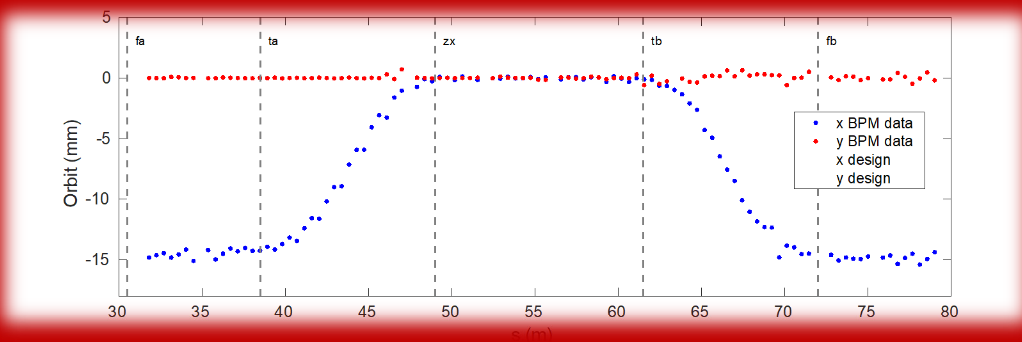
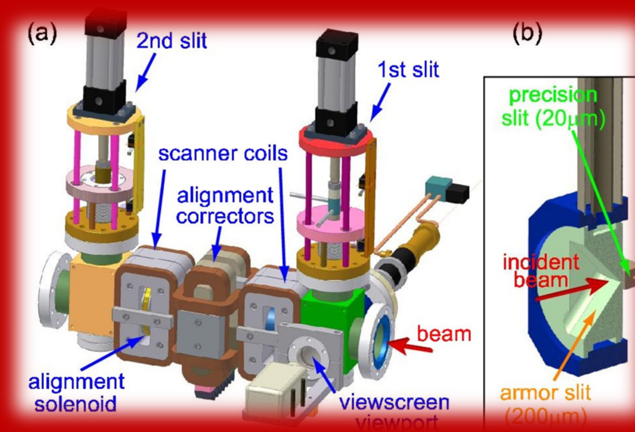
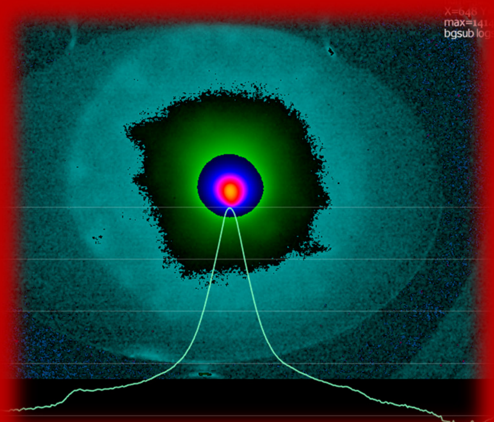
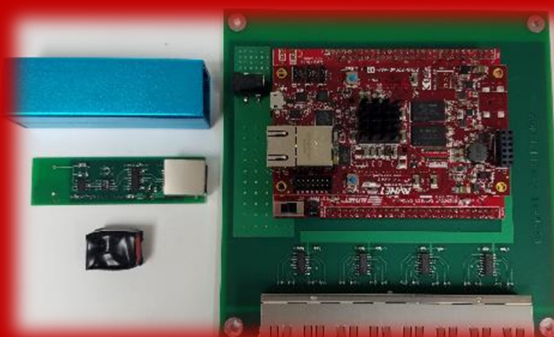
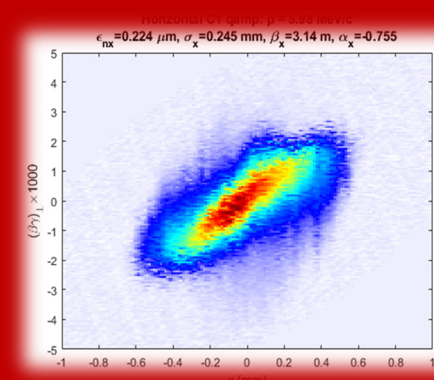










Essential Instrumentation for characterization of ERL beams

Nilanjan Banerjee
Cornell University

Overview

- Introduction
- Beam Centroid
- Phase Space
- Beam Halo and Losses
- Miscellaneous
- Conclusion

Introduction

Energy Recovery Linacs produce beams which are:

High-Brightness

Normalized transverse emittance of a few microns.

Short Bunches

Typical bunch length up to 10 ps.

CW High current

Unlike rings, the high current beams in ERLs are produced continuously.

ERLs are sensitive to:

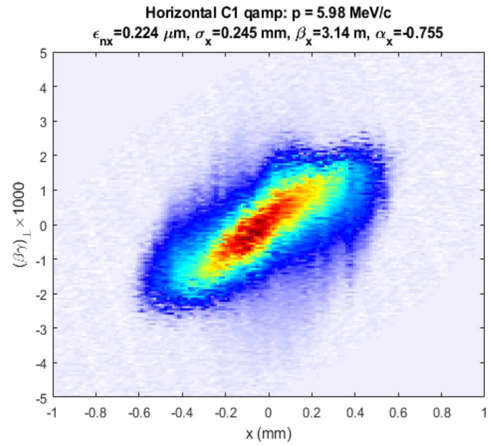
Time of flight

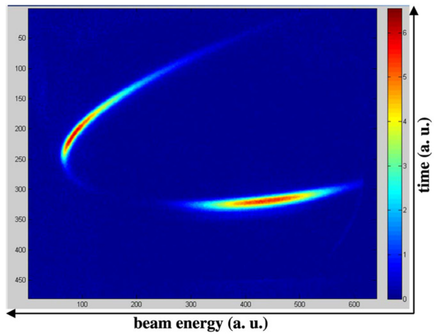
ERLs are very sensitive to time of flight jitter.

