Controls, Diagnostics and Operational Aspects for an ERL (injector)

Bruce Dunham

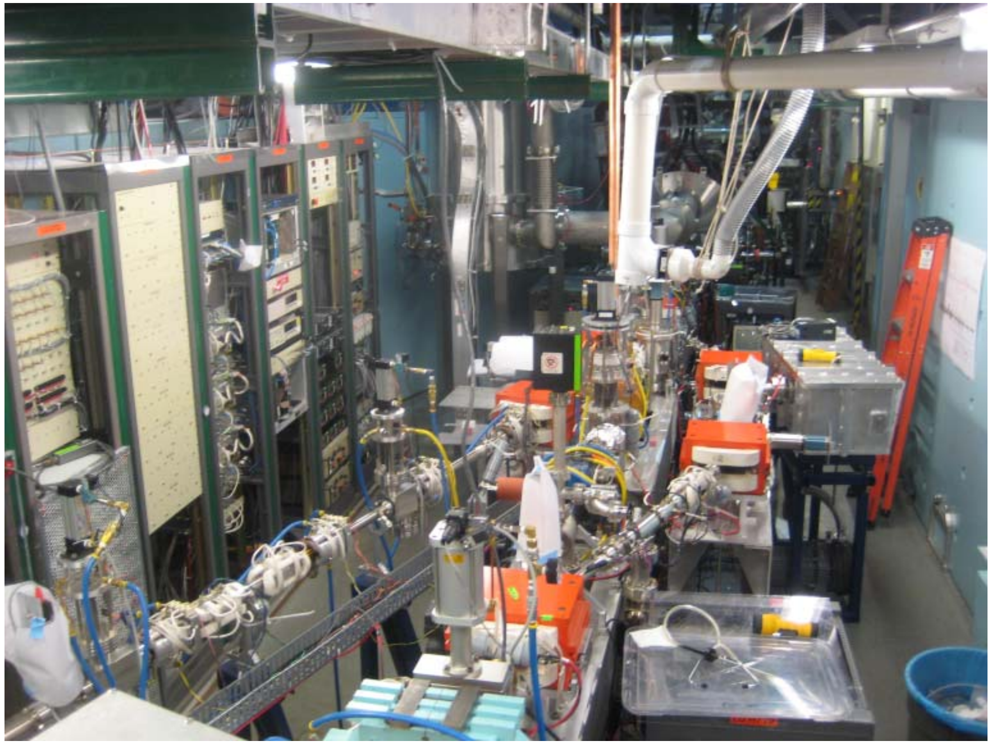
Outline

Overview
Introduction
Control Systems
Emittance
Longitudinal Phase Space and Timing, arrival time
High Power, current measurement
Halo
Operational Aspects

Look forward to seeing what WG4&WG5 have to say in ERL2011

Introduction

world's highest brightness CW photoinjector at Cornell!



A wide range of diagnostic tools helped us to get here!

Introduction

- No vacuum chamber. If its not a BPM, it's a profile monitor, SR port, cavity monitor…
- Basic issues
  - Resolution of phase advance & lattice functions limited by # diagnostics
    - Storage rings – measure over many turns, give, in effect, many iterates of datataking
    - ERLs – at most a few turns – limited resolution
  - Resolution of beam properties limited by # diagnostics (multimonitor), dynamic operating range of ERL (can't run full power beam into an intercepting diagnostic, can't change focusing dramatically for a quad scan/tomographic measurement with high power beam…)
  - Need to assure excellent beam stability & synchronization

Slide courtesy of D. Douglas (Jlab)

Introduction

- High resolution multipass BPMs working over broad dynamic range (μAs to 100s mA) and with flexible beam timing (single shot->CW)
- Beam time of flight, transfer function (M_{55}, BCM)
- Tomography: transverse and longitudinal
  - High resolution/ large dynamic range profile monitors
  - Bunch length – Martin-Puplett interferometer; THz spectrometer
- Halo monitor
- Streak camera
- Means of monitoring beam noise/stability
  - P. Evtushenko, BIW2008
- SYNCHRONIZATION (esp. FELs) & STABILITY (esp. light source ERLs)
  - Beam noise

Slide courtesy of D. Douglas (Jlab)

Cornell Laboratory for
Accelerator-baSed Sciences and Education (CLASSE)

Dynamic Range

ERL 2011
the 50th ICFA Advanced Beam Dynamics Workshop on Energy Recovery Linacs

100 mA	100 μA	100 nA	100 pA
Design current: Non-intercepting or minimally intercepting diagnostics	Phase space measurements: Non-intercepting or fully intercepting diagnostics	Beam setup: viewers, cameras	Halo, cathode lifetime: viewers, PMT's

10^3 10^3 10^3

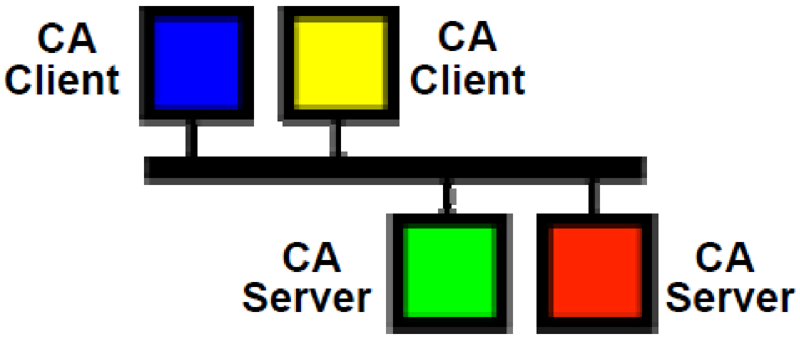
10^6 to 10^9

This huge dynamic range for ERL's means a lot of different diagnostics are needed

Control Systems

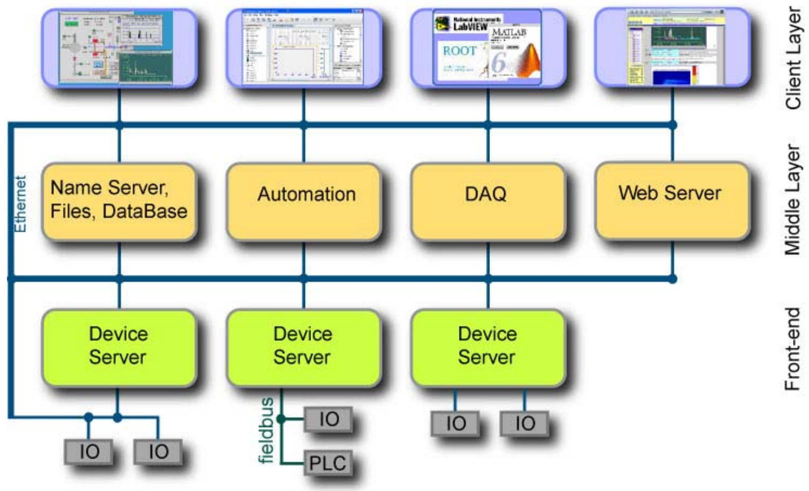
Control Systems - a few choices

EPICS



- 2 tier system
- Widely used
- Many drivers and apps exist
- Inexpensive – 1 person can handle our entire injector
- New version to address shortfalls due in ???

