LCLS
Stanford Linear Accelerator Center
Stanford Synchrotron Radiation Laboratory
Particle Accelerator Conference 2007
Albuquerque, New Mexico, June 25–29

Diagnostics for LCLS Commissioning

Patrick Krejcik, SLAC
on behalf of the LCLS commissioning team.

Introduction

- Layout of the Linac Coherent Light Source
- Special diagnostic needs for the LCLS
  - Beam position monitors
  - Beam size monitors and emittance measurement
  - Bunch length measurements
  - Time-resolved measurement of slice emittance and energy spread
  - Stability characterization
  - Electro-optic clocking of electron pulses with an ultrafast laser


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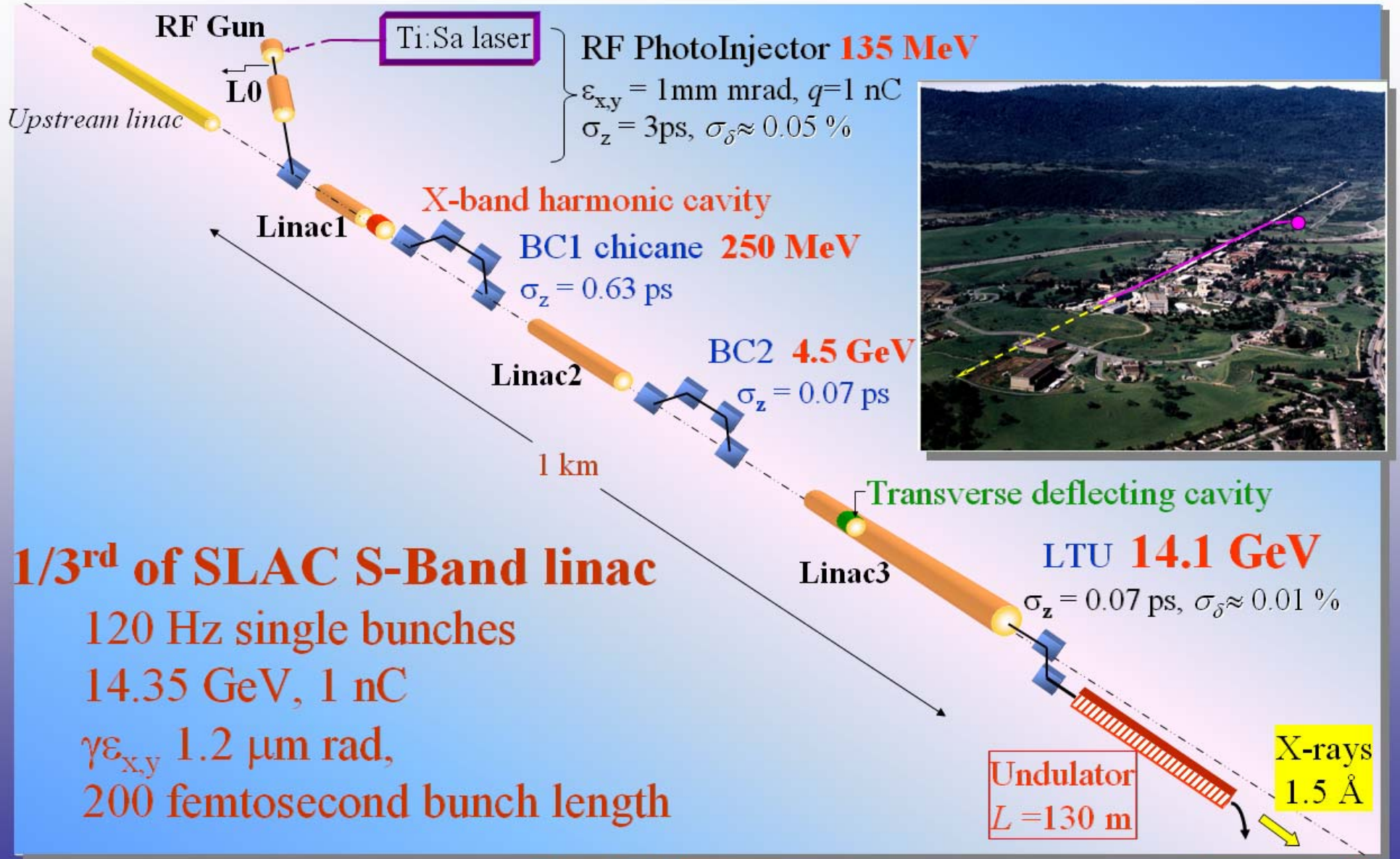

1/3rd of SLAC S-Band linac

120 Hz single bunches
14.35 GeV, 1 nC
$\gamma\varepsilon_{x,y}$ 1.2 μm rad,
200 femtosecond bunch length

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Diagnostic Challenges

- Very low emittance beams $\gamma\varepsilon_{x,y}$ 1 μm rad
  - Trajectory resolution as low as 1 μm in the undulator
  - Beam size resolution 7 μm
- Very short bunches
- Measure longitudinal profile
  - From 10 ps down to a few fs
- Measure time-resolved properties of a single bunch
  - Slice emittance and energy spread – *Key parameter for FEL*
- All measurements are single-shot
  - Synchronous at 120 Hz
- Femtosecond arrival time stamping against laser pulses

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Commissioning Schedule

- First photo electrons from the RF gun April 2007
- Followed by beam to BC1, first bunch compressor soon after
- 14 GeV electrons to end of linac last week
- Second installation phase begins September 2007
- Second commissioning phase December 2007
- First FEL light expected 2009

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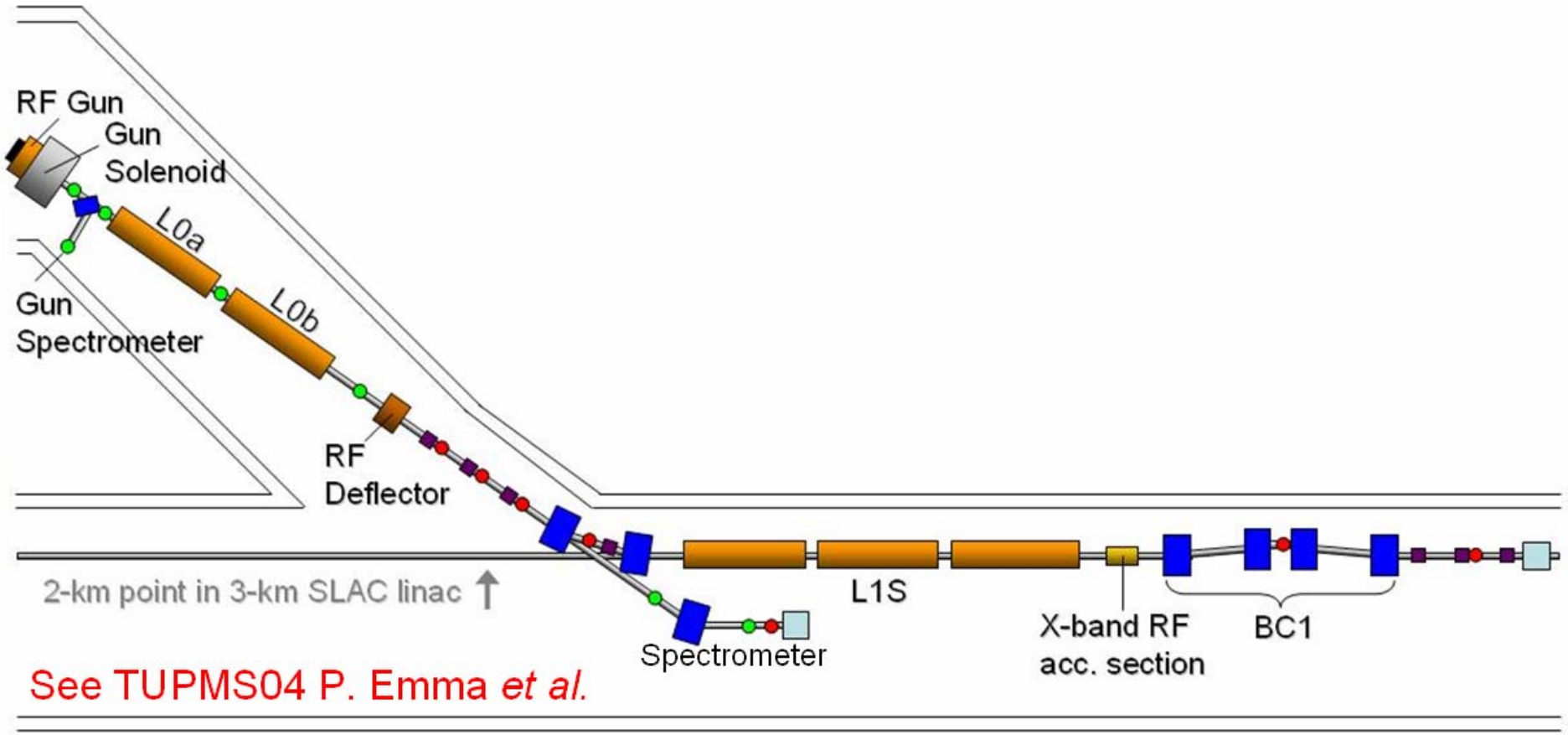
LCLS Injector and First Bunch Compressor Instrumentation



See TUPMS04 P. Emma *et al.*

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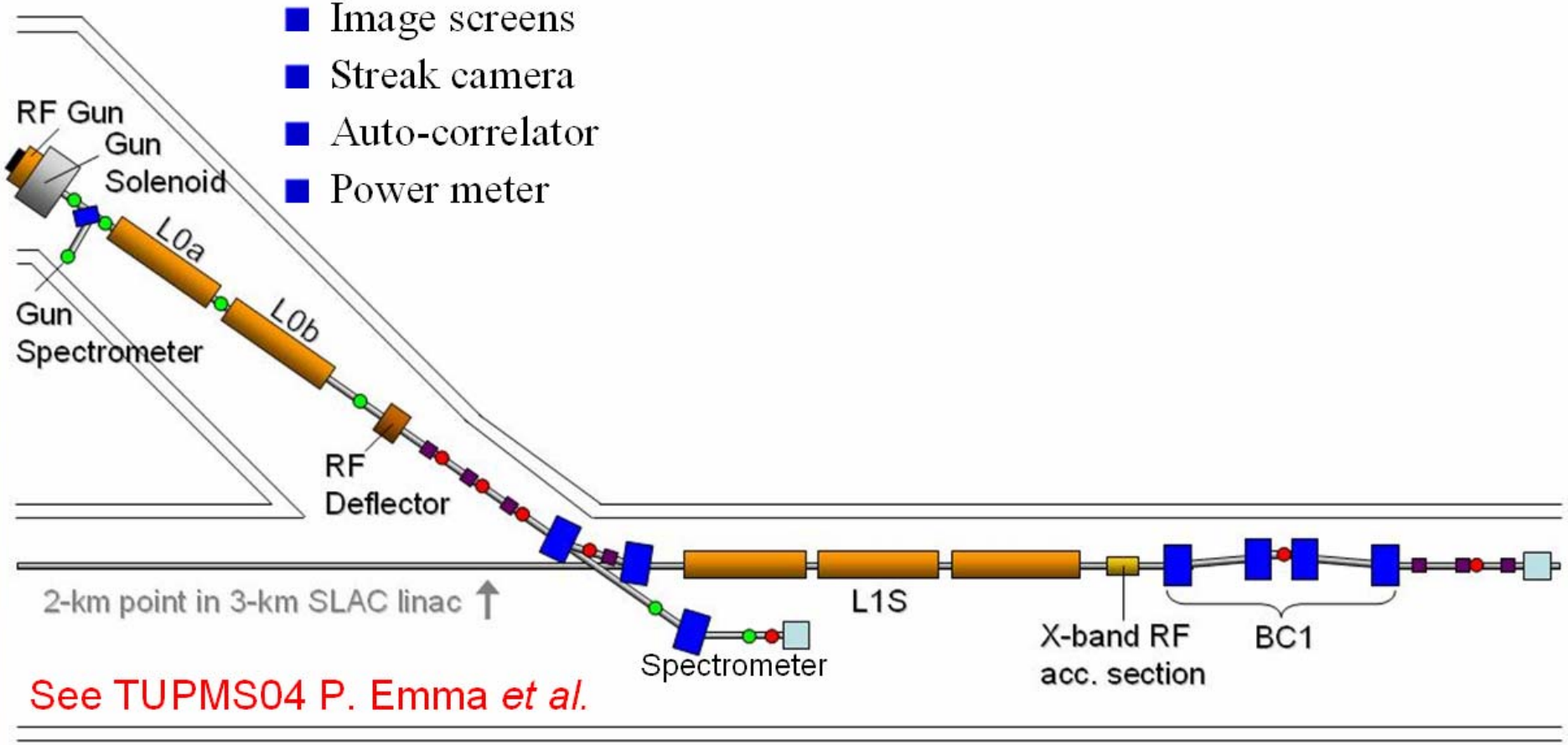
LCLS Injector and First Bunch Compressor Instrumentation

- Laser diagnostics
  - Image screens
  - Streak camera
  - Auto-correlator
  - Power meter



See TUPMS04 P. Emma *et al.*

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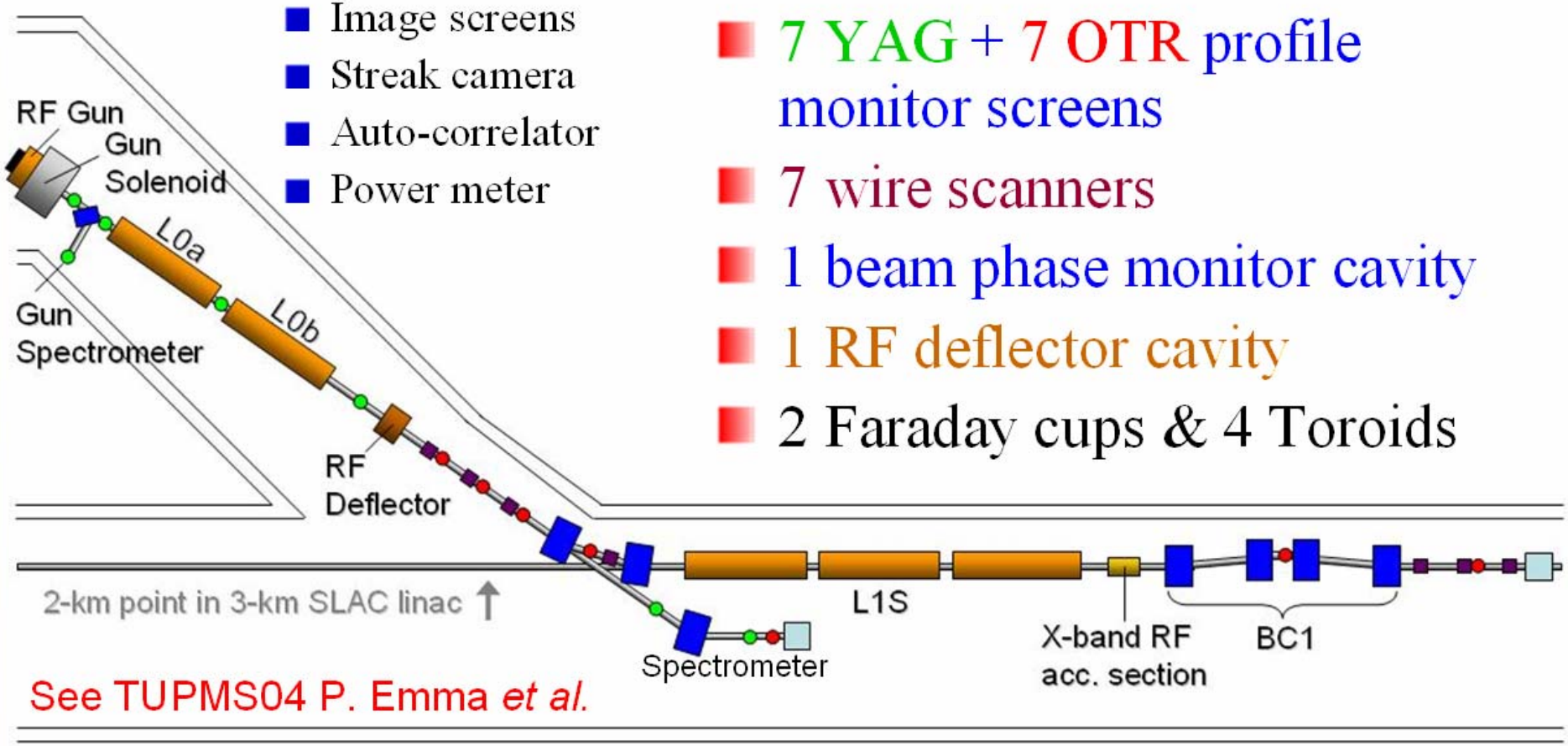
LCLS Injector and First Bunch Compressor Instrumentation

- Laser diagnostics
  - Image screens
  - Streak camera
  - Auto-correlator
  - Power meter
- 23 Beam Position Monitors
- 7 YAG + 7 OTR profile monitor screens
- 7 wire scanners
- 1 beam phase monitor cavity
- 1 RF deflector cavity
- 2 Faraday cups & 4 Toroids



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Some Photos Of The Injector Vault

