X-Ray FEL Oscillator: High Flux, Full Coherence, High Brightness, Narrow-BW

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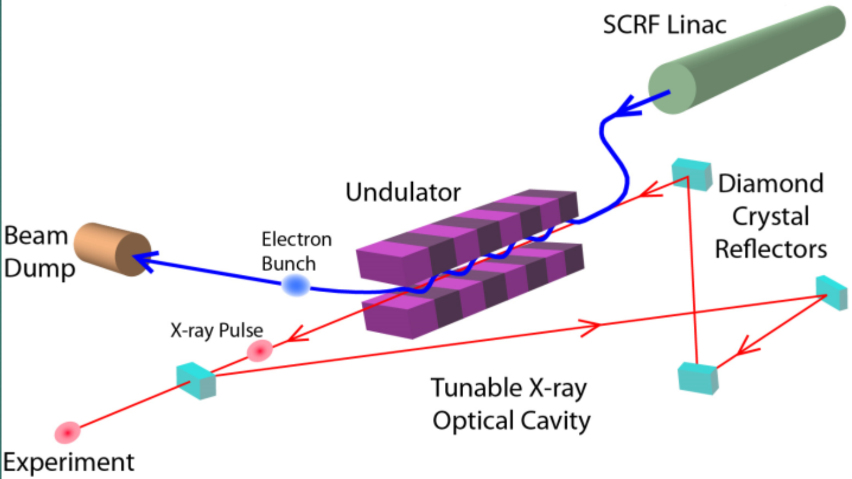
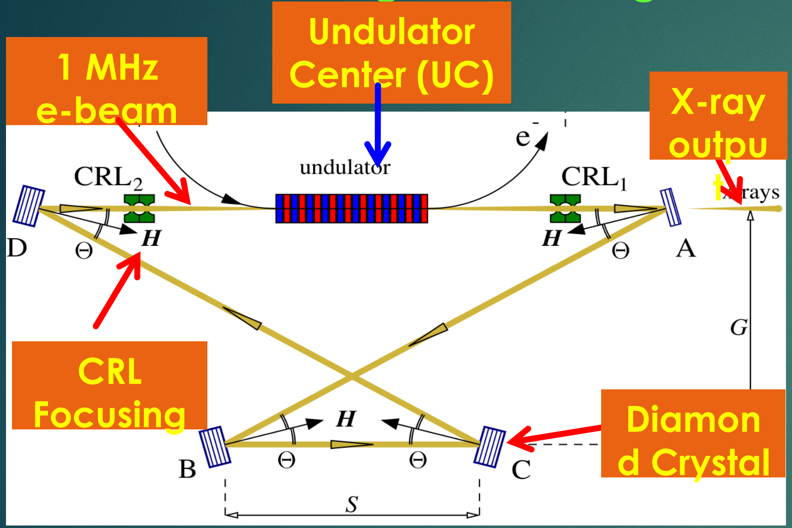
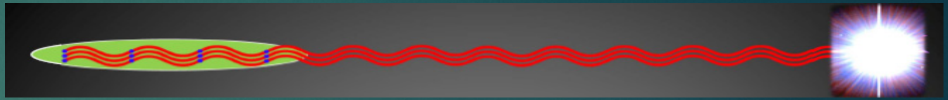
- Peking U./SLAC: W. Qin
- DESY: J. Zemella
- Cornell U.: S. Stoupin
- TISNCM: V. Blank, S. Terentiev
- CAS: N. Medvedev

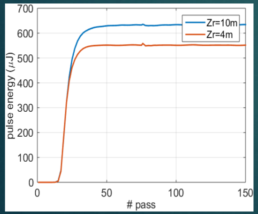


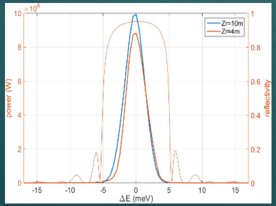
XFELO: Bragg refection for X-ray cavity

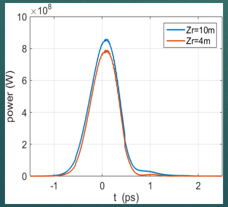
(R. Colella & A. Luccio,1983: KJK, Y. Shvyd'ko, S. Reiche, 2007
Harmonic lasing, H.X. Deng, 2012)





