Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
EuPRAXIA Advanced Photon Sources

The EuPRAXIA Advanced Photon Source (EuAPS)

Andrea R. Rossi
INFN - Section of Milan

On behalf of EuAPS collaboration

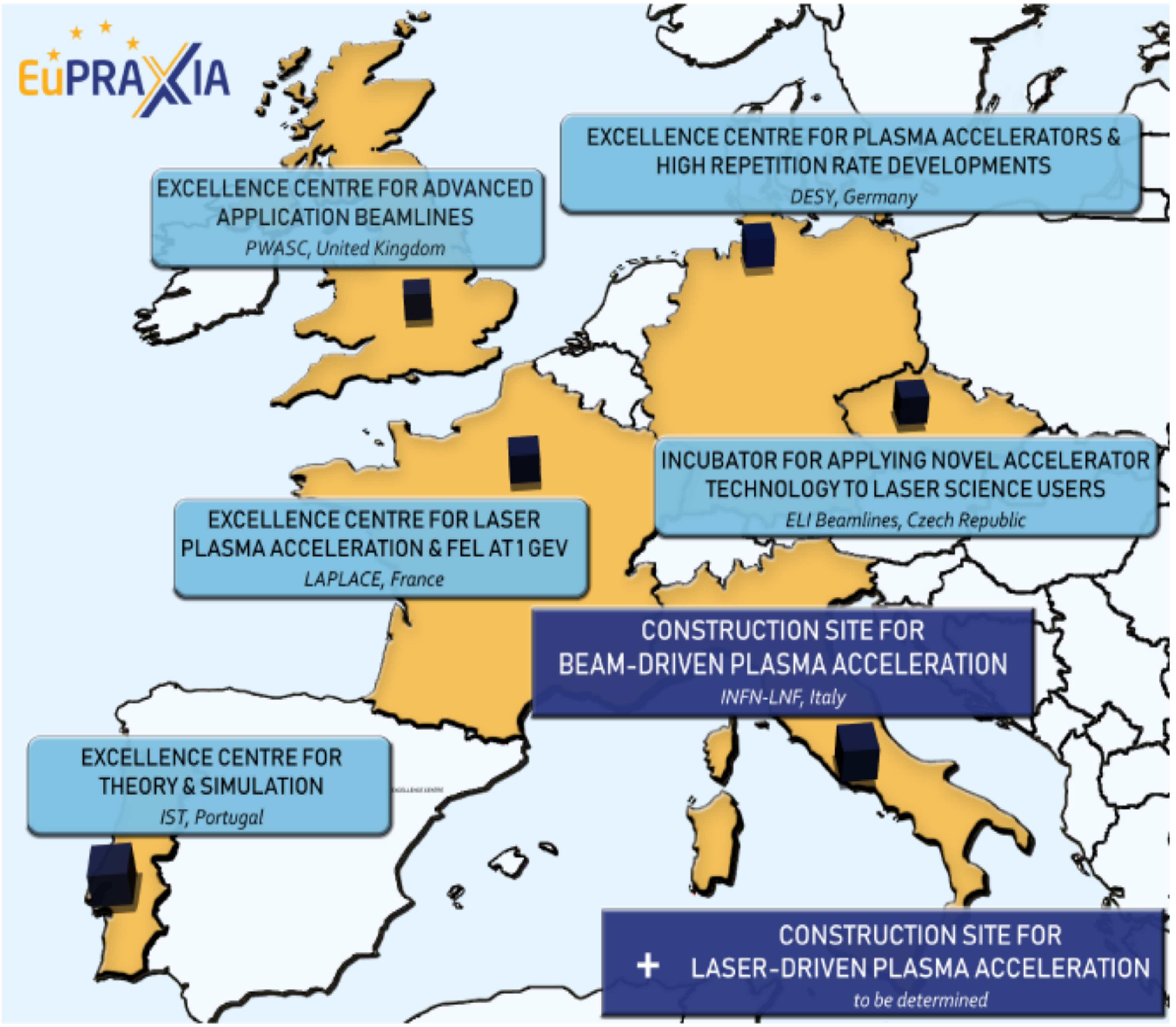
INFN

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

The EUropean Plasma Accelerator with eXcellence In Applications (EuPRAXIA)

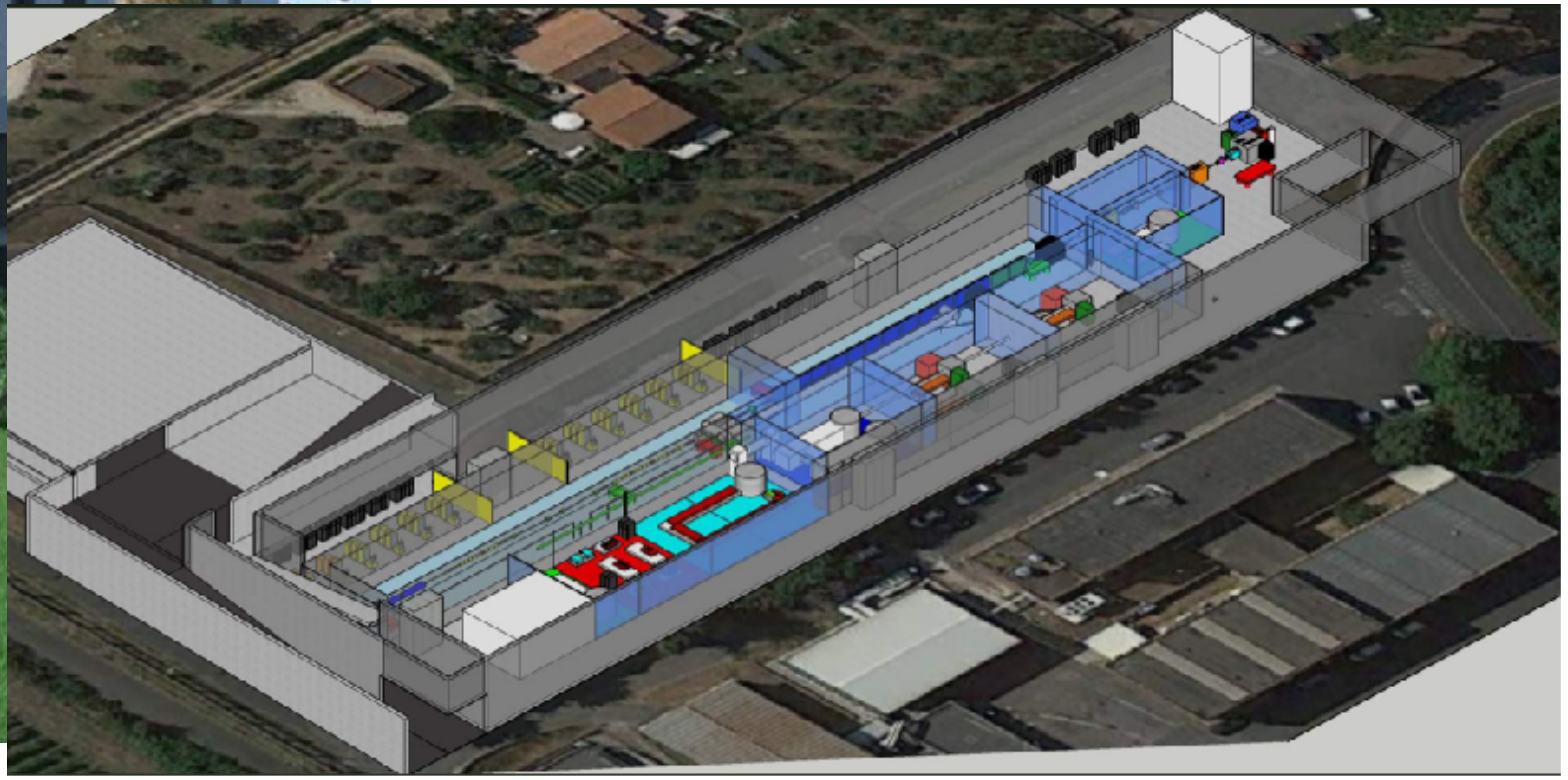
EuPRAXIA is an ESFRI distributed facility

1. Lean overall **EuPRAXIA management**
2. **Ten clusters:** Collaborations of institutes on specific problems, developing solutions, technical designs, driving developments with EuPRAXIA generated funding → **expertise of Helmholtz centers required - opportunities**
3. **Five excellence centers** at existing facilities: Using pre-investment, support tests, prototyping, production with EuPRAXIA generated funding → **DESY excellence center**
4. **One or two construction sites** at existing facilities with EuPRAXIA generated funding:
   - **Beam-driven** at Frascati (Italy).
   - **Laser-driven** at CLF/STFC (UK), CNR/ INFN (Italy) or ELI-Beamlines.



Headquarter and Site 1: EuPRAXIA@SPARC_LAB

- Frascati`s future facility
- > 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)



From the EuPRAXIA CDR

The EuAPS proposal benefits from the preparatory work done in the conceptual design phase of EuPRAXIA, both for the scientific case and the technology. It focuses on an ambitious but technically achievable goal and builds on the pre-existing investments at the SPARC_LAB facilities. As stated in the EuPRAXIA CDR the following EuPRAXIA Flagship Goals will be addressed by the EuAPS Project:

Flagship Innovation Goal 2: EuPRAXIA will develop together with laser industry a **new generation of high peak power lasers**, advancing the presently leading technology into the regime of 20 - 100 Hz repetition rate […].

Flagship Science Goal 2*:* EuPRAXIA will deliver **betatron X rays with up to 10^{10} photons per pulse**, up to 100 Hz repetition rate and an energy of 5-18 keV to users from the medical area. […].

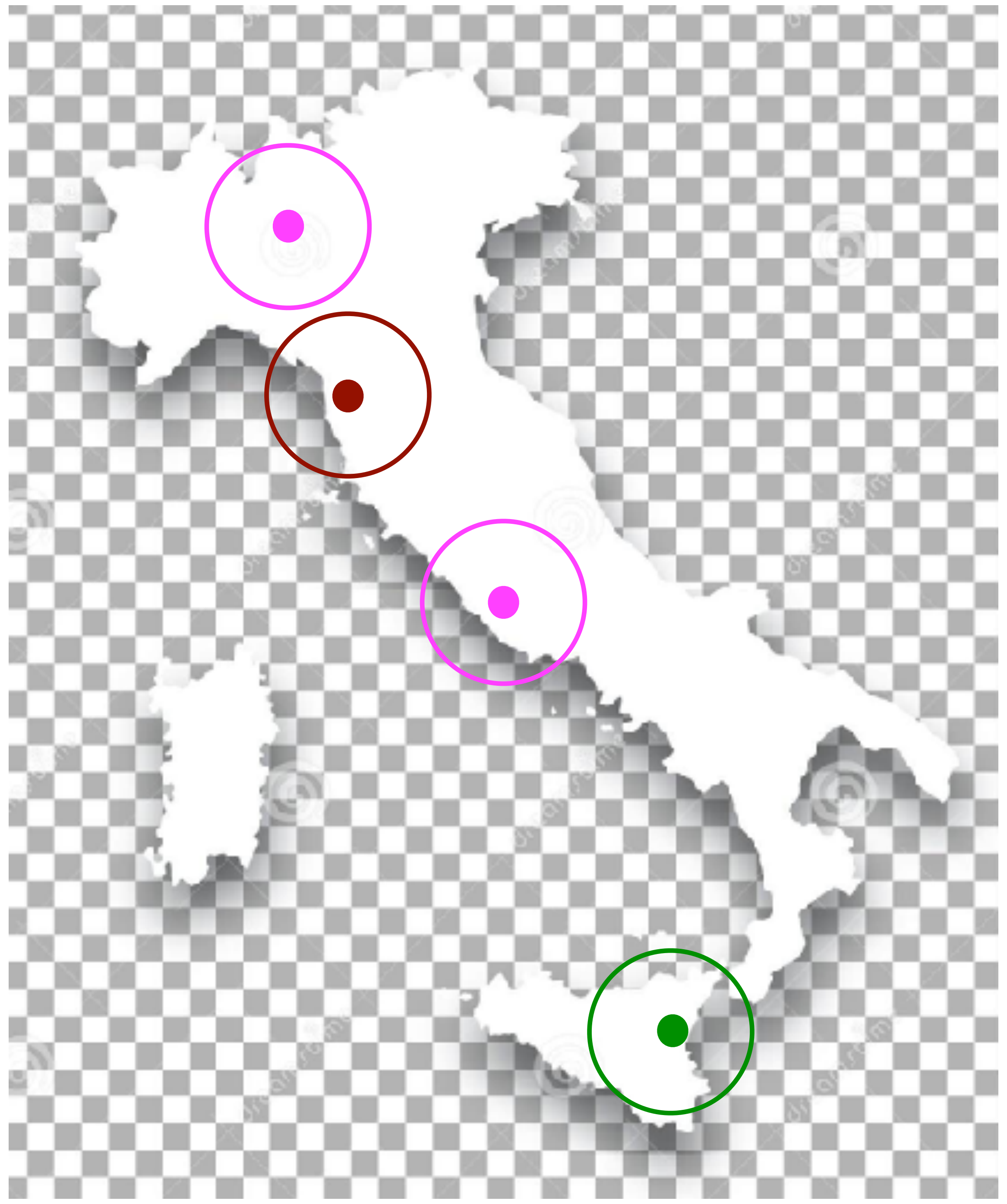
Flagship Science Goal 7*:* EuPRAXIA will provide access to cutting edge laser technology with **short pulse length in combination with high energy photon pulses** […].

We expect that the focus on a mature part of the EuPRAXIA project strongly supports project completion on the timescales that are required by PNRR.

The EuAPS Advanced Photon Sources

EuAPS is a distributed facility funded by the Italian government

Three pillars… … of curse…



Betatron X-Ray source: WP 2

Università di Roma Tor Vergata

INFN LNF Istituto Nazionale di Fisica Nucleare

Consiglio Nazionale delle Ricerche

INFN MILANO Istituto Nazionale di Fisica Nucleare Sezione di Milano

High power laser: WP 3

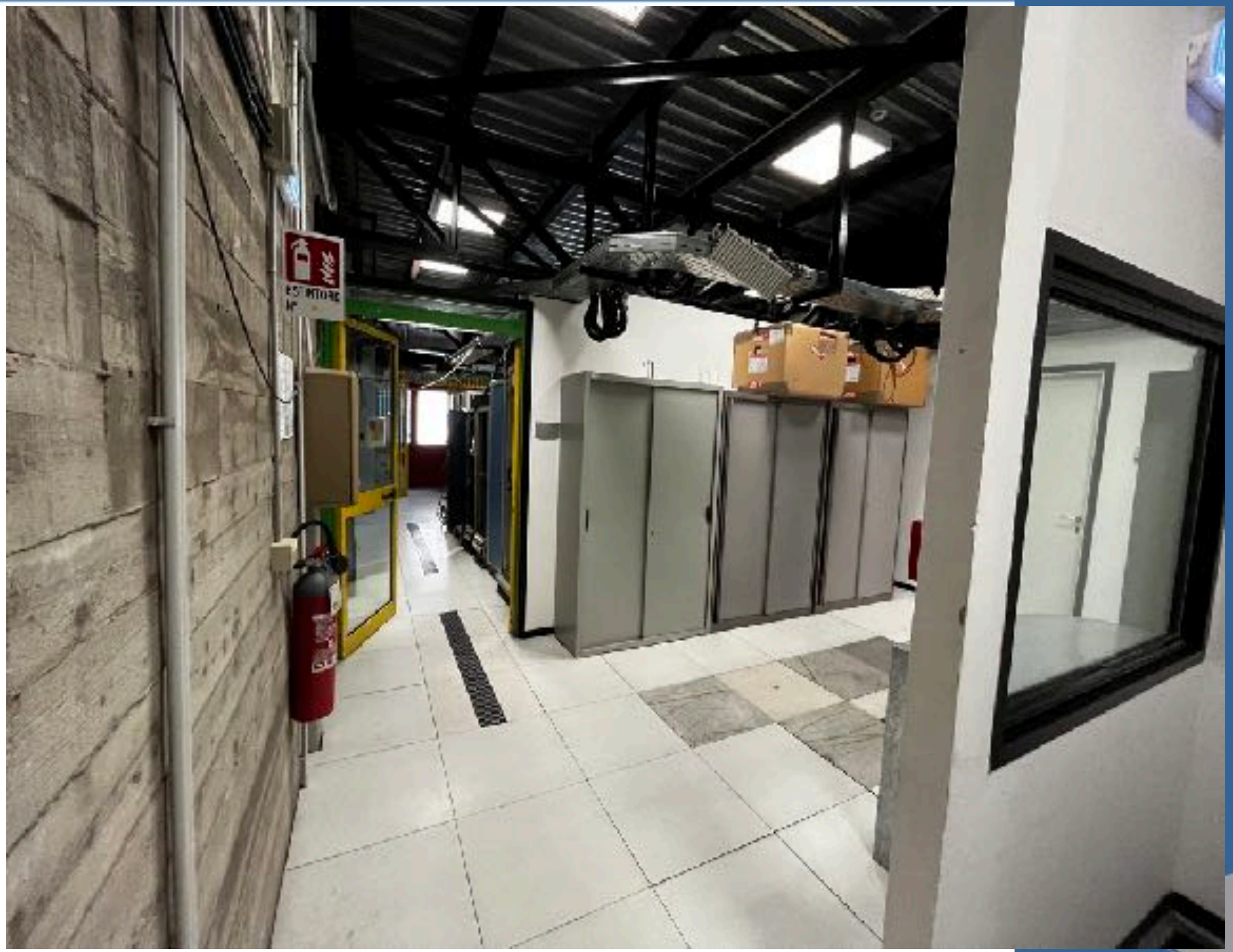
INFN LNS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Sud

