ESRF | The European Synchrotron

Accelerator Toolbox Training

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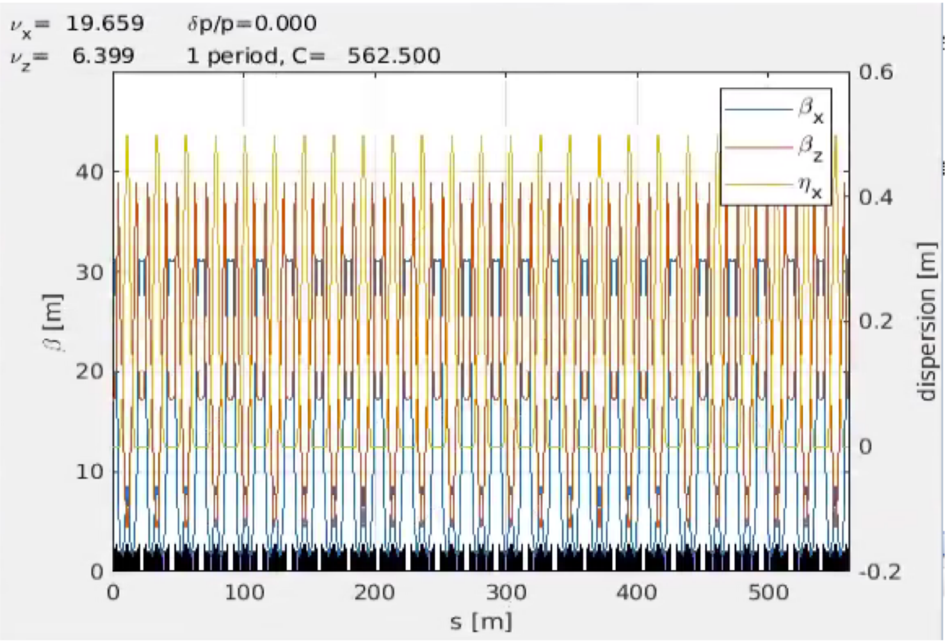
1) Build a FODO lattice
2) Introduce dipoles
3) Compute emittance
4) Move dipoles
5) Introduce straight sections
6) Match dispersion to zero at straight sections
7) Match periodic cell, verify total angle
8) Introduce sextupoles and correct chromaticity
9) Introduce an RF cavity
10) Match tune
11) Tracking and plot of phase space
12) transverse dynamic aperture

Objective:

Design a fully functional low emittance lattice



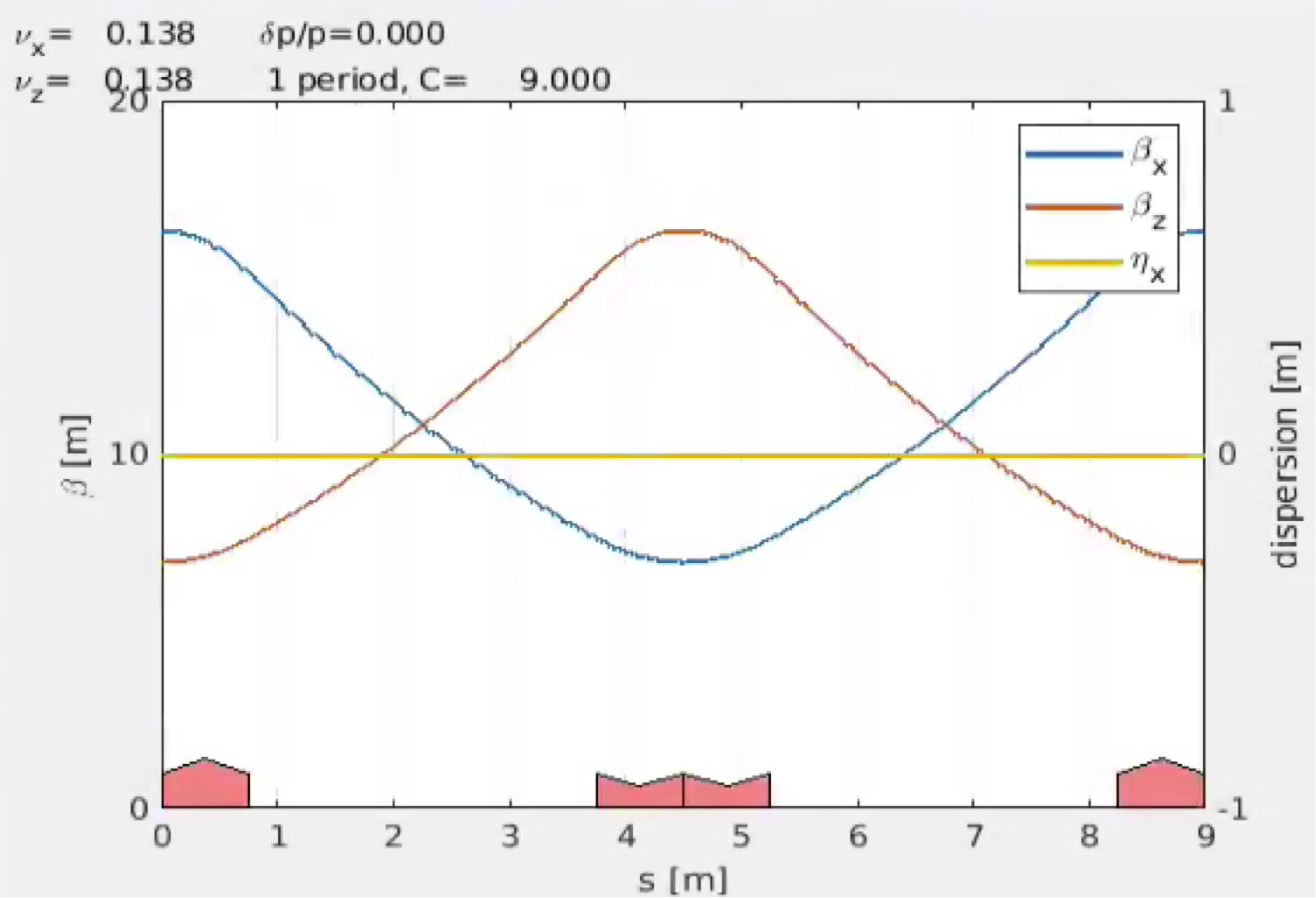
1) BUILD A FODO LATTICE

Use:
`atdrift`
`atquadrupole`

L = 3m
K = 0.1*sqrt(2)
L_drift = L
L_quad = L/4

Do the beta functions behave as you would expect?

What is the natural emittance of this lattice?

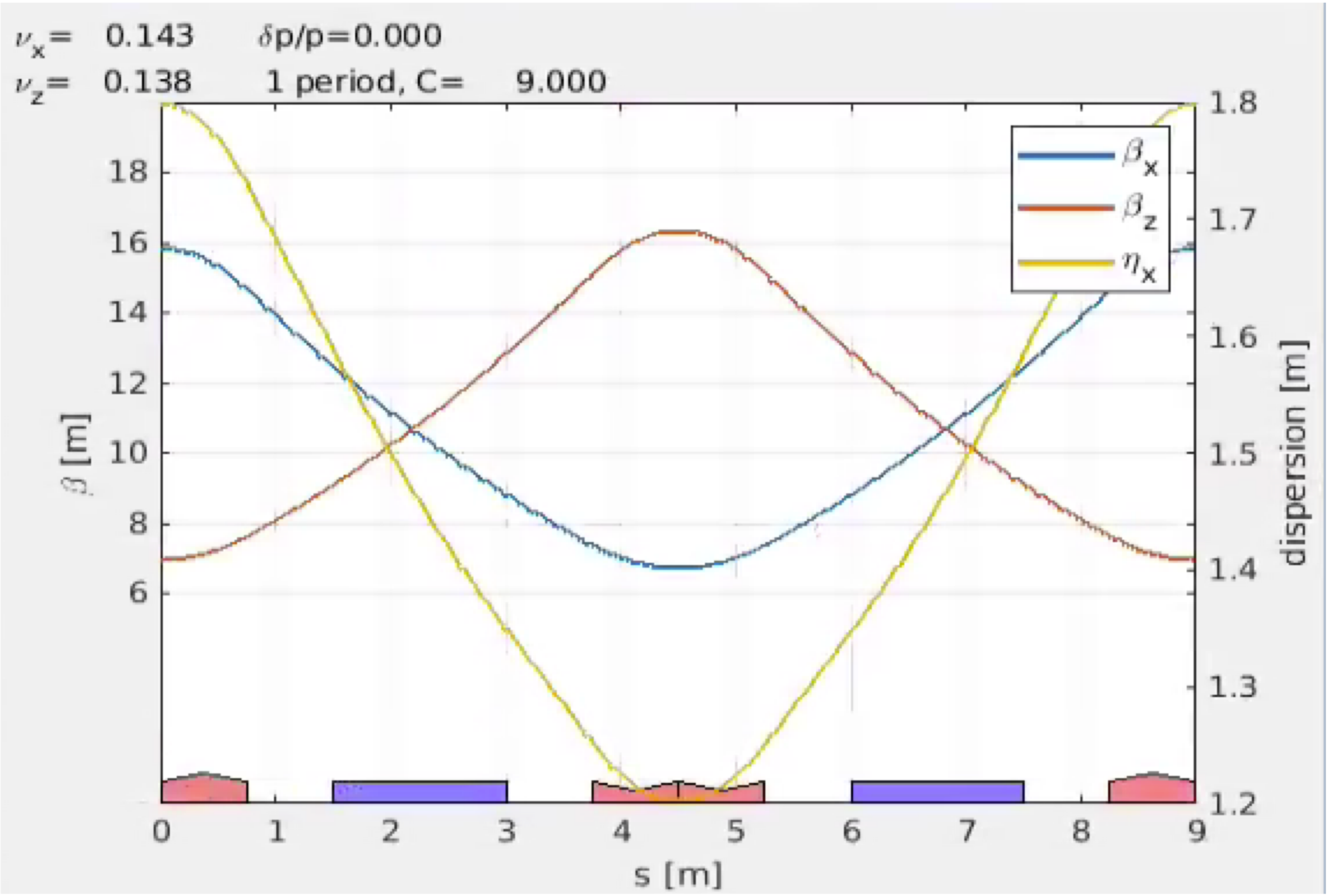


INTRODUCE DIPOLES

Use above +:

`atsbend`

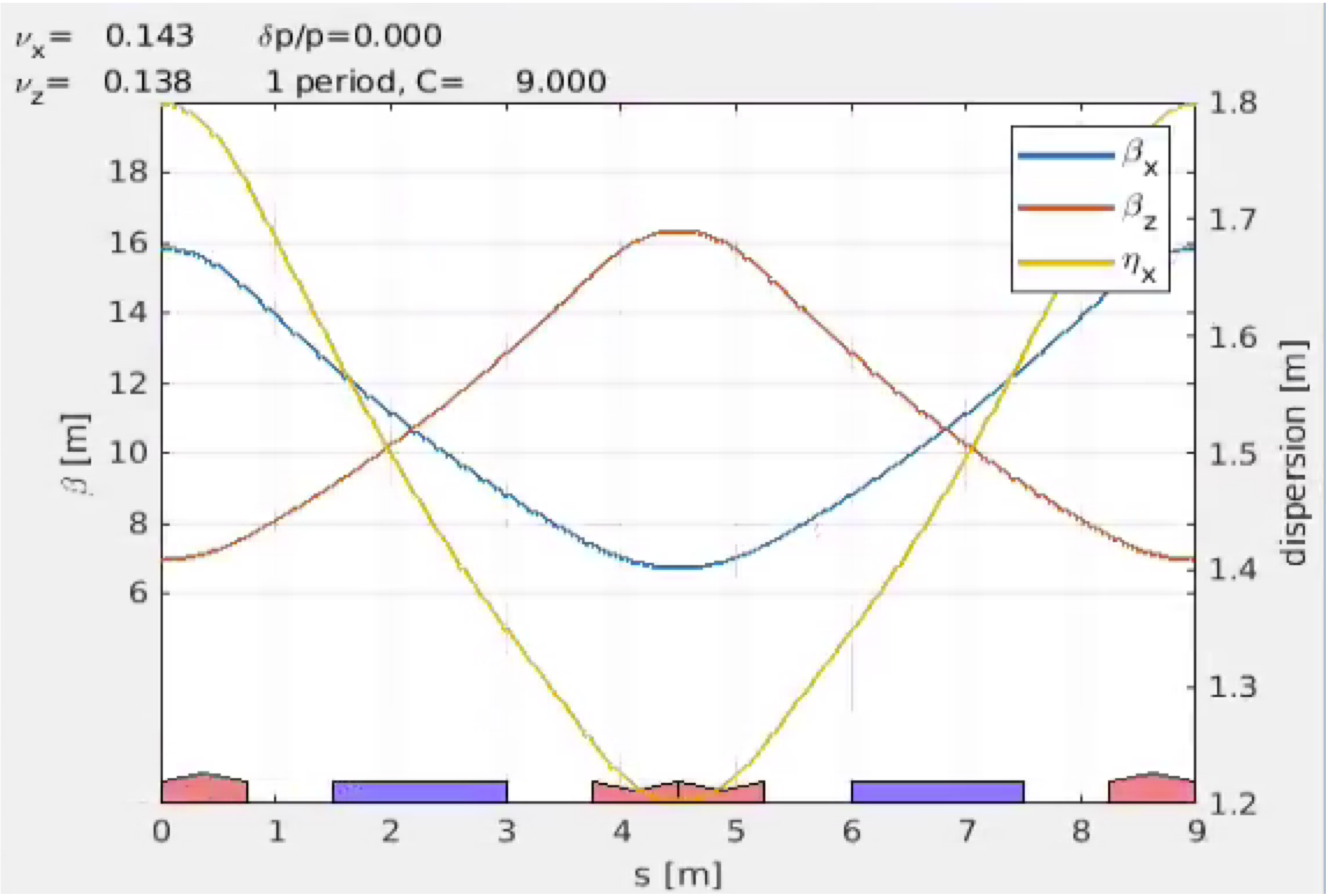
L = 3m
Ncells = 50;
K = 0.1*sqrt(2)
L_drift = L/4
L_bend = L/2
Ang_bend = ???
L_quad = L/4



Use above +:

`atsbend`

L = 3m
Ncells = 50;
K = 0.1*sqrt(2)
L_drift = L/4
L_bend = L/2
Ang_bend = *2pi/ Ncells /2*
L_quad = L/4



bx= beta_x
dx = Dispersion x
dxp = Disperison x’
ax = alpha_x
dipAng = dipole angle
dipLen = dipole length

Write this function and compute emittance for the above lattice.

Should be around 115 nm.rad

How to reduce the emittance?

Editor - /mntdirect/_machfs/ESRF_Russia_AT_Training/computeEx.m

```
function ex = computeEx(fodo)
% emittance for 3GeV lattice

```

Use atgetcells, atgetfieldvalues, atlinopt, arrayfun (optional), to get the relevant quantities

```
gx = (1+ax.^2)./bx; % beta*gamma - alpha^2 = 1

H = bx.*dxp.^2 + 2*ax.*dx.*dxp + gx.*dx.^2;

rho = dipLen./dipAng;

I5 = sum((H'./(abs(rho).^3)).*dipLen);

I2 = sum(1./(rho.^2).*dipLen);

Cq = 3.8319E-13;
E0 = 3e9; %eV

gamma = (E0*1e-6)/PhysConstant.electron_mass_energy_equivalent_in_MeV.value;

ex = Cq*gamma^2 * I5 / I2;

end
```

3) COMPUTE EMITTANCE

bx= beta_x
dx = Dispersion x
dxp = Disperison x'
ax = alpha_x
dipAng = dipole angle
dipLen = dipole length

Write this function and compute emittance for the above lattice.

Should be around 115 nm.rad

How to reduce the emittance?
Place dipoles in low beta and low dispersion regions.

Editor - /mntdirect/_machfs/ESRF_Russia_AT_Training/computeEx.m

```
function ex = computeEx(fodo)
% emittance for 3GeV lattice
```

Use `atgetcells`, `atgetfieldvalues`, `atlinopt`, `arrayfun` (optional), to get the relevant quantities

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E0 = 3e9; %eV

gamma = (E0*1e-6)/PhysConstant.electron_mass_energy_equivalent_in_MeV.value;

ex = Cq*gamma^2 * I5 / I2;

