CLIC
Frequency Multiplication System
aka Combiner Rings

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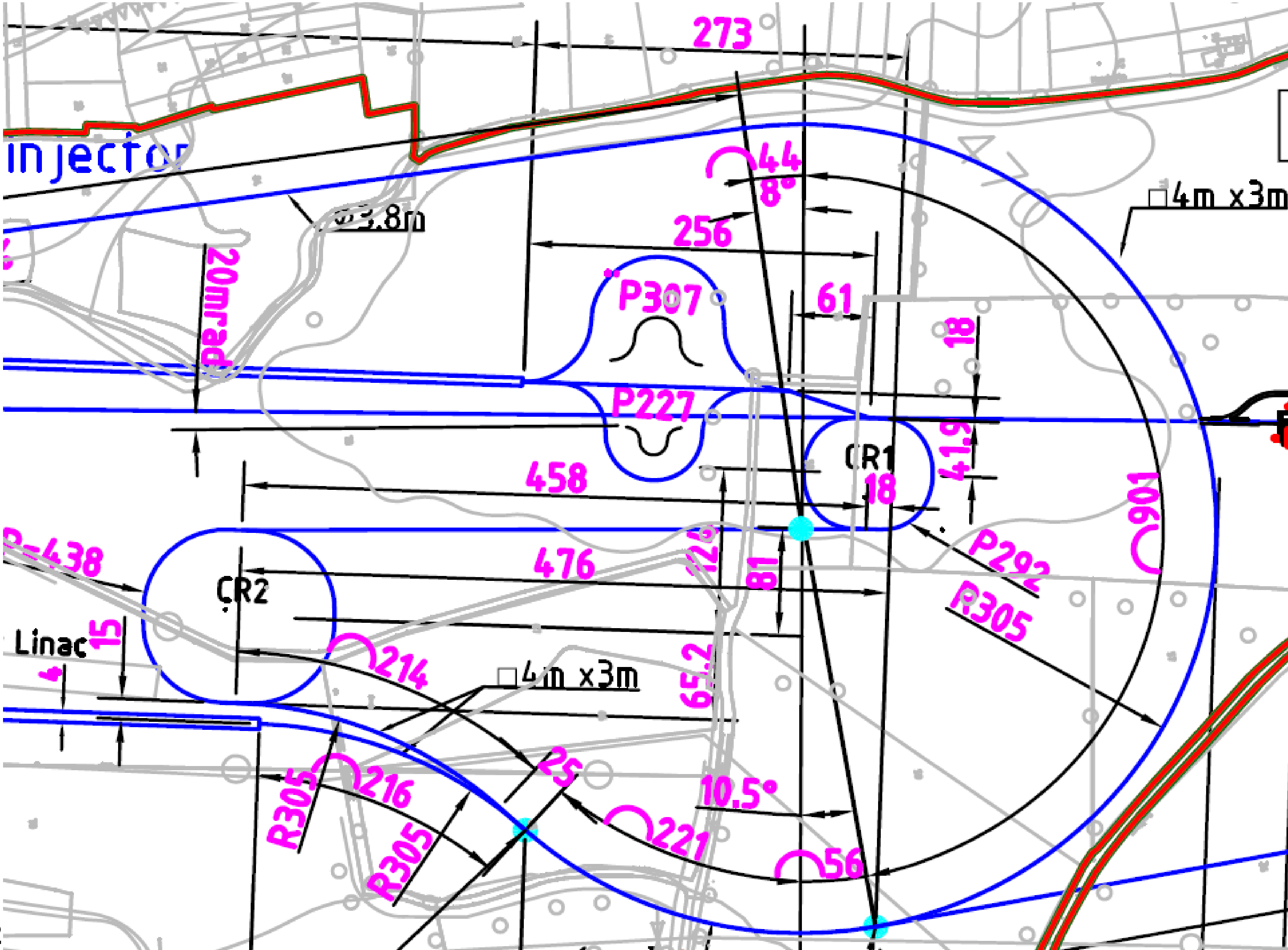
Sketch of layout



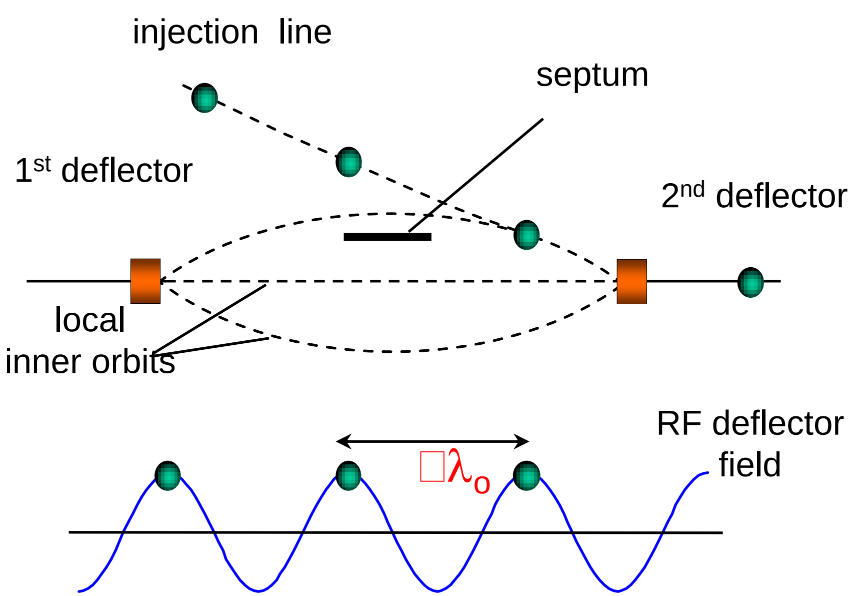
The Layout

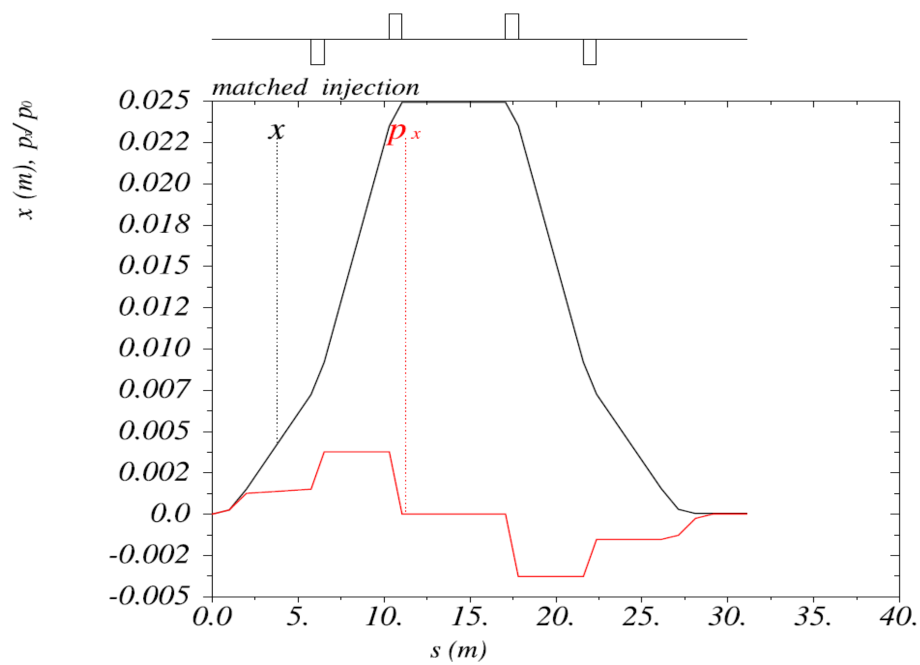
FMS Requirements

- Preservation of bunch length not depending on a particular bunch pathway
  - It implies that each segment must be **isochronous**
- Output emittance can not be bigger then 150μm·rad
  - Assumed input 130μm·rad (normalized)
  - Implies optimization of chromaticity and non-linear effects
- All above with large energy spread
  - At the moment 2% is assumed
    - Worst case scenario
  - The goal is to find a design with maximum acceptances

Requirements for rings optics

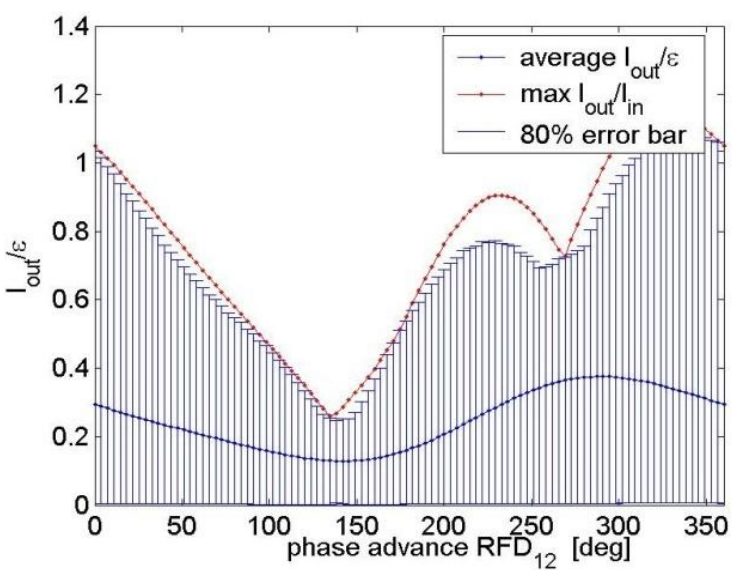
- The key component is time variable bump made with RF deflectors
  - The horizontal phase advance between RF deflectors is $\mu_x = 180$
  - The RF bump offset at injection should be 2.5 0.5 cm.
  - RF deflector kick should be as low as possible
  - Dispersion should be closed

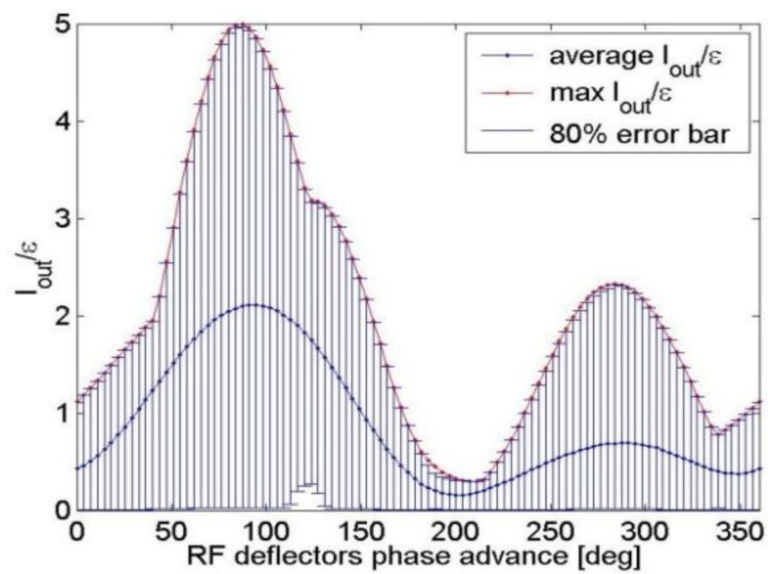




Requirements for Rings optics

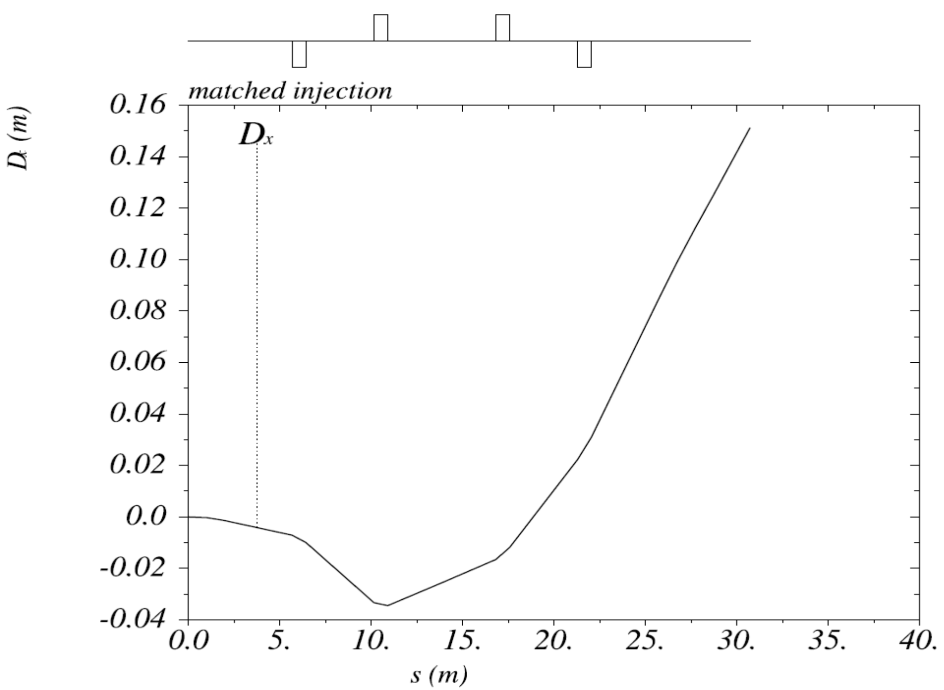
- In order to limit potential emittance growth due to wake fields in the RF deflectors
  - Beam size should be kept as smaller as possible inside RF deflector
    - Preferably below 2 m.
  - Tunes in both planes shall be around 0.6 0.04

