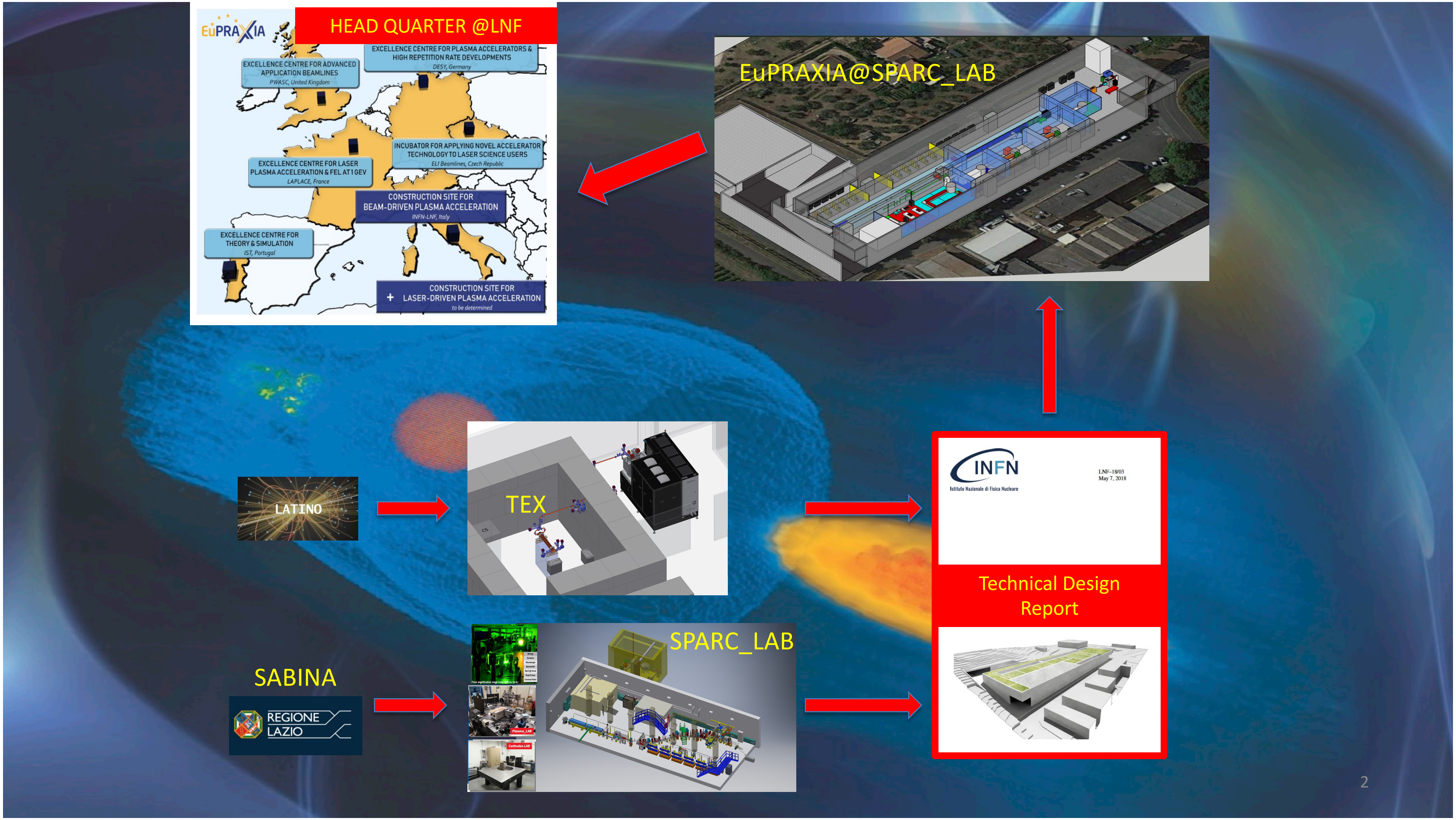
EuPRAXIA@SPARC_LAB

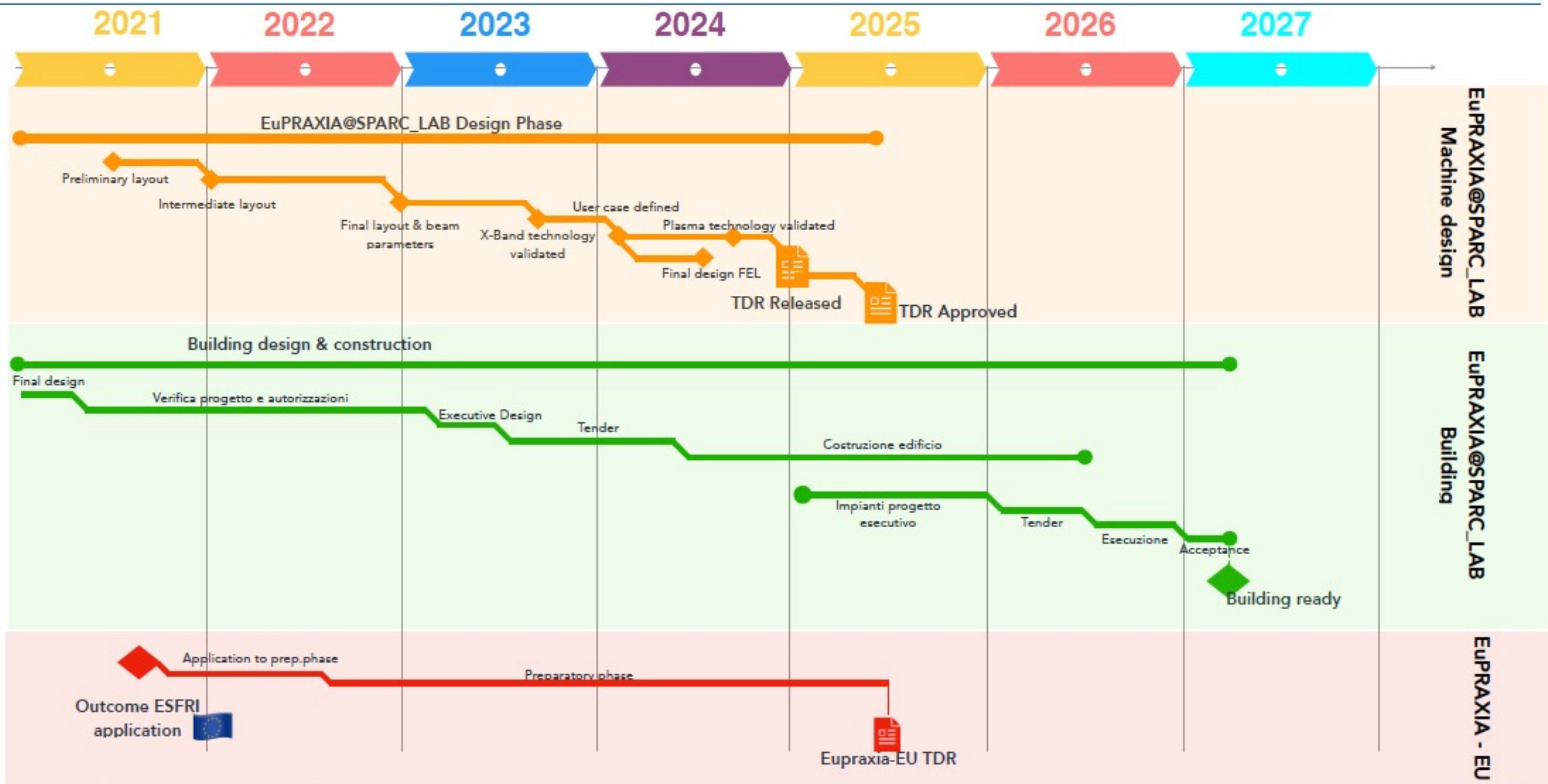
Massimo.Ferrario@LNF.INFN.IT

61 LNF Scientific Committee Meeting, May 6, 2021


HEAD QUARTER @LNF
EuPRAXIA
EXCELLENCE CENTRE FOR PLASMA ACCELERATORS & HIGH REPETITION RATE DEVELOPMENTS
DESY, Germany
EXCELLENCE CENTRE FOR ADVANCED APPLICATION BEAMLINES
PWASC, United Kingdom
INCUBATOR FOR APPLYING NOVEL ACCELERATOR TECHNOLOGY TO LASER SCIENCE USERS
ELI Beamlines, Czech Republic
EXCELLENCE CENTRE FOR LASER PLASMA ACCELERATION & FEL AT 1 GEV
LAPLACE, France
CONSTRUCTION SITE FOR BEAM-DRIVEN PLASMA ACCELERATION
INFN-LNF, Italy
EXCELLENCE CENTRE FOR THEORY & SIMULATION
IST, Portugal
CONSTRUCTION SITE FOR LASER-DRIVEN PLASMA ACCELERATION
to be determined
EuPRAXIA@SPARC_LAB
LATINO
TEX
SABINA
REGIONE LAZIO
SPARC_LAB
INFN
Istituto Nazionale di Fisica Nucleare
LNF–18/03
May 7, 2018
Technical Design Report

Istituto Nazionale di Fisica Nucleare

Road map

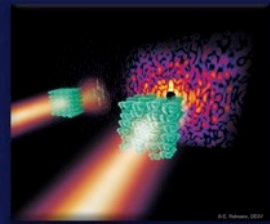


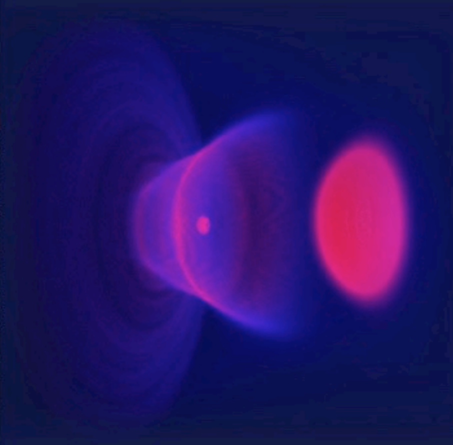
EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA ESFRI Hearing

