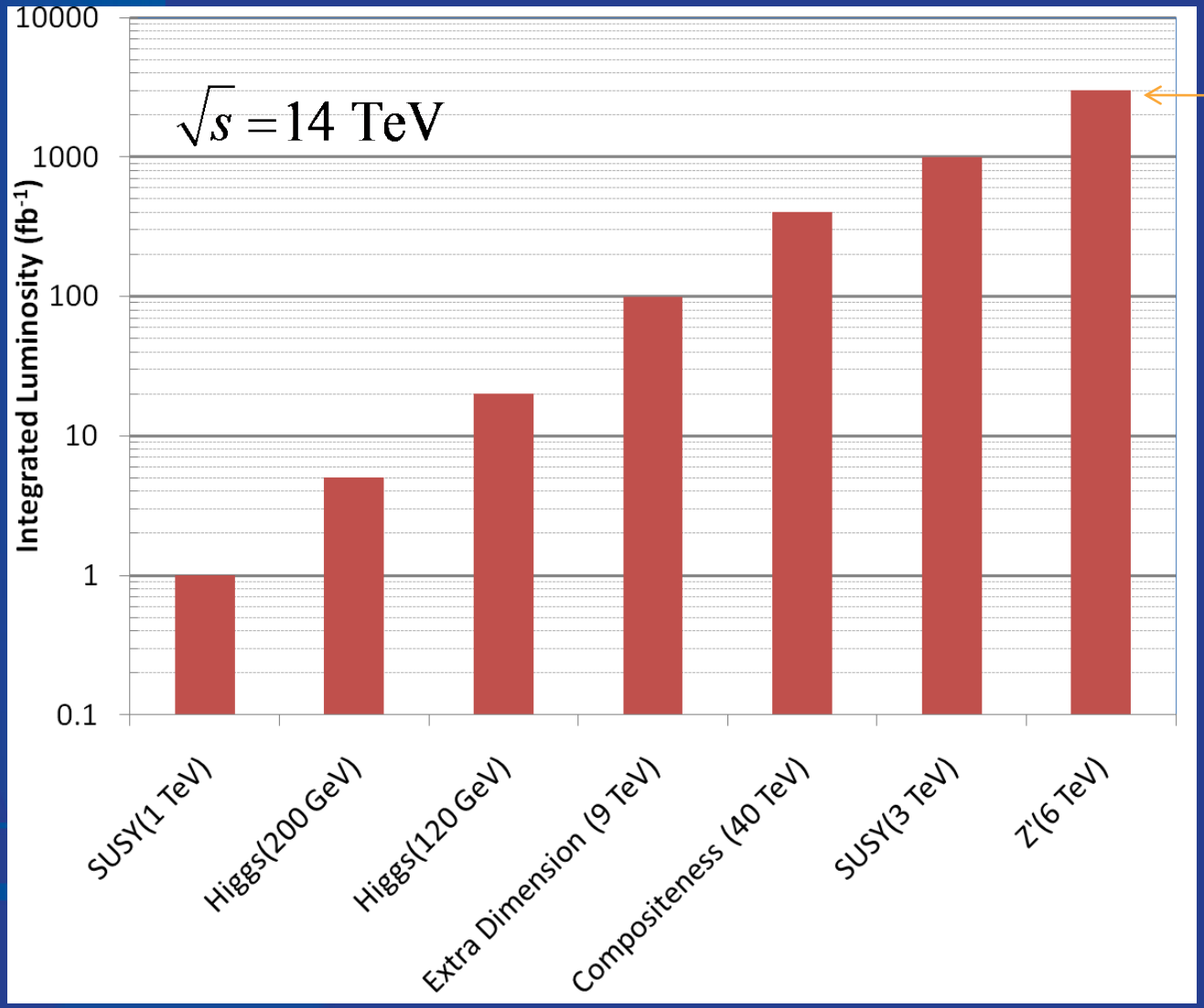
Proposed US Contributions to LHC Luminosity Upgrade

Eric Prebys
Director, US LHC Accelerator Research Program (LARP)
HEPAP Meeting, March 11, 2013

