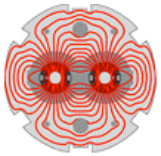


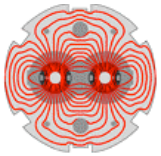
BNL - FNAL - LBNL - SLAC

LARP BEAM INSTRUMENTATION

A. Ratti
LBNL

Presented at the DoE review of LARP

Berkeley
June 19-20, 2008



LARP

Outline

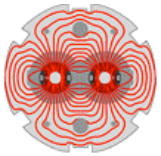
Overview of existing instruments
- Schottky Monitor (lead by FNAL)
- Tune Feedback (lead by BNL)
- Luminosity Monitor (lead by LBNL)
- AC Dipole (lead by UT)

Most of these transition to Beam Commissioning in FY09
- Not all lumi monitors will be installed but at least one will be operational

New tasks
- LHC RF Controls Modeling (lead by SLAC)

Integration at CERN

Budget and Schedule Status



Instrumentation Highligths

Instrumentation is a very active part of LARP's contribution to the LHC

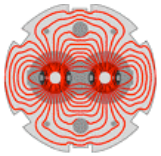
All LARP instrumentation projects will contribute to the LHC commissioning

Major contributions to the LHC:

- Tune and Coupling feedback is a world first
- The AC dipole concept came from LARPs collaborations and is now installed in all three hadron colliders part
- The schottky monitor work for the LHC lead to an upgrade of the Tevetron system
- The luminosity monitor is designed to survive a level of radiation 100x larger than ever seen before

US colliders remain an essential part of the LARP contribution to the LHC

Developing all instruments with experimental support of colliding beam operations



Introduction

First Four instruments are approaching completion at different stages

- Schottky monitors are delivered, installed and bench tested
- Luminosity monitors are in final production
  - could miss first beam in 2008
  - will be ready for LHC's 2009 run
- Tune and coupling feedback is evolving to chromaticity feedback during the RHIC run VII
- AC Dipole is mostly in the hands of CERN, US scientists ready to participate

Three tasks successfully completed in FY08 and move to LARP beam commissioning in FY09

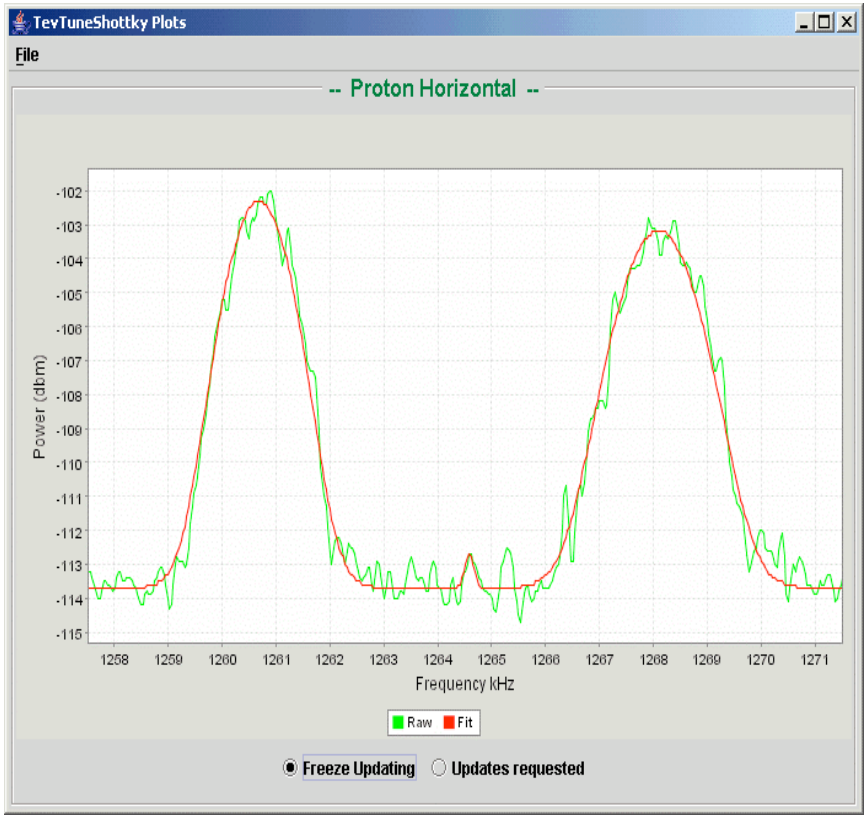
One new task added for FY09

- LLRF modeling for the 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



Build in capability to monitor gain variation with time

Measure individual or multiple bunches

Technical Approach

- Center frequency of 4.8 GHz
- 3dB BW - 300 MHz
  - Sufficient for 25ns bunch spacing
- Small longitudinal Z/n
  - No absorbers allowed
- Below frequency of Schottky band overlap
- Allows for adequate physical aperture
- Matched pairs of SiO_2 Coax cables

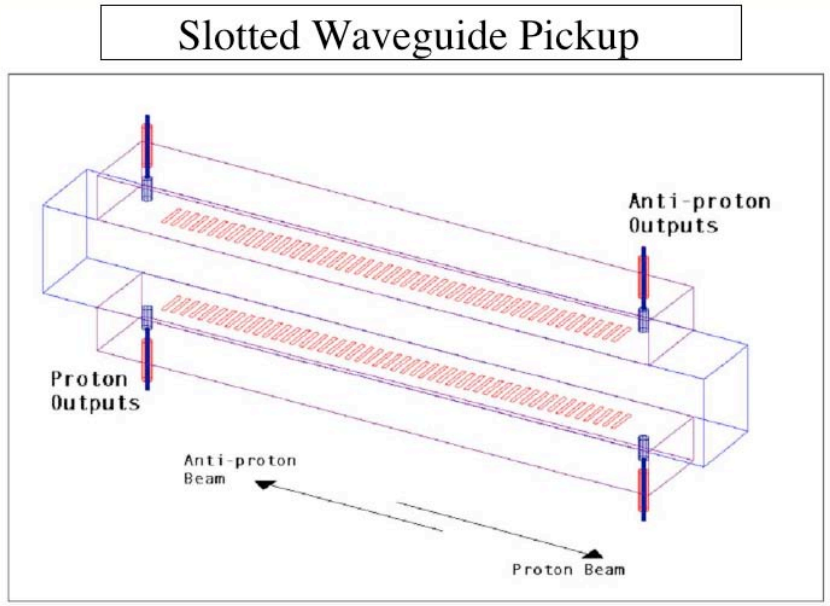
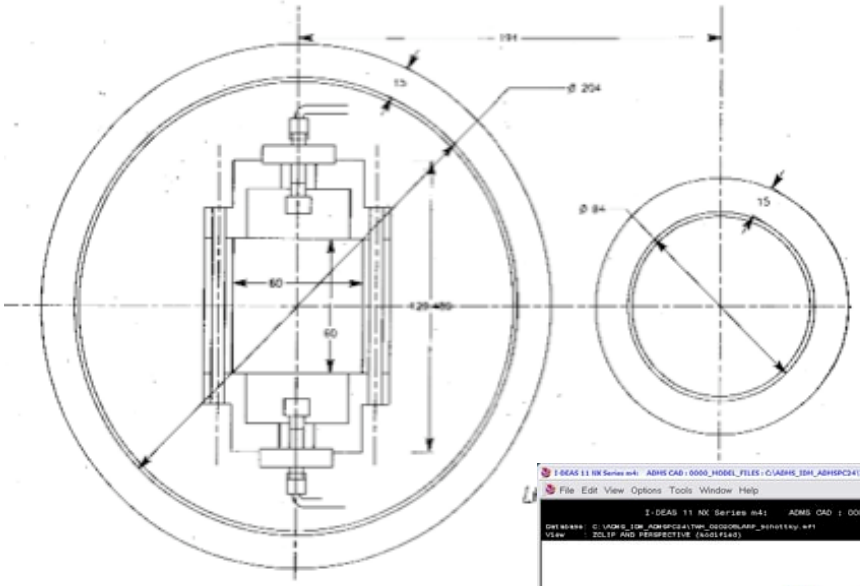
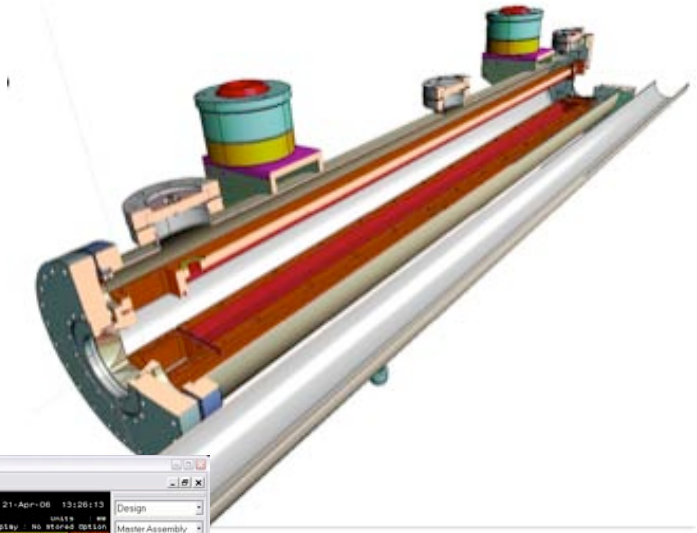


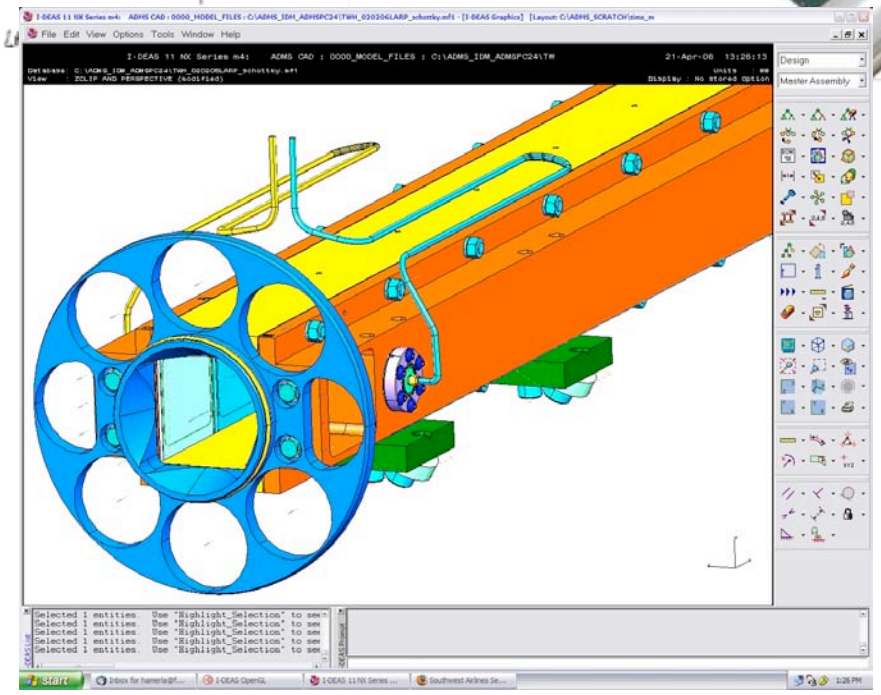
Table 1. Parameters of LHC Schottky Pickup (unit: mm)

