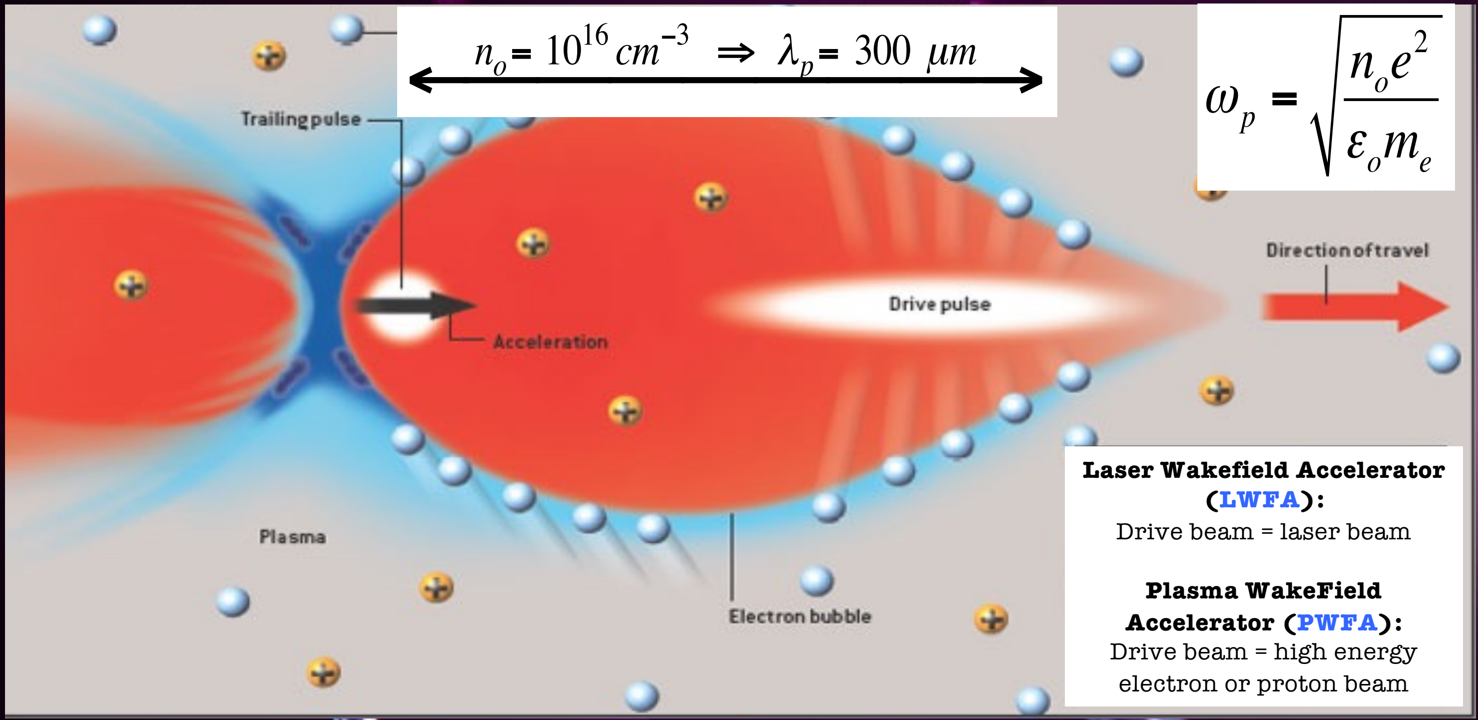
Plasma Acceleration



Laser Wakefield Accelerator (LWFA):
Drive beam = laser beam

Plasma WakeField Accelerator (PWFA):
Drive beam = high energy electron or proton beam

Principle of plasma acceleration

Driven by Radiation Pressure

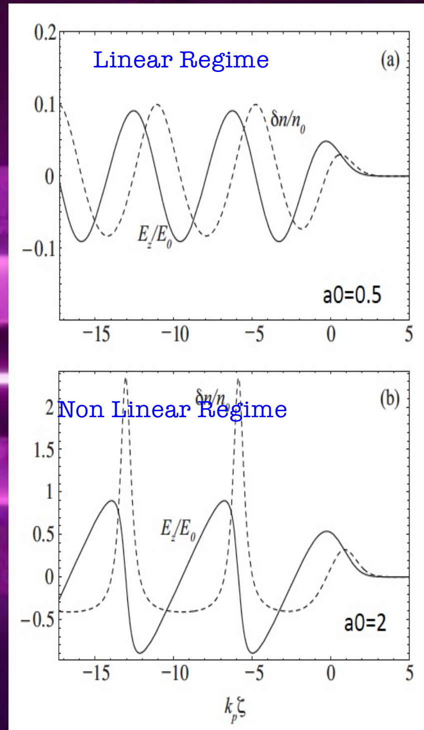
$$\left(\frac{\partial^2}{\partial t^2}+\omega_p^2\right)\frac{n}{n_o}=c^2\nabla^2\frac{a^2}{2}$$

$$a=\frac{eA}{mc^2}\propto\lambda J^{1/2}$$

Driven by Space Charge

$$\left(\frac{\partial^2}{\partial t^2}+\omega_p^2\right)\frac{n}{n_o}=-\omega_p^2\frac{n_{beam}}{n_o}$$

