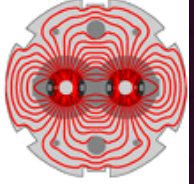
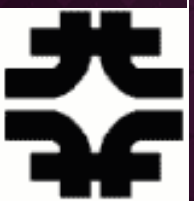


US LHC Accelerator Research Program (LARP)

Eric Prebys
Fermilab APC
Program Director, LARP



April 15, 2010

Motivation for this talk

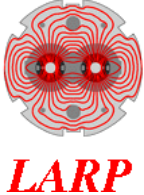
- There are many areas of common interest between LARP and EuCARD
  - Collimation
  - Crab cavities
  - Nb_3Sn magnet technology
- There's a lot of communication between the subtasks of the two programs, but very little in the way of overall coordination.
- Hopefully, this talk will be a start.*

*Thanks to Jean-Pierre Koutchouk for suggesting it.

Outline

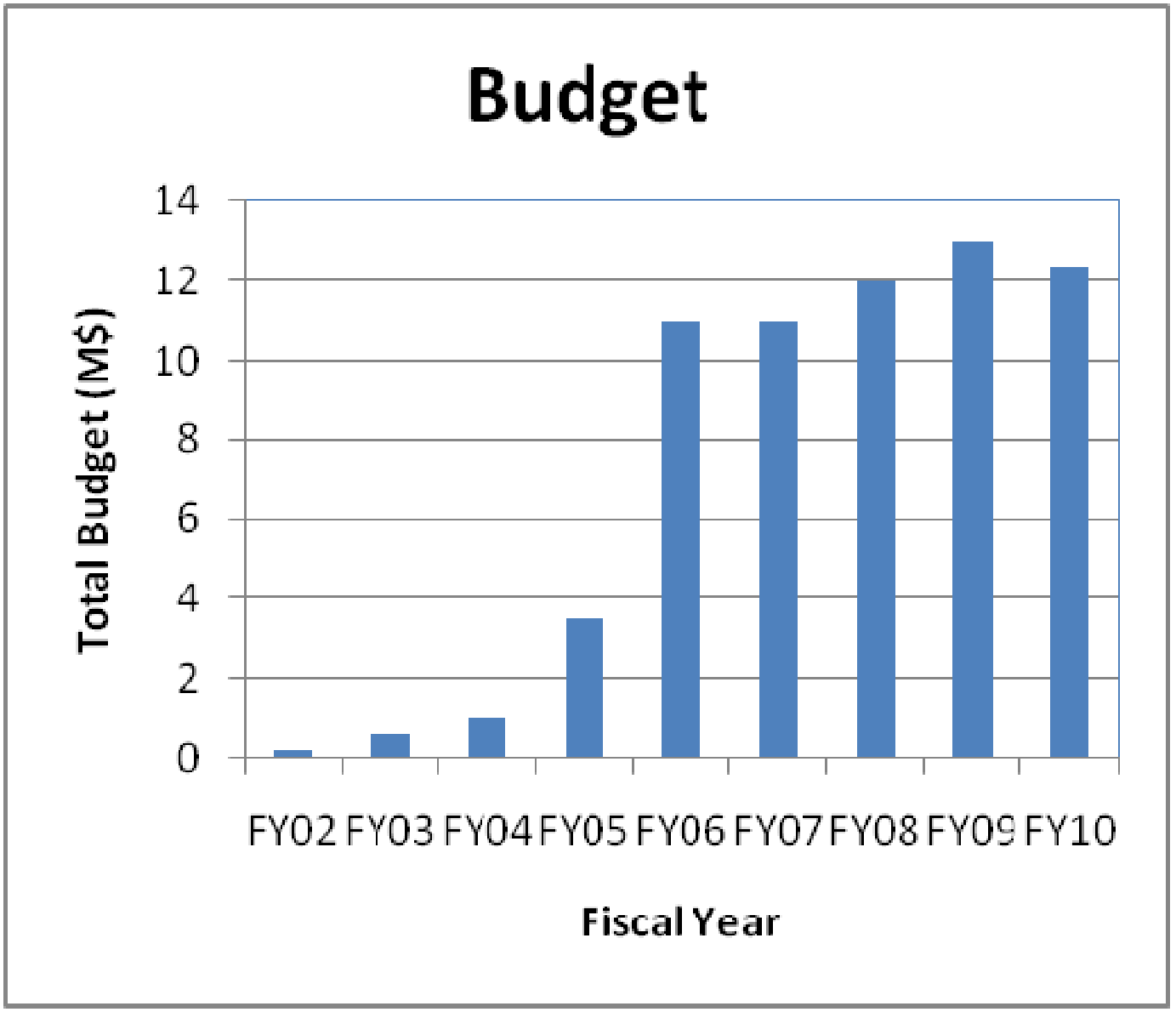
- Introduction and ishtory of LARP
- Current activities and status
- Impact of Chamonix
- Future plans
- Non-LARP US accelerator related activities

LHC Accelerator Research Program (LARP)



- Proposed in 2003 to coordinate efforts at US labs related to the LHC accelerator (as opposed to CMS or ATLAS)
  - Originally FNAL, BNL, and LBNL
  - SLAC joined shortly thereafter
  - Some work (AC Dipole) supported at UT Austin
  - Can consider new membership (Jlab?)
- LARP Goals
  - **Advance International Cooperation in High Energy Accelerators**
  - **Advance High Energy Physics**
    - By helping the LHC integrate luminosity as quickly as possible
  - **Advance U.S. Accelerator Science and Technology**
- LARP includes projects related to initial operation, but a significant part of the program concerns the LHC upgrades

Budget

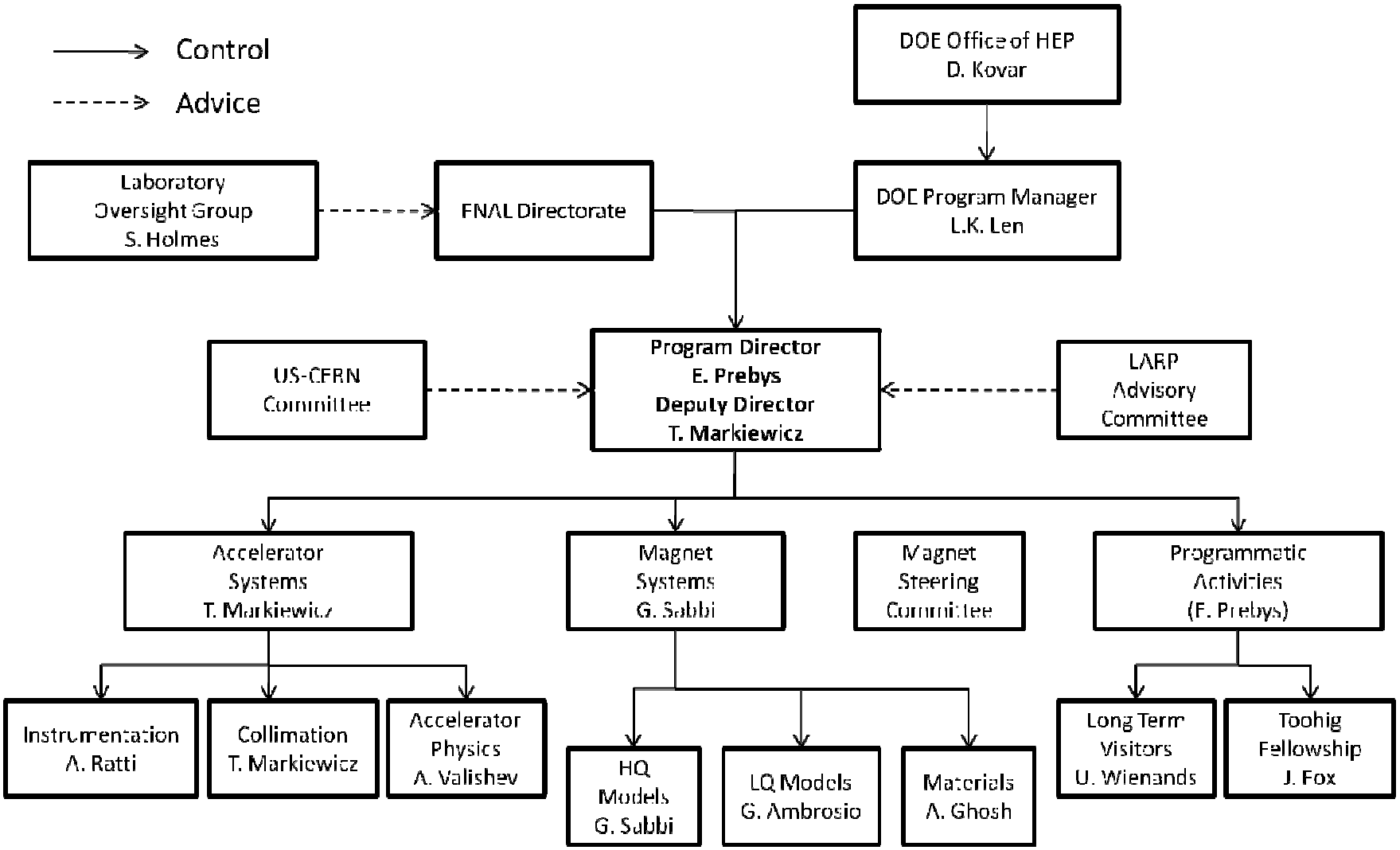

Budget
Total Budget (M$)
14
12
10
8
6
4
2
0
FY02 FY03 FY04 FY05 FY06 FY07 FY08 FY09 FY10
Fiscal Year

LARP Subtasks

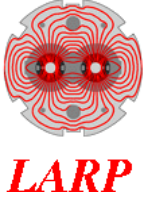
- Accelerator Systems (currently ~$3M/year)
  - Accelerator physics
  - Instrumentation and other hardware
    - Collimation
    - LLRF
    - Crab cavities?
    - Injector chain?
- Magnet Systems (currently ~$5M/year)
  - Goal: demonstrate Nb_3Sn as a viable technology for the quadrupoles in the ultimate upgrade of the LHC
- Programmatic Activities (currently ~$2M/year)
  - Program management, travel, meetings, etc
  - Toohig Fellowship
  - Long Term Visitor (LTV) program

+~$2-3M contingency divided among tasks as needed throughout year

LARP Organization Chart



Assumed LHC Upgrade path (pre-Chamonix)



- Initial operation (now)
  - Ramp up to $1x10^{34}$ $cm^{-2}s^{-1}$

- Phase I upgrade — No major changes to optics or IR's
  - After ~2 years of operation (~2014)
  - Replace 70 mm triplet quads with 120 mm quads
  - β^* goes from 50->30 cm
  - Linac4 to increase PSB injection energy to reduce space charge effects
  - Luminosity goes to $2\text{-}3x10^{34}$ $cm^{-2}s^{-1}$

- Phase II upgrade — Possible Significant Changes
  - After Phase I triplet burns up (nominally ~2020)
  - Peak luminosity goal: $1x10^{35}$
  - Details still under study
    - New technology for larger aperture quads (Nb_3Sn)
    - crab cavities?
    - Improved injector chain (PS2 + SPL)?

