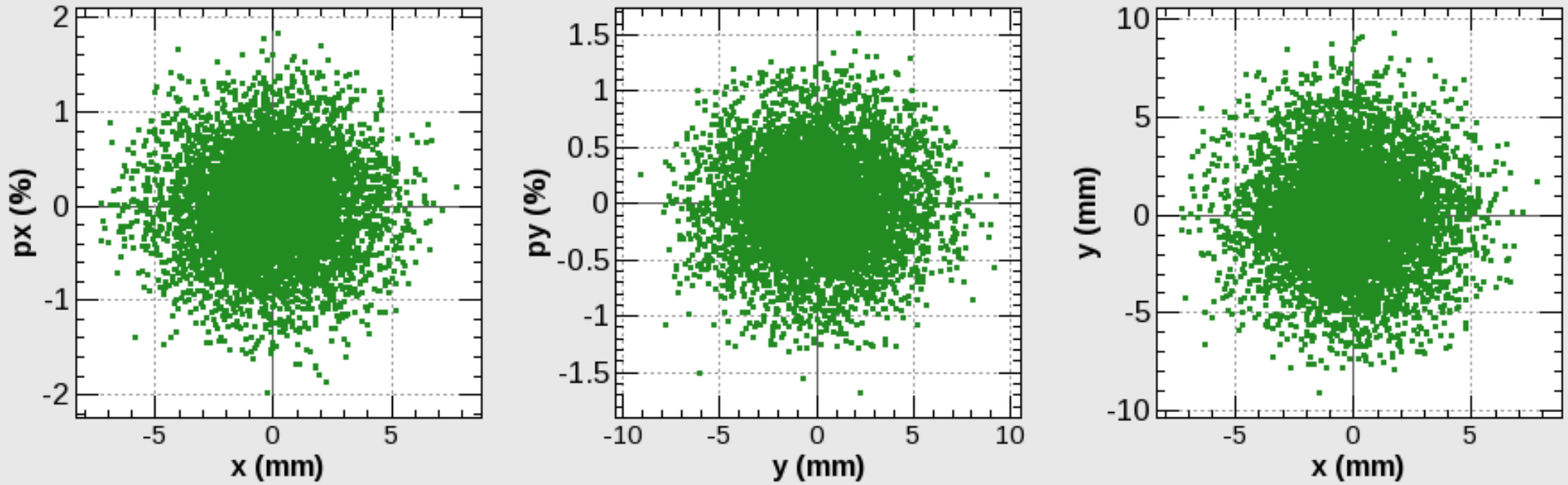


Parameter	Value
tau_x	10.6 ms
tau_y	11.0 ms
tau_z	5.6 ms
natural emittance (x/y/z)	1.16 nm/- 1.46 μm
circumference	241.8 m
# of cells (FODO w/ sextupoles)	114
dipole field	0.66 T
no. of wigglers, field	4, 1.80 T
cell tune (x/y)	0.193 rad/0.183 rad

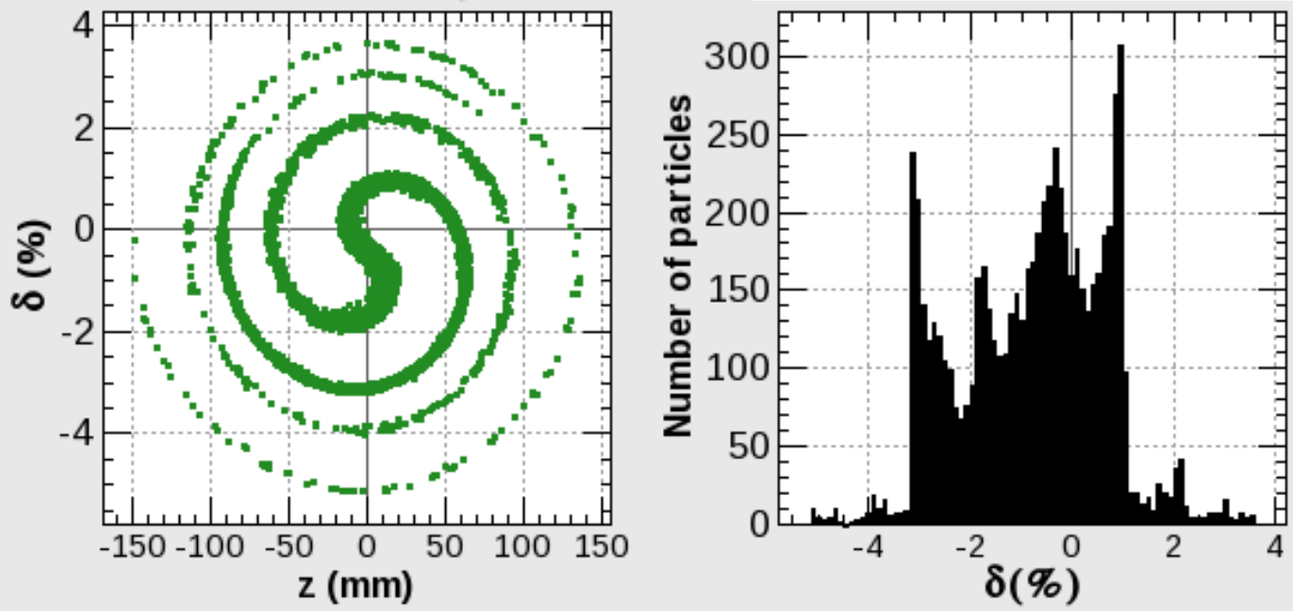
- The positron bunches have 45 milliseconds, whereas the electrons have 25 ms to spend in the damping ring !

2. Multiparticle e+ Tracking in DR

- 1000 Turns in the DR, the synchrotron radiation is ON.



