Application of Lasers for Diagnostics of Negative Hydrogen Ion Beams

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Outline

- Negative Hydrogen Ions
- Few Words About Beam Diagnostics
- Why Lasers
- Transverse Beam Profile Diagnostics
- Longitudinal Beam Profile Diagnostics
- Transverse Emittance Diagnostics
- Longitudinal Emittance Diagnostics
- 'Laser Comb'
- Beam Energy Measurement
- Challenges in Real Applications of Laser Diagnostics

Acknowledgments

- Some material for this presentation is provided by members of SNS Beam Instrumentation and Accelerator Physics Groups.
- I am especially grateful to Yun Liu and Andrey Shishlo.

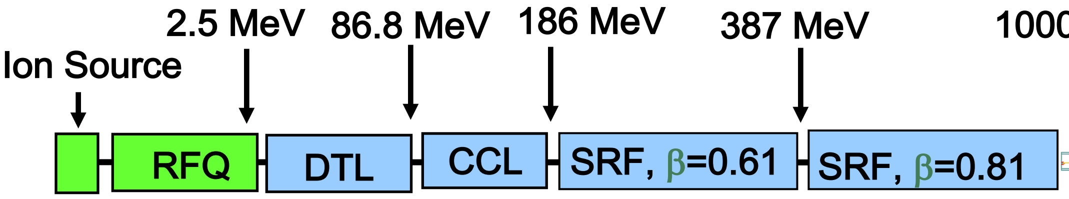
SNS Accelerator Complex

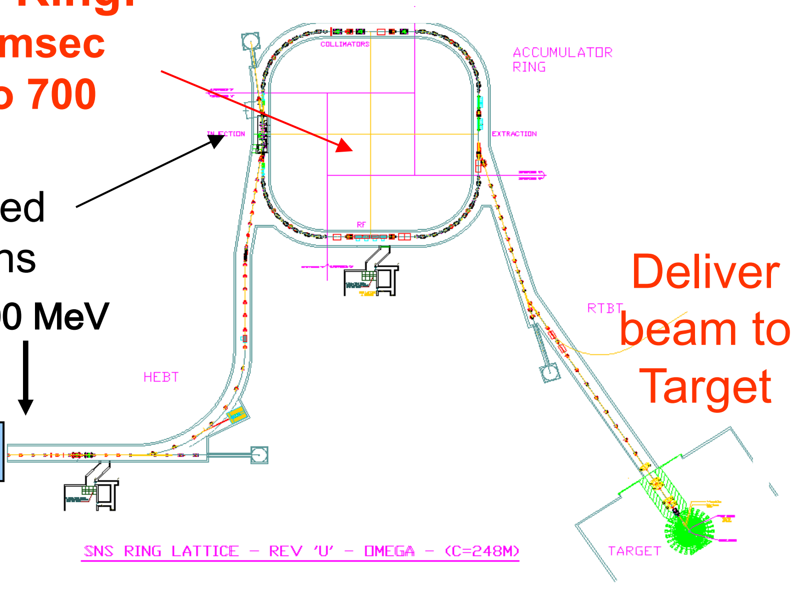
Front-End: Produce a 1-msec long, chopped, low-energy H- beam

LINAC: Accelerate the beam to 1 GeV

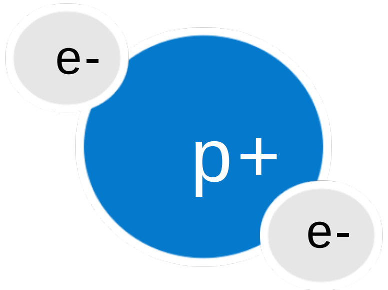
Accumulator Ring: Compress 1 msec long pulse to 700 nsec

H- stripped to protons





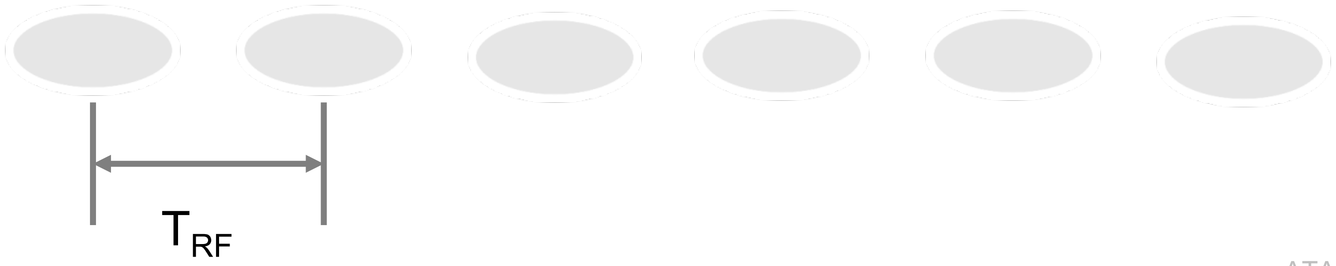
P beam on target :	1.4MW
I beam average:	1.4mA
Maximum Beam energy:	1 GeV
Duty factor:	6%
Rep. rate:	60Hz
Pulse width:	1ms



