DOE Review, Jul 2010

Comment:

The main goal of the crab cavity activities at this time appears to be prototyping to validate the crab cavity design.

Recommendations:

1. Work with the CERN-RF Group to develop clear specifications and a realistic R&D plan with goals for the crab cavities.

2. Prepare a technical design report with clearly-defined roles, responsibilities, schedules, and costs.

3. Subject the R&D plan and goals to a peer-review in 2011 (PENDING).

4. Write and submit a proposal to DOE on crab cavities prototyping (PENDING).

LHC Crabs, Status

Rama Calaga

LARP DOE Review, June 1-2 2011

- Crab Crossing & Summary of LHC-CC10
- FY11 highlights and LARP Effort
- Budget Overview (HL-LHC) & Future

Big thanks to E. Ciapala, E. Jensen, F. Zimmermann
And all LHC-CC collaborators

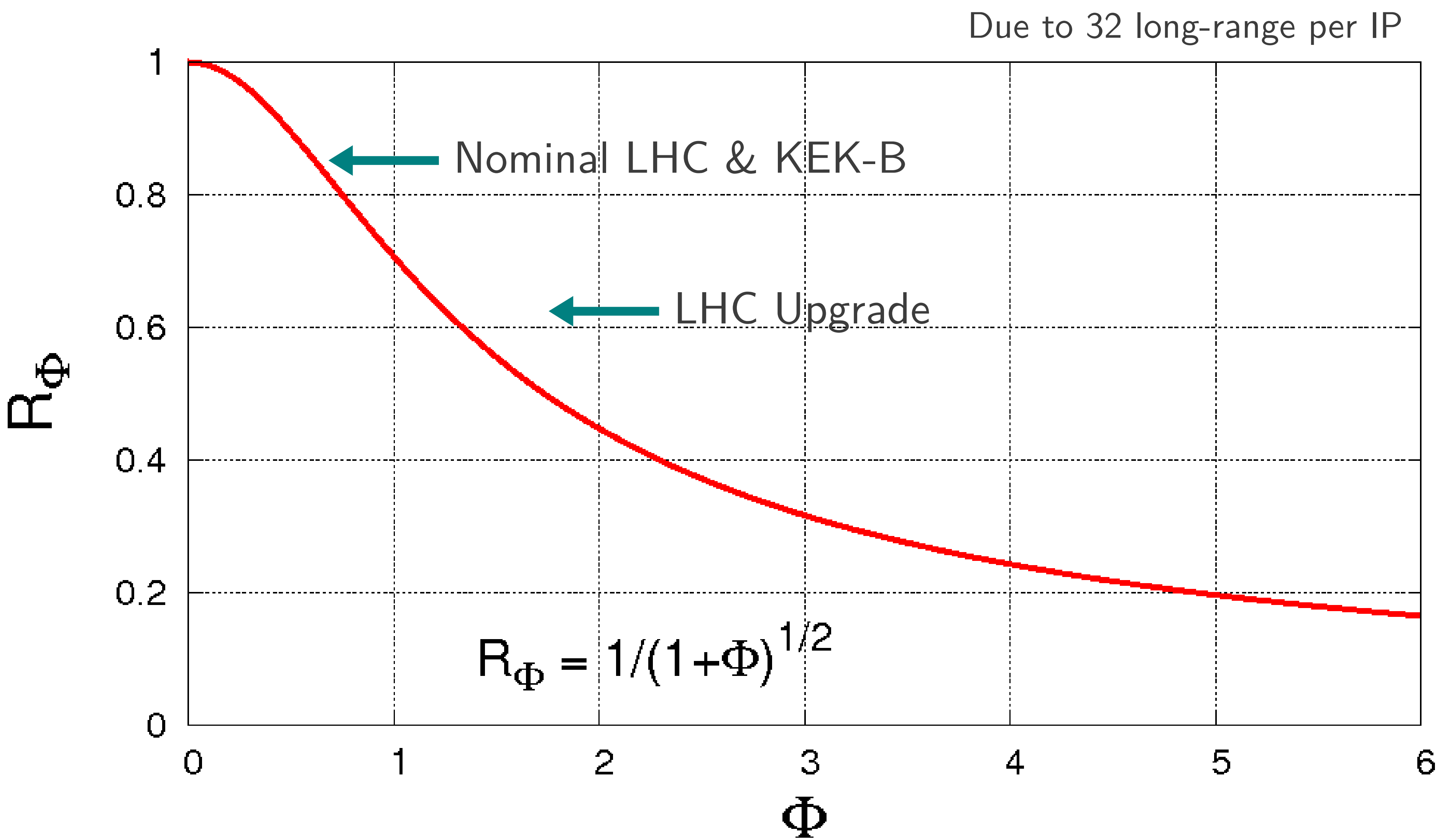
LHC: Today & Future

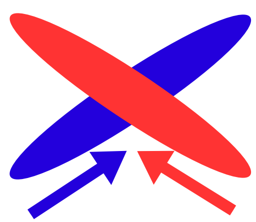
			2015	2021
		Today	Design	Upgrade
x4 →	Energy [TeV]	**3.5**	7.0	7.0
	Intensity [x 10^{11}]	**1.1-1.2**	1.15	≥ 1.7
	Emittance (μm)	**2.2-2.5**	3.75	≥ 3.75
x2 →	β* (cm)	**150**	55	25-15
x3 →	# of bunches	**1092**	2808	2808
	L_{peak} [x 10^{34}]	**0.12**	1	~8*
	L_{int} [fb^{-1}/yr]	**1-3**	67	250

*Luminosity leveling → 5 x 10^{34} [cm^{-1} s^{-1}]

Radiation damage limit ~700 fb^{-1}

Reduction Factor





Back of the envelope calculation:

$N_b = 1.7 \times 10^{11}$, $\beta^* = 0.15$ cm, Fill time = 10 hrs, TAT = 5 hrs

~20% increase in integrated luminosity (~2-3 yr of reduction to reach 3000 fb^{-1})

Therefore crab cavities are inevitable!

a. Recover geometric luminosity
b. Level luminosity w/o perturbing the machine

LHC-CC10, Summary (4^{th} Workshop)

Dec15-17, 2010

Workshop Charge:

1. Can compact cavities for the LHC be realized and made robust with the complex damping schemes ?
   3-4 candidates, dual crossing (HV) solution desired. Prototyping essential immediately

2. Are crab cavities compatible with LHC machine protection, or can they be made to be so ?
   More analysis with realistic cavity failures, lattices, upgraded collimation required

3. Should a KEKB crab cavity be installed in the SPS for test purposes ?
   NO (2.5 MCHF, 8 FTEs)

LHC-CC10, Summary

Key Action Items:

1. **Detailed roadmap & cavity specifications (LMC, summer 2011)**
   LARP involvement in simulations for all designs is highly desirable

2. **Prototyping should start soon to meet 2013 & 2015 deadline for technology choice**
   Mini-Engineering workshop to brainstorm mechanical design & fabrication

3. **Common platform development**
   Couplers, cryostats, instrumentation etc..