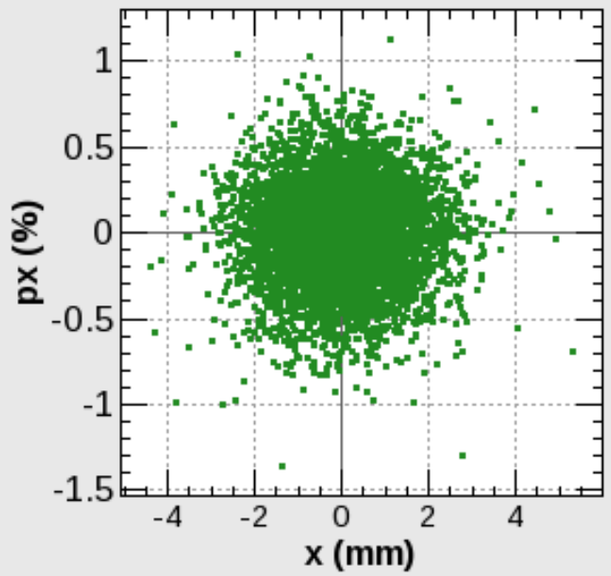
Filamentation due to longitudinal mismatch

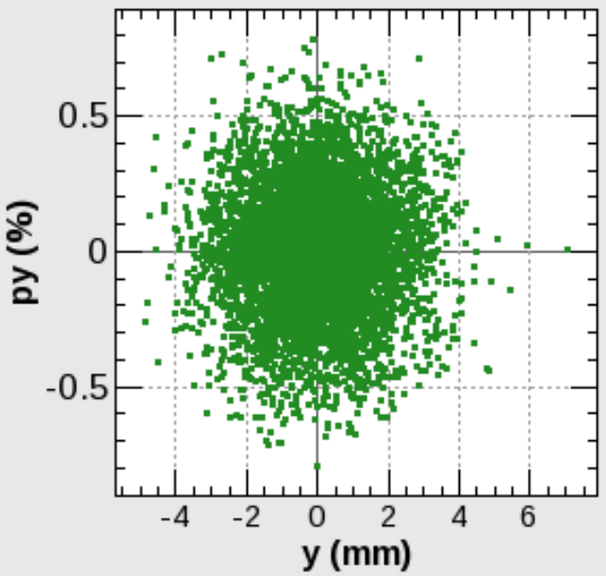


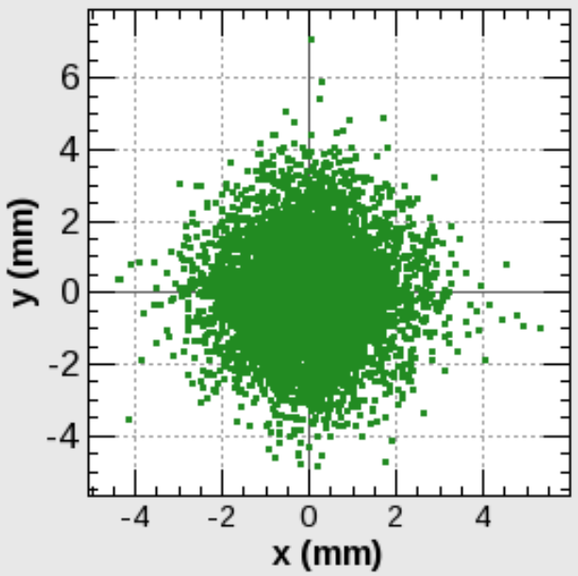
Notice that the graph shows the whole beam (not rms size!)

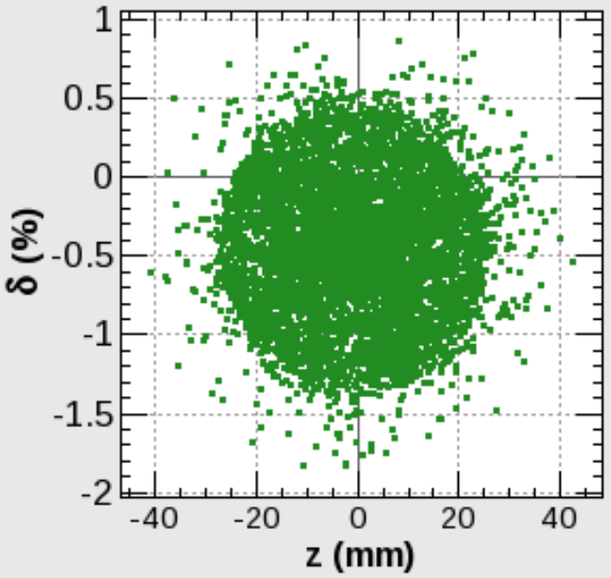
2. Multiparticle e+ Tracking in DR

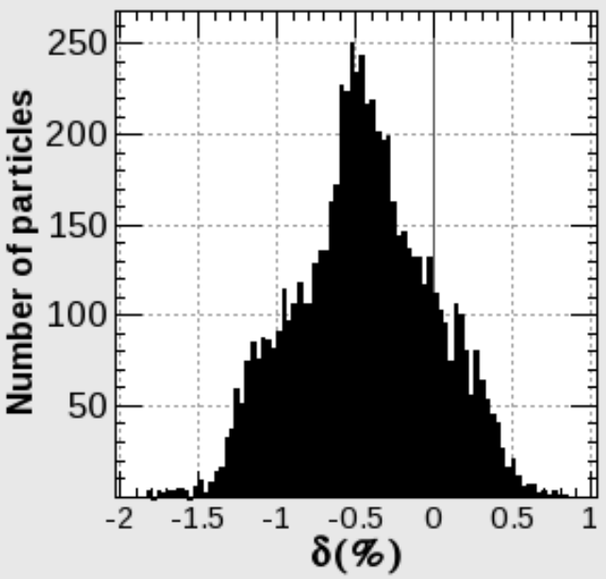
- 10 000 Turns (i.e. 8 ms out of 45 ms allowance) in the DR, the sync. rad is ON.