DOOCS



- 3 tier system (DESY)
- Easier to write apps
- Integrated DAQ for high data-rate streams
- Can talk to EPICS servers

Transverse Emittance

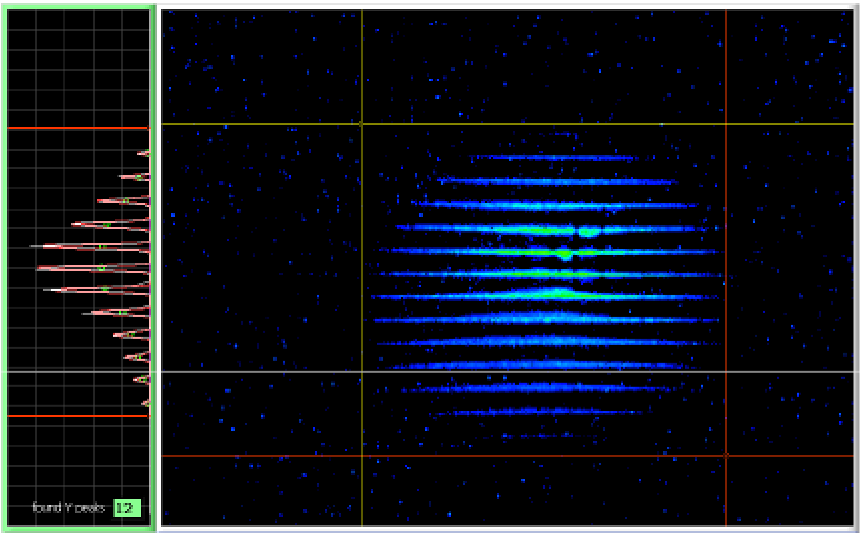
Transverse Emittance

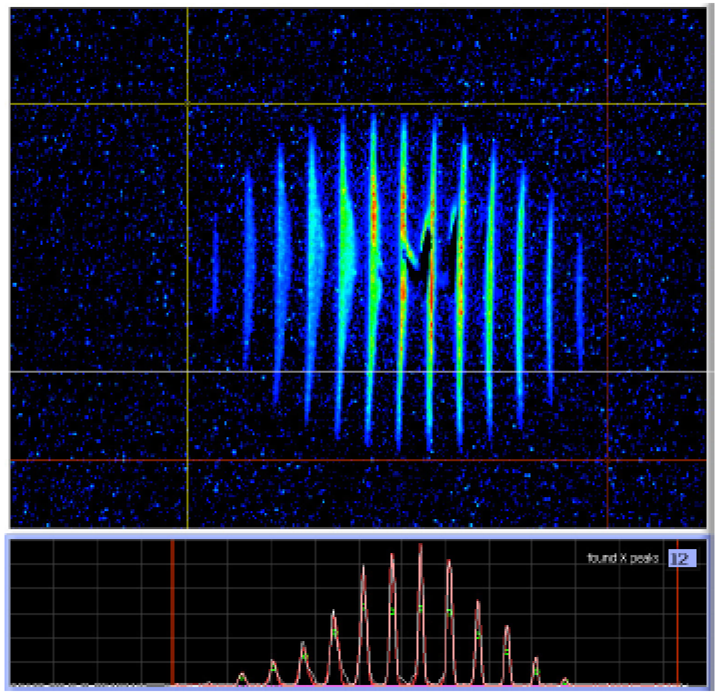
Solenoids scans
Quad scans
Pepper pot
Multiple wire scanners (laser wires too)
Multi-slit*
Scanning slits*
Stationary slits with scanning magnets*
Single slit with wire scanner or viewer*
Slice emittance*

* These are some of the most important methods for low energy, space charge dominated beams. Typically only for pulsed beams and are destructive – *ideas for non-destructive measurements*?

Transverse Emittance

Multi-slit



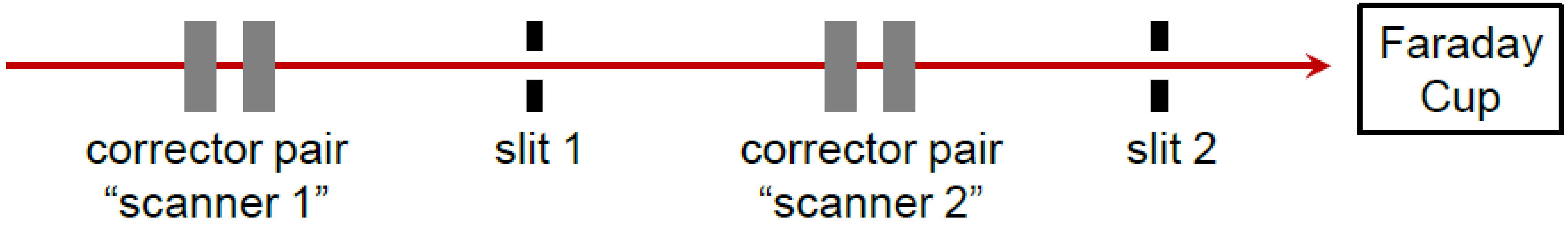


- well established technique
- works for space charge dominated beam
- beam profile is measured with YAG, phosphor or ceramic viewer
- measures not only the emittance but the Twiss parameters as well
- enough information to reconstruct the phase space
- has been implemented as on-line diagnostics
- works with diagnostics mode only (low duty cycle, average current)

Slide courtesy of P. Evtushenko, ERL2009

2 slit method

New way to use 2 slits



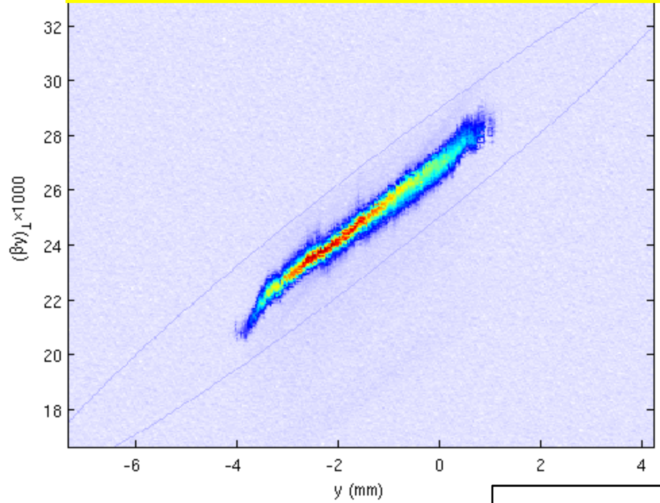
Leave the slits stationary and scan the beam across them. Using a faraday cup gives very wide dynamic range, no concerns about saturation.

We scan the correctors at several kHz rates and can get a good measurements in a few seconds.

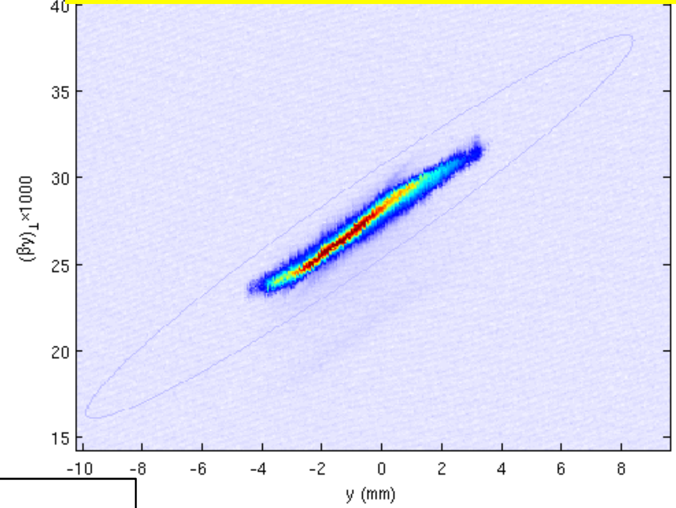
This turns our injector into an analog computer for performing multi-parameters optimizations.

