SRF Industrialization
American Region Laboratory Plans

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IPAC10/GDE industrialization

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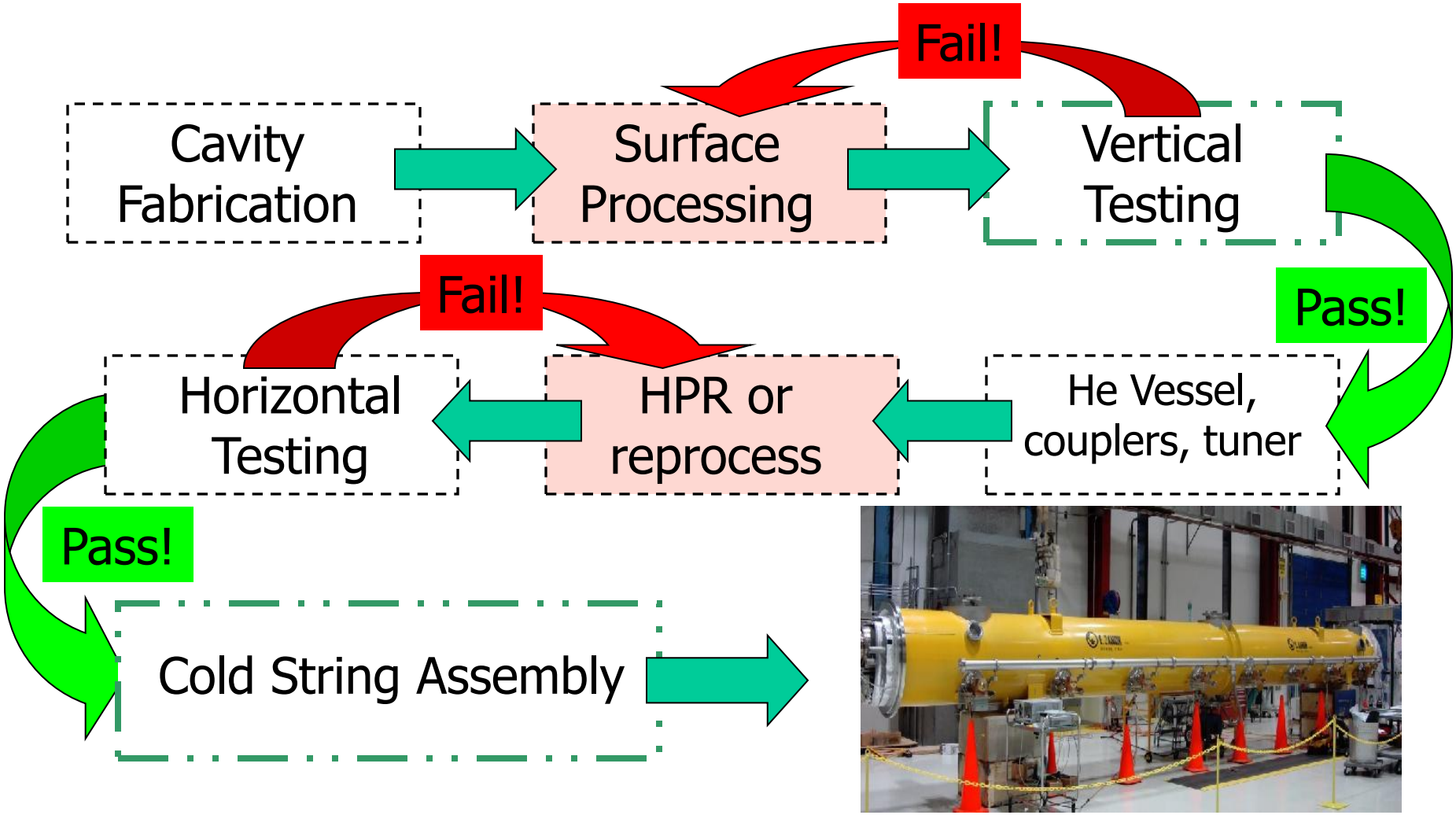
Introduction

- **Development of SRF capabilities in U.S. Industry has started in support of future SRF based projects. Examples:**
  - **ILC (by far the largest SRF project considered)**
  - **JLAB 12 GeV upgrade**
  - **FRIB**
  - **Project X (would employ ILC cavities)**
  - **ERL's**
  - **Etc**
- **U.S. SRF industrialization is funded with generic SRF and ARRA funds (vs ILC funds)**
  - **Addition activity is funded by future projects (e.g. above)**
- **In this talk I review the current status and plans for:**
  - **North American industrial fabrication of 1.3 GHz elliptical cavities**
  - **Industrial fabrication of ILC/PX cryomodule parts**
  - **Development of an industrial cavity processing capability**
  - **Development of RF components for ILC**

Strategy

- Develop SRF technology in labs, to the extent possible transfer technology to industry for project construction
- Motivation for Industrial Development:
  - Competition: which should lead to improved performance of SRF components and lower prices for future accelerators (ILC or Project X)
  - Availability: Multiple qualified vendors will ensure product availability in case one vendor ceases operations or has other large contracts
  - Capacity: Promotes increased industrial capacity in preparation for the construction of projects
- Concern: timing for industrialization
  - Project timescales (PX and ILC) are still uncertain
  - Once an industrial capability is created it atrophies if not used
- Concern: risk vs cost in industry ➔ Projects assume risks
- Assume: labs provide costly cryogenic & RF test infrastructure

