Remembrance of Sam Krinsky and His Achievements

Sam Krinsky

January 14, 1945-April 26, 2014

Among many of Sam Krinsky's Contribution to Accelerator Physics

- NSLS X-ray ring (1978) design and commissioning
- First short-period in-vacuum undulator at NSLS (1987)
- First global orbit feedback system at NSLS
- Design NSLS-II storage ring (2014)
- Important contribution to studies of impedances and collective effects
- Founded Source Development Laboratory at BNL

I will concentrate on his contribution to FEL:

Among many other contributions made by Sam, I would like to give a brief list of his most important seminal contributions to the FEL community.

Theoretical works

- **Universal gain scaling function**
- **Effect of wiggler errors**
- **3-D SASE start-up noise**
- **Average spacing of peaks in SASE spectrum**

Leading Experimental and Managerial Roles:

With his managerial skill and foresight, **Sam** contributed decisively to the formation of FEL team, the creation and successful execution of FEL projects at Brookhaven National Laboratory during his tenure as deputy chairman of the NSLS department, which led to many important accomplishments with important impact on the worldwide short wavelength FEL development.

- Sam facilitated the **1990 Sag Harbor** "Prospects for a **1 Å Free Electron Laser" Workshop** with R. Palmer

- **1997-1999 ATF HGHG Experiment at 5 μm**:

  Sam was instrumental in getting the NSLS to provide resources to the BNL Accelerator Test Facility to complete R&D on the photo-injector and to carry out the HGHG proof-of-principle experiment in the infrared.

- Sam's leading role in the construction of the **DUVFEL** at the **SDL for 2000 -2003 HGHG Experiment at 266nm**

Scaling Function of Gain

L.H. Yu, S. Krinsky, R. Gluckstern, PRL, **64**, 3012 (1990)

FEL differential integral equation describing evolution of E in an undulator, taking into account of diffraction, optical guiding, energy spread, emittance, detuning, focusing and betatron oscillation:

$$(\Delta_\perp^2 + \Omega)E(\mathbf{r})$$
$$= \frac{i}{2}(2\rho\gamma_0)^3 \int \frac{d\gamma}{\gamma^2} h'(\gamma) \int d^2p \int_{-\infty}^{0} ds e^{-i\alpha s} u(p^2 + \kappa^2 r^2) E[\mathbf{r}\cos(\kappa s) + \frac{\mathbf{p}}{\kappa}\sin(\kappa s)]$$

