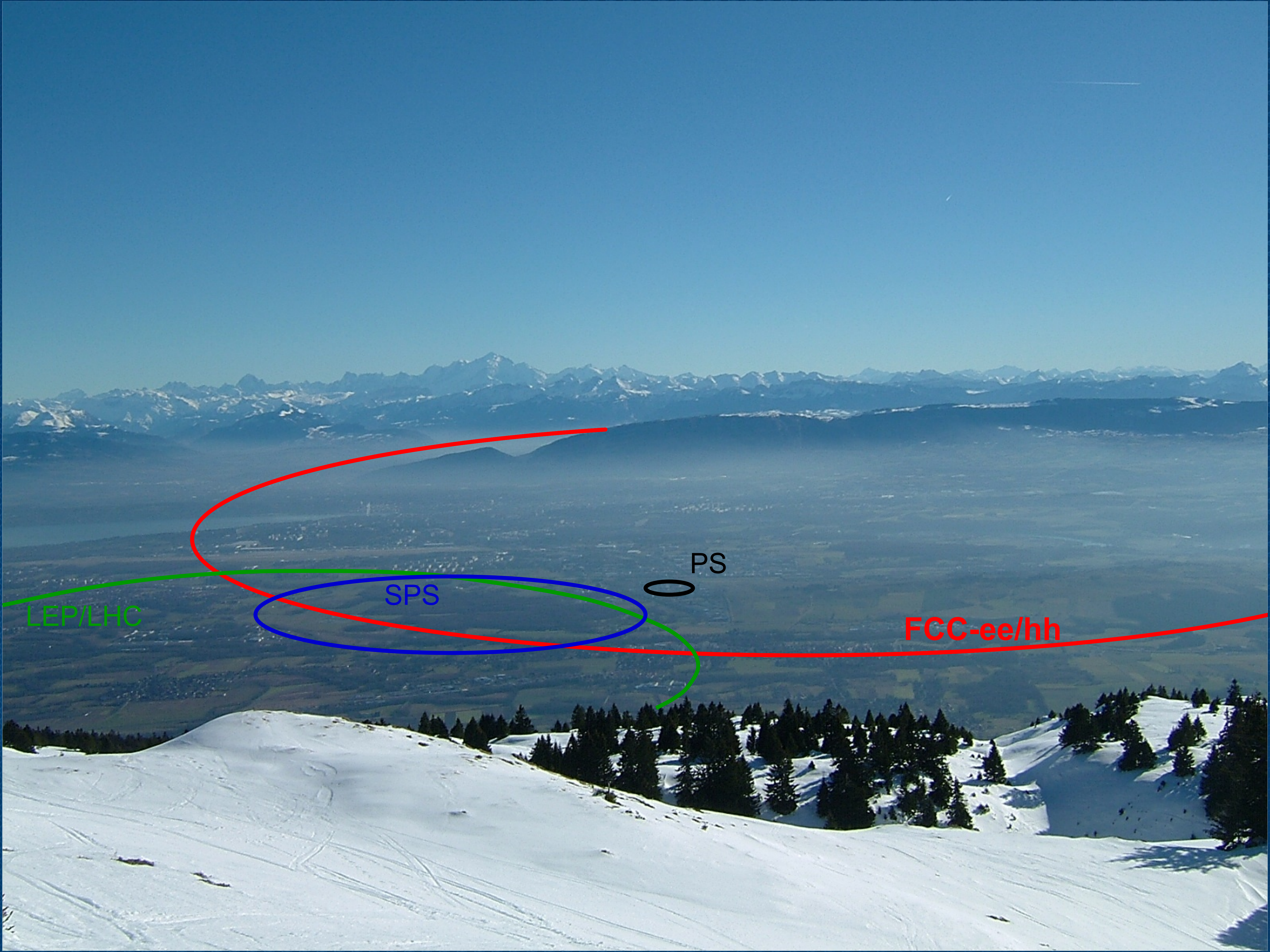
Salim Ogur

FCC-ee 20 GeV S-Band + C-Band Linac & Damping Ring

2017/12/1 KEK, Tsukuba, Ibaraki, Japan

Acknowledgements: K. Oide, F. Zimmermann, T. Charles, Y. Papaphilippou, L. Rinolfi,(CERN); A. Barnyakov, A. Levichev, P. Martyshkin, D.Nikiforov(BINP); Erkcan V. Ozcan (Bogazici Un.); K. Furukawa, N. Iida, T. Kamitani, F. Miyahara(KEK); I.Chaikovska, R. Chehab (LAL); S. Polozov (MePHI).


PS
SPS
LEP/LHC
FCC-ee/hh

Outline

1. Overview of Baseline & Accelerators

2. Linac Design

   2.1. Up to 1.54 GeV

   2.2. From 1.54 to 20 GeV

3. Damping Ring

4. Conclusion

+ Energy Compressor

Motivation:

Operation Type	Final Energy [GeV]	Bunches /Beam	Bunch Population	Horizontal Emittance [nm]	Vertical Emittance [nm]	Luminosity [$cm^{-2}\ s^{-1}$]
Z	**45.6**	**16640**	**1.7E+11**	**0.27 nm**	**1.0 pm**	**200E+34**
W	80	2000	1.5E+11	0.28 nm	1.0 pm	30E+34
H	120	393	1.5E+11	0.63 nm	1.3 pm	7E+34
tt	182.5	48	2.7E+11	1.45 nm	2.7 pm	1.3E+34

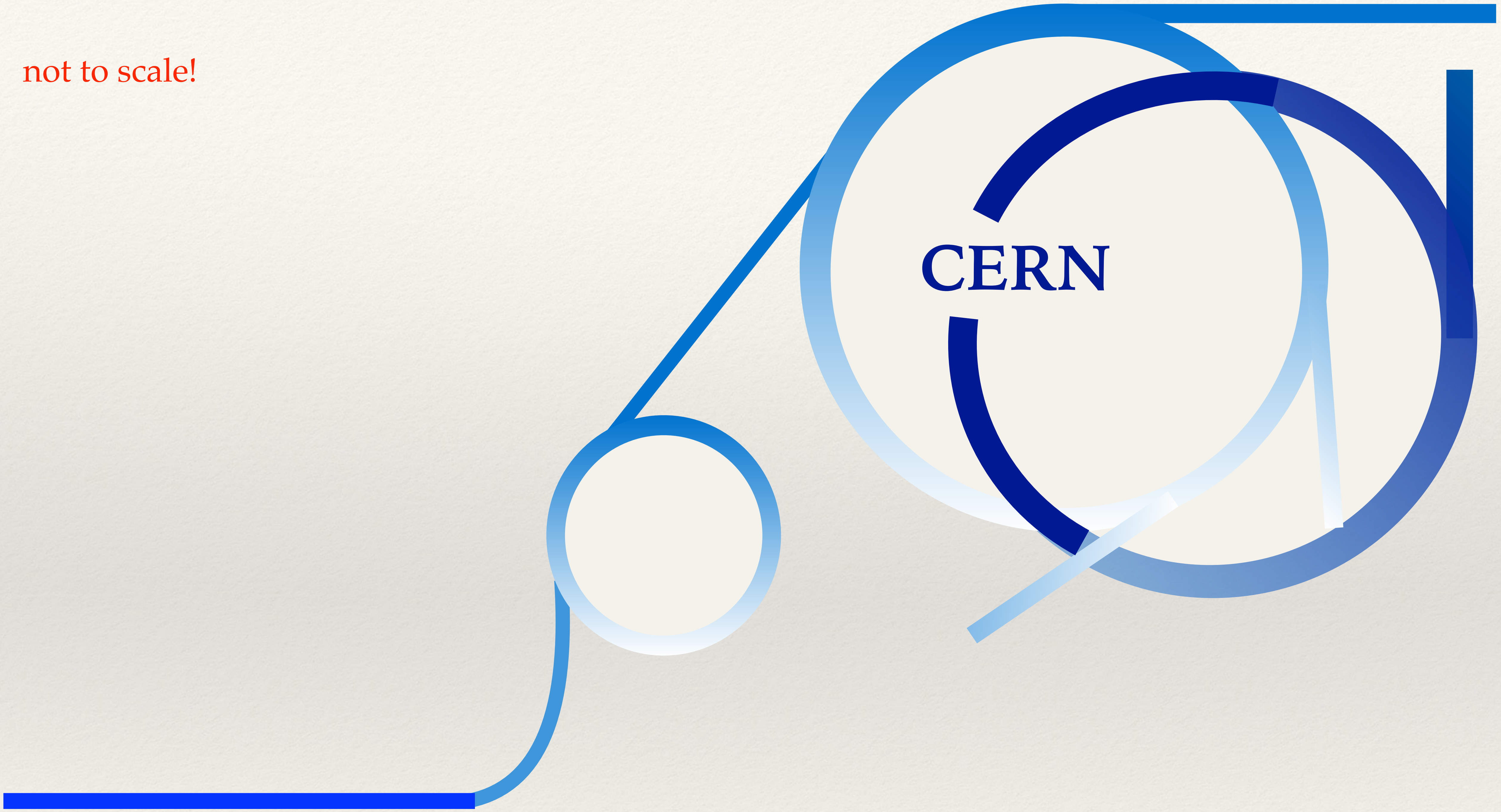
❖ FCC ee has 4 different operations, especially Z operation is challenging in terms of pre-injection since it requires the **highest total charge** and the **lowest emittance**.

❖ Therefore, **the fulfilling the requirements of Z-operation is to cover all other operations in terms of total charge and final geometric emittance in the collider.**

PS: All emittance values in this presentation are rms-geometric.

1. Overview of FCCe+e- Complex

not to scale!



6 GeV Linac: 2 Bunches/Pulse
B. Pop: 1.7E10

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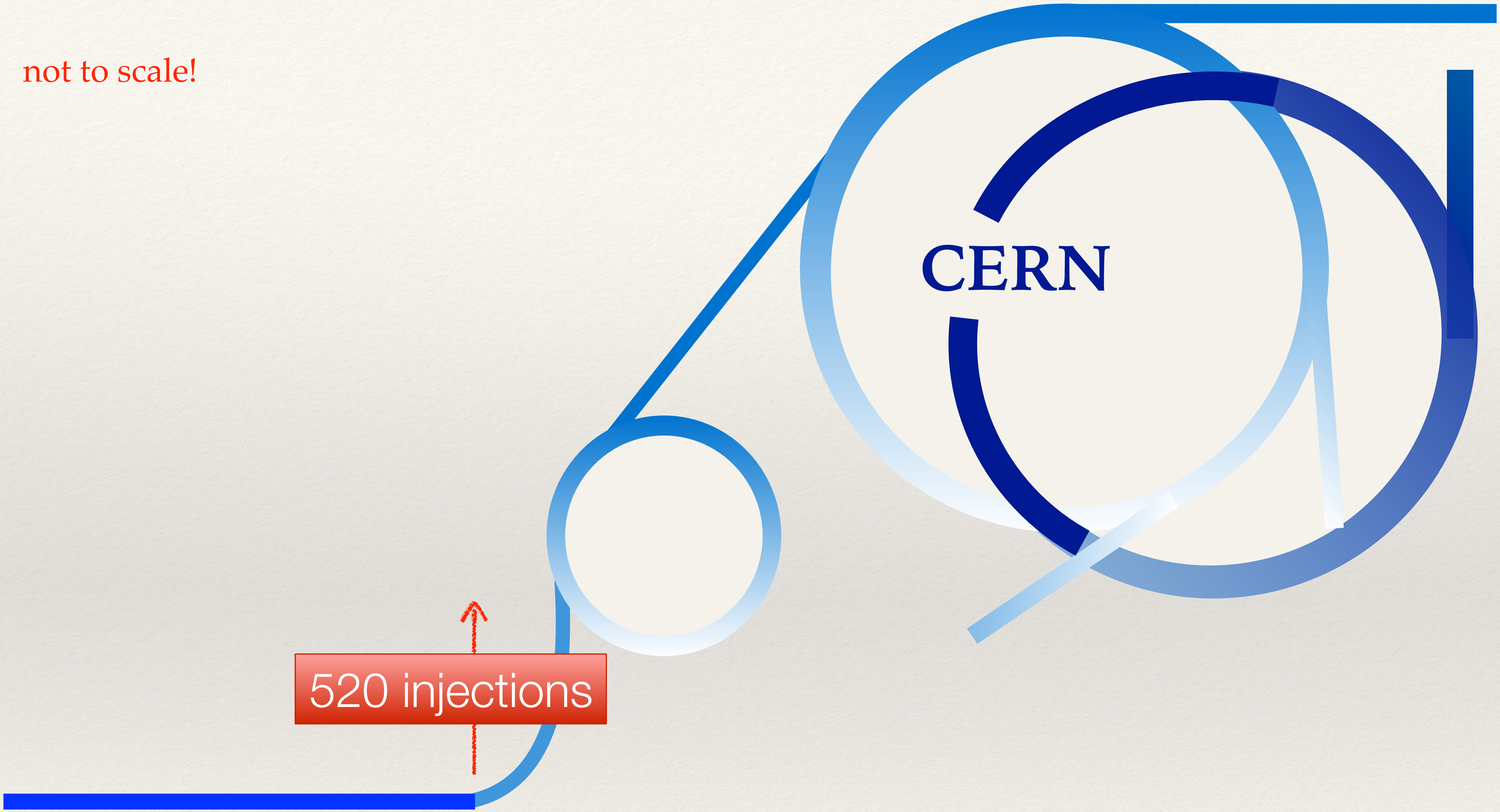

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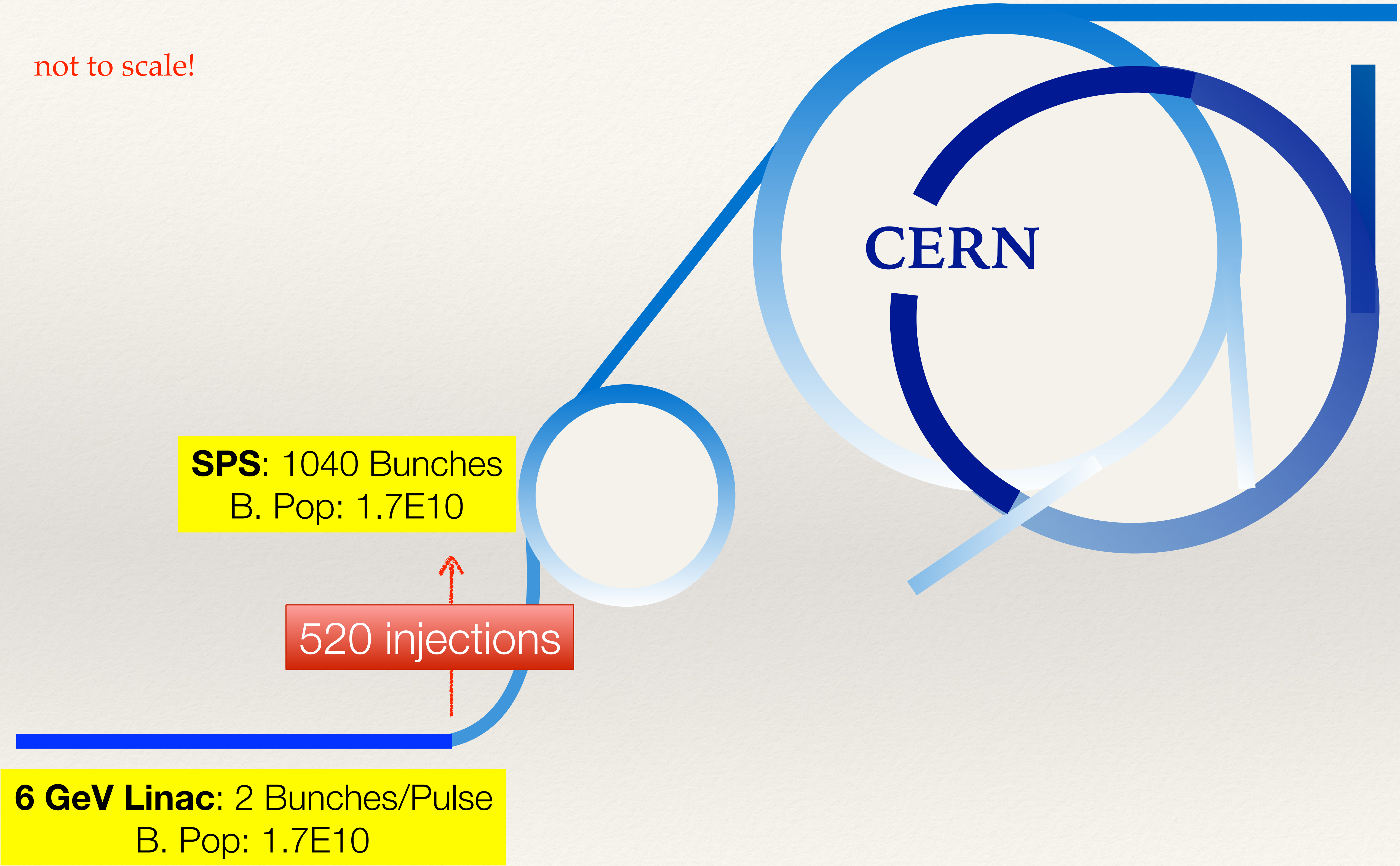

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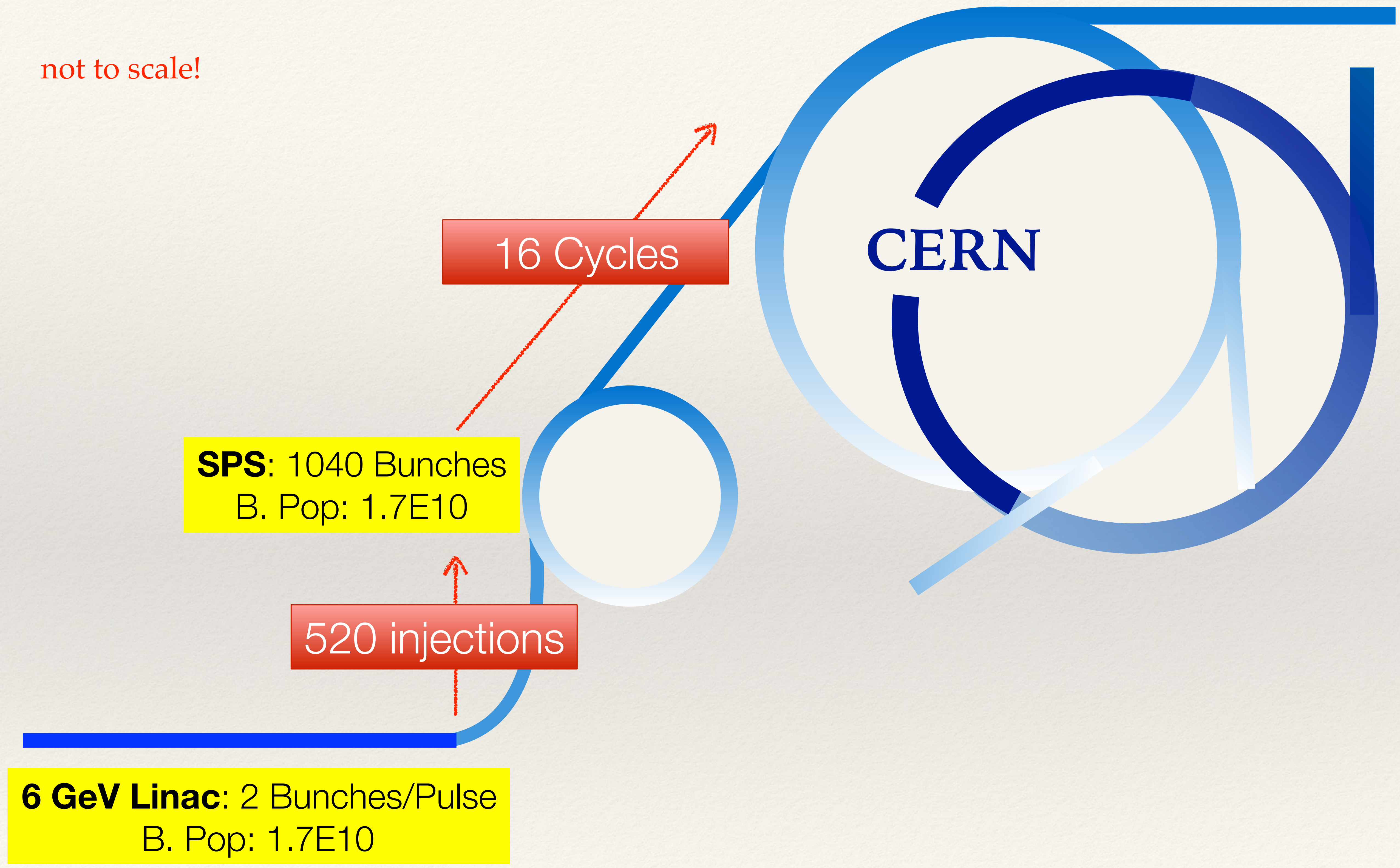

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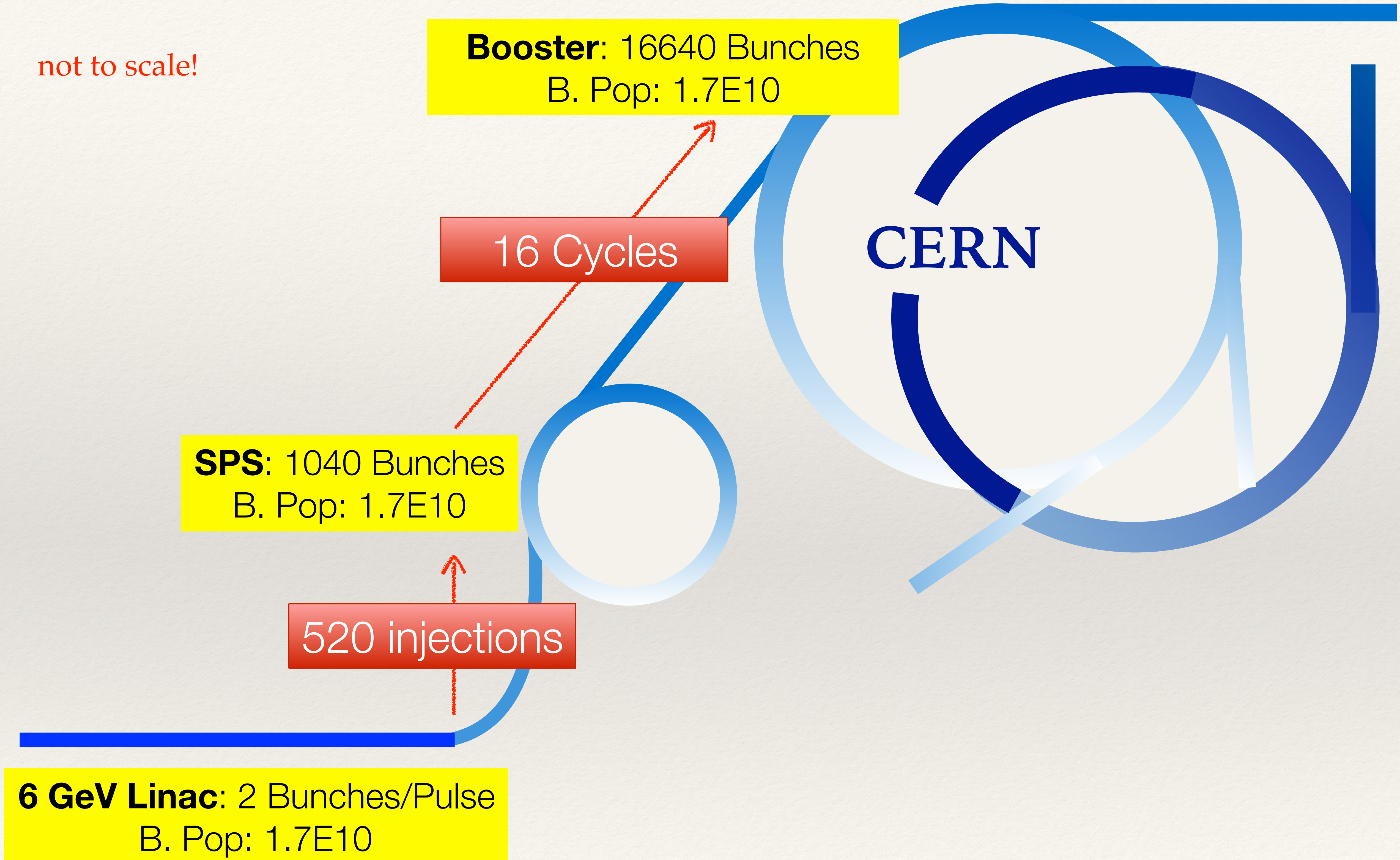

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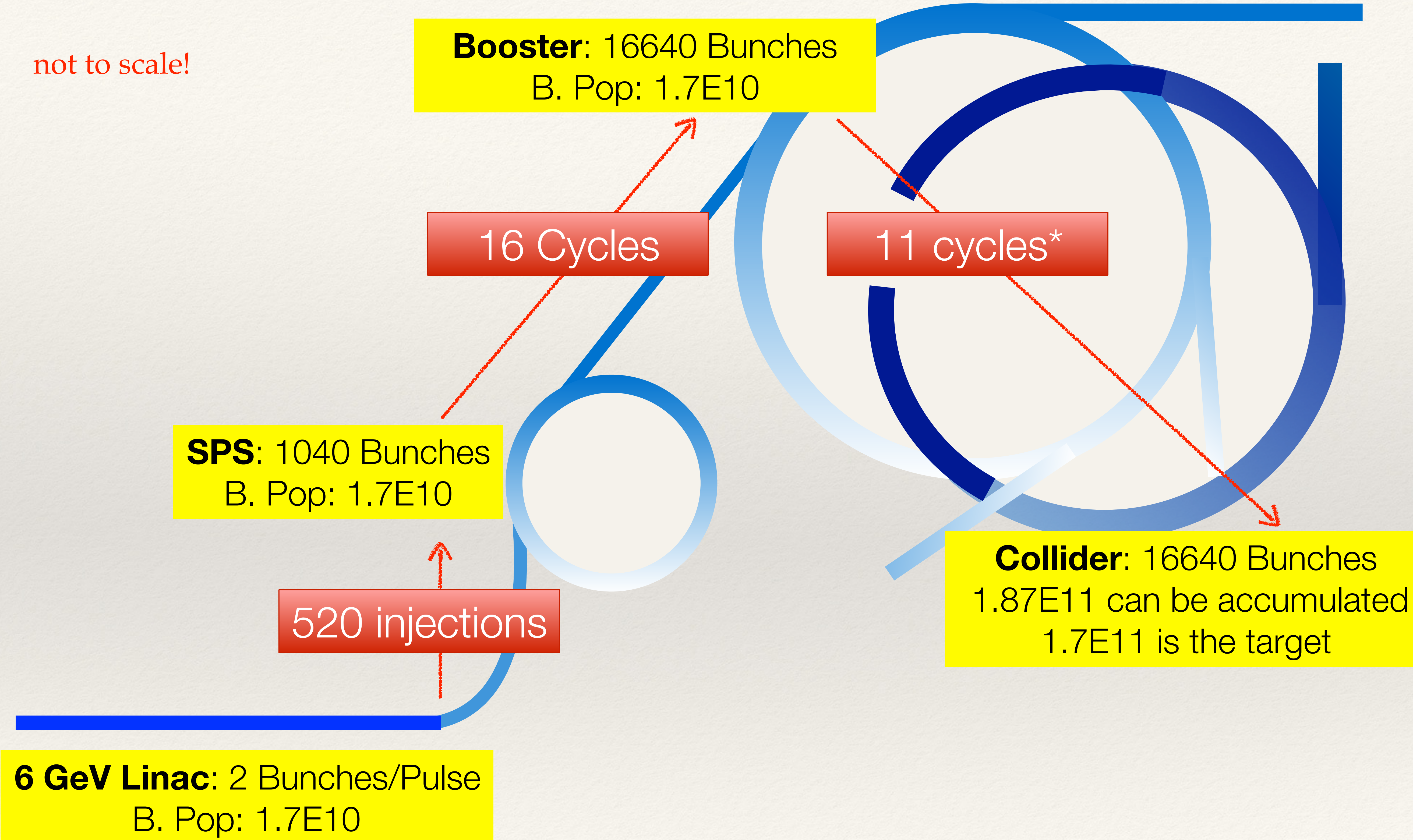

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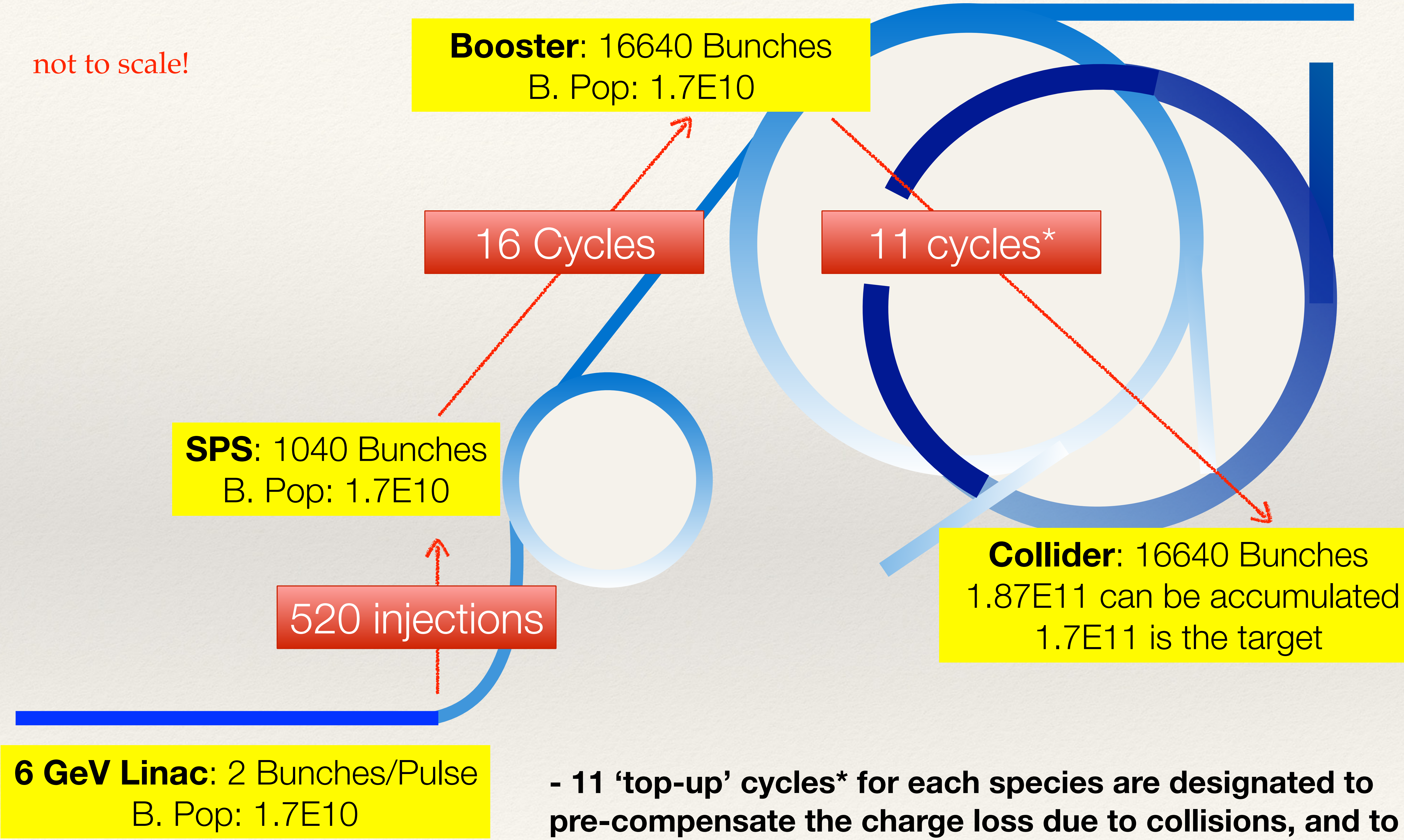
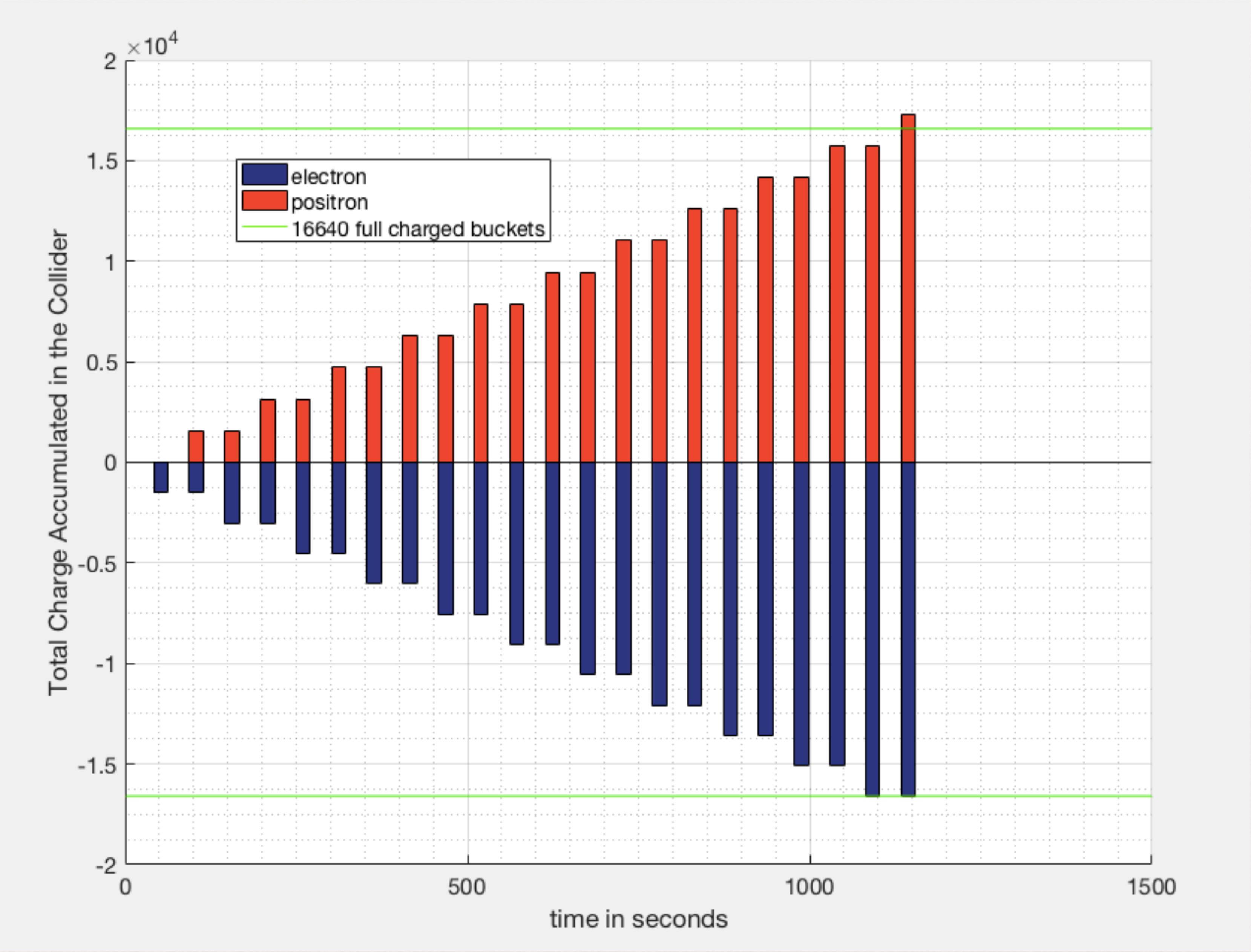


- 11 ‘top-up’ cycles* for each species are designated to pre-compensate the charge loss due to collisions, and to always keep the charge imbalance within the ±5%.

