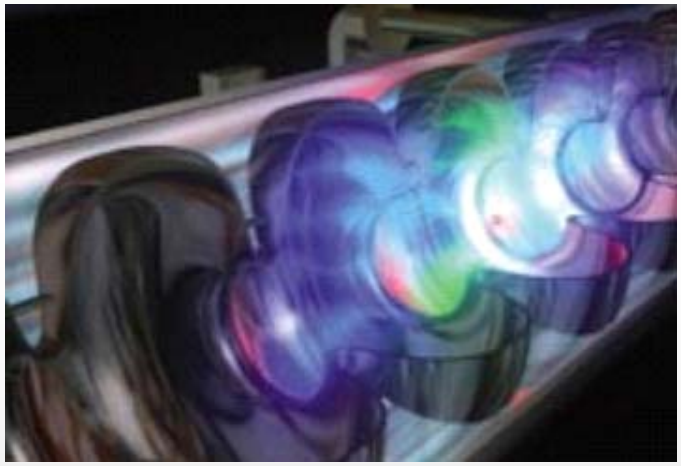
SCRF: US National Program

Scientific/Technical Thrust Areas, Collaborations and Resources



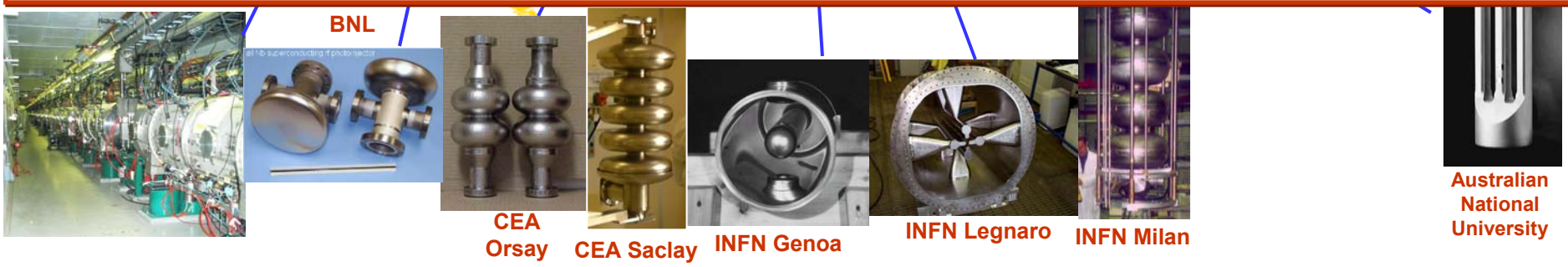
Swapan Chattopadhyay
Jefferson Lab
Newport News, Virginia

OUTLINE

- **International SRF Network**
- **US DOE, Office of Science 20 Year Outlook and National SRF Network**
- **SRF R&D Thrust Areas**
  - High Gradient (ILC)
  - Consistent Processing and Diagnostics for Robust and Predictable Performance (for all facilities)
  - High Current Capability (ERL/FEL)
  - Novel Cavities for Heavy Ions ($\beta<1$) and Speed-of-Light Particles ($\beta\sim1$) (RIA, Proton Driver, ν-factories, Muon Colliders)
- **US Capability for Medium-Scale SRF Production Towards Large Accelerator Facilities (SNS)**
- **Lab Profiles**
- **Summary and Outlook**
- **Appendix**
  - JLab Assessment of Required US Investment
  - Education and Training within the 20 Year Outlook
  - Planned SC Facilities: SRF Developments needed to provide Efficient and Quality Beam for Science
  - Superfluid 2K Cryogenics
  - JLAB/DESY Bench-marking

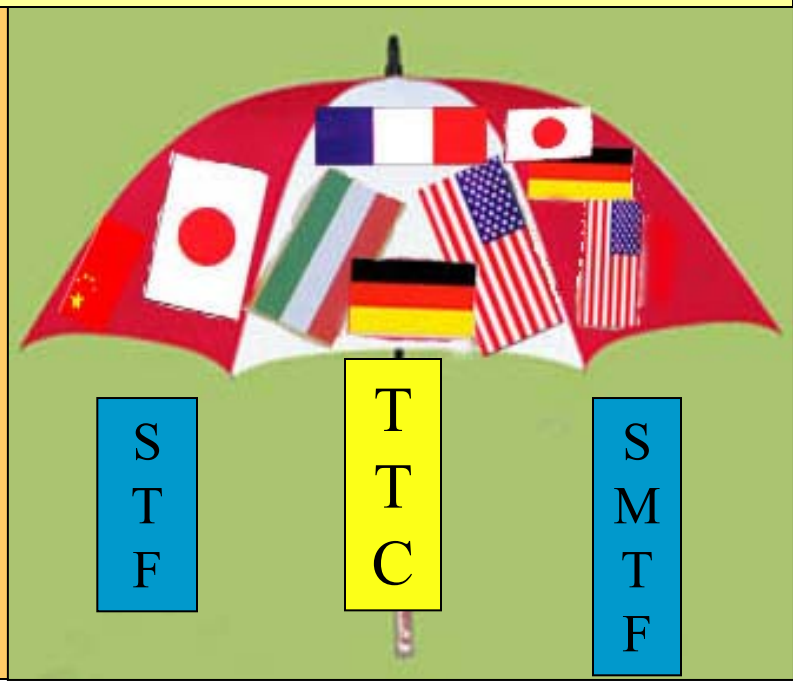
Global Network of Collaborations in Superconducting Radio-Frequency Science and Technology

Deliberate progress of existing highly successful international collaboration towards further focus and coherence



International SRF Collaborations

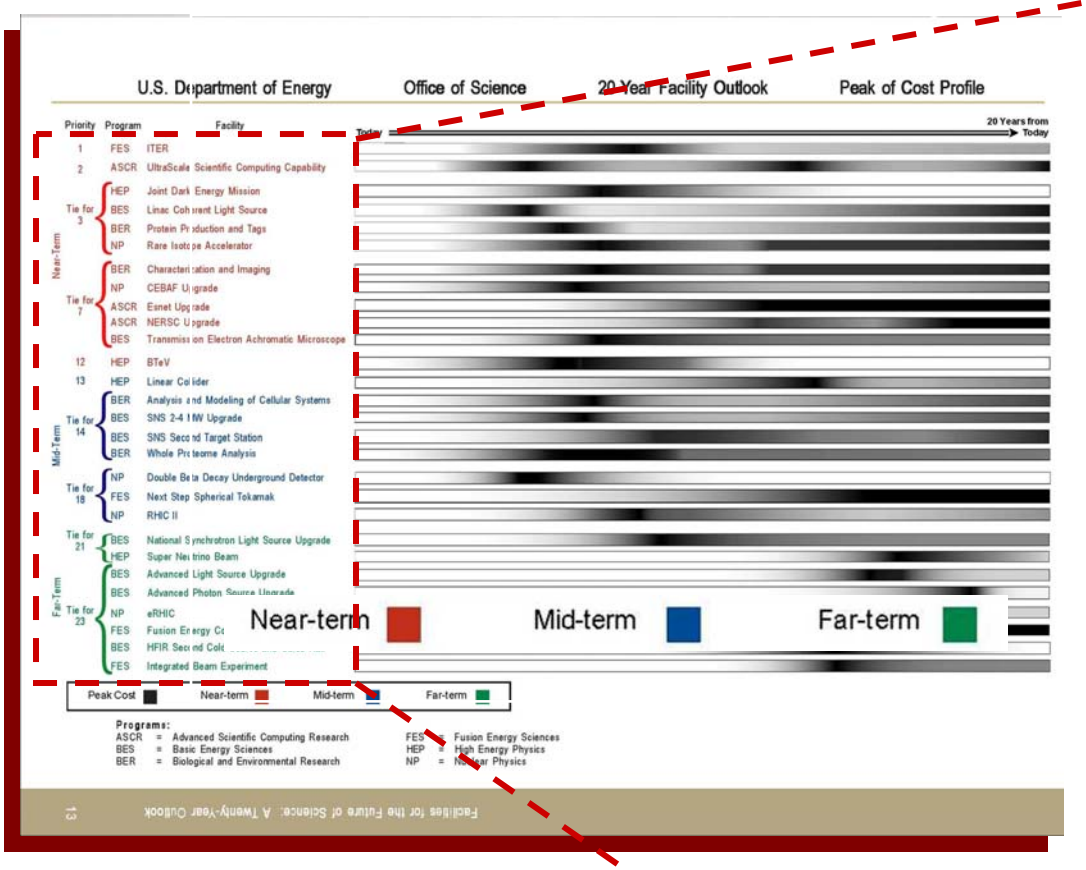
- TTC 50 members, 9 US (DESY)
- SMTF 21 members, 15 US (FNAL)
- STF (KEK)
- Collect world's experts in SRF and focus that knowledge on long-term research issues as well as issues relevant to several projects using SRF, e.g., ILC, XFEL, PD, RIA, ERL FELs and light sources, etc.



