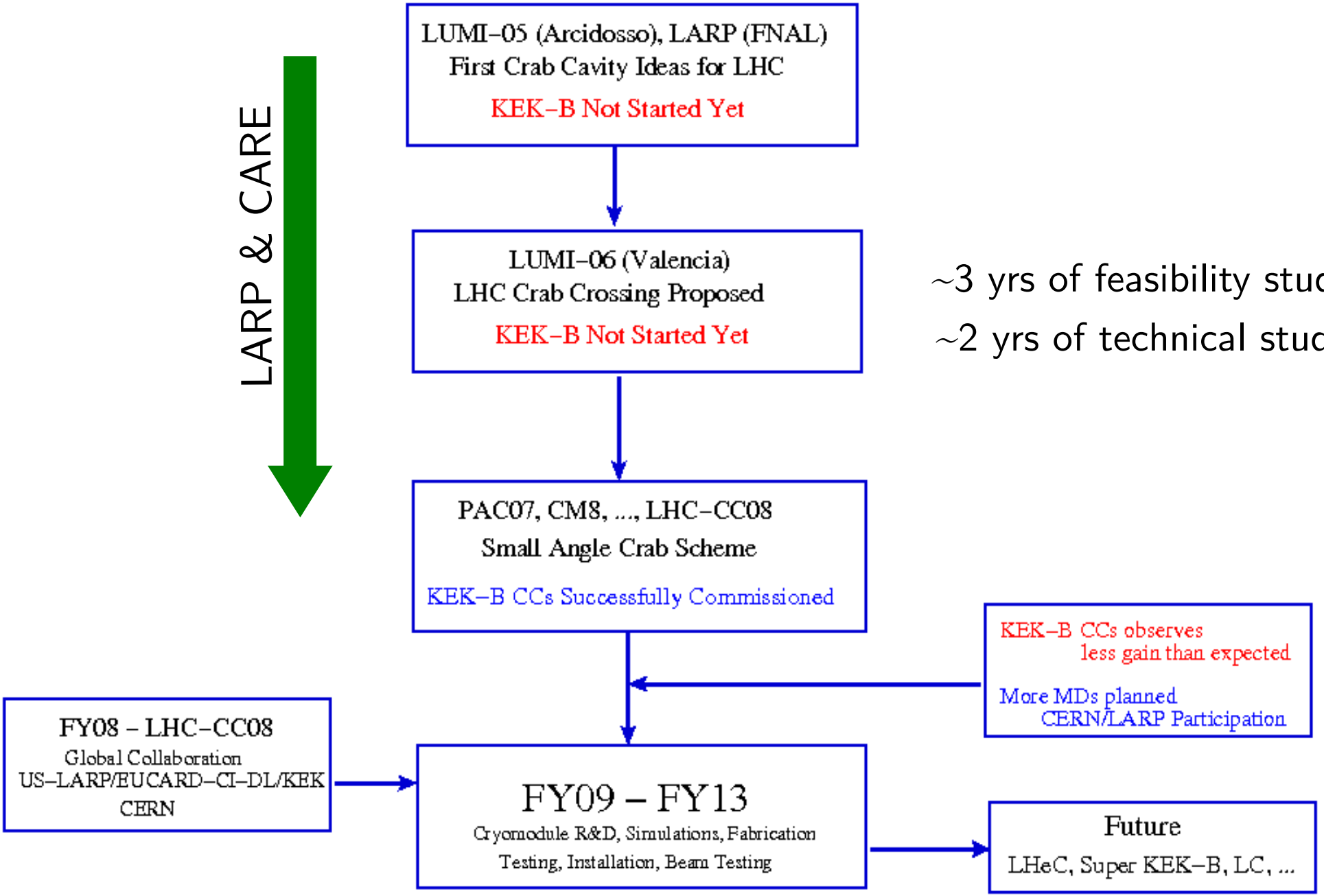
LHC Crab Cavities, LARP Review

R. Calaga, July 13, 2009

Ack: LHC-CC Collaboration

- Framework & Status
- Feasibility test & Challenges
- Milestones & Schedule
- Crab Project

Framework



~3 yrs of feasibility study

~2 yrs of technical study

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Interactions News Wire #28-09
11 May 2009 http://www.interactions.org
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Source: KEK
Content: Press Release
Date Issued: 11 May 2009
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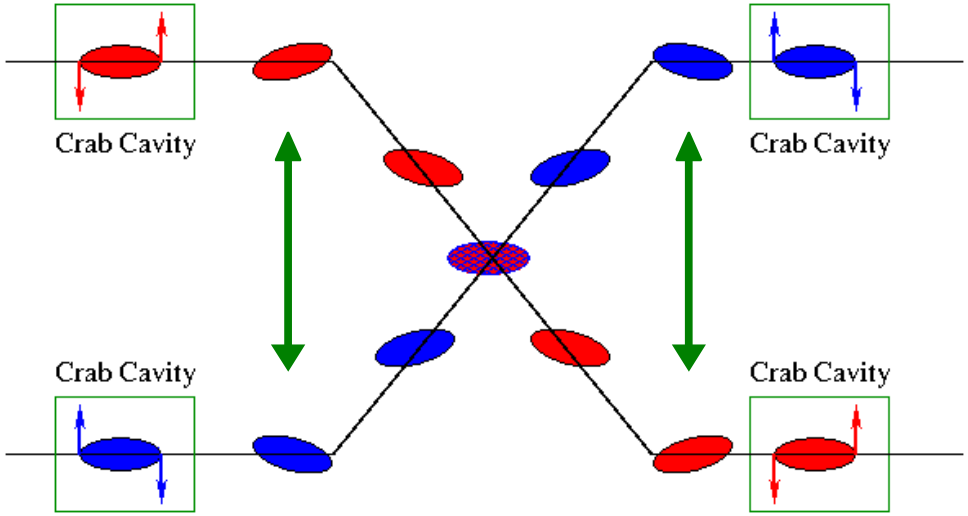
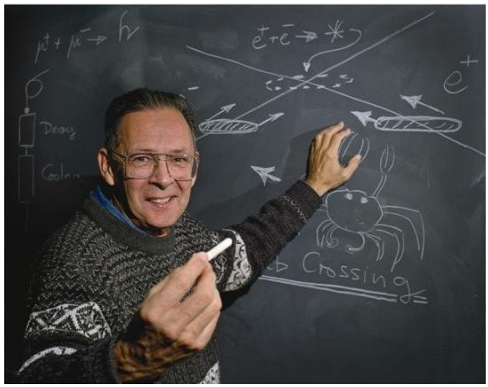
Using Crab Cavities, KEKB Breaks Luminosity World Record