EuPRAXIA Consortium

15.04.2021





Process of ESFRI Application

- Sep 2020 **Submitted**
- Nov 2020 Found eligible for ESFRI Roadmap

  Detailed assessment through ESFRI panels
- 30 Mar 2021 Critical questions received
- 6 Apr 2021 Dry run with INFN president plus Italian representatives
- 12 Apr 2021 Additional support letters on financial side submitted (CNRS, STFC, Queen's University)
- **15 Apr 2021** **ESFRI Hearing** (EuPRAXIA representatives for the hearing: R. Aßmann, M. Ferrario, M. Weikum)
- **July 2021** **Announcement of decision**

ESFRI Hearing on April 15

Questions for EuPRAXIA hearings

1. Is there major research of high socioeconomic impact in the area of H&F that can directly benefit from the development of this infrastructure? What is the range of applicability in medicine and food compared to other industries?
2. What measures are foreseen to ensure that proof of principle experiments will develop into robust operational devices ready to serve applications of societal interest, especially in H&F? Is there a detailed plan of user access/strategy for the area of health and food and on what grounds will the choices of the end-user beamlines be made and how the performance of these beamlines will be benchmarked and compared to e.g. existing beamlines at synchrotrons, FELs etc.?
3. How to integrate and maintain the integrity of the network and the individual nodes regarding long-term co-operation. What is the plan for ensuring that they each benefit from the collaboration?
4. What makes this an ESFRI infrastructure as opposed to EU funded networking activities, or integrated infrastructure projects, or an effort to incrementally improve over the existing similar test facilities?
5. There is definite funding commitment only from Italy. What are the prospects and plans to develop and secure the funding base?
6. What is the expected number of experiments and annual total volumes of data to be archived and exchanged among nodes - how are the networking capacities related to data management secured and what is the strategy for data archiving and openness?
7. What are the selection criteria for identifying the second construction site?
8. What is the plan for E-infrastructure resource use at institutional, regional, national, international level? Is there a plan for new member countries?
9. Every larger RI with sufficient construction expenses has high to very high risk of the proposed constructing costs in comparison to real (future) constructing costs. Please elaborate on this risk and how to solve this financial risk?

ESFRI Hearing on April 15

1. Closed session of the committee

   9 members, representing several ESFRI panels: PSE, F&H, implementation, e-infrastructure, many at leadership level headed by German ESFRI representative from BMBF

2. 40 minute presentation by us

3. 40 minute verbal questions and answers

4. Outcome expected by July/September

EUROPEAN
PLASMA RESEARCH
ACCELERATOR WITH
EXCELLENCE IN
APPLICATIONS

EuPRAXIA Collaboration Board

EuPRAXIA Consortium, Remote

16.04.2021

First EuPRAXIA Collaboration Board Meeting on April 16

13:00 → 13:05 **Approval of Agenda**

13:05 → 13:20 **Election of CB Chair** → Massimo Ferrario

13:20 → 13:35 **Election of Project Coordinator** → Ralph Assmann

13:35 → 14:05 **Report from ESFRI application**

Speakers: Ralph Assmann (Istituto Nazionale di Fisica Nucleare) , Ralph Assmann (DESY)

14:05 → 14:35 **Report from Frascati project on EuPRAXIA beam-driven site**

Speaker: Massimo Ferrario (LNF)

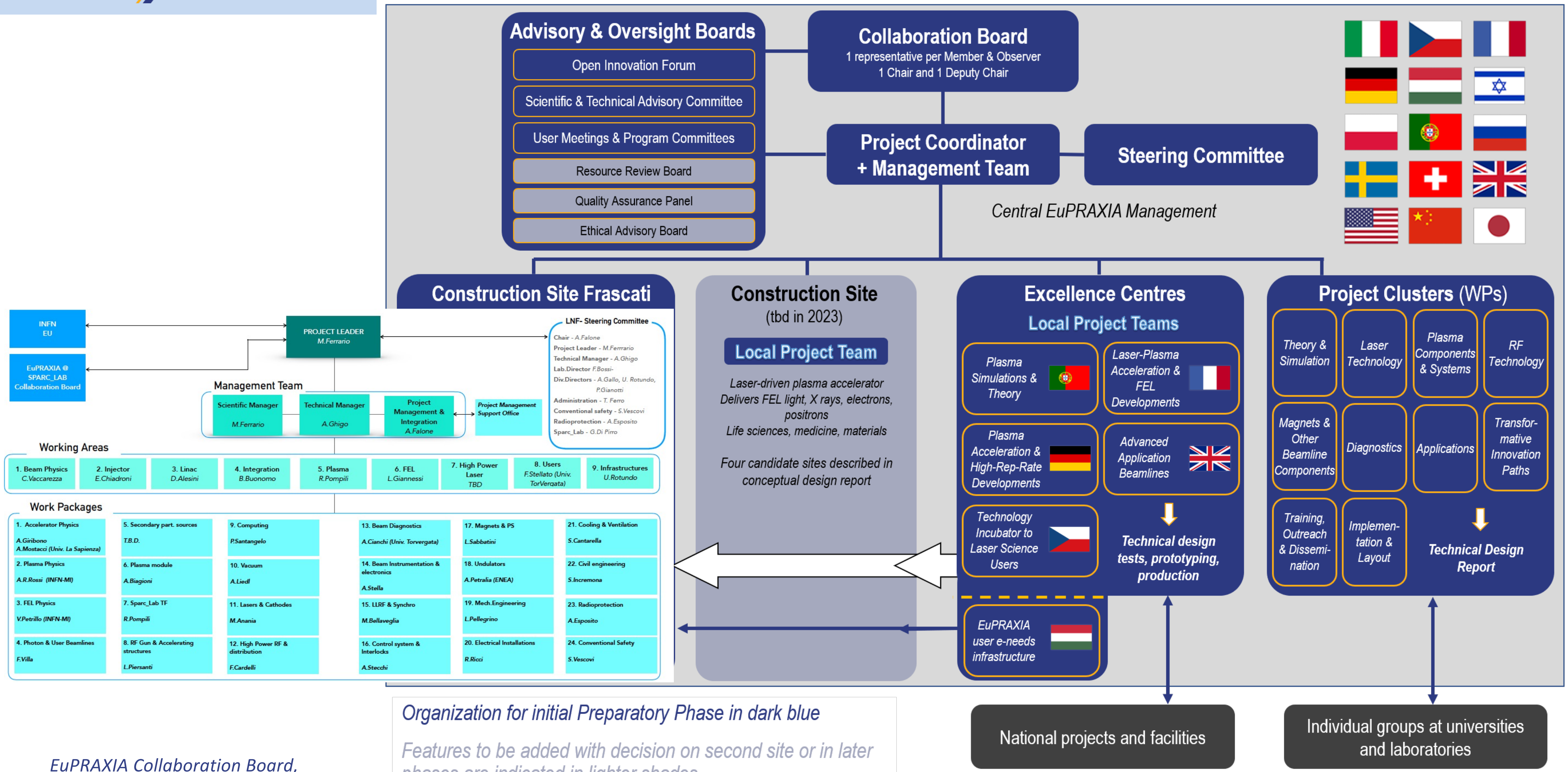
14:35 → 15:05 **Discussion on EuPRAXIA Work Breakdown Structure (WBS)**

