# EuAPS – X-rays Betatron Radiation Source at SPARC_LAB

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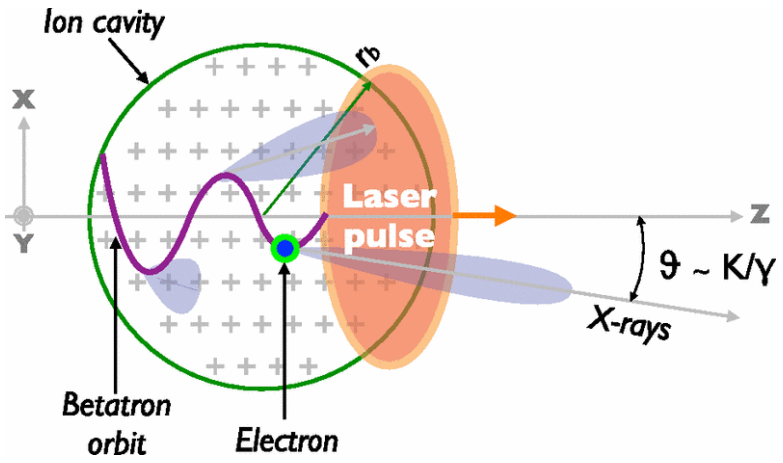
University of Rome Tor Vergata and INFN

On behalf of WP2 EuAPS project

# Outline

- Betatron radiation
- WP description
- Upgrade of the current layout
- Tentative agenda

# Betatron radiation scaling laws




$$\left.\frac{d^2I}{d\omega d\Omega}\right|_{\theta=0} = \sum_{n=1}^{\infty} \frac{e^2}{\pi\varepsilon_0 c}\frac{\omega}{\omega_n}\frac{\gamma^2 N_\beta^2 F_n R_n}{1+K_\beta^2/2}$$

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

$$r_\beta^{max} = \frac{2\sqrt{a_0}c}{\omega_p}$$

$$N_{ph} \propto N_e N_\beta K \propto N_e N_\beta \sqrt{\gamma n_e} r_\beta$$

$$\theta_r \propto K/\gamma \propto \sqrt{n_e}\, r_\beta/\sqrt{\gamma}$$

$$\hbar\omega_c \propto \gamma^{1.5}\sqrt{n_e}K \propto \gamma^2 n_e r_\beta$$

$$\Delta\theta_\perp \sim 1/\gamma$$

$$< N_{\gamma,\hbar\omega_c} > \simeq \frac{2\pi}{9}\frac{e^2}{\hbar c} K N_\beta \simeq 5.6\times 10^{-3} K N_\beta$$

# Starting point

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]

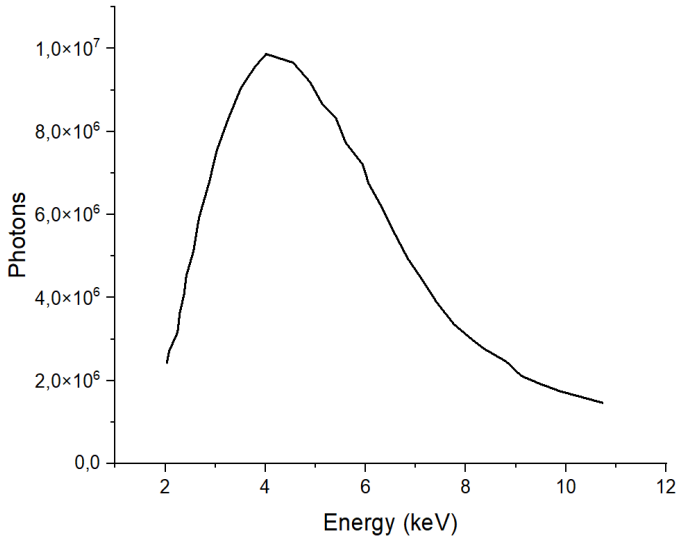



**Fig. 6.** Betatron radiation spectrum detected by the *CdTe* spectrometer. Laser, plasma and electron parameters: energy per pulse $E_L = 1.5$ J, pulse duration $\tau = 35$ fs, focus rms radius $\sigma_r \sim 5$ µm. Electron plasma density $n_e \sim 6 \pm 1 \times 10^{18}$ cm$^{-3}$, electron mean energy 200 MeV, energy spread 30%, electron beam divergence 12 mrad, bunch charge 20 pC. The acceleration length was 1 mm.

