150 MeV witness electron beam line for AWAKE Run2c

V. Bencini, R. Ramjiawan, F. Velotti

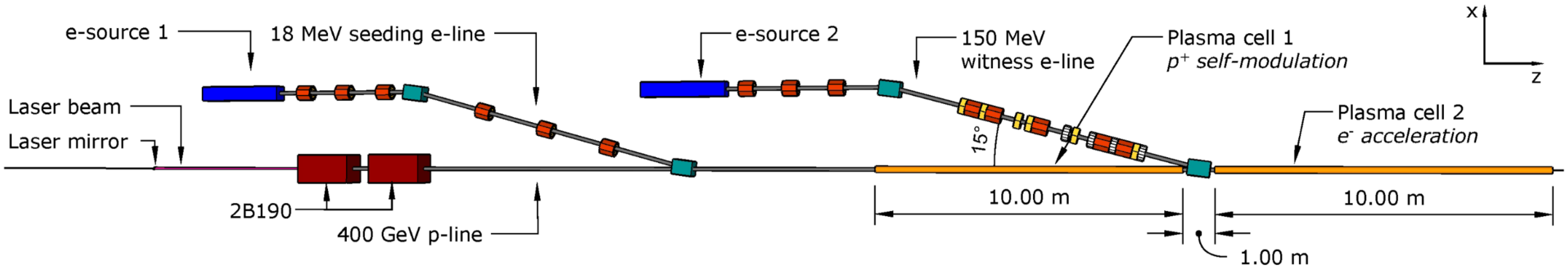
11/04/2022

Outline

- Introduction
- Beamline design
  - Design methodology
  - Baseline layout
- Error studies
  - Tolerances definition
  - Alignment procedure
  - Results
- Optimization with scattering foils
- Summary and next steps

AWAKE run2c

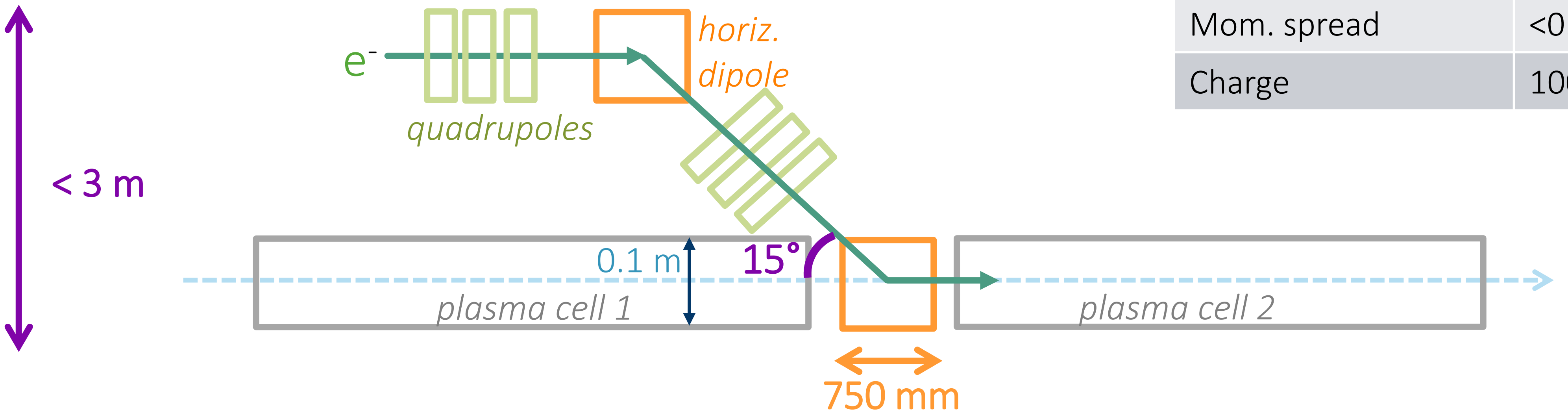
- AWAKE Run 1 achieved electron acceleration to 2 GeV via plasma wakefield acceleration driven by self-modulated proton bunches.
- AWAKE Run 2 is aiming to achieve higher energies maintaining higher beam quality.
- Will be two plasma cells so that the self-modulation of the proton bunch and acceleration of electron bunch are separated.
- Will need a new 150 MeV electron beamline to inject a witness bunch to probe the accelerating gradients of the plasma wakefields



