3rd European Advanced Accelerator Concepts Workshop

Lattice Design and Start-to-end Simulations for the ARES Linac

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HELMHOLTZ ASSOCIATION

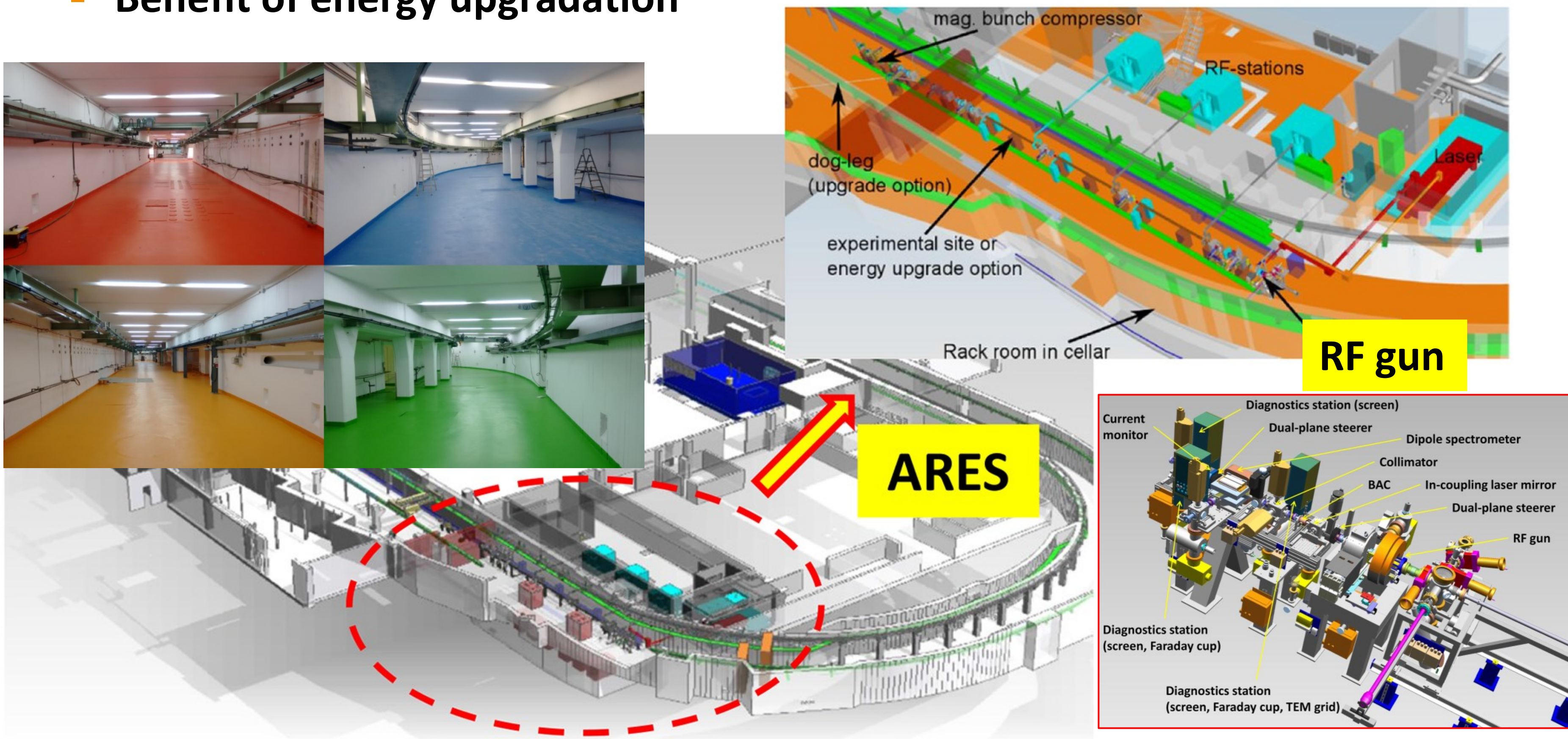
UHH

SINBAD

DESY

Outline

- Overview
- The ARES linac and its working points
- Benefit of energy upgradation



