Recirculating Linacs (RLAs) and beam parameters at RLA-RCS transfer

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Collider Concept

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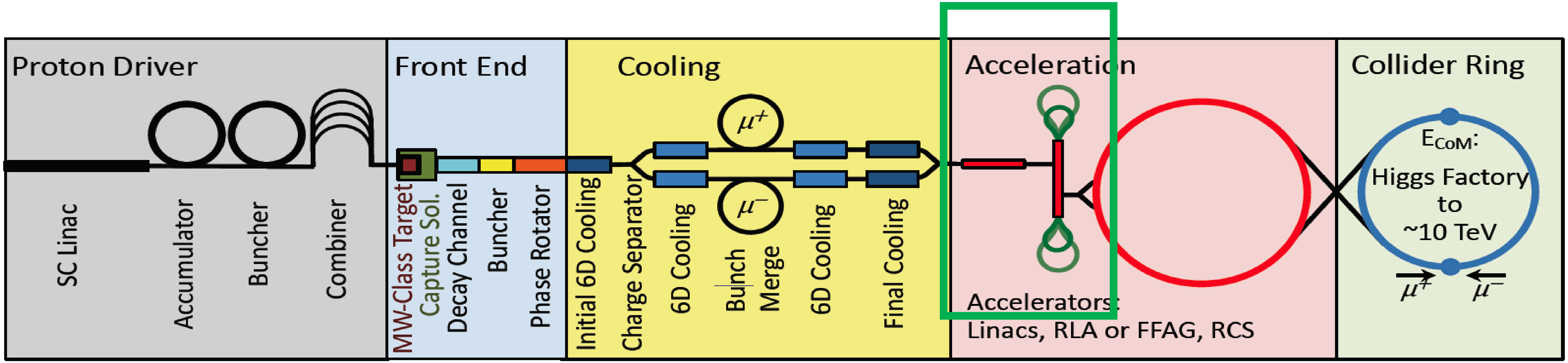
Collaboration

Acceleration
from 0.25 GeV to 63 GeV



Short, intense proton bunch

Protons produce pions which decay into muons, muons are captured

Ionisation cooling of muon in matter

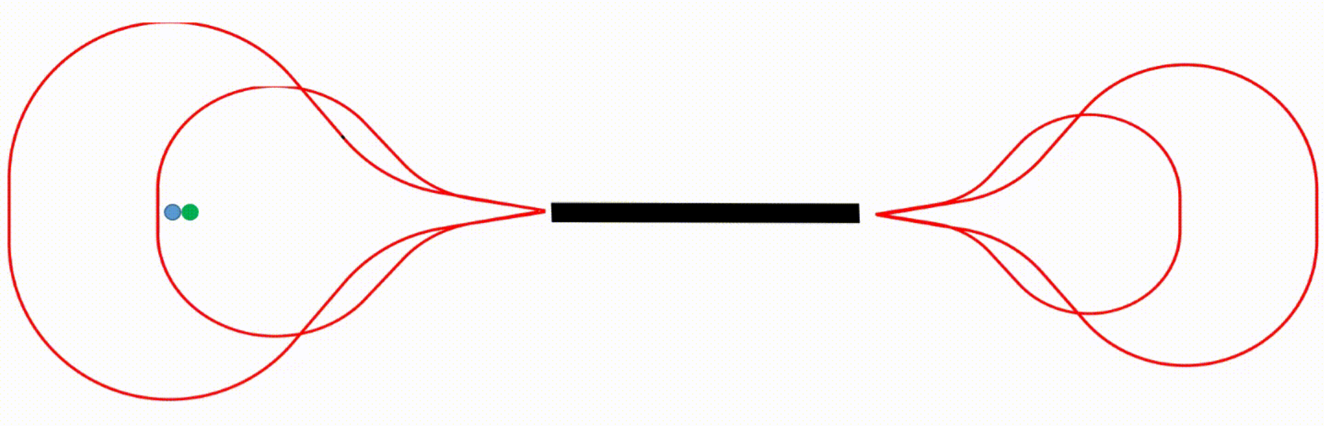
Acceleration to collision energy

Collision

Fully driven by muon lifetime

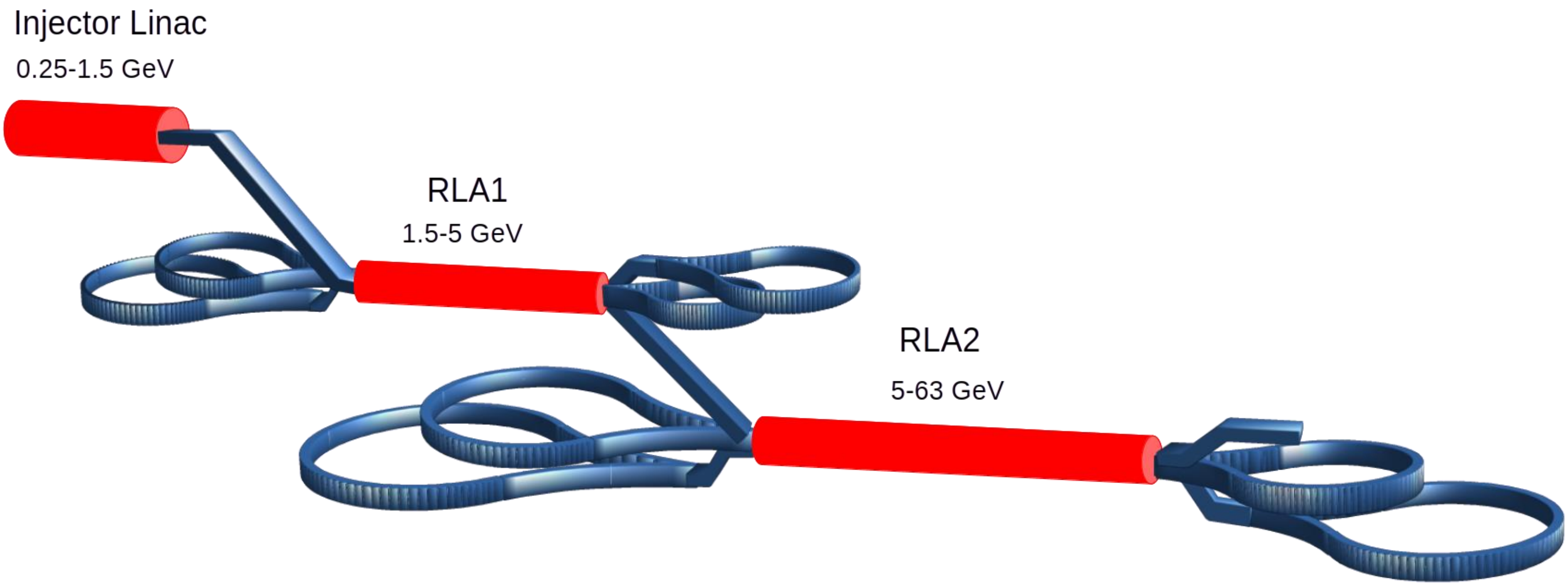
High efficient low cost acceleration for low energy Muons