15:05 → 15:50 **Report and discussion on next EU funding opportunities**

15:50 → 16:00 **AOB and Adjourn** ¶

EuPRAXIA Organisation Chart

EUROPEAN
PLASMA RESEARCH ACCELERATOR WITH
EXCELLENCE IN APPLICATIONS



EuPRAXIA Collaboration Board, 16/04/2021

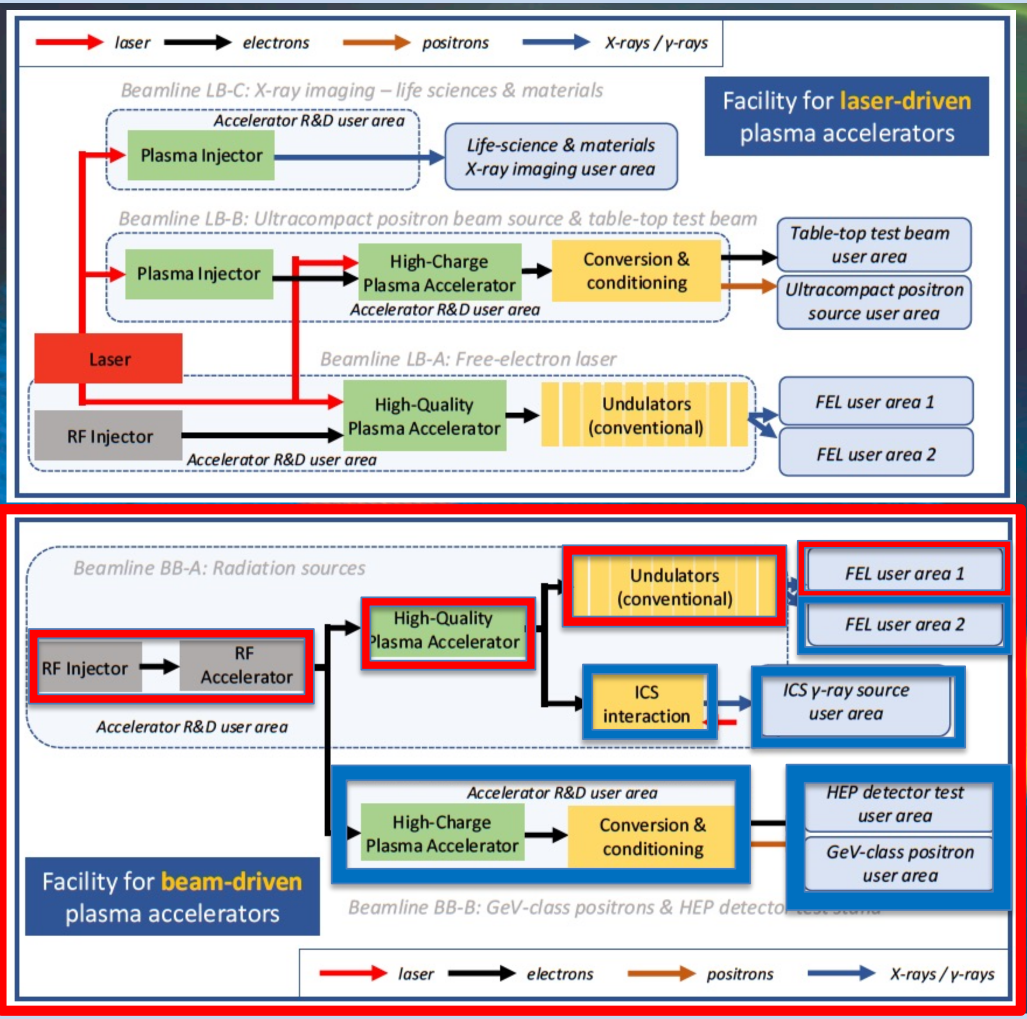
EuPRAXIA HQ Office at Frascati

• Ralph Assmann	EuPRAXIA Consortium Coordinator
• Massimo Ferrario	Project Leader EuPRAXIA at Frascati
• Antonio Falone	Project Manager, ESFRI Proposal Coordinator
• Giulia Vinicola	Adminstrative Management
• Massimiliano Lungo (**New**)	Project Planning and Organization

- **More to Come ……………..**

EuPRAXIA Conceptual Layout

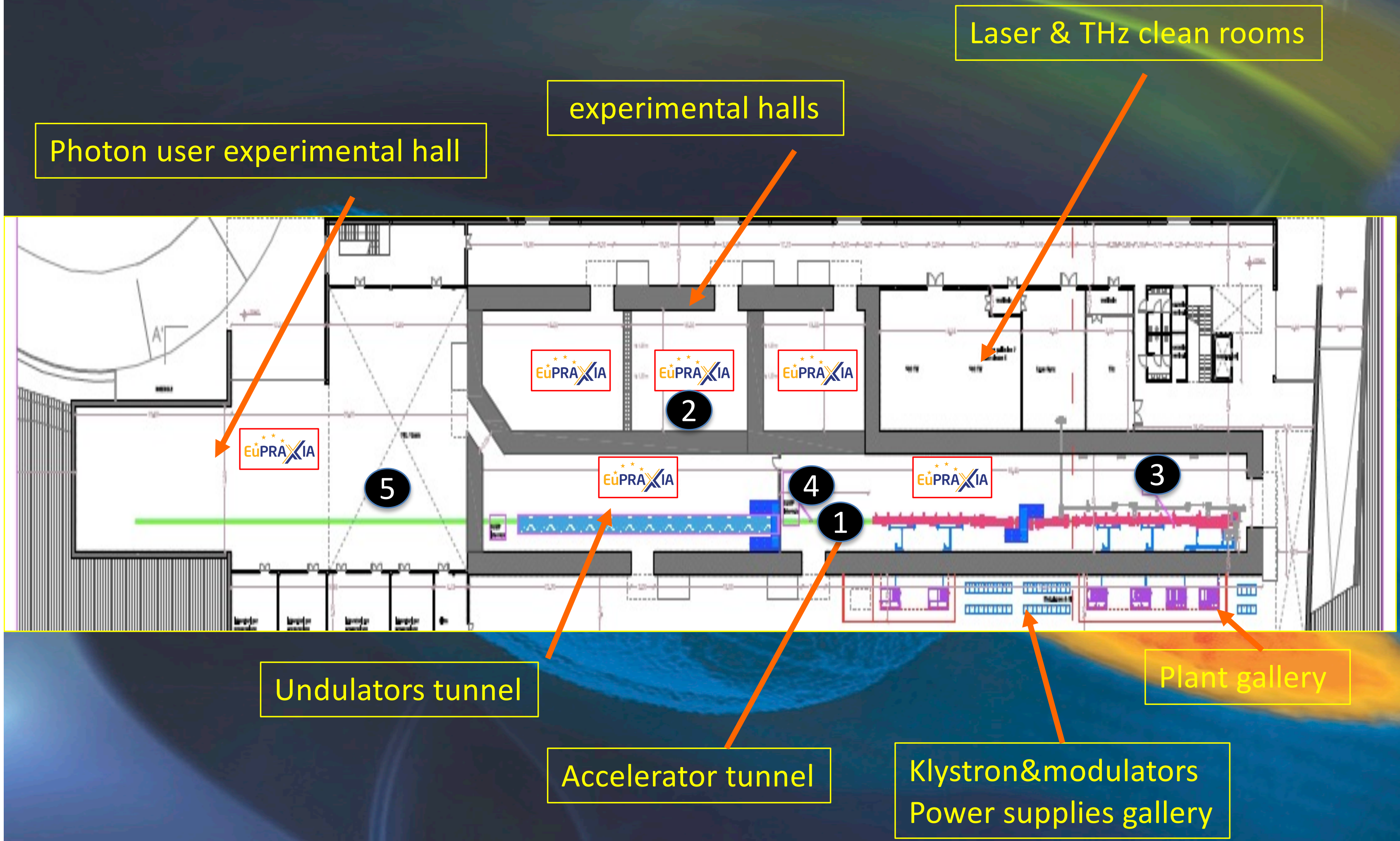
Horizon 2020



EuPRAXIA **lasers** will operate with high stability at 20 to 100 Hz, a modest advancement of a factor 2 to 10 over the current state of the art. In parallel, R&D activities will be pursued on the development of laser that can operate at kHz repetition rates and deliver peak-power at 100 TW or more.

EuPRAXIA also includes the development and construction of a compact **X-band RF** accelerator based on technology from CERN with up to 100 MV/m gradients to realise a beam-driven plasma accelerator.

Opportunities for Collaborations at EuPRAXIA@SPARC_LAB



European interests & possible contributions to Frascati site:

1. Plasma structure designs, devices
2. Compact positron source
3. HQ 150 MeV laser plasma injector
4. HQ laser driver
   - Hybrid concepts
   - Simulations
5. User experiments and lines

To be detailed in TDR phase.

First TDR Review Meeting on February 22

TDR Review Report

EuPRAXIA@SPARC_LAB: TDR Review Report

February 22-23, 2021 Meeting

Review Committee Members:
Deepa Angal-Kalinin (UKRI STFC, UK)
Patric Muggli (MPP, Germany, chair)
Marco Pedrozzi (PSI, Switzerland)
Siegfried Schreiber (DESY, Germany)
Luigi Scibile (CERN, Switzerland)

February 2021

Introduction

The meeting of the Review Committee (RC) took place on February 22 with presentations by the EuPRAXIA@SPARC_LAB team members (https://agenda.infn.it/event/25862/). The team was debriefed on February 23, after the RC closed session.

The charge of the the RC was defined as addressing only to the EuPRAXIA@SPARC_LAB project Technical design report (TDR). The SPARC_LAB and EuPRAXIA are evaluated by their own RC. This RC will meet twice a year (April/October) till completion of the TDR document.

General Remarks

In general, the RC was very impressed by the progress on all aspects of the project: building, management, science, etc., since the completion of the CDR. From the global project aspect, it is important to note that EuPRAXIA@SPARC_LAB is included in EuPRAXIA, and that EuPRAXIA was recently declared eligible to be considered for the next ESFRI roadmap. At the same time, LNF has become the headquarter of EuPRAXIA and is also the PWFA pillar, one of the two pillars, the other one being a LWFA pillar, whose location is to be determined. The EuPRAXIA@SPARC_LAB TDR document is in synchronism with the EuPRAXIA TDR document, which is due about a year after that of EuPRAXIA@SPAR_LAB. The design of the facility, especially the building, is fully compatible with the base-line water-window FEL user facility and plasma acceleration R&D projects, and also with the implementation of the EuPRAXIA PWFA pillar at LNF. Costing of the current facility shows that its price fits within the available budget.

Research at SPARC_LAB continues to contribute to science demonstrations necessary for the future of the project. This includes the experimental demonstration of the acceleration of electron bunches in a PWFA with very small final relative energy spread and of a method using passive plasma lenses for the disposal of

LNF Scientific Committee Recommendations

1. **Technology demonstration is clearly a key part of EuPRAXIA@-SPARC_LABs mission, therefore targeted preparatory R&D is an essential part of this activity. Appropriate funding needs to be secured for this R&D.**

2. The accelerating field of the X-band linac should be driven by investment and operation cost considerations. The new choice of 60 MV/m is a reasonable value, but in view of the very high cost of Xband RF power sources the cost saving potential of even lower gradients has to be considered.

3. The scientific case for the EuPRAXIA@SPARC_LAB FEL user program needs to be strengthened. In particular, the Italian user community of FERMI and EuXFEL should be more involved in the definition of FEL parameters and end-station capabilities before the TDR facility parameters are finalized.

4. The scientific potential of using the 0.5 PW Laser of EuPRAXIA@SPARC_LAB as a pump and the FEL as the probe for pump-probe experiments should be investigated. This may provide a unique experimental feature for future FEL users.

5. With the scientific programs of DAFNE and BTF flourishing, SPARC_LAB in operation and EuPRAXIA@SPARC_LAB in preparation, the demands on the RF-Linac technology team at LNF are increasing. LNF management should analyze potential synergies between the three activities and assure that sufficient resources to cover all these activities are available.

Project Management Office

EuPRAXIA@SPARC_LAB Project Management Plan towards TDR

This document summarizes scope, cost & schedule for the completion of the Technical Design Report of EuPRAXIA@SPARC_LAB

Autore	Verificato da	Approvato da
A.Falone M.lungo	A.Falone M.Ferrario	G.E. S.C.

