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EuPRAXIA

Discussion on RF Injector choices

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July 4-5, 2018 - 3rd Collaboration Week, Liverpool

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Beam Parameters Request

Horizon 2020

Target Values for the 1 GeV beam to drive a FEL SASE | **Target Values for OPA**

	Units	1 GeV case	0.2 - 1-5 GeV
Bunch charge	pC	30	>100
Peak current	kA	3	
Rep. rate	Hz	10	
RMS norm. emittance	μm	1	1
RMS Energy Spread	%	1	any
RMS Bunch length	fs	10	fs
Slice norm. emittance	μm	<1	
Slice Energy Spread	%	0.1	
Slice Length	μm	0.75	
Radiation wavelength	nm	4	
Pierce parameter ρ	10^{-3}	>1	
Undulator period	cm	1.5	
Undulator strength K		0.872	

From where we started

Horizon 2020

- These numbers, in particular kA current and 0.5 mm mrad emittance, are not consistent with the 150 MeV energy
  - Detailed study based on simulations to identify a consistent set of beam parameters for the photo-injector

Injector beams				
Quantity	**Symbol**	**Baseline value**	**Range of exploration**	
			Lower limit	**Upper limit**
150 MeV - RF injector beam: at entrance of plasma 2 for LWFA with external injection				
Energy	E	**150 MeV**	100 MeV	200 MeV
Charge	Q	**50 pC**	10 pC	50 pC
Bunch length (FWHM)	τ	**5 fs**	3 fs	30 fs
Peak current per bunch	I	10 kA	1 - 10 kA	
Repetition rate	f	**≥ 10 Hz**	≥ 10 Hz	
Number of bunches	N	**1**	1	20
Shaped profile	-	tbd	tbd	
Total energy spread (RMS)	σ_E/E	**0.1 %**	0.1 %	
Transverse normalized emittance	$\varepsilon_{N,x}$, $\varepsilon_{N,y}$	**0.5 mm mrad**	0.5 mm mrad	
Alpha function	α_x, α_y	**0**	0	
Beta function	β_x, β_y	**30 mm**	30 mm	
Transverse beam size (RMS)	σ_x, σ_y	7.1 µm	6.1 - 8.6 µm	
Transverse divergence (RMS)	$\sigma_{x'}$, $\sigma_{y'}$	0.24 mrad	0.2 - 0.29 mrad	
Jitter, beam to global reference (RMS)	$\sigma_{\Delta t}$	**10 fs**	10 fs	

Laminarity parameter

Horizon 2020

- The beam parameters at the plasma accelerating module must be those requested by the FEL
  - This requirement sets the minimum injection energy
- In principle, we could inject into the plasma even low energy beam, 10 MeV beam for instance, but not with kA current (and good quality)
- The minimum injection energy depends on the laminarity parameter rho

$$\rho = \frac{I}{2 I_A \gamma} \frac{\sigma^2}{\varepsilon_n^2}$$

The laminarity parameter represents the ratio between the space charge term and the emittance term in equation

$$\sigma'' + \frac{\gamma'}{\gamma}\sigma' + K\sigma = \frac{k_s}{\gamma^3 \sigma} + \frac{\varepsilon_{th}^2}{\gamma^2 \sigma^3}$$

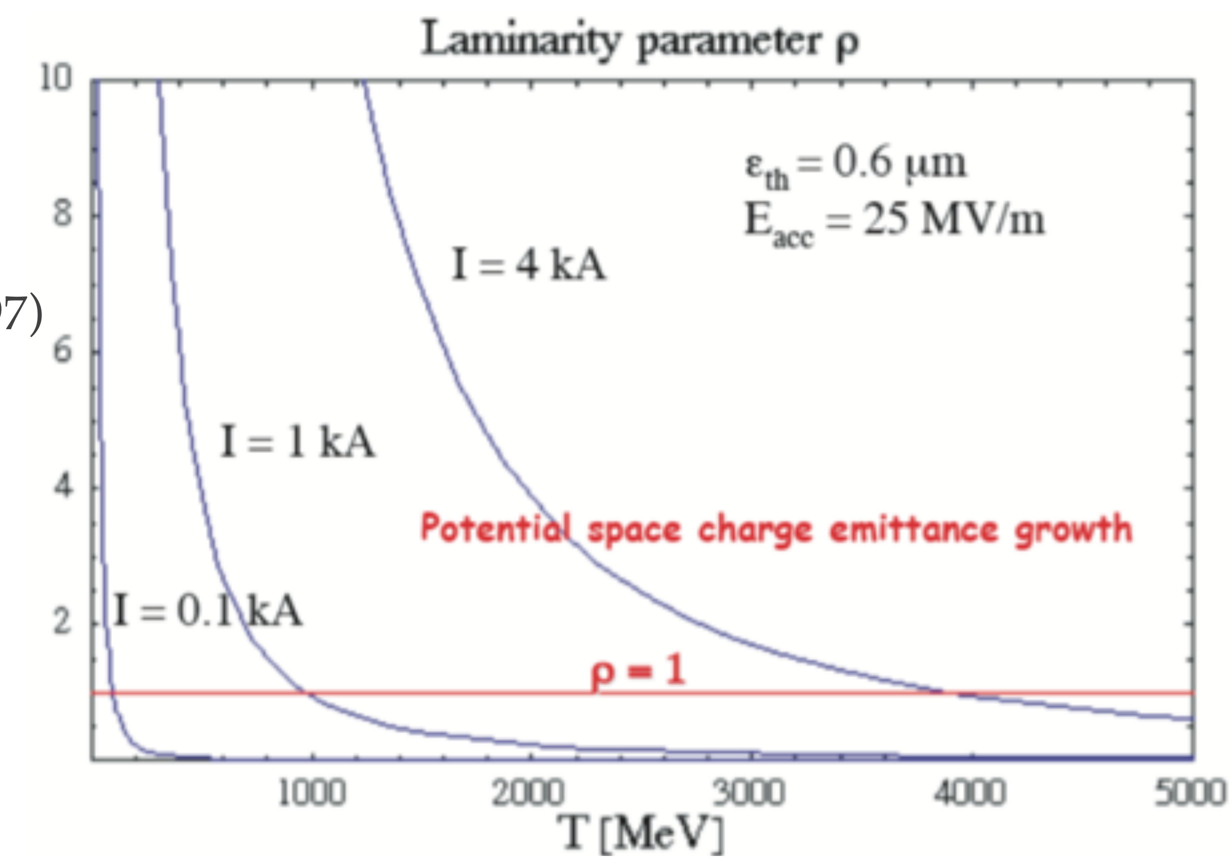
Transition energy

- For a typical electron linac driven by a photo-injector, the energy at which the transition occurs can be nevertheless quite high
- Space charge forces influence the beam dynamics and are one the main performance limitations in high brightness electron injectors

