RF Development Status at Iranian Light Source Facility

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(on behalf of RF Group)

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چشمه نور ایران
Iranian Light Source Facility

Outline

- Introduction to ILSF
- Injection
  - RF gun development
- Storage ring RF system (design, R&D status)
  - Specification
  - Cavity (main & HHC)
  - High power amplifier
  - LLRF

ILSF history

Iranian Light Source Facility

2010 Feasibility study project approved by the government

Executive Committee organized

Steering Committee formed (Synchrotron accelerator selected)

2011 Preliminary conceptual design completed

Site selection

2013 Conceptual Design Report (CDR) completed

2014 Design upgraded to lower emittance ring

2015 MAC meeting held to approve & freeze the design

2016 Basic design commenced

2018 Building of R&D lab and guest house started

2019 Basic design finished

2025 Current plan for commissioning

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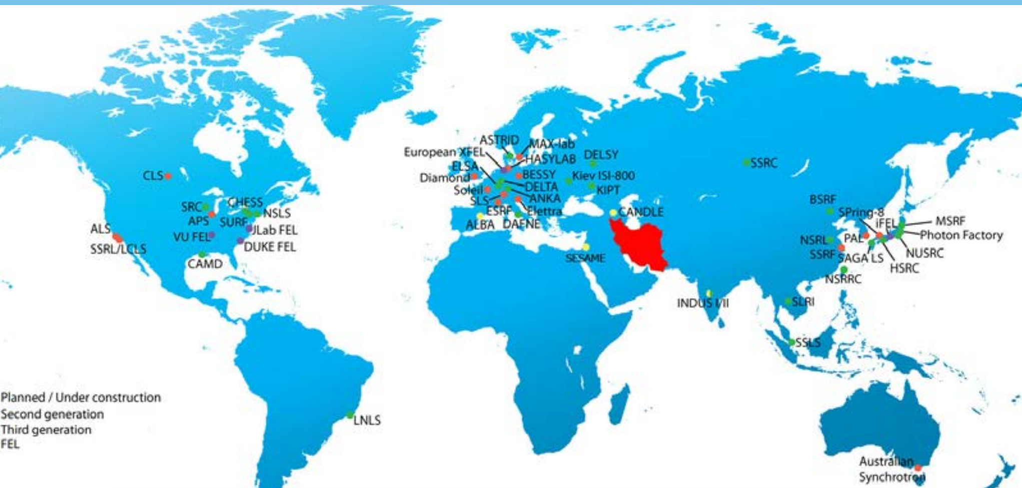
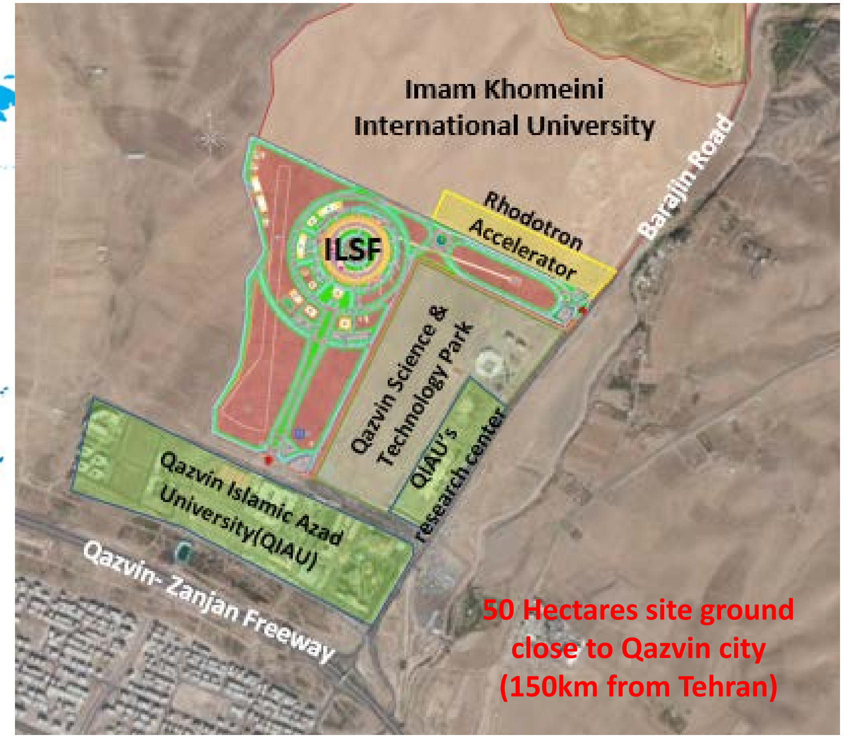
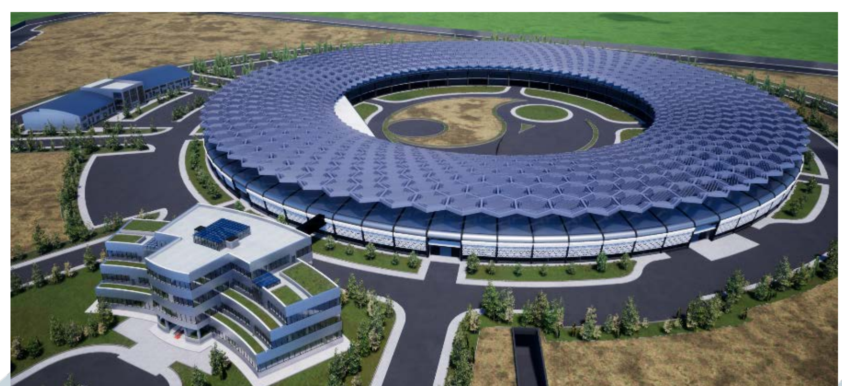
Site Location







Storage ring main parameters

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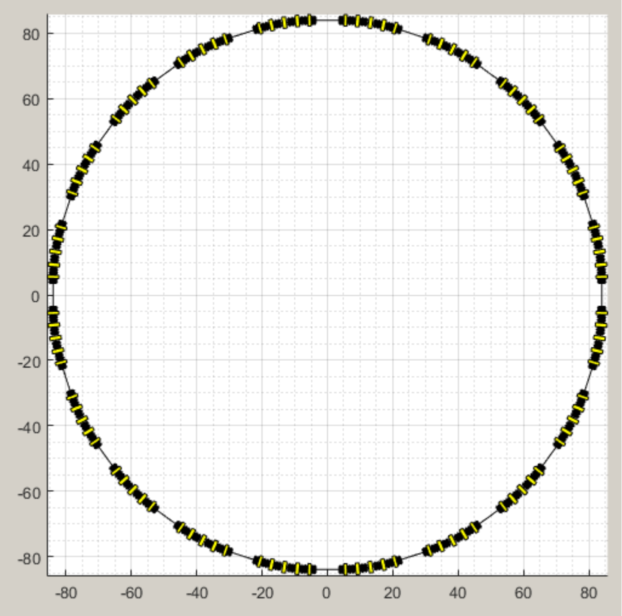
Parameter	Unit	Value (new-Lattice)
Energy	GeV	3
Maximum beam current	mA	400
Circumference	m	528
Lattice structure	-	5BA
Number of super period	-	20
Length of straight section	m	7.02
Natural emittance	pm rad	269
Betatron tune	-/-	44.16/16.20
Natural chromaticity	-/-	-107.79/-61.30
Natural energy spread	-/-	6.80×10^{-4}
1^{st} order momentum compaction factor	-	1.824×10^{-4}
Damping times	ms	18.857/26.002/16.03
Natural energy loss/turn	keV	406.4
Revolution time	μs	1.760
RF frequency	MHz	100
Harmonic number	-	176



Injection

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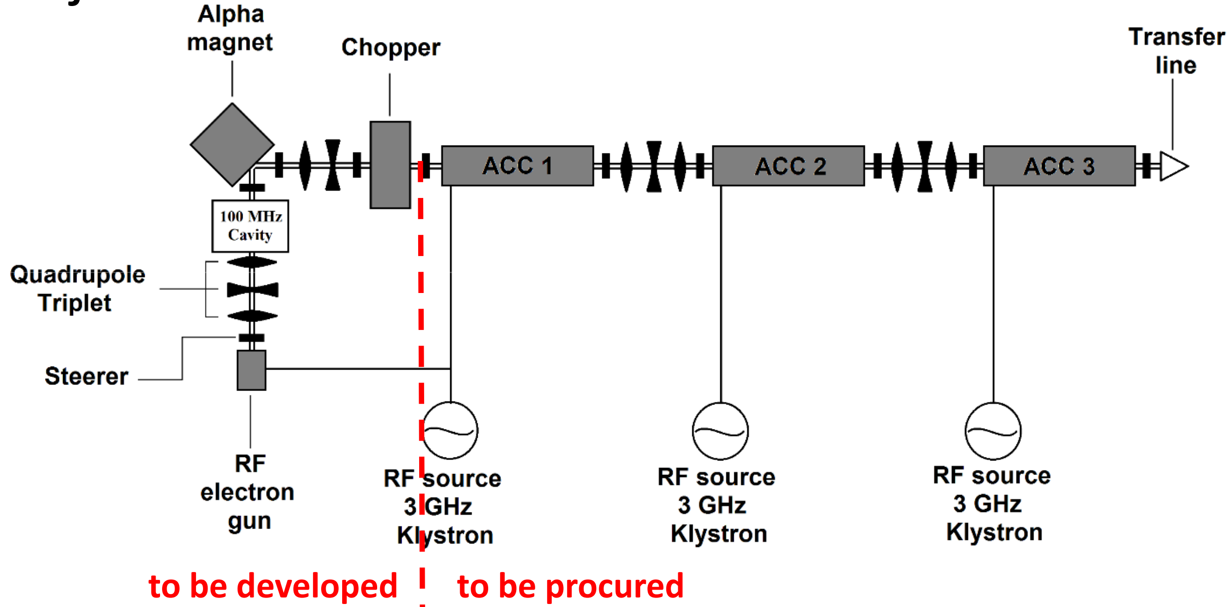
- Booster ring: Shared tunnel: Fodo lattice, 504m , 0.15-3GeV
- 150MeV Linac as pre-injector

Thanks to Helmut Wiedemann & Dieter Einfeld for the idea



Advantages:

- High energy gain in the RF gun and therefore, lower beam emmitance by a factor of at least 3
- No need for an expensive laser system to drive the cathode
- No need for heavy and bulky solenoid magnets

