Report of Working Group VII:
Photon- and Electron-Beam Characterization

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Group VII met at the ICFA Workshop to discuss the status of diagnostics to support the development and operation of future light sources. Participants in this working group are listed in Table 1. We heard presentations from a number of those listed in order to assess the state of the art and understand the limitations of existing diagnostics. For the electron diagnostics we summarize our conclusions below in Table 2 arranged by the particular parameter requiring measurement. We have used the LCLS specifications as our guidance for the parameter range required although a user facility will have substantially higher average beam power. The required resolution is our own assessment of the needs to understand the machine performance. Against each diagnostic type we have attempted to give a rough estimate of the presently available resolution. Note that in many cases the available absolute accuracy is substantially worse than the resolution that can be achieved. In many cases the technology is sufficiently well developed to support both the development and operation of the next generation light sources. However, the high average power of the e-beams will require non-intercepting techniques. There are however a number of key areas that have a significant need for additional research to support the understanding of how these light sources operate and are optimized. This is especially true for the temporal measurements.

Table 1: Group VII Participants

I. Ben-Zvi, G. Decker, P. Emma, W. Graves, G. Krafft, W. Leemans, J. Lewellen, A. Lumpkin, G. Naylor, G. Neil, P. Piot, D. Shu, T. Smith, B. Yang, M. Zolotorev

Table 2: Electron Diagnostic Methods

Parameter	**Range**	**Resolution**		**Technique**	**Comment**
		Required	**Available**		
E	1 – 20 GeV	0.01%	0.01%	Spectrometer	Standard technology
			0.1%	Undulator	Non-intercepting
Charge	0.1 – 5 nC	1%	< 1%	BPM, Cavity, Toroid	Standard technology
q(t)	0.1 – 5 kA	1%, 0.01 ps	Few %		Time resolution requires work[1]
			0.1 ps	CTR[2], CSR[3], CDR[4], COUR[5]	Uses auto-correlation
			~ 0.2 ps	Streak Camera[6]	Single bunch for > 1 nC
			~ 0.1 ps	Laser Cross Correlation[7]	Potentially < 0.01 ps
			~ 0.1 ps	Laser Sampling[8]	Potentially < 0.01 ps, jitter control?
			< 0.1 ps	PLAID[9], M56[10]	Manipulate e- phase space to transform longitudinal into transverse
			3 ps	Fluctuation measurement[11]	Potentially much faster, Needs development
Position	+/- 1 mm	1 um	< 1 um	Cavity, Buttons, Stripline[12]	Alignment for absolute accuracy is currently the question. Use

					beam based techniques?
				Imaging in wiggler or bends[13]	Non-intercepting but difficult to get to 1 um
Profile	+/- 1 mm	1 um	~ 5 um	Single crystal screens[14], OTR[15]	Intercepting, Crystal useful at lower energies
				Imaging in wiggler or bends[13]	Non-intercepting but difficult to get to 1 um
			? 50 um	Higher moment BPMs[16]	Immature technology
			? 50 um	DR	Needs development
			< 10 um?	Wires	Intercepting
				Laser wires[17]	Non-intercepting Potentially < 10 um?
Divergence	0.1 – 10 uRad	0.1 uRad	3 urad	Undulator[13]	Good potential
			30 urad (@600 MeV & 50 urad at 30 GeV)	OTR interferometer[15]	Intercepting
				Higher moment BPMs[16]	Needs development
				3 screens	Interfering
				DR interferometer	Development needed
Emittance	1 – 2 mm mrad	< 30%	30%?	FEL, combine above	FEL most sensitive measure of actual phase space Combination of techniques can probably meet resolution required
6D Phase Map	NA	NA	NA	Tomography (multiple techniques: rotate, slice) [18]	Many shots average, interfering, Used primarily during initial commissioning

CSR= coherent synchrotron emission
CTR= coherent transition radiation
CDR= coherent diffraction radiation
COUR= coherent off-axis undulator radiation
BPM= beam position monitor

Photons

The case for photon diagnostics was less completely treated since many of those experts were involved in discussions with other groups. A promising X-ray position monitor was discussed and the status of X-ray streak cameras for time and profile information was examined.[19] Improvement is need to extend the time response available (~ 0.2 ps) to even faster resolution using laser triggers for single pulses and synchro-scan techniques for repetitive signals. There was concern expressed that the temporal resolution available for UV cameras would not be achievable in the X-ray region because of higher photo-electron energy spread from the cathode. Significant challenges remain in dealing with the ultrahigh intensities, analyzing the coherence in this wavelength range, and, as with the electrons, dealing with temporal analysis at the femto-second level.

