FEL-quality 5GeV e-bunches with the Resonant Multi-Pulse Ionization injection

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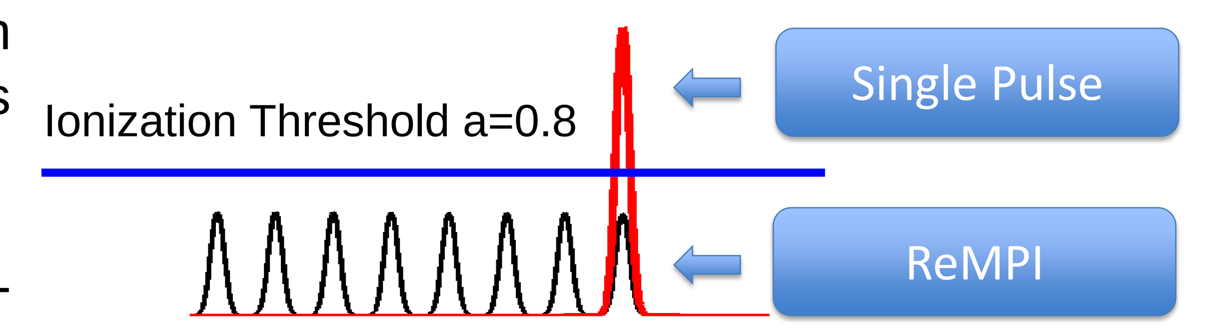
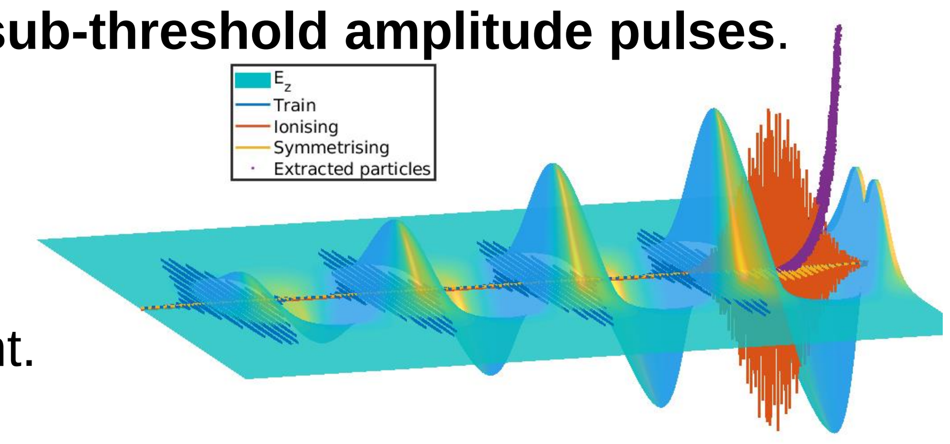
Abstract