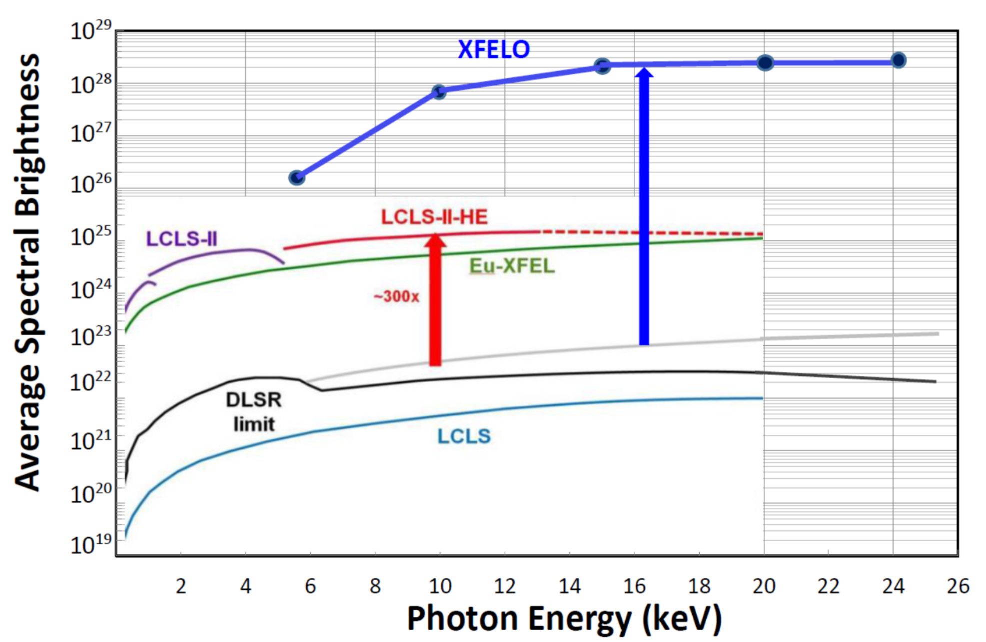






- Works best where Bragg scat. has high R and high(!) BW--- 5-25 keV
  - High energy, CW accelerator-- SCRF
- ~ 8 GeV SCRF linac with optimized injector (W. Qin)
  - LCLS-II-HE, Shanghai, EuroXFEL conversion
- For 14.4 keV λ_U=2 cm, K=1.49 → SC NbTi : Kmax=3.1→ 5.2 keV

XFELO with 8 GeV linac: B_{av}~ 10^{28} for ε_γ >10 keV



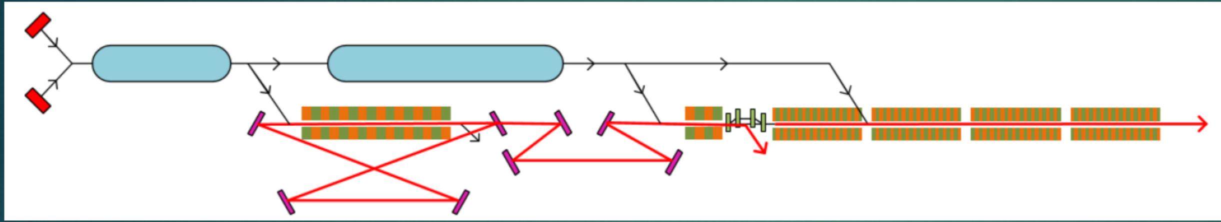
Brightness units [#/ (s mm² mrad² 0.1% BW)]

- #~10^{10} photons/pulse
  ~ 10^{-2} × SASE
- $\Delta\omega/\omega$ ~ 10^{-7}
  ~ 10^{-4} × SASE
- B~#/$\Delta\omega/\omega$
  - B (XFELO/SASE) ~100 !!
- For ε_γ >13 keV, XFELO >10^5 ×DLSR
- For 10 keV <ε_γ <13 keV, XFELO >10^3 ×SASE