Slot length	Slot width	Slot Spacing	Number of Slots	Waveguide width	Waveguide height	Beam pipe width	Beam pipe height
20.52	2.032	2.032	246	47.549	22.149	60.00	60.00

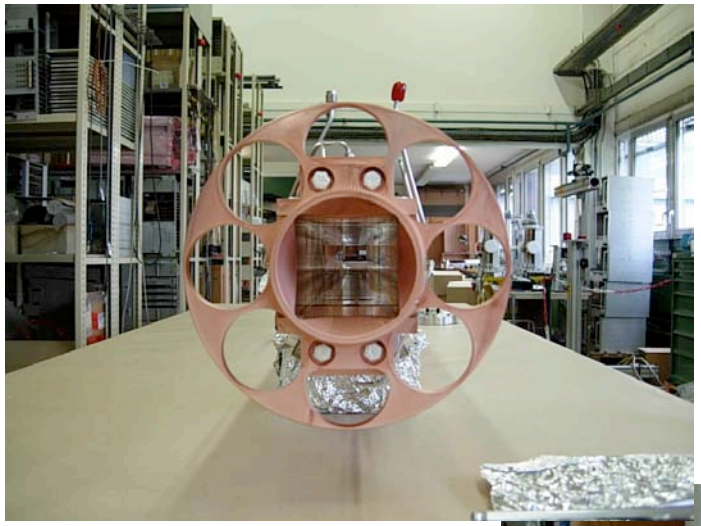
Pickup and Adjacent Beampipe Designed at FNAL

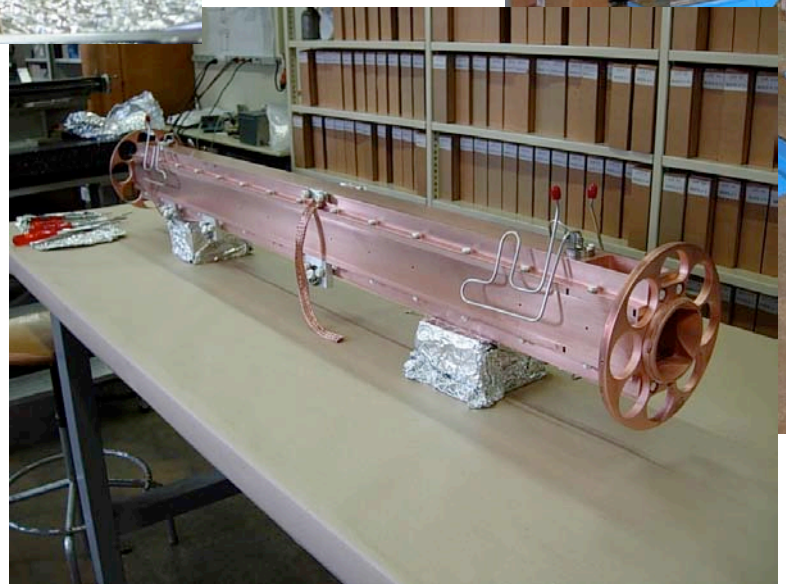


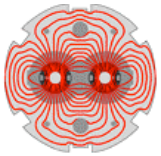




Hardware Built at CERN







Schottky Processing Electronics

Triple down-conversion preserves single sideband signal with Chromaticity information

- First IF uses the 11th harmonic of the 400MHz clock to convert the 4.8 GHz signal to 400 MHz

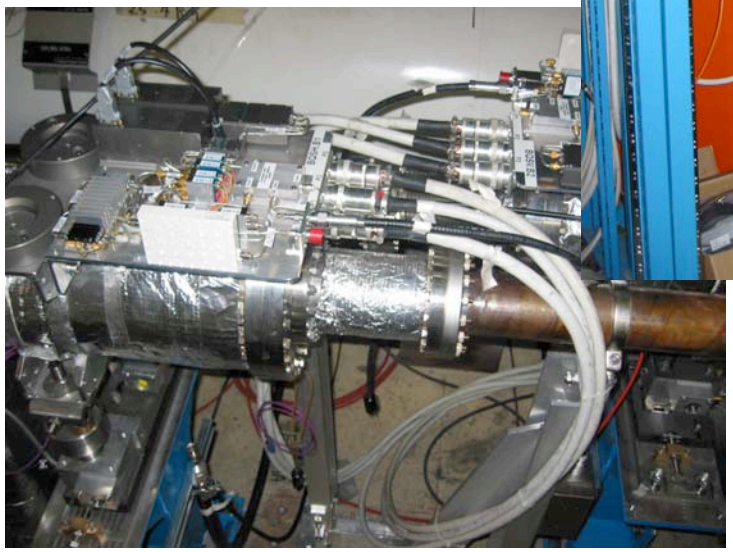
- Second at 45 MHz, using a LO locked to the 40MHz LHC clock reference

  A crystal filter selects a 15 kHz band of schottky signal

- Third IF takes the signal down to DC-80KHz baseband

Data is then collected with 20-24 bits CERN DAQ cards in DAB-IV environment

Electronics Hardware at CERN



Schottky Monitor - Roles and Responsibilities

LARP

FNAL

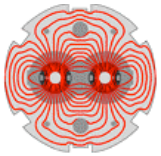
- Delivered a complete, ready to print drawing package to CERN
- Delivered a full set of front end electronics to connect to the detectors
- Provided installation and hardware commissioning support

CERN

- Built all beamline devices to FNAL's prints
- Provided local cabling, installation,
- Local Oscillators, Reference signals, Data Acquisition hardware
- Final integration with control system ….. interfaces by FNAL

LARP - Commissioning

The beam commissioning of these devices will be supported by the LARP Beam Commissioning group. The original instrumentation team will assist initial system commissioning



Schottky Monitor Planning

FY06

Beamline Hardware Completed

FY07

Processing electronics completed

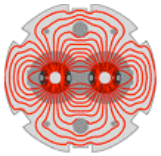
Installation and 'bench' testing at LHC completed

System documentation (120 MB) completed

FY08

Hardware Control interfaces (from FNAL)

Support Beam Commissioning



Tune and Coupling Feedback

Objective: Control Tune and Coupling feedback

- Develop chromaticity tracking during ramp and store

Recent Progress

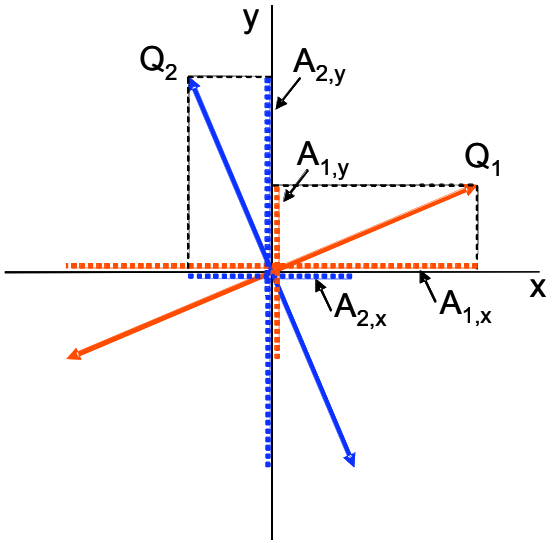
- Simultaneous Tune and Coupling feedback used in RHIC run 6, **a world first**
- RHIC run 7 and 8 - Tune and Coupling feedback operational
  - focusing on chromaticity tracking

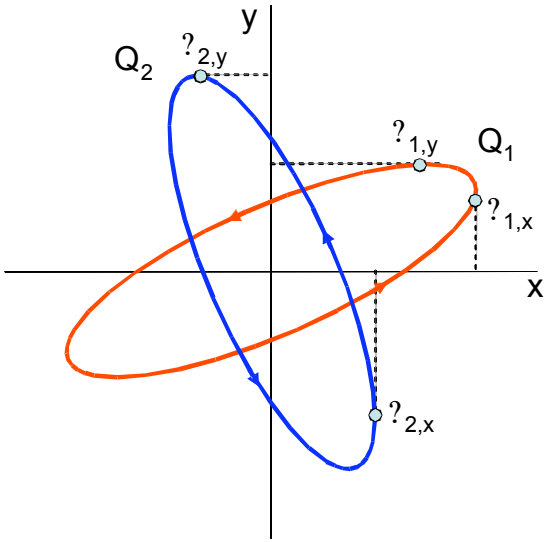
Task ended in FY07

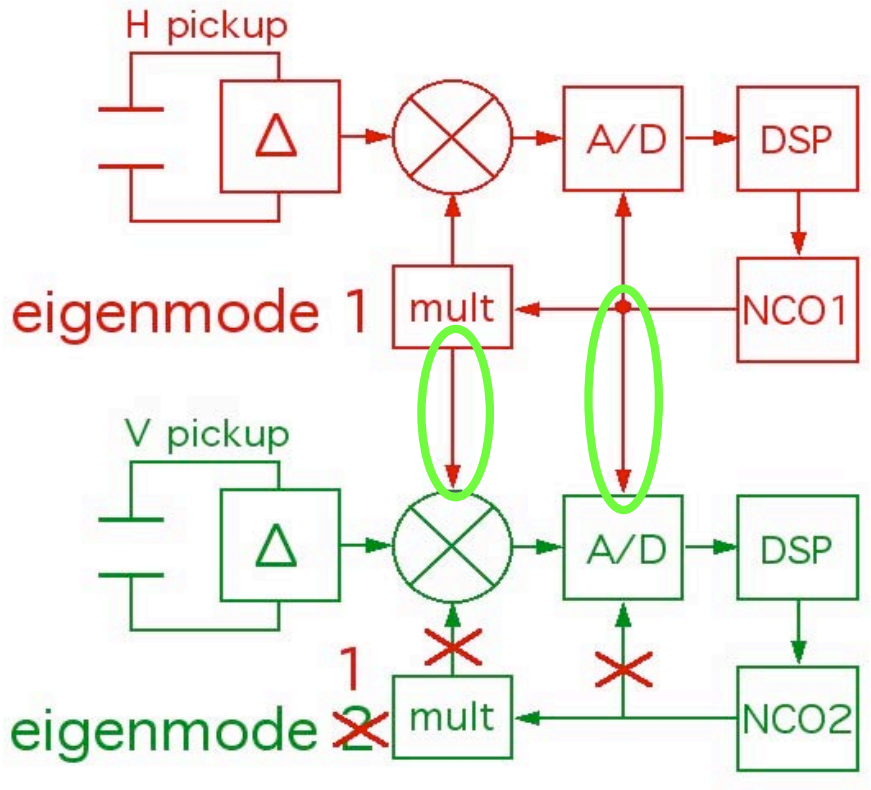
Moved on to chromaticity control studies

Direct Diode Detection system is an excellent tool for Beam Transfer Function Measurements