A team of accelerator physicists at the KEK High Energy Physics Laboratory in Tsukuba, Japan, has broken the world's luminosity record by utilizing new accelerator devices called "crab cavities." The team at the KEKB electron-positron collider, home to the world's highest luminosity particle accelerator, installed the first pair of these futuristic superconducting radio-frequency cavities over two years ago.

2.0183×10^{34} $cm^{-2}s^{-1}$, Jun 17, 2009

Why crab the LHC





Proposed by Palmer, 1988

+20 yr

KEK-B

+5 yr ?

LHC

Two Phase approach

Finite crossing angle due to parasitic interactions

- Luminosity reduction → Recover from crab crossing
- Luminosity Leveling

Real Motivation, Phase II

Upgrade scenarios aim at x10 Lumi increase ($\beta^*\downarrow$, Current $\uparrow$)

- D0 in detector (Experiments prefer not, may requires crab cavities)
- LPA scheme (requires x5 increase in intensity, problem in injector chain)
- Crab crossing (experiments favor, lumi-leveling, technological challenge)
- Low emittance (machine protection & stability issues ?)
- Large emittance (under study)

For crab crossing: The proposal is to do two-phase approach

Crab Crossing, Phase I

Prototype Tests (5-7 TeV):

- Feasibility
- Luminosity gain (15-21%)
- Luminosity leveling

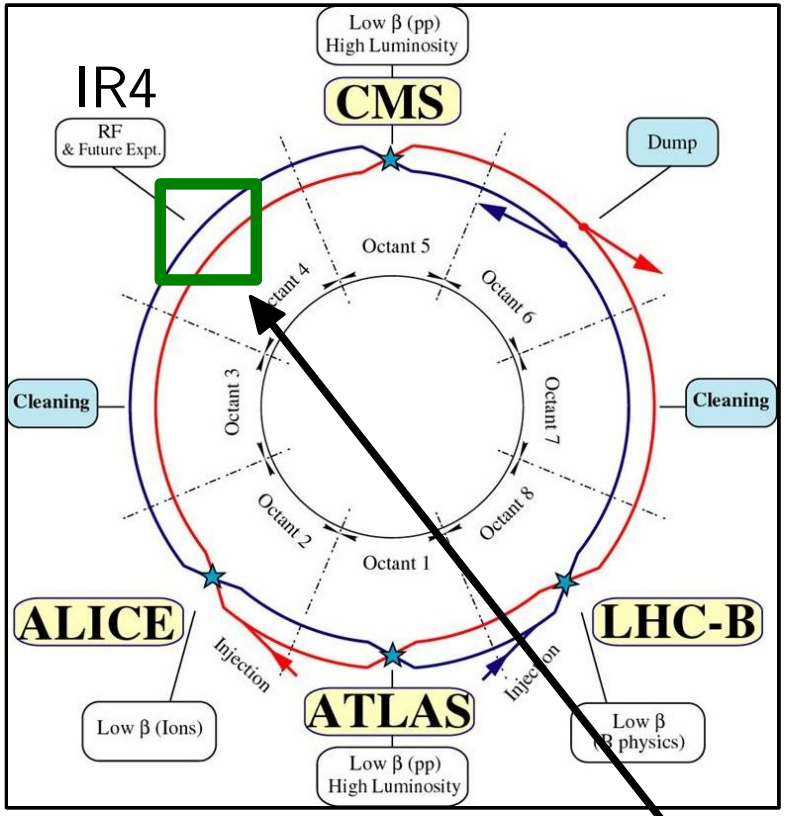
$\beta^* \leq 30$ cm

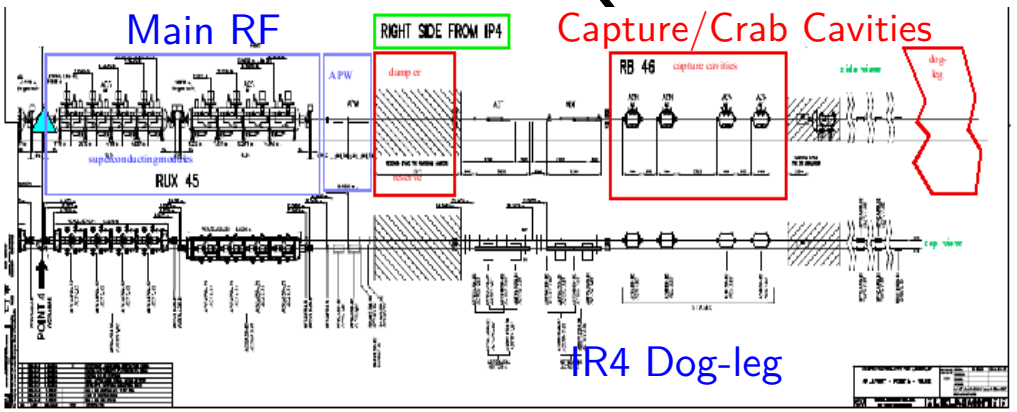
Bunch length: 7.55 cm

IR4 beam-line Separation: 42 cm

Crab RF frequency: <u>800 MHz</u>

