Electron Line Design for Run 2

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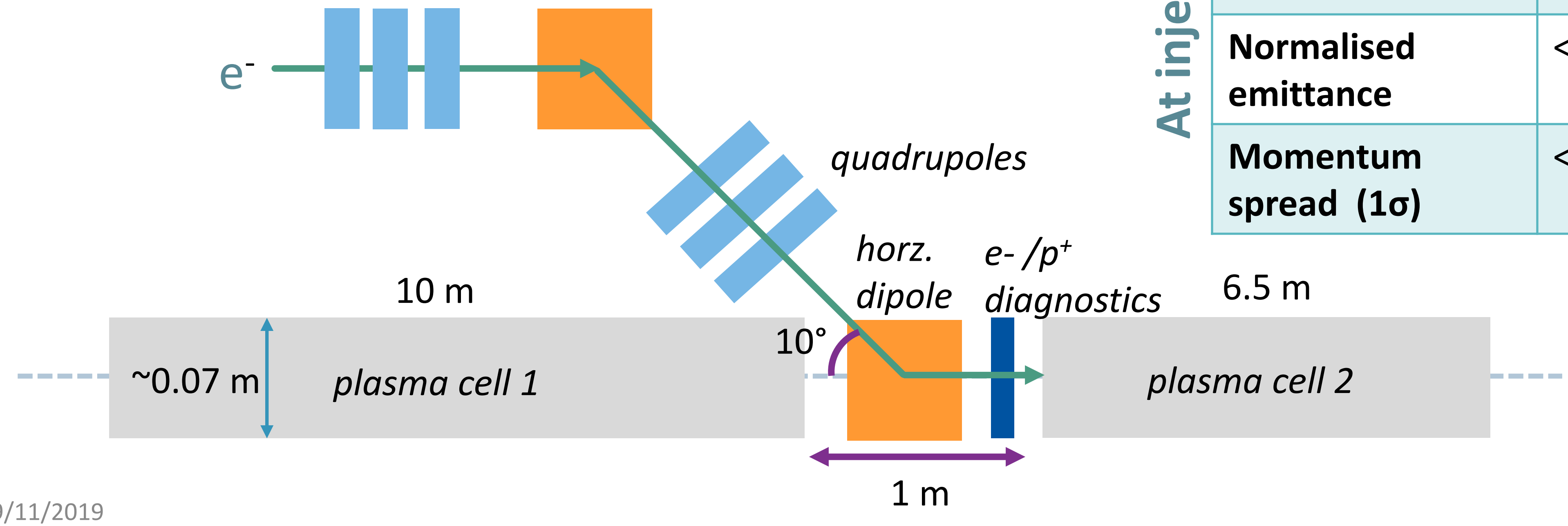
e- injection to the 2nd plasma cell

- Challenging requirements on the beam size at injection.
- Require a module which is isochronous and approximately achromatic.
- Design assumes the source is on the same vertical inclination as the proton beam.

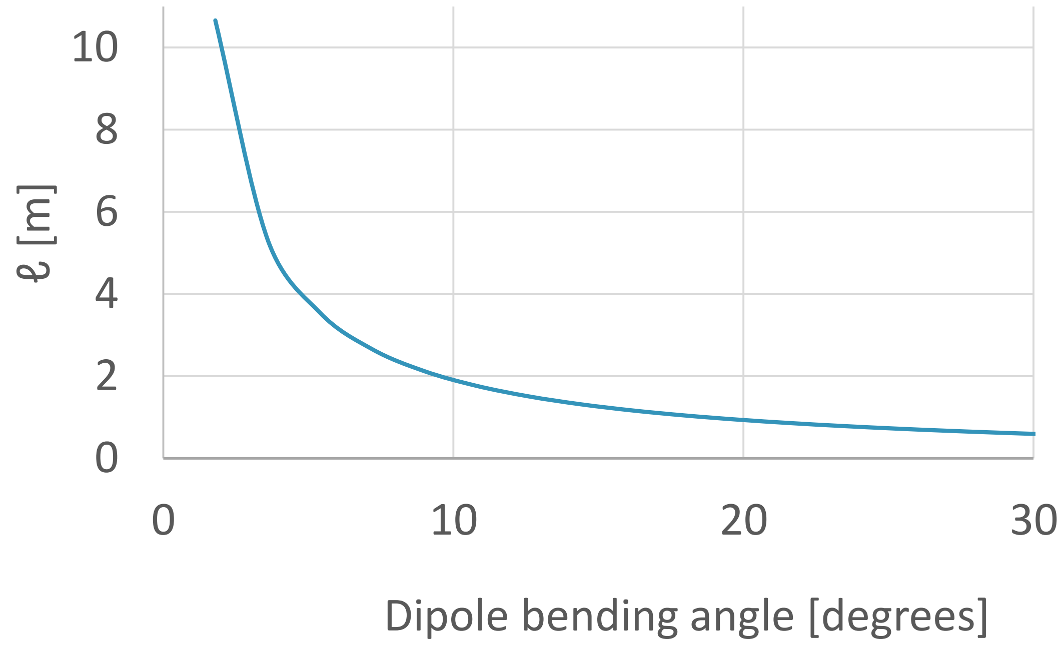
At injection point

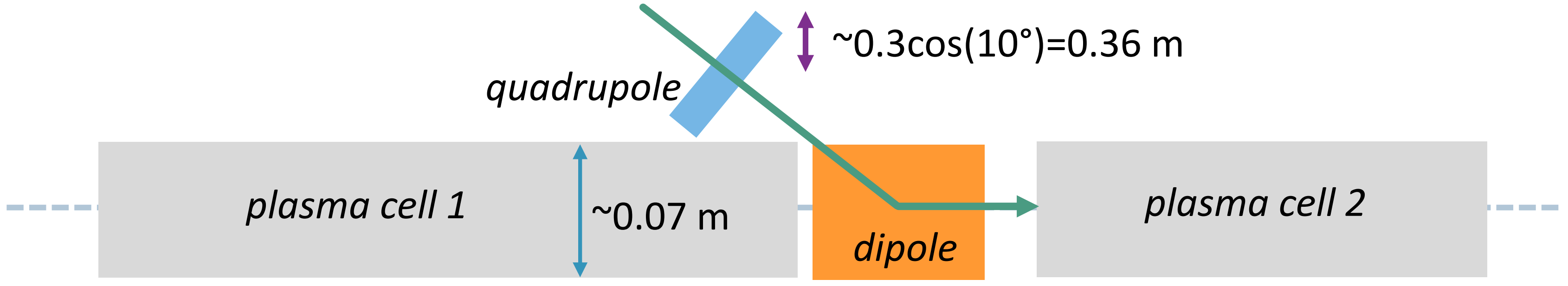
Dispersion	0 (achromatic)
R56	0 (isochronous)
Sigma (x,y) [um]	5.25
Electron energy	165 MeV
Normalised emittance	<2 mm mrad
Momentum spread (1σ)	<0.2%



Dipole parameters

- Dipole bending angle of 10° chosen as a compromise:
  - keeping the dipole angle as small as possible to reduce length of dipole and chromatic effects
  - keeping the distance between the dipole and the first quadrupole down, so as to fit the design into the tunnel
- Minimum distance from dipole to first quadrupole ℓ=1.9 m.
- Deflection of proton bunch by dipole of 0.004 degrees, requires a **~0.7 mm** offset of the proton beam at the start of the first plasma cell to correct for.