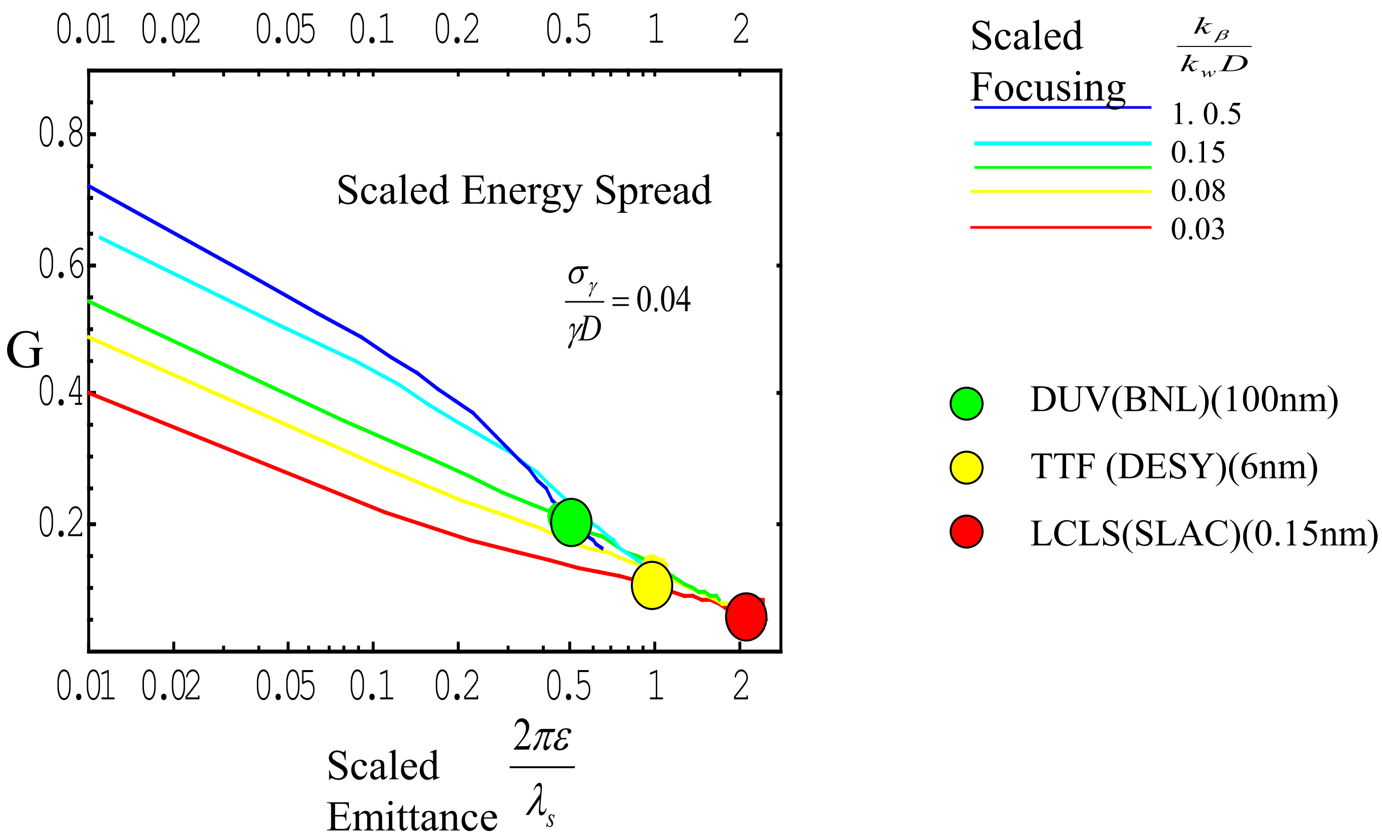
Has many roots, eigen-solutions, resulting in gain of E → highest growth rate gives scaling gain as function of scaled emittance, energy spread and beta function, detuning:

$$\frac{1}{2k_w L_G^{3D} \rho} = \frac{\mathrm{Im}\Omega}{\rho} \equiv G(\tilde{a}, \frac{\sigma}{\rho}, k_s \varepsilon, \frac{\omega - \omega_s}{\omega_s \rho})$$

In second form

$$\frac{1}{2k_w L_G^{3D} D} = \frac{\mathrm{Im}\Omega}{D} \equiv F(k_s \epsilon, \frac{\sigma}{D}, \frac{k_\beta}{k_w D}, \frac{\omega - \omega_s}{\omega_s D})$$

Sam and I calculated the Scaling function and checked with codes from Los Alamos and Lawrence-Livermore



- **On the scaled function plot of second form, operating points do not change too much even though the wavelength changes several orders of magnitudes**
- **Provides fast calculation of gain length, a benchmark vs. codes, serves as the basis for HG FEL calculations**
- **1992 Ming Xie fit our scaling function formula to polynomials, widely used in world FEL community**

1990 Sag Harbor
“Prospects for a 1 Å Free Electron Laser” Workshop

Sam initiated discussion with R. Palmer (BNL’s Dir. Office)
Worked out a table on blackboard, stimulated interest to X-ray FELs

E(GeV)	0.25	5	1.67	50	28
K	1	1	1	5.2	3.7
B_w	1.07	1.07	10.7	0.8	1
λ(Angstrom)	400	1	1	1	1
λ_w(cm)	1	1	0.1	7	4
ϵ_n(mm-mrad)	4	0.2	0.07	2	2
$\sigma(\times 10^{-3})$	1	1	1	1	1
I(Amp)	100	2000	670	10360	10360
power gain length (m)	1.73	1.73	0.17	12.1	9.9
λ_β(m)	6.28	6.28	0.628	44	26
natural λ_β(m)	6.9	140	4.8	1860	830

Sag Harbor 1 Å Free Electron Laser” Workshop

1992 Workshop on Fourth Generation Light Sources, SLAC

W. Barletta, A. Sessler, L.H. Yu, “Using the SLAC Two –Mile Accelerator for Powering An FEL”, SLAC-PUB-15126, 1992

C. Pellegrini "A 4 to 0.1 nm FEL based on the ***SLAC*** Linac" Proceedings *Workshop on Fourth Generation Light Sources, 1992*

LCLS

Quote from E-mail of H. Winick to A. Sessler
May 9, 2013

’The 1990 Sag Harbor workshop on “Prospects for a 1 A Free-Electron Laser” was a very important event. I point this out in my talks and recently received several copies of the proceedings from Gallardo, which I distribute to those interested.’