Motivation: The Big Picture

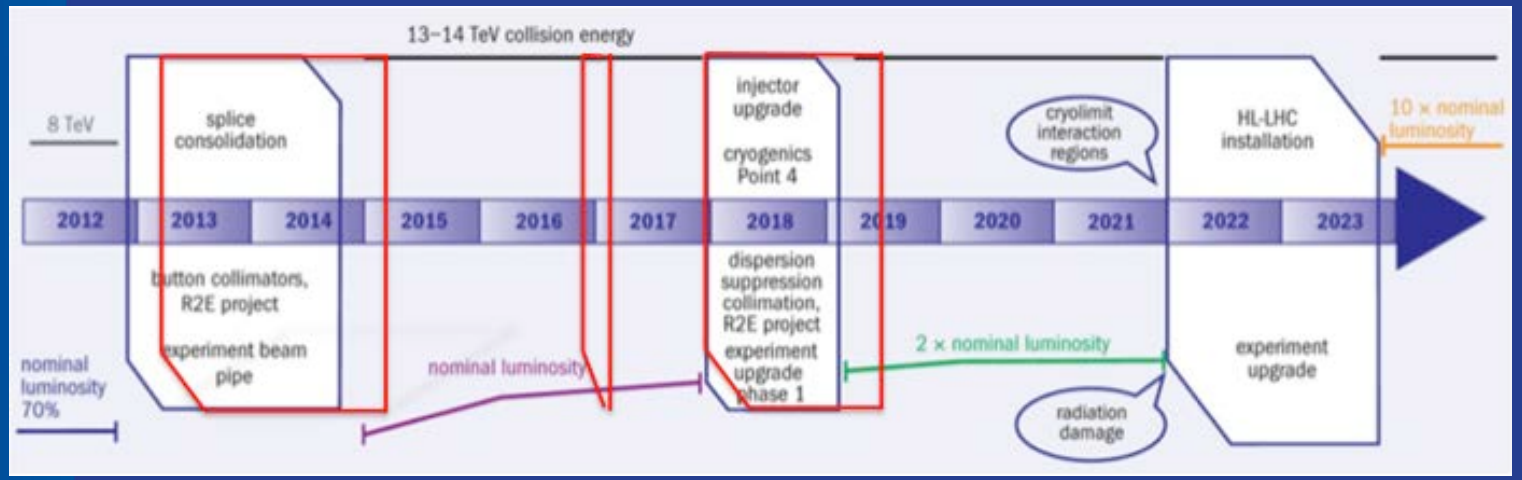


3000 fb^{-1}

~ 50 years at nominal LHC luminosity!

The future begins now

Baseline LHC Upgrade Path



- Time Line:
  - LS1*: “Nominal” (2013-2014)
    - Complete repairs of the superconducting joint and pressure relief problems which cause “the incident” in 2008 and currently limit the energy to 4+4 TeV.
    - “Lost memory” issues may limit the beam energy to somewhere between 6.5 and 7 TeV per beam.
    - At least 1×10^{34} $cm^{-2}s^{-1}$ peak luminosity
  - LS2: “Ultimate” (2017)
    - injector and collimation upgrades
    - At least 2×10^{34} $cm^{-2}s^{-1}$ peak luminosity
  - LS3: “HL-LHC” (~2022-2023)
    - Lower β^* and compensate for crossing angle to maximize luminosity
    - 5×10^{34} $cm^{-2}s^{-1}$ *leveled* luminosity

*LS = “Long Shutdown”

Fermilab

LARP History

- The US LHC Accelerator Research Program (LARP) was formed in 2003 to coordinate US R&D related to the LHC accelerator and injector chain at Fermilab, Brookhaven, and Berkeley
  - SLAC joined shortly thereafter
  - Has also had some involvement with Jefferson Lab, Old Dominion University and UT Austin
- LARP has contributed to the initial operation of the LHC, but much of the program is focused on future upgrades.
- The program is currently funded at a level of about $12-13M/year, divided among.
  - Accelerator research
  - Magnet research (~half of program)
  - Programmatic activities, including support for personnel at CERN

LARP Contributions to Current LHC Operation

- Schottky detector
  - Used for non-perturbative tune measurements (+chromaticities, momentum spread and transverse emmitances) – **Operational (currently some issues)**
- Tune tracking
  - Implement a PLL with pick-ups and quads to lock LHC tune **– Fully integrated**
  - Investigating generalization to chromaticity tracking
- AC dipole
  - US AC dipole to drive beam
  - Measure both linear and non-linear beam optics – **Primary tool for high energy optics**
- Luminosity monitor
  - High radiation ionization detector integrated with the LHC neutral beam absorber (TAN) at IP 1 and 5. **– Functional, becoming primary fast system.**
- Synchrotron Light Monitor
  - Used to passively measure transverse beam size and monitor abort gap
  - Not a LARP project, but significantly improved by LARP – **Operational (currently some issues)**
- Low level RF tools
  - Leverage SLAC expertise for in situ characterization of RF cavities – **Fully integrated**
- Personnel Programs
  - Toohig postdoctoral fellowship
  - Long Term Visitor Program

Impact of LARP Personnel Programs

Letter to Michael Procario, Acting Head, DOE Office of High Energy Physics, 9-MARCH-2011

Dear Dr. Procario,

We are writing to express our appreciation for the accelerator personnel who have come to CERN to participate in the LHC project with the support of the US LHC Accelerator Research Program (LARP). We strongly encourage continued support for such participation in the future.

As you know, LARP has two subprograms to support US accelerator scientists working at CERN. The Toohig Postdoctoral Fellowship is awarded to recent PhD recipients who are expected to divide their time between CERN and the LARP institution of their choice, while the LARP Long Term Visitor (LTV) program provides transportation and cost of living expenses to more senior personnel from US labs who wish to spend extended periods at CERN.

(…)

Both sides have benefited from this collaboration and it is our sincere hope that it continues in the future.