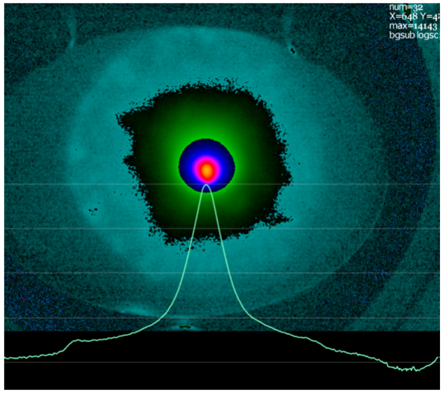
Losses

Large bunch charges frequently generate a lot of halo which can lead to significant continuous loss of beam power.

ERLs have specific instrumentation needs!







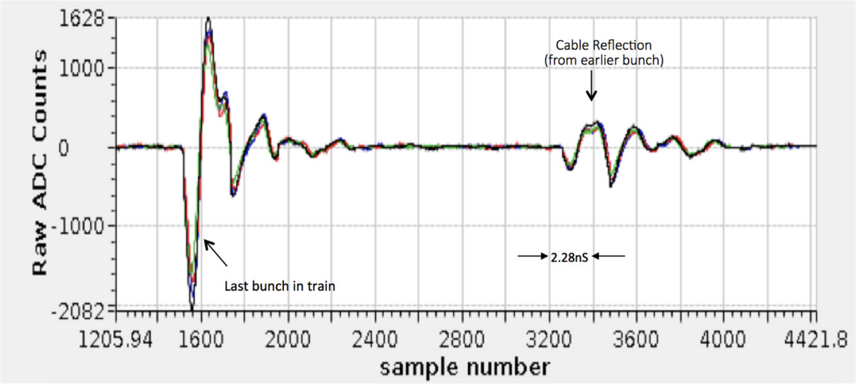
Beam Centroid

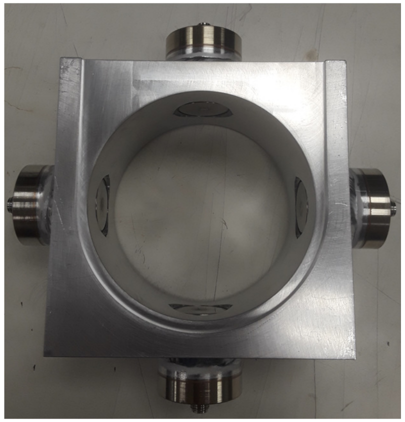
We need to measure beam orbits both in space and time.

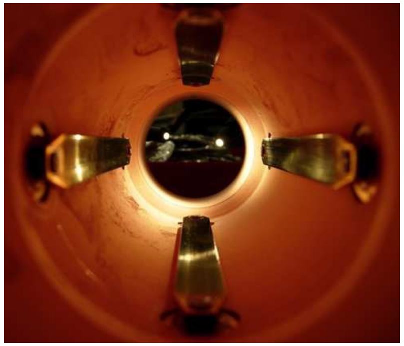
Beam Position Monitors (BPM)

Time domain

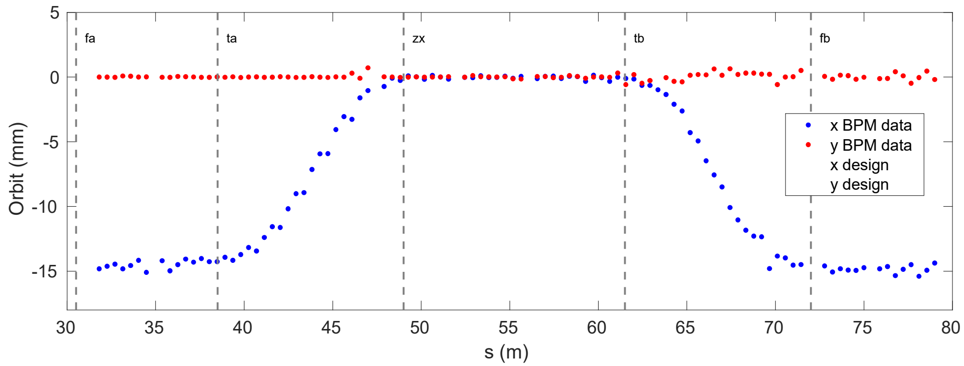
- Can handle multiple beams simultaneously.
- Ironically, timing information is not precise.