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DE91 007631

PROCEEDINGS OF THE WORKSHOP PROSPECTS FOR A 1Å FREE-ELECTRON LASER

SAG HARBOR, NEW YORK
April 22-27, 1990

Juan C. Gallardo, Editor

CENTER FOR ACCELERATOR PHYSICS

BROOKHAVEN NATIONAL LABORATORY
UPTON, LONG ISLAND, NEW YORK 11973

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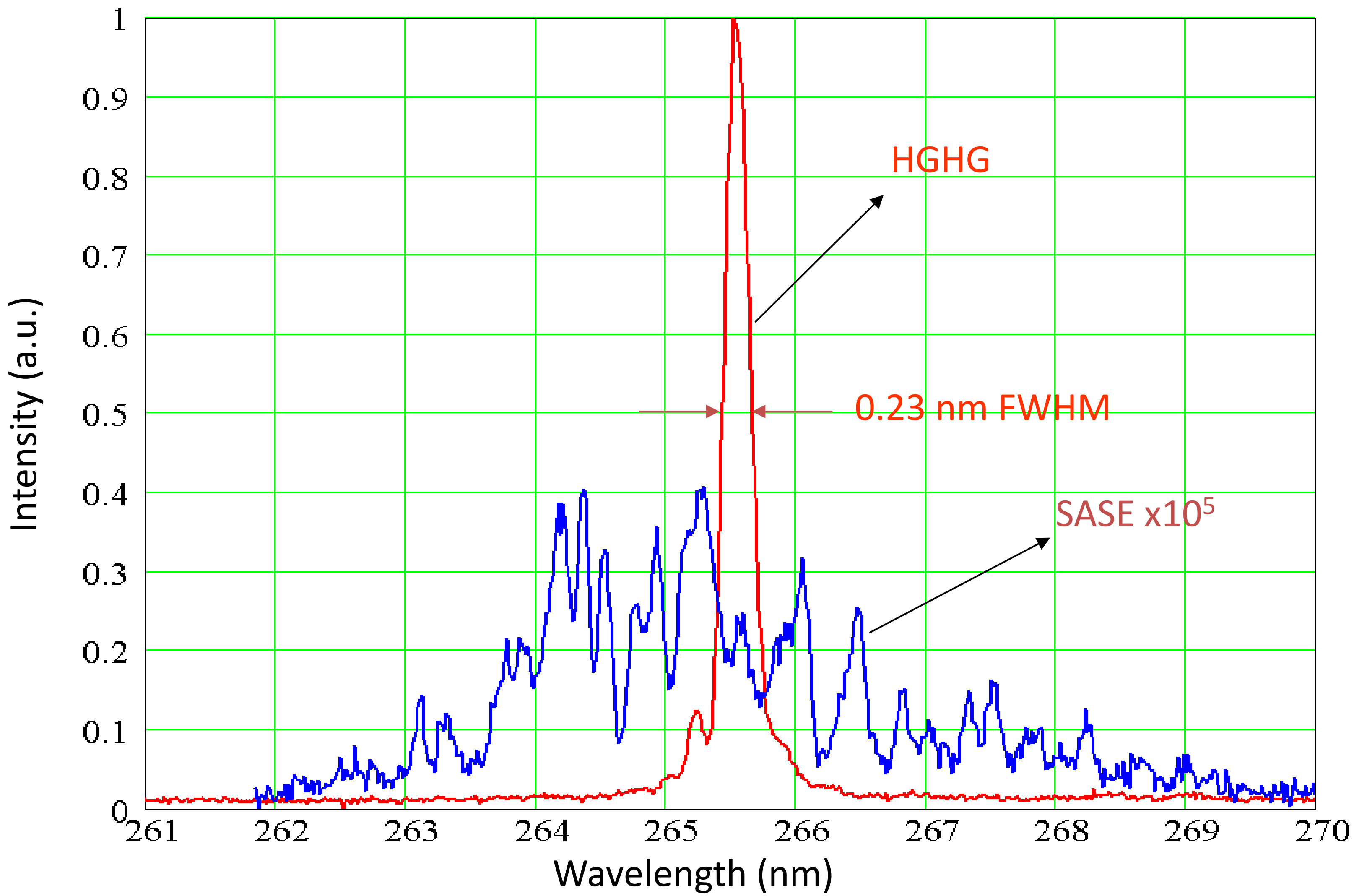
Participants in the Workshop "**Prospects for a 1 Å Free-Electron Laser**" gather outside the **Sag Harbor Inn** for a group picture. (1990)

