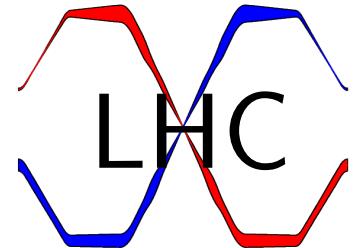


LHC CRABS, STATUS

RAMA CALAGA

CM15, Nov 1-3, 2010



- Overall Planning & US Roadmap
- Status of Technology R&D
- Status of Simulations & Experiments

LHC-CC10

Announcement of the 4th LHC-CC Workshop series

Venue: CERN

Date: Dec 15-17, 2010

Charge:

1. Can compact cavities for the LHC be realized and made robust with the complex damping schemes ?
2. Are crab cavities compatible with LHC machine protection, or can they be made to be so ?
3. Should a KEKB crab cavity be installed in the SPS for test purposes ?

<http://indico.cern.ch/conferenceDisplay.py?confId=100672>

GAIN, CRABS+LEVELING

HL-LHC, single upgrade envisioned for 2020-21:

IR magnet upgrade (HL-LHC, WP3)

Collimation upgrade (HL-LHC, WP5)

Crab crossing + luminosity leveling (HL-LHC, WP4 → project document)

$\{E, \beta_{\text{crab}}^{\max}\}$	7 TeV	
	Peak Lumi	Int. Lumi
$\beta^* = 55 \text{ cm}$	10%	-
$\beta^* = 25 \text{ cm}$	63%	22%
$\beta^* = 14 \text{ cm}$	190%	31%

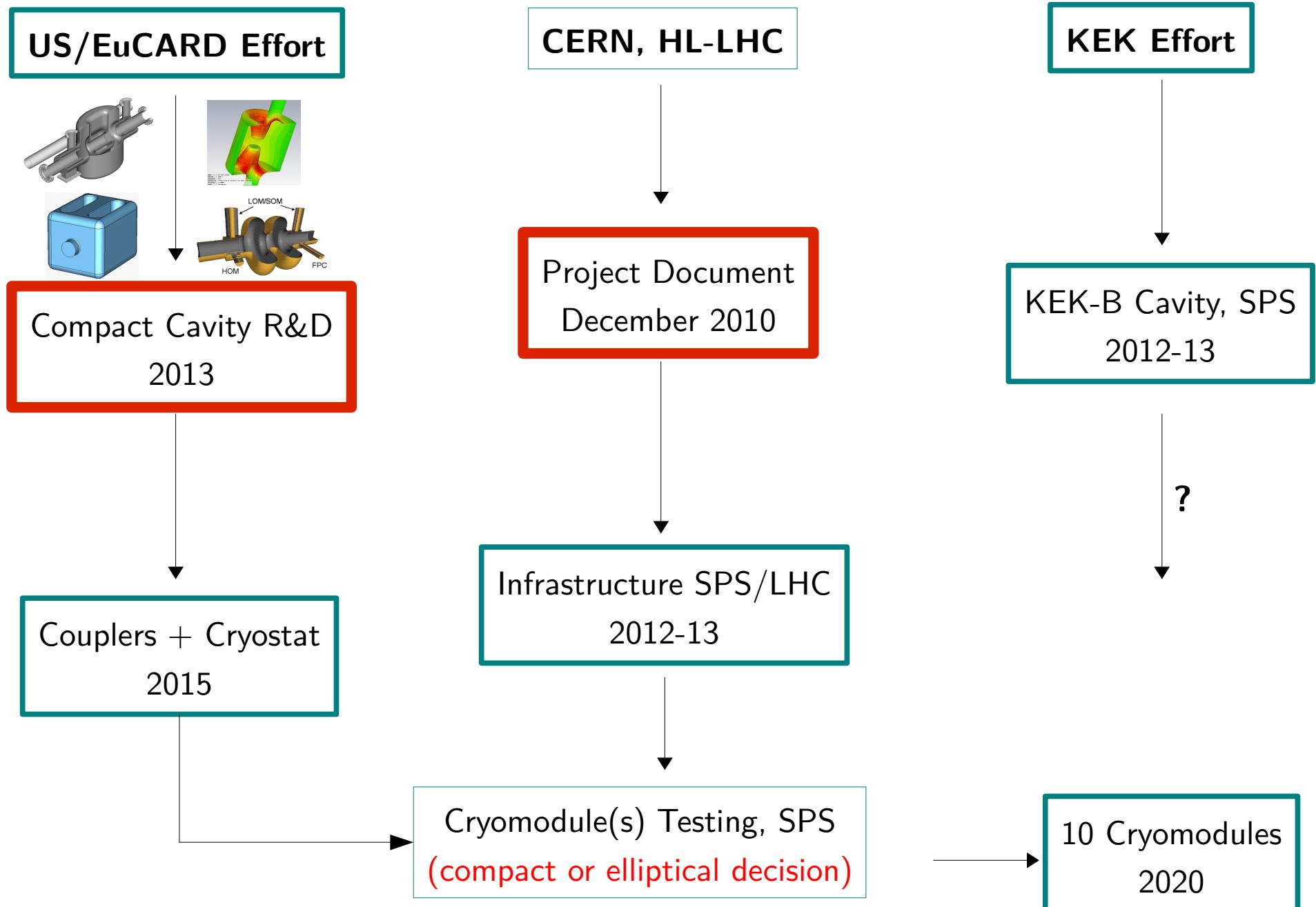
Freq: 400 MHz, Volt < 10 MV, β_{cc} : ~5 km

Integrated luminosities (G. sterbini):

$$N_b = 1.7 \times 10^{11}, \beta^* = 0.14 \text{ cm}, \text{Run time} = 10 \text{ hrs}, \text{TAT} = 5 \text{ hrs}$$

Approx: $265 \text{ fb}^{-1}/\text{yr}$ ($217 \text{ fb}^{-1}/\text{yr}$ w/o CCs) → 2 yr reduction in run time (for 3000 fb^{-1})

ROADMAP FOR CRABS



US EFFORT

US-LARP Effort

Already in advanced design studies stage for crabs (technology + simulations)

Could easily prototype a cavity (+ \$1 M/yr)

US SBIR/STTR (limited scope)

Phase I for two SBIR/STTRs awarded and completed successfully

Phase II for the ODU-Niowave cavity foreseen for 2013

US Crab-Project

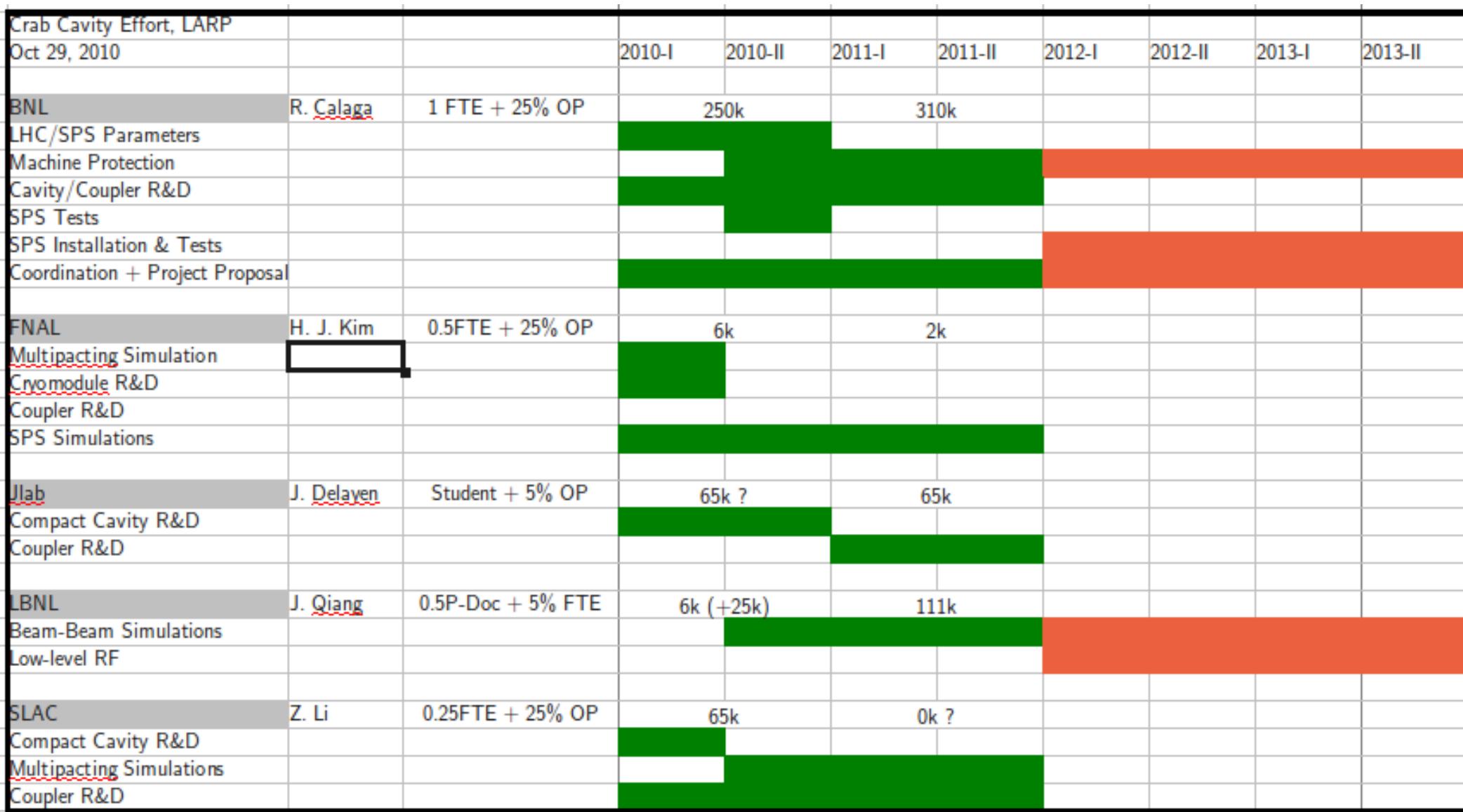
Exploit existing US-SRF expertise, infrastructure & synergies