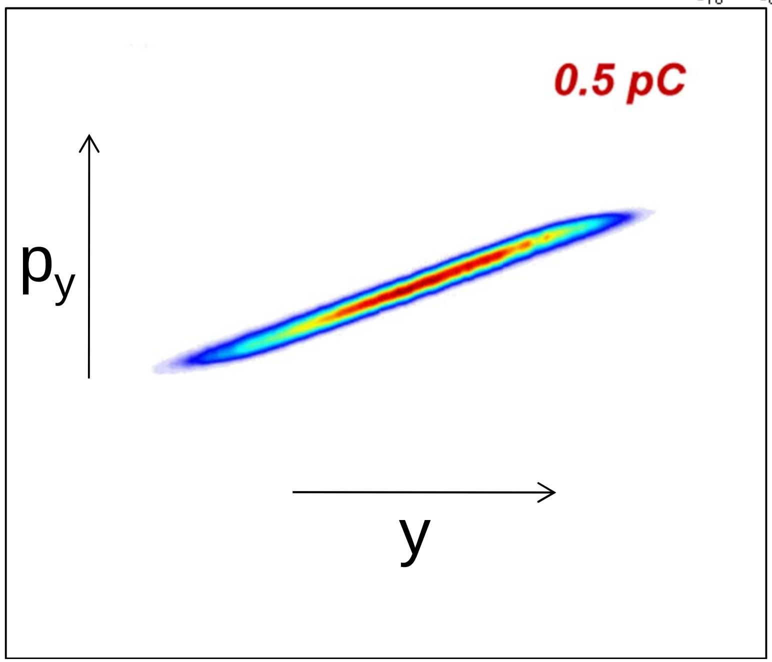
Cornell Results

ε_{ny}(100%) = 0.4 um @ 20pC/bunch



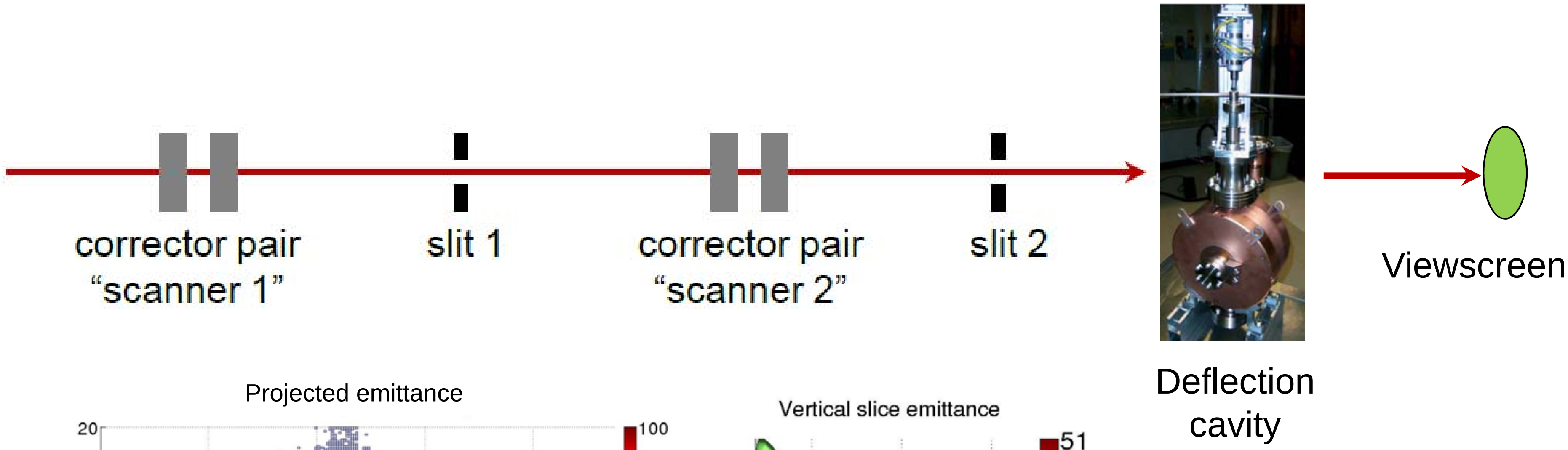
ε_{ny}(100%) = 0.8 um @ 80pC/bunch

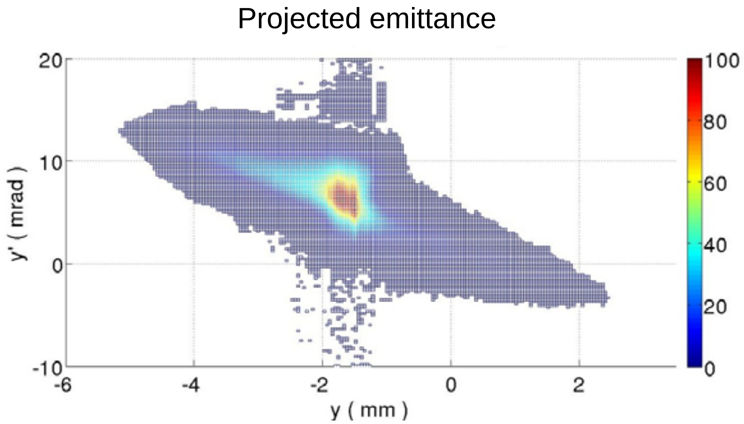


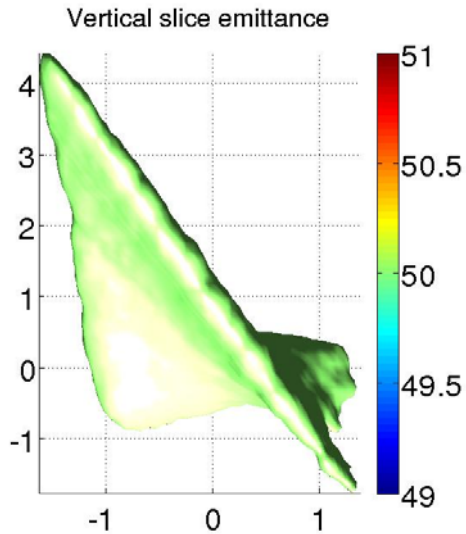


All at 5 MeV

Slice Emittance





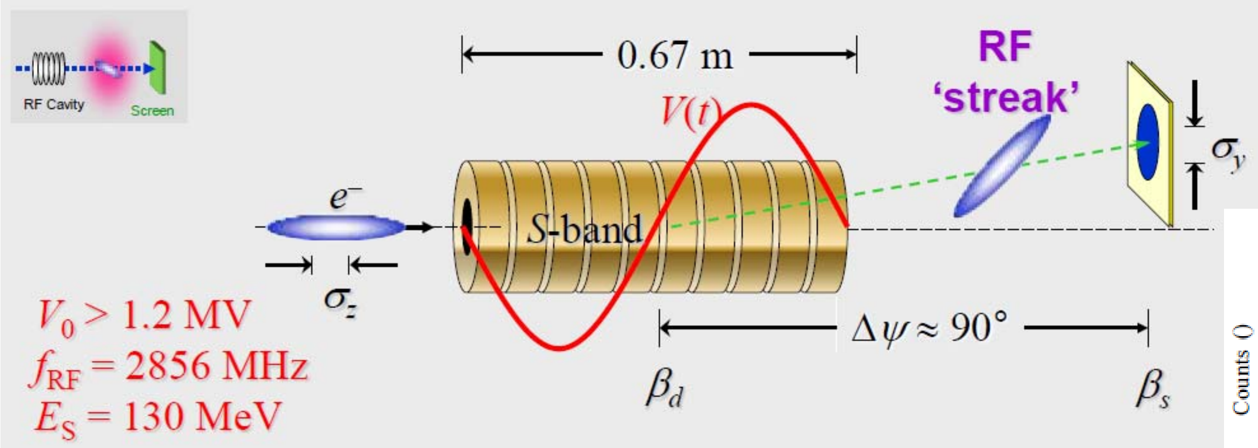


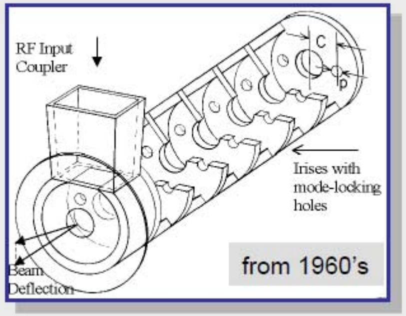
0.70 mm-mrad (100%)

