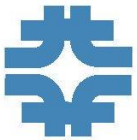
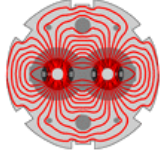
23-27 March 2015
Marriott Georgetown Hotel
Europe/Zurich timezone

LARP Program Perspective

G. Apollinari - LARP Director
FCC Week 2015

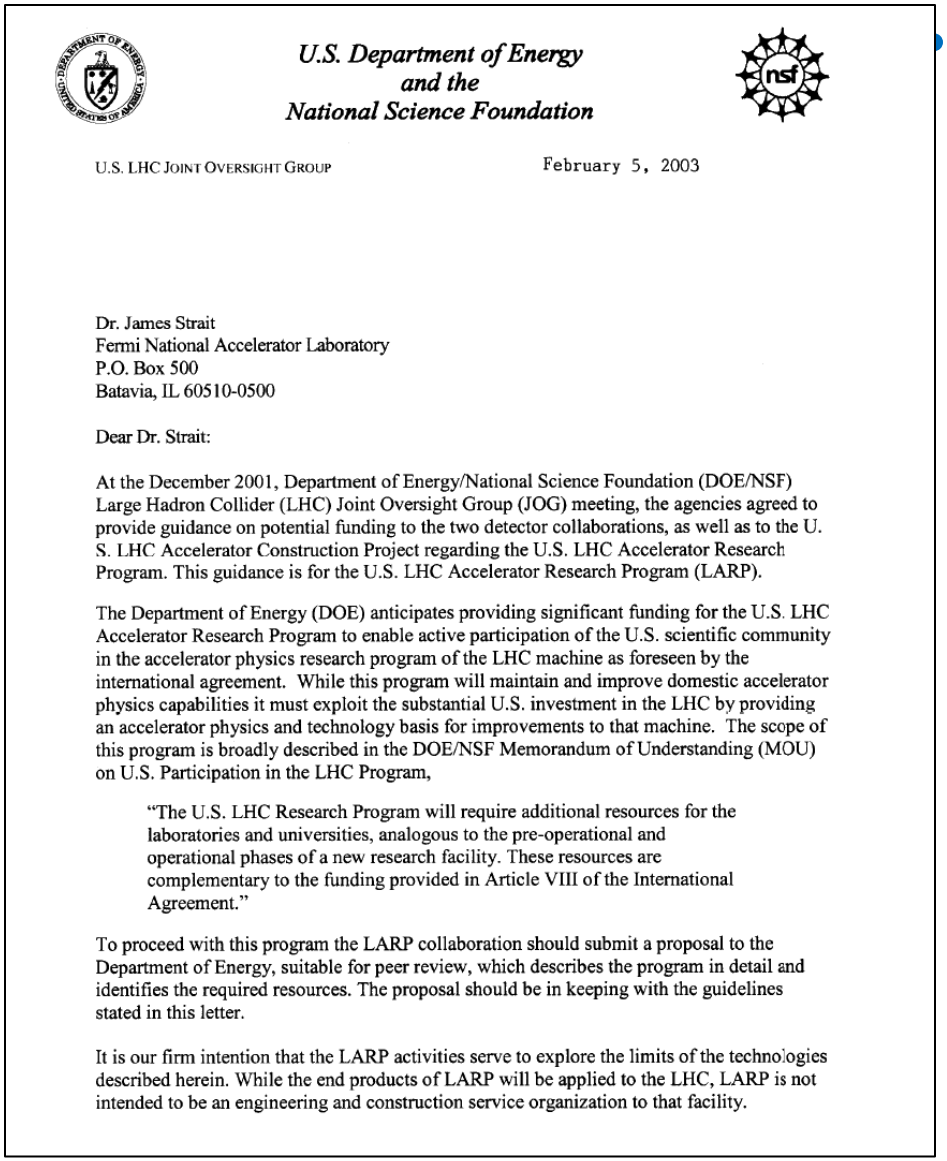




Content

- Origins of LARP
- LARP achievements before Hi-Lumi Project
- LARP Evolution to Hi-Lumi Project
- Reflections

Origins of LARP (I): a "First" in HEP Accelerators



U.S. Department of Energy and the National Science Foundation

U.S. LHC JOINT OVERSIGHT GROUP

February 5, 2003

Dr. James Strait
Fermi National Accelerator Laboratory
P.O. Box 500
Batavia, IL 60510-0500

Dear Dr. Strait:

At the December 2001, Department of Energy/National Science Foundation (DOE/NSF) Large Hadron Collider (LHC) Joint Oversight Group (JOG) meeting, the agencies agreed to provide guidance on potential funding to the two detector collaborations, as well as to the U. S. LHC Accelerator Construction Project regarding the U.S. LHC Accelerator Research Program. This guidance is for the U.S. LHC Accelerator Research Program (LARP).

The Department of Energy (DOE) anticipates providing significant funding for the U.S. LHC Accelerator Research Program to enable active participation of the U.S. scientific community in the accelerator physics research program of the LHC machine as foreseen by the international agreement. While this program will maintain and improve domestic accelerator physics capabilities it must exploit the substantial U.S. investment in the LHC by providing an accelerator physics and technology basis for improvements to that machine. The scope of this program is broadly described in the DOE/NSF Memorandum of Understanding (MOU) on U.S. Participation in the LHC Program,

> "The U.S. LHC Research Program will require additional resources for the laboratories and universities, analogous to the pre-operational and operational phases of a new research facility. These resources are complementary to the funding provided in Article VIII of the International Agreement."

To proceed with this program the LARP collaboration should submit a proposal to the Department of Energy, suitable for peer review, which describes the program in detail and identifies the required resources. The proposal should be in keeping with the guidelines stated in this letter.

It is our firm intention that the LARP activities serve to explore the limits of the technologies described herein. While the end products of LARP will be applied to the LHC, LARP is not intended to be an engineering and construction service organization to that facility.

- DOE guidance for LARP received on February, 2003
  - NSF/DOE supported
  - Follow in the foot-prints of HEP Experimental Physics endeavors:
    - Enable US scientists to maintain and expand world-wide technological leadership in accelerator physics and superconducting magnets
  - LARP goal to increase physics productivity by:
    - Commissioning of Triplets
    - Advanced beam Diagnostic
    - Simulation Studies

Origins of LARP(II): Seeds for the Future

> Members of the CERN staff, as well as U.S. scientists, have already proposed upgrades to the LHC at international conferences. These upgrades cover improved interaction region final focusing as well as an energy doubler. The U.S. team is in an excellent position to play a leading role to both of these activities because of the expertise developed in the U.S. LHC Accelerator Construction Project as well as the base program in high field magnet development. Importantly, should there be electron cloud effects in the LHC, the next generation final focus quadrupoles will be essential to achieving design luminosity.
>
> The United States has taken early leadership in high field dipole and high gradient quadrupole design. A program of engineering development will enable the community to be ready to construct the next generation of upgrades at the appropriate time.

- Need for R&D Program on elements of National Leadership (Superconducting Magnets) acknowledged from the get-go.
  - LARP not replacing existing Base R&D Programs at various Laboratories.
  - Specific R&D Programs aimed at enhancing machine capabilities beyond baseline deemed appropriate
    - but not the conversion of these programs into "deliverables"
  - Strong Management deemed necessary, serving as single point-of-contact with agencies and responsibility for a National Program
  - LARP IS A PROGRAM, not a PROJECT

Operative Concepts: *Initial Operation* and *Directed R&D*

Origins of LARP(III): the Proposal

The U.S. LHC Accelerator Research Program:

A Proposal

R. Kephart, M.J. Lamm, P. Limon, J. Marriner, T. Sen, J. Strait, A.V. Zlobin
Fermi National Accelerator Laboratory
Batavia, IL 60510

P. Cameron, A. Drees, W. Fischer, R. Gupta, M. Harrison, F. Pilat, S. Peggs
Brookhaven National Laboratory
Upton, NY 11973

W. Barletta, J. Byrd, P. Denes, M. Furman, S. Gourlay, A. Ratti, W. Turner
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

