





LARP Crab Cavities Program Overview

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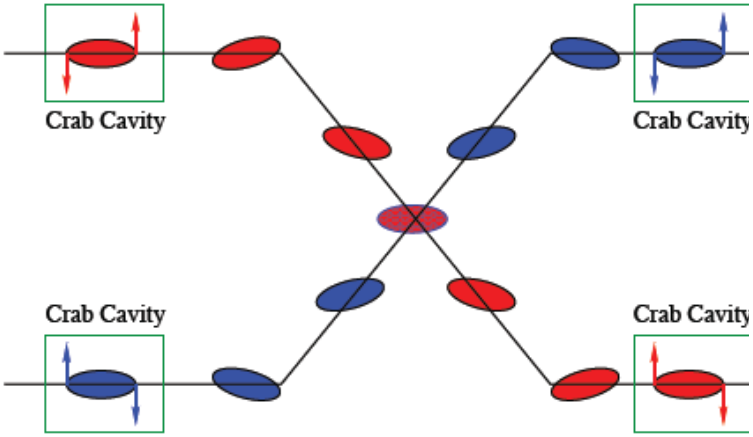






Outline

- Motivation and Overview of the CRAB program
- System requirements and description
  - CERN's functional specification (SPS)
  - LHC requirements
- Current status and LARP activity
  - PoP and Prototypes, integration
  - SPS test
- Next Steps and Planning - in the final talk
  - Including Cost and Schedule

