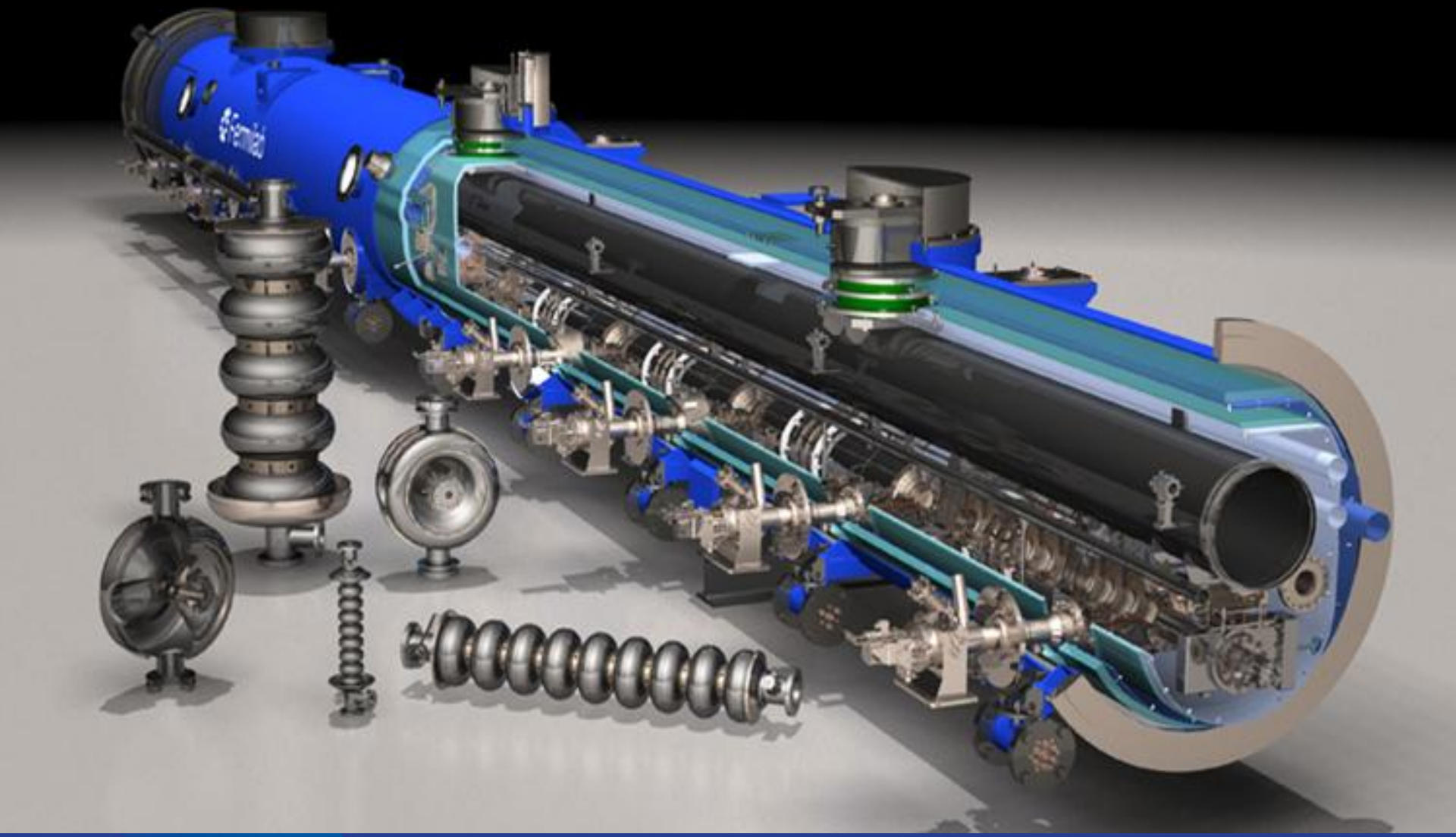
FNAL Superconducting RF Program



U.S. DEPARTMENT OF ENERGY

Bob Kephart

Fermilab

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 β=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