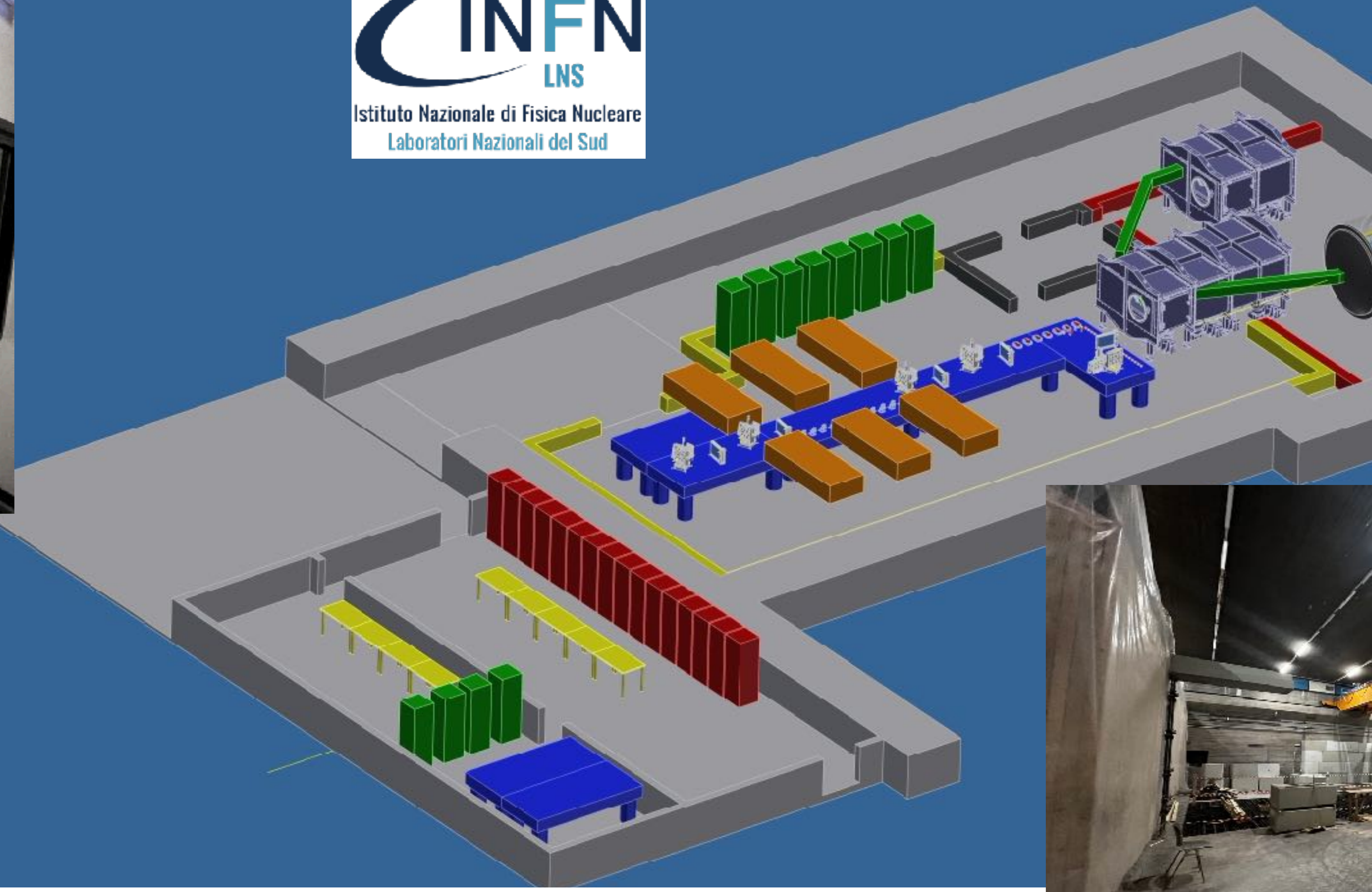
High rep rate laser: WP 4

CNR-INO ISTITUTO NAZIONALE DI OTTICA CONSIGLIO NAZIONALE DELLE RICERCHE

INFN - Laser indUced acCEleration

INFN LNS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Sud

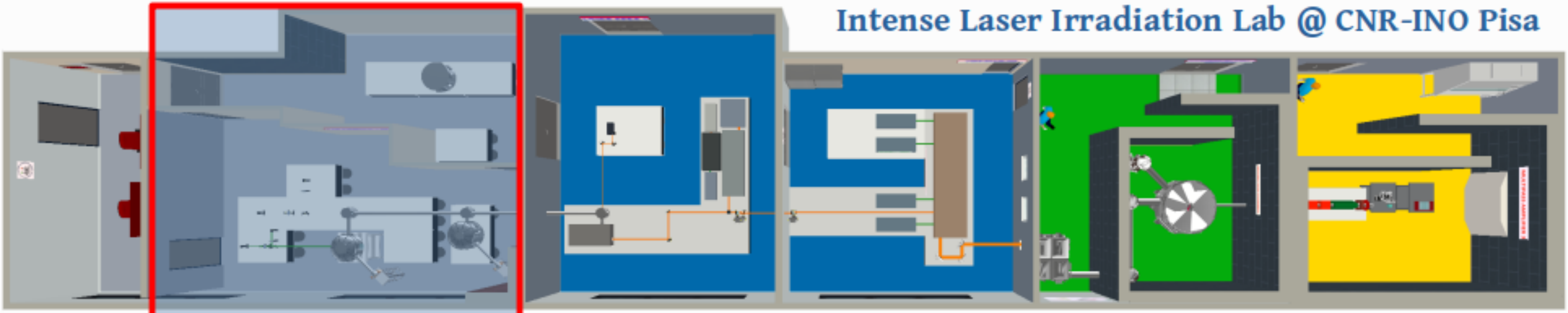




I-LUCE

1 PW @ $\lesssim$**10 Hz**

Intense Laser Irradiation Lab @ CNR-INO Pisa

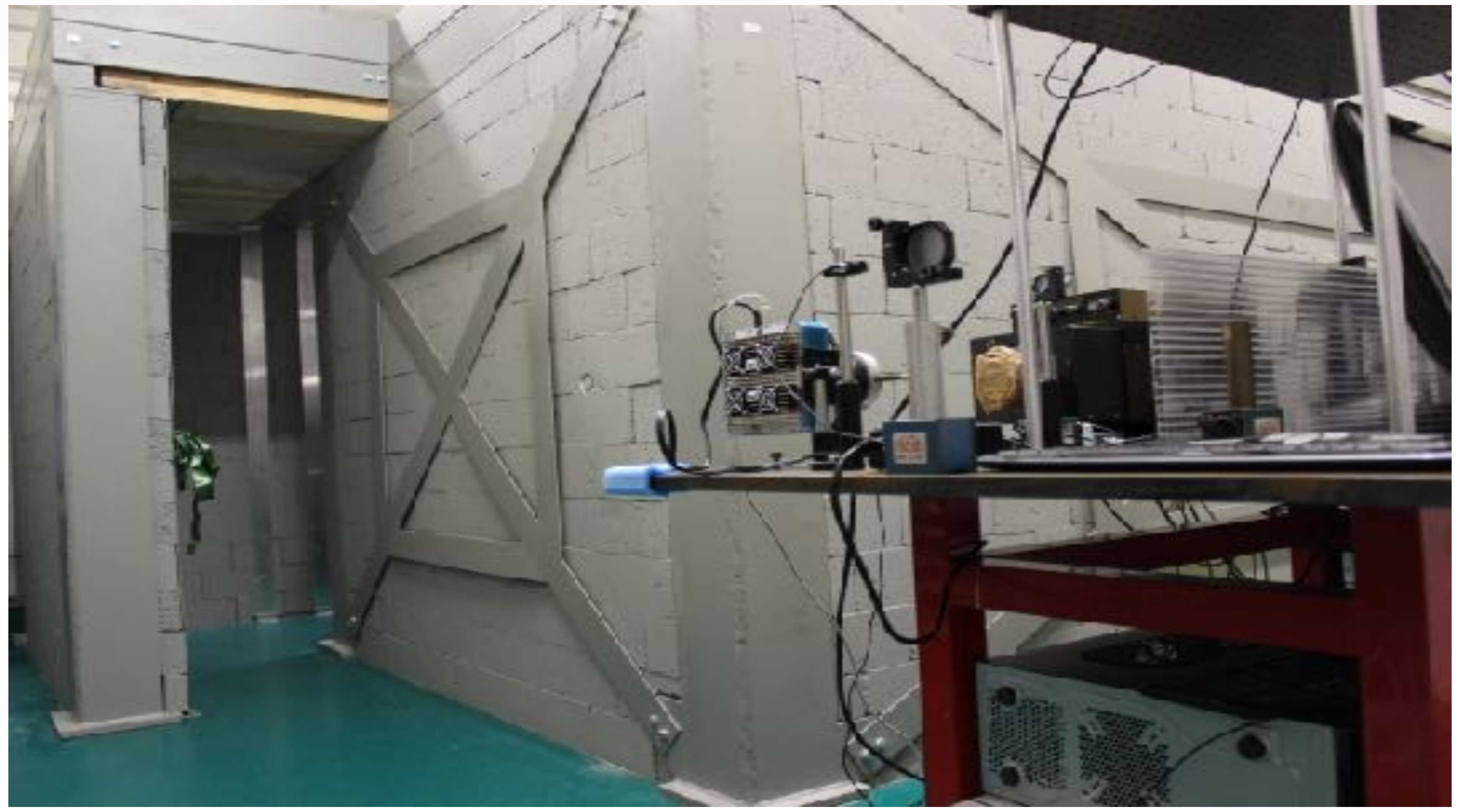


J-class, 100Hz
(currently used as 10TW Target Area)

200TW laser system

subPW Target Area(s)

CNR-INO ISTITUTO NAZIONALE DI OTTICA CONSIGLIO NAZIONALE DELLE RICERCHE



ILIL

~ 300 TW @ **100 Hz**

Betatron was always a hot topic

PHYSICAL REVIEW ACCELERATORS AND BEAMS 20, 012801 (2017)

Trace-space reconstruction of low-emittance electron beams through betatron radiation in laser-plasma accelerators

A. Curcio,[1,2,*] M. Anania,[1] F. Bisesto,[1,2] E. Chiadroni,[1] A. Cianchi,[3] M. Ferrario,[1] F. Filippi,[1,2] D. Giulietti,[4] A. Marocchino,[1] M. Petrarca,[5] V. Shpakov,[1] and A. Zigler[1,6]

APPLIED PHYSICS LETTERS 111, 133105 (2017)

CrossMark

Single-shot non-intercepting profile monitor of plasma-accelerated electron beams with nanometric resolution

A. Curcio,[1,2,a)] M. Anania,[1] F. Bisesto,[1,2] E. Chiadroni,[1] A. Cianchi,[3] M. Ferrario,[1] F. Filippi,[1,2] D. Giulietti,[4] A. Marocchino,[1] F. Mira,[5] M. Petrarca,[5] V. Shpakov,[1] and A. Zigler[1,6]

applied sciences

Article

Performance Study on a Soft X-ray Betatron Radiation Source Realized in the Self-Injection Regime of Laser-Plasma Wakefield Acceleration

Alessandro Curcio [1,*], Alessandro Cianchi [2,3,4], Gemma Costa [5], Francesco Demurtas [2], Michael Ehret [1], Massimo Ferrario [5], Mario Galletti [2,3,4], Danilo Giulietti [6], José Antonio Pérez-Hernández [1] and Giancarlo Gatti [1]

J. Plasma Phys. (2015), *vol.* 81, 495810513 © Cambridge University Press 2015 1
doi:10.1017/S0022377815000926

Resonant interaction between laser and electrons undergoing betatron oscillations in the bubble regime

Alessandro Curcio[1,2,†], Danilo Giulietti[3], Giuseppe Dattoli[4] and Massimo Ferrario[2]

Nuclear Instruments and Methods in Physics Research B 402 (2017) 388–392

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

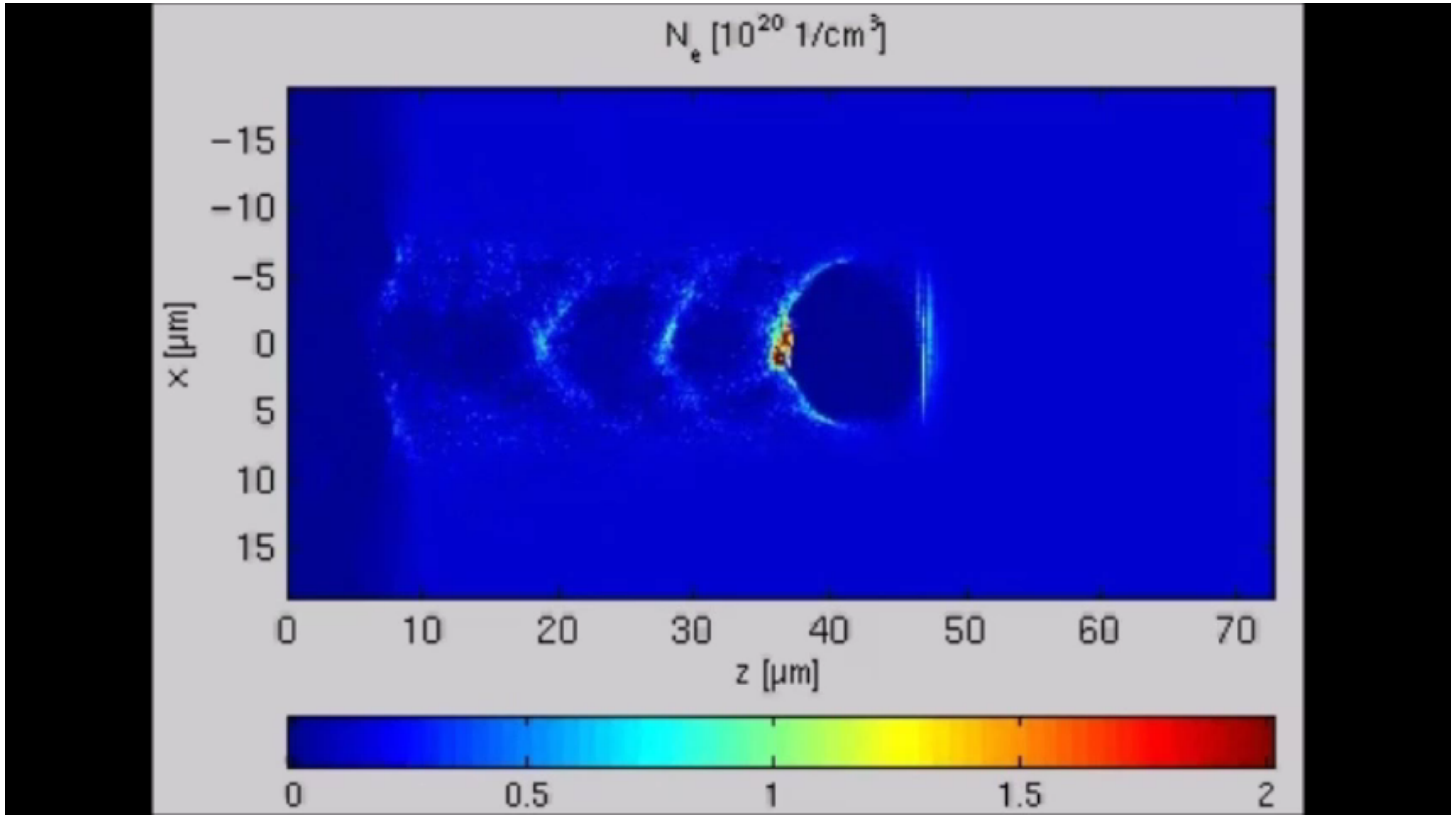
ELSEVIER

BEAM INTERACTIONS WITH MATERIALS AND ATOMS

First measurements of betatron radiation at FLAME laser facility

CrossMark

A. Curcio [a,b,*], M. Anania [a], F. Bisesto [a,b], E. Chiadroni [a], A. Cianchi [a], M. Ferrario [a], F. Filippi [a,b], D. Giulietti [c], A. Marocchino [a], F. Mira [b], M. Petrarca [d], V. Shpakov [a], A. Zigler [a,e]



- High power laser ionize the gas and create a plasma bubble
- Electron are self injected in the bubble
- These charges are accelerated by intense electric field (>GV/m)
- In the meanwhile electrons undergo transverse oscillations (betatron oscillations)

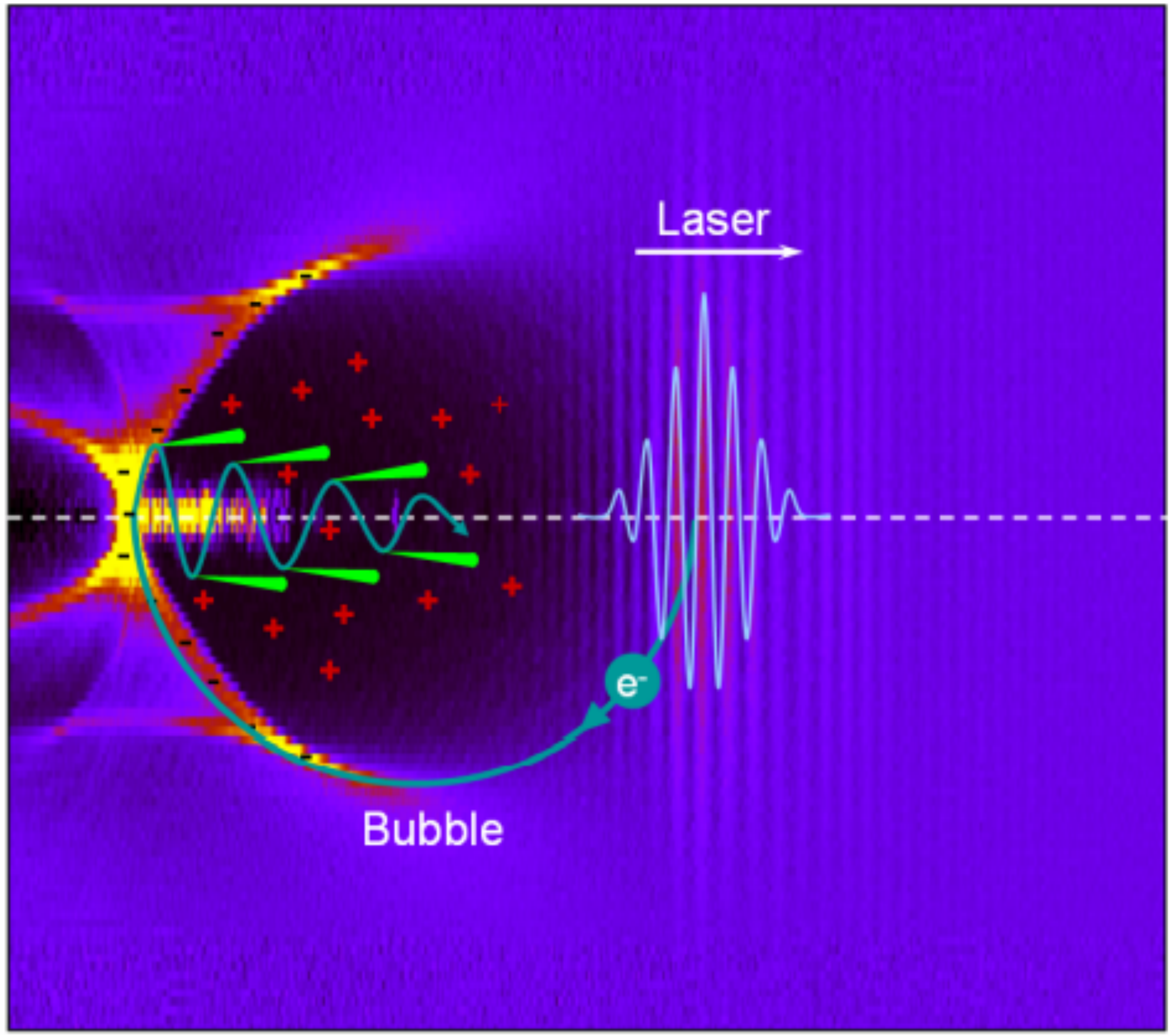
Betatron radiation

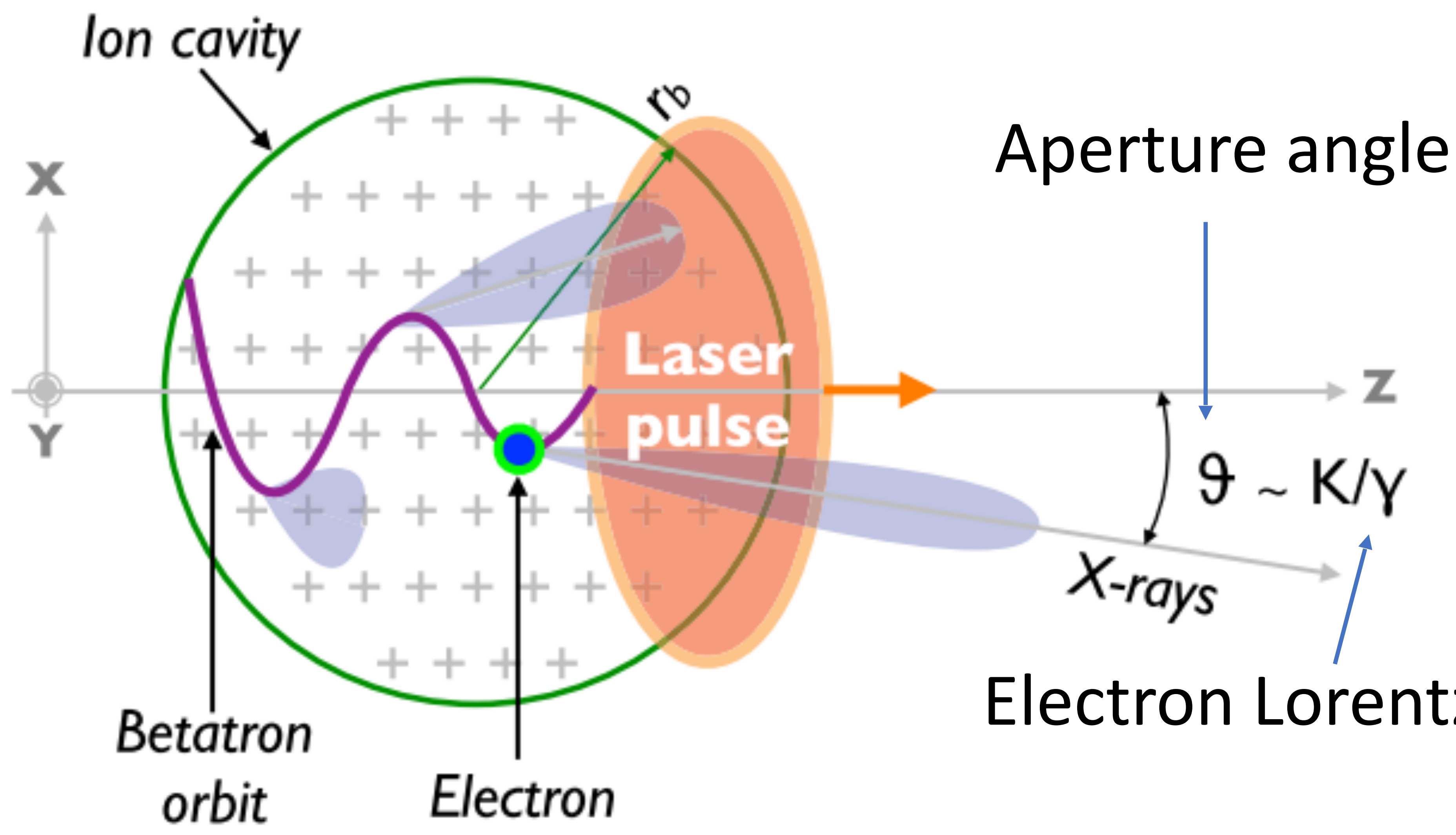
Betatron radiation is emitted by electrons accelerated in a plasma due to their **wiggling motion**