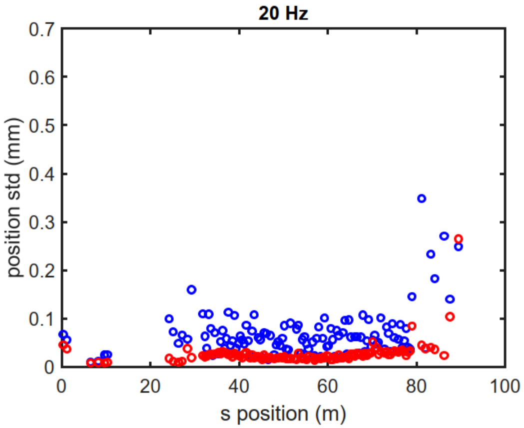






C. Boccard, *CARE-ABI Workshop Lueneburg 2006*



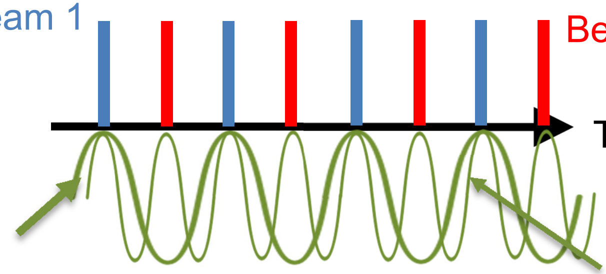


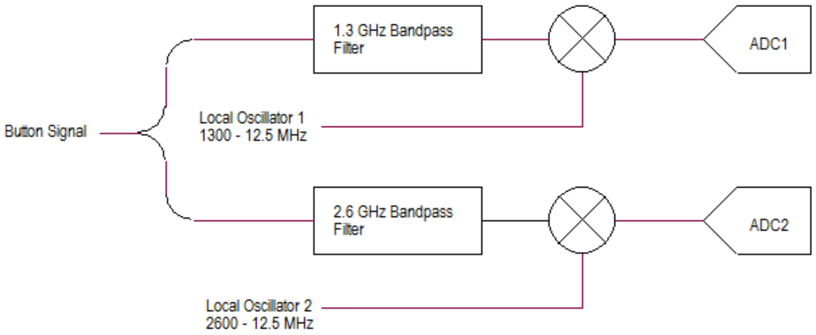
Typical position jitter using 5 pC bunches at a repetition rate of 20 Hz is 0.1 mm.

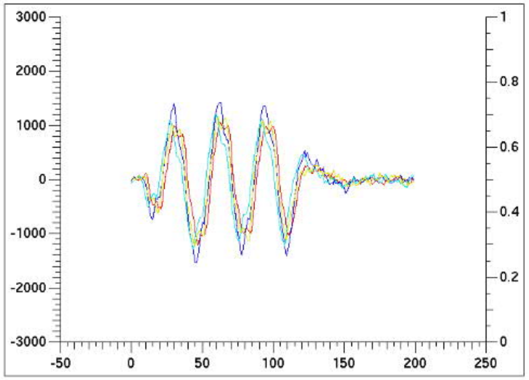
Beam Centroid:Frequency Domain

Frequency Domain

- Can be used as a **Bunch Arrival Monitor (BAM)**
- Requires some averaging.

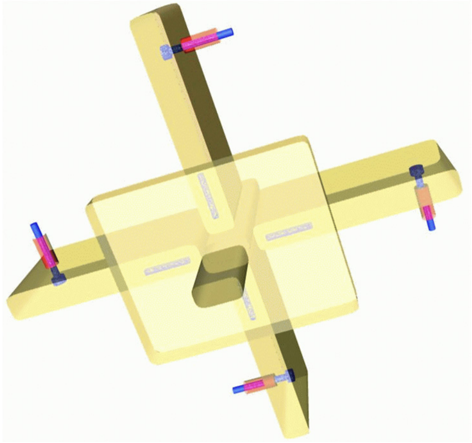






Typical uncertainty of 0.1° and 0.3 mm with a one shot measurement of a 5 pC bunch train of 10 – 20 bunches.

Cavity BPMs can provide both orbit and time information with high resolution.