✤ L. Serafini and J. B. Rosenzweig, Phys. Rev. E, 55(6) - 7566-7590 (1997)

✤ L. Serafini and J. B. Rosenzweig, PAC97

✤ M. Ferrario et al. *New Journal of Physics* **8** (2006) 295



$$\gamma_t = \sqrt{\frac{2}{3}\frac{2k_s}{\varepsilon_{th}\gamma'}}$$

ARES Case

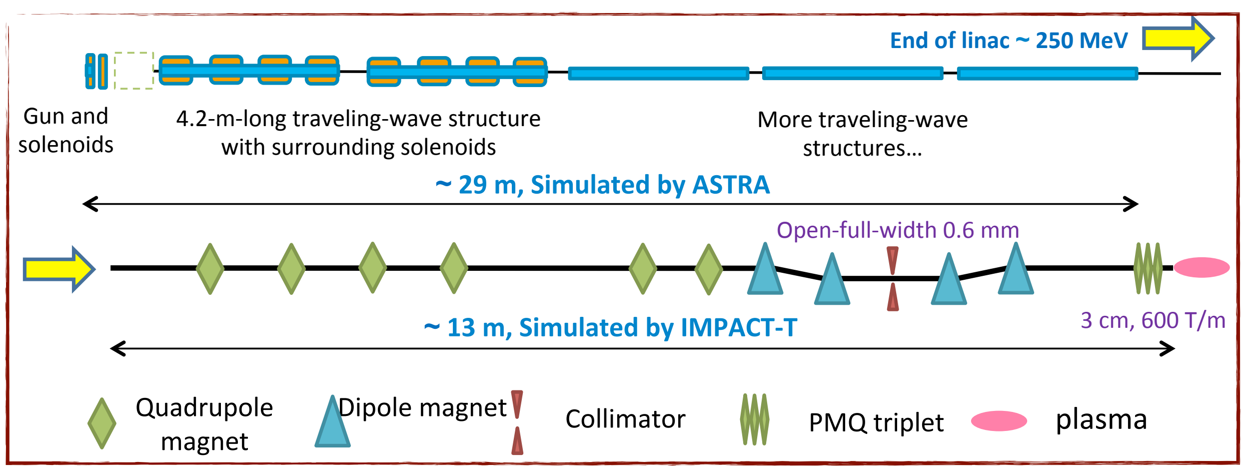
Horizon 2020

https://bib-pubdb1.desy.de/record/401420/files/Thesis-Jun-final.pdf

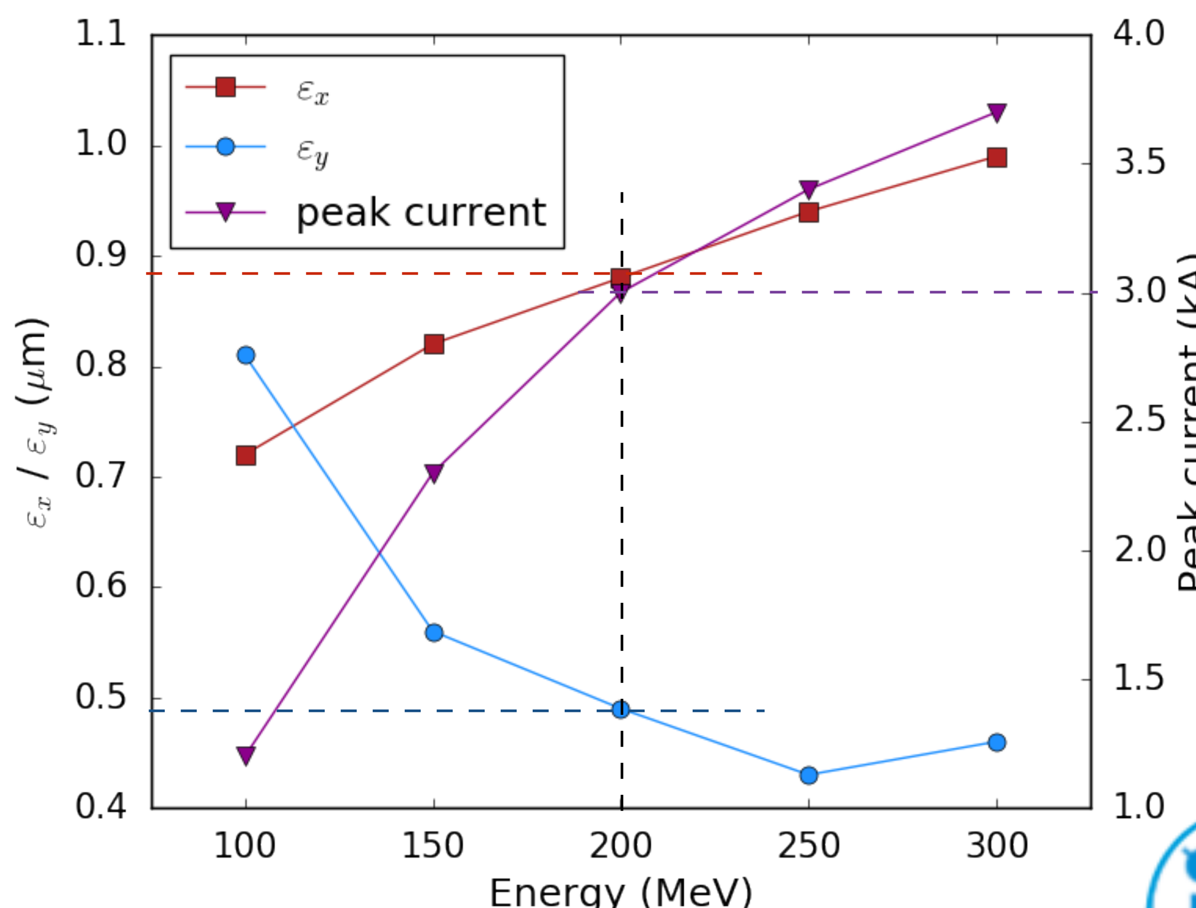
	WP1	WP2	WP3	WP4
Energy (MeV)	100.5	101.7	99.5	100.8
Bunch charge (pC)	0.75	5.5	28.5	16.5
Projected horizontal emittance (μm)	0.11	0.50	4.8	0.50
Projected vertical emittance (μm)	0.099	0.38	24.9	0.79
Slice horizontal emittance (μm)	0.10	0.32	4.2	0.42
Slice vertical emittance (μm)	0.077	0.37	12.1	0.82
β_x (mm)	1.1	1.8	1.9	2.3
α_x	-0.21	0.69	0.89	1.7
β_y (mm)	1.0	1.8	3.5	1.2
α_y	0.24	-0.58	0.14	-0.60
σ_x (μm)	0.76	2.1	6.9	2.4
σ_y (μm)	0.71	1.9	21.0	2.2
Bunch length [rms] (fs)	0.43	1.7	31.9	8.0
Peak current (kA)	0.62	1.1	0.54	1.5
Relative rms energy spread	0.0017	0.0043	0.0120	0.0027
Slice rms energy spread	0.0010	0.0028	0.0079	0.0021