The ARES linac - applications

Q (pC)	0.5 ~ 30
ε (μm)	< 1
σ_t (fs)	0.5 ~ 30
σ_{BTJ} (fs)	< 10

B. Marchetti, TUPAB040, IPAC17

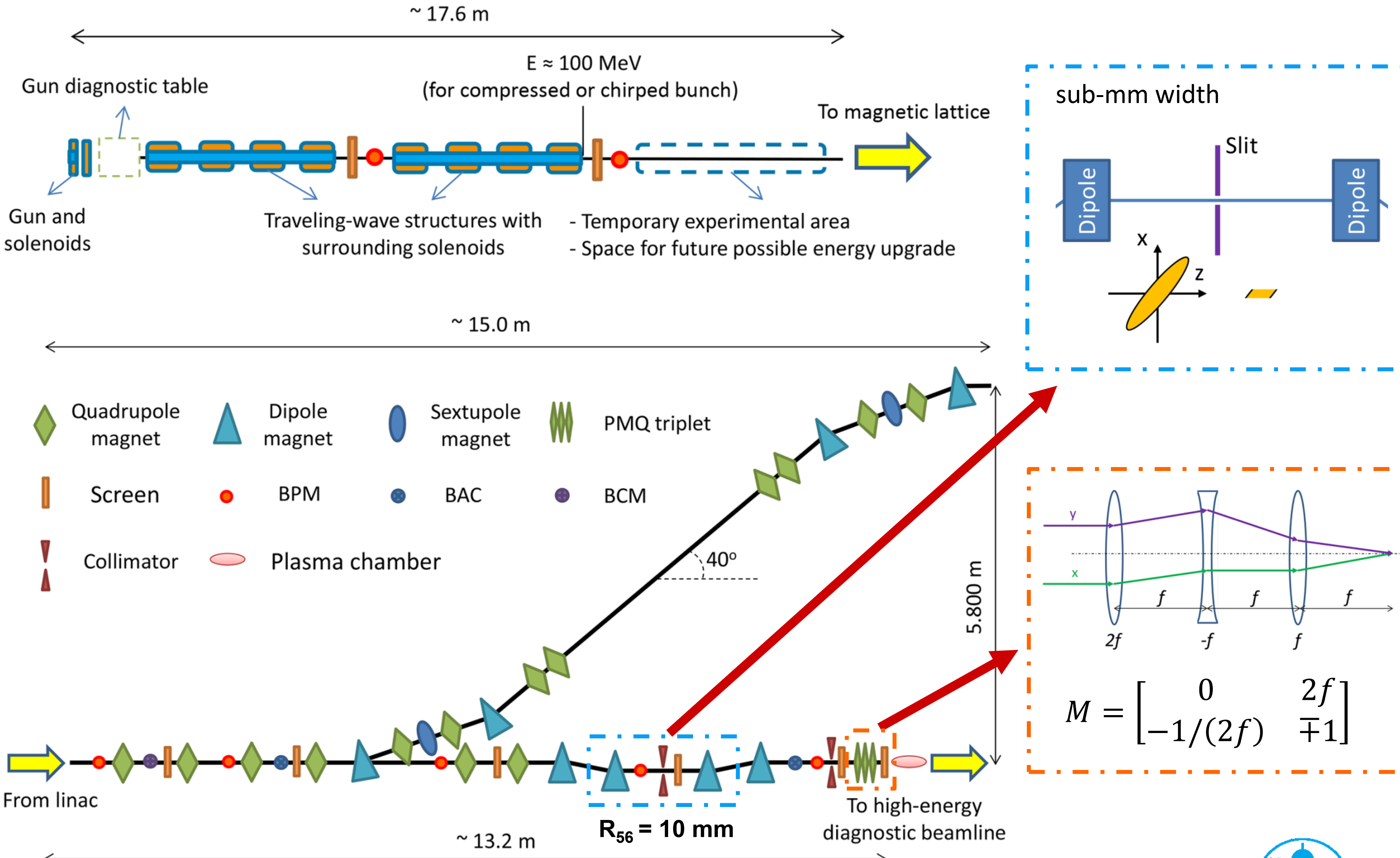
100-MeV ARES linac

- Beam dynamics studies, e.g. bunch compression schemes comparison
- R&D on advanced beam diagnostics, e.g. 3D charge distribution reconstruction for ultra-short bunches
- LWFA → FEL
- Other advanced accelerating structures, e.g. DLA
- Other applications

Energy upgradation in the future.

- Monday - WG3 parallel - U. Dorda, Status and Objectives of the Dedicated Accelerator R&D Facility "SINBAD" at DESY
- Monday – WG5 parallel – D. Marx, New Measurement Techniques Using a Novel X-band Transverse Deflecting Structure with Variable Polarization
- Monday – Poster – A. Pousa, Limitation On Slice Energy Spread in a Plasma Accelerator
- Wednesday – Poster – E. Svyten, Beam Quality Preservation in a Laser-Plasma Accelerator with External Injection in the Context of EuPRAXIA
- Monday – Poster – F. Mayet, Simulations and Plans for Possible DLA experiments at SINBAD
- Monday – Poster – W. Kuropka, Full PIC Simulation of First ACHIP Experiment @ SINBAD

