# JLab 10kW FEL Driver Beam Diagnostics

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# Outline

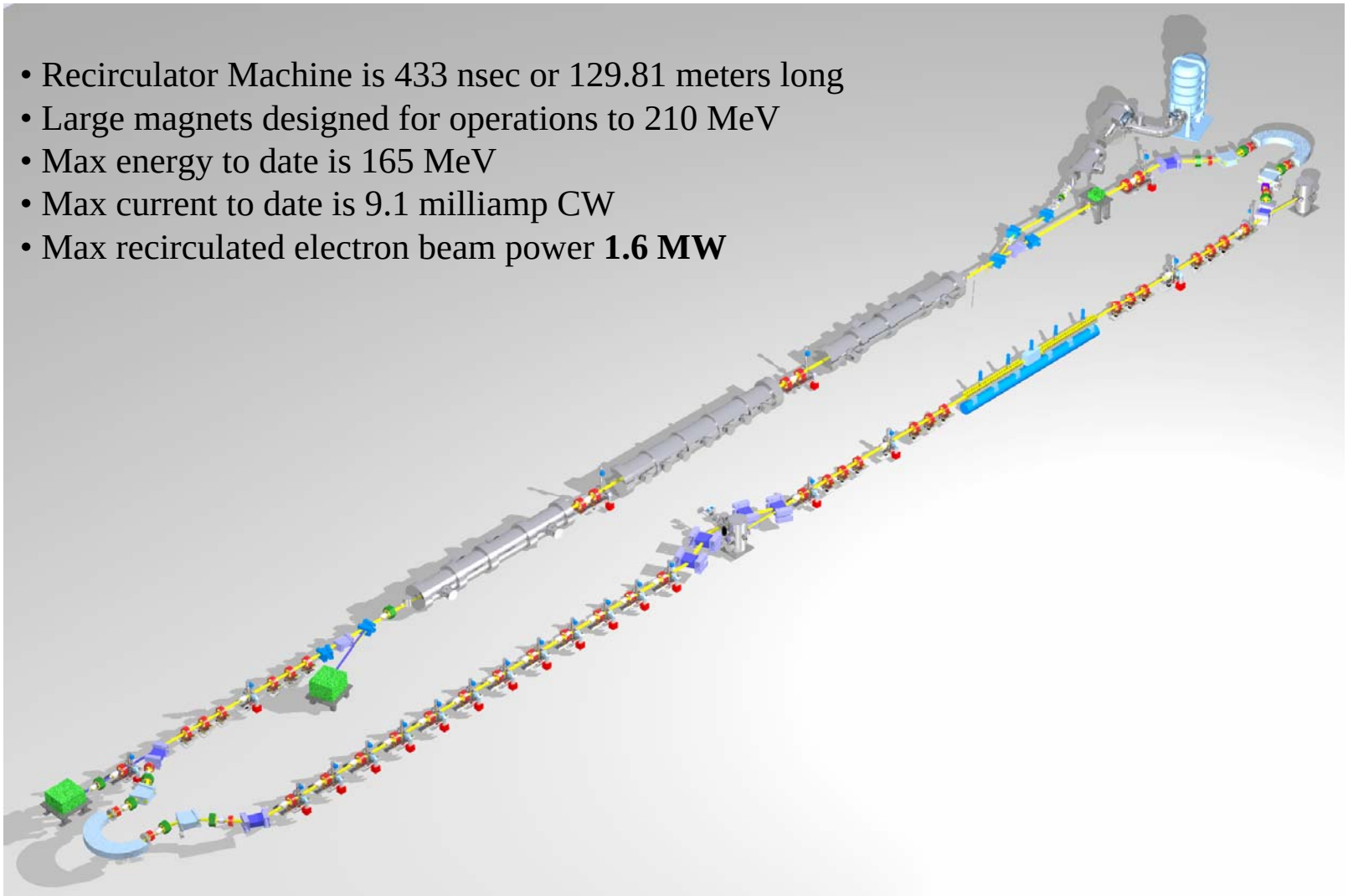
- Philosophy
- Beam Viewers
- Beam Position Monitors
- Synchrotron Light Monitors
- Beam Loss Monitors
- Bunch Length Monitors
  - Streak camera measurements
  - “Happek” Interferometer
  - M55 Bunch length & curvature
  - THz Spectrometer
- Emittance Measurements
  - Quad Scan Technique
  - Multislit monitor
- WesCam Frame Grabber System
- Analog Monitoring System and Video Distribution
- Conclusions

# Philosophy

- Leave the bunch long (especially out of injector) – then compress at wiggler
  - Recompress during energy recovery
- Limit shunt impedance of beam line componants
  - Shield all devices – viewers, bellows…
- Minimize radiation
  - HUGE apertures; 15% energy acceptance
  - Use as thin as possible Al foil for OTR viewers
- Maximize use of non-invasive diagnostics
  - Install synchrotron light ports wherever possible
- Beam Loss Monitors are crucial for machine setup
- Monitor RF gradient & phases (GASK/PASK) through linac to setup path length
- Analog Monitoring System (AMS) and Video System allow operator instant access to RF phases and gradients, BLM analog outputs, and a host of other signals throughout the accelerator (put a camera on it & patch it back)

# 10 kW IR FEL Driver Accelerator

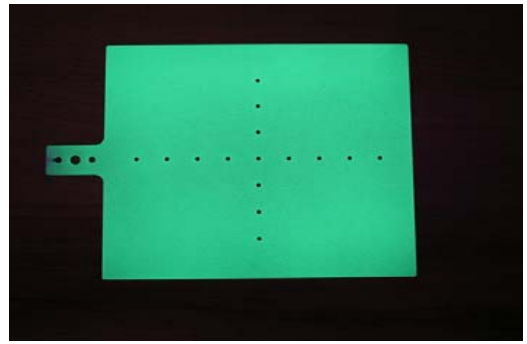
- Recirculator Machine is 433 nsec or 129.81 meters long
- Large magnets designed for operations to 210 MeV
- Max energy to date is 165 MeV
- Max current to date is 9.1 milliamp CW
- Max recirculated electron beam power **1.6 MW**



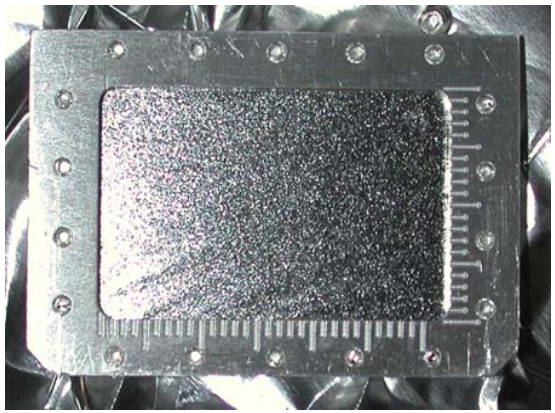
# Beam Viewers

- Variety of flag materials & coatings
  - Cromox ceramic in the 350KeV region – subject to blooming
  - “DESY” style phosphor coated Al in the 10 MeV regions – both the injection line & ER dump – extremely linear!
    - 2 insertable neutral density filters (OD1 & OD2) available for attenuation 10 to 1000
  - Thin Al flags elsewhere, 1 to 10 microns thick
  - Forward and backward OTR used
  - Two locations Silicon wafers for mirror finish
- Cohu series 1100 CCD cameras used, 0.05 Lux sensitivity
  - Bare board cameras mounted in home built enclosure, $100 CCD elements are replaced 3 months to 2 years when radiation damaged
- Red LEDs are used for illumination, **band pass filters used to limit OTR flux** (562nm;10 & 80 nm width) without attenuating the fiducial visualization.
  - The problem is that the OTR is too bright & ghost pulses contaminate spot size measurements
- Linux based Frame grabber, Scion model LG3-64

