LHC Accelerator Research Program
Beam Instrumentation and Diagnostics

DOE Lehman Review

10-11 June, 2003

John Byrd

LARP Beam Instrumentation and Diagnostic Techniques

LARP will help the LHC in 3 key areas:

- *Bring LHC to full energy*

  Betatron tune, coupling, and chromaticity control during ramp

- *Bring LHC to design luminosity*

  Real-time luminosity monitor

- *LHC machine protection*

  Longitudinal density monitors

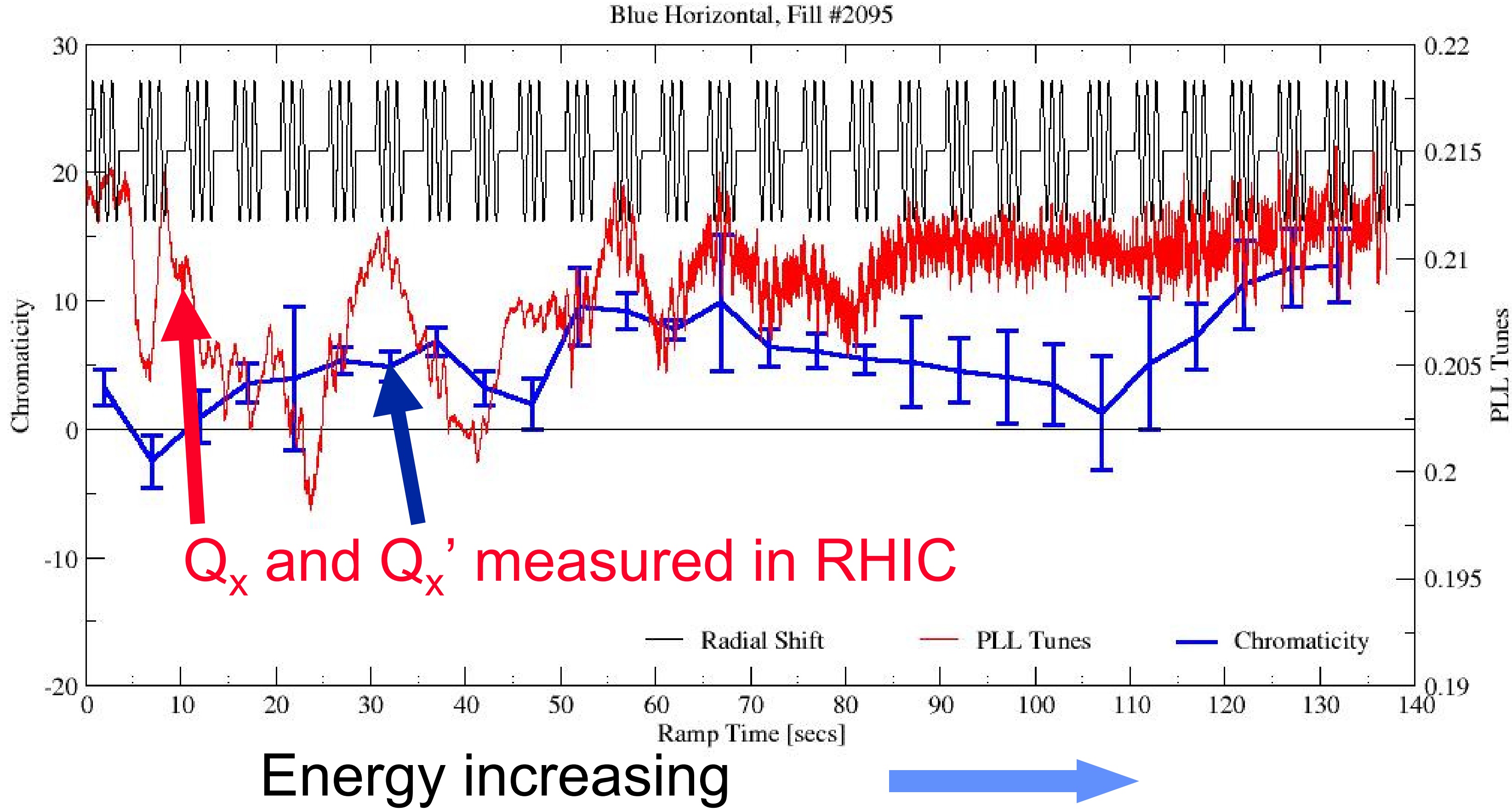
These contributions advance the state-of-the-art in beam instrumentation and have direct contributions to present and future US accelerator projects.

Also planning for R&D on additional instrumentation

Tune Control

- Challenge: persistent current effects in SC magnets can strongly perturb machine lattice, especially during energy ramp (aka "snapback"). Effects for LHC predicted to be large.
  - 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.
- Solution: make fast, precision Q, Q' measurements and use these signals to feedback to tuning quadrupoles and sextupoles.

Effects of persistent currents in RHIC



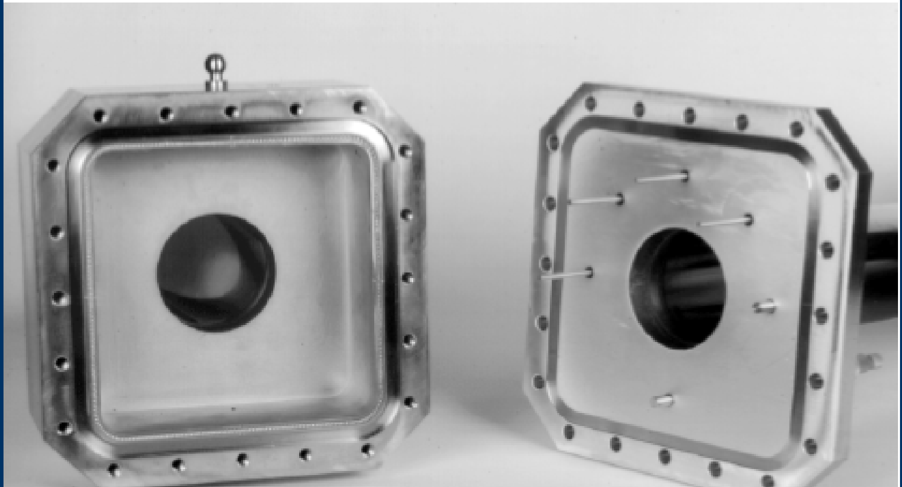
Tune and Chromaticity Measurement

Tunes

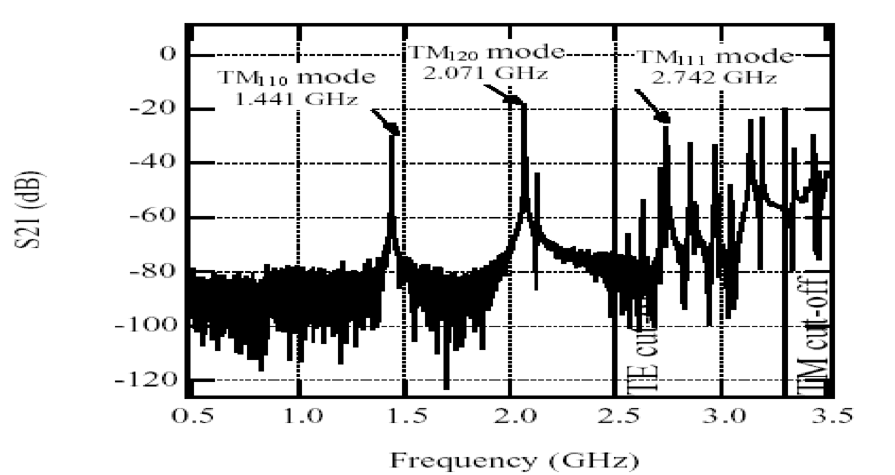
- EM Pickups
  - resonant cavity
  - high bandwidth Schottky array
- Optical position monitor
  - use edge radiation at low energy