Weilun Qin, et al., TUC05

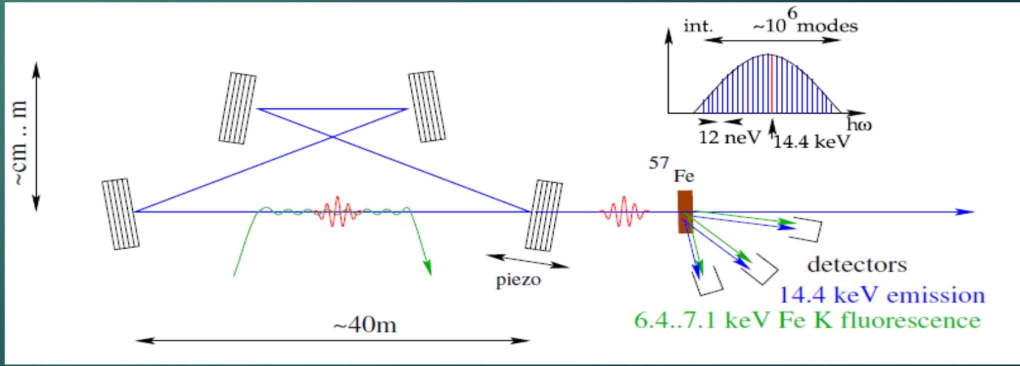
Further developments

MOPA for Coherent high-power ultrashort
MOHGPA for 40-50 keV (MaRIE) –W. Qin, KJK, R. Lindberg, J.H. Wu, MOP062



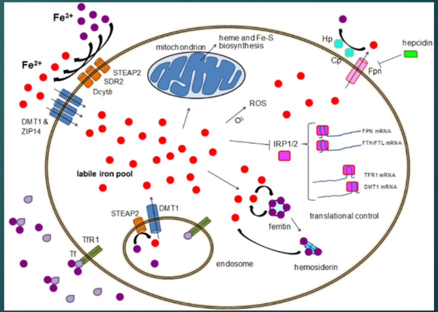
Harmonic XFELO (2012), Cascade scheme,… H.X. Deng MOBB

Stabilized XFELO referenced to ^{57}Fe
X-ray spectral comb
(B. Adams, KJK, PRSTAB,18, 030711 (2015)



XFELO Science Retreat : 6/29-7/1, 2017

- Techniques developed/started at 3rd gen source and SASE-XFEL will be enhanced to unprecedented level
  - Smaller sample, shorter data collection time, higher resolution (IXS, XPCS, NRS)
- Techniques in infancy
  - Nonlinear X-ray optics—PDC probing optical mudlation with X-ray resolution
- New approaches to new areas
  - X-ray spectral comb→ metrology for fundamental physics, revolution in nuclear physics (laser to atomic physics)
- Sciences for narrow BW are as exciting as that for ultrashort



Iron metabolism in living cell: no need to enrich

Technical Issues

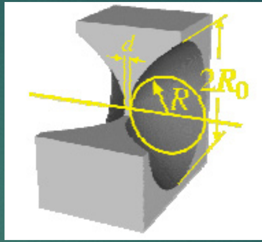
- Intra-cavity focusing elements
  - Grazing incidence, curved mirror or CRL?
  - CRL quality?
- Bragg Reflector
  - Reflectivity, thermo-mechnical properties?
  - Widthstand the high intra-cavity X-ray power (~ 10-20 kW/mm^2) ?

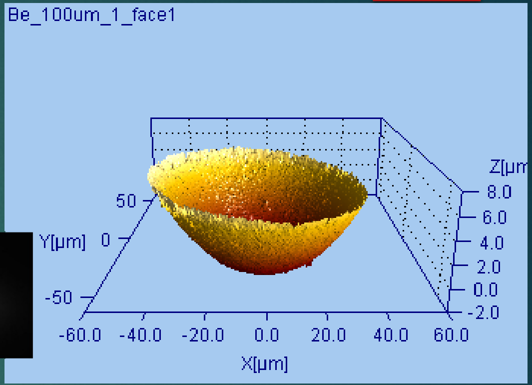
Be-CRL as a compact, low-loss focusing element

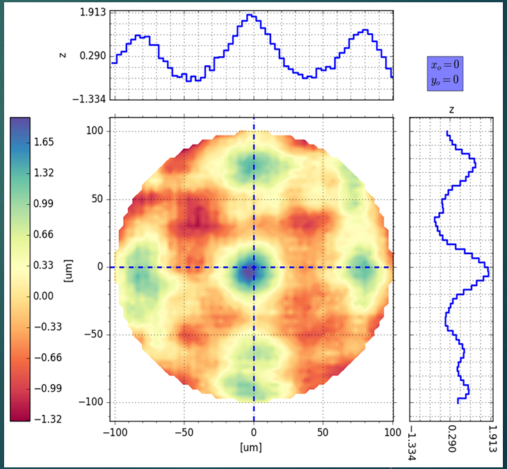
CRL normally used with many lenses compounded → High loss