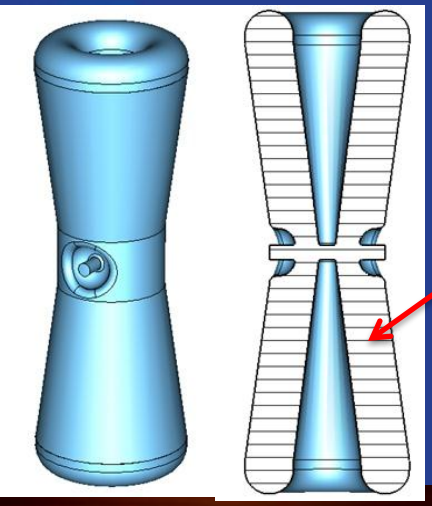
PX SRF Linac Technology Map

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

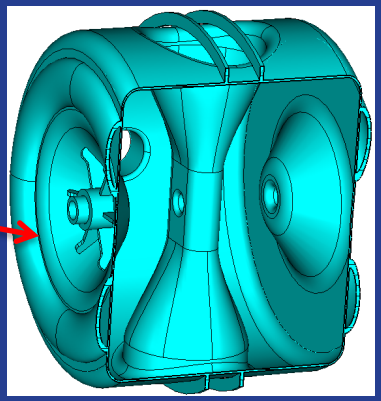
162.5 and 325 MHz Cavities



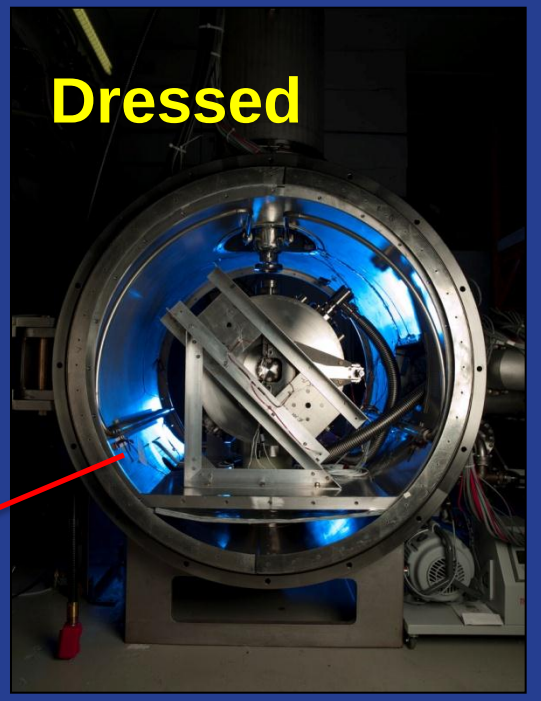
- Three designs cover the beta range 0.07 → 0.52
- **HWR (β = 0.11) Half Wave Resonator**
  - EM and Mechanical Design starting at ANL
  - Very similar to cavities & CM already manufactured by ANL
  - Optimize to achieve tight packing in PX front end

- **SSR1 (β = 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(β = 0.47)**
  - EM design complete
  - Awaiting Mechanical Design
  - Prototype in FY12-FY13



New 325 MHz Test Capabilities Developed

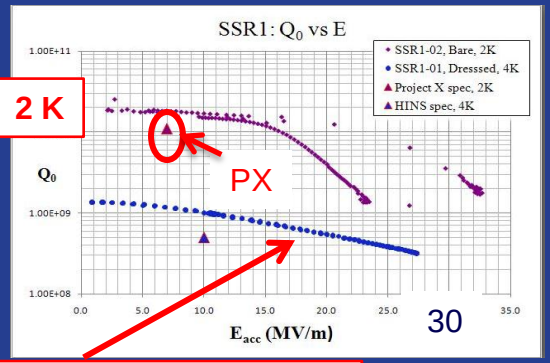


SSR-1 prototypes were tested in the VTS-1 vertical dewar (normally used for 1.3 GHz cavity testing) with the addition of new electronics and tooling.

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

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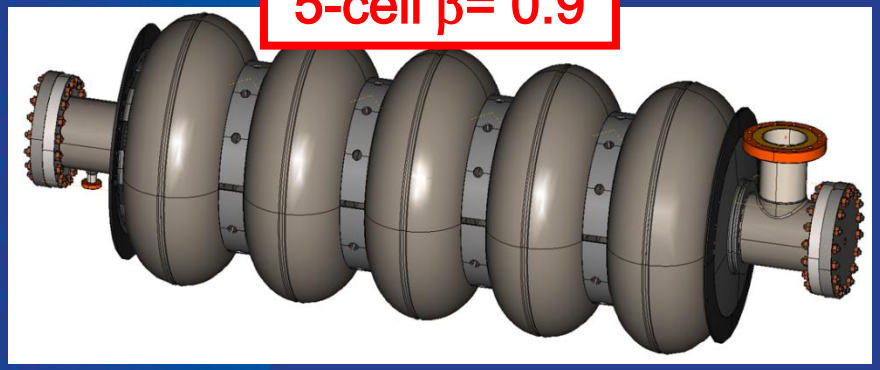
650 MHz Electromagnetic Cavity Design

