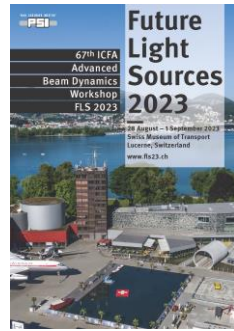




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FERMI FEL Upgrade Plans, an Overview

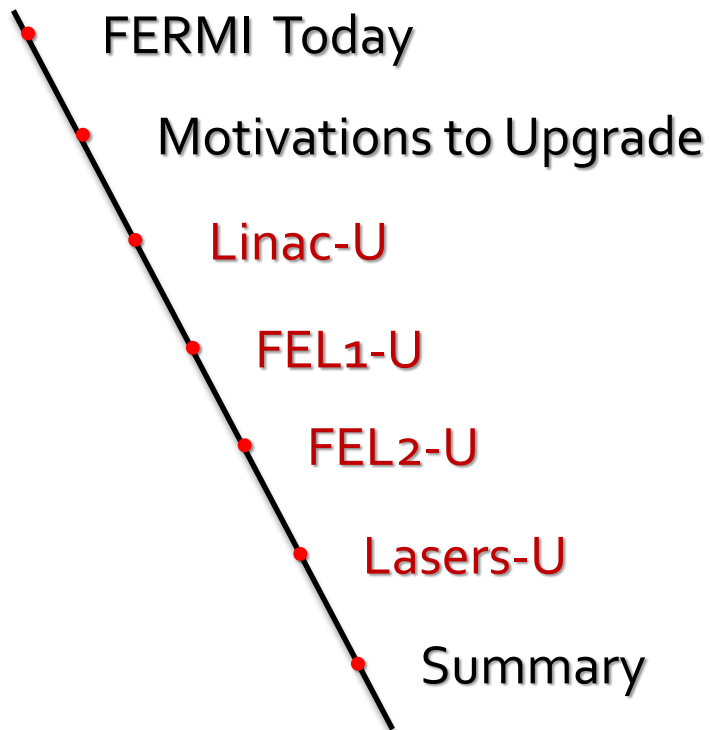
Simone Di Mitri

Elettra Sincrotrone Trieste & University of Trieste

on behalf of the FERMI Team



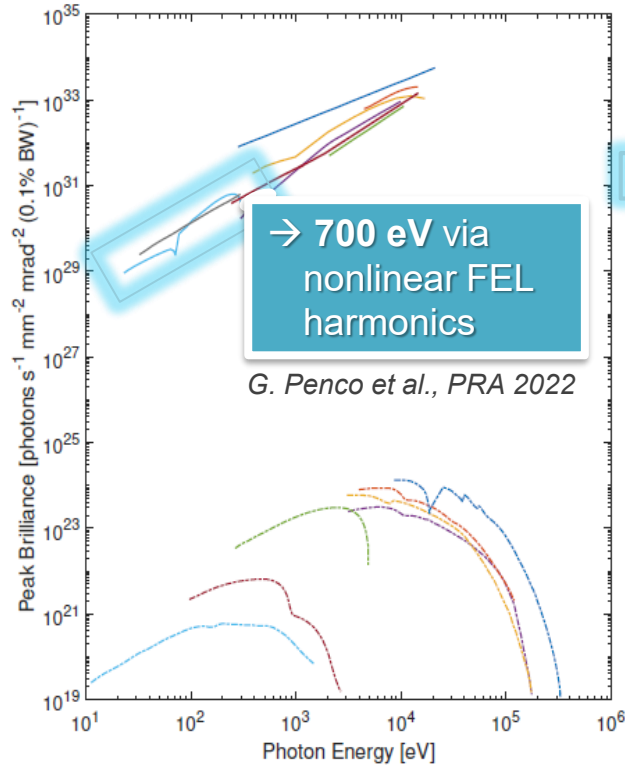
Outline & Credits



Special thanks for input, figures and data:
C. Masciovecchio, L. Giannessi, E. Allaria,
C. Spezzani, G. Penco, M. Trovò, P.
Delgiusto, N. Shafqat, M. Danailov



