Motivation and CERN Strategy for Crab Cavities

E. Ciapala (CERN)

With thanks to R. Calaga (BNL), E. Jensen and J. Tuckmantel (CERN)

ICFA Beam Dynamics Mini-Workshop on Deflecting/Crabbing Cavity Applications in Accelerators,
September 1-3, 2010.

Motivation and CERN Strategy for Crab Cavities

- Crab/deflecting cavity applications at CERN

  (**CTF3**, CLIC (A. Dexter, this WS), LHEC, **LHC**…)

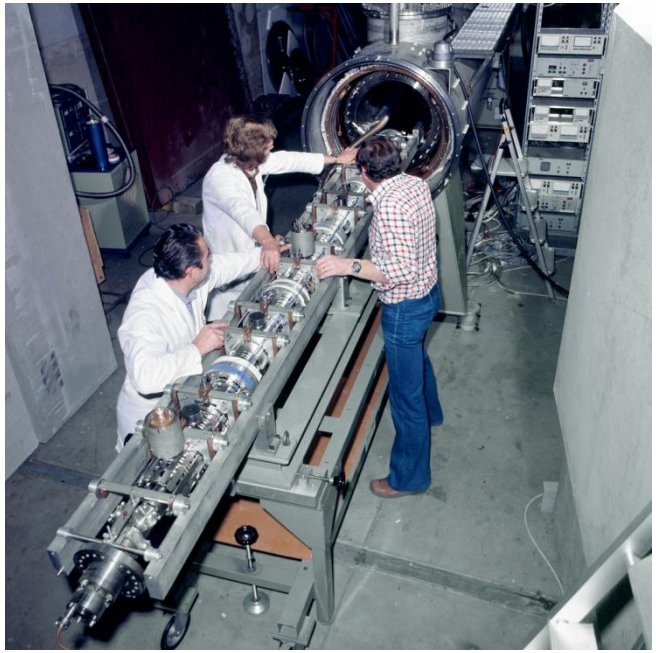
- The LHC High Luminosity Upgrade (HL-LHC)
  - Crab Cavities for HL-LHC
  - Strategy and major milestones
  - Project organization and planning

- Conclusions and Outlook

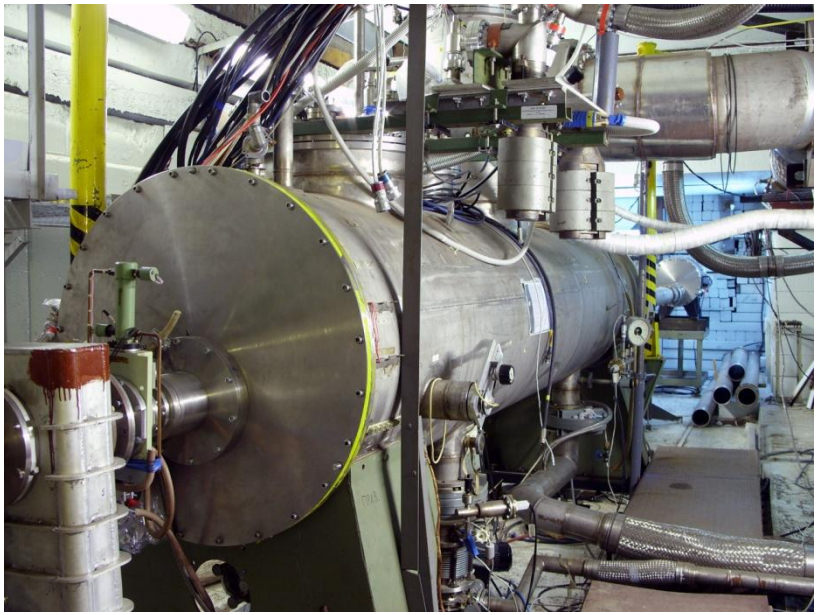
Deflecting cavities at CERN

Early Example - Superconducting Separators:

- Developed early 70's by Karlsruhe and CERN for SPS physics, to separate kaons and antiprotons in energy range 10 to 40 GeV/c (W. Bauer/H. Lengeler)
- Superconducting 104 cell 3 GHz structure in 5 sections
- Mean deflecting field of 3 MV/m (47 mT peak)
- Early use of SC cavities … Precursor LEP…



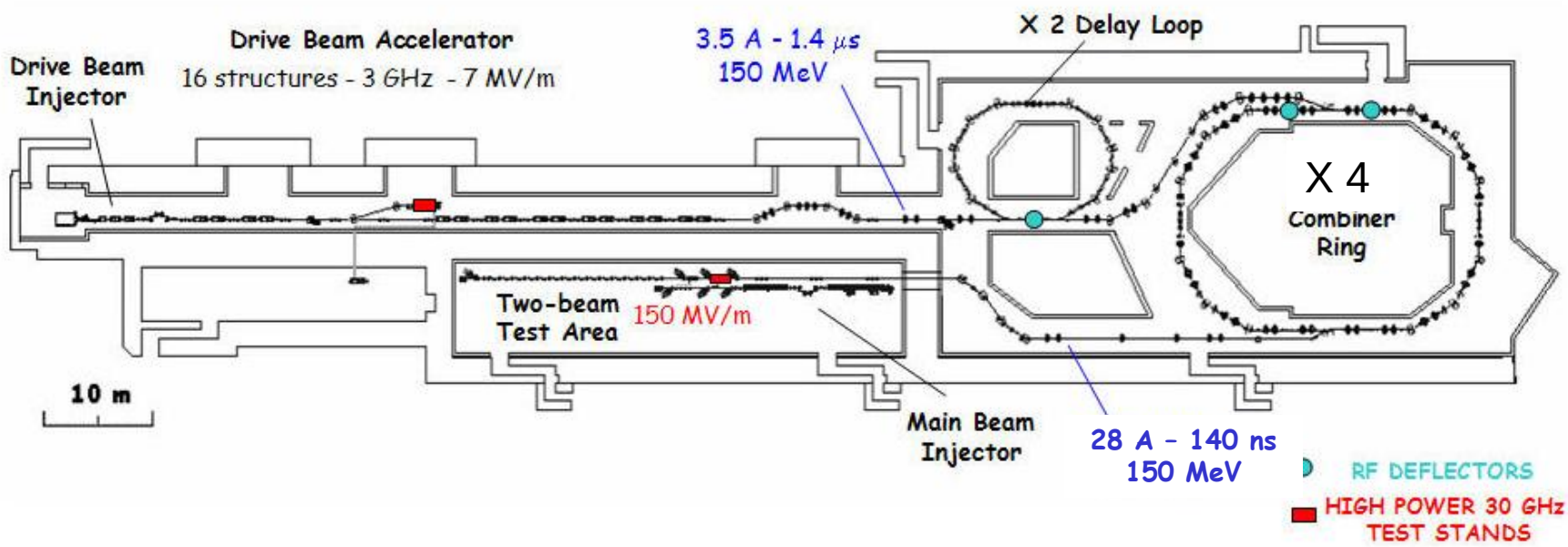
Superconducting RF separator for Omega Spectrometer



Still in beam line at Serphukov – May 2009
(Courtesy Boris Prossine IHEP)

