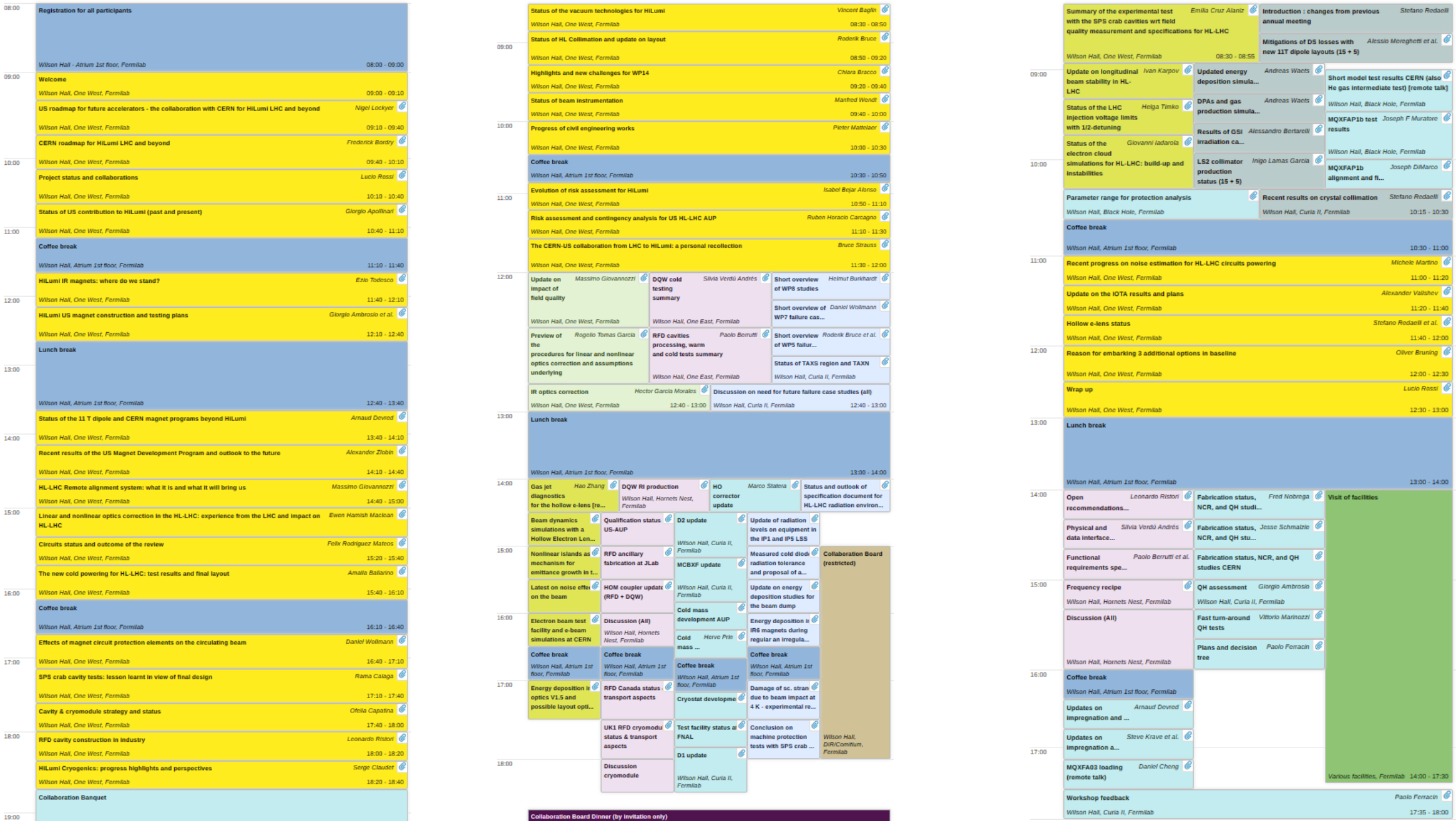
Crabs at HiLumi Collaboration meeting

9th HiLumi Collaboration Meeting, 14th-16th Oct 2019 at Fermilab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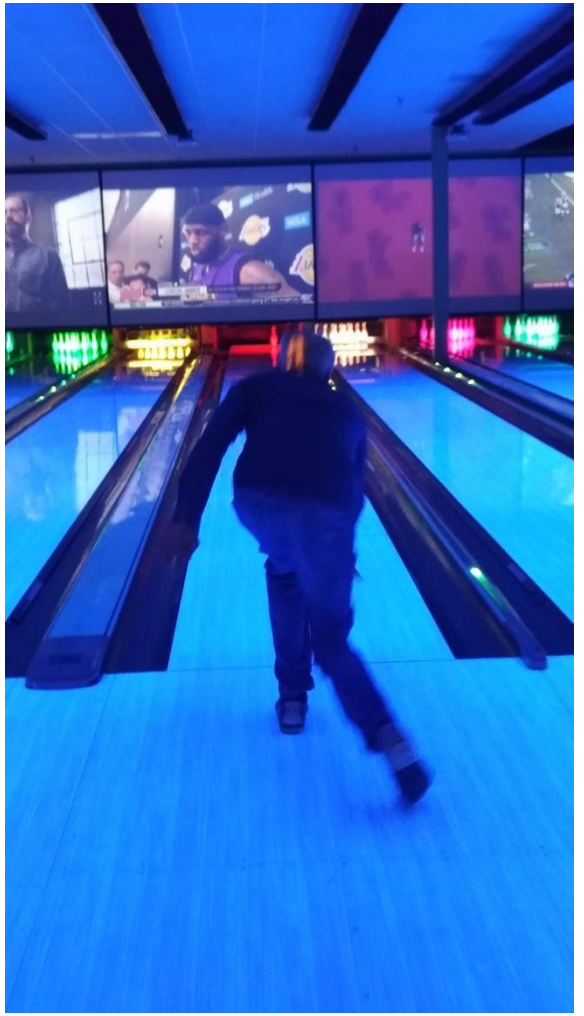
M.Narduzzi	Qualification status of US-AUP
N.Huque	RFD ancillary fabrication at JLab
E.Montesinos	HOM coupler update (RFD + DQW)
B.Laxdal	RFD Canada status & transport aspects