The ARES linac - Layout



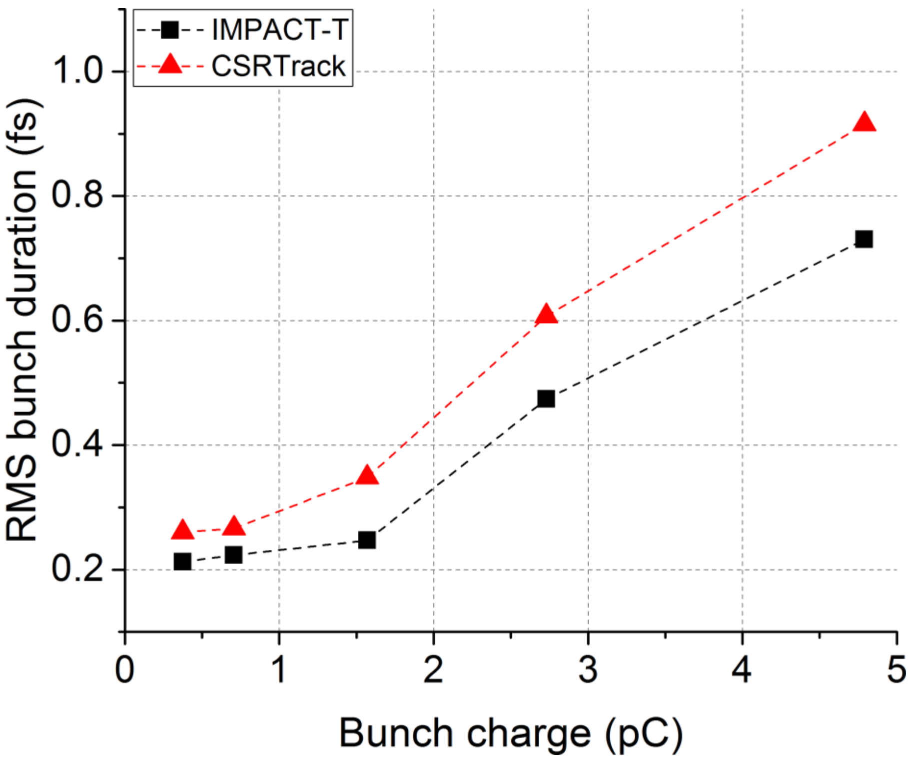
Beam dynamics simulations

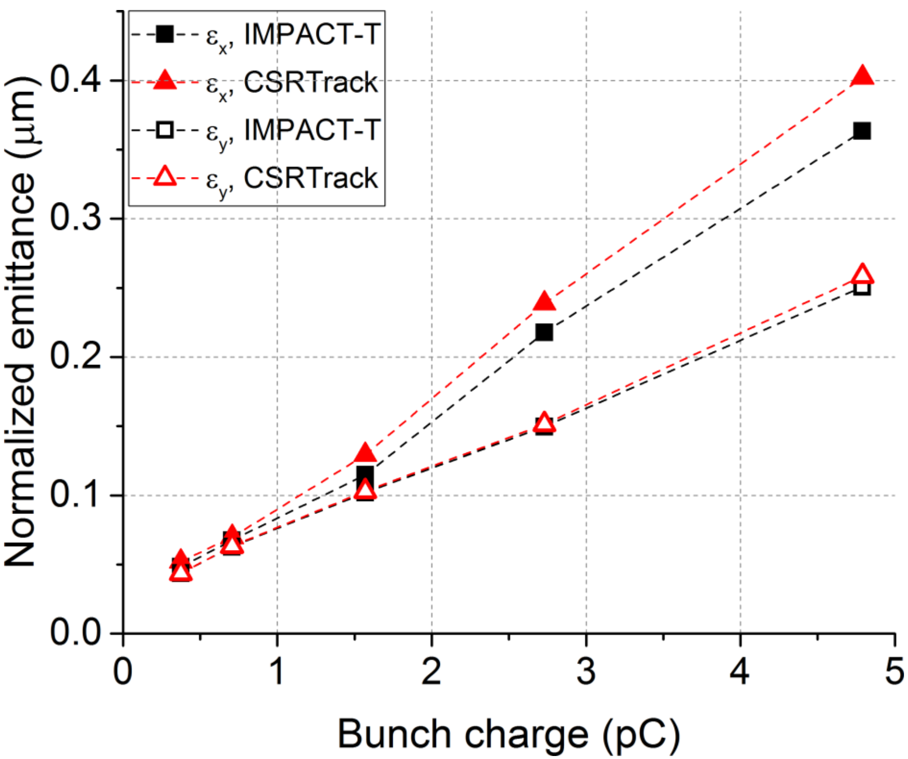
- Linac
  - ASTRA
- Timing / position / pointing stabilities
  - ASTRA + ELEGANT
- **Matching / bunch compression / final focus**
  - IMPACT-T (cross-checked by CSRTrack)
- Collimation
  - Shower
- Dogleg
  - ELEGANT

The ARES linac – generation of sub-fs bunches

Initial bunch charge (pC)	10	20	50	100	200
Final bunch charge (pC)	**0.4**	**0.7**	**1.6**	**2.7**	**4.8**
Initial bunch length (ps)	2.0	2.1	2.2	2.5	2.8

Beam parameters at the chicane exit

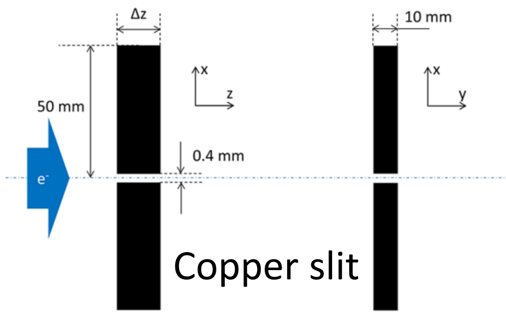




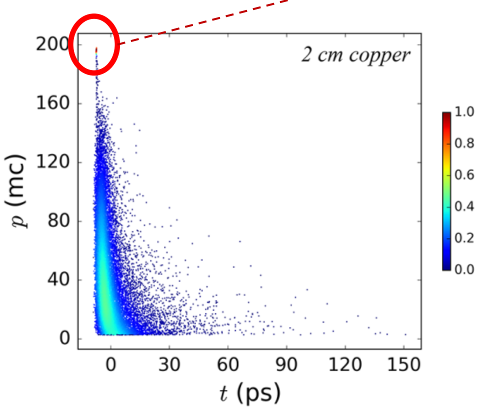
J. Zhu, et al., *Phys. Rev. Accel. Beams* 19, 054401 (2016)

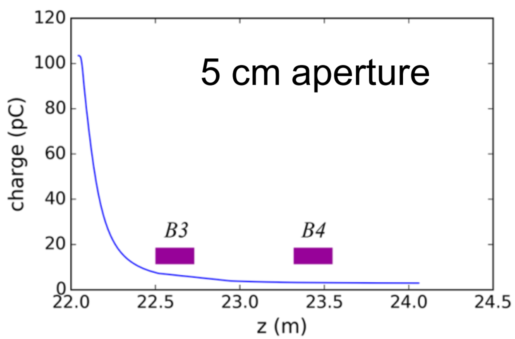
The ARES linac – Ideal slit vs. real slit

Simulated by Shower (EGS4)



Slow down the unwanted electrons!

