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PIP II SRF linac: challenges, issues and status

Slava Yakovlev on behalf of SRFDD

PIP II meeting

16th February, 2016

Outline

- The goal is to remind the PIP-II SRF linac challenges and issues: what has been done, and what still should be done.
- General issues
- General design approaches
- Status of R&D
- Status of design and prototyping.

PIP II linac basic requirements:

Linac Beam Energy	800	MeV
Linac Beam Current	2	mA
Linac Beam Pulse Length	0.55	msec
Linac Pulse Repetition Rate	20	Hz
Linac Upgrade Potential	CW	

Pulsed operation issues compared to CW:

- Efficiency
- High Q_0
- Lorentz Force Detune
- HOMs

Efficiency (CW):

CW operation:

CM type	Number of CMs	Static loads per CM, (W)			Q_0 at 2K (10^{10})	Dynamic loads per CM, (W)	Total load at 2 K per CM, (W)
		70 K *	5 K *	2 K		2 K	2 K
HWR	1	250	60	14	0.5	23.3	37
SSR1	2	194	71	12	0.6	23.1	35
SSR2	7	145	50	9	0.8	52.5	62
LB650	11	64	8.7	3	1.5	75.5	79
HB650	4	118	17.2	5	2	195	200
Total		2828	715	146		2048	**2194**

2.5 kW ESS-type cryo-plant is considered to be delivered in the frame of IFCC.

- Beam power: 1.6 MW;
- RF power (r.m.s): ~ (1.6 MW + 20% overhead*) × 1.7** (eff) = 3.3 MW;
- Cryo: 2500 W (ESS cryo-plant) × 700(conv. factor)*** = 1.75 MW

Efficiency: $\lesssim$ 30% (small beam current!)

* microphonics, transmission line losses; best guess;

** RF source wall plug efficiency up to 60%, best guess;

***best guess – J. Theilacker, private communications.

Efficiency (CW):

Efficiency improvement:

- Q_0 increase: 2e10 → 4e10@2K → savings ~ 0.9 MW*, or ~$1M per year of operation;
- RF efficiency increase (smaller r.m.s. overhead for microphonics, higher RF source efficiency). 10% overhead decrease + 80% of the RF source efficiency give savings of 1.1 MW, or ~$1.4M/year of operation. Note that lack of success in resonance control may require additional RF power, and thus, additional money.

High Q_0 program and resonance control program are critical!

- *Smaller turbine and smaller cold compressor wheels.

Efficiency (pulsed operation):

Table 2.8: Cavity parameters for operation in the pulsed regime

CM type	Time constant τ, (ms)	Normal cavity discharge		Accelerated cavity discharge	
		Cryo-duty factor, %	Dynamic cryo-loads per CM (W)	Cryo-duty factor, %	Dynamic cryo-loads per CM (W)
SSR1	3.6	6.8	1.6	3.8	0.88
SSR2	5.8	9.9	5.2	5.3	2.8
LB650	5.6	9.7	7.3	5.2	4.0
HB650	5.6	9.8	19.2	5.2	10.3
Total*			220		130

* This value includes contribution of HWR cryomodule operating in CW mode.

2.5 kW ESS-type cryo-plant: probably, may operate at 30-40% of the full power (best guess, details depend on the specific plant/vendor)

- Beam power: 17.6 kW;
- RF power (r.m.s): 3.3 MW × 0.09 (Rf duty factor*) ≈ 300 kW;
- Cryo: 2500 W (ESS cryo-plant) × 700(conv. factor)) × 0.35 ≈ 610 kW (efficiency driver)

Efficiency: $\lesssim$ 2% (small beam current!)

* RF duty factor =($\tau \times \ln 2 + t_{beam}$)*20 Hz = 0.09

Efficiency (pulsed operation):

- Possible efficiency improvement:
  - Q_0 increase from 2e10 to 4e10, and
  - Buy smaller turbine and smaller cold compressor wheels*:

  Cryo plant: ~90 kW, and efficiency $\lesssim$ 4-5%

  High Q_0 program is useful even in pulsed regime.

- Further efficiency increase:
  - Optimization of the cavity filling process and
  - Faster cavity discharge
  - RF source efficiency improvement

*J. Theilacker, private communications

Resonance Control (pulsed operation):

Lorentz Force Detune:

Table 2.11: Requirements for RF power*

CM type	Power transferred to beam per cav. (kW)	Microphonics amplitude (Hz)	Cavity half-bandwidth, $f/2Q_L$, (Hz)	Power transfer efficiency	Power margin	Peak RF power per cavity (kW)
HWR	4	20	33	90%	80%	6.5
SSR1	4.1	20	43	90%	80%	6.1
SSR2	10	20	28	90%	80%	17
LB 650	23.8	20	29	94%	80%	38
HB 650	39.8	20	29	94%	80%	64

Table 2.12: Functional requirement specifications on cavity detuning due to helium pressure variations and Lorentz force detuning (LFD)

CM type	HWR	SSR1	SSR2	LB650	HB650
Sensitivity to He pressure (FRS), df/dP, Hz/Torr	<25	<25	<25	<25	<25
… (measurements), df/dP, Hz/Torr	13	4.0	-	-	-
Estimated LFD sensitivity, df/dE^2, Hz/(MV/m)^2	-	-5.0	-	-1	-1
… (measurements), df/dE^2, Hz/(MV/m)^2	-1.5*	-4.4	-	-	-
Estimated LFD at nominal voltage (FRS), Hz	-	-500	-	-253	-317
… (measurements) at nominal voltage, Hz	-122.4	-440	-	-	-

Pulsed SRF accelerators, existing and projects	Half-bandwidth, Hz	LFD, Hz	LFD/HBW
SNS (LB/HB)	550/500	300/100	0.55/0.2
ESS (HB)	500	400	0.8
FLASH/XFEL (electrons)	185/141	550	3/4
PIP II (LB/HB)	29/29	253/317	9/11

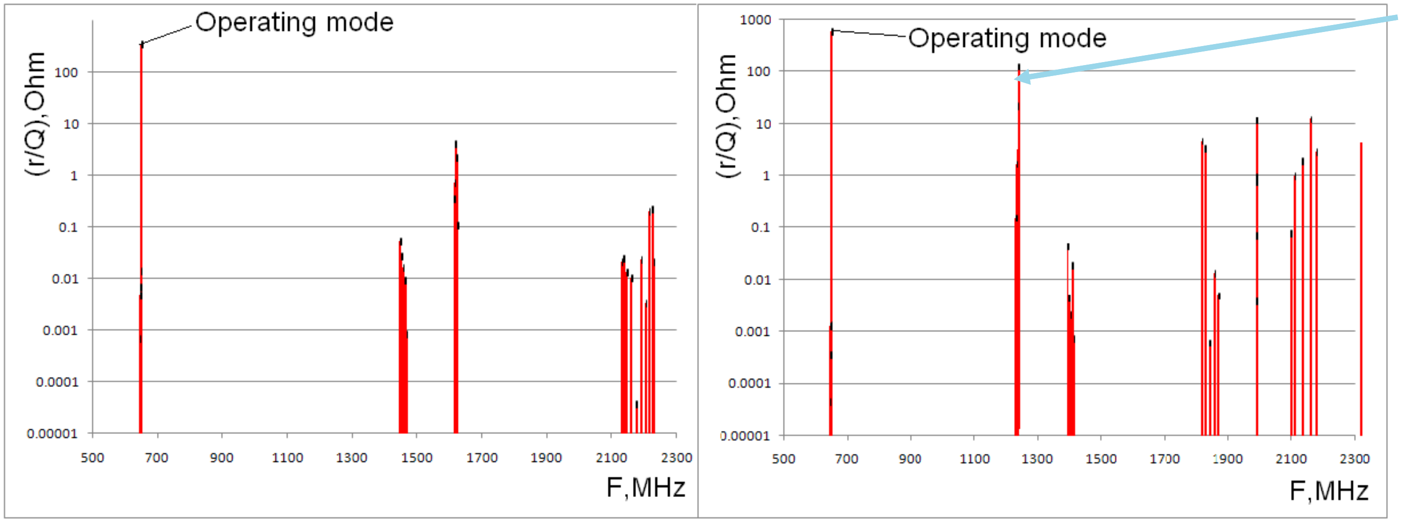
Lorentz Force Detune is an issue!

HOMs:

Short beam pulse, t_{beam} =0.55 msec:

- Resonance excitation if $|f_{HOM}-f_{beam\ spectrum\ line}| \gtrsim 1/2t_{beam}$=1 kHz;
- HOM voltage: $U = 1/2(r/Q)\omega I_{beam}t_{beam}$ ~ 560 kV, or 3% of acceleration voltage.

Both resonance excitation and BBU should not be an issue, but should be checked!



(r/Q) = 130 Ohm:
f=1241.1 MHz

β = 0.61 β = 0.9

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General Design Approaches:

a. All the CMs are based on SSR1-type concept
b. SSR1 and SSR2 should be as much similar as possible:
   - SSR2 should be based on the same concept of the He vessel as SSR1 with small df/dP;
   - SSR2 should have similar tuner as SSR1, the tuners should contain as much identical parts as possible. The goal is to use identical tuners.
   - SSR2 should have the same HP coupler as SSR1.
   - SSR1 and SSR2 CMs should contain as much identical parts as possible;
   - SSR1 and SSR2 CMs have the same solenoids.
c. LB 650 and HB should be as much similar as possible:
   - LB 650 should be based on the same concept of the He vessel as HB 650 with small df/dP;
   - LB 650 should have similar tuner as HB 650, the tuners should contain as much identical parts as possible. The goal is to use identical tuners.
   - LB 650 should have the same HP coupler as HB 650.
   - LB 650 and HB 650 CMs should contain as much identical parts as possible;

General Design Approaches:

a. The first HB 650 CM will contain 3 beta=0.9 cavities (Fermilab) and 3 beta=0.92 cavities (IIFC);
  - Beta=0.9 cavity should fit exactly the slot for beta=0.92;
  - Beta=0.9 cavity should have almost the same tuner as beta=0.92;
  - Beta=0.9 cavity should have the same coupler as beta=0.92;

b. IIFC organizations responsible for the PIP II CMs:
  - SSR1 – Fermilab
  - SSR2 – BARC (dressed cavity only)
  - LB 650 – VECC (dressed cavity only);
  - HB 650 – RRCAT/Fermilab (strong overlap).

c. Strong cooperation is necessary between:
  - Fermilab and BARC on SSR1 and SSR2 CMs;
  - Fermilab, VECC and RRCAT on LB 650 and HB 650.

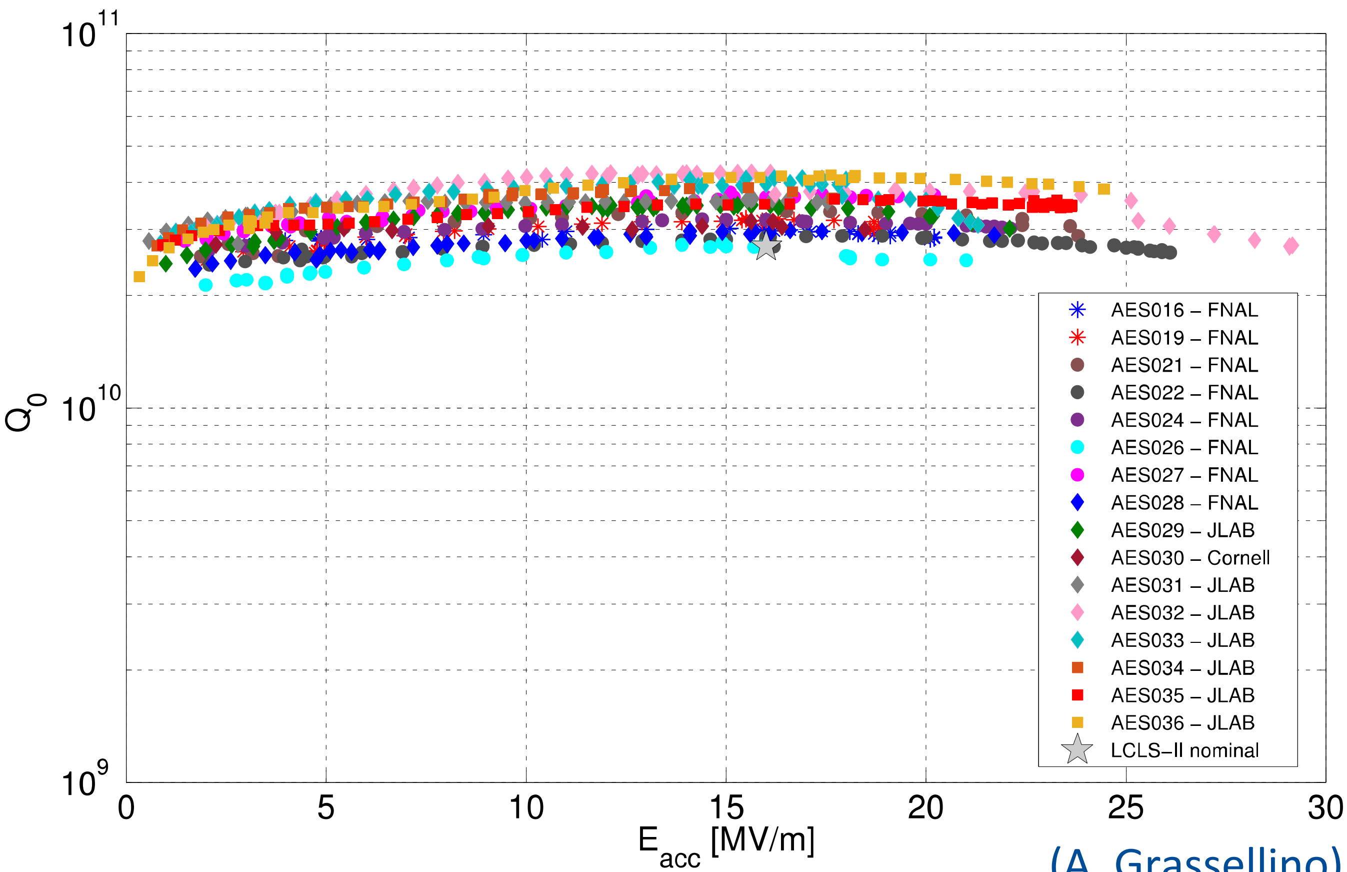
Status of R&D:

High Q0:

- N-doping evolved from discovery to proven technology;
- It is a basic technology for LCLS II, operating at 1.3 GHz;
- Same sequence of investigations
  - Single cell cavity tests;
  - Five cell cavity tests;
  - Dressed five cell cavity tests

  is necessary to finalize the technology proof at 650 MHz.