- Well known acceleration scheme in literature is ‘dogbone’ RLA proposed for a future Neutrino Factory (Alex Bogacz)



- Single linac is used to accelerate consecutive μ- and μ+ bunches in one RF pulse with many passes
- Independent arcs due to large energy variation between passes..

Low Energy Acceleration Layout



Beam Parameters along the acceleration chain

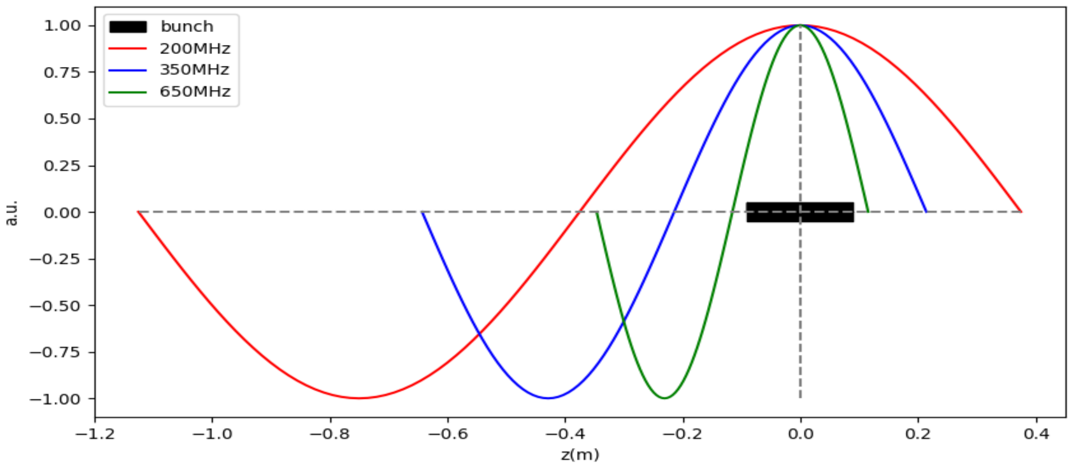
Parameter
Beam total energy
Muons/bunch
Longitudinal emittance
RMS bunch length
RMS rel. momentum spread
Transverse norm. emittance

- Very large energy spread
  - Chromatic aberrations by quadrupoles at low energy
- Both longitudinal and transverse emittance has to be preserved
  - Quasi-Isochronous arcs are necessary (with flexible momentum compaction)
- Two bunches with opposite charge
  - Good matching for both bunches (i.e. round beam at injection/extraction to arcs)
- Rapid acceleration
- …

- Very long bunch after final co
  - One can use induction linacs ir … tor 10.
- 10 % emittance growth in the transverse and longitudinal planes, both for 3 and 10 TeV.
  - Very tight tolerance with given longitudinal emittance!

Choice of RF frequency

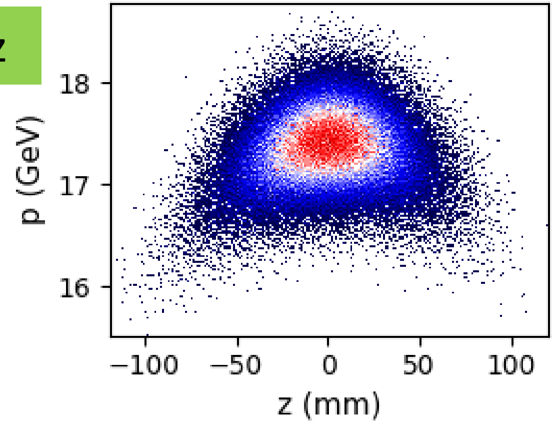
- If we have RMS ~ 30 mm Gaussian bunch → 200 mm full length
- Typically the total bunch length should be < 10% of λ_{RF}
- To preserve longitudinal emittance lower frequency is preferable



- Reasonable frequency would be SC 350 MHz cavity (LEP cavity)

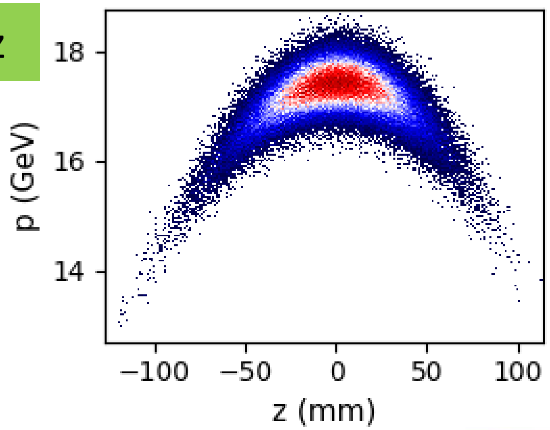
Parameter	Value
p_0 (GeV)	17.32
ε_z (mm.keV)	11.33
σ_z (mm)	30.12
σ_p (MeV)	378.04
$\Delta p/p_0$ (%)	2.18