$$n_{beam}=\frac{N}{\sqrt{(2\pi)^3}\sigma_r^2\sigma_z}$$



LWFA limitations: Diffraction, Dephasing, Depletion

PWFA limitations: Head Erosion, Hose Instability

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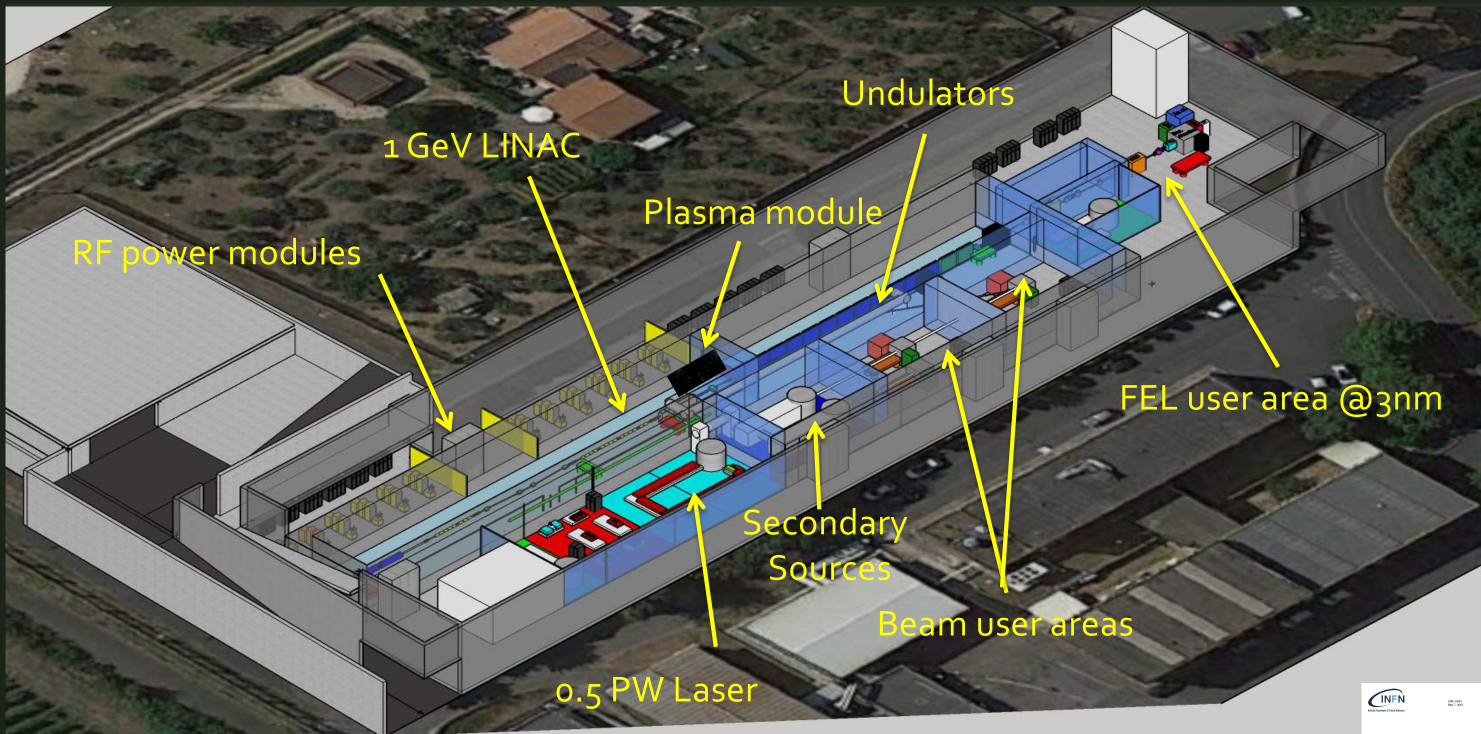