Plasma is a natural **continuous focusing channel**

There are betatron oscillations in any accelerator, but their contribution is usually negligible

In a plasma stage, there are about **tens of oscillations in a typical accelerating length**





Aperture angle

Electron Lorentz factor

Undulator parameter

Betatron wavenumber

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

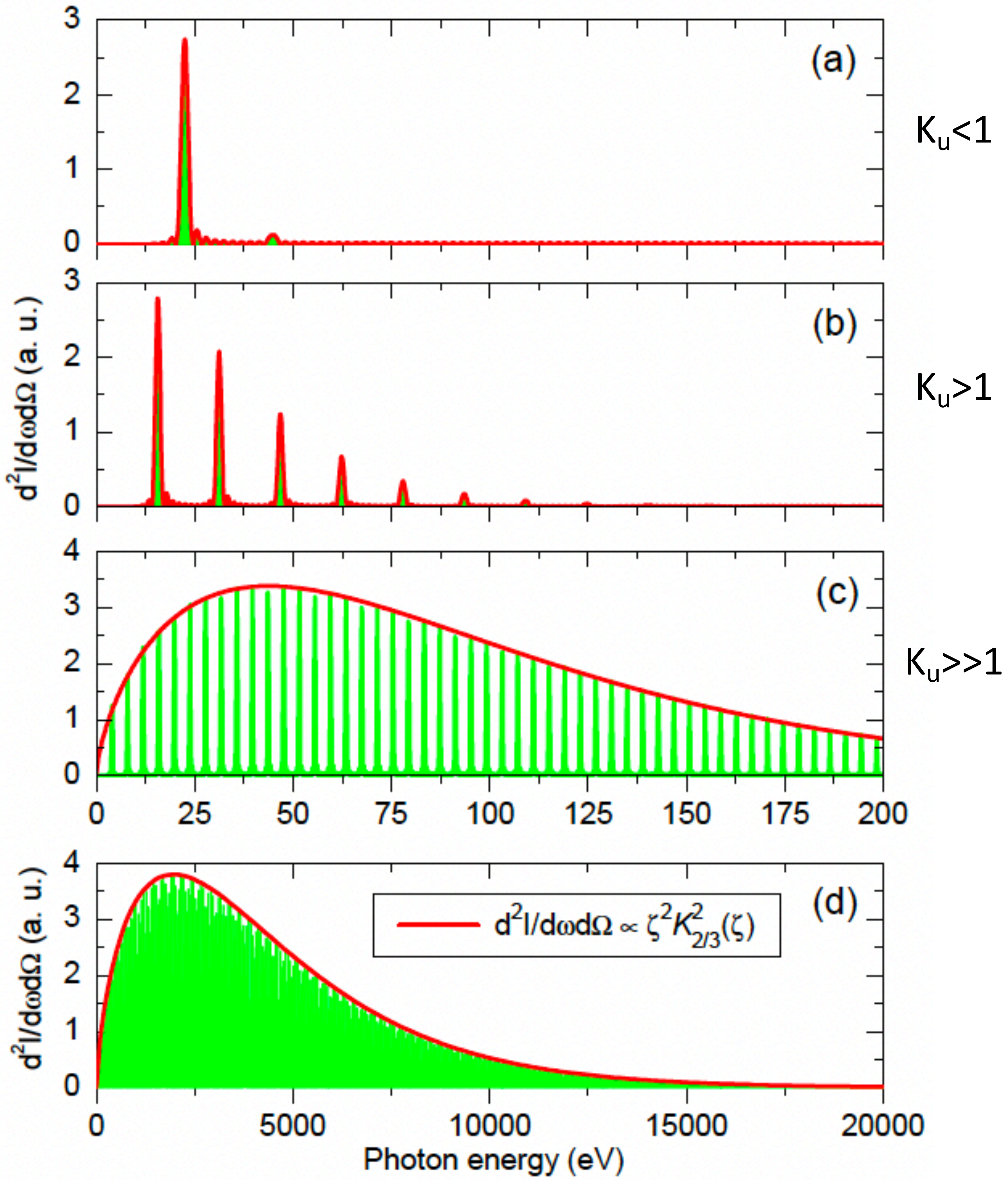
Oscillation amplitude

$$k_\beta = \frac{k_p}{\sqrt{2\gamma}}$$

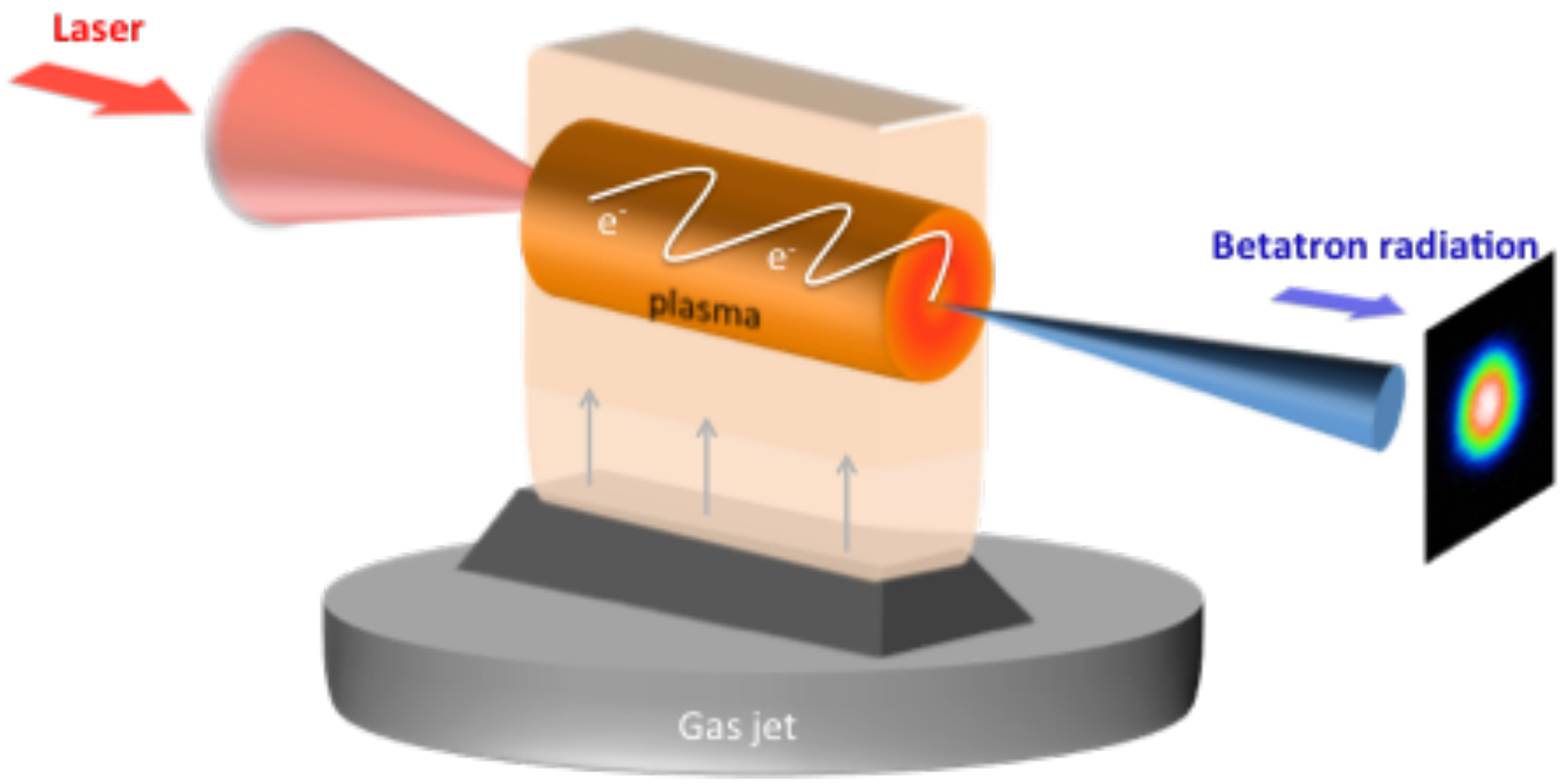
$$k_p \propto \sqrt{n_p}$$

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

Betatron frequency

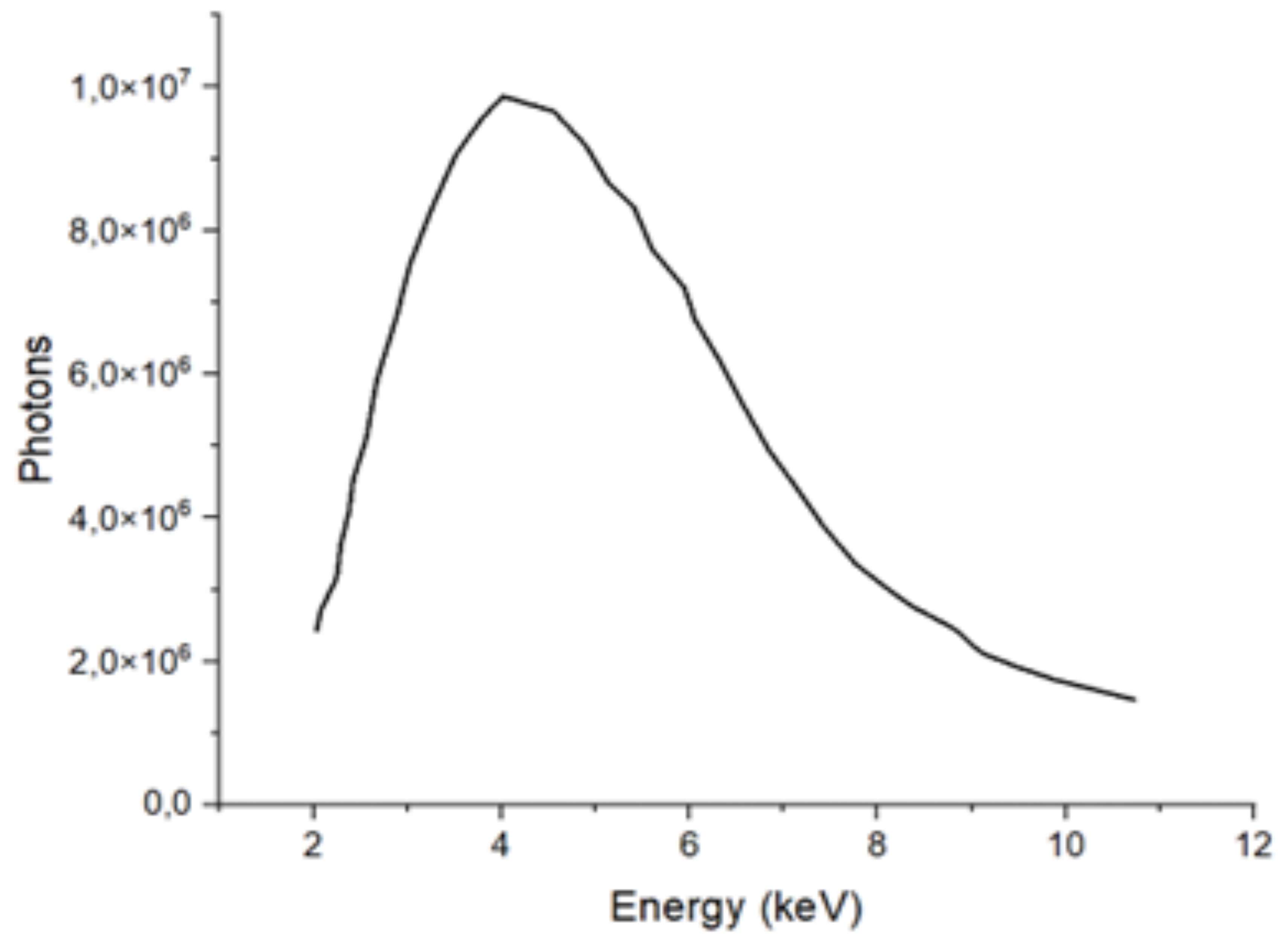


Betatron radiation emission



First measurements of betatron radiation at FLAME laser facility

A. Curcio [a,b,*], M. Anania [a], F. Bisesto [a,b], E. Chiadroni [a], A. Cianchi [a], M. Ferrario [a], F. Filippi [a,b], D. Giulietti [c], A. Marocchino [a], F. Mira [b], M. Petrarca [d], V. Shpakov [a], A. Zigler [a,e]



- The radiation has its own characteristics of both FELs and synchrotrons
  - Large bandwidth as Synchrotrons
  - Short pulse duration like a FEL

Expected Parameters @ EuAPS

Parameter	Value	unit
Electron beam Energy	100 - 500	MeV
Plasma Density	10^{17} - 10^{19}	cm^{-3}
Photon Critical Energy	1 - 10	keV
Number of Photons/pulse	10^{6} - 10^{9}	
Repetition rate	1 - 10	Hz
Beam divergence	3 - 20	mrad

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Simulations: common setup

Laser parameters

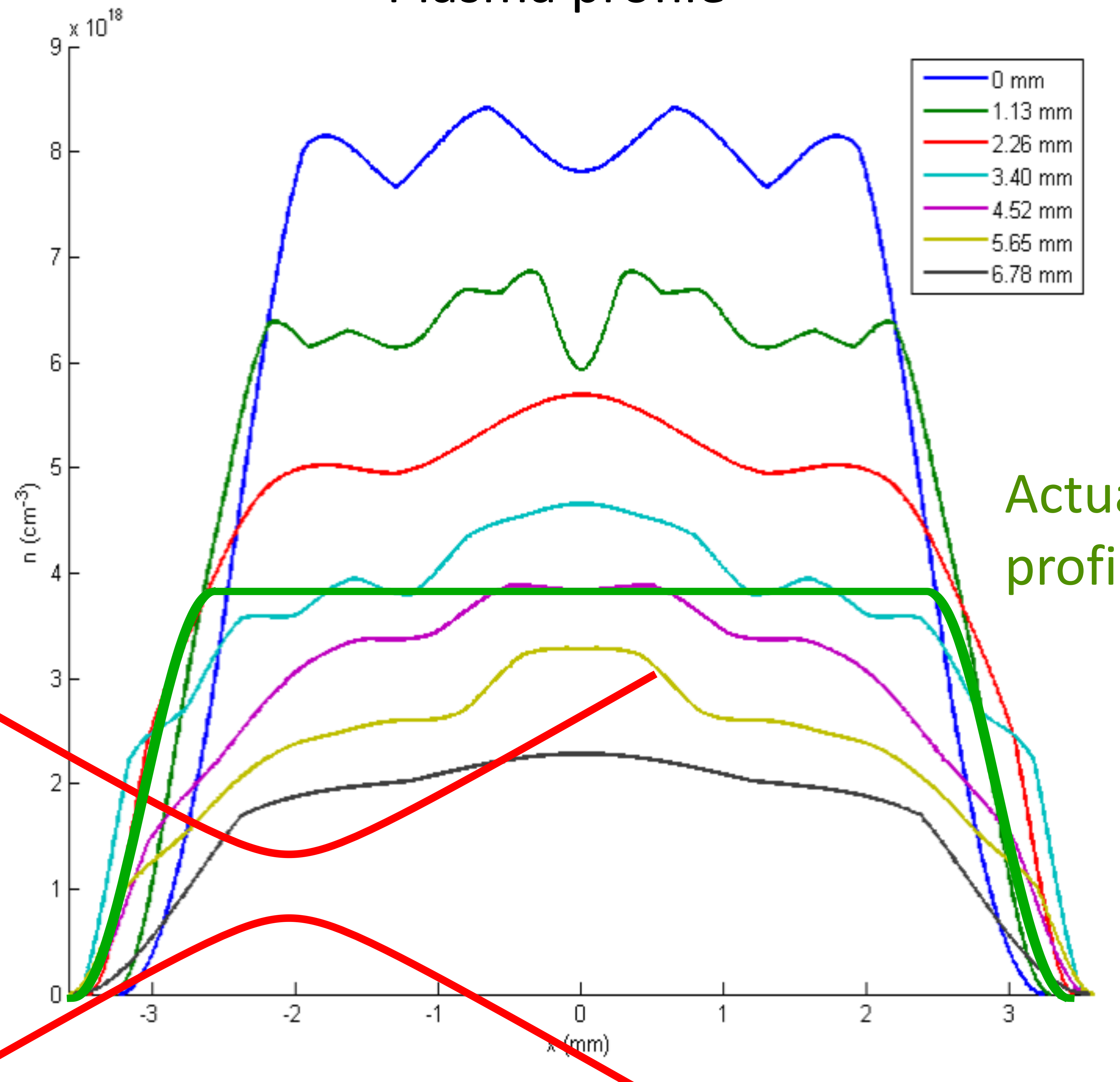
Minimun Energy	*0.25 J*
Maximum Energy	*3 J*
Temporal length	*25 fs*
Wave length	*800 nm*
Beam Waist ✻	*15 μm*
Min Plasma Density	10^{17} cm^{-3}
Max Plasma Density	10^{19} cm^{-3}

✻ FWHM Intensity

NB: $z_R = \frac{\pi \omega_0^2}{\lambda} = 0.9\ mm$

Simulation performed with FBPIC

Plasma profile



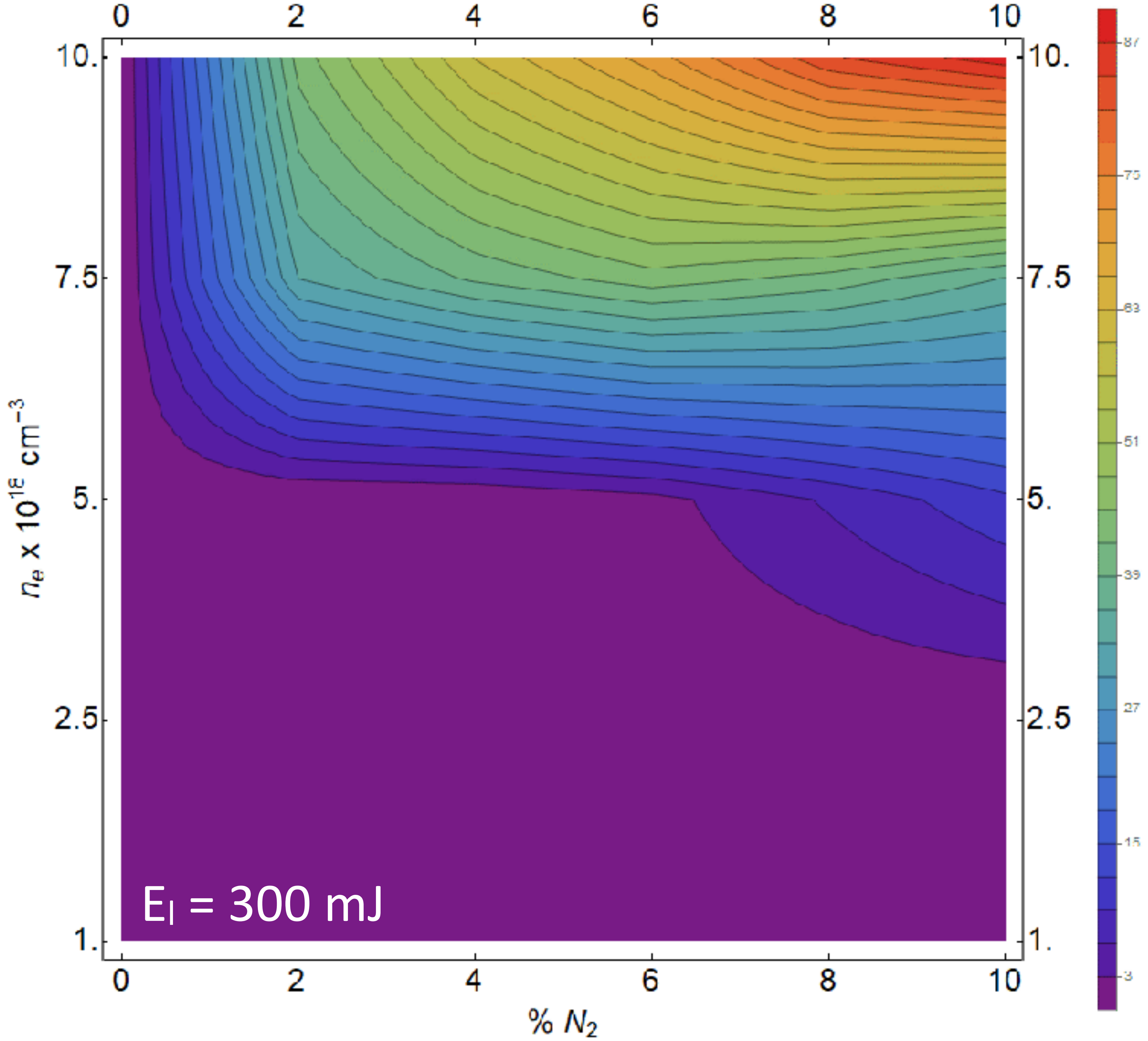
Density lineout of nozzle BM5_1 for N_2 at 70 bar at different distances from nozzle edge.

