Introduction to the 56 MHz Project Review

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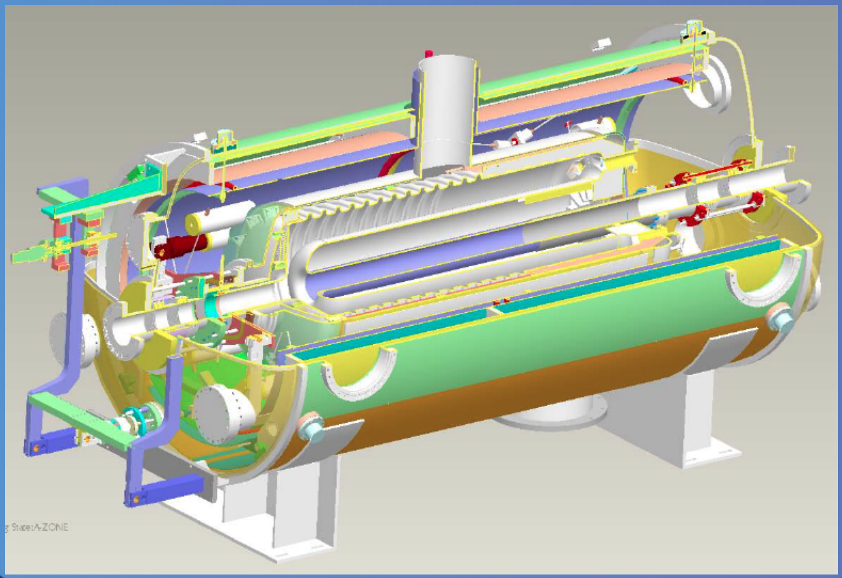
BNL
March 8, 2011