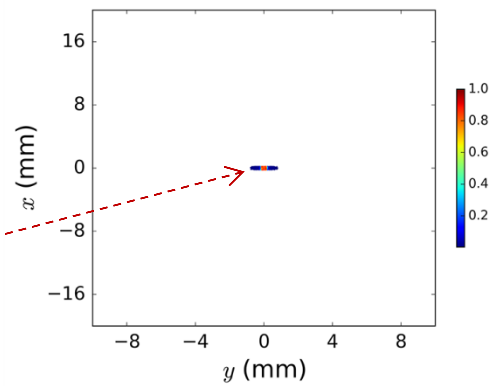


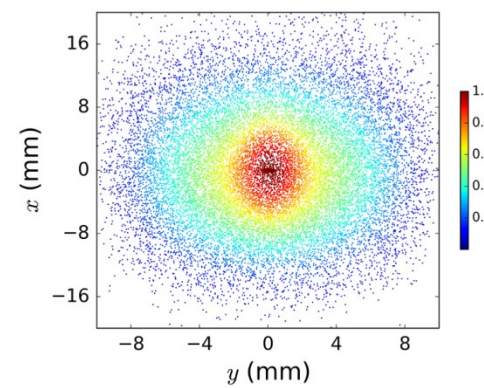


Ideal knife edge

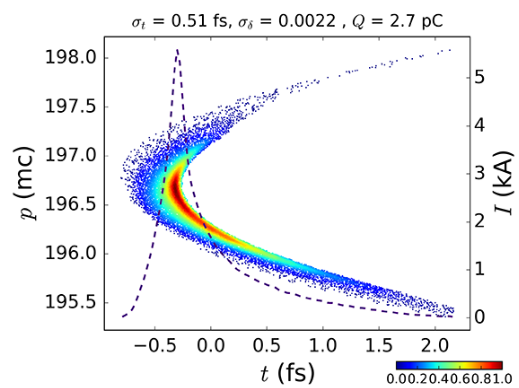
Monte-Carlo simulation

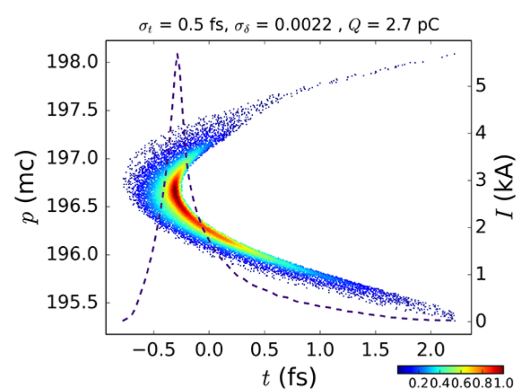
After the slit





After compression





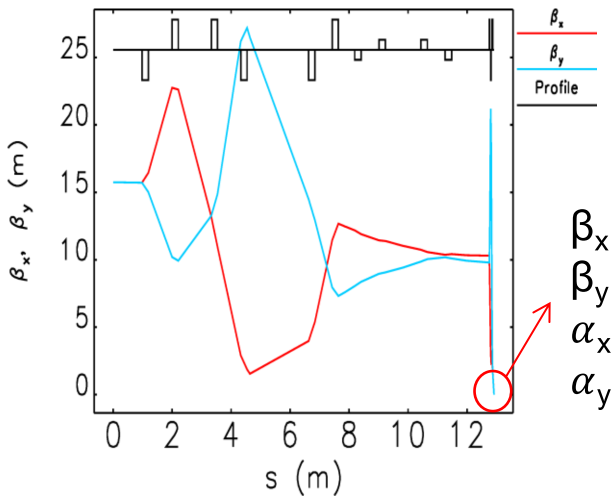
The ARES linac – working points

Beam parameters at the plasma entrance

MC: pure magnetic compression, VB: pure velocity bunching, HB: hybrid compression

	WP1	WP2	WP3	WP4
Q (pC)	**0.8**	**5.7**	**30**	**17.3**
σ_t (fs)	**0.5**	**2.0**	**29.6**	**12.2**
I (kA)	**0.6**	**1.1**	**1.6**	**1.5**
$\varepsilon_{x,\ slice}/\varepsilon_{y,\ slice}$ (µm)	**0.11 / 0.11**	**0.38 / 0.33**	**0.64 / 0.64**	**0.28 / 0.38**
β_x / β_y (mm)	**1.8 / 3.1**	**5.2 / 1.5**	****	**4.5 / 0.9**
Compression method	**MC**	**MC**	**VB**	**HB**

Linac exit (without final focus)

