Diagnostics for High-Power, High-Brightness Electron Injectors

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Outline

- Overview
- Emittance Measurements
- Longitudinal Phase Space and Timing
- High Power Operations and Measurements
- Conclusion

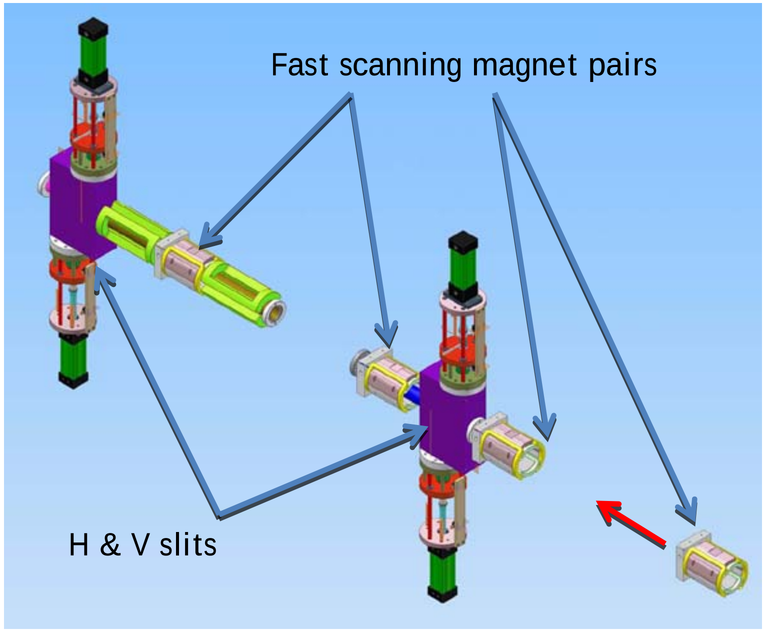
Emittance

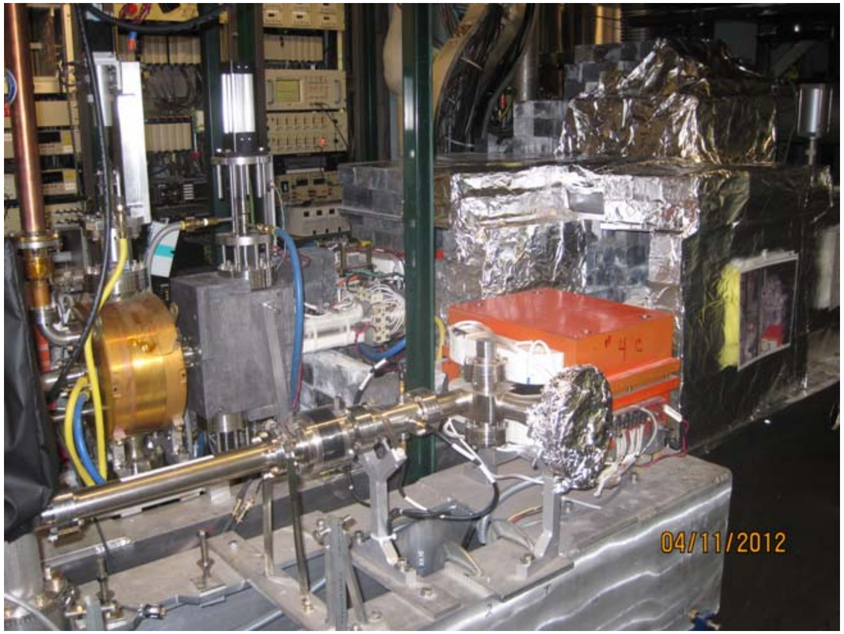
Leave the slits stationary and scan the beam across them. Using a faraday cup gives very wide dynamic range, no concerns about saturation. Can measure charge ranges from 0.1 pC to > 100 pC.

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-parameter optimizations.