Initiate from an advanced stage (LARP + SBIR/STTR work)

Aggressive prototyping for compact validation (immediate need)

Leading into a construction project to build 10 cryomodules

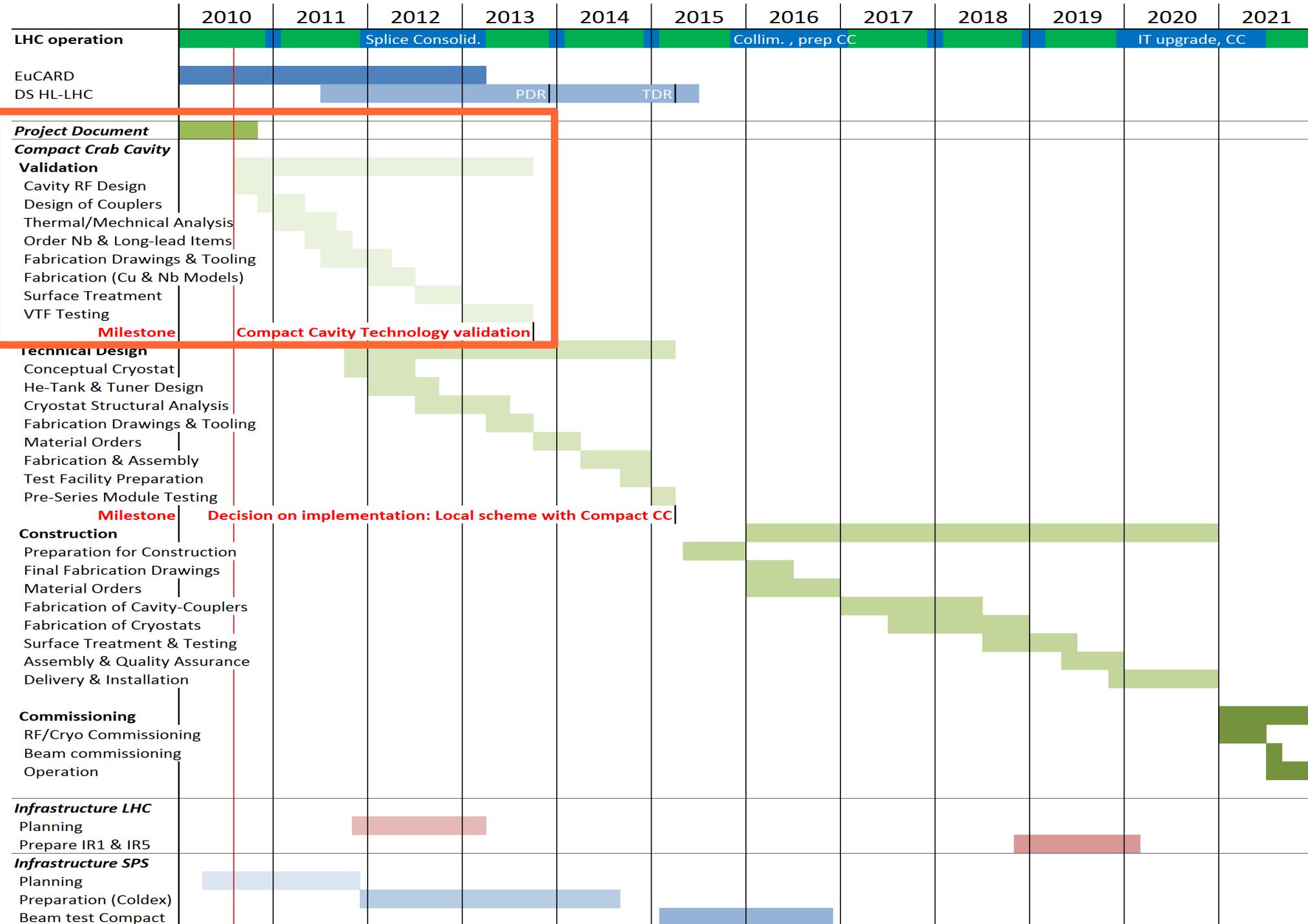
US-LARP, TIMELINE



** Partial support from TOOHIGH fellow(s)

** Additional request for a student to work on machine protection

US-PROJECT, TIMELINE



COMPACTS, STATUS

4 primary compact candidates + 1 elliptical back up

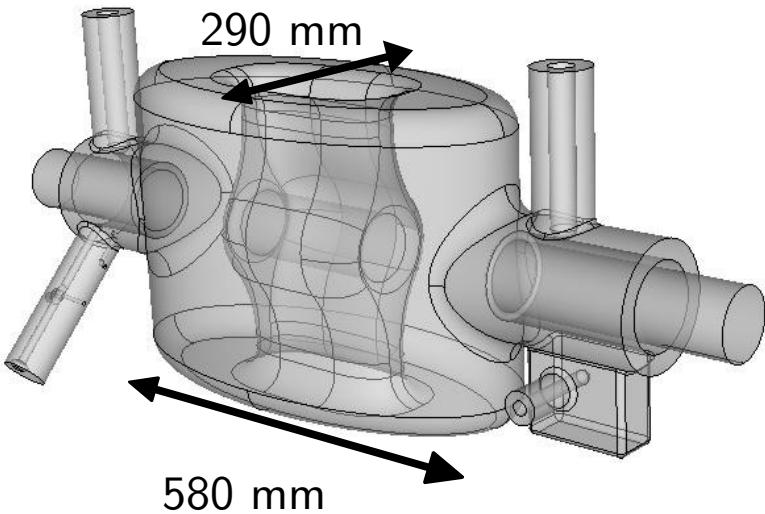
	HWDR (J. Delayen)	HWSR (Z. Li)	4-Rod (G. Burt)	Rotated Pillbox (N. Kota)
Geometrical	Cavity Radius [mm]	150	145	115
	Cavity Height [mm]	380	391	668
	Beam Pipe [mm]	42	45	75
RF	Peak E-Field	29	52	62
	Peak B-Field	105	97.5	113
	R _T /Q	413	215	802

