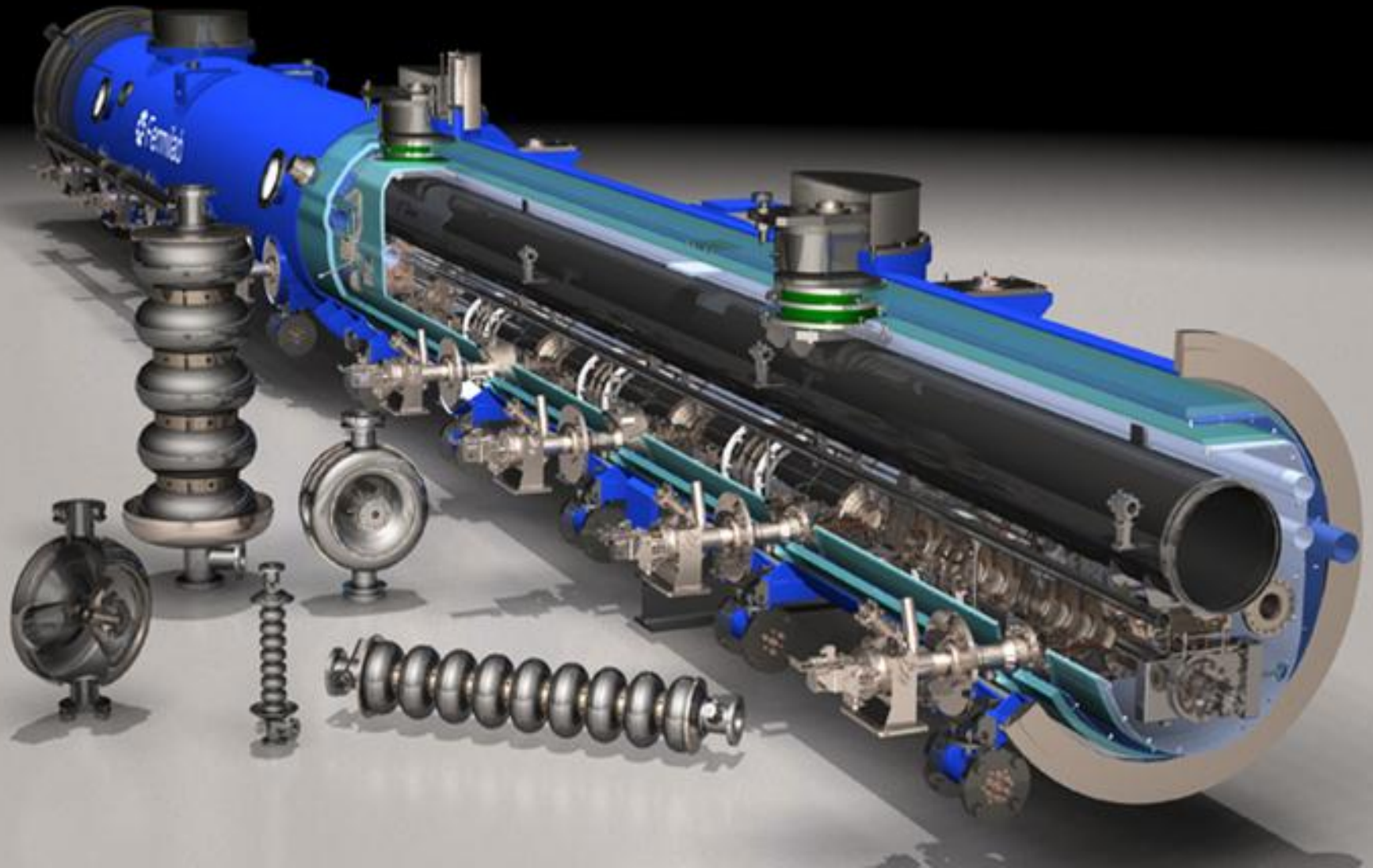


FNAL Superconducting RF Program



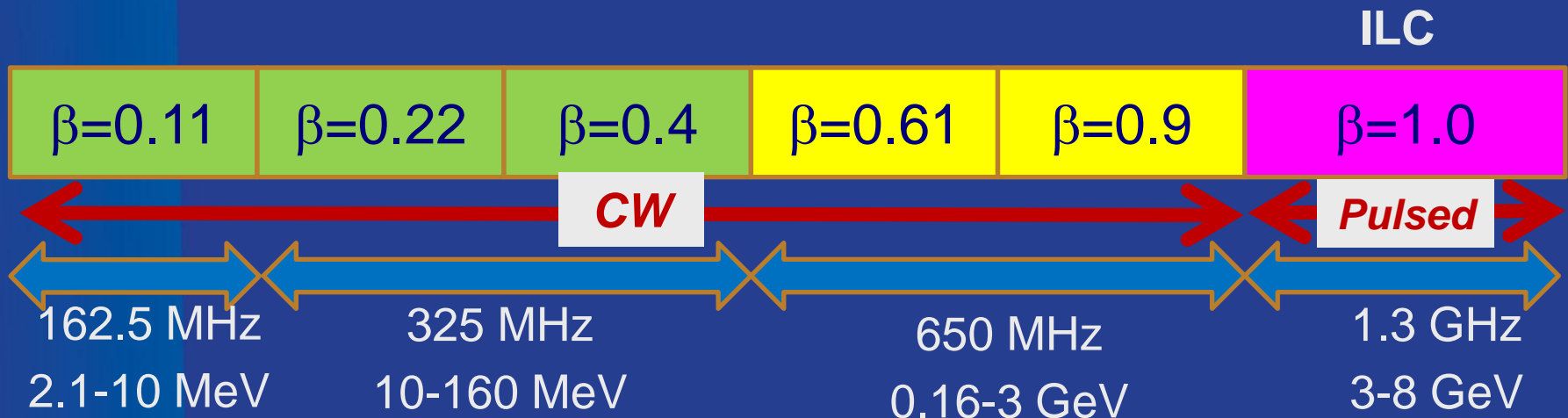
Goals of the Fermilab SRF Program

- Support the strategic goals of the U.S. HEP program
 - Energy frontier: International Linear Collider (& Muon Collider)
 - Intensity frontier: Project X
- Develop low-beta SRF cavities and cryomodules for the acceleration of high intensity Proton beams
 - Subharmonics of 1.3 GHz
 - SRF starting from very low beam energy of 2.1 MeV (New!)
- Develop $\beta=1$ SRF cavities and cryomodules for ILC and/or the Project X pulsed linac (3-8 GeV)
- Develop related SRF infrastructure and technology that can be applied to future Office of Science projects
 - Infrastructure and expertise at Fermilab and U.S. partners
 - U.S. Industrialization to permit fabrication of SRF projects

Context of SRF Activity at Fermilab

- The FNAL SRF effort ramped up substantially in 2006 in support of ILC R&D (thru at least FY12)
- Because of past emphasis on ILC R&D → There is substantial ongoing activity on 1.3 GHz technology
- Adoption of a 3 GeV CW linac followed by a 3-8 GeV pulsed linac for Project X has added new challenges
 - Need six different families of cavities optimized for changing velocity (β) of Protons
 - Four different frequencies (162.5, 325, 650, 1300 MHz)
 - Five of these cavities are completely new for Project X (vs 2 for SNS)
- The development of these cavities is a major new effort
- Fermilab SRF activities are managed as an integrated program to avoid duplications and insure efficiency

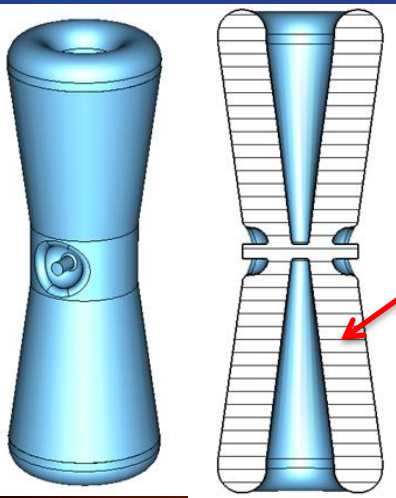
PX SRF Linac Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