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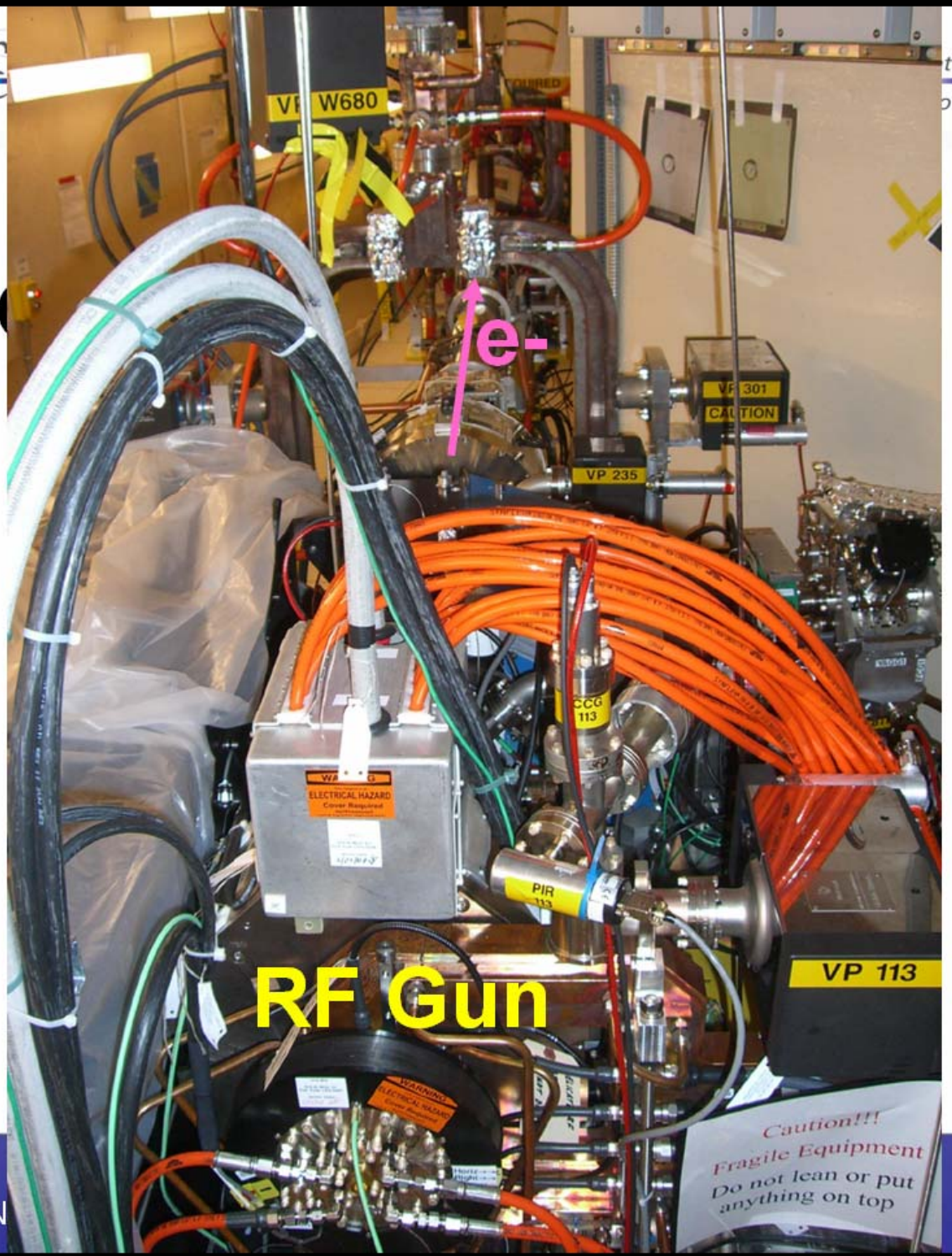
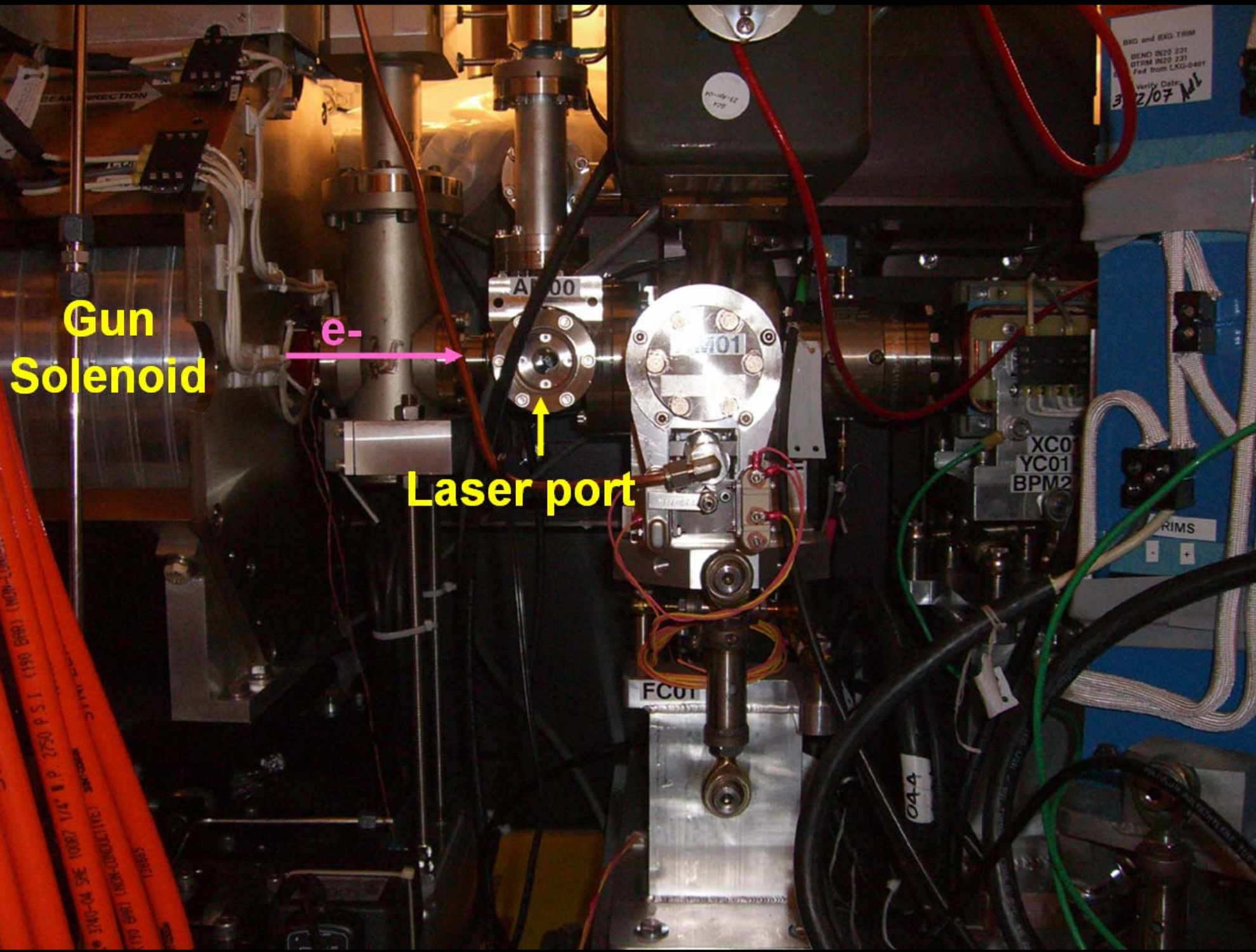

e-
VP 301
CAUTION
VP 235
ELECTRICAL HAZARD
PIR
VP 113
RF Gun
Caution!!!
Fragile Equipment
Do not lean or put
anything on top


Gun
Solenoid
e-
Laser port
XC0
YC01
BPM2
FC01


VP 235
XCG1
BPMG1
XCG2
YAGG1
FCG1
Gun Spectrometer Beam Line

Laser Systems
Image Acquisition and Steering Feedback

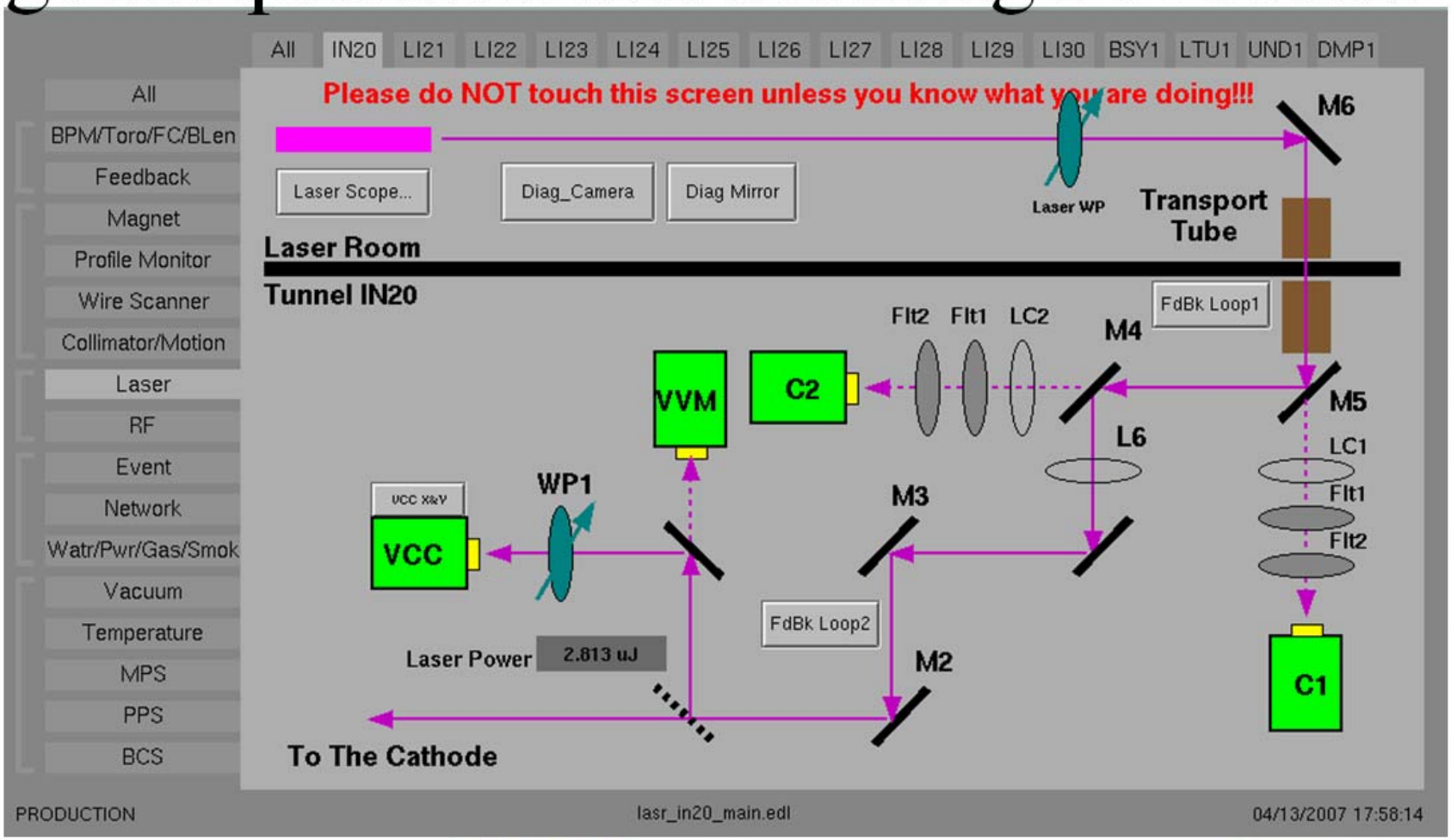


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Image Acquisition and Steering Feedback

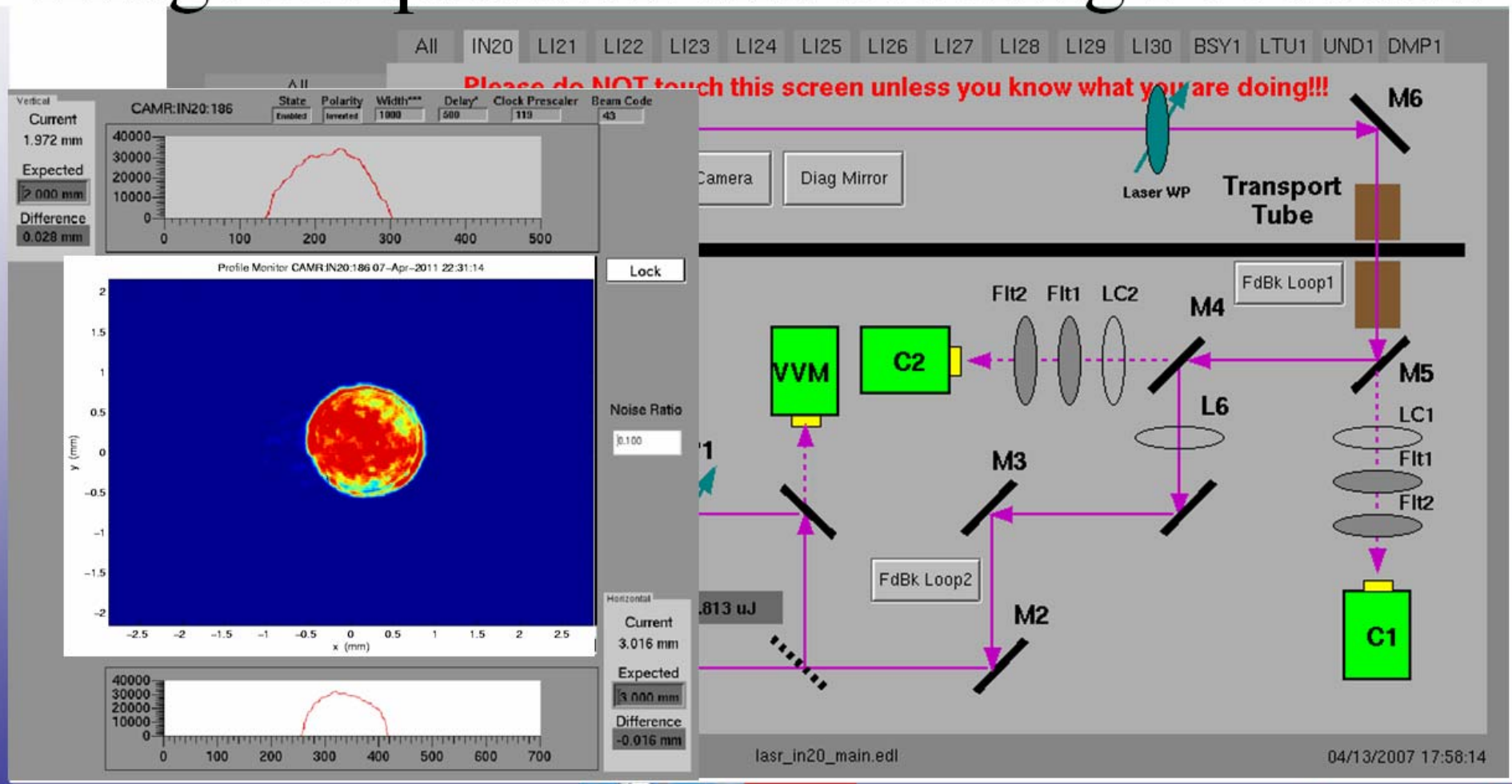

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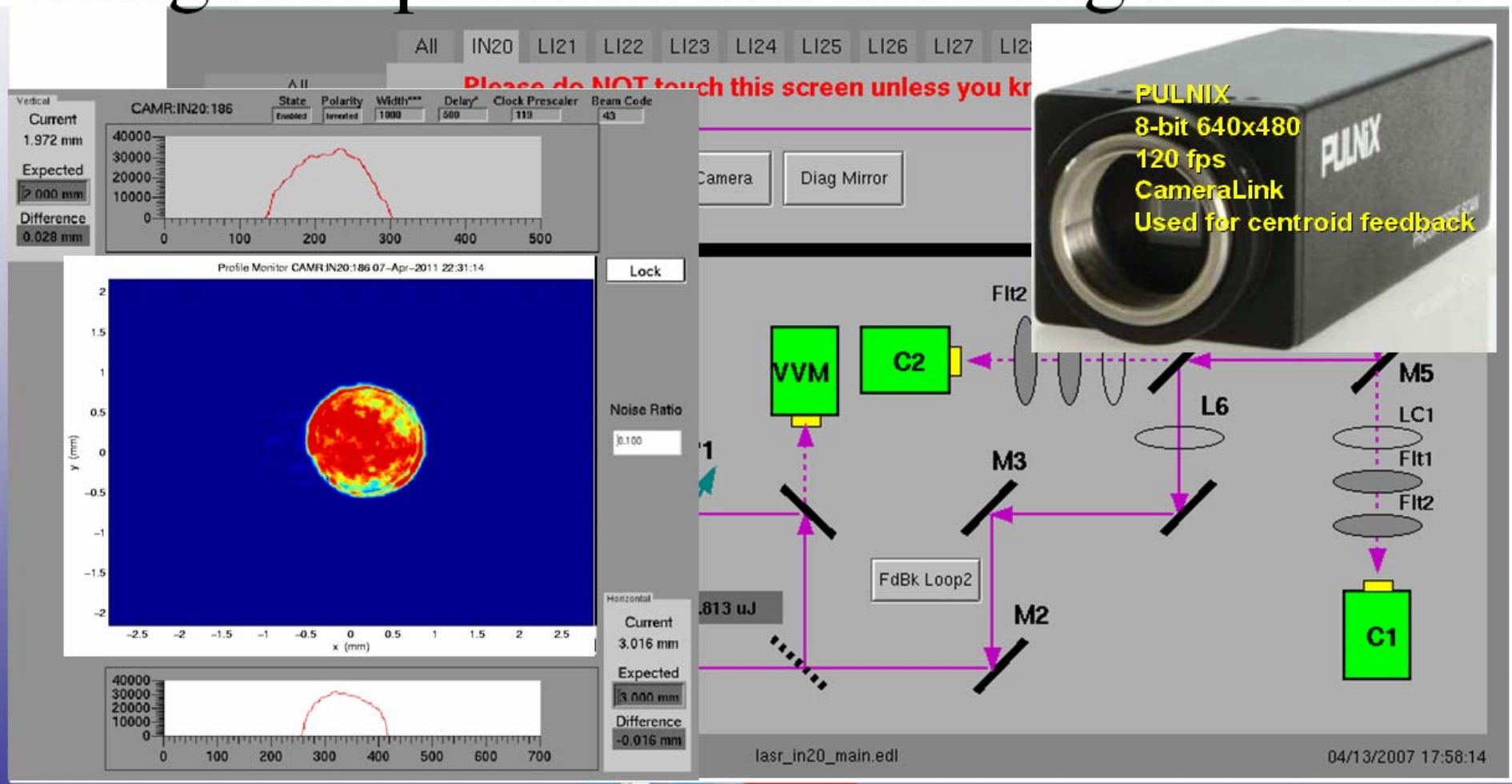
Image Acquisition and Steering Feedback