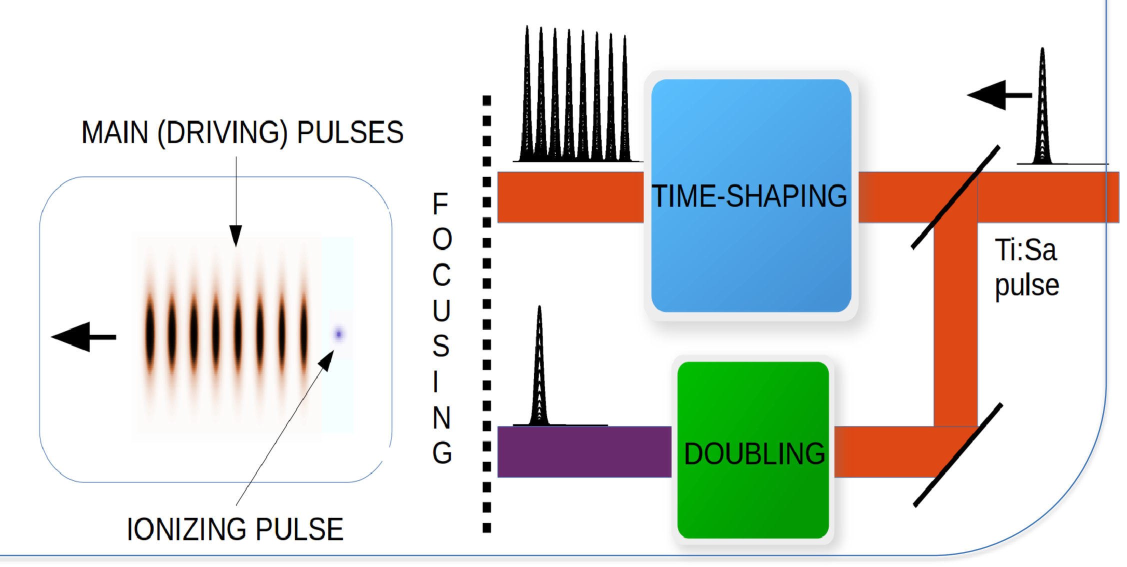
The **Re**sonant **M**ulti-**P**ulse **I**onization injection (ReMPI) scheme [1,2] is a very flexible LWFA scheme that aims at generating high-quality bunches with tunable duration by using a single 100-TW/1-PW class Ti:Sa laser system. As in the *two-color* ionization scheme, ReMPI employs a frequency doubled (or more) pulse so as to extract electrons from the dopant (e.g. Nitrogen, Argon) and trap them in the correct phase of the bucket. Instead of using a second, long-wavelength (5-10 microns), laser system to generate the pulse driving the wakefield, in the ReMPI scheme the most energetic portion of the Ti:Sa pulse is **longitudinally split in a train of resonant pulses**, each having intensity well below the threshold of ionization for the chosen dopant. ReMPI can be used to generate **high brightness beams with normalised emittance of tens nm scale**. We show a simulation [3] for single-stage injection and acceleration with a standard 1PW Ti:Sa laser system, generating a 30pC, 5GeV e-beams with **normalized emittance of 0.08 mm mrad,** slice energy spread **below 0.1% and peak 6D brightness of 2x10^18 [A/m^2/0.1%bw]**

The ReMPI scheme

- The Resonant Multi-Pulse Ionization injection (ReMPI) [1] is a new bunch injection/acceleration scheme aiming at generating low-emittance bunches [as low as 0.05 mm mrad]
- ReMPI requires **one** short-pulse (e.g Ti:Sa) laser system. Since a unique very large-amplitude Ti:Sa pulse would fully ionize the atoms (Ar8+ in the present scheme), **the pulse is shaped as a resonant sequence of 4/8 sub-threshold amplitude pulses**.
- In ReMPI a separate (single) pulse in **second or higher harmonics** is tightly focused after the last pulse in the driver train, thus acting as ionization pulse that extract electrons from the dopant.