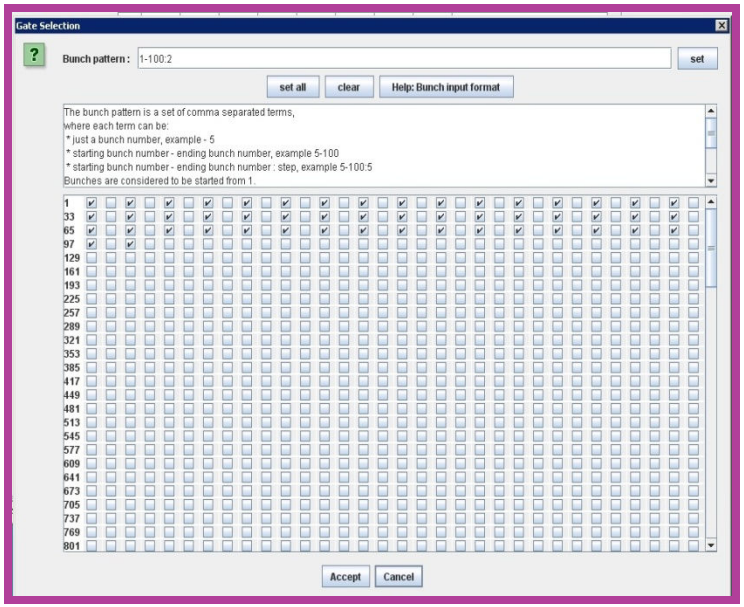
LARP Magnet Program

Contributions to initial LHC Operation

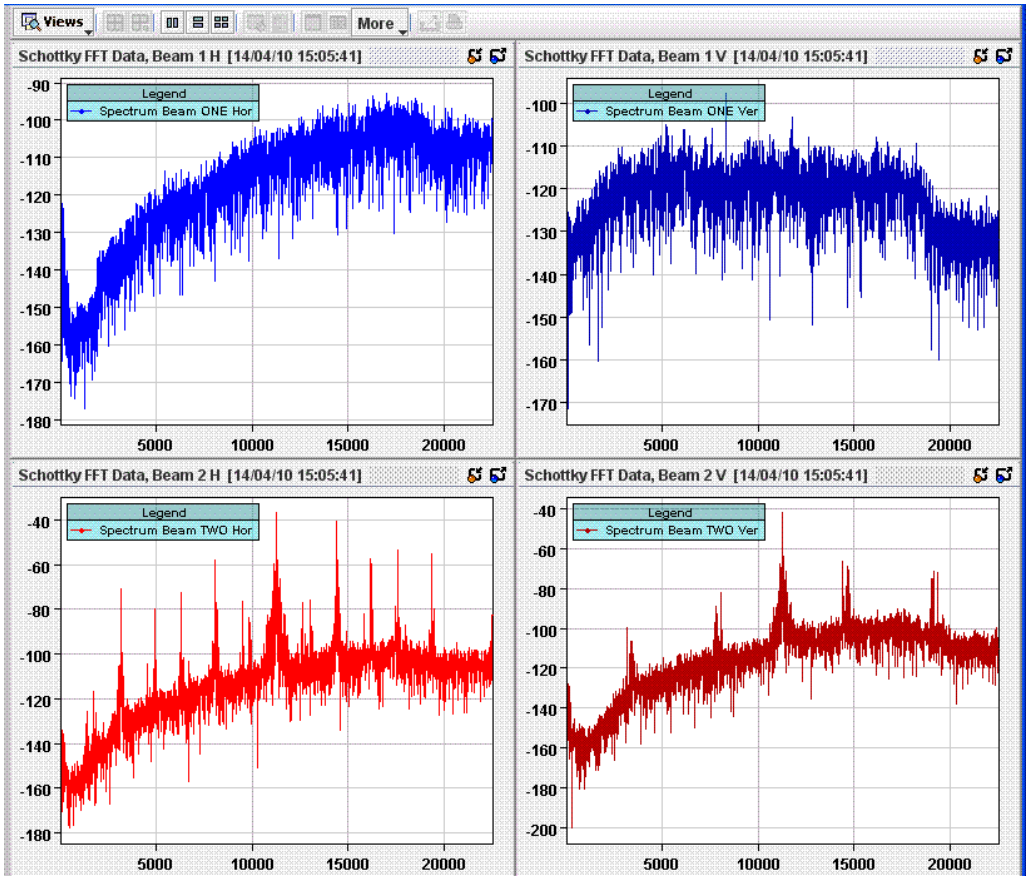
- Schottky detector
  - Used for non-perturbative tune measurements (+chromaticities, momentum spread and transverse emmitances)
- Tune tracking
  - Implement a PLL with pick-ups and quads to lock LHC tune and chromaticity
- AC dipole
  - Measure both linear and non-linear beam optics by using AC dipole to drive beam.
- Luminosity monitor
  - High radiation ionization detector integrated with the LHC neutral beam absorber (TAN) at IP 1 and 5.
- Synchrotron Light Monitor
  - Not a LARP project, but…
  - LARP provided improved optics
  - Monitor transverse bunch profile
  - Monitor abort gap
- Low Level RF tools
  - Provided simulation and analysis tools to characterize and optimize RF cavities

Schottky detector

- Proposed by LARP, based on experience with Tevatron
- Installed in collaboration with CERN
- Application written by LAFS (J. Cai)

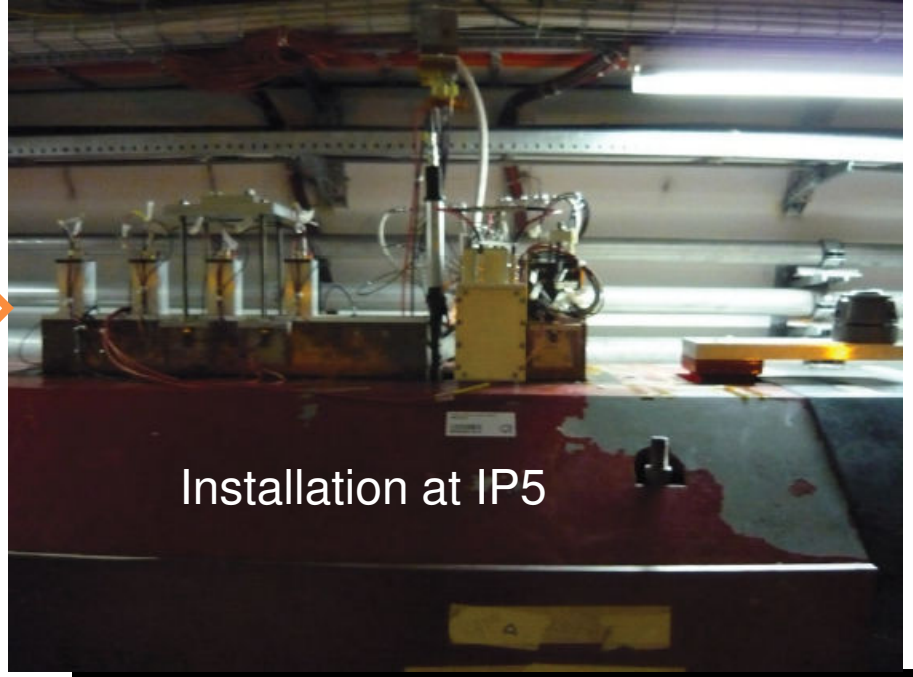


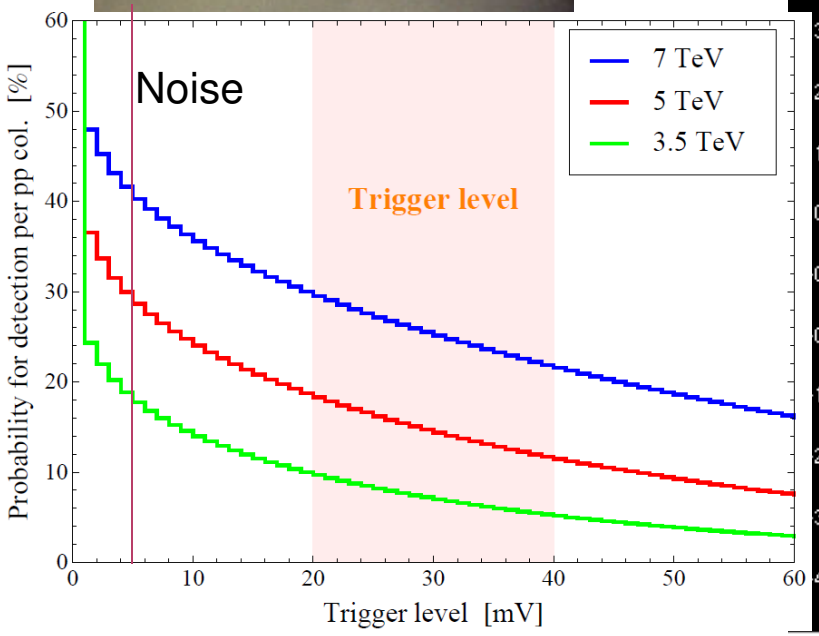
Allows tune to be monitored on selected buckets