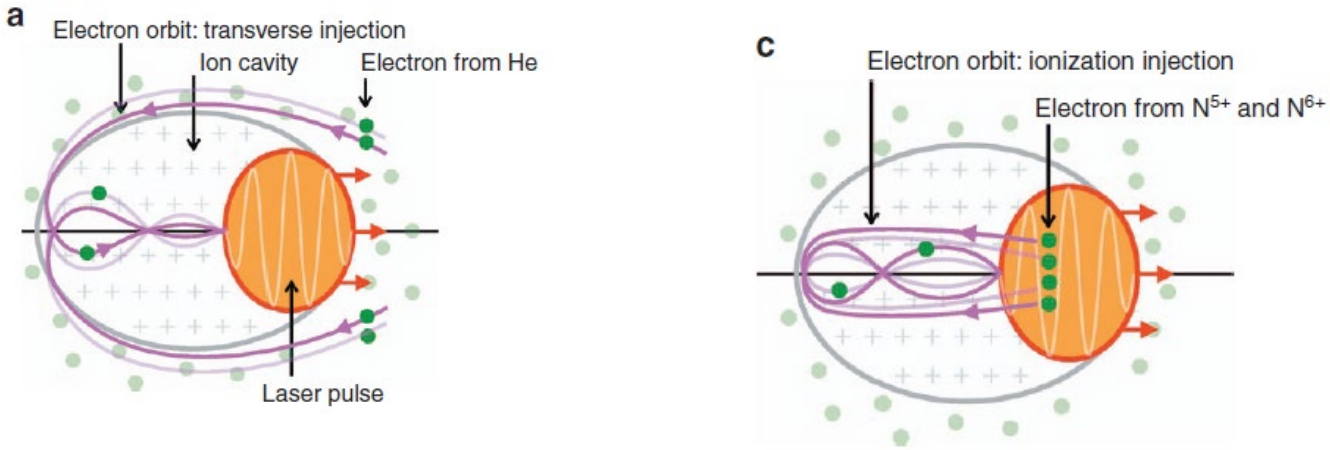
- **Result already obtained at Flame with He**

# But there are many thing to be investigated

## Stable femtosecond X-rays with tunable polarization from a laser-driven accelerator

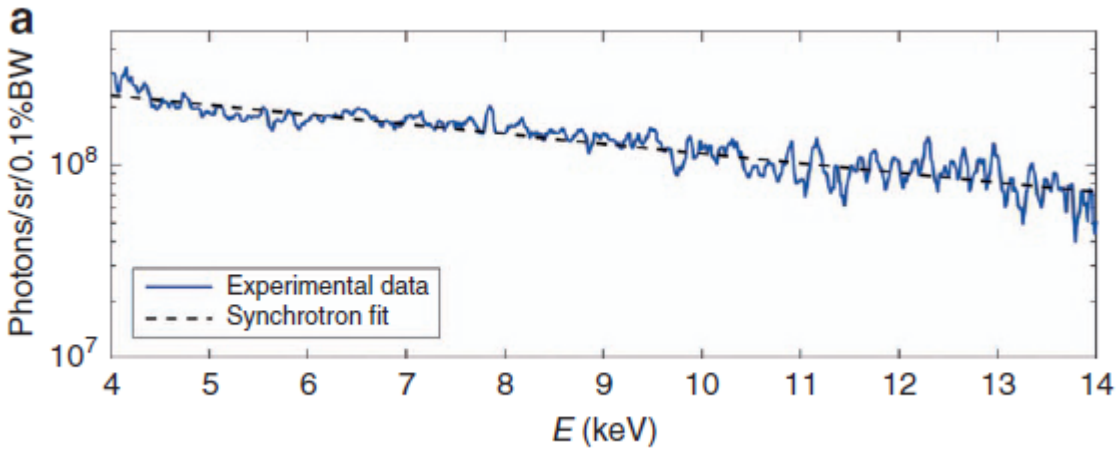
Andreas Döpp[1,2,*], Benoit Mahieu[1,*], Agustin Lifschitz[1], Cedric Thaury[1], Antoine Doche[1], Emilien Guillaume[1], Gabriele Grittani[3], Olle Lundh[4], Martin Hansson[4], Julien Gautier[1], Michaela Kozlova[3], Jean Philippe Goddet[1], Pascal Rousseau[1], Amar Tafzi[1], Victor Malka[1,5], Antoine Rousse[1], Sebastien Corde[1] and Kim Ta Phuoc[1]