4. **Source of the SPS emittance growth should be identified as it will be the key test bench**
   2011 Experiments (@120 GeV finished, @270 GeV -Jun 8)
   Earliest cavity-beam testing foreseen in 2016

DOE-R: Recommendation 1

Develop clear specifications along with CERN

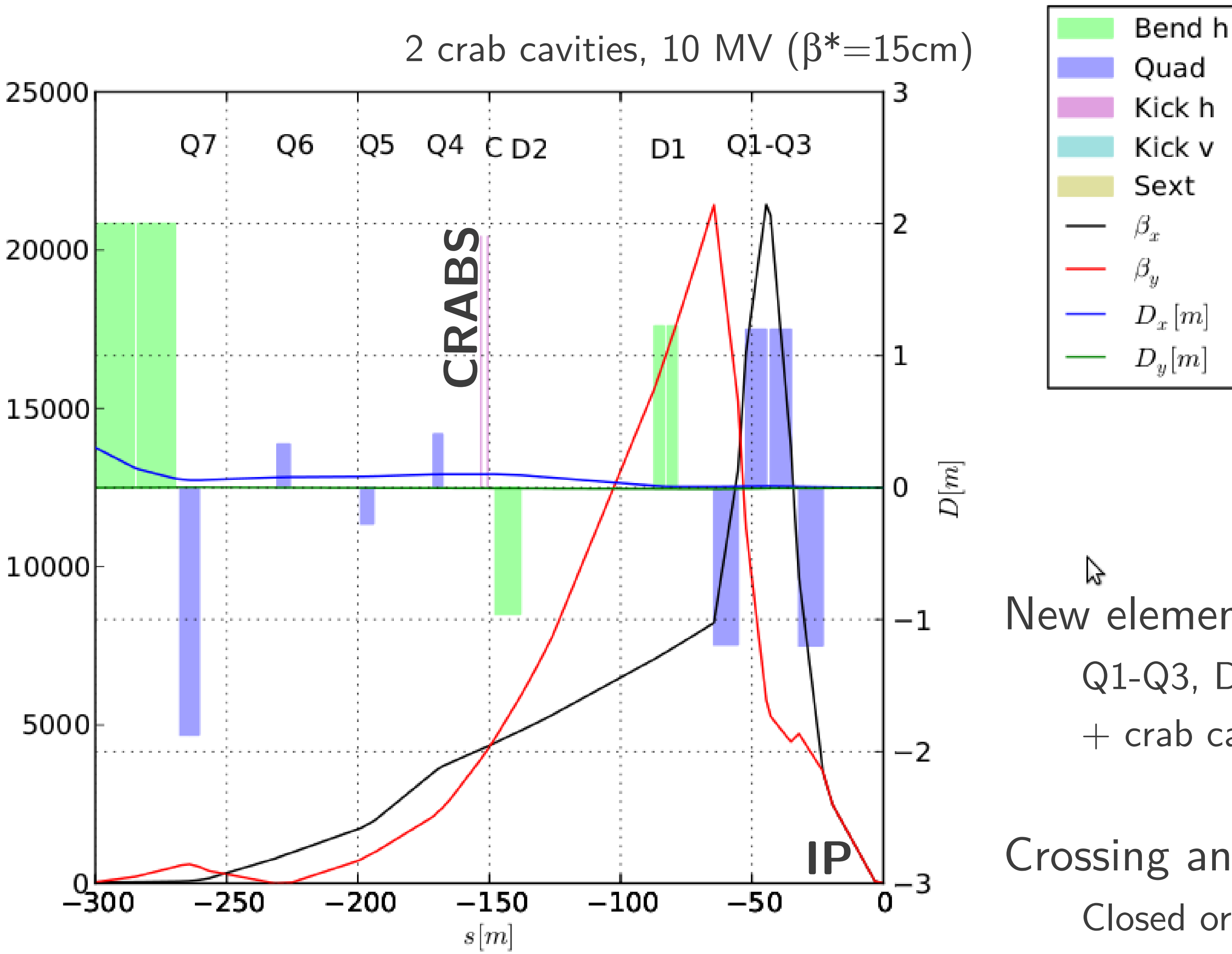
a. Optics & layout

b. Cavity-cryomodule

c. Machine protection tolerances

Draft Optics (SLHC v3)

S. Fartoukh, R. deMaria



New elements (SLHC v3)

- Q1-Q3, D1, TAN, D2, Q4-Q5
- + crab cavities (~10 m, 10 MV)

Crossing angle change

- Closed orbit excursion (~3 mm)
- Remote cavity alignment

What Are The Specs ?

	Baseline	Unit	Value	
RF	Frequency	MHz	400	
	Deflecting Voltage	MV	5 (/Cavity)	
	Peak E-field	MV/m	< 45	
	Peak B-field	mT	< 80 mT	
Geometrical	Aperture (radius)	mm	42	
	Cav Outer Radius	mm	< 150	
	Cavity length	m	< 1m	
	HV crossing	-	Desirable	
Optics	β* (IR1/IR5)	cm	15-25	
	β crab	km	~ 5	
	Non-linear harmonics	units	?	→ M. Giovannozzi et al.
	Impedance Budget	Long, Trans	60kΩ, 1MΩ/m	→ E. Metral et al.

First order parameters available

Detailed specs will evolve with LHC & simulations

Machine Protection

Requirement

Stay above the 3-turn beam-abort threshold

Tracking studies

Losses due 1-turn voltage/phase failure → non-issue for nominal (PAC11)

→ Additional checks needed for different distributions

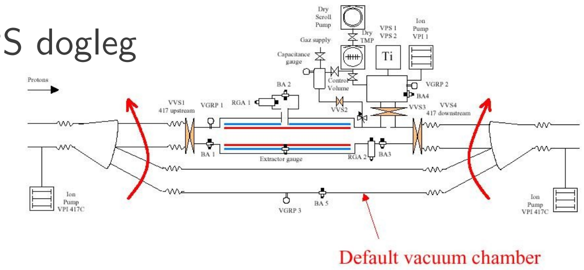
Upgrade optics (SLHC v3) under study

→ Realistic failures + upgrade collimation vital

Small team at CERN (with LARP folks) are studying this topic

Some Other Highlights

Compact cavities to be tested in SPS dogleg



SPS studies

Emittance growth studies (2010 & 11) to determine appropriate energy

→ 55 GeV natural emittance growth too large

→ 120 GeV growth also not small (is there an external source)

Simulations are being performed to understand source (H. -J. Kim)

	Unit	Sep 2010	Oct 2010	May 2011
Energy	GeV	55	120	120
Qx,y	-	0.13/0.18	0.13/0.18	Several tunes
ξx,y		2-3	2	0.5
Intensity	x 10^{11}	1.1	0.5 (12 bunches)	0.2
$\varepsilon_{x,y}$	μm	3.1/2.8	1.5-2.0	2.5
RF Voltage	MV	3.0	4.0 (also 2)	4.6 - 6.5

