Development of High-Charge, Short-Pulse Photocathode Accelerator Systems

International Symposium on Ultrafast Accelerators For Pulse Radiolysis
Brookhaven National Laboratory, Upton, NY, June 26, 2004

Advanced Energy Systems, Inc.

Scientific Research
Homeland Security
Medical Imaging
Drug Discovery
Defense

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Putting Accelerator Technology to Work

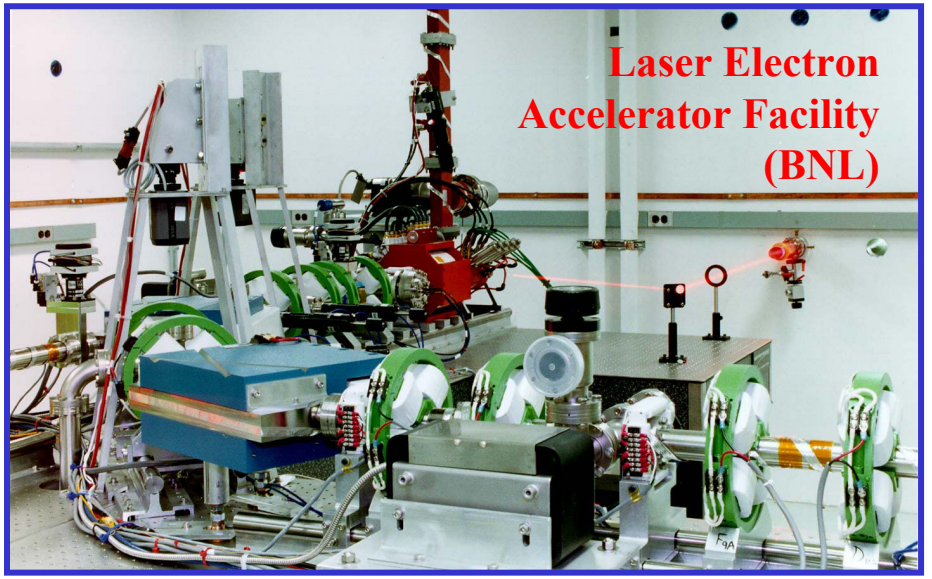
Outline

- **Advanced Energy Systems (AES) Overview**
- **Photocathode Accelerators**
  - "Conventional" Photocathode Guns
  - Low-Emittance Guns
  - High-Current CW Injectors
- **Pulse Radiolysis Systems**
  - BNL LEAF Beamline
  - Compact Beamline
  - L-Band Beamline
  - Notre Dame Beamline
- **Summary**

Advanced Energy Systems

Mission Statement

AES seeks to be the supplier of choice for advanced radiation sources based on high-brightness electron accelerator technology. AES teams with market leaders in the medical imaging, homeland security, defense and other industries to provide diagnostic systems for cancer and drug discovery, explosives and chemical/biological agent detection, and directed energy weapon systems. AES is committed to providing best value and reliability with unsurpassed after sale support.



Corporate Profile

- Privately held company incorporated in New York in September 1998 (formerly an operating group of Northrop Grumman)
- Located in Medford, NY, and Princeton, NJ
- 24 employees
- Annual sales of $5.5M
- NC prototype machine shop with class 100 clean room and co-ordinate measurement capability
- State-of-the-art engineering and physics design and analysis capability

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Product Areas

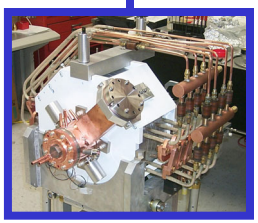
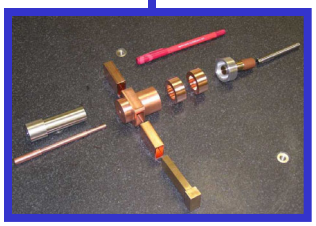
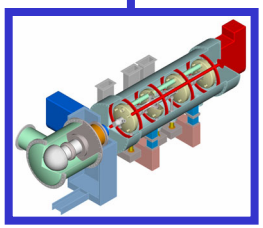
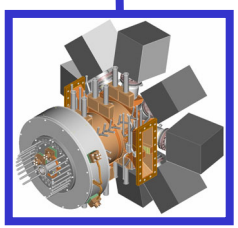
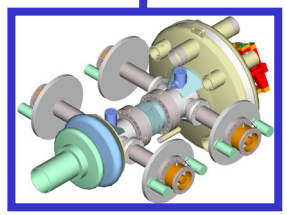
- **Advanced Radiation Sources**
  - Free Electron Lasers (FEL)
  - High-Power Microwaves (HPM) Sources
  - High-Power TeraHertz (THz) Sources
  - Tunable, Monochromatic X-Ray Sources
  - Other
- **Turnkey Accelerator Systems & Components**
  - Photocathode Injectors
  - Superconducting RF (SRF) Accelerators
  - Normal-Conducting Accelerators
  - Beam Transport Systems
  - Turnkey Beamlines
- **Integrated Engineering & Physics Services**