Beamline specifications

- Requirement of $\sigma^* = \sqrt{4.8 \text{ mm} \times \epsilon}$ at injection to be "matched to the plasma" → for $\epsilon_{x,y} = 2$ µm: $\boldsymbol{\sigma^* = 5.75}$ **µm**.
- Gaussian bunch at injection.
- Transfer line should be achromatic, with no bunch lengthening.
- Spatial constraints shown below.
- Electron beam jitter at target <1 $\boldsymbol{\sigma^*}$

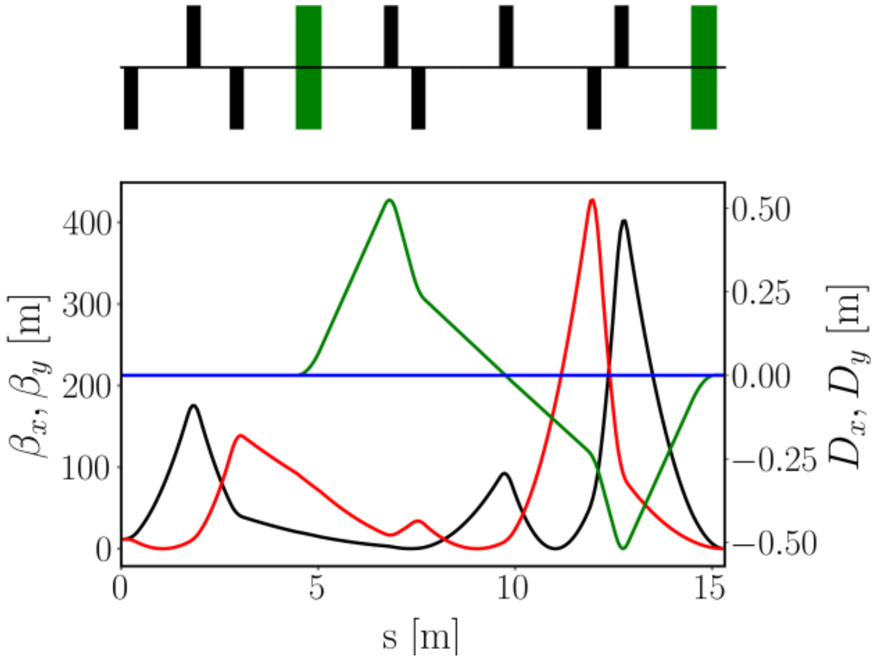
Parameters	Nominal value
Dispersion	0
$\sigma_{x,y}$	5.75 µm
Bunch length	200 fs/60 µm
Electron energy	150 MeV
$\epsilon_{x,y}$	<2 mm mrad
Mom. spread	<0.2%
Charge	100 pC

