Task 10.3 "Crab Cavities" Report

CERN LHC Crab Requirements and LHC-CC10 Impact

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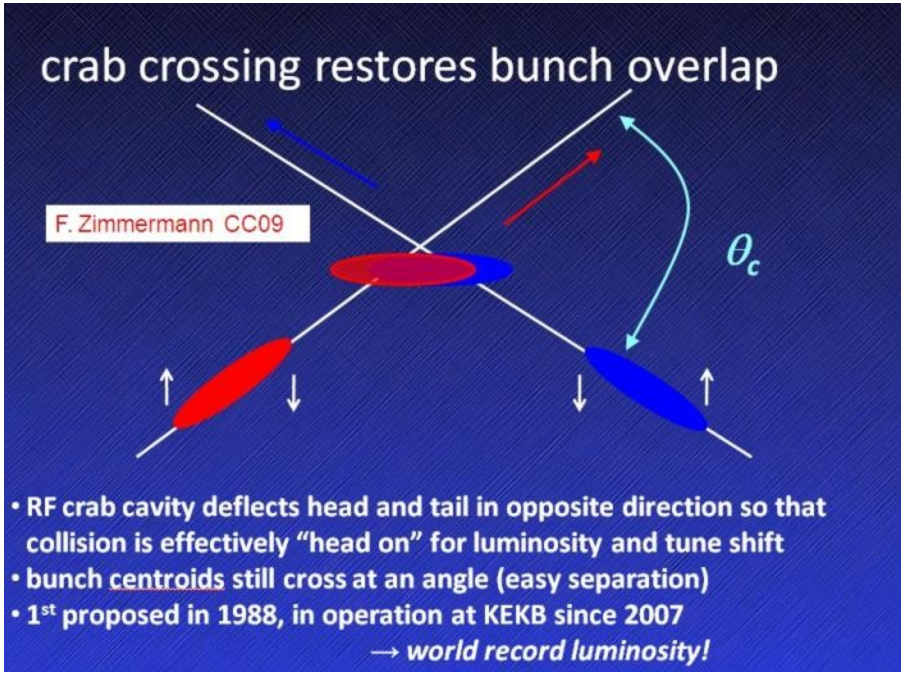
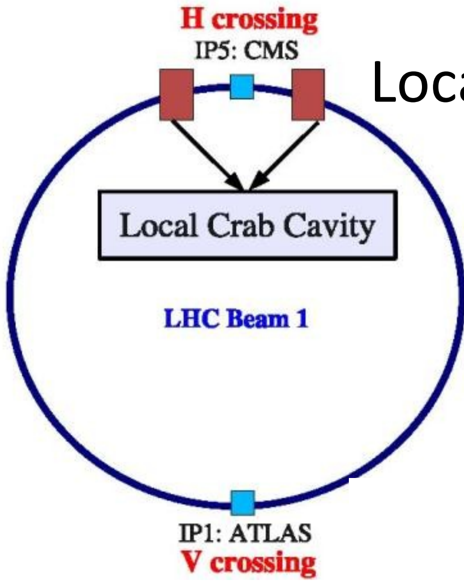
CERN LHC Crab Requirements and LHC CC10 Impact

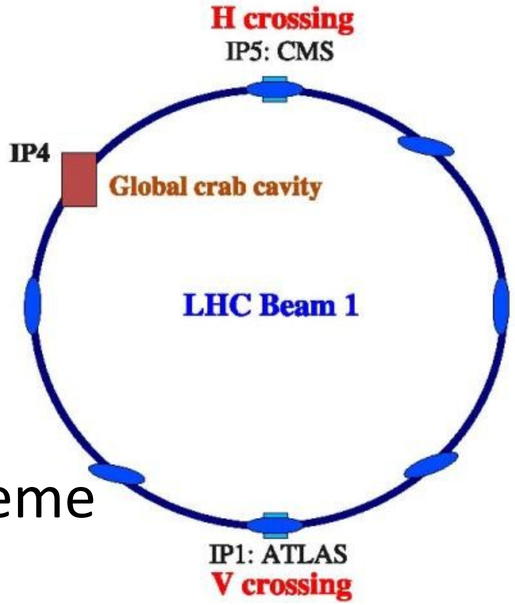
- Introduction – CC Motivation
- Events in 2010
- HL-LHC project, planning and design study proposal in FP7
- CC10 Meeting at CERN
  - Workshop goals, summary
  - Highlights – Cavity Technology
  - Workshop summary and recommendations
- Future work plan and events.

