

IMPERIAL

Final Focus Optimisations for 1cm baseline 15 MeV proton beam at the Stage 1 In-Vitro Endstation

Quadrupole doublet & triplet: Differential Evolution + Nelder-Mead vs. Bayesian Optimisation + Nelder-Mead

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12/10/2026



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Problem statement

Specification & Constraints



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Goal

Focus to rms $\sigma < 0.5$ mm at $z = 2$ m with $\alpha = 0$ (a waist) whilst minimising divergence, using a quadrupole doublet or triplet.

Beam

5000 tracked particles from the 1cm Gabor-lens 15 MeV protons source .dat file.

Magnets

$L_{\text{quad}} = 0.1$ m

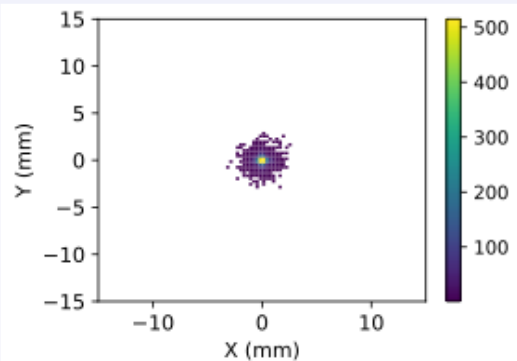
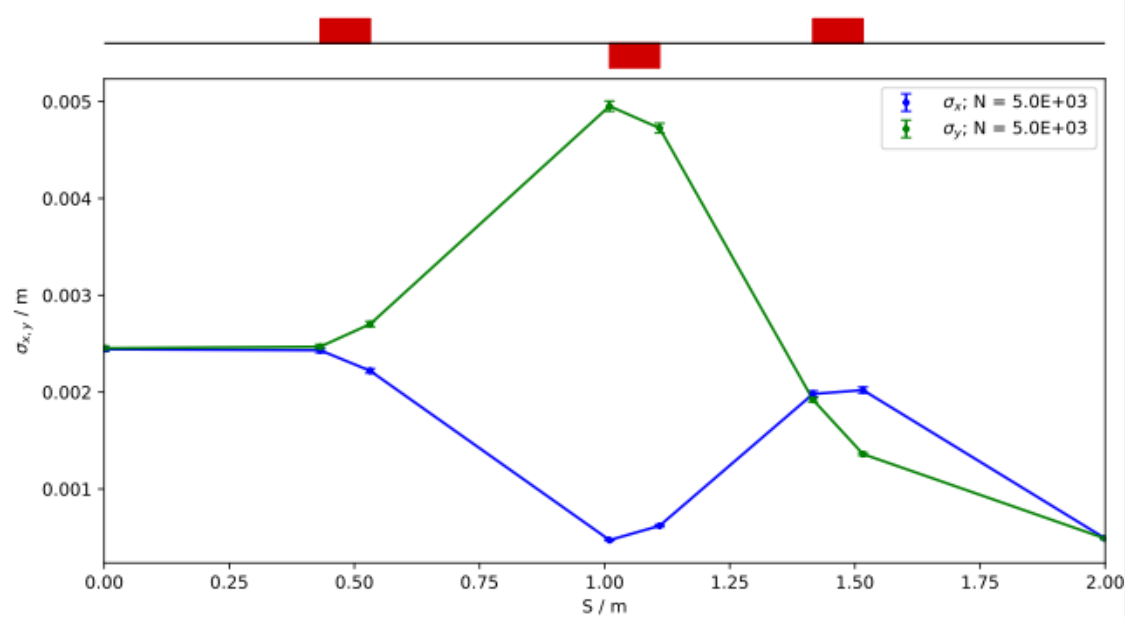
Aperture of quad $a = 25$ mm

- The optimisers worked on the input particle file directly to calculate the lattice needed to meet the constraints.
- Output: drifts and k_1 values, written as a BDSIM lattice.