Coupling Measurement with PLL Tune Tracker



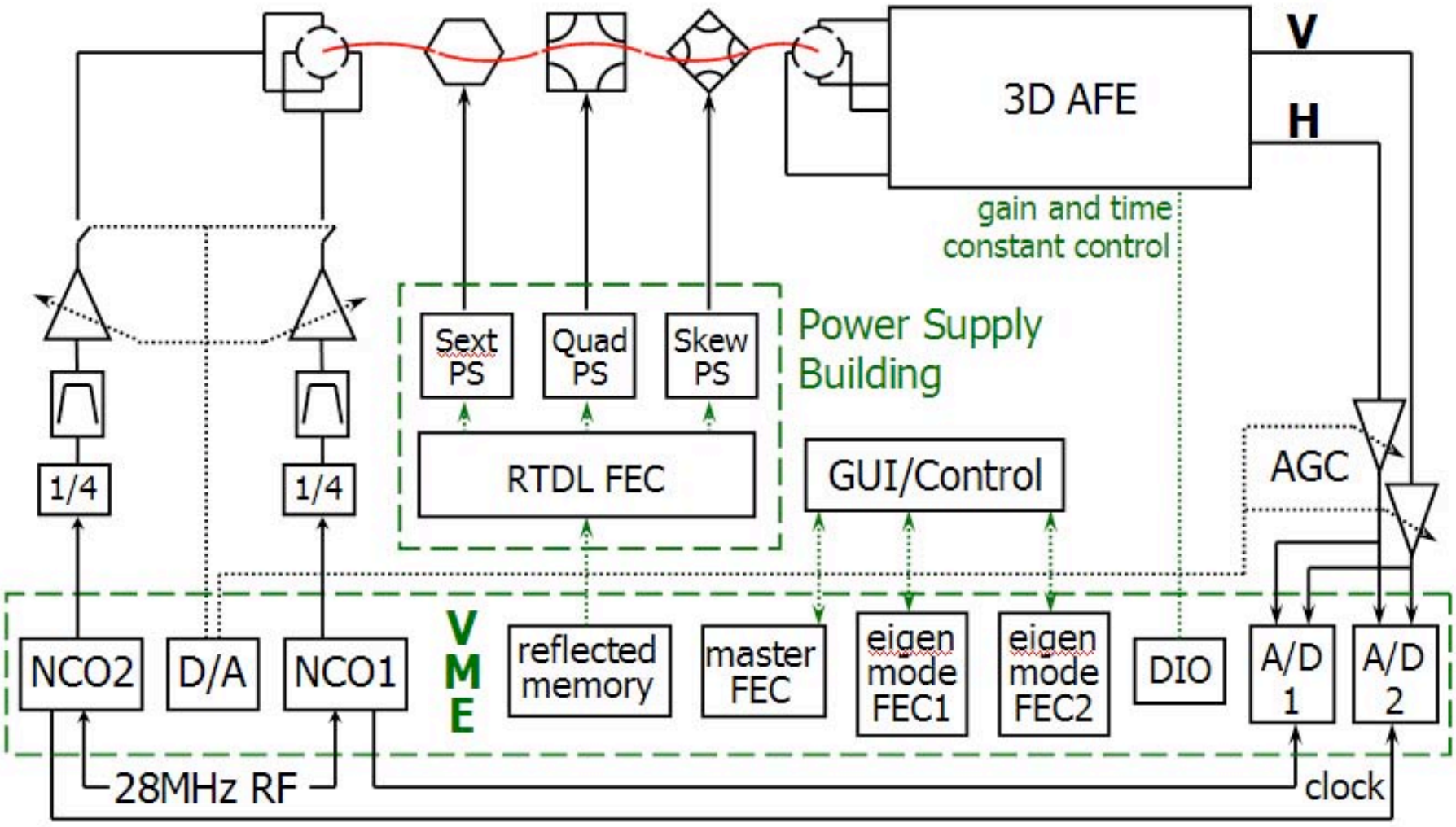




Tracking the vertical mode in the horizontal plane & vice-versa allows the coupling parameters to be calculated

C-A/AP/204 - Towards a Robust Phase Locked Loop Tune Feedback System, R. Jones et al
http://www.rhichome.bnl.gov/AP/ap_notes/cad_ap_index.html

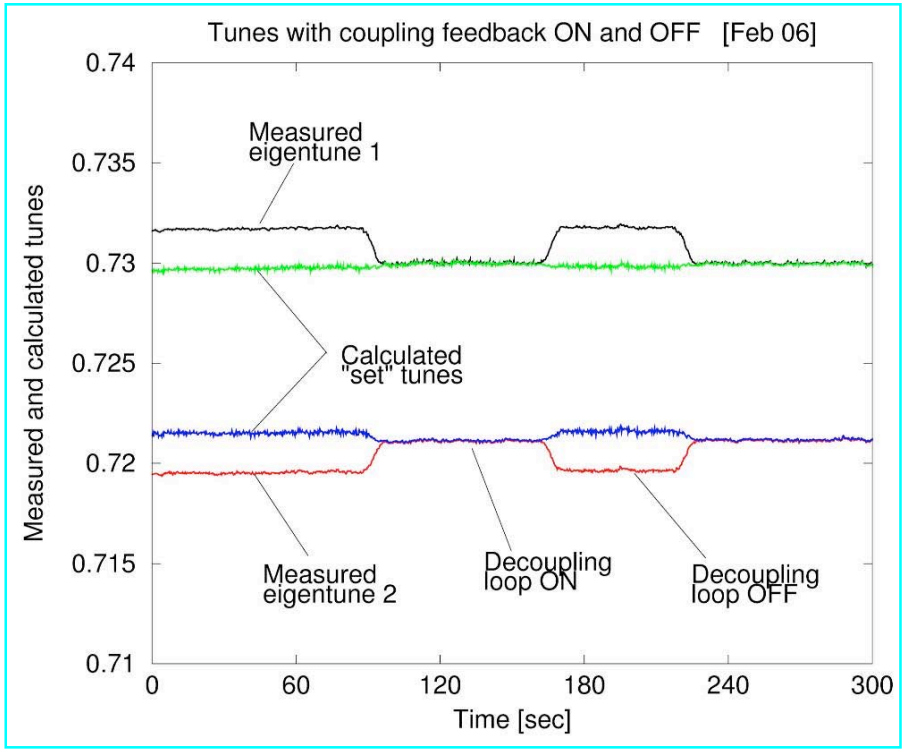
RHIC VME-based System Diagram



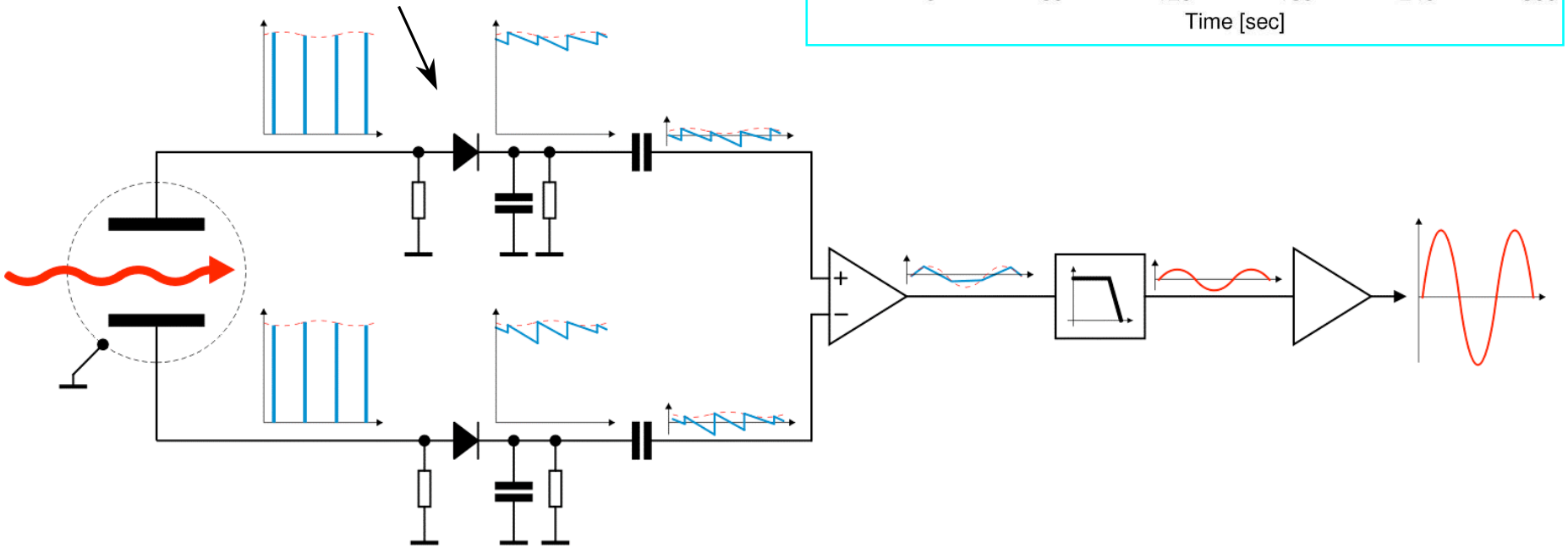
VME BBQ in RHIC - 2 improvements

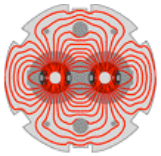
LARP

Continuous coupling measurement – made coupling feedback possible, which made tune feedback possible



Direct Diode Detection Analog Front End (3D AFE) – improved sensitivity **(~10nm!)** and dynamic range





LARP

Chromaticity Tracking and Feedback

Challenge:

- persistent current effects in SC magnets can strongly perturb machine lattice, especially during energy ramp (aka "snapback")
  - Betatron tunes ($Q_{x,y}$) and chromaticities ($Q'_{x,y}=EdQ_{x,y}/dE$) can vary significantly due to "snapback" resulting in beam loss, emittance growth.
- Effects for LHC predicted to be large.

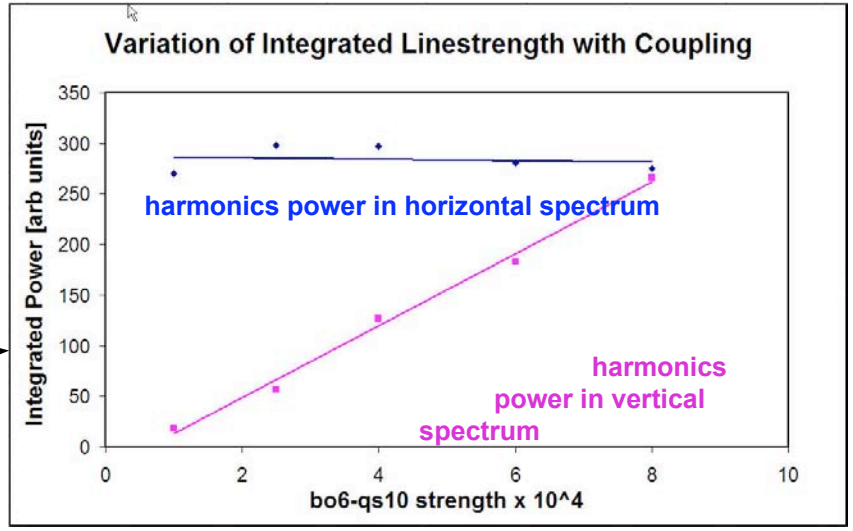
Solution: make fast, precision Q, Q' measurements and use these signals to feedback to tuning quadrupoles and sextupoles.

This effort is ideally suited for a collaboration with RHIC, which can be the benchmark and testing ground for this effort.