Lista di distribuzione:

- Public

-> TDR Rev. Com. for Technical evaluation

-> INFN Giunta Esecutiva for final approval

The total R&D Cost excluding manpower is therefore 6.5 M€ that are approximately equally splitted in 3 years. Here a short summary of the main procurement that will be done.

Tab3. R&D cost per working area

Working Area	Amount (k€)
WA1- Beam Physics	250
WA2 - Injector	1550
WA3 - Linac	1400
WA4 - Integration	2380
WA5 - Plasma	330
WA6 - FEL	200
WA8 - Users	225
WA9 - Infrastructures	100
Subtotal	6435
Contingencies	320
TOTAL	6755

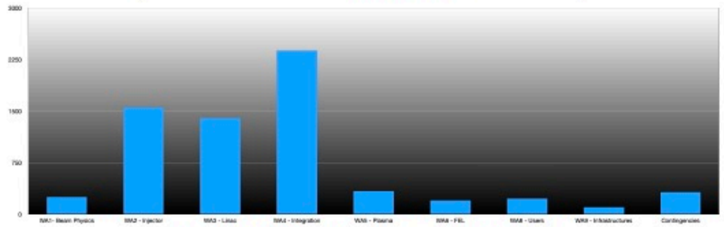


Fig. 4: R&D Cost distribution per working area

Tab.5 R&D Cost distribution per year

Year	Amount (k€)	Contingency (k€)	TOT. k€
2021	3275	120	3395
2022	2020	100	2120
2023	1140	100	1240

Requested urgent pre-allocation of fundings:

Computing Cluster	250 kEuro
CPI High Efficiency Klystron	1300 kEuro
TEX Setup	195 kEuro
Warranty Extension	35 keuro
Totale	**1780 kEuro**

LNF Scientific Committee Recommendations

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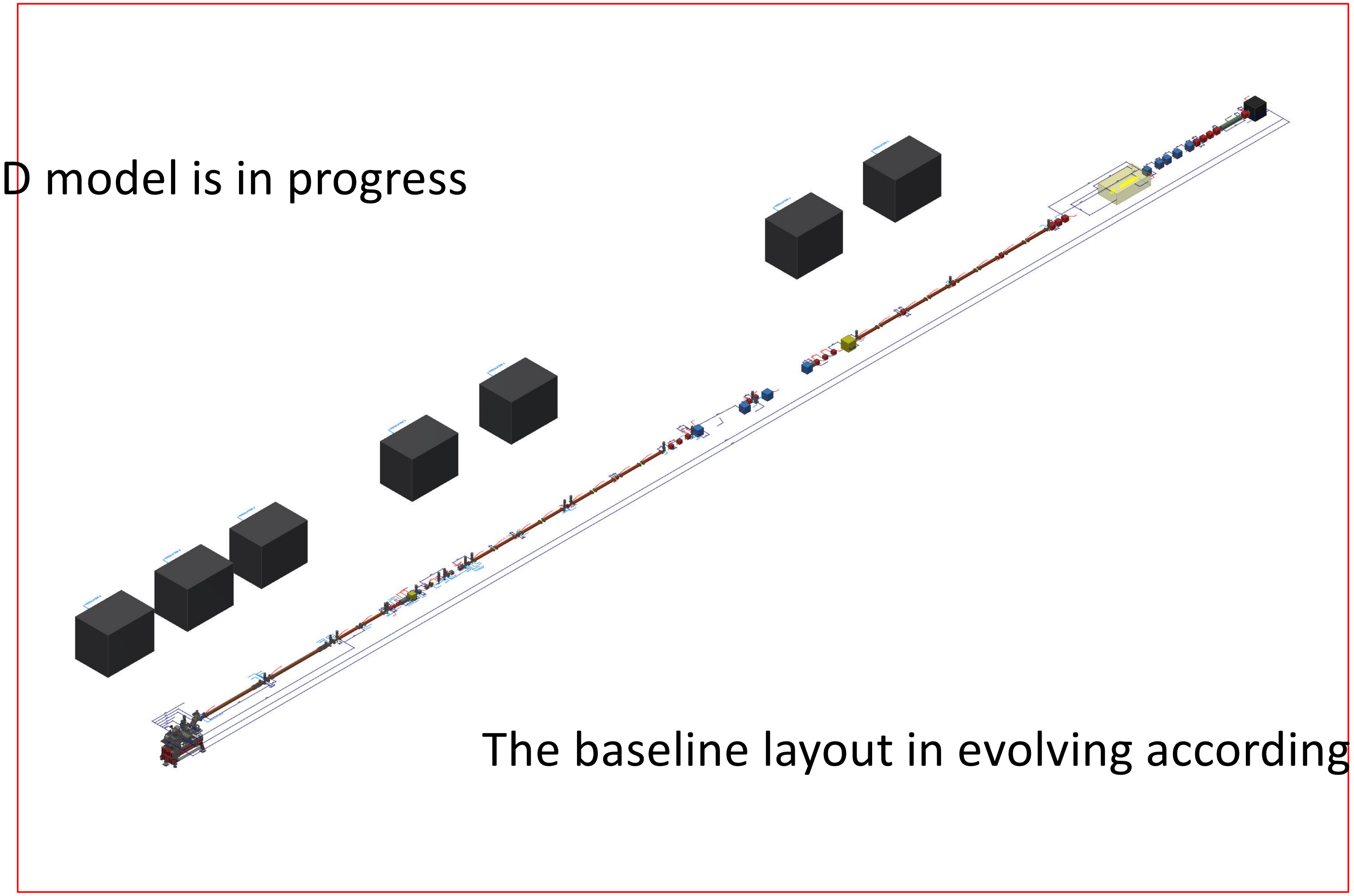
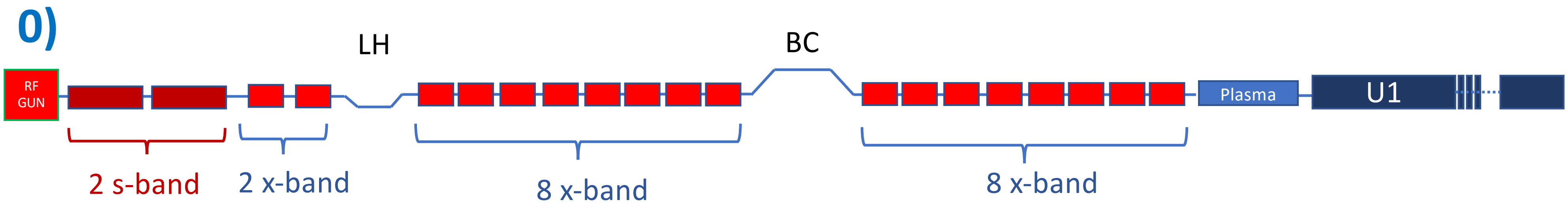
Preliminary baseline layout in progress

A detailed CAD model is in progress



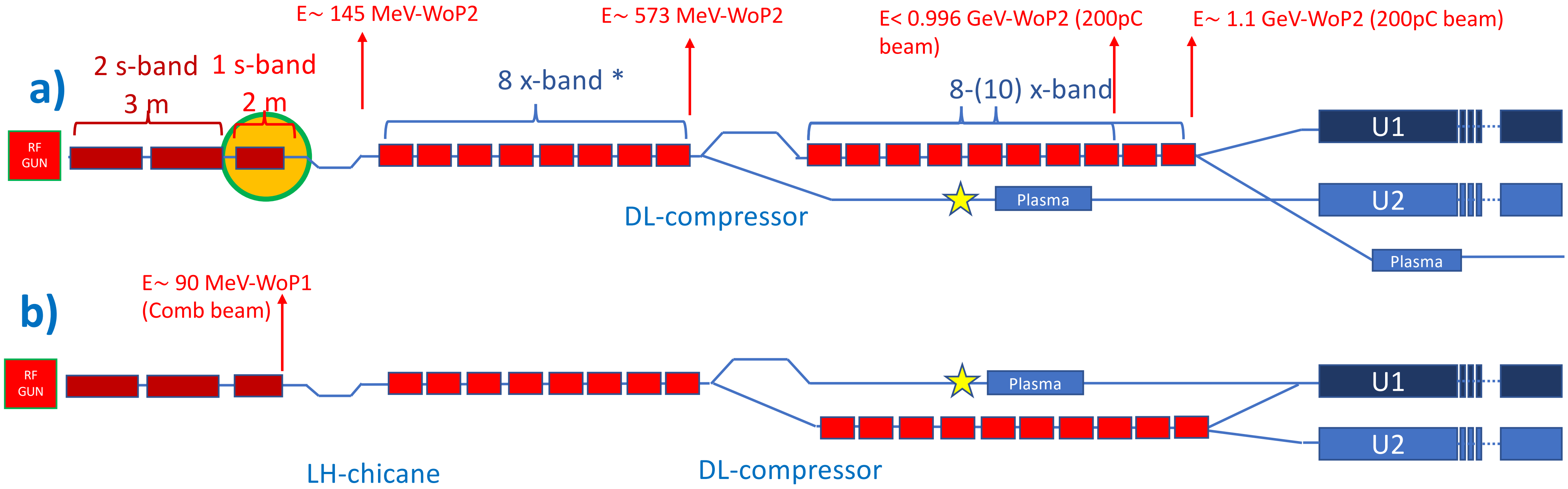
The baseline layout in evolving according to the BD results

The basic all-in-one layout Fall 2020



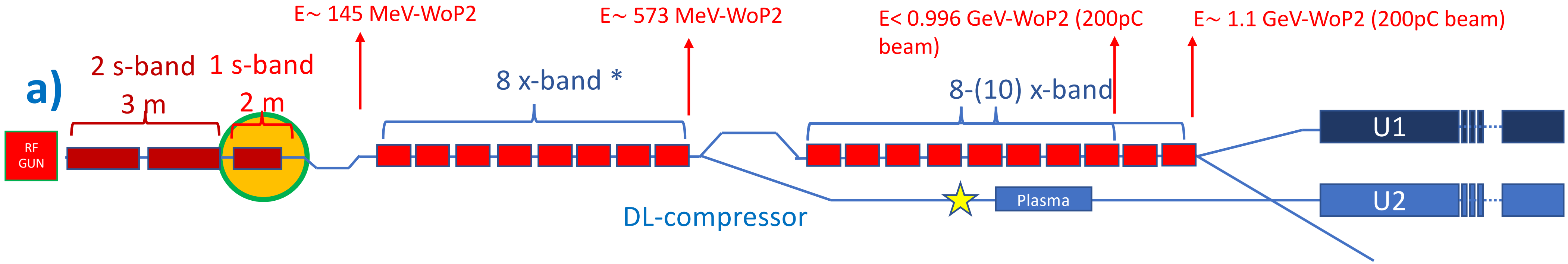
- Emax=1.03 GeV for all X-band configuration(w 10% contingency on Kly output power)
- Lmax =~ 60 m (ex. 59.52 m) from cathode + 1 m distance from the wall
  vs 59 m nominally available
- Extremely tight in:
  - plasma in&out matching
  - Diagnostic sections for characterization
  - No room for doglegs upstream the undulator

WA1-Beam Physics: Layout brainstorming
two layouts for comparison up to now (Apr 2021)....