f Cavity/CM process and Testing

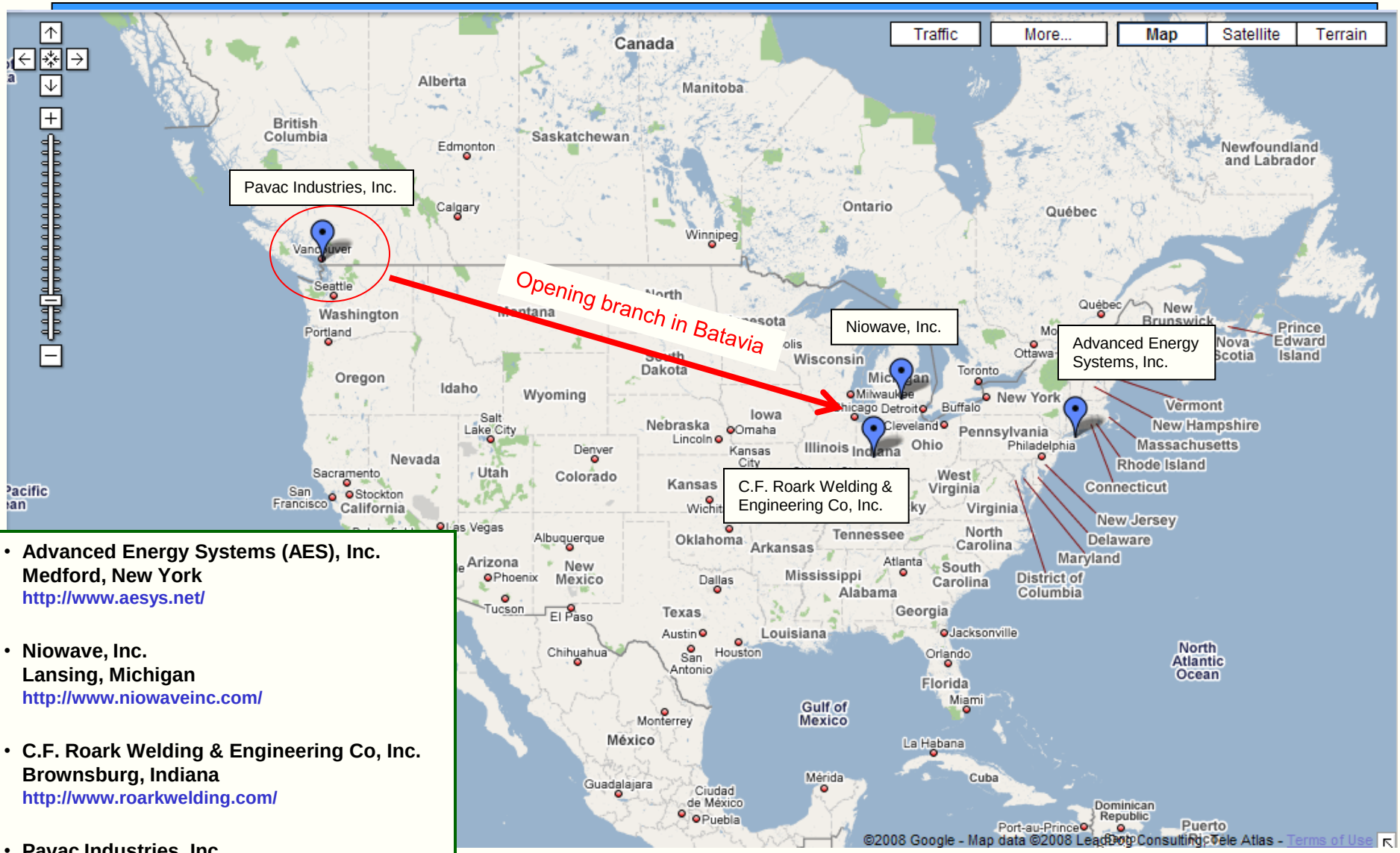


Plan… Develop in labs then transfer technology to industry

ILC Cavity Industrialization

- **1.3 GHz cavity procurements support**
  - Cavity R&D towards the ILC S0 goals (FNAL, ANL, JLAB, Cornell effort)
  - Construction of CM's to attempt to meet ILC S1 & S2 goals
  - Construction of prototype CM's for Project X
  - Development of qualified cavity vendors
- **Currently plan to purchase Cavities with the "TESLA" shape**
  - But may consider other shapes in the future
- **Vendors of course also acquire valuable SRF experience by fabricating cavities of other shapes and frequencies for Projects other than ILC**

North American Cavity Vendors

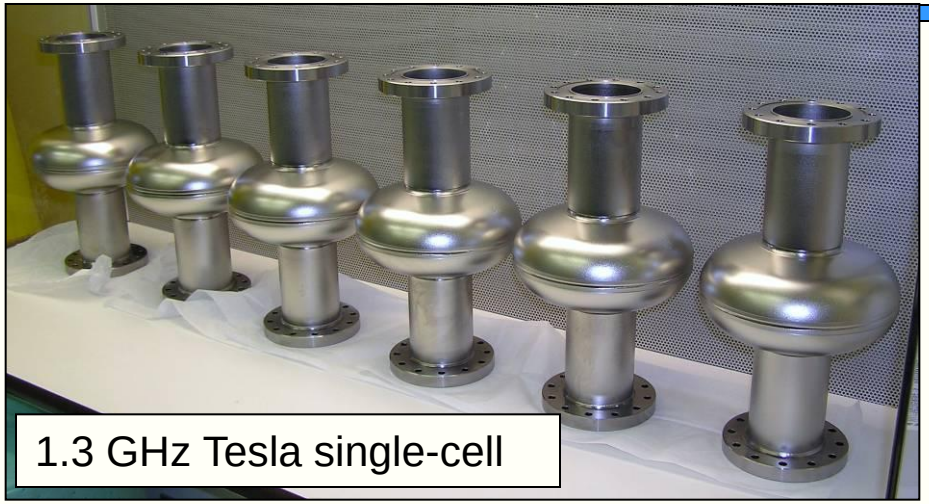


- **Advanced Energy Systems (AES), Inc.**
  Medford, New York
  http://www.aesys.net/
- **Niowave, Inc.**
  Lansing, Michigan
  http://www.niowaveinc.com/
- **C.F. Roark Welding & Engineering Co, Inc.**
  Brownsburg, Indiana
  http://www.roarkwelding.com/
- **Pavac Industries, Inc.**
  Richmond, British Columbia
  http://www.pavac.com

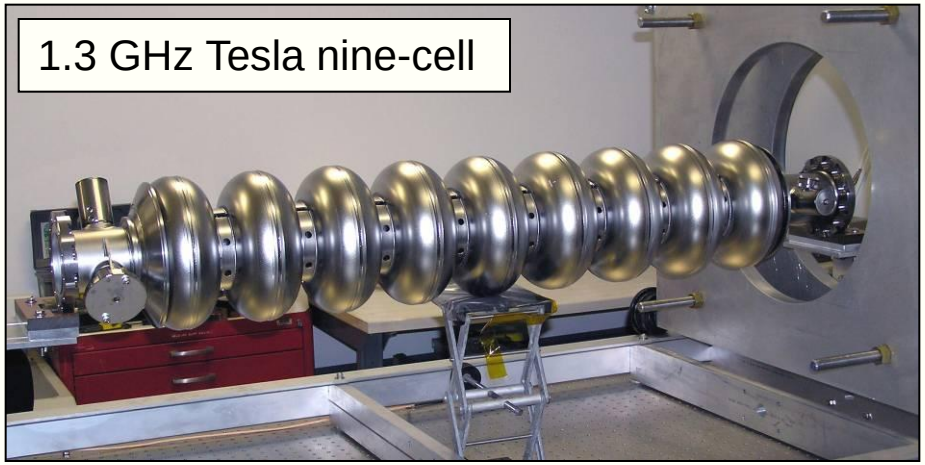
U.S. Cavity inventory and planned procurements

