EUROPEAN PLASMA RESEARCH ACCELERATOR WITH EXCELLENCE IN APPLICATIONS

External Injection in the Context of SINBAD

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 653782.

Outline

- Introduction to SINBAD
- Optimisation studies:
  - Beamloading compensation
  - Matching into plasma
- Start-to-end simulations

SINBAD – Short INnovative Bunches & Accelerators at Desy

ARES linac: E-beam at plasma entrance
(based on simulations by J. Zhu)

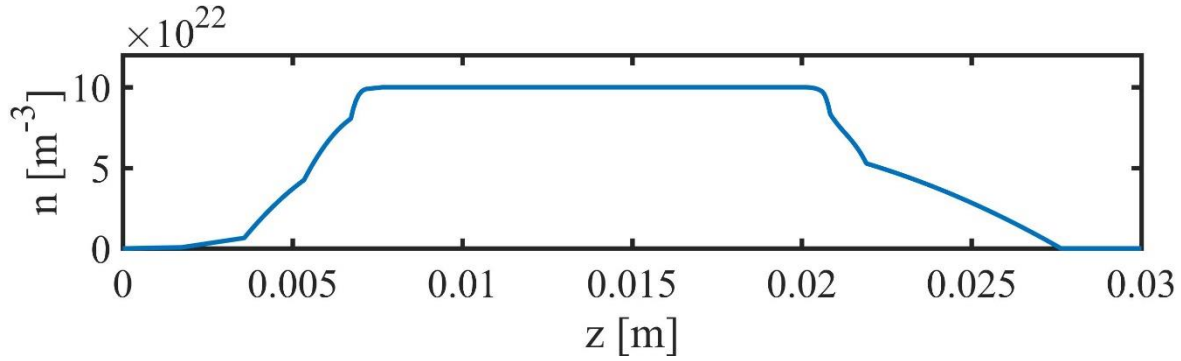
Charge	0.7 pC	RMS duration	0.77 fs
Energy	~ 100 MeV	RMS width σ_x	5.1 μm
E-spread	0.37 %	Norm emittance	0.17 μm

+ excellent arrival time stability

ANGUS laser

Power	~ 200 TW
a_0	1.8
Spot size w_0	42.5 μm
FWHM duration	25 fs

Setup Optimisation



Plasma Density: $n=10^{23}m^{-3}$

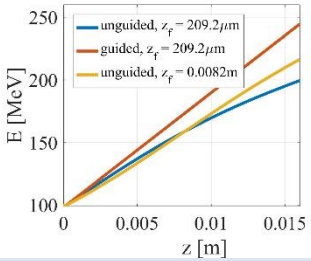
Profile based on OpenFoam simulations (C. Thornton, Oxford University)

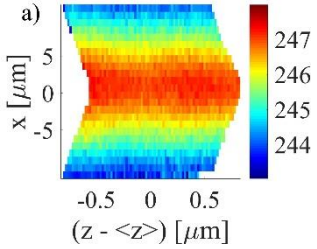
M. Weikum, IPAC 2017, TUPIK013

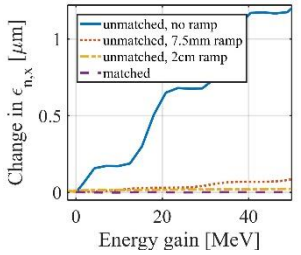
Two cases:

- **Acceleration to 200 MeV in 2.75cm (energy doubling)**
- **Acceleration to 1 GeV in 11.5 cm (GeV-stage)**