CTF3 - Delay loop and Combiner Ring

CTF3 Layout

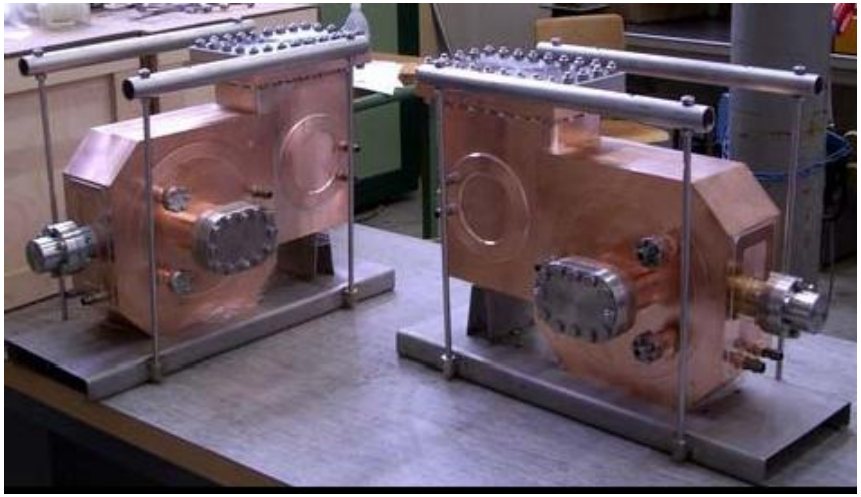


At the input to delay line (DL) , bunches are spaced by 20 cm (two 3 GHz buckets) and have a charge of 2.3 nC per bunch, corresponding to an average current of 3.5 A. with a beam energy of 150 MeV.

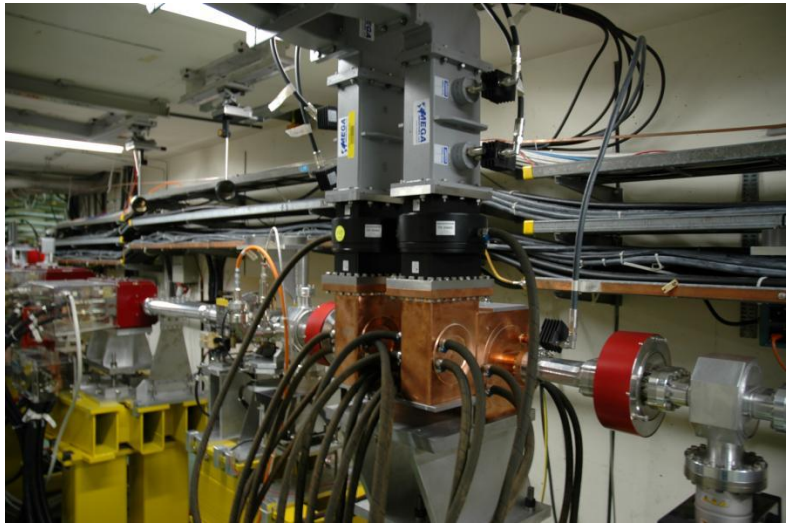
In the DL. A first stage of electron pulse compression and bunch frequency multiplication is obtained using a 1.5 GHz transverse RF deflector and a 42 m delay loop.

This is followed by a 84 m combiner ring (CR), in which a further factor four in pulse compression and frequency multiplication is obtained. At this point the drive beam pulse is 140 ns long with a current of 28 A. The 2.3 nC bunches are spaced by 2.5 cm.

Deflector in the CTF3 Delay Loop



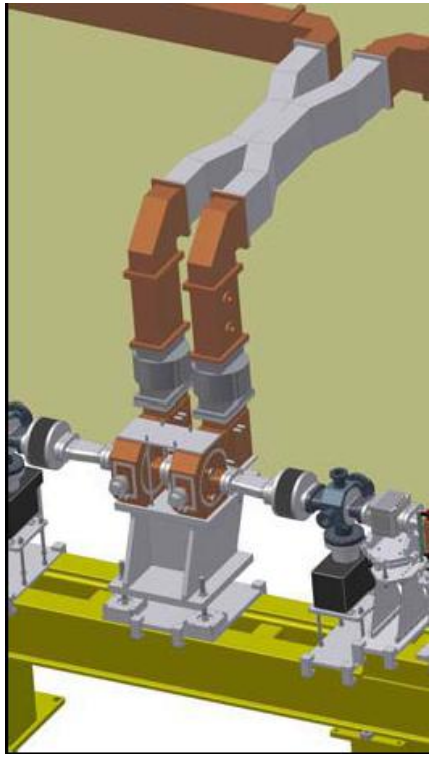
The two RF cavities of the DL deflector



Designed and built by INFN Frascati

See Fabio Marcellini, David Alesini, EPAC 2006

Cavities operate in TM110 mode, spaced 5/4 λ apart, connected via hybrid with reflected power going to a load

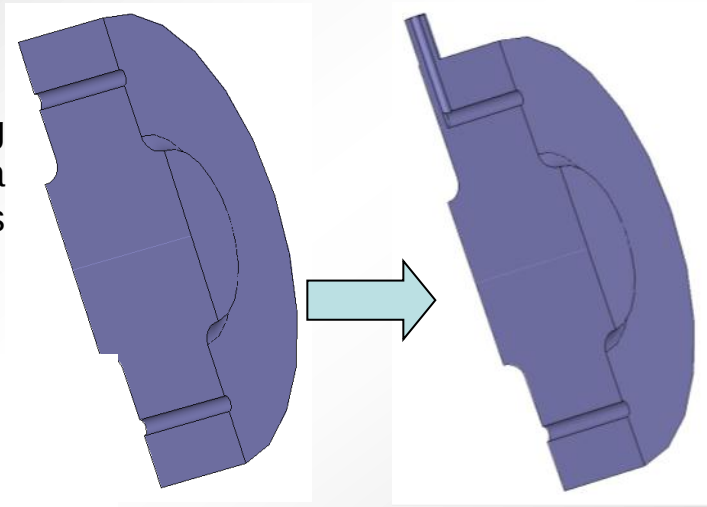


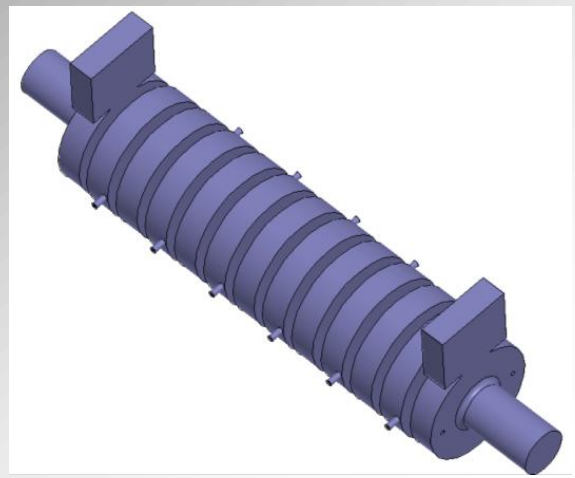
NEW CR RF DEFLECTOR DESIGN: (D. Alesini, LNF-INFN, Frascati.

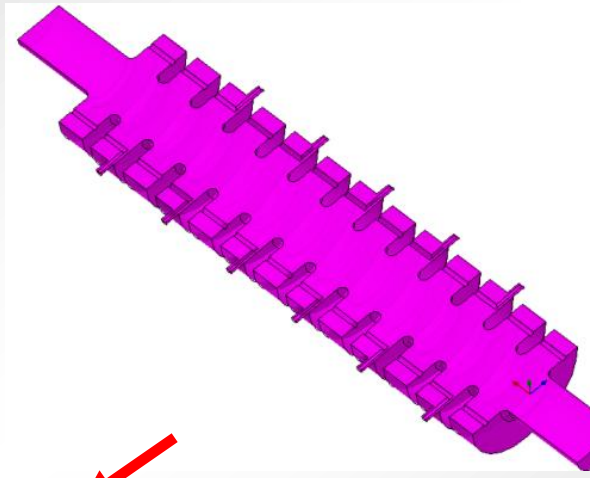
CTF3 Collaboration Meeting January 2009

To damp the vertical modes excited by the beam the rods in the cell have been modified in order to act as damping antennas.

