Proton and Electron Beamline Studies Update

R. Ramjiawan, F.M. Velotti

AWAKE Run 2 Meeting, CERN

Wednesday 15th July 2020

Overview

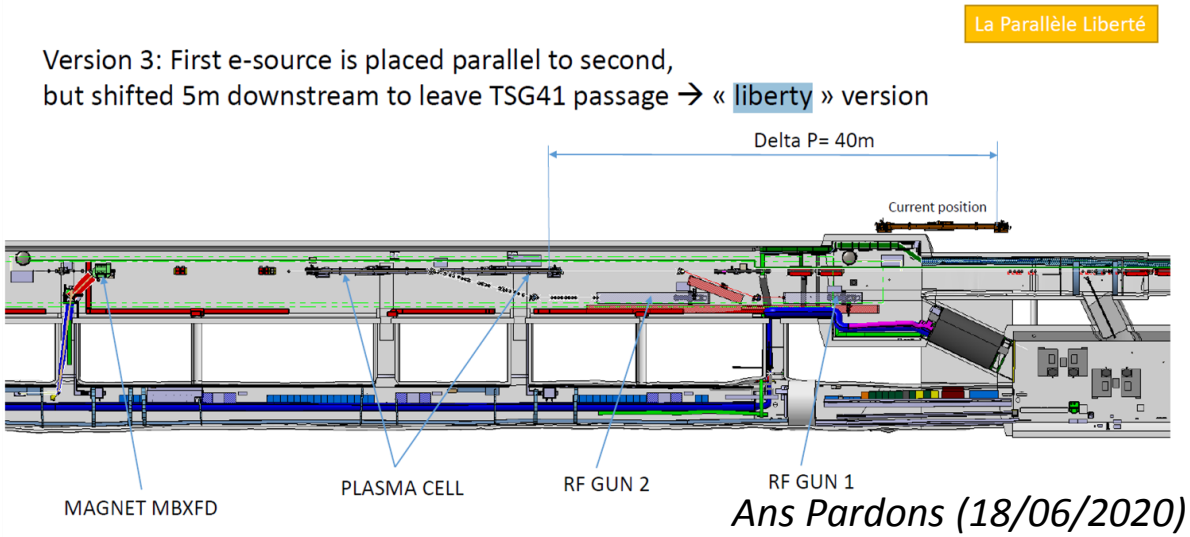
- **Proton line**
  - Is it possible to shift the plasma cell 40 m from its Run 1 position without additional elements?
  - What would be the limitations of such a design?
- **Electron line**
  - Update on progress with the design.
  - How well can we achieve matching into the plasma cell?
  - What are the next steps with this study?

“Liberty” Proton Line

- Design with first plasma cell +40 m compared with Run 1

"*Parallel liberty*" integration version

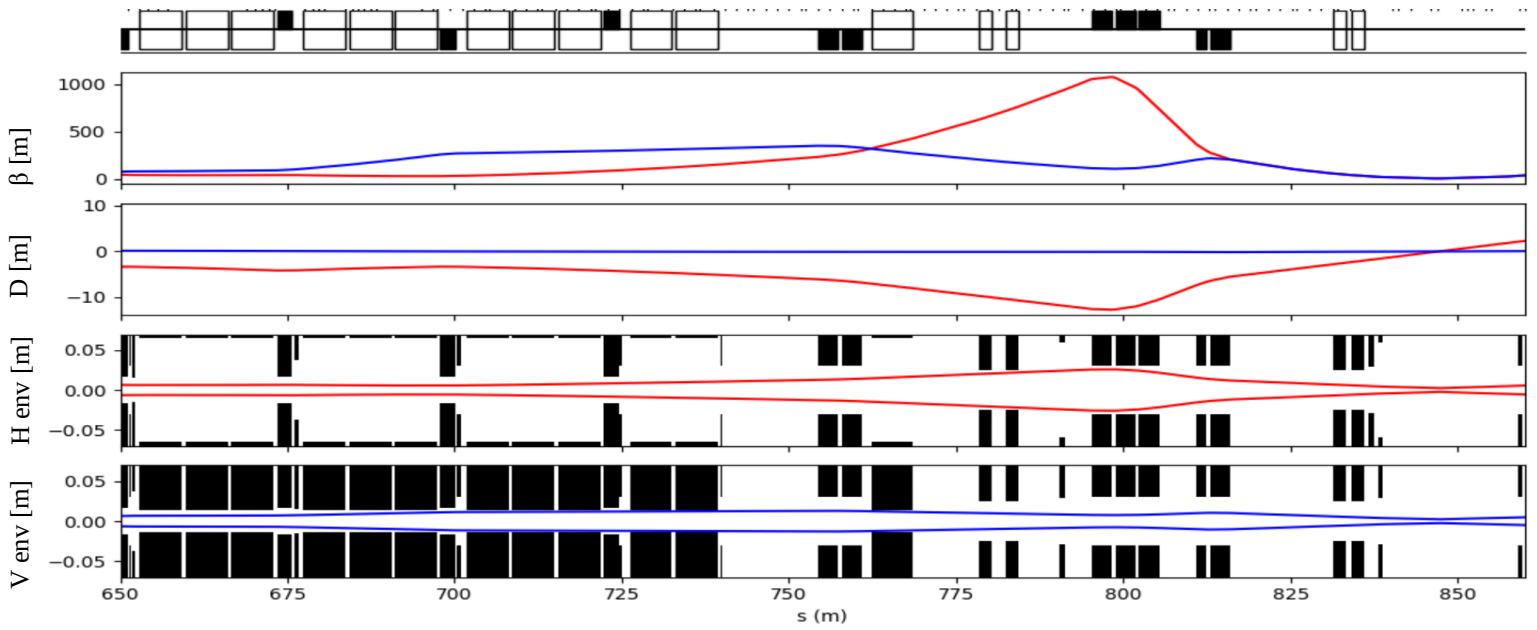
- **Task:** check whether a +40 m shift of the plasma cell is feasible for the beamline without additional magnets.
- **Restrictions:**
  - Laser mirror to be kept approximately the same distance from the plasma cell as for Run 1
  - Start of chicane cannot be moved more than 28 m or it will hit the tunnel wall
  - Maximum chicane width is specified by the maximum bending angle of B190 chicane dipoles
  - Respect aperture constraints



Ans Pardons (18/06/2020)

Possible solution

- Initial studies suggest shifting the plasma cell by 40 m could be possible without any additional magnets, although it is *incredibly* tight in terms of magnet apertures.
- Further studies are still required to determine whether there are any other show-stoppers which have not yet been identified e.g vacuum chamber placement or integration issues...



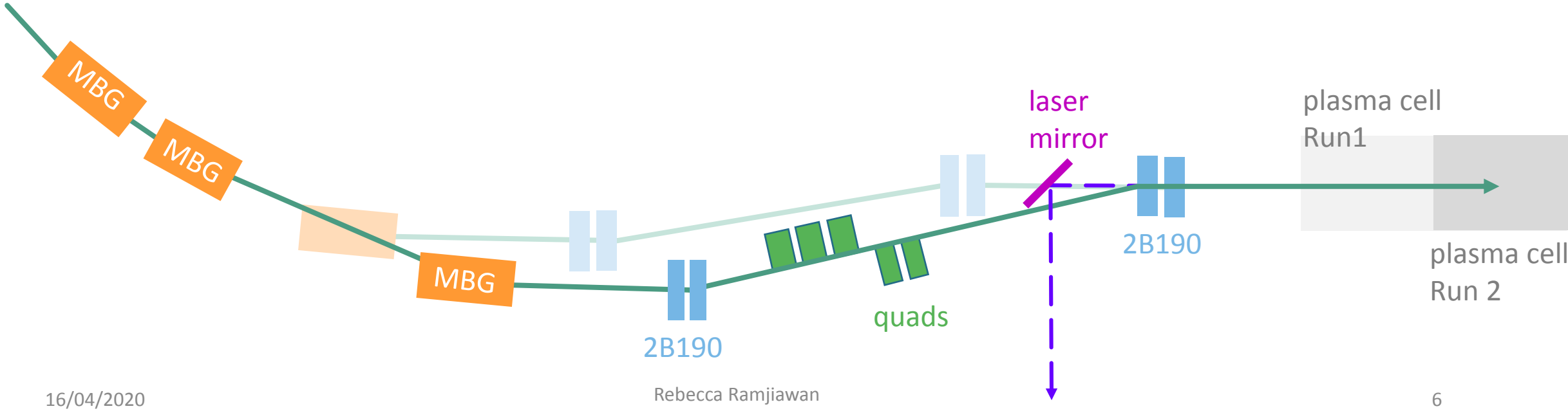
Parameters at merge-point

- $\beta_x = 4.900$ m
- $\beta_y = 4.900$ m
- $\sigma_x = 200.53$ µm
- $\sigma_y = 200.97$ µm
- $\alpha_x = -3.8 \times 10^{-5}$
- $\alpha_y = 4.6 \times 10^{-5}$
- $D_x = 0.00$ m
- $D_y = -0.036$ m

Chicane configuration

Main adjustments

- MBG dipole shifted by **+12.5 m** increasing the chicane width from 8 cm to 18 cm.
- Start of the chicane shifted by **+20 m**
- end of the chicane shifted by **+40 m** preserving the distance from the end of chicane to the plasma merge-point.
- Laser mirror shifted by **+40 m** so it would maintain the same distance from the mirror to the plasma-cell.