Photocathode Accelerators

- **Photocathode-based linacs have unique features that are very attractive for Pulse Radiolysis**
  - produce single (or trains of) intense pulses of electrons
  - adjustable pulse width can be extremely small
  - timing can be precisely controlled

AES Photocathode Injectors

Pulse Radiolysis ⟷ **High-Power Applications**

"Conventional" Guns	Low-Emittance Guns		High-Current CW Injectors		
					
Copper S-Band	Niobium Cathode L-Band	Coaxial X-Band	DC/SRF 750 MHz, 100 mA	Normal-Conducting 700 MHz, 1 A	N/C Cathode SRF 703 MHz, 1 A
Funding Agencies	DOE	DOE	DTRA, NAVSEA	ONR	ONR, BROOKHAVEN NATIONAL LABORATORY
Administrator	DOE	DOE	DTRA	NNSA	NNSA
Collaborators	BROOKHAVEN NATIONAL LABORATORY		Jefferson Lab	Los Alamos NATIONAL LABORATORY	Forschungszentrum Rossendorf, Jefferson Lab

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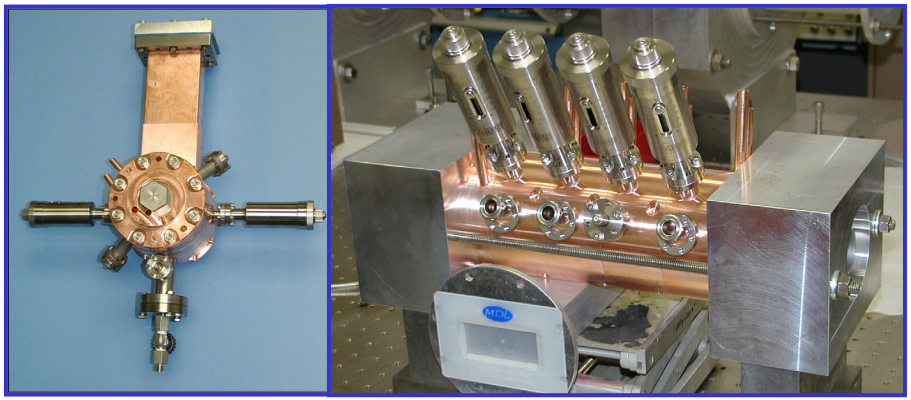
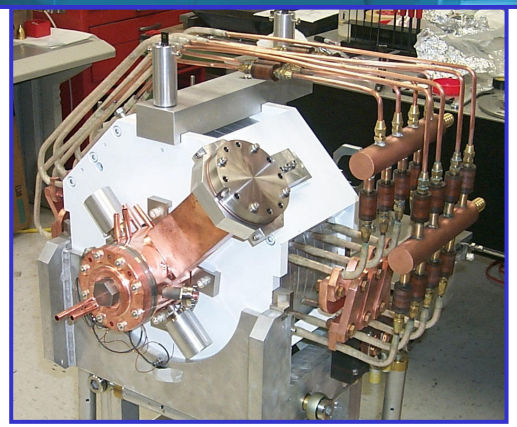
"Conventional" S-Band Guns

NRL Gun and Booster



MXISystems Gun and Linac



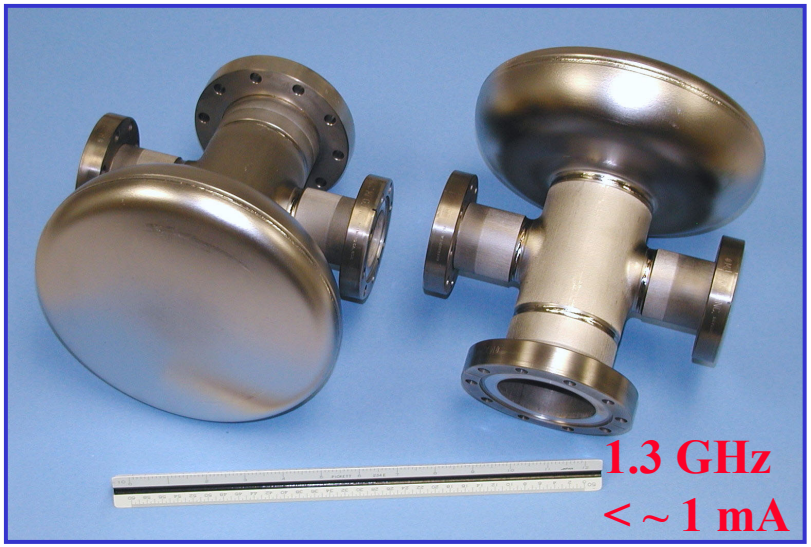
Comments

- AES has fabricated several BNL Gun-IV-style and other S-band photocathode guns
- Customers include BNL LEAF, NRL, MXISystems
- Devices are operating successfully at all locations