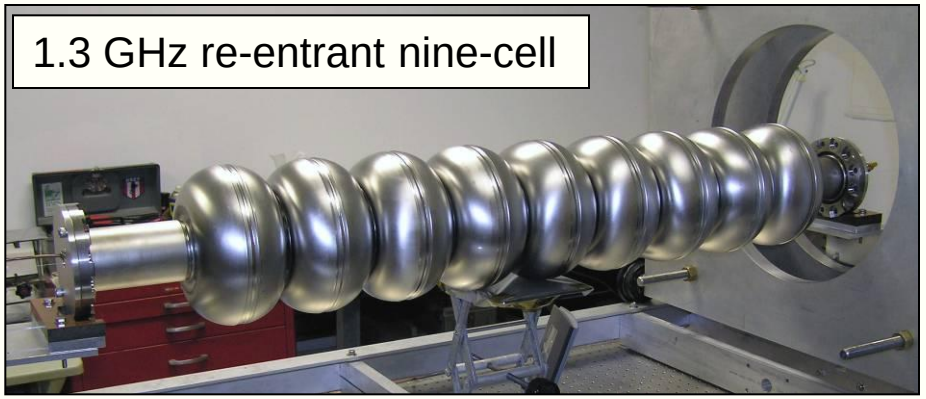
Tesla-shape nine-cell cavities		
Description	**No. Cavities**	**Status**
AES 1-4	4	Tested: AES2 at 32 MV/M, AES3 at 34 MV/m after repair
AES 5-10	6	Tested: 4 of 6 tested at over 35 MV/m
AES 11-16	6	Due soon
AES 17-36	20	Ordered Feb 2010 with ARRA funds
Accel 6-9	4	Tested: 2 of 4 above 35 MV/m at one point, degraded in subequent tests
Accel 10-17	8	Tested: 5 of 8 over 35 MV/m. (ACC12 and ACC14 damaged)
RI 18-29	12	Testing just started, 6 with bulk EP at RI, 6 delivered
Jlab fine-grain 1-2	2	Fabrication complete at JLAB; J2 at 30 MV/M, J1 usable?
Niowave-Roark 1-6	6	2 delivered, 4 close awaiting test of 1st two
Additional ARRA	20	Evaluating bids from Roark/Niowave and PAVAC
Total	**88**	
	37	Cavities received by end of March 2010
	23	Processed and tested
Tesla-shape single-cell cavities		
Description	**No. Cavities**	**Status**
AES1-6	6	tested at Cornell; further testing in progress
Accel 1-6	6	received Dec 2008; further testing in progress
Niowave-Roark 1-6	6	tested at Cornell; further testing in progress
PAVAC	6	3 delivered, testing in progress
Total	**24**	
Already Received	21	

AES has complete production capability on-site
10 nine-cells delivered & tested; 6 + 20 more ordered


