LHC Crab Cavities

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LARP DOE Review, Jul 15-16, 2010

- Post Chamonix
- Current R&D Activities
- Towards a Cryomodule

Ack: LHC-CC Team

Chamonix: " Upgrade Scenarios"

	Nominal	Ultimate +Crabs	Phase II +Crabs/D0	Phase II +LPA
N_b [$\times 10^{11}$]	1.1	1.7-2.3	2.3	4.2
β^* [cm]	55	25-30	14-25	25
θ_c [μrad]	285	315-348	509	381
Pile Up	19	44-111	150	280

- Aim at x3-10 Luminosity increase
- Luminosity leveling vital → constant luminosity
- Bunch intensity beneficial, NOT easily digestible in the injectors (safety!)

$$L = \frac{f_r n_b}{4\pi} \frac{N_b^2}{(\gamma \epsilon)} \frac{R_\Phi}{\beta^*}$$

Outcome Thereafter

Potential upgrade

Increase intensity as possible $\rightarrow$ 1.7 x 10^{11} (2.3x10^{11} limit)

Reduce β* $<$ nominal & compensate Piwinski angle (better IT's + crabs)

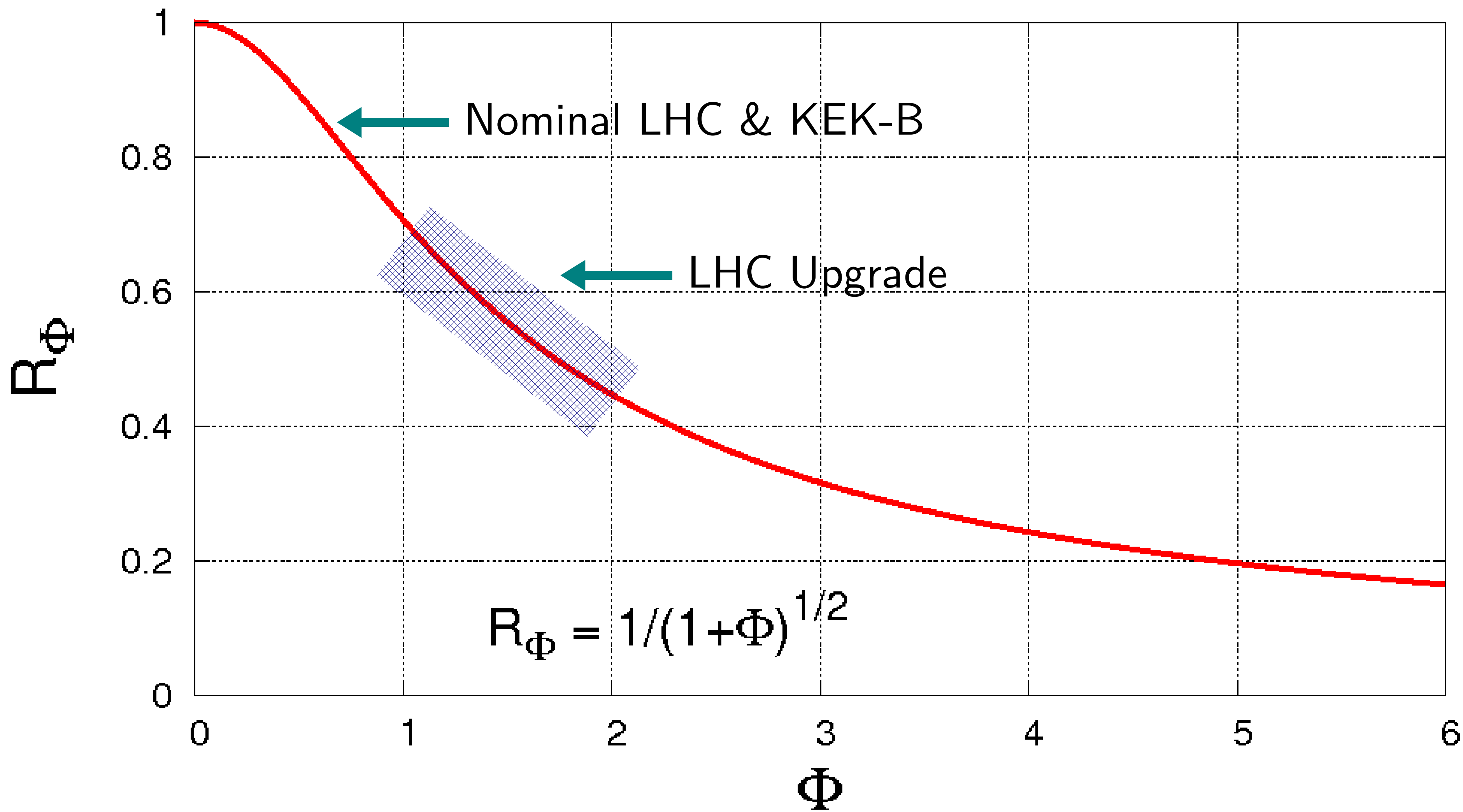
β* $<$ Nominal

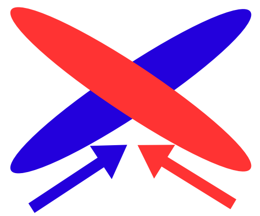
Previous upgrade optics, limited to $\sim$30 cm (chromatic limits)

Solution (S. Fartoukh, SLHC V3.0) $\rightarrow$ β* $<$ 25 cm (flat-beams)