end
```

4) MOVE DIPOLE TO LOW HORIZONTAL BETA REGION

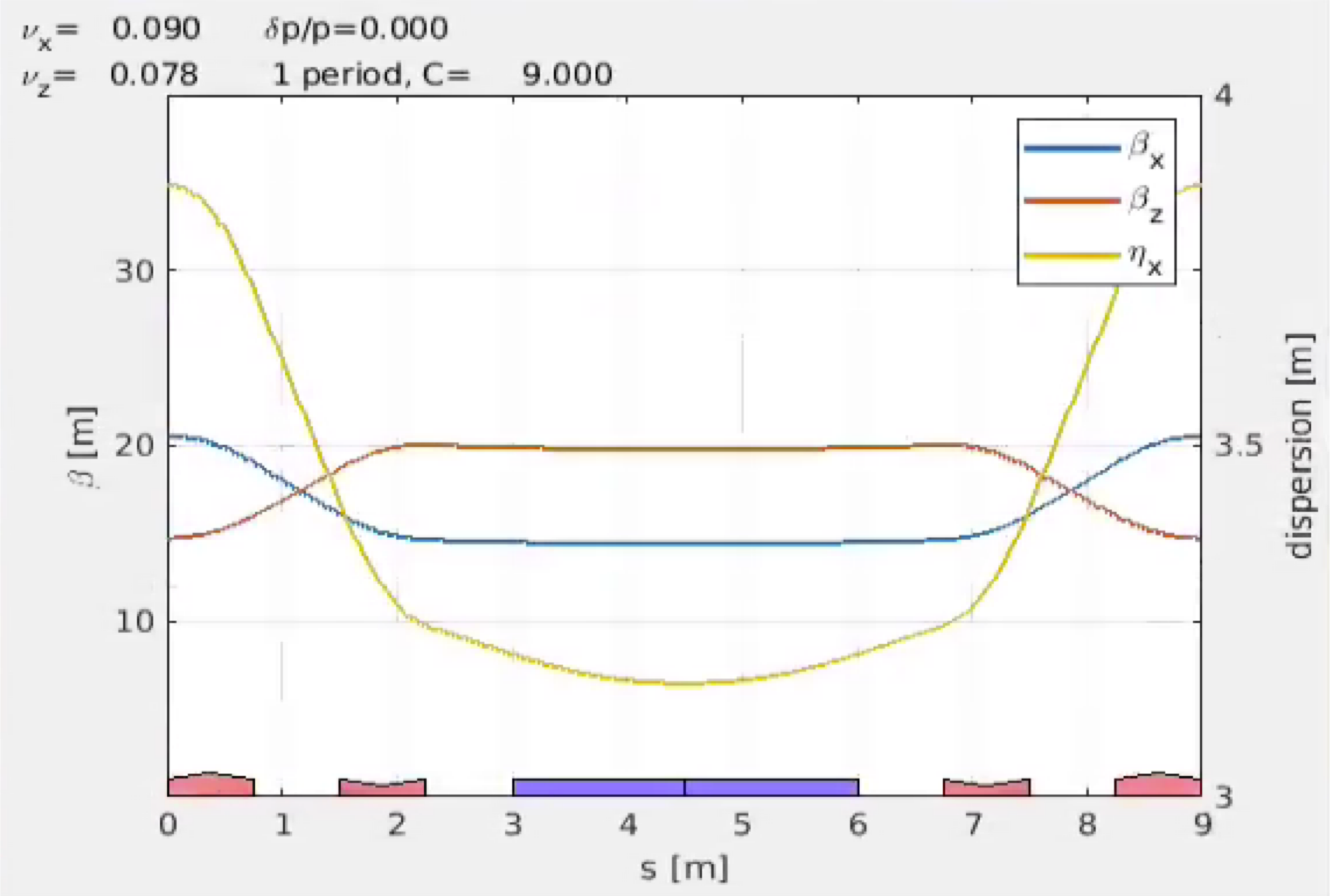
Use:
`atdrift`
atsbend
`atquadrupole`

L = 3m
K = 0.1*sqrt(2)
L_drift = L/4
L_quad = L/4

compute emittance for this lattice.

Should be around 392 nm.rad (!)

Why?



4) MOVE DIPOLE TO LOW HORIZONTAL BETA REGION

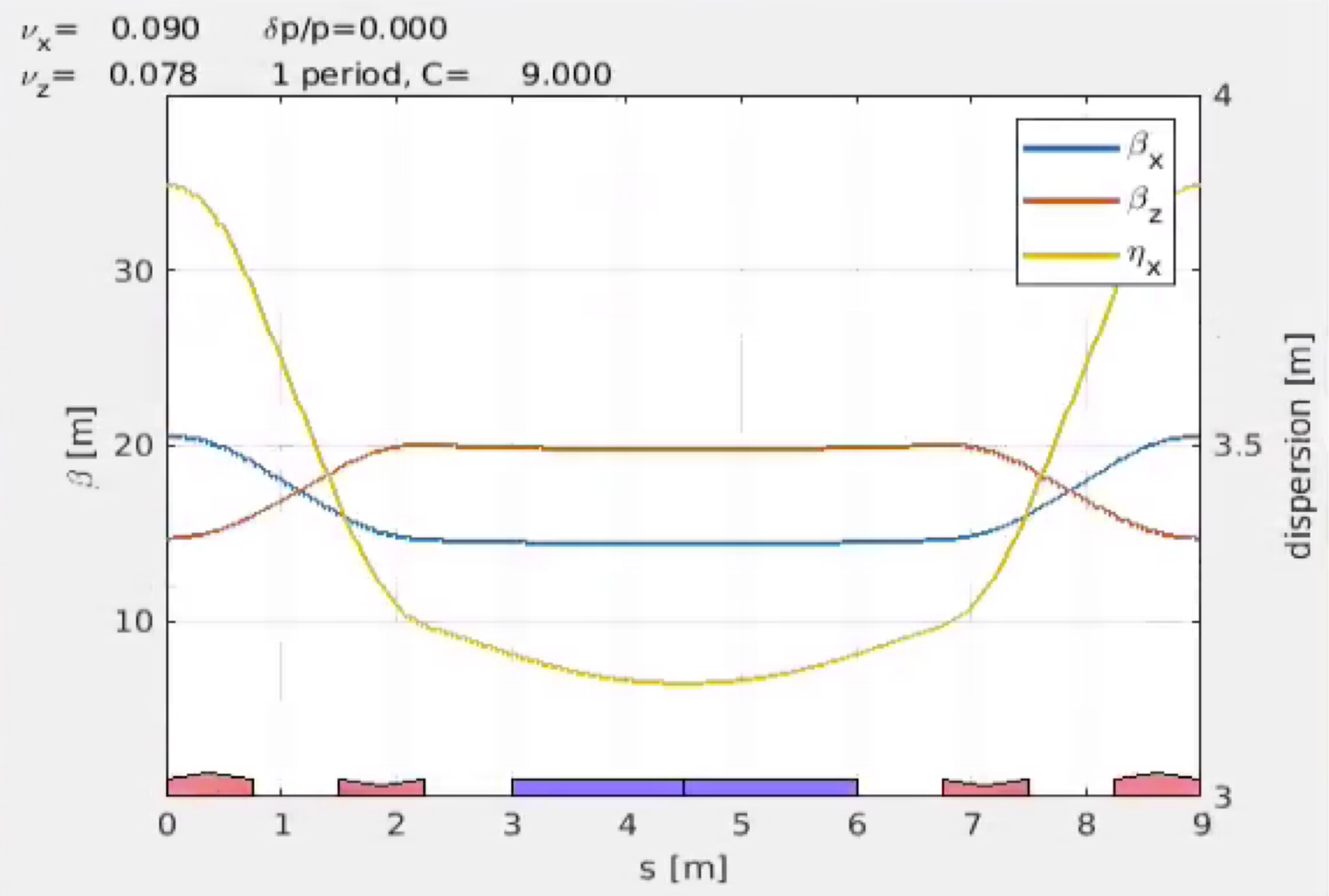
Use:
`atdrift`
atsbend
`atquadrupole`

L = 3m
K = 0.1*sqrt(2)
L_drift = L/4
L_quad = L/4

compute emittance for this lattice.

Should be around 392 nm.rad (!)

Why? The dispersion function is now much bigger than before.

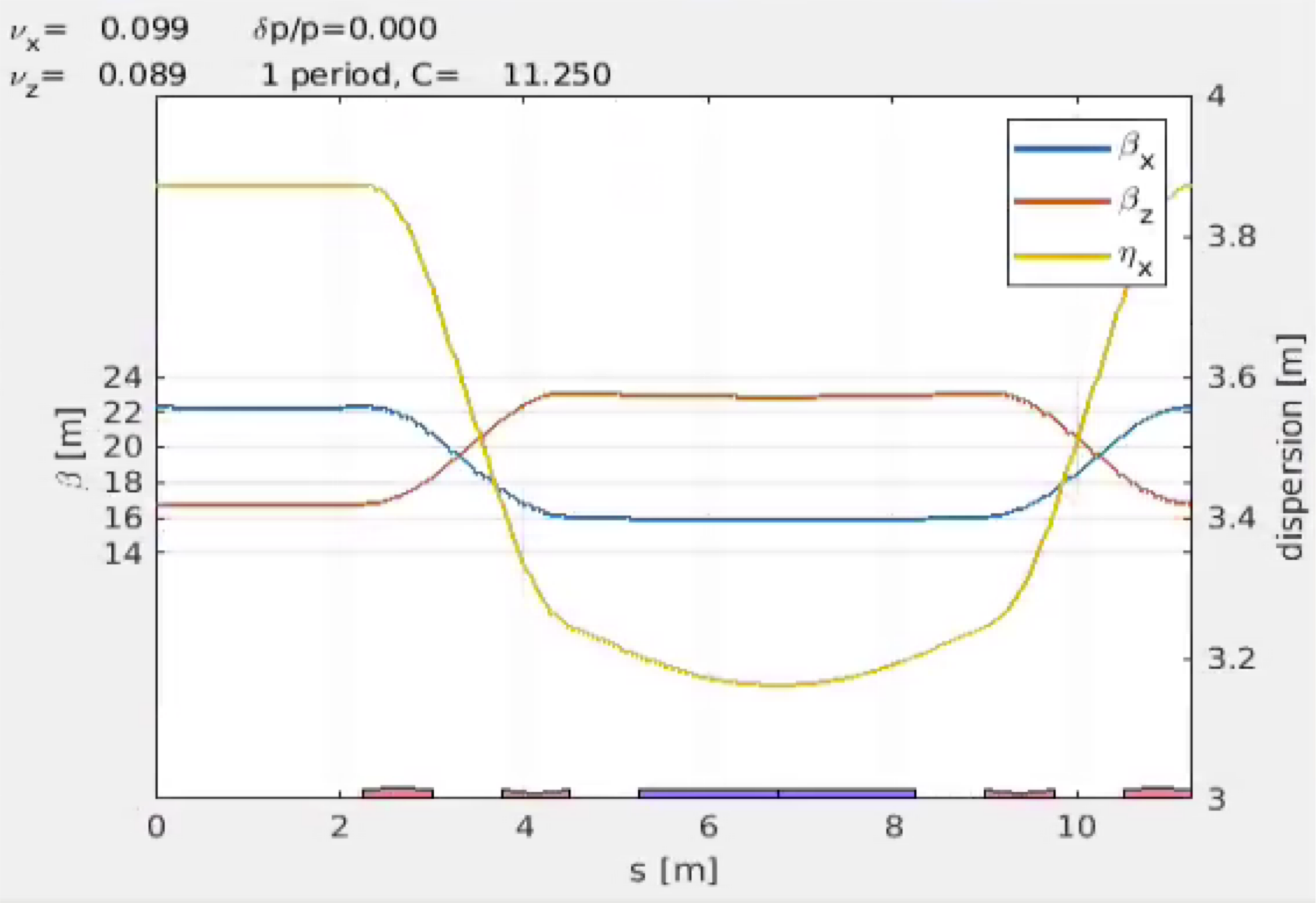


5) INTRODUCE STRAIGHT SECTION

Use:
`atdrift`
atsbend
`atquadrupole`

L = 3m
K = 0.1*sqrt(2)
L_drift = L/4
L_quad = L/4
L_straight = 3 * L/4

compute emittance for this lattice.



Define magnetic fields to obtain wished parameters:

Ex : vary QUADRUPOLES

obtain wished tunes, or anything else

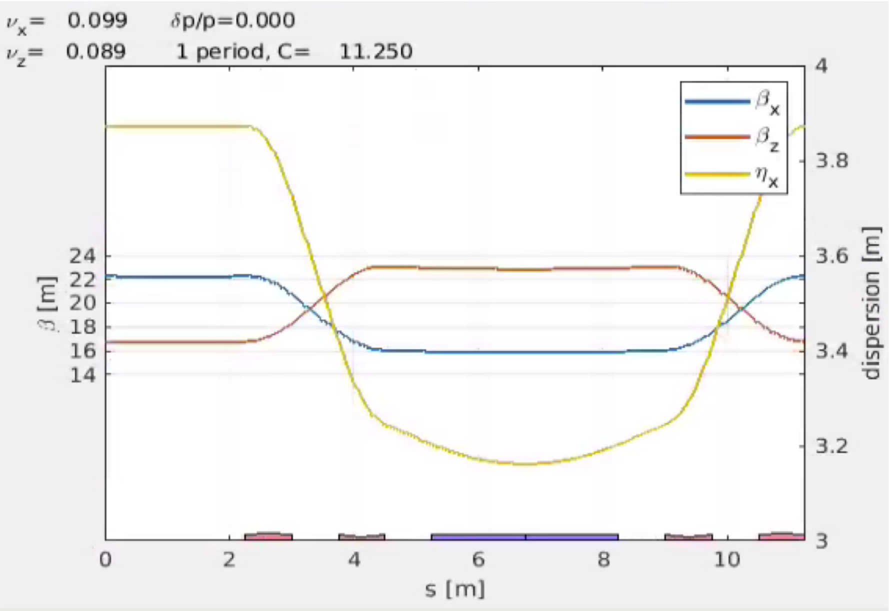
Can be

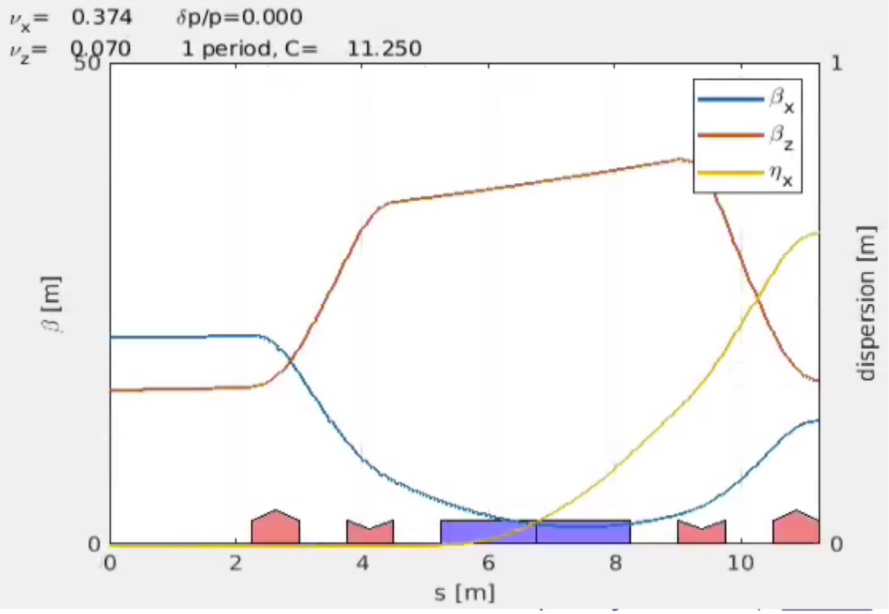
transferline : need input Twiss parameters

periodic : will enforce initial and final Twiss parameters to be identical. Good for symmetric cells.

An optimizer (ex: `fminsearch`) is run to find (if it exist) the optimal set of quadrupole strengths that best match the wished requirements.

same magnets layout, different gradients!





6) MATCH LATTICE OPTICS

Is this lattice acceptable for synchrotron Radiation production?

Dispersion is large at the straight sections (SS), and at the dipoles!

Let's set the dispersion at the SS to zero and see it's evolution.

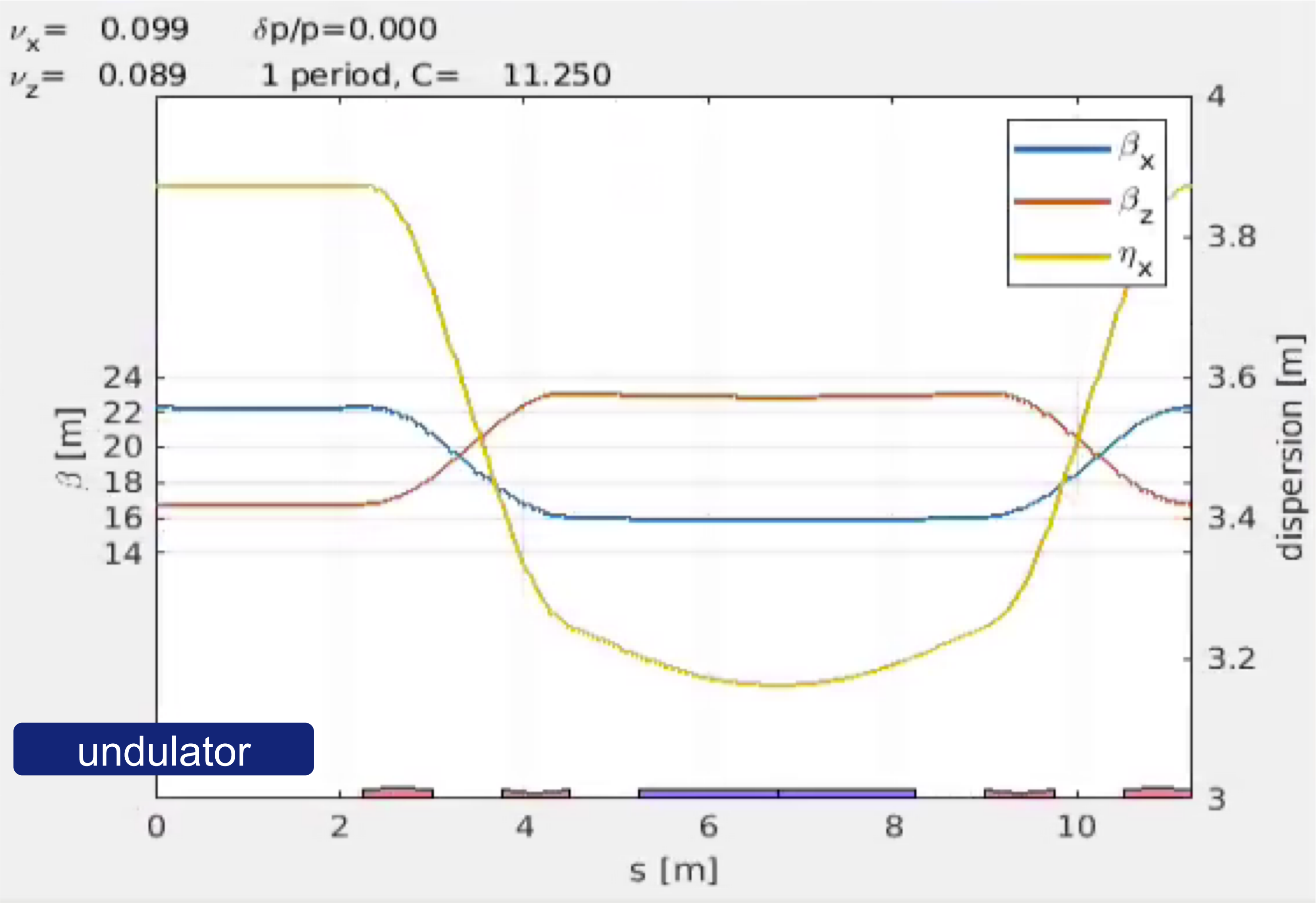
Use