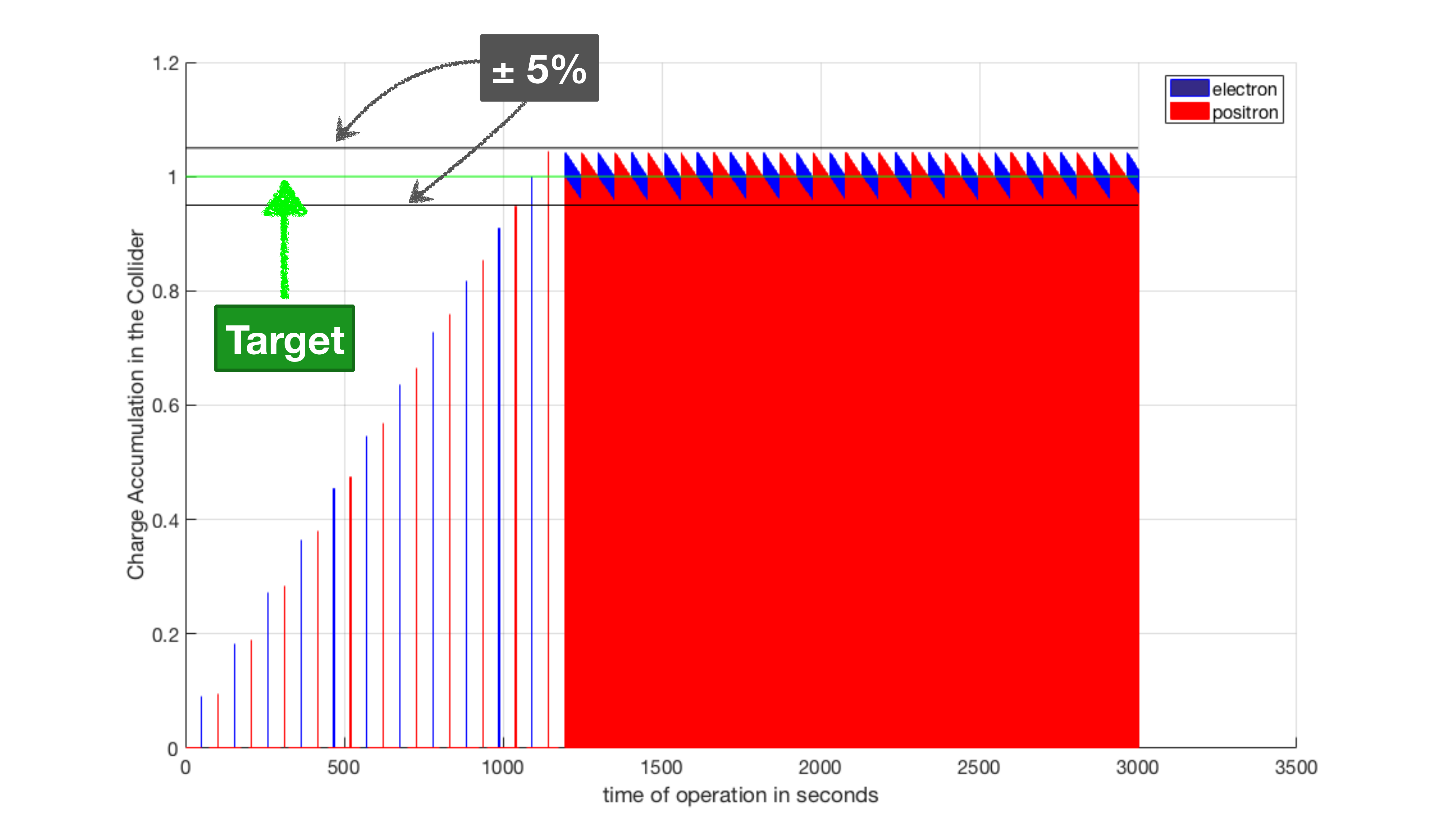
Collider Charge Accumulation: Pre-compensation & Bootstrapping



- ➡ Notice that the e- and e+ charges are asymmetric, e+ buckets of collider has 104% while e- buckets are with 100%. To obtain that configuration, for example, we add 9.5% to the e+ at the last cycle.
- ➡ D. Shatilov's proposed bootstrapping to keep the horizontal emittance fluctuations low.

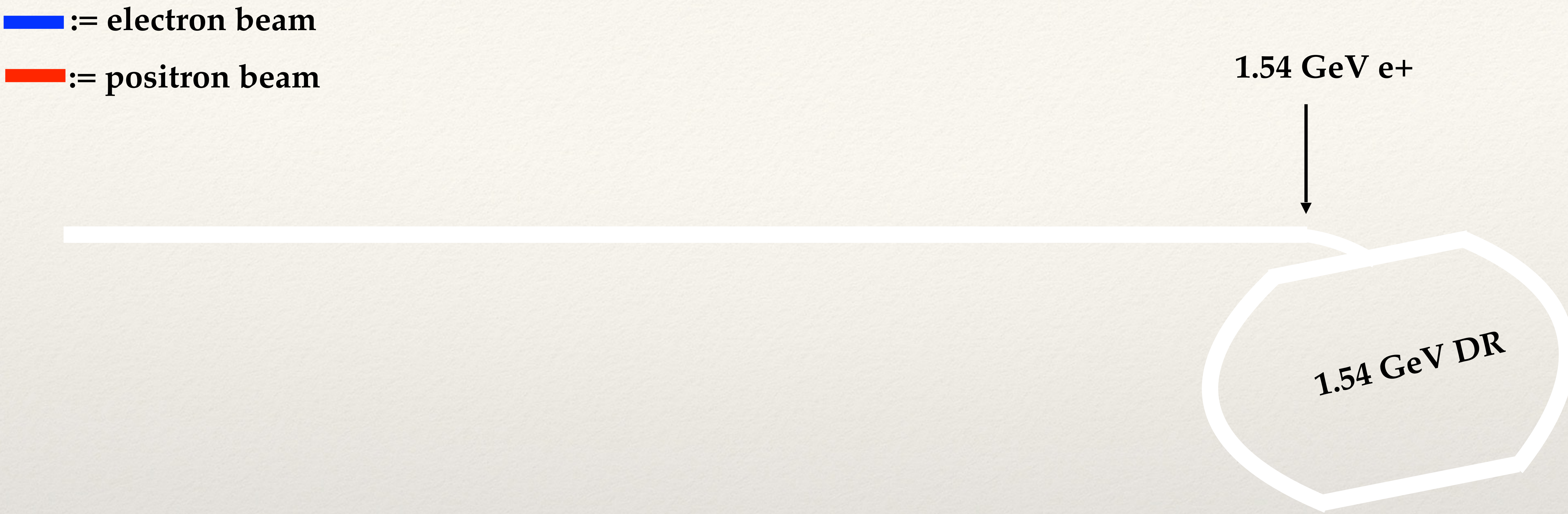
✓ Charge is distributed equally to all 16640 buckets. The full charge, taken as 1, in the collider is reached at 1154 s, as foreseen. The bootstrapping due to interleave and step-wise charge increase is achieved.

After First Fill: Quasi-continuous Top up Injection



❖ The topped up charge for each species ~8.7% per cycle. Linear Decay is assumed for simplicity. 20 GeV linac would shorten the cycle time enabling less charge per period given to the collider that would reduce the emittance fluctuations.

Positron Flow Scheme



- No Energy Compressor, direct injection to the DR.

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 as suggested by K. Oide. 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.

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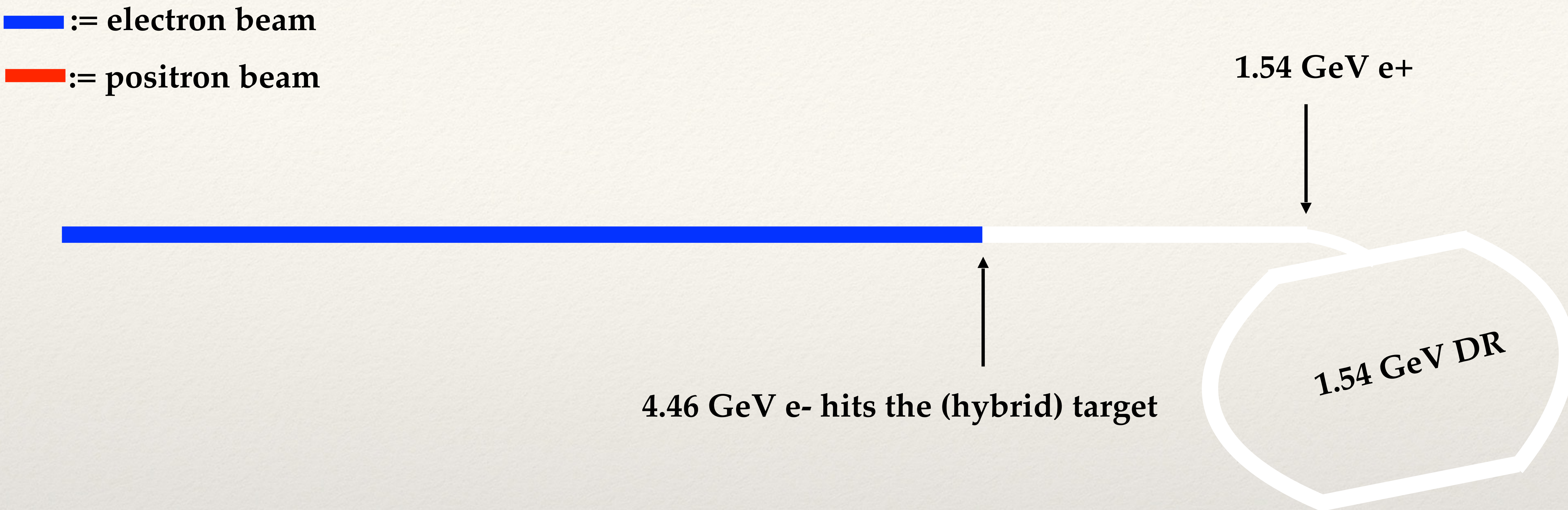

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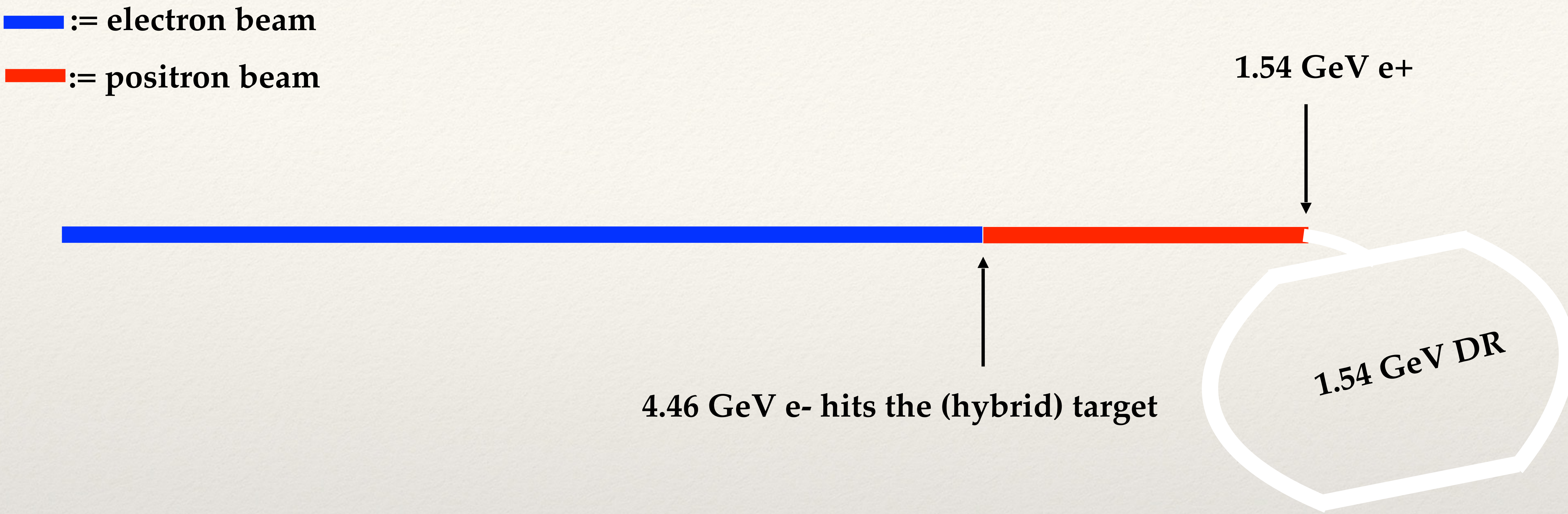

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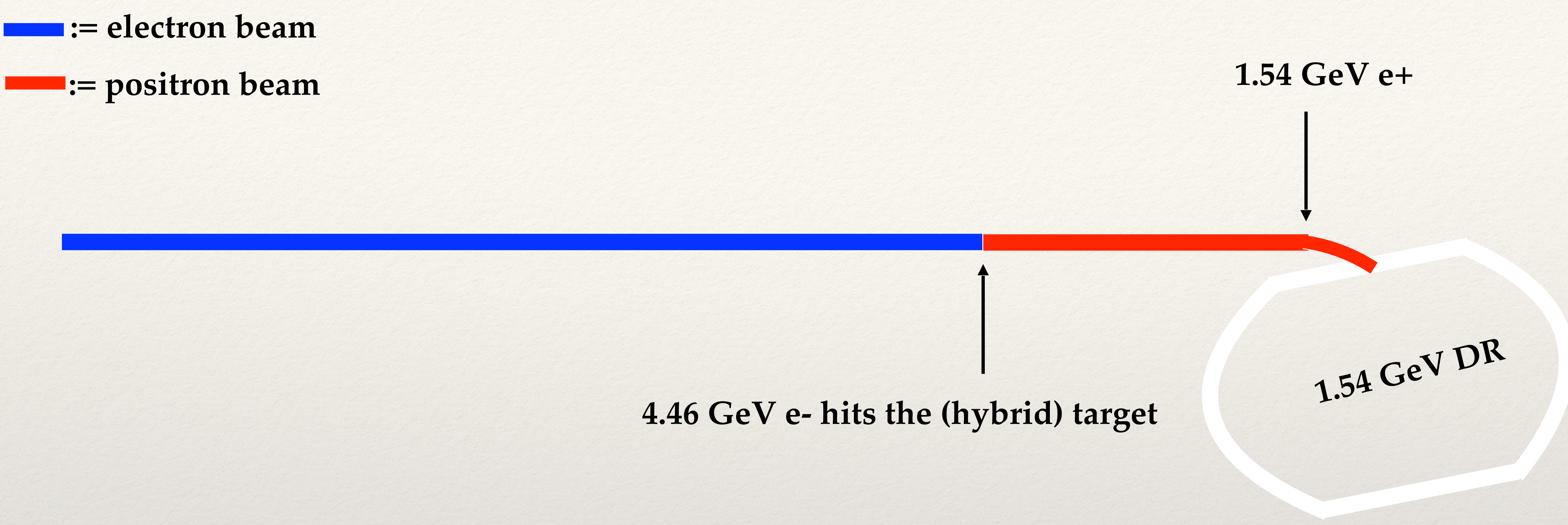

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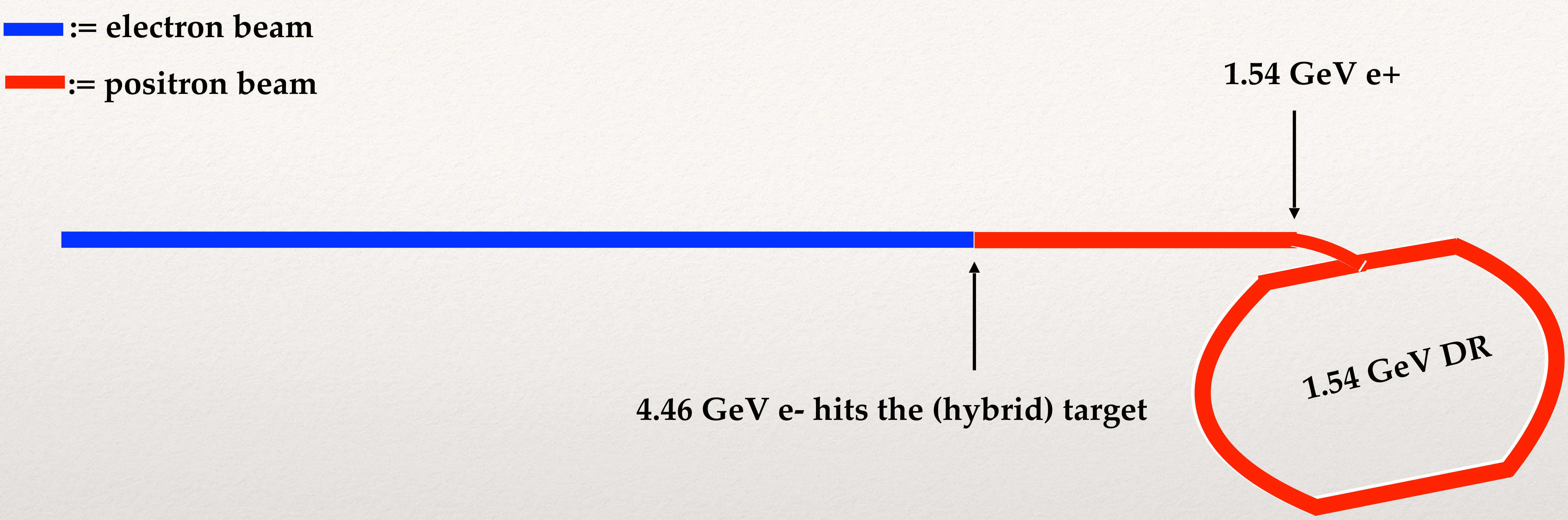

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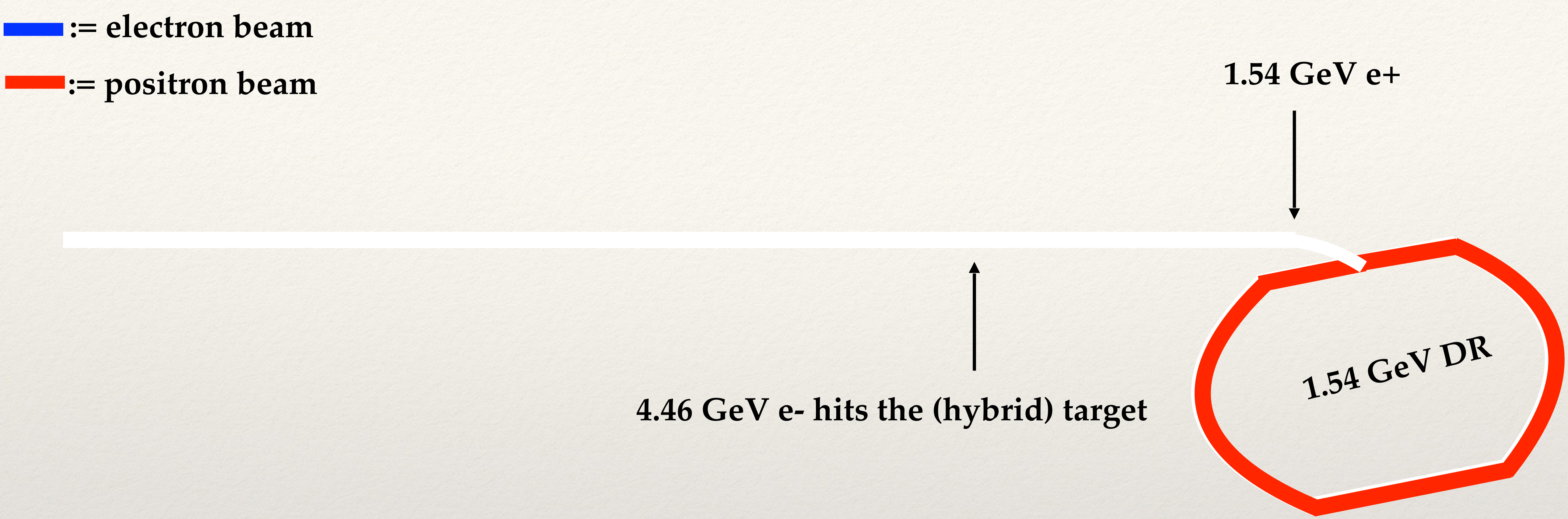

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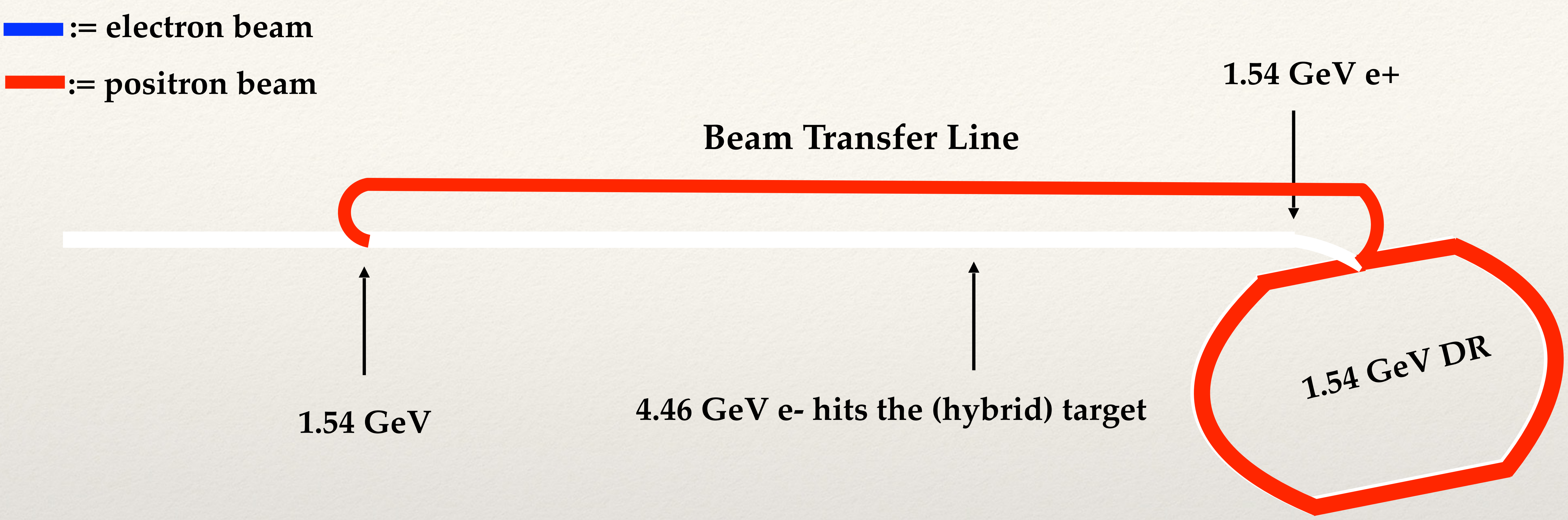

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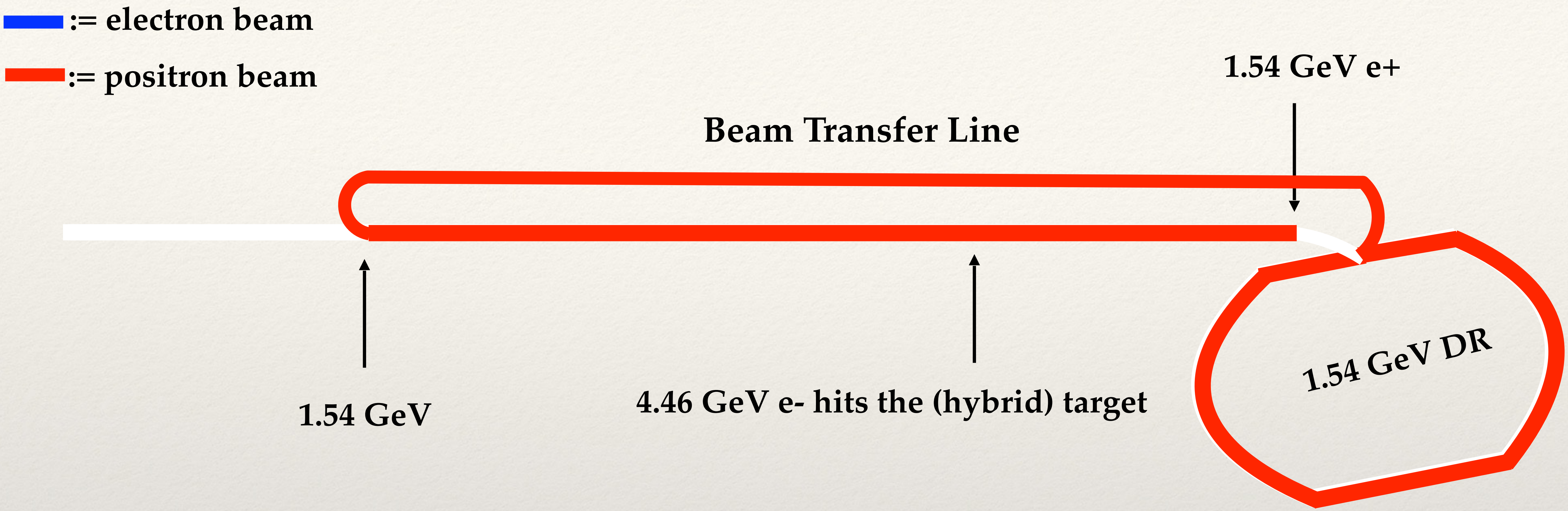

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Alternative Overview of FCCe+e- Complex

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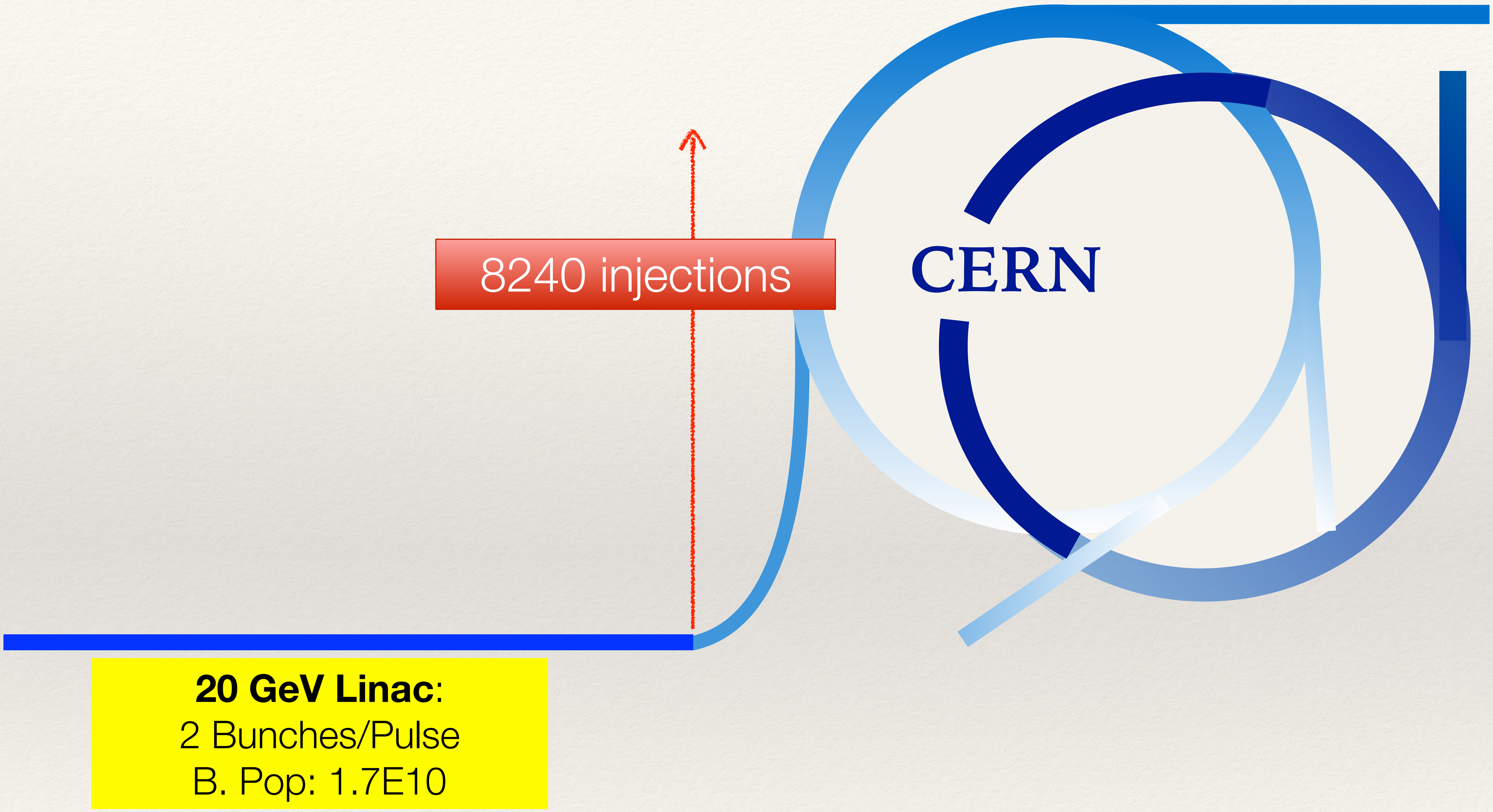