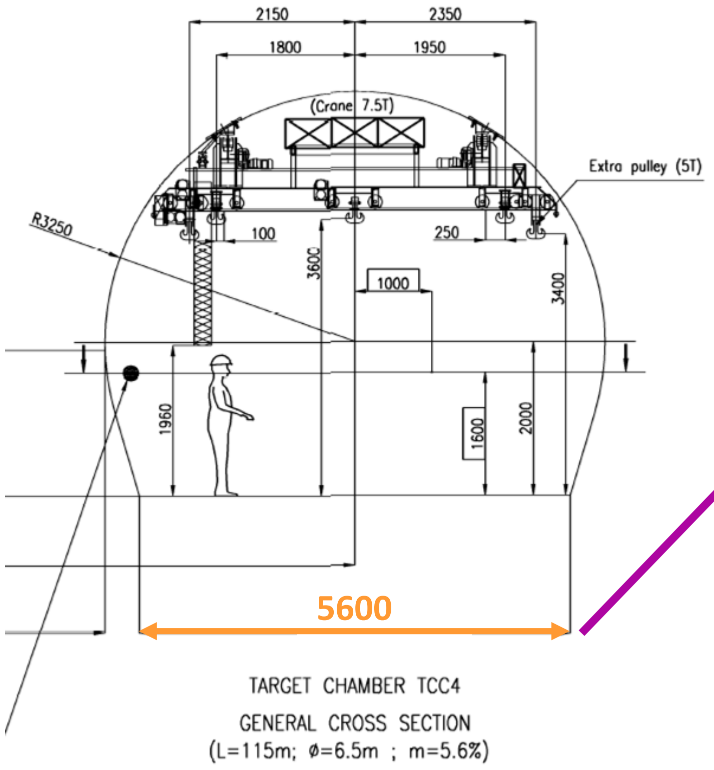


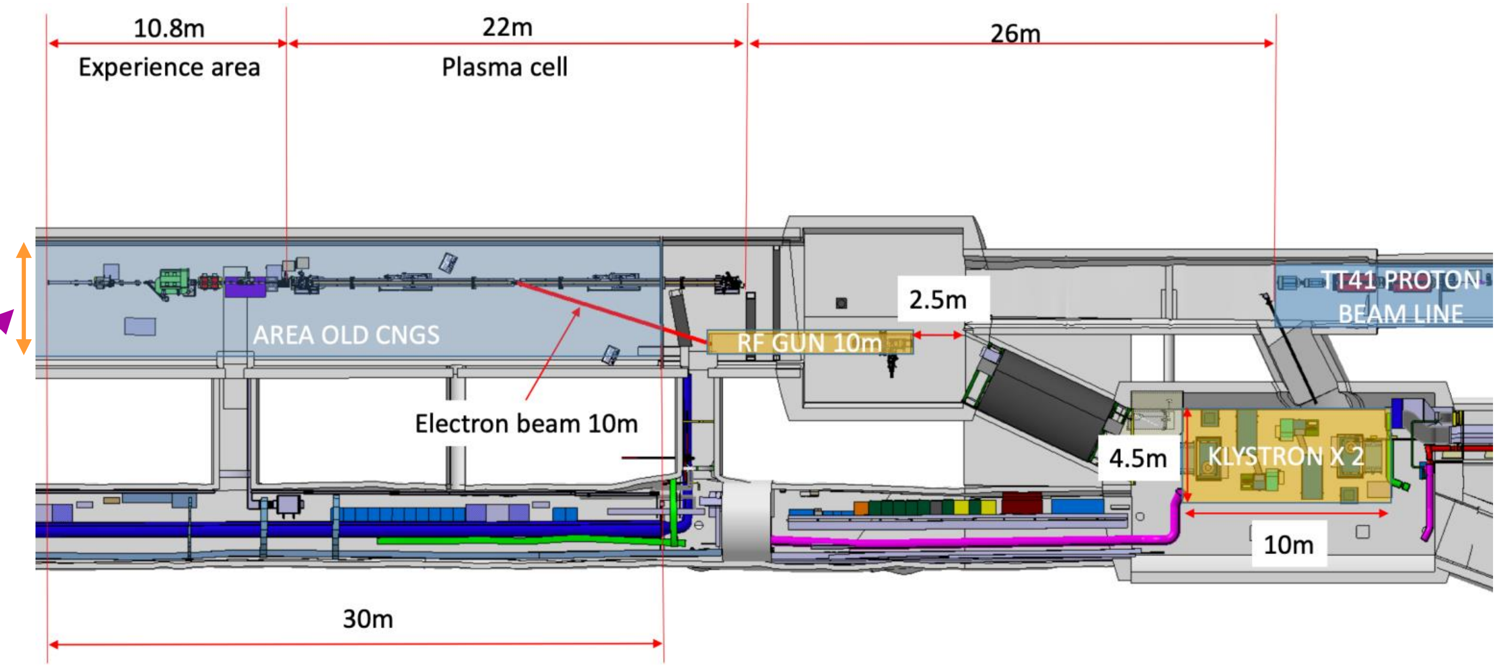


Dimensions of the tunnel

Target Chamber

Length of target chamber	115 m
Diameter of target chamber	6.5 m (int.)
Floor width of target chamber	5.6 m

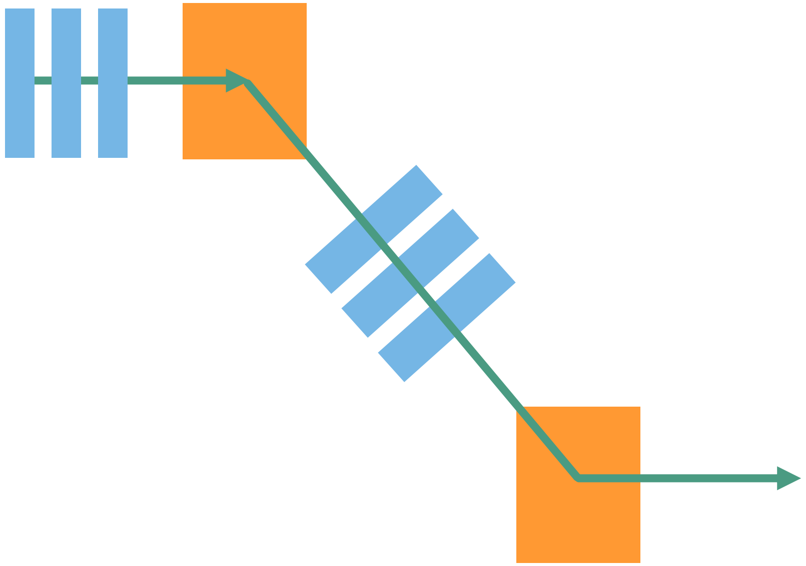




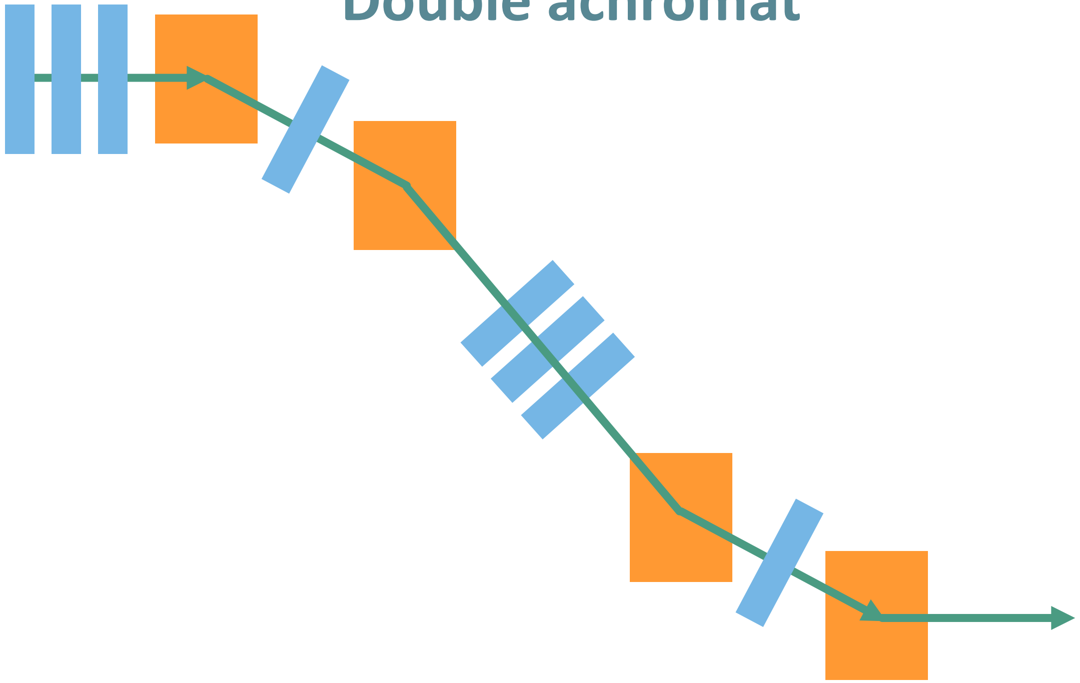
Design for the dog-leg

- By symmetry requirements, we could have either two or four dipoles.
- Require a module which is isochronous and approximately achromatic.
- Focusing performed just before the dog-leg so that the dog-leg is used to map the focal point 1-to-1 to the injection point.