Typical Performance

- 2.86 GHz RF frequency
- 1 + nC bunch charge
- 4 + MeV electron energy
- 3 mm-mrad transverse normalized rms emittance @ 1 nC
- up to 0.3 mA average current @ 0.01% duty factor

Niobium Cathode L-Band Gun

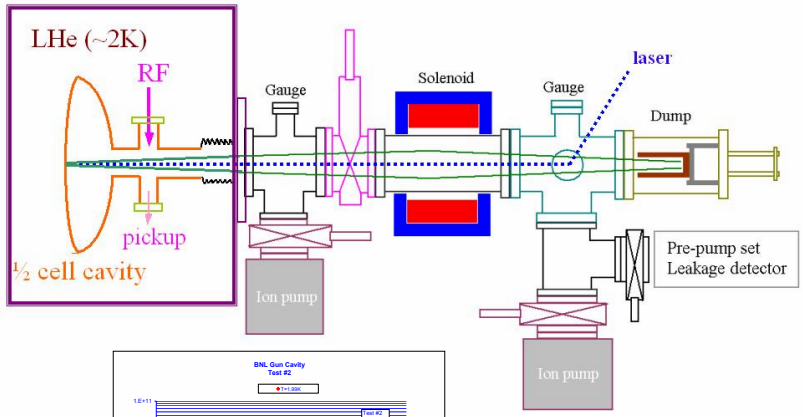


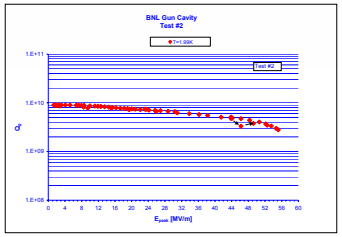
Comments

- Two guns fabricated
- First article currently in test at BNL
- Plan in process to modify second article and use it for test of novel BNL cathode concept

Projected Parameters

Frequency	1.3	GHz
Energy	2.1	MeV
Current	0.1	mA
Bunch Charge	0.01	nC
Transverse Emittance	0.748	mm-mrad rms normalized
Longitudinal Emittance	1.1	keV-psec rms
Bunch Length	1.4	psec rms
Beam Radius	7.3	mm rms





BROOKHAVEN NATIONAL LABORATORY

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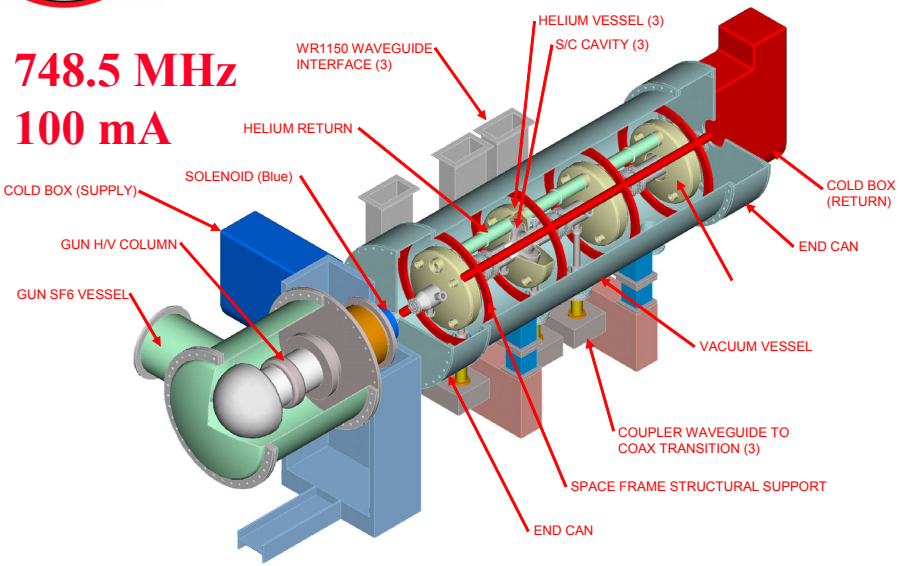
Putting Accelerator Technology to Work