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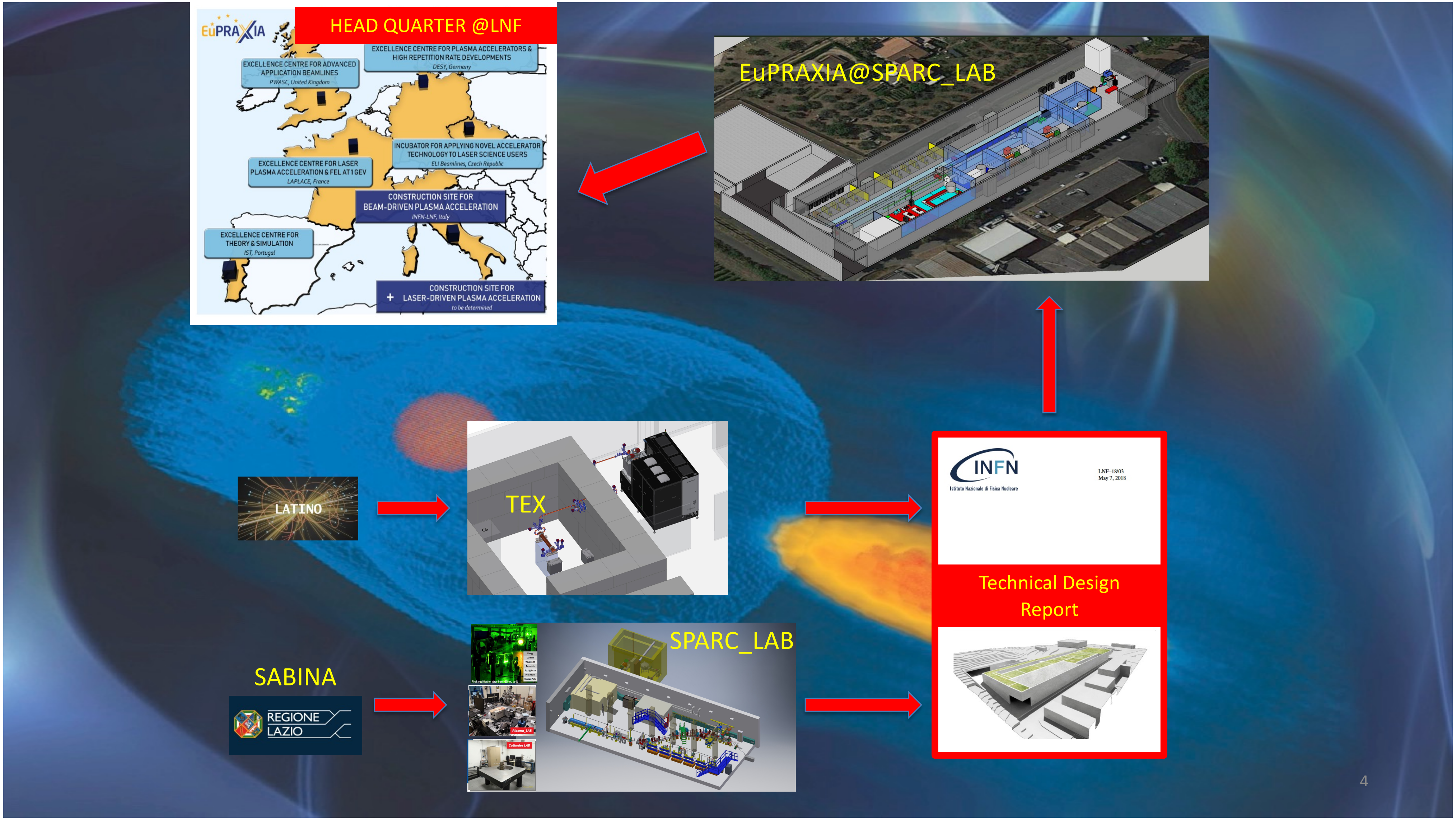
HEAD QUARTER @LNF
EuPRAXIA
EXCELLENCE CENTRE FOR PLASMA ACCELERATORS & HIGH REPETITION RATE DEVELOPMENTS
DESY, Germany
EXCELLENCE CENTRE FOR ADVANCED APPLICATION BEAMLINES
PWASC, United Kingdom
INCUBATOR FOR APPLYING NOVEL ACCELERATOR TECHNOLOGY TO LASER SCIENCE USERS
ELI Beamlines, Czech Republic
EXCELLENCE CENTRE FOR LASER PLASMA ACCELERATION & FEL AT 1 GEV
LAPLACE, France
CONSTRUCTION SITE FOR BEAM-DRIVEN PLASMA ACCELERATION
INFN-LNF, Italy
EXCELLENCE CENTRE FOR THEORY & SIMULATION
IST, Portugal
CONSTRUCTION SITE FOR LASER-DRIVEN PLASMA ACCELERATION
to be determined
EuPRAXIA@SPARC_LAB
LATINO
TEX
INFN
Istituto Nazionale di Fisica Nucleare
LNF-18/03
May 7, 2018
Technical Design Report
SABINA
REGIONE LAZIO
SPARC_LAB
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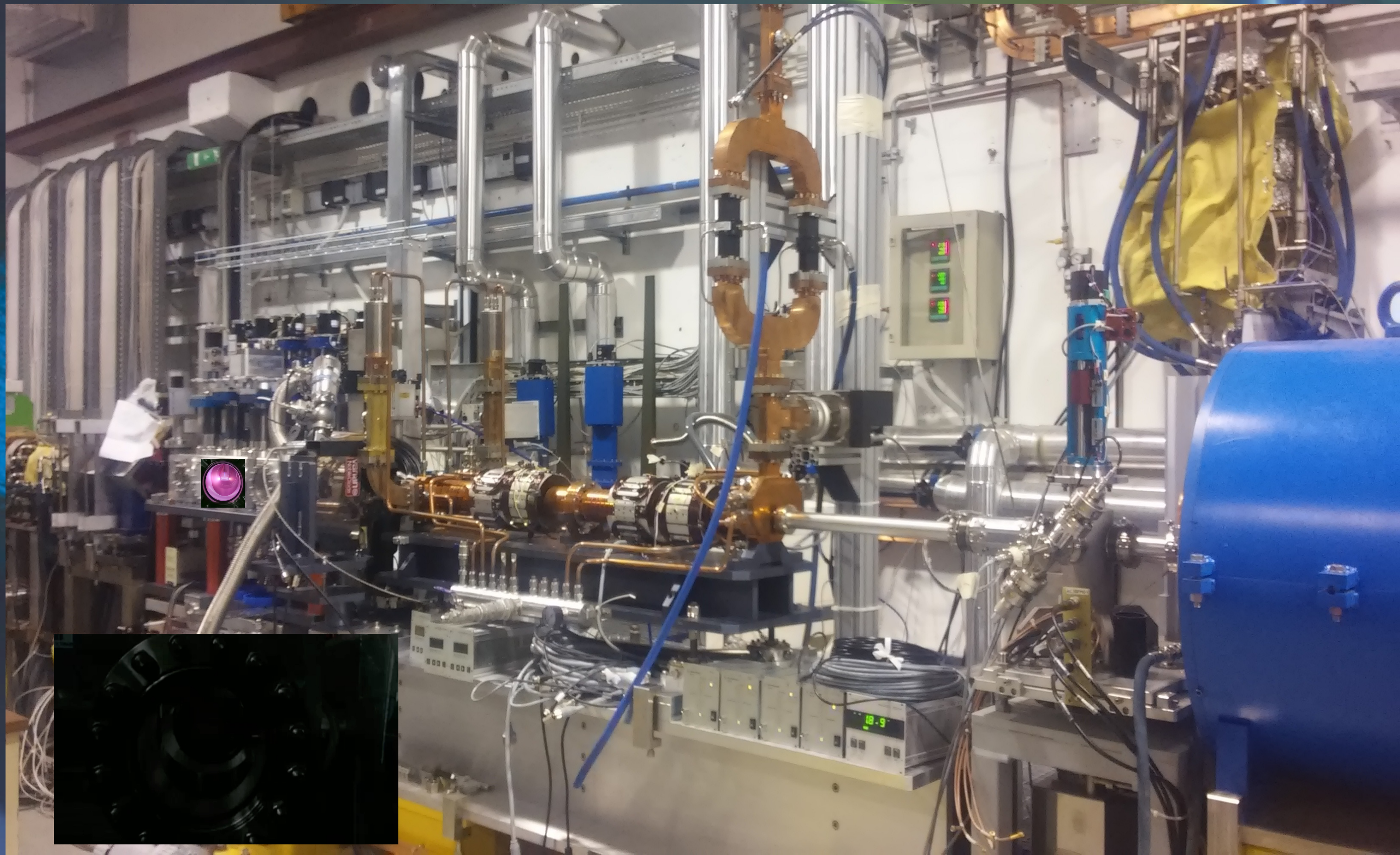
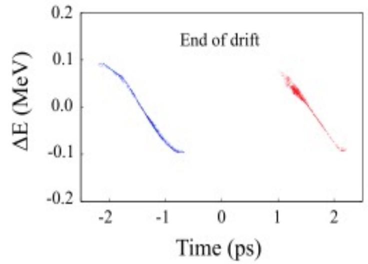
SPARC_LAB is the test and training facility at LNF for Advanced Accelerator Developments (since 2005)
Self-LWFA
TNSA
Thomson
Ext-LWFA
PWFA
FEL
SABINA

