LHC Crabs, Status

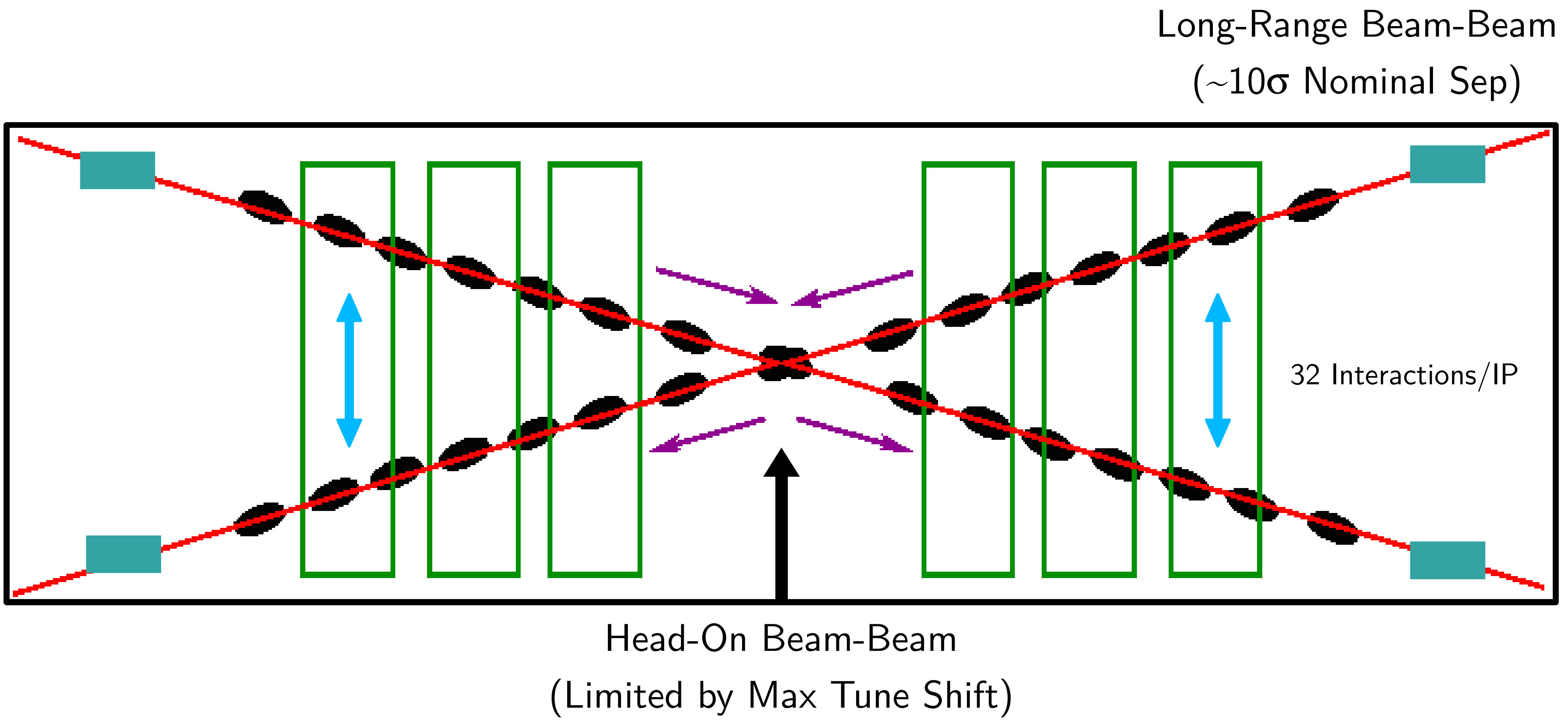
Rama Calaga

RFTECH, Dec 2-3, 2010

- Brief Overview
- Status of Technology R&D
- Status of Simulations & Experiments

Thanks to all LHC-CC collaborators

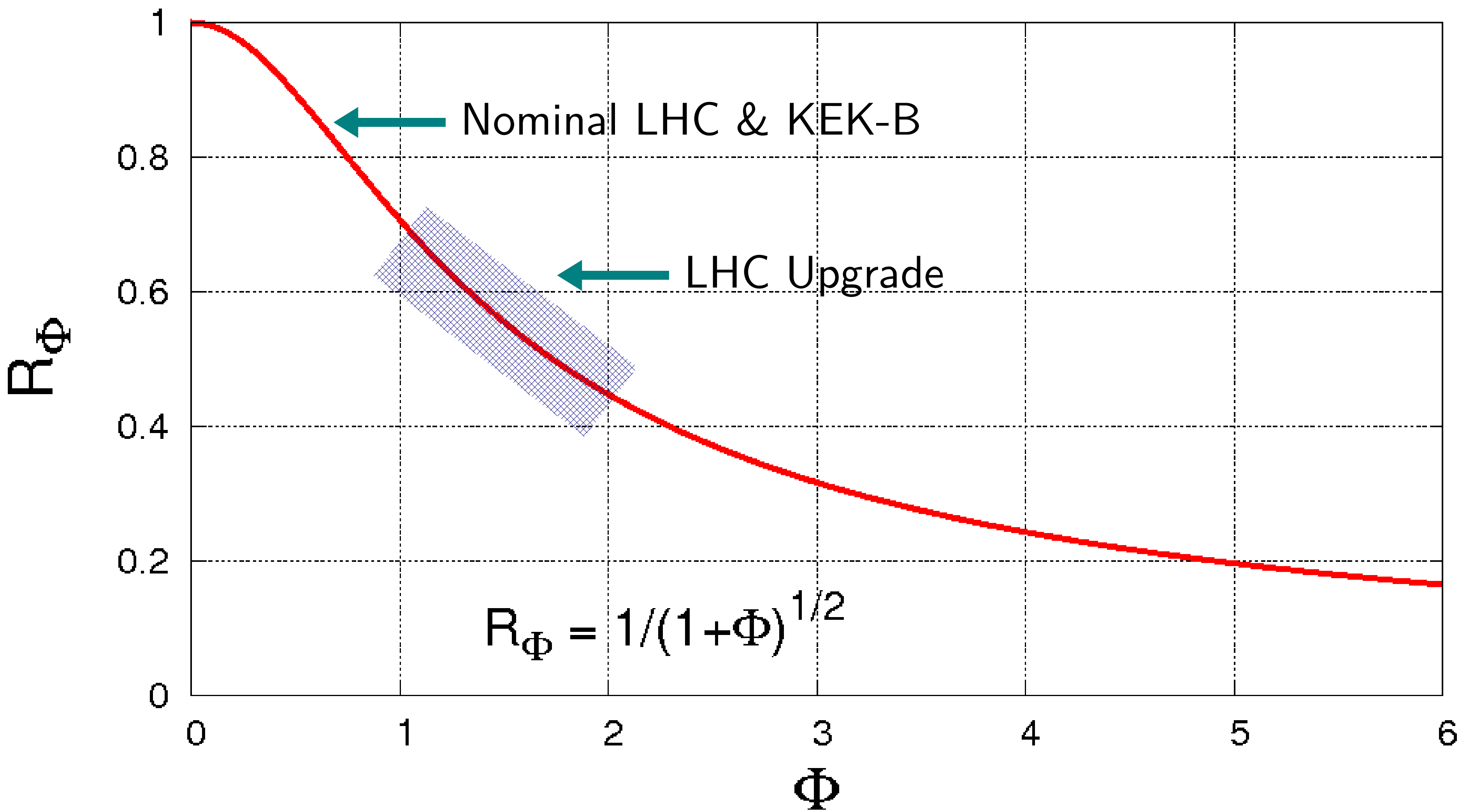
X-Angle & Crab X-ing

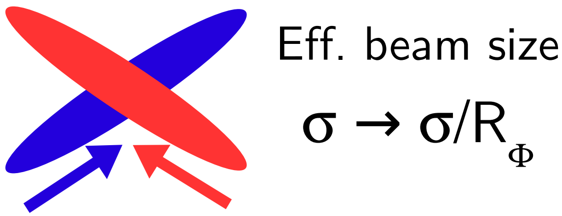


With crab crossing

- Increase peak luminosity with increasing x-angle due LR Beam-Beam
- Increase intensities and smaller emittances beyond head-on beam-beam limit
- Level luminosity (reduce Pile-up, radiation damage)

Reduction Factor





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)

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

Freq: 400 MHz, Volt < 12 MV, β_{cc}: ~3 km

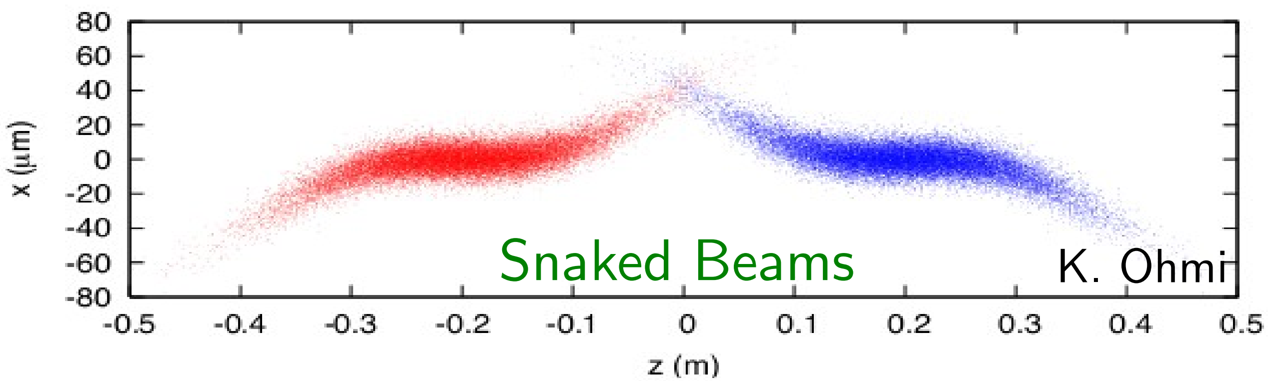
Integrated luminosities (G. sterbini):

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

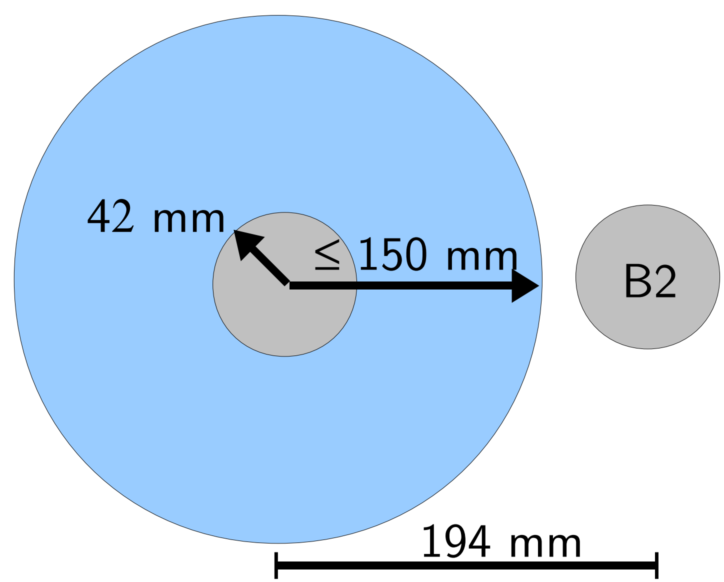
Approx: 265 fb^{-1}/yr (217 fb^{-1}/yr w/o CCs) → 2 yr reduction in run time (for 3000 fb^{-1})

LHC Constraints

Bunch length: 7.55 cm (highest frequency 800 MHz)



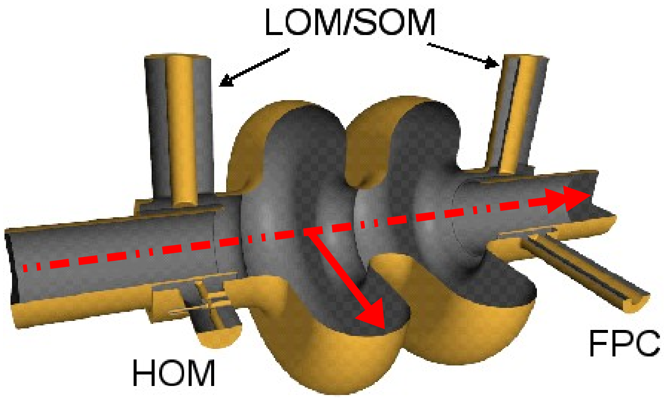
B1-to-B2 separation: 194 mm (PB 800 MHz ~ 250mm radius)



With few exceptions....

