LARP BEAM INSTRUMENTATION

A. Ratti, LBNL
and many others

Fermilab
October 27-28, 2008
Outline

LARP

Progress update of existing instruments
   Schottky Monitor (lead by FNAL)
   Chromaticity Feedback (lead by BNL --> FNAL)
   Luminosity Monitor (lead by LBNL)
   AC Dipole (lead by UT --> BNL)

Most of these transition to Beam Commissioning in FY09
   Not all lumi monitors are now installed but plan to have all system installed well in advance of 2009 run

New tasks
   LHC RF Controls Modeling (lead by SLAC)

Integration at CERN
Introduction

First Four instruments are approaching completion at different stages
- Schottky monitors are delivered, installed and bench tested
- Luminosity monitors are in final production
  - will be ready for LHC’s 2009 run
- Tune and coupling feedback is evolving to chromaticity feedback
- LHC AC Dipole is mostly in the hands of CERN,
  - US scientists ready to participate and continue to develop “local” systems

Three tasks successfully completed in FY08
- Maintain a minimum level of funding to support LHC beam commissioning

One new task added for FY09
- LLRF modeling for the LHC
Schottky Monitors Status

Project complete
  Documentation delivered

One trip taken in June to complete hardware commissioning

Waiting for beam

Early circulating team likely have gave signals

CERN staff if monitoring the devices

LAFS integrating software interfaces
Schottky Hardware Commissioning at CERN

Tested:
The hardware control interface and cabling.
   all switches, amps, attenuators in situ.

The scope was installed, but it did not have a working interface at the time.
CERN combined the Labview software from Fermilab for controlling amps,
   switches, attenuators with Labview software written at CERN to control the
   DAB board and FFT.

As a final test of the system, we demonstrated remote control of most of the
   hardware from the meeting room (except MUX and front end phase shifter
   and attenuator).
Schottky Next Steps

Complete hardware for automation of measurements
  Part of CERN’s original responsibility
  Motor control drivers for the front end phase shifter and variable attenuator.
  Signal multiplexer for timing channels to the oscilloscope.

Develop automation software
  LAFS could help

LARP (FNAL) ready to take beam commissioning trip(s) in support of device operations
Chromaticity Tracking - History

Objective: Develop chromaticity tracking during ramp and store

Tune and Coupling Feedback
- Simultaneous Tune and Coupling feedback used in RHIC run 6
- RHIC run 7 and 8 - Tune and Coupling feedback operational
- Task ended in FY07

P. Cameron now working at NSLS-II
- Available to participate in short term visits

CY Tan (FNAL) now leads the activity
Chromaticity Tracking and Feedback

**LARP**

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
- faster phase modulation
LARP CM11 - Oct 08  
Beam Instrumentation- A. Ratti

Plans for FY09

1. Continuous head-tail  
Machine studies at the SPS during the first week of November where head-tail data will be collected

   Participate remotely using LHC@FNAL and will analyse the data.

2. Phase modulation method  
The method has been recently made operational in the Tevatron.  
A write up of the technique will be made to the collaborators very soon.

3. Travel to CERN  
   - tune tracker, chromaticity tracker commissioning  
   - machine studies for continuous head-tail.
AC Dipole

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Started in FY07 under by S. Kopp (UT, Austin)
FNAL graduate student -- now Toohig fellow
with support from FNAL scientists

VERY active involvement from BNL, FNAL and CERN

All three labs have 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
Status of AC dipole

All collider labs actively involved

- FNAL implemented a system (aka musical dipoles)
  - Tested non linear optics at Tevatrons injection
  - Part of Ryoichi’s PhD work
- BNL developing a high Q power system as a supply for these applications
- CERN has own group and has built a system
  - Benefit from LARP’s experience

Mei Bai new task leader
Ryoichi now a Toohig fellow at BNL

FY09:
- Plan to perform design studies at BNL for validation of measurement methods in preparation of LHC commissioning
- Participate in LHC commissioning
AC Dipole Task, FY08 Activity

- **Tev. Nonlinear Dynamics Study (FNAL)**
  Spectrum of TBT data tells distribution of nonlinear driving terms in a ring.

- **AC Dipole Tuning Scheme (BNL)**
  Capacitor bank allows ±15% (0.255 - 0.345 in tune, 2.867-3.880kHz) of tuning range.

- **Further Development of Tuning Scheme (BNL)**
  A dynamic tuning technique using single switched capacitor (simulation).