T.Jones	UK1 RFD cryomodule status & transport aspects
L.Ristori	Open recommendations from past AUP reviews, also involves TRIUMF
S.Verdu	Physical and data interfaces between HL-LHC WP4 and US AUP
P.Berruti	Functional requirements specification
A.Castilla Loeza	Frequency recipe

Social event Tuesday evening



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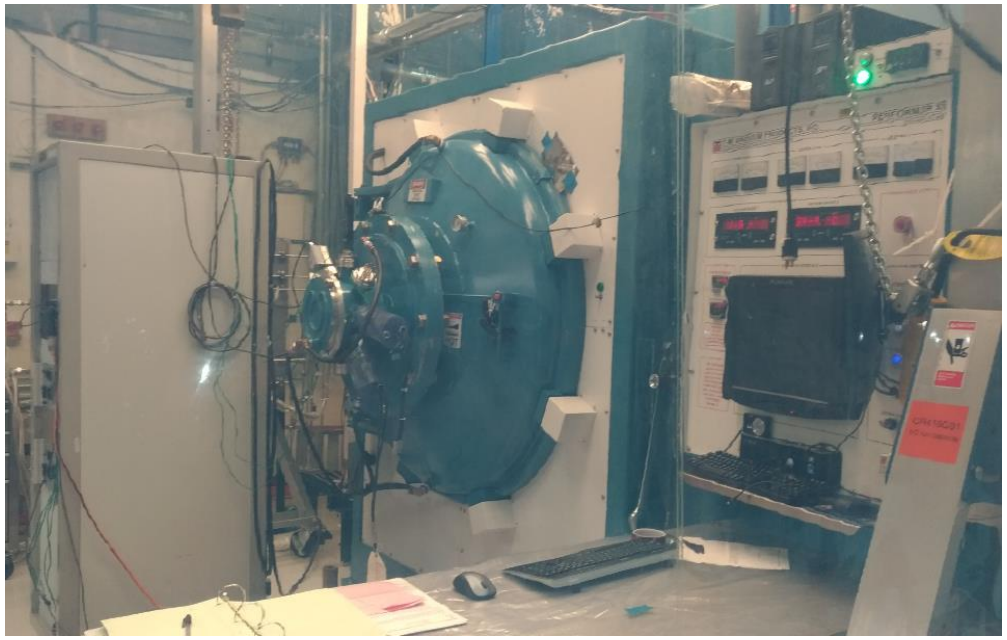