HWR ($\beta_G=0.11$)	162.5	2.1-10	9 /6/1	Half Wave, solenoid
SSR1 ($\beta_G=0.22$)	325	10-42	16/8/ 2	Single Spoke, solenoid
SSR2 ($\beta_G=0.47$)	325	42-160	36/20/4	Single Spoke, solenoid
LB 650 ($\beta_G=0.61$)	650	160-460	42 /14/7	5-cell elliptical, doublet
HB 650 ($\beta_G=0.9$)	650	460-3000	152/19/19	5-cell elliptical, doublet
ILC 1.3 ($\beta_G=1.0$)	1300	3000-8000	224 /28 /28	9-cell elliptical, quad

Current Activities

- Project X:
 - 162.5 Cavity and Cryomodule Development (ANL)
 - 325 MHz Cavity & Cryomodule Development
 - 650 MHz Cavity & Cryomodule Development
- ILC and Project X
 - 1300 MHz: Cavity gradient improvement, CM development, and industrialization
 - 1300 MHz: SRF Infrastructure Operations
- Additional SRF Infrastructure Construction
- RF unit test facility at New Muon lab
- CryoModule Test Facility (CMTF)
- Design, Construction of Project X Injector Experiment (PXIE)



162.5 and 325 MHz Cavities

- Three designs cover the beta range $0.07 \rightarrow 0.52$
- **HWR ($\beta = 0.11$) Half Wave Resonator**
 - EM and Mechanical Design starting at ANL
 - Very similar to cavities & CM already manufactured by ANL
 - Optimize to achieve tight packing in PX front end



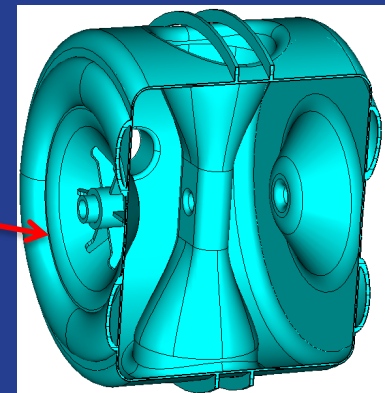
SSR1 ($\beta = 0.22$) Single Spoke Resonator

- Started under HINS program and is therefore more advanced
- Two prototypes have been fabricated by industry, processed in collaboration with ANL, and tested at Fermilab
- Two cavities in fabrication at IUAC-Delhi (Fall 2011)
- Ten cavities in fabrication by US industry (4 have arrived)
- One cavity dressed with He vessel, coupler tuner
- Tests in progress (next slides)