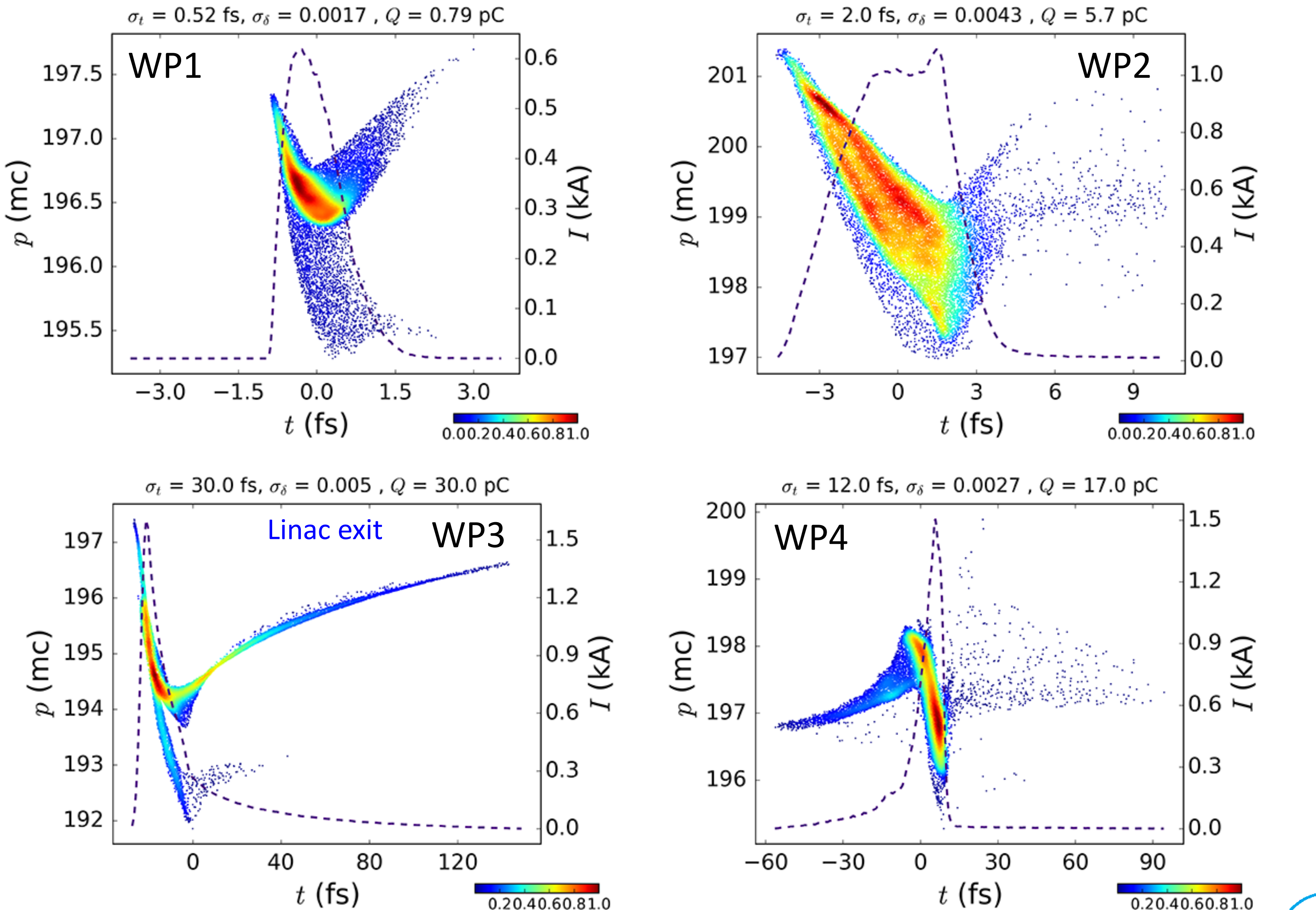


β_x = 1 mm
β_y = 1 mm
α_x = 0
α_y = 0

Challenges at ARES:

1. Matching section between chicane and plasma is not feasible due to space-charge effects
2. The Twiss parameters at the chicane exit have a small range

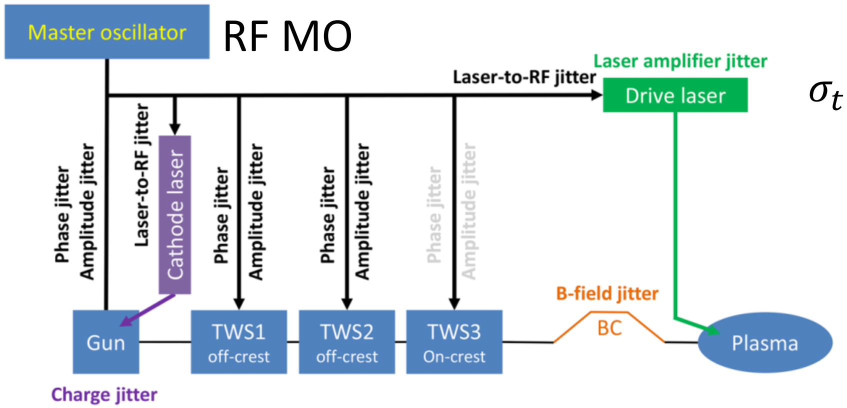
The ARES linac – LPSs at the plasma entrance



The ARES linac – timing stability

J. Zhu, et al., *Phys. Rev. Accel. Beams* 19, 054401 (2016)

The reference is the **Master oscillator**



10 fs bunch arrival-time jitter ~0.01 deg

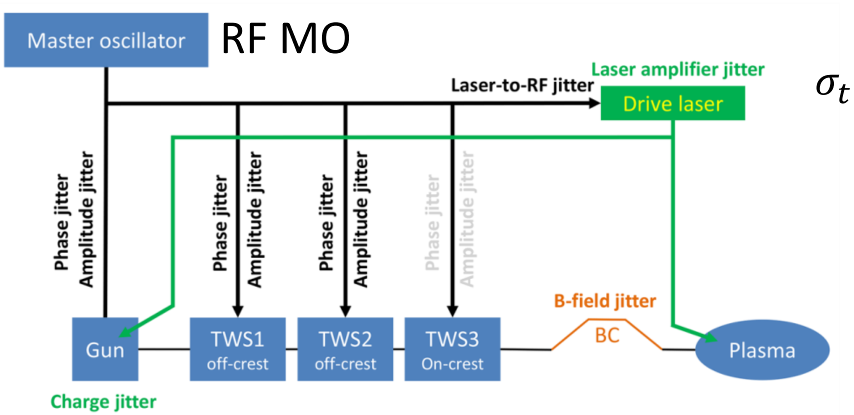
$$\sigma_t = \sqrt{\sigma_{B2RF}^2 + \sigma_{L2RF}^2 + \sigma_A^2}$$

$$\approx \sqrt{\frac{R_{56}^2}{c^2}\left[\left(\frac{E_0}{E}\right)^2 \sigma_{\delta_{E_0}}^2 + \frac{1}{N}\left(\frac{E-E_0}{E}\right)^2 \sigma_{\delta_V}^2 + \frac{h^2}{Nk_{rf}^2}\sigma_\phi^2 + \sigma_{\delta_B}^2\right] + (1+hR_{56})^2\sigma_{t_0}^2 + \sigma_{L2RF}^2 + \sigma_A^2}$$

