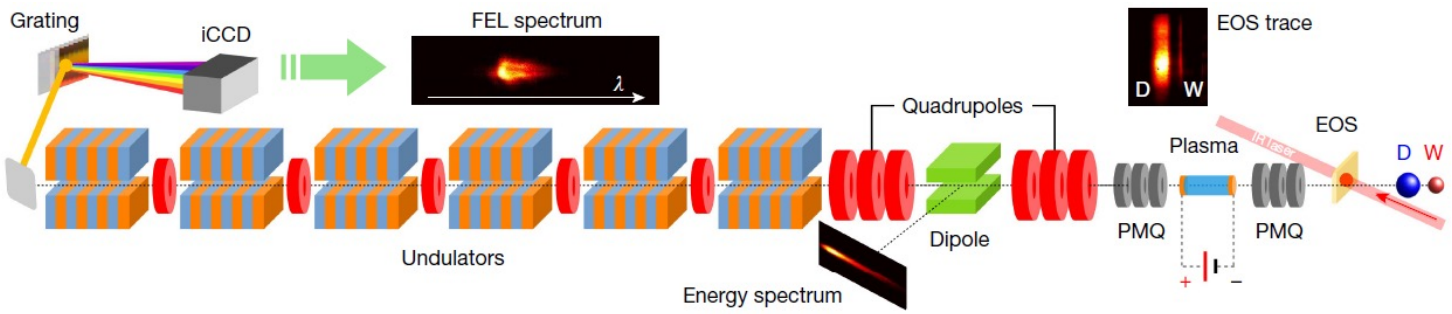
SL_BETATEST

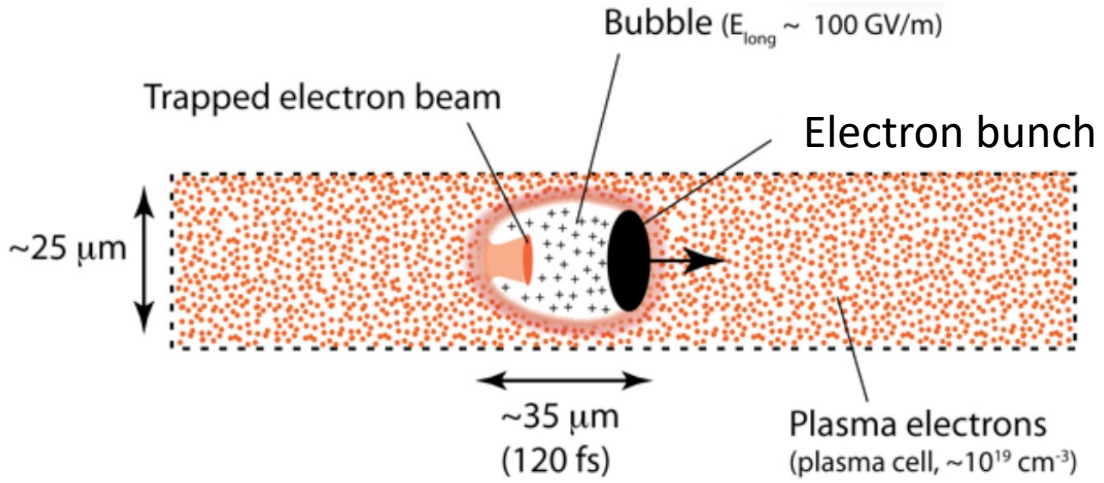
Alessandro Cianchi
University of Rome Tor Vergata & INFN
On behalf of SPARC_LAB & Eupraxia collaborations