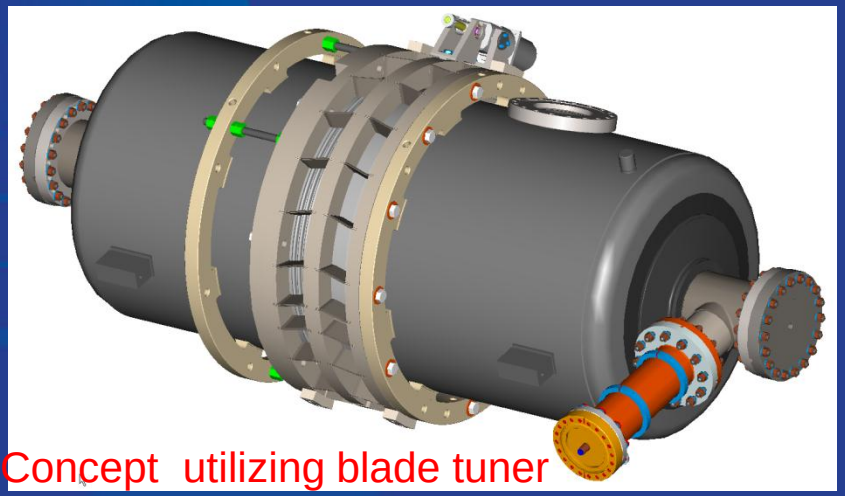
β = 0.6 & 0.9 Five-Cell Cavities is Complete

- Cavity prototypes under construction

5-cell β= 0.9

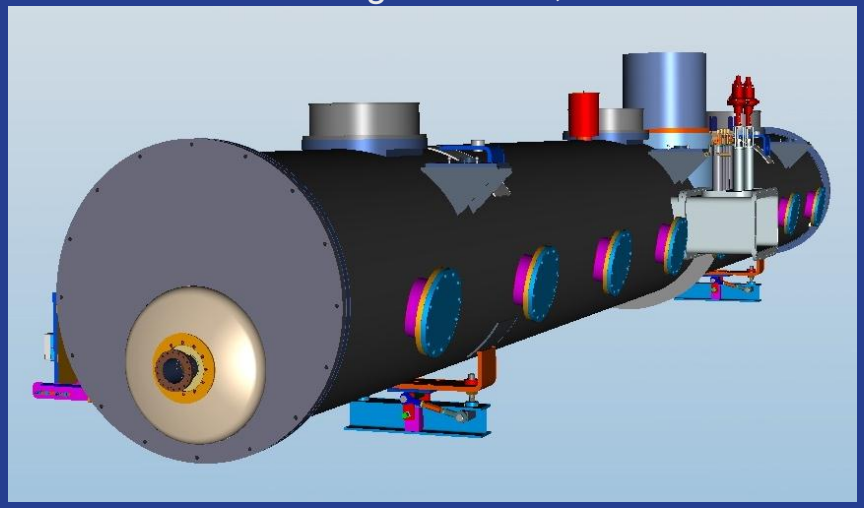


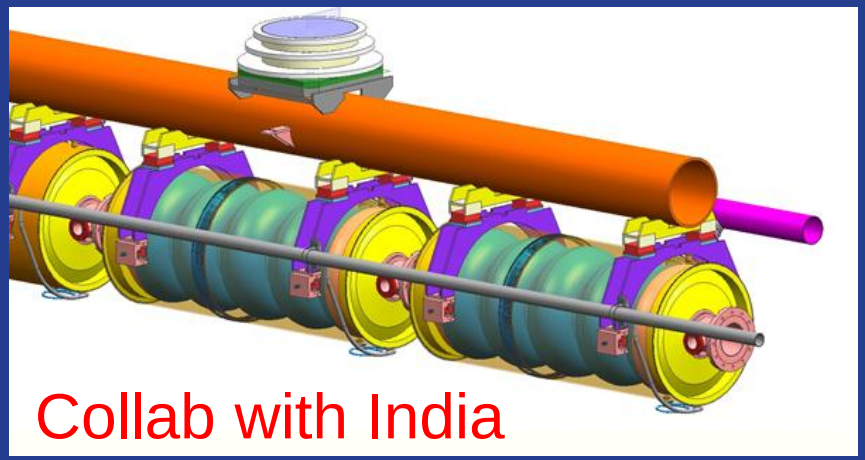
- Stiffening rings located to minimize dF/dP while maintaining tunability



Concept utilizing blade tuner

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

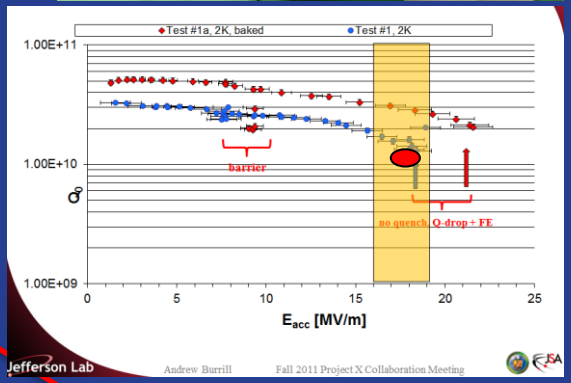


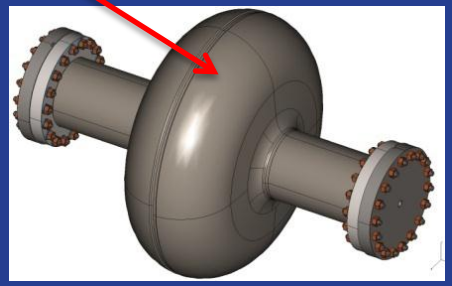


Collab with India

650 MHz Cavity Prototypes

- Single-cell designs complete: for β = 0.6 & 0.9 cavities
- Prototypes fabricated:
  - Single-cell β = 0.6: 2 prototypes@JLab, meet PX goals
    -6 more ordered industry
  - Single-cell β = 0.9: 5 cavities ordered from industry
  - Prototypes at both β are also being fabricated in India
  - Two 5-cell β = 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