1 cavity/beam: 2.5 MV kick

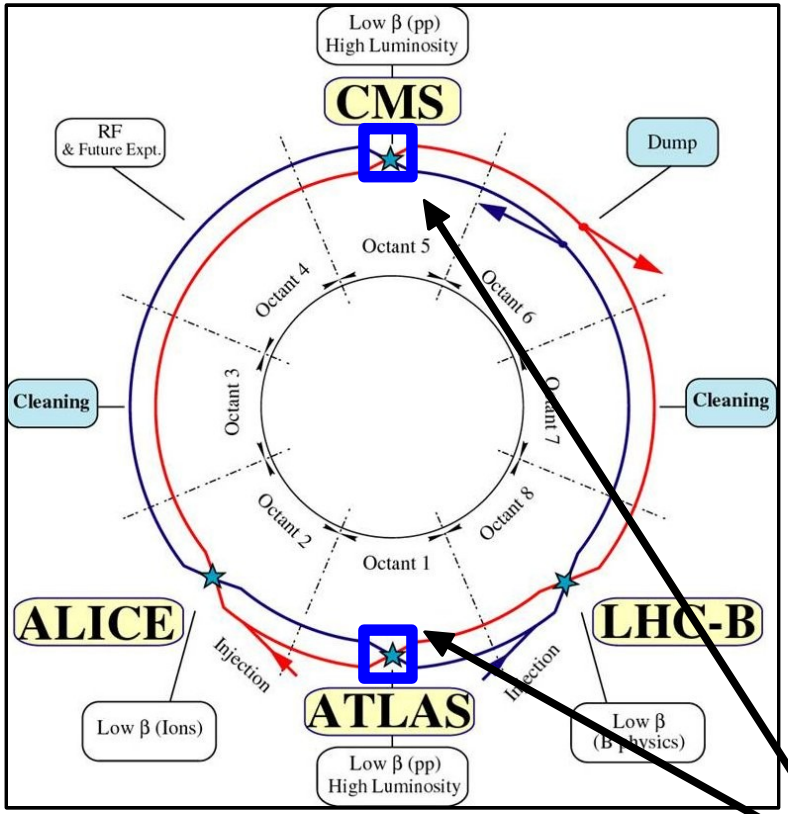




Crab Crossing, Phase II

Full Crossing Scheme

- Luminosity gain: 43-62%
- Leveling on

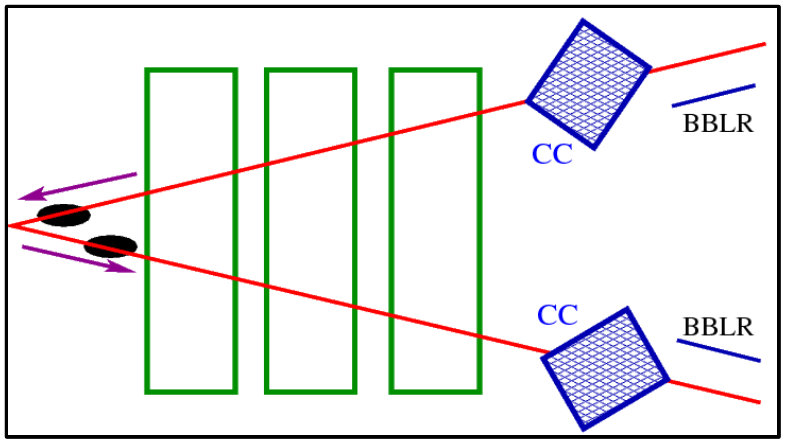


$\beta^* \leq 25$ cm

Crab Freq: 800 (or 400) MHz

Kick Voltage: ~5 MV

cavities/IP: 4-8



What has been done

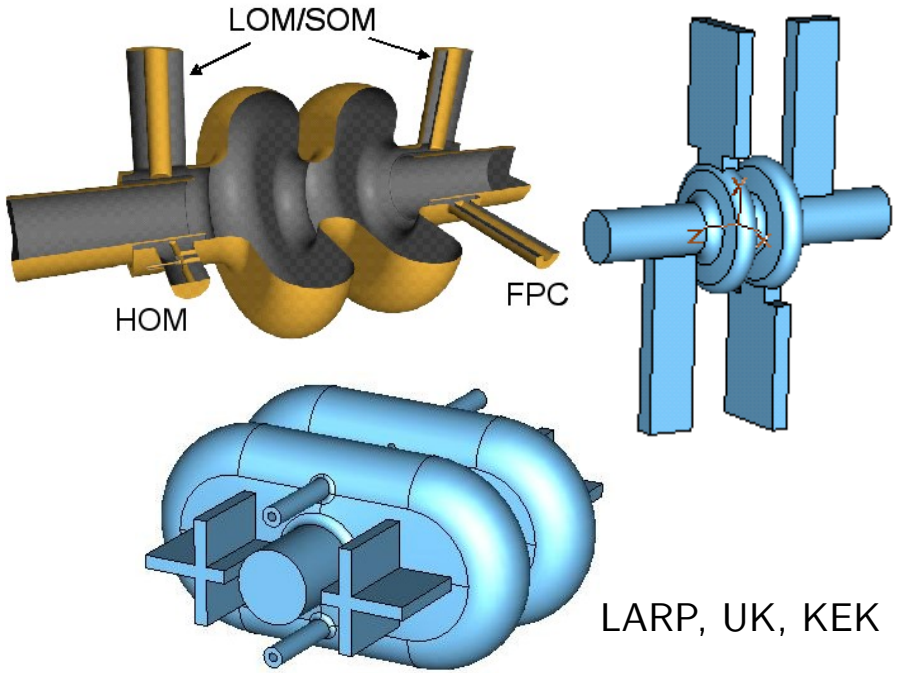
https://twiki.cern.ch/twiki/bin/view/Main/LHCCrabCavities

- Layout
  - Several layout schemes were explored & final solution in place
  - Crab optics for Phase I & II are available and evolve with LHC needs
- Beam simulations
  - Detailed collimations simulations done, no show stopper (Y. Sun, PRST-AB)
  - Detailed beam-beam & noise simulations and experiments (KEK-B) done. Specifications are set and more detailed studies underway
  - Impedance budget laid out (PAC09)
- Cryomodule
  - Cavity-coupler designs almost at final stages, well under impedance budget, multipacting, thermal and mechanical studies ongoing
  - Cryostat design advancing & will be ready for 2011 construction phase
- Operational Scenarios
  - Procedures for crab cavity and safe beam commissioning is well advanced, different scenarios for lumi gain and leveling for prototype tests are proposed, failure scenarios are laid out with possible remedies
- LHC Integration
  - Layout, cryogenics, RF power, transmission lines, instrumentation, water cooling, controls & additional items are advancing for both phase I & II