Jun Zhu's study

- Starting point: 100 MeV, 50 pC, 180 fs (rms)
    - ARES working point simulated by ASTRA using 1e6 particles: velocity bunching in the 1st S-band section for first compression stage down to 180 fs, then magnetic chicane with a slit collimator to reduce the charge from 50 pC to 30 pC and finally compress the beam down to the final bunch length

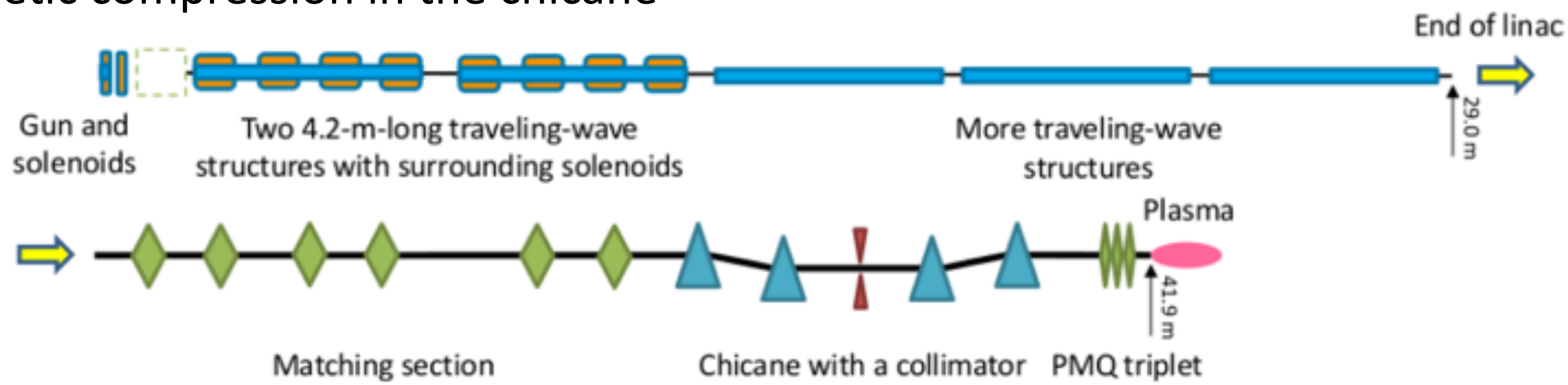


RF compression in the 1st S-band structure and magnetic compression in the dogleg



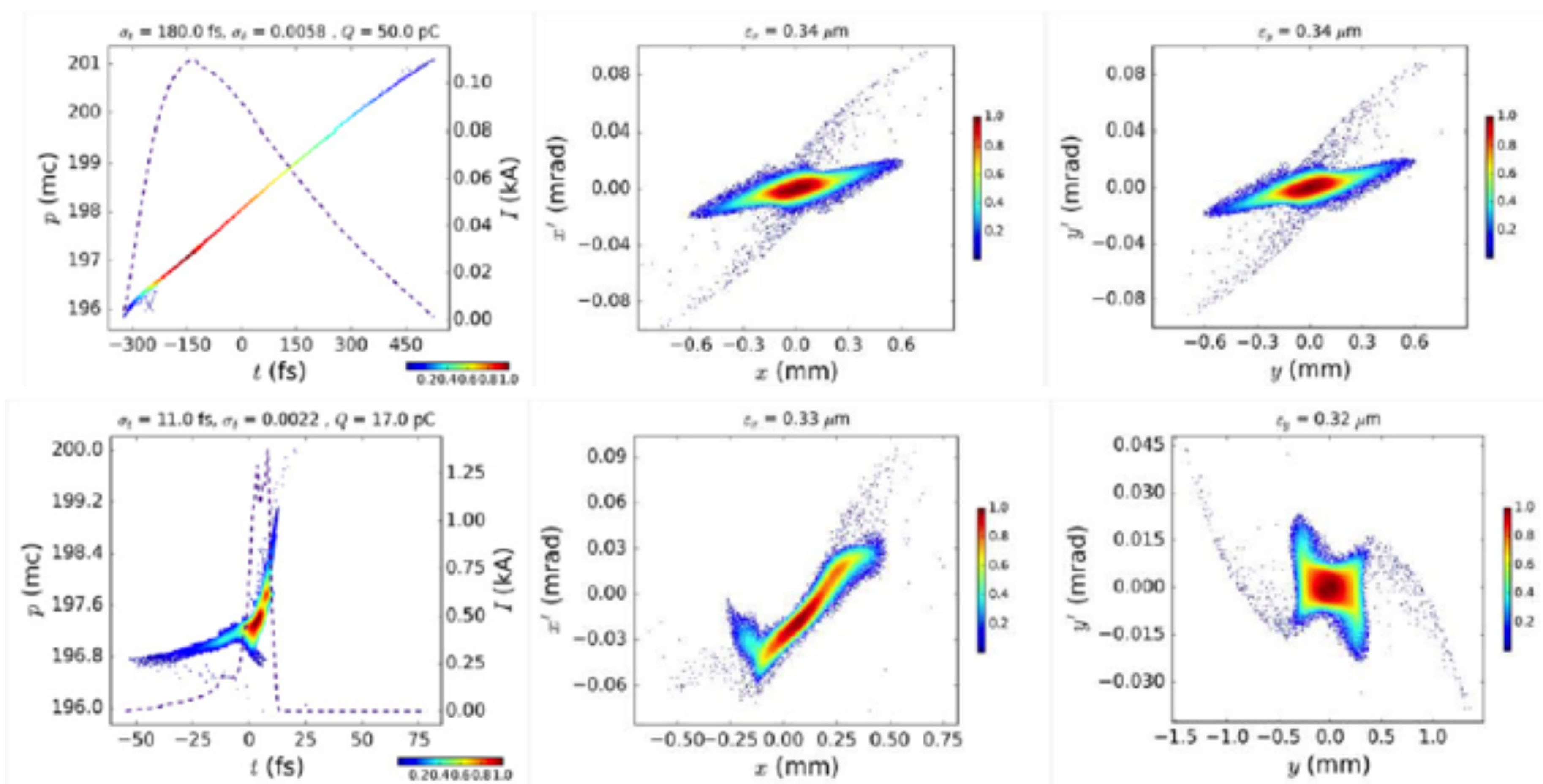
LWFA external injection

- **Two-stage hybrid compression**: Velocity Bunching in the first S-band section and magnetic compression in the chicane