Optimisation of plasma setup





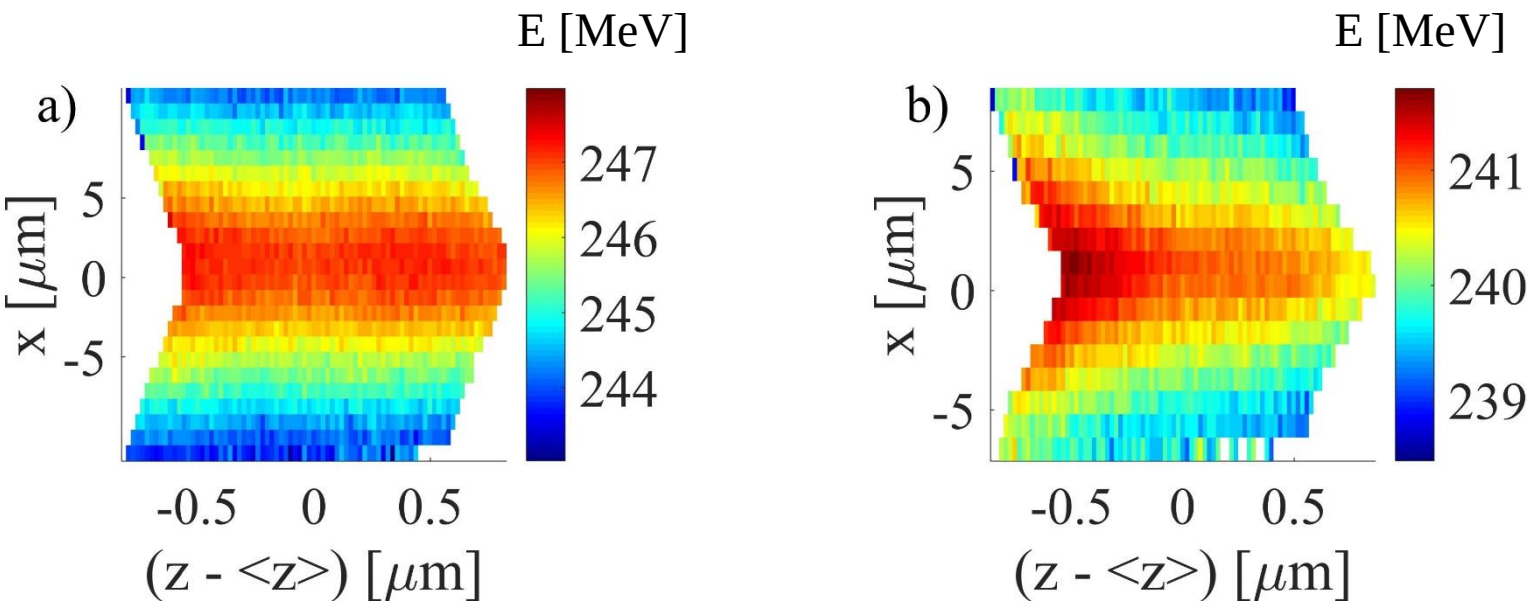


Laser guiding...

Beamloading...

Plasma matching...

Beamloading Compensation



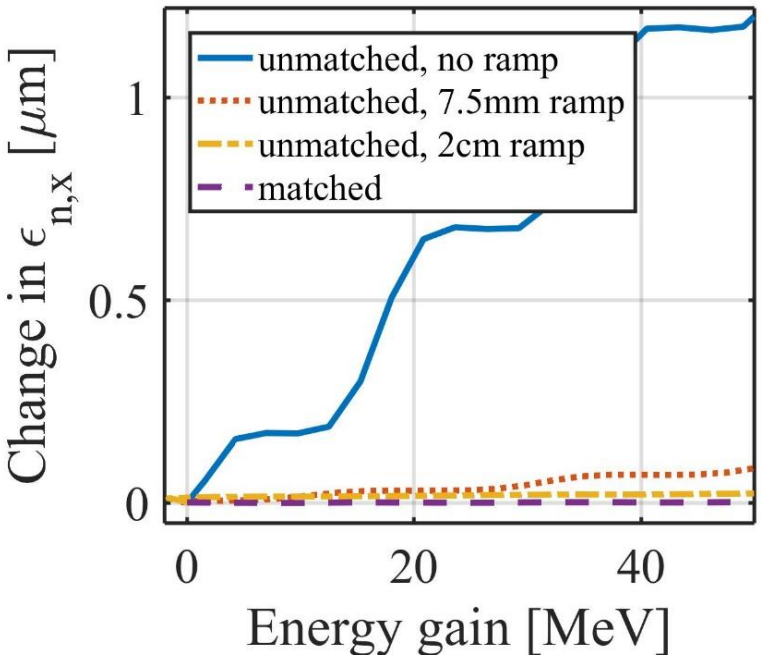
With beamloading optimisation: 0.35% E-spread