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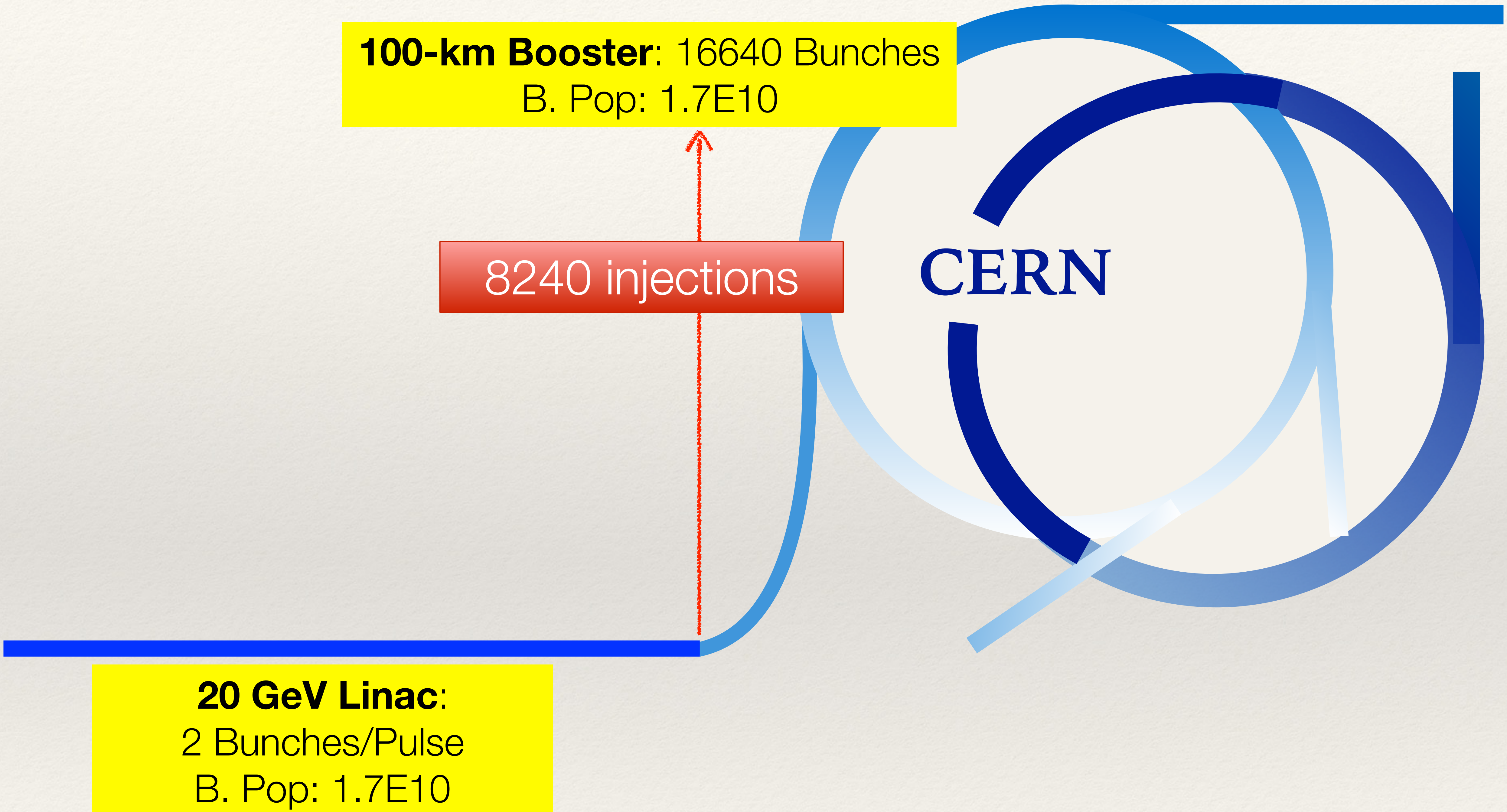

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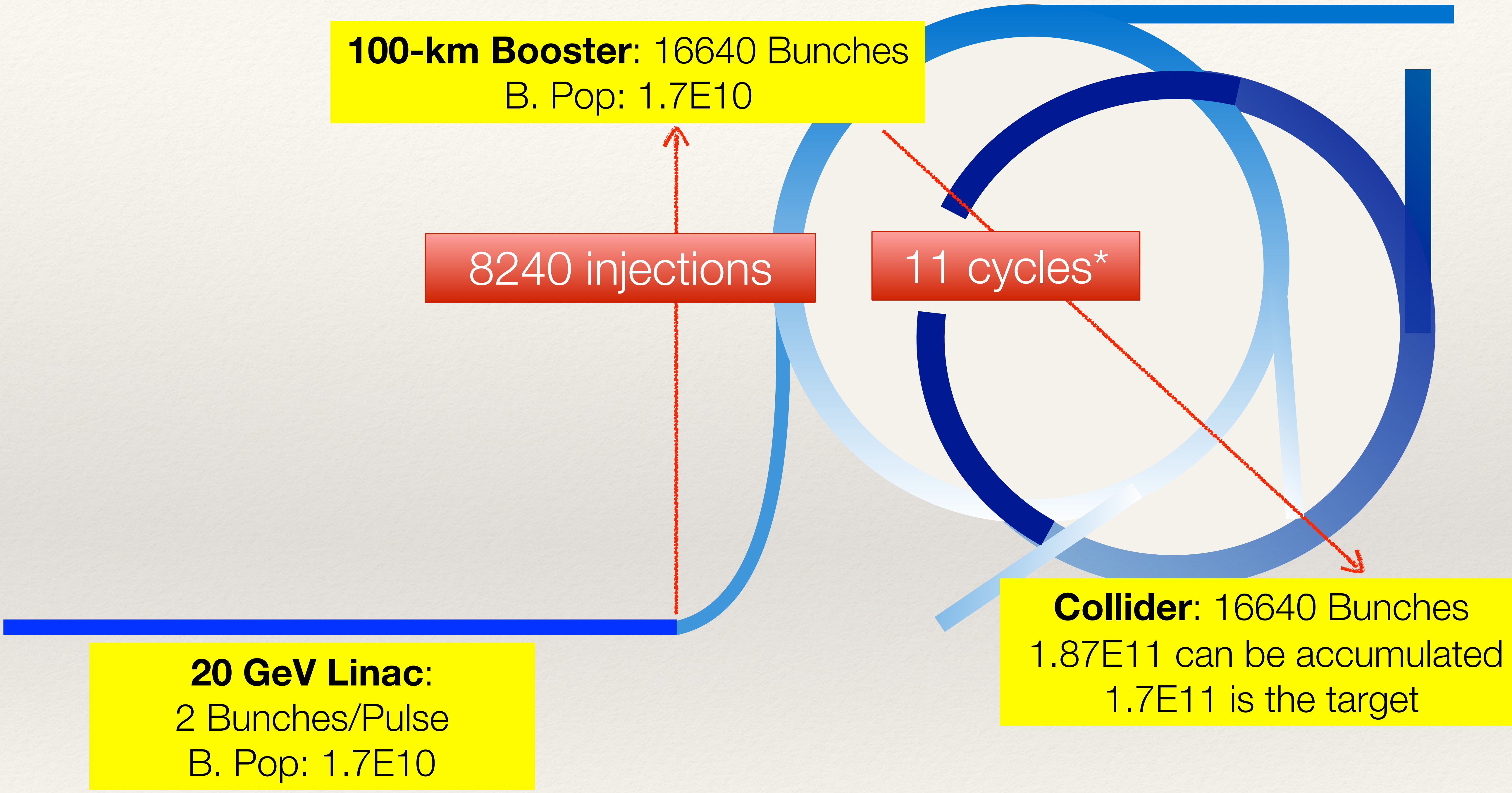

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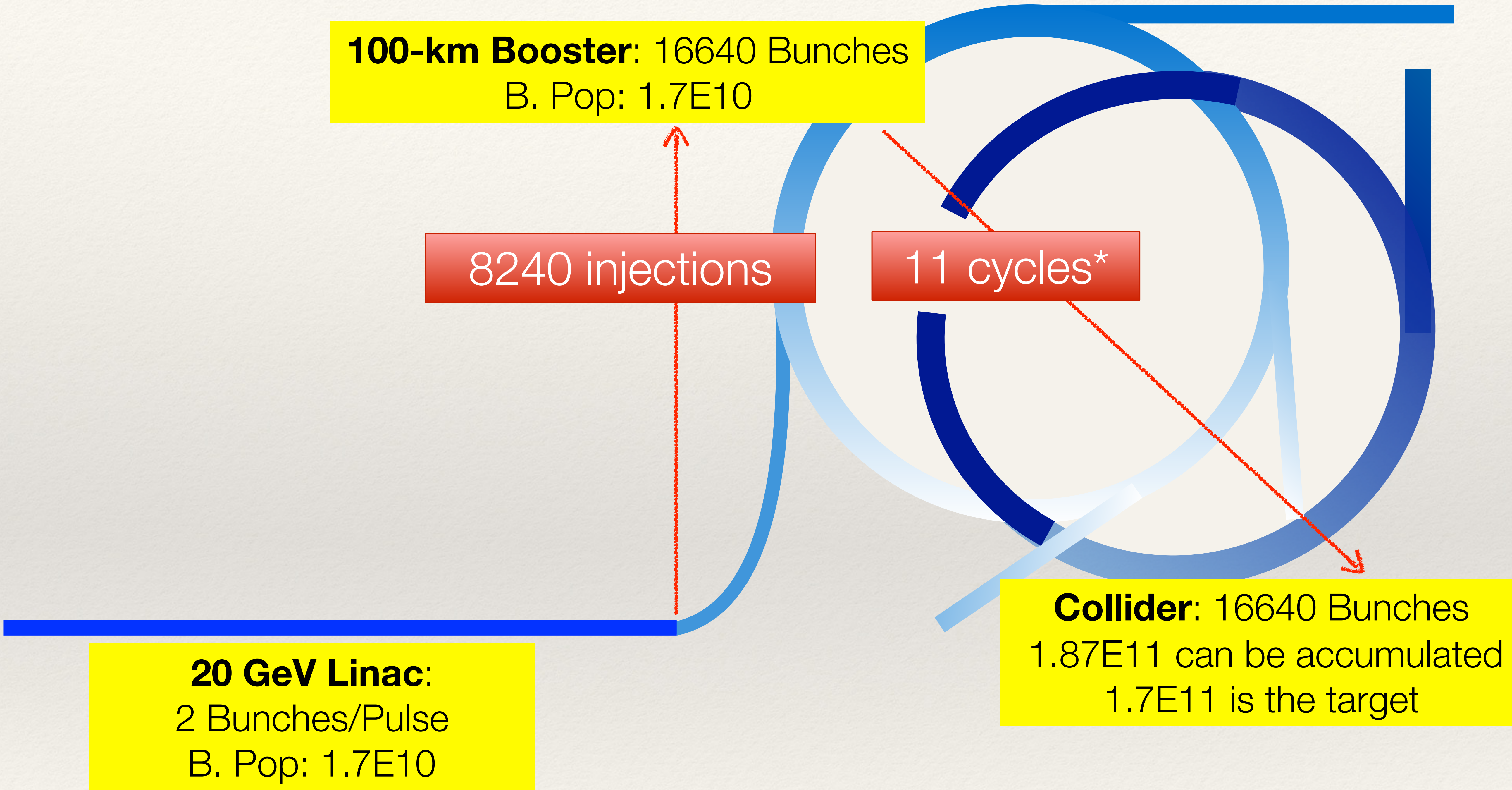

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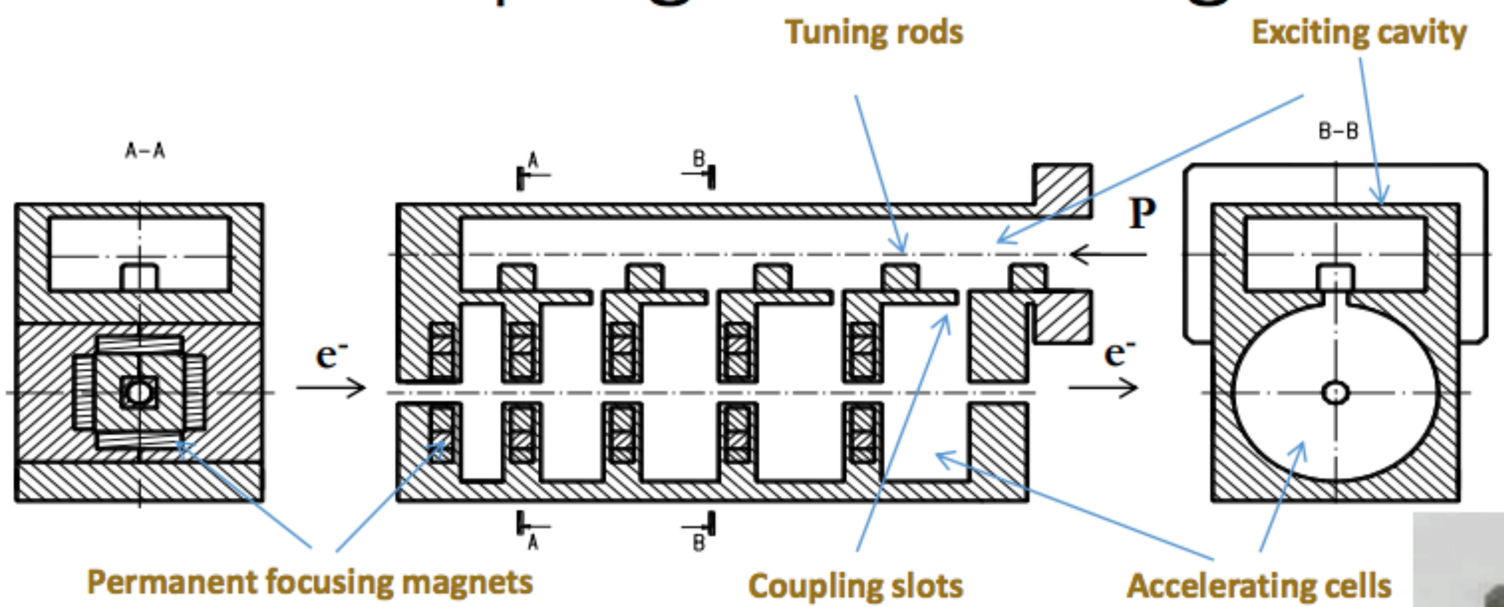
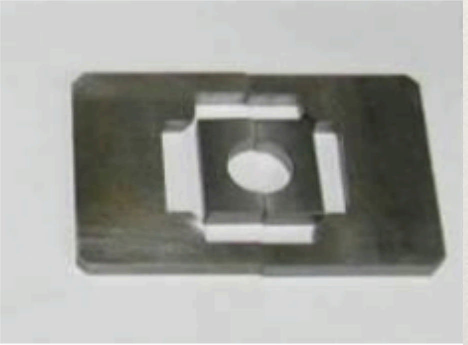
RF gun

Parallel coupling accelerating structure



A. Levichev,
D. Nikiforov et al



Features:

1) Parallel RF power feeding.
2) Cavities are not connected with each other by RF power: process in one cavity doesn't influence on every cavities
3) Organization of the free electric field distribution along the structure can be obtained by changing the individual coupling slot
4) In order to develop accelerating structure only one accelerating cells have to be calculated due to absence of the cavities connection by electromagnetic field
5) Aperture of the structure is defined by only beam motion and can be considerably reduced
6) **Design of the structure allows using internal permanent focusing magnets.**

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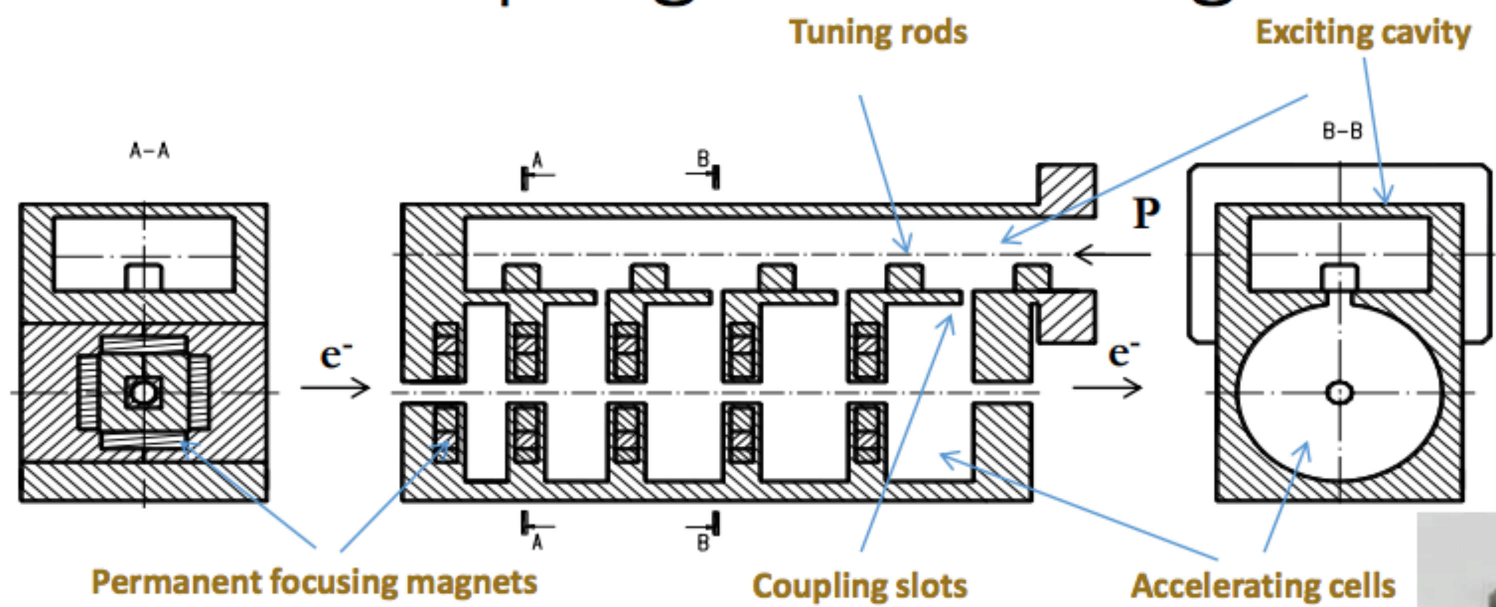

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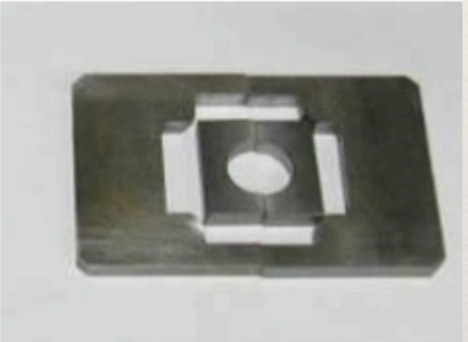

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★Screenshot from the presentation: https://indico.cern.ch/event/655723/contributions/2670903/attachments/1498777/2333386/RF_gun_based_on_parallel_coupling_accelerating_structure_FCC.pdf

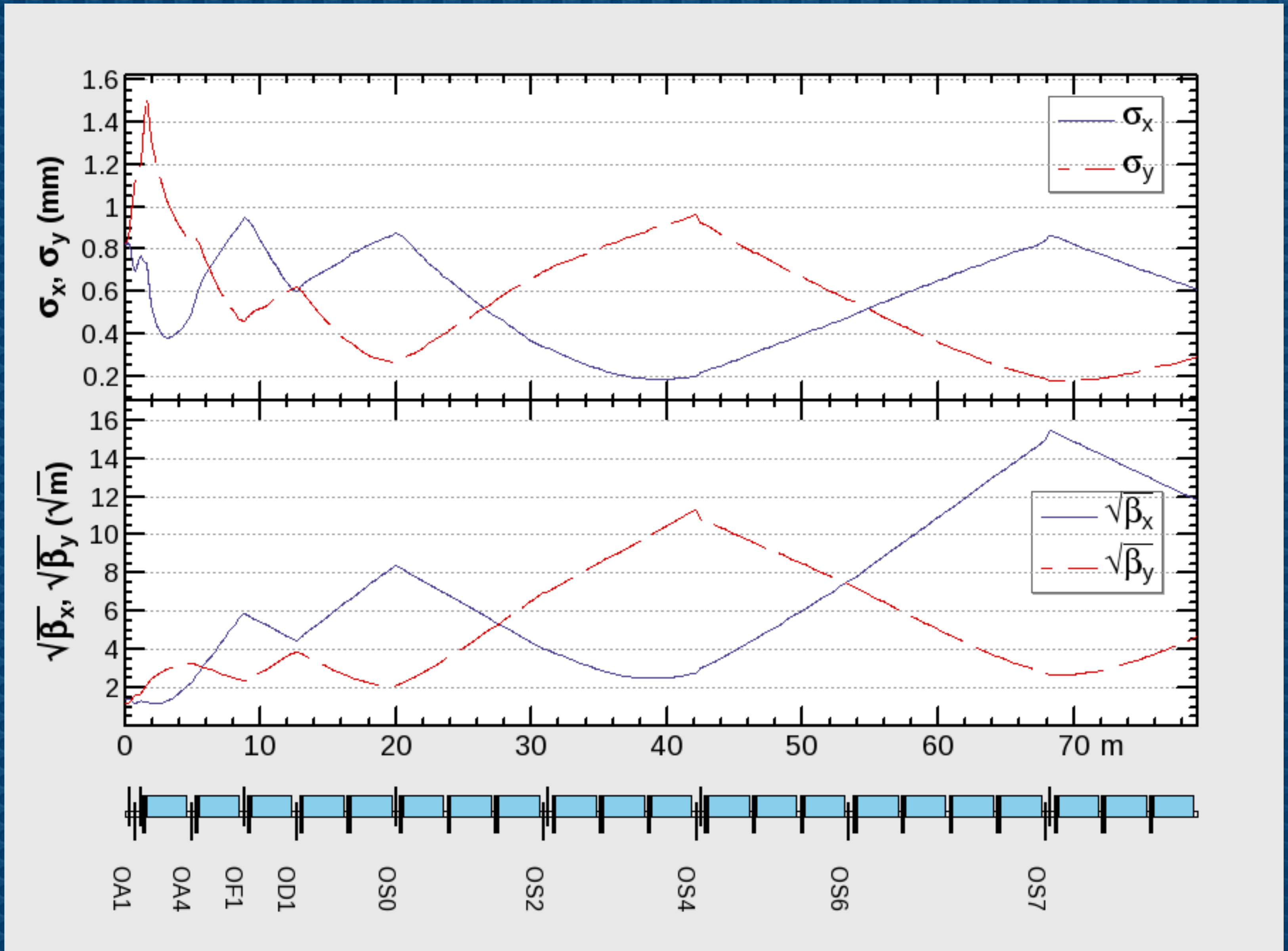
2. Linac - Introduction

Cavities	S-Band	C-Band
Frequency (MHz)	2855.98	5711.96
Length (m)	2.97	1.80
Cavity Mode	2π/3	2π/3
Aperture Diameter (mm)	20	14
Unloaded Cavity Gradient (MV/m)	25	50

❖ Linac will have a repetition of 100 Hz with 4 Bunches per RF pulse or 200 Hz repetition with 2 Bunches per RF pulse. The bunch charge is 1.7E10 particles. **Throughout e+ creation, 100Hz with 8 bunches, or 200 Hz with 4 Bunches per RF pulse, or simply another linac for e+ creation.**

2.1 Linac up to 1.54 GeV

❖ An S- Band Linac has been simulated starting from an RF- Gun which provides 2E10 particles* in a bunch around 12 MeV with 0.35/0.5 μm emittance. The initial beam is created with 1% energy spread and sigma_z=1 mm Gaussian randomly.



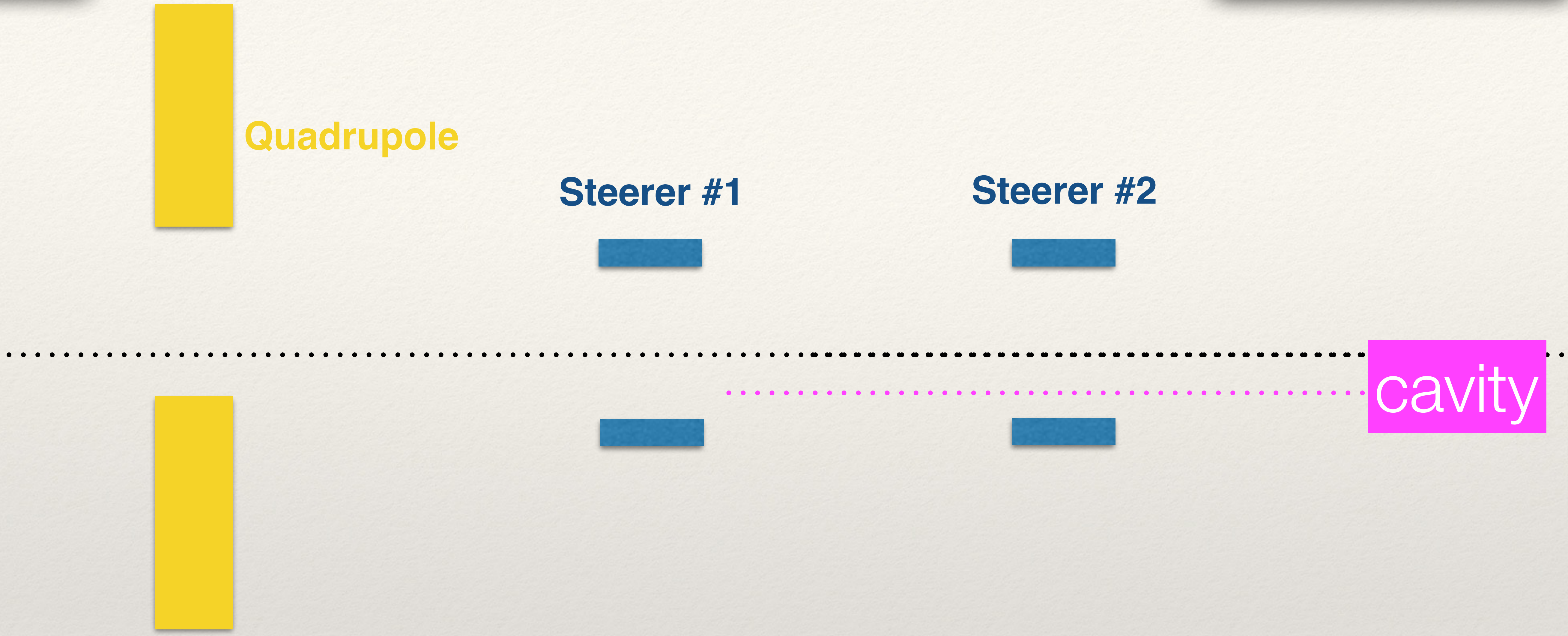
* normally we may need 1.7E10 particles in a bunch, 2E10 is chosen for pre-compensation, and safety.

Error Study

Element	Simulated Error
Injection Error (h/v)	0.1 mm
Injection Momentum Error (h/v)	0.1 mrad
Quadrupole Misalignment (h/v)	0.1 mm
Cavity Misalignment (h/v)	0.1 mm
BPM reading error (h/v)	0.1 mm

- Realistic errors have been introduced to study transmission and orbit correction. Each error refers to 1 sigma in Monte Carlo simulation (i.e. Gaussian distribution) and no truncation has been made. The wake fields (by K. Yokoya) are always ON!

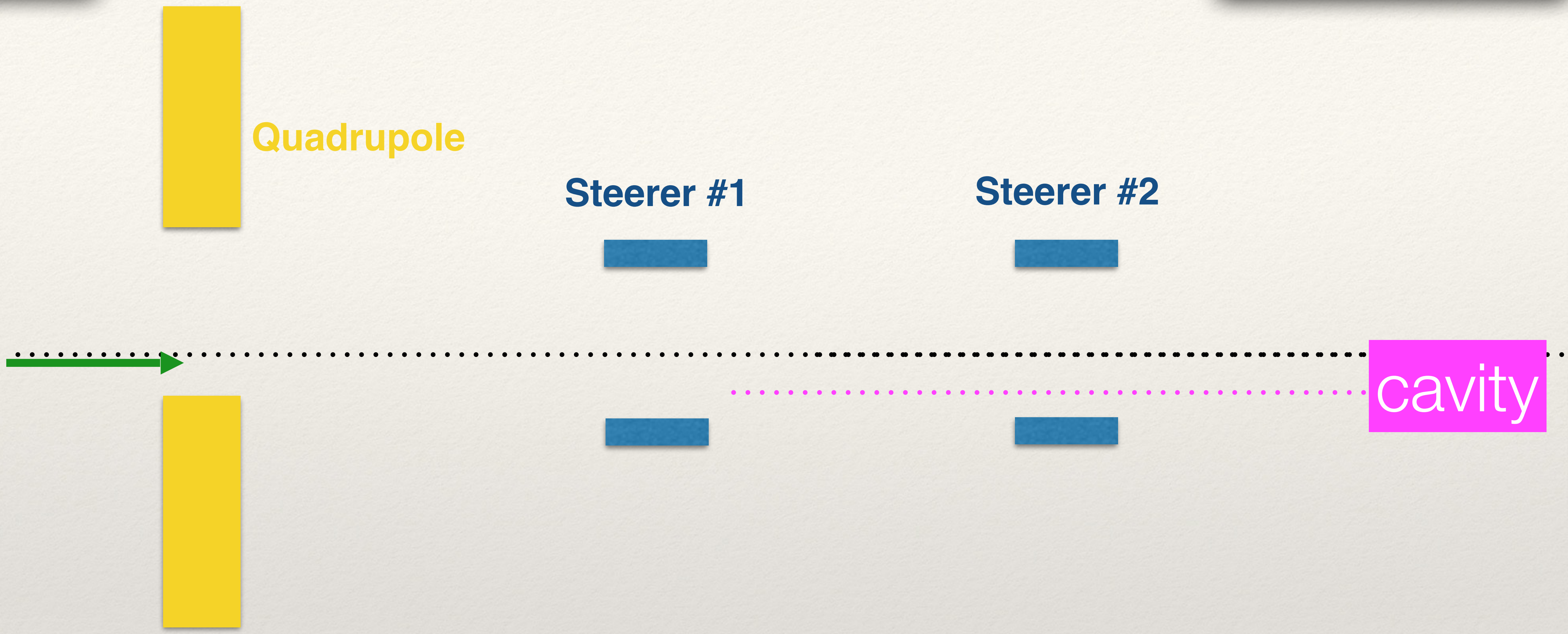
Orbit Steering



❖ We deploy two correctors in a row, especially at low energy part and after the Quadrupoles. Surely, we should have a BPM for each magnet and two BPMs at each cavity (1 at the entrance and 1 at the exit of the cavity).

