Higher Harmonic XFELO with the Planned LCLS II SCRF Linac

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ANL
Z. Huang
LCLS

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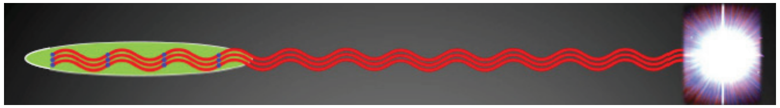
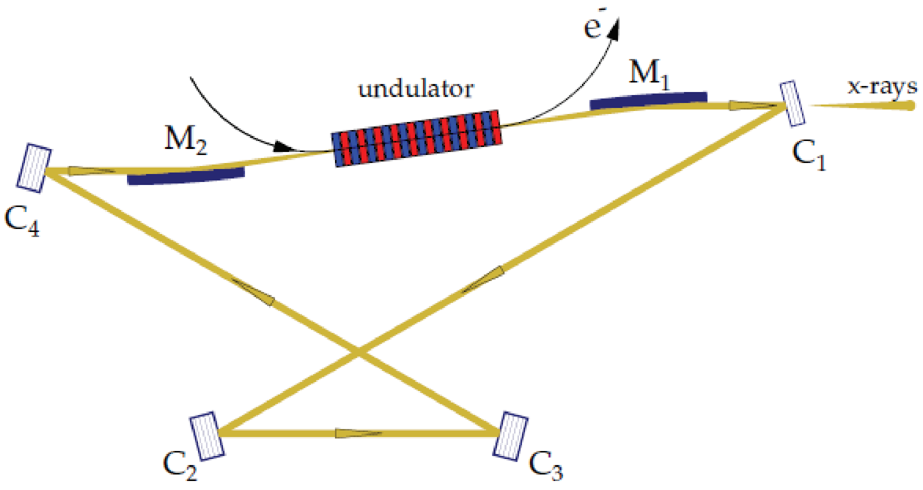
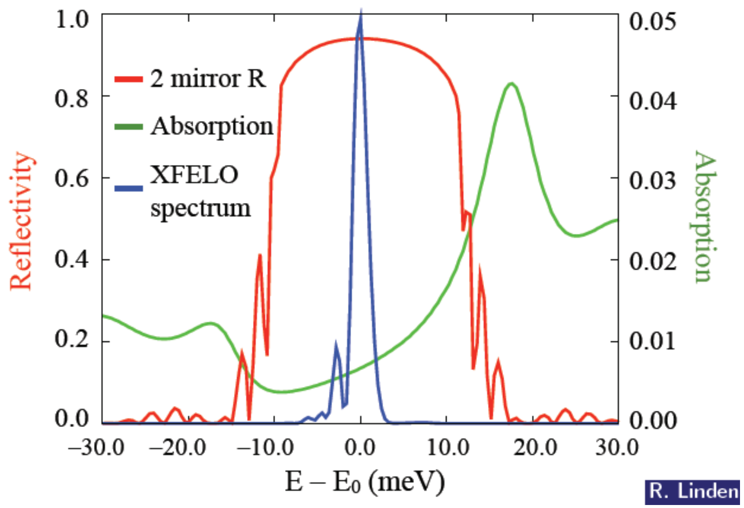
X-Ray FEL Oscillator



