

PSI Center for Accelerator Science
and Engineering

Plasma Discharge Undulator

**A novel concept for
plasma-based
radiation sources**

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PhD activities and acknowledgments

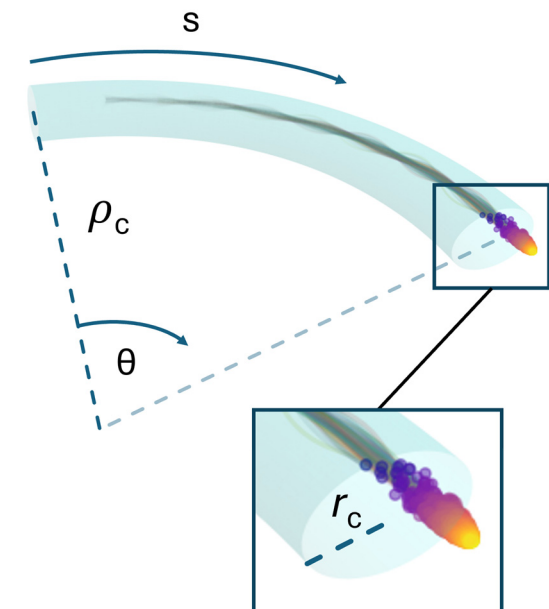
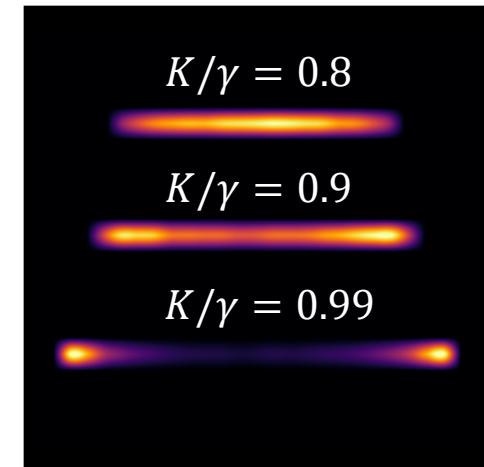
Context: plasma acceleration, **EuPRAXIA** and EuAPS projects, PhD with Sapienza University and based in **INFN Milano**

Thesis work main topics:

- **Betatron radiation studies:** accelerated self injection and extreme emission regimes in focusing ion channels
- **Plasma-based advanced beam manipulation studies:** theoretical modelling and numerical simulations

Collaboration and joint publications with **INFN LNF** (SPARC_LAB), **UCLA** (PBPL) and **DESY** (EuXFEL and REGAE).

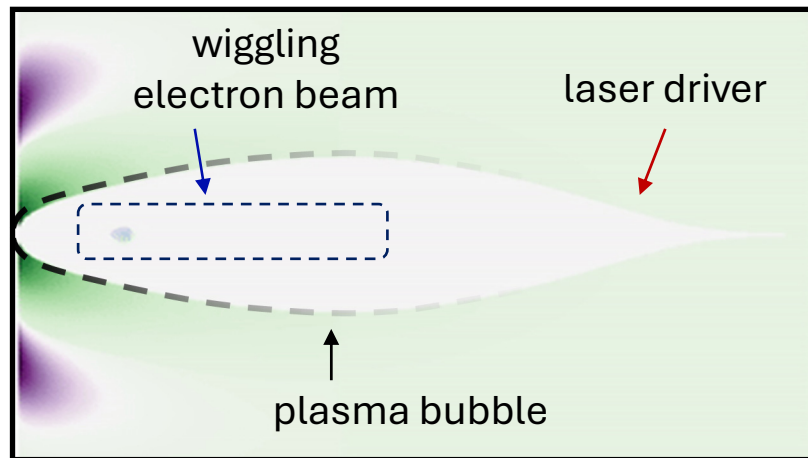
Thanks for the opportunity!



Plasma Wakefield and Plasma Lensing

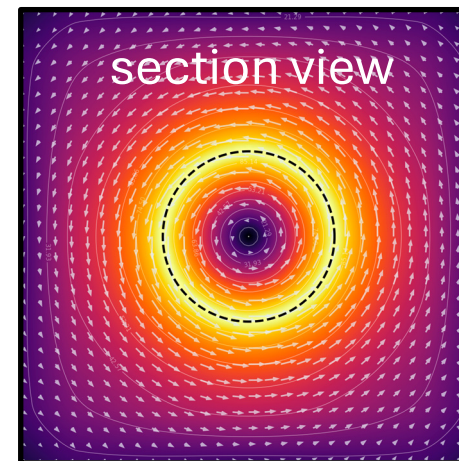
Plasma Wakefield:

- **Driver-based**, either short laser pulse or particle beam
 - Mainly **electrostatic forces**, both focusing and accelerating
- Baseline for **betatron radiation sources**
- Driver energy loss and **dephasing** (laser) requires **driver staging** for long interaction distances