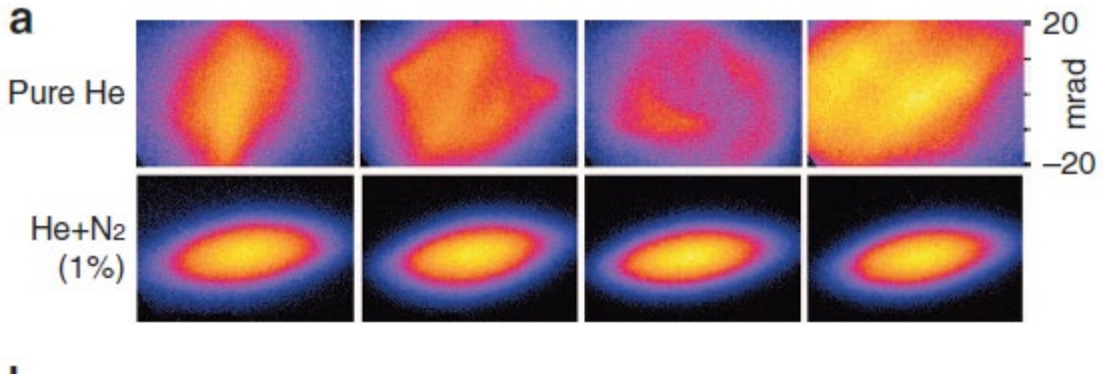
*Light: Science & Applications* (2017) **6**, e17086; doi:10.1038/lsa.2017.86; published online 17 November 2017




- Higher charge -> higher photons
- Higher stability
- Polarized X- rays

# Results


a
Photons/sr/0.1%BW
$10^8$
$10^7$
Experimental data
Synchrotron fit
4
5
6
7
8
9
10
11
12
13
14
E (keV)


a
Pure He
He+N2
(1%)
20
mrad
–20

# Off axis injection

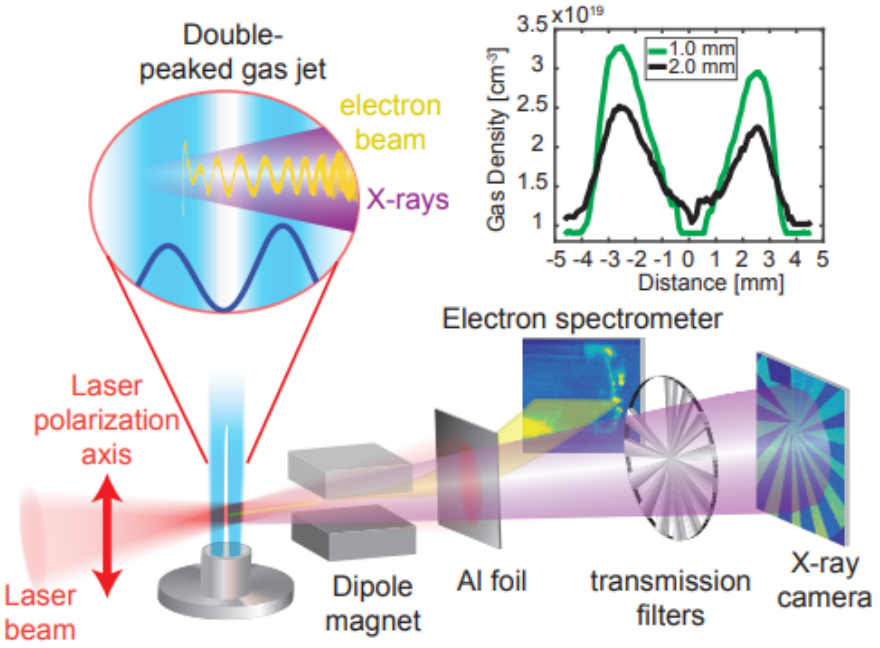
**Transverse Oscillating Bubble Enhanced Laser-driven Betatron X-ray Radiation Generation**