1.3 GHz Tesla single-cell

Electron-beam welding facility

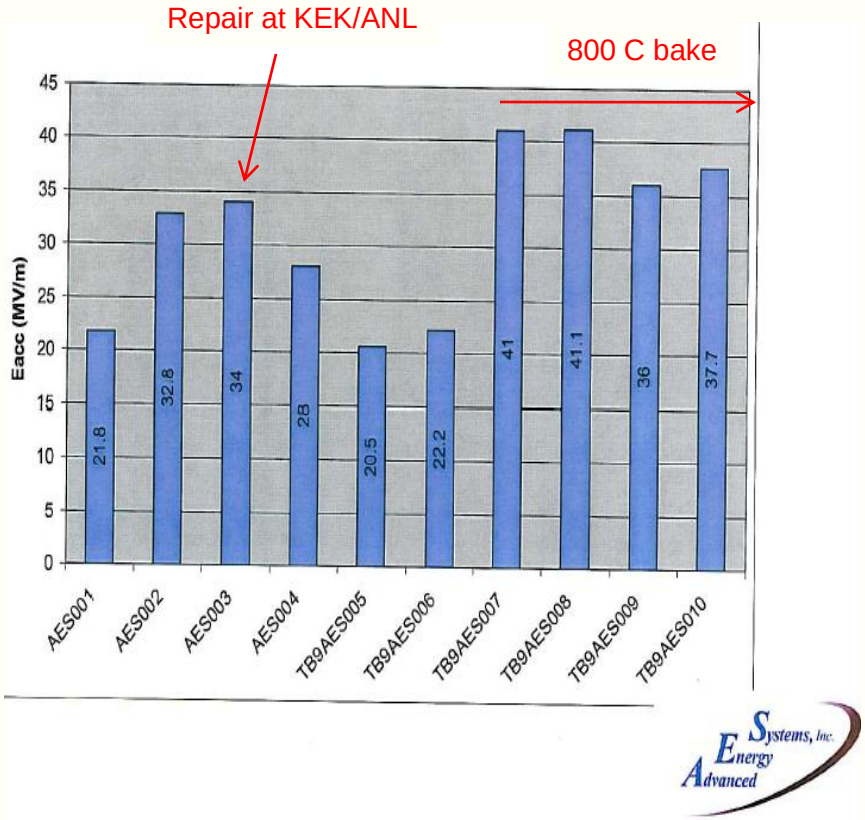

1.3 GHz Tesla nine-cell

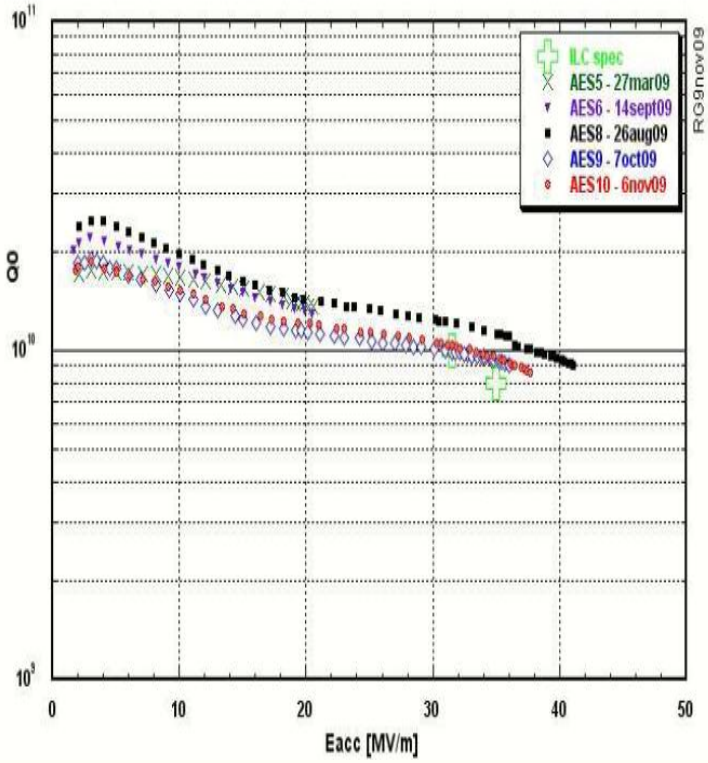

1.3 GHz re-entrant nine-cell

AES cavities

- Total number of cavities delivered and tested is still small !
- However, results are very encouraging
- Batch 1 (4 cavities) (used EBW from another company)
  - Delivered, tested
  - 1 cavity (AES002) exceeded 32 MV/M
  - 3 cavities, limited in 20's by defects (mostly pits),
  - AES003 repaired by local grinding of defects at KEK and EP at ANL, now 34 MV/M in VTS at Fermilab) (1st example of repair by grinding)
- Batch 2 (6 cavities) (EBW at AES with new welder)
  - Delivered, tested
  - Two cavities have defects (20, 22 MV/M)
  - Four cavities exceed 35 MV/M ! (41, 41, 36, 38 MV/M)
  - Last four cavities processed with 800 C bake…does this prevent pits ?
- Batch 3 (6 cavities)
  - Not yet delivered but expected soon
- Batch 4 (20 cavities)
  - Recently ordered with ARRA funds

AES 9-cell test results, 1st two batches

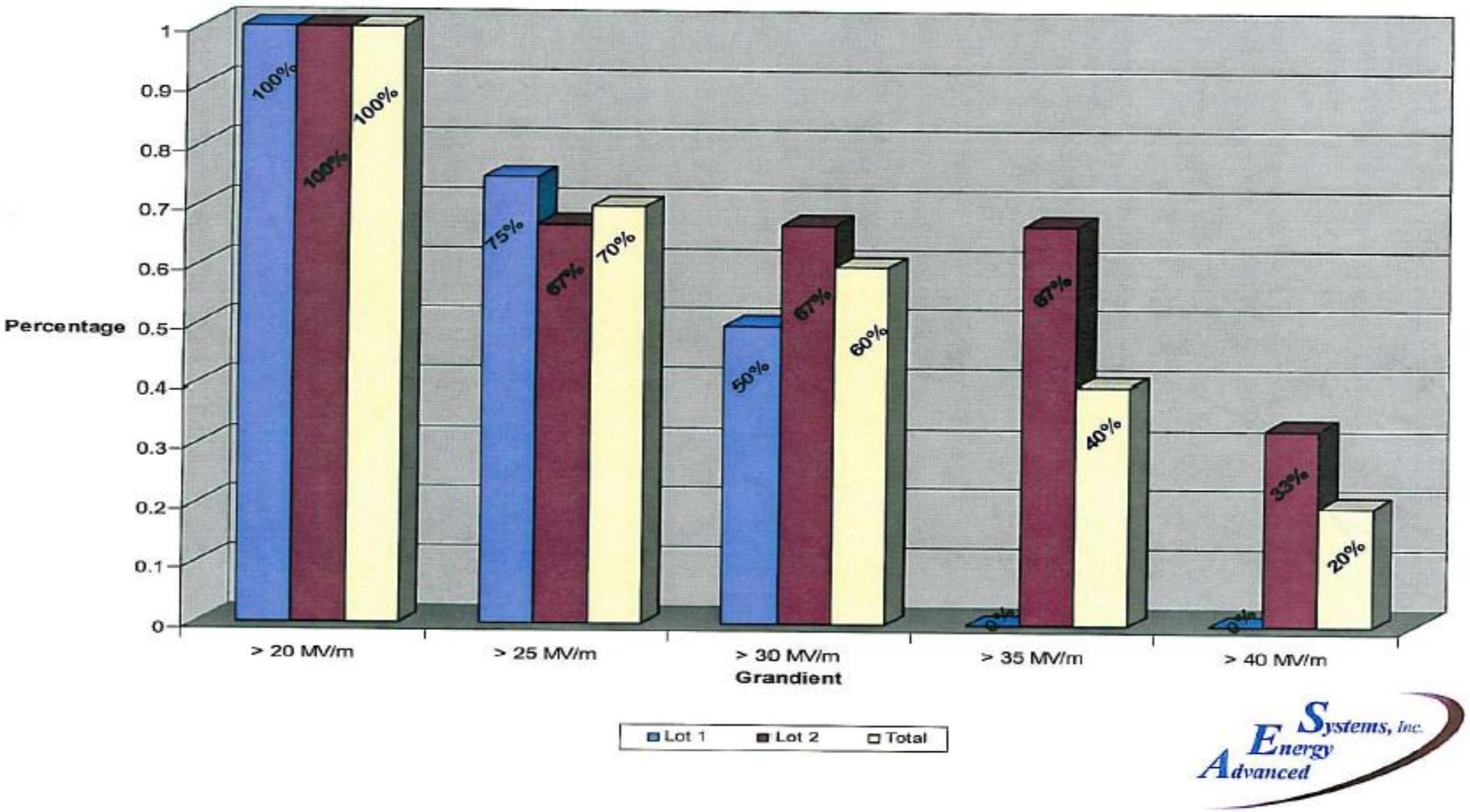




Low statistics, difficult to separate fabrication vs processing issues

Q0's look reasonable

AES Yield vs gradient



- **Based on low statistics but AES yields in batch 2 are as good as achieved anywhere. Will be interesting to see next 6 cavities**