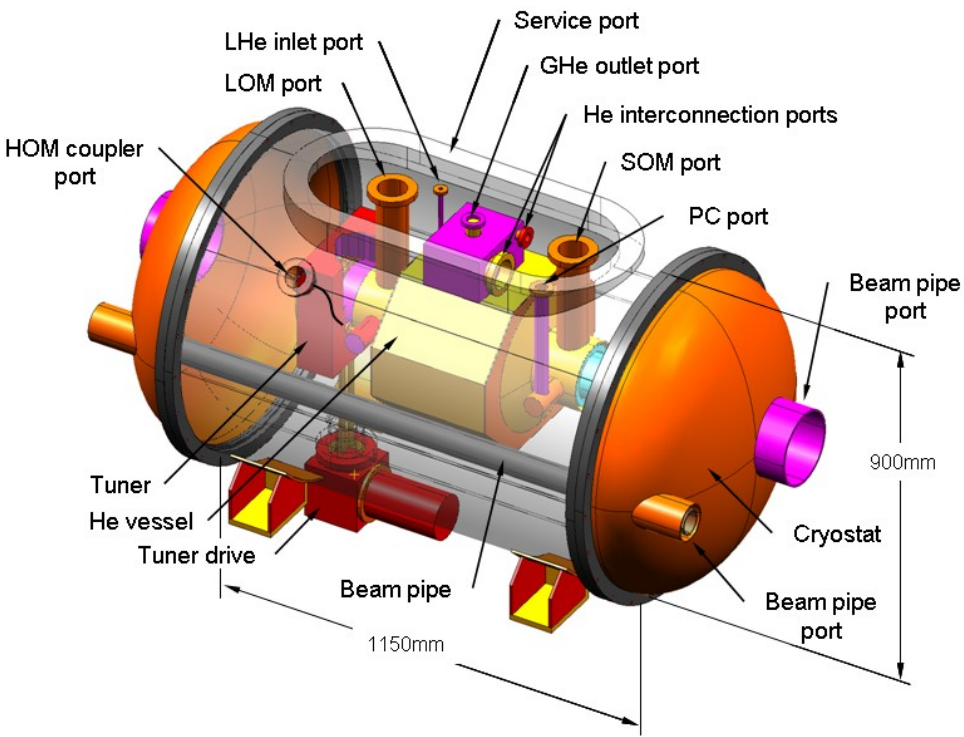
Cavity & Cryomodule

- 2 cell SRF cavity @800 MHz
- 3 aggressive damping schemes
- Down selection

  Multipacting, thermal, mechanical etc...



LARP, UK, KEK Designs



Cryostat development underway (FNAL), interfaces, RF-cryogenic-mechanical constraints

5-6 yr Proposal

	LHC Crab Cavities 04/09/09		Progress	Milestones	Future							
WBS	**Task**	**POC**	**Status**	**Request**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
					$0k	$25k	$300k+	~$700k	~$700k			
0	LHC-CC08	LARP-EUCARD	Completed									
1	Beam Simulations	BNL/KEK/CERN	In Progress									
2	RF Simulations	KEK/LBL/SLAC/UK	In Progress									
3	Cryomodule Development	FNAL	In Progress									
4	LHC-CC09	LARP-EUCARD	In Progress									
5	Warm Model Testing	UK/LARP	Not Started									
6	Coupler Testing	UK/LARP	Not Started									
7	LHC-CC10	LARP-EUCARD	Not Started	Project Engineer								
8	Fabrication	SBIRs	Not Started									
9	Processing	-	Not Started									
10	Testing	-	Not Started									
11	Cryostat Assembly	FNAL	Not Started									
12	LHC-CC11	LARP-EUCARD	Not Started									
13	CERN Test Stand	CERN	Not Started									
14	LHC-CC12	LARP-EUCARD	Not Started									
15	Integration	CERN-RF	In Progress									
16	Controls	CERN-RF	Not Started									
17	LHC-CC13	LARP-EUCARD	Not Started									
18	OP Procedures	CERN	Not Started									
19	Beam Tests	CERN	Not Started									

- LARP deliverable: Cryomodule TDR FY10-11
- Assist in fabrication & testing
  - "Crab Project": Project Engineer ?

LHC-CC09: "Prelim Review"

Dates: September 16-18, 2009

Venue: CERN

Format:

- Advisory board – 12 Members (7 Institutes)
- Scientific program committee – 17 Members (10 Institutes)

- 9 Sessions (2.5 days)
  - Introduction, layout & design, cavity design, cryomodule design, cavity integration, Cryomodule construction, phase I validation, phase II validation, planning & milestones
- 1 Long discussion session + 1 Closed AB session (day 3)

- Advisory board Summary & Recommendations

AB: I. Ben-Zvi, S. Chattopadhyay, G. Hoffstaetter, E. Jensen, S. Myers (Chair), M. Nessi, T. Raubenheimer, E. Tsesmelis, J. Virdee, A. Yamamoto

Program: http://indico.cern.ch/conferenceDisplay.py?confId=55309

SBIR & Warm Models, FY10-11

- Cavity SBIR of the proposed four was accepted for phase I
- Based on LHC-CC09 outcome:
  - AES will move towards detailed enginnering design and development
  - Detailed cost estimate

- 2-cell cavity model (more than one design ?)
- Coupler Model(s) & Mock-up Cryostat ?
- Engineering design and fabrication
  - Sort all possible difficulties (by LHC-CC11)
  - Benchmark RF simulations

Construction Proposal

To DOE: Separate crab cavity project for the construction of 2-cryomodules (suggested during a meeting with Kovar @CERN)

- LARP studies and cavity SBIR will ideally place the start around FY11
- Identify host U.S. Lab & project engineer (follow LHC triplet construction example)
- Additional help from KEK & Europe maybe available (cavity treatment, testing...)