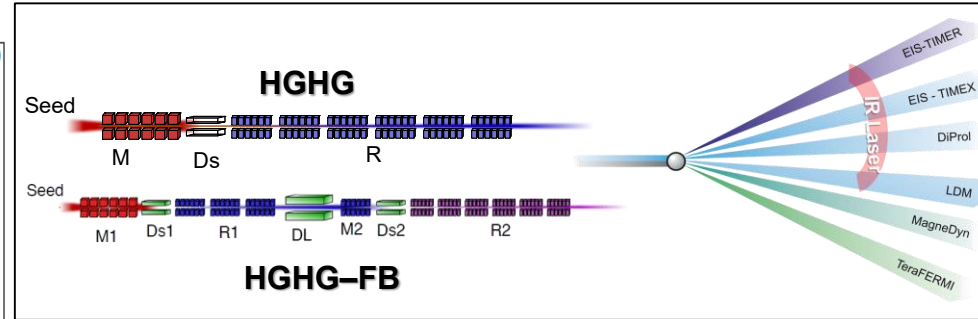
FERMI Today



- European XFEL (Germany)
- SACLA (Japan)
- PAL XFEL (South Korea)
- LCLS (USA)
- Swiss FEL (Switzerland)
- Target of CompactLight
- FERMI (Italy)**
- FLASH (Germany)
- Spring-8 (Japan)
- PETRA III (Germany)
- ESRF (France)
- APS (USA)
- NLS II (USA)
- SLS (Switzerland)
- BESSY (Germany)

2 FEL lines

5 + 1 beamlines



electrons:	seed laser:	FELs:
0.9 – 1.5 GeV	200 – 360 nm	100 – 20 nm
< kA, 0.5 ps	> 50 fs, 100 MW	20 – 4 nm
10 / 50 Hz		< 1 mJ, FTL

- ❑ User experiments/year: 20 – 30
- ❑ Over-subscription rate: 3 – 4
- ❑ Uptime/planned: > 95%



Key Features – Recent Achievements

nature photonics

P. K. Maroju et al., 2023

Article

<https://doi.org/10.1038/s41566-022-01127-3>

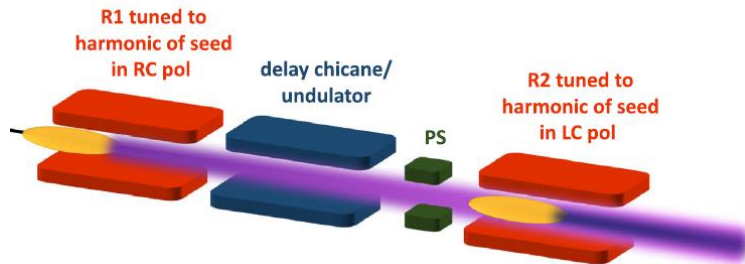
Attosecond coherent control of electronic wave packets in two-colour photoionization using a novel timing tool for seeded free-electron laser

PHYSICAL REVIEW LETTERS **131**, 045001 (2023)

Editors' Suggestion

Femtosecond Polarization Shaping of Free-Electron Laser Pulses

G. Perosa, P. Rebernik et al.



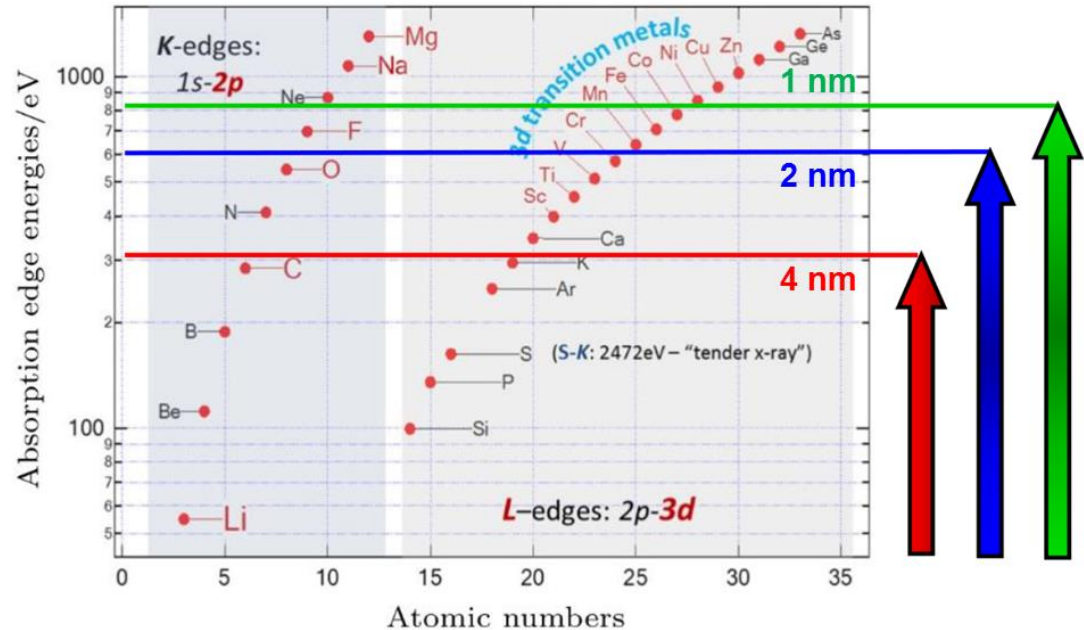
- **Phase-control** of superimposed **FEL colors** generates a train of as-pulses.
- New exp. technique to determine the synchronization of as-train and NIR laser.
→ *Wave packet dynamics*