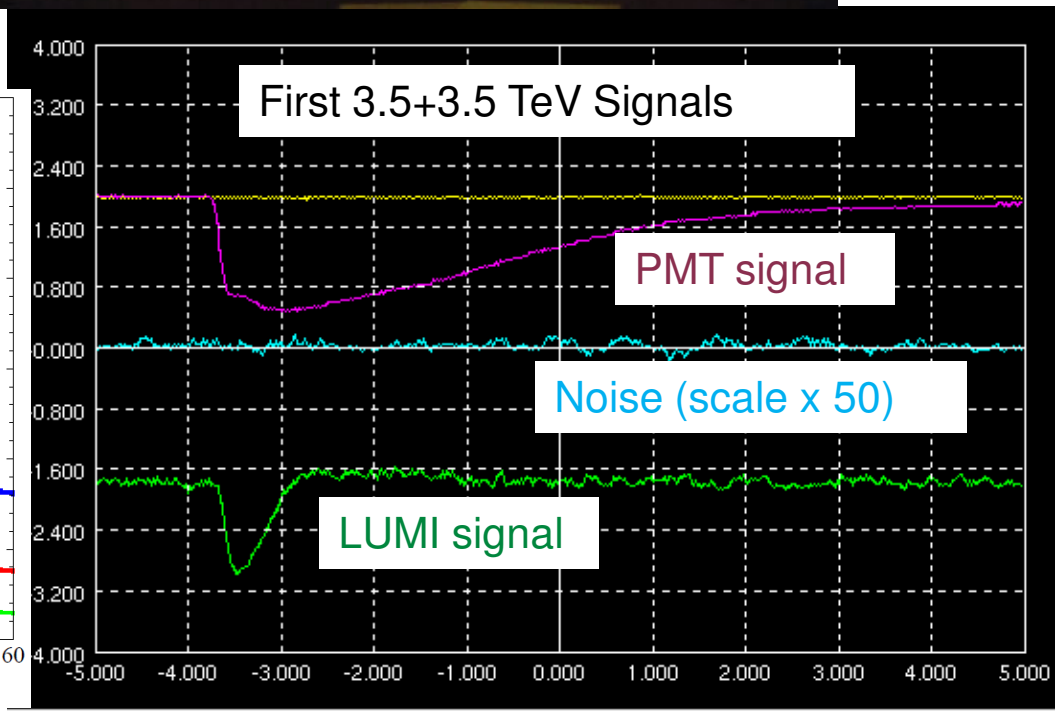


Data from 450 GeV LHC Beam

Lumi Detector

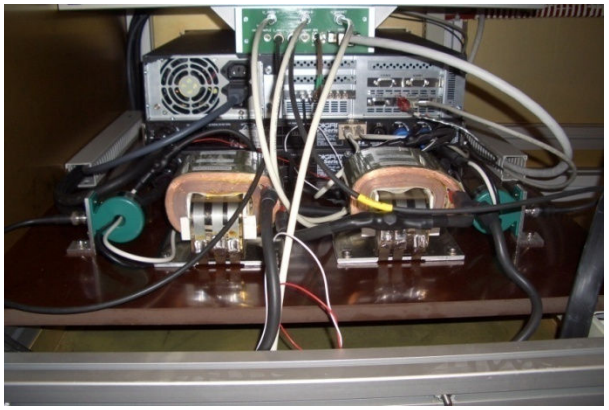






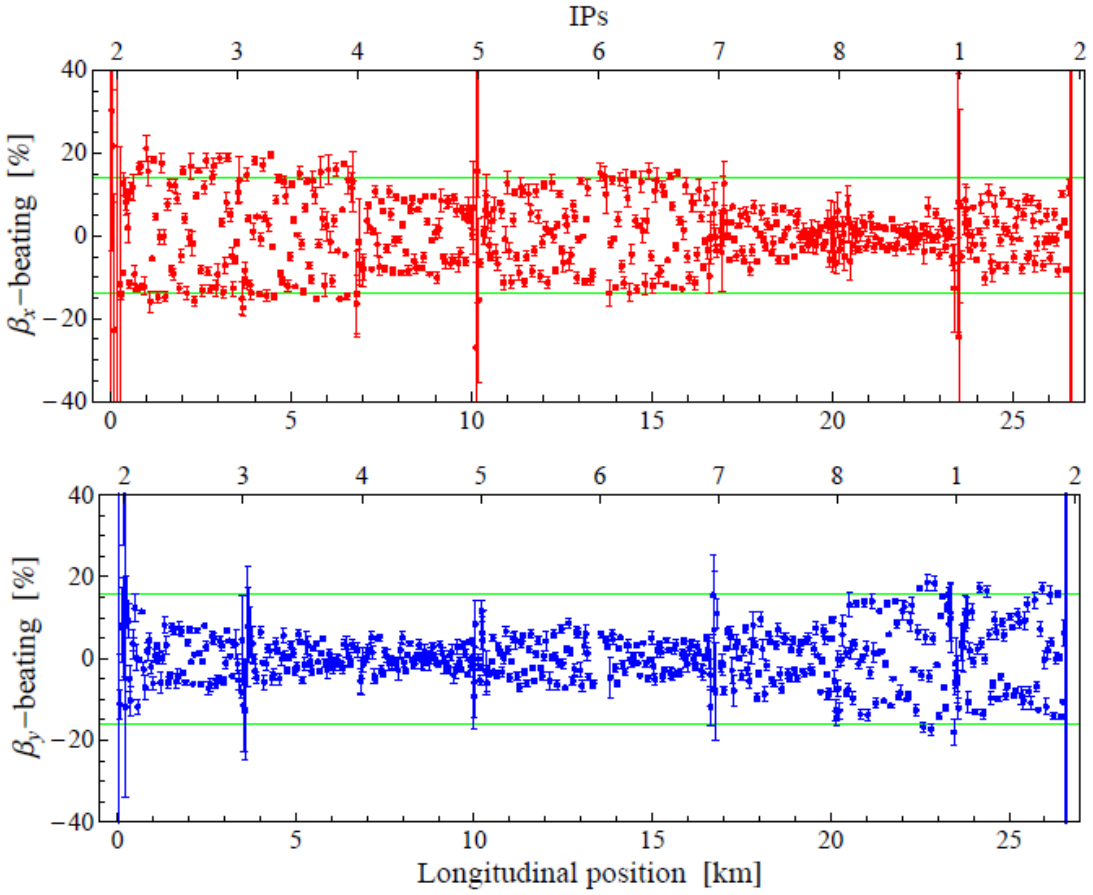
AC Dipole

- By driving the beam near the (aliased) tune, one can probe linear and non-linear optics
- 4 AC dipoles installed at CERN based on tests in the Tevatron (R. Miyamoto)



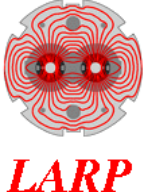
Audio amplifiers

- OK'd for operation
- Primary tool for 3.5 TeV β measurement.



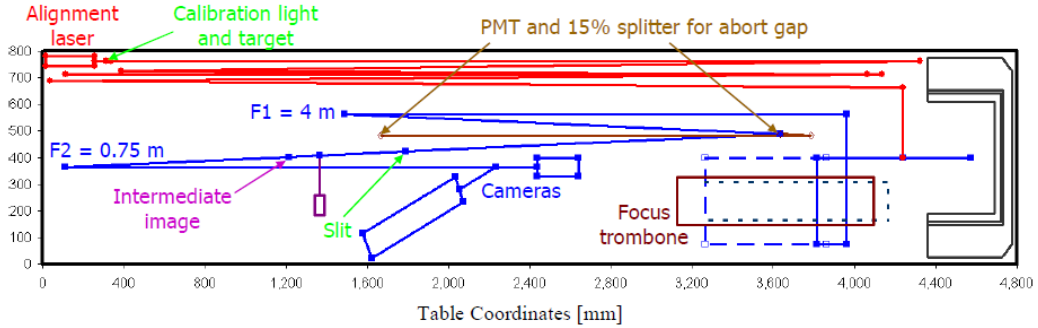
β measurement at 3.5 TeV

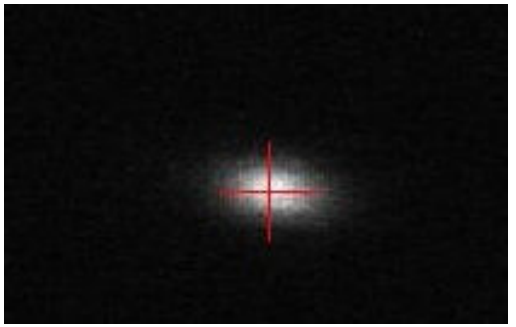
Comments on AC Dipole Project



- Developed for the Tevatron in collaboration with UT Austin, under the auspices of the Joint PhD program
  - Ryoichi Miyamoto, supervised by Sacha Kopp (UT) and Mike Syphers (FNAL)
  - Won 2009 APS award for "Outstanding Doctoral Thesis Research in Beam Physics"
- Established as a viable technology for the LHC through the LARP program
  - Hardware installed by CERN (that's really the way LARP is supposed to work).
  - Ryoichi is helping with commissioning and analysis as a LARP Toohig Fellow working for Brookhaven.

Sync. Light Monitor (Improved by LARP and LAFS)

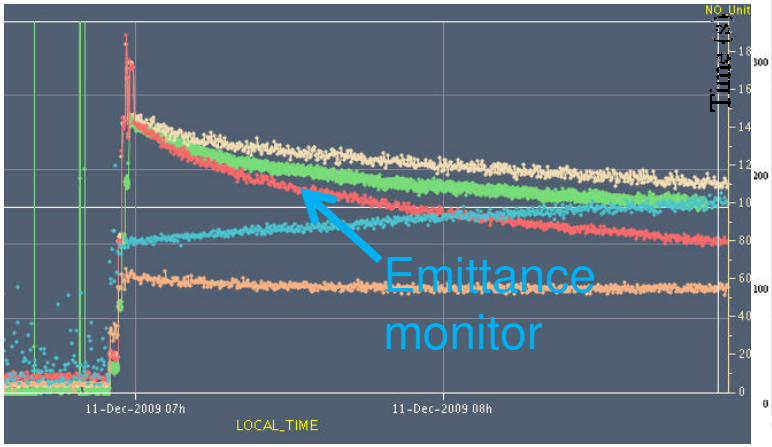


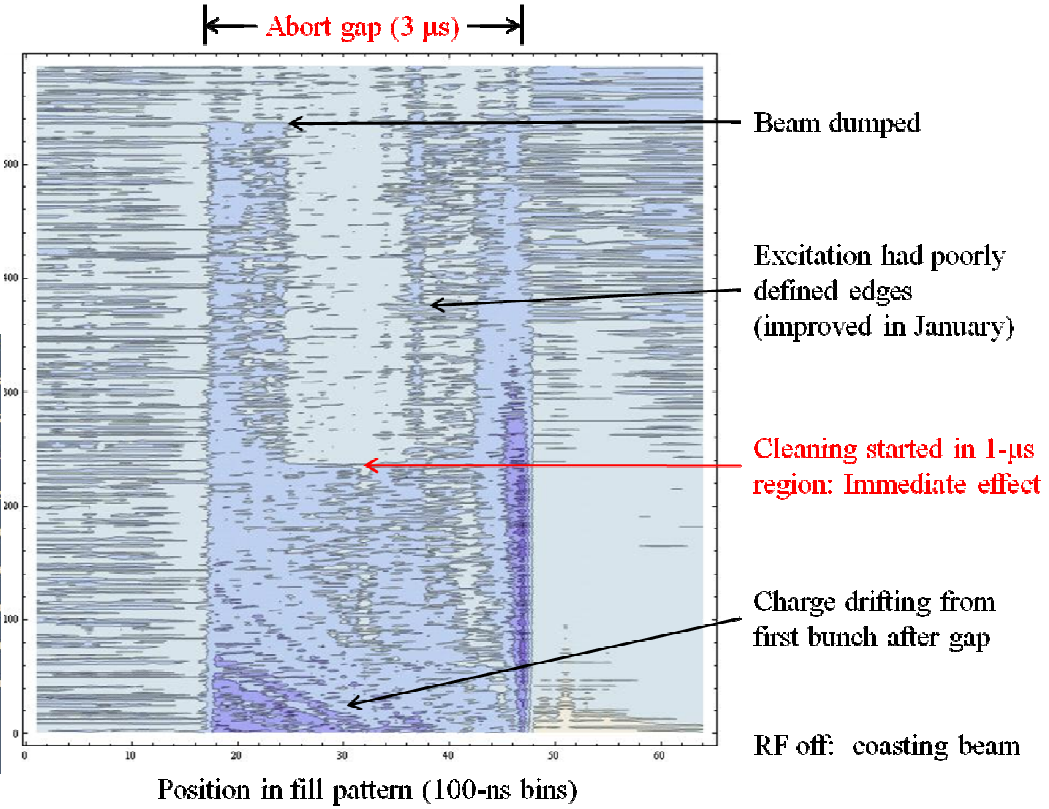


LARP

Passive profile measurement

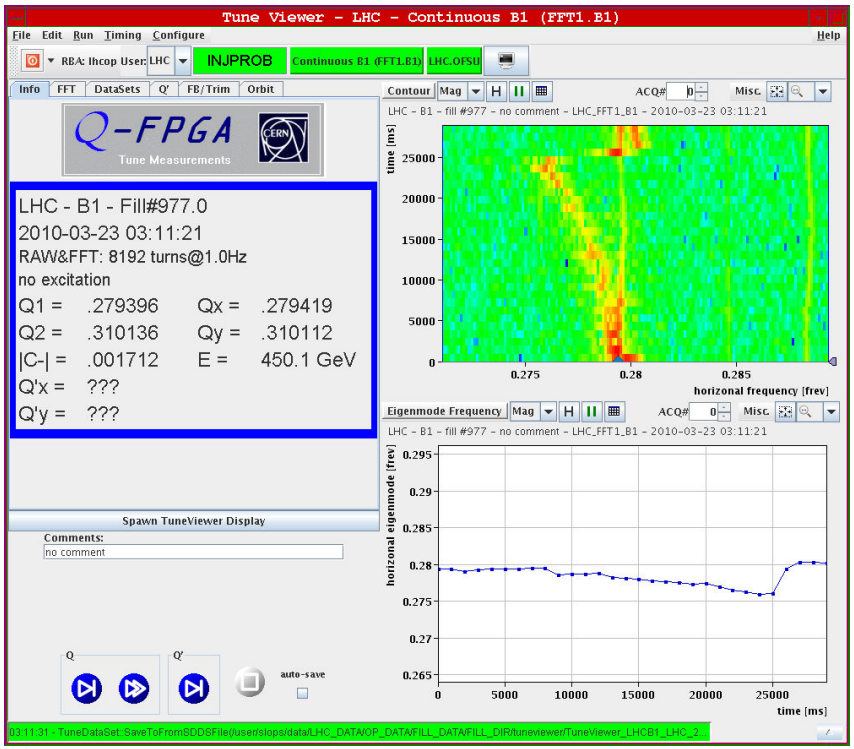
- Used to measure beam profile and monitor abort gap
- Not originally a LARP activity.
- Alan Fisher (LARP LTV from SLAC) proposed and implemented dramatically improved optics to accommodate shifting source location

