Plans for HL-LHC Upgrades: US Contributions

Giorgio Apollinari
US LARP Director

BNL P5 Meeting, Dec 15-18, 2013

P5 Questions (S. Ritz)

- For the machine contributions:

  a) The US scope and how the US contributions are necessary, as well as how the effort would benefit facilities and development of key US capabilities [Q:a1] [Q:a2]

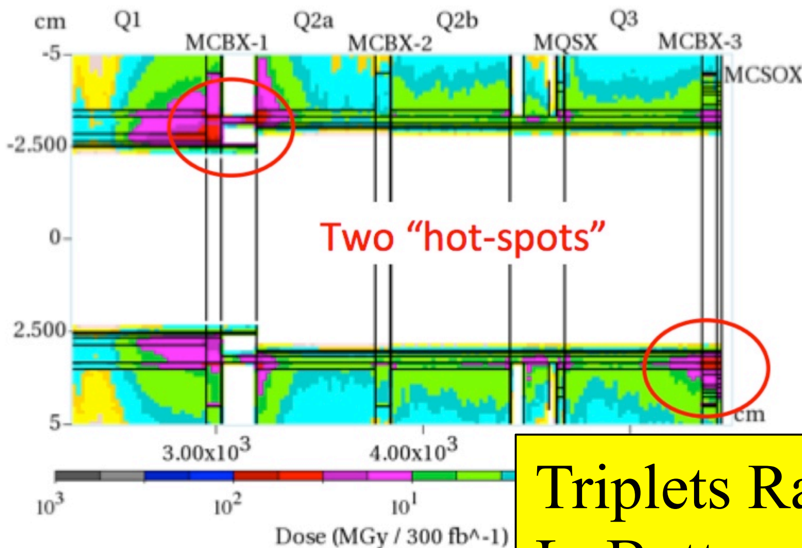
  b) the notional timeline for any remaining R&D, [Q:b1] construction ~~and installation~~ [Q:b2]

  c) Your estimate for the US construction cost, [Q:c1] the basis of estimate [Q:c2] and contingency. [Q:c3] ~~If multiagency, the envisioned roles and division of sco~~

  d) The priority of the efforts, [Q:d1] along with any option for reduced scope [Q:d2]

  e) Continued support for non-projectized activities [Q:e1]

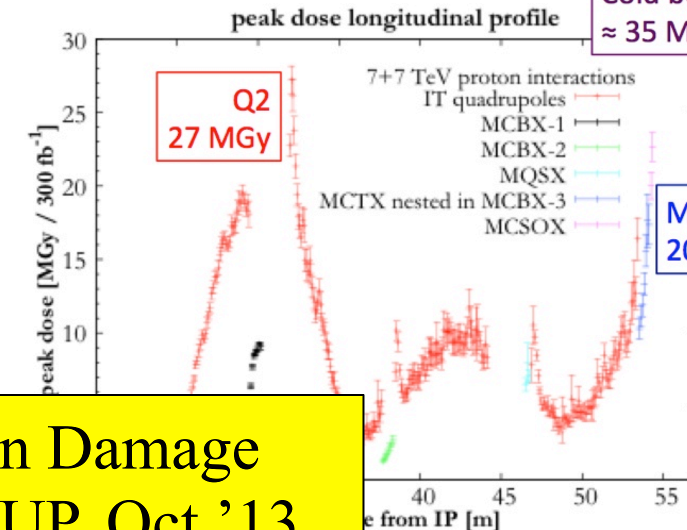
Radiation dose in the present triplet (300 fb^{-1})



. Cerutti, et al., WP10: Energy Deposition and Radiation D...
ttps://indico.fnal.gov/conferenceDisplay.py?confId=6164

Radiation dose in the present triplet (300 fb^{-1})

Cold bore insulation ≈ 35 MGy



...d Radiation Damage in Triplet Magnets, April 2013

Triplets Radiation Damage
L. Bottura – RLIUP, Oct ’13

- *Executive Summary:*
  - Present triplets in NbTi will integrate ~20-30 MGy after 300 fb^{-1} (~50% uncertainty)
  - Experimental measurements on elements of NbTi triplets show considerable mechanical degradation in epoxies, kapton and other insulation elements at 20 to 50 MGy
  - These conclusions were already reached back in ~2001.

Su...
- E...
- B... (8...
- F... 5... k...
- I...
- T... i... (...

Q:a1 ...echanical failure (nested coils in MCBX)

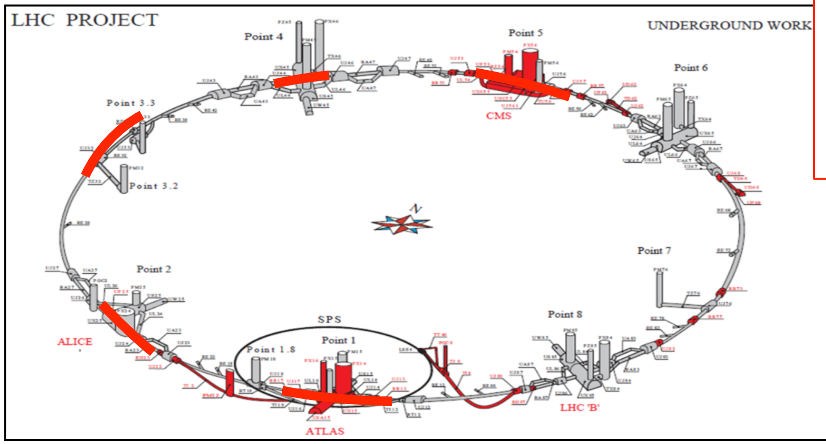
...on)

is hence **consistent with previous analyses**

HL-LHC Upgrades post LS-3

LARP

High Luminosity LHC



https://espace.cern.ch/HiLumi/2013/SitePages/Home.aspx

Q:a1 Q:d2

- Synergetic with technology and intellectual leadership in US Accelerator HEP
- Preserve US Acc. Community role as major player in large collider endeavors

1.2

ted

- – Major revamp of IP
  - *Focusing Triplets*
  - Crab Cavities
  - *D1-D2 Separator Dipoles*
- – Hollow e-Lens
- – Collimators/11 T
- – Instrumentation and Control
- – Cryogenic Upgrades
- – Magnet Power Distribution
- – 200, 800 MHz Harmonics & Injectors
- – ....

- Preliminary TDR by '15. Finalized by 2016/2017
- Next few slides: down-scoping decisions

LARP/GARD History and Transformation

- 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, Berkeley and SLAC
  - Some involvement from Jefferson Lab, ODU and UT Austin
- The program is currently funded at a level of about $12-13M/year:
  - Magnet research (~half of program)
  - Accelerator research (Crab cavities, WBFS, Collimators, e-hollow lens,..)
  - Programmatic activities, including support for Toohig fellowship
- LARP has benefited from synergy with GARD (General Accelerator R&D) activities, mostly in High Field Magnet developments.
- FY13-FY18 Evolution…
  - Initial convergences on deliverables for HL-LHC
  - <u>Program to be handled like a "project" to Reduce Risk of Construction Project</u>
- *... however the need for continued innovation will not disappear and a "LARP-like" program has proved to be ideal in coordinating cross-Labs resources and to continue to participate in Hardware and Beam Commissioning at LHC ("HL-LARP or LARP-2" in next decade)*

Q:b1 Q:e1

LARP

US in-kind Contribution to HL-LHC: scope selection

High Luminosity LHC

- Process of convergence among CERN-DOE-U.S. Labs-LARP initiated in Dec '2012
- Budget Guidance
  - Flat-Flat LARP funding @ ~$12.4M/year through FY16/FY17
  - A total of $200-210M (then year dollars) TPC, assuming CD-3 in ~FY17
  - "Some amount" of GARD funds:
    - Expected: 2 M$ in FY14, 4 M$ in FY15 – Actuals: 0 M$ in FY14 IF

~ 75% of US contribution to HL-LHC

- Initial consensus on core Priorities:
  - Comittment to a major stake in Nb_3Sn quads
  - Crab cavities up to the SPS test and production
  - High bandwidth feedback system was seen as a high impact contribution for modest resources.
- Back up options:
  - 11 T dipoles for use with new DS Collimators
  - Hollow electron beams for halo removal
- "Internal" Cost Review in June '13 with DOE representatives attending.

Q:a1 Q:d2

LARP

Feedback from CERN

High Luminosity LHC

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 ← Top Priority
b. 11 T dipole (cold mass no cryostat)/electron-lenses ← 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.