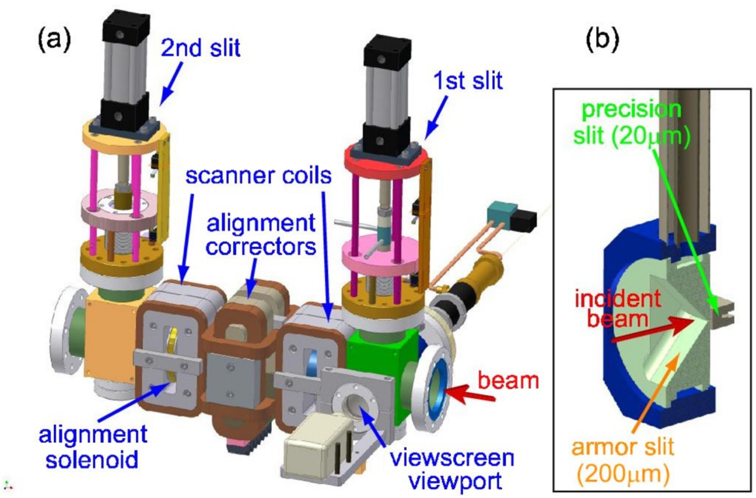


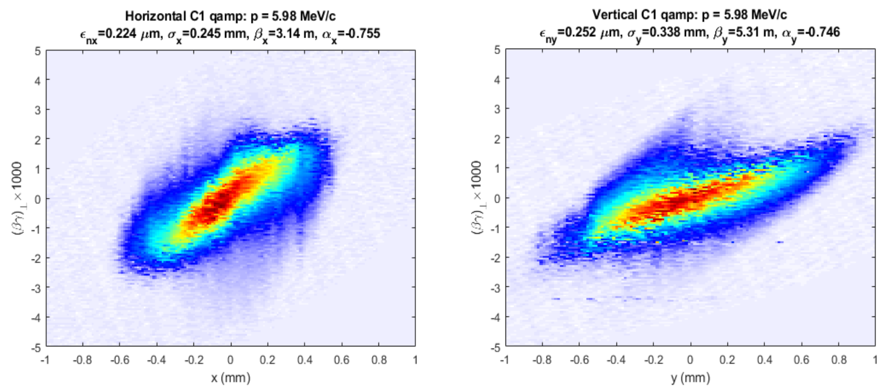
Inoue, Yoichi et al. Phys.Rev.ST Accel.Beams 11 (2008) 062801

Phase Space: Transverse

A “good” phase space distribution of the beam is required to ensure optimal transmission and suitability to the particular user application.

Double Slit

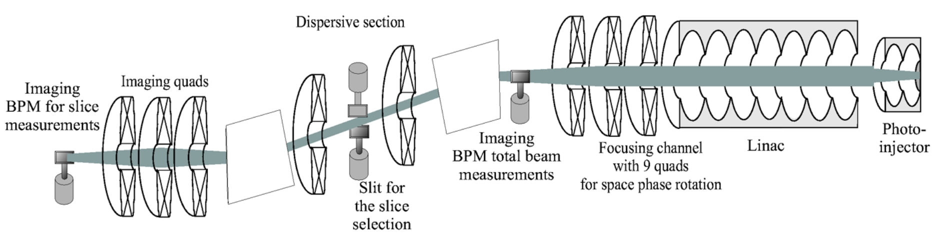




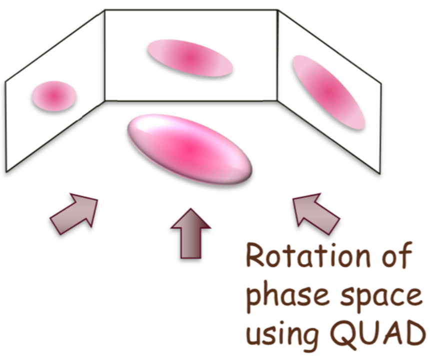
Measurement resolution of ~ 0.1 μm

Bazarov, I. V., et al. Phys. Rev. ST AB, 11 (100703) (2008)

Tomography



V. Yakimenko et al., Phys. Rev. ST AB, 6 (122801) (2003)



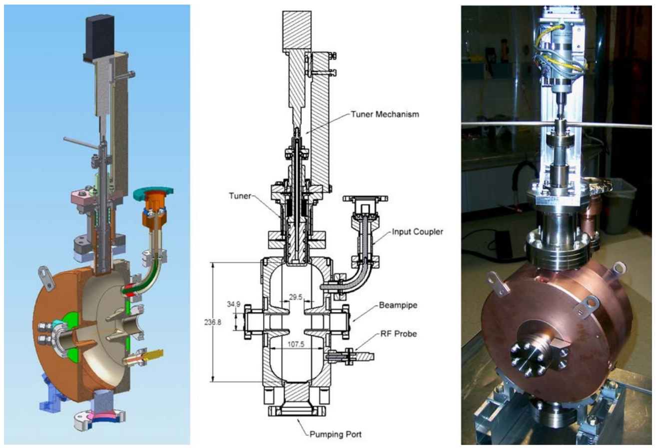
Manoel Conde, “*Proof-of-principle experiment for single-shot transverse phase space measurement* ”, IPAC 2018

Both these methods are destructive and can be used in a separate diagnostic line.

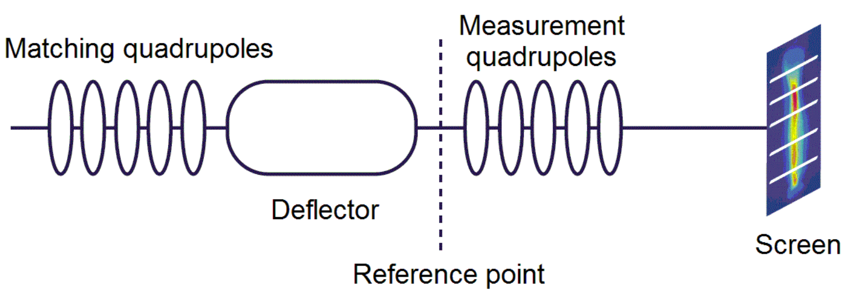
Phase Space: Longitudinal

Depending on applications, ERLs need to produce beams with suitable longitudinal phase space; long bunches with very small energy spread for coolers, very short bunches for FELs etc.