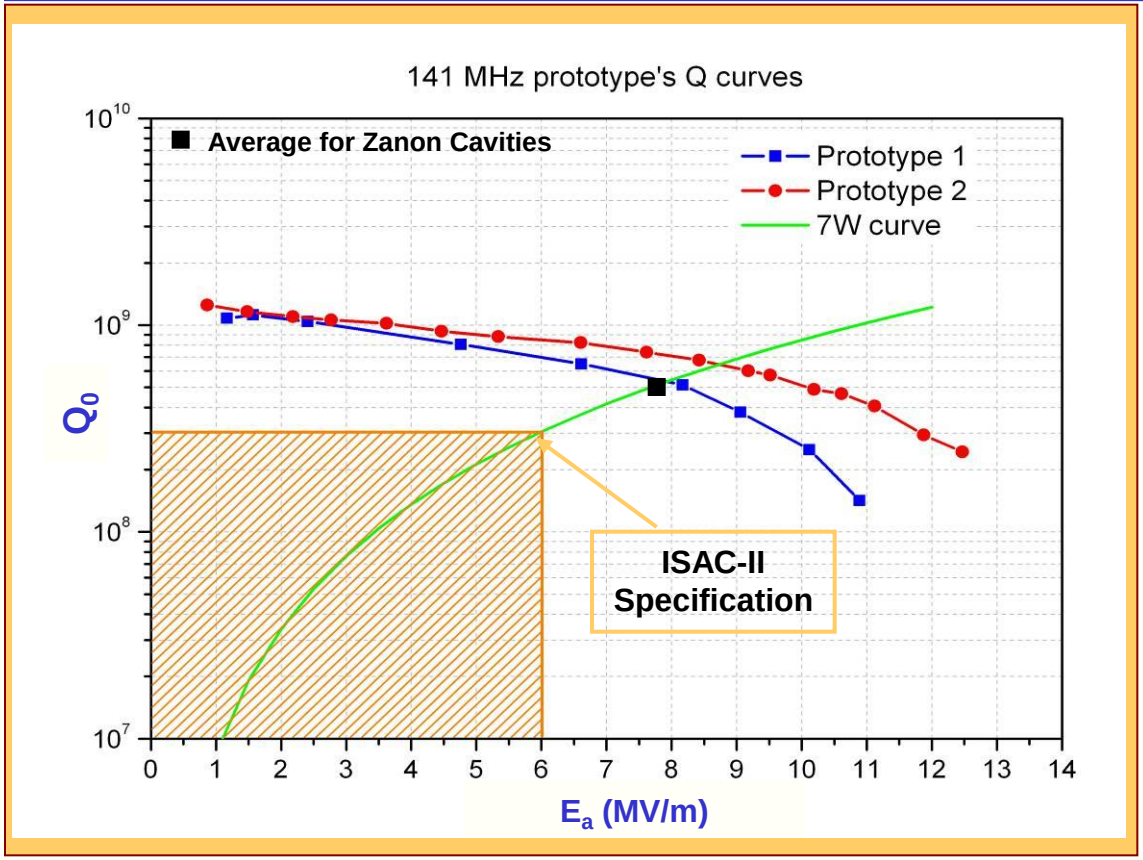
Niowave & Roark collaborate on 1.3 GHz cavities
Roark is working independently on low-beta structures

- 6 Single-cell cavities deliver Jun 08
- Performed well
- 6 nine-cell cavities in fabrication
- 2 delivered (EBW/HOM problems)
- Evaluating bid on ARRA cavities

- Roark 325 MHz beta=0.22 single-spoke cavity
- Delivered Summer 2008
- Design = 10 MV/M @ 4K
- Exceeded 30 MV/M @ 2 K
- Ordered 10 more for Project X

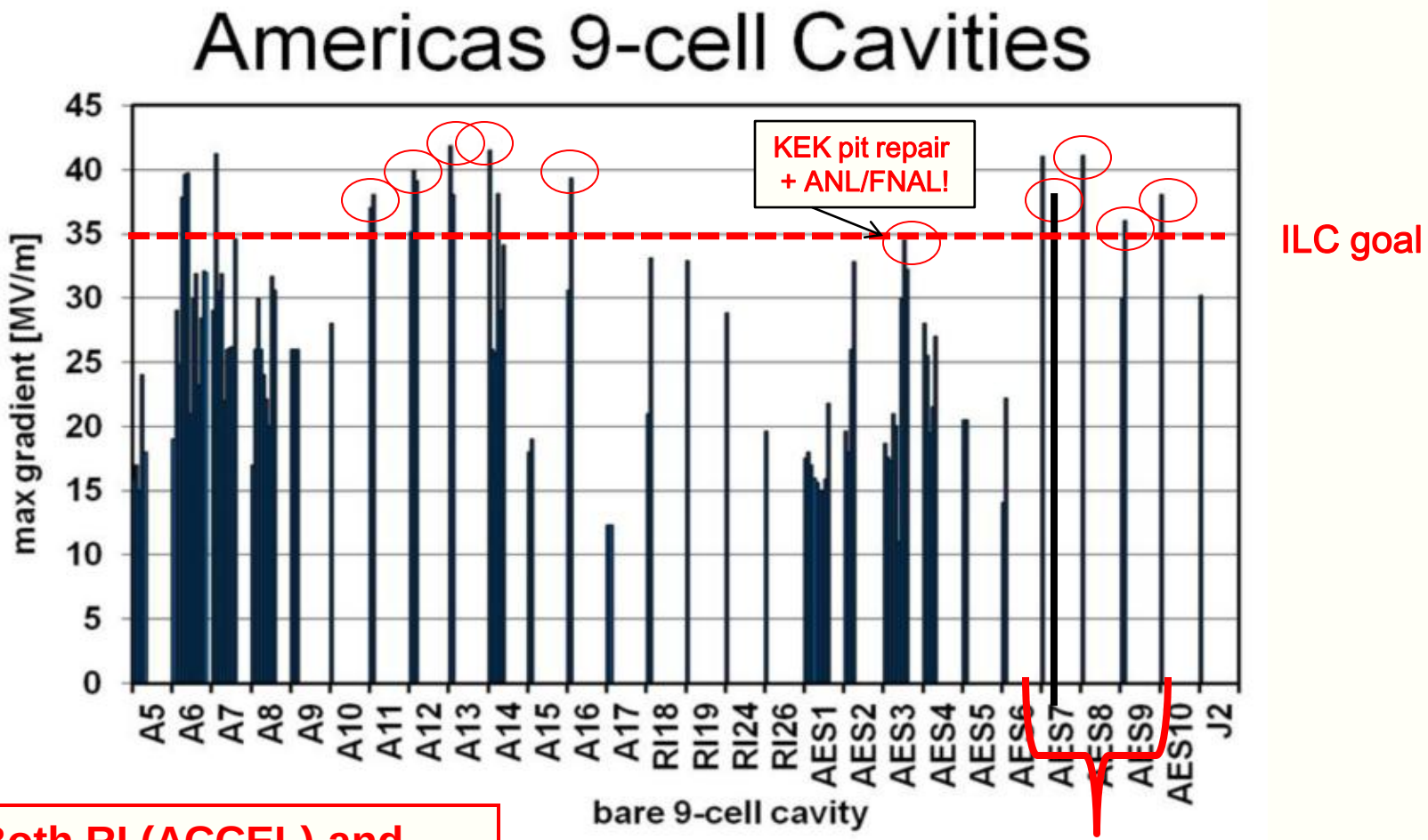
PAVAC is producing 20 coaxial resonators in collaboration with TRIUMF for the ISAC-II Phase-II extension