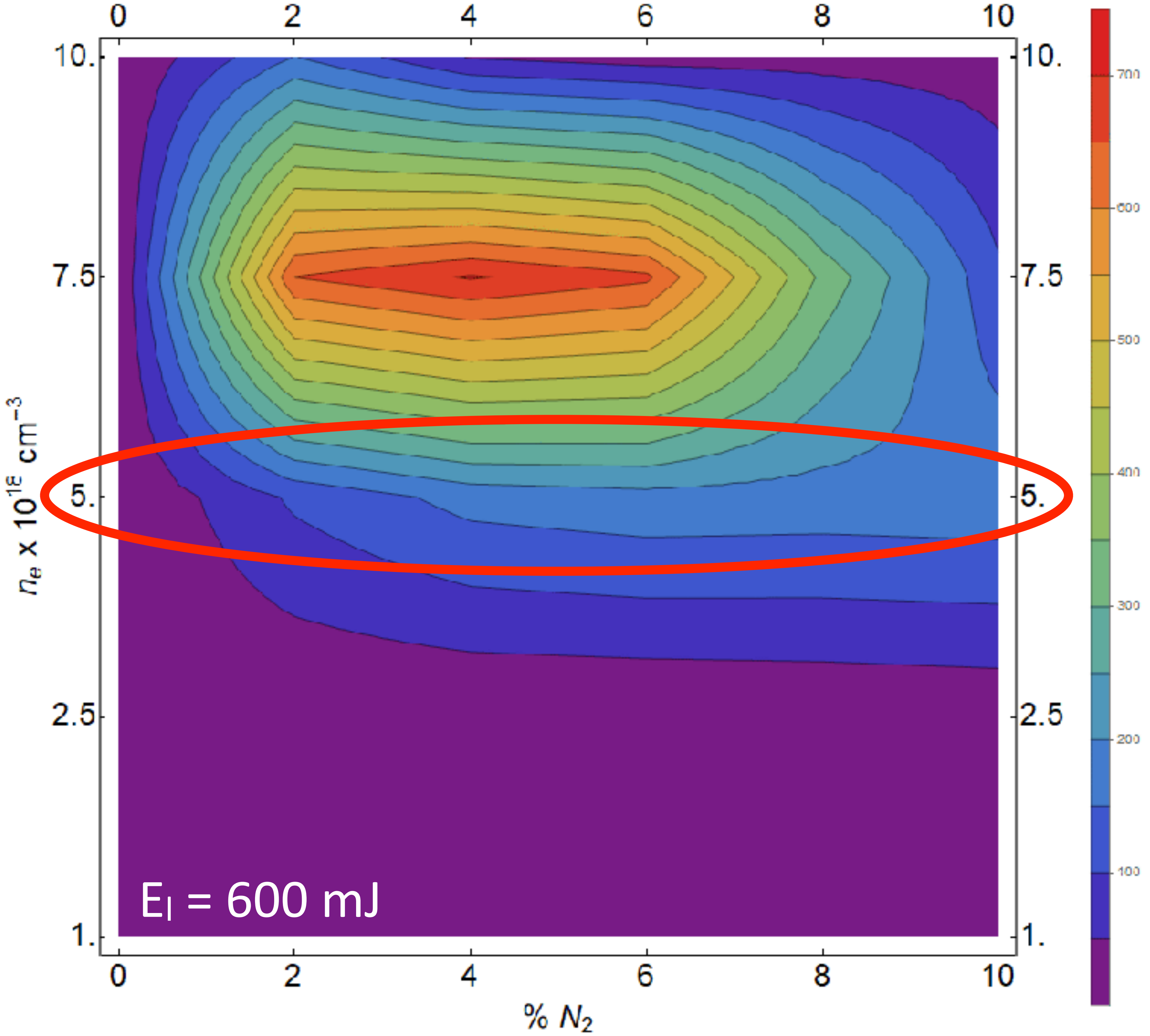
Actual plasma profile

Laser envelope

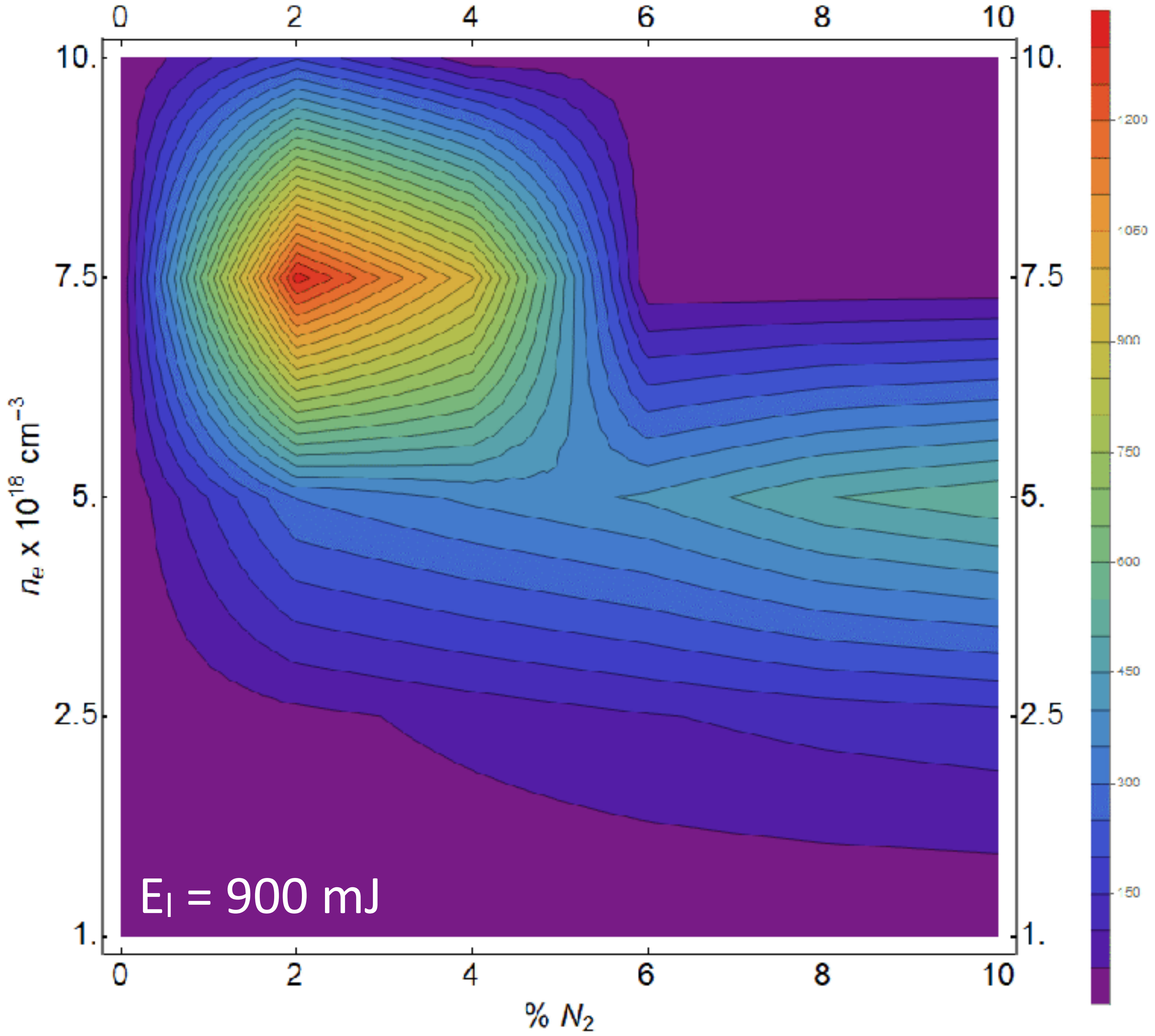
He^{+} plus some percent N^{5+} dopant, ionization on

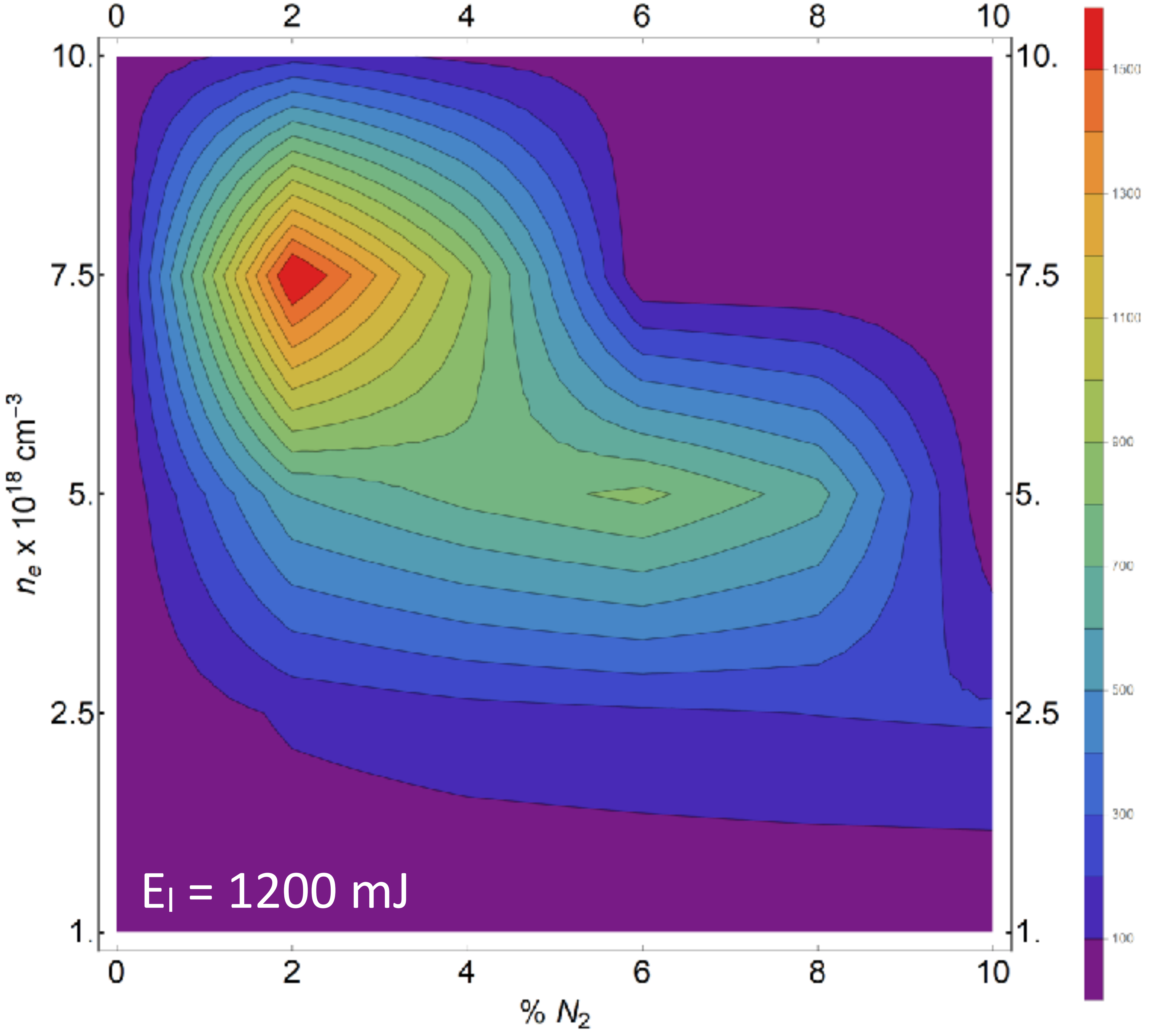
Parameters scan: accelerated charge vs plasma and dopant density 1





