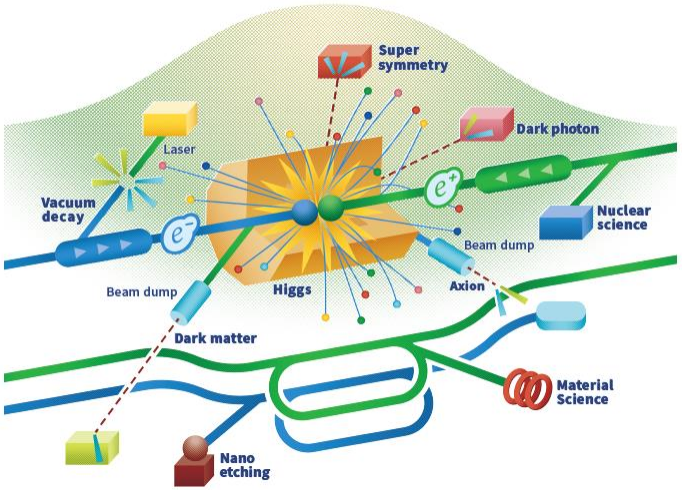
QMiR Crab Cavity for ILC

Andrei Lunin, Vyacheslav Yakovlev

October 13, 2023

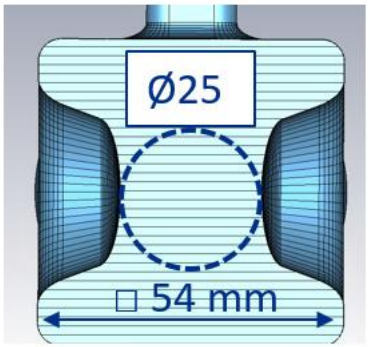
WP3 Crab Cavity Design Meeting #6

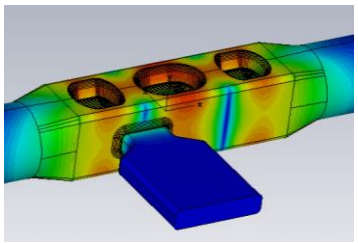


Requirements for QMiR 2.6 GHz Crab Cavity

	Parameter	Post-TDR Specification		10Hz Upgrade[1,2]		1 TeV CoM Spec [2]		
2	Beam Energy (GeV) e-	125				500		
3	Crossing Angle (mrad)	14						
4	Installation site (m from IP)	14						
5	RF Repetition Rate (Hz)	5		10		4		
6	Number of bunches	1312		2625		2450		
7	Bunch Train Length (ms)	727		961		897		
8	Bunch Spacing (ns)	554		366				
9	Beam current (mA)	5.8		8.75		7.6		
10	Operating Temp (K)	2						
11	Cryomodule installation length (m)	3.8 (incorporating gate valves)						√
12	Horizontal beam-pipe separation (m)	0.1967 (centre) ±0.0266 (each end of installation length)						√
13								
14	Cavity Frequency (GHz)	3.9	2.6	1.3	3.9	2.6	1.3	
15	Total Kick Voltage (MV)	0.615	0.923	1.845	2.5	3.7	7.4	√
16	Max Ep (MV/m)	45						√
17	Max Bp (mT)	80						
18	Amplitude regulation/cavity (% rms)	3.5 (for 2% luminosity drop)						
19	Relative RF Phase Jitter (deg rms)	0.069						
20	Timing Jitter (fs rms)	49 (for 2% luminosity drop)						
21	Max Detuning (kHz)	240	170	100 - 180	240	170	100 - 180	√
23	Longitudinal impedance threshold (Ohm)	Cavity wakefield dependent						√
24	Trasverse impedance threshold (MOhm/m) (X,Y)	48.8, 61.7						
26	Cavity field rotation tolerance/cavity (mrad rms)	5.2 (for 2% luminosity drop)						
27	Beam tilt tolerance (H and V) (mrad rms and urad rms)	0.35, 7.4 (for 2% luminosity drop)						
28	Minimum CC beam-pipe aperture size (mm)	>25 (same as FD magnets)						√
29	Minimum Exraction beam-pipe aperture size (mm)	20						
36	Beam size at CC location (X, Y,Z) (mm,um,um)	0.97, 66, 300						
37	Beta function at CC location (X, Y) (m,m)	23200, 15400						
41	Horizonal kick factor (kx) (V/pC/m)	<< 1.6 x 10^3						√
42	Vertical kick factor (ky) (V/pC/m)	<< 1.2 x 10^2						√
43	CC System operation	assume CW-mode operation						