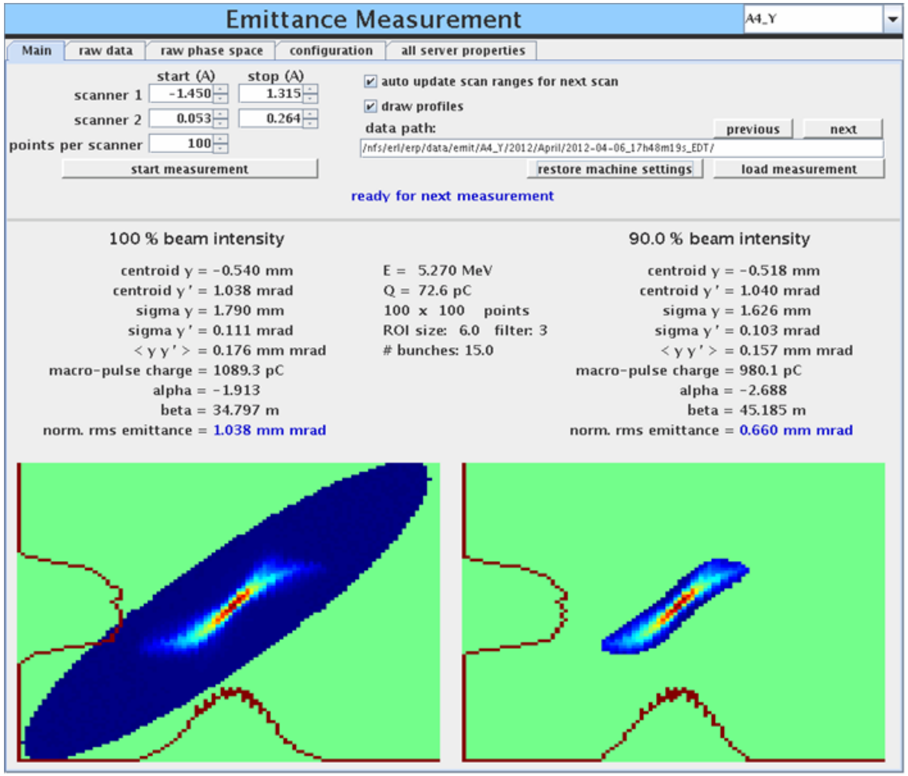
Emittance Scanners





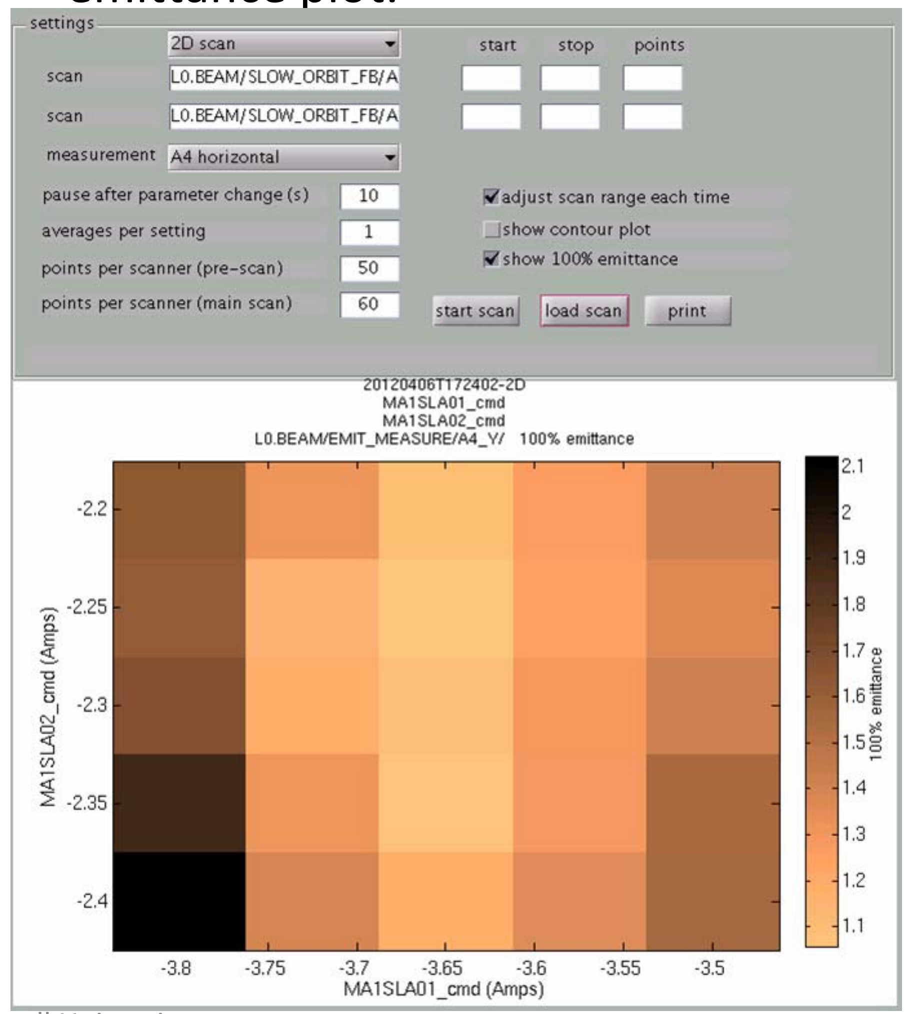
- The slits can absorb ~ 1kW of power, and the slit opening is 20 μm.
- For 77 pC bunch charge, a charge amplifier is connected to the faraday cup and scan rates up to 2 kHz are used (limited by the magnets).
- For low bunch charges, a picoammeter or SRS current preamplifier is used, but at lower acquisition rates.
- Lead shielding is needed to reduce radiation for personnel safety reasons.