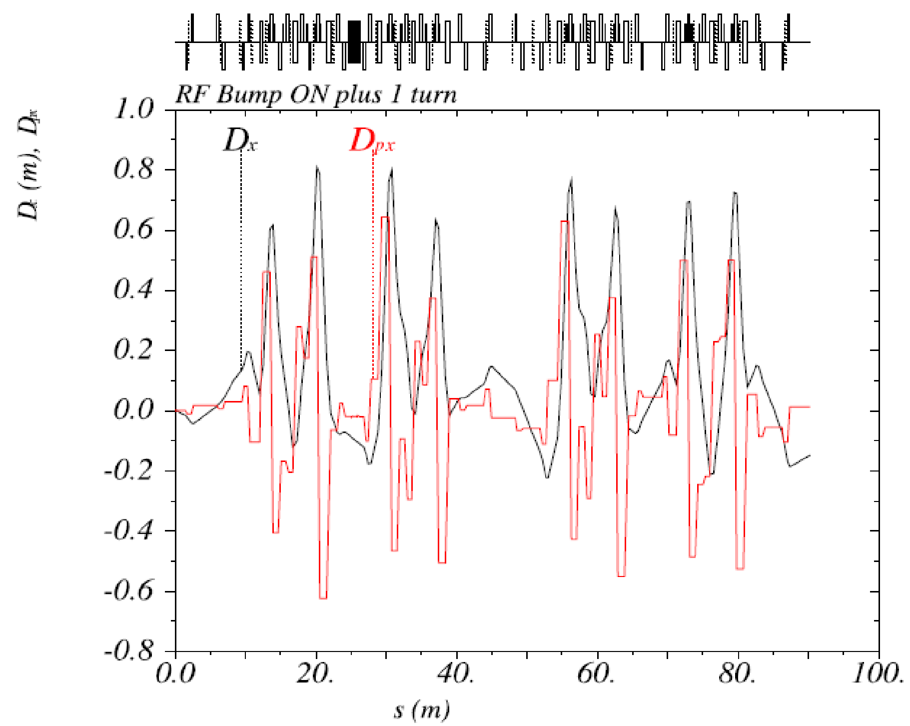




Dispersion in RF bump

- The CTF's RF bump has not closed dispersion
  - In such configuration it can not be closed
  - It creates dispersion wave on the last turn



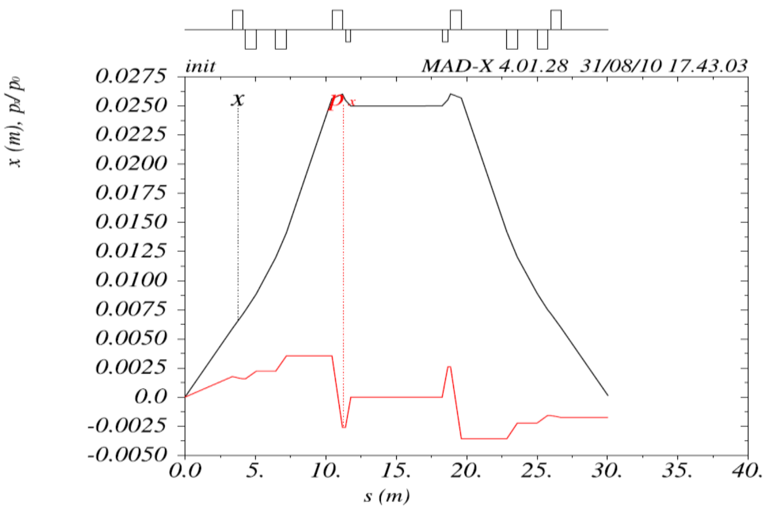


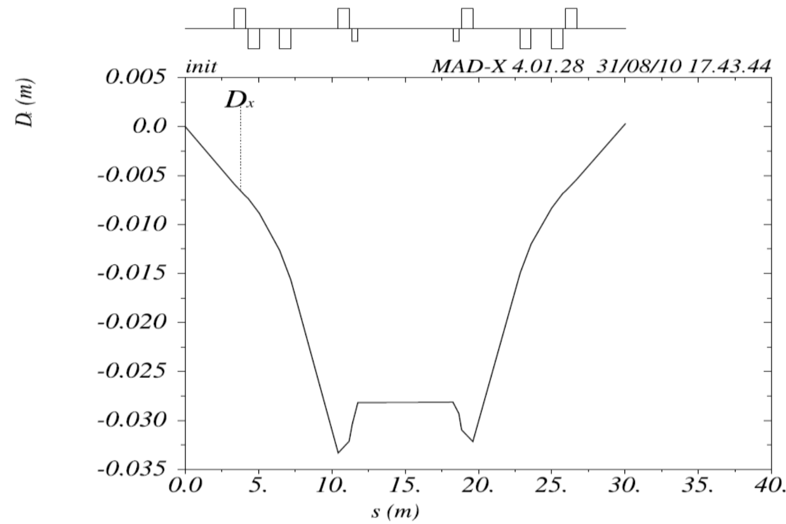
Dispersion in RF bump

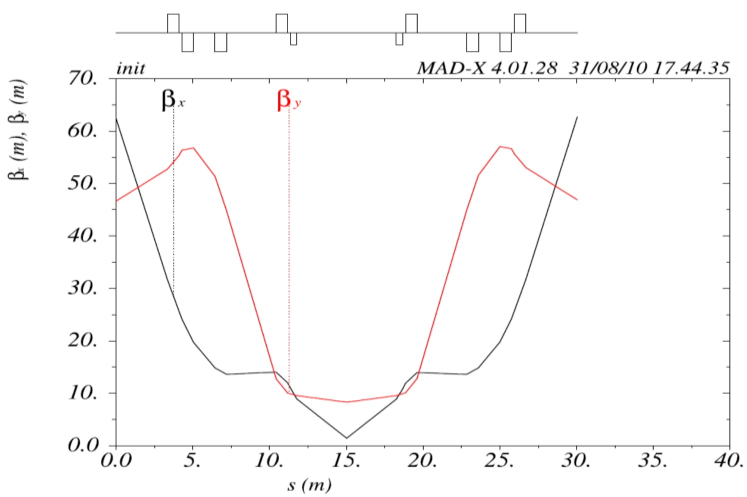
- **Solution**: use sextupoles inside the bump
- **Drawback**: phase advance changes with the amplitude of the bump
  - For "bump off" configuration it is not 180 deg anymore
    - the kick along the bunch is not automatically compensated by the second RF deflector

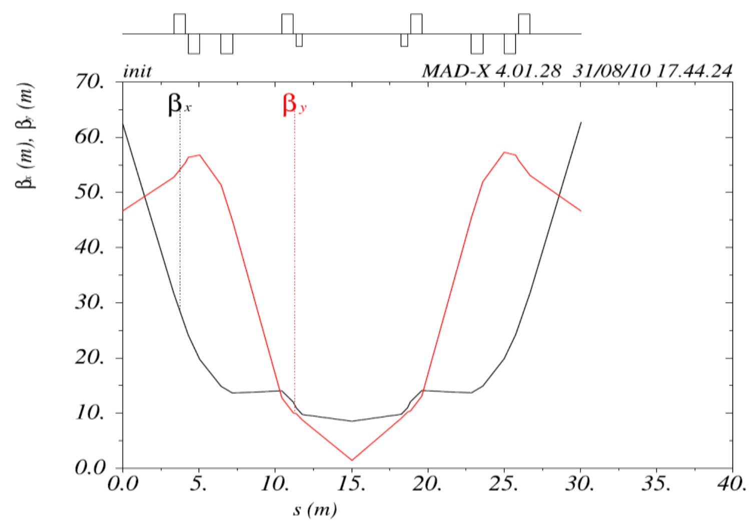
Dispersion in RF bump

- **Solution:** use sextupoles inside the bump



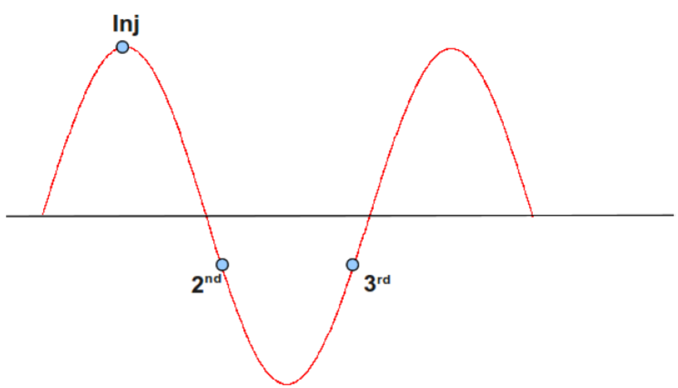


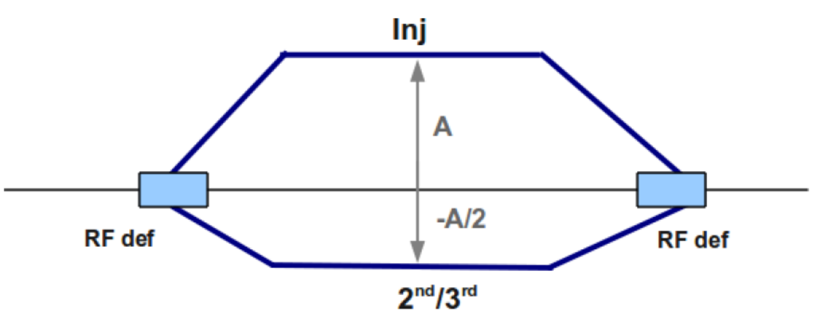


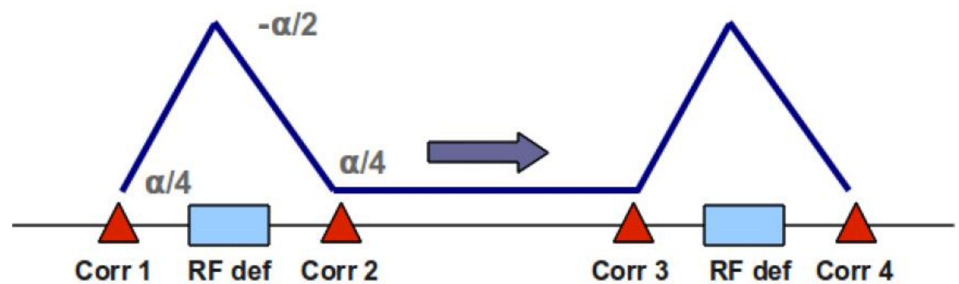


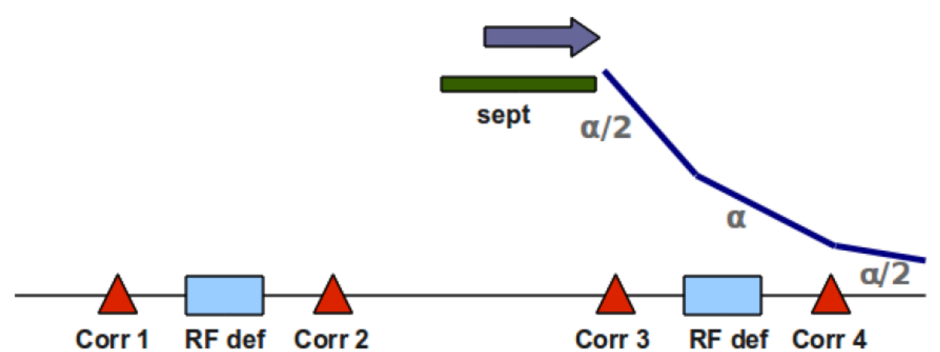
Dispersion in RF bump

- For CR1, which recombines factor 3 there exists another solution: static correctors around each of the RF deflectors
  - Close dispersion the orbit locally
  - Help to at injection so the RF deflector kick can be reduced