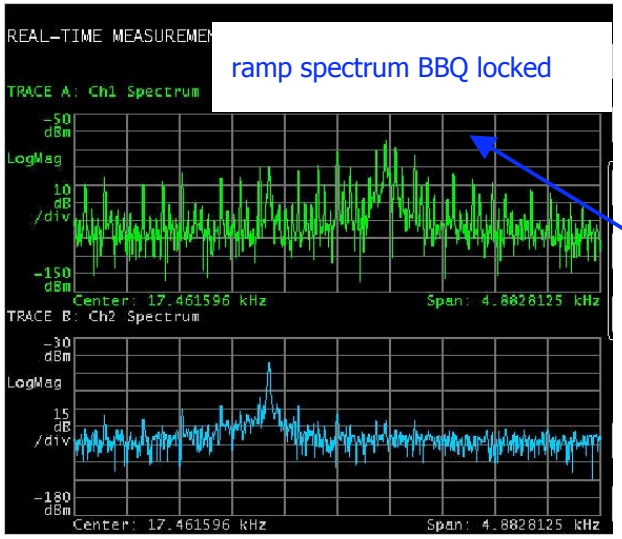
- slow (1Hz) radial (1mm) modulation – next slide
- faster phase modulation – under investigation

Mains Harmonics

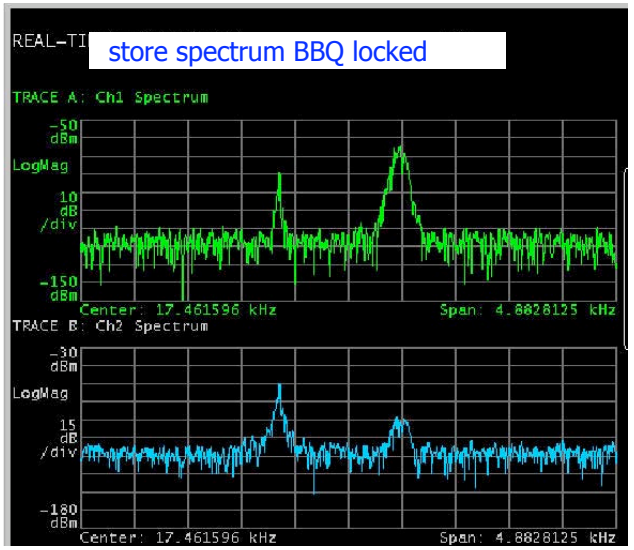
- Direct excitation of betatron line by high harmonics of power line frequency
- Recent measurements show it ~80dB above 3D noise floor
- Studies identified it as main dipoles
  - correlation with coupling
  - correlation with ramping
- Seen at all accelerators where 3D AFE has been installed
- ~50dB stronger at RHIC than elsewhere

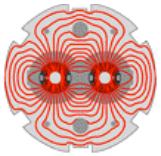


skew quad strength



Mains harmonics compete with tune peak





Chromaticity Tracking Experiments in FY08

RHIC run reduced in length due to funding limitations

Ongoing practical problems
- Beam Transfer Function measurements gave unexplained results
- Noise from mains harmonics adds complications

These problems may not apply to LHC

Started feedback development, but run ended before loop was closed

Preliminary data from CERN indicates LHC system could work

RHIC experience has shown that chroms too small or too large can break feedbacks, due to effect of weak instabilities on BBQ peak detector, and reduced S/N of the tune signal.

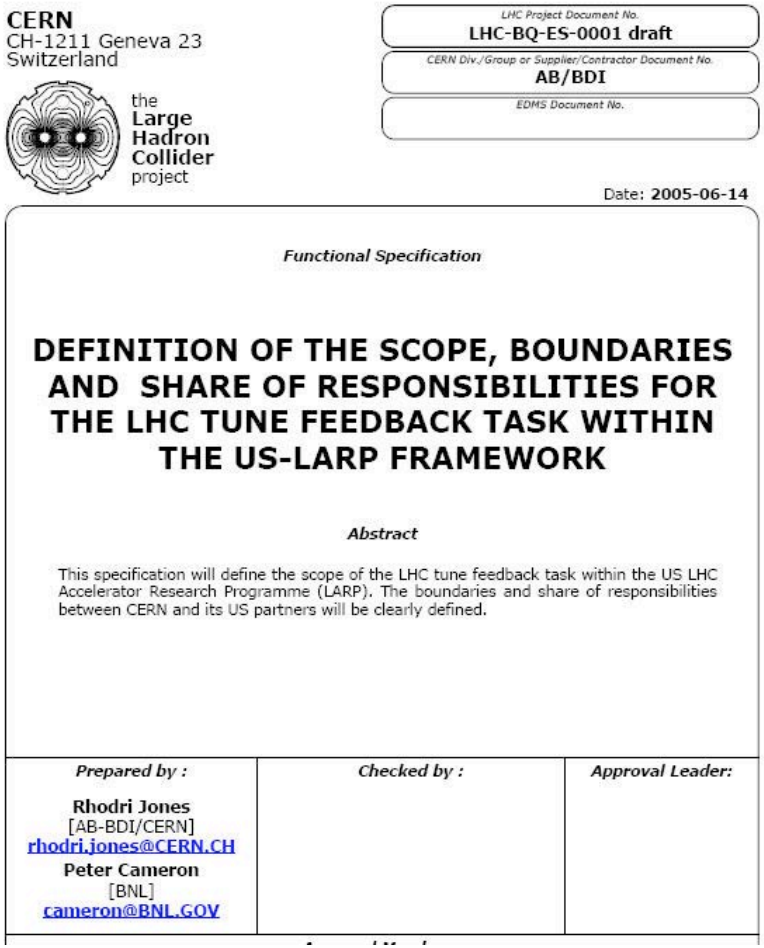
This has been seen with chrom ~2 (the nominal LHC chromaticity)

Scope, Boundaries, Responsibilities...

CERN provides all hardware for LHC
- kicker amplifiers, kickers, and pickups
- Direct Diode Detection AFEs
- Digitizer boards
- DAB64 Boards
- VME crates and crate computers
- non-PLL gate array code

LARP provides software
- PLL-specific gate array code
- LabVIEW control program
- testing at RHIC, with and without beam
- commissioning support at LHC

LARP deliverable complete



CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC Project Document No.
LHC-BQ-ES-0001 draft
CERN Div./Group or Supplier/Contractor Document No.
AB/BDI
EDMS Document No.

Date: 2005-06-14

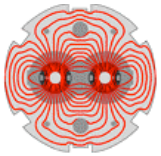
Functional Specification

DEFINITION OF THE SCOPE, BOUNDARIES AND SHARE OF RESPONSIBILITIES FOR THE LHC TUNE FEEDBACK TASK WITHIN THE US-LARP FRAMEWORK

Abstract

This specification will define the scope of the LHC tune feedback task within the US LHC Accelerator Research Programme (LARP). The boundaries and share of responsibilities between CERN and its US partners will be clearly defined.

Prepared by :	*Checked by :*	*Approval Leader:*
Rhodri Jones [AB-BDI/CERN] rhodri.jones@CERN.CH **Peter Cameron** [BNL] cameron@BNL.GOV		



Tune Feedback Planning

FY06

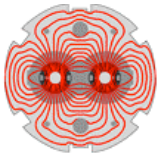
- System design and demonstration in RHIC

FY07

- Operation of DAB-based BBQ at SPS
- further evaluation of VME-based Baseband Tune (BBQ) in RHIC
- evaluation of DAB-based BBQ in RHIC
- July – finalization of LHC system

FY08

- LHC commissioning support
- Chromaticity feedback development



AC Dipole

Started in FY07, lead by S. Kopp (UT, Austin)

FNAL graduate student on board (soon to be Toohig fellow) with other support

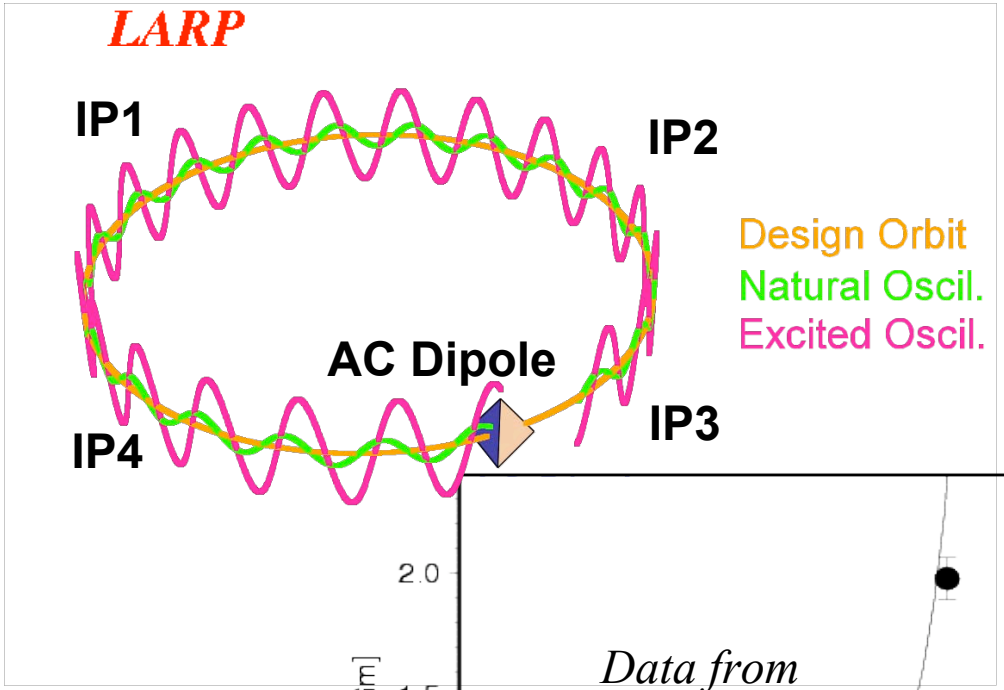
VERY active involvement from BNL, FNAL and CERN

All three labs are implementing or planning for AC dipole activities

All labs contributing resources to make it happen

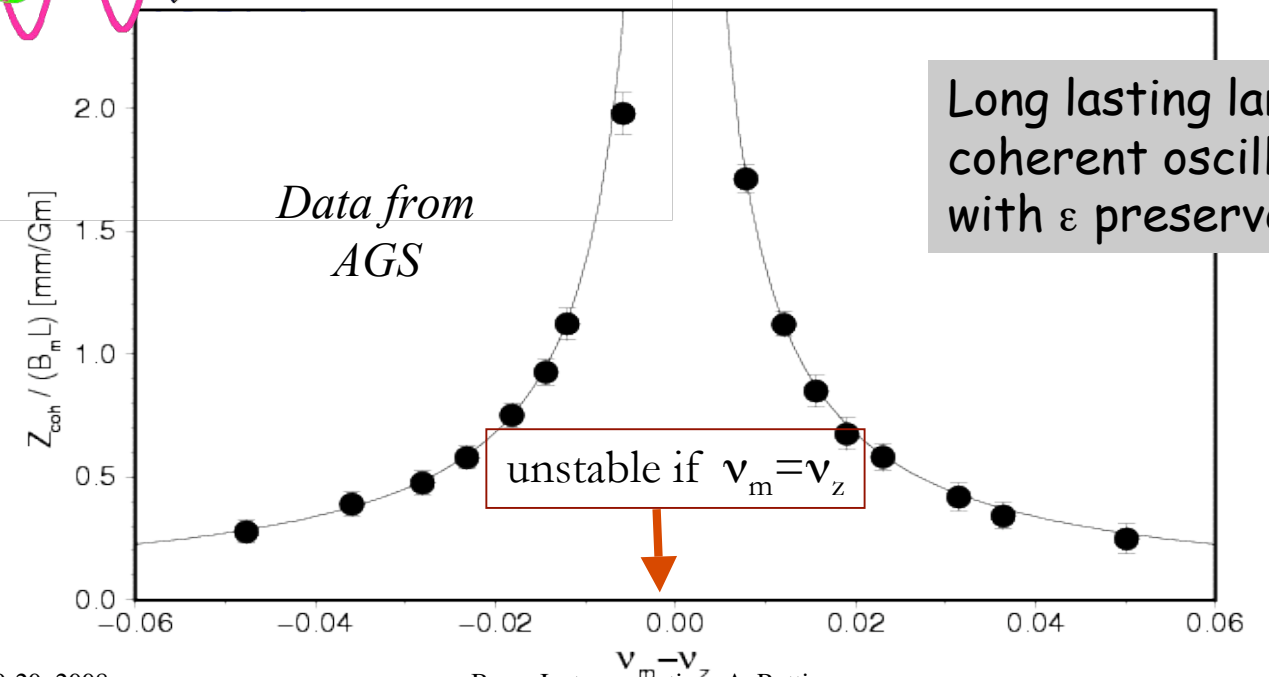
LARP committed to develop concepts on US colliders and provide system description for CERN to implement in LHC

What is an AC Dipole?



$$Z_{\mp}^{(m)}(s) = \frac{B_m L}{4\pi(B\rho)\delta_{\mp}}\sqrt{\beta_m \beta(s)}$$

$$\delta_{-} := \nu - \nu_m$$
$$\delta_{+} := (1-\nu) - \nu_m$$



Long lasting large coherent oscillation with ε preserved

What is an AC dipole for the LHC?