Proceeding with the development of the next generation light source will require the concurrent development of the associated diagnostics. We believe the following areas are likely to be fruitful in extending our ability to analyze beams:

Coherent Radiation Techniques (CTR, CDR*, COUR*, CSR*, …) * non-destructive
Higher Moment BPMs
Tomography
Ultrafast techniques at the fs level especially laser based
Streak Cameras for X-ray
Diagnostic undulator techniques
Alignment techniques for accuracy
Precision timing(overlap with user needs
Xray optics techniques (overlap with user needs) especially non-linear approaches
All non-intercepting techniques

Bunch length measurement

1) Alex H. Lumpkin, “Overview of Bunch Length Measurement” Photonics West ’99 International Symposia, Fee Electron laser Challenges II, San Jose, CA (1999).

CTR

2) H.-C. Lihn, et al., "Measurement of subpicosecond electron pulses", Phys. Rev. E53, 6, (1996) 6413-6418.

CSR

3a) T. Nakazato, et al., "Observation of Coherent Synchrotron Radiation", Phys. Rev. Let. vol. 63, 12, (1989) 1245-1248.

3b) R. Lai et al., "Measurement of the longitudinal asymmetry of a charged particle bunch from the coherent synchrotron or transition radiation spectrum", Phys. Rev. E50, num. 6, (1994) R4294-R4297.

CDR

4) Y. Shibata, et al., "Observation of Coherent Diffraction radiation from bunched electrons

passing through a circular aperture in the millimeter- and submillimeter-wavelength regions", Phys. Rev. E52, 6, (1995) 6787-6794.

COUR

5) M. L. Ponds, Y. Feng, J.M.J. Madey, P.G. O'Shea, "Non-destructive diagnosis o relativistic electron beams using a short undulator," Nucl. Instr. And Meth. in Phys. Rsch. A375, (1996) 136-139.

Streak Camera

6a) A. H. Lumpkin, B. X. Yang, V. Litvinenko, B. Burnham, S. Park, P. Wang, Y. Wu, "Initial Streak Camera Measurements on the Duke Storage Ring OK-4 UV/visible FEL" Nucl. Instr. And Meth in Phys. Rsch A407 (1998) 338-342.

6b) Z. Chang et al.," Demonstration of a Sub-Picosecond X-ray Streak Camera" Appl. Phys. Lett. 69 (1) (1996) 133.

Laser cross correlation

7) C. W. Rella et al., "Pulse Shape Measurements Using Differential Optical Gating of a Picosecond Free electron Laser Source with an Unsynchronized Femtosecond Ti Sapphire Gate", submitted to Optical Communications, 1998.

Laser sampling

8) W. P. Leemans, "Survey Talk – New Laser and Optical Radiation Diagnostics," Proceedings of Linac98, Chicago (1998).

Plaid (Phased Longitudinal Acceleration Improved by (temporal) Dispersion):

9a) K. N. Ricci, T. I. Smith and E. R. Crosson, "Sub-picosecond Electron Bunch Profile Measurement Using Magnetic Longitudinal Dispersion and Off-phase RF Acceleration", Proceedings of the Advanced Accelerator Concepts workshop, Baltimore MD, July 5-11, 1998 (AIP Conference Proceedings No.472)

9b) K. N. Ricci, T. I. Smith and E. R. Crosson, "Electron Bunch Profile Measurements with 300 Femtosecond Resolution", 20th International Free Electron Laser Conference, Williamsburg, VA, August 1998 (accepted for publication in Nucl. Instr. and Meth. in Phys. Rsch.).

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10) D. X. Wang and G. A. Krafft, "Measuring Longitudinal Distribution and Bunch Length of Femtosecond Bunches with RF Zero-Phasing Method" Proc. Of PAC97, IEEE Piscataway, NY (1998) 2020.

Fluctuation measurement:

11a) P. Catravas, M. Babzien, I. Ben-Zvi, W. P. Leemans, Z. Segalov, X.-J. Wang, J. S. Wurtele, V. Yakimenko, and M. S. Zolotorev, "Non-destructive, Single Shot Electron Beam Diagnosis

Based on Fluctuational Characteristics of Microwiggler Emissions", Proceedings of the Advanced Accelerator Concepts Workshop, Baltimore Maryland, July 5-11, 1998. (AIP Conference Proceedings No.472).

11b) P. Catravas, W.P. Leemans,W.P., J.S. Wurtele, M.S. Zolotorev, M. Babzien, I. Ben-Zvi, Z. Segalov, X.-J. Wang, V. Yakimenko, "Measurement of electron-beam bunch length and emittance using shot-noise-driven fluctuations in incoherent radiation", submitted to Phys. Rev. Lett. (1999).

BPMs

12a) Robert Shafer, Beam Position Monitoring, Accelerator Instrumentation, AIP Conference Proceedings 212, 1989.

12b) S. Smith, et al., " Beam Position Monitor System for PEP-II", Proceedings of PAC '97.

12c) R. Aiello, et al., Beam Position Monitoring for PEP-II, Beam Instrumentation, AIP Conference Proceedings 390, 1997.

12d) A. Fisher, et al., Diagnostics development for the PEP-II B-Factory, Beam Instrumentation, AIP Conference Proceedings 390, 1997.

