LCLS-II

LCLS-II: 5 KeV, 1 MHz FEL

Driven by a 4 GeV SRF linac – based on XFEL / ILC technology

Chris Adolphsen and Marc Ross

Tokyo LCWS13 Meeting, 11/14/13

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

High-Level Parameters

Basic Energy Sciences Advisory Committee (BESAC) report:

"… It is considered essential that the new light source have the pulse characteristics and high repetition rate necessary to carry out a broad range of coherent "pump-probe" experiments, in addition to a sufficiently broad photon energy range (at least ~0.2 keV to ~5.0 keV) and pulse energy necessary to carry out novel "diffract before destroy" structural determination experiments important to a myriad of molecular systems. …"

Goals:

0.2 – 5 keV photon range with high rate (10 kHz ~ MHz) beam

1.0 – 20 keV photon range with LCLS-similar performance

SLAC's proposed answer to BESAC challenge:

Current Baseline

- 4 GeV CW Superconducting RF Linac
  - Based on XFEL / ILC 1.3 GHz cavities
  - 35, 8-cavity 1.3 GHz cryomodules / 280 cavities
  - 3, 4-cavity 3.9 GHz cryomodules / 12 cavities
  - 16 MV/m Gradient; Qo = 2e10 at 1.8 deg K
- 0.1 mA typical, 0.3 mA max at 1 MHz bunch rate
- 25 micron bunch length
- 1.2 MW Max Beam Power
- 5.5 MW Cryogenics power

Location of the SLAC SC Linac

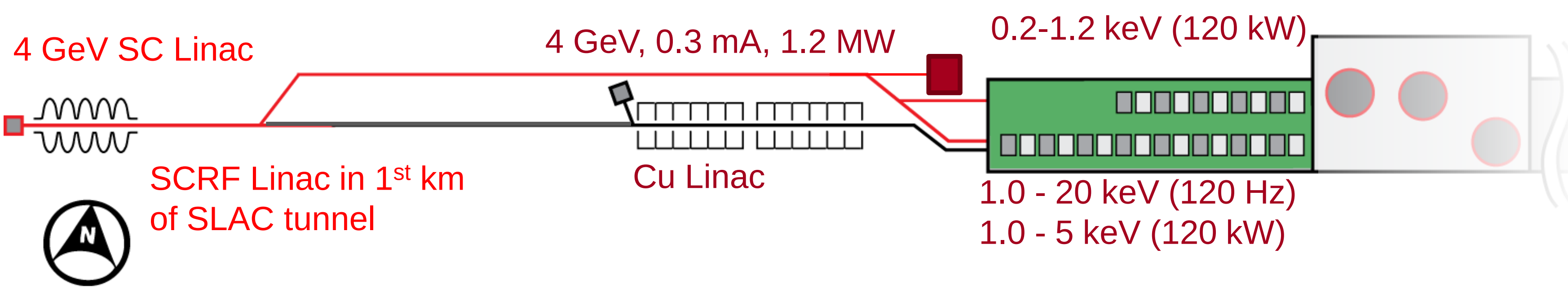
Replaces First Kilometer of the Normal-Conducting S-band Linac

Accelerator Operating Modes

- Two sources: high rate SCRF linac and 120 Hz Cu LCLS-I linac
- North and South undulators *always* operate simultaneously in any mode

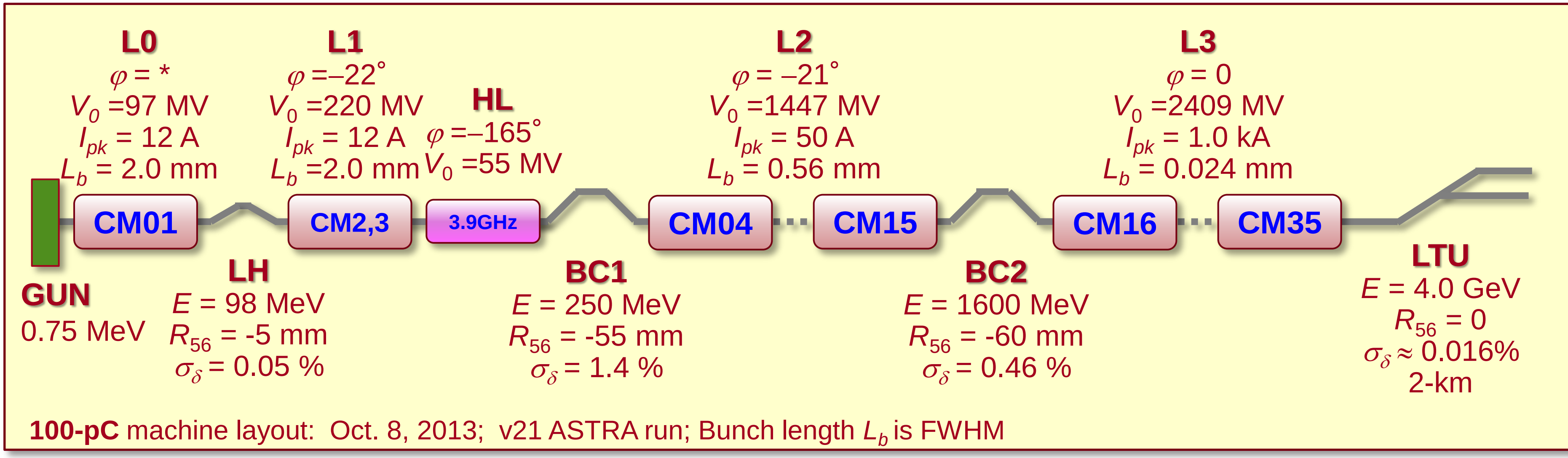
Undulator	SC Linac (up to 1 MHz)	Cu Linac (up to 120Hz)
North	0.25-1.3 keV	
South	1.0-5.0 keV	up to 20 keV higher peak power pulses

- Concurrent operation of 1-5 keV and 5-20 keV is not possible



New transport lines designed for <10 GeV beam
Existing LCLS transport lines for 17 GeV beam

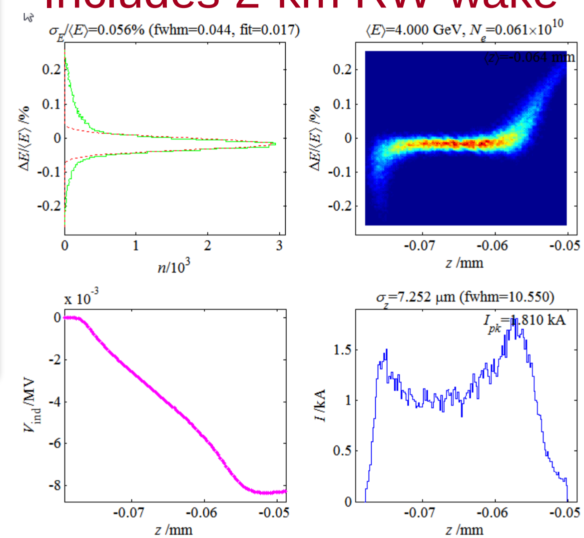
LCLS-II - Linac and Compressor Layout for 4 GeV



Linac Sec.	V (MV)	φ (deg)	Acc. Grad. (MV/m)	No. Cryo Mod's	No. Avail. Cav's	Spare Cav's	Cavities per Amplifier
L0	**97**	*****	**14.6**	**1**	**8**	**1**	**1**
L1	**220**	**–21**	**14.1**	**2**	**16**	**1**	**1**
HL	**–55**	**–165**	**14.5**	**3**	**12**	**1**	**1**
L2	**1447**	**–21**	**15.5**	**12**	**96**	**6**	**48**
L3	**2409**	**0**	**15.4**	**20**	**160**	**10**	**48**