Crabs considered key for phase II luminosity upgrade

R_Φ, Reduction Factor

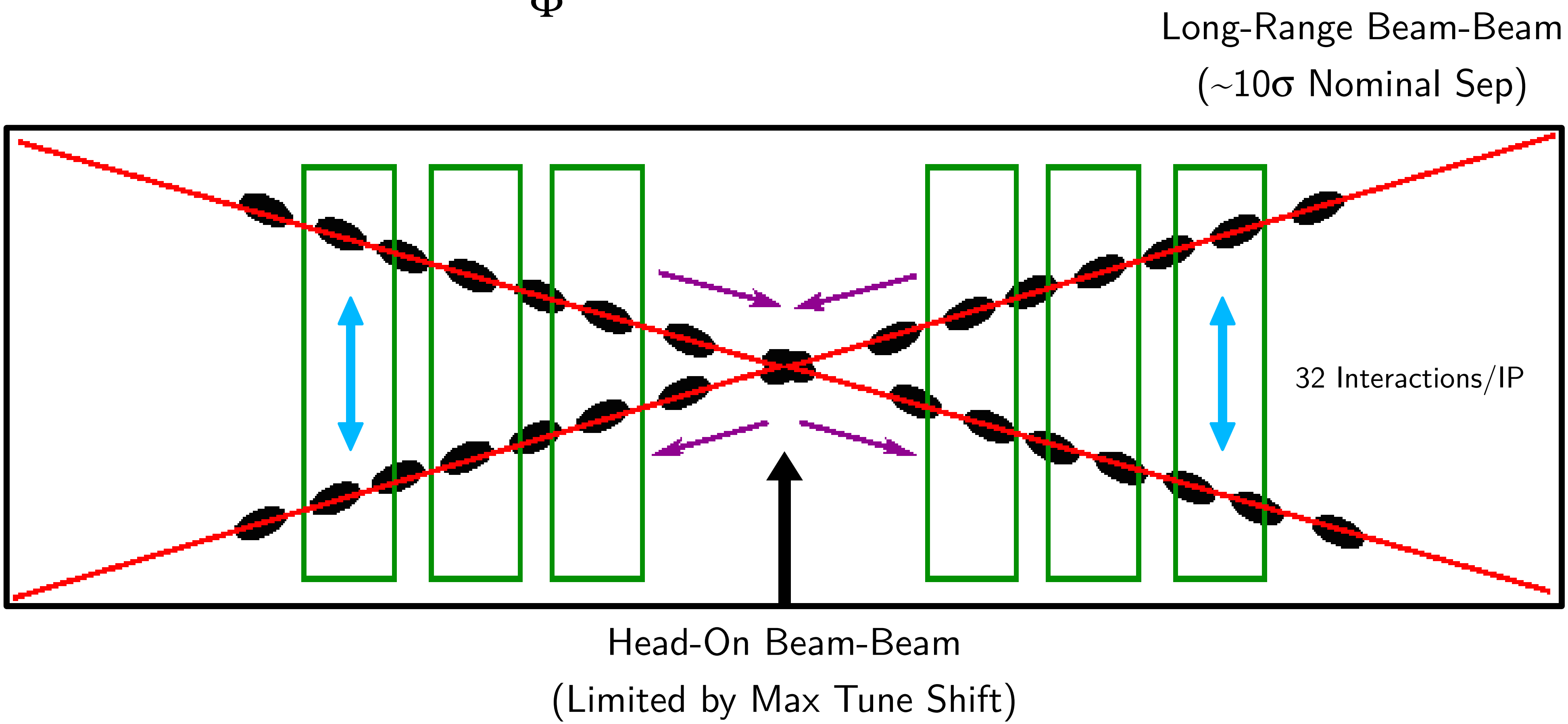




Eff. beam size

$\sigma \rightarrow \sigma/R_\Phi$

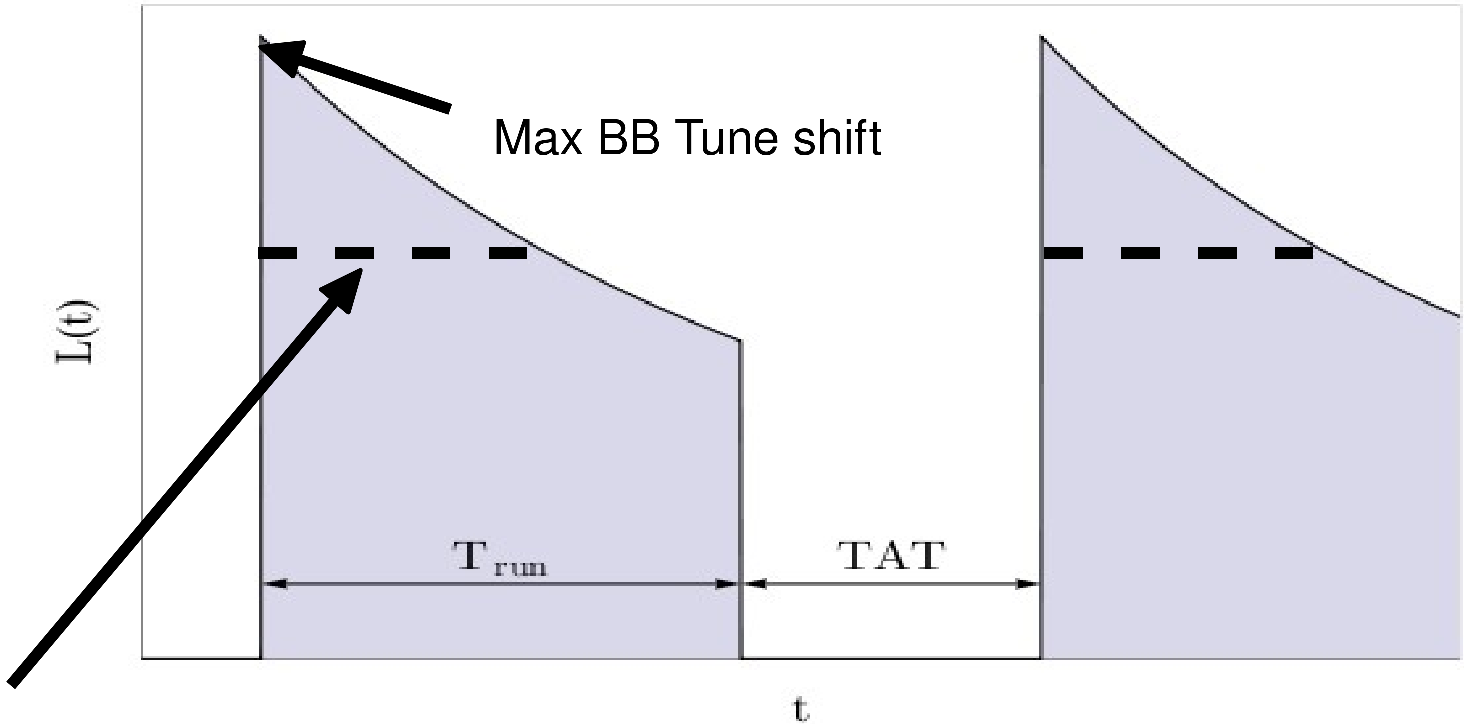
Compensate R_Φ!