❖ The former dipole steers the beam spatially to the cavity centre, and the latter cancels out the angular divergence so that the beam propagates through the central line of the cavity in order to avoid the BANANA shape.

Orbit Steering



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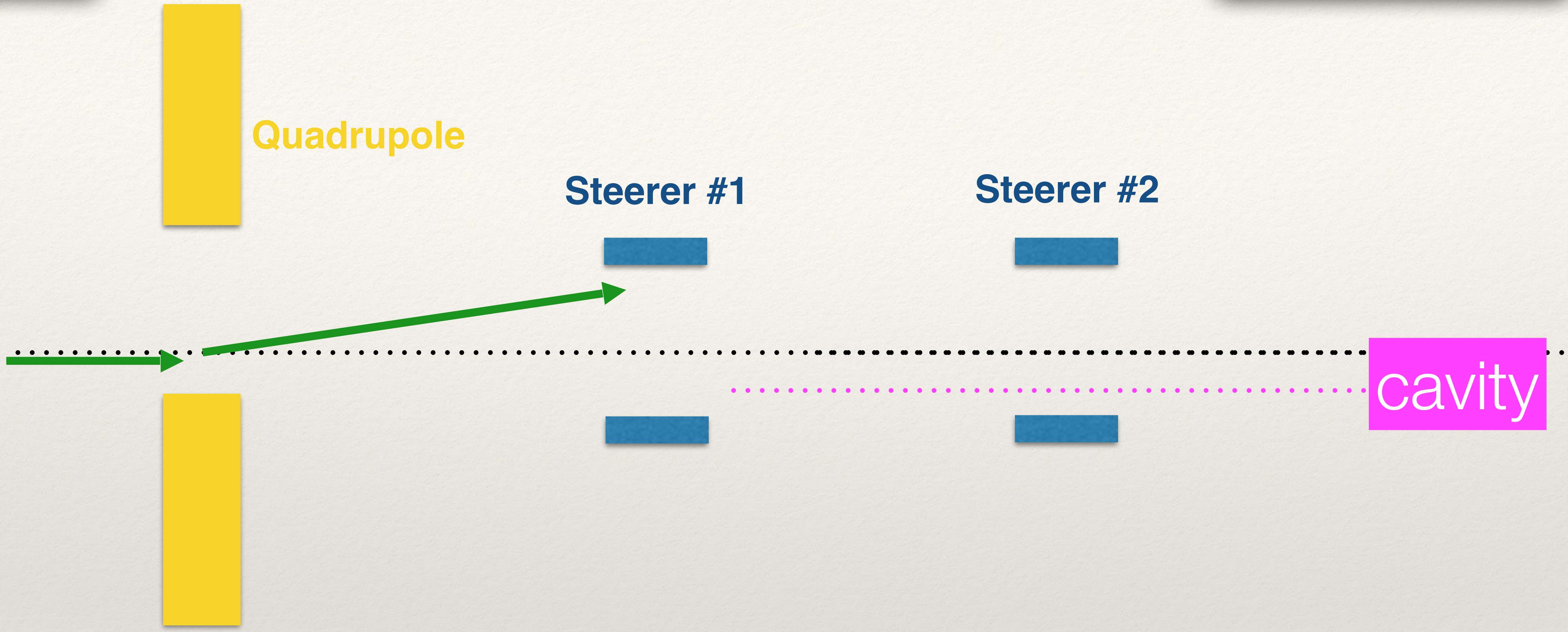

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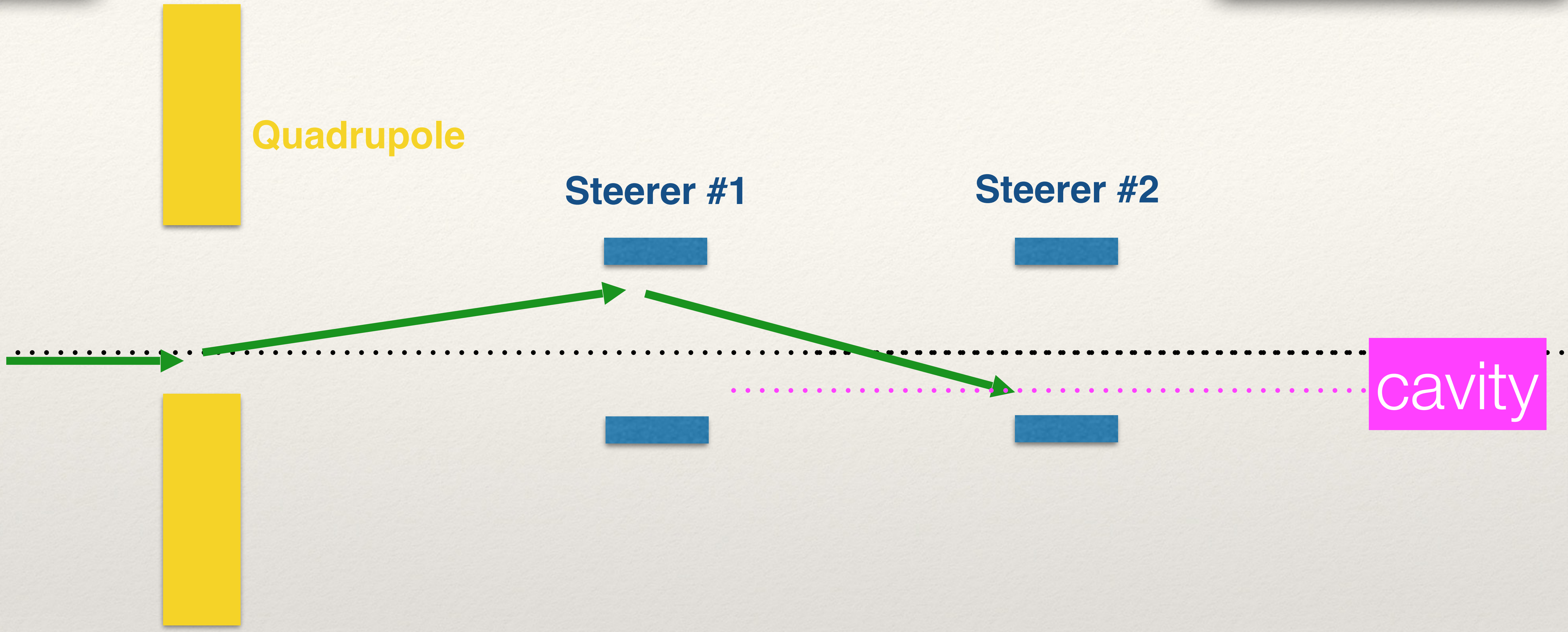

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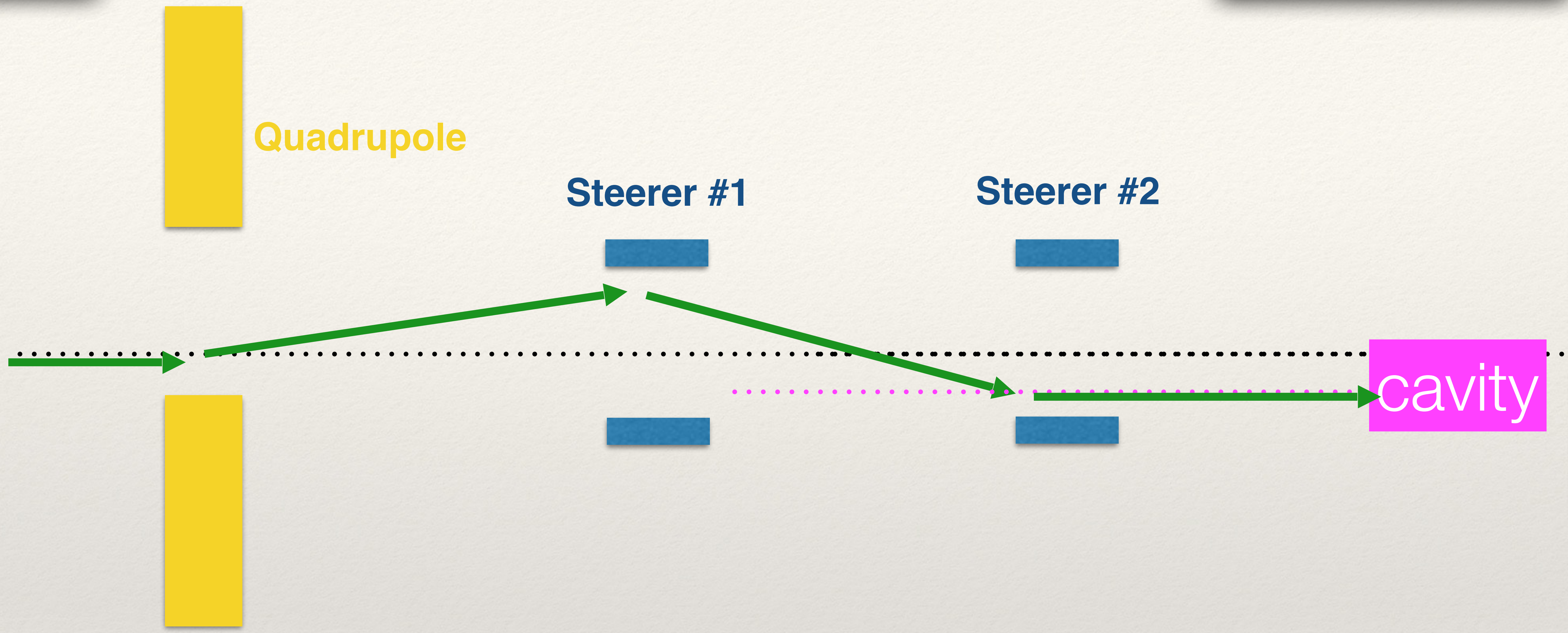

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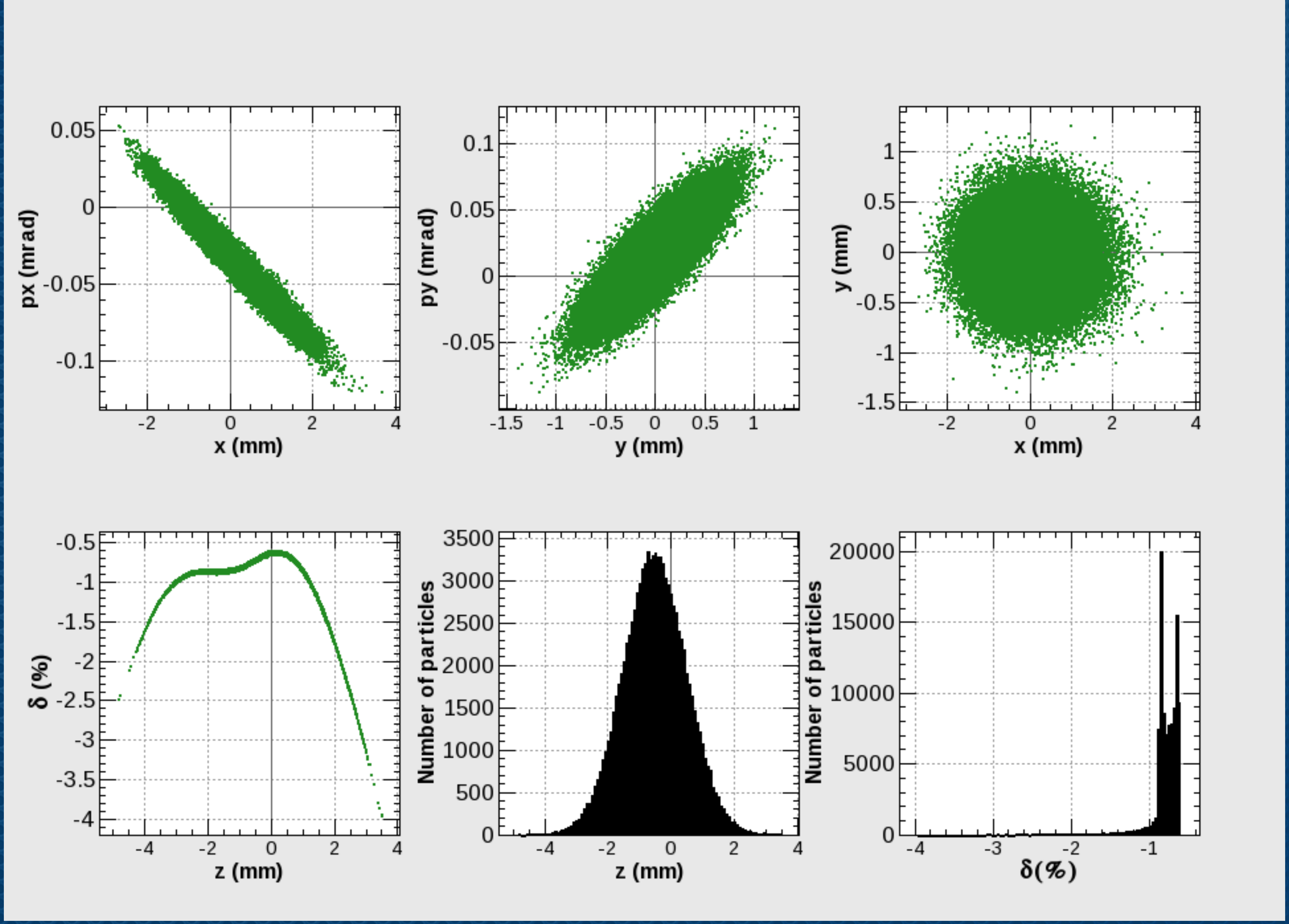
2.1 Linac up to 1.54 GeV

❖ Beam Profiles at 1.54 GeV. The RF phasing of cavities has been done to obtain two-horn distribution in the energy spread. The tracked emittance values 3.2/3.9 nm (h/v) whereas emittance with no blow up would be 2.7/3.8 nm. The transmission is 100%.



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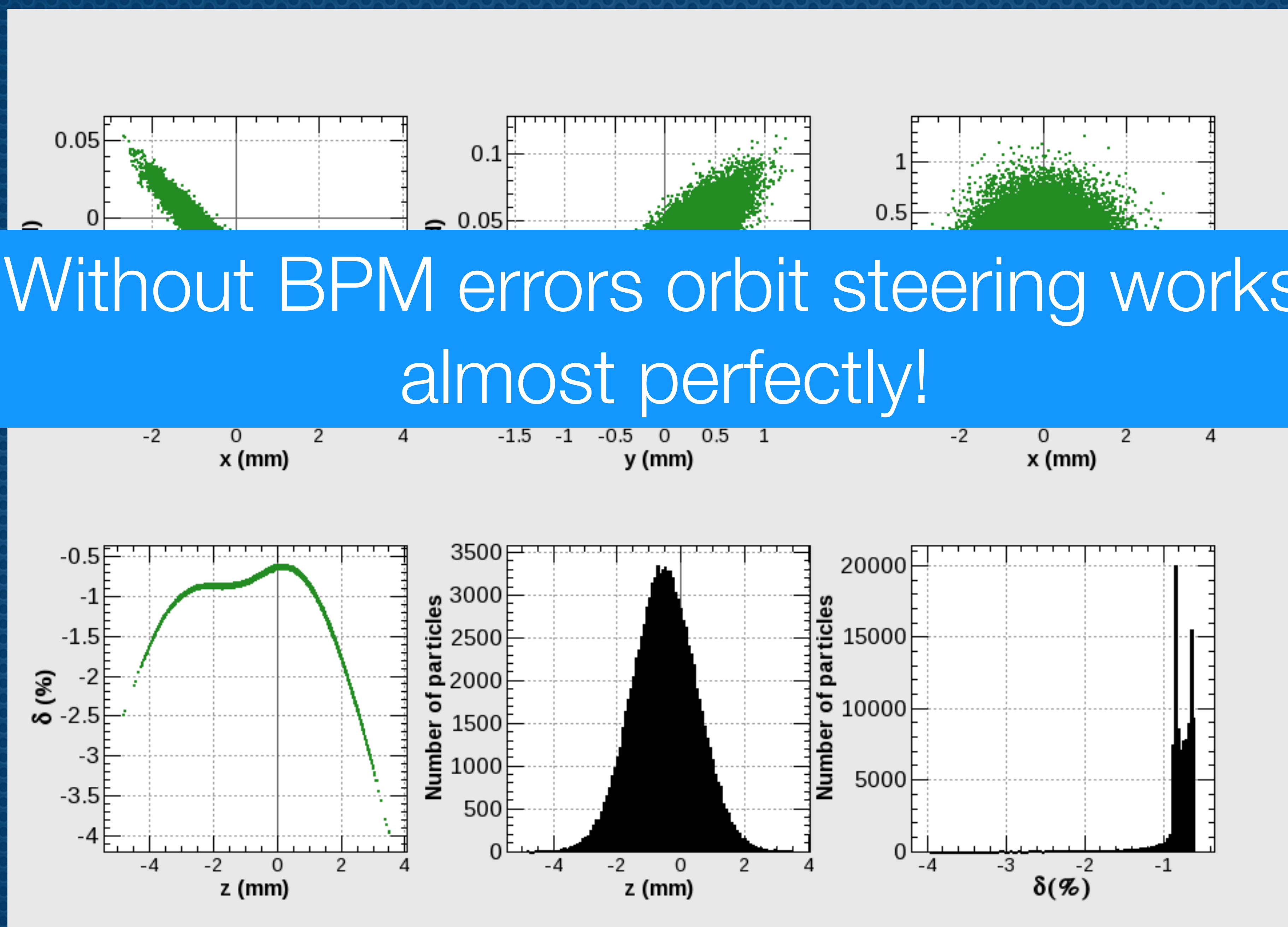


Without BPM errors orbit steering works almost perfectly!

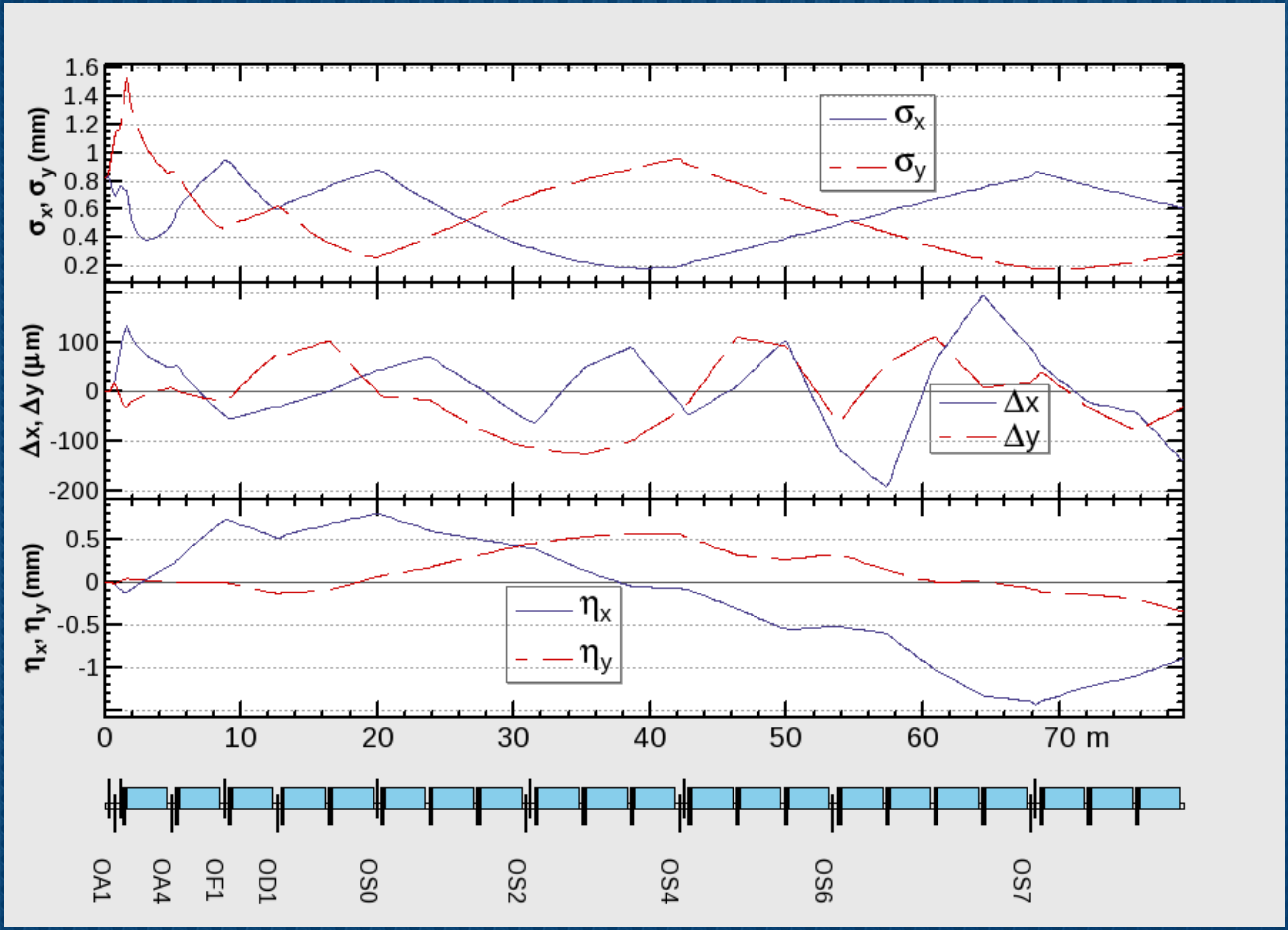
2.1 Linac up to 1.54 GeV

Some results for different seeds using 1M macro-particles for Gaussian random beam:

Trial ID	Horizontal Emittance (nm)	Vertical Emittance (nm)	Transmission
1	2.78	3.96	100%
2	2.90	3.91	100%
3	2.87	3.89	100%
4	3.15	4.18	100%
5	2.84	3.99	100%
6	2.91	3.94	100%
7	3.43	3.94	100%
8	2.77	4.10	100%
9	2.77	3.96	100%
10	2.89	3.90	100%
11	2.90	4.00	100%
12	2.88	4.00	100%
AVERAGE	**2.92**	**3.98**	**100%**
IDEAL	**2.70**	**3.80**	**100%**

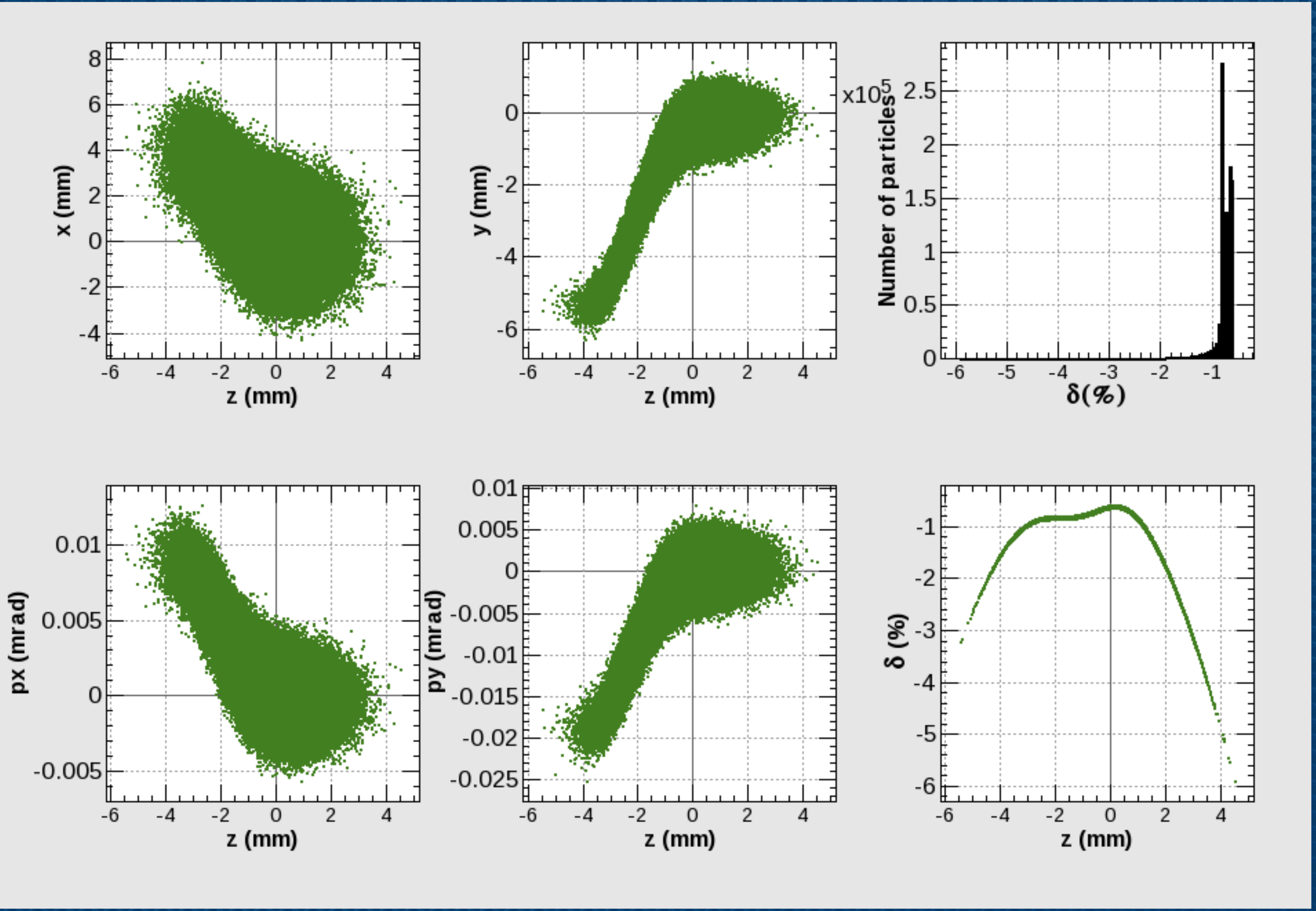
2.1 Linac up to 1.54 GeV

❖ The fluctuations and dispersion with the automatic orbit steering (with many thanks to K. Oide) .



2.1 Linac up to 1.54 GeV

❖ Beam Profiles at 1.54 GeV with misalignments, and BPM errors. The tracked emittance values 8.7/22 nm (h/v) whereas emittance with no blow up would be 2.7/3.8 nm. The transmission is 100%.



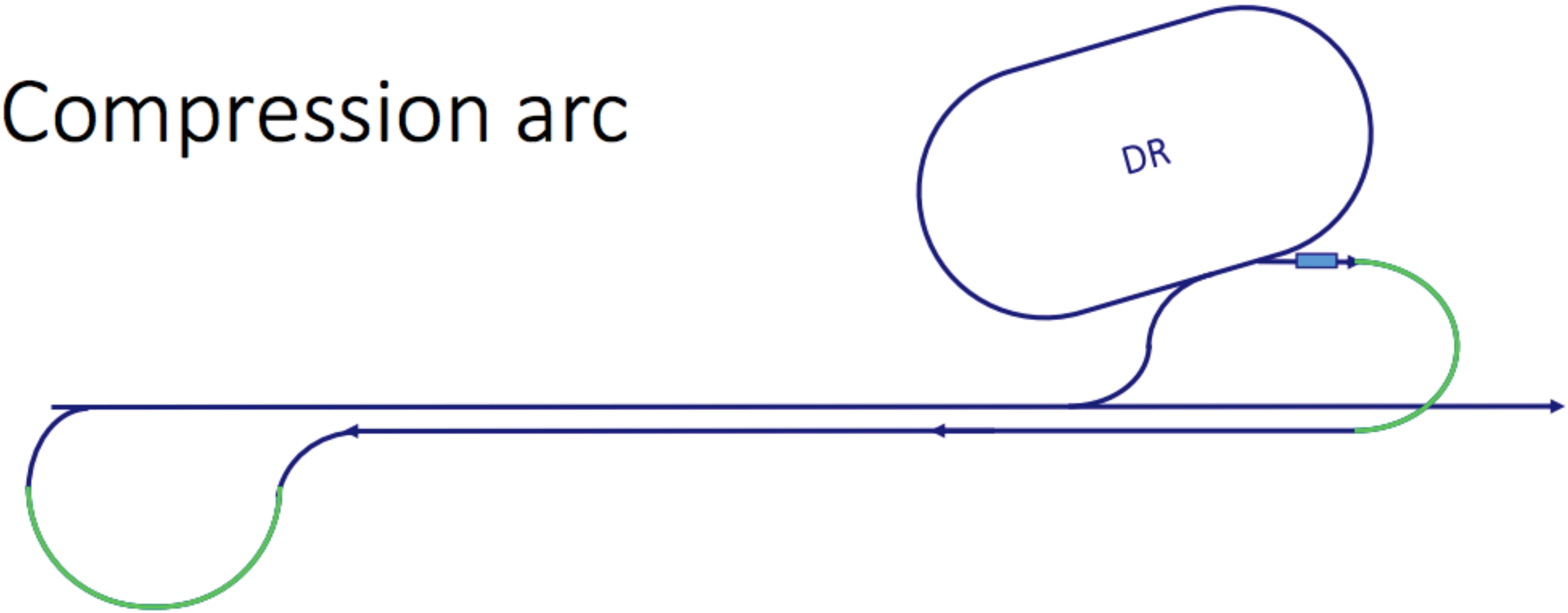
2.1 Linac up to 1.54 GeV

Some results, including misalignment, misinjection, and misreading of BPMs, for different seeds using 1M macro-particles for Gaussian random beam:

Trial ID	Horizontal Emittance (nm)	Vertical Emittance (nm)	Transmission
1	8.7	22.4	100%
2	3.8	7.1	100%
3	5.9	29.0	100%
4	11.4	18.2	100%
5	7.8	25.6	100%
6	11.6	18.0	100%
7	10.3	4.2	100%
8	3.1	28.9	100%
9	13.2	22.0	100%
10	24.2	4.1	96.3%
11	9.2	15.2	100%
12	3.6	13.0	100%
AVERAGE	**9.4**	**17.3**	**99.5%**
w\o BPM error	**2.9**	**4.0**	**100%**
IDEAL	**2.7**	**3.8**	**100%**

Beam after Damping Ring + Bunch Compressor

Compression arc



180 deg arc with R56 ≠ 0.