However, the filamentation is cured by the DR itself. The only concern remains the longitudinal emittance blow.

2. Results for Tracking

- 10 000 Turns (i.e. 8 ms out of 45 ms allowance) in the DR, the sync. rad is ON.

Emittance [μm]	Injected	*SAD* after Tracking	Analytical Expected *
Horizontal	1.29	0.277	0.28
Vertical	1.22	0.298	0.28

$$^{*}\varepsilon(t) = \varepsilon_{inj} e^{-2t/\tau} + \varepsilon_{equ}(1 - e^{-2t/\tau})$$

✓ These calculations are just to prove that the injected beam is **transversely matched** to the DR, and the DR shows a tremendous performance as expected! The very small transverse differences are most likely stemmed from the digits taken into account.

2. Results for Tracking

- 10 000 Turns (i.e. 8 ms out of 45 ms allowance) in the DR, the sync. rad is ON.

Emittance [μm]	Injected	*SAD* after Tracking	Analytical Expected *
Longitudinal	75.5	54.4	5.5
Filamented (i.e. @1000turn)	680	54.4	39

✓ In the longitudinal plane, we haven't made the matching. However, we can check the calculations using the filamented emittance (K. Oide)

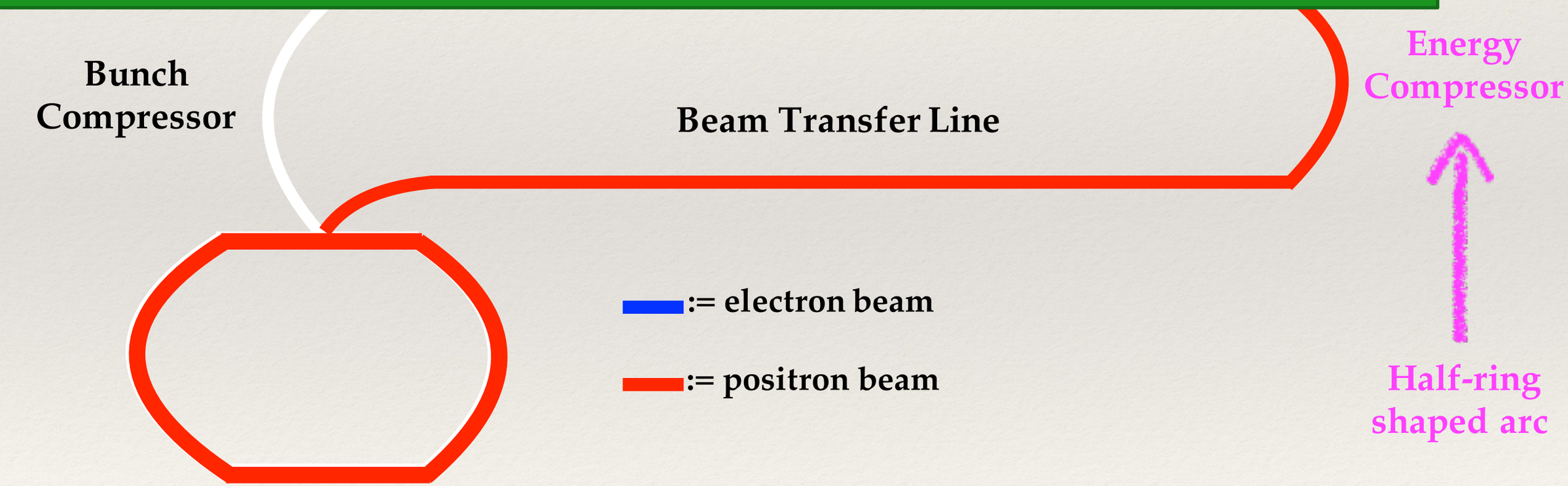
✓ YET, we can still reach the longitudinal equilibrium emittance in less than 30 ms (the allowed time in the DR is 45 ms, while tau_z is 5.6 ms)!

PS: 55600 Turns-simulation was dumped by CERN LSF due to the cpu usage limit.