Emittance Controls

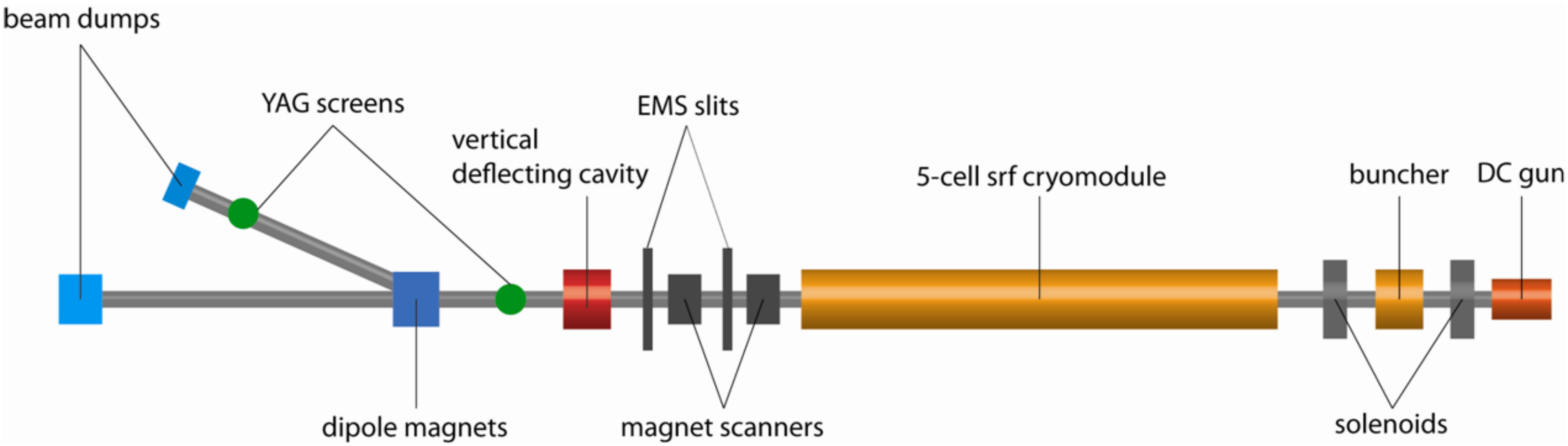


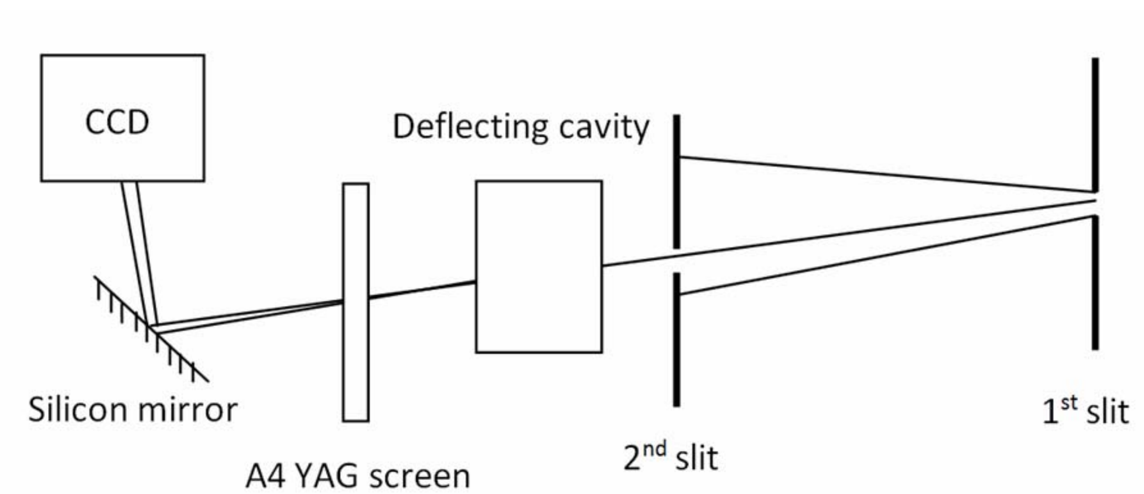
This GUI allows single emittance scans

This GUI performs 1D and 2D parameter scans and displays an emittance plot.



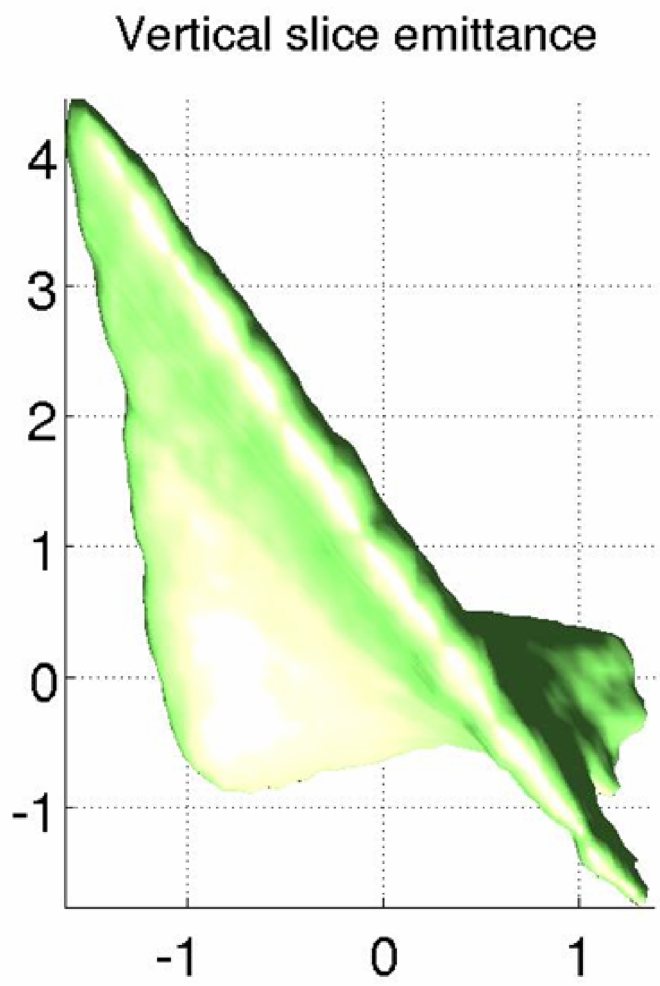
Slice Emittance





- Transverse phase space: two-slits method
- Temporal profile: the deflector + viewscreen
- 30-60 minutes per scan