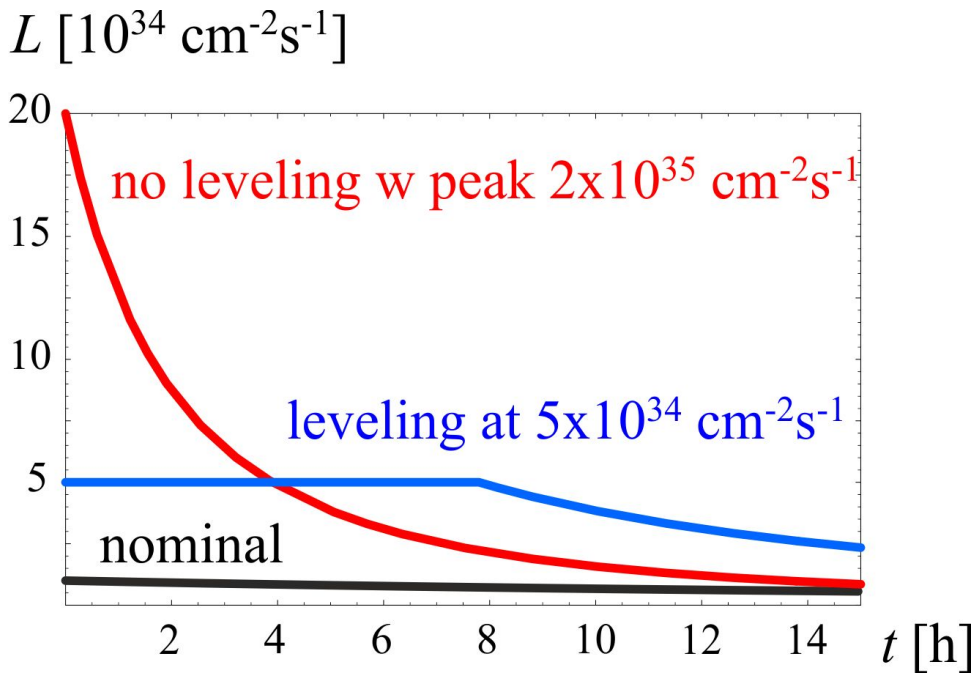


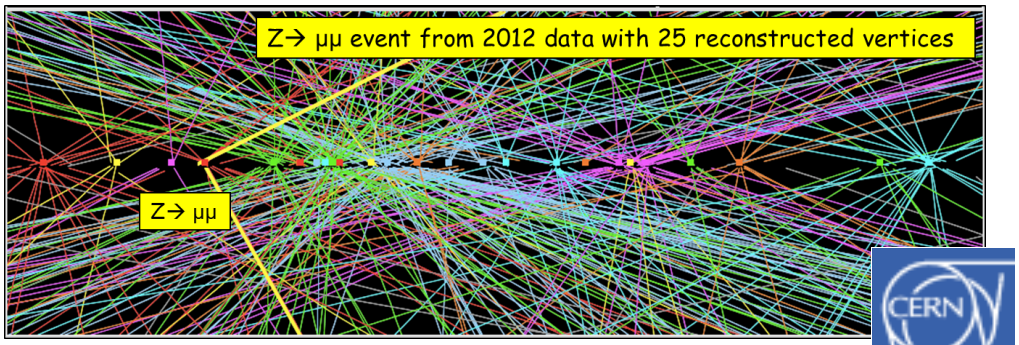
Why crabs?

- Substantial upgrade of integrated luminosity
  - Luminosity leveling, vertex density control
  - Effectiveness increases with larger crossing angles
  - Only known way to improve luminosity during the store
- Significant R&D on cavity technology for several years
  - Encouraging results are making this possible
  - Three designs under study in Europe and the US

Luminosity Levelling

- Luminosity decreases for proton burning (neglecting effects like emittance growth due to b-b, IBS, etc…)
- Total number of collisions ***∫Ldt*** in a run is limited by number of stored protons
- ⇒ store a lot of protons but keep instantaneous lumi «low» by detuning one (or more) parameter.
- ⇒keep the lumi constant by re-tuning the paramter(s) to compensate proton loss (and possibly any other effect).





System Requirements

- Voltage >= 13 MV (3.3 MV/cavity)
  - SPS test 2 cavities/module
  - LHC 4 cavities/beam/location
- Frequency = 400 MHz
- $Q_{ext} = 10^5 - 10^6$, R/Q ~300 W
- Cavity tuning/detuning ± 1.5-5.5kHz (or multiples of it)
- Available RF power source = 60 kW (< 18 kW nominal)
- Beam current ~ 0.5-1 A

Technical Specification

- Functional parameters
  - Including HOMs, Z…
- Enclosures (incl. materials…)
- Cryogenics
- RF Power incl. couplers
- LLRF
- SPS Integration

Released by CERN in Feb. 2013

CERN-ACC-NOTE-2013-003

HiLumi LHC

FP7 High Luminosity Large Hadron Collider Design Study

Scientific / Technical Note

Functional Specifications of the LHC Prototype Crab Cavity System

Baudrenghien, P

et al

28 February 2013

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

This work is part of HiLumi LHC Work Package **4: Crab cavities**.

The electronic version of this HiLumi LHC Publication is available via the HiLumi LHC web site <http://hilumilhc.web.cern.ch> or on the CERN Document Server at the following URL: <http://cds.cern.ch/search?p=CERN-ACC-NOTE-2013-003>

CERN-ACC-NOTE-2013-003

Overall CERN planning

LHC schedule beyond LS1

Only EYETS (19 weeks) (no Linac4 connection during Run2)

LS2 starting in 2018 (July) 18 months + 3months BC (Beam Commissioning)

LS3 LHC: starting in 2023 => 30 months + 3 BC

injectors: in 2024 => 13 months + 3 BC



L. Rossi: Dec 2013

Global Organization

- CERN leads the global collaboration
  - Directly responsible for several tasks
    - RF power and controls, local installation, cryogenics, machine protection…
  - Cross disciplinary working group to prepare SPS validation test
    - Operations, RF, Vacuum, Cryogenics, Beam Dynamics, Machine Protection, Collimation, Instrumentation…
- Lancaster Univ. and STFC actively involved
  - 4-rod cavity design and testing
  - Cryomodule design
- US proposes to contribute a well defined part of the activities
  - "Cold Masses" = Dressed Cavities with HOM couplers and filters, tuners, FPC ports.