Kick Voltage: 5 MV, 400 MHz

[†]Exact voltage depends on cavity placement & optics

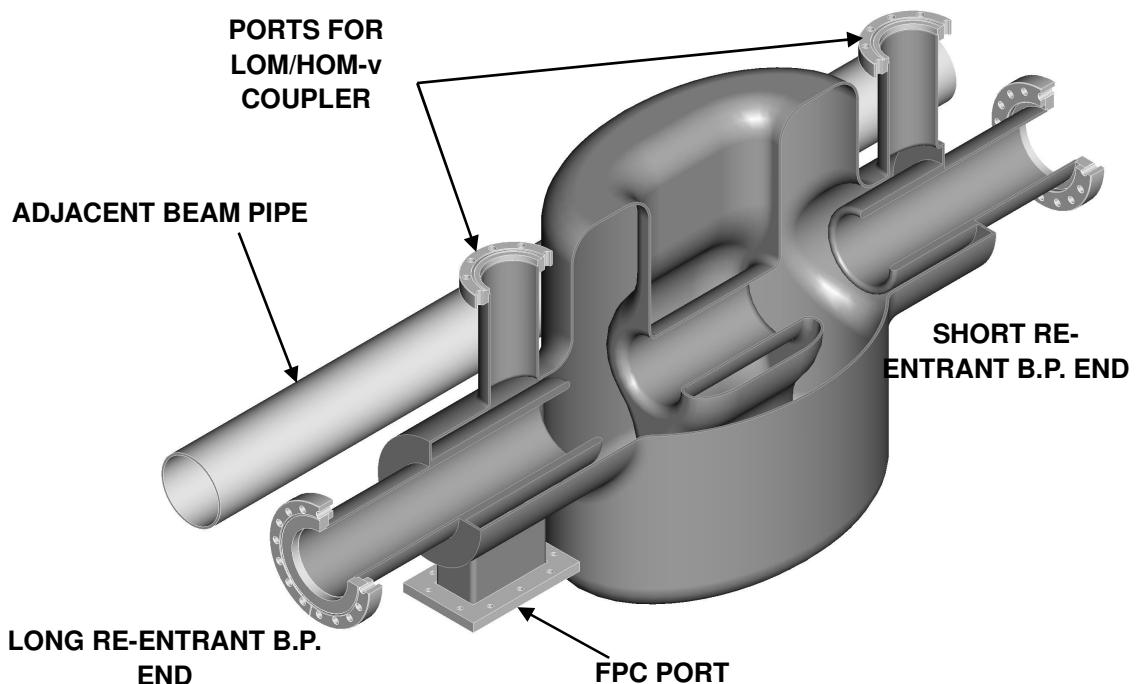
[‡]Cavity parameters are evolving

SLAC-LARP DESIGN



Fairly complete design of cavity-couplers

Prelim mechanical/thermal analysis also done



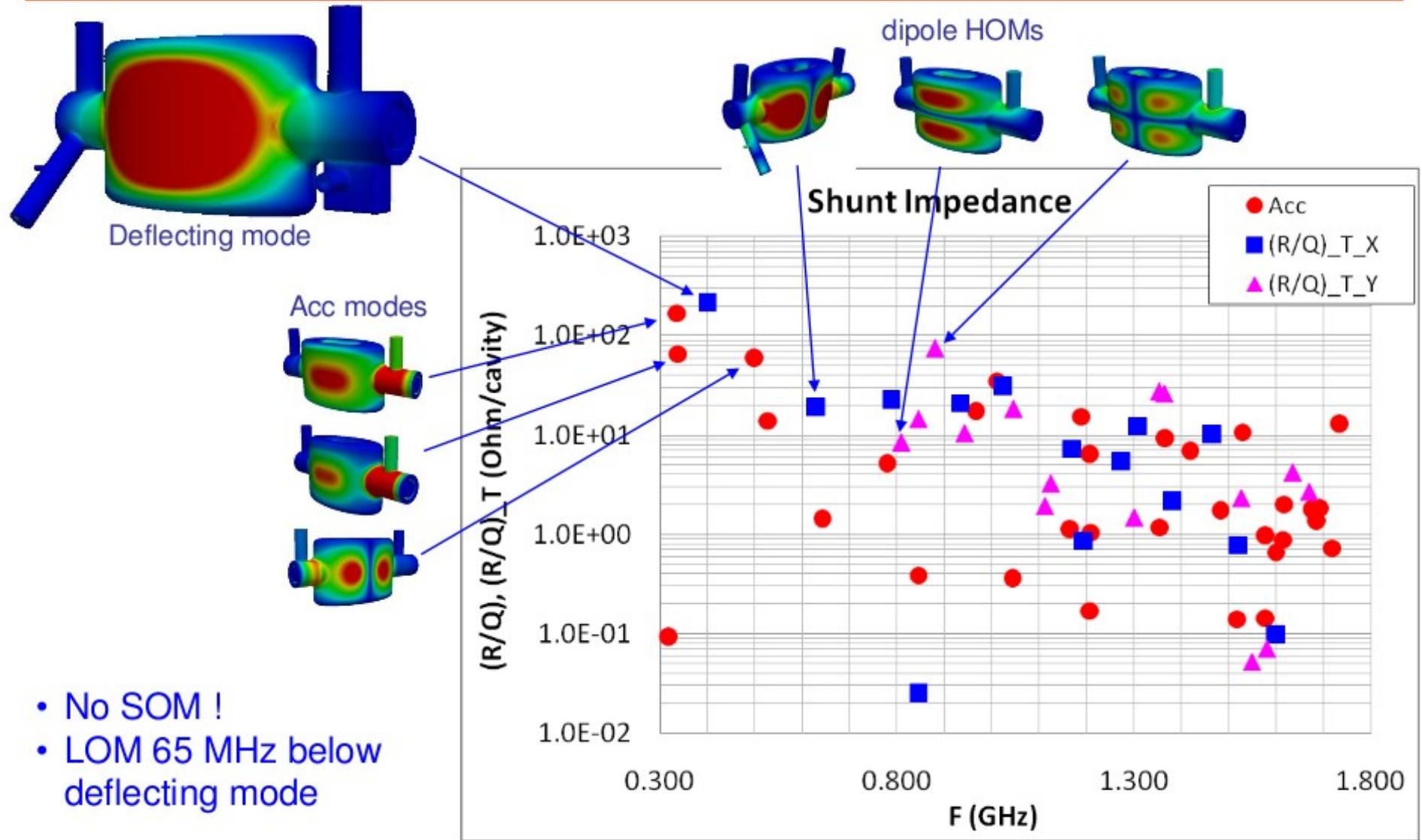
Details at:

<http://indico.fnal.gov/getFile.py/access?contribId=38&sessionId=3&resId=0&materialId=slides&confId=3205>

<http://indico.cern.ch/getFile.py/access?contribId=17&sessionId=9&resId=0&materialId=slides&confId=83532>

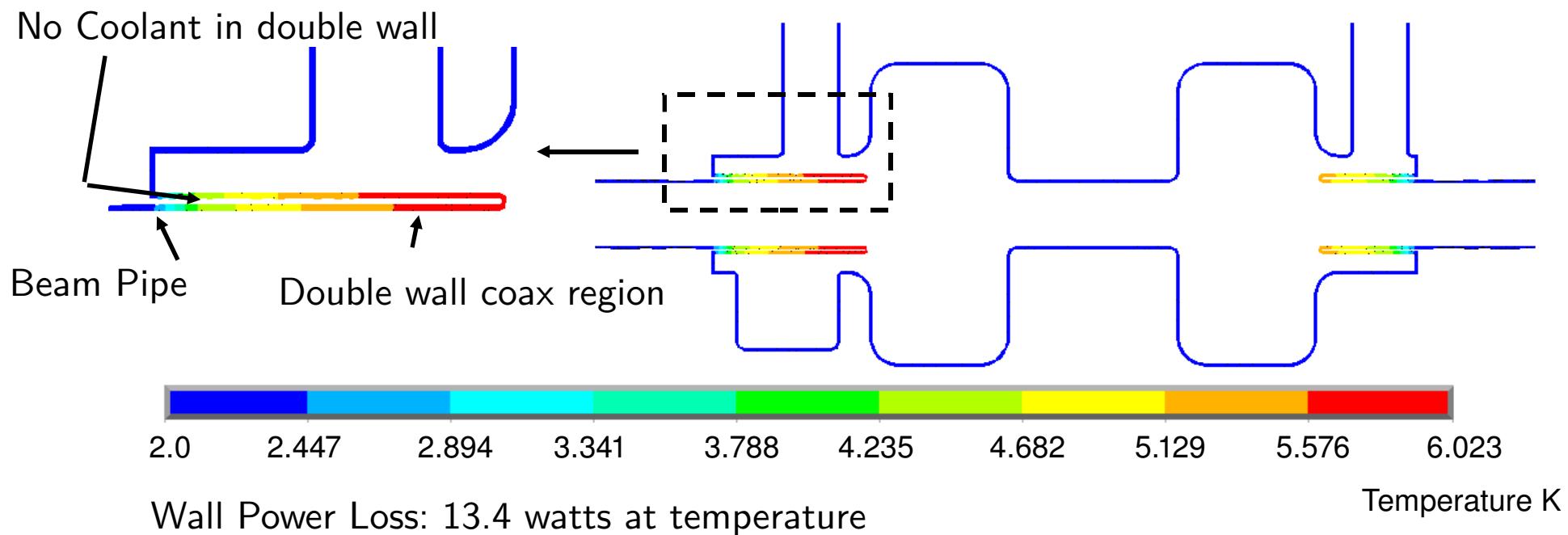
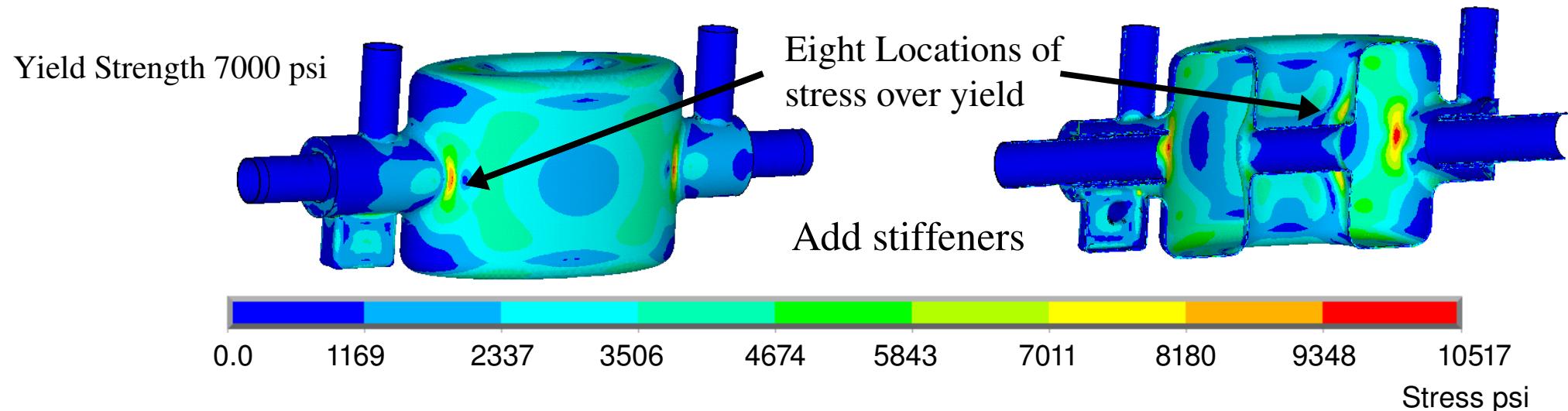
3D MODEL: <http://www.slac.stanford.edu/~lizh/.link/lhc/>

Shunt Impedance



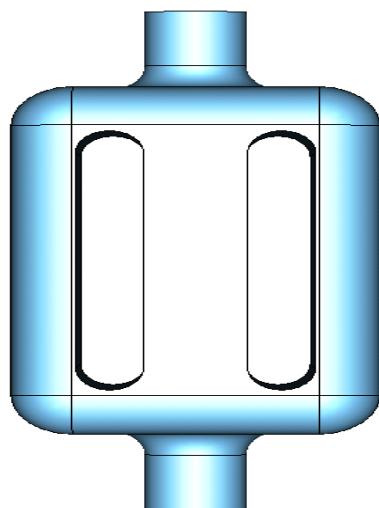
STRESS & TEMP DISTRIBUTION

AES-SBIR, Phase I



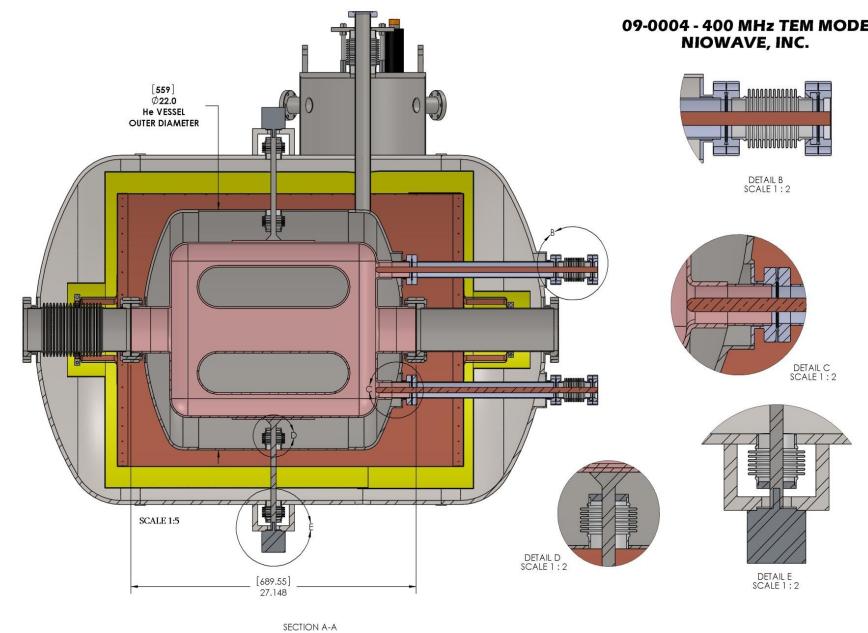
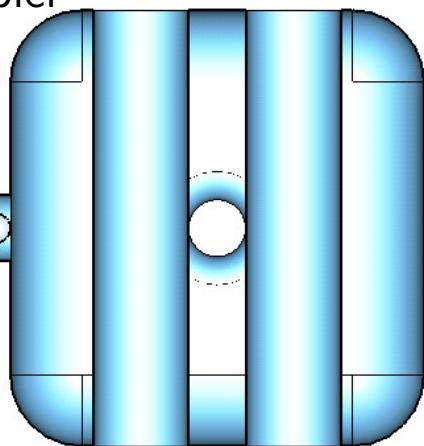
JLAB-ODU DESIGN