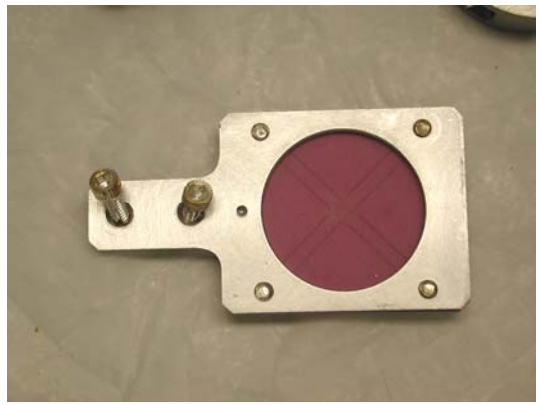
# Examples of Viewer Flags



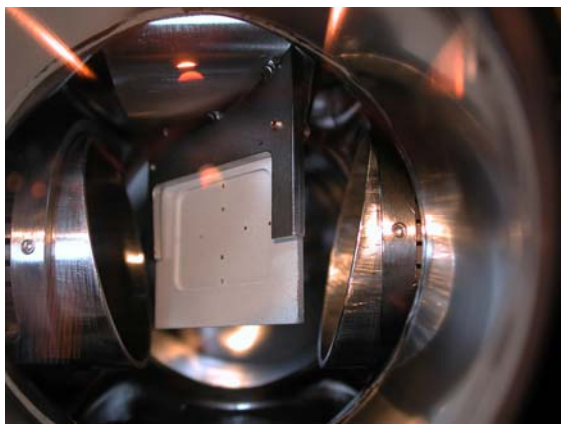
'DESY' coating under black light



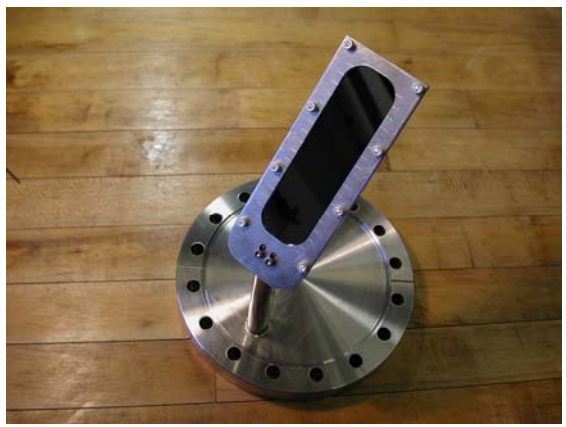
1.5 micron Al foil
1 mm reference marks



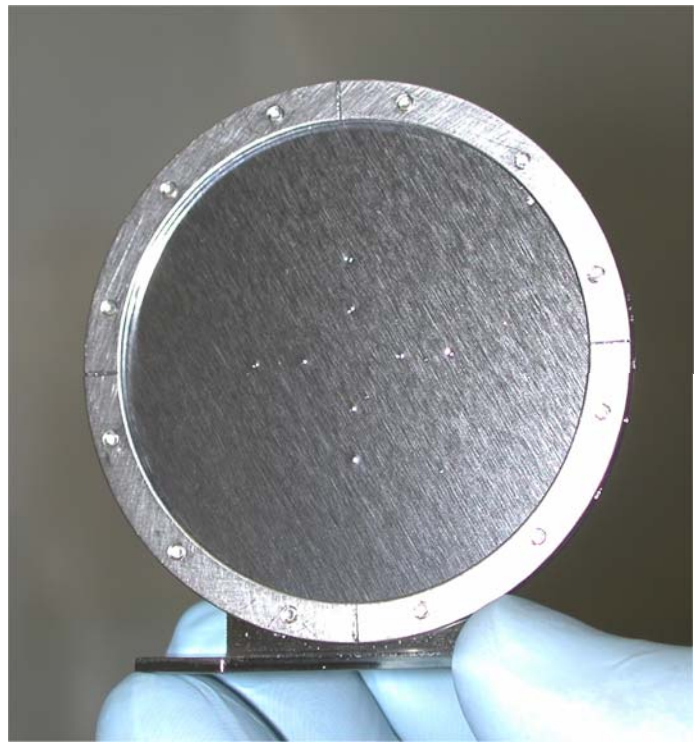
Cromox ceramic
1" dia. Used @ 350keV



'DESY' Phosphor coating



Si wafer fixed for spectrometer



5 micron Al 2" dia. $\pm$ 5, 10mm reference

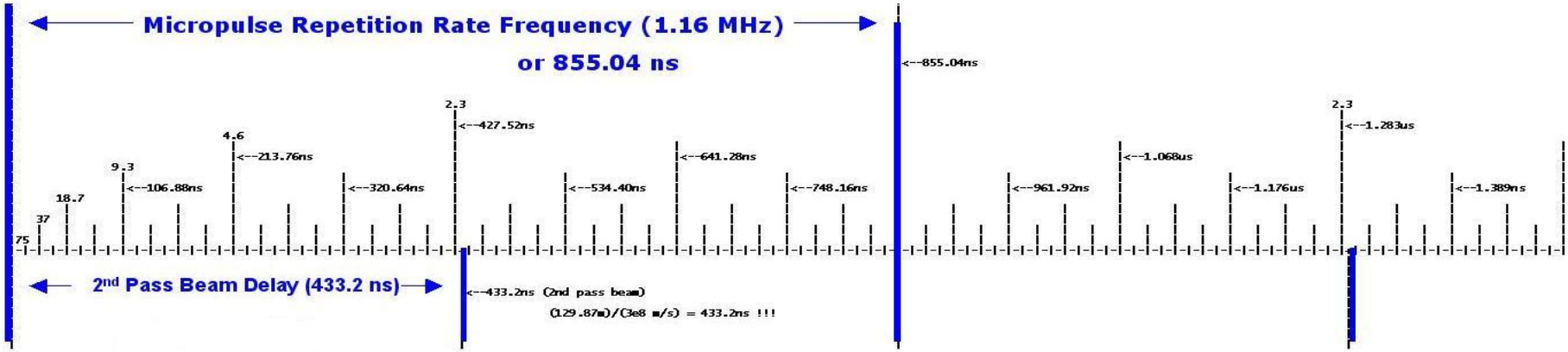
# Beam Position Monitors

- System requires low dynamic range since machine operates between 60 & 135 pC of charge per bunch
  - As micropulse frequency changes from 4MHz to 75 MHz current is; 0.3mA < I < 10mA
- Resolution requirement is ± 150 microns in linac, and 50 microns in the wiggler
- *Hand-me-down* electronics from CEBAF still in use, new electronics under development
- Shorted stripline BPMs used in areas with *round beam tubes*
  - Each electrode subtends 70 degrees
  - Injector before cryounit has 1.5” diameter (Qty. 1)
  - 10 MeV injector, after cryounit, has 2” diameter (Qty. 3)
  - Linac & back leg has 3” diameter (Qty. 26)
- Buttons used in rectangular chambers
  - Arrays of 4 and 8 buttons used in wide chambers
  - Only 4 of 8 readout with existing electronics