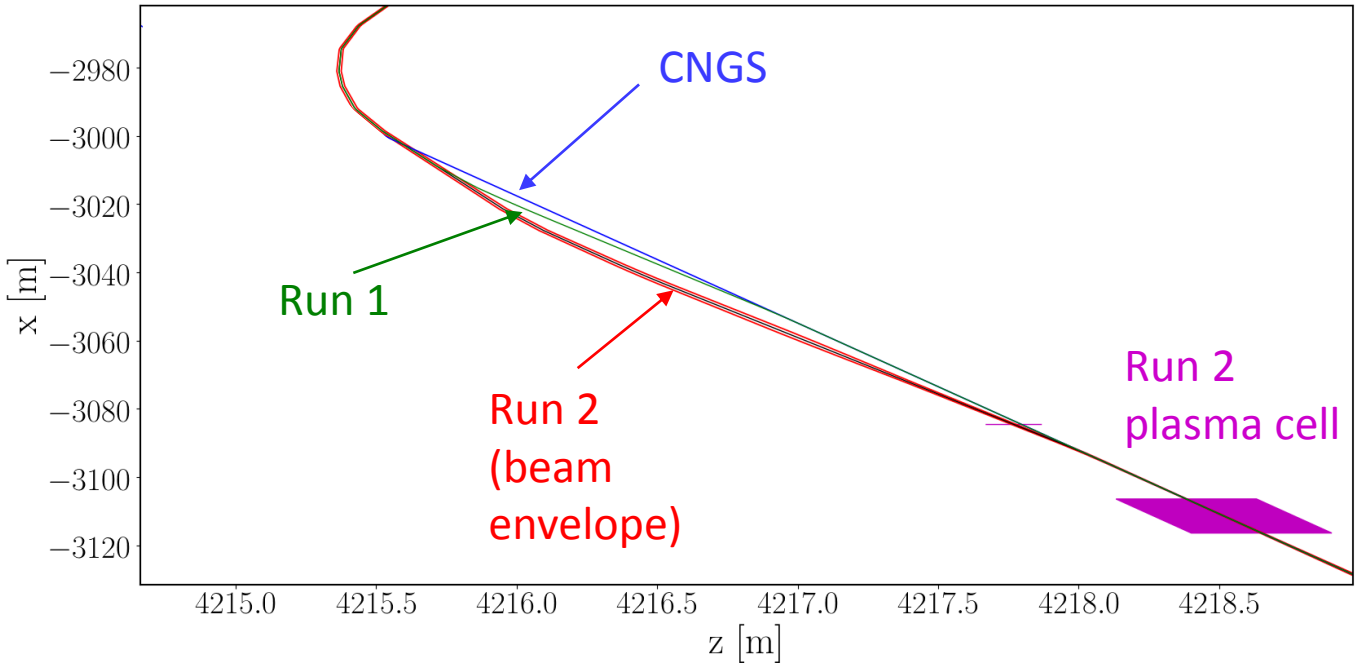
Change in element positions

- Having changed the chicane shape quite significantly, it would be useful to now check with the integration team whether there are any conflicts with other components.

ELEMENT ADJUSTMENTS

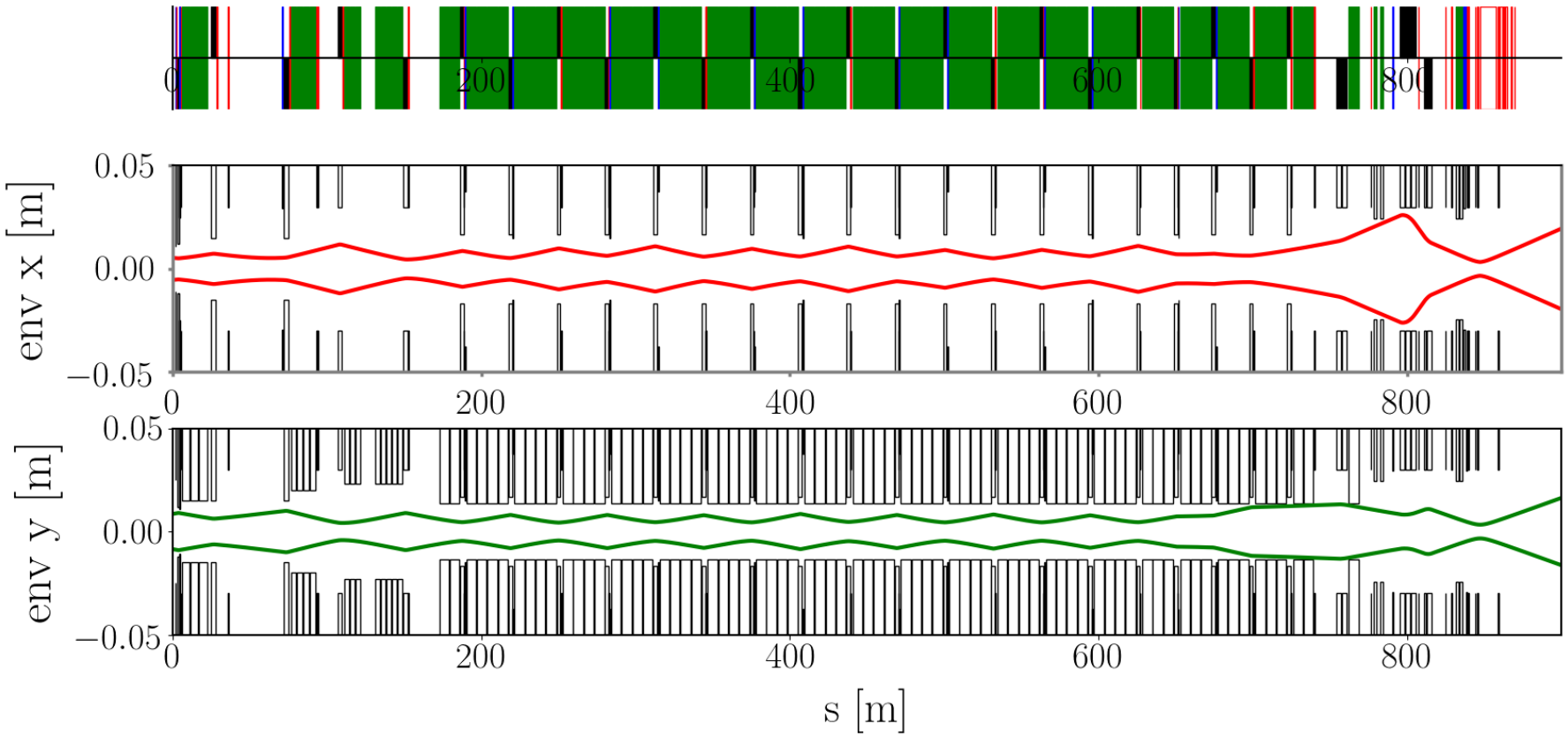
Element	shift [m]
qtld.412100:	+12
qtld.412108:	+12
mbg.412115:	+12.5
Chicane	
MBHFD.412133 & MBHFD.412141 :	+20
mdsh.412147:	+25
qtlf.412200 & qtlf.412208 & qtlf.412215 :	+28.5
qtsd.412300& qtld.412305 :	+31.5
laser.1:	+40
MBHFD.412324 & MBHFD.412330 :	+40
BPMs	
BPM.412128:	+20
BPM.412221:	+30
BPM.412311 (and BPMs downstream):	+40

Beamline zx projection for CNGS, Run 1, Run 2



Apertures

- Very tight in terms of aperture, both horizontally and vertically.
- Beam envelope comes within 1 mm of magnet edge in both planes.