Crab crossing and Crab schemes





Local Scheme



Global Scheme

Some Events in 2010 – Chronological

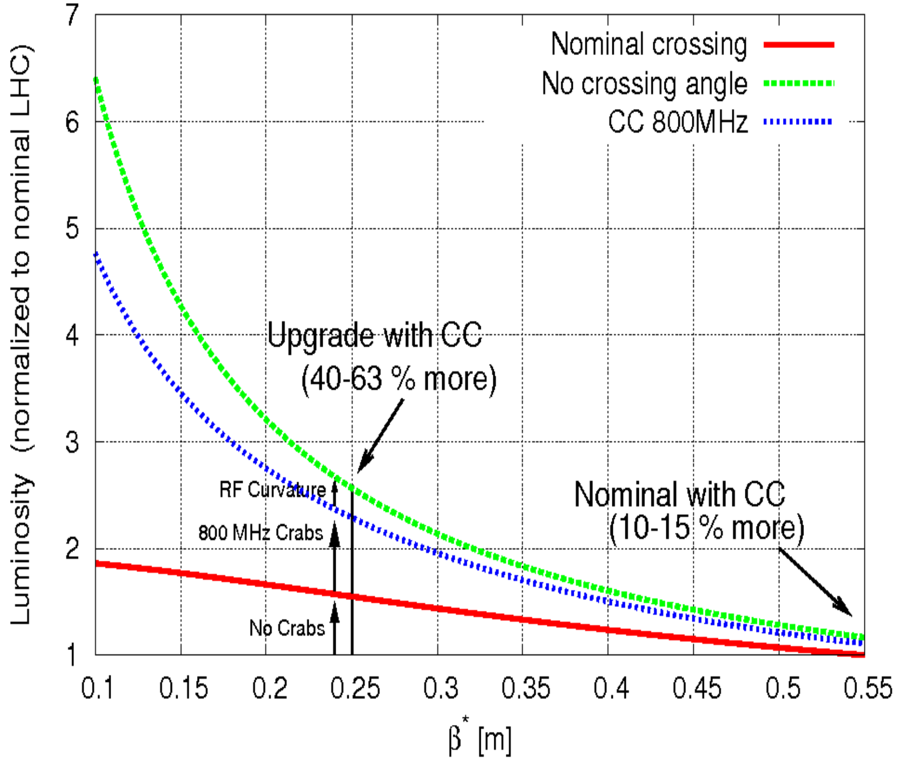
- Chamonix 2010 – LHC and Injector Upgrade Strategy examined
  (CCs presentation by R. Calaga in IR upgrade session)
- Set up of task forces on CERN Upgrades for LHC – Hi Lumi IR upgrade proposal
- EuCard SRF 2010 meeting at Cockroft Institute (April 8th)
- US LARP meeting at Fermilab (April 16th)
  => 'Mission Statement' for DoE support of US cavity prototyping
- Definition and approval of HL-LHC as one of CERN's four major projects
- **Preparation of LHC-CC project document** (July-present)
- EuCARD Milestone report on Crab Cavity Specifications (September)
- CI Workshop on deflecting cavities (September 10th)
- CERN / KEK discussions on test of a KEK B cavity in the SPS (September 17th)
- US LARP CM 15 meeting at SLAC (November 2nd)
- **FP7 EU proposal on HL-LHC Design Study** – (November 18th)
- **CC10 Meeting at CERN** (December 15th)

LHC IR upgrade proposal

Nominal luminosity 1.0E34 with 1.1E11 particles/bunch *(Now approaching **1.0E33**)*
Ultimate 2.3E34 with 1.7E11/bunch (Needs cryo upgrade in IRs)
Upgrade for 5-6E34, **keeping 1.7E11** needs (amongst other things)

- New triplets with lowest possible β* (~20 cm), based on high field Nb3Sn (or Nb3Al)