Strong LARP contribution

Beam-Beam Studies

Requirement

Tolerances on crab cavity RF noise for low emittance growth

Tracking studies

Some studies (and KEK experiments) already performed in the past

$\rightarrow$ 50% of a postdoc at LBL to bench LHC observations now

$\rightarrow$ And perform noise studies for the upgrade

Additional activities

$\rightarrow$ Partial Toohig fellow to study synchro-betatron resonances

$\rightarrow$ KEK support to be discussed

DOE-R: Recommendation 2

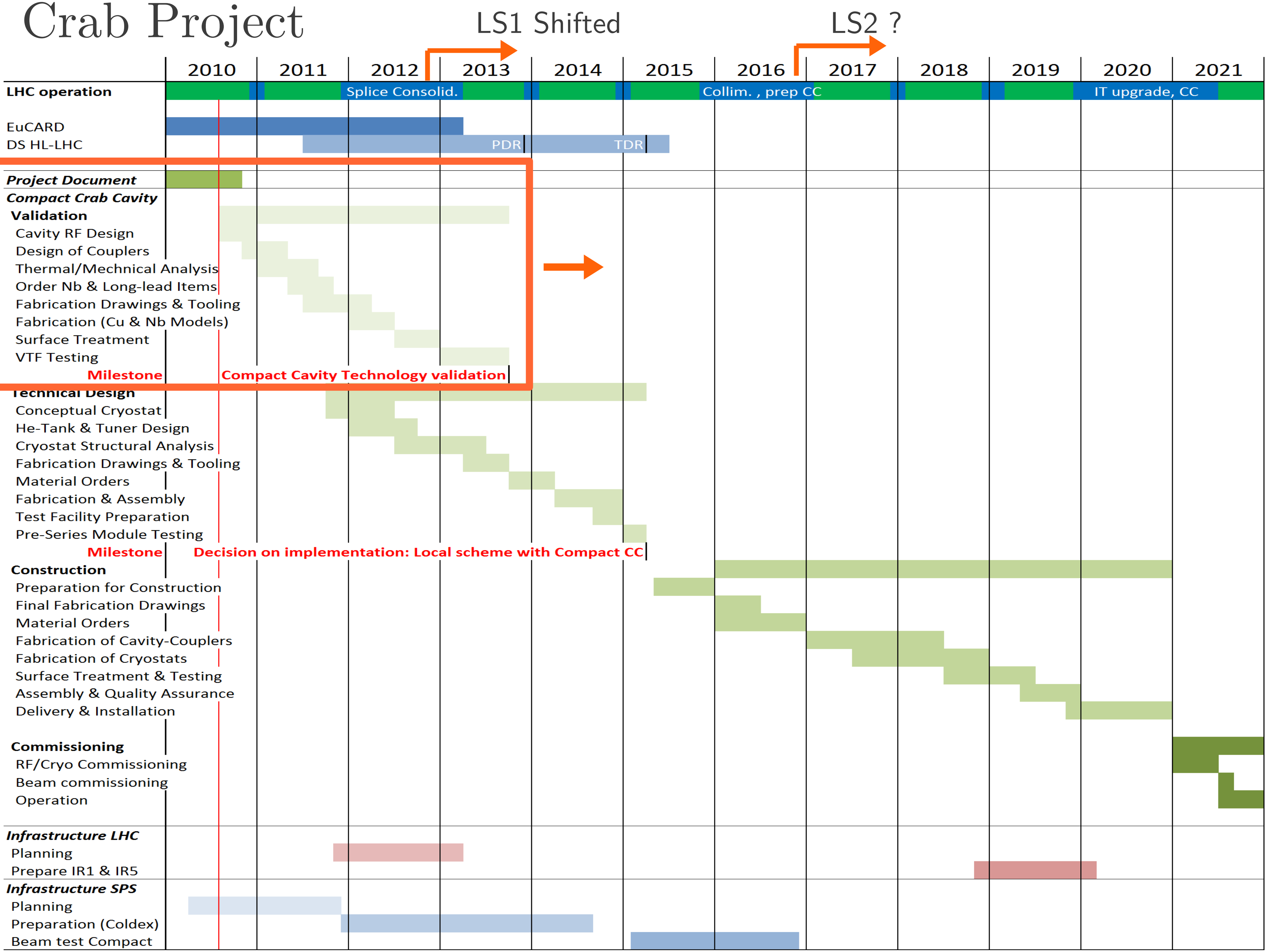
Technical design report (Roles, responsibilities, cost & schedule)

a. Overall project scope and timeline

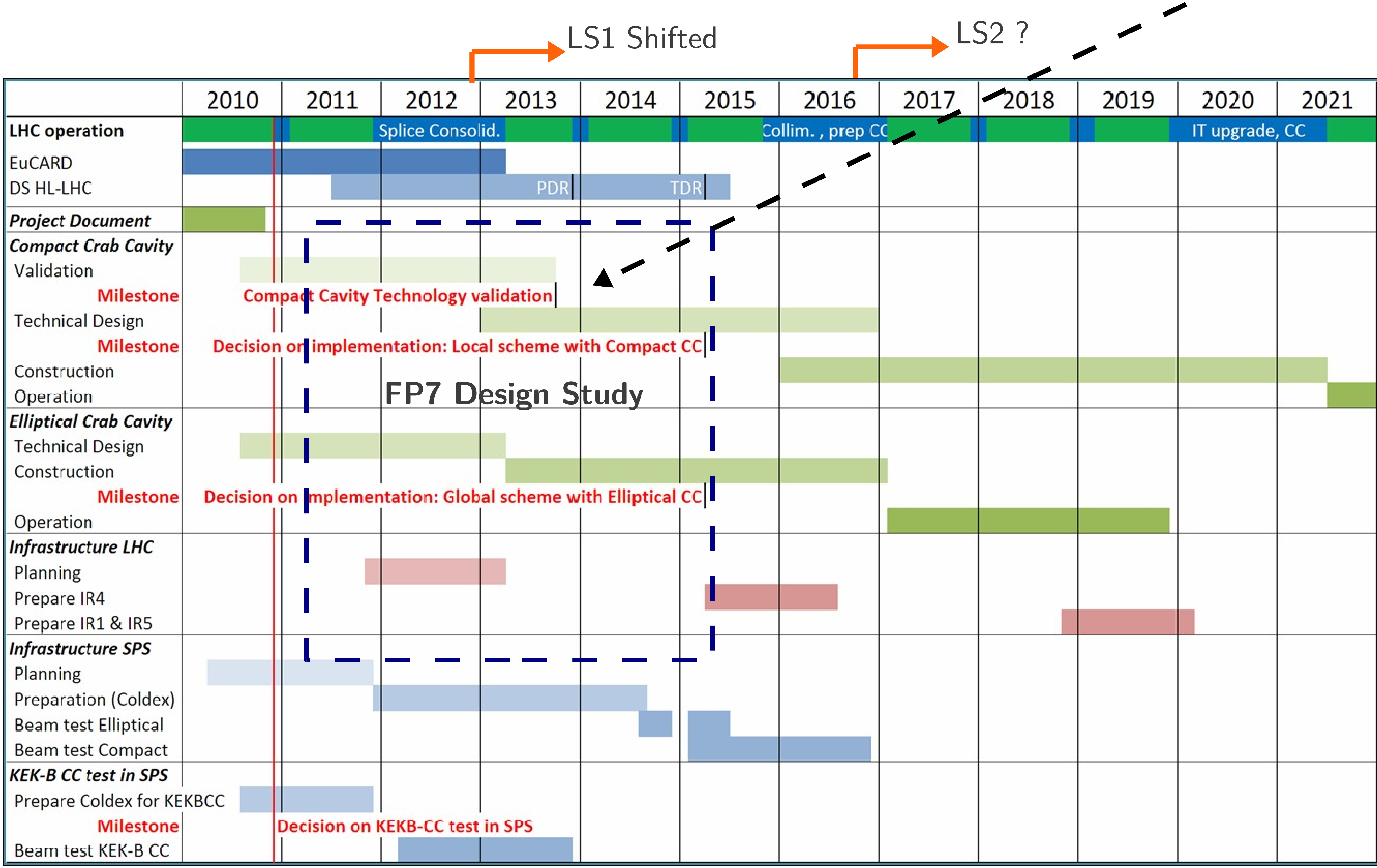
b. Cavity design & prototype(s)

c. Production prototype (test in SPS)

Crab Project



Crabs: Design Study & HL-LHC



Budget Overview (inside HL-LHC)

Material Budget

MCHF	2011	2012	2013	2014	2015	2016	2017-20
R&D (3-4 cavities)	3.55	5.6	3.4	2.35	3.3	1.15	0.1
Cavity Construction						3.5	17.5
Cryostats						4.0	30
RF Systems						1.0	6.5
LLRF & Controls						0.3	5