LCLS2 protoype cryomodules nine cell vertical test results doping recipe 2/6 (FNAL developed)

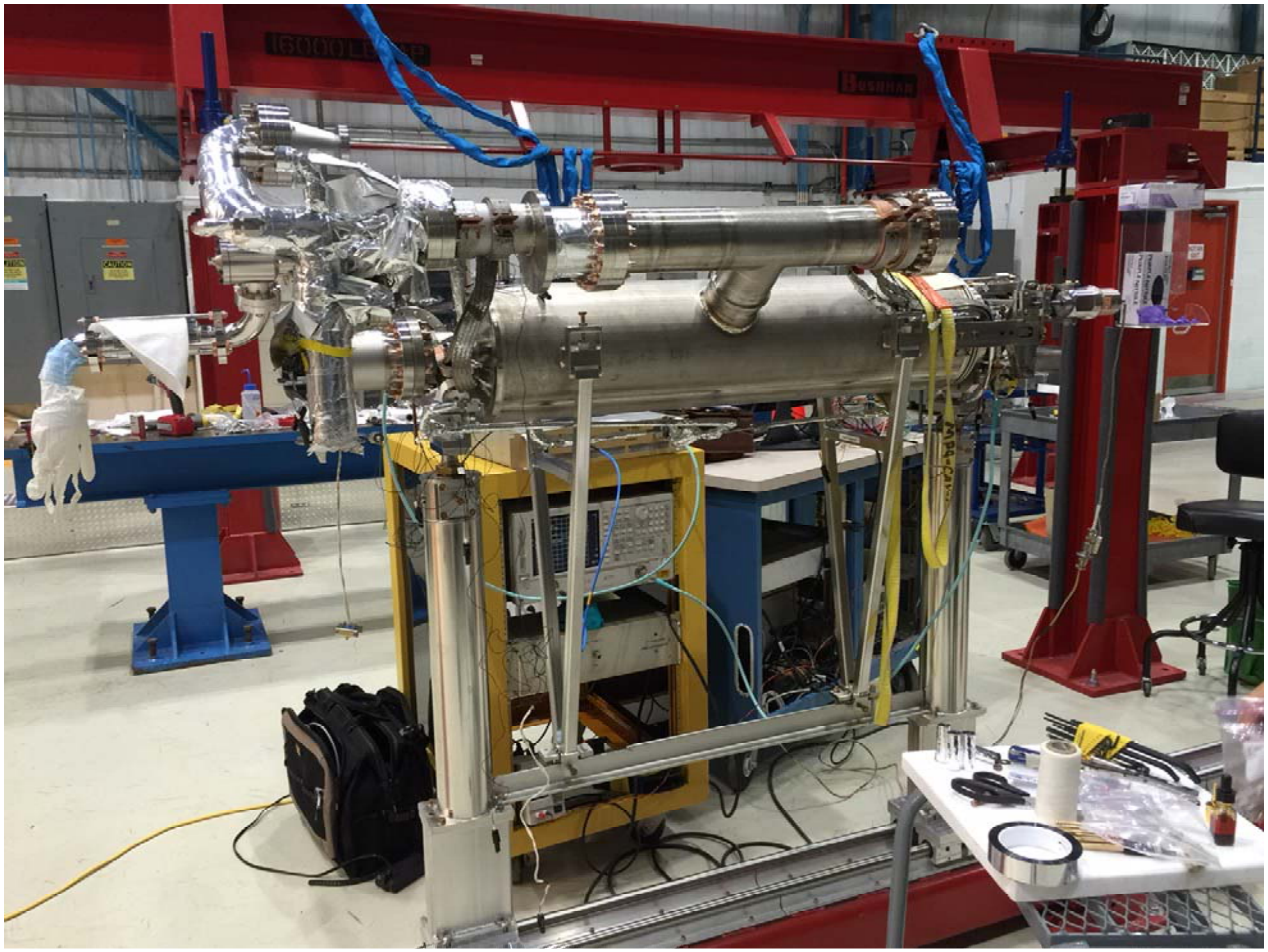


(A. Grassellino)

Jlab and FNAL prototype cryomodules cavities achieved world record values:
Avg Q (16 MV/m, 2K)= 3.5e10, Avg Quench field ~ 22 MV/m

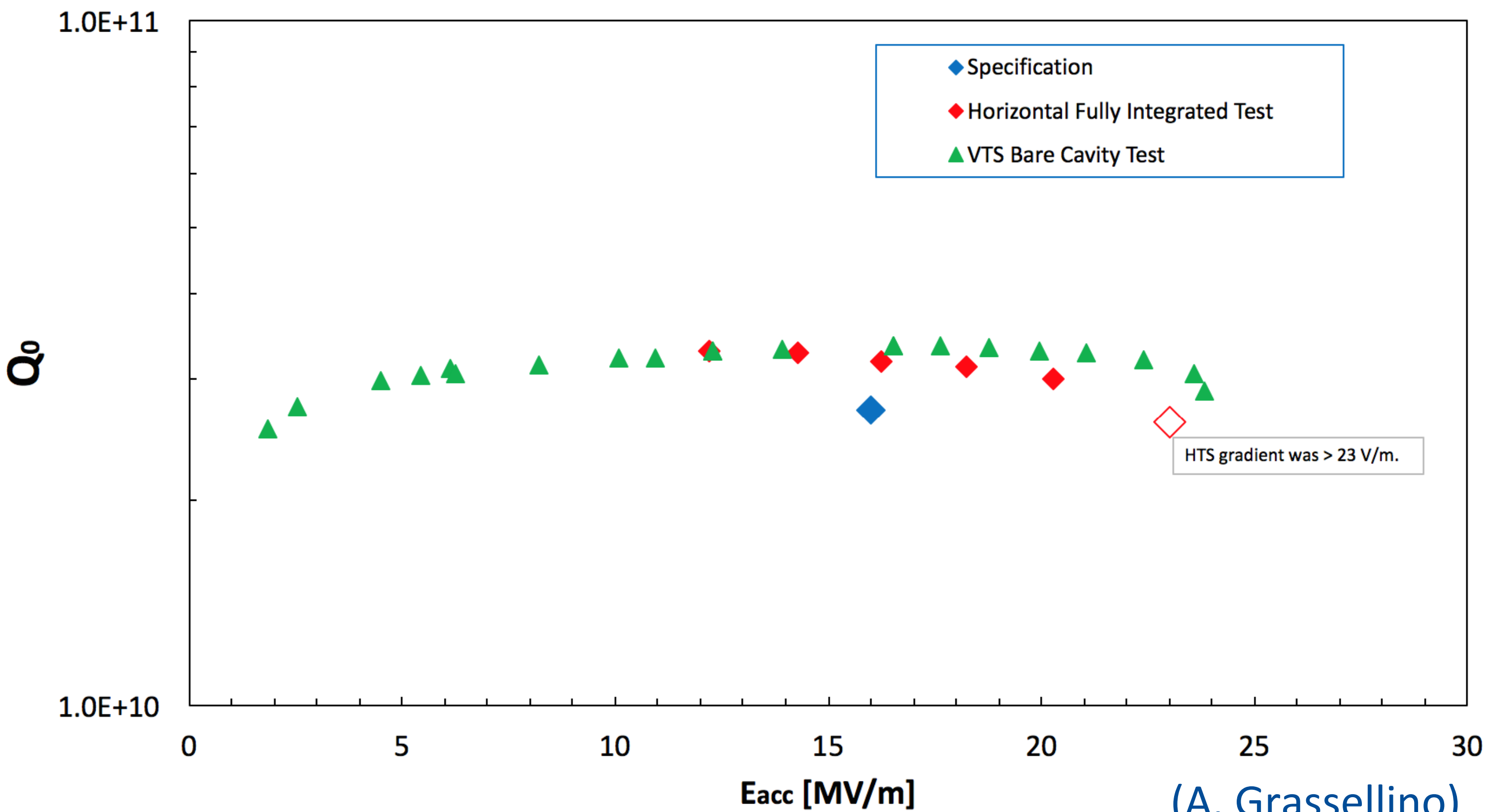
Fully Integrated Test at FNAL – TB9AES021

(A. Grassellino)



High power coupler, HOMs, tuner, double layer magnetic shielding…

Record Q > 3e10 at 2K, 16 MV/m in cryomodule environment for LCLS-II cavity

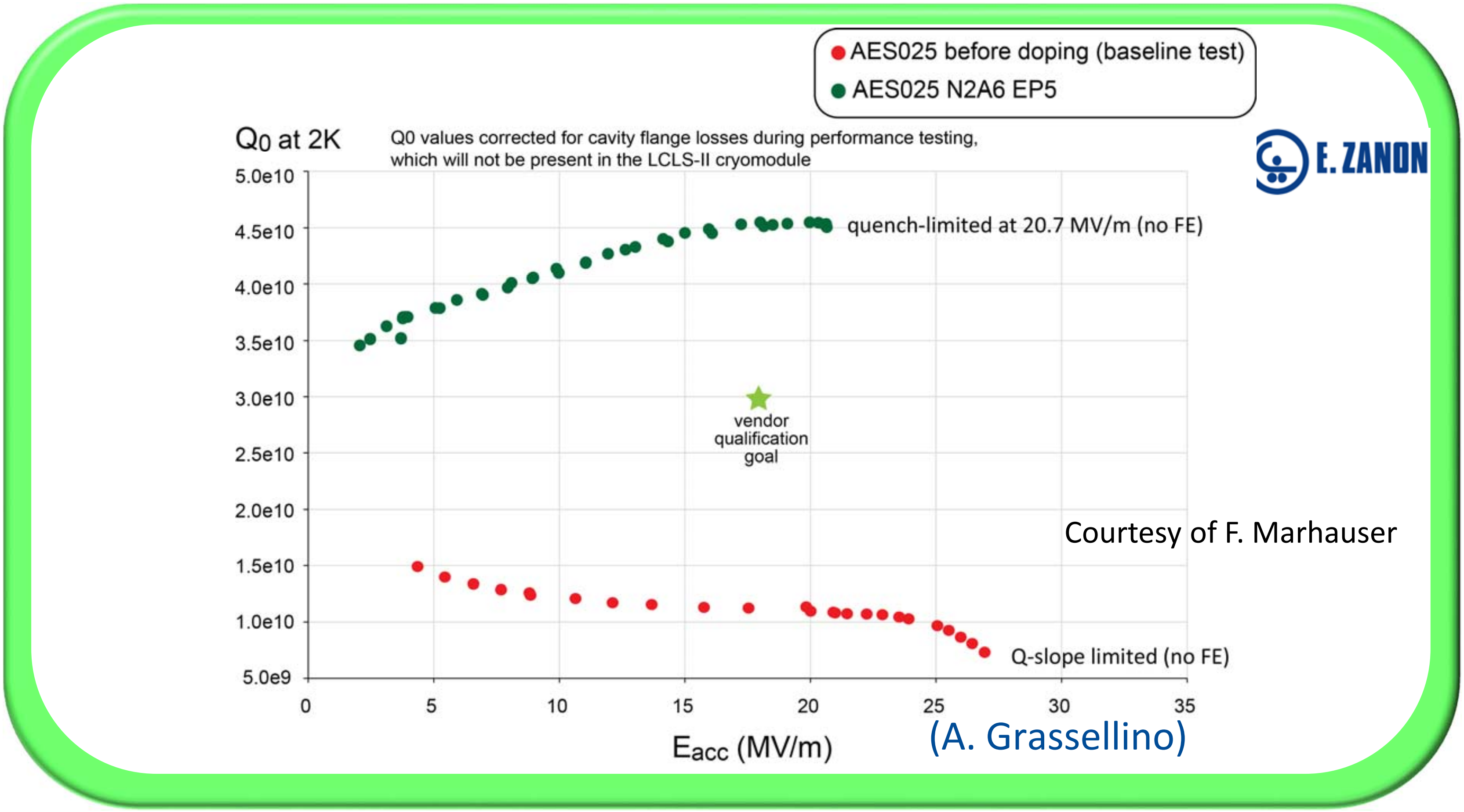


(A. Grassellino)

No Q degradation from vertical test to “accelerator conditions” with unique techniques discovered and developed at FNAL for: cooldown procedure through critical temperature, HOMs/high power coupler thermal strapping, and magnetic shielding

SRF Research milestone – Successful nitrogen doping technology transfer to industry for LCLS-II production

– Four times higher Q (cavity efficiency) at LCLS-II operating gradient



Status of R&D:

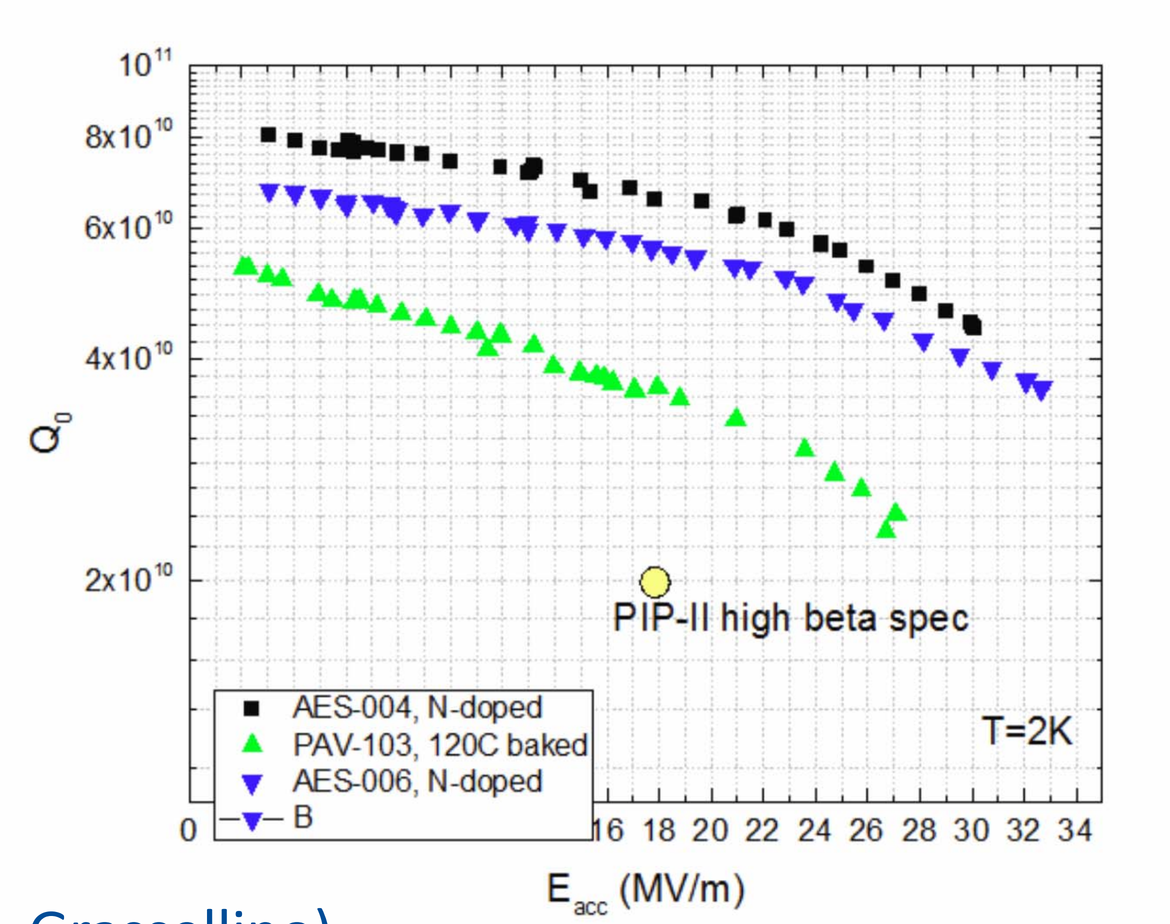
High Q status and plan forward:

- Surface treatment recipe established on single cell
- Apply doping to five cell cavities, and tune it to best performance
  - First five cell treated with baseline, for test next week
- Study flux expulsion and if poor, study pre - heat treatment step to achieve efficient magnetic flux expulsion
- Design of magnetic shield for low remnant magnetic field (double layer shield + coils, as LCLS-2?)