J. Strait
Interim Director

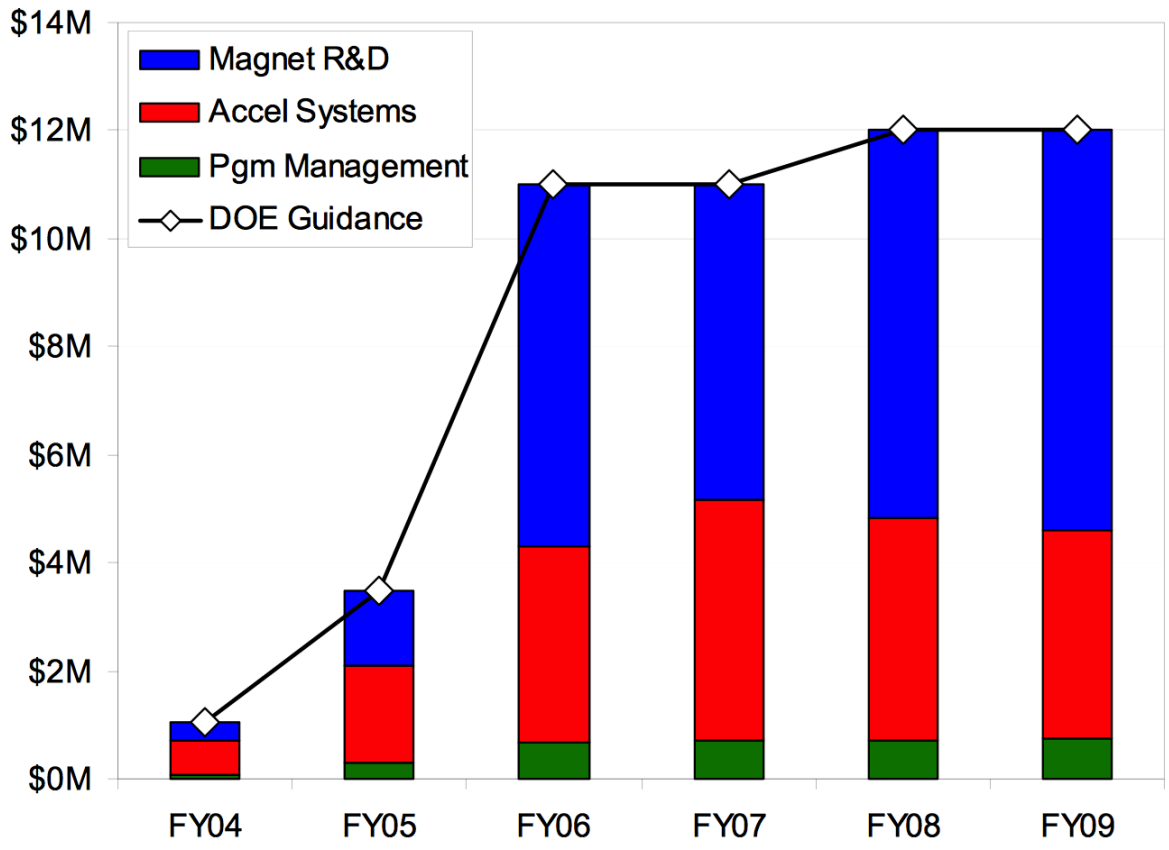
S. Peggs
Director 2004-2008

E. Prebys
Director 2008-2013

- LARP Will Advance High-Energy Physics
  - LHC Commissioning
  - LHC performance improvement through novel instrumentation
  - Extend LHC as a frontier high-energy physics instrument with a timely luminosity upgrade.
- LARP Will Advance U.S. Accelerator Science & Technology
  - Conduct forefront accelerator physics research and development.
  - Advance US national capabilities
- LARP Will Advance International Cooperation

Operative Concepts: *Funding Agency Mandate* hinged on *National Leadership R&D*

Initial LARP Funding Profile



- LARP funded consistently at 10-12M$/year (US accounting) since ~2006
- Split ~50/50 between Magnets Development and Accelerator System Development
- “Best effort” basis

CERN-LARP Interactions

- Very tight and frequent interactions between CERN and LARP to define viable and important R&D venues for LHC.
- Continued acknowledgments by CERN Management on value of LARP activities

Letter to Dennis Kovar, Head Office of DOE
Office of High Energy Physics, 17-August-2010

Dear Dennis,

We are writing to express our support for the US LHC Accelerator Research Program (LARP) and to clarify the relevance and priority of some of the activities within this program with respect to the current CERN upgrade plans.

First and foremost, we are relying primarily on LARP to establish Nb_3Sn as a viable technology for use in the high luminosity upgrade of the LHC (HL-LHC), currently scheduled to be implemented in 2020 or 2021. LARP's Nb_3Sn program has had some impressive achievements over the last few years, but there are still several key demonstrations which are needed to provide the confidence necessary to proceed with the design and production of the focusing quadrupoles to be used in the LHC. LARP is working closely with CERN to establish a set of milestones which must be met, and it is vital that LARP have sufficient resources to meet these milestones.

In addition to the magnet program, two LARP activities which are closely linked to the CERN schedule are the crab cavity effort and the rotatable collimator development. Following the 9th crab cavity workshop in the fall

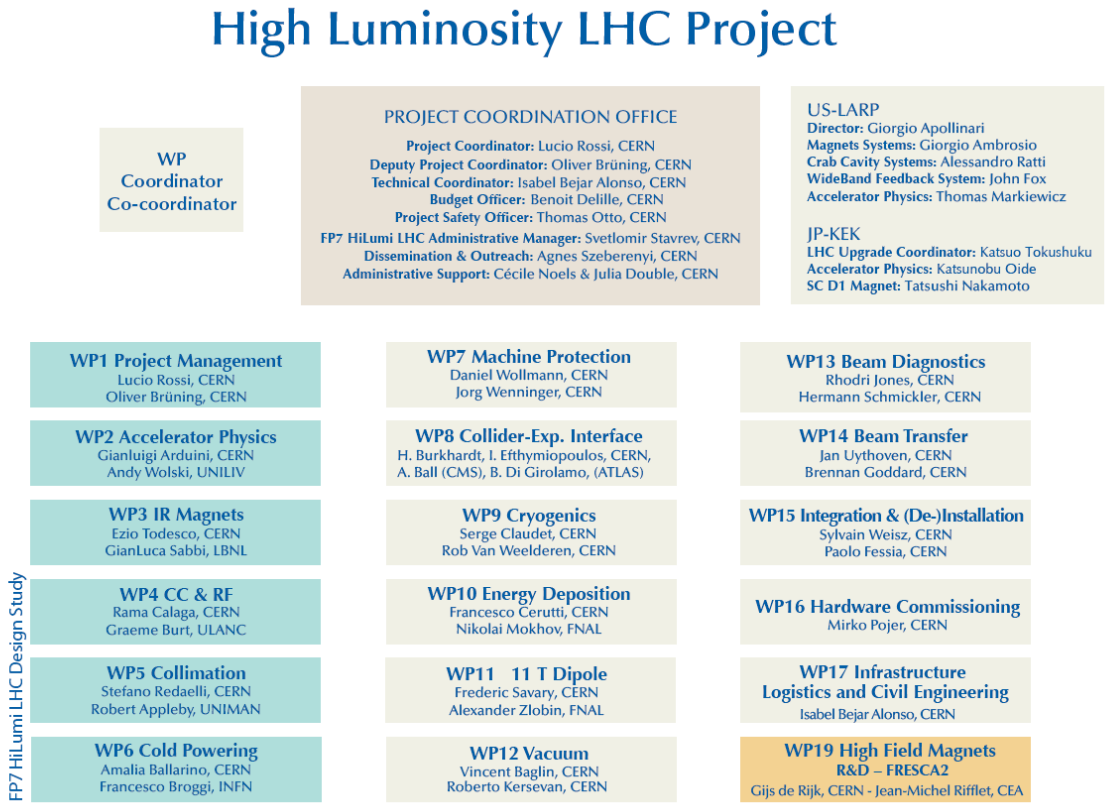
(…)

Prof. Rolf Heuer
Director-General

Dr. Steve Myers
Director for Accelerators

LARP and HiLumi: Interactions

- In 2011, the HiLumi-LHC Design study was initiated under the Framework program (FP7) of the European Commission (EC) to manage a strong Collaboration involving external expertise for the planning of HL-LHC.
- LARP full integration in HiLumi-LHC insured by several LARP associates involved in the HiLumi structure



- G. Sabbi
  - WP3 on Magnets
- (Previously) N. Mokhov
  - Energy Deposition
- A. Ratti
  - WP4 on CC
- (A. Zlobin)
  - WP11 on 11 T

LARP "before HiLumi Project"