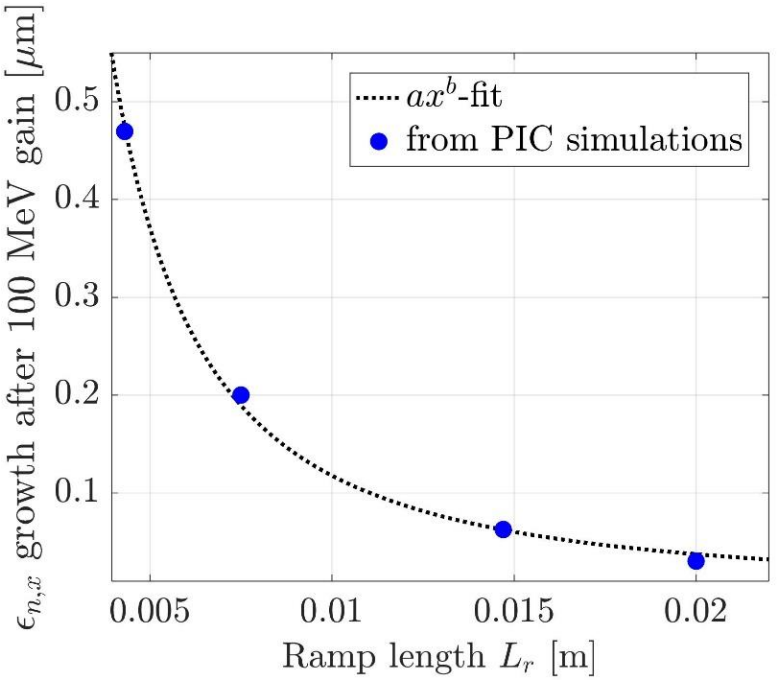
Without beamloading optimisation: 0.32% E-spread

- Overall, very small energy spread due to ultrashort bunch length
- Traditional beamloading compensation [1] flattens energy distribution along z
- BUT: energy spread due to transverse wakefield gradient becomes dominant

[1] M. Tzoufras et al., Phys. Plasmas, 16 (056705), 2009.

Matching into Plasma



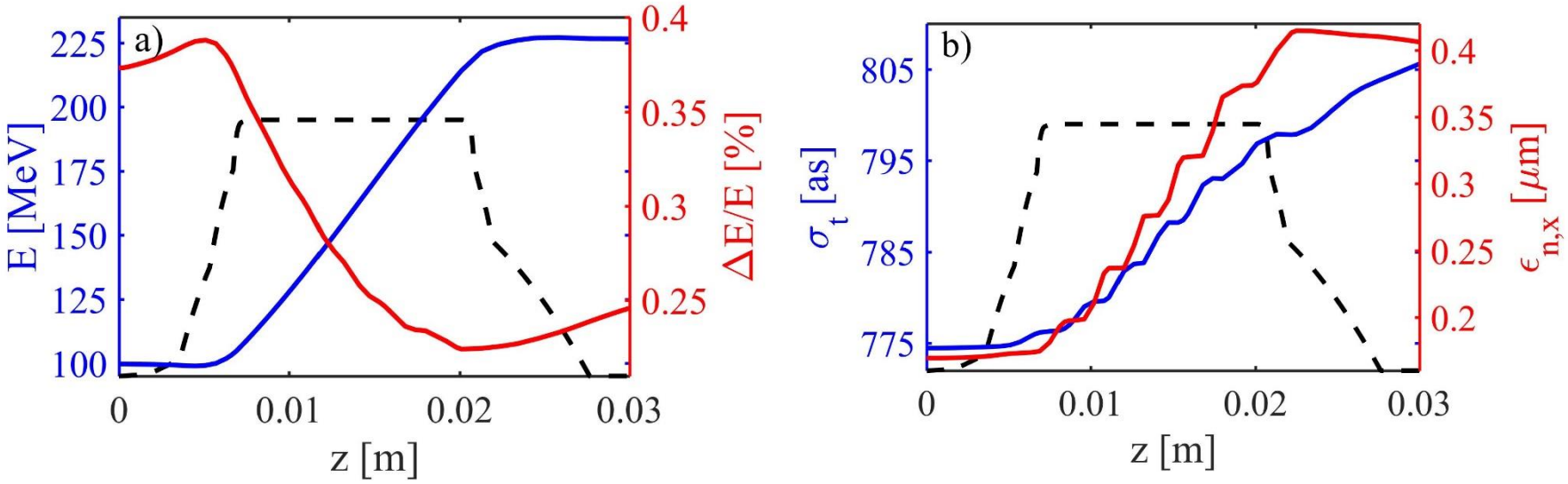


- Space-charge forces prevent focusing to matched spot size at plasma entrance → use of a density upramp [2]
- Significant reduction of emittance growth with increasing ramp length by factor >15
- Trade-off between acceptable emittance growth and minimal ramp length

[2] I. Dornmair et al., Phys. Rev. ST Accel. Beams, 18 (041302), 2015.