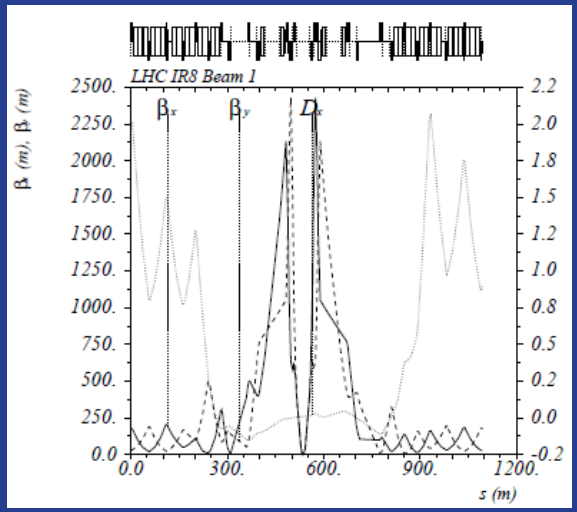
With our best regards,

Prof. Rolf Heuer
Director-General

Dr. Steve Myers
Director for Accelerators

Key Components of HL-LHC

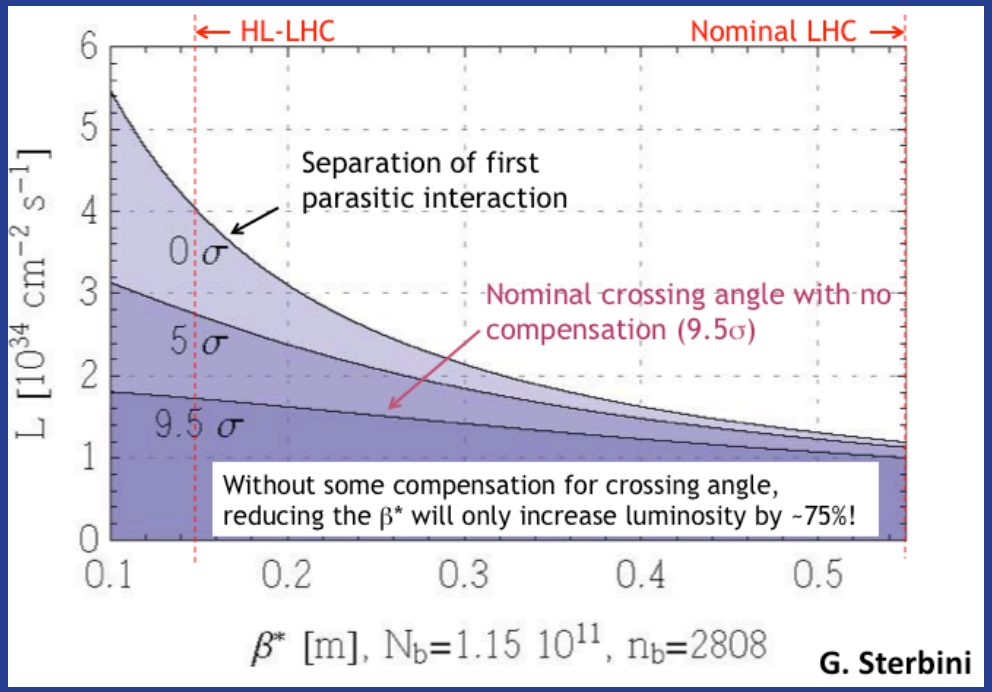
- Reduce β* from 55 cm to 15 cm
  - Requires large aperture final focus quads
  - Beyond NbTi
  - ➔Requires Nb_3Sn
    - never before used in an accelerator!
    - Nb3Sn R&D key component of LARP



- BUT, reducing β* *increases* the effect of crossing angle

$$L \propto \frac{1}{\sqrt{1+\left(\frac{\theta_c \sigma_z}{2\sigma_x}\right)^2}}$$

"Piwinski Angle"



Relevance of LARP to CERN Upgrade*

Letter to Dennis Kovar, Head, 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

New Direction for LARP

- LARP has historically been an R&D organization
  - Not well structured for hard deliverables
  - CERN upgrade plans in a state of flux
- Recent developments
  - CERN has formalized the planning for the luminosity upgrade
  - In June 2012, CERN chose 150 mm as the aperture for the final focus quads
- At the DOE's request, we are in the process of transforming LARP into a project to encompass *all* US contributions to the luminosity upgrade of the LHC.
- Budget Guidance
  - Flat-Flat LARP funding @ ~$12.4M/year through FY16
  - A total of $200M (then year dollars) TPC, assuming CD-3 at approximately the beginning of FY17
  - "Some amount" of General Accelerator Development (GAD) funds invested in support of this program (still being negotiated).