2 dipole dog-leg



Double achromat



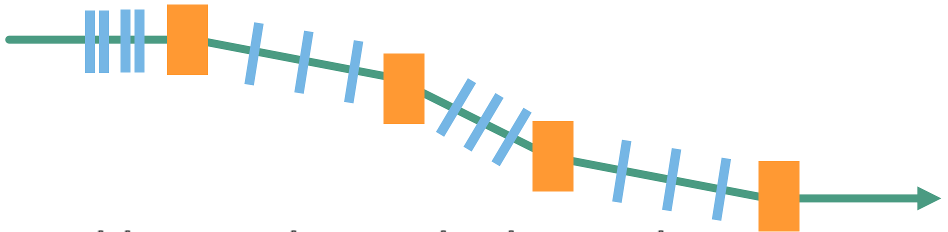
Double-achromat design

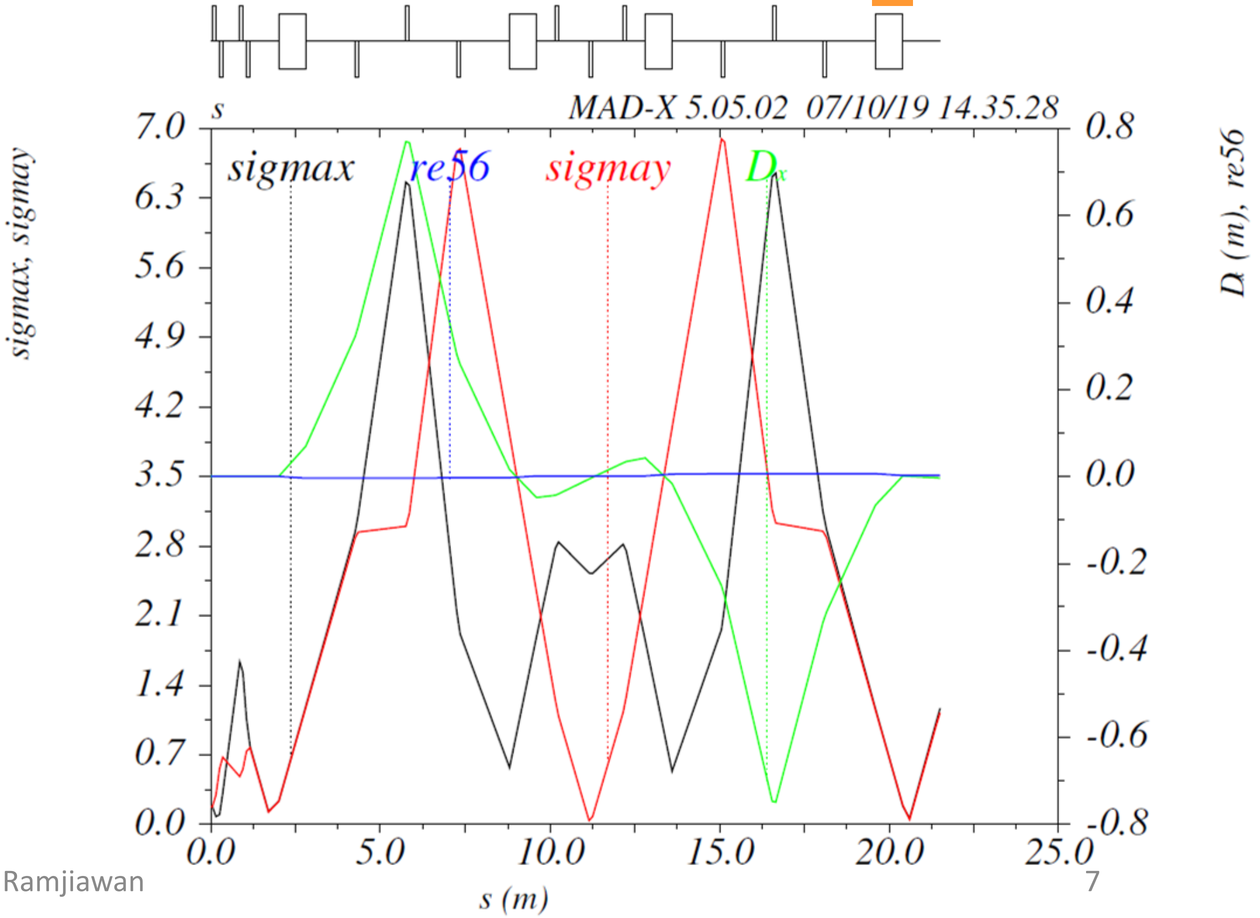
Double achromat design - optics

- 21.5 m length double-achromat design.
- Space for beam instrumentation in the line.
- Isochronous and achromatic.

Parameters at plasma merge-point – considering only **linear optics** with no errors

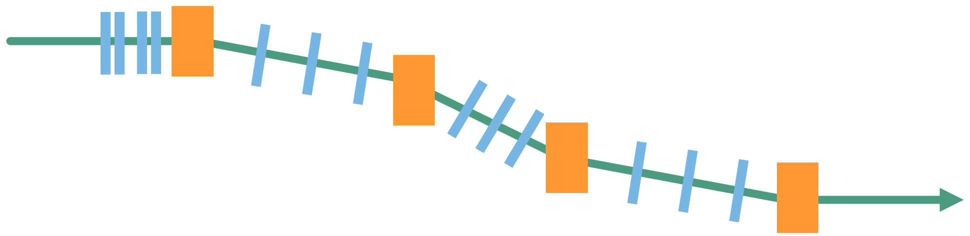
$\beta_x = 0.005,$
$\beta_y = 0.005,$
$\alpha_x = 0.000,$
$\alpha_y = 0.000,$
$D_x = 0.000,$
$D_y = 0.000,$
$R_{56} = -0.000,$
$\sigma_x = 2.45\ \mu\text{m},$
$\sigma_y = 2.50\ \mu\text{m}$