P. Emma, L. Wang,
C. Papadopoulos

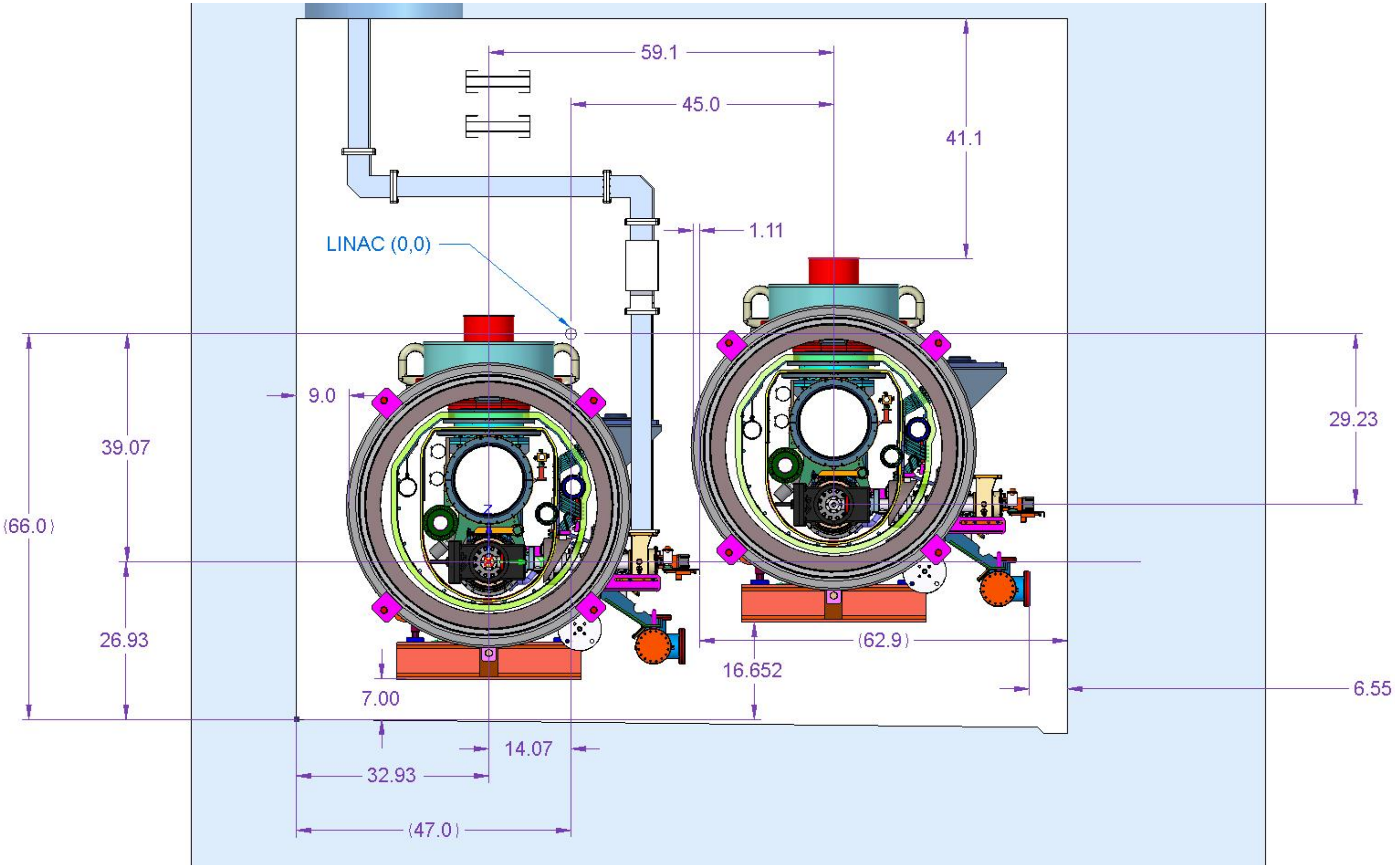
Includes 2-km RW-wake



* L0 cav. phases: ~(-40°, -52°, 0, 0, 0, 13°, 33°), with cav-2 at 20% of other L0 cavity gradients.

Cryomodules in SLAC Tunnel

SLAC Linac Tunnel (11 feet wide x 10 feet high) (3.35 m x 3.05 m)



LCLS-II SCRF development and production:

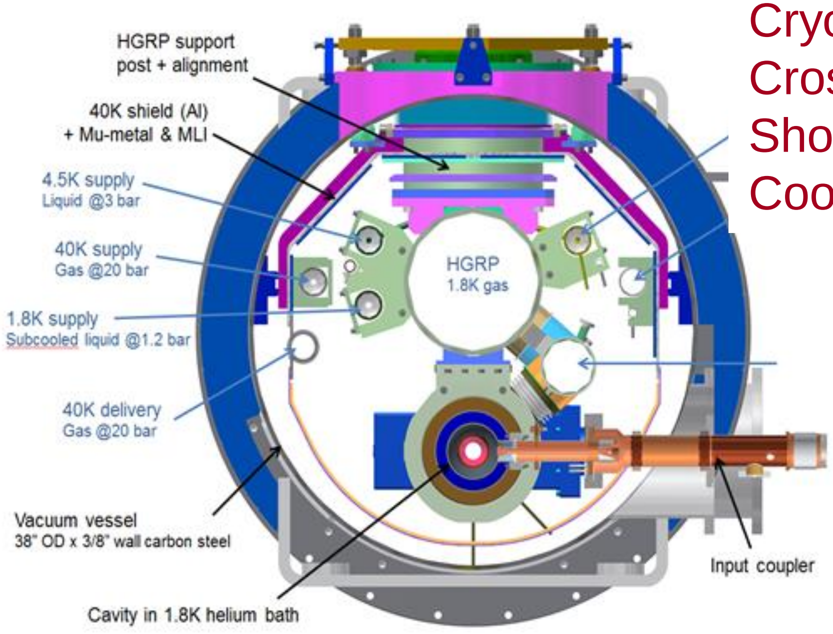
Fermilab

Jefferson Lab

Argonne Lab

Cornell Universit

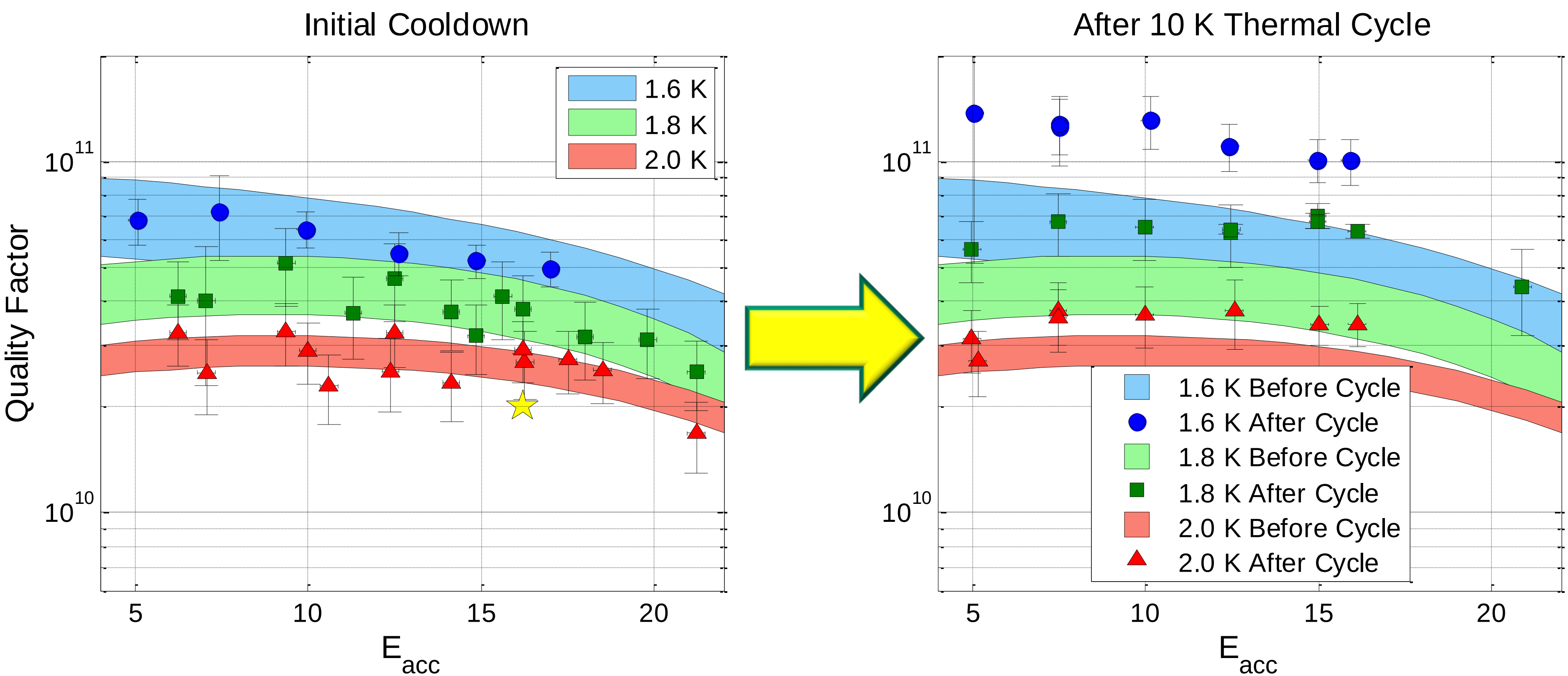
SLAC



Cornell ERL
Cryomodule
Cross-section
Showing increased
Cooling capacity

These labs will form an SCRF partnership for development, production and testing; supported by DoE Office of Science - BES

Horz Dressed Cavity Test (BCP, 120C, HF rinse)



Initial Cooldown at 16.2 MV/m

Q(2.0 K) = 2.5 x 10^{10}

Q(1.8 K) = 3.5 x 10^{10}

Q(1.6 K) = 5.0 x 10^{10}

10 K thermal cycle at 16.2 MV/m

Q(2.0 K) = 3.5 x 10^{10}

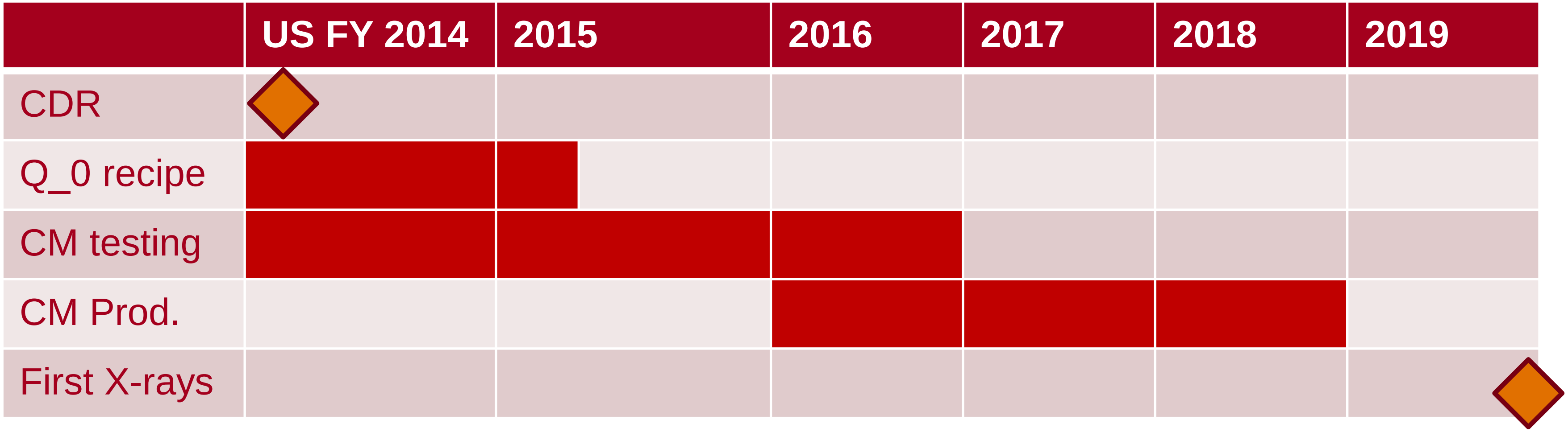
Q(1.8 K) = 6.0 x 10^{10}

Q(1.6 K) = 10.0 x 10^{10}

CM Development:

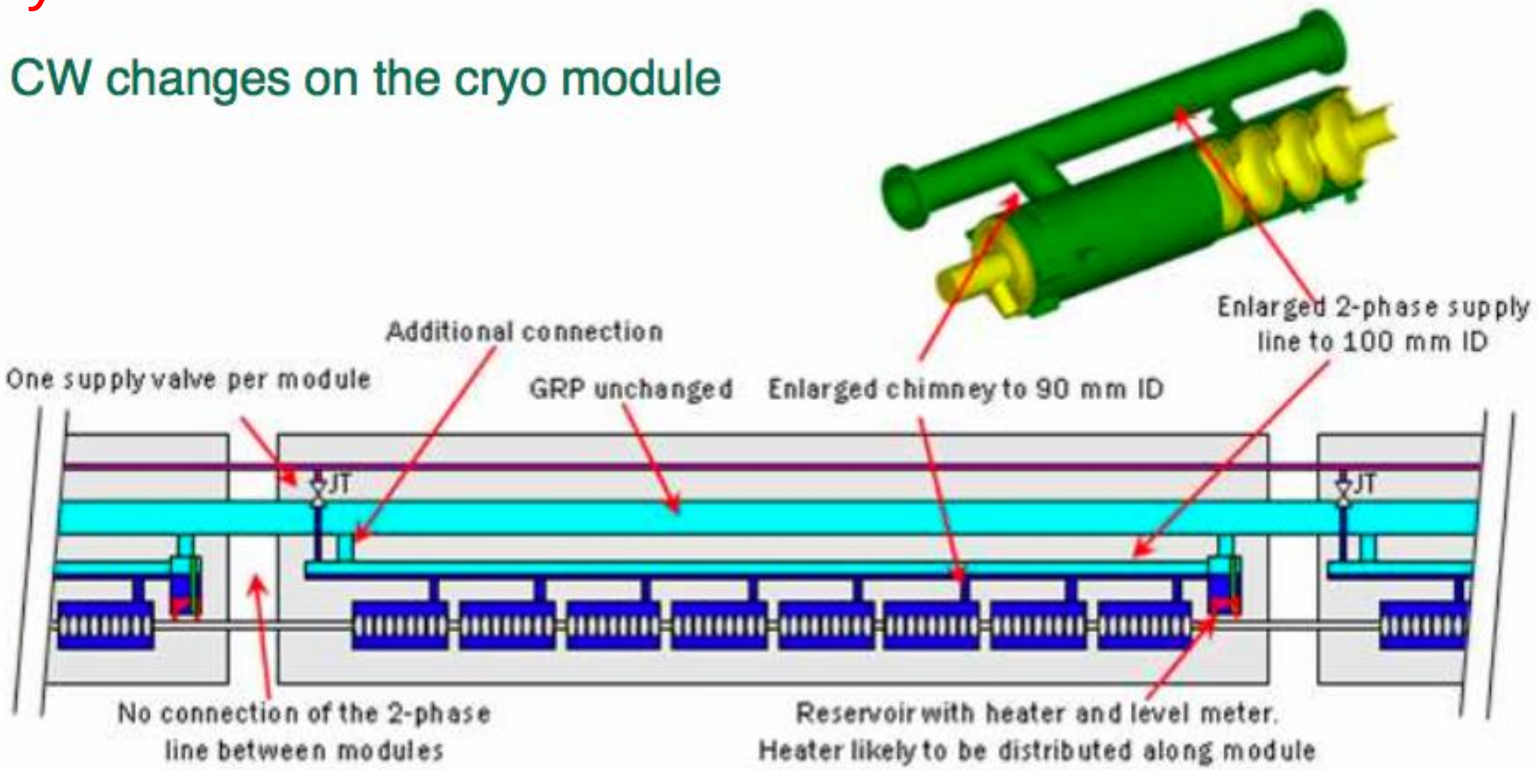
High Q_0 cryomodule with reduced cryogenics operating costs:

Improved cooling capability
New cavity surface processing recipe
Improved magnetic shielding
Adiabatic cool-down process



Separate liquid management in each cryomodule but no external transfer line

CW changes on the cryo module



CW TESLA Cavity Testing at HBZ*

Load at 17 MV/m is 19 W, well below measured 35 W flux limit

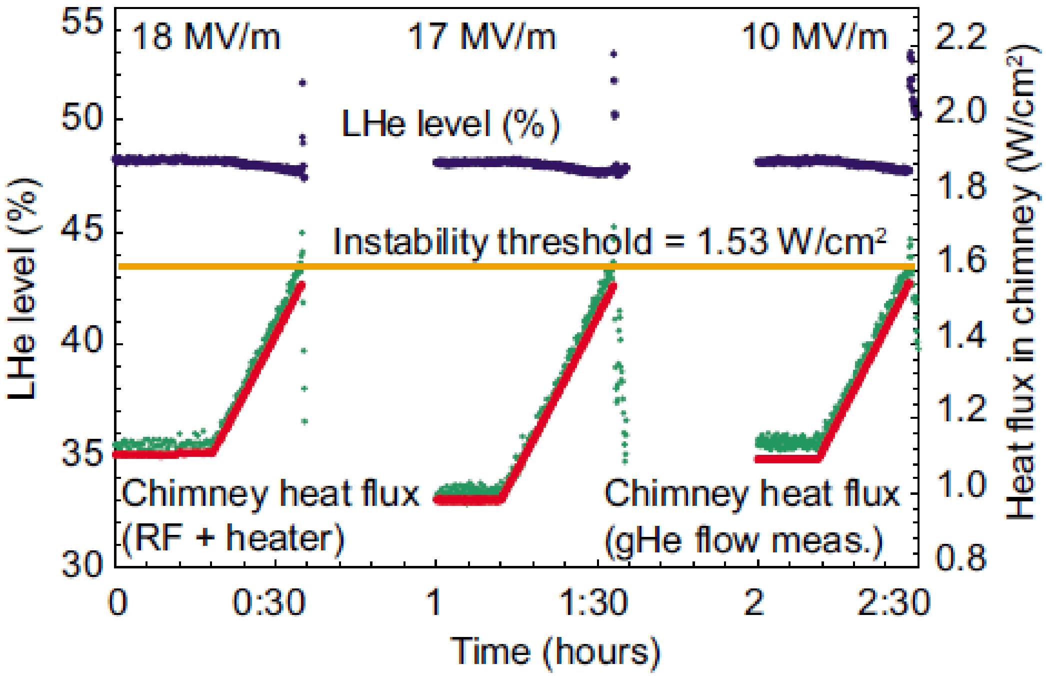


FIG. 6. (Color online) At three different cavity fields with corresponding rf power loads on the cryogenic system, the total losses (red lines) were increased by ramping an electrical heater attached to the cavity tank (green dots). Quenching occurred at total load of 35 W or 1.53 W/cm^2 in the chimney corresponding to a drop in the liquid helium level (blue).

* Rev Sci Instrum. 81, 074701 (2010)

Modifications to 2 K Pipes to Accommodate Larger Heat Flow

- Slightly larger nozzle from helium vessel to 2-phase pipe
  - Increase from 55 mm to about 70 mm
- Slightly larger 2-phase pipe
  - Depends on string lengths and liquid management plan
  - Retain option for 1.8 K in all piping
  - Increase from 72 mm to about 90 mm
- Segmentation of 2 K liquid and 2 K flow distances may also impact this pipe sizing
- The cryomodule itself will be the most likely source of fast (< 1 sec) pressure changes, so attention to piping and valve configurations are critical

Antenna Modifications for E-XFEL

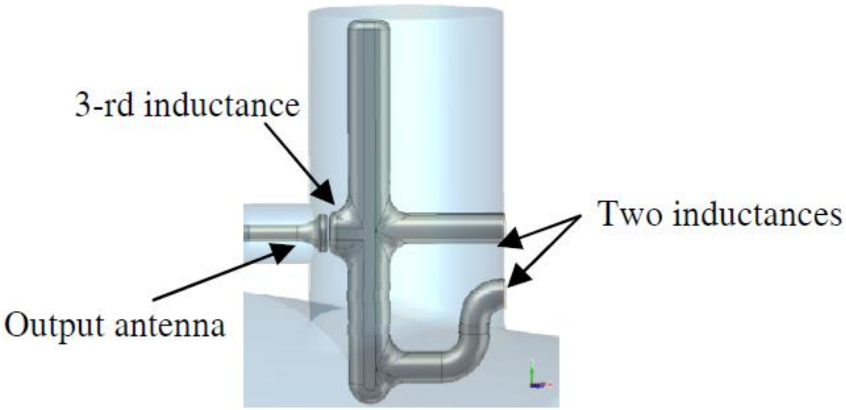


Figure 2: New HOM coupler with additional inductance and pulled back output antenna, *(Courtesy D. Kostin)*.

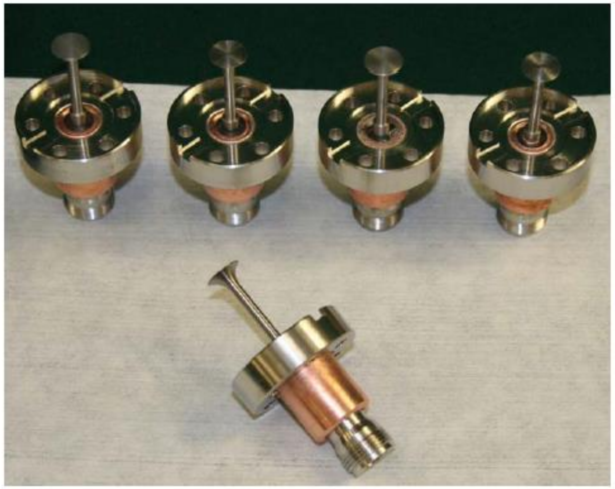


Figure 3: New feedthroughs for XFEL cavities.

Figure 4: Prototype of the thermal braids for standard TESLA cavities (*courtesy NCNR*).

"The feedthroughs are made of high conductivity materials, pure niobium, molybdenum and sapphire. They will be connected thermally to the 2-phase tube with copper braids for better heat transfer to the 2 K environment."