Challenges:

- Combines groups with different experiences/perspectives and creates a fertile environment for SRF discussions. But how to interface the collaborations to one another and to the needs of the major projects, e.g., ILC and XFEL.
- How to balance between Project driven R&D and more global/basic R&D

U.S. Department of Energy, Office of Science 20 Year Outlook



Near-Term

1	FES	ITER
2	ASCR	UltraScale Scientific Computing Capability
Tie for 3	HEP	Joint Dark Energy Mission
	BES	Linac Coherent Light Source
	BER	Protein Production and Tags
	NP	**Rare Isotope Accelerator**
Tie for 7	BER	Characterization and Imaging
	NP	**CEBAF Upgrade**
	ASCR	Esnet Upgrade
	ASCR	NERSC Upgrade
	BES	Transmission Electron Achromatic Microscope

Mid-Term

12	HEP	BTeV
13	HEP	**Linear Collider**
Tie for 14	BER	Analysis and Modeling of Cellular Systems
	BES	**SNS 2-4 MW Upgrade**
	BES	SNS Second Target Station
	BER	Whole Proteome Analysis
Tie for 18	NP	Double Beta Decay Underground Detector
	FES	Next Step Spherical Tokamak
	NP	**RHIC II**

Far-Term

Tie for 21	BES	**National Synchrotron Light Source Upgrade**
	HEP	**Super Neutrino Beam**
Tie for 23	BES	**Advanced Light Source Upgrade**
	BES	**Advanced Photon Source Upgrade**
	NP	**eRHIC**
	FES	Fusion Energy Contingency
	BES	HFIR Second Cold Source and Guide Hall
	FES	Integrated Beam Experiment

SRF will play a major role in the future of SC facilities

Planned SC Facilities grouped according to beam energy and current requirements

	Low beam current	ERLs-high beam current with low net rf power	High beam current (10 - 1000 mA)
Low Energy	RIA, SNS 12 GeV CEBAF	EIC, ELIC ERL light sources	Super-B Factory Light Sources Upgrades
High Energy	Linear Collider	eRHIC, RHIC-II	Super Beams (μ, ν)
Principal Challenge	Highest acceleration as cheaply as possible	Acceleration plus strong HOM damping	RF coupling - Fundamental rf in and HOMs out

Level 1 E_{acc} ~ 20 MV/m: robust rf control

Level 2 E_{acc} ~ 28 MV/m: well-damped higher-order modes for carrying high current

Level 3 $E_{acc} \geq 35$ MV/m: process control for reliable production

National Network of SRF Collaborations

ANL: RIA, Low-β Heavy Ions, ILC, PD

BNL: RHIC-II, eRHIC, ERL, FEL

Cornell: CESR, CESR-II, ERL, Light Sources, ν-factory, ILC

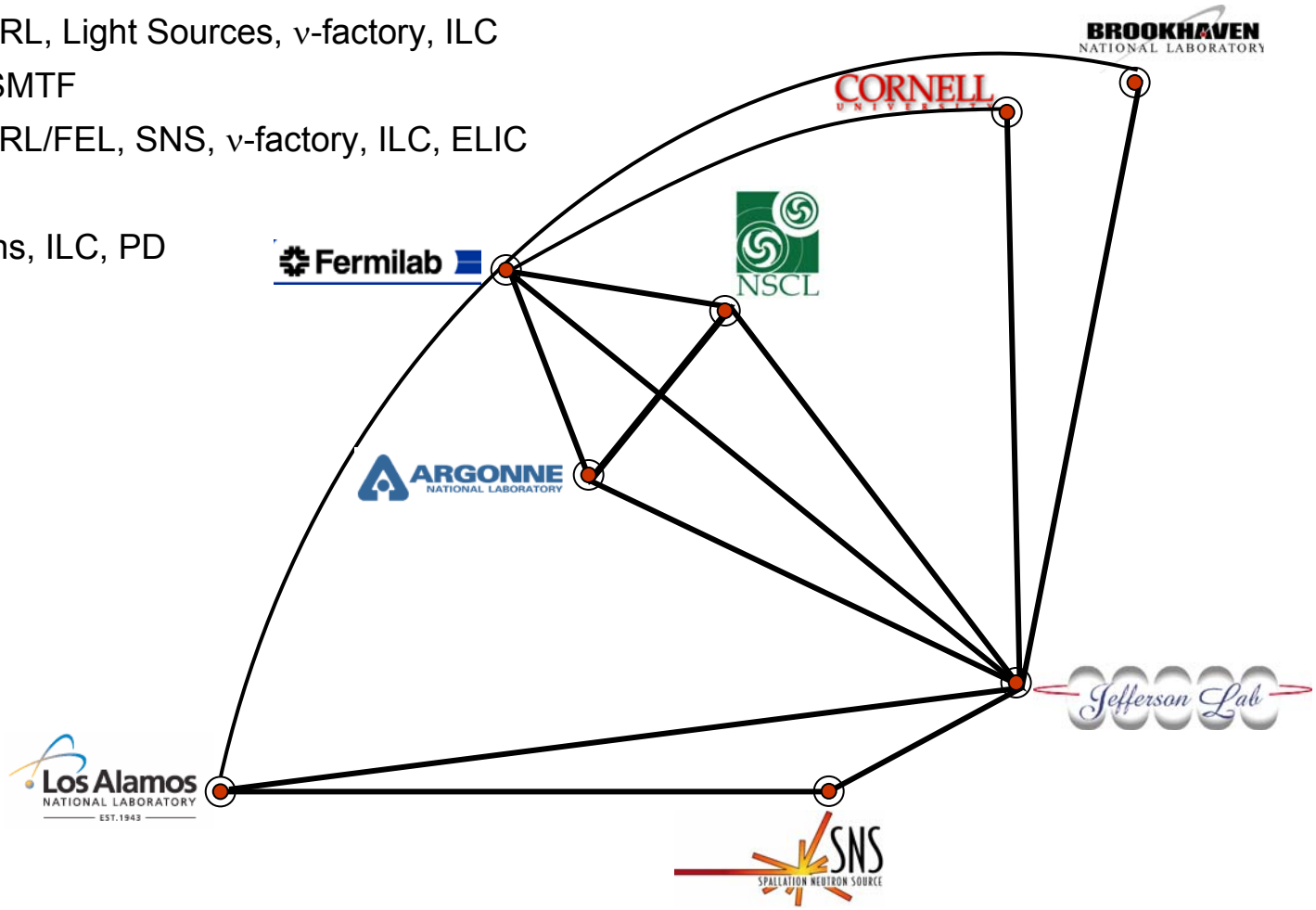
FNAL: ILC, Proton Driver, SMTF

JLab: CEBAF, CEBAF-II, ERL/FEL, SNS, ν-factory, ILC, ELIC

LANL: APT, SNS

MSU: RIA, Low-β Heavy Ions, ILC, PD

ORNL: SNS, SNS-II



Progress in Achieving High Gradient

Advances in SRF, Combined with Beam Recirculation and Energy Recovery

Gradient [MV/m] — **Accelerator Length to reach 200 MeV**

1985

5 MV/m, CEBAF design, 5 cells

1995

~7 MV/m, CEBAF as built, 5 cells

1998

10 MV/m, JLab FEL, 5 cells

2001

~20 MV/m, CEBAF Upgrade Prototype, 7 cells

* **2005** **~45-50 MV/m Cornell/KEK re-entrant cavity**

~45 MV/m, JLab R&D single grain, single cell result @ 2.2 GHz

SRF **enables: compact FELs to Linear Colliders**

With *recirculation*: 12 GeV, 25 GeV, ν Factory

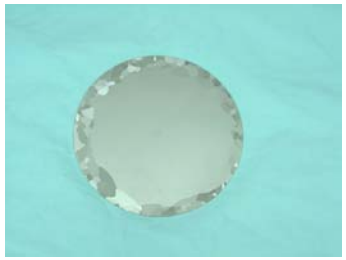
With *energy recovery*: e-cooling , EIC, Light Sources, MW FELs

R&D in High Gradient for the ILC

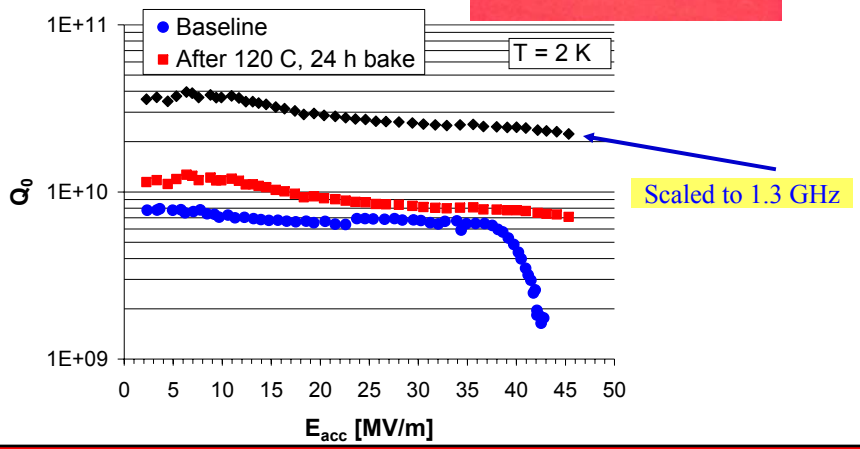
ILC-GDE/JLab/Cornell MOUs focus on Long-term R&D