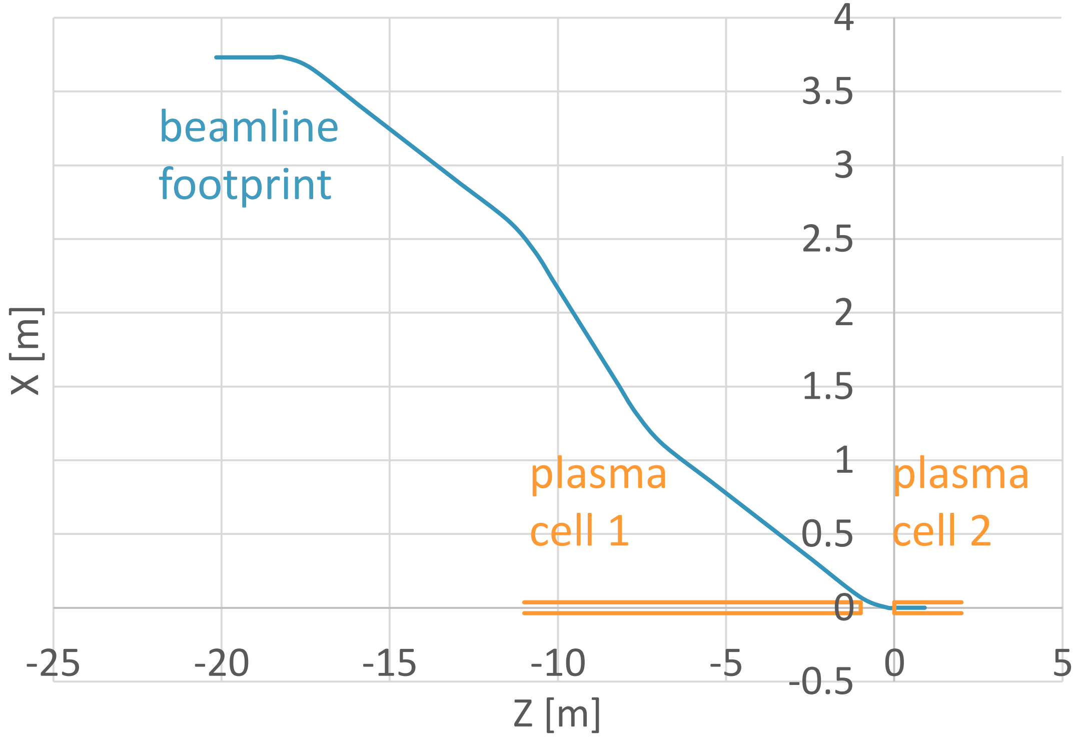




Double achromat design - survey

- While also including the dimensions of the components, the footprint of this design would be **~ 4.5 m x 21.5 m**.
- The width of the tunnel suggests that ~3 m would be our maximum width for a beamline without widening the tunnel.
- There is a possibility to produce a double-achromat design which is smaller width-ways but this would come at the expense of being able to fit the desired beam instrumentation into the line.





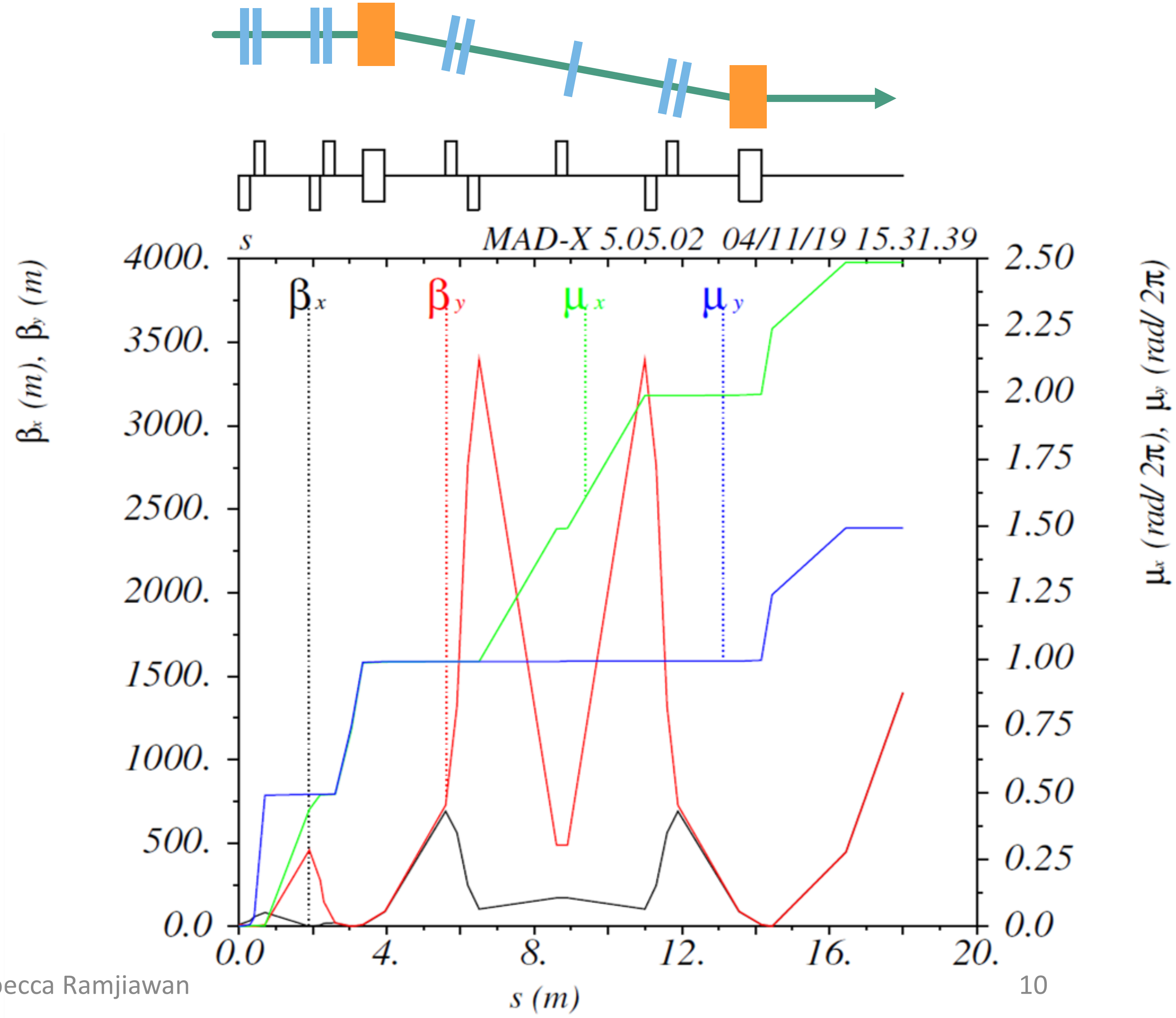
Two-dipole dogleg

Dogleg design - optics

- If we don't require complete isochronisity but instead keep the bunch lengthening to a minimum then we can have a two-dipole design.

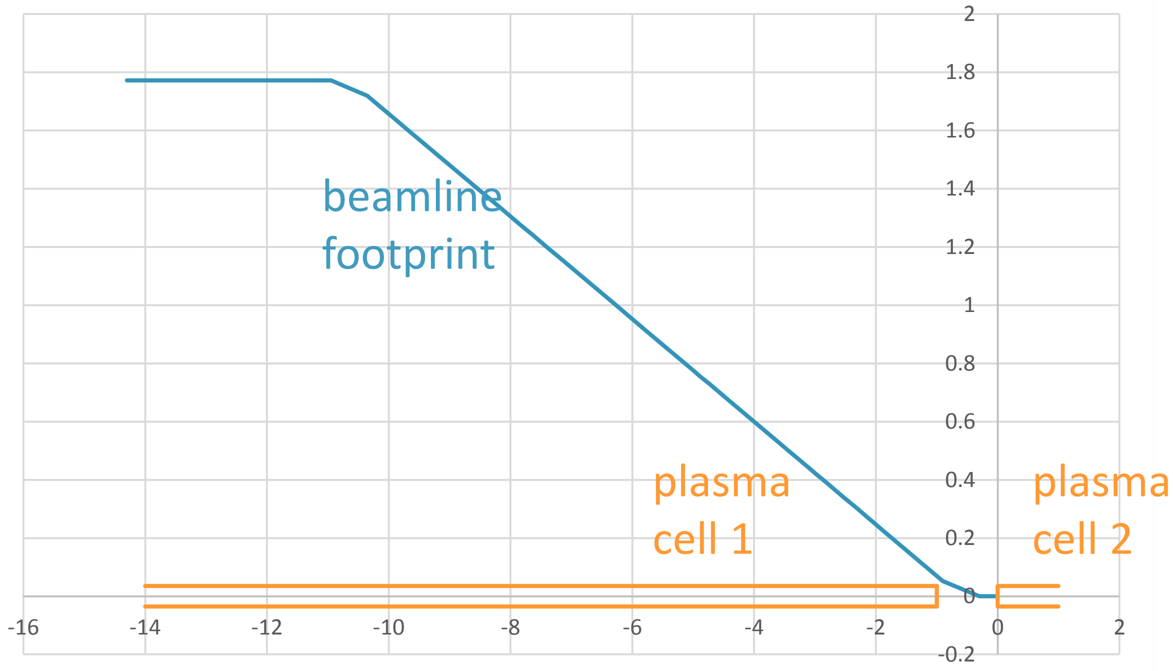
Parameters at plasma merge-point – considering **only linear optics** with no errors