56 MHz Project Review
BNL • March 8 – 9, 2011

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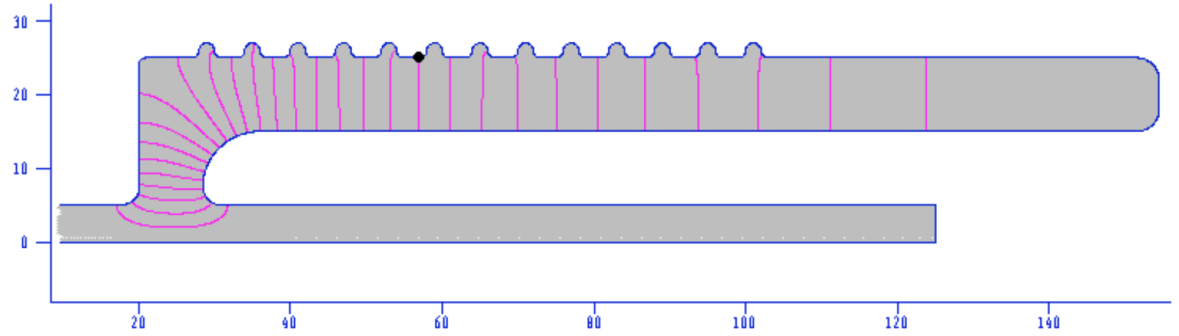
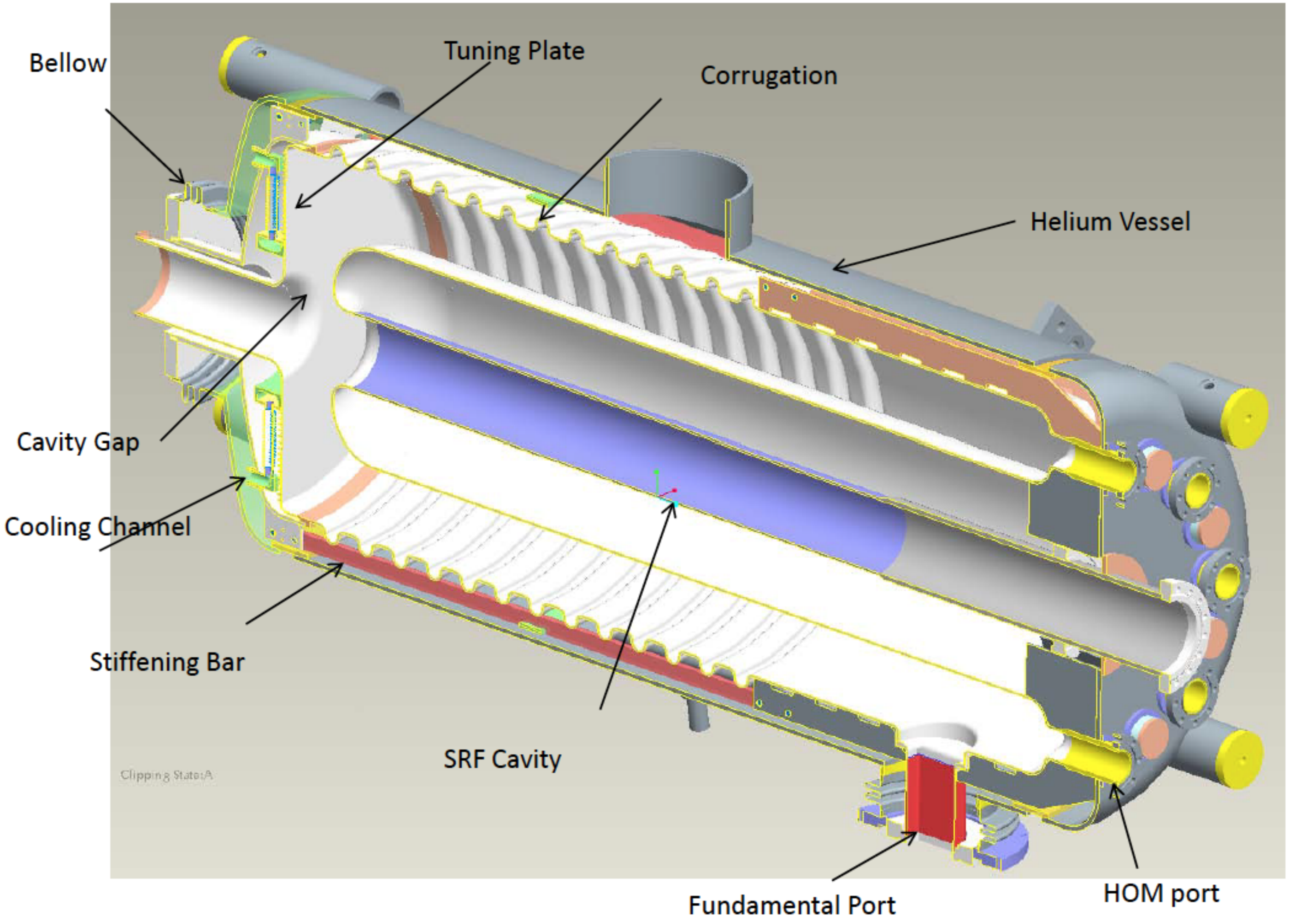
Introduction



- A quarter-wave superconducting 56 MHz cavity is under development at C-AD as an Accelerator Improvement Project (AIP).
- Its purpose is to provide a larger RF bucket (5 times larger than that of 197 MHz cavities) for particles, which should result in higher luminosity of RHIC by: direct adiabatic capture from 28 MHz system, better preservation of longitudinal emittance, elimination beam spillage in satellite buckets, improving luminosity by allowing shorter beat function at the IP.
- This is a “storage” cavity, that is it does not have large tuning range to follow the large frequency change during acceleration from injection energy to energy of experiment and is turned on only after that for re-bucketing.
- One 56 MHz cavity will serve both RHIC rings.
- The 56 MHz cavity will supplement other RHIC RF systems, which currently include two 28 MHz, and one 9 MHz copper accelerating cavities per ring (plus one 9 MHz cavity common to both rings) and five 197 MHz storage cavities, eventually replacing the latter.
- The goal is to install it in RHIC for operations in 2013.
- Presently the project is at the end of the design phase / beginning of the fabrication phase.