200MHz



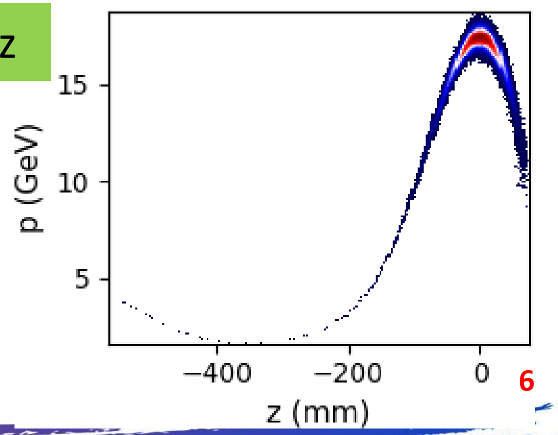
Parameter	Value
p_0 (GeV)	17.16
ε_z (mm.keV)	16.26
σ_z (mm)	30.12
σ_p (MeV)	543.24
$\Delta p/p_0$ (%)	3.17

350MHz



Parameter	Value
p_0 (GeV)	16.70
ε_z (mm.keV)	39.34
σ_z (mm)	30.01
σ_p (MeV)	1342.07
$\Delta p/p_0$ (%)	8.04

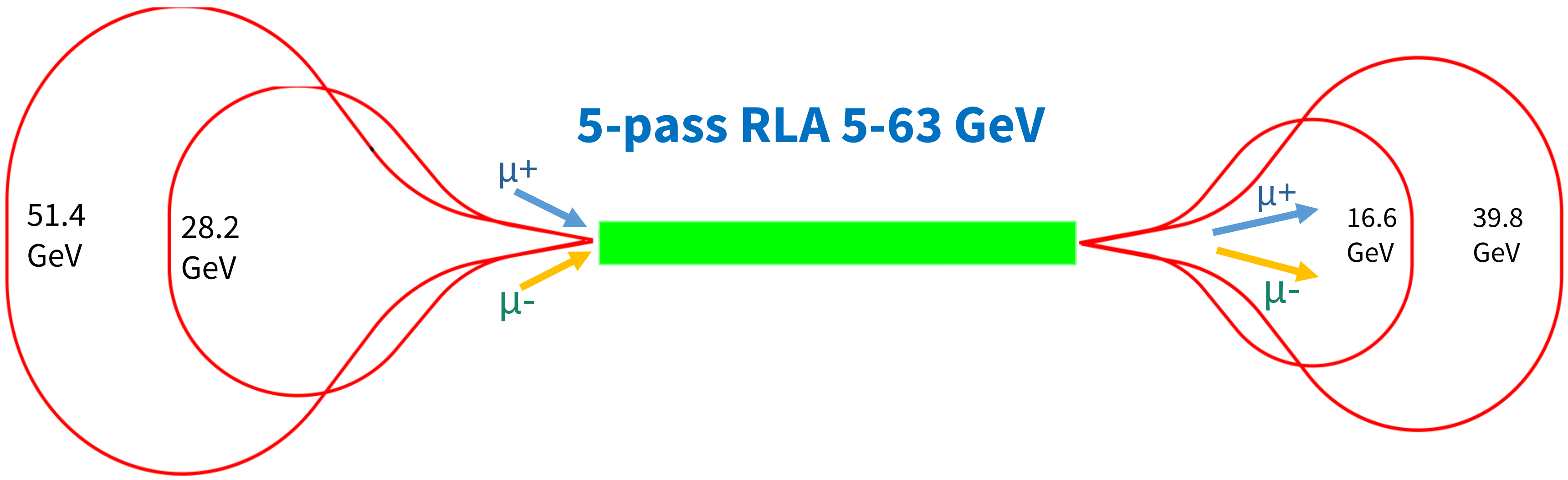
650MHz



Previous study

RLA2

- The goal is accelerating two bunches (μ+,μ-) spaced by λ_{RF} (n-1/2) from 5 to 63 GeV



- Energy gain : 11.6GeV / pass
- Total acceleration time ~25 μs
  - No RF parameters are possible to change within one RF pulse
- Minimum number of pulsed magnets
  - Preferred not to use any

Beam Dynamics in Linac

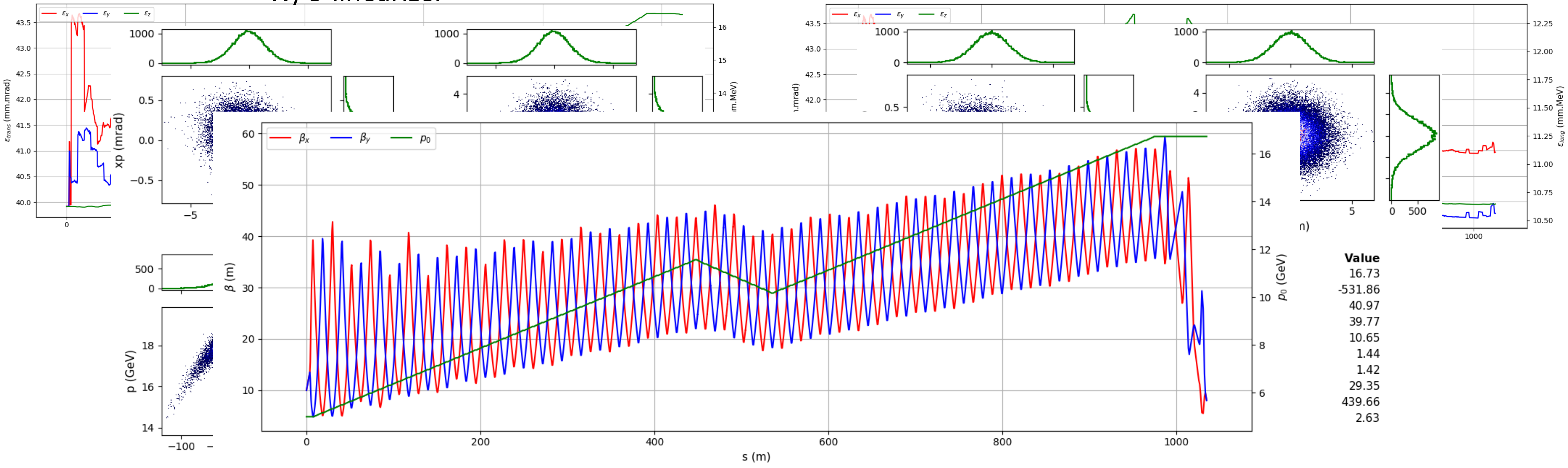
- Large initial energy spread causes emittance growth due to chromatic effects by quadrupoles
- We need to use weak quadrupoles to preserve emittance
  - Drawback: Sensitive to transverse wakefield effects