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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

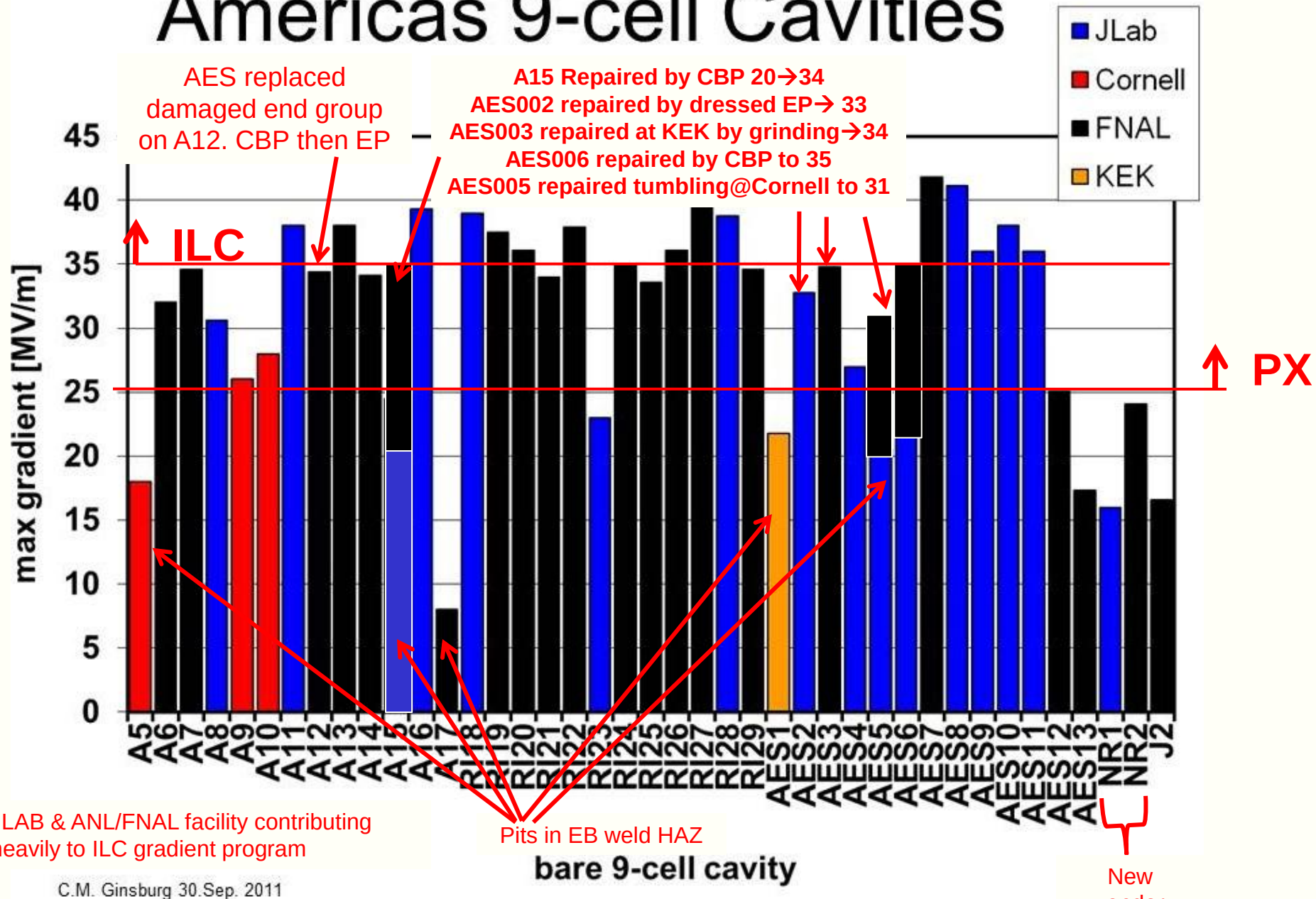
Dressed cavities in CAF

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

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



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

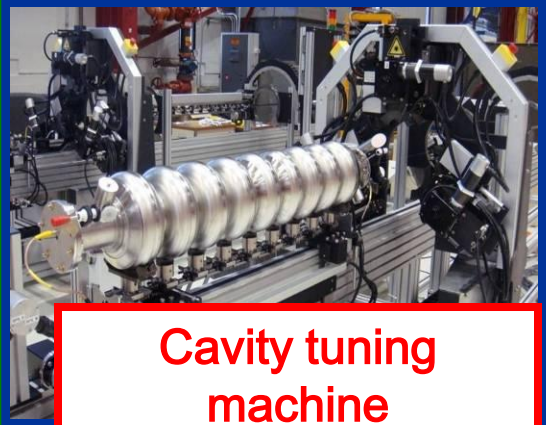
Accomplishments:

- 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

New Vacuum Oven for 1300 MHz

ANL/ FNAL cavity processing infrastructure

EP tool for 1300 MHz at ANL

New EP tool for ¼ wave and 650 MHz cavities at ANL

HPR and clean Rooms

New EP tool at FNAL

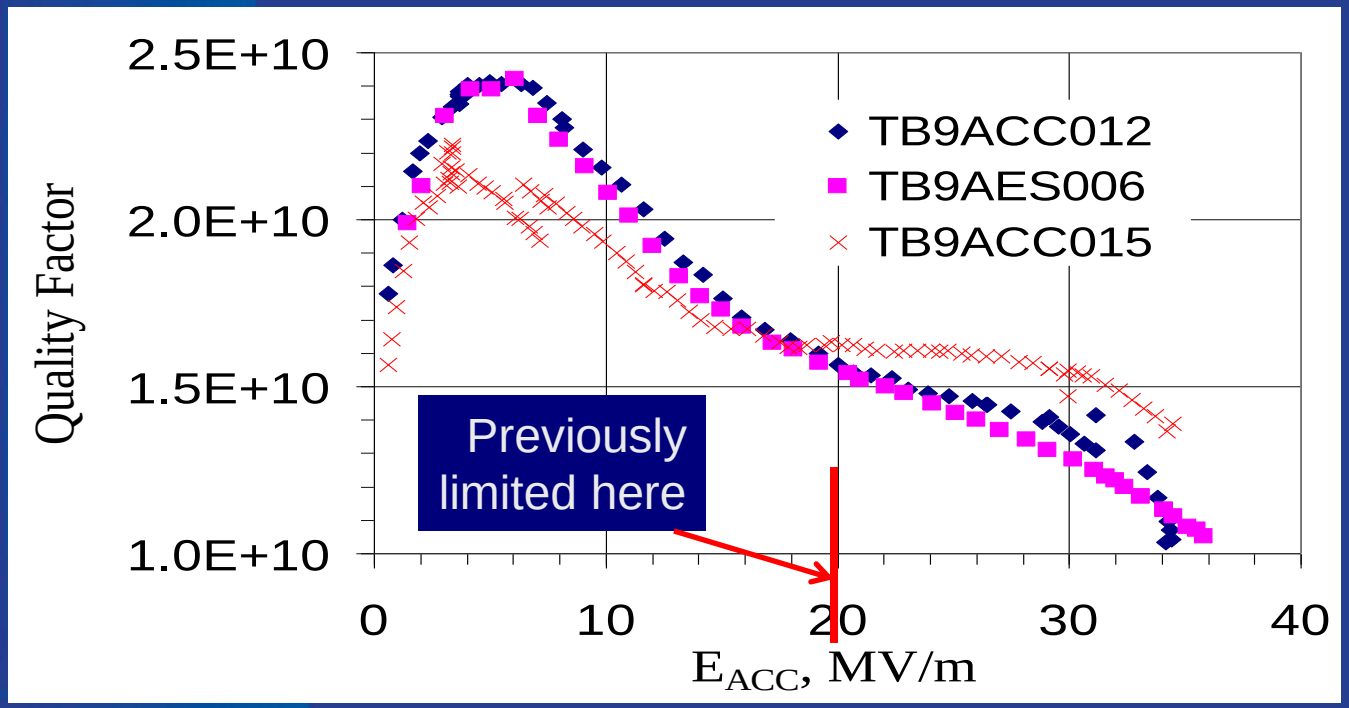
New Vacuum Oven for 650 MHz + SSR

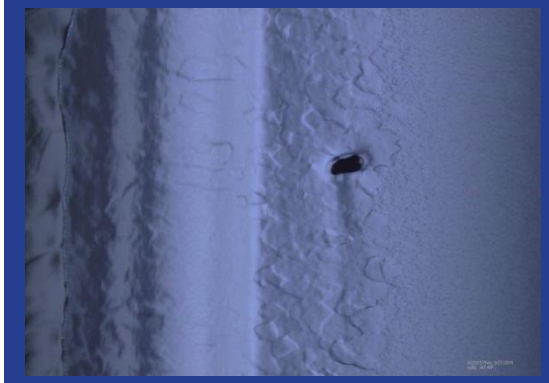
FNAL CBP Machine

C. Cooper Recipe Media

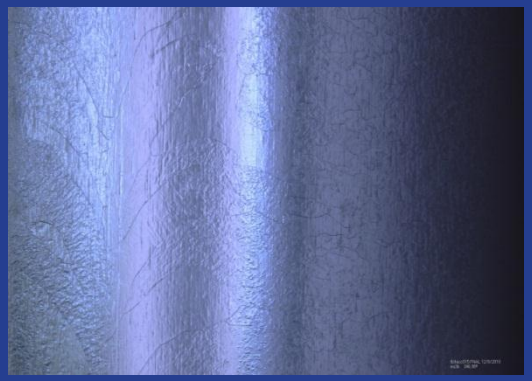
Tumbles 2 cavities/run, 2 complete cycles/week