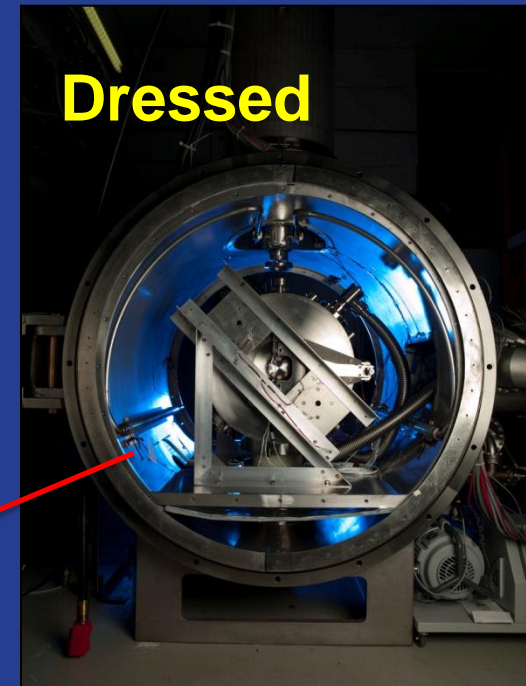


SSR2($\beta = 0.47$)

- EM design complete
- Awaiting Mechanical Design
- Prototype in FY12-FY13



New 325 MHz Test Capabilities Developed

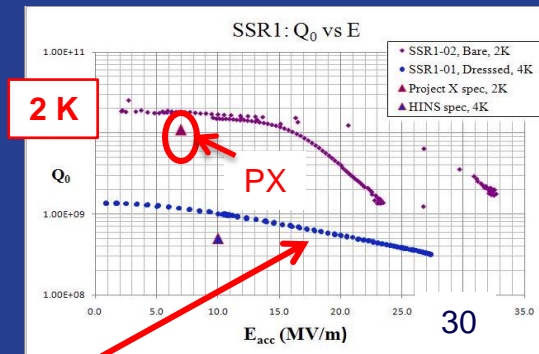


SSR-1 prototypes were tested in the VTS-1 vertical dewar (normally used for 1.3 GHz cavity testing) with the addition of new electronics and tooling.

Spoke Cavity Test Cryostat completed and commissioned.

Enables 4 K testing of “dressed” 325 MHz single-spoke resonators including RF couplers, tuners, and magnetic shielding

Upgrades for 1.8 K operation in process



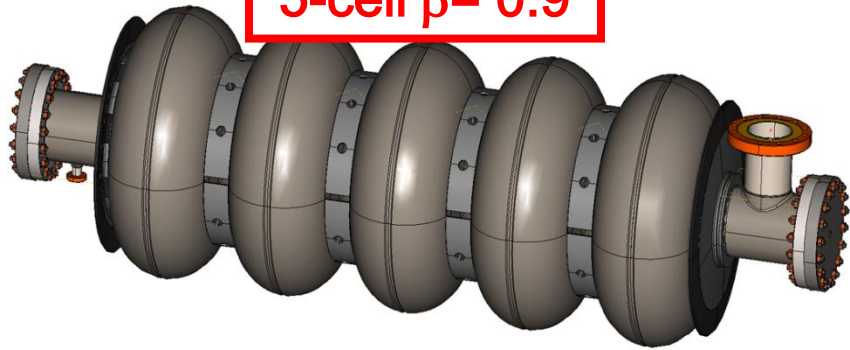
Dressed cavity at 4.8K

650 MHz Electromagnetic Cavity Design

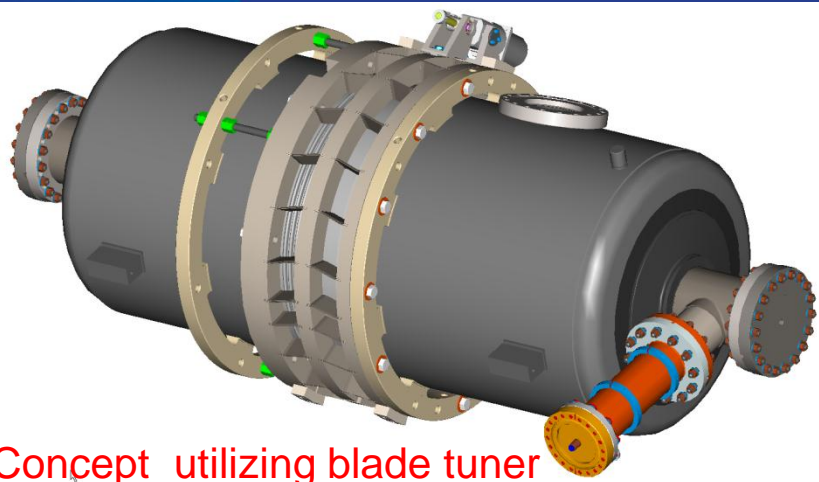
$\beta = 0.6$ & 0.9 Five-Cell Cavities is Complete