Linac exit

Chicane exit

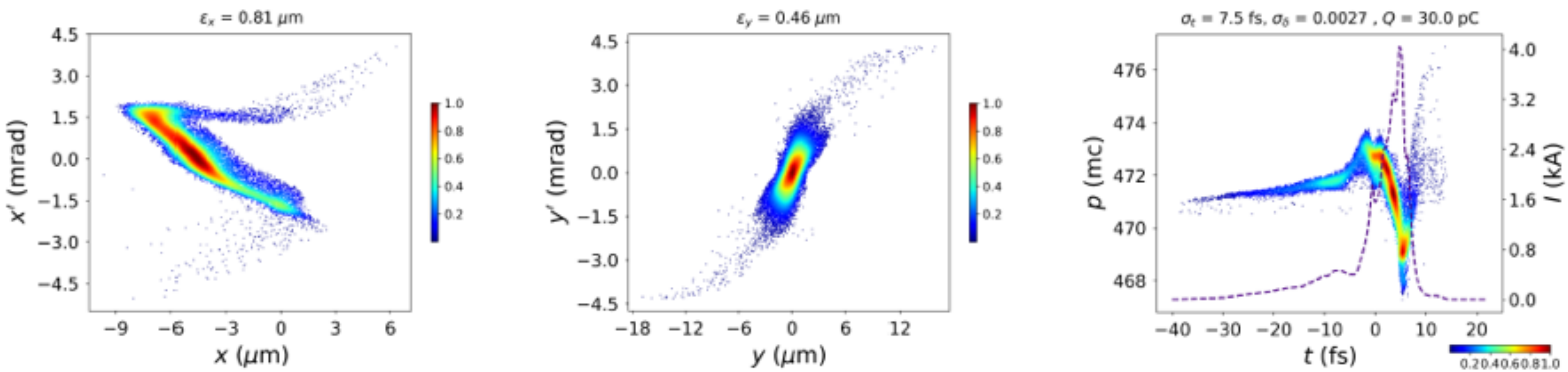


LWFA external injection

Horizon 2020

- **Two-stage hybrid compression**: Velocity Bunching in the first S-band section and magnetic compression in the chicane

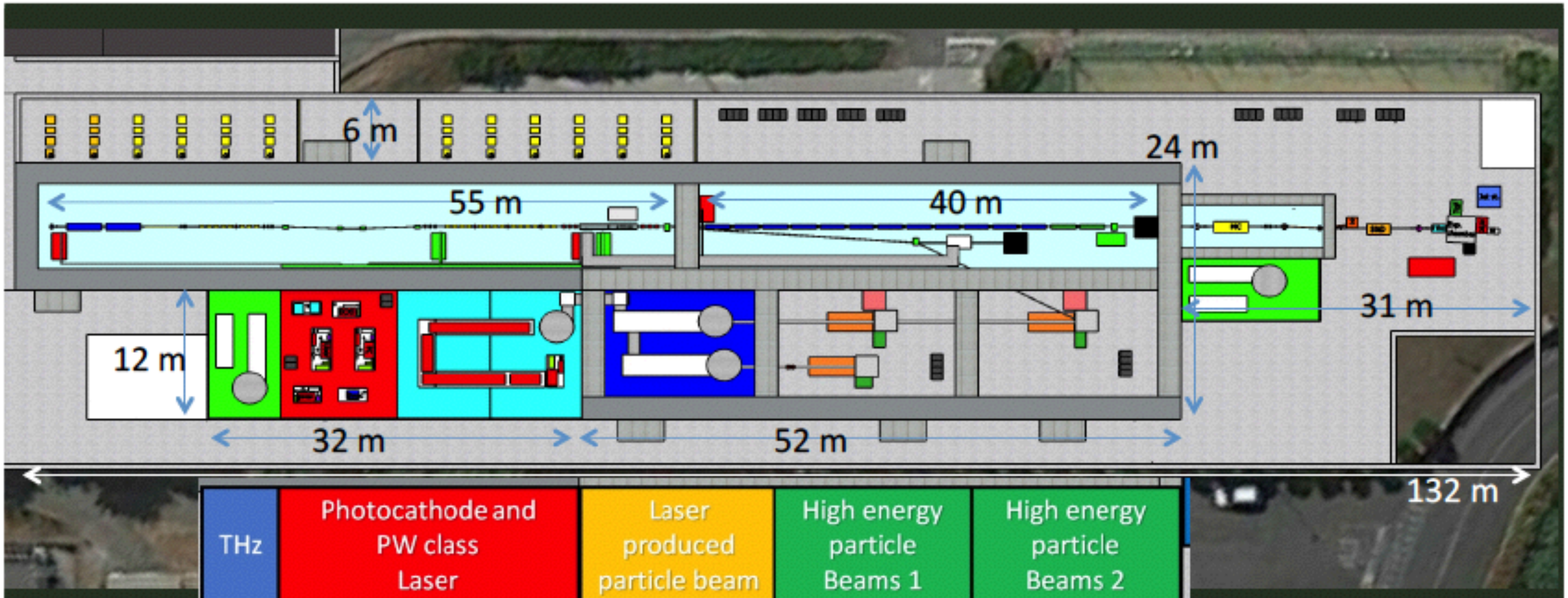
Injection at the plasma



	Linac exit	Injection point
Energy (MeV)	242.0	240.8
Bunch charge (pC)	50.0	29.8
RMS bunch length (fs)	160.0	7.5
Peak current (kA)	0.13	4.0
Projected ε_x / ε_y (μm)	0.30 / 0.30	0.81 / 0.46
Slice ε_x / ε_y (μm)	0.28 / 0.28	0.59 / 0.34
β_x / β_y (mm)	\	3.1 / 3.0
RMS energy spread (%)	0.50	0.27
Slice RMS energy spread (%)	0.05	0.23