Why Crab Cavities:

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

Luminosity Leveling



Advantages (perhaps a requirement):

- Constant Luminosity (~3 x 10^{34})
- Less pile up at start
- Less peak radiation on IR magnets/detector

Crabs → Natural knob w/o lattice change

Graphic courtesy G. Sterbini

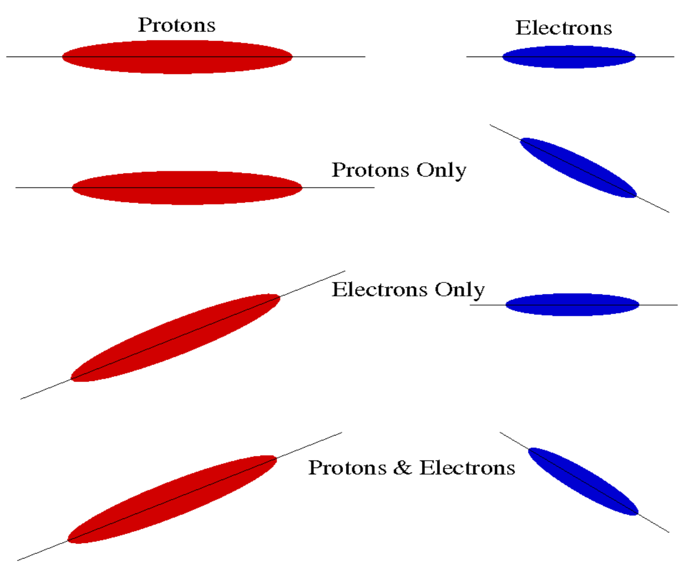
LHeC & Crabs

Reduce luminosity loss and help deviate synchrotron radiation

$$\Phi_p \sim \frac{\theta_c}{2\sqrt{2}\sigma_x^*}\sqrt{\sigma_{z,1}^2 + \sigma_{z,2}^2}$$

Par	KEK-B	LHC			LHeC		eRHIC
		Nominal	Phase I	LPA	RR	LR	
θ_c [mrad]	22.0	0.285	0.420	0.381	1.0	0.0 (4.0)	0.0 (5.0)
σ_z [cm]	0.7	7.55	7.55	11.8	7.55 (0.7†)		20/1.2†
σ_x^* [μm]	103	16.6	11.2	11.2	30 (15.8*)	-	32
Φ	0.75	0.64	1.4	2.0	0.9 (1.6*)	0.0	0.0 (11.0)

Scenario	$\Delta L/L_0$ [%]	
	400 MHz	800 MHz
Head-On (with CCs)	88	48
Uncross only e^-	0.7	
Uncross only p^+	88	48
X-Angle	1.0	

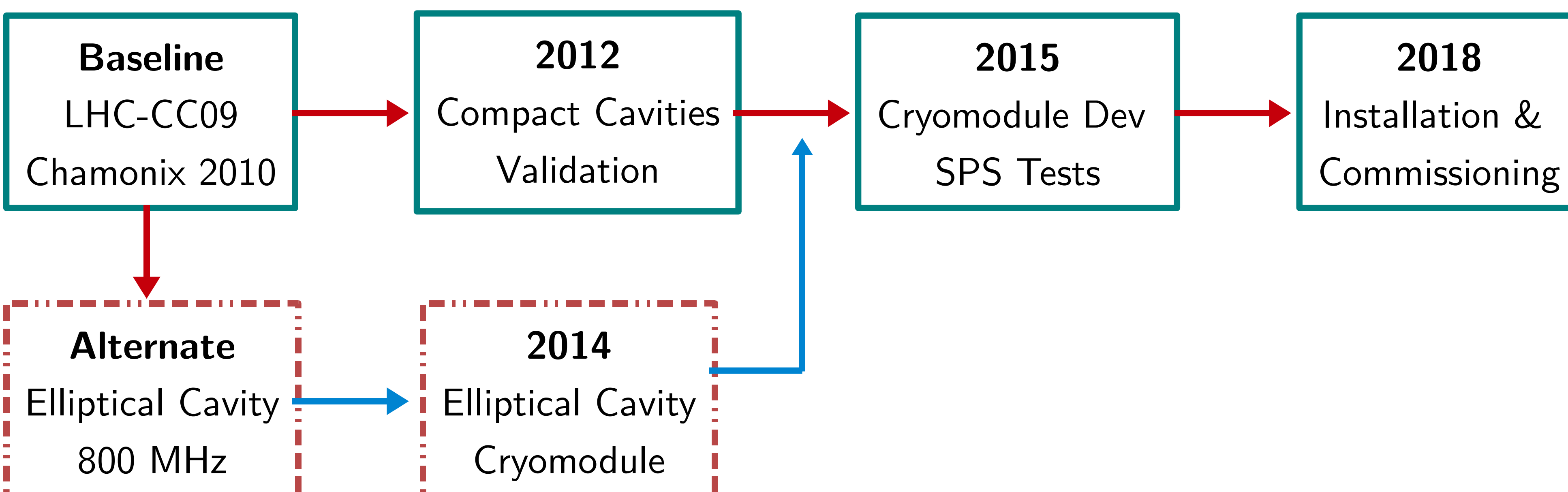


New Roadmap

Crabs considered key for phase II luminosity upgrade

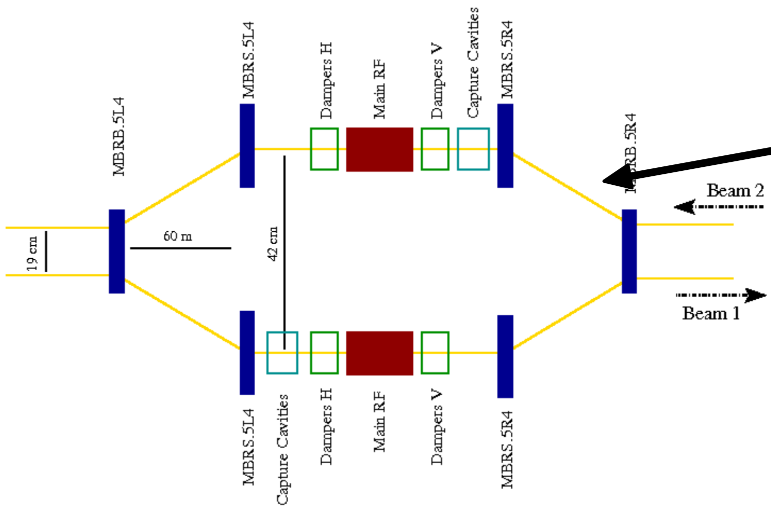
- CERN must pursue crab crossing following KEK-B success
- Both local (baseline) & global should pursued
- High reliability (cavity, machine protection, impedance & mitigation)
- No validation in LHC required (ex: SPS as test bed with KEK-B cavities)
- Coordination & timing: both short term & long term upgrades of LHC

