Multi-objective Optimization of the Matching Beamline for External Injection into a Laser-driven Plasma Accelerator.

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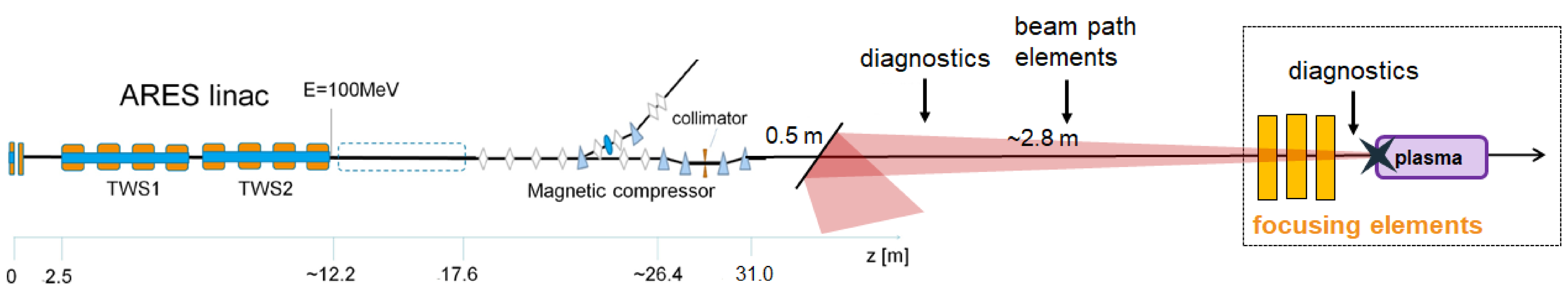
ID # 287

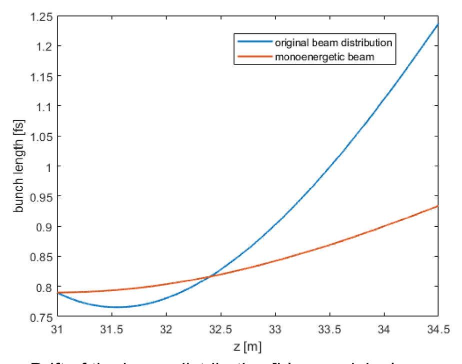
Electron beam matching to a plasma accelerator at SINBAD-ARES

The Accelerator Research Experiment at SINBAD (ARES) is a dedicated accelerator R&D facility at DESY [1].

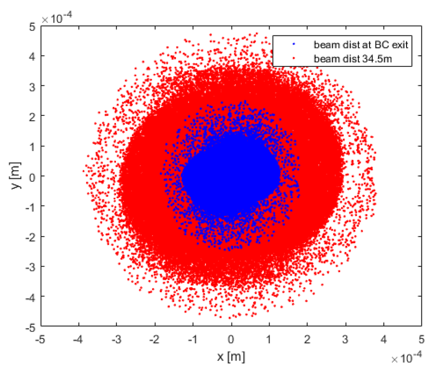


Motivation for optimizing the matching beamline

- Fit the requirements for the electron beam at the plasma entrance:
  - Keep the bunch length short from the bunch compressor to the plasma.
  - Focus the beam in the transverse plane.
- Space charge (sc) effects must be considered (see simulation results).
- Tool must be flexible to probe different focusing strategies (permanent quads, electrical quads, plasma lens, …).
- Several optimization tools do not include sc calculations, need a start setting or require a high CPU usage.



Drift of the beam distribution [blue = original distribution; orange = monoenergetic beam] from BC exit up to 3.5 m (ASTRA tracking). The bunch length is increased due to space charge and an energy chirp.