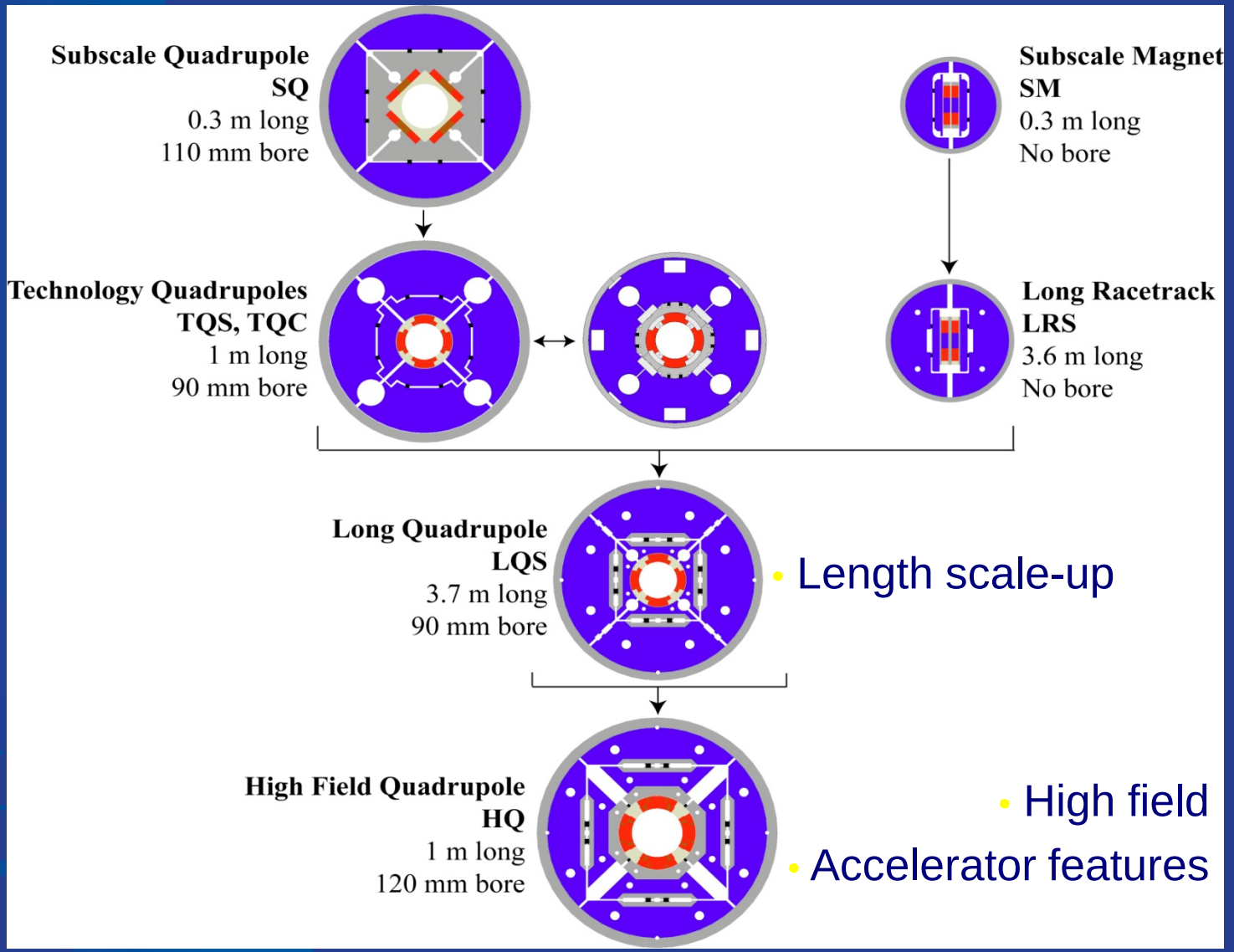
Candidate Projects Considered

- Traditional LARP Scope
  - 150 mm aperture Nb_3Sn quadrupoles
    - Likely just cold masses, divided between here and CERN
  - Crab Cavities
    - Prototypes. Production Units. Cryomodules.
  - High Bandwidth Feedback System
    - Pick-ups. Processing Systems. Response Kickers.
  - Collimation
    - Rotatable collimators.
    - Hollow electron beams.
- New Scope
  - 11 T Nb_3Sn dipoles
    - Used to make room for collimation in dispersion suppression region
    - Has been a bilateral CERN/FNAL effort
  - Large Aperture NbTi D2 separator magnets
    - First dual aperture magnets near Irs
    - Has been bilateral CERN/BNL effort

In Broad Strokes….

- A consensus quickly emerged among all concerned (CERN, DOE, LARP labs) regarding priority
  - Core Priorities:
    - Committed to a major stake in Nb_3Sn quads
      - Less than “about half” not considered attractive by anyone involved
      - This will eat up the lion’s share of resources
    - Would like to commit to crabs up to the SPS test.
      - As much production as possible
    - High bandwidth feedback was seen as a high impact contribution for modest resources.
  - Back up options:
    - 11 T dipoles
      - It was felt that the current R&D work should be continued, funded by GAD funds, up to a negotiated hand-off project.
    - Hollow electron beams for halo removal
      - Although there is no solid plan for collimation, it was felt R&D into this effort should be supported, in the event it’s chosen as a primary technology and circumstances allow its funding.
  - Low priority
    - There was not much interest in pursuing the D2 separators.