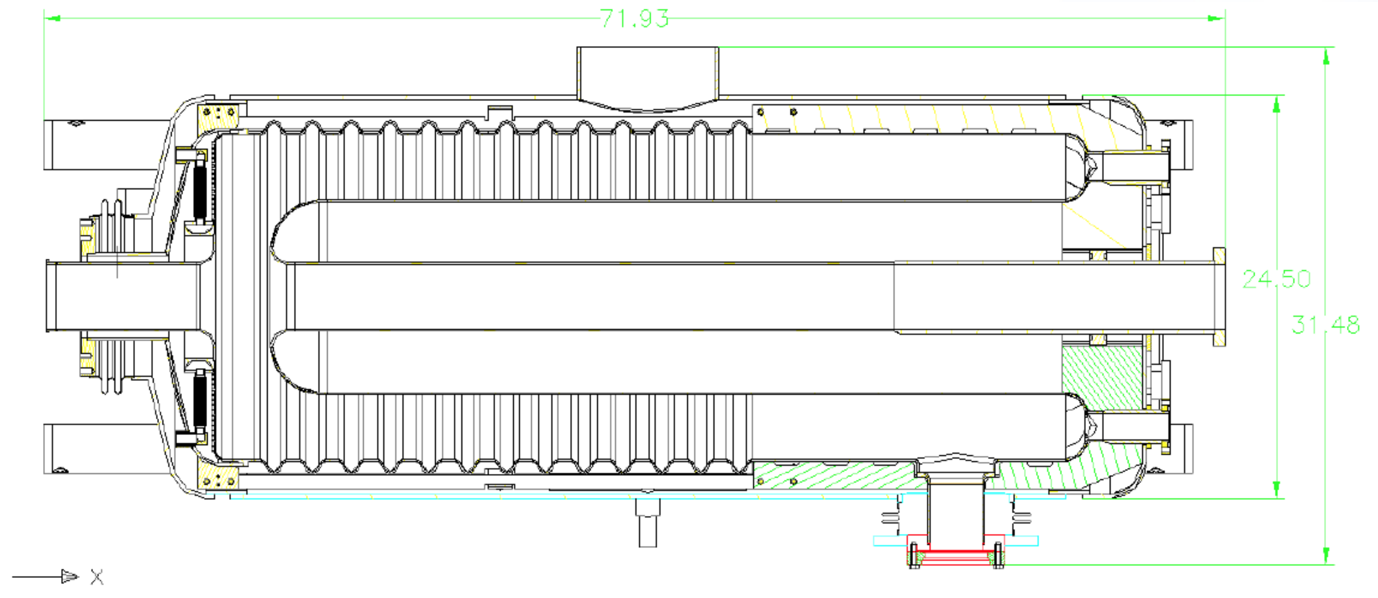
Main features of the 56 MHz cavity



- The 56 MHz cavity is tuned to 720th harmonic of the RHIC revolution frequency.
- It is beam driven cavity.
- However, there will be a 1 kW RF amplifier.
- The amplifier will serve to: i) achieve required amplitude and phase stability; ii) provide conditioning capability; iii) make up power for intrinsic losses.
- The cavity fundamental mode will be detuned and strongly damped during injection and acceleration.
- At the energy of experiment, first the fundamental damper will be withdrawn and then the cavity frequency will be tuned (approaching from below the beam harmonic) to achieve operating voltage of 2.0 MV.
- A piezo tuner will be employed to compensate any fast frequency changes.

