Electron Beam Matching Strategies for External Injection in LWFA for SINBAD-ARES.

E. Panofski#, R. W. Assmann, F. Burkart, U. Dorda, A. Ferran Pousa, F. Lemery, B. Marchetti, A. Martinez de la Ossa, E. Svystun, P. A. Walker, S. Yamin, DESY Hamburg, Germany

ID # 300

Electron beam matching to a plasma accelerator at SINBAD-ARES

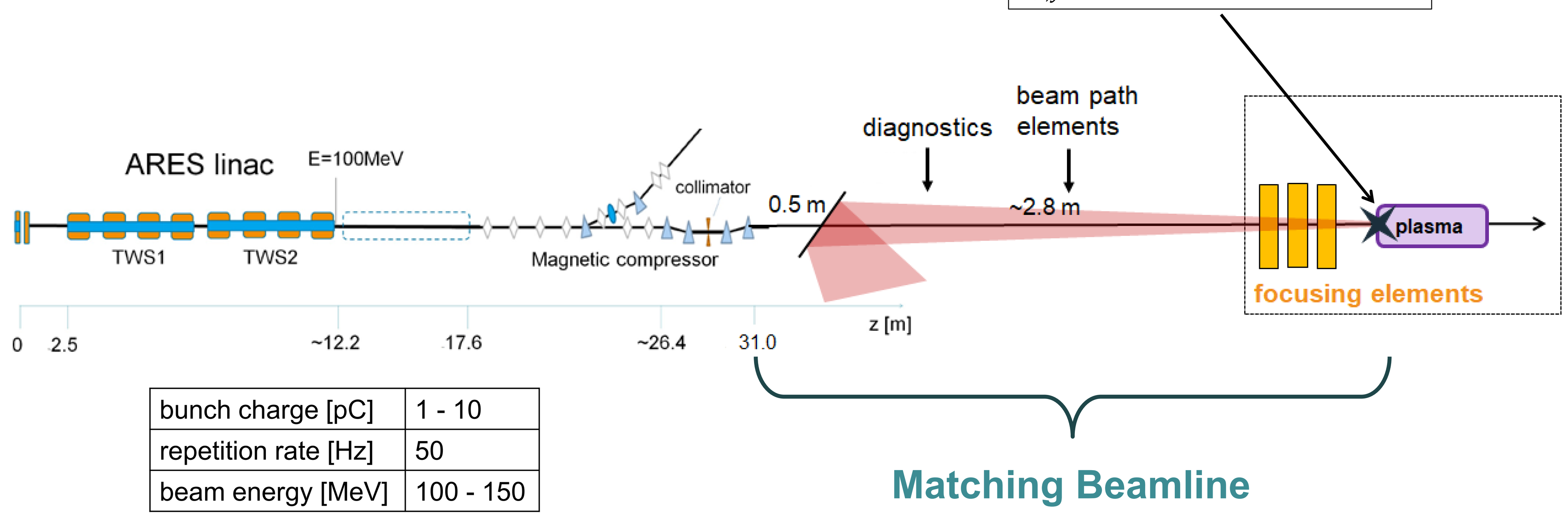
- The Accelerator Research Experiment at SINBAD (**ARES**) is a dedicated accelerator R&D facility at DESY Hamburg [1].
- ARES will be able to serve as a test facility for the generation of **high brightness probes** for LWFA (laser wakefield acceleration) and their external injection into a plasma.
- The ARES photoinjector and linac are currently in the **conditioning phase**. The setup and commissioning of the subsequent beamline (bunch compressor, X-band TDS) will follow in a staged approach.
- The **matching beamline** must include
  - → elements to **match the electron beam** into the plasma
  - → **beam diagnostics** to characterize the electron beam that will be injected into the plasma
  - → **incoupling of the high power laser** for driving the plasma

