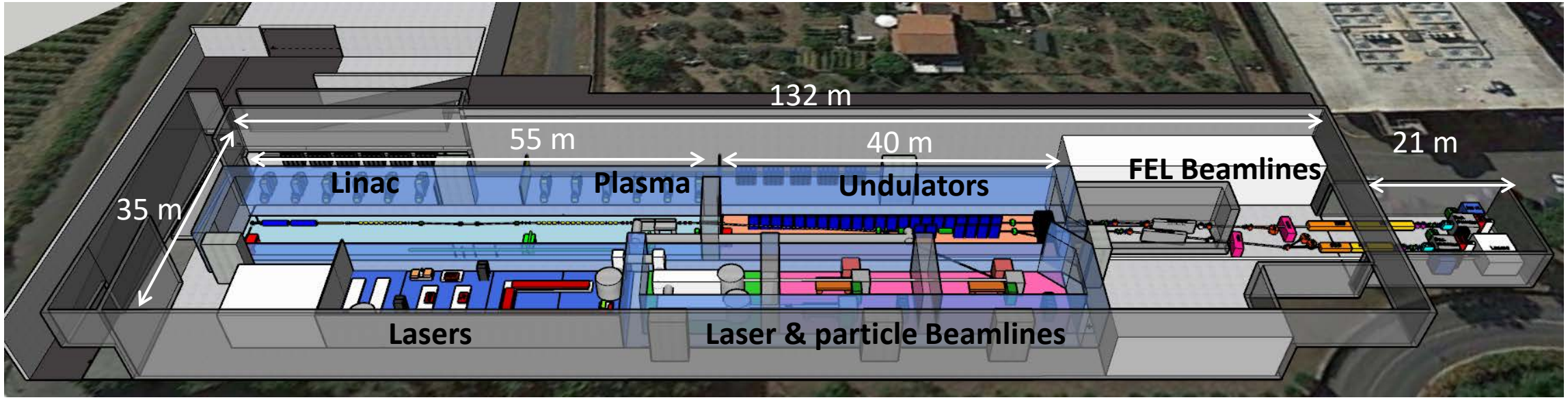
ARIA – A VUV beamline for EuPRAXIA@SPARC_LAB

F. Villa on behalf of EuPRAXIA@SPARC_LAB team

Outline

- EuPRAXIA@SPARC_LAB
  - AQUA and ARIA beamlines
- ARIA beamline
  - Scientific case
  - FEL preliminary simulations
  - Beamline description
- Conclusions

EuPRAXIA@SPARC_LAB



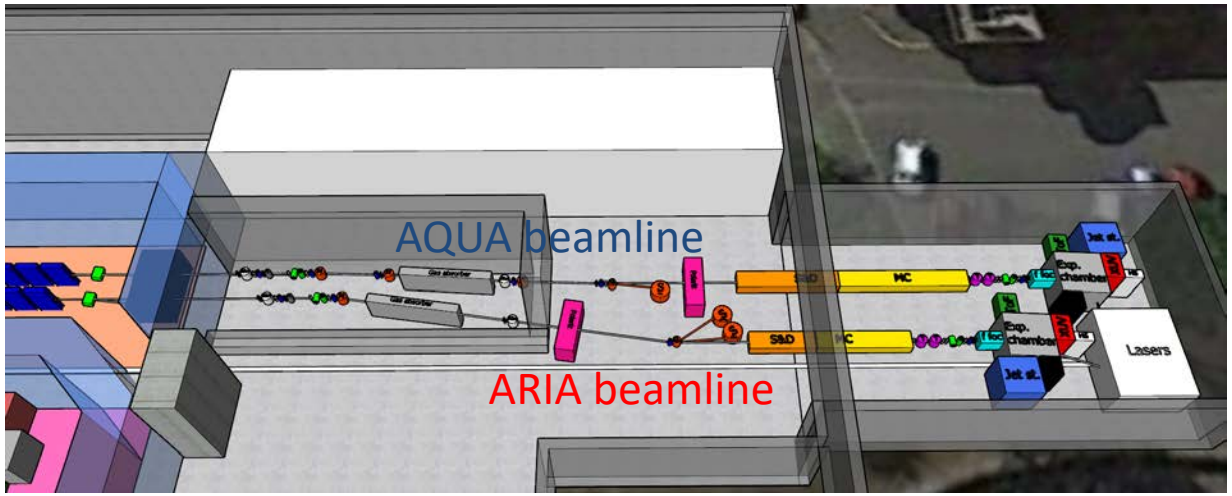
New facility proposed in Frascati National Laboratories, Italy