(IR4, collimation, exps)

Conventional to Compact

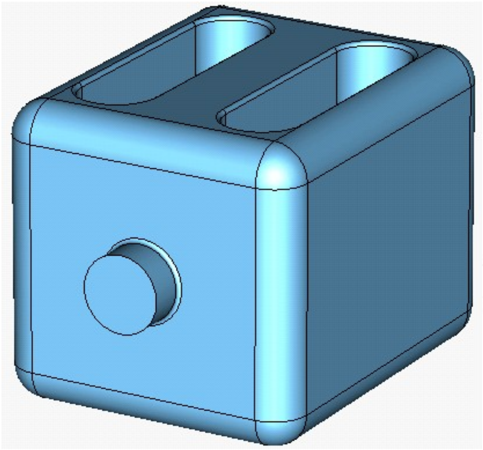


~250 mm outer radius

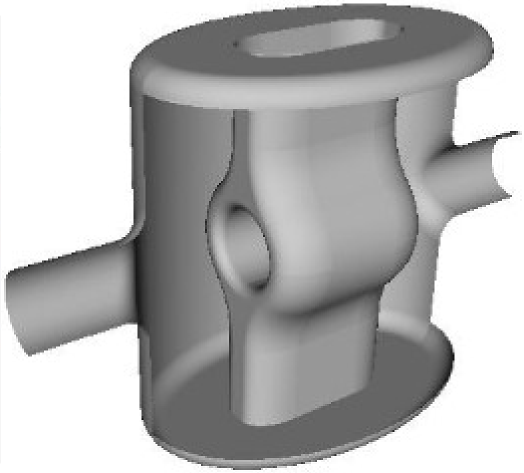
(Not compatible in most of the LHC ring)

Compact cavities aiming at small footprint (150 mm) & 400 MHz, 5-10 MV/cavity

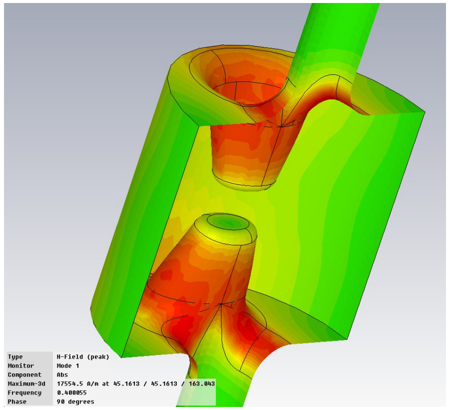
HWDR, JLAB,OD



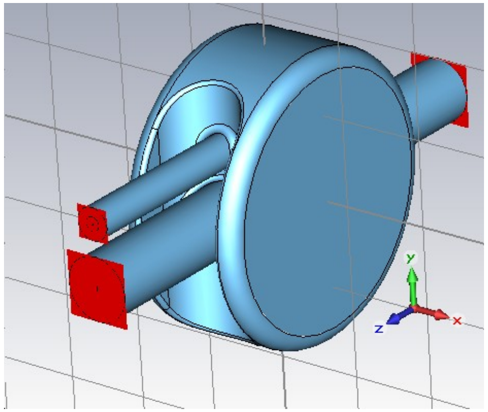
HWSR, SLAC-LARP



DR, UK, TechX



Rotated Pillbox, KEK



Compacts, Status

4 primary compact candidates + 1 elliptical back up

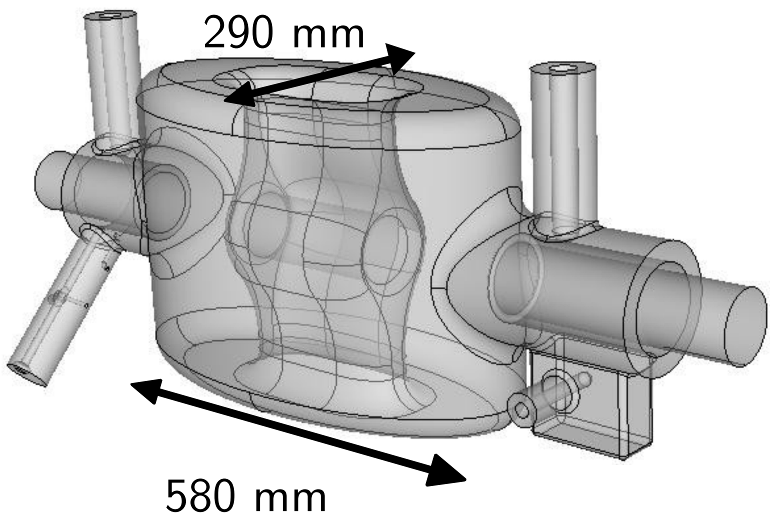
		HWDR (J. Delayen)	HWSR (Z. Li)	4-Rod (G. Burt)	Rotated Pillbox (N. Kota)
Geometrical	Cavity Radius [mm]	150	145	115	150
Geometrical	Cavity Height [mm]	380	391	280	668
	Beam Pipe [mm]	42	45	45	75
RF	Peak E-Field	29	52	62	85
RF	Peak B-Field	105	97.5	113	328
RF	R_T/Q	413	215	802	-