The reference is the **drive laser**

The phase jitter changes to $\tilde{\sigma}_\phi = \sqrt{\sigma_\phi^2 + c^2 k_{RF}^2(\sigma_{L2RF}^2 + \sigma_A^2)}$

$$hR_{56} \approx -1$$



$$\sigma_t = \sigma_{TOF}.$$

$$\approx \sqrt{\frac{R_{56}^2}{c^2}\left[\left(\frac{E_0}{E}\right)^2 \sigma_{\delta_{E_0}}^2 + \frac{1}{N}\left(\frac{E-E_0}{E}\right)^2 \sigma_{\delta_V}^2 + \frac{h^2}{Nk_{rf}^2}\sigma_\phi^2 + \sigma_{\delta_B}^2\right] + (1+hR_{56})^2\tilde{\sigma}_{t_0}^2 + h^2R_{56}^2(\sigma_{L2RF}^2 + \sigma_A^2)}$$

Chromatic aberration during matching (in)

Matching condition for a hard edge plasma $\beta_x = \beta_y \approx \frac{1}{\sqrt{K_r}}, \alpha_x = \alpha_y \approx 0$

With ANGUS laser	**Linear regime**			**Blow-out regime**		
Plasma density (cm^{-3})	10^{16}	10^{17}	10^{18}	10^{16}	10^{17}	10^{18}
Matched beta function (mm)	0.80	0.47	0.39	1.04	0.33	0.10

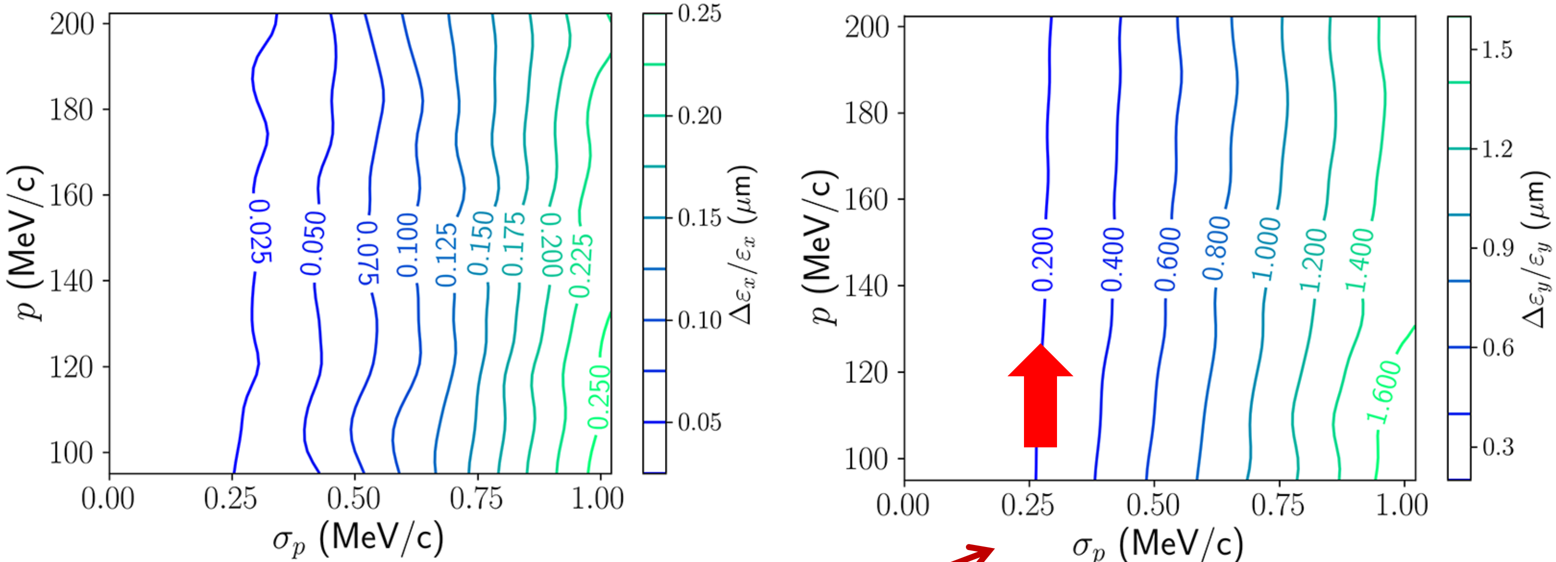
Final beta function: $\beta_{x_f} = \frac{f^2}{\beta_{x_i}} + \sigma_\delta^2 \beta_{x_i}$

Emittance growth: $\frac{\Delta\varepsilon_x}{\varepsilon_x} \approx \frac{\sigma_\delta^2 \beta_{x_i}^2}{2f^2}.$

Final focus triplet: 2-cm-long, 250 T/m, 500 T/m, 500 T/m PMQ

Incoming beta function ranges from 6 ~ 22 m

Goal: 1 mm beta function



Absolute momentum spread

J. Zhu, et al., THPVA007, *Proceedings of IPAC2017*

The ARES linac – LWFA driven FEL

FEL parameters are calculated using Ming Xie's formula

$\gamma = 430$ was chosen in light of the planned BELLA experiment

J. van Tilborg, AIP Conference Proceedings 1812, 020002 (2017)

Assume the relative energy spread can be preserved!