- **Compensation of geometric effect with crab cavities**



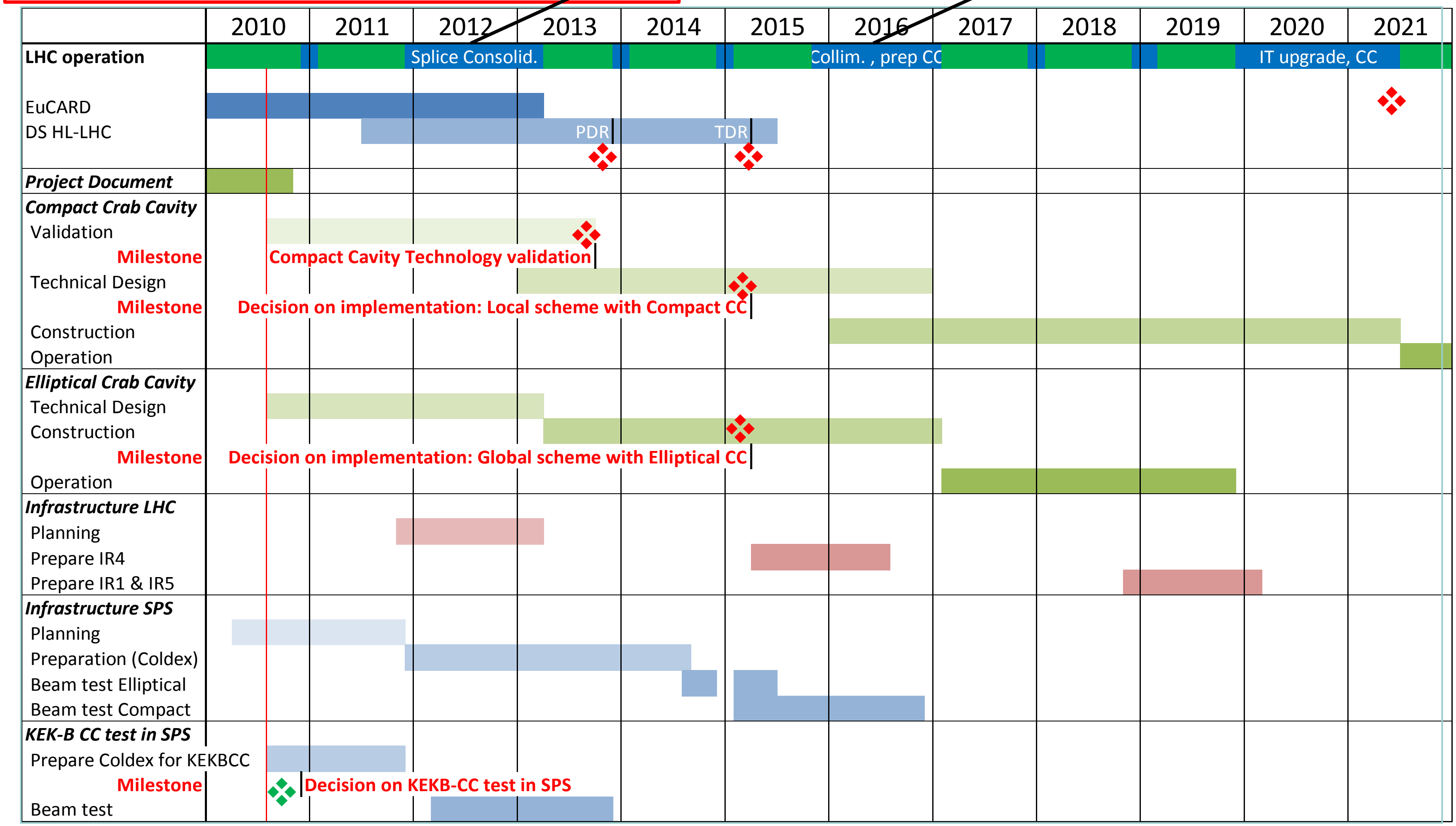
Considerable luminosity increase for β* <25 cm

Crab Cavities for HL-LHC – Project Planning

Original schedule of crab cavity activities synchronized with LHC operation & HL-LHC project. **TO REDO!**

LS1
Now Shifted – start end 2012, 20 mo. dur.

LS2



WP4: Tasks (after drastic reduction)

Task 1: Coordination and Communication (CERN, LARP, ULANC**)**	10 kCHF	8 pm
Task 2: Support studies • Tunnel preparation SPS and LHC (CERN) • Local IR layout and spatial integration (CERN, BNL) • Effect of phase noise , LLRF system conceptual design (CERN, ULANC, KEK, BNL, LBNL, SLAC) • RF power system specification (CERN, ULANC) • Operational aspects (how to commission/make invisible) (CERN, CNRS, BNL) • Interlocks and fast Feedback (CERN, LBNL)	18 kCHF	121 pm
Task 3: Compact Crab Cavity design • Cavity and cryomodule specifications (CERN, CEA, CNRS, STFC, ULANC, BNL, FNAL, ODU, SLAC, KEK) • Design optimisation for novel schemes (STFC, ULANC, BNL, ODU, SLAC, KEK) • Conceptual design of SOM, HOM and LOM couplers (STFC, ULANC, BNL, ODU, SLAC, KEK) • Conceptual design of helium tank and cryostat (CEA, CNRS, STFC, ULANC, BNL, FNAL, ODU, SLAC, KEK) • Multipacting simulations of cavity & couplers (STFC, ULANC, ODU, SLAC, KEK) • FEM simulations: mechanical & thermal aspects (STFC, ULANC, BNL, ODU, SLAC, KEK)	576 kCHF	235 pm
Task 4: Elliptical Crab Cavity Technical design • Coupler development and testing (CERN, CNRS, KEK) • Tuner design and mock up on copper models (CERN, • Study of mechanical effects: resonances, microphonics (CERN, • Cavity performance with couplers and horizontal cryostat (CERN, • Performance difference between 2 K & 4 K (CERN, • Cryostat and He Tank Design (CERN, CNRS	13.5 kCHF	86 pm
Task 5: Compact Crab Cavity Prototyping and Test • Construction of models to refine manufacturing techniques and tooling (CERN, ODU, KEK) • Fabrication of prototype niobium cavity (ODU, KEK) • Make the final CC design down-selection (CERN, ULANC, STFC, all US)	1,588 kCHF	28 pm

LHC CC10 Workshop 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 ?