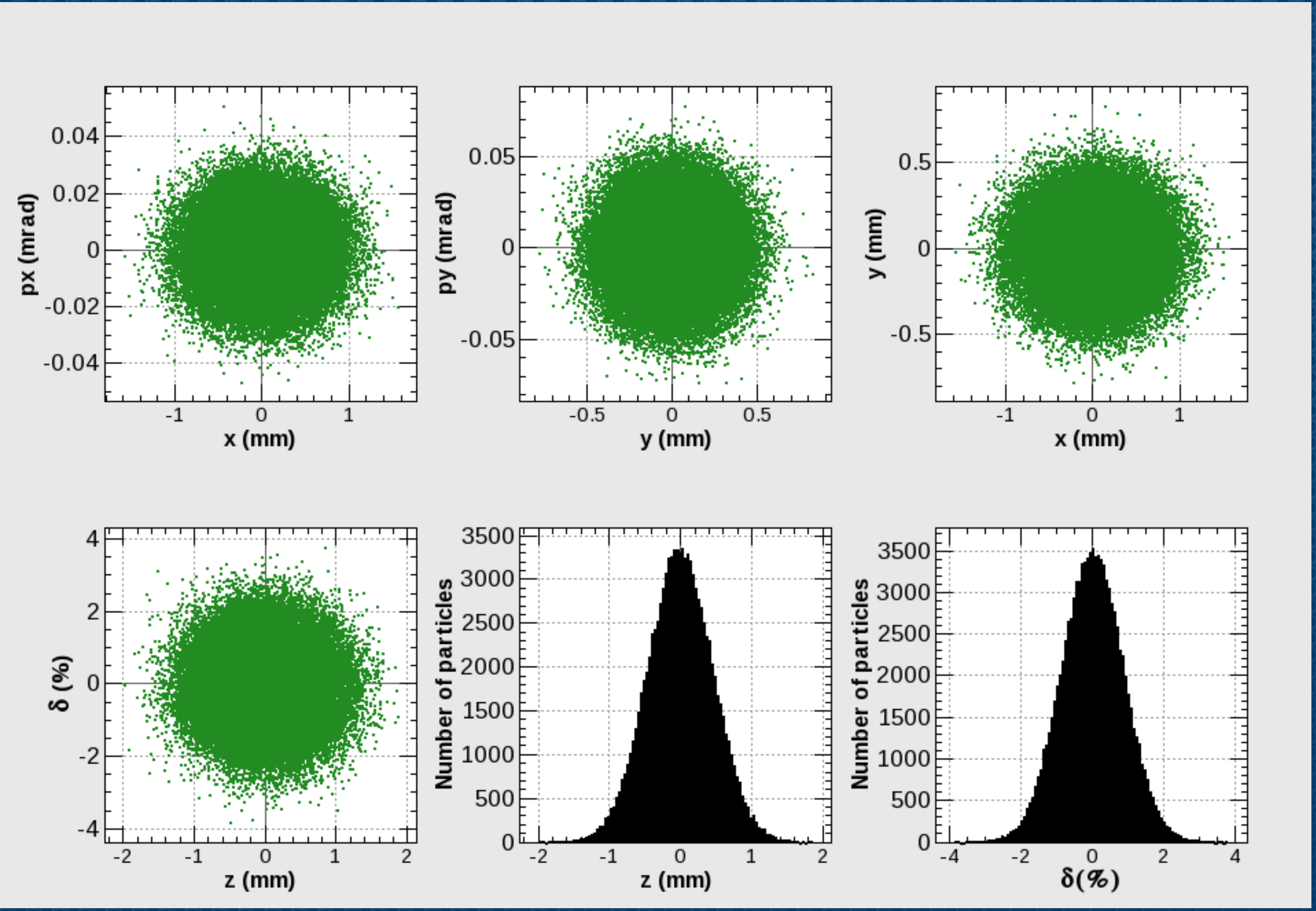
T. Charles

or a similar BTL and BC designs

- For the simplicity and safety, I continue with 2.0/2.0 nm beam at 1.54 GeV, energy spread of 0.86% and sigma_z=0.46 mm, and the following beam is created.

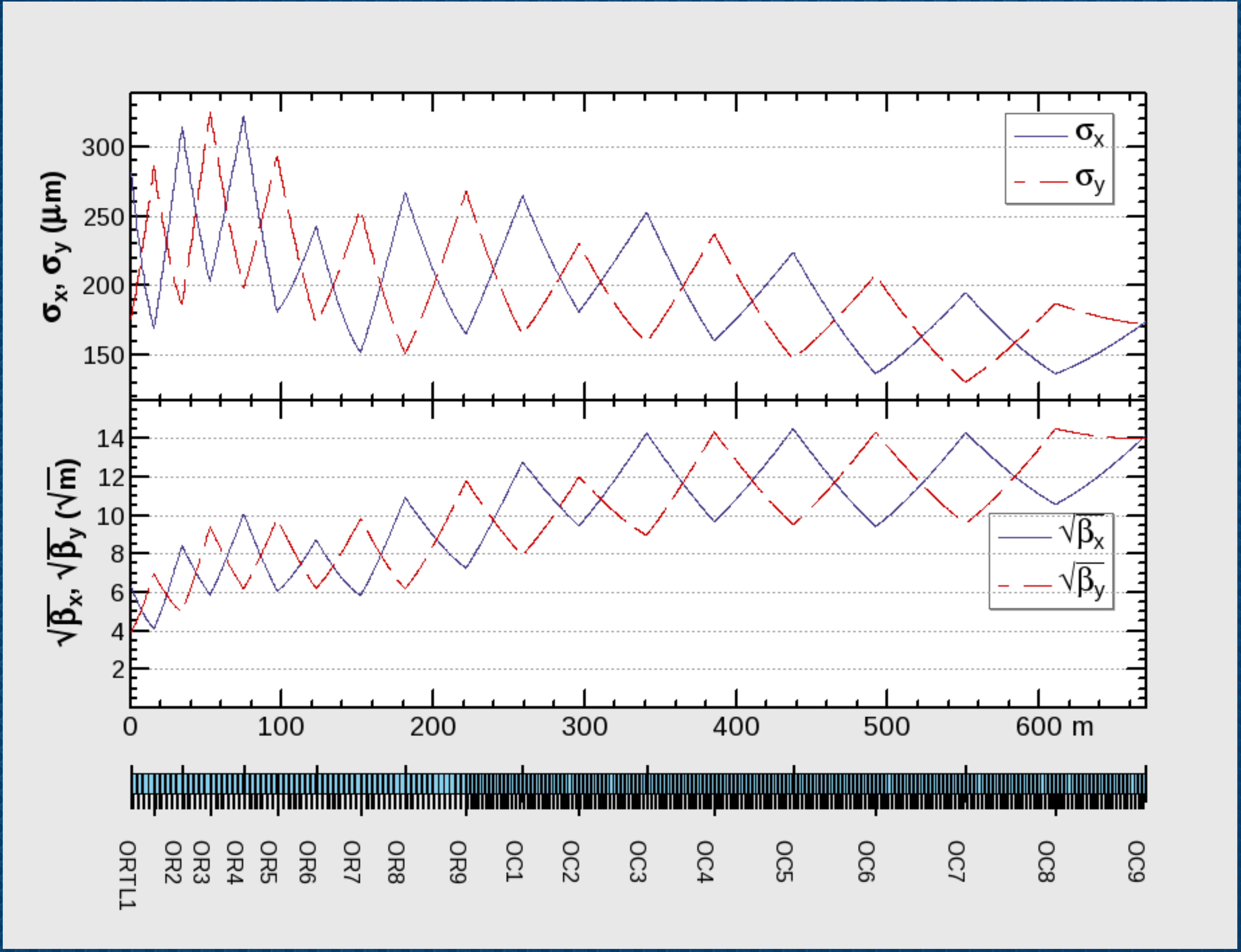
Beam after Damping Ring + Bunch Compressor

❖ For the simplicity and safety, I continue with 2.0/2.0 nm beam at 1.54 GeV, energy spread of 0.86% and sigma_x=0.46 mm, and **created the following beam with an injection error of 0.1 mm and 0.01 mrad, the injected emittance of the beam has become 4.0/3.3 nm for that seed! Indeed, this is the real or effective beam injected at 1.54 GeV to the linac simulations. On the other hand, this deviation may be artificial stemmed from the way we create the beam.**



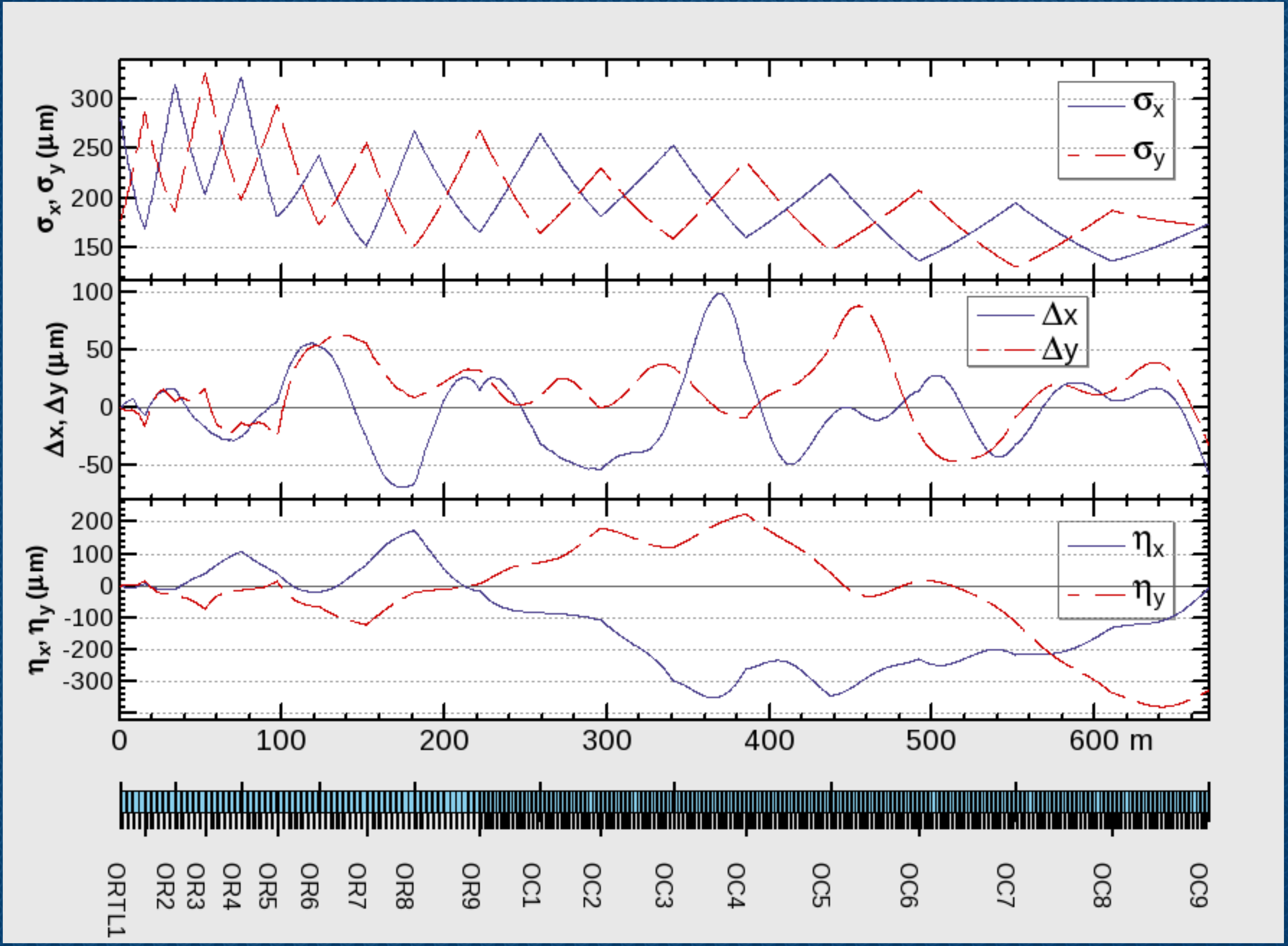
2.1 Linac from 1.54 to 20 GeV

❖ S-Band structures finish at 6 GeV (QR9 in the optics).



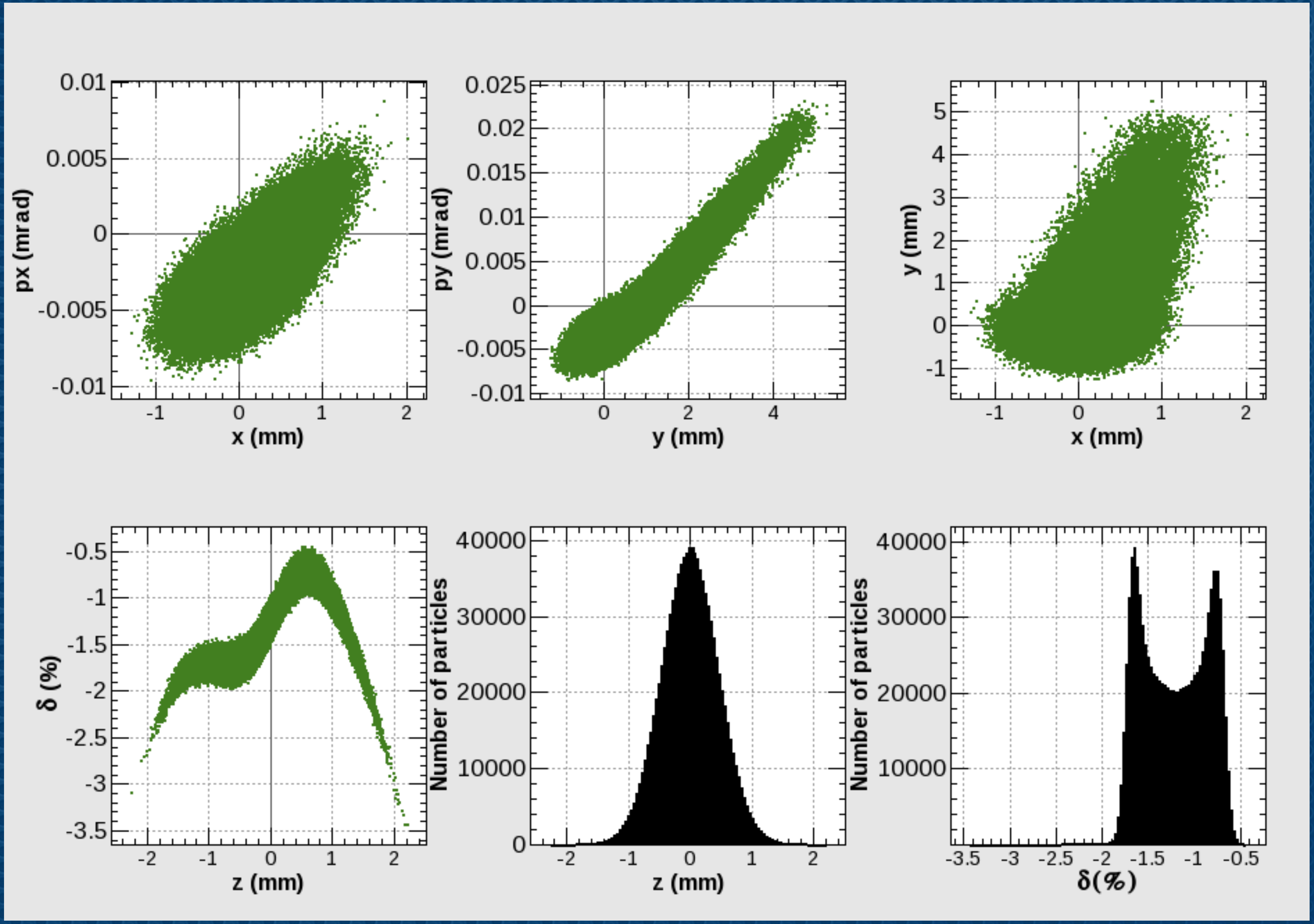
2.1 Linac from 1.54 to 20 GeV

❖ The fluctuations and dispersion with the automatic orbit steering.



2.1 Linac from 1.54 to 20 GeV

- The beam profile at 20 GeV with 1 Million macro particles. The emittances at 20 GeV are 0.37/0.64 nm respectively, the emittance without blow would be ~ 0.15/0.15 nm. **The emittance blow would be lower if we compare with the effective/diluted emittance of the diluted beam.** The transmission is 100%.



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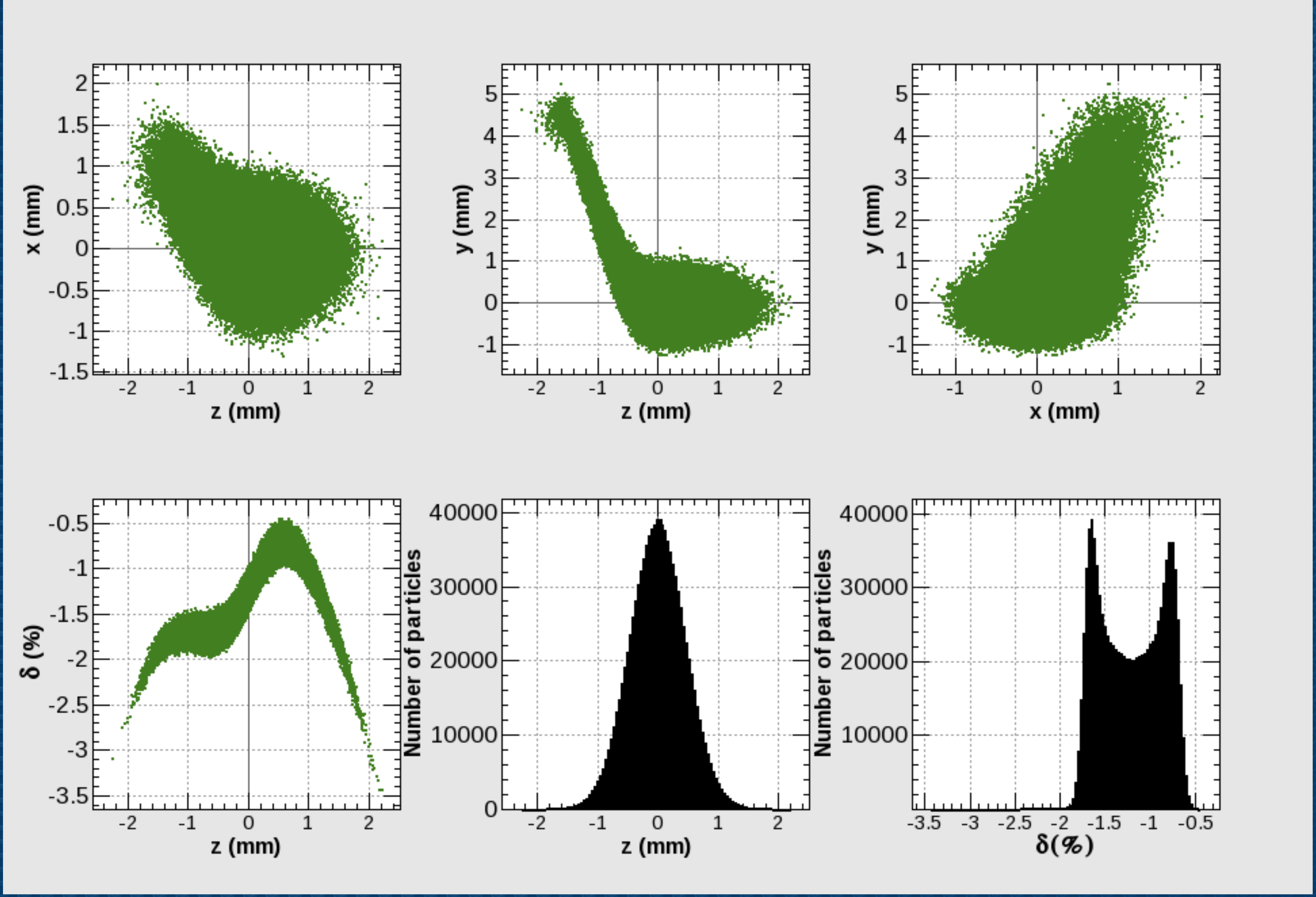

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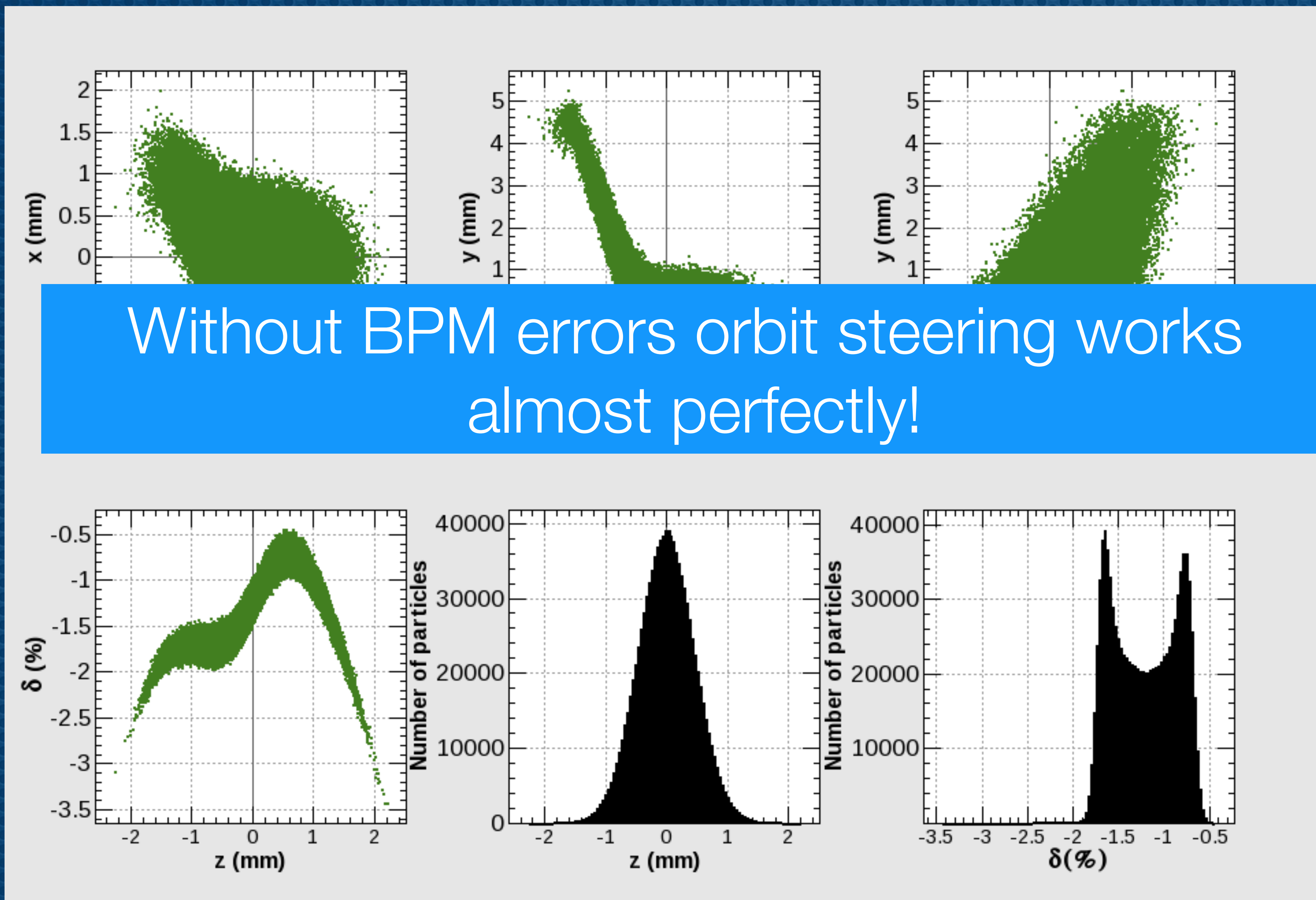


Without BPM errors orbit steering works almost perfectly!

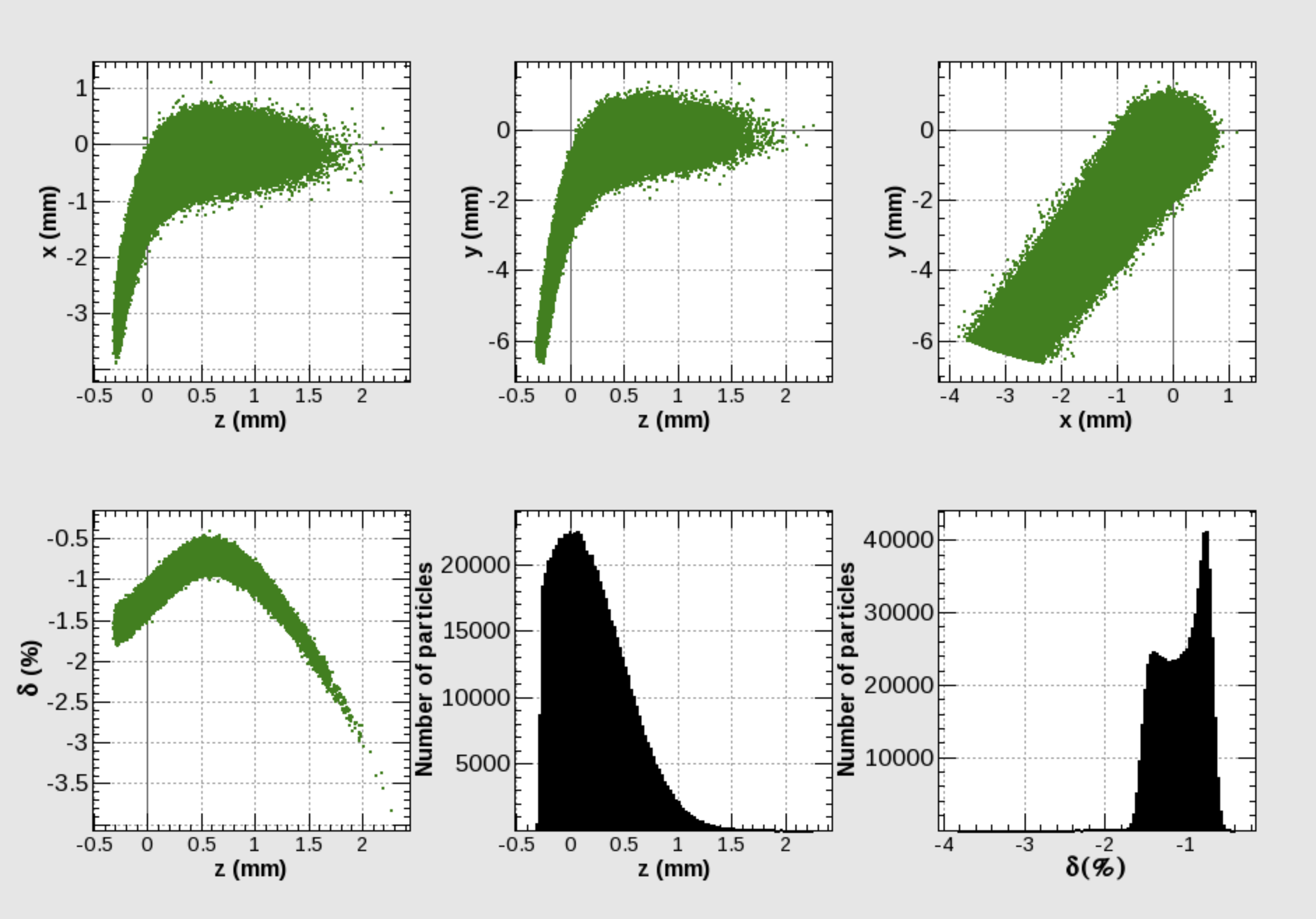
2.1 Linac from 1.54 to 20 GeV

- Some results for different seeds using 1M macro-particles for Gaussian random beam:

Trial ID	Horizontal Emittance (nm)	Vertical Emittance (nm)	Transmission
1	0.24	0.29	100%
2	0.37	0.64	100%
3	0.45	0.89	99.9%
4	0.42	0.21	100%
5	0.80	0.29	100%
6	0.31	0.24	100%
7	0.98	0.27	99.8%
8	1.30	0.76	99.8%
9	0.23	0.21	100%
10	0.26	0.23	100%
11	0.30	0.20	100%
12	0.46	0.18	100%
AVERAGE	**0.51**	**0.37**	**100%**
IDEAL	**0.15**	**0.15**	**100%**

2.1 Linac from 1.54 to 20 GeV

- The tracked emittances with BPM errors at 20 GeV are 0.8/2.4 nm respectively, the emittance without blow would be ~ 0.15/0.15 nm. The transmission is 74%.



2.1 Linac from 1.54 to 20 GeV

- Some results, including misalignment, misinjection, and misreading of BPMs, for different seeds using 1M macro-particles for Gaussian random beam:

Trial ID	Horizontal Emittance (nm)	Vertical Emittance (nm)	Transmission
1	0.7	1.9	60%
2	0.4	2.3	76%
3	1.6	1.4	70%
4	1.8	0.8	63%
5	1.7	0.6	62%
6	0.6	1.9	67%
7	1.8	0.4	62%
8	0.9	2.3	78%
9	1.1	2.4	81%
10	1.5	1.5	71%
11	1.7	1.1	67%
12	0.8	2.4	74%
AVERAGE	**1.2**	**1.6**	**69%**
w\o BPM	**0.5**	**0.4**	**100%**
IDEAL	**0.15**	**0.15**	**100%**

2.3. Linac- Results

Linac Results	S-Band up to 1.54 GeV	S-Band 1.54 -> 6 GeV	C-Band 6 -> 20 GeV
Length (m)	79.1	221.9	448.6
Transmission for 2E10 part.	100%	100%	70%
Number of Cavities	21	60	181
Number of Quadrupoles*	14	9	9
Injected Emittance (h/v) **	0.35/0.5 μm	2.0/2.0 nm	-
Extr. Emittance with no blow	2.7/3.8 nm	0.5/0.5 nm	0.14/0.14 nm
Avg. Extracted Emittance	9.4/17.3 nm	1.7/1.9 nm	1.2/ 1.6 nm

* excludes the quadrupoles for matching from/to other accelerators
** excludes the emittance dilution due the mis-injection!

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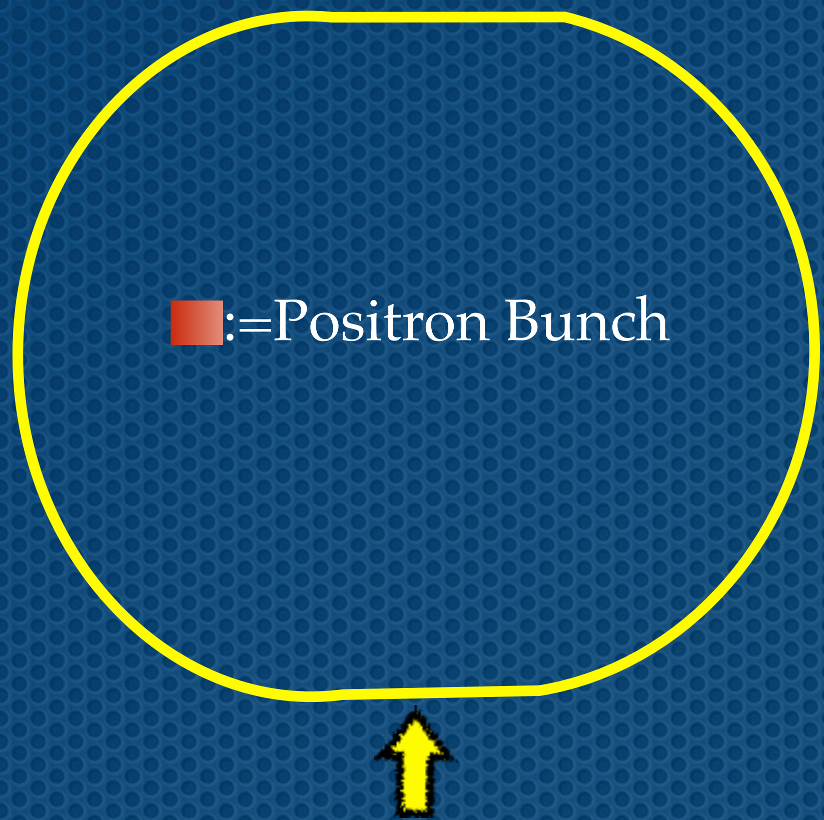
Avg. Extracted Emittance	9.4/17.3 nm	1.7/1.9 nm	1.2/ 1.6 nm

Damping Ring can damp the emittance of app. 0.27 μm

SPS expects 1 nm emittance, but SPS can have stronger wigglers

MB expects .5 nm emittance, but with the wigglers, it can accept bigger emit

3. Damping Ring - Basics



RF Section: 400 MHz - LHC type
2 Super Conducting Cavities with 1 m of drift space beforehand and afterwards to deploy the cryostat

✓ asymmetric straight sections brought about wider dynamic aperture, as pointed out by F. Zimmermann

The circumference of the DR is 241.8 m:

➡ 806 ns for the speed of light.
➡ 5 trains each with 100 ns of spacing
➡ Each train (i.e. 2 Bunches) with 61 ns bunch to bunch spacing.