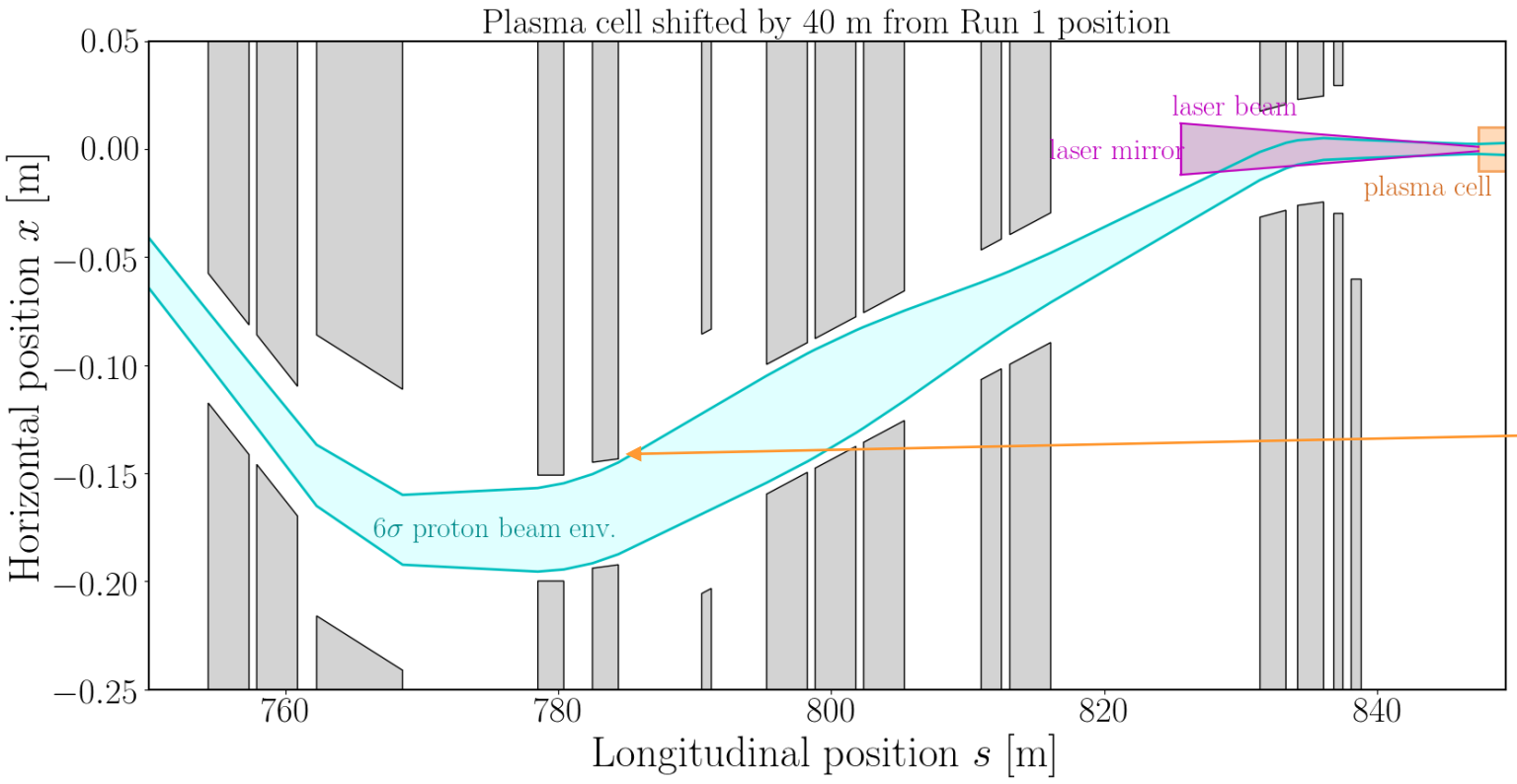


Envelope parameters

- 6σ + errors
- DeltaP/P = 0.00035
- Emittance= 3.5 mm mrad
- Orbit error = 2 mm× $\sqrt{\frac{\beta_{local}}{\beta_{max}}}$
- Alignment error = 2 mm
- +20% beta error

Laser-mirror chicane

- Same distance between laser mirror and plasma cell as for Run 1 (22 m), is this still ideal?
- Chicane now 17.98 cm wide, and clearance at laser mirror of several mm.



1.5 mm clearance

Magnet limits

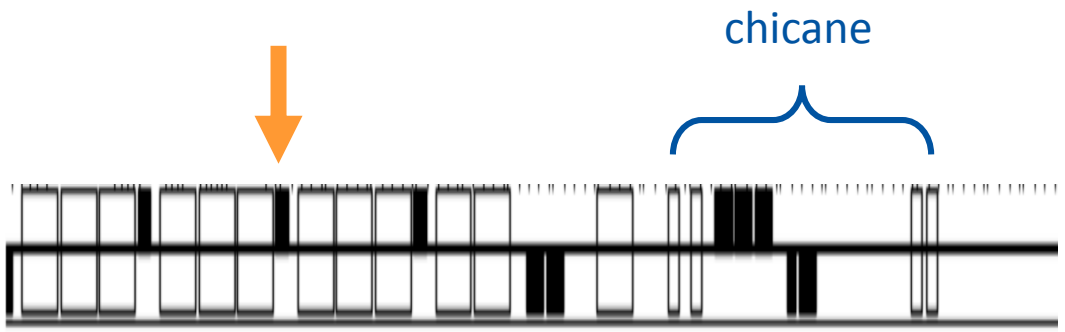
CHICANE

Power convertor limits

- Power convertor for the B190 (chicane) dipoles has max current 300A, meaning a maximum bending angle of 1.8 mrad.
- Run 1: B190 $\theta = \pm 1.18226$ mrad
- Proposed Run 2 value: $\theta = \pm 1.685$ mrad is within allowable range.

QUADRUPOLES

- Safely within limits for strength of all quadrupoles.
- Would need to change the polarity of quadrupole (qtgf.411900) back to defocussing (as it was for CNGS).

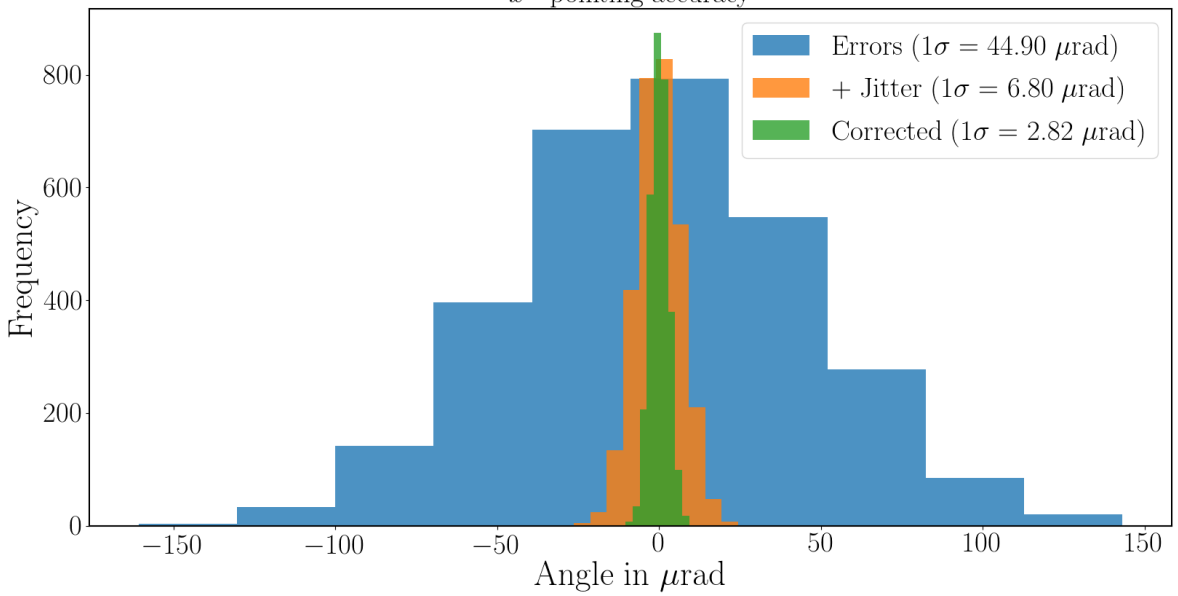


Current Run 1 line has three focussing quadrupoles consecutively, for Run 2 it would be required to reverse the polarity of the middle quadrupole.