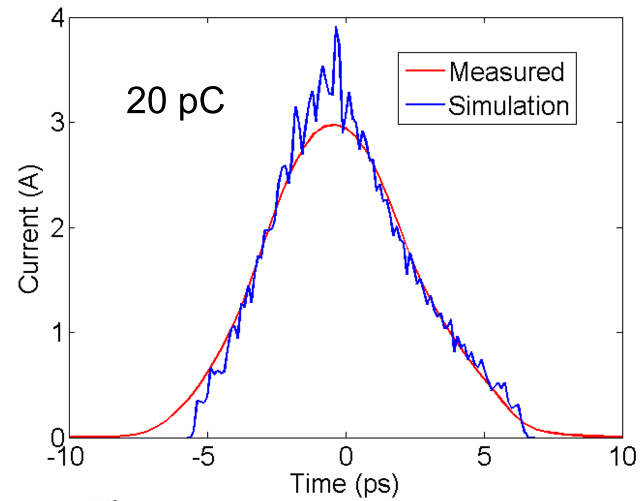
Deflector Cavities

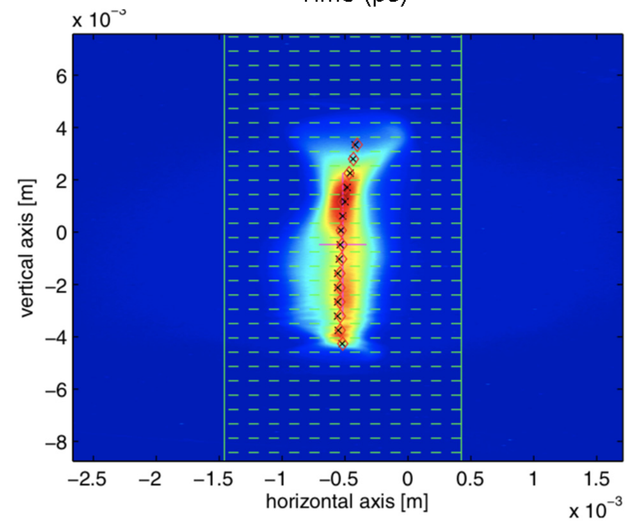


Belomestnykh, Sergey et al. Nucl.Instrum.Meth. A614 (2010) no.2, 179-183



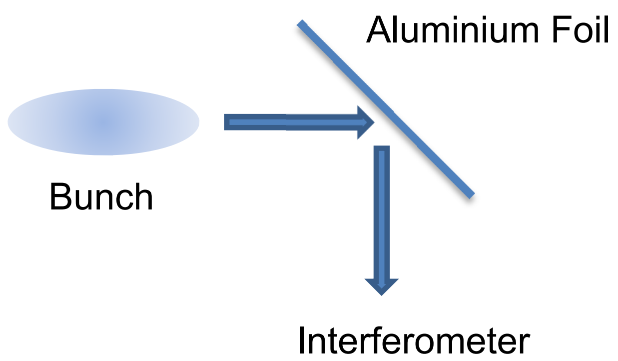
Eduard Prat et al., Phys. Rev. ST AB, 17, 104401 (2014)



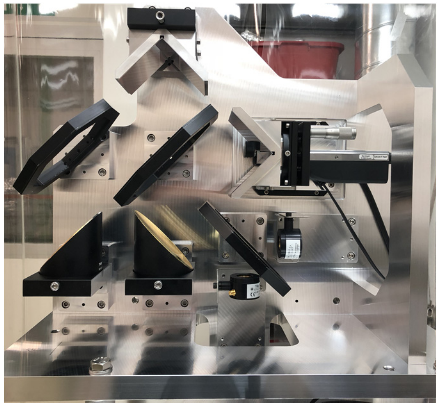


Phase Space: Longitudinal

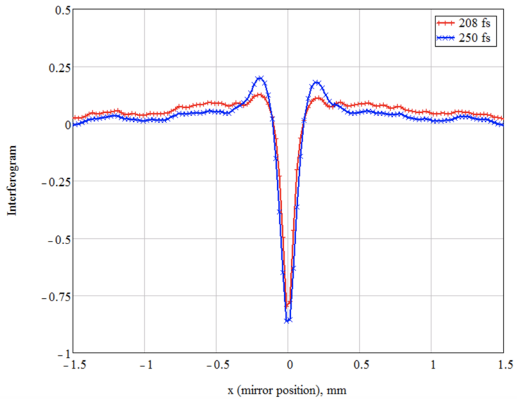
Coherent Transition Radiation



Happek, U. et al. Phys.Rev.Lett. 67 (1991) 2962-2965



Martin-Puplett Interferometer



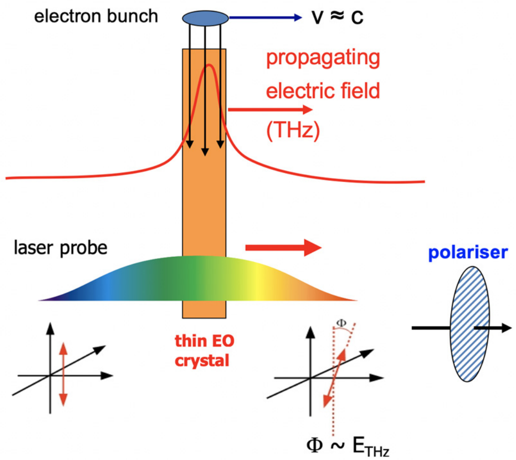
Pavel Evtushenko et al., ELBE, HZDR, Dresden, Germany