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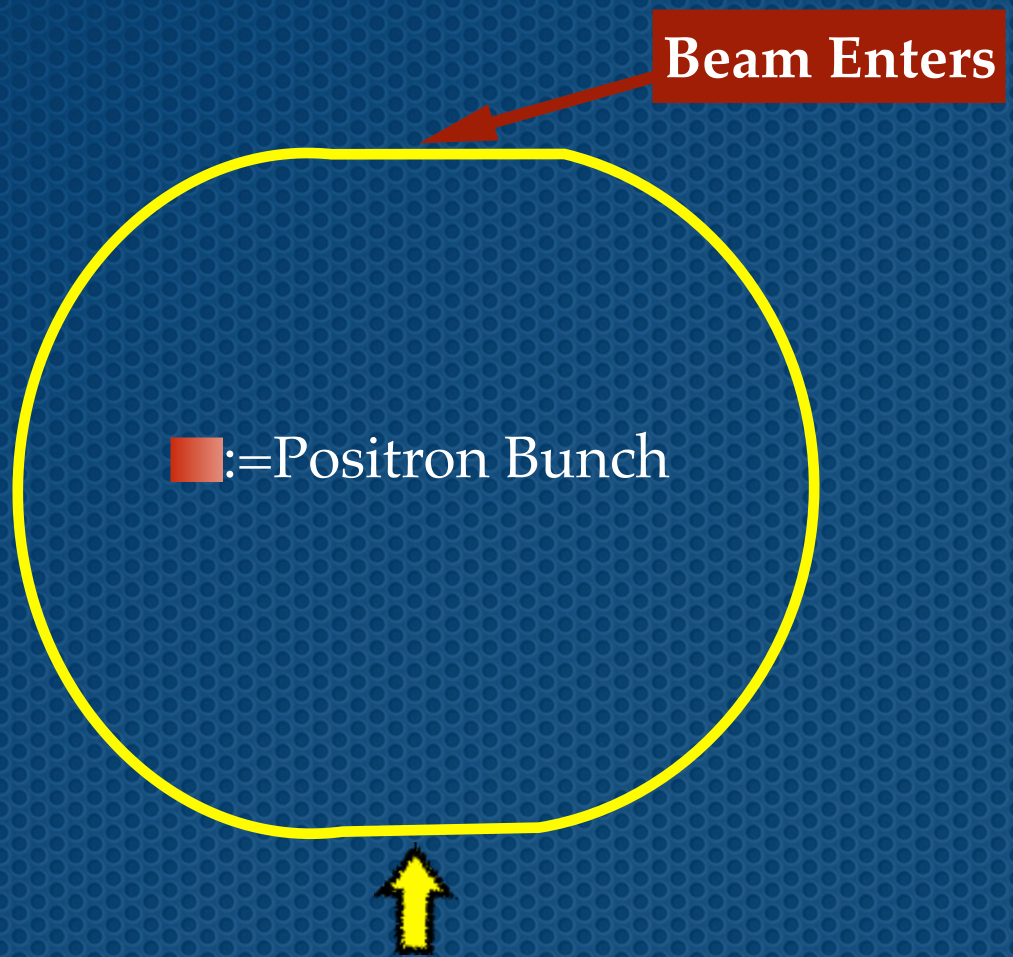

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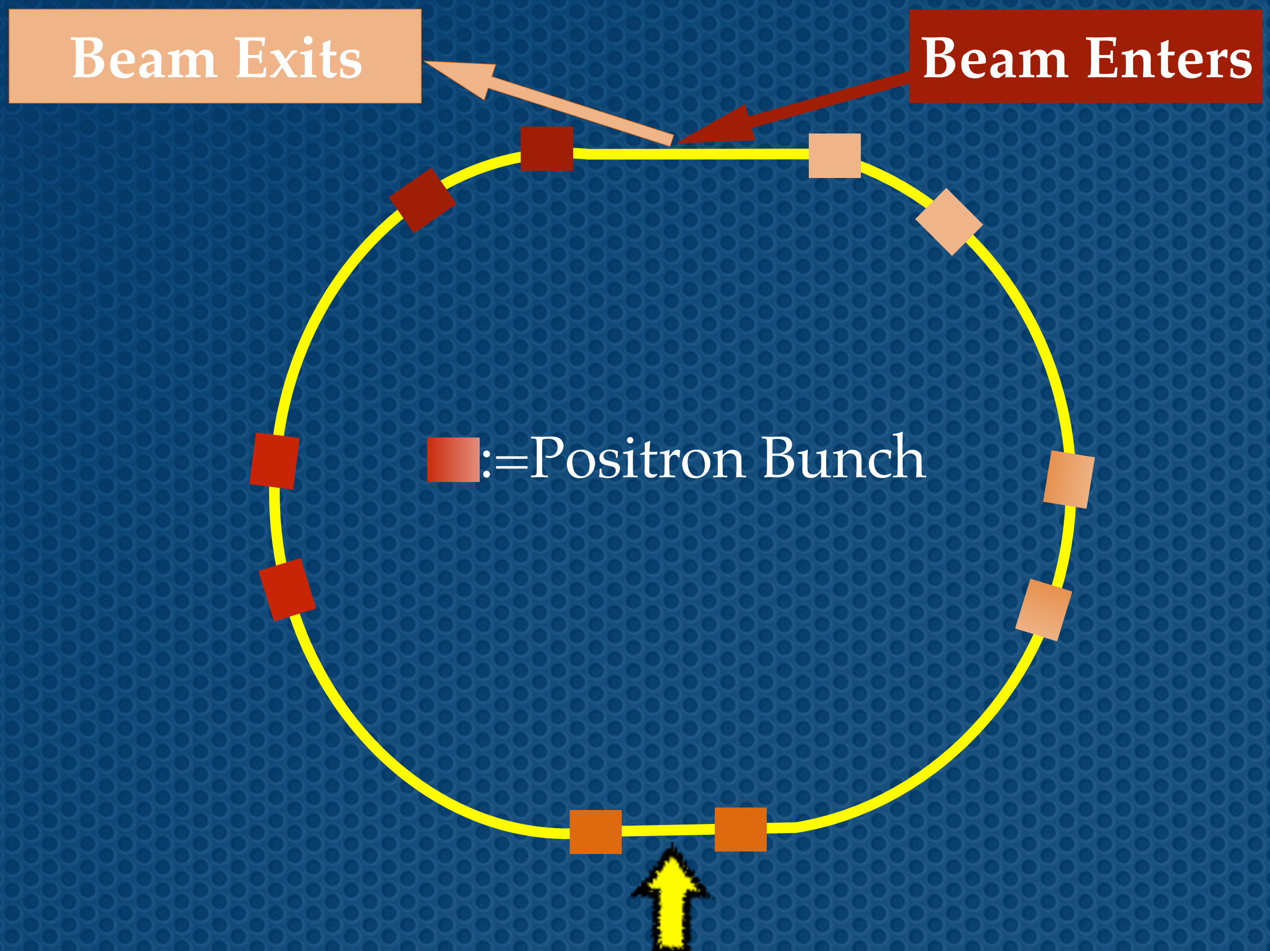

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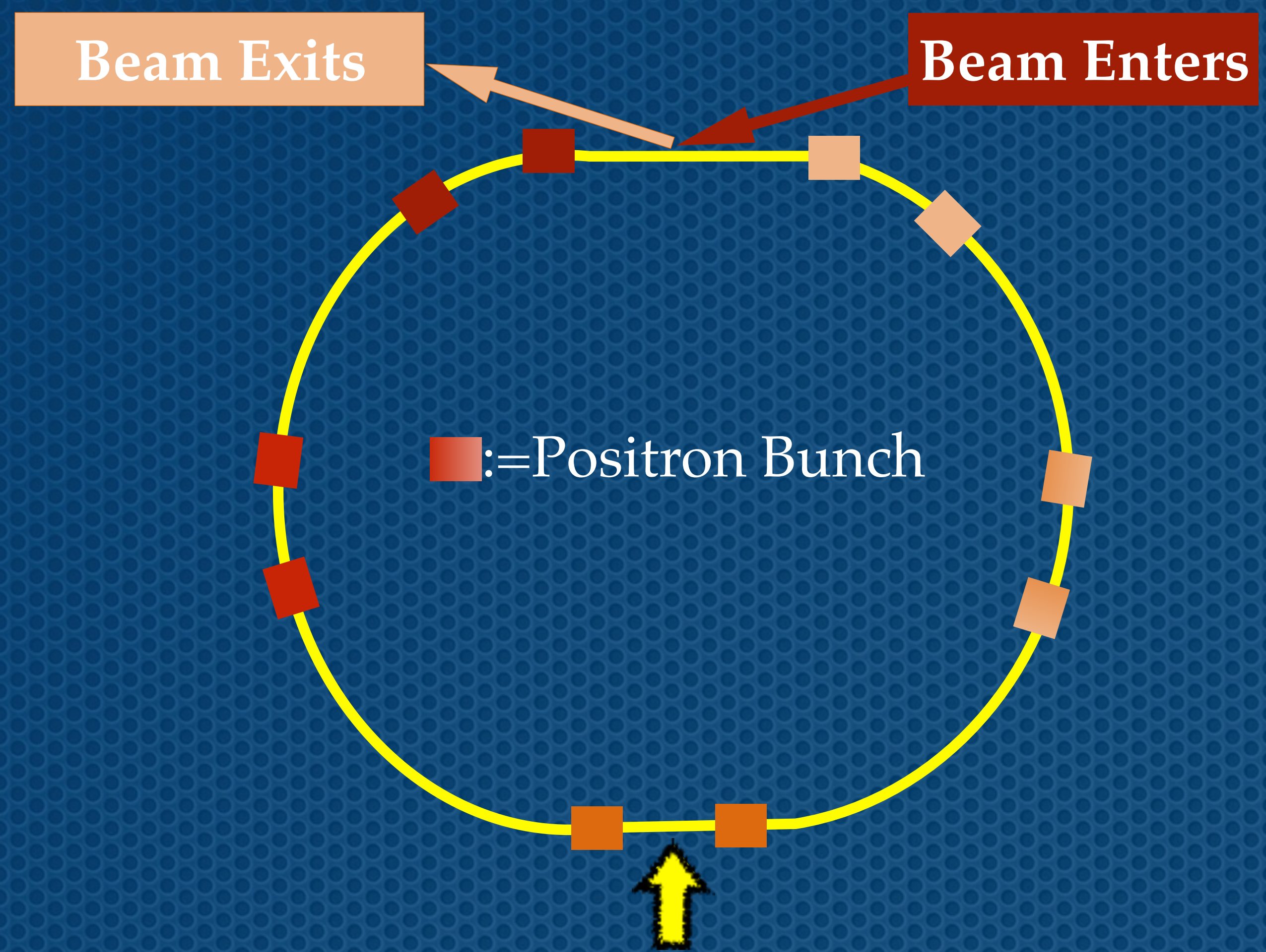

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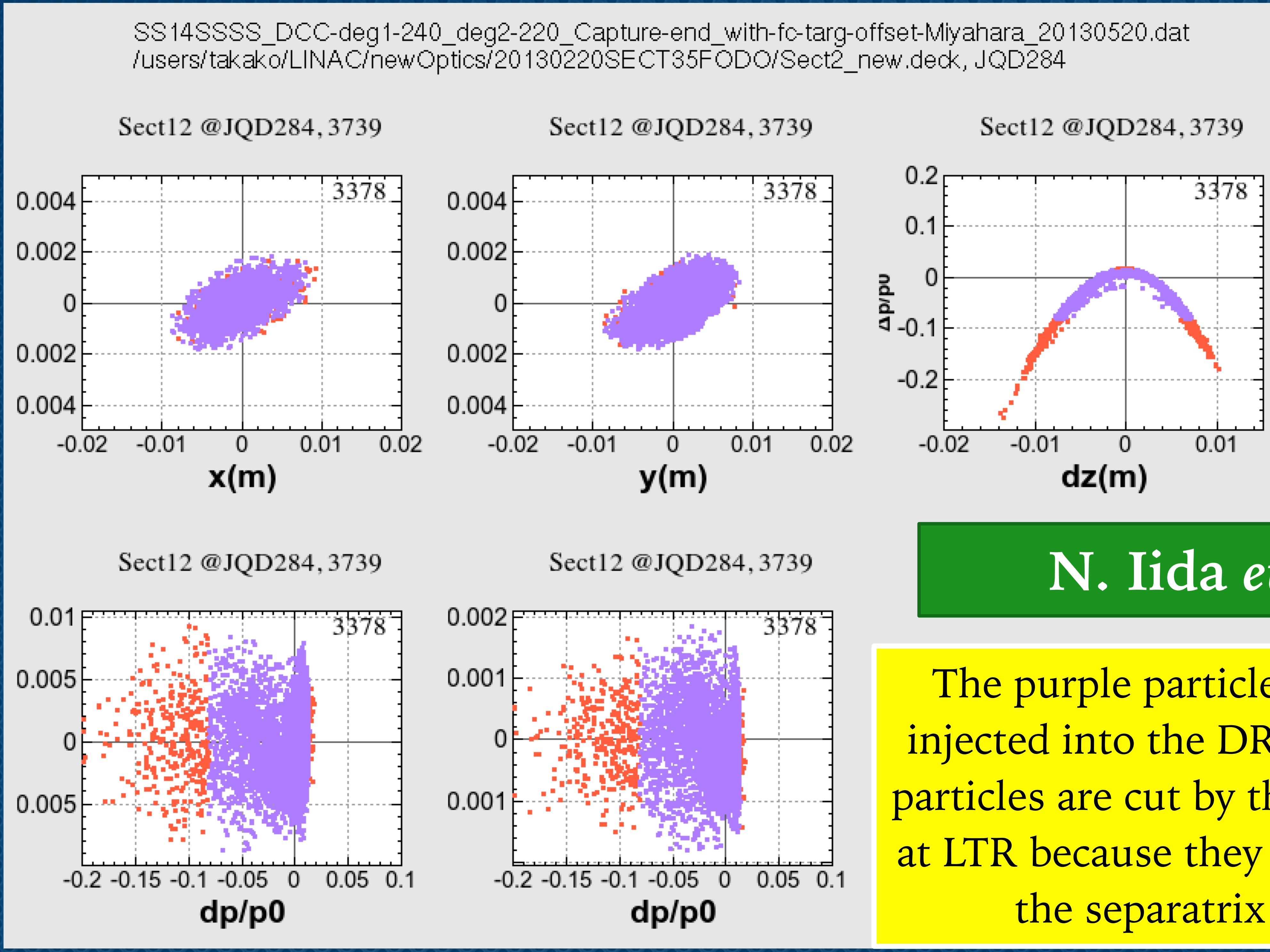
The same orientation but opposite circulation for e- beam !

KEK e+ simulation



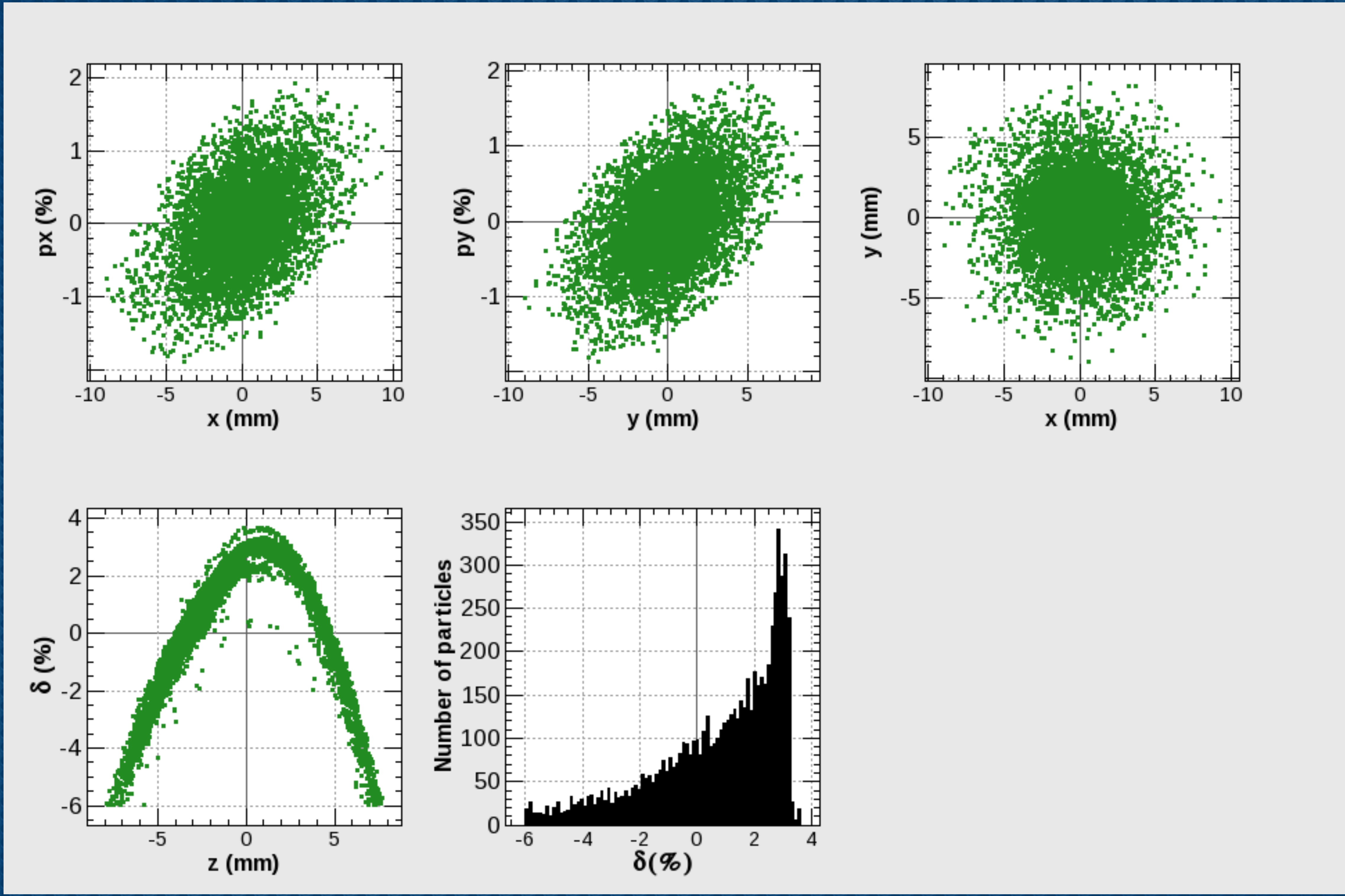
N. Iida *et al.*

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 e+, and inject ±5% energy spread of the e+ into the ECS.

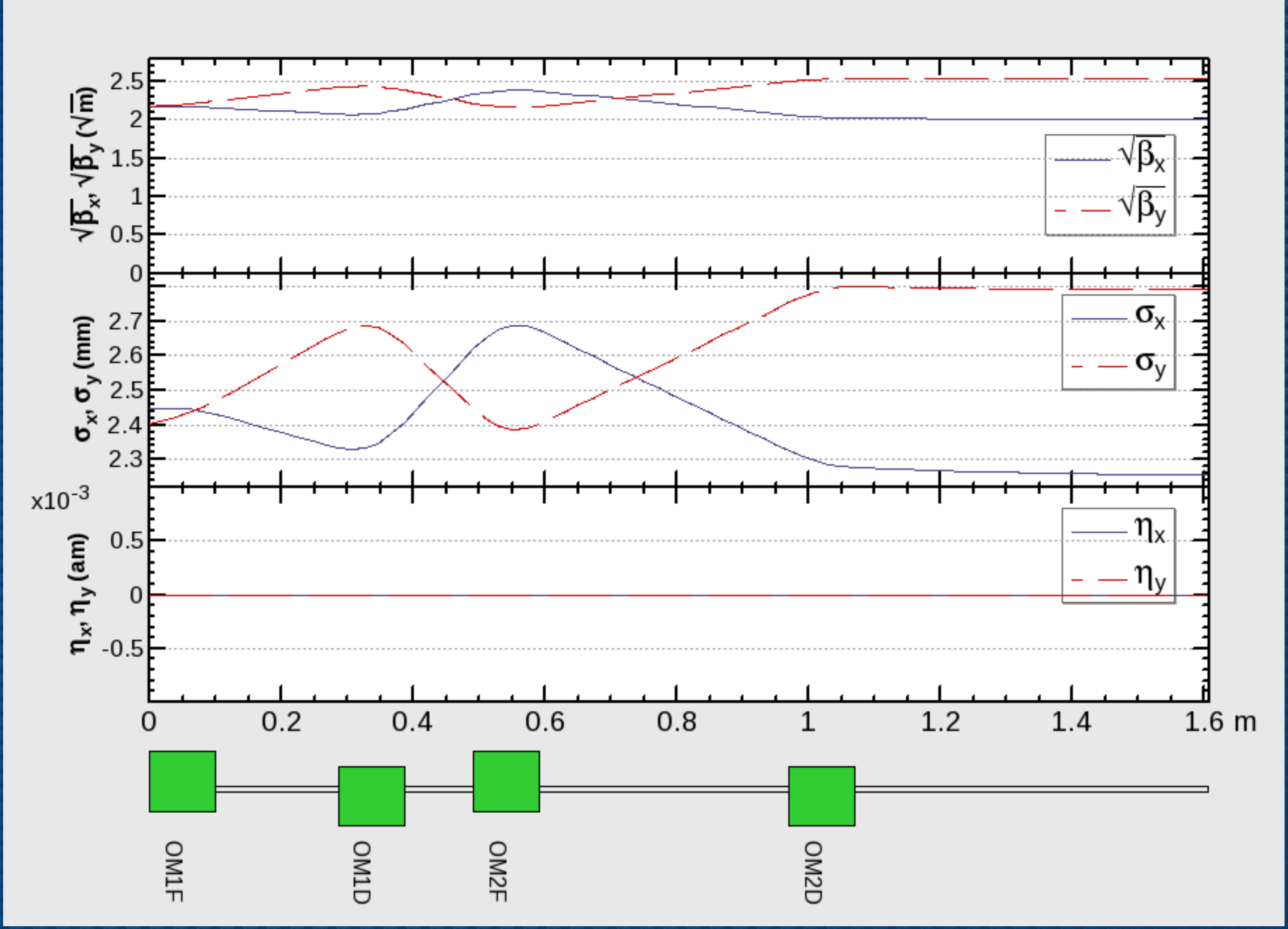
KEK e+ simulation

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



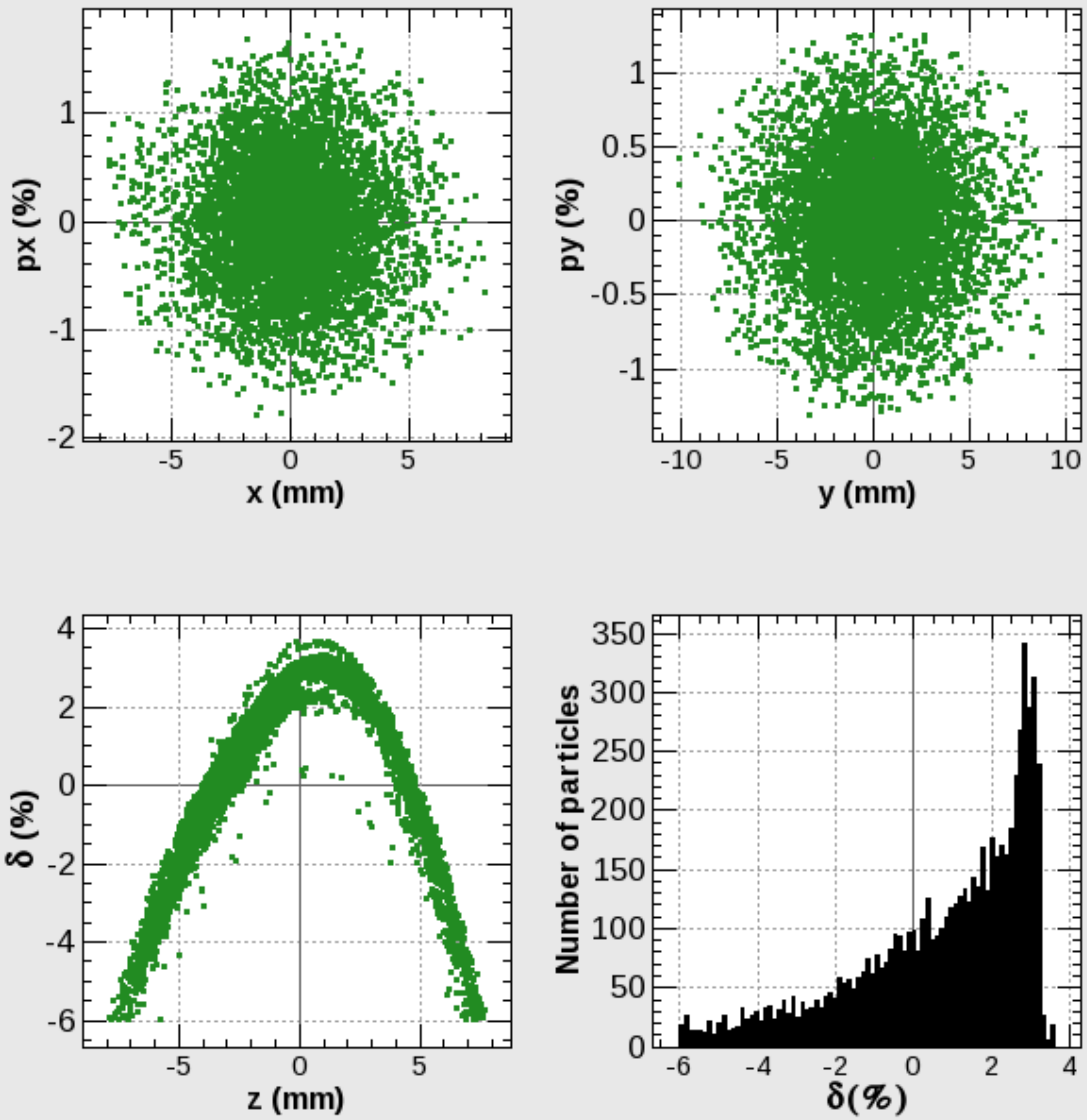
3.1. Linac to Damping Ring

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



3.1. Linac to Damping Ring

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



$\varepsilon_x = 1.26\ \mu m$

$\varepsilon_y = 1.21\ \mu m$

$\varepsilon_z = 75.5\ \mu m$

$\alpha_x = 0.006$

$\alpha_y = 0.006$

$\alpha_z = -0.15$

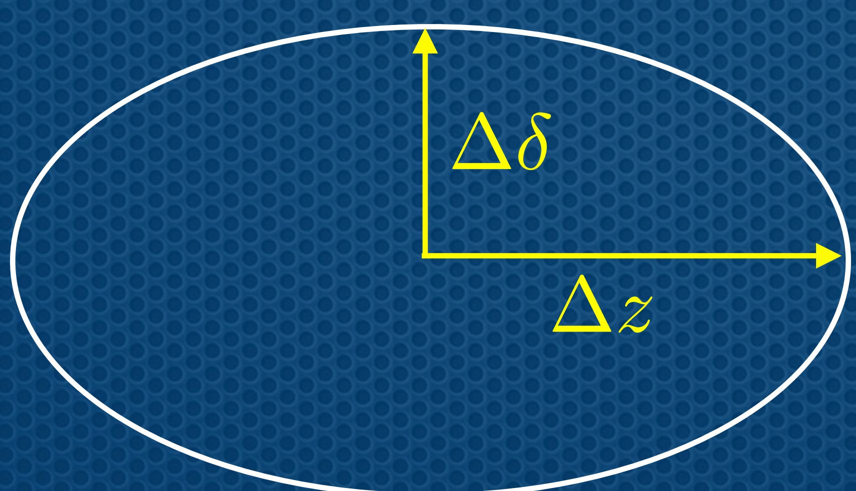
$\beta_x = 4.00\ m$

$\beta_y = 6.38\ m$

$\beta_z = 0.15\ m$

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	1.2 m	0.15 m	2.96 m



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

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

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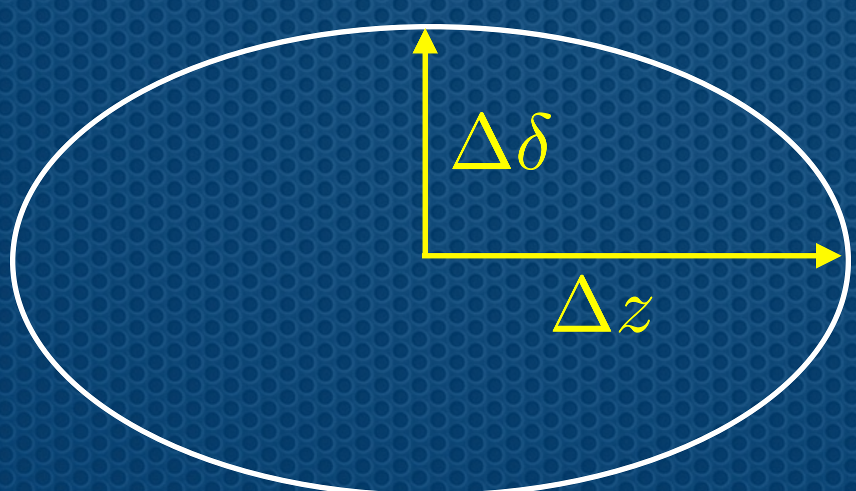
Energy Spread (total)	$\pm 12\%$	$\pm 5\ \%$	$\pm 7.9\%$
Bunch Length (total)	$\sim \pm\ 12$ mm	$\pm\ 8$ mm	± 92.4 mm
β_z	1.2 m	0.15 m	2.96 m



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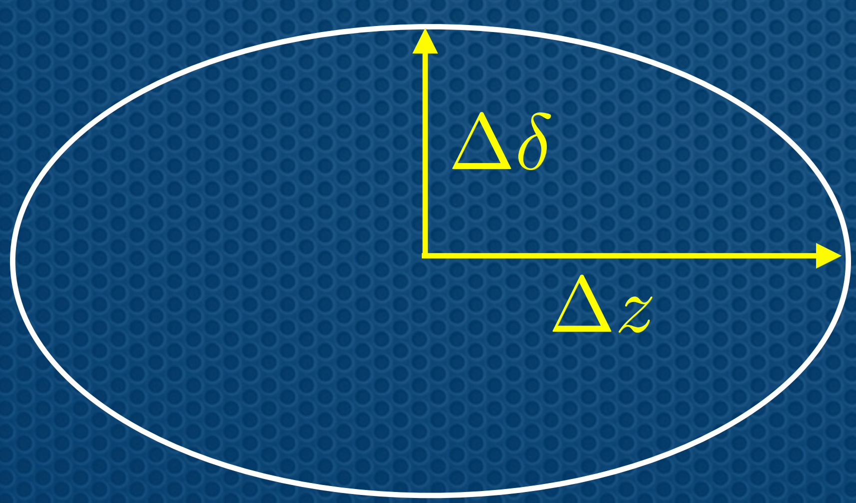