Acquisition of "Cornell Wiggler A" for **1997-1999 ATF HGHG Experiment at 5 µm**

HGHG Experiment at SDL: First UV FEL

L.H. Yu, A . Doyuran, L. DiMauro, W. S. Graves, E. D. Johnson, R. Heese, S. Krinsky, H. Loos, J.B. Murphy, G. Rakowsky, J. Rose, T. Shaftan, B. Sheehy, J. Skaritka, X.J. Wang, Z. Wu, "First Ultraviolet High-Gain Harmonic-Generation Free Electron Laser", PRL, 91, 7, 074801 (2003)



Spectrum of HGHG and SASE at 266 nm under the

Demonstrated HGHG theory in 2002.

Effect of Wiggler Errors L.H. Yu , S. Krinsky, R.L. Gluckstern , J.B.J. van Zeijts, PR 45, 2 (1992)

- Reduce complicated FEL equation with errors to a simple form

$$y''' - i(\delta' y)'' = i(2\rho k_w)^3 y$$

δ' is phase error due to wiggler errors

- Peak to peak amplitude error criterion is largely relaxed:

$$\frac{2\pi}{9\sqrt{3}} \frac{K_0^4}{(1+K_0^2/2)^2} \frac{(\Delta B/B)^2_{\rm rms}}{\rho} \ll 1.$$

For LCLS, ρ ~10^{-4} , first impression→ $(\Delta B/B)_{\rm rms}$ ~ 10^{-4}

This work points to $(\Delta B/B)^2_{\rm rms}$ ~ 10^{-4}

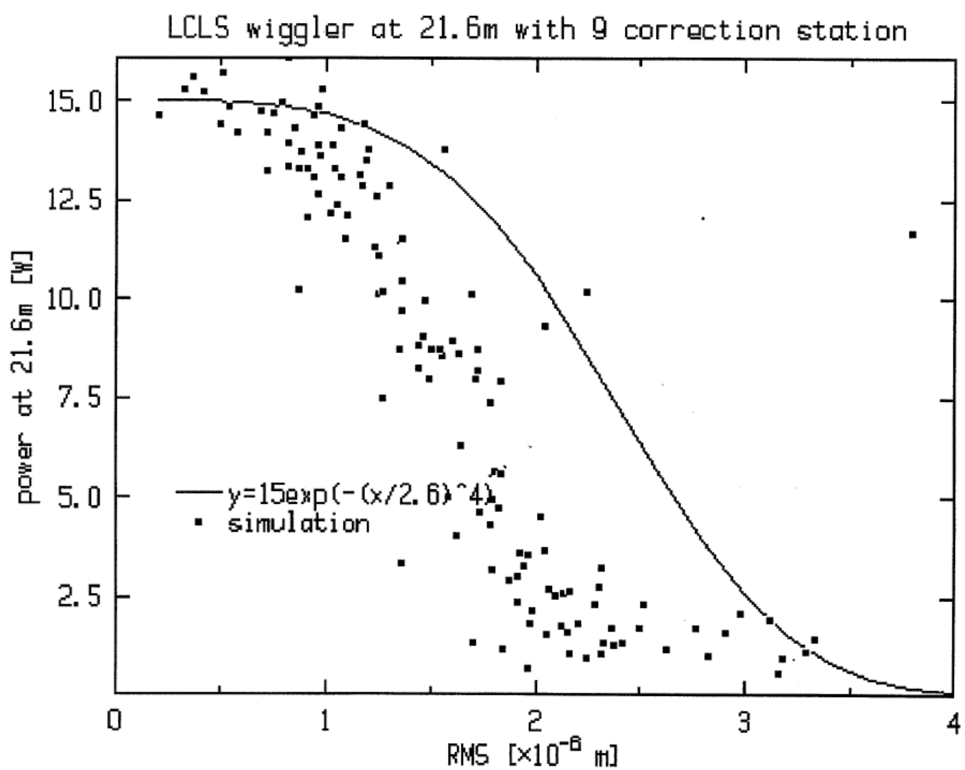
- The work emphasizes the importance of phase error in one gain length dominated by error of mean value in one gain length and the trajectory deviation from the axis→ prescribes alignment tolerance

