The X-band technology for FELs (XbFEL) Project

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On behalf of the XbFEL collaboration

Outline

- **The X-band technology for FELs (XbFEL) project**
  - ***The XbFEL Collaboration***
  - ***Motivations for using X-band***
  - ***Objectives***
  - ***Concept and approach***
  - ***Work packages descriptions***
  - ***RF module and tests***
- **The FERMI FEL project in Trieste**
  - ***FERMI linac upgrading***
- **Outlook and conclusions**

The "X-band technology for FELs (XbFEL)"

is a project recently submitted for funding to

HORIZON2020 - Work Programme 2014 – 2015

Research & Innovation Action (RIA)

INFRADEV-1-2014 Design Studies

……………………………………

The specific challenge and the aim of this activity are to support the conceptual and technical design and preparatory actions

for new research infrastructures,

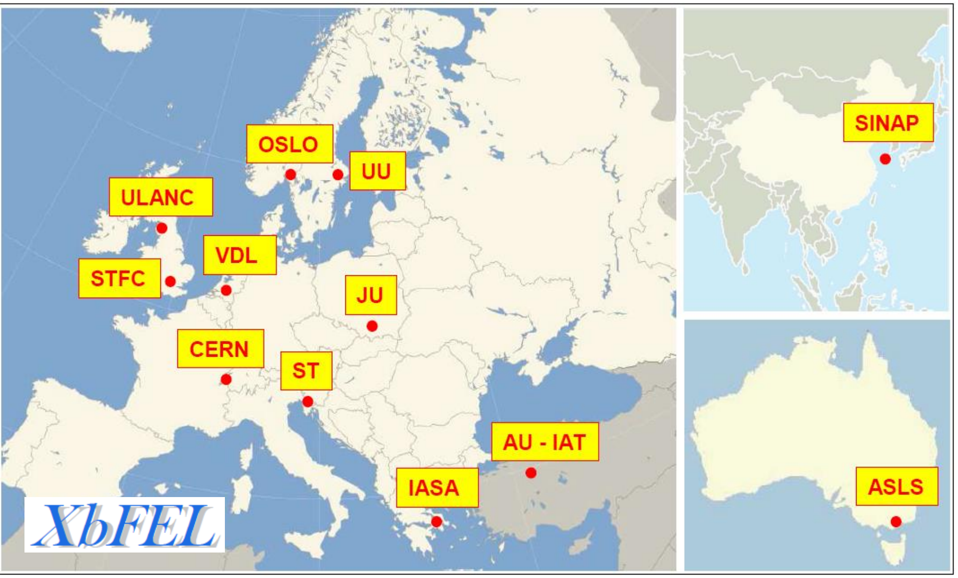
which are of a clear European dimension and interest.

Major upgrades of existing infrastructures

may also be considered if the end result is intended to be equivalent to, or capable of replacing, an existing infrastructure.

XbFEL Collaboration

XbFEL is a collaboration among several laboratories aimed at promoting the development of X-band technology for FEL based photon sources.



ST	*Elettra - Sincrotrone Trieste, Italy.*
CERN	*CERN Geneva, Switzerland.*
JU	*Jagiellonian University, Krakow, Poland.*
STFC	*Daresbury Laboratory Cockcroft Institute, Daresbury, UK*
SINAP	*Shangai Institute of Applied Physics, Shanghai, China.*
VDL	*VDL ETG T&D B.V., Eindhoven, Netherlands.*
OSLO	*University of Oslo, Norway.*
IASA	*National Technical University of Athens, Greece.*
UU	*Uppsala University, Uppsala, Sweden.*
ASLS	*Australian Synchrotron, Clayton, Australia.*
UA-IAT	*Institute of Accelerator Technologies, Ankara, Turkey.*
ULANC	*Lancaster University, Lancaster, UK.*

Elettra Sincrotrone Trieste · CERN · JAGIELLONIAN UNIVERSITY IN KRAKOW · Science & Technology Facilities Council · SINAP · VDL

NTUA · IASA · UPPSALA UNIVERSITET · Australian Synchrotron · LANCASTER UNIVERSITY

Motivations for using X-band

Motivation:

- **Increasing interest by the Scientific Community for very compact Normal Conducting Linacs for FELs (i.e. ~6 GeV, ~150m, for 1 Å wavelength).**
  - *"Support for feasibility studies of new research infrastructures (i.e. Ankara University, Australian Synchrotron,….), or major upgrade of existing ones (i.e. FERMI FEL,….)".*

Advantages:

- **Compactness, efficiency, possibility to go high repetition rate (kHz regime), costs reduction.**

XbFEL objectives

- With the XbFEL project we intend to validate the use of the X-band technology for the construction of the future FEL based photon sources.