e^- beam requirements defined by the plasma wakefield

$\sigma_t \leftarrow \lambda_P$

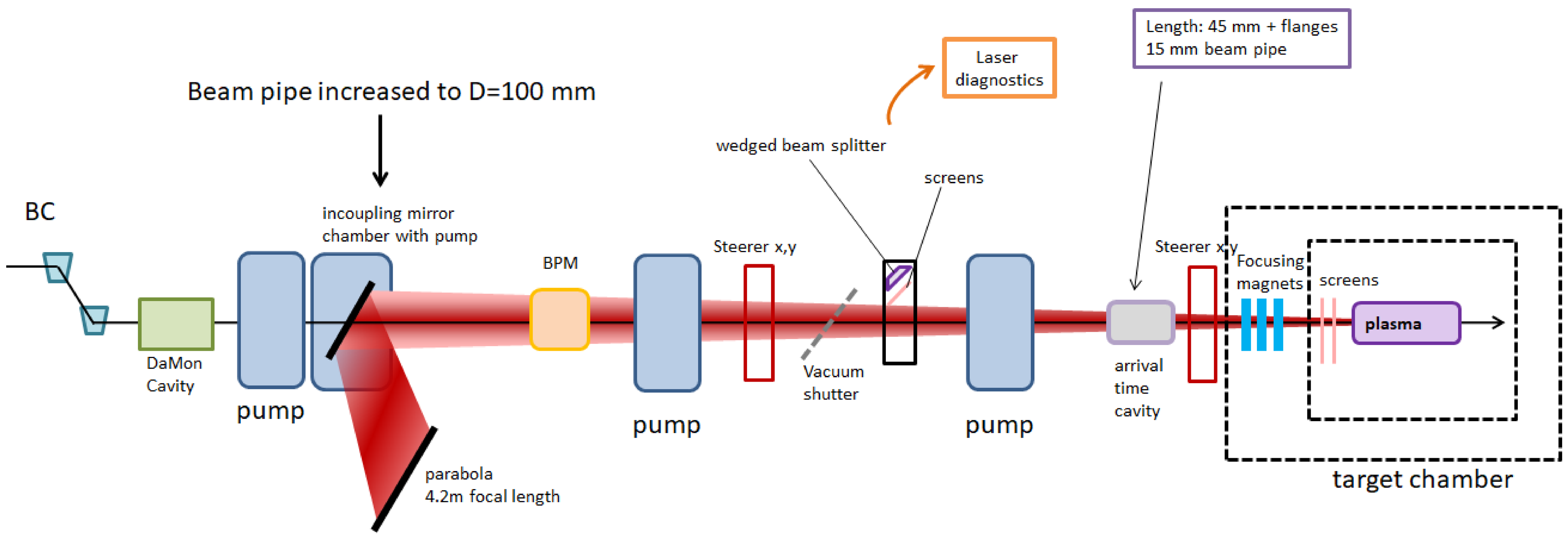
$\beta_{x,y} \leftarrow K_P$, plasma ramp

$\alpha_{x,y} \cong 0$



bunch charge [pC]	1 - 10
repetition rate [Hz]	50
beam energy [MeV]	100 - 150

First layout proposal for the matching beamline from bunch compressor to plasma



Laser

Kilowatt Lasers at DESY for Revolutionary Accelerators [2]

KALDERA parameters

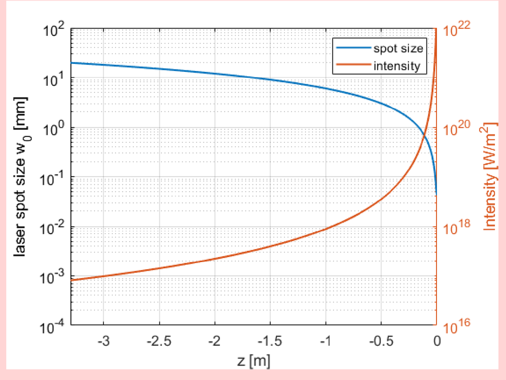
λ = 800 nm

P_0 = 100 TW

E = 3 J (on target)

w_0 = 40 µm

Δt_{FWHM} = 30 fs



Diagnostics

Characterize e^- beam and high power laser before injection into plasma:

bunch charge → resonator for charge measurements [3]
e^- beam position → BPM, screens
e^- beam spot size → screens
e^- beam arrival time → arrival time cavity [4]

Use a small part of the laser for diagnostics (wedged beam splitter)

Design comparable to REGAE at DESY Hamburg.