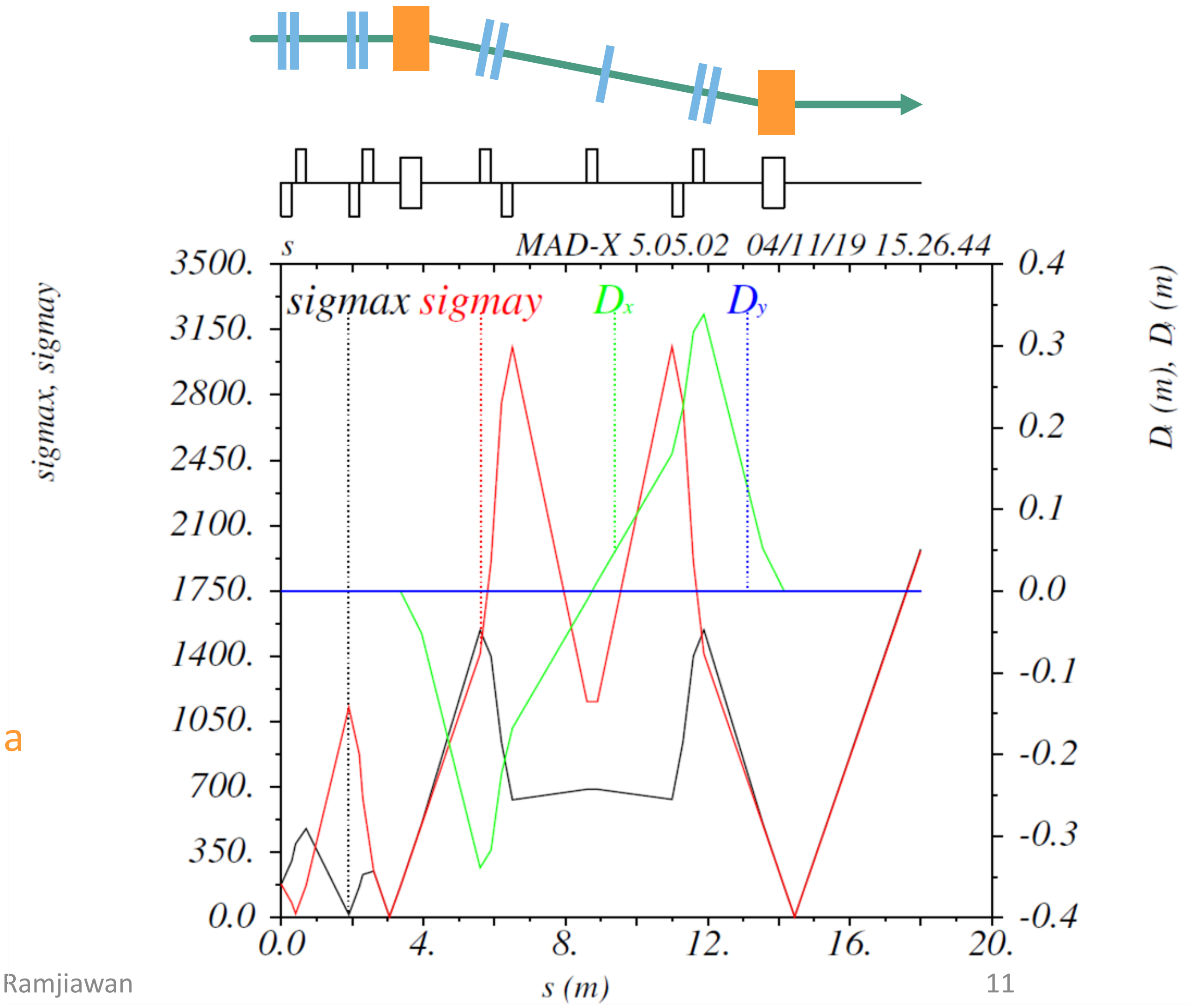
$\beta_x = 0.0025,$
$\beta_y = 0.0025,$
$\alpha_x = -0.000,$
$\alpha_y = -0.000,$
$D_x = 0.000,$
$D_y = 0.000,$
$R_{56} = -0.0059,$
$\sigma_x = 1.72\ \mu\text{m},$
$\sigma_y = 1.76\ \mu\text{m}$



Dogleg design - survey

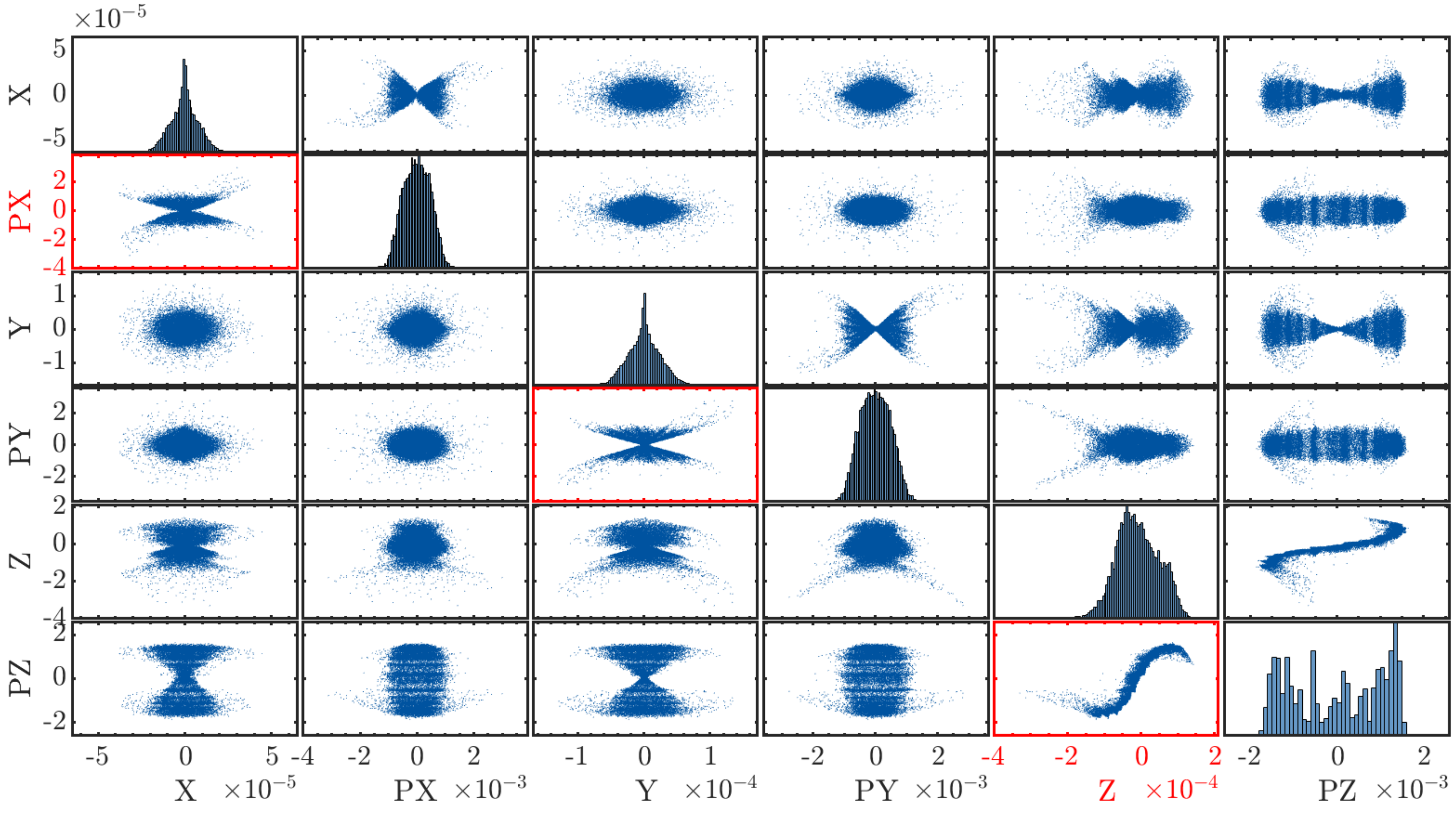
- While also including the dimensions of the components, the footprint of this design would be **~ 2.5 m x 14.5 m**.
- This design **should fit within the tunnel** as the width of the tunnel floor is 5.6 m.