Rafal Rakowski,[1, a)] Ping Zhang,[1, a)] 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] and Matthias Fuchs[1, b)]

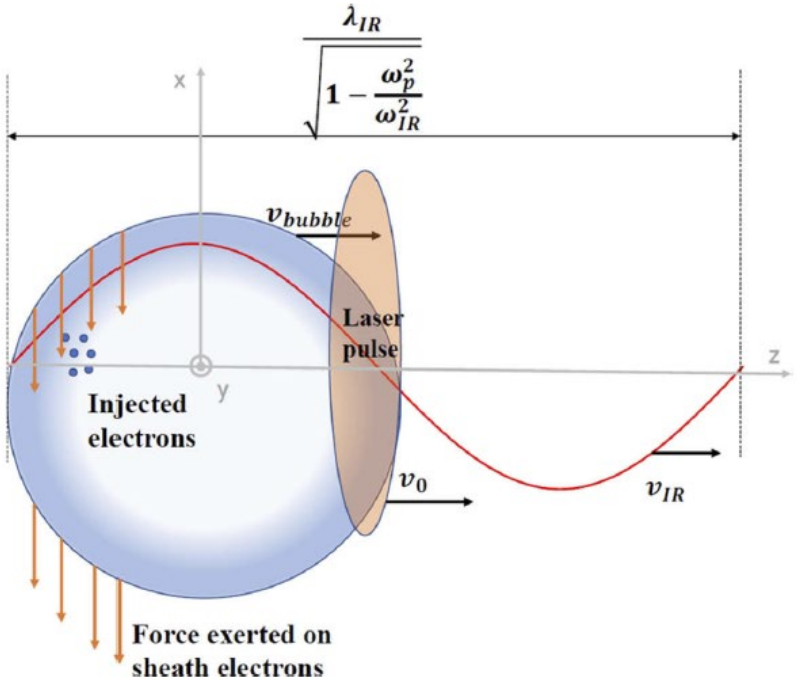
[1] *Department of Physics and Astronomy, University of Nebraska - Lincoln, Lincoln, Nebraska 68588, USA*

(Dated: 4 February 2022)

- A high-power laser (red) is focused into a double-peaked "M" shaped gas jet (blue).
- The laser evolution during the first density peak leads to off-axis electron injection during the following density downramp.
- Subsequent large-amplitude betatron oscillations (yellow) cause emission of intense X-ray radiation (purple).



# Two lasers




- The blue circle represents the plasma bubble.
- The bubble is moving downwards due to the transient positive mid-infrared control field.
- The injected electrons thus experience a transverse force downwards from the restoring field of the bubble.
- Due to the superluminal phase velocity of the mid-infrared control laser field, the bubble and injected electrons experience high frequency transverse oscillation when the control laser field rapidly changes its sign.

Chen, Jiyuan, et al. "Enhanced soft x-ray betatron radiation from a transversely oscillating laser plasma wake." *Optics Express* 29.9 (2021): 13302-13313.

# Betatrone R&D

- We need to make R&D @FLAME to:
  - Define the scheme to use
  - Define the spectrum and the tunability
  - Define the source properties in terms of flux and spatial properties
- This work is fundamental for the best design of the X rays beamline
- The final design of this beamline depends on these results!