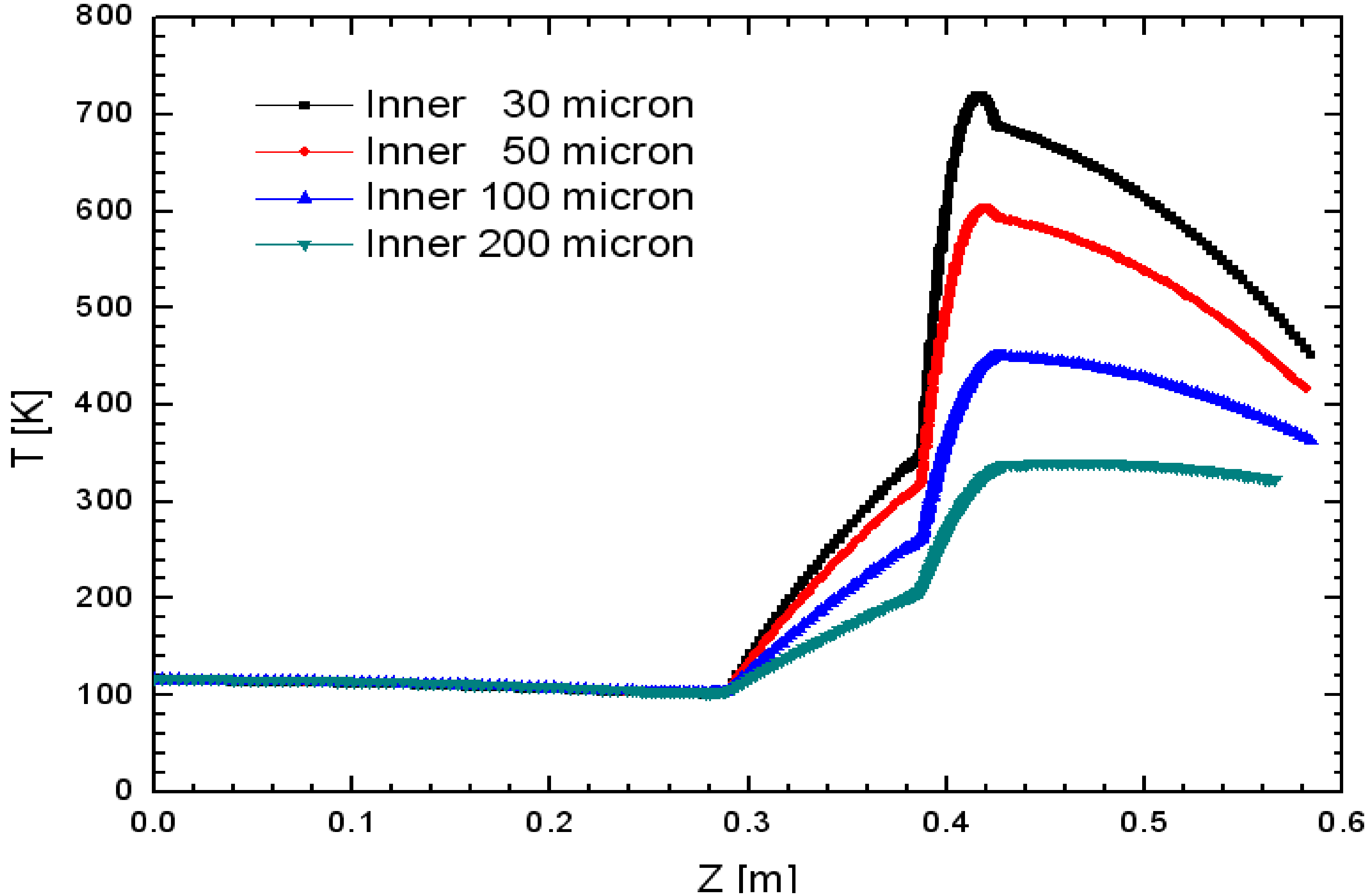
J. Sekutowicz

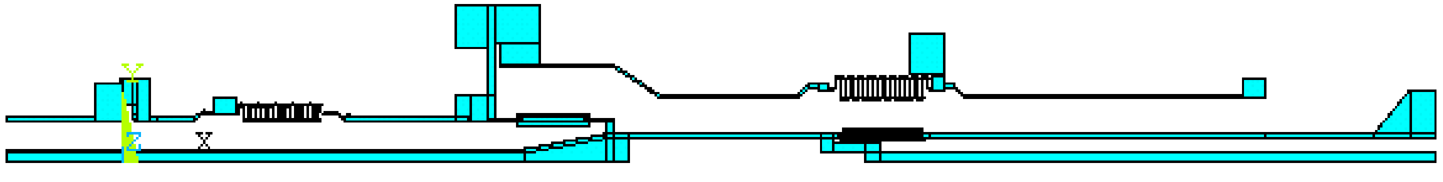
RF Power, QL and Overhead

Parameter	Value	Comment
Gradient	16 MV/m	On crest
Beam Current	0.3 mA	
Cavity QL	4.12 e7	Based on formula on next slide – minimizes power for 10 Hz microphonics (MP) offset
Max Power per Cavity (w MP w/o overhead)	5.72 kW	Power with 10 Hz MP offset – no overhead
Max Power per Cavity (w MP w overhead)	6.32 kW	Assume 94% transmission and 4% overhead
Max Power for 48 cavities (w MP and w overhead)	303 kW	Either one source per cavity so can track MP locally or one source for 48 cavities
RMS MP offset allowed with a 300 kW source	9 Hz	For Gaussian distributed MP

Inner Conductor Temperature Distribution with Different Thicknesses of Copper Coating for 15 kW CW RF Power

10µm on outer conductor with RRR=10





Shilun Pei

CM Gradient (Vector Sum) Stabilization at DESY

Goal: Stability of the vector sum for the cw operation with the new µTCA LLRF.

Conditions: E_{acc} = 3.5 MV/m, mode cw, piezo feedback off, bias on.

QL = 1.5e7

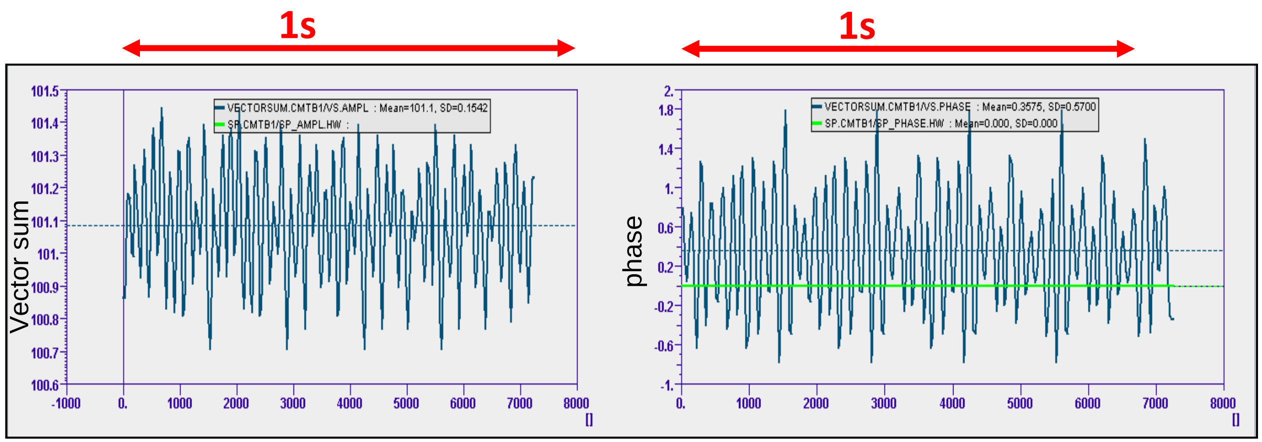
Test Result:

RF-feedback off

Standard deviations for:

Amplitude = 1.5E-3

Phase = 0.5°

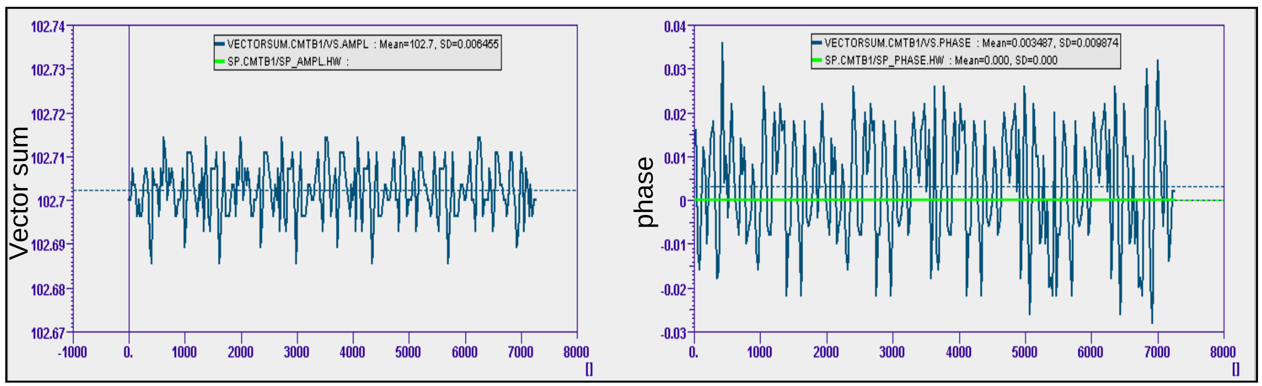


RF-feedback on

Standard deviations for:

Amplitude = 6.2 E-5

Phase = 0.0098°



Conclusion:

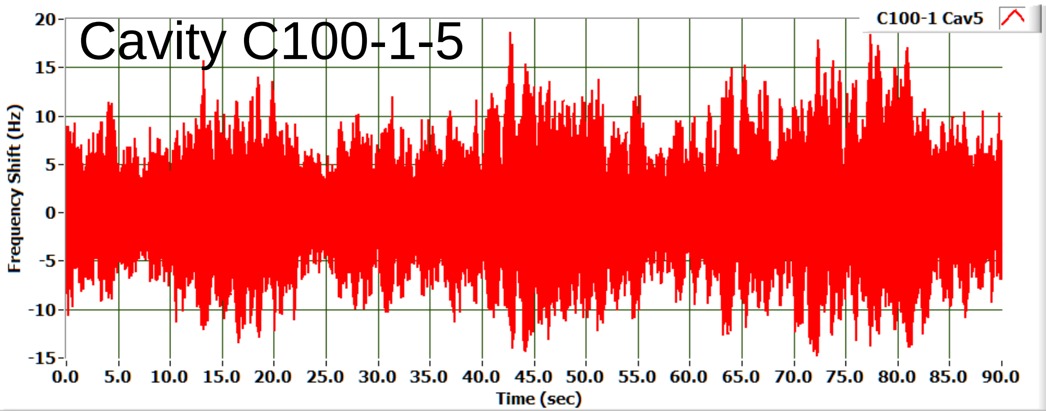
New µTCA RF-feedback improves amplitude and phase stability by factor of 24 and 51 respectively, and fulfills spec for the XFEL linac.

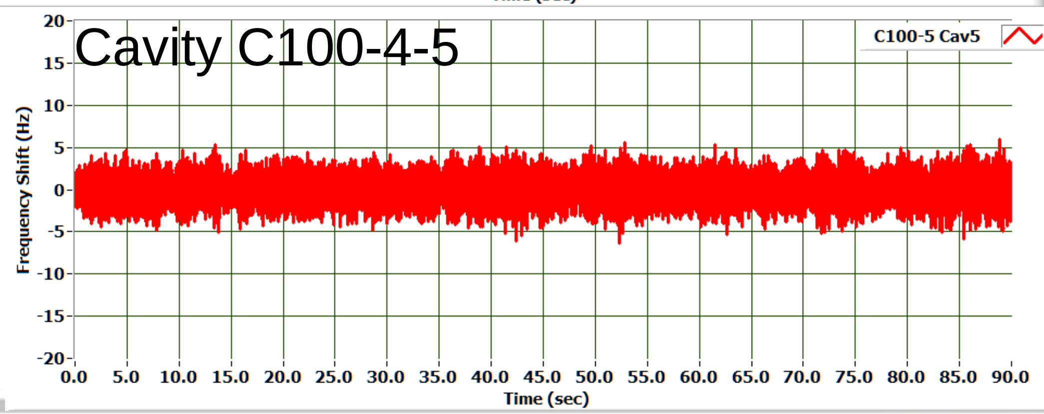
JLAB Upgrade Cavity Microphonics

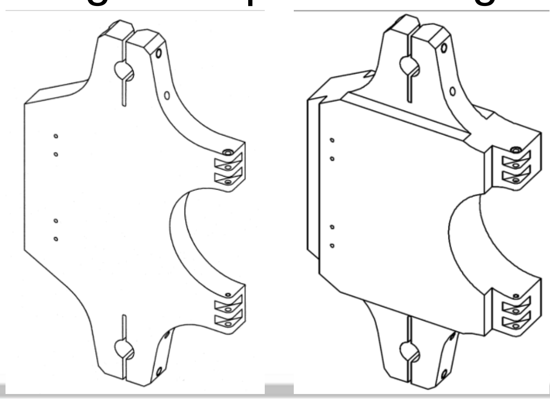
- Determines the Feedback Gain needed for control.
- Effects are driven by Q_L and the available klystron power for lightly loaded cavities

Microphonic Detuning*	C100-1	C100-4
RMS (Hz)	2.985	1.524
6σ(Hz)	17.91	9.14

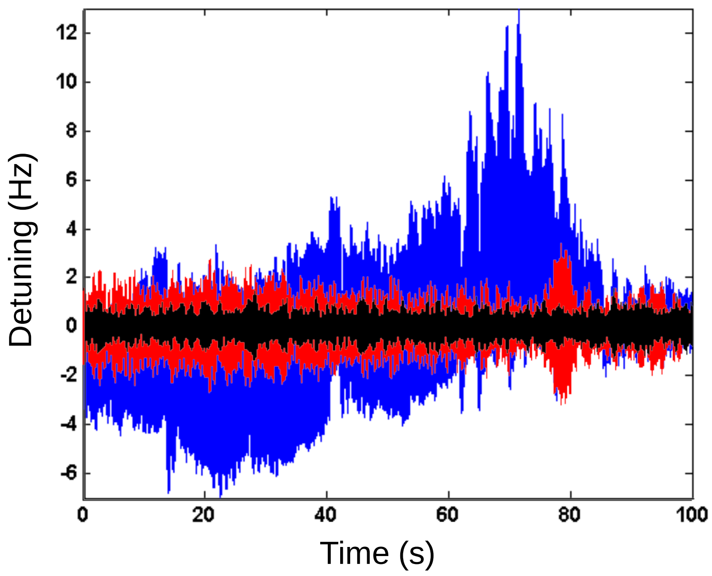
- Minor change to the **tuner pivot** plate substantially improved the microphonics for the CEBAF C100 Cryomodules.
- While both meet the overall system requirements the improved design has a larger RF power margin