Start-to-end Simulations: 200 MeV

2.75 cm plasma stage – no laser guiding, laser focus at 1.39 cm – no beamloading optimisation – 7.5 mm long ramps

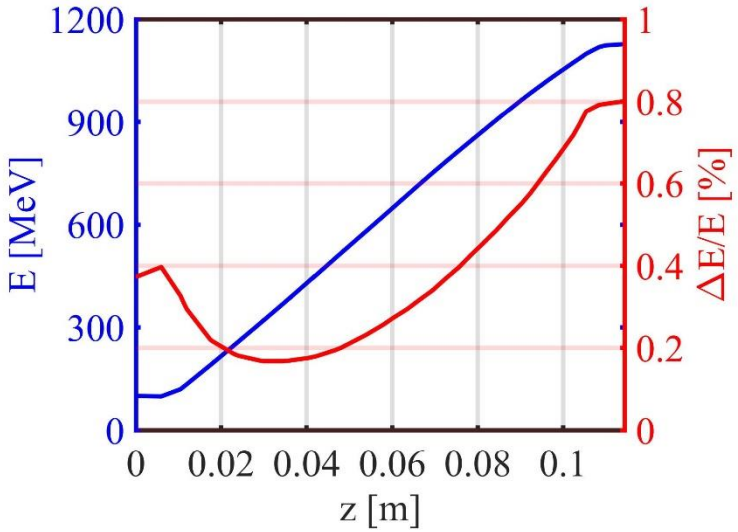


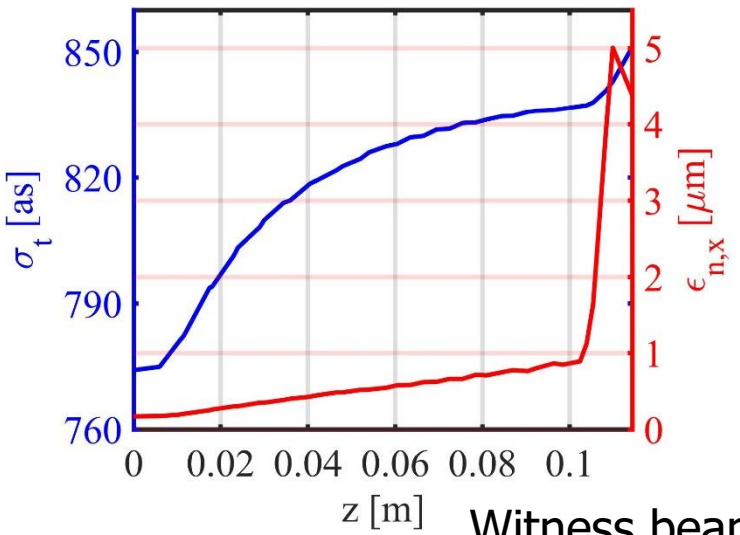
- Almost linear energy gain between 6.9 mm & 2.13 cm → no laser guiding required
- Increase in longitudinal duration due to bunch reshaping with off-axis electrons moving backwards in beam
- Increase in energy spread in low plasma density regions due to dominant beamloading fields
- Final decrease in emittance from re-aligning of phase-space areas of centre and sides of beam [3]

[3] P. Tomassini et al., Plasma Phys. Controlled Fusion, 58 (034001), 2016.

Start-to-end Simulations: 1 GeV

11.5 cm plasma stage – laser guiding, laser focus at 1.01 cm – no beamloading optimisation – 1 cm long ramps





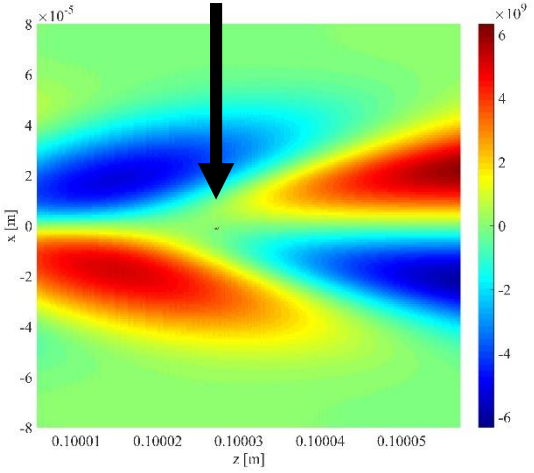
- Sudden increase in emittance and bunch length after z~10cm
- Increase in relative energy spread from z~3cm

→ Numerical dephasing between drive laser and witness beam due to laser group velocity above c for Lehe solver

➢ **Alternative solvers?**

Laser position z	Laser – Ebeam Offset
84.07 μm	52.85 μm
11.46 cm	76.21 μm

Witness beam



Focusing field at z~10cm