1.5 cm SLAC type button

Array of 8 buttons used in wide chamber

# Multi-pass BPMs in the FEL LINAC (under development)

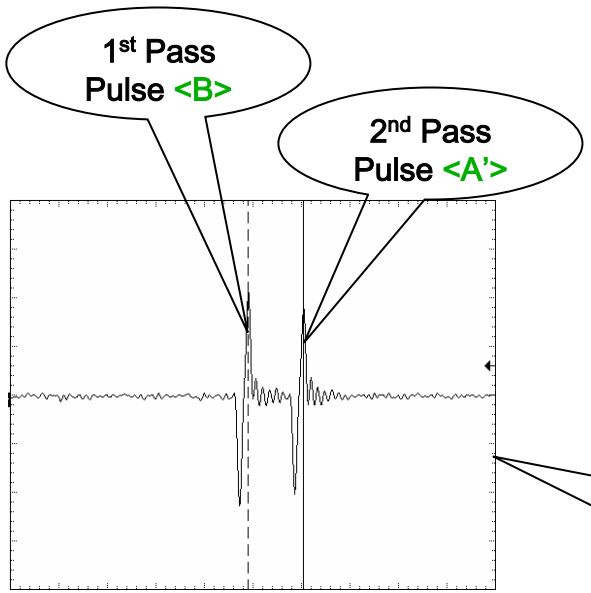



**PULSE LEGEND**

Pulse **<A>** is the 1st injected pulse into the machine at 1.16 MHz
Pulse **<B>** is the 2nd injected pulse into the machine at 1.16 MHz

Pulse **<B>** occurs **855.04** ns AFTER pulse **<A>**

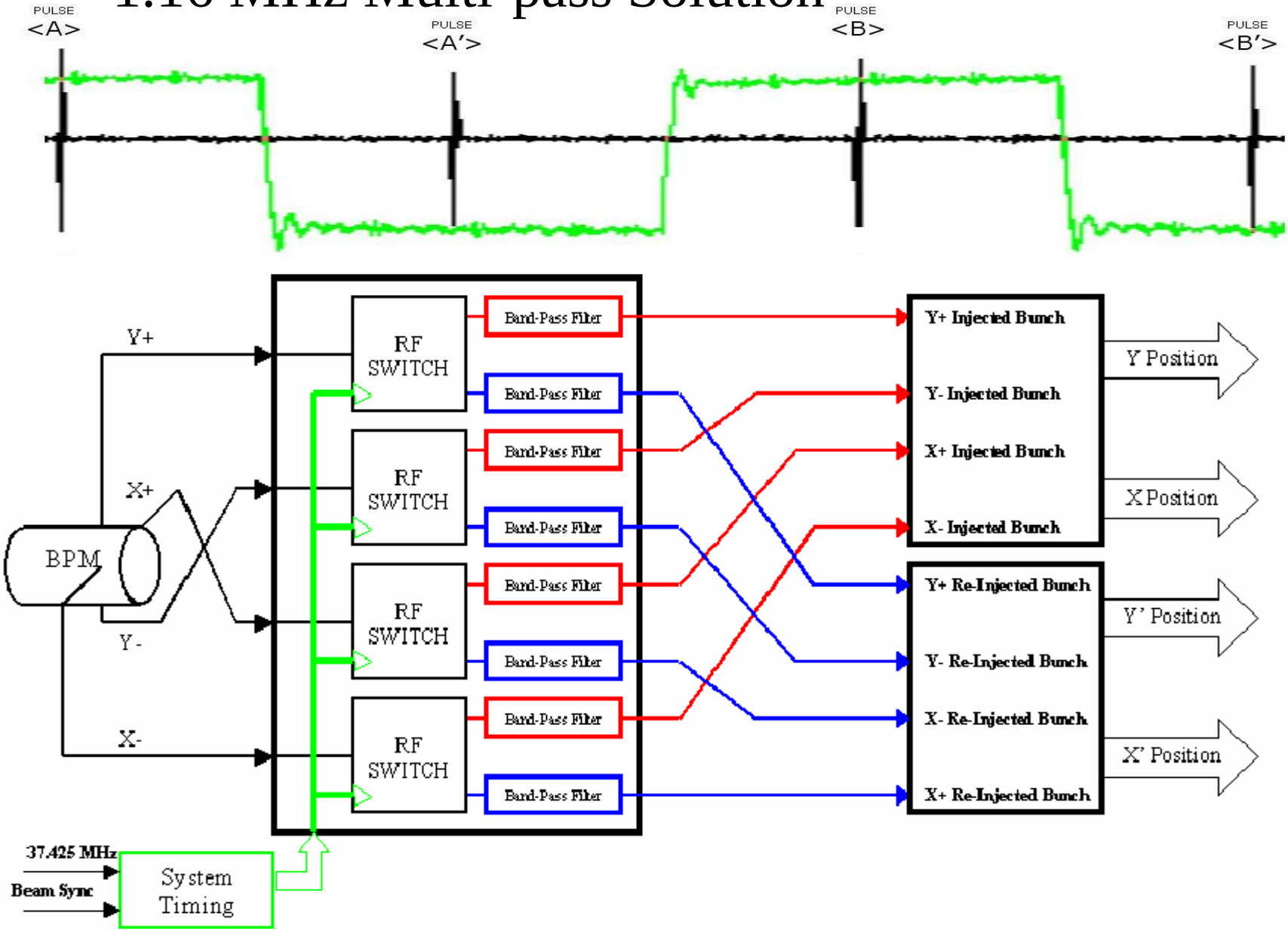
Pulse **<A'>** is pulse **<A>** *re-injected* after **433.2 ns** recirculation path delay
Pulse **<B'>** is pulse **<B>** *re-injected* after **433.2 ns** recirculation path delay




**Long term goal is to separate pulses at higher Micropulse Repetition Rate Frequencies.**

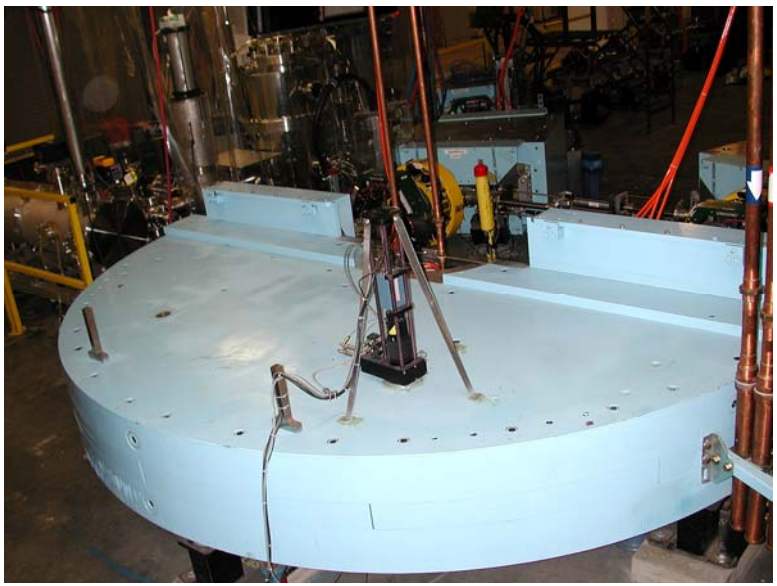
**Micropulse Repetition Rate Frequency (9.425 MHz)**