- The objective is to design, assembly and test an X-band accelerating module that can be used as a baseline element for new or upgraded FEL photon facilities, supporting and strengthening the growing requests from the user community.

XbFEL_Concept and approach

- **The X-band accelerator technology, has recently demonstrated acceleration of electron beams at gradients of more than 100 MV/m (CLIC collaboration).**
- **To reach the XbFEL objective, three different FELs facilities will be considered:**
  1. **a green field hard X-ray FEL;**
  2. **a green field soft X-ray FEL;**
  3. **an upgrade of an existing FEL.**

The project will be carried out in close collaboration with industry, member of the consortium, for the technology development and dissemination of the results.

XbFEL Specific goals

a. Develop CDRs for the three different scenarios already mentioned in order to fully understand the requirements for the linacs and identify common, standard specifications.
b. Design a common RF unit for the linacs.
c. Develop and test prototypes of the key components of this common solution.
d. Analyze and develop plans for the integration of the X-band technology for new Research Infrastructures at European level and Worldwide.
e. Promote the capability of industry to provide such components.

XBFEL Work Packages_I

WP1: Project management and Technical Coordination

It will be focused on management and coordination of all the WPs and deliverables, budget and implementation plans.

WP2: FEL Science Requirements and Facility Design

Starting from the FEL specifications provided by users (i.e. wavelength range, energy per pulse, pulse duration, structure, etc.), this WP will develop the accelerator requirements and the major hardware choices, based on the X-band technology, for the three different scenarios: a hard X-ray FEL facility, a soft X-ray FEL facility and the upgrade of an existing facility, FERMI.

WP3: Linac Standard Solutions and Hardware Specifications

The objective of WP3 is to elaborate the overall facility designs, developed in WP2, and produce detailed hardware specifications for the corresponding linacs.

XBFEL Work Packages_II

WP4: Component Validation and Test Programme

The specifications and relevant mechanical drawings developed in WP3 will be used for component fabrication, RF module assembly, high power tests and system validation. The objective of WP4 is to demonstrate the manufacturability and operation of one RF unit, representative of an X-band FEL.

WP5: Global integration of X-band technology for new Research Infrastr.

This WP will focus on gathering the user demands on FELs and accelerator upgrades in the near and mid-term future, services to be provided and will make preliminary estimation of construction/operation costs.

WP6: Relation with industry

It will cover the collaboration with industry and will be focused on dissemination of results, spreading of information, industry outreach and technology development.

Interest in the XbFEL project_I

- **FERMI FEL Elettra – Sincrotrone Trieste**
  - *Linac energy increase → FEL shorter wavelenghts (≤ 1 nm)*
  - *Possibility to operate with two pulses*
- **Ankara University (Turkish X-ray FEL)**
  - *6 GeV linac → FEL wavelengths 0.1-10 nm*
  - *Possibility to operate at high rep rate (up to 500 Hz)*
- **Australian Synchrotron (AXXS–Australian X-band X-ray Source)**
  - *Plans for a 6 GeV linac*
- **SINAP Shangai**
  - *Proposal for hard X-FEL (6.5GeV) submitted to Chinese government.*
- **Jagiellonian University_Polish Synchrotron Light Source SOLARIS**
  - *Solaris linac energy increase 600 MeV → 1.5 GeV, allowing full energy injection without any additional costly civil engineering.*
  - *Long-term development of a compact VUV - Soft X-ray HGHG.*
- **STFC**
  - *CLARA FEL Test Facility (Ultra short pulse generation). An S-band linac module (Linac 4) will be replaced with an X-band module as test bed for this technology on FELs.*