(A. Grassellino)

Status of R&D:

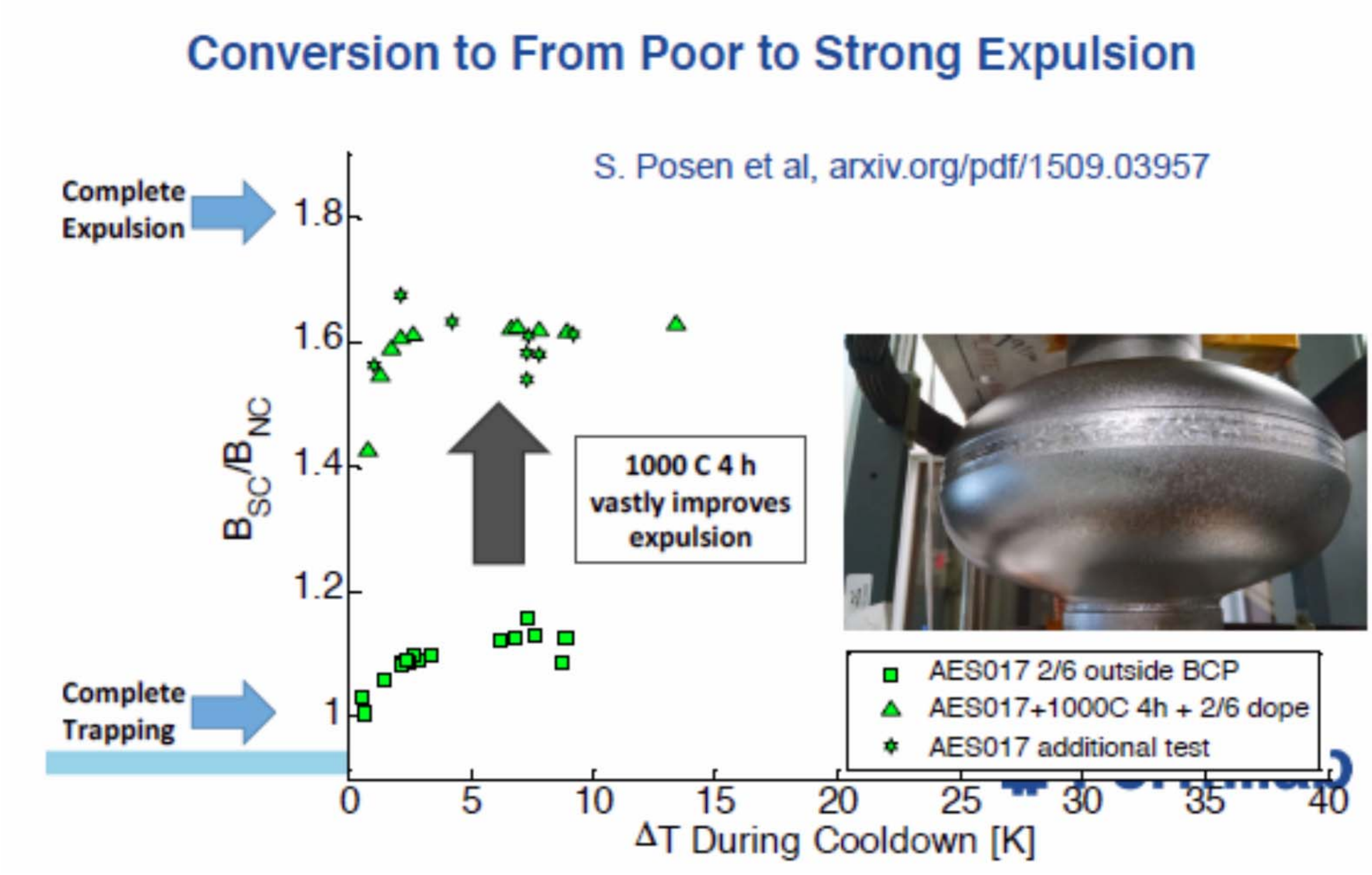
High Q status and plan forward:



(A. Grassellino)

Status of R&D:

High Q status and plan forward:



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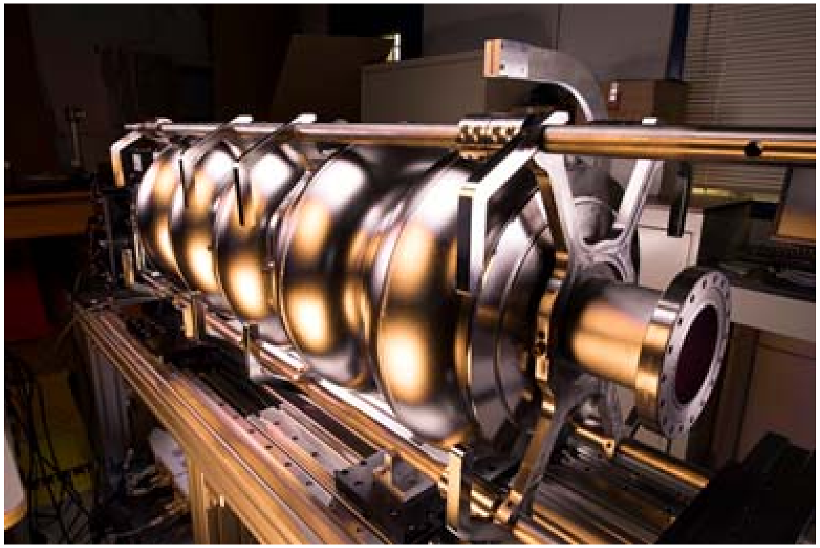
Status of R&D:

Cavity processing and testing – plan forward:

Five cell 650 MHz, beta=0.9 cavity preparation for VTS

5-cell B=0.9 650 MHz cavity prepared for vertical testing in February, 2016.



Optical Inspection of 5-cell B=0.9 650 MHz cavity

A. Rowe

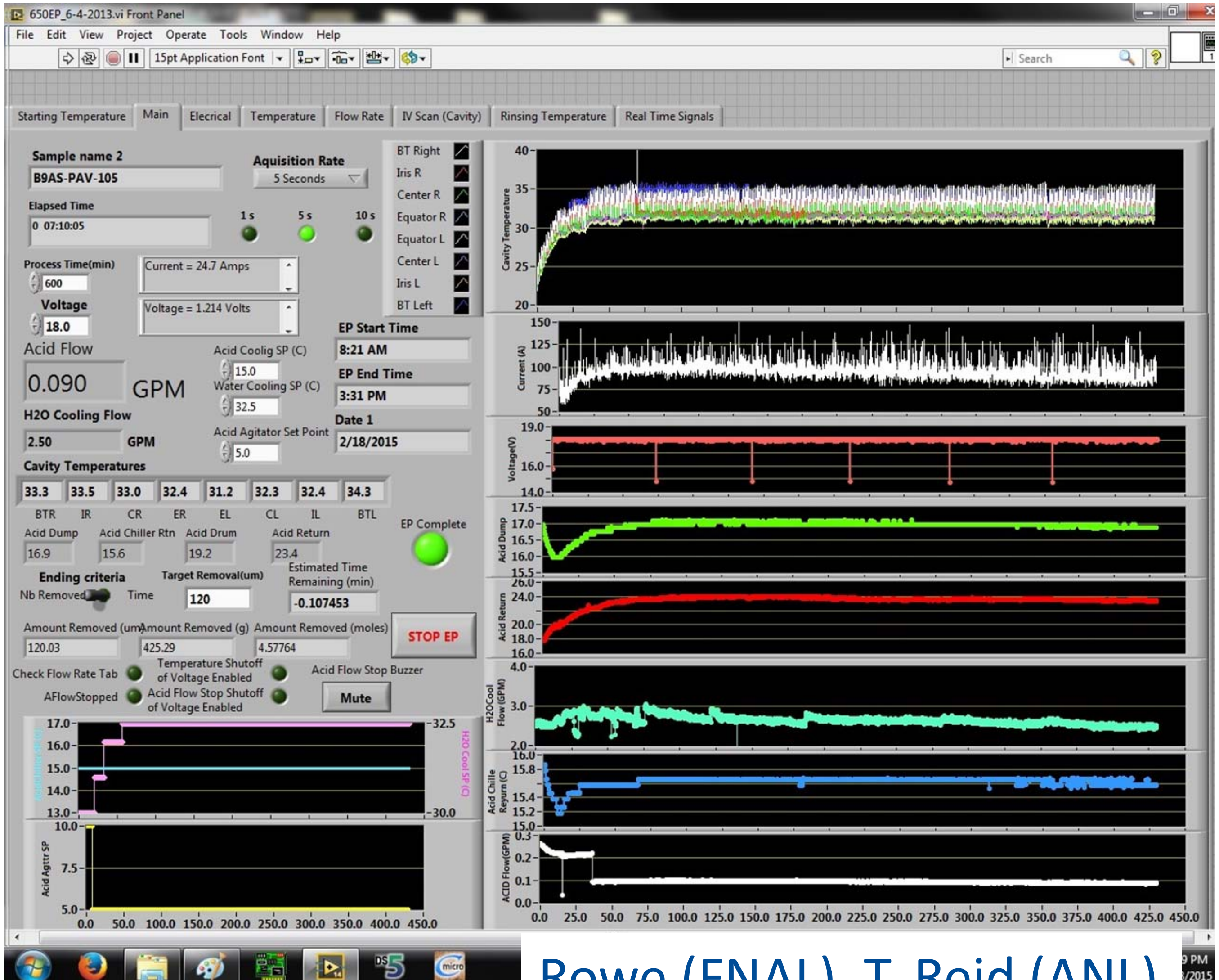
650 MHz EP + Vertical Test Prep (ANL + AES)

ANL EP Data Set

- Meets desired criteria for both 1-cell and 5-cell EP.
- HPR and VT prep for 1-cell proven, 5-cell TBD next 5-cell test in Feb.

AES EP Data Set

- Does not meet expectations, but issues have been identified and will be corrected prior to 5-cell EP in March 2016.



Rowe (FNAL), T. Reid (ANL)

Status of R&D:

Resonance control (LFD and microphonics)

- Controlling detuning in the PIP-II cavities
  - Is critical to the successful operation of the machine
  - Will require a combination of passive and active measures
  - Requires a coordinated effort across the entire machine
    - Cavity, Cryomodule, Cryogenic, RF, Mechanical, Civil,…
- Even with the best passive measures, active control will be required
  - Without passive measures, active control may not be enough
- Considerable progress on active control has already been made here at FNAL
- Considerably more work on active control will be required before a viable resonance control system for the machine can be designed and deployed

(W. Schappert, Y. Pischalnikov)

Status of R&D:

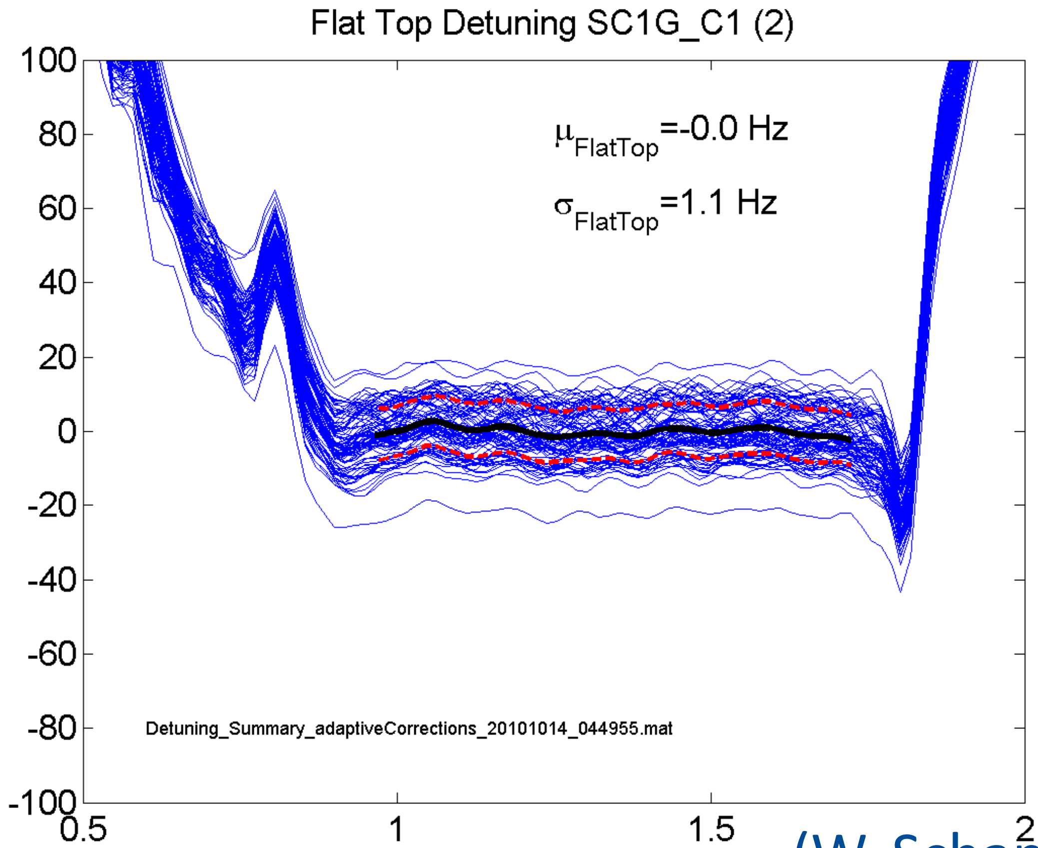
Resonance control (LFD and microphonics)
What Has Been Accomplished So Far

- Adaptive LFD Control Algorithm
  - developed at FNAL for NML/CM1
  - Tested at KEK during the S1G cryomodule test at KEK in 2011 with 4 distinctly different ILC cavity/tuner designs
  - Suppressed detuning from several hundreds of Hz to several 10s of Hz in all four cavity/tuner types
- Microphonics suppression in SSR1
  - CW tests using in 2011 and 2014 yielded promising results <1 Hz RMS

(W. Schappert, Y. Pischalnikov)

Status of R&D:

Resonance control (LFD and microphonics)
What Has Been Accomplished So Far



(W. Schappert, Y. Pischalnikov)

Status of R&D:

Resonance control (LFD and microphonics)
What Still Needs to be Done

- Detuning control program for LCLS-II outlined in conjunction with Larry Doolittle of LBL in early 2014
  - Measure cavity piezo/detuning and stored-energy/detuning transfer functions
  - Extract an approximate low order transfer function using proven system-identification techniques (Kalman-Ho Minimal State Space Realization)
  - Construct a combined optimal electro-mechanical controller (Linear-Quadratic Gaussian Regulator) from the low-order transfer function
- Program is equally applicable to PIP-II
  - Resulting controller is mathematically optimal in the Least-Squares sense
- Improvements and testing of algorithm will be implemented during cold testing program at STC.