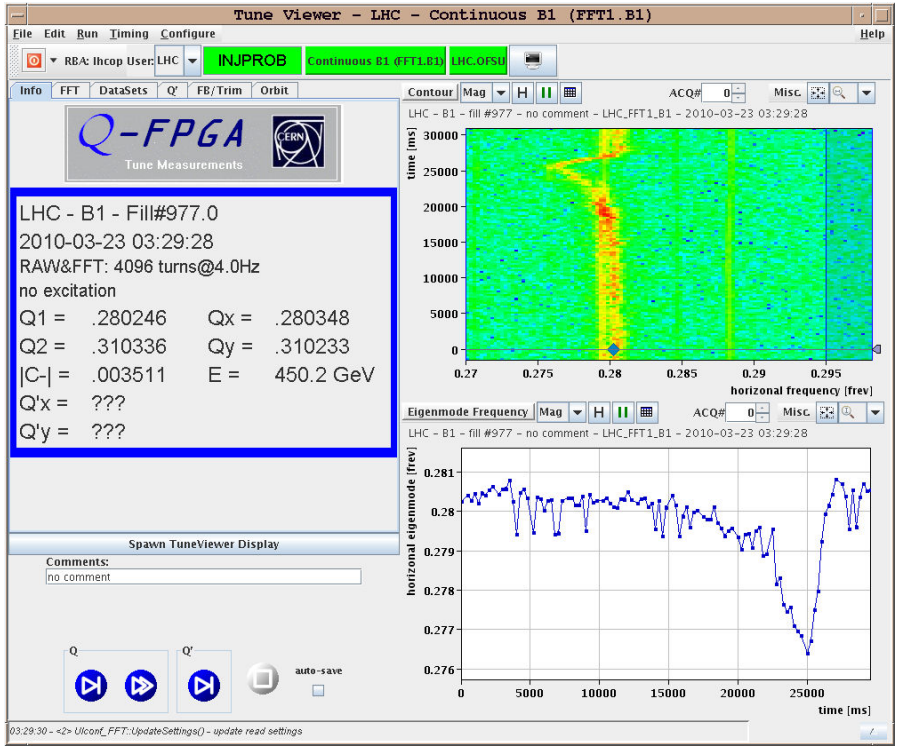




Tune Feedback

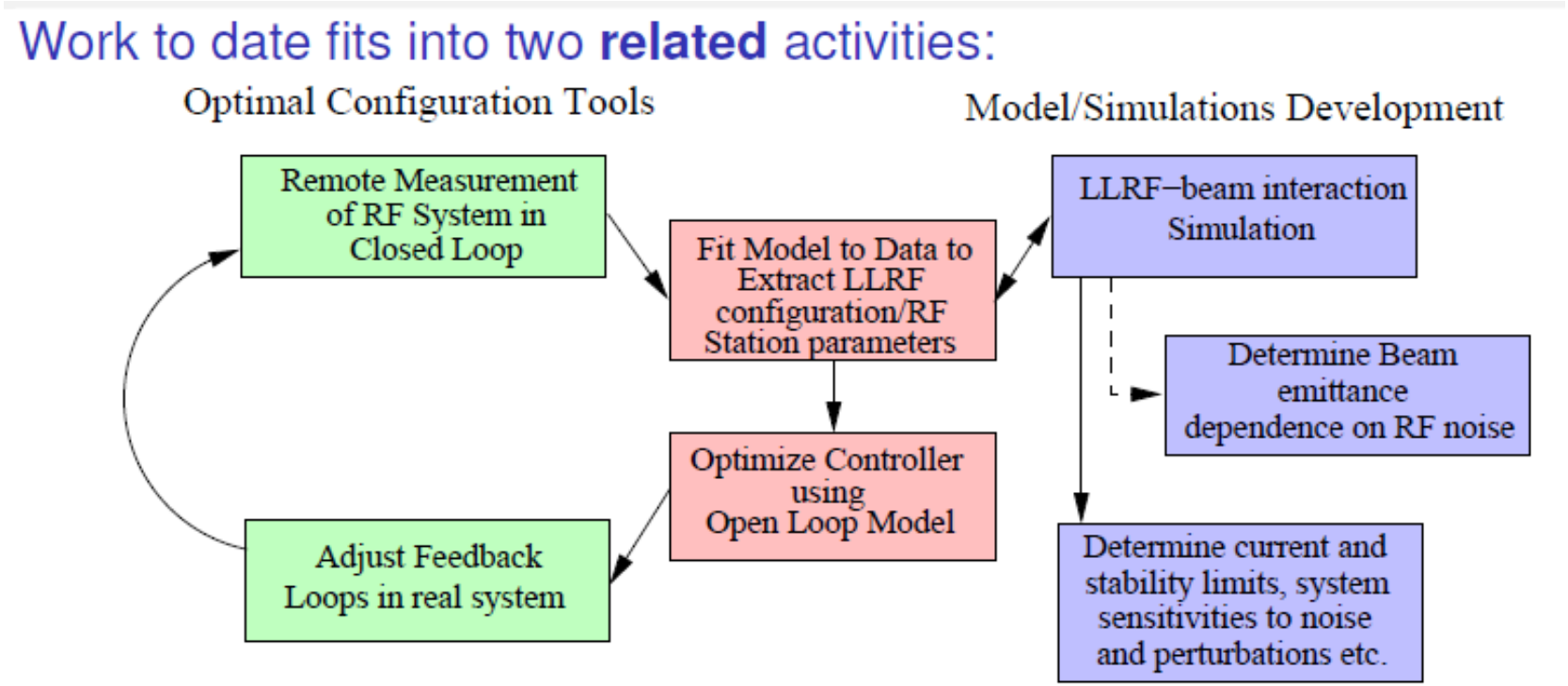
- LARP contributed to the development of the tune feedback system.
- Incorporated into LHC design
- Some initial problems with trips of the trim quads caused by tune feedback as 3.5 TeV
  - Fixed by lowering bandwidth of system
- Part of standard operation now.





LLRF Tools

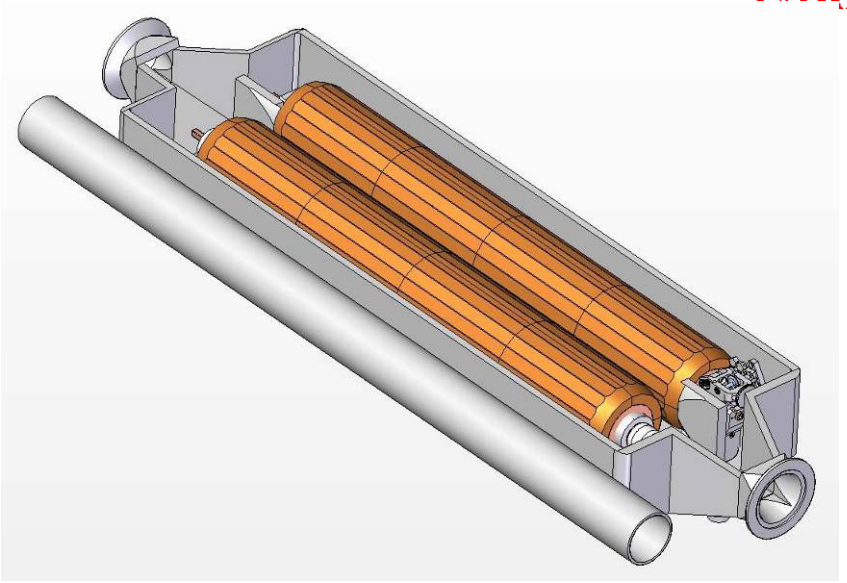
- Leverage RF tools and techniques developed at PEP-II
  - Effort led by John Fox



- Configuration tools used extensively during LHC RF commissioning

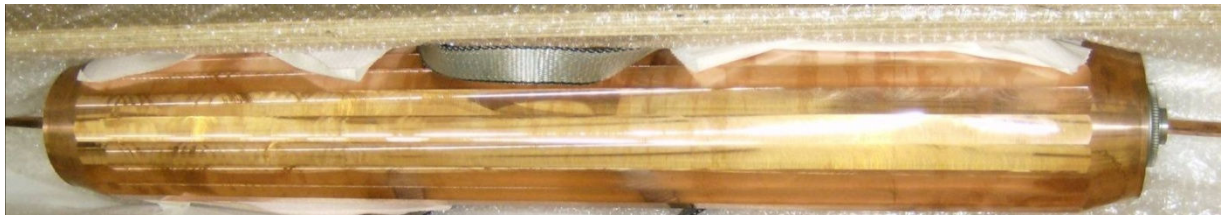
LARP Accelerator R&D for future LHC

- Rotatable collimators
  - Can rotate different facets into place after catastrophic beam incidents
  - First prototype nearly complete
- Crystal Collimation
  - UA9 at CERN
  - T980 at Fermilab
- Beam-beam studies
  - General simulation
  - Electron lens
    - Being retasked to hollow beams for scraping
  - Wire compensation
  - Flat bunches?
- Electron cloud studies
  - Study effects of electron cloud in LHC and injector chain

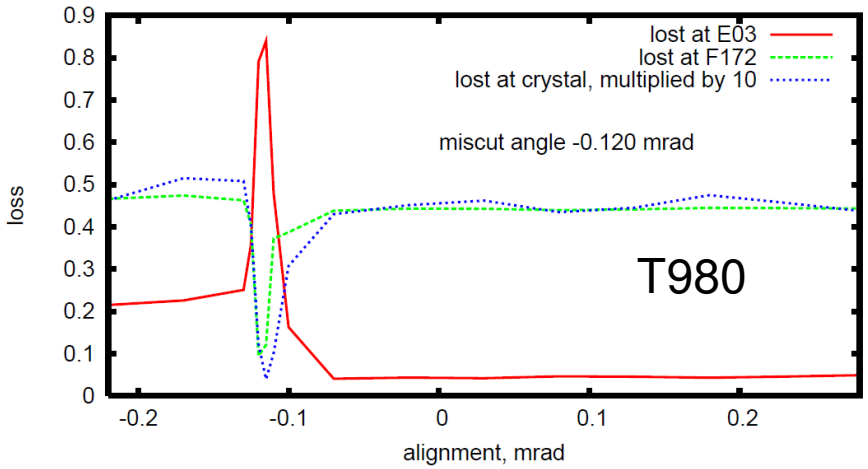


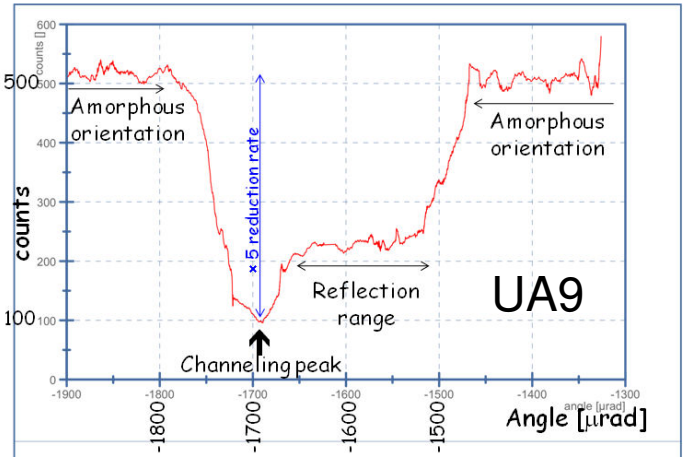
Collimation

- Rotatable Collimators
  - Continued good coordination with CERN Phase II collimation plan