Chromaticities

- Slightly vary energy and measure tunes
  - DC phase modulation
  - fast phase modulation
- Direct measurement along bunch length



RHIC Schottky cavities and response



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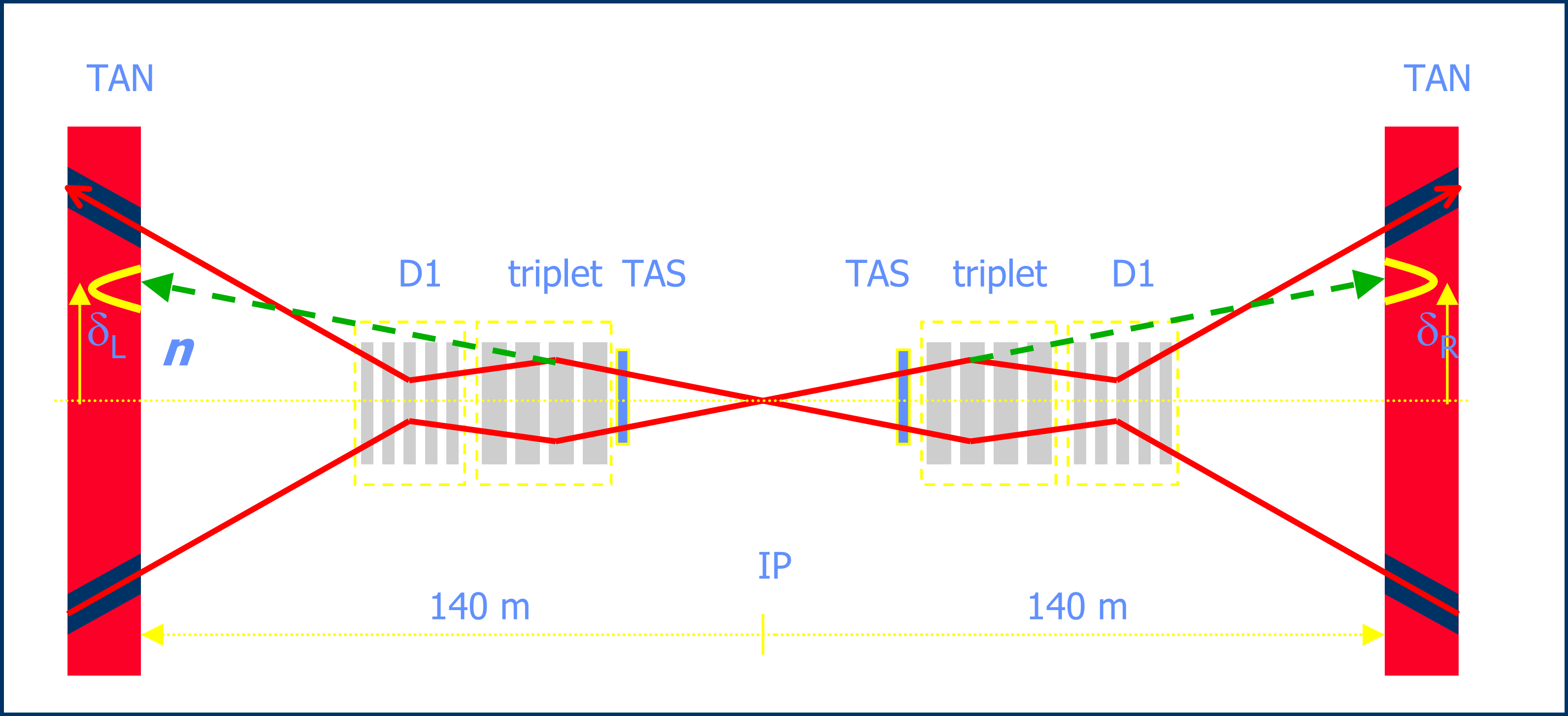
Tune Control Status

- Serious work just getting started…
- RHIC/CERN collaboration established
- Workshop held at Fermilab in May 03
- Discussions on choice of tune pickup in progress
- Coordinate LARP efforts with ongoing work at RHIC and Tevatron.

High Bandwidth Luminosity Monitor

Instrument US-built TAN absorbers to measure and optimize the luminosity of colliding bunch pairs with 40 MHz resolution



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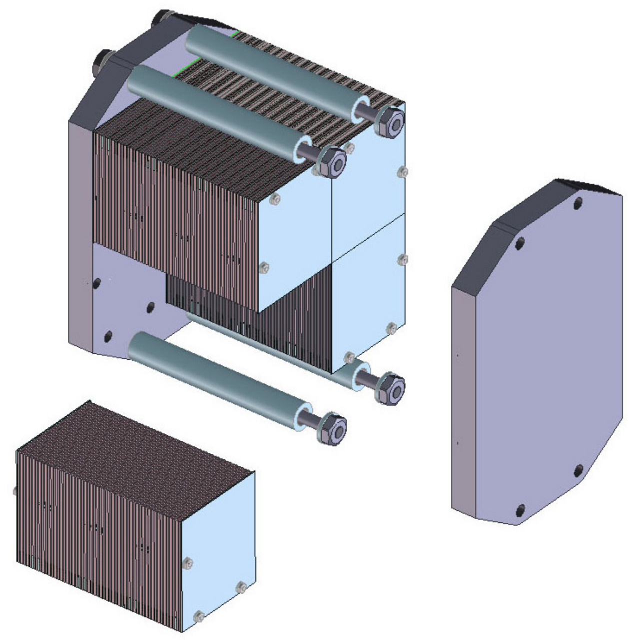
LHC Luminosity Measurement

The challenge:

- 1% absolute precision and <0.5% relative precision as a feedback signal for luminosity optimization
- Long term stability (~1 month) for calibration with detectors
- High radiation environment (100 MGy/year)
- Bunch-by-bunch capability (25 nsec separation)

The solution:

- Segmented, multi-gap, pressurized ArN_2 gas ionization chamber constructed of rad hard materials
- CERN group is developing CdTe technology in parallel.