Parameters scan: accelerated charge vs plasma and dopant density 2

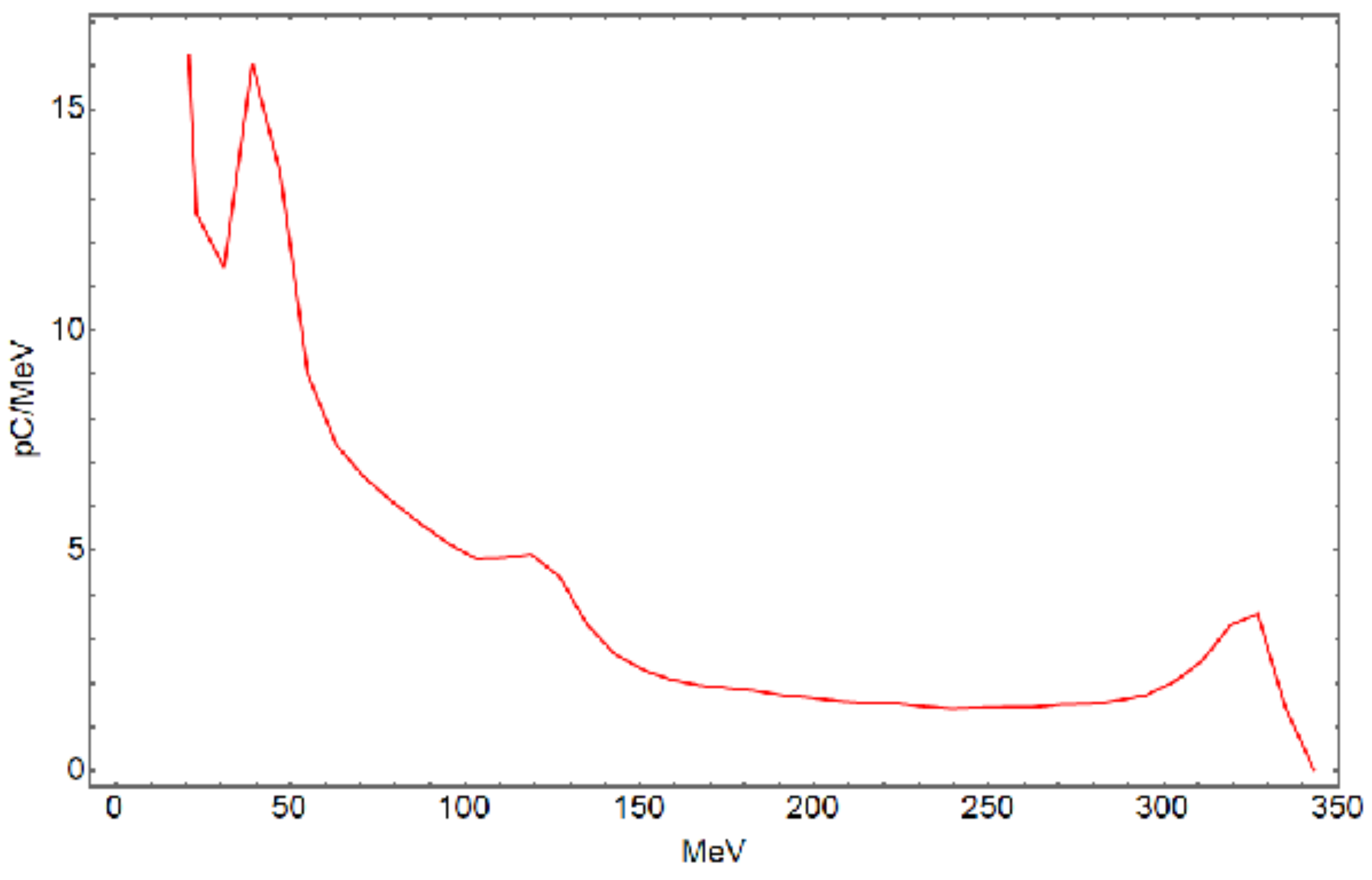




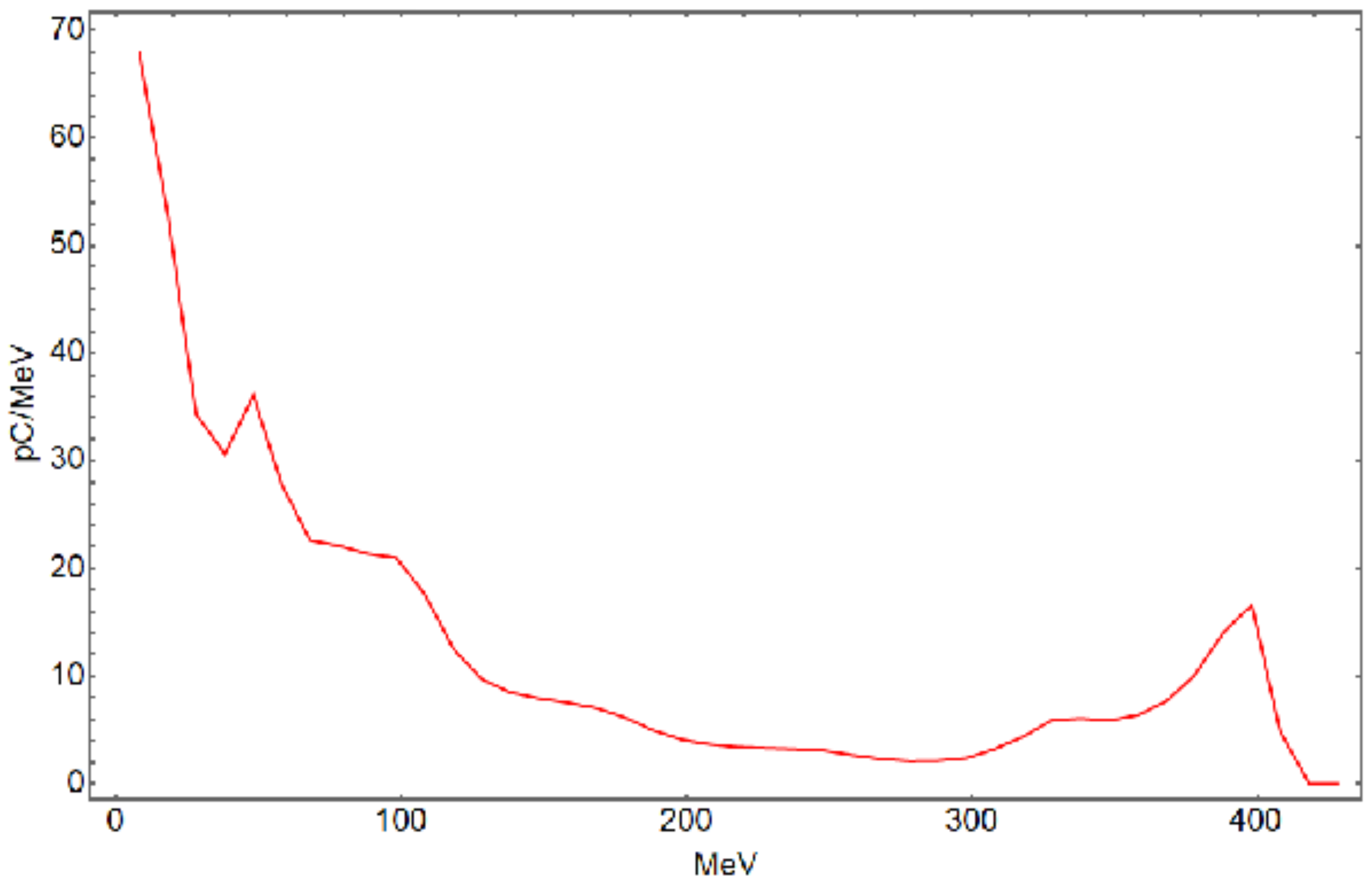
Electron spectra: best simulated shots

$n_0 = 5.0 \times 10^{18}\ cm^{-3}$

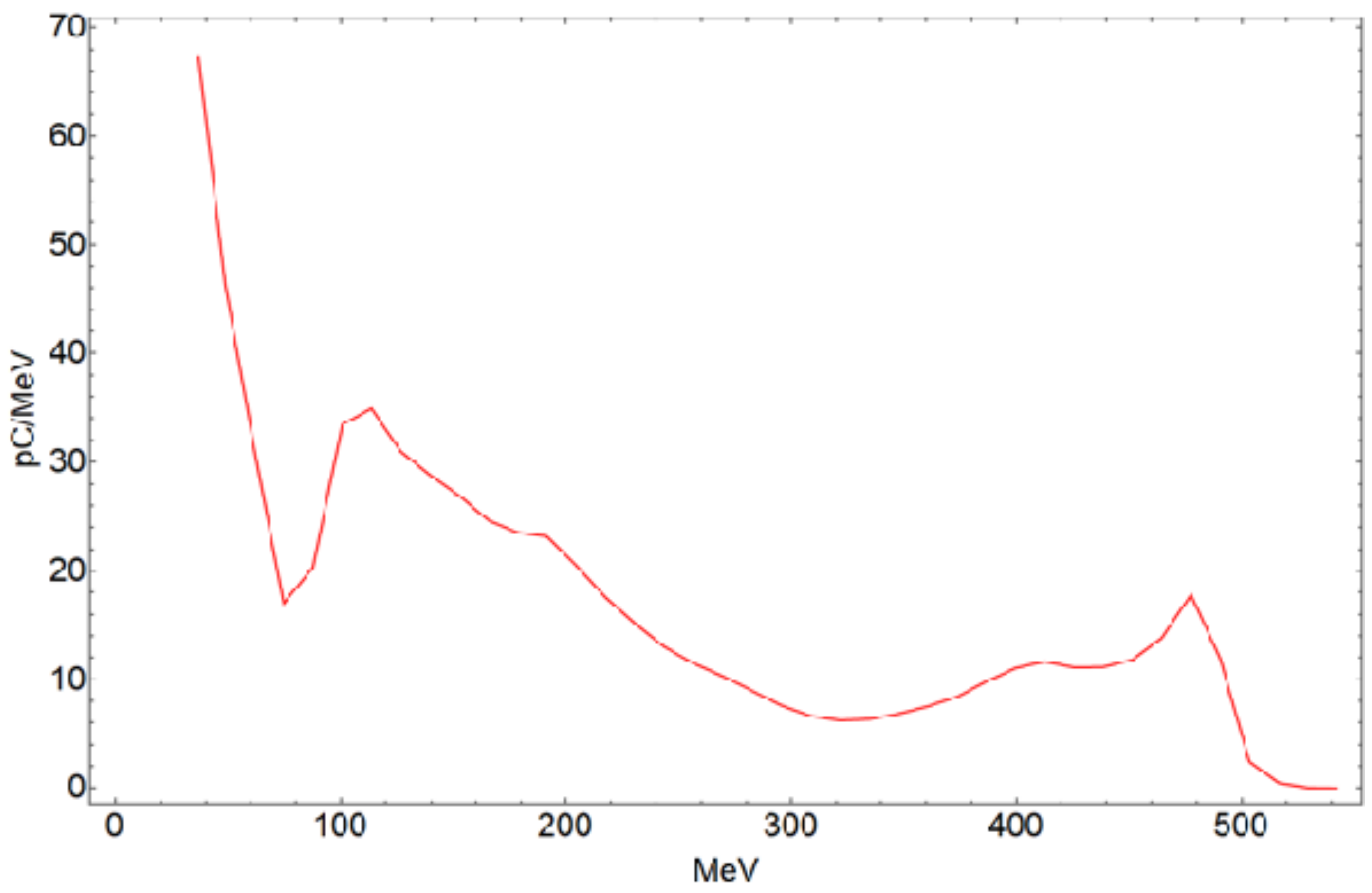
E_l = 600 mJ, 2% N_2



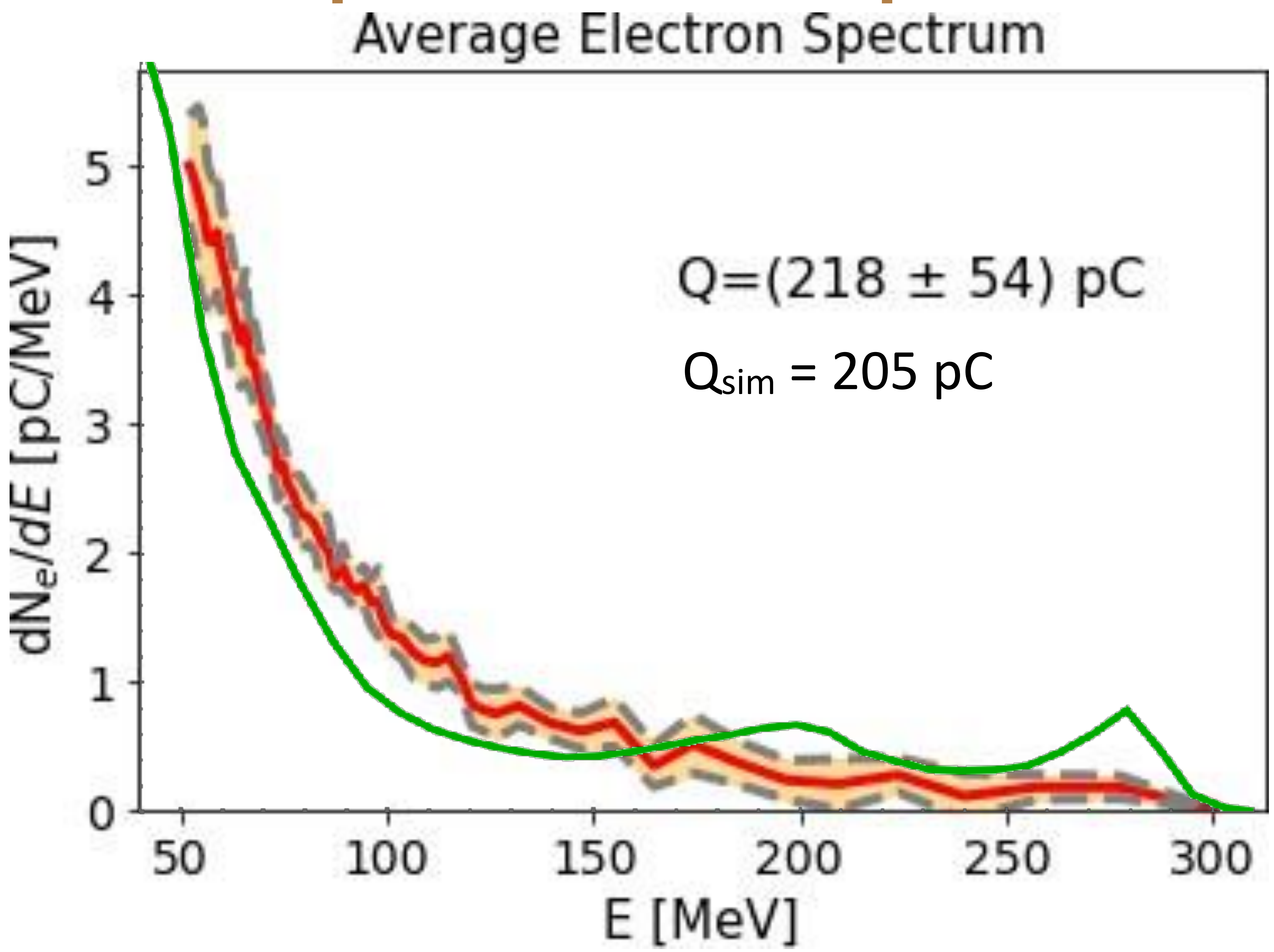
E_l = 900 mJ, 2% N_2



E_l = 1200 mJ, 2% N_2



Electron spectra: comparison with experimental data



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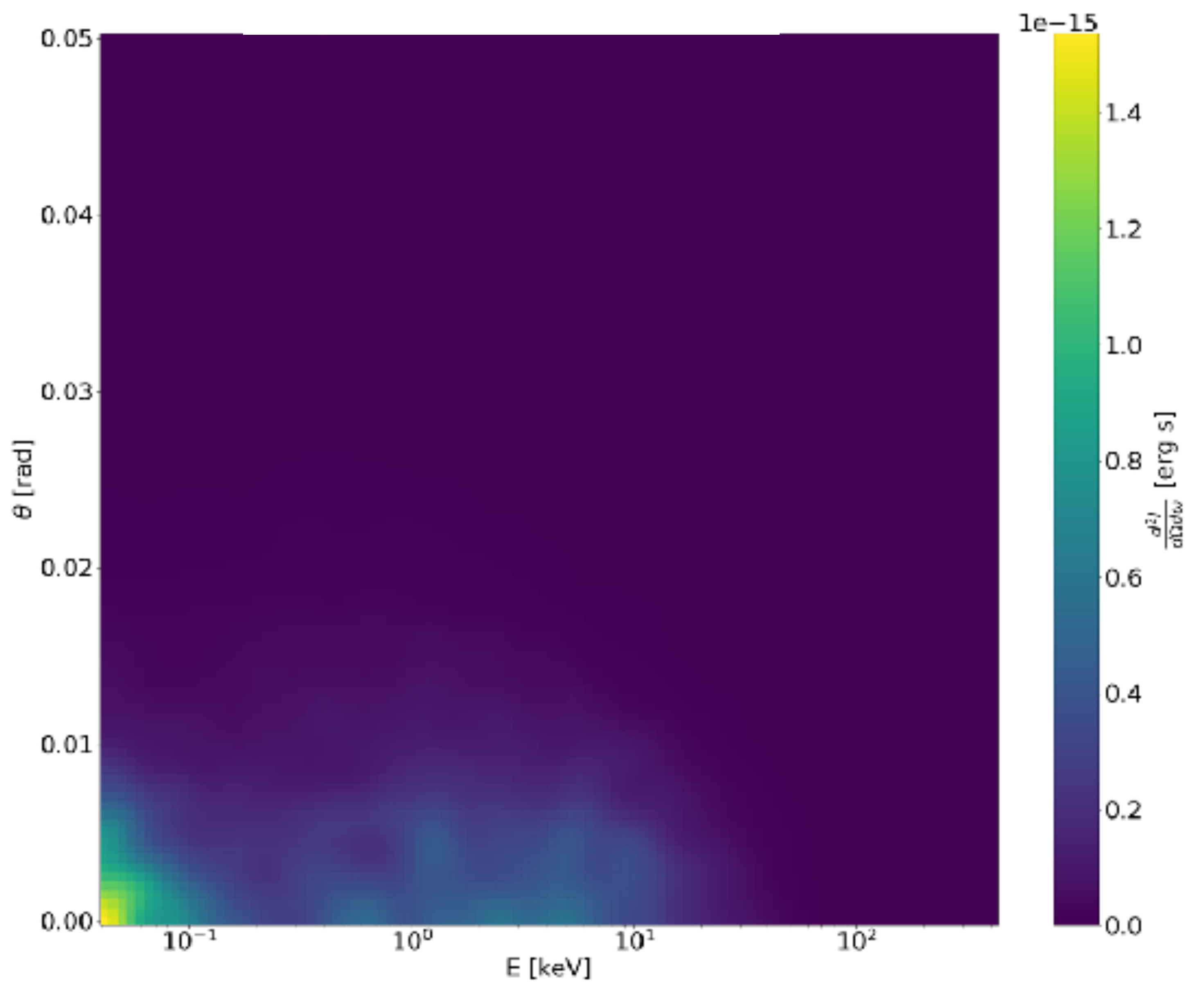
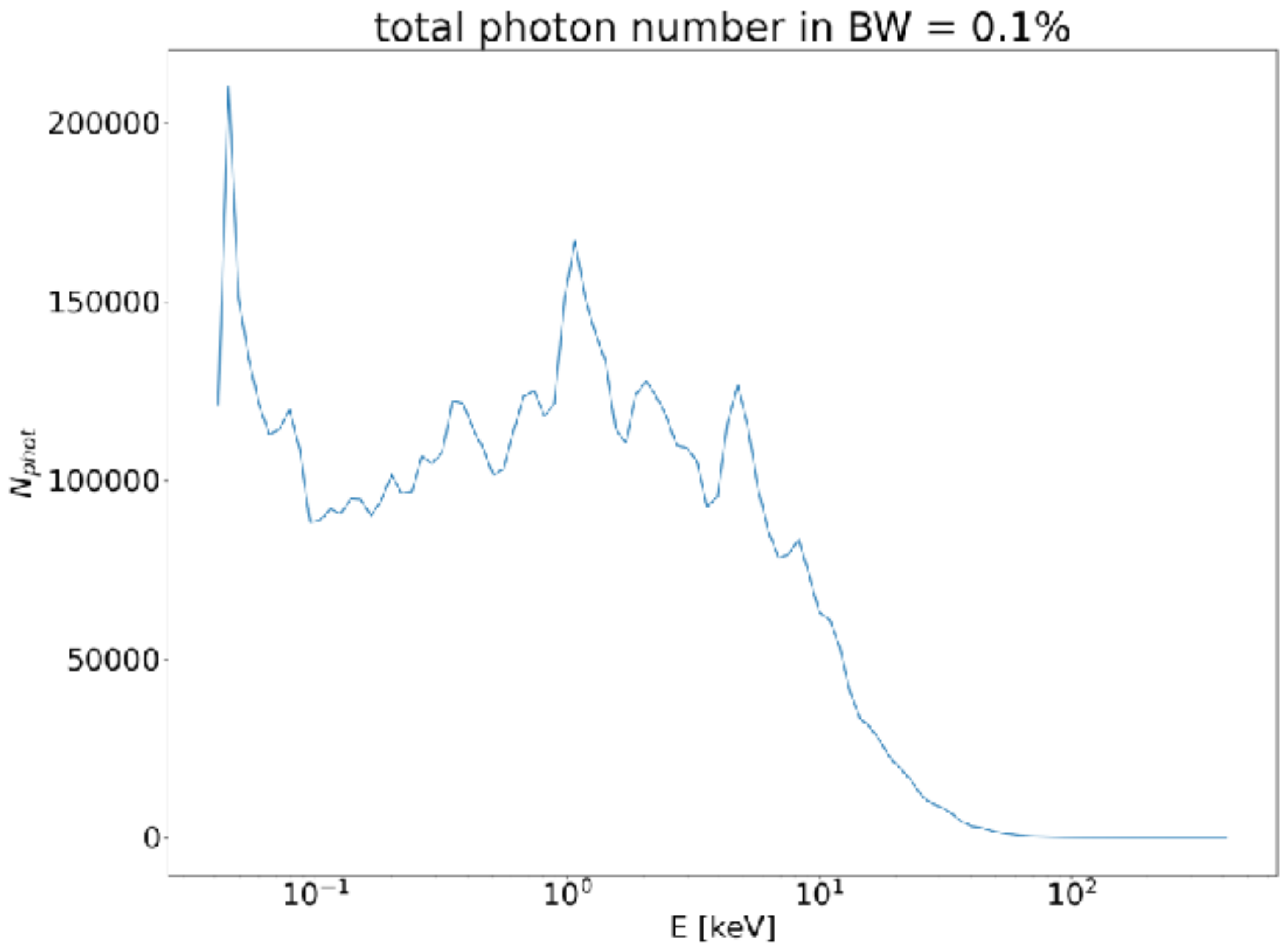
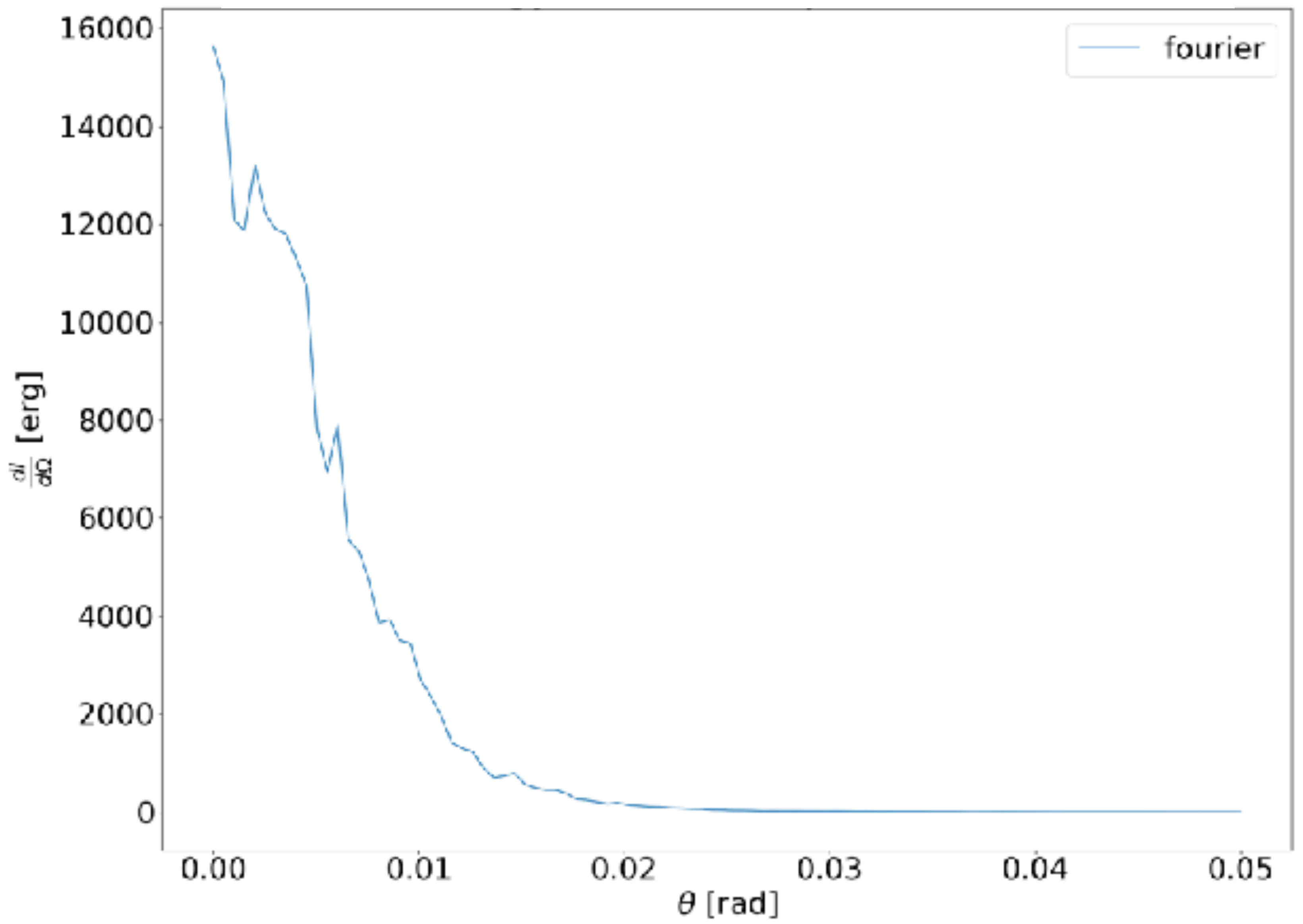
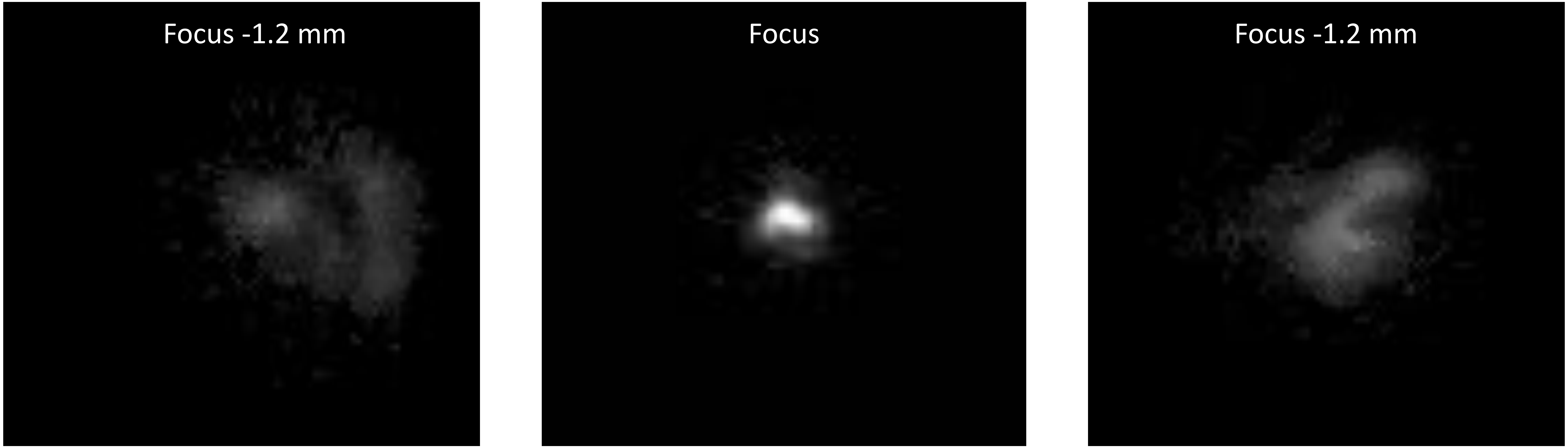
Radiation spectra







What's next: reconstructed laser spot[1] (1/2)



Laser phases reconstruction done by LASY[2]

[1] I. Moulanier et al., J Opt. Soc. B 40 (9), 2450 (2023).

