

# Particle Accelerator Conference 2007

*Albuquerque, New Mexico, June 25-29*

## Diagnosics for LCLS Commissioning

Patrick Krejcik, SLAC

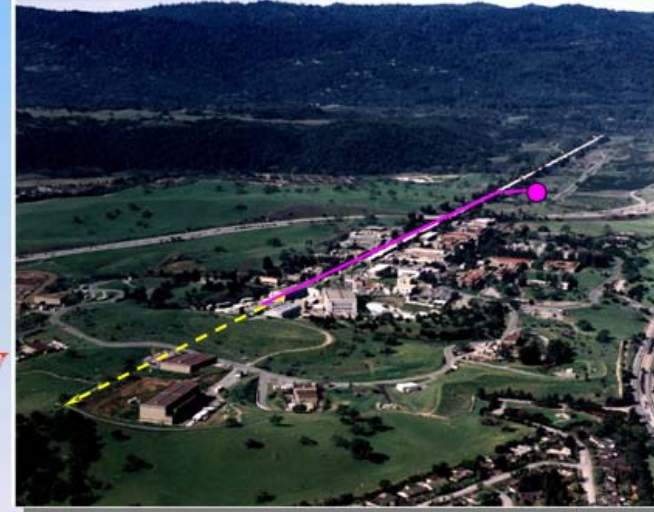
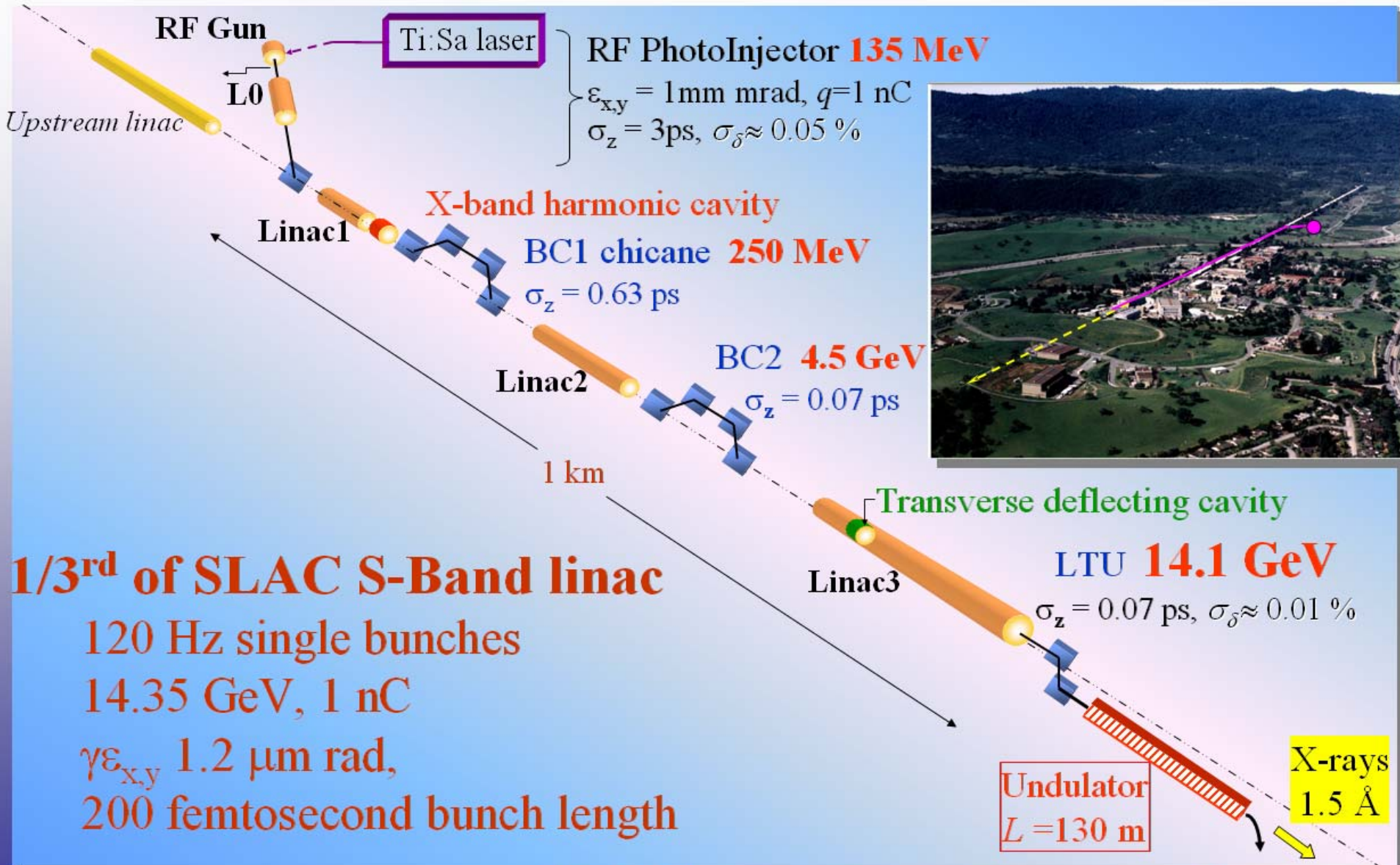
on behalf of the LCLS commissioning team.



# 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





# Diagnostic Challenges

- Very low emittance beams  $\gamma\epsilon_{x,y} \sim 1 \mu\text{m rad}$ 
  - Trajectory resolution as low as  $1 \mu\text{m}$  in the undulator
  - Beam size resolution  $7 \mu\text{m}$
- 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

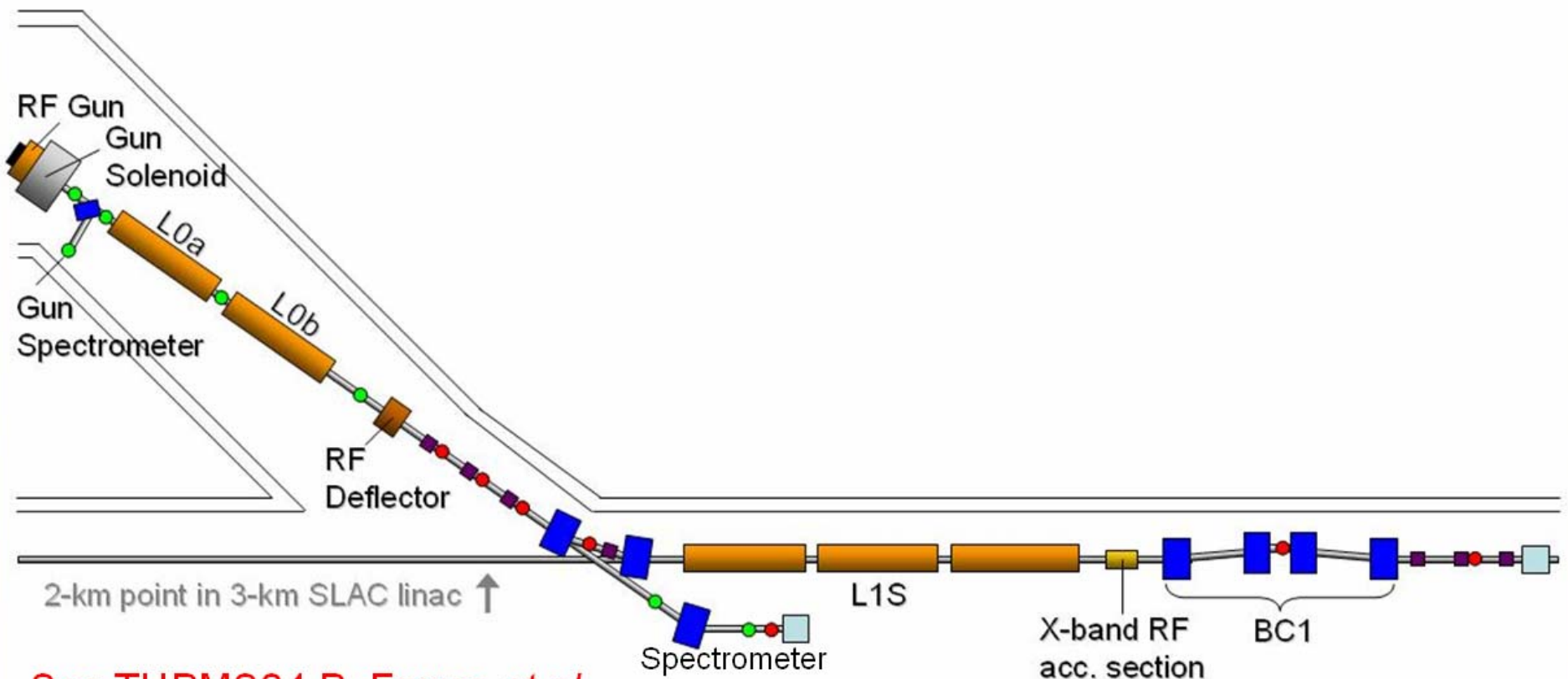


## Commissioning Schedule

- 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



# LCLS Injector and First Bunch Compressor Instrumentation

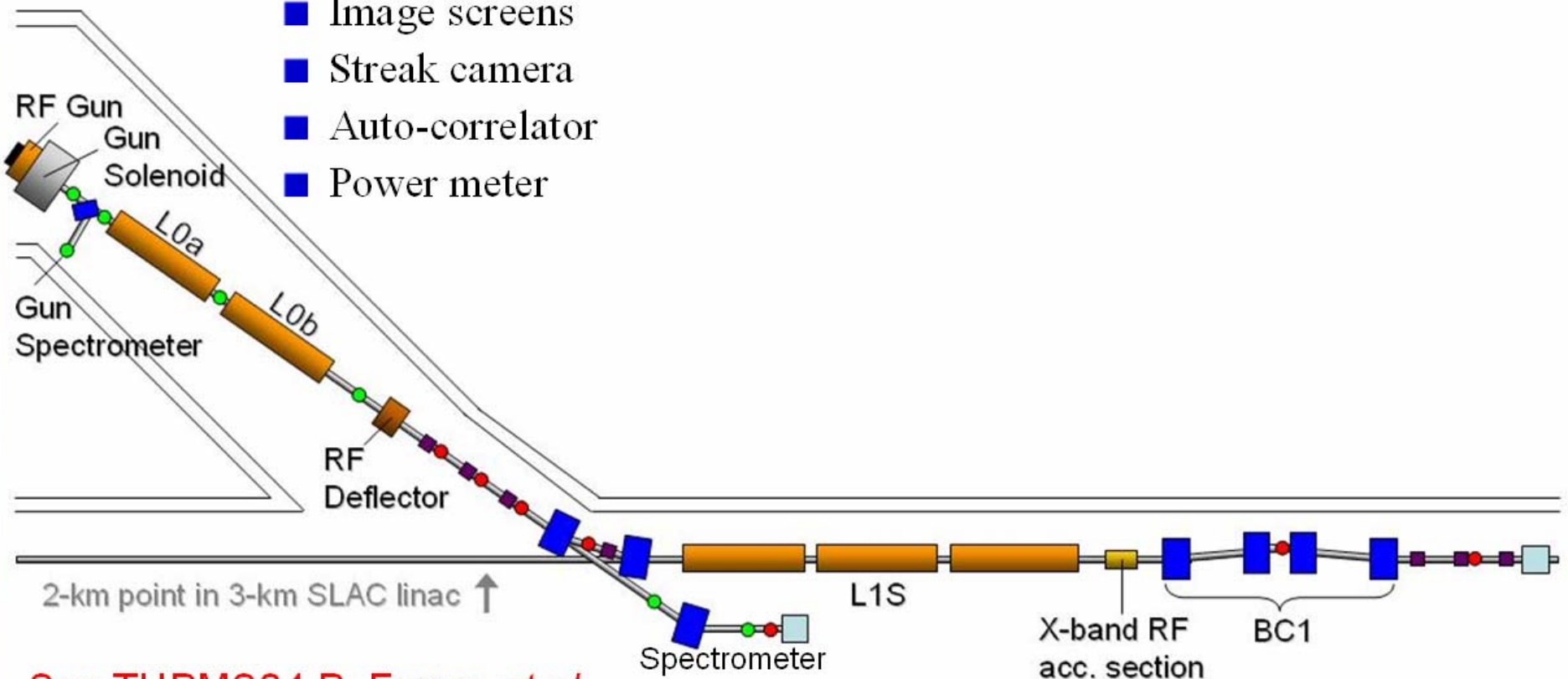


See TUPMS04 P. Emma *et al.*

# LCLS Injector and First Bunch Compressor Instrumentation

## ■ Laser diagnostics

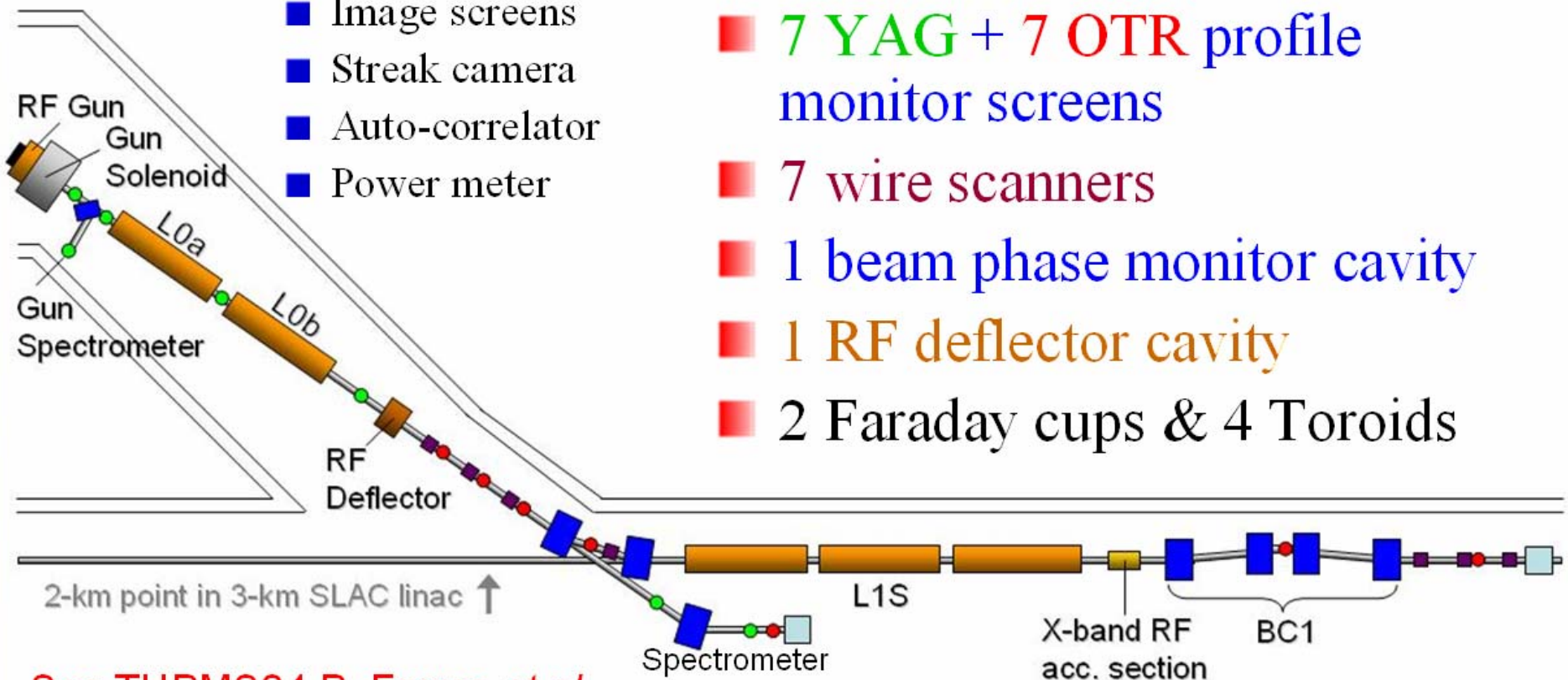
- Image screens
- Streak camera
- Auto-correlator
- Power meter