Cavity complete,. HOM couplers etc.. underway



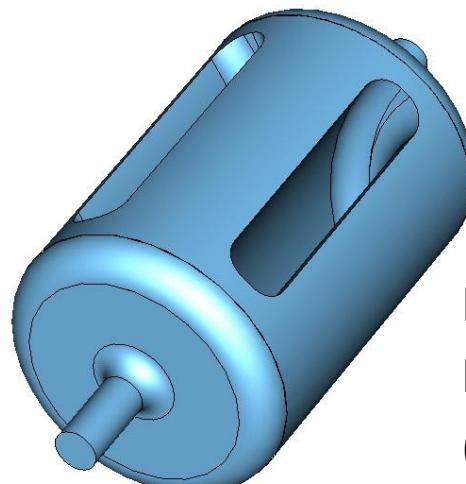
Power Coupler

4.6 cm



Niowave-STTR, Phase I

Moving Towards
Cylindrical shape



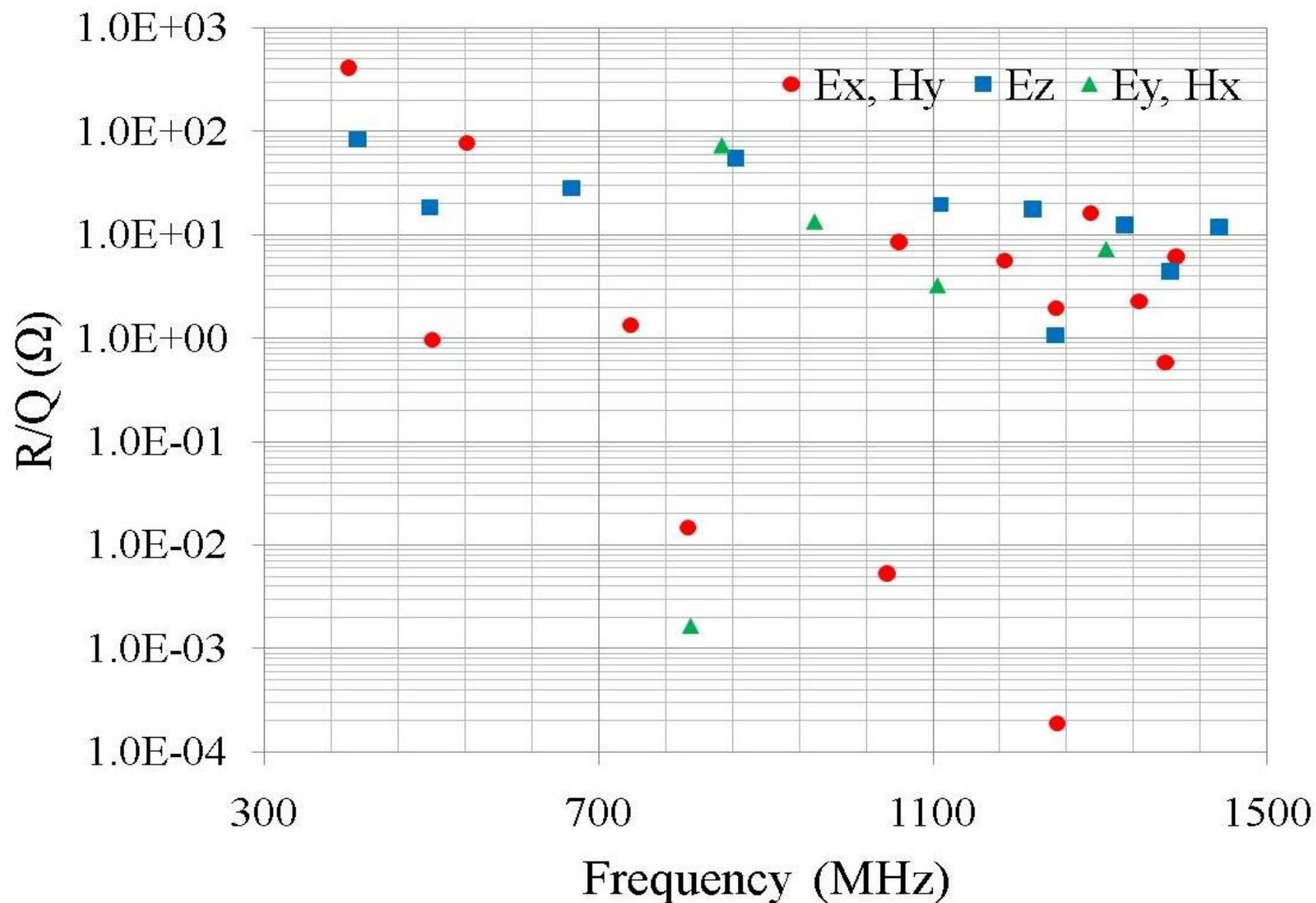
Phase II approved
For building cavity prototype
(ODU-Niowave)

Details at:

<http://indico.fnal.gov/getFile.py/access?contribId=37&sessionId=3&resId=0&materialId=slides&confId=3205>
<http://indico.cern.ch/getFile.py/access?contribId=30&sessionId=6&resId=1&materialId=slides&confId=83532>

JLAB-ODU, HOMs

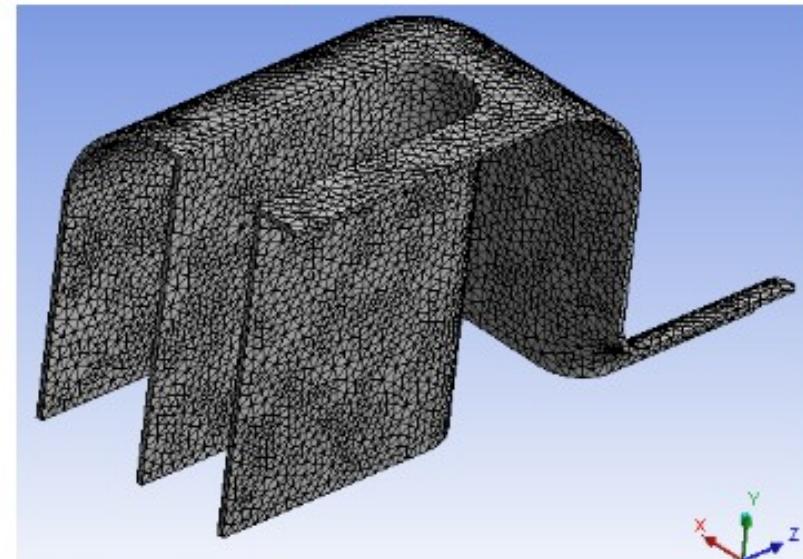
HOMs identified and damping scheme under study



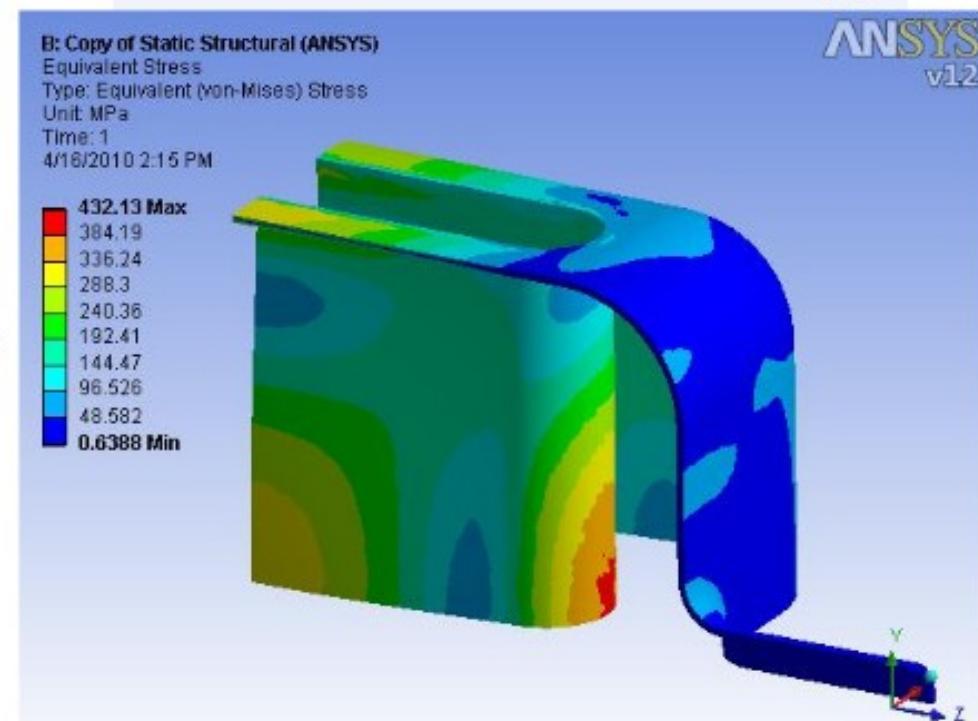
Preliminary Stress Analysis

Material Properties of Nb^{*}

Property	SI Units	English Units
Modulus - Room Temp	1.03 E+11 Pa	1.49 E+07 psi
Modulus - Cryo Temp	1.23 E+11 Pa	1.79 E+07 psi
Poisson's Ratio		0.38
Density	8.58E-03 g/mm ³	0.31 lb/in ³
Yield - RT	4.83 E+07 Pa	7.0 ksi
Yield - Cryo	5.77 E+08 Pa	83.7 ksi