For XFELO, we need at most two face-units

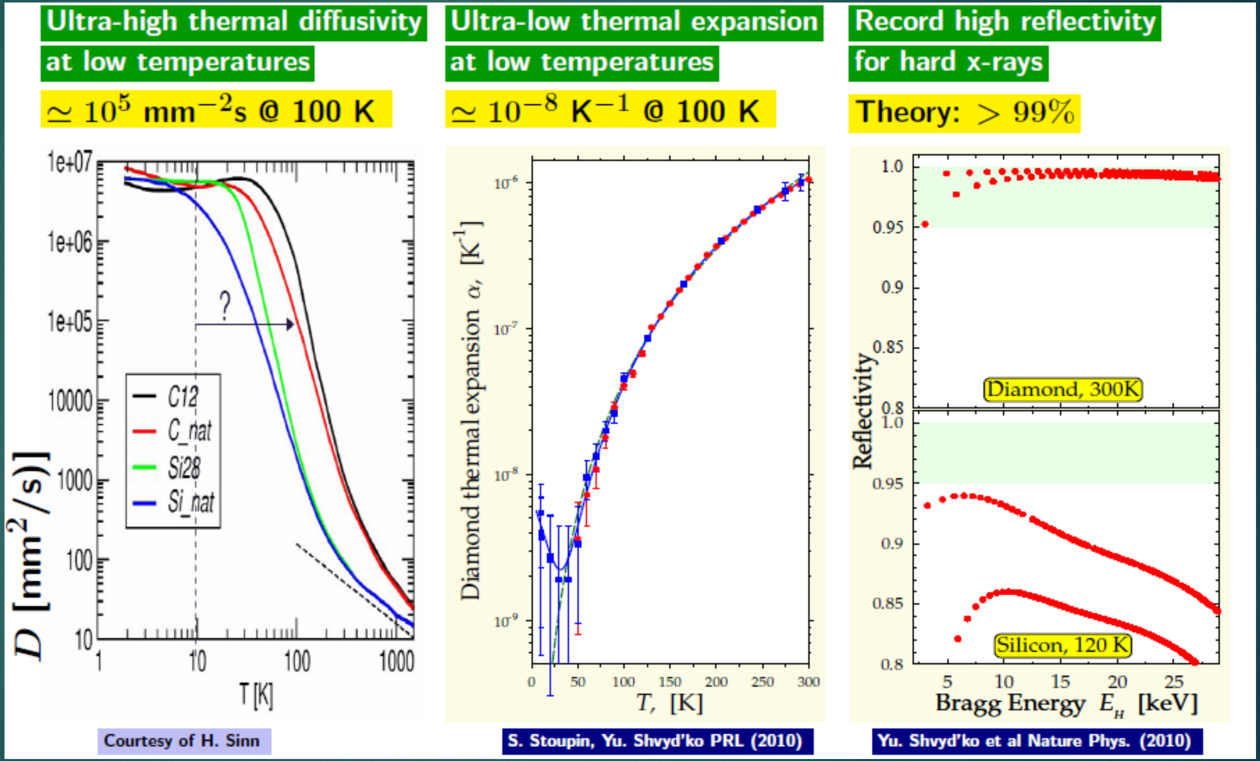
- Test Be-CRL R= 100 μ at APS
  - Transmission @14 keV is higher than 98%
  - Metrology and Talbott interferometry show that the deviation from parabolic profile is less than 1 μm
  - Good imaging quality
  - Can withstand the intra-cavity X-ray power