```
[TwissStart,~,~]=atlinopt(…,0,1)
```

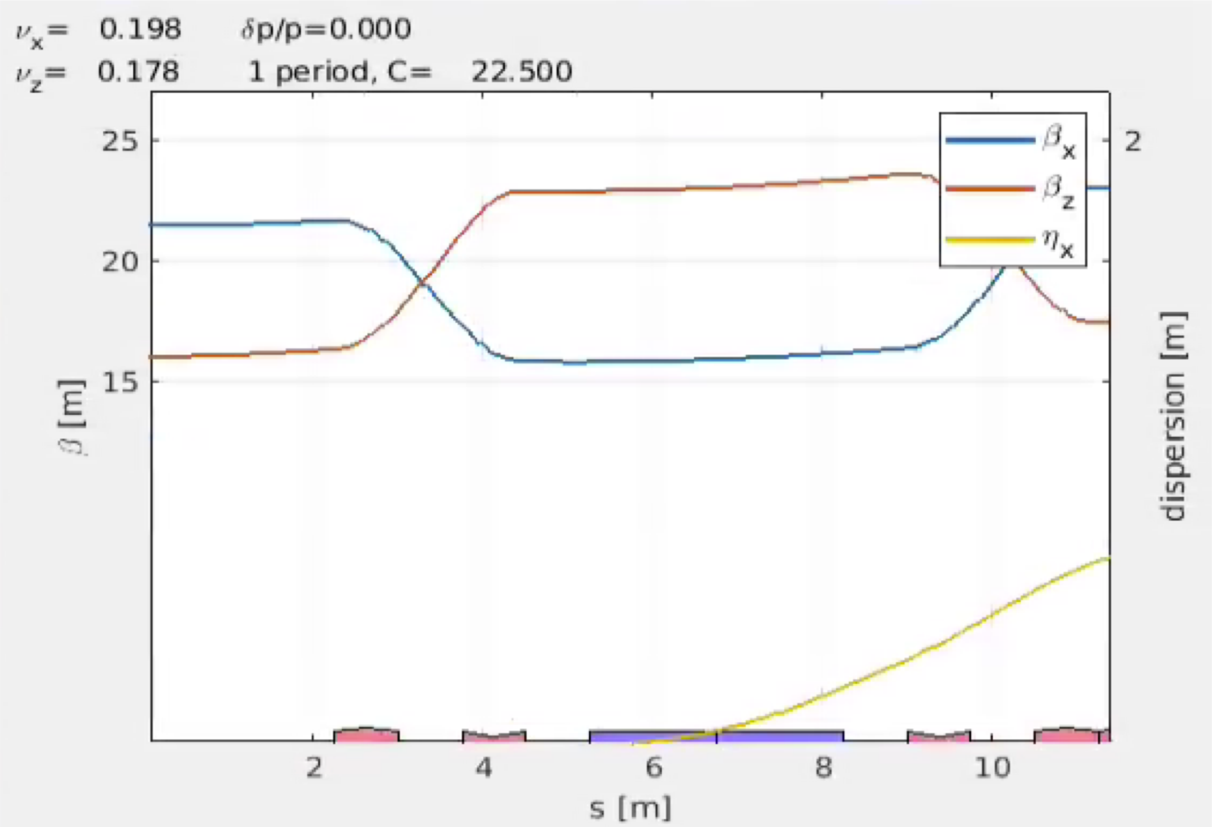
and

```
atplot(…,'inputtwiss',TwissStart)
```

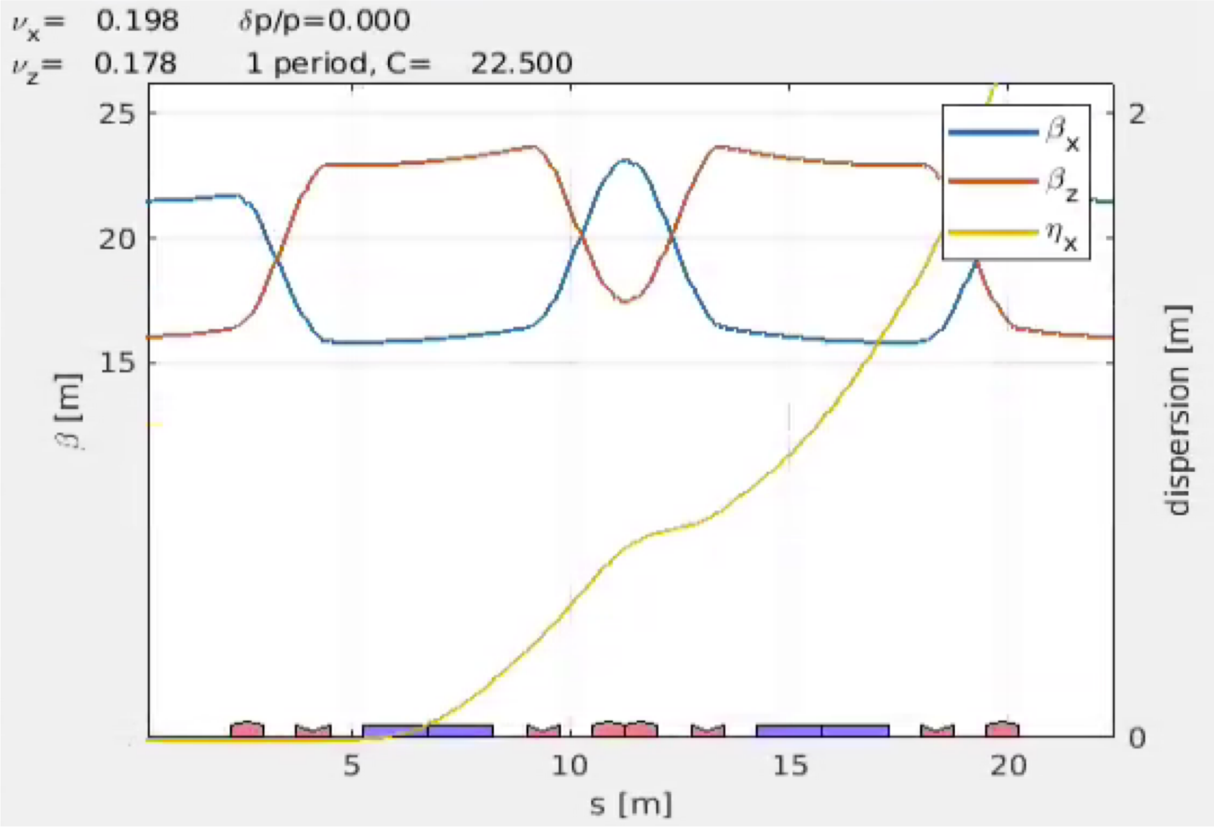
to observe the dispersion evolution in the cell



EVOLUTION OF DISPERSION



One cell



2 cells : [arc ; arc (end:-1:1)]