S/X band Injector

Horizon 2020



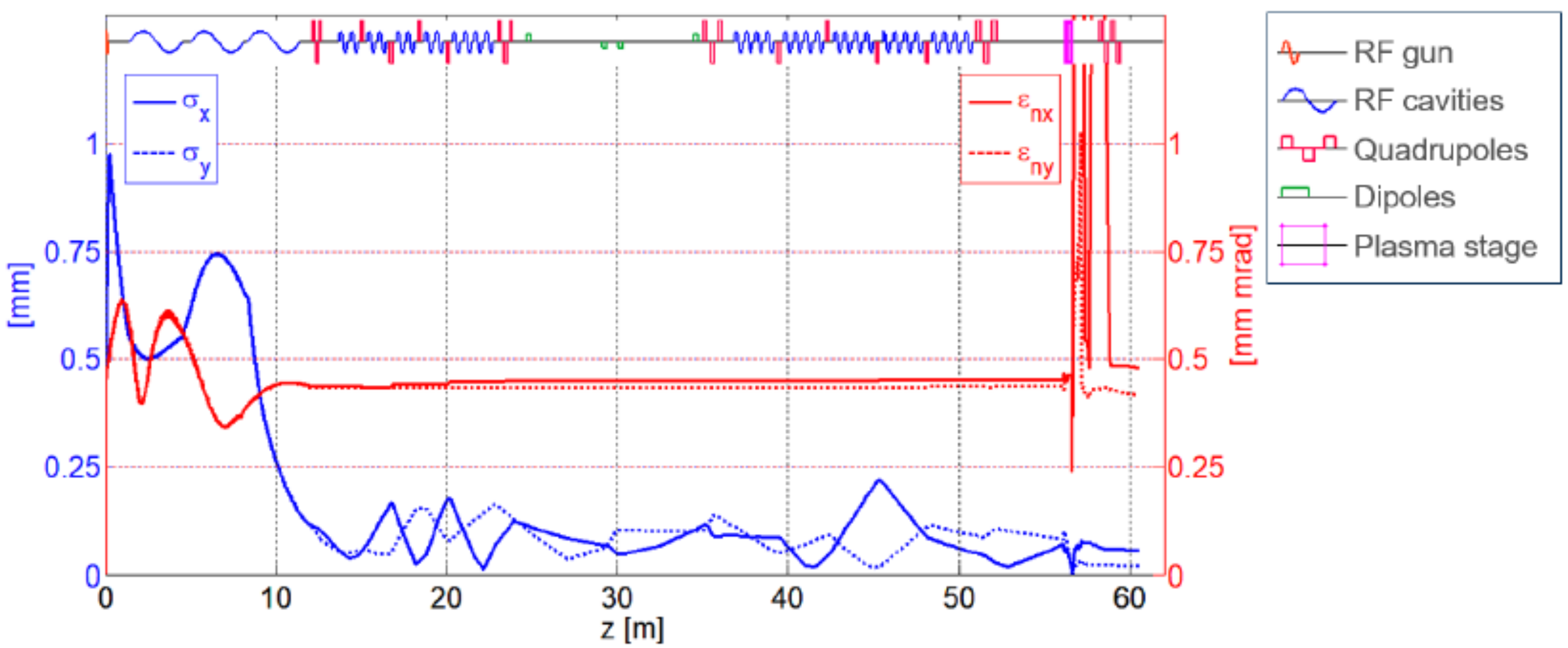
- 500 MeV by RF Linac + 500 MeV by Plasma (LWFA or PWFA)
- 1 GeV by X-band RF Linac only
- Final goal compact 5 GeV accelerator