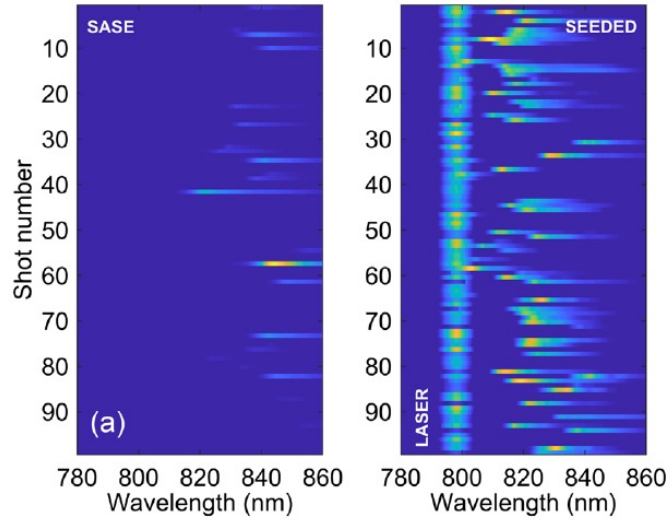
Past Episodes

- SL_COMB2FEL is going to finish this year.
  - The goal was to drive an FEL with a plasma accelerated beam!!
- The outcomes:
  - Pompili, R., et al. "Free-electron lasing with compact beam-driven plasma wakefield accelerator." *Nature* 605.7911 (2022): 659-662.
  - Galletti, M., et al. "Stable operation of a free-electron laser driven by a plasma accelerator." *Physical Review Letters* 129.23 (2022): 234801.