[2] https://lasydoc.readthedocs.io/en/latest/

What's next: reconstructed laser spot[1] (2/2)

[1] I. Moulanier et al., J Opt. Soc. B 40 (9), 2450 (2023).

What's next: plasma target optimization

scientific reports

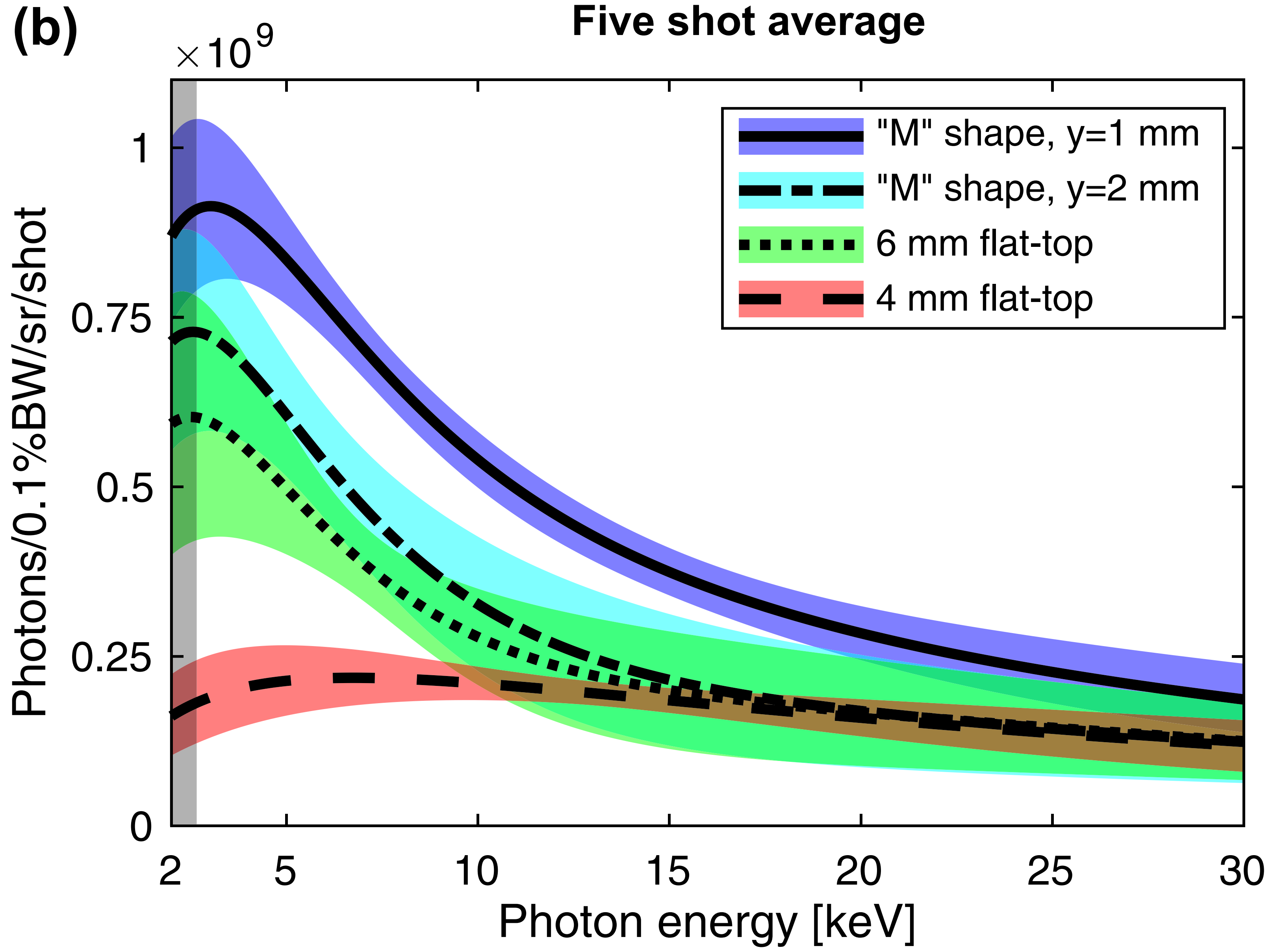
Check for updates

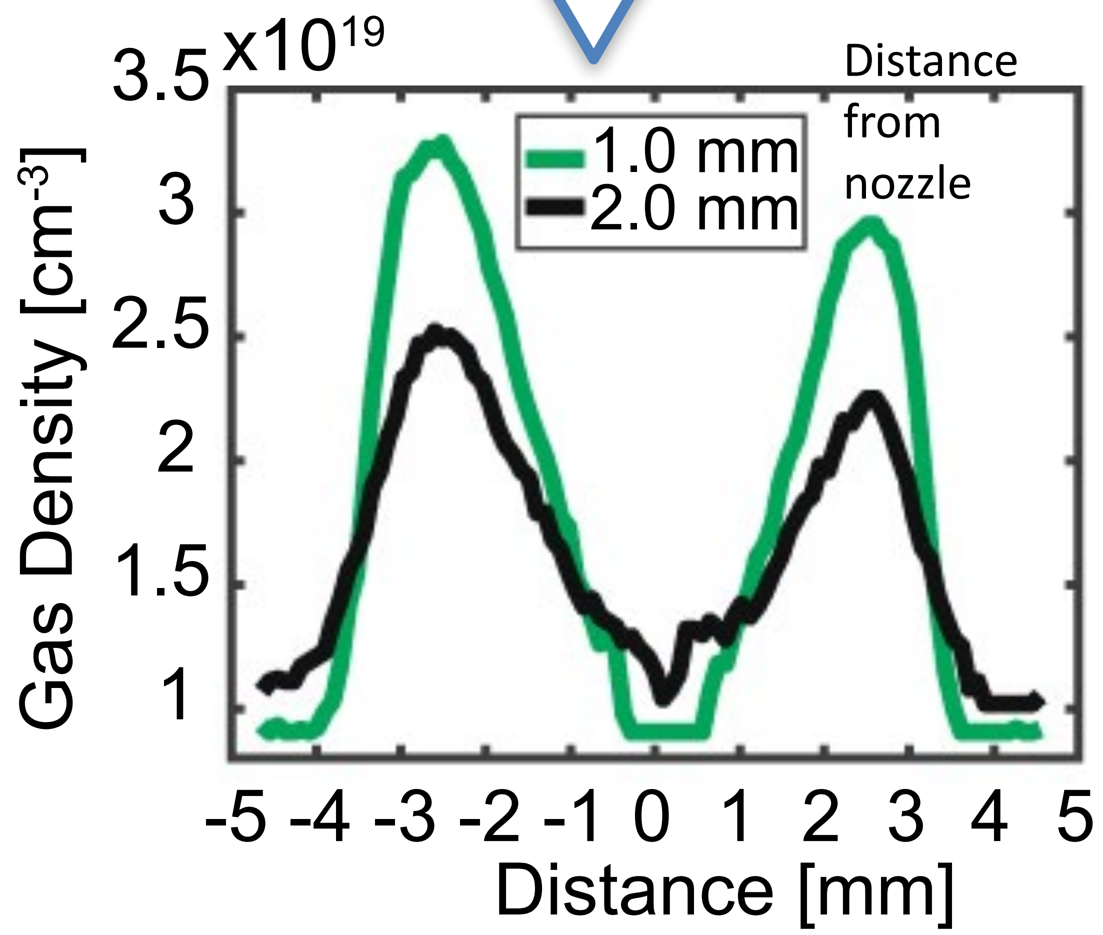
OPEN **Transverse oscillating bubble enhanced laser-driven betatron X-ray radiation generation**

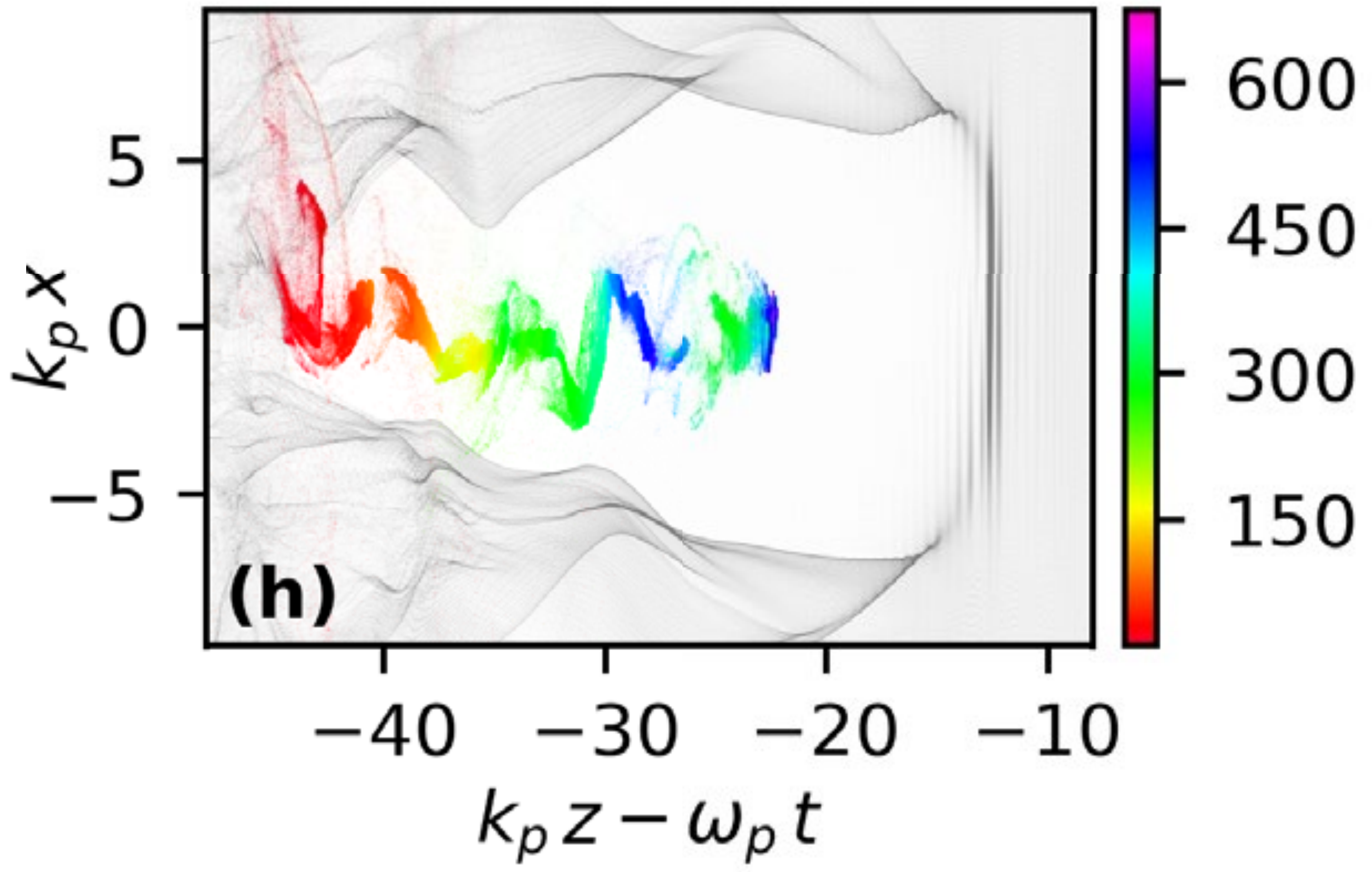
Rafal Rakowski[1,2], Ping Zhang[1,2], Kyle Jensen[1], Brendan Kettle[1], Tim Kawamoto[1], Sudeep Banerjee[1], Colton Fruhling[1], Grigory Golovin[1], Daniel Haden[1], Matthew S. Robinson[1], Donald Umstadter[1], B. A. Shadwick[1] & Matthias Fuchs[1]✉

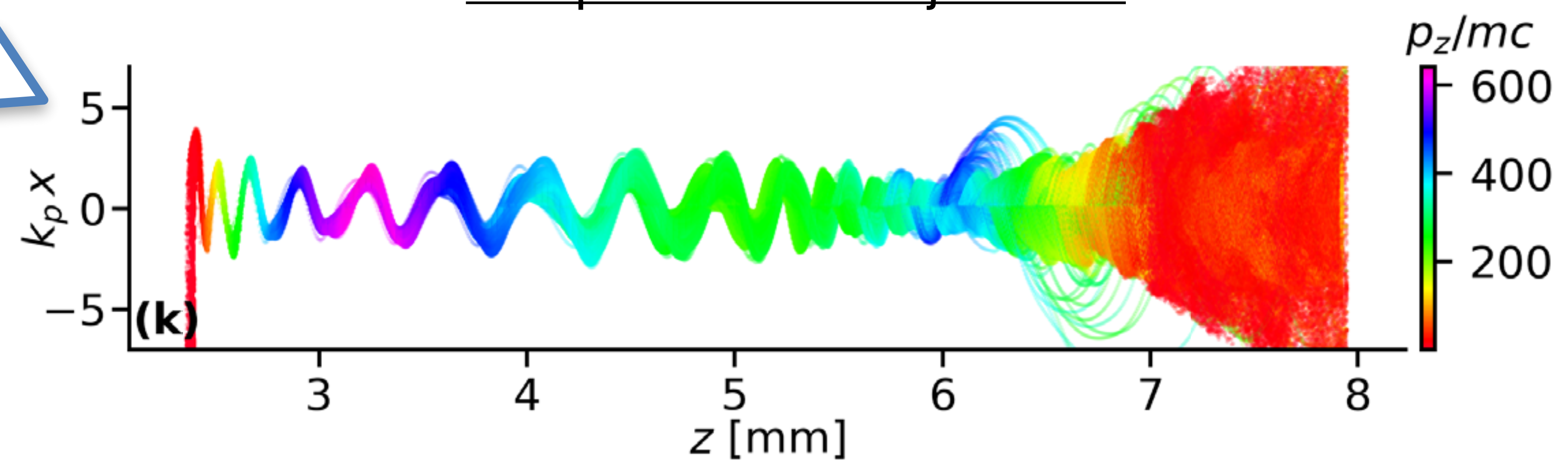
Scientific Reports | (2022) 12:10855 | https://doi.org/10.1038/s41598-022-14748-z nature portfolio

Based on published works, we will try to improve photon yield and spectral properties by engineered plasma targets.









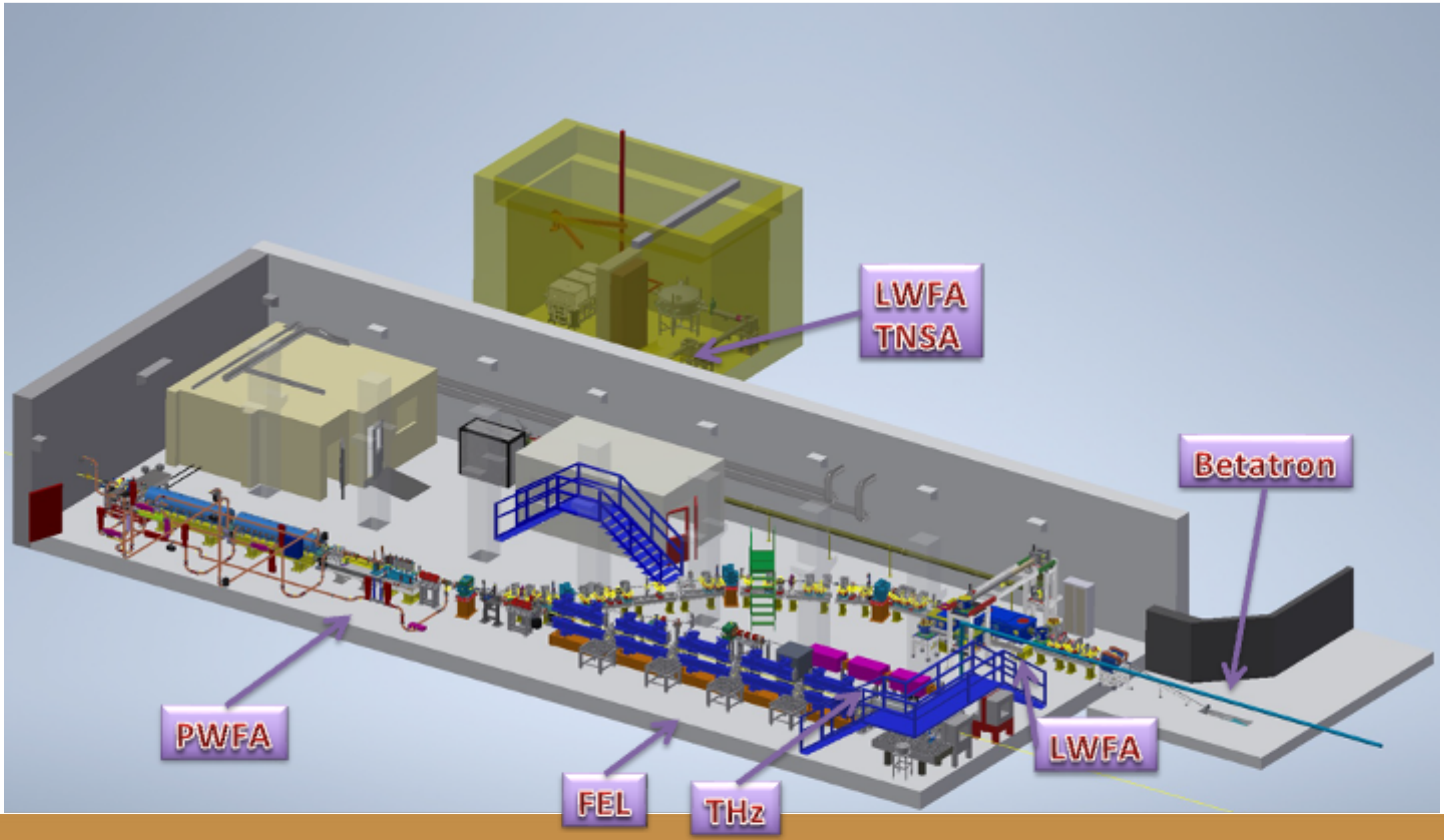
Possible applications

In order of increasing difficulty

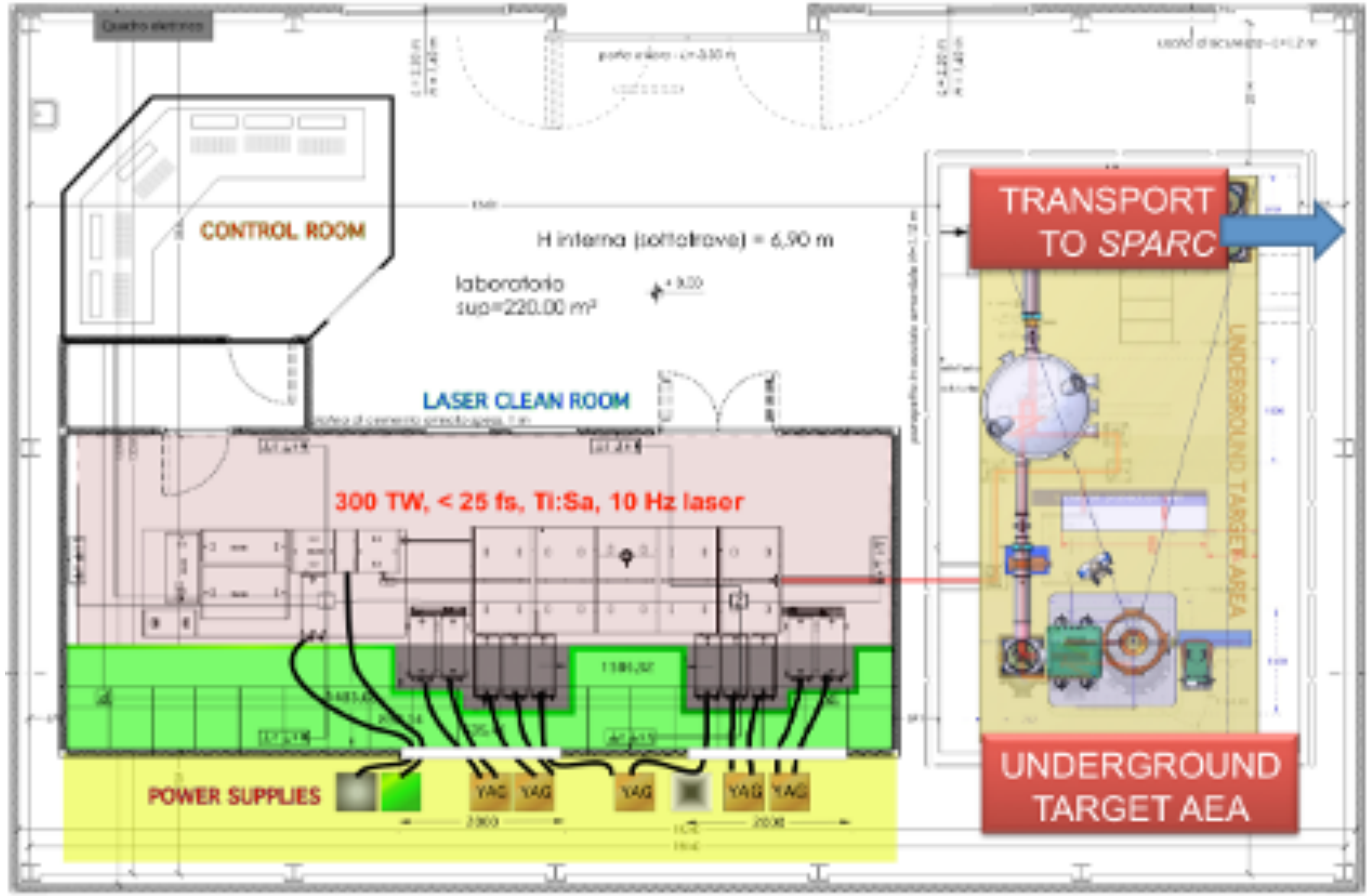
- 1- Static imaging
- 2- Static absorption spectroscopy
- 3- Static emission spectroscopy
- 4- Time-resolved pump-probe absorption spectroscopy
- 5- Time-resolved pump-probe emission spectroscopy
- 6- Time resolved imaging (plasma dynamics).