Visit to Fermilab SRF facilities

Rama

Lessons learnt

1: We can crab proton beams at 3ns
No noticeable effect on beam in many different conditions

2: Transparency
Intra cavity phase regulated in precise and stable way. Need to understand timescale of phase drifts: if we leave the cavities for hours, how does phase drift?

3. Voltage ramp is not nice: long conditioning to get to stably 1MV, max 2.5MV, took a long time
No time for conditioning in SM18 but this is not sufficient to explain this time

4. Freq tuning. 300kHz achieved with resolution some 10Hz
But then sudden increase of stiffness and therefore motor gear slippage at end 2018. Needs repair of warm part

5. Alignment, static alignment <0.5mm in both planes. Included validation of FSI system. No active alignment required

Lessons learnt

5b. Beam loading & electrical center. Validated the alignment. Static realignment to be done in LS2 and remeasure with beam 150micron

6. Field antenna couples strongly with beam instead of just measure the cavity field variation
Design change for field antenna was necessary to minimize decrease effect by factor 10

7. RF feedthroughs: vacuum leaks at 2K, solved with redesigning window brazing. Impedance in SPS was 38Ohm, we should have 50Ohm but finally went to 25Ohm for more robustness and standardization for all couplers

8. Electro acoustic instabilities: very high sensitivity to Lorentz detuning. An instability at 1MV detuning 400Hz which is ½ bw of cavity, so self excited loop is essential, in place only now (not during 2018 run)

9. Microphonics: non issue, small detuning and sufficient RF bandwidth

10. Voltage program, ramp: the easiest was to run cavities off, unplugged, to circulate beam. Cavities tuned to low voltage, counterphase, bring up to field, then rephase. But the scheme in LHC could be much easier

11. Emittance growth: lower by 2-4 factor wrt expectation, not fully understood because kind of systematic

Lessons learnt

12. impedance. HOM lot of design work, integrated power in SPS is 3W, overall scaling looks reasonable

12. Vacuum dynamics. From single to train of bunches, 60 nominal ones, no obvious problem with cavities, but scrubbing needed to fill max current: bypasses were coated but not conditioned. We need scrubbing.

13. Cryogenics. 15W for cavity 1 and 8W cavity 2 at 2.1MV, much higher than resulting from vertical tests (5W), we don't' completely understand the very high heat load: is it the estimate or the lacking conditioning?

14. RF Power. Phantastic. Only notable issue is lack of linearity at low power of the amplifiers. Gain is not linear. Now the rest of the RF chain is validated. The linearity was added to the specification

Lucio: what will we learn more on RFD? Major modification to the module with field antenna, ok, but what else ? We need to see the effect of the modification, and RFD is the first to come. Also limitation in voltage, which was 1MV in SPS. For RFD we go for well above nominal voltage. We need to show that we can easily reach nominal voltage and beyond.
Bob: tuner not working? Disassembling warm part, it looks as if something was blocking, not cavity becoming stiffer. We don't completely understand. Motor slippage problem related to this.