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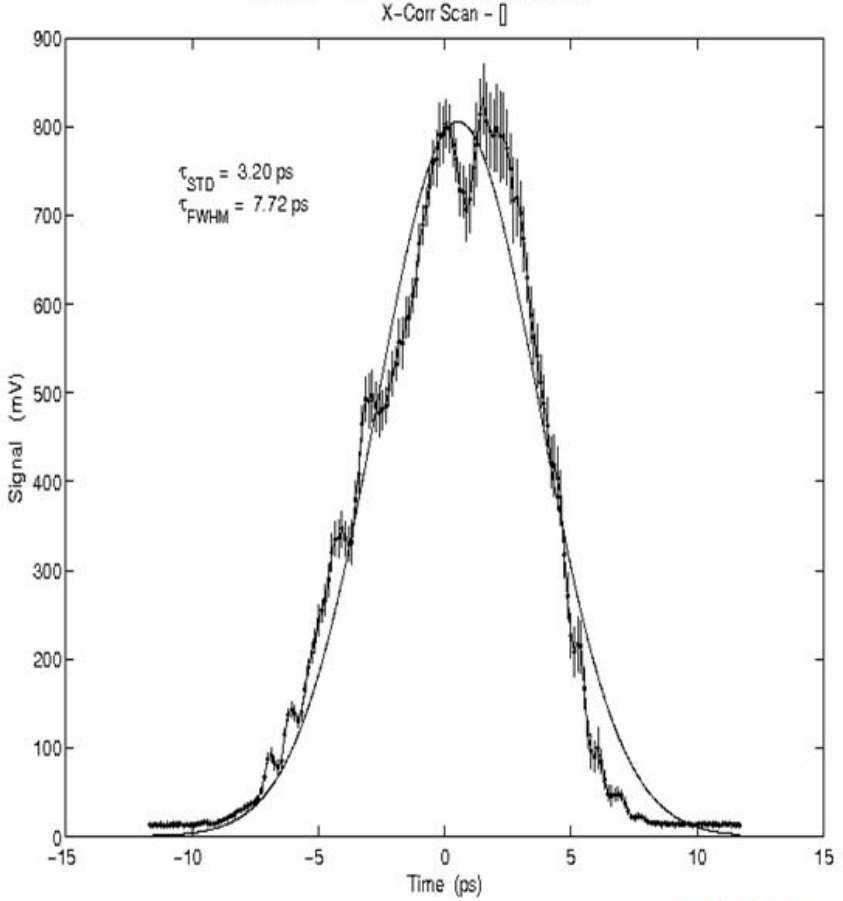
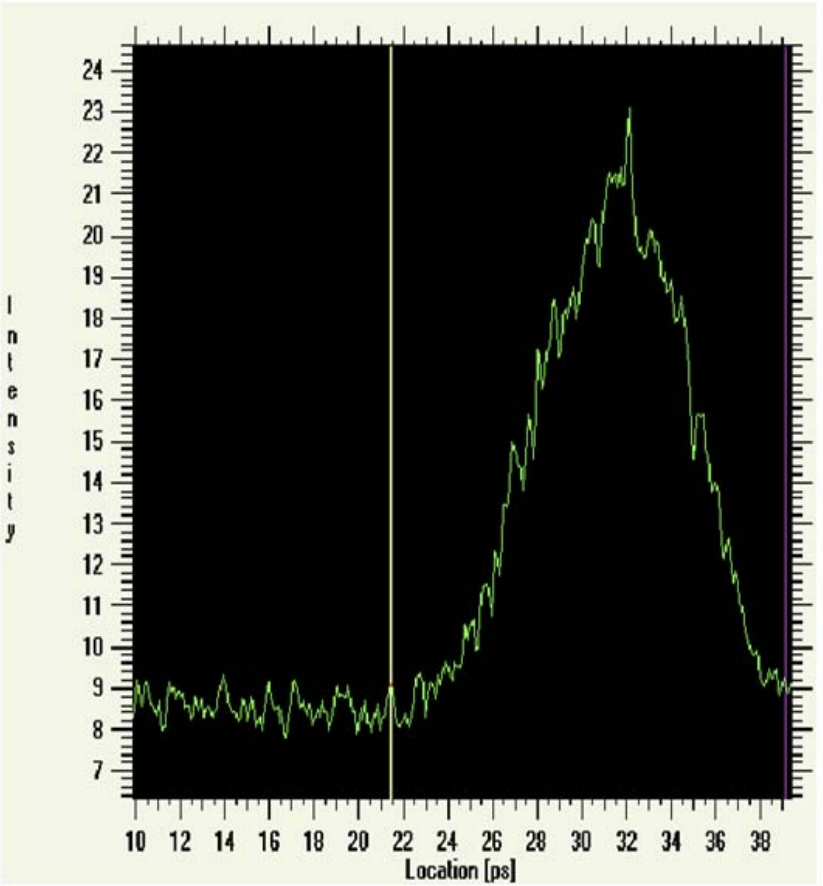
Laser Temporal Profile

8 ps fwhm – see TUPMS054 H.Loos *et al.*

Cross correlator



Streak camera



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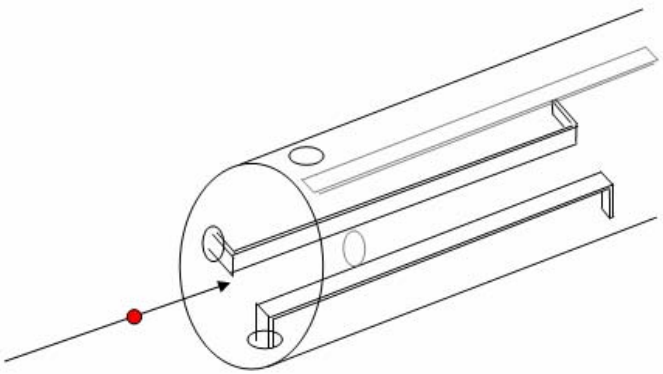
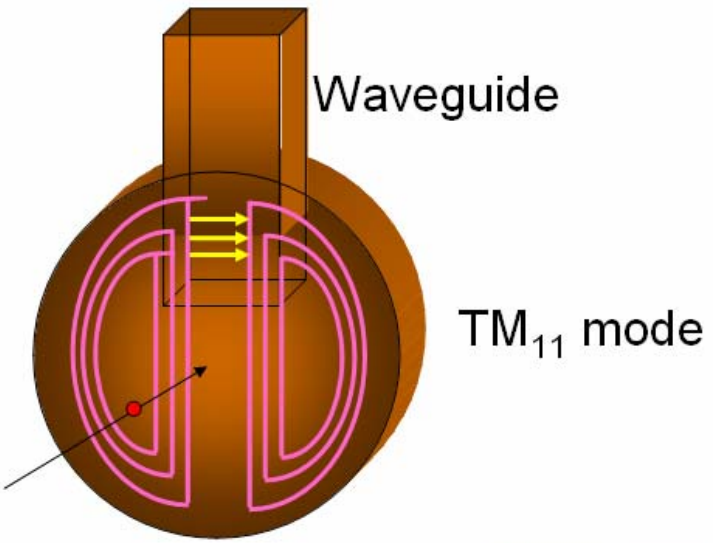
Beam Position Monitors

- Striplines
  - 144 in the linac and beam lines
  - Filter and digitize the baseband signal
  - Calibration scheme feeds test signal on adjacent strip



- Cavities
  - Between undulator modules
  - X-band TM_{11} mode
  - Downmix signal and digitize the IF



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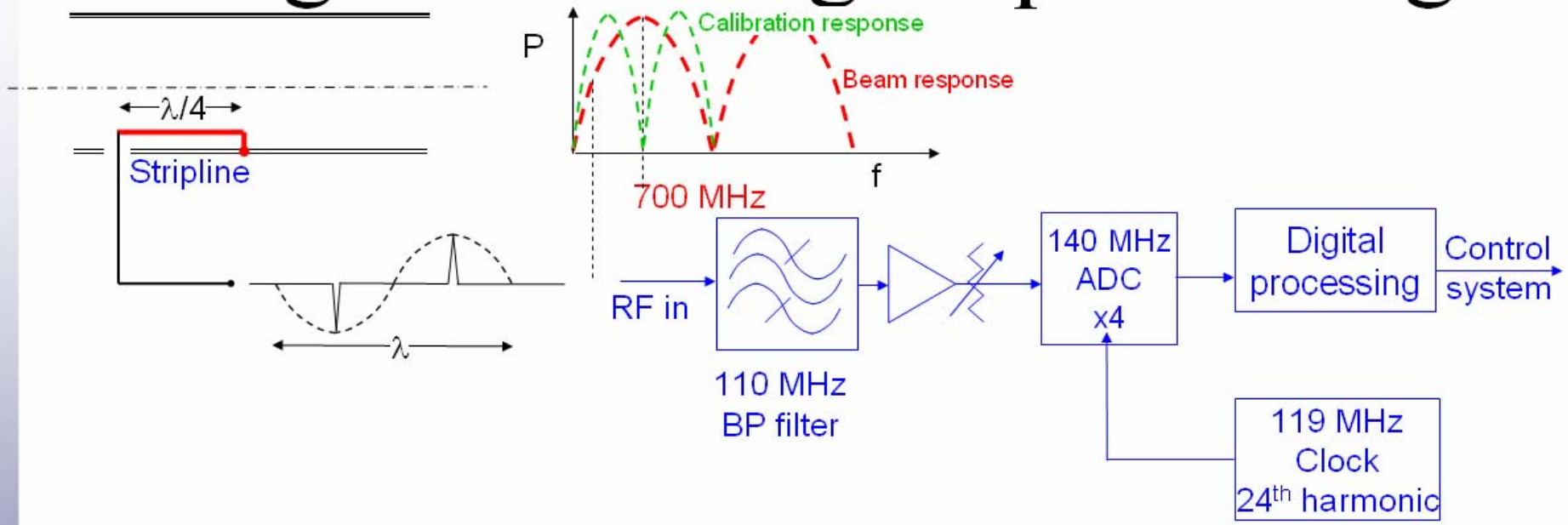
Digital BPM signal processing



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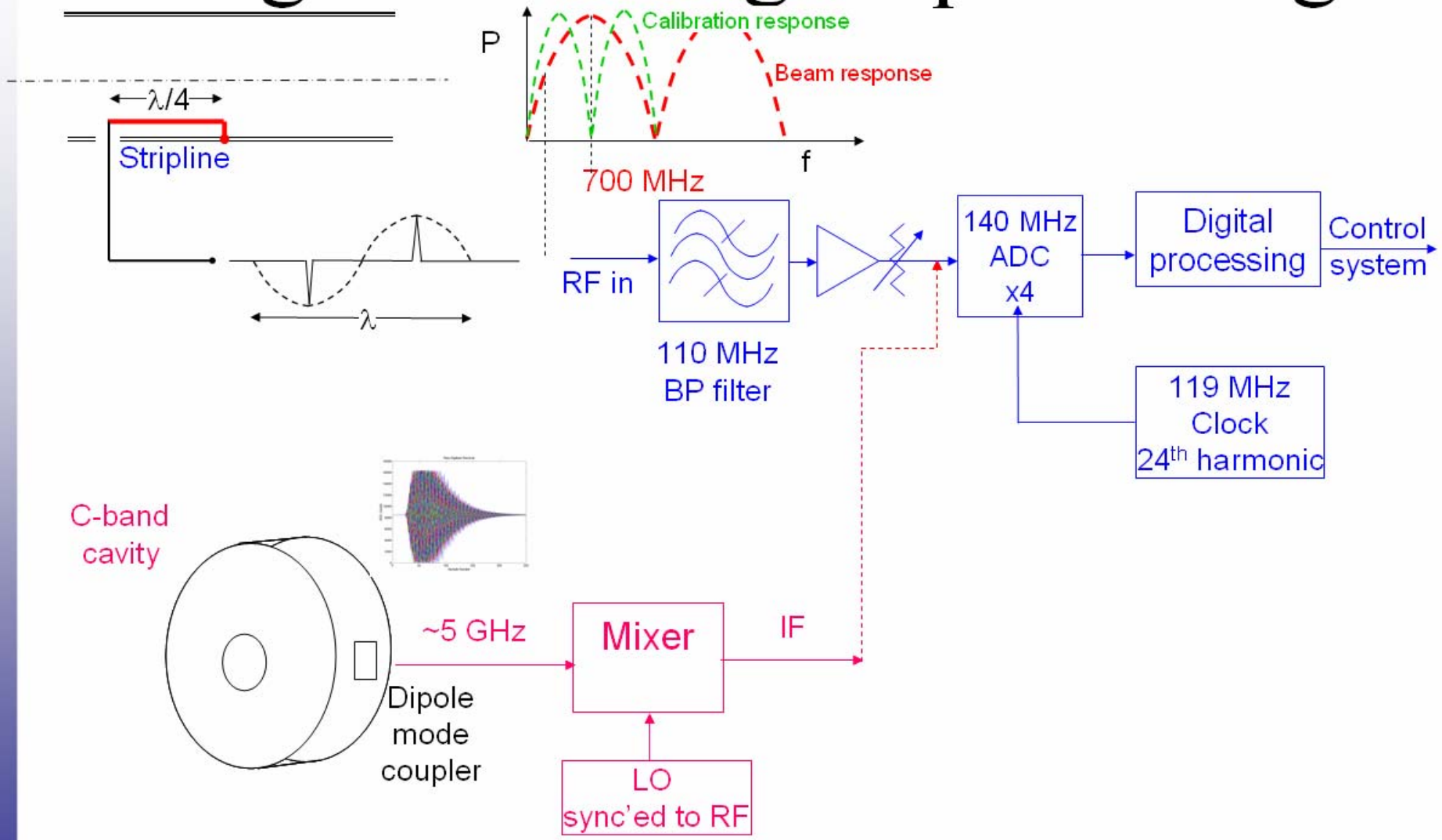
Digital BPM signal processing



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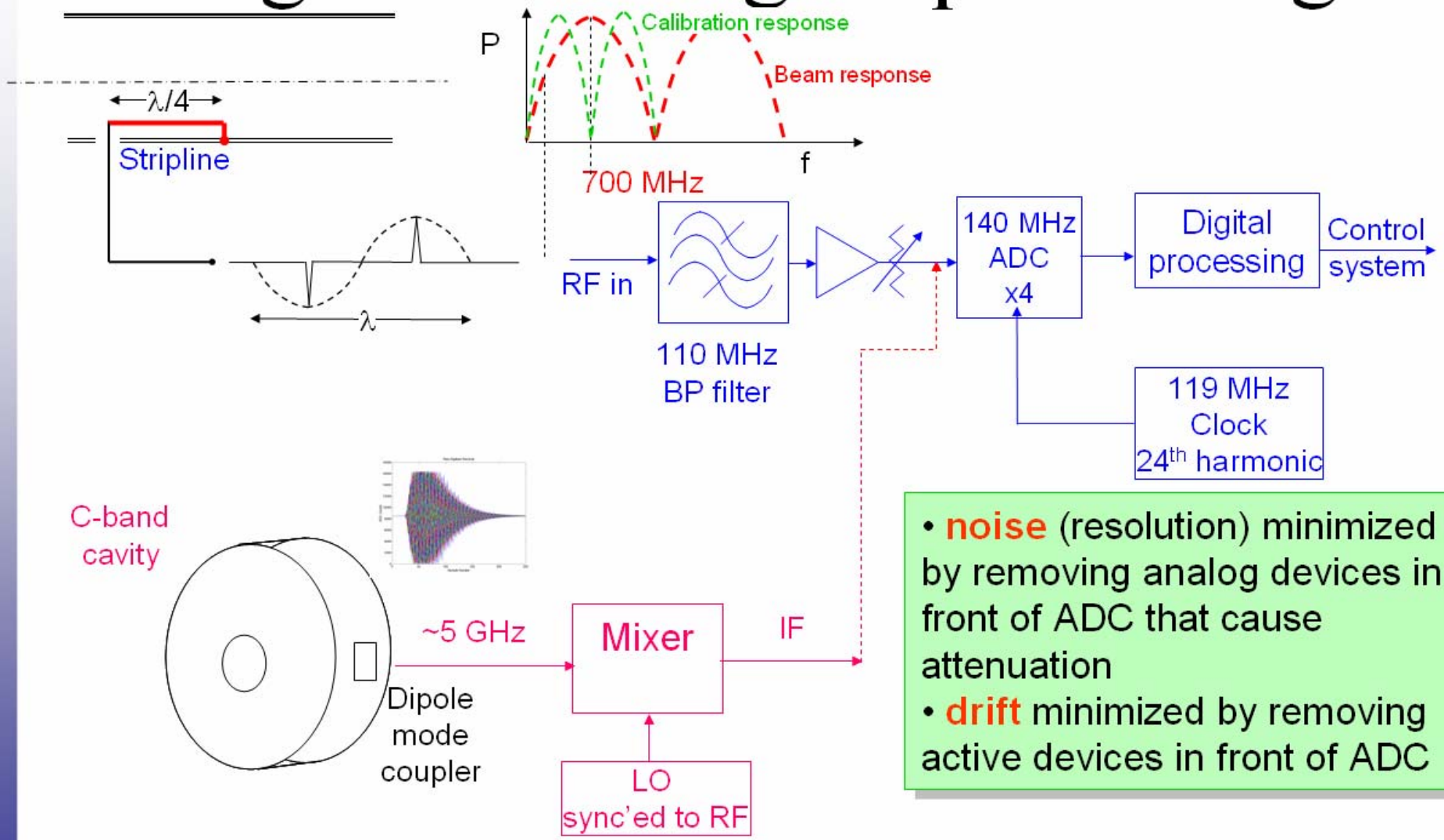
Digital BPM signal processing



- **noise** (resolution) minimized by removing analog devices in front of ADC that cause attenuation
- **drift** minimized by removing active devices in front of ADC

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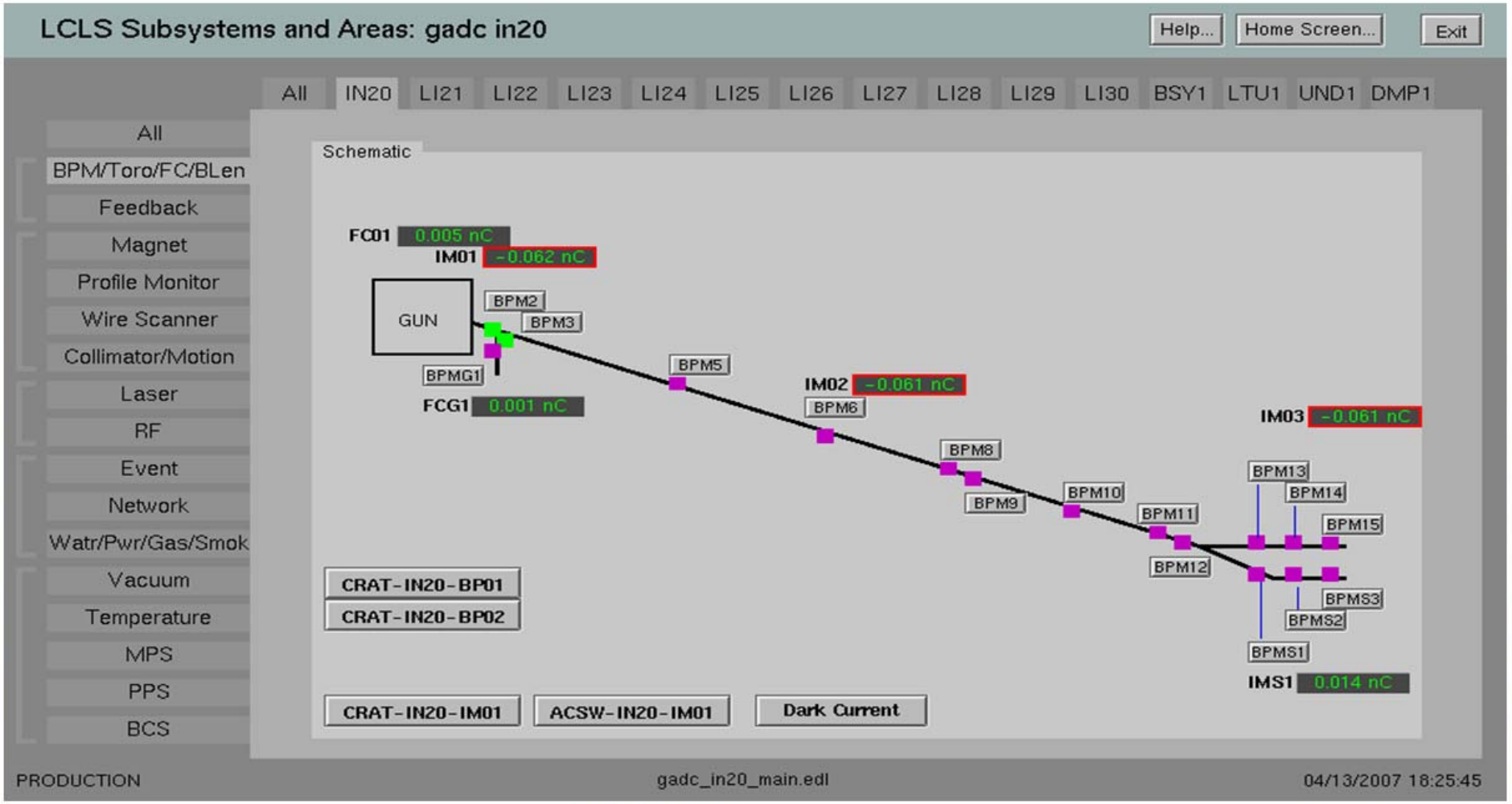
Beam Position Monitors