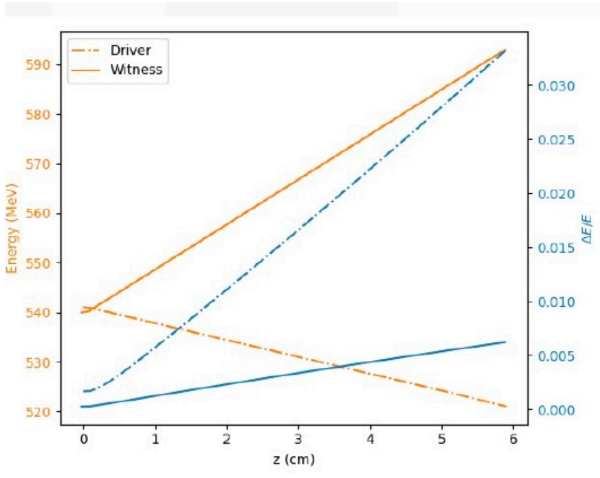


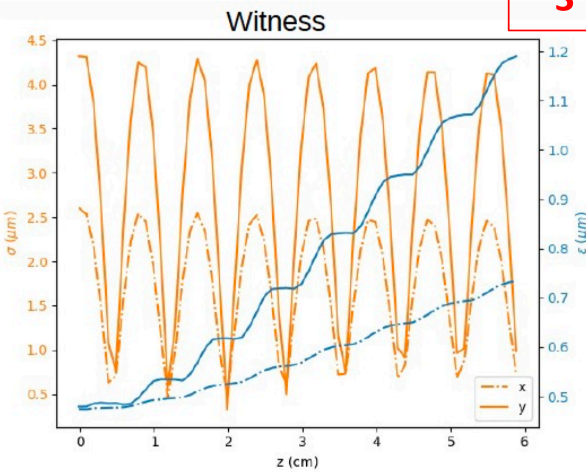
* The location of the 10 x-band linac downstream or upstream the chicane is under study

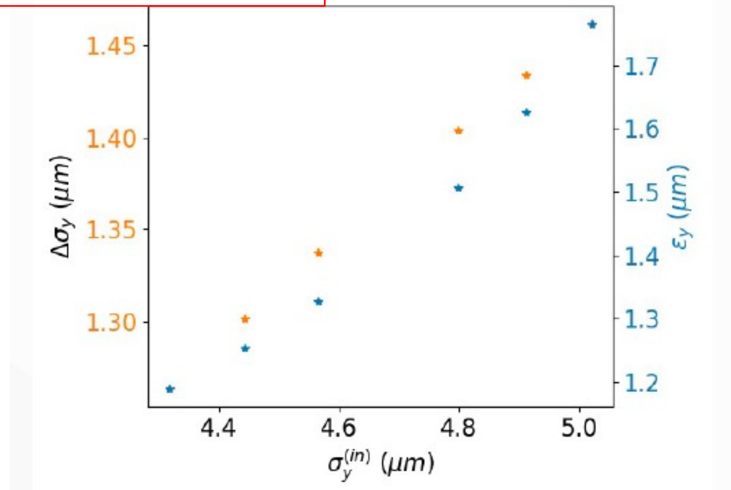
Comb Beam Quality and Stability analysis – case a)



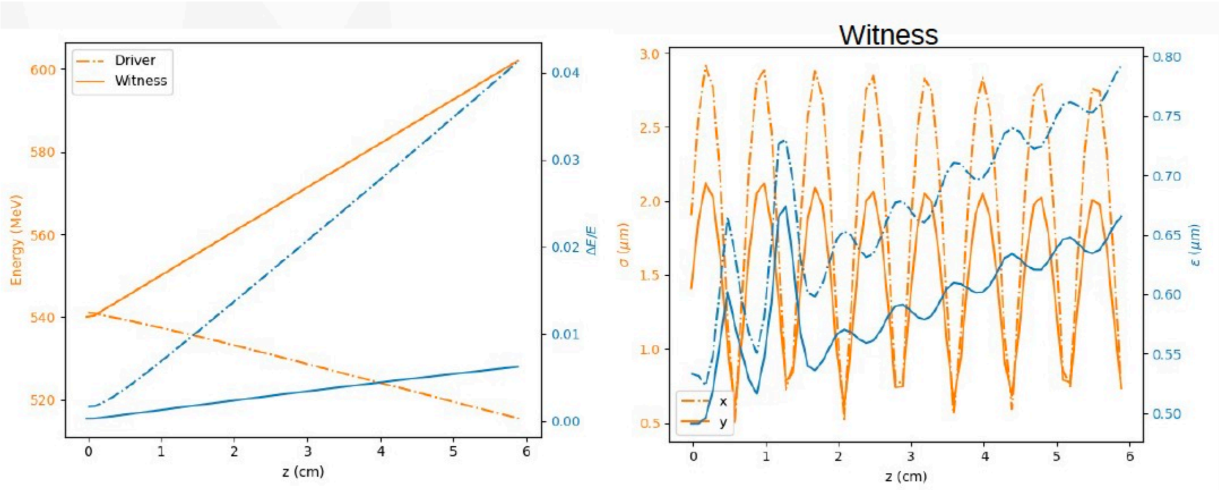
*** 3 weeks for 40 cm simulation**

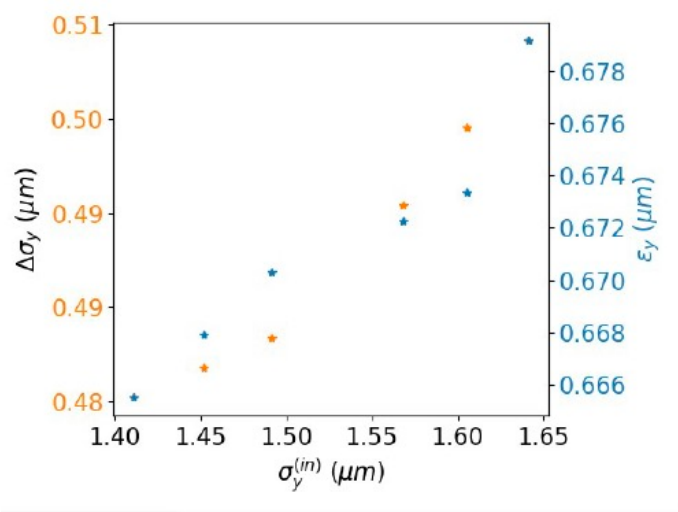


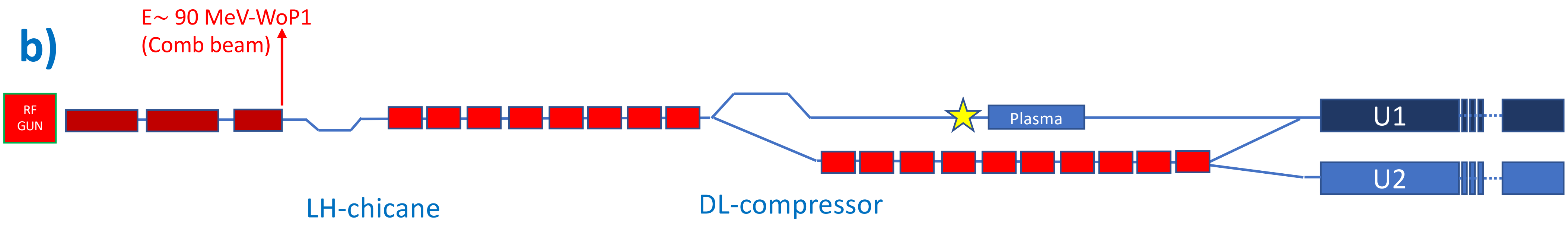




Comb Beam Quality and Stability analysis – case b)