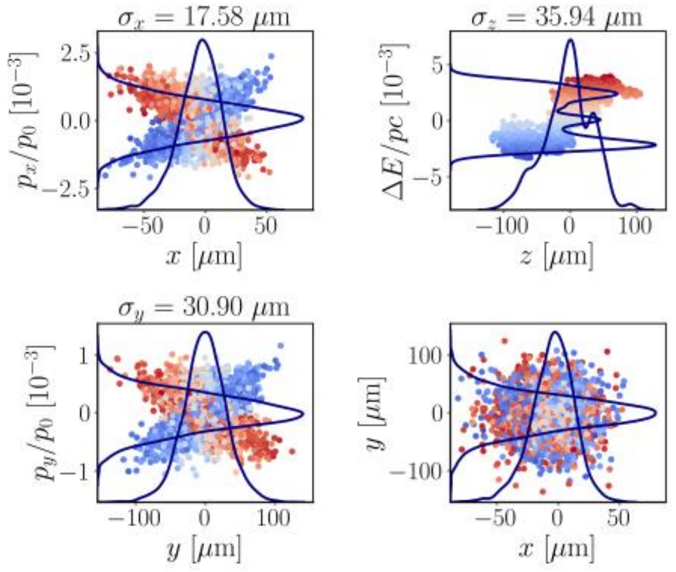


Beamline design

Design of the transfer line

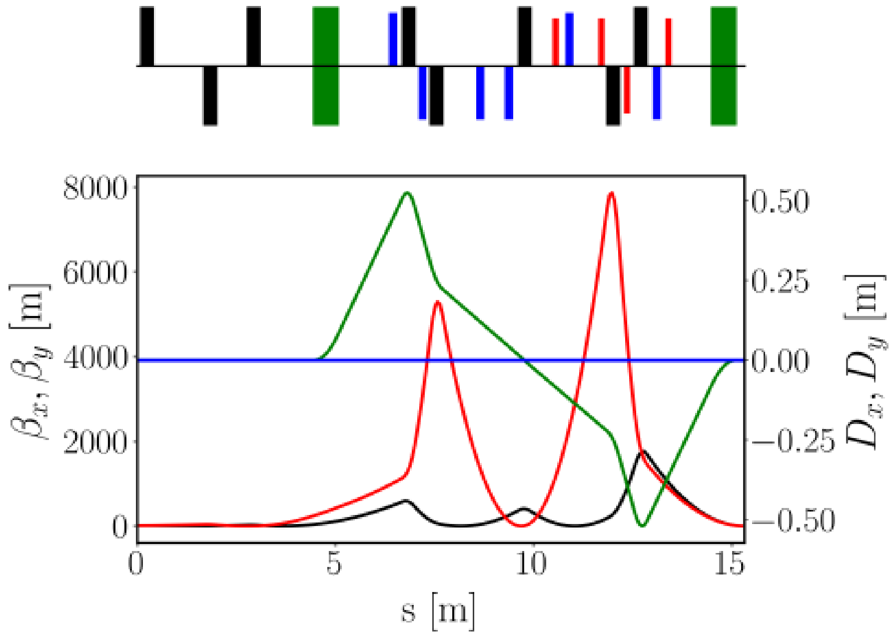
- Design starting point was considering only quadrupoles
- It was not possible to achieve the beam specifications due to chromatic contribution to the beam size