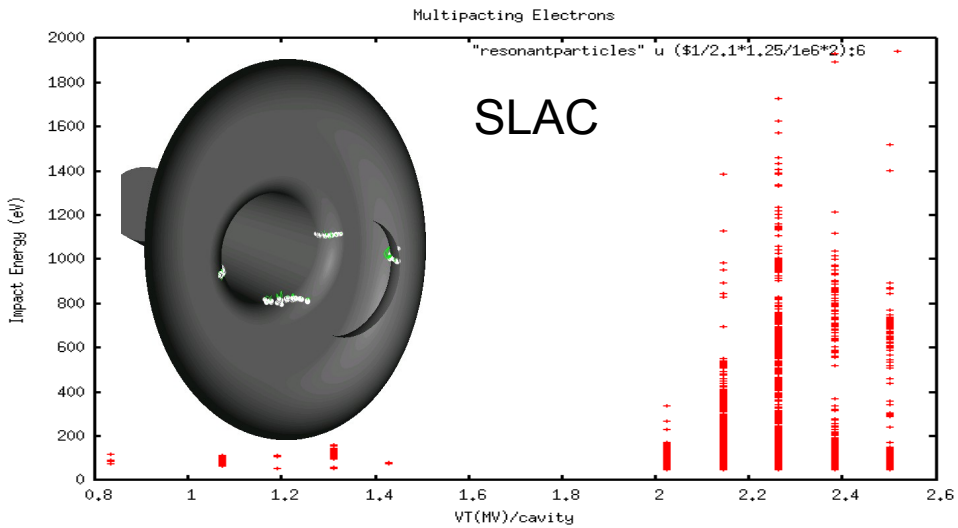
	Module I	Module II
Cost	**$4.0 M**	**$2.0 M**
Contingency	40%	20%
Design	38%	-
Materials	38%	61%
Fabrication	20%	32%
Integration & Support	4%	7%

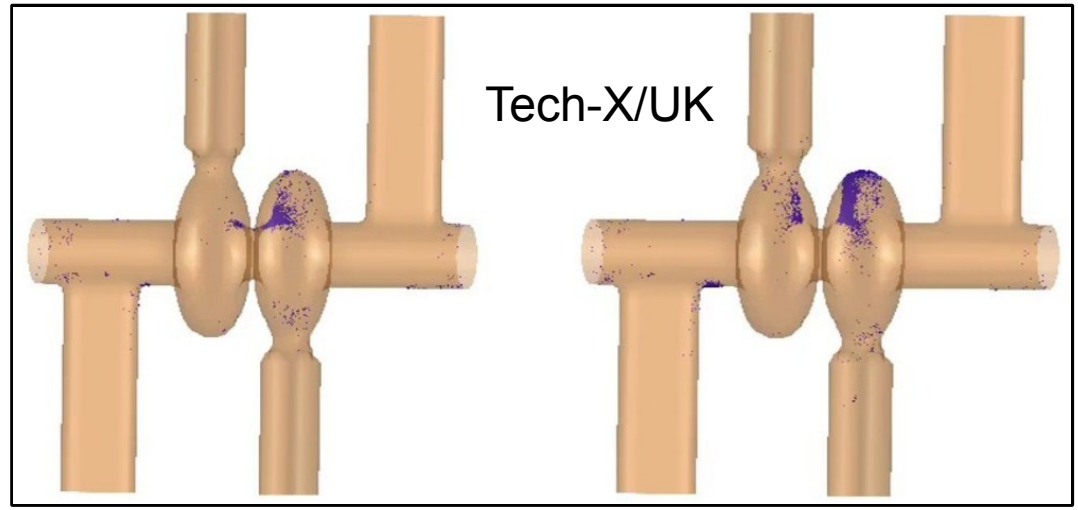
Courtesy AES

Conclusions

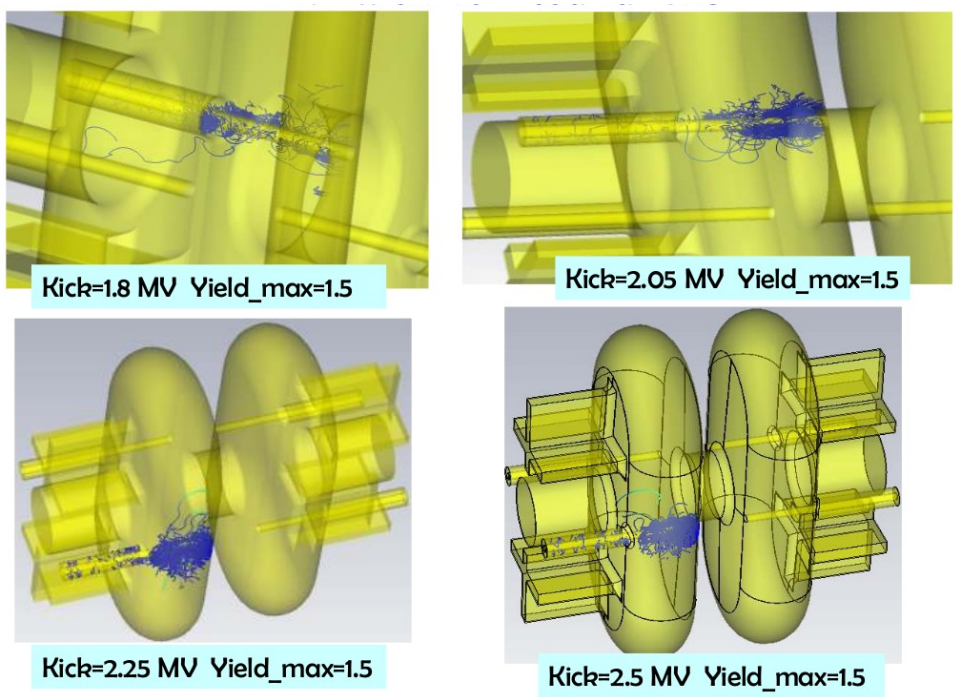
- Very detailed crab-crossing schemes (Phase I/II) is in place
- Tremendous progress in a short time, due to large interest in community
- Continue the momentum into FY10/11 (700 k/yr, 0.5 FTE/lab)
  - "TDR": cryomodule, integration, OP procedures, simulations
  - More detailed studies on LHC beams and safe operation
  - Continue with KEK-B experiments and any other if relevant
- Beyond FY10-11: LARP to play an assisting "physics" role
- Positive outcome of 2010 Review $\rightarrow$ "Crab Project"

