Working Group 5 Summary: High Brightness Electron Guns

Fay Hannon, Fernando Sannibale

Large Number of Participants and Contributors

Full Name	Institution
Ben-Zvi, Ilan	Brookhaven National Laboratory
Candel, Arno	SLAC
Chou, Ping J.	Taiwan Light Source (NSRRC)
Chu, Tak Sum (Sam)	LLNL
D'Auria, Gerardo	Sincrotrone Trieste
Dowell, David	SLAC
Faillace, Luigi	Radiabeam Technologies
Hannon, Fay	Jefferson Lab
Harkay, Katherine	Argonne National Laboratory
Hernandez-Garcia, Carlos	Jefferson Lab
Hess, Wayne	Pacific Northwest National Laboratory
Huang, Yen-Chieh	National Tsinghua University
Huang, Wenhui	Tsinghua University
Jarvis, Jonathan	Vanderbilt University
Kabel, Andreas	SLAC
Lewellen, John	Naval Postgraduate School
Li, Zenghai	SLAC
Li, Derun	LBNL
Limborg, Cecile	SLAC
Marsh, Roark	LLNL
Musumeci, Pietro	UCLA
Nishimori, Nobuyuki	JAEA
Padmore, Howard	LBNL
Papadopoulos, Christos	LBNL
Rao, Triveni	Brookhaven National Laboratory
Sannibale, Fernando	Lawrence Berkeley National Laboratory
Schmerge, John	SLAC
Schreiber, Siegfried	DESY
Sereno, Nicholas	Argonne National Laboratory
Sinclair, Charles	Cornell University
Smedley, John	Brookhaven National Laboratory
Teichert, Jochen	FZD
Vicario, Carlo	Paul Scherrer Institut
Wan, Weishi	LBNL
Wells, Russell	LBNL
Zhou, Feng	SLAC

Thank you for your contribution and participation!

36 participants from
19 institutions, 7 from abroad
More than 20 contributions

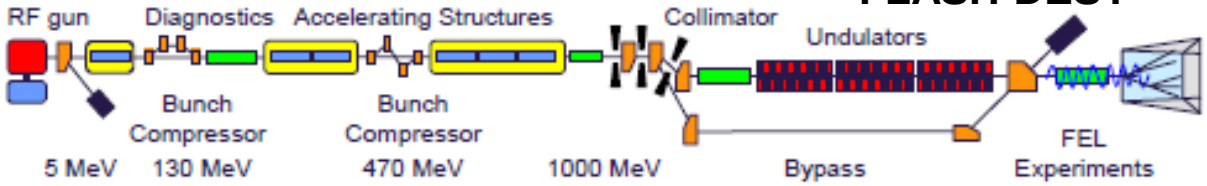
Complete set of expertise and capabilities for an exciting discussion.

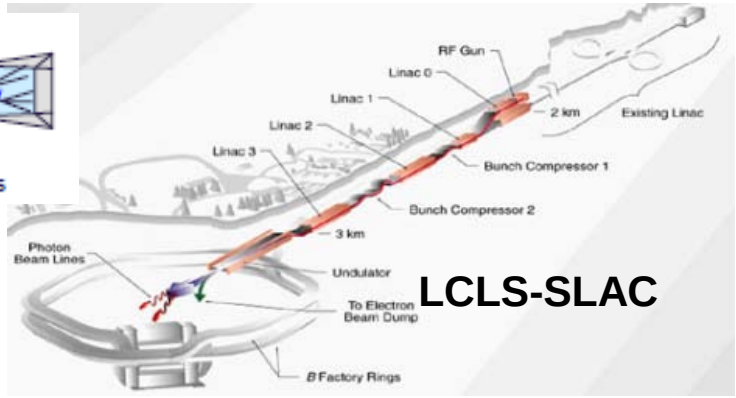
Working Group No. 5
High Brightness Electron Guns
F. Hannon - F. Sannibale