Total: 87.25 MCHF

Present Funding

	Year	$M	Usage
US-LARP	2007-11	1.2	Approx 2 FTEs + 1 postdoc + 2 students
US-SBIR/STTR	2010-13	1.25	2 compact mechanical designs + 1 prototype
FP7 DS	2011-14	(6.25)*	Compact design + prototyping

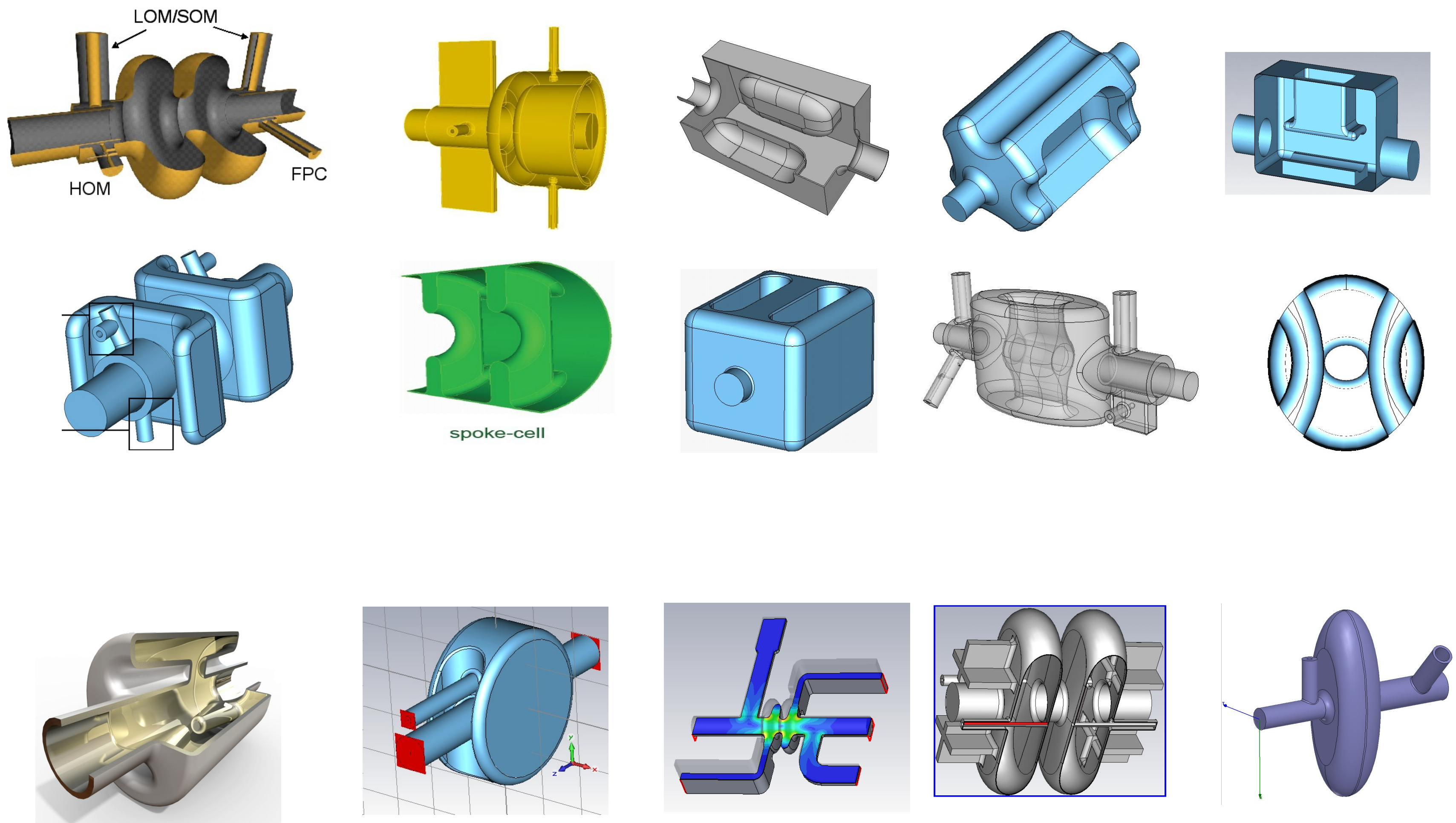
US-LARP expects to fund ~$0.42 M in FY12†

*Expected funding

†If funding stays flat

LARP & Worldwide Effort, Cavities

2008-11

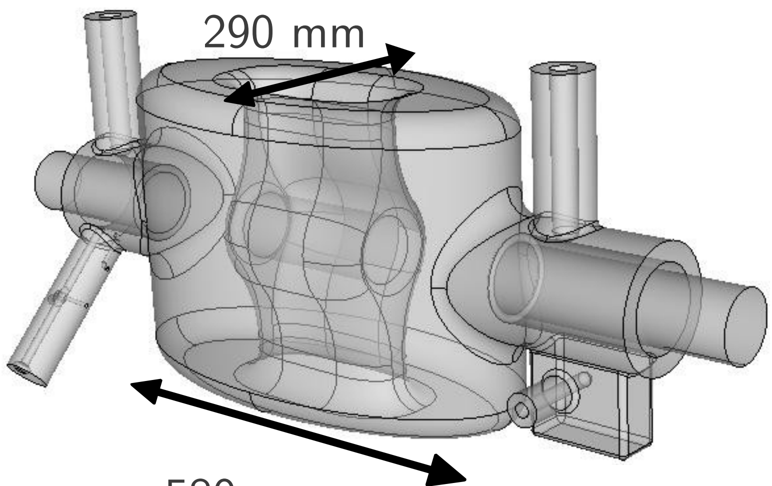


Exciting & rapid development of deflecting cavities

(BNL, CERN, CI-DL, FNAL, KEK, ODU/JLAB, SLAC)

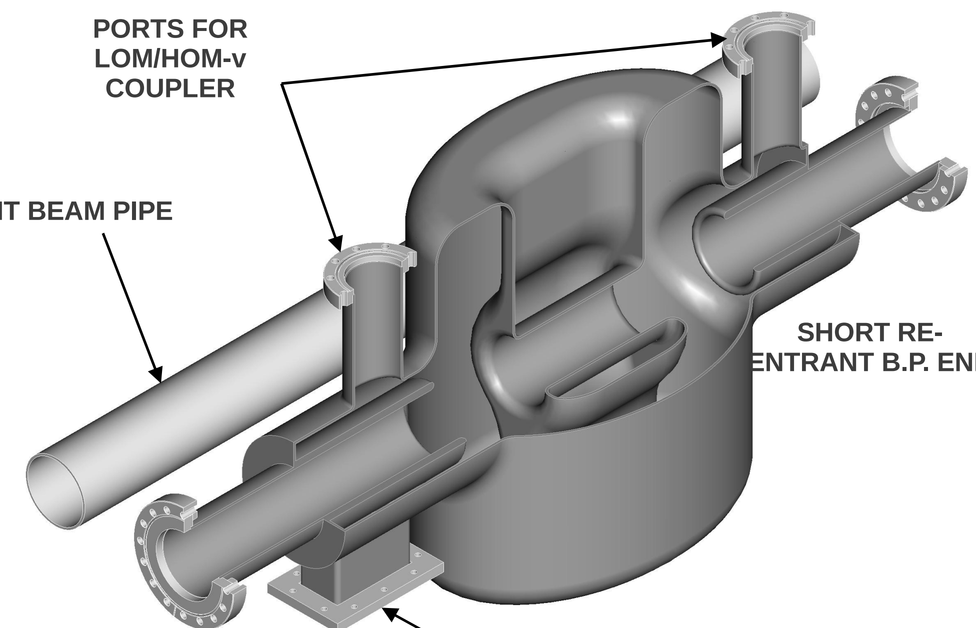
SLAC-LARP Design

Zenghai Li et al.