Thermionic RF gun

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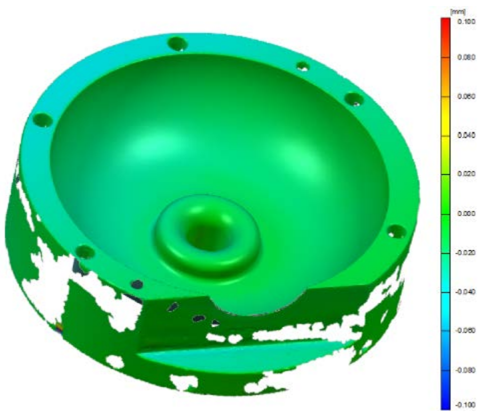
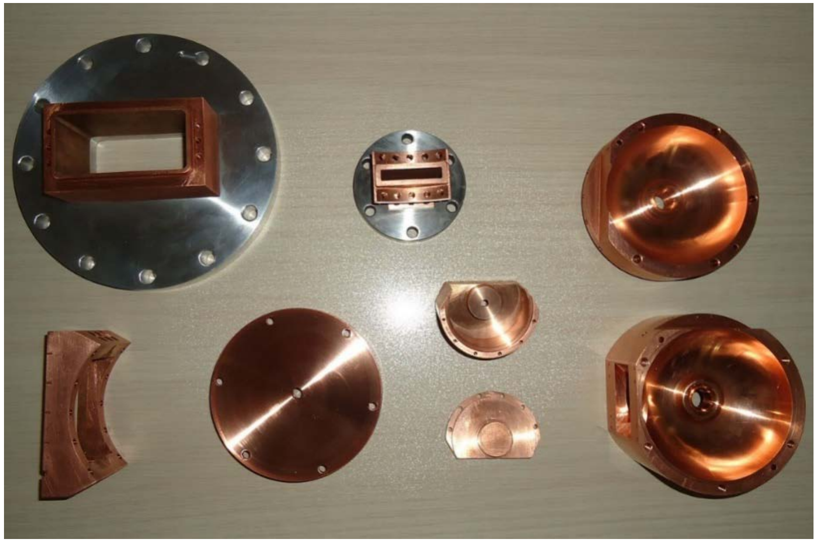
- 1^{st} prototype
  - Normal copper
  - Joined together using screws and conductive paste.
  - Mechanical accuracy
    - Dimensions error < 20 μm
    - Surface roughness, RA < 0.8 μm





Thermionic RF gun (cont.)

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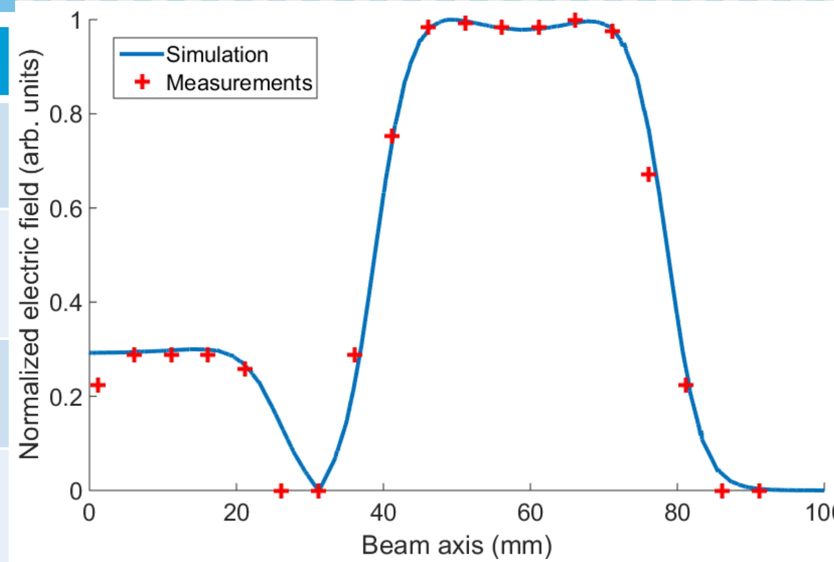
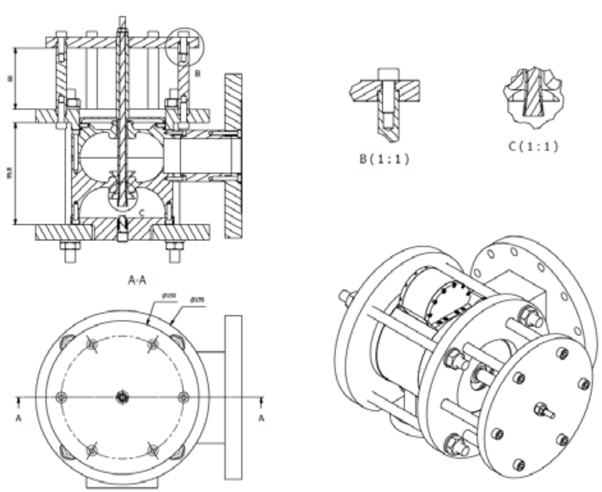
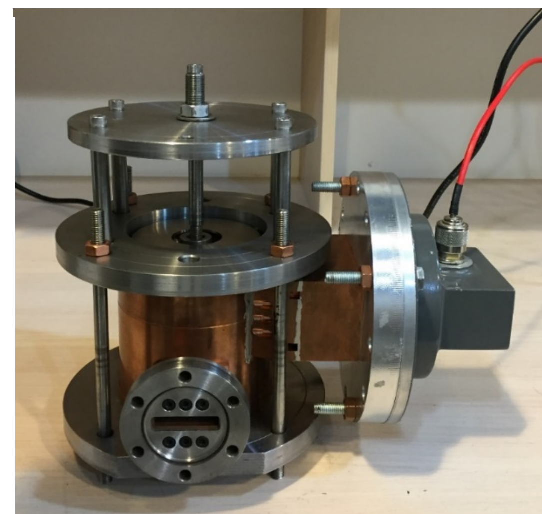
Parameter	Unit	Simulation	Measurement
Resonance frequency	MHz	2859.38	2859.57
Unloaded quality factor	-	13200	9300
Shunt impedance	MΩ/m	86.2	60.4
unloaded coupling (S11)	dB	-20	-19.6



In several steps, it was tuned to resonant frequency of 2855.8 MHz & 38% (half cell to full cell E field ratio)

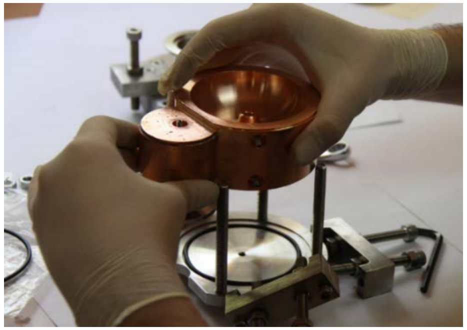




Tuning fixture

Thermionic RF gun (cont.)

- Sample for brazing test
  - Simpler structure to test the brazing
  - 3* 10-7 torr achieved by K-type flange & turbo pump

- 2nd prototype
  - Re-designed for 2998MHz (3002.38MHz in simulation)
  - Plan :
    - Brazing the parts
    - Vacuum test
    - Conditioning
    - High power test
      - Initials tests by available 2MW klystron
      - Final tests by 4MW klystron (to be procured)

Storage ring RF system specification

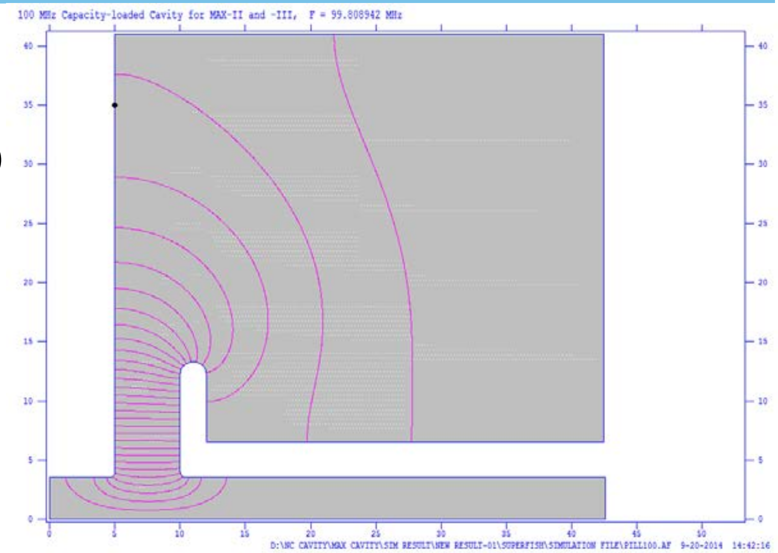
Parameters	Phase 0 (Commissioning)	Phase 1 (Initial user mode)	Phase 2 (intermediate user mode)	Phase 3 (Final user mode)
Beam current (mA)	100	100	250	400
No of beam lines	0	7	12	17
Beam loss per turn (keV)	406.4 (Dipoles)	547.8	721.9	1005.6
Beam power (kW)	40.6	54.8	180.5	402.2
Total RF voltage (MV)	1.1	1.5	1.5	1.8
Synchronous phase (degree)	158.3	158.6	151.2	146
Synchrotron tune	0.0013	0.0013	0.0015	0.0016
Cavity phase stability (degree)	0.42	0.36	0.37	0.35
Cavity amplitude stability (%)	1.8	1.6	1.2	0.9
Shunt Impedance (MΩ)	1.6	1.6	1.6	1.6
No. of cavities	5	5	5	6
Cavity voltage (kV)	220	300	300	300
RF power/cavity (kW)	5*23 (15+8)	5*39 (28+11)	4*54(28+26) + 1*105 (28+77)	6*95 (28+67)
RF Amplifier Power (kW)	5*26	5*43	4*60 + 1*117	6*106
Optimum coupling	1.54	1.39	1.92 , 3.74	3.38

RF system realization strategy

- Cavity
  - Type: Capacity-loaded cavity (similar to MAX-IV cavity)
  - In-house design, prototype fabrication
- High power amplifier
  - Type: Solid state amplifier
  - Procurement (abroad or domestic)
    - domestic companies' experiences up to 20kW SSA FM transmitters
- LLRF
  - Type: Digital
  - In-house development
- Transmission line
  - Type: 6 1/8" coaxial lines
  - Procurement (abroad or domestic)

