Photodetachment Profile Monitor Proposal for H^- Beams at BNL

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Laser Beam Profile Monitor

First ionization potential for H^- ions is 0.75eV.

Photons with λ<1500nm can separate H^- ion into free electron and neutral H.

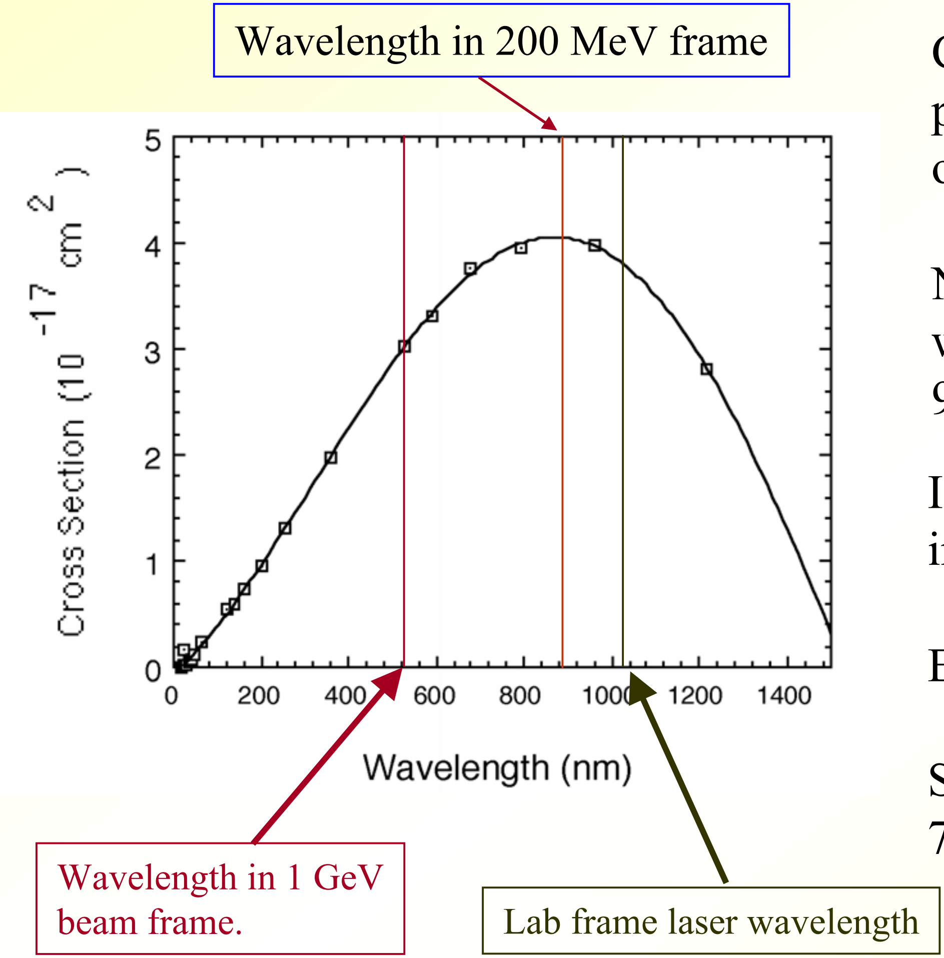
Laser can be used to mark a portion of beam by neutralization.

Once a portion of the beam is marked, measurements can be made on the neutral beam, the removed electrons, or the reduced beam current with beam current transformer or BPM stripline.

This method has been used at Los Alamos for transverse and longitudinal emittance measurements.

It is being used on SNS for measurement of transverse beam profiles.

Laser neutralization cross section



Calculated cross section for H- photoneutralization as a function of photon wavelength.*

Nd:YAG laser has λ=1064nm where the cross section is about 90% of the maximum.

If laser beam crosses ion beam at angle θ_L, in lab the center of mass energy is given by,

$$E_{CM}=\gamma E_L[1-\beta\cos(\theta_L)]$$

So Nd:YAG cross section at 1GeV is about 70% of low-energy cross section.

*J.T. Broad and W.P. Reinhardt, Phys. Rev. A14 (6) (1976) 2159.

Development work for SNS

1. Three experiments have been done to demonstrate method and develop technique.

2. All were done with Q-switched Nd:YAG lasers. Experiments at 750 keV and 200 MeV used 200 mJ pulse and measurement at LBNL at 2.5 MeV used 50 mJ pulse.