9-Cell Cavity Results – CBP Repairs





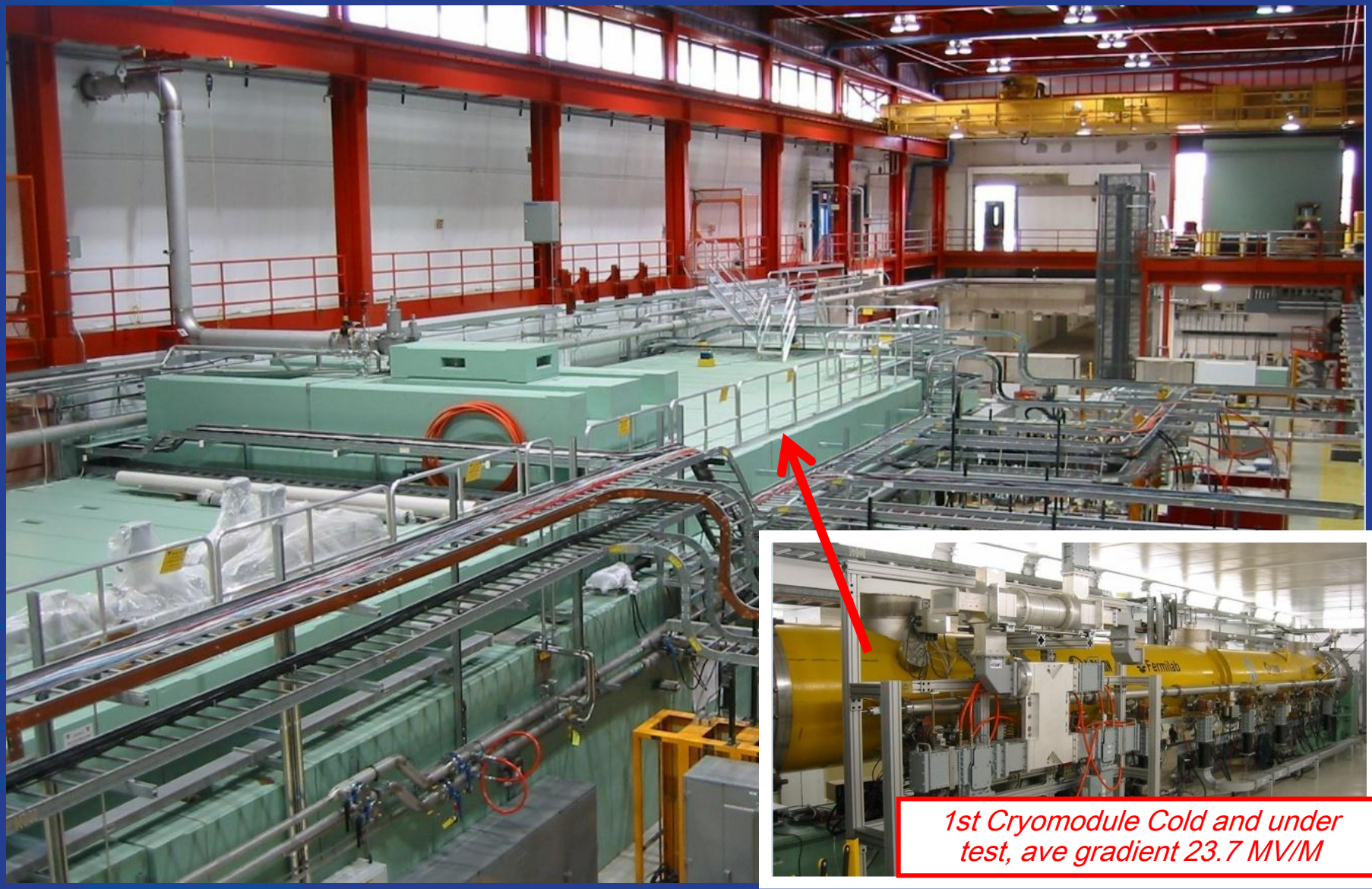
ACC015
Before CBP



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



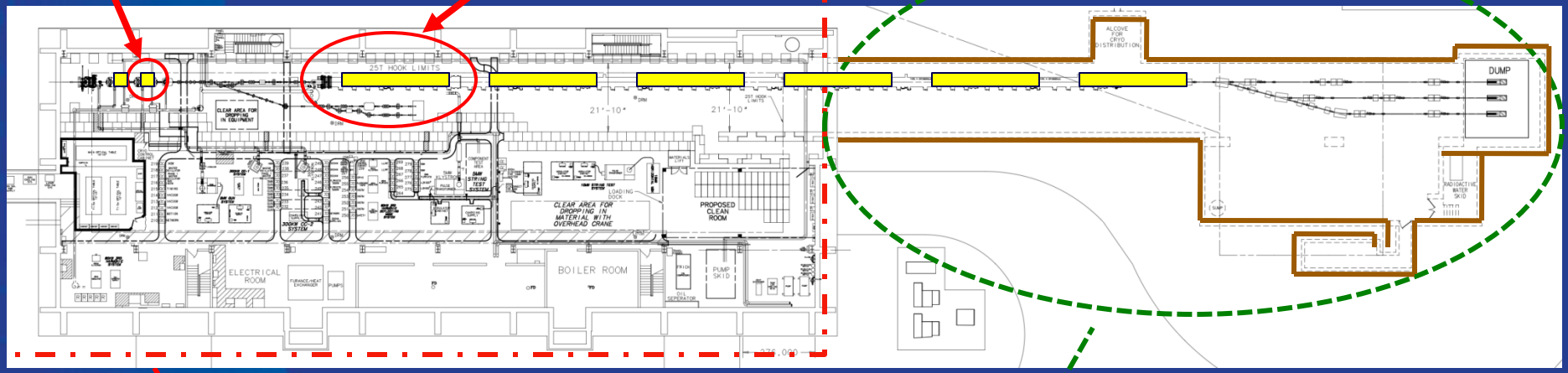