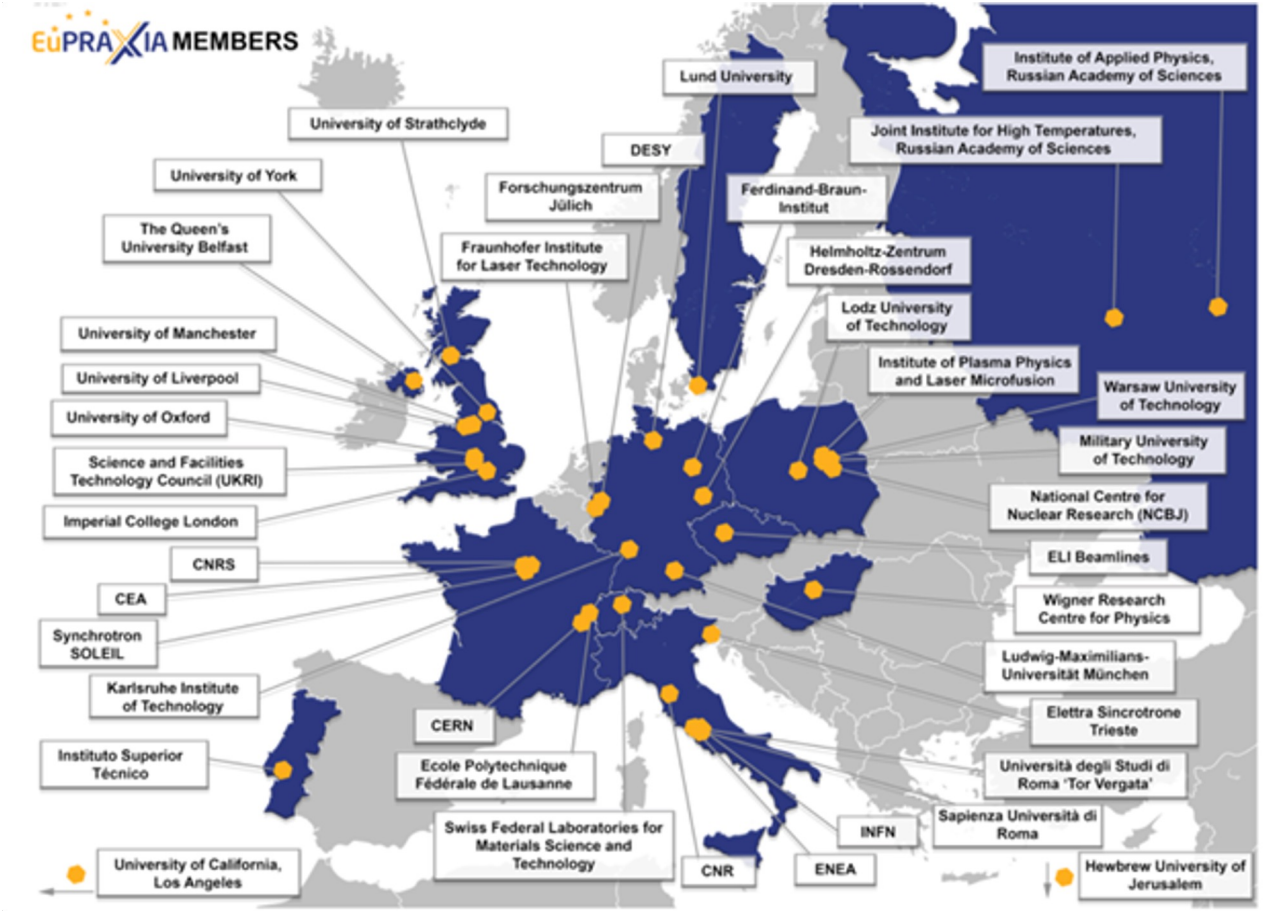
Fel plasma driven in a nutshell







EuPRAXIA
Advanced Photon Sources



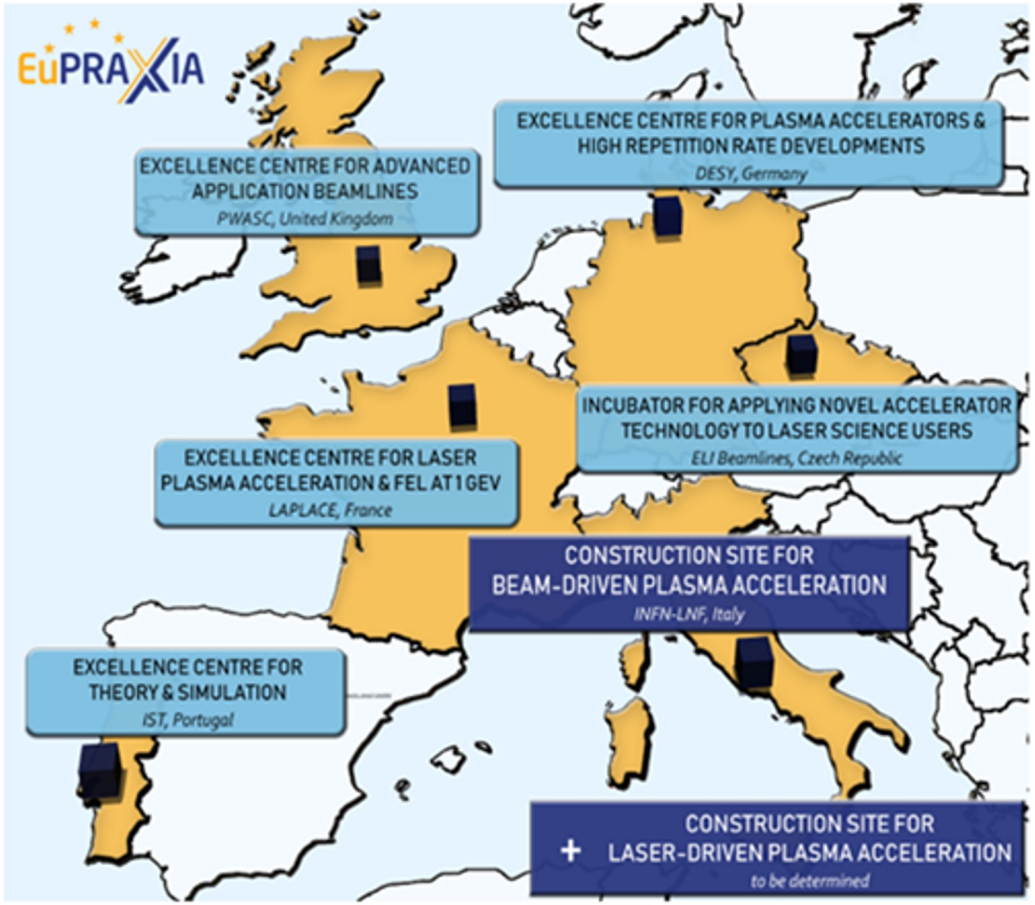
40 Member institutions in:

- **Italy** (INFN, CNR, Elettra, ENEA, Sapienza Università di Roma, Università degli Studi di Roma "Tor Vergata")
- **France** (CEA, SOLEIL, CNRS)
- **Switzerland** (EMPA, Ecole Polytechnique Fédérale de Lausanne)
- **Germany** (DESY, Ferdinand-Braun-Institut, Fraunhofer Institute for Laser Technology, Forschungszentrum Jülich, HZDR, KIT, LMU München)
- **United Kingdom** (Imperial College London, Queen's University of Belfast, STFC, University of Liverpool, University of Manchester, University of Oxford, University of Strathclyde, University of York)
- **Poland** (Institute of Plasma Physics and Laser Microfusion, Lodz University of Technology, Military University of Technology, NCBJ, Warsaw University of Technology)
- **Portugal** (IST)
- **Hungary** (Wigner Research Centre for Physics)
- **Sweden** (Lund University)
- **Israel** (Hebrew University of Jerusalem)
- **Russia** (Institute of Applied Physics, Joint Institute for High Temperatures)
- ***United States*** (UCLA)
- **CERN**
- **ELI Beamlines**

EuPRAXIA
Advanced Photon Sources

European Distributed Facility

- 5 excellence centers
- 2 Construction sites



EuPRAXIA@SPARC_LAB

- > 108 M€ invest funding
- Beam-driven plasma accelerator
- Europe`s most compact and most southern FEL
- The world`s most compact RF accelerator (X band with CERN)

Framework

- EuPRAXIA-Preparatory Phase:
  - four years European Project to prepare the TDR
  - WP13 Diagnostics coordinated by Alessandro Cianchi (University of Rome "Tor Vergata«) and Rasmus Ischebeck (EPFL)
  - WP5 User Strategy & Services coordinated by Francesco Stellato (University of Rome "Tor Vergata") and Emiliano Principi (ELETTRA)

Finanziato dall'Unione europea NextGenerationEU

MUR

I 3.1, Fund for the creation of an integrated system of research and innovation infrastructures
Action 3.1.1 " Creation of new IR or strengthening of existing IR involved in the Horizon Europe Scientific Excellence objectives and the establishment of networks "

Graduatoria definitiva ESFRI area: PSE - Physical Sciences and Engineering

Position	Proposal code	Applicant	Eligible costs	Total Score	Reduction %
1	EuPRAXIA	INFN	22.350.588,00 €	191	-17.6
2	I-PHOQS	CNR	50.000.000,00 €	188	-16.7
3	LNGS	INFN	20.058.826,53 €	185	-19.0
4	K3NET	INFN	67.186.973,06 €	183	-13.0
5	IR0000027	CNR	75.165.077,53 €	182	-21.1
6	IR0000037	ISPRA	16.671.850,52 €	181	-12.5
7	IR0000012	INAF	71.477.540,83 €	181	-19.9
8	IRIS	INFN	59.996.968,15 €	180	-20.0