Kick Voltage: 5 MV, 400 MHz

†Exact voltage depends on cavity placement & optics

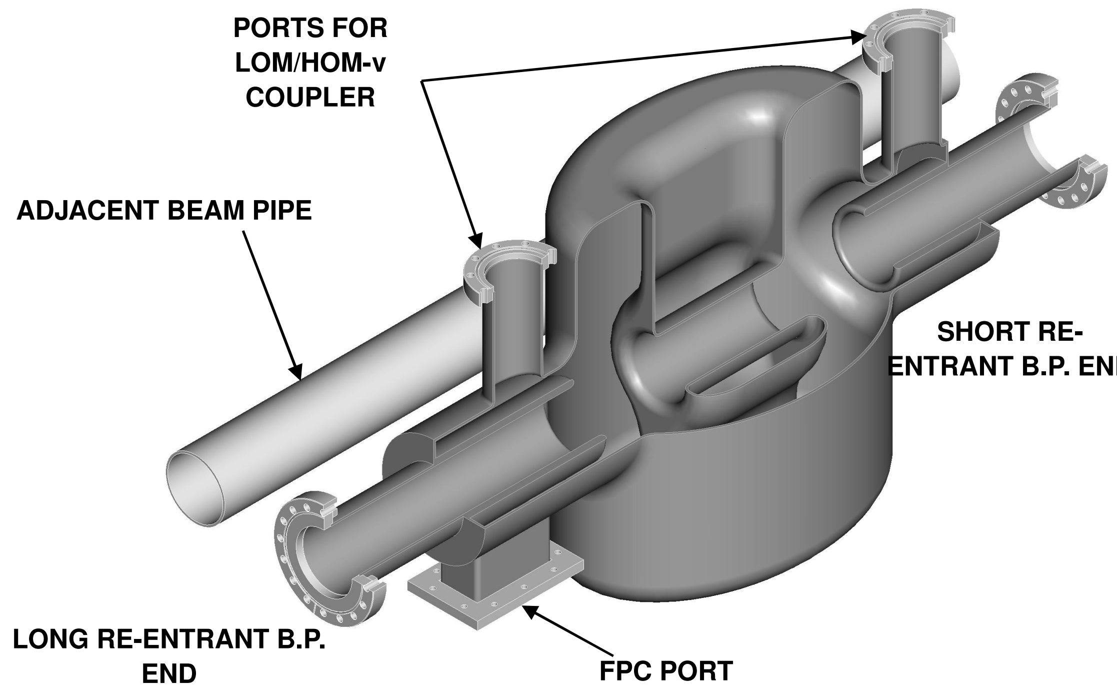
†Cavity parameters are evolving

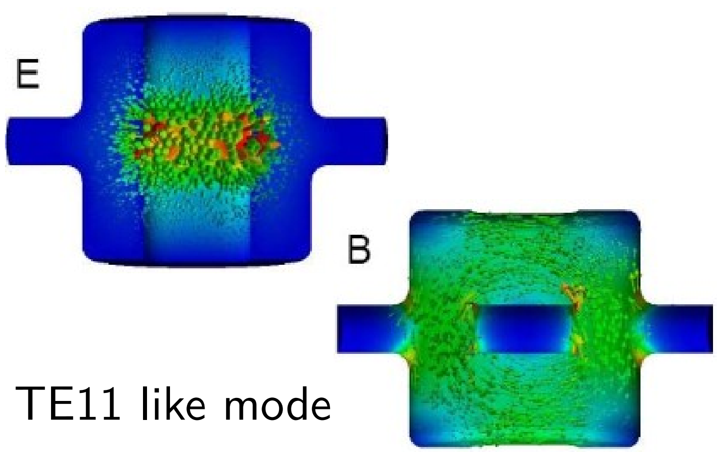
SLAC-LARP Design



Fairly complete design of cavity-couplers

Prelim mechanical/thermal analysis also done

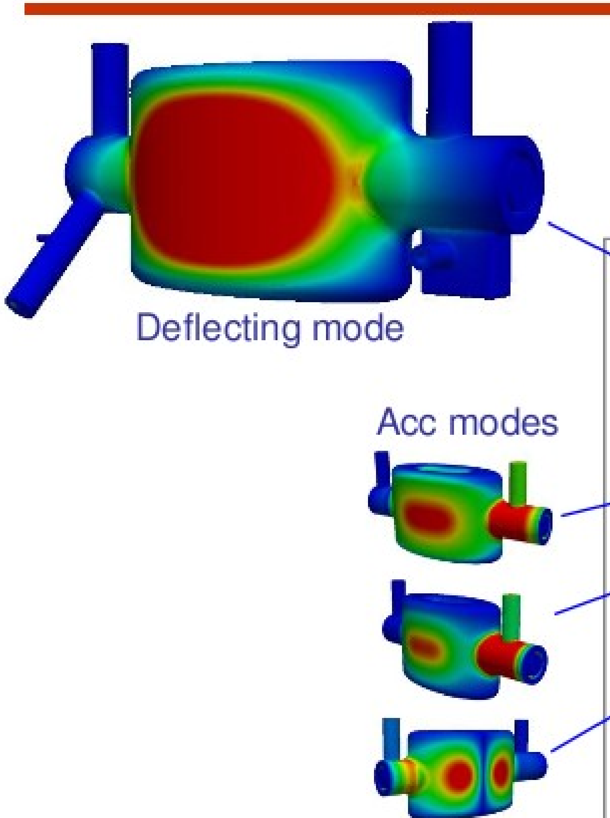


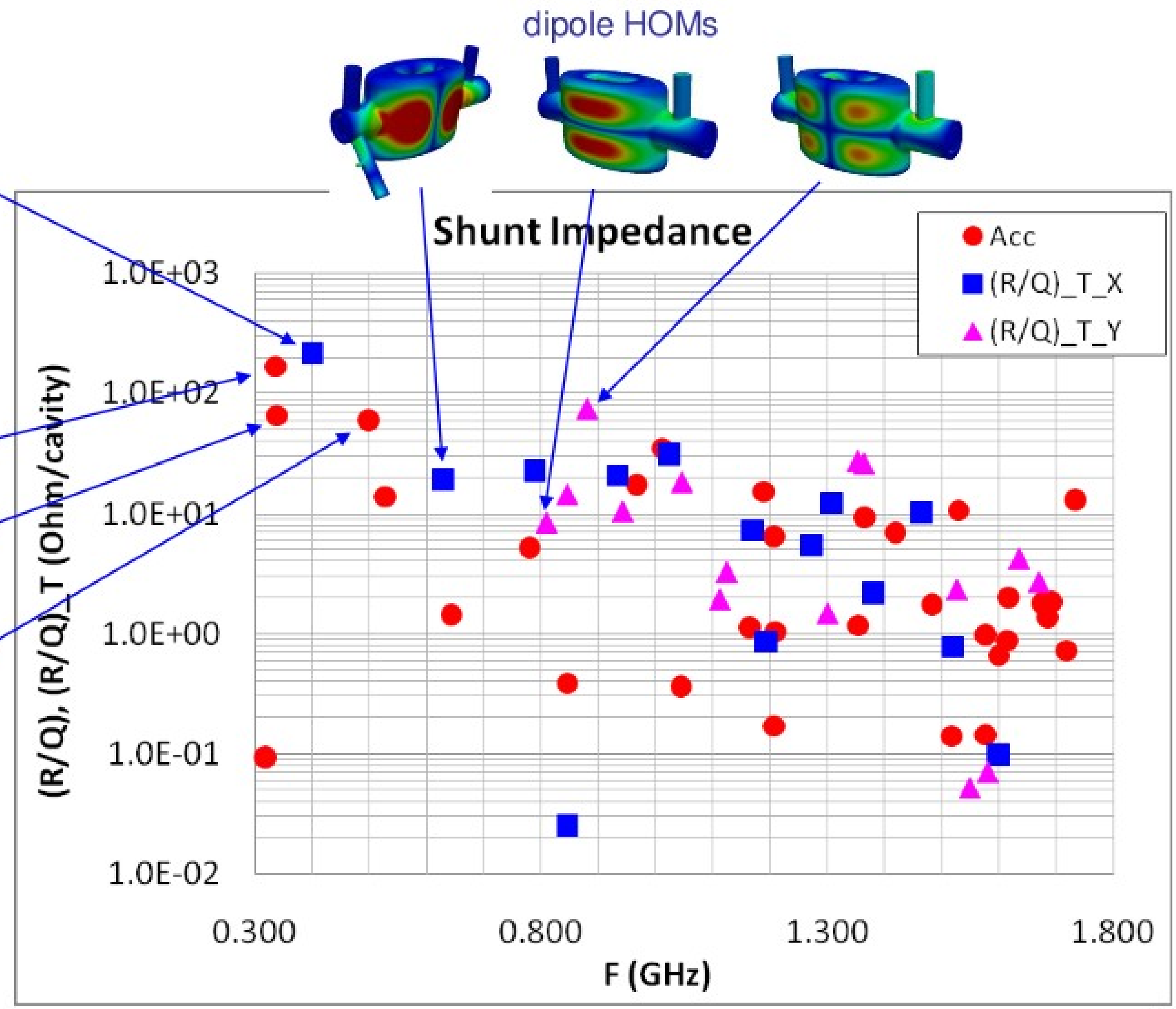


TE11 like mode
B-field deflection

Courtesy Z. Li et al.