Ofelia

Cavity and cryomodules

Recap of complicated gymnastics of collaborations.
Including the Russian ancillaries for the CERN UK part of the collab

RFD1:
Design updated after SPS tests.
Ancillaries construction see tomorrow
Cold magnetic shield built in UK
Dressed cavities fully validated at CERN the UK in Oct 2020
Test in SM18 Aug2021 for installation in SPS end of the year

Cold magnetic shield also being modified in UK
Cryomodule is identical to LHC one: second beam pipe, beam screen, RF shielded bellows

For LHC DQW

DQW
Design of cavities also modified after test
Cavities w magnetic shield and He vessel being manufactured
Production in industry to be presented by Nuria
Collab agreement with Russia is under preparation

Module: also to be redesigned with features for LHC, then first assembled at CERN, following 4 in UK
Industrial production in RI

Integration of modules in LHC being worked out:
Interchangeability between P1 and P5, plus more accessibility behind the line
Remote alignment of full cryomodule

RFD for LHC

Cavities and module identical to SPS one
10 deliverables for 2+2+10 even if collaboration agreement is for 10 only.
Pass lessons to industry from CERN fabrication. Leonardo, Naeem, Emanuele

Canada, also presentation by Bob tomorrow

QA plan implemented, with engineering specs being written, status shown.
Transport aspects being addressed already now

Torg: equivalent specs for both cavity types? Why 2 types then?
Different stages in the story: not too many designs, focus on 2 for natural RF topology, both installed in both planes but very different environment if turning cavity by 90. So choosing 2 types was easing the integration in 2 different cryomodules. If one type would fail, we can use the other one in both planes. Rama adds: harmonizing cryomodules, but also naturally spread the HOM spectrum by having 2 types: HOM spectrum is not the same. Impedance is automatically a factor 2 smaller if 2 types are used instead of one.

Leonardo

RFD USA

Bare RFD
2 prototypes, 2 pre series, 10 series, but ultimately 10 delivered, according to collab agreement
Bare, qualified at FNAL

Recent RF changes to the pickup, no more changes expected
Summary RFD tests in FNAL and Jlab: all tests exceeding 3.4MV, with max 5.5MV achieved with dampers. Highest Q0 7e9 with dampers, which is twice the requirement
For dressed cavities, AUP aims at 4.1MV, as acceptance value, to be sure to reach 3.4MV in the cryomodule. In US if not 4.1MV, not good enough for US. This is more than nominal

RF Leakage in HHOM, discovered and resolved, tests at JLAB
For the project, Argonne and FNAL facilities for BCP and HPR, with rotational and tilt of the cavity
High temperature degassing to get rid of hydrogen
All this is now validated, without dampers, including heat treatment and cleanroom assy.

Fabrication at Zanon:
Sep 2018 for 2 proto bare cavities.
Options: 2 preseries and 10 series
March 2020, then Apr 2020 for the first 2 prototypes

RFD USA -2-

Waveguide box forming, copper HHOM. See tomorrow Manuele
EBW also started on HHOM boxes. Looks really great

Needs:
Drawings for magnetic shields and helium tank, as mechanical design is CERN responsibility
Frequency shift estimates for prototypes needed, to communicate to supplier
Functional requirements specifications before end 2019 to be formally completed. Draft exists
Address open recommendations before next AUP review in Jan2020

Delivery delays
2 independent companies now at Zanon. This froze placing contracts for a while, now back to business as usual
Still 4 months delay, although final delivery dates are not changed

QA: If CERN requires a procedure, AUP makes a proposal and puts on EDMS the version which has undergone internal AUP approval. MTF is to be used as well

RFD USA -3-

Acceptance
We have drafts but didn’t make progress since last meeting
Which and how many tests?

Goals for 2020
See slide, a lot

Reviews coming up
In one of these, Final design review, summer 2020, needs WP4 to defend mechanical design.