12e) R. Johnson, et al., Performance of the Beam Position Monitor System for the SLAC PEP-II B Factory, Beam Instrumentation Workshop, AIP Conference Proceedings 451, 1998.

12f) A. Fisher, Instrumentation and Diagnostics for PEP-II, Beam Instrumentation Workshop, AIP Conference Proceedings 451, 1998.

12g) E. Medvedko, et al., "A Two-bunch Beam Position Monitor", Proceedings of PAC '97.

12h) R. Traller, et al., "A Two-Bunch Beam Position Monitor Performance Evaluation", Beam Instrumentation Workshop, AIP Conference Proceedings 451, 1998.

12i) S. Hartman, et al., Nanometer Resolution BPM Using Damped Slot Resonator, Proceedings of PAC '95.

12j) R. Lorenz, Cavity Position Monitors, Beam Instrumentation Workshop, AIP Conference Proceedings 451, 1998.

Image in wiggler

13a) Alex H. Lumpkin and Bingxin X. Yang, "Use of Few-Angstrom Radiation Imaging to Characterize Ultrabright Multi-GeV Particle Beams" Phys. Rev. Lett. (1999) 3605.

13b) B. X. Yang and A. H. Lumpkin, "Simultaneous Measurement of Electron Beam Size and Divergence with an Undulator" Proc. 1999 Particle Accelerator Conference, New York (1999).

13c) Alex H. Lumpkin, "Comprehensive, Nonintercepting Electron-Beam Diagnostics using Spontaneous-Emission Characteristics" Nucl. Instr. and Meth. in Phys. Rsch. A296 (1990) 134-143.

YAG

14a) W. S. Graves, R. D. Johnson, and P.G. O'Shea, "A High Resolution Electron Beam Profile Monitor",Proc. of 1997 PAC, Vancouver,B.C., (1998) 1993-1995.

14b) A.H.Lumpkin et al., "Optical Techniques for Electron-Beam Characterizations on the APS SASE FEL Project", Proc. Of FEL'98,Williamsburg,Va., NIMA (in press).

OTR interferometer

15a) A. H. Lumpkin, R. B. Feldman, S. A. Apgar, D. W. Feldman, P. G. O'Shea, R. B. Fiorito, and D. W. Rule. "Initial Electron beam Characterization for the Los Alamos APEX facility" Nucl. Instr. and Meth. in Phys. Rsch A318 (1992) 415-421.

15b) P. Catravas, W.P. Leemans, E. Esarey, M. Zolotorev, D. Whittum, R. Iverson, M. Hogan and D. Walz, "Beam profile measurement at 30 GeV using optical transition radiation", Proc. 1999 Particle Accelerator Conference, New York (1999).

Higher Moment BPMs

16) S. Russell, "Emittance Measurements of the Sub-Picosecond Accelerator electron beam using beam position monitor", Rev. Sci. Instr., Vol. 70, 2, (1999) 1362-1366.

Laser wires

17) W.P. Leemans, R. W. Schoenlein, P. Volfbeyn, A.H. Chin, T.E. Glover, P. Balling, M. Zolotorev, K.J. Kim, S. Chattopadhyay and C.V. Shank, "X-ray based subpicosecond electron bunch characterization using 90 degree Thomson scattering," Phys. Rev. Lett. 77, (1996) 4182.
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Tomography:

18a) I. Ben-Zvi, M. Babzien, R. Malone, X.-J. Wang and V. Yakimenko, "Advanced diagnostics for developing high-brightness electron beams," International Symposium on Environment-Conscious Innovative Materials Processing with Advanced Energy Sources (ECOMAP-98), Kyoto, Japan, November 23-271998. BNL 66228.

18b) V. Yakimenko, M. Babzien, I. Ben-Zvi, R. Malone, X-J. Wang, "Emittance Control of a Beam by Shaping the Transverse Charge Distribution, Using a Tomography Diagnostic," 6th European Particle Accelerator Conference (EPAC), June 22-26, 1998, Stockholm, Sweden. Page 1641, BNL 65675.

X-ray BPM

19a) D. Shu, J. Barraza, T. M. Kuzay, G. Naylor, and P. Elleaume, "Tests of the APS X-ray Transmitting Beam Position Monitors at ESRF," Proceedings of the 1997 International Particle Accelerator Conference (1998) 2210 – 2213.

19b) D. Shu, J. Barraza, H. Ding, T. M. Kuzay, and M. Ramanathan, “Progress of the APS High Heat Load X-ray Beam Position Monitor Development,” Synchrotron Radiation Instrumentation: Tenth U.S. National Conference, ed. E. Fontes (American Institute of Physics, 1997) 173-177.

19c) D. Shu, P. K. Job, J. Barraza, T. Cundiff, and T. M. Kuzay, “CVD-Diamond-Based Position Sensitive Photoconductive Detector for High-Flux X-rays and Gamma Rays,” Proceedings of the 1999 International Particle Accelerator Conference (1999) WEA-90.