Interest in the XbFEL project_II

- **CERN**

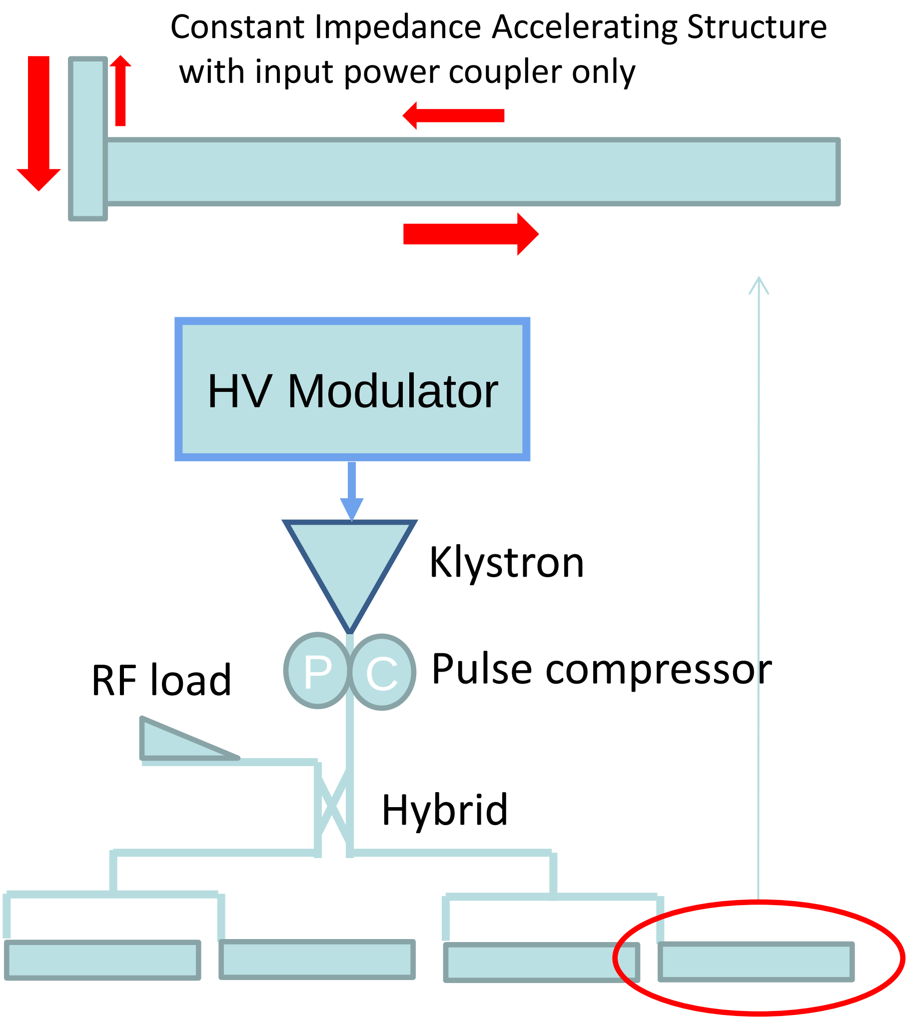
  CERN has no direct interest in Synchrotron Light Sources and FELs, but the activities on XbFEL will also have strong return value for the CERN CLIC project:
  - *accelerator and RF components optimization*
  - *further technical developments with industry*
  - *costs reduction………*

- **A long-term interest in the technology also exists for**
  - *University of Oslo*
  - *University of Uppsala*
  - *National Technical University of Athens*
  - *Lancaster University*