LHC CC10 Program

Overview
KEK-B Achievements & Crabs , LHC luminosity achievements & limitations, LHC beams and luminosity evolution during the 2010 Run with some estimates on future projections. Perspective from the Experiments. HL-LHC Design Study & Crab Cavities.

Optics & Beam Physics Aspects
Upgrade optics with crab cavities, Effect of non-zero dispersion, Impedance effects during injection, energy ramp & store, Luminosity leveling with crabs, Very large crossing angle & magnet technology

Cavity Technology
ICFA deflecting cavity workshop summary, EuCARD cavity developments, LARP cavity developments KEK cavity developments, ODU/JLab cavity development, The Quarter Wave Resonator as a Crabbing Cavity

Cryomodule & Instrumentation
Slim elliptical cavity at 800 MHz for local crab crossing, Coupler (FPC & HOM) concepts for compact cavities, Thermal & mechnical analysis for compact cavities, Tuner concepts for compact cavities.

Crab Cavity Beam Studies
KEK-B noise experiments, SPS beam tests with crab cavities, Beam simulations for SPS tests, SPS (and LHC) instrumention for crabbed beams

Machine Protection
How to make crabs LHC safe & collimation compatible, Failure scenarios and mitigation, KEK-B crab trips & RF signals, LHC studies for RF trips, Interplay of transverse damper and crab cavities.

RF Controls & Testing
KEKB crab RF architecture & controls , Cryogenics for SPS, LHC & SM18, LLRF considerations for Crab Cavities

Schedule & Future Outlook
Field quality and non-linearity of deflecting mode, Overall planning of RF infrastructure, LHeC, HE-LHC other crab cavity applications

Cavity technology & cryomodule session

Presentations:

- Report on ICFA Deflecting Cavity Workshop (Alireza Nassiri)

- EuCARD Cavity Developments (Graeme Burt)
- LARP Cavity Developments (Zenghai Li)
- ODU/JLAB Cavity Developments (Jean Delayen)
- KEK Cavity Developments (Kenji Hosoyama)
- Quarter wave resonator as a Crab Cavity (Ilan Ben-Zvi)
- Slim Elliptical Cavity (Luca Ficcadenti)

- Coupler Concepts for Compact Cavities (Wolfgang Weingarten)
- Thermal & Mechanical analysis for CCs (Vittorio Parma)
- Tuner Concepts for Crab Cavities (Alireza Nassiri)

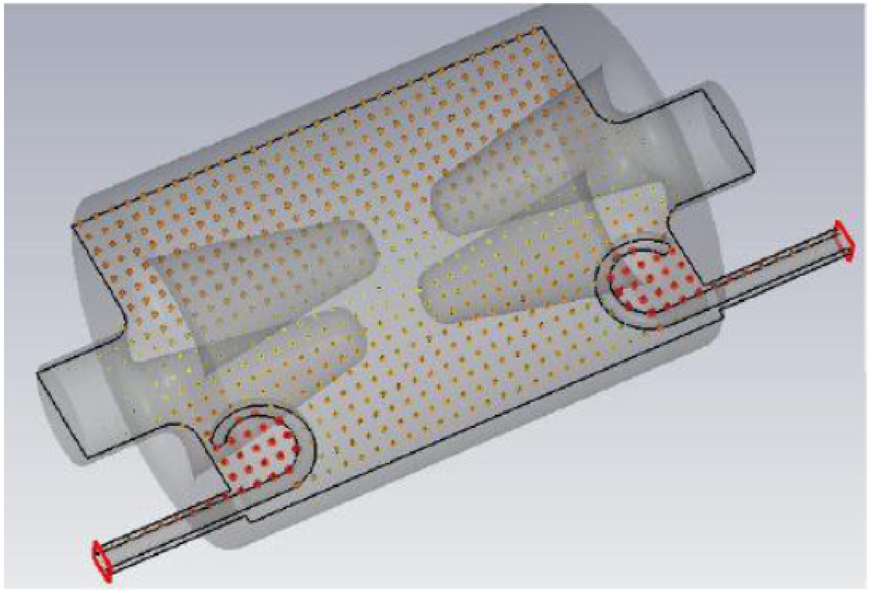
Session Goals – to present, for each design:

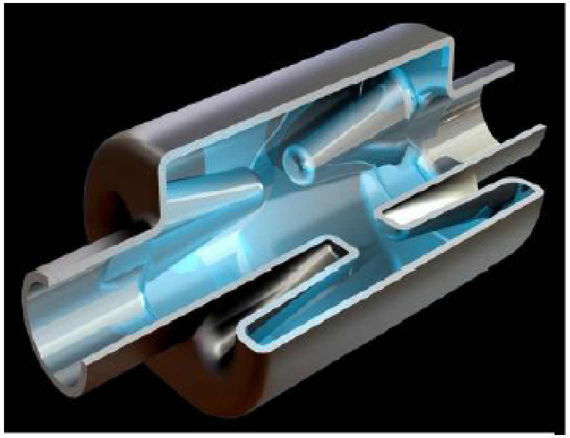
- Status of design & developments
- Detailed cavity coupler design, deflecting mode characteristics
- HOM spectra and achievable damping
- Coupler configurations
- Mechanical tolerances
- Multipactor
- Tuning concepts
- Cavity fabrication, treatment,
- Assembly of couplers
- He vessel, ancillary equipment
- Non linearity of deflecting voltage with transverse displacement

Complete, but ambitious!

Four Rod CC (Cockroft) (G. Burt)

Four Rod Compact Crab Cavity (Cockcroft)



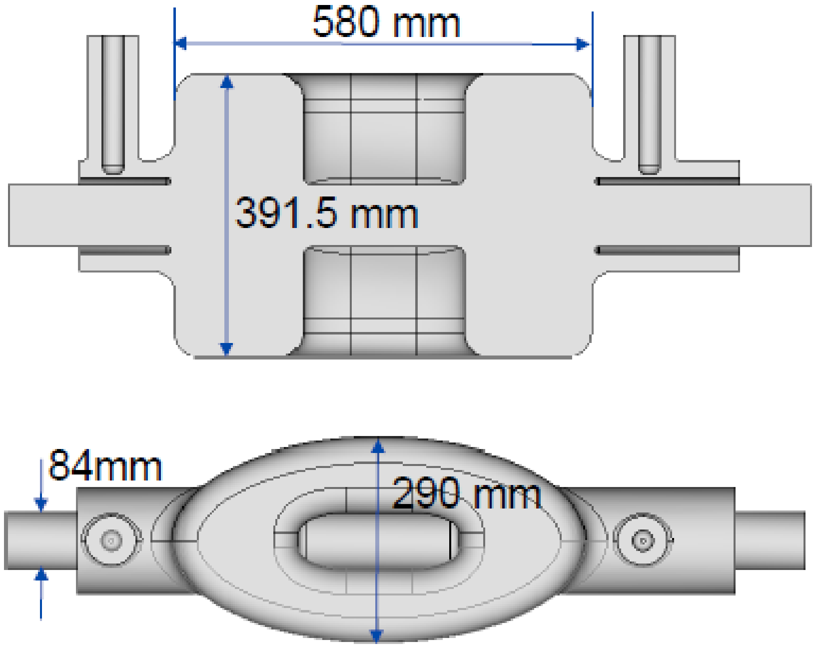


FPC: on cell waveguide coupler

LOM/HOM coupler: on cell waveguide coupler, achieved Q_{ex} ~ 100; on cell coaxial loop couplers under study, meet requirement Q_{ex} ~ 70

→ promising ongoing design

400 MHz HWSR Cavity Parameters



RF parameters calculated with all damping features included

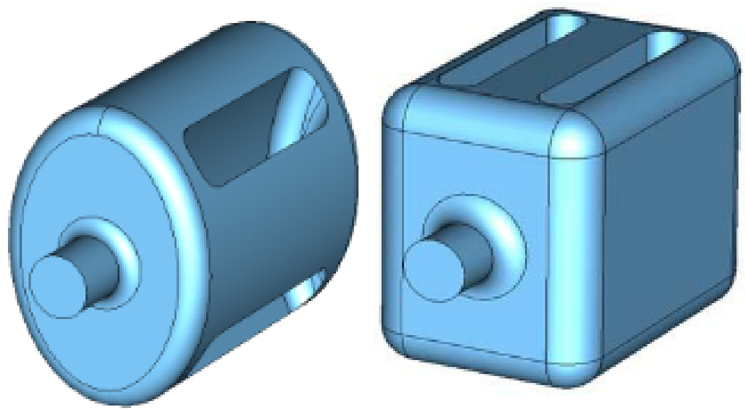
Parameters	
Cavity Width (mm)	290
Cavity Height (mm)	391.5
Cavity Length (mm)	580
Beam pipe radius (mm)	42
$(R/Q)_T$ (ohm/cavity)	215
E_S/V_T ((MV/m)/MV)	**10.4**
B_S/V_T (mT/MV)	**19.5**

- 10 MV deflecting voltage required
- 2 cavities/beam, 5 MV each

TESLA TDR cavity peak fields for comparison
Eacc: 35 MV/m: Epeak: 66 MV/m; Bpeak: 140mT