From S. Myers
LHC-CC09

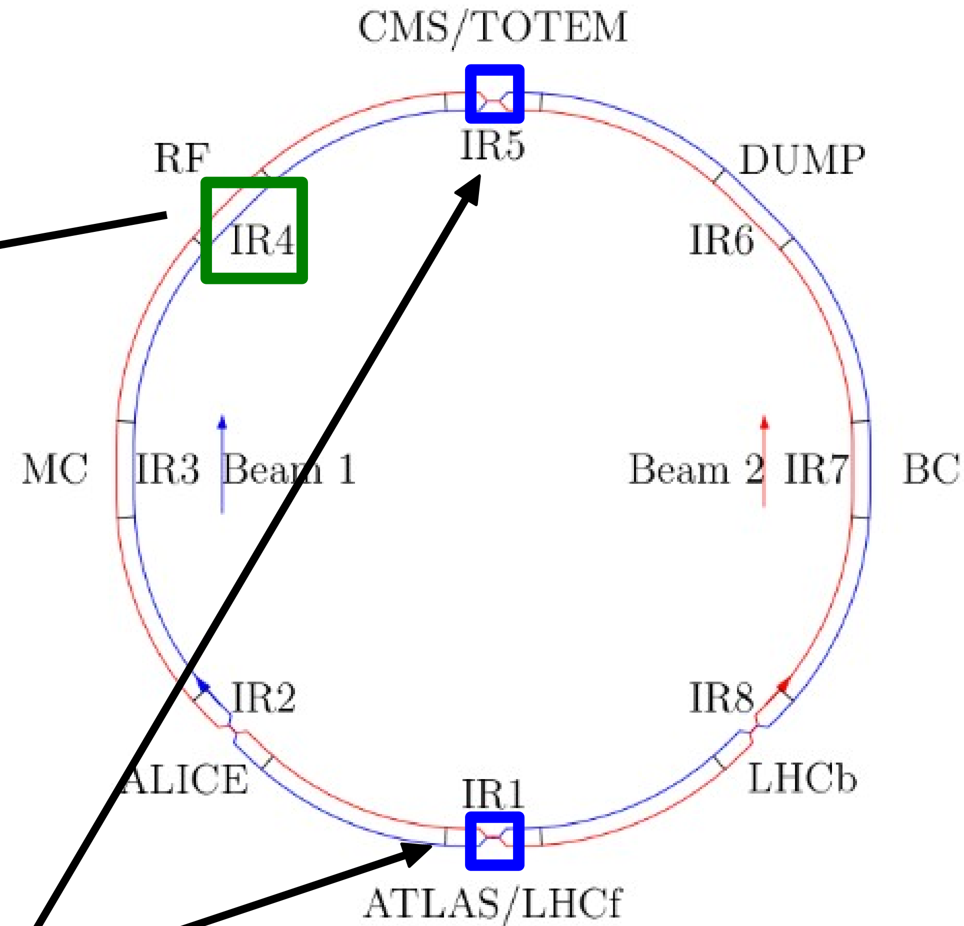


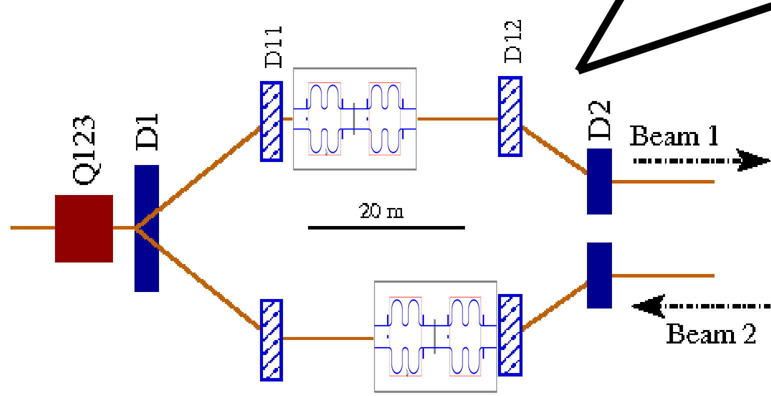
†Time scales approximate

Possible Schemes



Backup Option, Conventional
1-2 Cavities/beam

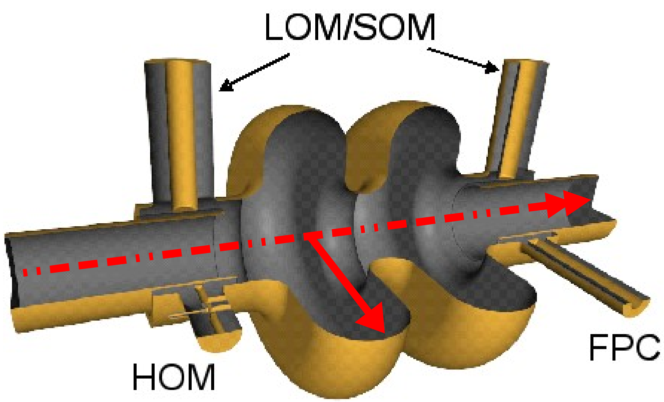




Baseline Option
4 Cavities/IP

Compact cavities -OR- doglegs needed for conventional cavities (impractical)

Conventional to Compact

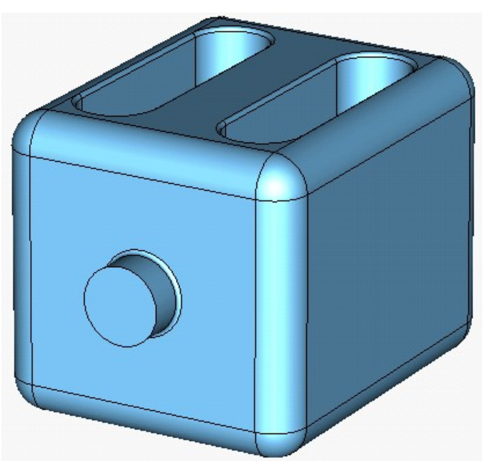


~250 mm outer radius, 800 MHz

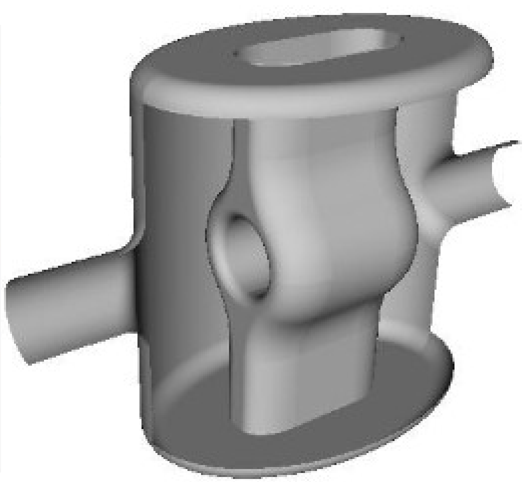
(Developed, but only foreseen as backup for LHC)