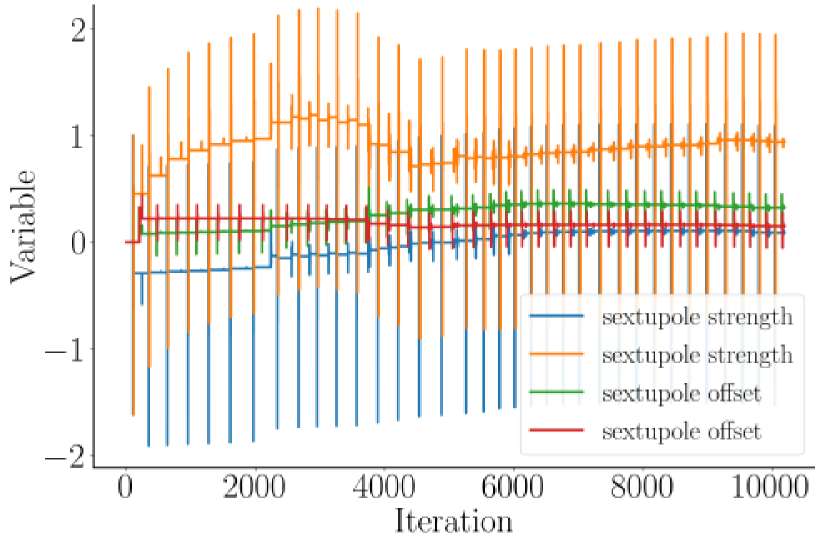




Design of the transfer line

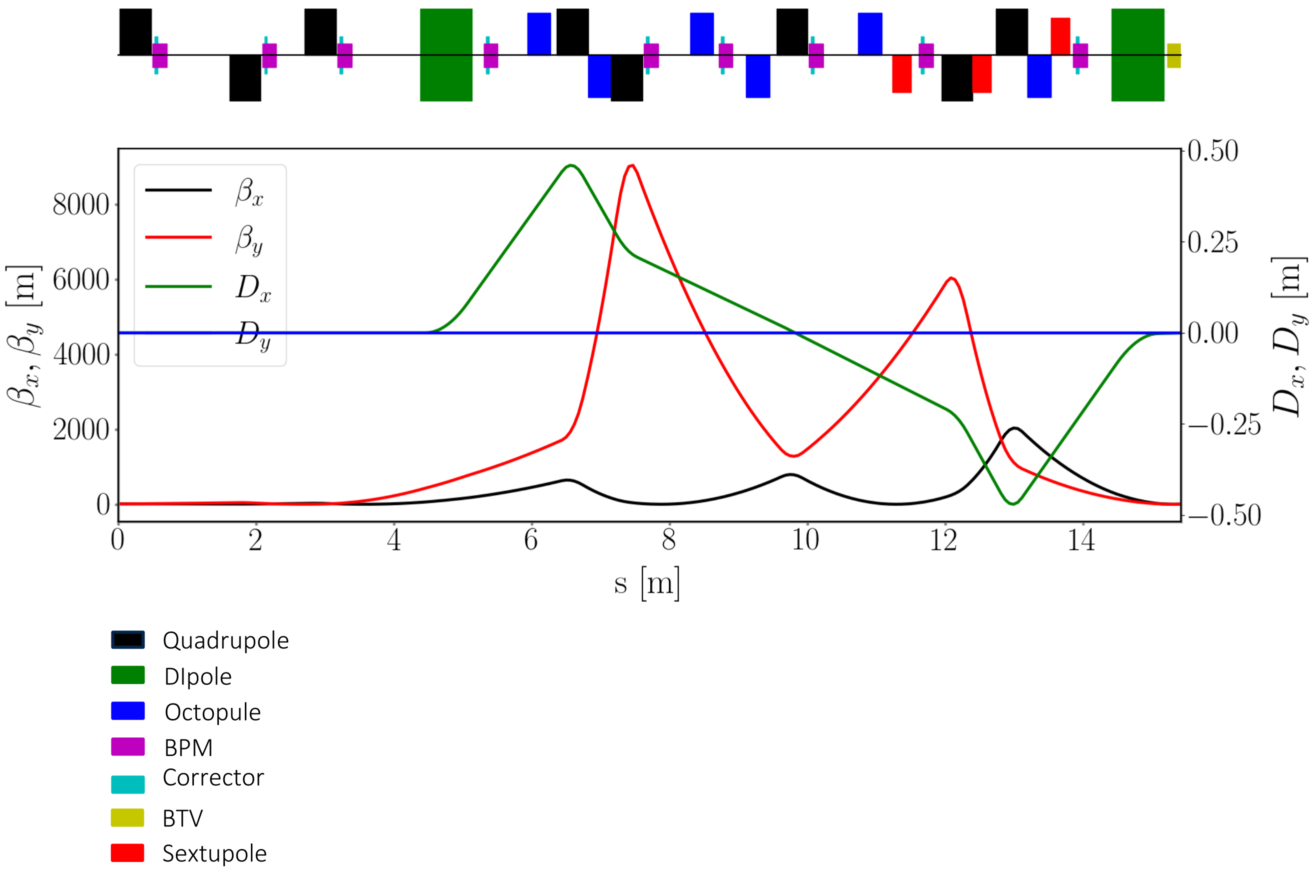
- Design starting point was considering only quadrupoles
- It was not possible to achieve the beam specifications due to chromatic contribution to the beam size
- Sextupoles and octupoles added to the line to compensate for high order effects
- Iterative optimization (25 variables) to find the best configuration