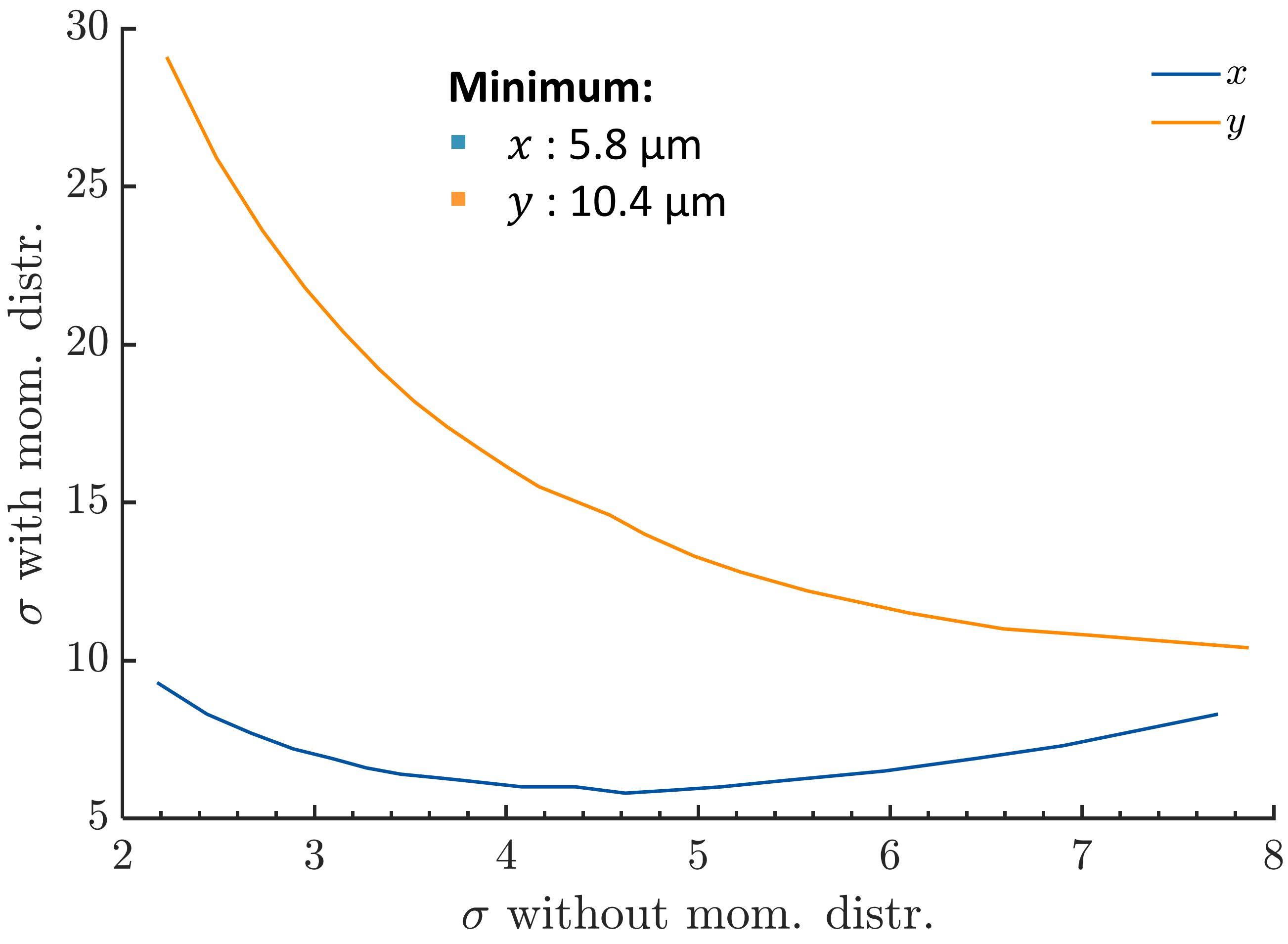
Beam distribution at injection point

- Representations of 6D beam distribution at injection point.
- x-px, y-py and z-pz are highlighted in red.



Chromatic effects (no errors modelled)

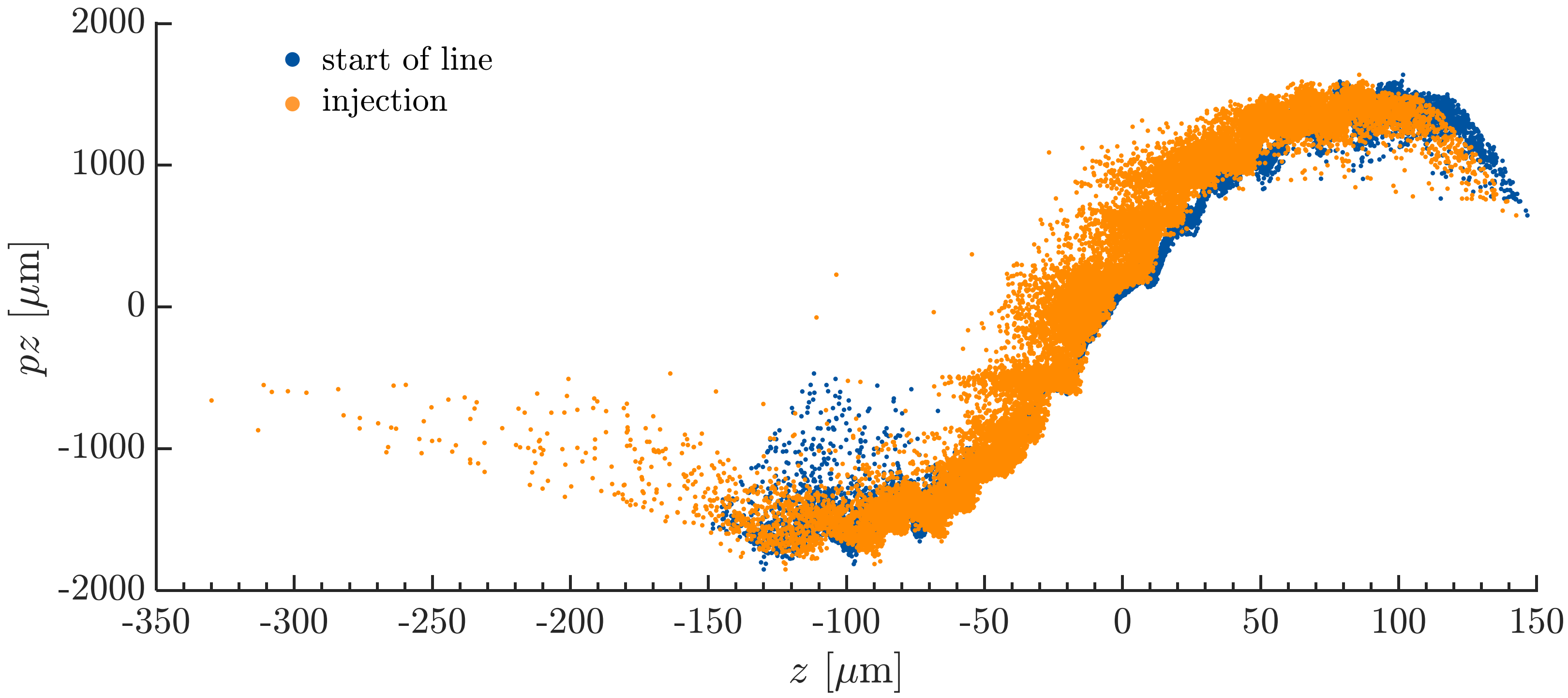
- Although, with linear optics we can match a beam to <2 μm, when we include chromatic effects the beamsize is much larger.
- When we squeeze the beamsize (while considering only linear optics) we increase the quad strengths and then become more sensitive to chromatic effects thus increasing the beamsize.
- Even without considering errors we **cannot** achieve a 5 μm beam unless either the momentum distribution is smaller or we can reduce the chromatic effects using sextupoles.