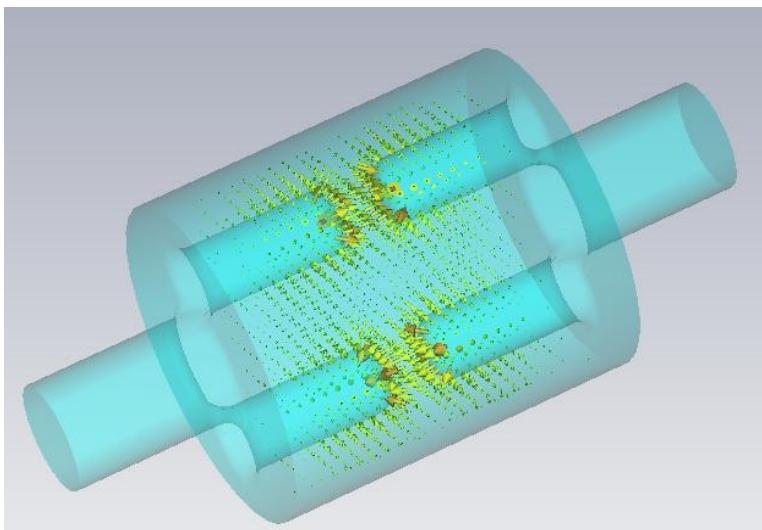
- Analysis using properties at room temperature
- Cavity wall thickness = 3 mm
- Mechanical model
 - Standard gravity = 9.806 ms^{-2}
 - Pressure normal to the cavity outer surface = 0.20265 Mpa (29.392 psi)
- Stress = 432 MPa > Yield Strength = 48 MPa



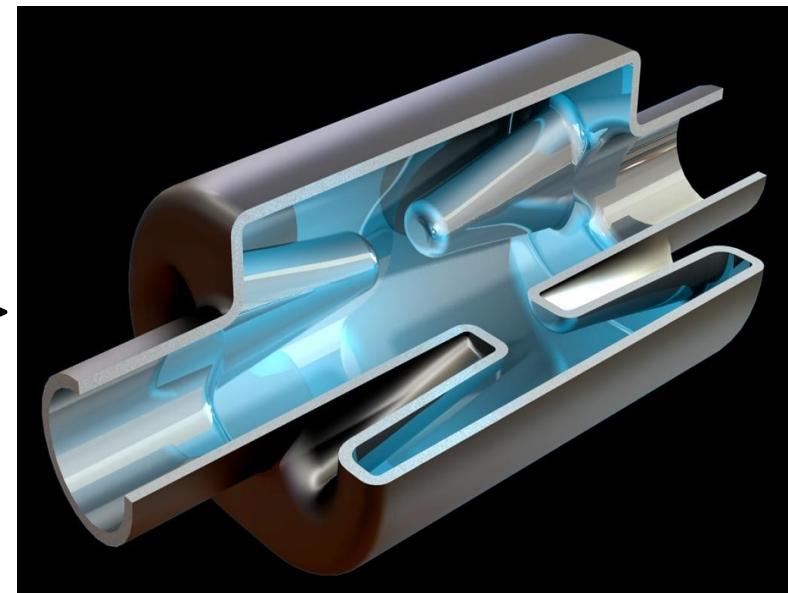
* K.M.Wilson et al. "Mechanical cavity design for 100MV upgrade cryomodule" Proceedings of PAC2003

UK (JLAB) DESIGN

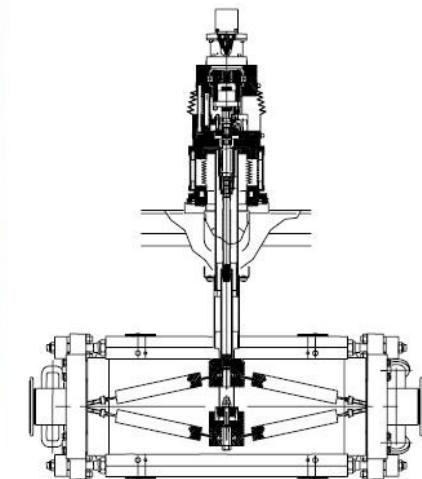
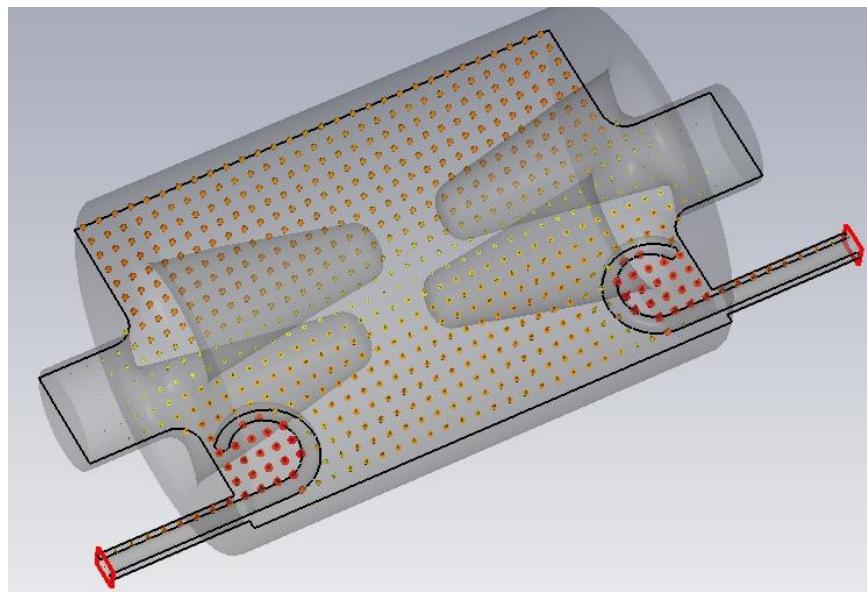
Cavity complete,. HOM studies underway



Towards
Conical rods



Prototype Tuner for CEBAF Upgrade

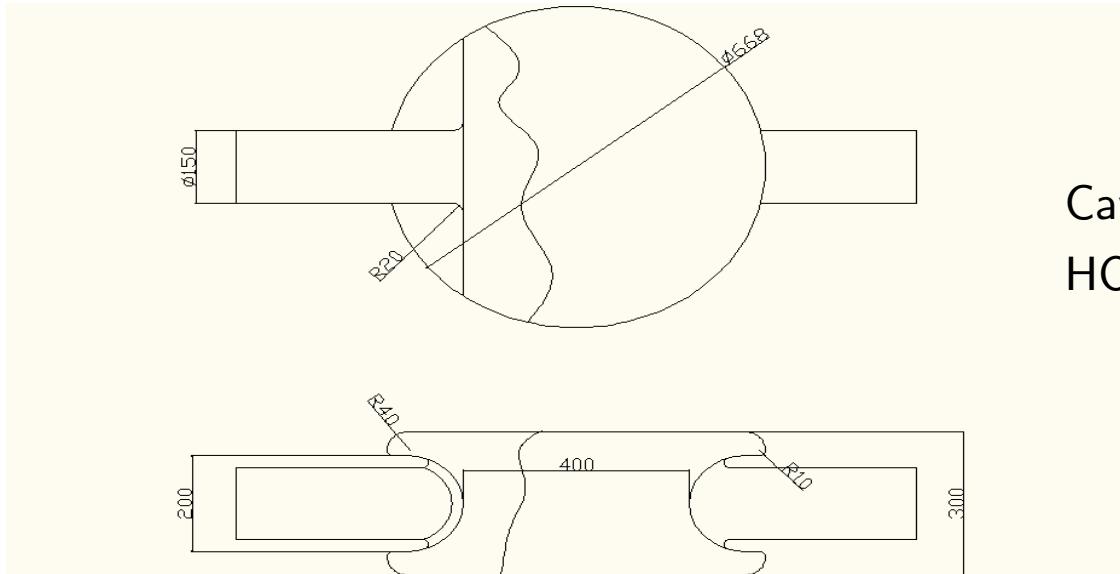


Details at:

<http://indico.cern.ch/getFile.py/access?contribId=50&sessionId=12&resId=1&materialId=slides&confId=83532>

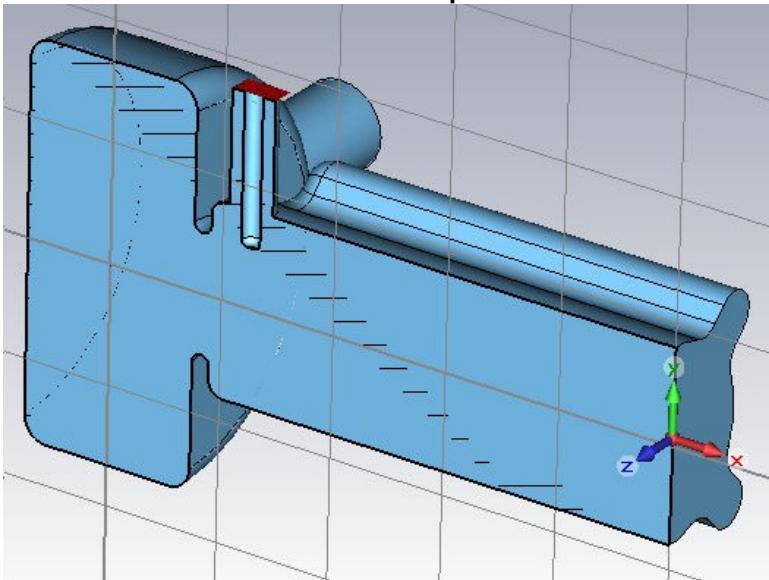
3D MODEL: http://rcalaga.web.cern.ch/rcalaga/LHCCRABS/CAVITY.FILES/UKCAV_Burt.SAT.gz