Compact cavities aiming at small footprint & lower frequencies, 5-10 MV/cavity

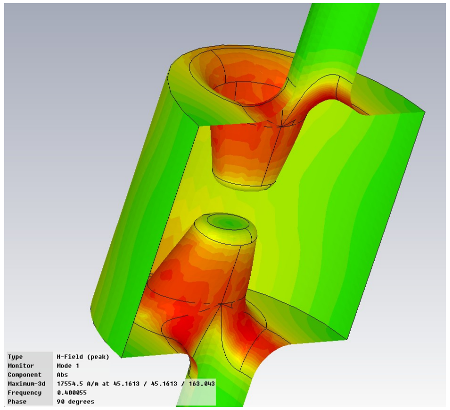
HWDR, JLAB,OD



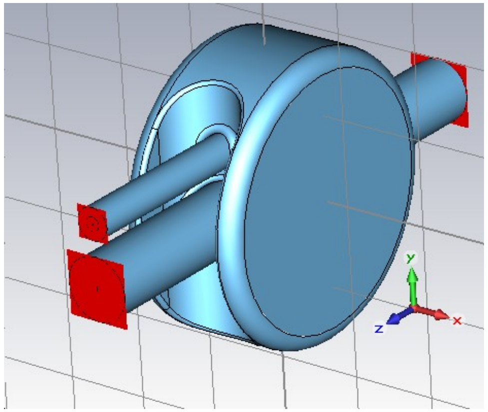
HWSR, SLAC-LARP



DR, UK, TechX



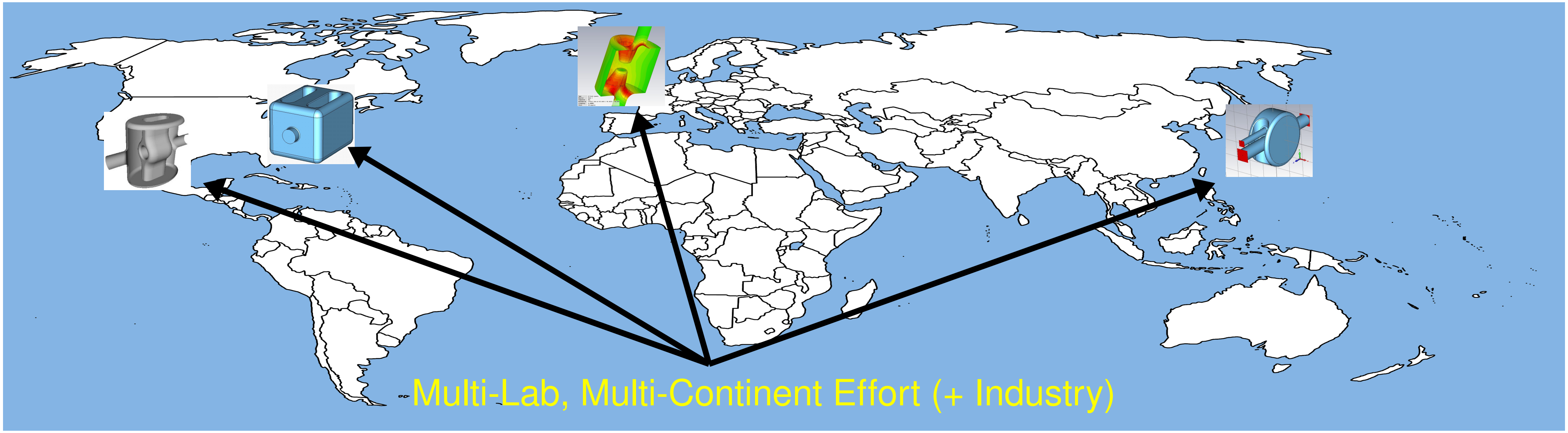
Rotated Pillbox, KEK



Performance Chart

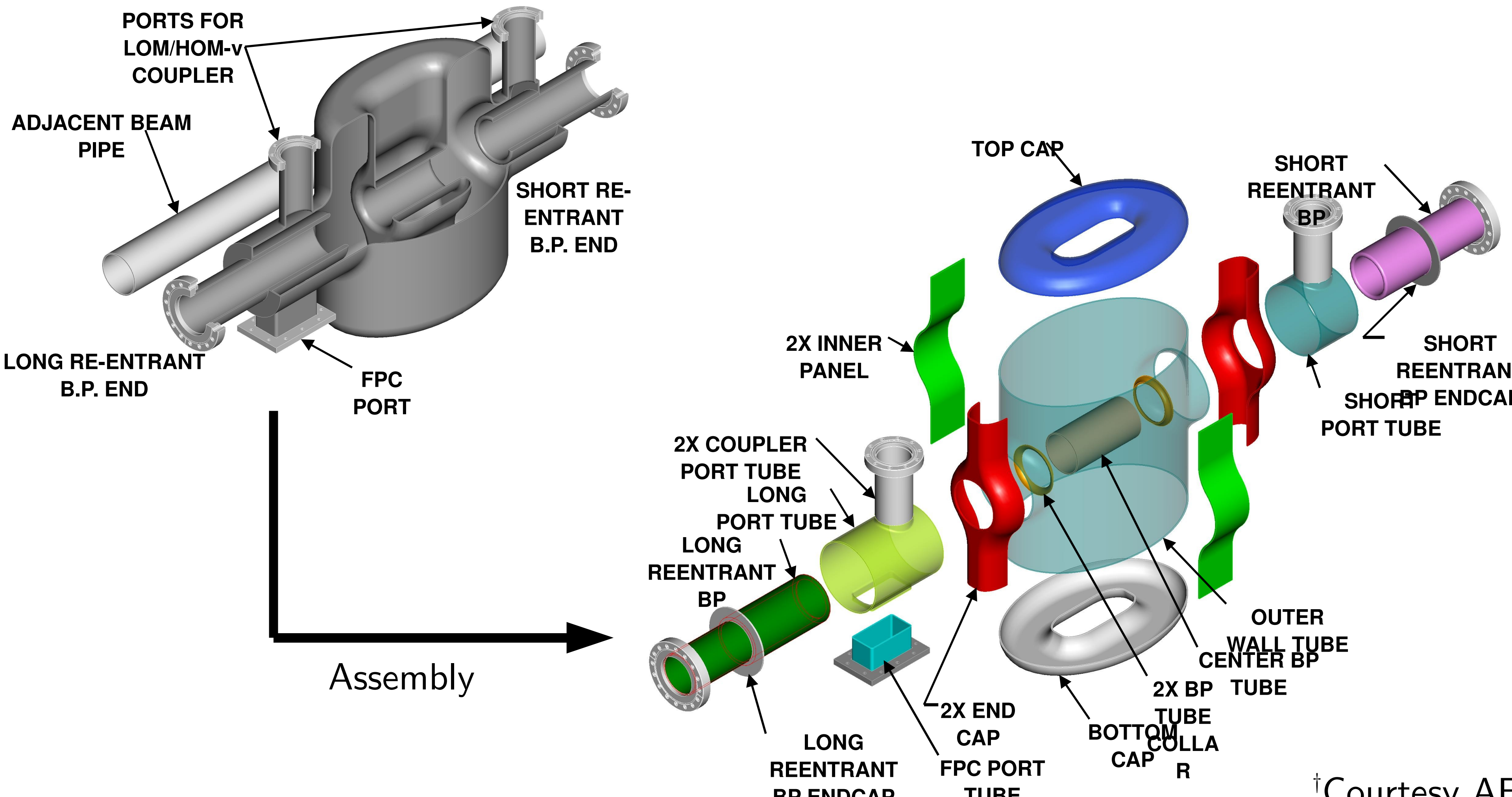
Kick Voltage: 5 MV, 400 MHz

		HWDR (J. Delayen)	HWSR (Z. Li)	4-Rod (G. Burt)	Rotated Pillbox (N. Kota)
Geometrical	Cavity Radius [mm]	200	140	140	150
	Cavity Height [mm]	382	194	230	668
	Beam Pipe [mm]	50	45	45	75
RF	Peak E-Field	29	65	62	85
	Peak B-Field	94	135	113	328
	R_T/Q	319	275	800	-