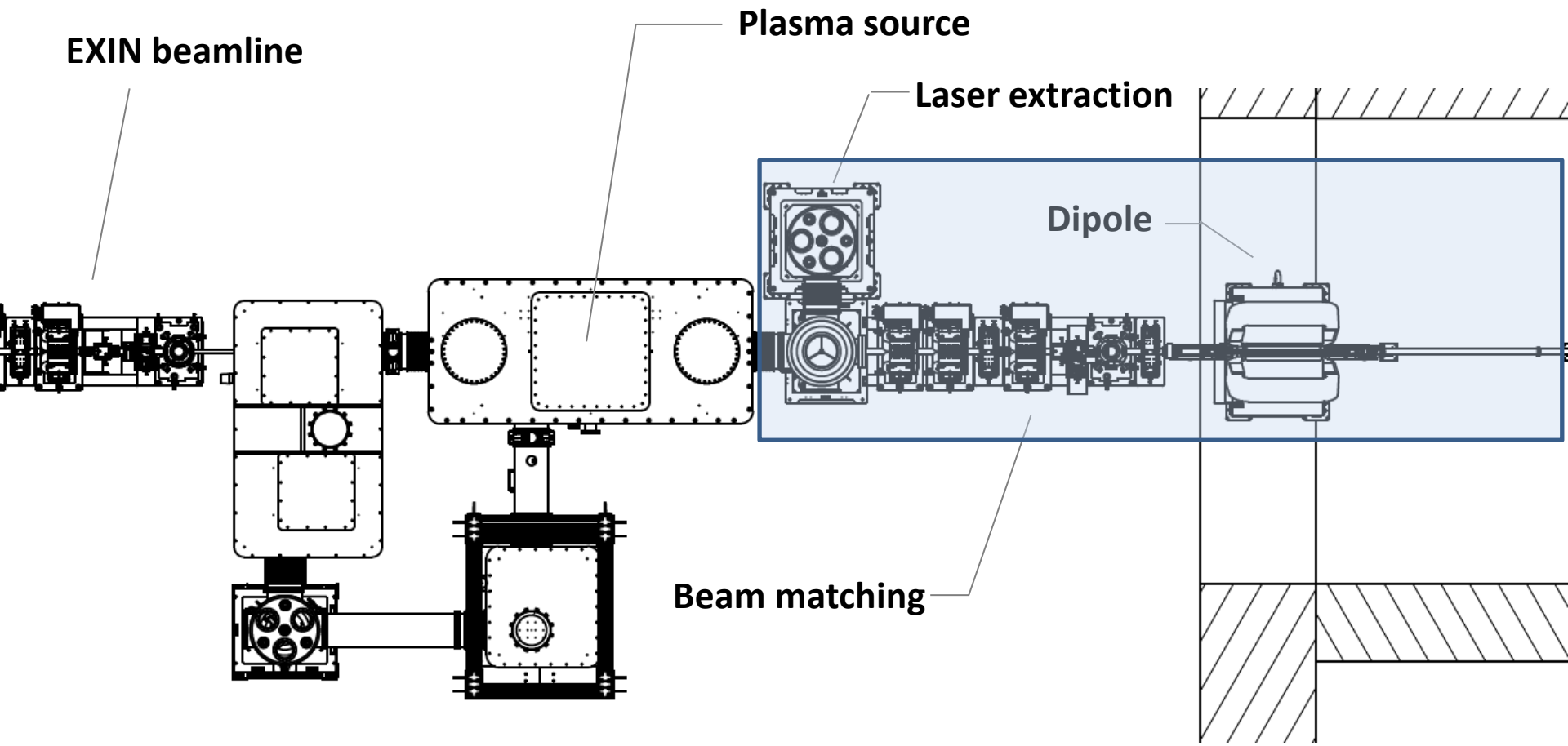
# WP description

| COSTS (€)<br>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 |

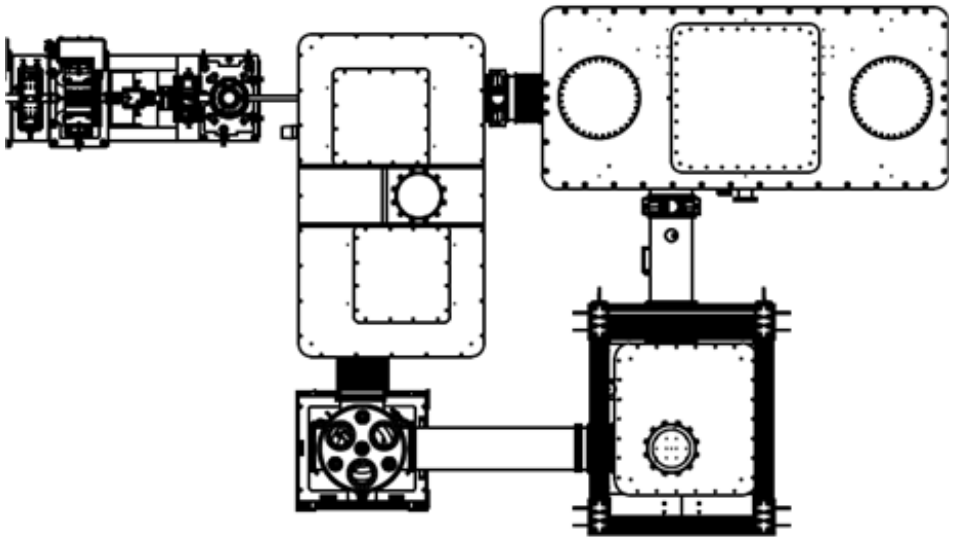
# Subtasks

- 2.1 INFN-Milan simulations
- 2.2 Plasma source INFN-LNF
- 2.3 Synchronization INFN-LNF
- 2.4 X rays diagnostics CNR-ISM-Potenza
- 2.5 End user station Unitov