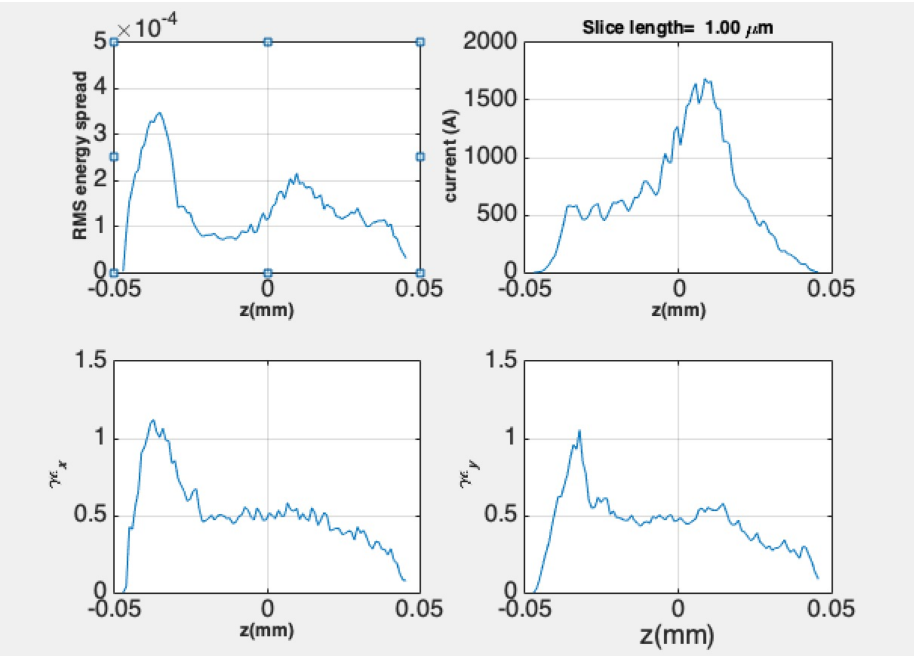




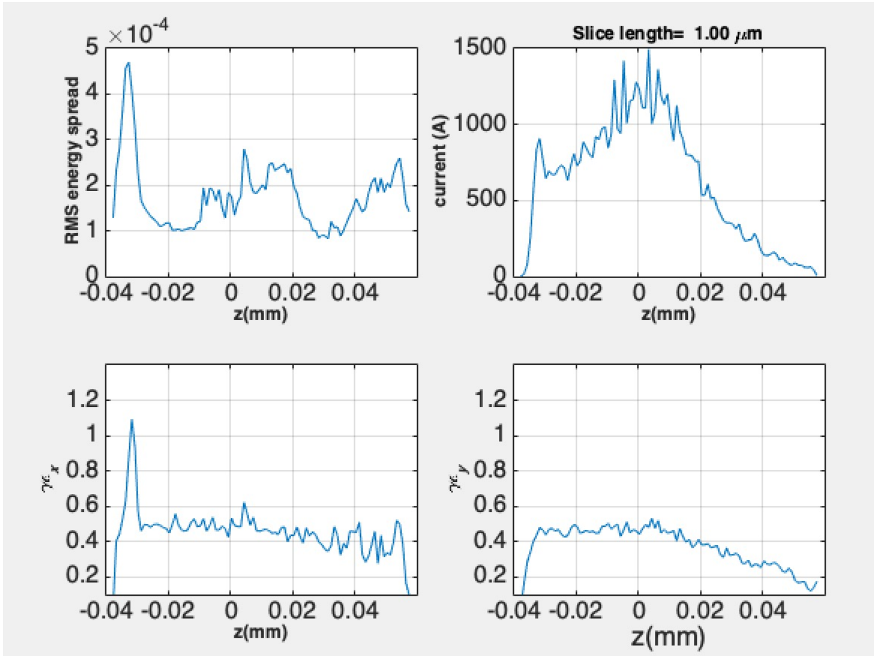


First results for 200pC (RF only) at undulator entrance

a) Chicane compressor



b) Dogleg compressor



WA1-Milestones

Dec 2023

TDR completion

June 2023

Completion of machine layout&integration and S2E simulations (8-6 months for writing the TDR

July 2021 machine layout «coarse» finalization in terms of :

- Number and type of undulators
- Number and type of transfer lines
- Spectrometer /extraction lines
- 5GeV plasma acceleration line
- Submitted to «first magnets design and feasibility verification (April-May 2021)»

Dec 2021–Mar 2022 final machine layout refinement

Dec 2021 Nominal WP finalization

Jun 2022 Virtual measurements-Diagnostic functional check-High level SW & Operating procedure definition

Dec 2022 Assesment of lattice robustness and jitter/alignment sensitivity & counteractions

June 2023 Commissioning strategy

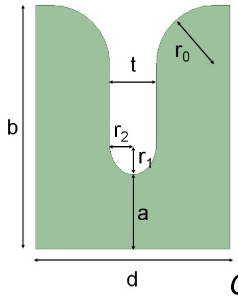
WA3: X BAND STRUCTURES AND PROTOTYPING ACTIVITY

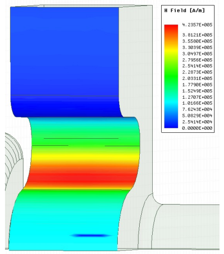
1. **X band structures**: e.m. defined, the prototyping activity is in progress to arrive to the final mechanical design

2. **The final mechanical drawing of the final X band structure** is strongly related to the result of the prototyping activity: brazing test, cell to cell alignment, tuning-precision, etc...

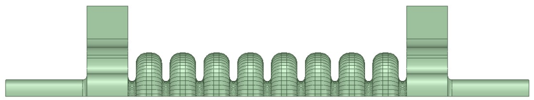
3. Synergies with Int. projects: in the context of **the I.FAST European** project there is a Work Task on XLS-Compact light structure realization coordinated by G. D'Auria, to be fabricated in 2 years from May 2021. It is a structure very similar to the EuPRAXIA@SPARC_LAB one.

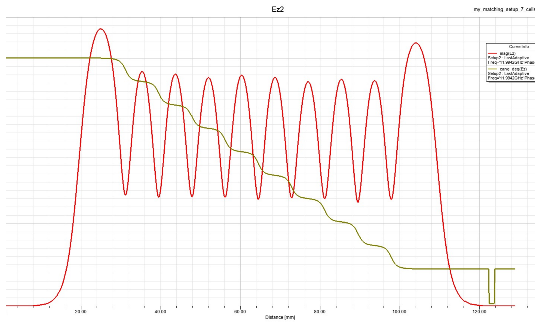
4. Timeline: first **few cells rf prototype for hig power text ready by the beginning of 2022**



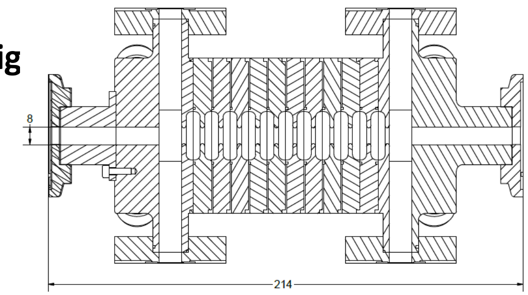


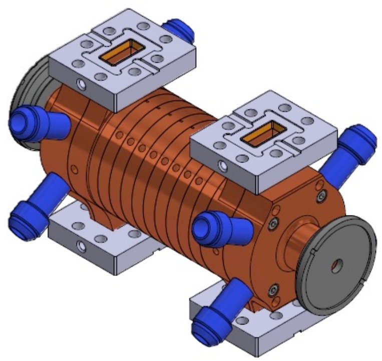
Courtesy M. Diomede

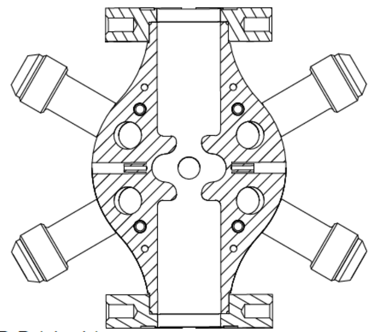




Parameter	Value
Frequency [GHz]	11.9942
Iris radius a (linear tapering) [mm] <a>=3.5	3.8-3.2
Tapering angle [deg]	0.04
Structure length L_s [m]	**0.9**
No. of cells	109
Shunt impedance R [MΩ/m]	94-107
Filling time [ns]	126
Effective shunt Imp. R_s [MΩ/m]	350
Unloaded SLED/BOC Q-factor Q_0	150000
External SLED/BOC Q-factor Q_E	21000
Required Kly power per module [MW]	**37**
RF pulse [μs]	**1.5**
Klystron power (available) [MW]	**50 (45)**
Rep. Rate [Hz]	**100**







B-B (1 : 1)