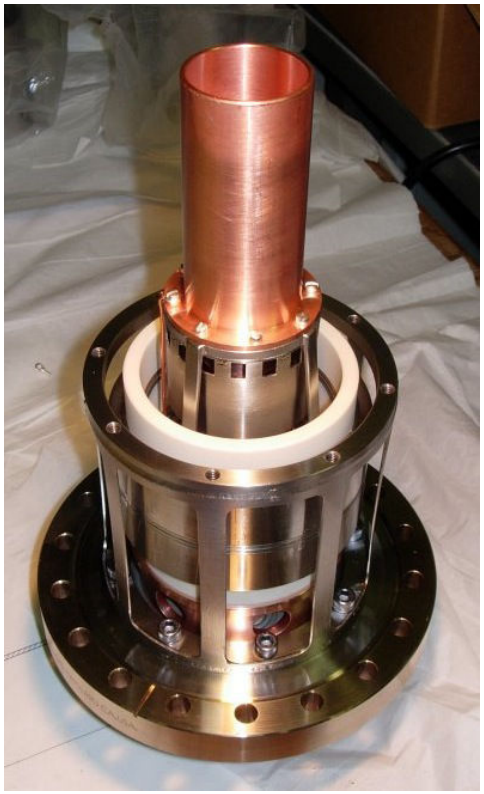
  - On track for prototype delivery, August 2010
  - Planning for SPS installation and testing after the 2010 run.
  - Will test in HiRadMat facility when facility is complete (mid-2011).
- Crystal Collimation
  - Exciting demonstrations from both T980 (FNAL) and UA9 (CERN)
  - Test proposed in LHC

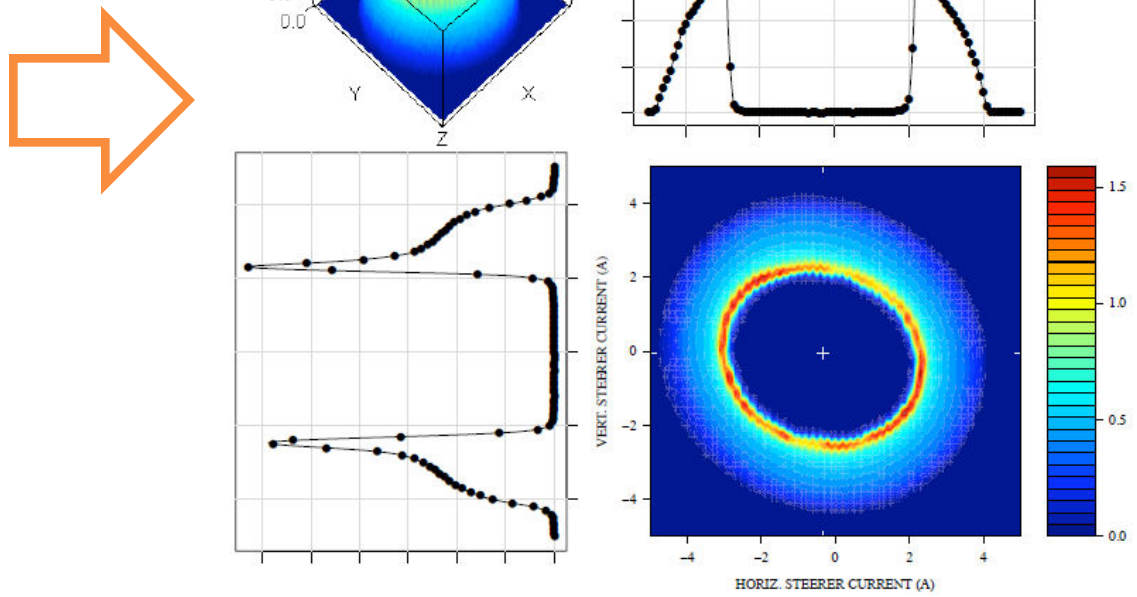




Collimation (cont'd)

- New idea: hollow electron lenses as collimators/scrapers
- Lots of interest from CERN
- Demonstration of hollow beams at FNAL

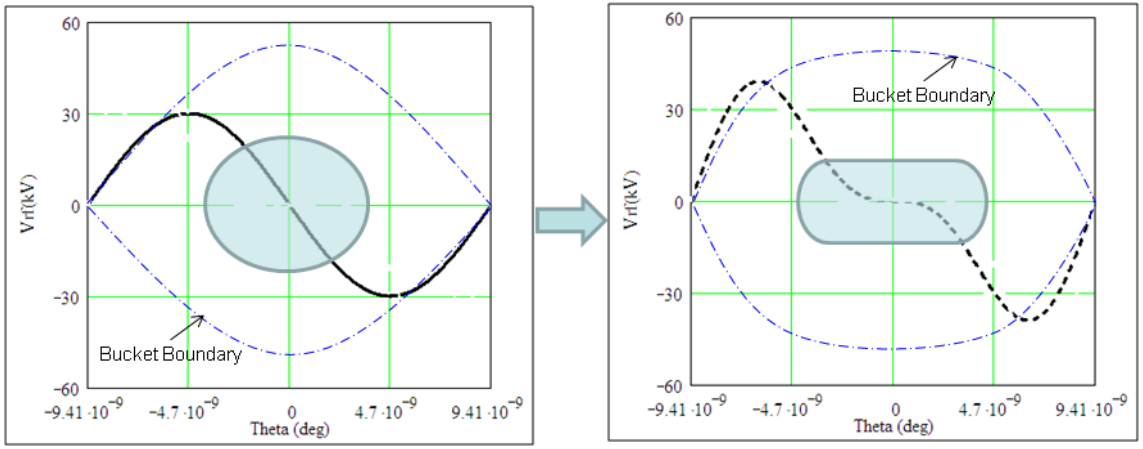


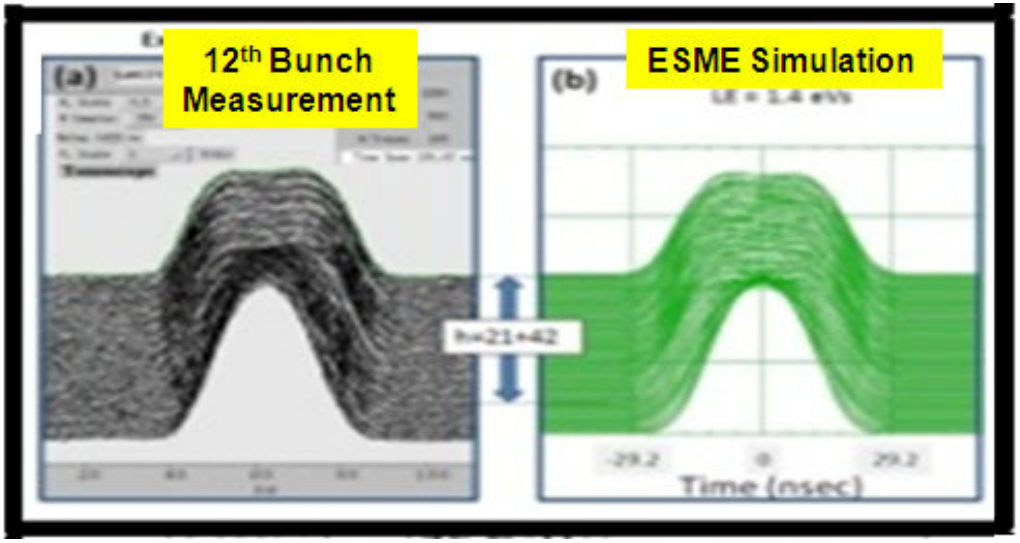


Beam-beam (cont'd)

- Flat beam studies for LPA solution
  - C. Bhat undertook a series of studies in PS to investigate flattening bunches with higher harmonic for LPA solution

Theory:





Measurements and simulation at 26 GeV in PS

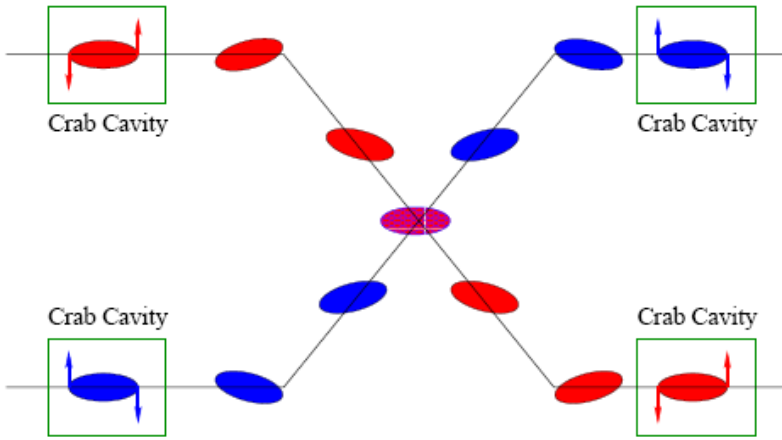
Note: Bhat starts as an LTV later this year

Future Plans: Accelerator Systems

- LARP will complete work on existing projects
- Whenever possible, we will try to take part in the accelerator physics opportunities provided by our hardware
  - Lumi monitor
  - Shottky detector
  - AC Dipole
  - Etc
- As work is completed on existing projects, we will look for new opportunities that will certainly arise once the LHC starts operations in earnest.

Future directions for LARP

- Crab cavities
  - Transverse fields rotate bunches to compensate for crossing angle in final upgrade
  - Significant opportunity
    - LARP has played a major role
  - Collaboration with KEK, CERN, and Daresbury
    - Endorsed by CERN in Sept. 2009
  - But big job, lots of $$
- ~~PS2 opportunities~~
  - ~~Significant synergy with Project X~~
  - ~~Ecloud~~
  - ~~Injection, collective instabilities~~
  - ~~Laser stripping~~
  - ~~RF~~



The PS2 will likely be canceled, but LARP has focused on instabilities and collective effects, which will have applicability toward improving the PS

Crab Cavities

- Crab cavities have now become the base line plan for Phase II luminosity and luminosity leveling.

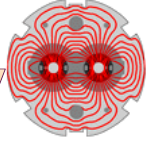
Statements on Crab Cavities from CERN

(Steve Myers, Director of Accelerators and Technology)

1. Following the success of KEKB, CERN must pursue the use of crab cavities for the LHC, since the potential luminosity increase is significant.

- LARP has played a major role in bringing crab cavities to this point, however the resources needed to fully manage this effort are well beyond LARP
  - The infrastructure requirements alone demand a central CERN role.
- Discussion: What are CERN's plans to move forward with the crab effort and how can we best contribute?