The slice emittance rotates 55º from head to tail

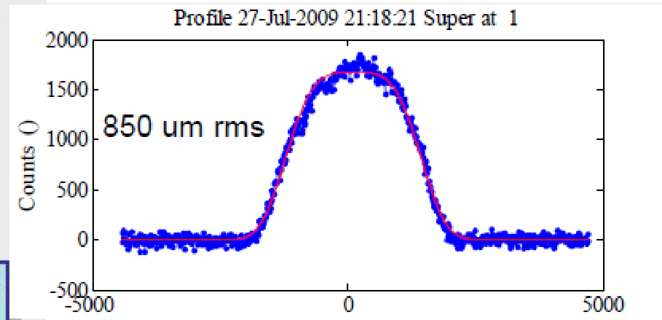
Longitudinal Diagnostics

Deflection Cavity





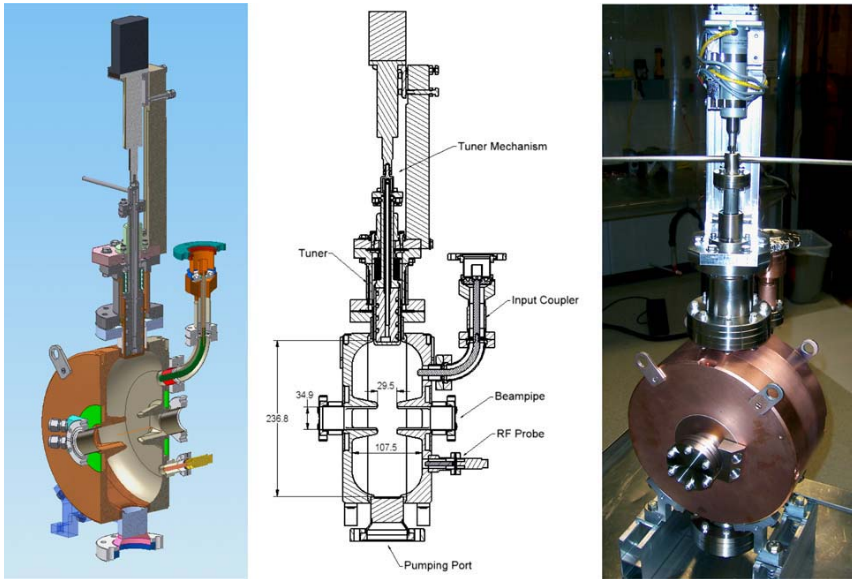
$$\sigma_y^2 = \sigma_{y0}^2 + \beta_d \beta_s \sigma_z^2 \left(\frac{k_{RF} e V_0}{E_s} \sin \Delta\psi \cos\phi \right)^2$$



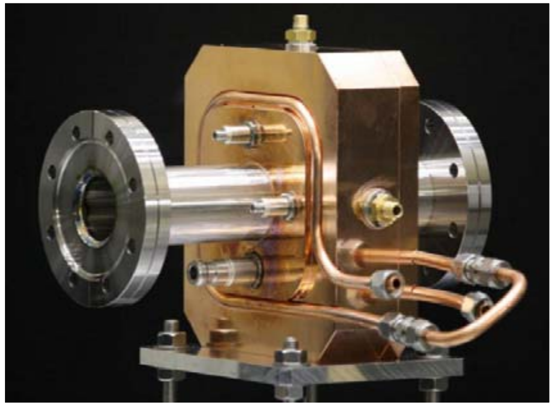
- Map time axis onto transverse coordinate
- Simple calibration by scan of cavity phase
- Typical calibration factor ~1 from z → y

From Henrik Loos, FLS2010

A few deflection cavities



Cornell deflector at 1.3 GHz

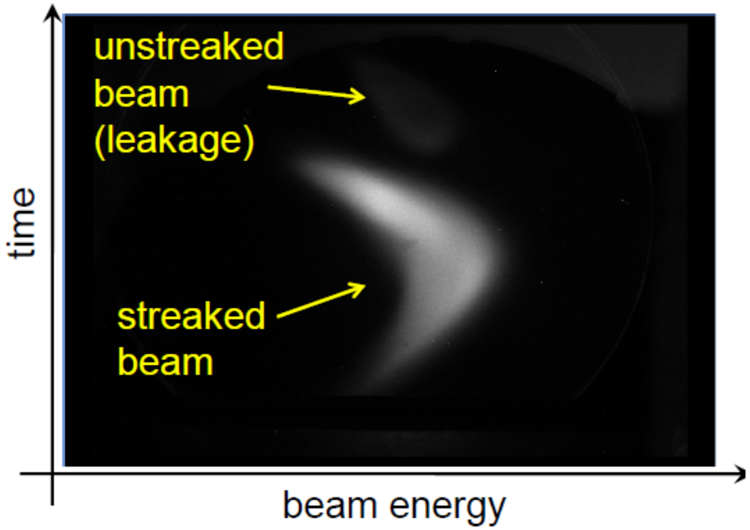


2.6 GHz Dipole Mode
0.5 ps resolution with beam slit

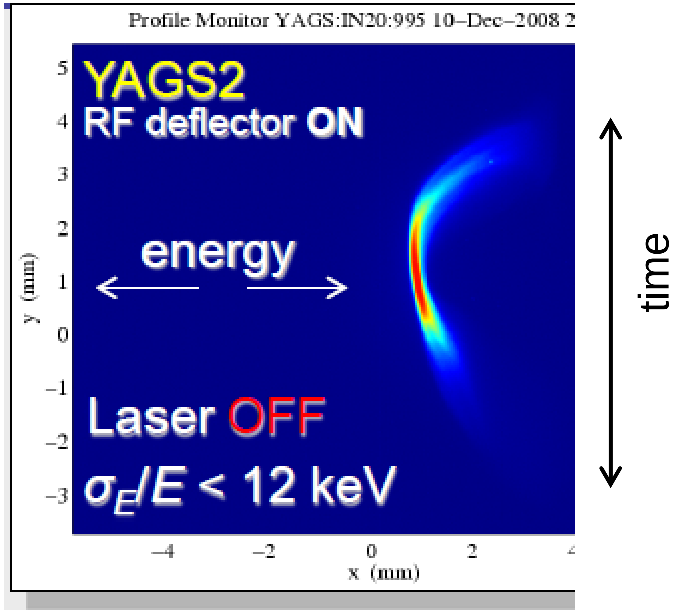
KEK (S. Matsuba, Y. Honda, T. Miyajima)