See TUPMS04 P. Emma *et al.*

# 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



See TUPMS04 P. Emma *et al.*





# Some Photos Of The Injector Vault



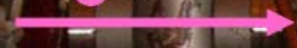


# RF Gun

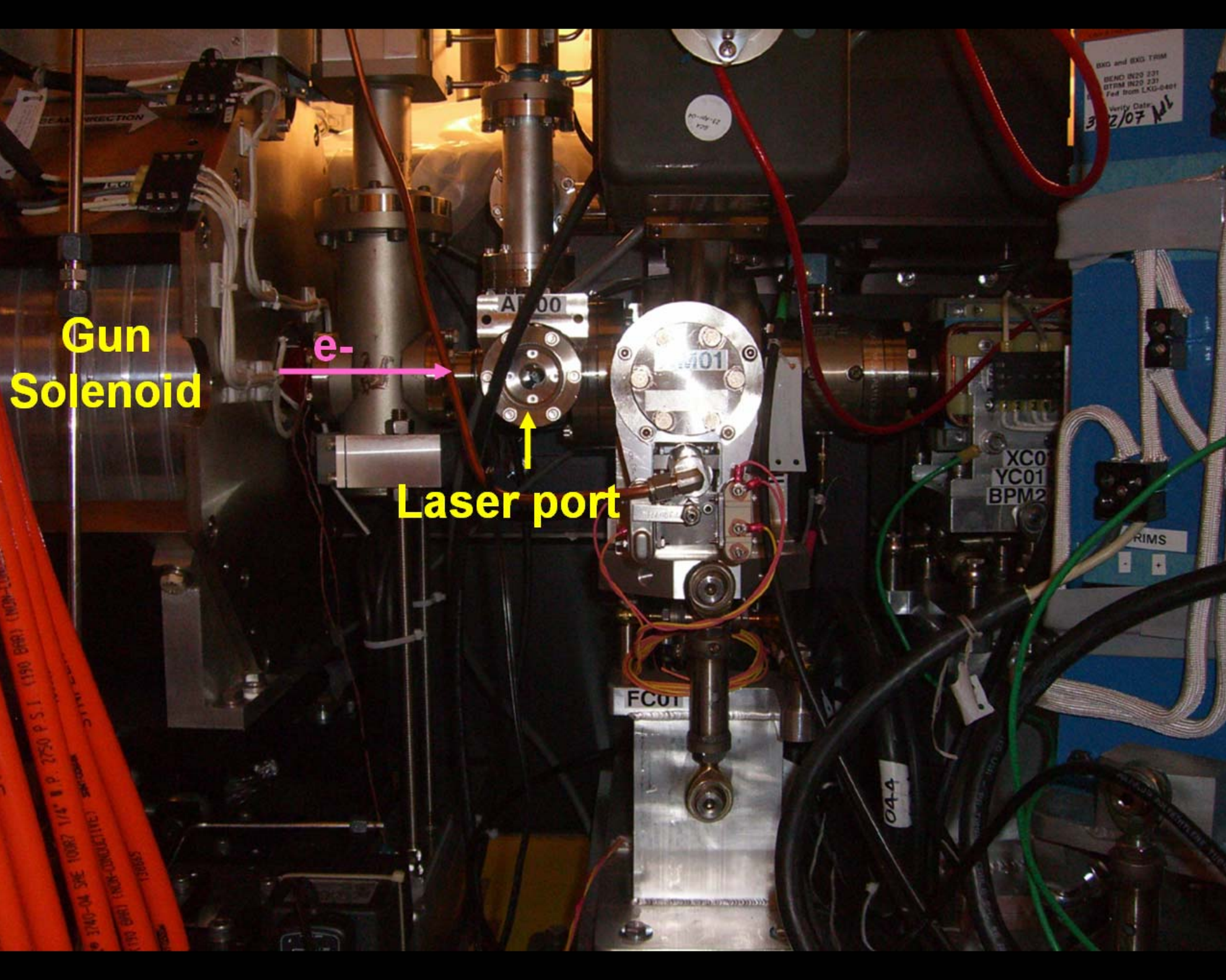
June 25-29  
PAC 2007, Albuquerque N

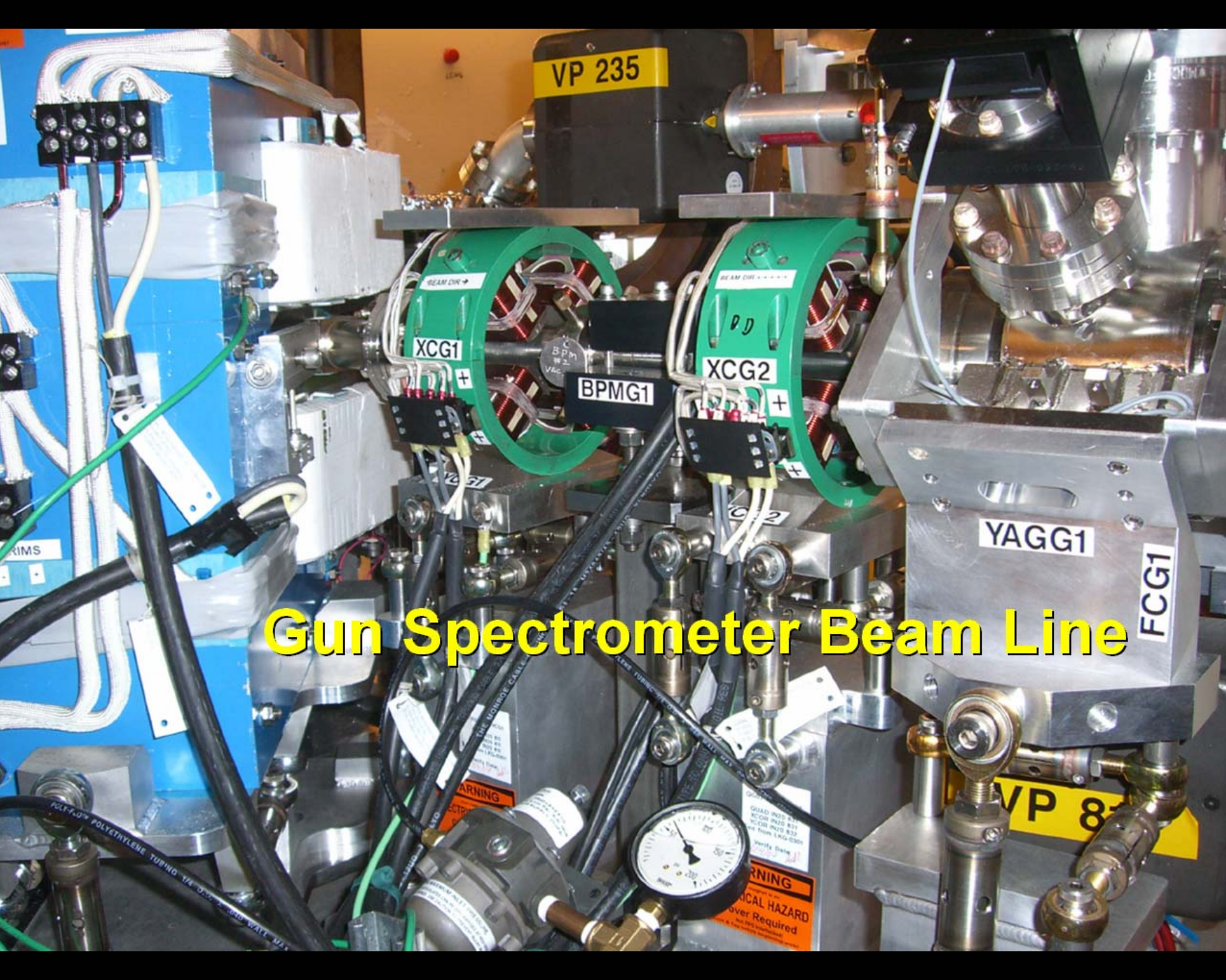
**Gun  
Solenoid**

**e-**



**Laser port**

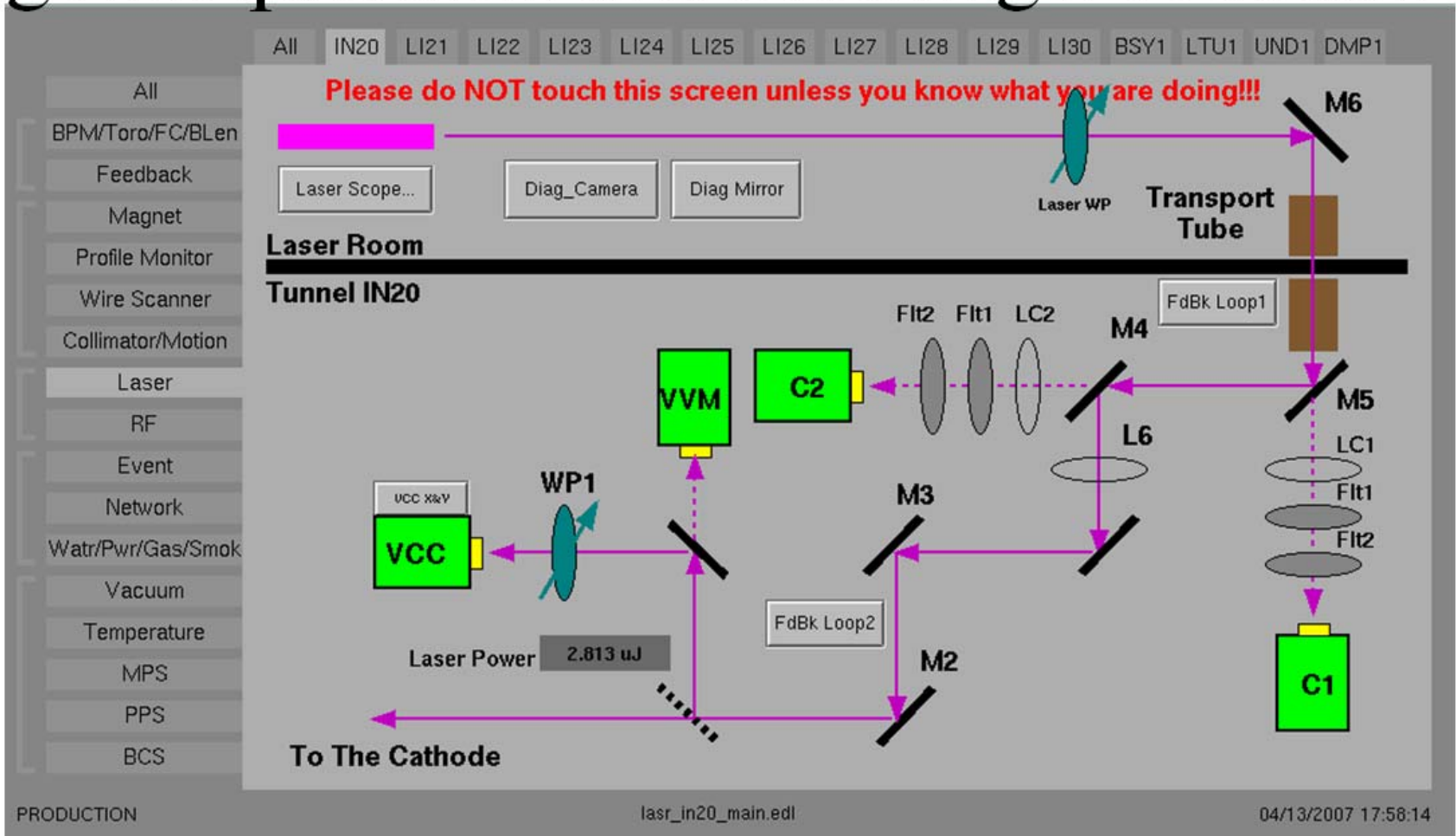




# Gun Spectrometer Beam Line

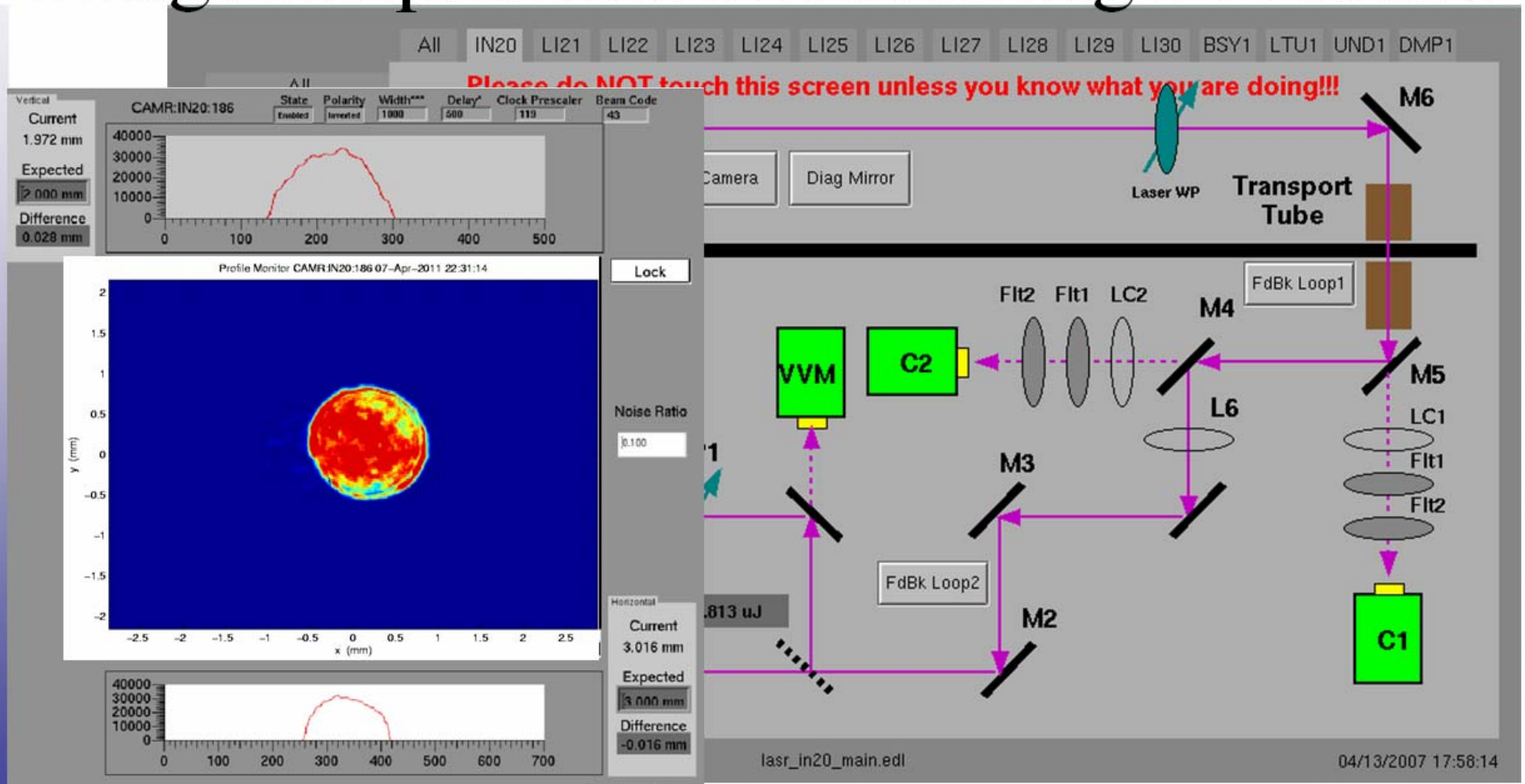
# Laser Systems

## Image Acquisition and Steering Feedback



# Laser Systems

## Image Acquisition and Steering Feedback



# Laser Systems

## Image Acquisition and Steering Feedback

The screenshot displays a control interface for a laser system. At the top, there are tabs for various components: All, IN20, LI21, LI22, LI23, LI24, LI25, LI26, LI27, LI28. A red warning message reads: "Please do NOT touch this screen unless you know what you are doing".

On the left, a "Vertical" control panel shows:
 

- Current: 1.972 mm
- Expected: 2.000 mm
- Difference: 0.028 mm

 Below this is a graph of a beam profile. A "Profile Monitor" window shows a 2D heatmap of the beam spot with axes x (mm) and y (mm) ranging from -2.5 to 2.5. A "Horizontal" control panel at the bottom left shows:
 

- Current: 3.016 mm
- Expected: 3.000 mm
- Difference: -0.016 mm

On the right, a schematic diagram of the optical path is shown. It includes components: VVM, C2, M3, M2, M5, LC1, Flt1, Flt2, L6, and C1. A feedback loop labeled "FdBk Loop2" is connected to the system. A purple laser beam path is indicated. A "Camera" button and "Diag Mirror" button are visible. The interface also shows a "Noise Ratio" of 0.100 and a "Lock" button.

At the bottom right of the interface, the text "lasr\_in20\_main.edi" and the timestamp "04/13/2007 17:58:14" are present.

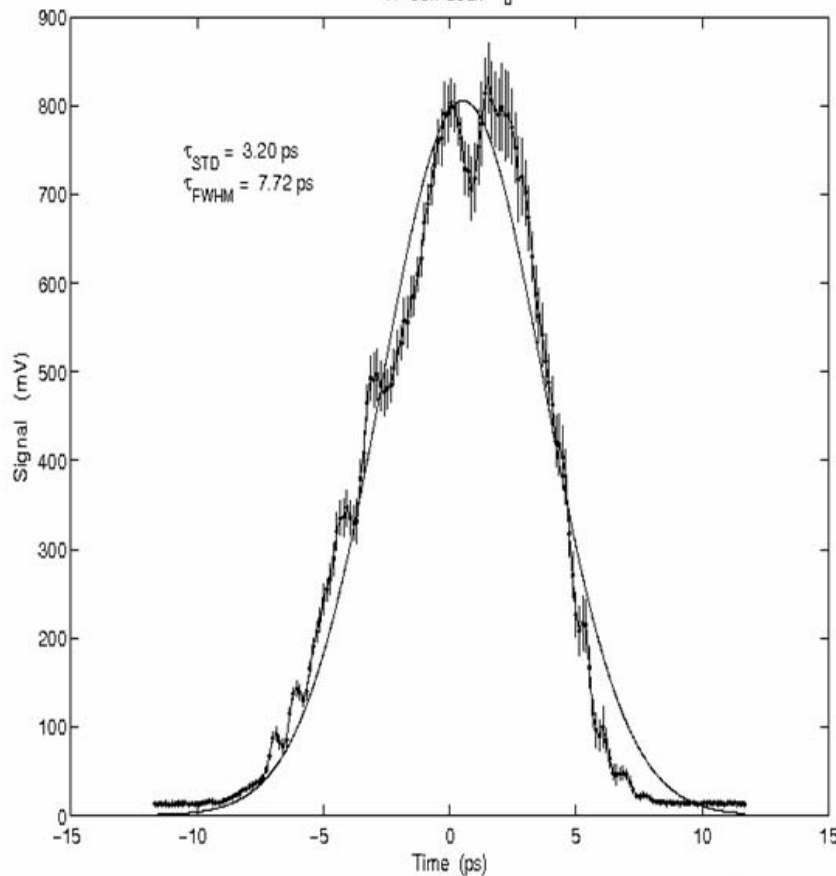


# Laser Temporal Profile

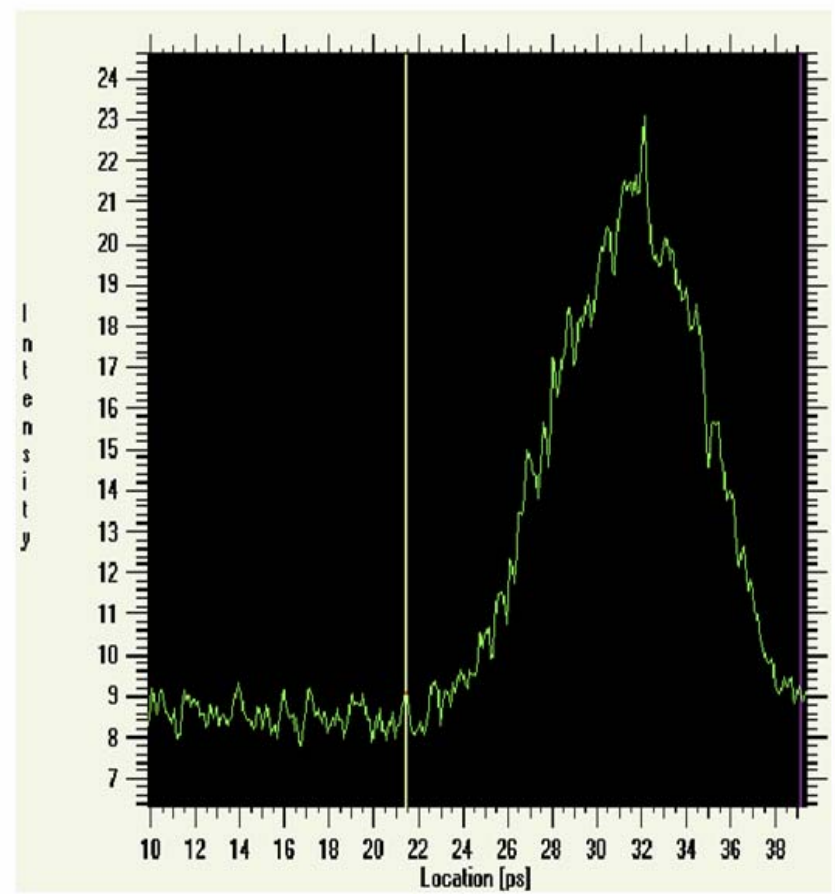
8 ps fwhm – see TUPMS054 H.Loos *et al.*