Results: Spot Focus - Triplet

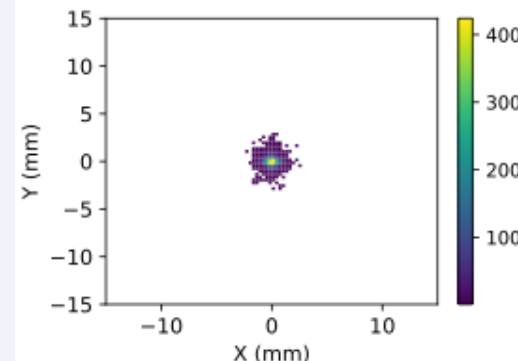
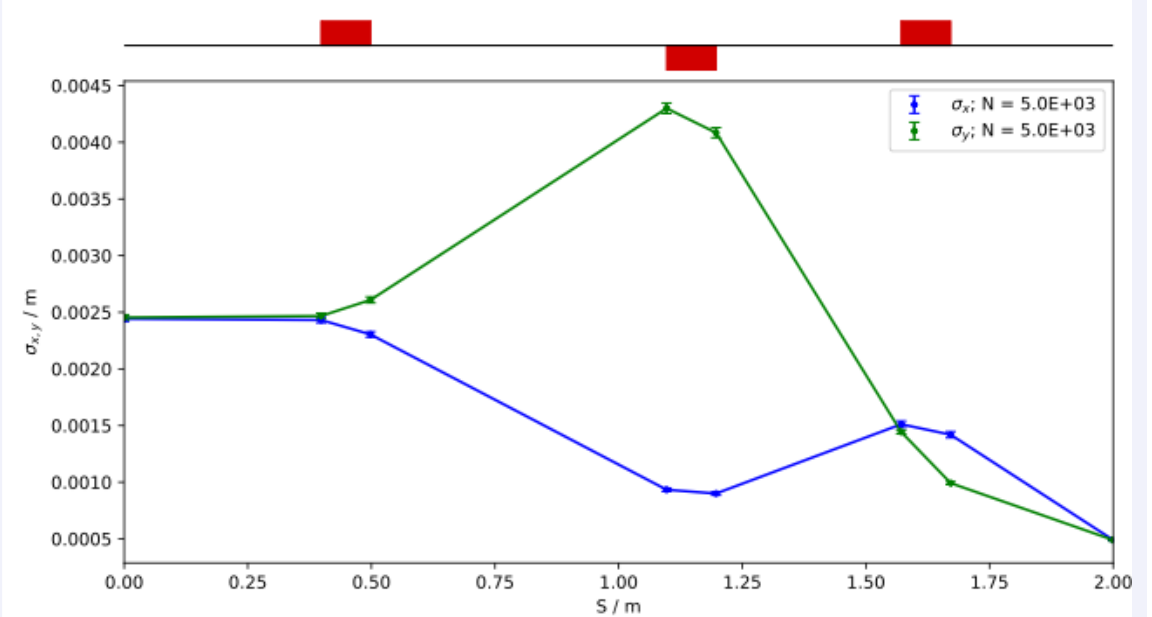
Optimisation Results Comparison

Differential Evolution + Nelder-Mead



d1: drift, $l=0.43164^*m$;
q1: quadrupole, $l=0.1$, $k1=18.1543$;
d2: drift, $l=0.47814^*m$;
q2: quadrupole, $l=0.1$, $k1=-27.9845$;
d3: drift, $l=0.30646^*m$;
q3: quadrupole, $l=0.1$, $k1=41.8689$;
d4: drift, $l=0.48376^*m$;

Bayesian Optimisation + Nelder-Mead



d1: drift, $l=0.39825^*m$;
q1: quadrupole, $l=0.1$, $k1=10.9008$;
d2: drift, $l=0.59869^*m$;
q2: quadrupole, $l=0.1$, $k1=-23.1634$;
d3: drift, $l=0.37442^*m$;
q3: quadrupole, $l=0.1$, $k1=39.2355$;
d4: drift, $l=0.32864^*m$;