```
[TwissStart,~,~]=atlinopt(…,0,1)
atplot(…,'inputtwiss',TwissStart)
```

Dispersion increases at each dipole

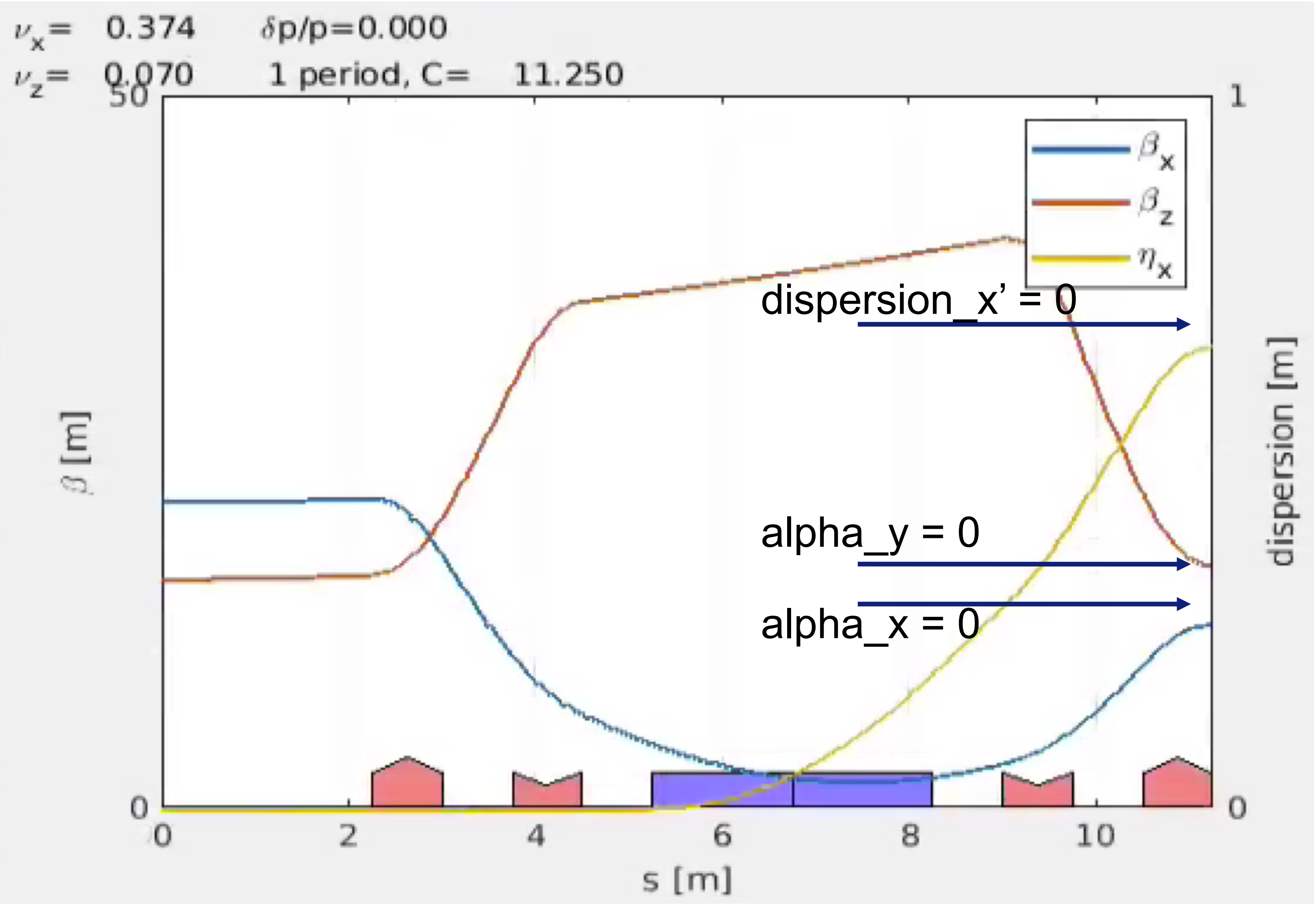
Use above +:

```
atlinopt
atmatch
atVariableBuilder
atlinconstraints
```

Rename quadrupoles: QF1, QD2, QD3, QF4.

Twiss input: from atlinopt modified
Dispersion = [0 0 0 0];

Requirements @end of cell:
Alpha_x, alpha_y, dispersion_x' = 0
Beta_y all over the cell < 40m
1000 calls
Tolerance = 1e-15

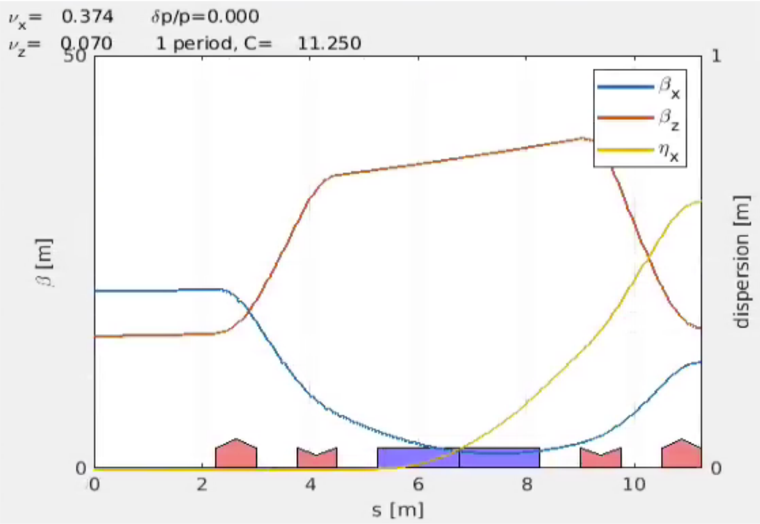


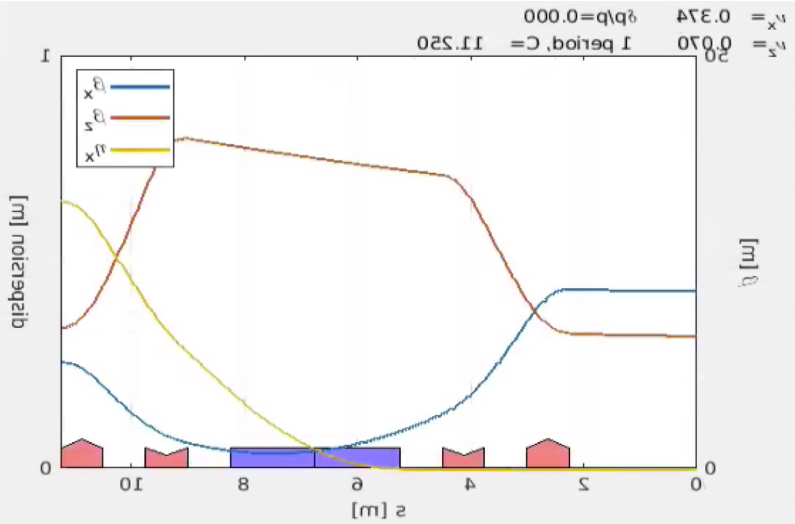
$$\alpha = \frac{\partial \beta(s)}{\partial s}$$

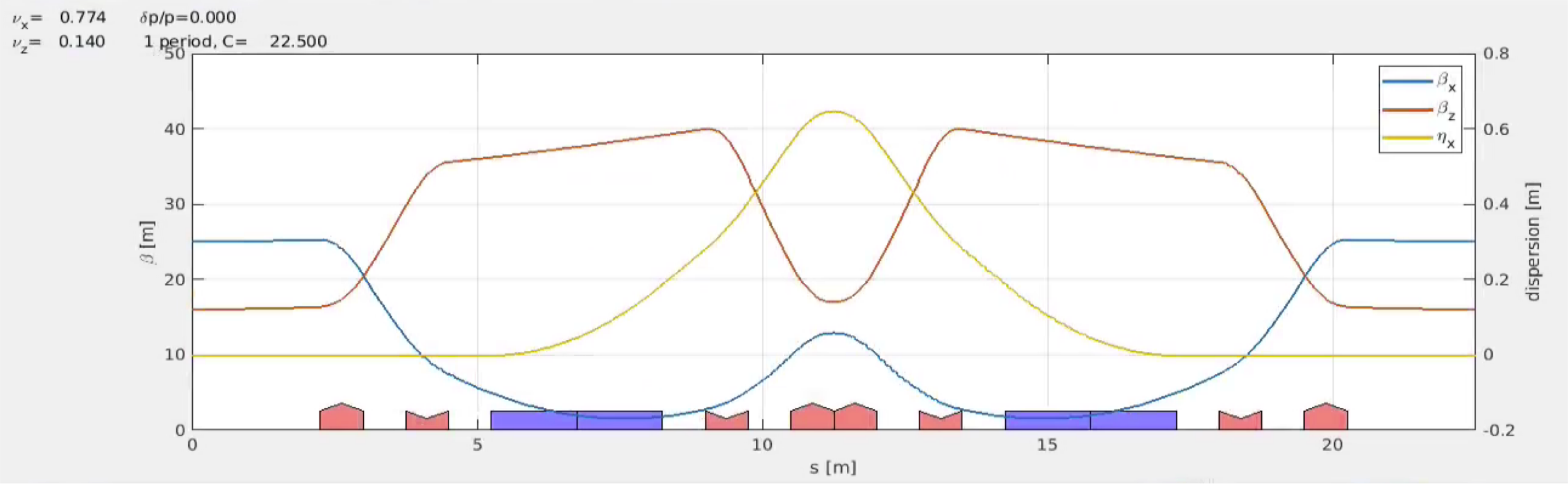
BUILD A SYMMETRIC CELL

Use matlab array slicing
To build a symmetric cell.

Compute the emittance.







MATCH PERIODIC CELL

Store quadrupole gradients from previous matching.

Match full cell (DBA) as periodic cell, without any input optics.

Use as constraints:

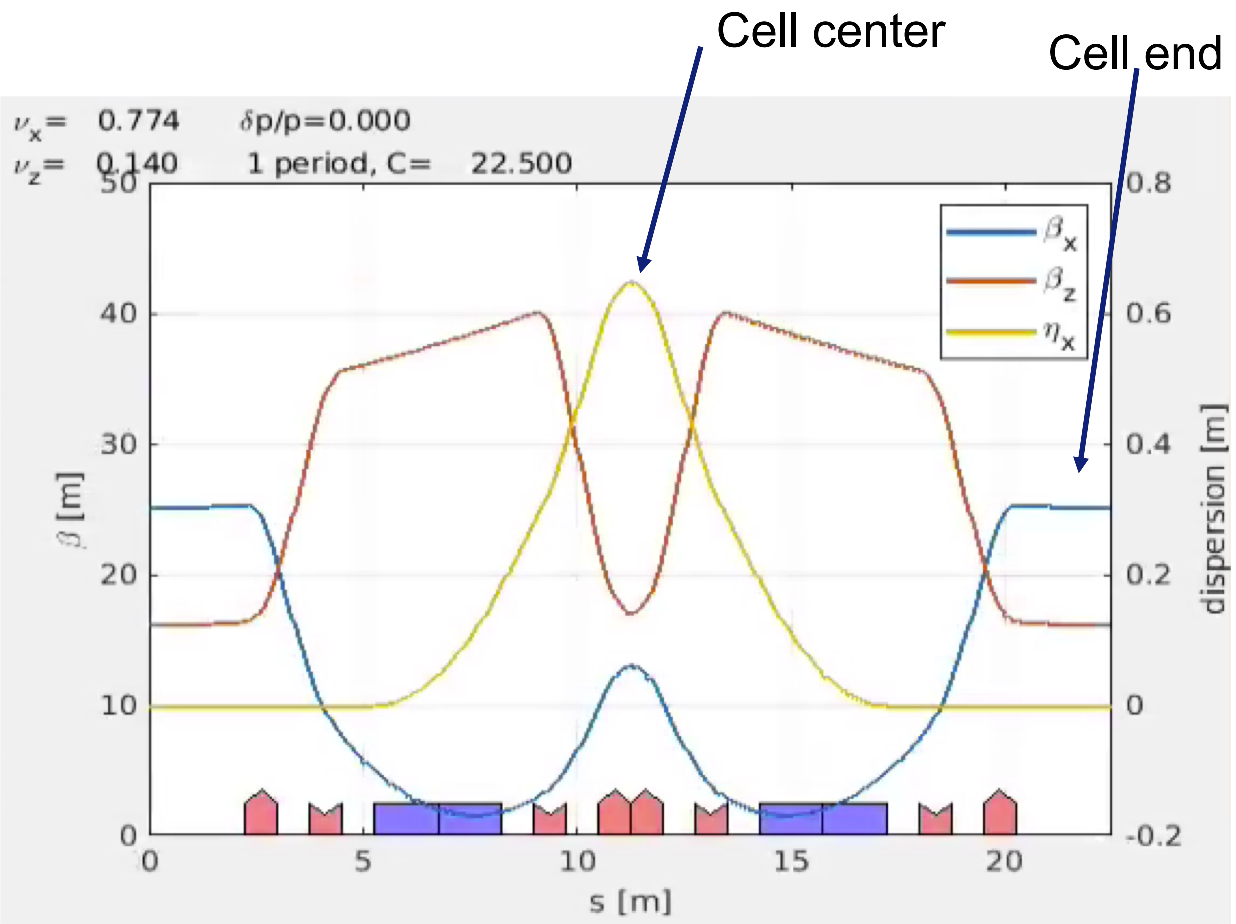
Beta_x < 60m

Beta_y < 60m

Dispersion_x' @ cell center =0

Dispersion x @ end of cell = 0

Get emittance of this lattice



7) INTRODUCE SEXTUPOLES

Use: `atsextupole, atlinopt`

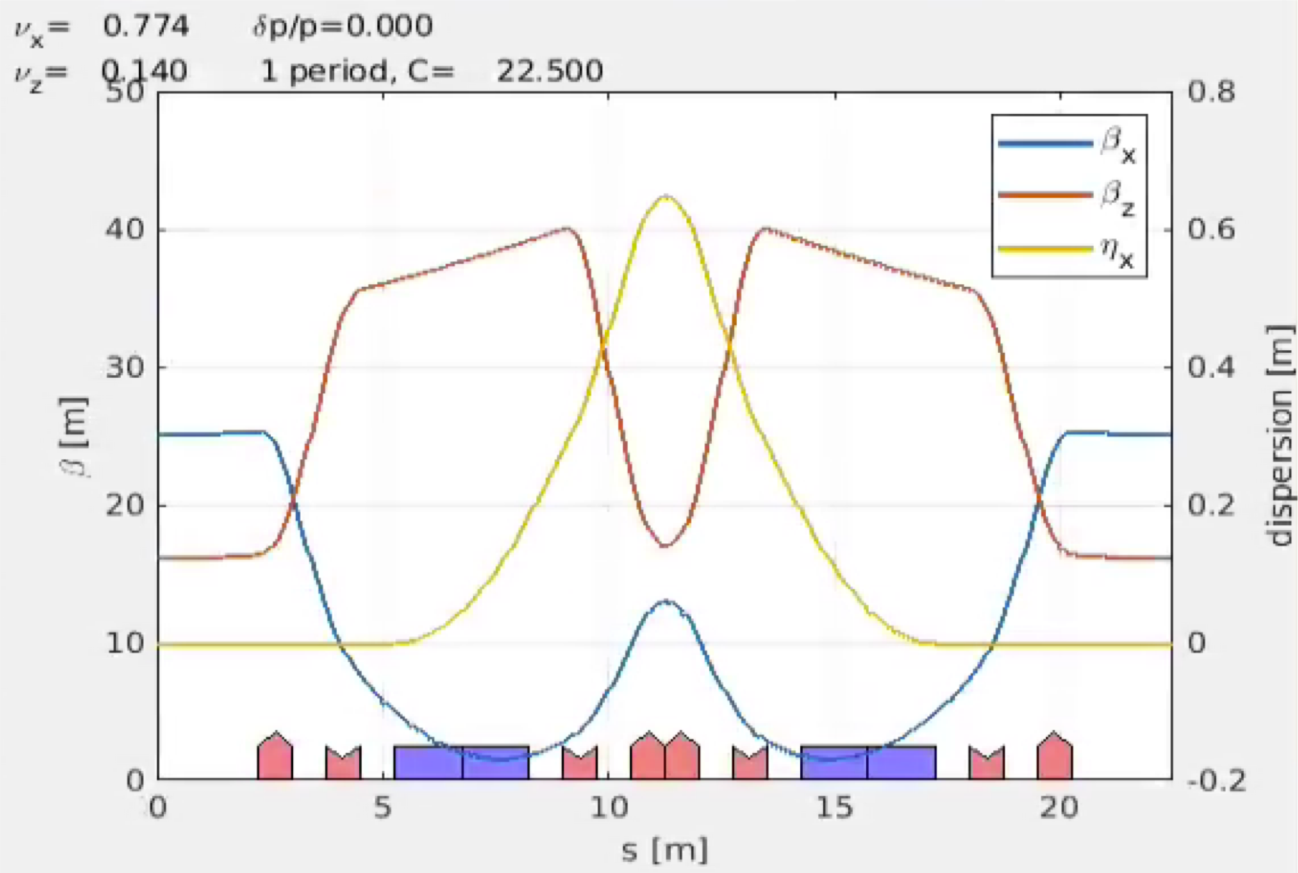
What is the best location for sextupoles?

Add sextupoles to the lattice (without changing the length of the lattice)

Rematch optics if needed.

Correct chromaticity either from scratch or using `atfitchrom`

`Compare initial chromaticity to final chromaticity.`



7) INTRODUCE SEXTUPOLES

Use: `atsextupole, atlinopt`

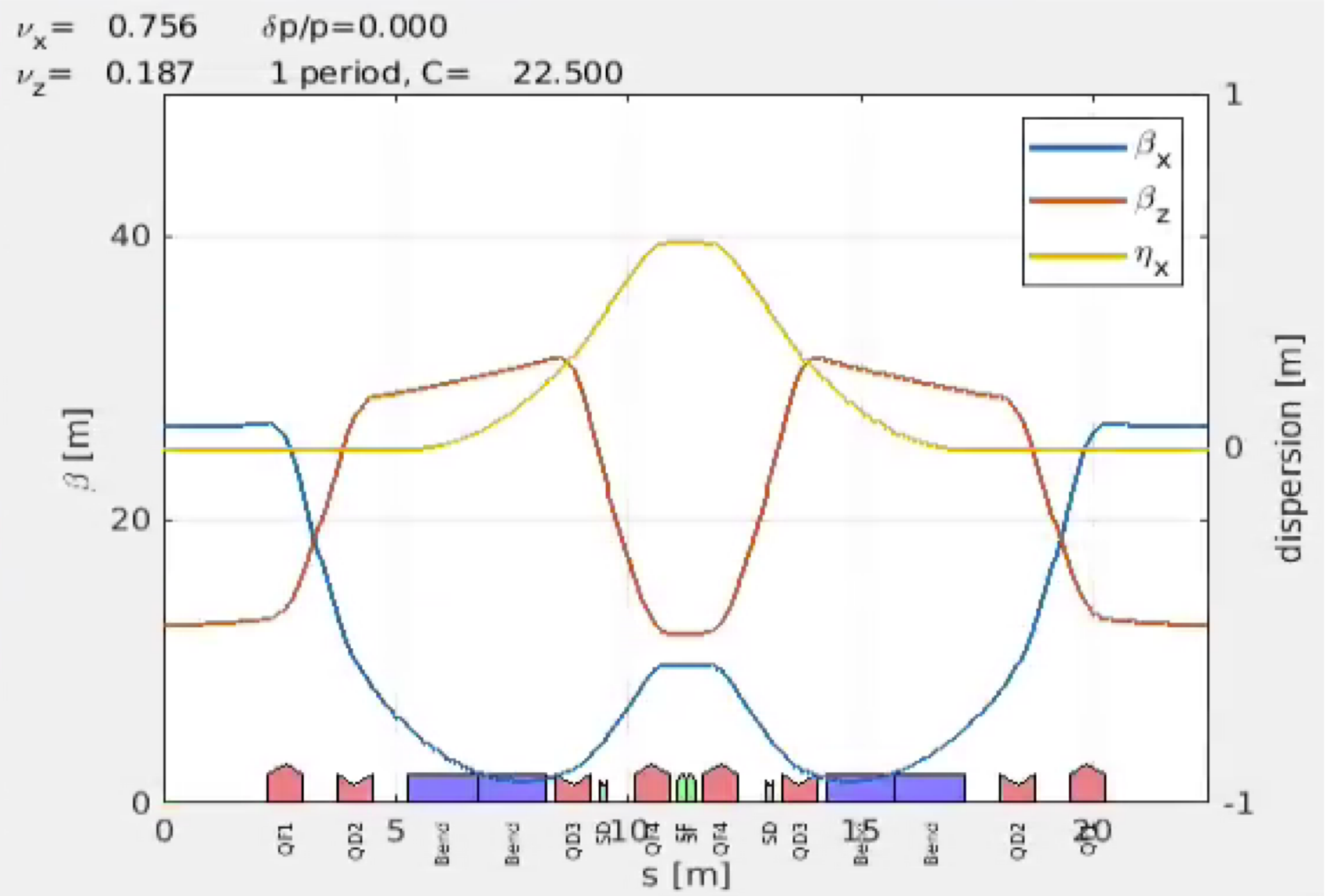
Find best location for sextupoles

Add sextupoles to the lattice (without changing the length of the lattice)

Rematch optics if needed.

Correct chromaticity either from scratch or using `atfitchrom`

`Compare initial chromaticity to final chromaticity.`