Electron beam matching

Options to focus the beam in the transverse plane for matching:

- permanent quadrupole triplet
- electrical quadrupoles
- combination of electrical and permanent quadrupoles
- active/passive plasma lens

Align e^- beam → steerer magnets, screens before/after plasma

Control bunch length → adjust β-functions

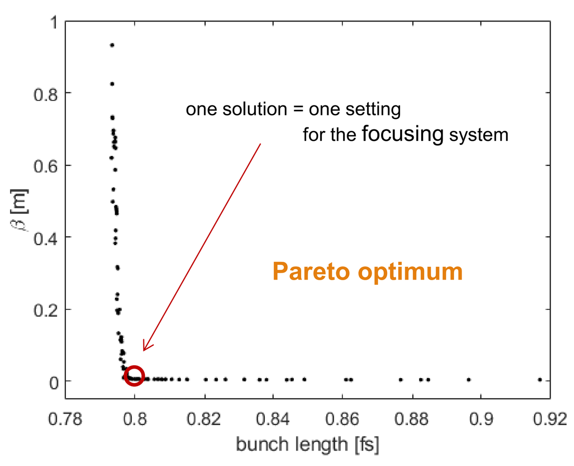
Optimization of the matching

The design of the matching area is done using an **optimizer** based on a MOGA algorithm and the particle tracking program ASTRA [5].

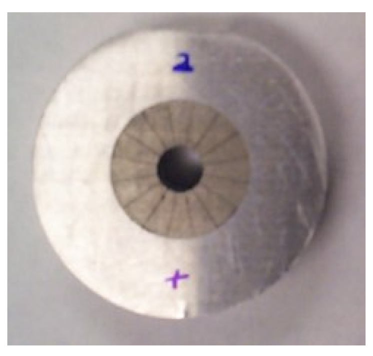
→ Finds stable settings for a focusing system from the Pareto optimum.
→ Enables to optimize different focusing strategies.
→ Allows to study beam dynamics in the matching area.

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

Computational run time: ~12 h, 40 parallel Astra runs

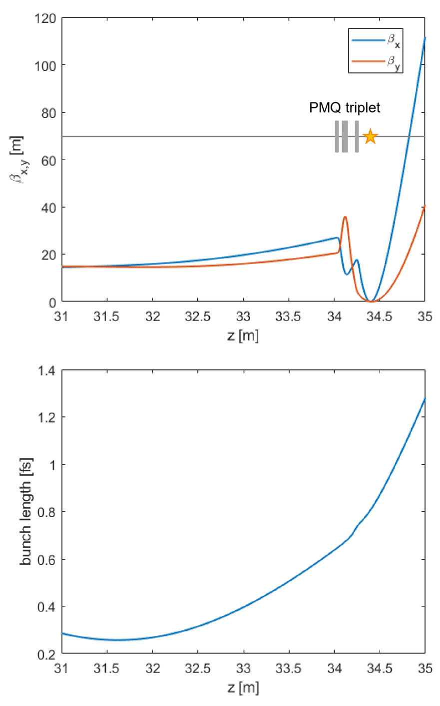


Permanent quadrupole triplet (PMQ)



[6]

q_b [pC]	0.78
σ_z [fs]	0.79
$\beta_{x,y}$ [mm]	13.0/13.0
$\varepsilon_{x,y}$ [mm mrad]	0.14/0.16
$\sigma_{x,y}$ [µm]	2.5/3.3
$\alpha_{x,y}$	1.21/1.01
σ_E [%]	0.4
I_{peak} [kA]	0.98

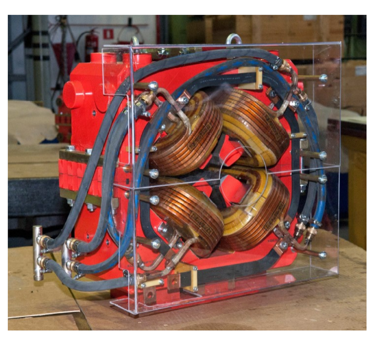


✔ allow strong focusing to small β-function (gradients up to 500 T/m possible).