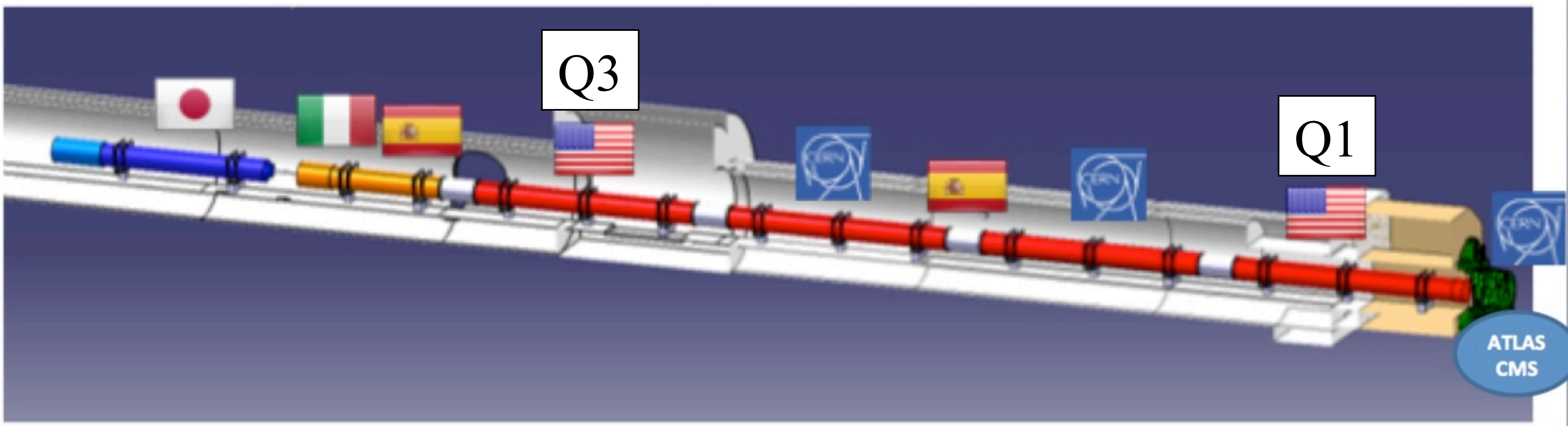
Yours sincerely,

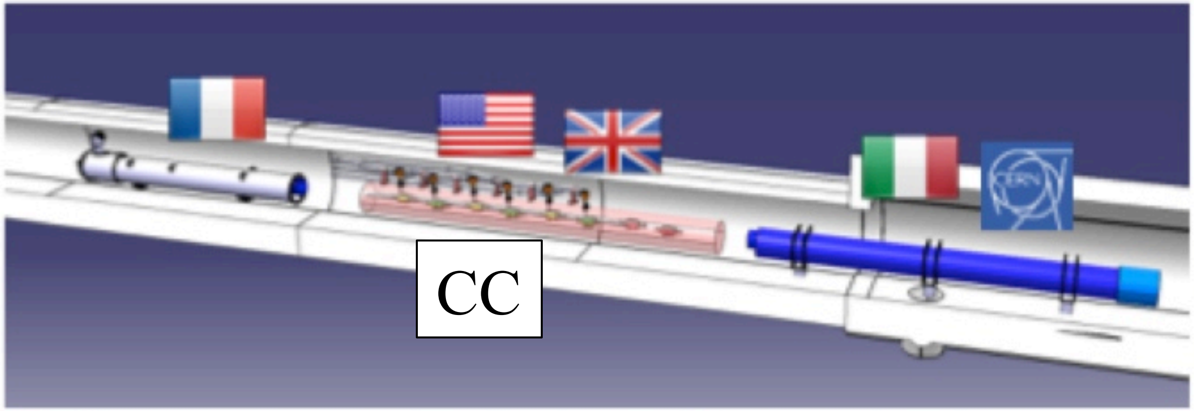
Rolf Heuer
Director-General

Stephen Myers
Director of Accelerators and Technology

Q:a1 Q:d1

In-kind contribution and Collaboration for HW design and prototypes



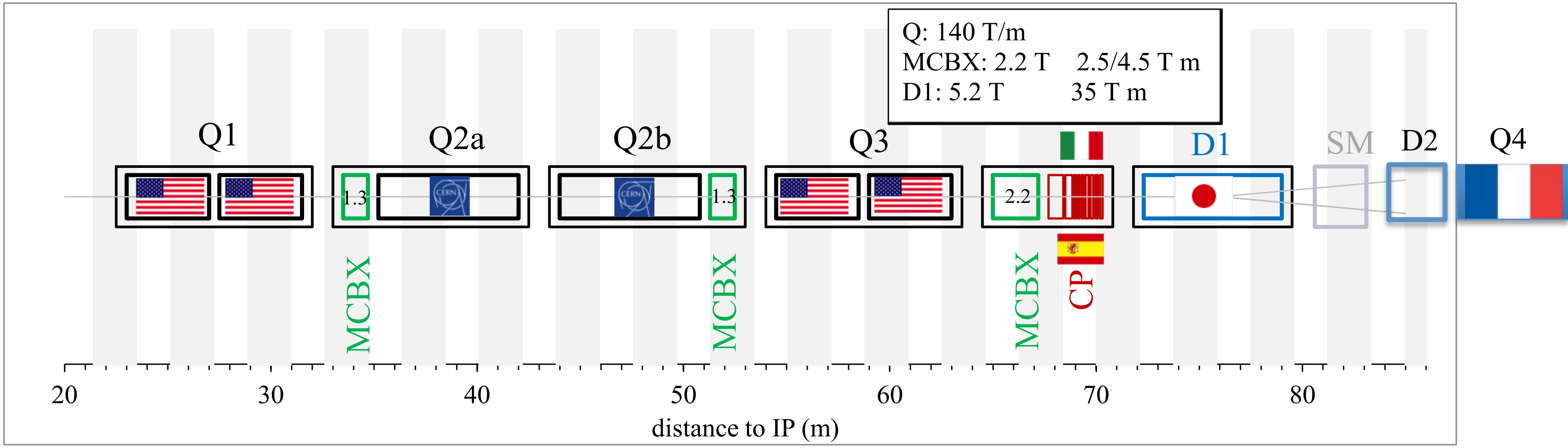


Q1-Q3 : R&D, Design, Prototypes and in-kind **USA**
D1 : R&D, Design, Prototypes and in-kind **JP**
MCBX : Design and Prototype **ES**
HO Correctors: Design and Prototypes **IT**
Q4 : Design and Prototype **FR**

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

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

Focusing Magnets: Close-up

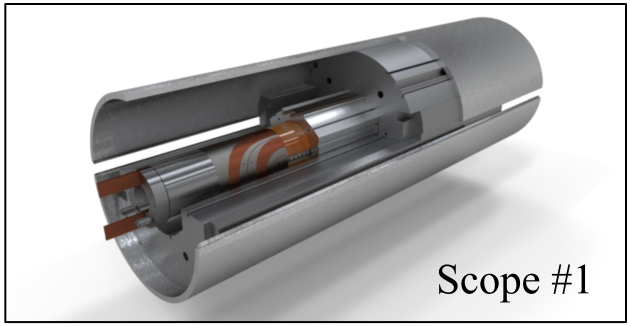


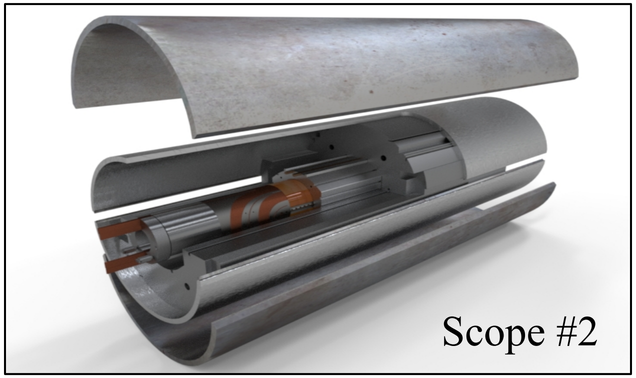
- IP Deliverables count:
  - Cold masses for 4 Q1 and 4 Q3 magnets, each needing 2 4 m long cold masses : 16 + 4 spares
  - 2 Crab Cavities Cryostat per beam per IP each containing 6 cavities: 4 CM + 1 spare (and 30 CC)

SCOPE/TIME/COST Triangle

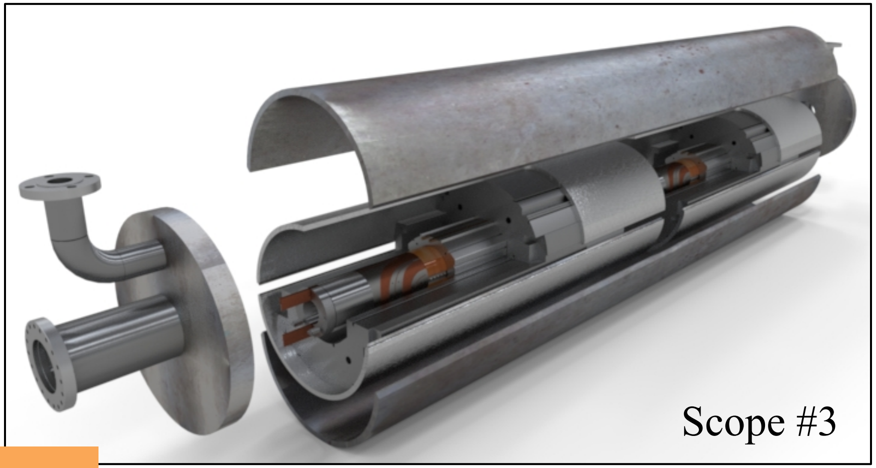
- A successful project must satisfy three basic objectives:
  - Cost: all the work must be finished within budget
    - Initial discussion placing US HL-LHC contribution in the ~200 M$ range (TY$)
  - Schedule: the project must finish on time
    - End of LS3 must see elements integrated and performing in the LHC tunnel
  - Scope: amounts of performing deliverables
    - Product must be fit for intended purpose (also "quality")
- It is probably not incorrect to state that "cost" is the least flexible of the constraints. "Schedule" will have to abide to the HL-LHC overall schedule while "scope" is the *negotiable* variable as the project matures.
  - Caveat on "Schedule": Completion of US contribution to HL-LHC Machine must happen ~1 y before completion of HL-LHC to allow for installation and commissioning at CERN.
- Once "Cost" is defined by appropriate negotiation among Project stakeholders, "scope" for US in-kind deliverables needs to be handled between US-Project Office and CERN.
- Ex: QXF deliverable

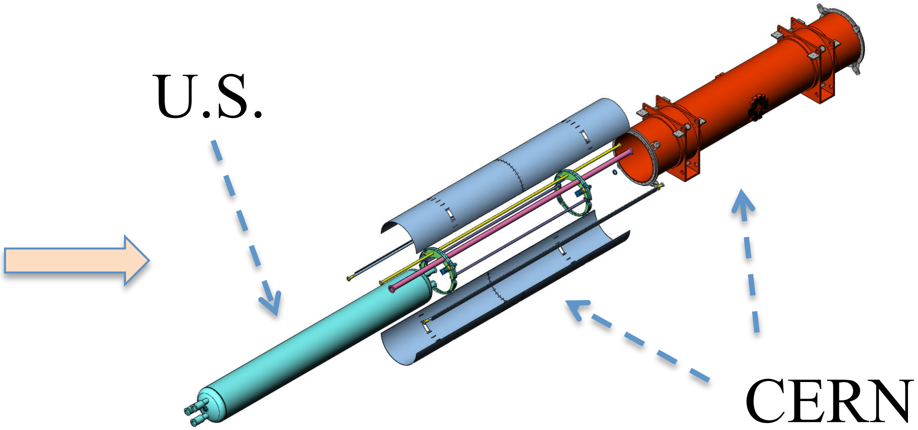
Ex: IR Magnets Deliverable QXF





- QXF Magnets
  - Options
    1. Cold Mass (coils and Al. Shell), ~4.3 m long, no test
    2. He SSL vessel 4.3 m long single tested magnet to be paired, aligned, welded and tested as a cryostated assembly at CERN.
    3. Fully finished SS He Vessel double magnet, ~9 m long, with inter-magnet connection(s)
  - Cost differential: ~+/- 3 M$ respect to cost estimate to be presented later





Q:a1

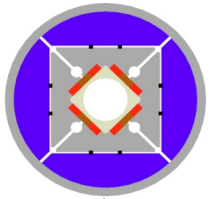
10 y of LARP Magnet Development

LARP

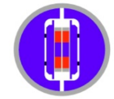
High Luminosity LHC

SQ Series: 19 coils, 11-12 T
SQ02: **54/61 MJR** J_c>1800
- 97% at 4.3/4.5 K
- 97% at 1.8 K

Subscale Quadrupole
SQ
0.3 m long
110 mm bore



Subscale Magnet
SM
0.3 m long
No bore

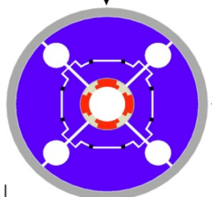


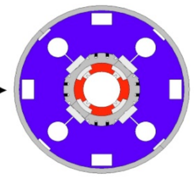
LR Series: xx coils, ~12 T
LRS02: 54/61 RRP J_c>2700
- 96% at 4.5 K

TQ Series: 33 coils, 12-13 T
TSQ02**: 54/61 RRP** J_c>2800
- 88% to 97% at 4.3
- "Erratic" @ 1.9 K

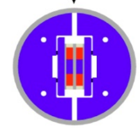
TQS03: **108/127 RRP** J_c>2800
- 93% at 4.3 K
- 93% at 1.9 K

Technology Quadrupoles
TQS, TQC
1 m long
90 mm bore

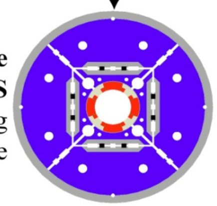




Long Racetrack
LRS
3.6 m long
No bore



Long Quadrupole
LQS
3.7 m long
90 mm bore



LQ Series: 19 coils, ~12 T
LSQ01**: 54/61 RRP** J_c>2700
- 93% at 4.5 K
- Marginal Increase at lower T

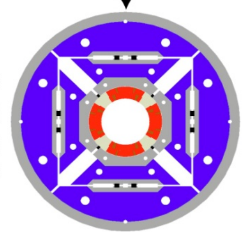
LQS03: **108/127 RRP** J_c>2800
- 91% at 4.6 K
- No increase at lower T