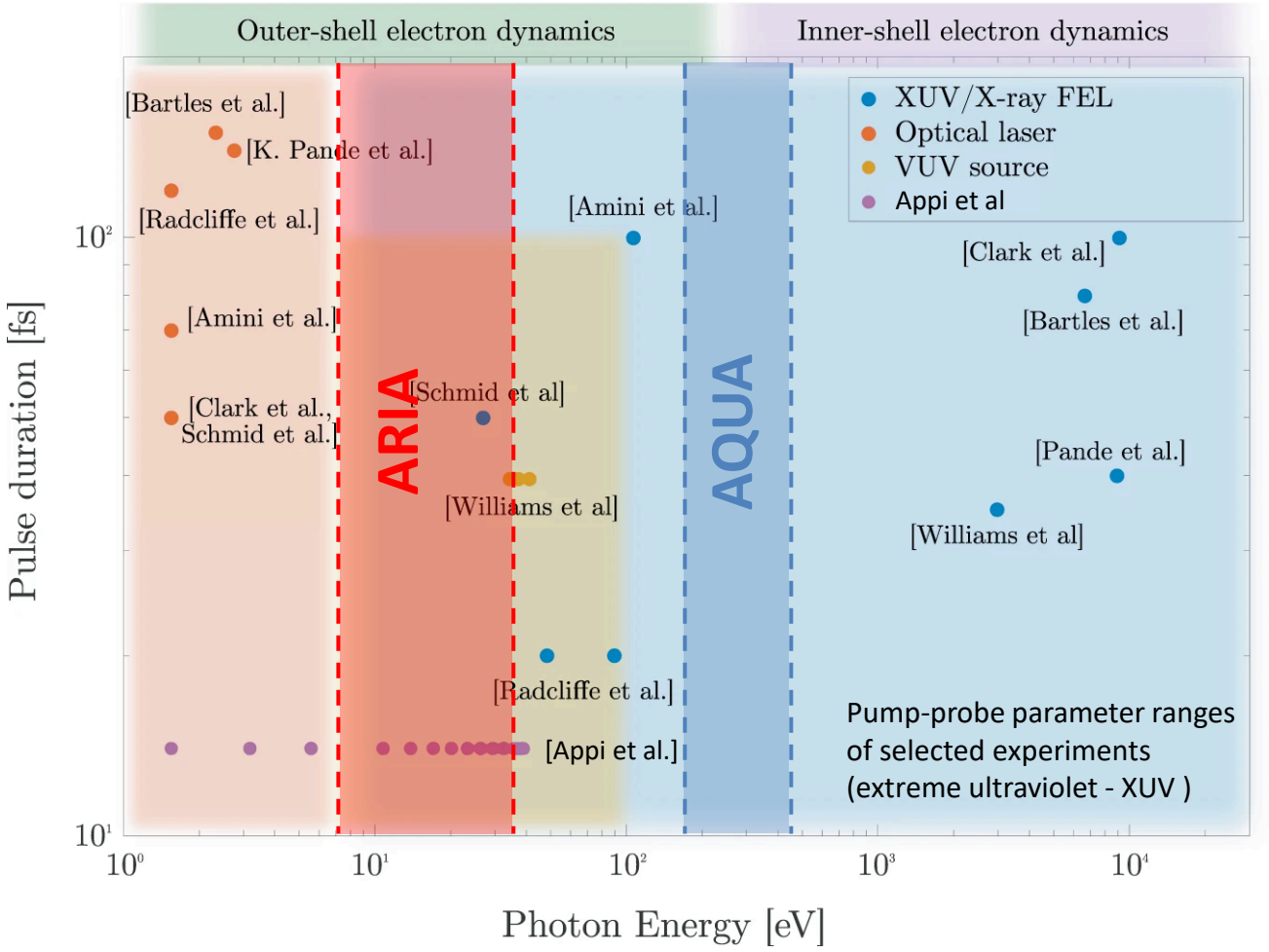
1GeV high brilliance electron beam via plasma acceleration and x-band linac
0.5 PW Ti:Sapphire laser system (with ancillaries for photocathode, FEL, users, THz, …)

Compactness

M. Ferrario presentation (Tue 8/6, The EuPRAXIA@SPARC_LAB project and related R&D activities at LNF)

EuPRAXIA@SPARC_LAB FEL beamlines





AQUA: SASE water window (~3 nm) beamline
ARIA: seeded VUV-XUV (50-160 nm) beamline

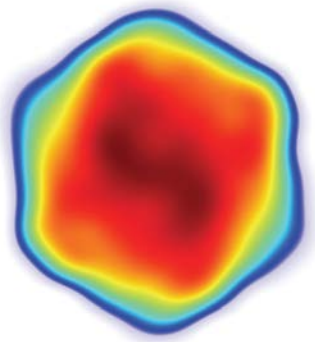
+ Short, coherent, tunable FEL pulses
+ Compact design
- Low rep rate, photon per pulse

E. Appi et al. *A synchronized VUV light source based on high-order harmonic generation at FLASH*. **Sci Rep** 10 (**2020**) 6867 DOI: https://doi.org/10.1038/s41598-020-63019-2

AQUA - Techniques & Samples @ 3 nm

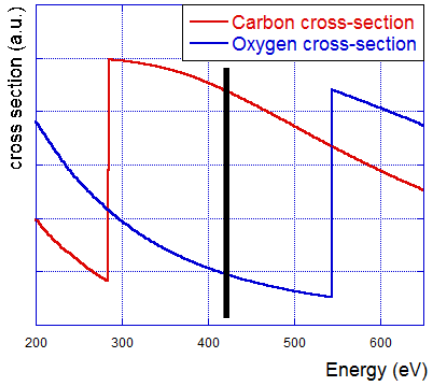
Experimental techniques and typology of samples

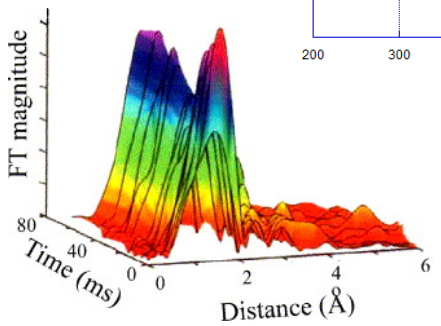
Coherent imaging



X-ray absorption spectroscopy

Element selectivity





Raman spectroscopy

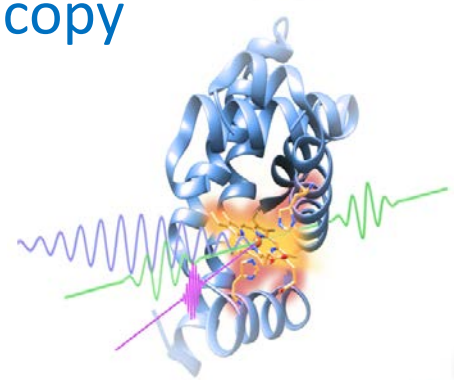
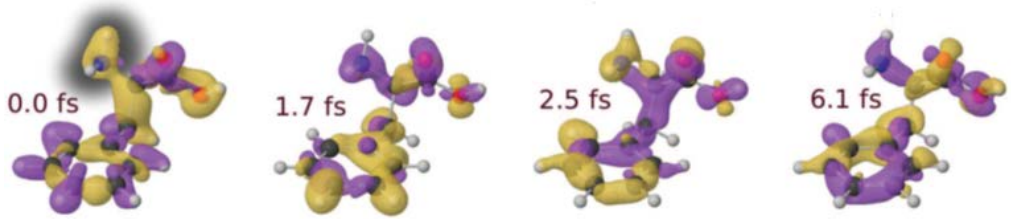