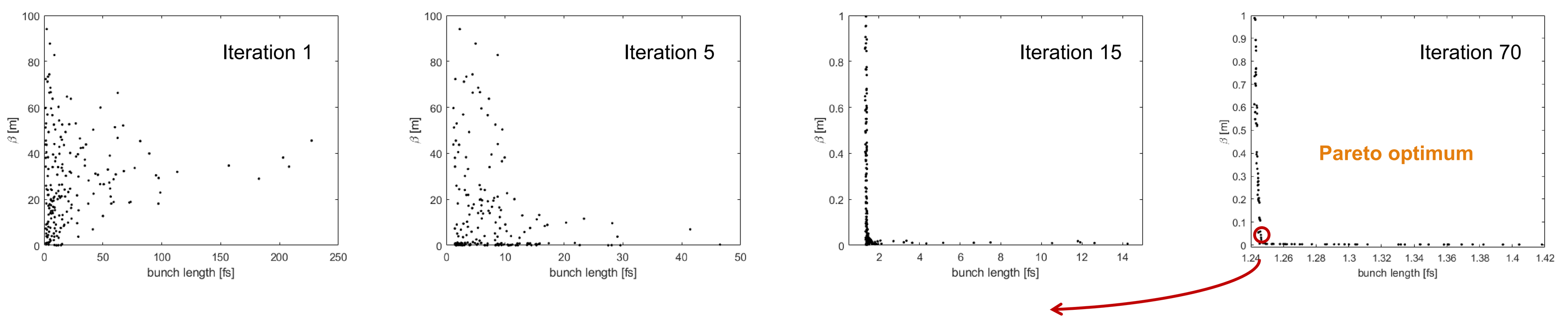


Growth of the transverse spot size over the drift due to space charge.

→ **New optimizer based on a multi-objective generic algorithm with particle tracking including space charge**

Multi-objective optimization for plasma matching

Evolution of the Pareto optimum front | Optimization of a PMQ triplet



First optimization results for the electron beam matching into plasma at SINBAD-ARES

$\beta_{x,y}$ (@BC exit) = 6 m

Computational run time:

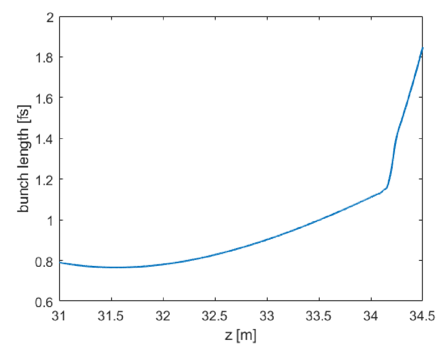
12 h, 40 parallel Astra runs

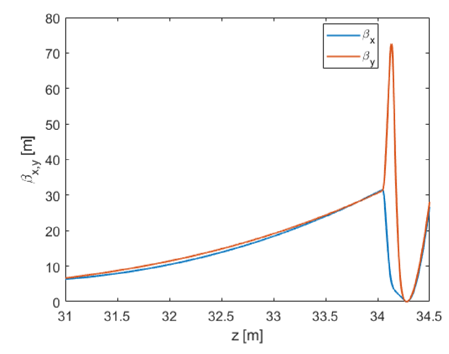
One setting for the PMQ triplet

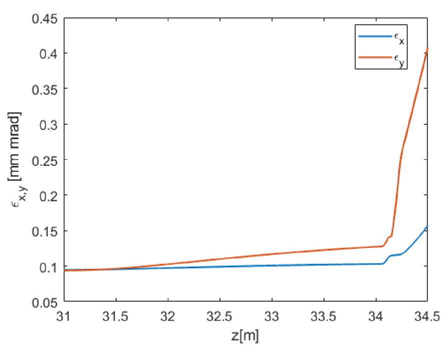
Q1 position [m]	34.06
Q1 gradient [T/m]	102.97
Q1 length [m]	0.03
Q2 position [m]	34.14
Q2 gradient [T/m]	-117.72
Q2 length [m]	0.04
Q3 position [m]	34.25
Q3 gradient [T/m]	160.47
Q3 length [m]	0.05
Plasma entrance (start ramp) [m]	34.28

Beam parameters at the plasma entrance

q_b [pC]	0.78
σ_z [fs]	1.38
$\beta_{x,y}$ [mm]	2.6 / 1.2
$\varepsilon_{x,y}$ [mm mrad]	0.12 / 0.27
$\sigma_{x,y}$ [µm]	1.27 / 1.29
$\alpha_{x,y}$	1.38 / 1.0
σ_E [%]	0.3

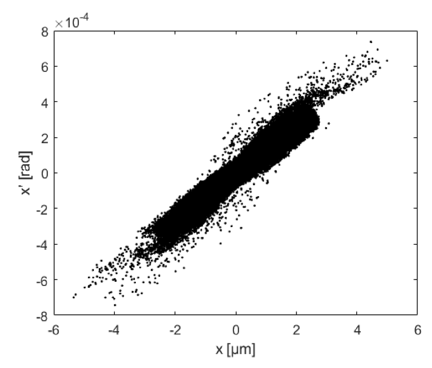


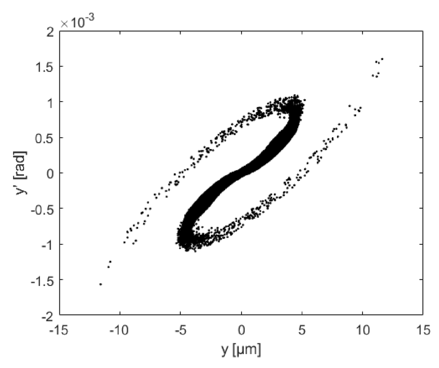




Check beam distribution in a plasma simulation [3]