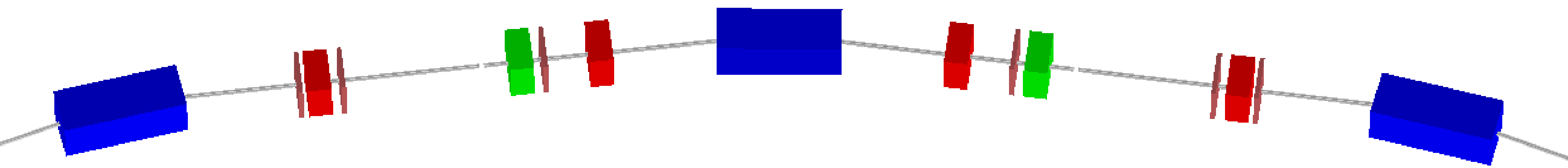




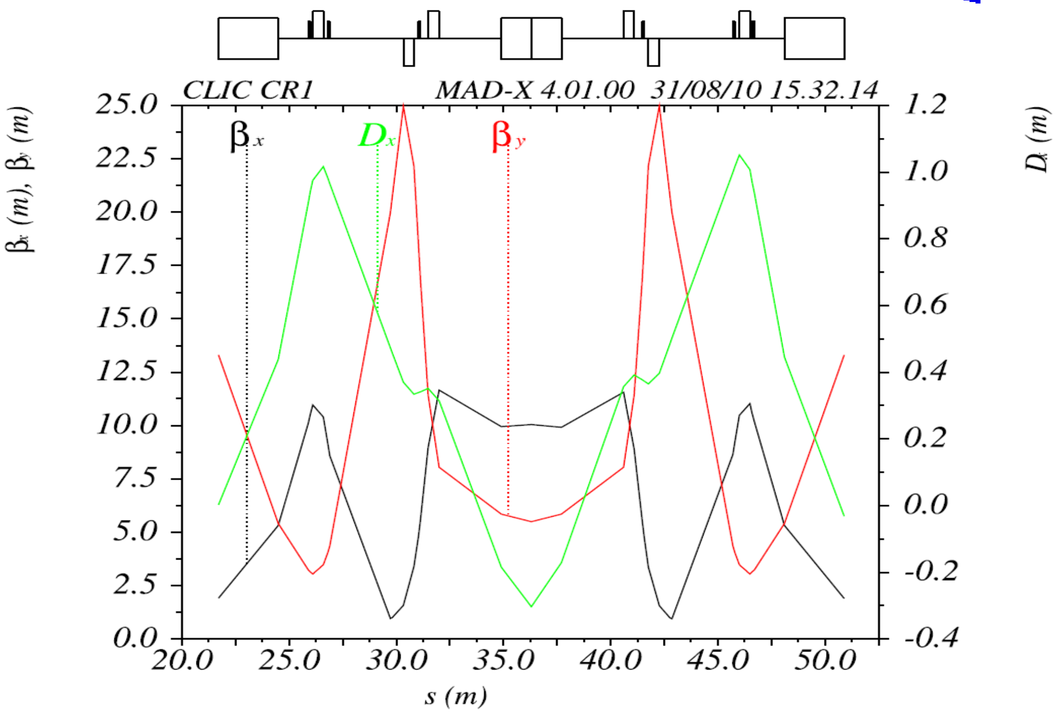


Three Bend Achromat

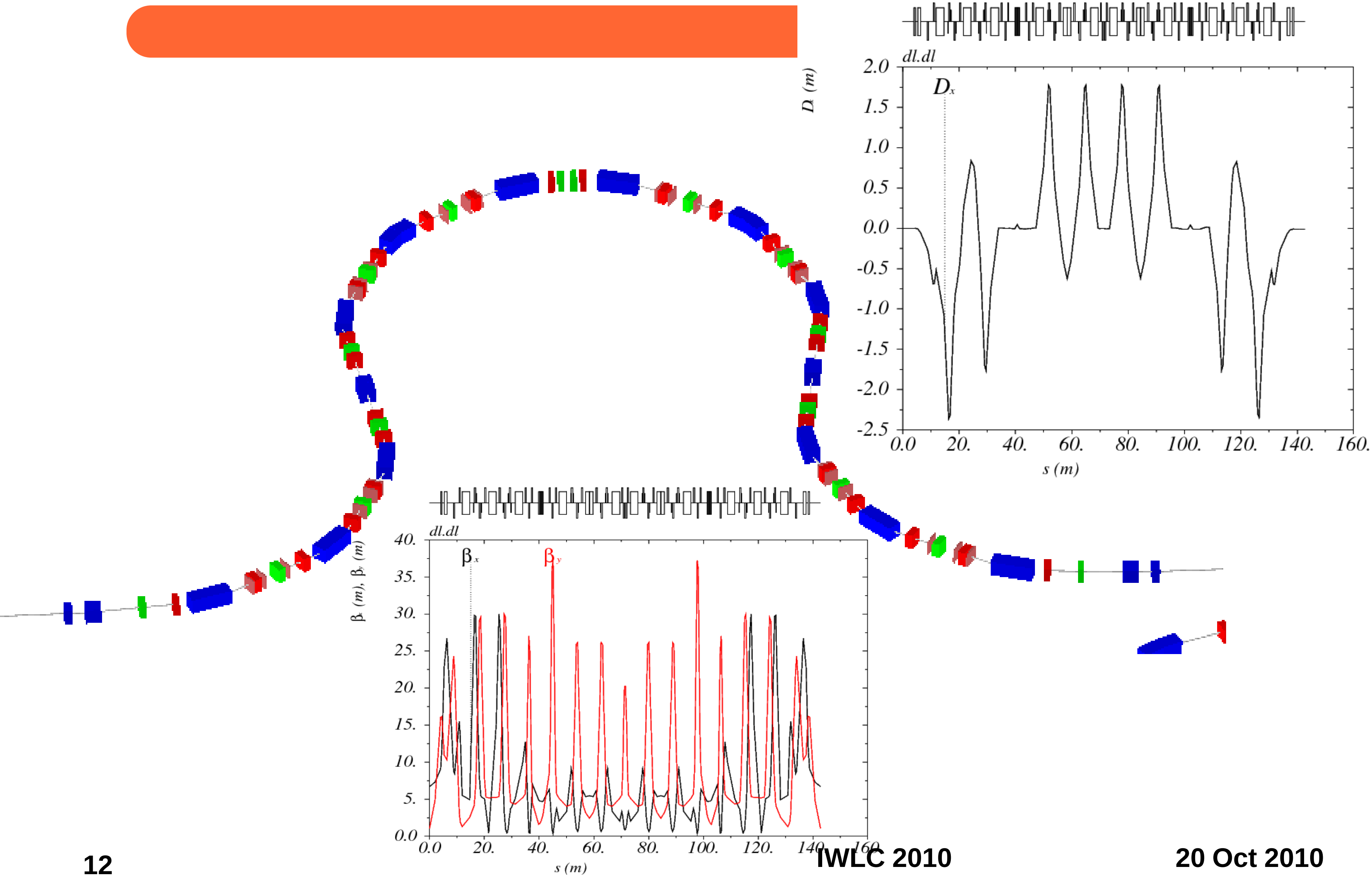
- All lines are based on Three Bend Achromat



- R_{56}=0, i.e. isochrounous
- Quite stable under small errors
- Robust for tuning