Slice Emittance

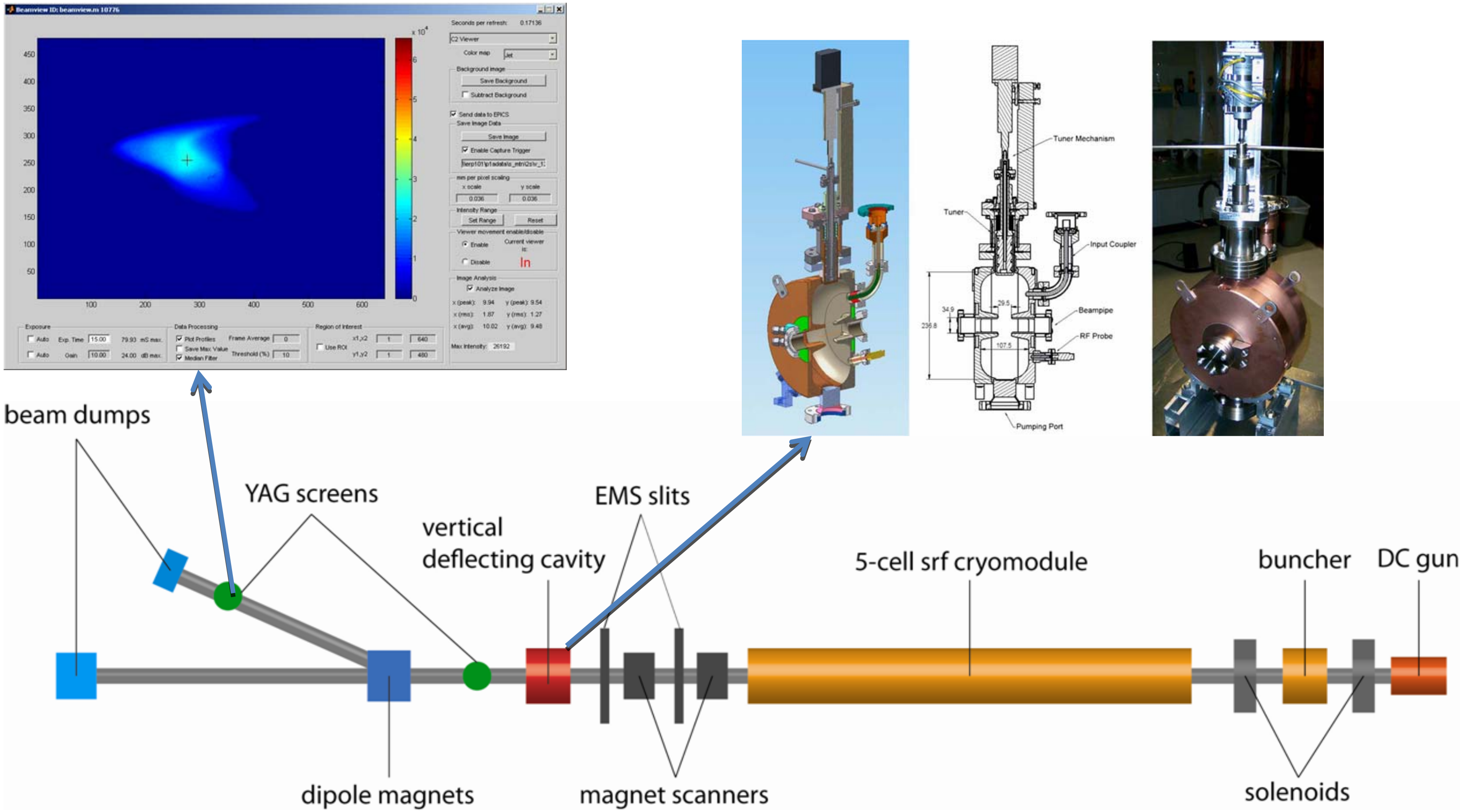


0.70 mm-mrad (100%), slice emittance

The slice emittance rotates 55 degrees from head to tail.

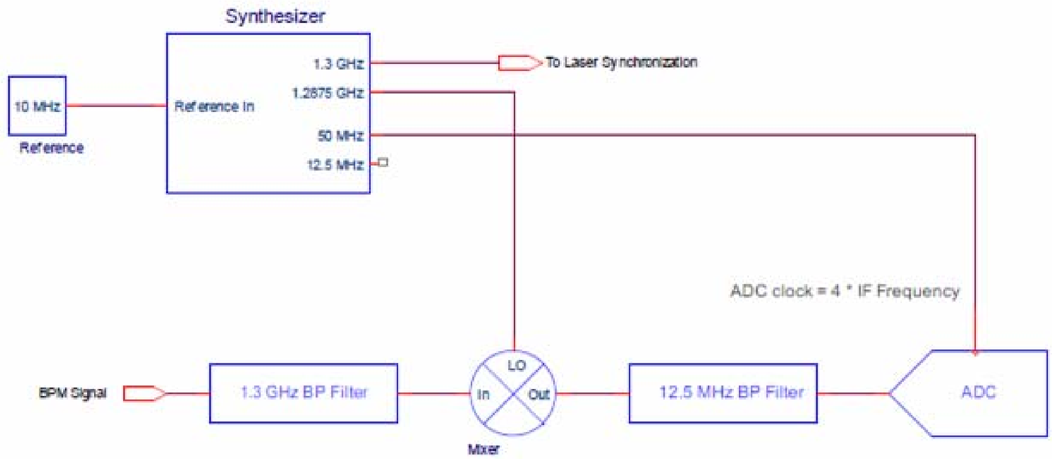
Accomplished by setting the first cavity 30 degrees off crest.

Longitudinal Phase Space

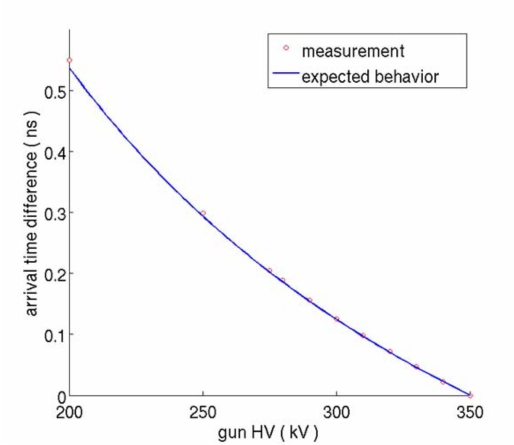


Easy to get a direct measurement of energy spread vs time

Time-of-Flight



Stripline bpm



Example: gun HV calibration using TOF difference between 2 bpms

We can extract phase information from our bpm's and use them as TOF/phase detectors.

