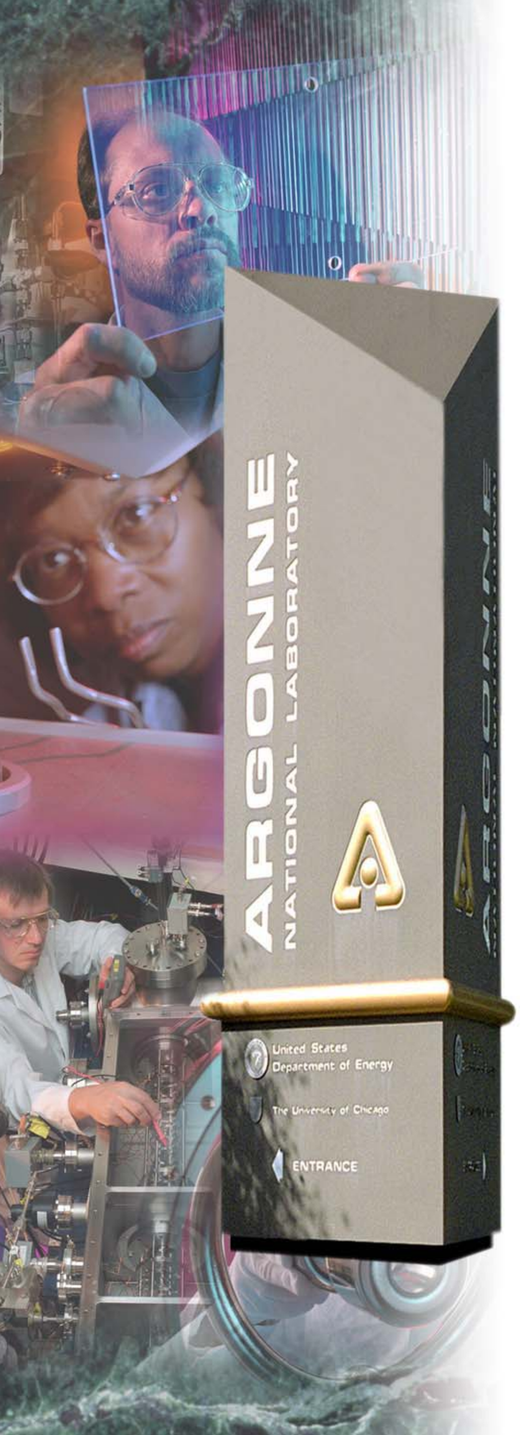

Introductory Remarks

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ANL Theory Institute on Production of Bright Electron Beams
September 22-26, 2003

Argonne National Laboratory

Office of Science
U.S. Department of Energy

A U.S. Department of Energy
Office of Science Laboratory
Operated by The University of Chicago

BESAC Subcommittee Workshop (Feb. 2003) Report 20-Year Basic Energy Sciences Facilities Roadmap

"The BESAC Subcommittee recommends that development in the following areas be a priority: electron gun technology, detector technologies, …"

"Critical areas that need improvement include gun technology …"

"The critical enabling technology to advance linac-based light sources is the electron gun. … Performance enhancements in RF photocathode guns are crucial to advanced FELs and extended capability undulator sources such as LUX. …"

"These order of magnitude improvements in electron guns (DC, RF, and superconducting RF) will allow qualitative advances in light sources capabilities at reduced costs. They are the highest-leveraged technology for next generation light sources. THE BESAC Subcommittee recommends that DOE BES strongly support and coordinate research and development in this unique and critical technology."

X-ray FEL Projects in Preconstruction

	LCLS (upgrade)	TESLA (upgrade)
Operation start	**2009 (2013)**	**2012 (?)**
# endstations/FEL	**6**	**5**
# FEL undulators	**1 (8)**	**3 (5)**
Spectral coverage (fundamental)	**≤ 8 keV (<12.4 keV)**	**≤ 12.4 keV**
$\Delta\omega/\omega$	**10^{-3} (10^{-6})**	**10^{-3} (10^{-6})**
$\Delta\tau$	**100 fs (10 fs)**	**100 fs (10fs)**
Peak spectral brightness*	**10^{33} (10^{36})**	**10^{33} (10^{36})**
Linac	**S-band RT**	**L-band SCRF**
Electron energy	**15 GeV (15-45 GeV)**	**20 GeV**
Pulse format (linac)	**1 (<32) pulses per 1-μs burst × 120 Hz**	**4000 pulses per 1 ms × 10 Hz**
Burst format (@endstation, per undulator)	**120 Hz to one (40 Hz to three)**	**5 Hz to three (2.5 Hz to five)**
I_p ($Q/\Delta t_{FWHM}$)	**4.3 kA**	**5 kA**
Emittance	**1.2 mm-mrad (?)**	**1.4 mm-mrad (?)**
λ_u minimum	**3 cm (?)**	**3.8 cm**
K	**3.7**	**3.8**
Undulator length	**115 m**	**145 m**

A Future Light Source

- Several high-gain FEL facilities based on the state-of-the-art of the current accelerator technologies are being studied/started construction around the world to begin operation in a decade.
- A “Future Light Source” is a facility that could be built based on lessons learned from experience with the first generation FEL facilities.
- *R&D progress in accelerator science and technology over the next 5-10 years could lead to an improved design and performance of a FLS.*

