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A concept design driven by X-ray science needs

Science requirements
- Soft X-ray probes
- High average brightness
- Moderate peak-power
- Ultrafast pulses, coherence

NGLS R&D work geared toward a design of a 4th generation FEL-based Light Source:
- Soft X-rays
- Ultrafast
- Coherence
- 2-color (X-ray pump-probe, non-linear spectroscopy)
- High repetition rate (SC CW Linac)
A high average power X-ray laser facility with high rep-rate CW beam and flexible pulse format

Intense coherent pulses at high rep rate – high average coherent X-ray power

Today’s X-ray laser sources

Intense coherent pulses at low rep rate

Today’s storage ring sources

Weak coherent pulses at high rep rate
Layout and radiation characteristics

High repetition rate soft X-ray laser array
- Up to $10^6$ pulses per second
- Average coherent power up to $\sim 100$ W

Spatially and temporally coherent X-rays (seeded)
- Ultrashort pulses from $\sim 1$ fs to $\sim 300$ fs
- Narrow energy bandwidth to 50 meV

Tunable X-rays
- Adjustable photon energy from 100 eV – 1.25 keV, 2 keV achievable [baseline, 2.4 GeV]
- Moderate to high flux with $10^{10} – 10^{12}$ photons/pulse

Expandable
- Capability (e.g. higher photon energy, higher repetition rate)
- Capacity (multiple FEL beamlines)
**Linac layout**

- **“APEX” injector**
- **TESLA/ILC SC structure technology**
  
  *(modified for NGLS)*
- One or two-stage compression
- “Dechirper”
- RF deflector-based beam spreader
- 3 initial seeded / self-seeded FELs

- **300 pC bunches**
- **1 MHz bunch rate**
- \( \gamma \varepsilon_\perp = 0.6 \mu m \)
- \( I_{pk} = 500 \ A \)
- \( \sigma_E = 150 \ \text{keV} \)
- **Final useable bunch 300 fs**
Linac beam dynamics

- **S2E modeling using** ASTRA, ELEGANT, IMPACT, GENESIS, GINGER

- **Special attention to minimization of** microbunching instability, CSR-induced emittance growth

- **Electron beam meets requirements for FEL**
**Cryomodule concept**

- TESLA/ILC (1.3 GHz) technology modified for CW operation in NGLS
- Use existing expertise, designs, infrastructure, industrialization
  - Discrete cryomodules each with cold/warm end transitions
  - Magnets, diagnostics & HOM absorbers in warm sections
  - Distribute 5 K liquid, cool to 1.8 K at cryomodule
- **E ~14-16 MV/m**
- **Q₀ = 2x10¹⁰**
- **Heat load @ 1.8K**
  - ~12 W / cavity
  - 90–130 W / cryomodule
CW superconducting linac + high bunch rate + fast feedback = highly stable beams

- Goal of stability similar to existing storage rings
- CW measurements allow broadband feedback to control residual jitter

- $\frac{\Delta E}{E} \approx 10^{-5}$
- $\Delta \tau < 10$ fs
- $\frac{\Delta x_{rms}}{\sigma_x} < 5\%$
Beam spreader

- RF deflecting cavity and magnetic lattice distributes bunches to FEL beamlines
  - *Flexible time structure*

from linac

Lambertson septa 38mrad

RF Dipole 3 MeV / 1.15mrad

FEL 1

FEL2

FEL3

Dipole magnet

RF deflecting cavity and magnetic lattice distributes bunches to FEL beamlines.