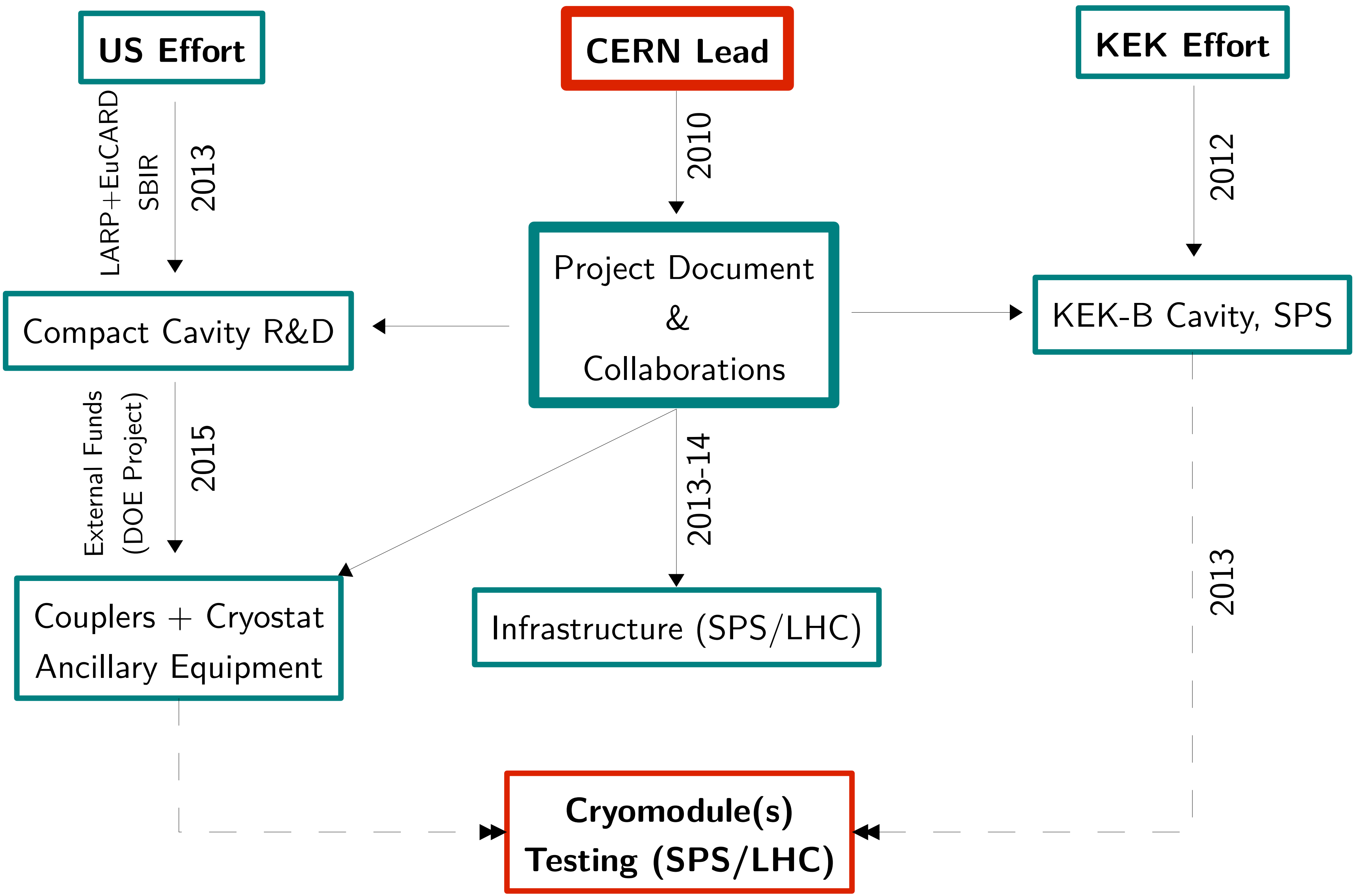
Example Outcome: LARP + AES-SBIR

- Detailed multipacting analysis of cavity & couplers – LARP
    - Also help with other cavity development
- Cavity engineering (mechanical & thermal analysis) - AES