List of topics for discussion of next days

Goals for FY2020

- Launch procurement of magnetic shields and Helium tanks for prototypes
- Complete fabrication of 2x prototype bare cavities at supplier
- Assess quality and 2K performance of prototypes
- Converge with CERN on MIP for bare cavity by February 2020 (PRR)
- Launch fabrication of pre-series bare cavities
- Complete fabrication of 3x sets of Proto-HOM dampers at Jlab and assess quality & performance

Topics for Discussion

- Fully integrated test of dressed cavity + dampers + FPC
  - It's a necessary validation for entire collaboration
  - Who/how/when/funding?
- Best use of AUP Prototypes in early 2021?
- Details of Final 2K tests at FNAL
  - 50 Ohm ←→ 25 Ohm
  - Converge on Traveler for cold test
- Verification at receiving end (Triumf)
  - Cold tests for prototypes?
  - Warm measurements for series?
- Transportation specification
  - CERN recently defined transportation requirement for the design of all crab cavity components (10g,…)
  - Transportation will need to be carried out avoiding exceeding design requirements

Silvia

Cryogenic RF (2K) Performance Requirements

Eng. Spec. EDMS 1389669 [1]

- ***Resonant frequency of crabbing mode at 2 K*** **400.79 MHz**

  RF surface resistance: $R_S = \underbrace{R_{BCS}(\omega^2)}_{1\ n\Omega} + R_{res,H}(\sqrt{\omega})$

- ***Nominal deflecting voltage V_t*** **(3.4 MV) + 20% margin** **≥ 4.1 MV**

- ***Dynamic heat load for dressed cavity at 2 K and 4.1 MV*** **≤ 10 W**

  $Q_0 \geq 5.4 \times 10^9$ for operation at 2 K and 3.4 MV

  (For DQW SPS-series, R_t/Q = 430 Ω and G = 87 Ω, allows R_S = 16 nΩ)

DQW PoP cold testing

PoP DQW fabricated by Niowave, then tested at BNL and CERN
Used for EP, tuner testing, measurement of multipoles etc
No helium tank, no couplers. They exceeded nominal voltage with 38% margin, P< 10W at 4.1MV as required.
However, RF surface resistance of 22 nOhm (should be <9nOhm) at 1.9 K leading to Q0 = 4 10^9

Then design of the SPS DQW. Here, input power ports and HOMs, integration, full design of CM with 2 cavities. There are the rings to integrate the helium tank. One would except better performance for the SPS models than for the PoP.

DQW prototypes, bare and with HOM

Now AUP has 2 bare cavities built at Niowave and followed by JLAB. Used to investigate the limit s of performance
Plus another 2 built at CERN

All 4 bare cavities surpass the 4.1MV with Qo equal or above what required for SPS
One cavity goes to 5.9MV, 135mTesla, very good for a bcp'ed cavity
FE onset starting after 4.1MV

With HOM couplers: early quenches both for CERN cavity with 3 couplers and LARP cavity with one. Couplers treated only by BCP flash and rinsing. As a result, quench at 3.4MV. All HOM should therefore receive the same surface treatment as cavities do
Got to 4.7MV once treatment applied (bulk bcp, rinse, 600C, light bcp), the largest Vt to date in any DQW with HOM

Try to discriminate if quench in cavity or coupler.
Retracted filter by inserting a 20mm spacer in HOM, reduces Bp by 50%, allows reaching 5.1MV
Simulation in UK, including thermal and RF modelling. Extraction of more than 1W in the superfluid helium, which is too high in the small channel: filter may become thermally unstable and quench.

DQW prototypes, bare and with HOM

2HOM couplers in cavity, tested: large leakage of fundamental mode through 2nd coupler
Then the HOM coupler was rotated – magnetic coupling, so you change it easily by rotation – then less coupling to fundamental mode, so power leakage supposed reduced. Test today!

Summary
Sound design, below 5W, treat HOM couplers like any other SRF cavity

Limitations are quenches – likely thermal quench in HOM filter
And recurrent multipacting band below 0.5MV

Next tests:
LARP#1: cryogenic tests at CERN to benchmark JLAB
LARP#2 test with 2 filtes, then BNL for benchmark of best result, field mapping and multipoles
LARP PoP: EP again at KEK, for ultimate RF performance.

Future: translate the experience to LHC series and also eRHIC DQW
Extend studies of N-doping to 400MHz

Questions to Silvia

Ofelia: leakeage of HOM coupler at the baseline position?
Yes. But cavity was detuned. Since the LARP cavity is 2MHz away from the nominal, it may be that this is the reason
The physical frequency not being correct, the HOM rejection may not be correct
Ofelia wonders if we need to dig more into the issue – filtering capacity

Ofelia: best result of dressed: quenches at lower but has better Q than the same, bare.