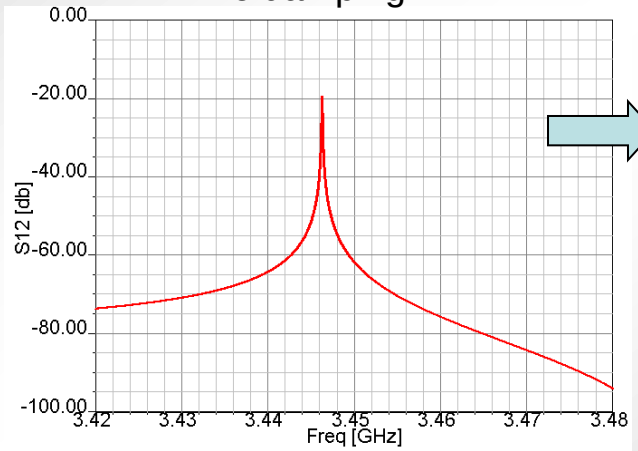
The result is a strong damping of the vertical modes and a further shift of the frequencies of the vertical modes.
Example: Mode $2\pi/3$



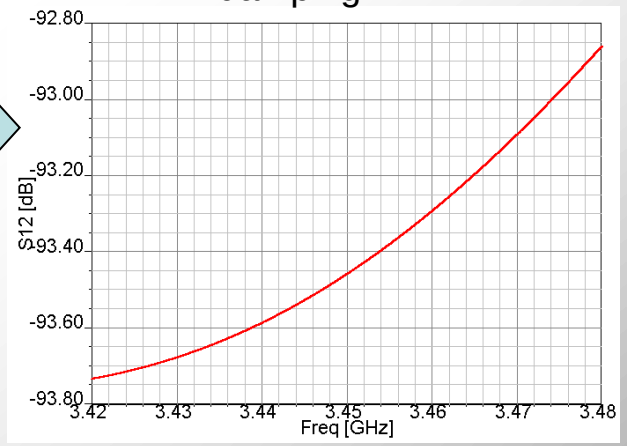


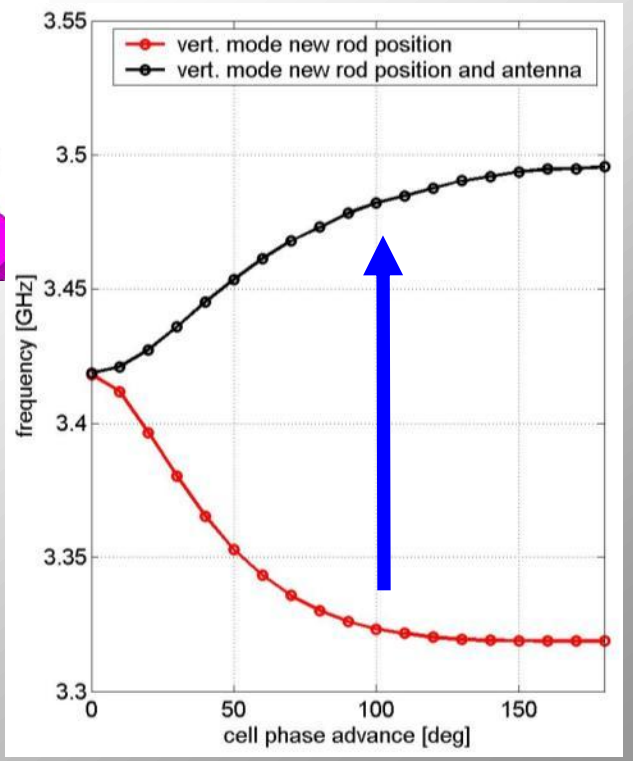


No damping



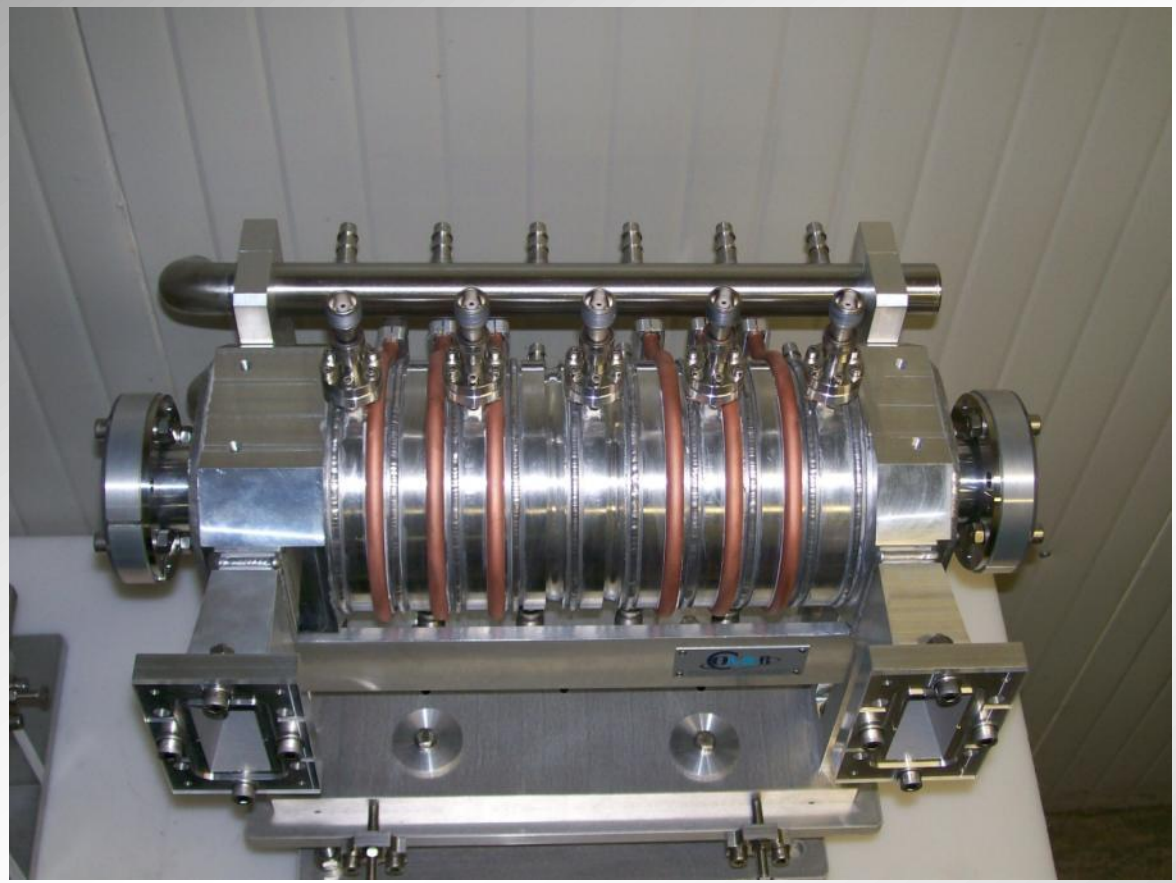
damping

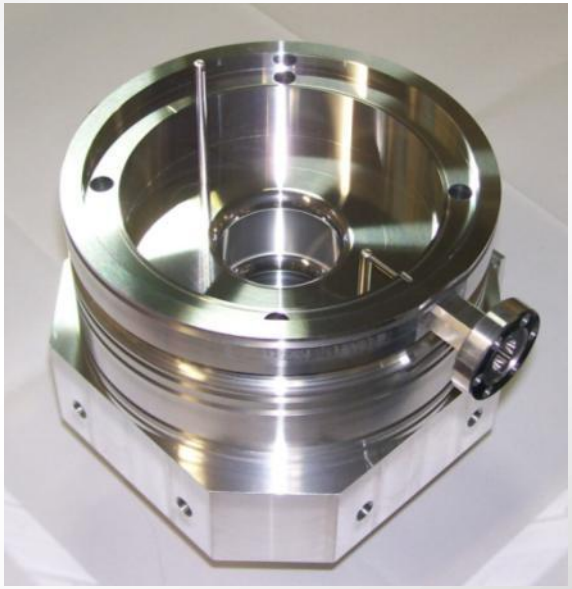




DEFLECTOR REALIZATION

To reduce the cost and the delivery time of the device we decided to built the new RFDs in ***aluminium***. The cells have been machined, clamped together with tie rod to guarantee the RF contacts and welded.