PSB Energy Upgrade: New Potential Opportunity



LARP

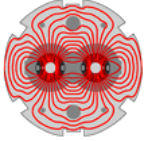
- It has been pointed out that increasing the energy of the PSB from 1.4 ⇒2.0 GeV could potentially provide improvement similar to that promised by the PS2

Intensity Limitations (10^{11} protons per bunch) *			
	Present	SPL-PS2	2GeV in PS
LINAC4	4.0	4.0	4.0
PSB or SPL	3.6	4.0	3.6
PS or PS2	1.7	4.0	3.0
SPS	1.2	1.2	1.2
LHC	?	?	?

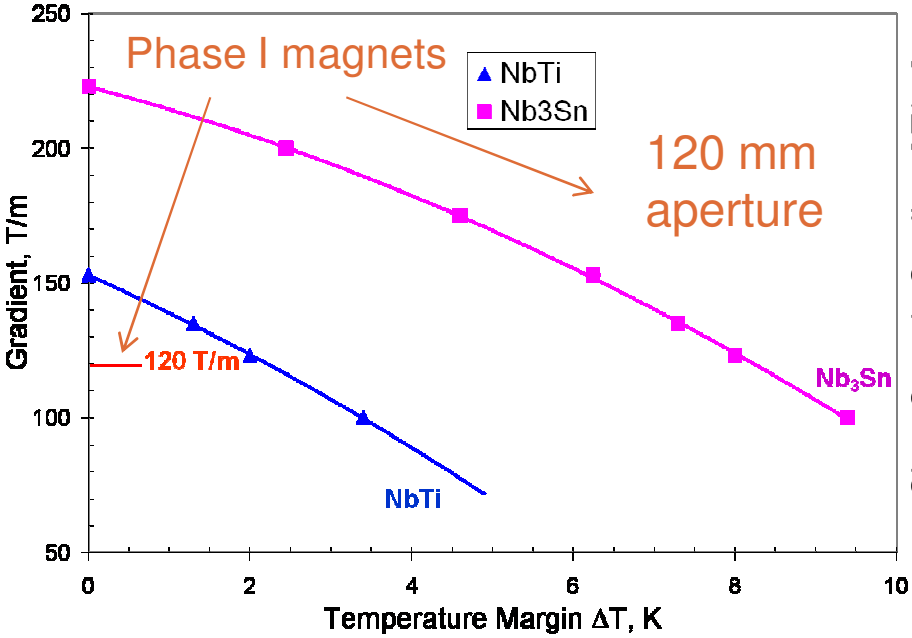
- A CERN working group led by Klaus Hanke has examined this, found no show stoppers, and is currently working on a conceptual plan.
- We are discussing potential LARP involvement
  - Shielding/beam dump calculations?
  - Space charge modeling?
  - MD studies?
  - Other?

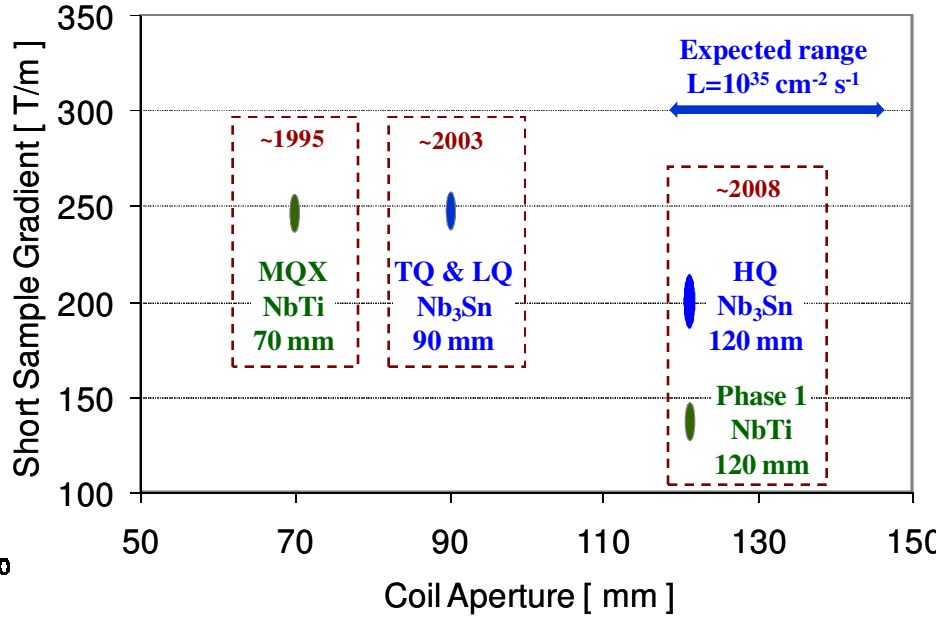
*S. Myers' summary of talk by M. Giovanozzi at Chamonix 2010

LARP Magnet Program



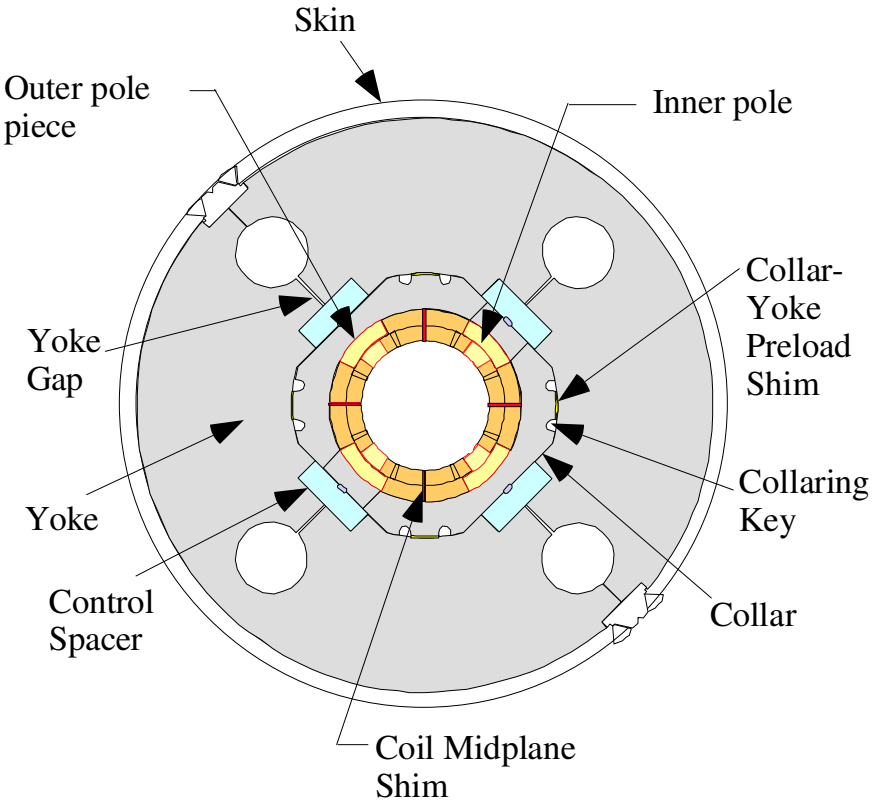
- Goal: demonstrate Nb_3Sn as a viable technology for the "Phase II" upgrade of the LHC
- Nb_3Sn can be used to increase aperture/gradient and/or increase heat load margin, relative to NbTi

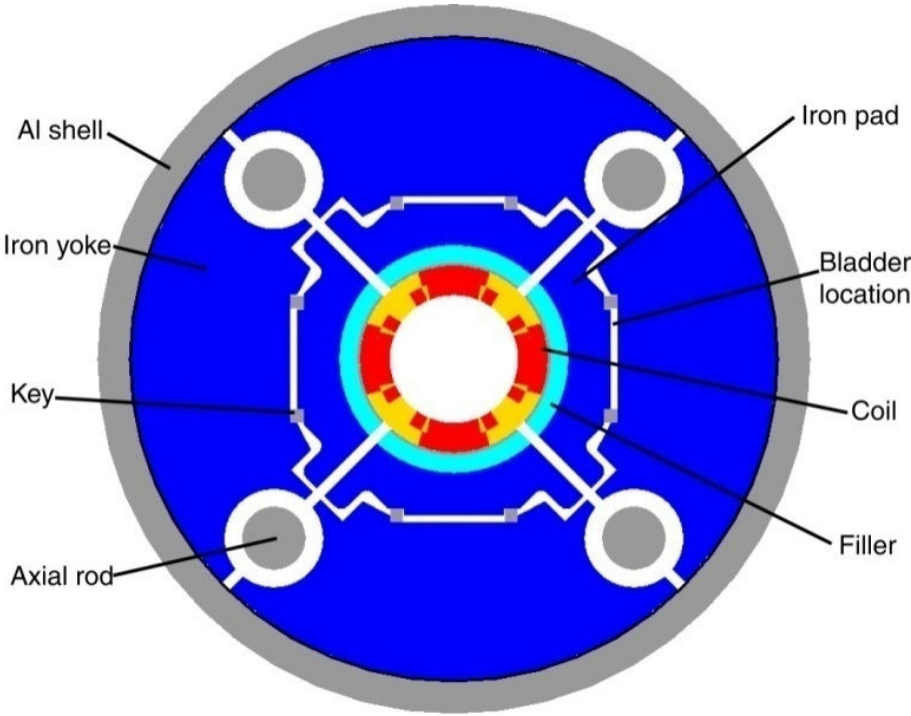




- Very attractive, but no one has ever built an accelerator quality magnet out of Nb_3Sn
  - Unlike NbTi, Nb3Sn becomes brittle during the reaction process, so it must be wound on a mandril and reacted prior to installation in the magnet, significantly complicating the production process.