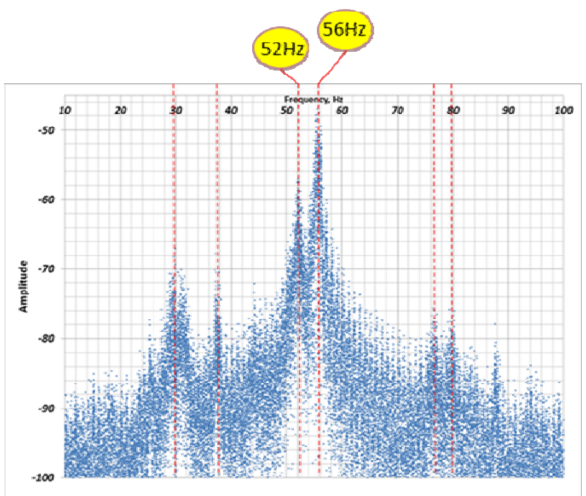
  \- Some work can be done with simulators but simulators are only as good as the experience that goes into building them.

(W. Schappert, Y. Pischalnikov)

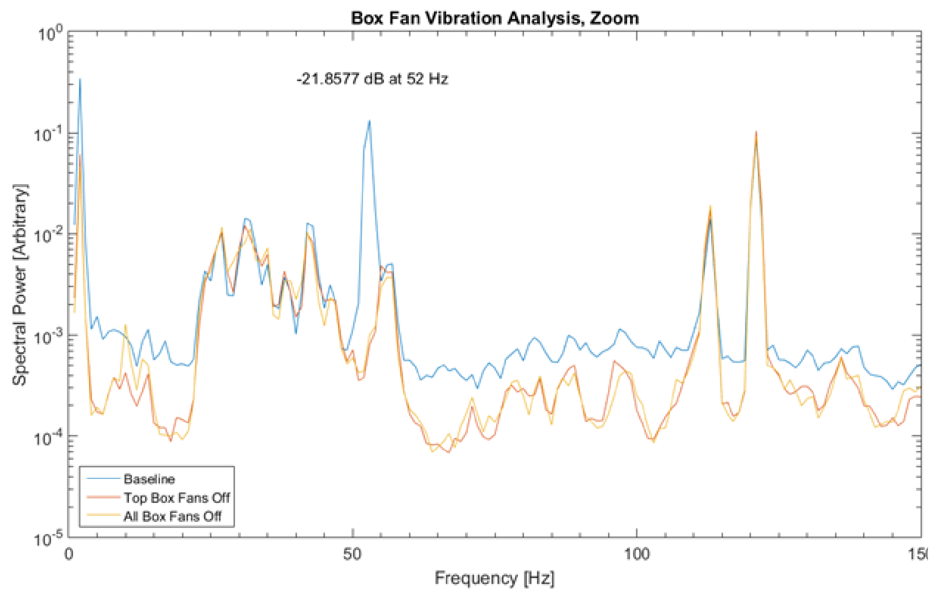
Status of R&D:

Active compensation alone may not work if other aspects ignored. Resonance Control Team is working with PIP II engineers to develop "Best Practice" recommendations. -- Will be involved into review of the cryomodule designs & design verification efforts to address passive microphonics during the stage of the design

Example at HTS(FNAL). Box fans installed on the top of the cryogenics system feed-can (to prevent valve from freezing) Created large 52Hz ibration/microphonics on the SRF cavity. As soon as fan OFF 52Hz components dropped on 22db.
It is simple way to mitigate this problem– for example to install some type of heater… <u>(small modifications—large effect)</u>



(W. Schappert, Y. Pischalnikov)

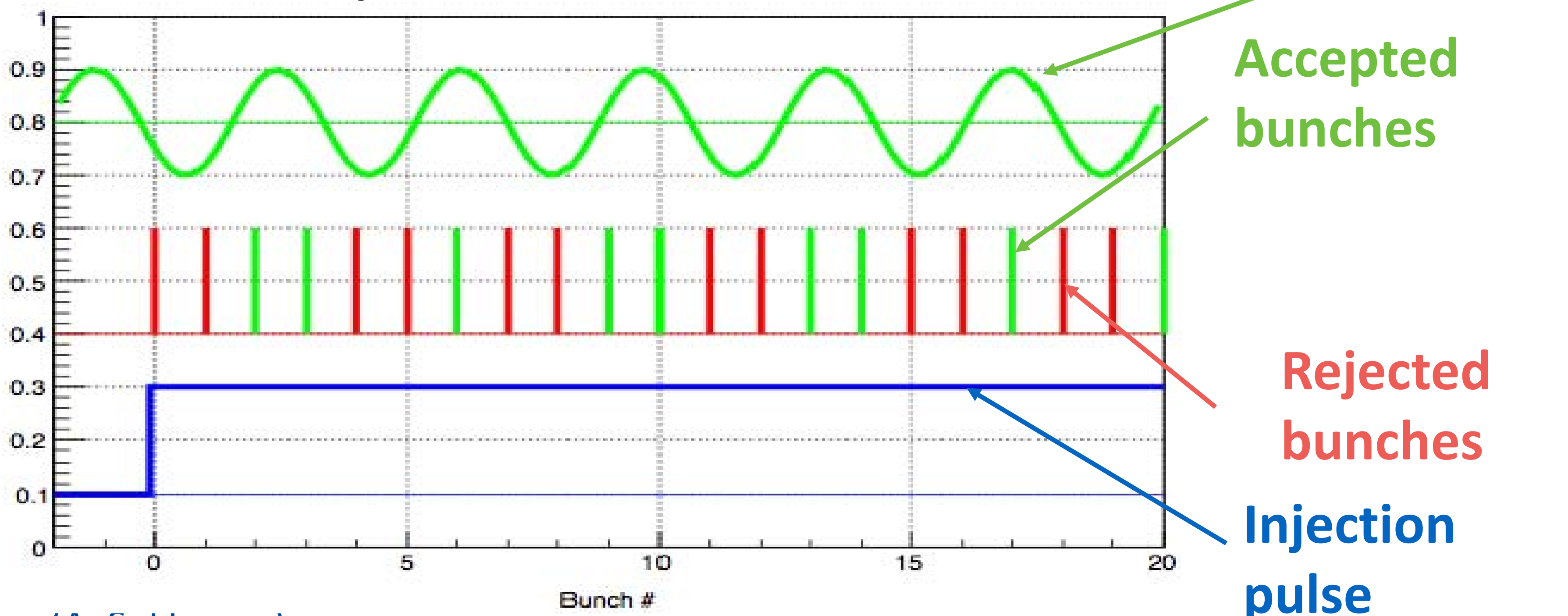


Status of R&D:

HOMs:

Bunch structure for injection to Booster

- Injection pulses 0.55 ms, 20 Hz
- Bunch frequency 162.5 MHz, bunch charge 30 pC, 5 mA from RFQ
- Booster RF at injection 44.705 MHz

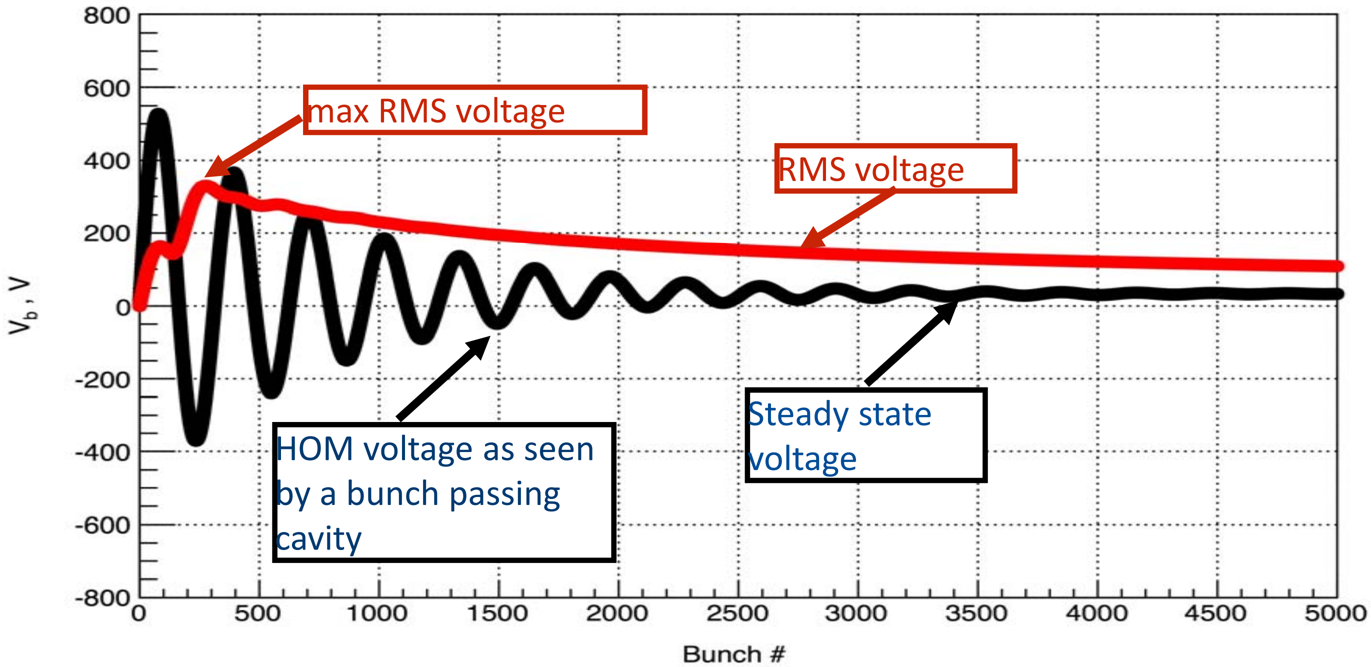


(A. Sukhanov)

Status of R&D:

HOMs: **Transition at the beginning of injection pulse**

- Transition effects on longitudinal beam dynamics in HB650 section of linac
- Example: monopole mode #4 (649.5 MHz, R/Q=178 Ohm)
- Use unrealistically small value of Q_L = 1e4 here to demonstrate transition to steady state; no bunch removal (44.705 MHz)
- We can use max RMS voltage to characterize energy spread from bunch to bunch



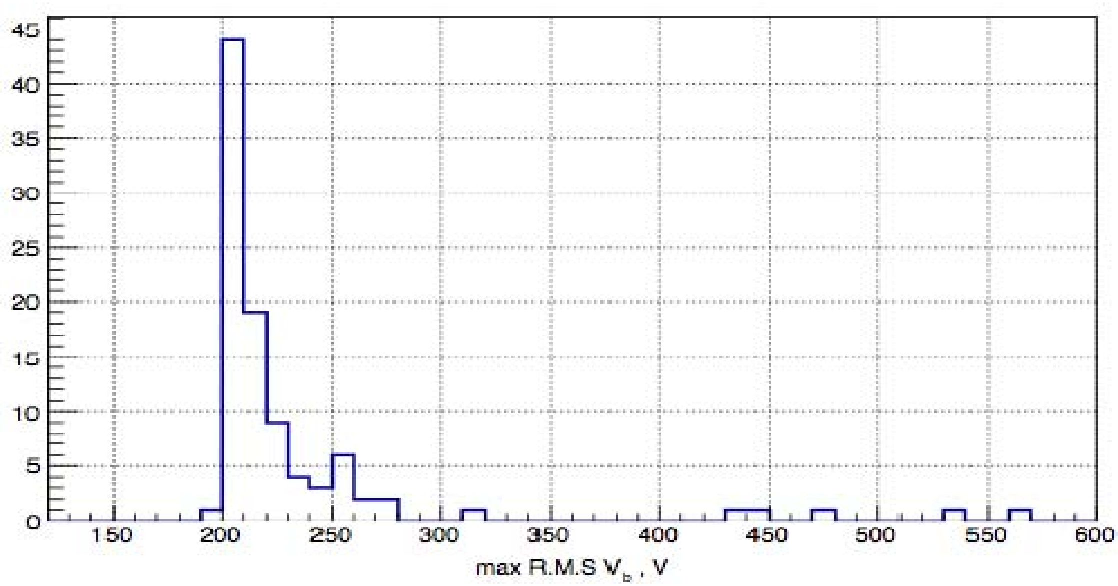
(A. Sukhanov)

Status of R&D:

HOMs: **Transition at the beginning of injection pulse**

- Non-propagating monopole HOMs (freq. below 2.3 GHz) in 5-cell HB650 cavities
  R/Q depends on bunch velocity; use max R/Q w.r.t. beta; Q_L = 1e7
  Random variation of HOM freq. from cavity to cavity with sigma = 1 MHz
  Max value of bunch voltage RMS characterize bunch energy spread
  Relative energy variations of bunches in injection pulse 230V/400MV ~ 6e-7

  - Not an issue! However, more detailed simulations are necessary, for both resonance excitation and BBU.



(A. Sukhanov)

Status of design and prototyping.

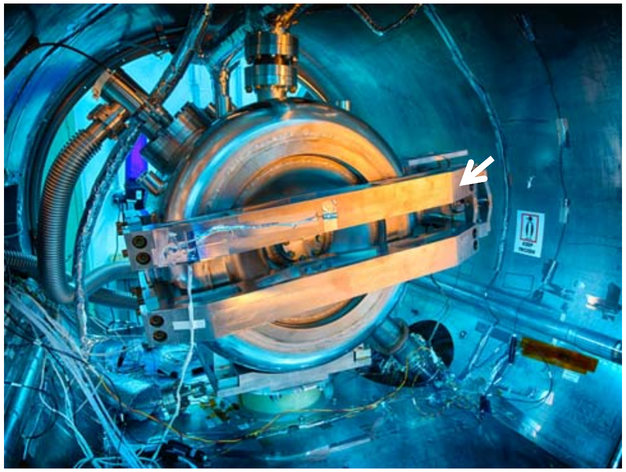
SSR1: cavities and helium vessel

Status

- The SSR1 cavities were designed and optimized to work in CW mode only. Effort was put to minimize the df/dp (dominant source of cavity detuning in CW) and validate the structural design according with the ASME Code.
- The production of 10 cavities with helium vessel is completed and they will be processed for the validation of performance in STC. The first jacketed cavity was successfully processed and tested with production coupler and prototype tuner.
- The LFD was not optimized for PXIE (PIP-II). The performance rely on the active resonance control only.

	df/dp [Hz/Torr]	S106	S107	S108	S109	S110	S111	S112	S113	S114
Measured	Bare cavity (with transition ring)	-564	-561	-553.5	-555.1	-568.8	-525.8	-524.6	-544.7	-557.2
	With new designed He Vessel (without Tuner)	0	8	-1.2	5.4	7.9	2.7	9.0	6.3	10
	In operating condition	0*	4	0*	2*	4*	2*	5*	3*	5*