- Cavity prototypes under construction

5-cell $\beta = 0.9$

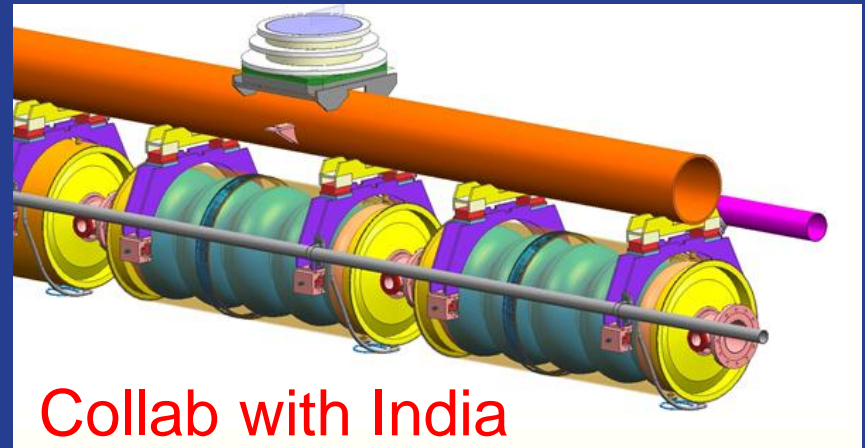
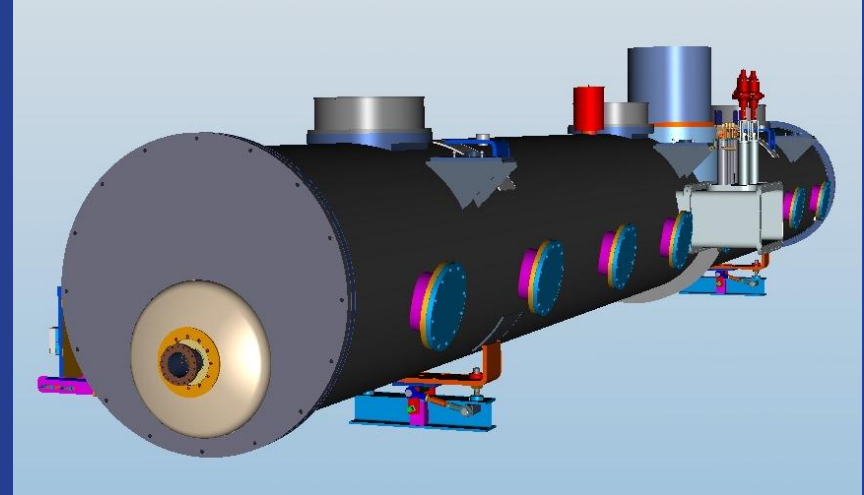


- Stiffening rings located to minimize dF/dP while maintaining tunability



Concept utilizing blade tuner

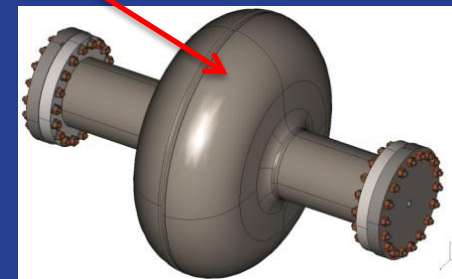
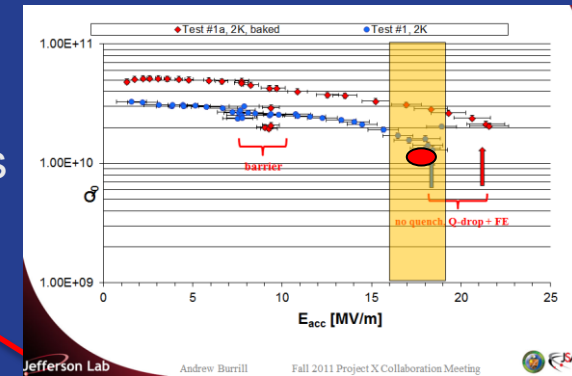
- CW CM conceptual design advanced
 - stand-alone 8-cavity cryomodule
 - Overall length: ~ 12 m, 48 " O.D.



Collab with India

650 MHz Cavity Prototypes

- **Single-cell designs complete:** for $\beta = 0.6$ & 0.9 cavities
- **Prototypes fabricated:**
 - Single-cell $\beta = 0.6$: 2 prototypes@JLab, meet PX goals
-6 more ordered industry
 - Single-cell $\beta = 0.9$: 5 cavities ordered from industry
 - Prototypes at both β are also being fabricated in India
 - Two 5-cell $\beta = 0.9$ cavities ordered from industry
- **Infrastructure modifications:** for 650 MHz in process
 - FNAL: Vertical Test Stand: Electronics, amplifier, tooling
 - FNAL: Cavity handling & HPR tooling, etc.
 - FNAL: Optical inspection system modifications
 - ANL: New electro-polishing tool
 - Industry: EP/BCP capability in US industry



1300 MHz Development for ILC and PX

- **Goals:** ILC SRF goals remain
 - S0 >35 MV/m bare cavities
 - S1 31.5 MV/m dressed cavities in a ILC Cryomodule
 - S2 Beam test of full ILC RF unit (CM, klystron, modulator)
 - Build and test ~ 1 CM/yr
- All of this will benefit the 3-8 GeV pulsed linac for Project X
- **Accomplishments:**
 - Excellent progress on gradient improvement
 - ANL/FNAL EP facility: world class throughput & yield
 - 19 Dressed cavities, HTS tests in progress for CM2
 - Parts for 4 more 1.3 GHz cryomodules (ARRA funds)
 - Cost reduction (e.g. tumbling vs. EP, & cavity repair.)
- Excellent progress on all of these
- **CM1 cold and under test at NML (All 8 cavities powered)**
- **CM2 nearly complete**