Exciting Times for Light Sources

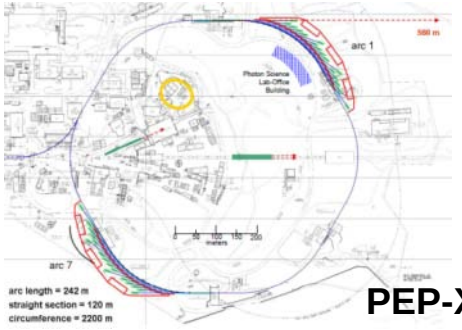
A number of future light sources are being proposed, in construction phase and in operation. For example:

FLASH-DESY

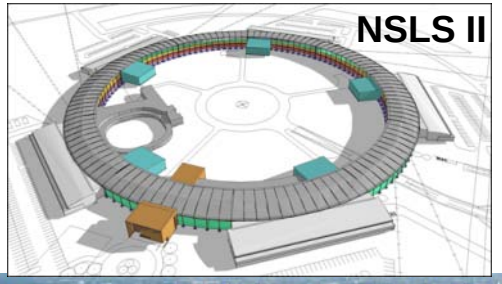




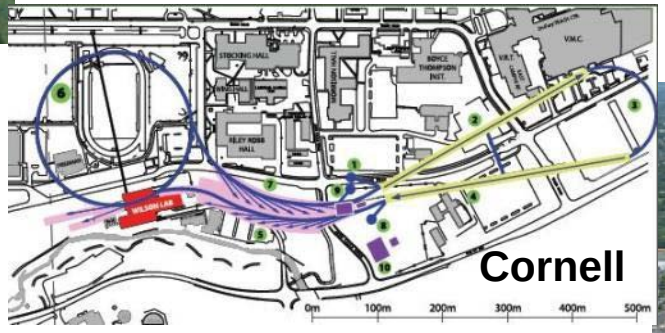
LCLS-SLAC



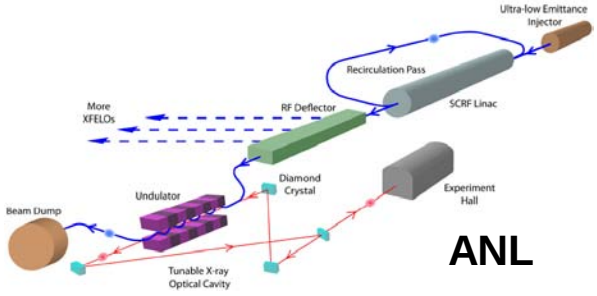
PEP-X



NSLS II

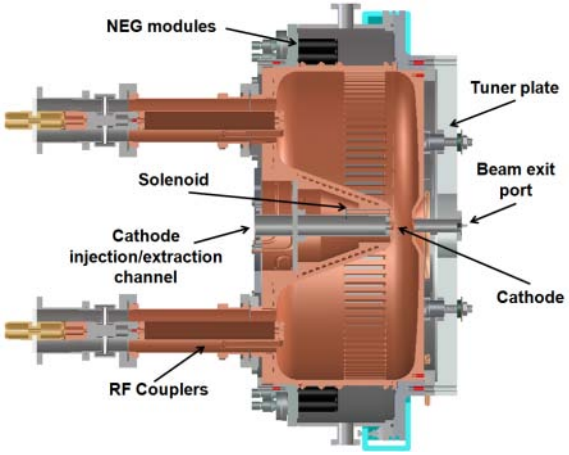


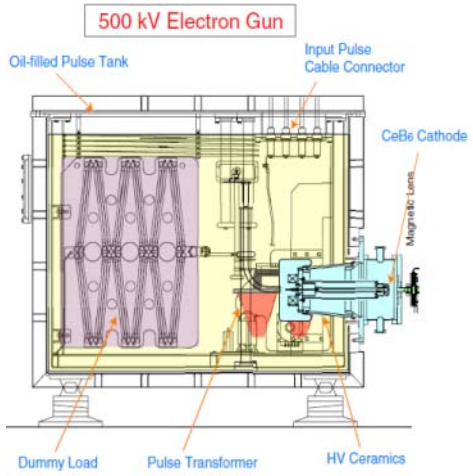
Cornell

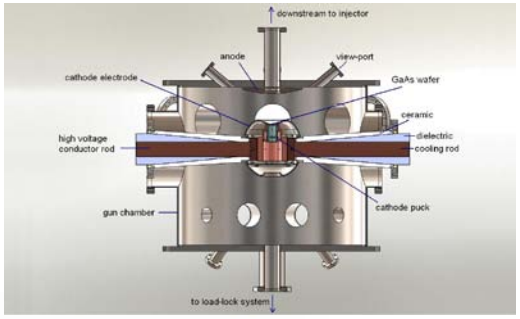


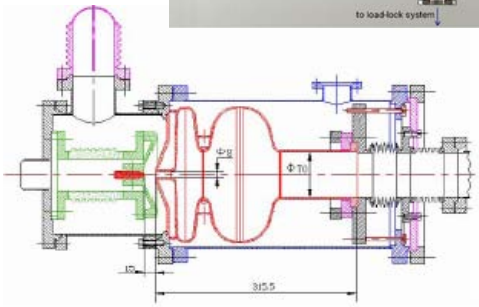
ANL

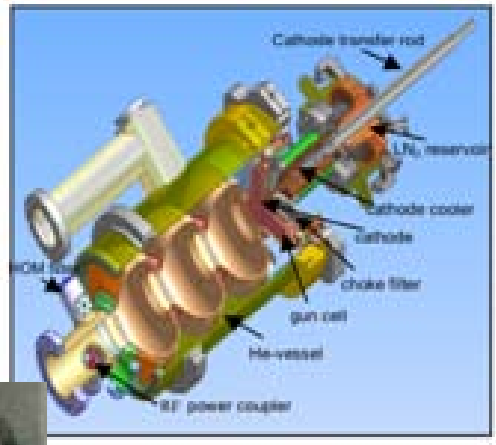
…Exciting Times for Electron Sources

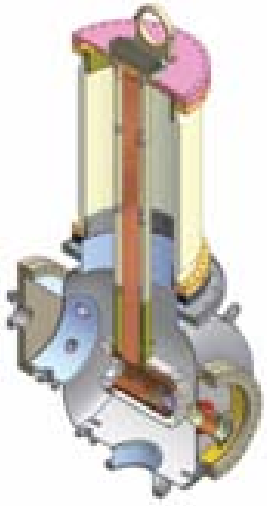












Working Group Charge

"Identify promising R&D areas that may be high risk but offer high value and could have significant impact on future light source designs."

High risk/high return...

Question: was that the recent stock market strategy?

WG Agenda and Structure

- An electron gun is complex system that includes several subsystems. The structure and agenda of the 3 days of WG tried to address and cover all these aspects of a gun system

Monday afternoon: Light sources and electron gun requirements

Monday afternoon: Low repetition rate (< ~10 kHz) electron guns

Tuesday afternoon: high repetition rate electron guns (joint session with ERL WG)

Thursday morning: Beam dynamics

Thursday morning & afternoon: Photo-cathode/laser systems

Thursday afternoon: Injector beam diagnostics (joint session with beam diagnostics WG)

Disclaimer

The opinions and comments in the following viewgraphs represent the "almost real time impressions and perception" based by attendees comments and opinion of the WG conveners.

A more consistent and "digested" analysis of the results of the working group will be contained in a summary document to be generated with the participation and input from all the participants.
Prepared in the next 4 – 5 weeks.

Many exciting important results were presented during the WG.
The few highlights reported in the next viewgraphs are an incomplete sample of those because of obvious time limitations.
The conveners apologize with the contributors whose work has been undeservedly not included.