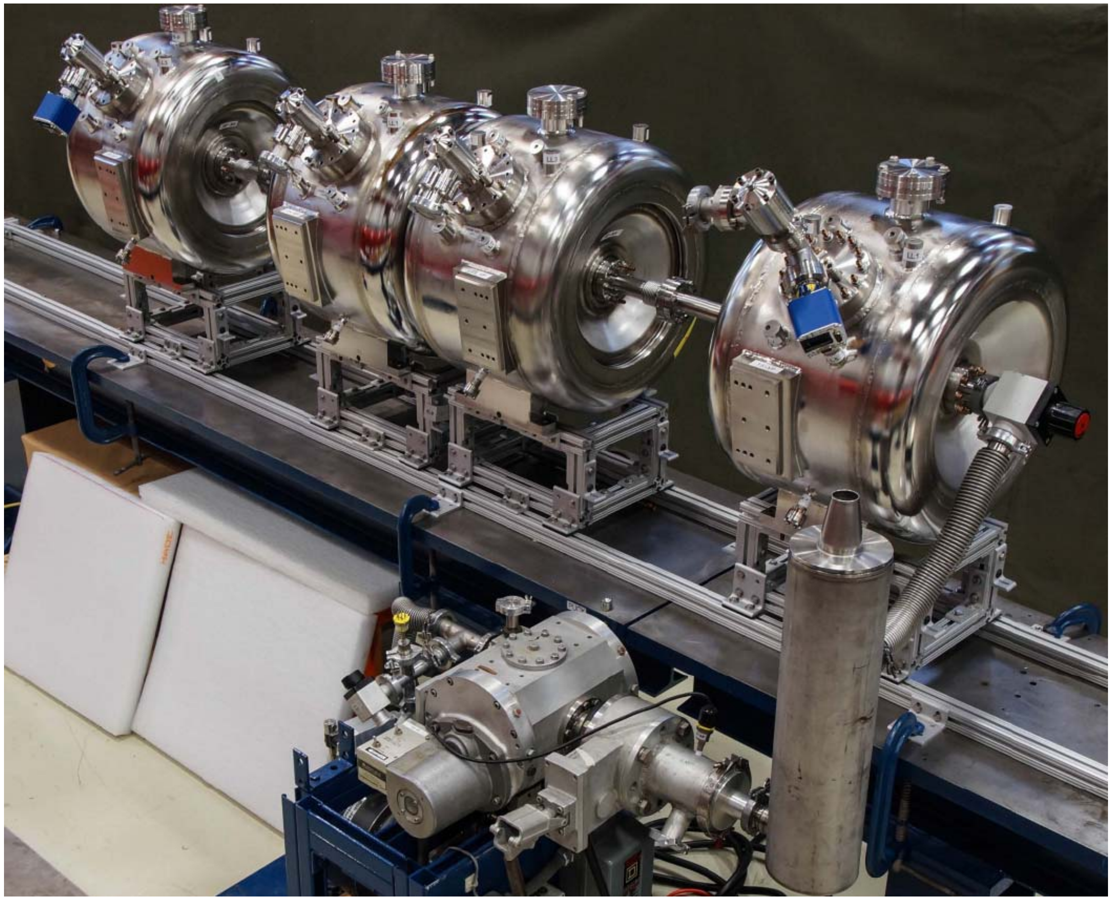
* Not measured yet (they are based on the test results in STC of S1H-NR-107)



(D. Passarelli, L. Ristori)

Status of design and prototyping.

SSR1 cavity string mock-up



(D. Passarelli, L. Ristori)

Status of design and prototyping.

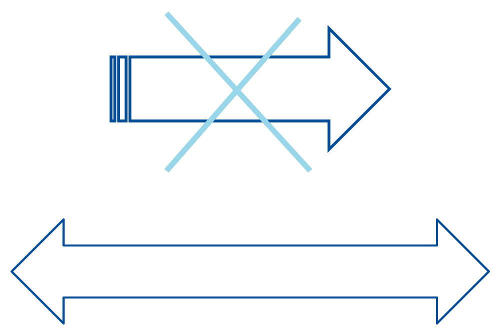
SSR1: cavities and helium vessel

Suggested R&D activities

- Study of the vibrations' effects on the resonance frequency of the cavity in operating condition (cryomodule in the tunnel). Mathematical model to describe the influence of each single source of vibrations on the cavity performance.
- Minimization of LFD during design phase (passive compensation).
- Consider other manufacturing technologies to speed up the production of such cavities with complex shape.
- Improve the "parallel design" RF/mechanical:

Electromagnetic Design

- Shape optimization
- Multipacting analysis
- Higher order modes
- Kick analysis
- Multipole effect
- Pressure Sensitivity
- Lorentz force detuning



Mechanical Design

- Niobium shell design
- Vessel design
- Shape optimization
- Pressure Rating
- Stiffening and detuning
- Modal analysis
- Tuner Design

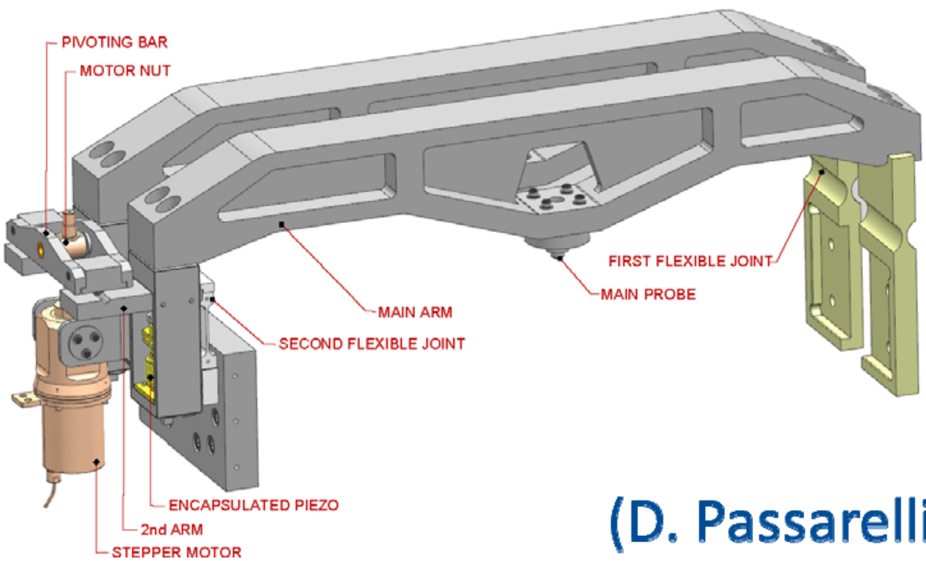
(D. Passarelli, L. Ristori)

Status of design and prototyping.

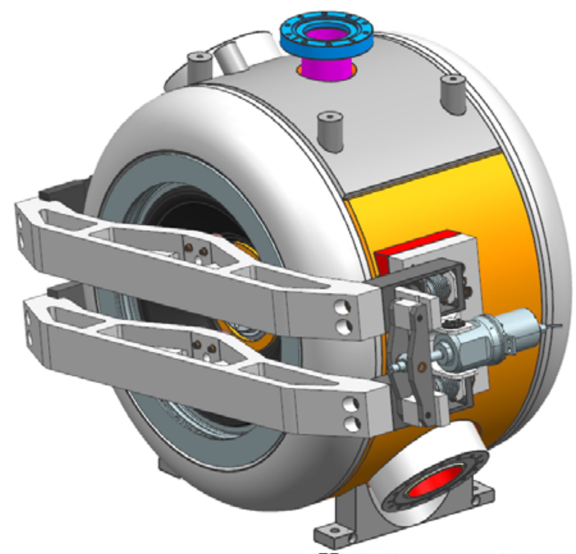
SSR1 Tuner

Status

- The first prototype tuner was designed, prototyped and tested.
- It satisfies the technical requirements and it is structurally sound.
- Several structural details will be improved in the design of the production tuner based on the tests experience.
- The stepper motor appears to be reliable and adequate for such type of tuner.
- Instead, the piezos "homemade encapsulated" appears to have some issue. It will be considered to adopt the same piezo "pre-encapsulated" used in LCLS-II tuners.



(D. Passarelli, L. Ristori)



Status of design and prototyping.

325 MHz coupler:

- Three couplers and DC blocks were fabricated.
- Couplers test stand were created. Test stand allows to test couplers up to ~50 kW, CW (with 10 CW RF source)
- Two couplers and DC blocks were tested at test stand.
- One coupler was tested with SSR1 cavity in STC.
- Ten 325 MHz couplers are under production. First couplers will be delivered in this month.

Test results:

- Design of DC blocks was improved. Current DC block power capability ~ 50 kW, full reflection.
- Couplers demonstrated power capability ~ 30 kW, full reflection, CW. One coupler was destroyed at power level ~ 50 kW, full reflection, CW.
- At STC test the coupler demonstrated thermal parameters close to calculated, they meet the FRS.

S. Kazakov

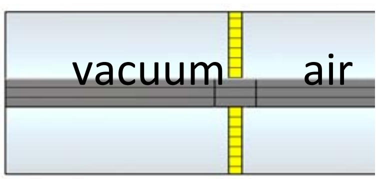
Status of design and prototyping.

325 MHz coupler: Lessons of the test.

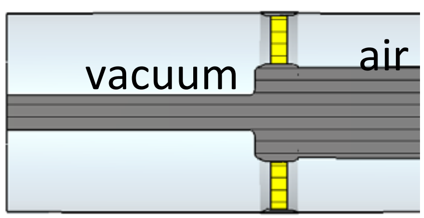
Reason of failure is not quite clear – the quality of brazing was not good enough, or, may be it is real power limit of this kind of window. Window is powerful enough for SSR1 and may be for SSR2, but probably not for 650 MHz cavity.

We decided to re-design window.

Impedance of vacuum part of couplers was chosen rather high, 105 Ohm because of two reasons: to decrease the dynamic cryogenic load (~ 1/Z) and to increase the multipactor threshold (~ Z). But high Z increases the current density and electric field at inner conductor surface. The place of brazing of inner conductor to ceramic is probably the weakest point of window. In next generation of couplers (325MHz and 650 MHz) we will keep high impedance of vacuum part but will increase the diameter of brazing place.

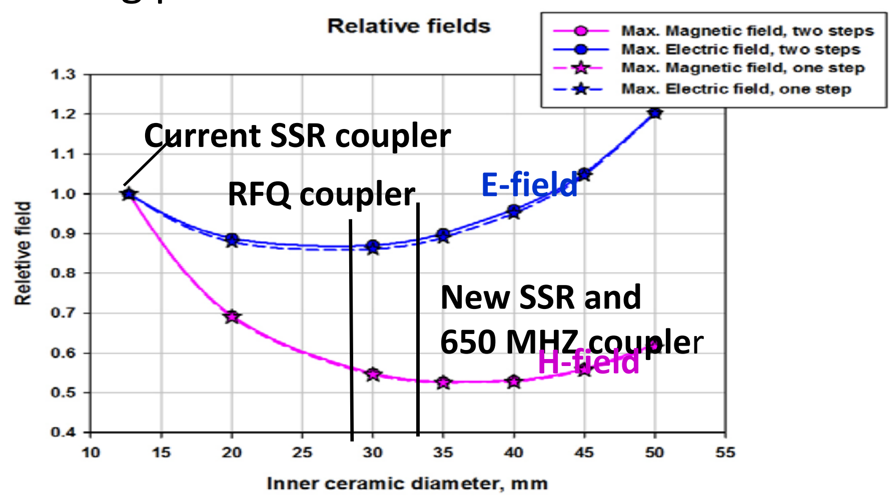


Original design



new design

S. Kazakov



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Status of design and prototyping.

Status of SSR1 CM design:

- 3D model F10002433 in Team Center -90 % done.
- All components for cavity string, F10044251-assembly in clean room: SSR1 resonators, solenoids, BP bellows, BPM's, end plate weldment's and gate valves, are ordered and ~ 80% are in house.
- Cavity string assembly, F10005014-Aseembly cavity string
  - Strong back –in house
  - Support posts- in house
  - Solenoid supports- DWG exist, order status-?
  - 80K shielding lower with extrusion - needs DWG and needs to order
  - Alignment control system - needs DWG and needs to order
  - SSR1 Tuner's; only prototype, needs to finalizing in design, DWGs and place the order.
- Power coupler: 3 prototypes in house, place order for 10, delivery ~Feb/March 2016
- Piping system: exist only in 3D, need's in modification, for creating DWG for order
- Upper 80K shielding: exist only in 3D, need's in modification, for creating DWG for order
- Magnetic shielding: exist only in 3D, need's in modification, for creating DWG for order
- Solenoid Current Leads: prototype of CL is ordered.
- Vacuum Vessel, F10010433 – done, in house
- Cryogenic parts(Y. Orlov)

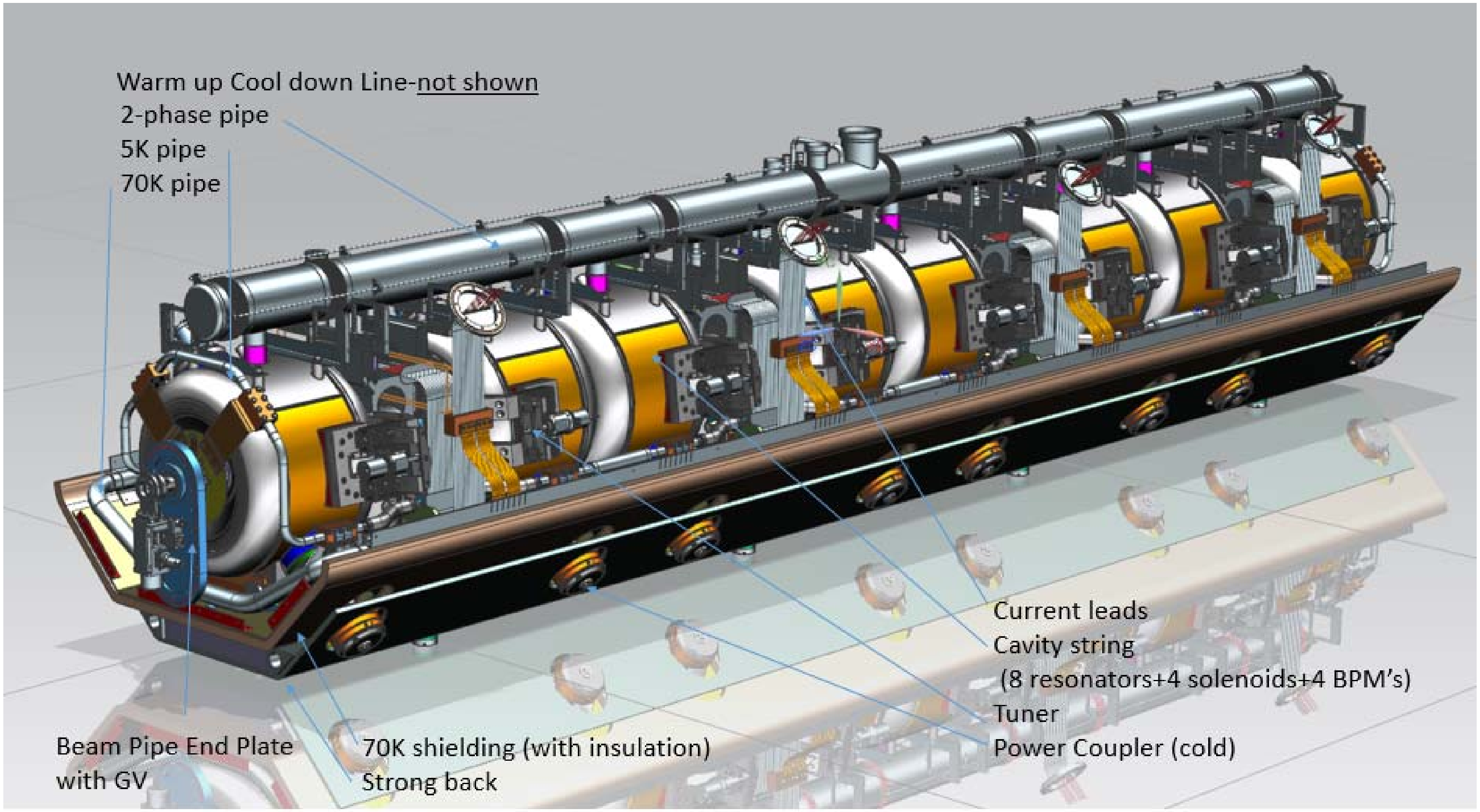
  Needs to specify JT & warm up cool down valves and put the order

  Need's to specify Bayonet's and put the order.