Current 1300 MHz cavity status

# ordered	90
# received	50
# processed	43
# vertically tested	42
# dressed	19
# horizontally tested	14
# CM2 qualified	8

- Full suite of facilities in use
- New vendors being developed

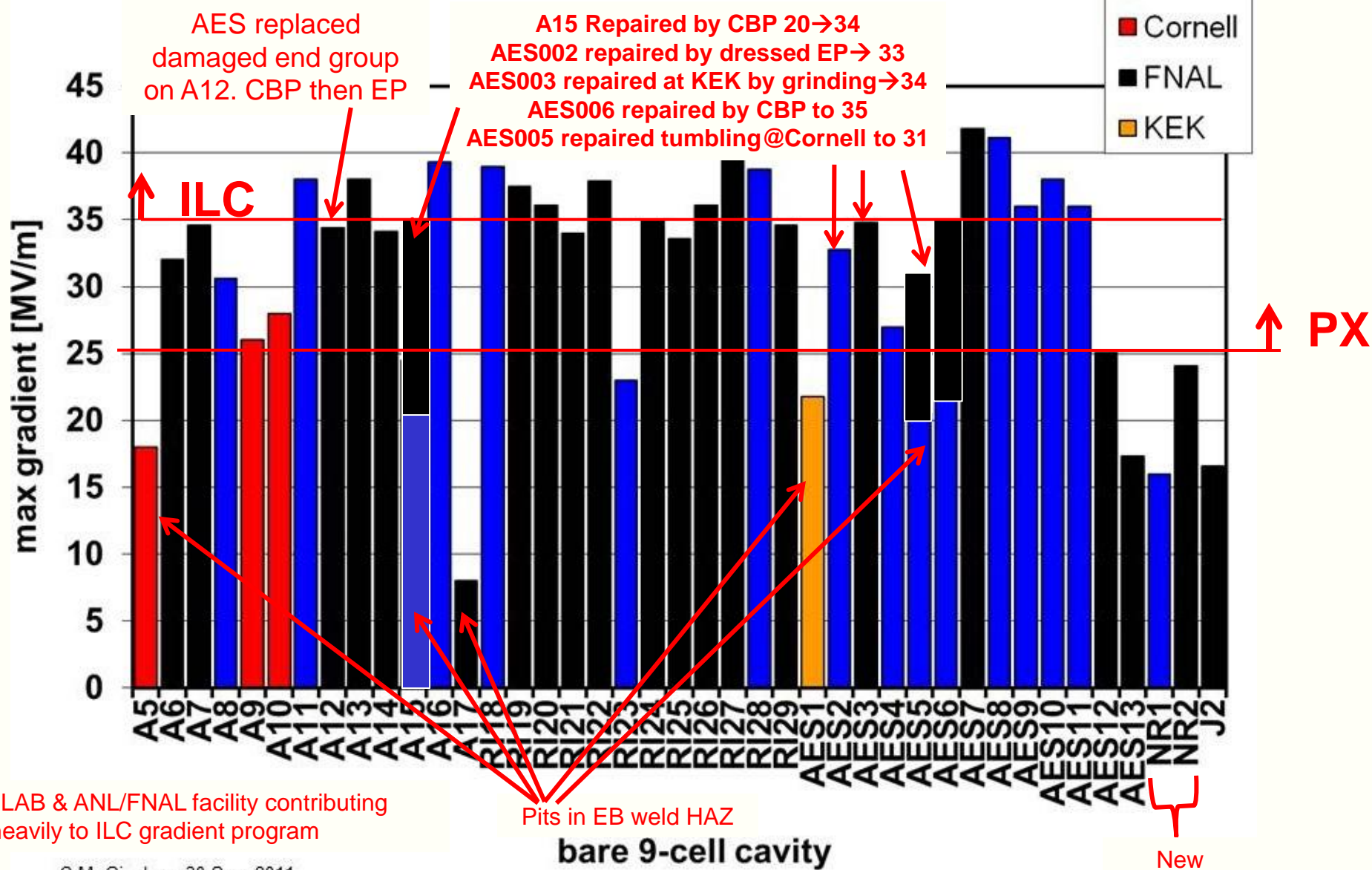


Dressed cavities in CAF

Cryomodule 2: cold mass parts from Europe in hand, 8 dressed cavities tested >35 MV/M, string assembly

**U.S. built ILC/PX Cryomodule Parts
CM 3, 4, 5, 6 for NML in hand,
funded by ARRA**

Americas 9-cell Cavities



C.M. Ginsburg 30.Sep. 2011

FNAL SRF Infrastructure

Goals:

- Build generic SRF infrastructure at FNAL
 - Particularly large cryogenic & RF systems, cavity & cryomodule assembly and test facilities, etc. that are hard for industry to provide
- Develop SRF capability in U.S. Industry

Accomplishments:

- Vertical test stands (VTS1) fully operational, VTS 2/3 dewars delivered installation in progress
- Horizontal Test Stand (HTS1): fully operational
 - Tests 1300 MHz dressed cavities for CM's, tuner studies, LLRF, etc
 - HTS-2: Design in collab with India (2 dressed 650/1300 CW cavities)
- ANL/FNAL joint cavity processing facility (EP, BCP, HPR, clean rooms)
- Cryomodule Assembly Facility & other infrastructure
- Excellent progress on NML and CMTF (slides)