Photo-fragmentation of molecules



in liquid

- Proteins
- Viruses
- Bacteria
- Cells
- Organic molecules
- Metals
- Semiconductors
- Superconductors
- Magnetic materials

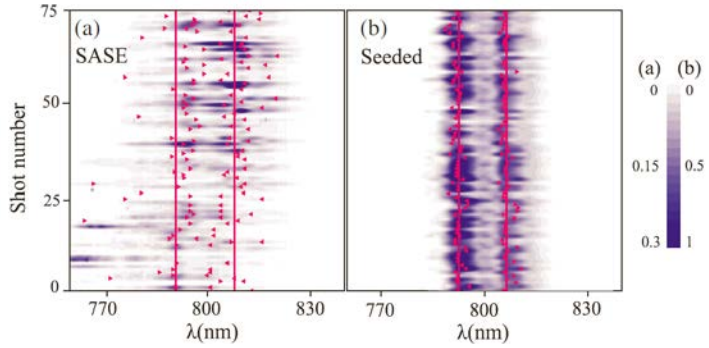
CDR: http://www.lnf.infn.it/sis/preprint/pdf/getfile.php?filename=INFN-18-03-LNF.pdf

Beamline: F. Villa et al., *J. Phys.: Conf. Ser.* 1596, 012039 (2020)

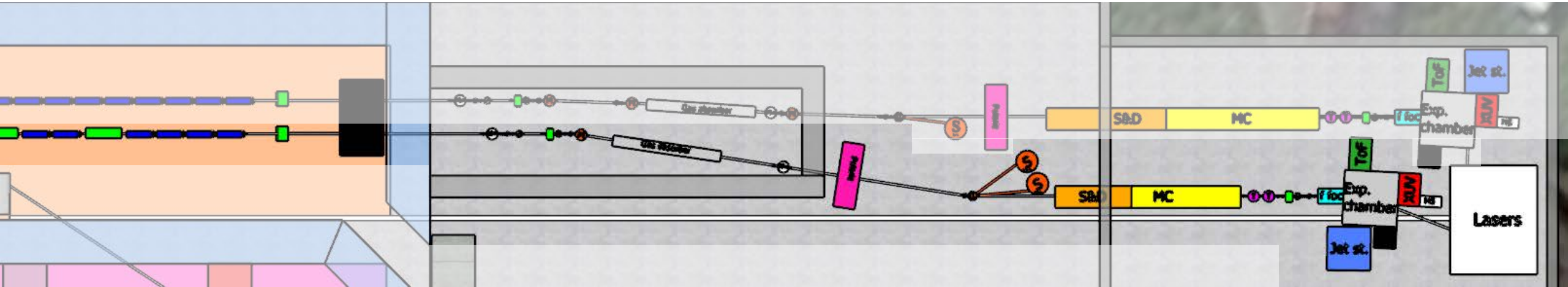
Scientific case: A. Balerna et al. *Condensed Matter* 4, 30 (2019)

ARIA VUV-XUV beamline

- Seeded FEL beamline => 2nd order coherence
- Wavelength range 50-160 nm, continuously tunable
- 10-100 uJ energy per pulse
- Tunable polarization (linear and circular)
- Larger electron beam parameter acceptance (simplifies facility commissioning)



Sample of experimental data of the same configuration in SASE and seeding (PRL 115, 014801 (2015))

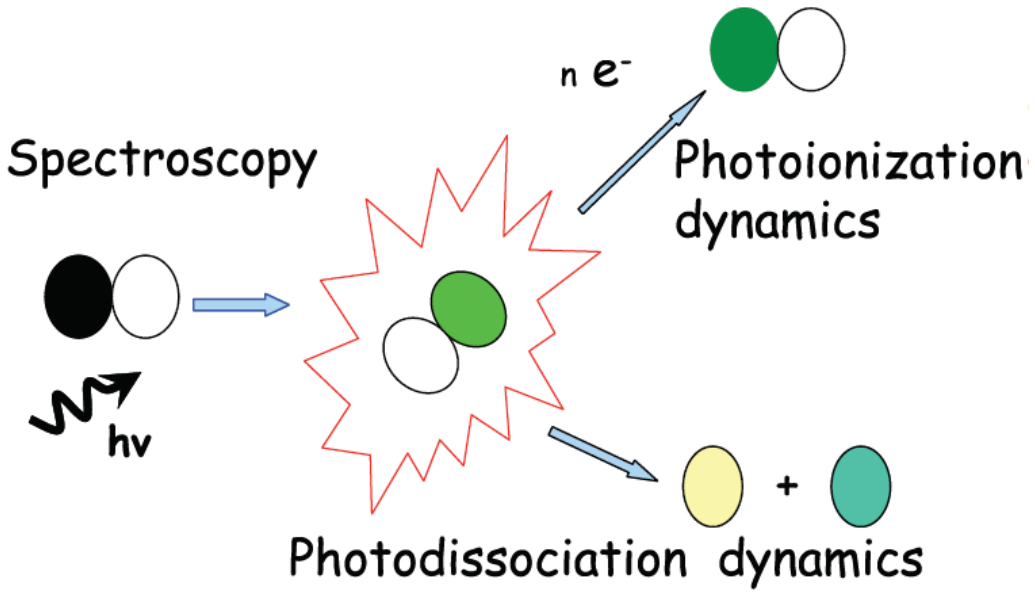


ARIA – Scientific case

Photoemission Spectroscopy

Raman spectroscopy

Photo-fragmentation of molecules
Time of Flight Spectroscopy



Gas phase & Atmosphere
(Earth & planets)