$$x = R_{11}x_0 + R_{12}x'_0 + T_{116}x_0\delta + T_{126}x'_0\delta \ldots$$

$$x' = R_{21}x_0 + R_{22}x'_0 + T_{216}x_0\delta + T_{226}x'_0\delta \ldots$$

W/O linearizer

With linearizer



Droplet Arcs

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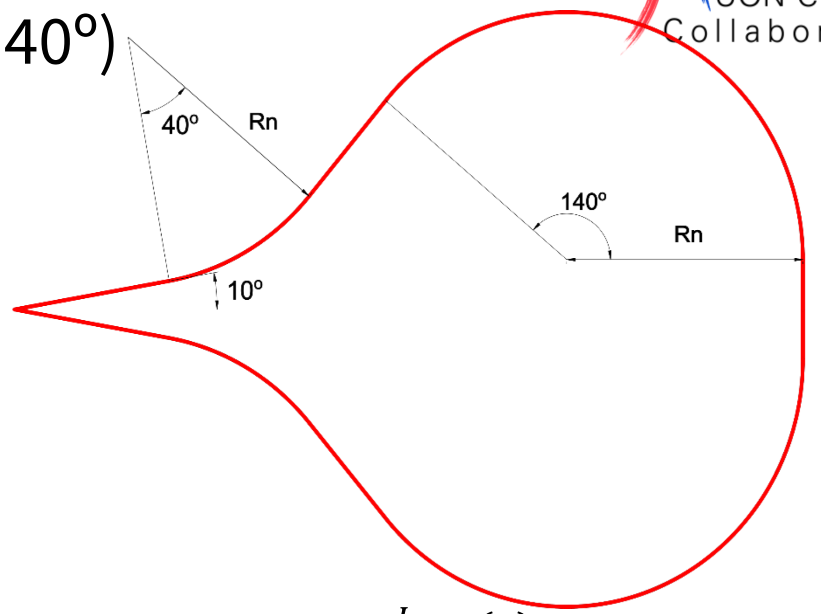
- Arcs consists of two symmetric sections (-50° and 140°) and total turn is 380°, net turn is 180°
- The curvature changes with energy
  - Large energy acceptance
    - we still have large energy spread at the exit of first pass
      - $\sigma_{\Delta p}$ ~ 500 MeV → $\sigma_{\Delta p/p}$ 3% (16.6 GeV ± 1.2 GeV)
  - Longitudinal emittance ≤≥ bunch length needs to be preserved/controlled
    - Small Momentum compaction factor ($R_{56} \approx L\, \alpha_c$)
  - We also need small dispersion in bending magnets to preserve transverse emittance
  - Small betatron oscillation to minimize chromaticity



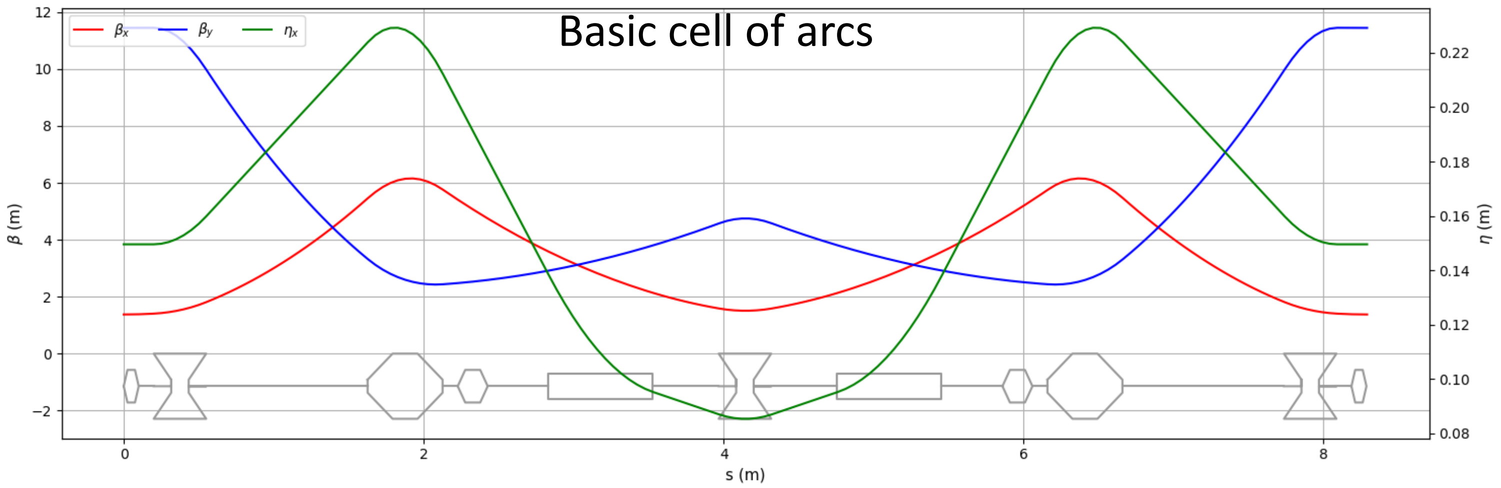
$$\alpha_c = \frac{1}{L_c}\int_0^{L_c} \frac{D(s)}{\rho} ds$$