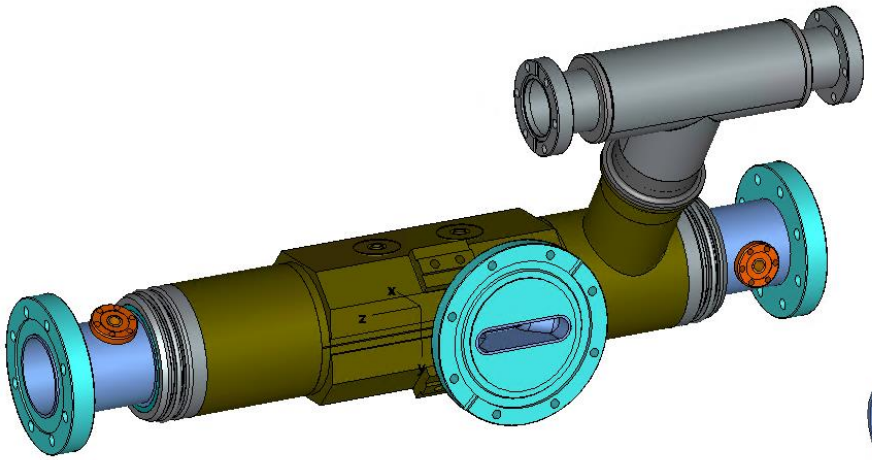
Freq	2600 MHz
V_{kick}	0.92 MV
$(R/Q)_t$	225 Ω
G-factor	160
Bp, max	70 mT
Ep, max	35 MV/m
W_{STORED}	0.24 J
Length	500 mm