Cross correlator

X-Corr Scan - []



Streak camera

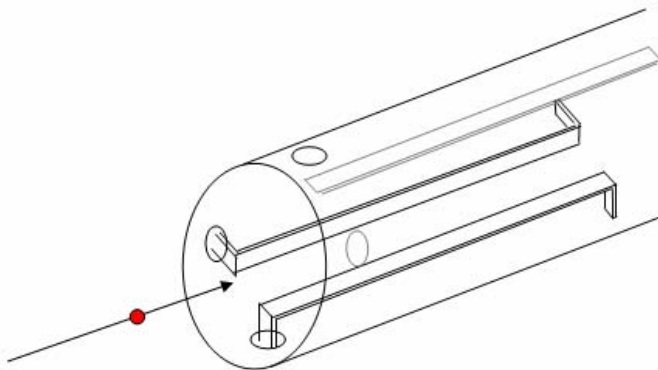




# Beam Position Monitors

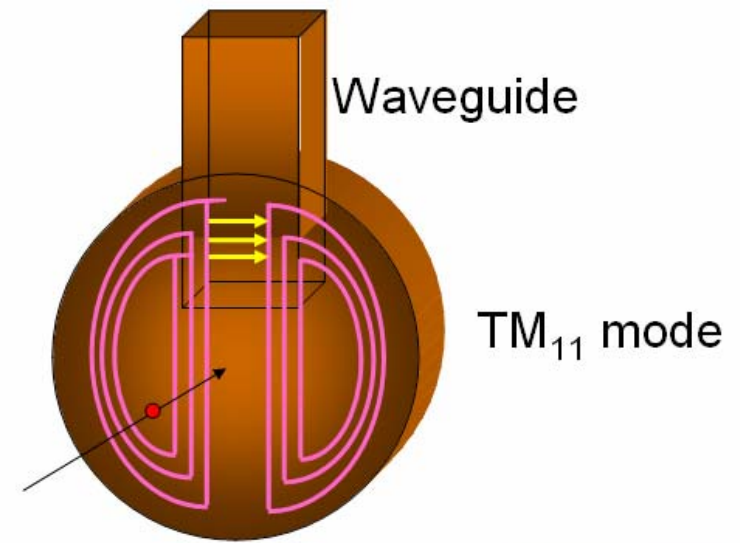
## ■ Striplines

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

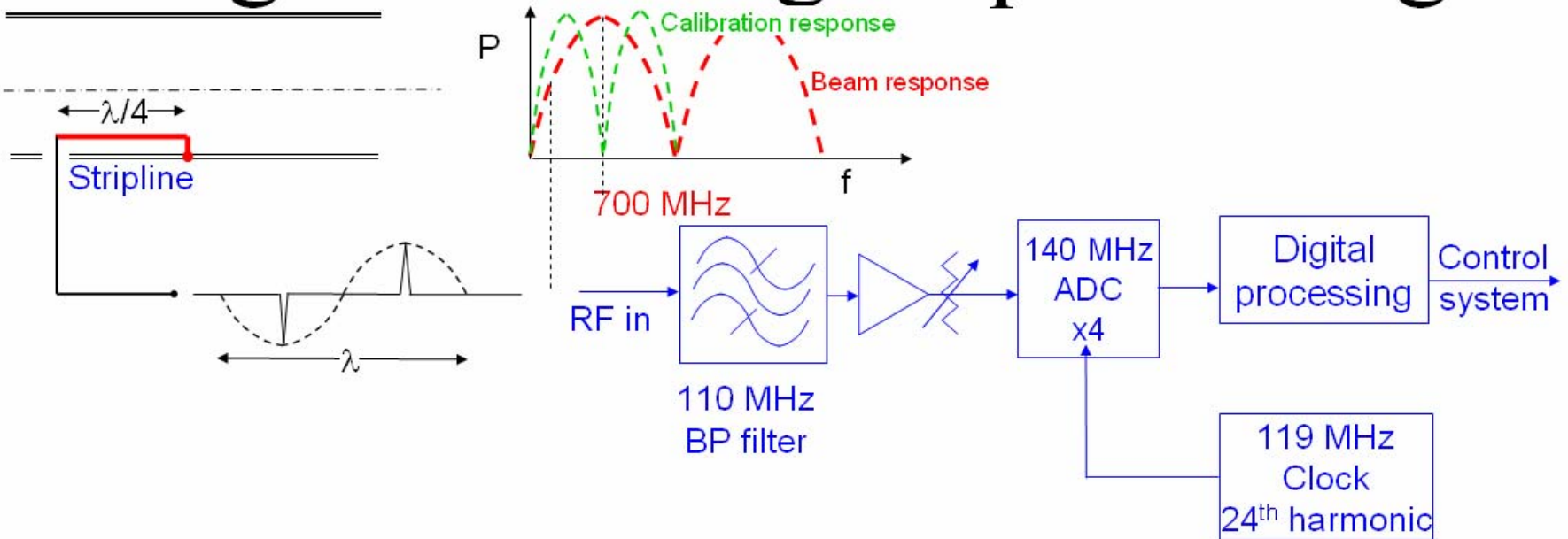


## ■ Cavities

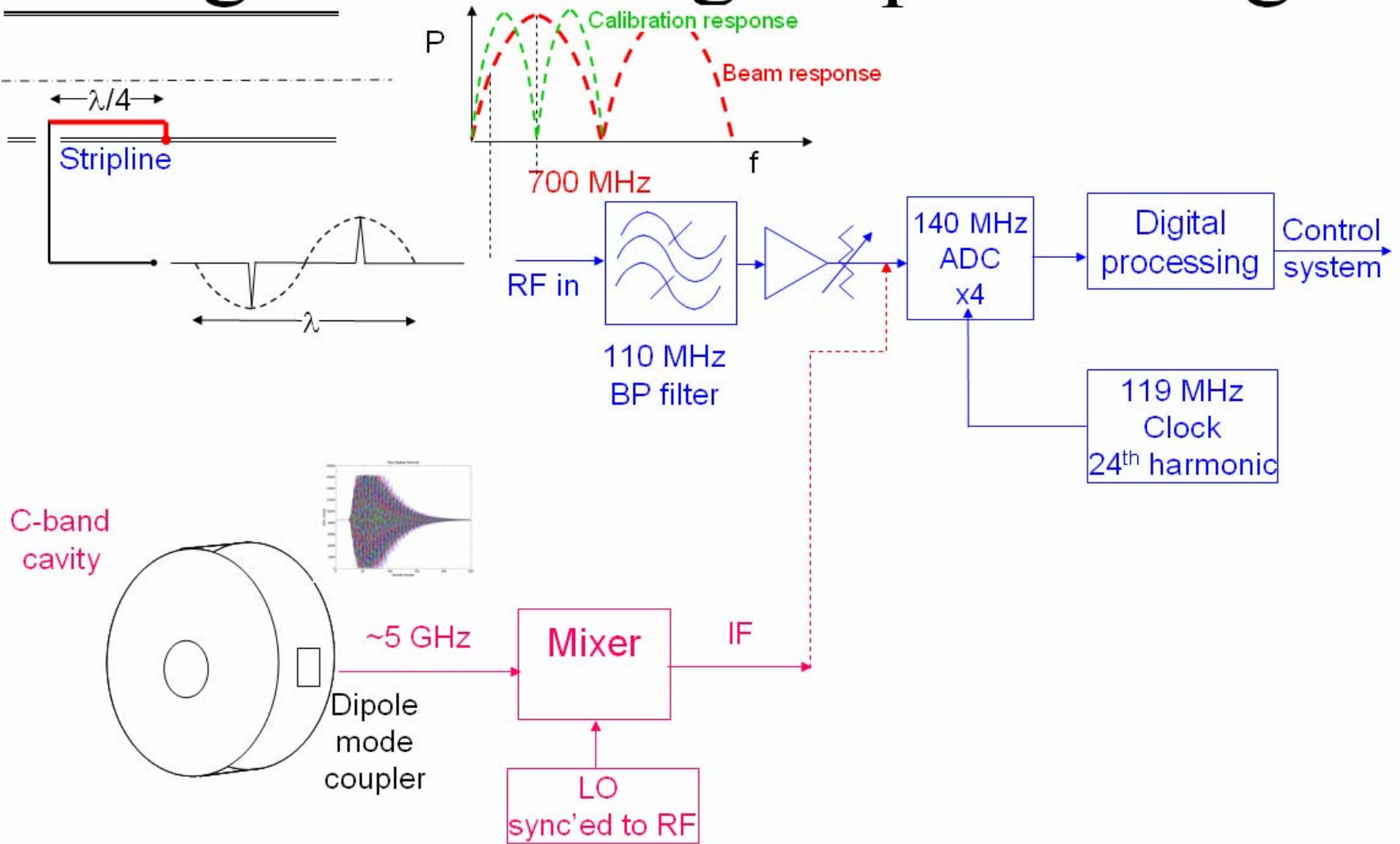
- Between undulator modules
- X-band  $TM_{11}$  mode
- Downmix signal and digitize the IF



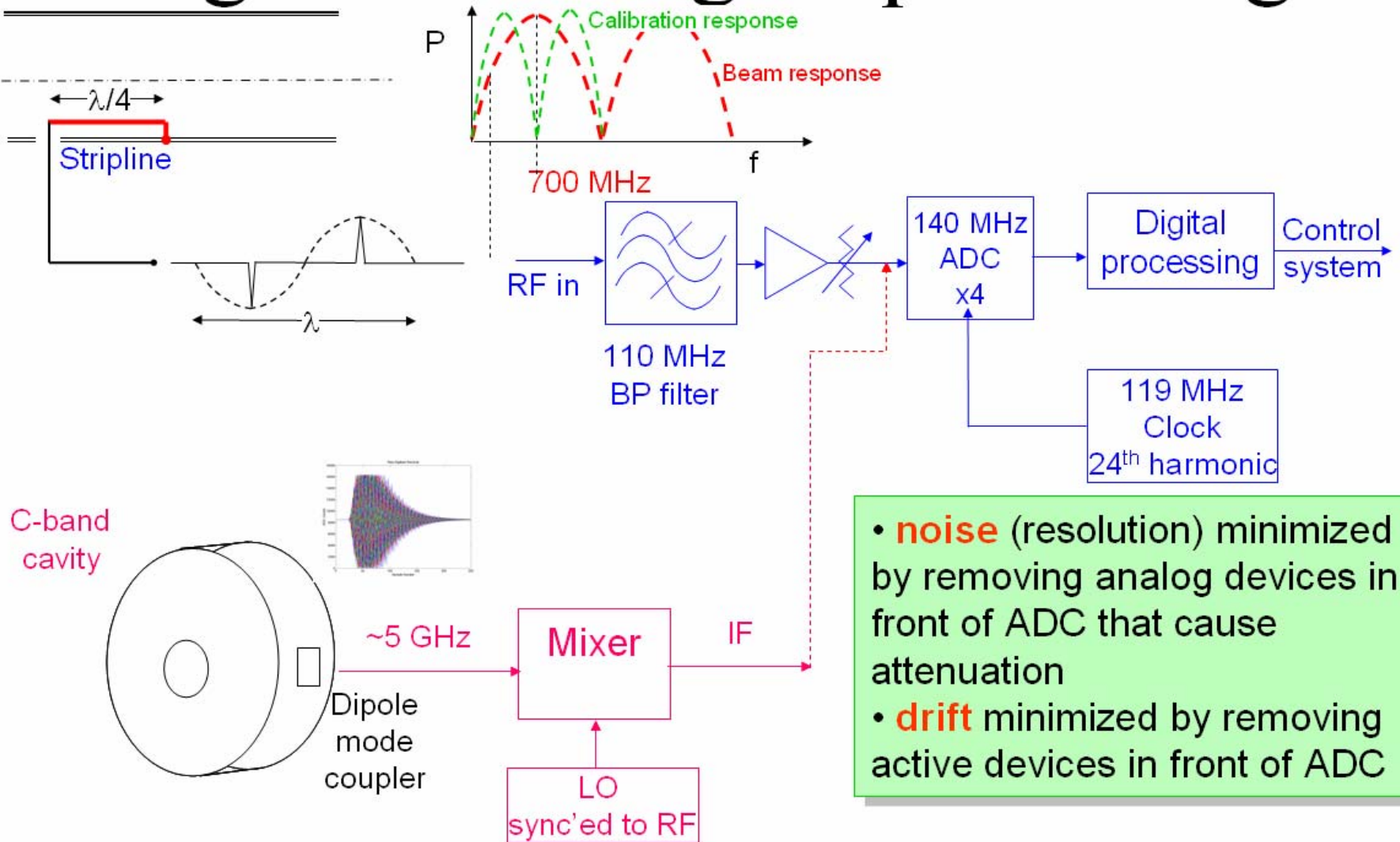
# Digital BPM signal processing



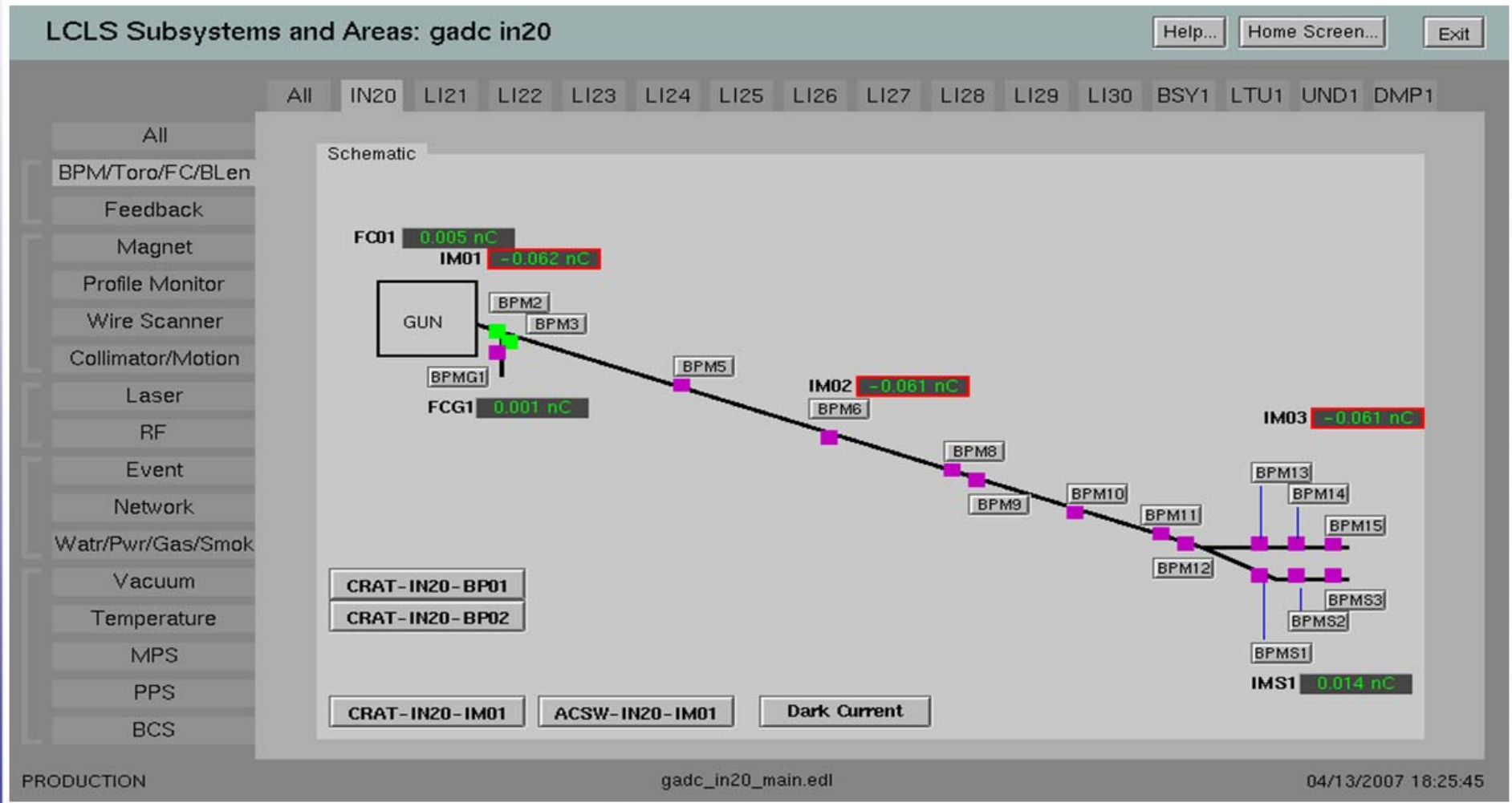
# Digital BPM signal processing



# Digital BPM signal processing



# Beam Position Monitors



# Beam Position Monitors

### LCLS Subsystems and Areas: gadc in20

All IN20 LI21 LI22 LI23 LI24 LI25

- All
- BPM/Toro/FC/BLen
- Feedback
- Magnet
- Profile Monitor
- Wire Scanner
- Collimator/Motion
- Laser
- RF
- Event
- Network
- Watr/Pwr/Gas/Smok
- Vacuum
- Temperature
- MPS
- PPS
- BCS