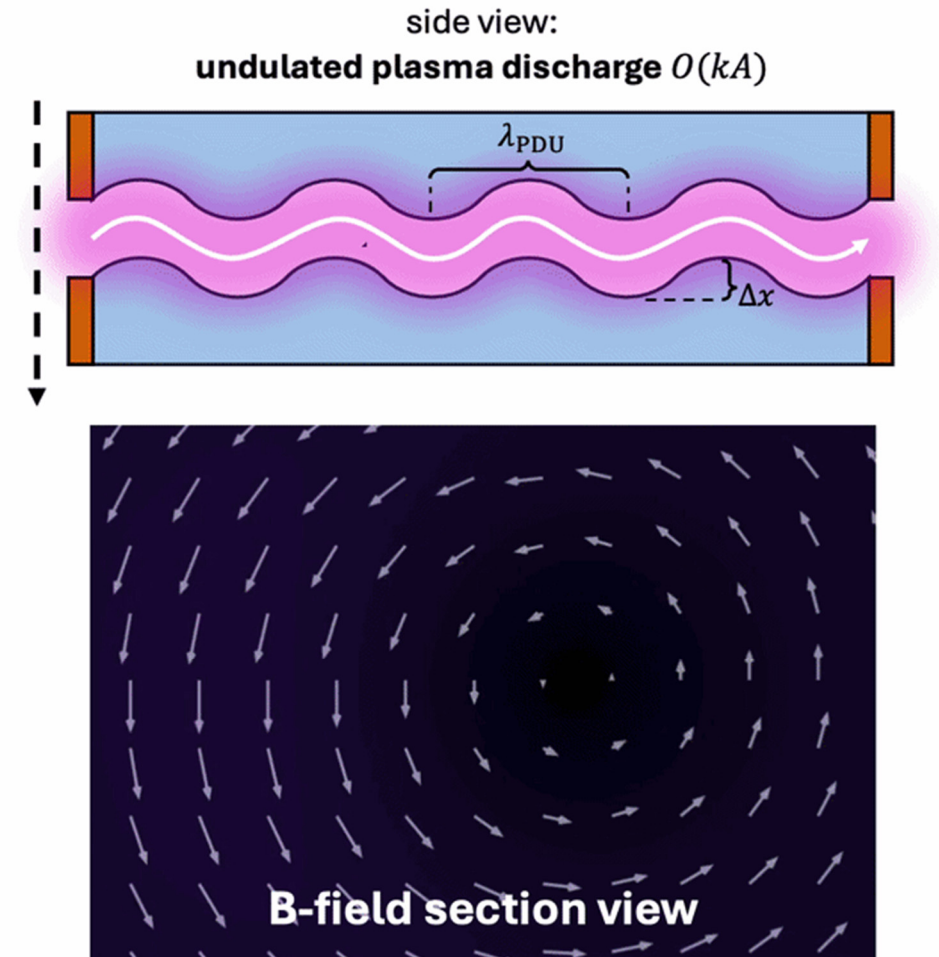
Plasma Lensing (active):

- **Driverless** beam optics element ($O(1)$ kT/m)
 - **Magnetic linear focusing** is generated by **plasma discharge** current density
- First order **preservation of beam energy**
- **Focusing** and **bending schemes** already successfully tested, ...what is missing?



Plasma Discharge Undulator: lensing-based

- Proposed concept: **spatially modulated plasma discharge** to reproduce the magnetic undulator behavior through an **alternated dipolar kick**
 - *Betatron motion*: **beam matching** and transport, with focusing in both transverse planes
 - *Geometric wavelength*: **controlled, in phase undulation** of all beam particles
- **High spectral purity** with **small bandwidth emission**
- **Driverless operation**: ease of device length scaling
- Possibly **millimeter-range undulation period**