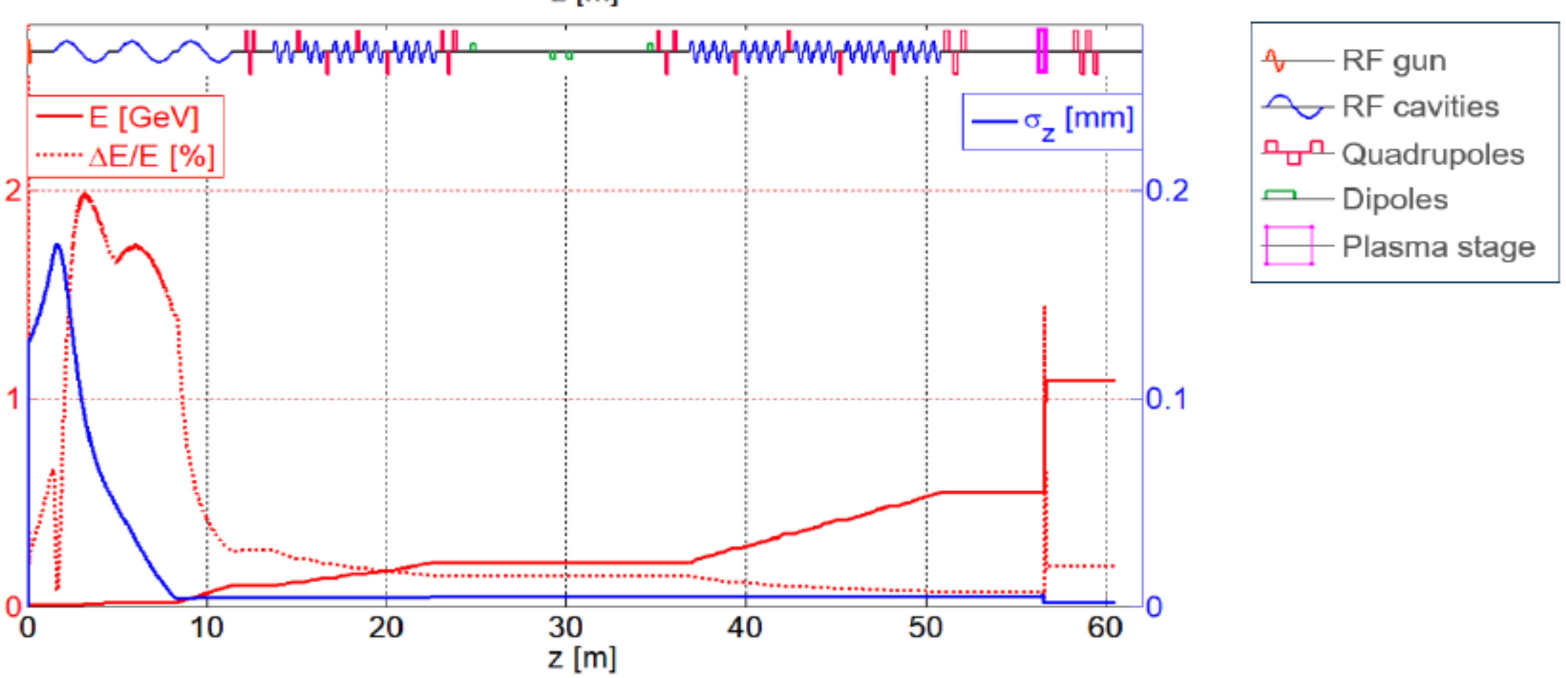
EuPRAXIA@SPARC_LAB case

LWFA external injection

Horizon 2020

- Full RF compression based on Velocity Bunching in the first 2 S-band sections