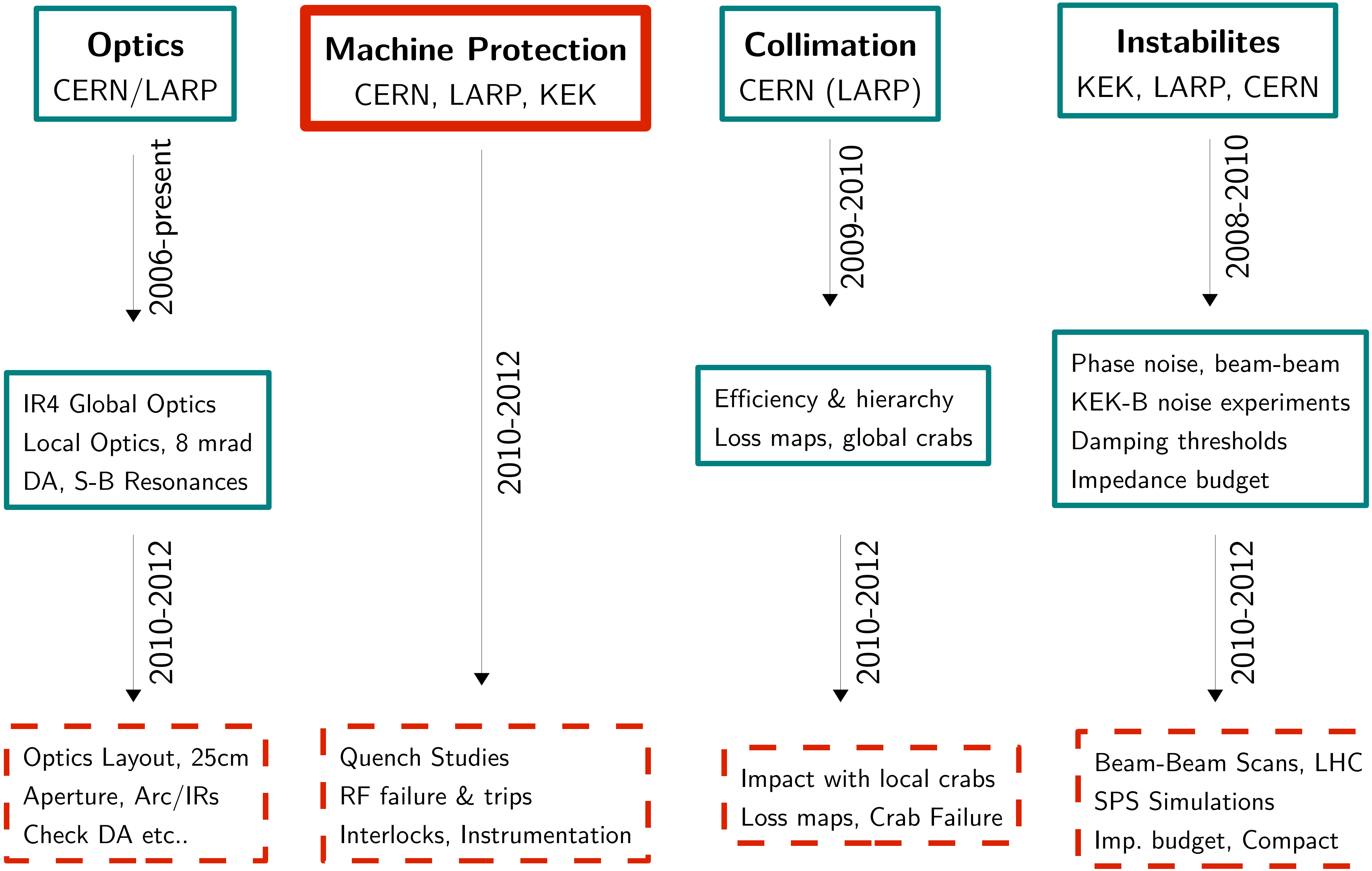


†Courtesy AES

Work Flow, Technology



Work Flow, Simulations



SPS Tests, WG

Courtesy E. Metral

No real showstoppers were identified.

- Earliest availability, Dec 2010, estimate SPS test date Dec 2012 – May 2013

The best location in SPS is at COLDEX.41737 (4020 m, LSS4)

Collimation with integrated instrumentation

- 1st (SLAC) collimator sees no effect & full crab effect at 2^{nd} second (CERN) collimator

Integration

- Removal of COLDEX ~2-3 weeks, cryogenics refurbish ~ 200kCHF
- RF Power: IOTs (1-2), 400 kCHF & space requirements
- After 2 MHz tuning at KEK-B, re-assembly and test at SM18?

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

Machine protection

- Primary goal is beam measurement (No implementation of interlocks, BPMs-fast & RF-slow)
- Failure scenarios (for example: measure evolution of RF phase and effect on the beam)

Crab Bypass

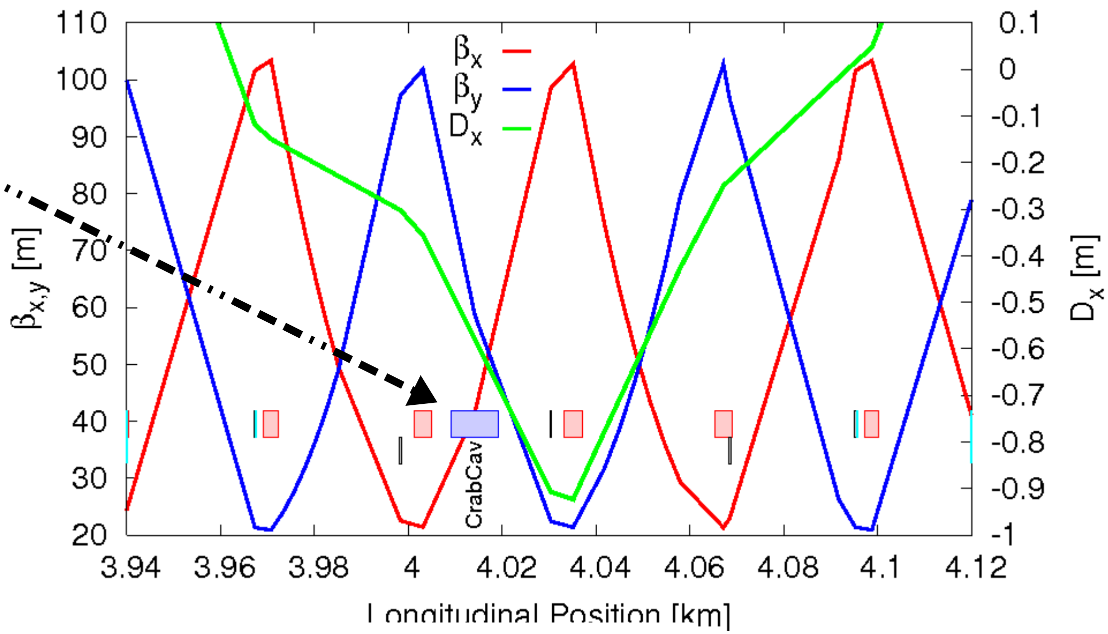
- Similar to COLDEX to move it out of the way during high intensity operation
- Technical details (RF connections, cryogenics, size, weight etc...) needs to be sorted out