LARP Organization

- Defined roles within LARP collaboration:
  - BNL, ODU – cavity development with aux systems
  - FNAL – Leads and coordinates cryomodule integration in the US
  - SLAC – Leads and coordinates EM modeling support
  - FNAL, LBNL - beam dynamics, dynamic quench and energy deposition studies
    - Not shown here

Today's presentations will cover each of these areas

(Unless otherwise noted)

- US Industry - Niowave
  - Built all three PoP cavities to date
  - Funded by DOE SBIR phase II program to build prototypes

- Points of contacts defined at each institution

Scope of US Contribution

- LARP proposes to contribute R&D until the SPS test
  - 4 cavities (two of each kind) for testing in the SPS during the 2017-18 runs
    - 2 cavities, He vessels, tuners, HOM mode dampers
    - RF couplers provided by CERN
    - Cryogenics, RF power, local installation provided by CERN

- Proposal to DOE for a US Contribution to HL-LHC
  - All cold masses (fully dressed cavities)

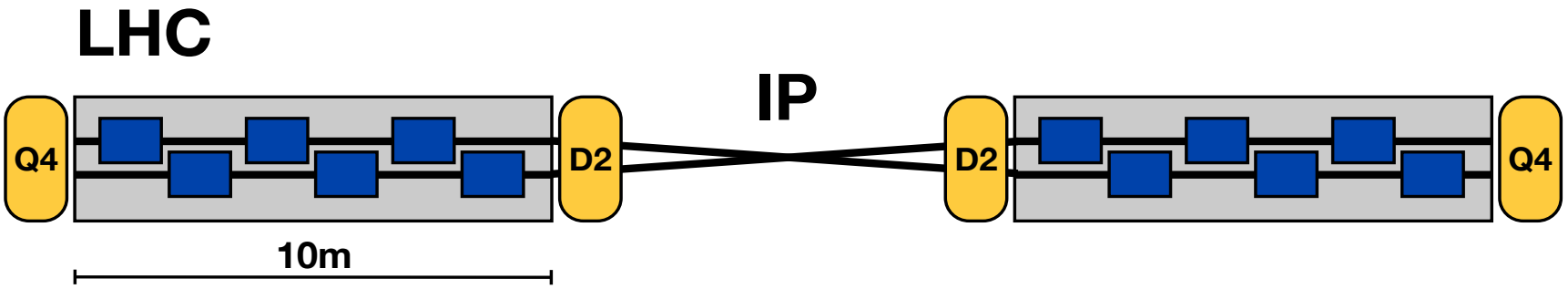
Feedback from DOE reminds that the effort on crab cavities should be carried through construction and not be limited to the SPS test

Focus on SPS Tests

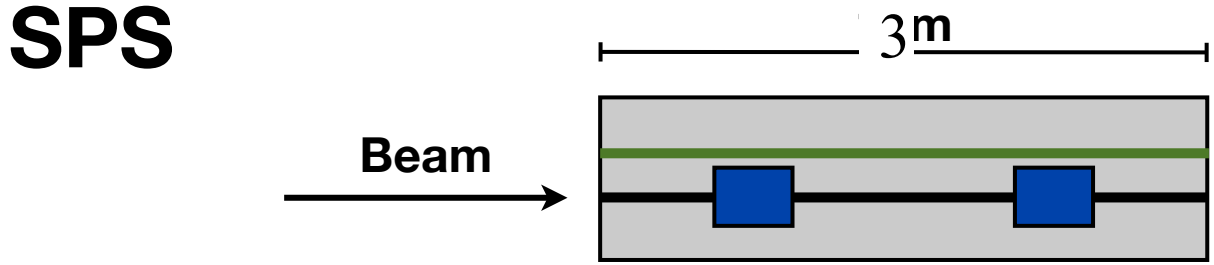
- SPS Validation Tests
  - Validate crab concept with proton beams
  - Machine protection
  - Beam studies (kick, LLRF, noise....)