Longitudinal Phase Space

A deflection cavity + a dipole + a viewscreen gives an easy way to measure the longitudinal phase space

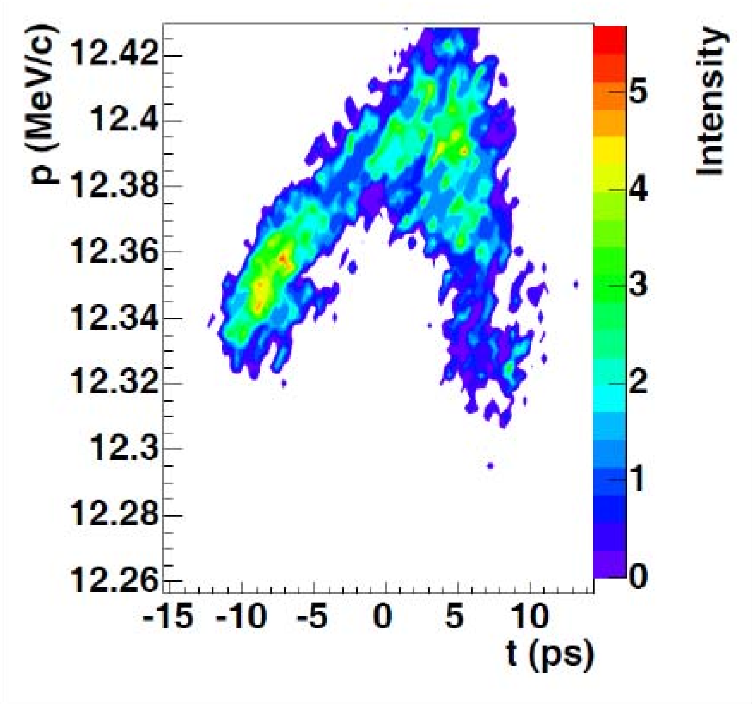


Cornell image, showing the contribution from less than perfect laser extinction ratio between pulses.



From Henrik Loos, FLS2010

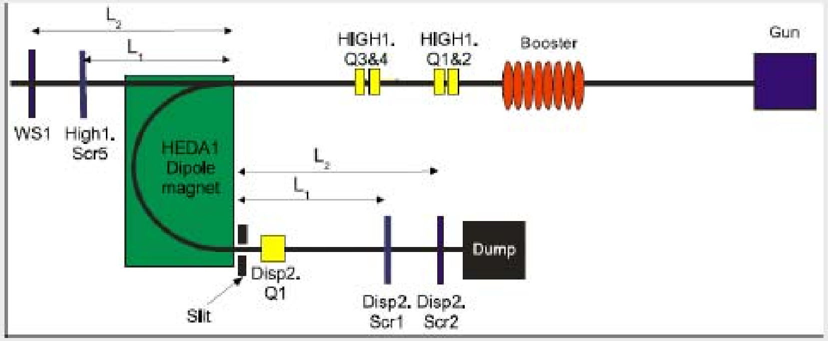
Another Method



Energy scale from beam in spectrometer
Signal from Cherenkov radiator
Time scale with streak camera

Technique requires light transport to streak camera
Dispersion effects need to be considered

PITZ Test Facility



J. Rönsch, DIPAC 09

Bunch Arrival and TOF

Bunch Arrival-Time Monitor (BAM) (Ref.: [2,3]).

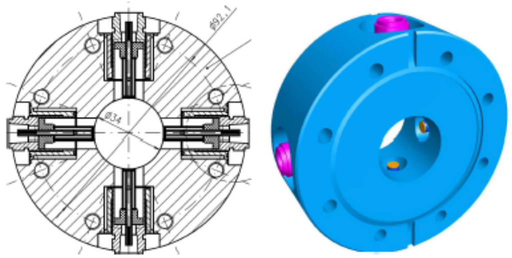
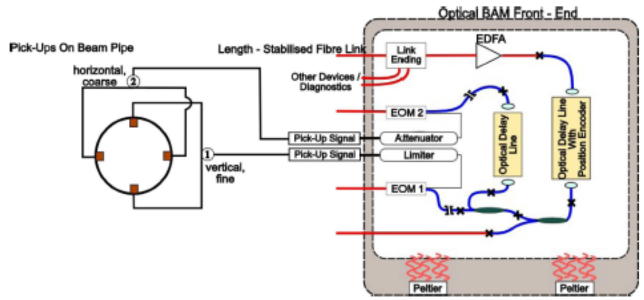


Figure: Beam pick-up.



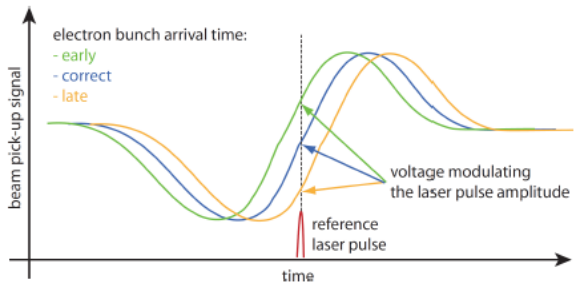


Figure: Working principle.

- Beam pick-up: Signal generation.
- MLO: Reference laser pulse train.
- EOM: Bunch arrival time is encoded in amplitude modulation.

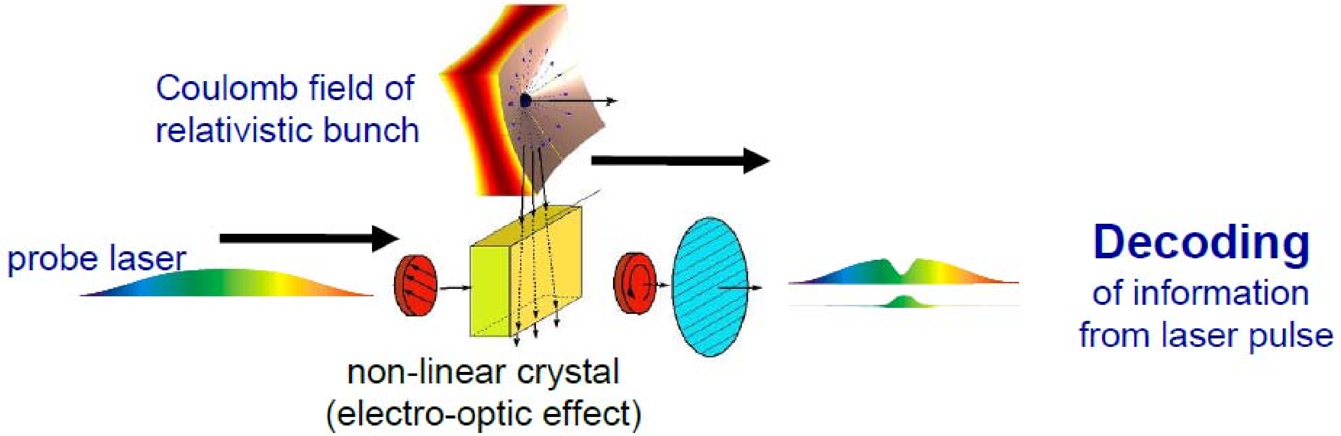
Dynamic ranges: 65 ps (coarse) and 4 ps (fine).