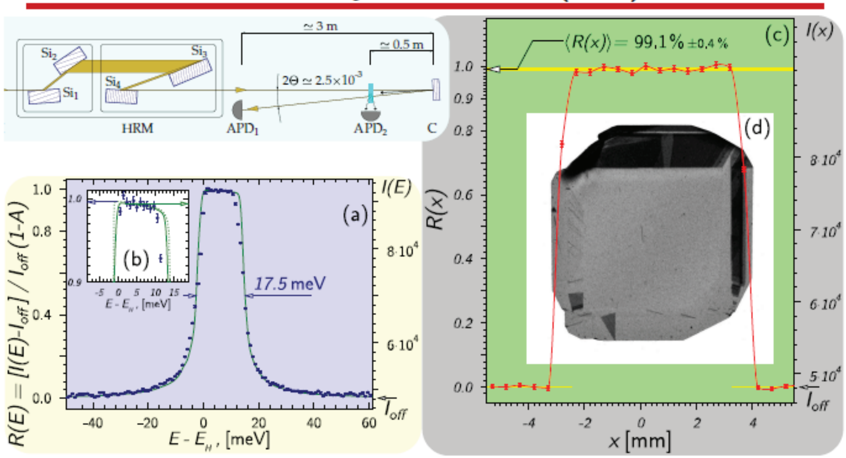


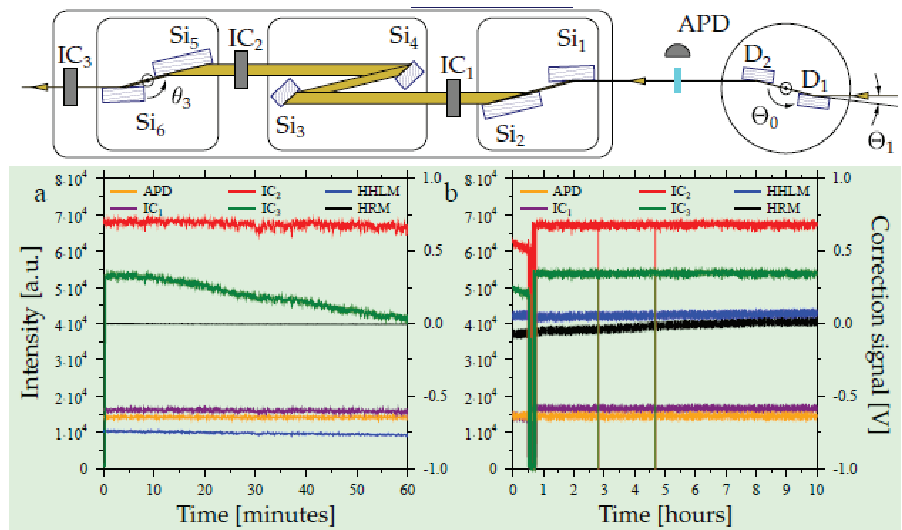


- **A hard x-ray FEL oscillator is feasible by using an optical cavity with Bragg mirrors**
  - **R. Collela and A. Luccio, 1983; KJK, Y. Shvyd'ko, and S. Reiche, 2008**
  - **Tuning scheme by R.M.J. Cotterill in 1968**
- **Fully coherent, ultra-high spectral resolution(~meV) with storage-ring like stability: *A real laser!***

Diamond Crystal is well-Suited for XFELO

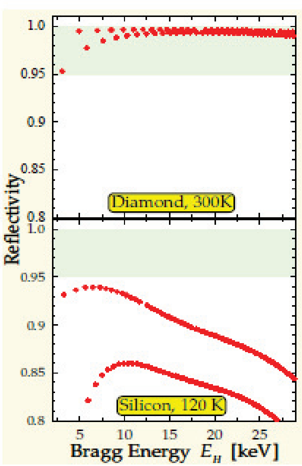
Diamond Reflectivity Studies: C(008) @ 14.3 keV





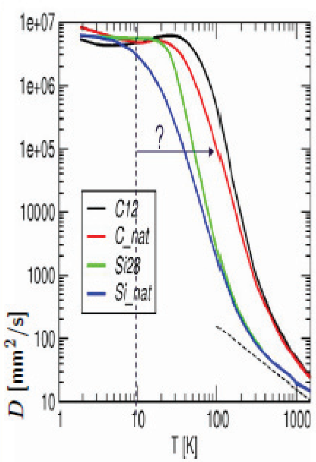
Record high reflectivity for hard x-rays

Theory: > 99%



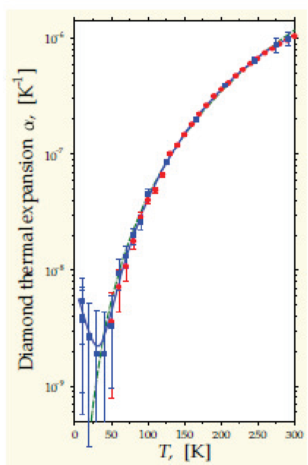
Ultra-high thermal diffusivity at low temperatures