Cavity EM Design

- Initial dimension from MAX-IV CDR
- Detailed and optimized at ILSF RF Group
- EM design
  - 2D : Superfish
  - 3D : CST MS, HFSS



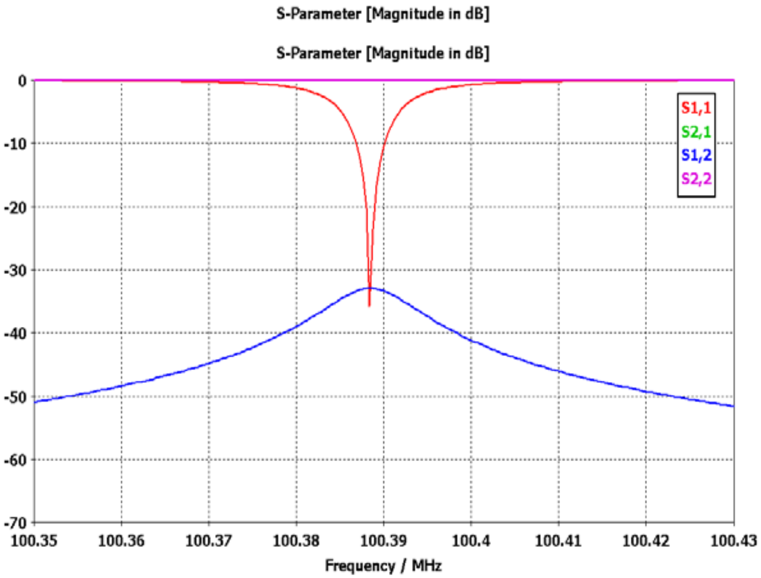
Cavity simulation results comparison for Superfish and CST

Parameter	SuperFish	CST
Resonant frequency (MHz)	100.563	100.135
Q factor	21335	22886
Shunt impedance	1.69 MΩ	1.75 MΩ

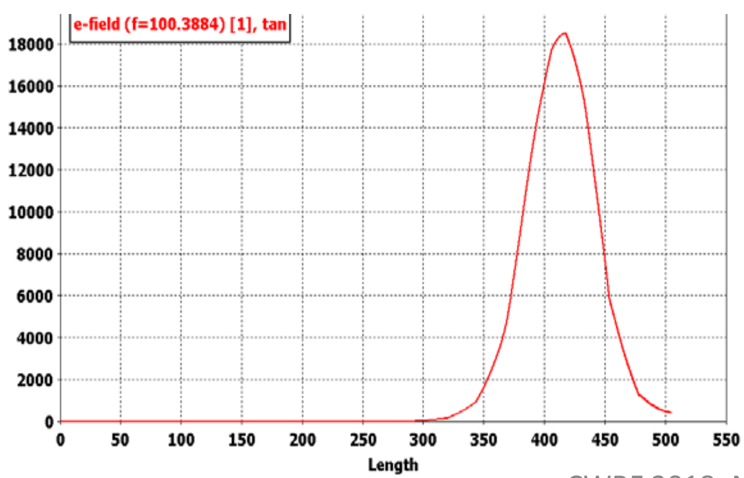
Cavity EM Design (cont.)

- CST Simulation

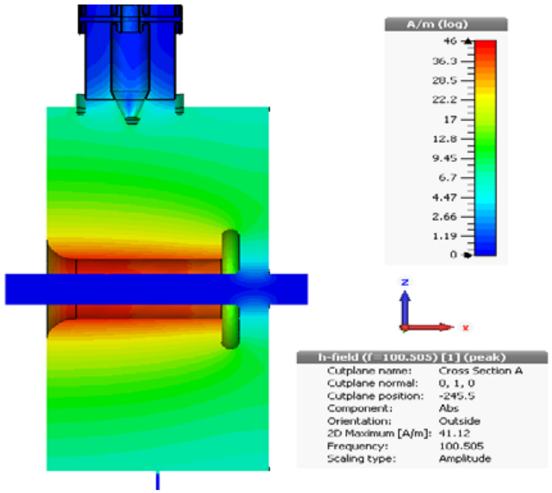
S-parameter response



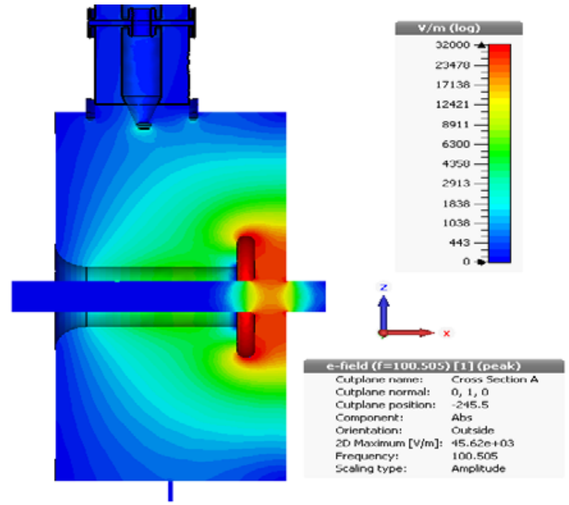
Longitudinal E-field for 1W RF input



Magnetic field



Electric field



EM fields of cavity fundamental mode (CST simulation)

Cavity HOM calculations

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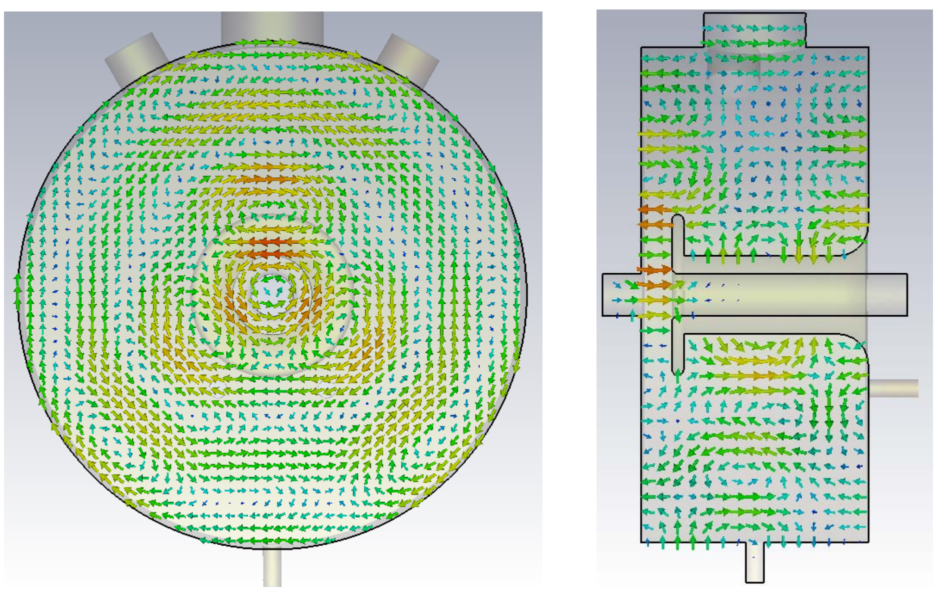
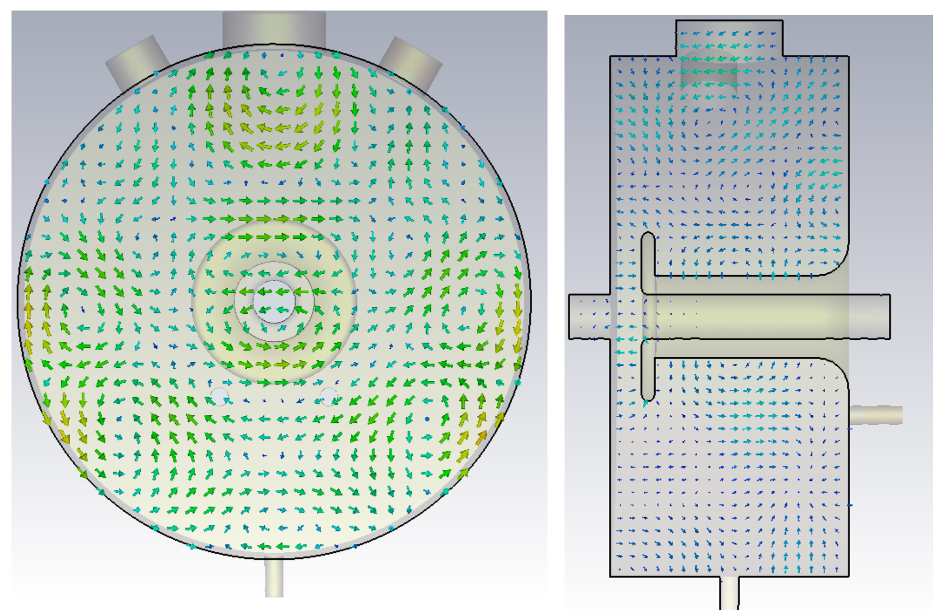
- Detailed analysis of the HOMs
  - HOMs simulations by CST
  - Identification of dipole & monopole modes
  - Calculation of R_shunt & Q
  - Comparison with instability thresholds
  - Identification of modes close to beam modes