Applications. . .
-cavity phasing
-voltage calibration for cavities and gun HV
-laser phase monitoring (first bpm after the gun)
-working on synchronous phase wobble measurements for beam diagnostics and setup

What is important for running high currents?

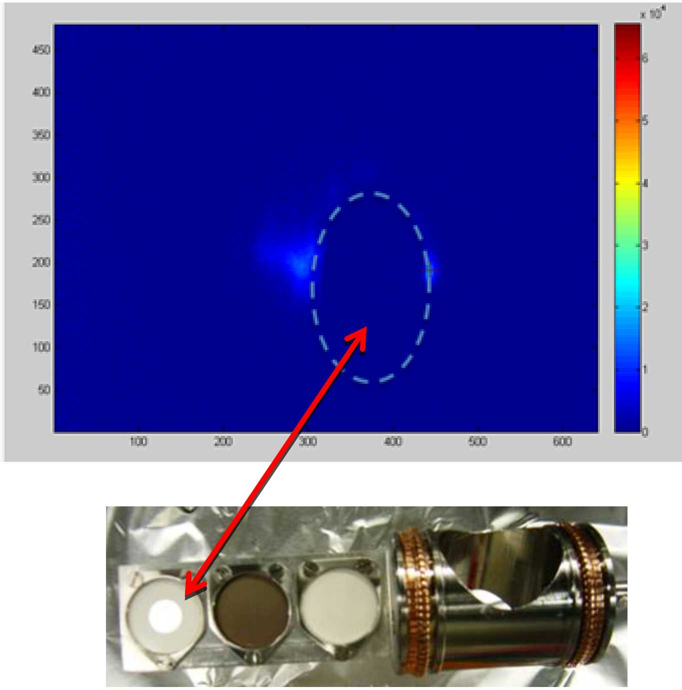
- Halo is a major problem (tuning, radiation shielding and machine protection)
- Beam dump monitoring and protection
- Fast shutdown – want to block the laser before anything else trips . . .
- Catching transients (due to FE, ions, scattering, . . .) for troubleshooting
- RF trips (mostly due to coupler arcs)
- Feedback for bunch charge, laser position and beam orbit
- Current measurement
- Measurements of RF response to the beam, HOM’s
- Monitoring HV power supply ripple and frequency response
- Vacuum monitoring, fast and slow
- Personnel protection
- Overall machine stability

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 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

Halo Measurement

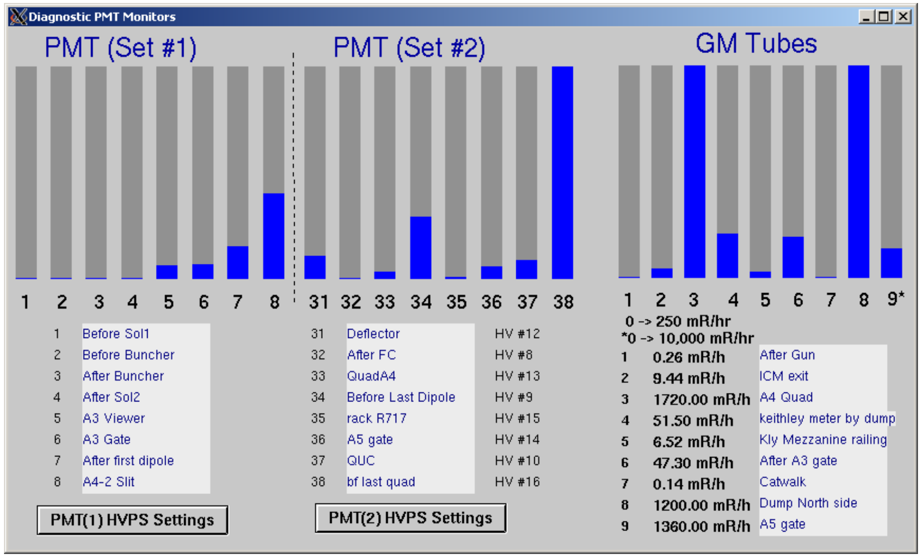
A viewer with a hole for imaging halo



But a little dangerous for high currents . . .