- **Industry (VDL) for technology development.**

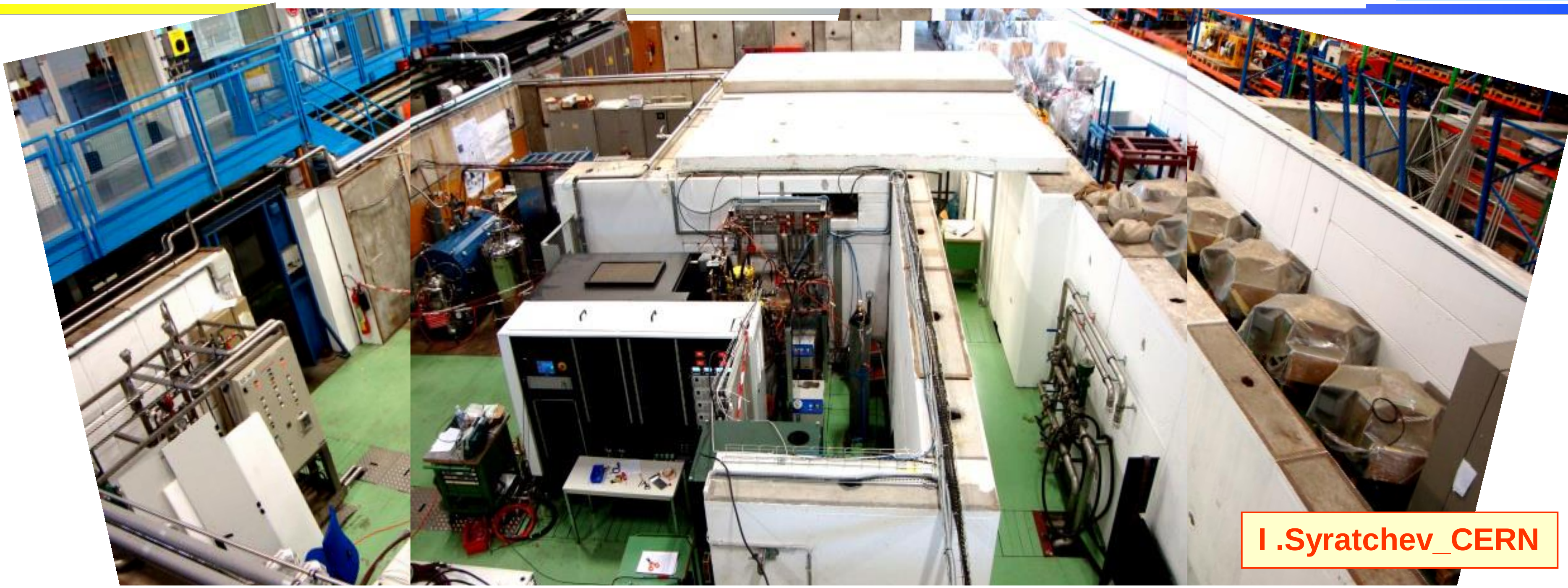
X-band module layout

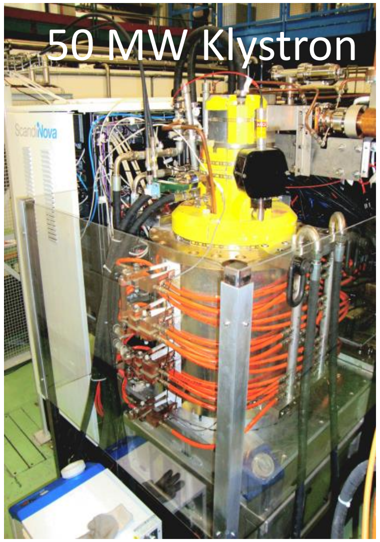
RF phase advance	2π/3	3π/4
a/lambda	0.145	0.145
d/h	0.1313	0.1
Pt	401 MW	401 MW
Ls	1 m	1 m
# klystrons	10	10
# structures	10 x 4 = 40	10 x 4 = 40
a	3.62 mm	3.62 mm
d	1.09 mm	0.937 mm
vg/c	3.75 %	3.29%
tp	90 ns	102 ns
Qe	18000	19000

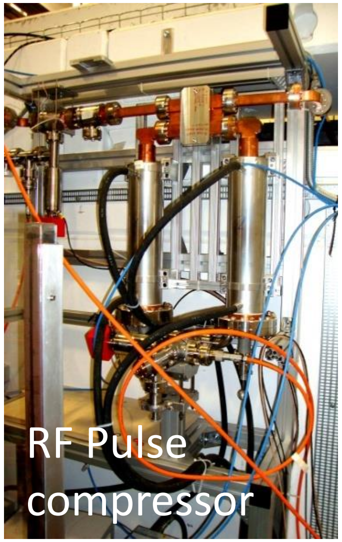


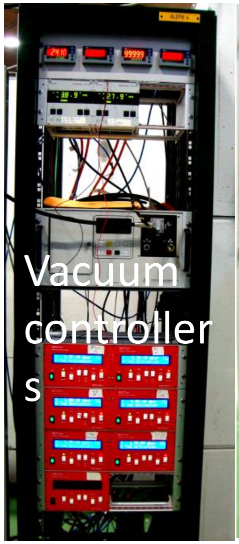
A. Grudiev, HG2013 workshop

CERN X-band test station_XBOX#2









Elettra Sincrotrone Trieste

XbFEL Time schedule

XbFEL

WP Task	Description
1	Project Management and Technical Coordination
2	FEL Science Requirements and Facility Design
2.1	Hard X-ray FEL
2.2	Soft X-ray FEL
2.3	Upgrade of an existing facility
3	Linac Standard Solutions and Hardware Specifications
3.1	RF system parameters
3.2	Accelerating structures design
3.3	RF powering system design
3.4	Low-level RF and instrumentation
3.5	Module mechanical design
3.6	Manufact. procedures, quality assur. and test progr.
4	RF Components Validation and Test Programme
4.1	Construction of accelerating structures
4.2	Construction of the RF pulse compression system
4.3	RF distribution system
4.4	Construction of the RF unit mechanical support
4.5	RF unit final assembly
4.6	High power tests
5	Global integration of the X-band technology
5	Integration of the new Research Infrastructures
5	Research services to be provided at internat. level
5	Preliminary estimation of constr. and operat. costs
6	Relation with Industry
6	Accelerator technology, overview and needs
6	Collaborative relationship with industry
6	Preliminary analysis of technology tranfer process