100 mA DC Gun & SRF Injector

748.5 MHz
100 mA



Objectives & Comments

- Design and fabricate a 100mA-capable SRF Injector for integration with a JLAB DC Gun.
- Test the device at the JLAB ITS
- MDA and NAVSEA Phase II SBIR ends 11/04
- Design shown to be extrapolable to 1 A with addition of harmonic cavity

Projected Parameters

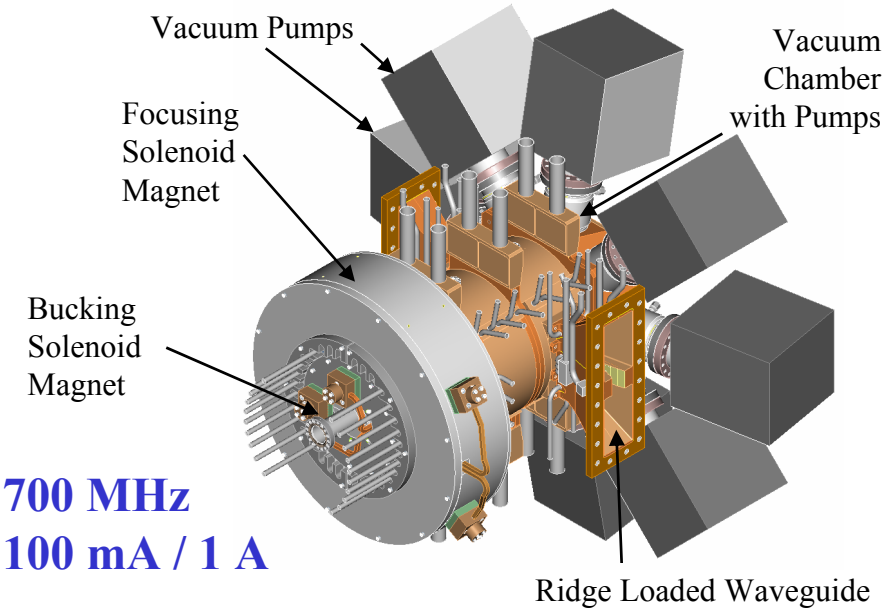
Frequency	748.5	MHz
Energy	7	MeV
Current*	100	mA
Bunch Charge	0.133	nC
Transverse Emittance	1.2	mm-mrad rms normalized
Longitudinal Emittance	44	keV-psec rms
Energy Spread	0.5	%
Bunch Length	6.3	psec rms

* FPCs set for projected JLAB 30 mA current limit

Schedule

- Vacuum vessel completed – at JLAB
- Power couplers completed – at AES
- SRF welding proceeding - complete 9/04
- All remaining hardware to JLAB 11/04
- Final Report 11/04

100 mA Normal-Conducting Injector



700 MHz
100 mA / 1 A

Objectives & Comments

- Design and fabricate a 100 mA-capable Normal-Conducting Injector for delivery to Los Alamos
- Demonstrate CW thermal performance at 7 MV/m (no cathode)
- Demonstrate 100 mA beam performance (not yet authorized)

Projected Parameters

Frequency	700	MHz
Energy	2.54	MeV
Current @ 35 MHz*	105	mA
Bunch Charge*	3	nC
Transverse Emittance	6	mm-mrad rms normalized
Longitudinal Emittance	~200	keV-psec rms
Energy Spread	< 1%	%
Bunch Length		psec rms

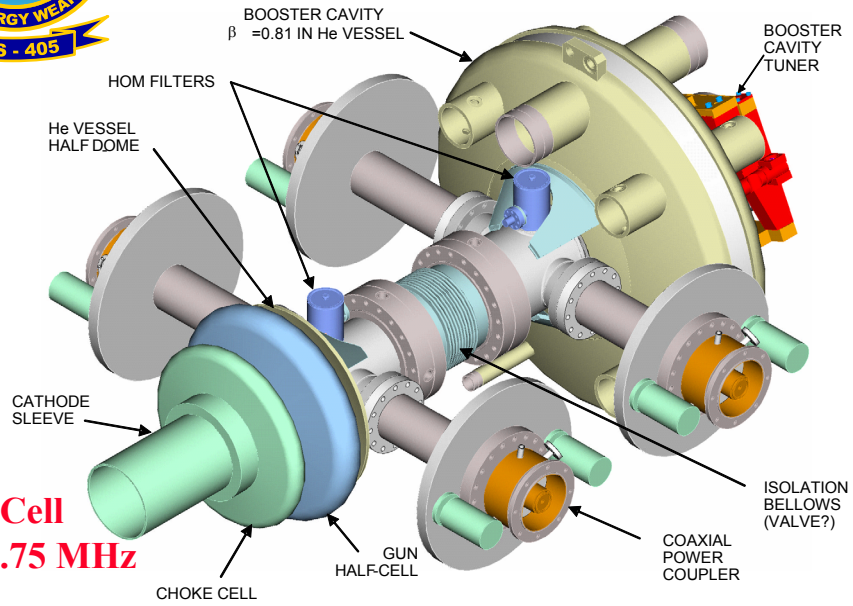
* 100 mA-capable but no cathode at present
1 A-capable at 350 MHz PRF