Most useful @ commissioning
- Measurements are FAST!

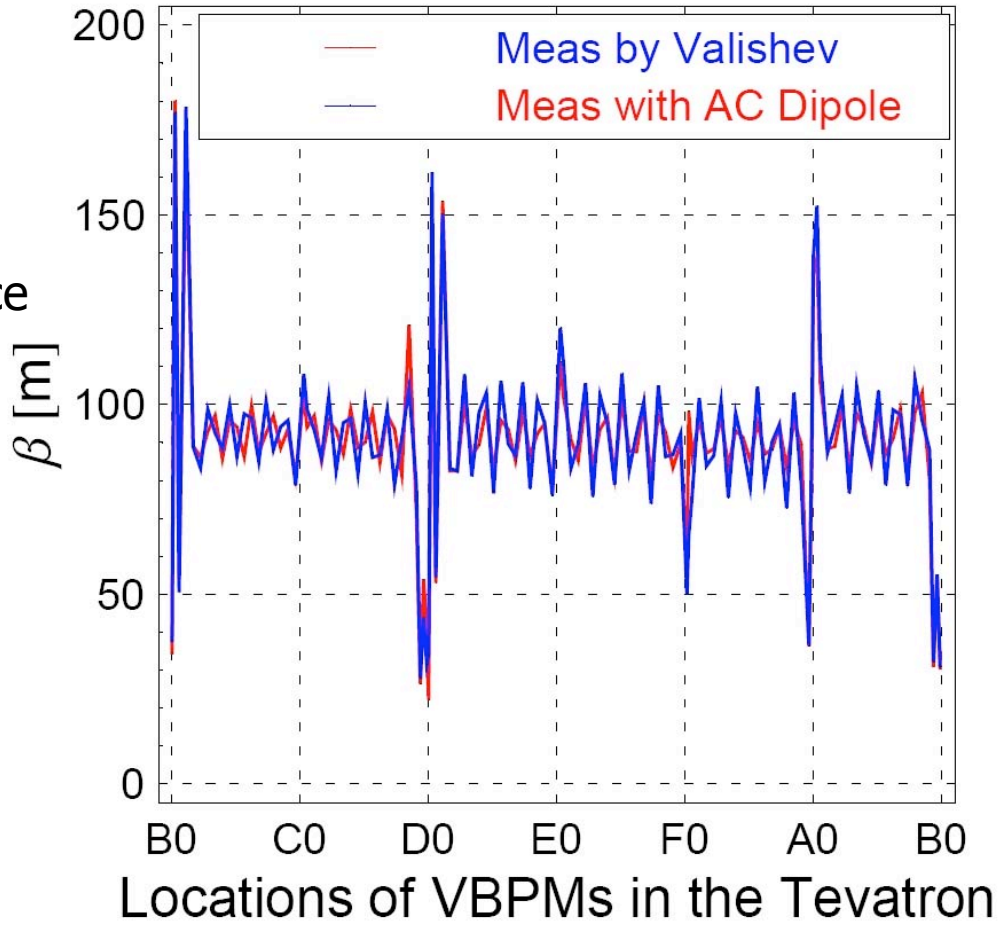
Linear optics measurement
- Measure β function and phase advance
- Measure β function at IP
- Linear coupling measurement

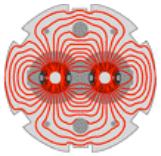
Local coupling measurement

Non-linear driving term measurement

Dynamic aperture measurement

FNAL TeV @ 150 GeV





Parameters of RHIC, TeV, and LHC

Machine	RHIC	Tevatron	LHC
E [GeV]	250	980	7000
f_{rev} [kHz]	78	48	11
γ, 1- γ	0.69, 0.31	0.58, 0.42	0.3, 0.7
f_d [kHz]	55	20.5	3, 8,…
δ	≥ 0.01	≥ 0.01	≥ 0.01
β_{arc} , β_d [m]	45, 11	80, 47	180, 260
σ [mm]	0.75	0.5	0.3
$\beta_d l$ [Gm] (4 σ)	140	140	165

AC Dipole at FNAL - "Musical Dipoles"

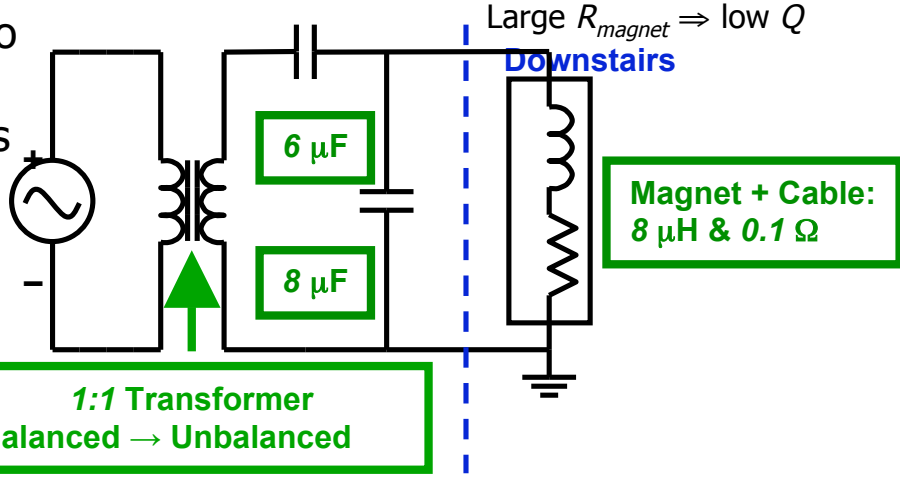
LARP

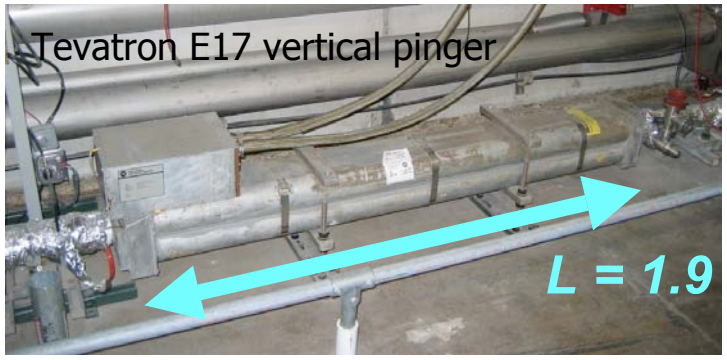
Successfully share the FNAL musical ac dipole technique with LHC ac dipole system
- transform a kicker to an ac dipole
- take advantage of commercially available audio power amplifier
- impedance matching between ac dipole and its power amplifier

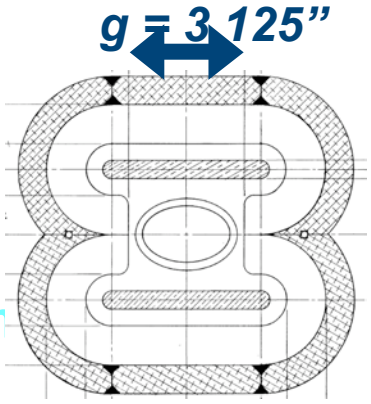
Measured linear optics using its musical ac dipole
- confirmed the effect of the secondary driving term on the measured optics

Parallel resonant circuit
- Match Z of the amp
- Maximize I in magnet

Use pinger magnet
- Iron core ⇒ good field
- Large R_{magnet} ⇒ low Q





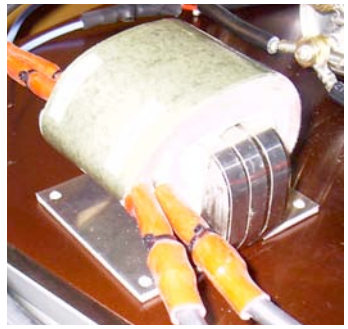


- Single turn
- Iron core
- 0.30 Gm/A

Status of the LHC AC Dipole

the FNAL solution of audio amps (Lab-Gruppen Class-H amp) driving pinger (MKQs)

Spec: 1800 A in MKQ for 7σ @ 7 TeV.



Two Lab.Gruppen FP13000 amps and 4:1 transformers

$1500A_{pk}$ magnet current achieved

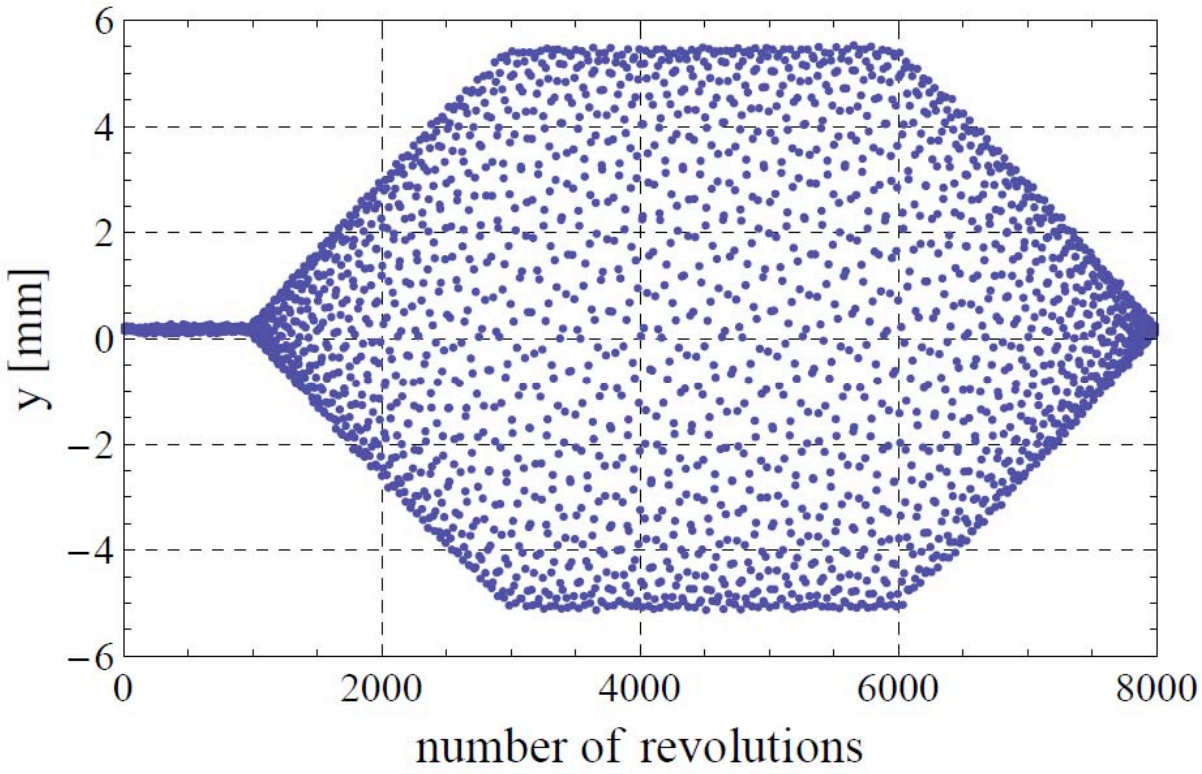
$2128A_{pk}$ should be possible at resonance with an adequate AC-supply

The 7σ ($1800A_{pk}$) goal seems in reach

Nonlinear Optics Measurements Test in the Tevatron

LARP

- At the injection energy (150 GeV), a (skew) sextupole and an octupole family are set to various values.
- Large amplitude oscillations are produced by a vertical AC dipole and the turn-by-turn data and its Fourier spectrum are observed.