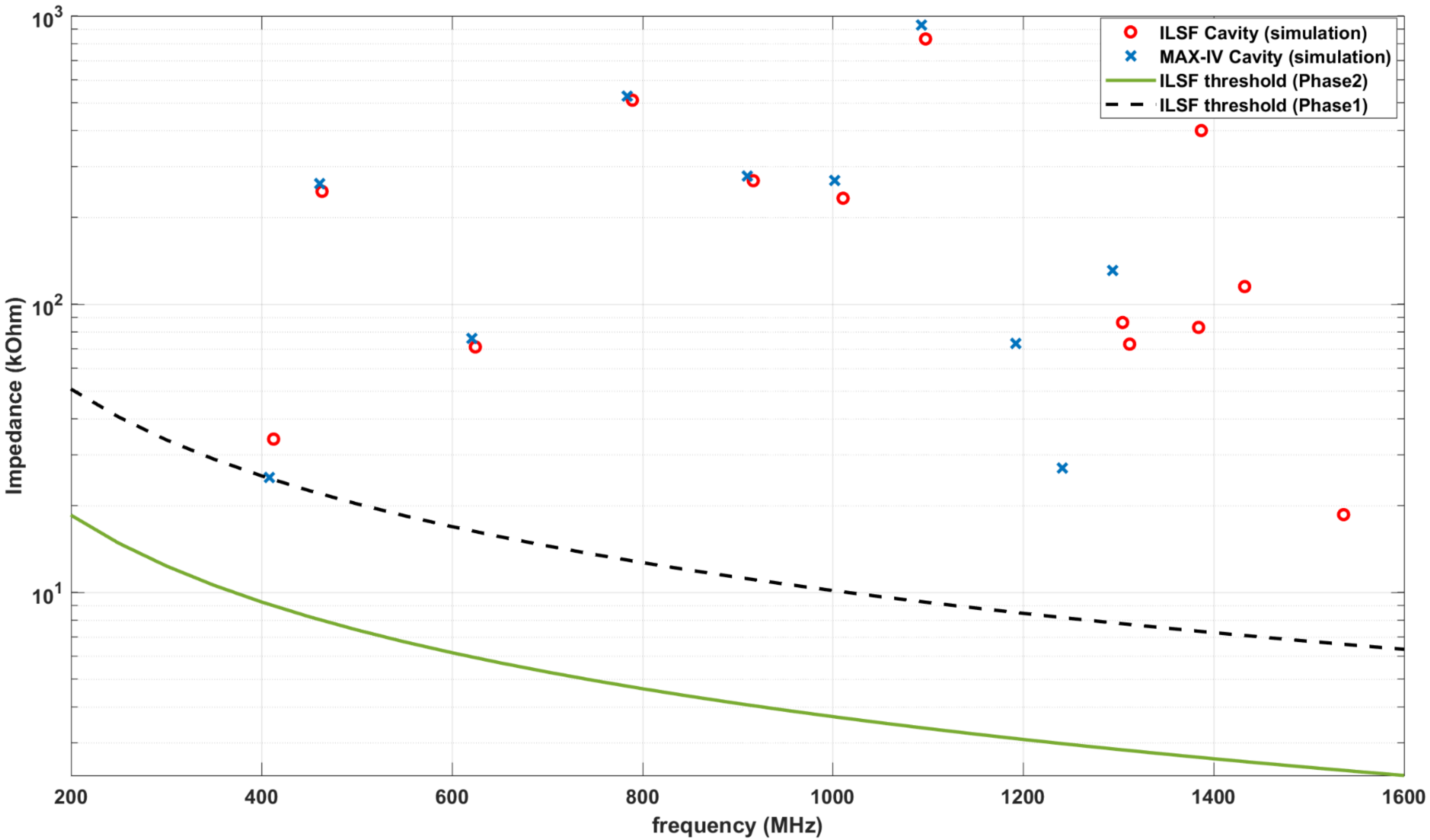
1536.477 MHz (monopole like mode)



1485.951 MHz (Dipole)

Cavity HOM calculations (cont.)

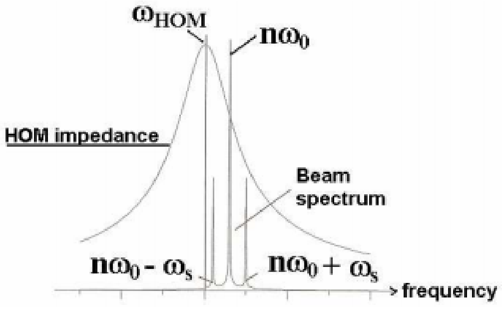
- Cavity monopoles impedances (CST simulation) & longitudinal instability threshold



Cavity HOM calculations (cont.)

- Monopoles (CST simulation)

f (MHz)	R (kΩ)	Q	Distance to beam modes Δf = f_HOM - f mnp (MHz)
412.77	34	35069	0.191,0.773,1.355
463.682	246	36260	0.051,0.633,1.215
624.67	70.8	31079	0.4552,1.037
789.56	510	40360	0.181, 0.763, 1.345
916.54	268	43029	0.3152, 0.8972,1.479
1010.8	233	43299	0.152, 0.597, 1.179
1097.47	832	35403	0.032, 0.5492, 1.131
1304.346	86.3	64370	0.263,0.8452,1.427
1311.78	72.6	62846	0.4372,1.019,1.601
1384.151	83	68880	0.058, 0.6402,1.222
1387	400	53163	0.0027, 0.5792,1.161
1432.55	115	65458	0.4572,1.039
1536	18.6	55332	0.03523, 0.617,1.199



$$f_{m,n,p} = p.Mf_o + n.f_o + m.f_s$$

Cavity HOM calculations (cont.)

- Monopole modes are inserted in the storage ring lattice and tracking is done by Elegant code. (Beam Dynamics Group)
  - One mode (1097.47MHz, 800kOhm) will cause unstable longitudinal oscillations at 100mA current (1st phase)
    - Solutions (tracking simulation results):
      1. 2MHz shift is required.
      2. Using a fast feedback system.
      3. Adding 3rd harmonic cavities. (not simulated yet)
  - Almost all modes will cause unstable longitudinal oscillations at 400mA (final phase)
    - Solutions:
      1. These modes have to be damped by a factor of 100! (simulation results)
      2. Shifting the frequencies but time-consuming simulations. Might be better to measure the prototype.
      3. Adding higher harmonic cavities to the ring in addition to the fast feedback system (similar to MAX-IV) (not simulated yet)

Cavity tuning system

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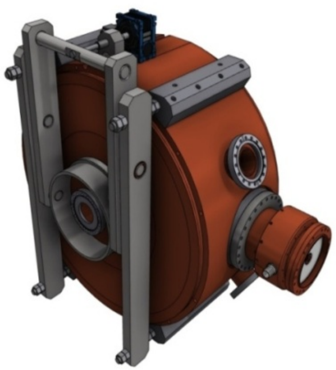
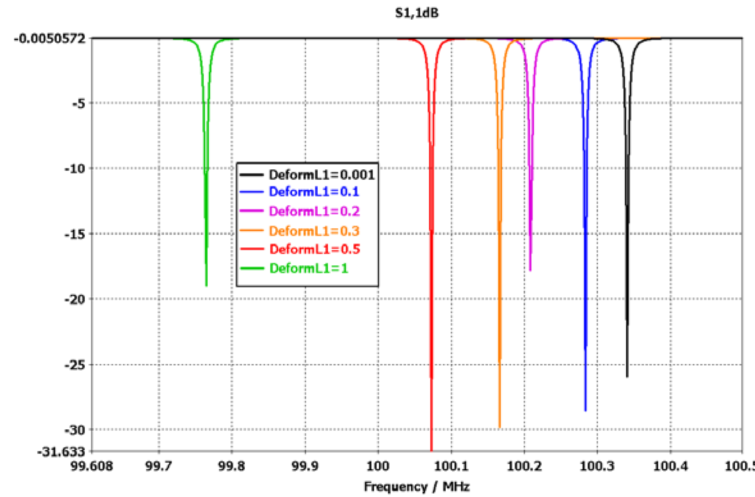
- Comparison of 2 tuning systems



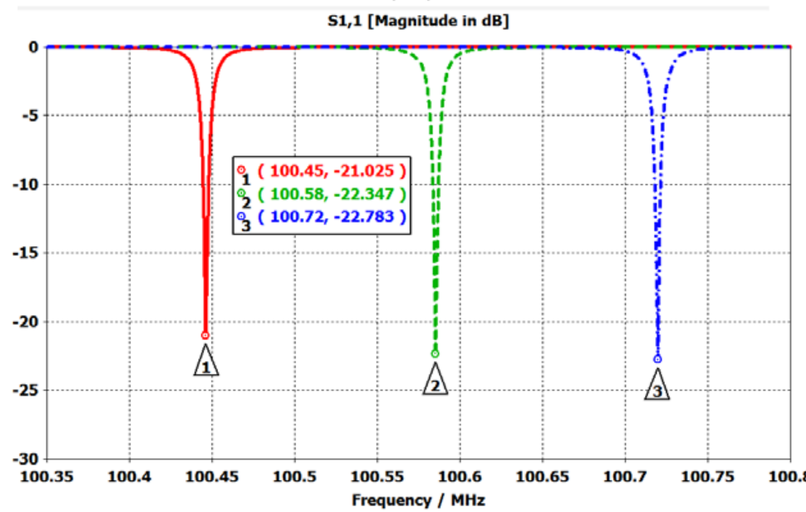
Squeezing the sidewall

1MHz tuning by 1mm deformation



2 plungers

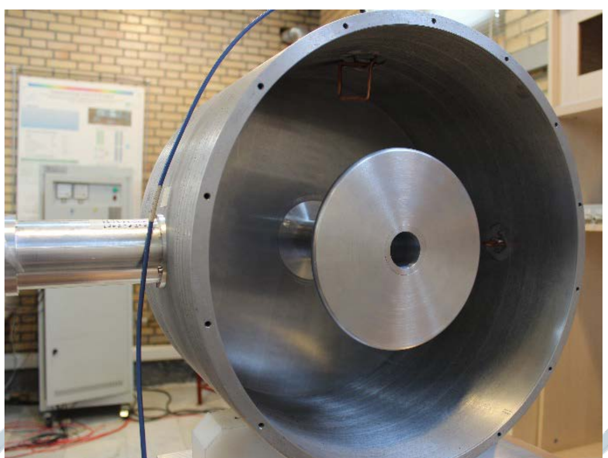
Red: no penetration
Green: 10cm of plunger1 (130kHz tuning)?
Blue: 10cm of both plungers (280kHz tuning)?