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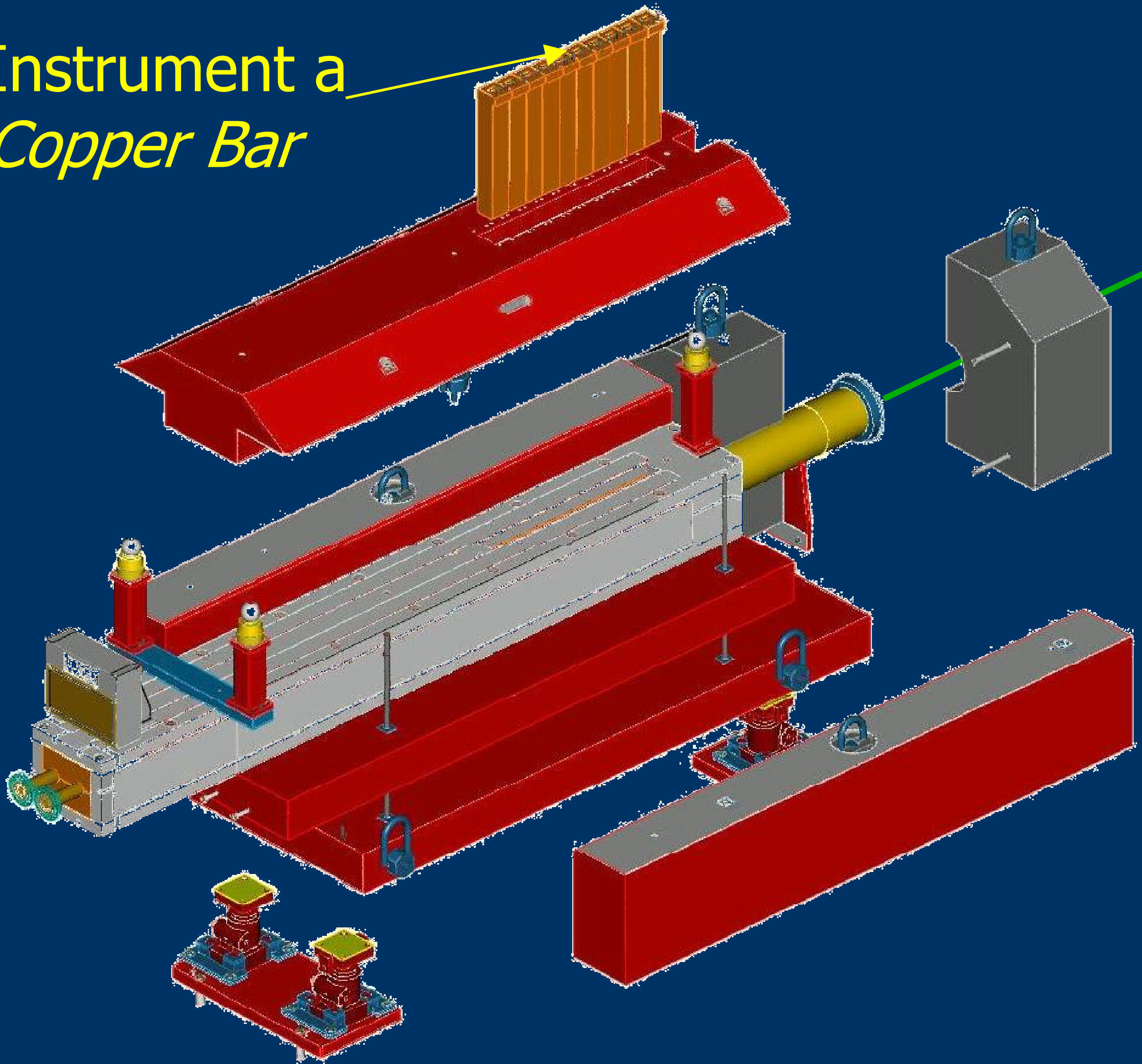
Luminometer details

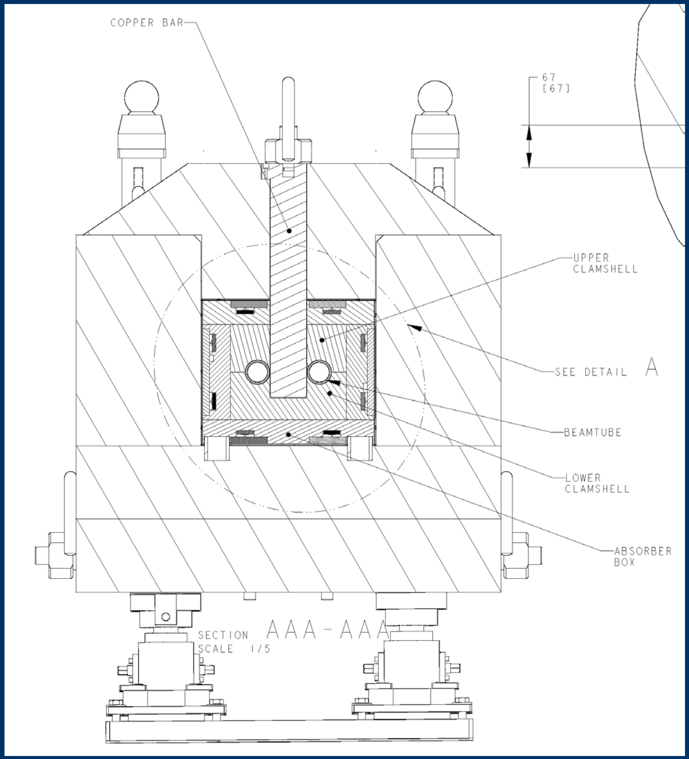
- Segmented, multi-gap, pressurized gas ionization chamber constructed of rad hard materials
- 3-11 atmospheres Ar + 2%N_2 gas mixture, e^- drift velocity 3.2 cm/μs
- Low noise bi-polar transistor pre-amplifier "cold" cable termination, $ENC_\delta \sim 1{,}824\ e^-$
- Pulse shaper, $\tau = 2.5$ ns
- 3 m radiation hard cable between ionization chamber and front end electronics, radiation dose to electronics < 100 Gy/oper yr
- S/N ~ 5 for single pp interaction