1st Cryomodule Cold and under test, ave gradient 23.7 MV/M

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)

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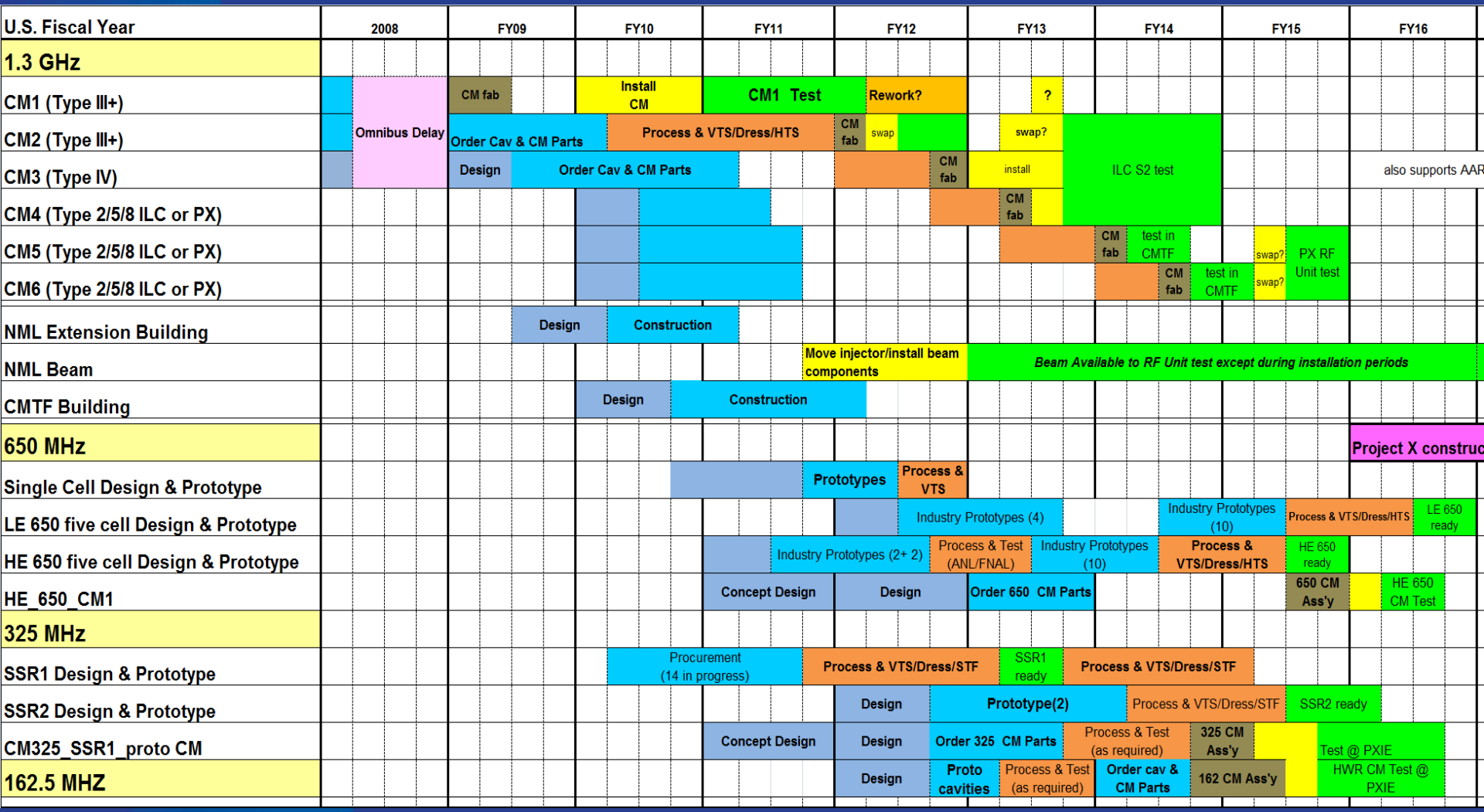
New NML Buildings (ARRA funded)