$\simeq 10^5$ mm^{-2}s @ 100 K



Ultra-low thermal expansion at low temperatures

$\simeq 10^{-8}$ K^{-1} @ 100 K

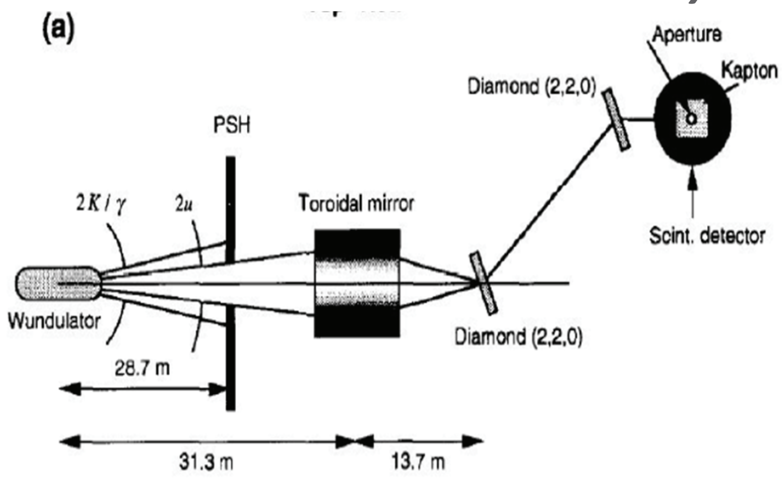


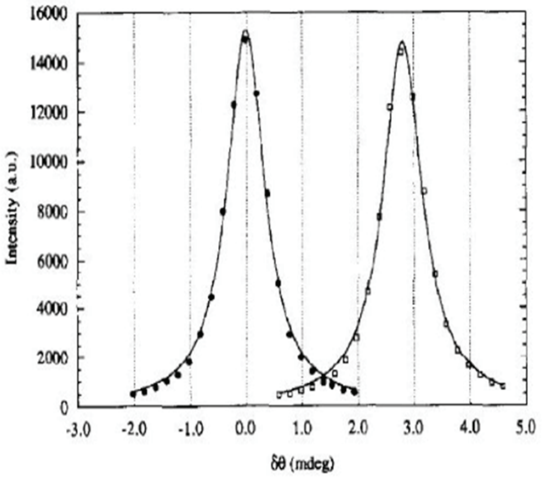
- **Null-detection FB achieving 50 nr stability f<2 Hz**
- **Nano-radian stage**
- **Strain-free crystal holder**
- **experience with LCLS SS**

Y. Shvyd'ko, D. Shu, S. Stoupin, V. Blank,

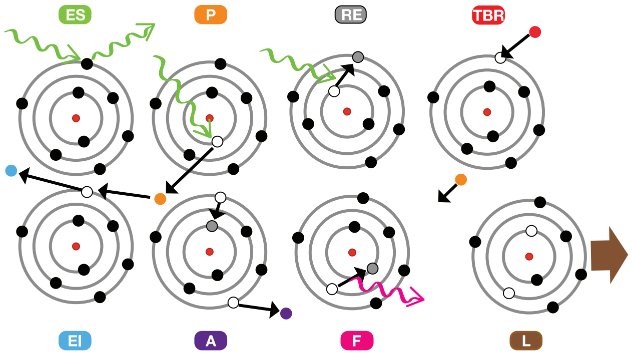
Test of possible diamond damage

J. Als-Nielsen, A.K. Freund, M. Wulff, M. Hanfland, and D. Häusermann.
Nucl. Instrum. Methods Phys. Res. B 94, 348 (1994)





- **Planning for a new test at the APS: 34-E (μ–Diff) or 35 ID (Dynamic Comp)**
- **Monte-Carlo /Molecular-dynamics simulation of nano /mesoscopic diamond (P. Ho and C. Knight)**