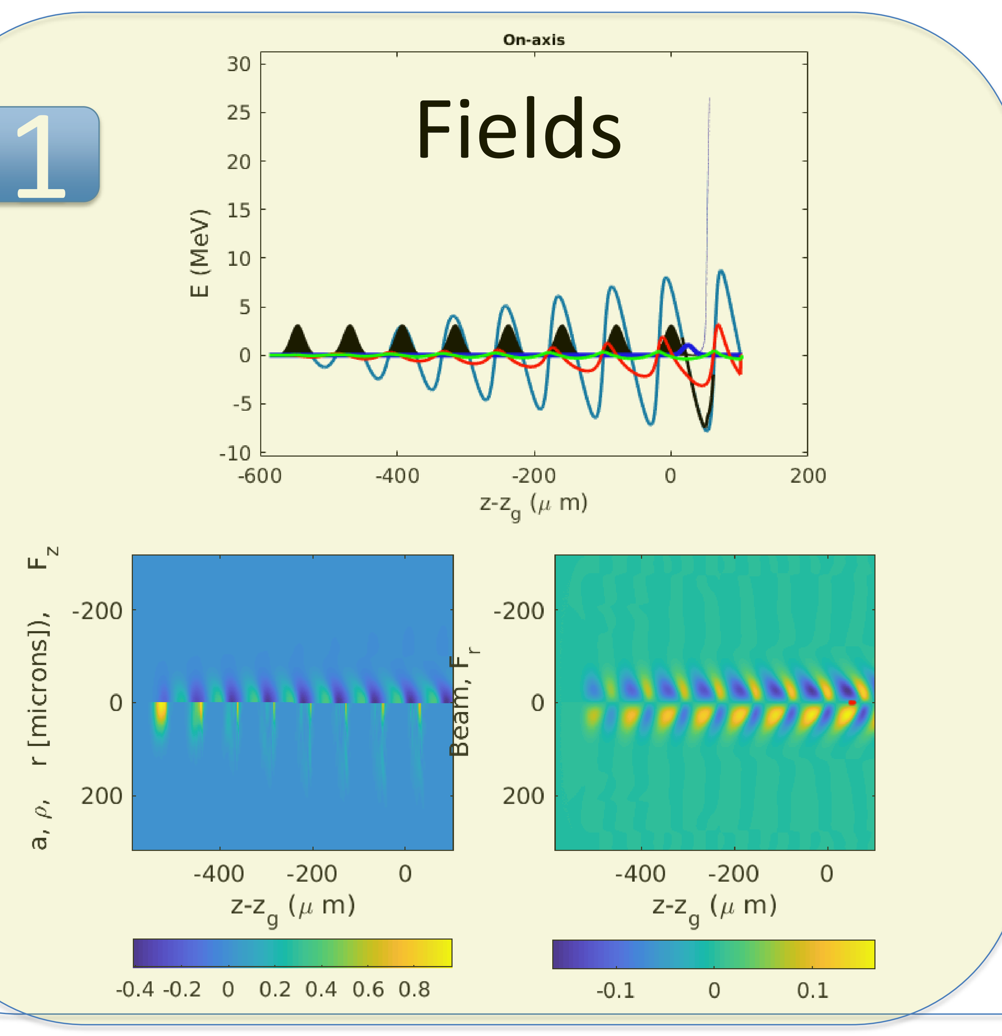




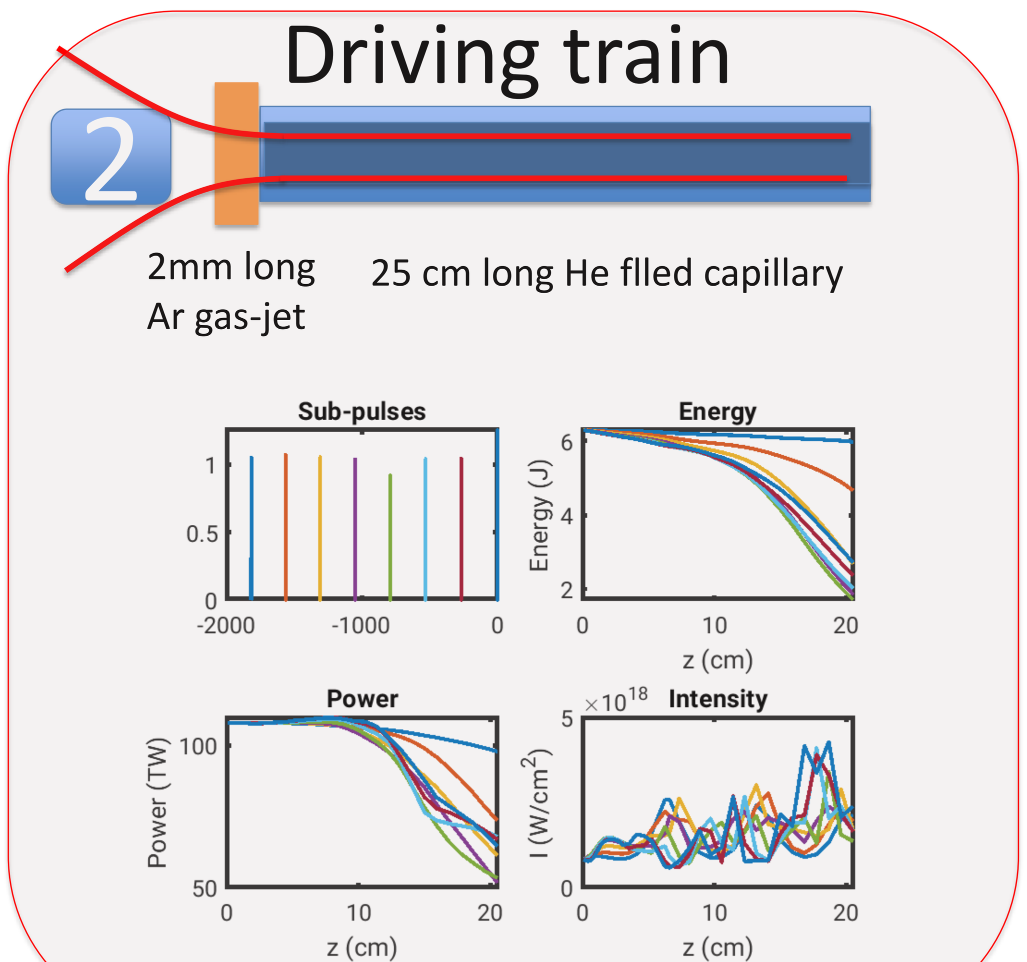
5GeV Simulation results: fields and projected beam-quality