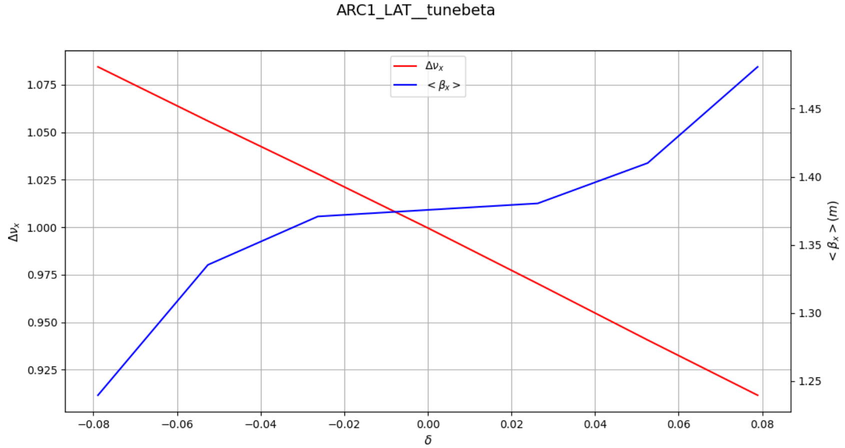
$$H = \gamma_x D_x^2 + 2\alpha_x D_x D_x' + \beta D_x'^2$$

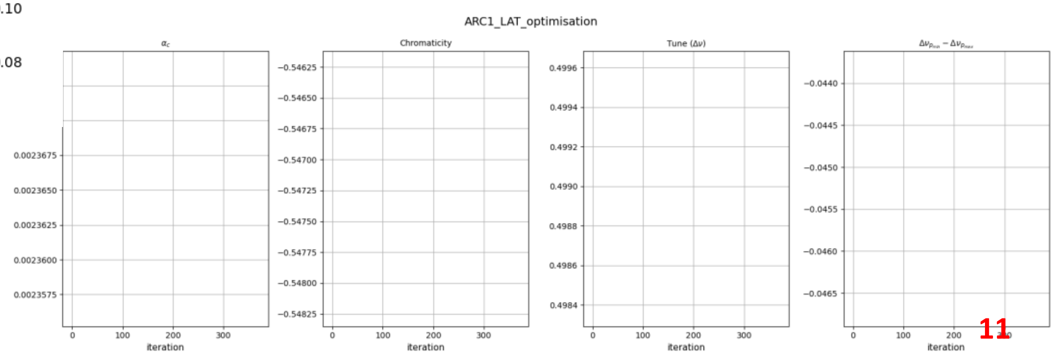
$$\xi = -\frac{1}{4\pi}\oint k(s)\beta(s)ds$$

Basic arc cell

- Different lattice configuration has been studied
  - FODO, Triplet. TME : The sign of R_{56} is fixed. Control of bunch length can be done only with RF.
- DB(A) lattice allows to control R_{56} with quadrupole strength as well as the chromaticity
- To optimize individual arcs a tool (based on second order optics and tracking) has been developed