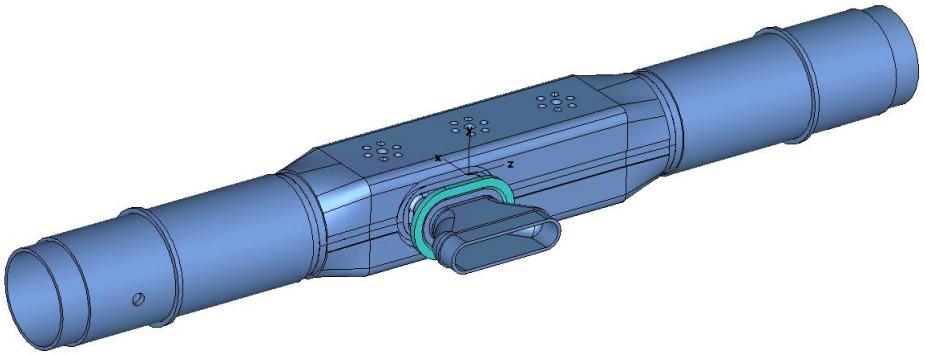




Fermilab

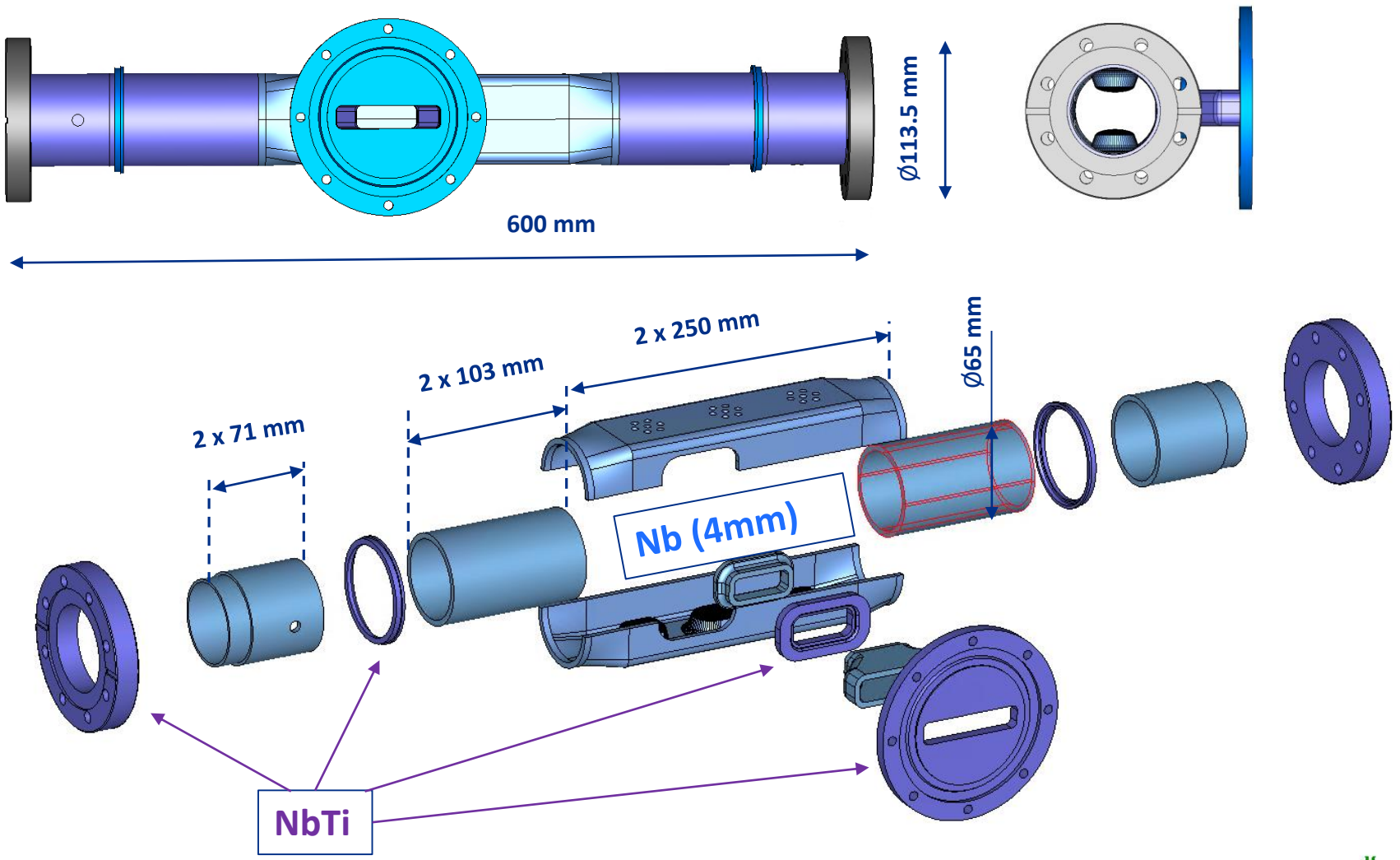
Finalized Mechanical Design of QMiR (Y. Orlov)





- The cavity body divided into several shorter parts
- Nb thickness is 4 mm (reduced to 3 mm for welds)
- NbTi Transition Rings for welding the LHe-vessel
- NbTi End Flanges with Al diamond seal