3. Experiments at 750 keV and 2.5 MeV measured notch in beam current with current transformers.

4. Measurement at 200 MeV measured current notch with BPM striplines.

750 keV experiment, using BCT

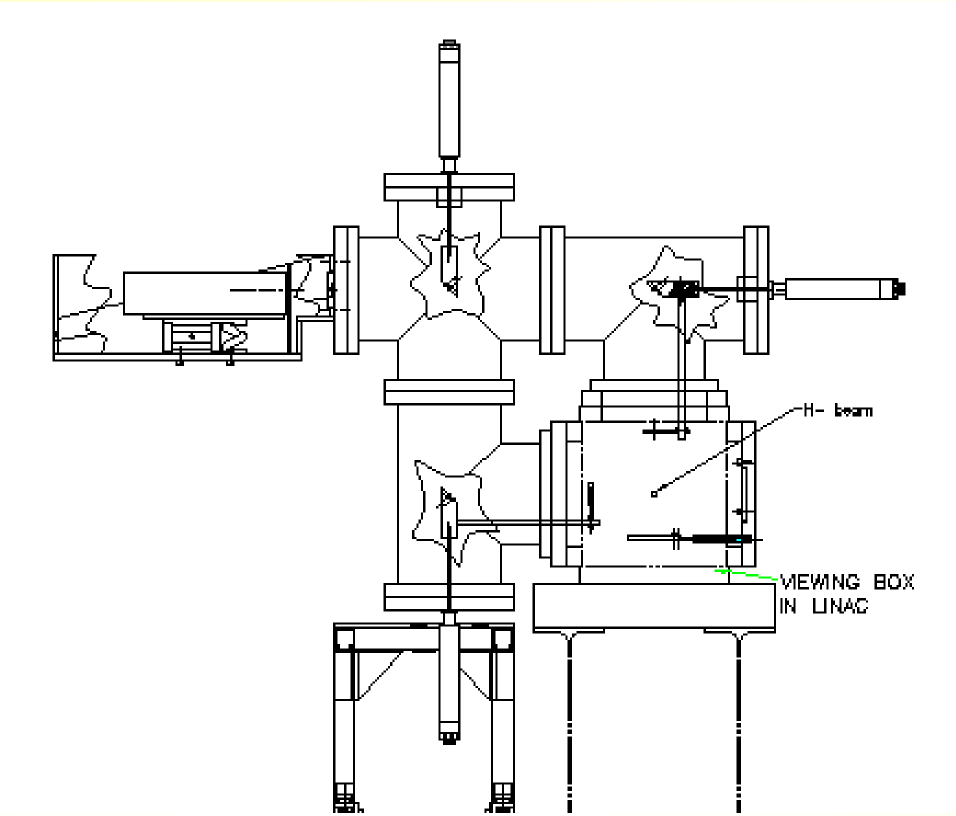
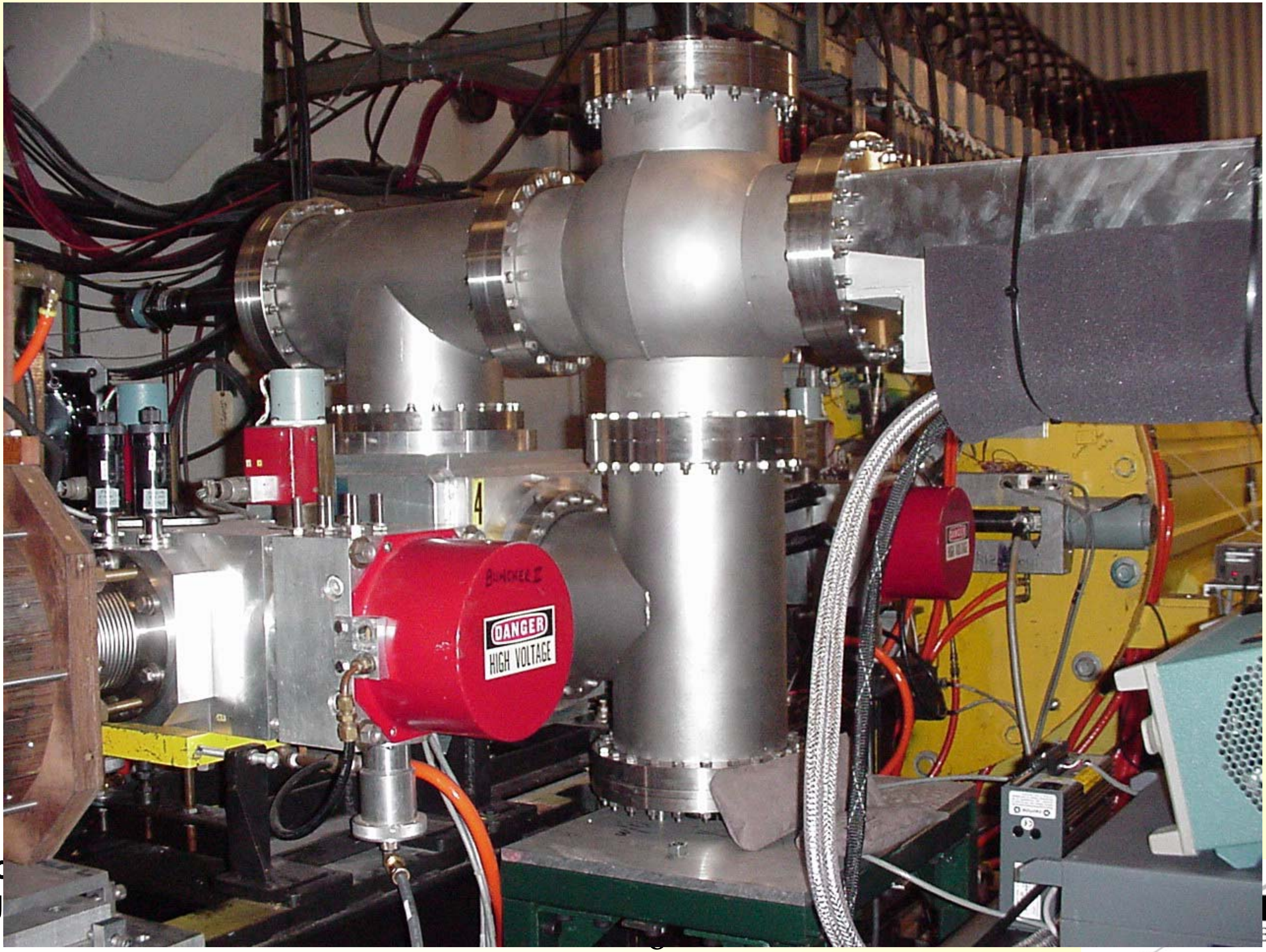
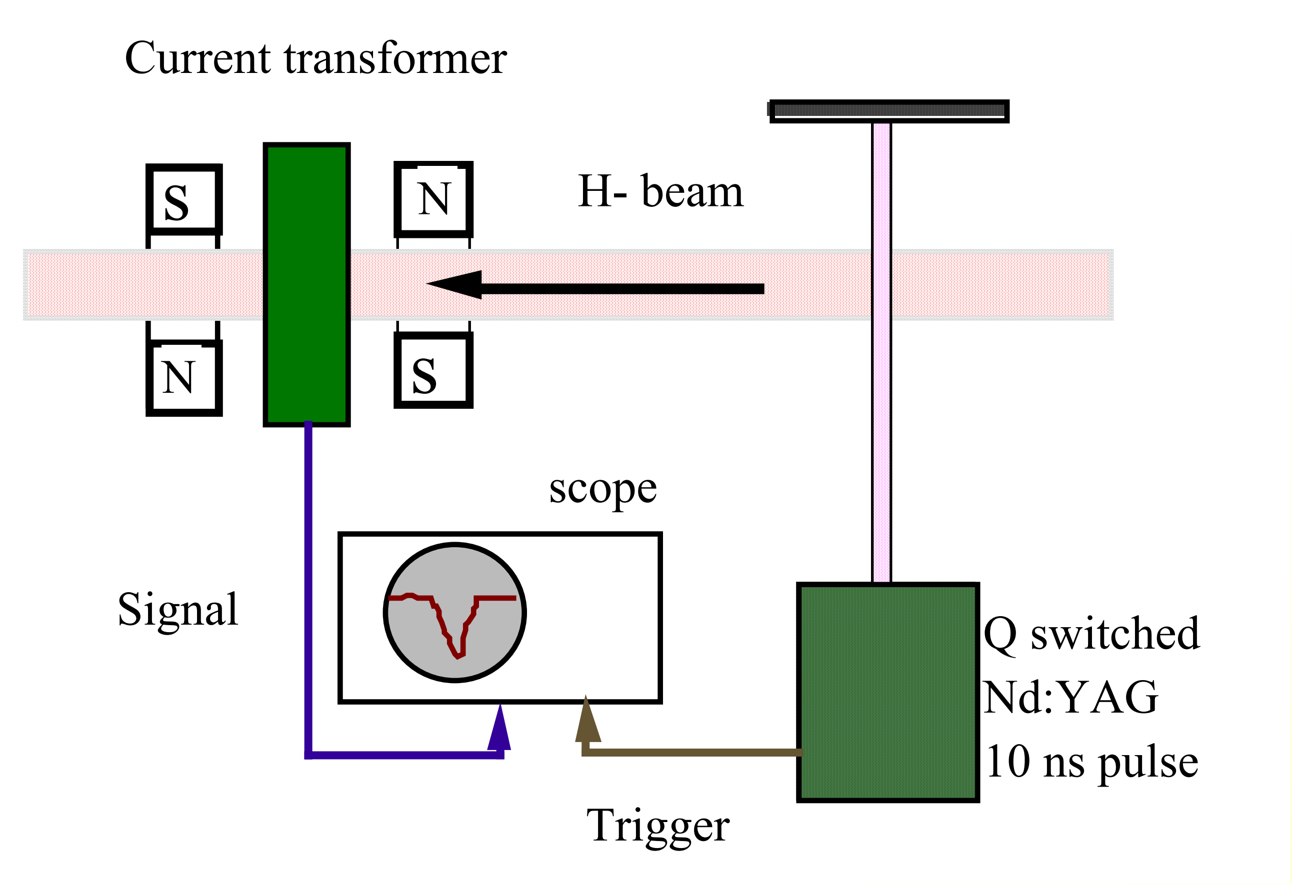