Principal Investigator
M. Ferrario (INFN)
22.350.588,00

Betatron X rays source
A. Cianchi (Tor Vergata)
9.457.088,00

High power lasers
P. Cirrone (INFN)
7.864.500,00

High repetition lasers
L. Labate (CNR)
4.863.150,00

INFN CNR

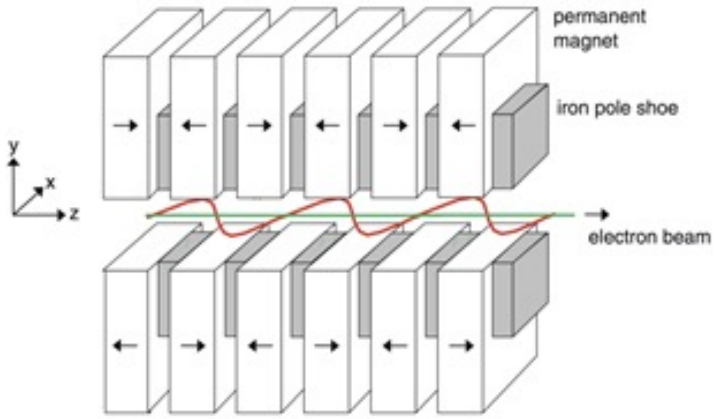
TOR VERGATA UNIVERSITÀ DEGLI STUDI DI ROMA

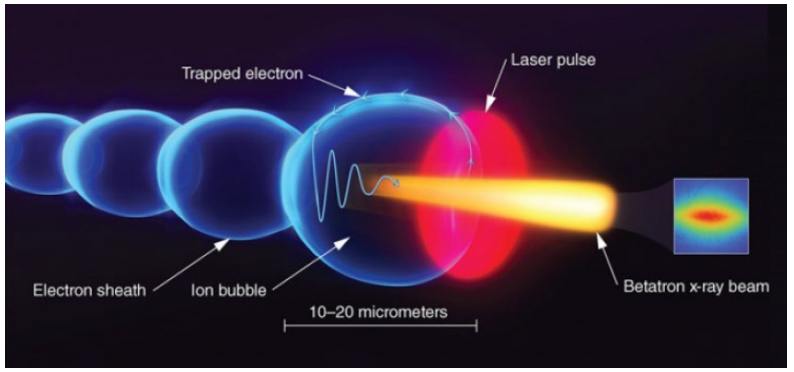
EuPRAXIA Galaxy @ TOV

- Alessandro Cianchi – PA-PNRR and EuPRAXIA beam instrumentation
- Francesco Stellato – PA-PNRR and EuPRAXIA user experiments
- Mario Galletti – RTdA-PNRR and laser
- Federico Galdenzi – Tecnologo – PNRR
- Federica Stocchi – Laureanda - PNRR
- Mauro Sbragaglia – PO – EuPRAXIA Simulazioni
- Daniele Simeoni -Assegnista - EuPRAXIA Simulazioni
- Fabio Guglietta -RTdA - EuPRAXIA Simulazioni
- Gianmarco Parise – Dottorando – EuPRAXIA Simulazioni