3. Energy Compressor with Double Bend Achromat

0. Positron Flow Scheme

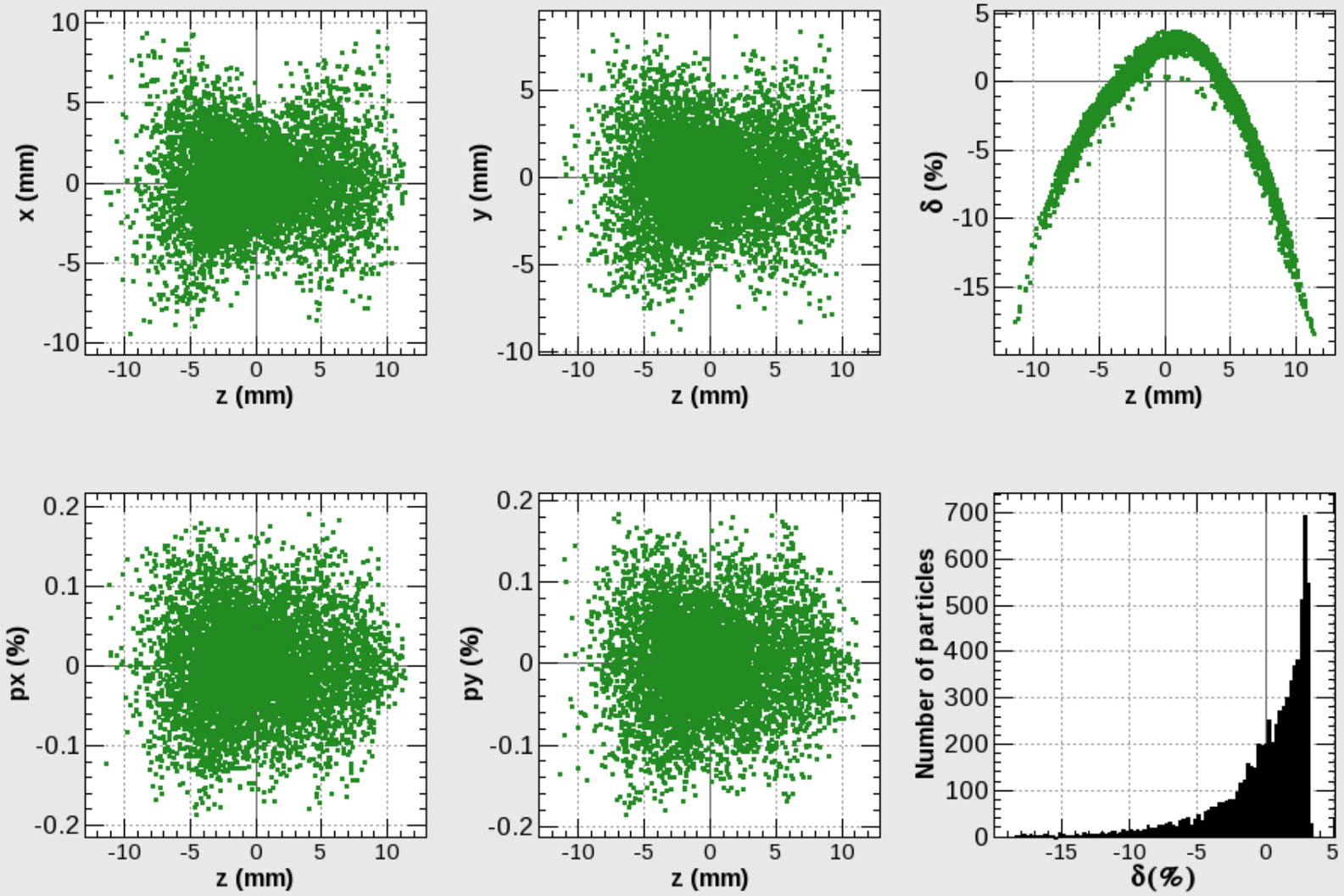
Yet, bending the positrons dilutes the emittance, and we observed some chromatic aberrations.



not to scale!

KEK e+ Data

- KEK simulated e+ data; when small head and tail are truncated (actually we still have 99% of no truncation case), the resulting *main bunch* would have a profile as presented:



$$\sigma_z = 4.01\ mm$$

$$\varepsilon_x = 1.29\ \mu m$$

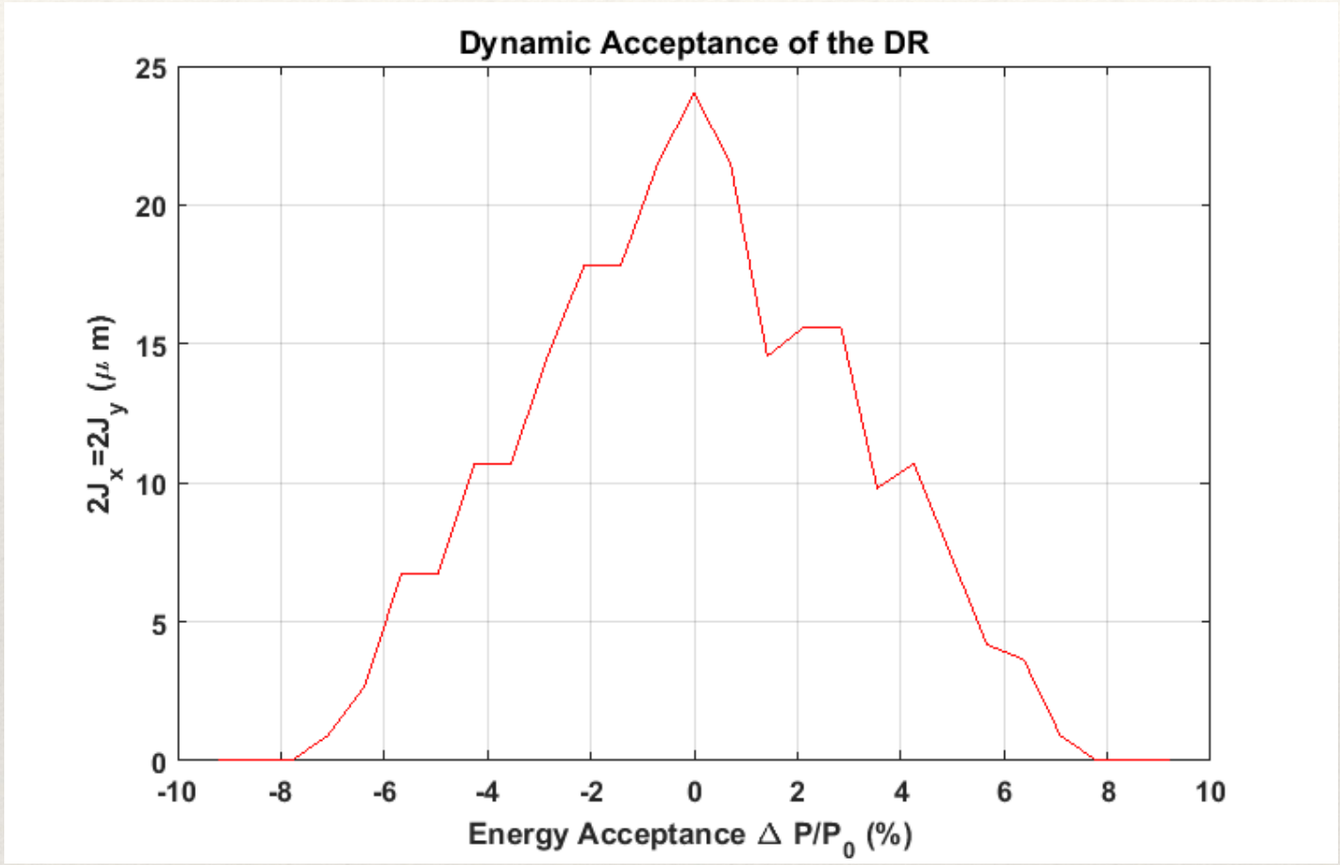
$$\varepsilon_y = 1.22\ \mu m$$

$$\varepsilon_z = 1.36\ mm$$

$$\beta_z = 0.12\ m$$

DR Acceptance

- DR provides $\pm 8\%$ energy acceptance, but we may inject the beam within $\pm 2.4\%$.



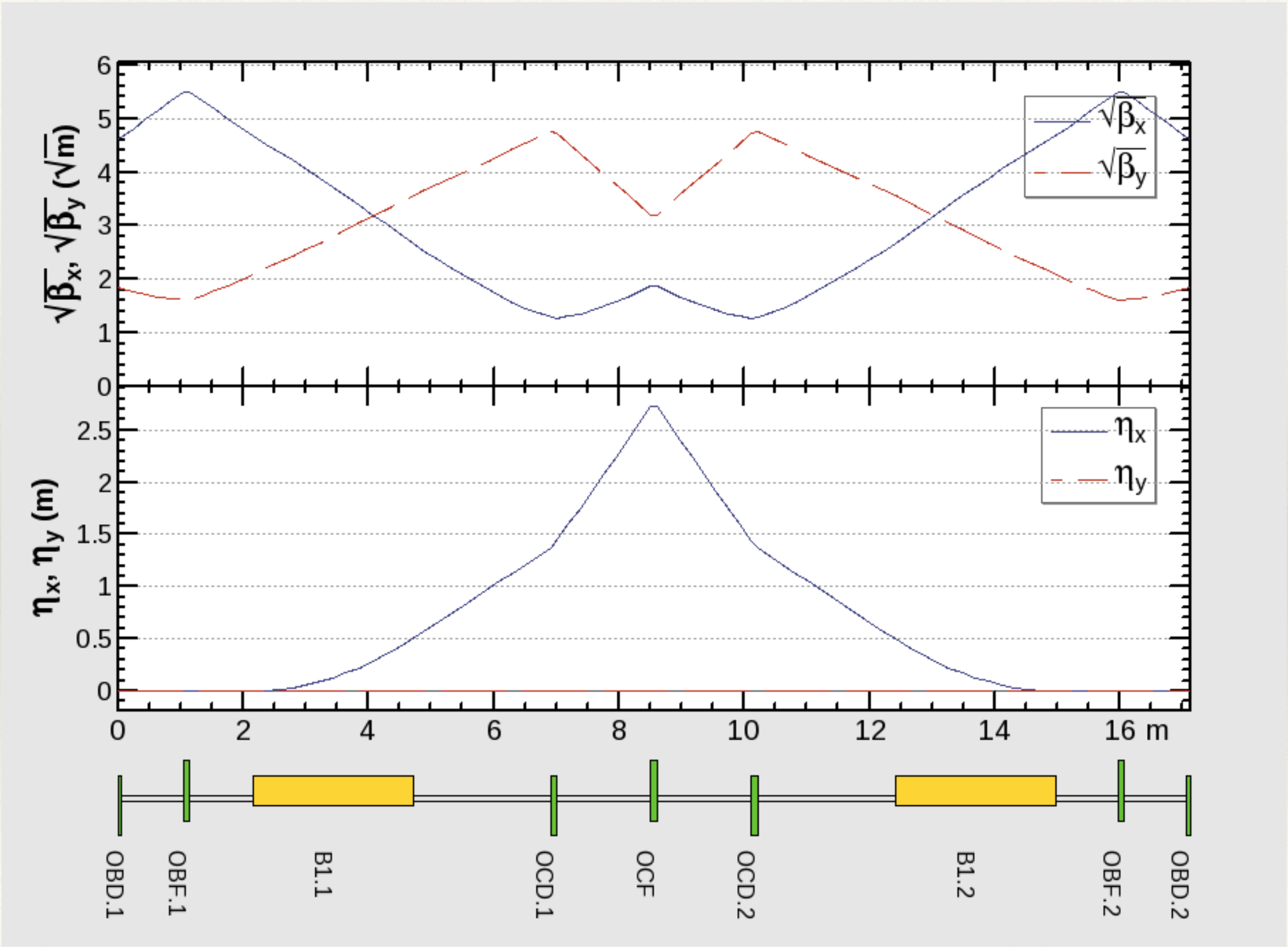
$$\beta_z = 0.12\ m$$

$$\beta_z = \frac{\sigma_z^2}{\varepsilon_z} = \frac{(2.07\ mm)^2}{1.47 \mu m} = 2.91\ m$$