Coldex Location

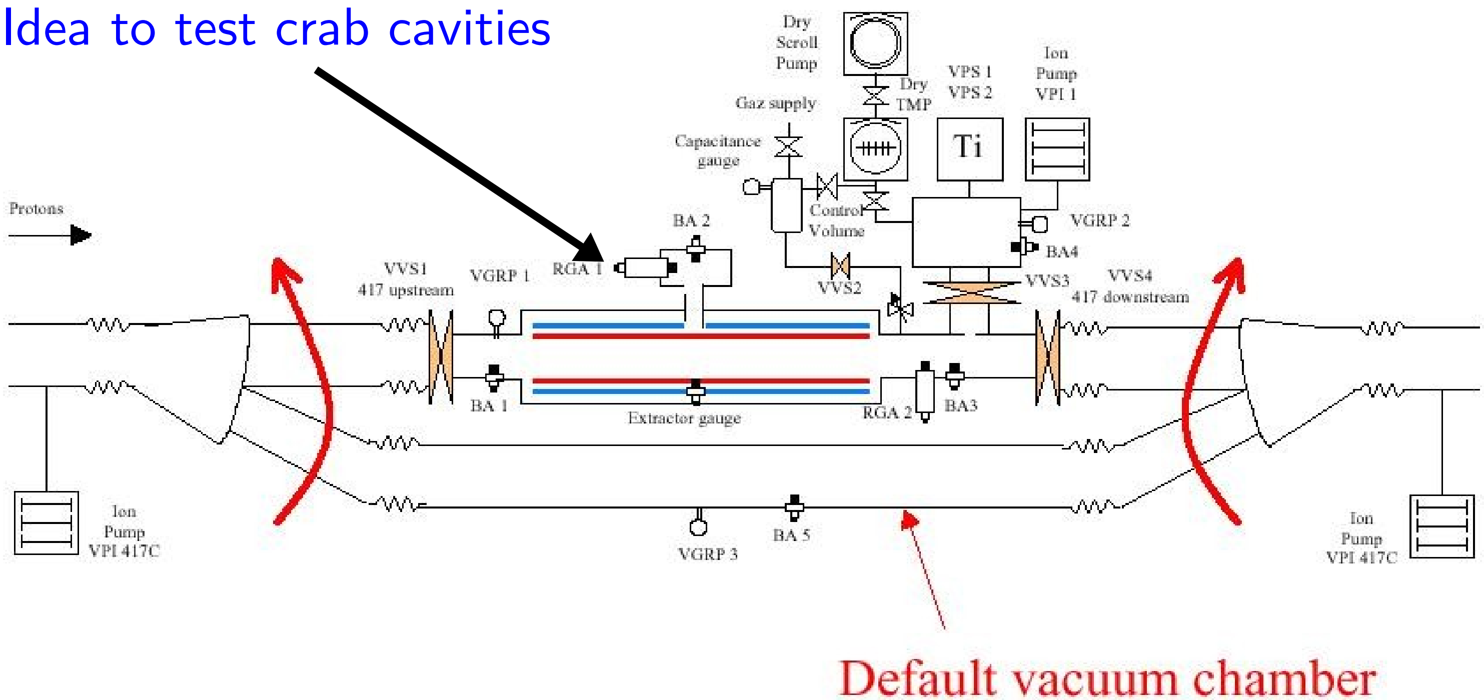
Longitudinal Position: 4009 m +/- 5m

Total length: 10.72 m

βx, βy: 30.3m, 76.8m



Idea to test crab cavities



LARP Activities, Outlook

Crab Cavity Effort, LARP										
June 23, 2010			2010-I	2010-II	2011-I	2011-II	2012-I	2012-II	2013-I	2013-II
BNL	R. Calaga	FTE + 25% OP	250k		300k					
LHC/SPS Parameters										
Machine Protection										
Cavity/Coupler R&D										
SPS Test Objectives										
SPS Installation & Tests										
Coordination + Project Proposal										
FNAL	Y. Yakovlev	0.5FTE + 25% OP	6k		75k					
Multipacting Simulation										
Cryomodule R&D										
Coupler R&D										
SPS Simulations										
Jlab	J. Delayen	Student + 25% OP	65k ?		65k					
Compact Cavity R&D										
Coupler R&D										
LBNL	J. Qiang	0.5P-Doc + 10% FTE	6k (+25k)		50k + 6.5k					
Beam-Beam Simulations										
Low-level RF										
SLAC	Z. Li	0.25FTE + 25% OP	65k		75k					
Compact Cavity R&D										
Multipacting Simulations										
Coupler R&D										

* Lab funds, SBIR/STTR & outside funding are complementary

Strawman Schedule

LHC-CC Workshops

Plan for LHC/SPS infrastructure installation

Task	Sub-Task	FTE Request	Fund Request	2010 1st	2010 2nd	2011 1st	2011 2nd	2012 1st	2012 2nd	2013 1st	2013 2nd	2014 1st	2014 2nd
Cavity													
	Cavity Design			■	■								
	Couplers & HOM Damping			■	■								
	Multipacting & Mitigation				■	■	■						
	Mechanical/Thermal Analysis				■	■							
	Instrumentation								■	■			
	Copper Models & Testing						■	■					
	Niobium Specification & procurement					■							
	Niobium Fabrication & Processing							■	■				
	Low Power Testing (VTA)									■	■		
	Couplers Fabrication & Testing								■	■	■		
	Complete Assembly & Testing											■	■
Cryostat													
	LHC Tunnel Constraints				■								
	Conceptual Design, Nominal					■	■						
	Technical Design & Analysis							■	■				
	Procurement, Fabrication								■	■	■		
	Assembly & Test Stand										■	■	■
Cryogenics													
	Test Stand Specs				■								
	4K (2K) Circuits				■	■							
	Interface with SPS/LHC Cryo					■							
	Safety Valves, Interlocks						■						
	CERN Test Stand Preparation							■	■				
RF Controls													
	LLRF Simulations & Specs				■	■							
	RF Controls & Testing								■	■			
	Integration with LHC controls											■	■
Infrastructure													
	Infrastructure Specifications				■								
	Power Amplifiers, 400 MHz					■	■						
	Transmission Lines Layout							■	■				
	Survey and Alignment									■	■		
	Radiation Issues										■		
	Cryomodule Installation											■	
	RF Powering & Beam Tests												■

LHC Shutdown

Waiting for Input from CERN-RF

↑ 2012-2013

* Being revised by CERN-RF

Conclusions

- Post Chamonix
  - LARP contribution via crab studies vital
  - Fabrication funds external (CERN, DOE, EuCARD, KEK)
  - Upon approval SBIR/STTR may help with near term R&D
- Current Activities
  - Aggressive R&D on compact cavities (need additional funds to prototype)
  - Outline and address machine protection issues
  - SPS tests & preparation (appropriate technology ?)
- Towards a cryomodule
  - "LHC note" with CERN-RF to detail "scope, parameters & schedule"
  - US Project proposal to construct 2-cryomodules spanning 4-5 yrs

Why not participate in prototyping now ?

LHC

SPS Test Objectives, Protons

- Safe beam operation (low intensity) & reliability
  - Tests, measurements (orbits, tunes emittances, optics, noise)
  - Voltage ramping & adiabaticity
  - Collimation, scrapers to reduction of physical aperture with & w/o crabs
  - DA measurements (possible ?)

- Intensity dependent measurements (emittance blow-up, impedance)
  - Coherent tune shift and impedance
  - Instabilities
  - Beam-beam effects (BBLR – tune scan, current scan)
  - Other non-linearities (octupoles)

- Operational scenarios
  - Accumulation of beam with crab-on & crab off
  - Beam loading with & w/o RF feedback & orbit control
  - RF trips and effects on the beam
  - Energy dependent effects
  - Long term effects with crab-on, coasting 120 GeV