RF design: supported by LARP

Mechanical design: supported by Phase I SBIR



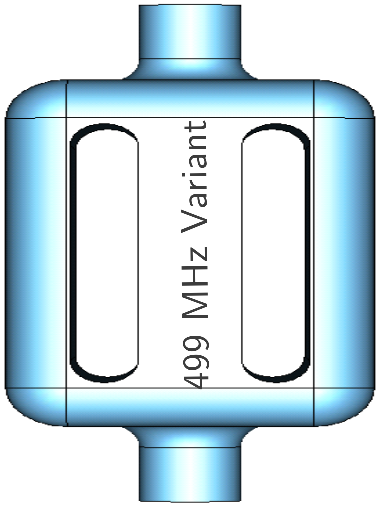
Details at:

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

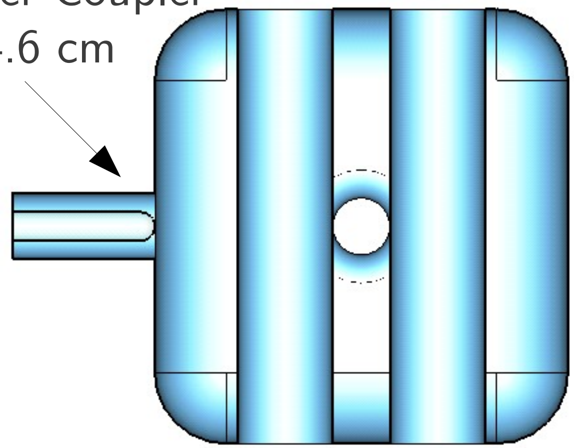
http://indico.cern.ch/getFile.py/access?contribId=17&sessionId=9&resId=0&materialId=slides&confId=83532

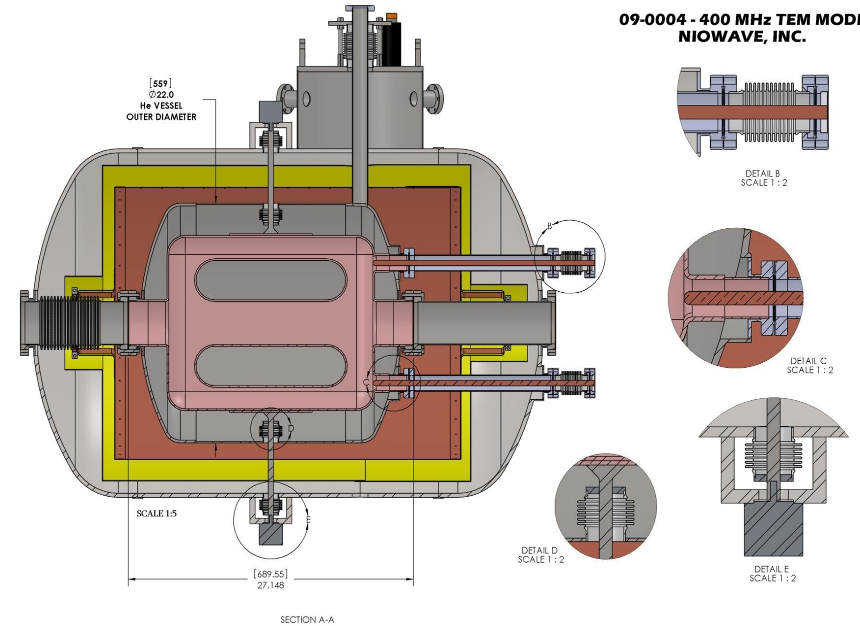
JLAB-ODU Design

Jean Delayen et al.



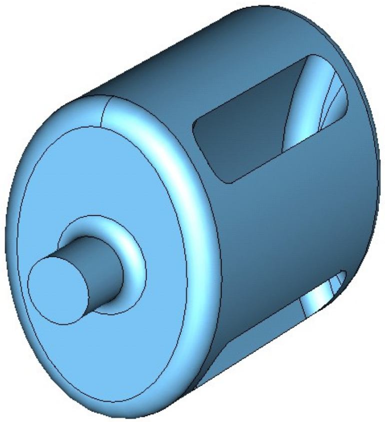
Power Coupler
4.6 cm





Niowave-STTR, Phase I

Moving Towards
Cylindrical shape



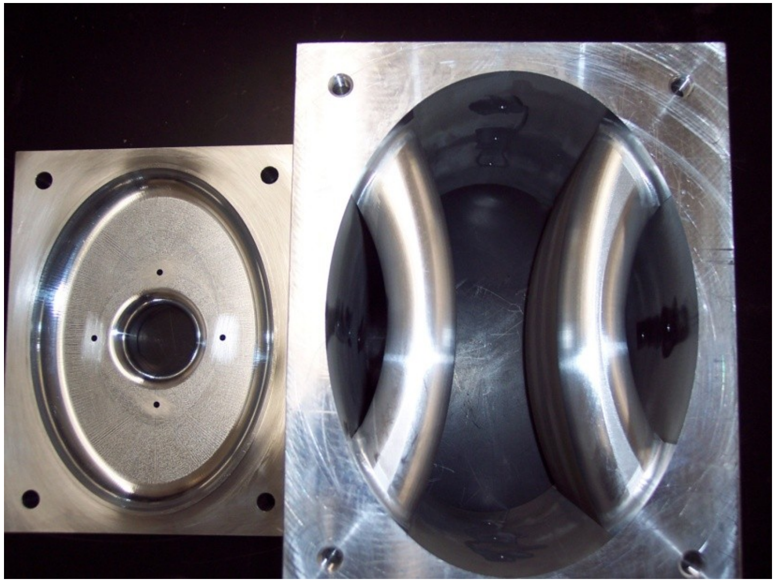
Phase II approved
For building cavity prototype
(ODU-Niowave)

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

ODU-JLAB Design, Contd.

Jean Delayen et al.