(Y. Orlov)

Status of design and prototyping.

Status of SSR1 CM design:



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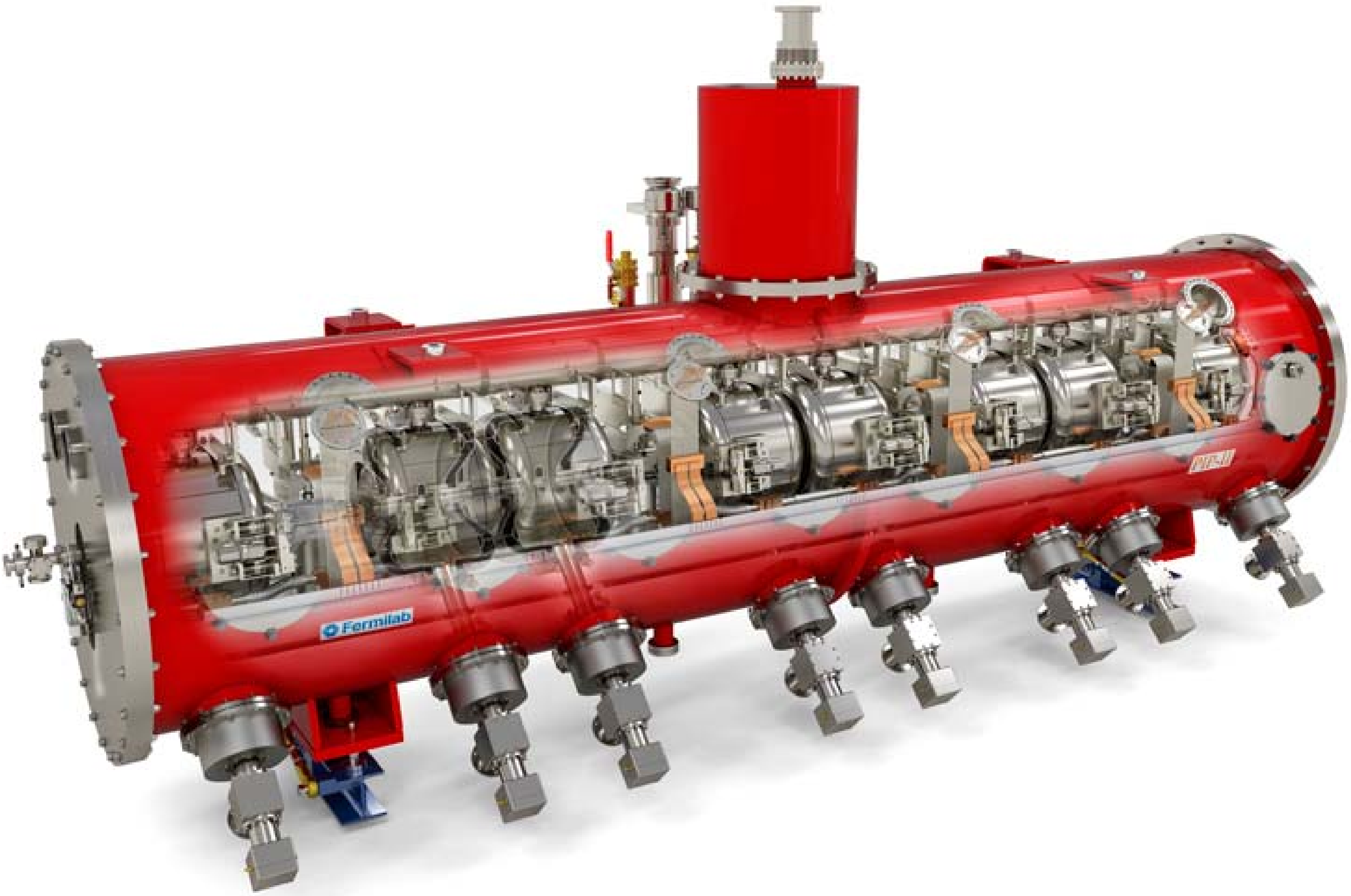
Status of design and prototyping.

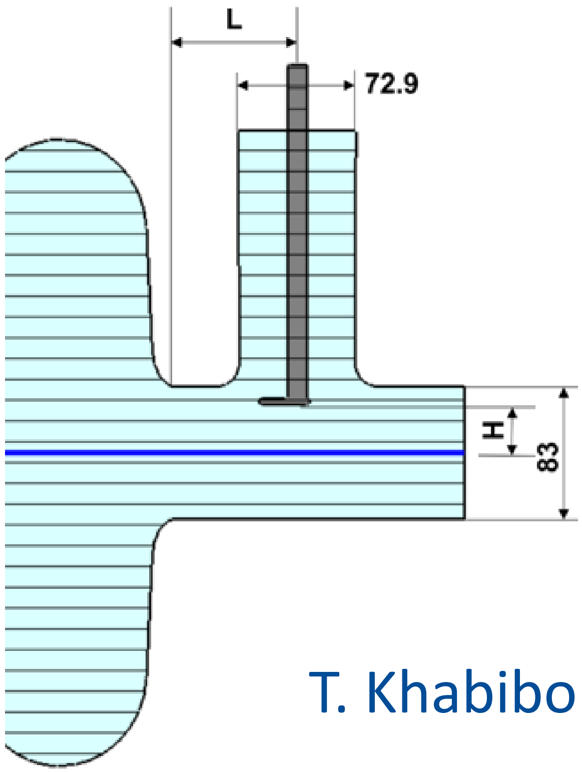
Status of SSR1 CM design:



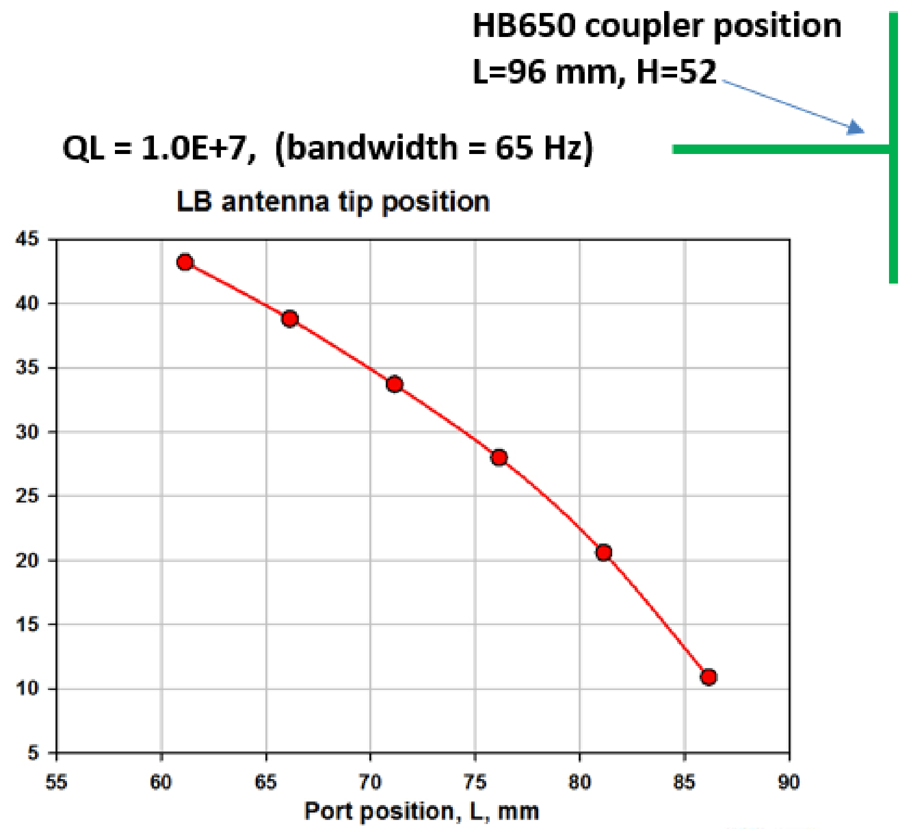
LB650 MHz cavity EM design status

Preliminary design with D=83 mm beam pipe coupler simulation:

- Coupler port located too close to the cavity
- Very limited space for helium vessel
- Need to increase beam pipe diameter



T. Khabiboulline



LB650 MHz cavity EM design status

LB650 cavity RF parameters summary	FNAL 83 mm	JLAB 100 mm	FNAL 83/118 mm
β_G	0.61	0.61	0.61
β_{opt}	0.647	0.645	0.650
$R/Q(\beta_G)$, Ohms	351.5	297.2	327.4
$R/Q(\beta_{opt})$, Ohms	377.0	317.5	356.3
$E_{surf}/E(\beta_G)$	2.34	2.73	2.43
$E_{surf}/E(\beta_{opt})$	2.26	2.64	2.33
$B_{surf}/E(\beta_G)$, mT/MeV/m	4.36	4.80	4.6
$B_{surf}/E(\beta_{opt})$, mT/MeV/m	4.21	4.64	4.41
G, Ohms	191	185	187

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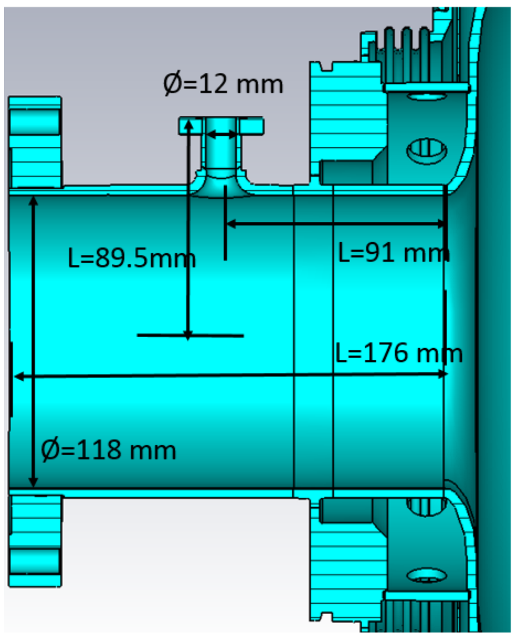
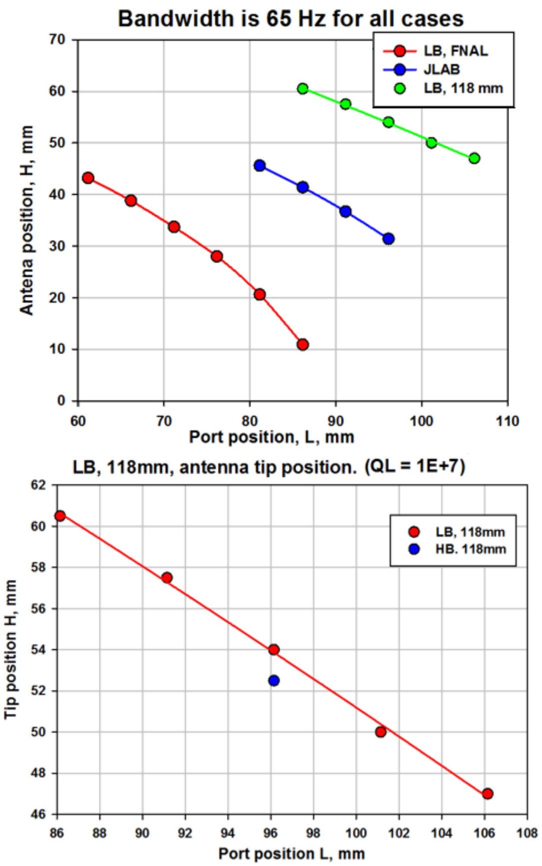
LB650 MHz cavity design status

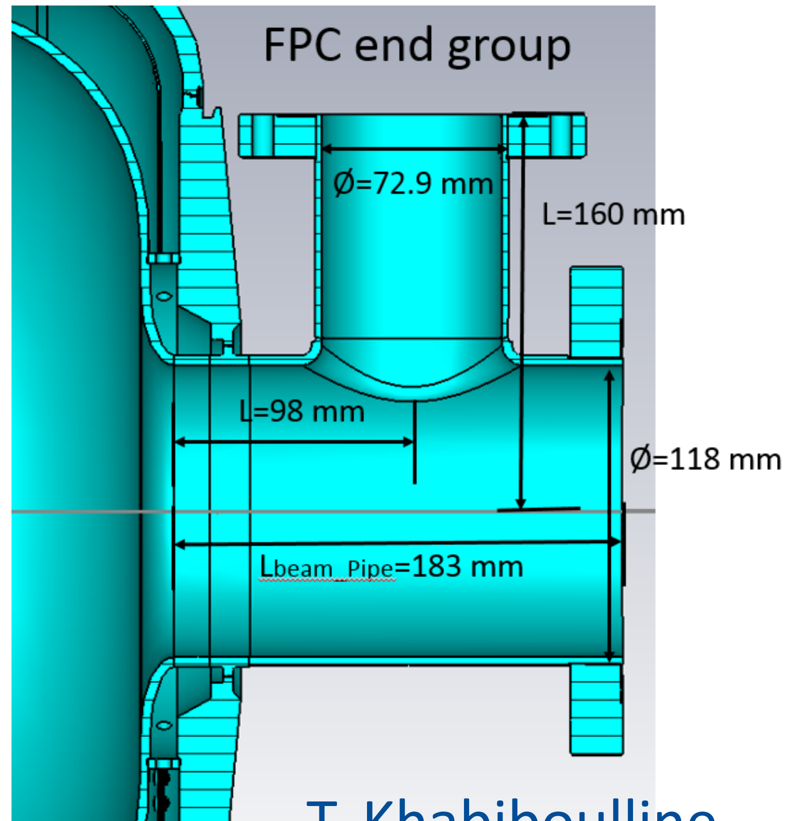
Proposed design with D=118 mm beam pipe coupler:

- Same end assemblies as in HB650 cavity
- Same coupler position as in HB650 cavity

Field probe end group







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LB650 MHz cavity design status

Completed:

- RF design
- Mutipactor simulations
- HOM analysis

To do:

- Dressed cavity design
  - LFD optimization
  - df/dP minimization
- Stress analysis
- Pressure cases analysis
- Mechanical resonances
- Tuner simulations
- Complete mechanical design for fabrication

T. Khabiboulline

HB650 MHz cavity status

Completed:

- RF design
- Mutipactor simulations
- HOM analysis
- Dressed cavity design
  - LFD optimization
  - df/dP minimization
- Stress, gravity analysis
- Pressure case analysis
- Mechanical resonances
- Complete mechanical design—released to RRCAT for fabrication

To do:

- Tuner simulations
- Helium vessel integrated mechanical design

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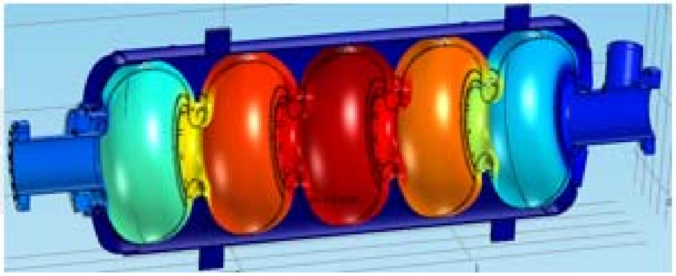
HB650 MHz cavity status