- Two prototypes manufactured and tested; production under way.
- Both prototypes perform significantly above ISAC-II specifications; average values of E_a=8.2MV/m, Ep=40MV/m cw (specification 6MV/m)
- Pavac delivered 3 of 6 1.3 GHz single cell cavities, Evaluating bid on ARRA 9-cell cavities
- Excellent expertise in EB welders… NEW! Opening a branch in Batavia




Beta = 0.11 resonator

Performance of AES vs RI 9-cell cavities



Both RI (ACCEL) and AES have cavities limited by pits

4 of 6 recent AES cavities exceed 35 MV/M at JLAB

U.S. Plan for Cavity Vendor Development

- The vendors learn through experience, so in general they will improve their manufacturing processes over time
- But, feedback from the laboratories is key to obtaining performance improvements
  - Careful QA and optical inspection of incoming cavities
  - Process & test cavities quickly
- Relatively small cavity orders allow for feedback between productions
  - AES made substantial improvements in tooling and installed an electron-beam welder after their first production of 4 nine-cell cavities
- Larger orders will allow us to better understand costs
- Close communication and regular visits
- Assistance from experts at Cornell and JLab
- Stimulus procurements will give cavity vendors a big boost

Industrial Surface Processing

- **Industrial Electro-polish**
  - **ARRA funds make it possible for us to develop Electro-polish capability in U.S. industry**
    - **Competition to perform design study; AES won the bid**
  - **AES will construct a horizontal EP facility**
    - **Capable of processing 1300 and 650 MHz elliptical cavities**
    - **Benefits from existing clean room, HPR, and chemistry infrastructure funded at AES by Brookhaven National Lab**

- **Eco-friendly Surface Processing**
  - **Funded with ARRA funds**
  - **Goal is to produce smooth clean cavity surfaces without using HF and other toxic chemicals**
  - **3 companies bid for design study**
    - **2 selected to submit design study (Faraday bipolar EP, Cabot =CMP)**
  - **Fund best to demonstrate performance with single cells**

U.S. Industrialization of Cryomodules

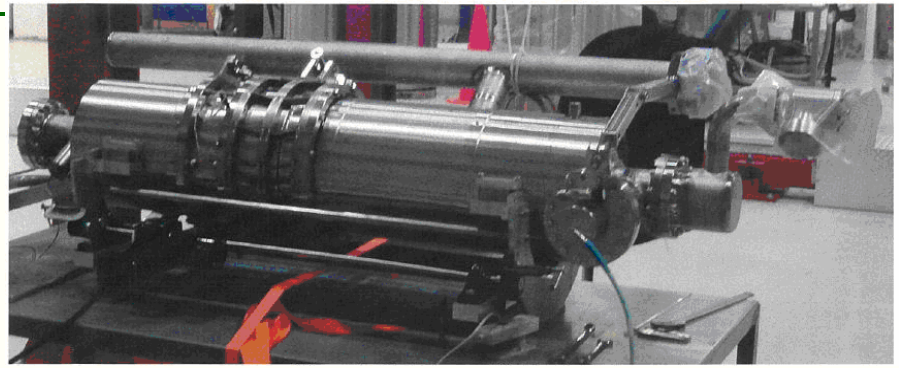
- **Strategy on Cryomodule Industrialization**
  - **The value added during CM assembly is < 10% the value of the cryomodule.**
  - **The number we will assemble over the next few years is very small ➔ have no plans to train industry to do assembly of ILC CM**
    - **Any training likely to be lost… without follow on work**
    - **Not even clear this would make sense for Project X volumes**
- **Strategy is to design CM at labs, order parts from industry, assemble at Fermilab**
  - **ILC may require a different strategy**

U.S. Industrialization of Cryomodules

- **CM1: is a TTF Type III+ and was assembled at FNAL in our CAF facility from a kit of parts provided by DESY/INFN**
  - Dressed cavities from DESY
  - DESY style lever tuners
  - Magnet package located at end of cavity string (but no magnet)
  - DESY and INFN provided assistance in assembly
- **CM2: will be built in 2010 at CAF.**
  - Another Type III+
  - Cold mass parts were procured in Europe with help from INFN
  - Populate with U.S. processed and dressed cavities (accumulating)
- **CM3-CM6:**
  - Type IV ILC/Project X design (larger pipe sizes)
  - Magnet package can be located in positions 2,5,8 (5 = center of CM)
  - Cold mass parts ordered in U.S. industry with ILC and ARRA funds
  - Populate with U.S. processed and dressed cavities
  - CM6 will be a CW cryomodule for Project X
- **Cryomodules will go to NML: will try to meet ILC S1 and S2 goals**

U.S. Industrialization of Cryomodules

CM3-6 Parts



- **He Vessels:**
  - **Fabricated of Titanium (like XFEL)**
  - **20 already procured from Hi-Tech (4637 N. 25th Ave., Schiller Park, Il 60176)**
  - **40 more being procured with ARRA funds**
    - **Likely vendors Hi-Tech, INCODEMA (www.INCODEMA.com), Titanium Fabrication Corp. (110 Lehigh Drive, Farifield, N.J. 07004), and Titan Metal Fabricators Inc. (835 Flynn Rd. , Camarillo, CA. 93012)**
- **Tuners**
  - **For CM2 and beyond we will use Blade tuner developed by INFN**
  - **CM2 and S1-Global: 12 tuners provided by INFN, built in Europe**
  - **CM3-CM6: Tuners made by U.S. industry (ARRA)**
    - **20 Ti blade tuners from INCODEMA; 20 from Hi-Tech**