Results: Spot Focus - Triplet

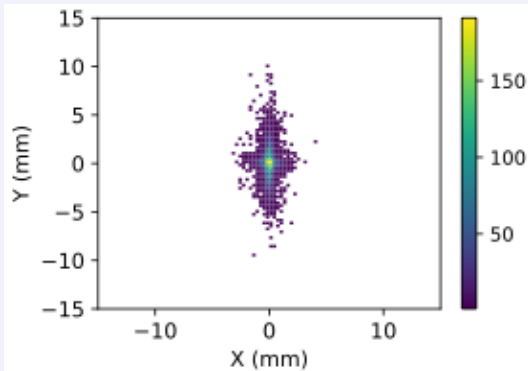
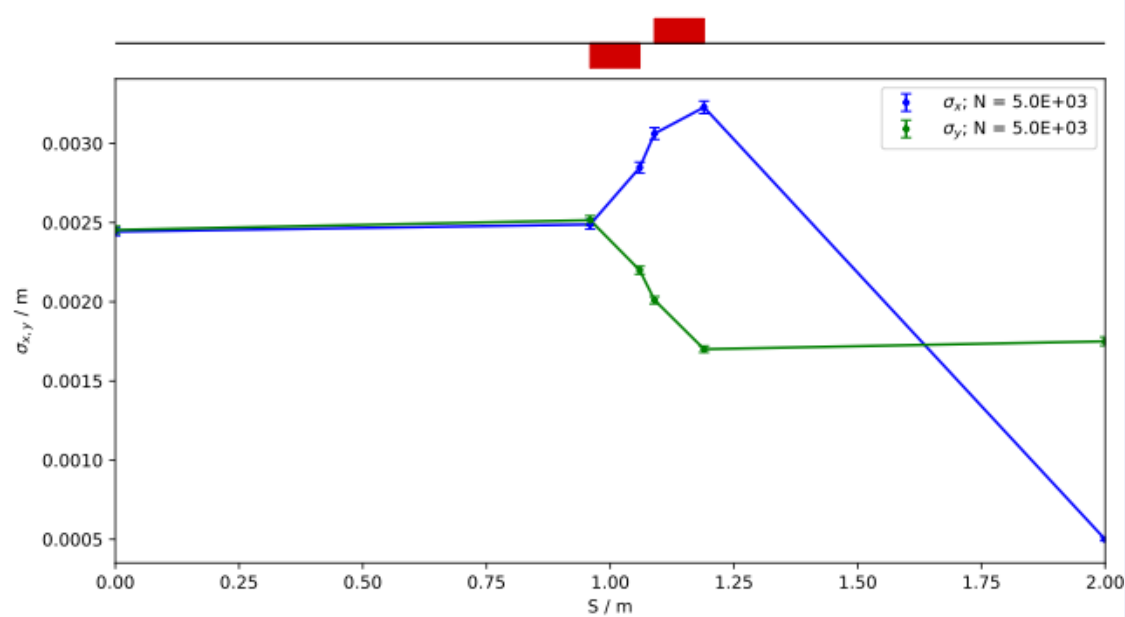
Twiss Parameters Comparison

At $z = 2$ m	DE + Nelder–Mead		Bayesian + Nelder–Mead	
	x	y	x	y
α	4.63e-16	1.79e-16	-8.63e-13	-8.42e-13
β / m	0.1207	0.1861	0.1207	0.1861
σ / mm	0.49	0.49	0.49	0.49
σ' / mrad	4.05	2.63	4.052	2.625
$\epsilon / \text{mm mrad}$	1.99	1.29	1.99	1.29