# 1.16 MHz Multi-pass Solution

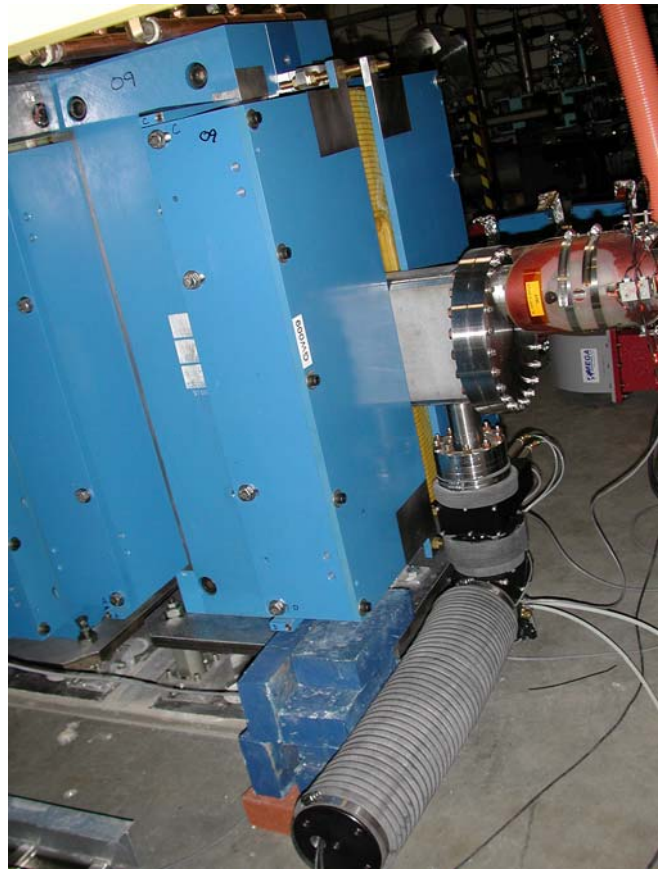


# Synchrotron Light Monitors

- SLM ports are installed even in unlikely locations
- Large dipoles were built with telescopes to bring out light
- THz chicane has a mirror in vacuum to *peek* into magnet
- All locations have insertable neutral density (ND) filters to attenuate signal, SLM bright even at 88MeV pulsed beam
    - OD1 (10x) and OD2 (100x) filters extend dynamic range of cameras 3 orders of magnitude