HQ Series: 25 coils, 13-15 T
HQ01e: **54/61 and 108/127 RRP**
- 85% at 4.5 K
- No Increase at lower T

HQ02: **108/127 RRP** J_c>2800
- 98% at 4.5 K
- Not fully trained at lower T

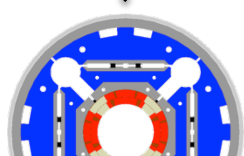
LARP Focus until ~2012

High Field Quadrupole
HQ
1 m long
120 mm bore



New IR quad Aperture

High Field Quadrupole
SQXF/LQXF
1 m / 4 m long
150 mm bore

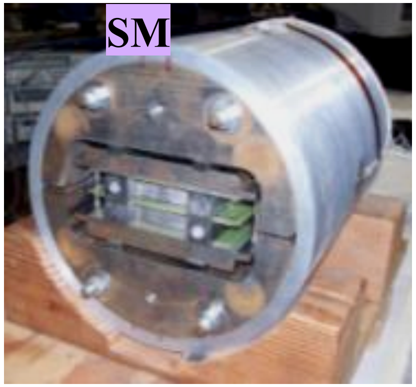


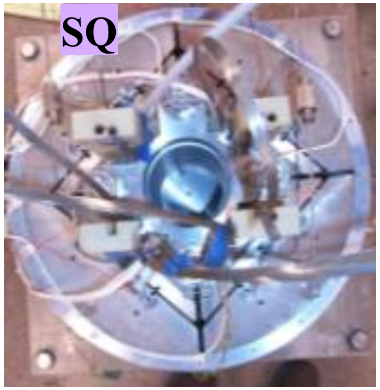
US SQXF Series: 13/18 Coils
- *2 or 3 1m long models*
- *2014-2016*

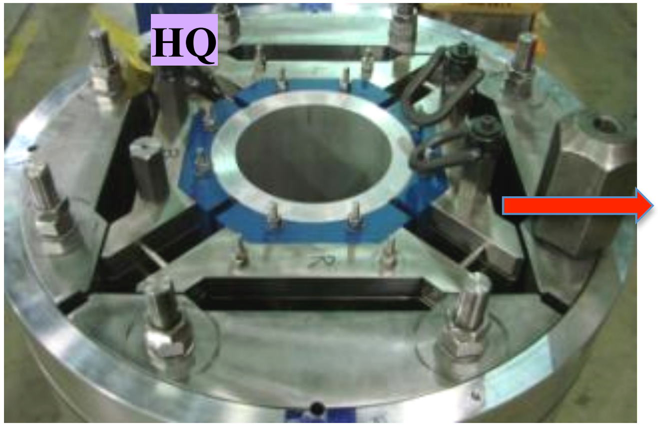
US LQXF Series: 18 Coils,
- *3 ~4.3 m Long Models*

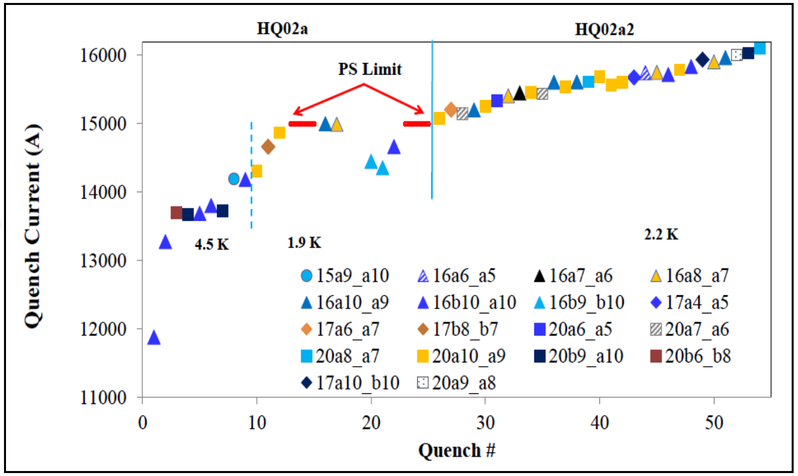
Every new design takes ~3 years for Short Model Development

LARP Quadrupole Magnet Development

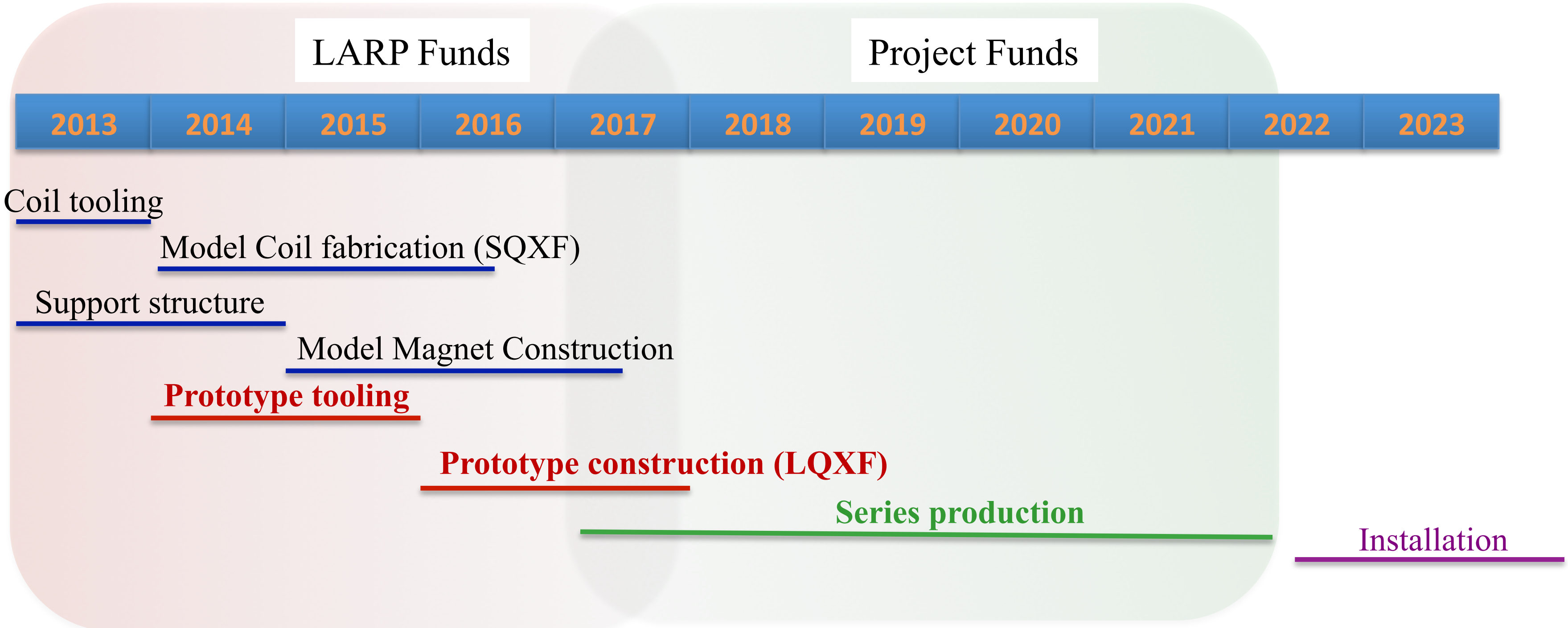








S(L)QXF Models & QXF Production



- US industry on the leading edge of Nb_3Sn SC development in terms of I_c
  - ITER experience (60+ metric tons) good demonstration and experience for HL-LHC needs (10+ metric tons)

Q:b1 Q:b2

Magnet Production Cost and Schedule: BOE and Assumptions

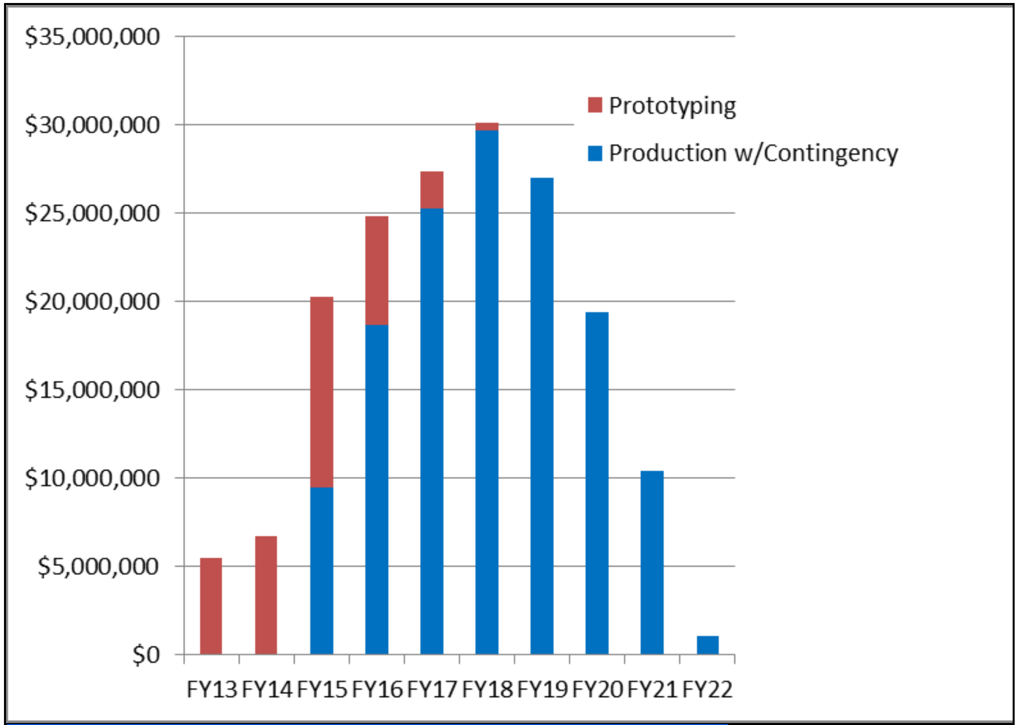
- Bottom-up based on LARP labor/material experiences
- CD-3 in FY2017/18. CD-0,1,2 schedule unclear, but assume that CD-like readiness is required on timeline consistent with CD-3
- Production window is FY2017/18-2021.
  - Goal is >1 year schedule contingency relative to CERN schedule. Deliver production cold masses by end of FY21 for 10/2022-3/2023 installation in LHC.
- Funds for SC wire purchase available in FY2015. Up front payment of 13% required, with another 27% less than one year later. Overhead only applied to first $2M (based on current BNL policy)
  - Similar comment (on different $ scales) applies to the other 2 HL-LHC deliverables
- CERN Hi-Lumi TDR is complete in 2015 *(in preliminary form)*.
- FNAL and BNL each produce coils -> cold masses. LBNL performs cabling and structure sub-assembly.
- Coil yield is 8/9.
- Test facility upgrades complete in time for production.