C. Behrens (DESY) | Beam Monitors and Longitudinal Feedback Schemes | FLS-2010 Workshop at SLAC | 6 / 18

Useful for synchronization, cavity phasing, stability, time-of-flight (using two cavities)

Concept of electro-optic profile diagnostic

all-optical intra-beamline pickup of bunch Coulomb field



Encoding

- same for all techniques
- limiting factor for high time resolution techniques

Decoding

- choices for complexity
- limiting factor for spectral decoding

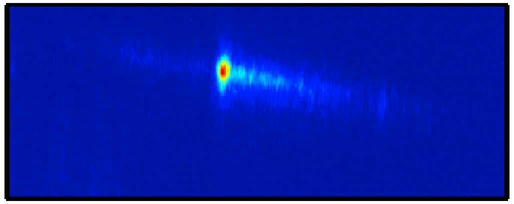
A great non-intercepting monitor, but resolution is probably not good enough for lower energies (5-15 MeV)

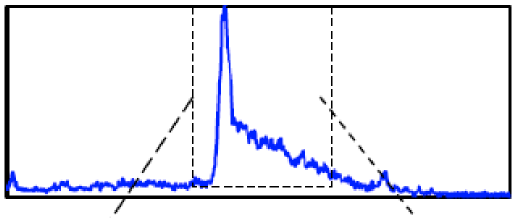
Benchmarking of EO diagnostics

comparison with transverse deflecting *(LOLA)* cavity

DUNDEE

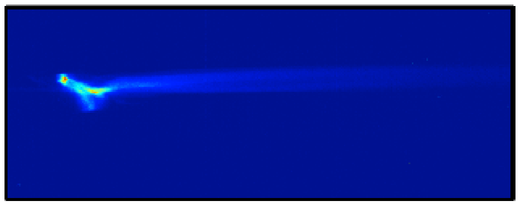
Electro-Optic

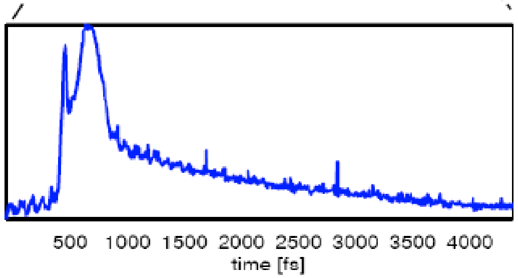


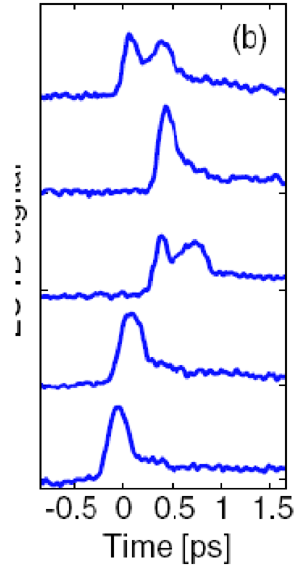


shot-shot variations

Transverse Deflecting Cavity







PRL **99**, 164801 (2007) PHYSICAL REVIEW LETTERS week ending 19 OCTOBER 2007

Benchmarking of Electro-Optic Monitors for Femtosecond Electron Bunches

G. Berden,[1] W. A. Gillespie,[2] S. P. Jamison,[3] E.-A. Knabbe,[4] A. M. MacLeod,[5] A. F. G. van der Meer,[1] P. J. Phillips,[2]
H. Schlarb,[4] B. Schmidt,[4] P. Schmüser,[4] and B. Steffen[4]

plus ***Phys. Rev. ST,*** *12 032802* ***2009***

High Current Issues

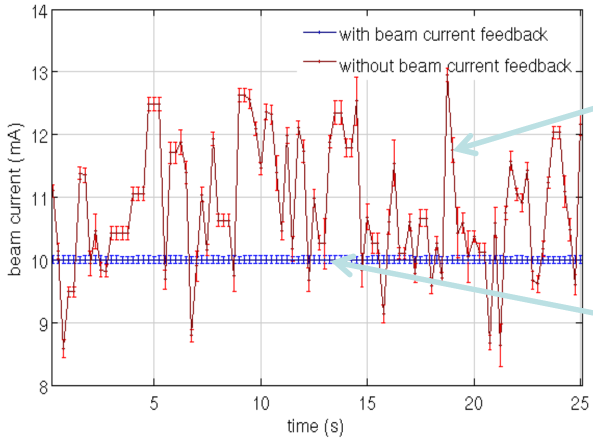
Non-intercepting devices
- beam position monitors
- bunch arrival time
- bunch length (EO cells, THz interferometers)
- flying wire

Laser Stabilization

Halo

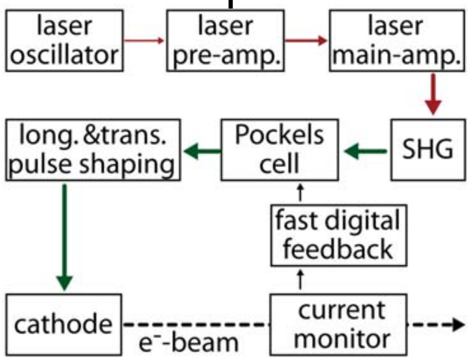
Beam Dump

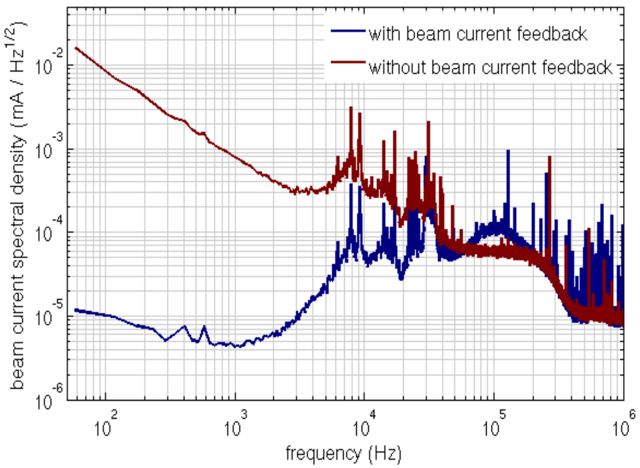
Laser Stability



Beam current fluctuations made the RF unstable during high current operations at Cornell, due to laser intensity and position changes.

A fast-feedback system was installed, using a BPM as the sensor. This dramatically reduced the RF trip level. Thanks to F. Loehl





We also need the laser position stabilized to 10 μm. This feedback system is being designed, but is more difficult due to the large dynamic range needed

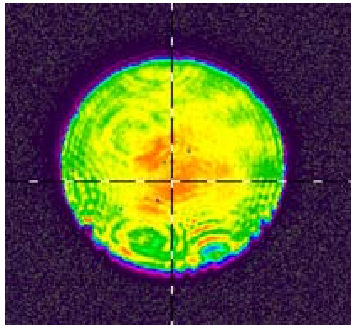
Causes of Halo

- field emission from the cathode
- field emission from the gun electrodes
- discharges from the gun insulator
- stray light reaching the cathode (big problem for high QE cathodes)
    - room lights, scattered laser light
    - x-rays/UV light from SRF cavities
    - x-rays/UV from gun electrode discharges
- field emission from SRF cavities that gets accelerated and exits the cavity
- space charge
- aberrations
- non-uniform laser which makes long tails in time or space
- ghost pulses from the laser,
- cathode response time too long which produces tails in time
- electron scattering