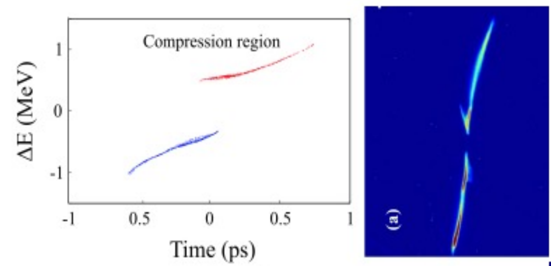
PWFA vacuum chamber at SPARC_LAB

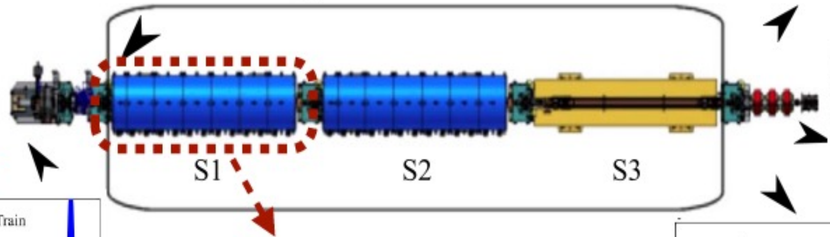


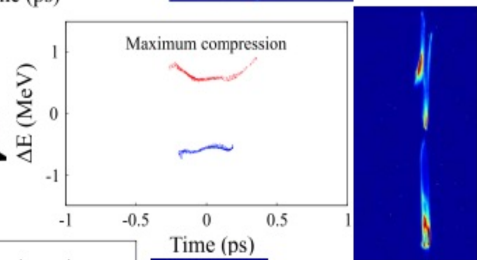
Generation of multi-bunch trains

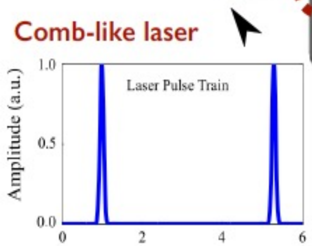
Sub-relativistic electrons ($\beta_c < 1$) injected into a traveling wave cavity at zero crossing move more slowly than the RF wave ($\beta_{RF} \sim 1$). The electron bunch slips back to an accelerating phase and becomes simultaneously accelerated and compressed.



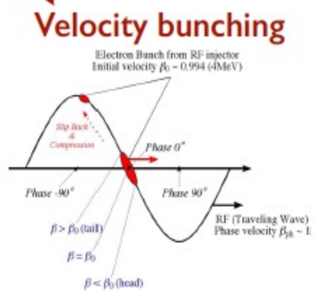


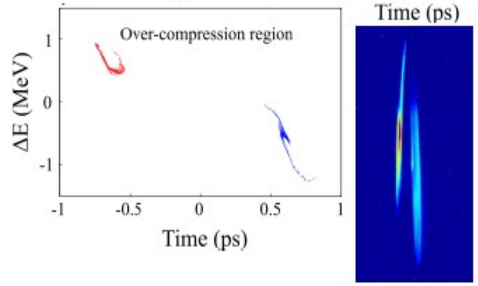




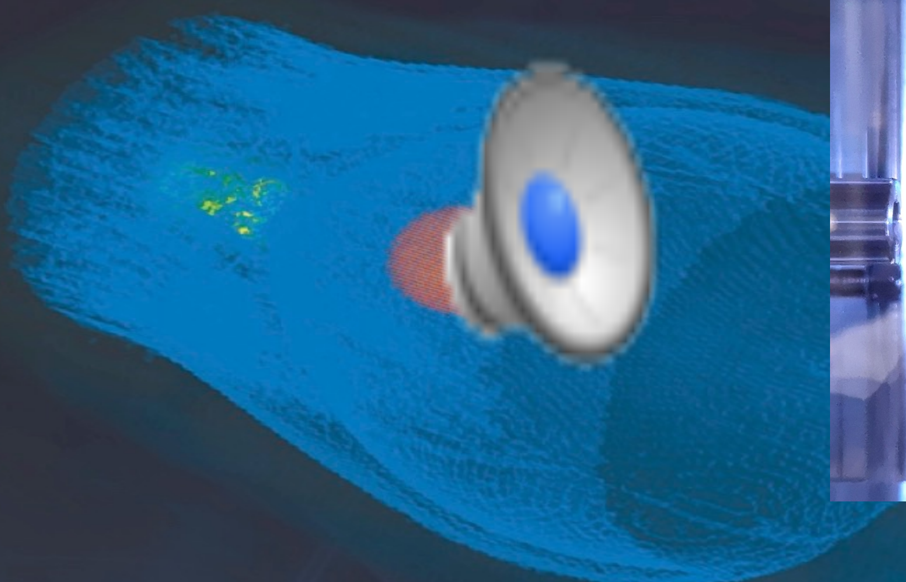


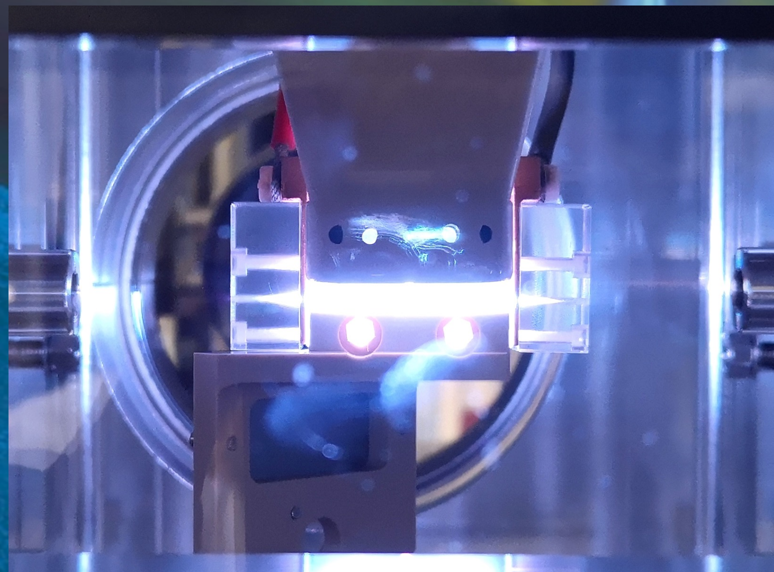
$$\Delta\phi_\infty = \frac{\sin\phi_0}{\sin\phi_\infty}\Delta\phi_0 + \frac{1}{2\alpha\gamma_0^2\sin\phi_\infty}\Delta\gamma_0 + \frac{1}{2}\left[\frac{\cos\phi_0}{\sin\phi_\infty} - \frac{\cos\phi_\infty\sin^2\phi_0}{\sin^3\phi_\infty}\right](\Delta\phi_0)^2.$$