Delay Loop



Combiner Ring 1

$L = 292$ m

$N_{dipoles} = 18$

Angle = $20°$

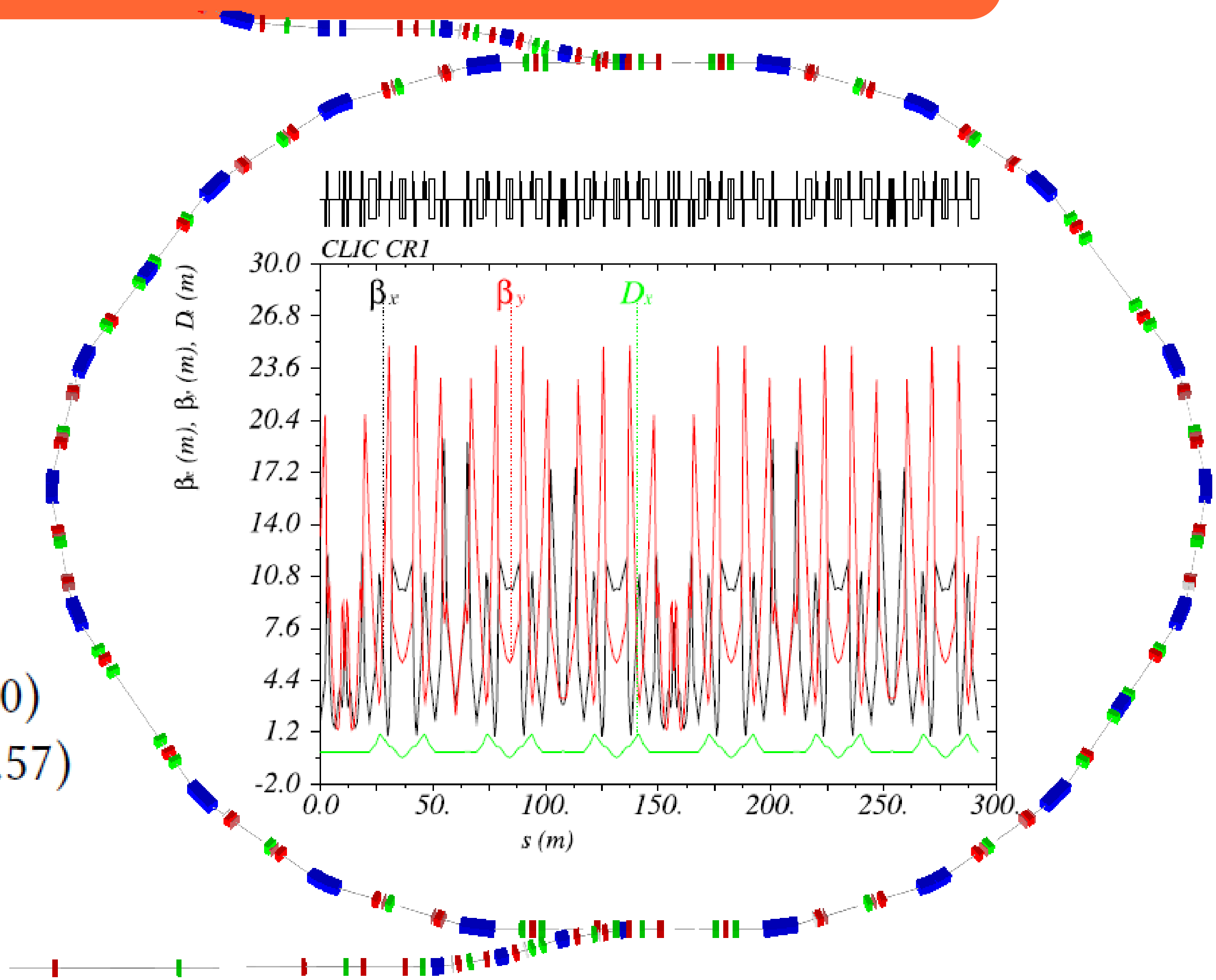
$\beta_{x,max} = 19.3$ m

$\beta_{y,max} = 25.0$ m

$R_{56} = 0.0044$

$(Q_x,Q_y)=(12.64,7.60)$

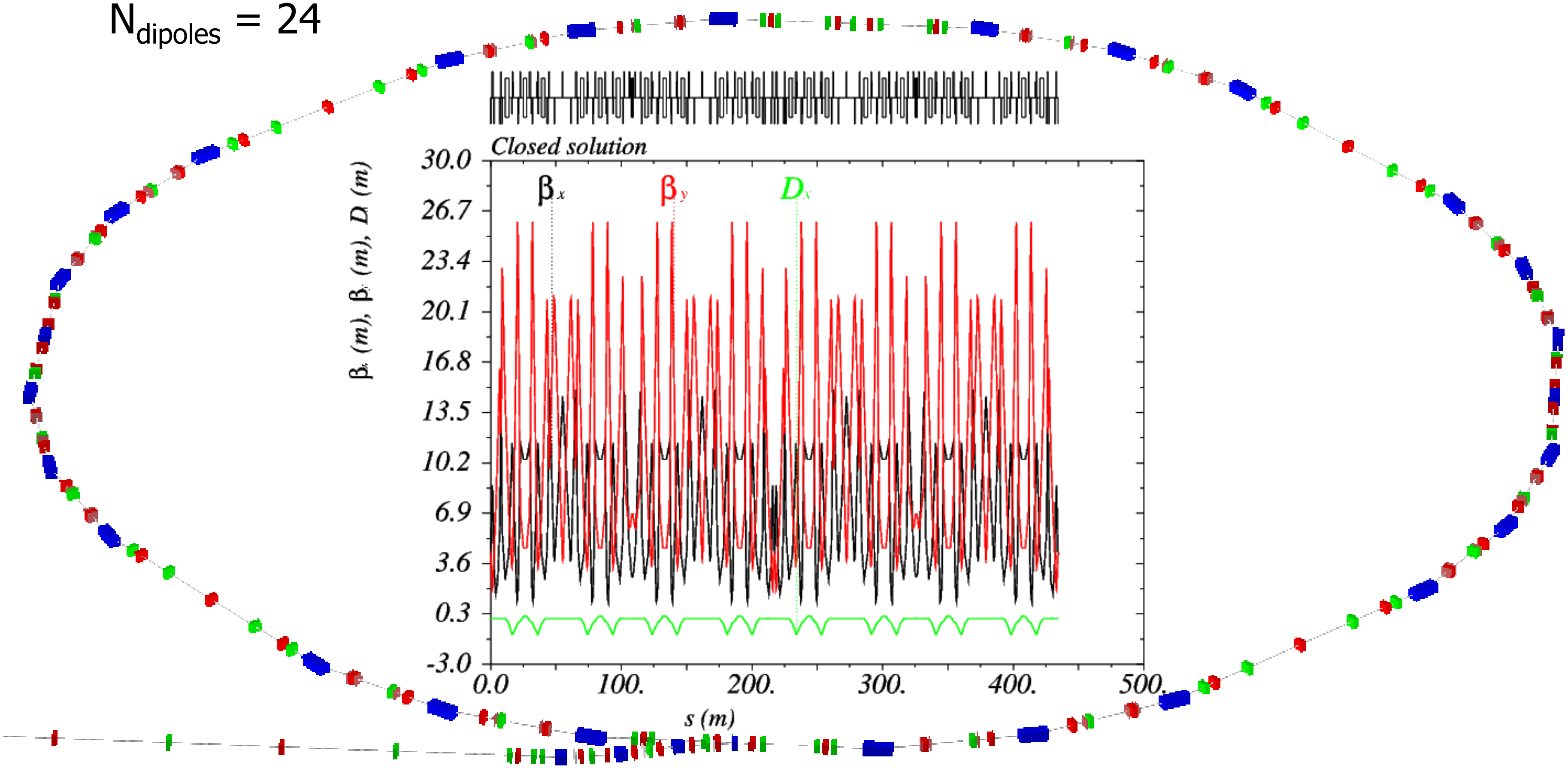
$(\xi_x,\xi_y)=(-18.87,-17.57)$

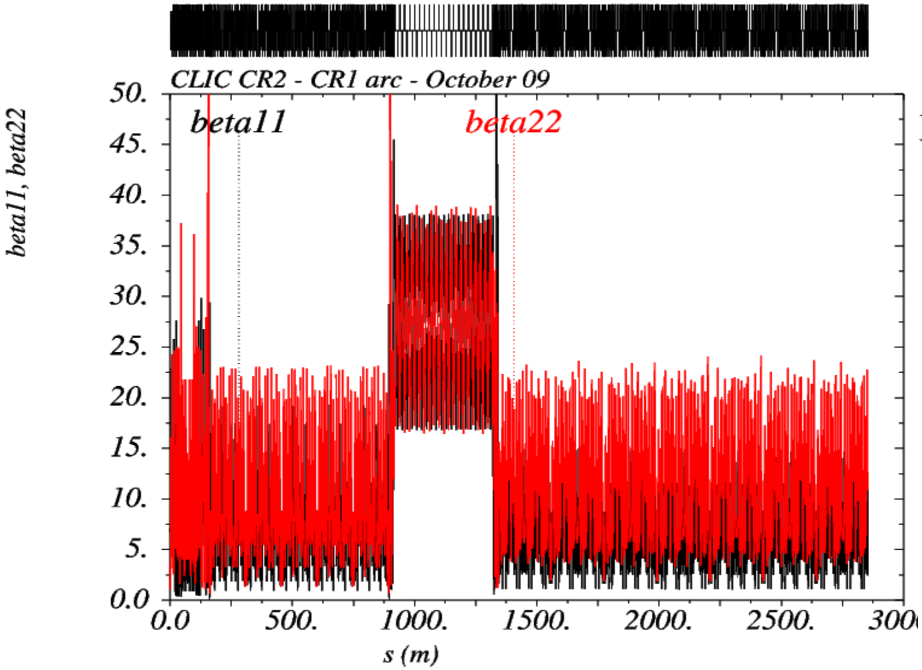


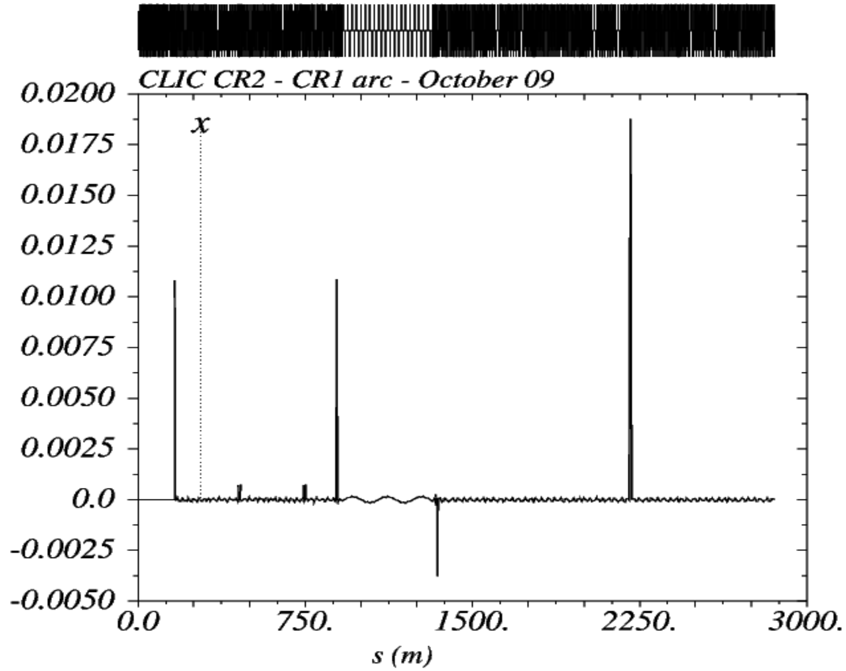
Combiner Ring 2

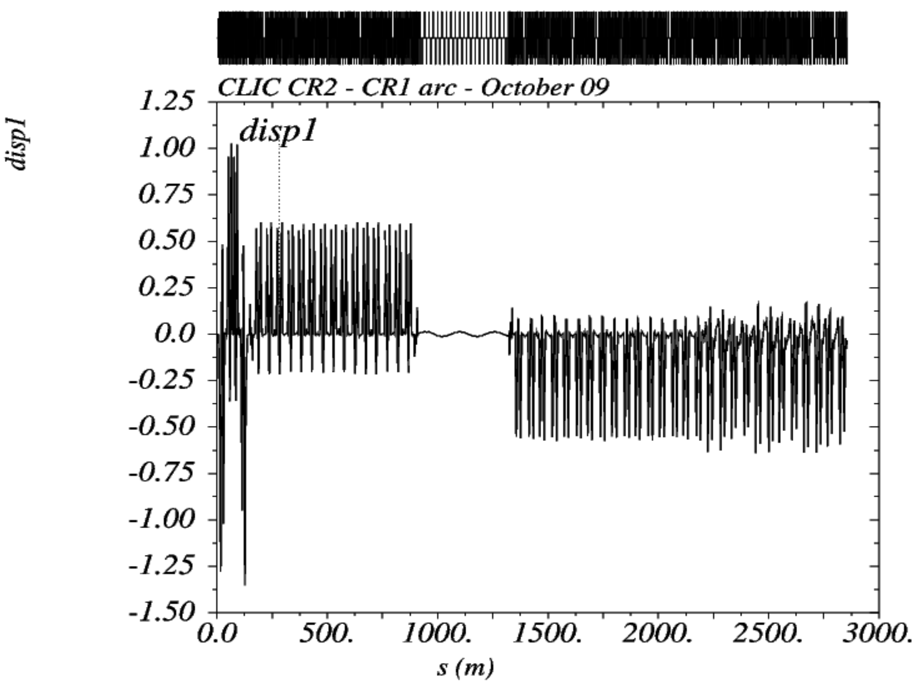
L=434.36m

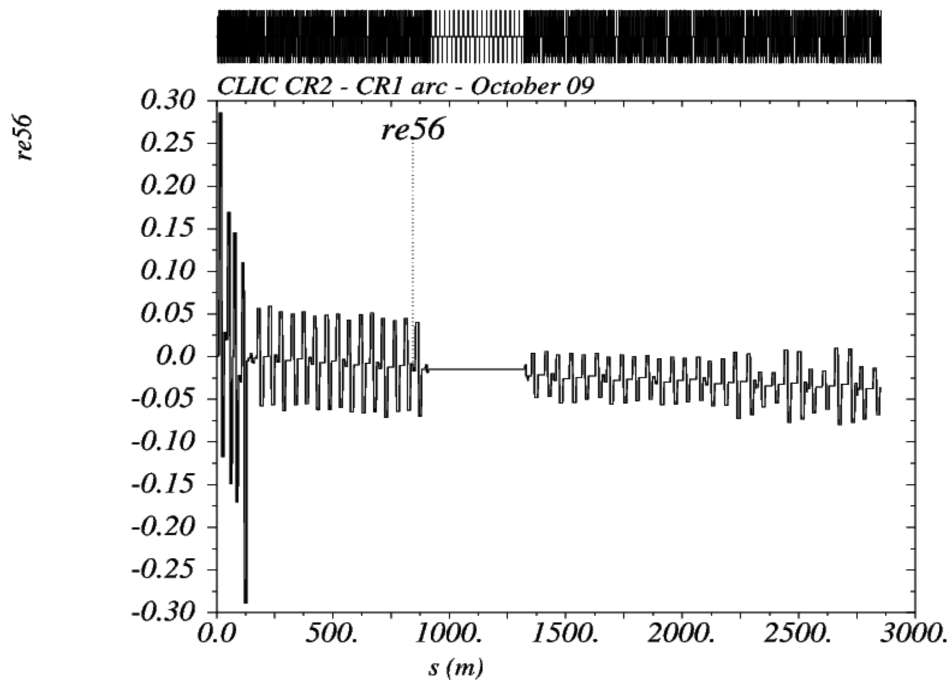
$N_{dipoles}$ = 24




CLIC CR2 - CR1 arc - October 09
beta11
beta22
beta11, beta22
50.
45.
40.
35.
30.
25.
20.
15.
10.
5.
0.0
0.0
500.
1000.
1500.
2000.
2500.
s (m)

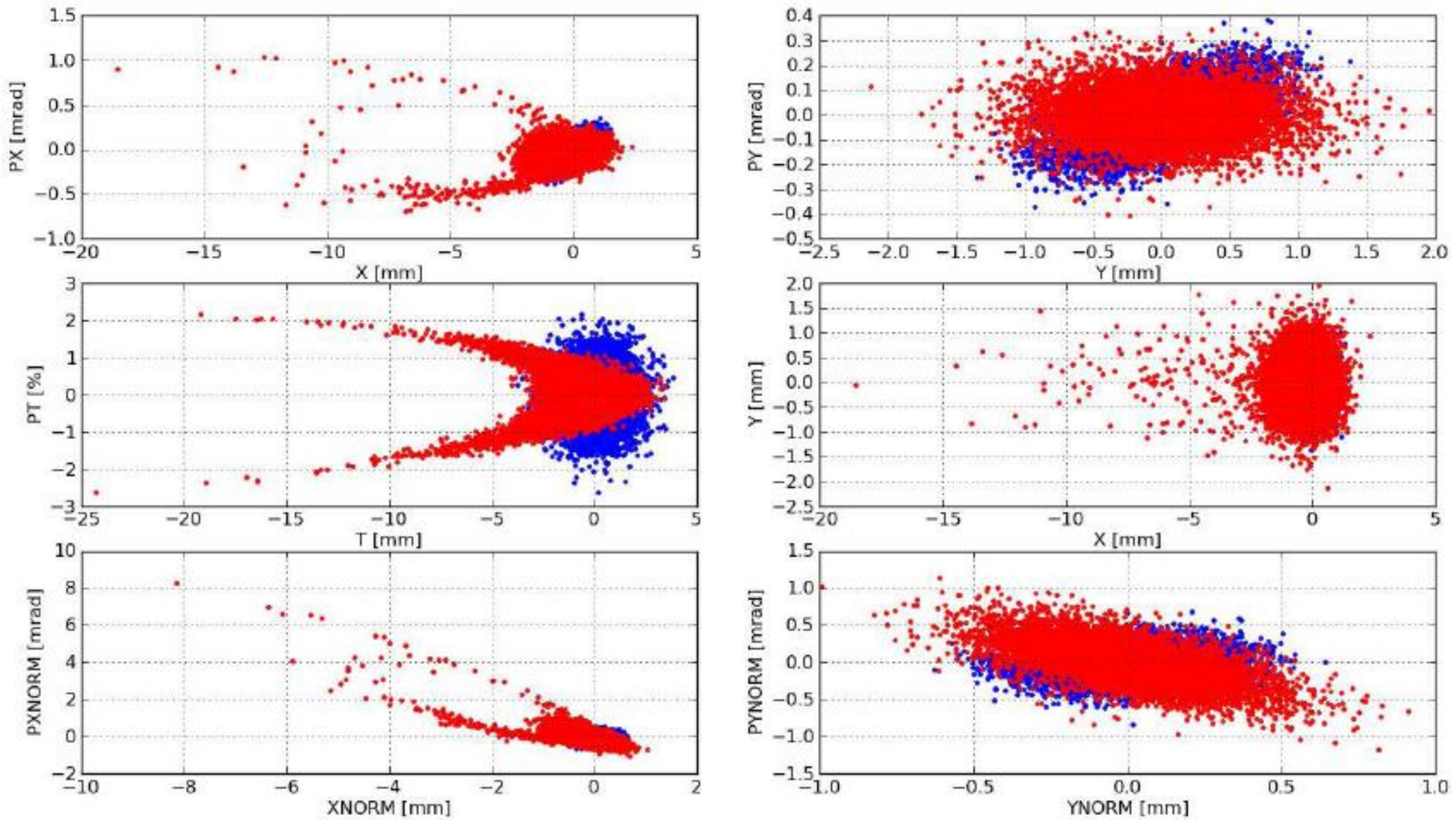

CLIC CR2 - CR1 arc - October 09
x
x (m)
0.0200
0.0175
0.0150
0.0125
0.0100
0.0075
0.0050
0.0025
0.0
-0.0025
-0.0050
0.0
750.
1500.
2250.
3000.
s (m)