$$P = P_0\, e^{-\left(\frac{x_{rms}}{x_{tol}}\right)^4}$$

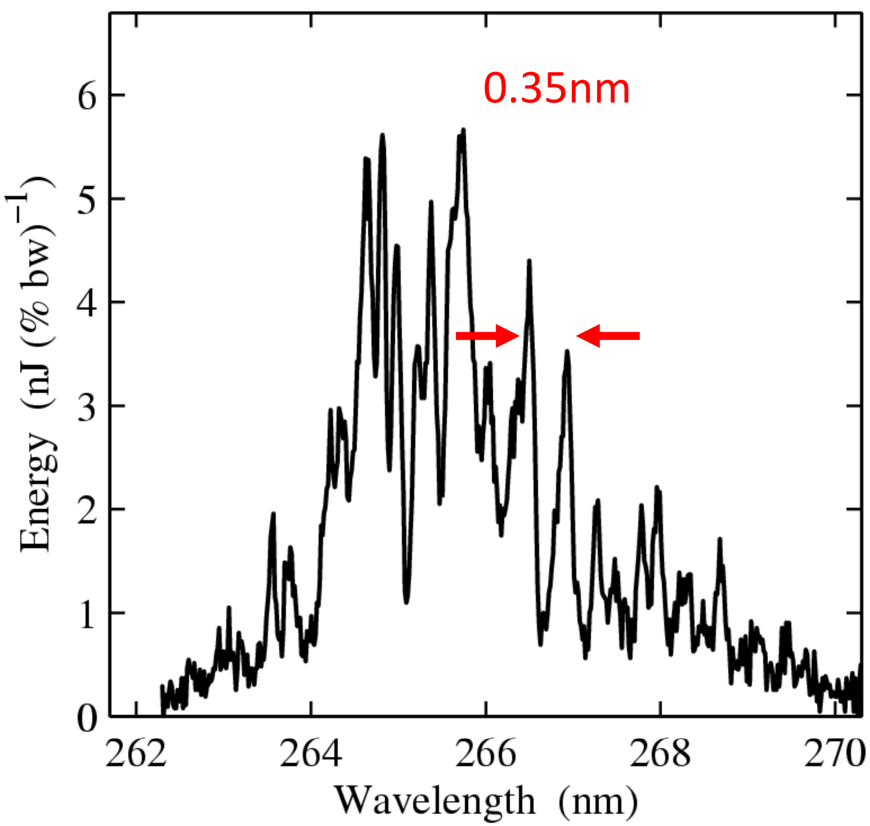
When distance between correction station L_s << gain length L_G

$$x_{tol} = \left(\frac{L_s}{L_G}\right)^{\frac{3}{4}} \times 0.266\sqrt{\lambda_s L_G}\left(\frac{L_G}{z}\right)^{\frac{1}{4}}$$

For LCLS we find $x_{tol} = 2.6\mu m$



Average spacing between peaks in SASE spectrum also gives pulse length 1ps



$$T_b = \frac{\lambda^2}{0.64\ \ c\Delta\lambda} = \frac{(266nm)^2}{0.64 \times 3 \times 10^8 m/s \times 0.35nm} \approx 1ps$$

S. Krinsky and R.L. Gluckstern, Phys. Rev. ST-AB 6:050701 (2003).

End

Dear Andy; May 9, 2013

Thanks for copying me on your note to John Galayda.

5/9/2013 mail from Winick

I agree that "getting it straight is important", so let's work on the origin of the LCLS.