Backup: Multipacting





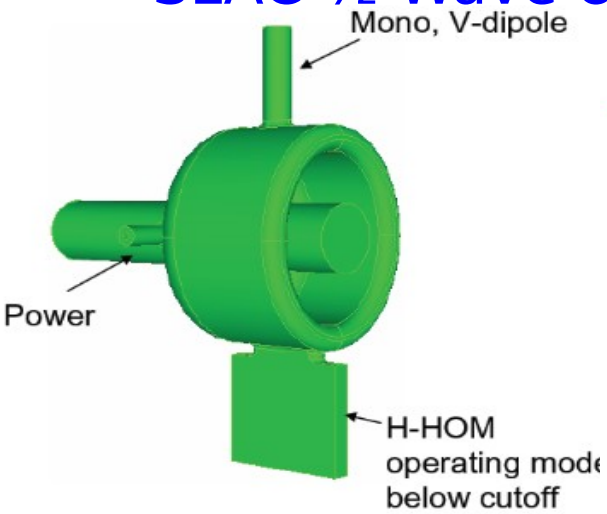
FNAL/KEK

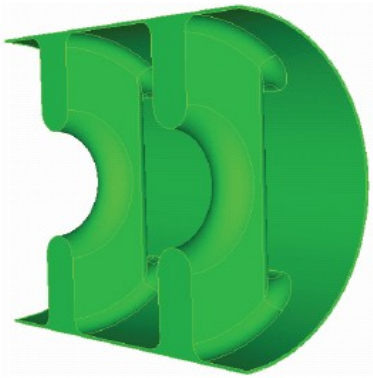


Excellent progress on multipacting and cures to overcome. Continue the effort towards LHC-CC09.