2D-3V cylindrical Qfluid [4] simulation, pulses move through the left*. A 1PW Ti:Sa laser system is required. The eight-pulses (8x100TW, 60 fs long each)* ***train resonantly drives*** *a nonlinear plasma wave with amplitude of approx. 0.6 E_0. The ionizing pulse (IV harm, 4TW) extracts new particles that are suddenly trapped by the wake. The driving train is focused with a waist w0=60 micron on Argon, supposed to be ionized up to level 8+ and generating a pre-plasma with background electronic density n0=2.5x10^17 1/cm^3. The guiding of the pulse so as to reach about 25 cm of propagation is obtained with a standard parabolic channel.*

1 Fields

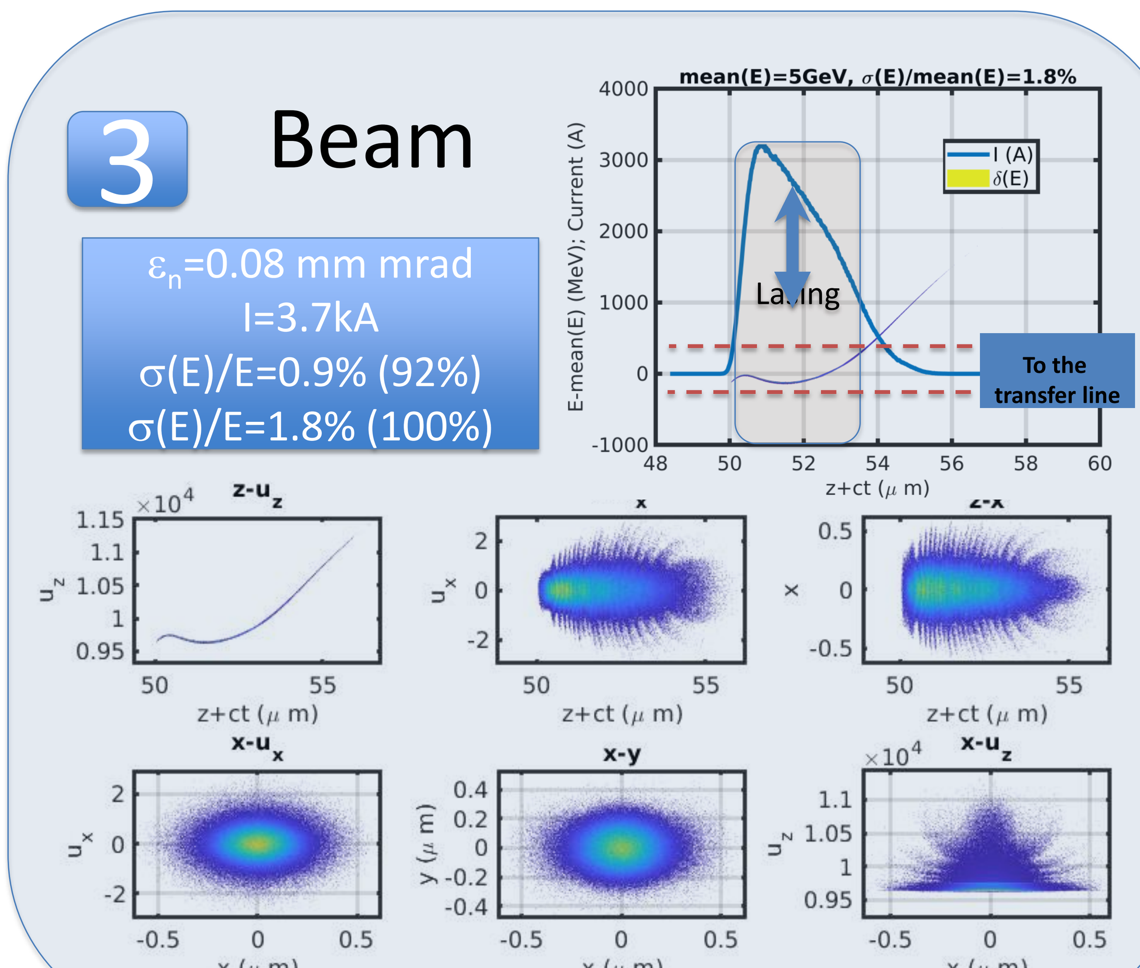


2 Driving train



3 Beam

ε_n=0.08 mm mrad
I=3.7kA
σ(E)/E=0.9% (92%)
σ(E)/E=1.8% (100%)