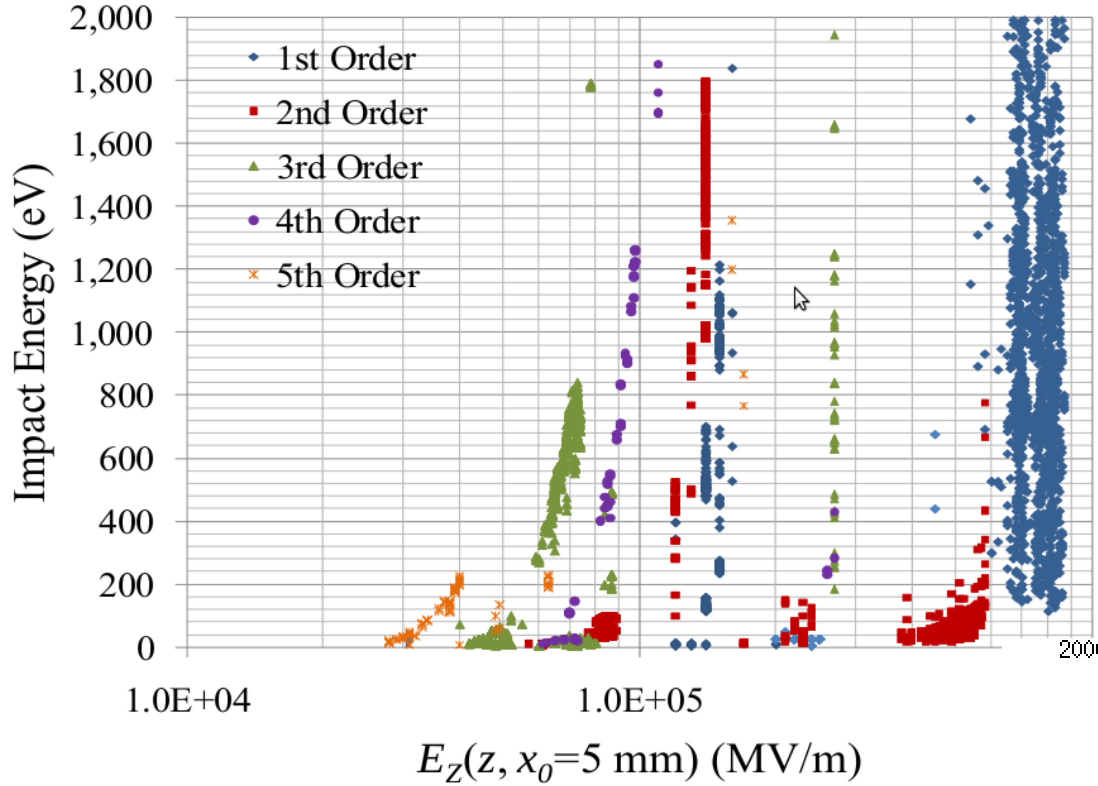
RF design: ODU-JLAB (partially by LARP)

Mechanical design: supported by Phase I STTR
Fabrication: supported by Phase II STTR

RF measurements on 800 MHz Al-model show precise frequency measurements for HOMs.

Nb prototype will most likely be circular cross section (RF & mechanical advantages)

Multipacting Analysis



Parallel bar cavity

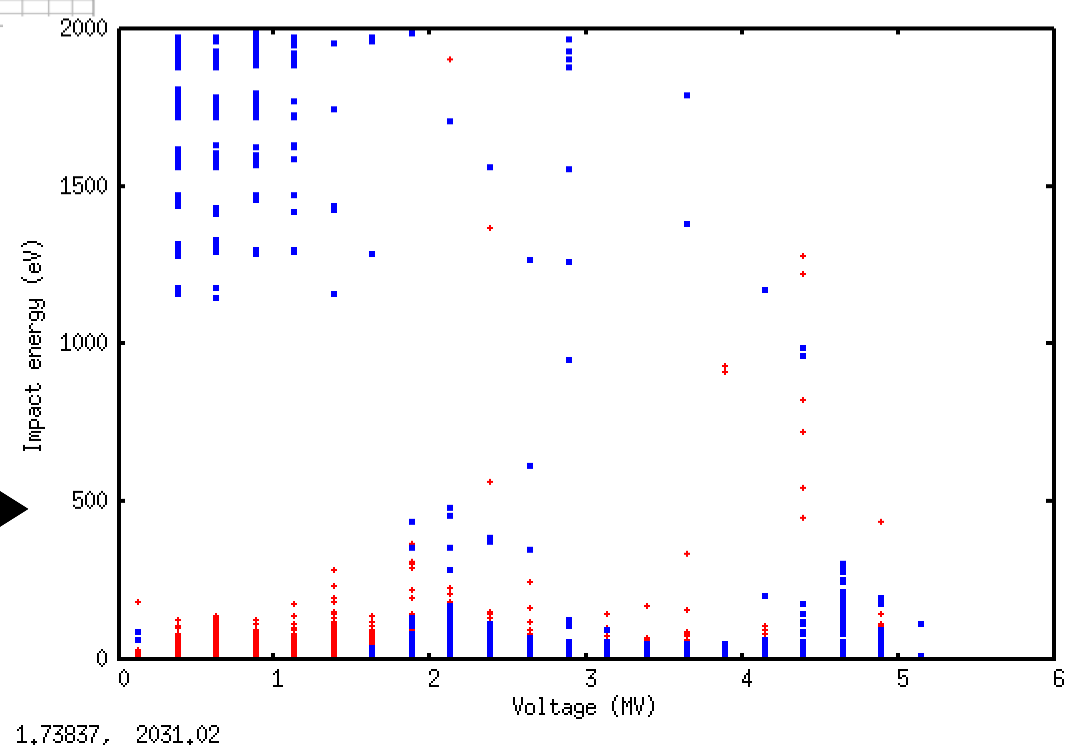
Low energy: higher order

High gradient: low order & strong

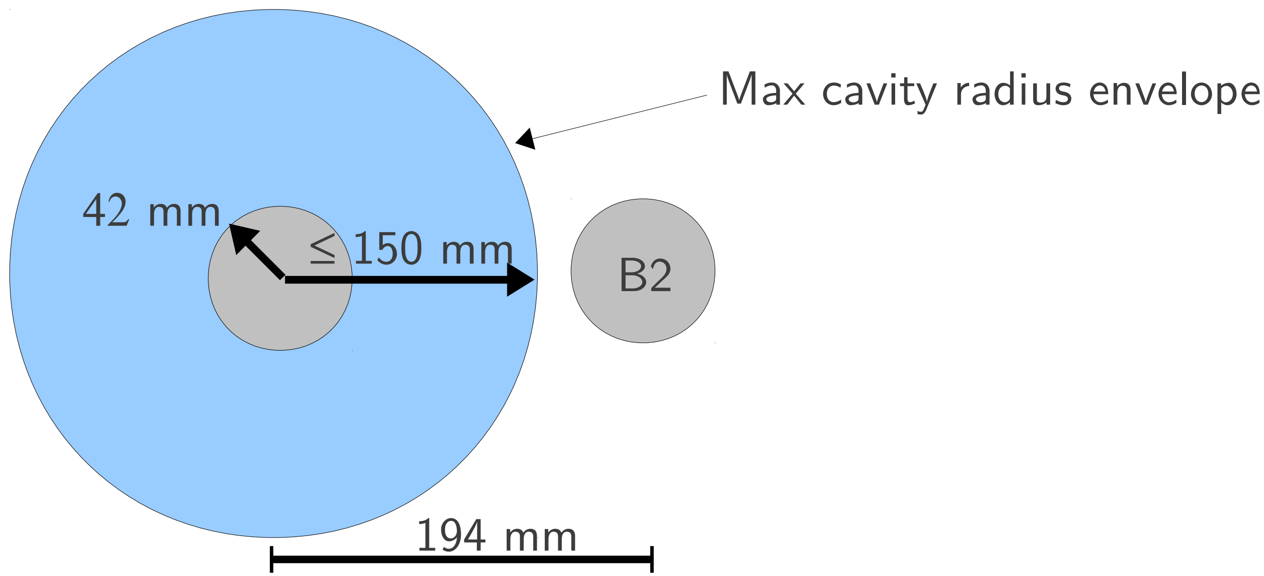
½-Wave Resonator

Low energy: higher order

High gradient: low order & strong



Reminder: Physical Constraint



Both cavities fit in horizontal crossing (nominal configuration)