Instrumented TAN absorber

US LARP

Instrument a *Copper Bar*

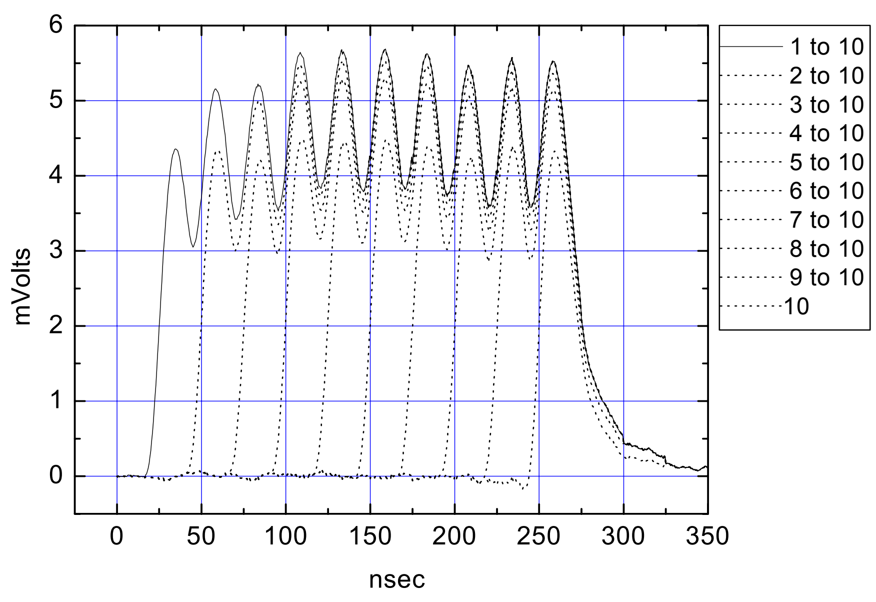




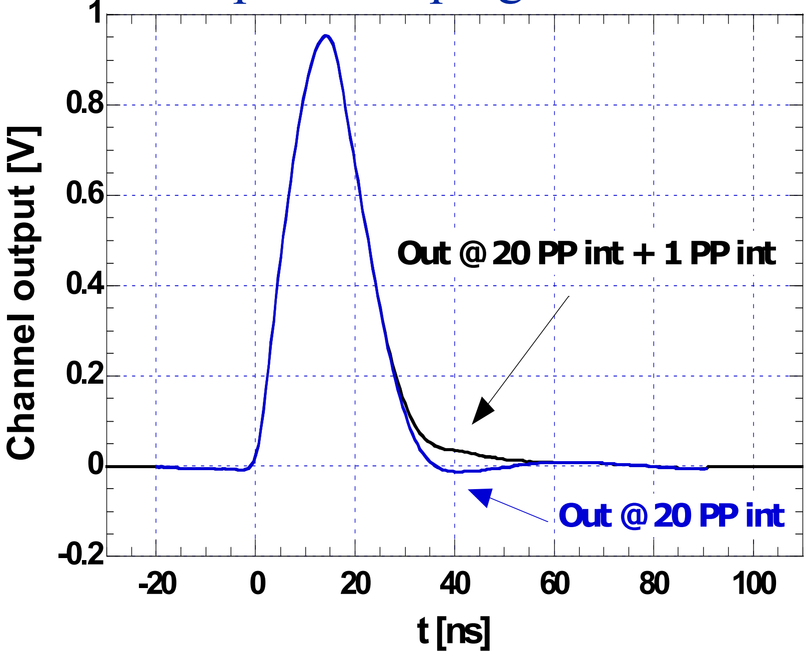
Bunch-to-bunch Luminosity Measurement

- Peaking time is less than the 25 ns bunch spacing
- Pulse train obtained by superposition of single pulses

Beam test at SPS- Sept. 01

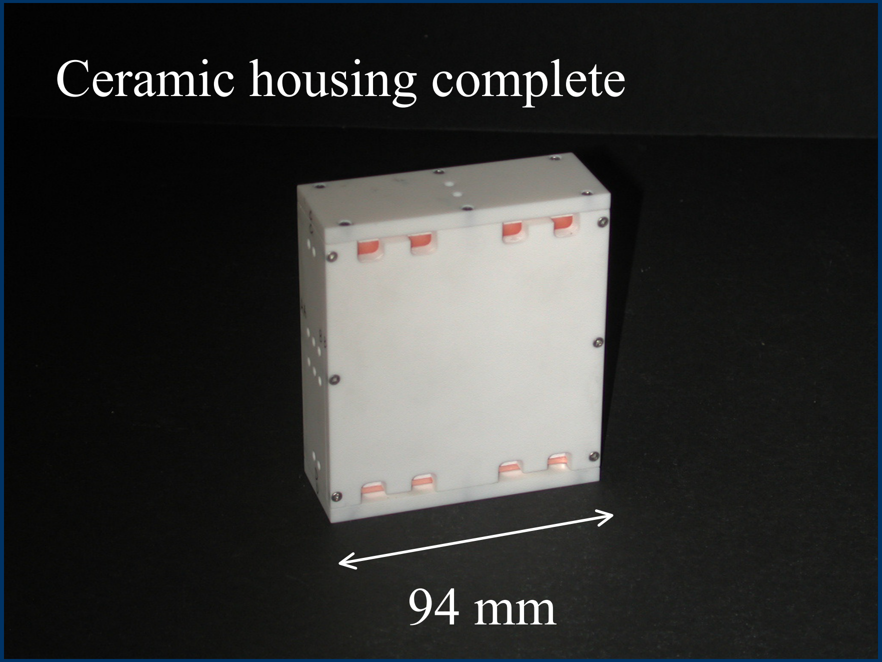


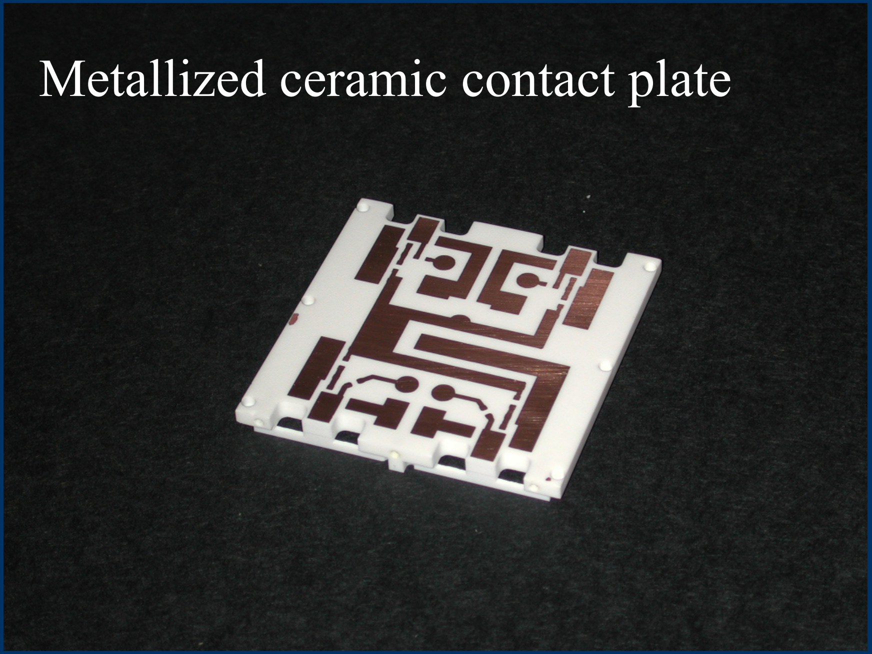
Faster pulse shaping electronics



LUMI Status

- Second prototype under construction
- Beam tests planned at ALS and Fermilab Booster ($Ar\text{-}N_2$ and CdTe). Tests of time response and radiation hardness.





LHC Longitudinal Charge Density

LHC beam carries 350 MJ. Beam loss in magnets can cause severe damage.

- Machine protection issues for study include:
  - Debunched beam at injection
  - Population in abort gap
  - Ghost bunches
  - Bunch core and tails
- Requirements:
  - 10^4 dynamic range
  - 20 samples/bunch giving $\pm 2\sigma$ (1120 psec). Corresponds to 50 psec sampling resolution.
  - Do this for all buckets (h=35640!). Drives overall sampling rate.

The LDM will also be an invaluable tool for beam dynamics studies in LHC.