Everybody is invited to join

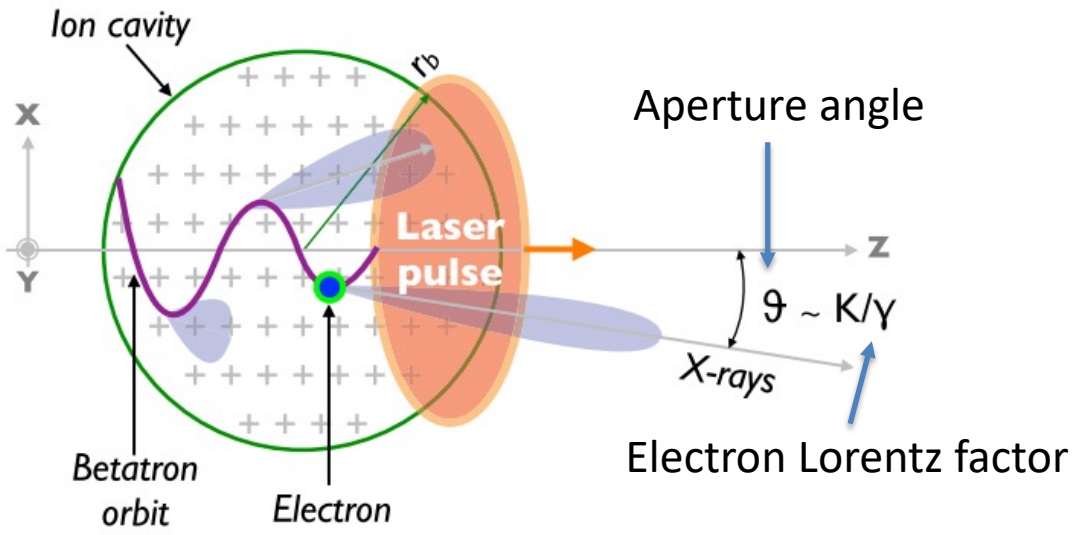
Short accelerator but long undulator…

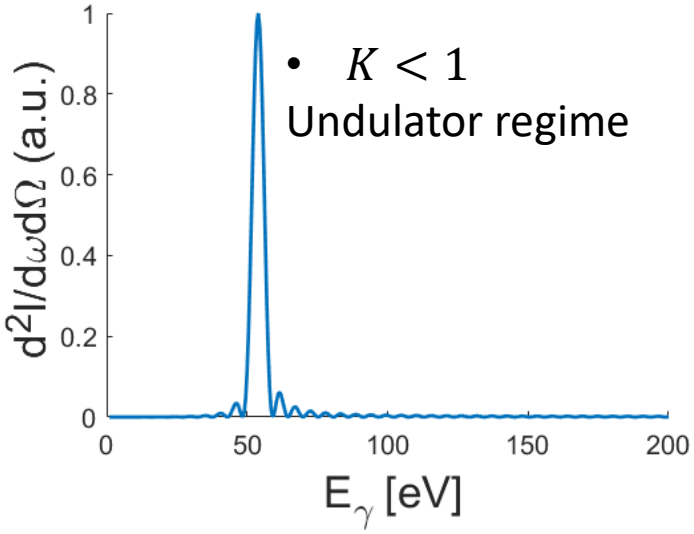




- Typical length of magnetic undulators for a XFEL are in the order of hundreds of meters
- Next step is the reduction of the magnetic undulator with plasma undulators!

Betatron radiation in a nutshell





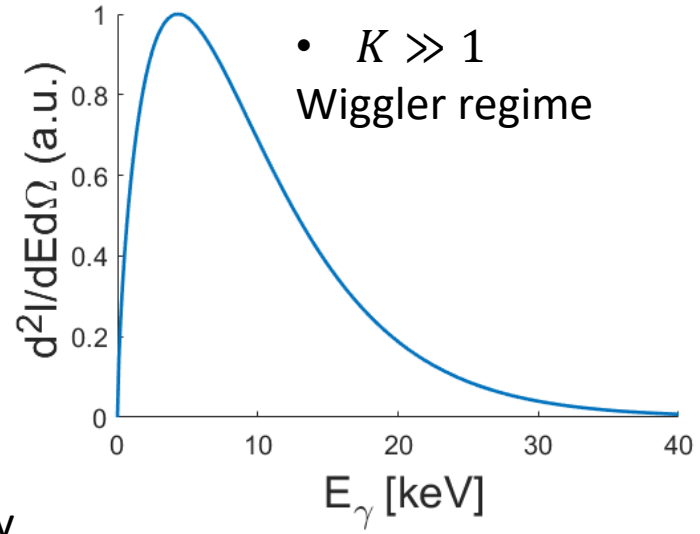
- $K < 1$
  Undulator regime

Undulator parameter

Betatron wavenumber

$$K = \gamma k_\beta r_\beta$$

Oscillation amplitude



- $K \gg 1$
  Wiggler regime

Critical energy $E_c \propto \gamma^2 \omega_\beta K$

Betatron frequency

Inhomogeneous broadening

- Plasma bubbles act as accelerating but also focusing elements
- Focusing fields are quasi-electrostatic
- In **magnetic undulators** the strength parameter, *K*, depends only on physical constants and the magnetic field
- In a **plasma focusing bubble** the strength parameter is different for each electron and depends on the oscillation amplitude, leading to inhomogeneous broadening of the radiation spectrum