U.S. Industrialization of Cryomodules

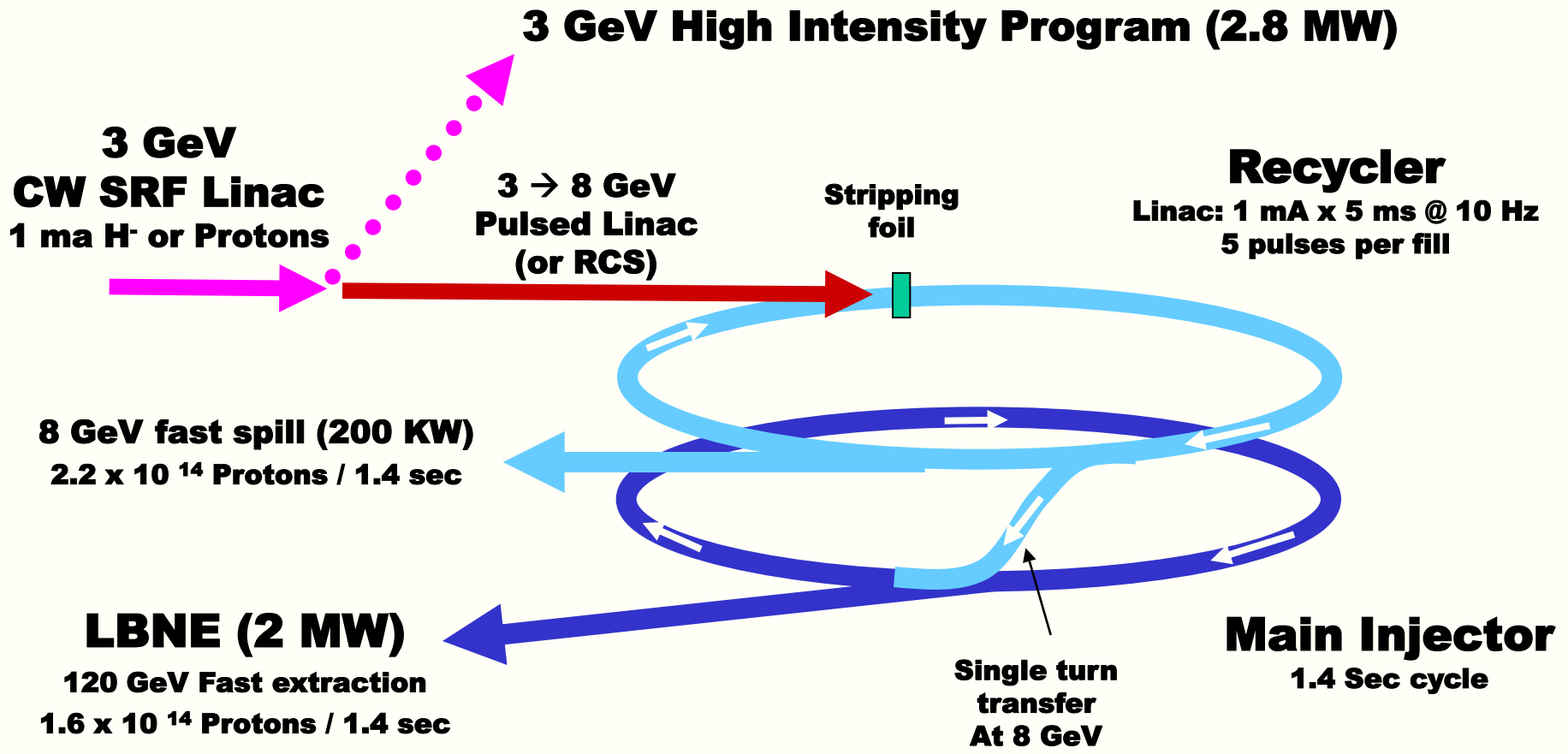
CM3-6 Parts

- Couplers (1300 MHz, TTF type)
  - Vendor is Communications and Power Industries, CPI, (150 Sohier Road, Beverly, MA. 01915-5595)
  - 74 couplers built for DESY, Orsay and SLAC/Fermilab
  - SLAC inspects, tests, and conditions couplers for Fermilab
  - 12 couplers delivered (via SLAC) for S1 global and CM2;
  - 10 more ordered via SLAC by ILC, delivery soon
  - 22 more ordered via SLAC (using ARRA funds), delivery ~7 months
- Cold mass parts and Vacuum Vessels
  - 4 cryomodules worth of Type IV parts on order
  - Vendor is PHPK Technologies (2111 Builders Place, Columbus, OH 43204)
  - 1st vacuum vessel (CM-3) has been delivered to Fermilab

ILC RF Power components, electronics, etc

- CPI has built a two 10 MW multi-beam klystrons
  - One vertical, one horizontal (for DESY)
  - Vertical delivered and under test at SLAC
  - CPI building another for NML at FNAL
- ILC Marx modulators have been built on SBIR funds by the companies ISA Corporation (in the East Bay) and DTI.
- SLAC is working with other labs (in particular DESY) to develop an ATCA electronics module standard for ILC

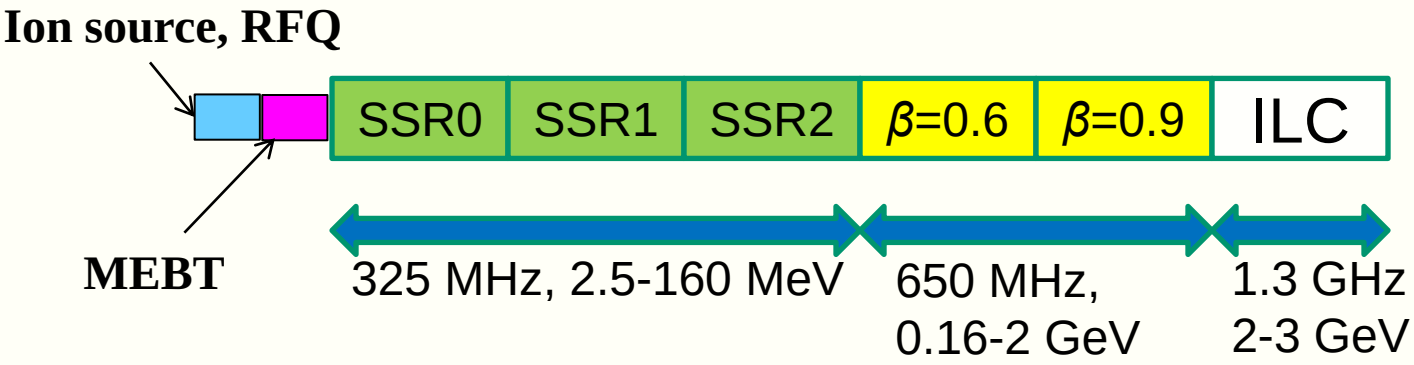
Project X & SRF industrialization



3-8 GeV linac would be 1300 MHz pulsed ➔retains synergy with ILC R&D but long pulse R&D needed