✔ compact setup possible (placed in interaction chamber).

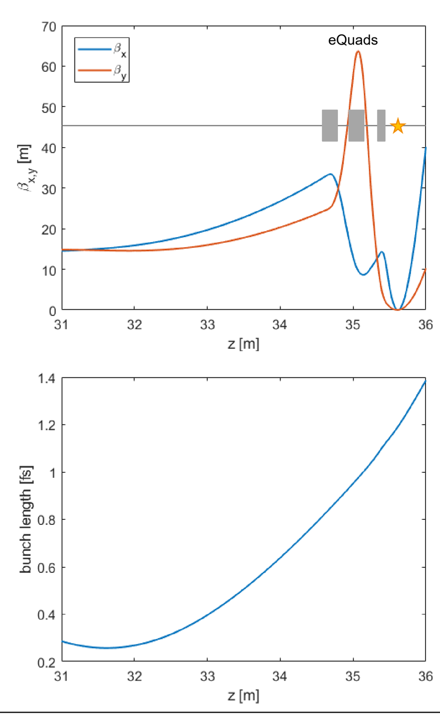
✘ β-function only tunable using linear stages (limited dynamic range).

Electrical quadrupoles



[7]

q_b [pC]	0.78
σ_z [fs]	1.18
$\beta_{x,y}$ [mm]	15.0/15.0
$\varepsilon_{x,y}$ [mm mrad]	0.12/0.12
$\sigma_{x,y}$ [µm]	3.0/3.0
$\alpha_{x,y}$	2.3/2.4
σ_E [%]	0.5
I_{peak} [kA]	0.66



✔ wide tuning range (flexible β-function for various working points).

✔ DESY design for XFEL quads can be used.

✘ matching takes more space than with permanent quads (placed outside vacuum).

Next steps

Study an active **plasma lens** for electron beam matching [8]:

- more compact than a PMQ triplet.
- focus in the transverse and longitudinal plane simultaneously.
- tunable by changing the current that drives the focusing magnetic field.
- external injection with a plasma lens is also interesting for plasma staging.

Risks:

- high power laser (nearly focused close to the plasma entrance) can drive wakefields in the lens.
- the e^- bunch must be symmetric at the plasma entrance (electrical quadrupoles are required in the matching beamline).
- challenges: passive plasma lensing distortions, temperature non-uniformities (→ non-linear magnetic field profile), gas scattering,…

References

[1] B. Marchetti *et al.*, presented at *EAAC'19*, Isola d'Elba, Italy, Sept. 2019, paper ID #134, this conf.
[2] W. Leemans *et al.*, presented at *EAAC'19*, Isola d'Elba, Italy, Sept. 2019, paper ID #342, this conf.
[3] D. Lipka, J. Lund-Nielsen and M. Seebach, in *Proc. IBIC'13*, Oxford, UK, Sep. 2013, paper WEPF25, pp. 872-875.
[4] M. Hansli *et al.*, in *Proc. IPAC'14*, Dresden, Germany, May 2014, paper TUPRI104, pp. 1820-1822.
[5] E. Panofski and R. W. Assmann, presented at *EAAC'19*, Isola d'Elba, Italy, Sept. 2019, ID #287, this conf.
[6] http://pbpl.physics.ucla.edu/Research/Technologies/Magnets/UCLA_PMQ/ (12.09.2019).
[7] DESY Hamburg, Magnetdatenblatt XFEL quadrupole type XQE.
[8] C. A. Lindstrøm *et al.*, *Phys. Rev. Lett.*, *vol*. 121, p. 194801, Nov. 2018. doi: 10.1103/PhysRevLett.121.194801

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ATHENA Accelerator Technology Helmholtz Infrastructure

Eva Panofski
eva.panofski@desy.de