Dogleg design - bunch length

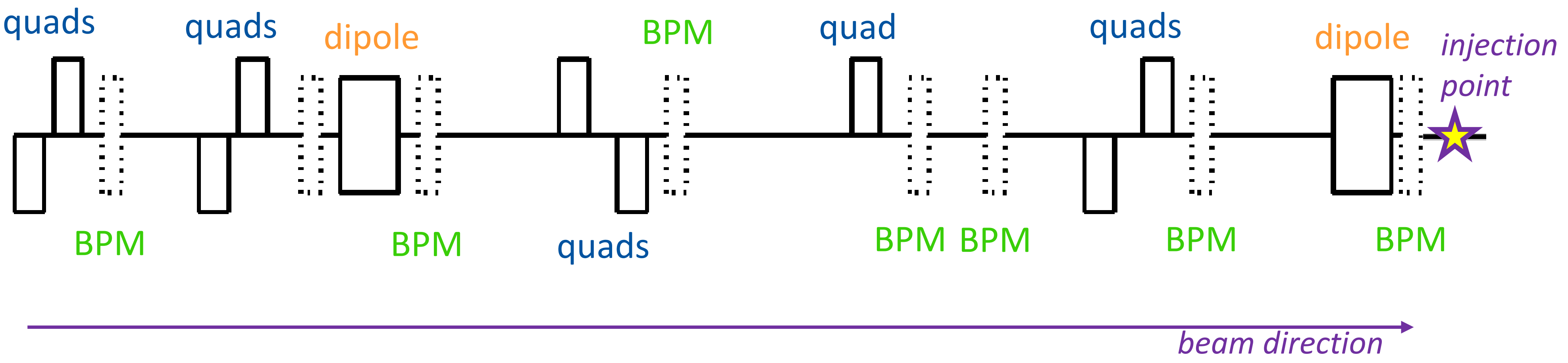
Line has a $R_{56} = -0.0059$, corresponding to approximately no change in bunch length across line. By tracking 20,000 macro-particle:

- Bunch length at start of line: 61.6 μm (205.5 fs)
- Bunch length at injection point: 58.9 μm (196.5 fs) is 95.6% of bunch length at start.



Beam instrumentation

- So far static errors have been modelled and the effectiveness of a correction system using 8 BPMs (locations shown as dotted line below) and 7 correctors studied.
- BPMs located π out of phase from injection point for both horizontal and vertical, and correctors located $\frac{\pi}{2}$ out of phase.



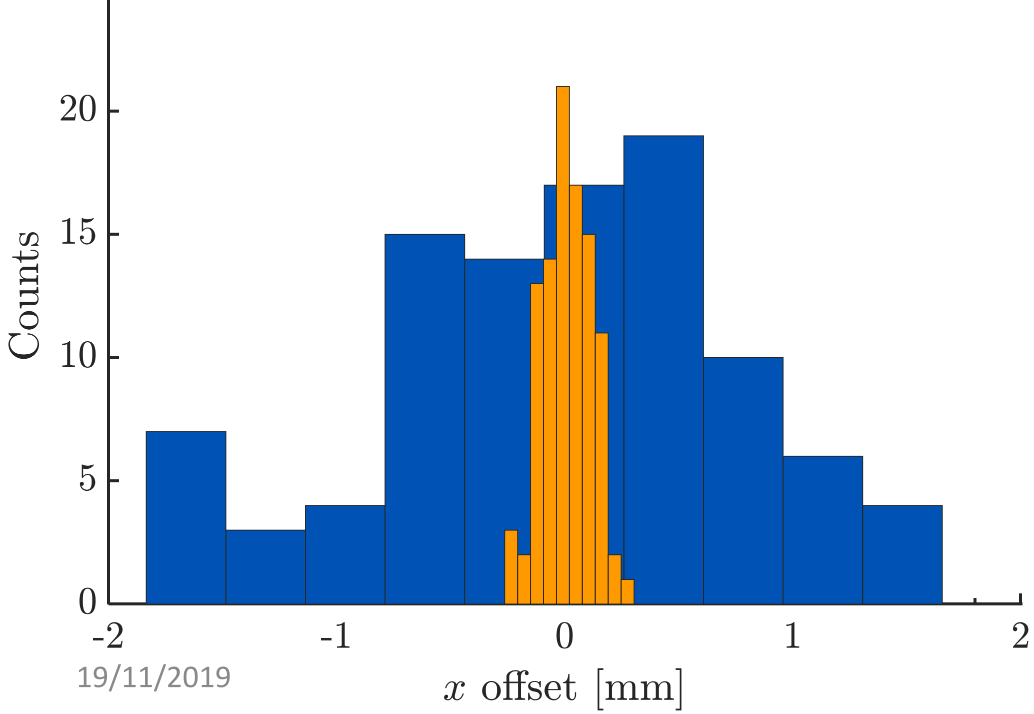
Beam offset at injection

- Model including static errors, BPM resolution and correction errors only.
- Dynamic errors still to be studied, so this is a best-case scenario.