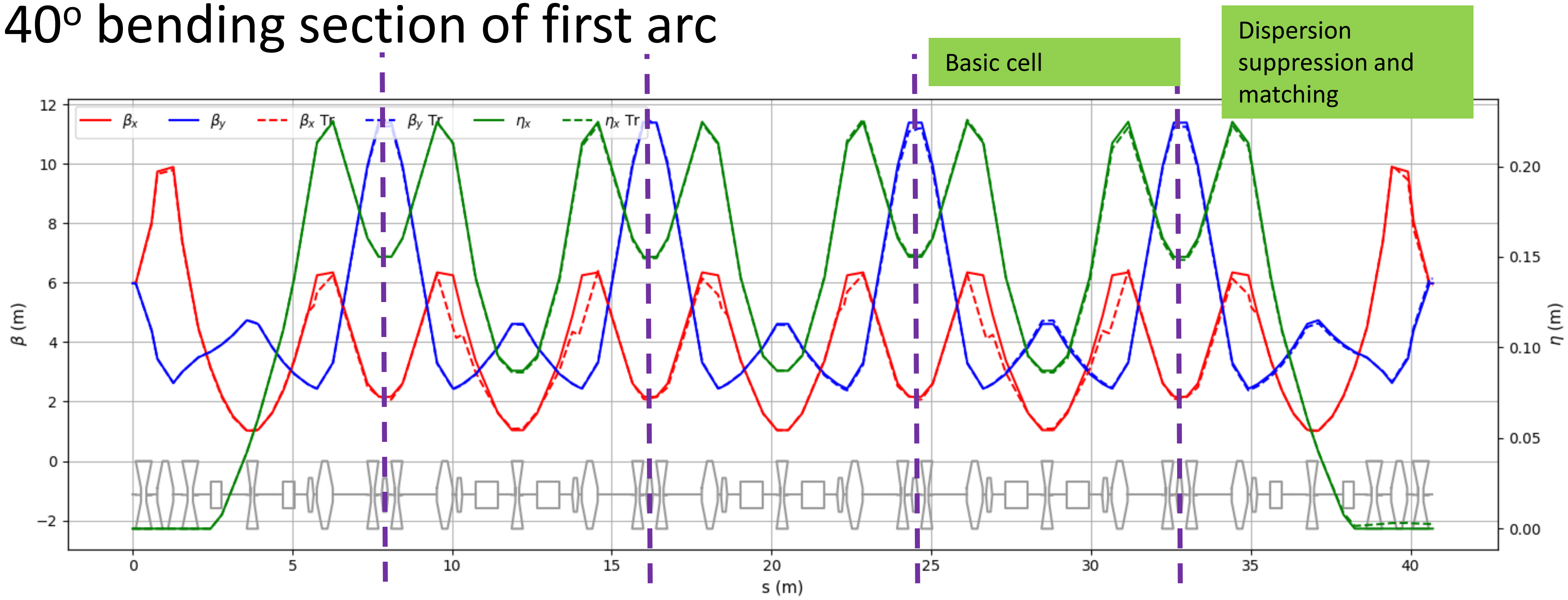


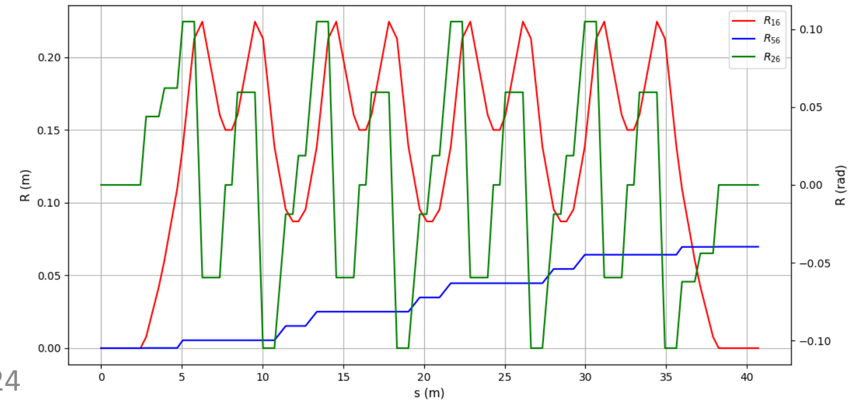


Bending angle/cell =10°
B_{max} =7T
Aperture =50mm

Arc Lattices

- 40º bending section of first arc



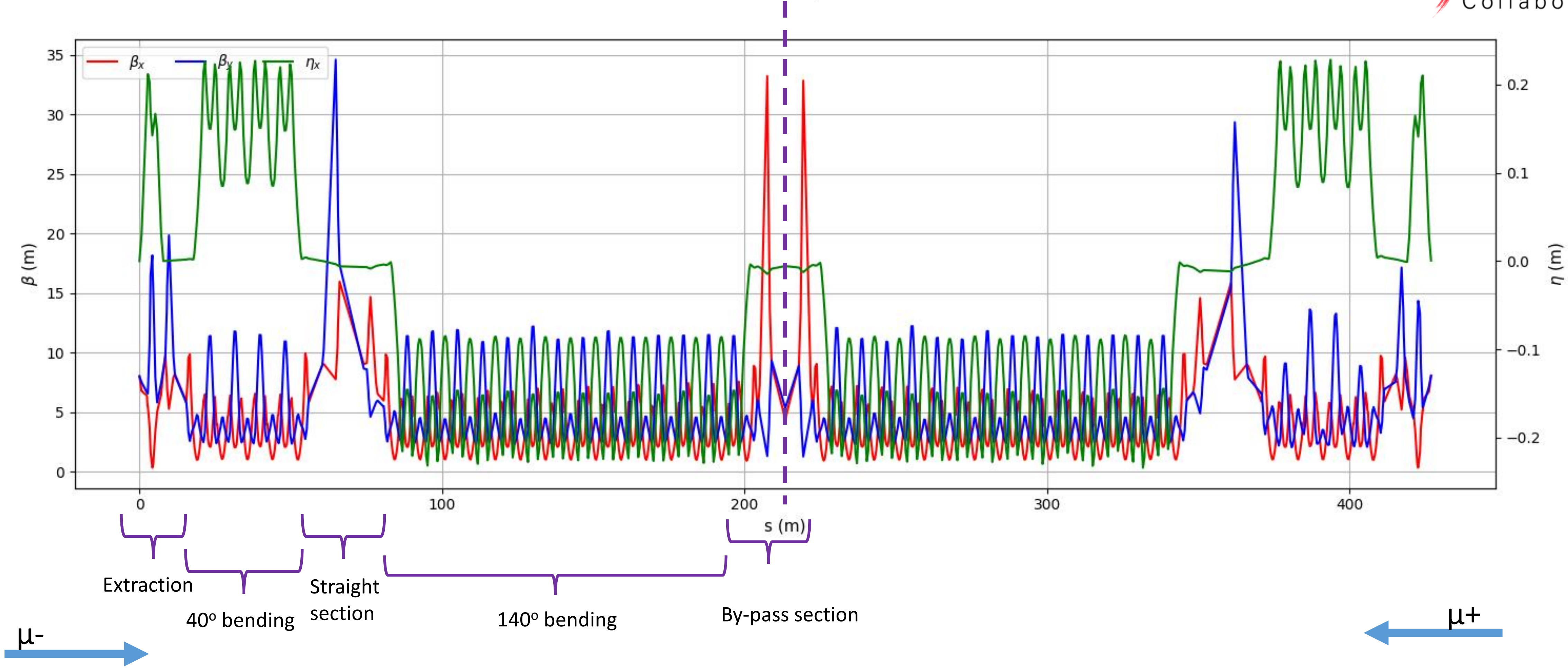


Dispersion is suppressed with half bending angle

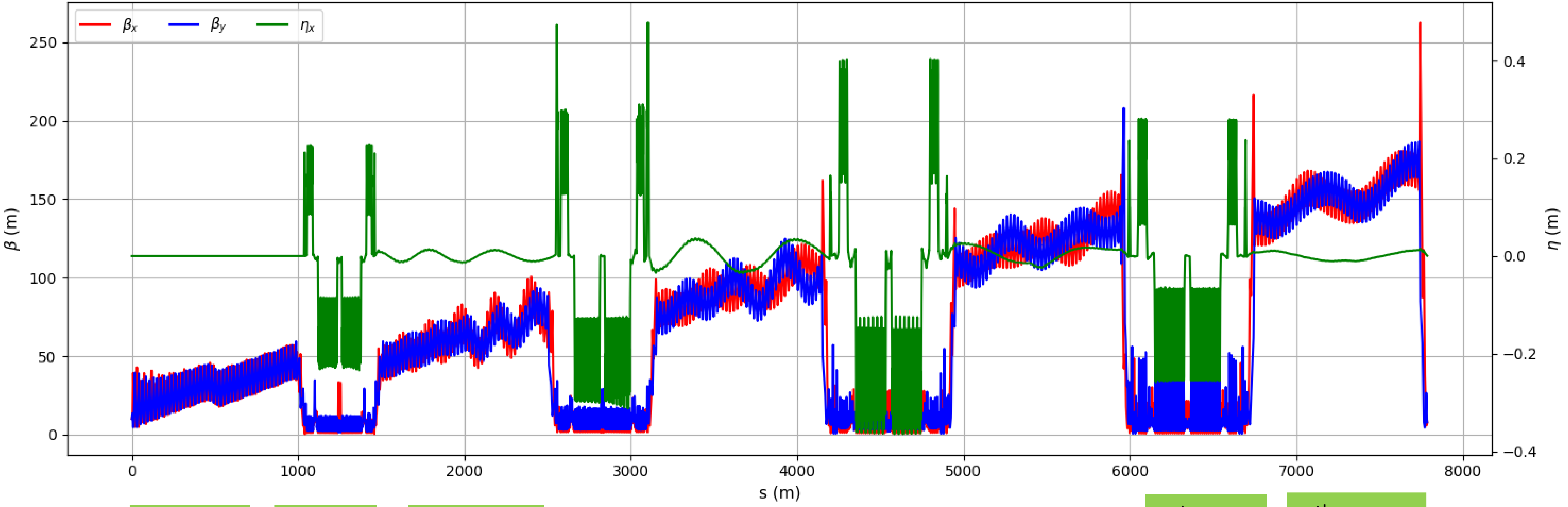
Sextupoles are optimized with second order optics.