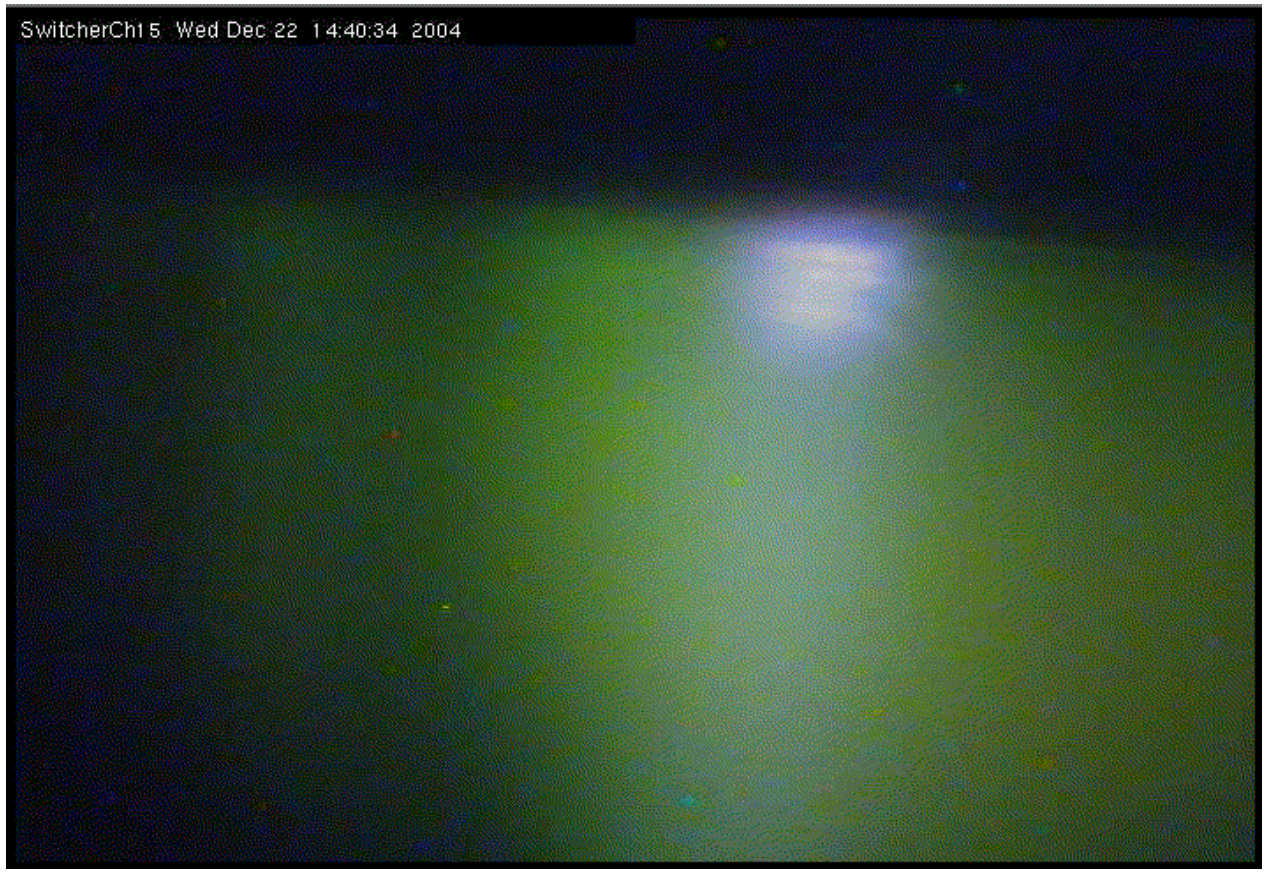


SLM port 5F02 with CCD camera and attenuators



THz debuncher SLM port

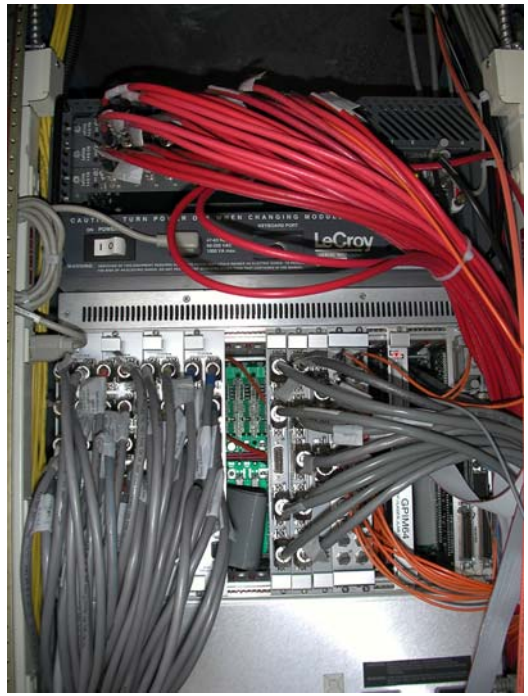
# SLM port on THz De-buncher



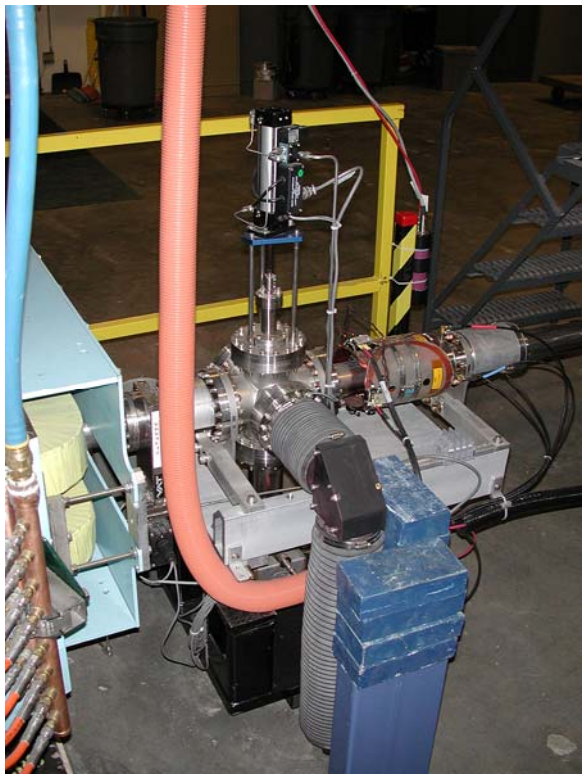

Lasing at 2.8 microns, white spot is SL and yellow/green is the 5$^{th}$ harmonic

# Beam Loss Monitors

- Crucial to setting up machine and
- 931B PMTs used with programmable HVPS
- All 48 analog signal available through the AMS
- Trip levels are set to 1 micro amp CW loss



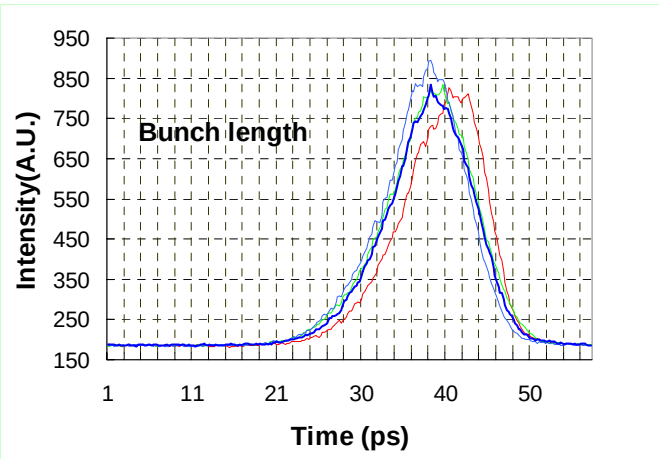

48 channels shown, 4 x 12 channel VME BLM boards shown with AMS and FSD connections on front and tube and high voltage on rear, also shown are the connections to the MPS system



Left is a typical beam viewer with BLM mounted in background, note air core correctors mounted on top of BPMs

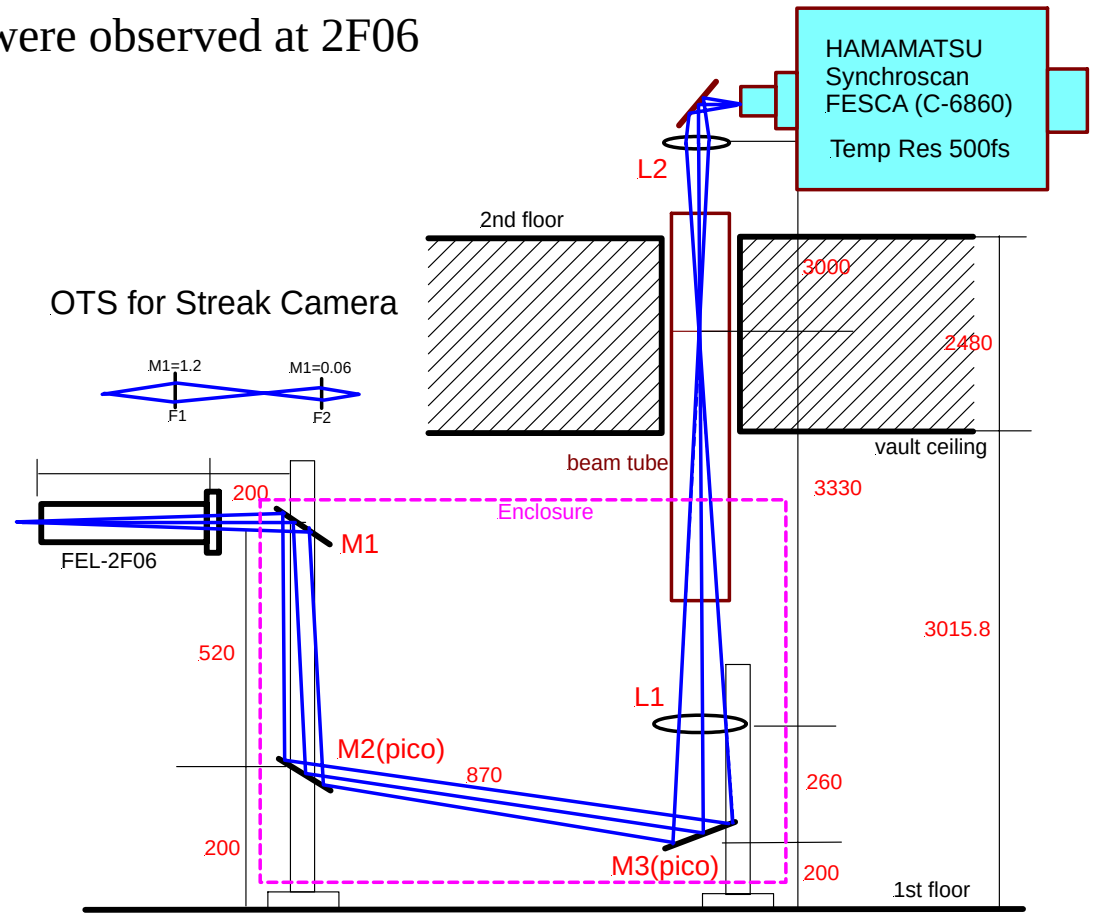
# Bunch Length Measurement by Streak Camera

- We have established a bunch characterization system with a femtosecond Streak Camera (Shukui Zhang)
- Bunch length and timing jitter were observed at 2F06 region before ARC1 magnet
- More OTS will be available for further beam characterization (Tomography…)