Krzystzof: heat load per cavity, right? Ofelia is talking per cryomodule. Rama means you are off by 2.5 factor not factor 5

Krzysztof: if cavity voltage and temperature stable, what is the limit of temperature you reach? Rama: below 4.7MV you don't excite 1W in the HOM channel. So at 4.1MV heat load is less than 1W in this channel.
KB insists that if we go out of superfluidity in this mode, we will quench.
Heat load to be estimated correctly here because critical for cryo operation here.

Paolo

Processing of RFD cavities, warm and cold testing

Bare RFD cavities cold test and processing
RFD cavity +HOM couplers tests and processing
HOM couplers at warm
Bead pull

Test to compare at JLAB and at FNAL
Cleaner situation determined better result at FNAL due to magnetic *hygiene* in the cryostat

RFD#1 never exceeded the 20% margin. So the whole processing was run through again to check it.
Processing flowchart is described here
Complete processing was done at Argonne. Rotational bulk and light bcp
Heat treatment under vacuum, then clean room assy for vertical test
At the end of the process, the cavity exceeded 4.1MV by far, getting to 5MV and slightly beyond

RFD#2 These were processed with HOM being only ultrasonic degreased.
No quench but Qo is one order of magnitude too low
Limitation was not quench but significant RF leakage into the stainless steel flange
The sc portion of the hom filter was shortened by the flange
Solving the HOM rf leakeage, the cavity went above nominal

Measurements of HOM

Now cavities not affected by HOM dampers anymore but we want to check the HOM themselves, QL, at room temperature, then at 2K. Not only Qloaded, but now also Qext
So from 200MHz to 2 GHz the expected Qext range is matched, no increase nor drop
HOM performance validated with a test box.
A “test box can” is used, to measure the transmission of the filter. Scan of frequencies, to measure the dB or attenuation. Want to be within 3-1dB
The location of the notch can be tuned with radius on the probe, from 6mm to 8mm, to see the notch frequency change. You can then be as close as possible to the cavity frequency for LHC operation

Now bead pull: difference between el center and magn center// plus multipoles B3 components
XY motors to position the beads
Deviation was 0.66mm, then system was realigned using previous measurement
Multipoles are field values at constant radius. Good agreement btw simulation & measurement

Questions on the processing and procedure. If at normal baseline 50% cavities don’t make it, then re-processing. Of course if all cavities have issues, then we will get into schedule issues. Re-processing is light BCP
Multipacting is light, but then after overcoming barrier no more issue. Fixed coupler. At 5e9. cleaned completely in less than 1 hr.
Port configuration between rfd now and new? Very little difference, we also need rf gaskets for all homs, both dqw and rfd.

Nuria

Contract

1 jacketed cavity pre series
Option for 10
She presents the workflow between RI and CERN
Do all BCP at RI but we can also have the option to do HPR at CERN
Change of schedule for 2 preseries and 9 series, change of pickup
Then design modification of pick up flanges, but no schedule changes resulted: once the bare cavities are validated they can start the bare cavity series, which allows to advance 6 months on planning. Then validation of jacketed and production of jacketed
In Dec we get the first bare cavity test - time until May, then green light for bare cavity
Series: 1 bare cavity every 6 weeks, 1 jacketed cavity every 6 weeks
All pieces for the 2 preseries in Nb are fabricated, bowls as well as elliptical caps
EDMS is used, then doc released at CERN
Many iterations, to achieve high quality documentation
She explains the approval process and the follow up of fabrication with implementation of MIP in MTF

Experience with RI contract

She details the reasons fo the delay.
Documentton, codes not existing for Nb, not used to Pressure equipment besides xfel.

List of NCr

Collaboration with AUP

Several docs already on EDMS and in approval
She asks for some info on wether documents uploaded by AUP on EDMS are to be considered approved or not by AUP

Jean
Closed with warning, what does it mean? To remember that an action is needed. Like grain size smaller, one action required is that flange is acceptable and update of technical specification required. After the action is done, the NC is closed.