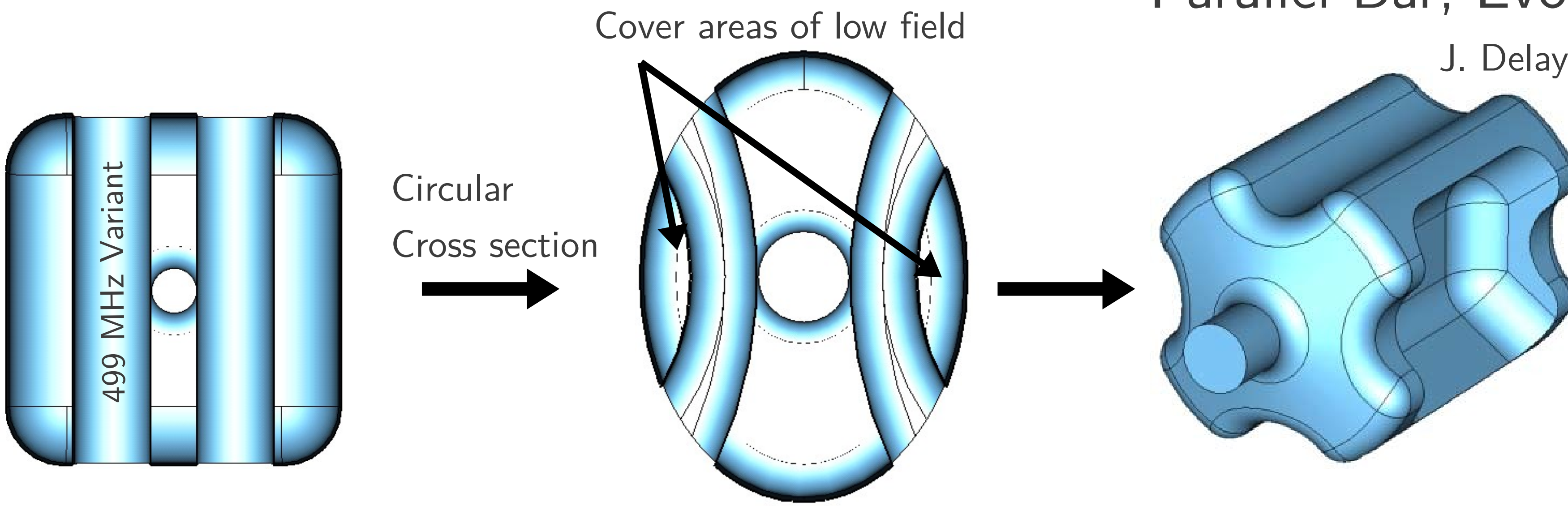
Only works for CMS for the moment

After **LHC-CC10**, design effort towards dual crossing (HV)

After LHC-CC10

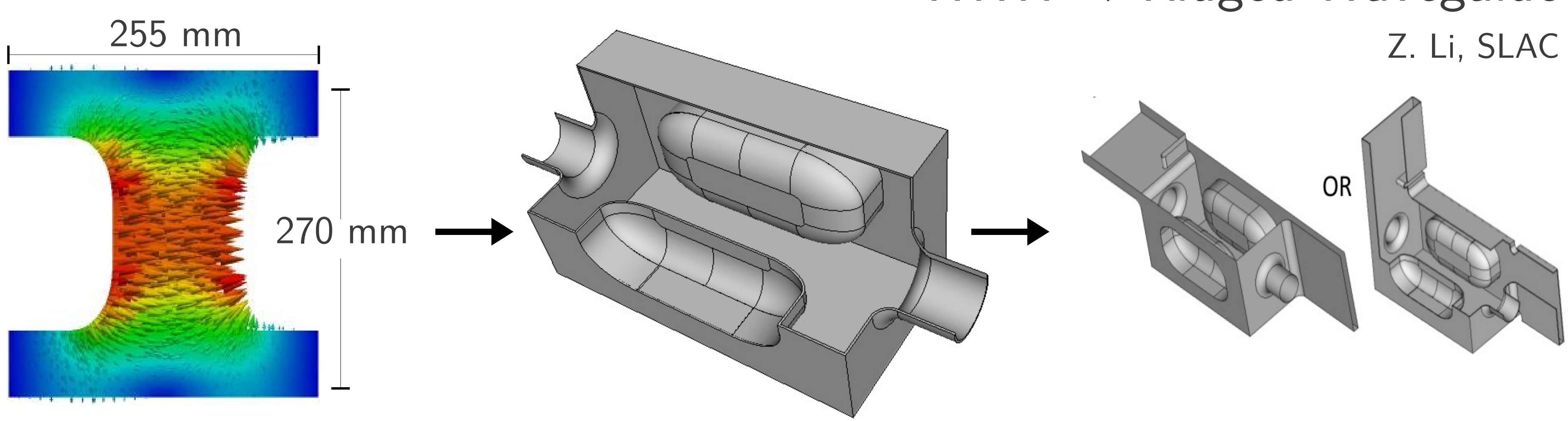
Parallel Bar, Evolution

J. Delayen, ODU



HWR → Ridged Waveguide

Z. Li, SLAC



Rapid Convergence

Converge to similar cavity design from very different concepts

$\longrightarrow$ cavity geometry simpler

Circular cross section more stable for "long" cavity (J. Delayen)

Both experts to merge forces to work on common design

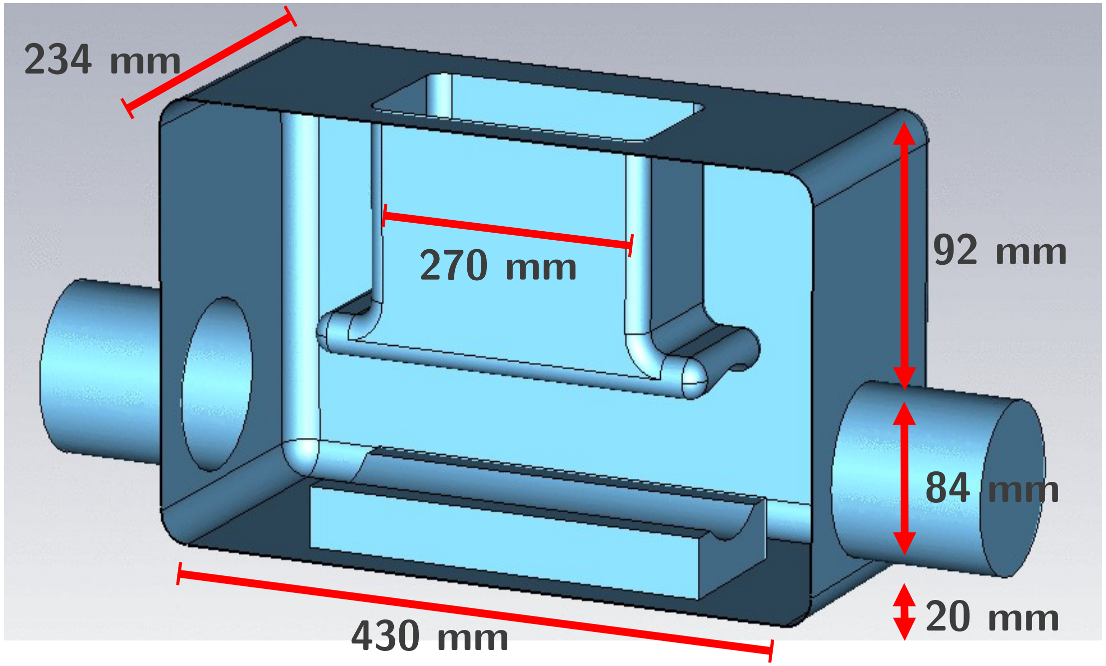
Exploit the powerful SLAC computing resources (workshop Sep10-14)

October 2011 Crab-Meeting under preparation, FNAL

(Engineering and fabrication issues of various designs)

¼ Wave (First Draft)