LARP Magnet Development Tree



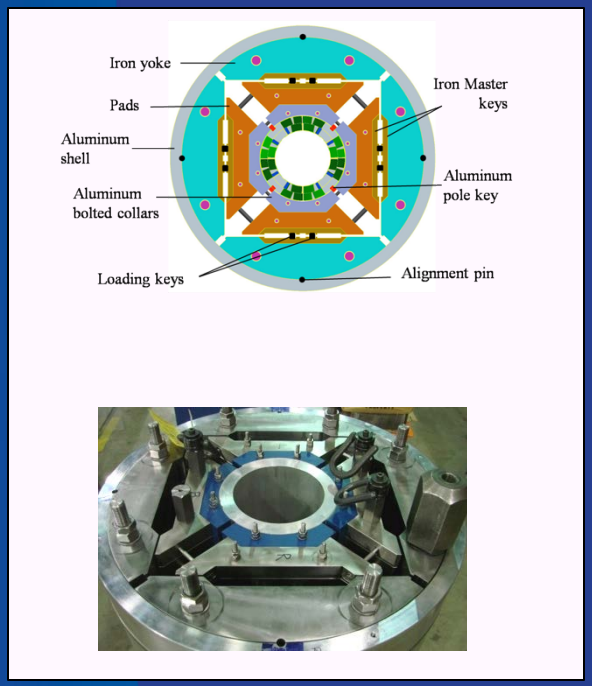
Completed

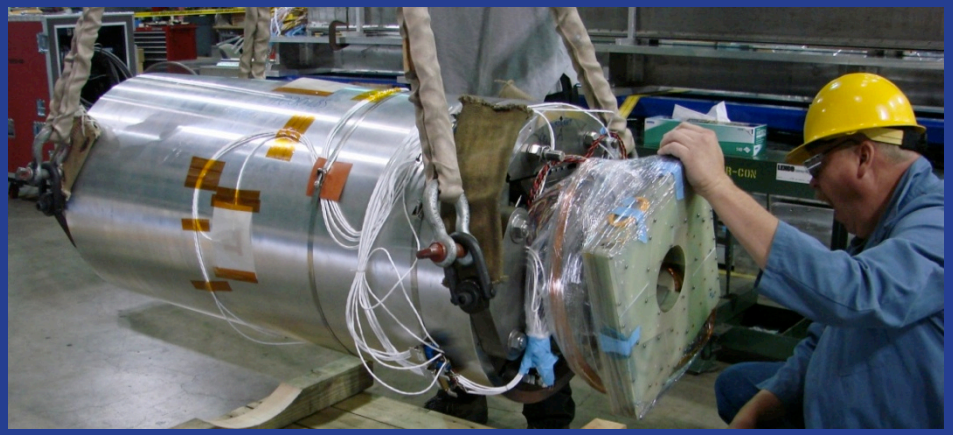
Achieved
220 T/m

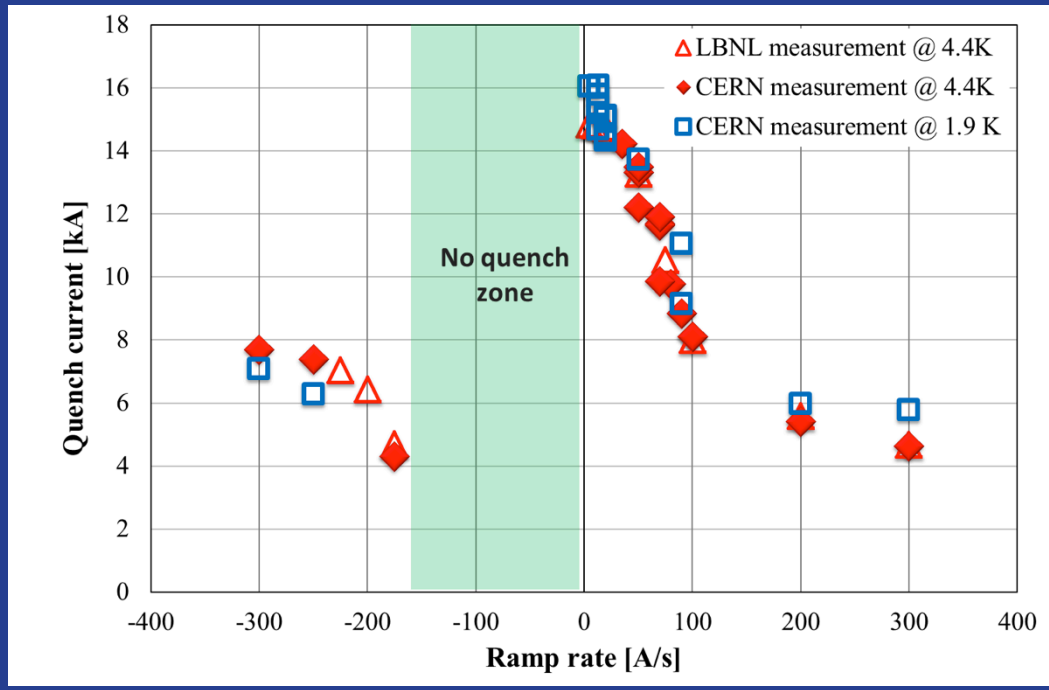
Being
tested

Fermilab

HQ Tests





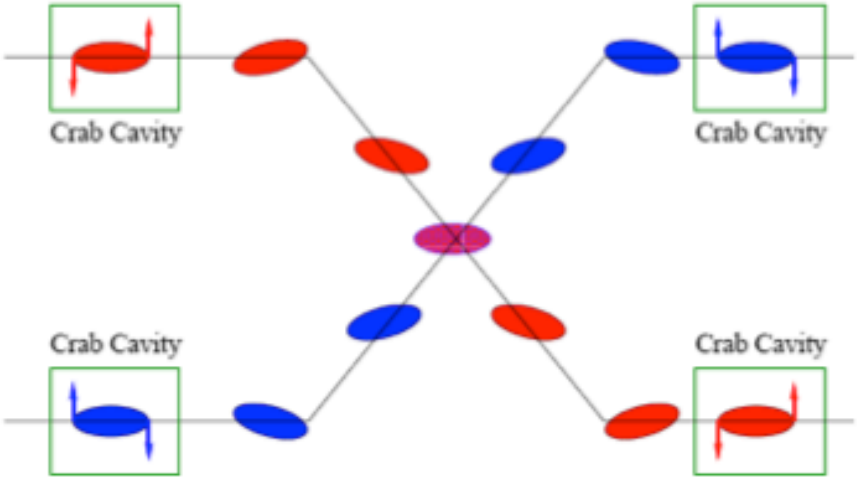


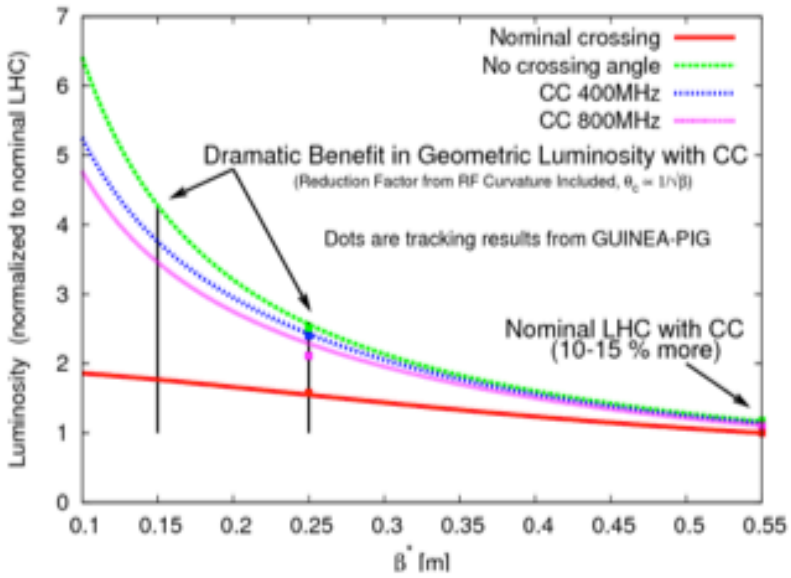
- Initial tests at LBNL
  - Reached 14.6 kA @ 4.2K
- Recent tests at CERN
  - Good agreement with LBNL results
  - Reached 16.2 kA @ 1.9K
    - 85% of short sample limit
    - > nominal current of 14.9 kA!

Proposed Magnet Contribution

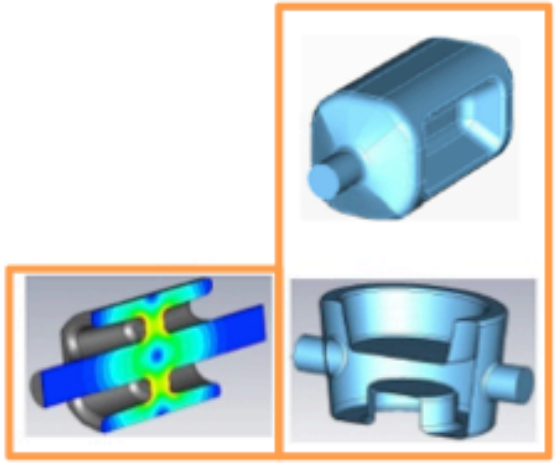
- In June, 2012, the choice was made of 150 mm as the aperture for the focusing quads in the LHC upgrade.
- LARP activities have been modified in accordance with this decision and recommendations of the July 2012 review
  - Curtail existing 120 mm program
  - Work with CERN to develop a 150 mm prototype (LQXF)
- The program will then full transition into a production project to produce the focusing quadrupoles for the LHC upgrade
  - US contribution
    - Cold masses for the Q1 and Q3 quads, to be cryostated at CERN
    - A total of 20 half length (4 m) cold masses, including 2 pre-series units, 16 production units, and 2 spares

Crab Cavity Development





- Technical Challenges
  - Crab cavities have only *barely* been shown to work.
    - Never in hadron machines
  - LHC bunch length ➔ low frequency (400 MHz)
  - 19.4 cm beam separation ➔ "compact" (exotic) design
- Additional benefit
  - Crab cavities are an easy way to level luminosity!
- Currently aiming for:
  - Down-select –next year
  - SPS test in 2015