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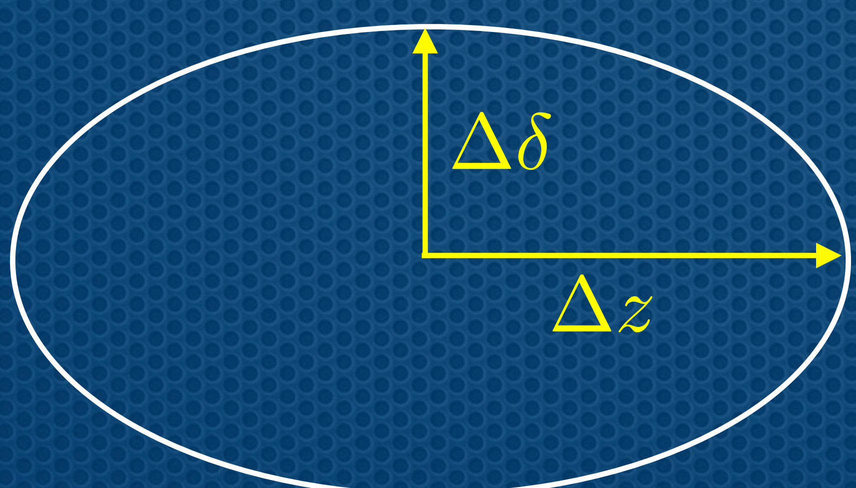

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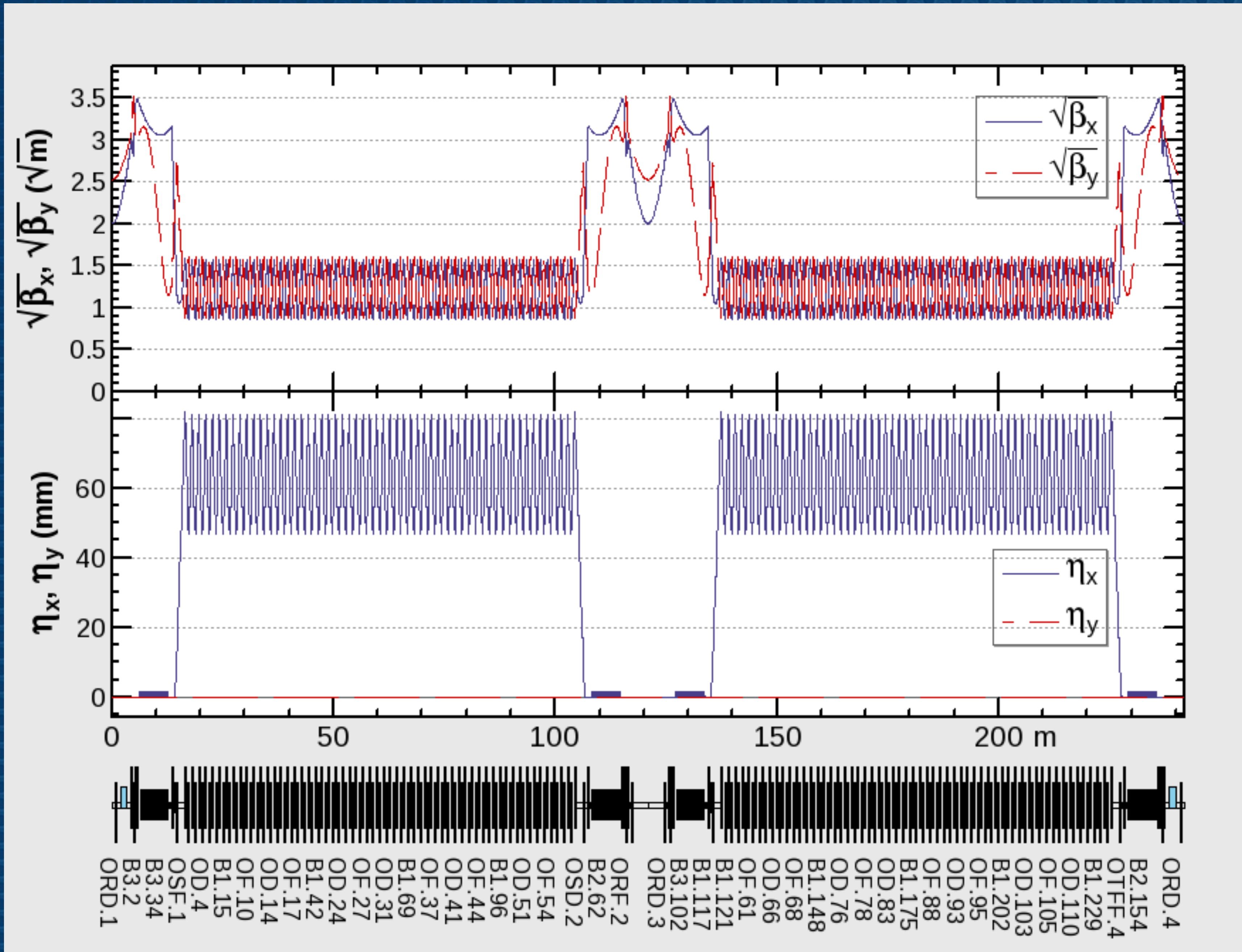
3.2. Damping Ring Optics

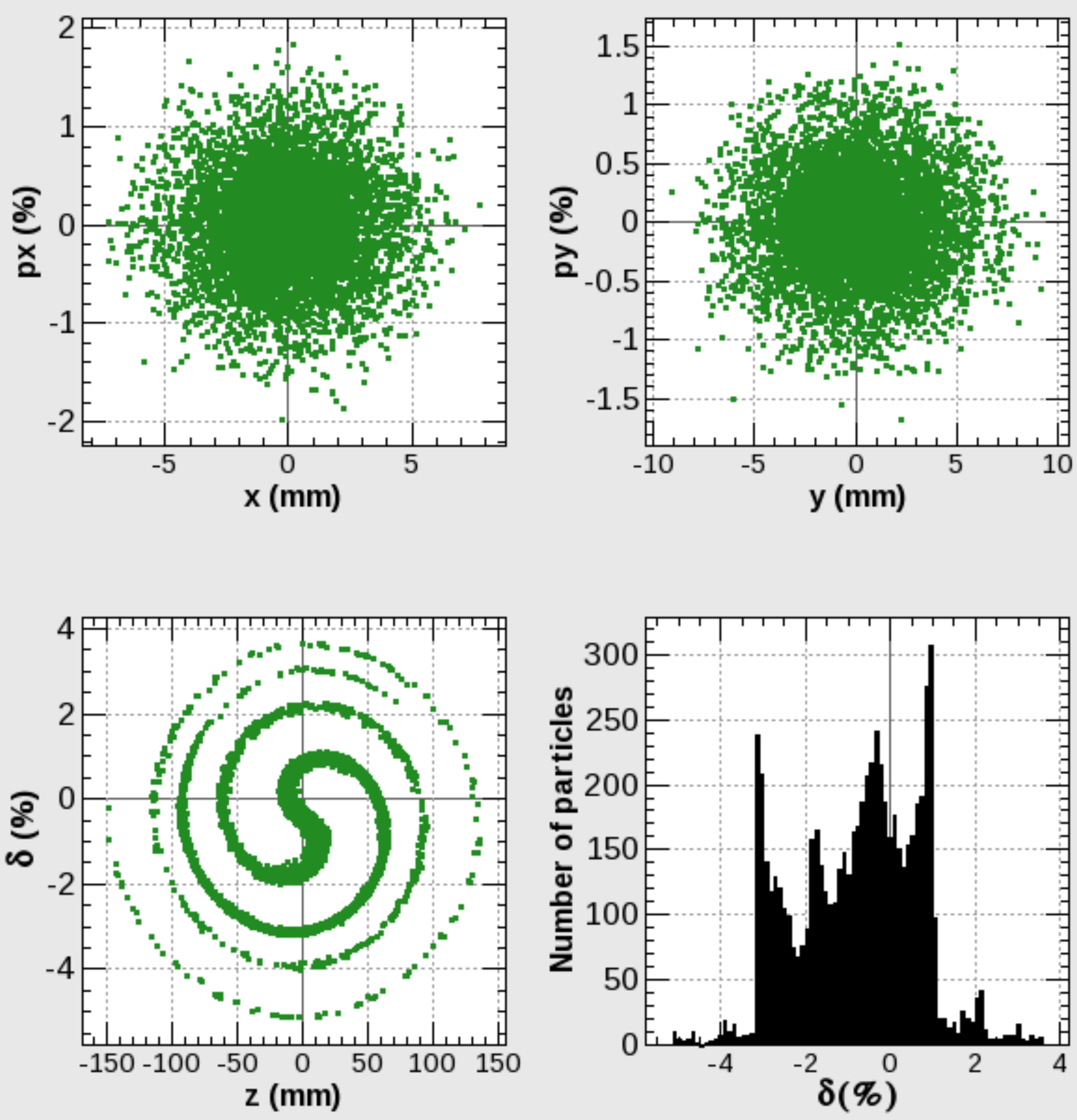


Parameter	Value
tau_x	10.6 ms
tau_y	11.0 ms
tau_z	5.6 ms
natural emittance (x/y)	1.16 nm/-
circumference	241.8 m
# of cells (FODO w/ sextupoles)	114
dipole field	0.66 T
no. of wigglers, field	4, 1.80 T
cell tune (x/y)	0.193 rad/ 0.183 rad

❖ The positron bunches have 45 milliseconds, whereas the electrons have 25 ms to spend in the DR !

3.3. Multiparticle e+ Tracking in the DR

❖ 1000 Turns in the DR, the synchrotron radiation is ON, the aperture set to ± 15 mm in the injection (i.e. straight sections).



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

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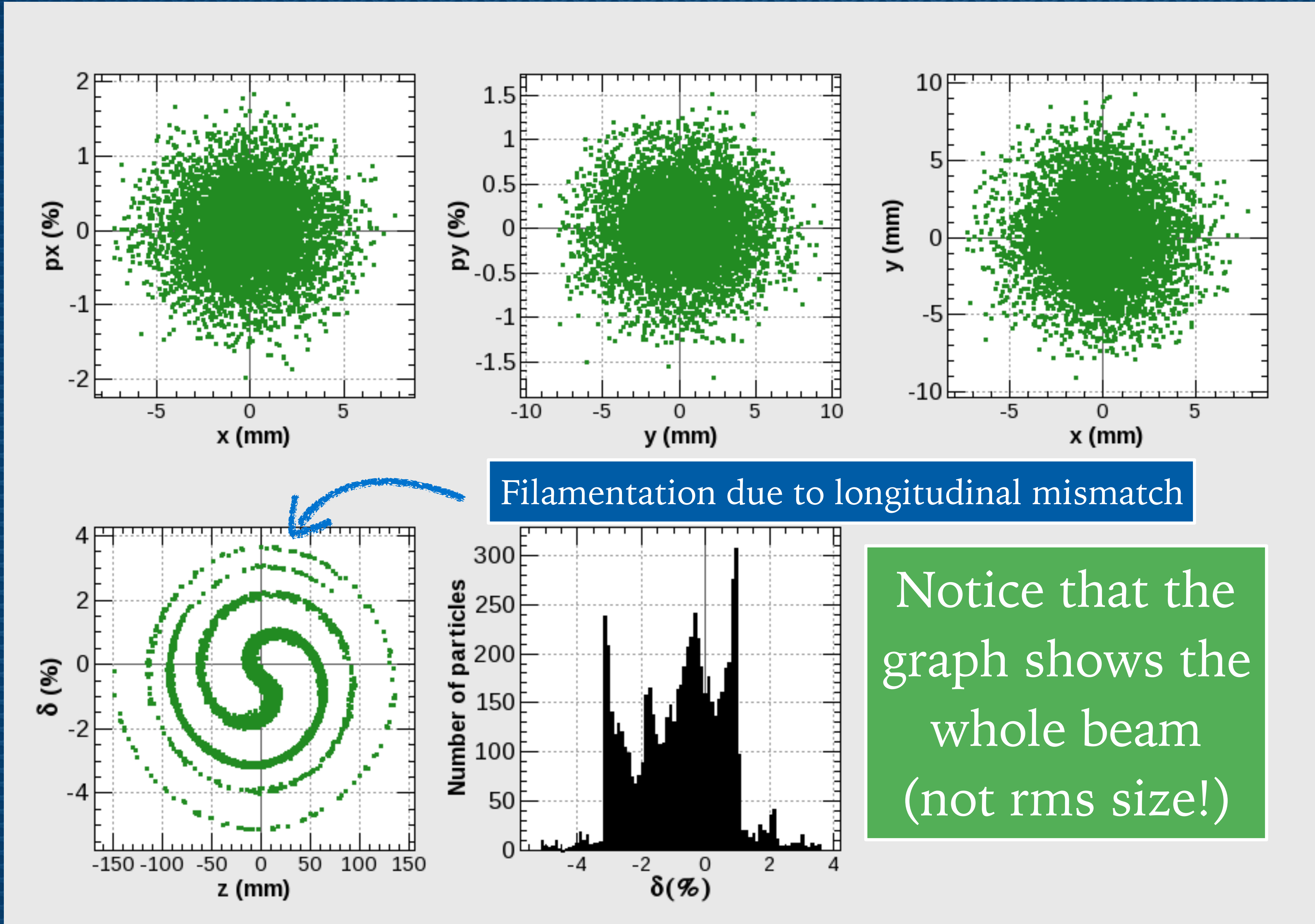
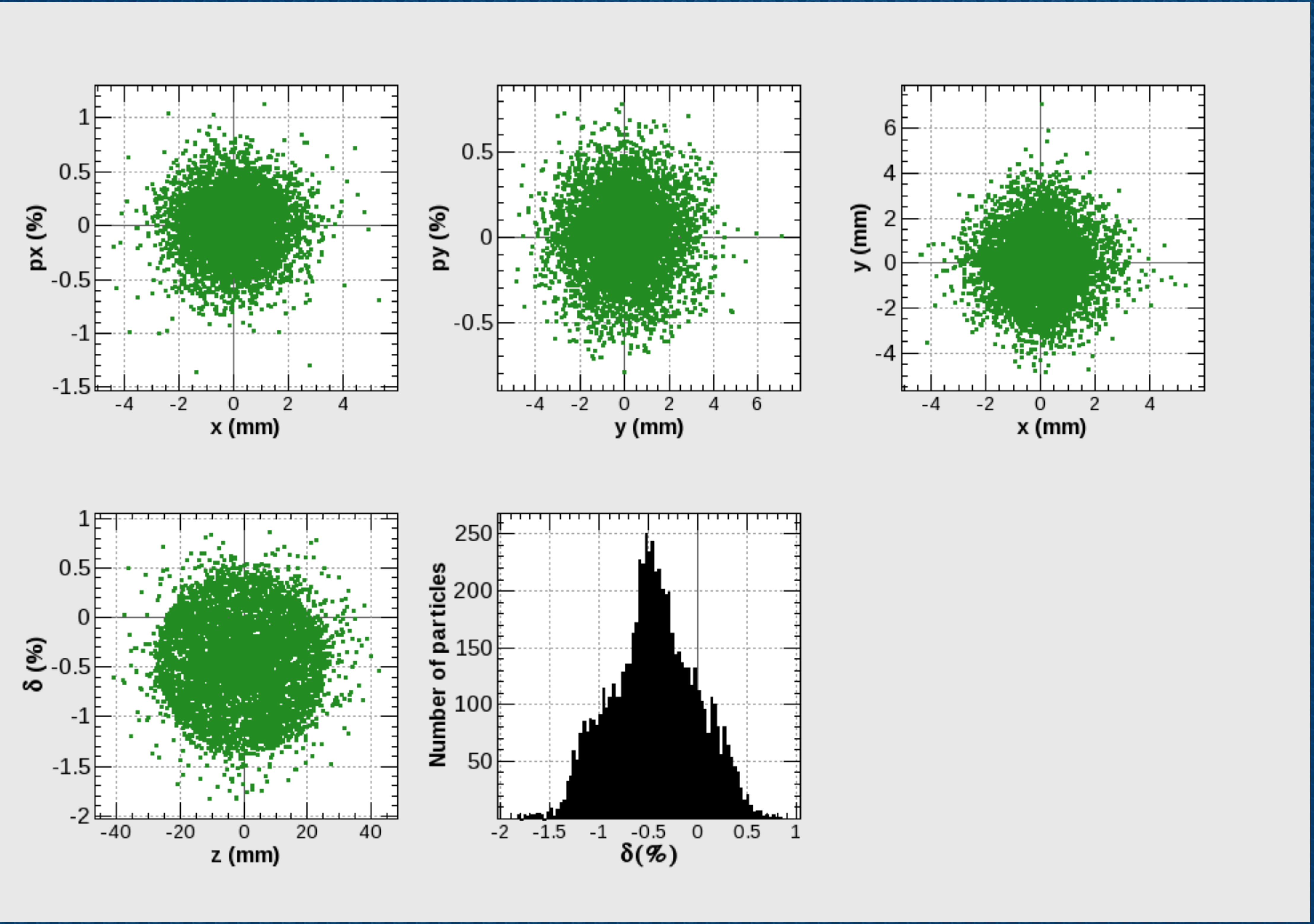


3.3. Multiparticle e+ Tracking in the DR

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



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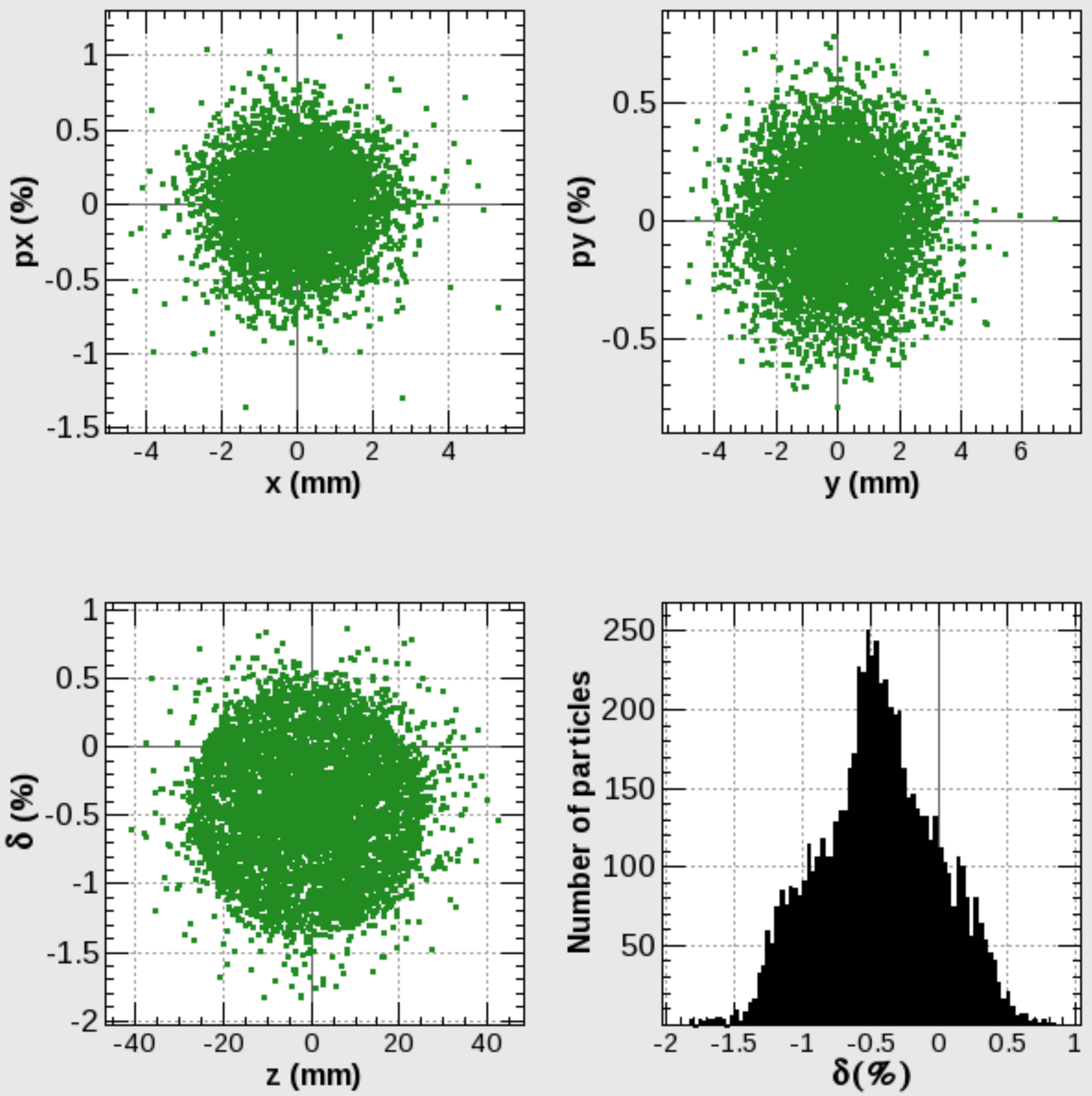
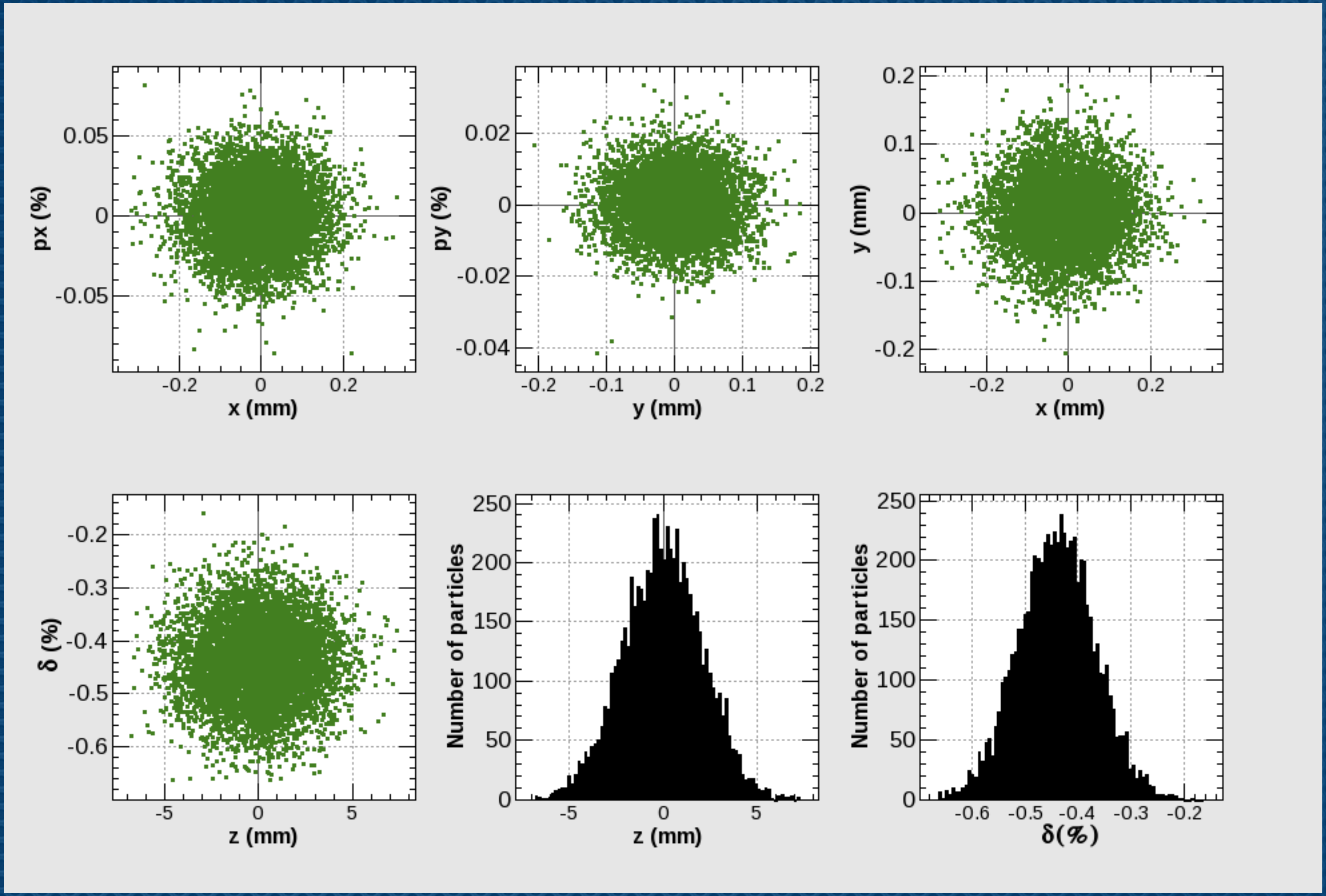


However, the filamentation is fixed by the DR itself. The only concern remains the longitudinal emittance blow.

3.3. Multiparticle e+ Tracking in the DR

- 55600 Turns (i.e. 45 ms out of 45 ms allowance) in the DR, the sync. rad is ON.



- Coherent Synchrotron Radiation is under study. We may reduce the cavity voltage in the DR, which results in the shrinkage of energy acceptance. For that reason, we will need the ECS!

3.4. Damping Ring- Results

Parameter	Injected	Analytical	SAD after Tracking
Horizontal Emittance	1.26 µm	1.3 nm	1.81 nm
Vertical Emittance	1.21 µm	0.3 nm	0.37 nm
Longitudinal	75.5 µm	1.46 µm	1.52 µm

❖ Actually, the design has been made to give a factor 2 of safety margin in horizontal emittance. Please notice that the tracking has already reduced the safety margin a little.

4. Conclusions - Injector Chain

- The emittance evolution through FCC-ee is under study, wigglers are being added to the SPS to simulate injected/extracted emittance, and in case the top-up booster may have a wiggler, too. Currently, SPS expects 1 nm emittance horizontally at 6 GeV.

- Injection from linac at 20 GeV to the top up Booster is also under study, this case may include no wiggler in the BR.

- Bunch compressor from the damping ring back to the DR is under study.

4. Conclusions - Linac

up to 1.54 GeV:

❖ No beam loss is expected. Emittance blow up to 100 times with respect to no blow up emittance can be cured in DR within given 25 ms of store time for electrons.

up to 6 GeV:

❖ No beam loss is expected. The average extracted emittance is almost twice of the target (more damping in the DR or stronger wigglers in SPS).

6-20 GeV:

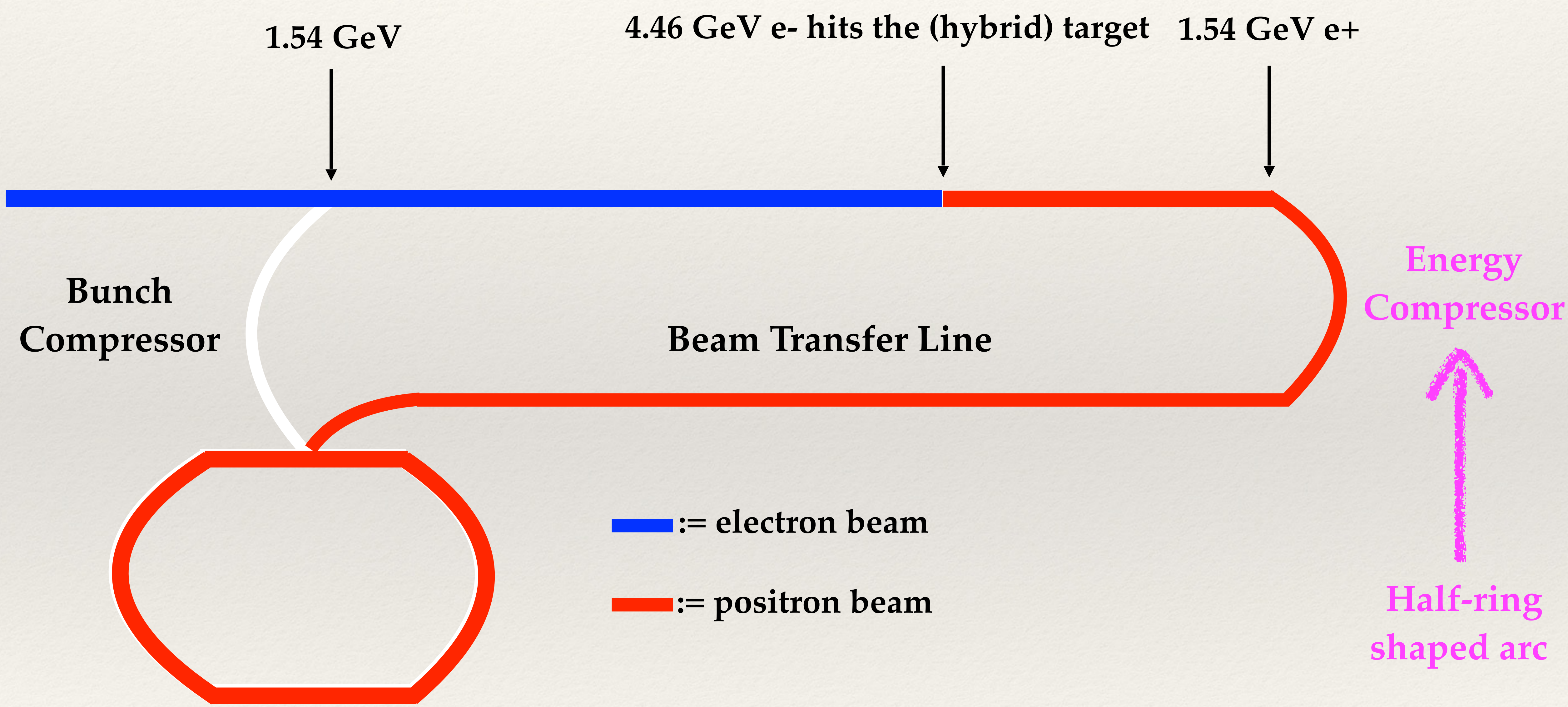
❖ Beam loss needs to be mitigated together with the emittance blow. A new orbit steering like QuadBPM method required and may be written soon.

4. Conclusions - Damping Ring

- ❖ Misalignment study for the DR has not been done.
- ❖ Study for the Coherent Synchrotron Radiation is the priority now. It seems that the cavity voltage needs to be lowered to extend the equilibrium bunch length. Thus, it would result in a narrower dynamic aperture which requires an energy compressor before the DR.
- ❖ The Damping Ring tracking simulations needs to be re-done for lower cavity voltage. due to CSR. Unfortunately, we may need an Energy Compressor before DR due to shrunk in energy acceptance due to lower cavity voltage.