Development of "single crystal" niobium technology

promises "streamlining" of fabrication and processing procedures, for comparable performance at lower costs

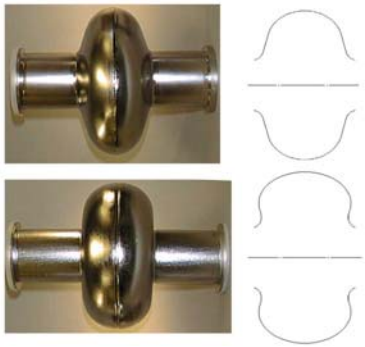


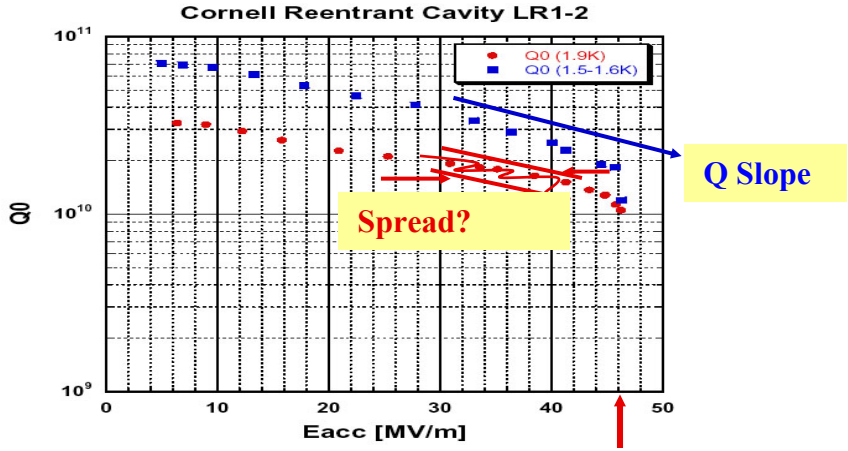
2.3 GHz Low Loss Shape



Re-entrant Shape Single Cell Cavity Reached 47 MV/m in May 05

2nd Re-entrant Cavity (built at Cornell) Treated and Tested at KEK Reached 50+ MV/m at KEK (Sept 05)





$[E_{max}, dQ/dE_{acc}, \sigma_E]$

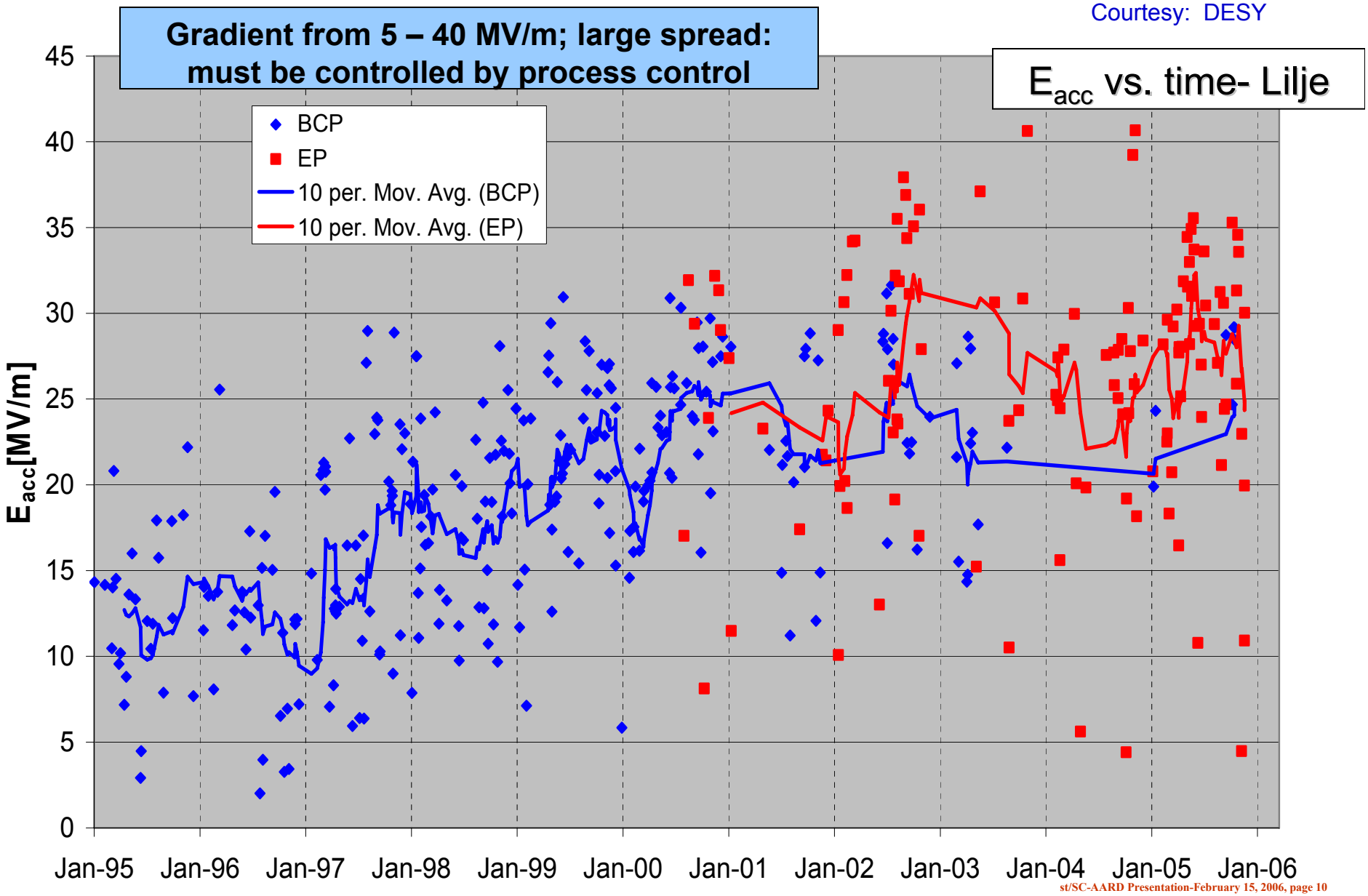
Highest Achievable Gradient?

Continued Studies of New Materials (e.g. Single Crystal Nb, Nb_3Sn, etc.) as well as Cavity Dynamics will be Essential to Securing Colliders beyond 1 TeV cm Energy in the Long-term (covered in talk by Padamsee)