New FNAL SRF infrastructure



VTS



VTS



Cavity tuning
machine



HTS



String Assembly



MP9 Clean Room



Final Assembly

VTS2
Dewar



RDK, US-UK Workshop, Jan 2012



New Vacuum Oven
for 1300 MHz

ANL/ FNAL cavity processing infrastructure



EP tool for 1300 MHz at ANL



New EP tool for $\frac{1}{4}$ wave and 650 MHz cavities at ANL



HPR and clean Rooms



New EP tool at FNAL



New Vacuum Oven for 650 MHz + SSR

FNAL CBP Machine

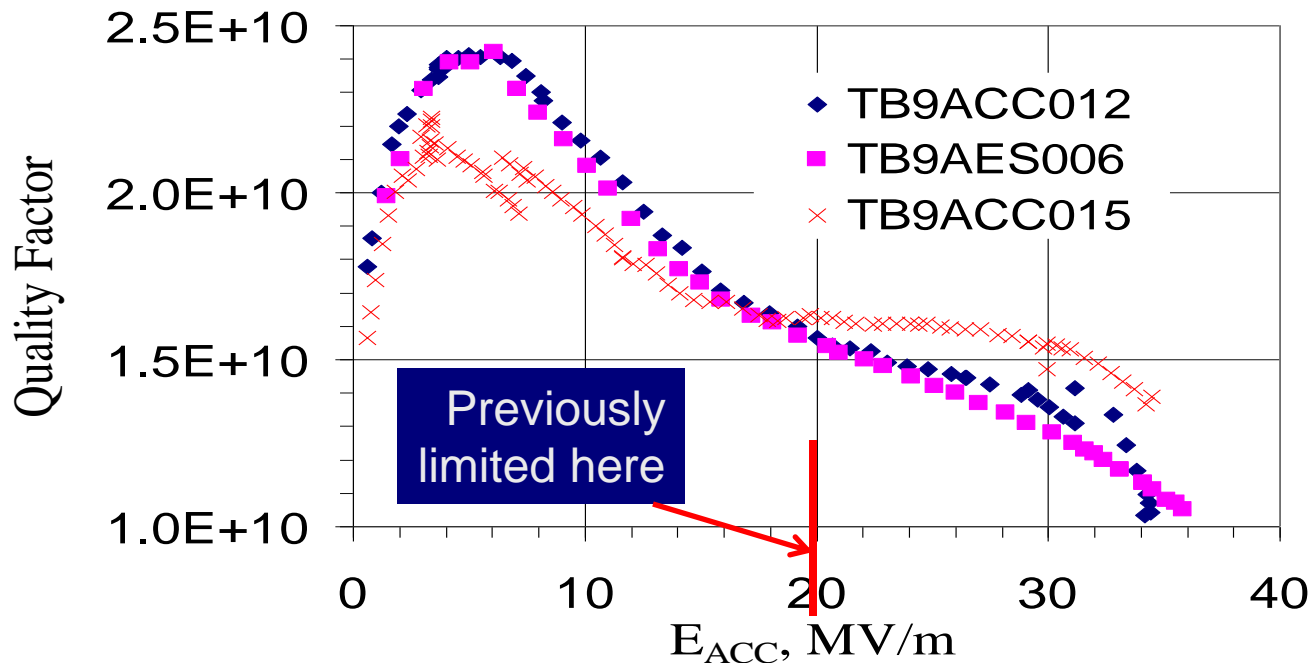


C. Cooper Recipe Media

Tumbles 2 cavities/run, 2 complete cycles/week



9-Cell Cavity Results – CBP Repairs



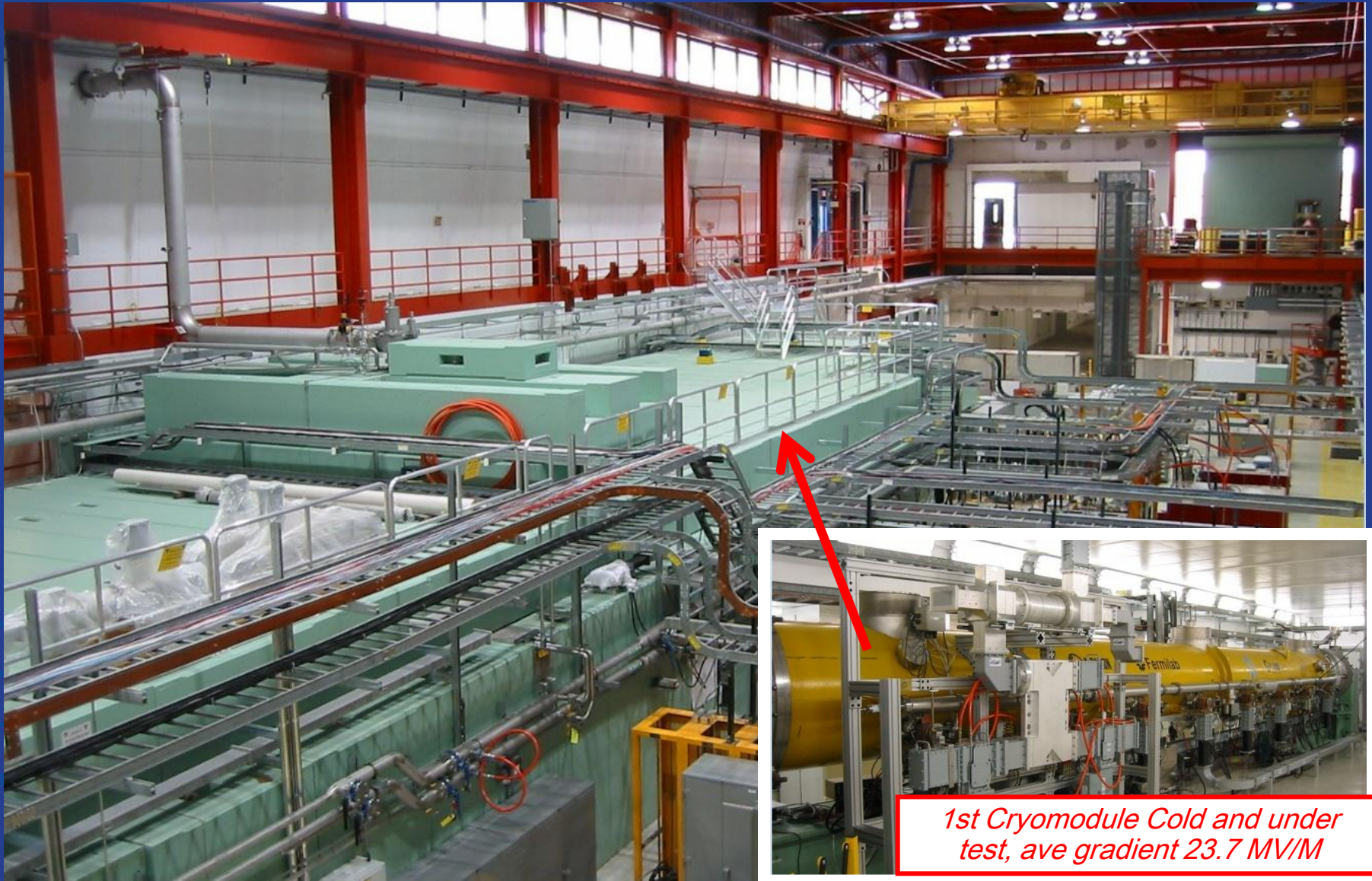
ACC015
Before CBP



After CBP and 40
microns EP – Pit