Beam parameters	at plasma entrance	at plasma exit
q_b [pC]	0.78	0.78
E [MeV]	100	1064
σ_z [fs]	1.38	1.61
$\beta_{x,y}$ [mm]	2.6 / 1.2	30.6 / 26.5
$\varepsilon_{x,y}$ [mm mrad]	0.12 / 0.27	0.12 / 0.45
$\sigma_{x,y}$ [µm]	1.27 / 1.29	1.32 / 2.36
$\alpha_{x,y}$	1.38 / 1.0	-4.14 / -3.61
σ_E [%]	0.3	0.7
I_{peak} [kA]	0.56	0.48



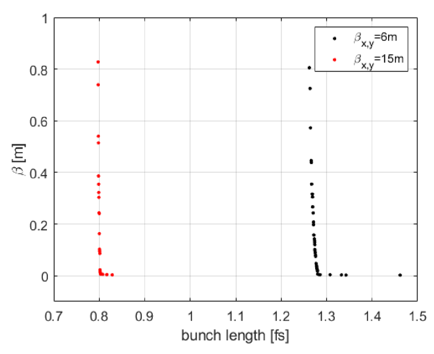


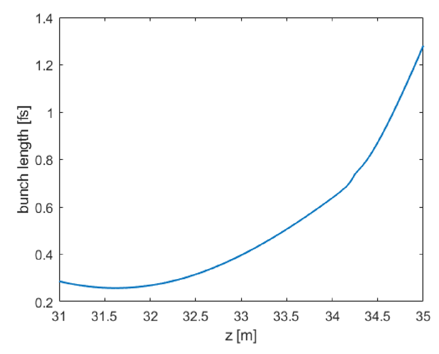
- ➡ Acceleration of the beam to 1 GeV
- ➡ Emittance preserved in the horizontal plane
- ➡ Bunch length too long
- ➡ Beam asymmetric in the transverse plane ($\Delta\beta_{x,y}$<1 mm at plasma entrance)

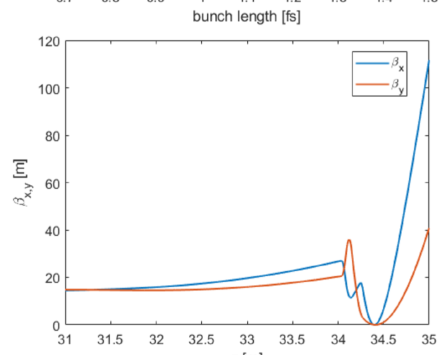
Improved optimization results

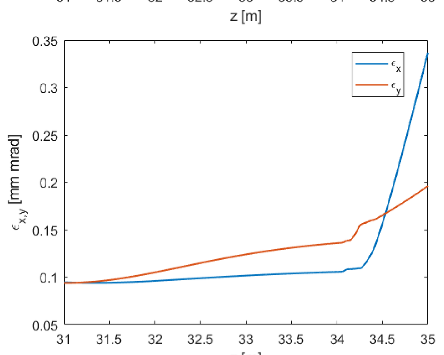
$\beta_{x,y}$ (@BC exit) = 15 m

- β-function at the BC exit artificially increased to $\beta_{x,y}$= 15 m.
- Final bunch length at plasma entrance significantly improved. Peak current I_{peak}= 0.98 kA
- Additional constrain: $\beta_x - \beta_y < 1$ mm