Aerosols
(Pollution, nanoparticles)

Molecules & gases
(Spectroscopies, time-of-flight)

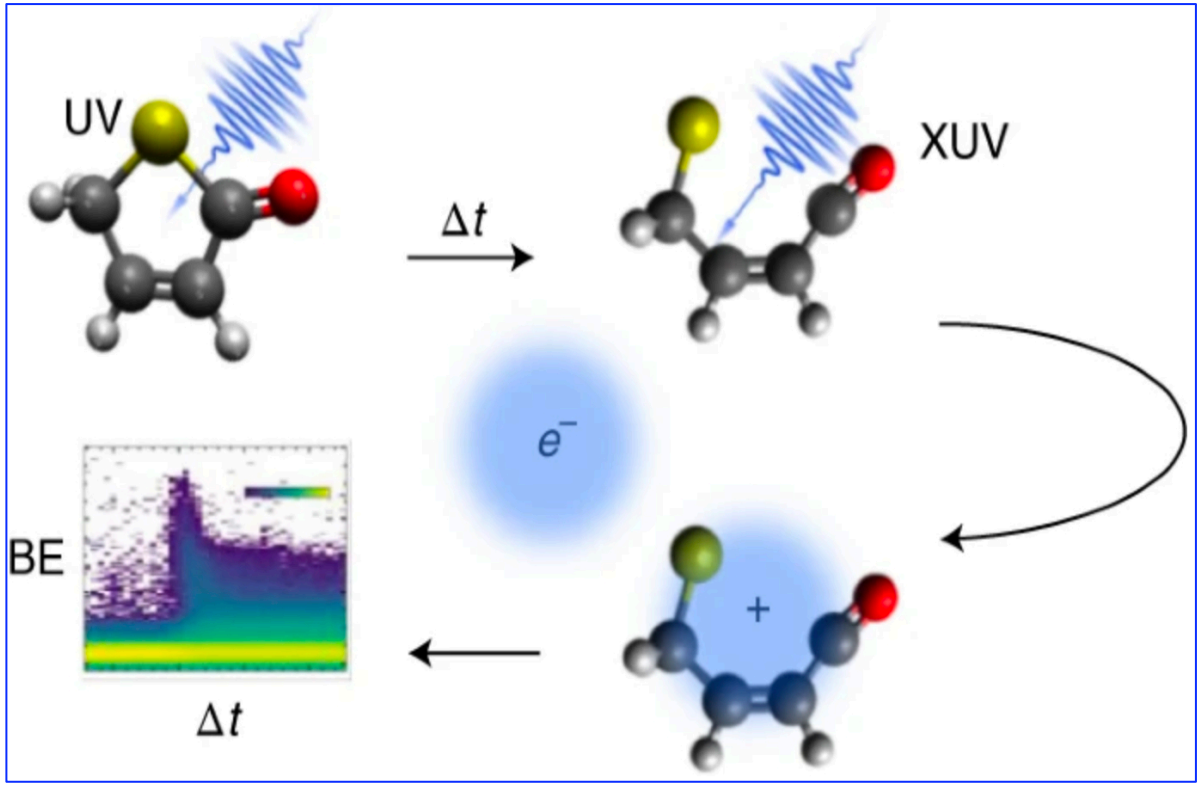
Proteins
(Spectroscopies)

Surfaces
(Ablation & deposition)

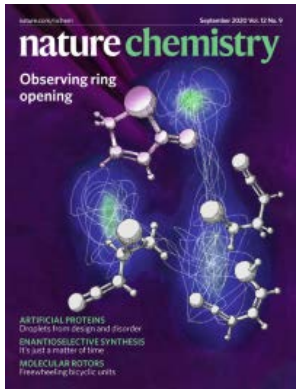
ARIA – Scientific case

Ring opening reactions are observed in nature and an example is the **formation of vitamin D_3 in skin**. When sunlight shines on skin, there are big compounds that have these small ring structures that help with the **absorption of UV light**. **The ring opens to form the precursor to vitamin D_3 formation**.

Making vitamin D involves various biological functions and this ring opening is just one small - very small - part of the process. Understanding the process has big technological implications but is also important for developing general rules that can be applied to similar reactions.



Pathak, S., Ibele, L.M., Boll, R. *et al.* **Tracking the ultraviolet-induced photochemistry of thiophenone during and after ultrafast ring opening**. *Nat. Chem.* **12,** 795–800 (2020). https://doi.org/10.1038/s41557-020-0507-3

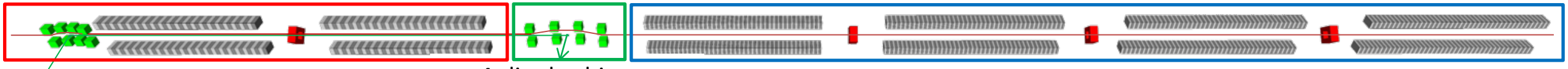


ARIA – HGHG seeded FEL scheme

Modulator (λ_w=10cm)

Dispersion chicane

Radiator (λ_w=5.5cm)