CLIC CR2 - CR1 arc - October 09
disp1
disp1
1.25
1.00
0.75
0.50
0.25
0.0
-0.25
-0.50
-0.75
-1.00
-1.25
-1.50
0.0
500.
1000.
1500.
2000.
2500.
3000.
s (m)


CLIC CR2 - CR1 arc - October 09
re56
re56
0.30
0.25
0.20
0.15
0.10
0.05
0.0
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
0.0
500.
1000.
1500.
2000.
2500.
3000.
s (m)

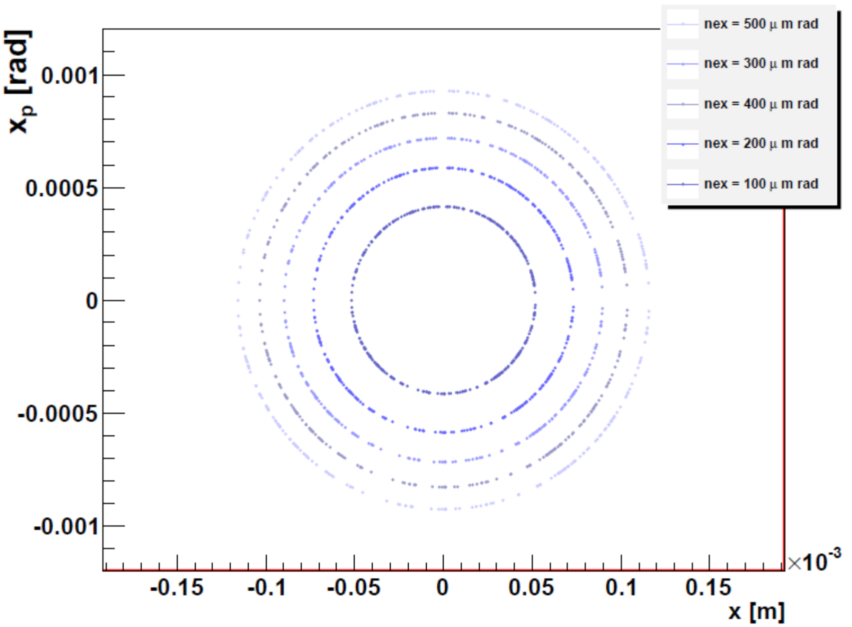
FMS performance

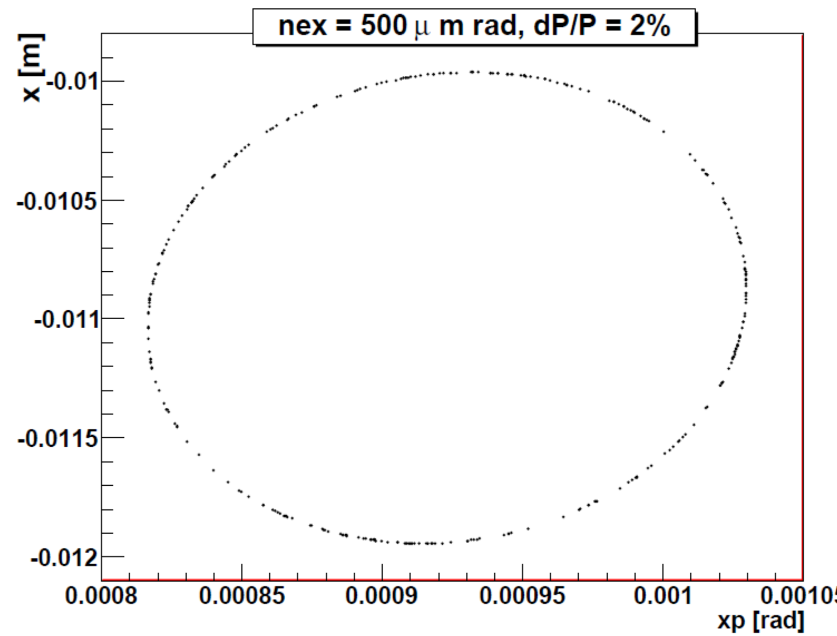
- Tracking in CR1 over 3 turns
  - Looks bad



Source of the Emittance Growth

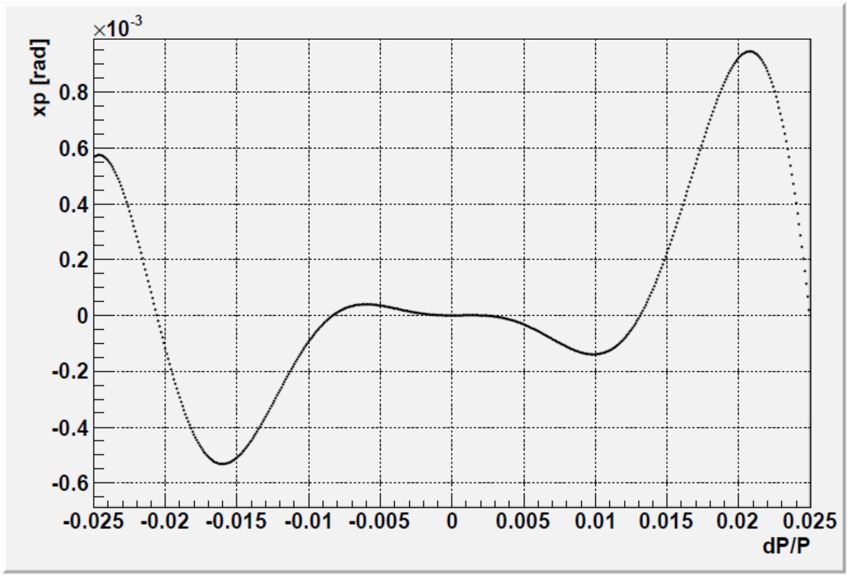
- Tracking ellipses
  - With different action variables
  - Different dP/P
- Even big ellipses are not distorted
- But its center changes position with dP/P
  - Non-linear dispersion

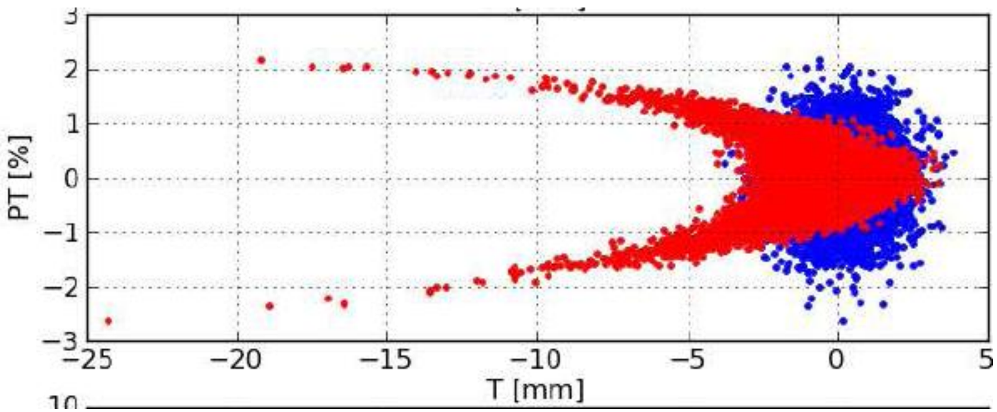


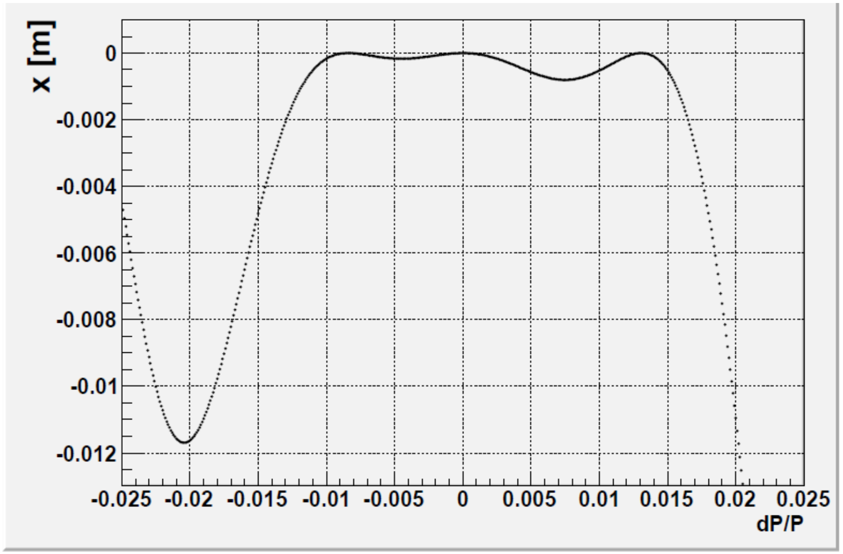


Non-linear dispersion

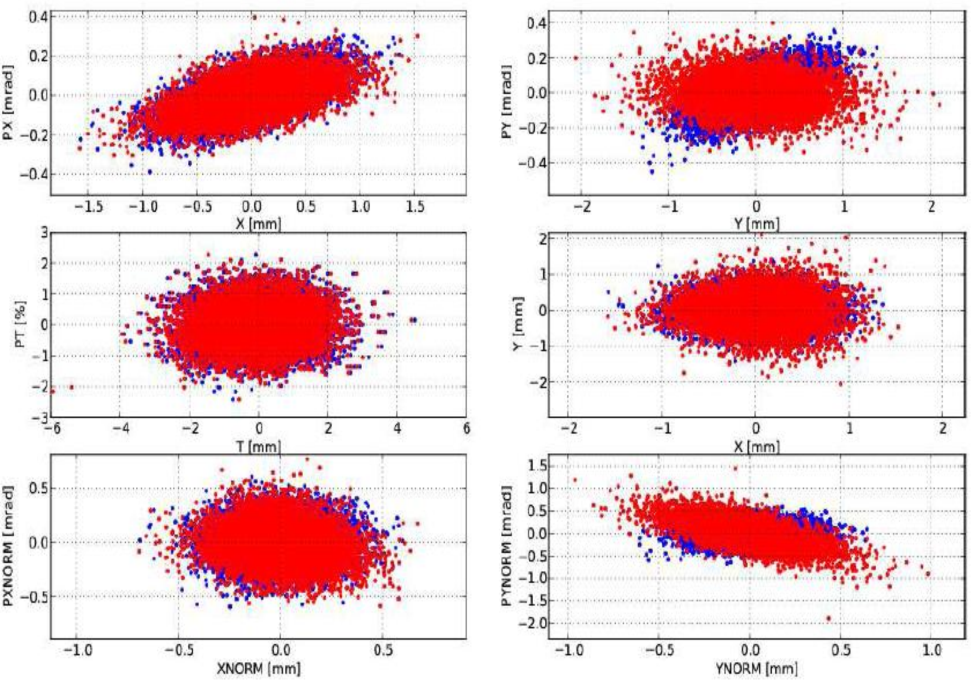
- Non-linear dispersion leads to large emittance growth
- Sextupoles are matched to minimize
  - Dispersions up to 4th order
  - R566
  - Chromaticities
    - Quite difficult to get it all