Spread in Accelerating Gradient

Cavity Process Control – Immediate Near-term R&D Goal for the ILC

Courtesy: DESY



Cavity Process Control

JLab/FNAL/Cornell MOUs focus on cavity Processing R&D at six major laboratories

Closed Chemistry Cabinet

Electropolish Cabinet

Hi Pressure Rinse Cabinet

Class 100 & 10 Clean Rooms

Cavity Processing Facilities

NSCL

Los Alamos NATIONAL LABORATORY EST. 1943

ARGONNE NATIONAL LABORATORY

Fermilab

Jefferson Lab

CORNELL UNIVERSITY

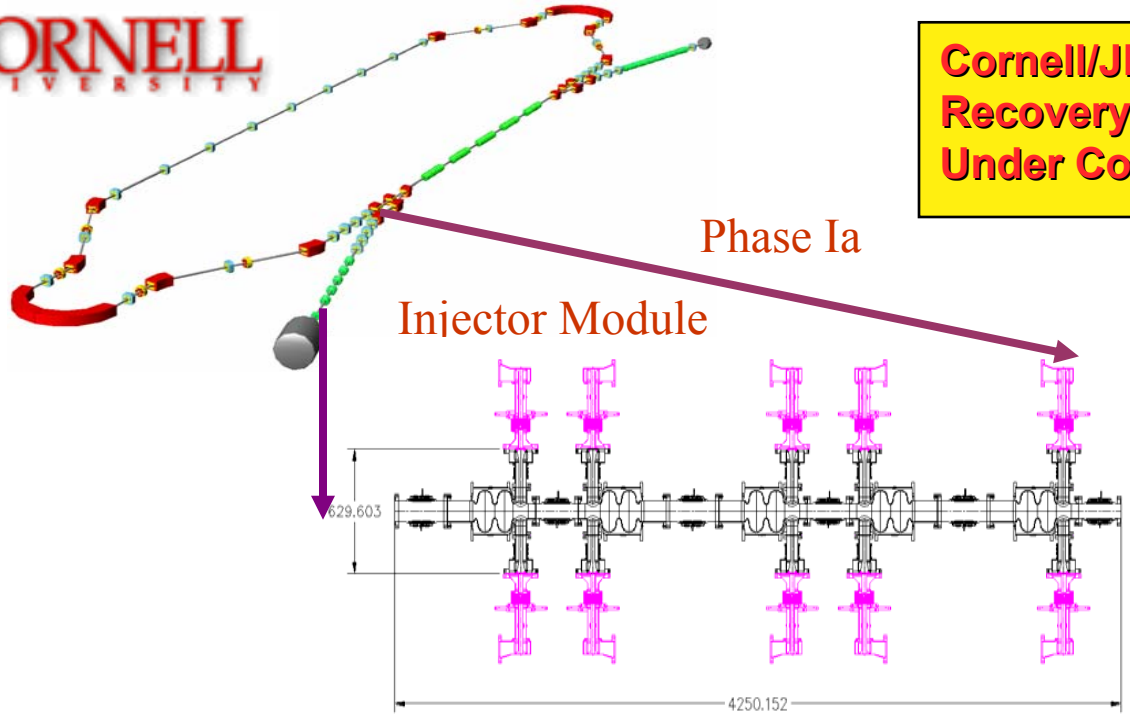
2600 ft² Clean Room

Ultra-Pure Water Supply 2000 G/day with 1500 G Tank

High Current ERL/FEL

JLab/Cornell MOU focus on Near-, Mid- and Long-term R&D on High Current ERLs

CORNELL UNIVERSITY

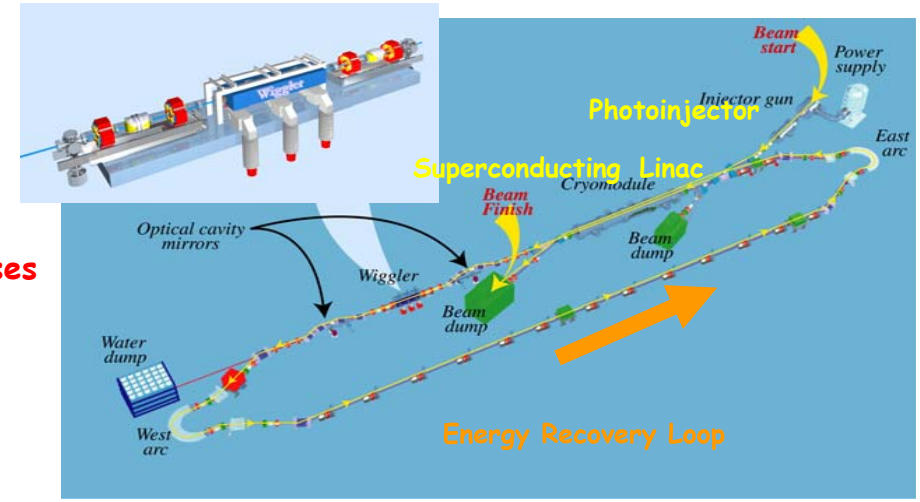


Cornell/JLab Jointly Designed Energy Recovery Linac Prototype (Phase I a) Under Construction

Jefferson Lab

JLab ERL-based Free Electron Laser

- 10 kW average power
- 2-6.5 microns
- 500 femtosecond pulses
- 75 MHz rep rate

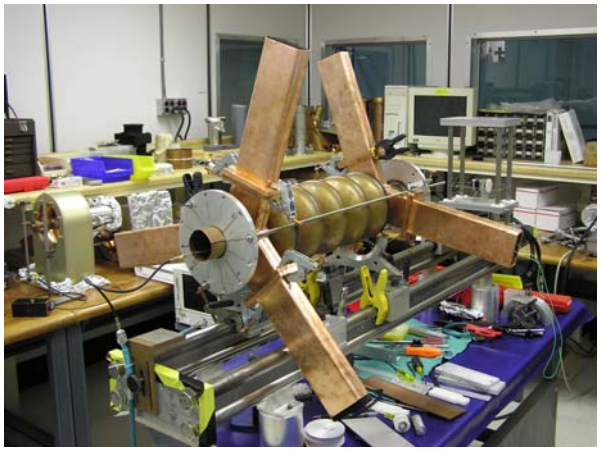


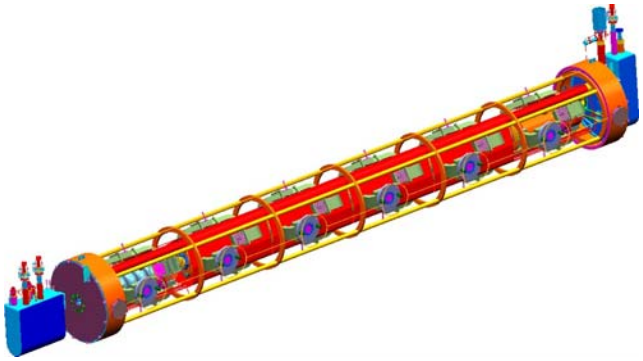
High Current ERL/FEL

JLab/BNL MOU focus on Near-, Mid- and Long-term R&D on High Current ERLs

BNL/JLAB Collaboration

JLab Ampere-class cavity/cryomodule

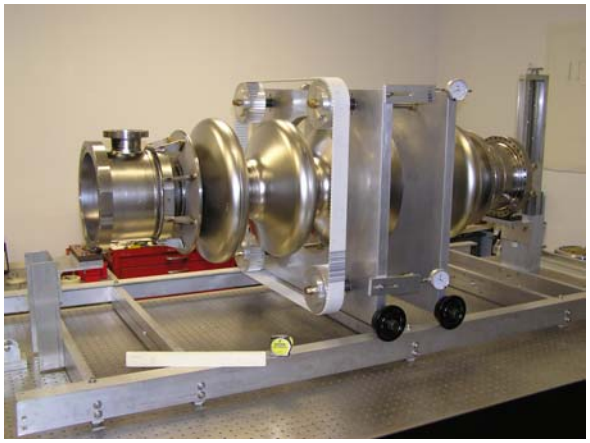


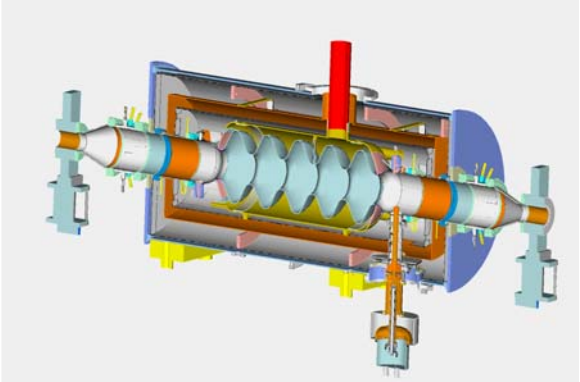


1.3 GHz all-niobium RF gun.

Presently fitted with a choke-joint to enable changing photocathodes.

BNL Ampere-class cavity/cryomodule





Novel Cavities for Heavy Ion (β<1) and Speed-of-Light Particles (β~1): RIA, Proton Driver, ν -factories, Muon Collider

FNAL, JLab, Cornell, MSU, ANL and LANL in Collaboration

LANSCE Superconducting RF Structures Laboratory Web Page

This website is a forum to present the research and experimental results of the work in the LANSCE-1 RF Structures Laboratory in MPF-17.

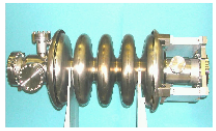


Figure 1: APT 700 MHz, Beta=0.64, 5-cell Cavity

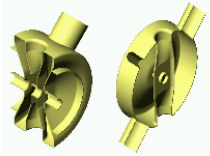
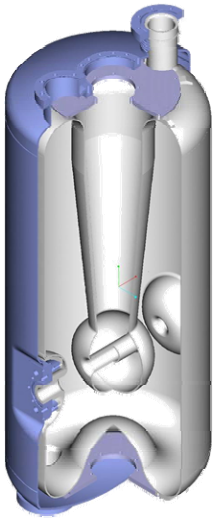


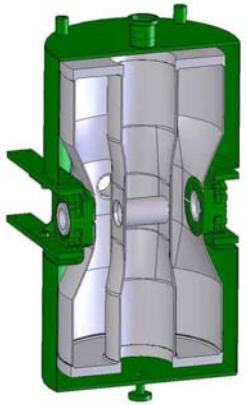
Figure 2: 350 MHz, Beta=0.175 Spoke Resonator

ANL

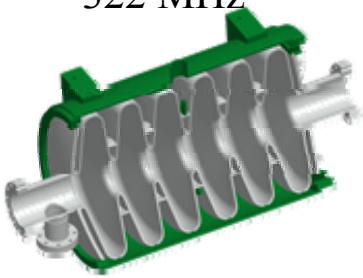


ANL 115 MHz, beta=0.15 Quarter-wave Cavity

Completed



β_{opt}= 0.285
322 MHz



β_{geo}= 0.47 - 805 MHz
MSU/JLAB

Nb-Cu Cavities for Neutrino Factories and Muon Colliders

Cornell

Proton Driver Cavity
1.3 GHz β=0.81

MSU/FNAL/JLAB

Current US Capability for Medium-scale SRF Production Facilities

SNS Construction Project

- ✓ Project complete – final module shipped to ORNL March 16, 2005 -- On schedule; on budget; cavity performance exceeds specification!
- ✓ Demonstrated rapid cavity prototyping: international collaborative design + fabrication, integration, and testing at JLab

Formal Handoff Ceremony April 8, 2005

- Cryomodules developed and built by JLab
- Tested all 81 cavities at 4.2 and 2.1 K
- Linac operational at over 950 MeV for H^-
- Preparing for long term operation at full specifications (1 GeV, 60 pps)

- Machine regularly running at 4.2 K with beam
- Functioning test bed for pulsed RF superconductivity applied to particle accelerators