Year 1: months 1–12; Year 2: months 13–24; Year 3: months 25–36

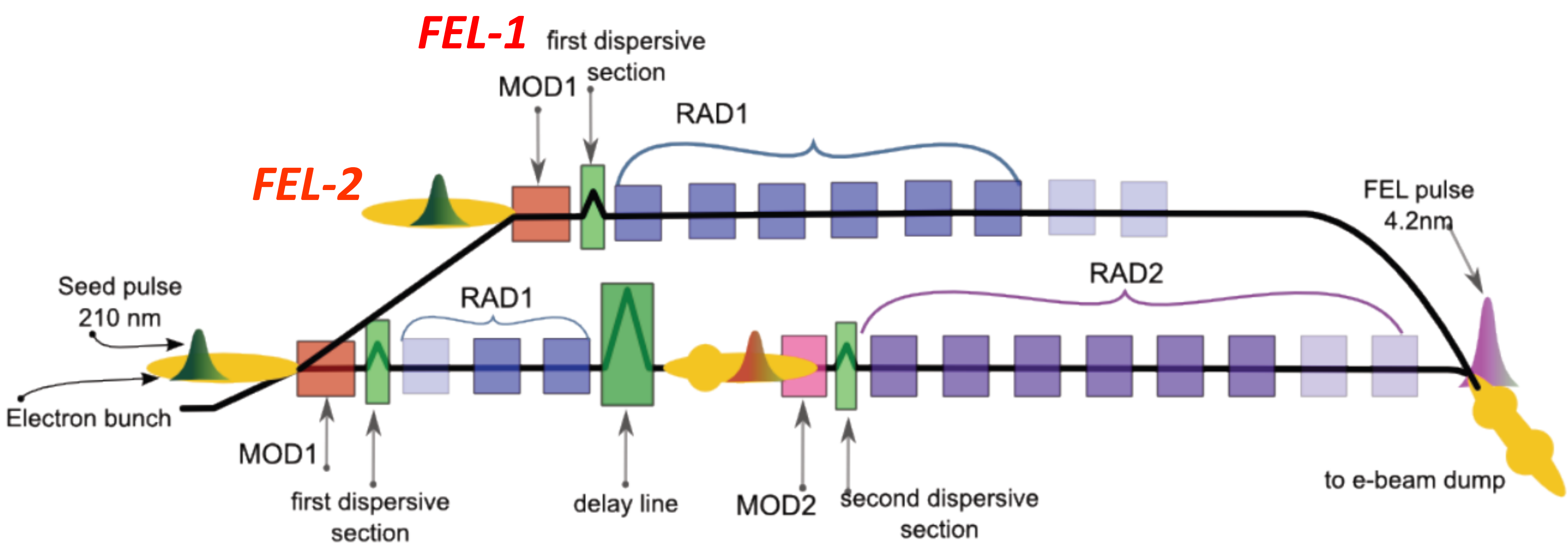
FERMI FEL

FERMI is a fourth generation light source user facility in operation at the ELETTRA-ST laboratory producing photons in the ultraviolet and soft X-ray regions.

In the current configuration, FERMI is a seeded Free Electron Laser, based on a normal conducting S-band linac (3 GHz) operated up to 1.5 GeV, with two different FEL lines:

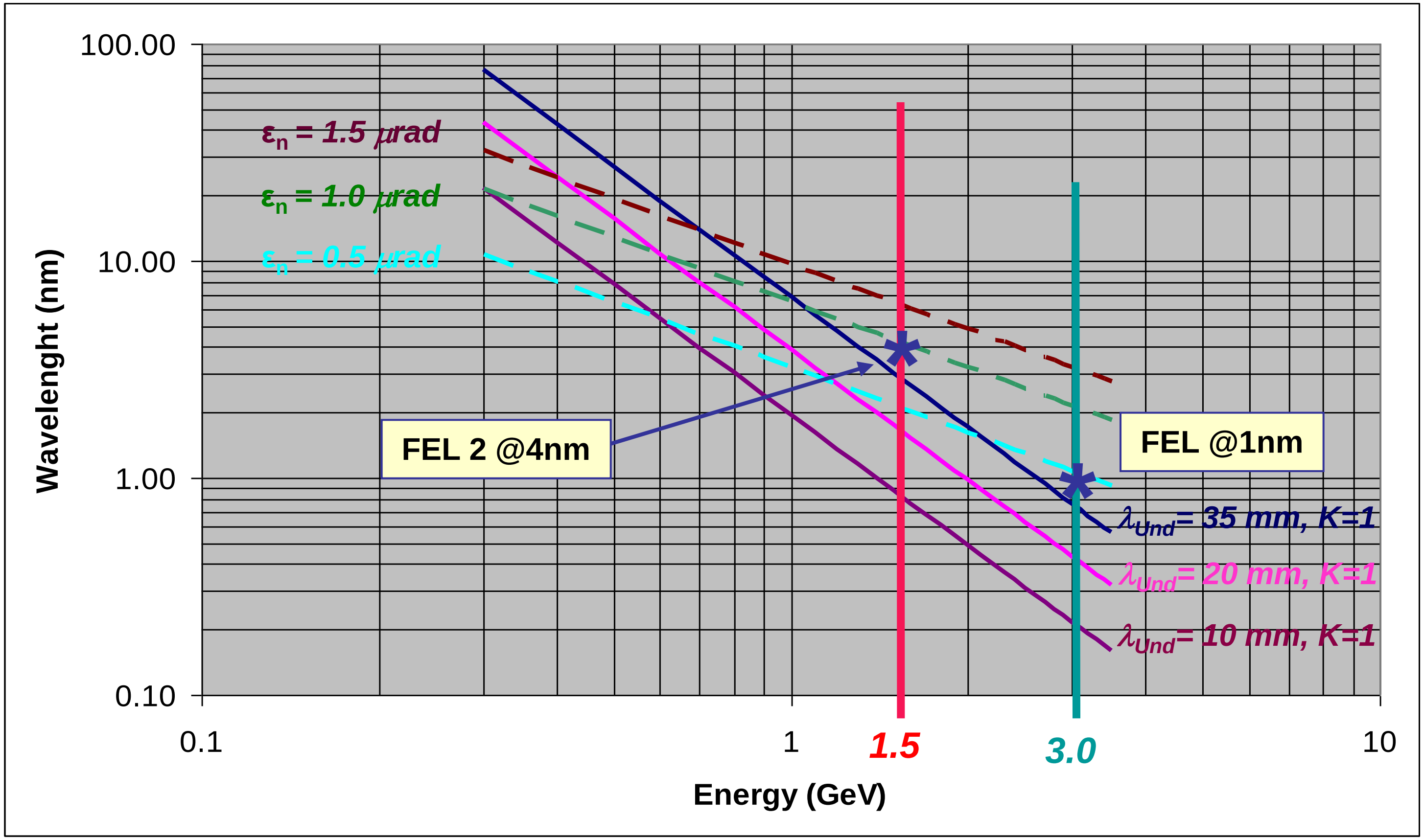
a. *FEL-1, based on a single stage High Gain Harmonic Generation (HGHG), with a UV Seeding Laser, that covers the spectral range 80-10 nm.*

b. *FEL-2 based on a two stages HGHG scheme, with the "fresh bunch technique",* that covers *the wavelength range 10-4 nm.*



FEL scaling laws

An extension of FERMI capabilities in terms of wavelength (i.e. down to 1 nm or lower), is very attractive for the all the Users Community.



—— ***Resonance condition*** $\lambda_L = \frac{\lambda_{Und}}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$

------ ***Emittance condition*** $\varepsilon_n/\gamma \leq \lambda_L/4\pi$

FERMI linac energy upgrading

To reach the above mentioned wavelength region, it is necessary to bring the electron beam energy up to 3 GeV or more.

Considering the limited space available in the present machine tunnel, this would require the use of very high gradient structures.

The main idea is to install an X-band linac segment, in parallel with the existing linac, downstream the second bunch compressor, using the bunch already compressed.