- Essential to finalize LHC design
  - A final decision on a crab cavity system for the LHC will only come after a successful SPS test

SPS vs. LHC



NOTE: LHC now requires 4 cavities per location



Current LARP Activities

- Proof of Principle Cavities – DQW, RFD
  - Validated geometries and expected performance
    - **Both design met CERN's kick requirements**
- Prototypes
  - Plan to build 2 cavities of each designs
- Cryostat
  - Support CERN in design and integration of two designs
- Modeling Support
  - EM cavity design with peripherals
  - Beam beam studies
- Beam-Beam and energy deposition studies
  - Also important, although not described here
    - Reported in AP session

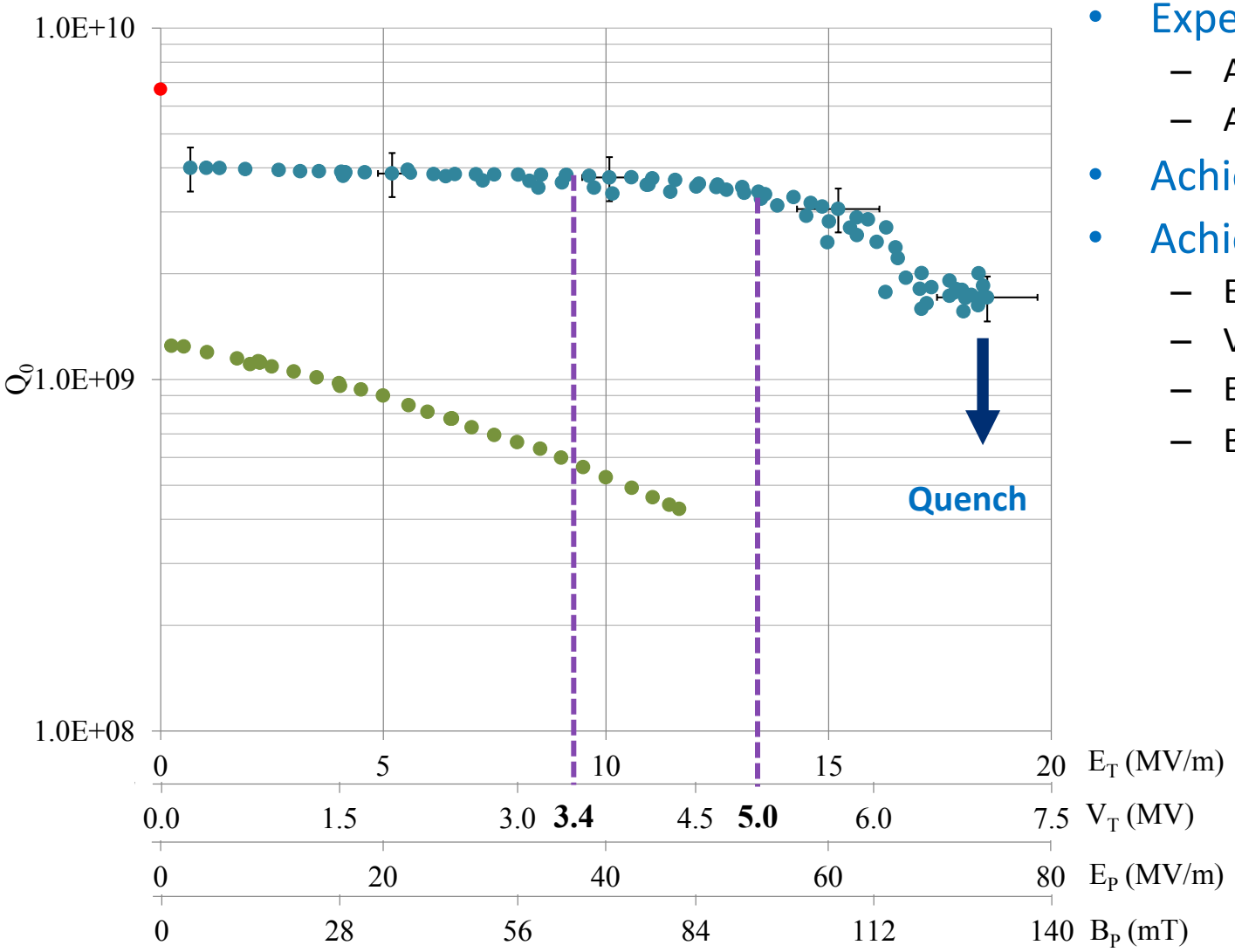
Status – Proof of Principle

- Proof of Principle (PoP) Cavities
  - Successful test of both LARP cavity designs proves that we **can** achieve the required fields
  - Yet reaching 7 MV in a vertical test does not mean we can assume cavities will operate at that gradient.
  - 4-Rod test also successful
- Focus now on peripherals and integration
  - Tuners, dampers, power couplers…





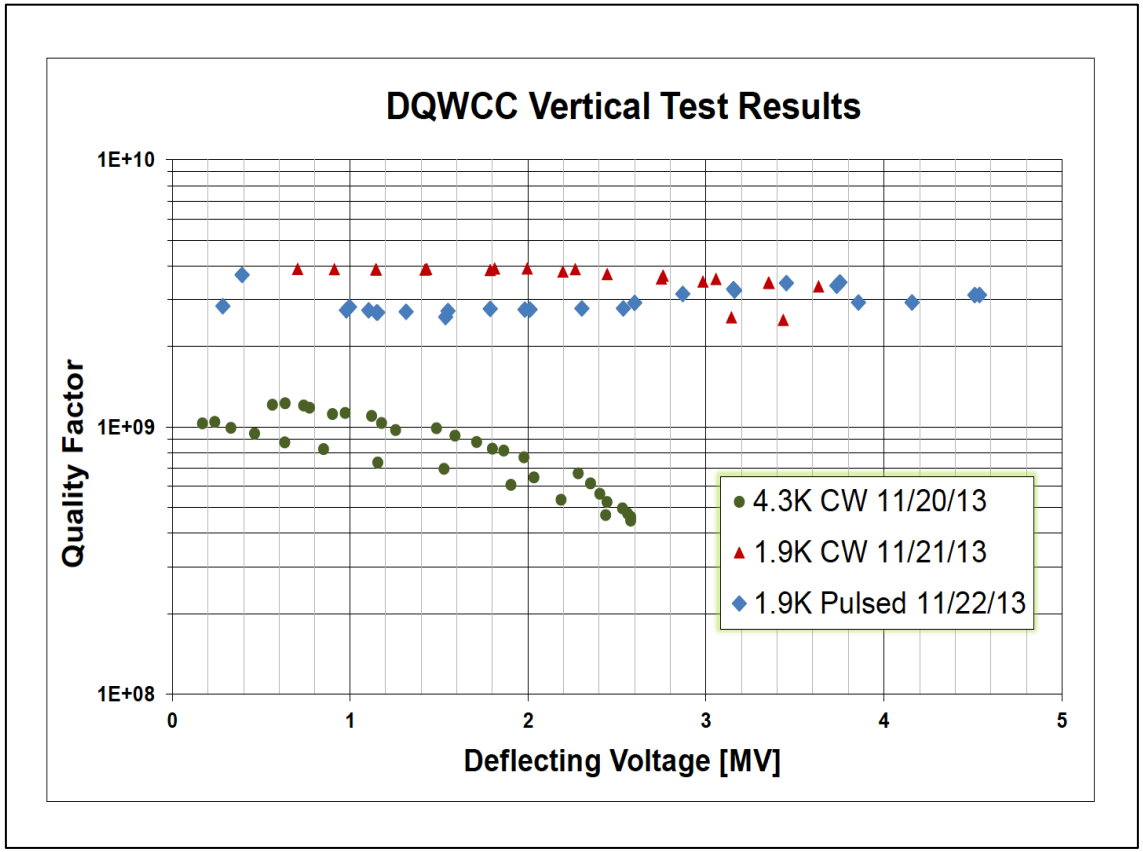
PoP RF Dipole 4.2 K and 2 K Test Results