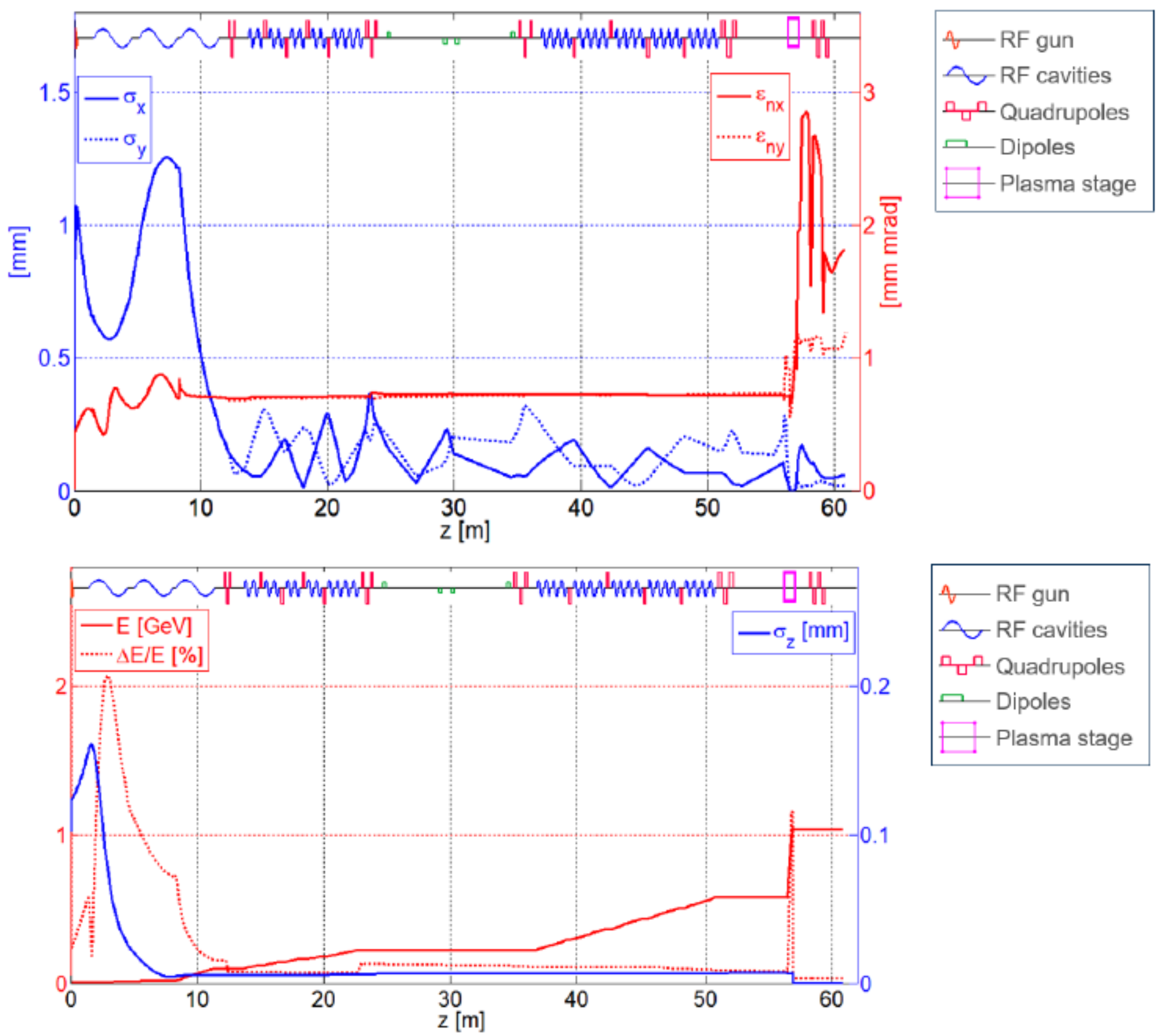




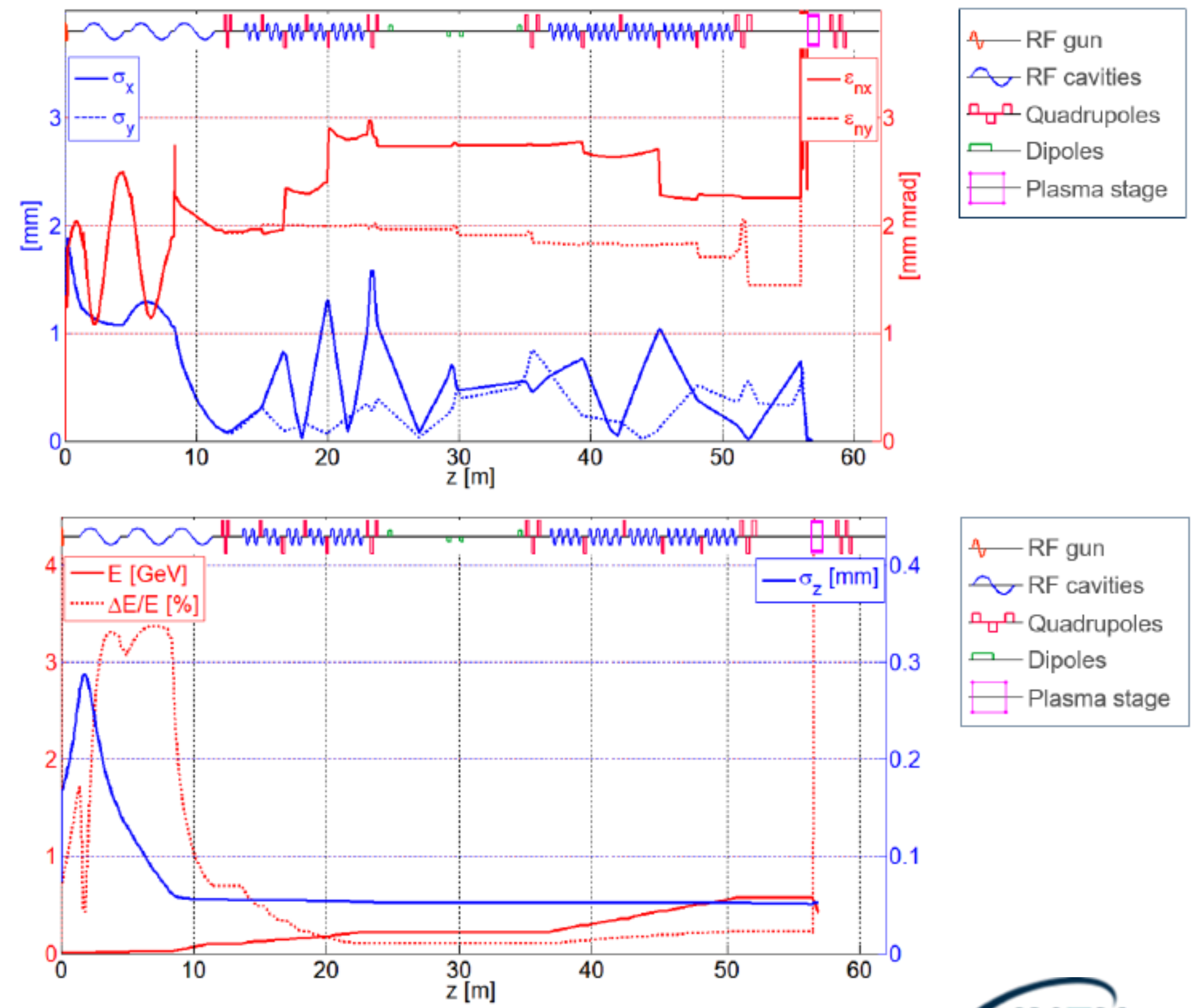
PWFA scheme

- Laser Comb Technique and full RF compression based on Velocity Bunching in the first 2 S-band sections