LHC Longitudinal Charge Density Specs

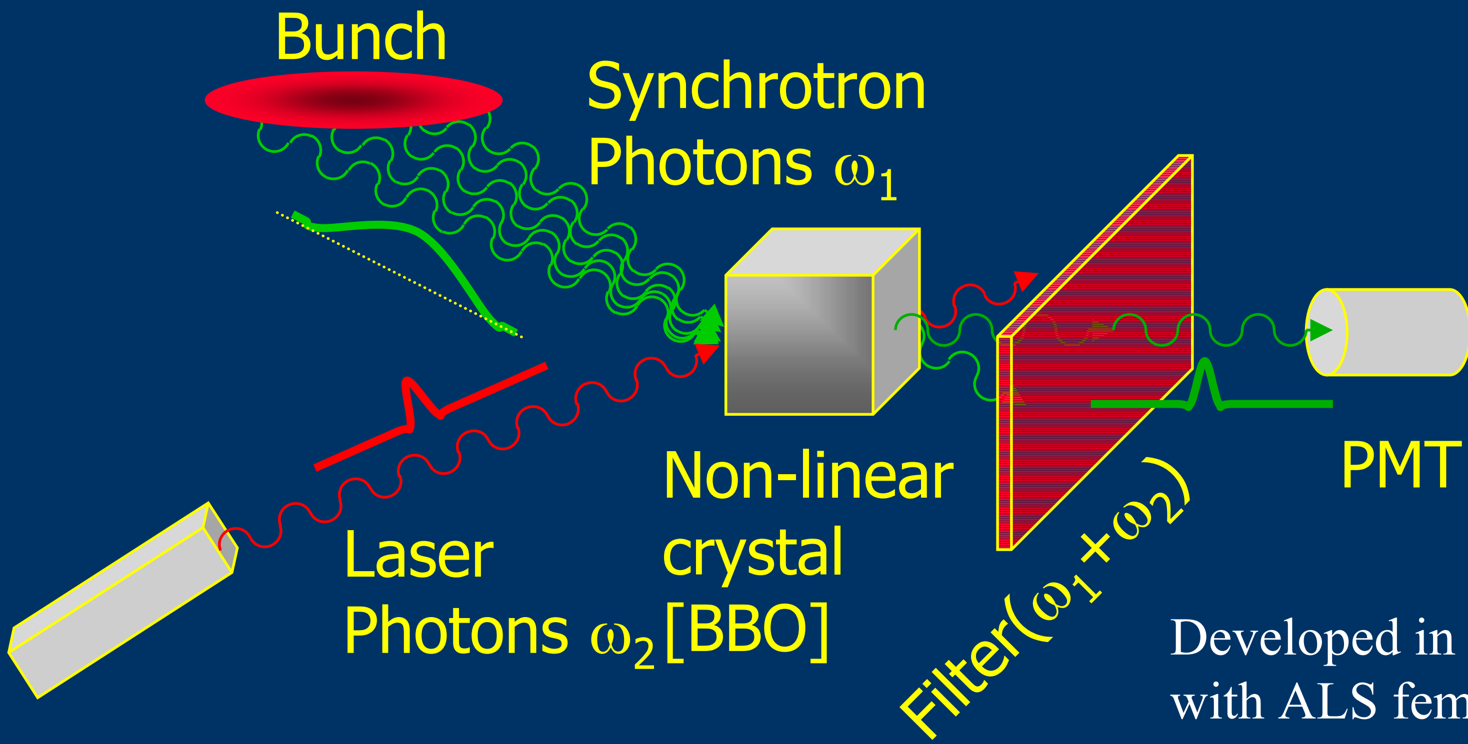
Function	Beam energy TeV	Nominal peak density*, p/ps	Resolution, p/ps	Integration time
Debunched beam	0.45	$1.0\text{x}10^{8}$	$2\text{x}10^{4}$	~10 sec
Abort gap population	7.0	$2.0\text{x}10^{8}$	60	~ 100 ms
Ghost bunches	7.0	$2.0\text{x}10^{8}$	$2\text{x}10^{4}$	~ 10 sec
Tails	7.0	$2.0\text{x}10^{8}$	$2\pm1\text{x}10^{4}$	~ 10 sec
Bunch core	7.0	$2.0\text{x}10^{8}$	$2\pm1\text{x}10^{6}$	~ 1 msec

* $N_b = 10^{11}$

Requirements (from. C. Fischer, LHC-B-ES-0005.00 rev 2.0, 07 Jan 03)

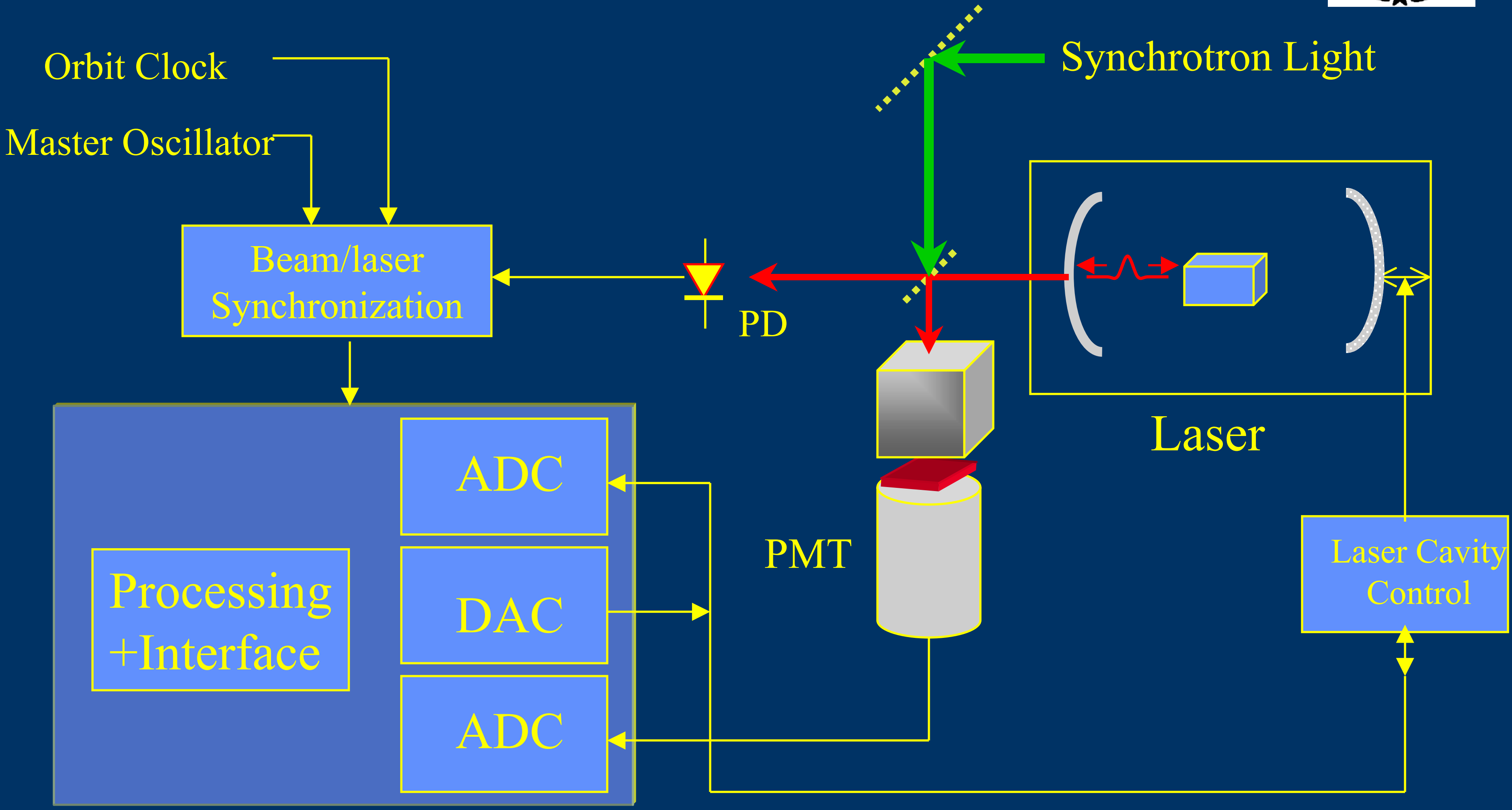
Solution: Optical Sampling Technology

- Use nonlinear mixing of synchrotron radiation with a 50 psec laser pulse to sample the longitudinal bunch profile



Developed in collaboration with ALS femtoslicing program.