FEL-oriented slice analysis of the 5GeV bunch

$\varepsilon_{n,s}$<0.08 mm mrad, min (σ(E)/E slice)=0.03%, @peak 0.06%

Analytical formulas from [3]

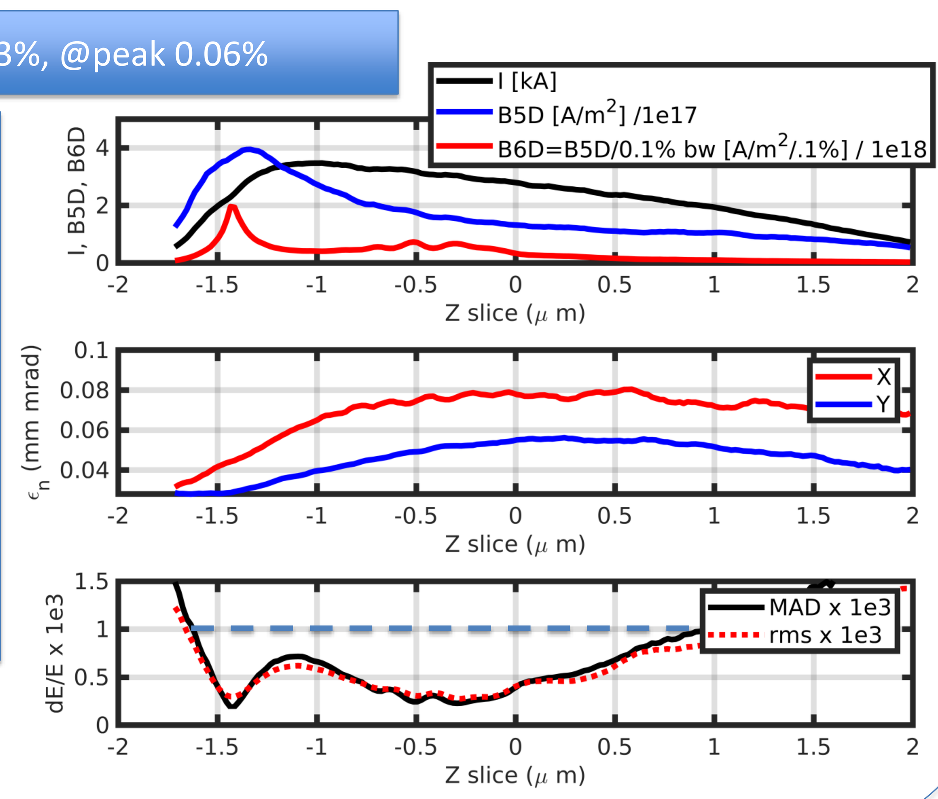
$$\rho = \frac{8.36\times 10^{-3}}{\gamma}\sqrt[3]{\lambda_U^2 \frac{I_{peak}[A]}{2\pi\beta\gamma^{-1}\varepsilon_n} K^2 f_B^2(K)}$$ =0.12% >δ E/E

$$\beta_{Twiss}[m] = \frac{\sqrt{2}\gamma}{2\pi K}\lambda_U[m] \qquad \lambda_{FEL} = \frac{\lambda_U}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

$$L_G = \left[1+\frac{0.641}{\rho^2}\left(\frac{\sigma_E}{E}\right)^2\right] \exp\left[\frac{0.136}{\rho^2}\left(\frac{\sigma_E}{E}\right)^2\right] \frac{\lambda_U}{4\pi\sqrt{3}\rho}$$

$$L_C = \frac{\lambda_{FEL}}{4\pi\sqrt{3}\rho}$$

Analytical results show that radiation will saturate in about 10 m. Full FEL simulation are ongoing



FINAL beam parameter table

	δE/E	δE/E SLICE	ε_n SLICE	Q	I peak
OBTAINED	0.9%	**0.03% (min)**	**<0.08 μm rad**	30 pC	3.5 kA
EuPRAXIA REQUEST	1%	0.1%	<1 μm rad	>=30 pC	>1 kA

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