Can we use a similar idea with

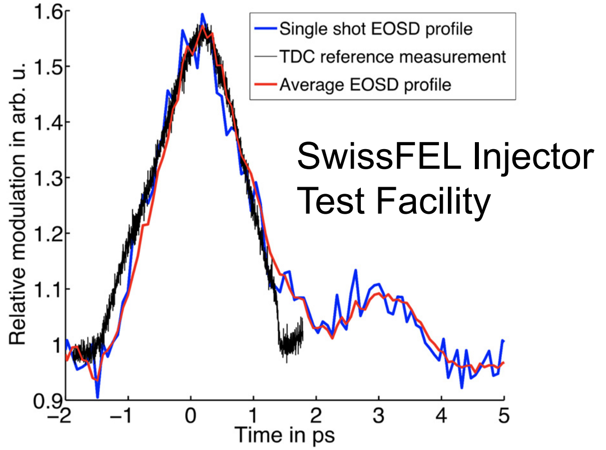
Coherent Synchrotron Radiation?

Electro-optic Modulation

Non-destructive measurement!



David A Walsh, STFC Daresbury Lab



Electro-Optic Spectral Decoding

Borysenko, A. et al. Phys.Procedia 77 (2015) 3-8

Beam Halo

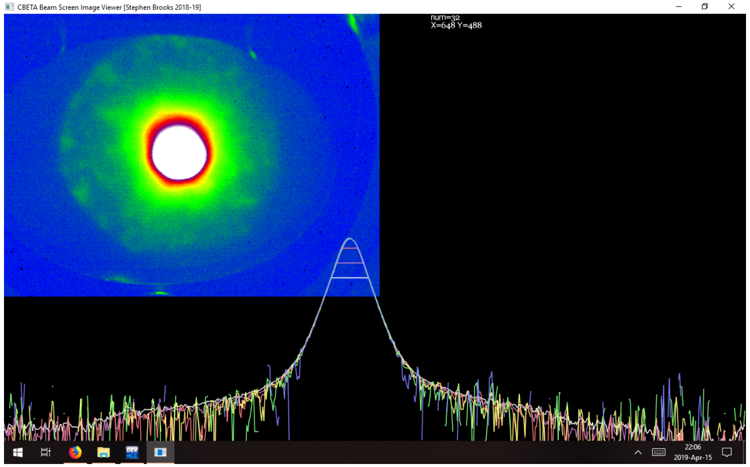
Beam halo and losses become really important for ERLs operating with high beam power.

Viewscreens

By itself they have limited dynamic range.

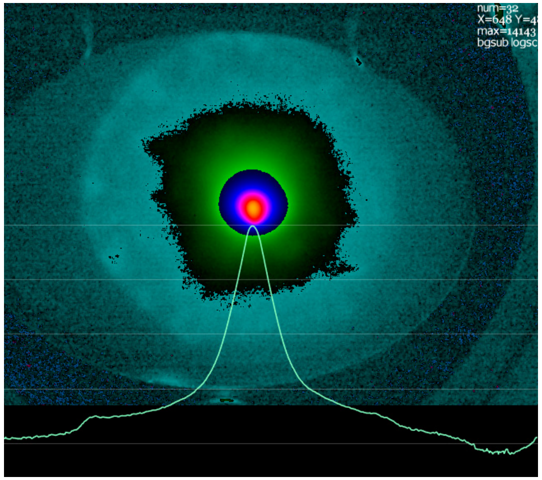
- Switch on median filter on the camera, and use frame averaging. We used 10.
- Take multiple exposures 0.0025, 0.005, 0.01, 0.02, 0.04, 0.08 seconds.
- Scale with 1/exposure and subtract background frame.

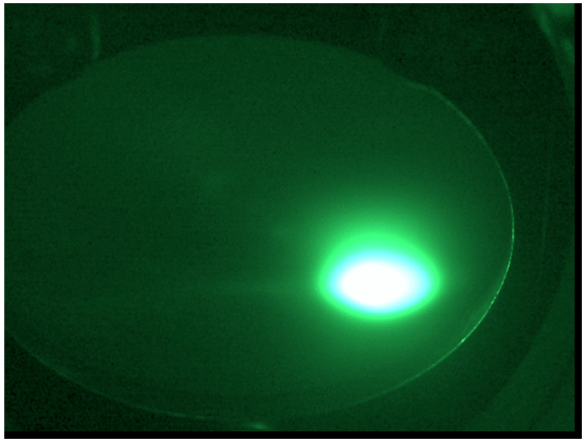
400Hz, 42 bunches per train



The halo was detected at an intensity of about 3 x 10^{-4}.

Halo ~ 3% of total charge

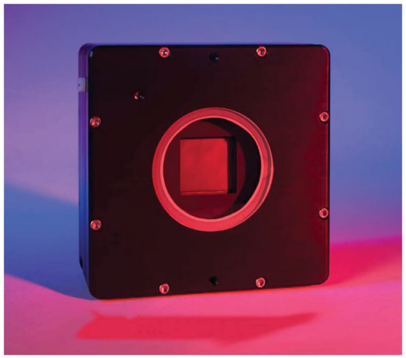




Beam Halo

CID (Charge Injection Device) Camera

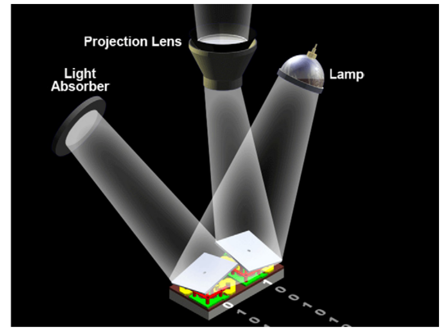
Adjust exposure time for each individual pixel to achieve large dynamic range.