- *Flexible time structure*
Three concepts developed for the initial X-ray FELs

Self-seeded

- SASE radiator
- Chicane
- Self-seeded radiator

Trade-off: time/energy resolution

- ≥1 μs
- ~30–300 fs

MHz pulse repetition rate
High power ~100 W

2-stage HGHG

- Seed laser
- Chicane
- Radiator-1
- Modulator-1
- Radiator-2
- Modulator-2

Trade-off: time/energy resolution

- ~5 – 50 fs
- ≤100 fs (+ X-ray delay)
- ~1 – 5 fs

Chirped-pulse / tapered SASE

- Seed laser
- Chicane
- Modulator-1
- SASE radiator 1
- Seed laser
- Modulator-2
- SASE radiator 2

Trade-off: time/energy resolution

- ≤100 fs (± X-ray delay)
- ~1 – 5 fs

fs pulse capability
2 color X-ray pulses
“Pulse on demand”

- Photodiodes measure timing and predict the path of droplet from dispenser
- The photocathode laser is then triggered to provide pulse coincident with droplet arrival at the FEL focus

Droplet dispenser

\[ \Delta t \approx 10 \text{ ms} \]

\[ \Delta t \approx 100 \text{ ns} \]
NGLS technical challenges

Challenges mostly in handling high rep-rate and high average power
Advanced Photoinjector Experiment (APEX): Demonstrate MHz high-brightness electron source

Beam characterization at gun energy (750 keV):
Tests started

Beam characterization at 15–30 MeV
6-D brightness measurements:
Beam tests planned to start Sept. 2014

186 MHz CW copper cavity photo-gun: Commissioned

1.3 GHz copper accelerating cavities (pulsed), diagnostics systems

Emittance compensation solenoids, buncher cavity

186 MHz CW RF photocathode gun
APEX on track, gun technology demonstrated

- Gun operating at full RF power
  - 120 kW
- Dark current characterized
  - ~1 nA close to exit of gun
- Excellent vacuum demonstrated
  - $8 \times 10^{-10}$ Torr with RF on

- Photo-emitted electron beam energy demonstrated (750 keV)
- MHz photoemission from high-QE cathode demonstrated
  - $Cs_2Te$, 1 W Yb-fiber laser

- Good lifetime in initial measurements
  - 10%–>4% after 40 C extracted
Undulator technology and R&D

Nb$_3$Sn prototype
20 mm period, 7.5 mm gap, 50 cm length

Hybrid-Permanent-Magnet
(g$_m$ = 7.5 mm)

APS SCU0
(g$_m$ = 9.5 mm)

LCLS
(g$_m$ = 6.8 mm)

Hybrid-Permanent-Magnet
(g$_m$ = 7.5 mm)
Soft X-Ray Self-Seeding (SXRSS)

Vacuum pump (1 of 2)
M2 & M3-mirror vessel
Isolation valve (1 of 2)
Control motors (1 of 9)
Chicane dipole magnet (1 of 4)
Grating & M1-mirror vessel

Existing undulator girder, ~4 m

Hardware installation under way at LCLS
Plans for initial experiments this year

Slit
Soft X-Ray Self-Seeding (SXRSS)

Existing undulator girder, ~4 m

beam direction

QU08 (existing quad)
Grating (toroidal VLS)
B1 (+0.8°)
B2 (~0.8°)
B3 (~0.8°)
M3 (plane mirror)
B4 (+0.8°)

QU09 (existing quad)

M1 (rotating planar mirror)

M2 (tangential cylindrical mirror)

\( \Delta t = (\sim 660\ \text{fs}) \)
The NGLS collaboration has developed a science-driven design concept for a future FEL facility

• Multi-beamline soft X-ray laser array
• Powered by a high-stability CW superconducting linac
• High repetition rate (MHz) and uniform time structure

Provide missing capabilities in X-ray science, (needed e.g. to observe and control function of materials)

✓ Soft X-rays
✓ Ultrafast
✓ Full coherence
✓ 2-color (X-ray pump-probe)
✓ High repetition rate

The NGLS design effort has now come to an end.

• We hope that many of the ideas developed will find good use in the next FEL light source to be built in the USA
NGLS R&D, design collaboration


*Now at SLAC.  **Visiting from ANL.

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