Diamond: Excellent Thermo-Mechanical Properties

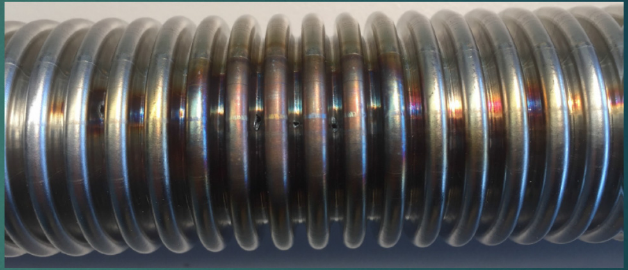


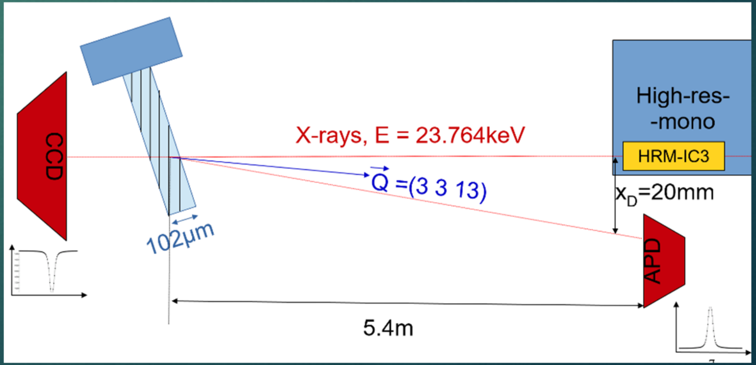
For a review, see Y. Shvyd'ko, V. Blank, S. Terentyev, MRS Bull.,42, 437 (2017)

Can diamond survive the X-ray power 10-20 kW/mm² ?   Tests at the APS

- Two tests irradiating spots up to 4 hrs at power level expected in an XFELO:
  - 9 kW/mm² in 30x120 μm² spots (K-B mirror focusing) under medium vacuum
  - 12.5 kW/mm² in 30x40 μm² spots (Be-CRL focusing) under UHV (~10^{-8})
- High-resolution (meV) topography

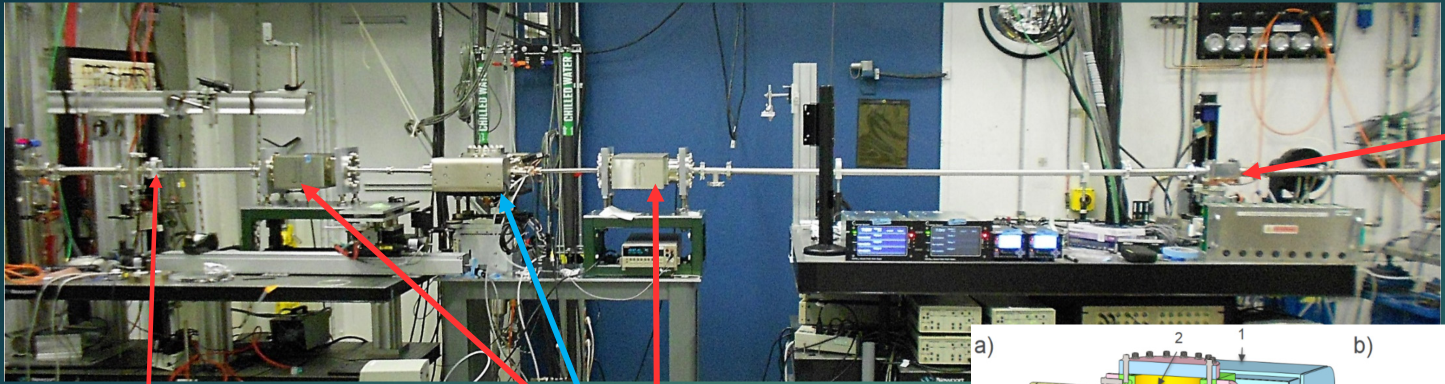
Unfocussed X-ray beam burns stainless steel in few minutes