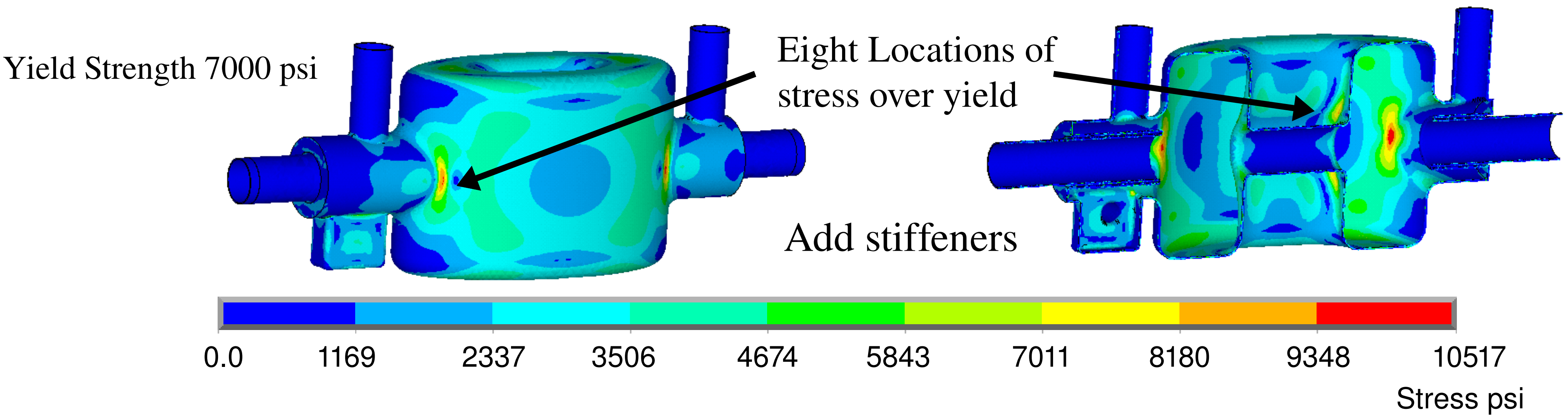
Shunt Impedance

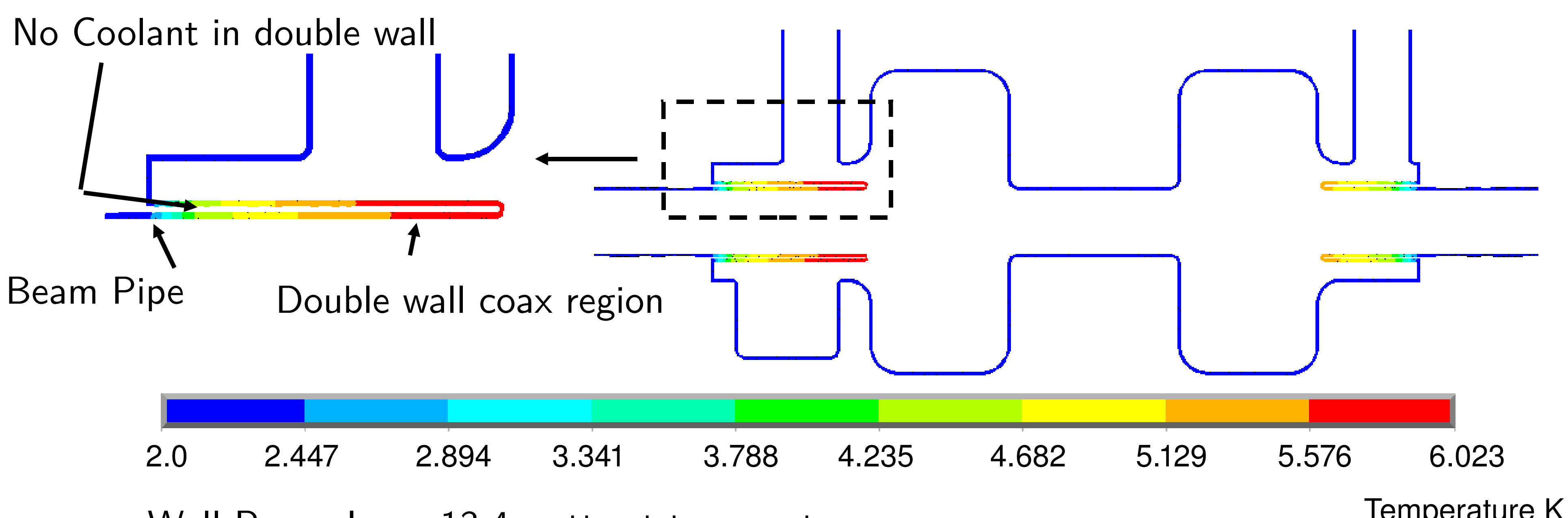




- No SOM !
- LOM 65 MHz below deflecting mode

Stress & Temp Distribution

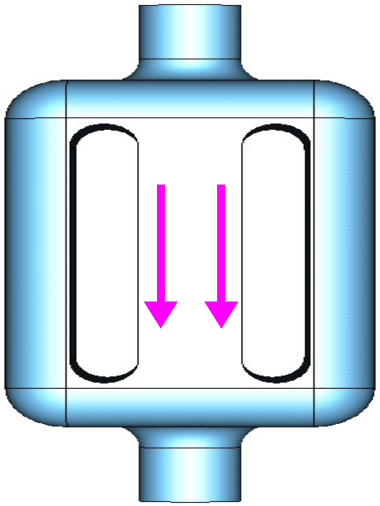




Wall Power Loss: 13.4 watts at temperature

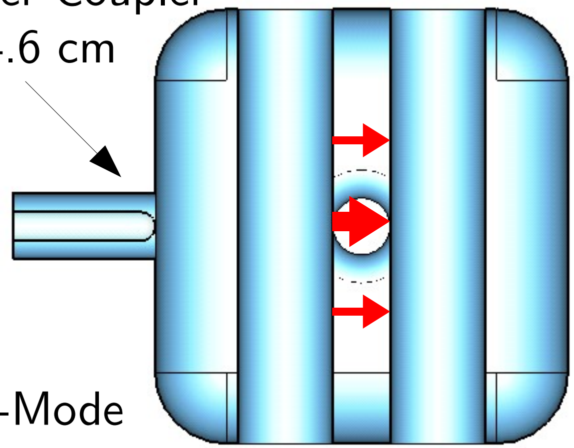
JLAB-ODU Design

Cavity complete,. HOM couplers etc.. underway



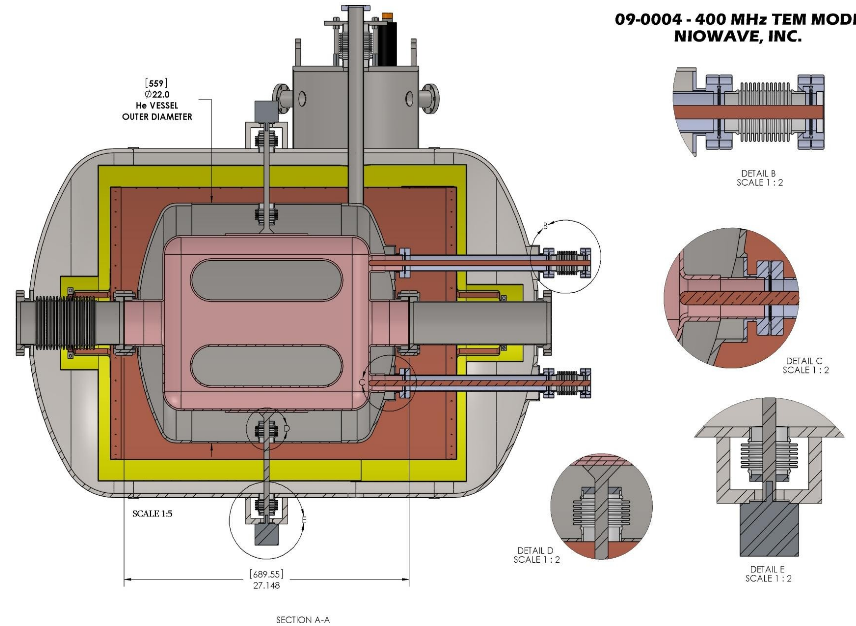
B-Field
Top plane

Power Coupler
4.6 cm



TEM-Mode

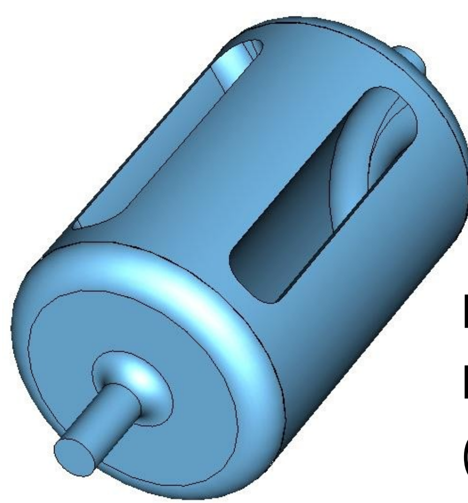
E-Field deflection
Mid plane



Niowave-STTR, Phase I

Moving Towards
Cylindrical shape

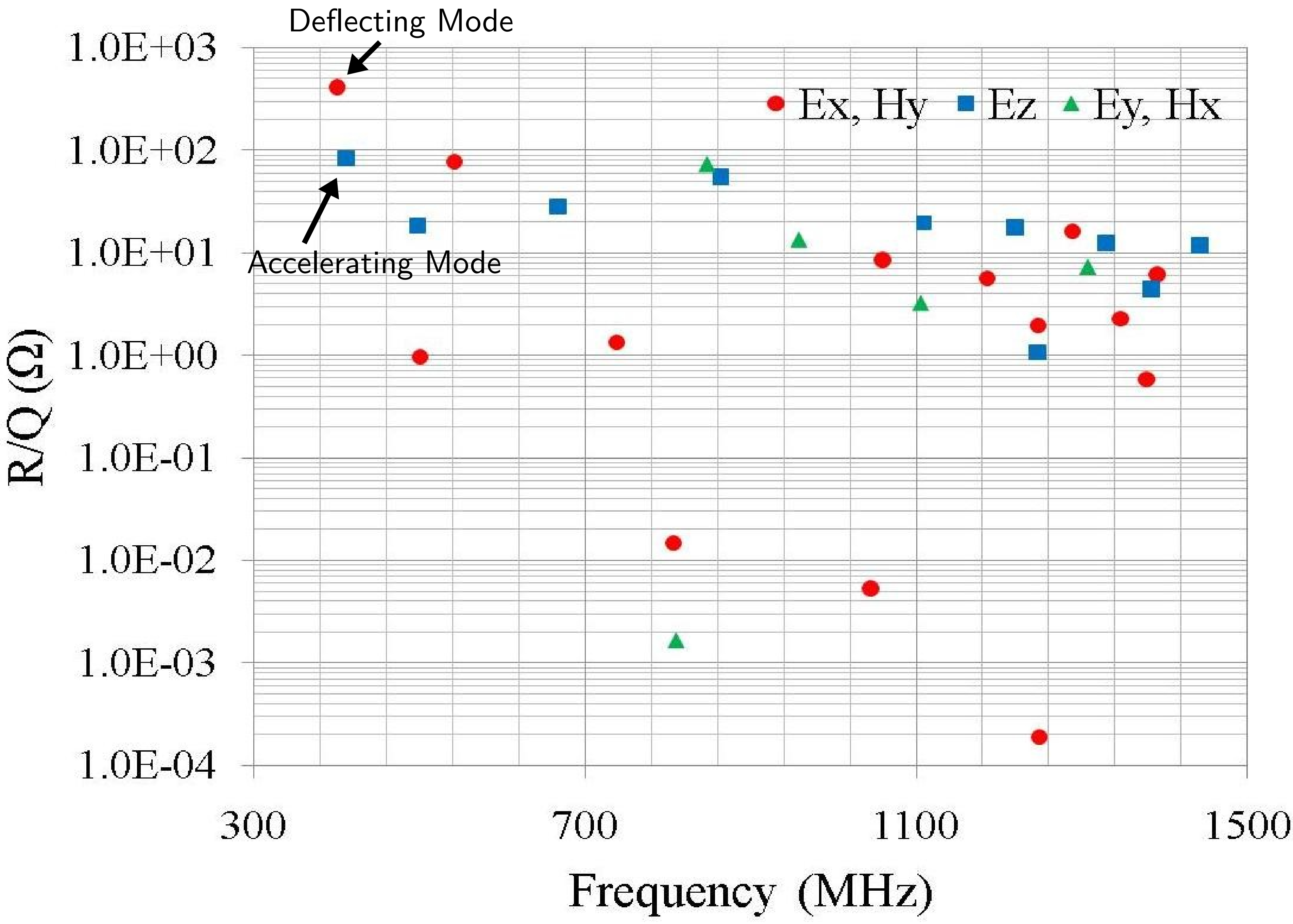
Fewer HOM modes



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

Courtesy J. Delayen et al.

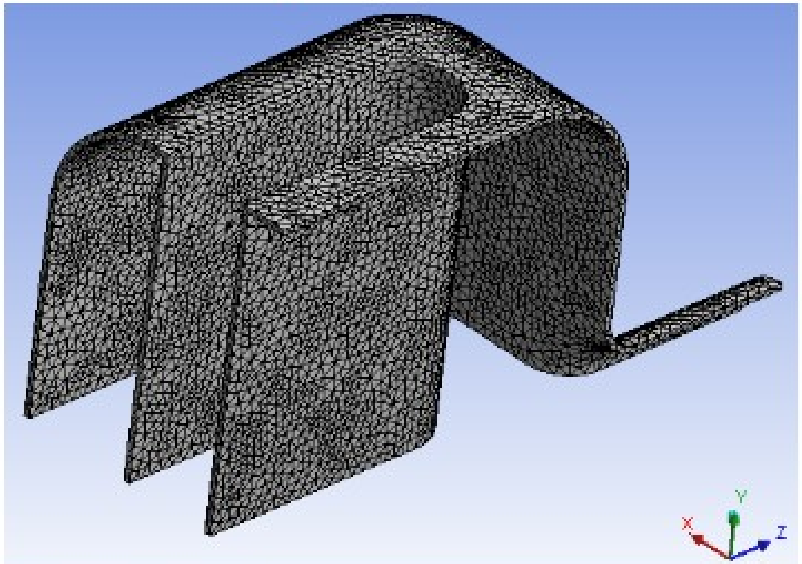
JLAB-ODU, HOMs



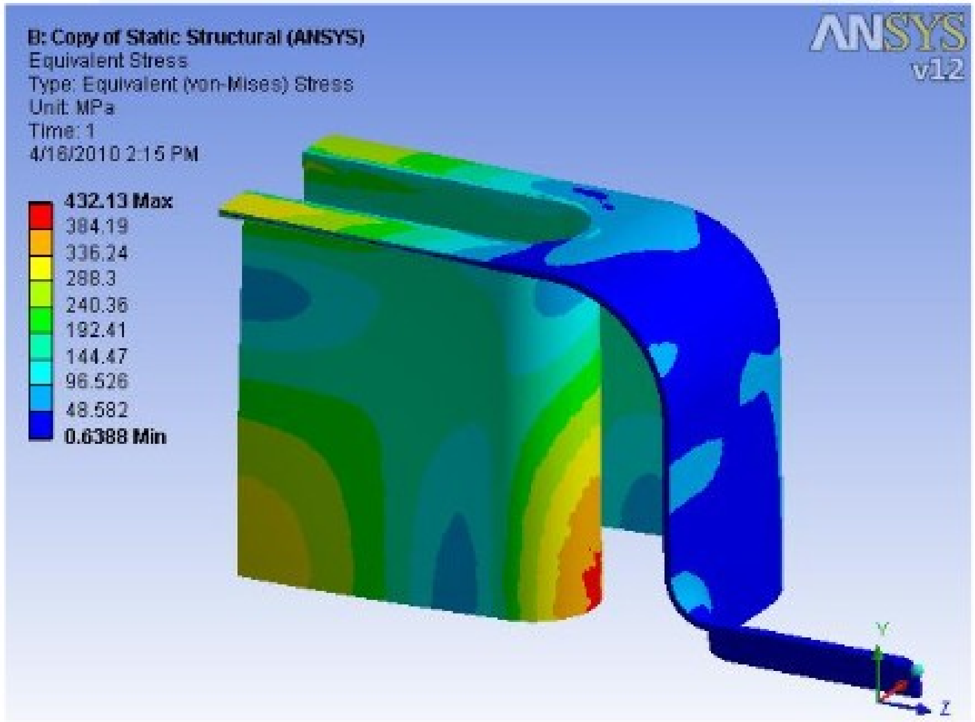
Preliminary Stress Analysis

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



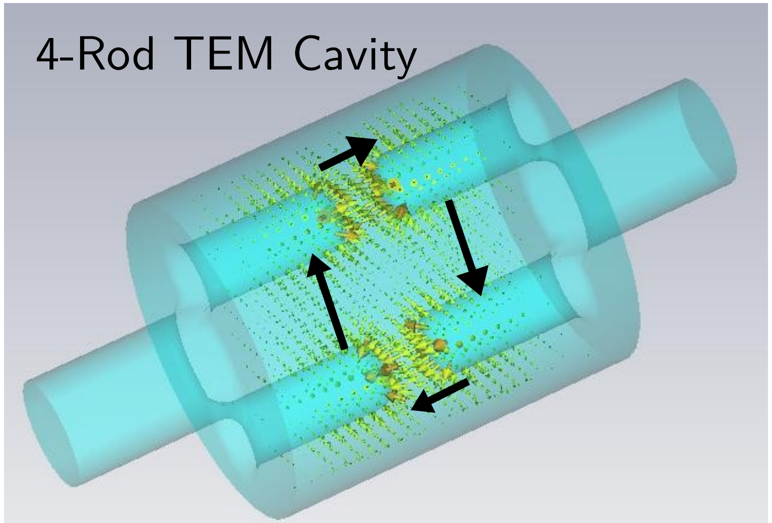
- Analysis using properties at room temperature
- Cavity wall thickness = 3 mm
- Mechanical model
  - Standard gravity = 9.806 ms^{-2}
  - Pressure normal to the cavity outer surface = 0.20265 Mpa (29.392 psi)
- Stress = 432 MPa > Yield Strength = 48 MPa