Q:c2

LARP

Magnet Prototyping & Production: Combined Cost Profile

High Luminosity LHC



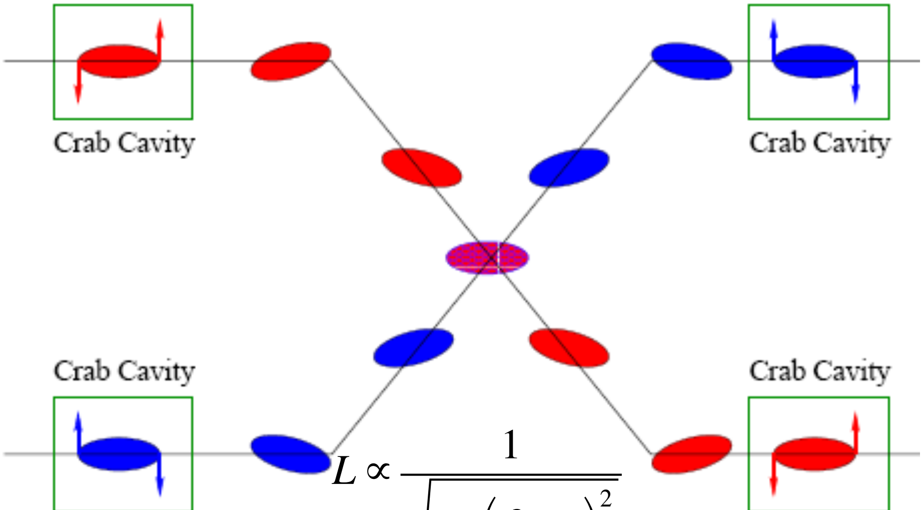
- Prototypes (LARP) 31 M$
- Production 140 M$
  - M&S 53 M$
  - Labor 51 M$
  - Conting. (35%) 36 M$
- Caveat #1: Funding for raw materials (SC) needs to be available ~2 y before "production start"
- Caveat #2: LARP funding level is proving unrealistic (at east in FY14 IFP)

No Contingency in this portion of table, spread uniformly elsewhere

Costs	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Total w/o Contingency	Contingency %	Total incl. Contingency
Production Design	$0	$0	$3,244,236	$4,537,989	$0	$0	$0	$0	$0	$0	**$7,782,225**	35%	**$10,506,004**
Production Materials	$0	$0	$3,752,662	$9,271,542	$12,426,873	$13,274,542	$10,361,123	$4,692,332	$343,599	$0	**$54,122,674**	35%	**$73,065,609**
Production Labor	$0	$0	$0	$0	$6,247,958	$8,712,794	$9,597,658	$9,634,288	$7,368,300	$772,643	**$42,333,642**	35%	**$57,150,416**
Total Production	**$0**	**$0**	**$6,996,899**	**$13,809,531**	**$18,674,831**	**$21,987,336**	**$19,958,781**	**$14,326,620**	**$7,711,899**	**$772,643**	**$104,238,540**	**35%**	**$140,722,029**
Prototyping	**$5,428,000**	**$6,674,495**	**$10,787,491**	**$6,128,707**	**$2,092,806**	**$432,039**	**$0**	**$0**	**$0**	**$0**	**$31,543,537**	**0%**	**$31,543,537**
GRAND TOTAL (Proto + Prod)	**$5,428,000**	**$6,674,495**	**$17,784,389**	**$19,938,237**	**$20,767,636**	**$22,419,375**	**$19,958,781**	**$14,326,620**	**$7,711,899**	**$772,643**	**$135,782,07[illegible]**		**$172,265,566**

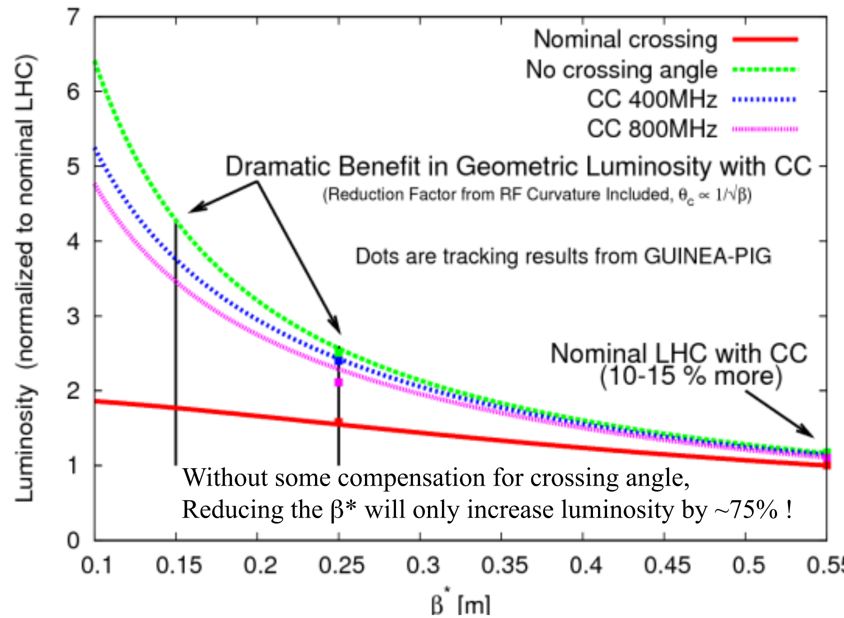
Q:c1 Q:c3 Q:b2

Crab Cavities

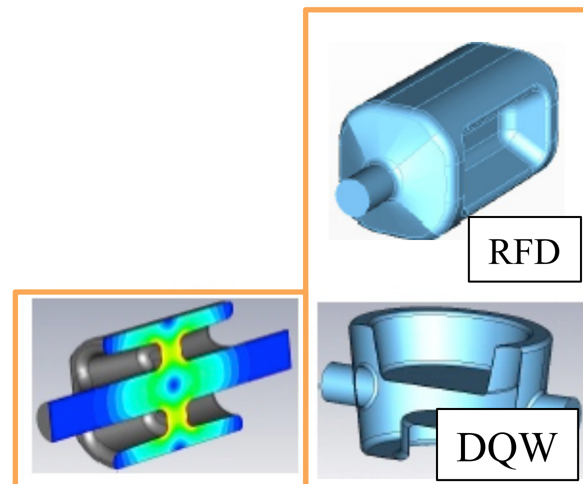


$$L \propto \frac{1}{\sqrt{1+\left(\frac{\theta_c \sigma_z}{2\sigma_x}\right)^2}}$$

"Piwinski Angle"



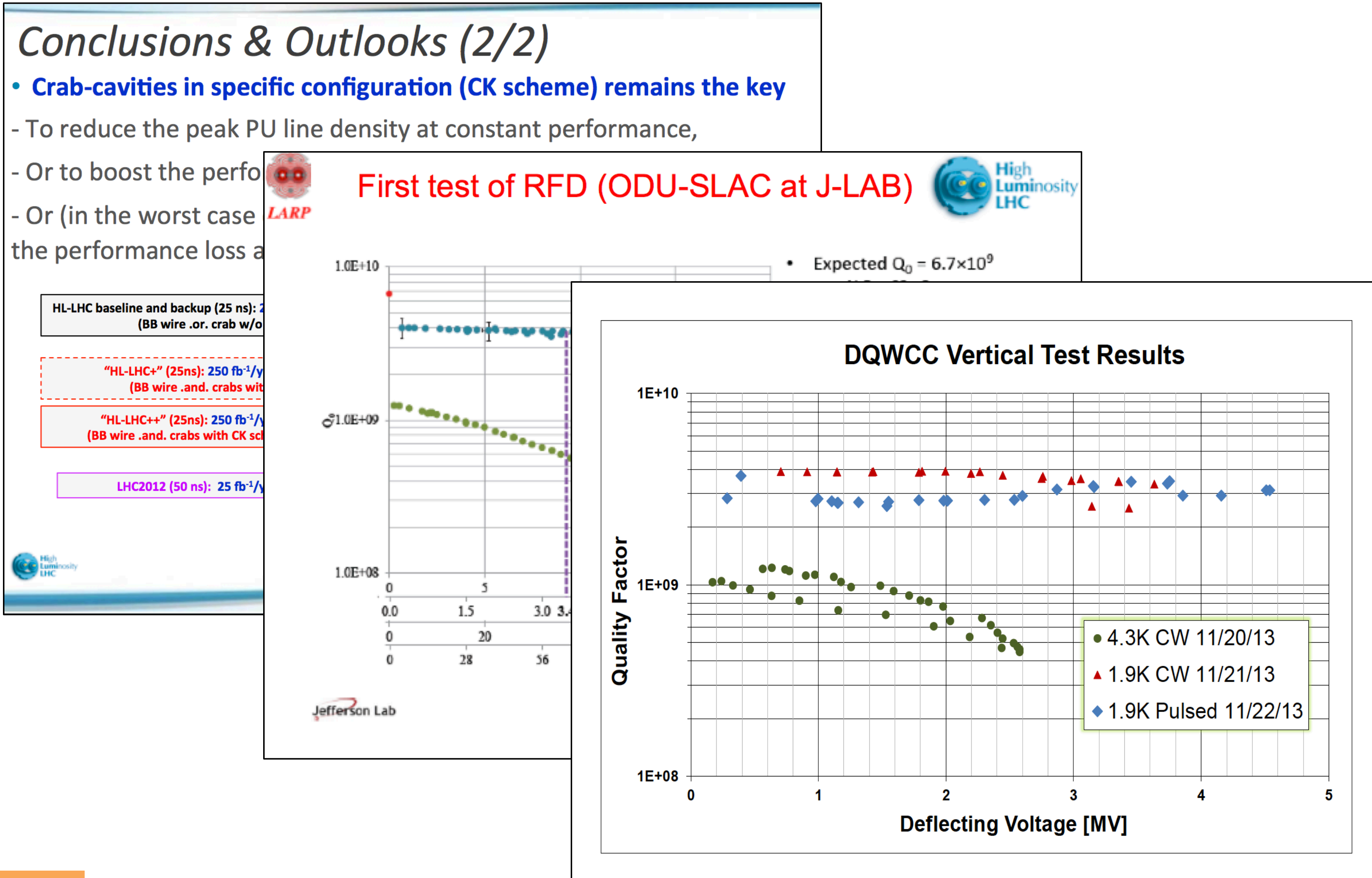
- Technical Challenges
  - Crab cavities have only *barely* been shown to work.
    - Never in hadron machines
  - LHC bunch length requires low frequency (400 MHz)
  - 19.4 cm beam separation needs "compact" (exotic) design
- Additional benefit
  - Crab cavities are an easy way to level luminosity!