- **TBT data of a BPM in the arc**
- **$\sigma \sim 1.3$ [mm]**
- **$\beta \sim 100$ [m]**

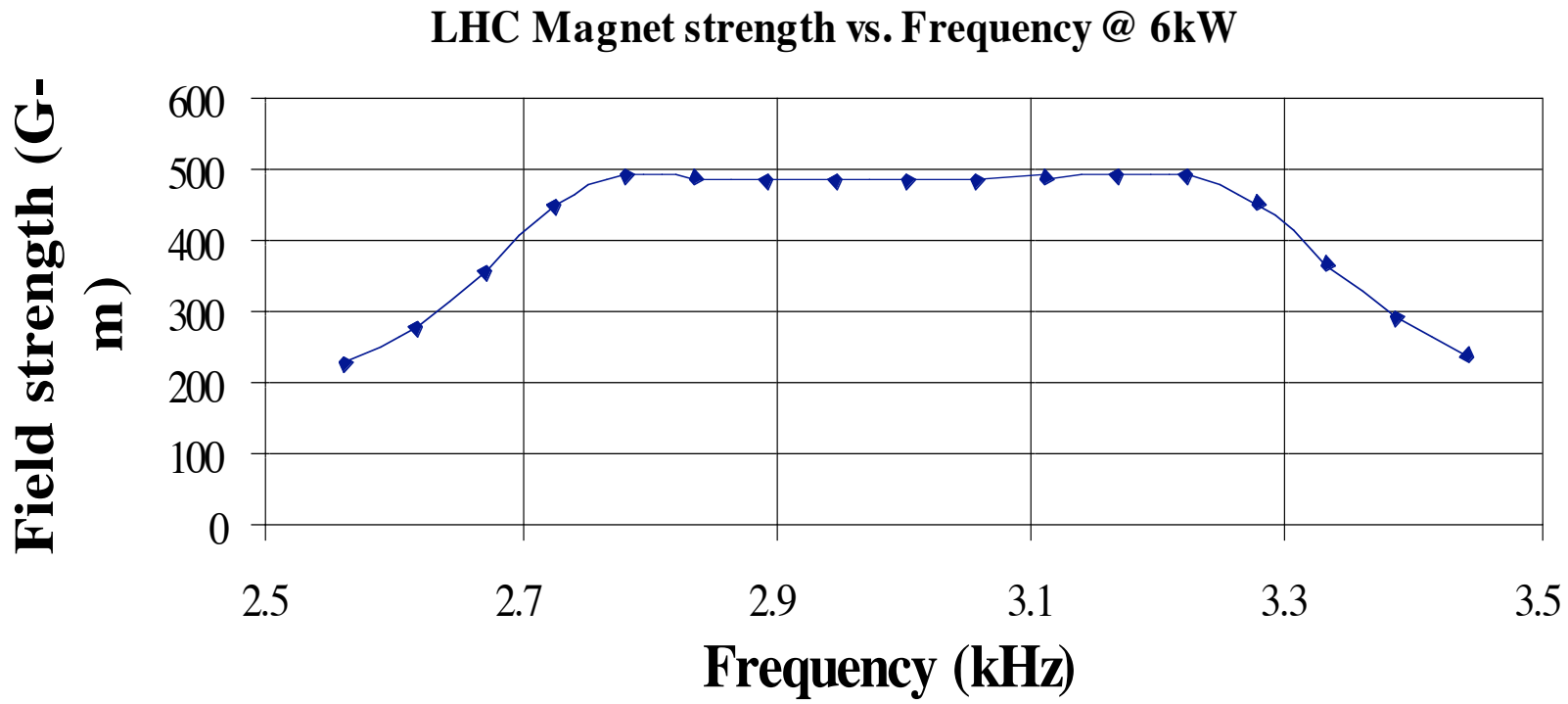
Dynamic Tuning Development at BNL

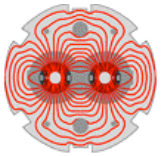
A dynamic tuning technique using single switched capacitor with MOSFT was proposed by P. Oddo at BNL

High Q circuit, more power efficient

Simulations shows a tuning range of $\Delta\nu$ +/- 0.01, should be achievable

A test setup using a half meter RHIC type ac dipole is under construction.





LUMI - Requirements

Requirements (Lumi mini Workshop, 16-17 Apr. 99)

- Absolute L measurement with $\delta L/L \sim 5\%$ for $L > 10^{30}$ $cm^{-2}sec^{-1}$
- Cross calibration with LHC experiment measurements of L (every few months)
- Sensitivity of L measurement to variations of IP position ($x^*, y^* < 1mm$) and crossing angle ($x^{*\prime}, y^{*\prime} < 10\mu rad$) less than 1%
- Dynamic range with "reasonable" acquisition times for 1% precision to cover $10^{28} cm^{-2}$ sec^{-1} to $10^{34} cm^{-2}$ sec^{-1}
- Capable of use to keep machine tuned within ~ 2% of optimum L
- Bandwidth 40 MHz to resolve the luminosity of individual bunches
- Backgrounds less than 10% of the L signal and correctable

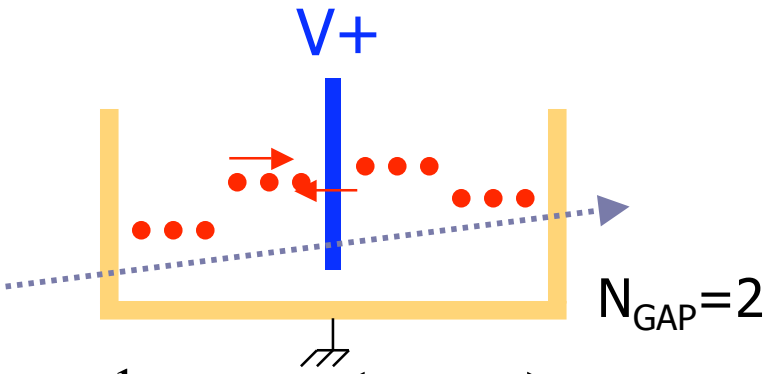
LBNL
25 Jan. 2002

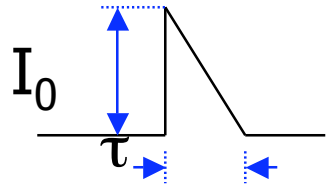
40 MHz Ionization Chamber
W.C. Turner

11

First, help bring beams into collisions

LUMI - Conceptual Design
Argon Ionization Chamber



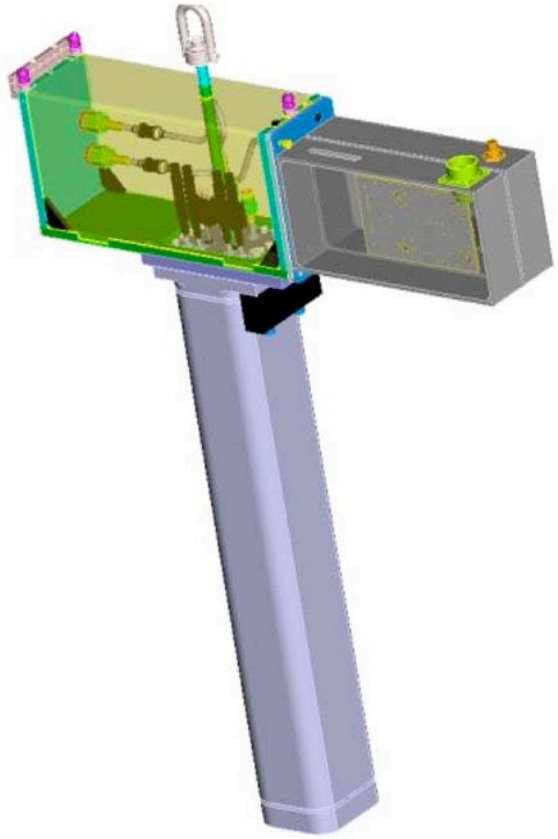


$$\tau = x_{GAP}/v_D \qquad Q = \int_0^{\tau} I(t)dt = \frac{1}{2} I_0 \tau$$

Signal is proportional to the number of parallel gaps
Capacitance add up with n. of gaps + slows down the signal

→Optimized for 6 gaps
→Must live in a radiation environment 100x worse than accelerator instruments have ever seen
→~10GGy/yr, ~10^{18} N/cm^2 over lifetime (20 yrs), ~10^{16} p/cm^2 over lifetime