Gun Requirements

Many different light source schemes:

- FELs
- ERLs
- Ultimate storage rings
- Sources based on plasma wakefield accelerators

Many different modes of operation:

- Low and high charge
- short and extremely short pulses
- low and high repetition rate
- high energy resolution
- full coherence
- …

No present electron gun scheme and technology is capable to match all such challenging requirements simultaneously

Gun Requirements

In storage ring based light sources the injector typically contains a booster ring that dramatically relaxes requirements on the e^- gun. Such electron sources were not addressed by the WG.

A category apart is represented by the injector requirements for plasma wakefield accelerators where in all present schemes the accelerated electrons are "generated" in the plasma itself (see E. Esarey talk).

A large overlap between gun requirements for ERL and FELs based light sources exists.

The required beam quality, in terms of 6D brightness (emittance, energy spread and bunch length) is very similar for both the low and the relatively higher charge regimes.

A discriminating factor is often the repetition rate that forces designers to significantly different technological choices.

Low Repetition Rate Regime

Low repetition (<~ 1kHz) X-ray FEL based sources already found their "champion" guns in high frequency (>~ 1 GHz) normal conductive RF guns.

The spectacular results achieved by the FLASH and LCLS are in significant part due the quality of their 1.3 GHz and 3 GHz photo-injectors

The high gradients >~ 100 MV/m achievable with such guns have fully proved their capability to deal with the space charge in the high charge regime (from several hundreds pC to ~ nC)

In the low charge regime (tens of pC down to pC levels) the space charge effects are much smaller and the limiting performance factor starts to become the intrinsic or thermal emittance of the cathode.

In this low reprate regime it is possible to use low QE (but robust) metal cathodes with present laser technology

Low charge bunches requires beam diagnostics with adequate sensitivity.

Low Repetition Rate Highlights

After the brilliant results of the LCLS, also the PITZ Gun has achieved and surpassed the requirements for the European X-FEL in both the high and low charge regimes (S. Schreiber talk Monday afternoon).

Spring-8 "pulsed DC" gun, the only operating high brightness electron gun using a thermionic cathode, has shown long and reliable operation (H. Maesaka talk)

X-band RF guns have the capability of peak fields up to ~ 200 MV/m. Beam dynamics studies shown the capability of short bunches that could potentially reduce the required compression in the downstream linac (F. Zhou talk)

Low Repetition Rate Challenges

Develop and use lower thermal emittance cathodes (specially for the low charge regime)

Develop diagnostics with sensitivity required by pC class bunches

Optimize RF structures for higher repetition rates without dramatically reduce the gradients

High Repetition Rate Challenges

Several schemes have been proposed to generate the required beam quality at high repetition rate.
but none of such schemes have demonstrated that capability yet!

All proposed schemes show accelerating fields smaller than those in high frequency normal conductive low frequency RF guns.
This situation has important consequences in beam dynamics and requires longer bunches at the cathode to control space charge effects, and higher compression factors in the downstream accelerator.

Present laser technology forces the use of high QE (>~ 1%) photocathodes

Such cathodes are usually represented by "delicate" semiconductor cathodes which require extremely low vacuum pressures to operate with a reasonable lifetime.

Beam diagnostics at high repetition rate can be challenging in terms of bandwidth, very high beam power and required dynamic range.

High Repetition Rate Highlights

JAEA DC gun with a new segmented ceramic held for many hours 500 kV voltage without any evidence of discharge or dark current. Extremely promising result (N. Nishimori talk)

The Rossendorf group proved reliable operation of Cs_2Te photo-cathodes in a SRF gun (J. Teichert talk)

Los Alamos has conditioned to full RF power a 700 MHz CW normal conducting gun.