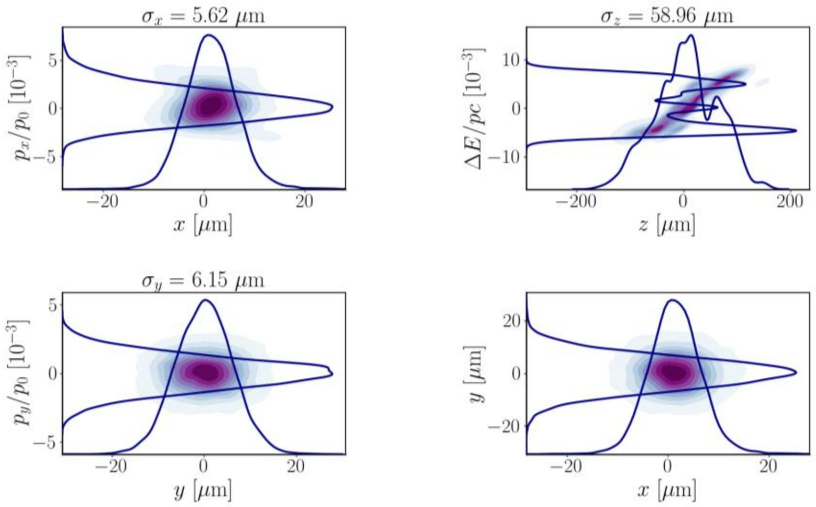




Design of the transfer line

- Final nominal design very close to specifications





	Specifications	x-plane	y-plane
$\sigma_{x,y}\ [\mu m]$	5.75	5.62	6.15
$\sigma_z\ [\mu m]$	60	58.96	
$\beta_{x,y}\ [\mu m]$	4.8	2.6	5.1
$\alpha_{x,y}$	0.0	0.0	0.0
$\varepsilon_{x,y} [\mu m]$	2	2.2	2.3
$D_{x,y}\ [m]$	0.0	0.0	0.0

Error studies

Introducing errors

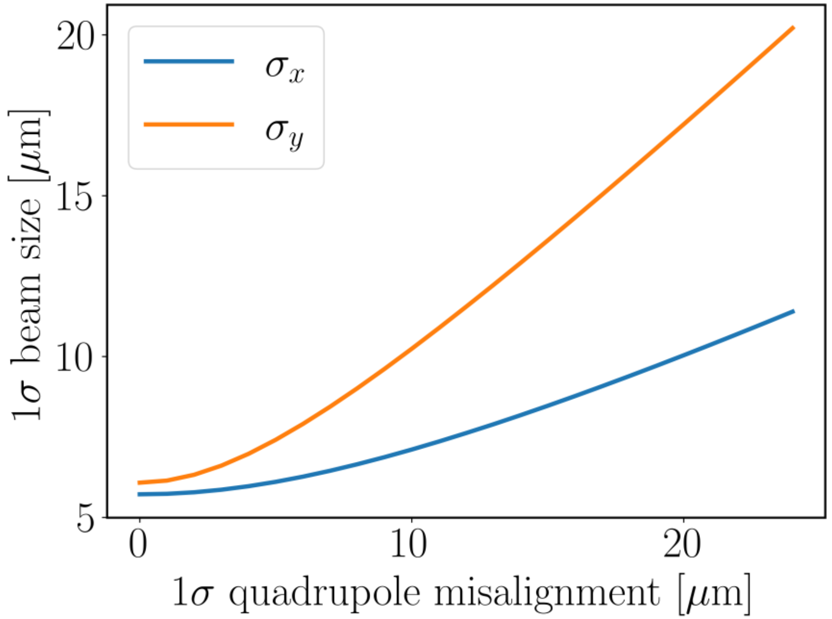
Line tolerances and beam alignment procedures were developed in parallel to find best compromise between achievable tolerances and alignment efficiency (time, feasibility)