- **Phase stabilization** and control of delayed **FEL polarizations** allow ultra-fast polarization switching.
→ *Coherent control of electron wave packets, dichroic spectroscopy of molecules, ultra-fast magnetism*

- ❑ Resonant expts. exploiting processes of few fs-lifetime (X-Abs., Small Ang. XS, CDI,...)
- ❑ Nonlinear optics (large wave-vectors)
- ❑ Ultra-fast chemistry & Chirality
- ❑ Water window
- ❑ Coherent control



1. shorter Δt (<10 fs)
2. shorter λ (N,O K-edge)
3. longitudinal coherence





Linac Upgrade

1.5 GeV @ 10Hz



1.5 GeV @ 50Hz



1.8 GeV @ 50Hz

Solution

Low Wakefield
S-band 30 MV/m

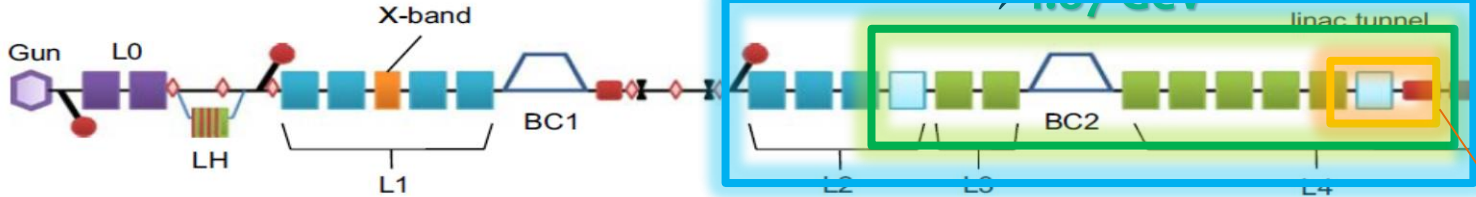
Elettra design.
Commitment to
PSI for fabrication.

Arcing and rusting issues in
30-years old RF structures

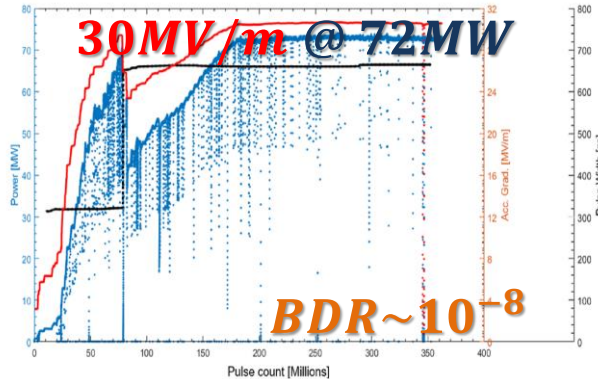
Today

→ 2 GeV

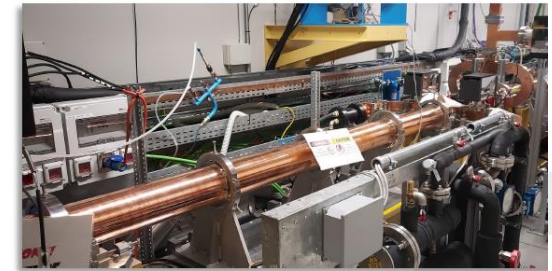
→ 1.87 GeV



Iris is doubled, W_T is 4-fold smaller
 → $\Delta\varepsilon_{n,pr}$ and d^2E/dz^2
 are cancelled out