KEK-KOTA DESIGN

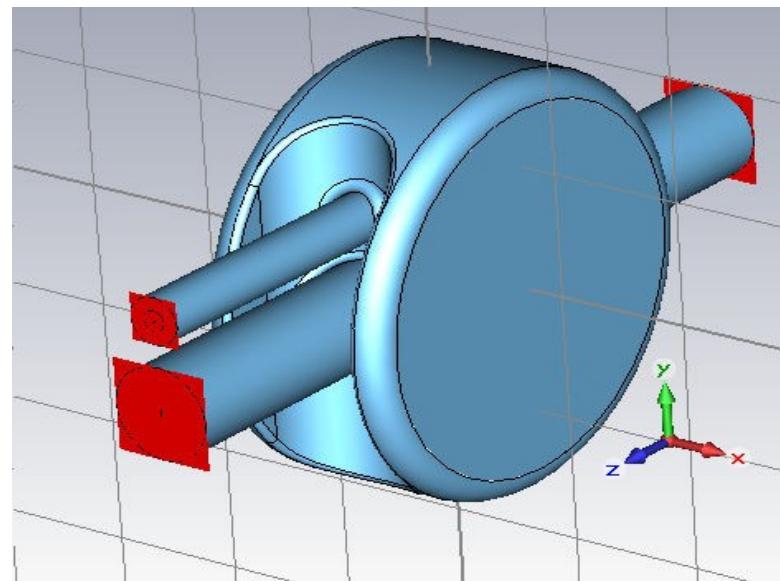


Cavity complete,,
HOM studies and damping scheme underway

Power Coupler



HOM Damping



Details at:

<http://indico.cern.ch/getFile.py/access?contribId=87&sessionId=6&resId=1&materialId=slides&confId=55309>

3D MODEL: http://cern.ch/ricalaga/LHCCRABS/CAVITY.FILES/KEKCAV_Kota.SAT.gz

KEK-KOTA, PRELIMINARY HOMs

mode	Frequency [MHz]	V_kick [V/J ^{1/2}]	Vz [V/J ^{1/2}]	R_z/Q [Ohm]	E_sp [MV/m/J ^{1/2}]	H_sp [Oe/J ^{1/2}]
TM010*	400.389	238192	0.290838	0	4.08	156
TE111	440.813	0.296713	464509	78	9.27	107
TM011	471.037	0.089472	453144	69	7.74	127
TM110	574.368	40614.4	0.290216	0	8.44	152
TE211	576.627	0.633024	0.123273	0	10.1	484
TM110	587.357	0.131659	0.005841	0	3.26	175
TE211	600.556	0.593295	0.344733	0	10.4	589
TM111	678.981	0.43519	313611	23	7.03	135
TE111	681.778	0.058524	0.05005	0	3.75	130
(TM310)**	700.339	253646	0.466292	0	9.28	229

HOM damping calculations still underway

NEXT STEPS

- Cavity fabrication and treatment → field validation (+3 yrs)
- Coupler(s) fabrication & integration → Damping validation
- Cryomodule (+5 yrs)
 - Cryogenics and instrumentation
 - Tuning system (compression or bellows)
- Horizontal RF testing & CERN test stand (SM18) → SPS Tests

Most of these topics will be covered in LHC-CC10

ARMY OF SIMULATIONS

Machine protection (New tools)

Sixtrack collimation loss maps for failure scenarios (R. Calaga, B. Yee)
MADX tracking with crab failures (T. Baer, J. Wenninger)

Crab RF noise, Beam-Beam

Noise simulations: Weak-strong & Strong-strong (K. Ohmi, J. Qiang et al.)
Synchro-betatron resonances and dispersion (R. Miyamoto, R. Calaga)
KEK-B RF noise measurements (R. Tomas et al.)

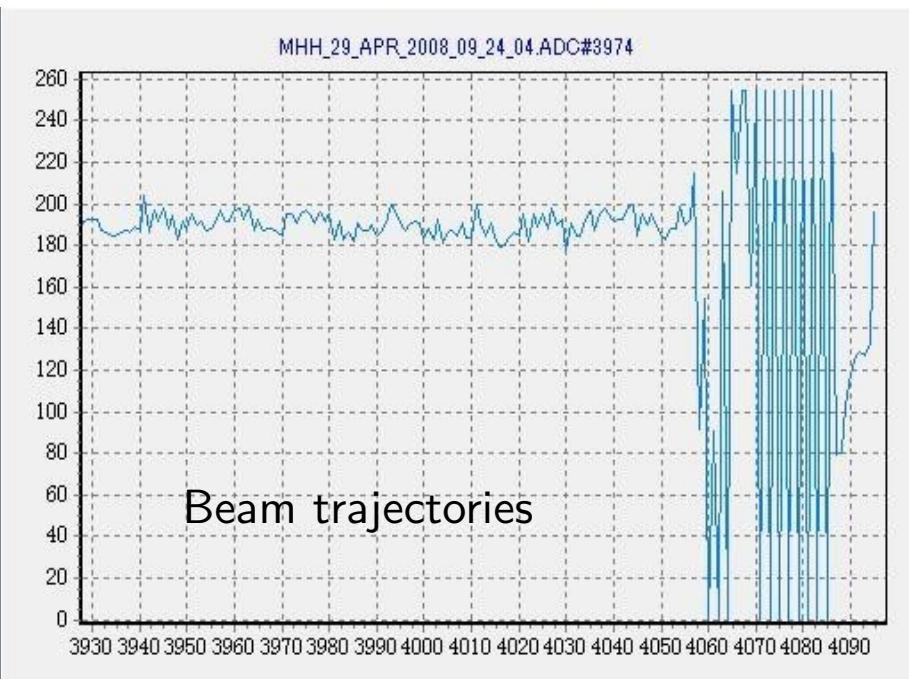
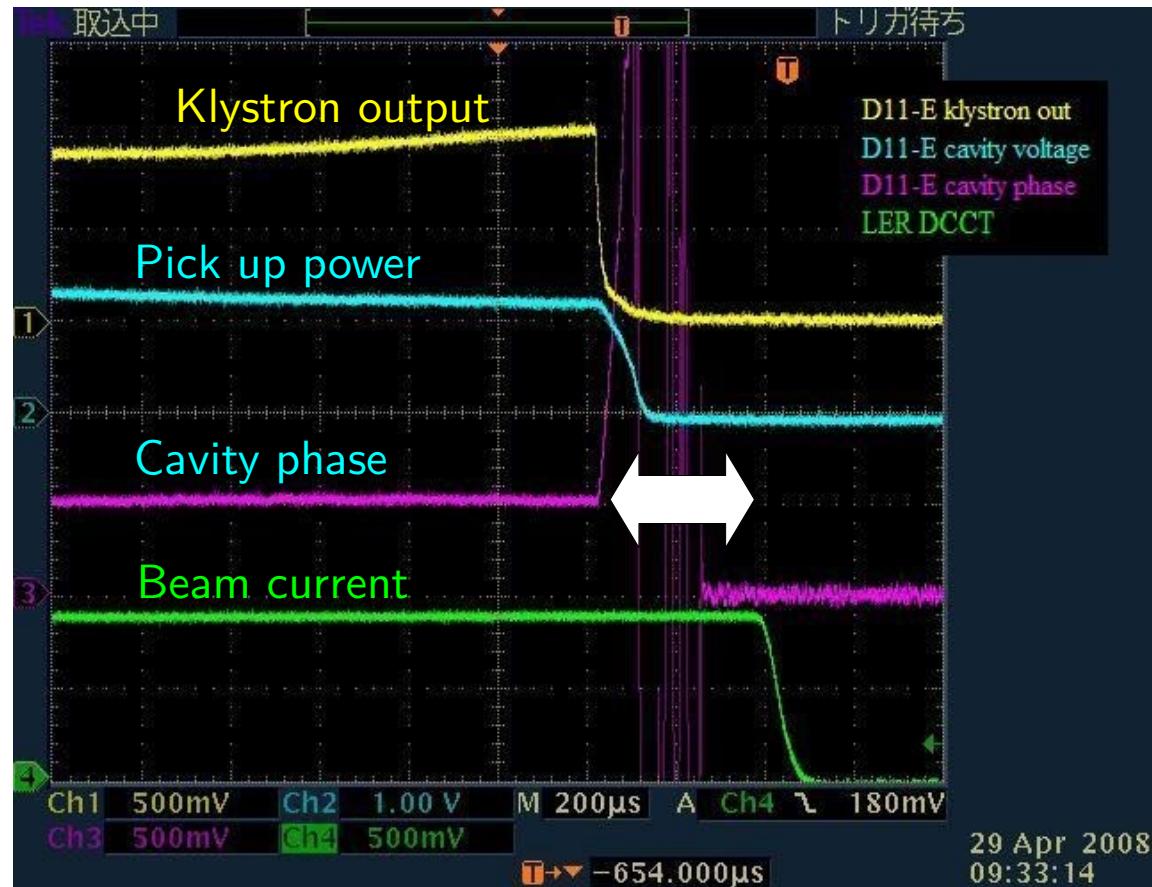
RF & Impedance

Cavity simulations (Z. Li, G. Burt, J. Delayen, N. Kota, L. Ficcadenti et al)
RF failures and system configuration (J. Tukmantel, P. Baudrenghien)
Analytical estimates (R. Calaga, E. Metral, E. Shaposhnikova, F. Zimmermann)
Growth rates and damping criteria (??)