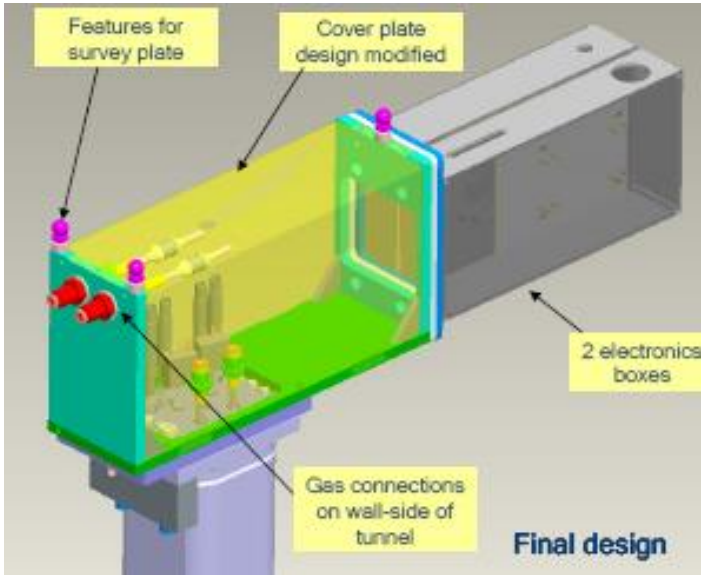
- Accelerator System Development
  - Instrumentation
  - Collimation
  - Accelerator Physics
- Magnet System Development
  - IR Focusing Quadrupoles

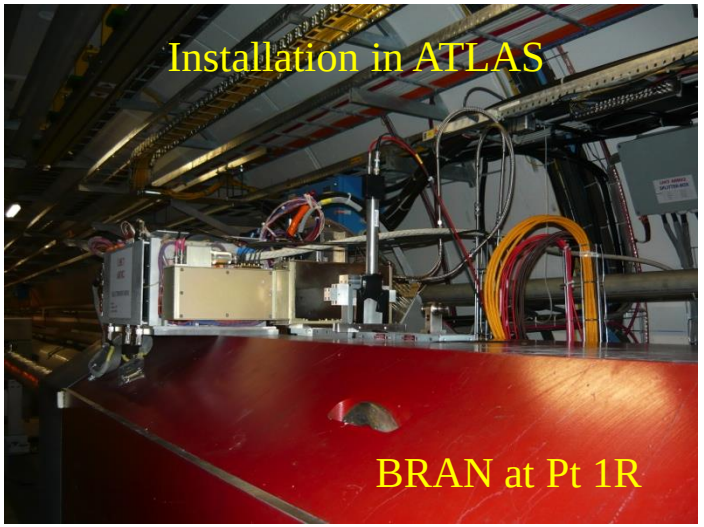
LARP Accelerator Systems: Instrumentation

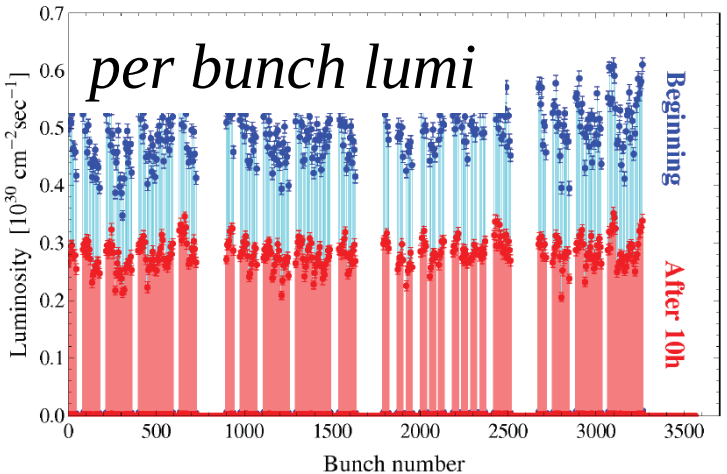
- Beam Commissioning of:
  - Luminosity Monitor
  - Tune & Coupling feedback systems
  - Schottky Monitor
  - Synchrotron Light Monitor
  - AC Dipole
    - UT Austin proposal, resulting in PhD and Toohig Fellow
  - LLRF modeling and commissioning
    - PhD and CERN staff position

Luminosity Monitor

- Recall:
  - Argon Ionization Chamber
  - System operational since LHC commissioning
    - Used at every store to bring beams in collision and through the beta squeeze
    - Not a single operational failure
  - Handoff completed in 2010
- Maintenance underway during LS1
- Contributions to early discussions of the conceptual design of the luminosity monitors for the HL-LHC

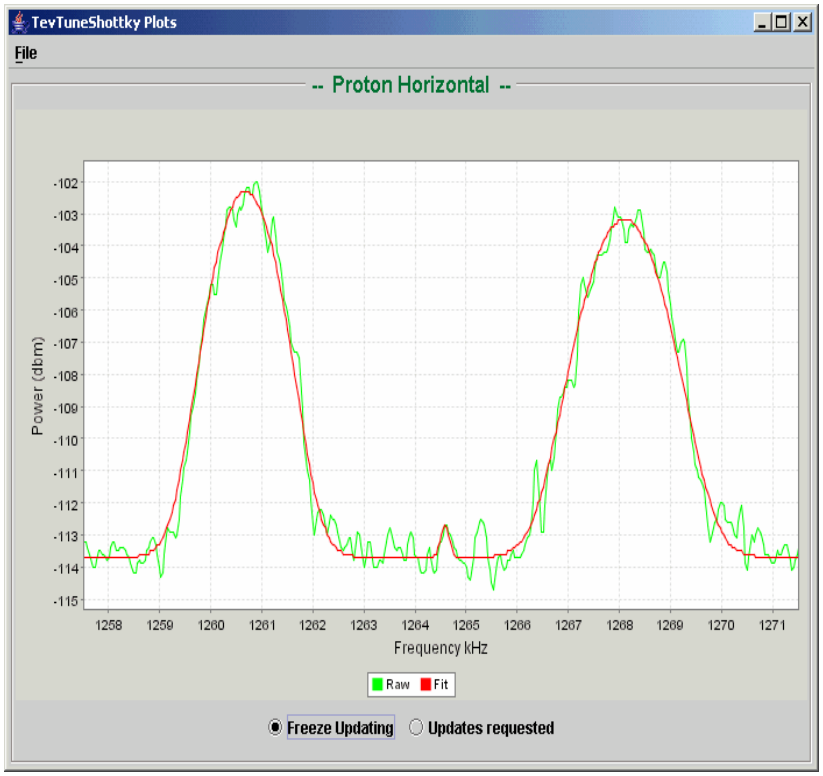






Schottky Monitors

- Advanced enabling technology for:
  - Non invasive tune measurement for each ring from peak positions
  - Non invasive chromaticity measurements from differential width
  - Measure momentum spread from average width
  - Continuous online emittance monitor from average band power
  - Measure beam-beam tune shift
- Built-in capacity to monitor gain variation with time
- Measure individual or multiple bunches

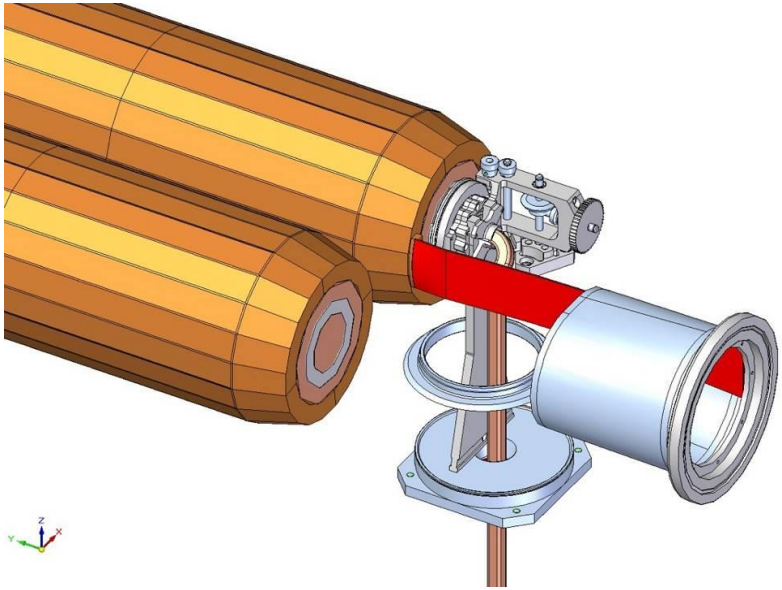


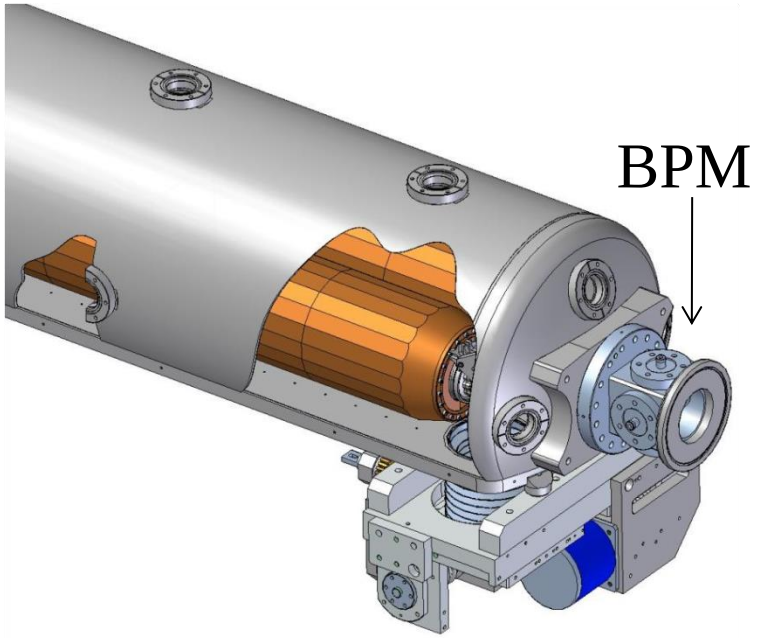
LARP Accelerator Systems: Collimation

- Rotatable Collimator as a Phase II Secondary Collimator candidate
- T980/UA9 Crystal Collimation Study at the Tevatron & SPS
- Hollow electron-lens as a scraper for LHC
- Irradiation studies at BLIP (BNL)