MICROPHONICS COMPENSATION AT HZB

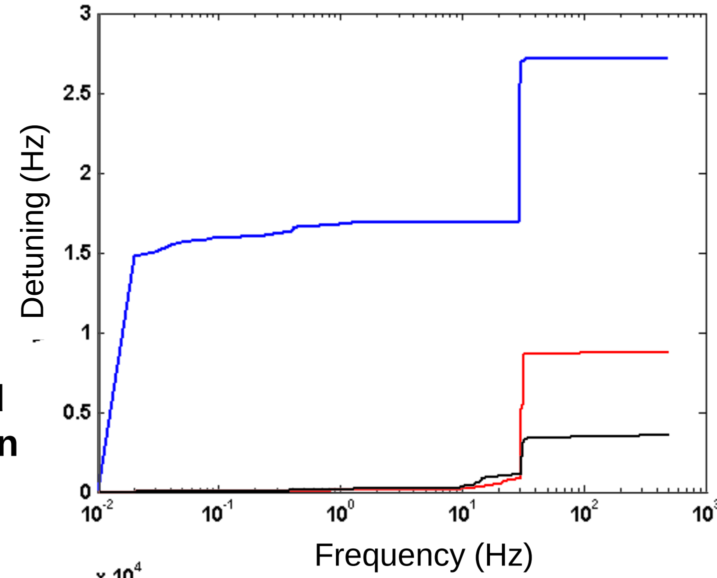


ΣFFT

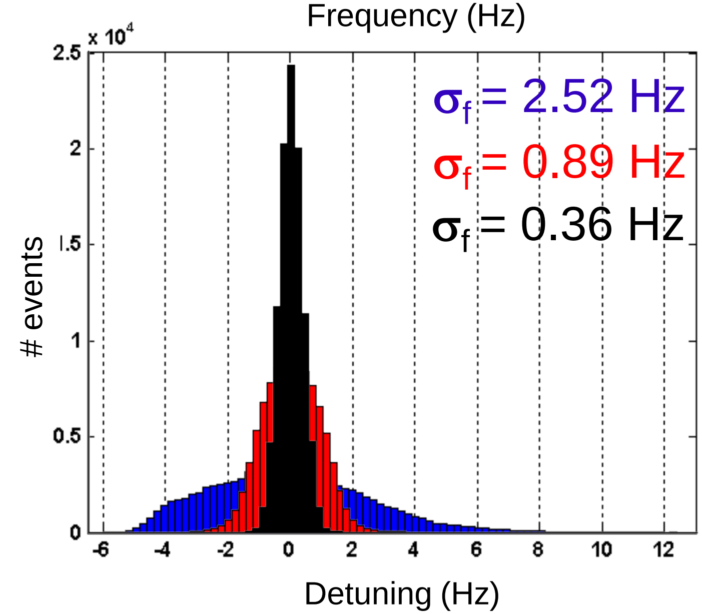
w/o control

feedback

feedback & feed-forward compensation

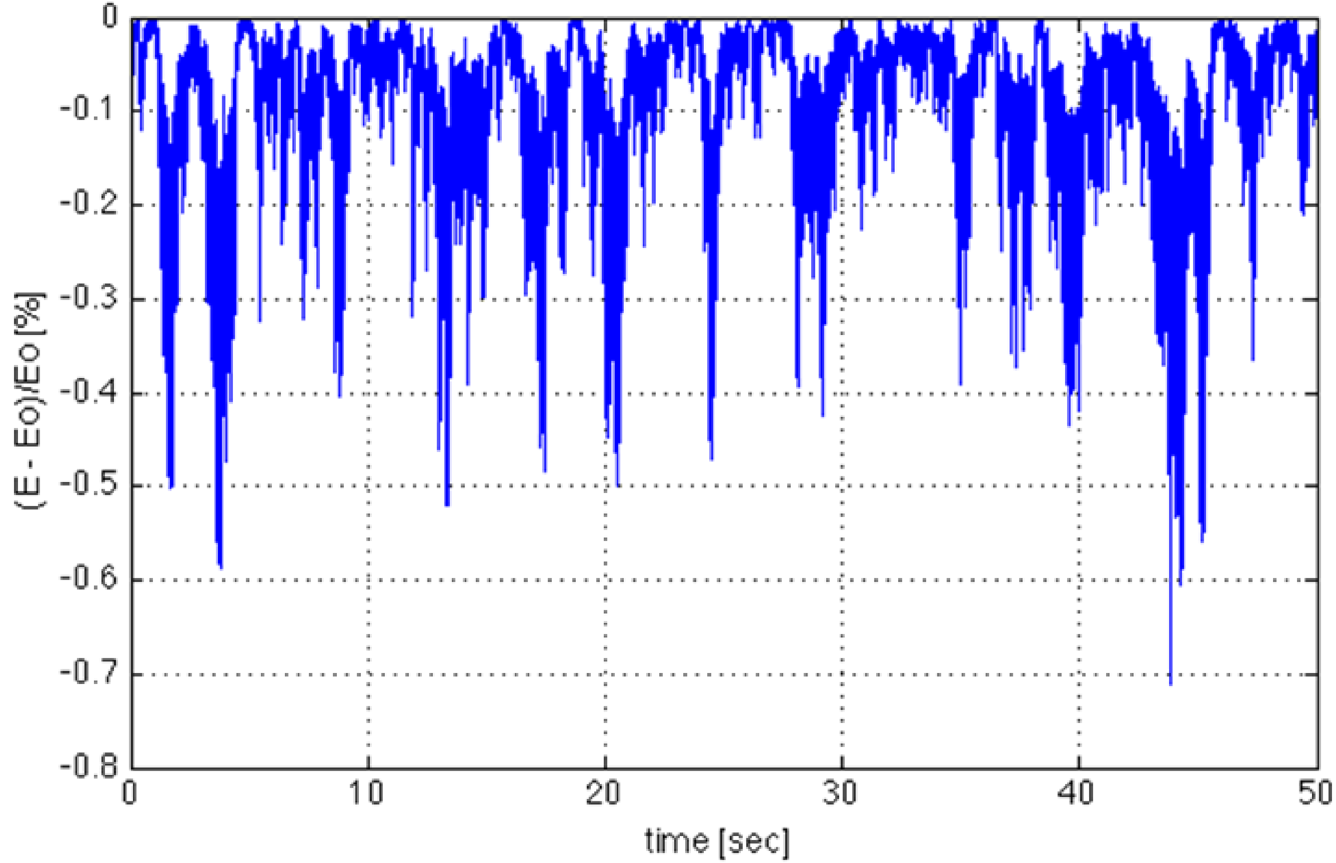


- Reduced detuning by an order of magnitude
- Achieved „open loop“ phase stability:13.2° → 2.0°
- 0.02° phase stability achievable
- Compensate multiple resonances
- Needs implementation into LLRF control and operation with beam



'BESSY' Microphonics Example

41 Hz mode driven randomly to yield a 1.5 Hz rms frequency variation – then solve cavity field level with a constant rf input and beam current



Resulting Energy Variation over Time: 9e-4 variation in a cavity energy gain, which if uncorrelated cavity to cavity, would produce 7e-5 beam energy variation at the end of the linac (ignoring the BCs and the various FB systems)

Claudio Rivetta

Bruker 10 kW CW Source

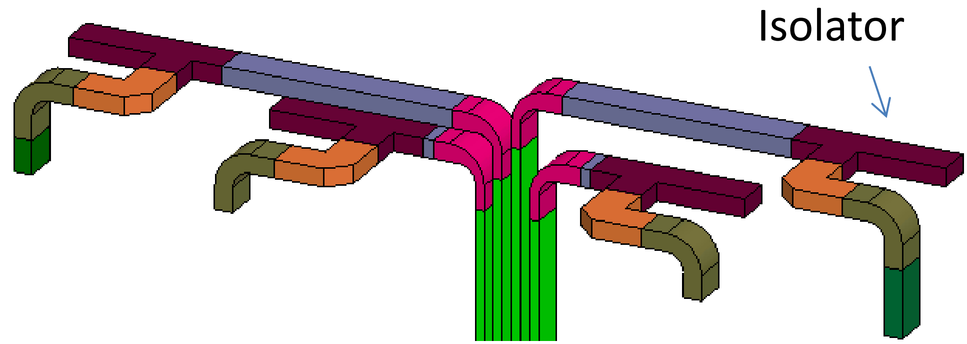
Consists of eight 1.25 kW water-cooled modules - each module has eight 160 W, isolated transistor units that are summed in a coaxial combiner – the output of the each module drives a common WR650 waveguide – no solenoid, HV PS, filament PS nor vacuum pump