- Expected $Q_0 = 6.7\times10^9$
  - At $R_S = 22$ nΩ
  - And $R_{res} = 20$ nΩ
- Achieved $Q_0 = 4.0\times10^9$
- Achieved fields
  - $E_T = 18.6$ MV/m
  - $V_T = 7.0$ MV
  - $E_P = 75$ MV/m
  - $B_P = 131$ mT



PoP DQW 4.3k and 1.9k Test Results



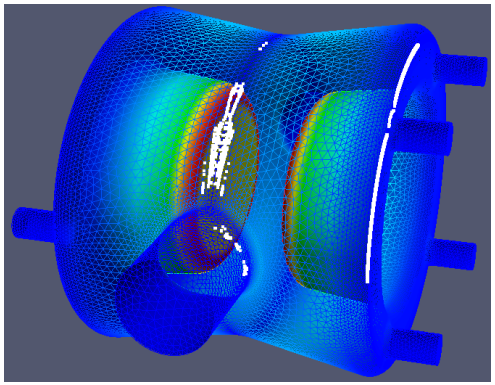
- Q_0 at around 3~4.5e9
- In CW mode, temperature of beam pipe flanges increase.
- Reached 4.5MV kick in pulsed mode, limited by quench, consistent with conditioning test.
- Temperature increase on pickup port blending area.
- Quench field at ~110mT, with peak E field at 52.8MV/m

Status - Prototypes

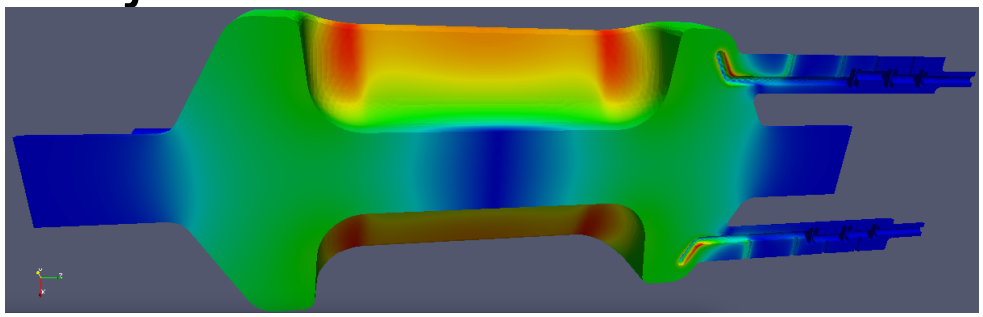
- Finalizing the design of a prototype system to use in the SPS test for both cavity designs
  - Fundamental differences in the approaches in tuning and coupling (FPC and HOM)
- Cryostat concepts are starting from studies made in the UK
- Plan to carry both US designs until final integration in SPS cryostat
  - Greatly reduces technical and schedule risk

Modeling

- Supporting EM design of cavities and auxiliary systems
  - Multipacting analysis



  - Mode dampers coupling
  - …and fundamental power rejection



- Comparative studies of three candidate designs

Other Studies

- Energy deposition (FNAL)
  - Neutron shower could compromise cavity integrity
- Dynamic Quench (FNAL)
  - Extreme stored energy planned for HL-LHC dictates extreme care managing rapid changes
- Beam beam with crab scheme (LBNL and FNAL)
  - Studies with increasing crossing angles planned for HL-LHC

Conclusions

- Crab cavities have been selected as one of the activities in the construction project for the HL-LHC
- R&D program is making great progress
  - Very encouraging initial results
  - Detailed design of prototype cavities and integration of a system for SPS test underway
- CERN very actively involved
- Systems requirements document released
- US industry remains involved in a key role

Financial and planning details at the end of the session

Questions?