Use `atrfcavity` and `atsetcavity` to add an RF cavity

Compute emittance

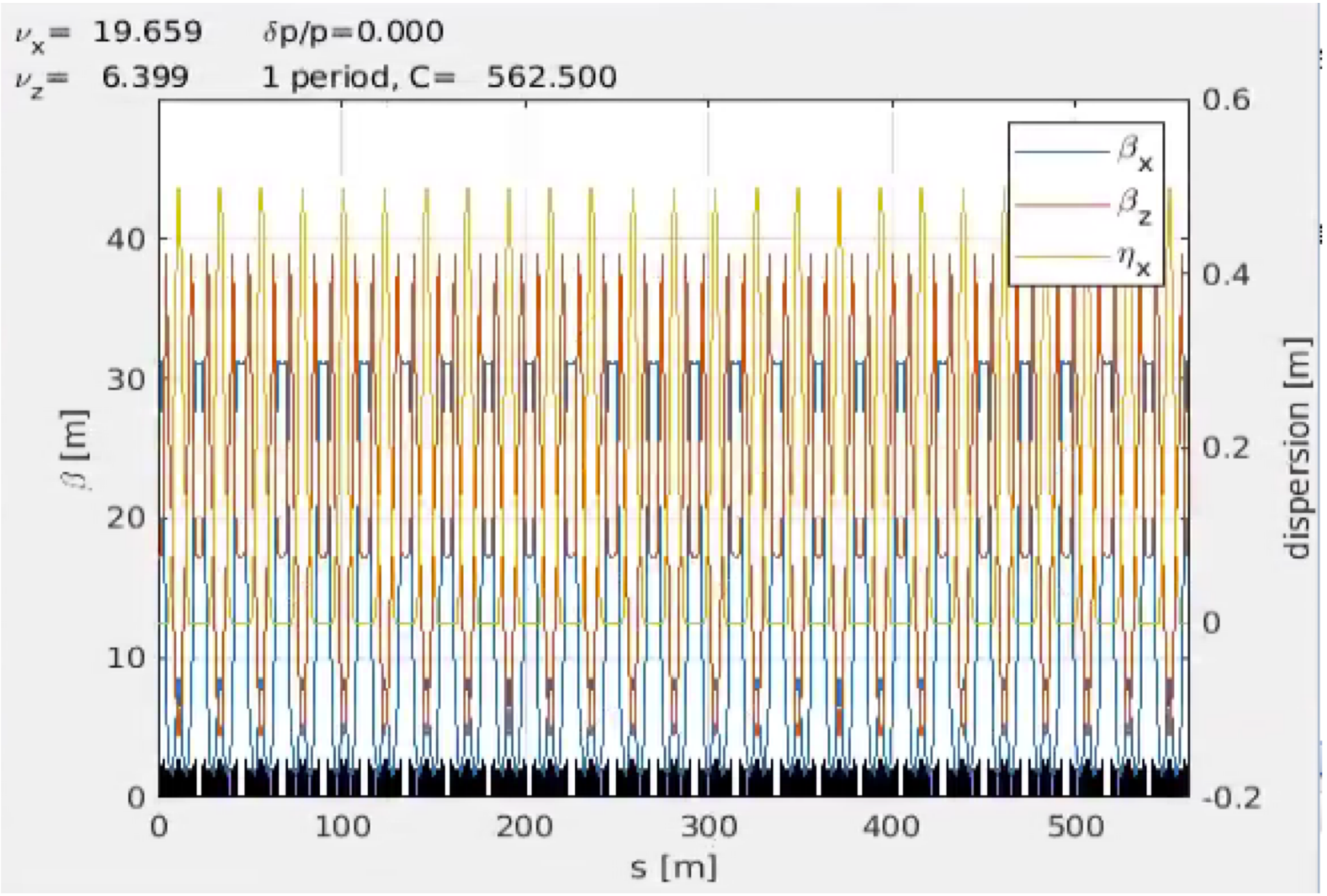
Compute emittance using `atx`

Compute emittance using `ringpara`

Use `atgeometry` to

verify total angle is correct

Verify lattice geometry (full ring)



9) MATCH TUNE

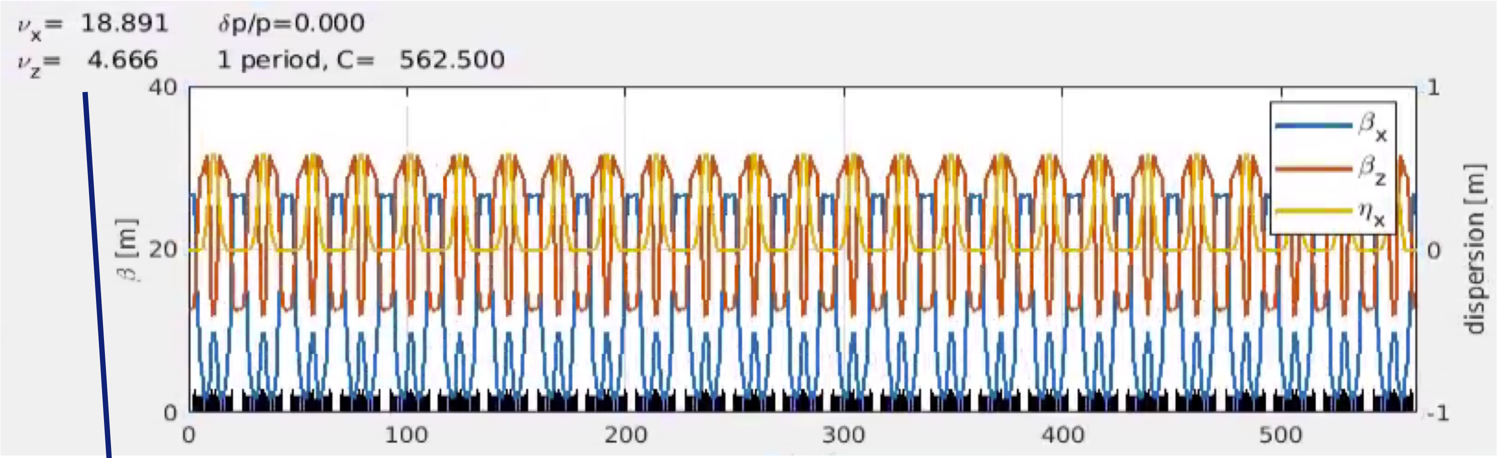
Use `atfittune`

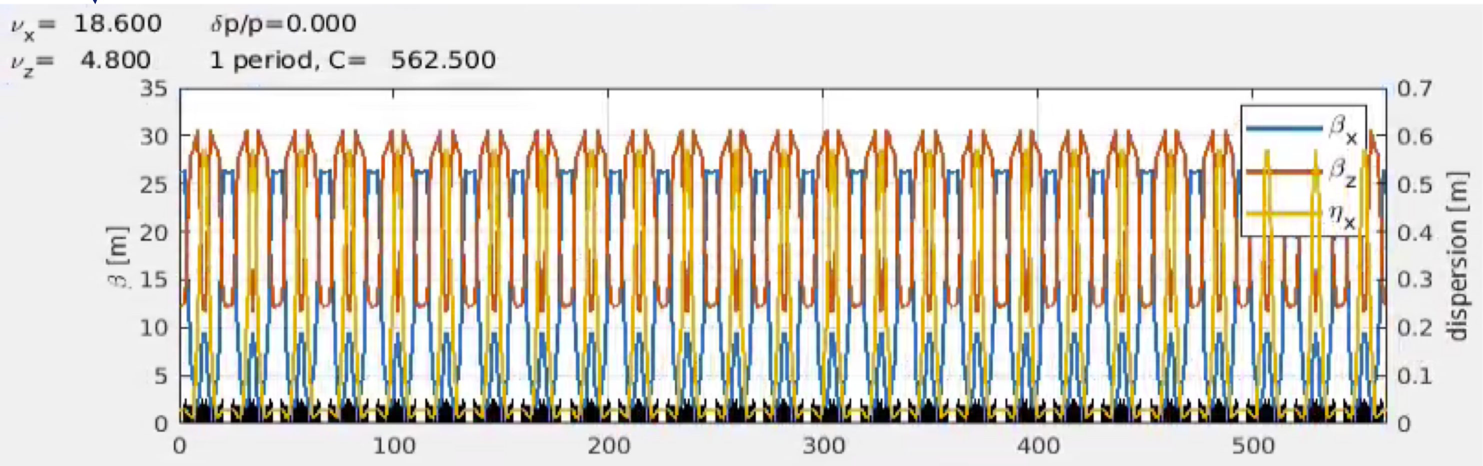
Match tune to some value

ex [.44 .39]

Compare `atx` outputs

Compare quadrupole gradients





Use:

`ringpass`

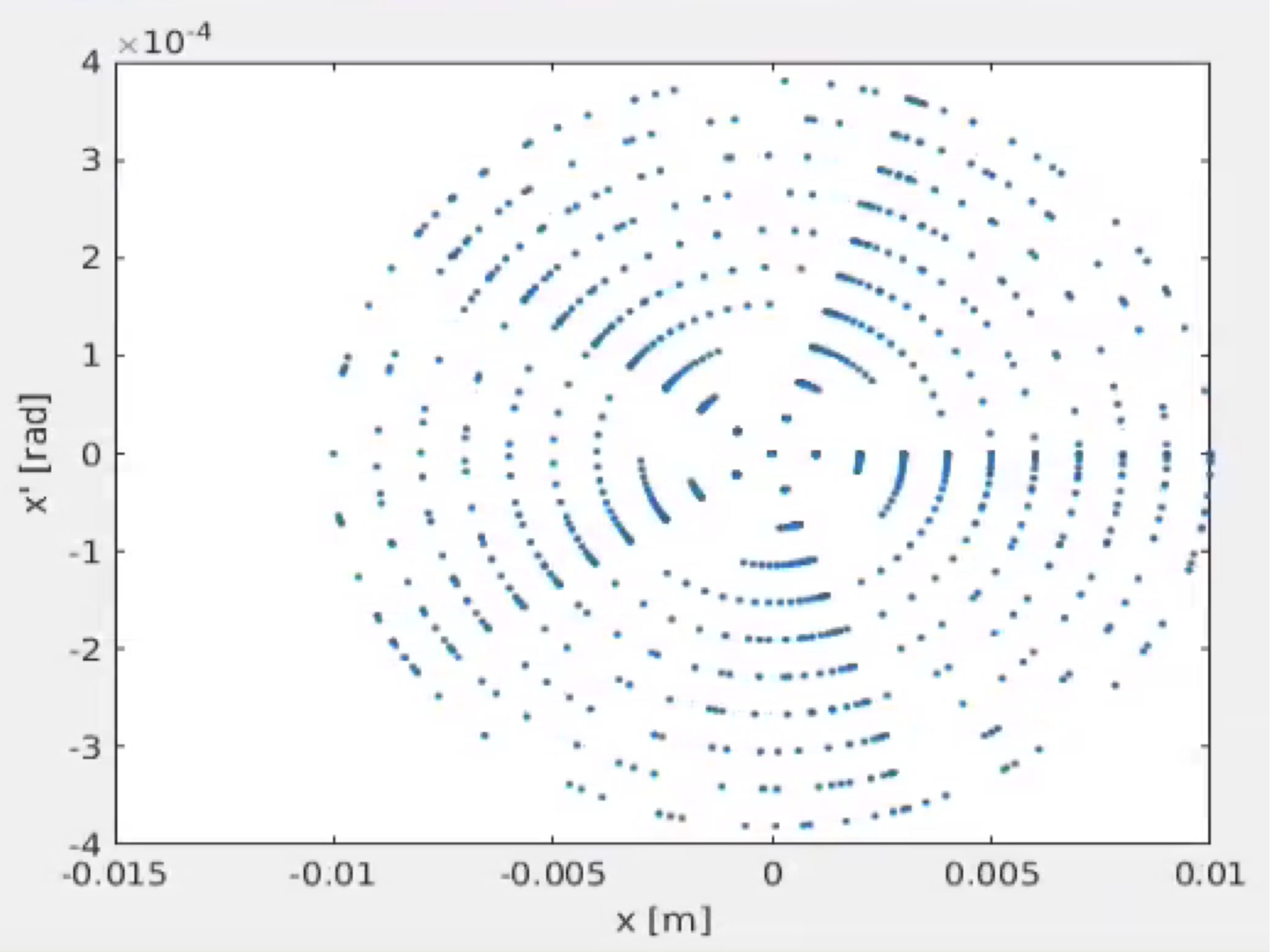
Track 10 particles with initial amplitudes at

1 - 10 mm for 4000 turns

Plot phase space x-x', y-y', ct-delta

Same with:

- **Turn on radiation** `atradon`
- **Sextupoles off** `atgetcells atsetfieldvalues`
- **Larger initial amplitudes**



What differences do you notice?

10) TRACKING

Use:

`linepass`

Track 10 particles with initial amplitudes at

1 - 10 mm for 4000 turns

No radiation

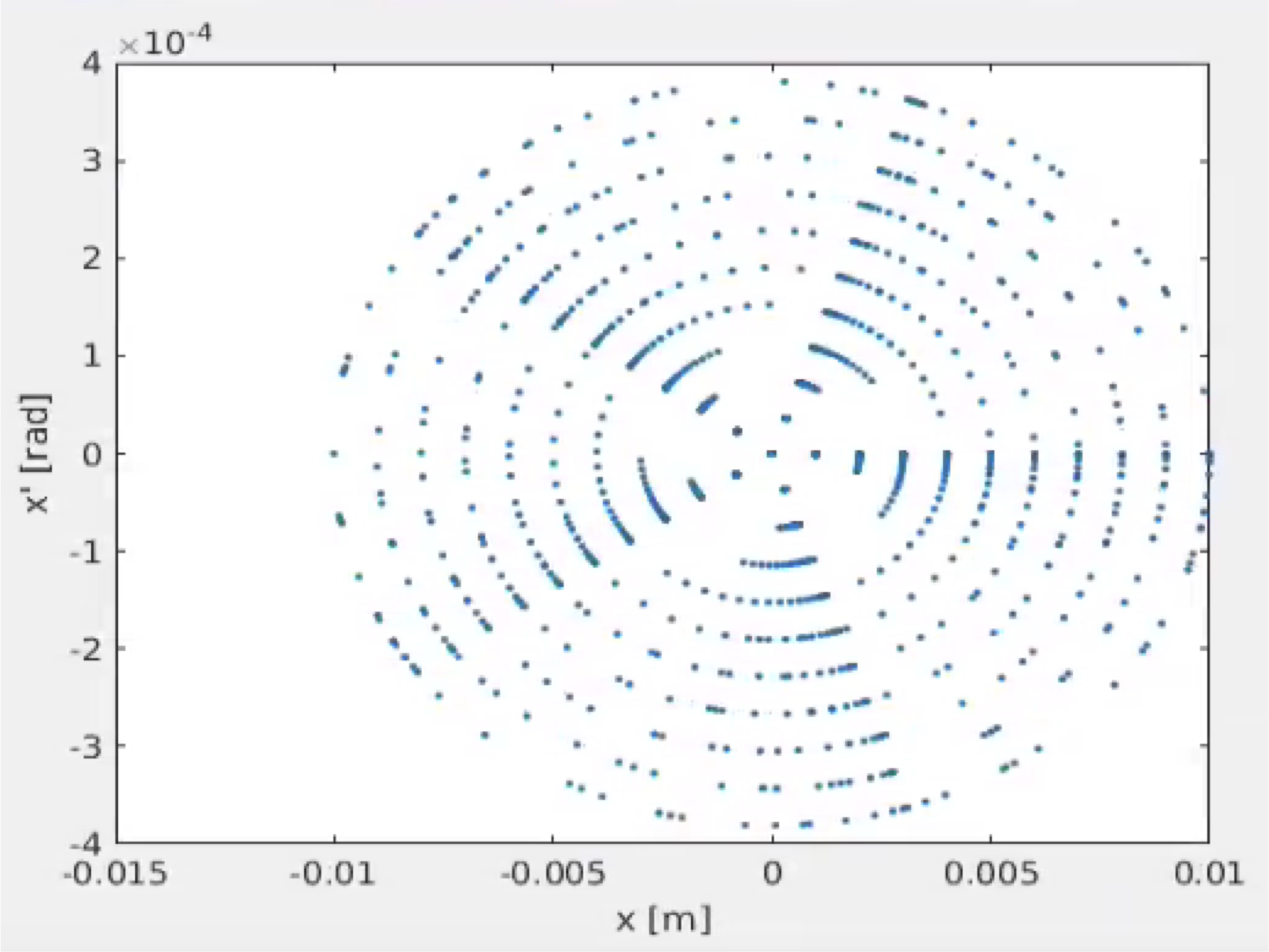
Plot phase space x-x', y-y', ct-delta

At QF1 center,

QD2 center,

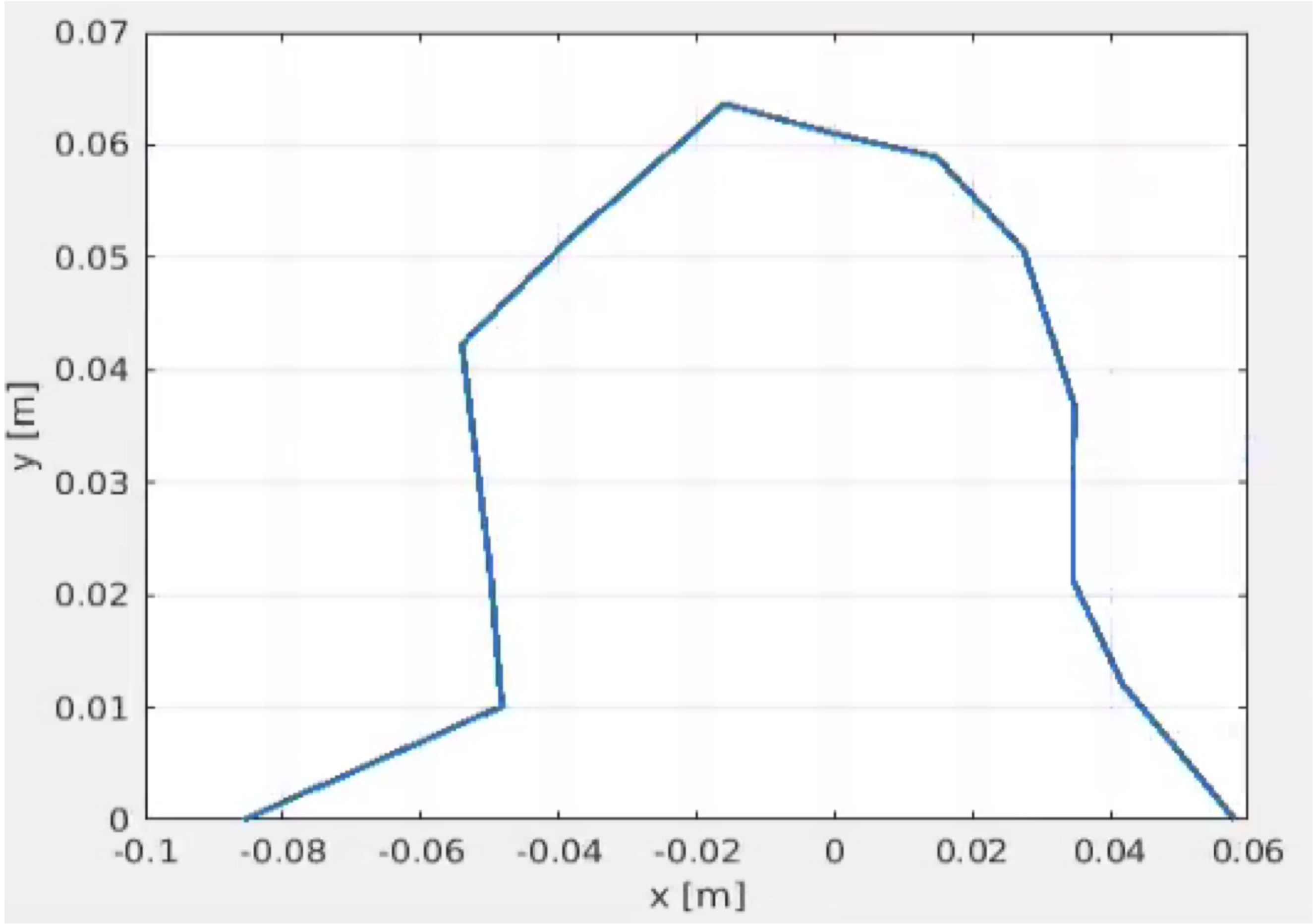
Lattice entrance

Sext. entrance



11) DYNAMIC APERTURE

Use `atdynap` for a rough computation of transverse D.A.



Compute for 2 different tunes and compare also natural emittances.

Compute sextupoles off

FURTHER EXERCISES

OUTLINE

Install AT

AT concepts: integrators, coordinate system

Build a lattice: lattice elements, tune, chrom, compute and plot optics (periodic and open line)

Tracking, phase space, single turn with initial conditions

DA, MA

Cavity setting

Lattice geometry

Exercises:

1) Build a FODO: 2 quads + dip + sext + bpm/corr
2) Phase space: linear lattice, lattice with sextupoles, lattice with RF, lattice with radiation
3) Compute detuning with amplitude and momentum
4) Compute DA
5) Injection efficiency (atbeam)
6) Tune scan (DA@inj vs tunes)

MATCHING

Exercises:

1) Match beta functions in FODO lattice
2) Match dispersion suppressor
3) Match with initial conditions
4) Optimize dipole field profile to minimize effective emittance

OUTLINE

Errors and correction: set errors, look at orbit, dispersion, beta-beating, coupling

Exercises:

1) Produce a closed orbit bump
2) Measure dispersion
3) Correct orbit: measure orbit, simulate/measure RM, correct. Compare simulated/measured
4) Set gradient quad errors, correct tune. Same with sextupole misalignments.
5) Several error seeds, look at distribution of emittances.
6) DA evolution increasing errors.

MATCHING

Exercises:

1) Match beta functions in FODO lattice
2) Match dispersion suppressor
3) Match with initial conditions
4) Optimize dipole field profile to minimize effective emittance

REAL WORK

In December we had an open list of topics to study:

- 8 bend achromat option
- short bend in the middle of the cell for Bending Magnet beamlines
- long straight section of 10-15m for large beta at injection, symmetric on both sides of the ring.

Should we work on this topics?

If we have sufficient time and manpower we could also include:

- error tolerance studies
- dynamic aperture/ lifetime/ injection efficiency estimates (cluster computing)
- booster lattice optics
- transfer line optics

CONCLUSION

You know how to use AT.