Goals

- Beam size within $1.5\boldsymbol{\sigma}^* = 8.6\ \mu m$
- Relative beam offset between e- and p+ beam < $10\ \mu m$

R.M.S of errors used in simulation

- BPM resolution: $10\ \mathrm{\mu m}$
- BTV resolution: $1\ \mathrm{\mu m}$
- Magnet mover error: $1\ \mathrm{\mu m}$
- Corrector error: $1\ \mathrm{\mu rad}$
- Initial magnet offsets: $100\ \mathrm{\mu m}$ r.m.s
- e-line power converter ripples = 7 ppm
- Momentum jitter = 1e-3
- e-line input position jitter = 10 μm



Alignment procedure

Movers installed on quad, sextupoles and octupoles

- Quad shunt* (with quad movers) – 1 loops, gain 0.5
- Quad shunt – 1 loop, gain 0.7
- Quad shunt – 1 loop, gain 1 (15 minutes for all quad alignments)
- DFS† – higher order magnets off – 3 loops gain 0.7, DFS weight 1 (15 minutes)
- Align sextupoles and octupoles using optimiser and movers – 70 cycles (10 minutes for optimisation)

Estimate that this full alignment process would take 60 minutes (if all went well).

- *Quad shunt: vary the quad strength (between 80% and 100%) and measure the deflection of the beam at a downstream BPM. This deflection can be used to estimate the offset of the quadrupole from the beam.

- † DFS: minimise the parasitic dispersion by steering the beam through the centre of quadrupoles. This is achieved by steering the beam both to minimise the offset of the beam w.r.t BPMs and to minimise the difference in trajectory for different beam energies.

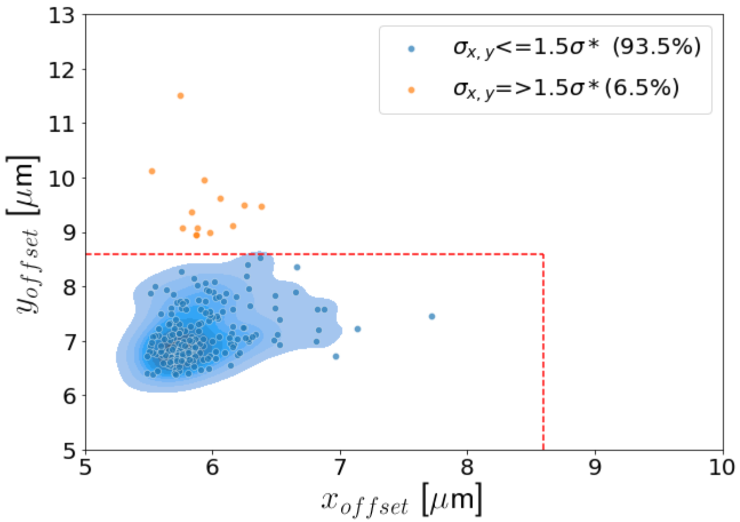
Alignment results

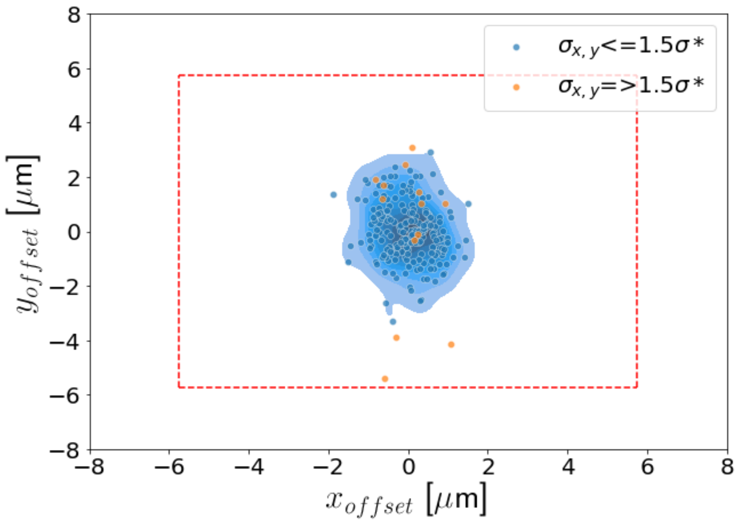
Test the alignment by simulating the alignment procedure for 200 error seeds