Bob
How is the expectation of documentation communicated to user. Everyone is surprised by the amount asked. They bid and underestimate required resources. They came to CERN and spent ½ day to look into our experience of DQW. They didn’t say they wouldn’t do it but was a little more difficult to convince them, lot of effort from Nuria

Frank
Nuria is working full time on this, for construction follow up in RI, check of documents, EDMS in correct way. Message for AUP that this is a considerable amount of work. Ofelia: this is not only quality control.

Collaboration with AUP

Leonardo
Potentially tunnel equipment, and Nb material for series placed, also tunnel equipment. What kind of reviews to get to this result? Review at RI before giving ok to cut. Any other test? Ofelia: when we issue such a contract, before the spec we have internal reviews of the spec to check that all drawings are signed, every requirement covered etc, with technical experts outside the project. This is all before placing the order. Leonardo: same for AUP but needs to understand what requirements other than doc check. Leonardo insists on clarifying the expectations, to invite Isabel or WP4 to check matching. A production readiness review is done at CERN. Ofelia explains what CERN requires (spec committee) and for hilumi (production readiness reviews, like with Diego) which is more complete and technical.

Lluis
Schedule (Ofelia explains that the schedule is still under discussion). Comment. Dates are contractual? How does this time related with approval process and agreement there? Introducing delays?

Manuele Narduzzi

Fermilab

Qualification status of US AUP

Design for fabrication
Fabrication status
QA doc

Design for fabrication, similar to the CERN one, HOM transitions are the same for the 3 ports, from hollow tube and not rolled one
Assembly strategy detailed: same as used at CERN for prototypes, with some smaller differences
Validation of drawings and tools or manufacturing ongoing. Very few items not started
Example of the waveguide boxes forming by deep drawing shaping, then metrology
All this on copper, then going over to Nb. They still follow CERN's procedures applied for prototypes
Lots of details on these then on HOM extrusion and in the end on the Nb pole

Recap of QA at Zanon and EDMS uploading of documents

Leonardo
Do you guys think that from now in less than 6months we can have it all, /impossible /easy /confident? Or rather summer 2020 to start welding? Which portion do we need to say start working on preseries? Add a column to set some goals: this before placing order, this before cutting metal, this before welding etc

Naeem Huque

JLAB

RFD ancillary production at JLAB

HHOM, VHOM and field antenna all to fabricate at JLAB, started under LARP now AUP
17 sets of ancillaries: one HHOM, one VHOM, one pickup
3 prototypes, then 4 preseries, then 10 units of series

Prototypes are based on logics of best effort, not strict adherence. All material is complying with specs from CERN
Planning presented (FY = from October 1 to end September)

One MIP for each ancillary
Each part drawing is in the JLAB pansophy system, similar to MTF traveler. Test data and materials certificates are also collected here. Then all this info goes into CERN's MTF.
Two sets of HHOM dampers were fabricated to use on RFD

HHOM is bulk Nb. Lessons learnt from the first prototype best effort type HHOM

Eric Montesinos

HOM couplers, antenna and FPC

Weekly meetings with AUP colleagues, view from CERN side.
Couplers to be connected to outer world.
Provided by CERN, or China, or AUP-Triumf
Now China has become Russia, with prequalification with RI and UK. If failed, then CERN to do it.
Eric explains the redesign of the field antenna starting from Rama's presentation
Shocks expected. Main reason to go to 25Ohm because then larger diameter, mechanically more robust
This redesign impacts on all devices, ceramics, titanium flanges and cavity flanges
Tested by drop test and thickness optimized
Design of RFD first, then DQW
Raw material ordered
Once the HOM couple is done, you have now to connect the RF power transmission lines which are 50Ohm now and must become 25Ohm. Redesign. Then high power testing in preparation
Consider we won't be changing lines easily in the cryomodule
FPC tests demonstrated very good design of FPC for 100kW CW for SPL, 62mm line.
Cryogenic event not explained (Rama's #13): thermal distribution along double wall tube
Flip book for clean room
Test boxes for high power and HOM preconditioning
Interesting list of "still to be done"