Compact Structures, Phase II

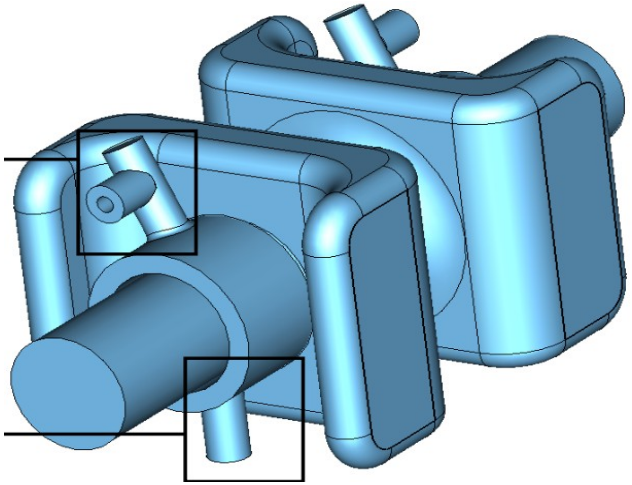
SLAC ½ Wave & Spoke Structures



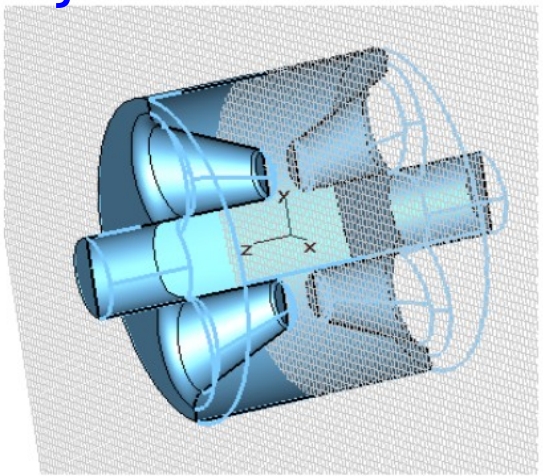


spoke-cell

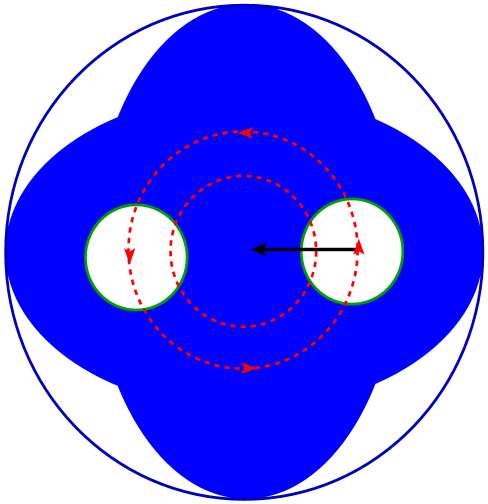
FNAL Mushroom Cavity



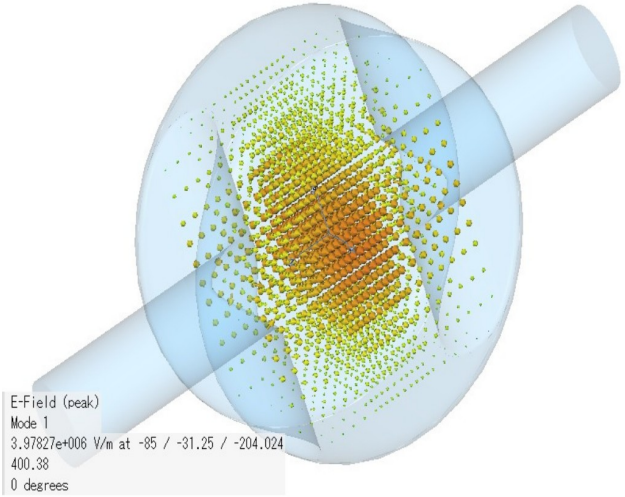
UK-JLAb Rod Structure



BNL TM010, BP Offset

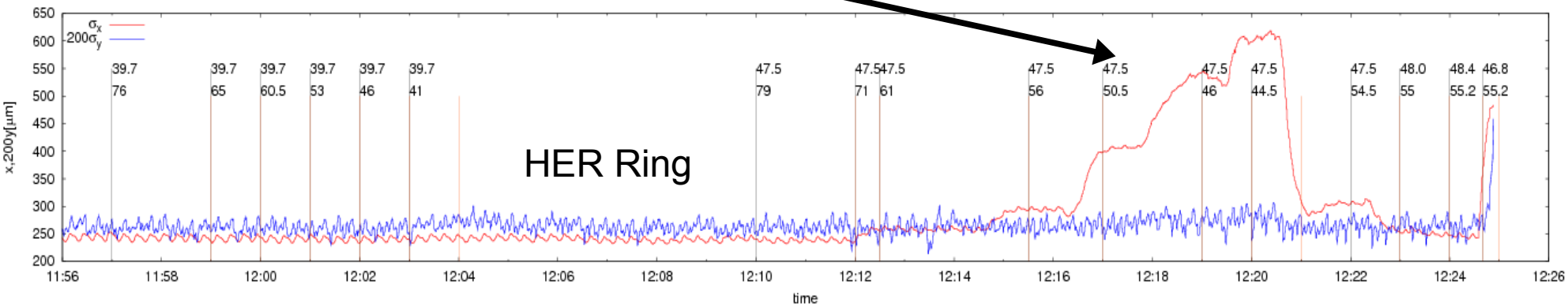


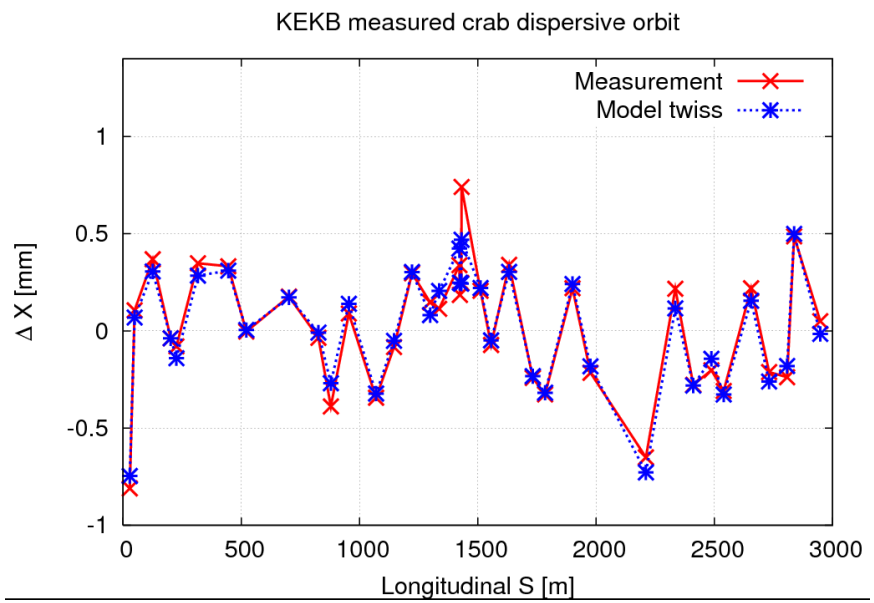
KEK Kota Cavity



Backup: KEK-B Experiments

Artificial modulated noise (inside and outside betatron spectrum)





1st measurement of crab-dispersion

R. Tomas et al., PRST-AB to be submitted

Backup: Impedance Estimates

Longitudinal criteria:

Narrow band impedance threshold, $R_{sh} < 200\ k\Omega$

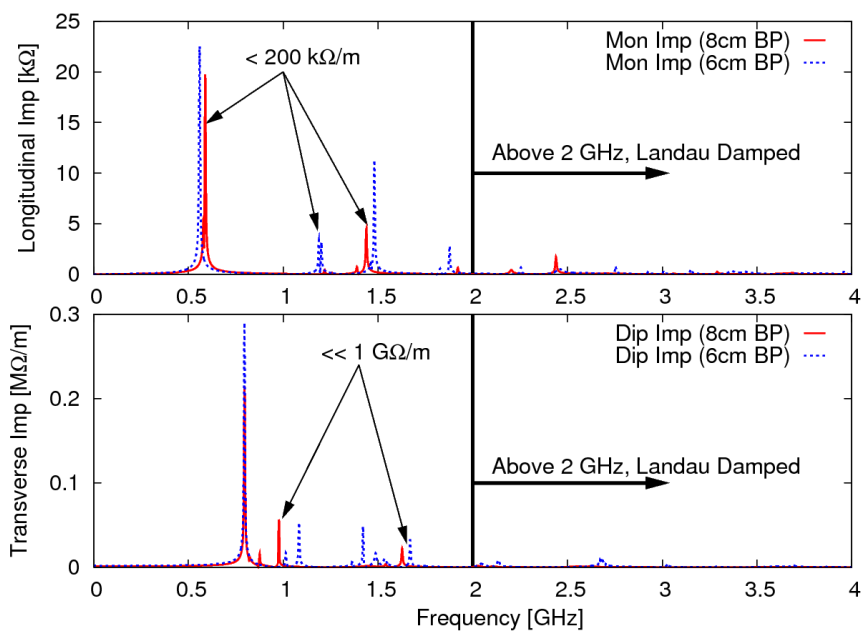
Inductive low freq & broadband $\rightarrow$ $Im\{Z/n\} < 0.15\Omega$ (loss of landau damping)

Landau damped for ≥ 2 GHz (synchrotron freq. spread)

Transverse criteria:

Landau octupoles, chromaticity, feedback (Landau damped ≥ 2 GHz)