Longitudinal Density Monitor



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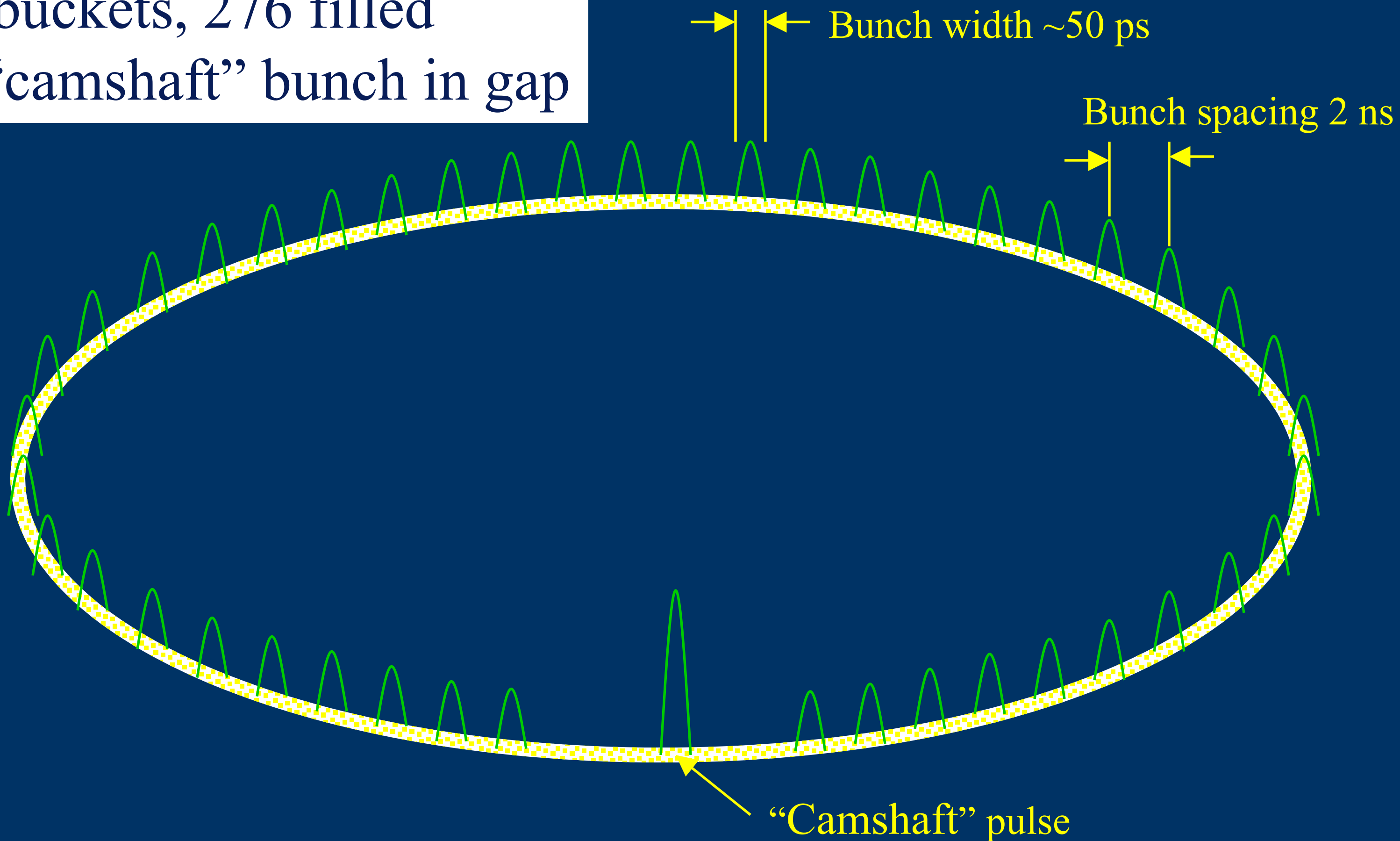
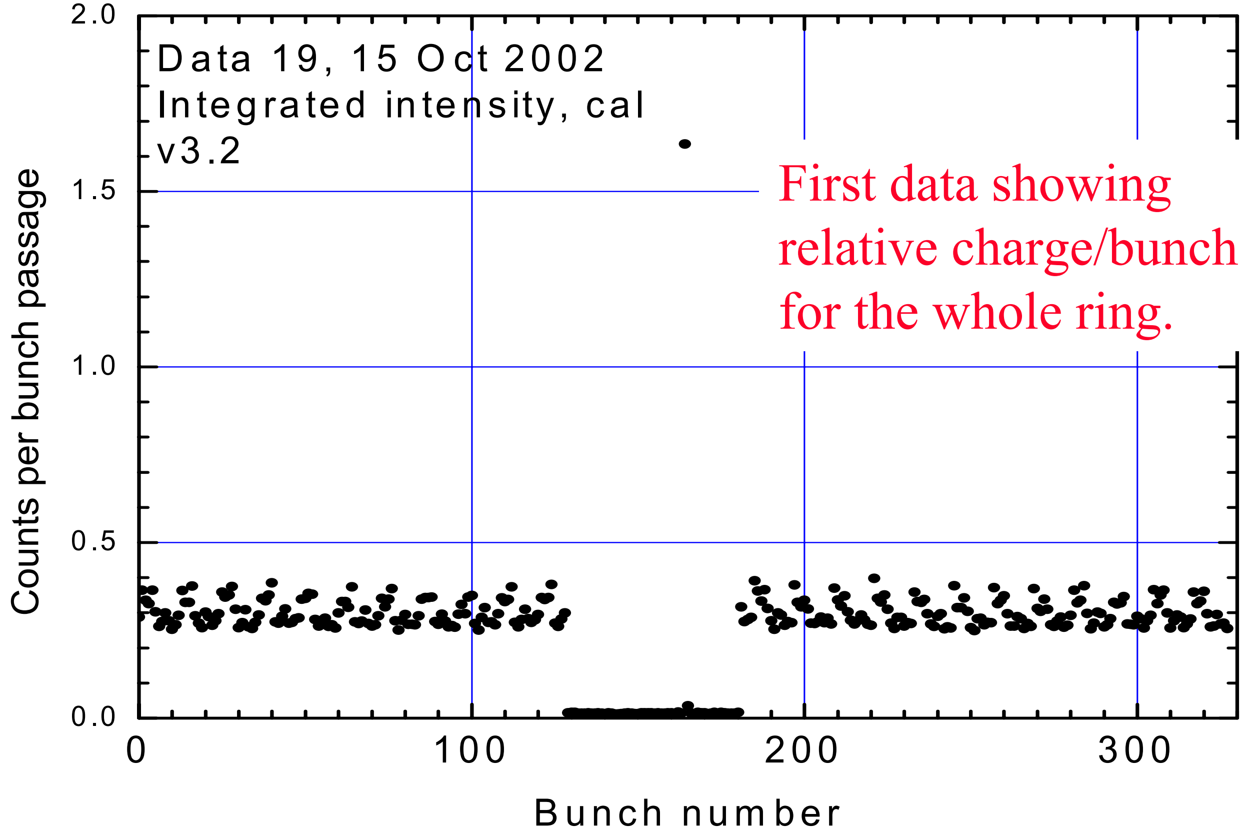
Test the concept at the ALS