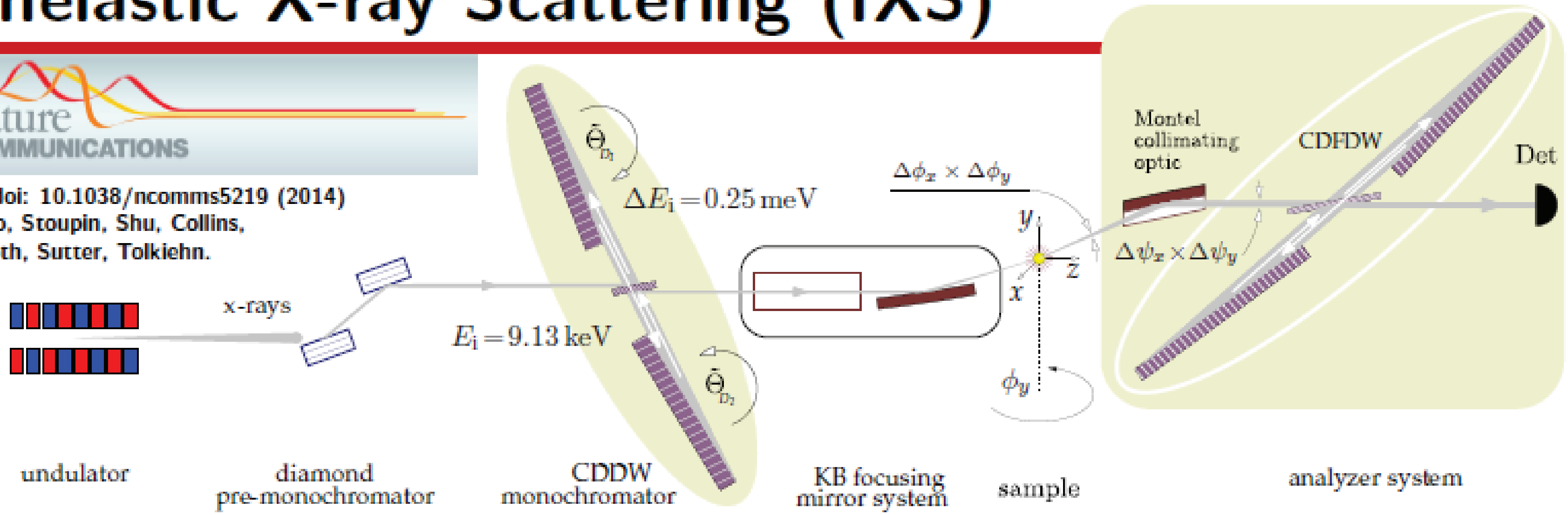


Ultra-high-resolution (< meV) inelastic scattering will be revolutionized: from ~10^9 to 10^{15} photons /sec

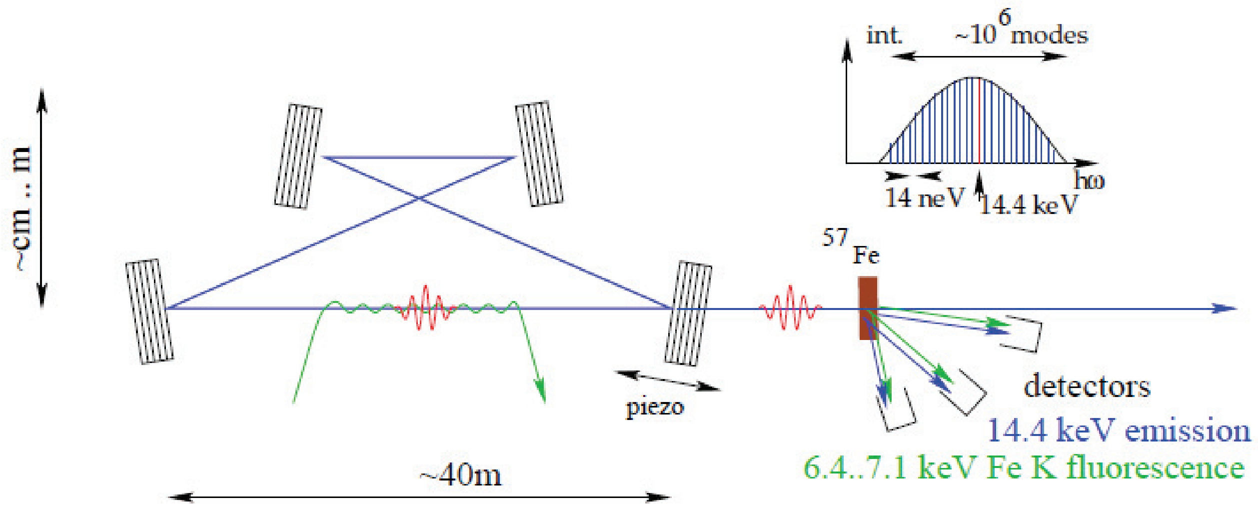
High-contrast Sub-millivolt Inelastic X-ray Scattering (IXS)

nature COMMUNICATIONS

5:4219 doi: 10.1038/ncomms5219 (2014)
Shvyd'ko, Stoupin, Shu, Collins, Mundboth, Sutter, Tolkiehn.



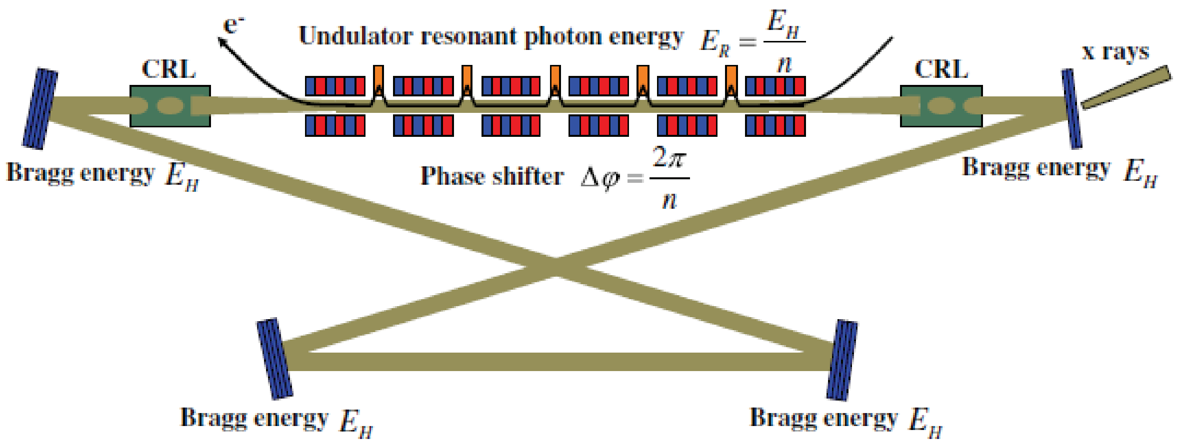
The XFELO output pulses are identical copies of the circulating intra-cavity pulse