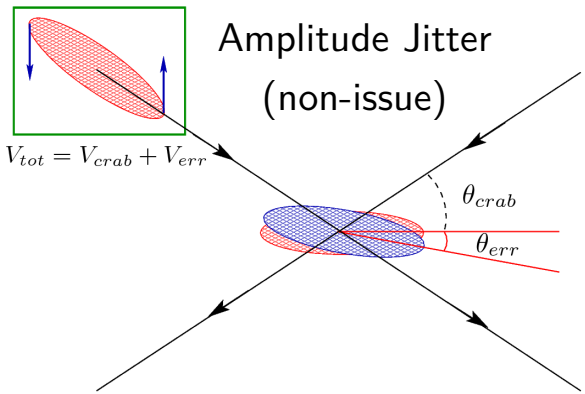
Re, $Im\{\Delta Q\} < 10^{-4}$ Coupled bunch $(\beta_\perp / \beta_\perp)R_\perp/Q << 1\ G\Omega/m$

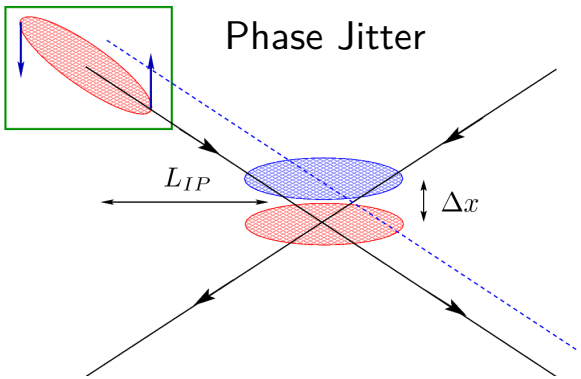


	Freq [GHz]	R/Q [Ω]	Q_{ext}
Monopole	0.54	35.17	~10^2
	0.69	194.52	
Dipole	0.80	117.26	10^6
	0.81	0.46	~10^2
	0.89	93.4	
	0.90	6.79	

** Main RF cavities, $Q_{ext} \sim 10^2$ - 10^3

Backup: Crab Noise, Tolerances





Modulated noise (measured, ex: 32 kHz)

Strong-strong BB $\leq 0.01\sigma$ (1%/hr)

Weak-strong BB ≤ 0.01-0.1σ

White noise (pessimistic)

Strong-strong BB $\leq 0.002\sigma.(\tau)$

correlation time

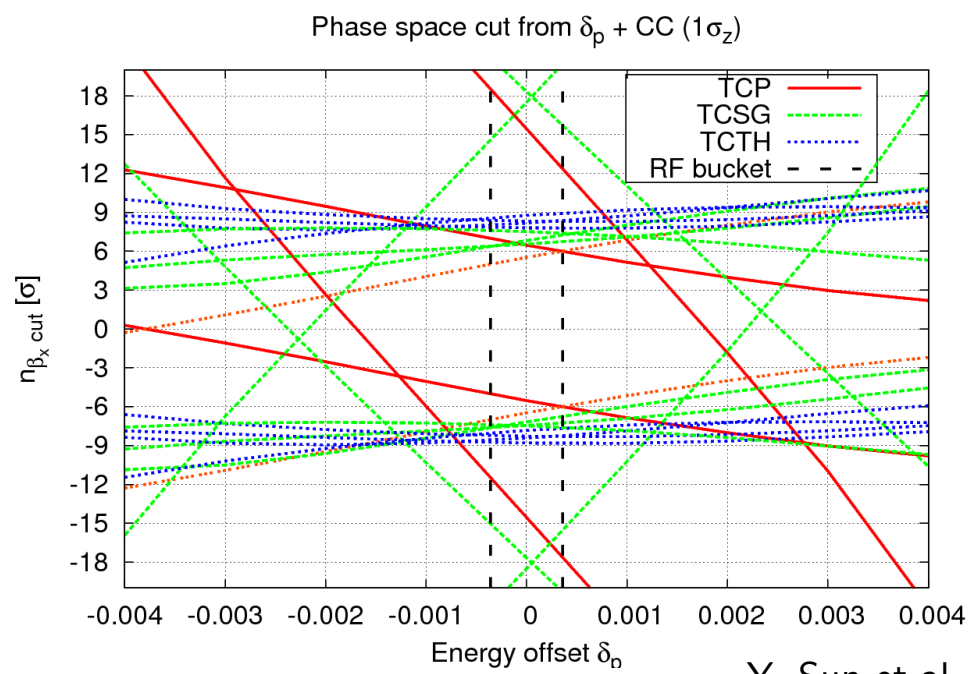
KEK-B crab spectrum

K. Akai et al.

Backup: Collimation Studies

- Loss maps with crabs similar to nominal LHC
  - Heirarchy preserved, impact parameter investigation
- Not a serious concern for prototype tests
  - Fine tuning with crabs-collimator setup maybe needed

		Nominal		Crab Cavity	
		$2\sigma_z$	$3\sigma_z$	$2\sigma_z$	$3\sigma_z$
$\delta p/p=0$	1st turn [μm]	0.78	0.78	3.84	3.84
	All turns [μm]	0.153	0.154	0.147	0.147
	Part. absorbed.	70.2%	70.2%	68.5%	68.5%
$\delta p/p\neq0$	1st turn [μm]	50.61	59.82	76.16	79.03
	All turns [μm]	36.1	40.44	66.47	67.03
	Part. absorbed	96.5%	97%	99.56%	99.56%



Y. Sun et al.

Backup: Prototype Test Scenarios

Prototype test scenarios are proposed and being studied

Adapt to various LHC configurations while maintaining safe operation

Identifying all failures scenarios and corresponding remedies

$\{E, {}^{max} \beta_{crab}\}$	3 TeV, 1 km	5 TeV, 2 km	7 TeV, 3 km
$\beta^* = 25$ cm	Reduce Emittance Increase X-Angle Artificial		56%
$\beta^* = 30$ cm	Enhancement		40%
$\beta^* = 55$ cm			10%