Competing Magnet Designs

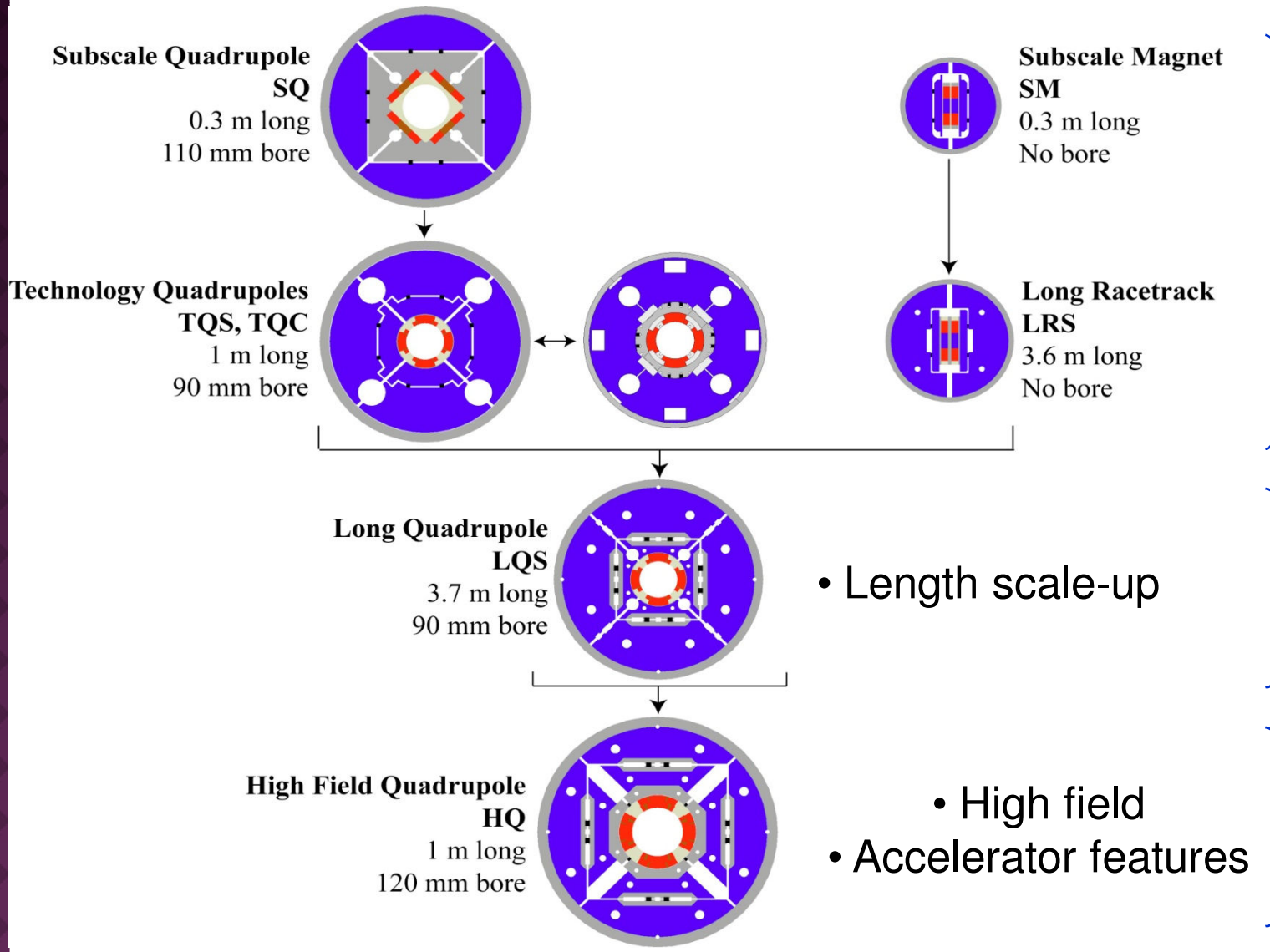




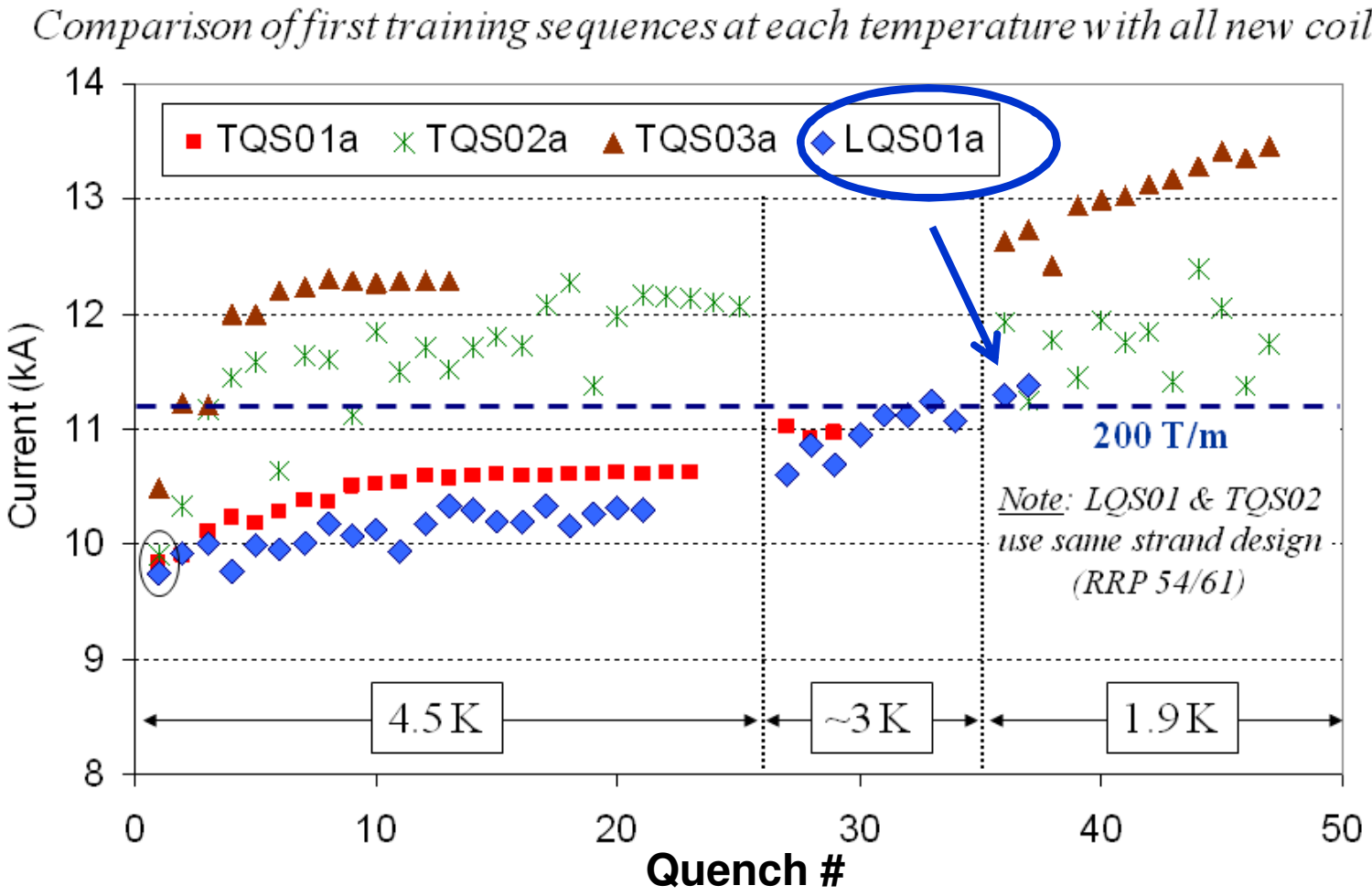
- **Collar:**
  - Traditional magnet design
  - Pre-load provided by a series of collars which hold coils in place.

- **Shell:** Adopted by LARP
  - New concept
  - Pre-load produced by inflatable bladder, and secured by insertable keys.

LARP Magnet Development Chart

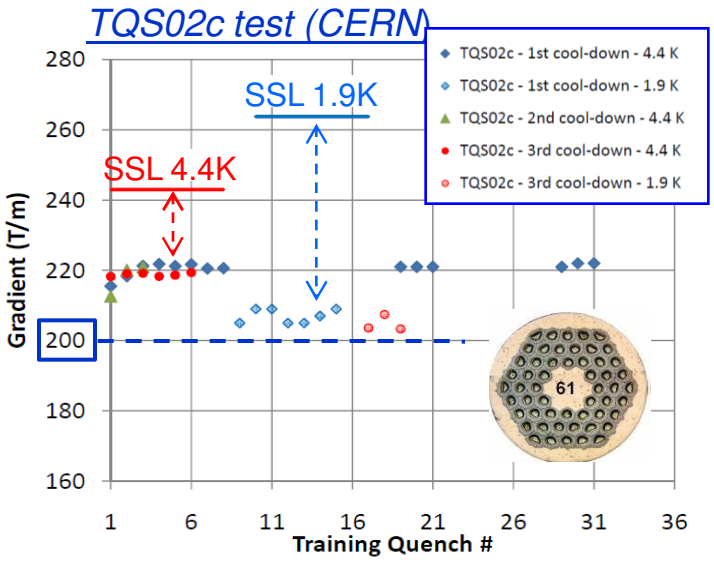


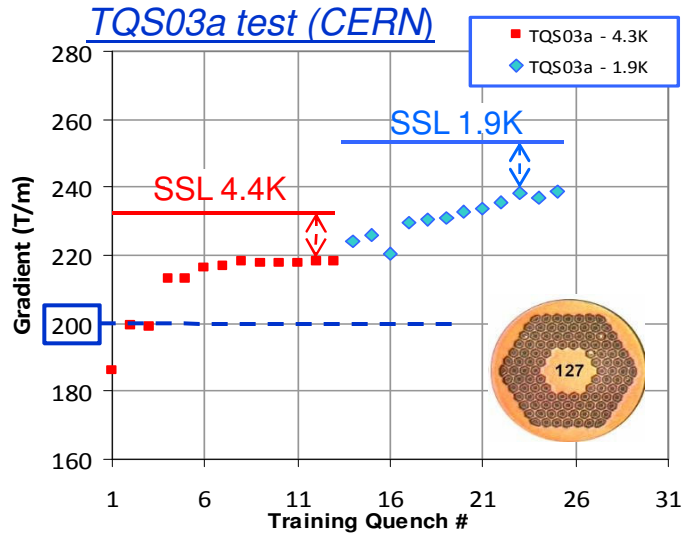
LQ Results: Fermilab Vertical Test Facility



- The first LQ met 200 T/m design spec !!,
  - However, based on TQ results, we expect it to go higher
  - Believe this can be done by mechanically shimming the coils

Conductor Choice





- The 54/61 conductor which we have traditionally used showed instability problems at 1.9K
- These appear to be solved with the finer filament 108/121 conductor
  - The 108/127 conductor will be the choice for all future magnets.

Baseline Magnet Plan

2010-2012: complete technology demonstration (original goal)

LQ to address all length-related issues (& fully reproduce TQ results):

- 2010-2011: 2-3 additional tests using 54/61 coil series
- 2010-2011: Fabricate 4-6 additional coils using 108/127
- 2011(2012): ~2 tests with 108/127 coil series

HQ to address field/energy limits and accelerator quality

- 2010-2011: 3-4 tests with 1 m models
  Progressively push performance
- 2011-2012: Extend to 1.5 or 2 m length
  Use Phase 1 specifications as reference

2012-2014: fabricate and test IR Quad prototype

2015-2020: IR quad production for Phase 2 upgrade

LARP personnel programs

- Long Term Visitors program
  - Pay transportations and living expenses for US scientists working at CERN for extended periods (at least 6 months/year)
  - Coordinated with CERN sponsor
  - Past:
    - Steve Peggs (BNL): crystal collimatoin (UA9)
    - Jim Strait (FNAL): machine protection, incident analysis
  - Current/Future:
    - Alan Fisher (SLAC): synchrotron light monitor
    - Rama Calaga (BNL, former Toohig): crab cavities, commissioning
    - Eliana Gianfelice (FNAL): abort gap, commissioning
    - Chandra Bhat (FNAL): Flat bunches
    - Uli Wienands (SLAC): PS2/PS

LARP personnel programs (cont'd)

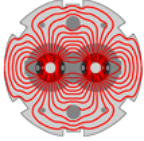
- Toohig Fellowship
  - Named for Fermilab's Tim Toohig
  - Open to recent PhD's
  - ½ time at CERN, ½ at host lab
  - Apply to John Fox, SLAC
  - Past
    - Helene Felice (LBNL, now postdoc)
    - Rama Calaga (BNL, now LTV)
    - Riccardo DiMaria (BNL, now CERN Fellow)
  - Current
    - Ryoichi Miyamoto (BNL, former FNAL joint PhD)
    - Dariusz Boican (FNAL)

Key Chamonix Decisions

- Energy
  - Joints not reliable above 3.5 TeV
  - Run at 3.5+3.5 for ~fb^{-1} or roughly end of 2011, then shut down for ~18 months to do all repairs to get to 6.5-7.0.
- Collimation
  - Initial (Phase I*) collimation only good to a luminosity of a few 10^{33}.
  - A plan is in place for collimation which is good to "ultimate" luminosity of a few 10^{34}.
    - Schedule being worked out
    - Will involve LARP collimators, if they pass tests in SPS and HiRadMat
- Crab Cavities
  - In a major shift from last year, crab cavities are now considered part of the base line plan for the Phase II upgrade
    - They worked at KEK
    - They don't require PS2
    - They lead to lower instantaneous rates than Large Pewinski Angle Solution
  - LARP has played a major role in this

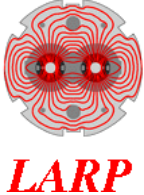
*note confusing inconsistent "phases" for collimation and triplet upgrade

Chamonix wrt CERN Upgrades



- In 2014, the LHC will optimistically accumulate ~10's of fb^{-1}, and the luminosity will still be increasing.
  - The lifetime of the existing triplet magnets is ~500 fb^{-1}
  - Is it likely the experiments will want to stop for a year upgrade followed by a year of re-commissioning?
- Consider two possibilities
  - Delayed scenario
    - Phase I upgrade delayed until ~2017
    - Phase II upgrade delayed until ~2023
  - Skip Phase I entirely
    - Phase II still in 2020, or maybe even earlier
- CERN is supposed to make a decision regarding the Phase I upgrade "soon"
  - Need to start moving on magnet production if it's really going to happen.