Newer units with higher power transistors produce 16 kW in one rack

Two 10 kW units at HZDR and a 5 kW unit at Cornell

Waveguide Run between Gallery and Tunnel

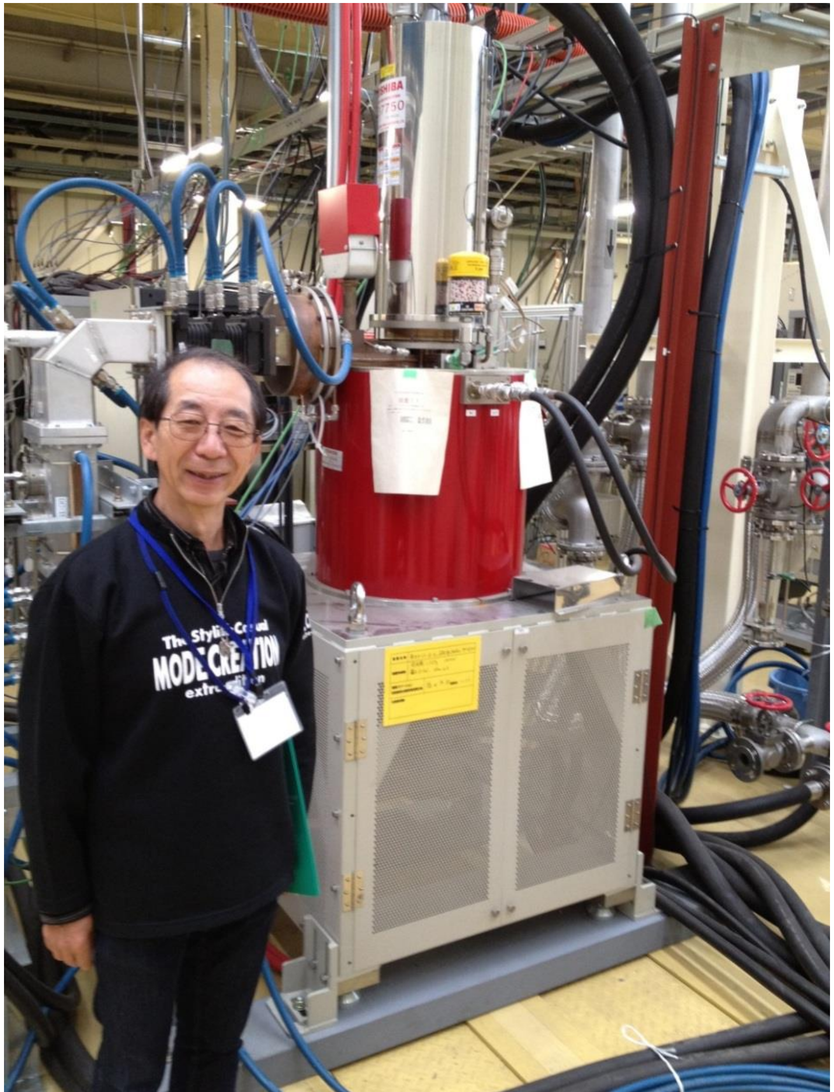
(Also considering 3” coax with ~ 2% additional loss)



27 in diameter,
15 feet long
penetrations
spaced by 6 m

Toshiba E37750 300 kW CW Klystron

(Need 5 Units plus Spare)



Beam Voltage	49.5 kV
Beam Current	9.8 A
Output Power	305 kW
Input Power	34 W for sat.
Perveance	0.89 uP
Efficiency	63.2 %
Gain	39.5 dB

Thompson 540 kVA, 55 kV PS for NSLS II

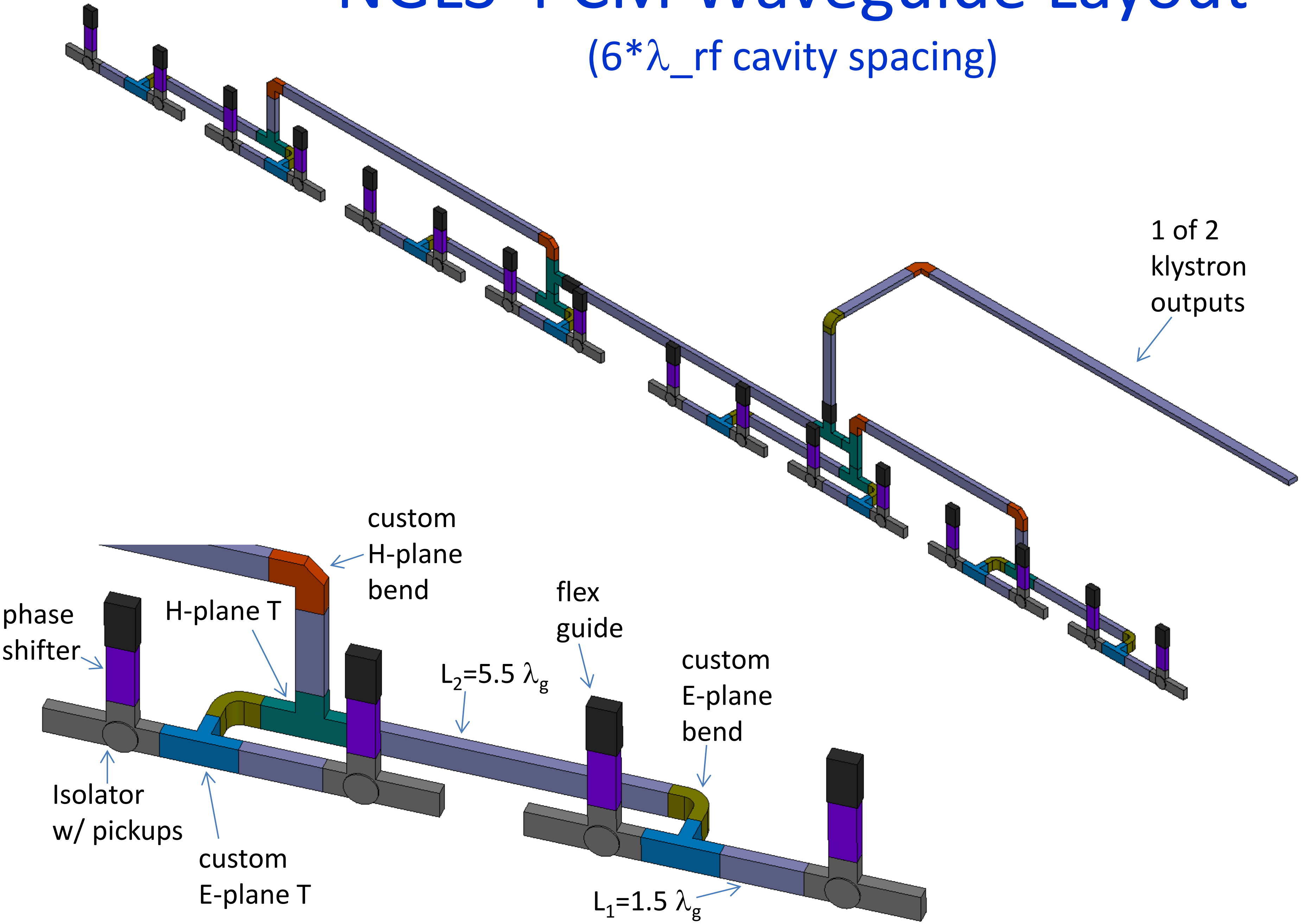
(PSM - summed switching supplies – claim 95 % eff)

Need 5 Units plus spare – maybe cluster so rotate role of spare

12 kV AC In
50 kV Out

NGLS 4 CM Waveguide Layout

(6*λ_rf cavity spacing)



SC Linac Milestones (version 03.10.2013)

SLAC

SC Linac Preliminary Design Review	03.2014
CM Pre-production Start	10.2014
SC Linac Final Design Review	12.2014
Begin SC Linac Procure / Fab	03.2015
Start CM Production	04.2015
(Start D & D SLAC Linac 0-10)	04.2016
Begin SC Linac Installation	10.2016
Cryomodule Production Complete	10.2018
Complete SC Linac Installation	02.2019
Complete Checkout & no-beam Comm	03.2019
Complete Checkout & beam Comm	05.2019
FIRST LIGHT	09.2019

Production:

48 months
2 yr start +
2 CM / 3
months

Installation:

28 months
2 CM / 3
months