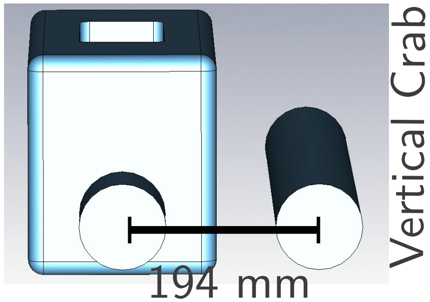
Ben-Zvi/Calaga



	Unoptimized
Frequency	400 MHz
Tran. Volt	2.5 MV
Epk	75 MV/m
Bpk	111 mT
Eacc	0.6 MV

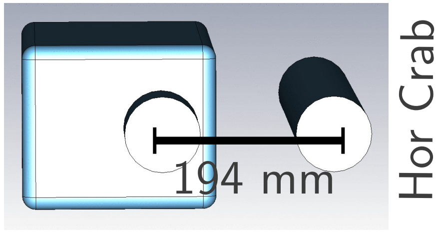
Ultra-compact in both transverse dimensions

- Optimization for surface fields (x2-3 improvement needed)
- Very few HOMs spaced (700 MHz and after)



Additional longitudinal voltage

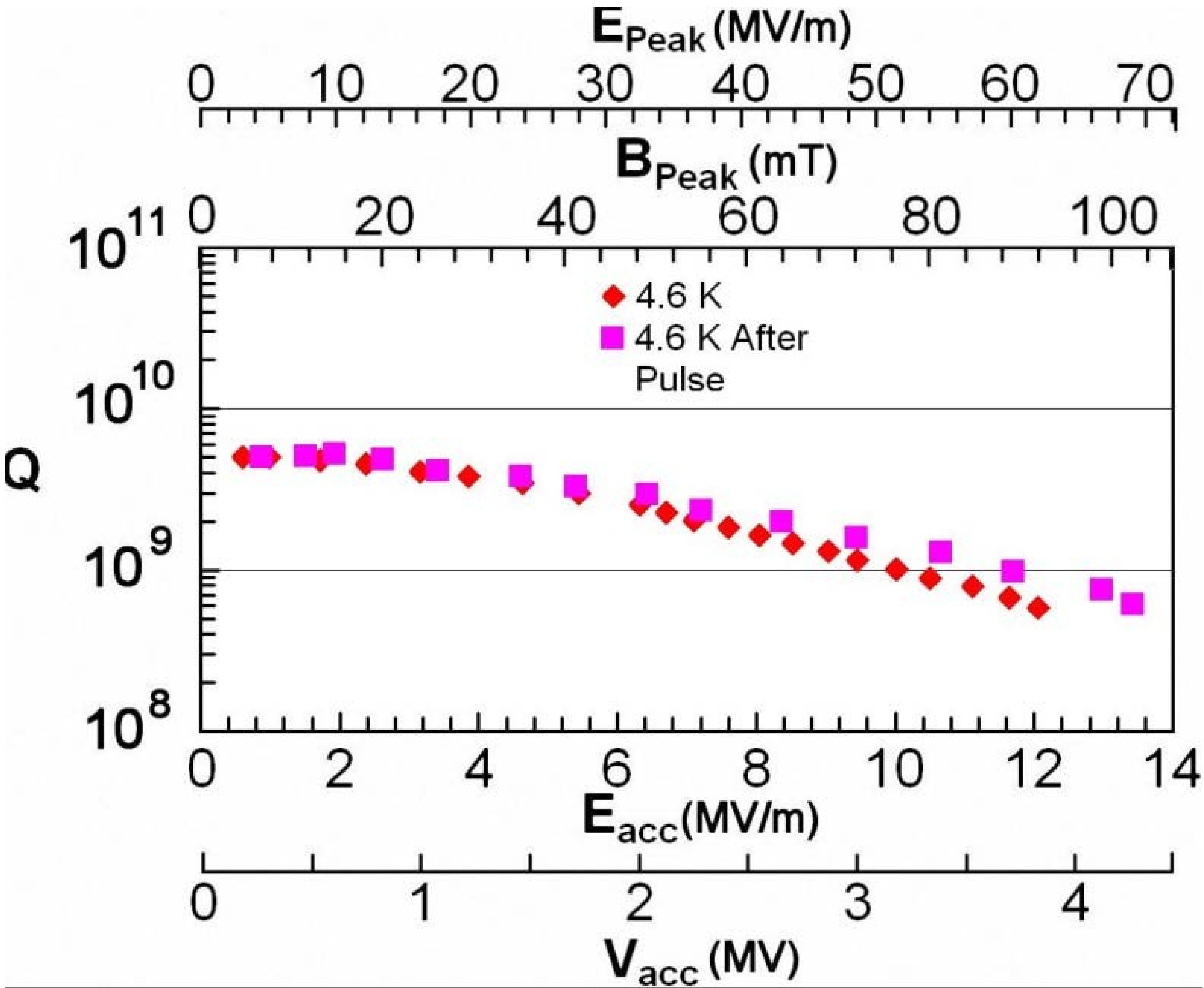
- Modify the inner conductor ends to suppress
- Two cavities flipped 180 degrees transversely to cancel

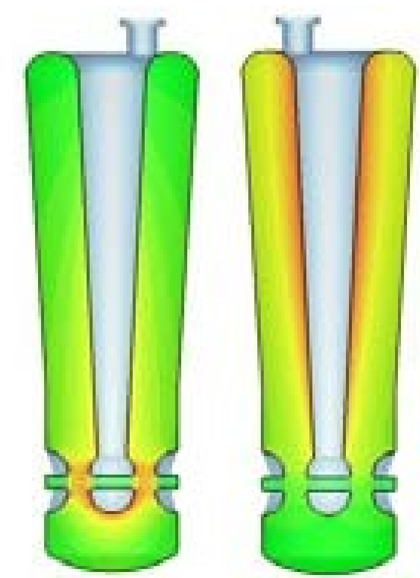


Experience with Complex Shapes

Argonne: 72 MHz

¼ wave @4.6 K





a.

Recommendation 2: Summary

Draft "CDR" available:

http://indico.cern.ch/getFile.py/access?contribId=6&resId=0&materialId=1&confId=103203

Overall effort/timeline/schedule to be presented at LMC (2011)

Official CDR → 2014 (to coincide with HiLumi DS – CDR)

→ Prototype tests leading toward cryomodule

Official TDR → 2015/16 (also to coincide with HiLumi DS – TDR)

→ optimistically a production prototype

Recommendations 3 & 4

Peer review the R&D plan and goals

a. Have to coordinate with HL-LHC WP4 & CERN

Proposal to DOE for cryomodule construction

a. Overall project plan **draft** available

b. CERN letter of intent sent to DOE

c. Technology demonstration vital for before construction proposal

US Effort, Future Prospects

Near Term (2012-13):

- US-LARP
  - Continue current effort (with HL-LHC) $\rightarrow \sim$ \$0.42 M/yr
  - Potential increase (?) $\rightarrow$ prototype a cavity (+ \$0.78 M/yr)
- Additional support (+1 postdoc)
  - ODU-SLAC common design (+SBIR/STTR)
  - Foresee ¼-wave development

Long term (2013-2021):

- Continue US-LARP effort, (prototyping cavity $\rightarrow$ cryomodule)
- Transfer effort into a US-crab project (2015 TDR)

Your Feedback

- Is LARP involvement adequate ?
  - Add more support for cavity R&D and simulation effort
- Should LARP venture into prototyping ?
  - OR just continue to support modeling and simulations
- What are we missing to reach milestones 1 & 2 ?

LHC