How to measure halo? Ask WG4/5

Halo Generation

Image on the cathode using normal dielectric mirror



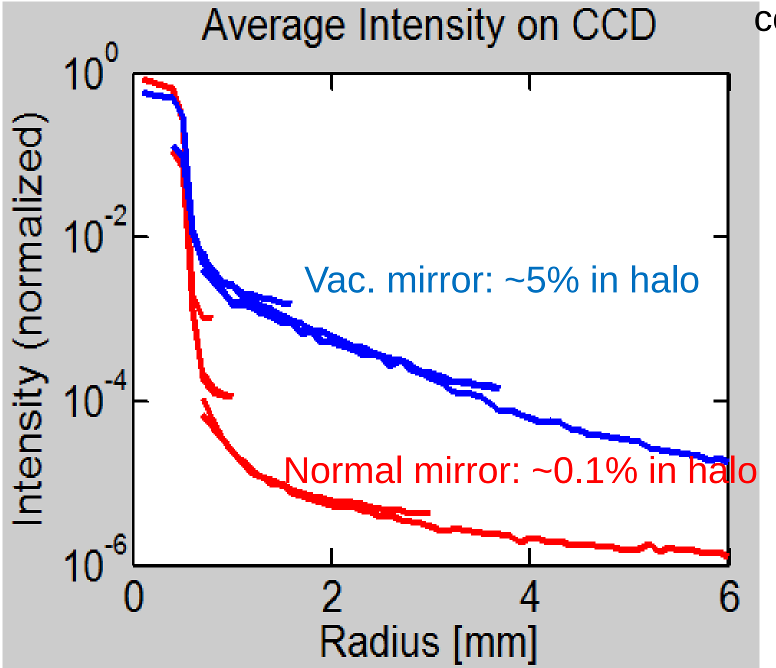
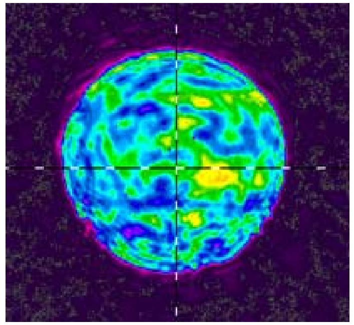


Image on the cathode using coated metal mirror



Our current laser mirror (in-vacuum) scatters ~50x more light compared to dielectric mirrors (which we cannot use). This can generate halo from the cathode, so we are having new ones made soon. Need better than 2 nm rms surface roughness

Following work by a group at DESY

Halo Measurement

Proceedings of DIPAC 2005, Lyon, France

BEAM HALO OBSERVATION BY CORONAGRAPH

T. Mitsuhashi, KEK, TSUKUBA, Japan

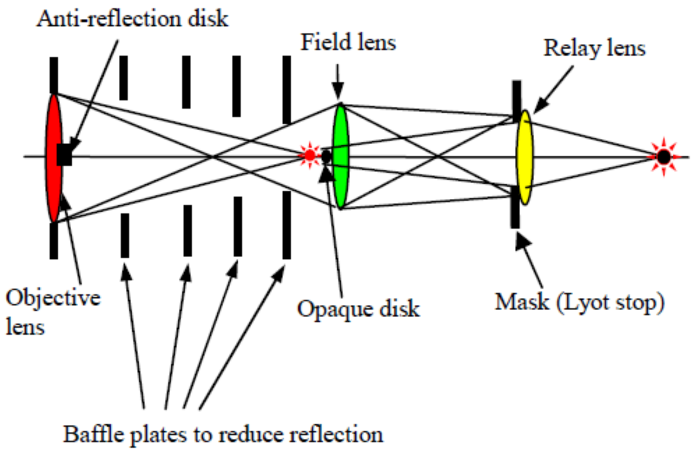


Figure 3: Layout of optical system of the coronagraph.

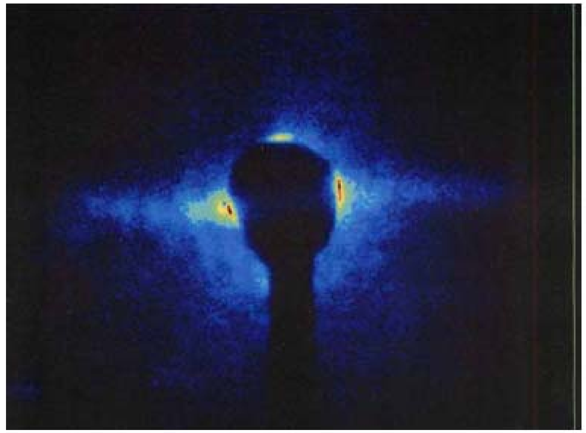


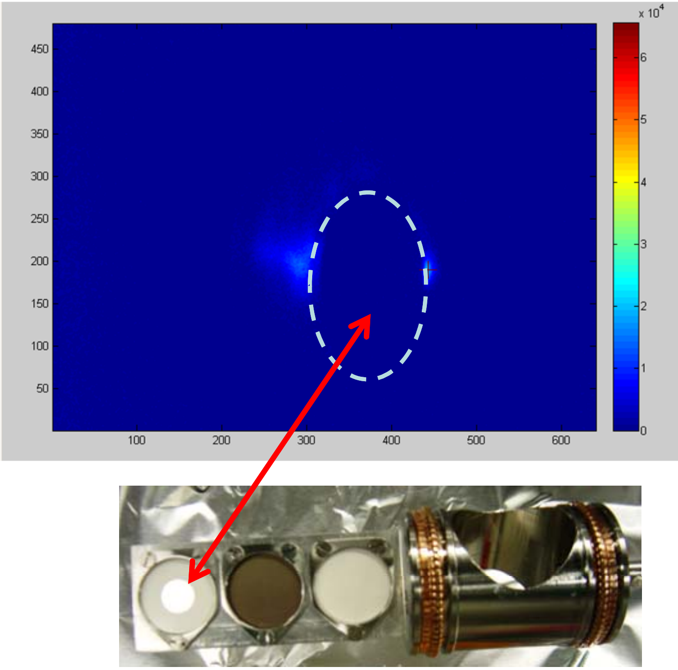
Figure 10: Image of beam halo with the opaque disk. Transverse magnification is same as in Fig. 9. Exposure time of CCD camera is 10 msec.

10^6 to 10^7 dynamic range

Halo Measurement

Simple! ~10^5 range

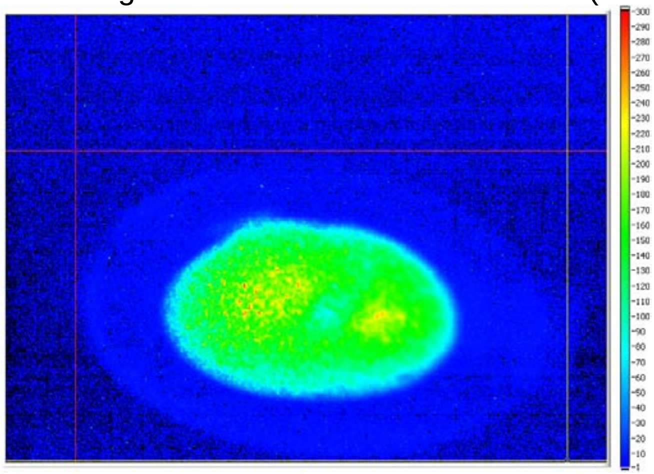
A viewer with a hole for imaging halo



But a little dangerous for high currents

Solid viewers

Can see ~500X range with one camera and an OTR (Jlab)



Can use multiple cameras to cover a wider dynamic range, and different view screen materials

Courtesy of P. Evtushenko

Adaptive Masking

Beam Halo Imaging using an Adaptive Optical Mask*

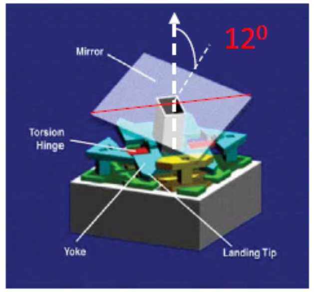
R. Fiorito, H. Zhang, A. Shkvarunets, I. Haber, S. Bernal, R. Kishek, P. O'Shea
Institute for Research in Electronics and Applied Physics
University of Maryland