- 2.6 X rays temporal characterization CNR-ISM-Montelibretti

# Actual situation



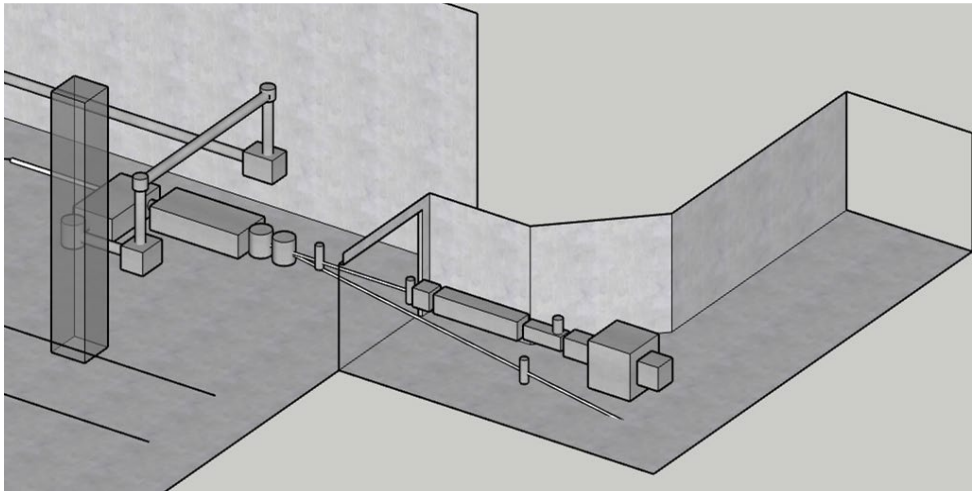
# Modified layout

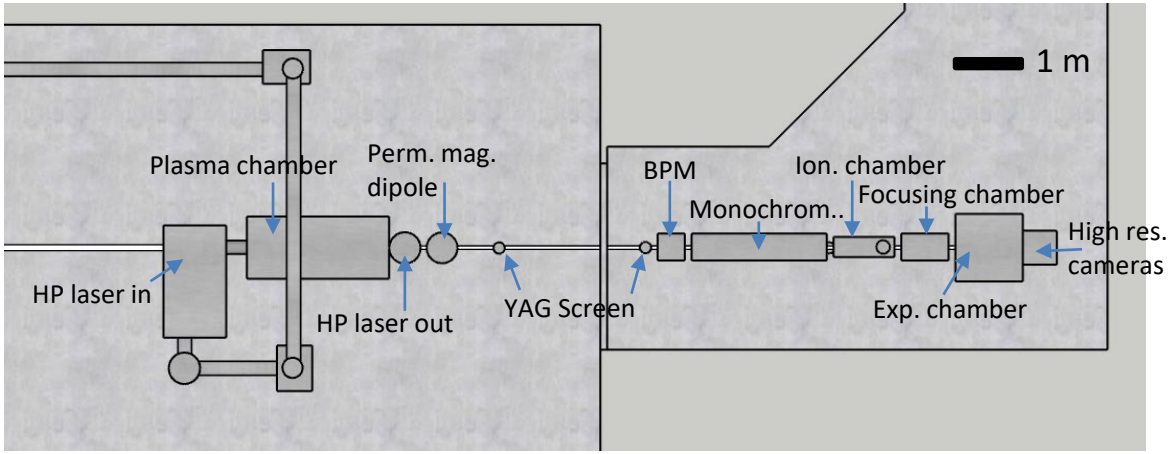


- Laser removal with a dedicated chamber maybe only for EXIN
- Electron and photons separation as soon as possible, big energy spread can be a problem