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

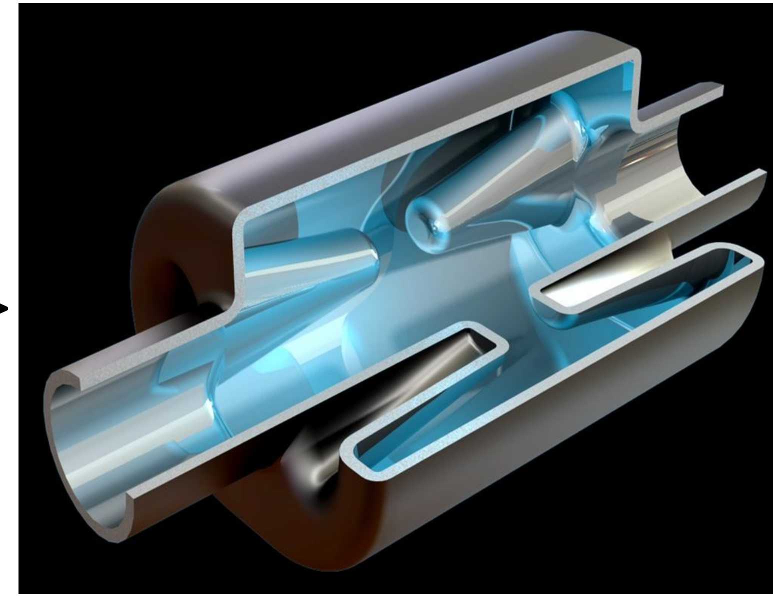
UK (JLAB) Design

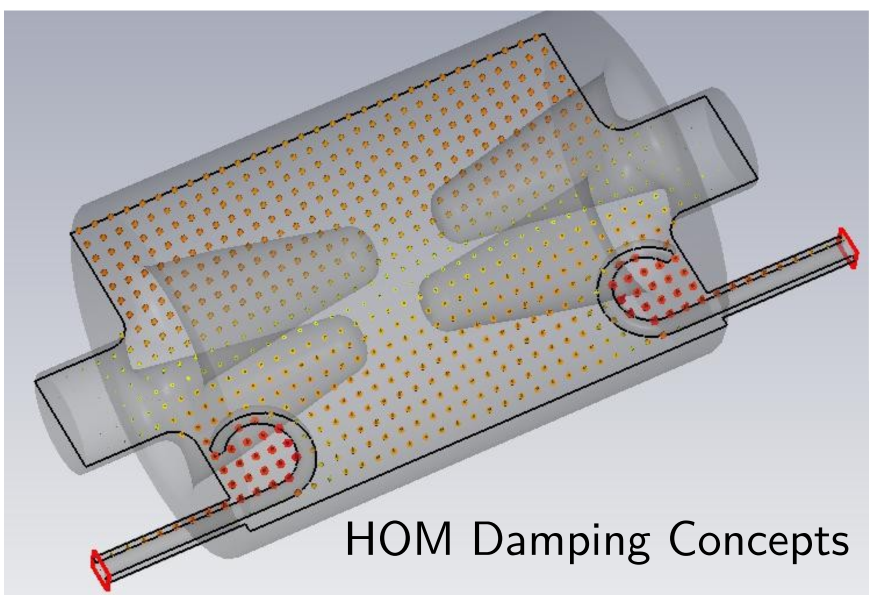
Cavity complete,. HOM studies underway



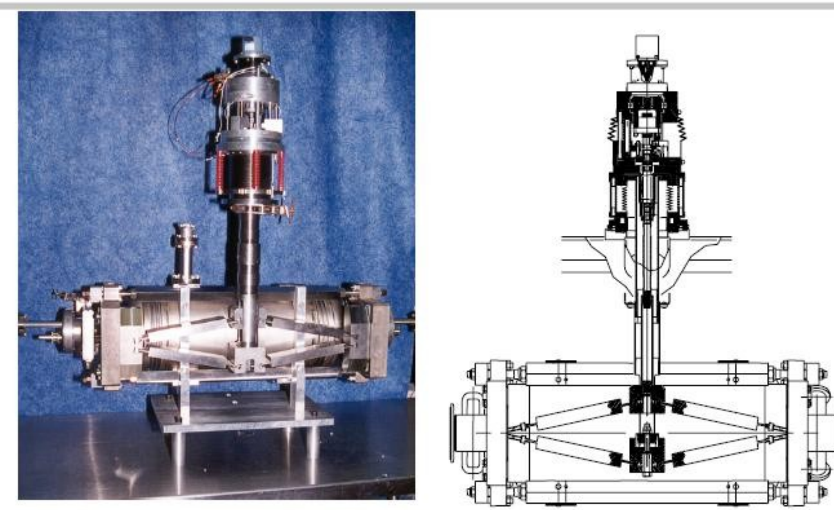
Towards

Conical rods



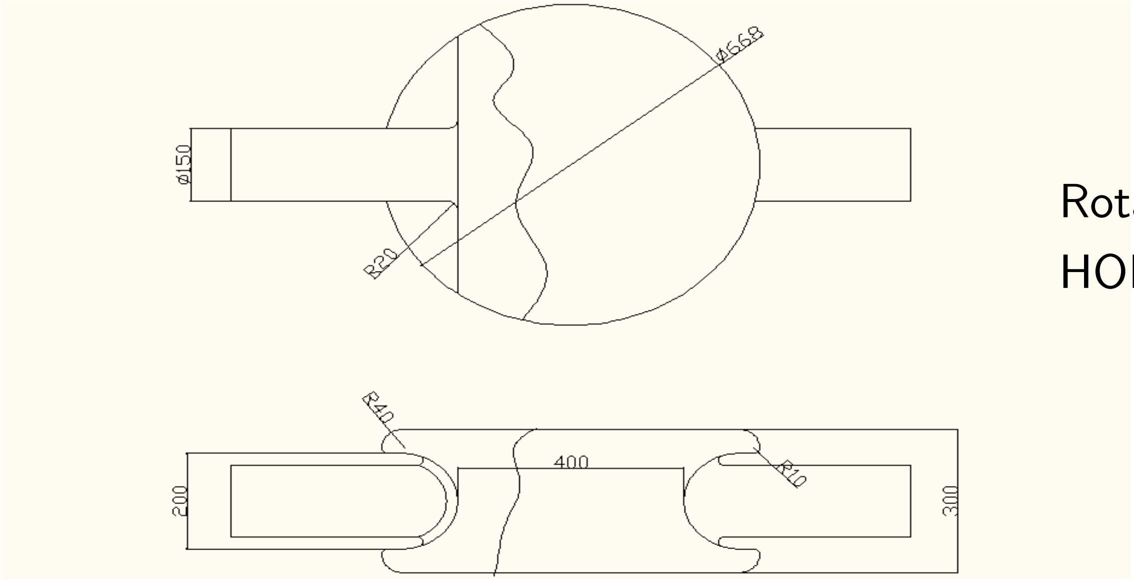


Prototype Tuner for CEBAF Ugrade



Courtesy G. Burt et al.