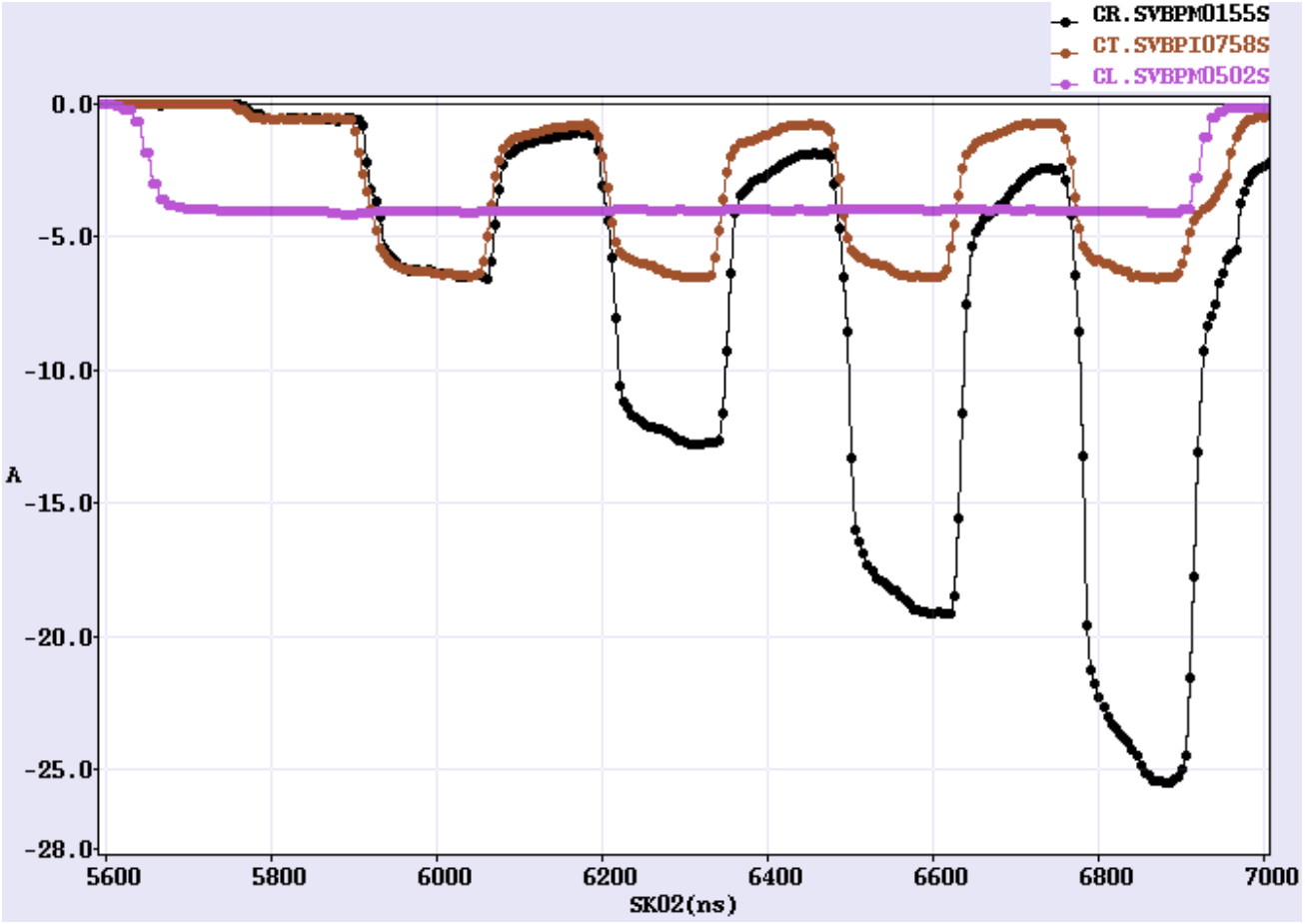
Aluminium design was very successful, very little multipactoring and rapid conditioning…

Delflecting cavities at CERN

CTF3: Combiner Ring

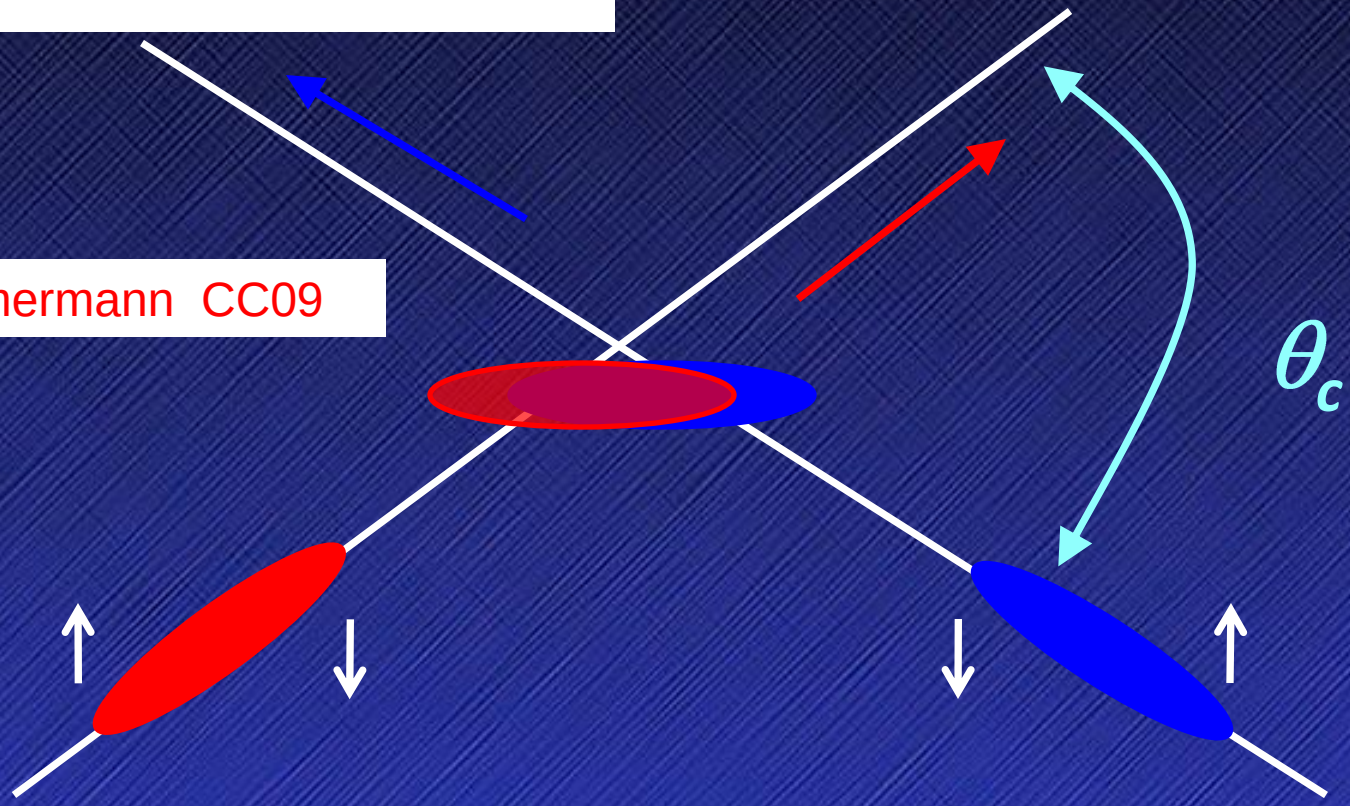
Bunch frequency multiplication (x 4) in the CTF3 Delay Loop.