Baseline Optics

SLHC V3.0 + Crabs (R. de-Maria, S. Fartoukh)
Physical & dynamic aperture, β^* , chromatic compensation, field non-linearity

RF TRIP EXAMPLE (KEKB)

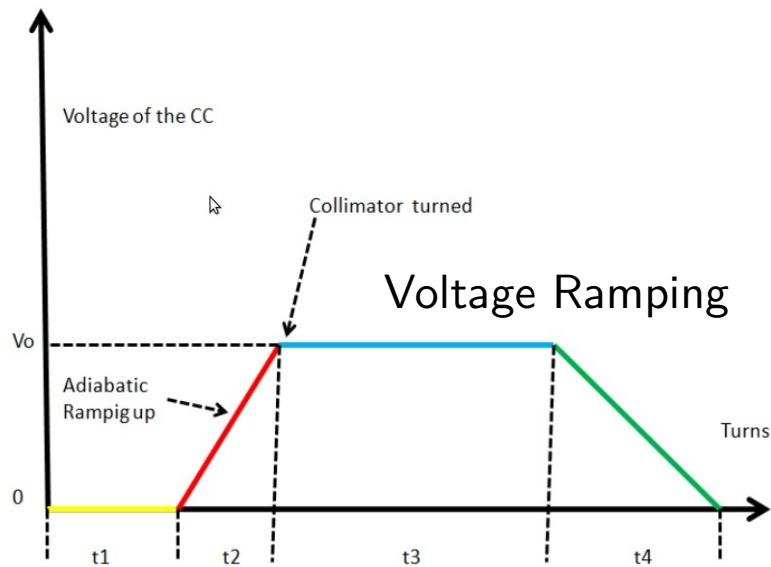


Intentional/non-intentional phase changes → corresponding orbit changes and beam losses

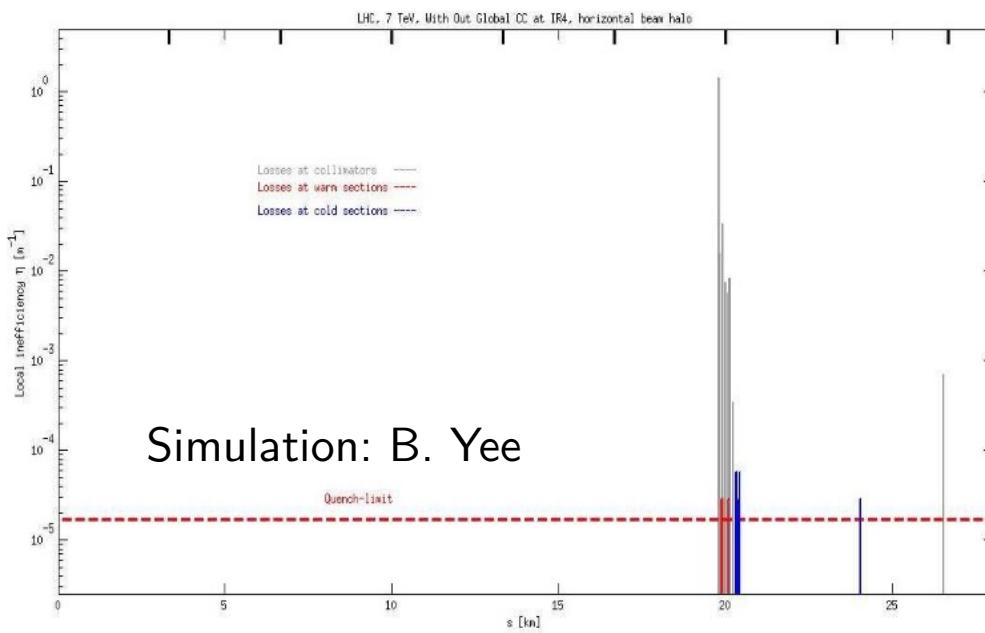
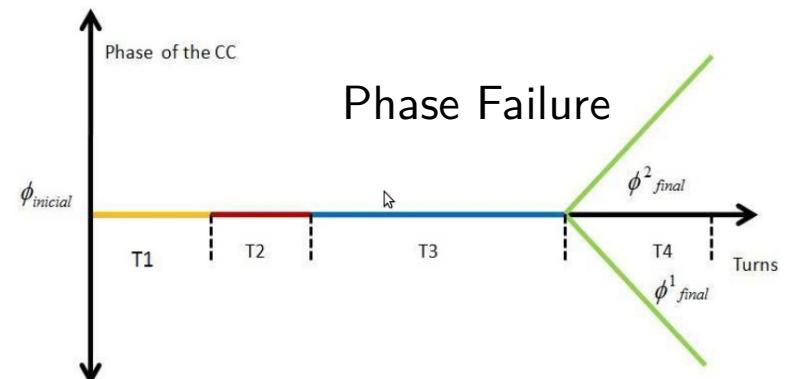
Approx time scale → 400 ms (4 turns)

Courtesy KEK-B

SIMULATIONS OF FAILURES



Sixtrack & MADX are setup now for abrupt failure scenarios
(J. Barranco, R. Calaga, R. Tomas)



Only preliminary:

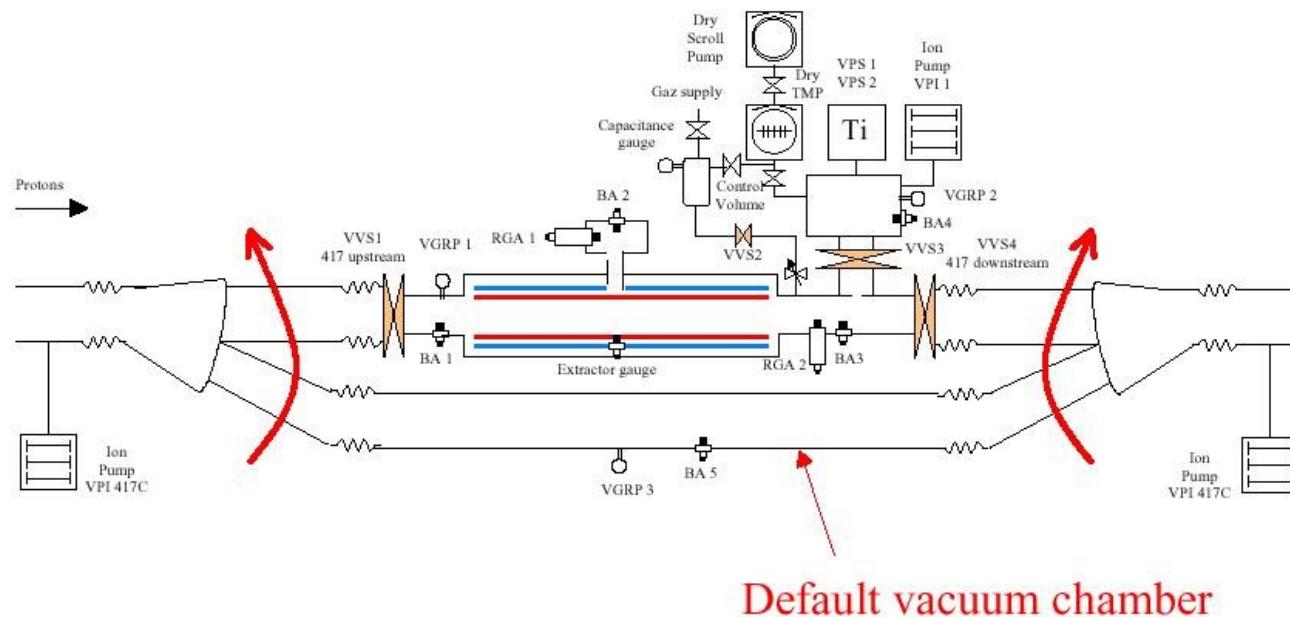
Overall loss maps show no significant changes due to a 50 deg phase change in 1 turn

But detailed simulations are needed for turn-by-turn loss maps to determine the impact locally

SPS TESTS

Crabs potentially in SPS is at [COLDEX.41737](#) (4020 m, LSS4)

Crab Bypass similar to COLDEX to move it out of the way during high intensity operation



SPS beam tests, 2010 to check emittance lifetime @55/120 GeV coast with $2\mu\text{m}$ norm emittance

Machine protection

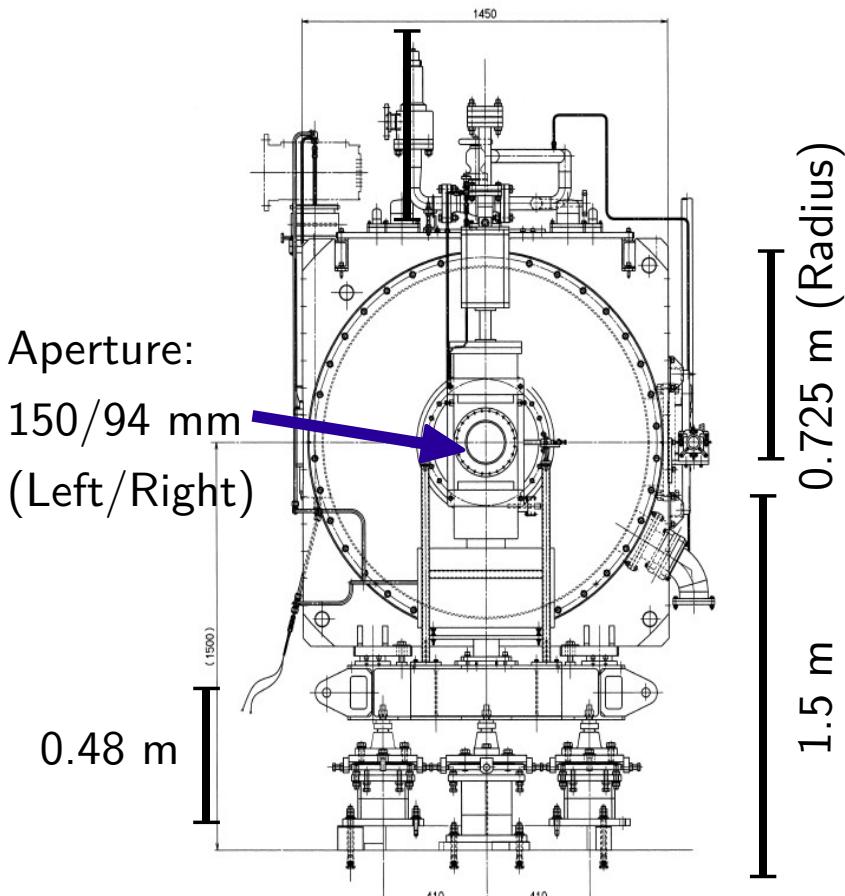
Setup with 2 collimators: No effect at 1st & full crab effect at 2nd second collimator

Primary goal is beam measurement (No implementation of interlocks, BPMs-fast & RF-slow)

Failure scenarios (for example: abrupt voltage/phase changes, RF trips etc..)