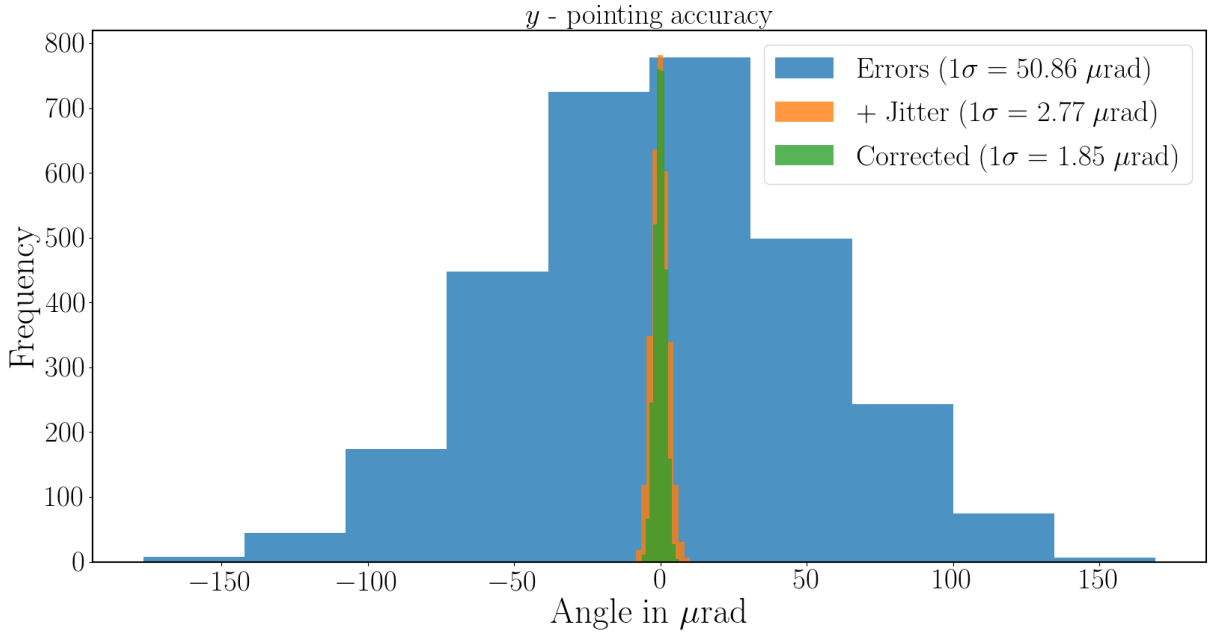
Pointing angular precision

- Angular pointing precision for Run 1 was required to be less than 15 µrad, for Run 2 it will need to be better as there are two plasma cells for the proton beam to remain aligned for.
- Dipole power convertor ripples (max. 1×10^{-4}) occur on a timescale that mean they can't be compensated for using correctors and so will degrade the position and angle stability, this is the "+ Jitter".
- Poorer horizontal angular stability than Run 1 – possibly as larger chicane bending angles
- **Run 1: x: 43.8 µrad (err), 1.72 µrad (corr), 5.03 µrad (+jit), y: 46.2 µrad, 0.56 µrad, 4.9 µrad.**

x



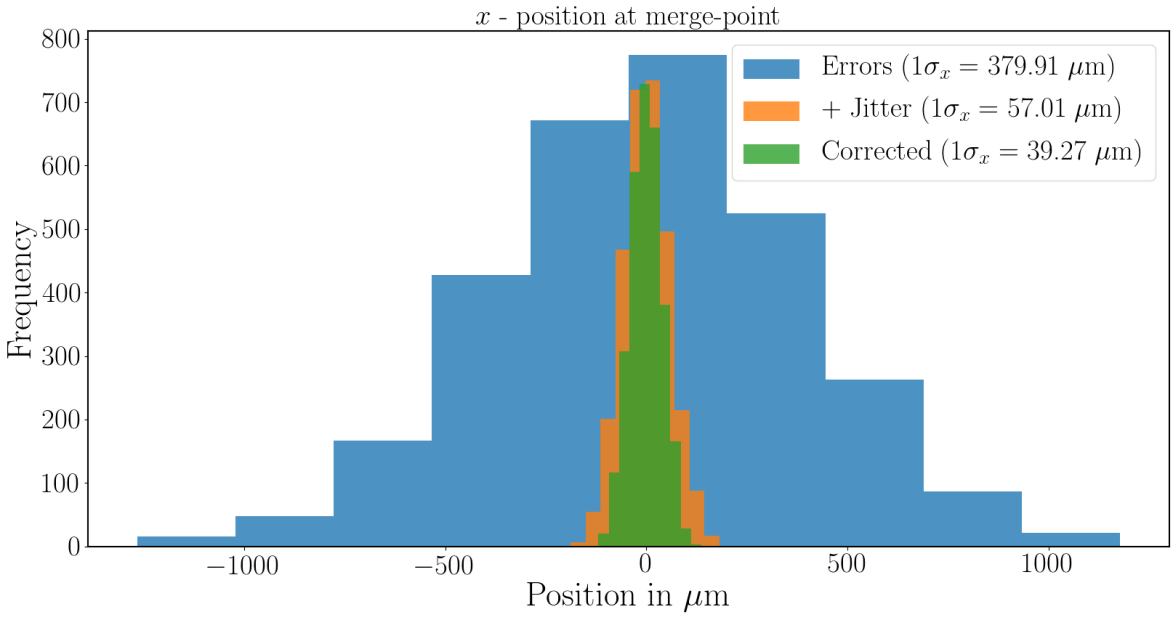
y



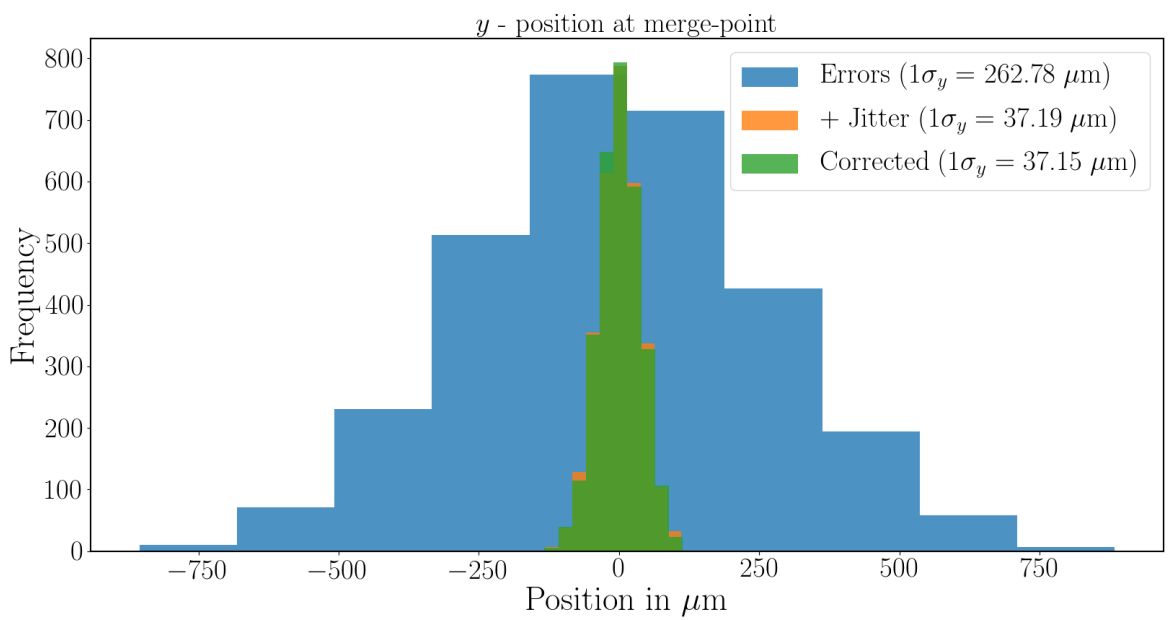
Position stability at merge-point

- Position stability of better than 100 µm required for Run 1 at the entrance to the plasma cell.
- Vertical stability 50% worse than for Run 1, possibly due to larger $\beta_{\mathrm{max.}}$ values.
- **Run 1: x: 949 µm (err), 46.6 µm (corr), 93.0 µm (+jit), y: 927 µm, 6.6 µm, 19.9 µm**