Laboratory Profiles

	Accelerator Facilities: Their Goals and time scales of achievement	Five Accomplishments	Impacts to HEP	Budget	Facilities	Effort *Near/Mid/Long-term	Management Oversight and Review	Service to Others
JLAB	• CEBAF/CEBAF-II (NP): Study Quark Confinement and Strong QCD; Construction 2008-2011; Operations 2011-2020 • ELIC (NP); Study transversity and exotic quark-gluon color glass condensates; Construction 2015-2020; Ops 2020 • 10-100 kW FEL in IR and 2 kW in UV (DOD); Basic and Applied Sciences of materials, nano-structures, micro-fabrication and life sciences; 5-10 year program; future x-ray facility beyond 2020 • ILC Contribution: cost-effective SRF for >1 TeV cm collider for Higgs; 2015-2025 • World's first Energy Recovery Linear acceleration demonstration at high currents of 10 mA CW in 2000 - 2004; basis for Daresbury, Cornell and BNL ERL designs • Embodies US national SRF developments for NP, HEP, BES and DOD • Linear Collider parameter developments 2001-present • SRF-based Linear Collider Cost estimates, 2003 and continuing	• 5 MV/m → >20 MV/m operating gradient in CEBAF from 1985 to present • Large-scale robust operation of SRF linacs 1995 to present • Medium-scale SRF production capability, 2005 (e.g. SNS SRF linac) • Single crystal/large grain niobium @ 46 MV/m with minimal processing, promising cost-effective ILC at greater than 1 TeV cm energy, 2005 • World's first demonstration of High Current 10 mA CW SRF/ERL in 2000-2004	• Demonstration of reliable and robust "SRF" operation in large-scale in CEBAF • Cost reduction via simplified design and processing • Enhanced technical reach beyond 1TeV cm energy for electron-positron colliders • Leveraging of already existing infrastructure and investments at JLab to benefit US-HEP developments in SRF and ILC • First US national kick-off collaboration meeting at JLab in September 2004 amongst all US labs in the wake of the ITRP decision on "cold technology" • Muon cooling cavity development for Neutrino factories and Muon Colliders • Novel muon cooling schemes without solenoids • "TESLA/TTC" contributions	• $4M/year (NP): Mostly in support of Operations of CEBAF with R&D at $0.5M/year level. • $1M/year (HEP) • $.0.5/year (DOD), mostly in support of FEL SRF cryomodule production, testing and operation	• Investment: $40M to date • Self-contained cavity and cryomodule fabrication, testing, processing & production • Test beam available in the FEL • Injector Test cave • State-of-the-art Surface Science Analytical Instruments and lab	• 30 FTEs • Students: 2-4 • 1 Ph.D./ year; Total: 17 to date • 1 Master's • R&D Profile: *85%/10%/5%	• Annual DOE Science & Technology Review • Institutional Management Review every 2 years • Recommendation implemented annually • Director's Reviews when needed • Ad-hoc External reviews	• ILC(GDE) • SNS (ORNL) • RIA (ANL, MSU) • eRHIC (BNL) • PD (FNAL) • TTC/XFEL (DESY
FNAL	• 3.9 GHz cavity R&D, 2 cavity types for Photoinjector & 4 cavity module for TTFII, also TESLA cavity operation 1998-2007 • ILC R&D, prepare for project 2005-? • Proton Driver R&D, be prepared to implement if ILC delayed, efforts complementary to ILC R&D 2005-?	• Provide FNAL experience in all aspects of SRF development & operation, initiating polarized gun effort • Develop necessary infrastructure • Initiate materials effort • Design concepts for a PD using ILC technology	• Bunch compression, diagnostic & crab cavity applications. efficient FEL SASE • ILC major future goal of HEP • PD major thrust for neutrino physics. Preproduction test vehicle for ILC	**SRF only** R&D (direct M&S+SWF) FY05 • 3.9 2M$ • ILC 3.2 M$ • SRF Infra & Mat Dev 2.1 M$ • PD 0.5 M$ FY06 • 3.9 2.8M$ • ILC 4.4M$ • SRF Infra & Mat 3.2 • PD 2M$	• 3.9 modest facilities developed- CR, UPW, HPR, oven, Vert Test • Chemical processing – joint facility with ANL for BCP & EP • Under construction –major CR facility, module assembly, Horiz & Vert Test dewars, module test area	**SRF only** • 3.9 ~11FTE FY05, 20 FTE FY06 • ILC 9FTE FY05, 10 FTE FY06 • SRF infrastr & Mat 6FTE FY05, 12 FTE FY06 • PD 3FTE FY05, 10FTE FY06	• ILC Program Director w Div Leaders • PD Program Leader • DOE reviews • FNAL AccAdv Com • GDE • Individual reviews and advisory committees	Strong collaboration with DESY MOUs w CU, JLab, ANL, MSU and others

Laboratory Profiles cont'd

	Accelerator Facilities: Their Goals and time scales of achievement	Five Accomplishments	Impacts to HEP	Budget	Facilities	Effort *Near/Mid/Long-term	Management Oversight and Review	Service to Others
Cornell	• SRF development for high energy synchrotrons and storage rings: 1970 – 1985, CEBAF Adopted Cornell SRF Technology and Cavity Design in 1986, Gradient > 5 MV/m • High Luminosity Storage Rings CESR (1998): First Storage Ring to Run Entirely on SRF Cavities, Ea = 7 MV/m, I = 700 mA •Storage Ring Light Source Using CESR technology (2000 – 2010: CHESS (Cornell), Canadian Light Source, Taiwan Light Source, Diamond Light Source (UK), Shangai Light Source, BESSY (Berlin Light Source). •Linear Collider: Parameter developments, Technology Developments (1987 – 2025) •Energy Recovery Linac Light Source : Concept development (collaboration with Jlab) (2002 – 2004), Prototype (under construction) (2005- 2008), ERL (2010) • Neutrino Factory and Muon Collider Accelerator technology Development 2000 – 2030	•1975: First Test of SRF Cavities in a HEP Accelerator (2.86 GHz, Ea= 4 MV/m, 110 mA, 4 GeV) •1994: First Demonstration of 500 MHz High Current Operation (Ea = 5 MV/m, 200 mA) •1995: First Demonstration of Eacc > 25 MV/m for LC, several 5-cell cavities •2002 First Test of 200 MHz Nb-Cu Cavity (in collaboration with CERN) •2005 Record accelerating gradient 47 in single cell with new shape (re-entrant) and 52 MV/m in collaboration with KEK	•Development, demonstration and implementation of SRF cavitieis for high current high luminosity machines, CESR, KEK-B •First International Linear Collider (TESLA) workshop at Cornell LEPP – 1990, Baseline parameter set •TESLA (now ILC) collaboration activities •Muon collider conceptual design •Neutrino Factory Conceptual designs • First multi-cell meeting TESLA requirements	• Currently 1M/yr NSF, 0.3M grants and subcontracts DoE • Formerly 1.5 M /yr NSF	• Investment 15M to date • cavity and cryostat fab, test, process, synch and storage ring and low emittance gun for beam tests • surface analytical instruments – sem, auger, sims	• 10 FTE • 2-4 students • ~ 6- PhD grads 5 masters in srf • R&D Profile: * 90%, 5%,5%	• Director's reviews • Ad hoc external reviews • NSF reviews	ILC, Canadian Light Source, Taiwan Light Source, Diamond Light Source (UK), Shangai Light Source, BESSY (Berlin Light Source).
ANL	• ATLAS (NP): 50 MV, 64-cavity SC ion linac, Nuclear Structure near the coulomb barrier, Atomic Physics with ion beams. Operations and Upgrades 1978 - present. • ATLAS upgrade to 70 MV (NP): 2007 • RIA (NP): Rare-isotope production facility, 1 GeV multi-ion SC driver linac (proposed).	• First SC ion linac - set standard for reliable and flexible performance • Extended SC velocity range down to 0.01c (ATLAS Positive Ion Injector) • Extended SC velocity range up to 0.63c (spoke cavities) • Phase-stabilization of a wide variety of SC cavities • Design, construction, processing, and testing of high-performance TEM-class cavities @ Epk>40 MV/m	• Reliability -longest time operating with SC cavities • Extended SC technology for high-energy proton linacs	• $1.5M/year (NP) • $300K/year (HEP)	• Cavity and cryomodule development, fabrication, processing, testing, • Cavity production integrated with U. S. vendors • Processing and test facility replacement value $5M	• 5 FTEs Students: undergraduate trainees 2/yr; 1 PhD student	• Annual DOE Science & Technology Review Institutional Review every other year	• RIA(NP) • PD (FNAL) • ILC (FNAL) • Numerous SC ion linacs world-wide (INFN-Legnaro, New Delhi, Sao Paulo, FSU, KSU Host visitors (JAERI, NSC New Delhi, TRIUMF, Orsay, etc.)