UK LARP

Q:a1 Q:a2

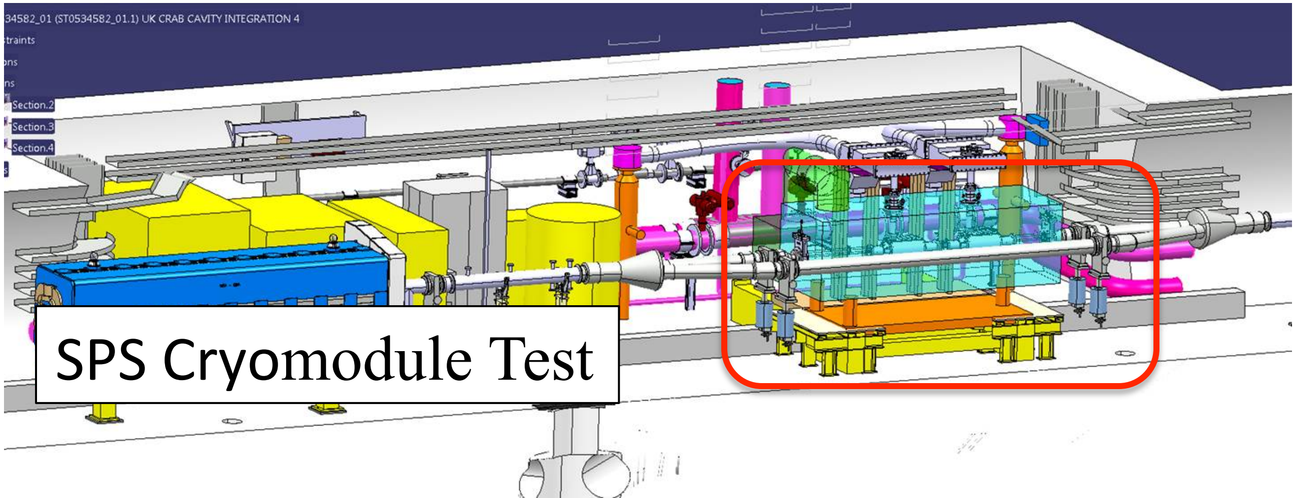
Recent Developments



Q:a2

CC: Scope of US Contribution

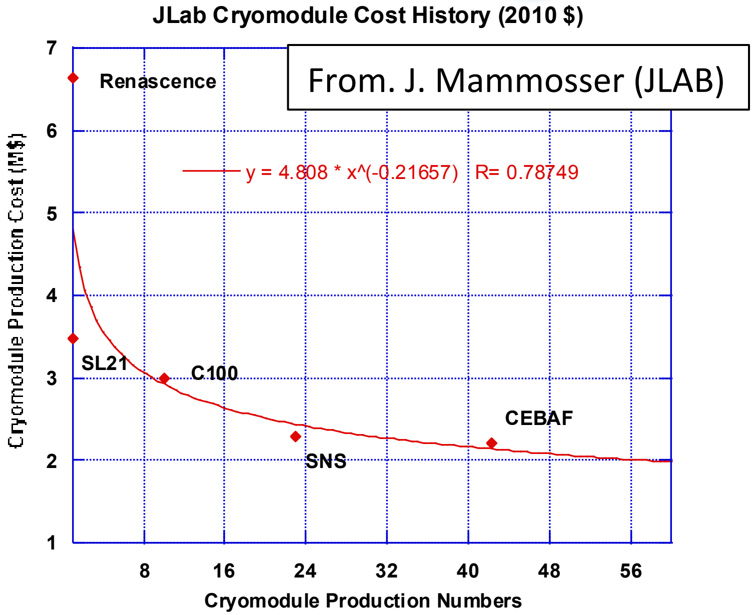
- LARP funds R&D until the SPS test
  - Deliver one cryomodule (or 4 cavities) for testing in the SPS before LS2
    - 2 cavities, He vessels, tuners, HOM mode dampers
    - RF couplers & power, cryogenics provided by CERN
- US Construction Project funds production
  - Deliver 10 cryomodules of 3 cavities (or 5 CM with 6 CC) each …
    - Contain cavities, He vessels, tuners, HOM mode dampers
    - Cryogenics, RF power, local installation provided by CERN
    - 8 CM needed in pts 1 and 5, 2 spares (one per IP)
  - ….or provide 40 Crab Cavities (after recent HL-LHC scope change from 3 cavities/beam to 4 cavities/beam)



Q:b1

CC Cost estimate

- Production estimate is ~$2.5M per CM in quantities of 10 from *bottom-up* estimate
  - Top-down JLAB cost analysis helps getting another perspective
    - Very different, yet relevant
- SPS Prototypes (LARP) ~6 M$
- Production 38 M$
  - Prototype 6 M$
  - Production (6 CM/30 CC) 26 M$
  - Proj. Ctrl & Supp. 6 M$



38 M$ w/o Contingency
(48 M$ w/Contingency)

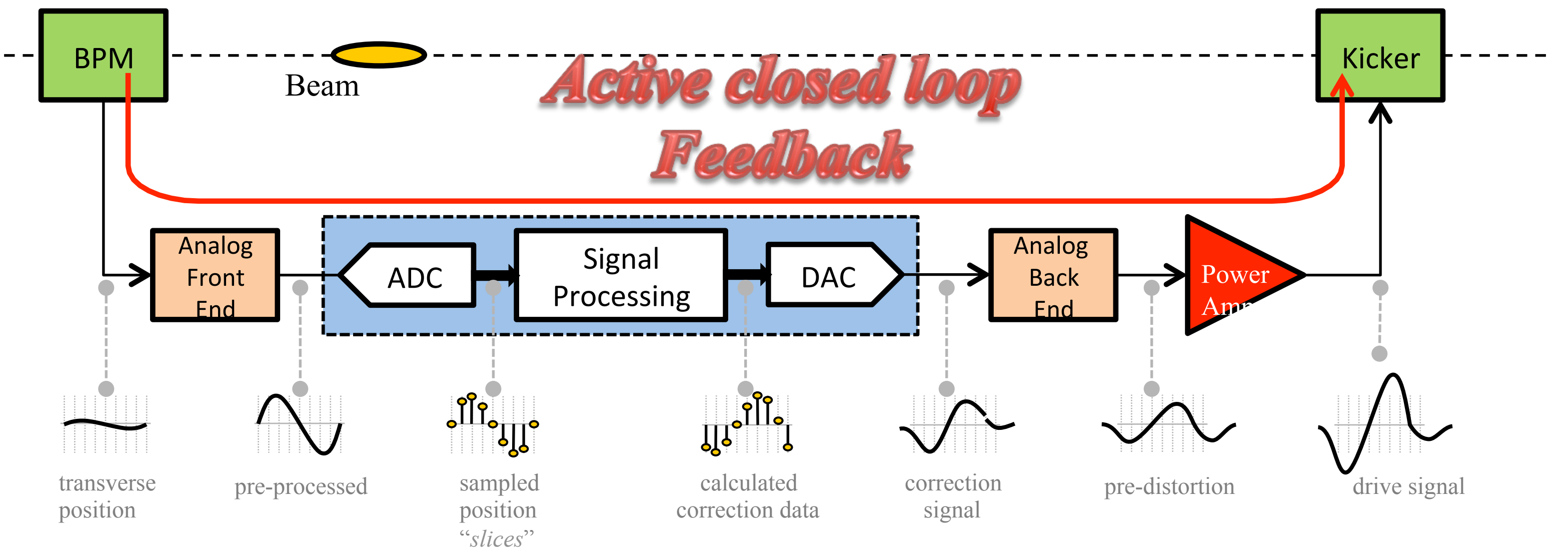
- Alternative look at Production (40 CC, no CM):
  - Cavities ~24M$ ->
  - Cryomodules ~14M$

32 M$ with 33% scope increase
(40 M$ w/Contingency)

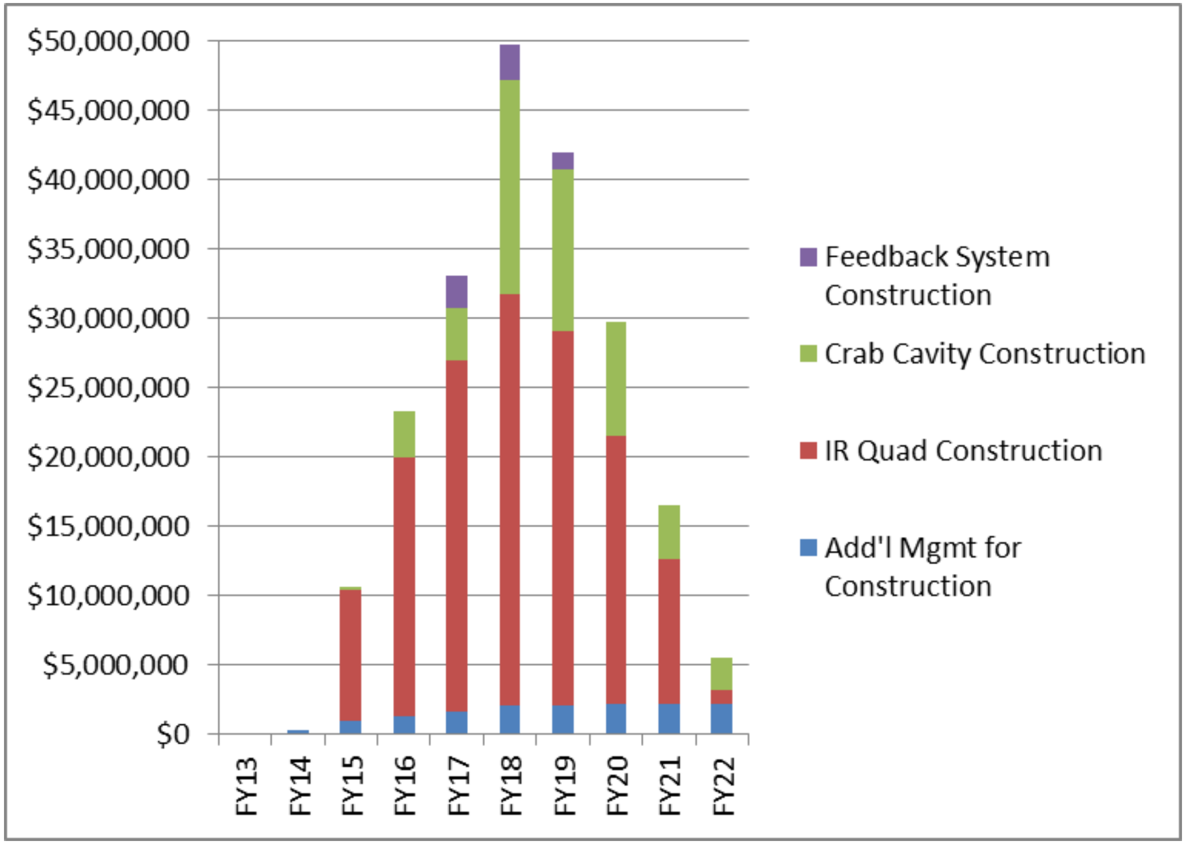
Q:c1 Q:c2 Q:c3

High Bandwidth Feedback System

- The high bandwidth feedback system is a GHz bandwidth instability control system
  - Increases LHC luminosity via higher SPS currents
  - Improves HC beam quality and allows SPS operational flexibility
  - Leverages US expertise
- LARP continues technology R&D & development of novel control methods
- Aiming for a deliverable (with LARP or pre-project funding) of an SPS full-function instability control processing system hardware, firmware and diagnostic for use at SPS post LS2.
  - CERN to contribute beam-line components (kickers, cable plant, etc.)
  - will continue the R&D related to the system.
- Technology applicable to LHC providing beam diagnostic as part of control



Construction Cost Profile (w/Contingency)



Construction w/Distributed Contingency	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	Total
Add'l Mgmt for Construction	$0	$302,287	$991,260	$1,300,231	$1,678,290	$2,075,913	$2,132,028	$2,189,578	$2,248,830	$2,152,449	$15,070,867
IR Quad Construction	$0	$0	$9,445,813	$18,642,867	$25,211,021	$29,682,904	$26,944,355	$19,340,937	$10,411,064	$1,043,069	$140,722,029
Crab Cavity Construction	$0	$0	$195,681	$3,386,538	$3,831,668	$15,353,475	$11,615,261	$8,190,661	$3,800,762	$2,342,882	$48,716,928
Feedback System Construction	$0	$0	$0	$0	$2,330,342	$2,536,272	$1,199,412	$0	$0	$0	$6,066,027
Totals	**$0**	**$302,287**	**$10,632,754**	**$23,329,636**	**$33,051,322**	**$49,648,565**	**$41,891,056**	**$29,721,175**	**$16,460,656**	**$5,538,400**	**$210,575,850**