x



y



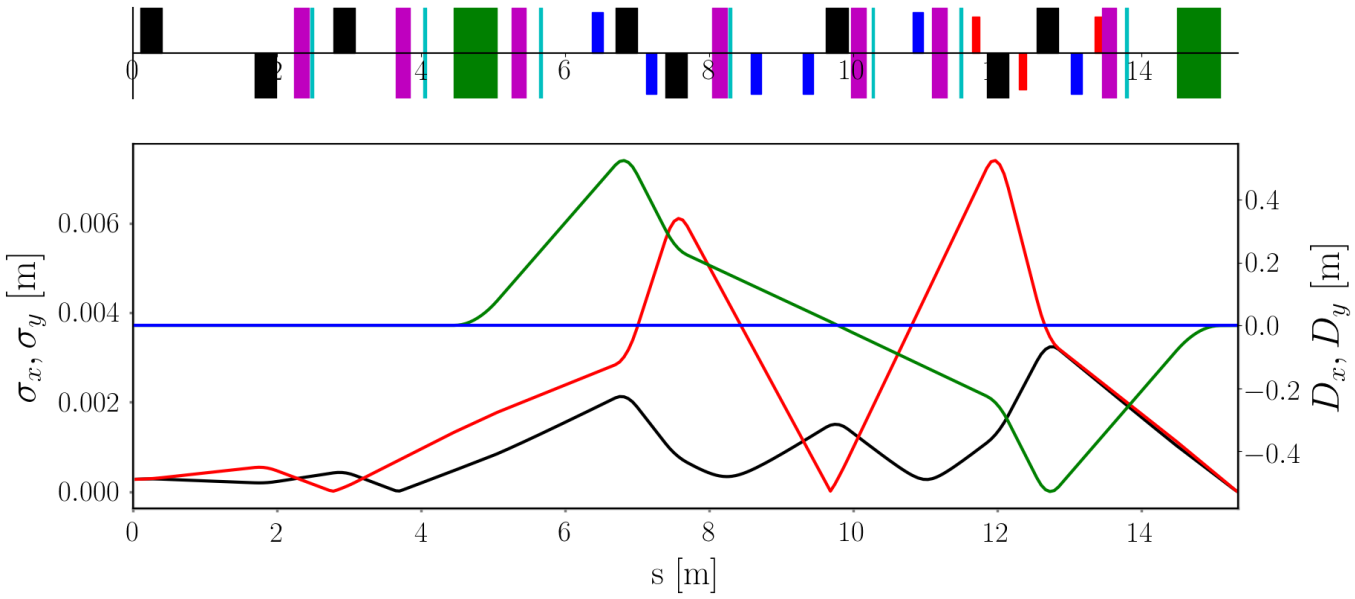
150 MeV electron line

Matching condition

- Progress has been made with reaching the matching condition at the plasma merge-point, which requires:

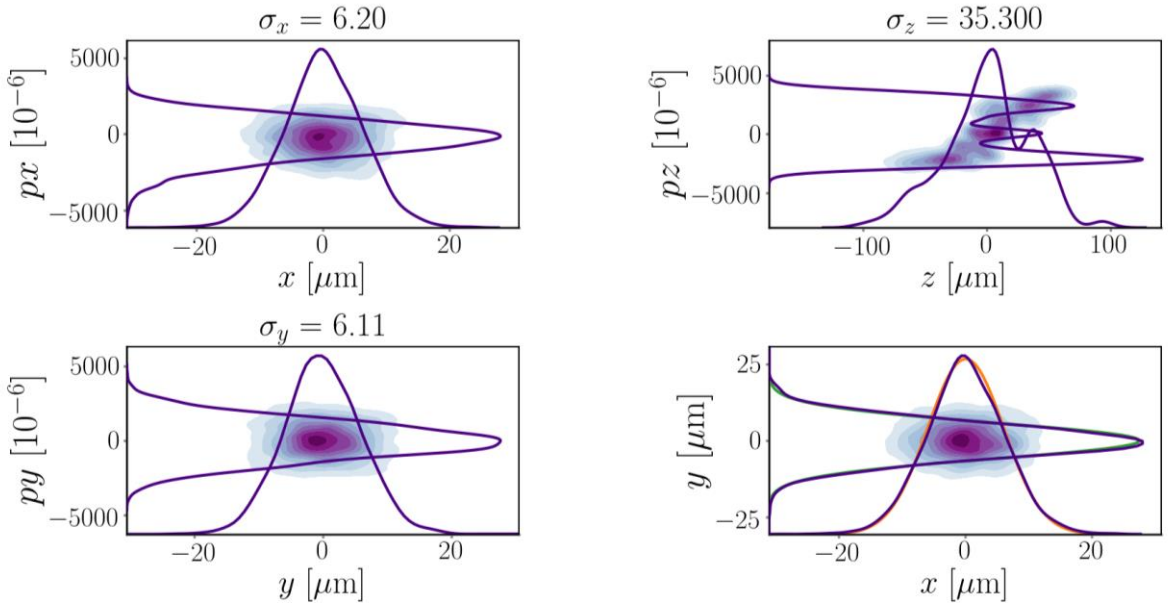
$$\sigma^2 = 4.87 \times \epsilon$$

- The effective emittance at end of line ~10% larger than input emittance (2 μm) so that matched beam sizes are
  - $\sigma_x^{\text{matched}} = 6.20\ \mu\text{m}$
  - $\sigma_y^{\text{matched}} = 6.11\ \mu\text{m}$
- The effective emittance is larger than the input/betatronic emittance because it contains other contributions e.g dispersion. While the reference particle might see zero dispersion at the merge-point, there is a distribution of particles and this isn't the case for them all.



Beam at plasma merge-point

- It is possible to reach the matched beam size of 6.2, 6.11 µm with a Gaussian beam at the merge-point.
- Gaussian distributions are shown on the xy plot in orange and green and show very good comparison with the tracked distributions.
- At the merge-point, $\alpha = 0$, which is also required for matching.
- This isn't the smallest beam sizes we can achieve (see appendix), but it's the smallest matched beam size given the effective emittance.



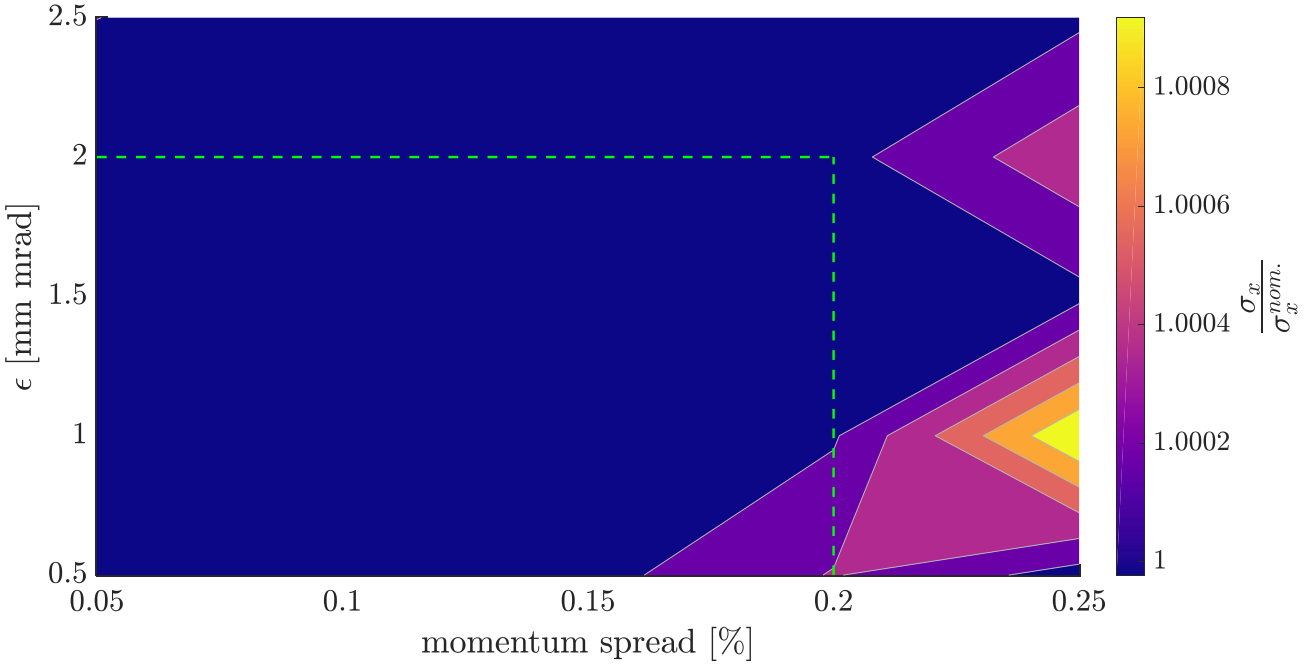
Parameters at merge-point

- $\sigma_x = 6.2$ µm
- $\sigma_y = 6.11$ µm
- $\alpha_x = 0.00$
- $\alpha_y = 0.00$
- $D_x = -0.0003$
- $D_y = 0$