Energy Compressor: an on-going work

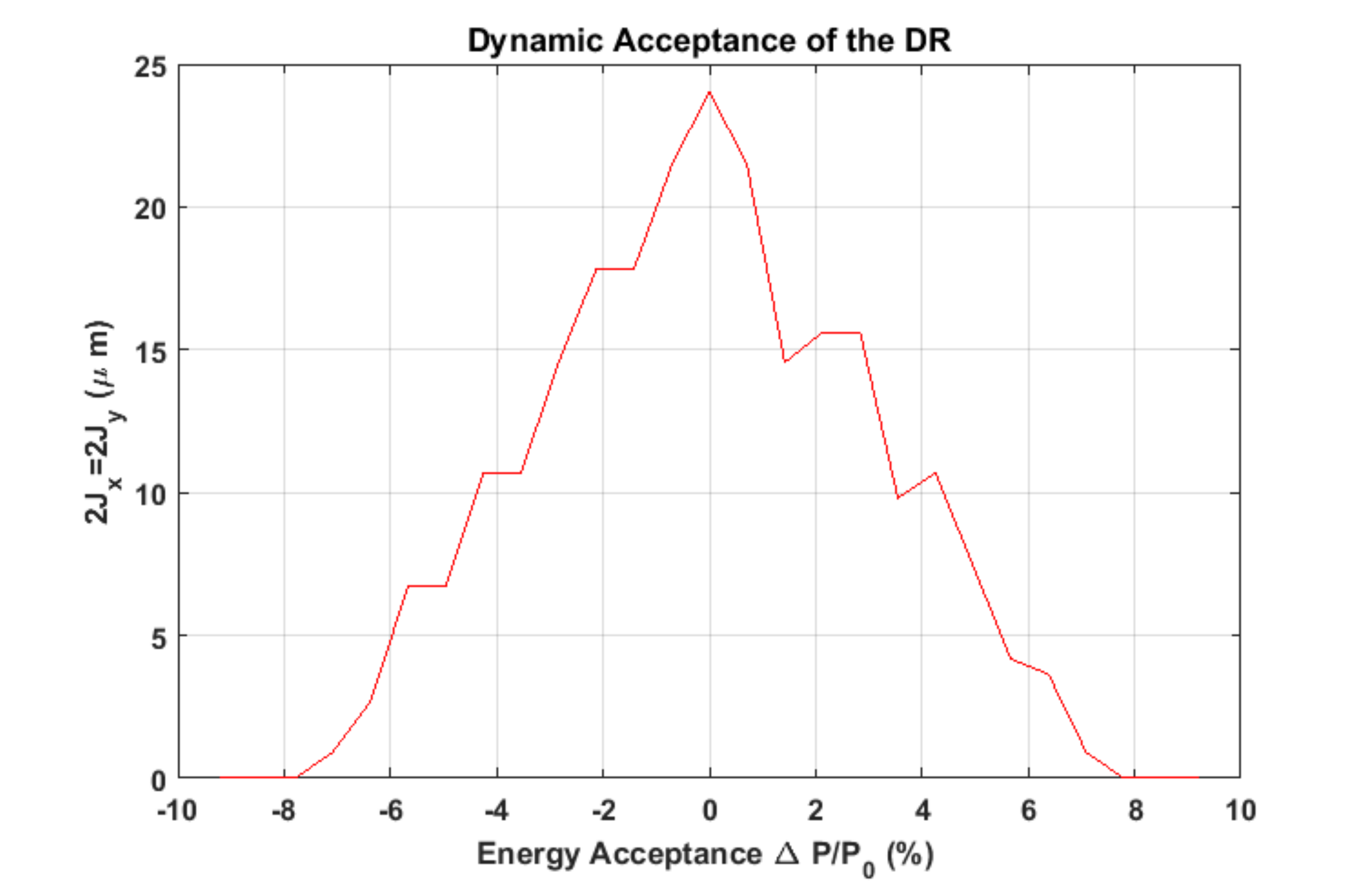
Positron Flow Scheme



not to scale!

DR Acceptance

- DR provides $\pm 7.9\%$ energy acceptance, but we may inject the beam within $\pm 2.2\%$.



$$\beta_z = 0.12\ m$$

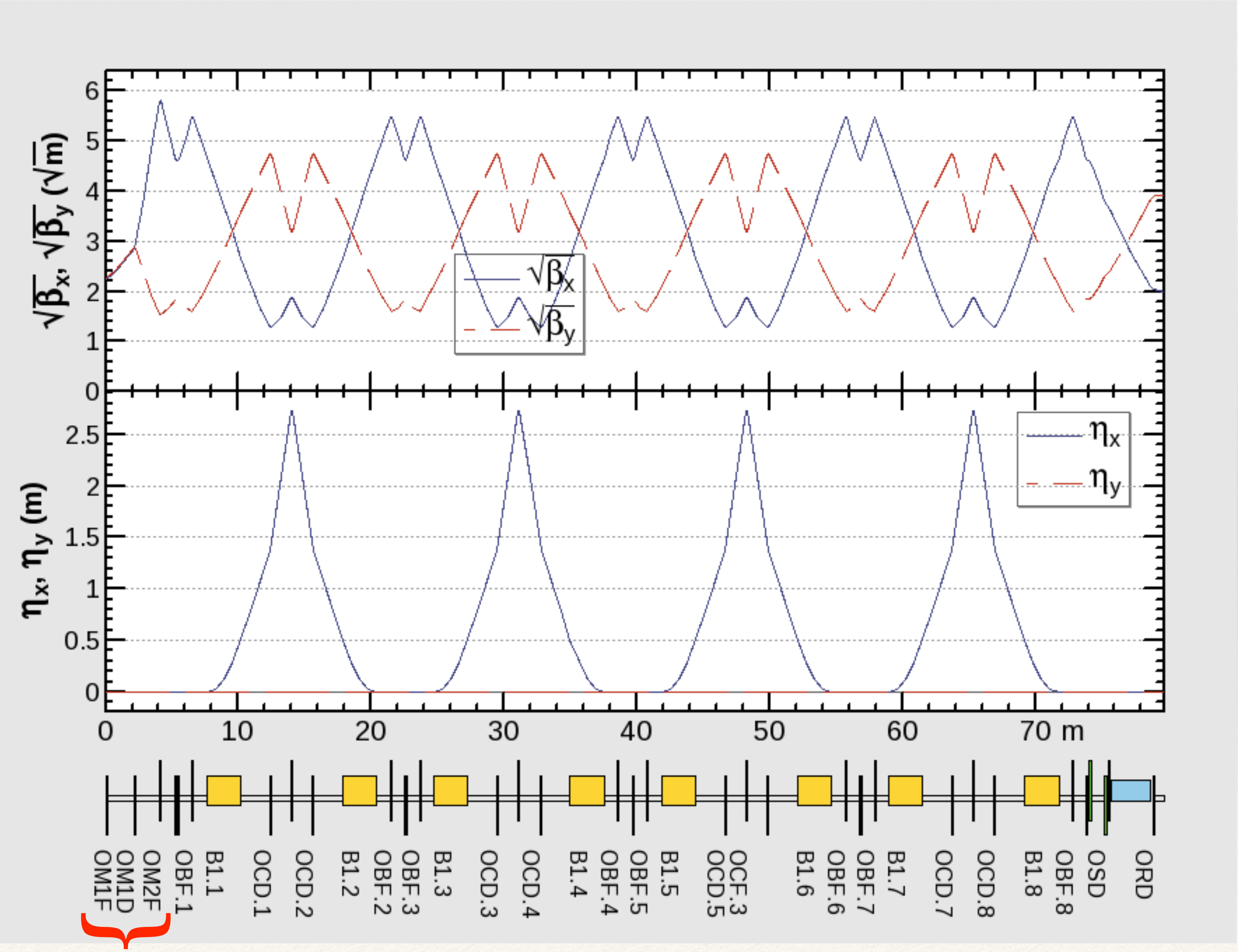
$$\beta_z = \frac{\sigma_z^2}{\varepsilon_z} = \frac{(2.07\ mm)^2}{1.47\mu m} = 2.91\ m$$

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

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

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 (6 GeV Linac to Energy Compressor)

Half Ring Energy Compressor

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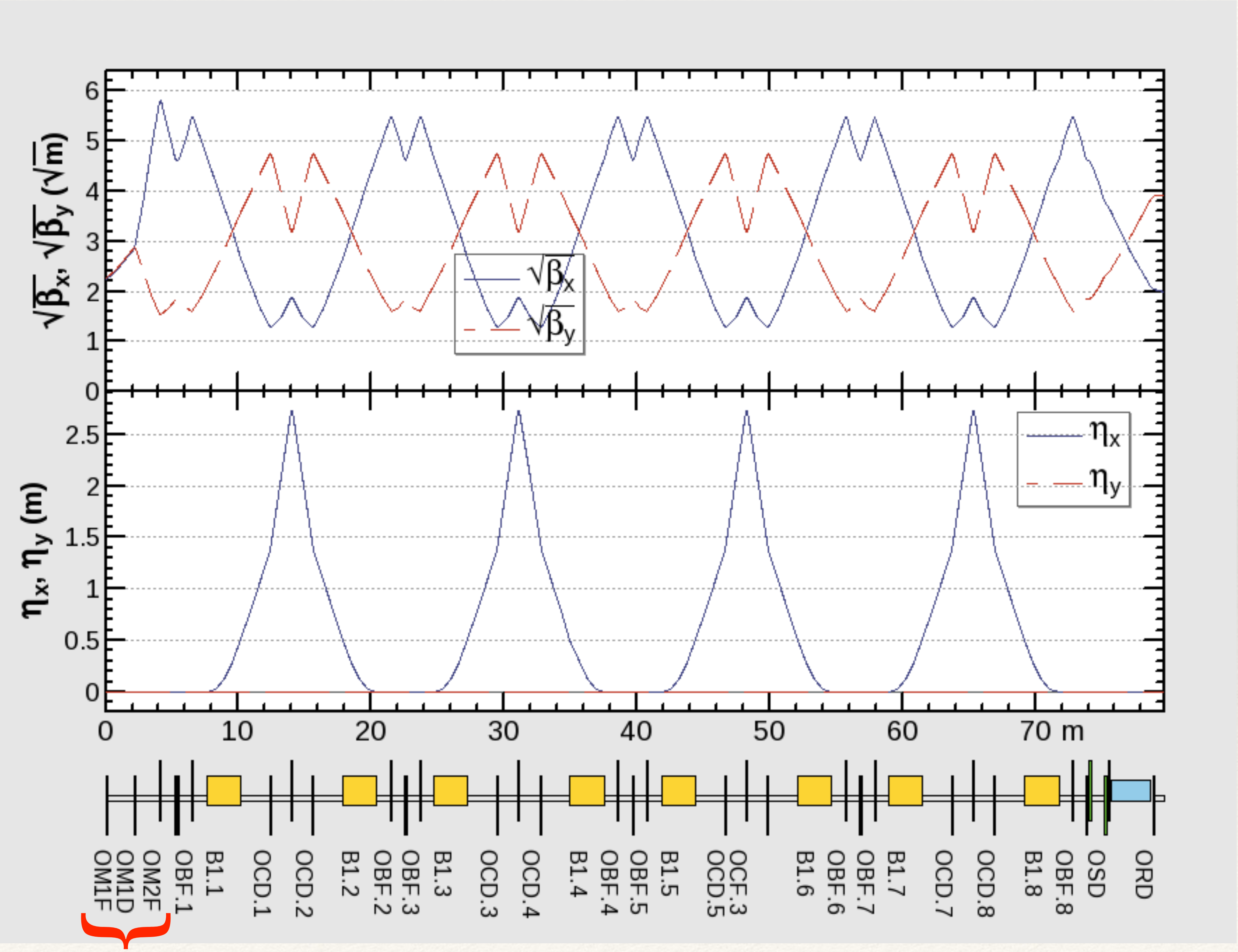

S-Band Cavity:

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

matching section: LitEC (6 GeV Linac to Energy Compressor)

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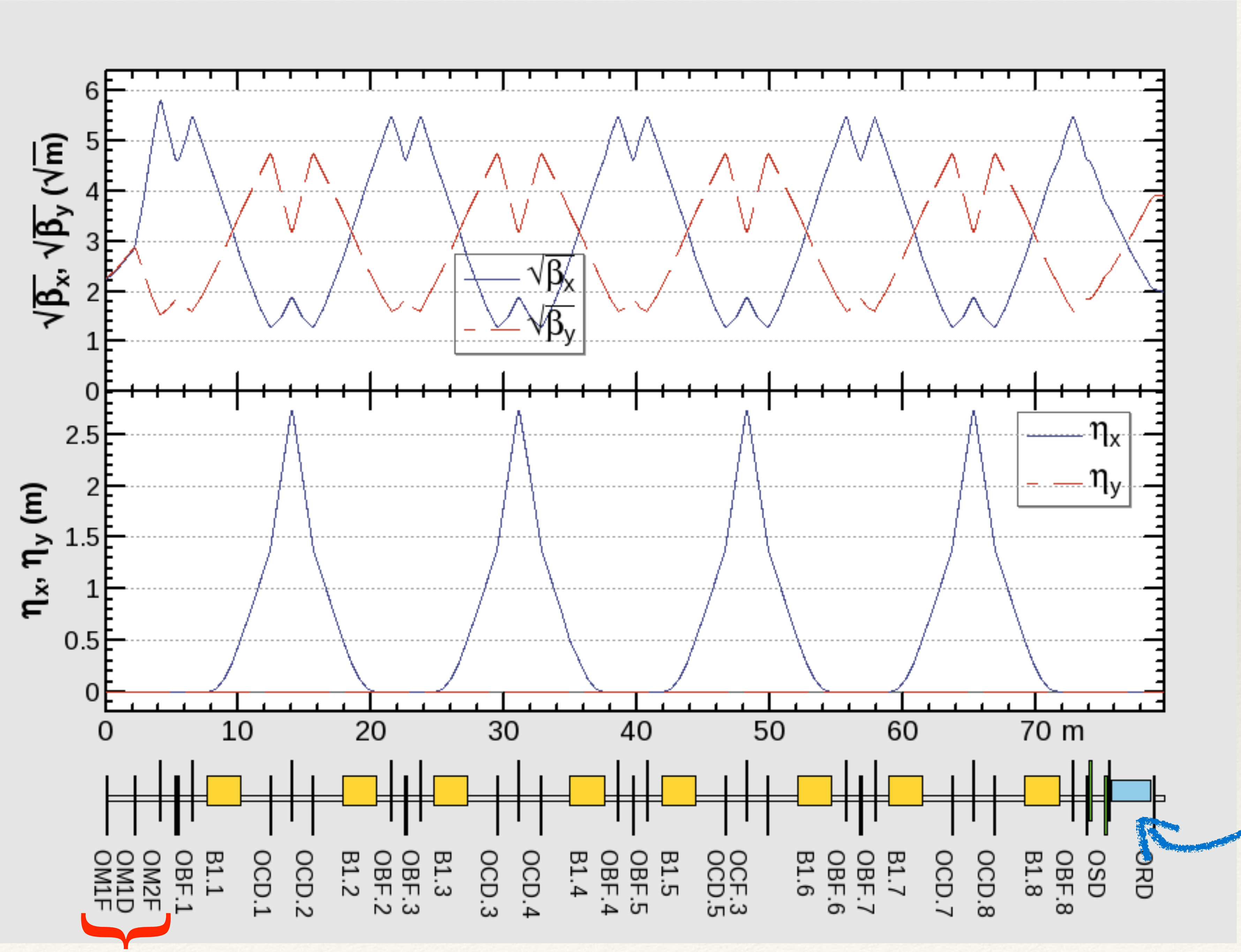

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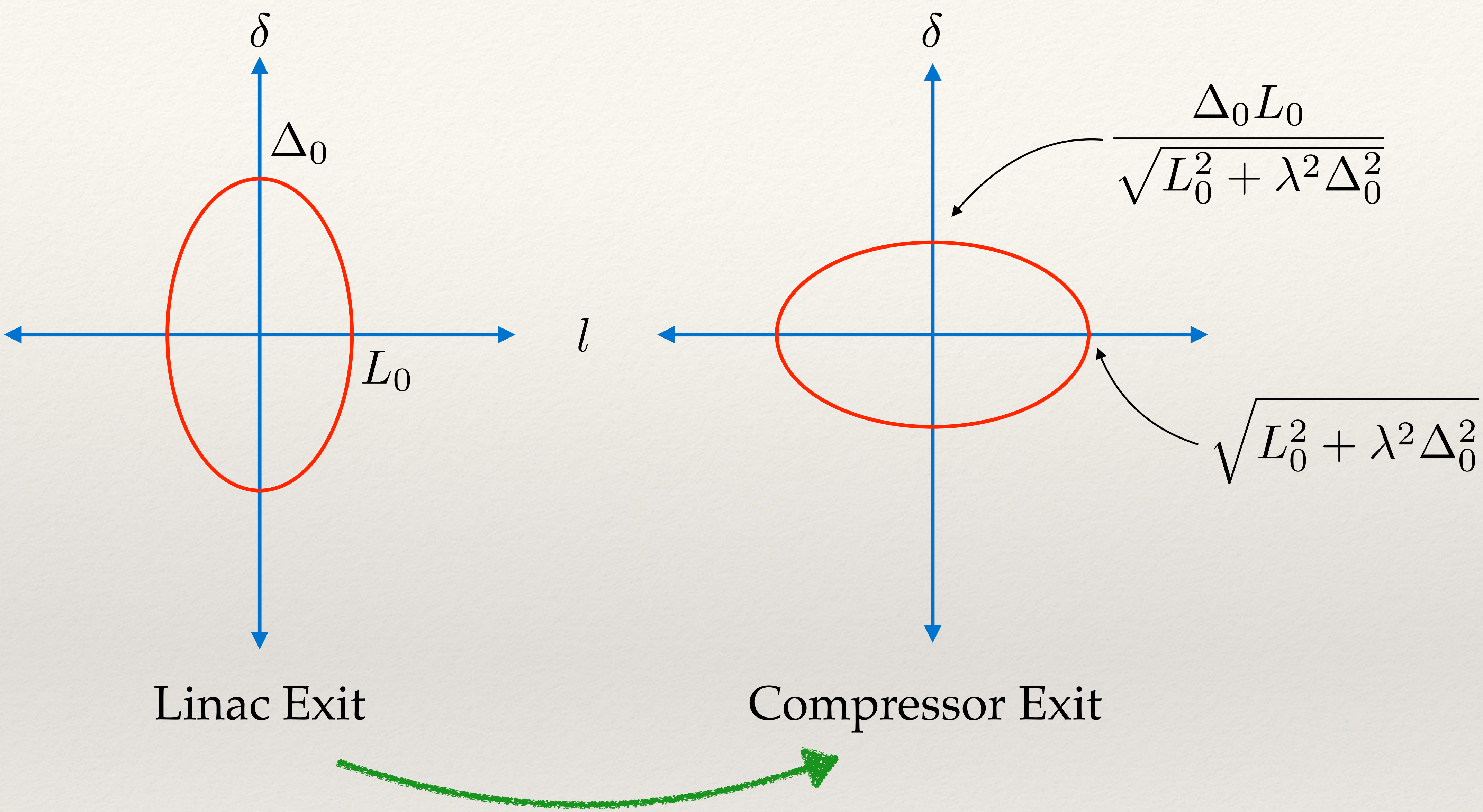
ECS- Compression



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

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

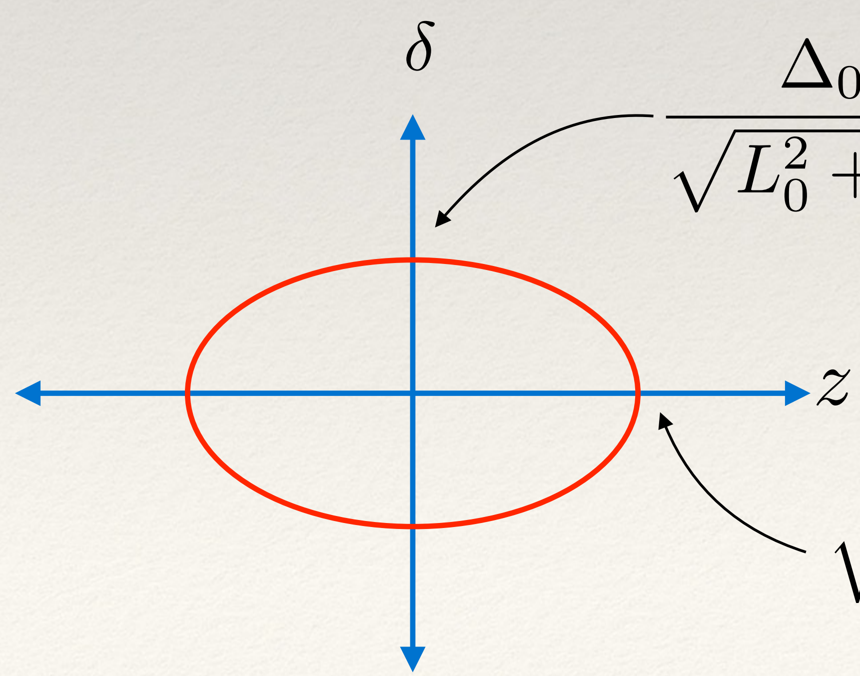
ECS- Transfer Matrix

```
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

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



$$\frac{\Delta_0 L_0}{\sqrt{L_0^2+\lambda^2\Delta_0^2}} = 2.17\%$$

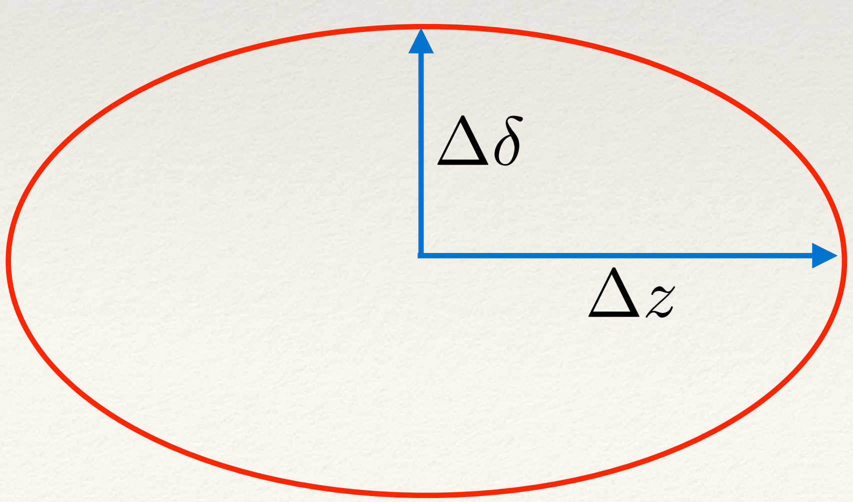
$$\sqrt{L_0^2+\lambda^2\Delta_0^2} = 0.0637 \text{ m}$$

ECS - Calculations

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

matched

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



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

ECS - Calculations

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

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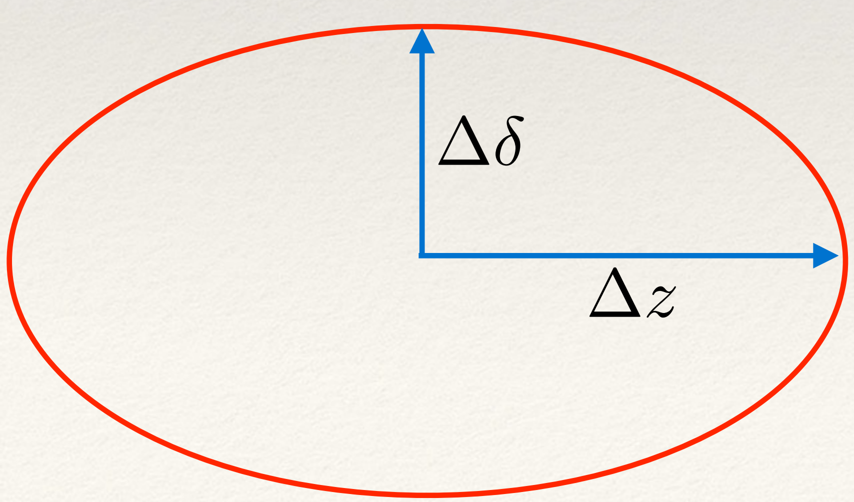

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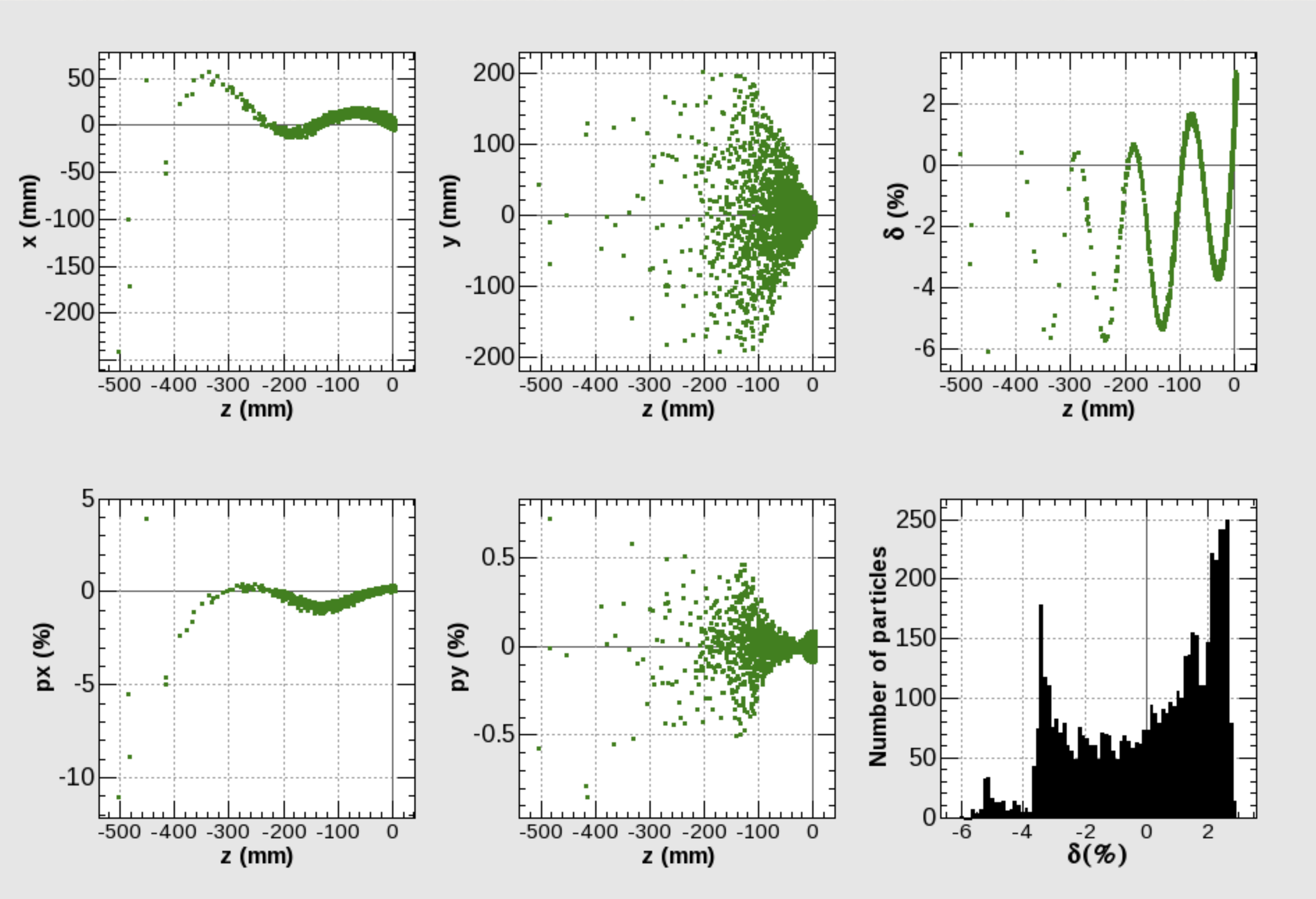
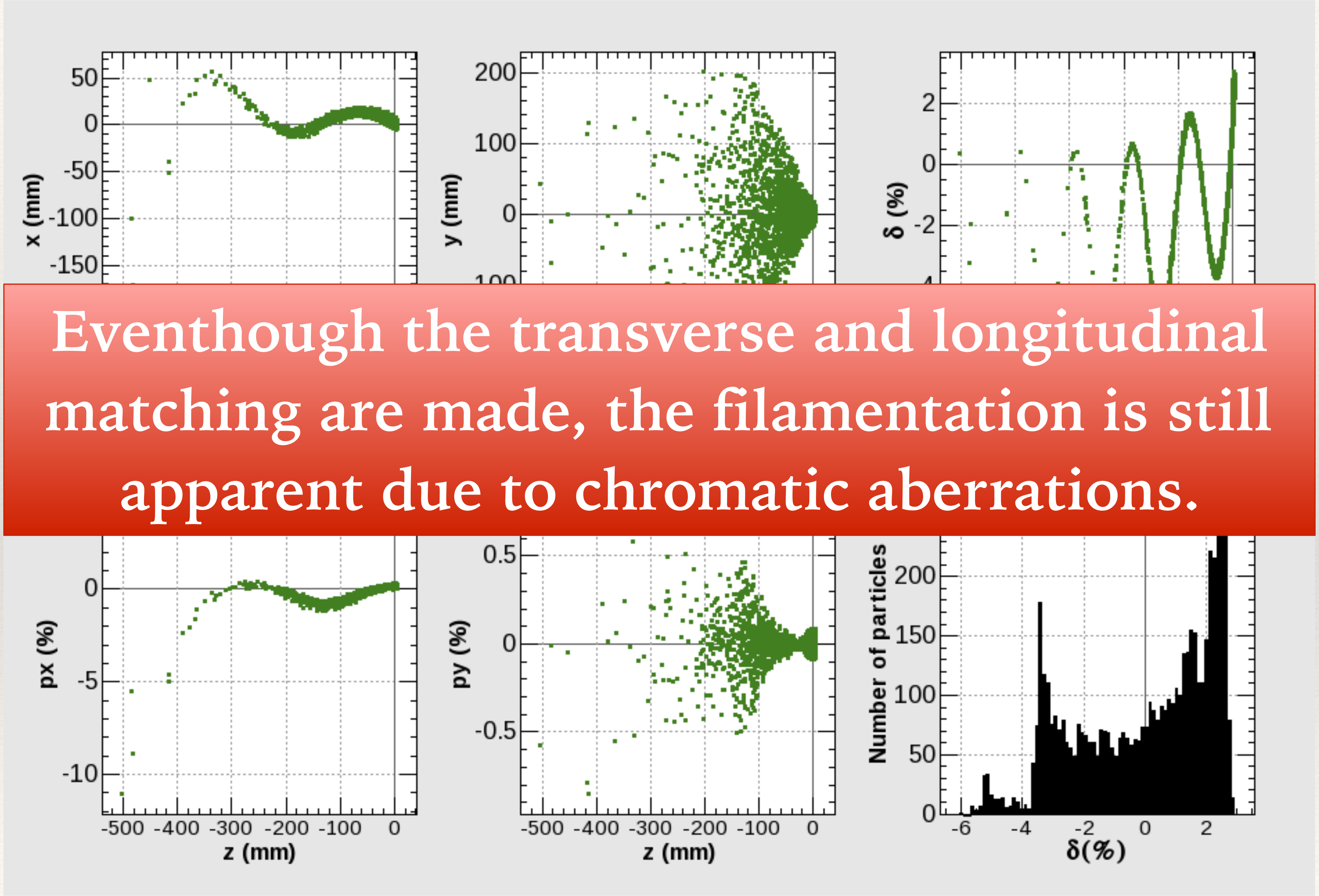
ECS - Results



ECS - Results



Eventhough the transverse and longitudinal matching are made, the filamentation is still apparent due to chromatic aberrations.

Domo Arigatou Gozaimasu

Back-up Slides

Injector Table with 20 GeV linac

- A case with an injection to the BR with 20 GeV linac, using Y. Papaphilippou's injector baseline table.

Linac Repetition [Hz]	200
Bunches per RF pulse*	2
Bunch Population **	1,70E+10
Linac Duty Factor [%]	94,5
BR Bunch charge **	1,70E+10
BR Number of Bunches	16640
BR Ramp time [sec]	2,4
BR Cycle Time [sec]	44
BR Number of Cycles	11
BR Duty Factor [%]	100,0
Collider Number of Bunches	16640
Collider Bunch Charge	1,87E+11
Collider Bunch Target Aim	1,70E+11
Transmission Target [%] >	90,9
BR cycle for both species [sec]	88
Collider Fill time full charge (e-&e+)	968
Collider Bunches	16640

Linac from 1.54 to 6 GeV

- Some results, including misalignment, misinjection, and misreading of BPMs, for different seeds using 1M macro-particles for Gaussian random beam:

Trial ID	Horizontal Emittance (nm)	Vertical Emittance (nm)	Transmission
1	2.7	2.3	100%
2	2.3	2.6	100%
3	1.1	0.8	100%
4	1.9	0.9	100%
5	0.6	1.5	100%
6	1.9	1.8	100%
7	1.3	3.6	100%
8	0.7	1.6	100%
9	3.0	4.9	99.4%
10	2.5	1.6	100%
11	0.7	0.6	100%
12	1.2	1.0	100%
AVERAGE	**1.7**	**1.9**	100%
IDEAL	**0.5**	**0.5**	**100%**