S. Artikova
MPI- Heidelberg

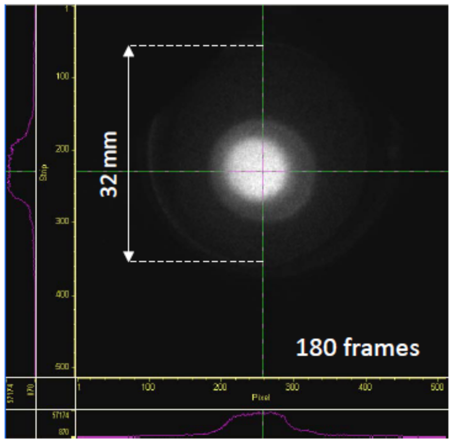
C. Welsch
Cockcroft Institute, University of Liverpool

Presented at Beam Instrumentation Workshop, Santa Fe, NM May 3-6, 2010
*Work Funded by US ONR, DOD JTO and DOE Office of HEP

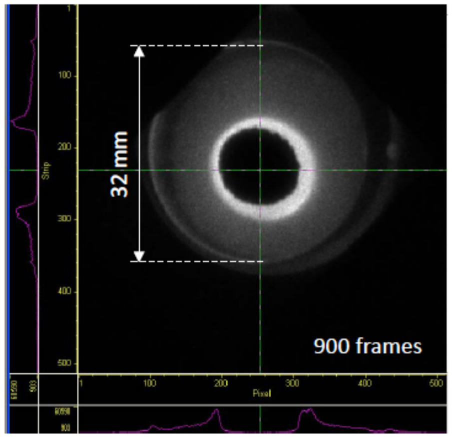
Micro mirror architecture:



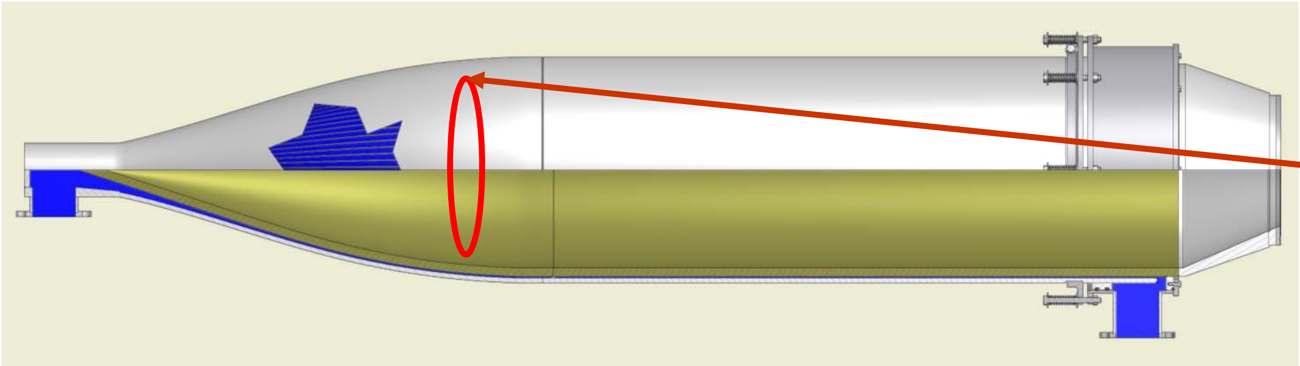
Whole Beam shows halo +core



Masked Beam shows Halo Alone



Beam Dump

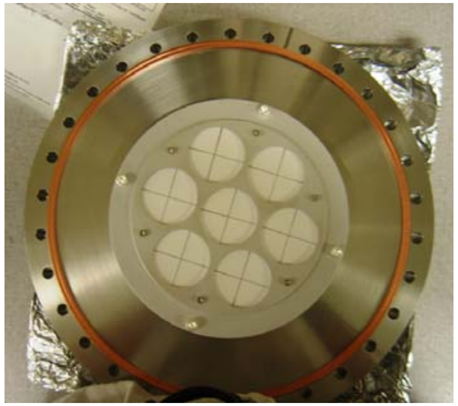


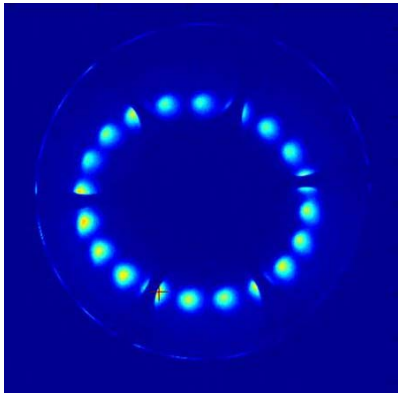
Designed for 600 kW average power

At Cornell, we burned a hole in the aluminum dump at 25 mA. This was due to the incorrect setup of the raster/defocusing system, and one shorted magnet.

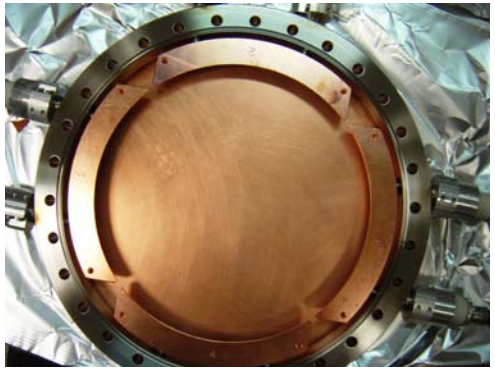
Beam Dump Monitoring

Large BeO viewscreen at the dump location



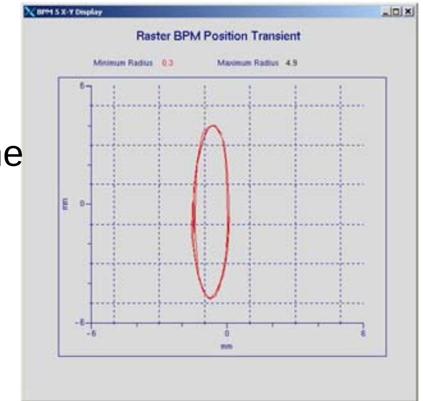


Beam image beyond the raster during calibration



A large quadrant detector before the dump ensures that the beam cannot get too big

A bpm located after the raster for continuous monitoring



.

- The defocusing/rastering system is calibrated using the large viewscreen (shown above) before installing the dump.
- A bpm will be used for continuous monitoring, and an array of 80 thermocouples around the dump will monitor hot spots.

Other Items

Items I did not cover but are very important

-wide dynamic range bpms
-wide dynamic range CCD camera+viewscreen
-OTR screens and DTR
-wire scanners, laser wires, flying wire
-wakefield concerns
-beam diagnostics inside the cryomodule
-longitudinal matching
-THz bunch length devices
-machine protection
-RF monitoring
-gun and HV monitoring
-faster vacuum monitors
. . .

Conclusion and Wish List

There has been a lot of great developments for ERL diagnostics in the past 2 years, but there is still a long list of things we need and want

- Easy to use fast DAQ and transient capture
- Large dynamic range CCDs (that don't cost $$$)
- Non-intercepting emittance measurements
- Really fast laser monitoring (to look between pulses)
- Smarter sub-systems (dummy lights)
- Simpler non-intercepting bunch length monitors
- A streak camera that I can afford
- …..