Project X Linac's

- **Design based on 3 families of 325 MHz Spoke resonators, two families of 650 MHz elliptical cavities, then 1300 MHz ILC cavities**



Note: 650 MHz, β=0.9, 5-cell cavities are same physical length as 1300 MHz, β=1.0, 9-cell cavities so cryomodules are similar

Summary of PX 3 GeV CW linac

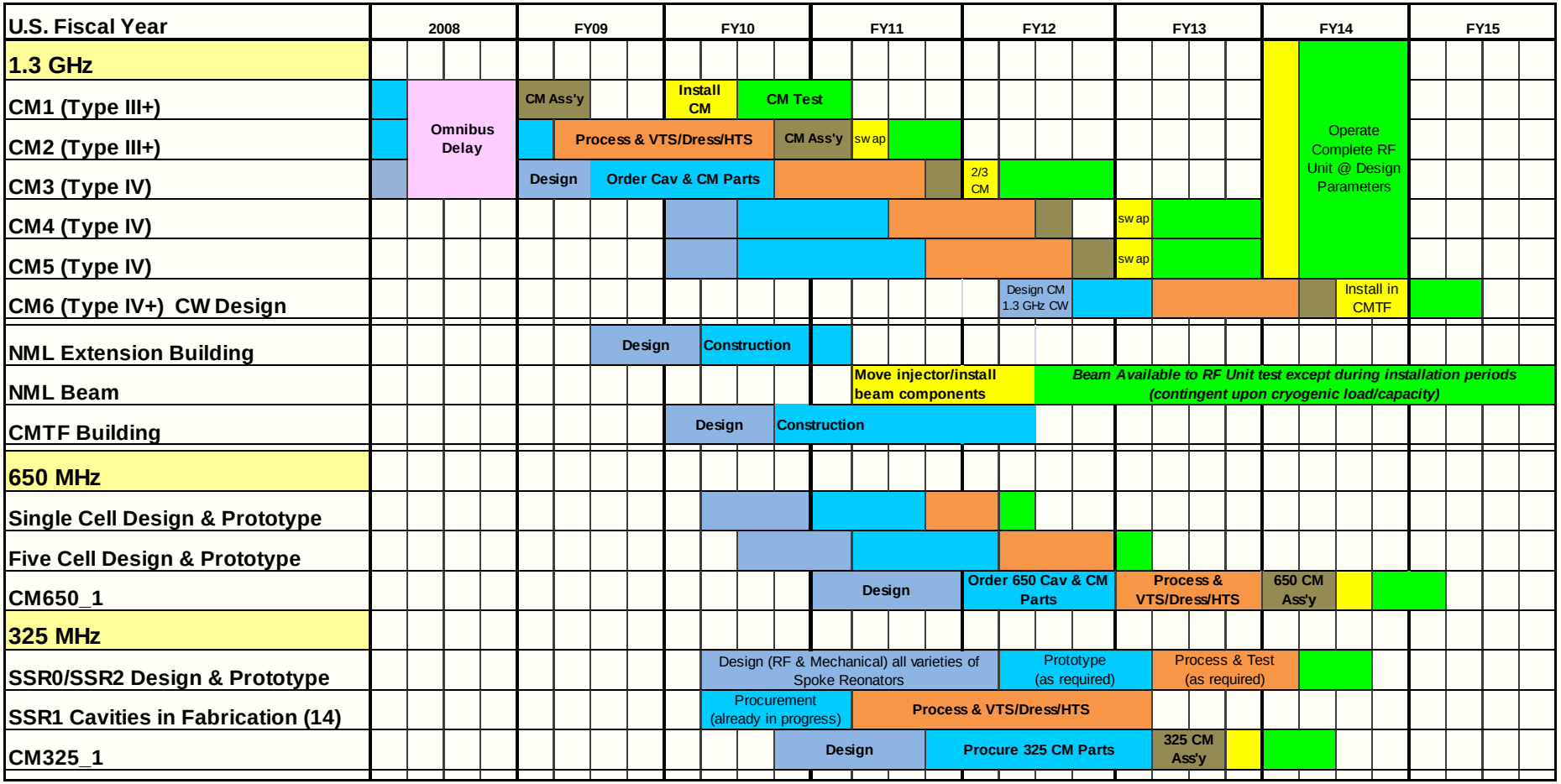
Section	Freq	Energy MeV	Number of cav/magn/CM	Type of
SSR0 (β_G=0.11)	325	2.5-10	26/26/ 1	Single spoke cavity, Solenoid
SSR1 (β_G=0.22)	325	10-32	18 / 18/ 2	Single spoke cavity, Solenoid
SSR2 (β_G=0.4)	325	32-160	44 / 24 / 4	Single spoke cavity, Solenoid
LB 650 (β_G=0.61)	650	160-520	42 / 21 / 7	5cell cavity, doublet
HB 650 (β_G=0.9)	650	520-2000	96 / 12 / 12	5cell cavity, doublet
ILC 1.3	1300	2000-3000	64 / 8 / 8	9-cell cavity, quad

290 Cavities, 34 cryomodules

Summary of PX 3-8 GeV Linac

- Gradient ~ 25 MV/m
- 1 mA 5 ms beam pulse @ 20 Hz (Upgradeable to CW)
- 25 cryomodules ILC Type IV (2/5/8)
- 400 9-cell 1300 MHz TESLA/ILC type cavities
- Construction of Project X would substantially contribute to U.S. industrialization of SRF for ILC

Integrated ILC/PX SRF Plan (Cryomodules)



Cryomodule activities at FNAL

CM1 String Assembly

MP9 Clean Room

Final Assembly

CM1

Move to NML

CM1 installed

Dressing cavities for CM2

FNAL S1 global Cavities @ KEK

Summary

- Fermilab is engaged in vendor development with three North American cavity vendors:
  - AES, Niowave/Roark, and PAVAC
- Also engaged in industrialization of cryomodule parts, surface processing, RF equipment
- Industrialization is being funded by ARRA funds
  - but one time infusion of funds
- U.S. participation in the construction of ILC would require a large scale up of these efforts
- Likely that, Project X or other similar projects are the near-term path to U.S. SRF industrialization for a future ILC project