PRODUCTION

**BPMS:IN20:221** Stripline BPM Diagnostics

alias **BPM2** Home Screen... Exit

<p><b>Status</b></p> <p>Position, X: <span style="background-color: #e0e0e0; padding: 2px;">-0.0596 mm</span></p> <p>Position, Y: <span style="background-color: #e0e0e0; padding: 2px;">0.1376 mm</span></p> <p>TMIT: <span style="background-color: #e0e0e0; padding: 2px;">0.470 nC</span></p> <p>Status Summary: <span style="background-color: #00ff00; padding: 2px;"> </span></p>	<p><b>Control</b></p> <p>U Offset: <span style="background-color: #e0e0e0; padding: 2px;">0.0000 mm</span></p> <p>V Offset: <span style="background-color: #e0e0e0; padding: 2px;">0.0000 mm</span></p> <p>Scale: <span style="background-color: #e0e0e0; padding: 2px;">12.0000 mm</span></p> <p>Rotation: <span style="background-color: #e0e0e0; padding: 2px;">0.0 deg</span></p> <p>Axes Ang.: <span style="background-color: #e0e0e0; padding: 2px;">90.0 deg</span></p> <p>TMIT Scale: <span style="background-color: #e0e0e0; padding: 2px;">1.200e-06 nC</span></p> <p>ATT 1: <span style="background-color: #e0e0e0; padding: 2px;">0 12 15 dB</span></p> <p>ATT 2: <span style="background-color: #e0e0e0; padding: 2px;">0 14 15 dB</span></p> <p>Diag. Mode: <span style="background-color: #e0e0e0; padding: 2px;">OFFLINE</span> <span style="background-color: #e0e0e0; padding: 2px;">ONLINE</span></p>	<p><b>Calibration</b></p> <p>Gain Ratio U: <span style="background-color: #e0e0e0; padding: 2px;">0.8353</span></p> <p>Gain Ratio V: <span style="background-color: #e0e0e0; padding: 2px;">0.8432</span></p> <p>Gain Ratio U/V: <span style="background-color: #e0e0e0; padding: 2px;">0.9517</span></p> <p>ATT [dB]: <span style="background-color: #e0e0e0; padding: 2px;">0 20 31</span></p> <p>RED Cal. Waveform (RED, YLO, BLU, GRN)</p> <p>GRN Cal. Waveform (RED, YLO, BLU, GRN)</p>
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**Processing**

Raw Digitizer Waveforms (RED, YLO, BLU, GRN)

Hardware Status

- Fatal Error
- PAD Connection Timeout
- YLO Underrange
- BLU Underrange
- RED Underrange
- GRN Underrange
- YLO Overrange
- BLU Overrange
- RED Overrange
- GRN Overrange

Time of Arrival: 0 127

Detected Amplitude:

Schematic

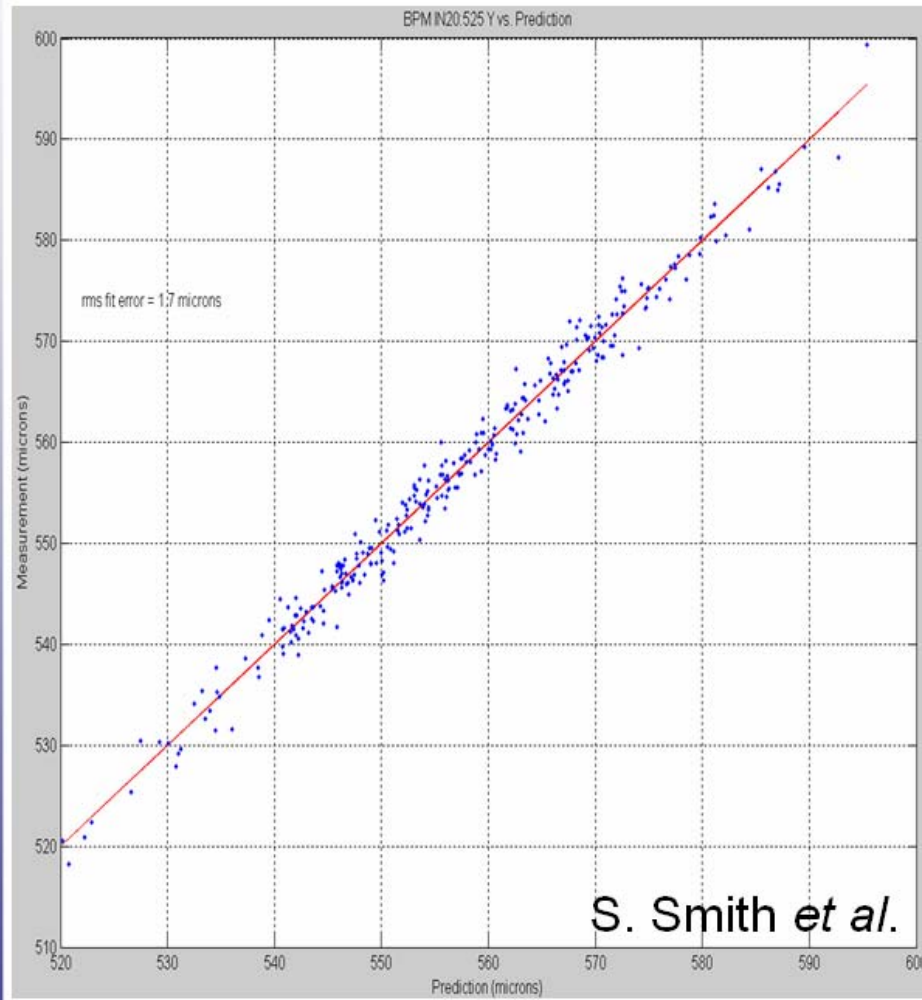
FC01: 0.005 nC  
IM01: -0.062 nC  
FCG1: 0.001 nC

CRAT-IN20-BP01  
CRAT-IN20-BP02  
CRAT-IN20-IM01  
ACSW-IN20-IM01

gadc\_in20



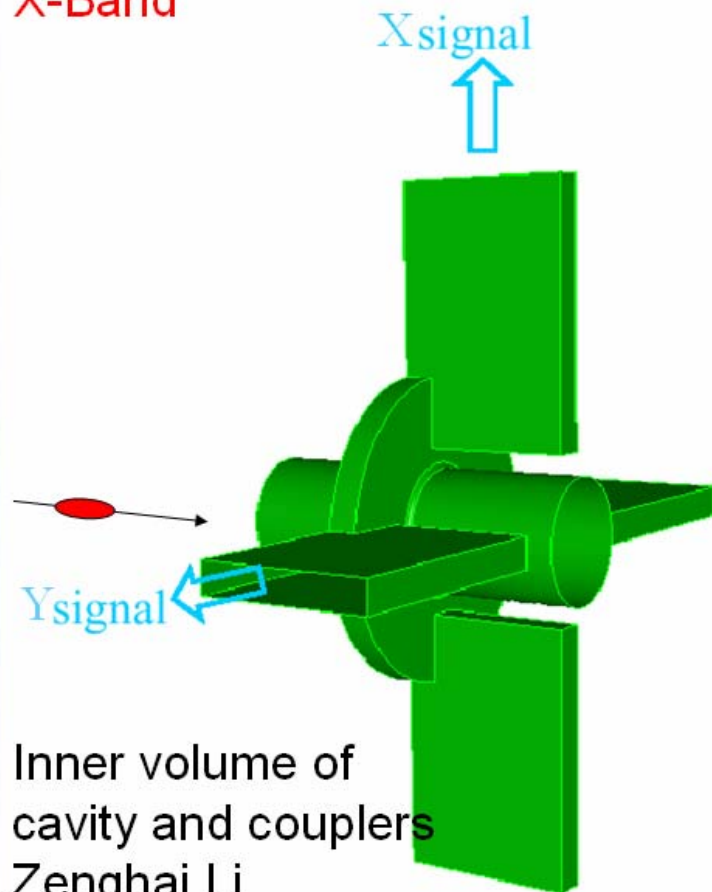
# Synchronous Acquisition to measure Resolution



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

# Cavity BPM with $TM_{11}$ mode Selective Coupler

X-Band



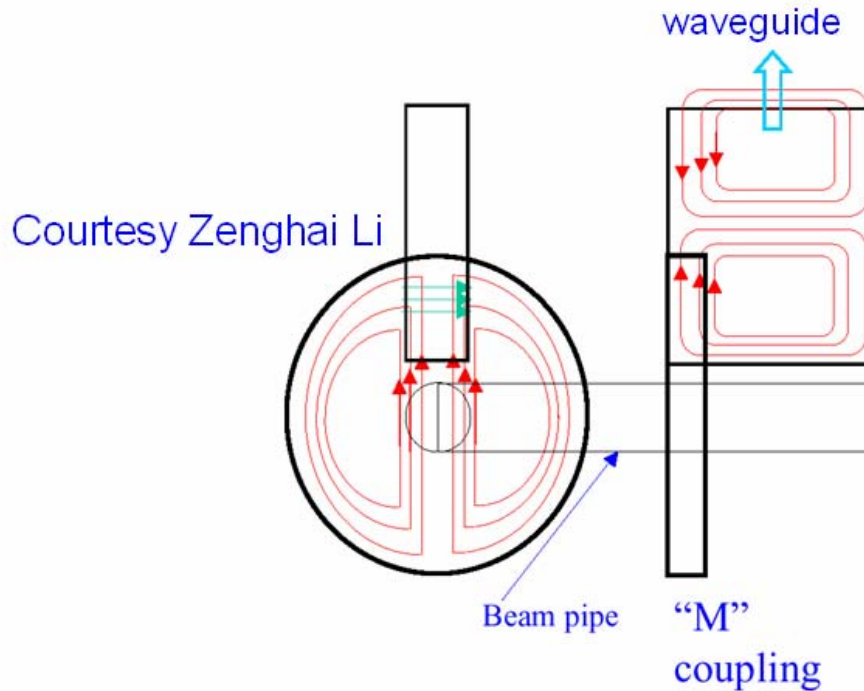
- Dipole mode:
  - $TM_{11}$  at 11.424 GHz
- Magnetic coupling to waveguide:
  - Horizontal couples to vertical port
- Waveguide does not couple to fundamental  $TM_{01}$  mode
- Sensitivity

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

- **1.6 mV/nC/mm**



# TM<sub>11</sub> Selective Coupling Scheme



ANL cavity prototypes

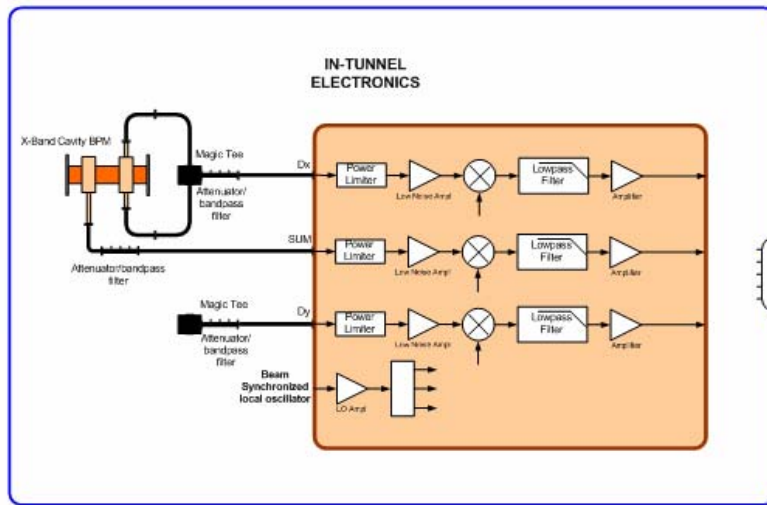
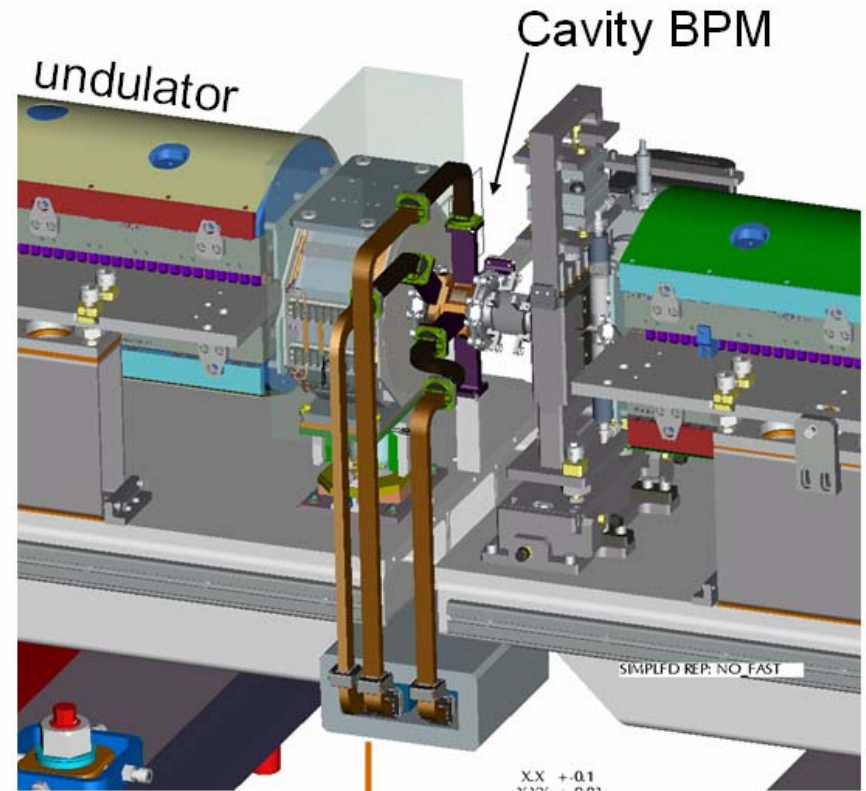


■ First beam tests have begun at ANL (R. Lill)

# ANL Undulator Cavity BPM



Miteq X-Band Low Noise Receiver

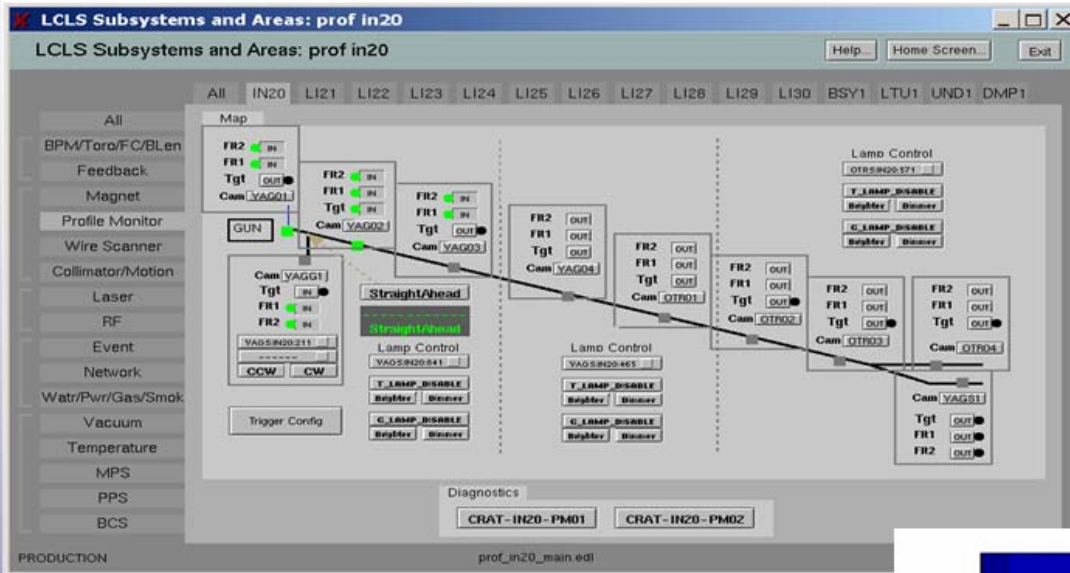


IF signal to digitizer

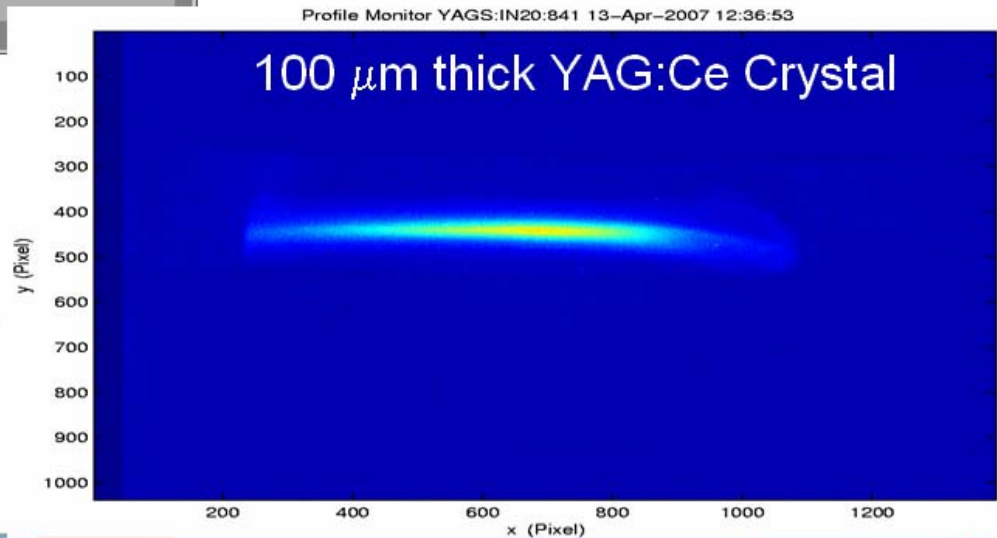


# Profile monitor

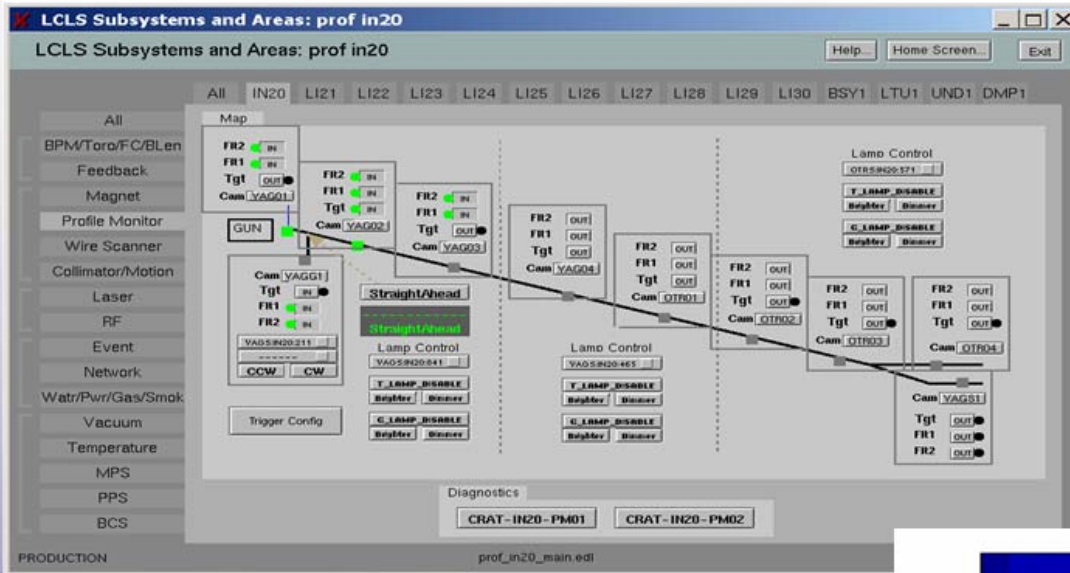
- control and diagnostics through EDM screens