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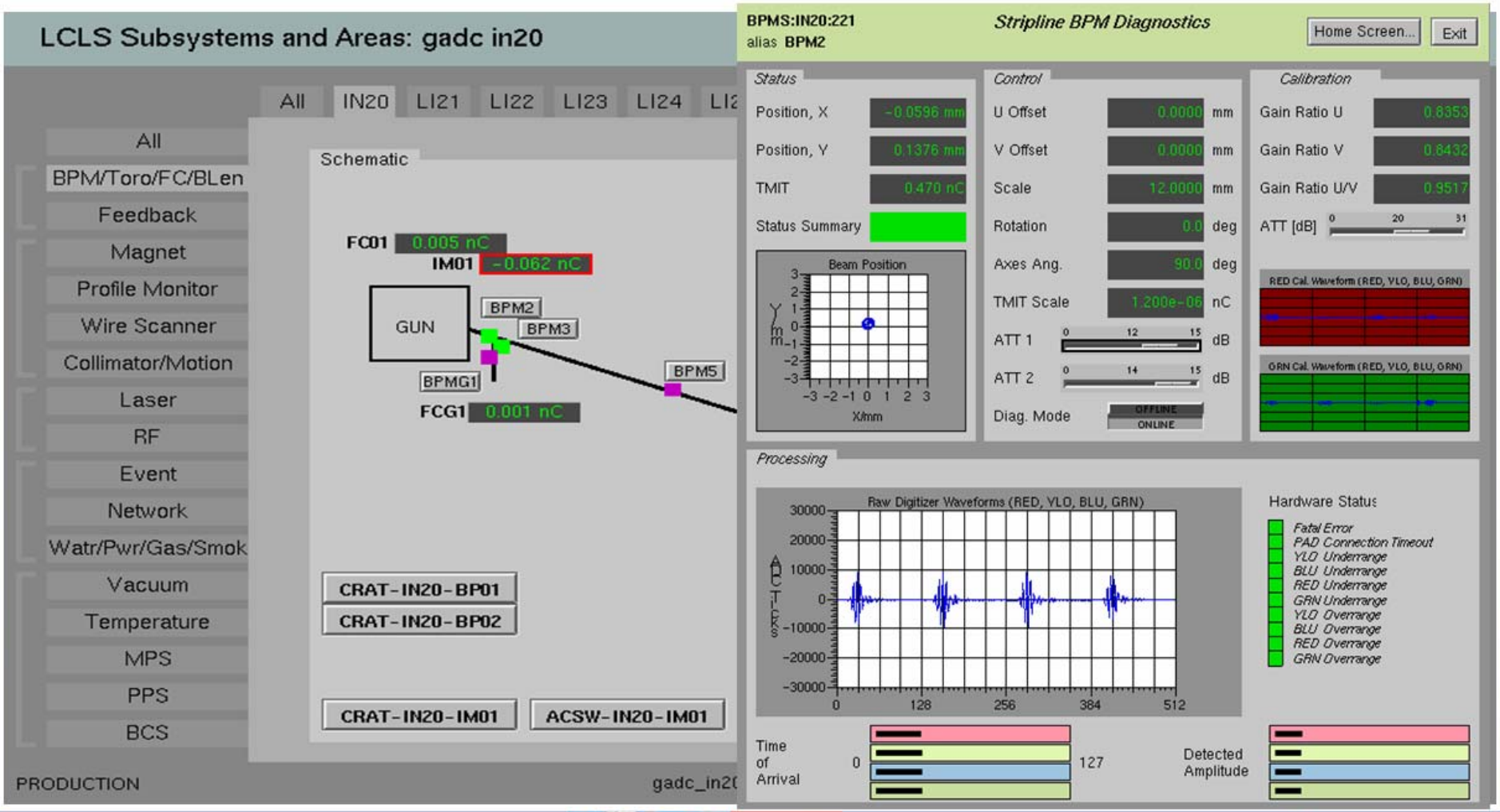
Beam Position Monitors



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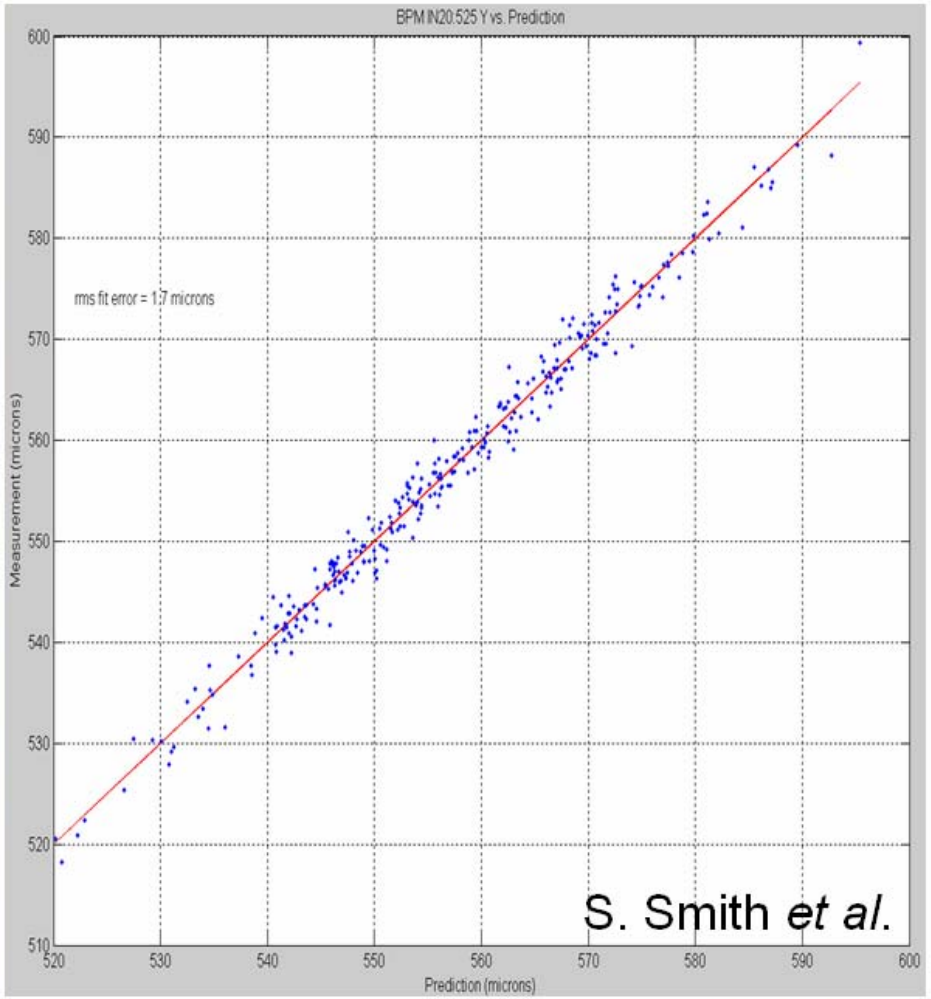
Synchronous Acquisition to measure Resolution



- Simultaneous measurement of all BPMs
- Fitted beam position versus measured yields resolution
- 2 microns
- at 400 pC

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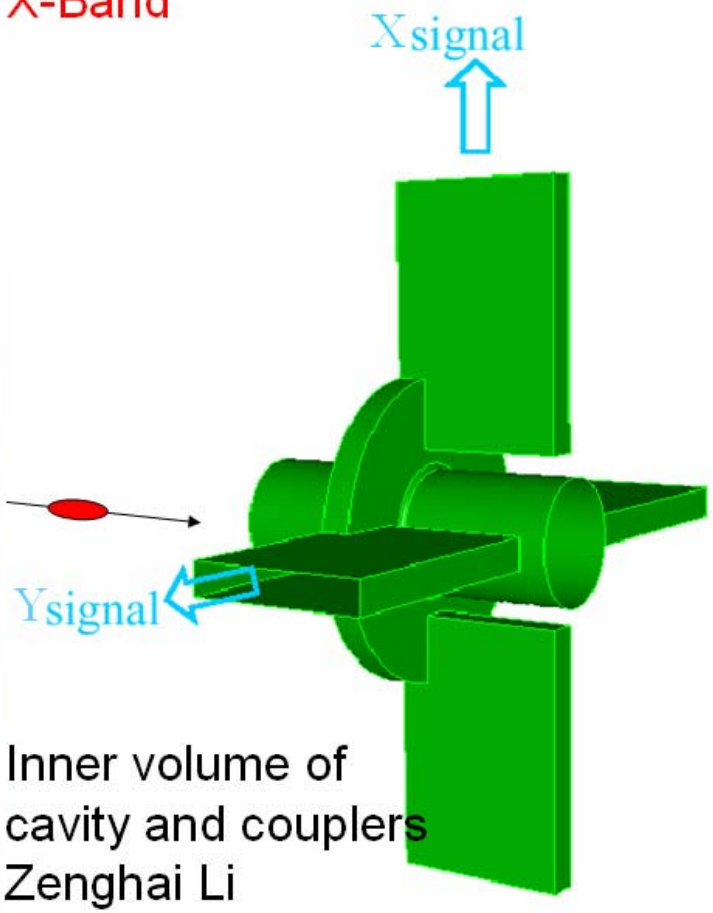
Cavity BPM with TM_{11} mode Selective Coupler

X-Band



Inner volume of cavity and couplers
Zenghai Li

- Dipole mode:
  - TM_{11} at 11.424 GHz
- Magnetic coupling to waveguide:
  - Horizontal couples to vertical port
- Waveguide does not couple to fundamental TM_{01} mode
- Sensitivity

$$V_{beam}(q,x) = \sqrt{q^2 Z_0 \frac{\beta}{1+\beta} \frac{\omega_0 k_{loss} x^2}{Q_L}}$$

  - **1.6 mV/nC/mm**

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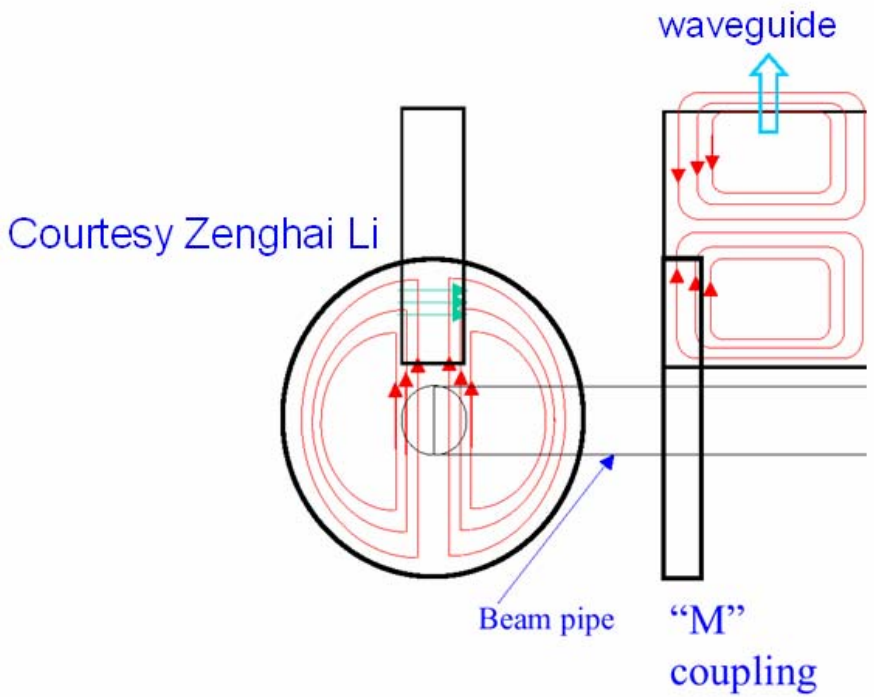
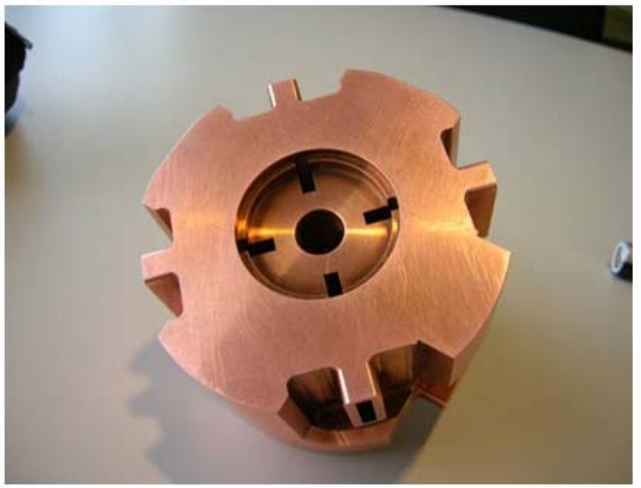
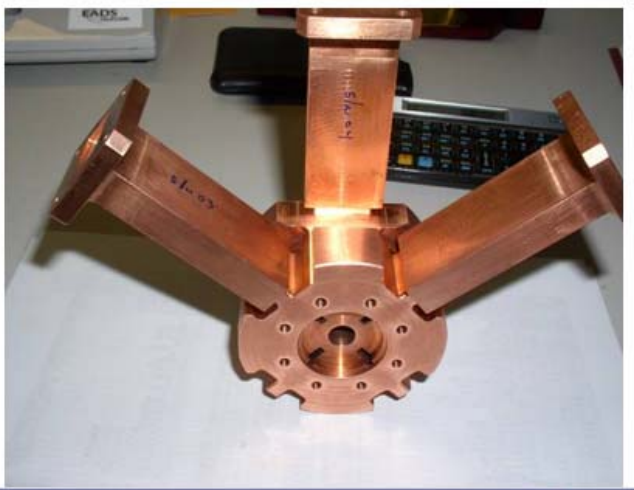
TM_{11} Selective Coupling Scheme





ANL cavity prototypes



- First beam tests have begun at ANL (R. Lill)

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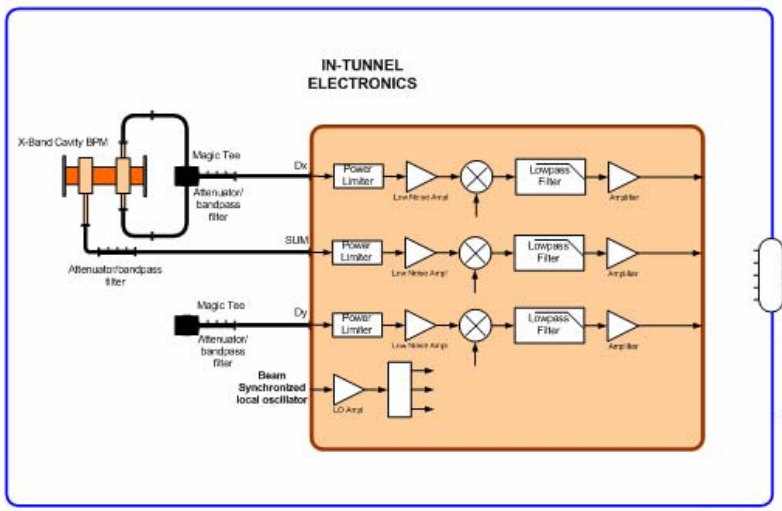
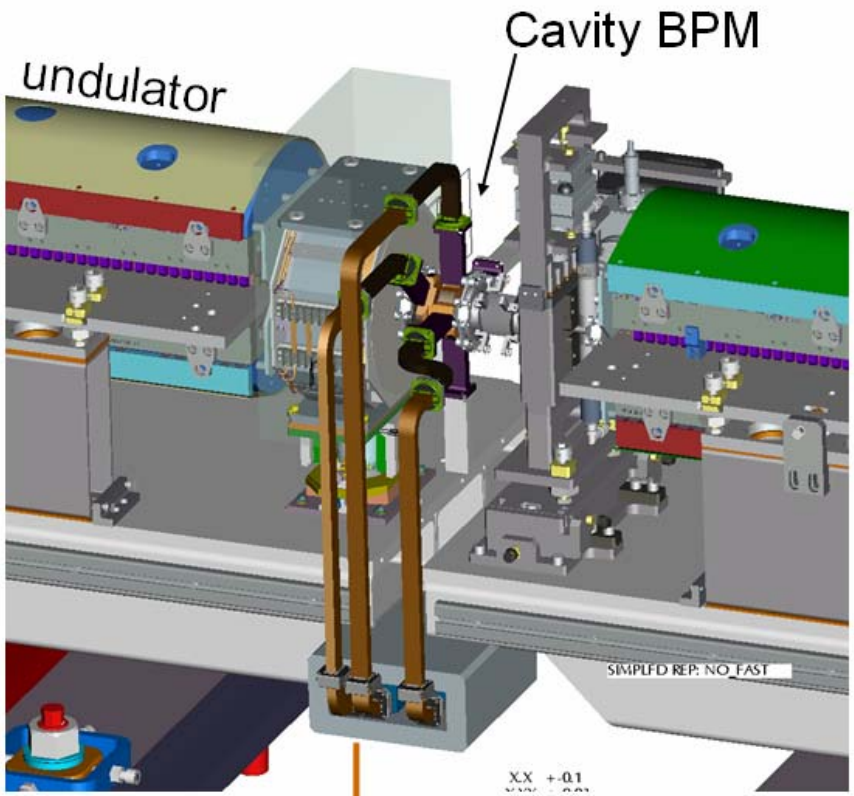
ANL Undulator Cavity BPM