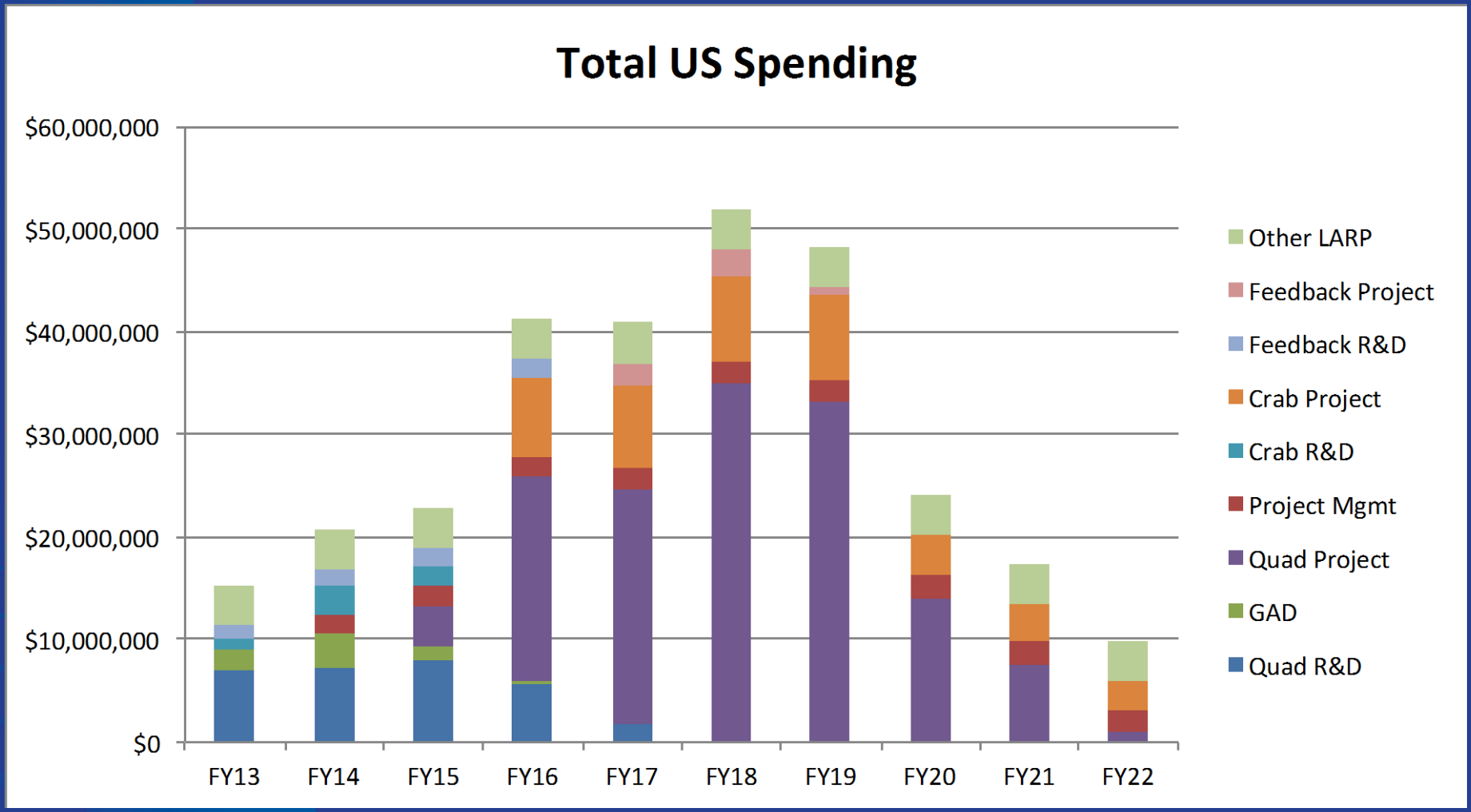
Proposed Crab Cavity Contribution

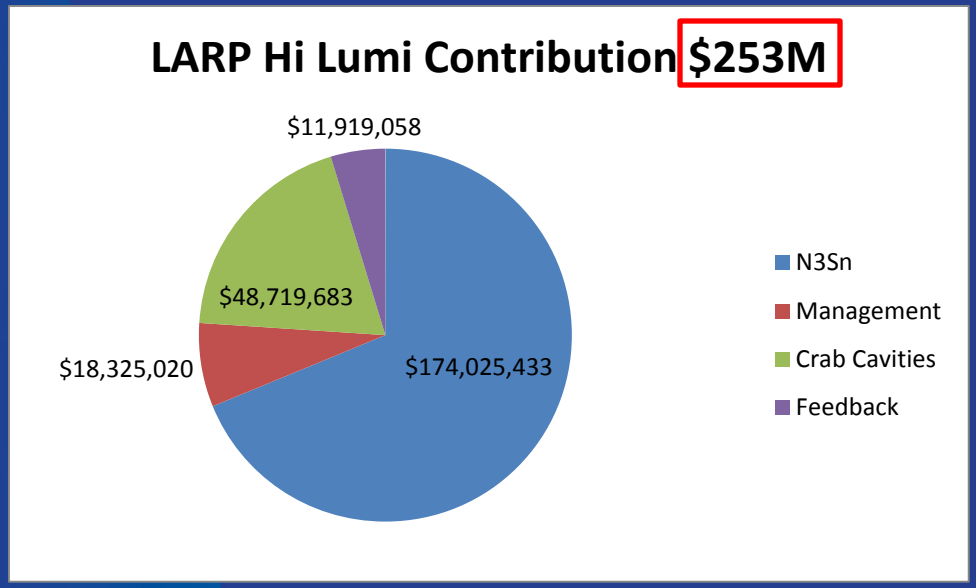
- LARP has been a major proponent of crab cavities since the beginning
  - Currently two of the three candidate designs are from within LARP
- Crab cavities leverage US expertise and US industry
  - All prototypes, including the UK prototype, have been built in the US.
- Proposal
  - The LARP R&D program will continue work on the SLAC/ODU and BNL cavity designs
  - Efforts will increase at FNAL on cryostat design
  - This will culminate with the delivery of a test cryostat with cavities of one of the designs for a beam test in the SPS (2015 or 2016)
  - The project will undertake the production of 10 cryomodules (4 per IP + 2 spares) for installation in the LHC upgrade
    - CERN will provide RF couplers and all required infrastructure

High Bandwidth Feedback System

- The high bandwidth feedback system is a proposed feedback system for the SPS, which leverages LARP experience with the LHC LLRF system
- Proposal
  - LARP will continue R&D related to the system.
  - The deliverable would be a functional prototype in the SPS, for which
    - The US contribution would be the complete “full-function” instability control system hardware, firmware and software necessary to operate at the SPS (and potentially LHC, PS).
    - The CERN contribution will include the vacuum structures (pickup(s) and kicker(s)) and all tunnel related cable plant.