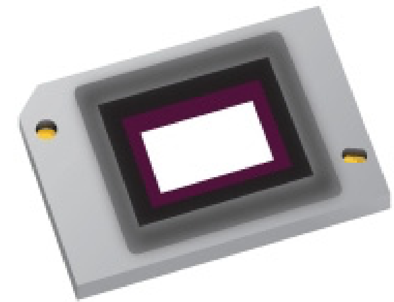


SpectraCAM™ 84 Cooled Scientific Imaging System, https://www.thermofisher.com/order/catalog/product/SPECTRACAM84

Micro Mirror Array

Selectively mask light going into camera.

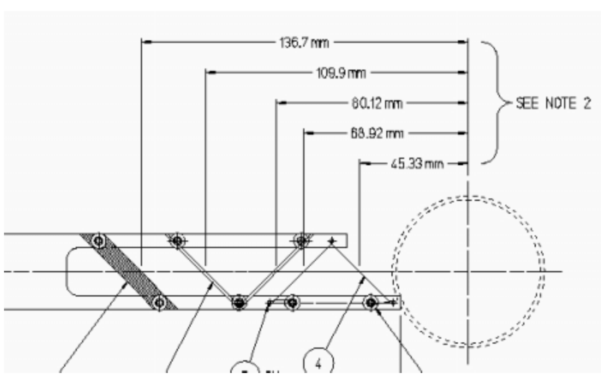


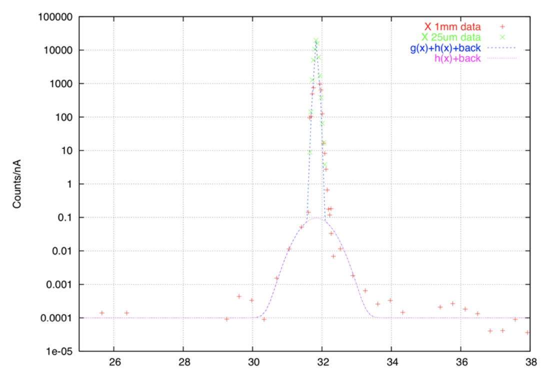


©Texas Instruments, http://www.ti.com/lit/an/dlpa008b/dlpa008b.pdf

Wirescanners

Direct measurement by inserting an intercepting monitor.



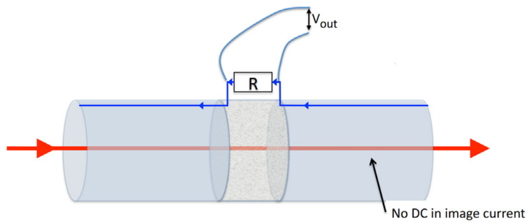


Large Dynamic Range Beam Profile Measurements, T. Freyberger, DIPAC05

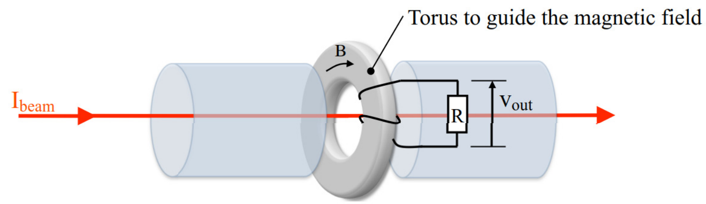
Beam Loss

Current Monitors

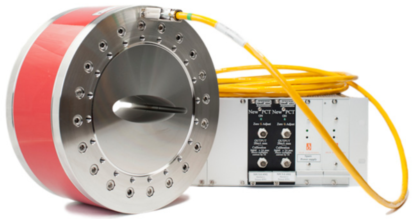
Direct measurement of beam loss.



Wall current Monitors:
Large Bandwidth



Current Transformers:
Various types

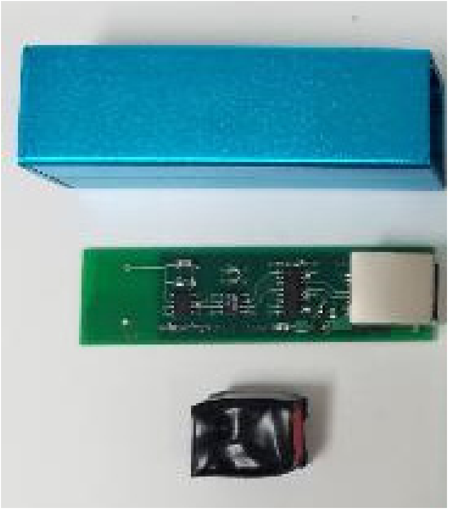


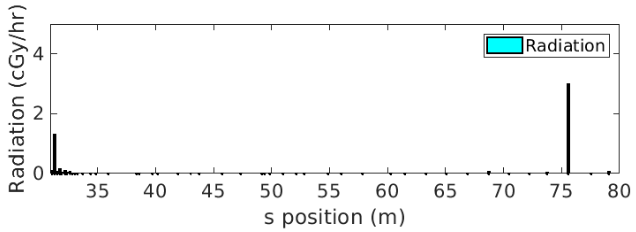
DC Current Transformer (DCCT)
Bergoz In-flange NPCT