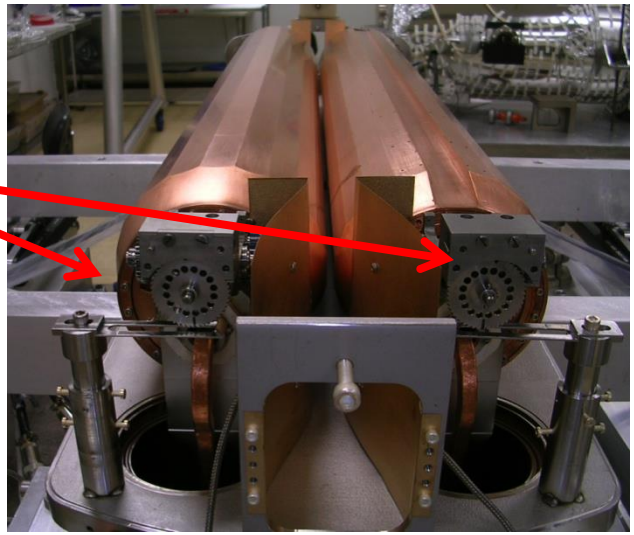
Rotating Collimators

LARP

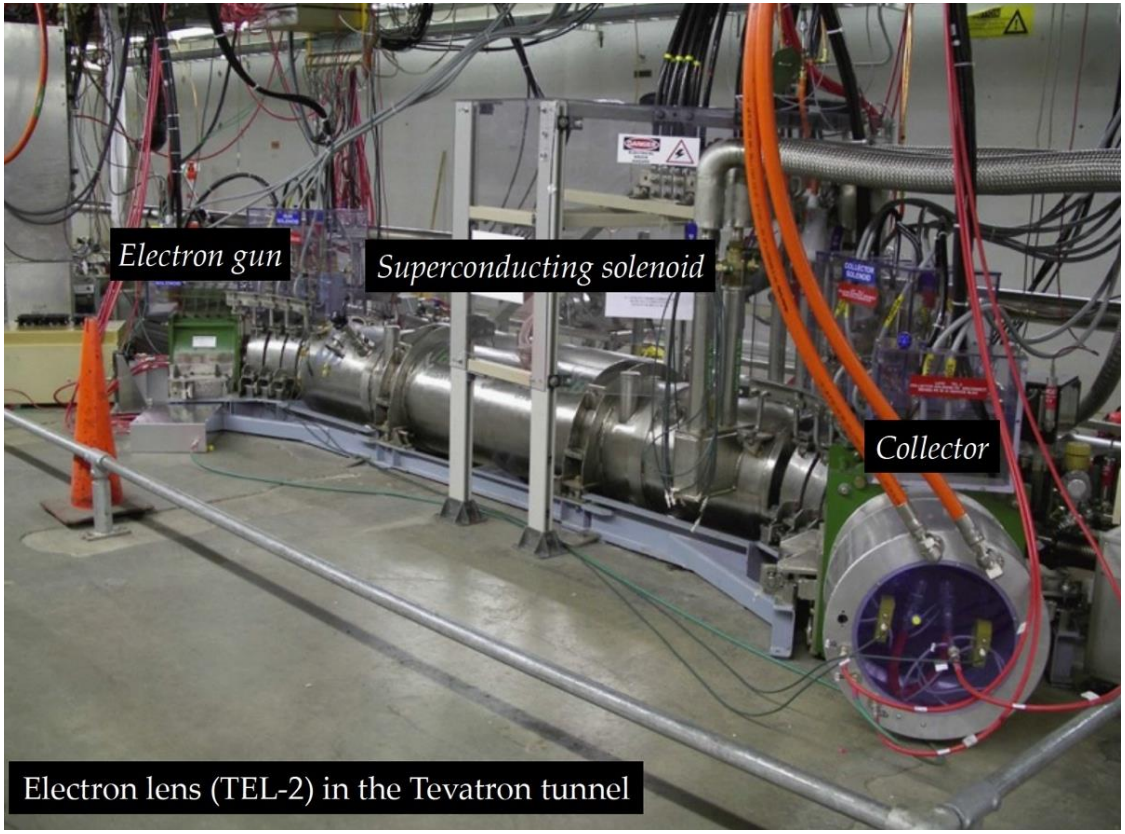


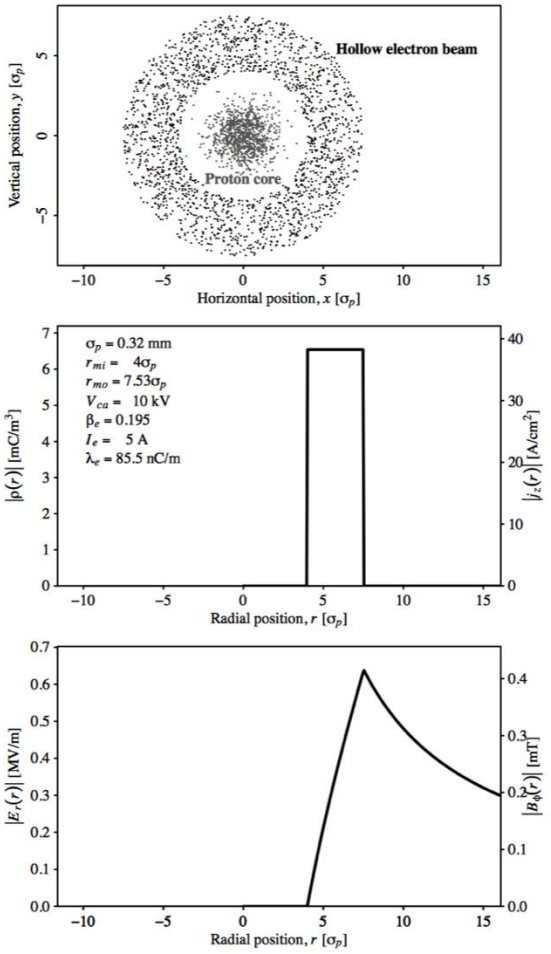


Rotation Drives



Hollow electron-lens





Conceptual design of hollow electron lenses for beam halo control in the Large Hadron Collider

Giulio Stancari, Valentina Previtali, Alexander Valishev (Fermilab) , Roderik Bruce, Stefano Redaelli, Adriana Rossi, Belen Salvachua Ferrando (CERN)

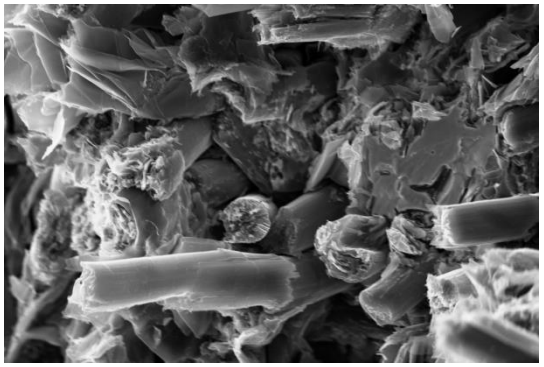
May 8, 2014 - 23 pages

FERMILAB-TM-2572-APC
e-Print: arXiv:1405.2033 [physics.acc-ph] | PDF

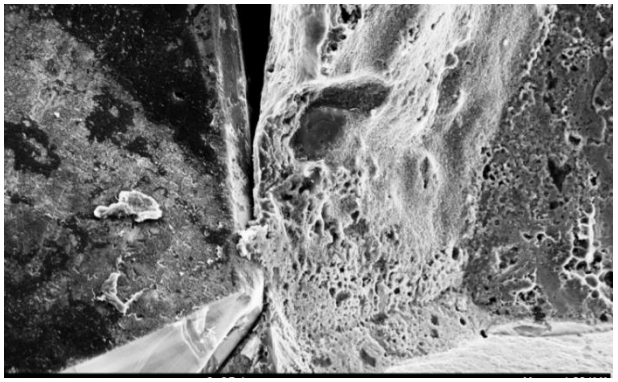
Irradiation of Collimator Materials

- CERN will install a “Phase 2 Secondary” collimator made of an advanced material in one of the reserved LHC slots during Xmas shutdown 2015. They need to decide on material in ~June 2014.
- Candidates:

Moly-Graphite/Carbon Fibers coated with Moly



Cu-Diamond Composite



- LARP initiated effort to test materials at BNL BLIP+Hot Cell facility to measure physical properties before and after irradiation.