- The 93.3% of the cases the beam is within $1.5\boldsymbol{\sigma}^*$
- 100% of the case has a beam offset within $\boldsymbol{\sigma}^*$

When the alignment procedure fails, it has to be performed again

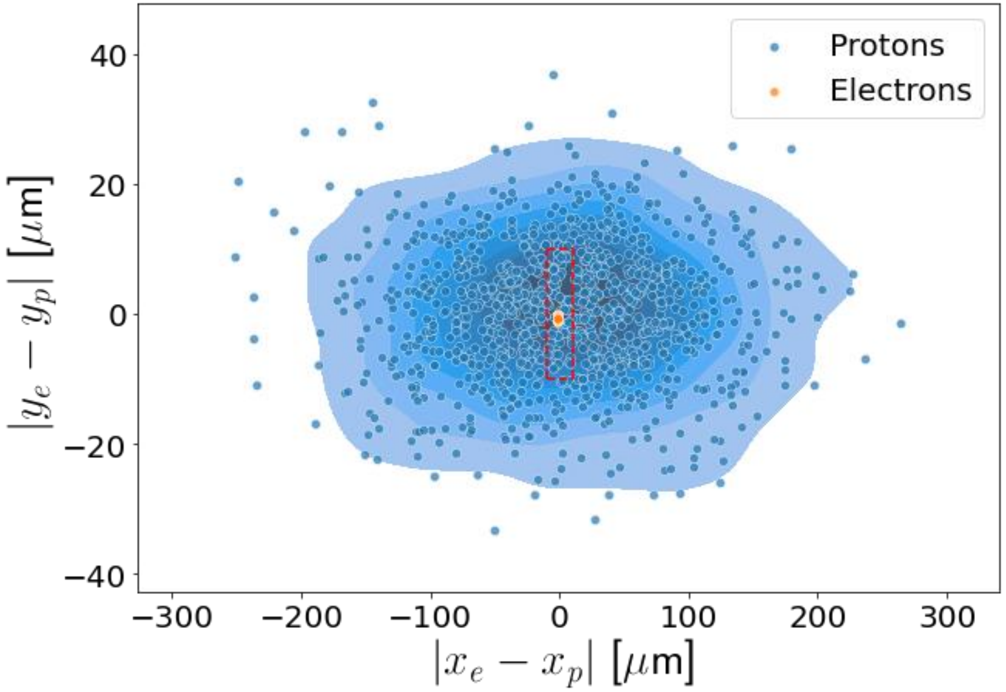
- The result of the alignment is dependent on the initial positions of the magnets
- With different initial conditions the alignment converges





Alignment results

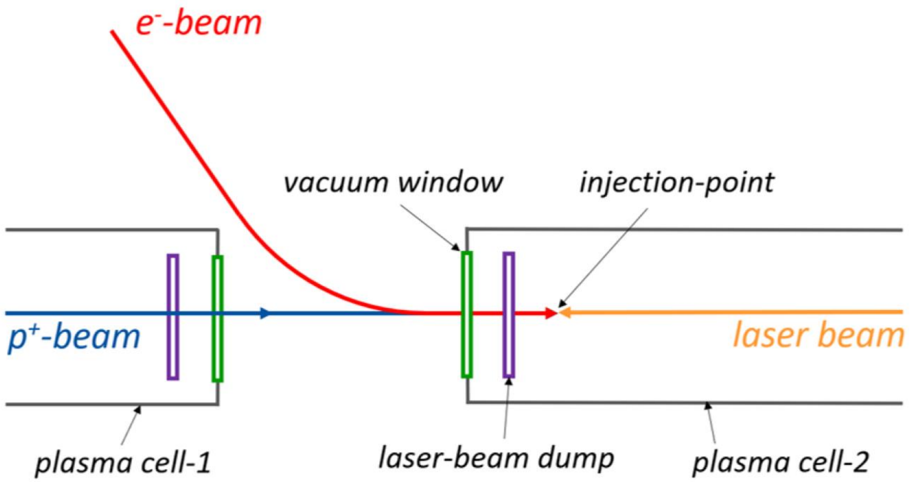
- Study on power converters ripple and beam simulations to quantify the p+ beam jitter at injection point
- Only in the 6% of the cases the alignment between the p+ and e- beam is better than 10 um
- It is completely driven by the proton beam jitter!