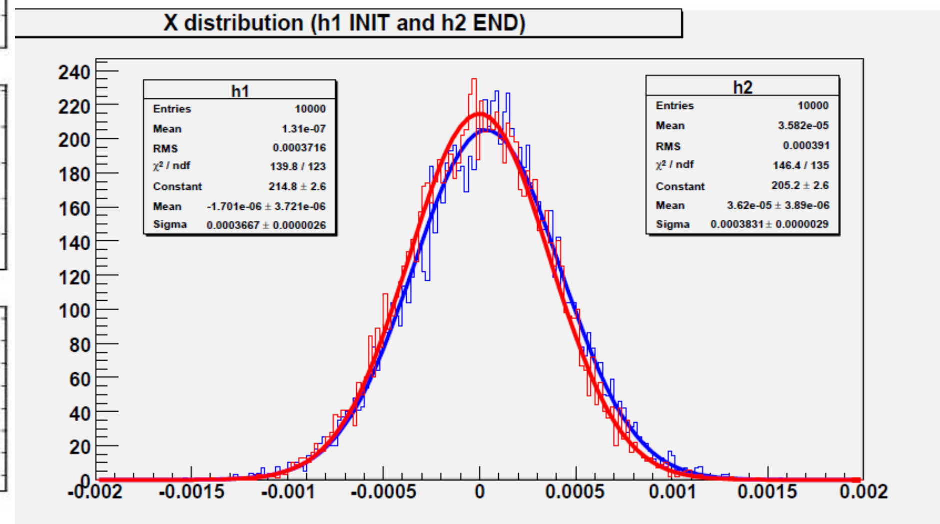


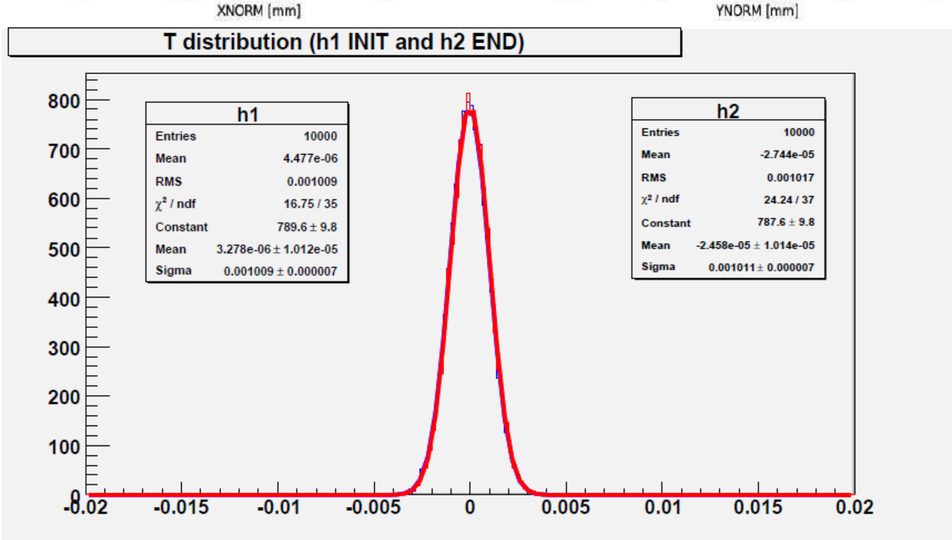


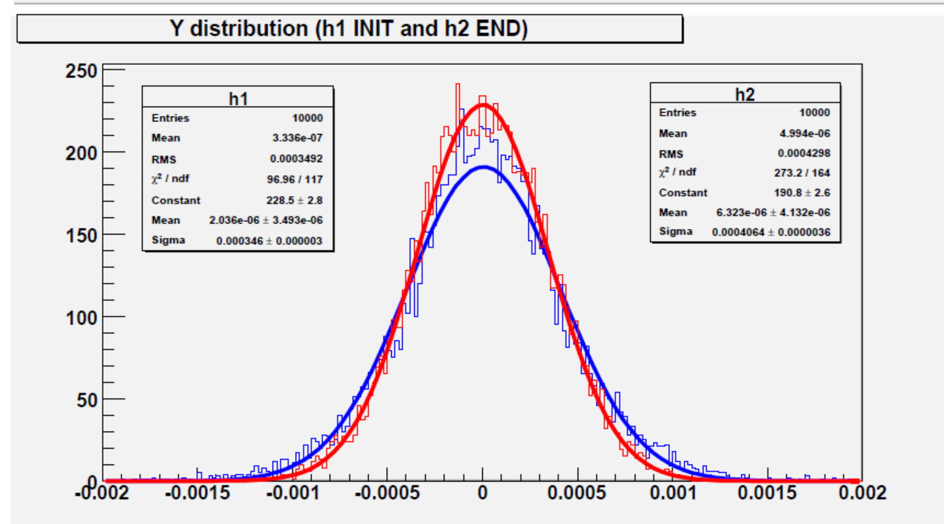


Corrected non-linearities in CR1

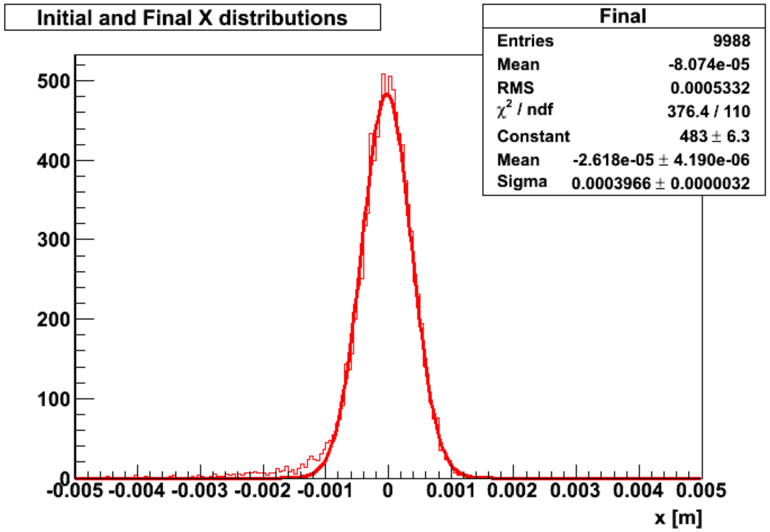




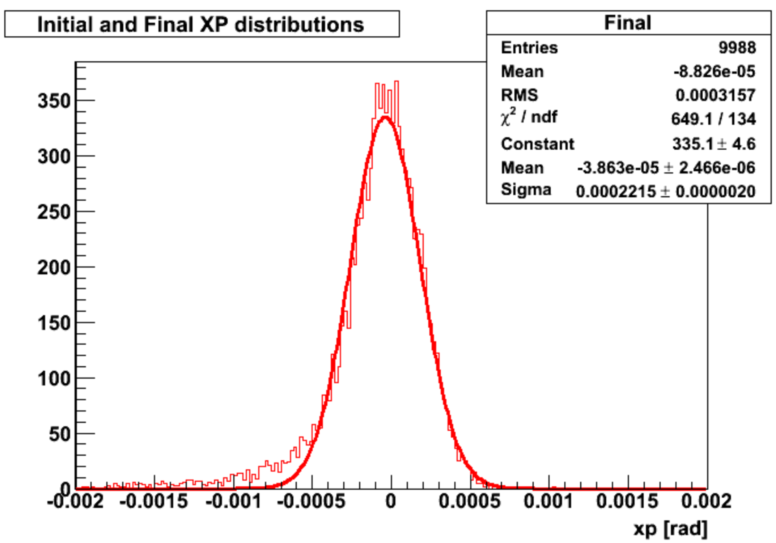


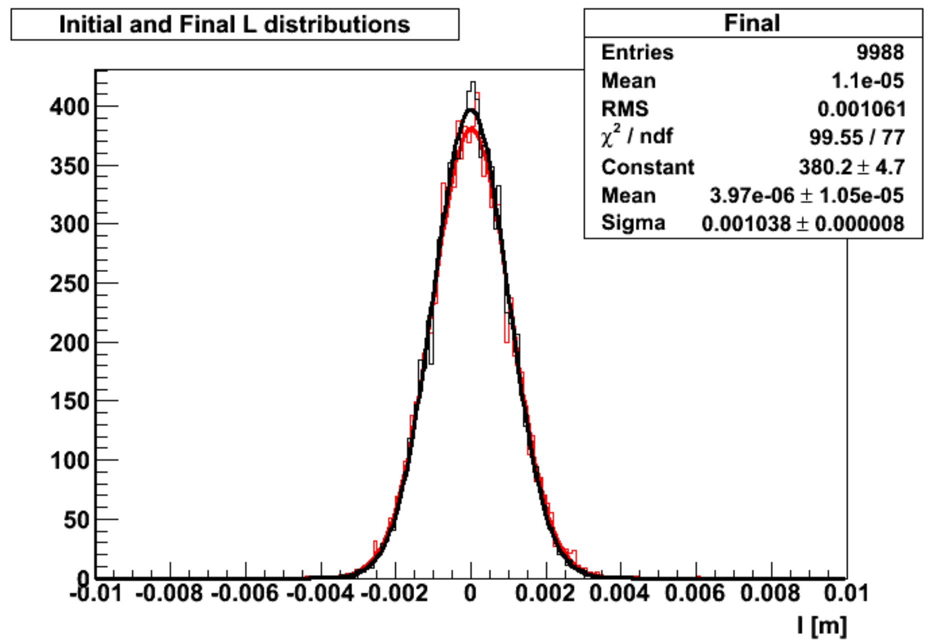


From beginning of DL to 3rd turn in CR1 ($\sigma_{dP/P}$=0.6%)



- E_{xini} =21.46 nm ▪ rad
- E_{xfinal} =30.37 nm ▪ rad
- 12 particles lost
- As smaller dP/P as the result better





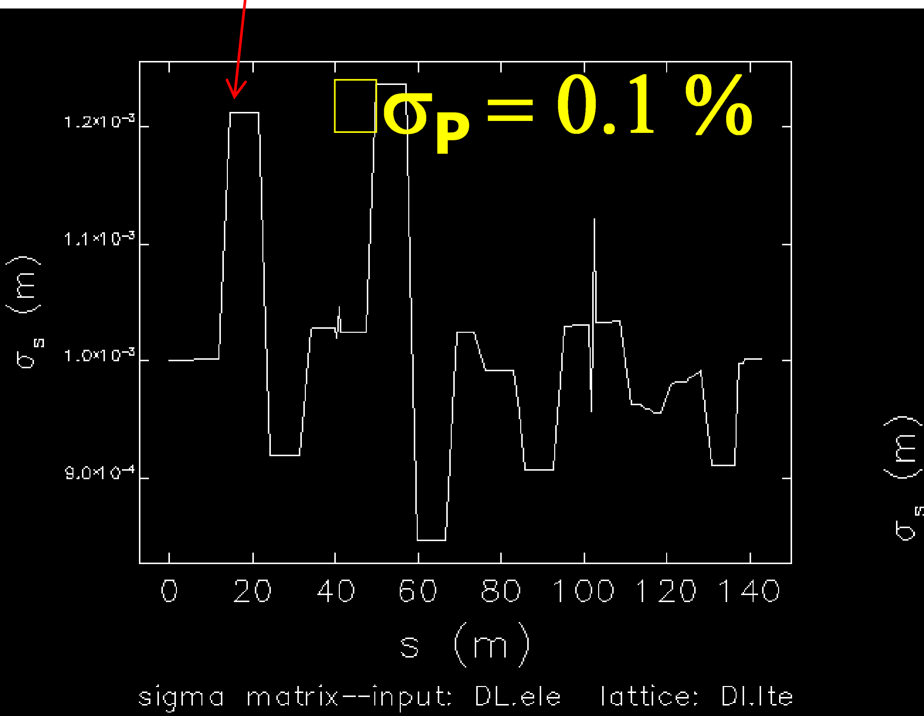
Tracking with ELEGANT including CSR

- Q = 8 nC per bunch, # macroparticles = 50000
- DL is the one with shorter dipole bending radius and hence is the most critical