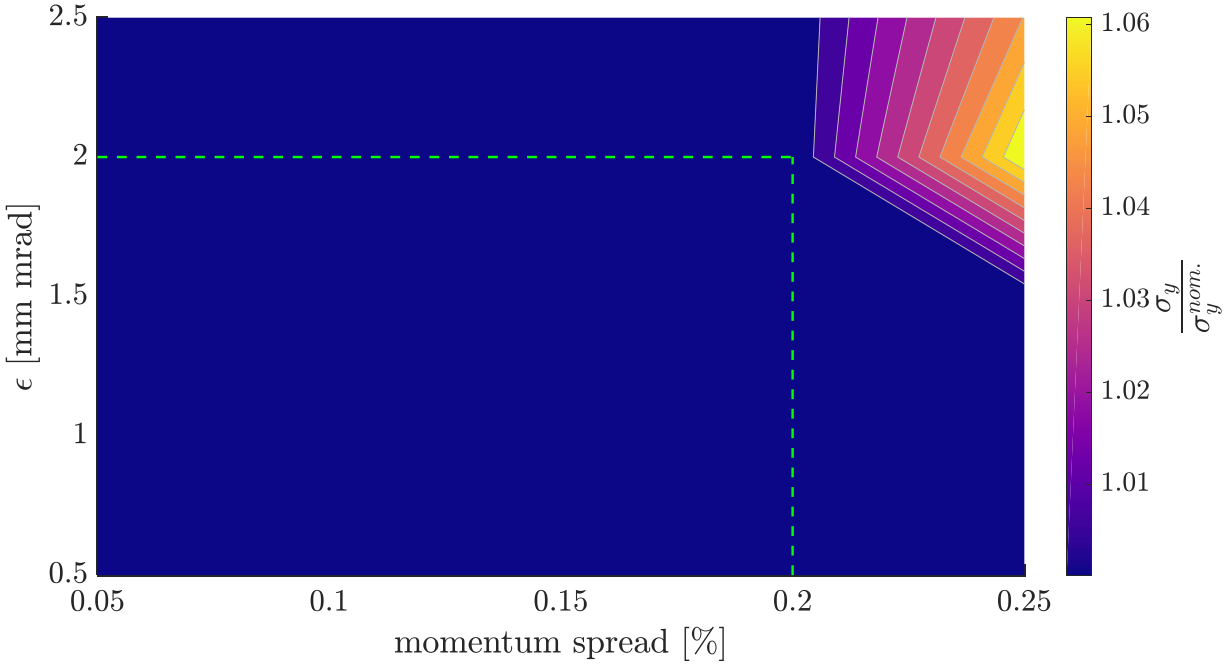
Parameter scan

- Beam size at merge-point scaled by matched beam size ($\frac{\sigma}{\sigma^{mat}}$) for a range of emittances and momentum spreads, nominal values are shown with dotted green line.

$\frac{\sigma_x}{\sigma_x^{mat}}$

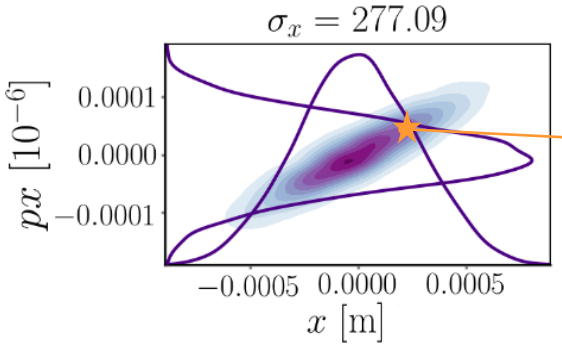


$\frac{\sigma_y}{\sigma_y^{mat}}$



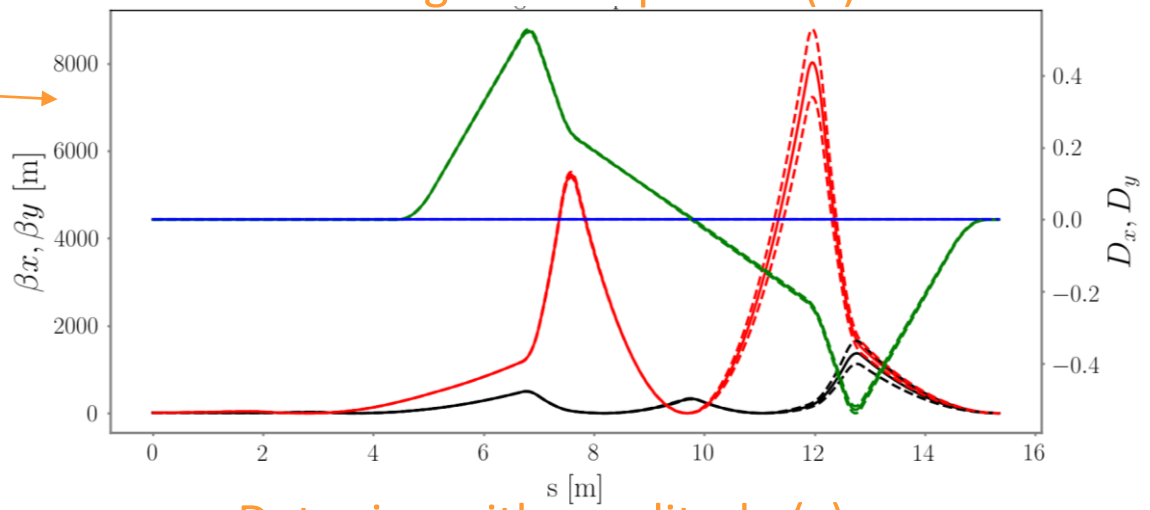
Sensitivities to offsets

- Plots show variation of the beta function and dispersion on the momentum offset and particle amplitude.

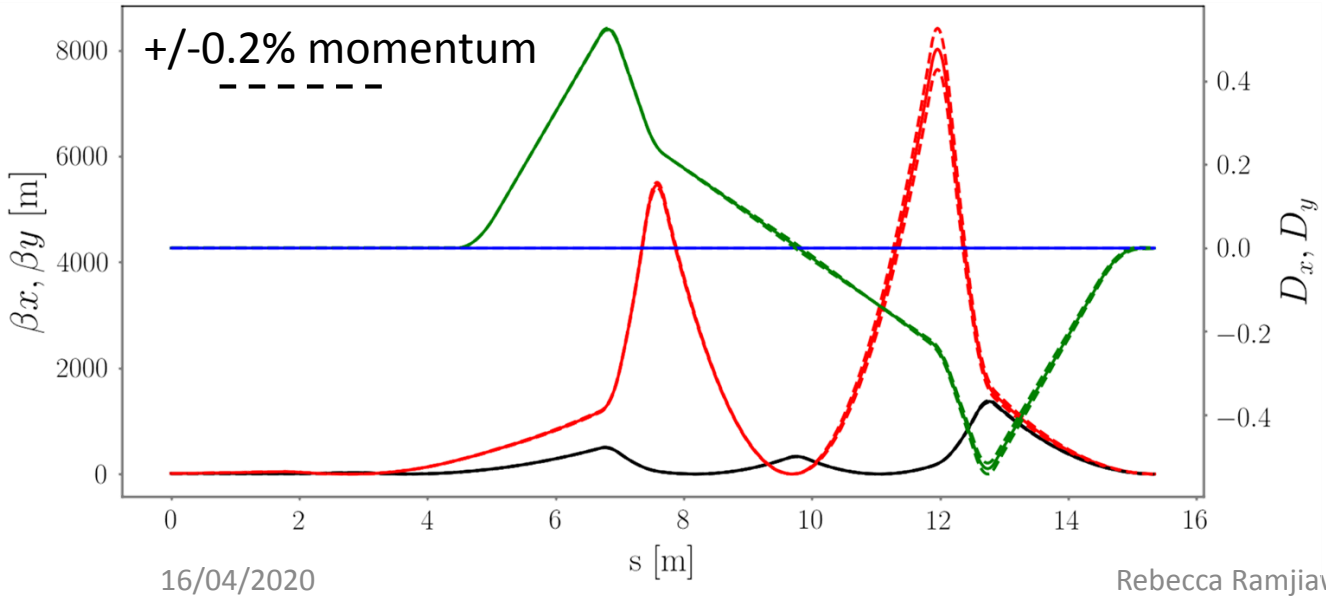


Input distr.