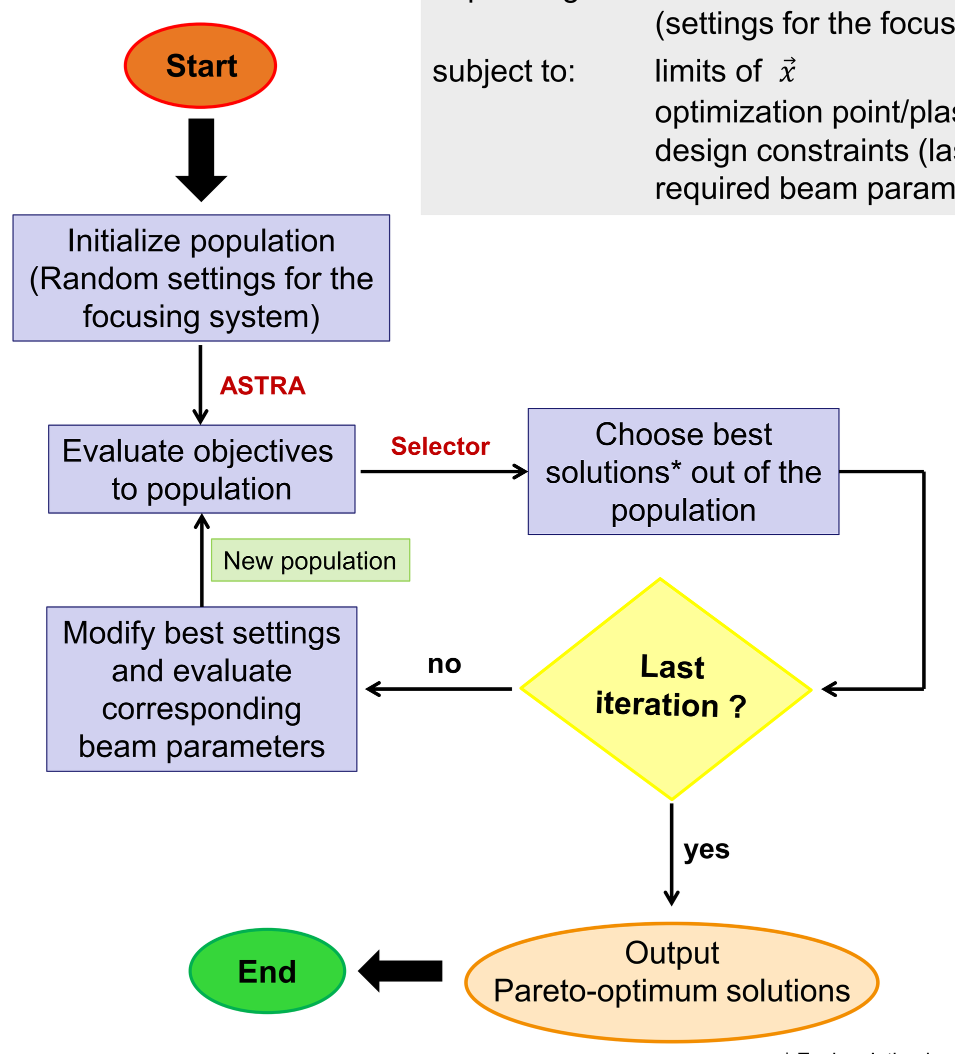




Program Setup

SPEA2 algorithm [2] implemented in a MATLAB script
Beamline simulated with the particle tracking program ASTRA

Minimize:	objectives $\beta(\vec{x}) = \sqrt{{\beta_x}^2 + {\beta_y}^2}, \sigma_z(\vec{x})$
depending on:	decision variables $\vec{x}$ (settings for the focusing system)
subject to:	limits of $\vec{x}$ optimization point/plasma entrance design constraints (laser, diagnostics,…) required beam parameters at the plasma



* Each solution in a population is one complete setting for the focusing system [magnet position(s), magnet length(s), focusing strength(s), ...]

Summary and Outlook

Developed optimization tool based on a MOGA algorithm:

- finds **stable settings** for a focusing system to match an electron beam to a plasma accelerator.
- maps out the **physical limits** of the matching area and the focusing system.
- enables to test/optimize **different focusing strategies**.
- allows to **study beam dynamics** in the matching area.

Next steps:

- The limits of the decision variables should cover the full dynamic range of the parameter space.
  → Calculate suitable settings based on the effective focal length.
- The optimizer can be used for the design of the matching area at SINAD-ARES.

References

[1] B. Marchetti *et al.*, presented at *EAAC'19*, Isola d'Elba, Italy, Sept. 2019, paper ID #134, this conf.
[2] E. Zitzler, M.Laumanns and L.Thiele, *Tech. Rep. Swiss Federal Institute of Technology*, Zurich, Switzerland, 2001, pp. 1–21.
[3] E. N. Svystun *et al.*, in *Proc. IPAC'19*, Melbourne, Australia, May 2019, paper THPGW023, pp. 1820-1822.

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