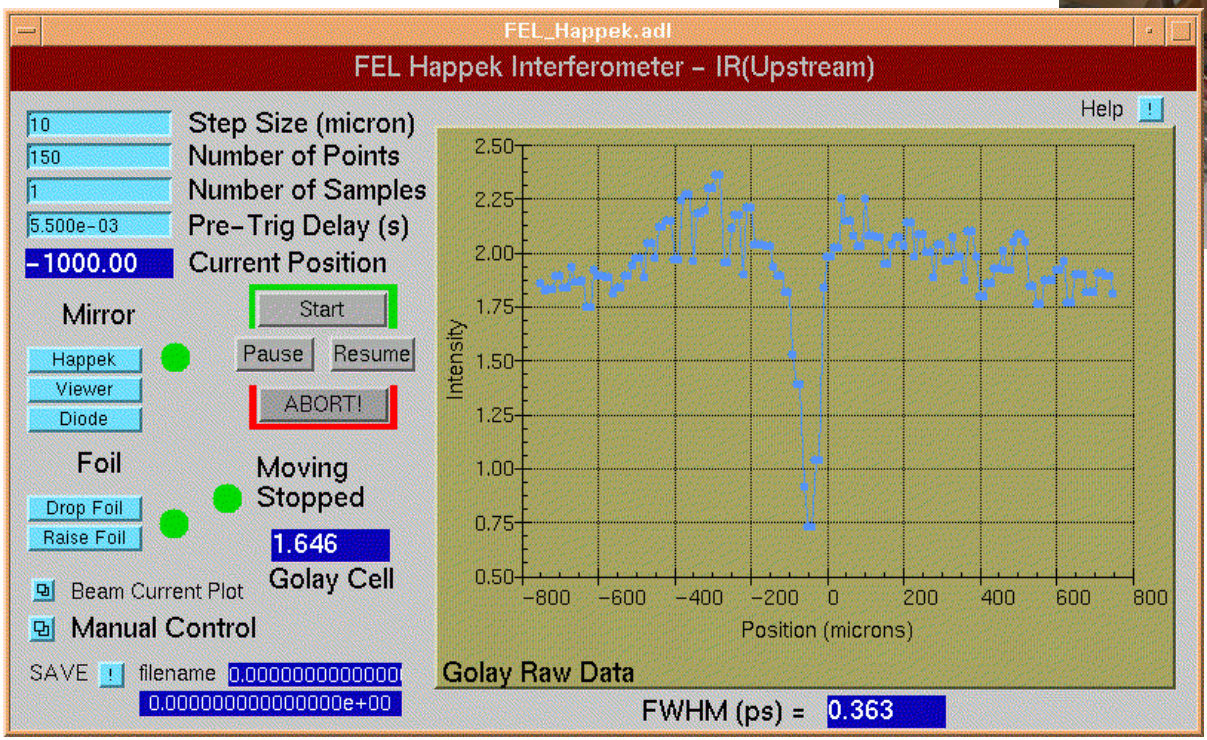

Bunch length measurements for e-beam energy 88Mev/CW 9MHz

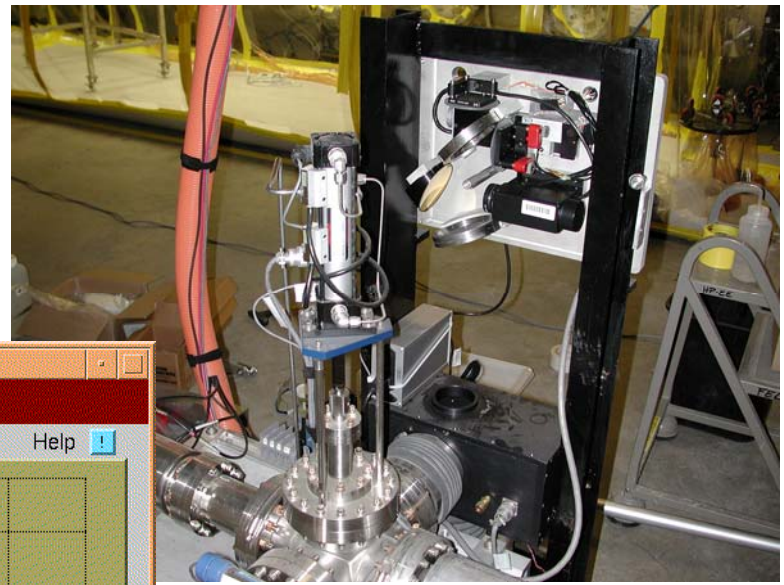
OTS for Streak Camera



# ‘Happek’ Bunch Length Monitor Installation

- Happek used to set injector phase, then bunch is optimized using FEL
- OTR signal from beam viewer
- Movable mirror to direct signal to interferometer or CCD camera
- Broad band lens (Shiny Bald Guy) used to collimate the THz signal to Golay cell detector in Martin-Puplett interferometer