Diagram of experiment installed on BNL linear accelerator. The laser is on the platform at the left. The top-center mirror switches between vertical and horizontal scans. Mirror at top-right scans horizontally and mirror at bottom left scans vertically.

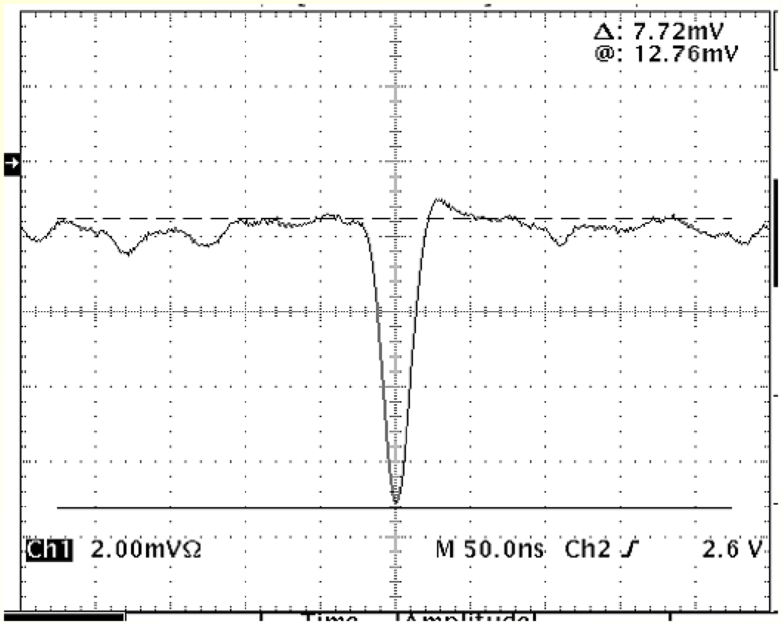
LPM on linac. Laser is upper right



Laser profile experiment on BNL linac



Scope trace of current notch



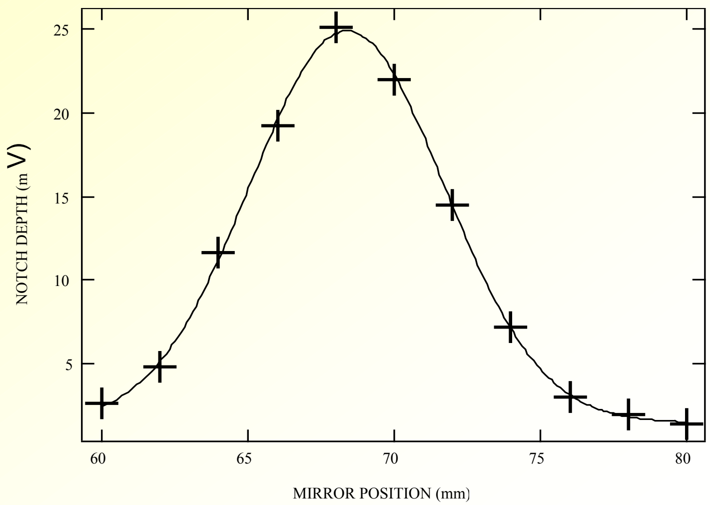
Ocilloscope trace of output of current transformer showing current notch created by laser.

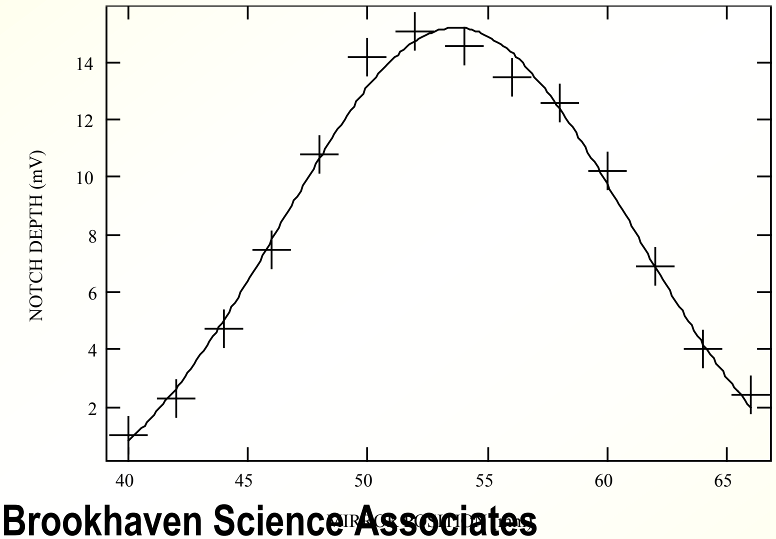
The signal is filtered with a 50 MHz low pass filter to remove the linac 200 MHz rf.

Profile measurements were made by measuring the notch depth at each mirror position.

S/N at beam center of 25dB. Signal to ~2.5 σ.

Beam Profiles Measured on BNL linac





Horizontal (top) and vertical profiles of the BNL linac beam. Measurements were made after the rfq with 750 keV beam.