Q:c1 Q:b2

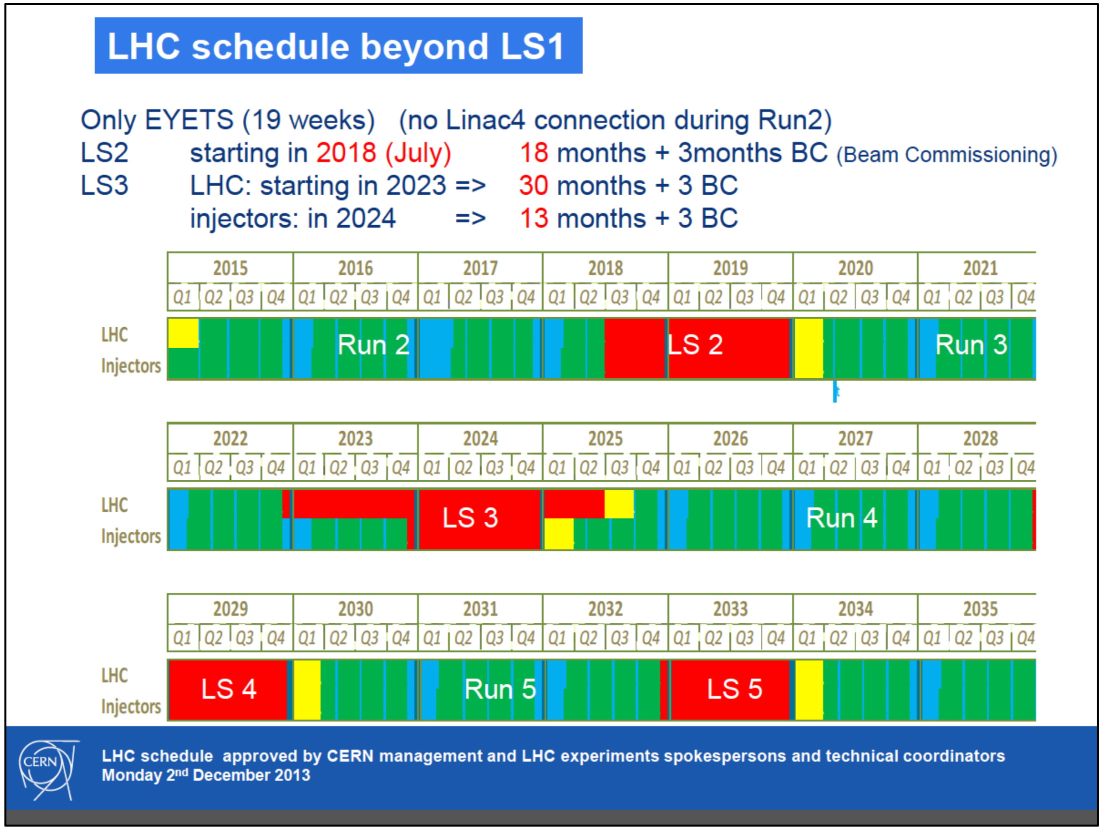
Conclusions

- Presented proposed US contribution to HL-LHC in:
  - IR Nb_3Sn focusing quadrupoles
  - CC System
  - High Bandwidth Feedback System
- Contributions fit in ~210 M$ (TY$) budget envelope
  - Funding peaking in FY17-FY21 period
  - ~30% level contingency included
  - some M&S needed earlier in FY15 for raw material purchases
- Limited possibilities for scope reduction*
  - Cryomodule in CC System, deliverables for quads cold masses
- LARP tasked with risk reduction in 2014-2017/2018 in preparation for Project era while maintaining the successful Toohig Fellowship program and Accelerator Physics activities as funding allows

* in the context of Contingency Management

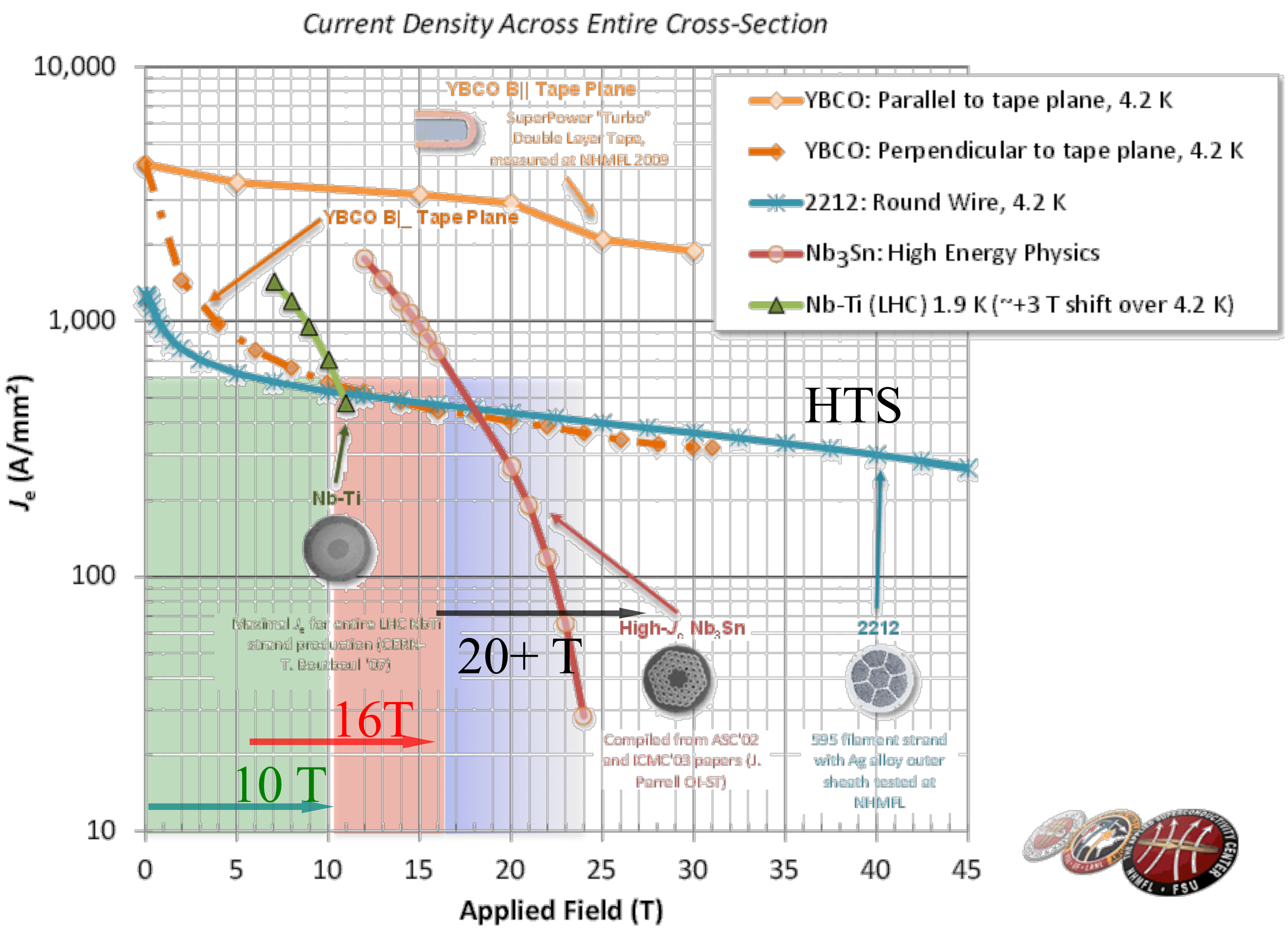
Back-up Slides

New LHC Schedule (Dec. 2nd, 2013)



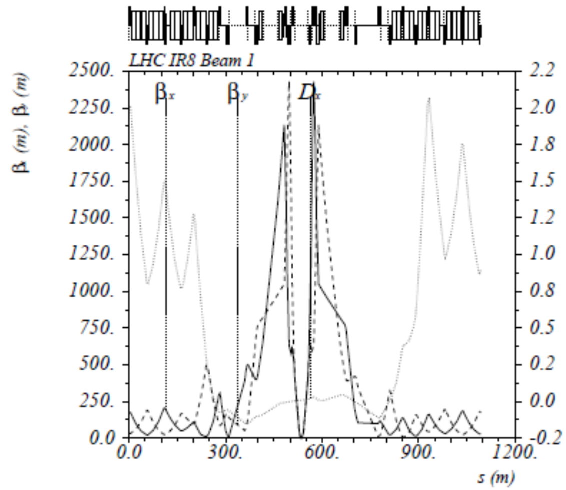
- No time to re-cost US contribution to HL-LHC
  - Expect small “inflationary” increase in TPC
  - On the other hand, funding profile could be redistributed from 8 to 9 years
    - *Modulo* needs of final customer (CERN)
    - Manpower considerations

Magnets: a Matter of conductor !



Key Components of HL-LHC

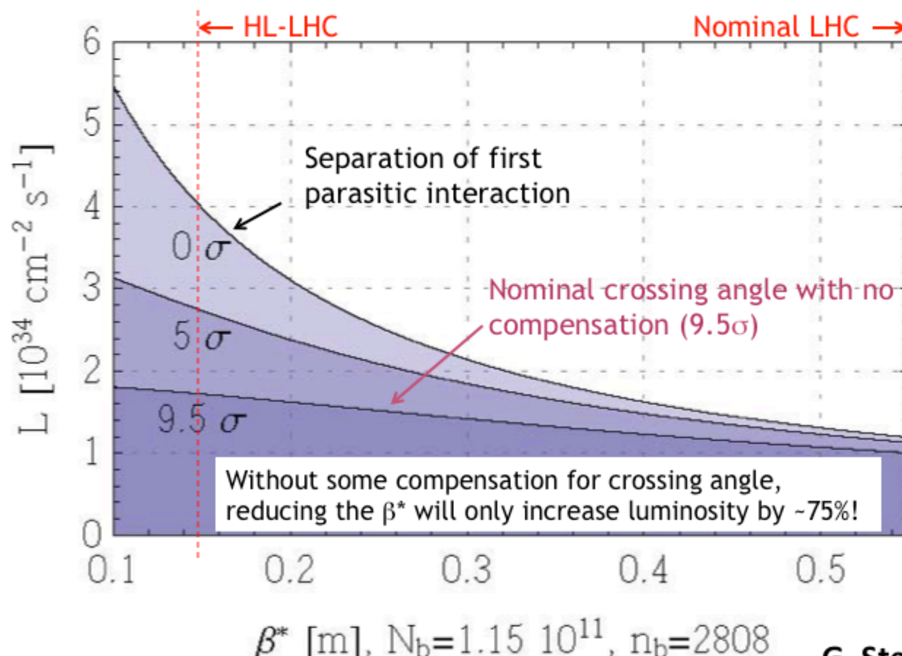
- Reduce β* from 55 cm to 15 cm
  - Requires large aperture final focus quads
  - Beyond NbTi
  - ➔Requires Nb_3Sn
    - never before used in an accelerator!
    - Nb3Sn R&D key component of LARP