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**Measurement of Amplitude modulation due to detuning**

- 2νd
- 1−3νd
- 3νd
- 1−2νd

**AC Dipole Task, FY08 Activity**

**Spectrum of TBT data**

- BPM #52
- I_{sext} = 30 [A]
- V_{d}
- I_{ac dipole} = 70 [A]
- I_{ac dipole} = 280 [A]

**measurement of amplitude modulation due to detuning**

- LARP CM11 - Oct 08
- Beam Instrumentation - LARP
- (Details in PhD thesis of R. Miyamoto)
LARP CM11 - Oct 08

Beam Instrumentation - A. Ratti

AC Dipole Task, Plan in FY09

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Focusing on Commissioning

LHC AC dipole system to achieve the design goal of delivering 1800 Amps @ 3kHz
Control software

Development of Measurement Technique/Application

Linear optics measurement

A lot of data have been taken in RHIC and Tevatron
Help the development of LHC on-line optics measurement/gradient error correction application such as SVD and MIA

Dynamic aperture measurement
Non-linear resonance driving term measurement
New Task - LHC LLRF Modeling

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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
LHC LLRF Modeling

Scope of work:
• PEP-II and LHC LLRF systems are very similar
• LHC work fits into two related activities:
  – RF Station/Beam Dynamics Interaction Model
  – LLRF Commissioning and optimal configuration tools
    • Allows estimation of open-loop stability margins from closed-loop data. Model based station configuration allows station and beam dynamics to be optimally configured in operating stations with beam.
LHC LLRF Plans FY 2009

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Expand configuration tools for CERN use, including full LLRF controller (Direct and 1-Turn Feedback loops)
Participate in commissioning measurements
Validation of simulation
In depth beam/model verification
Study of imperfections, technology limits
Estimation of noise floors and impact on machine performance
Estimation of system limits
Longitudinal emittance analysis
Use simulation and commissioning experience to improve LLRF implementation.
Luminosity Monitor

Two separate activities:

1. Fabrication project --> deliver 4 detectors and all auxiliary equipment
   Install well in advance of 2009 run
   Well in advance = end of February 2009
   Task to end in FY09

2. Physics studies and beam commissioning
   Work will carry on into LHC operations
First beam at CERN

Taking beam on Sep. 10 at PT5R
Accomplishments in FY08

- Recorded first beam on day one
- Delivered four detectors to CERN
- Completed (simplified) gas systems
- Completed phase 1 firmware and software programming
- Systems integration underway
FY08 Highlights

HV cables performance
  Initial design had unexpected leaks
    Caused noise comparable to actual lumi signals
    Resulted in the complete redesign of the flange/HV cable assembly

Recovered from HV cable leaks
  Now working on integration of PA and Detector

As we were developing a solution for HV cables, we completed the detectors
  Two shipped and installed in LHC in Spring
    Adequate for low luminosity run in 2008
    Must be retrofit to match final design
  Balance (2 more) at CERN ready for installation
    New configuration completed in September
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
New Cable Design

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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
GAS Systems

Reduced scope to conserve money
   No active pressure/flow control
   Simple readout system

Delivered to CERN in June
Installed by CERN both at pt1 and pt5
Detector Assembly with new cables
Detector Assembly
Detector Assembly - 1

1. Install inner conductors, glass and ceramic insulators

2. Safety wiring holds ceramic stops
3. Mount copper support block to flange
   Gas feedline connected
4. Mount sensor assembly on copper support block
Detector Assembly - 3

5. Custom made connections to each quadrant

Adjusted for HV performance
Detector Assembly - 4

Install on housing
TiN seal
Pre-Amplifier Assembly
Pre-Amplifier Production

**PA Assembly process**

- PA board loaded by vendor
- Load HV board
- Mate HV board to PA board
- Fab and mount shield board
- Connect HV relays board and compartment
- Wire 28 pin Burndy connector
  - 4x2 DC bias supplies, 3x3 RTD signals, 4+2 Relay selector bias, 5 BJT damage

All parts at LBL (need shield boards)

Several cleaning steps and slow soldering of ground shields to maintain HV performance

6-8 days per unit
Electronics - Shapers
Shapers - Plans

Package in separate chassis
  Control noise and interference
  Does not require VME installation
  Needs independent power supply

Bench test and integrate with Pre-Amps
Need 2 per IP, 4 total
  Will assemble one spare
DAQ System Layout

Control room

Other luminosity monitor results

PC-LabVIEW
1. Read omega server
2. Read HV and counter?
3. Read DAQ boards
4. Set omega server
5. Set usb-vme
6. Soft spark warning
7. Interlock
8. Luminosity display
9. Result comparison

Ethernet

PC-LabVIEW ..........

Omega I server
Pressure RTD1 RTD2 Flow control

USB-VME
HV board Counter? DAB Board X7X2?
DAQ programming
DAQ interface panel
Test during SPS beam test

First test in the SPS
  Good agreement with NIM scalers
  Some adjustment required
Learned we need an even/odd gain and offset adjustment
IBMS boards have two digitizers each
Detector-PA Integration

Detector - Pre-Amp studies
  Understand interdependencies
  Optimize configuration

Test pulse - with and without load (detector)
Pre-Amp Shaper Integration

Pre-Amp Shaper studies

- Optimize => minimize peaking time
- Package shaper in shielded box
- Study interaction with PA
- Study/measure effect of long cable
Detector Testing @ ALS

Since LHC beam returns in 2009 we plan to test the (spare) detector @ ALS BTS line in November-December

Validate new cable configuration on ALS beam

Test cable performance with high intensity signals

Infrastructure available from previous test
  2 axis table, gas lines, signal lines