T. Kolodziej, Y. Shvyd'ko, D. Shu,et al., MOP057

Irradiation 12.5 kW/mm^2 at APS 7-ID-B

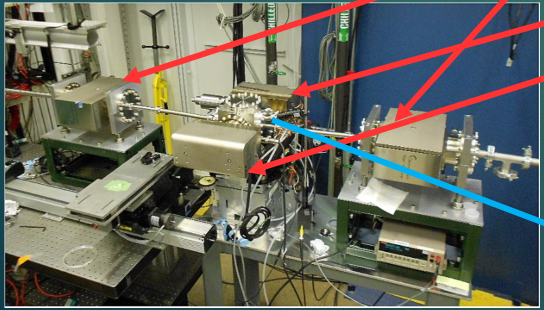


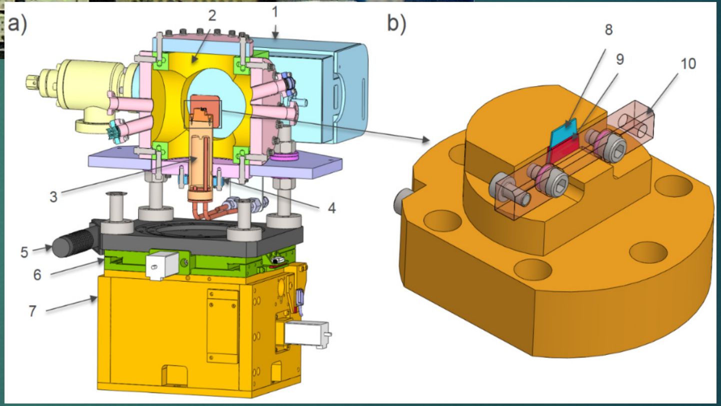
Be-CRL

Scattering detector

Differential ion pumps

Side ion pumps

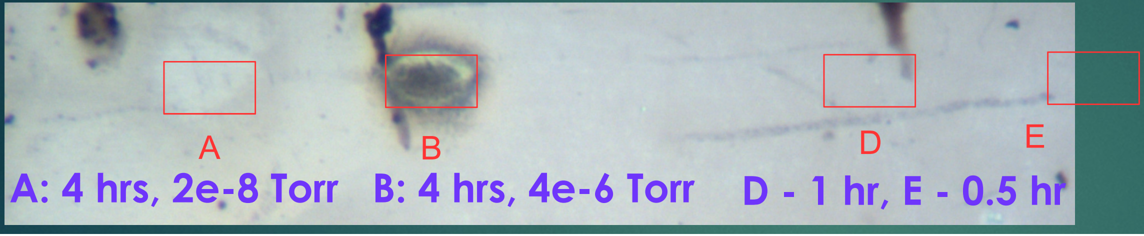


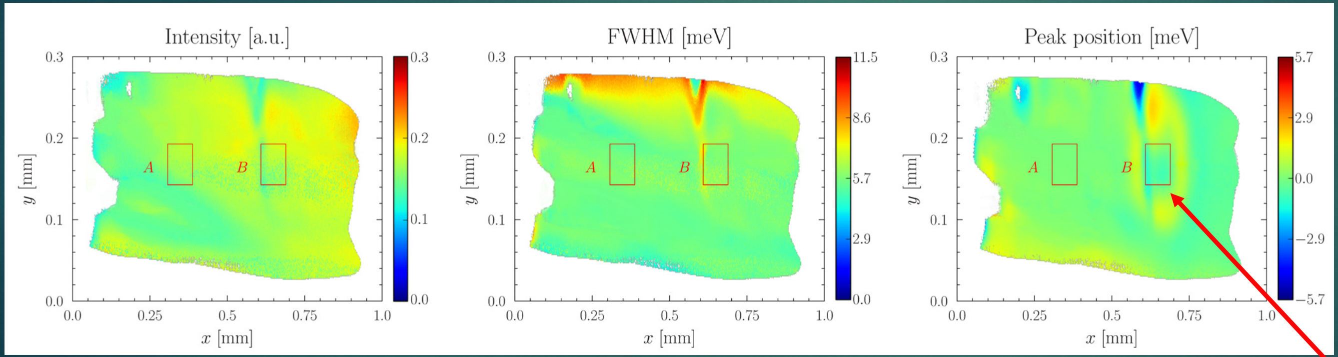


UHV irradiation Chamber (gold-coated)

See S. Kearney, et al, MOP056

Topograph after irradiation indicates no structural damage but Bragg peak shifts by ~ 1 meV of the rocking curves near the carbon deposits





$\delta E/E=\delta d/d=1.6 meV/24 keV$

Relative d-spacing change =$7\ 10^{-8}$

Conclusions

- **An XFELO is feasible from beam dynamics and X-ray optics**
- **Several projects for construction of ~8 GeV SCRF linac exist**
  - LCLS-II-HE, Shanghai, EuroXFEL,..
- **An XFELO with an optimized injector will producing fully coherent x-rays with $\mathcal{B}_{av} \sim 10^{28}$**
  - $>10^5$ than DLSR
  - For < 13 keV, XFELO >100 than SASE
  - For >13 keV, SASE is supressed
- **Strong scientific cases exist for narrow BW, coherent X-rays**
  - An XFELO will drive the techniques already developed to a new level of capabilities
  - Novel techniques can be developed for novel sciences