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

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

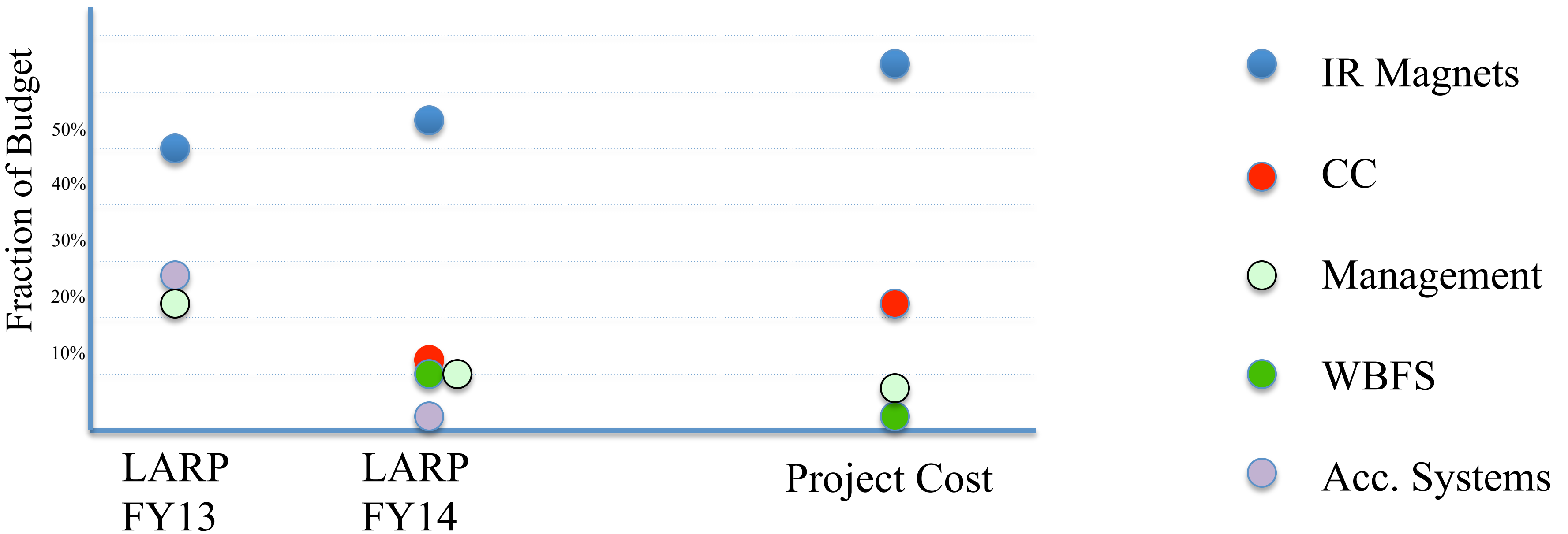
"Piwinski Angle"



G. Sterbini

FY14 LARP Funding

- In June '13 the LARP Collaboration prepared plans for FY14 under a guidance of ~12.6 M$ excluding GARD contributions (~2-3 M$ range). The expected FY14 funding was ~14.6-15.6 M$
  - GARD=General Accelerator R&D, program in US Labs and Universities covering basic Accelerator R&D, a.k.a. "Core Program".
- In July '13, DOE communicated that LARP IFP for FY14 would be 12.4 M$ ***inclusive*** of a 2M$ GARD contribution. A funding increase in FY15-FY17 will represent a challenge.



LARP "Good Intentions"

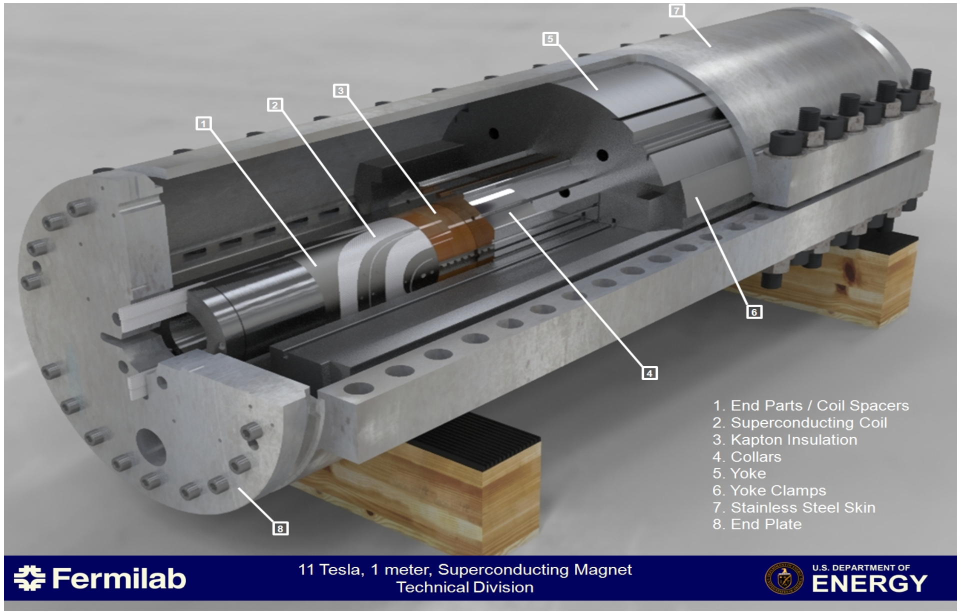
	"Wish List" in June '13 for LARP funding in FY14-FY17	Expected Funding if FY15-FY17 Budget continues at FY14 IFP levels.
Magnets	~28 M$	~25 M$
CC	~8 M$	~5 M$
WBFS	~7 M$	~5 M$

- It is in our highest common interest to use LARP to facilitate the HL-LHC upgrades within available funds and resources
- However, LARP is not a project and scope/deliverables are not negotiated and/or endorsed by the funding agencies/Labs
- The previous comments affect SPS Studies pre & post-LS2 and specifically the tests for Crab Cavities and the WBFS
- Redefinition of pre or post-LS2 studies in the SPS and expectations in terms of LARP contributions is needed as a function of LARP funding.
- DOE LARP Review in Feb '14 will be chance to plea for funding removed in FY14 IFP.

Internal LARP "Project" Review Main Feedbacks

- Magnets
  - The technical feasibility of the quad program seems reasonable.
  - The cost have a decent basis in the LARP R&D program
  - The scope is reasonable for a $200M US contribution.
  - The major uncertainties and risk appear to be programmatic in nature.
- CC
  - The down selection on the cavity choice drives the schedule and should be made as soon as possible.
  - Closely monitor integration of LARP funding, CERN schedule, GARD funding & priorities, and SBIR performance since they are all external risk elements…
  - …..
- Feedback System
  - The R&D has made significant progress in the last year with succesfull single-bunch testing in the SPS
  - Presented schedule estimates are optimistic and have minimal headroom to react to additional budget pressures.
  - To meet LS2 schedule for installation into the SPS, the engineering effort must clearly pivot from development mode to production mode by 2017.
  - We feel that proposed manpower allocations may be underestimated. To appropriately amortize the engineering work done in the research phase of the project (through 2016), there has to be continuity in engineering manpower.
  - …..

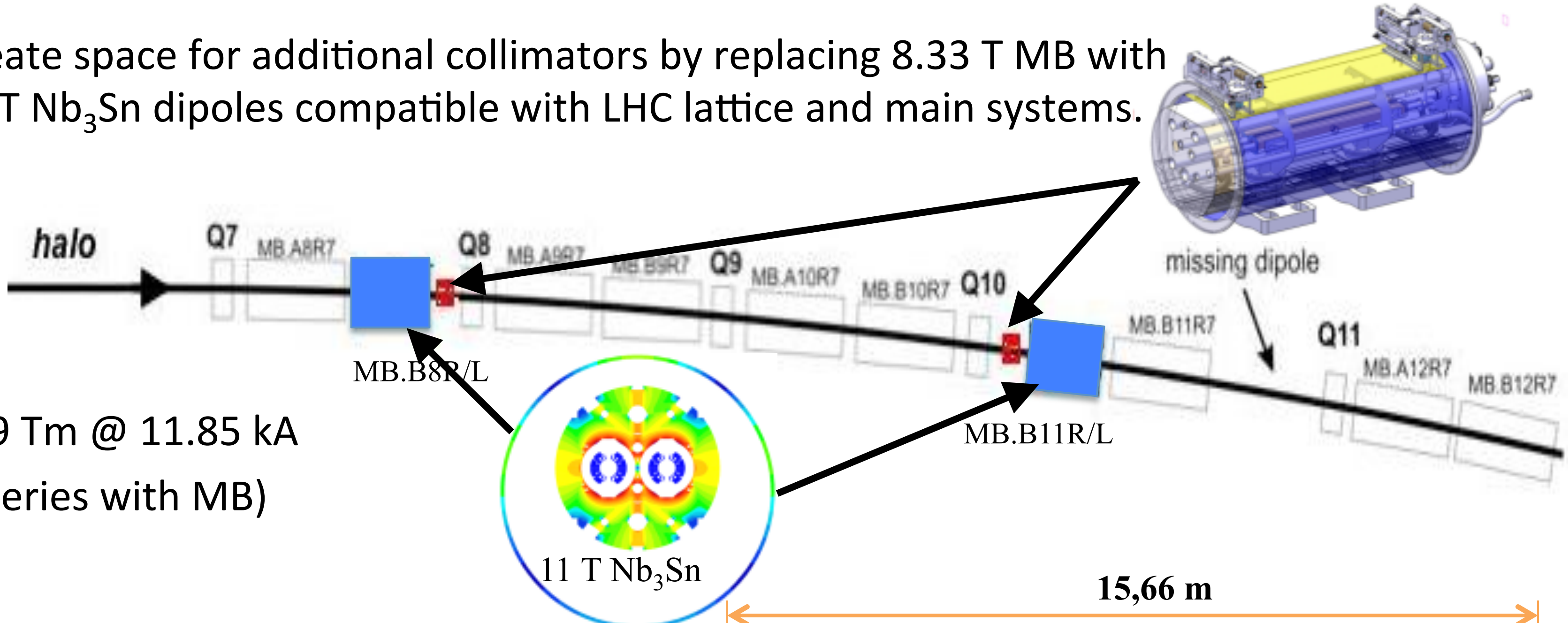
11 T Development



- At this time not a US in-kind contribution. Intellectually relevant as R&D program toward high field, accelerator quality, dipoles and a possible 100 km machine

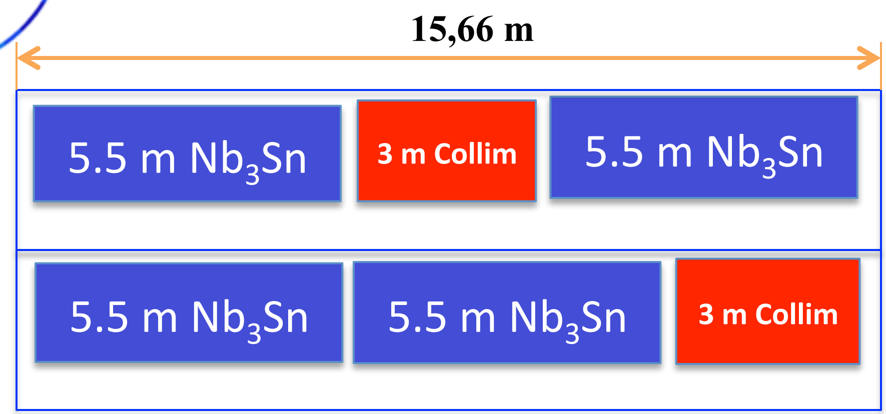
Collimators and 11T Dipoles

- Create space for additional collimators by replacing 8.33 T MB with 11 T Nb_3Sn dipoles compatible with LHC lattice and main systems.