ALS bunch structure
328 buckets, 276 filled
big "camshaft" bunch in gap

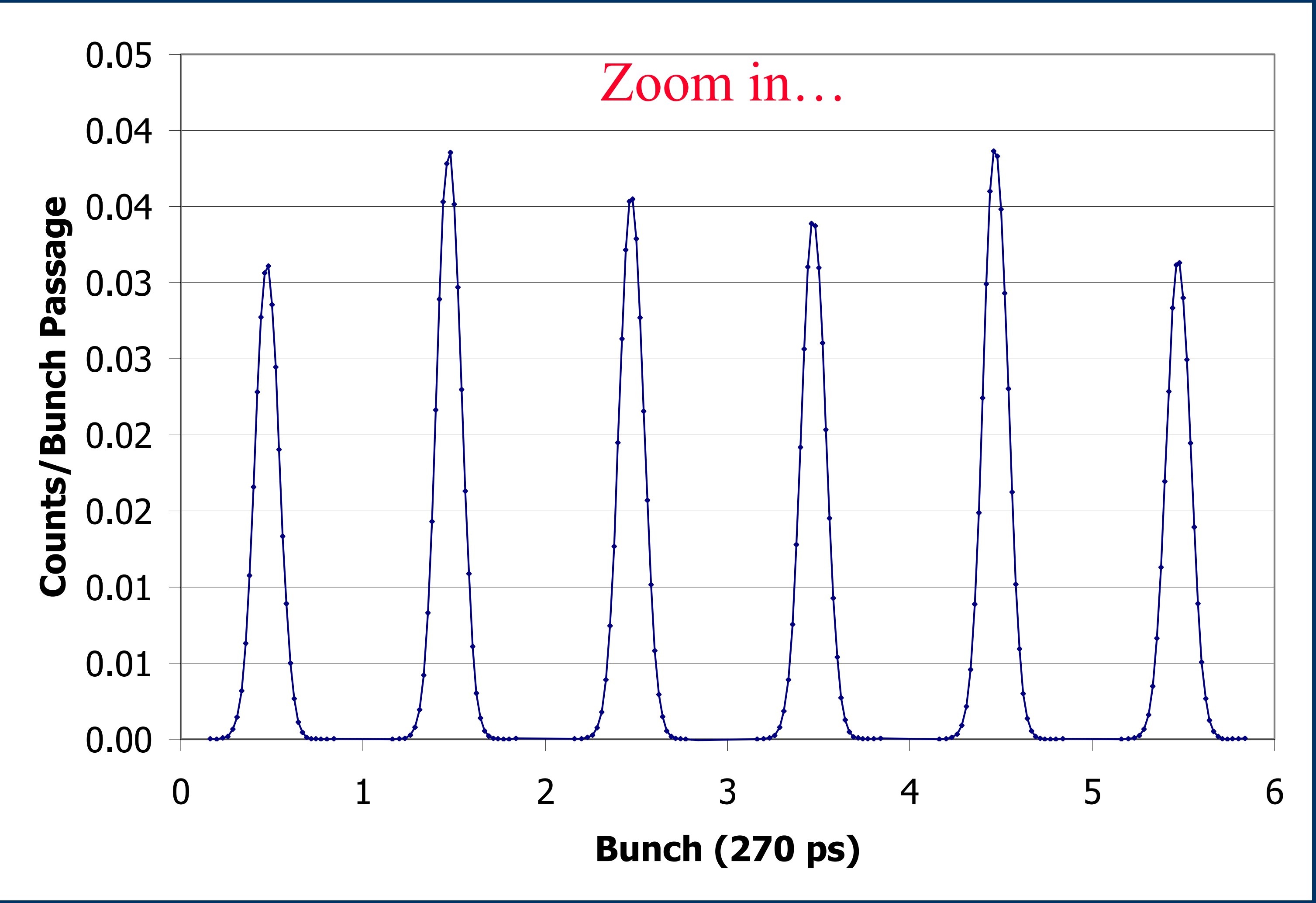


ALS LDM Tests

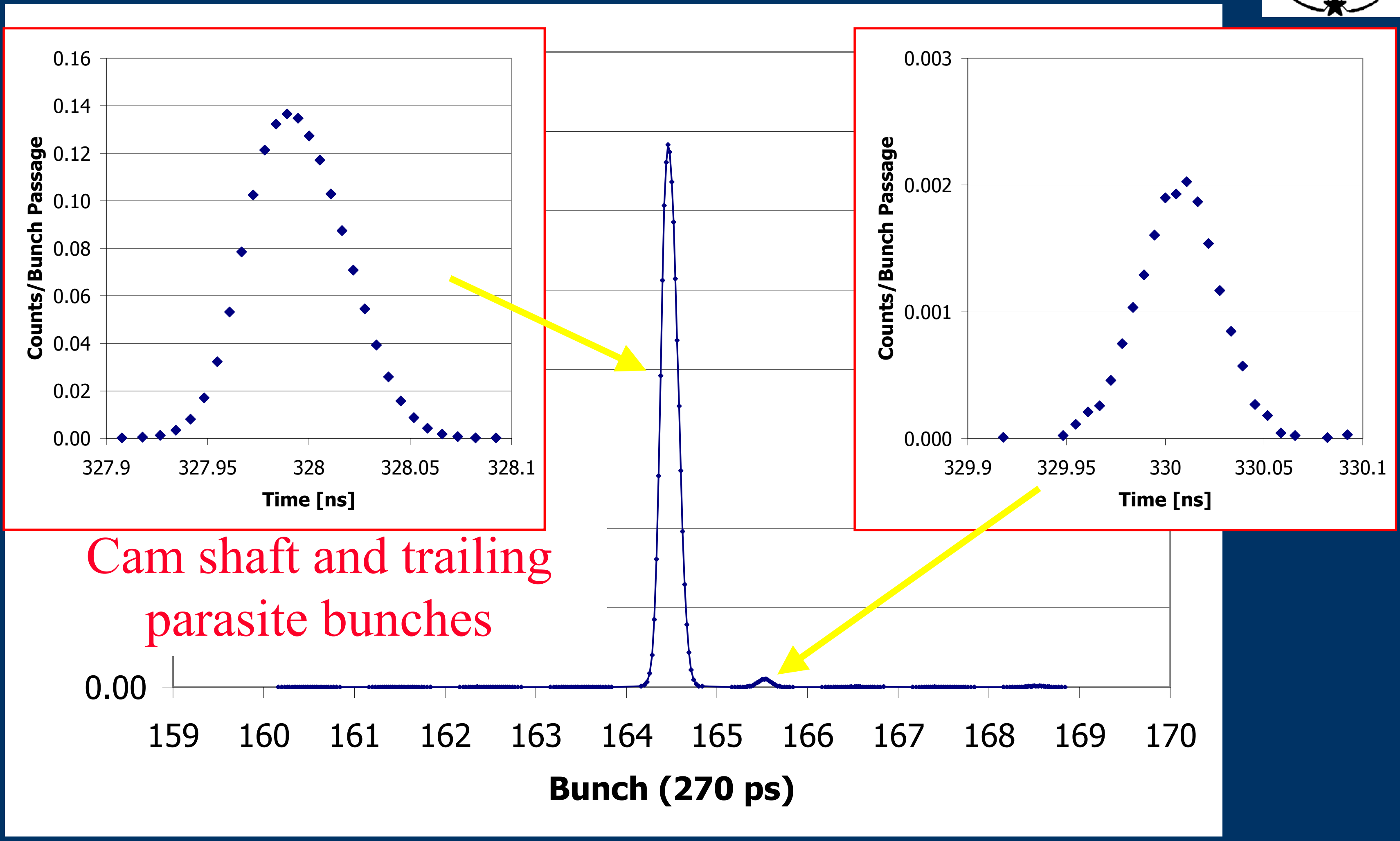


First data showing relative charge/bunch for the whole ring.