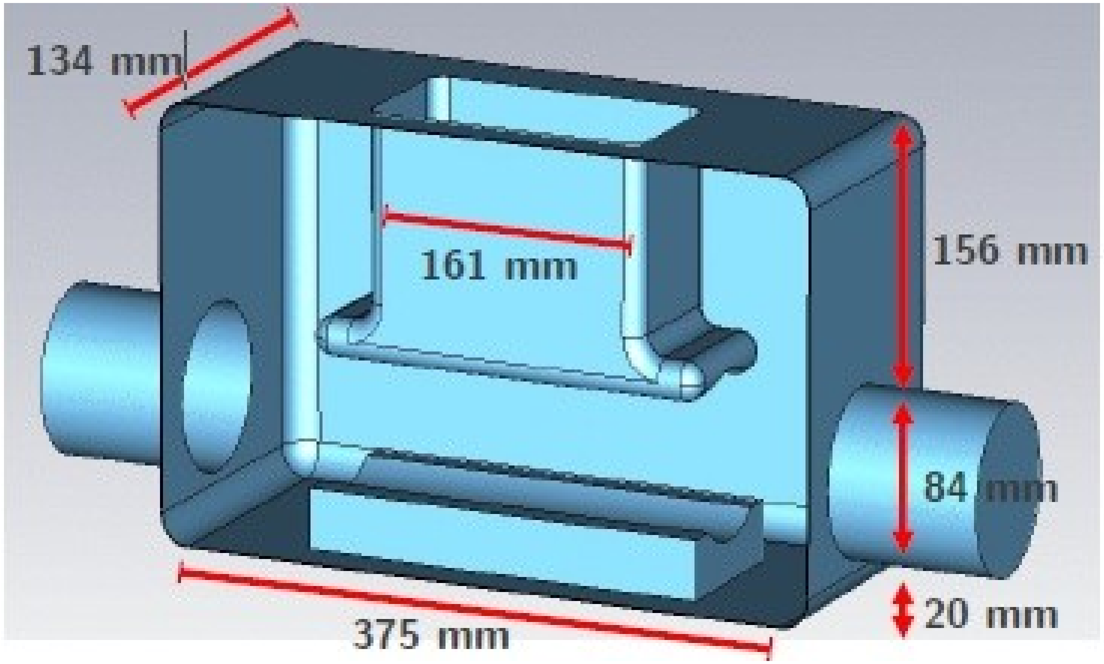
Cavity Properties – Elliptical Design

Parameter	Rectangular Shaped	Elliptical Shaped	Unit
Frequency of π mode	400.0	400.1	MHz
λ/2 of π mode	374.7	374.7	mm
Frequency of 0 mode	411.0	677.1	MHz
Nearest mode to π mode	411.0	609.2	MHz
Cavity reference length	444.7	445.0	mm
Cavity width / diameter	300.0	295.0	mm
Cavity height	383.2	406.0	mm
Bars length	330.0	330.0	mm
Bars width	55.0	60.0	mm
Aperture diameter	84.0	84.0	mm
Deflecting voltage (V_T^*)	0.375	0.375	MV
Peak electric field (E_P^*)	2.2	2.7	MV/m
Peak magnetic field (B_P^*)	7.9	6.03	mT
B_P^* / E_P^*	3.6	2.23	mT / (MV/m)
Geometrical factor ($G = QR_S$)	74.1	108.9	Ω
$[R/Q]_T$	413.34	262.63	Ω
$R_T R_S$	3.1×10^4	2.7×10^4	Ω^2
At E_T^* = 1 MV/m			



- Surface magnetic fields have improved by 24%
- Frequency separation of the first two modes ~ 209 MHz compared to 11 MHz in the rectangular design
- Reduced cavity width to meet the LHC crab cavity specifications

Quarter Wave Resonator as a Crab Cavity



- The QWR is a simple, ultra-compact and efficient crab cavity.
- Outstanding separation of the unwanted modes.
- A small disadvantage is the (small) acceleration imparted to the beam
- It fits with both beam line cavities side-by-side!