WP2 (slightly decompressed)

Q (pC)	I_{beam} (kA)	σ_t (fs)	$\varepsilon_{x,slice}$ (µm)	$\bar{\beta}_x$ (m)	$\sigma_{\delta,slice}$ (%)	γ	λ_u * (cm)	K_0*	λ_r (nm)	ρ_P	L_G (m)	L_c (µm)
5.7	0.41	3.3	0.38	0.7	0.18	430	1.5	1.00	60.8	0.0053	0.262	1.06
				2.7	0.18	1663	1.5	1.00	4.1	0.0014	4.87	1.32

* A. Maier, *Matter and Technologies Kickoff Meeting*, DESY Hamburg (2015)

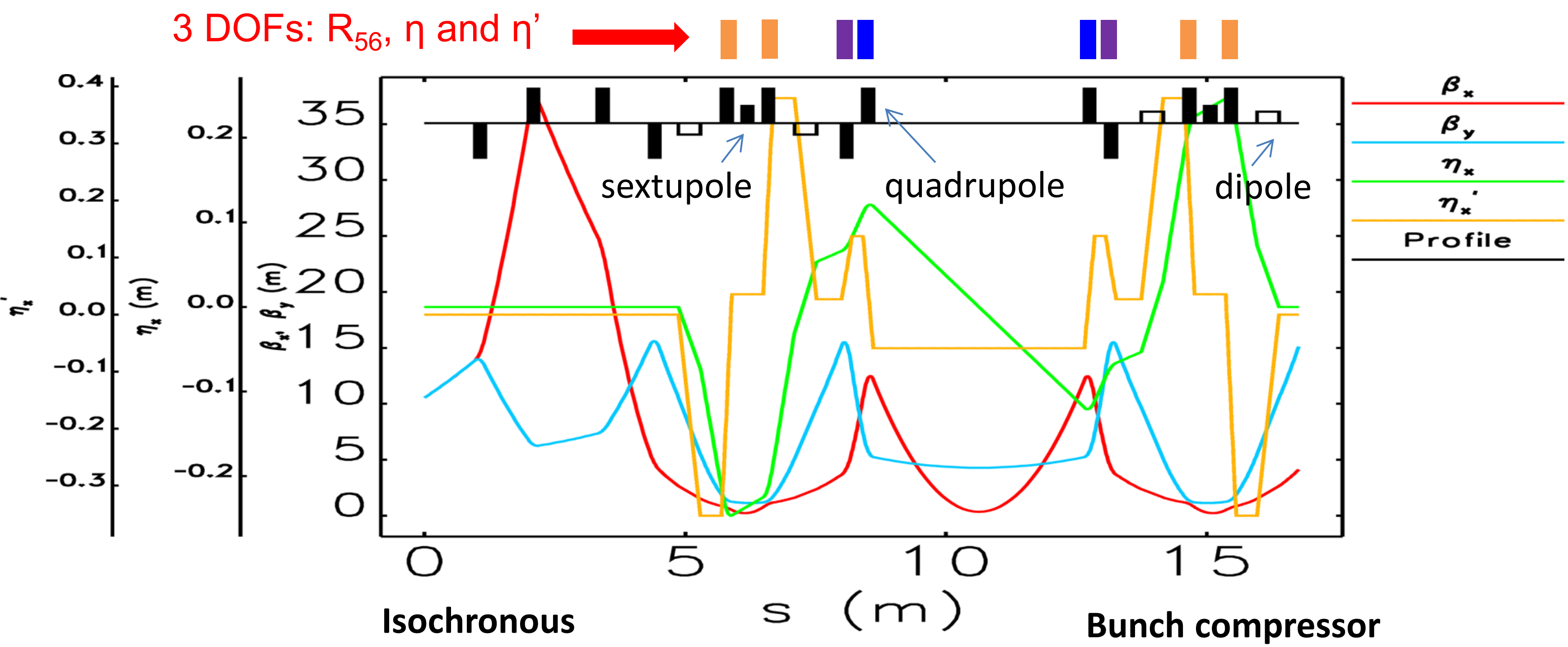
WP4

Q (pC)	I_{beam} (kA)	σ_t (fs)	$\varepsilon_{x,slice}$ (µm)	$\bar{\beta}_x$ (m)	$\sigma_{\delta,slice}$ (%)	γ	λ_u (cm)	K_0	λ_r (nm)	ρ_P	L_G (m)	L_c (µm)
17.3	1.5	12.2	0.28	0.7	0.16	430	1.5	1.00	60.8	0.0090	0.114	0.46
				2.7	0.16	1663	1.5	1.00	4.1	0.0023	0.718	0.20