The markers are the data and the lines are gaussian fits.

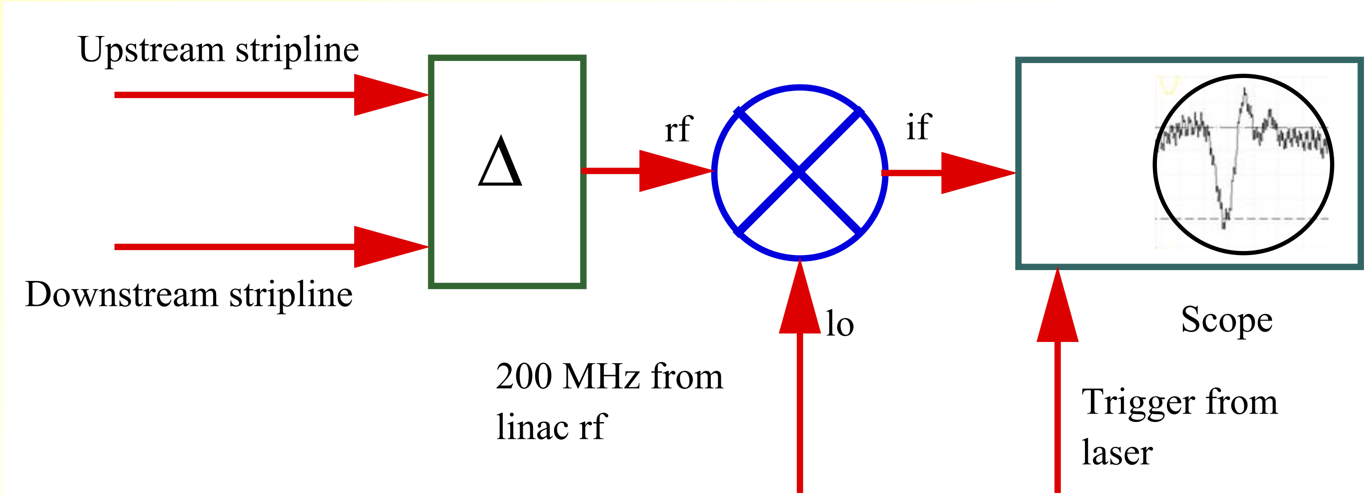
Widths of fits:

$$\sigma_x = 3.32 \pm 0.05 \text{ mm}$$

$$\sigma_y = 7.3 \pm 0.6 \text{ mm}$$

Each data point is from averaging 15 pulses.

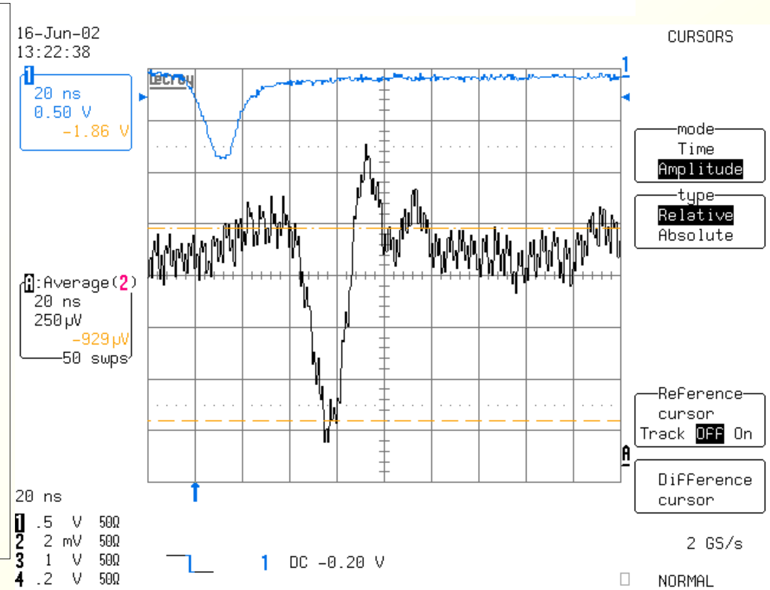
Signal detection of current notch using striplines



The signals from one upstream and one downstream stripline are subtracted and the difference signal is mixed With 200MHz from the linac rf to remove the carrier frequency. The mixer output is passed through a 50MHz low-pass filter.

We were 40m from the end of the linac so the 1% energy jitter became a ±70° phase jitter. This is the source of the rf on the scope trace.

The phase jitter would not be a problem with a detector located in the linac.