W. Blokland, Beam Current Monitors, United States Particle Accelerator School, 2009

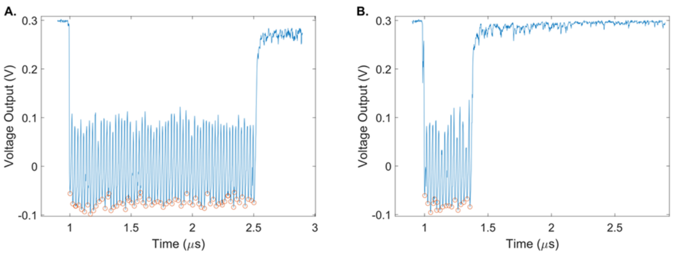
Beam Loss Monitors

Detects radiation generated by beam loss.





Slow BLM: CsI crystal coupled to a PiN diode

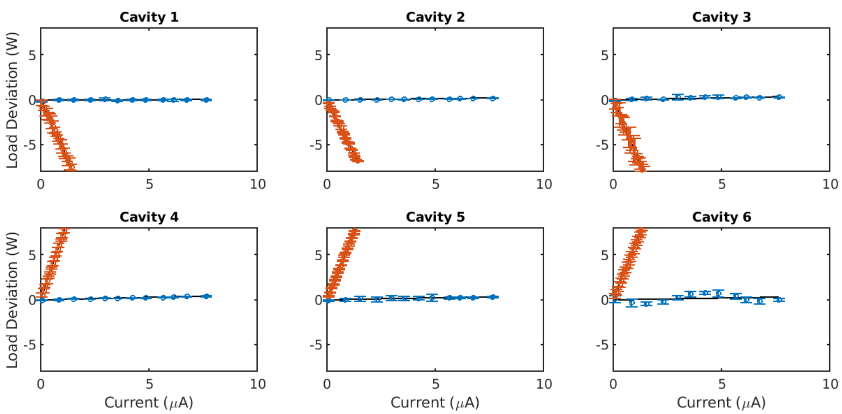


Fast BLM: Polystyrene Fiber coupled to PMT

Cavities

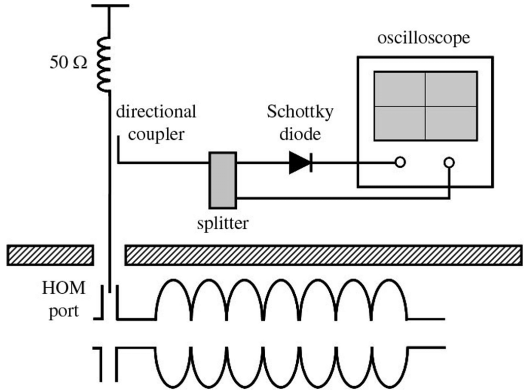
They can give us a lot of useful information about the beam!

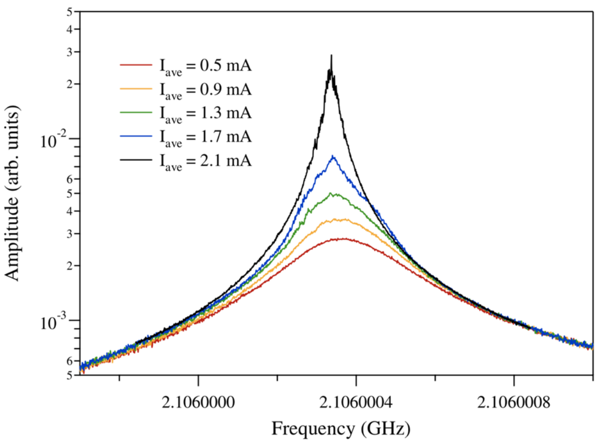
Net Loss Monitor



Transmission efficiency: 99.6 ± 0.1 %

Beam Breakup Monitors





Measures threshold current and quality factor of the excited HOMs.

Douglas, D.R. et al.Phys.Rev.ST Accel.Beams 9 (2006) 064403

Conclusion

Bright High Power CW Beams

ERLs produce high power bright CW beams while being very sensitive to time of flight and losses. This necessitates an unique set of minimal diagnostics.

Beam Centroid

We need to measure the space and time coordinates of the centroid of the beam sometimes for multiple beams in the same pipe.

Phase Space

We typically need the transverse and longitudinal distributions to match various applications. Unfortunately, most of the methods are destructive! Electro-optic methods for longitudinal measurement are an important exception.

Beam Halo and Loss

Measuring halo requires a device with high dynamic range. At CBETA we have used some tricks on viewscreens with success. We can use current and radiation monitors to measure loss.

Miscellaneous

Cavities are an important diagnostic tool! Very useful in measuring BBU and net transmission.

Acknowledgements

I would like to thank the CBETA diagnostics team.

Adam Bartnik, Ivan Bazarov, Stephen Brooks, Kirsten Deitrick, John Dobbins, Colwyn Gulliford, Malida Hecht, Georg Hoffstaetter, Yulin Li, Karl Smolenski

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Thank you!