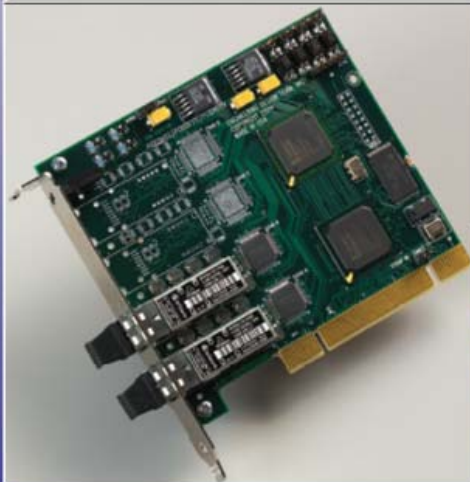
Gun spectrometer  
YAG Profile Monitor Screen



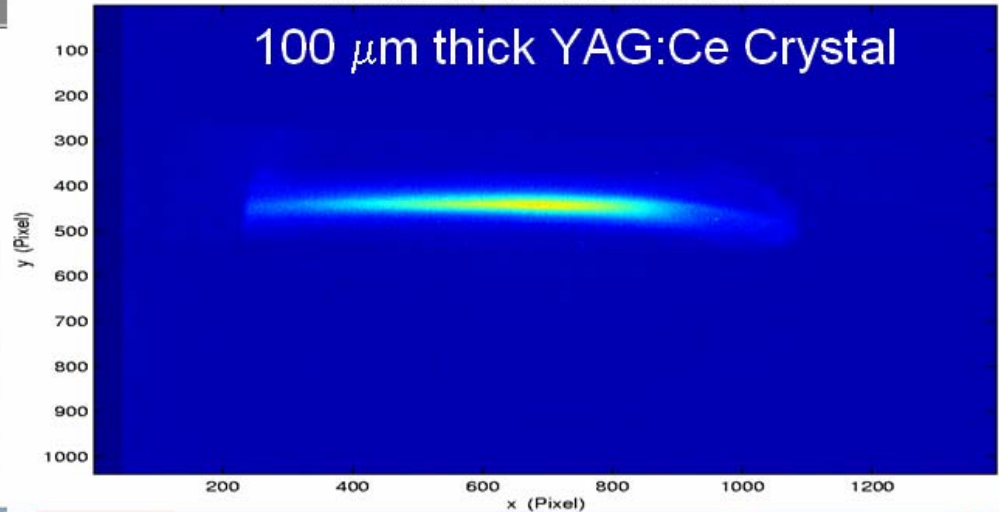
# Profile monitor



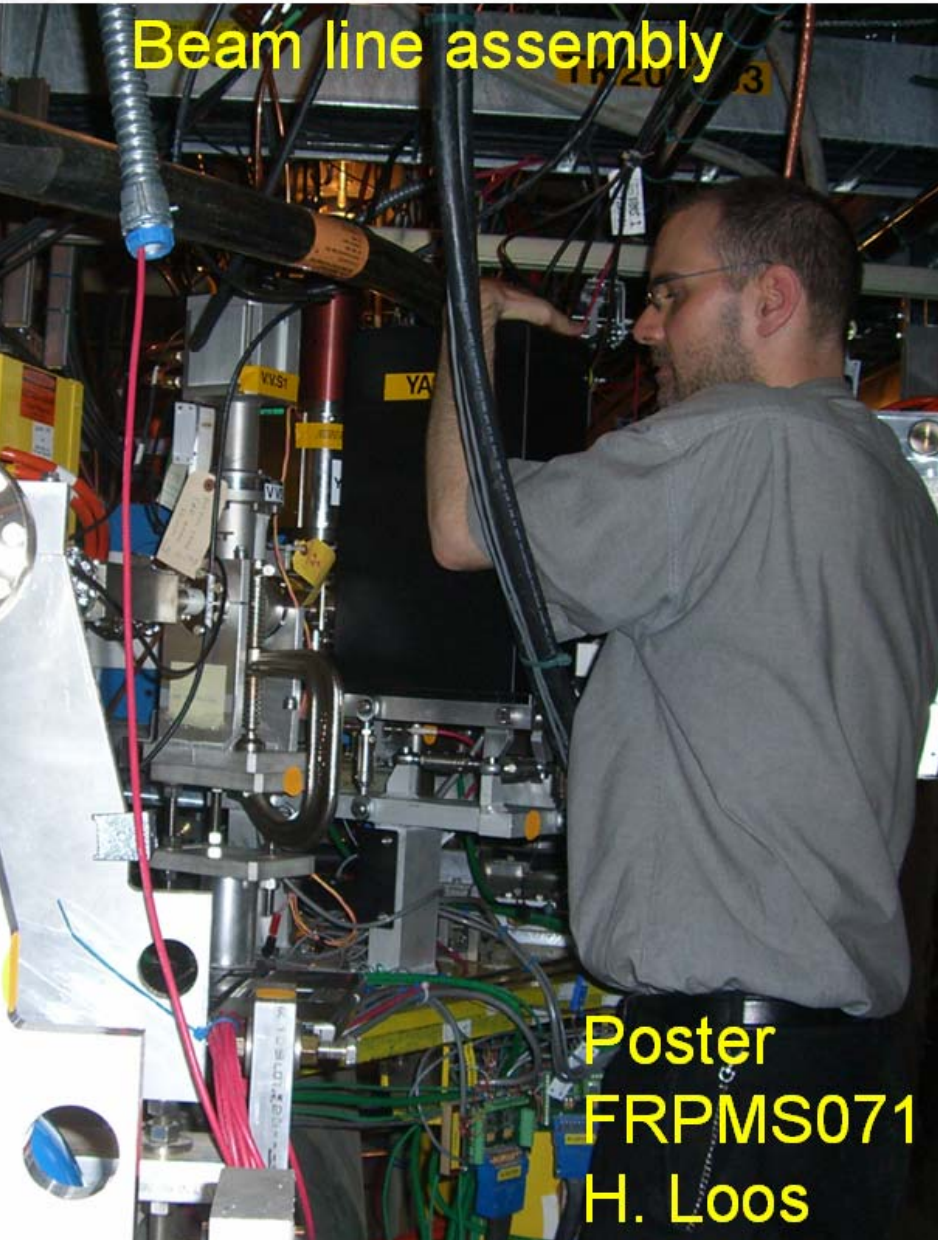
Profile Monitor YAGS:IN20:841 13-Apr-2007 12:36:53



RCX Camera link extender over fiber optic



# Profile monitors



Beam line assembly

Poster  
FRPMS071  
H. Loos

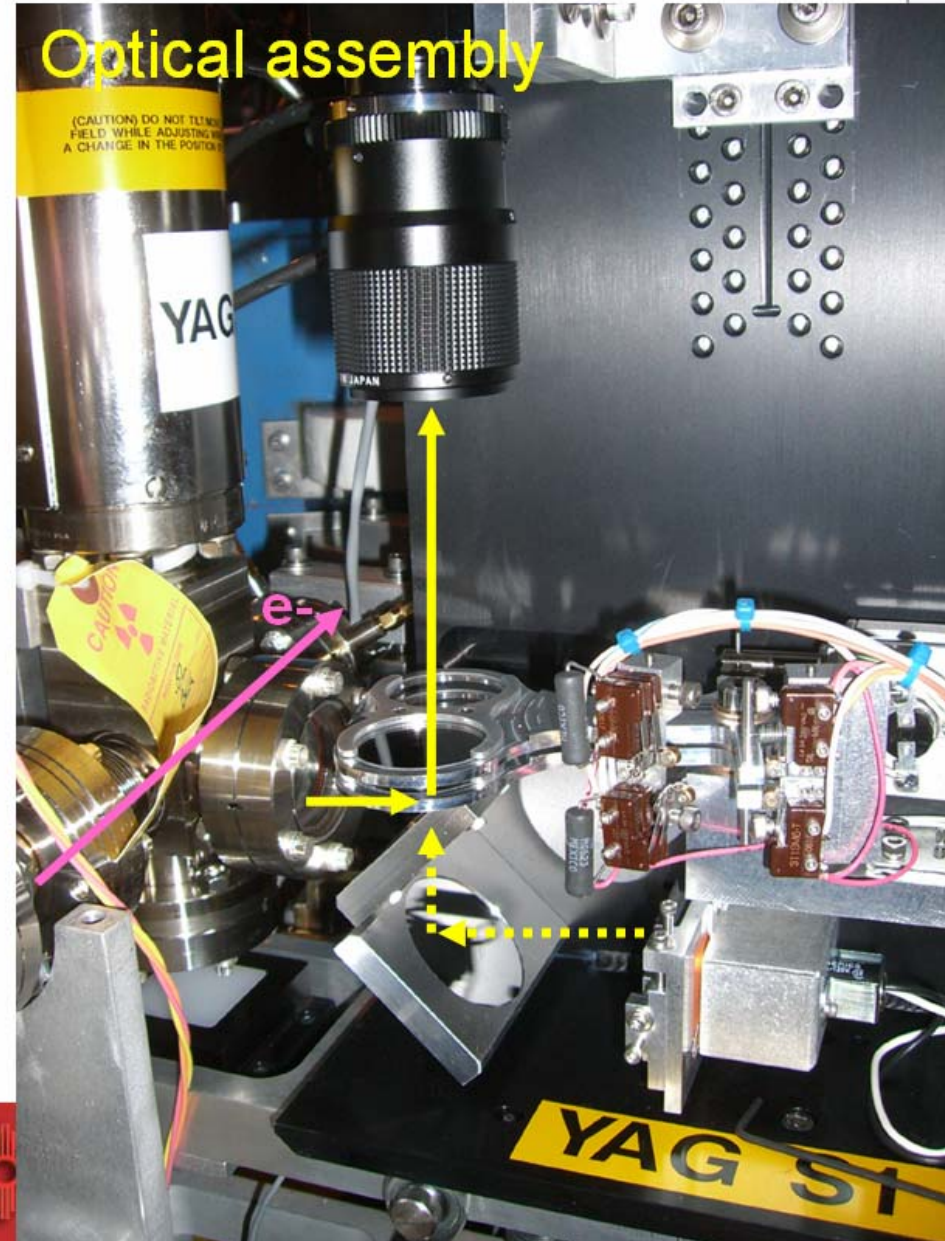
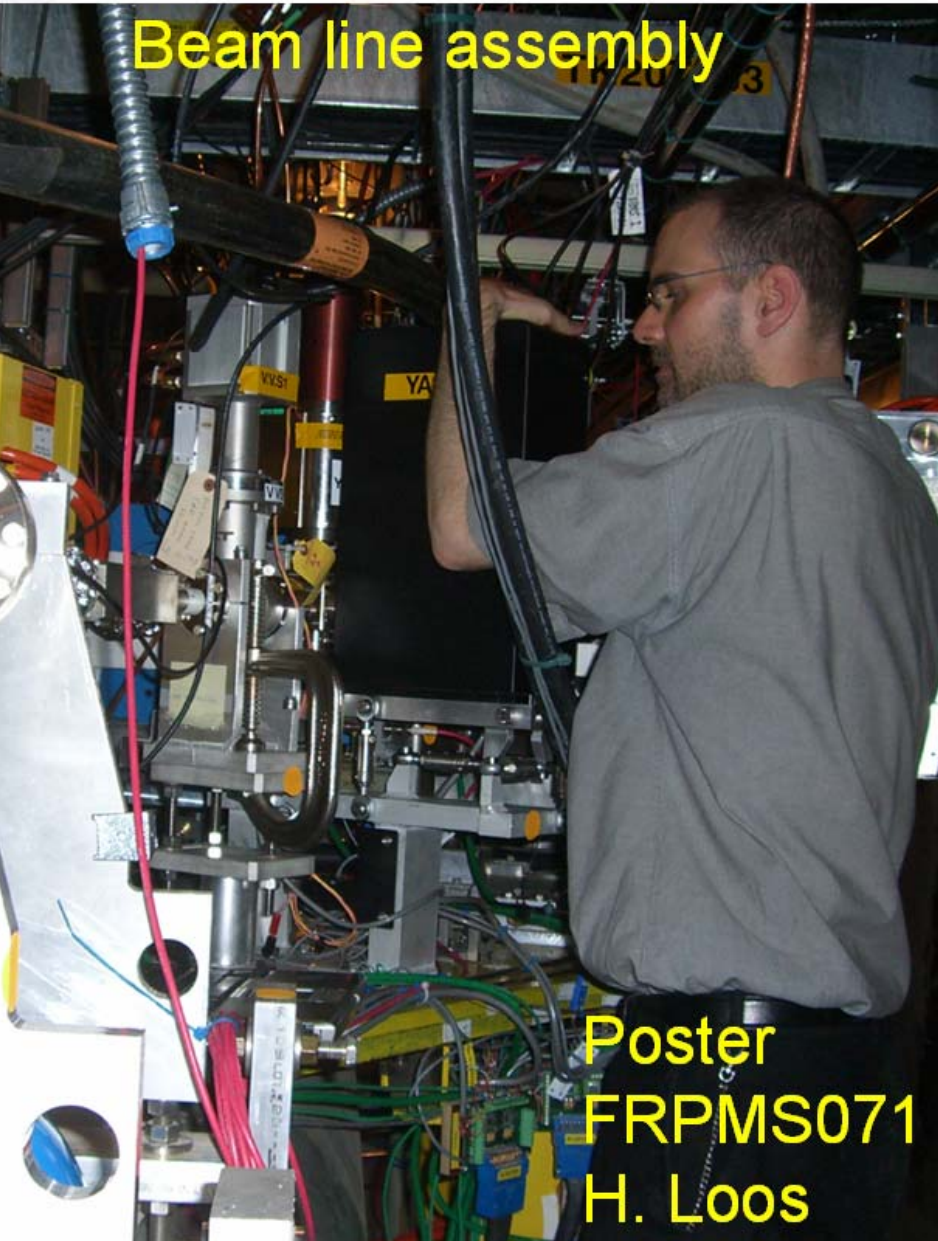


Patrick Krejcik  
pk@slac.stanford.edu

Stanford  
Linear  
Accelerator  
Center



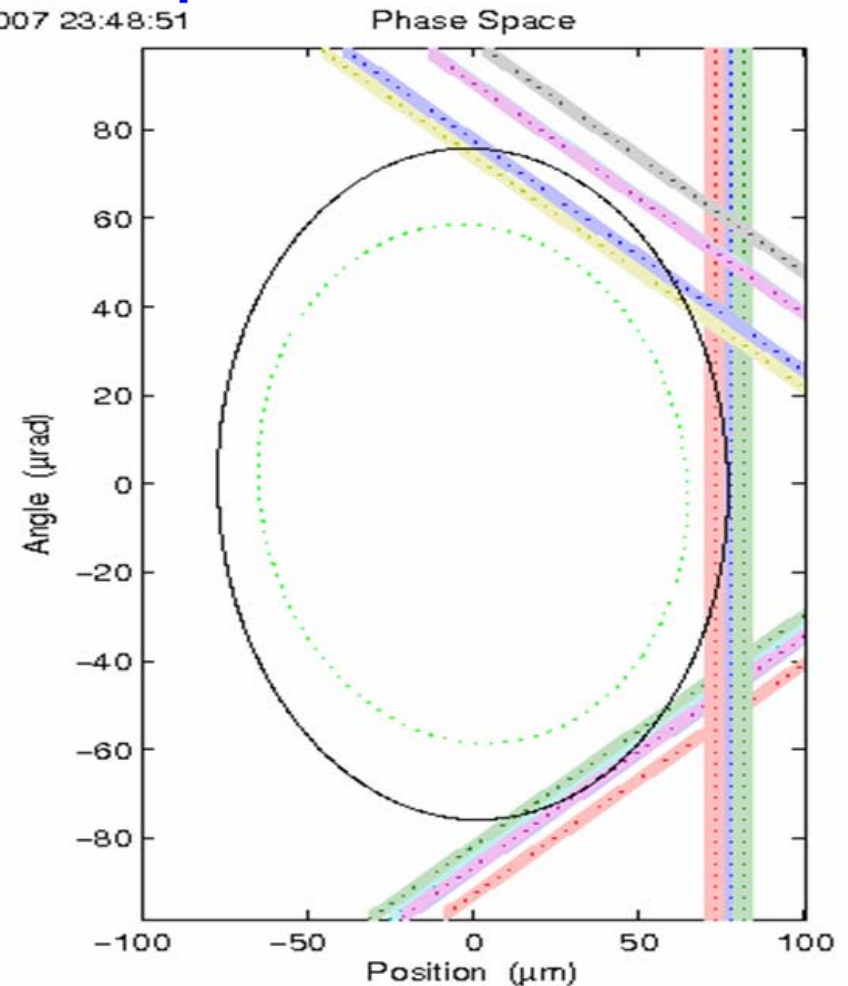
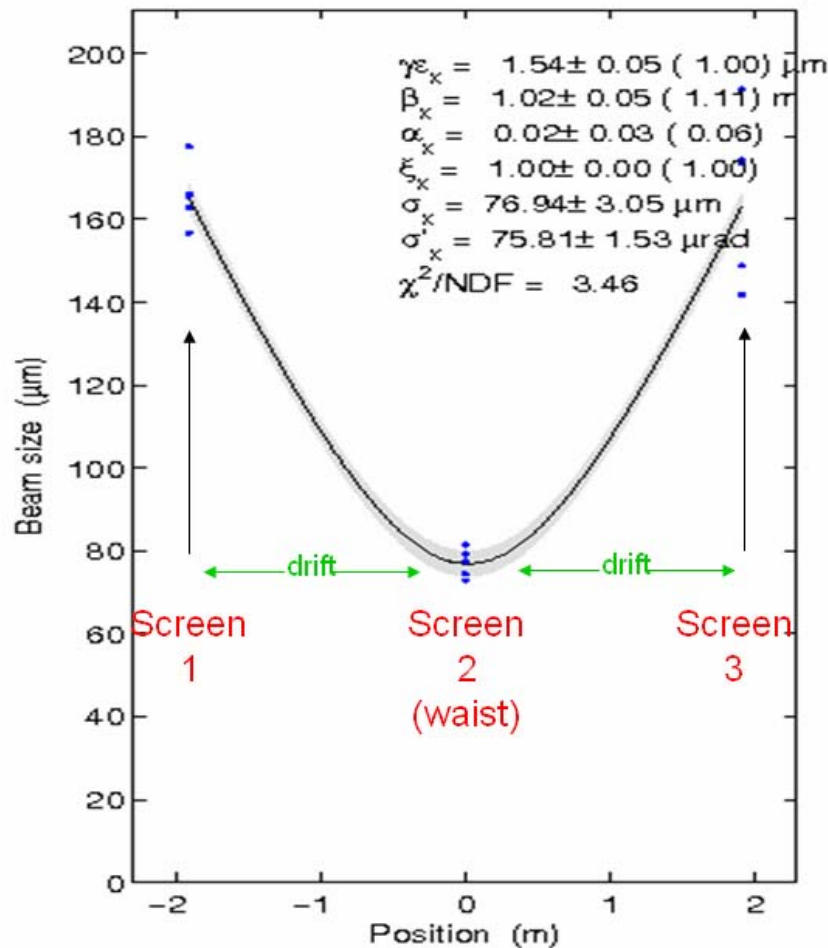
# Profile monitors