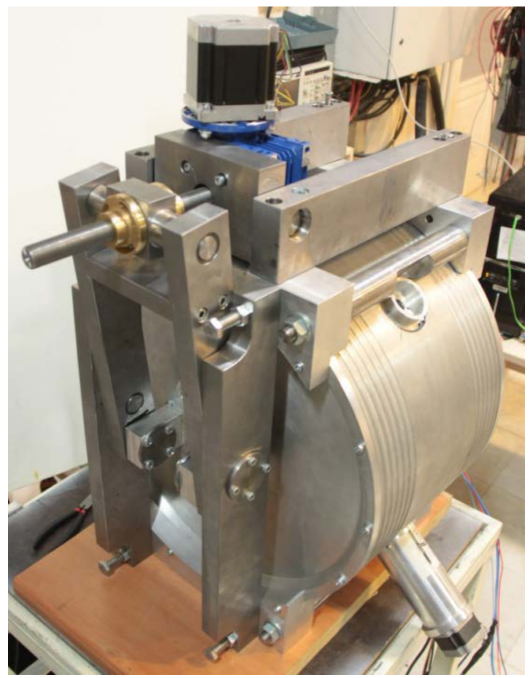


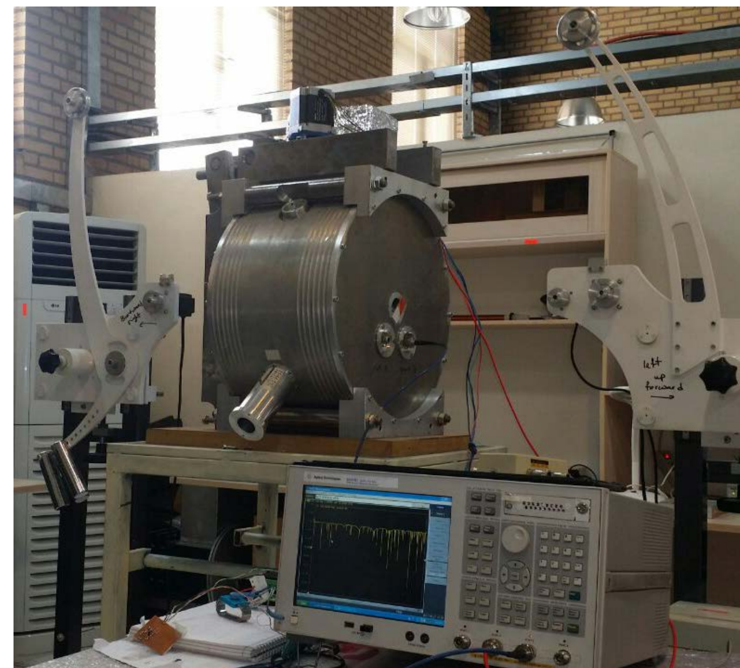
Final choice will be made after practical measurements on Al prototype (built at RF Lab.)

Comparison of tuning methods

- Existing 500MHz pillbox is modified to 125MHz capacity loaded type
  - Comparison of 2 tuning methods & effects on HOMs
  - Comparison of wire impedance method & beadpull measurement , Adding HOM dampers (in future)





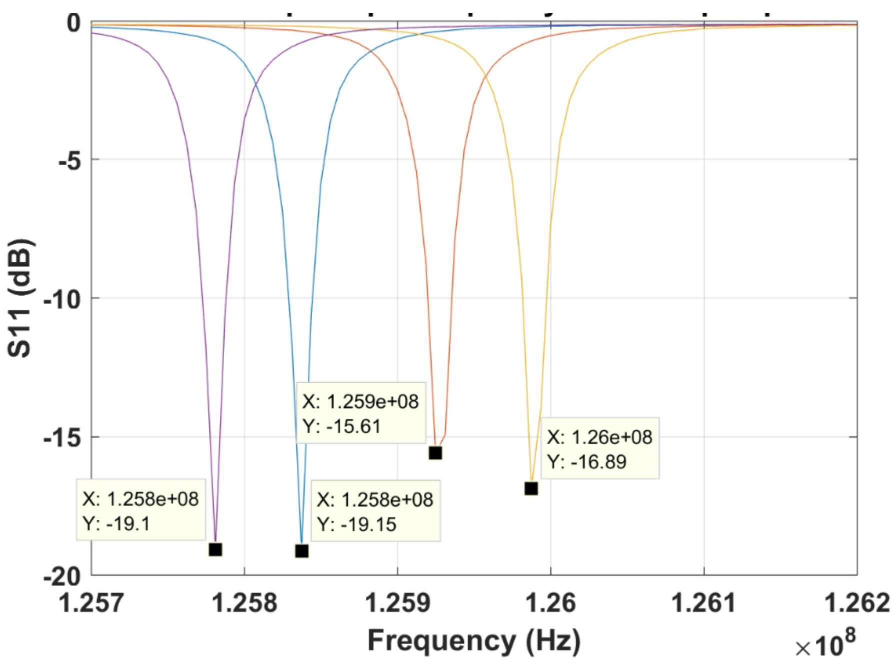


Note: plunger was installed at the center of the AL cavity cylinder, not at the optimum place.

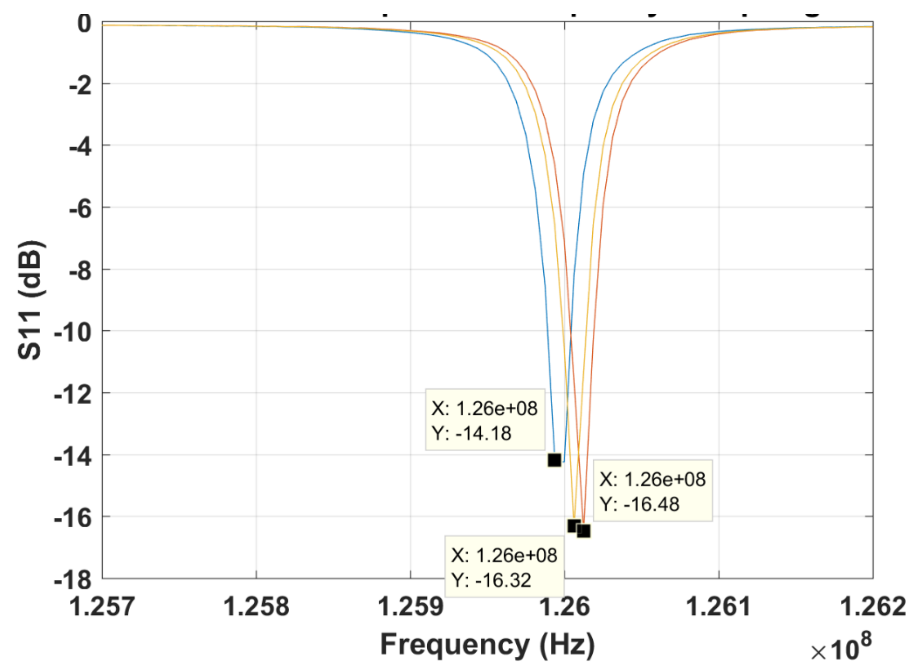
Comparison of tuning methods (cont.)

Effect on fundamental mode (126.2MHz)

Side wall squeezing



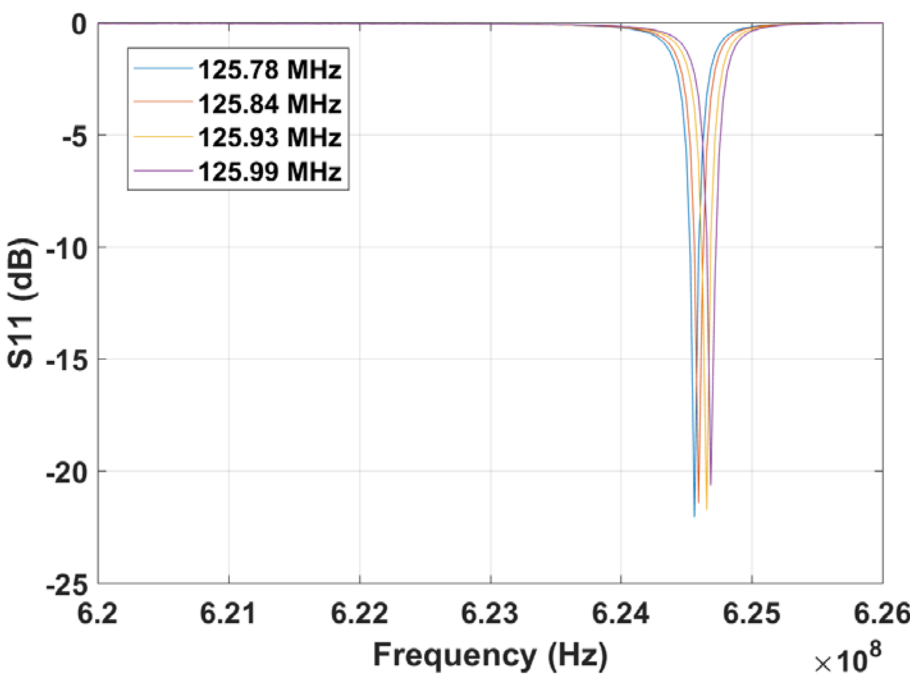
Plunger tuning



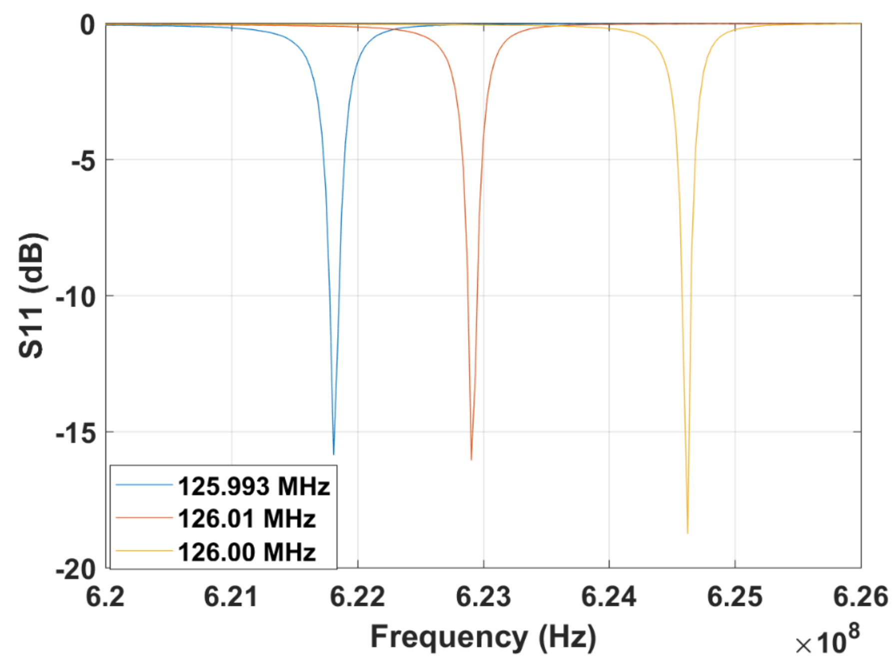
Comparison of tuning methods (cont.)