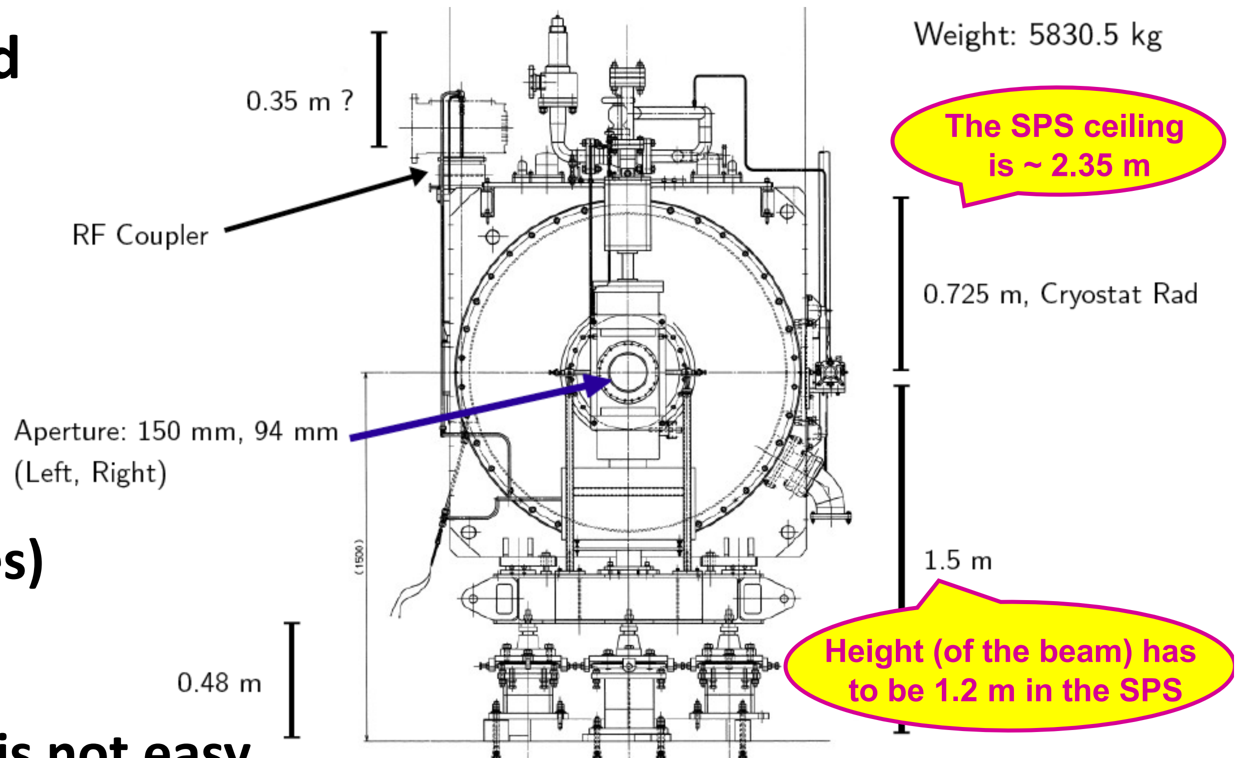
Installing a KEK-B Cavity in the SPS

Practical details studied

No show-stoppers

But …

- **It is big (r = 73cm)**
- **High (beam height nominally 1.5m)**
- **And Heavy (~6 Tonnes)**



Integration into the SPS is not easy.

- **The beam axis must be lowered by 30cm to fit the SPS (1.2m)**
- **Installing it with a bypass looks very difficult because of the weight and also the stroke of the bypass**
- **Not cheap. Including modifications and testing here >2MCHF.**

CC10 Cavity Design Session - Conclusions

- Three - four CC design presented, they have reached initial design specifications
- Good progress has been made since CC09.
- Engineering designs advanced or complete
- For all, plans exist on how to to reach HL-LHC Milestone 1 of bare cavity test and validation.
- We are ready for prototyping.
- The designs of cryomodules and ancillaries will continue in order to be finalized for Milestone 1.

Have reached the stage where there is no fundamental show stopper for embarking on first hardware prototypes

CC10 Executive summary

- **Crabs are the *baseline* tool for geometric compensation and luminosity leveling for the HL-LHC**.
- **No show stoppers have been identified for the compact cavity designs** .
  Three or four promising designs exist.
- **Cavity engineering design and prototyping should follow**.
- **No cavity down selection to be made now.** Down selection after conclusive results from prototyping , by the end of 2013.
- **Identical systems for both IPs are preferable but this is not an absolute requirement.**
- **KEK-B crab cavities will not be installed in the SPS**
- **Machine protection with crab cavities** needs detailed investigation with realistic RF failure signals in conjunction with the upgraded collimation system**.**
- **A clear timeline for cryomodule development and prototype testing** to be put in place

Future work plan and events

- **Machine protection**:
  - RF modeling of cavity and feedback behavior with beam AND
  - Tracking simulations with HL-LHC 'Nominal' collimator system .
- **Beam dynamics and optics:**
  - Specialist input on transverse impedances effects with actual cavity modes - Present global boundary limits too pessimistic ?
  - Field linearity limits to be specified by machine physicists.
- **Horizontal / Vertical crossing**
  - Cavity designers are looking at variants…
- **Main immediate technical goal is to RF test hardware prototypes:**
  - To this end a **1 day meeting on Cavity Engineering** is planned for September, focused on engineering/fabrication aspects of the crab cavity candidates. Will be organized jointly with CERN, LARP & EuCARD.
- **Cavity-beam testing foreseen in 2016 in SPS:** Test bench beam experiments 2011-16, Sources of the SPS emittance growth should be identified/studied