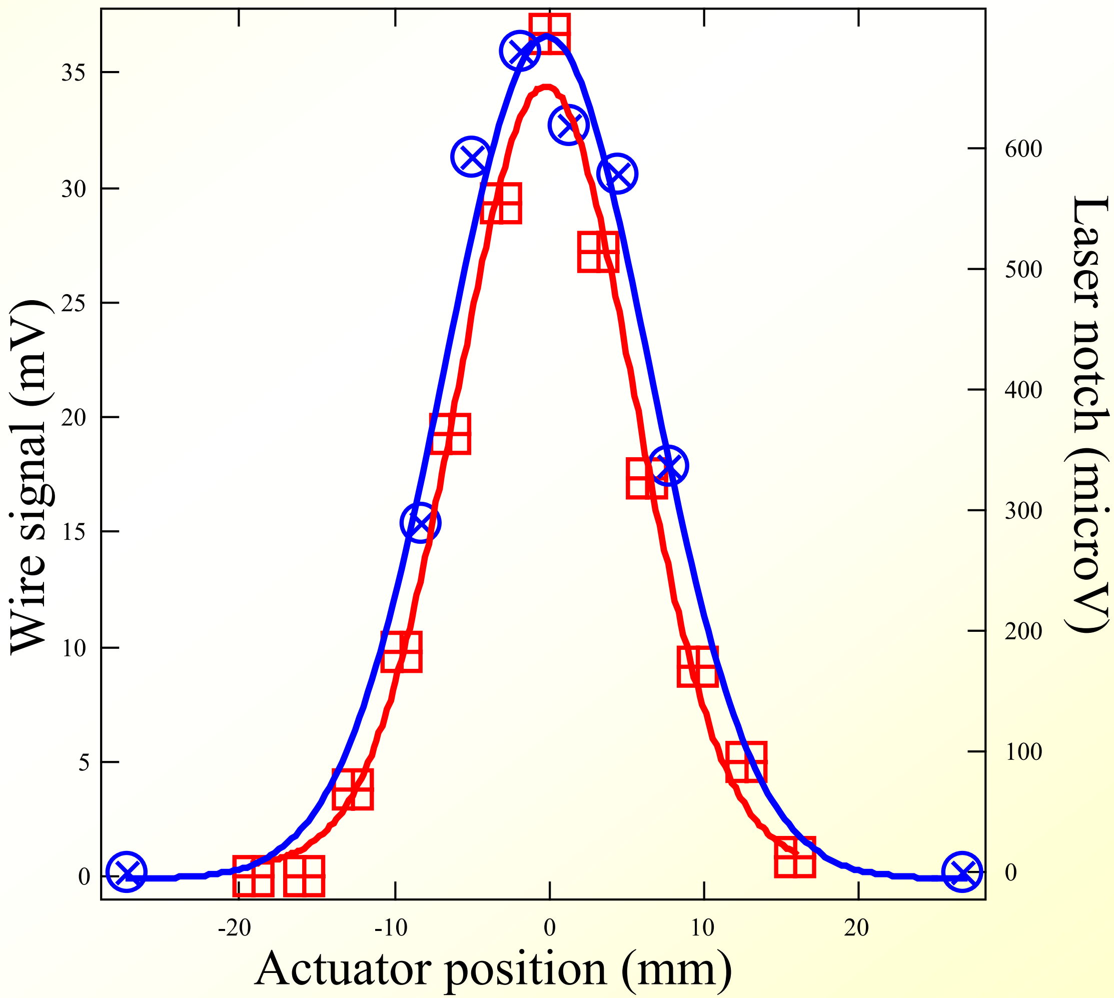
Beam profiles measured at 200 MeV

A carbon-wire beam scanner was also mounted in the laser chamber. Profiles were taken with both the wire scanner and the laser.

The laser profile is the blue, dotted curve. When the laser-beam width was deconvolved the measured widths are:

σ_{laser}=6.45±0.6 mm

σ_{wire}=5.7±0.3 mm



Permanent BNL linac profile monitors

1. Detection of notch in beam current requires short, intense pulse. Measurements at BNL used 10 MW laser (200 mJ for 20 ns).

2. Such pulses have to be transmitted by mirrors through interlocked beam line. It will be difficult to retrofit existing linac tunnel.