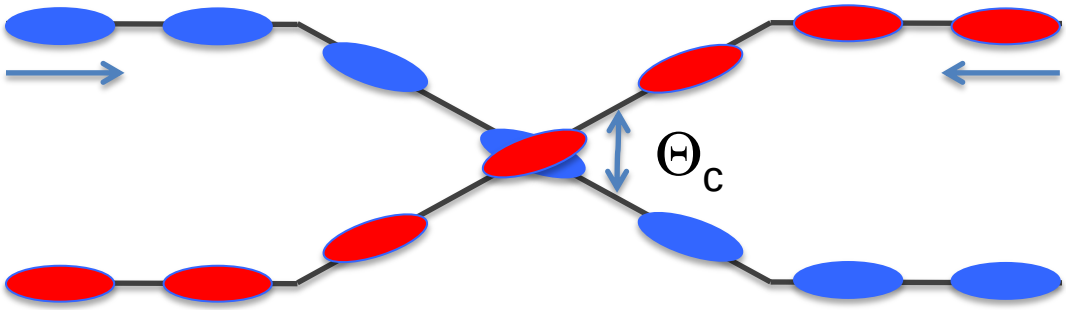
LARP Accelerator Systems: Accelerator Physics

- Electron lens as a Beam-Beam interaction compensator
- Control of E-cloud induced beam instability in SPS through RF feedback (WBFS)
- Crab Cavity program
- Energy Deposition studies
- Beam-Beam Simulation
- Interplay between magnet design and LHC Lattice

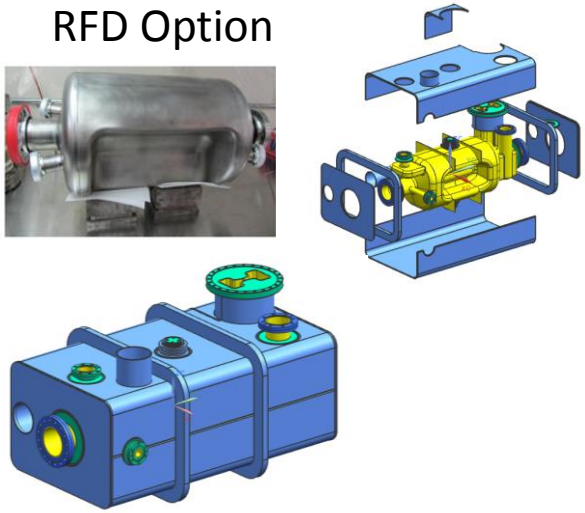
Facilitation and exchange of critical intellectual contributions to the planning for HL-LHC

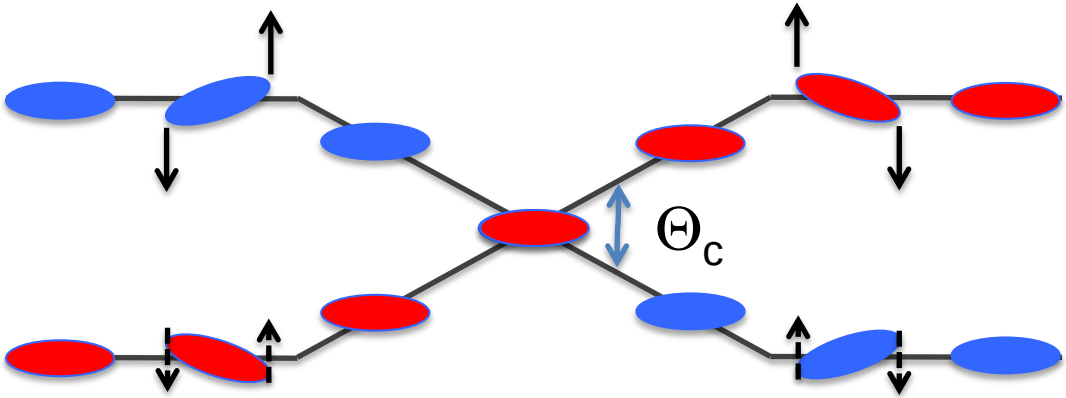
Crab Cavities

- Larger Crossing angle (~300 μrad in HL-LHC vs. ~150 μrad in LHC) calls for a correction of individual bunches orientation

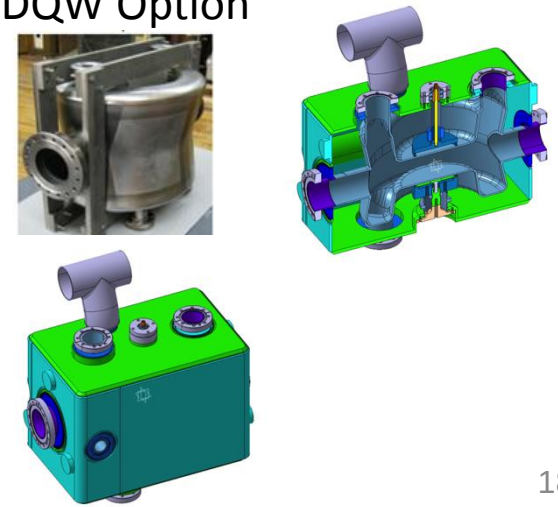


RFD Option





DQW Option



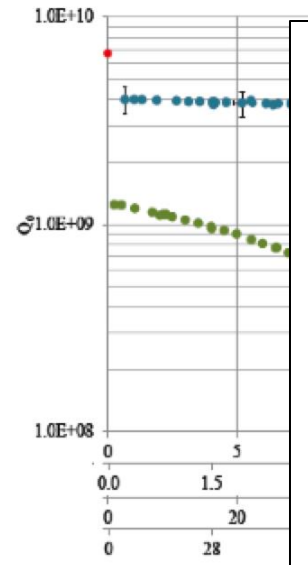
Crab Cavities (cont.)

LARP

First test of RFD (ODU-SLAC at J-LAB)

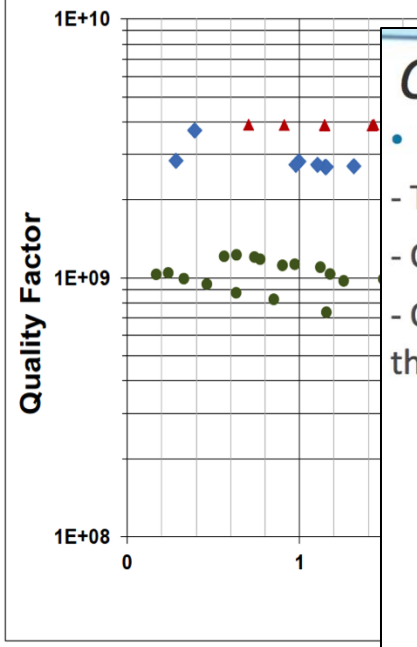
High Luminosity LHC

- Expected $Q_0 = 6.7 \times 10^9$



Jefferson Lab

DQWCC Vertical Test Results



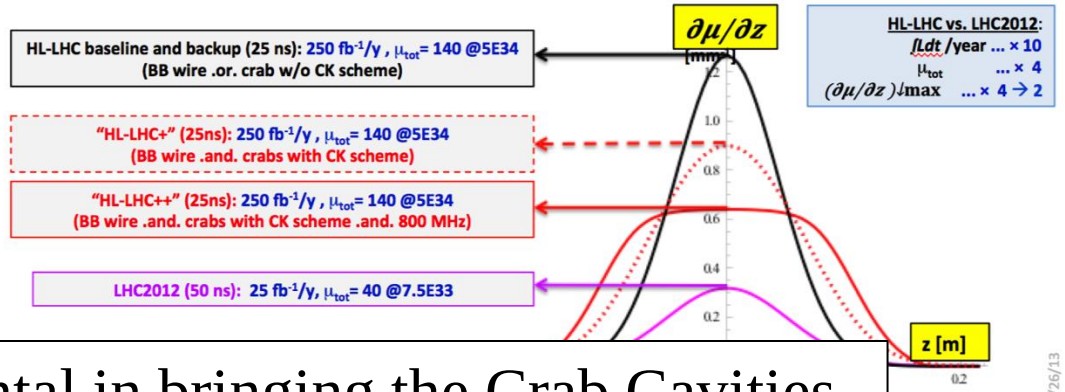
Conclusions & Outlooks (2/2)