Major milestone for CTF3 in 2009…



LHC Crab Cavities

F. Zimmermann CC09

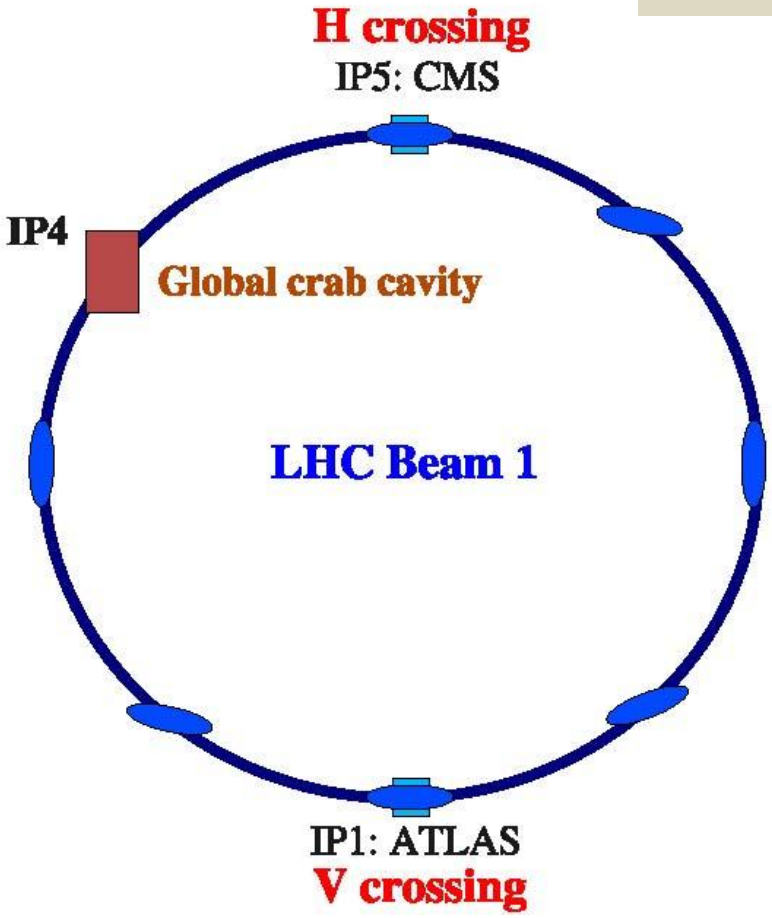


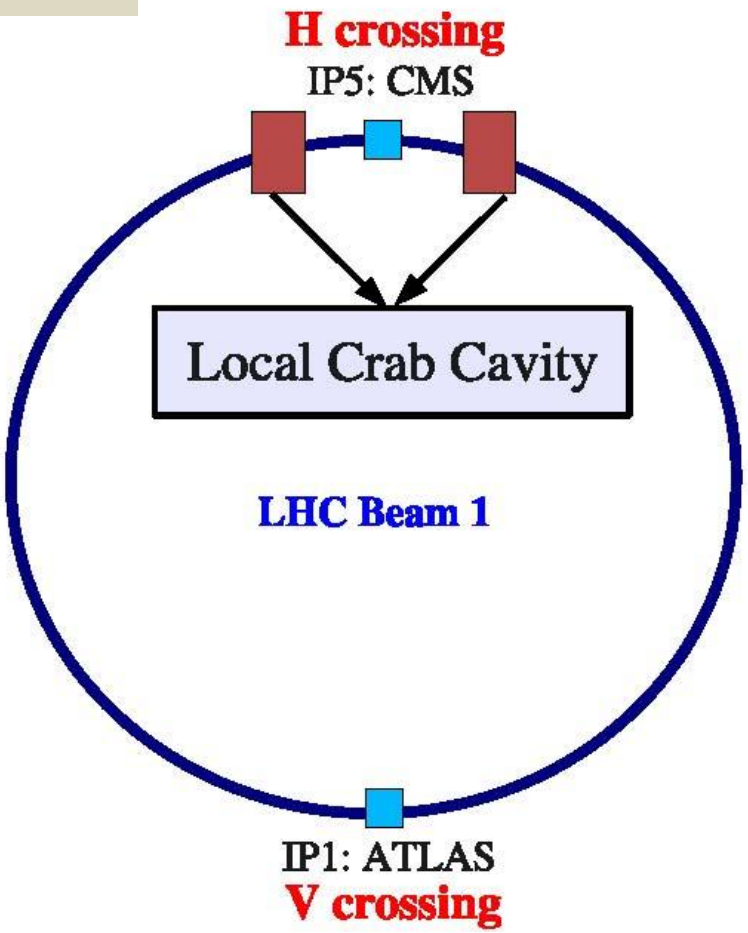
- **RF crab cavity deflects head and tail in opposite direction so that collision is effectively "head on" for luminosity and tune shift**
- **bunch centroids still cross at an angle (easy separation)**
- **1st proposed in 1988, in operation at KEKB since 2007**