Courtesy G. Di Raddo

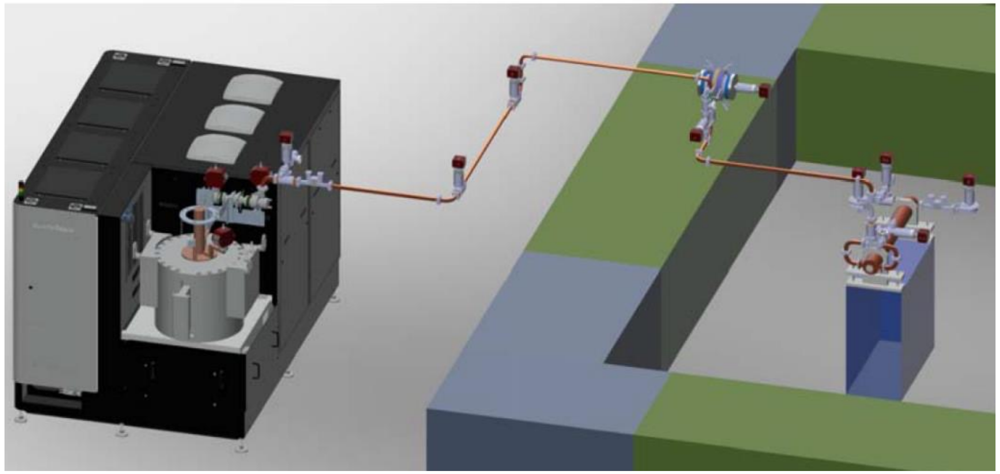
WA3: INFN-LNF X BAND TEXT FACILITY TEX

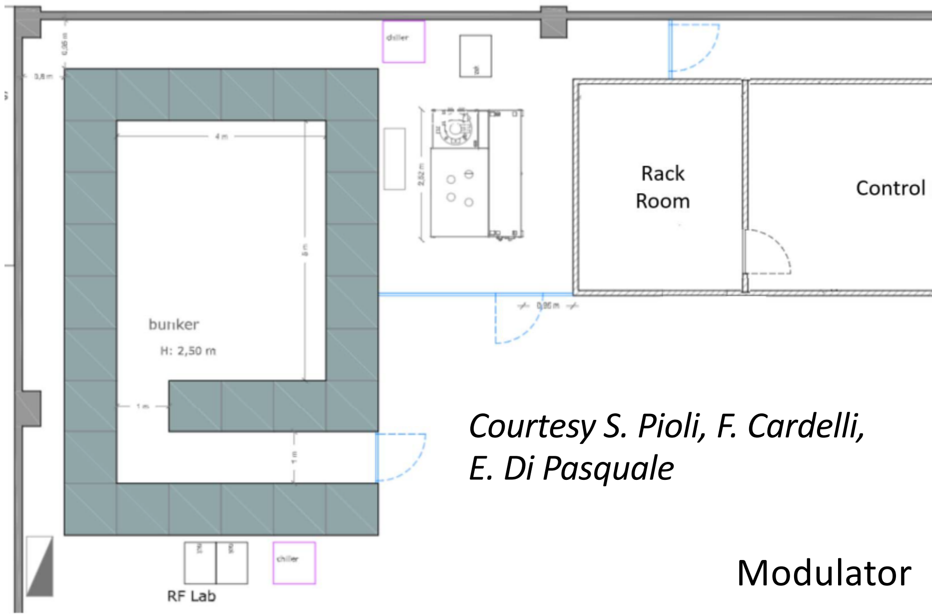
⇒ The **TEX test stand** (currently under implementation at LNF) has been conceived to **test all the RF components and structures necessary for EuPRAXIA** (including LLRF system, Vacuum, Control System,…).

⇒ **TEX:** it is fundamental to test all RF components at the nominal power and X band prototypes, there is a necessity to acquire asap a CPI klystron with the nominal parameters in term of power and rep. rate;

⇒ It has been **co-funded by the Regione Lazio in the framework of the LATINO project**

⇒ The setup of the test stand has been done in **collaboration with CERN** that provided the first **CPI klystron** and some waveguide component and will be also used to test CLIC structures.

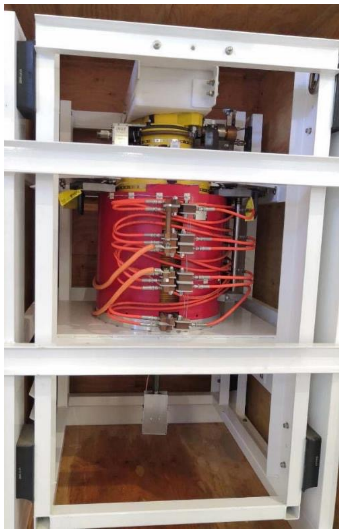


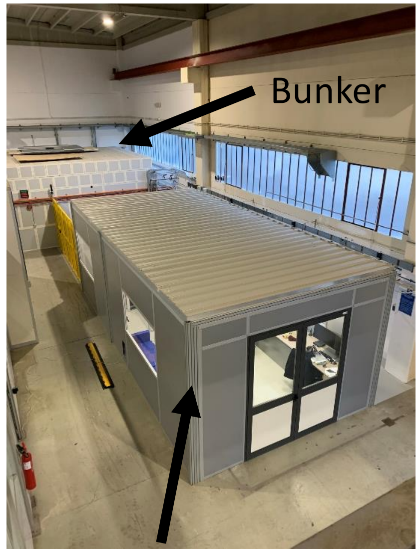


Courtesy S. Pioli, F. Cardelli, E. Di Pasquale

Modulator

klystron





TEX Control Room

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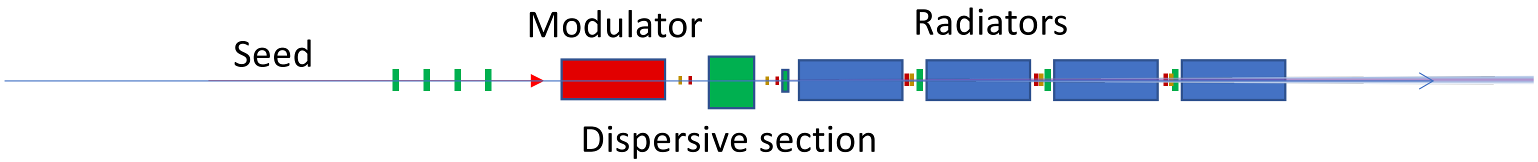
Eupraxia at SparcLab

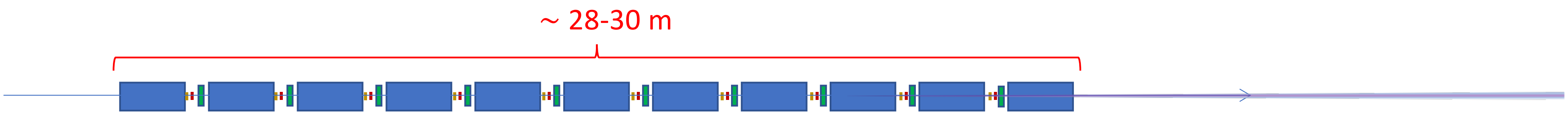
Studying two FEL lines:

1) AQUA: Soft-X ray SASE FEL – Water window 3 nm shortest wavelength (baseline)

2) ARIA: VUV seeded HGHG FEL beamline for gas phase (not yet in the baseline)



AQUA: General constraints on FEL area



- Target wavelength 3 nm @ 1 GeV – Relatively short period required (12-20 mm)
- Total Available length ~ 28-30 m, depending on linac spreader system, matching section, e-beam diagnostics and main beam dump.
- Hypothesis:
  - 10 modules ~2 m each
    - Optimize magnetic length/available length filling factor
    - Ensure gain length shorter than UM length
  - 80 cm intra-undulator sections:
    1. Quadrupole
    2. Beam position monitor
    3. Corrector
    4. Phase Shifter
    5. Vacuum components
    6. Diagnostics/alignment

Undulator technology important to preserve **photon energy tuning at fixed** beam **energy** and to guarantee **contingency on required beam quality**

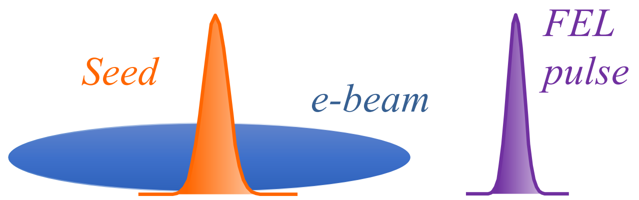
We explore:

Low gap Permanent Magnet Undulator
CPMU Cryogenic PMU
Super Conducting Undulator

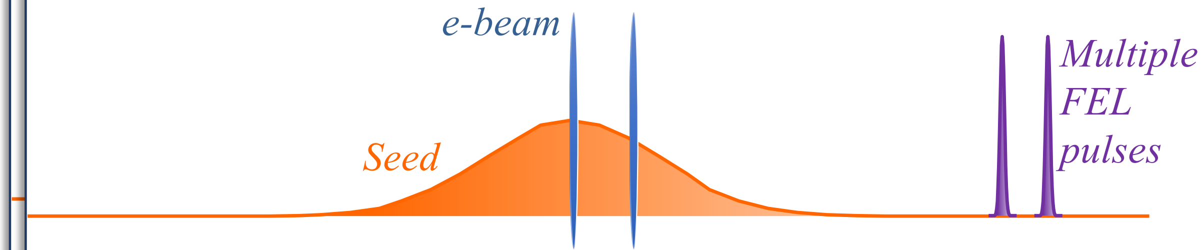
ARIA: exploit EuPRAXIA @ SparcLab special features

1) **E-bunch shape flexibility**: low charge short pulse operation mode – high charge long bunch mode – <u>double pulses</u>
2) **Synchronization** with external lasers
3) Very **low e-beam temporal jitter** (a pre-requisite for PWA and LWA acceleration)

We propose a «Special» SEEDED FEL line in the long wavelength range (50-180 nm)



Long-e bunch, low current – short seed.
Pulse duration at "long wavelengths" limited by **narrow gain bandwidth** (***FERMI*** like)



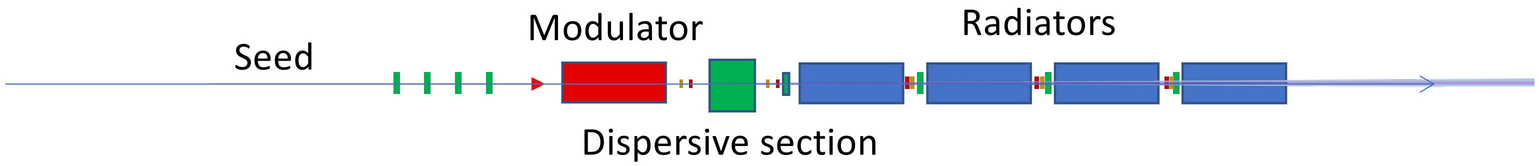
Short & high current e-bunch, long seed.
Pulse duration limited by **e-bunch duration** & large **gain bandwidth**

(Flexible: can produce multiple phase-locked pulses)

- **No other seeded FEL facility** covers the range **50-180 nm**, except fo the DALIAN light source (specialized in long pulses)
- Superposition with HHG sources, but **without their limitations on POLARIZATION, phot. energy tuning & intensity**
- **Can be synchronized** with HHG sources or external lasers for **multicolor multi-pulse pump and probe operation**

ARIA

SEEDED FEL line – Full coherence = laser-like statistics



- Wavelength range 50 – 180 nm – continuously tunable – 10-100 uJ pulse energy
- Total physical length 20 m (not just magnetic) modulator – dispersive section – 4 radiators
- Variable polarization (circular left/right, horizontal and vertical)
- Design almost readily available. Could be ready for users since the first commissioning phase. Would contribute to establish a user community for the EuPRAXIA at SparcLab user facility
- Undulator cost estimate 3.5 M€ - not yet in the baseline