compress energy to $\sqrt{\frac{0.12}{2.91}} = 20\%$

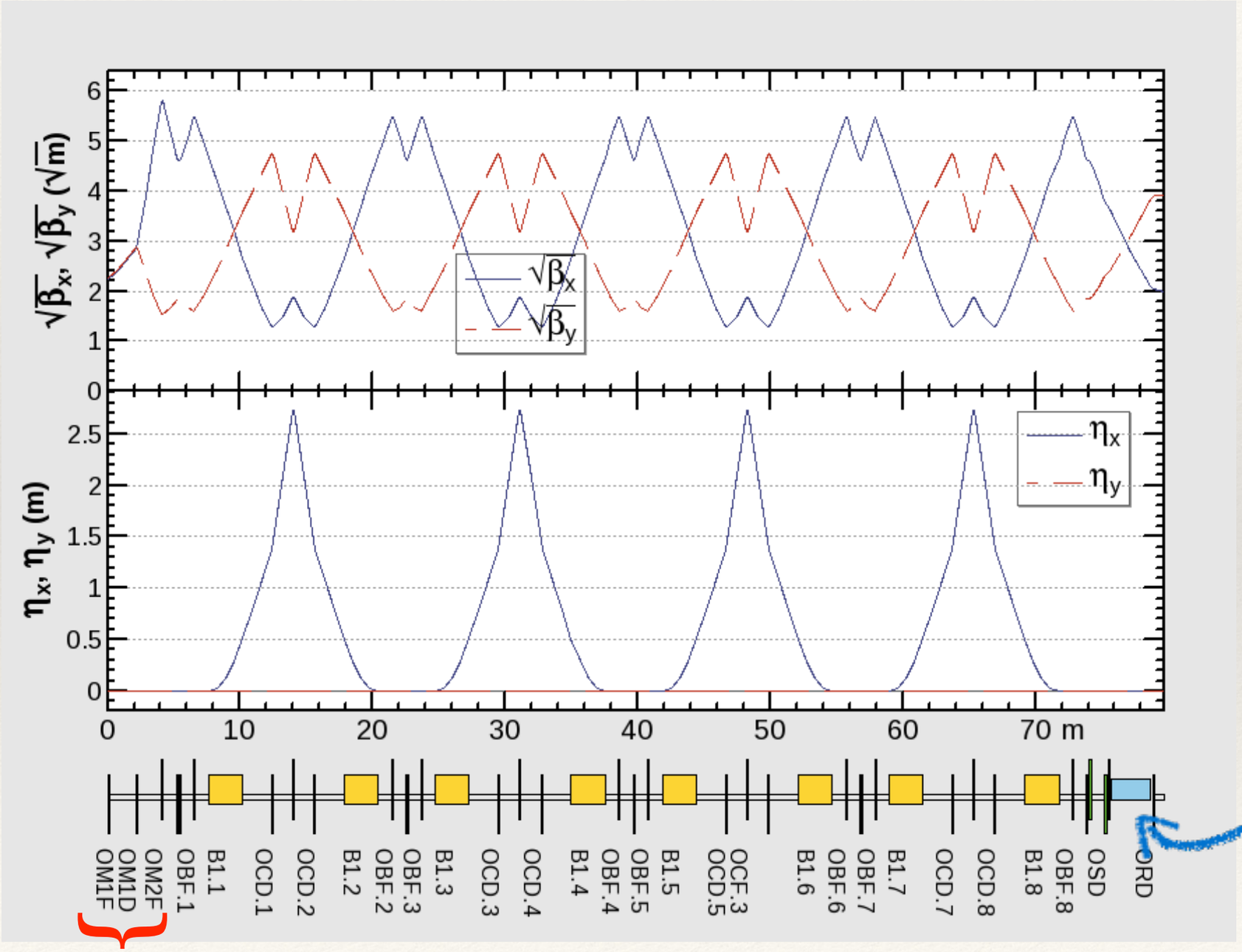
in other words, the total energy spread of e+ data should be compressed from ±12% to ±2.2% .

ECS - DBA Supercell



Half Ring Energy Compressor

- 180 degree arc is consisting of 4 DBA supercells corresponding to 8 dipoles each with ~2.6 m long supplying 0.8 Tesla. The cavity phase is set to zero!