Bob Laxdal

TRIUMF

RFD cryomodule fabrication at TRIUMF

Develop RFD design, assembly tooling fixtures etc, receiving cavities, assemble hermetic string

Transport

Team: 10 people
1 technical coordinator, 1 deputy, 1 engineer 1 designer, 2 string assembly, 2 cryomodule assembly, 1 cabling, plus some technical support from the services providing cryo, HLRF and alignment

Planning: they have to cross a series of 4 gates, until the commissioning phase
Gate 1 is conceptual design, WBS, budget and resources, hazard and risk analysis Dec 19 if possible
Gate 2: project plan and full WBS and budget, technical design doc Feb20
Gate 3A May20, launching TCM0

TCM0 similar to the Ariel ACM zero prototype, with ideally two cavities, but may also be one cavity and one dummy
He asks whether there is there a risk in launching the procurement before the SM18 test?
Procurement TCM0 launched in May20, it still needs a push to get to ready when the cavities are ready

SM18 and SPS tests are after the date TRIUMF would like to fix the CM design

RFD cryomodule fabrication at TRIUMF

Bob proposes to test a part of the cavities, including test coupler, without venting, at cold in their big cryostat
Then assemble with FPC and test the fully assembled unit
With this test, full qualification would be assured before CM assembly
Shipping always under vacuum. But assembly under vacuum? CERN doesn't plan to ship under vacuum. Fears deformation for bare cavities, with the vacuum push. In US shipping is always under vacuum, consensus in the community
PoP went to CERN under vacuum, as much as the RFDs
Leonardo thinks no frequency shift was shown from RFD cavity under vacuum being shipped around USA

Goals for 2020: a) establish scope b) agree on design, c) establish acceptance criteria for cavities from AUP and cryomodules

The story of the VECC Injector cryomodule transport
One rigid external transport frame, holding via springs a yellow internal skeleton which contains all fixtures for the cavities and bellows and couplers of the assembly, all hanging from top plate, without vacuum vessel
Monitoring by slamsticks, 3, installed on batteries 7.2Ah AGM batteries, autonomous for 15 days, 3 axis accelerometers, 8Gb storage, 12.5 to 3G. Data show suppression of vibration amplitude between external and internal frame

Ofelia: drop test? With the cryomodule
Batteries run out? Yes, twice. During detention, update of battery pack, then updated again just before it left. Flight data are available
Rama schedule: July 21 fix design of series. SM18 test will come first.

Discussion

Discussion on planning of TCM0 where Bob would like to have power couplers (not 2 available) beam screens (not available yet) 2 cavities (but AUP then misses the testing cavity to troubleshoot stuff).
Ofelia explains that there is a welding interface for what? Which is done at CERN before sending to UK. Should this welding be done at Triumf ?
Practising in clean room with particle counters etc
Alignemnt team: do you have laser tracker? This is an essential tool according to Mateusz. Bob thinks he wants to look into CERN procedure for alignment. Procedure to be reviewed.
Laser tracker present on all steps of assembly. FSI to be delivered for preliminary tests after assembly
If the alignment team is already identified, then discuss and exchange experience.
Tom proposes that the guys come over to CERN together from Canada and UK

Tom Jones

STFC UK

Contents

- UK Design Contribution to SPS-RFD Cryomodule
  - Magnetic Shielding
  - Thermal Shield
  - Assembly tooling
  - Transportation Frame
- Schedule for SPS-RFD Cryomodule build in UK
- HL-LHC-UK2
- Scope of WP2, Series Crab Cavity Cryomodule Build in UK
- Schedule for Series Crab Cryomodule Build

SPS RFD

Major change is beam screen inside vacuum pipe
Interchangeable level probes, for test of cm with nitrogen different level probes are used, so good design point

Cold magnetic shield designed and delivered to CERN
Modify and reuse existing shields. Lead time is 4-6months.
Willebrand cableflex