Horizontal

Uncorrected –
Max: -1.8 mm
RMS: 0.80 mm

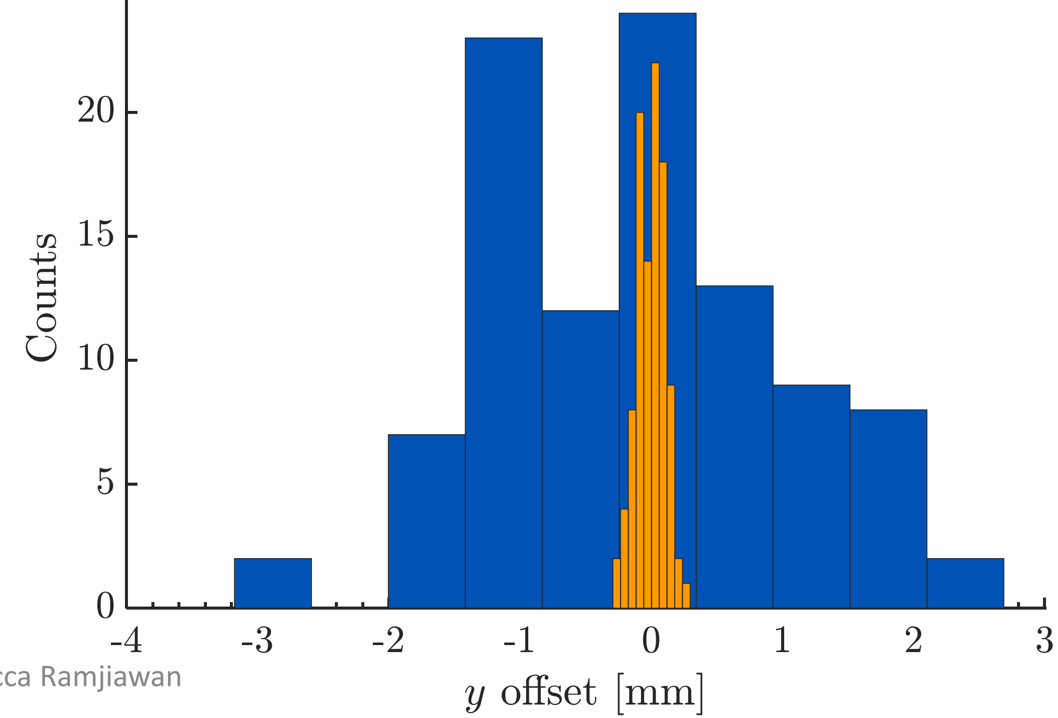
Corrected-
Max: 0.3 mm
RMS: 0.11 mm



Vertical

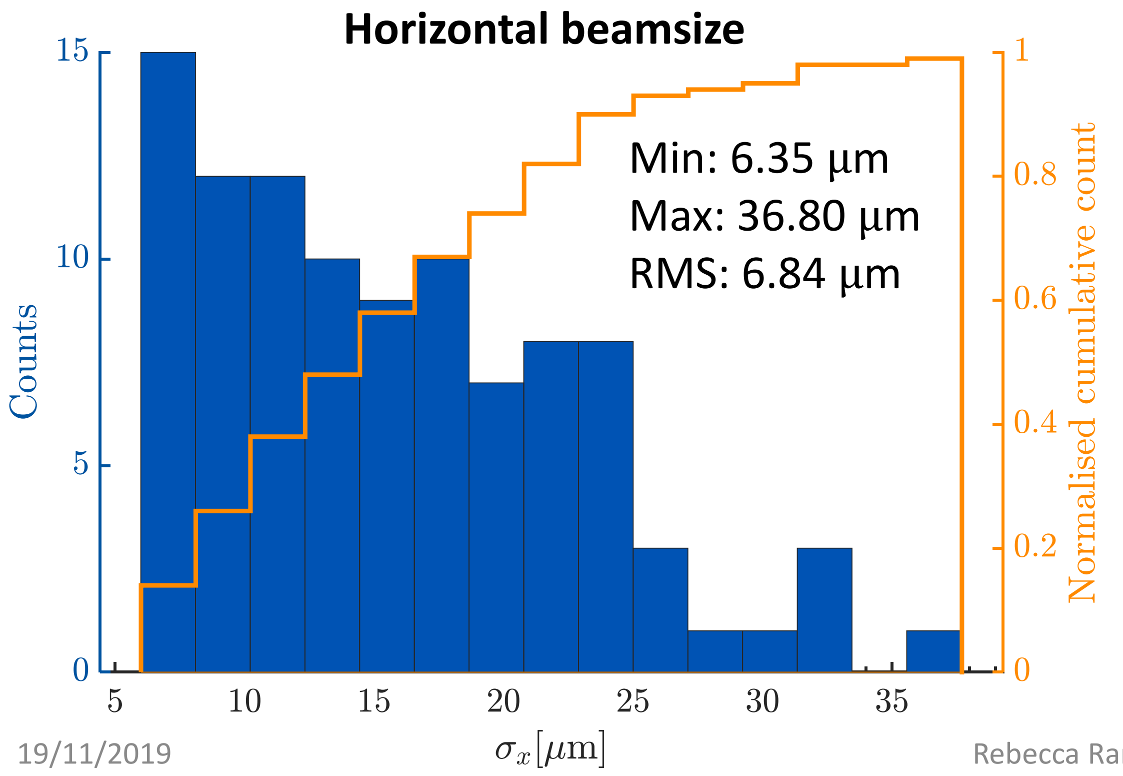
Uncorrected –
Max: -3.2 mm
RMS: 1.1 mm

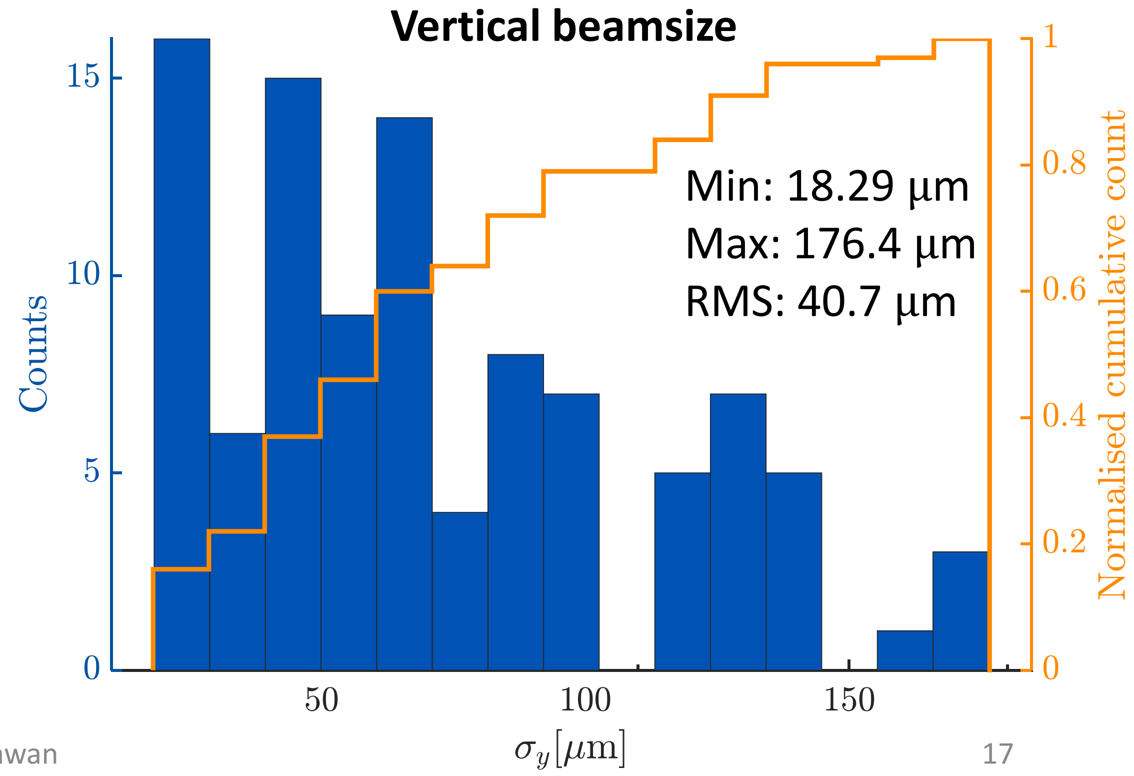
Corrected-
Max: 0.3 mm
RMS: 0.10 mm



Tracking bunched with errors

- Beamsize was calculated using tracking of particle distribution (provided by Steffen) for 100 seeds with static errors modelled from a Gaussian distribution.
- Static errors, BPM resolution and correction errors have been modelled.
- The minimum beam sizes reached are very dependent on the momentum spread, particularly vertically.





Further work

- Look into minimising the chromatic effects in the line with the introduction of sextupoles.
- Continue studying the effect of static and dynamic errors on beam trajectory, beam size and bunch length.
- Consider the effect of momentum jitter (shot-to-shot).
- Consider how correction system introduces parasitic dispersion.
- Create a plan to measure the optics, and discuss with BI to optimise the diagnostics.
- Determine space charge and CSR effects.

Thank you for listening