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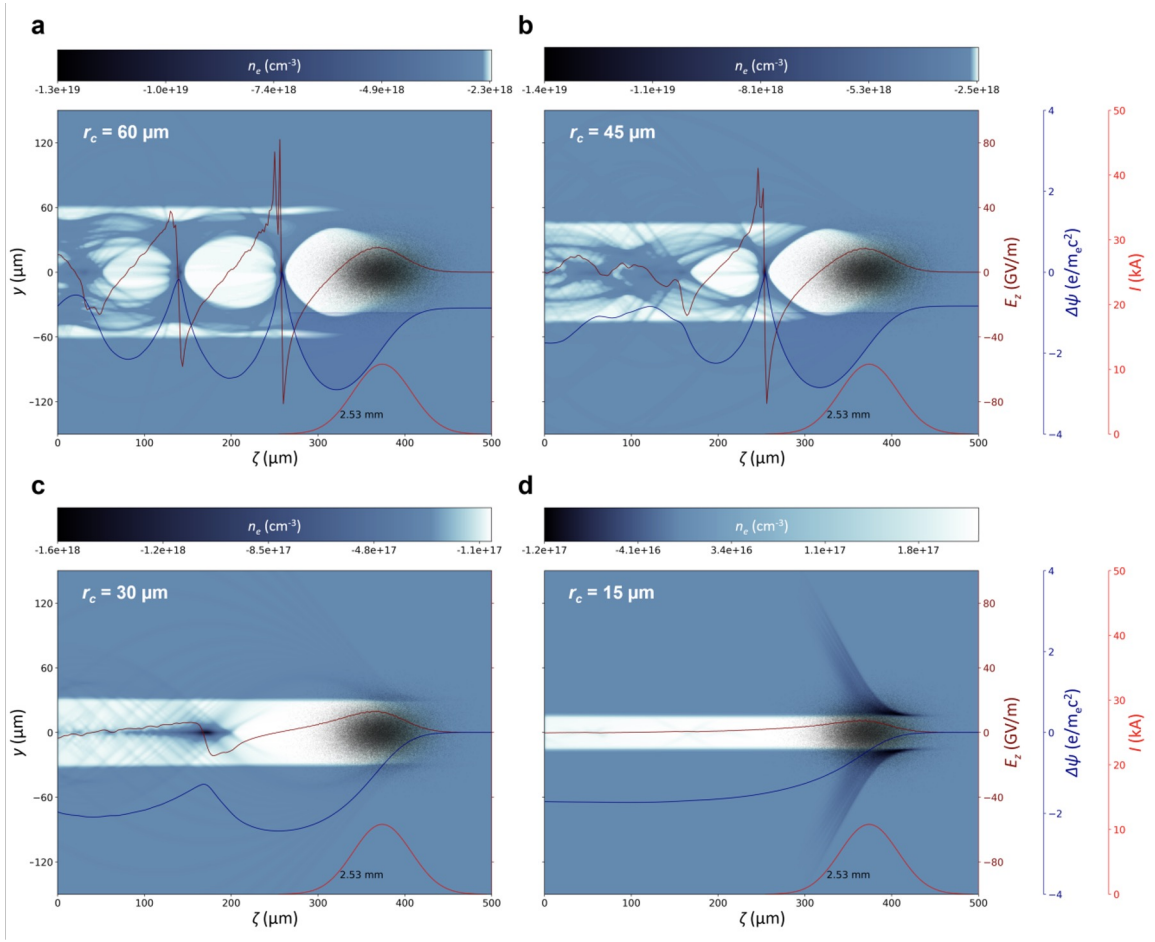
⇒ Uniform ion column