# 3-screen OTR Emittance Measurement

## 135 MeV, 200 pC

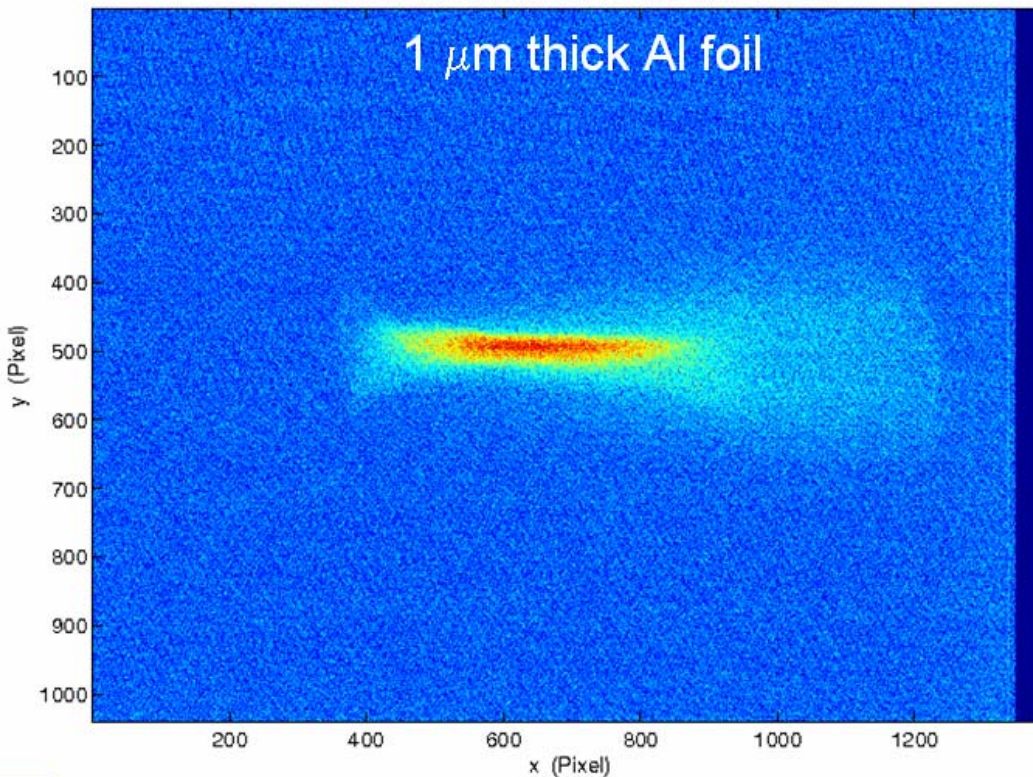
Emittance Scan on OTRS:IN20:541 OTRS:IN20:621 14-May-2007 23:48:51



# BC Chicane OTR Screen

- Energy spread in BC1
- at  $-40^\circ$  off crest
- $(4.1 \text{ mm}) / (230 \text{ mm}) = 1.8\% \text{ rms.}$

Profile Monitor OTRS:LI21 237 13-May-2007 18:11:52

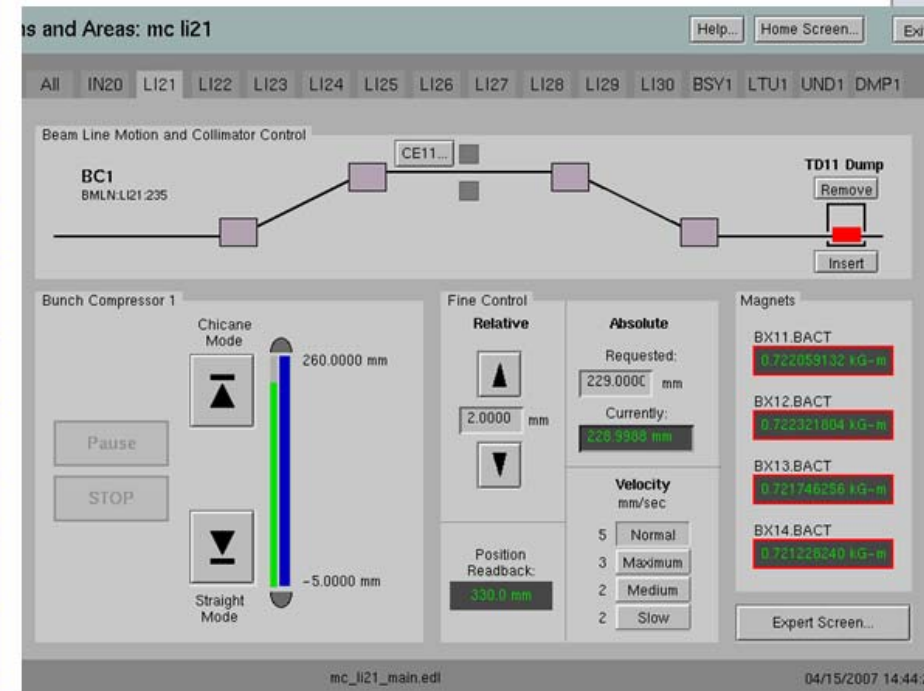
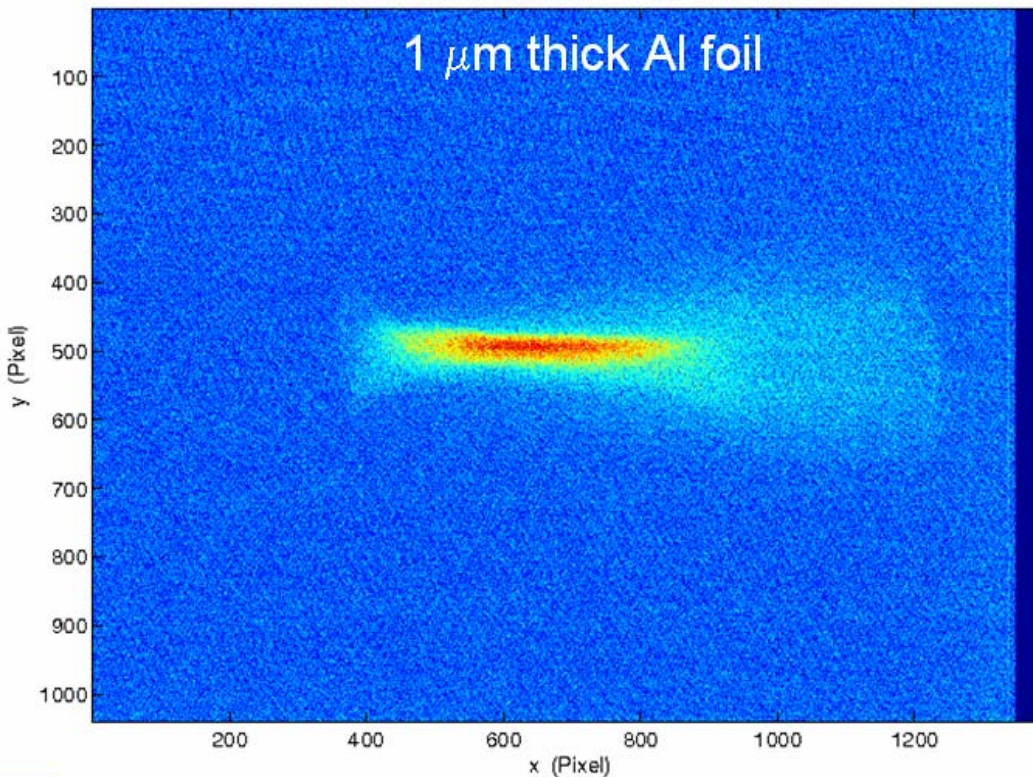




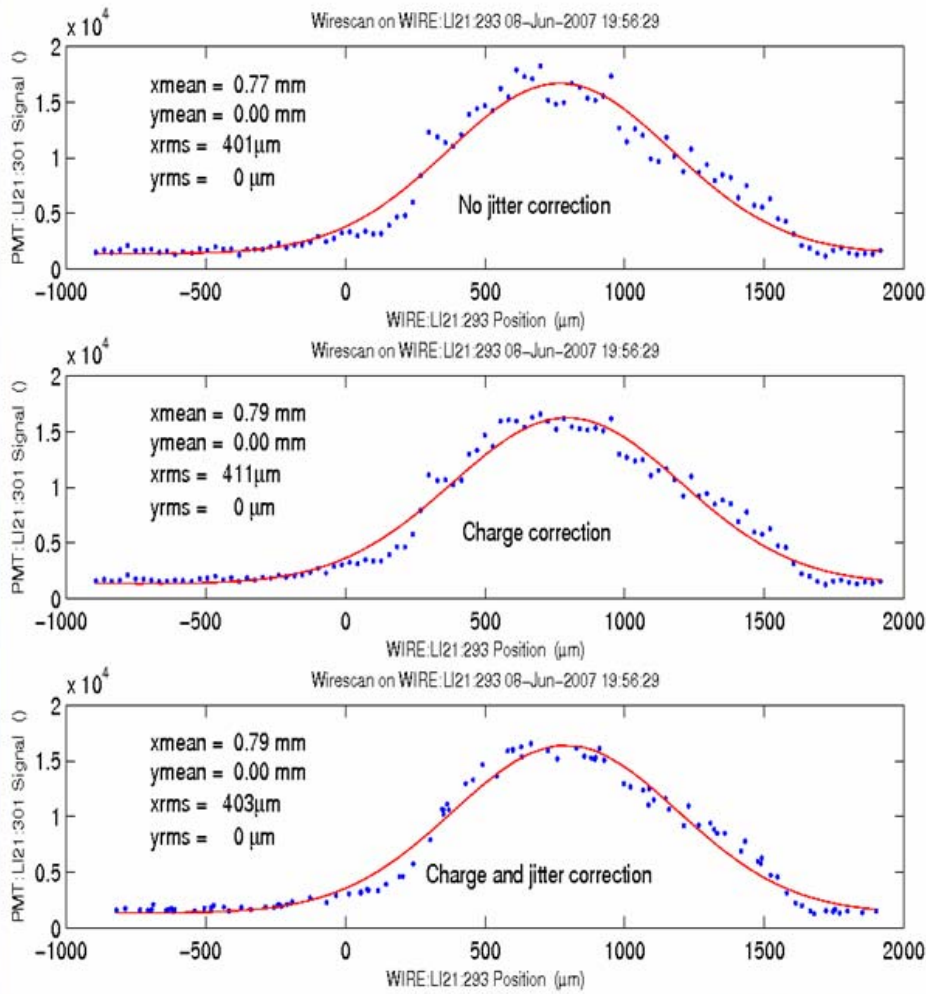
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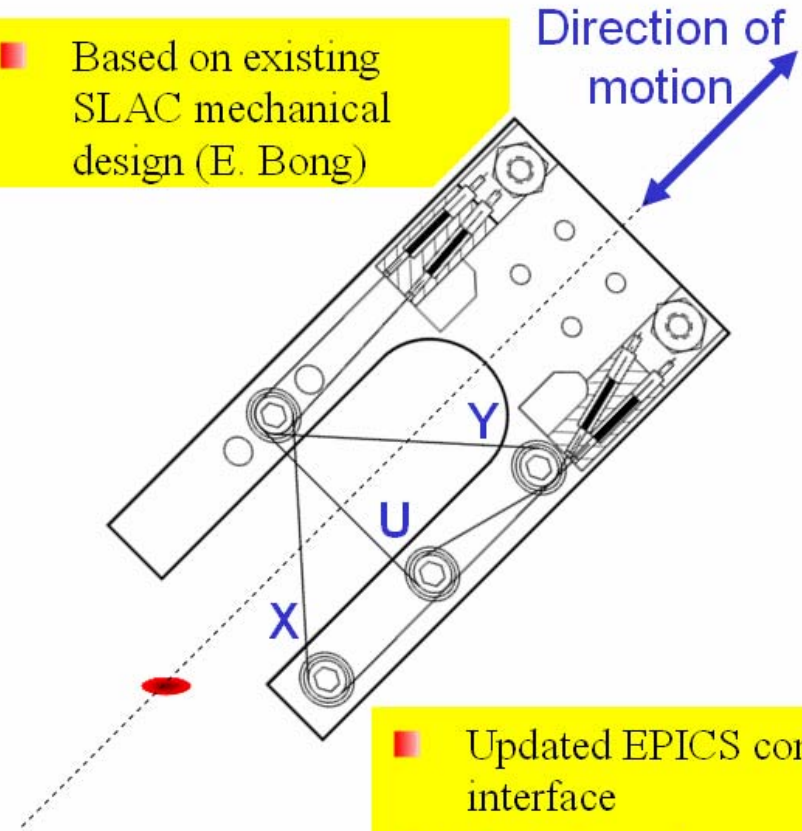
Profile Monitor OTRS:LI21.237 13-May-2007 18:11:52



# Wire Scanners



Based on existing SLAC mechanical design (E. Bong)



Updated EPICS controls interface

Pulse-by-pulse compensation of bunch charge and trajectory jitter

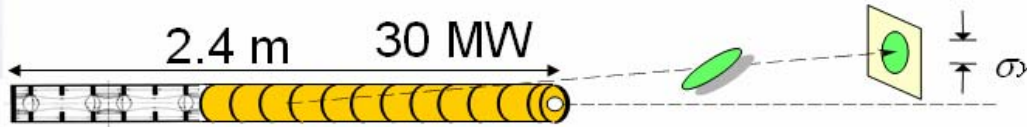


## Two types of beam size measurement

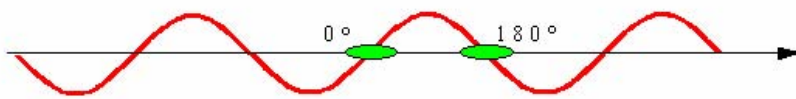
- Profile monitor screens gives complete transverse profile of beam on a single shot
  - But inserting it in the beam is disruptive to FEL
- Wire scanner gives projected X, Y, and U profiles over several consecutive shots
  - But is minimally invasive
- Redundant measurements are good for commissioning



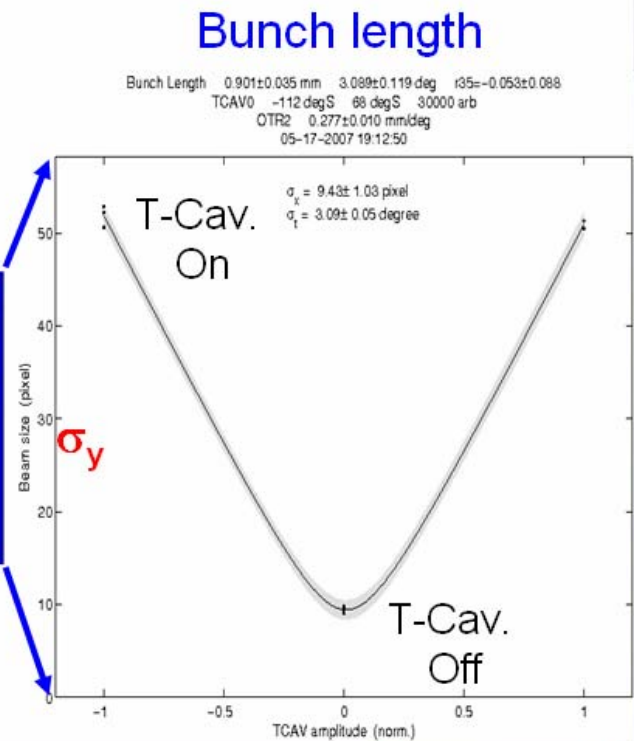
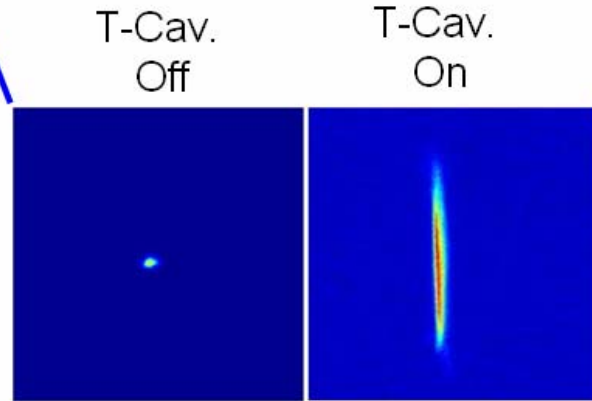
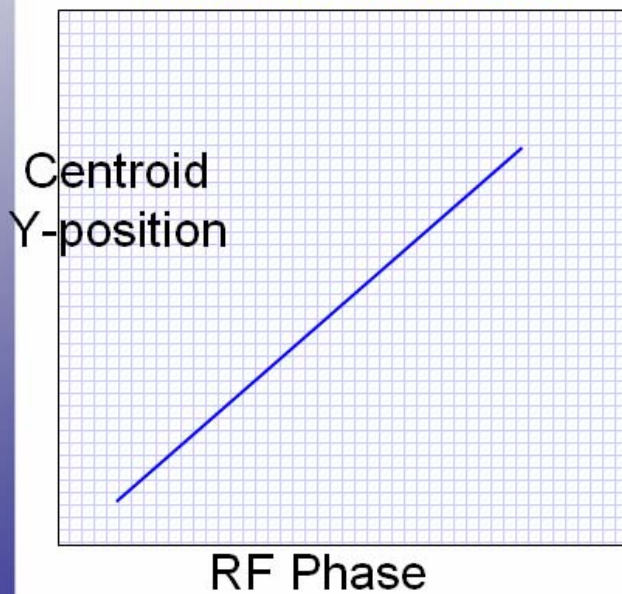
# RF Transverse Deflecting Cavity