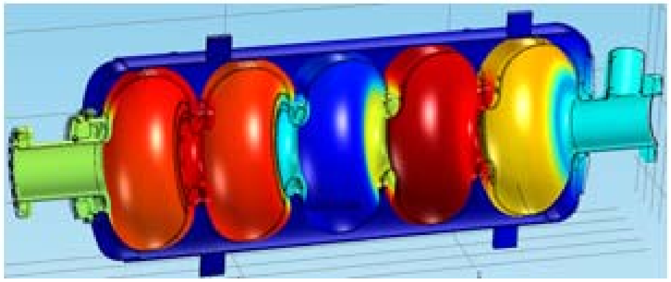
L#1

F, Hz
102.9



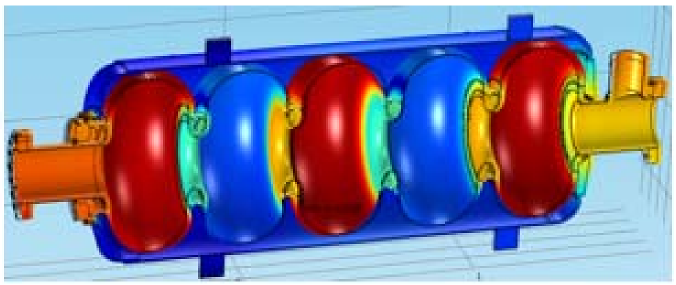
L#2

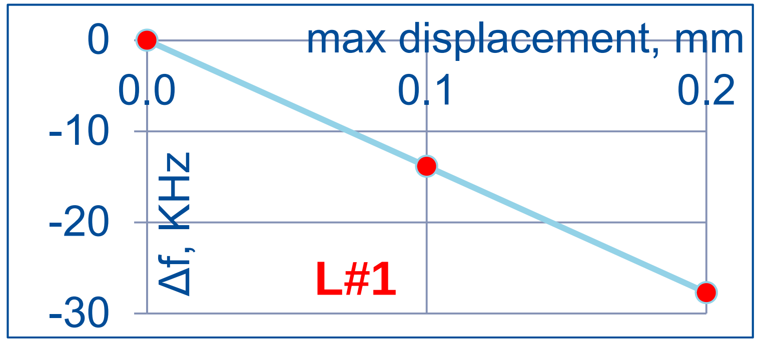
F, Hz
194.6



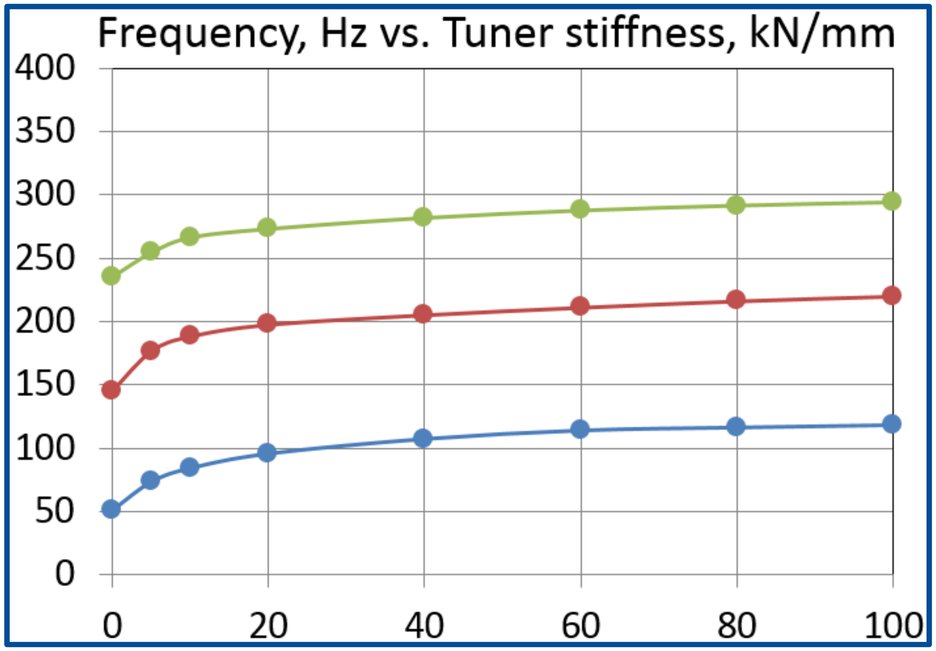
L#3

F, Hz
265.6





RF Frequency shift



Longitudinal modes in HB650 cavity,
Tuner stiffness 40 kN/mm

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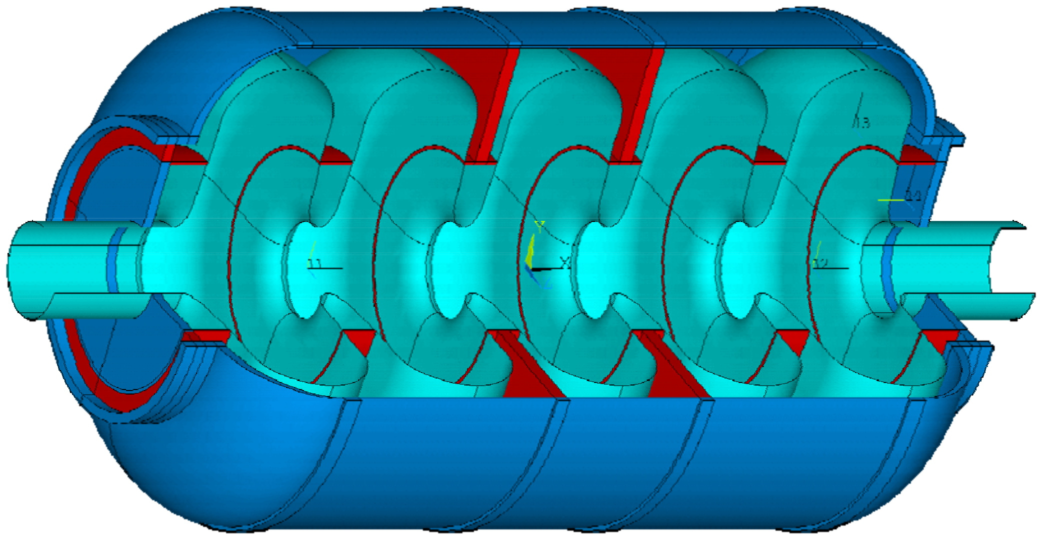
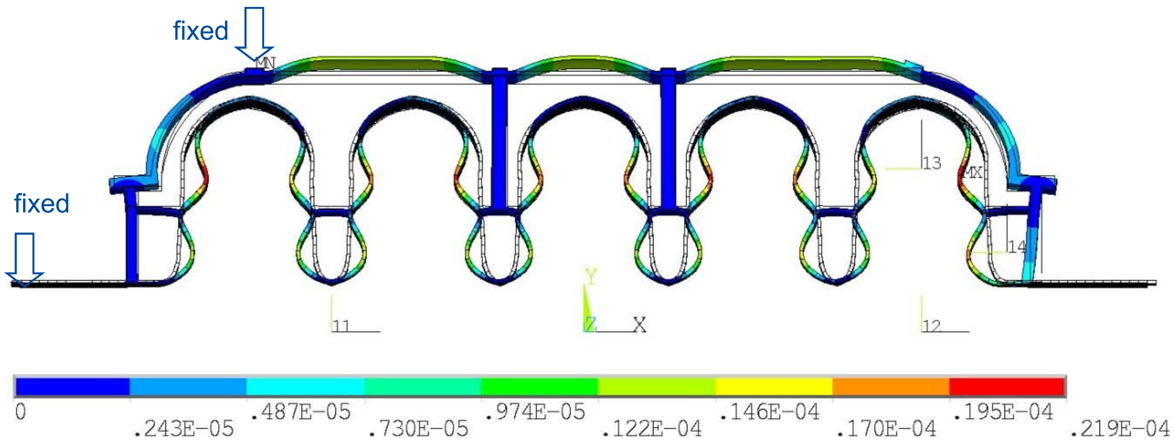
LFD minimization R&D





Mechanical coupling of the He vessel to the Cavity (as in SSR1) to be explored

T. Khabiboulline

650 MHz cavity and cryomodule status

- Of the four beta 0.9 cavities from AES one is in house and three are back at AES for processing. Five more are in production at Pavac.
- Bulk electro-polishing facility being commissioned at AES.
- Beta 0.61 RF and end group design is complete and nearly ready for transfer to VECC (DAE) for bare and dressed cavity design and manufacture.
- Beta 0.92 bare cavity design complete and transmitted to RRCAT (DAE) for cavity design and manufacture.
- Dressed beta 0.92 cavity design, modeling, and analysis are complete.
- Prototype tuner design and mechanical analysis are nearly complete. Expect to start prototype fabrication in spring 2016. The same tuner is expected to work for all three 650 MHz cavity designs.
- Preliminary coupler work completed ~2 years ago needs to be restarted.
- High beta cryomodule design well advanced at Fermilab.

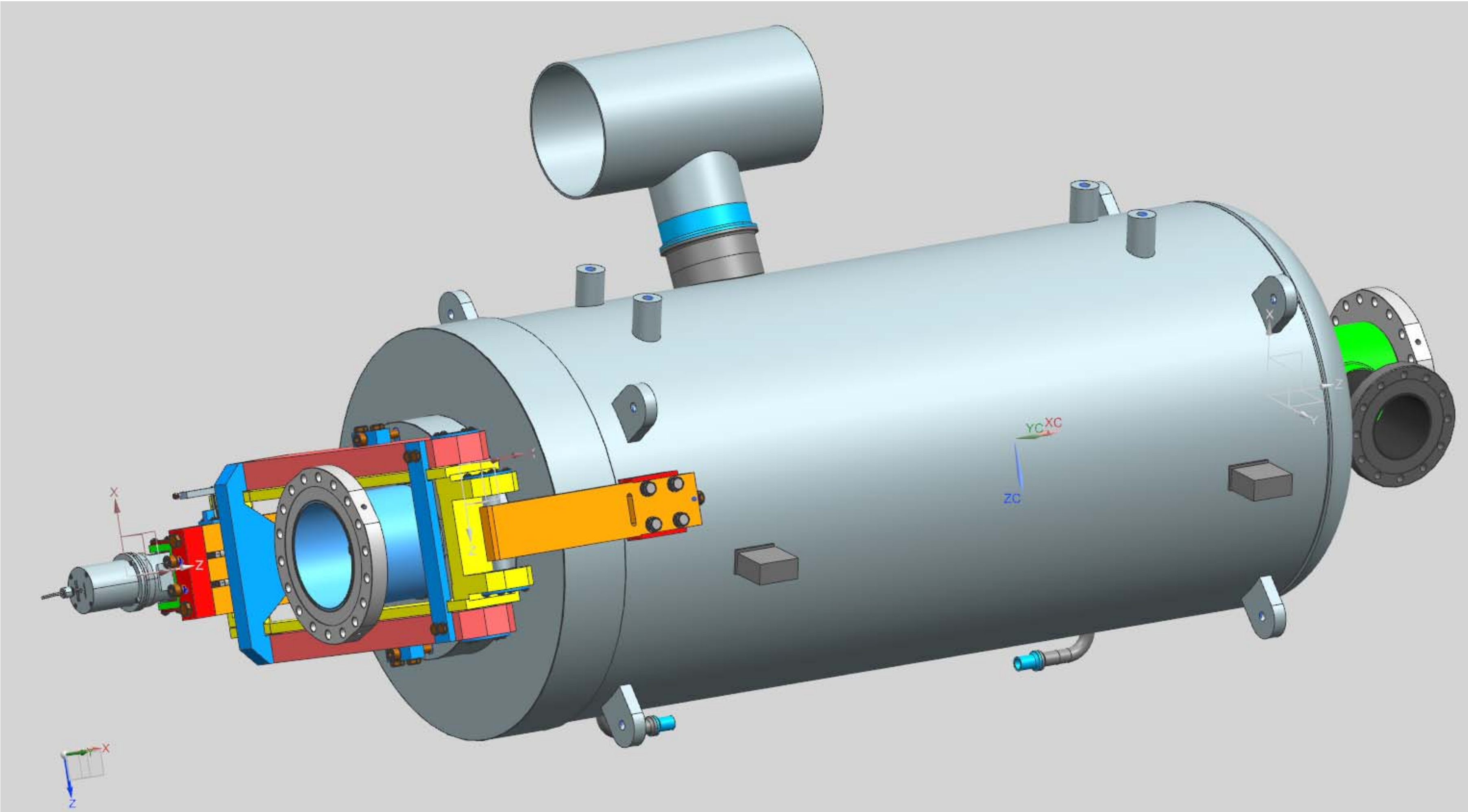
T. Nicol

FY16 650 MHz Processing and Testing Plans

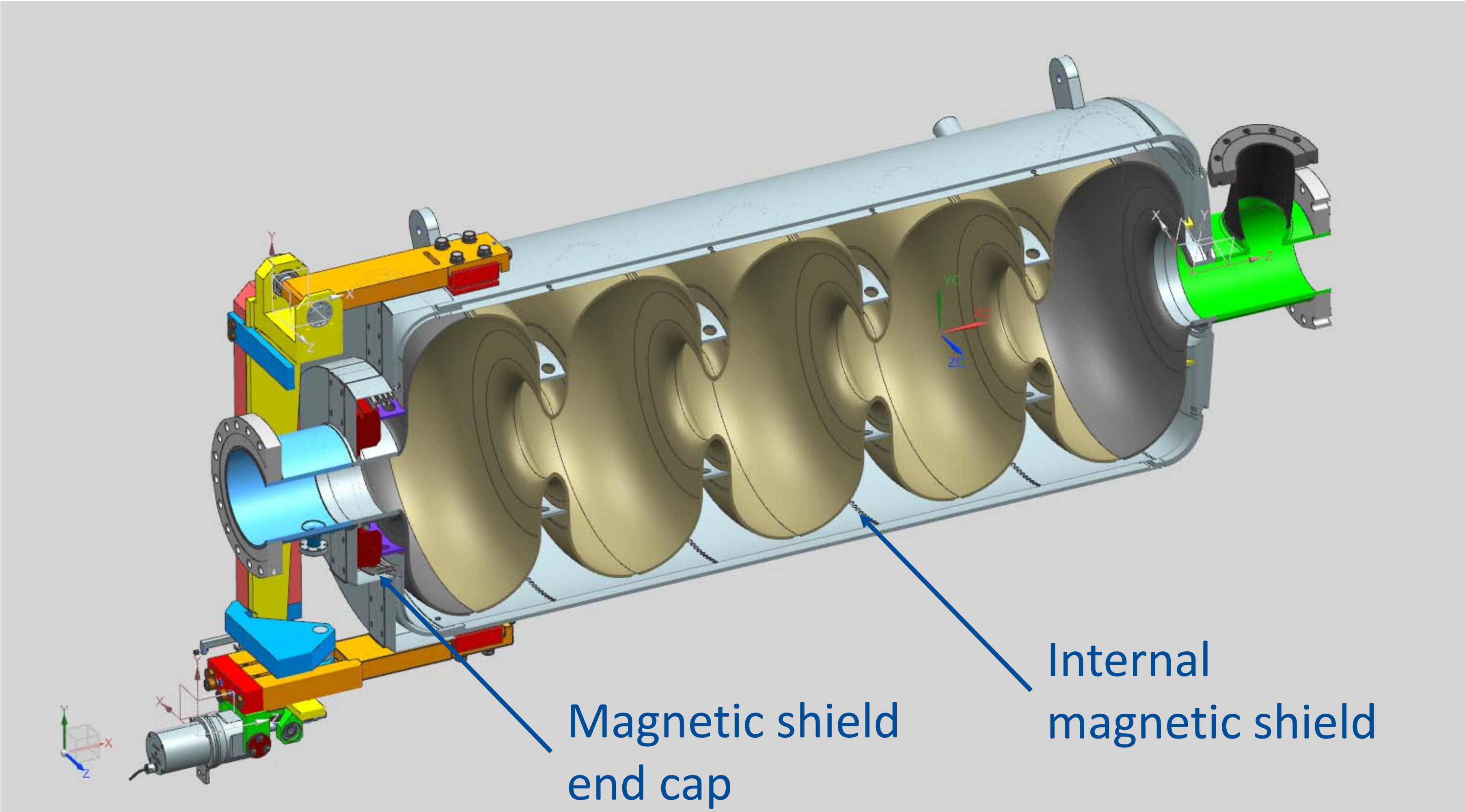
- B=0.61 VECC 1-cell cavity
  - Complete processing and testing sequence in March with VECC visitors
- B=0.9 AES 1-cell
  - Complete EP tool qualification for 650 MHz
  - EP process evaluation at AES for industrial bulk EP
  - Modify recipe for 5-cell input as necessary
- B=0.9 AES 5-cell cavities
  - Three 5-cell bulk EP's at AES
  - Final prep and testing at FNAL
  - High Q0 testing + baseline testing = 4-5 multicell test cycles.
- B=0.9 AES 5-cell cavity – ANL Complete Process
  - Cavity ready for testing at VT at next opportunity (see photo)
- Additional testing activities
  - 1-cell, 5-cell Flux expulsion/field sensitivity studies
  - High Q0 recipe (N2 doping) verification