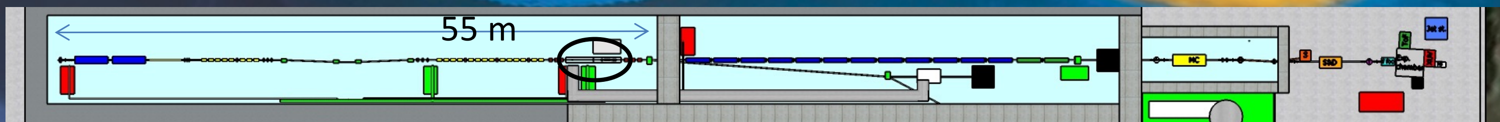


Plasma WakeField Acceleration

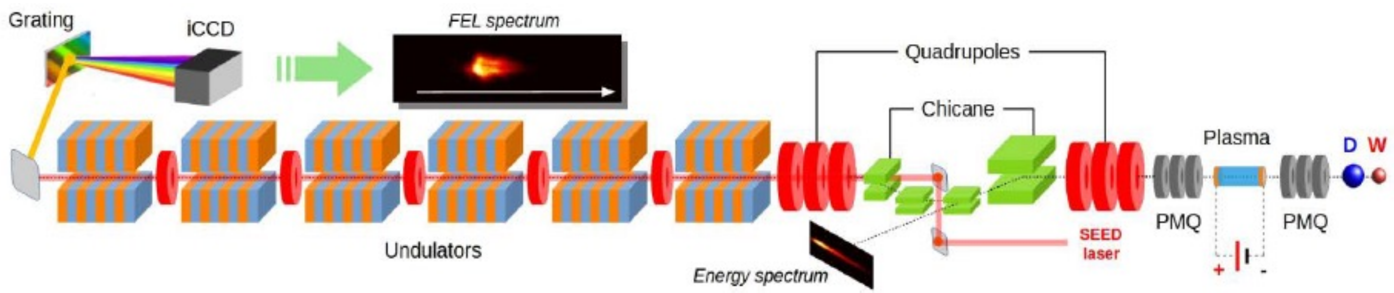




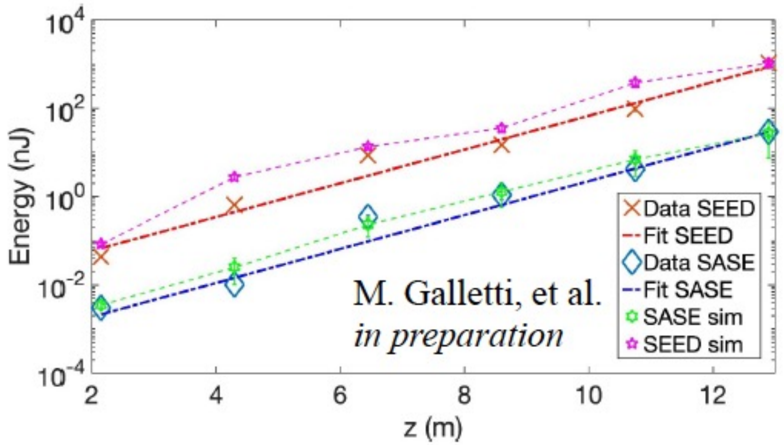
Capillary discharge at SPARC_LAB



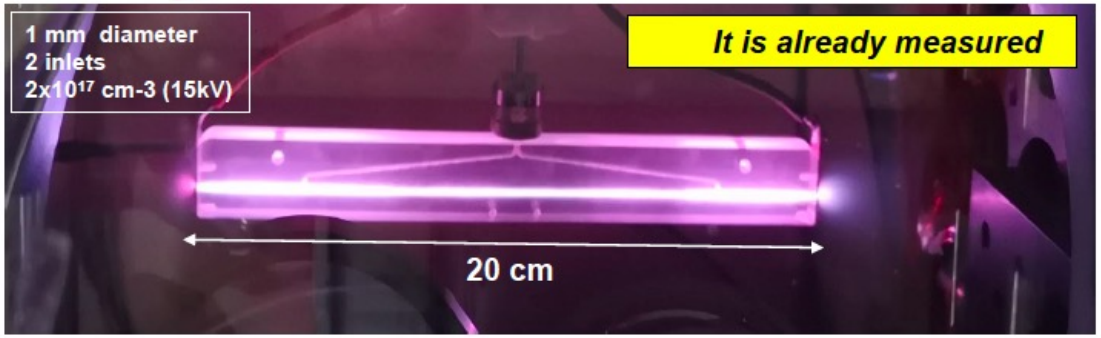
First Beam Driven SEEDED - FEL Lasing at SPARC_LAB (June 2021)



Seeded FEL radiation:
- part of the EOS laser was used as a seed;
- seed laser 795 nm, FEL peak still at 827 nm;
- pulse energy increase from ~30 nJ up to ~ 1 μJ;
- increased stability of radiation.