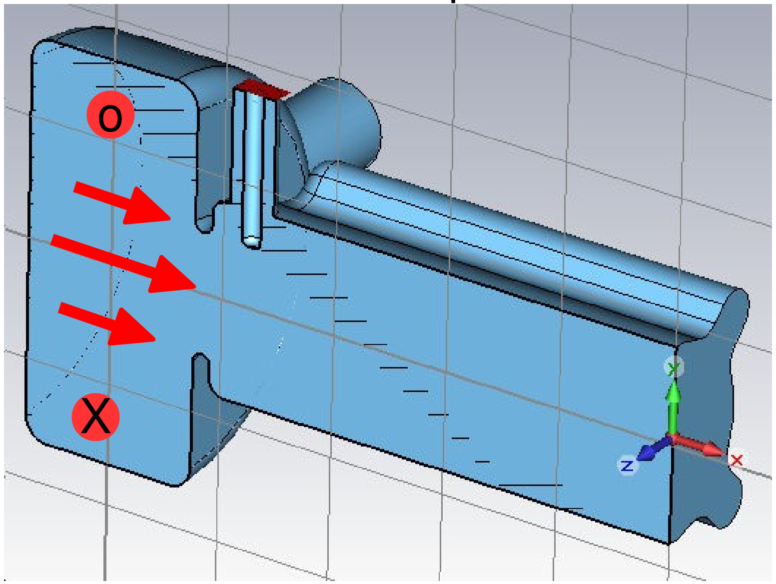
KEK-Kota Design



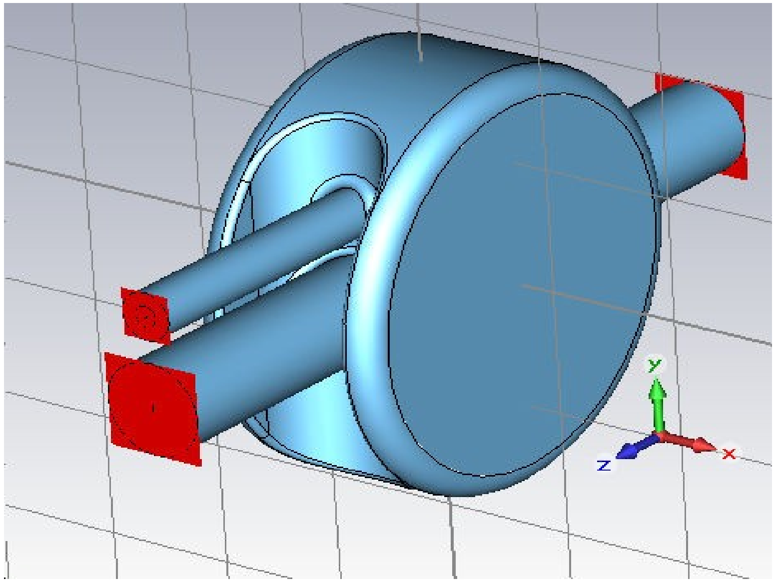
Rotated Pillbox with shielding cones

HOM studies and damping scheme underway

Power Coupler



HOM Damping



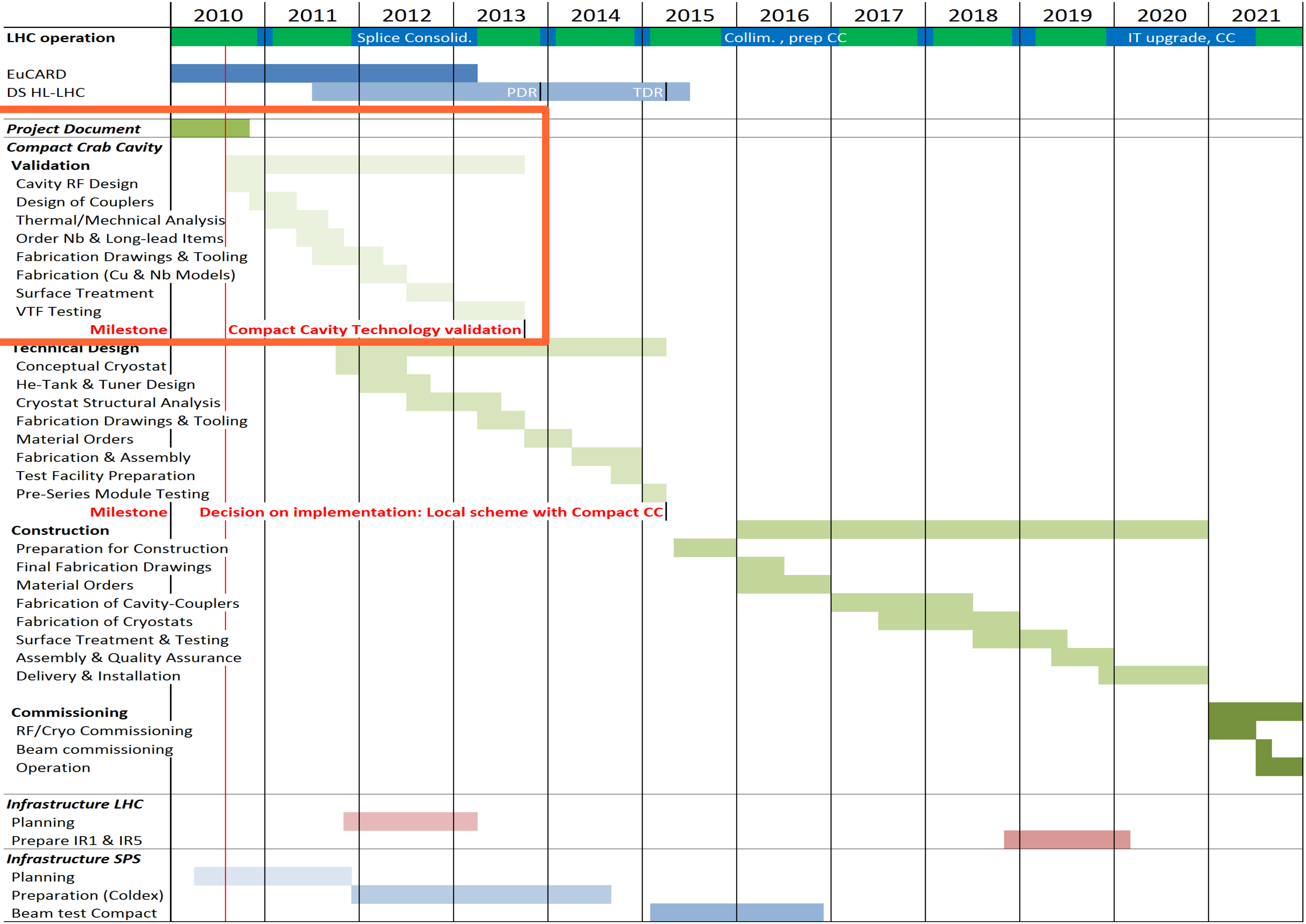
Courtesy K. Nakanishi et al.

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

US-Project, Timeline



Simulations Overview

Machine protection

- Sixtrack collimation loss maps for failure scenarios
- MADX tracking with crab failures

Crab RF noise, Beam-Beam

- Noise simulations: Weak-strong & Strong-strong
- Synchro-betatron resonances and dispersion
- KEK-B RF noise measurements

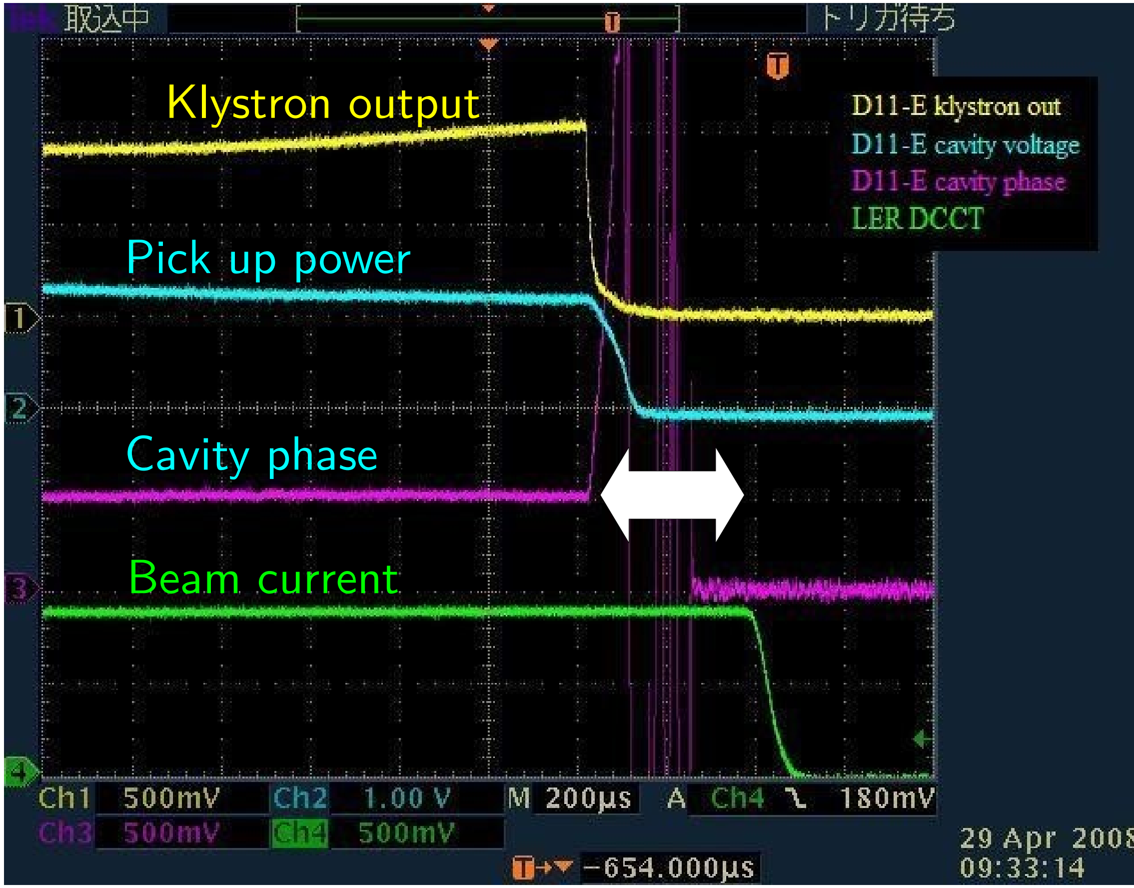
RF & Impedance

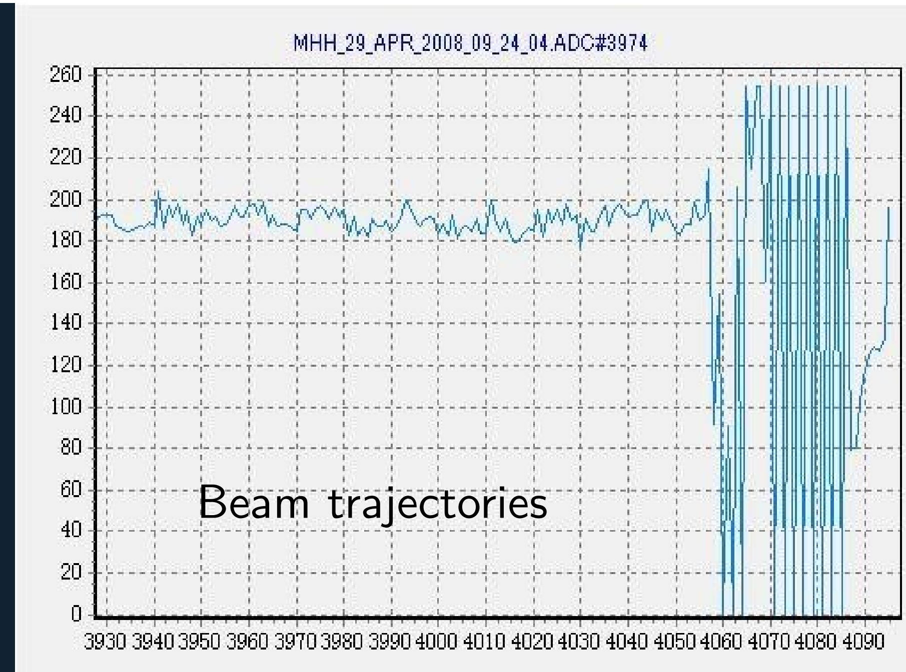
- Cavity simulations
- RF failures and system configuration
- Analytical estimates and Growth rates and damping criteria

Baseline Optics

- SLHC V3.0 + Crabs
- Physical & dynamic aperture, β^*, chromatic compensation, field non-linearity

RF Trip Example (KEKB)