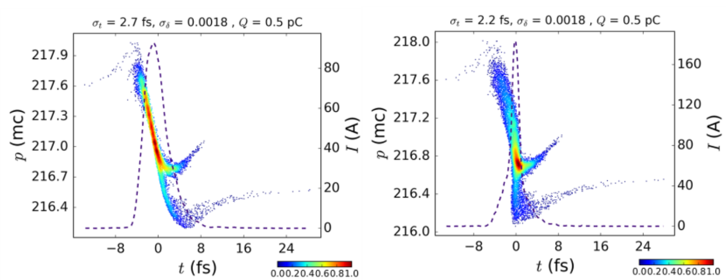
Dogleg beamline with tunable R_{56}

Geometrical constraints inside the SINBAD tunnel

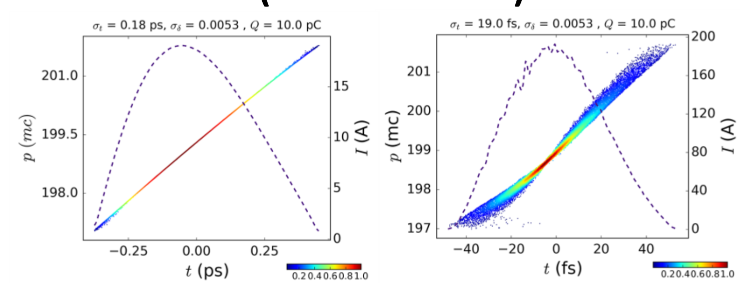
Horizontal displacement: 5.8 m, Length: ~10 m, Bending angle: 20 deg



Isochronous
(2.7 fs -> 2.2 fs)

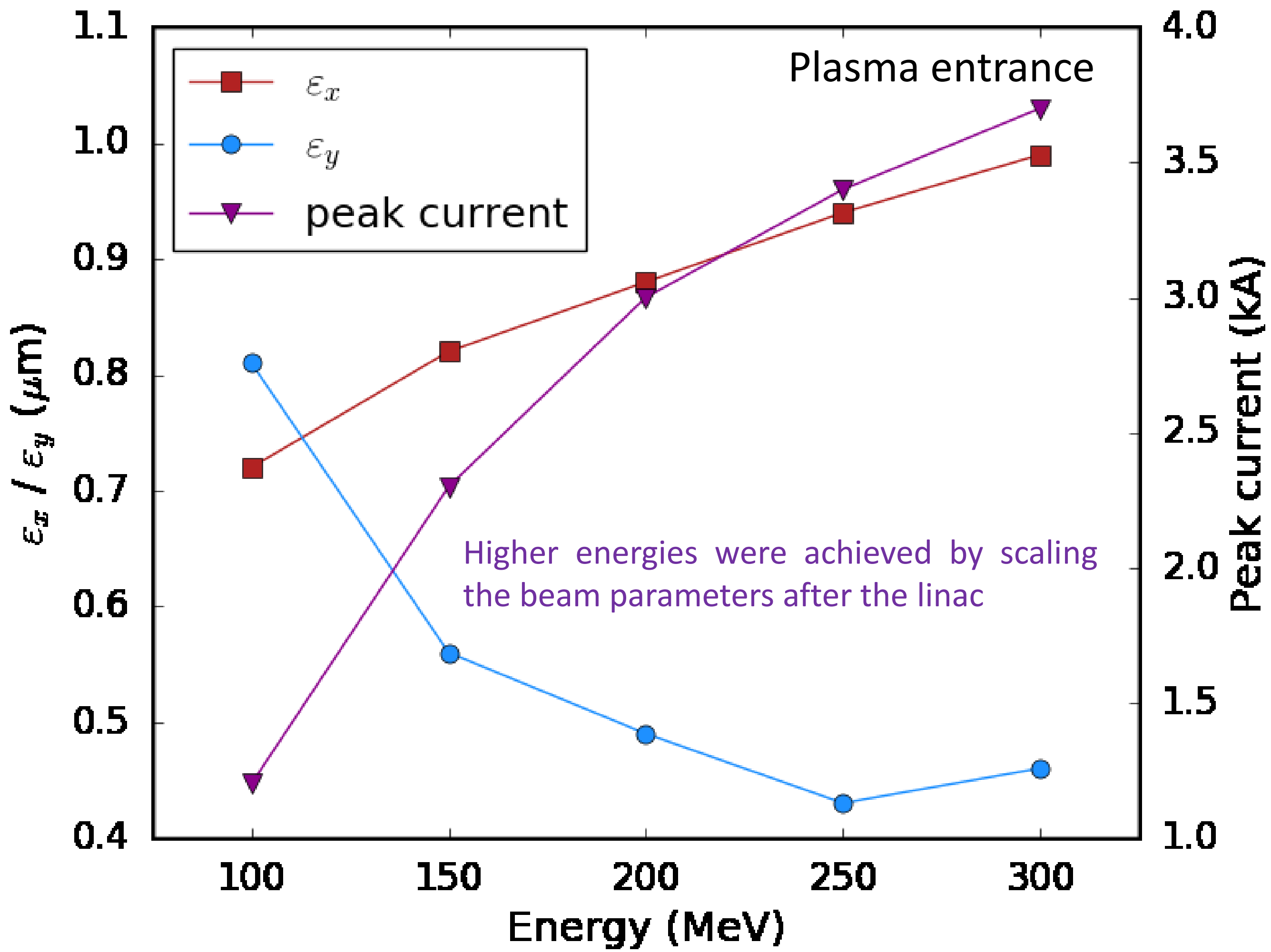


Bunch compressor
(180 fs -> 19 fs)



Energy upgradation

We like the EuPRAXIA's working point: **3 kA**, **30 pC**!



Summary

- The start-to-end simulations have shown different working points (0.8 ~ 30 pC, 0.5 ~ 30 fs rms) at the ARES linac, aiming typically for LWFA and LWFA-driven FEL.
- The peak current is limited to around 1.5 kA due to the space-charge effects. The space-charge effects also make the matching (in) very challenging. Energy upgradation is highly desirable.

Thank you!