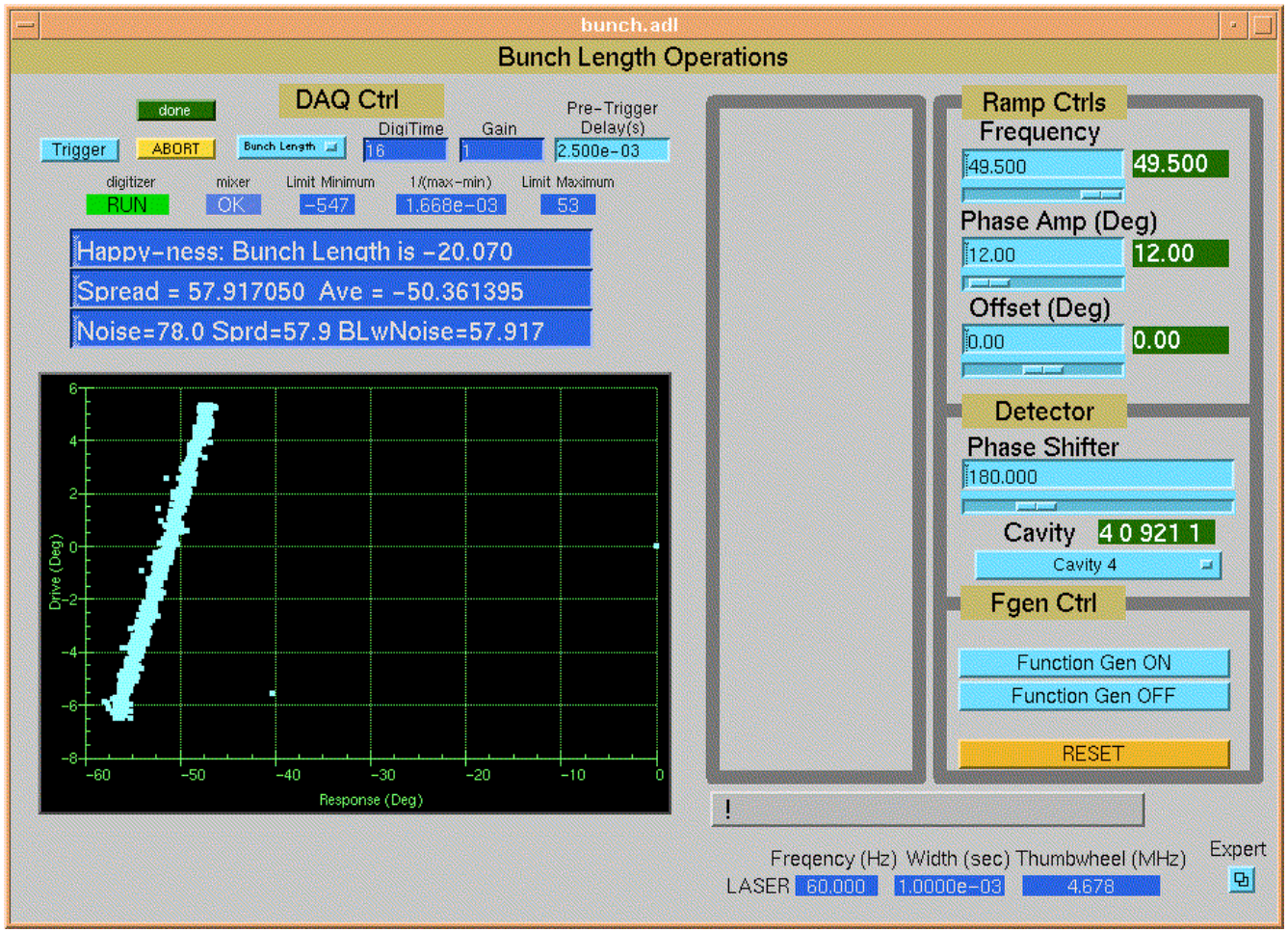



Interferometer shown with cover removed

# Phase Transfer Measurements

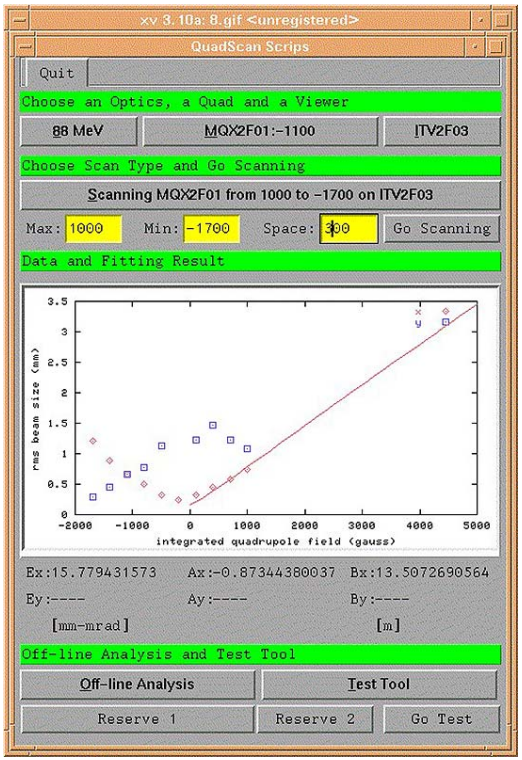
• Drive laser phase is varied and the arrival time is measured at cavities at various points in the accelerator

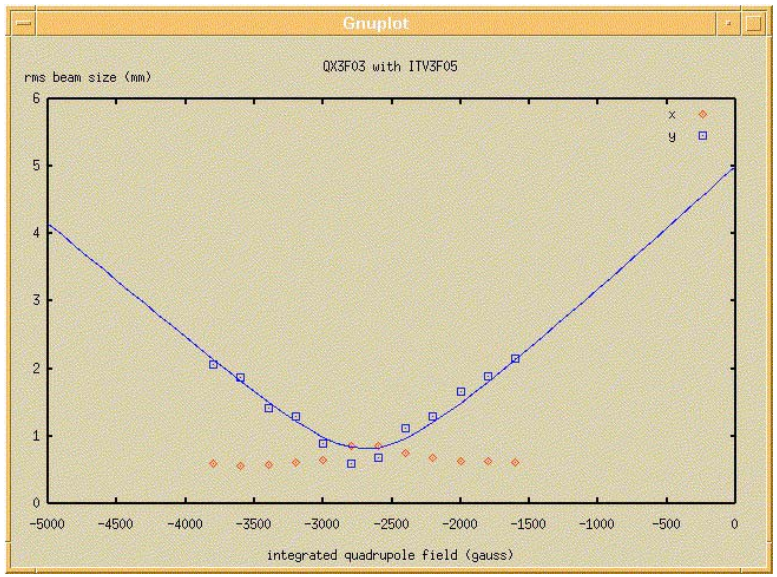
ref. G. Krafft WG4 talk



# Emittance Measurements

- New slit system has been designed with independent horizontal and vertical slits for ease of alignment
  - Slit width is 127 microns, cut by wire EDM
  - This system will be recommissioned over the next weeks
- An automated quad scan technique being developed by Noboyuki Nishimori (below)




Quad strength vs. spot size plot

Old Multislit w/o horizontal slits

New slits, wire EDM cut

# Beam Profile Measurements with WesCam Frame Grabber

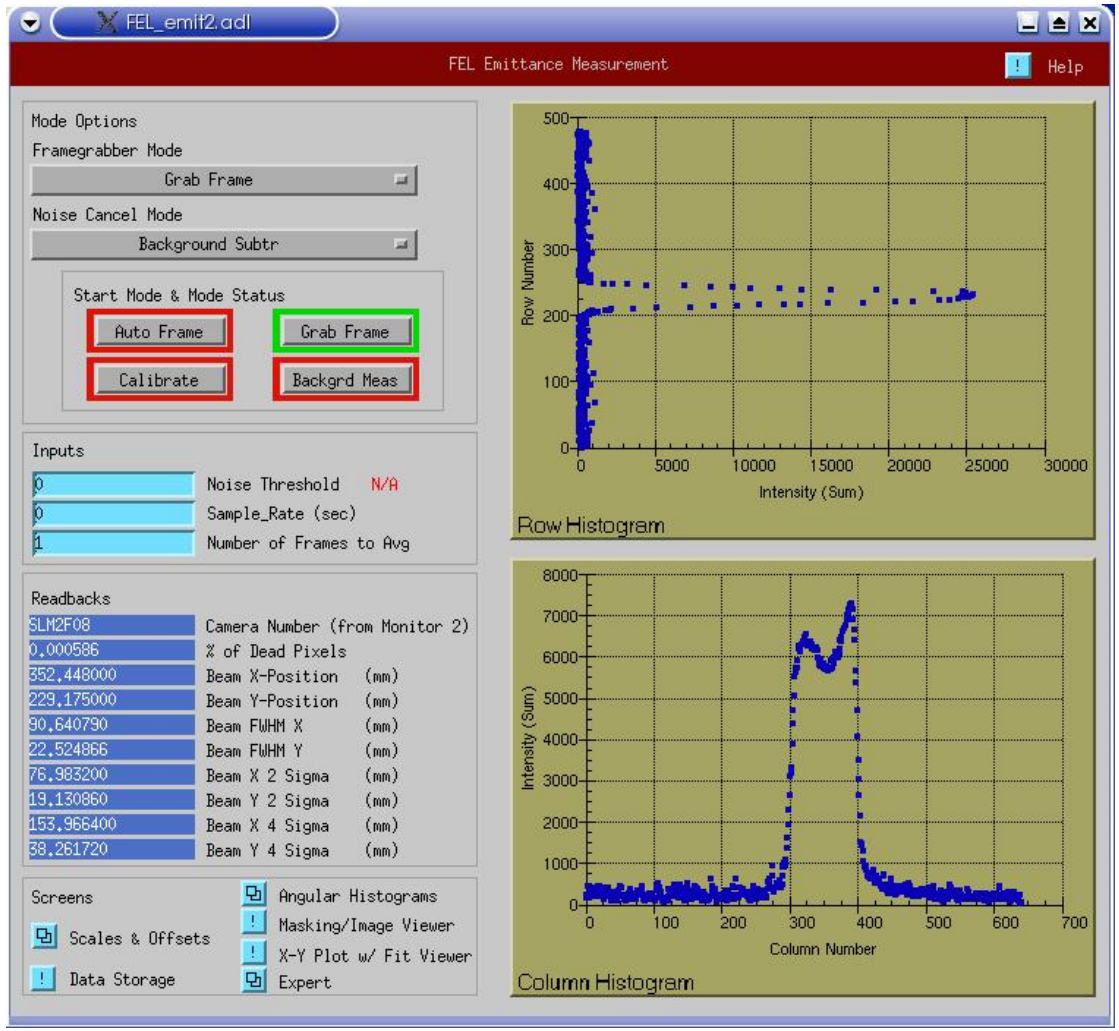
SLM2F08

## Uses

- Injector phasing
- Beam spot sizes for Emittance Measurements
- Recirculator setup based on beam size and position
- Determining the energy distribution of the bunch
- Determining the energy spread