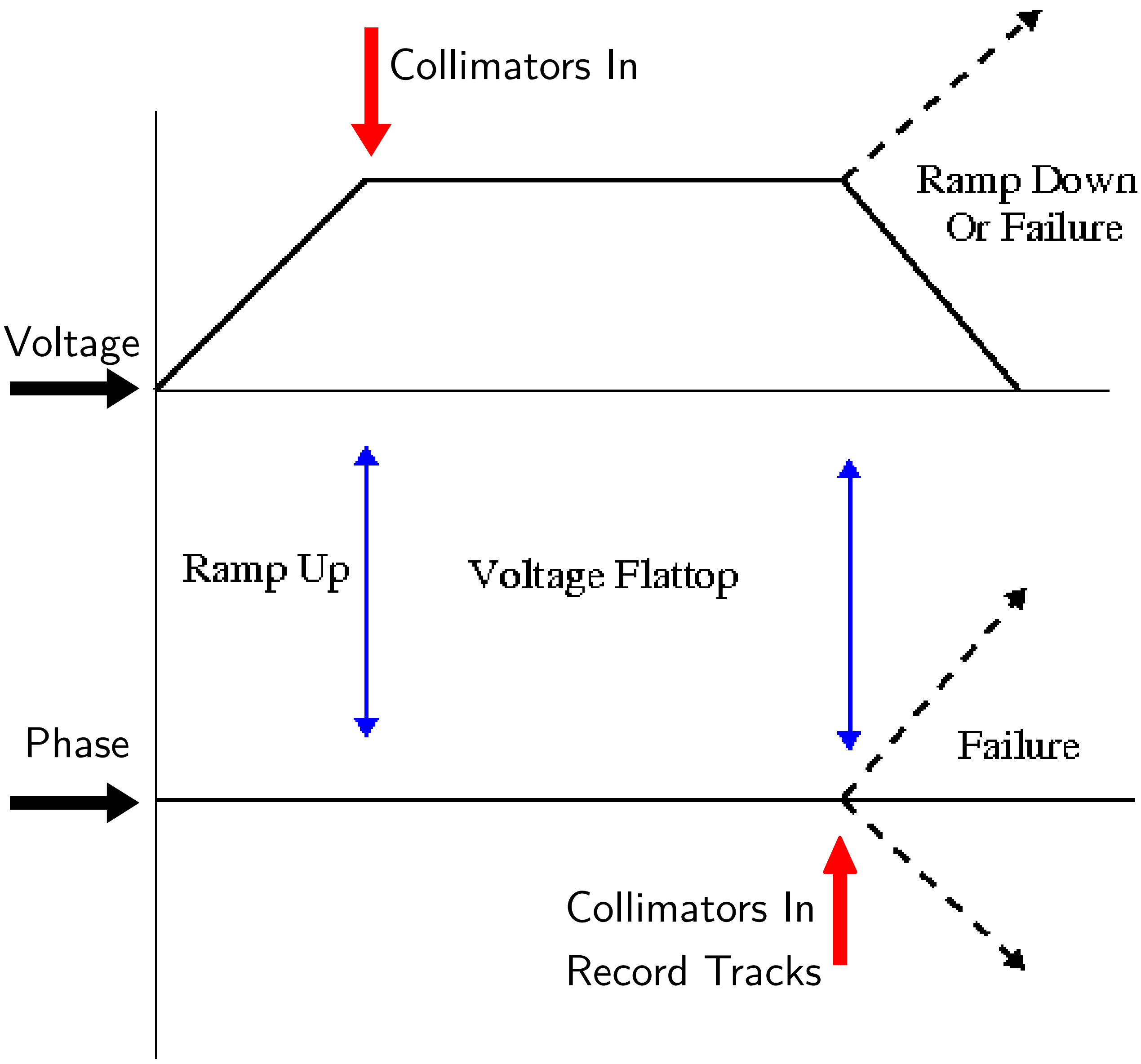
Intentional/non-intentional phase changes → corresponding orbit changes and beam losses

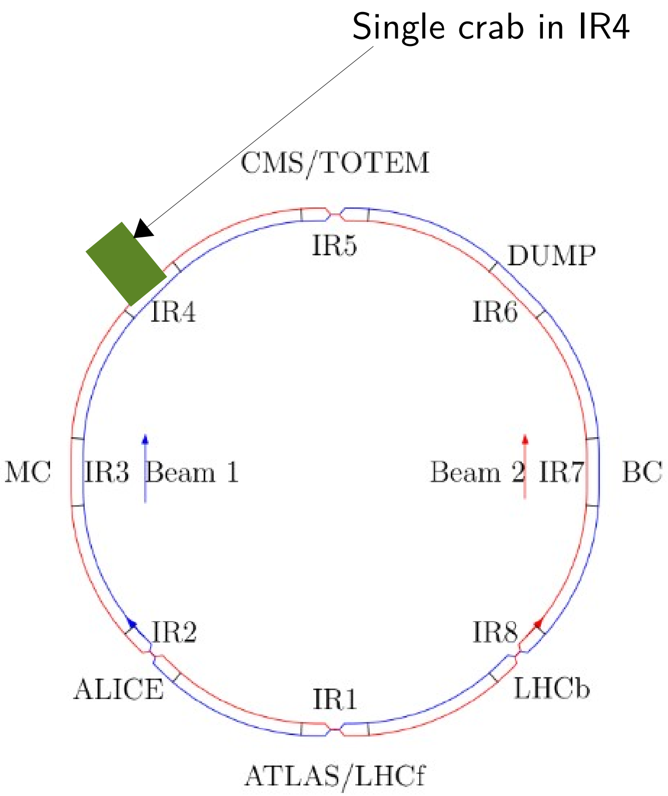
Approx time scale → 400 ms (4 turns)

Courtesy KEK-B

Simulation Setup

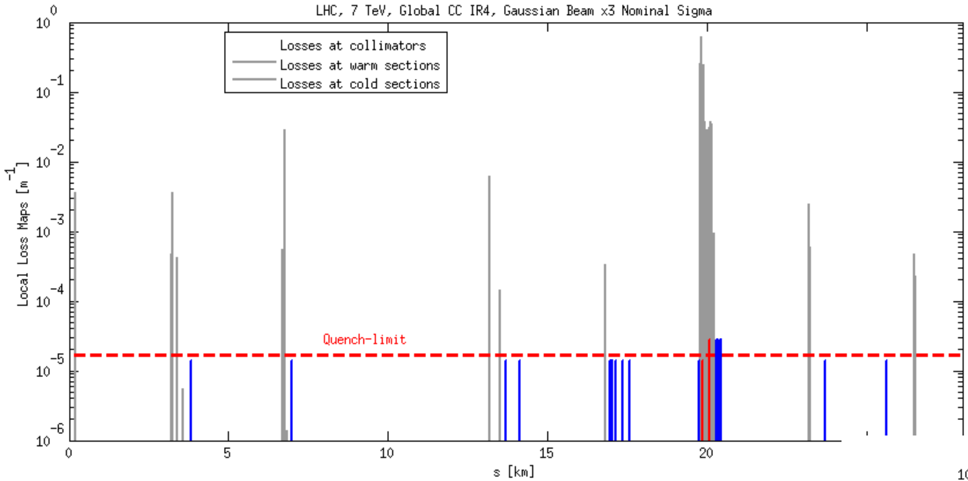
Sixtrack & MADX are now setup for abrupt failure scenarios
(J. Barranco, R. Calaga, R. Tomas)





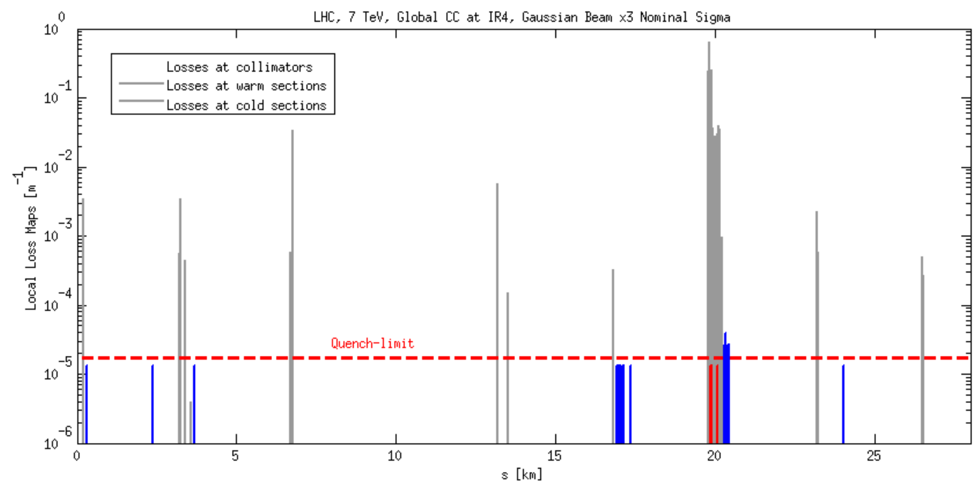
MADX has update function (more flexibility)

Loss Maps, Abrupt Phase Failure



No phase failure but with 1 global crab

3 turn phase failure with 1 global crab



	W/O Crabs	1 Global Crab, IR4
Initial Distribution	Gaussian	Gaussian
Sigma [nominal]	x1.5-3	x1.5-3
Particles lost	0.009-12.6%	0.01-13.7 %