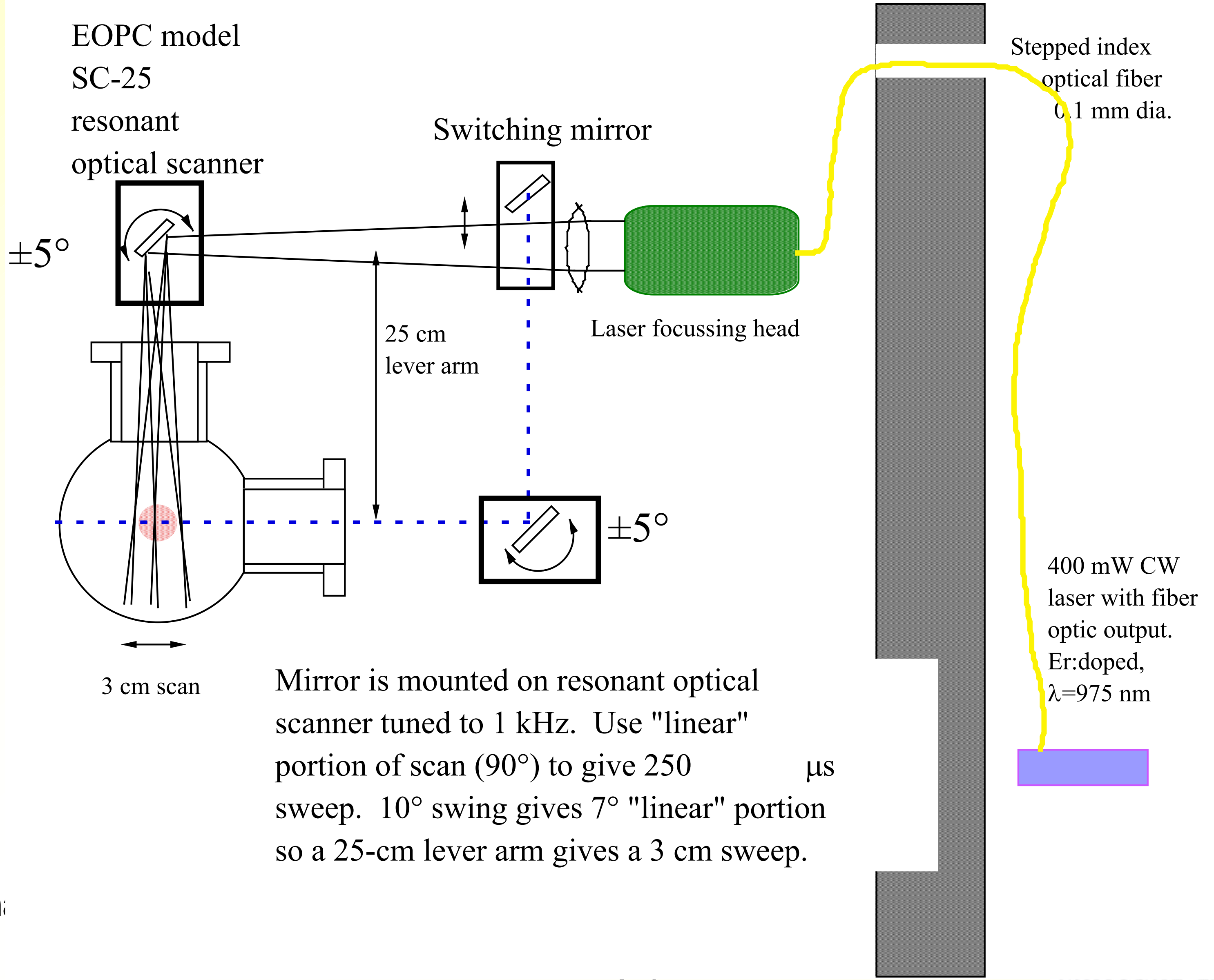
3. Detection of electrons requires far lower neutralization rate.

4. A microchannel plate can amplify the electron signal by 10^4-10^6.

5. Proposed laser is solid-state, CW diode laser with fiber-optic output. Power ~1W and λ= 975-980 nm. Edmunds sells one for $3.7k (there are lots to choose from).

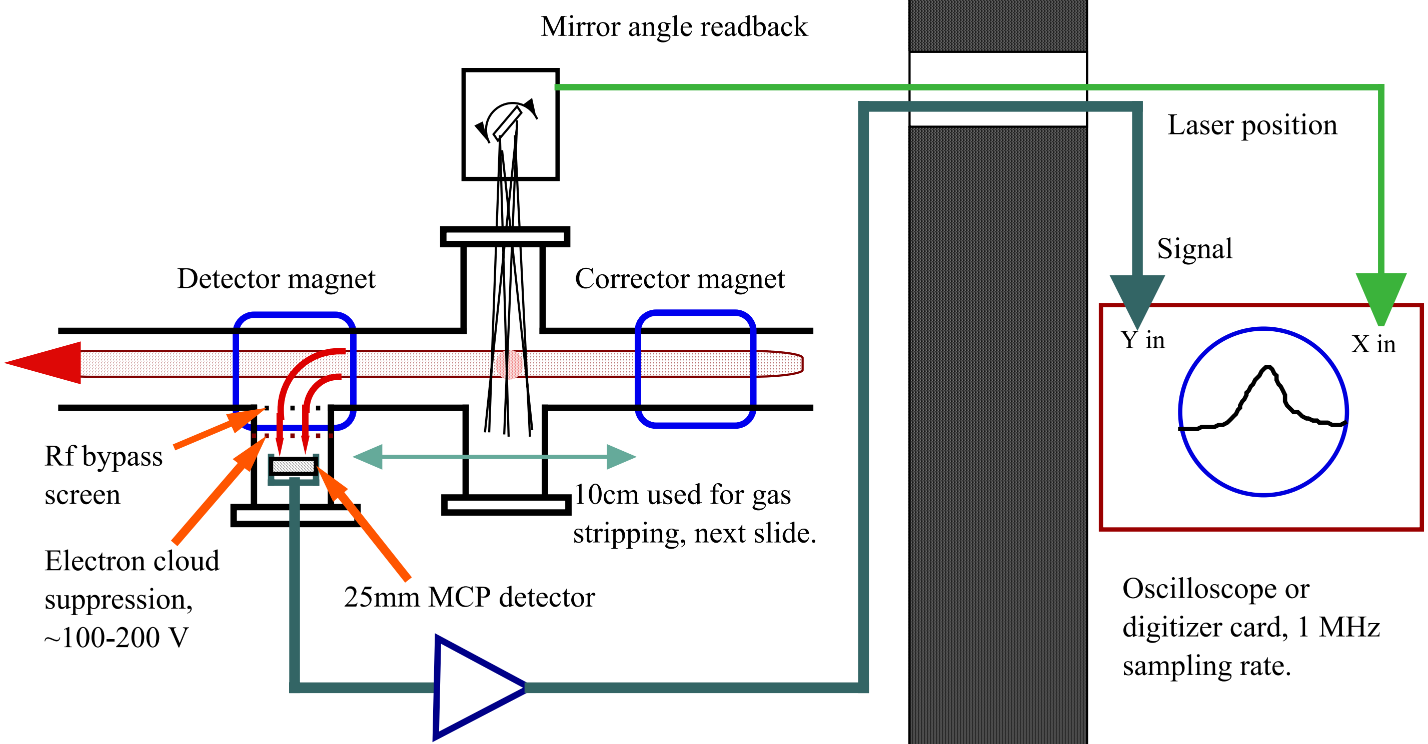
6. With CW laser and electron collection we can scan with optical scanner and get full beam profile in one machine pulse (300μs).