→ ***world record luminosity!***

LHC Staged implementation – Original Proposal

F. Zimmermann

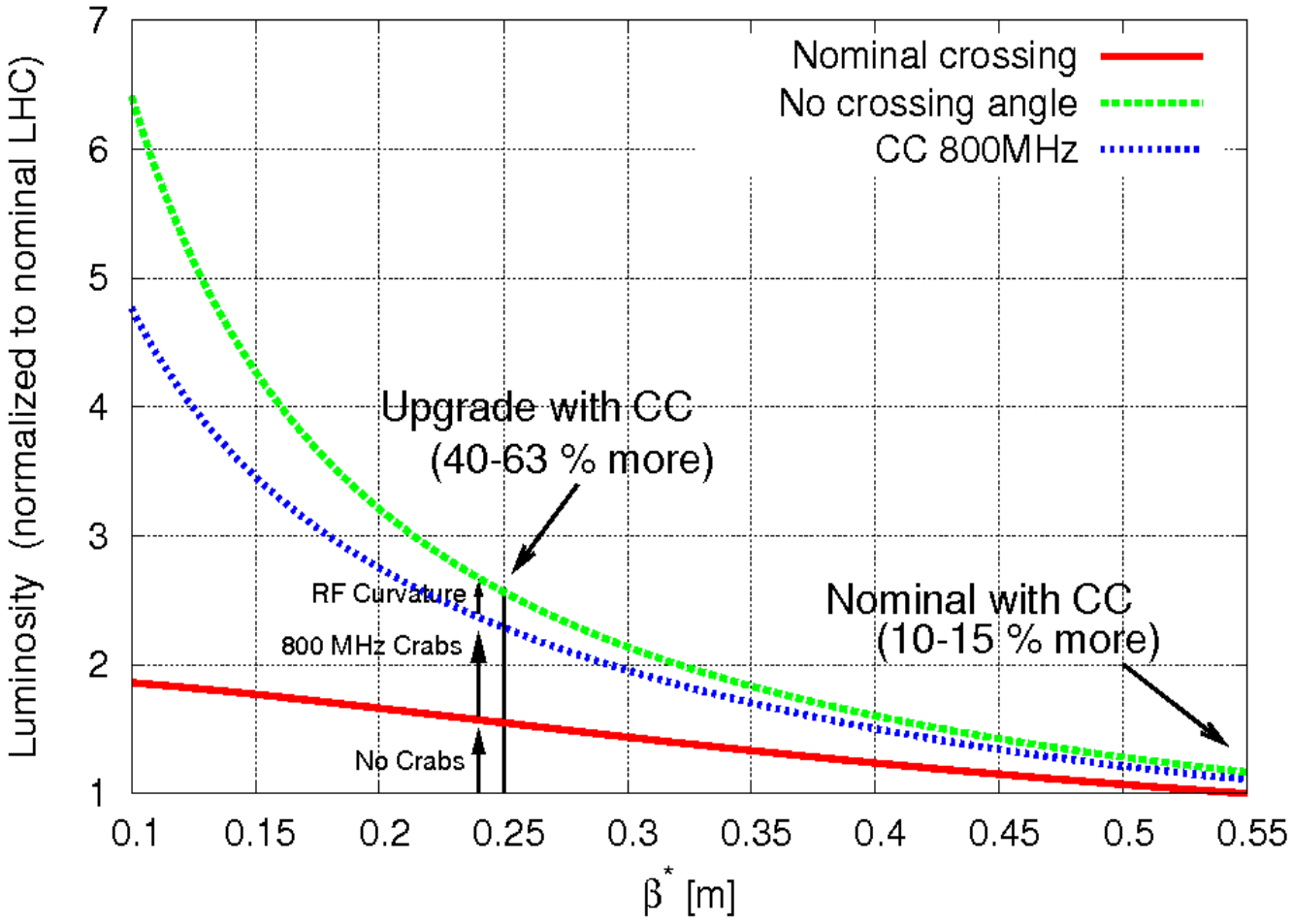




phase I – Global Scheme

phase II – Local scheme

Luminosity Increase with CC



LHC-CC Workshop 2009 - Conclusions

- Time scale for 2014/15 shutdown too short, even to install a Global Scheme in IR4
- Space reservations in IR4 for ADT upgrade and ACN installation needed to be kept open
- Better to pursue longer-term Local Scheme around the experimental IRs, using compact cavities.

- Look at possibility of installing the ex-KEK crabs in SPS.
- 'Downsize' the number of compact cavity options to one or two

- ! Crab Cavities - Considered a very attractive option compared to intensity increase, further work strongly encouraged by CERN management.

- **BUT** do not use LHC as a test bed !
- Issue with machine protection to be studied

- Also many other issues under study

LHC and the HL-LHC Luminosity Upgrade

- The LHC has made an excellent start to its physics program.
- It will be the energy frontier machine in high energy particle physics for the foreseeable future.
- Maximum effort is now being put into ensuring that machine and experiments operate optimally at their design performance in order to allow full exploitation of the present physics potential.
- Now reached >**10^{31}cm^{-2}s^{-1}**, (50 on 50) aiming for **10^{32}cm^{-2}s^{-1} by end 2010**, and total integrated luminosity of **1 fb^{-1} by end of 2011**
- Push towards 7 TeV after 2012 shutdown and consolidation
- After reaching nominal parameters the challenge is to aggressively pursue the experimental goal of **3000 fb^{-1}**.
- This can only be achieved with an LHC upgrade **HL-LHC** that can reach beyond the ultimate intensities, with β^* well below the nominal and by having luminosity levelling.
- The IR upgrade will use Nb_3Sn magnets at 13-15 Tesla, β^* down towards 22 cm.
- => Compensation of beam crossing angle **essential**.

LHC Luminosity Upgrade – HL-LHC

- HL-LHC *is one of CERN's four major planned upcoming major projects, along with:*
- LHC and Injector consolidation,
- Injector intensity upgrade and
- Future linear collider.

- HL-LHC Project leader will be Lucio Rossi
- Overall project planning and costing in progress
- CERN BE-RF takes responsibility for CC activities , an essential part of HL-LHC, and a **major project** in itself. (E. Ciapala/E. Jensen)
- CERN's role is Project Coordination, Integration, some technical work…

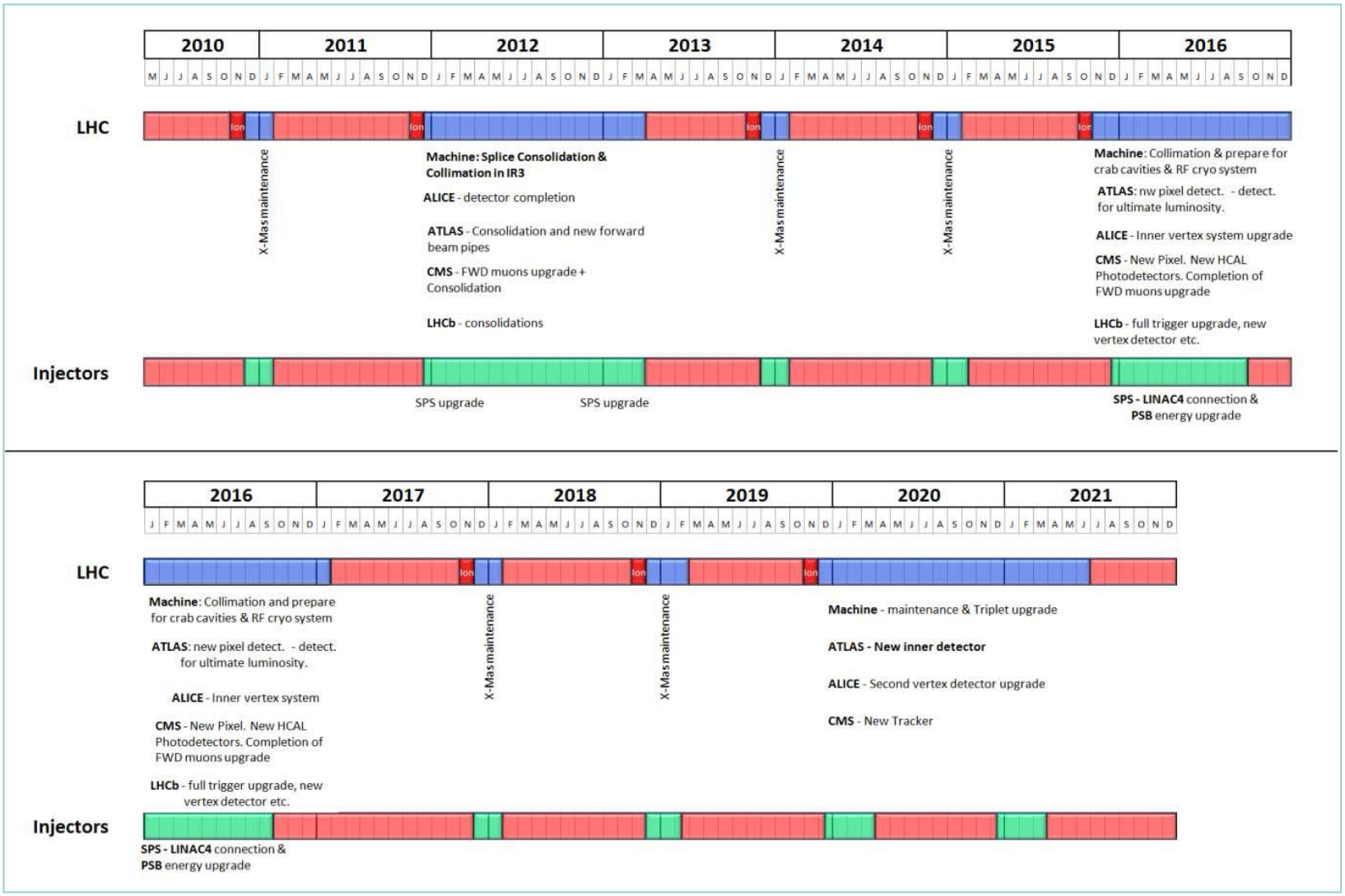
- A very large part of the effort - study, design and technical, will hopefully come from outside partners - partnerships and collaborations are essential.