PDU expected performance

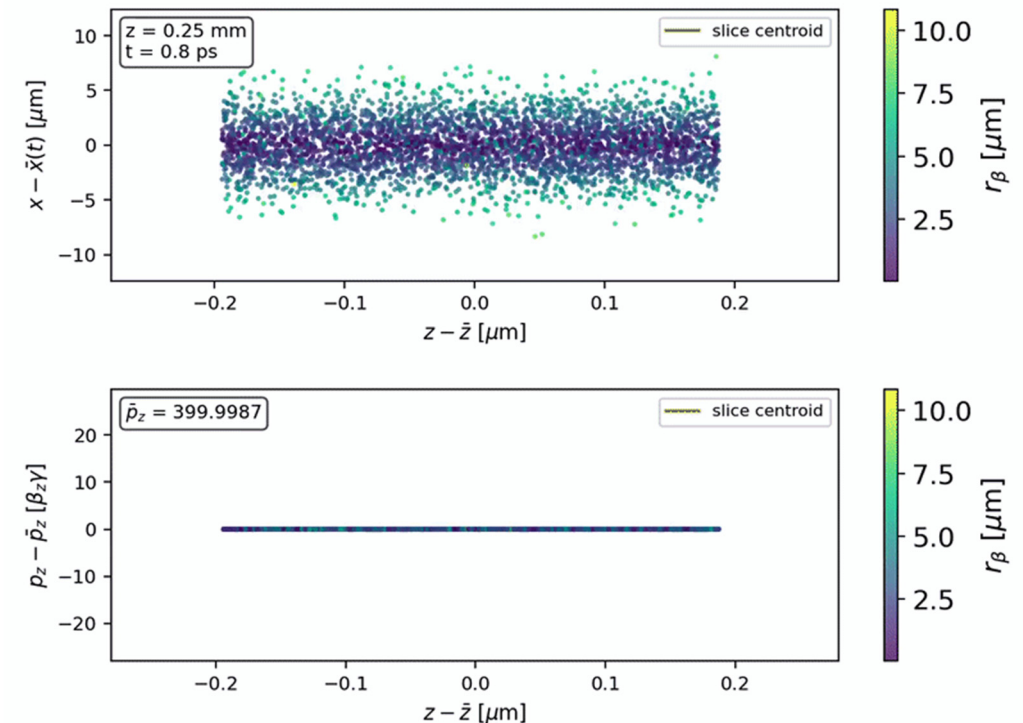
- Simulations show **undulator-like emission**, with **discharge current I** acting as the gap in conventional undulators, linearly tuning **undulator strength K**
- The field features should allow **longitudinal-type microbunching**, suggesting the possibility of **FEL process**
- Millimeter-range period, fixed target wavelength:
 - **Reduced beam energy requirements (factor 3)**
 - **Reduced FEL saturation lengths (factor 10-100)**

λ_1	λ_{PDU}	E	ϵ_n	$L_{sat,1D}$	$P_{sat,1D}$
4 nm	5 mm	400 MeV	0.1 mm mrad	0.4 m	70 GW

$$\lambda_{rad} \propto \frac{\lambda_{PDU}}{2\gamma^2}$$

$$L_{sat,FEL} \propto \lambda_{PDU}^{1/6} I^{-2/3}$$

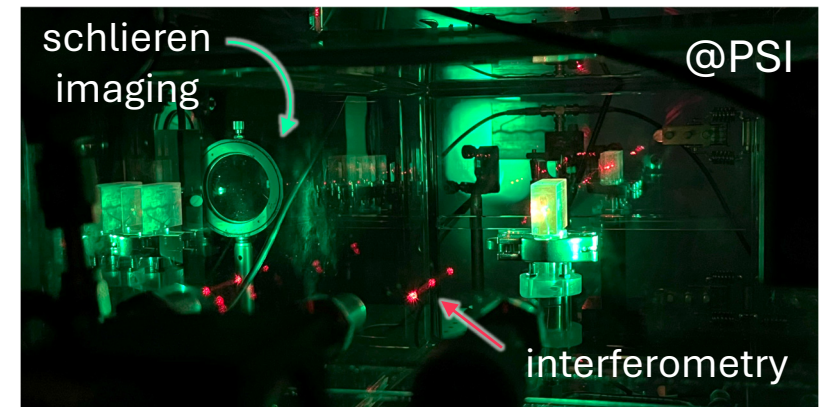
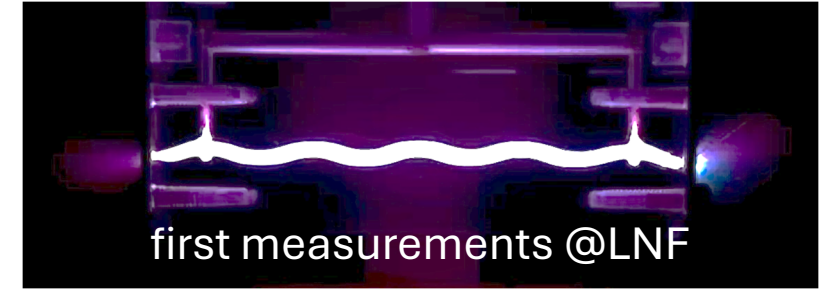
microbunching simulations



Towards PDU experimental realization



- **First discharge tests** performed at **INFN LNF** in January showed a promising plasma distribution
- Experimental roadmap @PSI: a **simulation-driven complete characterization** of the modulated discharge source
 - ✓ **Modeling and numerical simulations**
 - ≈ Controlled and **stable operation** of the kA-range plasma discharge test bench
 - ≈ **Magneto-optical imaging** of time- and space-resolved discharge magnetic field
 - Device testing with electron beam for **monochromatic radiation production** at a facility to be designated



A. Frazzitta, "**Plasma discharge undulator: concept, theory, and numerical study**"
Phys. Rev. E 113, 055204 (2026), doi.org/10.1103/g2z4-wgbn



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Thanks for your attention!