Spare slides

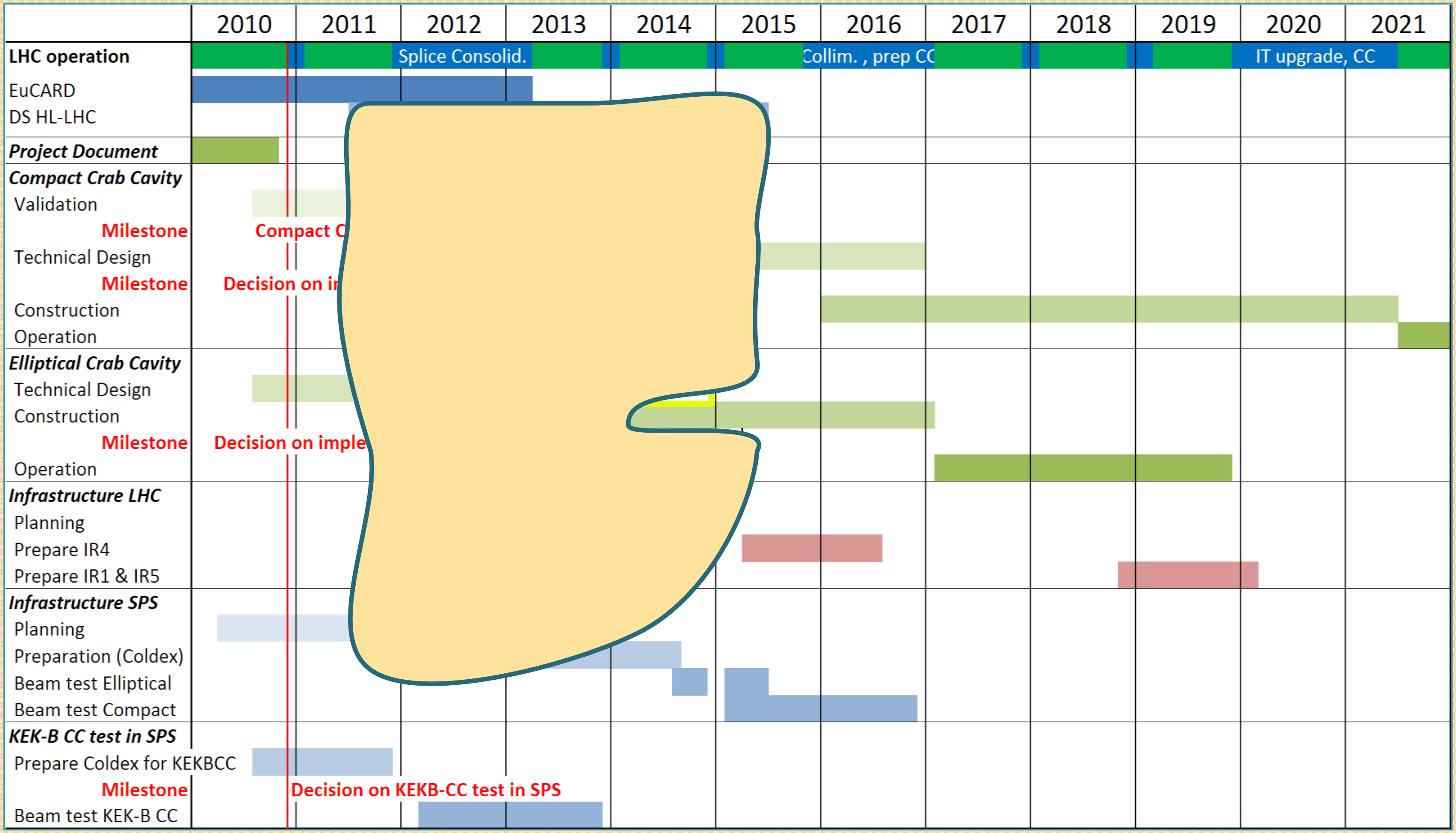
Task 3. LHC Crab cavities:

- Design, build and test a single LHC and CLIC crab cavity module, including input coupler, mode couplers and tuners.
- Design, build and test a LLRF and synchronization system that meets the crab cavity phase and amplitude control specifications for LHC and CLIC.
- If the beam time and the necessary hardware become available, validate and test the assembled crab system solutions and LLRF control systems on LHC and CTF3 in 2011; otherwise make performance predictions based on the measured noise characteristics.

Sub-task 1:

- STFC, ULANC and CERN will determine the full LHC system requirements for the crab cavity system and then STFC and CERN will develop a suitable crab cavity design which meets these requirements;
- ULANC will develop suitable input and mode couplers to allow for damping of the dangerous trapped modes. The global non-EU collaboration will develop the SOM and HOM couplers.
- A suitable frequency tuner will be developed by ULAN-CI and CERN.
- Validation of expected cavity performance will be completed by fabrication of a model test cavity and collectively STFC, ULAN-CI and CERN will perform mode characterization measurements

FP7 DS: Within the bigger picture



plus: new cryoplant IR4, RF power systems, LLRF, ...