Main features of the 56 MHz cavity (2)

- The 56 MHz cryomodule is compliant with ASME Pressure Vessel Code.
- The cavity is quite rigid: its first mechanical mode frequency is 98.5 Hz; sensitivity to the helium bath pressure is 0.282 Hz/mbar; Lorentz force detuning is -37 Hz/(MV)^2, or 148 Hz at 2.0 MV.
- The cavity is designed to be multipacting-free.
- High degree of HOM damping is provided by 4 dampers asymmetrically placed at the “short” end of the cavity.
- Fundamental mode Damper (FD) reduces the cavity fundamental mode *Q* to ~300 during beam injection and acceleration.
- Cryogens will be provided from a low-noise cryogenic system (separate AIP, not under review today).
- The cavity shape was optimized so that at 2.0 MV we get E_{pk} = 35.3 Mv/m, B_{pk} = 83.9 mT, power dissipation < 20 W.
- These numbers are below what was already achieved on SPIRAL2 QWR at 88 MHz: 62 MV/m; 112 mT; 4.5 Hz/mbar; -1.58 Hz/(MV/m)^2, equivalent to 191 Hz at 11 MV/m.



The previous review

- The previous external review was held about two years ago, on January 8-9, 2009.
- At that point the physics design had been mostly finished and the engineering detailed design was in progress.
- The committee was requested look for errors or weak points in the design and to provide advice on how to proceed with the project and recommend changes as necessary.
- The committee had not identified any fundamental issue of serious concern and felt that that was the appropriate time for a review. The project was advanced enough for evaluation but there was still time to incorporate changes while maintaining schedule.
- We will address the committee recommendations and our response to them below.

Response to the recommendations

The surface fields at design voltage are not unrealistic but are still somewhat ambitious. Since the cavity would perform almost as well at 2 MV (where the surface fields are still challenging) and still be useful at 1.5 MV, it might be unnecessary to set such a high goal which, if not achieved, would make the Project run the risk of being perceived as having failed.

- The spec for cavity operating voltage was reduced to 2.0 MV.

We recommend redoing the calculations for the HOM spectrum and quality factors of the final HOM damper design. R/Q's can be taken from computer simulations with Omega 3P or MWS and Q's from measurements on the copper model of the 56 MHz cavity. A caveat is that measured Q's around and higher than 10,000 may be much higher yet in the superconducting case. Ideally, measurements and final design of the damper should be done on a superconducting prototype.

- The HOM spectrum was recalculated for the final HOM damper design. It will be presented in Q. Wu's presentation. The measurements will be done during one of the cavity cold tests.

Response to the recommendations (2)

It is thought that dipole HOMs are not an issue. This should be confirmed. In particular, the 579 MHz labelled by Choi as "quadrupole?" should be investigated, as it apparently does not couple well to the damper.

- The 579 MHz mode is damped well by the new HOM dampers design/layout.

The calculations indicate that on transition crossing, if the existing 197 MHz cavities are removed, the 56 MHz system will lead to improved beam quality. It would be good to establish quantitative agreement between the emittance growth observed, and the simulations for the existing cavities.

- Has not been done yet.

Local enhancement of the magnetic field caused by the penetrations in the high magnetic field region may cause uncontrolled heating of the auxiliaries leading to a quench. The committee recommends a very careful electromagnetic and thermal modeling with a 3D software to address that problem. While 3D codes are quite good at predicting the frequency of complex geometries they can often be inaccurate in determining peak surface fields so using a range of mesh sizes and several 3D codes is recommended.

- Careful 3D field modeling was performed. The cavity is designed to avoid any significant local field enhancements.

Response to the recommendations (3)

The most likely site for field emission is between the high voltage end of the quarter-wave line and the end plate. Even a few µA's of dark current, when accelerated by substantial fraction of the gap voltage, could deposit several watts of heat over a small area of the end plate. The Committee is concerned that, in such an event, the cooling of the end plate may be inadequate leading to a thermal quench of the cavity.

- Cooling of the end has been added.

The Committee suggests evaluation of using the fundamental mode damper as a variable coupler for the RF conditioning process.

- This is possible and re-arranging RF cables should be straightforward.

As any mechanical contact between the FD structure and Nb cavity can destroy cavity performance, the needed clearance during motion and assembly should be confirmed, and assembly procedure and hardware designed accolrdingly.

- We recognize this danger and paid careful attention to this while designing the FD.

The Committee recommends to carefully study multipacting in this highly complicated 3D structure.