WA8 - Photon & Users Beamline(s)
The road to the TDR

AQUA – Photon beamline @ 3 nm

- User Science: fine tuning of samples & techniques
- Details of instrumentation (detector, sample delivery) for the experimental endstation at a TDR level
- Photon transport study and simulations up to the user endstation

ARIA – Photon beamline @ 50-180 nm

- Detailed definition of the scientific case
- Users' community commitment
- Photon transport study and simulation up to the user endstation
- Study and design of optics and diagnostic components

AQUA + ARIA

- Connections with correlated services (low and high power lasers and THz)

AQUA - Techniques & Samples @ 3 nm

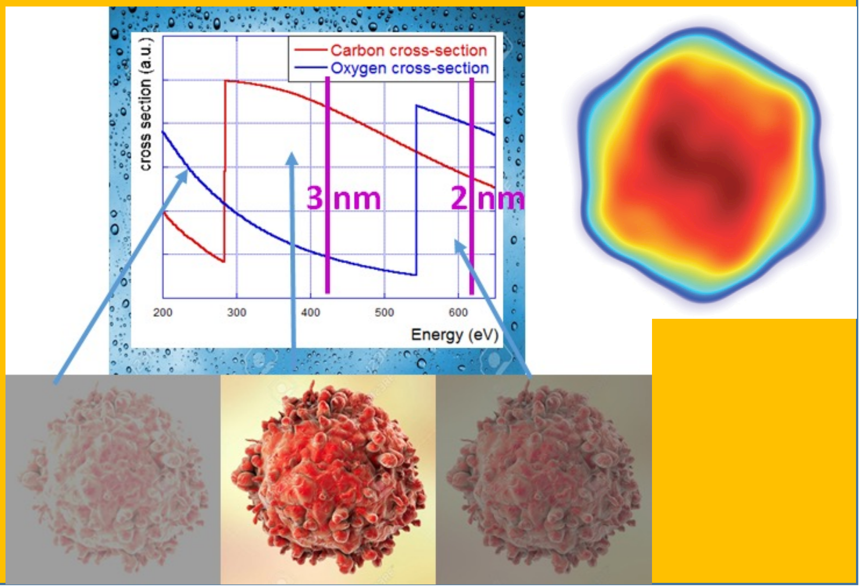
Scientific case assembled and published.
Contributions from >15 different institutions

Balerna *et al.* Condensed Matter 4, 30 (2019)

Bio
& **Samples**
Inorganic

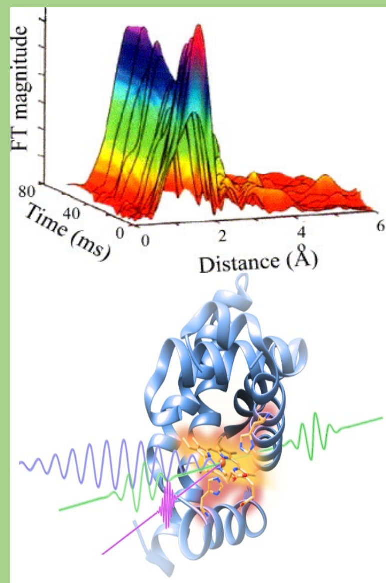
Proteins - Viruses
Bacteria- Cells
Metals – Magnetic materials
Superconductors -Semiconductors

Coherent imaging



X-ray absorption spectroscopy

Raman spectroscopy



ARIA - Techniques & Samples @ 50-180 nm

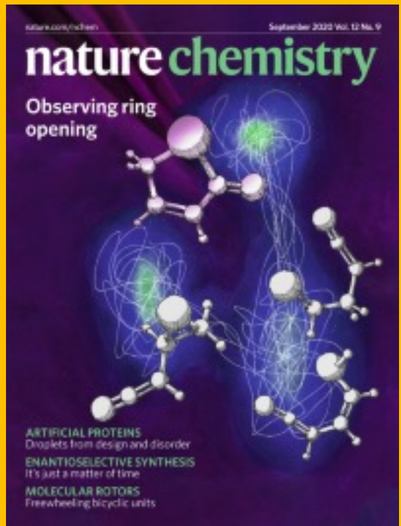
Scientific case in the DUV (DeepUV) and VUV (VacuumUV) is being assembled
Wavelength interval **complementary** with FEL1 @ Fermi

Samples & (techniques)

Gas phase & Atmosphere (Earth & Planets)
Aerosols (Pollution, nanoparticles)
Molecules & gases (spectroscopies, time-of-flight)
Proteins (spectroscopies)
Surfaces (ablation e deposition)

Photoemission Spectroscopy

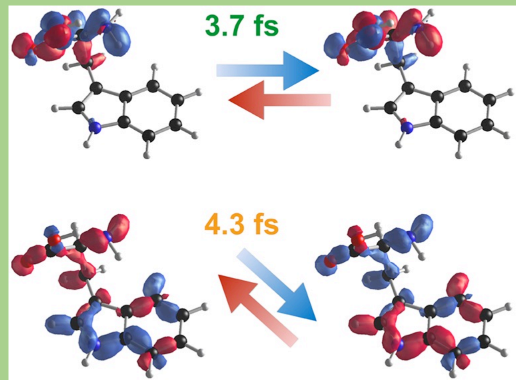
Ring opening in organic molecules
Pathak *et al. Nature Chemistry* 2020



Raman spectroscopy

Photo-fragmentation of molecules

Ultrafast Quantum Interference in the Charge Migration of Tryptophan.
J Phys Chem Lett 2020



Time of Flight Spectroscopy

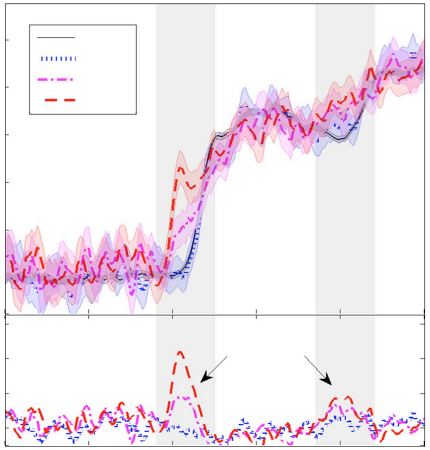
Towards X-rays: betatron emission @ ~ Å

Wiggler-like radiation emitted by electrons accelerated in laser-plasmas wakefields gives rise to brilliant, ultra-short X-ray pulses, called **betatron radiation**.

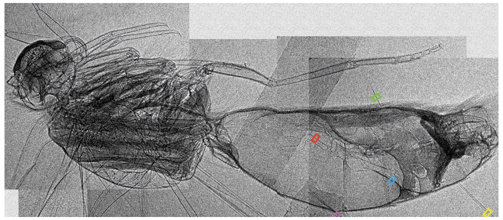
BetaX – Betatron X-ray photons

- Preliminary **scientific case**:
  ultra-fast X-ray **spectroscopies**

Probing warm dense matter using femtosecond X-ray absorption spectroscopy with a laser-produced betatron source *Nat Comm 2018*



- **Technology/technique** development:
  X-ray sources for **imaging**



High-resolution phase-contrast imaging of biological specimens using a stable betatron X-ray source in the multiple-exposure mode *Scientific Report 2019*

- Pump-probe experiments:
  Coupled to FEL to act as an **X-ray pump pulses** for FEL experiments

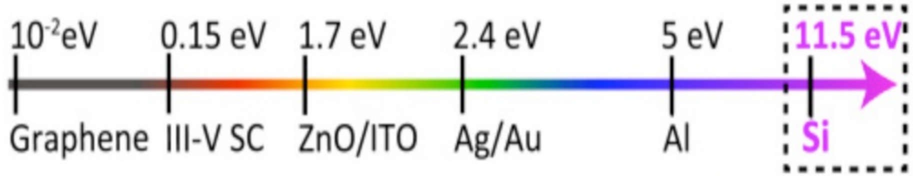
- Ultrafast X-ray source for **testing FEL instrumentation** (detectors, sample delivery)

External – Laser & THz - Radiation Sources

Time-resolved pump-probe experiments require coupling to an **external radiation sources** :

A **high-power** laser (FLAME-like, hundreds of TW) will allow pump-probe experiments on exotic states of matter in extreme conditions, close to celestial bodies or nuclear explosions [Chen *et al. PRL* 2010].

A high-power optical laser allows the modulation of high-energy modes through the effective excitation of low-energy degrees of freedom-
An application is the tuning of plasmon modes through the excitations of phonons in dielectric nanoparticles decorated with metals.



Lupi *et al., Nature Comm. 2010*

LNF Scientific Committee Recommendations

1. Technology demonstration is clearly a key part of EuPRAXIA@-SPARC_LABs mission, therefore targeted preparatory R&D is an essential part of this activity. Appropriate funding needs to be secured for this R&D.

2. The accelerating field of the X-band linac should be driven by investment and operation cost considerations. The new choice of 60 MV/m is a reasonable value, but in view of the very high cost of Xband RF power sources the cost saving potential of even lower gradients has to be considered.

3. The scientific case for the EuPRAXIA@SPARC_LAB FEL user program needs to be strengthened. In particular, the Italian user community of FERMI and EuXFEL should be more involved in the definition of FEL parameters and end-station capabilities before the TDR facility parameters are finalized.

4. The scientific potential of using the 0.5 PW Laser of EuPRAXIA@SPARC_LAB as a pump and the FEL as the probe for pump-probe experiments should be investigated. This may provide a unique experimental feature for future FEL users.

5. With the scientific programs of DAFNE and BTF flourishing, SPARC_LAB in operation and EuPRAXIA@SPARC_LAB in preparation, the demands on the RF-Linac technology team at LNF are increasing. LNF management should analyze potential synergies between the three activities and assure that sufficient resources to cover all these activities are available.

⇒Strong and open collaboration at LNF.

⇒A detailed Manpower requirements analysis is in progress and will be released by July.

Acknowledgements