Effect on 1st monopole HOM (625.312MHz)

Side wall squeezing



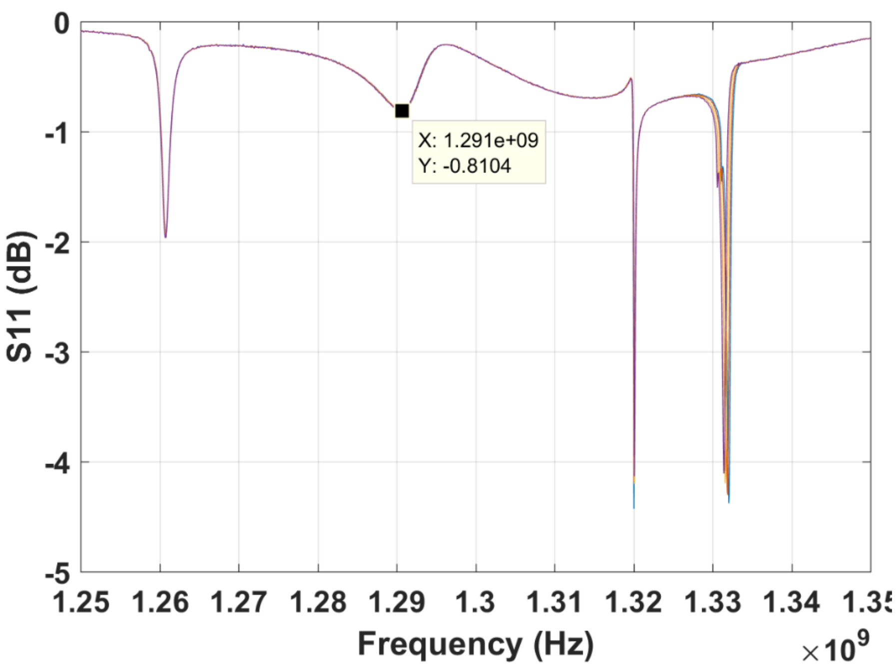
Plunger tuning



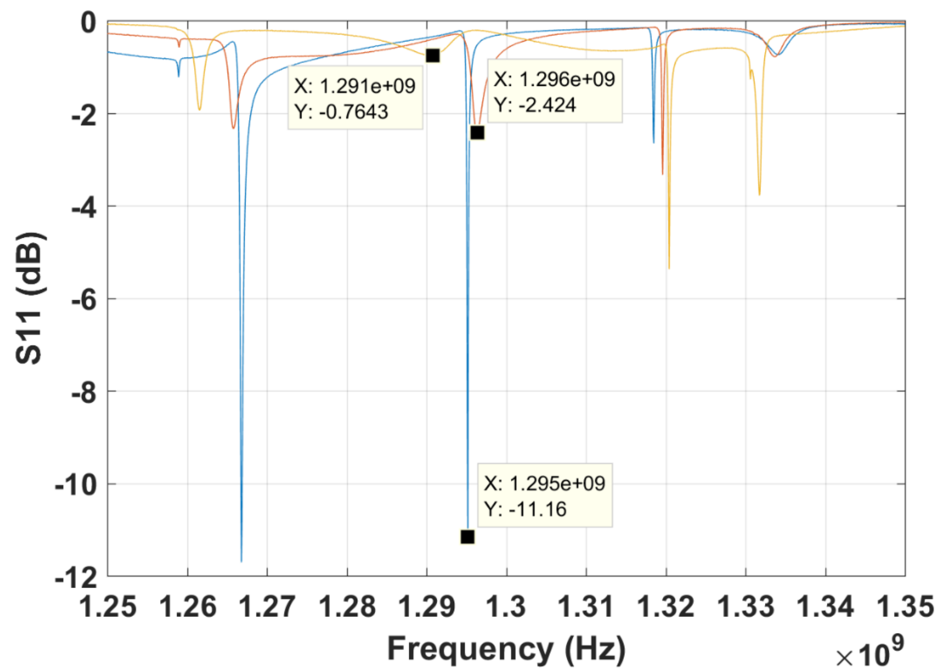
Comparison of tuning methods (cont.)

Effect on 3rd monopole HOM (1289.78MHz)

Side wall squeezing



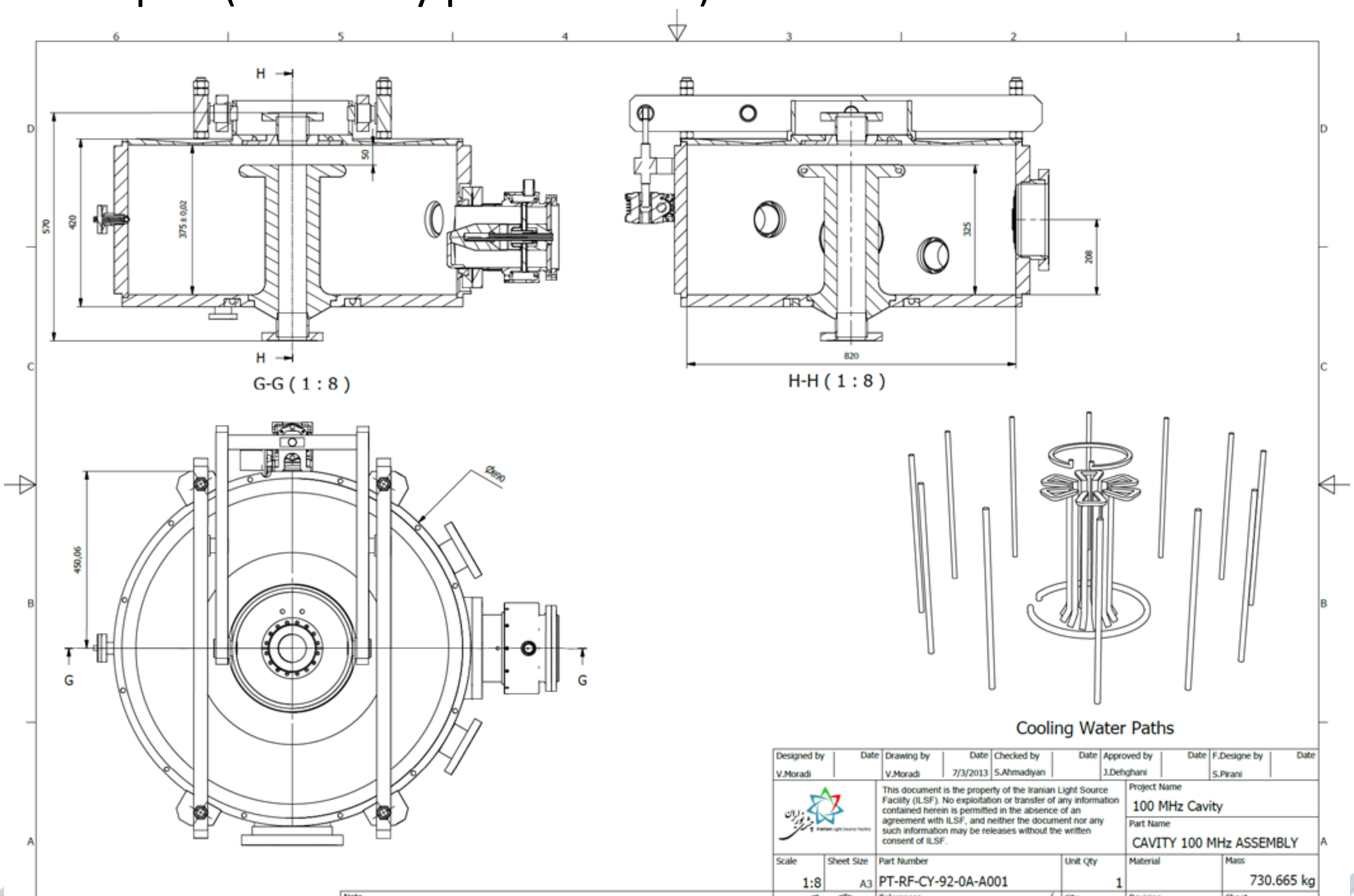
Plunger tuning

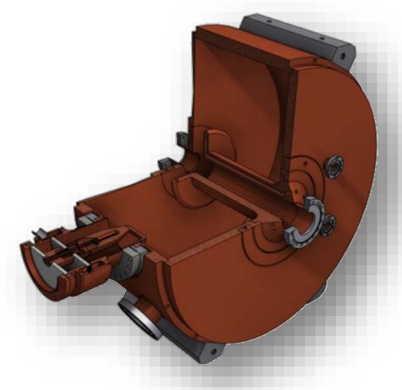


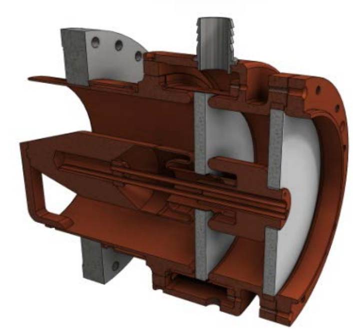
- Tuning by plunger shifts the HOMs => we may hit the beam instabilities during fundamental frequency tuning. But might be good for shifting HOM.
- We will probably use
  - "squeezing sidewall" for main frequency tuning.
  - Plunger for HOM tuning

Cavity mechanical design

- Initial cooling simulation & stress calculation (needs optimization)
- Moving arm and tuning mechanism shall be modified and strengthened
- Coupler (Preferably procurement)

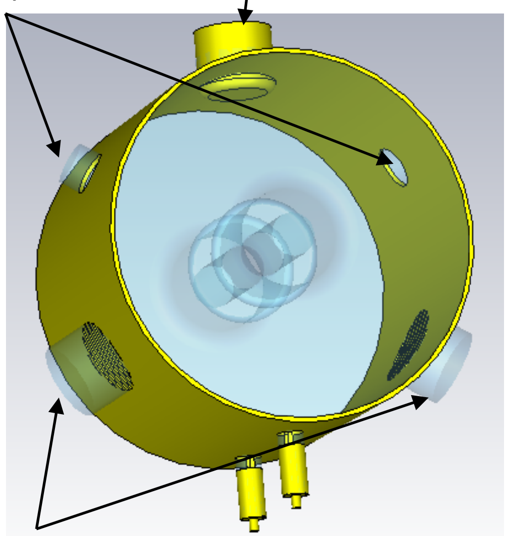






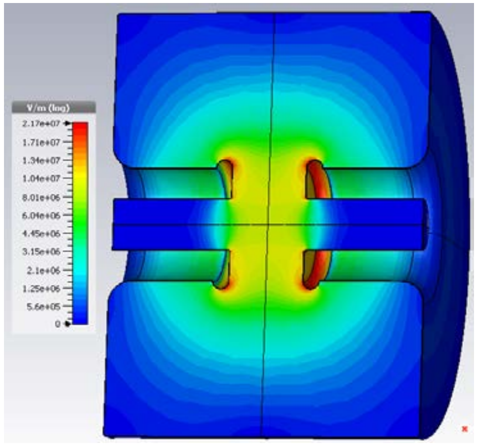
3rd Harmonic Cavity

- As a pre-prototype cavity for cavity fabrication process:
  - Goals of pre-prototype: Test of fabrication methods, RF design, vacuum, … with lower cost (smaller structure-less material but meaningful RF, similar structure to the main cavity)
- EM design