Laser-scanning schematic for BNL linac installation



Mirror is mounted on resonant optical scanner tuned to 1 kHz. Use "linear" portion of scan (90°) to give 250 μs sweep. 10° swing gives 7° "linear" portion so a 25-cm lever arm gives a 3 cm sweep.

Signal-processing schematic for BNL linac installation



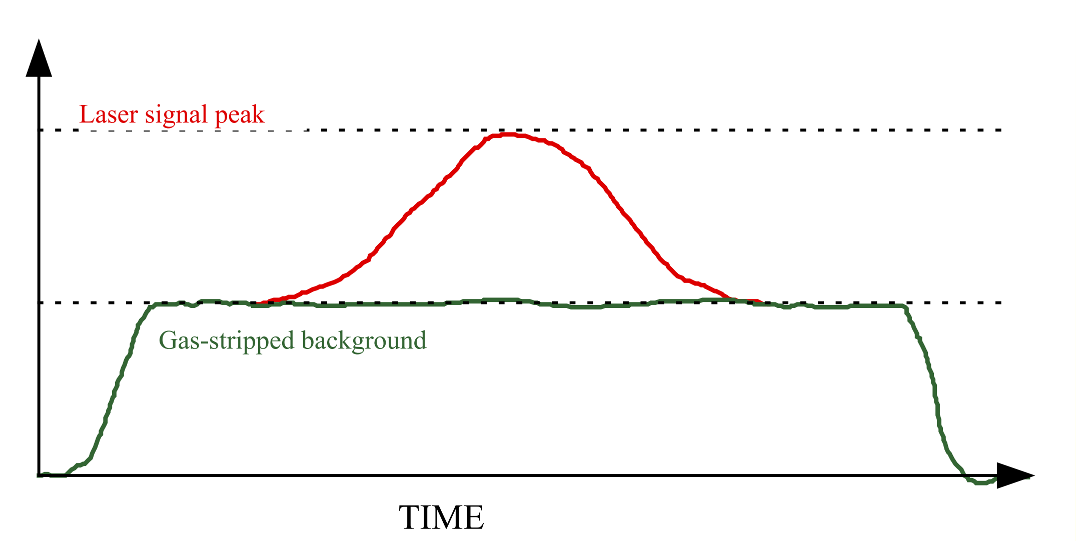
Peak electron current into MCP is 2.2 nA.
At 10^4 MCP gain, current into amplifier is 22 μA.
The rf coupling current at 200 MHz is ~2 nA.
Signal current=rf coupling current at ±4.3 σ.

Gas stripping *

At 200 MeV, 1 x 10^{-7} torr of nitrogen gives 1.5 x 10^{-6} stripping per meter. (Cross section ~ $1/\beta^2$).

10 cm of transport (distance between magnets) with 20 mA beam gives 3nA of current.

Peak laser signal (400mW, 0.1mm diameter) is 2.2 nA.



*R.E. Shafer, "Laser Diagnostic for High Current H^- Beams," AIP Conf. Proc. 451, Proc. 1998 Beam Instrumentation Workshop, Stanford, 1998.

Summary

1. Transverse profiles of H^- beams have been measured by laser photoneutralization.

2. The laser beam can be swept through the ion beam in one machine pulse with commercial optical scanners.

3. Electron collection with 1MHz electronics will give complete profile in one machine pulse.

4. Microchannel plate amplification of electron signal reduces laser power requirement to 1W or less. Light is transported from laser to beamline over optical fiber.