- **Crab-cavities in specific configuration (CK scheme) remains the key**

- To reduce the peak PU line density at constant performance,

- Or to boost the performance at constant PU line density,

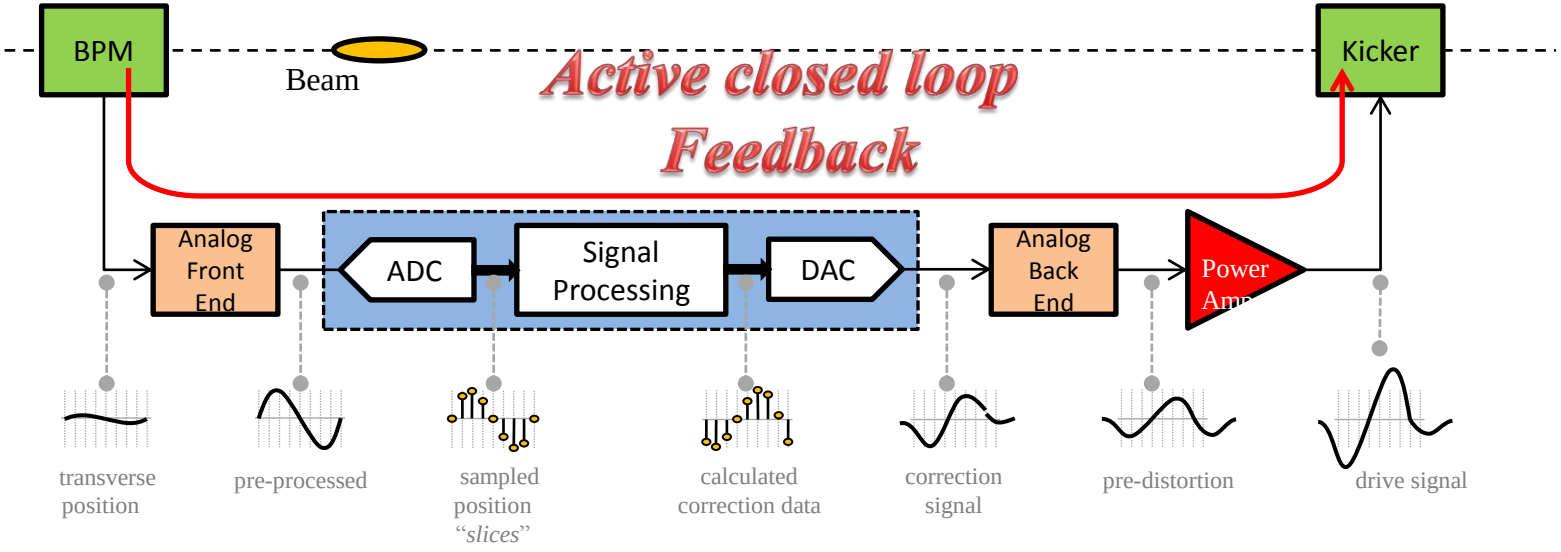
- Or (in the worst case of beam current lower than targeted) to mitigate the performance loss at constant PU line density.



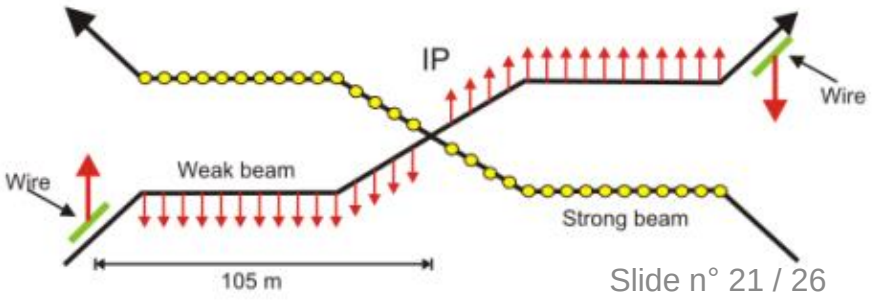
LARP has been instrumental in bringing the Crab Cavities solution into the baseline of HL-LHC

Wide Bandwidth Feedback System

- The high bandwidth feedback system is a GHz bandwidth instability control system
  - Increases LHC luminosity via higher SPS currents
  - Improves LHC beam quality and allows SPS operational flexibility
  - Leverages US expertise from e+e- @ SLAC
- LARP continues technology R&D & development of novel control methods
- Test of full functionality prototype in SPS by FY15-FY16



Beam-Beam Studies



Beam-beam compensation wires are in HL-LHC Plan B w/o crab-cavity

- Beam-Beam Simulation (FNAL and LBL)
  - Bench-marking with US simulation/experience for beam-beam computations performed at CERN
  - Assess new HL-LHC elements (large angles, CC, etc) and study all possible alternative schemes to achieve ultimate luminosity

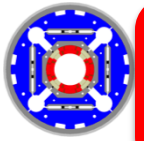
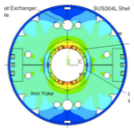
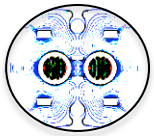
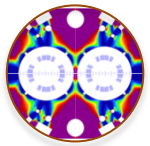
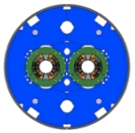
LARP Accelerator System "Score"

- Accelerator Systems LARP activities that have resulted in *baseline* or *alternative-baseline* choices for HL-LHC or LIU:
  - Collimation
    - Rotatable Collimator as a Phase II Secondary Collimator candidate
    - T980/UA9 Crystal Collimation Study at the Tevatron and SPS
    - ✓ Hollow e-lens as a scraper for LHC
  - Accelerator Physics
    - ✓ e-lens as a Beam-Beam interaction compensator
    - ✓ Control of E-cloud induced beam instability in SPS through RF feedback
    - ✓ Crab Cavity program
    - ✓ Energy Deposition studies
    - ✓ Beam-Beam interaction simulation

Impressive ~75% transition rate from R&D to LIU/HL-LHC *Baseline* (or "*alternative Baseline*")

Magnet System Development

- HL-LHC Main Magnet Needs

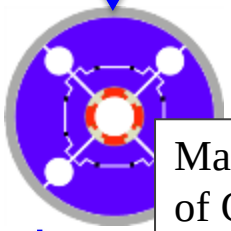
	Type	Material	Field/Gradient (T)/(T/m)	Aperture (mm)	Length (m)
	Q1,Q3 Q2	Single aperture	Nb_3Sn	(11.4) 133	150	8.4 7.3
	D1	Single aperture	Nb-Ti	5.2	150	6.7
	D2	Twin aperture	Nb-Ti	3.5…5.0	95…105	7…10
	Q4	Twin aperture	Nb-Ti	(5.9) 90	120	4.2
	DS 11T	Twin aperture	Nb_3Sn	10.8	60	11

Development History (LARP)

LARP

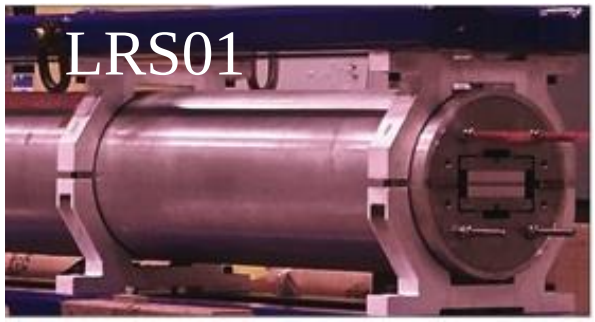
Subscale Quad. SQ
0.3 m long
110 mm bore
2004-2006

Technology Quadrupole TQS - TQC
1 m long
90 mm bore
2006-2010

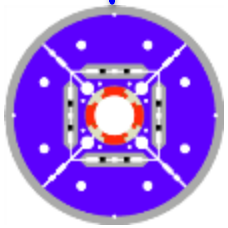


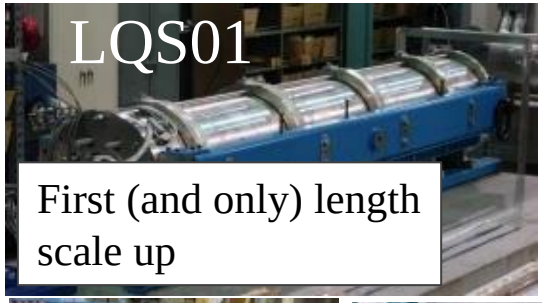
Manufacturing & Reproducibility of Cos2θ Coils, Mech. Structure