Much of the background behind the successful operation of the LCLS in 2009 has been described by Claudio in his recent paper published in the European Physical Journal H, which is attached. I believe he passed this in draft form to many of us to get input on the important contributions which led to this success. I encourage all to read this.

Here are recollections of my activities and events in the early and mid 1990's relevant to this.

The 1990 Sag Harbor workshop on "Prospects for a 1 A Free-Electron Laser" was a very important event. I point this out in my talks and recently received several copies of the proceedings from Gallardo, which I distribute to those interested. I had the good fortune to sit next to Alan Fisher at this workshop. He helped greatly to raise my understanding about FELs and the electron beam requirements to drive an x-ray FEL. I give credit for this workshop to the organizers, Bob Palmer and Juan Gallardo. Now I know that Bill Willis suggested it.

Although Claudio and others talked about linac-driven XFELs at Sag Harbor, I focused my efforts after the workshop on working with Alan, Heinz-Dieter Nuhn, Claudio, Juan Gallardo, Roman Tatchyn, and others on the use of the PEP ring to achieve the electron beams needed to drive an XFEL.

We continued this for several years, until Claudio proposed the use the SLAC linac to drive a SASE XFEL at the Feb. 1992 Workshop on Fourth Generation Light Sources that Max Cornacchia and I organized at SLAC. For me this was the turning point. Claudio pointed out that high brightness guns developed at LANL and BNL should be able to create the required electron beams; that experience with the SLC at SLAC showed that such beams could be transported, accelerated and compressed while preserving their brightness; and that these beams could be put through high precision, long undulators, so that SASE lasing would result.

This led me to organize monthly meetings to flesh out Claudio's ideas. A dozen of more interested scientists from SLAC, LBNL, LLNL, UCLA and elsewhere came regularly to these meetings starting one month after the Feb. workshop. I organized these meetings, and wrote minutes of each, including tasks to be carried out by the next meeting. Claudio includes the minutes of the first of these meetings in his attached paper on the history. The intellectual leadership at these meetings was provided by Claudio, who come to SLAC from UCLA each month. It is noteworthy that several of those who participated in these meetings did real work between monthly meetings, and presented results at the next meeting. This included Kwang-je Kim, Tor Raubenheimer, John Seeman, Karl Bane, Phil Morton, and others. They did not report to me, they all had day jobs, and were not being paid for this. It was an exciting time.

As Barletta says, I clearly remember his excellent talk on using the SLAC linac (SLAC-lite on May 30, 1992). As Bill does so well, he summarized the ideas presented by Claudio at the workshop and elaborated on these. His talk reinforced my commitment to gathering talent to address the many challenges.

In November 1992 I organized an external review of our work on a water-window FEL using the SLAC linac. You were on the review committee, chaired by Ilan Ben-Zvi. Bjorn Wiik was on sabbatical at SLAC during this time. He learned about our efforts and asked to sit in on the review. He returned to DESY and became director there on Jan. 1, 1993. I learned soon after that DESY staff was incorporating an XFEL in the plans for the TESLA linear collider.

We got good advice from the Nov. 1992 review committee, including the importance of developing the best possible electron gun. This led me to organize a collaboration of BNL, UCLA, and SLAC to develop an improved gun, and the SLAC Gun Test Facility (GTF) to characterize such guns. We succeeded in demonstrating a gun with 1 micron normalized emittance. This was the PhD thesis of Dennis Palmer, a student of Roger Miller. With further improvements this gun is now driving the LCLS.

Burt Richter and Artie Bienenstock, who was SSRL director at that time, encouraged me to continue the monthly meetings, and provided resources for the GTF. After several years Max was asked to lead efforts on the first design report for the LCLS. Some years later DOE provided some r&d funding.

I am copying others who might have better memories of these early days than I have, so that we can reconstruct events going back all these years.

Best regards,
Herman

Assistant Director and Professor (research), Emeritus Stanford Synchrotron Radiation Lightsource Division of the
SLAC National Accelerator Laboratory (www-ssrl.slac.stanford.edu)
Professor (research), Emeritus; Applied Physics Dept, Stanford University

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http://home.slac.stanford.edu/photonScienceFacultySearch.html#Winick

-----Original Message-----
From: Andy Sessler [mailto:amsessler@lbl.gov]
Sent: Monday, May 06, 2013 11:54 AM
To: Galayda, John N.
Cc: Winick, Herman
Subject: Origin of the LCLS

Monday, May 6
Hi !