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

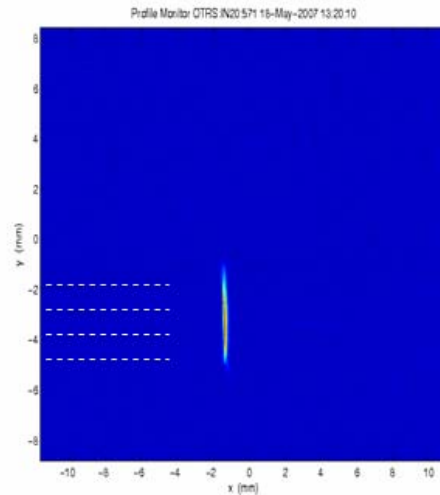


## Absolute calibration

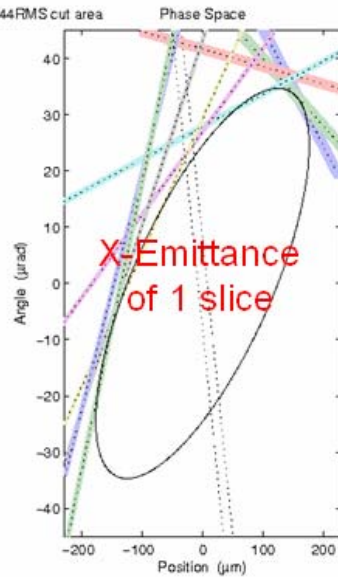
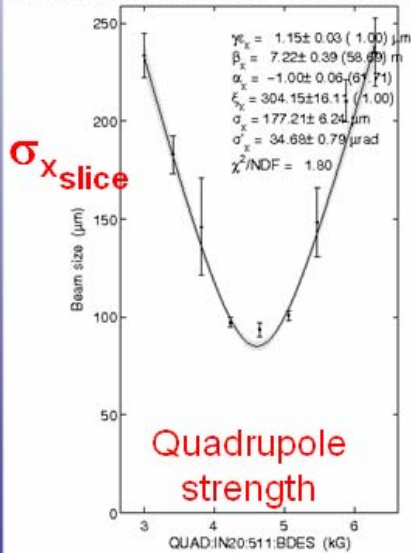