completely removed

- Break through !
- Demonstrated cavity gradients > 35 MV/M
- Drastic reductions in acid use.
- Demonstrated as a cavity repair method.

NML: RF Unit Test Facility

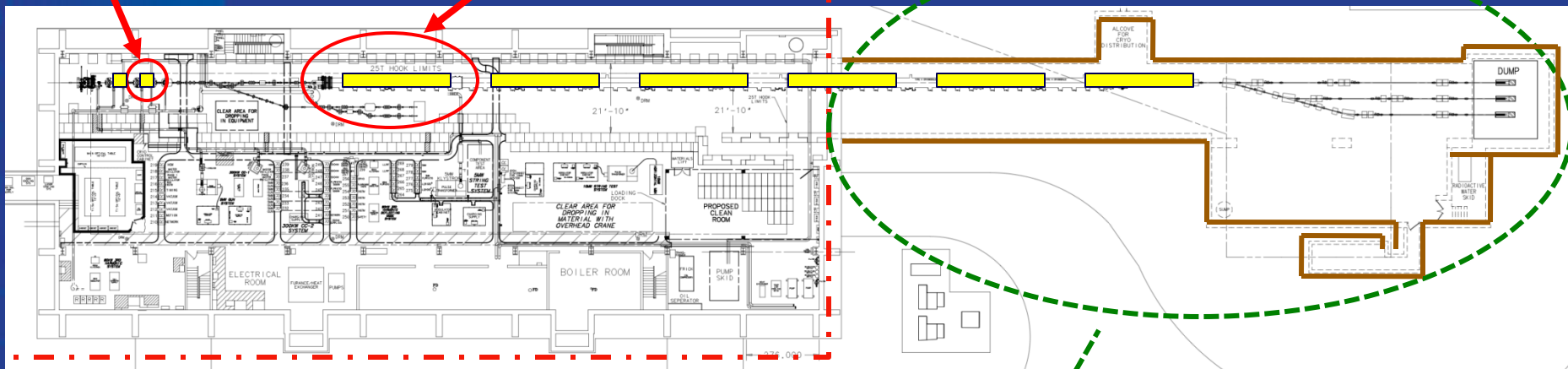


NML Status and Expansion

Capture Cavity II operational

CM1: cold and operational

CM2: Will swap for higher performance CM in Feb



Phase 1 NML Building

New Underground Tunnel Expansion

(Space for up to 6 Cryomodules (2 RF Units), AARD Test Beam Lines)
Civil construction complete (doubles tunnel length to 160 M)

New NML Buildings (ARRA funded)



**New Cryomodule
Test Facility**

New 600 W 1.8 K refrigerator
(under fabrication in industry)
will be located in CMTF bldg