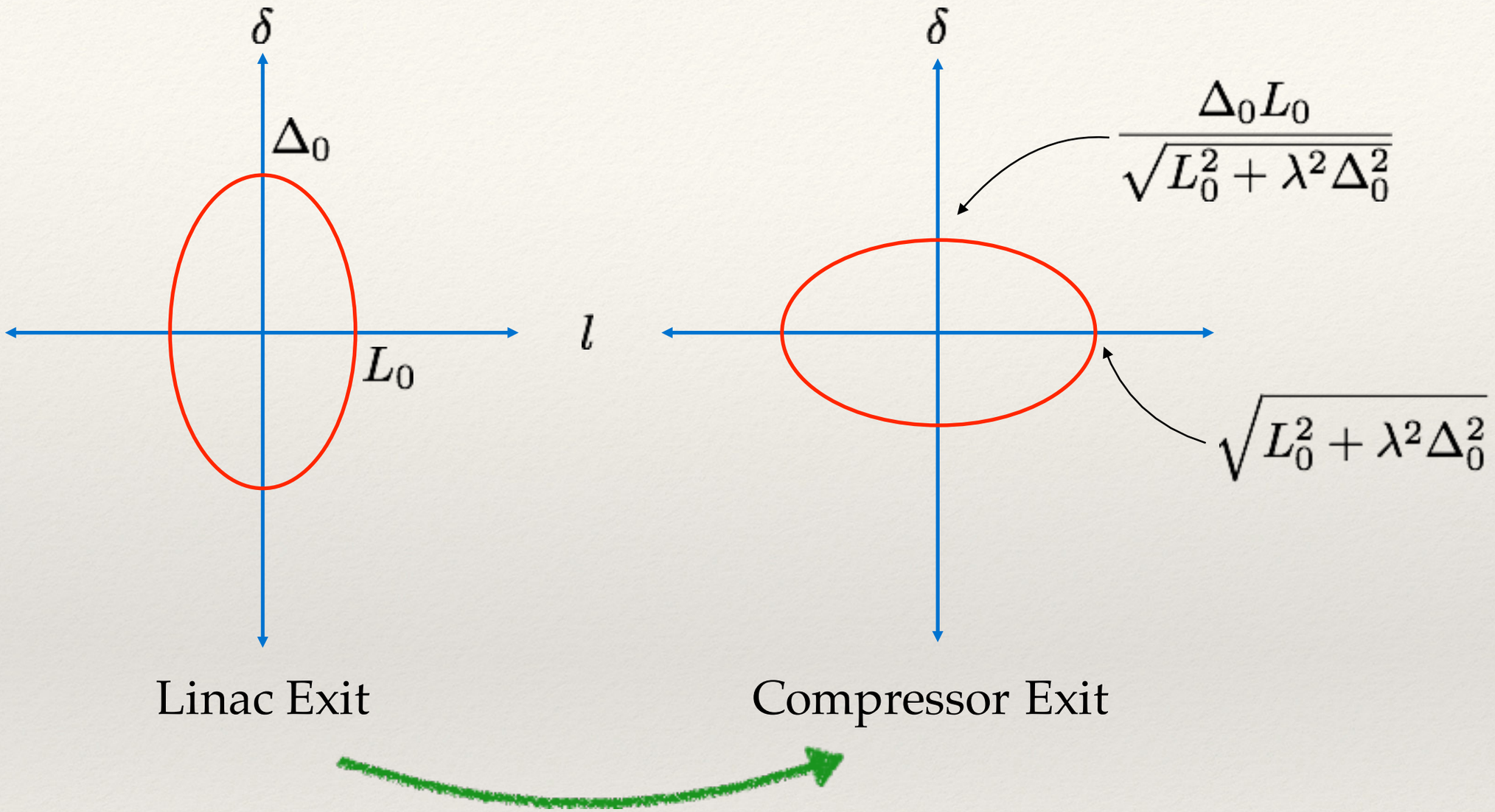


matching section: LitEC (Linac to Energy Compressor)

S-Band Cavity:

- 2.856 GHz
- Iris Φ=40 mm (to be determined by e+ tracking)
- 2.97 m long
- Voltage = 48 MV

ECS- Compression



$$\alpha = \frac{\lambda \Delta_0^2}{L_0^2 + \lambda^2 \Delta_0^2}$$

Reference: R. Chebab, ".. Compresseur d'Energie pour le Preinjecteur du LEP", - LAL/PI/80-79, 1980

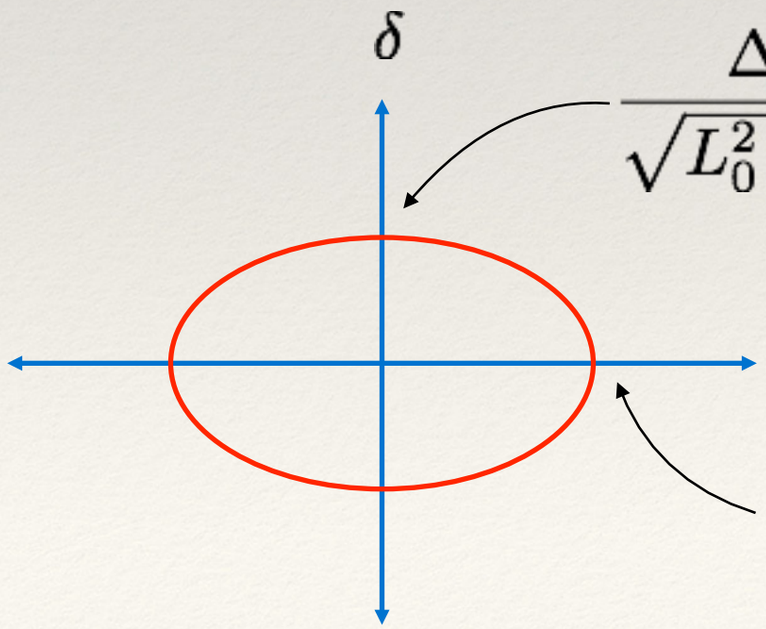
ECS- Transfer Matrix

```
Symplectic transfer matrix from IP1.1 to $$$
   -.094485   16.994154     .000000     .000000  2.8525E-16  3.49041E-9
   -.058286    -.100254     .000000     .000000  -7.517E-18  1.2357E-10
    .000000     .000000    -.509433  -48.417833     .000000     .000000
    .000000     .000000     .014782    -.558026     .000000     .000000
 -1.918E-10  -2.4499E-9     .000000     .000000    1.000001    -.522327
 -3.555E-10  -4.5422E-9     .000000     .000000    1.854011     .031599
```

matched

R56

$$-\alpha = -\frac{\lambda\Delta_0^2}{L_0^2+\lambda^2\Delta_0^2} = -\frac{-0.52*0.12^2}{0.0115^2+0.52^2*0.12^2} = 1.8532$$

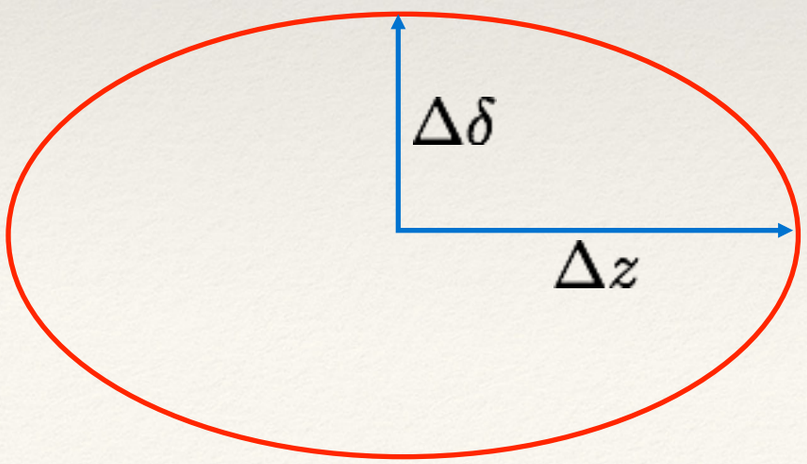


ECS - Calculations

in other words, the total energy spread of e+ should be compressed from ±12% to ±2.2% .