Laser seed:
λ_0=500 nm

1 T/m quad

4-dipole chicane
30 cm drifts,
10 cm 0.2-0.3 T dipoles

2 T/m quads

λ_0=500 nm modulation

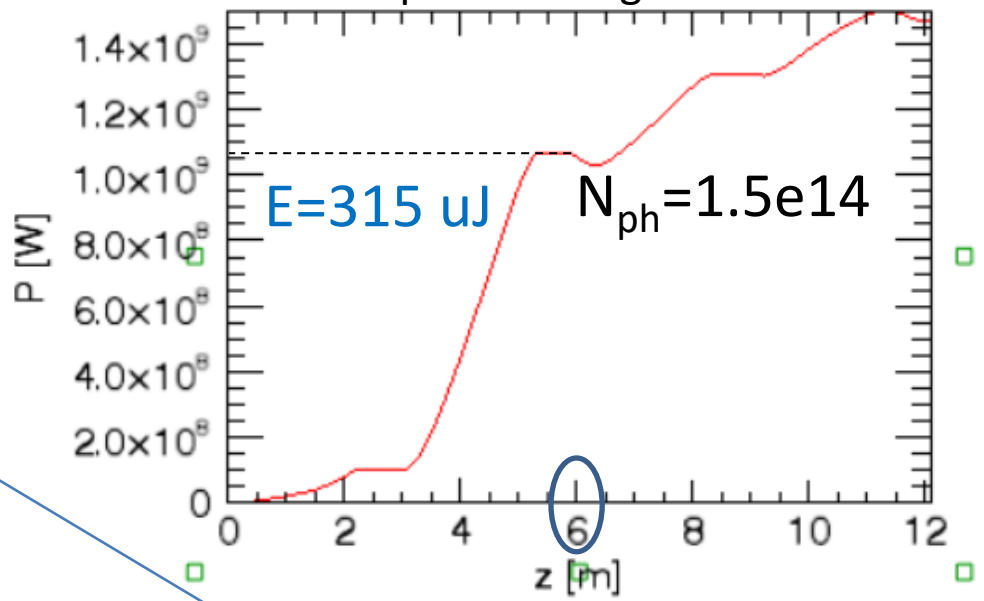
λ_n=50-160 nm via harmonic amplification (n=3-11)

Converts electron energy modulation
to spatial bunching in harmonics
Remove λ_0 radiation

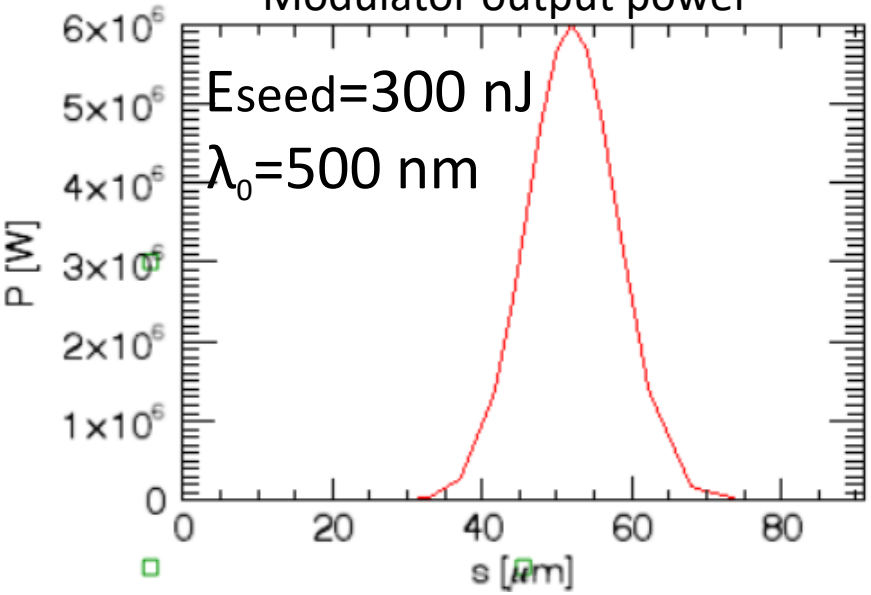
ARIA – FEL simulations for large charge & duration

Electron bunch
Charge: 200 pC
Beam length: 40 fs
Energy: 1 GeV
Energy spread: 200 keV
Slice $\varepsilon_{nx,y}$ = 0.5 mm mrad

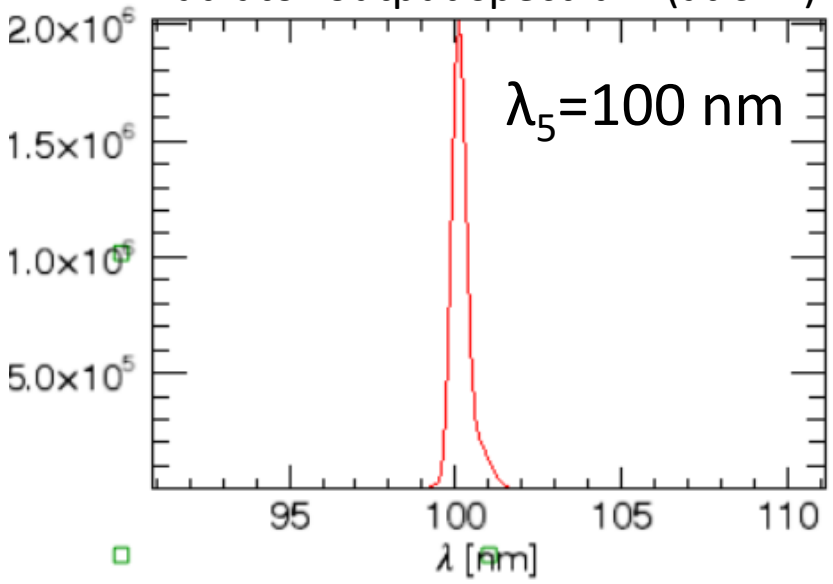
Radiator power along the undulators



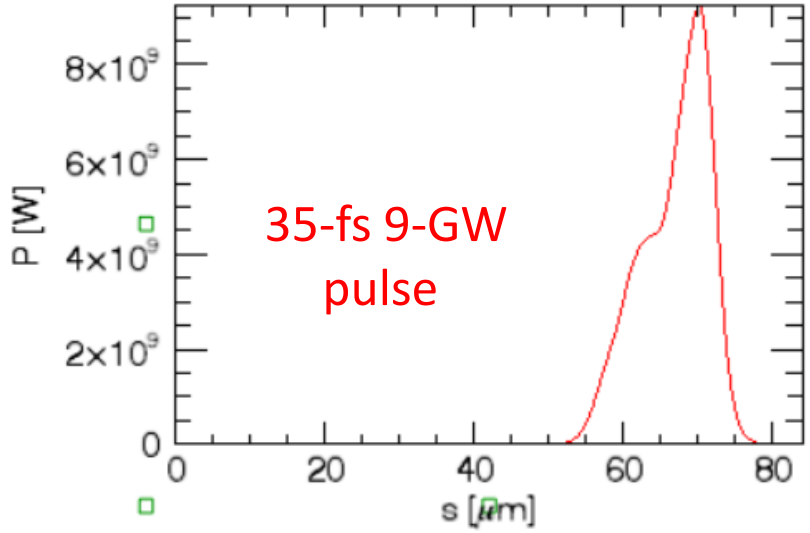
Modulator output power



Radiator output spectrum (at 6 m)