Significant interest and effort in the development of low frequency 100-200 MHz NC CW RF guns to operate with either thermionic or photocathodes. (F. Hannon, A. Nassiri and F. Sannibale talks)

Synergy with industry can allow for outstanding accomplishments. A full SRF gun system was designed and received within one year! (J. Lewellen talk)

Several schemes pursuing high brightness beams at high repetition rates are doing very important steps towards the goal. High chances of a near future success.

High Repetition Rate Challenges

Prove high brightness/high repetition rate operation in both low and charge regime

DC guns: increase the operation energy to higher values

SRF guns: prove high gradient operation with high QE photocathodes and the fields required for emittance compensation

NC low frequency guns: prove vacuum performance and RF performance.

Develop beam diagnostics for high repetition and/or high power beams.

Cathodes, Photo-Cathode/Laser Systems

Impressive intensity and quality of the research in this field conducted by a small number of groups.

Strong effort to move cathode science from the present significantly "empirical phase" to a situation with a better physical understanding of the photoemission process.

Cathode fabrication experts and other discipline scientist joining forces.

Characterization tools such as ARPES and others offered by synchrotron light sources are now being used.

Relevant efforts in understanding, QE, thermal emittance and lifetime limiting phenomena

(H. Padmore, K. Harkay, D. Dowell, T. Rao, J. Smedley talks)

Cathodes, Photo-Cathode/Laser Highlights

CsBr coatings on metal cathodes give several tens QE enhancement factors in Cu and other metals, and several hundreds in Nb (D. Dowell talk)

Significant progress in the development of suitable multi-alkali antimonide photocathodes with high QE (>~ 1%) and photo-emitting in the visible (T. Rao and D. Dowell talks)

Diamond "amplifiers" are ready for being tested in several guns (J. Smedley talk)

Thermionic cathodes successfully proved high brightness performance at Spring-8 and are now under consideration for the injector of the ANL X-FELO (N. Sereno talk)

Laser distribution control techniques have achieved a reasonable level of capability sufficient to generate measurable improvements of beam quality and are "routinely" used (W. White, C. Vicario talks).

Cathodes, Photo-Cathode/Laser Challenges

A significant effort and R&D is still necessary for a better understanding of the photo-emission in different photocathodes, for the improvement of cathode preparation, and for cathode characterization.
Significant margin for improvement.

Coordination between cathode producing groups, injector designers and injector facilities can synergistically boost the research.

Laser shaping techniques improvement required especially in generating fully ellipsoidal distributions.

Laser capability of fast switching between pulses with different characteristics should be investigated.
High benefit to multiuser facility with tailored FEL beamlines.

Beam Dynamics

The eigen-emittance description of the 6D emittance of a beam, shows potential for a proper emittance exchange between different planes in order to properly match the phase space requirements for optimal lasing in FEL schemes (B. Carlsten talk)

Further work is in progress for the definition of the characteristics of the beamline required for the proper phase space manipulation. Non-linear effects (space charge, collective effects, …) that could affect the scheme performance need to be investigated.

Injection in Plasma Wakefield Accelerators

Numerous schemes for the injection of electrons in the extremely small plasma "bucket" are under evaluation and experimental test.
(E. Esarey talk)

The solution of such a problem could allow the proper control of the characteristics of the beam from the plasma wakefield accelerator and could allow such accelerators to operate in a FEL scheme.

Thanks to the FLS2010 organizers for putting on a very interesting and useful workshop and for giving Fay and me the chance to convene such an active and important working group. We were honored and learned a lot!

And thank all of you for the attention!