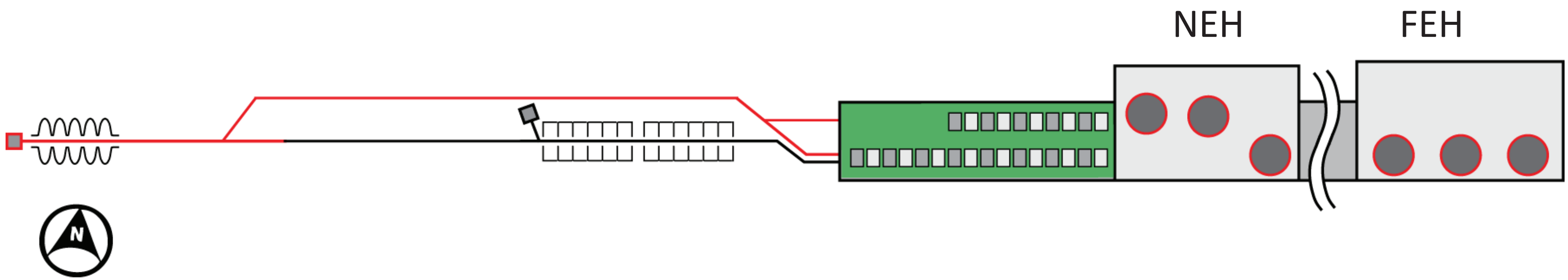
- **Inter-pulse coherence is possible, for example by FB referenced to a narrow nuclear resonance(^{57}Fe)**
  - ***X-ray spectral combs* & the field of experimental x-ray quantum optics for fundamental physics, x-ray metrology, etc (Bernhard Adams, KJK, 2012)**

Main Issue: The Cost of CW SCRF linac with MHz bunch rate

- EuroXFEL can be operated in CW at a reduced E-beam energy of 7 GeV (J. Sekutowicz)
  - Need new power couplers
- With higher harmonic FEL, the E-beam energy could be significantly lower than 7 GeV (H.-X. Deng & Z.-M. Dai)



LCLS-II Concept by August 2013 *(J. Galayda)*



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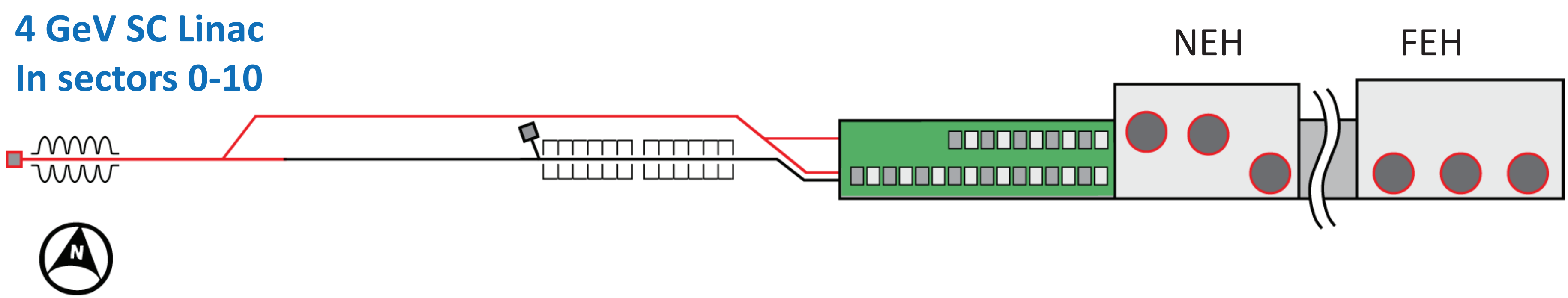
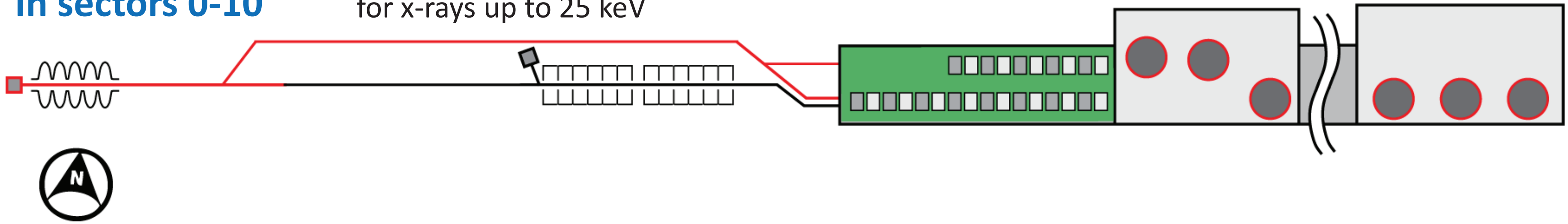