Courtesy F. Stellato

The SPARC_LAB facility (by end of 2023)



The FLAME laser @SPARC_LAB



Max energy: 7J

Max energy on target: ~5J

Min bunch duration: 23 fs

Wavelength: 800 nm

Bandwidth: 60/80 nm

Spot-size @ focus: 10 μm

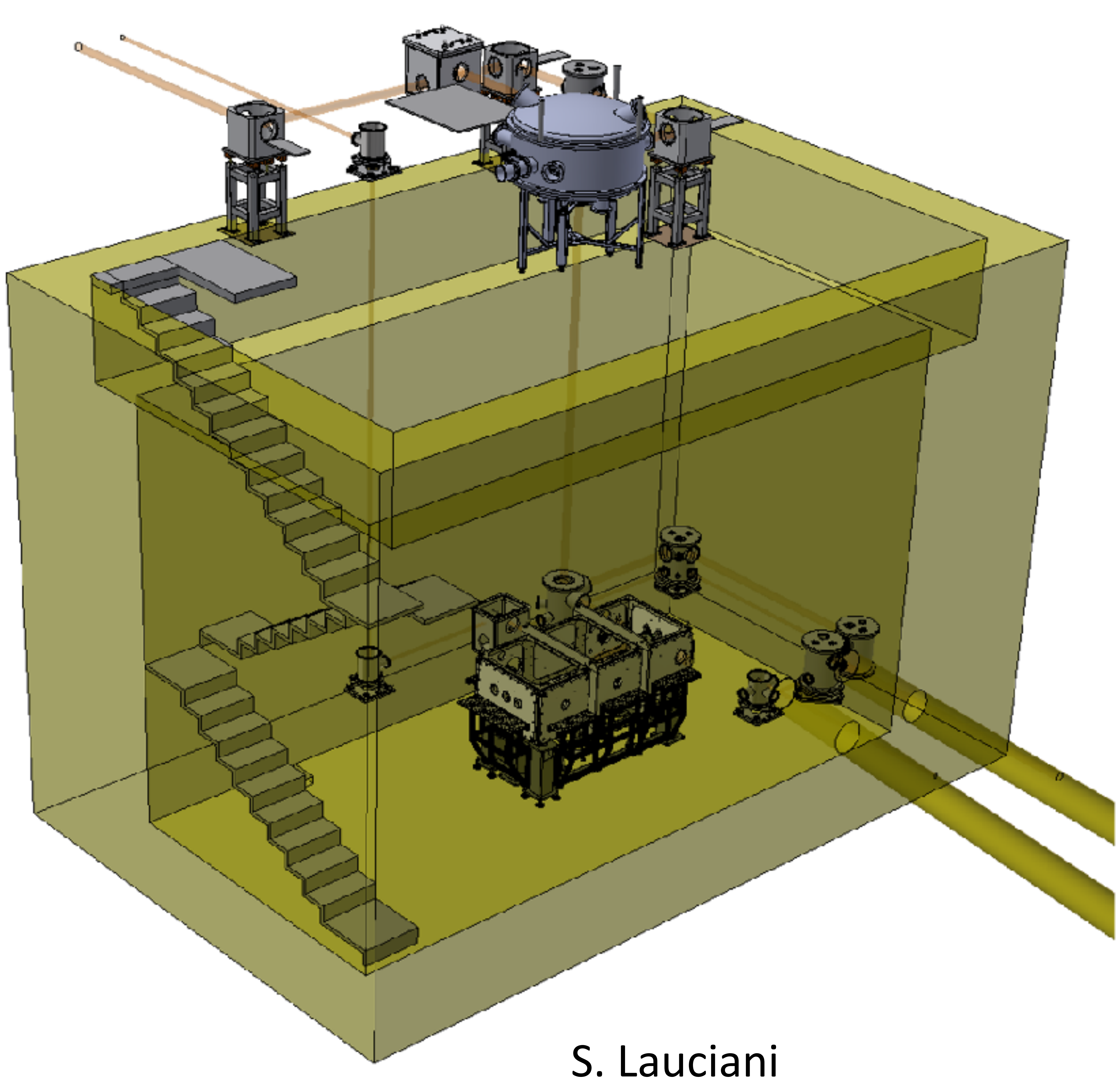
Max power: ~300 TW

Contrast ratio: 10^{10}

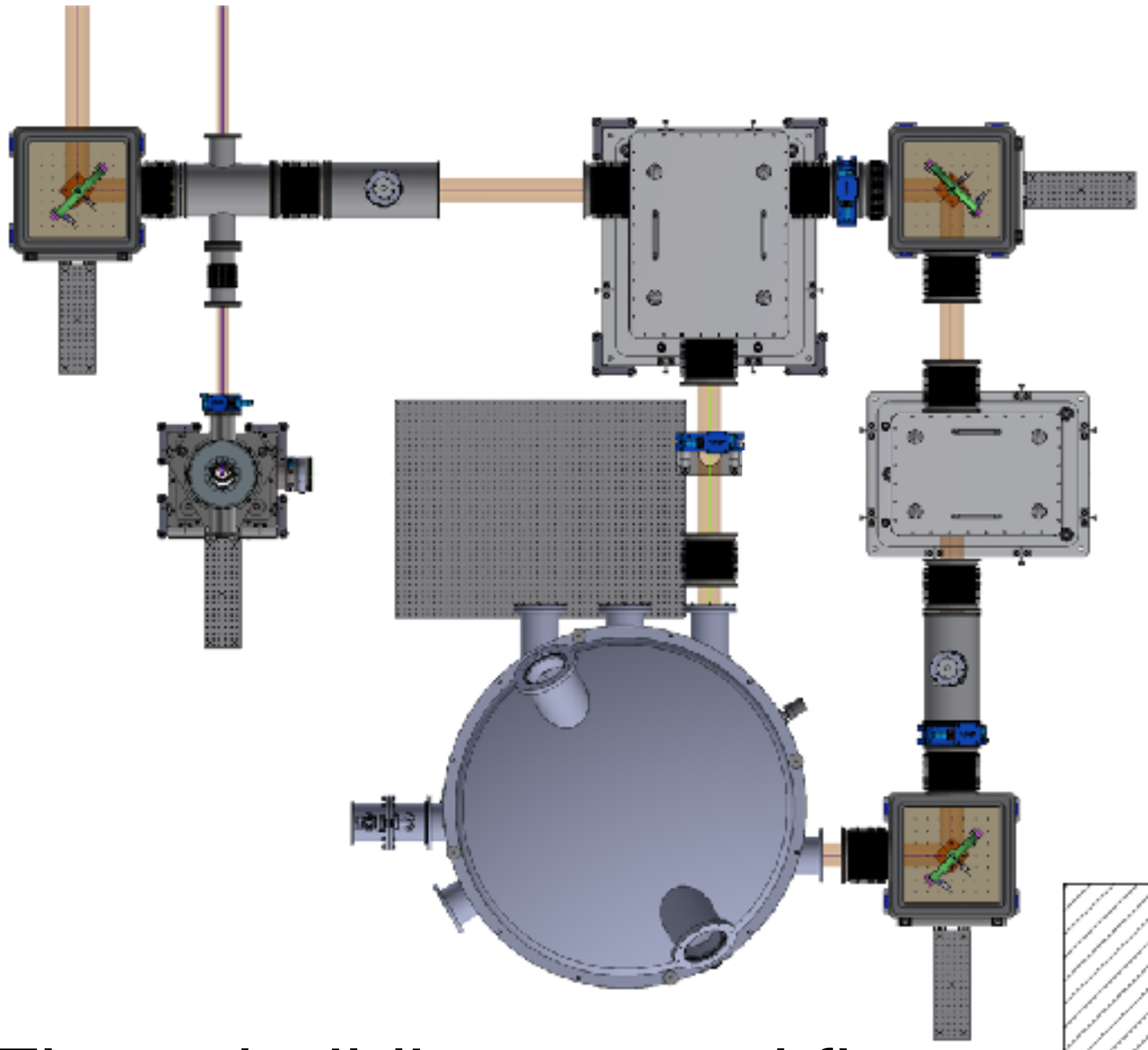
Article submitted to: High Power Laser Science and Engineering, 2024 *June 7, 2024*

Overview and recent developments of the FLAME laser facility at SPARC_LAB

M. Galletti[1,2,3], F. Stocchi[1,4], G. Costa[4], A. Curcio[4], M. Del Giorno[4], R. Pompili[4], L. Cacciotti[4], G. Di Pirro[4], V. Dompè[4], L. Verra[4], F. Villa[4], A. Cianchi[1,2,3], M.P. Anania[4], A. Ghigo[4], A. Zigler[4], and M. Ferrario[4]