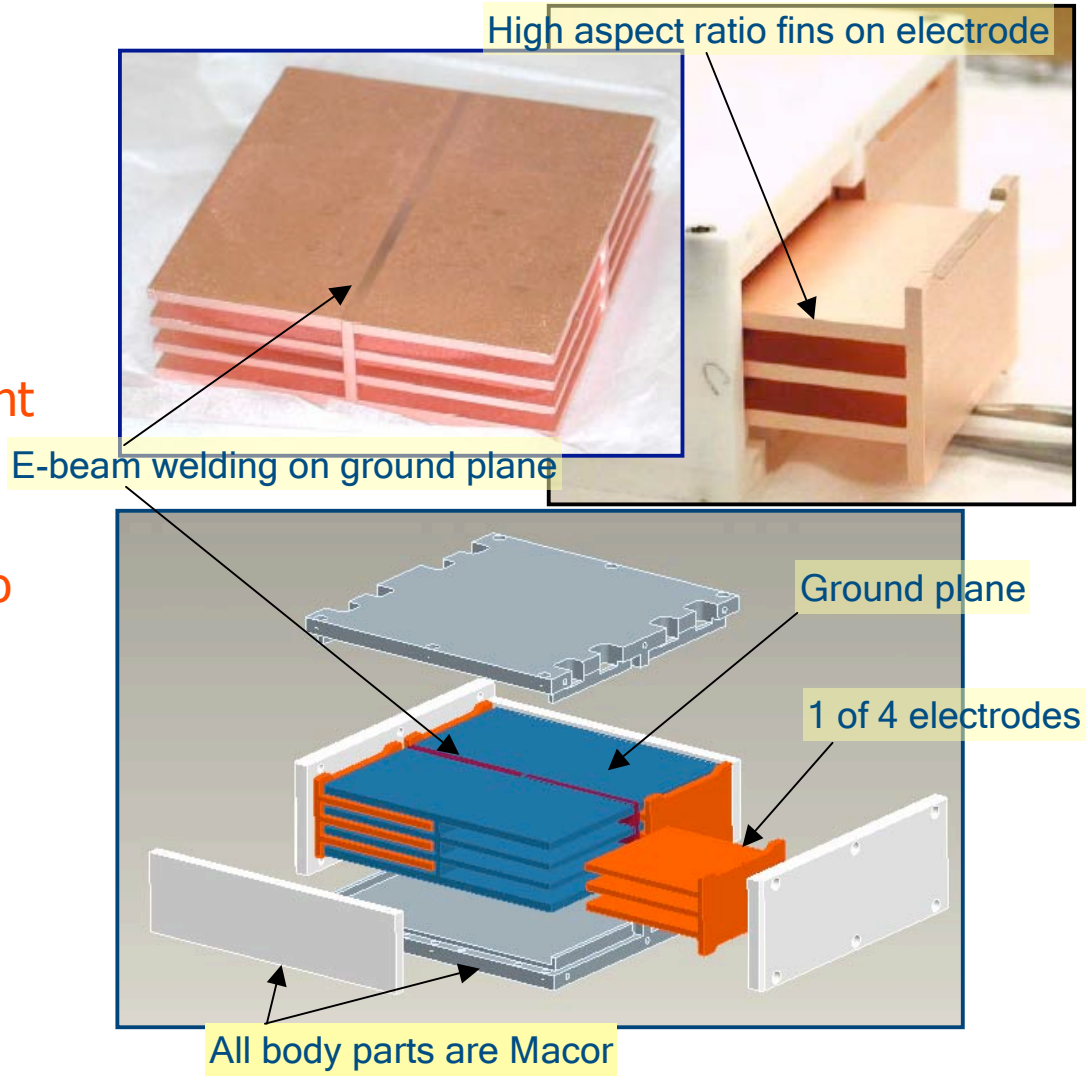
Mechanical Fabrication

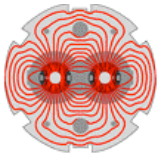


Ionization Chamber Fabrication

LARP

- Electrodes and ground plane
  - OFHC copper
  - Wire Electrical Discharge Machining (Wire-EDM)
  - High precision
  - Ground plane center element is e-beam welded
- Sensor body
  - Macor (Mycalex backup also available)
  - Several fine features with high precision
  - Fasteners for assembly
  - Over-constrained assembly requires some craftsmanship





HV Cable Problems

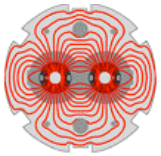
Original design implemented commercial rad-hard (SiO_2) cables
very long lead items (6-9 months)

When connected to very sensitive charge pre-amplifiers a small number of charges migrating across the gap results in pulses like those from the detector

In many cases high rates (> 100 Hz)
not acceptable

Unexpected, passed all project reviews

Resulted in the decision to design cables ad-hoc



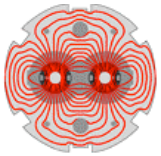
CERN Position

E. Bravin's letter of June 2

- CERN has decided to install PMTs and use them in 2008 run to monitor luminosity
- Software integration potentially delayed
- LUMI support will become secondary to other LHC instruments in 2008
- CERN counts on LUMI for the high luminosity run in 2009

LARP's response (SP, TM, AR)

- PMTs are welcome and an extremely helpful tool for commissioning LUMI
- LARP plans to have all detectors at CERN in July, install as LHC access permits
  - Some electronics will be completed later in the year
- Install at least one complete system to use with beam in 2008
- A full system will be tested with beam at SPS starting on June 30
  - Validate final design and operation of all components
  - Eric Prebys will attend the tests
- No doubt all systems will be ready in 2009
- Looking to allocate more funds to accelerate progress



New Cable Design

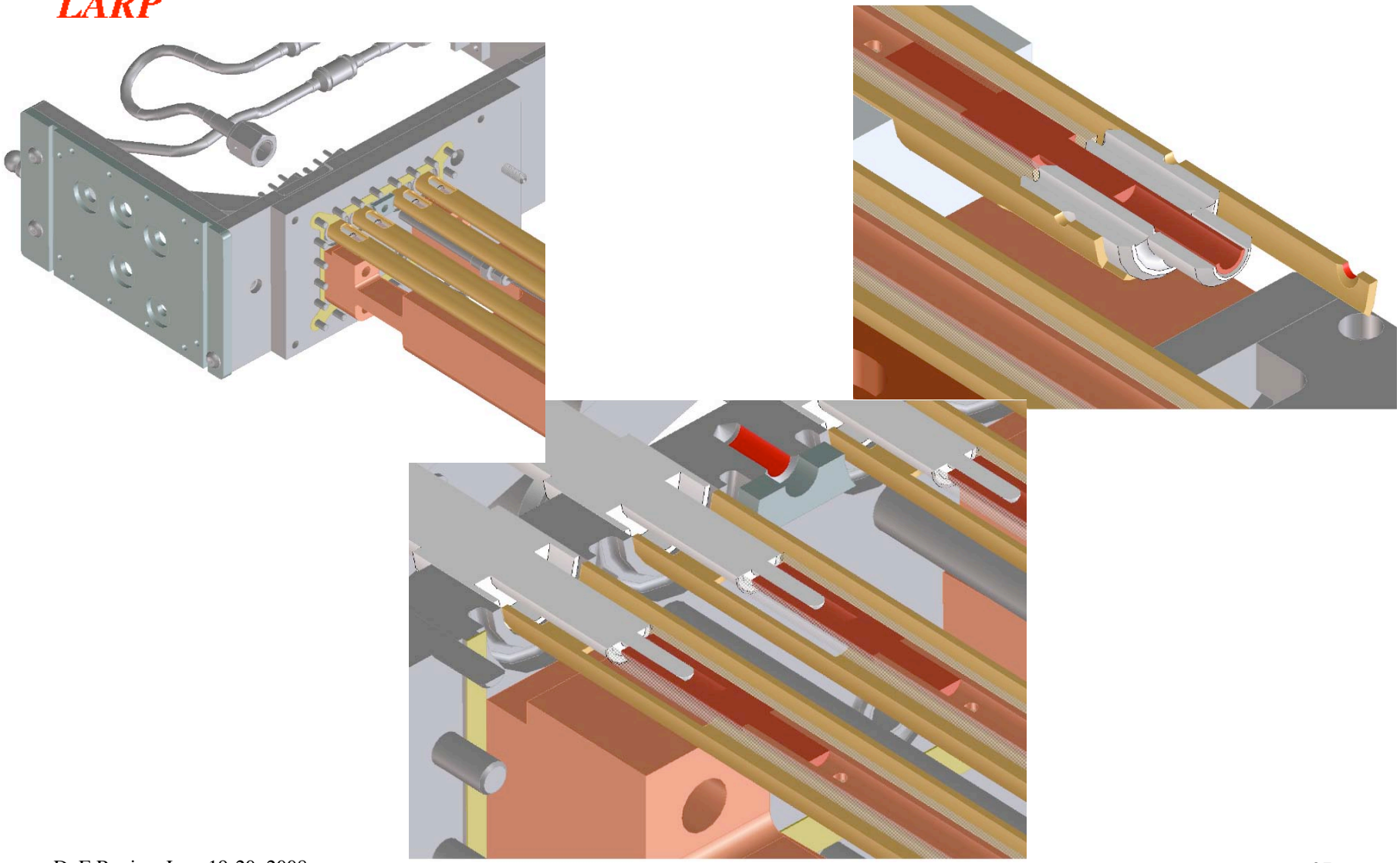
Strong boundary conditions:

- sustain GRad-doses of radiation
- 50 Ohms configuration
- no HV leaks
- no long lead items, or custom designed parts
- no gas volume to act as detector
- fit in existing space to prevent re-design/manufacturing of existing detector parts

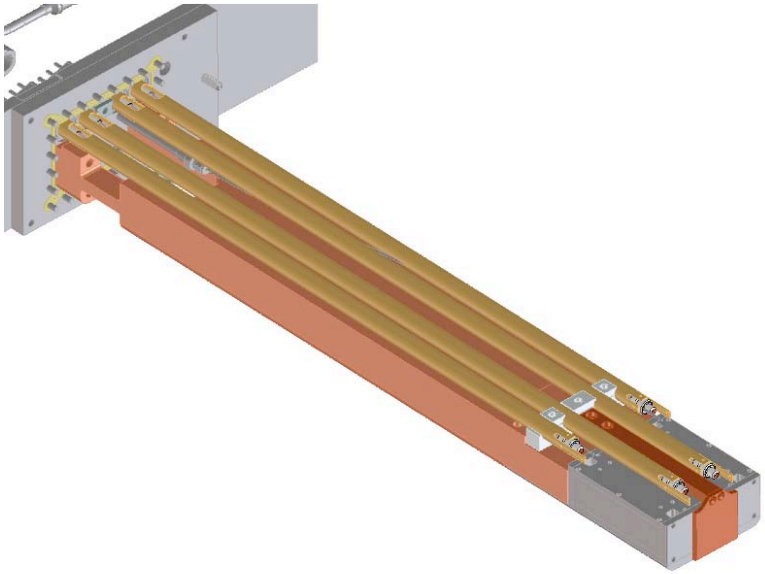
Engineered a solution using COTS

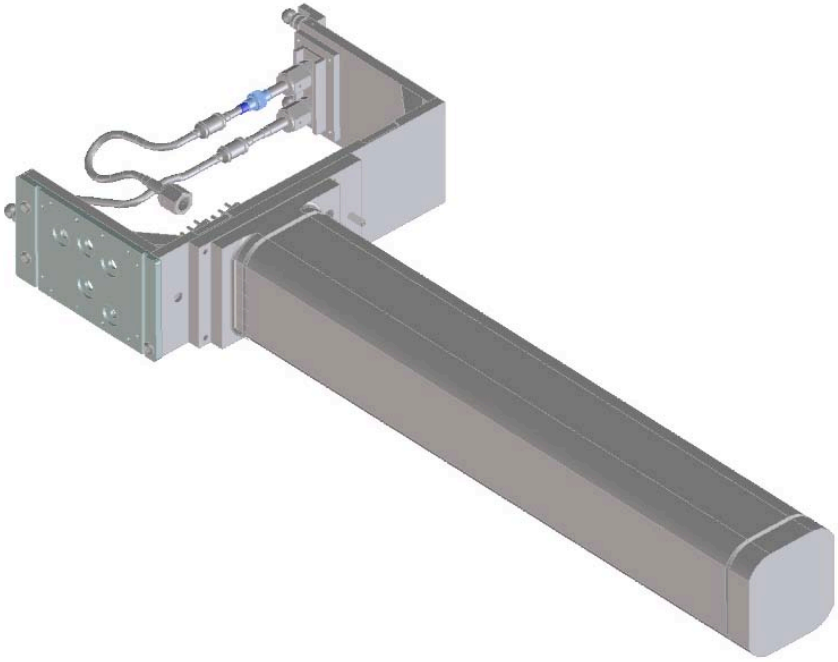
- 5 kV commercial feed-throughs
- glass and ceramic insulators
- standard copper tubes