LCLS-II Concept by August 2013 *(J. Galayda)*

4 GeV SC Linac
In sectors 0-10

14 GeV LCLS linac still used
for x-rays up to 25 keV



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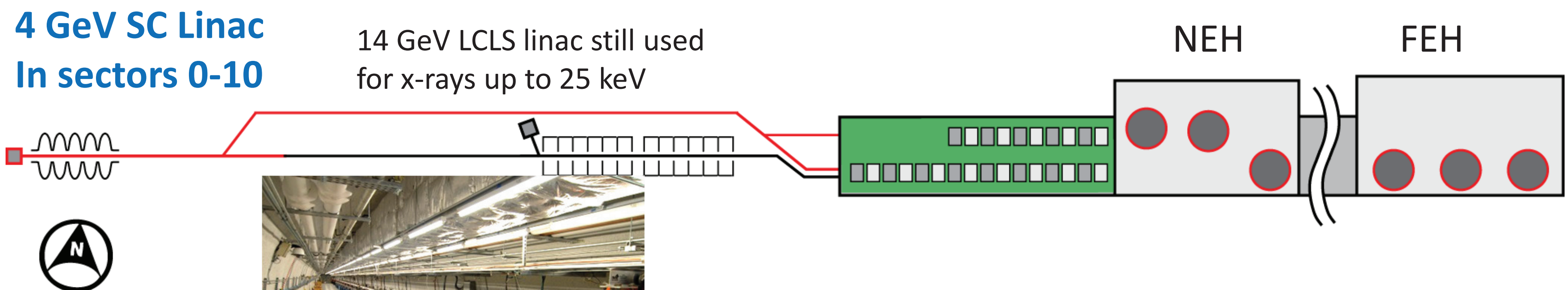

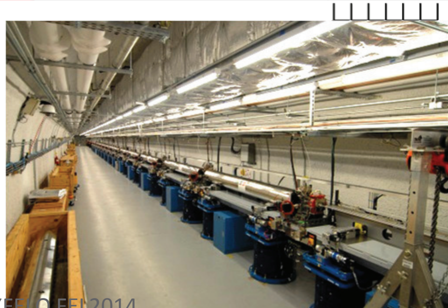

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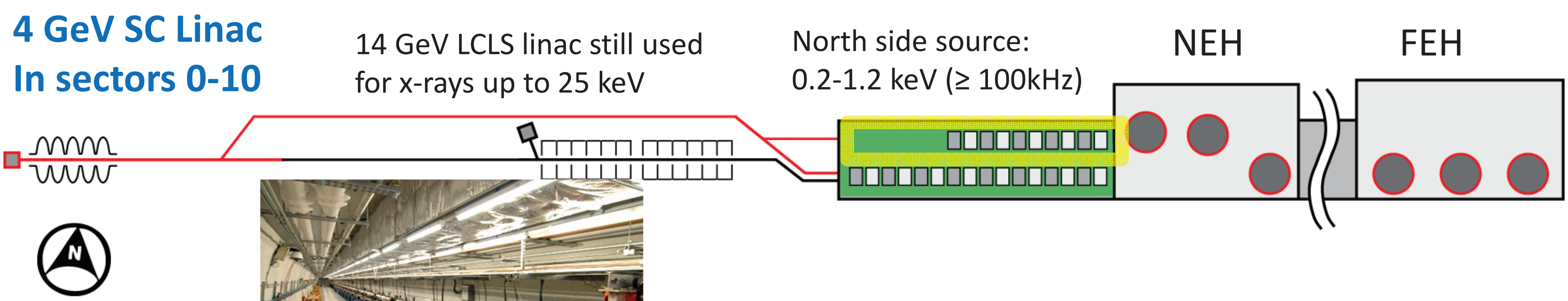