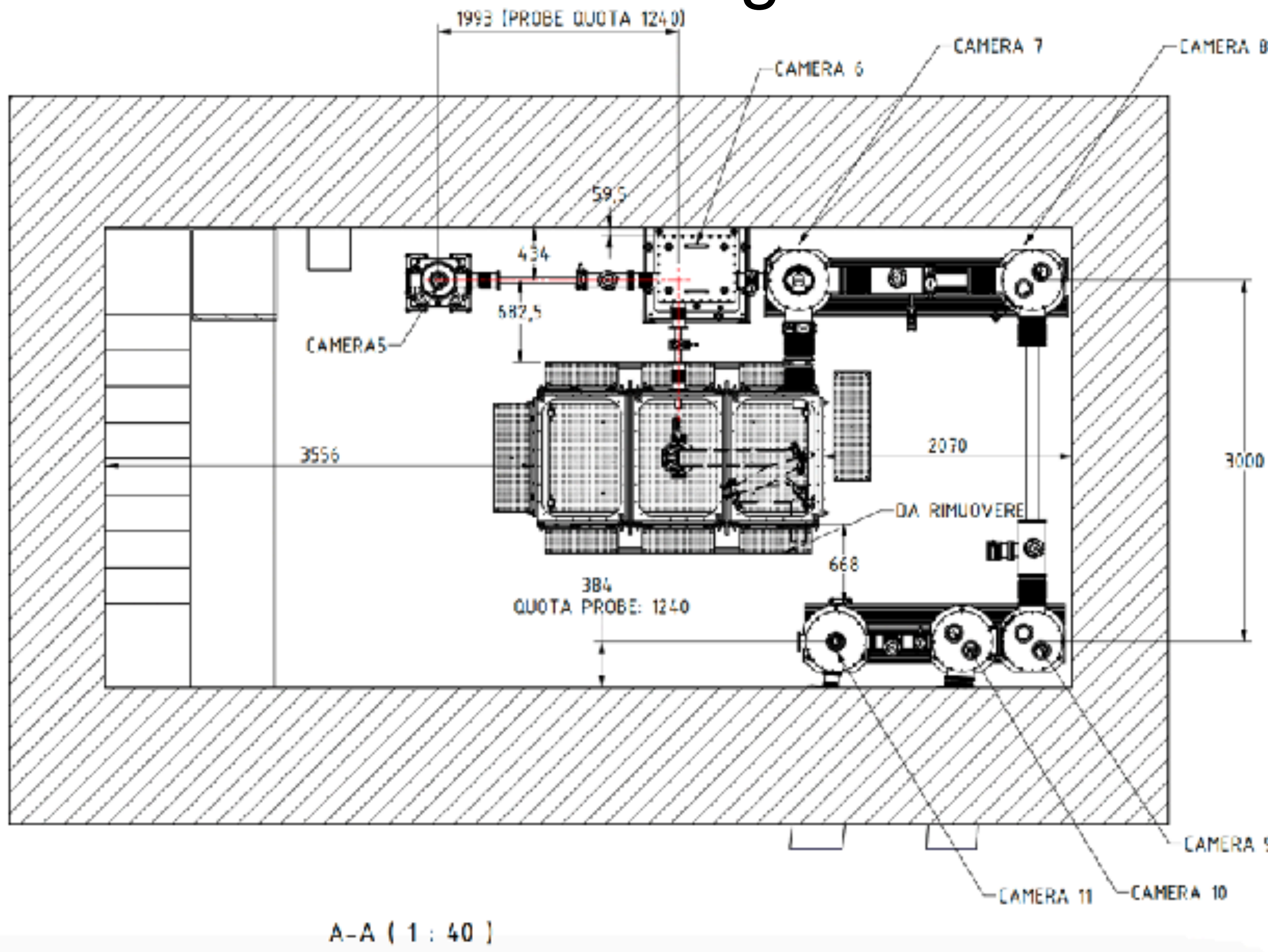


S. Lauciani

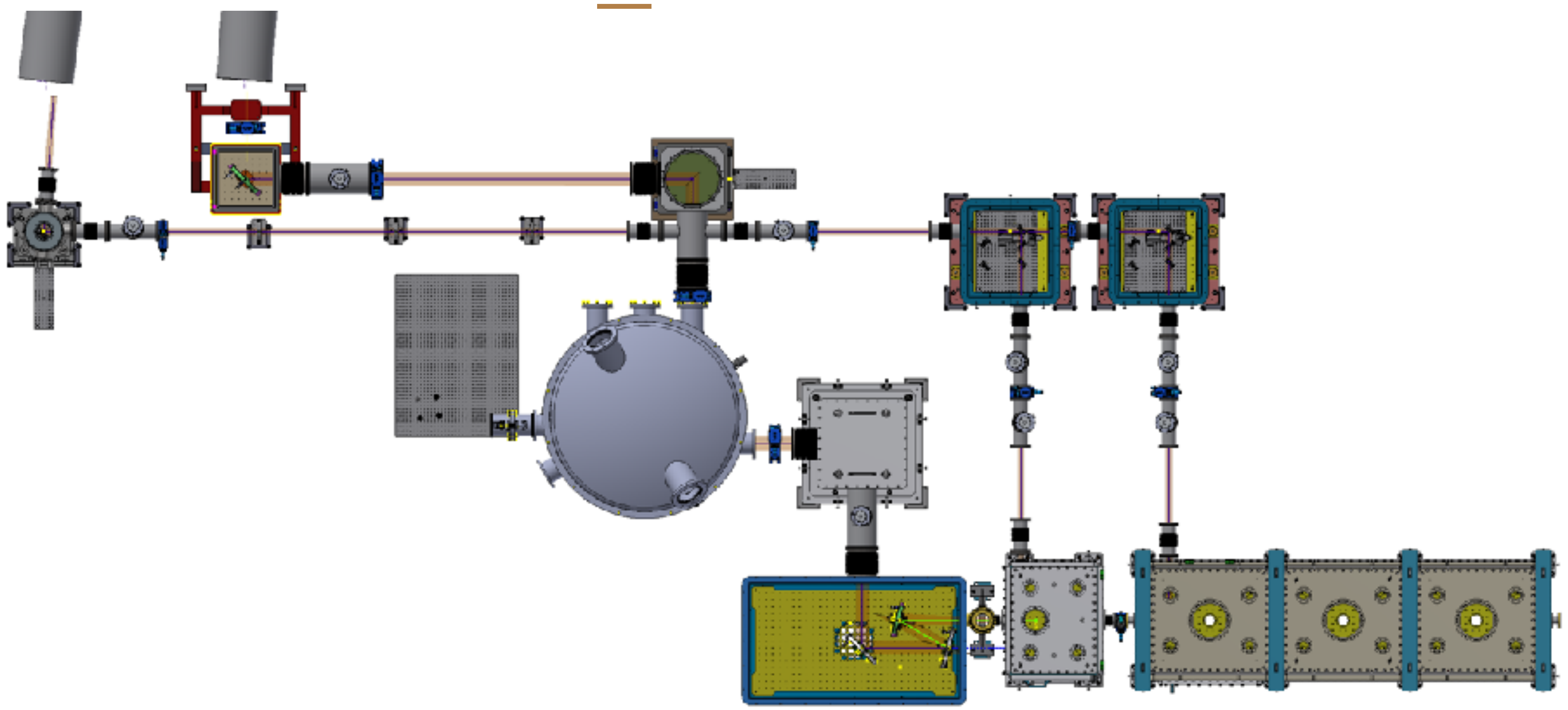


Flame building ground floor

Flame building underground floor

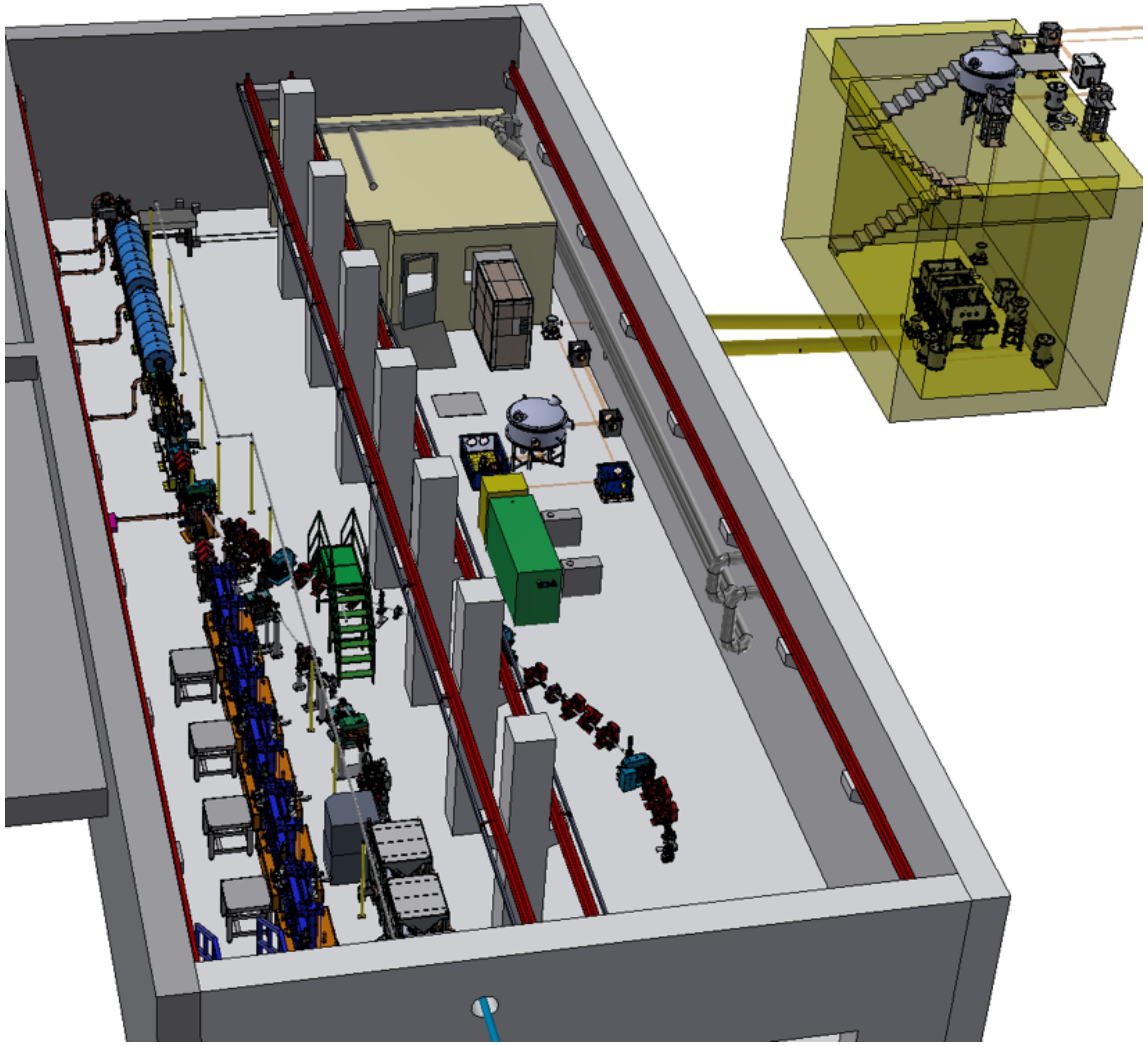


SPARC_LAB bunker



- Layout in the SPARC bunker and connection with FLAME building

S. Lauciani



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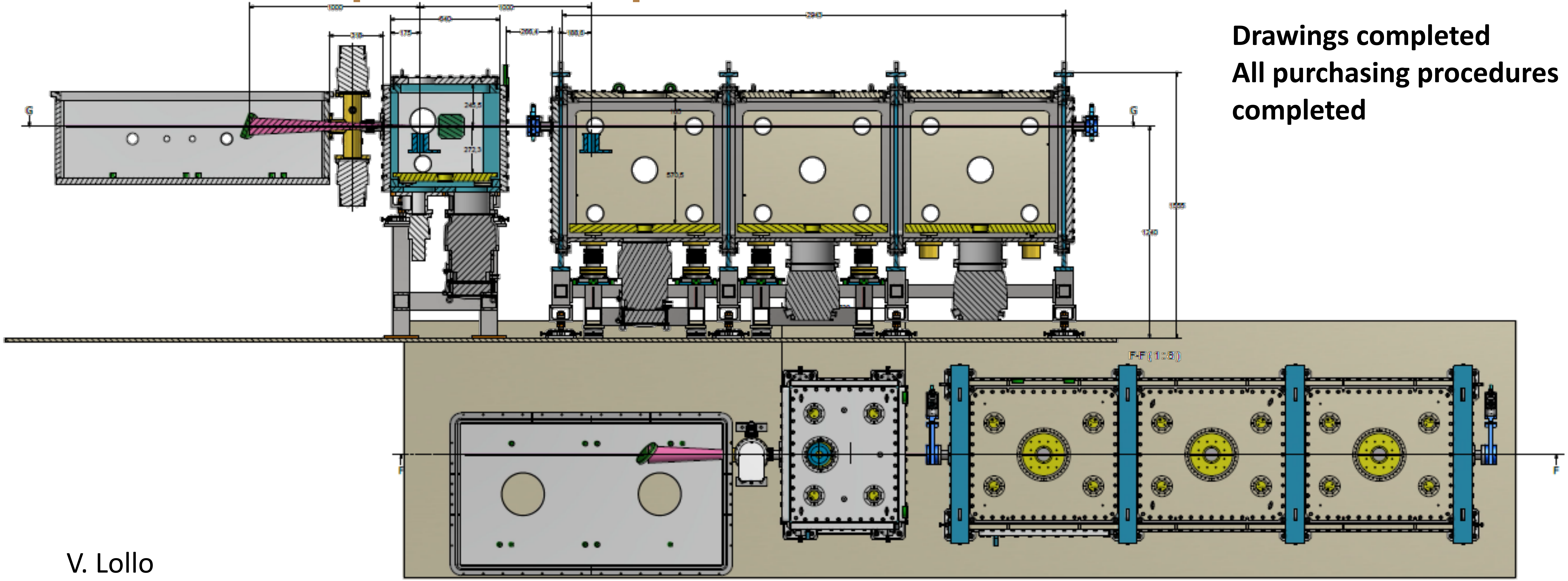
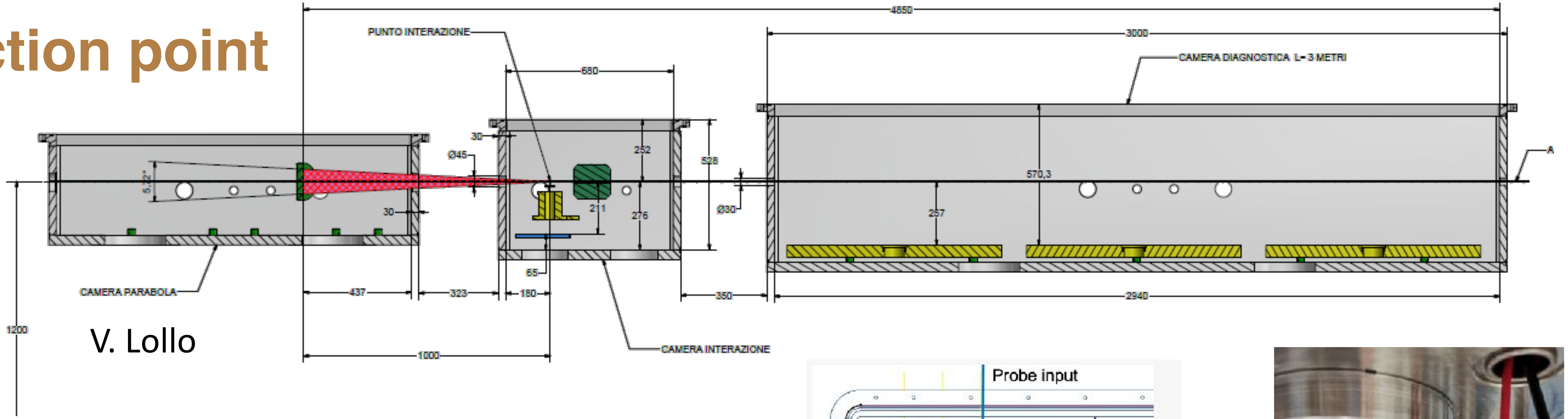
Interaction point and experimental chamber



Drawings completed
All purchasing procedures completed

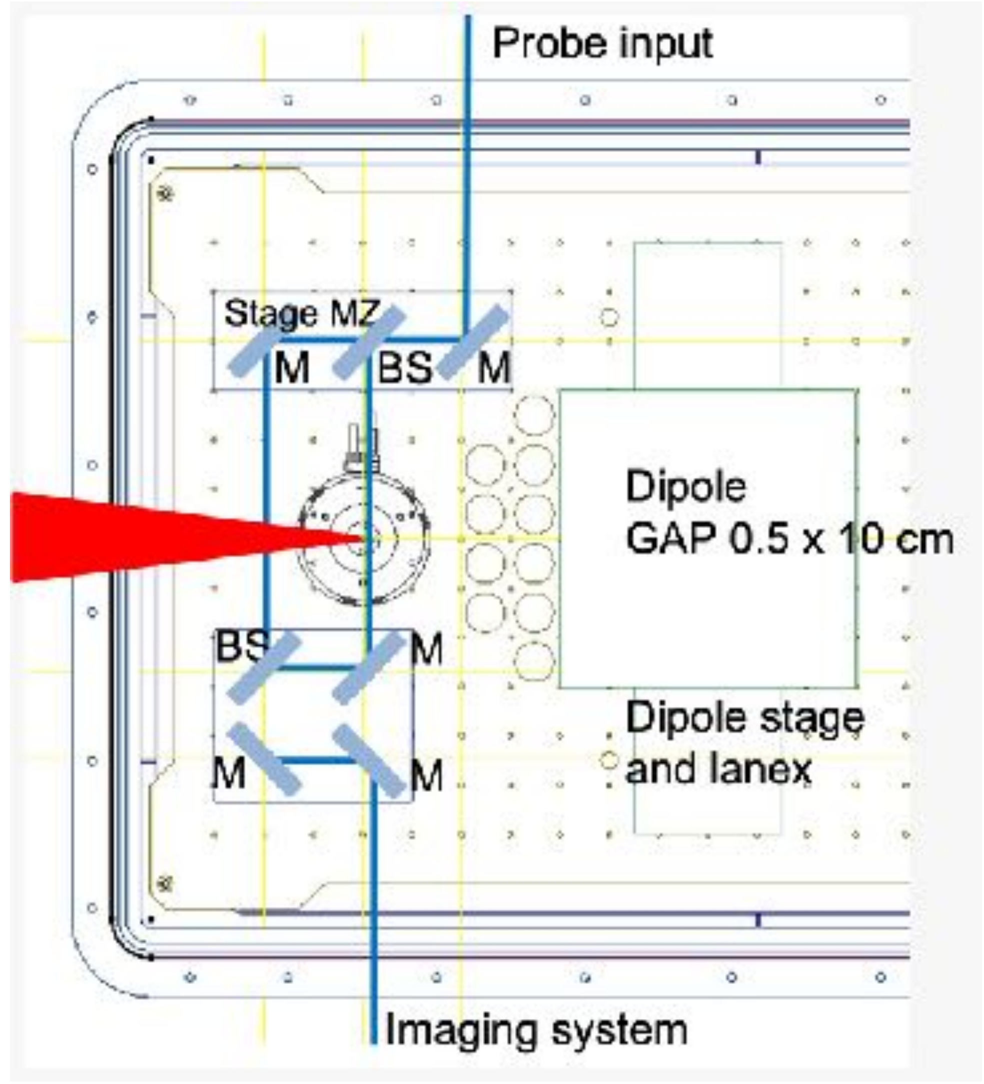
V. Lollo

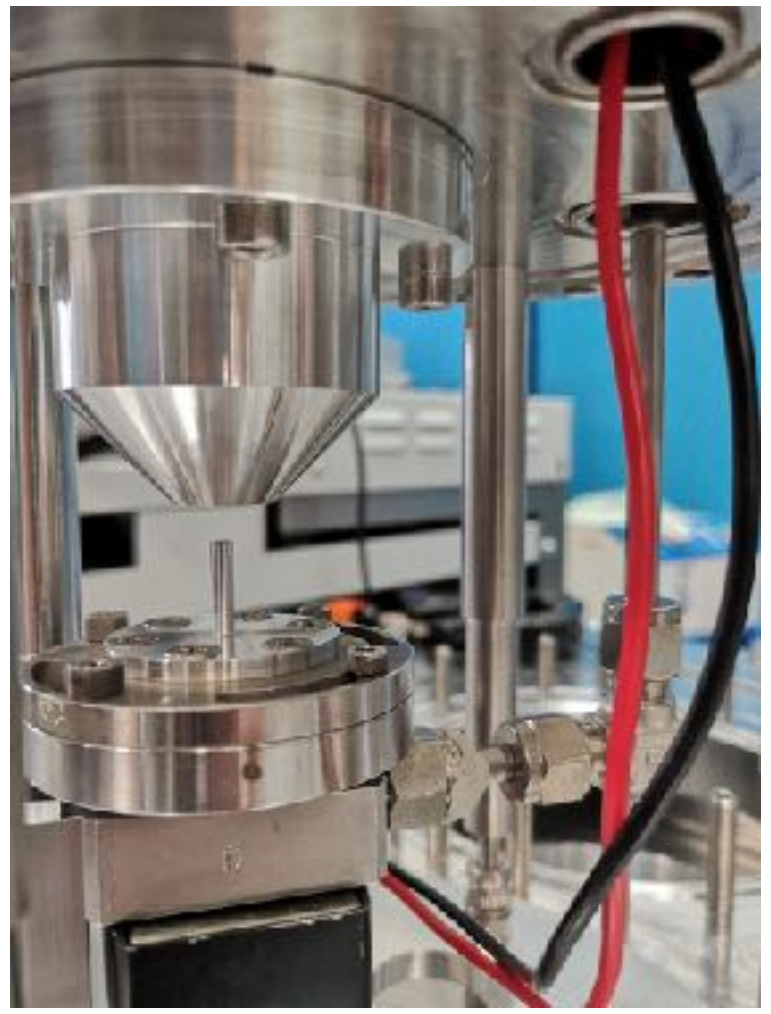
Interaction point



V. Lollo

- Main issue is the pumping of 20-30 bar with repetition rate at least 1 Hz
- The focusing parabola has to be at least at 10^{-4} mbar
- Prototype system developed and tested





Inside the user chamber

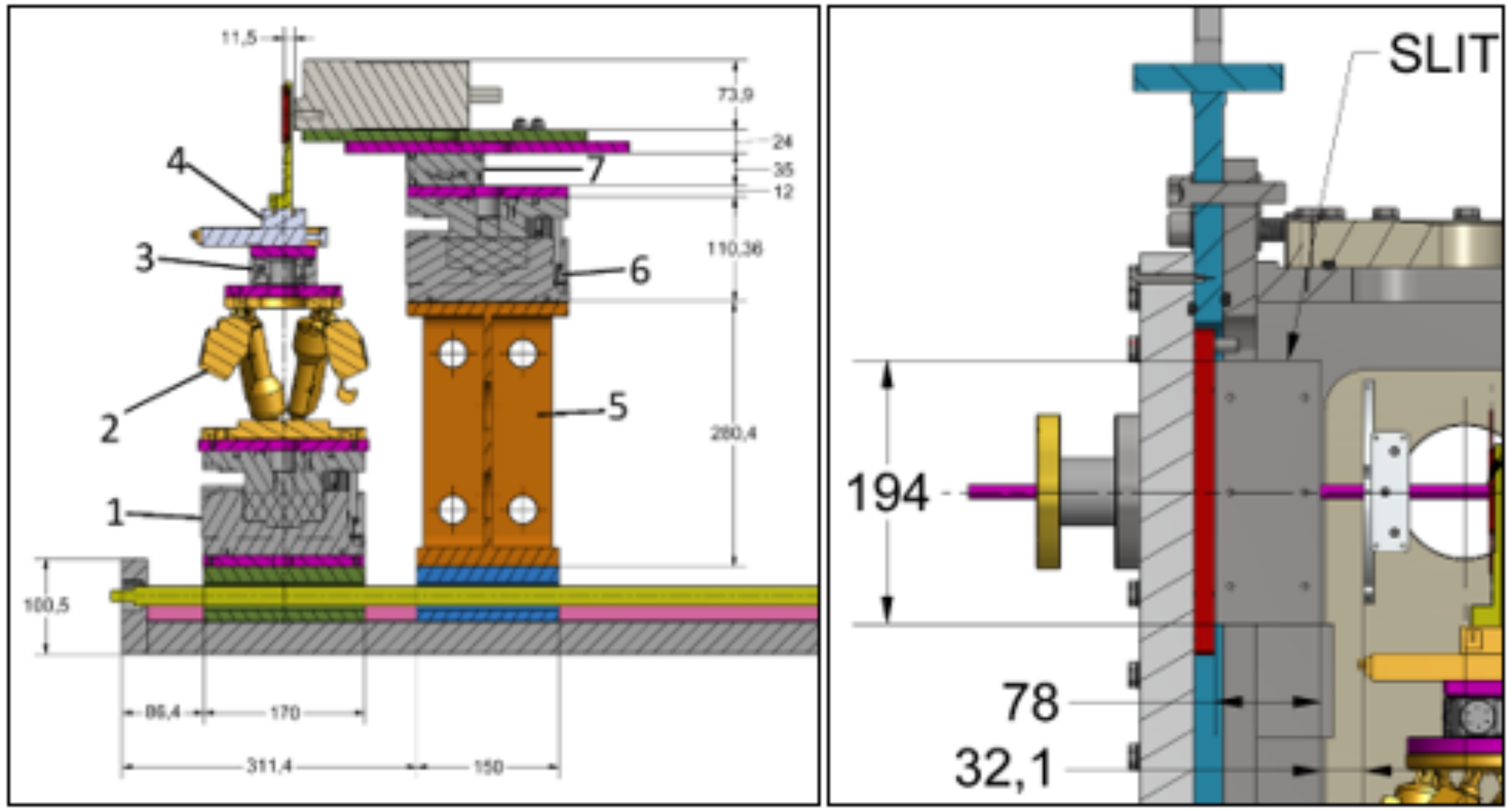


Figure 3 - Diagram showing the most important components other than the x-ray Camer and, the sample holder system (left), and the slit system (right), with distances expressed in mm . The numbered components are explained in the text..

- 1 - Linear stage XY, 25 mm travel range, 25 N load max, 133x35x20 mm size, 0,73 kg weight, stainless steel/aluminium.
- 2 - Rotary stage, 360° rotation, 0.125 Nm maximum torque, 50 N max load, ±20 mdeg accuracy, 0,7 kg weight, 194x90x70 mm size, Stainless Stee.
- 3 - Hexapod, ±17 mm travel range, 5 kg load capacity, Repeatability to ±0.06 μm, 2.2 kg weight, lower circular base 136 mm, higher circular base 100 mm, height 114 mm, stainless steel/aluminium
- 4 - Linear stage (z-direction, perpendicular to the ground), 40 mm travel range, 0,02 mm Spindle pitch, 0,05 μm resolution, 150 N max load, 0,3 Nm Min. Drive Torque, weight 7.5 kg, size 170x170x90 mm, aluminium.
- Not Numbered - Custom-built sample holder, 200 g weight, 133x23,5x7 mm size (with angular step for bolts), stainless steel.
- The X-ray Camera handling devices (hereby called collectively Camera Block) will be built with the subsequent devices:
- 5 - Custom Built steel pillar, 280x150x250 mm (higher base 170x170 mm) size, 6 kg weight, stainless steel.
- 6 - Linear stage (z-direction, same as Sample Block)
- 7 - Linear XY stage, 100 mm travel range, 20 μm accuracy, 1 mm Spindle pitch, 1200 N max load, 0,1 Nm drive torque, 1 kg weight, 80x144x35 mm size, aluminium/stainless steel.
- Not Numbered - X-ray Camera, imaging array 2048 x 2048, 15x15 μm pixel size, 2.3 kg weight, 217.6x102.3x7.39 mm size, aluminium/stainless steel.

Timeline

- Installation in FLAME in progress until 15/2/2025
- Upgrade laser FLAME up to March 2025
- Installation in SPARC up to May 2025
- Setup and startup May/July 2025
- Beam to users September/November 2025


That's all Folks!

Backup slides

EuAPS organization

EuAPS Scientific Coordinator:
M. Ferrario (INFN-LNF)
EuPRAXIA/EuAPS Integration:
R. Assmann (DESY & INFN)

LNF-LNS-MI

INO-ISM

WP1
MANAGEMENT & DISSEMINATION
A. Falone (LNF)

WP3
HIGH POWER LASER BEAM LINE
P. Cirrone (LNS)

WP2
BETATRON RADIATION SOURCE
A. Cianchi (Uni-ToV)

WP4
HIGH REPETITION RATE LASER BEAM LINE
L. Labate (CNR-INO)

Scientific Advisory Committee

Operating Units Board

Scientific and Technical Board

Funds application scoring

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	EuAPS	INFN	22.350.588,00 €	191	-17.6
2	I-PHOQS		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		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

Budget distribution

LNF-MI ISM LNS INO

COSTS (€) WORK PACKAGE [WP.2 - Betatron Radiation Source]	Costs included in the request for funding		
	To be located within the eight southern Regions	To be located outside the eight southern Regions	Total requested grant
a. Fixed term personnel specifically hired for the project	120.000,00	878.000,00	998.000,00
b. Scientific instrumentation and technological equipment, software licenses and patent	1.000.000,00	6.840.400,00	7.840.400,00
c. Open Access, Trans National Access, FAI principal implementation	0,00	0,00	0,00
d. Civil infrastructures and related systems	0,00	0,00	0,00
e. Indirect costs, including running costs	78.400,00	540.288,00	618.688,00
f. Training activities	0,00	0,00	0,00
Total	1.198.400,00	8.258.688,00	9.457.088,00

COSTS (€) WORK PACKAGE [WP.3 - High Power Laser Beam Line]	Costs included in the request for funding		
	To be located within the eight southern Regions	To be located outside the eight southern Regions	Total requested grant
a. Fixed term personnel specifically hired for the project	150.000,00	0,00	150.000,00
b. Scientific instrumentation and technological equipment, software licenses and patent	5.917.812,47	0,00	5.917.812,47
c. Open Access, Trans National Access, FAI principal implementation	0,00	0,00	0,00
d. Civil infrastructures and related systems	1.300.006,38	0,00	1.300.006,38
e. Indirect costs, including running costs	496.681,15	0,00	496.681,15
f. Training activities	0,00	0,00	0,00
Total	7.864.500,00	0,00	7.864.500,00

COSTS (€) WORK PACKAGE [WP.4 - High Repetition Rate Laser Beam Line]	Costs included in the request for funding		
	To be located within the eight southern Regions	To be located outside the eight southern Regions	Total requested grant
a. Fixed term personnel specifically hired for the project	0,00	240.000,00	240.000,00
b. Scientific instrumentation and technological equipment, software licenses and patent	0,00	4.024.986,00	4.024.986,00
c. Open Access, Trans National Access, FAI principal implementation	0,00	0,00	0,00
d. Civil infrastructures and related systems	0,00	280.000,00	280.000,00
e. Indirect costs, including running costs	0,00	318.164,00	318.164,00
f. Training activities	0,00	0,00	0,00
Total	0,00	4.863.150,00	4.863.150,00

Ionization injection vs self-injection