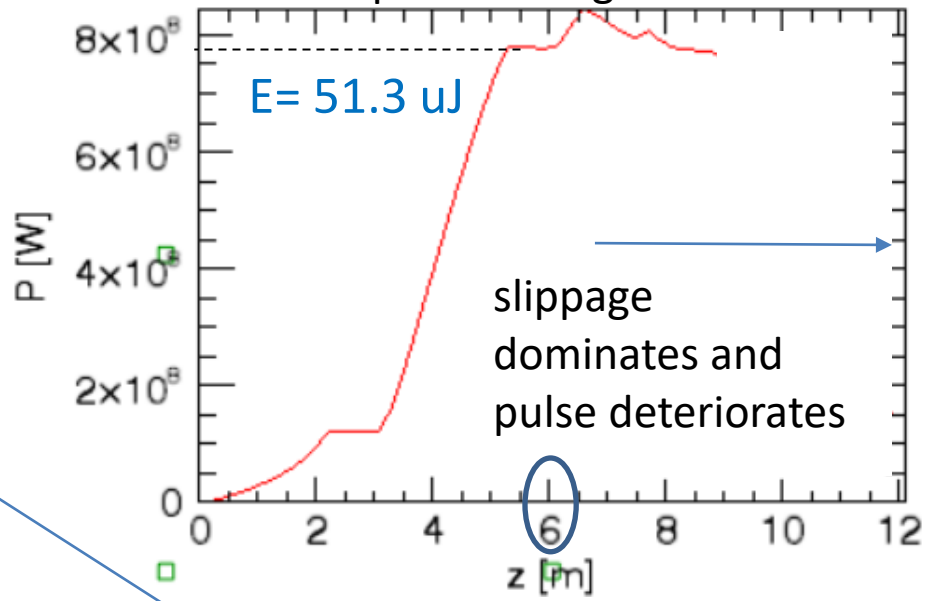
Radiator output time profile



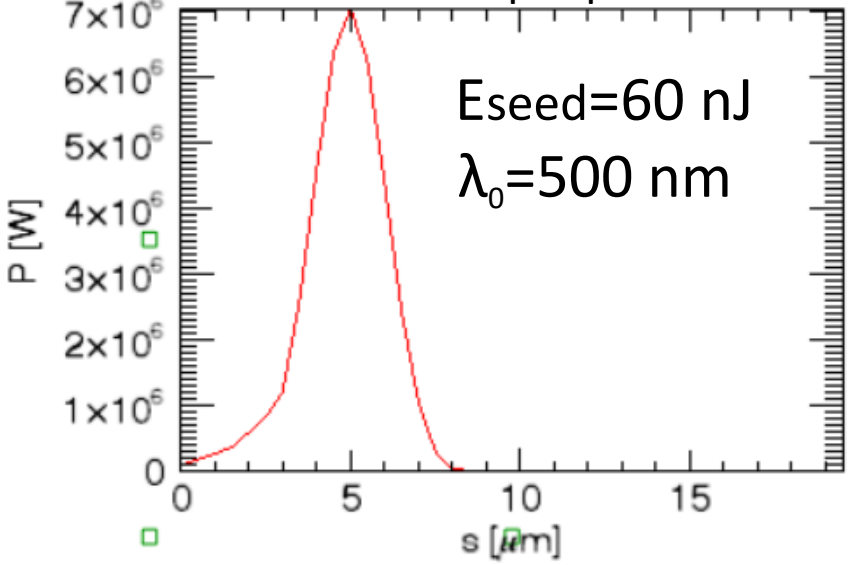
ARIA – FEL simulations for small charge & duration

Electron bunch
Charge: 30 pC
Beam length: 15 fs
Energy: 1 GeV
Energy spread: 170 keV
Slice $\varepsilon_{nx,y}$ = 0.5 mm mrad