- 119 Tm @ 11.85 kA

  (in series with MB)

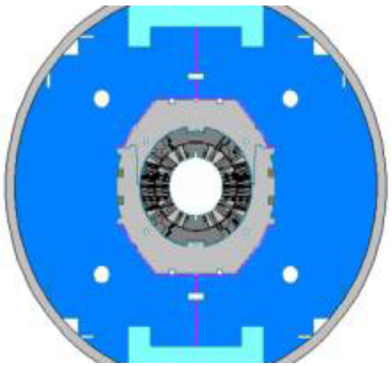


- LS2 : IR-2
  - 4 MB => 8 x 5.5 m CM + spares
- LS3 : IR-1,5 and Point-3,7
  - 4 x 4 MB => 32 x 5.5 m CM + spares

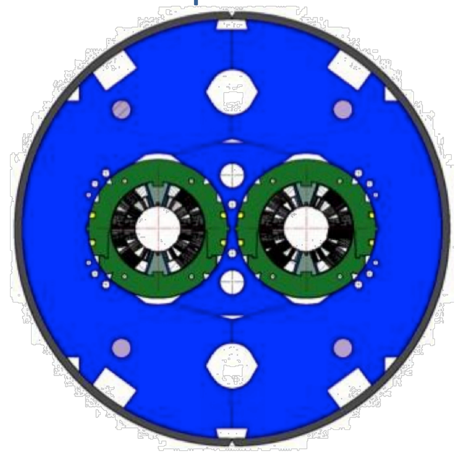
- Focus of joint R&D program aimed at Accelerator Quality Magnets between CERN and US. R&D program to be completed in US with conclusion of Short (1m) Models.

11T Dipole R&D

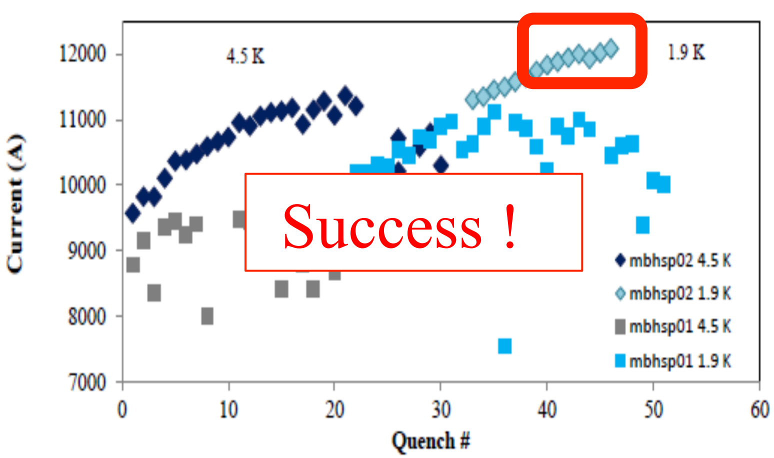
Single aperture model

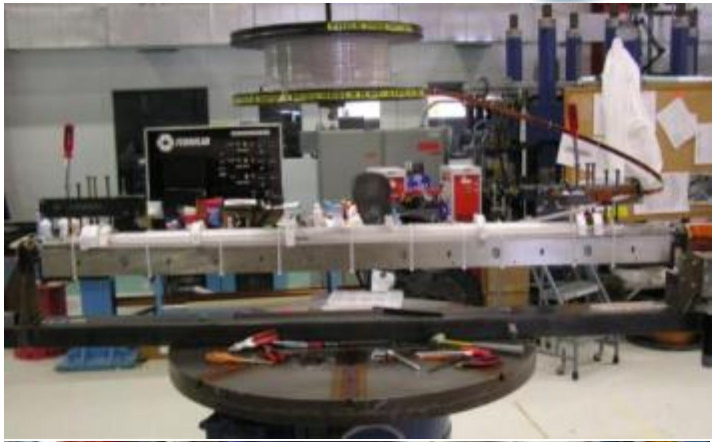


Twin aperture model



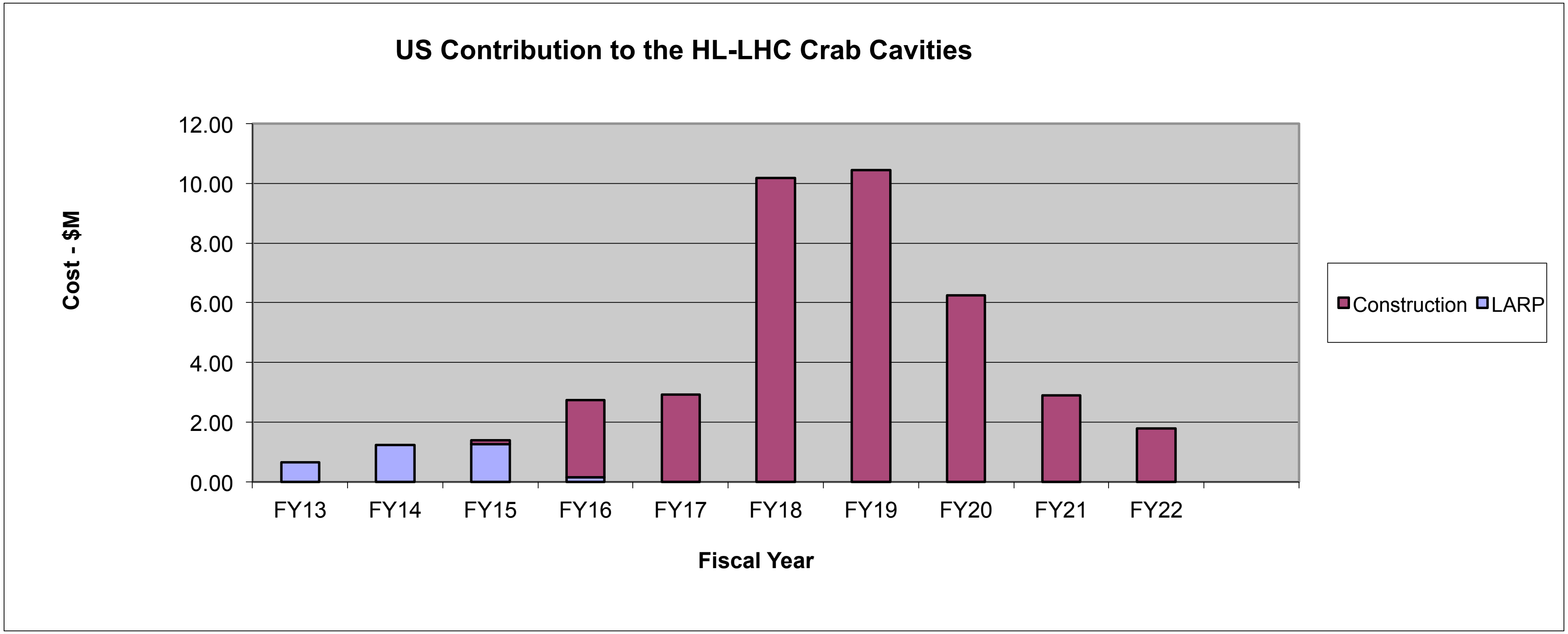
Second Nb_3Sn Accelerator Quality Dipole (1m long) – Dec '12





Fermilab

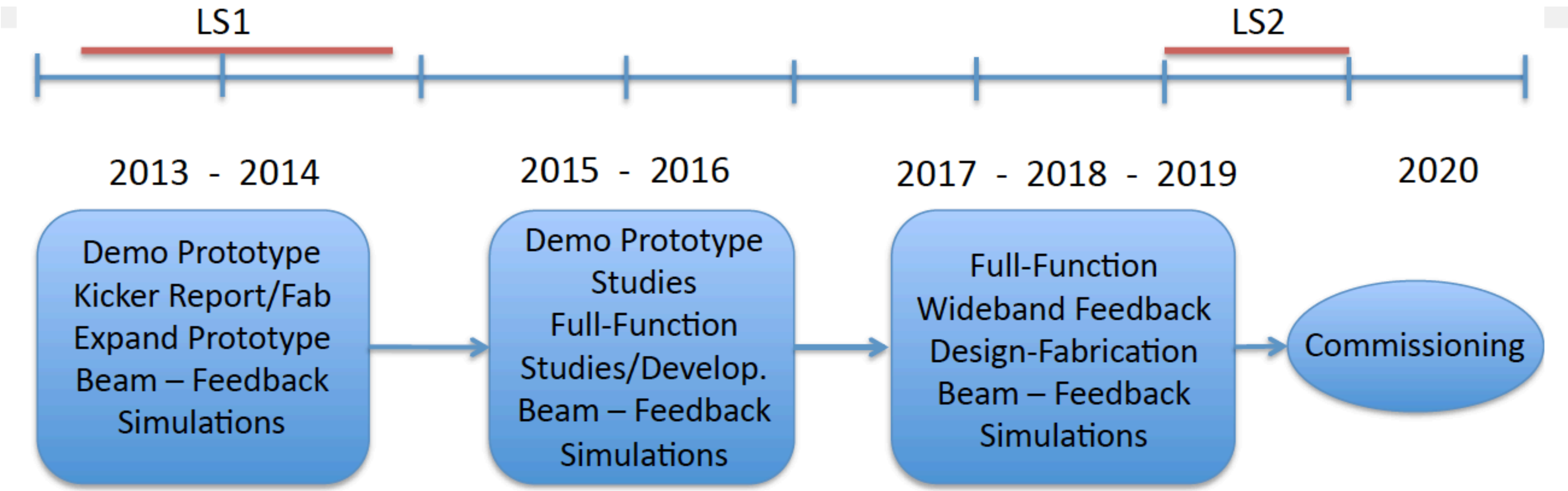
CC Spending profile



- LARP to Construction transition point could be modified as needed
- FY18 jump due to material procurement
  - Purchase order for cavities

Q:b2

High Bandwidth System Timeline



- Demo Commissioned
- MDs Jan.-Feb. 2013
- Kicker Design, Fabrication and Installation
- Data Analysis, Models and Simulation Tools
- Expand Hardware Capability
- MDs with new Hardware

- MDs with new hardware
- Multi-bunch operation
- Data analysis, models and simulation tools
- System specifications and capabilities
- Full-function Wideband Feedback Technology Development.

- Full-Function Wideband Feedback Design-Fabrication
- Continue MD studies
- Validate Energy Ramp
- Analysis, models and simulation tools

- System Integration
- Full interface with CERN Control Room
- Estimation of System Limits and Performance
- LHC? PS? SPS?

- Essential goal - be ready at end of LS2 with full-function system ready to commission
- SPS upgrade after LS2 (new injector, higher currents, new operational modes)
- We must use the demo system, MD time post LS1 to validate control ideas, validate kicker and technical approach. Fabrication of full-function system must start in FY18

High Wideband Feedback System: "Full-Function" Deliverables

- Full-Function deliverable completed in FY19 for commissioning in FY20
  - "Full-Function" - capability to control full ring at high intensity
  - "Full-Function" - synchronization during energy ramping
  - Integration of system control/beam diagnostics for operation
- System capability to control full SPS ring at HL upgraded intensity
  - Beam line pickups/kickers
  - Beam motion receiver, processing electronics
  - 4 - 8 Gs/sec DSP for intra-bunch feedback
  - System Timing, Synchronization Clocks/Oscillators
  - GHz bandwidth Kicker(s), Power Amplifiers
  - Operator interfaces, control/monitoring software
  - Beam diagnostic software, configuration software
  - Accelerator Dynamics models, Stability tools
- Areas of SLAC/CERN contributions
  - SLAC - Feedback signal processing and control software, diagnostic software
  - CERN - tunnel based vacuum Components (kickers) and cable plant
  - Opportunity for collaborative engineering team, shared operational expertise