Miteq X-Band Low Noise Receiver





IF signal to digitizer

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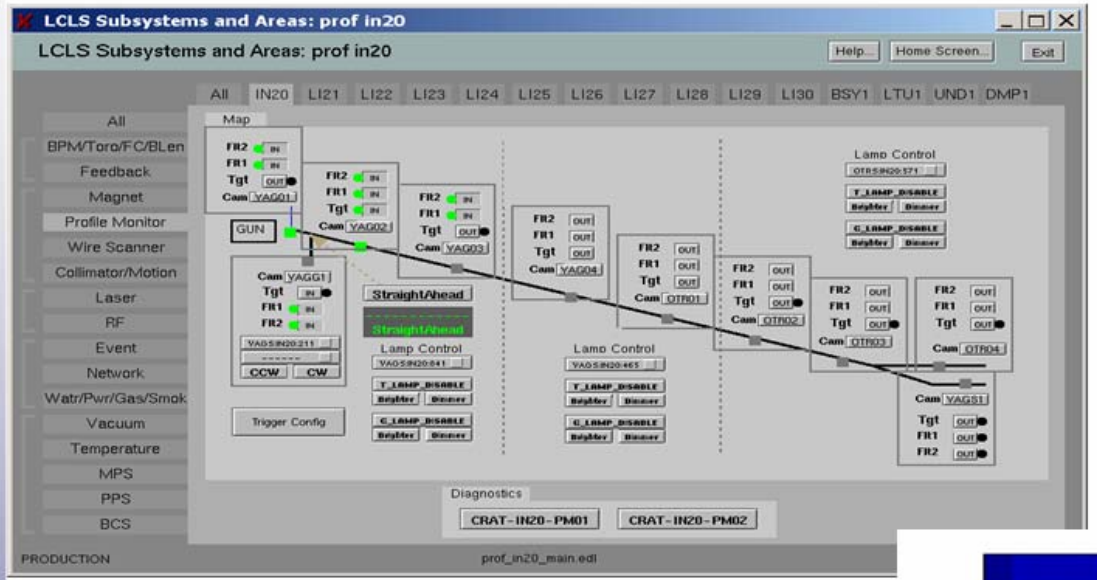
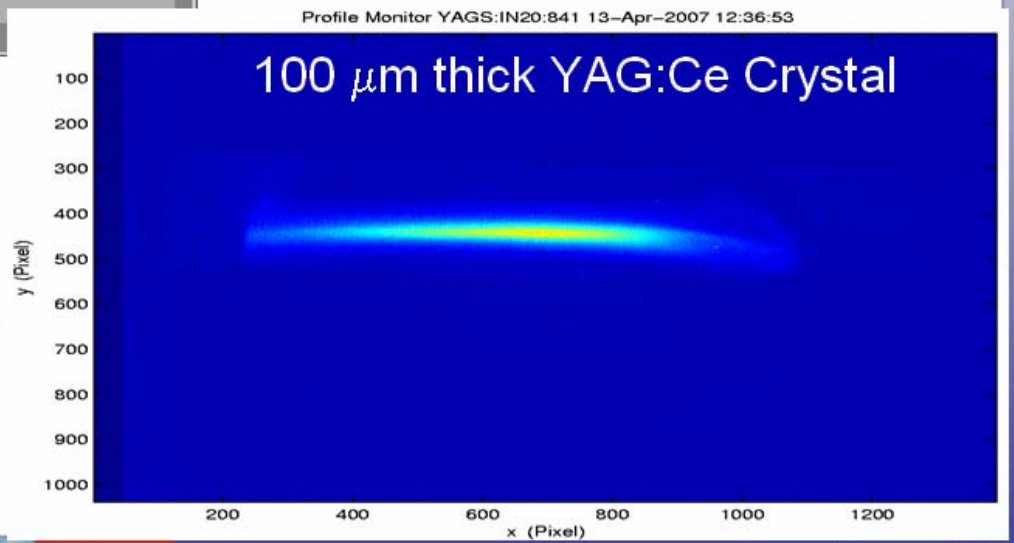
Profile monitor



- control and diagnostics through EDM screens

Gun spectrometer
YAG Profile Monitor Screen



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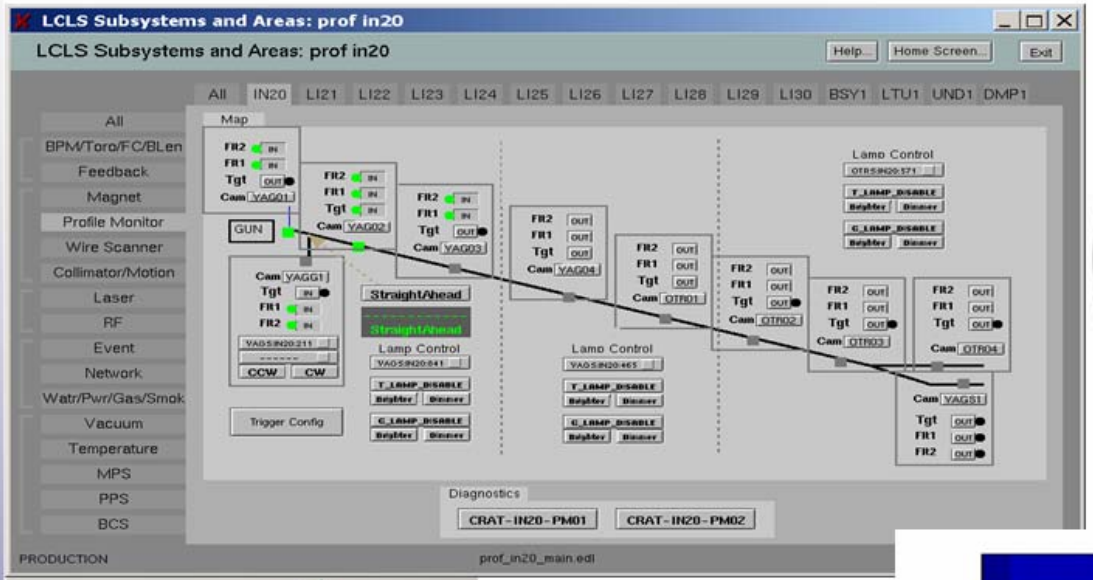
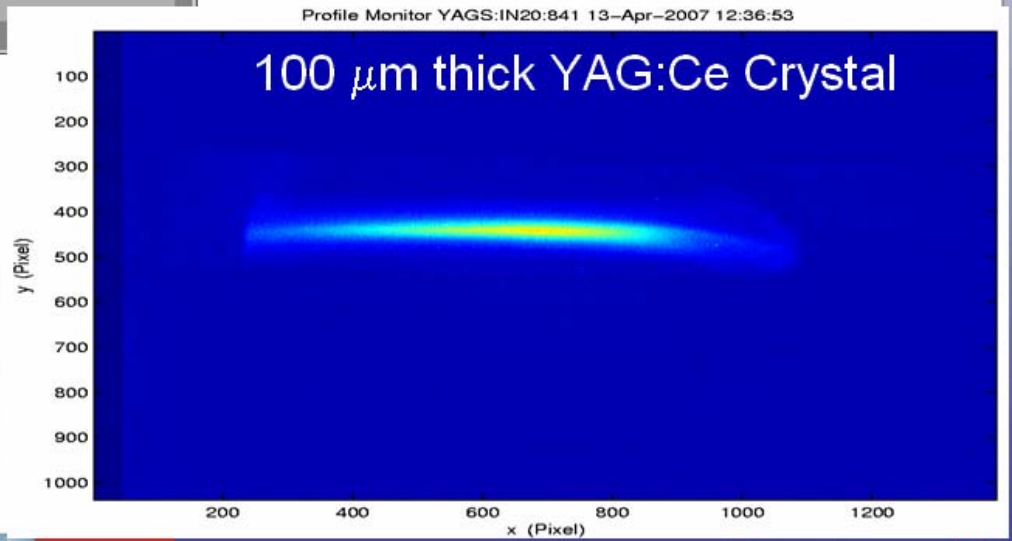
Profile monitor



UniqVision
12 bit, 1.4 MP
15 fps
CameraLink

RCX Camera link extender over fiber optic



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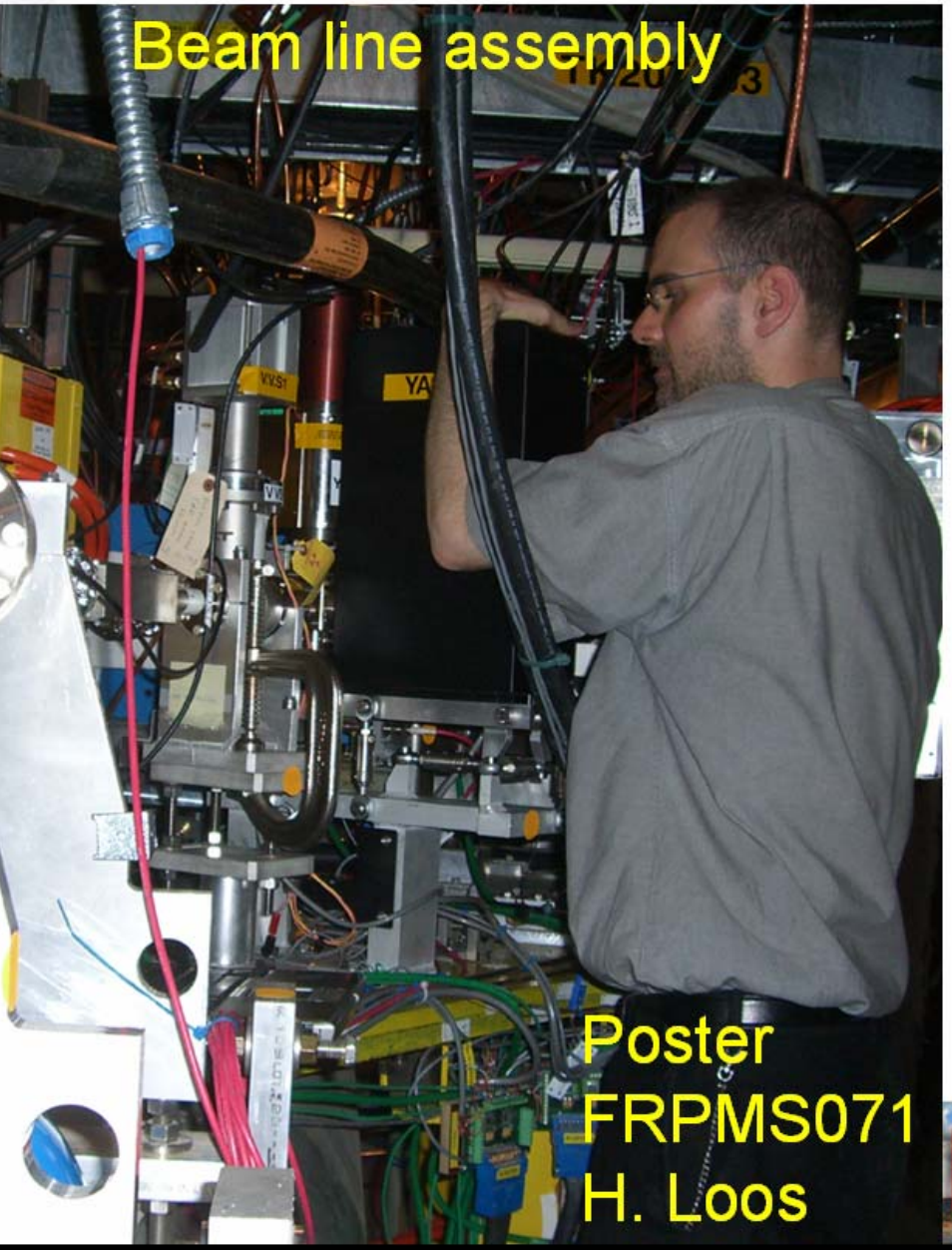
Profile monitors



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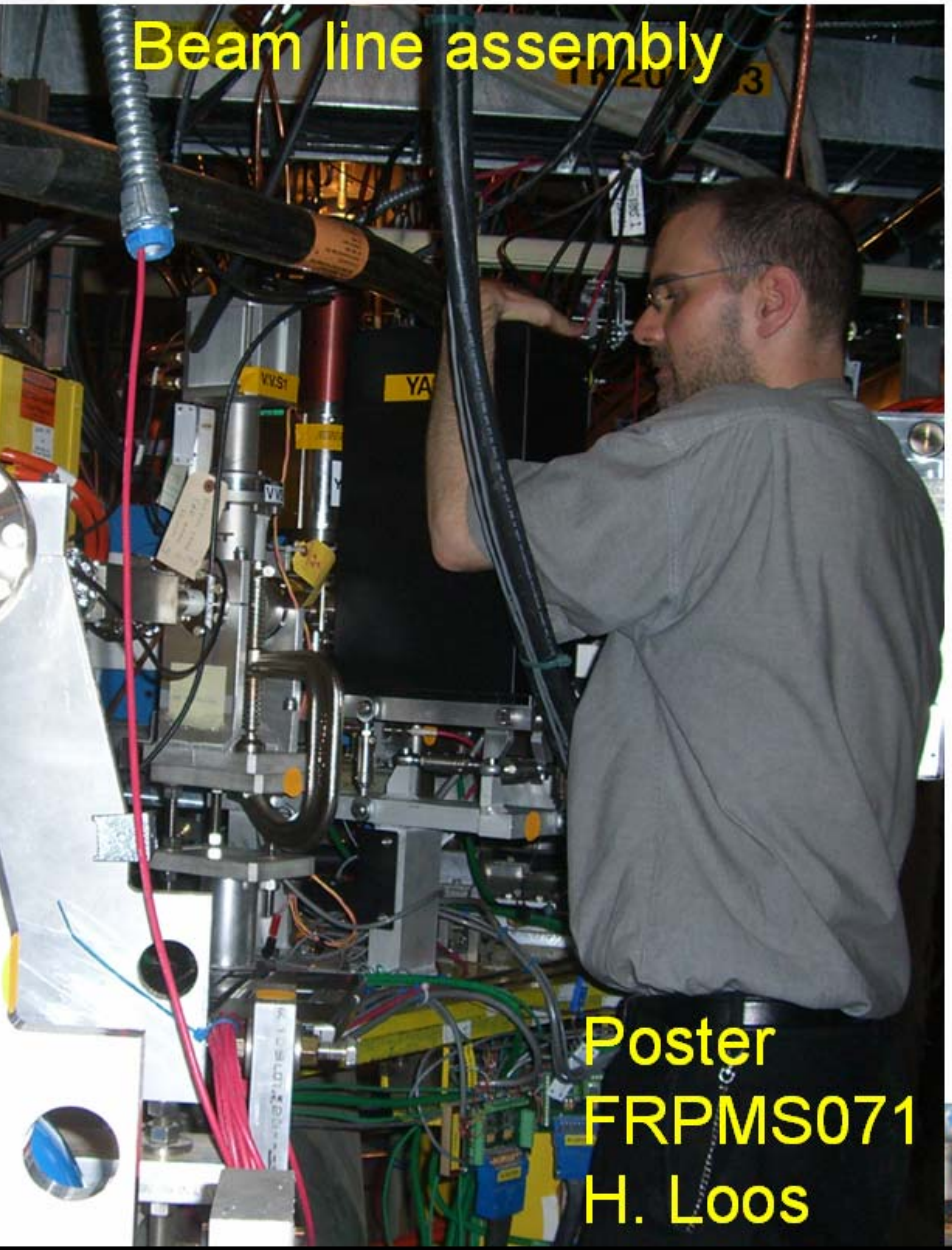
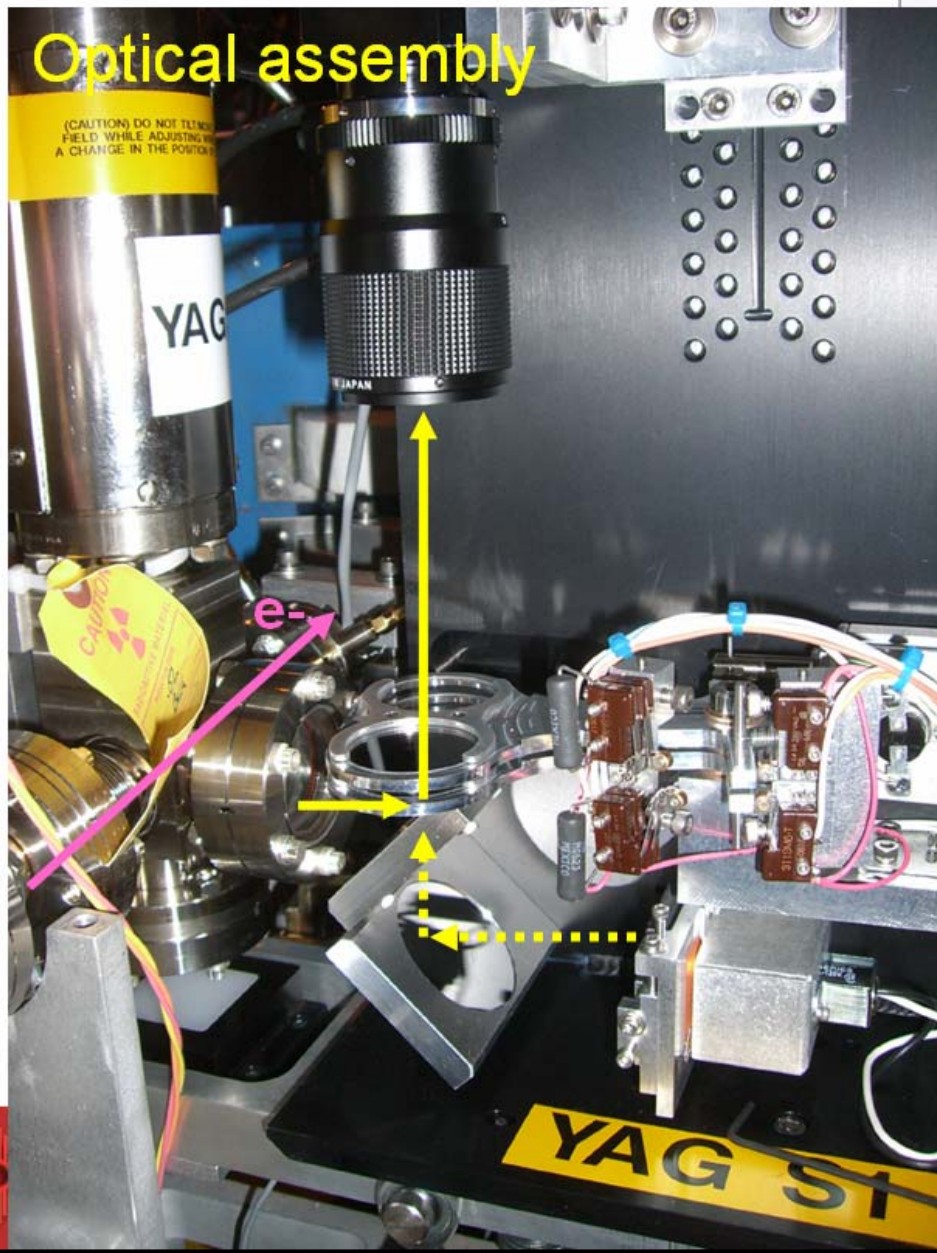
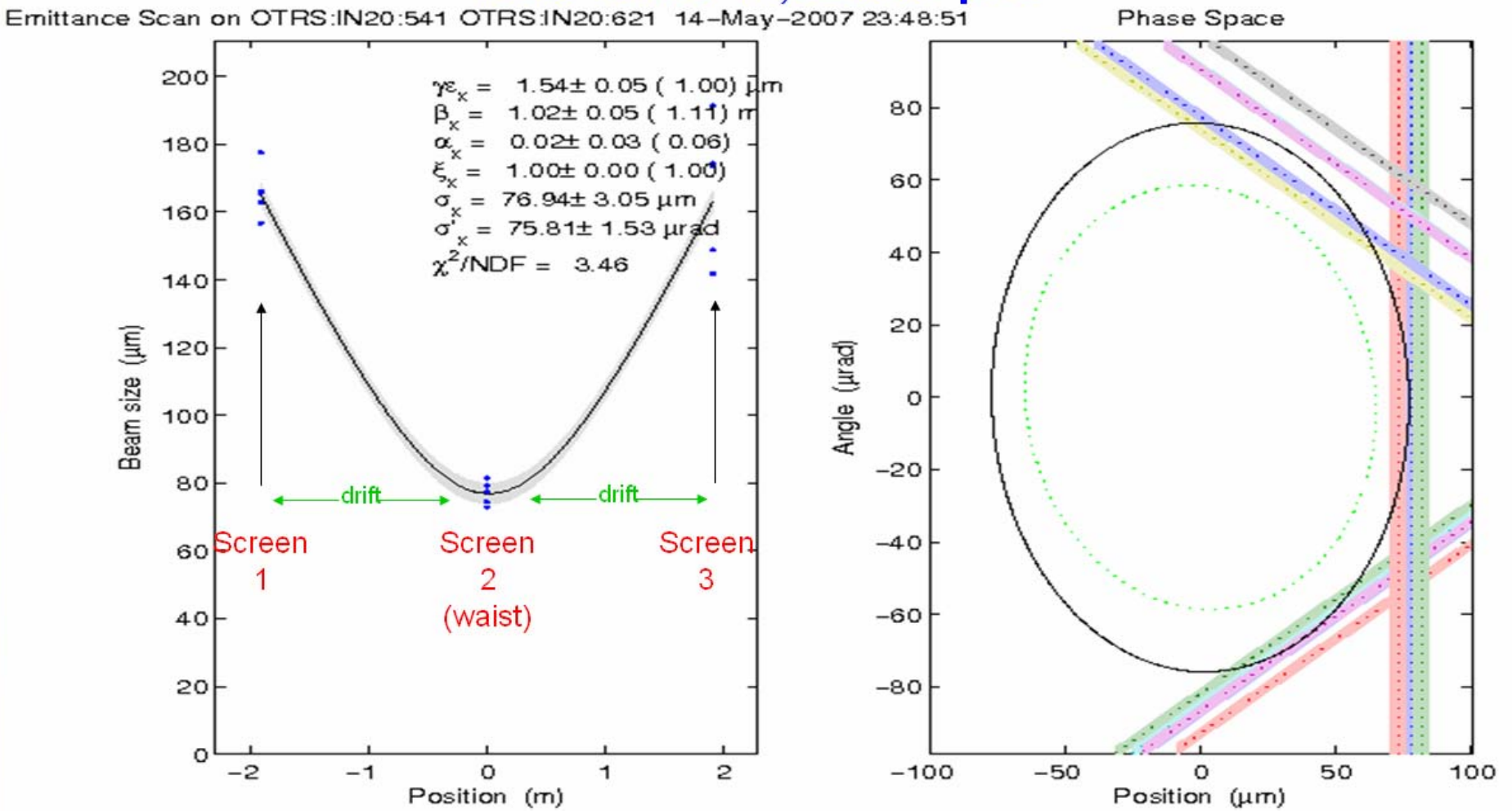