† Emittance values at 20 MeV after boosters

Schedule as of 6/04

- Fabrication operations - complete 4/05
- Stack tune - complete 4/05
- Stack braze - complete 5/05
- Deliver cavity to LANL – 5/24/05

Fully-SRF Injector Design



0.5 Cell
703.75 MHz
1 A

Objectives & Comments

- Complete the design and costing of a 0.5-cell Fully Superconducting RF gun and choke joint fed by two 1 MW RF power couplers
- Decision on whether to proceed to fabrication and test at program conclusion
- Collaboration with JLAB, BNL, FZR and other FEL-program stakeholders

Projected Parameters

Frequency	703.75	MHz
Energy	2	MeV
Current	1000	mA
Bunch Charge	1.33	nC
Transverse Emittance*	7.6	mm-mrad rms normalized
Longitudinal Emittance*	20	keV-psec rms
Energy Spread*	< 1%	%
Bunch Length*	8	psec rms

* Parameters at 3.76 MeV after single cell booster to develop emittance compensation

Schedule

- Testing alternate choke joint – complete 6/04
- Choke configuration downselect – 7/04
- Cavity and cryomodule preliminary design – complete 9/04
- Order niobium 10/04
- Cavity and cryomodule design and costing – complete 12/04
- Design and costing report 12/04

NORTHROP GRUMMAN Electronic Systems
BROOKHAVEN NATIONAL LABORATORY
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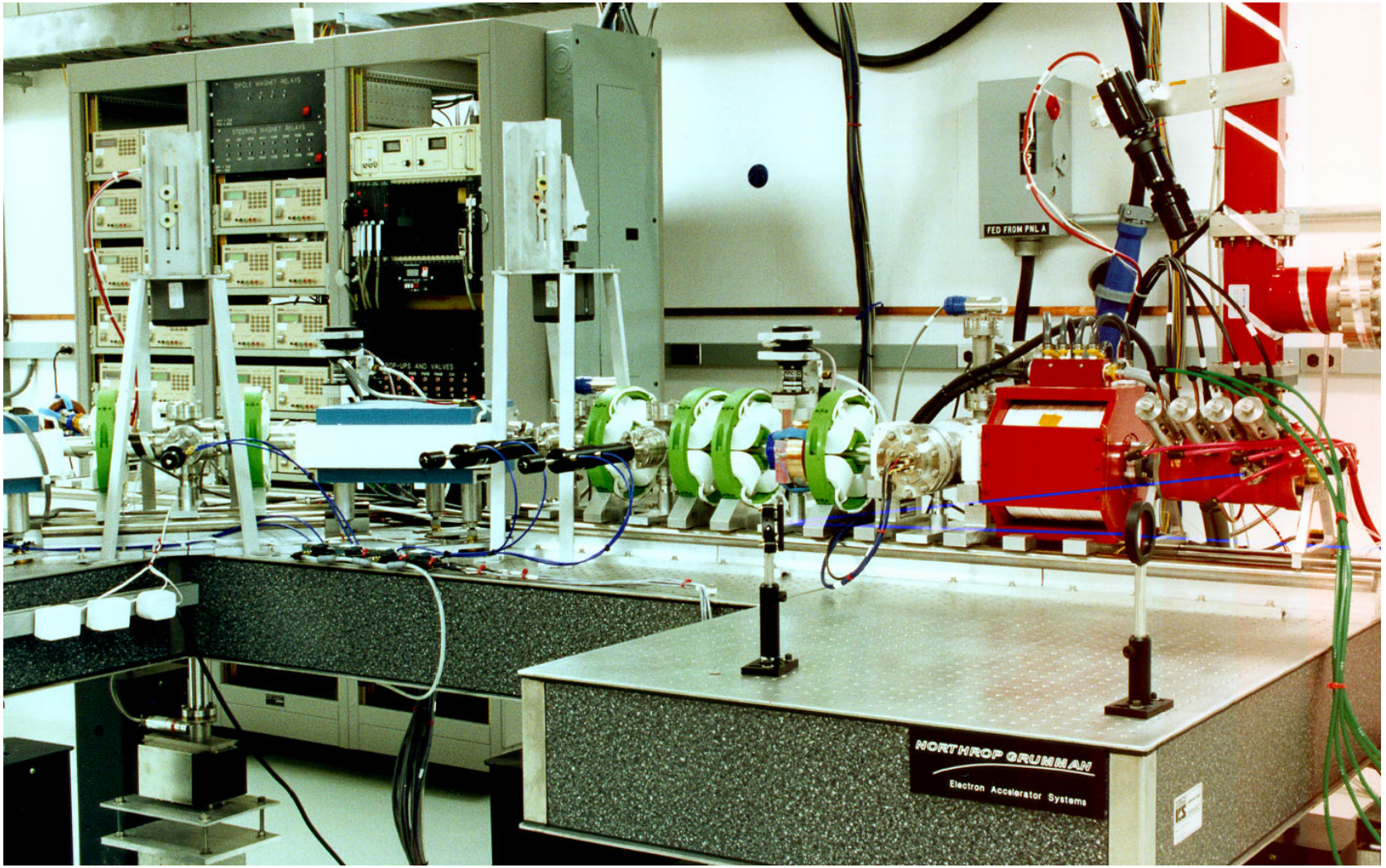
Putting Accelerator Technology to Work