3 Turn Phase Failure $\rightarrow 90^0$

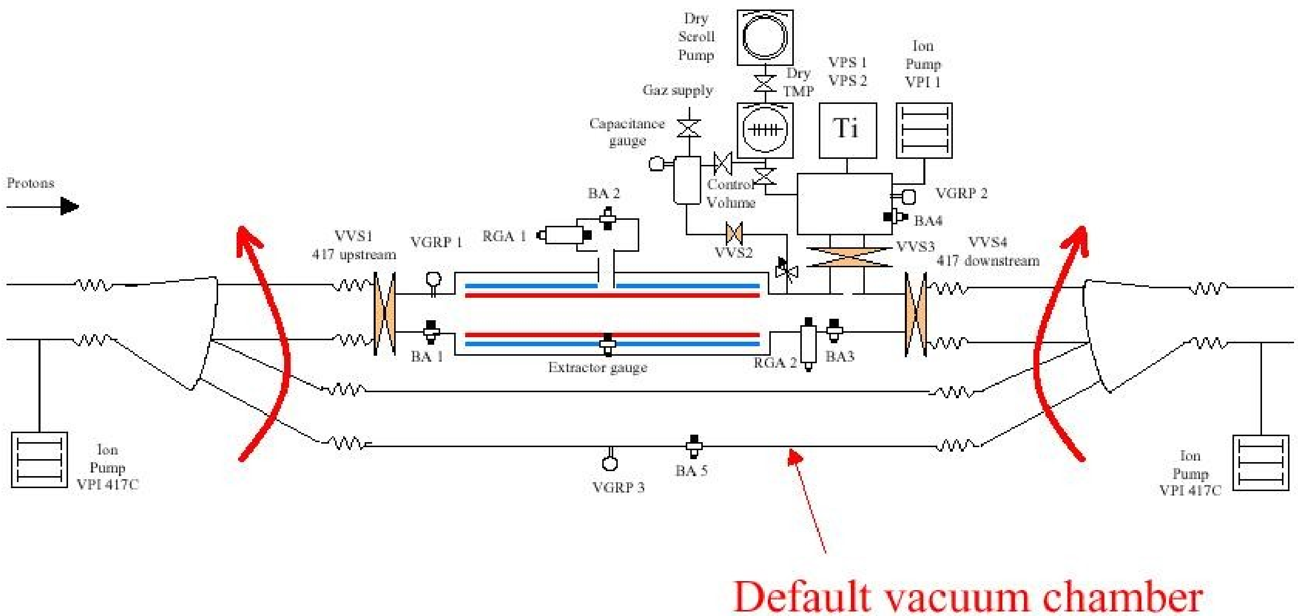
Voltage maintained constant

Beam size very large

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



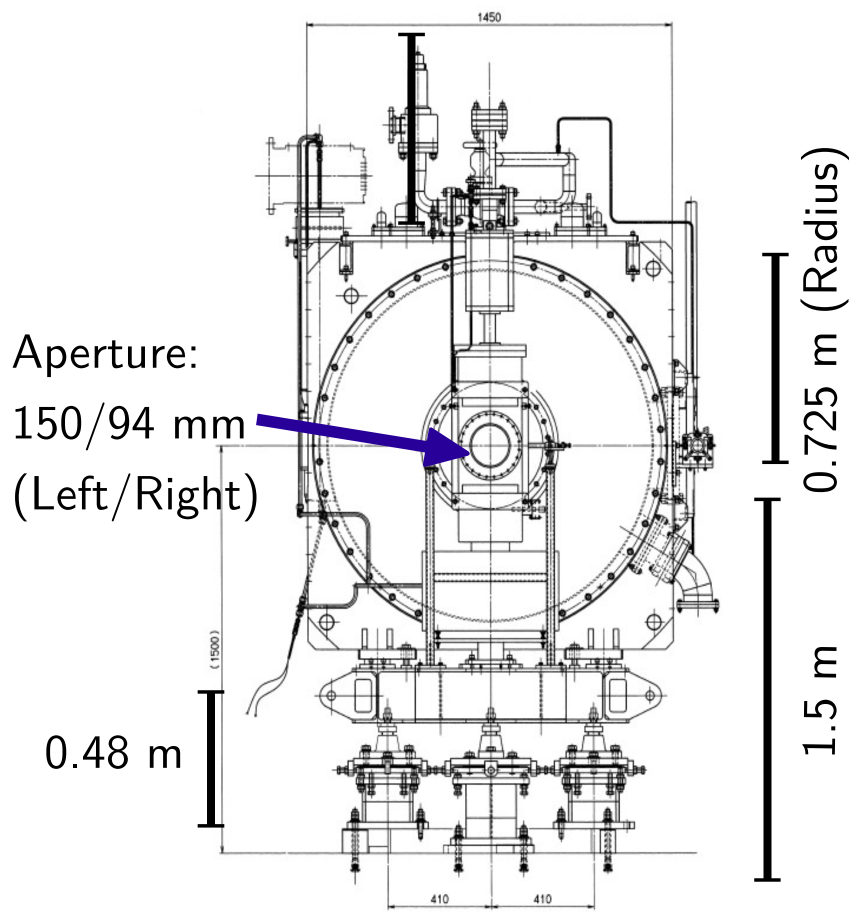
SPS beam tests, 2010 to check emittance lifetime @55/120 GeV coast with 2μm norm emittance

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..)

Details: http://emetral.web.cern.ch/emetral/CCinS/CCinS.htm

KEKB Cryostat



Weight: 5830.5 kg, Length: 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 + ancilliary 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

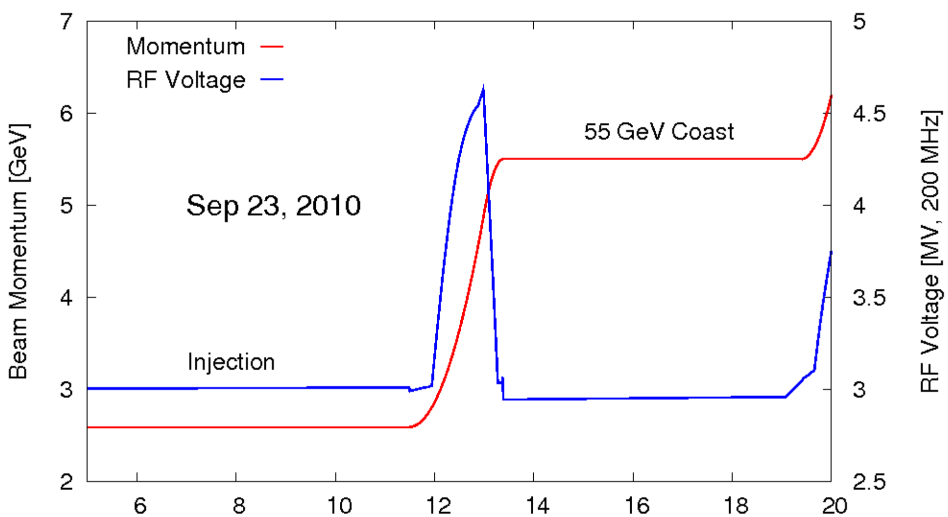
** Crab expert, K. Hosoyama, retires at end of 2010

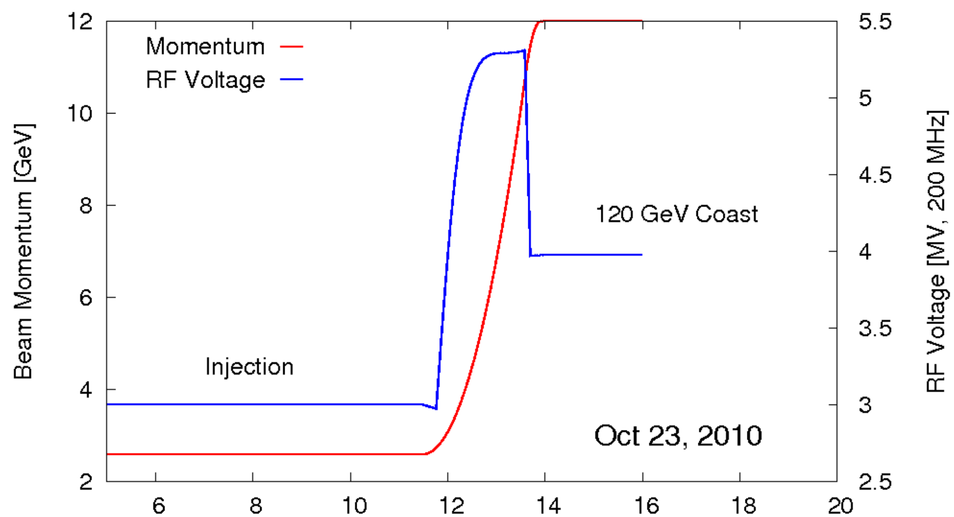
Courtesy KEK-B

Recent SPS Studies

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

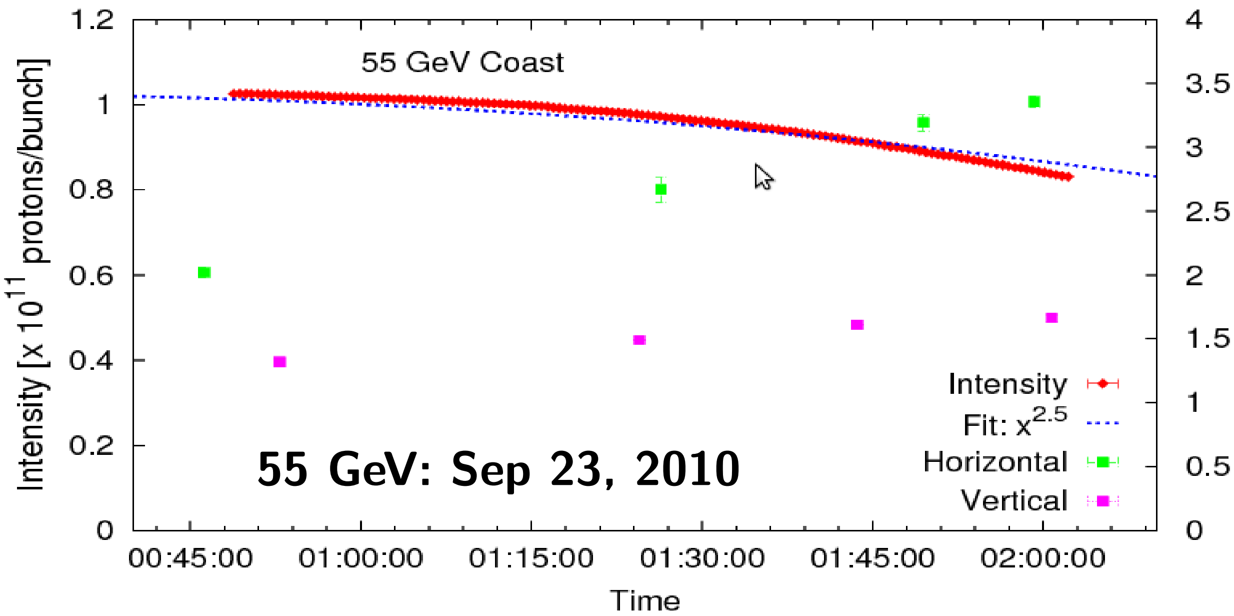
Parameter	Unit	Sep 23	Oct 20
Energy	GeV	55	120
Qx,y	-	0.13/0.18	0.13/0.18
$\xi_{x,y}$		2-3	2
Intensity	x 10^{11}	1.1	0.5 (12 bunches)
$\varepsilon_{x,y}$	µm	3.1/2.8	1.5-2.0
RF Voltage	MV	3.0	4.0 (also 2)





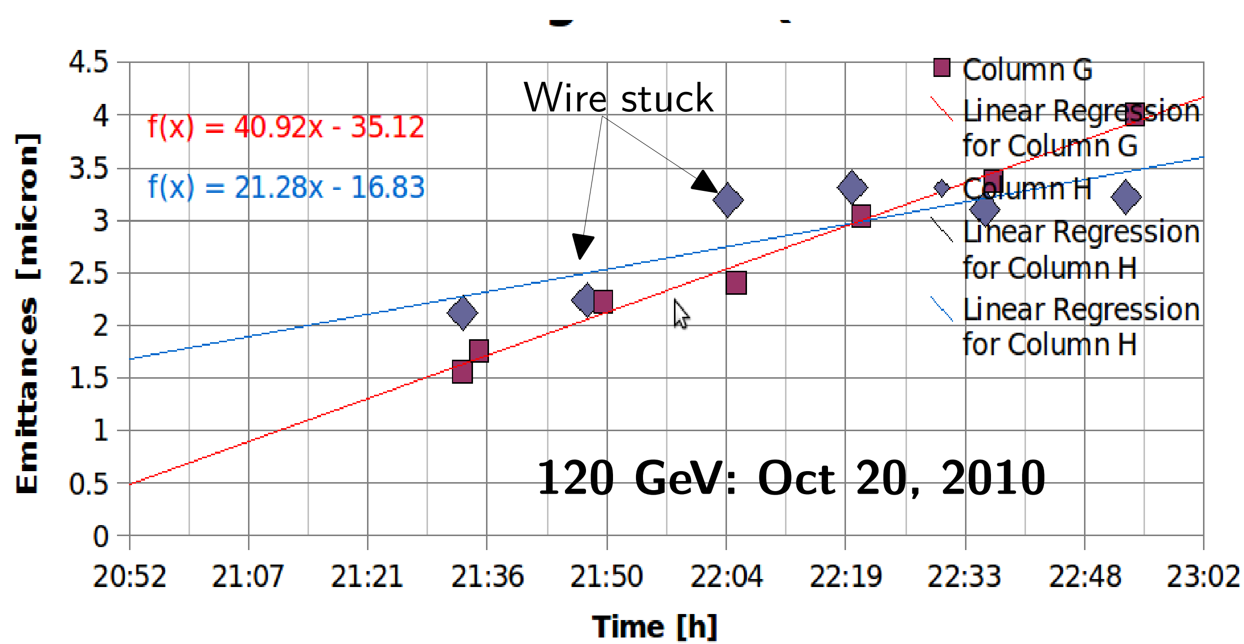
SPS Studies

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

- Crab R&D (EuCARD + LARP + KEK)
  - Advanced technology designs → waiting for prototyping
  - Advanced studies on several beam physics fronts

- Crab project under HL-LHC
  - Focus on development & construction of compact cryomodules
  - A draft report in place (schedule/resources)
  - Synchronize prototyping within the other major collaborators

- 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

LHC

LHC-CC10

Announcement of the 4^{th} 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