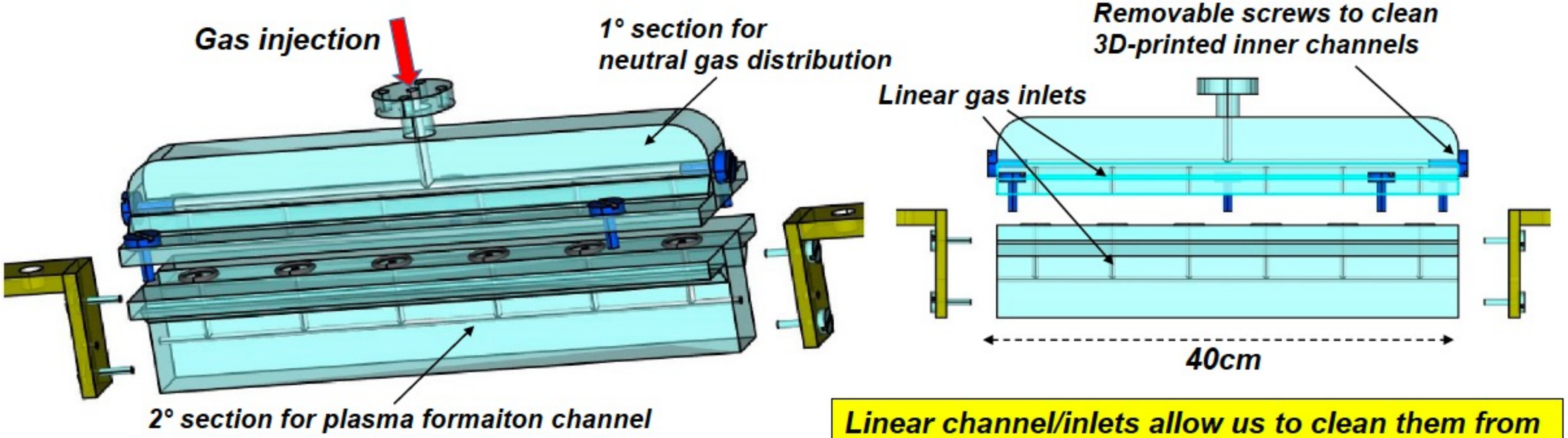


40 cm-long Gas-filled discharge-capillary

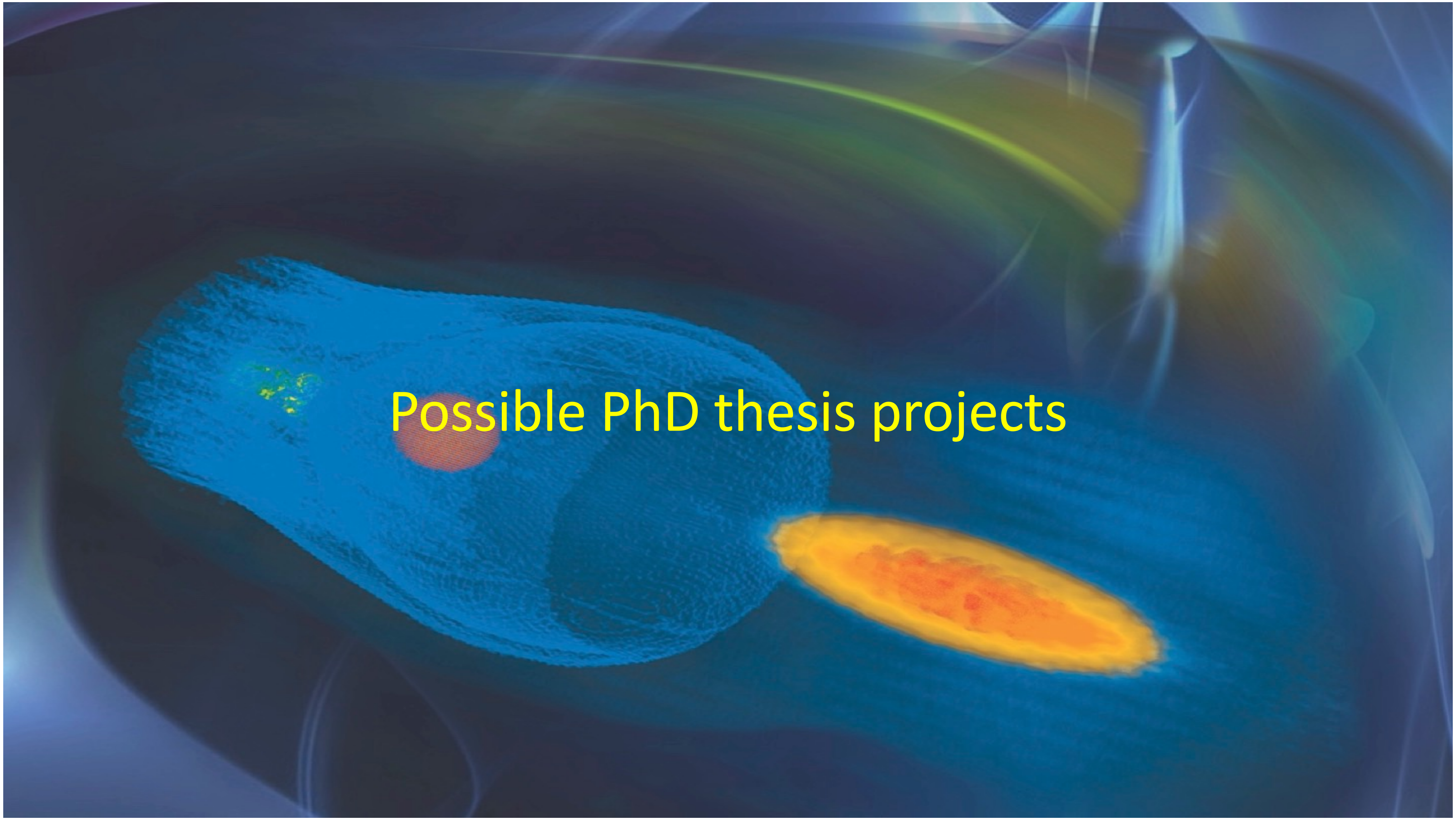


Paschen curves (50 mbar)

Length	*Density*	*Vb*
3 cm	$4x10^{16}$ cm-3	3 kV
10 cm	$4x10^{16}$ cm-3	8 kV
20 cm	$4x10^{16}$ cm-3	14 kV
40 cm	$4x10^{16}$ cm-3	23 kV