Ion Column formation

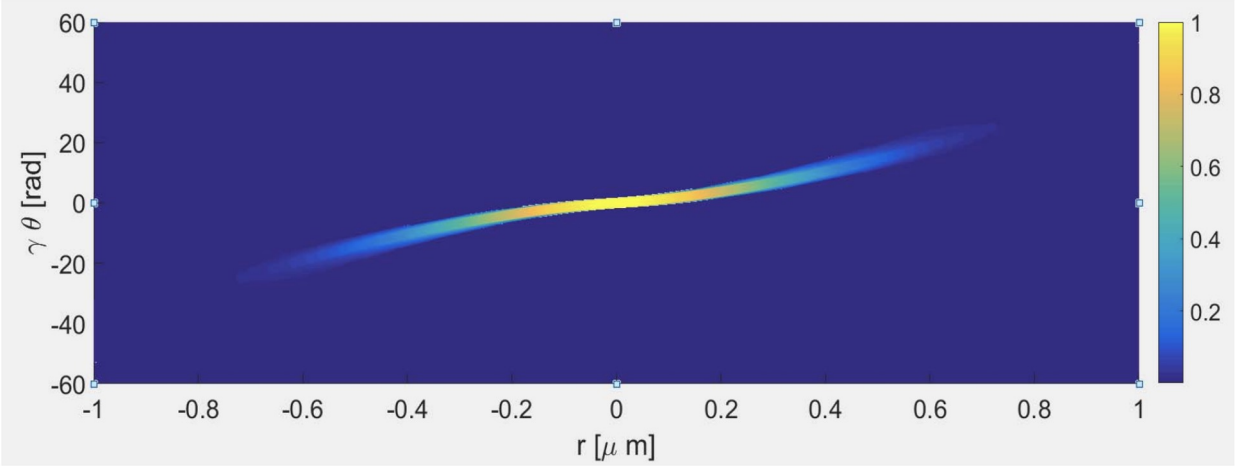
- ➔ Neutral plasma creation through ionization laser
- ➔ Blowout of the plasma electrons through the driver beam
  - ◆ **plasma electrons are expelled from the plasma region toward the neutral gas region**
    - **negligible restoring force** outside column
    - **negligible accelerating force** inside the column
    - **linear restoring force** inside the column



A.F. Habib et al.,
https://doi.org/10.48550/arXiv.2111.01502

Betatron radiation as non intercepting diagnostic

- Betatron radiation carries information about beam-plasma interaction
  - Both angular and spectral information yield information about the plasma accelerated beam
    - Single shot and non-intercepting electron beam diagnostic tool for plasma-accelerated witness
    - Possible to distinguish between driver and witness



$$\epsilon_{r_\beta N} = \gamma_0 \sqrt{(\sigma_\gamma/\gamma_0)^2 \sigma_r^2 \sigma_\theta^2 + \epsilon_{r_\beta}^2}$$

Normalized rms emittance (correlated): 0.6 mm mrad

A. Curcio et al., PR AB **20**, 012801 (2017)

Deliverables and milestones

- D1. Demonstration of high gradient and high brightness PWFA beam
  - M1.1 Simulations
- D2. Generation of plasma waves with sufficient numbers of wiggle periods
  - M2.1 Simulations of beam dynamics and beam/plasma interaction to
    - optimize the betatron radiation emission => Single, driver-like, bunch: 500 pC …
  - M2.2 Project of instrumentation and photon diagnostics
  - M2.3 Project of plasma diagnostics
  - M2.4 Experimental studies
- D3. Betatron-based emittance diagnostics
  - M3.1 Simulations of beam dynamics and beam/plasma interaction to
    - act as non-destructive, single shot, electron beam diagnostic => driver + witness configuration
    - Procurement of beam instrumentation
- D4. Study of the radiation emitted by an injected electron bunch in a ion column
  - M4.1 Plasma source design and project
    - Ion Channel Laser-driven
    - Ion Channel Particle-driven
  - M4.2 Implementation of plasma source, including diagnostics
  - M4.3 Experimental studies

Money for Tor Vergata

Anno	Hardware (k€)	Missioni (k€)
I	0	3
II	0	3
III	50	3
IV	0	3

Total cost 200 k€
Total cost for RM2 62 k€

Finally it’s over

Thank you for your attention