⇒ Strong involvement already from US-LARP, Cockroft Institute, Saclay and others..

- We are preparing a project description outlining the strategy, the planning, milestones, breakdown of activities and the costing of all the crab cavity options.

- Outlined in later slides…

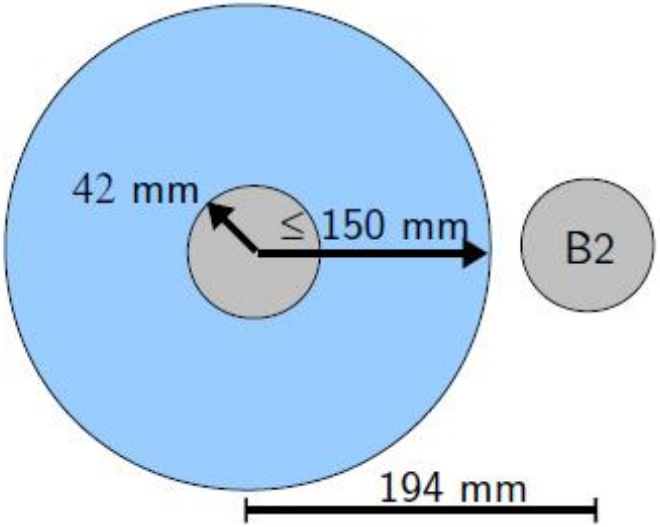
LHC and Luminosity Upgrade – Tentative Plan



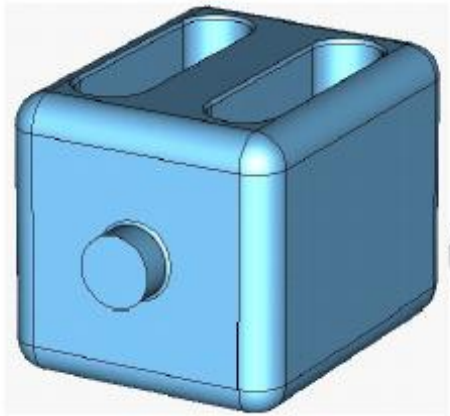
- Major shutdowns 2016 and 2020/21 (preparation & actual installation)

LHC Needs Compact Cavities

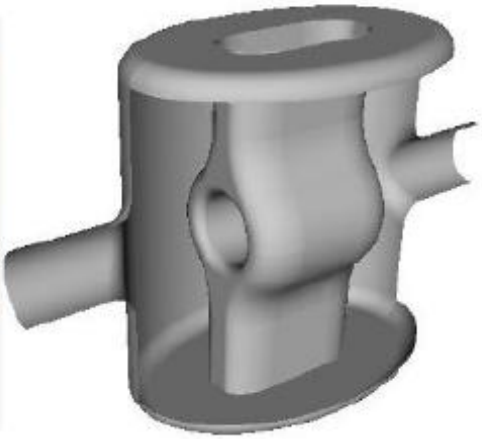
R. Calaga
Chamonix 2010



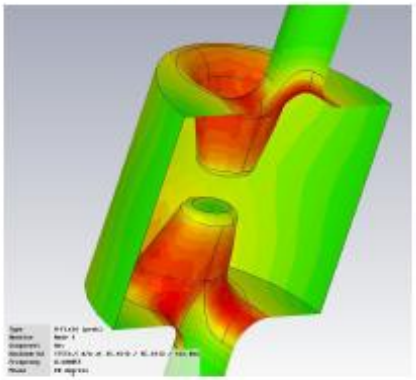
HWDR, JLAB,OD



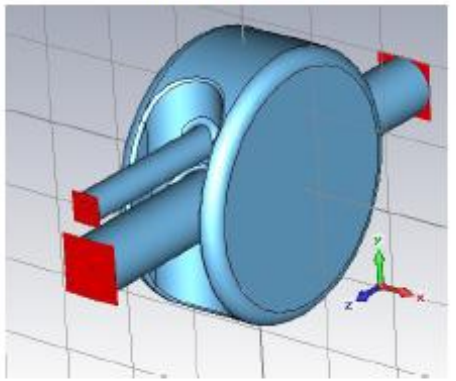
HWSR, SLAC-LARP



DR, UK, TechX



Kota, KEK



Compact cavities aiming at small footprint & 400 MHz, 3-8 MV/cavity

Proposed Strategy for Crab Cavities

Main Goal : Compact Crab Cavities for LHC Local Scheme

(Generally following CC09 workshop recommendation)

- Complete conceptual designs of the main candidates
- Down-select to at least two designs, for each:
  - Technical design: specification and mechanical drawings of cavity
  - Conceptual designs for tuner and He tank
  - Valid designs for the SOM,HOM and LOM couplers
  - Initial studies on cryostat design
- Hardware prototyping and test on above:
  - Construction of bare cavity prototypes (copper) tooling, manufacturing techniques.
  - Fabrication of a bare Nb cavity
  - Cleaning, electropolishing, surface inspection (all using all the necessary specific equipment and instrumentation
  - Low power tests and measurement in a test cryostat to confirm gradient and performance

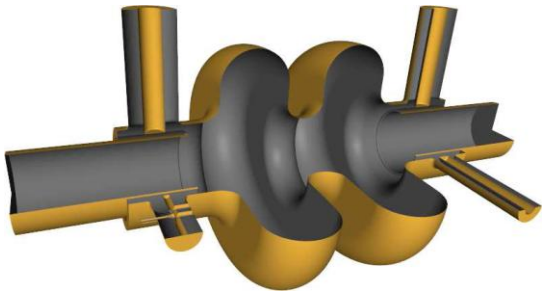
=> A substantial R&D program, leading to a decision on final design to be retained

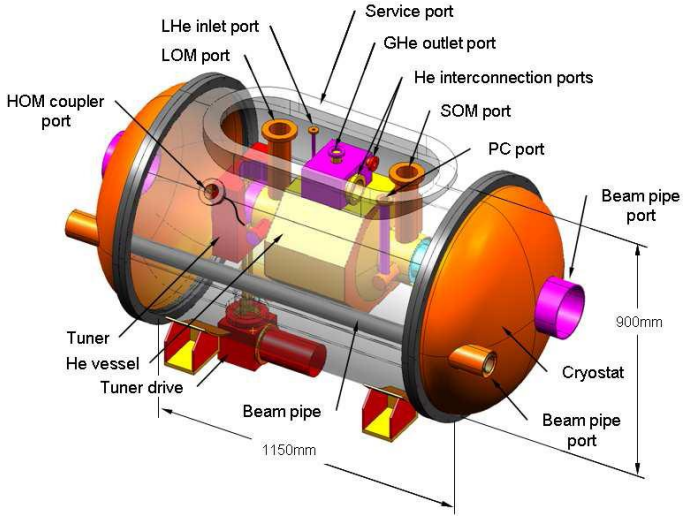
Back-up strategy for Crab Cavities

Retain a conventional cavity option in the unlikely event of major unforeseen 'show stopper' with all compacts…

- Would entail significant civil engineering costs and use of dogleg sections in the IRs, but this would still be acceptable, in view of the value of gaining back significant luminosity from the crossing angle.