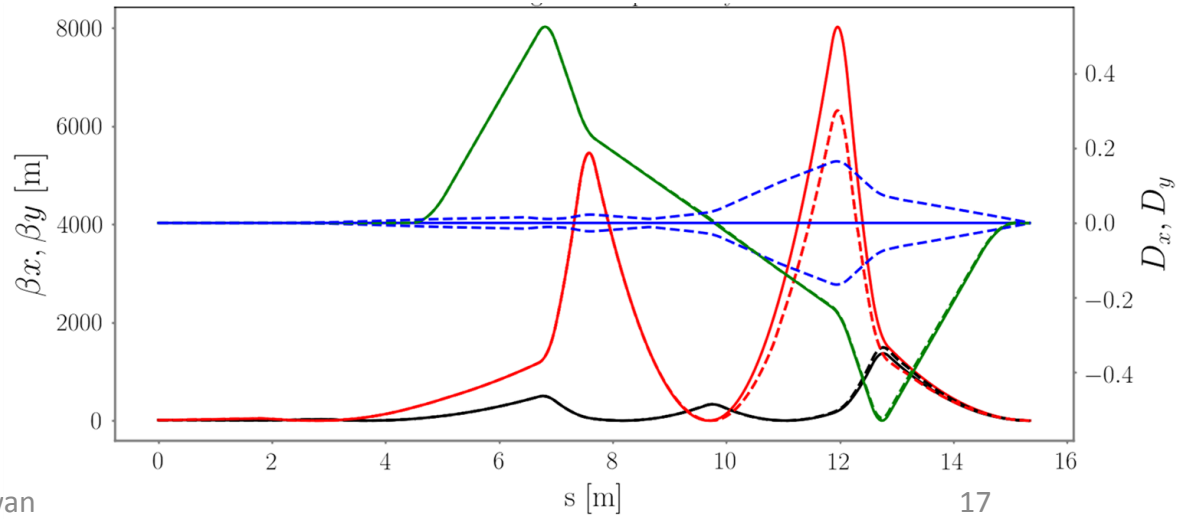
Detuning with amplitude (x)



Chromatic effects



Detuning with amplitude (y)



Summary

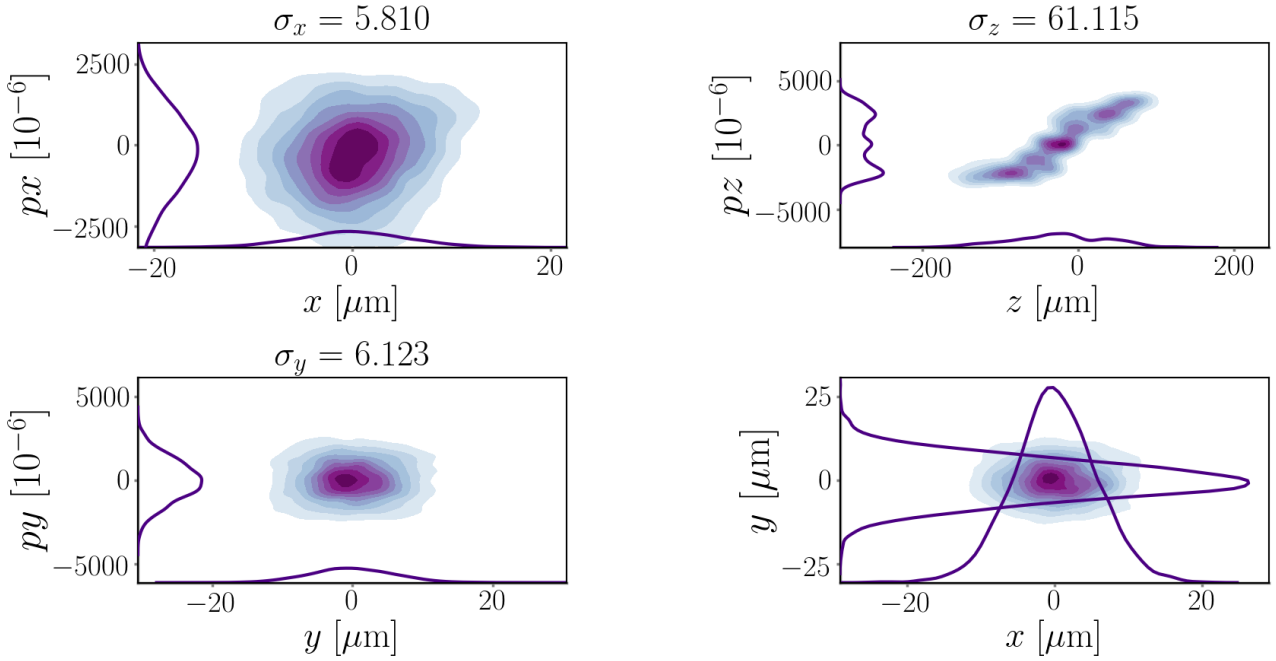
- **Proton line**
  - From preliminary studies, it looks like it might be possible to shift the plasma cell 40 m without additional elements, but it is at the very limit of our tolerances and so will need further detailed studies.
- **Electron line**
  - Ideally, the effective emittance at the plasma merge-point would be closer to the input emittance but with non-linear behaviours in the line this is difficult.
  - Now that we can meet the matching condition without any errors, I have begun to look at how different errors and misalignments would affect the beam. Requirements for diagnostics and a correction system are being studied.

Thank you for listening

Appendix

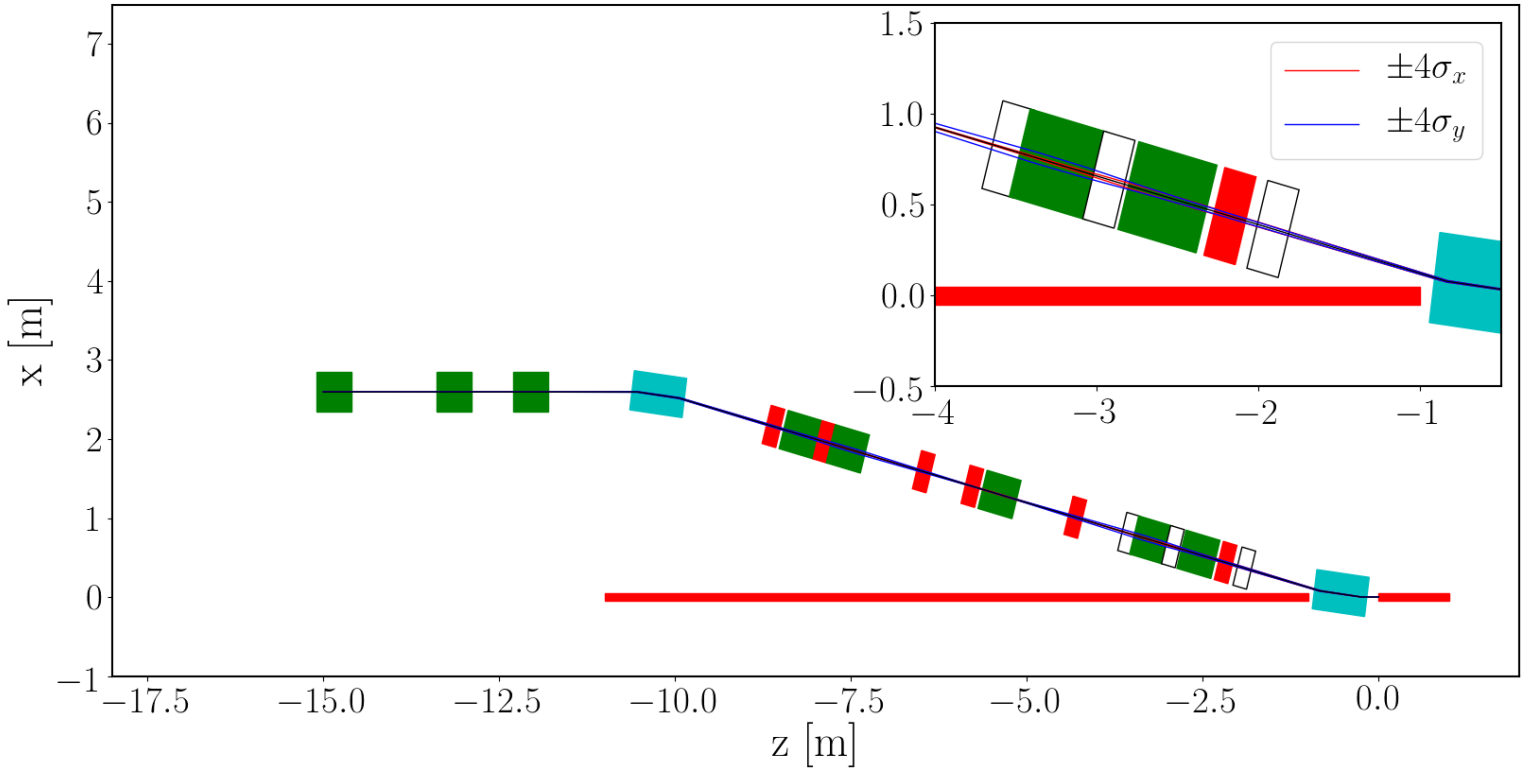
Minimum beam size

- Smallest beam size achievable (so far) at merge-point
- Beta (x,y) = 4.0, 3.8 mm
- Effective emittances at merge-point (x,y) = 2.4, 2.2 mm mrad
- Input beam length 1.4 x 60 um.