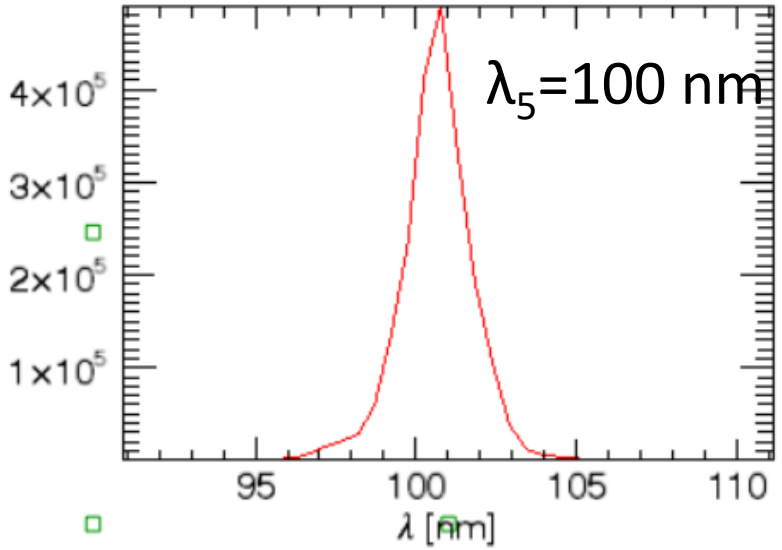
Radiator power along the undulators



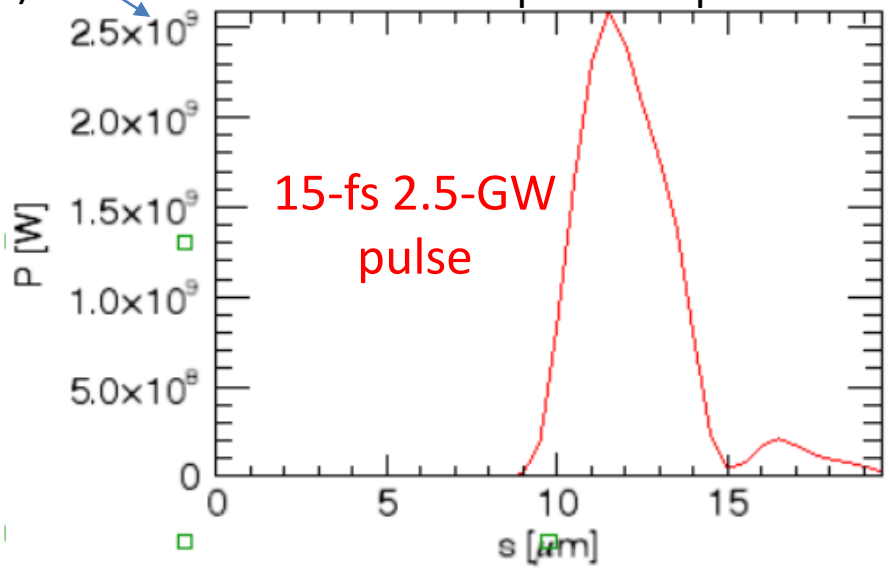
Modulator output power



Radiator output spectrum (at 6 m)