ALS LDM tests (cont.)



ALS LDM tests (cont.)



LDM Status

- Continuing studies on ALS.
- Considering applications at other facilities.
- Integrate experimental setup as an “instrument”
  - Identify appropriate laser for LHC
  - Combine all optics into laser housing
- Coordinate with CERN for use with synchrotron sources
- Coordinate instrument interface with LHC commissioning and operations

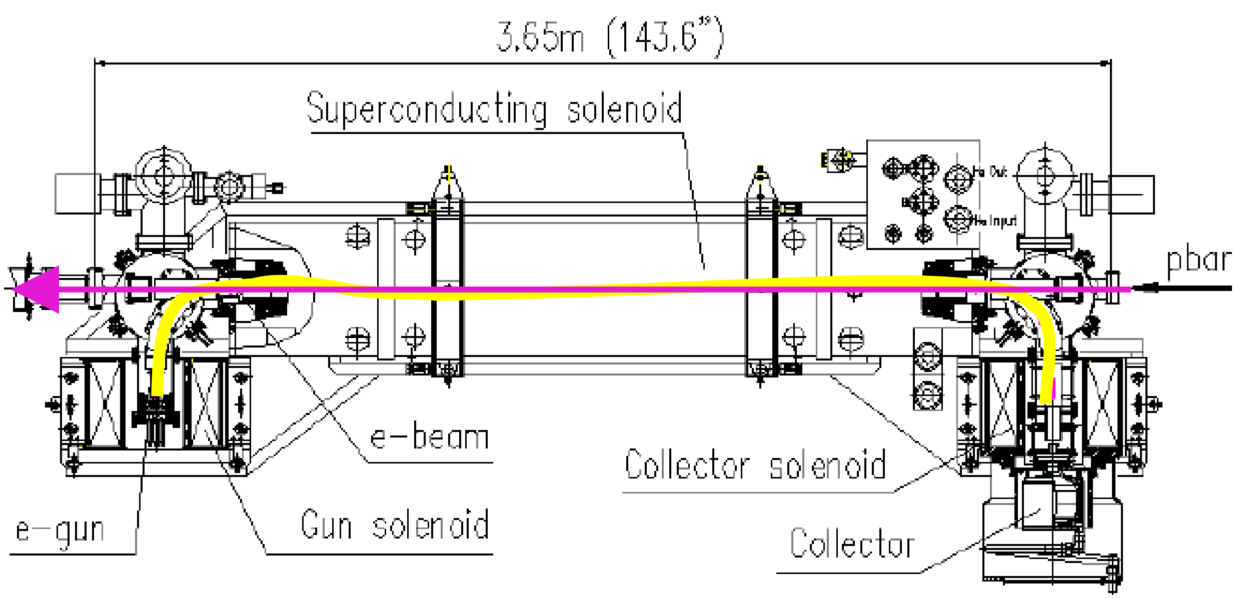
Additional instrumentation/techniques

- Beam/Beam studies
  - AC dipole for reactive excitation of beam
  - beam-beam compensation with electron lens or wire
- Electron Cloud
  - In situ low energy electron spectrometer

These will be added to the LARP program as need and funding permit.

Electron Lens

TEL-1: installed Mar.1, 2001

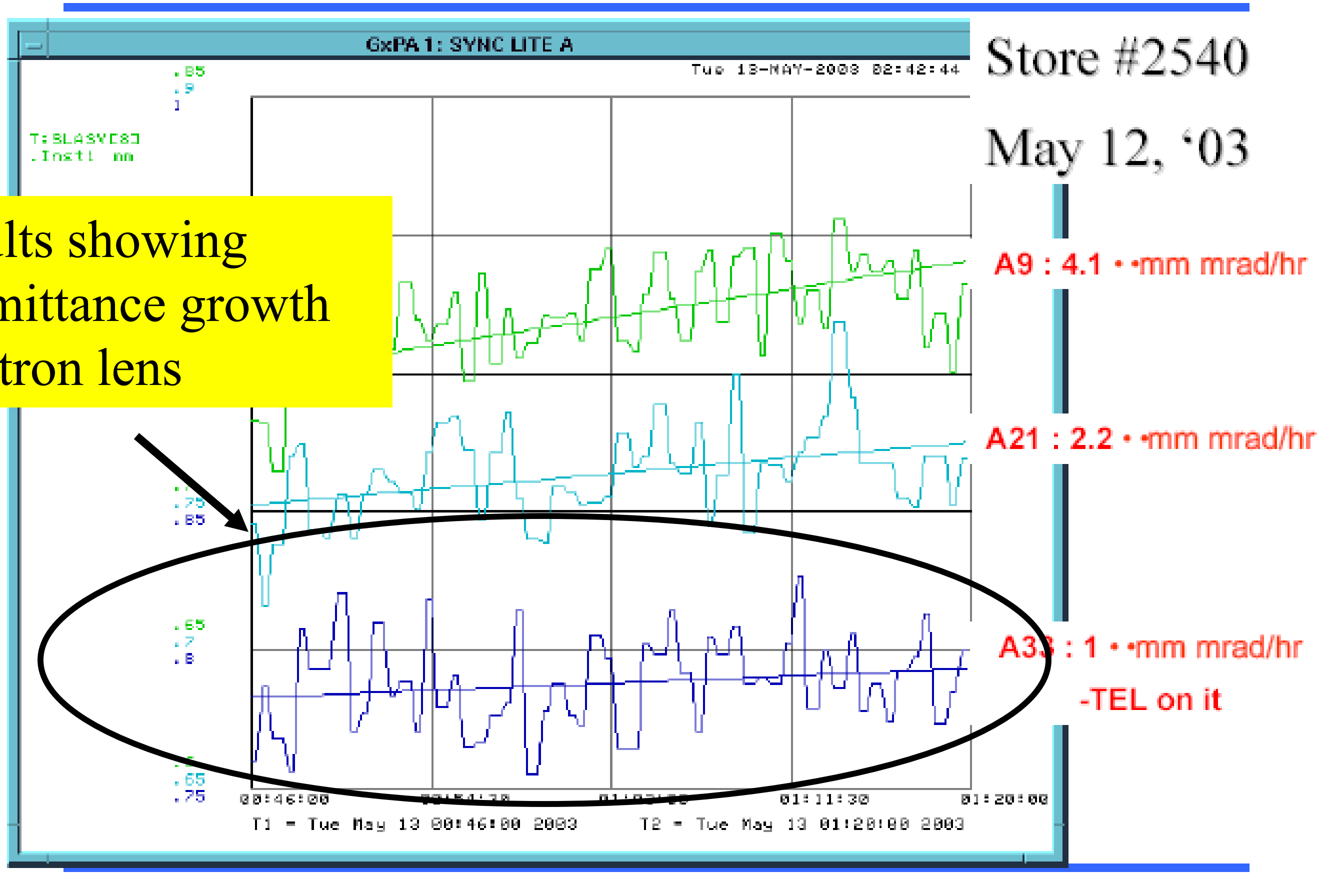


Concept: low energy electron beam with tailored profile to compensate beam-beam kick from proton beam.

Tevatron Electron Lens (TEL) has been installed and studied for the past two years.

Tevatron Electron Lens

Pbar V-Sizes 34 min after p-pbar collisions initiated



First results showing slower emittance growth with electron lens

Summary

We will build, commission, and integrate into LHC operations advanced instrumentation and diagnostics for helping LHC

- reach design energy
- reach design luminosity

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
- maximize LHC performance