A. Rowe, A. Grassellino

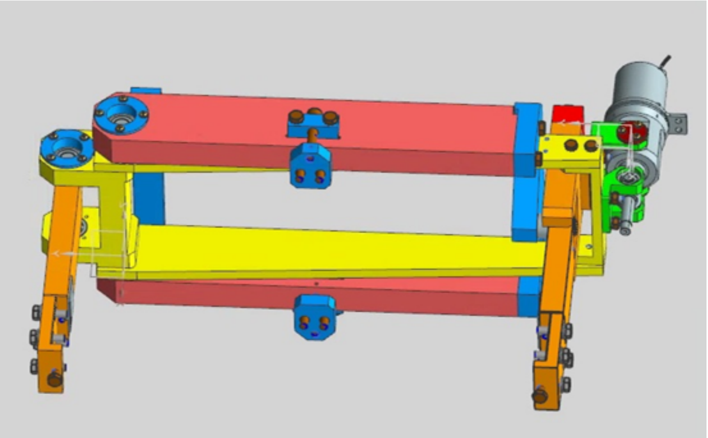
High beta 650 MHz dressed cavity



High beta 650 MHz dressed cavity



High beta 650 MHz tuner



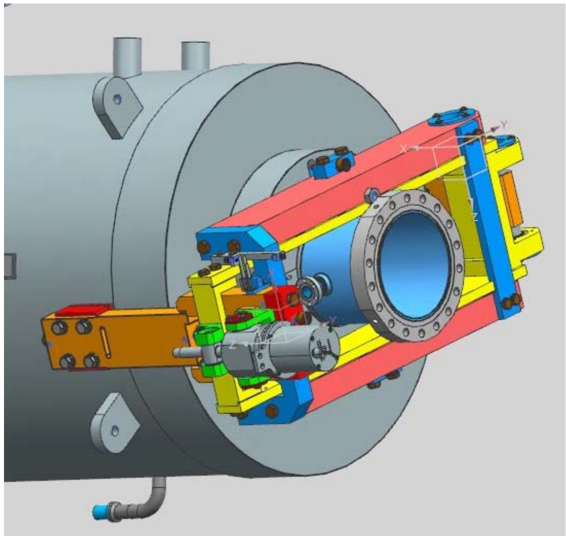
Double Lever Tuner for 650MHz

Based on LCLS II Tuner design
(synergy of the LCLS II & PIP II projects)

- **High reliability of tuner :**

Used the same active components
(PI piezo-actuators & Phytron electromechanical actuator)
Both components went through vigorous
Accelerated Lifetime Tests and Radiation Hardness Tests
in the frame of the LCLS II Program.

- **Tuner design with capability to replace active tuner components through special port**
- **Goal was to design "one tuner design " must serve for "0.9" "0.92 & "0.61" cavities.**
- **Tuner design went through several iterations to optimize performance of the cavity/He Vessel/Tuner system from the point of the view minimization LFD & dF/dP**



Tuner Team is ready put order to machine first Tuner prototype
We have PI piezo-actuators & Phytron electromechanical actuator (left-over from previous programs)
We will start design verification program on the cavity/He-vessel make-up system

Y. Pischalnikov

High beta 650 MHz cryomodule design status

What is done:

- **Strong-back**

  Pre-design have been done and the location of the supports have been decided. Need to perform a final element calculations and to write documentations for the review.

- **Vacuum vessel**

  All openings have been designed and are located at the good place. Calculations according to ASME have shown there is no issue. The relief valve required have been calculated. The final design will be done in India, they will take care especially of the supports of the vessel, the transport with a crane, the location of the stiffeners.

- **String line**

  Pre-design have been done. Bellows have been calculated according to ASME, finite elements calculation need to be done for final check. The society VAT have been contacted to design a gate valve with a removable actuator. Status: Standby until the line is fully validated on our side. Tooling and assembly process need to be done.

- **Support of the cavities**

  Pre-design have been done. First modal analysis have been done. Need to optimize the design.

- **Cryogenic lines**

  Heat-loads have been calculated. The needed diameter for the pipe have been calculated according to standards. Pressure vessel relief calculation has been performed according to scenario (vacuum break, …) All cryogenic lines have been pre-designed. A document have been written describing these lines in order to get a design approval (diameter of the lines, valves, exchanger, ….) The society DATE have been contacted to design the exchanger. Status: Standby until the lines are fully validated on our side. Some supports for the assembly need to be design. Bellows have been calculated according to ASME, finite elements calculation need to be done for final check. Once the design fully validated, documents need to be written to get the review.

- **Thermal shield**

  The bottom part of the thermal shield have been designed. The top part will be designed in India. Finite element calculations will need to be done to be sure about the thermal contraction.

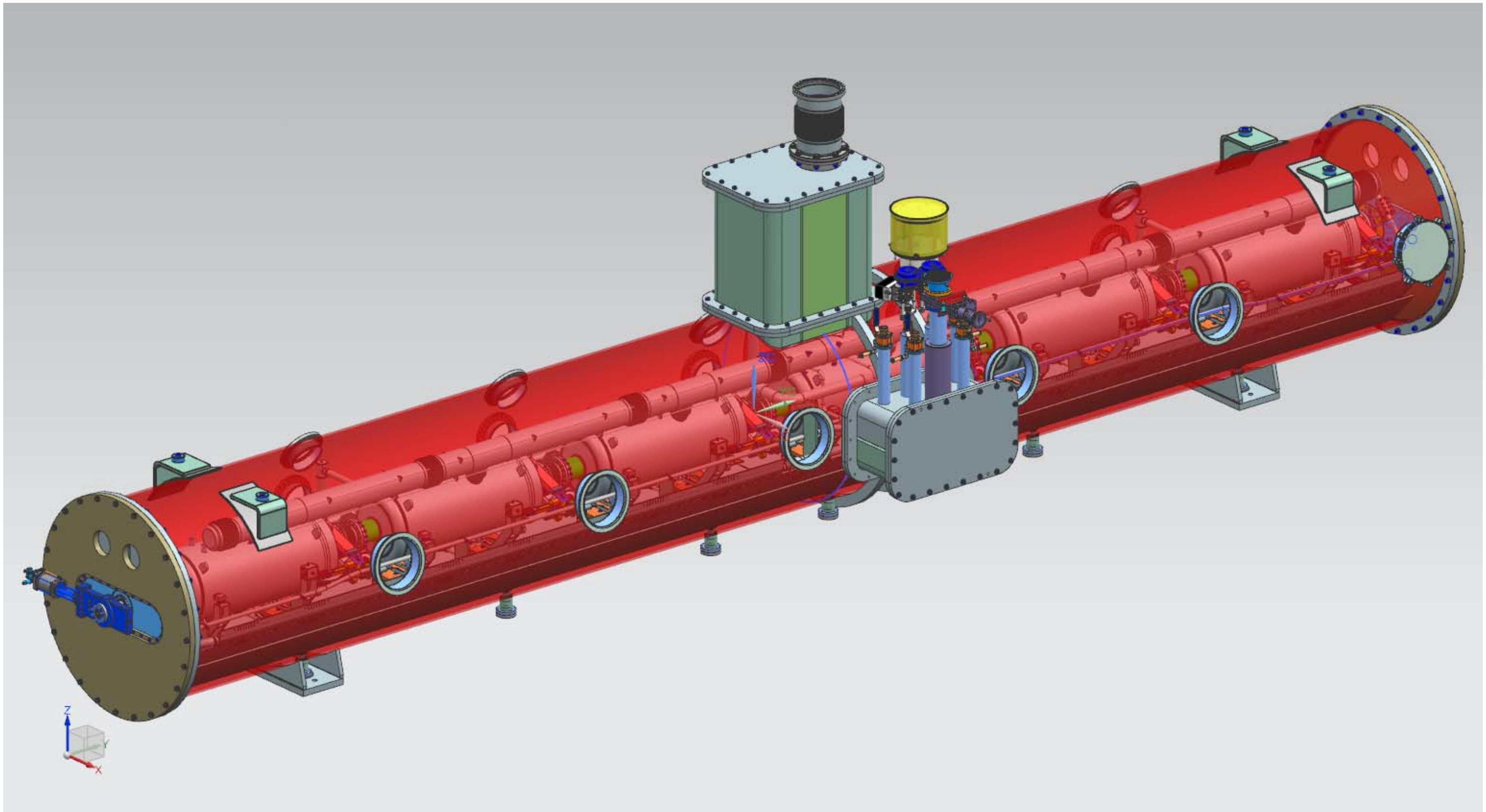
- **Instrumentations**

  Pre-study has been done. The number of sensors and connectors needed is known. A proposal has been done. The final design will be done in India.

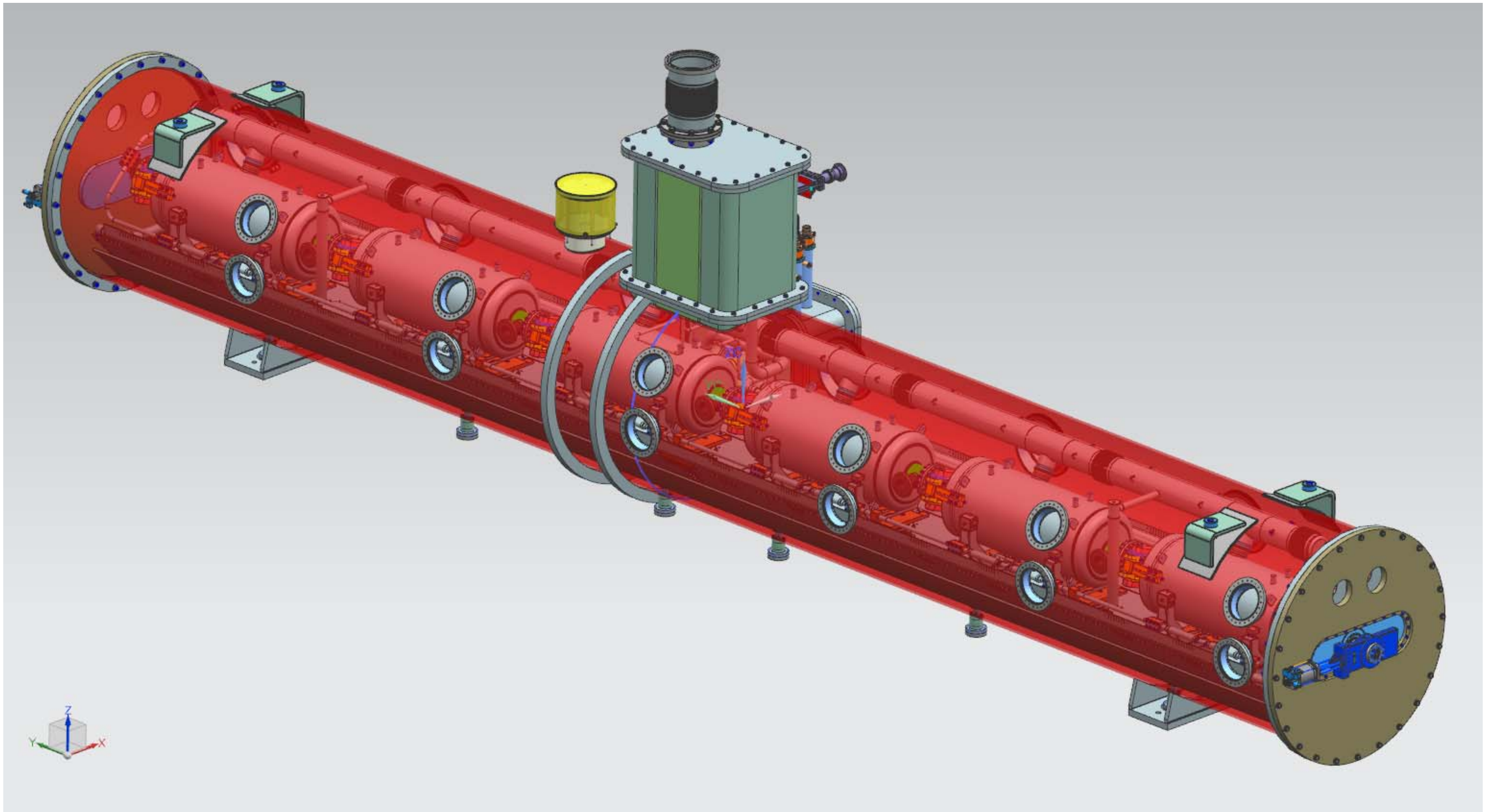
V. Roger

Fermilab

High beta 650 MHz cryomodule Concept



High beta 650 MHz cryomodule Concept



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High beta 650 MHz cryomodule design status

What is still should be done:

- **Strong-back**
  Final design : Calculations and documentations
- **Vacuum vessel**
  Final design : Calculations and documentations
  - Design of supports (top and bottom)
  - Instrumentations

  Tooling and assembly process to put the string line in the vacuum vessel
- **String line**
  Tooling and assembly process to assemble the string line
  Tooling and assembly process to put the string line on the strong back
- **Support of the cavities**
  Optimize the design
- **Cryogenic lines**
  Finite element analysis to validate the design
  Validation by cryogenic engineer
  Documentations
- **Thermal shield**
  Design of the top part
  Documentations
- **Alignment of the cavity with regards to the vacuum vessel**
  Design

V. Roger

Summary

- A lot of things (R&D, design work, prototyping) is done
- A lot of things (R&D, design work, prototyping) still should be done