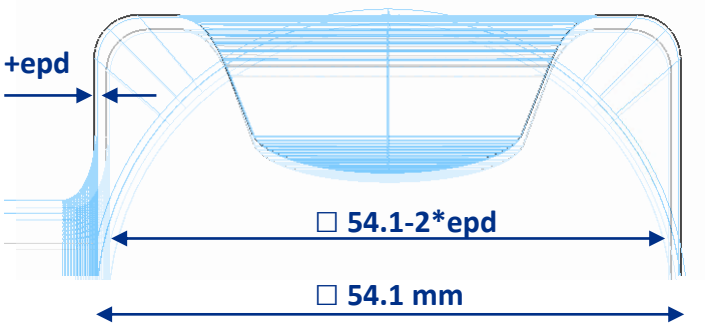
QMiR Parts

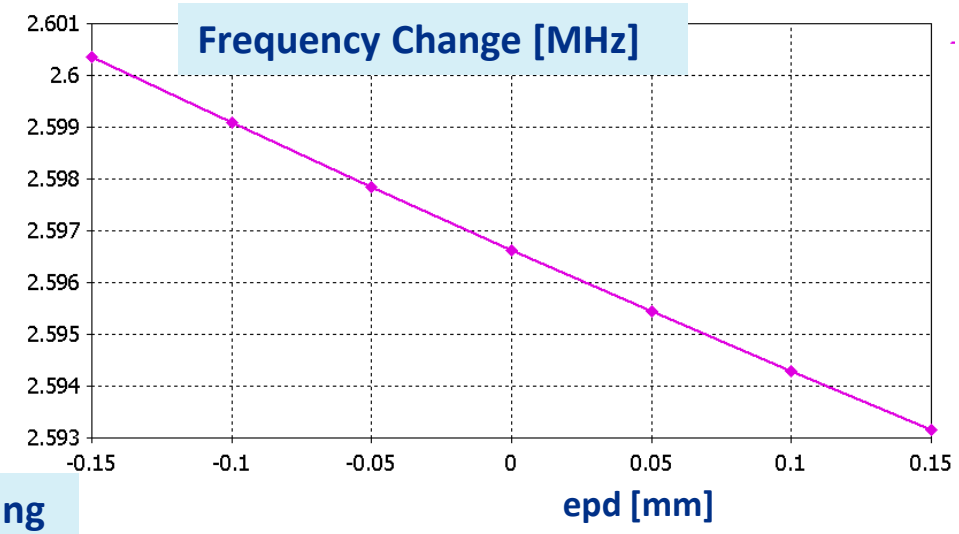


- **All parts are milled from solid Nb ingots**

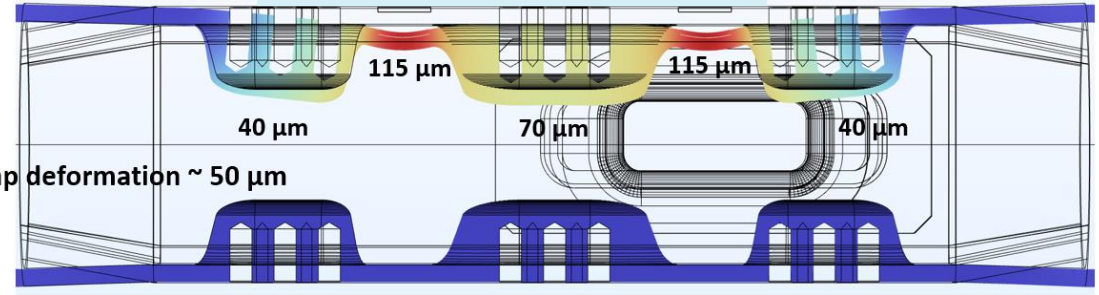
Fermilab

Cavity EP-cleaning and Final Frequency Tuning





Manual Frequency Tuning



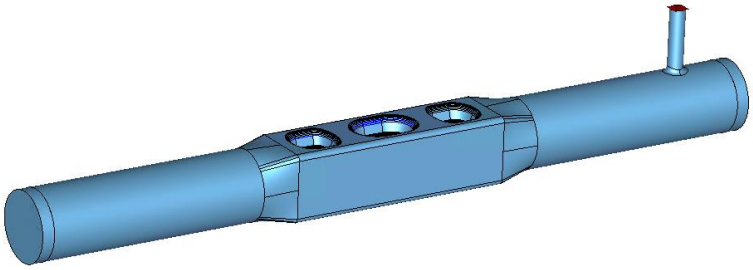
Δf ~ -2.01 MHz vs. 10 kN force

Δf/ ΔL ~ - 17.5 kHz/µm
Δ σ/ΔForce ~ 22 MPa/kN

~12 µm (1kN) tuner stroke for 200 kHz tuning

- **Nominal frequency @RT before cooldown, F0_RT** **≈ 2.6/1.00143 = 2596.3 MHz**
- **Expected frequency sensitivity of EP, df/d(epd)** **≈ -24 MHz/mm**
- **For maximum Nb removal of +150 µm, df** **≈ - 3.6 MHz**
- **Desirable cavity frequency before EP:** **≈ 2599 (+1) MHz**