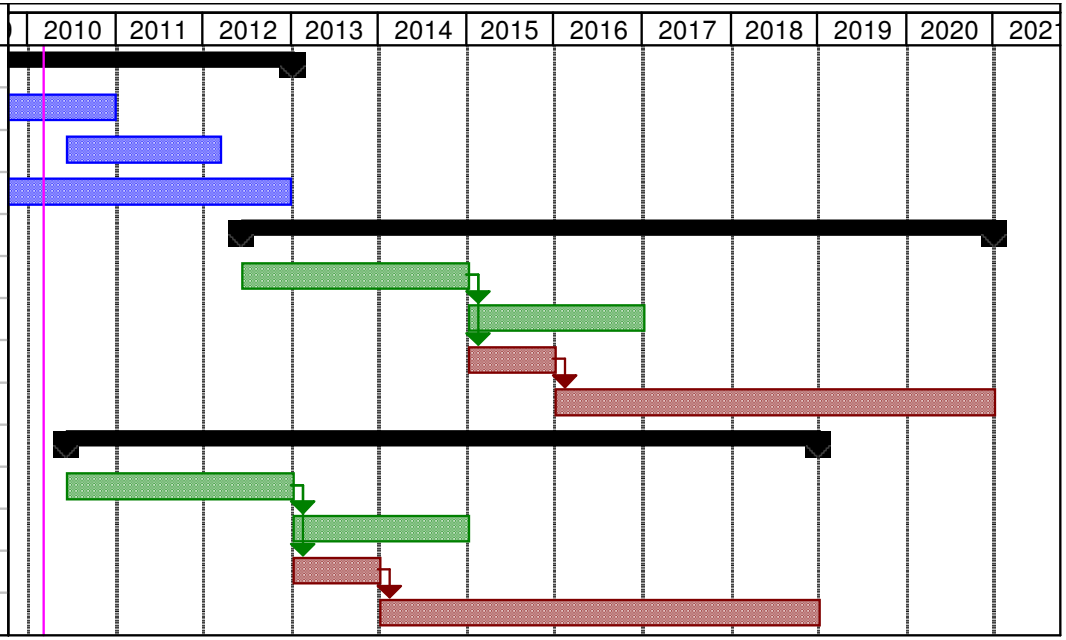
Impact of Chamonix Decisions on LARP



- The energy decision affects LARP only indirectly
  - e.g. we will have to maintain a presence to commision lumi. mon.
- Generally, all the decisions at Chamonix validate the LARP program
  - If we can deliver prototypes on time, at least some LARP collimators will play a role in the Phase II Collimation.
  - Crab cavities, which were championed by LARP, are now part of the base line planning for the Phase II luminosity upgrade.
  - Although the PS2 effort will likely be canceled, LARP has focused on instabilities and collective effects, work which will be fully applicable to improving the existing PS.
  - LARP is now acknowledged as the leader of the Nb_3Sn R&D.
- Upgrade
  - In the absence of further information, LARP will assume that either the Phase I upgrade will be skipped, or delayed sufficiently that Nb_3Sn becomes an option.

Schedule options

ID	Task Name
1	**Baseline plan (applies to both cases)**
2	LQ-54/61
3	LQ-108/127
4	HQ-1(1.5)m
5	**Option 1 (current plan)**
6	LHQ(4m) first model
7	LHQ(4m) additional models
8	Production set-up
9	Production
10	**Option 2 (accelerated plan)**
11	LHQ(4m) first model
12	LHQ(4m) additional models
13	Production set-up
14	Production



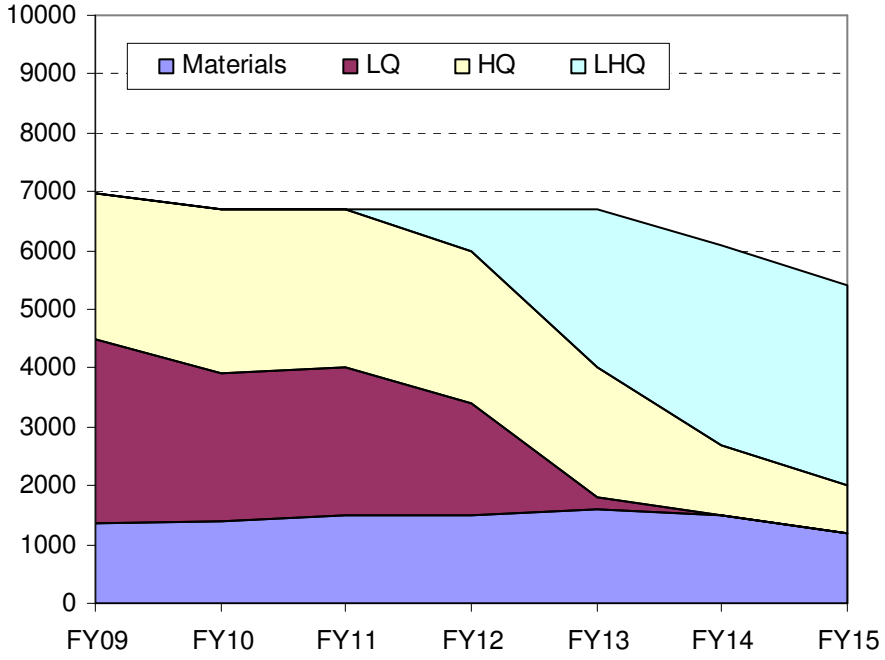
Option 2 makes sense in the context of:

- A determination that 120 mm aperture is a good choice for the upgrade
- A magnet R&D budget increase of ~6 M$ over 2010-12
- Additional resources for LARP in 2010-12 (from APUL)

Note: 1+5 years production schedule is just for illustration, could vary considerably depending on specs, infrastructure, resources etc.

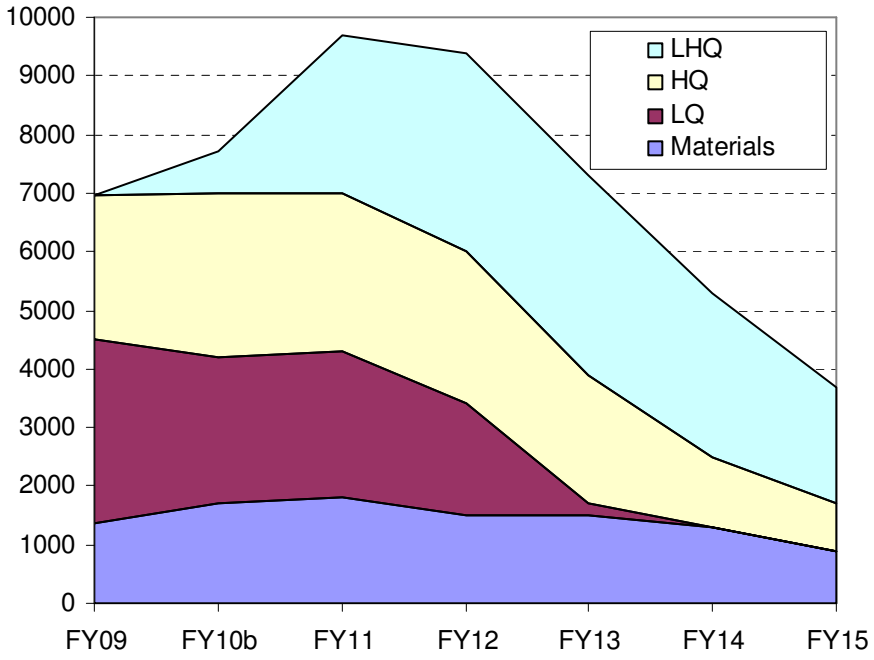
Magnet R&D Budget Profiles

Baseline (option 1)



	FY09	FY10	FY11	FY12	FY13	FY14	FY15
Materials	1352	1400	1500	1500	1600	1500	1200
LQ	3149	2500	2500	1900	200	0	0
HQ	2459	2800	2700	2600	2200	1200	800
LHQ	0	0	0	700	2700	3400	3400
Total	6960	6700	6700	6700	6700	6100	5400

Accelerated (option 2)



	FY09	FY10	FY11	FY12	FY13	FY14	FY15
Materials	1352	1700	1800	1500	1500	1300	900
LQ	3149	2500	2500	1900	200	0	0
HQ	2459	2800	2700	2600	2200	1200	800
LHQ	0	700	2700	3400	3400	2800	2000
Total	6960	7700	9700	9400	7300	5300	3700

Non-LARP LHC Accelerator Activities: LHC Accelerator-Fermilab Software (LAFS)

- It was decided early that LARP itself would not support software projects
  - The idea was the LARP would do R&D, and the promising technology (along with the required software) would be handed off to someone else.
- For this reason, the LAFS groups was created. Charter members:
  - Dave McGinnis
  - Jean Slaughter
  - Suzanne Gysin
  - Elliott McCrory
  - Jim Patrick

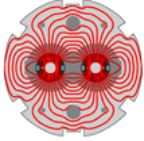
Major LAFS Tasks*

- Role-based access control (RBAC): sophisticated access control for accelerator related applications
  - Susanne Gysin spent 9 months at CERN gathering information, writing requirements and implementing version 1
- Wire scanner app.
  - Elliott McCrory worked on this app. during his two years at CERN
  - Already being used extensively
- Beam Synchrotron Radiation Monitor (BSRT) app And daemon:
  - Monitor beam synchrotron radiation to measure bunch shape and verify abort gap
- Schottky application:
  - Set schottky DAQ parameters, read and display data
- Lumi monitor application:
  - GUI to control and display data from the lumi monitor

Joint involvement with LARP

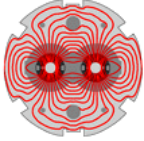
*courtesy Elliott McCrory

Non-LARP LHC Accelerator Activites: Accelerator Projects for the LHC Upgrade (APUL)



- LARP is an R&D program, and the structure is not really appropriate for significant, critical path, hard deliverables.
- For this reason, APUL was created.
  - Project Manager: Peter Wanderer, BNL
- Initial APUL projects:
  - Superconducting D1 separators, based on the RHIC dipoles.
  - New feedboxes with superconducting transmission lines to facilitate moving the triplet power supplies to a lower radiation area following the Phase I upgrade.
- Current status:
  - APUL is currently on hold pending the decision about the Phase I upgrade.
  - It's possible that one or both projects might still be viable even in the absence of the triplet upgrade.

Summary



- LARP has been an effective program for coordinating US accelerator related contributions to the LHC.
- LARP has taken the lead in R&D to demonstrate Nb_3Sn as a viable technology for the LHC quadrupoles.
- We look forward to new opportunities and challenges in the future.
- It would be mutually beneficial to develop a closer relationship between LARP and EuCARD to utilize our resources as effectively as possible and avoid duplicated effort.