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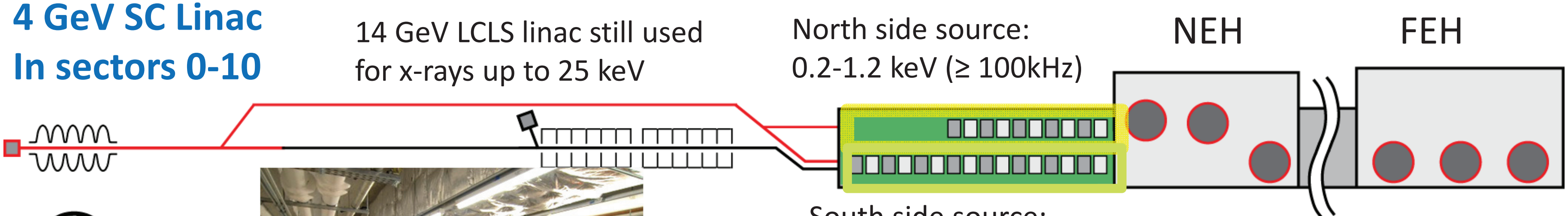
North side source:
0.2-1.2 keV (≥ 100kHz)



South side source:
1.0 - 25 keV (120 Hz, copper" linac)
1.0 - 5 keV (≥100 kHz, SC Linac)

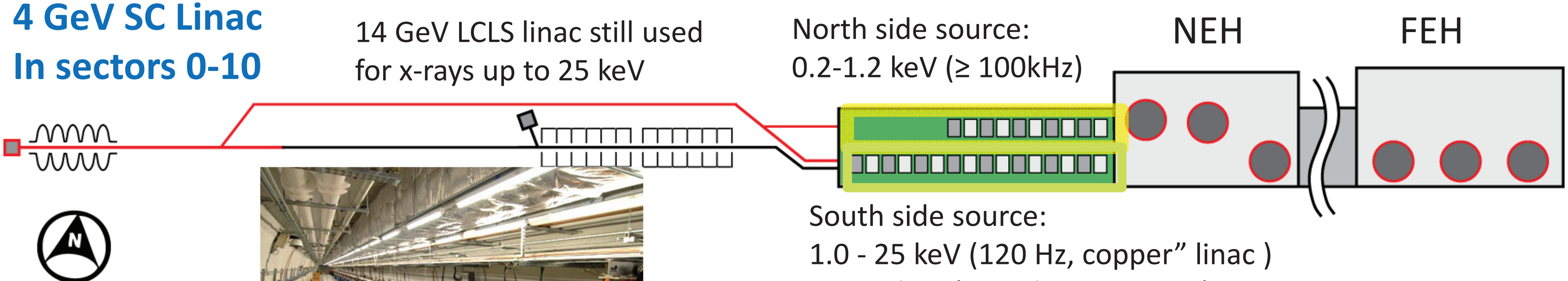
LCLS-II Concept by August 2013 *(J. Galayda)*

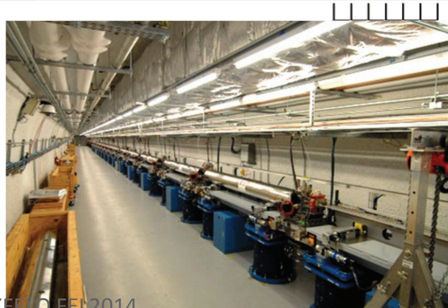
Accelerator	Superconducting linac: 4 GeV
Undulators in existing LCLS-I Tunnel	New variable gap (north) New variable gap (south), replaces existing fixed-gap und.
Instruments	Re-purpose existing instruments (instrument and detector upgrades needed to fully exploit)

4 GeV SC Linac
In sectors 0-10

14 GeV LCLS linac still used for x-rays up to 25 keV

North side source:
0.2-1.2 keV (≥ 100kHz)