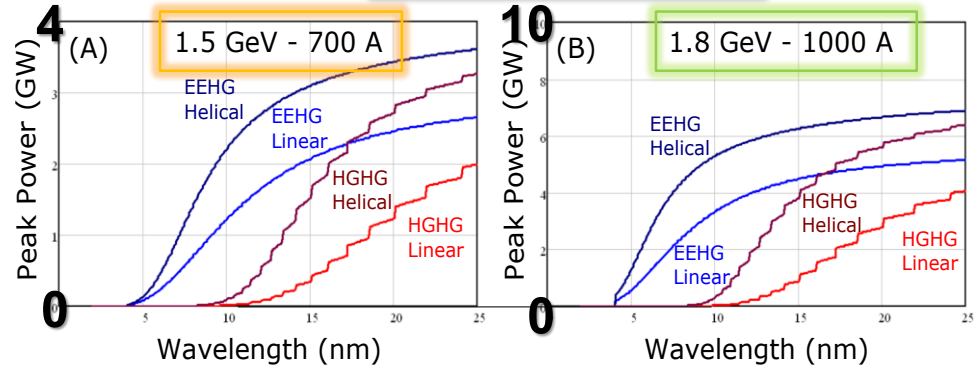
L4.7, H-TD replaced by 2 new structures in 2022 → 1.67 GeV





FEL1 Upgrade to EEHG

Gain in power:

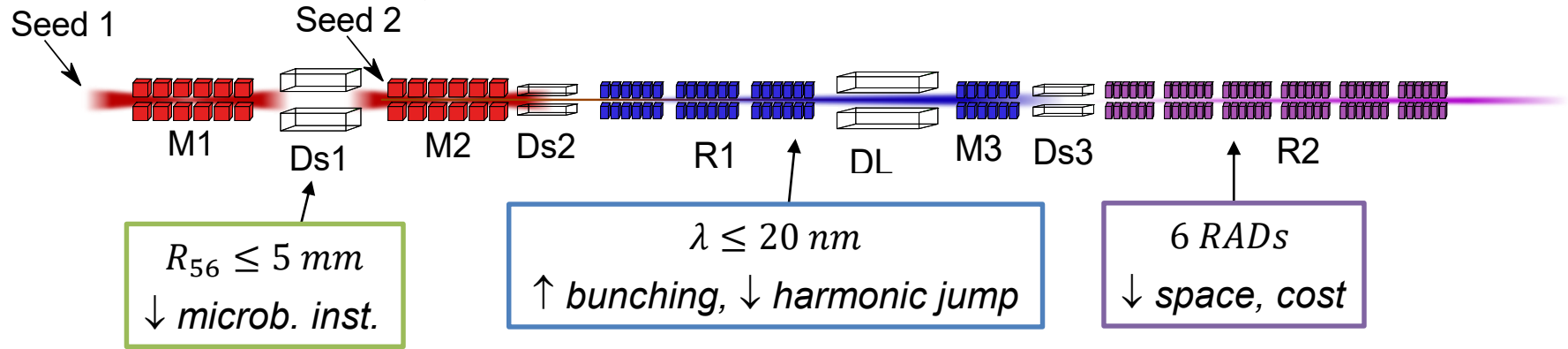


Not only power:

- ❑ Less sensitive to beam imperfections: multi-color, ~FTL up to 124 eV
- ❑ 2 independent pulses at low harmonics in HGHG
- ❑ Partial overlap with FEL-2 (62–124 eV)
- ❑ However: limited spectral tuning, higher complexity
⇒ complemented by “2-pulse HGHG”