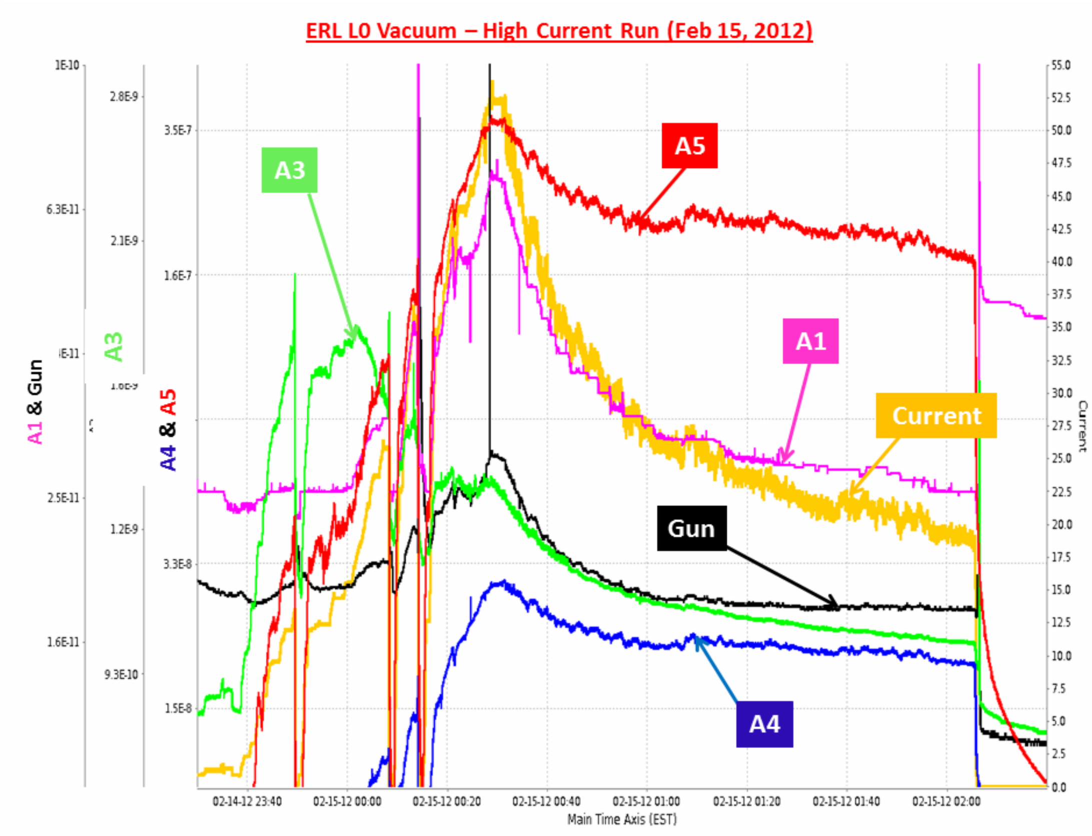
Simple! ~10^5 range

Arrays of PMTs and GM tubes



Can be confusing as we can get radiation from the dump, which is close by

Vacuum Diagnostics



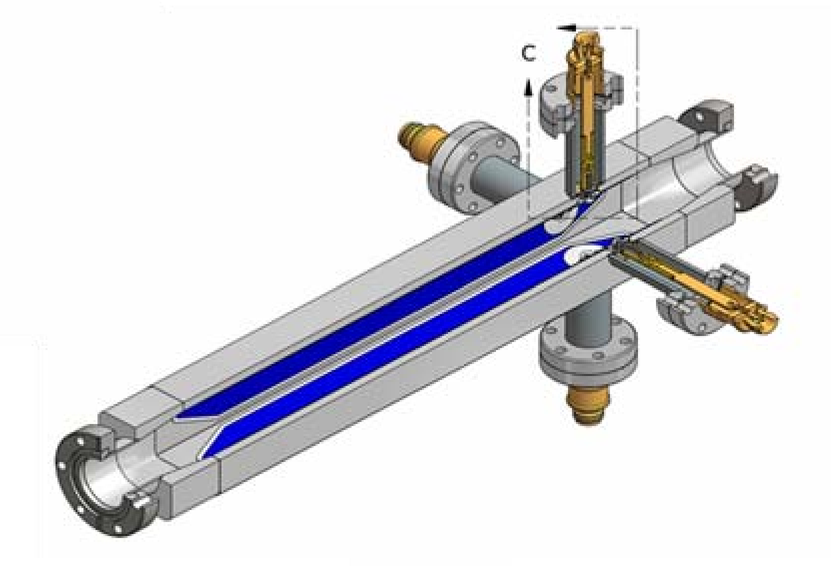
Vacuum pressure near the gun is one of the most sensitive measurements of halo (and cathode lifetime)

Extractor gauge for very low pressures.

Working on a fast (sub-msec) response ion gauge to look for transients

Granville-Phillips now has a new type of residual gas analyzer with very fast scan times (10s of ms)

Halo measurements



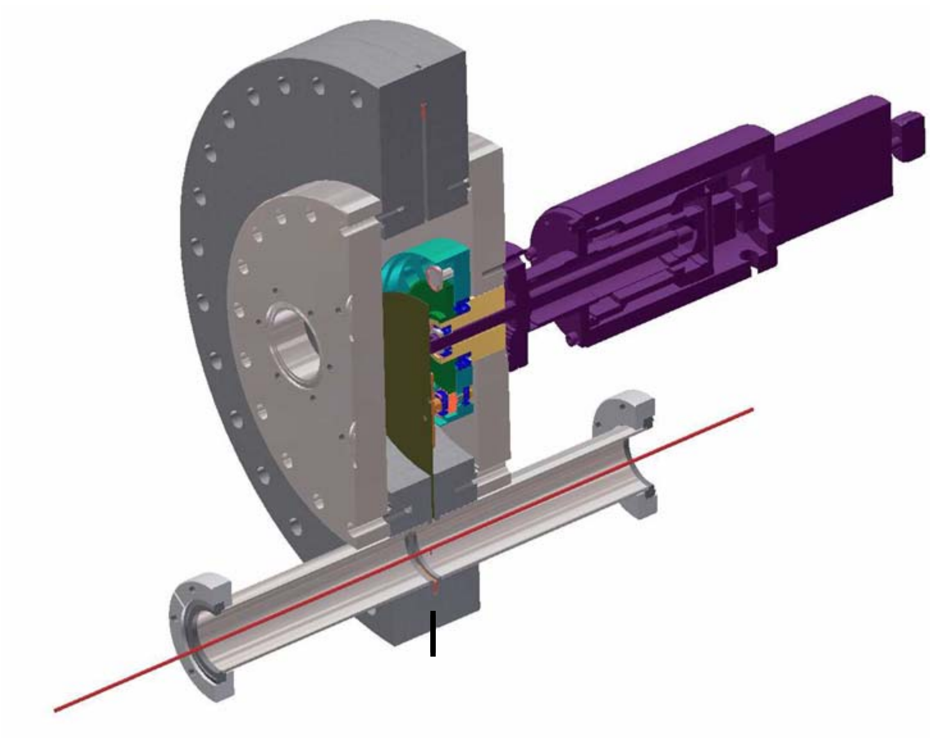
This is an ion clearing electrode we designed for the main ERL loop, and tested in the injector (the coatings were done at KEK).