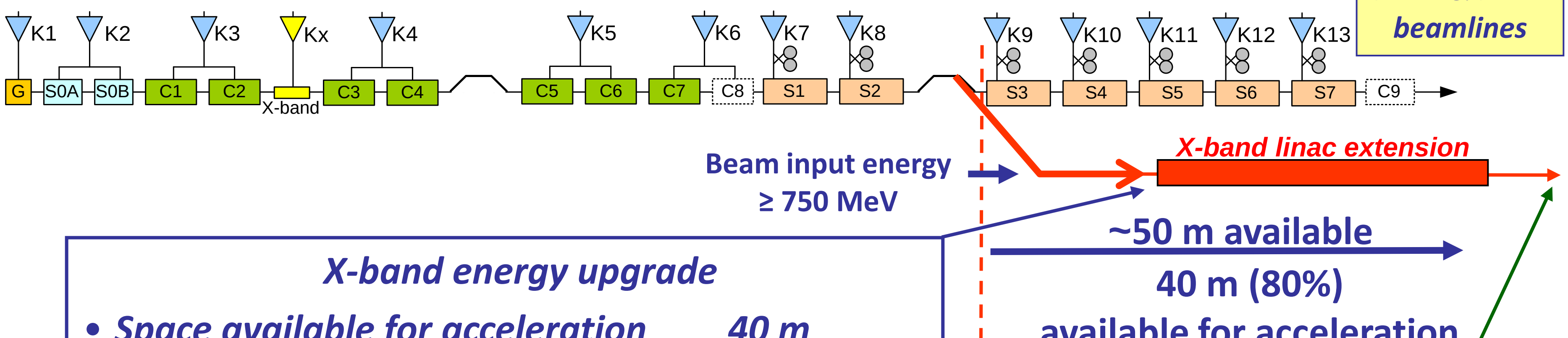
This layout could be implemented with a modular approach, leaving unchanged the present linac, minimizing costs, impact and interference with the existing plants.

In addition the scheme would provide two electron beams, with different energies, at linac output.

Present layout and proposed energy upgrade

FERMI current layout and performance:

- E_{beam} up to 1.5 GeV
- FEL-1 at 80-10 nm and FEL-2 at 10-4 nm
- Seeded schemes
- Long e-beam pulse (up to 700 fs), with "fresh bunch technique" for FEL-2



X-band energy upgrade

• Space available for acceleration	40 m
• Accelerating gradient @12 GHz	70 MV/m
• X-band linac energy gain	2.8 GeV
• Injection energy	.75 GeV
• Linac output energy	3.5 GeV

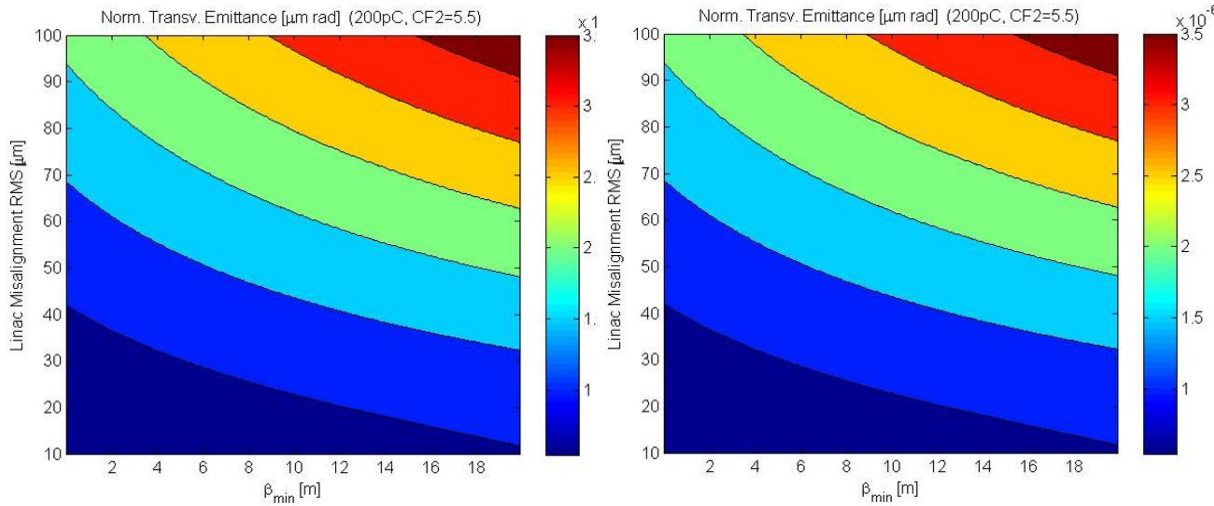
e-beam for a new FEL beamline

λ ≤ 1 nm

Operation:

- *short bunch (< 100 fs)*
- *low charge (< 100pC)*

FERMI Linac upgrade



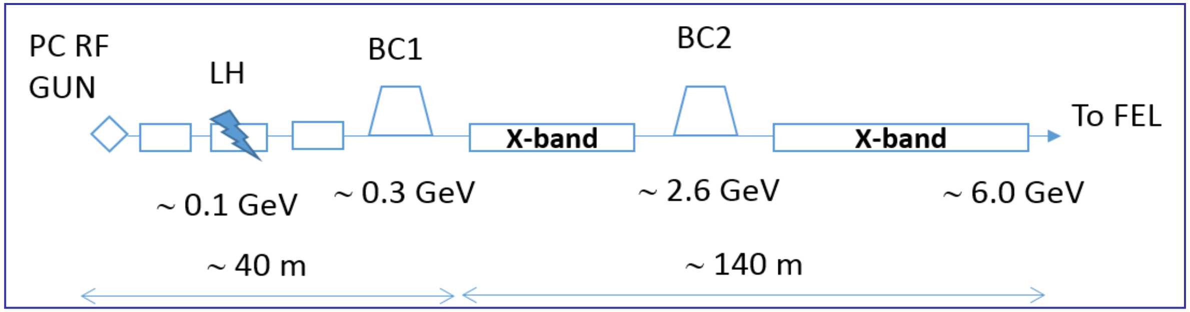
Normalized RMS projected emittance at the entrance of BC2 (left) and linac exit, as function of the linac-to-beam RMS misalignment and the horizontal betatron function in the BC1 (left) and BC2. The left plot assumes an initial emittance of 0.15 μm, the right 0.5 μm.

Expected FEL performance

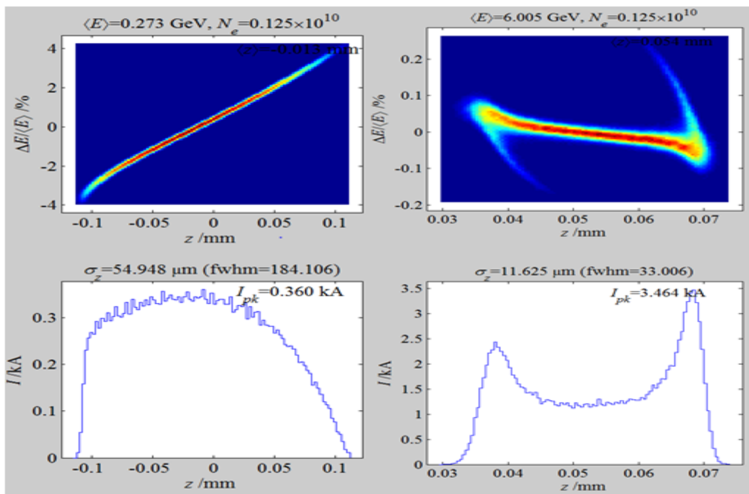
Undulator period	30	mm
Undulator parameter	1	
Fundamental wavelength	0.5	nm
Pierce parameter	0.11%	
3-D Gain length	1.6	m
3-D Saturation length	26	m
Peak power at saturation	5.6	GW

S. Di Mitri Elettra-ST

New hard X-ray FEL source



6 GeV Linac layout



Longitudinal phase space (top) and current profile (bottom) at the exit of BC1 (left) and linac end. The RMS energy spread is, respectively, 1.8% and 0.05%.

Table 1. FEL expected performance.

Undulator period	30	mm
Undulator parameter	1	
Fundamental wavelength	0.16	nm
Pierce parameter	0.1%	
3-D Gain length	1.7	m
3-D Saturation length	~ 40	m
Peak power at saturation	9	GW

Table 2. Linac and compressor parameters

Linac length downstream BC1	50	m
Linac length downstream BC2	70	m
Energy at BC1	0.285	GeV
R_{56} in BC1	-38	mm
Energy at BC2	2.630	GeV
R_{56} in BC2	-14	mm
Compression factors	12.5 × 5.5	m

Outlook and conclusions

- The XbFEL project strongly promote the use of the X-band technology for the future FEL based photon sources.
- This would allow the construction of these facilities with a technological solution that is more efficient in terms of costs, space and power than the conventional ones.
- If approved, the XbFEL grant agreements with EC should be signed in May-June 2015, with an expected starting date at July-2015 and a duration of three years.

!!!!!!!