Pulse Radiolysis Beamline Features

- Photocathode RF electron gun
- S-band and L-band designs exist
  - scalable to other frequency bands
- Energy range from 5 MeV to 15 MeV
- Pulse charge levels in excess of 50 nC
- Pulse durations less than 0.70 psec rms with ~ 2 nC
  - with longitudinal bunch compression
- Low dark currents possible
- Footprint as small as 6 m^2 (excluding RF system)
- Single shot with repetition rates to 60 Hz

Initial Section of the LEAF Beamline



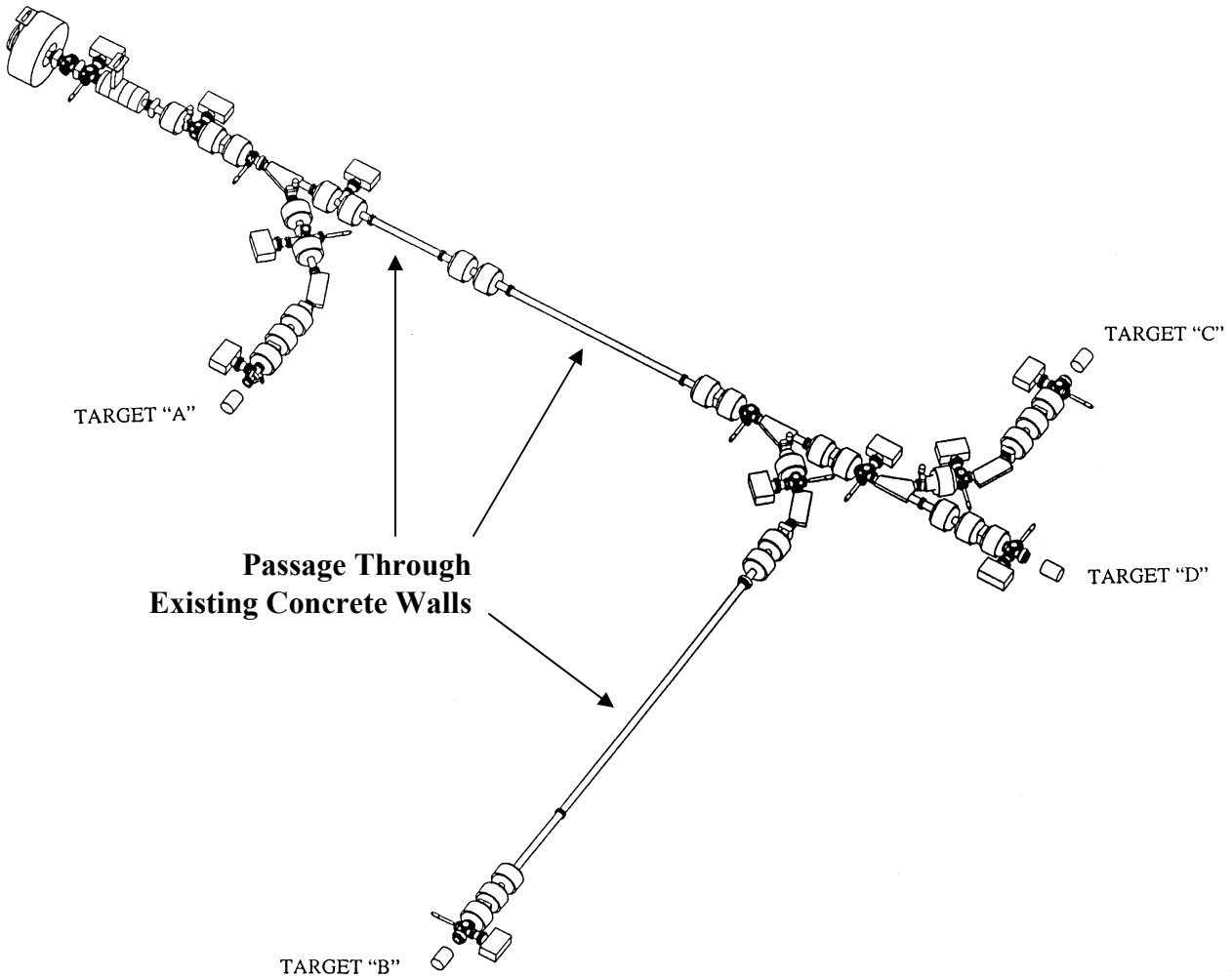
Compact Pulse Radiolysis Beamline

- Similar in design to LEAF beamline
  - electron optics much more compressed
- Entire beamline, from gun to targets, fits on a 3m by 2m optical table