Thanks for arranging pictures of the LCLS to be sent to me. They are fine and we shall select one and use it.

After our conversation in Denver I asked Bill Barletta what was his recollection of the origin of LCLS. He wrote:

"The date of the paper by you, Li-Hua and me way March 15, 1992. I certainly had discussed this possibility with Burt at dinner before then. Also I gave a Yellow Room seminar on the topic SLAC-lite on May 30, 1992. Herman Winick certainly remembers that and has mentioned it to me.

Claudio's talk at SLAC was also around the same time. So it is very hard to say just where the idea originated. I had been spending considerable time at UCLA then. As early as 1988 - 89 before Claudio arrived, Dave Cline and I had written a conference proceeding paper about using linear collider technology for an X-ray FEL. Also around that time Bob Palmer was talking about the possibility of a 0.1 nm FEL. So for the question of who originated the idea, that is far from clear. I'd say there were several of us and the idea became "in the air." In fact we say in the paper that the idea has been suggested by a number of people.

What Claudio did achieve was to push the idea with Burt sufficiently to get the activity off the ground under the leadership of Max Cornacchia.
Claudio then stayed with the effort until success was achieved."

Bob Palmer in his Christmas letter (only came yesterday!) writes:

"A decade later, Bill {Willis} got me to organize a workshop on a 1 Angstrom free electron laser, but kept in the background. This is the idea that blossomed into the now operating LCLS at SLAC. I got undeserved recognition for that meeting. It was Bill's idea and foresight."

I thought you might be interested in all this history. I think that getting it straight is important.

Andy

Among many other contributions made by Sam, I would like to give a brief list of his most important seminal contributions to the FEL community.

Theoretical works: the application of sophisticated analytic physics techniques to the study of single-pass FEL

- Calculation of **universal gain scaling function** for the exponential growth of a single pass FEL, which later was used by Ming Xie to create useful parameterization of FEL gain.
- Calculation of the **effect of wiggler errors** on the high gain FEL, which significantly relaxed the requirement on the pole to pole field error tolerance and put emphasize on the field error tolerance of mean field value over many periods.
- Calculation of **3-D start-up noise** in guided modes and its relation to spontaneous radiation of wigglers, which provided practical formula for comparison with SASE power in experiments.
- Analytical works on fluctuation and **spectrum structure of SASE** at the same time as the more complete works by Saldin et al. on the same subject. Statistical work on spectral structure led to simple and very useful formula on the relation between the average spacing of peaks in SASE spectrum and electron bunch length.

A brief on Sam's achievement in the field of FEL and accelerator physics in 80-90'th

Sam Krinsky has played a major part in the FEL community's program towards the development of single pass FELs, involving the application of sophisticated analytic physics techniques to the study of single-pass amplifiers, startup from noise, exponential regime growth, wiggler error effects, and much more. His leadership in FEL work, both theoretical and experimental, contributed to the important role that BNL has played in the area of short-wavelength FELs.

For these outstanding contributions, Sam received 2008 International Free Electron Laser Prize.

With his managerial skill and foresight, Sam contributed decisively to the formation of FEL team and the creation and successful execution of FEL projects at Brookhaven National Laboratory during his tenure as deputy chairman of the NSLS department, which led to many important accomplishments with important impact on the worldwide short wavelength FEL development. Sam was instrumental in getting the NSLS to provide resources to the BNL Accelerator Test Facility to complete R&D on the photo-injector and to carry out the HGHG proof-of-principle experiment in the infrared. From 1999-2002, Sam was the manager of the BNL FEL program overseeing both the FEL program at the ATF and the construction of the Deep Ultra-Violet FEL at the Source Development Laboratory.

In parallel with his management responsibilities, Sam carried out theoretical investigations in Beam Physics—especially the theory of collective effects. Of particular note in regard to the field of free-electron lasers is his work on the basic gain process, Self-Amplified Spontaneous Emission and coherent synchrotron radiation.