**Next step, automate Linac phasing using beam positioning**

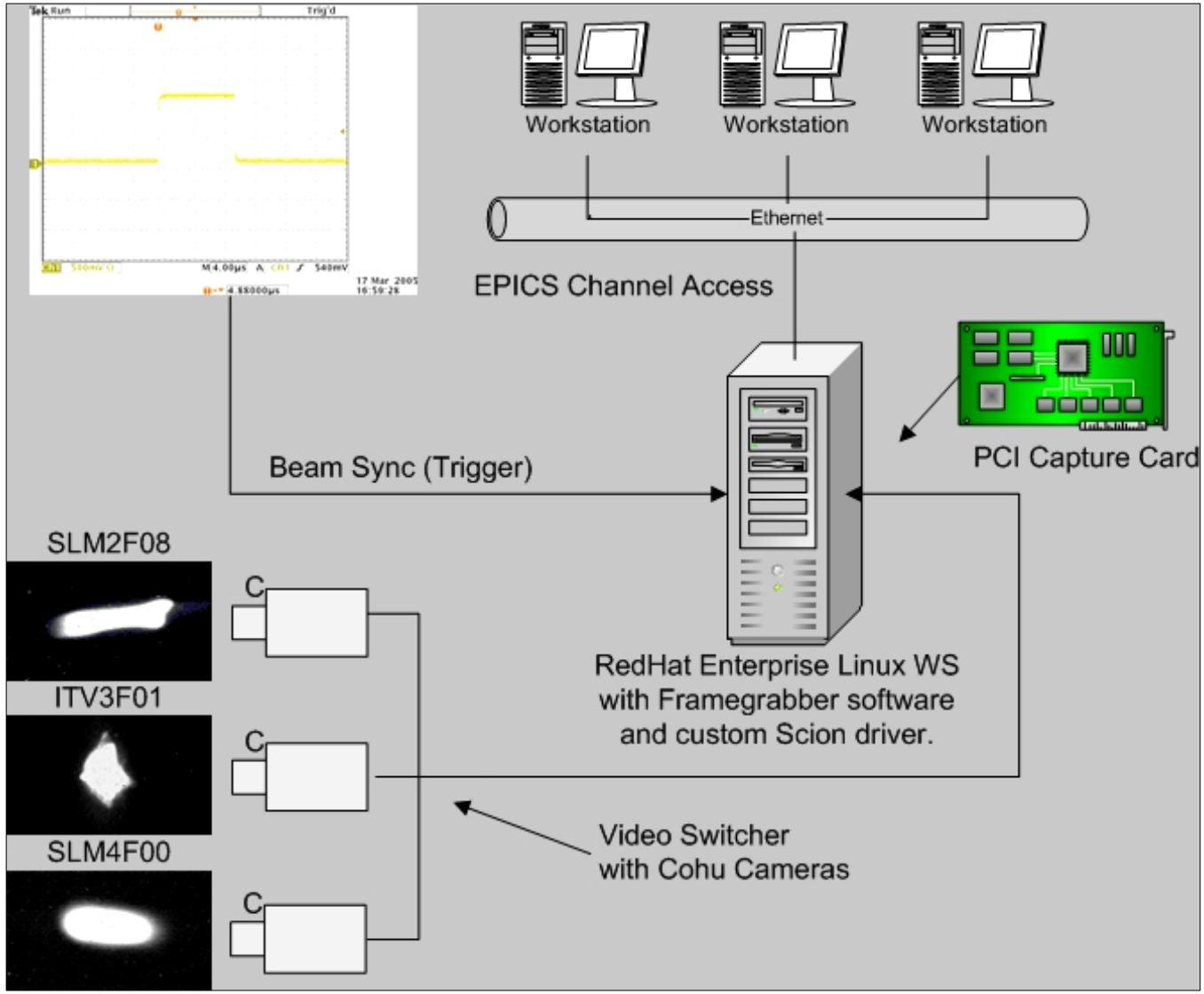
MEDM Controls Screen



# Organization of WesCam System

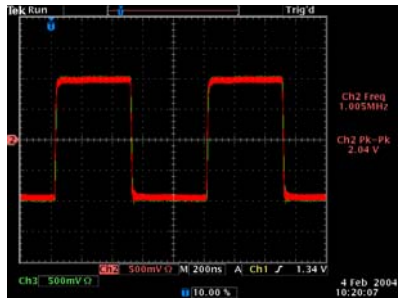
## Specifications

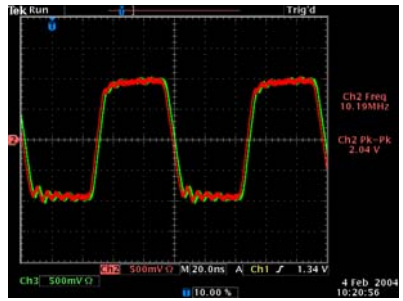
- Scion Corp LG3-64 PCI capture card
  - 640x480 Resolution
  - 64 Mb Frame buffer
  - Stores 128 Frames
  - External triggering
- Cohu 1100 Series camera
- Linux Workstation



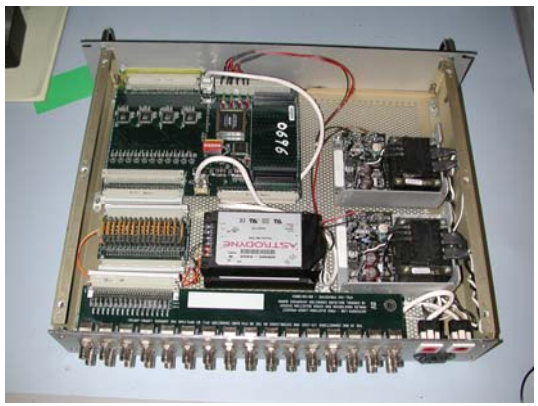
# Analog Monitoring and Video Distribution

- 256 X 32 full cross point switch capability for both AMS and Video
- AMS output drives Tek scopes with video output that is routed to the Video system
- Video system has 32 outputs that drive ~ 100 monitors including streaming 8 channels to the Web
- The only difference between the systems is a gain of 5 pre/post amplifier; ± 2volts for video, ± 10 volts for AMS



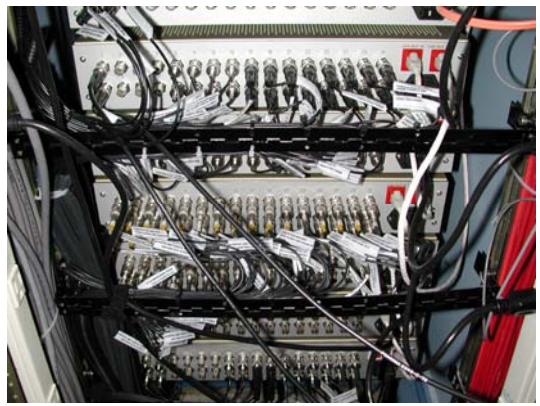




System INPUT and OUTPUT signal are shown overlaid, 2V P-P, left 1 MHz, right 10 MHz



32 X 32 Cross point chassis

Front view of 256 X 32 Configuration



Rear view showing cables

# Conclusions (What's not done yet or not right!)

- Better injector diagnostics are needed for understanding source of drifting injector phases
- More work to understand halo from gun/light box/cryo-unit
- Multi-pass linac BPM electronics need to be completed
- A longitudinal diagnostic would be helpful for injector characterization
- THz spectrometer makes a good non-intercepting bunch length monitor
- Full integrated Machine Protection System with defined Beam & Machine Modes has made commissioning less *painful*
- The AMS & Video System was essential for commissioning and daily operation FEL