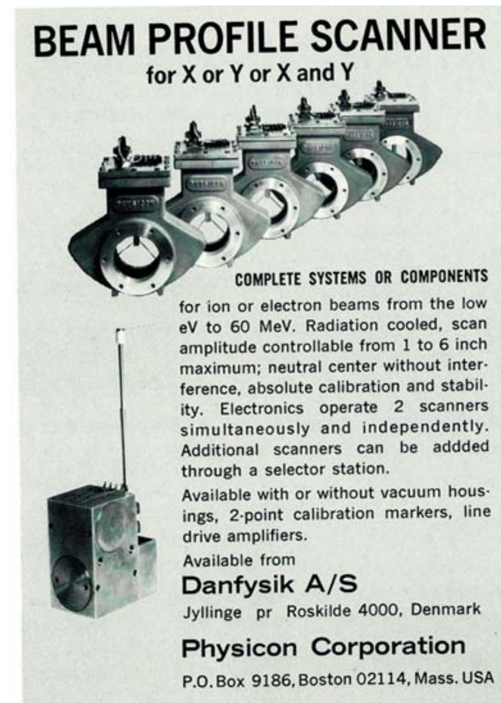
With a voltage applied across the electrodes, it functions as a clearing electrode.

We also used it to measure halo by connecting a picoammeter to each electrode -> see ~50 pA on a 30 cm electrode.

Note: all diagnostics are designed to minimize wakefields (that is, no discontinuities)

Flying Wire

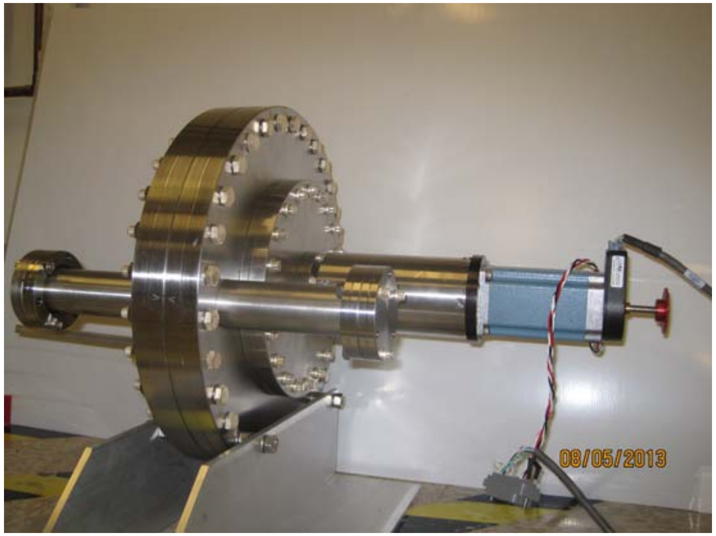




We have built a compact flying wire for high current beam profile measurements. Using an offset cam, a 9 μm carbon fiber passes through the beam a 20 m/s, and can accelerate/coast/decelerate in two rotations, intercepting the beam only once. The x-rays generated by the scattered electrons are detected with a PMT or MPPC.