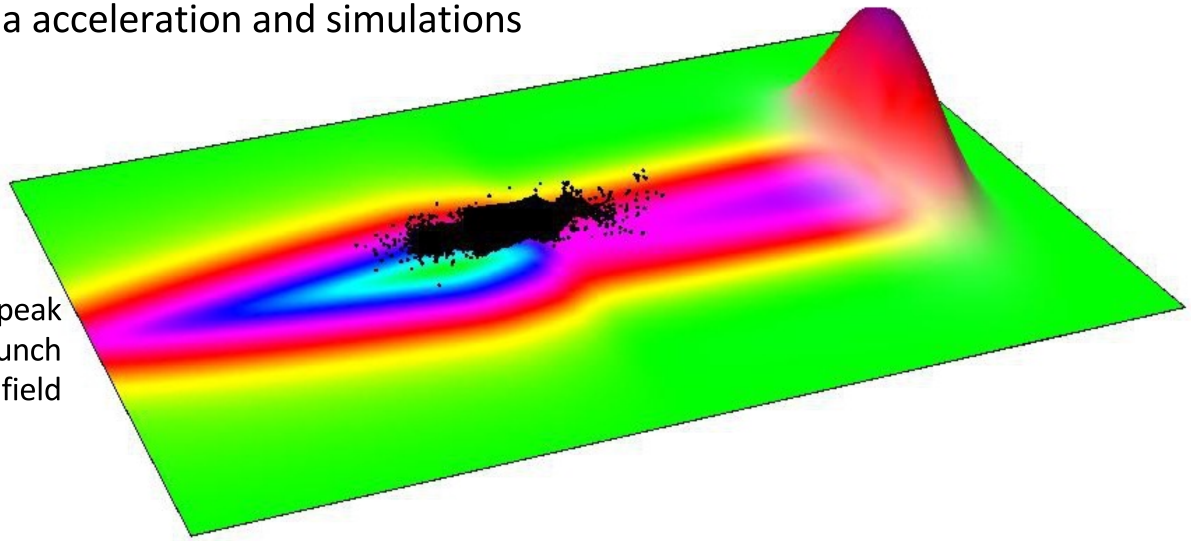
Linear channel/inlets allow us to clean them from printing residuals


Possible PhD thesis projects

1. Biagioni - Theoretical and experimental studies of plasma formation in capillary discharge waveguides for plasma-based accelerator
2. Del Dotto - Multi-objective bayesian plasma acceleration
3. Romeo - Positron acceleration in a linear plasma wakefield at EuPRAXIA
4. Costa - External injection and staging studies and tests for plasma wake field acceleration experiments at SPARC LAB
5. Bellaveglia - Theoretical and technological studies on a femtosecond synchronization system towards an efficient Plasma Wakefield Acceleration
6. Vaccarezza: "Analysis and optimization of the EuPRAXIA RF Linac for train generation of ultra-short electron bunch able to drive beam driven plasma wakefield acceleration of high quality electron beam for FEL applications"
7. Mostacci - Beam dynamics issues for the optimisation of beam measurements in Eupraxia plasma accelerator

Plasma Acceleration (A.R. Rossi)

- Numerical codes development for plasma acceleration and simulations



Plasma wave driven by a laser pulse (peak on the right) accelerating an electron bunch (black dots) by the plasma electric field (colormap)

Numerical simulations are a necessity to study plasma acceleration. However, a fully consistent simulation requires a very large computational power and time. Reduced models allow to further speed up simulations, as optimization of numerical routines does, so that code development is an always ongoing activity. By numerical simulations we:

- Design new plasma based accelerators (EuPRAXIA)
- Design working points of existing/future accelerators/experiments (EuPRAXIA, ExIn)
- Support and interpret experimental results

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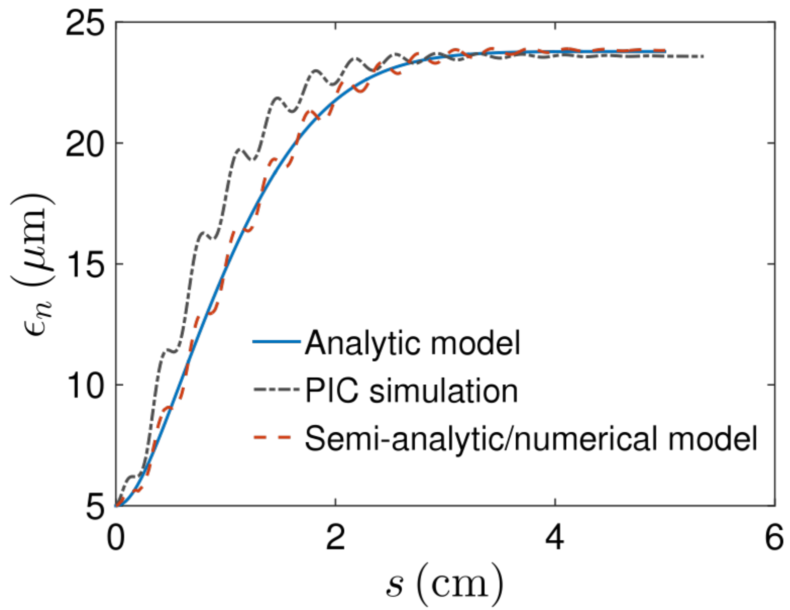
Plasma Acceleration (A.R. Rossi)

- Theory by reduced models

$$\sigma_{p_z}^2(t) = \left[F_1^2\sigma_2 + F_1F_2\sigma_3 + \frac{1}{4}F_2^2\left(\sigma_4 - \sigma_2^2\right)\right]t^2 + \left(2F_1\sigma_{zp_z}^{(0)} + F_2\Sigma^{(0)}\right)t + \sigma_{p_z}^{2\,(0)}$$

Longitudinal momentum spread, at second order, from moment equations



Chromatic emittance dilution from moment equation

Plasma simulations are expensive both in computational power and time. Analytical and semi-analytical reduced models are powerful tools to understand the underlaying fundamental physics and to derive scaling laws, for a fast evaluation of orders of magnitude. We study

- Moment equations
- Minimal plasma response models
- Minimal self consistent models
- …