South side source:
1.0 - 25 keV (120 Hz, copper” linac)
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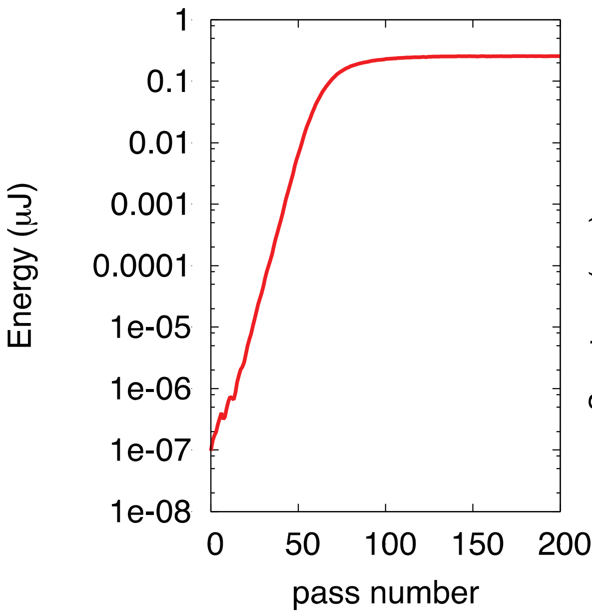
Harmonic XFELO performance (R. Lindberg, with a new code with exact total energy conservation)

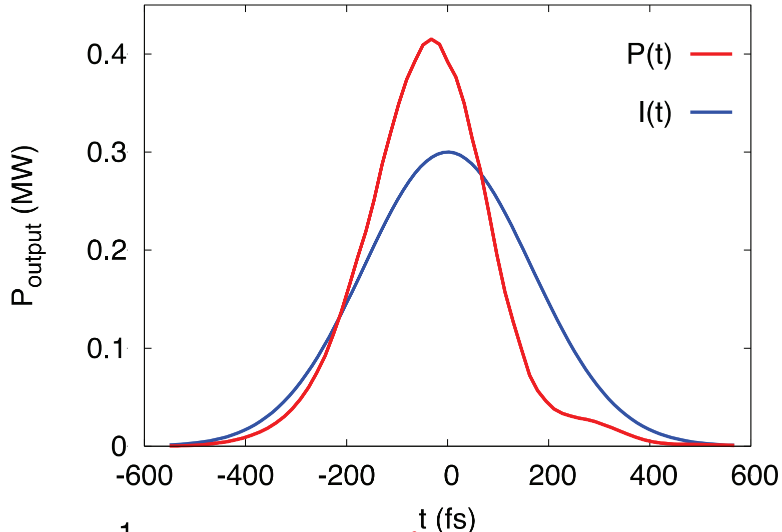
Input

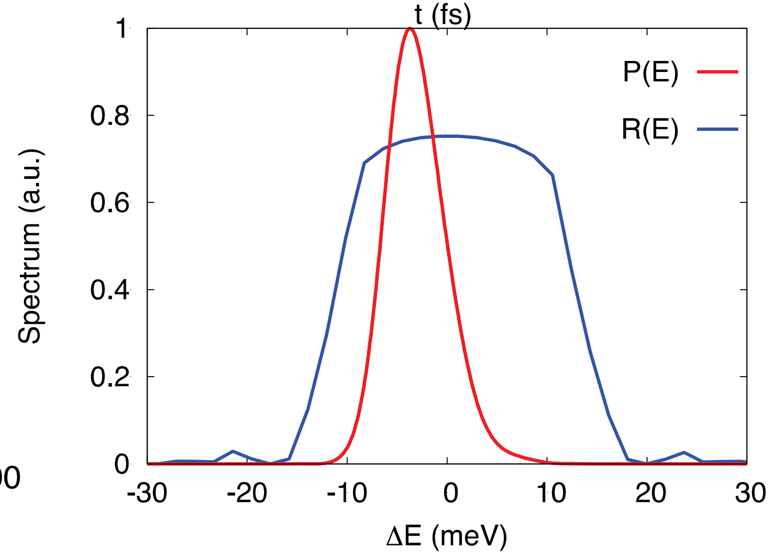
Electron beam	
γmc^2	4 GeV
σ_γ/γ	0.0125%
I	120 A
$\varepsilon_{x,n}$	0.2 μm
Undulator	
λ_u	2.6 cm
K	1.69
N_u	2500
Cavity	
Z_R	11 m
R	75%
Radiation	
λ_{rad}	1
harmonic	5

Output

Parameter	Value
Power	0.42 MW
# photons	1.6×10^8
ΔT_{FWHM}	265 fs
ΔE_{FWHM}	6.8 meV







Full scientific potential of x-ray FEL can be realized when both amplifiers and oscillators are available

- We have begun a modest 3 year R&D program, with emphasis on crystal damage issues.
- If we find that high-quality diamond crystals can withstand the intense x-ray exposure inside the x-ray cavity, the only real issue with an XFELO construction is the high-cost associated with high energy (~ 7GeV) SCRF linac.
- With a 5th harmonic operation, the LCLS II linac is a possible driver for a first XFELO- "*a real x-ray laser*"