Beam dynamics in arcs

- Start to end simulation in first arc (tracking)

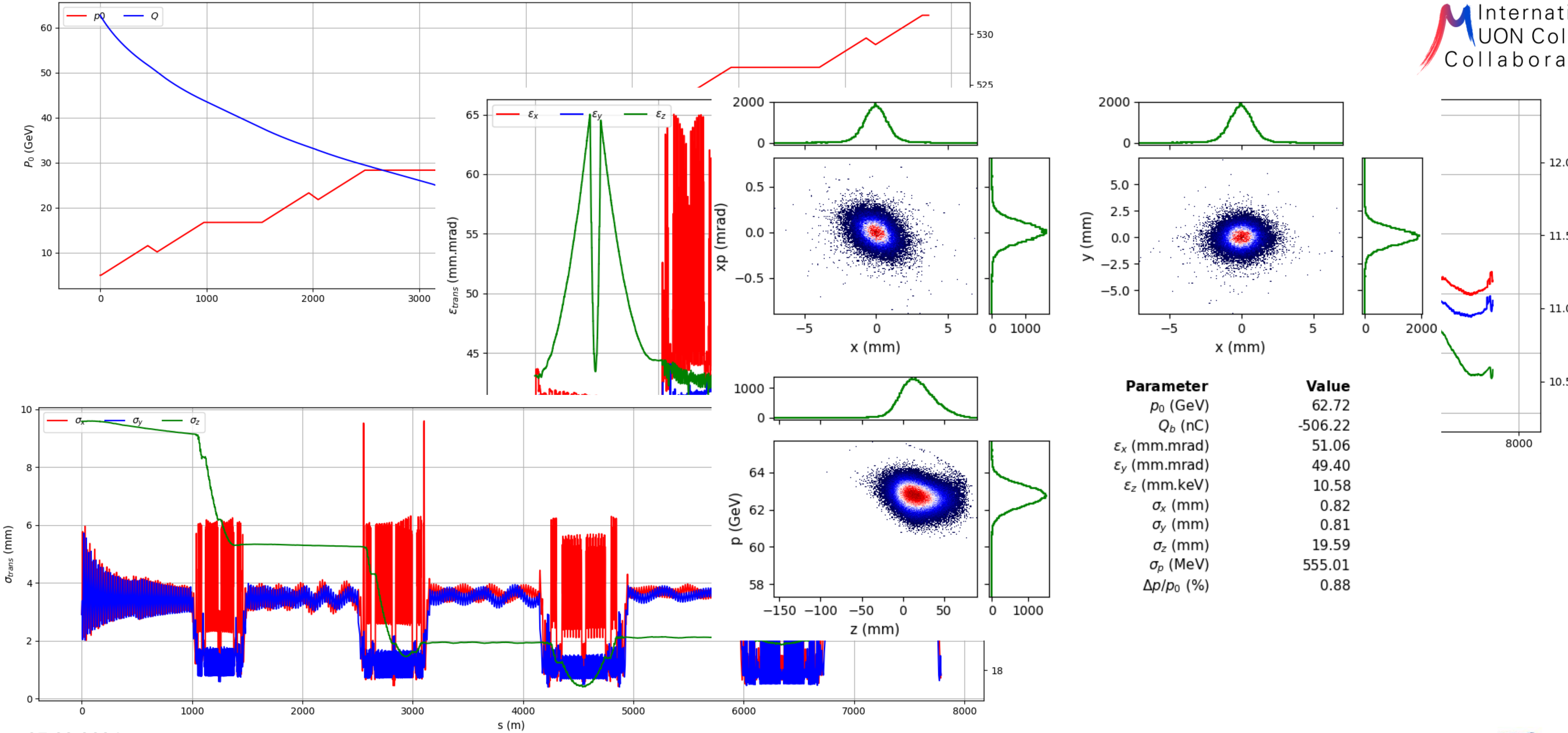


Start to end RLA2



1st pass | 1st arc | 2nd pass | .... | 4th arc | 5th pass

Start to end simulation for RLA2



Parameter	Value
p_0 (GeV)	62.72
Q_b (nC)	-506.22
ϵ_x (mm.mrad)	51.06
ϵ_y (mm.mrad)	49.40
ϵ_z (mm.keV)	10.58
σ_x (mm)	0.82
σ_y (mm)	0.81
σ_z (mm)	19.59
σ_p (MeV)	555.01
$\Delta p/p_0$ (%)	0.88