Integrated SRF Schedule - Cryomodules



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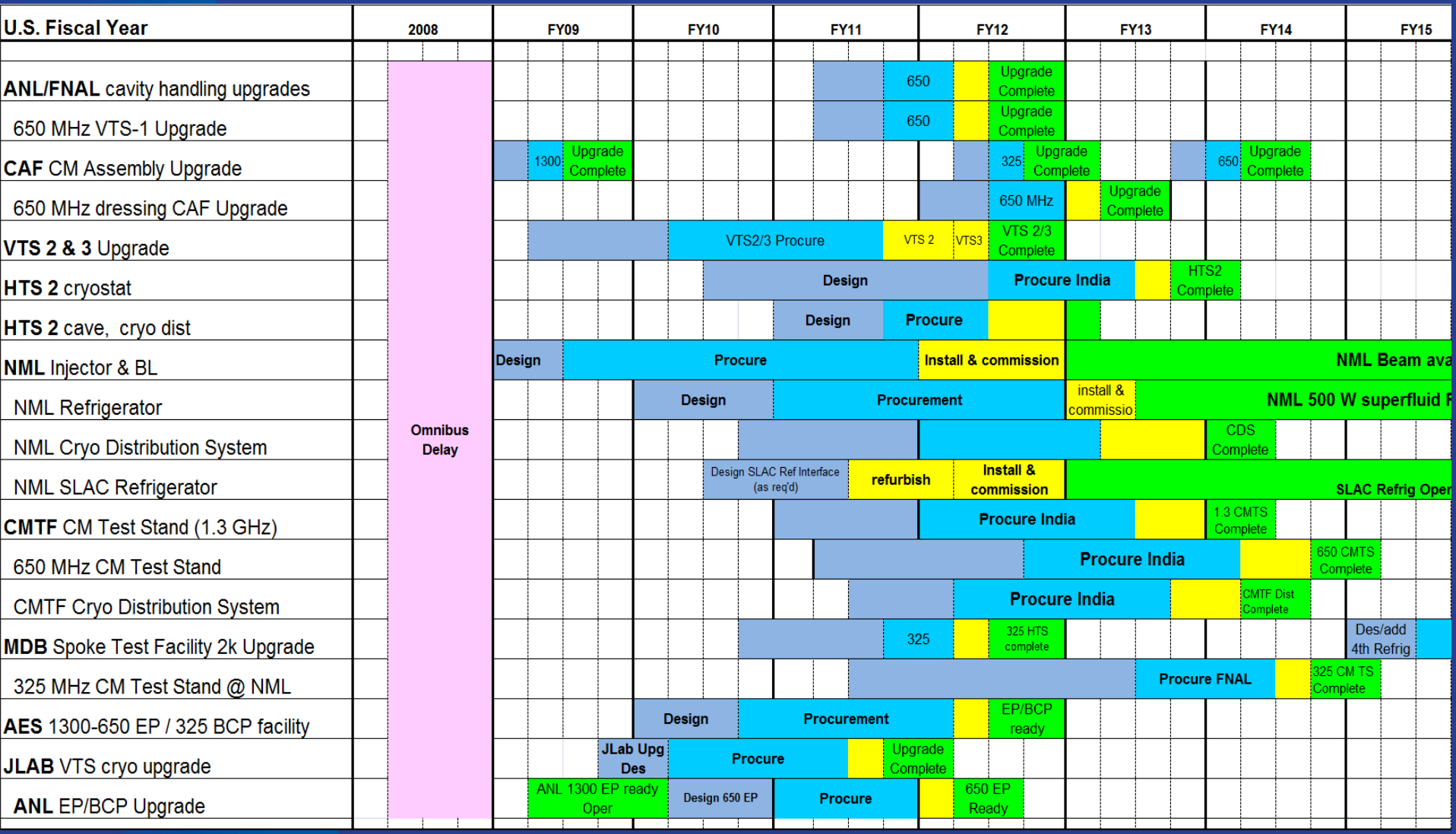
Summary

- 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



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