CSR effects in Delay Loop

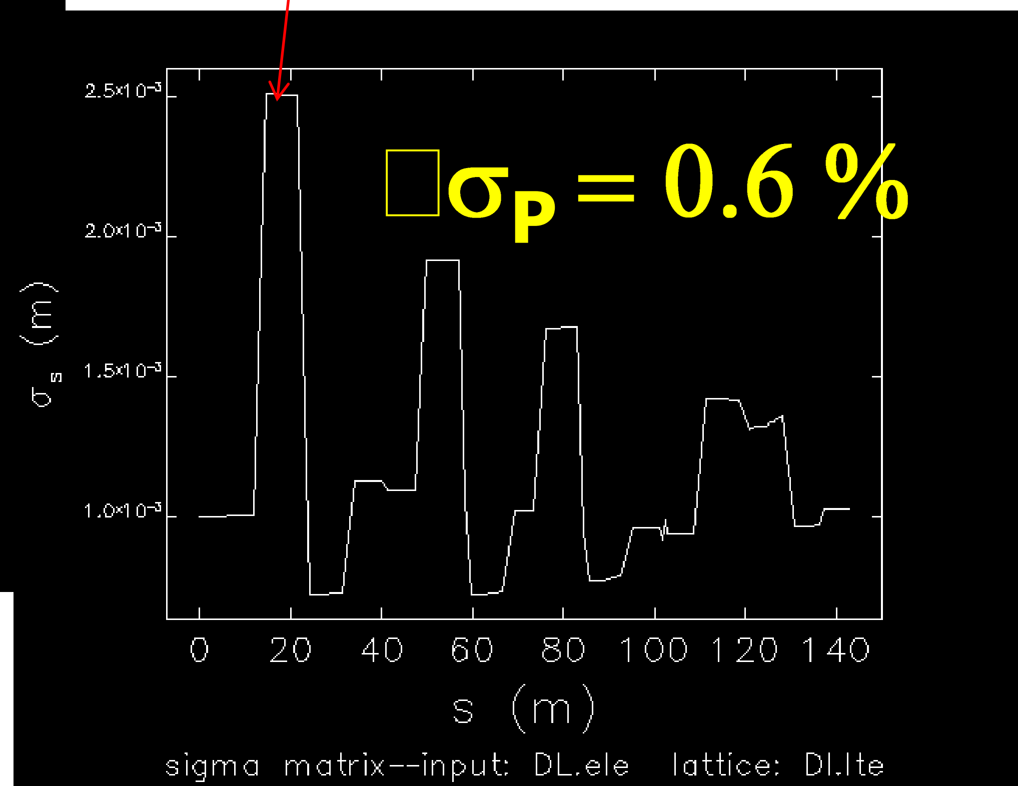
Elegant : Bunch length σ_L 1mm

1.2 mm

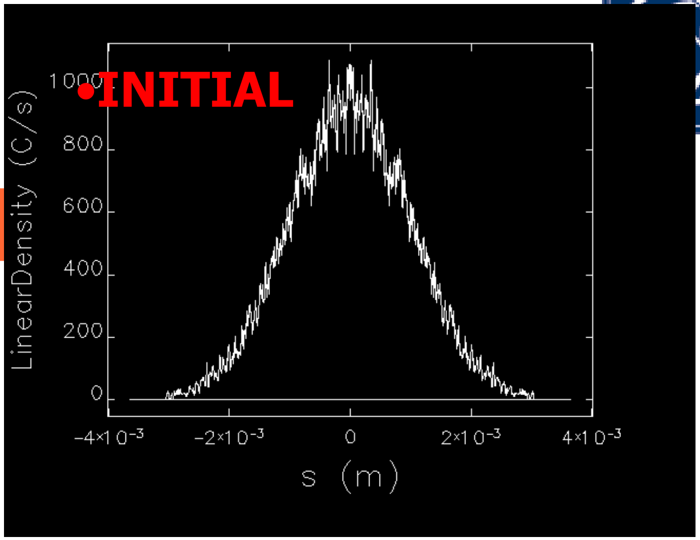


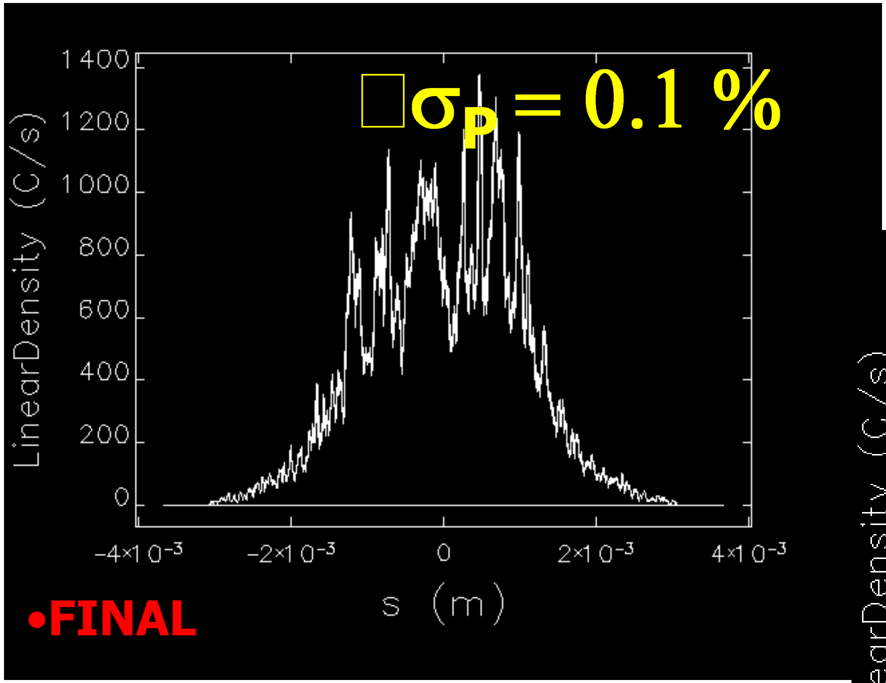
2.5 mm

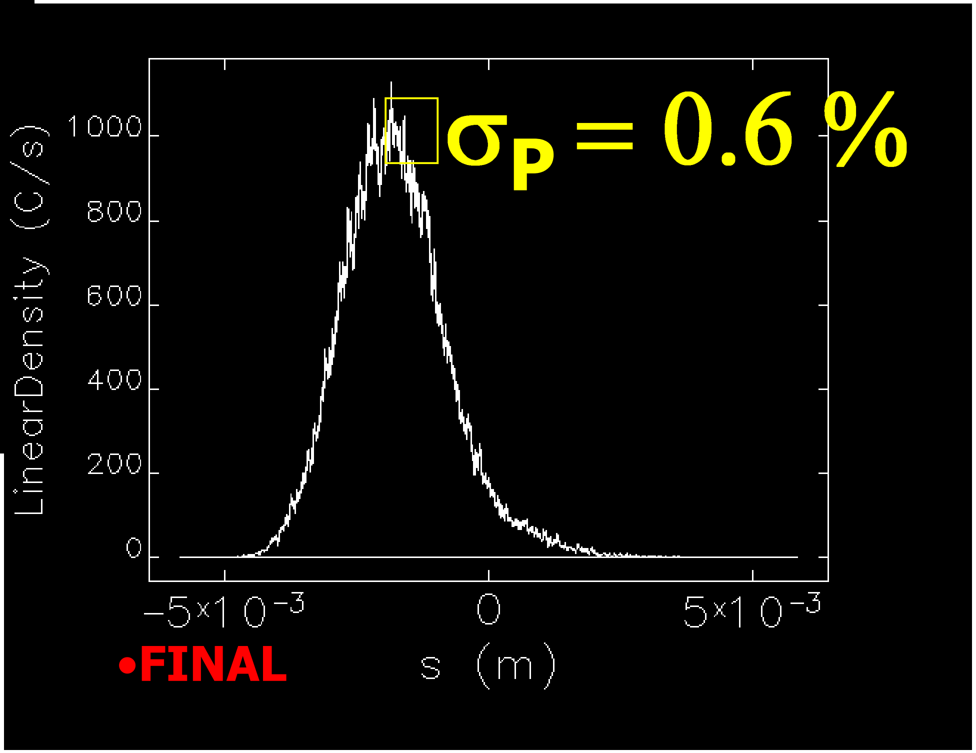
Nominal parameters



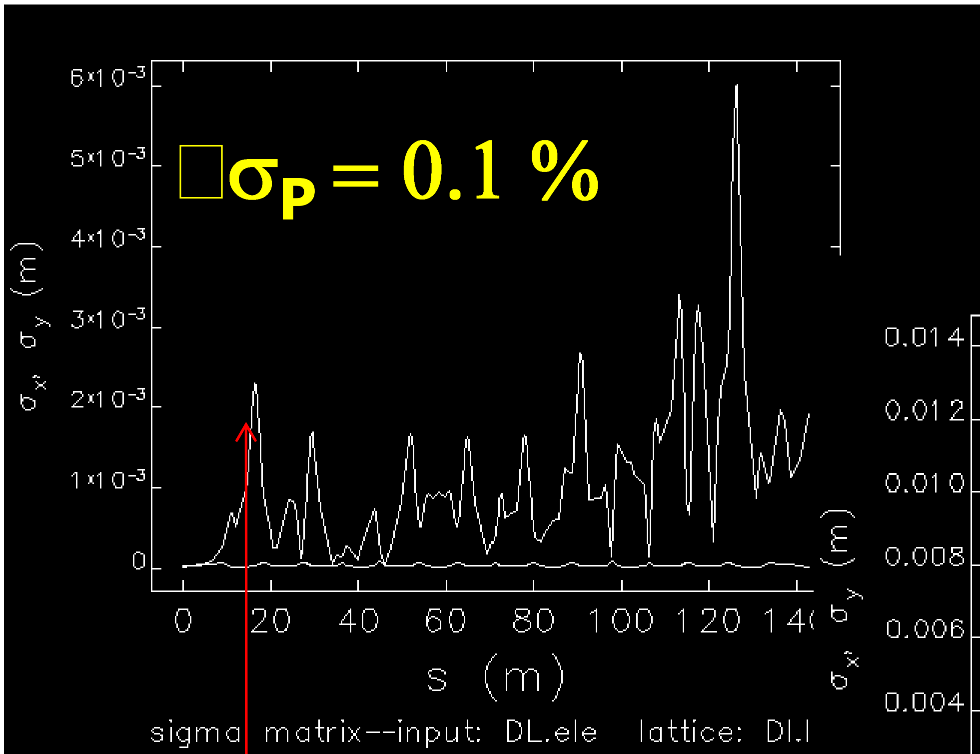
Bunch distribution





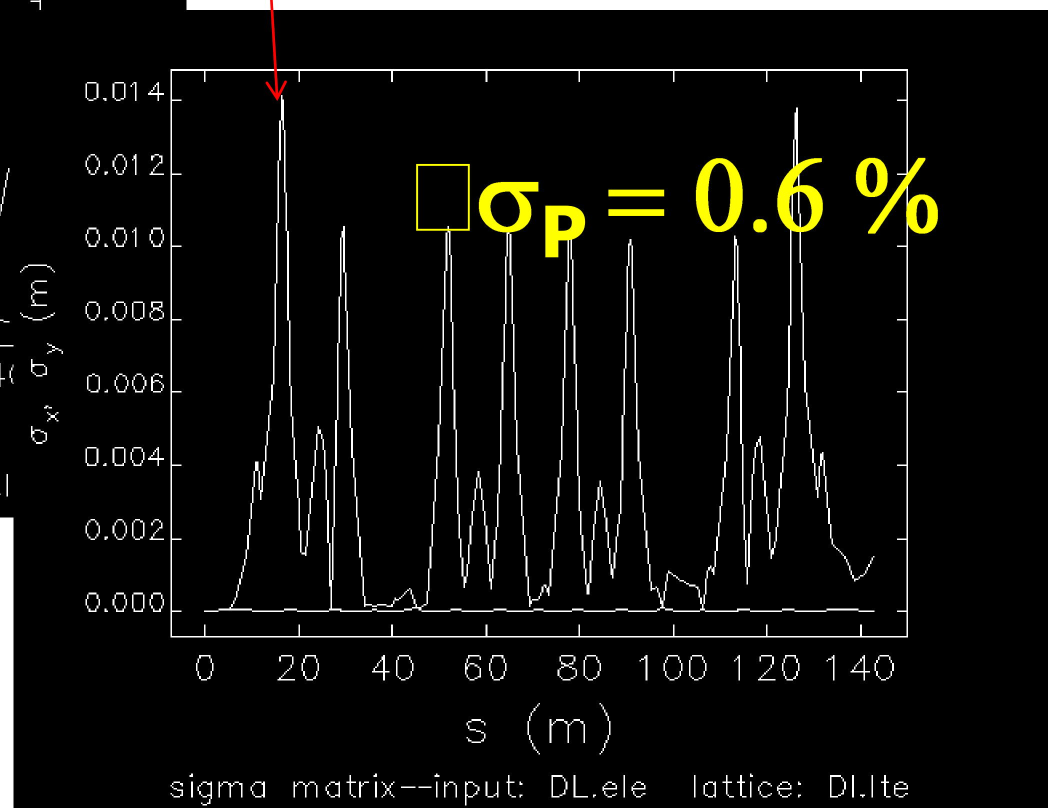


Transverse beam sizes



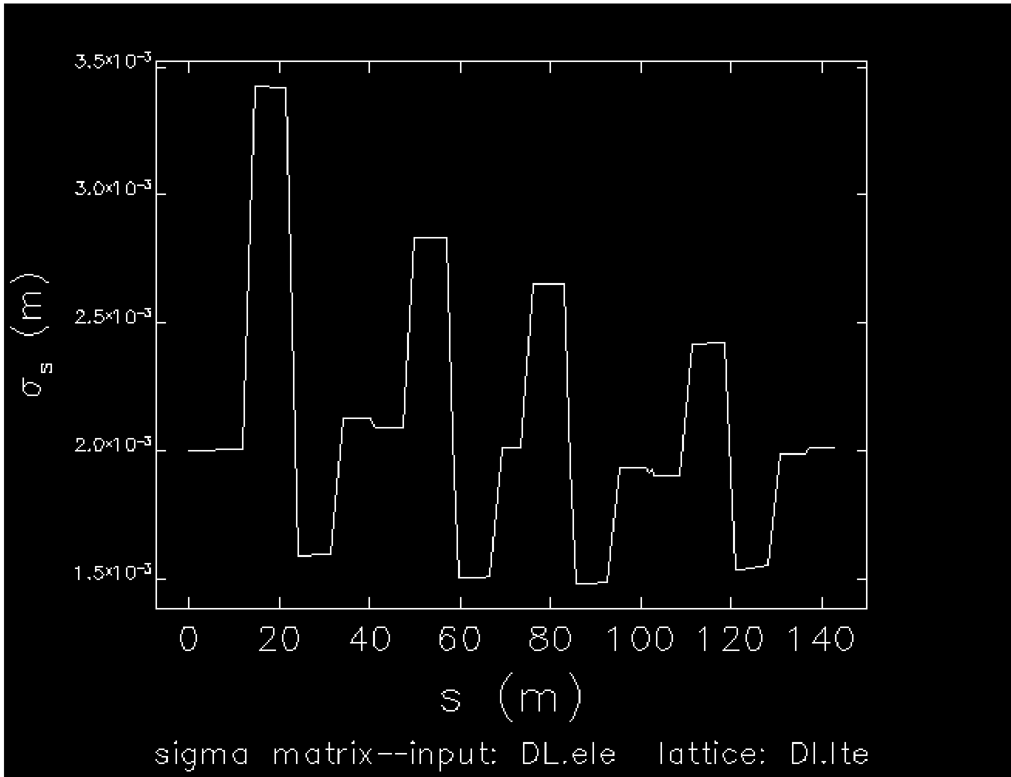
14 mm

Nominal : slight distorsion at line end

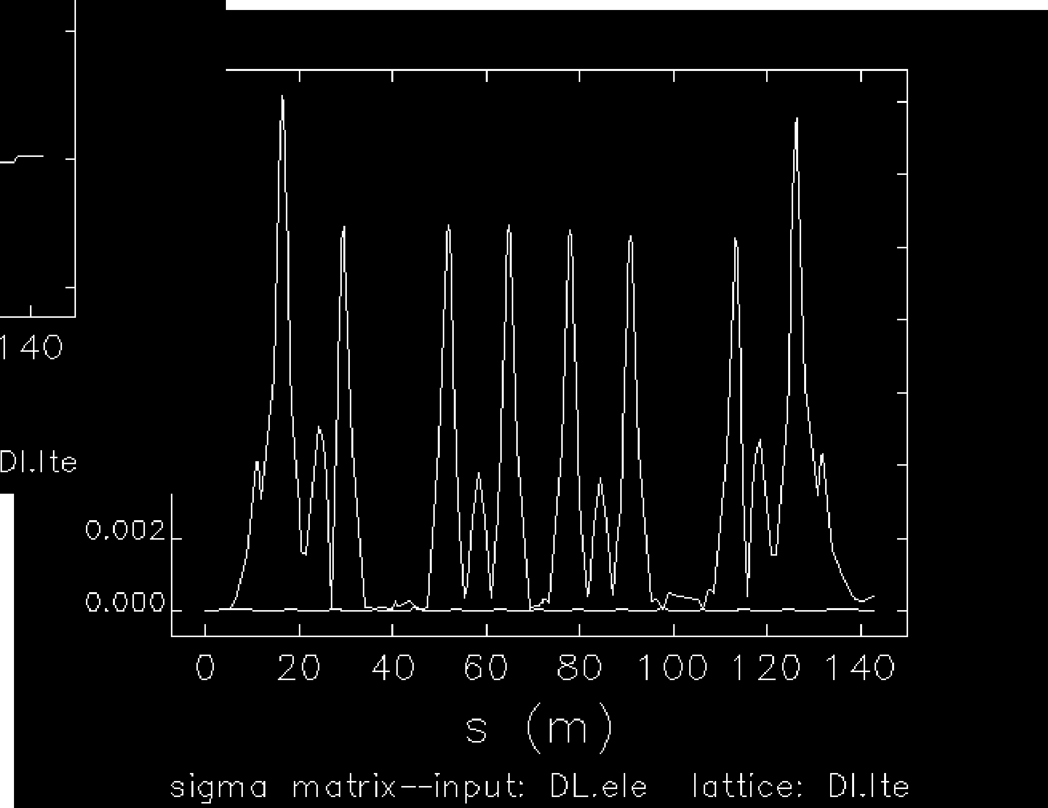


•2 mm

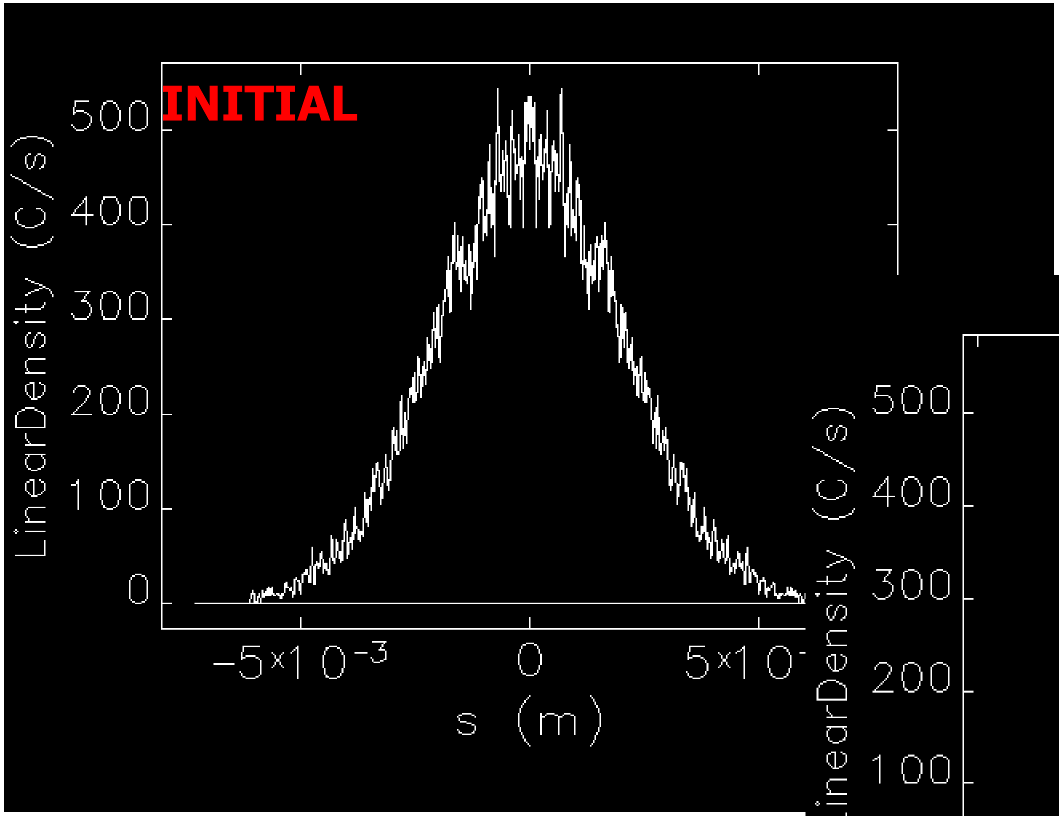
LONGER BUNCH LENGTH
σ_L 2mm and $\sigma_P = 0.6$ %

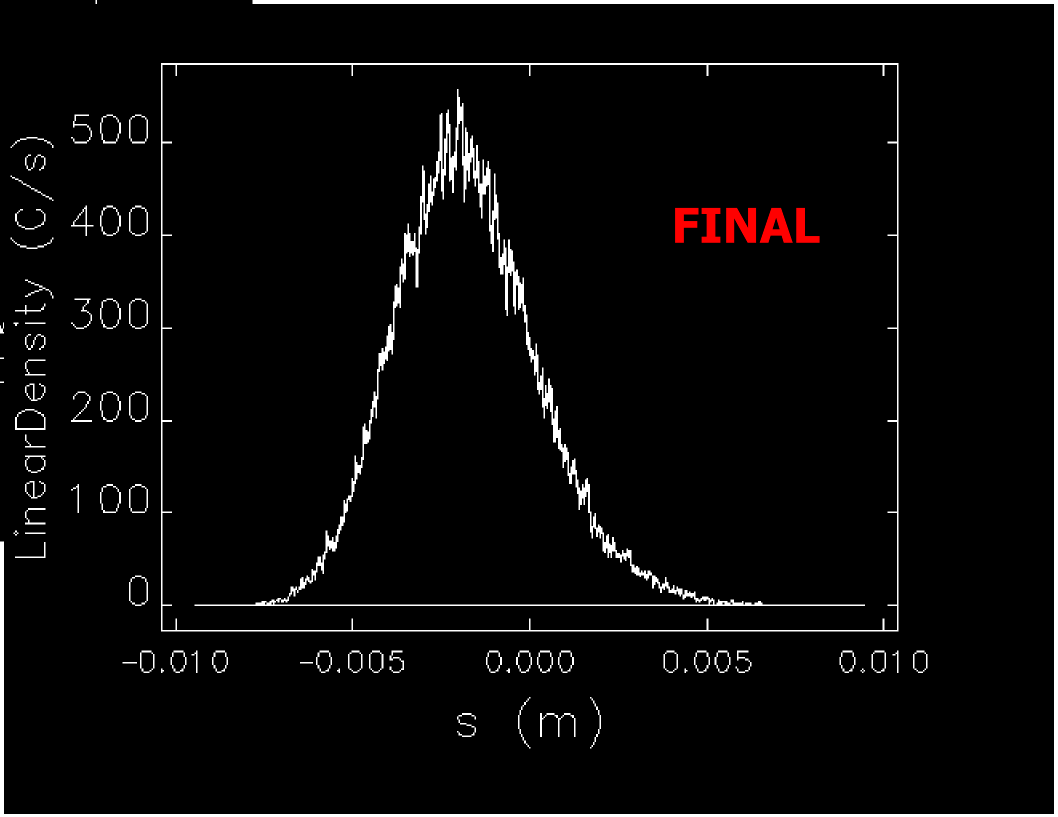


Negligible distorsion at line end



Bunch distribution at σ_L=2 mm





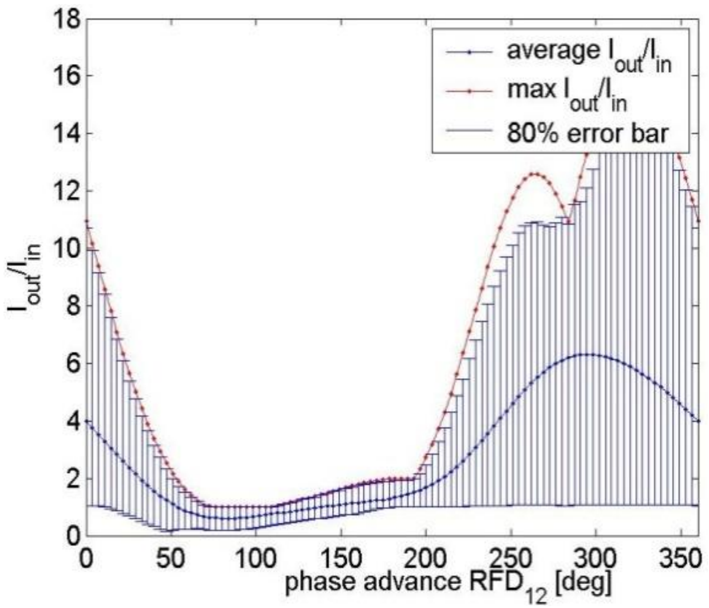
CSR: First Results

- σ_L= 2 mm: safe with the nominal energy spread σ_P=0.6%
- σ_L= 1 mm: slight distorsion with the nominal energy spread σ_P=0.6% on transverse and longitudinal plane