Laboratory Profiles cont'd

	Accelerator Facilities: Their Goals and time scales of achievement	Five Accomplishments	Impacts to HEP	Budget	Facilities	Effort *Near/Mid/Long-term	Management Oversight and Review	Service to Others
MSU	• RIA: Rare Isotope Accelerator (NP): Study of nuclei far from stability to understand the stellar processes leading to the production of the heavy elements: Complete cavity and cryo-module prototyping in 2006 • Develop elliptical cavities for FNAL Proton Driver (β=0.47, 0.61, 0.81); 2005-2008 • Develop half-reentrant cavity for ILC	• Prototyping of quarter-wave and half-wave cavities for RIA • Prototyping of reduced-beta multi-cell elliptical cavities for RIA • Low-beta prototype cryomodule design for RIA • Medium-beta prototype cryomodule for RIA: design, fabrication, and testing • Prototyping of single-cell reduced-beta cavity for FNAL proton driver	• Alternative cavity and cryomodule designs for cost reduction • Alternative cavity fabrication techniques for cost reduction • Cavity performance improvement studies: materials science, surface science, heat transfer	~$1.5M/year (DOE/NP, NSF/NP, DOE/HEP	• Self-contained cavity and cryomodule fabrication, testing, processing & production	• ~10 FTEs Students: 6 Ph.D R/D profile *60% , 25%, 15%	• National Superconducting Cyclotron Laboratory • NSF Nuclear Physics User Facility	• RIA (DOE) • ILC (GDE) • Proton Driver (FNAL) Materials Science (FNAL)
BNL	• RHIC e cooling 2009 • eRHIC future	• Design and construct ampere class ERL cavity 700 MHz • Design, build and test laser photocathode gun at 1.3 GHz • Advanced design of ampere class avg current high brightness SC laser photocathode RF gun at 700 MHz • Advanced development stage diamond amplified photocathode • Ampere class ERL under construction	• Potential use of SRF gun for flat beam, low emittance polarized electrons for ILC • Potential use of high current gun for driver of a two beam accelerator	• 4M/yr (NP+ONR)	• Investment ? • ERL under construction	• 15 FTE • 2 PhD to date • 1 student / yr • R&D Profile 100% medium term	• Managed as group in Collider-Accelerator Dept. • Annual review by DoE, bi-annually by MAC	• Collaboration in ERL w. JLab, AES
ORNL /SNS	• SNS will generate high flux neutrons by Spallation at various energies for studies of a variety of materials. Beam on target for production of neutrons is expected in Spring 2006. • Ramping to 1.4 MW proton beam will occur by early 2009. • The energy of the 1 GeV protons is provided by a pulsed superconducting linac, the core components of which were designed, processed, assembled and tested at JLab. • Beam energy in excess of 950 MeV has been achieved and is being maintained routinely • Superconducting linac has been operated with beam both at 2.1K and 4.2 K. • A power upgrade to a 1.3 GeV beam with 3 MW power will be completed by 2012.	Installation of the superconducting cryomodules and all auxiliary components has been achieved in record time. • The testing and commissioning of the superconducting linac has been performed for the first time at 4.2 K. • Gradients in pulse mode exceeding the design values have been achieved thanks to JLab's construction and to SNS's personnel testing skills • Low Level RF systems in place for pulse operation at SNS are being used for other pulse SRF applications • High peak current operation (40 mA) has been achieved in pulse mode	• New experience in operating pulse SRF linacs • Better understanding of the fundamental and accessory limitations of pulsed SRF at various temperatures • Proof of principle of pulse SRF-based proton drivers • Highest energy "Proton" superconducting linac in operation	• In the process of developing the SRF program for Operations support and for the Power Upgrade	• High pulse power (up to 5 MW) 805 MHz test facility • Fundamental power coupler test stand • Planned: test cave for cryomodule testing and single cavity horizontal cryostat testing • Planned: large clean room for disassemble and repair of existing cryomodules • Planned: simple chemistry processing facility for restoring cavity performance in installed cryomodules	• In the process of defining the scope of the SRF program for Operations support and for the Power Upgrade	• Internal evaluation of the facility priorities • DOE semi annual review • DOE power Upgrade formal reviews • Accelerator Systems Advisory Committee Reviews	• ILC • TTC • Provide operating experience of RF, SRF and pulse power components and systems to the community

Laboratory Profiles cont'd

	Accelerator Facilities: Their Goals and time scales of achievement	Five Accomplishments	Impacts to HEP	Budget	Facilities	Effort *Near/Mid/Long-term	Management Oversight and Review	Service to Others
LANL	Not active at present. Significant investment in the past (1990-1994)) in the context of technology development and for Pion Linacs (PILAC) via Laboratory Directed Discretionary Funds (LDRD), (1994-2001) towards DOE APT/AAA and (2001-2005) towards high Tc material research.	• Set up lab; fabricated 3 GHz cavities; performed about 100 tests on five 3 GHz cavities. • Built 1st double-sided Ti heat (before iris-welding) treated 4 cell beta = 0.85 niobium cavity at 805 MHz for high gradient pion acceleration; • Built first reduced beta elliptical cavities at 700 MHz at beta = 0.5,0.62 and 0.8; built multicell elliptical cavities at 700 MHz; demonstrated the effects of proton irradiation on an operating SRF cavity, rebuilt and upgraded the SRF laboratory space, built and tested 1 1 MW cw power coupler; • Demonstrated surface resistance of MgB2 lower than niobium at 4K and Q0 dependence with magnetic field much less than YBCO and other high Tc materials.	SRF Technology development	1990-1992: approx. $1M/year by LDRD for technology development; 1992-1994: approx. $1M/year by LDRD for Pion Linac (PILAC); 1994-2001: funded by DOE APT/AAA funds at approx. $70M total over 7 years; 2001-2005: approx. $400 k total for high Tc material research for SRF cavity applications.	Cavity fabrication, processing and testing facilities and laboratory space.	No one is funded for SRF activities at present. There were 11 people (1 manager, 6 scientists/engineers, 1 designer and 3 technicians) who were directly involved in SRF activities in the past.	LANL management and DOE reviews in the past.	Contribution to SNS RF systems at ORNL.

Summary and Outlook

Relevance

SRF is needed in all programs: High Energy Physics, Nuclear Physics and Basic Sciences as evidenced in the 20-year DOE/NSF roadmap.

Context

- Global: ILC, ν -factory/Muon Colliders
- National: Proton Driver (Super Beams), CEBAF-II, RHIC-II, EIC/ELIC, RIA, SNS-II, ERL/FEL Light Sources

R&D Issues

- High Gradient *(long-term R&D)*
- Controlled Cavity Processing for achieving reliable and robust cavity gradient *(near-term immediate R&D)*
- High Current Capability *(mid-term R&D)*
- Value Engineering: Cost-effective Development of Cavity, Cryomodule, and RF Subsystems *(mid- and long-term R&D)*
- Superfluid 2K Cryogenics *(mid- and long-term R&D)*

Goals

- Predictable Production *(near-term, immediate)*
- Cost Reduction (in units of $1B for ILC)*(mid- and long-term)*
- Highest Technical Reach
  - > 50 MV/m for > 1 TeV cm. Energy ILC *(long-term)*
  - 1 Amp CW ERL (mid-term)

Needed Investments

Capital invested in the US to date is in excess of $60M, while the invested effort in long-term AARD based on available manpower is relatively lean, almost non-existent (see Lab Profile in this and Tigner's talk).

The long-term AARD must have an absolute component in that there is a threshold for progress which involves a minimum number of people in more than one institution, collaborating and competing. Manpower support for using the existing infrastructure to our advantage is at a point of competitive disadvantage compared to Europe. A modest investment in long-term AARD, together with a focused training program to build up the necessary skills base, is urgently needed at a few laboratories.

A focused HEP effort calls for an incremental investment integrated over a 5-year period, comparable to the already existing investment in order to consolidate the three levels of SRF capability beyond current US base effort (see Appendix 1 and Kephart's talk).

- *US does have a viable SRF enterprise albeit distributed. There needs to be better integration, consolidation and significant augmentation of infrastructure and skilled personnel.*
- *Balance between near-, mid- and long-term R&D must be established.*
- *Balance between ILC/GDE and other SRF initiatives must be carefully maintained.*

Scope

SRF scope in High Energy Physics will have to grow dramatically over time. Similarly, growth is expected in other areas such as in Nuclear Physics and Light Sources.

Needed Education/Training

Enrollment/graduation in SRF/ERL-related fields at JLab, Cornell, MSU and BNL have risen from 50% in the past to 75% currently, relative to all fields related to accelerator science and technology (Appendix 2). We must enhance our SRF education and training program by at least 100%.