The culmination of Sam's work on FEL gain was the paper with Li-Hua Yu and Robert Gluckstern on the determination of the gain in the exponential regime incorporating the energy spread, emittance, and focusing of the electron beam, and the diffraction and guiding of the radiation. The scaling behavior of the gain on the system parameters was demonstrated and for the first time an accurate analytic approximation was presented. This work has significant impact on the later advent of x-ray FEL embodied by LCLS.

While these significant achievements, that have done so much to open new horizons in FEL R&D and establish BNL's role in Free-Electron Lasers, were done in collaboration with many accomplished persons, Sam's role in this endeavor is leading and most significant. While in this context we focus on FEL physics, one must note that Sam's horizons are quite broad. He has shared the 1989 R&D 100 Award for Global Orbit Feedback System to stabilize orbits in a storage ring, led many advances in light source physics and was a recipient of the 1994 Brookhaven National Laboratory Distinguished Research Award.

ICFA 17TH ADVANCED BEAM DYNAMICS WORKSHOP ON FUTURE LIGHT SOURCES

Workshop Proceedings

Presentations for
WORKING GROUP II: Linac-Based, High-Gain FELs

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wg2-00 **WG2 Summary Viewgraphs** (5.6 MB)
I. Ben-Zvi, BNL

wg2-01 **Several Formulas for High Gain FEL** (738 kB)
L. H. Yu, BNL

wg2-02 **Wakefields in the LCLS** (356 kB)
K. Bane, SLAC

wg2-03 **Bunch Compression** (5.6 MB)
P. Emma, SLAC

wg2-04 **Photoinjectors** (1.9 MB)
B. Carlsten, LANL; M. Ferrario, INFN-LNF

wg2-05 **Radiation Tutorial** (379 kB)
M. Zolotorev, LBNL

wg2-06 **Parameter Optimization for a 1.5 to 0.15 nm FEL for a Very Low Slice Emittance** (4.2 MB)
H.-D. Nuhn, SLAC/SSRL

wg2-07 **FEL Simulations in the VUV Regime** (1.8 MB)
S. Reiche, DESY

wg2- **Code Comparison with the APS SASE FEL Phase I Parameters** (400 kB)
S.G. Biedron, Y.-C. Chae, R.J. Dejus, ANL; B. Faatz, H.P. Freund, SAIC; S. Milton, ANL; H.-D. Nuhn, SLAC/SSRL, and S. Reiche

Beam quality requirement: Scaling Function of Gain

L.H.Yu, S.Krinsky, R. Gluckstern PRL. 64, 3011 (1990)

$$\frac{\lambda_w}{L_G D} = G\left(\frac{\varepsilon_n}{\gamma\lambda_s}, \frac{\sigma_\gamma}{\gamma D}, \frac{\lambda_w}{\lambda_\beta D} \right)$$

Electron beam energy γ Current I_0

Wavelength: $\lambda_s = \frac{\lambda_w}{2\gamma^2}(1 + a_w^2)$ ($a_w \sim 1$)

Emittance ε (transverse phase space size = beam size*angular spread)

$$\gamma \propto 1/\sqrt{\lambda_s} \quad , \quad I_0 \propto 1/\sqrt{\lambda_s} \quad ,$$

Scaling:

$$\varepsilon_n \propto \sqrt{\lambda_s}$$

The weak square root scaling is favorable for going to short wavelength

FEL Gain: power amplification per unit length. It determines the machine scale.

It is determined by many parameters:
Wiggler period, field, gap, wavelength of laser, focusing strength, beam energy, charge, bunch length, emittance, energy spread, etc.

We reduce to 3 scaled parameters: scaled emittacne, energy spread and focusing strength

Sam Krinsky and accelerator / FEL physics

- Contributed to development of 8 SP X-ray lattice for 170-m NSLS X-ray ring (1978)
- Developed first short-period in-vacuum undulator at NSLS in 1987
- Developed broad band global orbit feedback at NSLS X-ray ring
- Greatly improved beam stability at NSLS UV ring enabling vibrant UV / IR program
- Led conceptual to final lattice design of 892-m NSLS-II storage ring (2014)
- Tremendous contribution to studies of impedances and collective effects
- Founded Source Development Laboratory at BNL

Sam was instrumental in every project he was undertaking: from magnet alignment to non-linear dynamics or brightness of undulator light and FELs