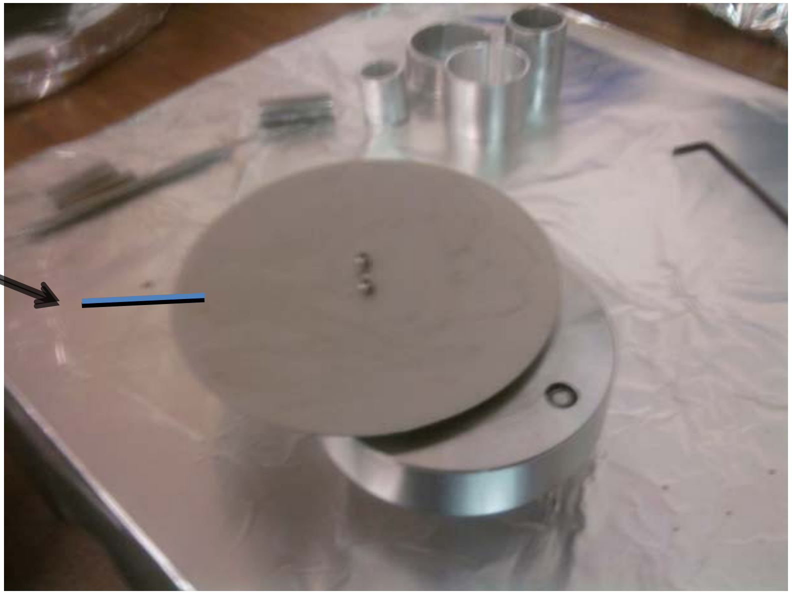
Flying Wire

Assembled Device



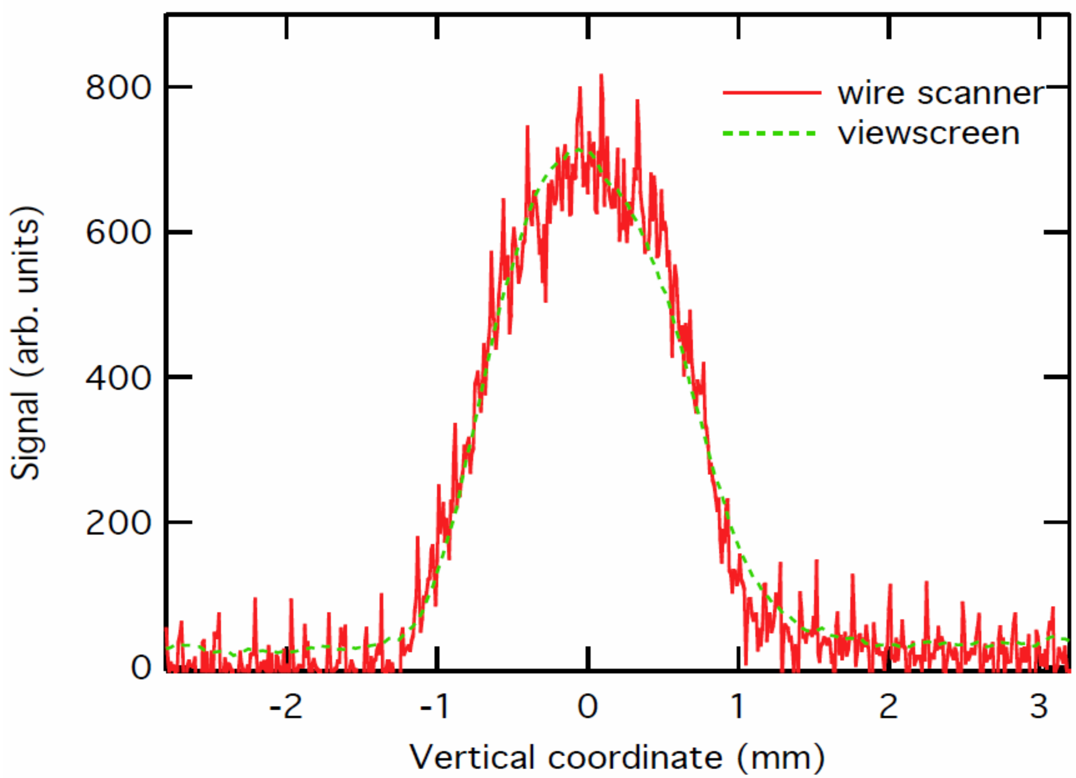
Offset Gear Assembly

Carbon fiber is glued to the large disk



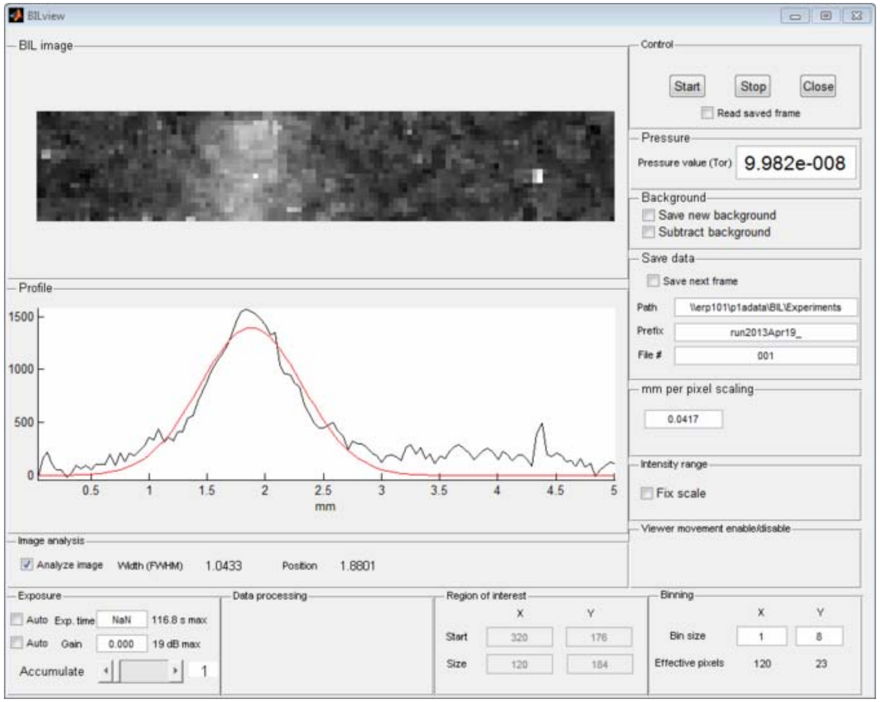
Flying Wire

Results with a 35 mA beam. The profile matches a viewscreen profile in pulsed mode.



We will use this to study the effects of ions and ion instabilities on the electron beam.
This flying wire is very cheap and easy to use (it was designed and built by one of our technicians!)

Beam Induced Fluorescence Profile Monitor



Introduce nitrogen gas at ~10^{-7} torr. The gas is ionized by the electron beam, emitting ~400 nm photons. The fluorescence is imaged onto at standard CCD camera, producing these images.

With our high beam currents, there is adequate signal to obtain nice images in a few seconds. This is a great, inexpensive diagnostic, and is also very inexpensive.

Other Projects

- We are developing and testing a transverse ‘laser wire’ profile monitor using Compton scattering (with Radiabeam Technologies LLC). During initial tests, the Compton signal was too low (compared to the x-ray background from halo). We will try again soon with a higher power laser.

- If you have any ideas for diagnostics for high power beams, or to measure halo distributions – we are interested in trying them out in our injector

Conclusion

For future high-brightness, high-power electron injectors, a wide range of diagnostics are necessary for testing, optimization and operations.

Important items:
Halo measurement and halo reduction
Wide dynamic ranges
Fast, accurate phase space measurements
Non-intercepting diagnostics

If you have any good ideas, let's talk . . .

Support

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