Compressor building

Integrated SRF Schedule - Cryomodules

U.S. Fiscal Year	2008	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16
1.3 GHz									
CM1 (Type III+)		Omnibus Delay	CM fab	Install CM	CM1 Test	Rework?	?		
CM2 (Type III+)			Order Cav & CM Parts	Process & VTS/Dress/HTS	CM fab swap	swap?			
CM3 (Type IV)			Design	Order Cav & CM Parts		CM fab	install	ILC S2 test	also supports AAR
CM4 (Type 2/5/8 ILC or PX)						CM fab			
CM5 (Type 2/5/8 ILC or PX)							CM fab	test in CMTF	swap? PX RF Unit test
CM6 (Type 2/5/8 ILC or PX)							CM fab	test in CMTF	swap?
NML Extension Building			Design	Construction					
NML Beam					Move injector/install beam components	Beam Available to RF Unit test except during installation periods			
CMTF Building			Design	Construction					
650 MHz									Project X construct
Single Cell Design & Prototype				Prototypes	Process & VTS				
LE 650 five cell Design & Prototype					Industry Prototypes (4)		Industry Prototypes (10)	Process & VTS/Dress/HTS	LE 650 ready
HE 650 five cell Design & Prototype				Industry Prototypes (2+ 2)	Process & Test (ANL/FNAL)	Industry Prototypes (10)	Process & VTS/Dress/HTS	HE 650 ready	
HE_650_CM1				Concept Design	Design	Order 650 CM Parts		650 CM Ass'y	HE 650 CM Test
325 MHz									
SSR1 Design & Prototype			Procurement (14 in progress)		Process & VTS/Dress/STF	SSR1 ready	Process & VTS/Dress/STF		
SSR2 Design & Prototype					Design	Prototype(2)	Process & VTS/Dress/STF	SSR2 ready	
CM325_SSR1_proto CM				Concept Design	Design	Order 325 CM Parts	Process & Test (as required)	325 CM Ass'y	Test @ PXIE
162.5 MHZ					Design	Proto cavities	Process & Test (as required)	Order cav & CM Parts	162 CM Ass'y
									HWR CM Test @ PXIE

Summary

- SRF program at FNAL supports both ILC & Project X strategic goals
 - Demonstrated world class performance of 1300 MHz cavities and CM
 - RF unit test facility and ASTA @NML will be a powerful new asset
 - Developing additional 162.5, 325, & 650 MHz cavity and cryomodule designs in support of Project X
- Application of SRF to the low energy extreme of 2.1 MeV is a new and significant development in high intensity hadron linacs
 - Project X Injector Experiment (PXIE) is a major new thrust
- Program leverages existing FNAL infrastructure (bldgs, cryo, etc)
 - Augmented with SRF and ARRA infrastructure funds
 - Lots of infrastructure is now in operation and is being used effectively
- Significant effort to transfer SRF technology to U.S. Industry
- Excellent team in place with growing SRF expertise

Collaborations (~20 MOU's)

- ANL: EP development and cavity processing
- Cornell: Cavity processing & test, materials R&D
- DESY: 3.9 GHz, cryomodule kit, FLASH
- Dubna: cavity development, bimetallic joints
- KEK: Cavity R&D, ATF II
- MSU: Cavity cost reduction, hydro-form, TIG
- TJNL: EP cavity processing and test, PX cavities
- INFN: tuners, HTS, NML gun cathodes
- TRIUMF: Vendor development (PAVAC)
- SLAC: RF power, klystrons, couplers
- CERN, DESY, KEK, INFN, etc: Type IV CM design
- BARC, RRCAT, IUAC, VECC (India) CM design, cavities, infrastructure
- China: Peking U, IHEP, cavity development (developing)
- UC,NW,NHMFL, UN Reno, Cornell, DESY, KEK...: Materials R&D
- **LBNL: NGLS ???**

Integrated SRF Schedule - Infrastructure

U.S. Fiscal Year	2008	FY09	FY10	FY11	FY12	FY13	FY14	FY15
ANL/FNAL cavity handling upgrades	Omnibus Delay				650	Upgrade Complete		
650 MHz VTS-1 Upgrade					650	Upgrade Complete		
CAF CM Assembly Upgrade		1300 Upgrade Complete				325 Upgrade Complete	650 Upgrade Complete	
650 MHz dressing CAF Upgrade					650 MHz	Upgrade Complete		
VTS 2 & 3 Upgrade		VTS2/3 Procure		VTS 2	VTS3	VTS 2/3 Complete		
HTS 2 cryostat			Design		Procure India		HTS2 Complete	
HTS 2 cave, cryo dist				Design	Procure			
NML Injector & BL		Design	Procure		Install & commission		NML Beam ava	
NML Refrigerator			Design	Procurement		install & commissio	NML 500 W superfluid F	
NML Cryo Distribution System							CDS Complete	
NML SLAC Refrigerator			Design SLAC Ref Interface (as req'd)	refurbish	Install & commission	SLAC Refrig Oper		
CMTF CM Test Stand (1.3 GHz)					Procure India		1.3 CMTS Complete	
650 MHz CM Test Stand					Procure India		650 CMTS Complete	
CMTF Cryo Distribution System					Procure India		CMTF Dist Complete	
MDB Spoke Test Facility 2k Upgrade				325	325 HTS complete			Des/add 4th Refrig
325 MHz CM Test Stand @ NML						Procure FNAL		325 CM TS Complete
AES 1300-650 EP / 325 BCP facility			Design	Procurement		EP/BCP ready		
JLAB VTS cryo upgrade		JLab Upg Des	Procure		Upgrade Complete			
ANL EP/BCP Upgrade		ANL 1300 EP ready Oper	Design 650 EP	Procure		650 EP Ready		

Shows only remaining items, many completed items are now not shown (VTS-1, HTS, STF, CAF)