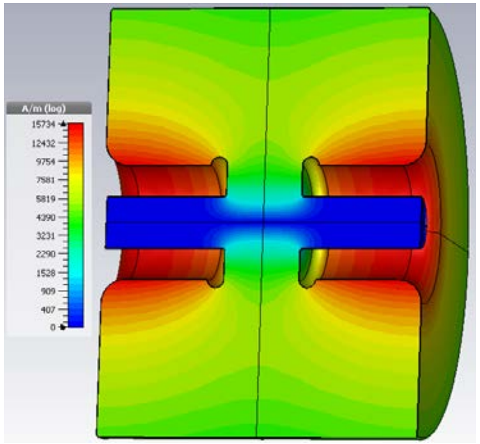


CST simulation results

Frequency (MHz)	300.159
Shunt Impedance (Mohm)	6.9
Quality Factor	23022



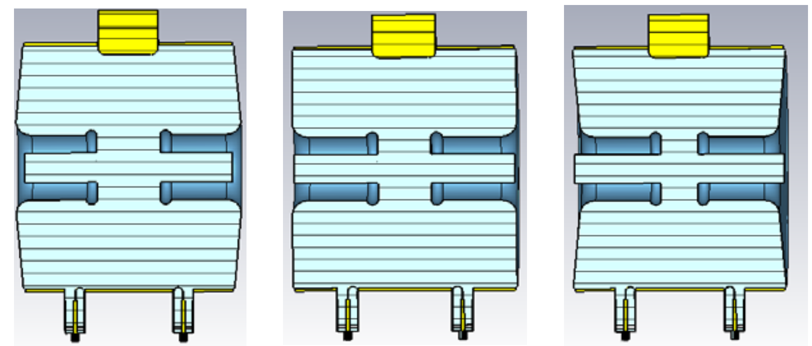
Electric Field Profile

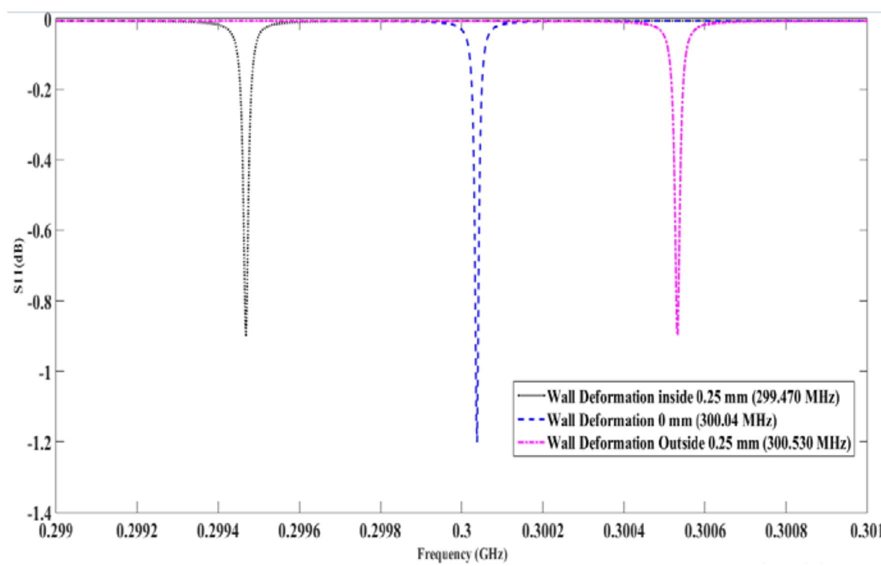


Magnetic Field Profile

3rd Harmonic Cavity (cont.)

- Other simulations in progress
  - Mechanical tolerances
  - HOMs
  - Coupler design
- Future simulations
  - Effect of HHC HOMs on beam stability
  - Plunger effect on HOM shifting

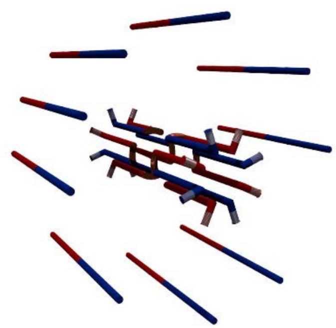


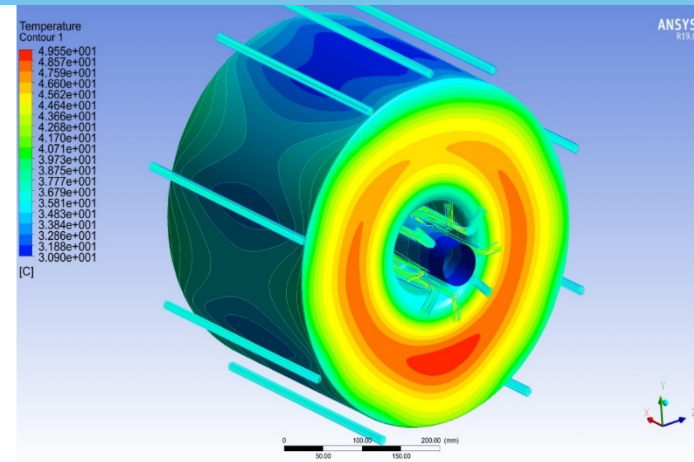


Frequency tuning by pulling/pushing wall (CST)
±0.25mm => 1MHz tuning

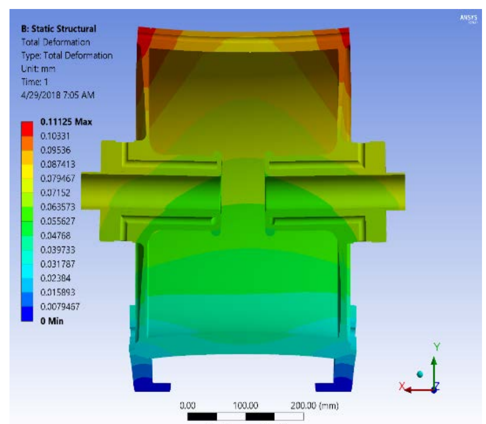
3rd Harmonic Cavity (cont.)

- Mechanical design
  - Cooling

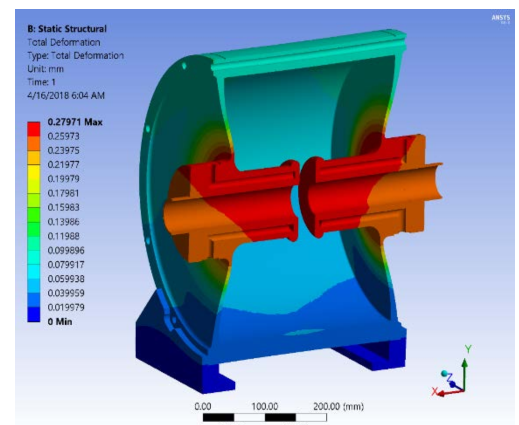




  - Stress calculation
    - Tuning arms are not included yet. (in progress)



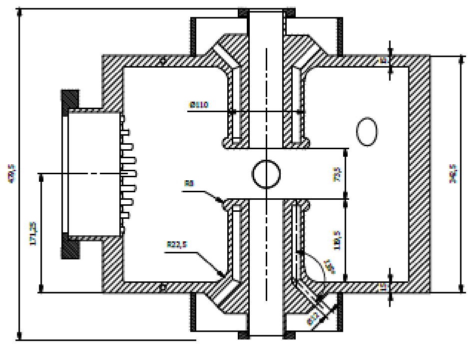
Cavity deformation (Vacuum effect)



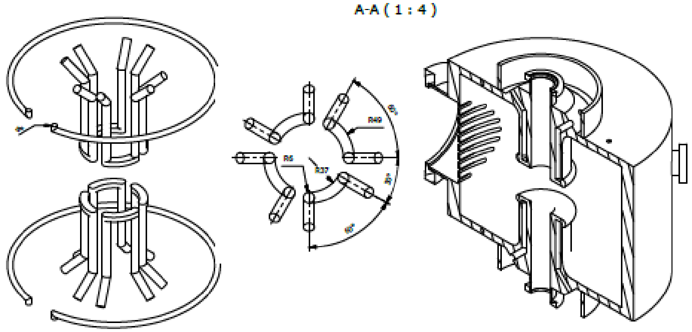
Cavity deformation (Thermal effect)

3rd Harmonic Cavity (cont.)