Monday March 1 Agenda

Day : 1. Monday (9)

3/1/2010 1:30 PM	02:00 PM	High Brightness Electron Guns: Working Group Introduction	Fernando Sannibale/ Fay Hannon
3/1/2010 2:00 PM	02:30 PM	Gun Requirements for ERLs	John Lewellen
3/1/2010 2:30 PM	03:00 PM	Gun Requirements for low repetition rate FELs	Siggi Schreiber
3/1/2010 3:00 PM	03:30 PM	Gun Requirements for high rep rate/ oscillator FELs	F. Sannibale/N. Sereno
3/1/2010 3:30 PM	04:00 PM	Gun Requirements for Plasma Accelerators	Eric Esarey
3/1/2010 4:30 PM	04:55 PM	Low rep rate guns: SPRING 8	Hirokazu Maesaka
3/1/2010 4:55 PM	05:20 PM	Low rep rate guns: SLAC	Dave Dowell
3/1/2010 5:20 PM	05:45 PM	Low rep rate guns: DESY/PITZ	Siggi Schreiber
3/1/2010 5:45 PM	06:15 PM	UCLA gun and multiphoton photoemission cathodes	Pietro Musumeci

Tuesday March 2 Agenda

Day : 2. Tuesday (11)

3/2/2010 1:00 PM		*** JOINT SESSION WITH ERL ***	
3/2/2010 1:30 PM	01:55 PM	High rep rate guns: JAEA	Nobuyuki Nishimori
3/2/2010 1:55 PM	02:20 PM	High rep rate guns: JLAB	Fay Hannon
3/2/2010 2:20 PM	02:45 PM	High rep rate guns: Cornell University	Charlie Sinclair
3/2/2010 2:45 PM	03:10 PM	High rep rate guns: KEK	Tsukasa Miyajima
3/2/2010 3:10 PM	03:35 PM	High rep rate guns: BNL	Ilan Ben-Zvi
3/2/2010 3:35 PM	04:00 PM	High rep rate guns: LBNL	Fernando Sannibale
3/2/2010 4:30 PM	04:55 PM	High rep rate guns: APS	Ali Nassiri
3/2/2010 4:55 PM	05:20 PM	High rep rate guns: NPS	John Lewellen
3/2/2010 5:20 PM	05:45 PM	High rep rate guns: FZD Rossendorf	Jochen Teichert
3/2/2010 5:45 PM	06:15 PM	High rep rate gun discussion	***All***

Working Group No. 5
High Brightness Electron Guns
F. Hannon - F. Sannibale

Thursday March 4 Agenda

Day : 4. Thursday (15)

3/4/2010 9:00 AM	09:25 AM	Injector Beam Dynamics, XFELO	Nick Sereno
3/4/2010 9:25 AM	09:50 AM	X-band injector beam dynamics studies	Feng Zhou
3/4/2010 9:50 AM	10:30 AM	Cathode Materials Overview	Dave Dowell
3/4/2010 11:00 AM	11:30 AM	Diamond Amplifier Cathodes	John Smedley
3/4/2010 11:30 AM	12:00 PM	Multi-Alkali & Metal Cathodes	Kathy Harkey
3/4/2010 12:00 PM	12:30 PM	Multi-Alkaline &GaAs Cathodes	Treveni Rao
3/4/2010 1:30 PM	02:00 PM	Enhancement of Emission from Metallic Photocathodes	Haward Padmore
3/4/2010 2:00 PM	02:25 PM	Limitations and Necessary R&D for UV lasers	Bill White
3/4/2010 2:25 PM	02:50 PM	Laser pulse shaping for high brightness electron sources	Carlo Vicario
3/4/2010 2:50 PM	03:15 PM	Status, prospect and challenge of High-rep-rate drive laser systems for future light sources	Shukui Zhang
3/4/2010 3:15 PM	04:00 PM	Discussion: Lasers and Cathodes	***All***
3/4/2010 4:00 PM	06:00 PM	*** JOINT SESSION WITH DIAGNOSTICS ***	
3/4/2010 4:30 PM	04:50 PM	Cornell DC Gun Diagnostics	Florian Loehl
3/4/2010 4:50 PM	05:10 PM	Diagnostics for low emittanc beams	Henrik Loos
3/4/2010 5:10 PM	06:00 PM	Discussion	*** All ***