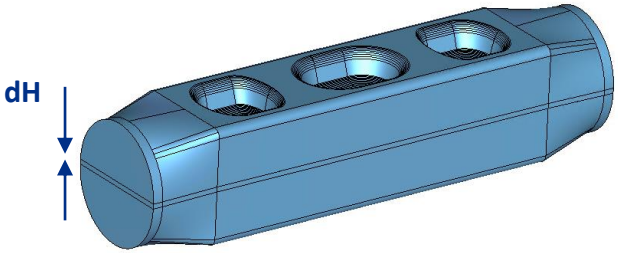
Central Part Frequency Tuning



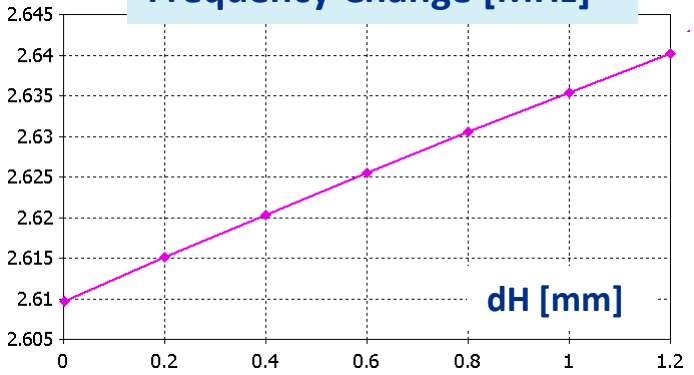
Frequency w/o WG

F0_RT_WG = 2596.3 MHz
F0_RT_NOWG = 2600.1 MHz

EBW-shrinkage sensitivity



Frequency Change [MHz]



- **Expected frequency sensitivity due to EBW shrinkage: ≈ -26.6 MHz/mm**
- **Expected frequency shift due to WG-coupling: ≈ -3.8 MHz**
- **Misalignment of cylindrical parts (Ø56) (< ±0.2 mm) leveled by the EBW seam.**

Summary of Cavity Tuning

Production step	Target Frequency, MHz	Remarks
1. Machined Central Part (CP)	2625.4	dH = +1 mm
2. Before CP EBW	2618.8	dH = +0.5 mm
3. Welded CP	2612.0	dH = 0 ±0.1 mm
4. Welded CP + BP	2602.9	1st freq. tune
5. Full cavity (CP+BP+WG)	2599.1	Final bead pull and freq. tune control
6. Full cavity after EP (@RT)	2596.4	EP ≈ < -100 µm
7. Cavity @2K	2600.1	dF_err = < (+1) MHz

- **Final cavity frequency @2K after cooldown is preferable to have a positive frequency error, less than the tuner range of ~ 1 MHz**
- **Frequency check is required after each step**

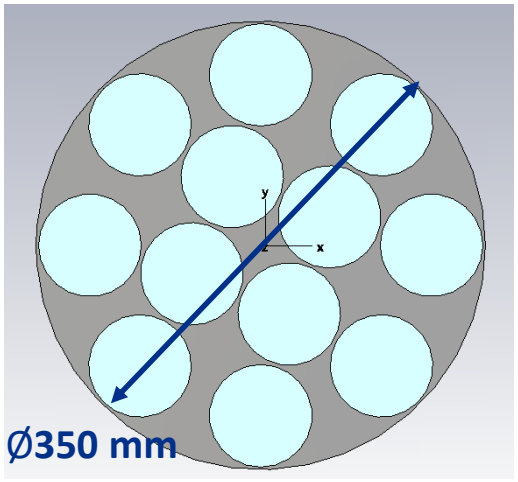
Nb Material Procurement

Companhia Brasileira de Metalurgia e Mineração

Córrego da Mata S/N - Araxá - MG
38.183-970 - Brazil
Tel: +55 (34) 3669-3000- Fax: +55 (34) 3669-3300