KEKB CRYOSTAT

Weight: 5830.5 kg, Length: 5 m



Aperture:

150/94 mm
(Left/Right)

0.48 m

0.725 m (Radius)
1.5 m

Crab voltage: {HER, LER} - 1.6 MV, 1.5 MV
(design: 1.44 MV)

Operational voltage: {HER, LER} 1.4 MV, 0.9 MV

Dismantle cavity + ancillary equipment in clean room → Stretch the cavity to arrive +2 MHz

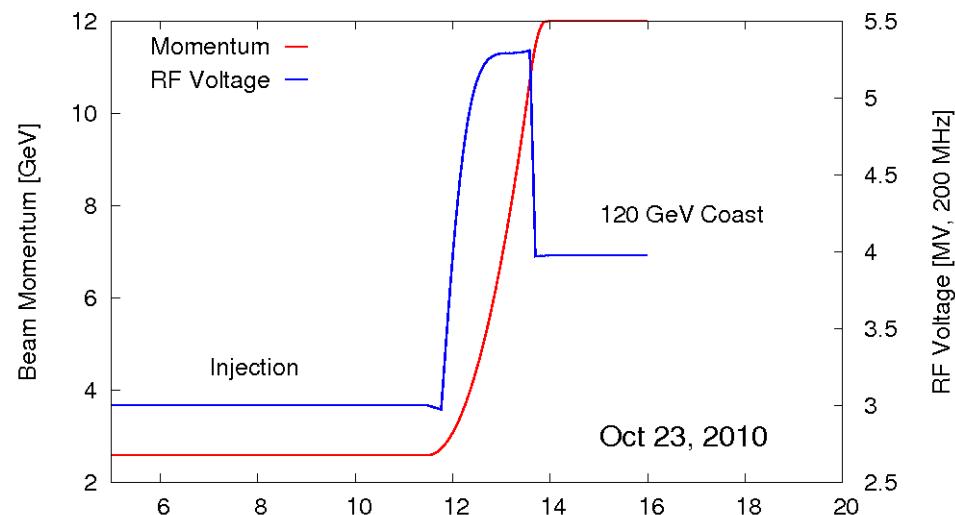
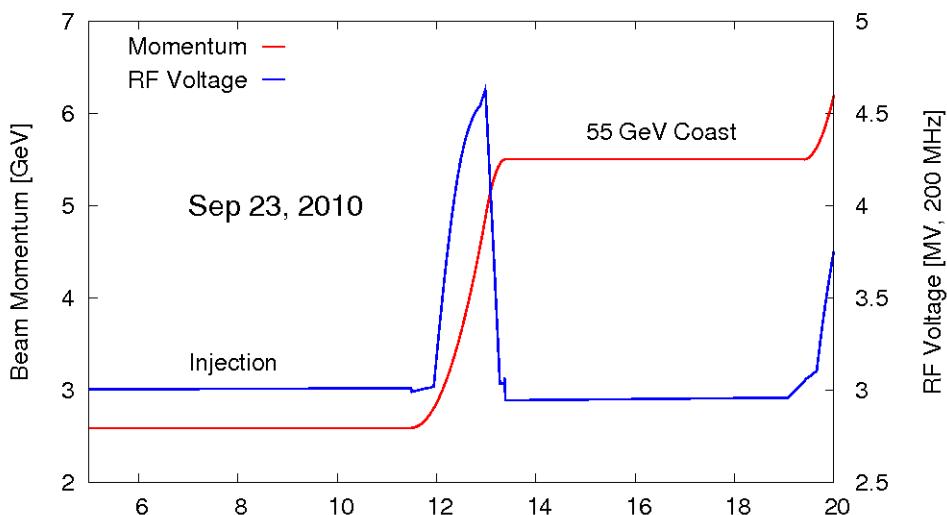
Cavity to HP rinsed, transported to CERN and assembled with coupler and cryostat

Need atleast 1 year and estimated at \$2.5 M

RECENT SPS STUDIES

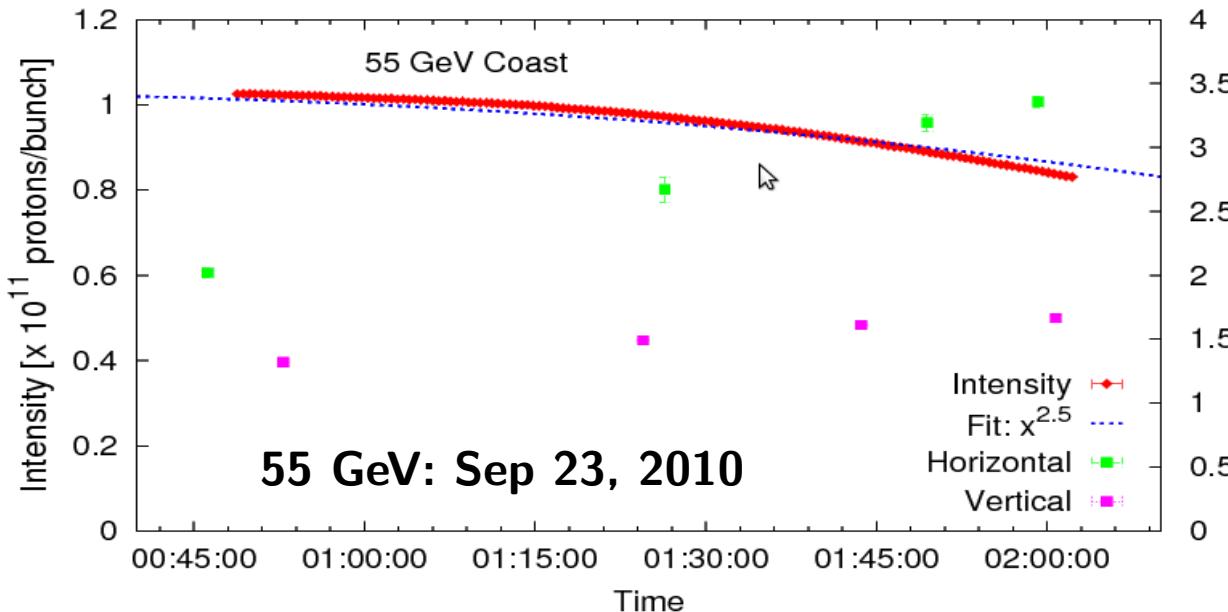
For final decision on crab tests in the SPS (natural emittance growth at 55/120 GeV)

Parameter	Unit	Sep 23	Oct 20
Energy	GeV	55	120
$Q_{x,y}$	-	0.13/0.18	0.13/0.18
$\xi_{x,y}$		2-3	2
Intensity	$\times 10^{11}$	1.1	0.5 (12 bunches)
$\epsilon_{x,y}$	μm	3.1/2.8	1.5-2.0
RF Voltage	MV	3.0	4.0 (also 2)

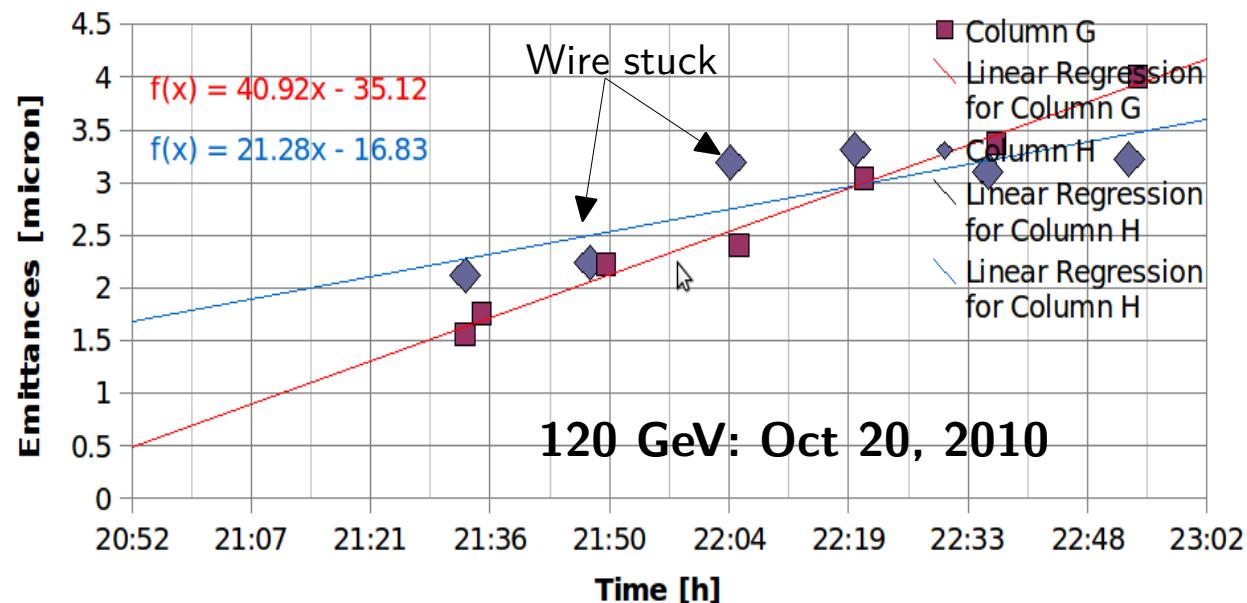


SPS STUDIES

R. Calaga, L. Ficcadenti, E. Metral, G. Rumolo, R. Tomas, J. Tuckmantel, F. Zimmermann



Emittance growth too large
for crab experiments (larger in
horizontal plane)



Emittance growth in vertical plane
seem reasonable (larger in H-plane)

Repeat the experiments with different horizontal tune (simulations H. J. Kim)

CONCLUSIONS

- US-LARP program
 - Most advanced on technology design → leading to prototyping (WP4)
 - Several beam simulations and experiments ongoing (WP2)
- US-Crab project under HL-LHC
 - Focus on development & construction of compact cryomodules
 - A preliminary resources loaded schedule in place
 - Synchronize prototyping with STTR/SBIR and other activities
- SPS tests
 - Initial tests promising but need more MDs to establish beam conditions
 - Finalize the use of KEK-B cavities and preparation of SPS (Dec 2010)

Many thanks to all the LHC-CC collaborators