FEL2 Upgrade to EEHG-FB

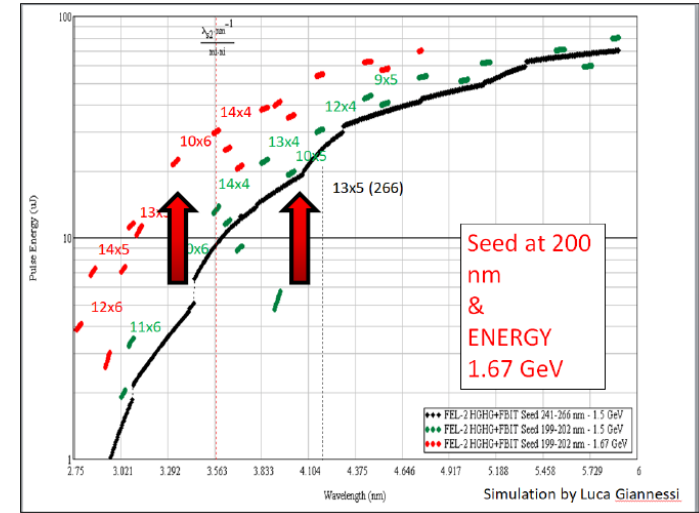


- EEHG-FB is less sensitive to electron energy-chirp and spurious modulations.
- EEHG-FB maximizes the final bunching (SASE noise kept low), thus generates higher harmonics in an “HGHG-equivalent” final radiator.
- However: limited spectral tuning \Rightarrow required new short period radiators for ultimate performance

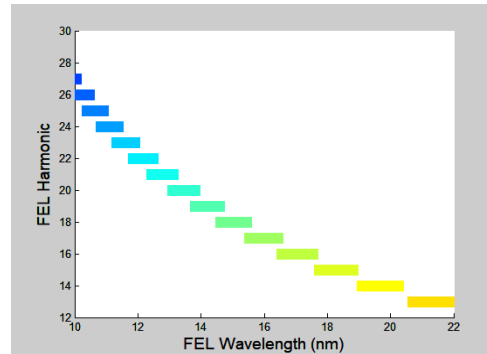


Lasers Upgrade

- PIL**: Ti:Sa amplifier upgraded to single pump for more reliable and stable operation.
- FEL seed lasers**: now available for users, < 60 fs-OPA on FEL1, < 45 fs-THG on FEL2, < 200 nm-OPA on FEL2.
- Pump laser for on samples**: hollow fiber pulse compressor provides < 15 fs-UV



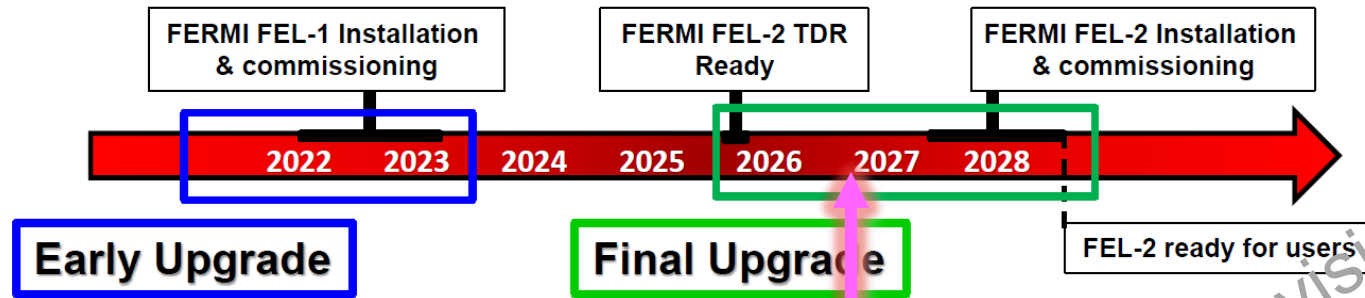
Seed laser for FEL-2 EEHG: substantial gain in pulse energy below 4 nm



Seed laser for FEL-1 EEHG: wider and continuous spectral tuning down to 10 nm

Summary & Outlook

- ✓ FERMI is a unique EUV **temporal & spectral synthesizer**
- ✓ Experiments largely exploit full **control** in radiation **phase & polarization**
- ✓ Scientific trend is towards **shorter durations & shorter wavelengths**.
- ✓ We want to extend full coherence and multi-color in the **soft X-rays**



Elettra 2.0 in operation



Elettra
Sincrotrone
Trieste

Join us!

WAVEMIX Network (50 Research Institutions)

<https://www.elettra.eu/Prj/WAVEMIX/>

Scope: Extend Wave Mixing at Shorter λ



WavemiX2023

Workshop WavemiX2023

11-13 September - Freiburg

Non-linear Extreme Ultraviolet and X-ray optics and spectroscopy

M. Chergui¹, M. Beye², S. Mukamel³, C. Svetina⁴, C. Masciovecchio^{5*}

Nature Rev. in press



Thank You for Your attention