- The multipacting study has not been finished yet. As the committee noted, it is a highly complicated 3D structure and MP analysis of such geometries is not trivial.

Response to the recommendations (4)

The Committee recommends investigation of active cooling of all superconducting loops located in or close to the maximum magnetic flux, unless the RF and thermal modeling, including normal-conducting spots on the surface, demonstrates that couplers will stay in the superconducting state (T< 9K). Preferably the modeling should be verified experimentally.

Thermal analysis should include the cryogenic feedthroughs which need to be selected carefully.

The impact of the HOM dampers on the fundamental mode should be assessed to assure that its external Q is sufficiently high (>>Q_0).

- Thermal analysis shows that active cooling of the loops is not necessary. However, active LHe cooling has been added to the HOM dampers.
- The heat leak through RF cables has been evaluated. More details will be presented in S. Bellavia's presentation.

Response to the recommendations (5)

- The committee had several comments and recommendations on cavity structural design, tuner design, fabrication procedures.
- We believed that we addressed most if not all concerns. The designs and procedures will be covered by C. Pai in his presentations.

> HOM couplers are notorious candidates for sources of multipacting barriers. The Committee recommends performing 3D simulations for the areas of auxiliaries' penetrations. These can be difficult and time consuming to simulate but should nevertheless be attempted.

- The multipacting study has not been finished yet. As the committee noted, it is difficult and time consuming.

> As presented, all the chemistry would be performed on the cavity after its completion. The Committee recommends evaluation of performing most of the chemistry on parts before closure of the cavity. This would allow performing EP on all the parts, with only a light BCP after the final weld.

- Due to large dimensions, performing chemistry on cavity parts is deemed impractical.

Response to the recommendations (6)

The most sensitive area for field emission is the high-voltage region at the end of the quarter-wave line. The high pressure rinsing should be done in the appropriate sequence and configuration to minimize the probability of contamination in that area.

- The appropriate HPR sequence and configuration will be implemented.

If the schedule permits, a full test of the completed cryomodule should be performed before installation in RHIC.

- A full test of the complete cryomodule is included in the project schedule.

Response to the recommendations (7)

Production

The stated completion date for installation is late 2010. Given the status of the project it seems to be a fairly tight schedule. The Committee recommends preparing a detailed plan for acceptance and commissioning consistent with that schedule.

- The installation date of late 2010 was indeed too optimistic. A detailed plan is in place. The new installation date is end of August 2013.

Off normal events, trips

The Committee recommends a thorough analysis and evaluation of the impact and consequences of so called "off normal events" such as: quenches, bursts of electron emission, vacuum breaks, *etc*. As an example for a cavity quench, if Q_0 drops to or below $5 \cdot 10^4$, an enormous amount of power could be deposited by the beam since the detuning of the cavity with respect to the nearest spectral line is small compared to the resonance width, and impedance is still very high ($80 \times 5 \cdot 10^4\ \Omega$). In such a case the beam must be dumped immediately.

A concept of the Machine Protection System and Interlock to prevent damage to the hardware or significant impact on the physics should be proposed.

- Our preliminary considerations will be presented, but this is still work in progress.

Response to the recommendations (8)

Tuning plate region

A number of significant interrelated issues were identified around the end/tuning plate region: field emission, cooling, mechanical stresses. A thorough integrated review of all the issues of this part of the cavity involving all the relevant expertise is recommended.

- The tuning plate region was redesigned and will be presented during this review.

Further reviews

At this stage of the project, the Committee has not identified any fundamental issue or potential showstopper and the project is in good shape. Nevertheless there are still many options to consider and details to finalize. Furthermore the schedule is tight. The Committee recommends an additional review later this year to assess progress.

Since ponderomotive instabilities, microphonics, and LLRF control are not expected to present insurmountable problems and be showstoppers, it was agreed between the Project and the Committee that they would not be subjects of presentations during this review. Nevertheless, if not addressed correctly they could degrade performance and availability. It is recommended that a careful analysis and design be pursued and that the status and results be presented at the next review.