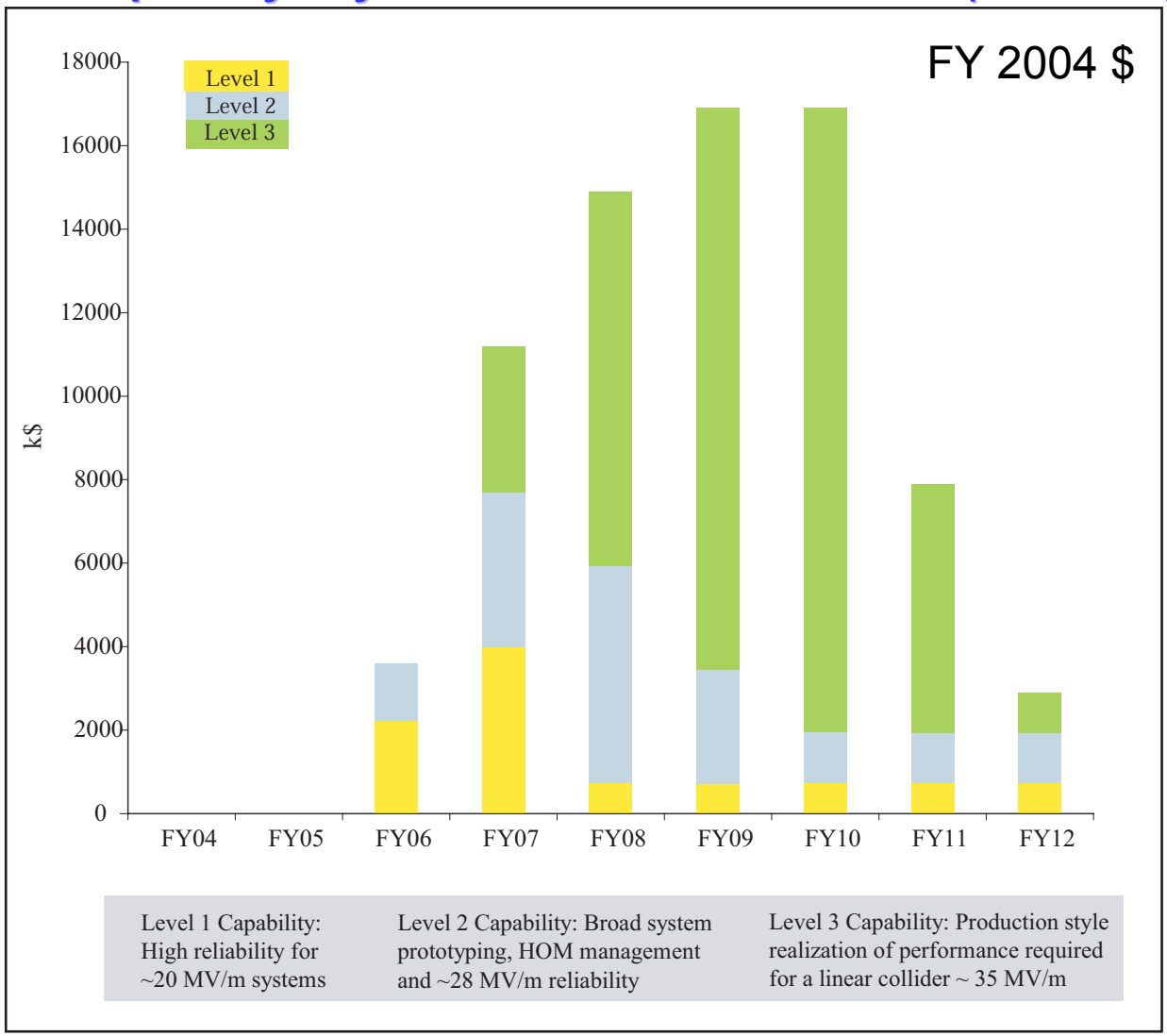
Stewardship

Critically dependent upon well-coordinated and managed Institutional collaborations through bi-lateral MOUs, centrally coordinated MOUs (e.g., ILC/GDE, TTC, SMTF, STF), grass-roots informal scientific collaborations and DOE/NSF/International Funding Agencies.

Appendix 1

Reference: White paper on "SRF Accelerator Science and Technology Center at Jefferson Lab" presented to Dr. Raymond Orbach, Director, DOE Office of Science, as part of Jefferson Lab DOE On-Site Institutional Management Review, 2004

JLab Assessment of Optimized Investments and Funding Profile Needed at the three levels of SRF capability beyond current US base effort (excluding production)



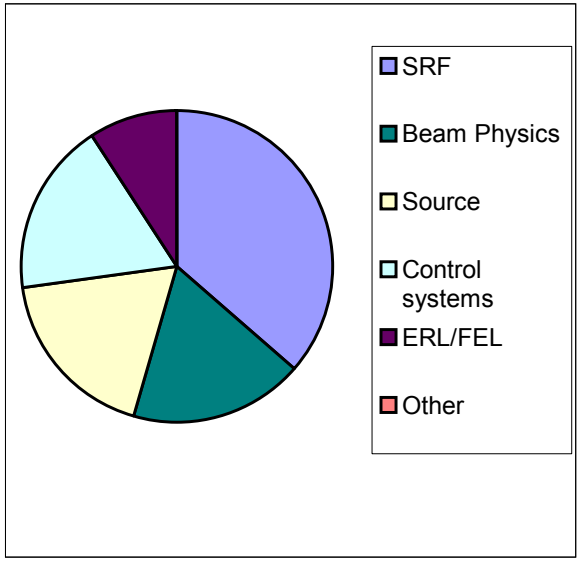
Appendix 2

Education/Training in SRF/ERL within the 20 Year Outlook (JLab, Cornell)

Jefferson Lab Graduate Program in Accelerator Science & Technology

Students who have graduated

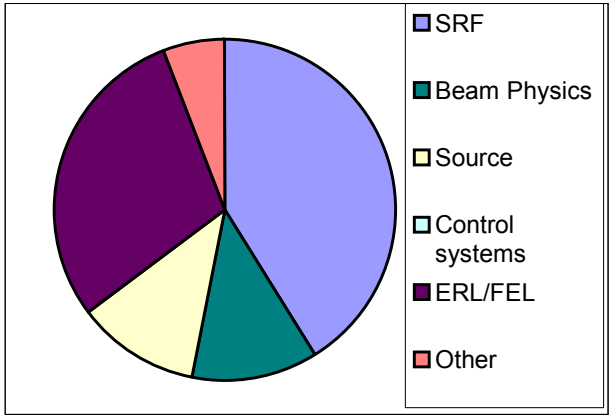
By Discipline	#Students
SRF	4
Beam Physics	2
Source	2
Control systems	2
ERL/FEL	1
Other (.magnet, secondary sources)	0



Past: Approximately 50% in SRF/ERL-related areas

Graduate Students presently enrolled

By Discipline	#Students
SRF	7
Beam Physics	2
Source	2
Control systems	0
ERL/FEL	5
Other (.magnets, secondary sources)	1



Current and future: Approximately 75% in SRF/ERL-related areas

PhD Theses Completed in SRF/ERL/Accelerator Research at JLab

★ •Nick Sereno (1994). Experimental Studies of Multipass Beam Breakup and Energy Recovery Using the CEBAF Injector Linac. U. Illinois, Urbana-Champaign.

•Zenghai Li (1995). Beam Dynamics in the CEBAF Superconducting Cavities. College of William and Mary.

•Mahesh Chowdhary (1996). Online System Identification for Control System Applications in Particle Accelerators. Old Dominion University.

•David Engwall (1998). High-Brightness Electron Beams from a DC, High-Voltage GaAs Photoemission Gun. U. Illinois, Urbana-Champaign.

•Philippe Piot (1999). High Brightness Electron Beam Diagnostics and their Applications to Beam Dynamics in a Superconducting Energy-Recovering Free-Electron Laser. Université Joseph Fourier Grenoble I, France.

•Joseph Grames (2000). Measurement of a Weak Polarization Sensitivity to the Beam Orbit of the CEBAF Accelerator. U. Illinois, Urbana-Champaign

•Raphael Akogyaram (2002). Basis Function Repetitive and Feedback Control with Application to a Particle Accelerator. Columbia University.

★ •Genfa Wu (2002). Energetic Deposition of Niobium Thin Film in Vacuum. Virginia Tech.

★ •Tong Wang (2002). Enhanced Field Emission Studies on Niobium Surfaces Relevant to High Field Superconducting Radio-Frequency Devices. Virginia Tech.

★ •David Smith (2004). Surface Analysis of acid treated SRF niobium cavities using SIMS and other surface analysis instruments. Virginia Commonwealth University.

★ •Gianluigi Ciovati (2005). Investigation of the superconducting properties of niobium radio-frequency cavities. Old Dominion University.

PhD Theses Completed in SRF Research at Cornell

- J Stimmel (80) Nb_3Sn for SRF Cavities
- K. Kraft (82)- Thermal Conductivity of Nb and Thermal Breakdown
- F. Palmer (88): Microwave Surface Residual Resistance
- J. Graber (93): High Power RF Processing of Field Emission
- J. Knobloch (95) Investigating Field Limitations in SRF Cavities with Temperature mapping
- G. Werner (04) Probing and Modeling RF Breakdown
- Present students: Olexandr Romanenko (New Materials), Grigori Eremeev (Q-slope), Walter Hartung Development of higher order mode absorbers for high luminosity storage ring srf cavities
- Master's Degrees:
- J. Shipman (AFM surface morphology), T. Hays: Nb3Sn Critical Field. L. Yang, Sputtering simulations

Year	# Degrees	
1994	1	Ph.D.
1995	1	Ph.D.
1996	1	Ph.D.
1997	0	Ph.D.
1998	1	Ph.D.
1999	1	Ph.D.
2000	1	Ph.D.
2001	0	Ph.D.
2002	3	Ph.D.
2003	0	Ph.D.
2004	1	M.S.
2005	1	Ph.D.