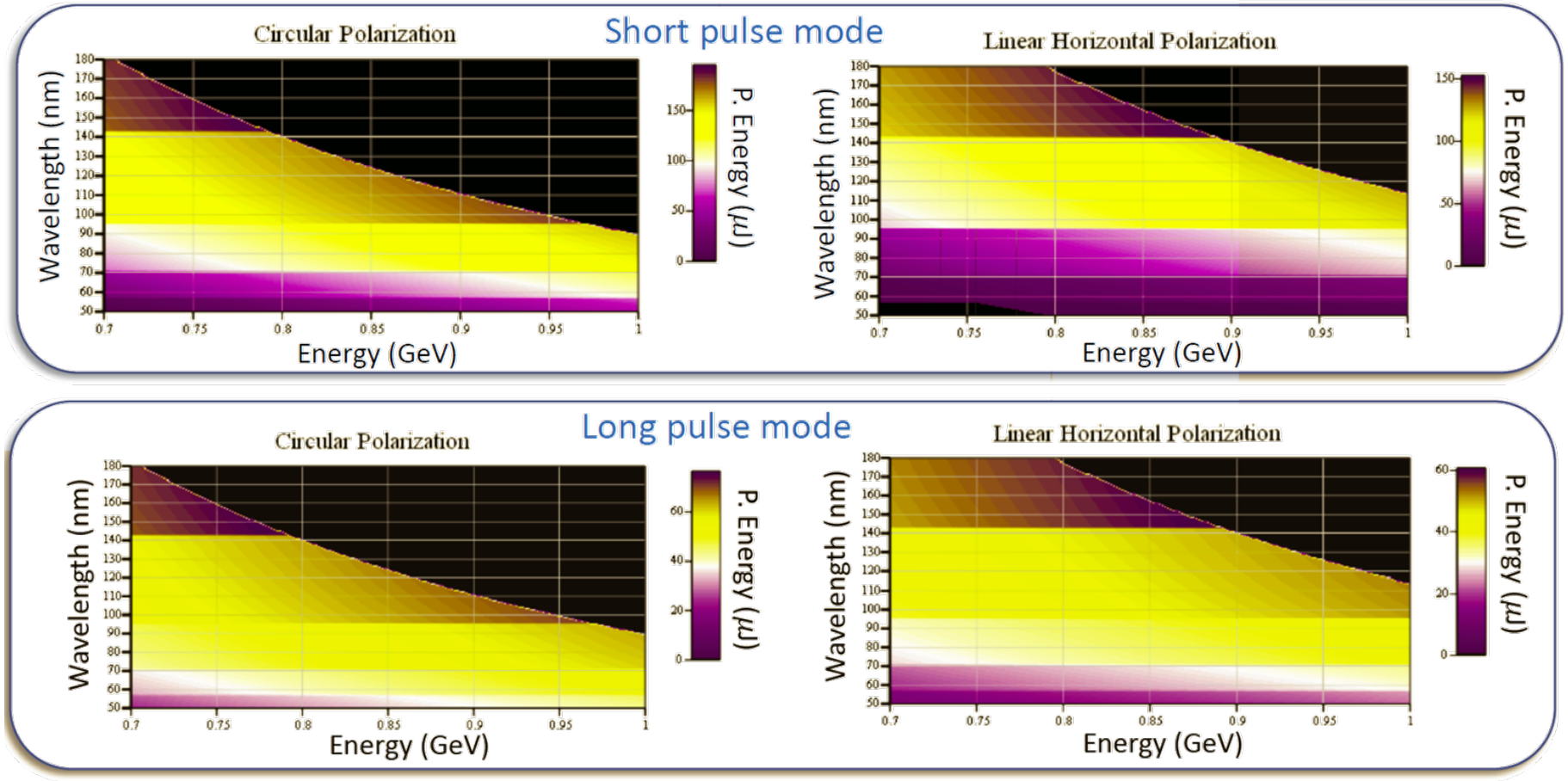
Radiator output time profile



ARIA – FEL tuning range simulations

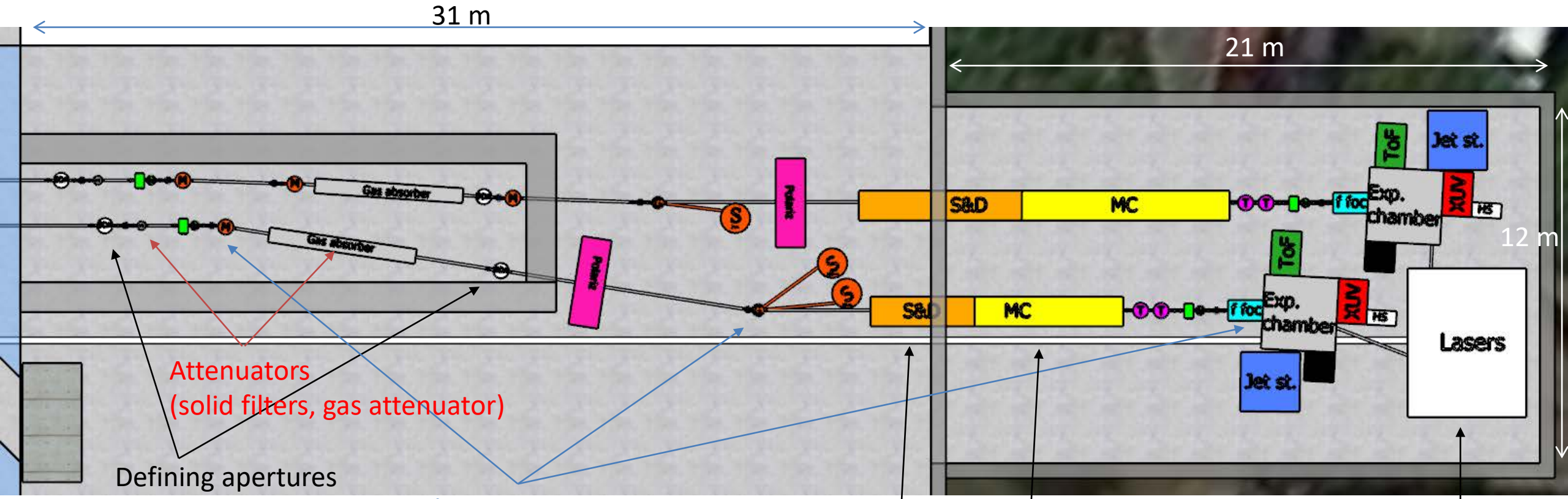
Electron beam	
Energy	0.7-1 GeV
Current (L-S)	700 - 1500 A
Charge (L-S)	200 - 30 pC
Emittance (L-S)	1.5 - 2 mm mrad
Ene. spread (L-S)	1 – 3 (x10^{-4})

Undulator type: APPLE II



Based on corrected Ming Xie equations

ARIA – Beam manipulation



Attenuators
(solid filters, gas attenuator)

Defining apertures

Mirrors
and focusing
K-B or zone plates

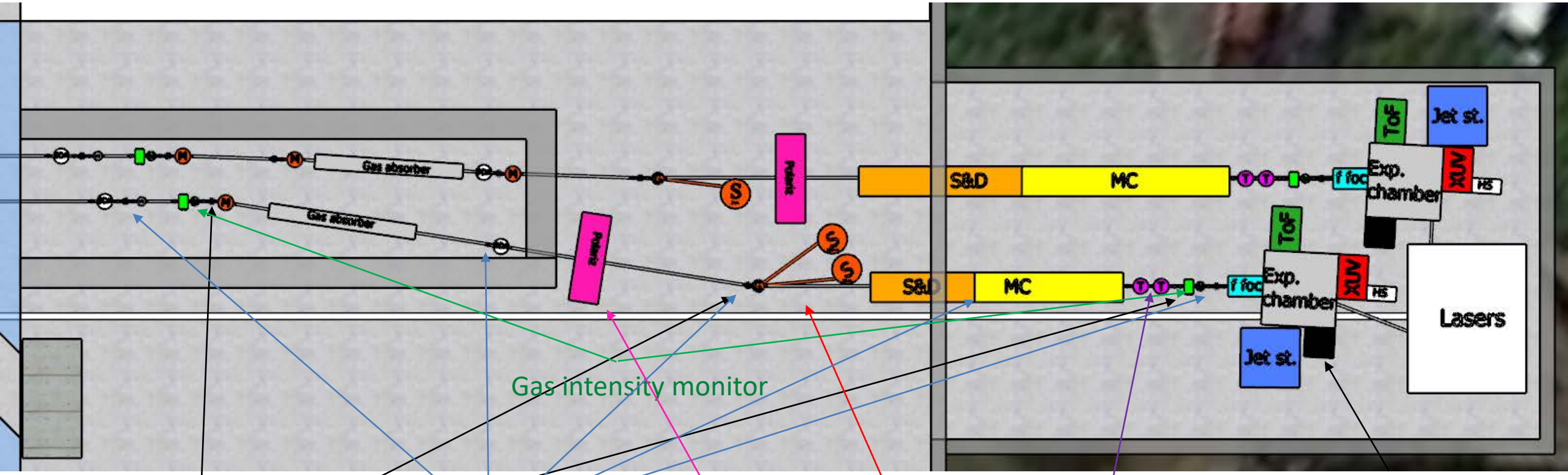
Split & delay line

Grating
Monochromator

Removable

Lasers
~100 mJ at 800 nm
for direct or HG p-p
synch. with FEL
duration down to 25 fs

ARIA – Beam characterization



Gas intensity monitor

Removable YAG Screens

Plate
BPMs

Polarization measure (angular resolved ionization)

Grating spectrometer (movable camera)

Time measure (THz streaking)

Experimental chamber
- ToF
- High res. camera
- Hartmann sensor
- Jet station

Conclusions

- EuPRAXIA@SPARC_LAB beamlines:
  - AQUA for water window experiments
  - ARIA for VUV - XUV experiments
    - FEL simulations, scientific case, beamline simulations

Not yet in the baseline

- Timeline
  - End 2024: TDR delivery
  - By 2027: building construction and delivery
  - By 2029-2030: commissioning and pilot users

Thank you for the attention