  - two target stations are provided
- Designed to deliver 10 nC to both targets
  - FWHM of less than 5 ps on bent path
  - FWHM of less than 10 ps on the straight path

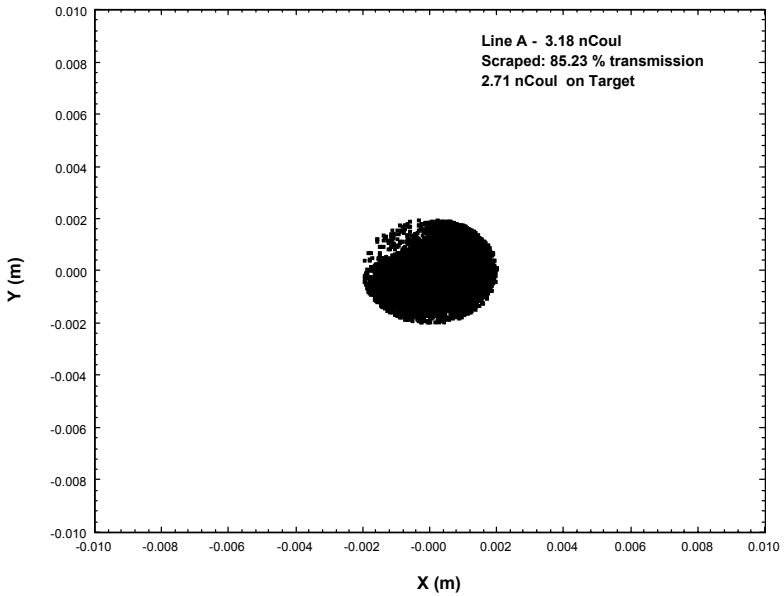
High-Charge, Short-Pulse Beamline

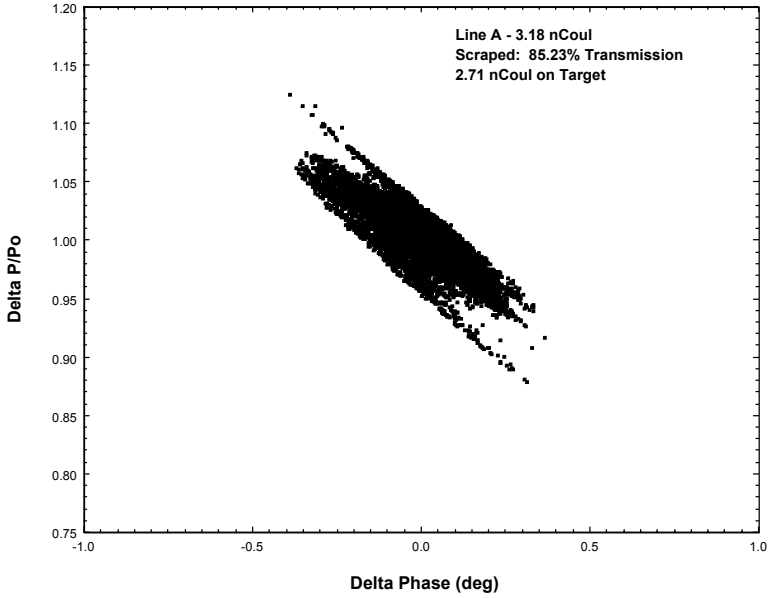
- Designed to provide very high charge per pulse or sub-picosecond pulse width at lower charge
  - Design charge levels to 90 nC per pulse
  - Design pulse widths less than 0.7 ps
  - Peak currents in excess of 5000 Amperes
- L-band photocathode gun and booster accelerator
  - lower frequency necessary to achieve higher charge operation
- Output Energy up to 15 MeV