- A straightforward conventional cavity installation in IR 4 as a global scheme would serve as an alternate option in the worst case. To this end, for the TDR, a full mechanical design of the elliptical cavity, its accessories and the elliptical cavity cryostat must be prepared.





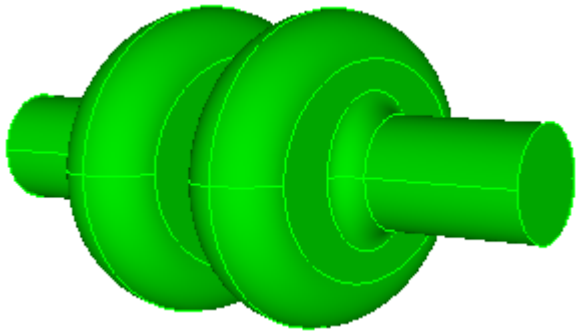
Proposed Strategy for Crab Cavities

Work program for 'Conventional' elliptical cavities

e.g.

800 MHz 2-cell elliptical, baseline design in LARP
Presented at LHC-CC09, Liling Xiao, Zenghai Li:

- Shape and frequency considerations
- 800-MHz elliptical cell optimization
- LOM, SOM, HOM damping coupler design
- Input power coupler design
- Multipacting analysis
- Tolerance Studies
- Beamloading and power requirements



Short development time, simpler than compacts, elliptical geometry.
800 MHz a 'standard' frequency at CERN

Proof of Principle and tests in other machines

KEK cavity – Proof of Principle in SPS

- Following CC09, the study of the feasibility of installing the ex-KEK crab cavities in SPS was proposed
- A working group under E. Metral made a preliminary study (2009) with some basic conclusions:
  - CCs needed by KEK to end of 2010
  - Need modification (at KEK) to get 511 MHz (present is 509 MHz)
  - Increase Qext
  - Space available in SPS at COLDEX.41737.
  - Cryogenics available (minor controls upgrade needed)
  - By pass needed to avoid high beam intensity, CC used only in MD

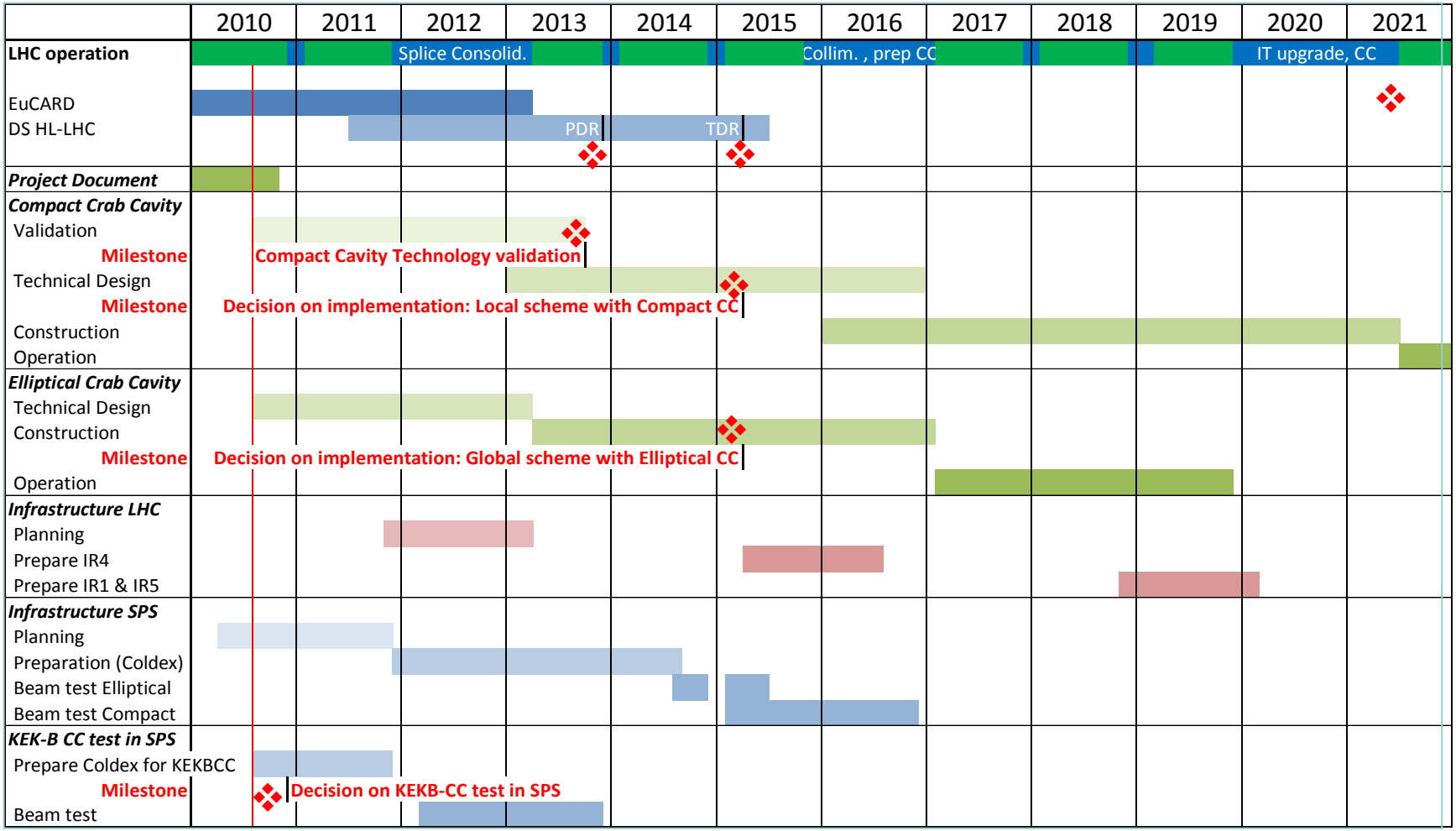
=> First tests could only be in 2012, but 2012 SPS running not now planned !

  - Power system (IOT) needed, LLRF & Controls
  - Need to power test & condition before installing in SPS..

- **Concern over effort needed and real value of the results, in view of the differing parameters . But needs serious consideration**
- **Nevertheless, any LHC design will have to be tested first in SPS**

Crab Cavities for HL-LHC – Tentative Plan

Overall schedule of the crab cavity project synchronized with the expected LHC operation schedule and the HL-LHC project proposal.



Production of Crab Cavities

⇒ **A substantial program involving:**

- Completion of specifications for cavity production, couplers, cryostats and other components,
- Launching series production of cavities, couplers and other cavity components,
- Launching series production of cryostats,
- Launching series production of RF and power equipment,
- Successful low power testing of series bare cavities,
- Completion of clean room assembly of series cavities and their ancillaries in their cryostats,
- Successful power testing of the completed series cryomodules in the dedicated test stand,
- Test in SPS of a completed CC cryomodule.

Other systems:

- RF SYSTEM – RF POWER, LLRF
- CRYOGENICS
- CONTROLS

Conclusions & Outlook – LHC crab cavities

- Main objective for LHC is full local scheme with compact cavities
- 'Conventional' SC Cavity 800 MHz is retained as an option in case of need
- Project breakdown, planning and costing in preparation
- Synergy with other deflecting cavity applications needs to be exploited
- CERN has always relied heavily on outside support for its deflecting cavity applications.
- Collaboration with outside partners essential and welcome.

Outlook for the near future:

- KEK cavity test decision
- Basic completion and refinement of LHC CC project document
- Look at how to start CC hardware prototyping, together with partners

Thanks for your attention

&

NOTE LHC Crab Cavity workshop CC10
CERN, November 2010