Choice of Energy & Undulator

- Assume $K = \sqrt{2}$
- $$\frac{\lambda}{\lambda_u} = \frac{1}{\gamma^2}$$

For 1 Å, $\gamma = \sqrt{\lambda_u(cm)} \cdot 10^4$

If λ_u = 1(2) cm*

⇨ $\gamma = 10^4$, E = 5(7) GeV

**May be superconducting helical or invacuum undulator*

Transverse Phase Space

- Single mode photon beam:

$$\Delta x \Delta \theta \Big|_{rms} \sim \frac{\lambda}{4\pi}$$

- Matched electron beam:

$$\varepsilon_x \sim \frac{\lambda}{4\pi}$$

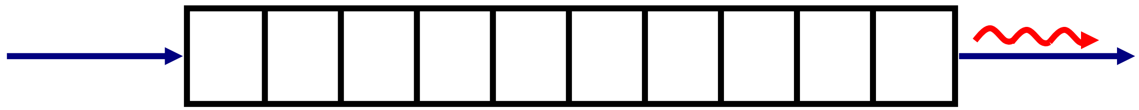
(for γ = 10^4, λ = 1 Å)

$$\varepsilon_n \sim \frac{\lambda}{4\pi}\gamma = 10^{-7}\, m - rad$$

⇨ 10 times smaller than state-of-the-art
Need a super-bright electron gun!

- *A linear collider can use a super-bright electron gun with an additional requirement on polarization*

SASE FEL for 30 keV



- LCLS reference parameters:

  λ = 8 keV, λ_u = 3 cm, K = 3.7, I_p = 3.5 kA, E_e = 15 GeV,

  $\Delta E/E$ = 0.01%, ε_n = 1.2 mm-mrad, L_{sat} = 100 m
- Vary K, ε_n, and E_e

K	E_e (GeV)	ε_n (mm-mrad)	L sat (m)
3.7	30	1.2	300
3.7	30	0.5	130
3.7	30	0.1	40
1	12	0.1	60

← **shorter undulator** (row K = 3.7, ε_n = 0.1)

← **shorter undulator and shorter linac** (row K = 1, ε_n = 0.1)

- ***It pays to strive for an ultralow emittance e-beam***

Beam Conditioning

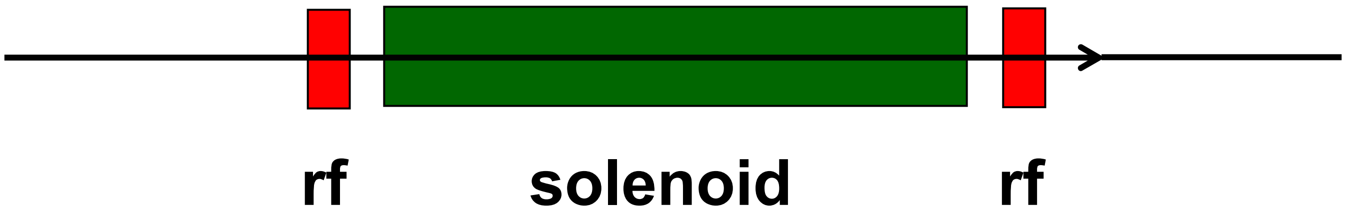
- Gain degradation is avoided if z-velocity spread is minimized:

$$L_G\,\Delta\beta_z = \left| \frac{\lambda}{\lambda_u}\left(\frac{2\Delta\gamma}{\gamma}\right) - \frac{x'^2 + y'^2}{2} \right| < \frac{2\pi}{4}$$

$$L_G \sim \lambda_u/4\pi\rho$$

- This can be satisfied by introducing correlation is $\Delta\gamma$ and ε_x. (A. Sessler, D. Whittum, L.-H. Yu, 1992)

Beam Conditioning Schemes



(Due to N. Vinokurov)

First rf → $z - \Delta E$ correlation

Solenoid → $z - \varepsilon_x$ correlation

→ $\Delta E - \varepsilon_x$ correlation

2nd rf → remove $z - \Delta E$ correlation

- However, conditioning also leads to z-dependent focusing & large projected emittance (P. Emma and G. Stupakov)

Temporal Phase Space

- Single mode photon beams

$$\left(\frac{\Delta\omega}{\omega}\right) \sim \rho \sim 10^{-3}$$

- Electron beams:

$$\frac{\Delta E}{E} \sim 10^{-5} < \rho; \; OK$$

but too small (CSR instabilities)!

Matching the 6-D Phase Space

$$\varepsilon_x \varepsilon_y \frac{\Delta\gamma}{\gamma} = \left(1\, mm - mrad\right)^2 \otimes 10^{-5}$$

$$\rightarrow \left(0.1\, mm - mrad\right)^2 \otimes 10^{-3}$$

– Beam conditioning?
– Harmonic generation?
– Emittance compensation?

Please take advantage of Theory Institute on Bright Beams experts gathered!

1. Emission process:
   a. What is thermal (intrinsic) emittance?
   b. How do we minimize the intrinsic emittance to below 0.1 mm-mrad?
   c. Polarization?
2. Beam manipulation:
   a. Does beam conditioning work?
   b. How do we rotate in phase space?
3. Beam dynamics:
   a. Need further theory?
   b. Any dangerous longitudinal oscillation?
4. R&D program:
   a. How do we convince DOE and management that beam research is a scientific endeavor, that accelerator physics is not a mere service discipline?
   b. A program to be pursued by several laboratories and universities in competitive fashion in collaboration with university?

Topical Session Chairs and ANL Liaisons

Topical Session	Chair	When
A. Emission Processes	Kevin Jensen (ANL liaison: M. Conde)	Monday
B. Beam Manipulation	Gennady Stupakov (ANL liaison: J. Power)	Tuesday
C. RF Photocathode Beam Dynamics	Klaus Flöttman (ANL liaison: J. Lewellen)	Wednesday
D. R&D Planning	Andy Sessler (ANL liaison: S. Milton)	Thursday

- 30 minute Oral Summary Friday
- Written summary by October 10, 2003