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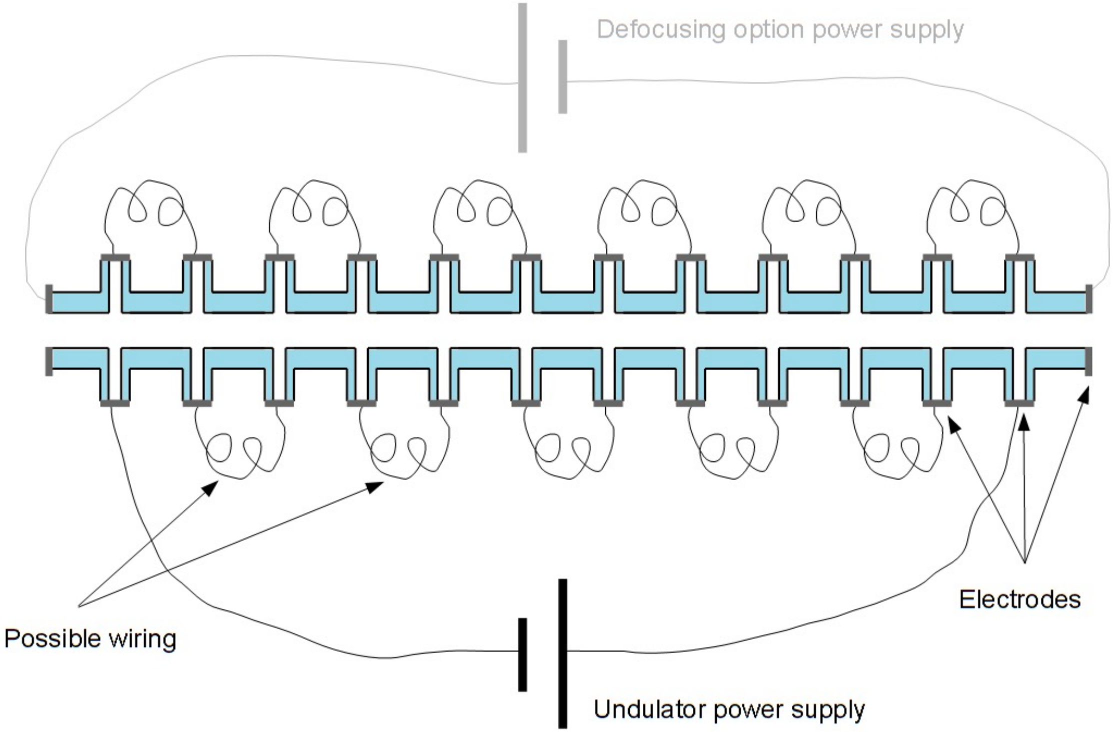
Plasma Acceleration (A.R. Rossi)

- Conceptual and numerical design of plasma based devices



Concept for an active plasma undulator

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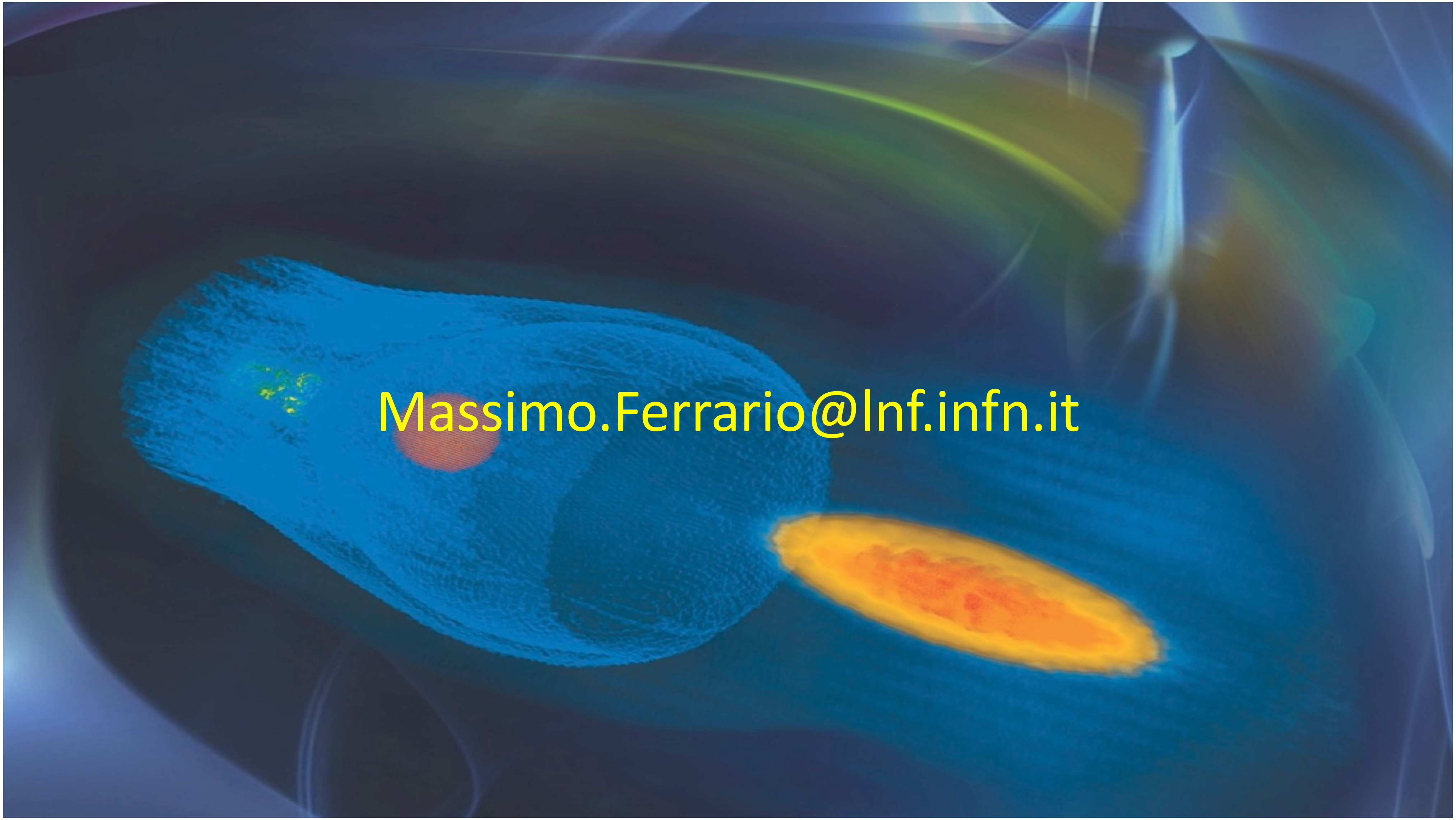
Plasma accelerators are meant to be small and performing. This means that optical elements equally small and performing are desirable additional components. We conceive and study

- Plasma lenses
- plasma pre-de chirper
- plasma undulators
- …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