Witness beam evolution

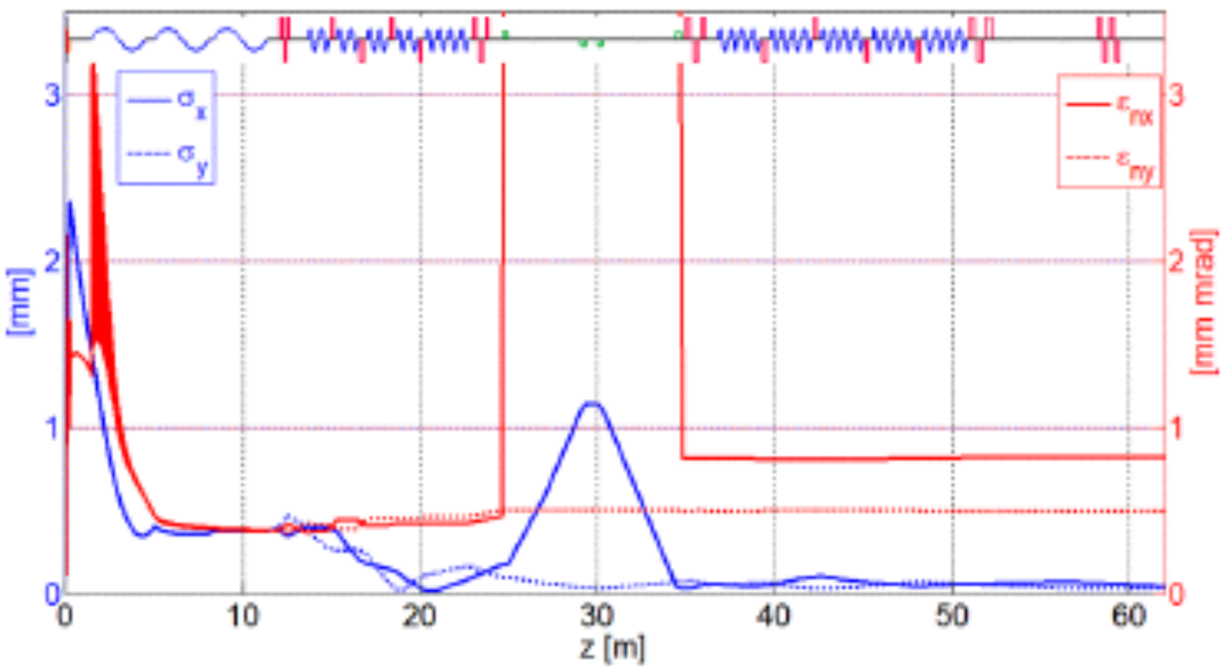


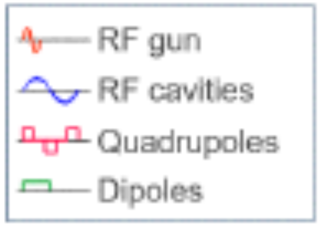
Driver beam evolution

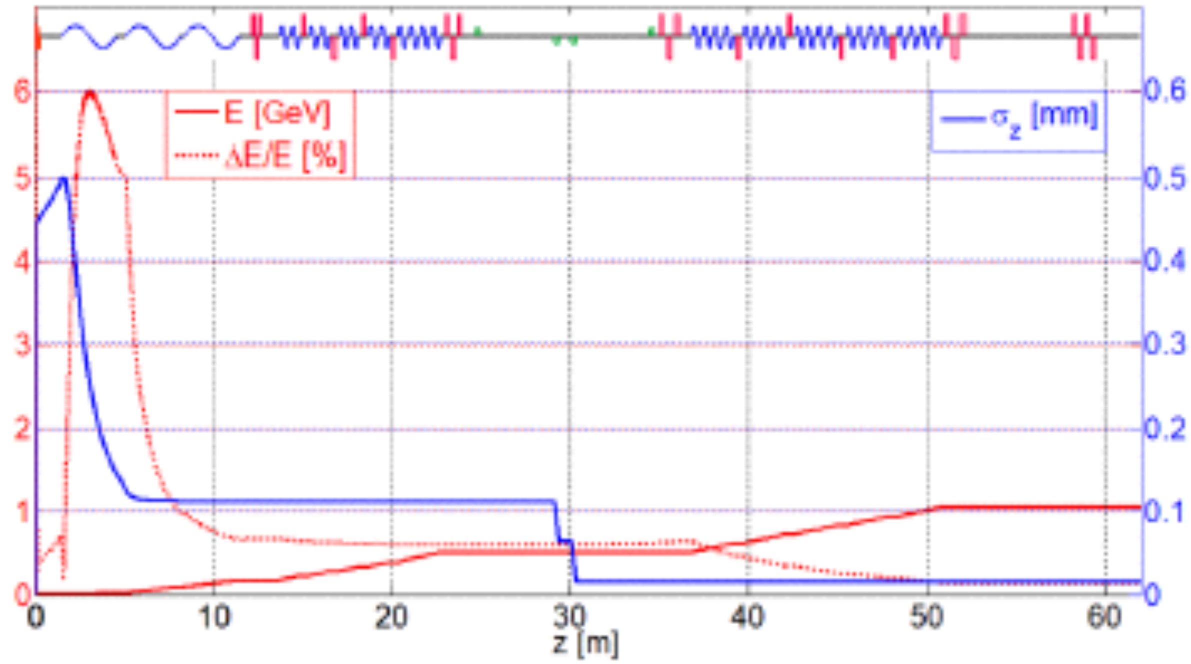


No plasma scheme (!!)

- Only RF linac to boost a **high charge beam up to 1 GeV energy**







RF Linac	Units	(a) 100 pC	(b) 200 pC
Rep. rate f	Hz	10	10
Exit linac energy	GeV	1.1	1
RMS Energy Spread	%	0.1	0.05
Peak Current	kA	2	1.79
Bunch Charge	pC	100	200
RMS bunch length	μm (fs)	12.7(38.2)	16.7 (55.6)
RMS norm. emittance	mm mrad	0.5	0.5
Slice Length	μm	1.25	1.66
Slice Charge	pC	10	6.67
Slice Energy Spread	%	0.018	0.02
Slice norm. emittance (x,y)	mm mrad	0.35-0.24	0.4-0.37

Considerations

If the request are

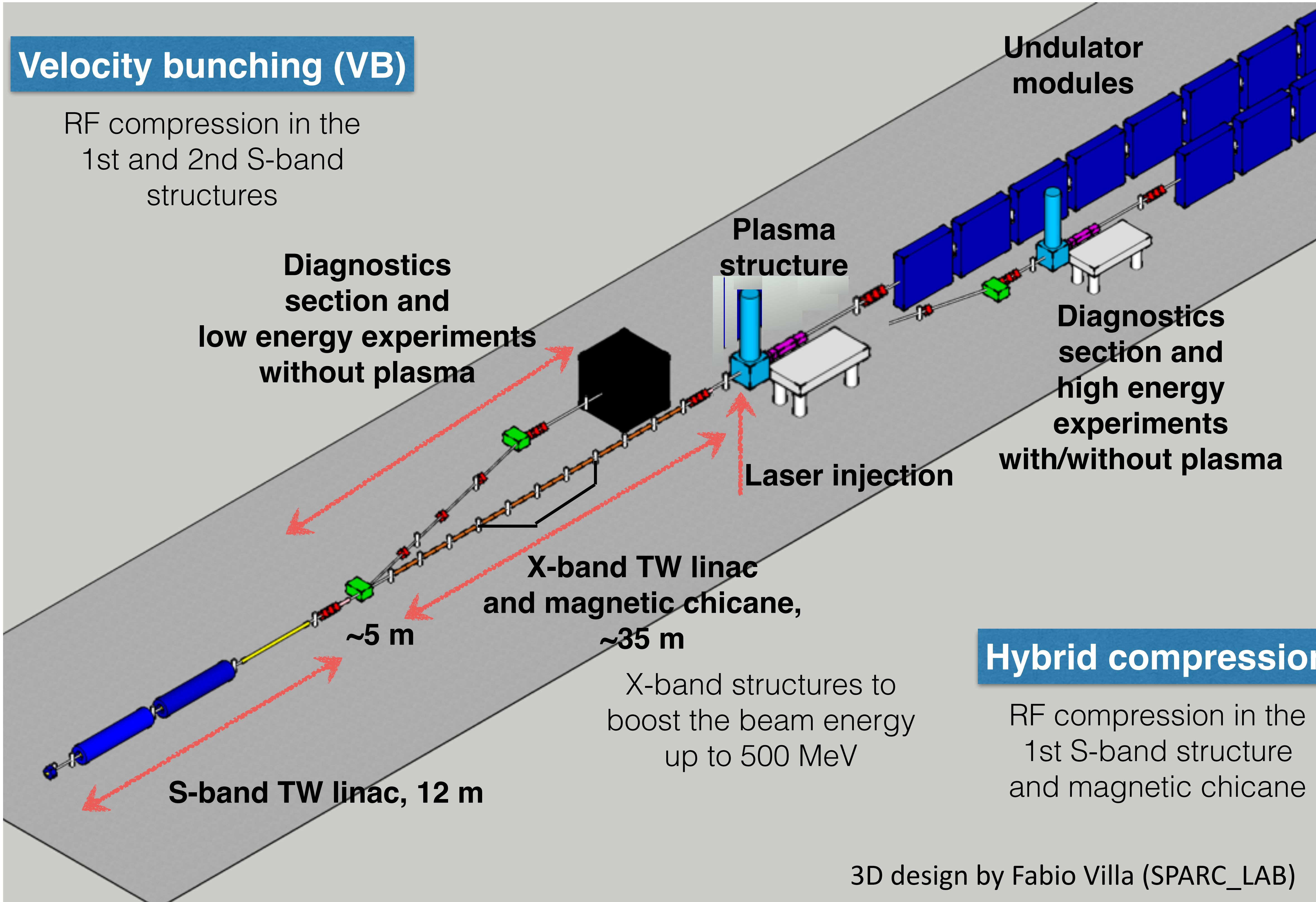
- 150 MeV
- 30 pC
- normalized emittance ~ 1 mm mrad,
- alpha (Twiss)=1,
- beta (Twiss)=0.03 m,
- sigmaz= 2µm (15 fs)
- energy spread 5% and slice energy spread 3% (*actually I do not understand which experiment needs these values*)
- **Peak current ~ 800 A**

then the RF injector is not the solution

If the 150 MeV wants to be considered, then the charge must be decreased down to 5 pC, but in any case the achievable peak current is only 1 kA!!!

Velocity bunching (VB)

RF compression in the 1st and 2nd S-band structures



X-band structures to boost the beam energy up to 500 MeV

Hybrid compression

RF compression in the 1st S-band structure and magnetic chicane

3D design by Fabio Villa (SPARC_LAB)

RF injector team

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- DESY: B. Marchetti, J. Zhu