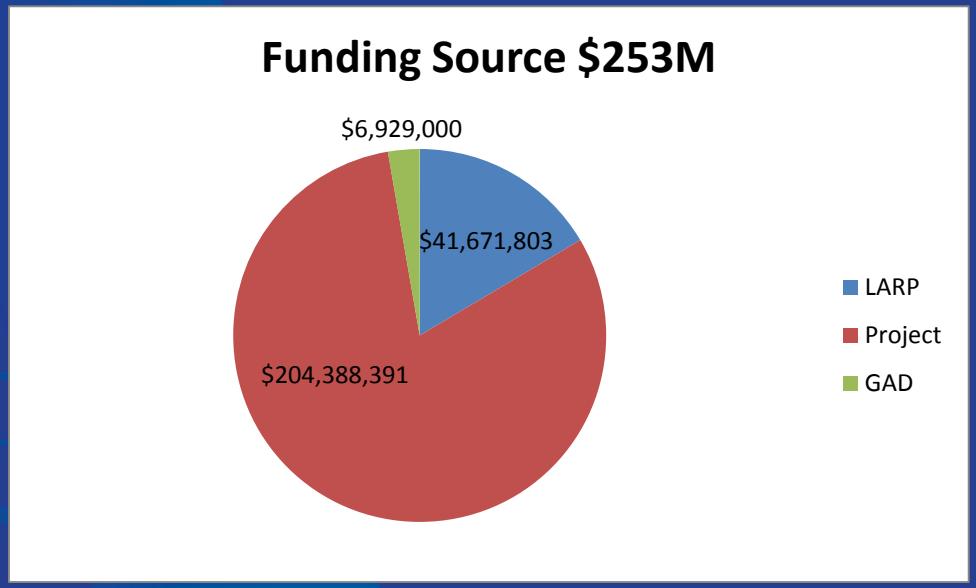
Budget Profile





Compare to:
$200M TPC
+4 years at ~$9M/year
≈$236M

➔Still work to do



Status and Plans

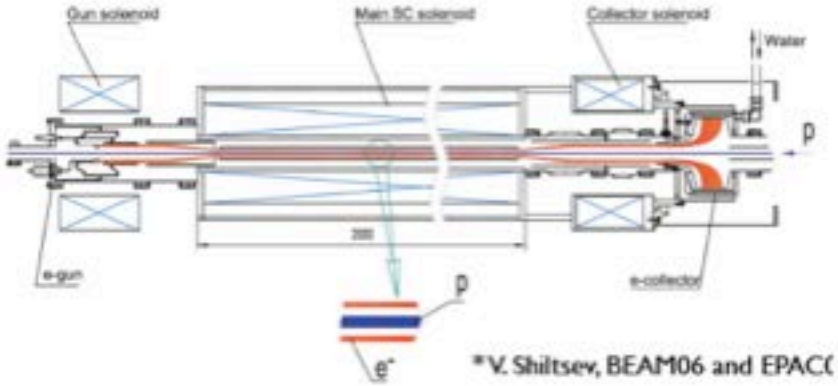
- Briefed DOE on Feb. 1, 2013
- Very supportive of proposed deliverables
- Working with us to divert necessary General Accelerator Research and Development (GARD) funds, as well as additional funding to support our planned spending profile prior to FY17.
- Moving ahead with planning
  - Internal reviews
  - Identifying GARD contributions
  - Refining the budget estimates in light of the clarified guidance.

Non-Project LARP Activities

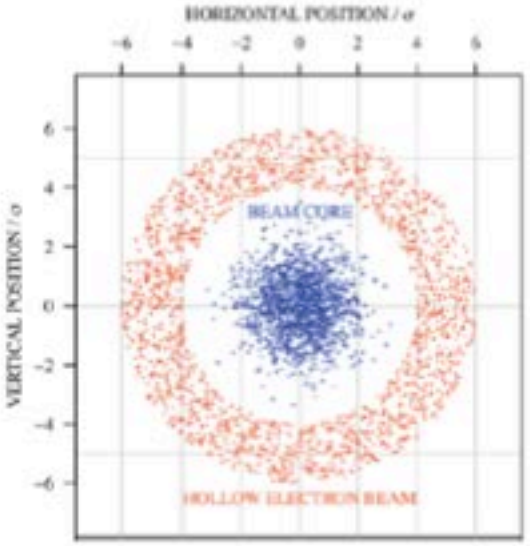
- LARP continues to have significant R&D activities that are not directly related to the project deliverables
  - Energy deposition studies
  - Beam-beam and general beam physics issues
  - Hollow electron beams for halo removal
  - Personnel programs
    - Toohig postdoctoral fellowship
    - Long Term Visitors (LTV) program
- We are committed to preserving at least some non-project activities after the project starts

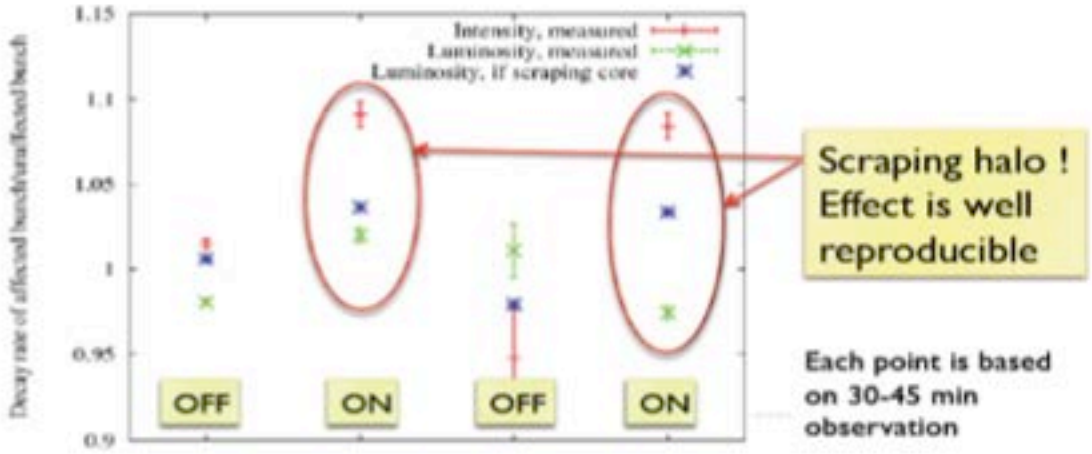
Example: Hollow Electron Beam R&D

- Grew out of electron beam-beam compensation
- Tested at Tevatron
- Tentatively planning a test in the SPS



*V. Shiltsev, BEAM06 and EPAC(





Conclusion

- LARP has been very successful at leveraging US capabilities to develop technology for the LHC.
- We are in the process of transforming the program into a production effort to produce hard deliverables for the LHC luminosity upgrade
  - TPC ~$250M