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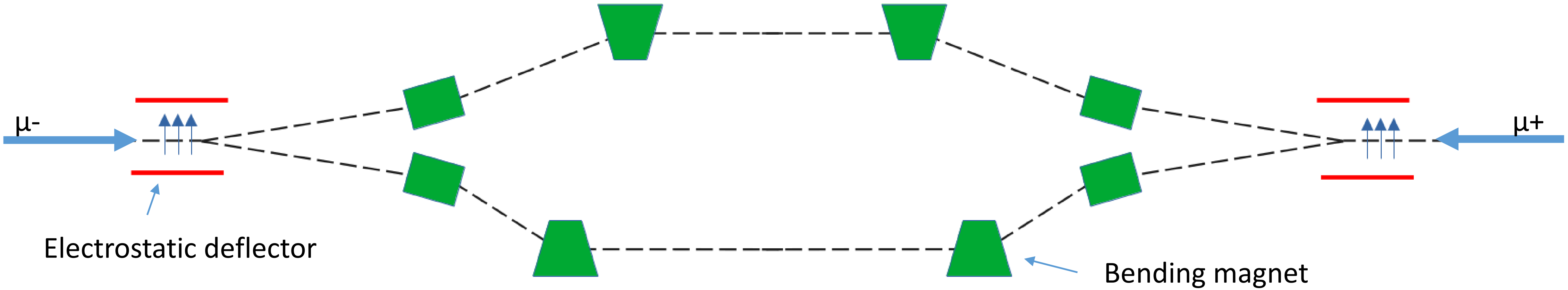
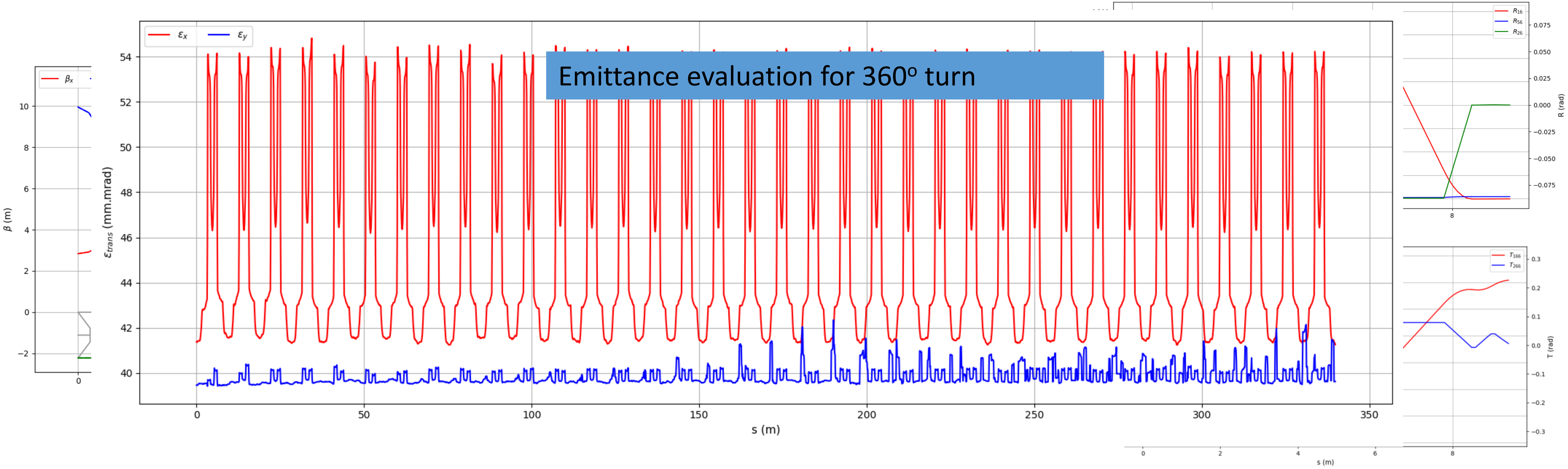
By-pass section

- The phase of beam respect to RF is defined by the arc length.
  - 1 degree RF phase (@350 MHz) is 2.4 mm (0.85 mm for 1 GHz)
- If the beam is injected off-energy to the arc it is impossible to adjust path length within ± several mm
  - Which is unlikely possible due to beam loading
- A chicane is necessary to adjust path length precisely
  - It can also be used to exchange of position of preceding/following bunch



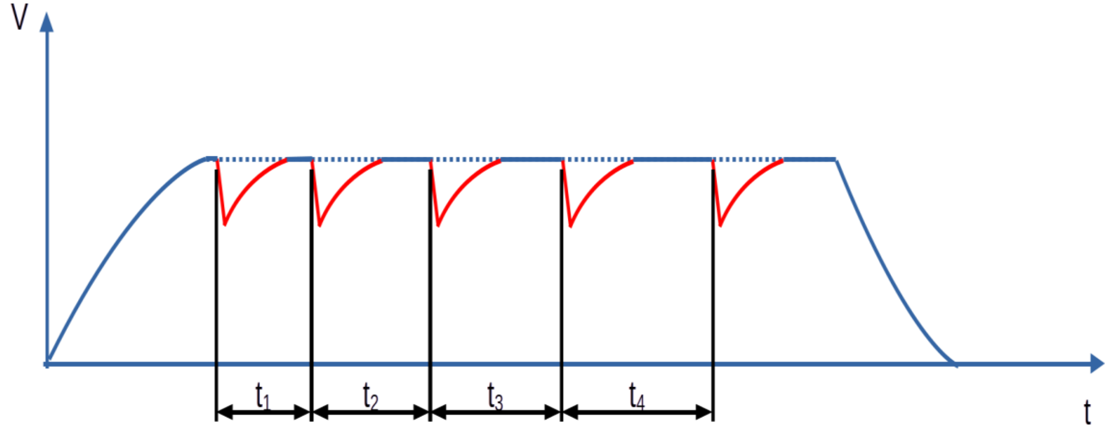
New DBA Lattice for Arcs

- Strong high order effects due to large energy spread
  - $x_1 = R_{11}\, x_0 + R_{12}\, x'_0 + R_{16}\, \delta_0 + T_{116}\, x_0\delta_0 + T_{126}\, x'_0\delta_0 + T_{166}\, x_0\delta_0^2 + \cdots$
  - $x'_1 = R_{21}\, x_0 + R_{22}\, x'_0 + R_{26}\, \delta_0 + T_{216}\, x_0\delta_0 + T_{226}\, x'_0\delta_0 + T_{266}\, x_0\delta_0^2 + \cdots$
- Nonlinear optimization based on tracking to minimize higher terms (dispersion + chromaticity + ..)
  - Thanks to Andrea



Questions

- Simulation results:
  - σ_z= 20 mm, δ_p= 0.9%
  - What is the requirement for RCS1? (In the tentative parameters it was OK)
- Is there any proposal for injection to RCS?
- Beam loading;
  - $\Delta G = \frac{\left(R/Q\right)\omega_{RF}}{2} Q \approx 70$ keV/structure → 22.5 MeV energy difference between bunches at the end of linac for single pass.
  - What about the second pass?
- It seems we need to use inductive linac after cooling..
  - Any proposal for the design?
  - What is the average gradient for such structure?



Thanks for your attention