Results: Line Focus - Doublet

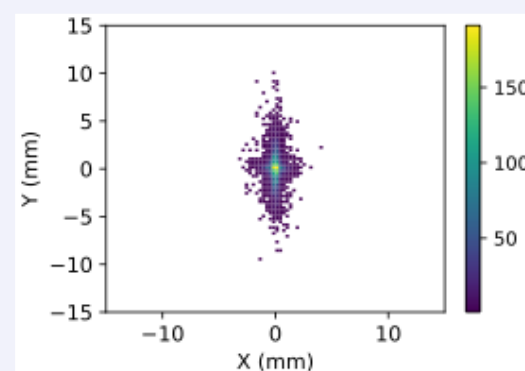
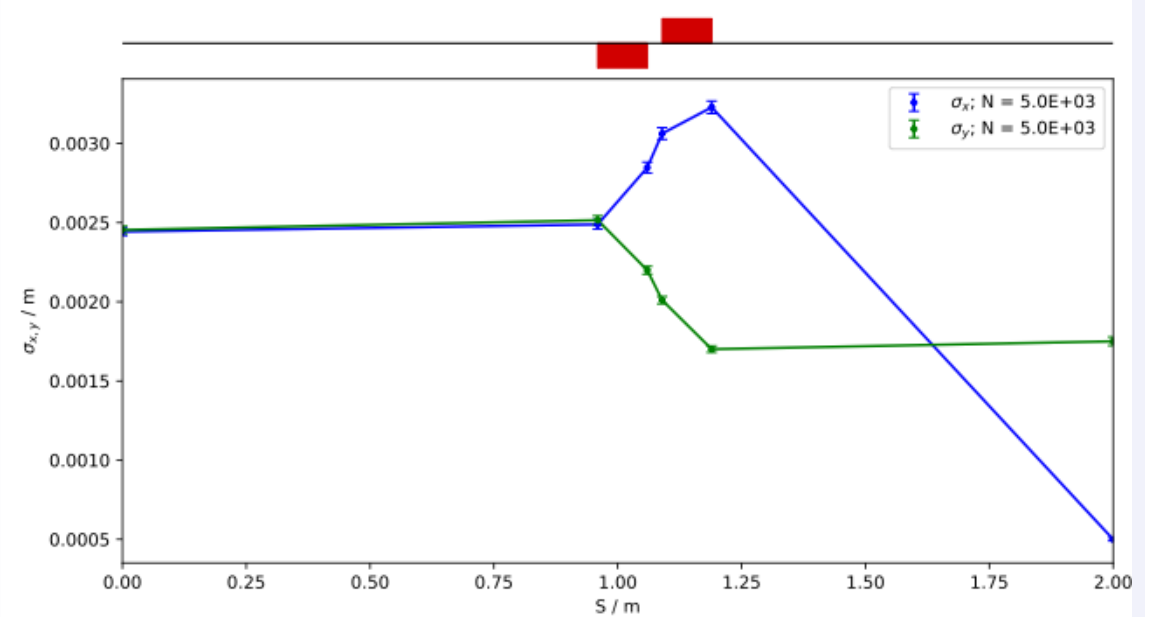
Optimisation Results Comparison

Differential Evolution + Nelder-Mead



d1: drift, $l=0.95959\text{m}$;
q1: quadrupole, $l=0.1$, $k_1=-26.6475$;
d2: drift, $l=0.03000\text{m}$;
q2: quadrupole, $l=0.1$, $k_1=34.2988$;
d3: drift, $l=0.81041\text{m}$;

Bayesian Optimisation + Nelder-Mead



d1: drift, $l=0.95959\text{m}$;
q1: quadrupole, $l=0.1$, $k_1=-26.6462$;
d2: drift, $l=0.03000\text{m}$;
q2: quadrupole, $l=0.1$, $k_1=34.2982$;
d3: drift, $l=0.81041\text{m}$;

Results: Line Focus - Doublet

Twiss Parameters Comparison

At $z = 2$ m	DE + Nelder–Mead		Bayesian + Nelder–Mead	
	x	y	x	y
α	-7.88e-02	-2.65e-01	-7.89e-02	-2.65e-01
β / m	0.1256	2.3757	0.1256	2.3762
σ / mm	0.5	1.7506	0.5	1.7508
σ' / mrad	3.984	0.760	3.984	0.760
$\epsilon / \text{mm mrad}$	1.99	1.29	1.99	1.29

Conclusions

Next Steps



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- The doublet configuration quadrupoles are too close together, so some further investigation is necessary
- Would like to do the same optimisations for 3cm baseline beam
- Will implement the scanning magnet optics into these lattices to see if the beam can be scanned:
 - In 1 plane, for the line focus, to deliver a strip like radiation pattern
 - In 2 planes, for the spot focus, to deliver a spotted grid like radiation pattern
- Will need to analyse the space charge effects for all configurations of the beamline