# T-Cav. Slice Emittance Measurement

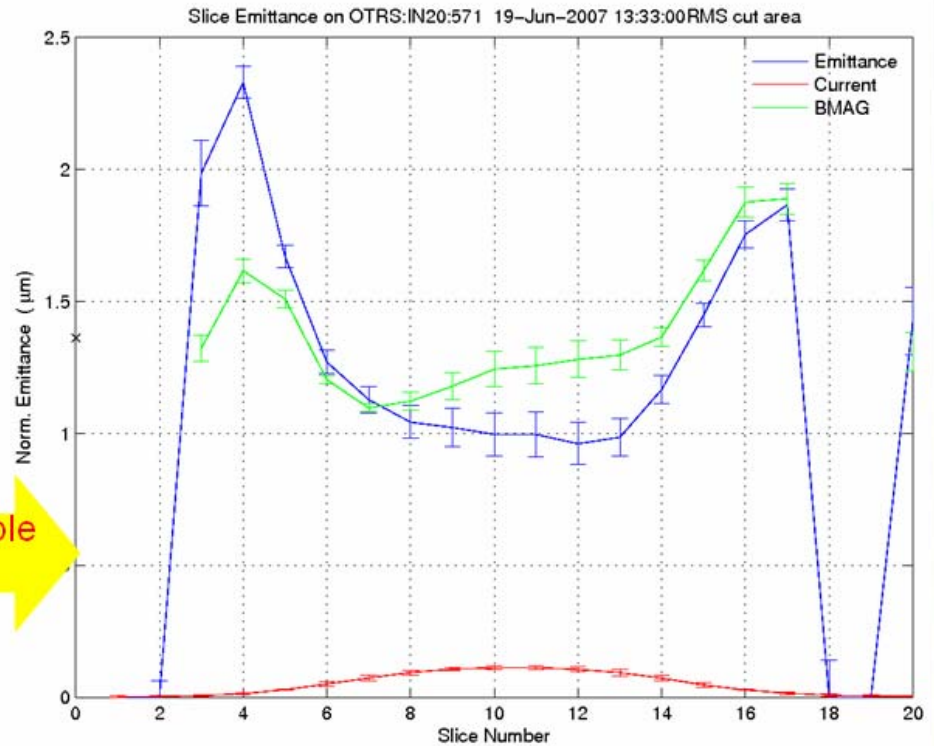
Slice up  
OTR screen  
image



Emittance Scan on OTRS:IN20:571 18-May-2007 10:14:44 RMS cut area

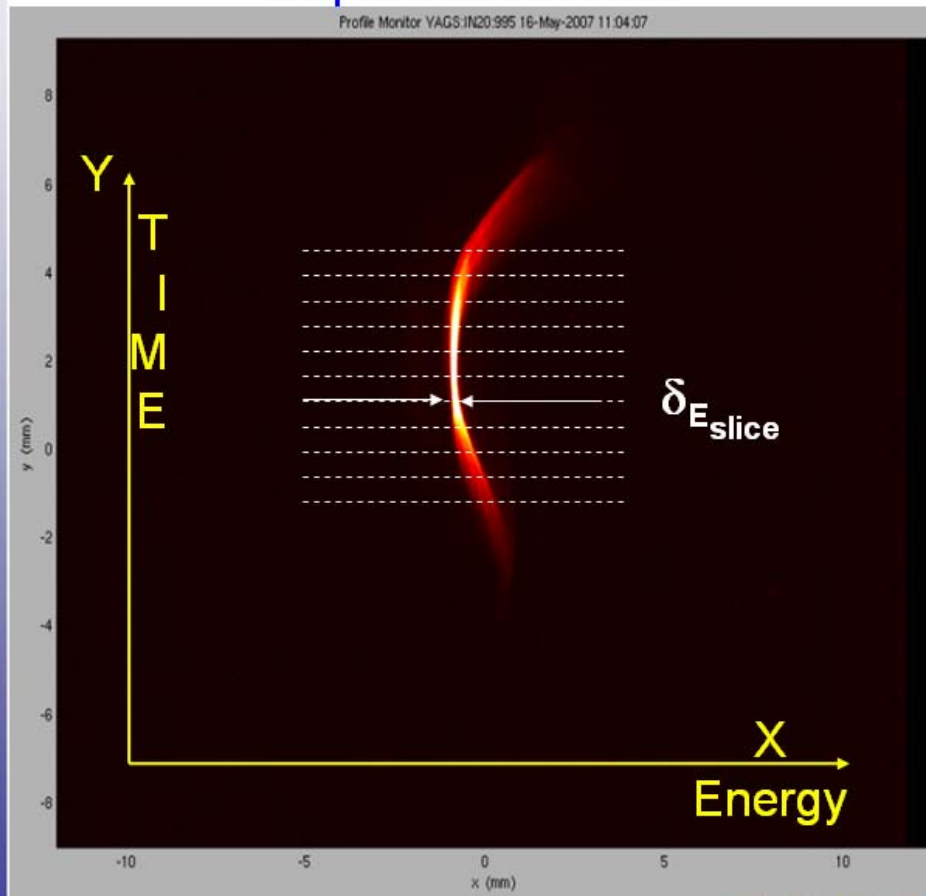


Reassemble  
slices

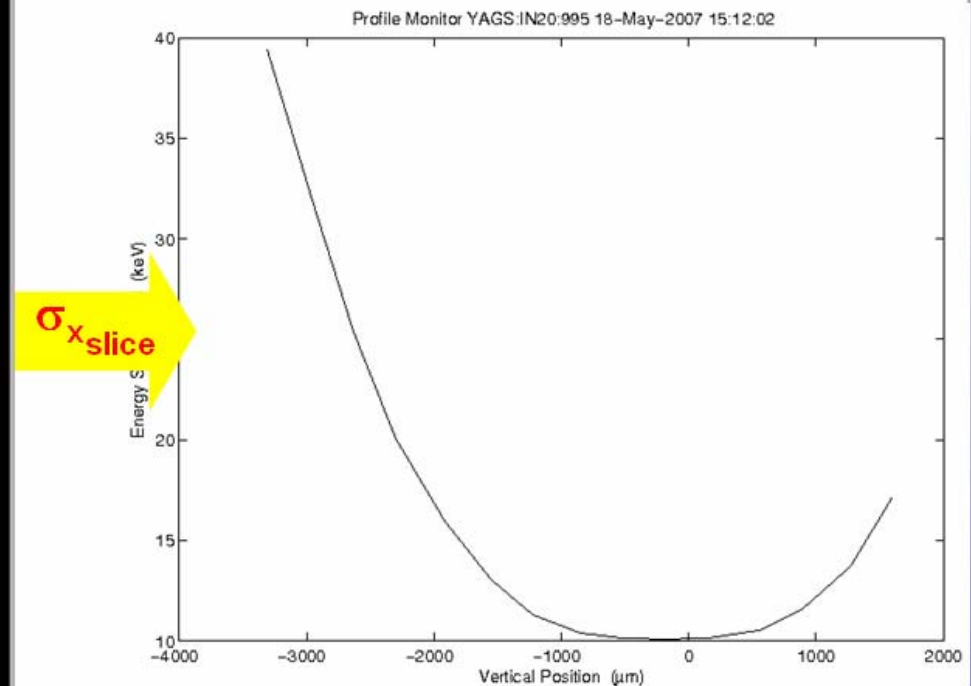


# T-Cav Slice Energy Spread Measurement

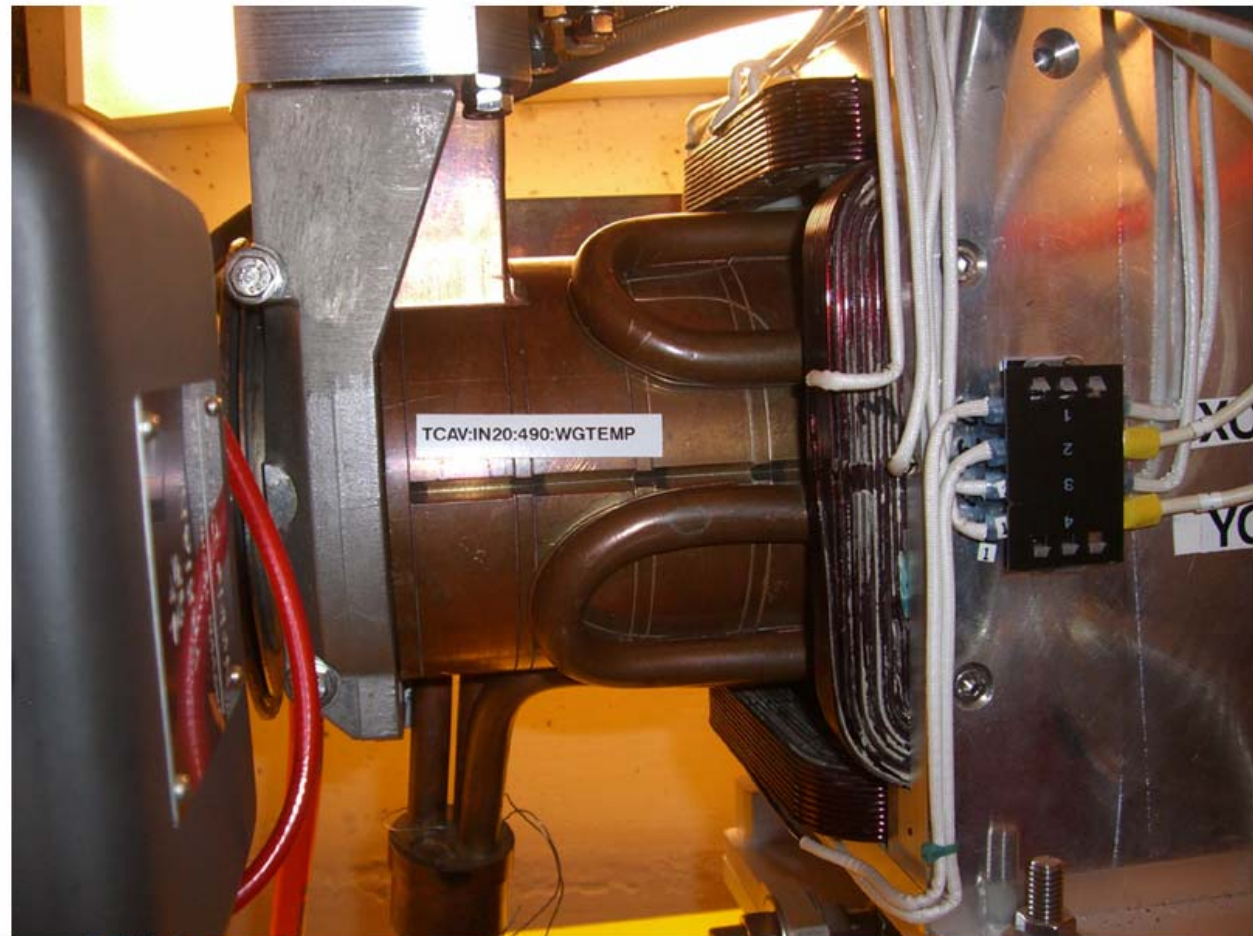
Screen at high dispersion location



Slice Energy Spread



# Transverse Deflecting Cavity Installation



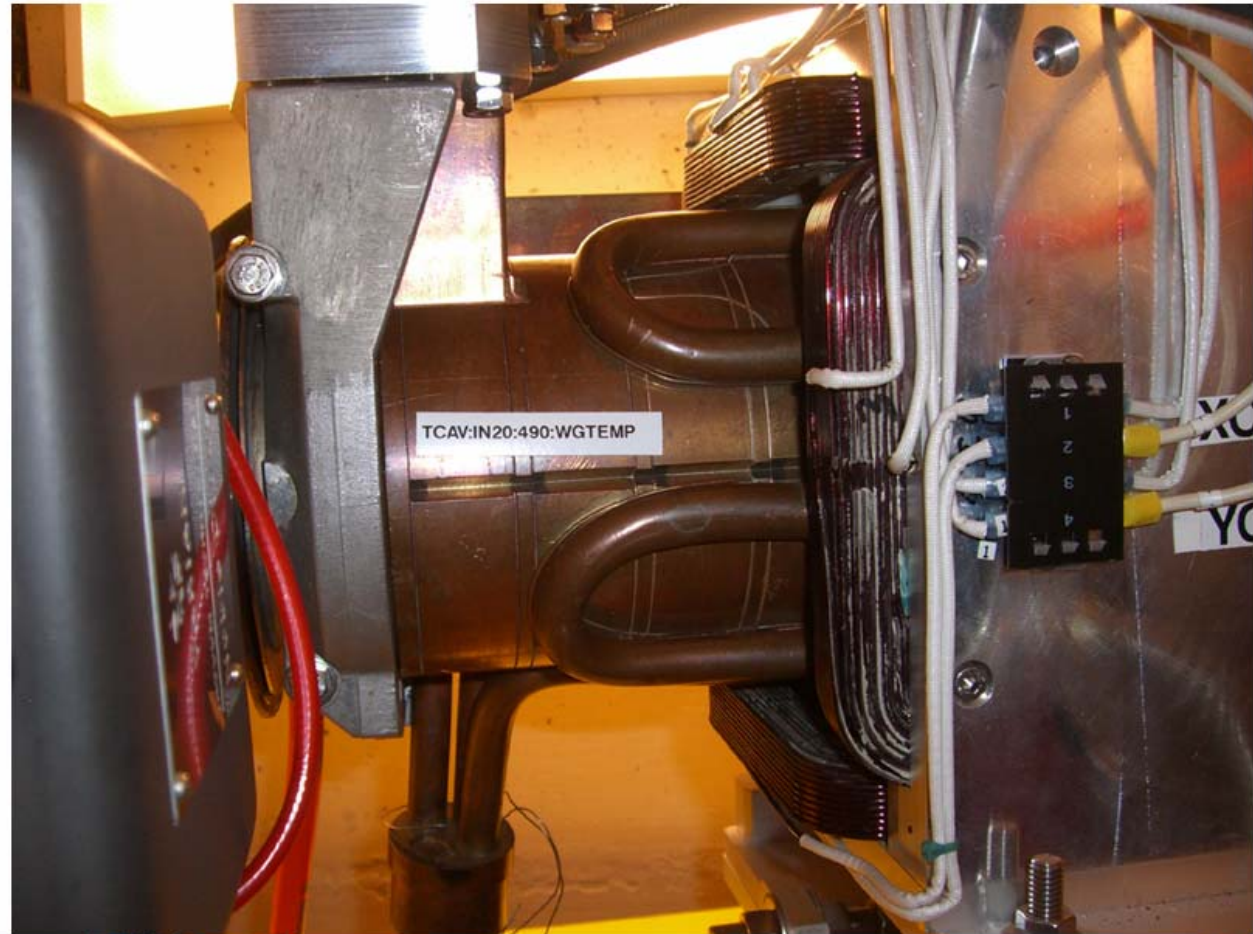
June 25-29  
PAC 2007, Albuquerque NM



Patrick Krejcik  
pk@slac.stanford.edu

# Transverse Deflecting Cavity Installation

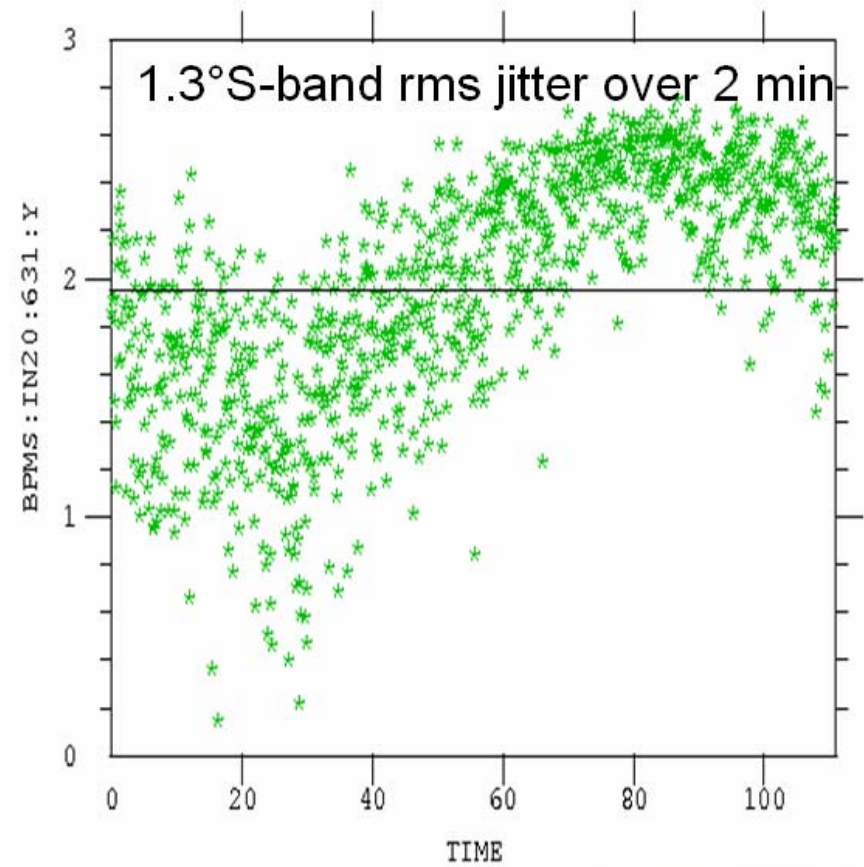
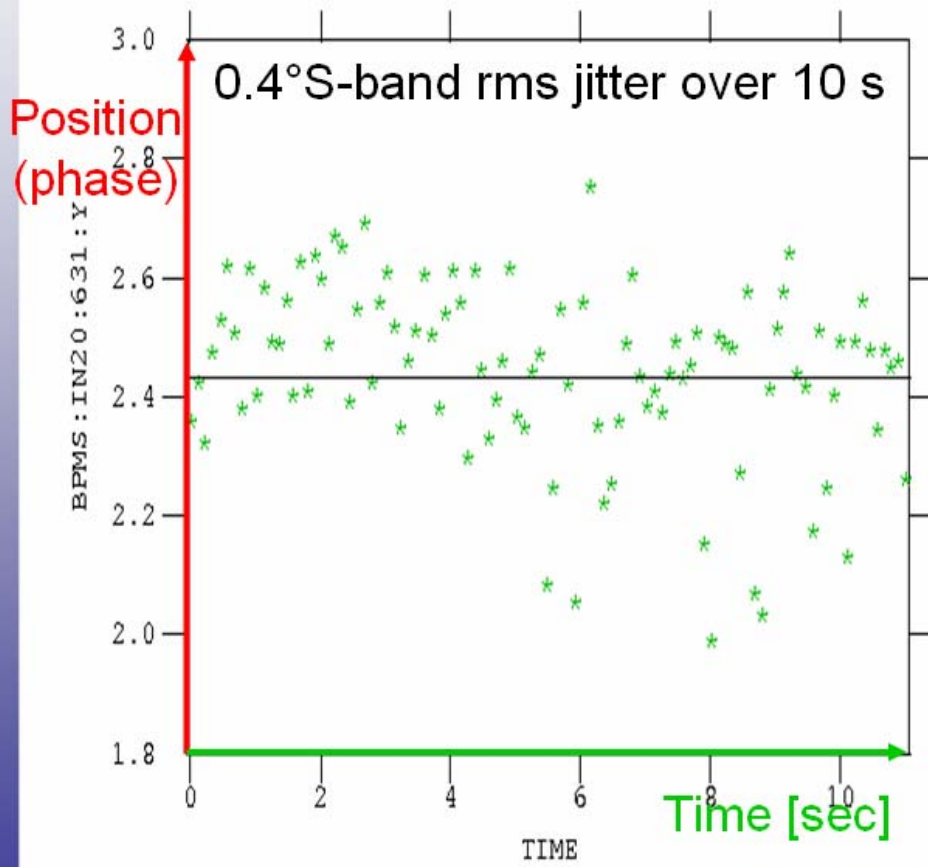
- Injector uses a short, 40 cm S-band traveling wave structure
- A second 2.4 m structure is located downstream of BC2





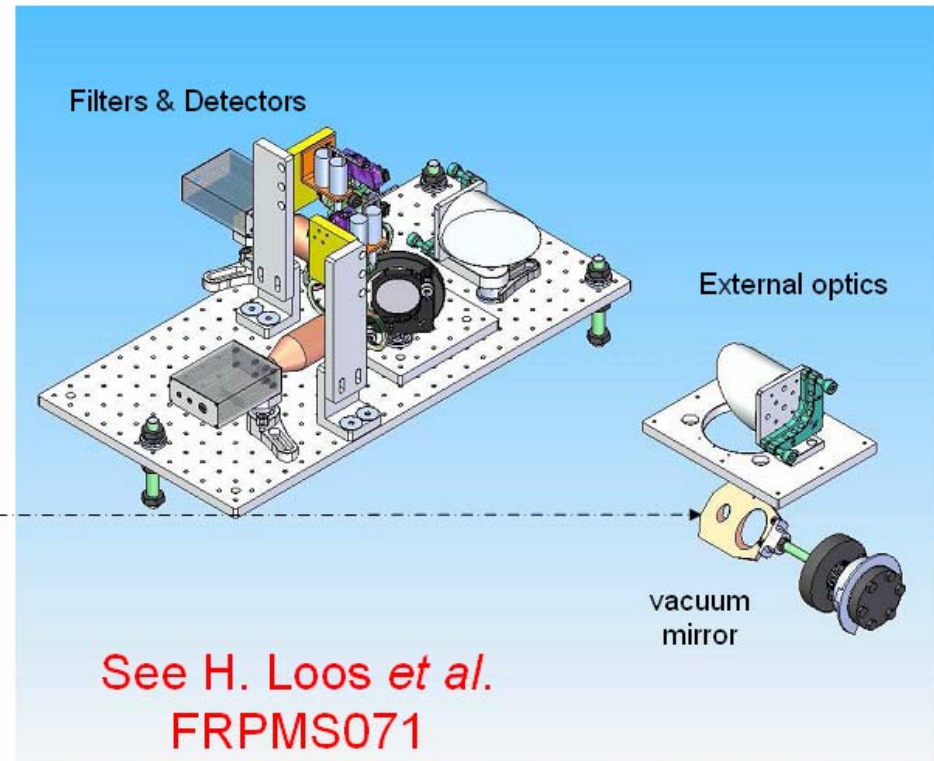
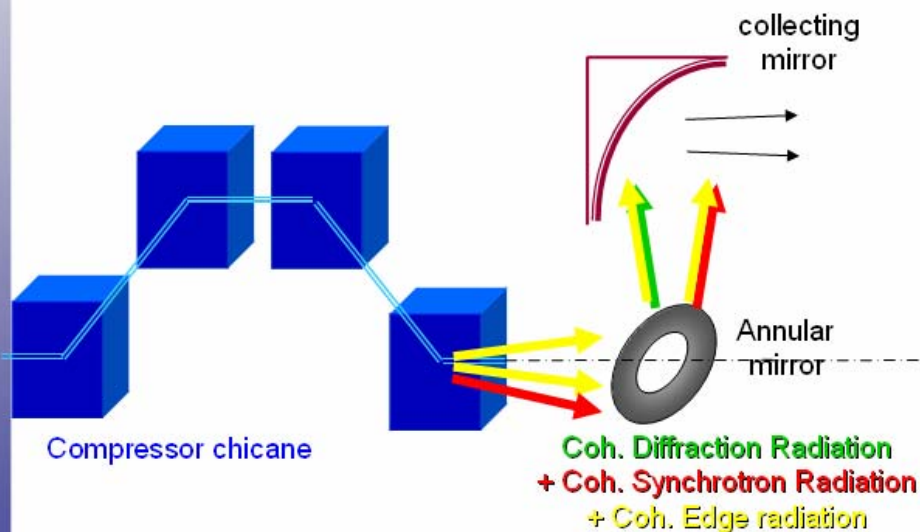
# T-Cav Measurement of LLRF phase jitter

Measure transverse position, shot by shot downstream of deflecting cavity



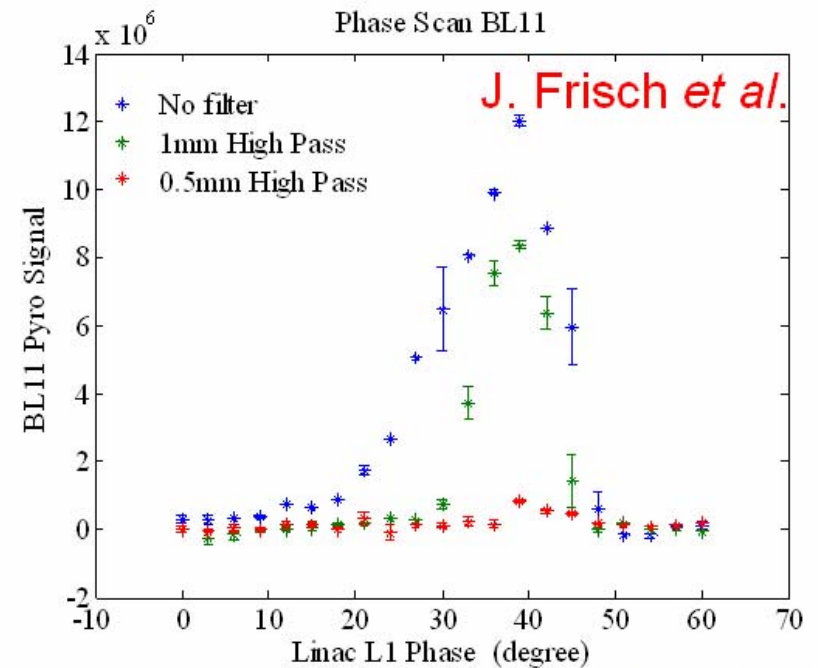
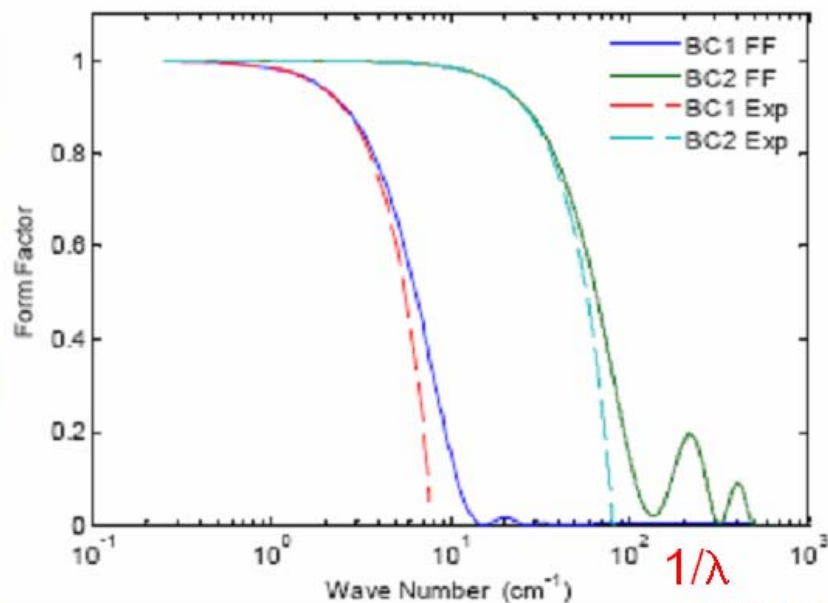
# Coherent radiation bunch length monitor

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



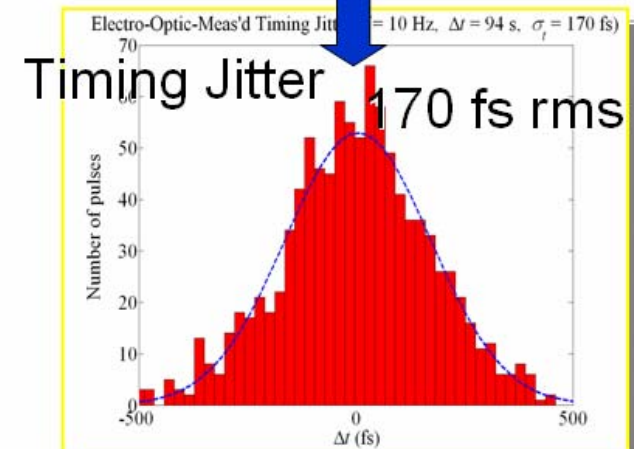
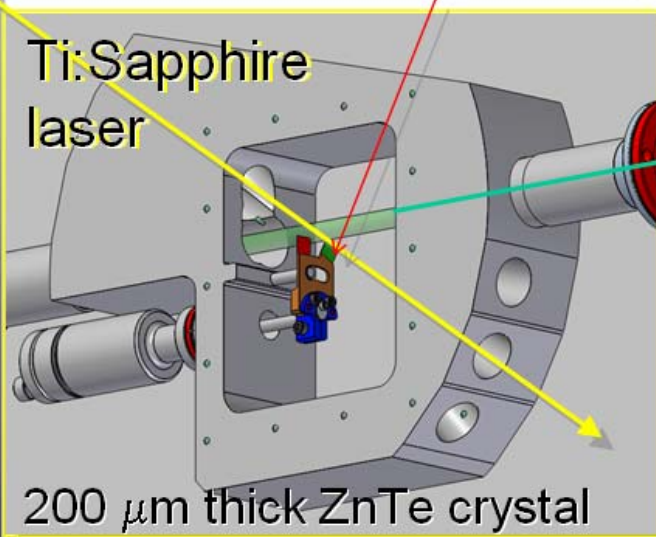
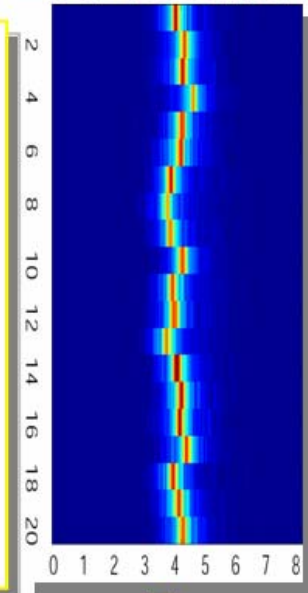
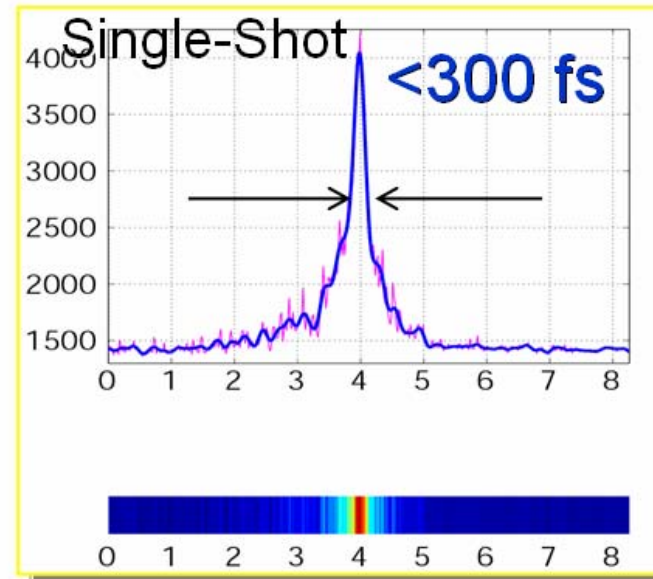
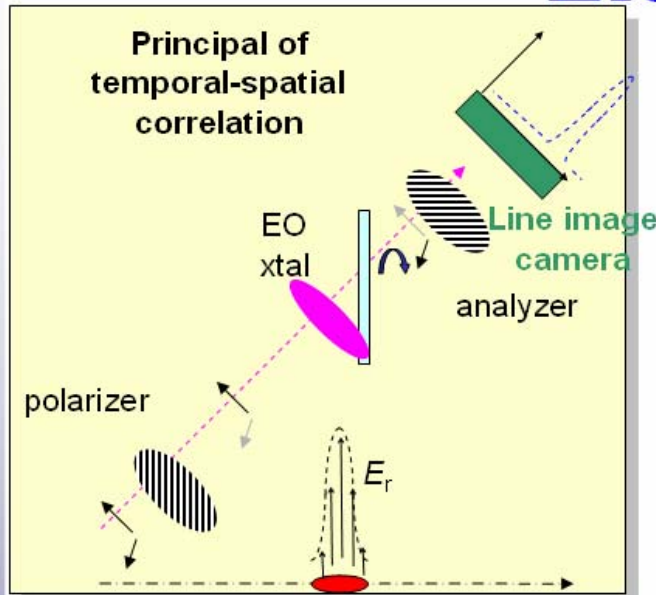
# First bunch length monitor data

- Radiation form factor depends on rms bunch length
- Bunch length after BC1: 60 – 200  $\mu\text{m}$
- Wavelength range to determine bunch length: 0.3 – 1 mm
- Measure integrated coherent power and use frequency filters



# Electro-Optical Sampling at SPPS

– A. Cavalieri et al.



# 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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