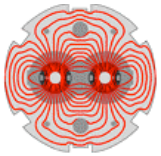
Detector Assembly with new cables



Detector Assembly







LARP

Readout System

Pre-amp board (in tunnel)

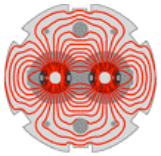
- Signal conditioning and amplification for ~300m cable

Shaper (in the counting room)

- Compensates for effects of detector capacitance as well as long cables
- Provides individual outputs as well as a sum of all quadrants
- Signals can be shared with experiments and are available in USA15 and USC55

VME-based DAQ (in the counting room) - hardware by CERN

- DAB-64X board
  - AB/BI framework for DAQ
  - Large Stratix FPGA for on-board signal processing
- IBMS mezzanine card
  - Single channel digitizer



LARP

Readout Systems Status

CERN's VME system, DAB and IBMS boards are ready

Pre-amps under final testing

- Delayed by lack of detector
- Measuring/reducing cross talk

Shapers built

- Need integration once pre-amps ready

Firmware and software programming underway

- First set ready for SPS beam test at the end of June
- Crossing angle calculations and deconvolution planned for 2009

Included in LAFS (thanks to FNAL)

- LAFS available to provide help in integrating the device in the LHC control system and to develop specific applications

LUMI System Fabrication Status

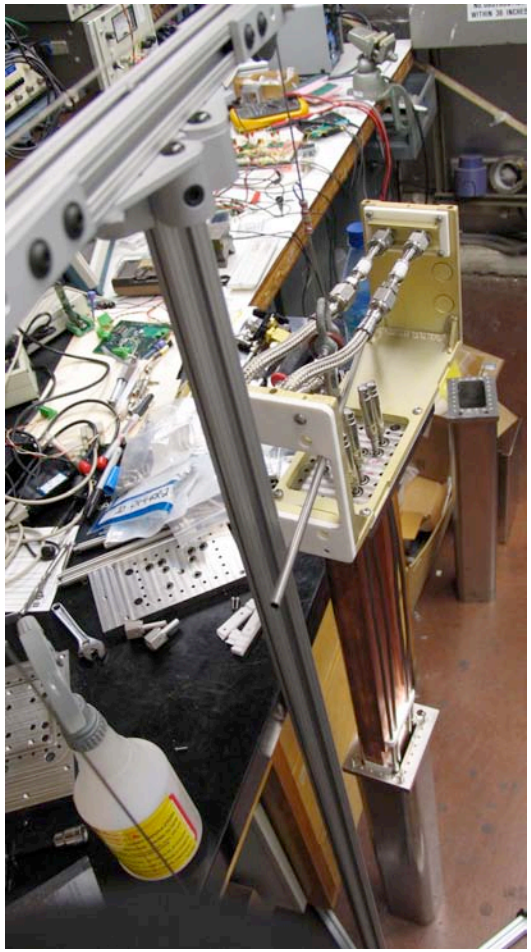
Recovering from cable problems

SPS beam test on June 30 - Jul 6 will validate final design of the cables

All detector components at CERN except for final flanges
- housings
- ionization chambers
- support bars

Will ship gas panels this month

Electronics production after successful beam test



Installation and Commissioning

LARP

Installation planned in collaboration with LHCf, Atlas and CMS ZDCs

- thanks to CERN's TS/LEA group

Extensive effort at CERN in integration activities

- Have office + lab at CERN
- A team account to support local expenses

Delays in production make it hard to predict access and final installation

- All auxiliary infrastructure can be installed and will be ready for beam
- CERN delivered its part (gas infrastructure, ac power, networking, cabling, plumbing)

LHC commissioning team starting to get involved

- Optimization of collisions
  - Helmut Burkhardt + PhD student (Simon White)

SLAC LTV (A. Fisher) available to participate to beam commissioning at CERN

Beam Testing at RHIC

Setup in IR10, former PHOBOS area

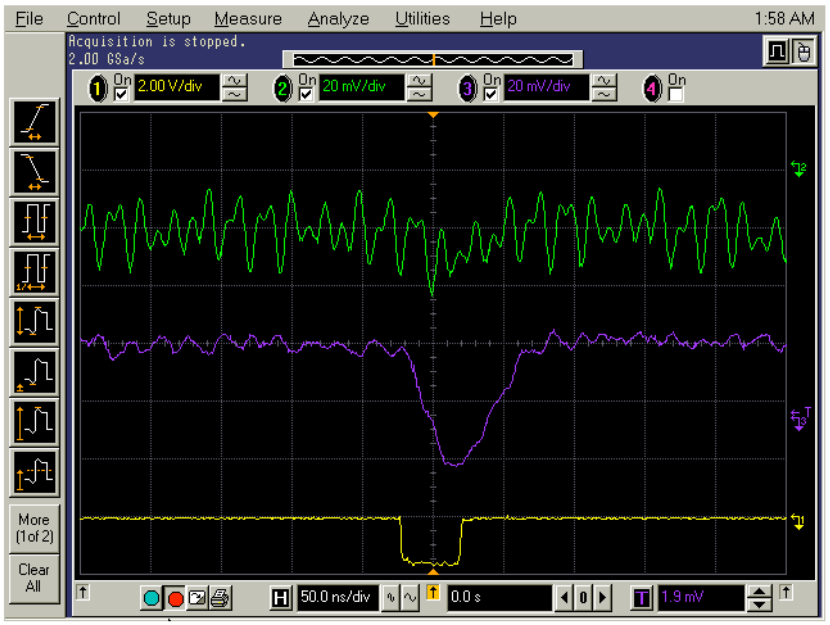
Ideal running condition is Au-Au

- Secondary neutrons > 1GeV

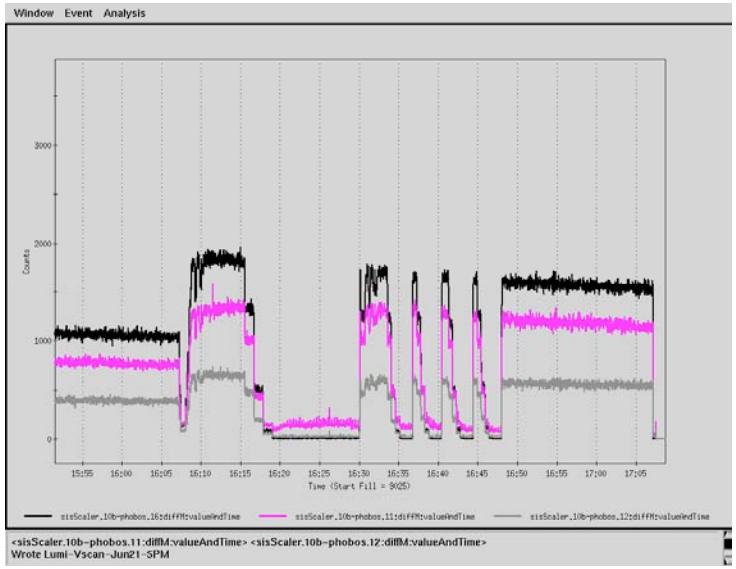
First Hadronic collisions seen by LUMI

Compared with RHIC ZDC

- Vernier scans



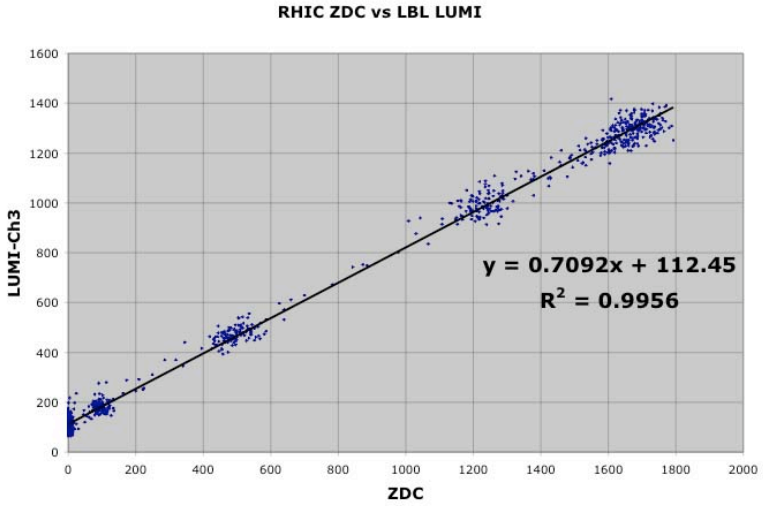
RHIC test results

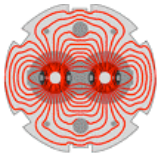


Vernier scan

- Black - RHIC ZDC
- Blue,Pink - LHC monitor

Scatter plot shows correlation better than 99.7%





LARP

LUMI Long Term Plans

FY07

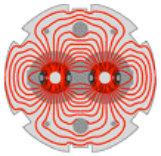
- Fabricate all units and deliver to CERN (in progress)
- Installation support
- Test in RHIC
- Finalize all electronics and auxiliary systems

FY08

- Fabricate balance of electronics
- Complete gas systems
- Hardware commissioning
- Beam commissioning support

FY09

- Post-commissioning and pre-operations support
- Advanced system programming for high luminosity operations
- Accelerator Physics
- END OF TASK

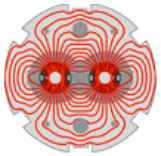


New Task - LHC LLRF Modeling

Lead by SLAC (J. Fox)

Apply extensive modeling experience developed and tested in PEP-II to
- understand the LHC RF controls
- identify optimal operating point
- determine weaknesses and derive solutions

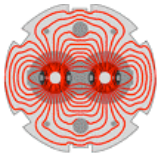
J. Fox and others from SLAC already involved in hardware commissioning and testing in 2008
- Effort supported with SLAC funds
- Travel by LARP



Spending to date

	Budget	Spent	Balance (as of 5.31.2008)
Tune Feedback	100*	71	44
Luminometer	870*	787	83
Schottky	15	8	7
AC Dipole	79*	17	62

Budget includes carryover from FY07 (TF $15; L $2; AC $19)
in $1,000s



Conclusions - Challenges

Funding

We are working with LARP management to continue securing adequate funding in support of the LHC commissioning schedule

LARP task sheets continue to define scope and budget year by year

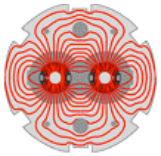
Funding requests are also managed through task sheets

Detail 'project' reviews validate overall cost and schedule for sizeable tasks

Integration with beam commissioning activities is essential to the survival of the instruments provided by the LARP collaboration and LARP is planning accordingly

Completed tasks are moving to LARP beam commissioning

LUMI delayed by unforeseen technical problems is recovering but could be late for 2008 beams



Summary

LARP Instrumentation has delivered and will commission into LHC operations advanced instrumentation and diagnostics for helping the machine

- reach design energy
- reach design luminosity

Strong collaborative efforts are in place and evolving

- Tune feedback is fully leveraging RHIC experience and includes CERN staff
- Lumi testing in RHIC is extremely valuable
- Schottky's experience at FNAL is a great asset
- US colliders are an essential test bed for system development

This program will advance the US HEP program by

- Enhancing US accelerator skills
- Developing advanced diagnostic techniques that will apply to present and future US programs
- Help maximize LHC performance