3-screen OTR Emittance Measurement
135 MeV, 200 pC



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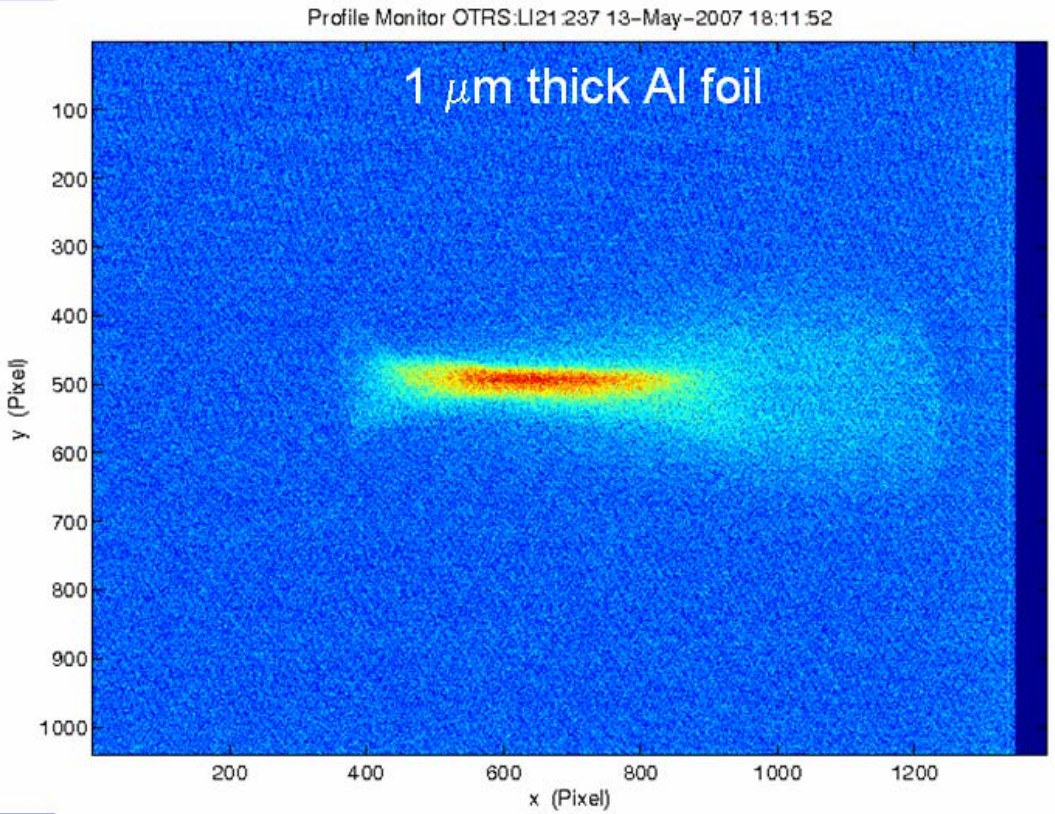
BC Chicane OTR Screen

- Energy spread in BC1
- at -40° off crest
- (4.1 mm)/(230 mm) = 1.8% rms.



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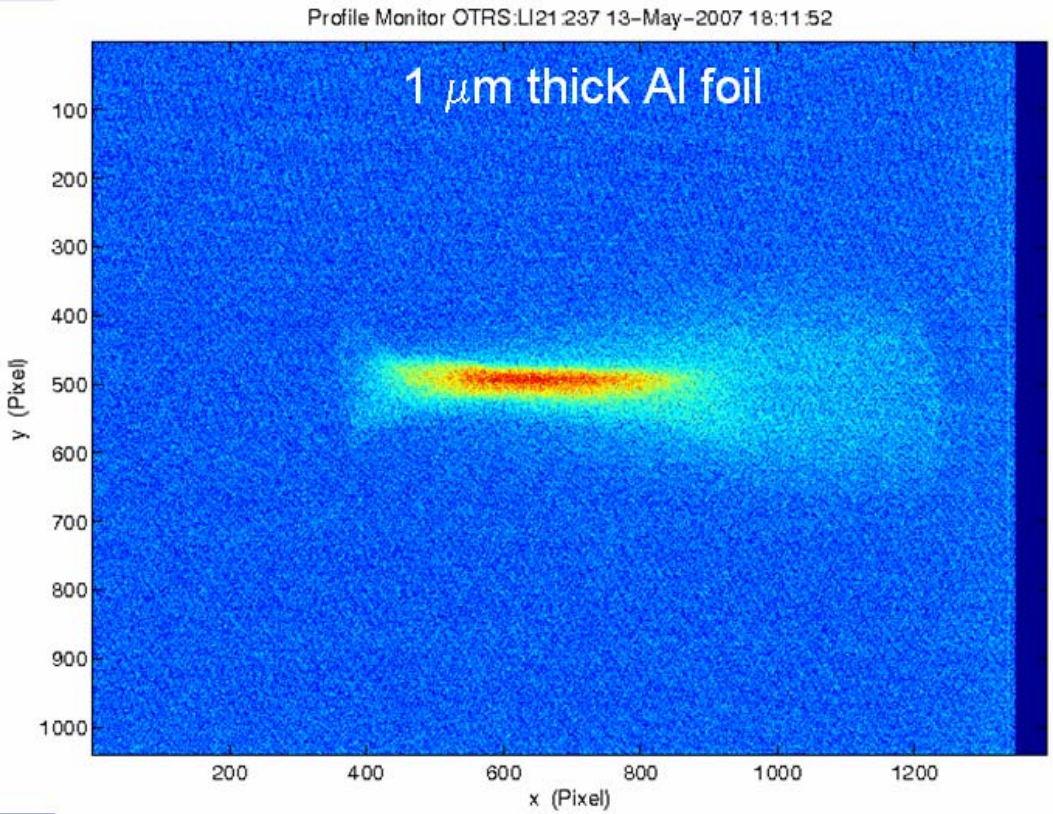

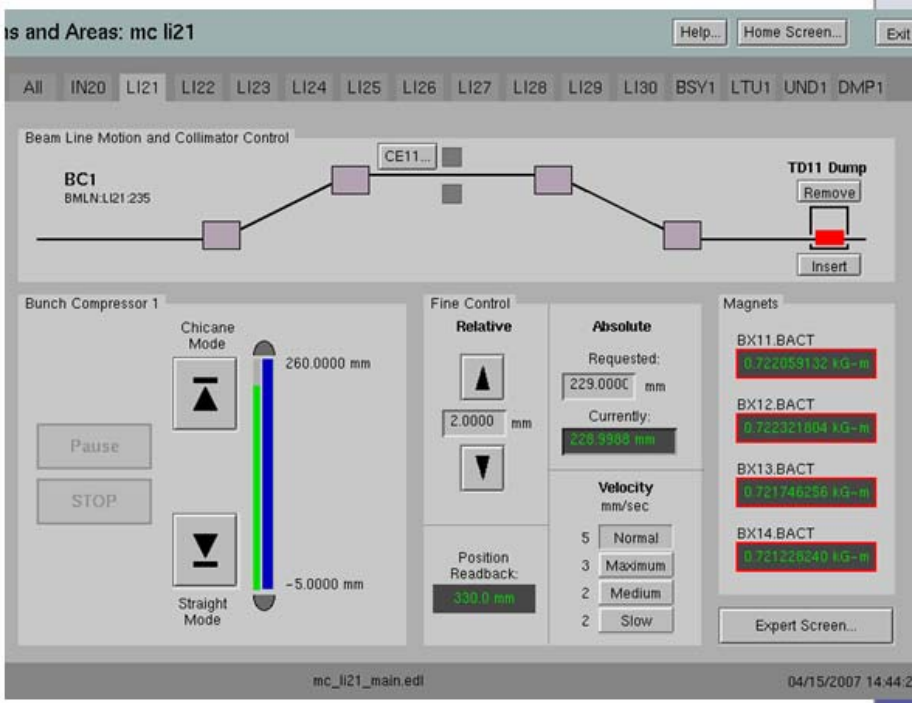

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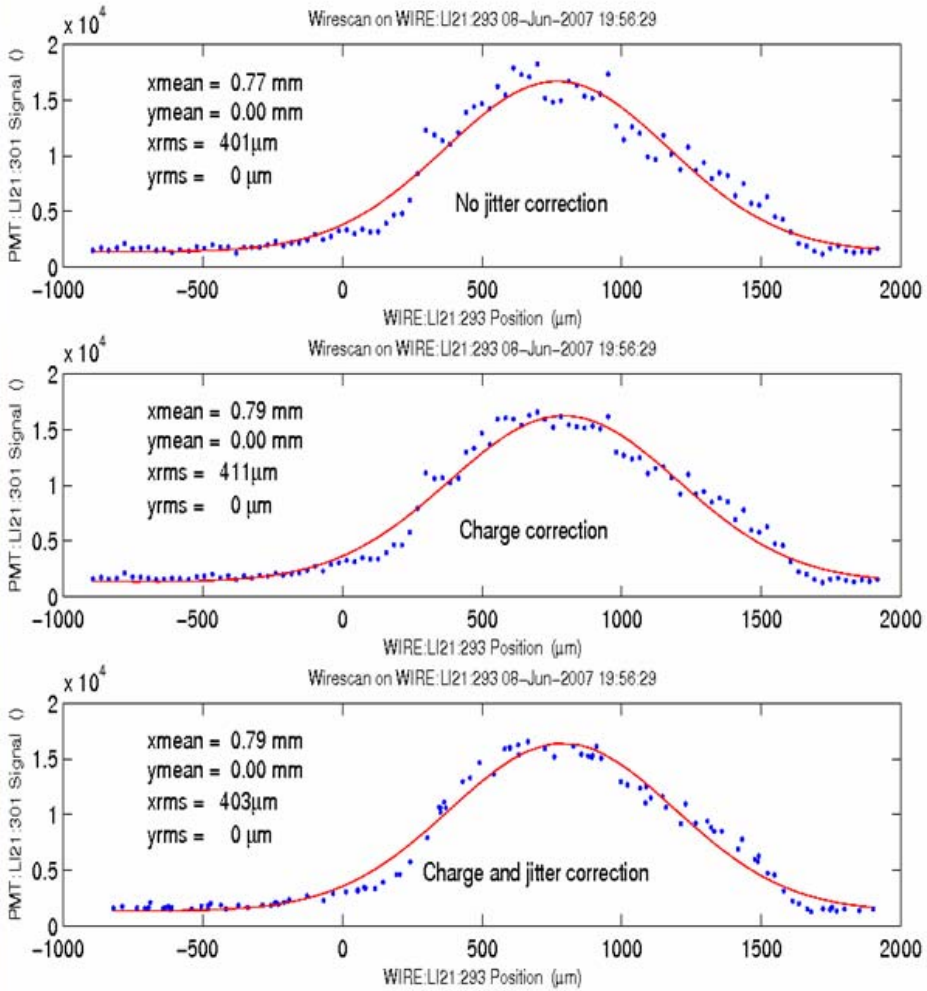
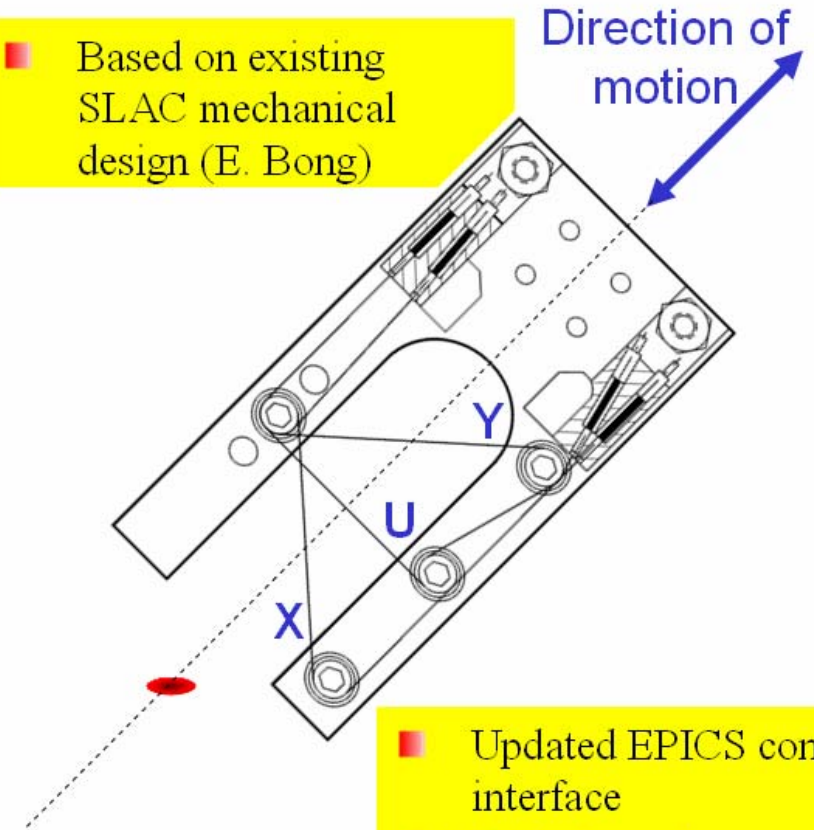
Wire Scanners



- Based on existing SLAC mechanical design (E. Bong)



- Updated EPICS controls interface
- Pulse-by-pulse compensation of bunch charge and trajectory jitter

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Two types of beam size measurement

- Profile monitor screens gives complete transverse profile of beam on a single shot
  - But inserting it in the beam is disruptive to FEL
- Wire scanner gives projected X, Y, and U profiles over several consecutive shots
  - But is minimally invasive
- Redundant measurements are good for commissioning

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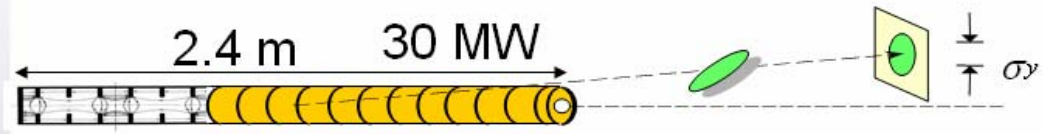
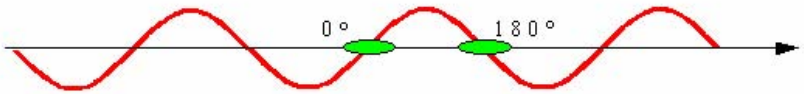
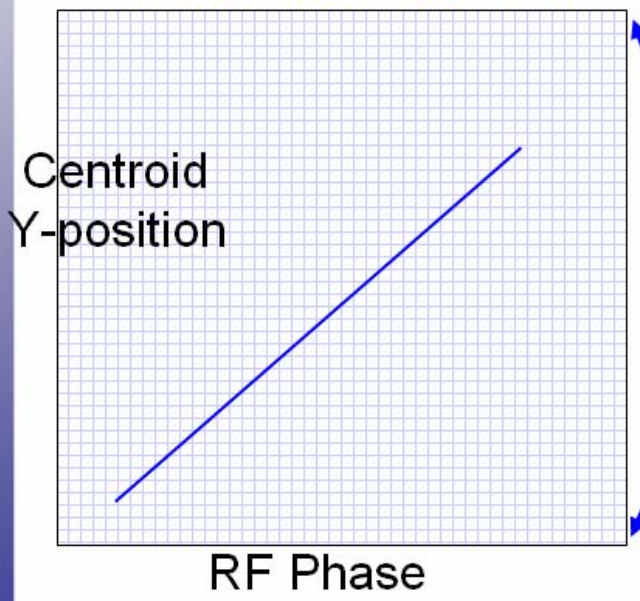
RF Transverse Deflecting Cavity