Parameter	KEK e+ data	Energy Compressor (EXIT)	Damping Ring (ENTRANCE)
Energy Spread (total)	±12%	±2.2%	±7.9%
Bunch Length (total)	±11.4 mm	±63.7 mm	±92.4 mm
β_z	0.12 m	2.96 m	2.96 m

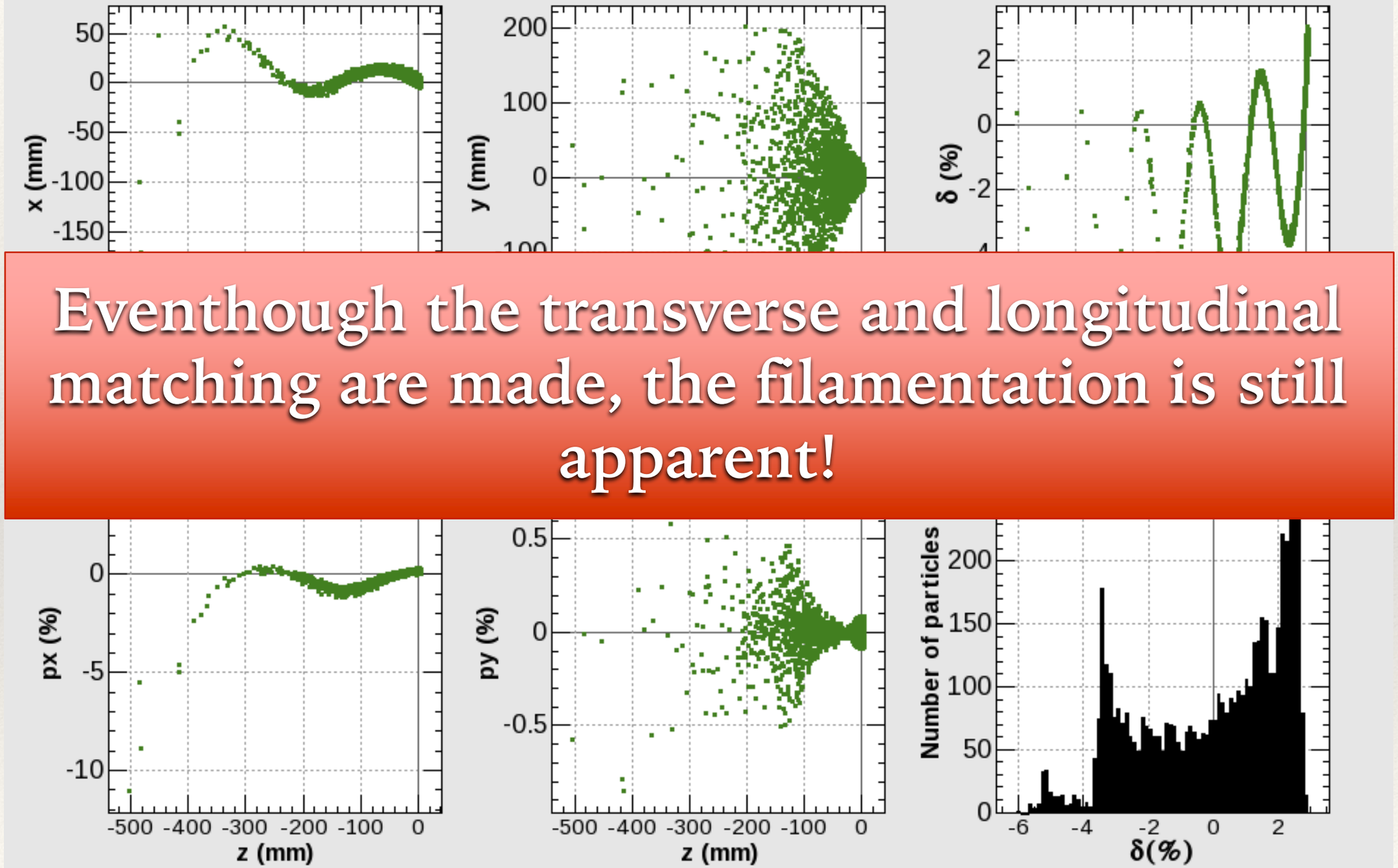
matched



$$DR_{acc.}^{long.} = (\pm 100)^2 \times 1.46\ \mu m = 14.6\ mm$$

$$\Delta z = \frac{7.3\ mm}{7.9\%} = 92.4\ mm$$

ECS - Results



Eventhough the transverse and longitudinal matching are made, the filamentation is still apparent!

Conclusions and Further Considerations

- Our earlier analytical calculations are **CONFIRMED** thanks to the large DA as promised. Both transverse and longitudinal target emittance values will be reached in **ideal** case.
- Until our e+ data will suggest an energy compressor, the ECS is out of table -for now.
- Energy Compression can also be made through the e+ linac by phasing the cavities and in capture section (KEK, CLIC), yet arising the question of capture yield.
- CERN LSF did not allow 3 days-long simulation, it dumped the simulation of 56k turn tracking which would be the extracted beam from the DR.
- The further effort will be drawn to the Linac & DR error studies and e- transfer line to the DR.