- With smaller energy spread the distortion is stronger
  - the bunch is shorter along the DL
  - the beam size smaller
    - lengthening comes through R56 and dispersion
    - beam size is energy spread dominated

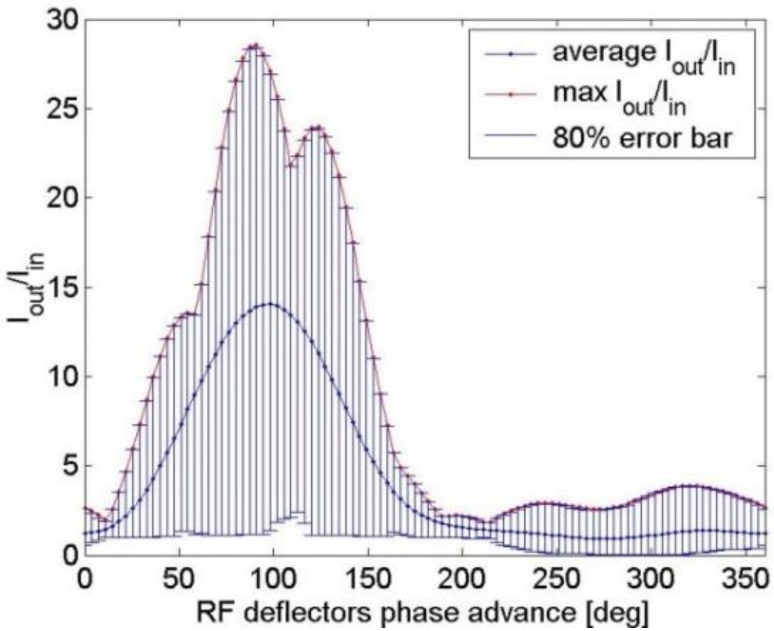
Conclusions

- Lattice design completed
- Non-linear dispersion is the most important factor limiting the energy acceptance of the FMS
  - Sextupoles can limit its influence such that acceptance in dP/P can be close to 2%, above the required value
- 2mm bunch length is safe from CSR point of view
- TO DO
  - Optimize transfer lines design for emittance preservation
  - Matching of sextupoles for Turn Around
  - Design an achromatic injection bump for CR2 that fulfills all the requirements

Backups



average I_{out}/I_{in}
max I_{out}/I_{in}
80% error bar
I_{out}/I_{in}
phase advance RFD_{12} [deg]



average I_{out}/I_{in}
max I_{out}/I_{in}
80% error bar
I_{out}/I_{in}
RF deflectors phase advance [deg]