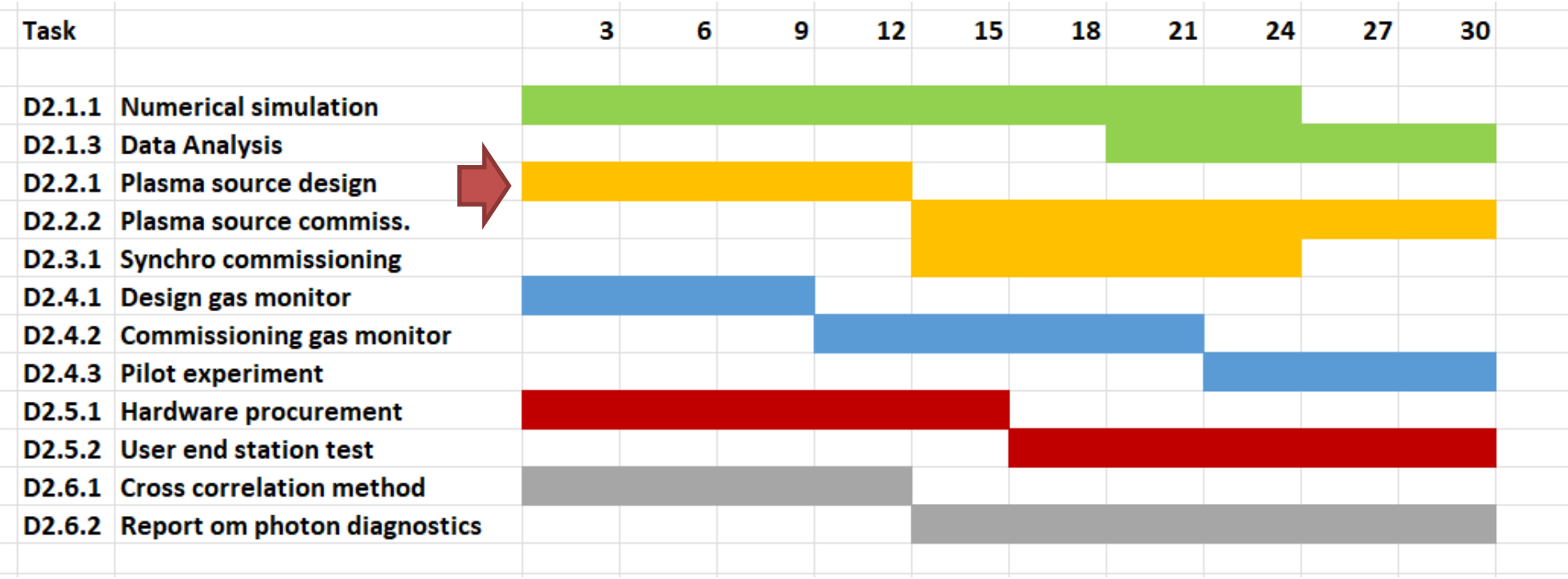
- Permanent tunable dipole to bend the beam to a parallel line to run below the X photons to the dump
- The laser removal is a bigger problem here because the focal is shorter and the laser divergence after the interaction is very large about 66 mrad.

# First attempt to be improved





# Official deliverables schedule



# Tentative schedule for betatron

- First year:
  - Betatron: parametric studies@FLAME
  - Definition of the new machine layout
  - Simulations
  - Starting hardware procurement for big parts
  - Vacuum tests
  - Design of the laser removal
  - Hire the personnel
- Second Year:
  - Installation of compressor @SPARC
  - Transport of laser and plasma source @SPARC
  - Installation of the new beam line
  - Starting source commissioning
- Last 6 months
  - Installation of X rays diagnostics
  - Installation of user chamber
  - Diagnostics commissioning
  - Pilot experiment

# Critical issues

- Define the radiation properties to tailor X ray beamline and pilot experiment
- Overlap between betatron radiation developing @FLAME and laser replacement @SPARC
- Gas removal
- Synchronize Flame with experiments
- Hardware procurement
- EuAPS installation will prevent future installations in SPARC, or we have to dismount the line every time that we need to move big hardware