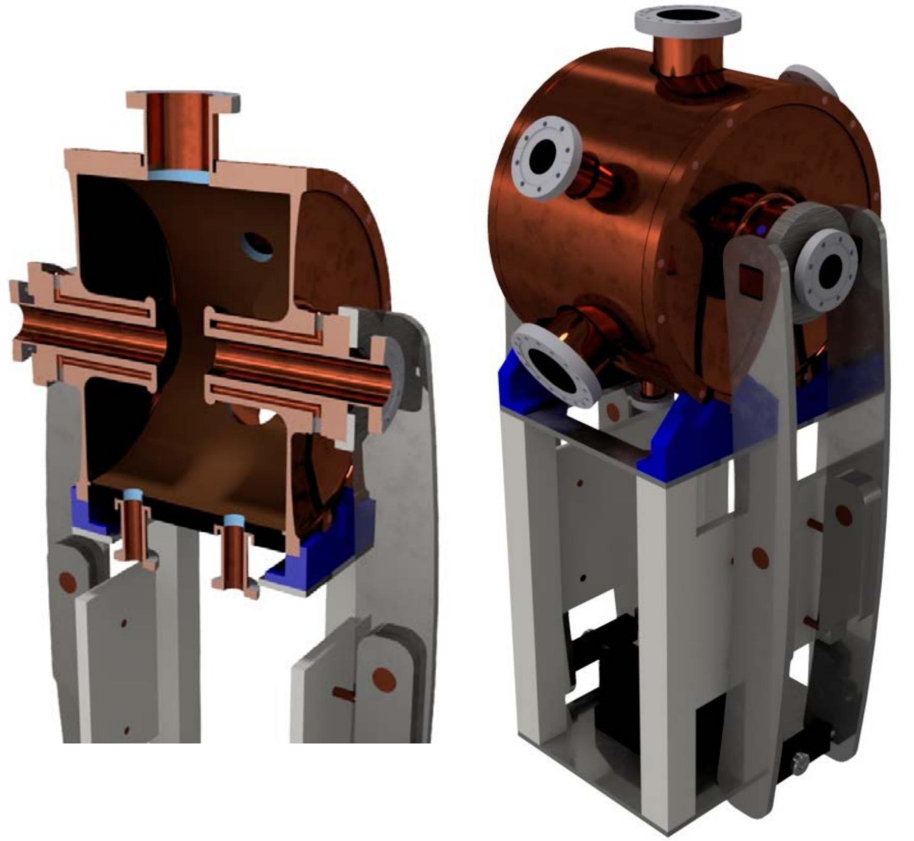
- Initial mechanical model



A-A (1 : 4)



Cooling Path



- Still a lot of details to work on
  - Flexibility of some specs:
    - Material : OFHC (5ppm O2, even if vacuum brazing?)
    - Grain size: less than 15um (RF or vacuum issue?)
  - …..

High power amplifier

- 100MHz
  - 3*30kW (for booster) + 5 *60kW (storage ring-phase 1)
  - 30kW for cavity R&D test
  - Solid state RF transmitters production in Iran

20kW SSA FM transmitter (87.5-108 MHz)
8*2.5kW modules, hot-plug, water-cooled
"30kW SSA is proposed for ILSF"

12kW SSA FM transmitter (87.5-108 MHz)
4*3.5kW modules, hot-plug, water-cooled
"20kW is in production"

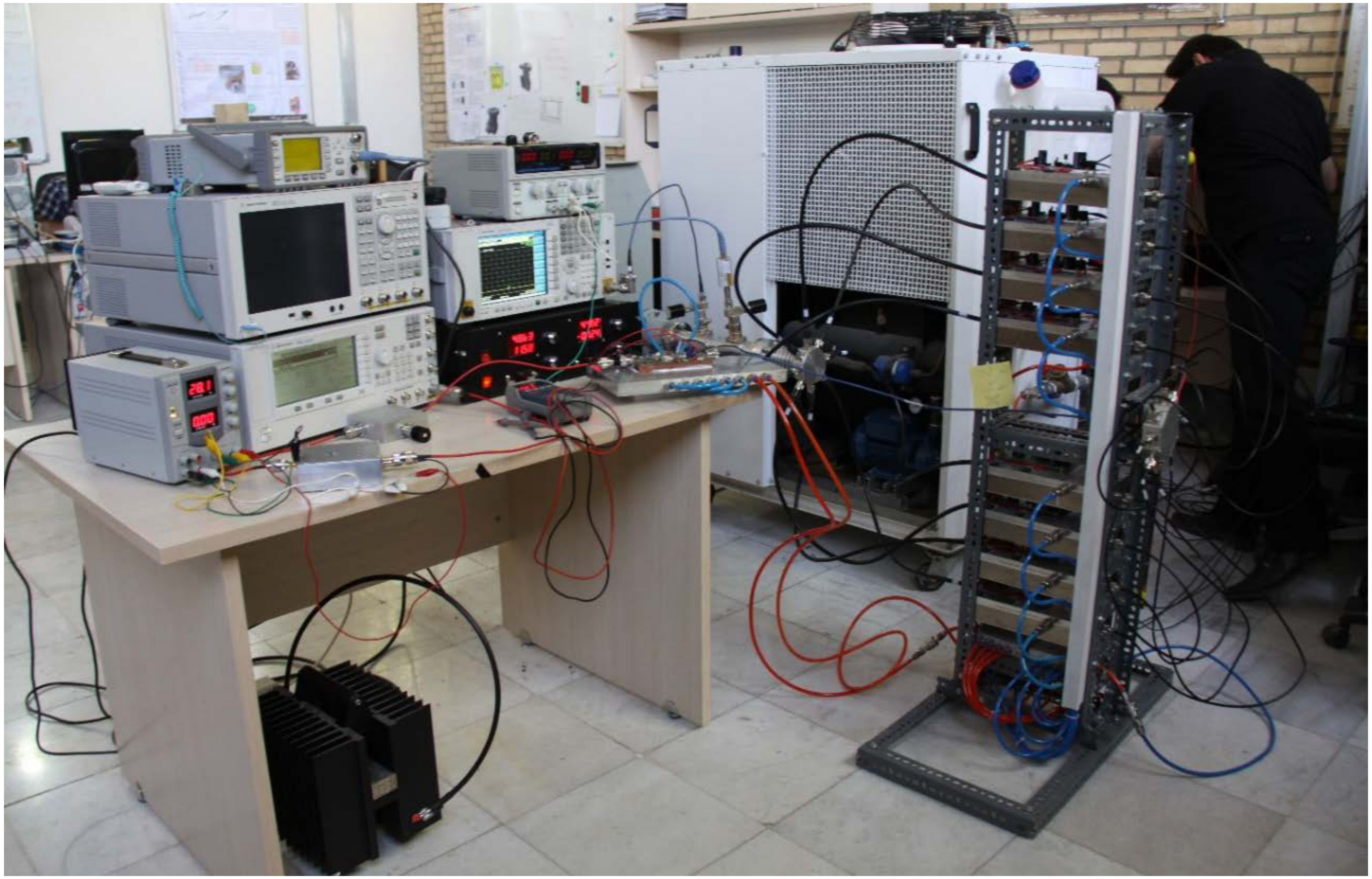
High power amplifier (cont.)

- 300MHz
  - 4-5kW is required for Harmonic cavity conditioning
  - Plan:
    - In-house development based on our 500MHz, 4kW experience.
    - MRFE6VP61K25HR6 or BLF888 transistors (Available in lab. stock)

High power amplifier (cont.)

- 500MHz

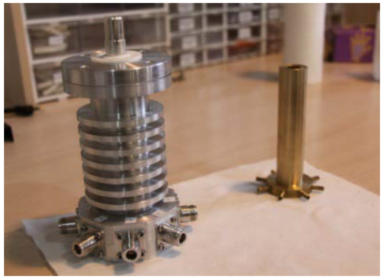
Module (Vdd=50V)	692W (limited to driver)	17.7 dB	67%
Overall (Vdd=45V)	4.2kW	15.6 dB	59%



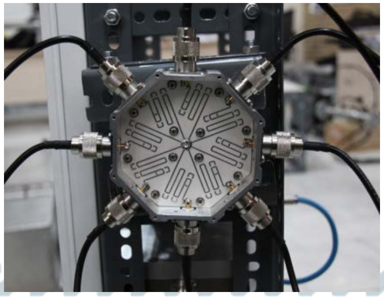
Poster at CWRF 2014

Amplifier Module
(Based on BLF578 Transistor)

8:1 Combiner



1:8 Divider



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Failures

- All 8 modules were gone (AC/PS trip)
  - Re-montage

- We lost 2 when using one module as a driver for another (our driver was 11.5w)

LLRF system

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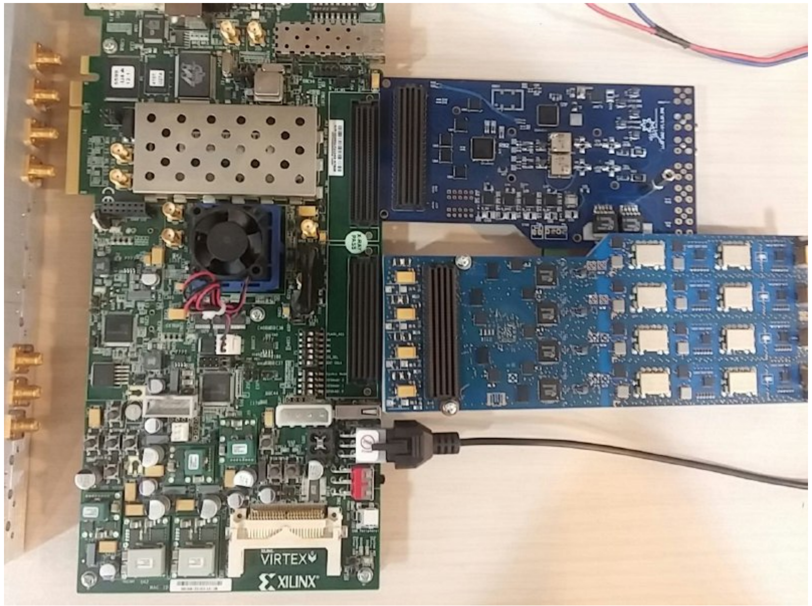
Parameter	Value
Phase stability (degree)	± 0.1
Amplitude stability (%)	± 0.1
Frequency stability (kHz)	<10
Dynamic range (dB)	35
Bandwidth (MHz)	1

- Fully-Digital
  - Accuracy & Flexibility
- Main components:
  - ADC:
    - 4 channels - 16 bit – 120 MSPS- LVDS
    - Developed at ILSF Diagnostics group for BPM, In Test.
  - DAC:
    - 2channel - 16 bit – 120 MSPS- LVDS
    - Developed at ILSF RF group, Tested.
  - Up/Down Converter:
    - Developed at ILSF, Tested.
    - High linearity
  - FPGA:
    - ML605
    - Algorithm implemented
- Whole system test (in progress)



RF Plant configuration


IPM
INSTITUTE FOR RESEARCH IN FUNDAMENTAL SCIENCES
Atomic Energy Organization of Iran
چشمه نور ایران
Iranian Light Source Facility
9th ILSF Users' Meeting
go.ilsf.ir/ilsfum2017
9th ILSF Users' Meeting
3rd & 4th May 2017
Qazvin, IRAN

Thanks for your attention
&
appreciate any advices and comments

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