Long Racetrack LRS
3.6 m long
No bore
2006-2008



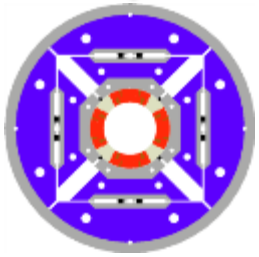
Long Quadrupole LQS
3.7 m long
90 mm bore
2007-2012





First (and only) length scale up

High Field Quadrupole HQ
1 m long
120 mm bore
2008-2014



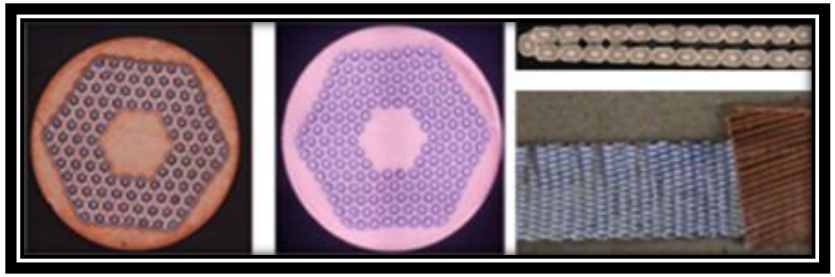
Aperture increase, Acc. Quality

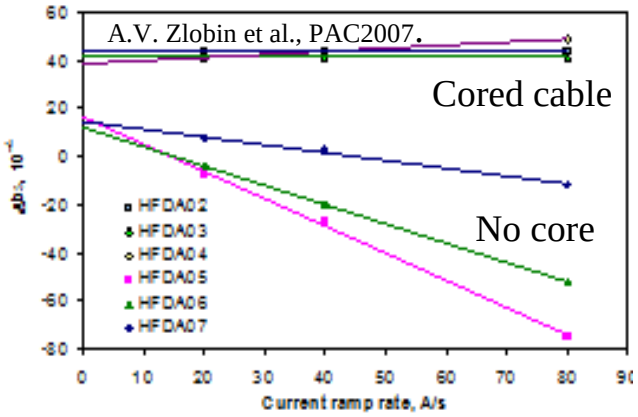
It Takes a Village !

Synergies between Core HFM program (GARD) and LARP

- Hard to give enough credit to the constructive "antagonism" that brought to the solution and control of accelerator-quality magnet problems such as SC instabilities, mechanical structure, coil fabrication techniques, etc …. contributed by GARD to LARP

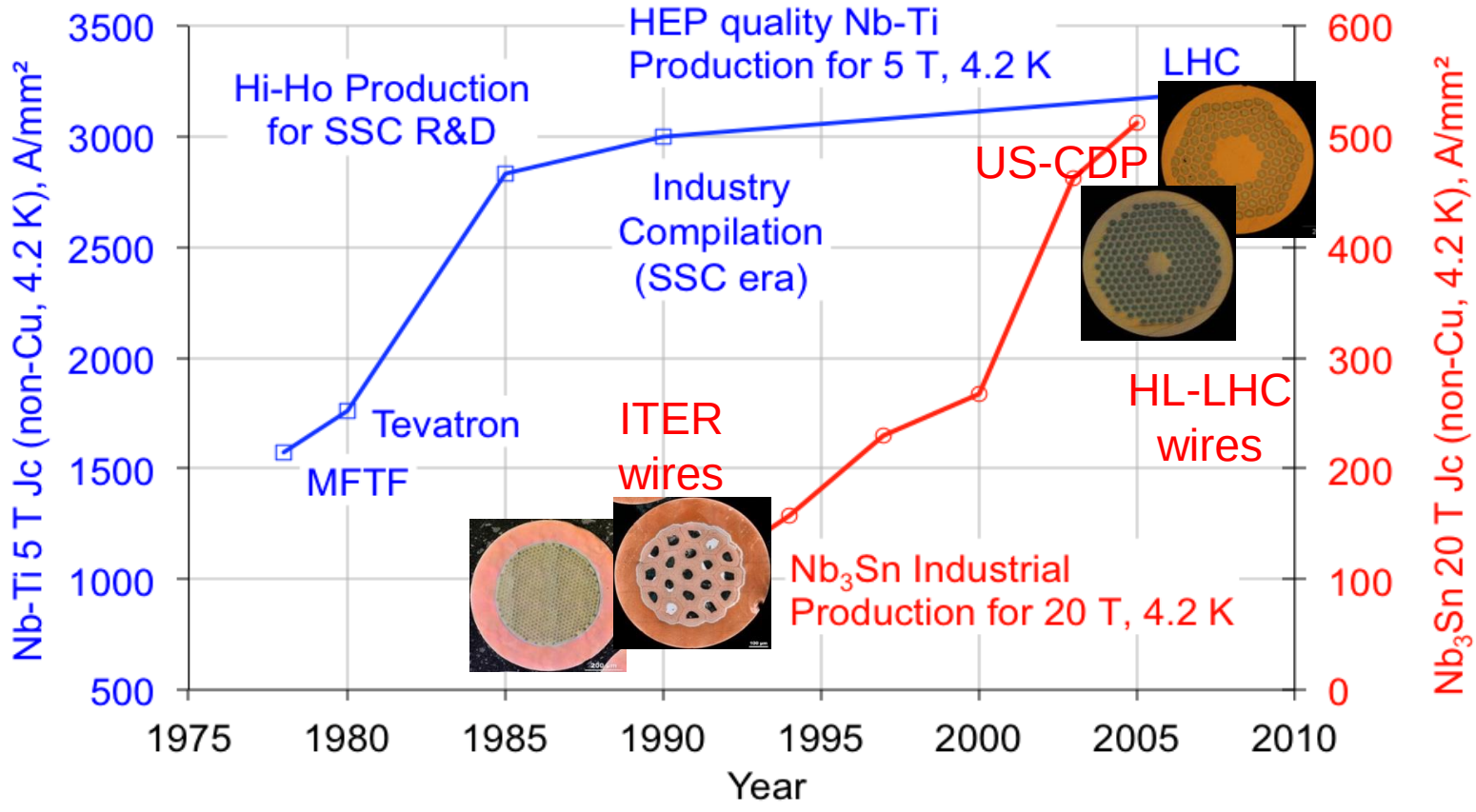
- Magnet Technology
  - W&R approach with reaction at ~650C lasting ~50 hrs
  - SC Strand Development – RRP108/127 and RRP150/169
  - Cable – 0.025 mm stainless steel core
  - cable insulation – ceramic, S2 or E-glass
  - coil end parts – water-jet/laser-sintering
  - coil curing – ceramic binder at ~150C
  - coil radial and azimuthal expansion gaps
  - coil impregnation – CTD101K
  - coil size control – CMM





CDP (Conductor Development Program) NbTi vs Nb_3Sn

- A Magnet can never perform better than the conductor it's made of



QXF (HL-LHC Quads) Plans

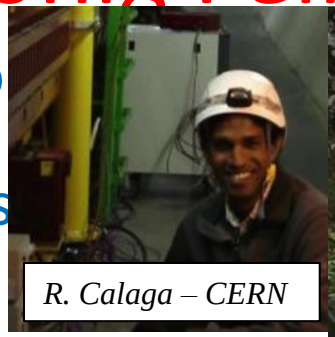
LARP

- Short model program: **2014-2016**
  - First SQXF coil test (Mirror struct.) in Dec. 2014
  - First magnet test (SQXF1) in May 2015
  - 2 (LARP) + 3 (CERN) short models + reassembly (~4)
- Long model program: **2015-2018**
  - Coil winding starts in 2015: Jan. (LARP)
  - First LQXF coil test (Mirror structure) in Dec. 2015
  - First model test in Oct. 2016 (LARP) and July 2017 (CERN)
  - 3 (LARP) + 2 (CERN) models in total
- Infrastructure and Resources at various Labs available *as long as* reasonable core program exist (see next slide)
- Series production: **2018-2022**

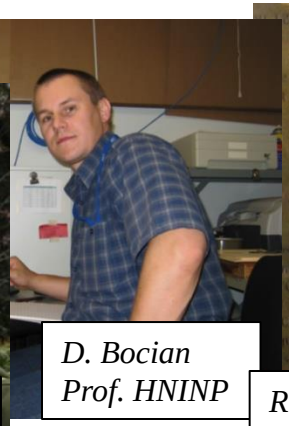
Operative Concepts: *LARP (with HFM and CDP) has brought Nb_3Sn to Readiness for Accelerator Applications*