Optimization with scattering foils

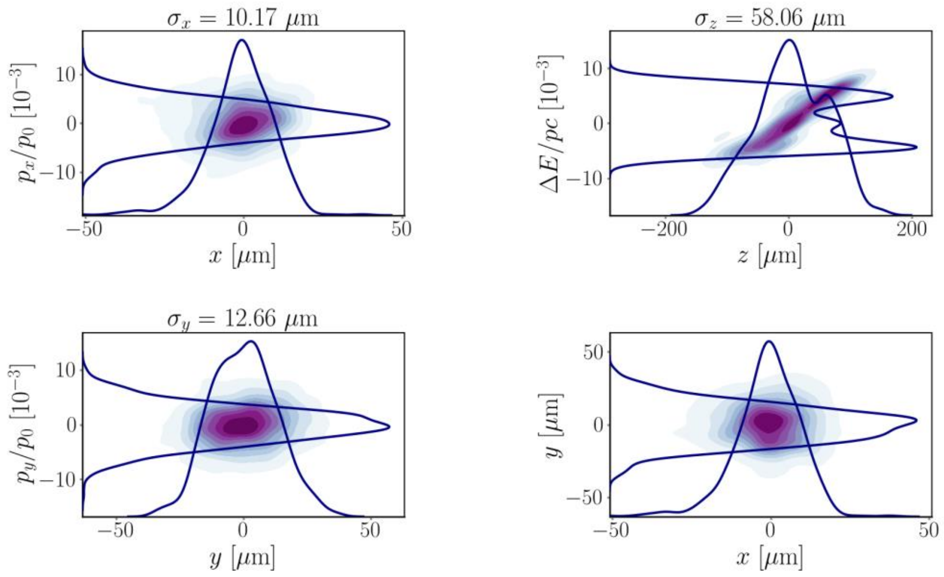
Adding the scattering foils

- Two scattering foils (vacuum window and laser beam dump) are needed upstream the injection point.
- Simulations were performed assuming a thickness of 100 um per foil and aluminum as reference material



Adding the scattering foils

- Two scattering foils (vacuum window and laser beam dump) are needed upstream the injection point.
- Simulations were performed assuming a thickness of 100 um per foil and aluminum as reference material
- Due to the scattering foil the focal point is shifted, and the matching had to be adjusted
- The matching conditions can be achieved, but with bigger beam size and emittances



	x	y
$\varepsilon_{RMS,Norm}\ [\mu m]$	11.2	12.6
$\beta\ [mm]$	2.5	2.87
$\alpha\ [mm]$	0.0	0.0
D_x	0.0	0.0

Summary and next steps

Summary

- The baseline design of the 150 MeV witness electron beam line has been defined, demonstrating the capability of achieving beam parameters very close to the requirements
- Simulations of the alignment procedures show the capability of the system of handling errors within the nominal tolerances
- The optics can be easily adjusted to rematch the beam when scattering foils are added to the line. Emittance and beam size are bigger than for nominal case

Next steps

- Implementation of beam characterization methods for operations (emittance reconstruction, energy spread, etc.)
- Continue study on beam matching with scattering foils.
- Continue development on alignment methods