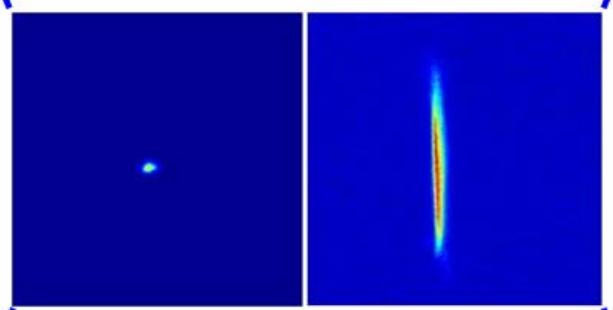


An S-band DLW structure with a TM_{11} transverse deflecting mode at 2856 MHz

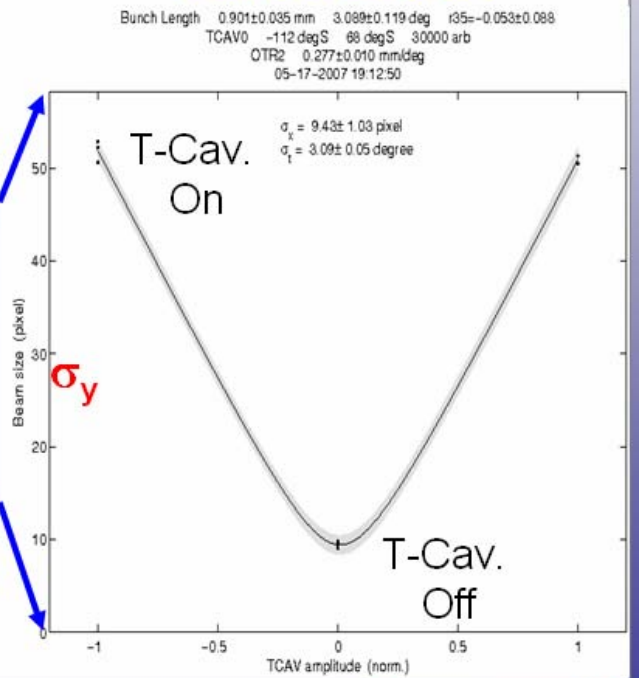


Absolute calibration





Bunch length



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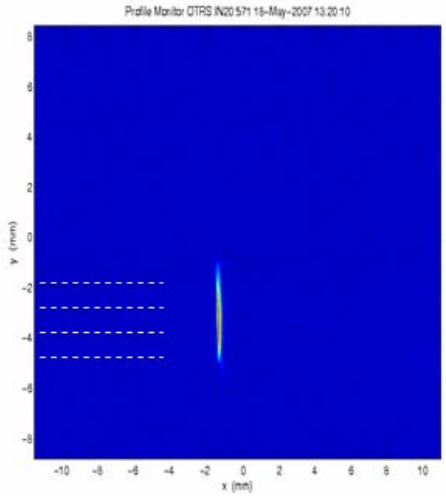
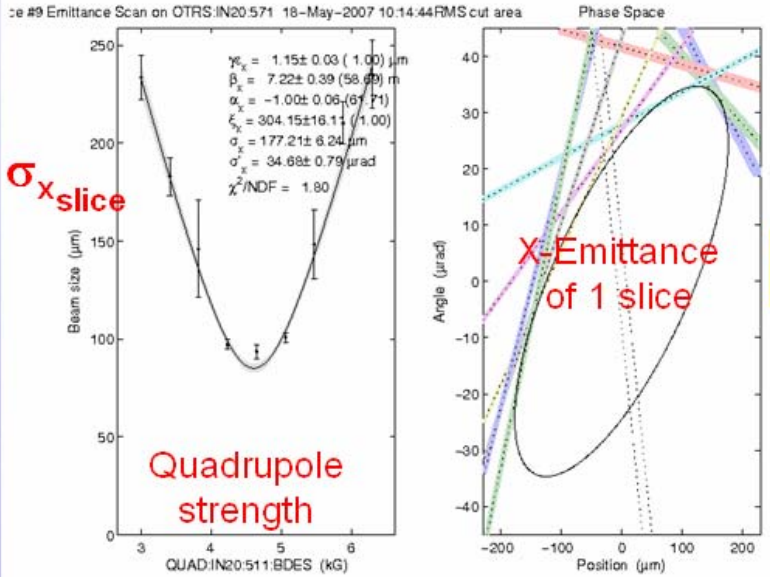
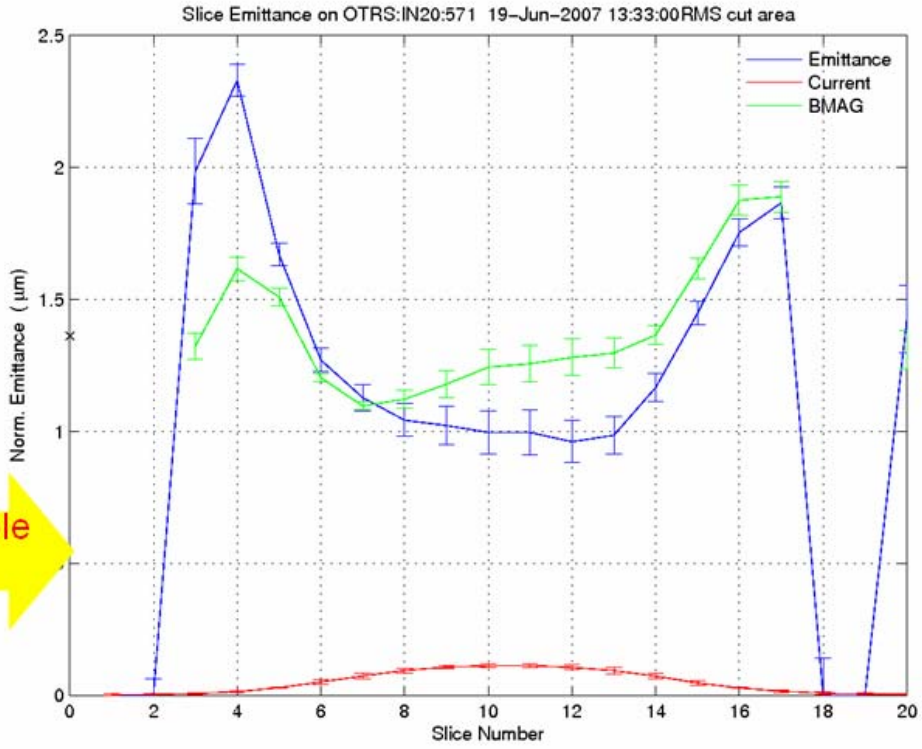
T-Cav. Slice Emittance Measurement

Slice up OTR screen image





Reassemble slices



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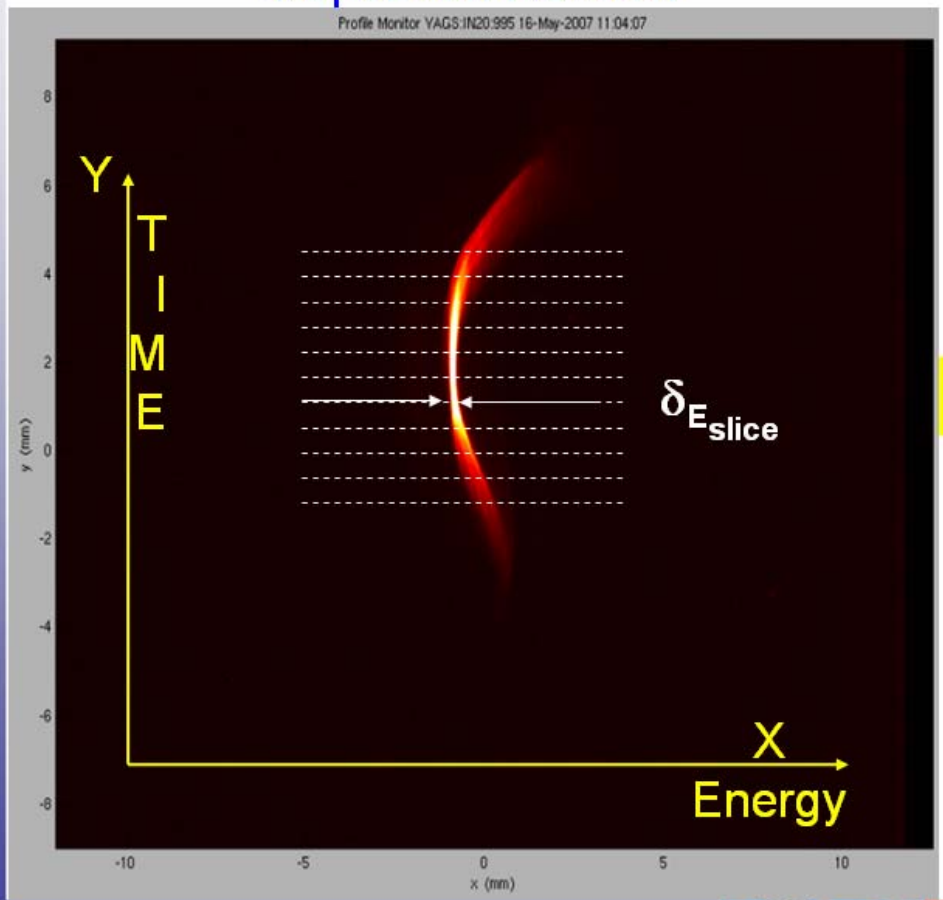
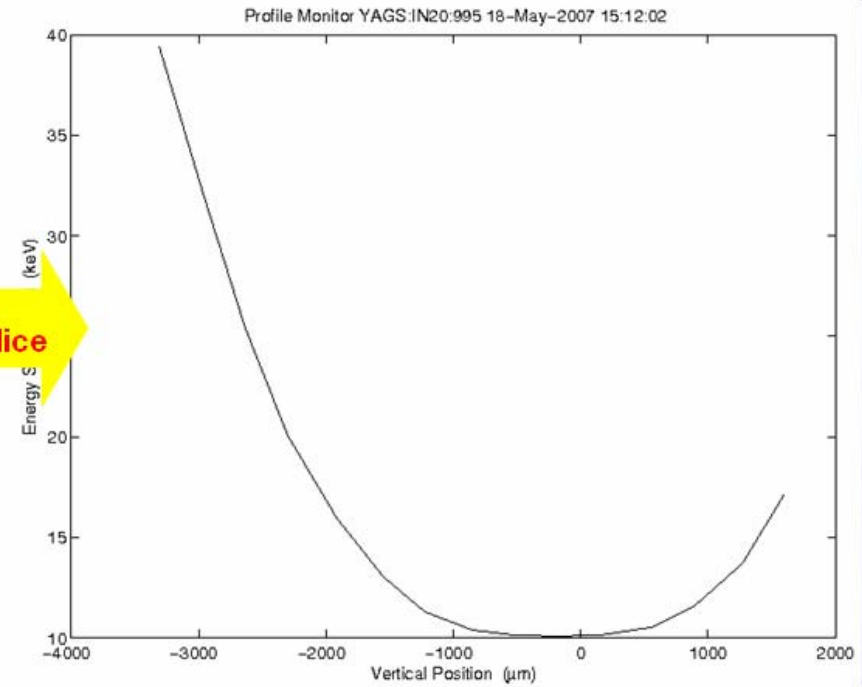
T-Cav Slice Energy Spread Measurement

Screen at high dispersion location



$\sigma_{x_{slice}}$

Slice Energy Spread



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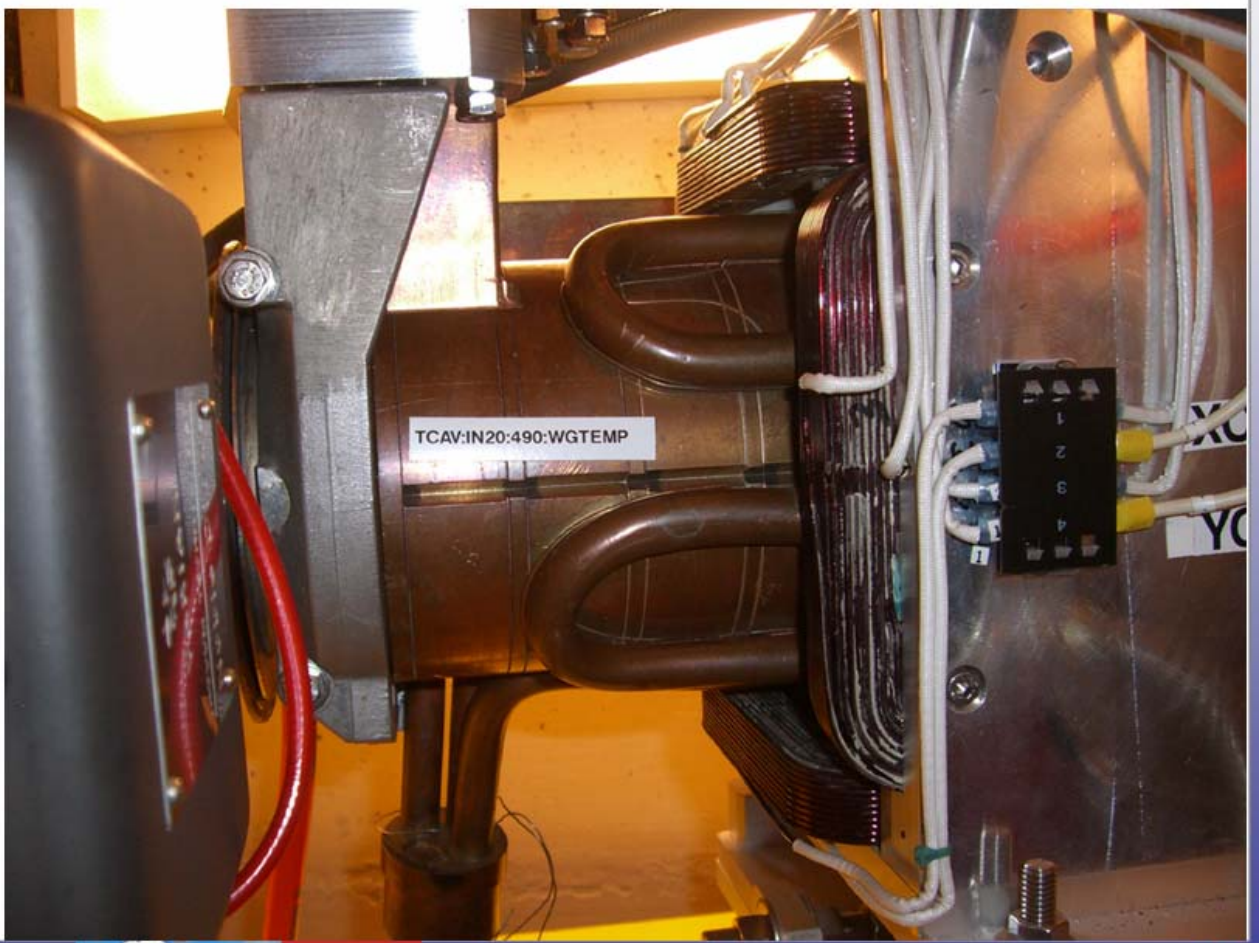
SSRL

Transverse Deflecting Cavity Installation



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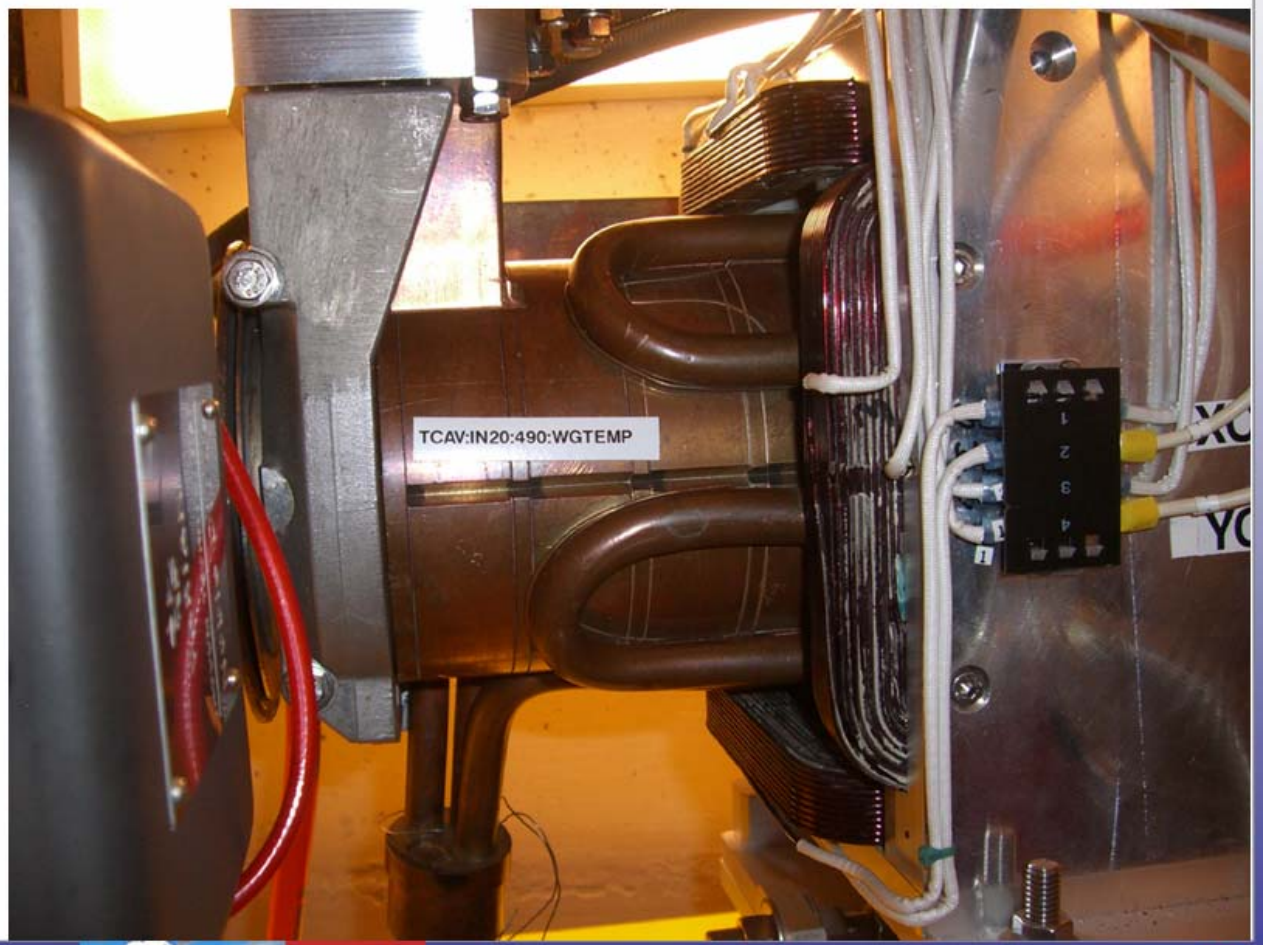
Transverse Deflecting Cavity Installation