5 Target L-Band Beamline

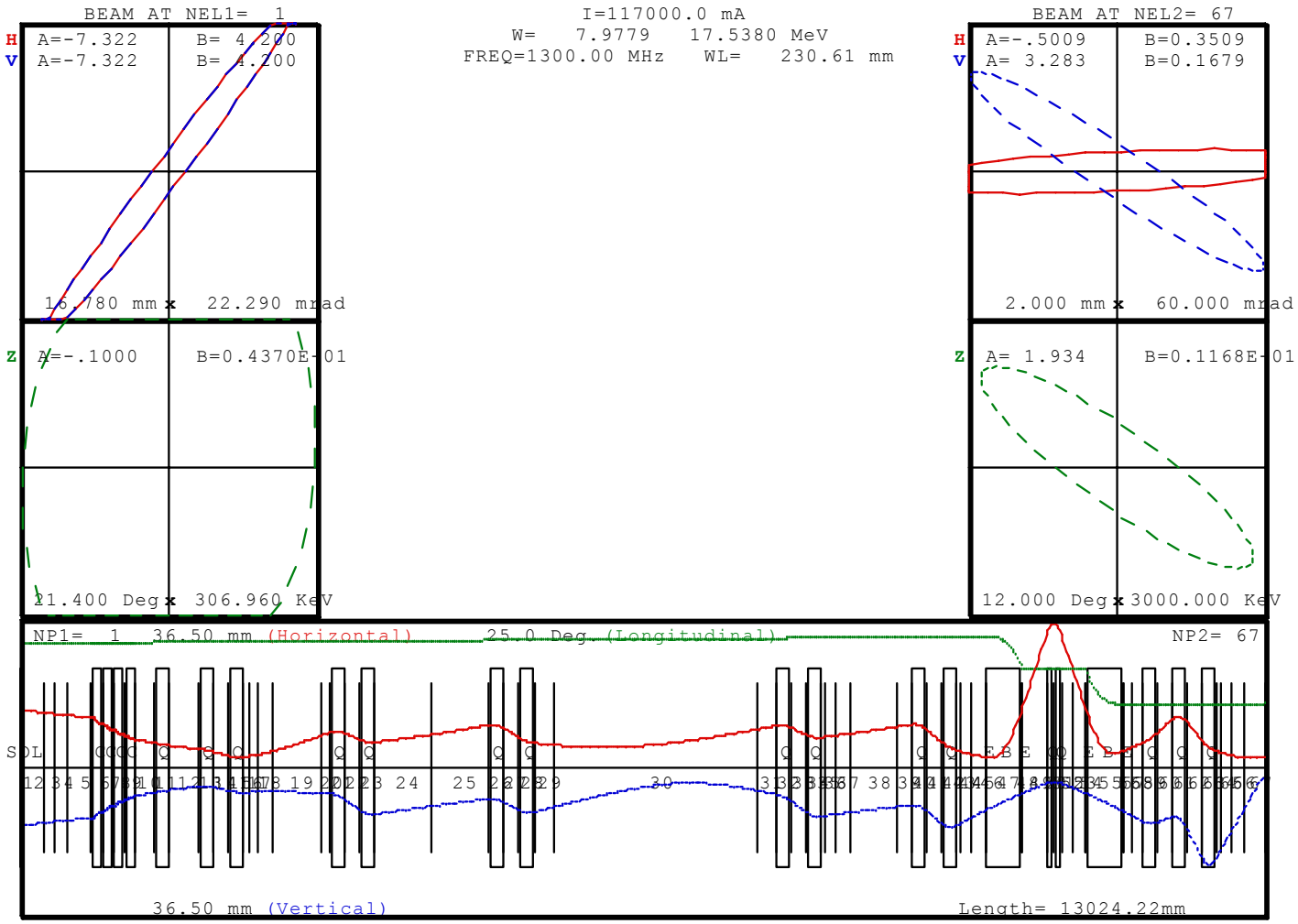


Phase Space Plots of Short Pulse at Target A





90 nC Trace-3D Results (Target C)



Putting Accelerator Technology to Work

Summary

- AES is a leading manufacturer of both high-performance and high-power photoinjector electron accelerator systems

- AES has designed state-of-the-art short pulse, intense beam electron accelerators
  - up to 20 - 30 kA/cm^2 in picosecond pulse lengths
  - charge up to 90 nC per pulse in less than 20 ps pulse length
  - low dark current
  - sub-picosecond pulse lengths

- Such electron pulses are useful for a variety of applications including radiation chemistry
  - BNL LEAF beamline is operational for radiation chemistry/pulse radiolysis applications

Acknowledgement

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