- As the schedule was pushed to a later date the next review is happening later than was suggested.

This review

- Timing: Engineering detailed design is nearly complete; the cavity / helium vessel are ordered from Niowave with delivery expected in September of 2011; procurement of other components will begin soon.
- **Charge to the Committee**
  1. Are the cost and schedule reasonable for this stage of the project?
  2. Review the testing and performance goals. Are proposed tests and procedures sufficient to reach those goals? Is tooling for the cavity processing and string assembly adequate? Does schedule provide enough time for testing?
  3. Evaluate the cavity and vacuum vessel design, fabrication progress and schedule.
  4. Evaluate the cryomodule design (tuner, vacuum vessel, shielding, support system).
  5. Review and comment on the designs of HOM and fundamental power dampers, FPC.
  6. Evaluate the use of an IR detector as a method to detect quench of HOM dampers.
  7. Review RF and vacuum sub-systems. Comment on soundness of their design and implementation.
  8. Are there open technical risks? If so, what additional steps are necessary to adequately answer them?

The Review Committee

▪ John Weisend	FRIB, Michigan State University, Chair
▪ Charlie Reece	SRF Institute, Jefferson Laboratory
▪ Jim Rose	NSLS-II, Brookhaven National Laboratory
▪ Jon Sandberg	C-AD, Brookhaven National Laboratory
▪ Joe Tuozzolo	C-AD, Brookhaven National Laboratory

56 MHz Project Review

BNL, Collider-Accelerator Department
Large Conference Room, Building 911B
Tuesday/Wednesday, March 8-9, 2011

The Review Agenda

Tuesday, March 8

8:30 – 9:00	**Executive Session: Charge to Committee/Continental Breakfast**	**– S. Belomestnykh**
9:00 – 9:10	Welcome	– I. Ben-Zvi
9:10 – 9:30	Introduction to the 56 MHz Project Review	– S. Belomestnykh
9:30 – 10:15	Overview of RHIC Layout, 56 MHz Cost and Schedule	– G. McIntyre
10:15 – 10:30	**Coffee Break**	
10:30 – 11:00	Testing and Performance Goals	– Q. Wu
11:00 – 11:45	Cavity & Helium Vessel Design Overview, Fabrication Progress, and Schedule	– C. Pai
11:45 – 12:15	Tuner Design Overview, and Schedule	– C. Pai
12:15 – 1:15	**Lunch Break (lunch provided for committee members and presenters)**	
1:15 – 1:45	Vacuum Vessel, Shielding, Support System: Design Overview, and Schedule	– C. Pai
1:45 – 2:30	HOM & Fundamental Dampers, FPC: Design, Fabrication, and Schedule	– S. Bellavia
2:30 – 3:00	Tooling for Cavity Processing and String Assembly	– C. Pai
3:00 – 3:15	**Coffee Break**	
3:15 – 3:45	IR Detector	– B. Sheehy
3:45 – 4:30	Cryogenic System – RHIC Tie-in, Cryogenic Instrumentation	– R. Than
4:30 – 5:00	Executive Session	
5:00 – 5:15	Questions, Homework Assignments from the Committee	
5:15	**Adjourn Day 1**	
6:30	**Dinner for the Committee members, hosted by C-AD**	

Wednesday, March 9

8:30 – 9:00	**Executive Session/Continental Breakfast**	
9:00 – 9:15	RF System	– K. Smith
9:15 – 9:30	Vacuum System & Instrumentation	– M. Mapes
9:30 – 10:00	Response to Questions/Homework	– S. Belomestnykh/G. McIntyre
10:00 – 10:15	**Coffee Break**	
10:15 – 11:30	Executive Session/Report Writing	
11:30 – 12:00	Closeout	
12:00	**Adjourn**	

Acknowledgements

I would like to thank C-AD staff, who participate in the 56 MHz cavity project and prepared presentation for the review.

Also, thanks to our colleagues for agreeing to serve on the committee and provide their valuable time and expertise to review our project.