Analysis Report

Date:	12 May 2023
Product:	NIOBIUM METAL
Packaging:	WOODEN BOX REINFORCED 2000KG
Lot Quantity (kg):	311
Labware Number:	2040482
Ingot:	4162-6/12
Nominal Diameter(mm):	350
Surface Condition:	Machined
Length (mm):	405

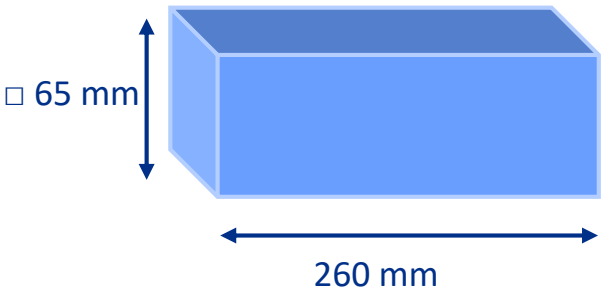


- ✓ **Purchase Order placed on 09/21/23**
- ✓ **CBMM is working on the logistics now**
- **Estimated delivery time is 4-6 weeks**
- **Next: Preparation for cutting samples (wired EDM)**
- **Next: RRR test and EB-welding test**

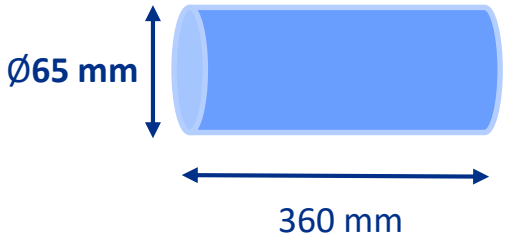
QMiR Raw Materials Needed

High-RRR Nb Ingots

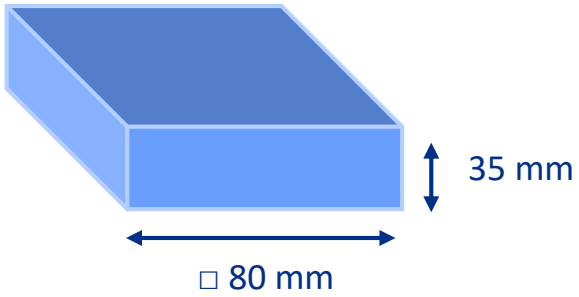
1 x Center part



1 x Cylinder

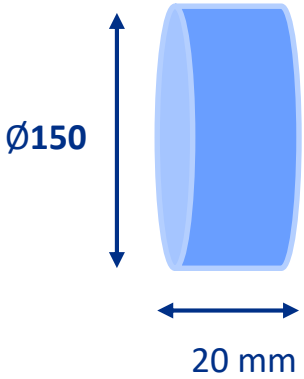


1 x WG Part

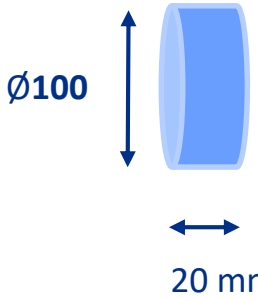


Nb-Ti Ingots

3 x Flange



3 x (WG Ring, 2 x LHe Ring)



Fermilab

Progress in Production of QMiR/CC Prototype

❑ Cavity Mechanical Design

✓ Validation of mechanical concepts completed

✓ Final mechanical drawings are ready

- Some parts may still require minor changes for better welding
- Series of meetings with ANL (paused until P5 report)

  - cavity fabrication plan, QA inspections, chemistry, etc.

❑ Production and prototyping

✓ Procurement of Nb material is completed

✓ Cavity frequency tuning plan is ready

- Close cooperation with ANL on the next steps:
  - Niobium QA (RRR, inclusions, …)
  - Develop EDM wire cut drawings for niobium
  - Develop a machining and EB welding fabrication plan

❑ Fermilab is open for collaboration

- loss/kick factor simulations with GdfidL
- multipactor analysis
- HOM analysis