★ **SRF and ERL/FEL related thesis**

Appendix 3

Planned SC Facilities: SRF Developments Needed to Provide Efficient and Quality Beam for Science

	Low beam current	ERLs-high beam current with low net rf power	High beam current (10 - 1000 mA)
Low Energy	RIA 12 GeV CEBAF	EIC, ELIC ERL light sources	Super-B Factory Light Source Upgrades
High Energy	Linear Collider	eRHIC, RHIC-II	**Super Beams (μ, ν)**
Principal Challenge	Highest acceleration cheaply as possible	Acceleration plus strong HOM damping	RF coupling - Fundamental rf in and HOMs out
Chief Technical Development Requirements	**Higher gradient** - reliable 20, 28 > 35 MV/m		
	Higher Q_0 - to keep cryo plants affordable		
	RF controls for precision regulation and rf efficiency		
	Microphonic control to maximize rf efficiency		
		Feedback Beam rf	
		HOM power management output couplers	
			Broadband **rf absorbers**
			Input power couplers
			Lower frequencies → **larger assemblies**
	Cost minimization - system engineering and new technology development		
Critical Required Disciplines	**SRF Materials Science and Technology**		
	RF Controls and Microphonic Engineering		
		RF Structure Engineering	
	Cryogenic Mechanical and Production Engineering		

Level 1
Level 2
Level 3

Reference: White paper on "SRF Accelerator Science and Technology Center at Jefferson Lab" presented to Dr. Raymond Orbach, Director, DOE Office of Science, as part of Jefferson Lab DOE On-Site Institutional Management Review, 2004

Appendix 4

Superfluid 2K Cryogenics

Cryogenics Research and Development

- ✓ As a key support technology for many DOE and NSF research there has been a past historical basis of supporting cryogenics R+D to meet the needs of future research. Helium cryogenics is not the fully developed and mature technology as many may believe.
  - Strong supportive ties between industry and laboratories in identifying and developing the necessary technologies in advance
  - Much of the US based industrial helium plant engineering support and design capability is gone after the demise of the SSC. Example: Linde and Air Liquide have no helium plant design or engineering support in the US.
  - Today, helium plants represent a substantial capital and operating investment in a higher energy cost environment.
- ✓ The sucessful merger of three of the former US commercial plant engineering with experienced laboratory operations engineering created the staff at JLab which has continued the tradition of moving cryogenic technology forward, refining and modifying plants to meet laboratory and DOE needs. In recent years there has been an outreach program to industry and other laboratories to exchange technology developments.

Future Needed R+D

- Current Warm helium compressors represent >50% of the remaining inefficiencies for helium cryogenic plants. Need to reestablish the unfinished R+D work of the 80's in the area of internal volume ratio and optimized skid assembly. Has current (BNL, SNS, JLab) and future planned facility benefits
- For both large and small investigation facilities, there is a need to develop a standard 2K to 300K heat exchanger designs so that 2K refrigerators are commercially available instead of using less efficient larger 4K machines for 2K applications. (Have received industrial collaboration R+D interest with JLab)
- Substantial loss of helium gas appears to be a major cost for university research and small lab machines. Need for development of improved low pressure recovery systems when experiments have very low set relief pressure settings such as some current magnet designs

Appendix 5

JLAB/DESY Bench-marking

Reference: White paper on “SRF Accelerator Science and Technology Center at Jefferson Lab” presented to Dr. Raymond Orbach, Director, DOE Office of Science, as part of Jefferson Lab DOE On-Site Institutional Management Review, 2004

Table I
Qualitative assessments of needed skill sets, with DESY comparisons

Symbol key: -- (non-existent) + (weak initial entry)
* (modest capability) ** (healthy capability) *** (strong leadership capability)
bold (priority improvement area) *italic* (additional needed improvement)

	JLAB '04	DESY '04	*Ideal Desired SRF Capability at Level 3*
SCIENTIFIC			
SRF cavity performance integration and testing	*	***	***
Surface science – characterization analysis	*	*	**
RF accelerator physics	**	**	***
Low-temperature physics	+	+	*
User facility management	--	***	*
Beam physics, ex. BBU simulation	**	***	**
Specialty materials engineering – brazing, thermal, etc.	**	**	**
ENGINEERING			
Clean process engineering – assembly	--	**	***
Mechanical engineering – vibration isolation/management	--	--	***
RF controls: analog and digital	*	***	***
Diagnostic instrumentation and controls	*	***	***
Data management engineering	**	*	***
Vacuum engineering – materials and pumping	--	**	**
Commercialization interface	--	+	**
Quality assurance engineering	+	**	**
RF test engineering	*	**	**
System integration engineering	*	*	**
Clean process engineering – water and chemistry	--	**	*
Mechanical engineering – structure design and fabrication	**	**	**
Refractory metals fabrication engineering	*	*	*
TECHNICAL STAFF			
Wide range of technical implementation skills (e.g., electrical, electronic, rf, instrumentation, cryogenic, vacuum, electron beam welding, mechanical fabrication, QA-metrology, chemical process, clean room, surface analysis, equipment support, systems maintenance, chemical handling, mechanical and electrical assembly)	**	**	***

Table II

Facilities Matrix

Symbol key: -- (non-existent) + (weak initial entry)
* (modest capability) ** (healthy capability) *** (strong leadership capability)
bold (priority improvement area) *italic* (additional needed improvement)

FACILITIES MATRIX	JLAB '04	DESY '04	*Ideal Desired SRF Capability at Level 3*
RF structure development			
RF design codes	*	**	**
Mechanical structural and thermal design codes	*	*	**
RF structure bench measurement – tuning and HOM measurements	*	**	**
Cu structure prototyping	**	+	**
Speciality fabrication			
Clean acid parts etching	*	*	**
Brazing and sputtering systems	*	**	**
New process Nb deposition systems	+	+	**
Electron beam welder – clean vacuum	**	**	**
Nb metal fabrication tools	*	*	*
Cavity processing			
Cleanroom systems	*	***	***
Particulate-free UHV vacuum systems	--	***	**
Emerging cleaning techniques	--	*	**
Emerging surface treatment techniques (surface annealing, passivation, diffusion barrier construction, etc.)	+	+	**
Ultrasonic cleaning	*	**	**
PLC-controlled custom whole-cavity automated electropolishing system	*	***	**
High pressure water cavity rinsing system – particulate removal	*	**	**
Clean furnace Nb cavity baking – H degassing, solid state gettering	**	**	**
Hydrofluoric, nitric, phosphoric, sulfuric acid safe handling systems	**	**	***
Supporting safety systems	**	**	**
Hazardous waste management facilities	**	**	**
Semiconductor grade ultra-pure water system	**	**	**
PLC-controlled custom whole-cavity automated acid etching and rinsing	**	**	**

Table II continued

FACILITIES MATRIX	JLAB '04	DESY '04	*Ideal Desired SRF Capability at Level 3*
Cavity testing			
Clean assembly tooling and fixtures	*	**	***
Diagnostic instrumentation – thermometry, etc.	*	**	***
RF controls and data acquisition systems – structure dependent	**	*	***
Liquid helium supply and cryogen recovery/management system	**	**	***
He liquefaction capacity to support frequent cavity tests	***	**	***
Personnel protection systems supporting the above	**	**	**
Low magnetic field cryostats	**	**	**
He evacuation/pressure regulation system for temperature control 4.2—1.6 K in cryostats	***	**	***
Radiation shielding for potential x-rays from $l \times E$(MV/m) electrons	**	**	**
Materials and surface analysis			
Secondary ion mass spectrometry	+	--	**
Scanning Auger electron microscope	+	--	**
Scanning field emission microscope	*	--	**
Transmission electron microscope	+	--	*
XPS	--	+	**
Metallographic microscope	**	--	**
Scanning Electron microscope	**	--	**
Profilometer	**	+	**
Thermal conductivity measurement	*	**	*
Cryomodule cavity string assembly			
Particulate-free UHV vacuum systems	+	**	***
Ancillary parts cleaning	+	**	***
High-pressure water cavity rinsing system – particulate removal	*	***	***
Carefully designed cleanroom assembly tooling	+	*	**
Cleanroom for string assembly	*	**	***
Cryomodule component prototyping			
Horizontal cavity system testing	+	**	**
Cryomodule assembly			
Cryomodule assembly station	*	*	***
Parts receiving/acceptance/handling	+	+	**
Parts staging	+	**	**
Component welding area	*	*	**
Cavity string handling and transfer tooling	*	**	**

Table II continued

FACILITIES MATRIX	**JLAB '04**	**DESY '04**	***Ideal Desired SRF Capability at Level 3***
Cryomodule and rf controls testing – without beam			
RF controls and data acquisition systems – various frequencies, powers, and duty factors	**	**	***
Liquid helium supply and cryogen recovery/management system	**	**	***
He liquefaction capacity to support frequent cryomodule tests	**	**	***
Diagnostic instrumentation – thermometry, etc.	*	**	**
Low magnetic field environment	***	**	***
Radiation shielding for potential x-rays from $l \times E$(MV/m) electrons – (cave)	**	**	**
Personnel protection systems supporting the above	**	**	**
Data and Information management system			
Procedure/traveler/database integration (such as JLab's *Pansophy system)*	**	**	***
Operational SRF accelerators			
CEBAF	***	--	***
FEL	***	--	***
TTF		*	
HERA		*	