Current electron beamline design

- Current beamline layout shown below with preliminary estimates of element sizes plotted.
- Dipole bending angle: 15°
- Gap between plasma cells 1 m



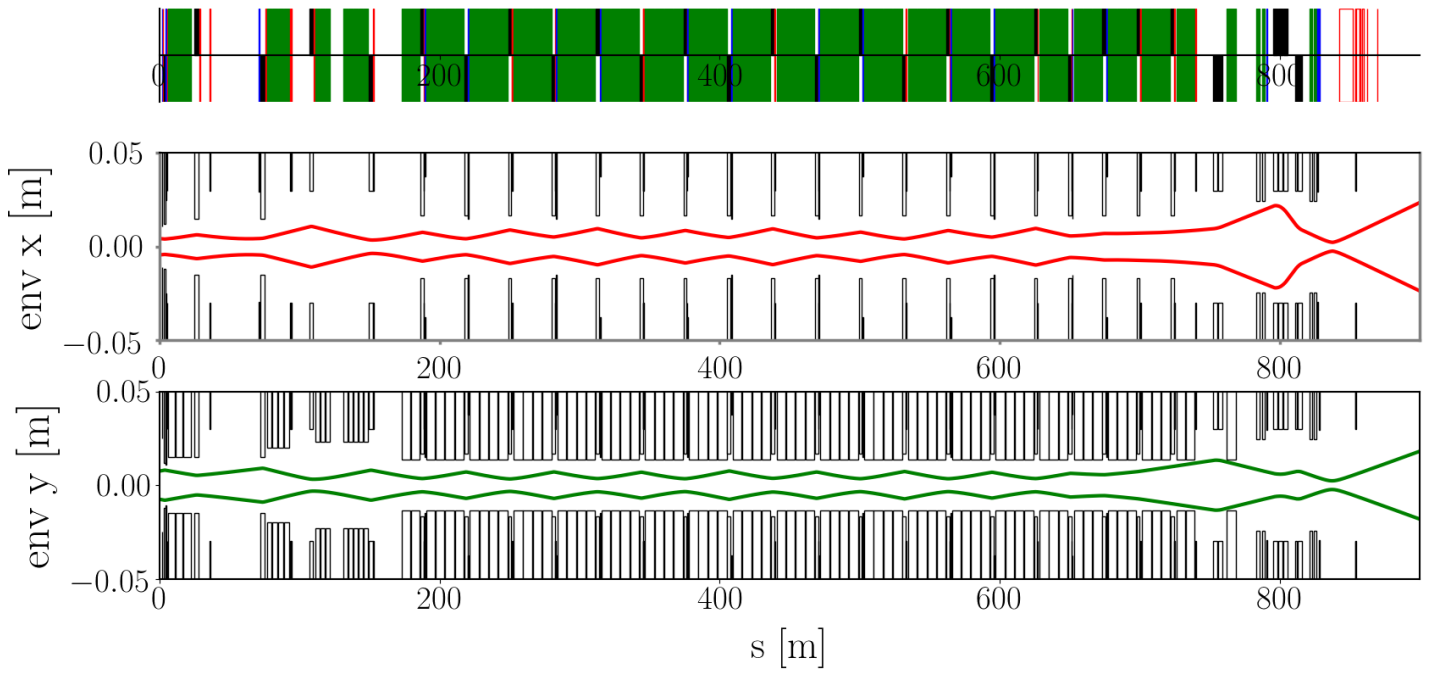
Estimated sizes:
- dipoles (0.75 m x 0.5 m)
- quadrupoles (0.5 m x 0.5 m)
- sextupoles (0.2 m x 0.5 m)
- octupoles (0.2 m x 0.5 m)
- plasma cells (10 m x 0.1 m)
- --- 4 sigma beam size (x)
- --- 4 sigma beam size (y)

Diagonal Proton Line

- Design with first plasma cell +30 m compared with Run 1

Proton beamline 30 m

- *6σ envelope with orbit and alignment errors vs. longitudinal position*



Parameters at plasma merge-point

$\beta_x = 4.900,$
$\beta_y = 4.900,$
$\alpha_x = 0.000,$
$\alpha_y = -0.000,$
$D_x = -0.000,$
$D_y = 0.035,$
$\sigma_x = 200.6\ \mu m,$
$\sigma_y = 201.0\ \mu m$

Changes in bending angle

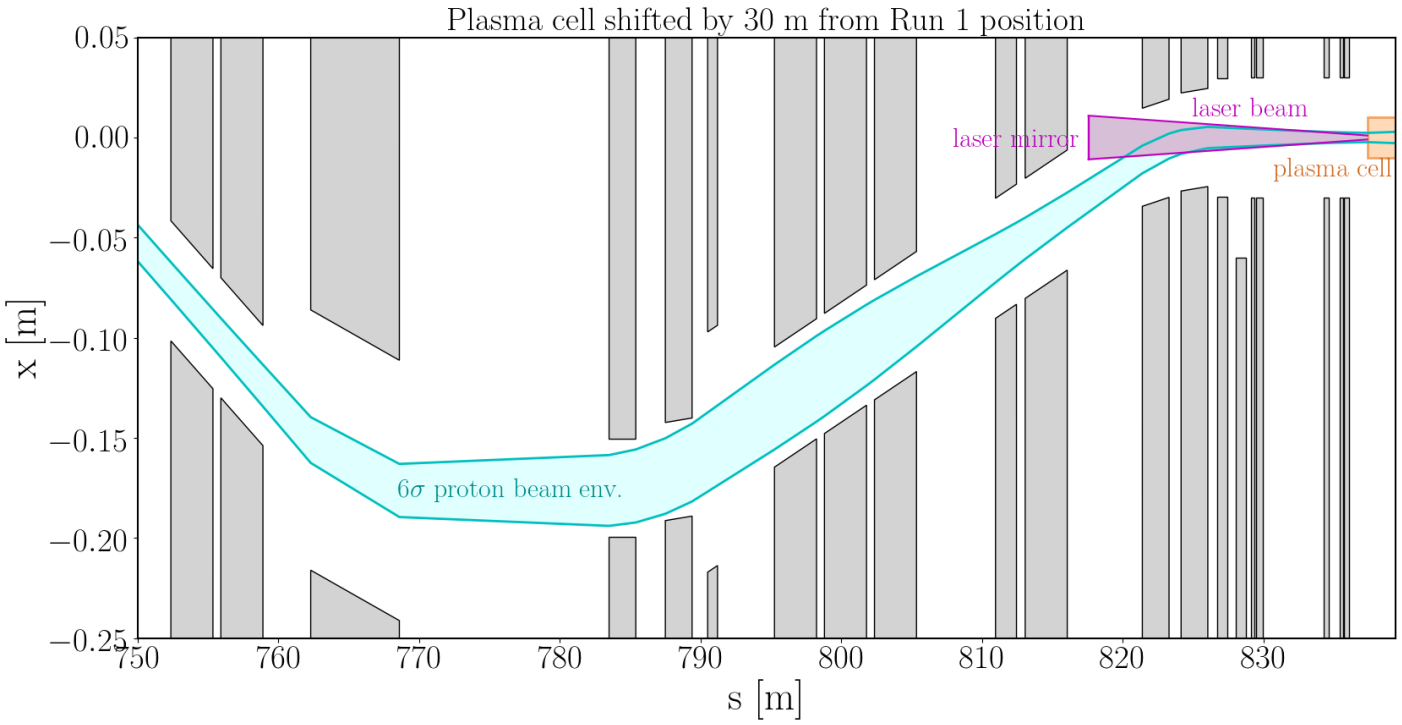
Chicane dipole increased to 2 times existing value, to increase offset at laser merge-mirror.

Changes in chicane position

Start of the chicane shifted by +25 m, end of the chicane shifted by +30 m.

List of changes to BPMs/BTVs/correctors

- Plasma cell moved 30 m.



INSTRUMENTATION ADJUSTMENTS

Element	shift [m]
qtld.412100:	+10
qtld.412108:	+10
mbg.412115:	+ 12.5
MBHFD.412133 & MBHFD.412141 :	+25
mdsh.412147:	+25
qtlf.412200 & qtlf.412208 & qtlf.412215 :	+28.5
qtsd.412300& qtld.412305 :	+31.5
laser.1:	+32
MBHFD.412324 & MBHFD.412330 :	+30

Magnet currents

CHICANE

Power convertor limits

- Power convertor RPPCQ.BB4.RBIH.412324 has max current 300A.

Max bending angle B190

- 0.7 T = 1 mrad for B190
- For B190 max is 375 A = 1.6 T
- ∴ with 300 A ≈ 1.28 T ≈ 1.8 mrad

- New value: $\theta = 0.001685$ rad is within allowable range.

QUADRUPOLES

Max. = 0.016

```
kqtl9      =   -2.47558e-003
kqtl101    =   6.69534e-003
kqtl111    =   -1.35973e-002
```

Max. = 0.023

```
kqtn5      =   -1.17101e-002
kqtn6      =   1.06670e-002
kqtn7      =   -7.00406e-003
kqtn8      =   2.42012e-004
kqtnd      =   1.80985e-002
kqtnf      =   -2.19348e-002
```

Changed polarity from Run 1

Spare magnets

QTL - 20 spares (1 certified)

QTS - 45 spares (2 certified)