- Injector uses a short, 40 cm S-band traveling wave structure
- A second 2.4 m structure is located downstream of BC2



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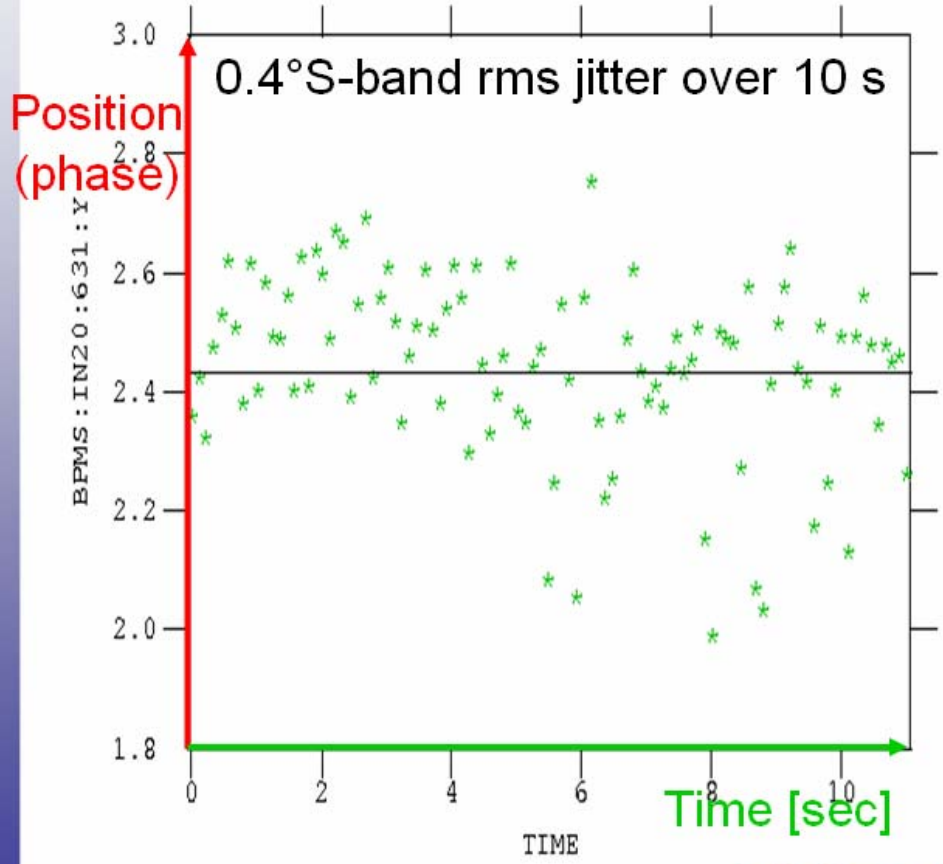
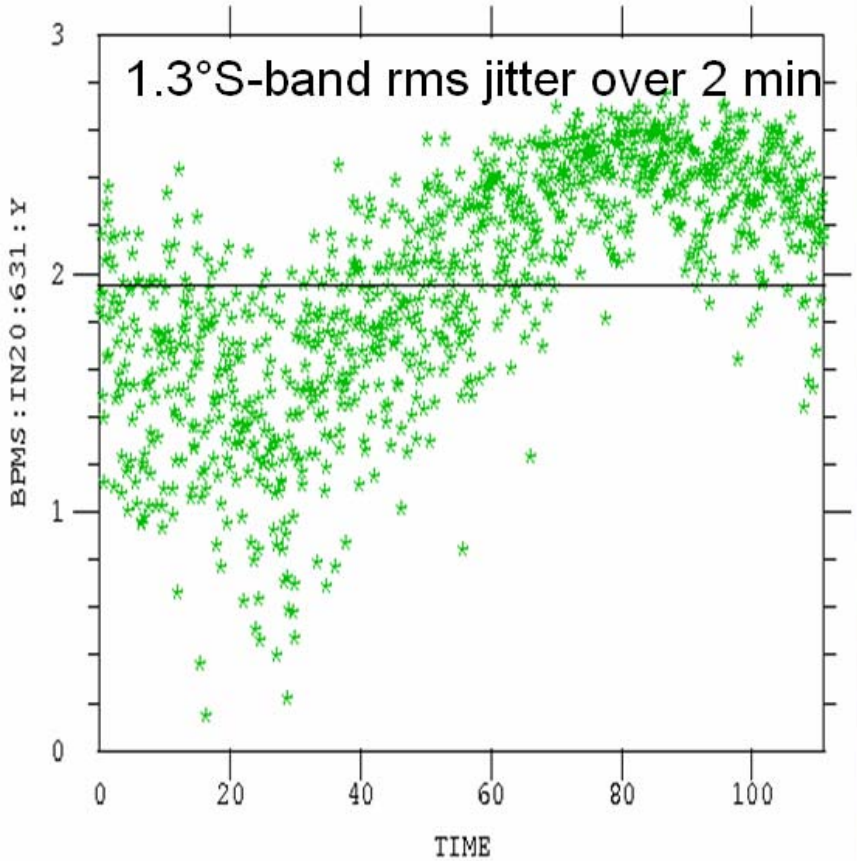
T-Cav Measurement of LLRF phase jitter

Measure transverse position, shot by shot downstream of deflecting cavity





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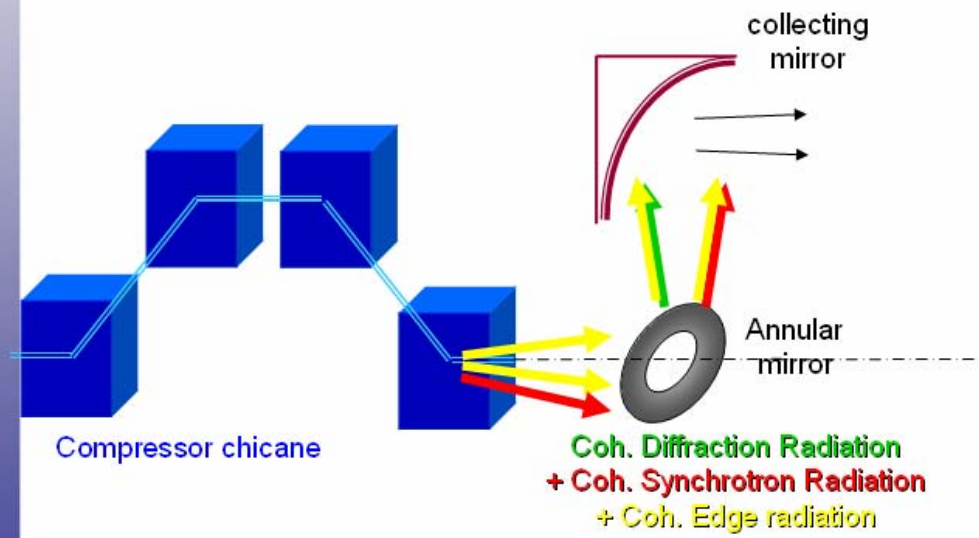
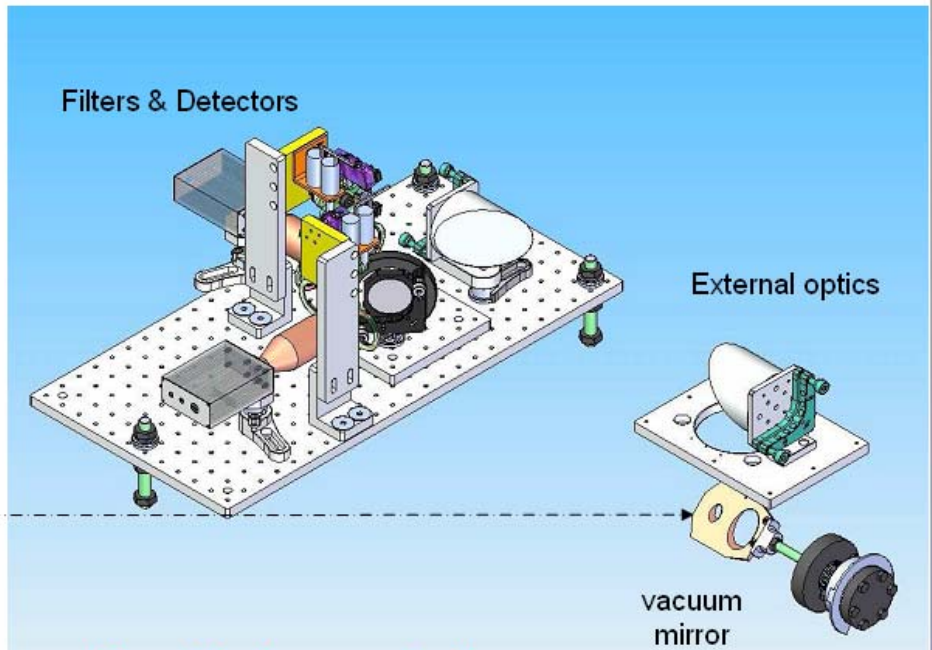
Coherent radiation bunch length monitor

- Radiation monitoring port at exit of bunch compressor chicane
- Preliminary results show good correlation between pyro-electric detector and the bunch length





See H. Loos *et al.*
FRPMS071

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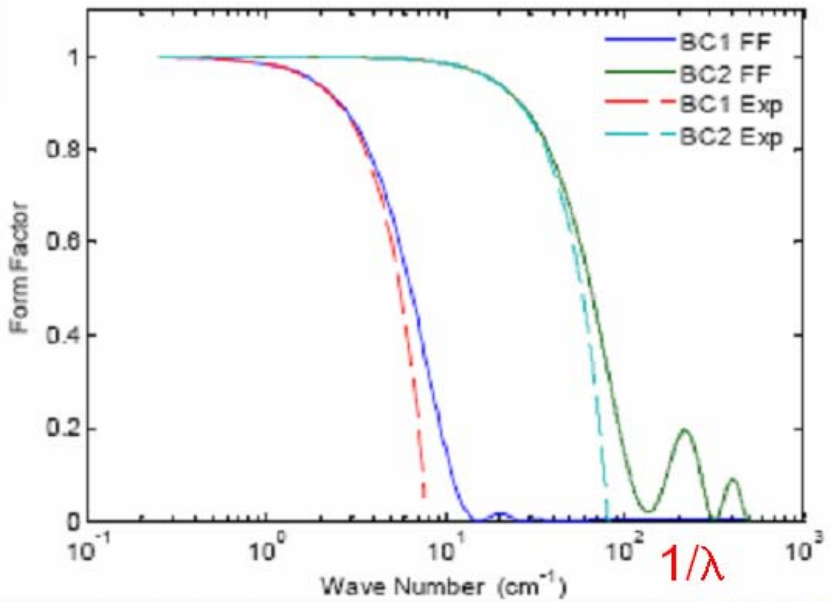
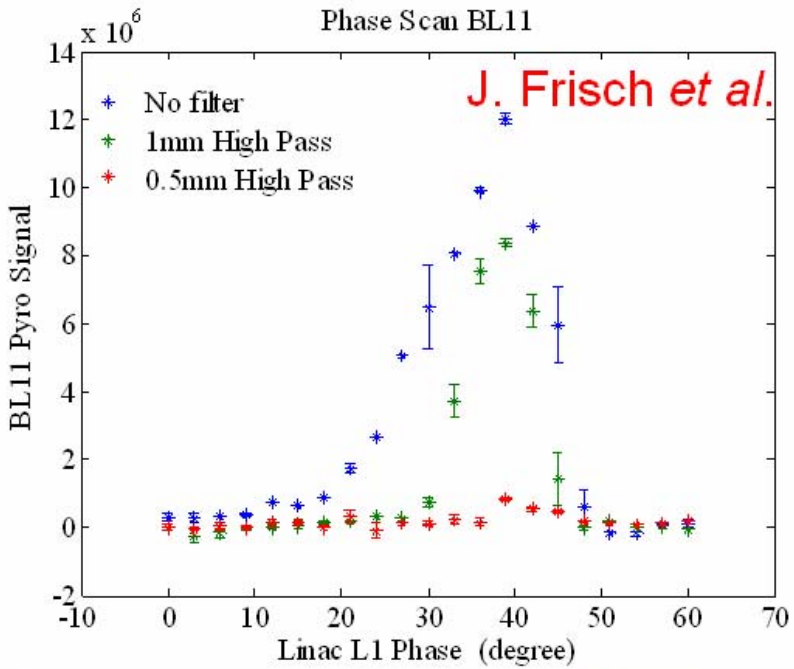
First bunch length monitor data

- Radiation form factor depends on rms bunch length
- Bunch length after BC1: 60 – 200 μm



- Wavelength range to determine bunch length: 0.3 – 1 mm
- Measure integrated coherent power and use frequency filters



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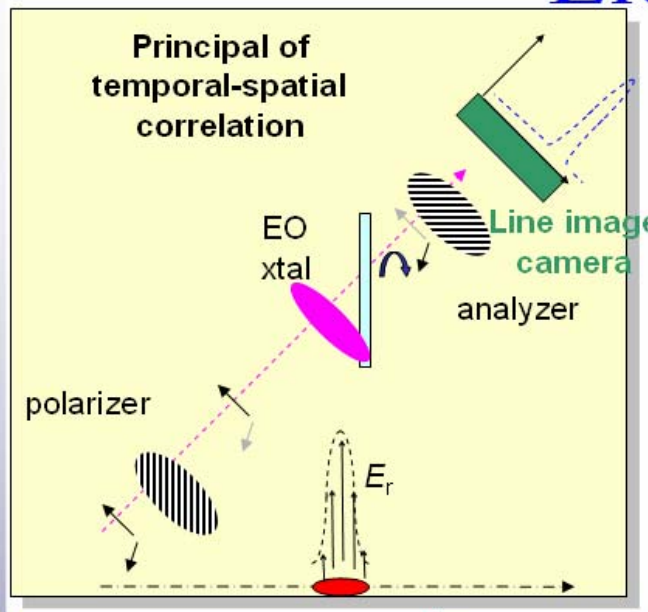
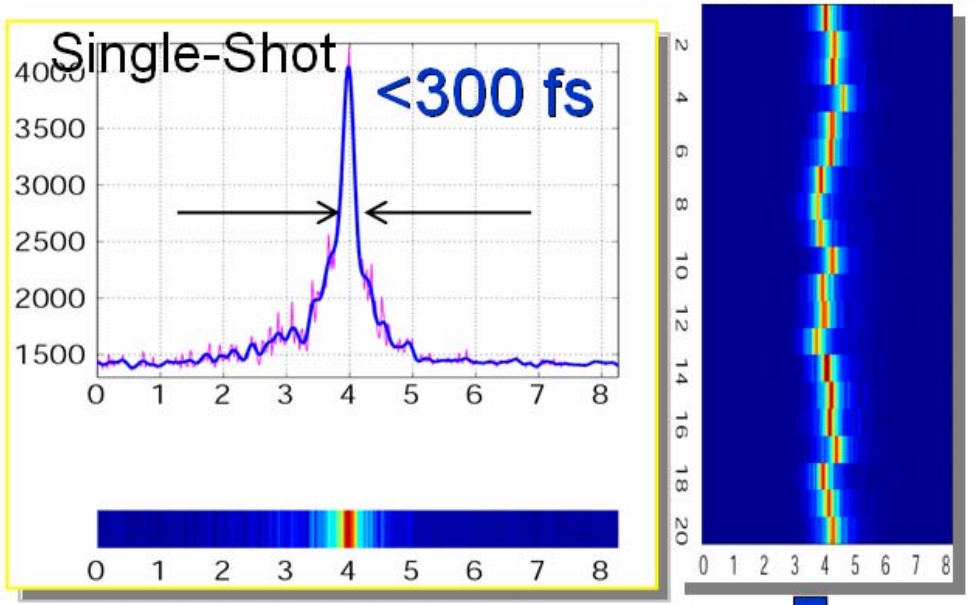
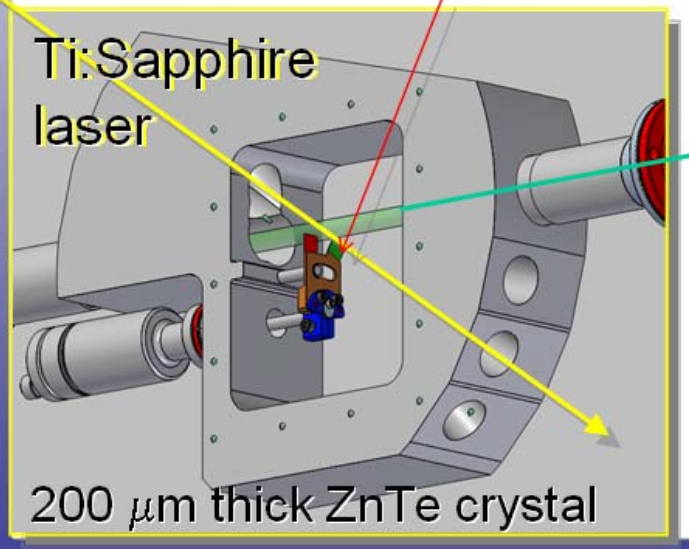
Electro-Optical Sampling at SPPS

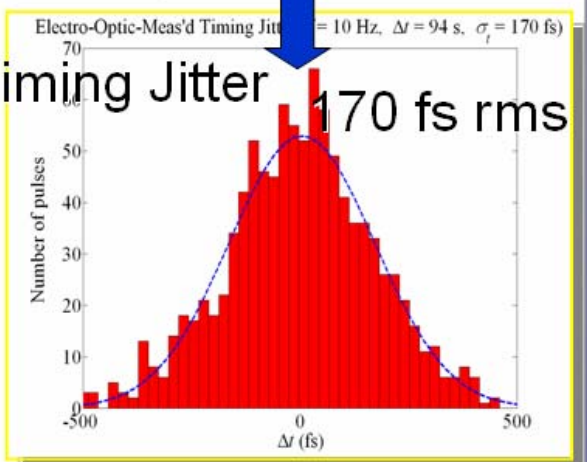
– A. Cavalieri et al.







e^-



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Summary

- Challenging to provide single shot measurements with high precision
- Implementation of new techniques for bunch length and time-resolved measurements
- Room for new techniques to be developed!
- Still to come
  - Photon diagnostics in the FEL
  - Optimization of SASE operation

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ACKNOWLEDGEMENTS

- R. Akre,
- E. Bong,
- J. Castro,
- F-J. Decker,
- D. Dowell,
- P. Emma,
- J. Frisch,
- S. Gilevich,
- R. Iverson,
- C. Limborg-Deprey,
- R. Lill,
- H. Loos,
- T. Montagne,
- H-D. Nuhn,
- S. Peng
- M. Saleski,
- J. Schmerge,
- S. Smith,
- J. Turner,
- J. Welch,
- W. White,
- M. Woodley,
- J. Wu

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