Important to coordinate with analog electronics integration
  Only one spare available
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

CERN (Enrico’s group) increasingly involved

LHC commissioning team starting to get involved
   Optimization of collisions

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

CERN has been involved with many aspects of systems
  Increased presence since 2007
    Contributions to detector rework and optimization
    Gas systems installation and commissioning
Inviting CERN to participate to Berkeley activities (visit in Nov.-Dec.)
  Beam test at ALS --> detector operation
  Bench test of DAQ phase I firmware
  Analog electronics modules production and testing
    pre-amp and shaper
Plan to continue during installation an HW commissioning at CERN
Continue CERN’s involvement in firmware development during phase II programming
Luminosity Monitor Commissioning Plans

Commissioning will continue with each change in LHC operating conditions
   Since LHC won’t reach nominal luminosity, must continue commissioning
     BRAN in FY10

Plan dependent on luminosity and fill pattern

Need simulations at each LHC energy

Need presence of personnel at CERN

Will take effort to make BRAN part of LHC beam instrumentation
# Stages to Maximum LHC Luminosity

**CERN EDMS 347396**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Bunches</th>
<th>Bunch Spacing</th>
<th>Luminosity [cm(^{-2}) s(^{-1})]</th>
<th>Interactions/Xsing</th>
<th>Mean pulse height/occupied bunch Xsing - mV</th>
</tr>
</thead>
<tbody>
<tr>
<td>A–Collision studies with single pilot bunch beam - no crossing angle</td>
<td>1</td>
<td>N/A</td>
<td>(2.5 \cdot 10^{26} \text{ - } 3.7 \cdot 10^{27})</td>
<td>0.0006-0.092</td>
<td>0.04-0.53</td>
</tr>
<tr>
<td>B–Collision studies with single higher intensity bunch - no crossing angle</td>
<td>1</td>
<td>N/A</td>
<td>(1.1 \cdot 10^{29} \text{ - } 4.3 \cdot 10^{30})</td>
<td>0.27-10.71</td>
<td>16-611</td>
</tr>
<tr>
<td>C–Early p-p luminosity</td>
<td>43</td>
<td>2.025 µs</td>
<td>(4.8 \cdot 10^{30} \text{ - } 8.4 \cdot 10^{31})</td>
<td>0.28-4.86</td>
<td>15-277</td>
</tr>
<tr>
<td></td>
<td>2808</td>
<td>25 ns</td>
<td>(6.5 \cdot 10^{32})</td>
<td>0.58</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>936</td>
<td>75 ns</td>
<td>(1.8 \cdot 10^{33})</td>
<td>4.79</td>
<td>273</td>
</tr>
<tr>
<td>D–Nominal p-p luminosity</td>
<td>2808</td>
<td>25 ns</td>
<td>(1.0 \cdot 10^{34})</td>
<td>8.87</td>
<td>506</td>
</tr>
<tr>
<td>E–Ultimate p-p luminosity</td>
<td>2808</td>
<td>25 ns</td>
<td>(2.3 \cdot 10^{34})</td>
<td>20.39</td>
<td>1163</td>
</tr>
</tbody>
</table>

Pressure = 8 atm - (57 mV for each 7 TeV collision)
BRAN Instrument Commissioning Plan

A–Collision studies with single pilot bunch beam - no crossing angle
- Collision rate too low to use as a luminosity monitor
- Minimize noise
- Get baseline software and hardware ready
- Study beam background (beam-gas, neutron ...)

B–Collision studies with single higher intensity bunch - no crossing angle
- Start in pulse counting mode
- Transition to pulse height mode
- Plan for crossing angle algorithms
- Need sustained presence at CERN

C–Early p-p luminosity
- Develop deconvolution algorithms
- May need deconvolution for this phase
- Study crossing angle algorithms
- Still in counting mode for most of this period
- Develop pulse height mode algorithms

D–Nominal p-p luminosity
- Pulse height mode
- Deconvolution
- Detector needs to fully commissioned with gas flow

E–Ultimate p-p luminosity
- Might need to lower pressure to reduce signal strength
Mode A + B-Circulating Beam

Measure noise rates and compare to expected

Measure interactions

  beam halo with beam pipe

  beam gas

  collimator

Synchronize DAQ

Measure for occupied and unoccupied bunches

  pulse height

  pulse shape

Compare to simulations
Mode C – Collisions

Synchronize DAQ and LHC clock
Measure counting rates as a function of measured voltage
Determine threshold for pulse counting
Verify bunch pattern
Compare luminosity measurement with other detectors
Analyze beam background
Develop and test deconvolution algorithms
Compare to simulations
Mode D – Nominal luminosity

Transition to pulse height counting mode
  Compare to counting mode
  Cross correlate with other luminosity detectors
  Compare with simulation and expected fill pattern

Study crossing angle calculation
  Test and calibrate with LHC beam
Lumi FY09 Beam Commissioning Plans

Commission detector with beam

Cross correlate with PMT luminosity system

Integrate DAQ into LHC control system

Compare with models
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, CERN involvement increasing
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