CERN Visitor Program and Toohig Fellowshi

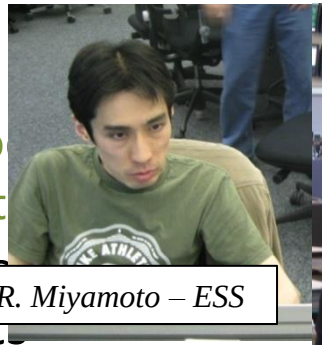
- Several Long Term Visito contributed to LHC Commissioning activities early LARP period
  - Among others:
    - Uli Wienands (SLAC)
    - Chandra Bhatt(FNAL)
    - Rama Calaga (former To
    - Eliana Gianfelice-Wendt
  - Program reduced in rec under budget constraint
- Extremely successful Fello program – Toohig Fellosh several young Accelerator Scientist providing vital contributions to the LHC a in general


R. Calaga – CERN


H. Felice – LBNL


D. Bocian
Prof. HNINP


R. DeMaria –CERN

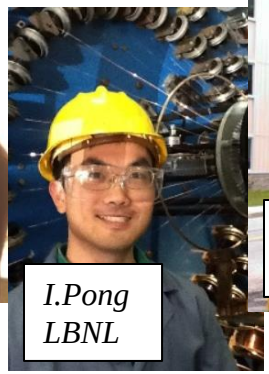

R. Miyamoto – ESS


T. Mastoridis
Prof. CPU


V. Previtali
Teacher, Geneve


S. White – ESRF


J.Cesaratto
Phillips


I.Pong
LBNL


S. Verdu
BNL


T. Helik
FNAL

LARP "after HiLumi Project"

Dear Prof. Siegrist,

Following recent discussions, CERN is assuming that the total US contribution to the Hi-Lumi project is of the order of US$200 million (construction project, excluding the R&D carried out within the LARP program that is due to continue for another 3-4 years in order to finish the R&D on the hardware and to continue the support for the important activities of accelerator physics and the long term visitor program).

The principle item of this contribution would be the Nb3Sn low-beta triplet. We understand that a preliminary evaluation of the quadrupoles (with 150 mm aperture) based on a joint study by LARP and CERN amounts to about 75% of the total US contribution, or US$150 million, for half of the magnets (i.e. 10 cold mass quadrupoles, without cryostat, with no integration nor installation). This proposal (half USA and half CERN) is the preferred solution not only to stay inside budget but it also leverages the advanced US technology (LARP) and would allow CERN to fully master the technology for future maintenance and consolidation. Mutual agreement on this proposal can be discussed at a later date.

CERN proposes that the remaining 25%, or US $50 million, be used to support hardware contributions on the following items (either full or part system):

a. High bandwidth feed-back system for the SPS/Crab cavity with a cryo-module
b. 11 T dipole (cold mass no cryostat)/electron-lenses

Top Priority

Backup

The feed-back system is of course subject to the success of the final prototype, like the Nb3Sn quadrupoles. Its cost is rather modest compare to the other items, so this could possibly leave some margin for other significant and visible contributions. The other items are not yet fully defined and/or their actual installation in the HL-LHC machine is not yet approved pending development of a final design and validation test results. So our suggestion is to keep the above list as a prioritized list to be reviewed depending on the outcome of the tests.

CERN would also like to express its gratitude if the DoE would support the continuation of the design of the D2 magnet based on the extensive expertise of BNL.

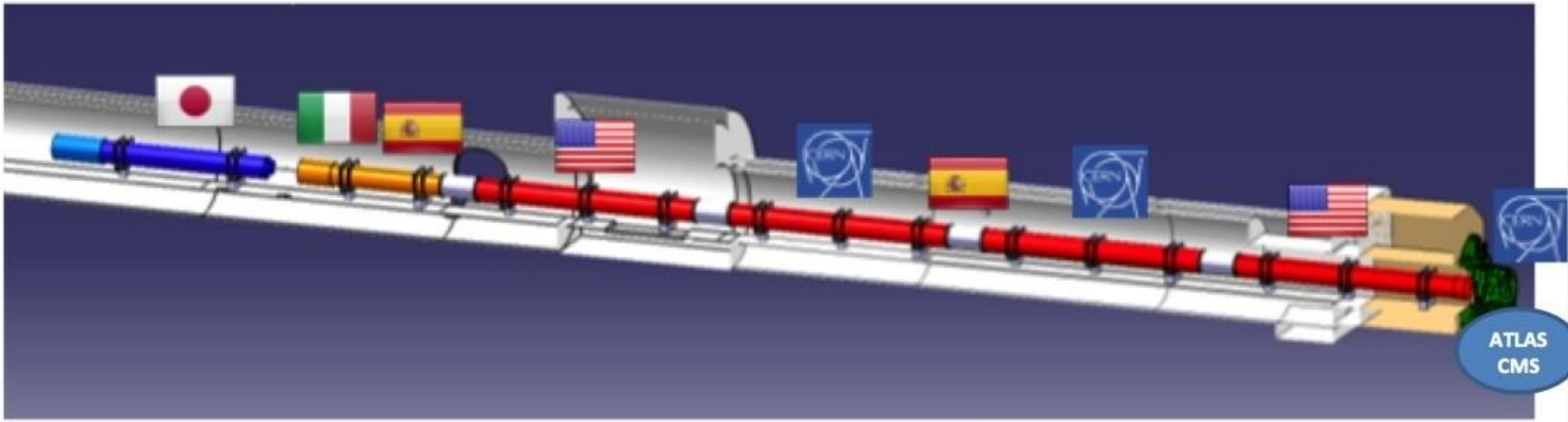
We remain at your disposal for any further information or clarifications.

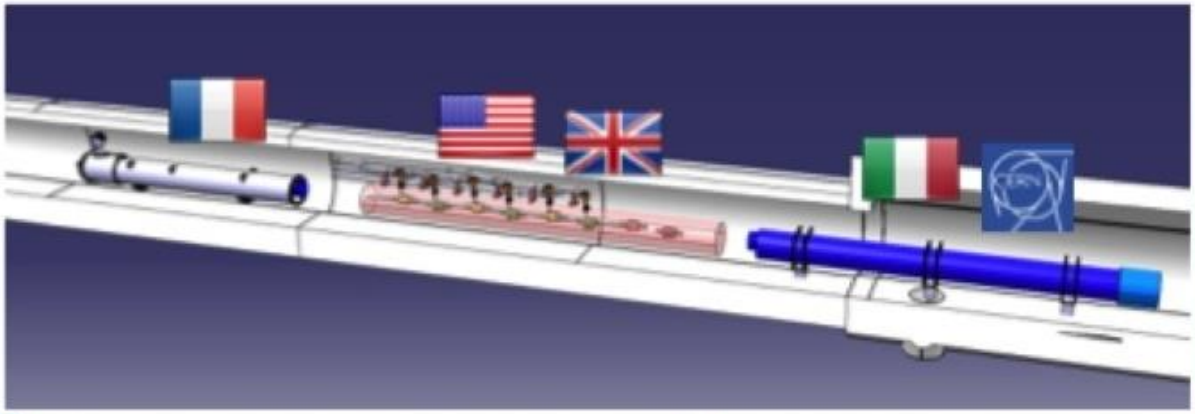
Yours sincerely,

Rolf Heuer
Director-General

Stephen Myers
Director of Accelerators and Technology

From LARP to US-HiLumi: US in-kind contribution to HEP in '25-'35





CC : R&D, Design and in-kind **USA**

CC : R&D and Design **UK**

Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**

D1 : R&D, Design, Prototypes and in-kind **JP**

MCBX : Design and Prototype **ES**

HO Correctors: Design and Prototypes **IT**

Q4 : Design and Prototype **FR**

LARP/HiLumi Collaboration Meeting – Napa, CA Nov 2013

Personal Reflections

- Essential foresight in 2003 has paved way for a program to support Accelerator Scientist in the operation, exploitation and development of equipment in a non-US Laboratory
  - Well-accepted concept in HEP Experiments, it was a *"first"* in the Accelerator environment.
  - LARP "breakthrough" must be preserved in the "Global Laboratories" scheme that appears to be forming in HEP.
- R&D program exploiting *National Leadership positions* are more likely to secure support from Funding Agencies
  - Magnets, SRF, etc in US.
- Directed R&D program at National level with clear milestones and decision points has worked for LARP.
  - Is it safe to extrapolate this point to future machines ?
  - Extrapolate to *International* R&D Program ?
- A small element of "*exploratory R&D*" is essential to investigate and benefit from new promising venues
  - Crab Cavities example in LARP
- World-wide efforts on accelerator simulation are a basic element of progress in this field, answering the need for continued cross-check, benchmarking and validation of critical and important results