Use of H- ions allows charge exchange injection

H- ions are accelerated in hadron RF Linac

- Time structure
  - Stream of identical bunches separated by T_{RF} , ~nsec
  - Possibly, temporal modulation is imposed on RF structure, with $T \gg T_{RF}$
- Typical bunch size is
  - ~mm , horizontal
  - ~mm, vertical
  - ~mm, longitudinal (tens of picosecond)
- Typical bunch population is
  - ~10^9 particles

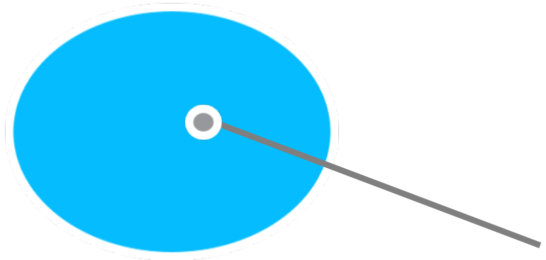


Beam Diagnostics Measure Parameters of Particles Distribution Inside Beam

- 0^{th} – order, bunch current or charge:
- 1^{st} – order, bunch center of mass position: x, y, z

Non-interceptive methods

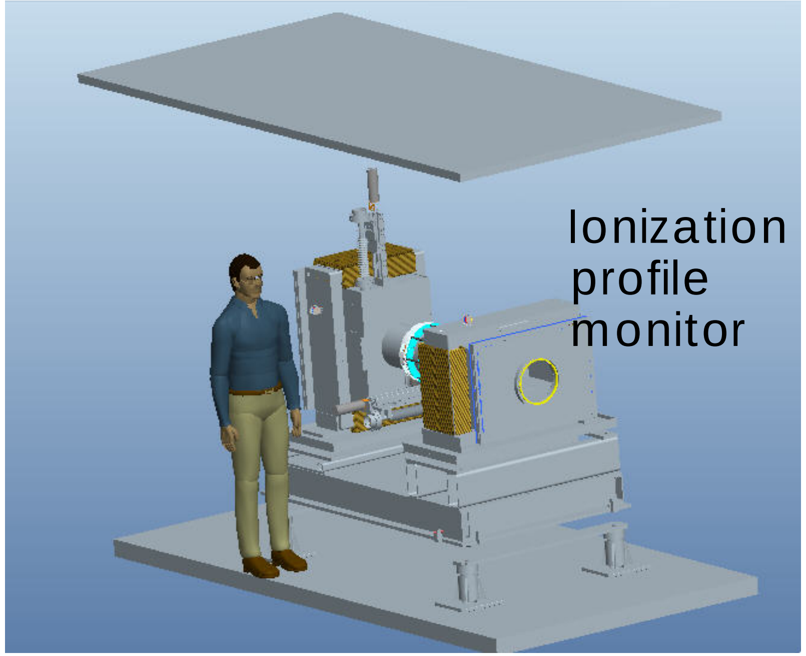
- 2^{nd} - order, bunch 'profile': f(x),f(y),f(z)
- 3d – order, bunch '2d-emittance': f(x, x'), f(y, y'), f(z, z')
- 4^{th} – order, ...

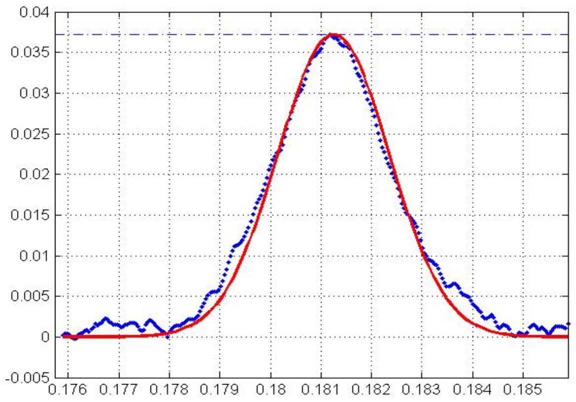


Need intra-beam probe
- interaction
- localization
- detection

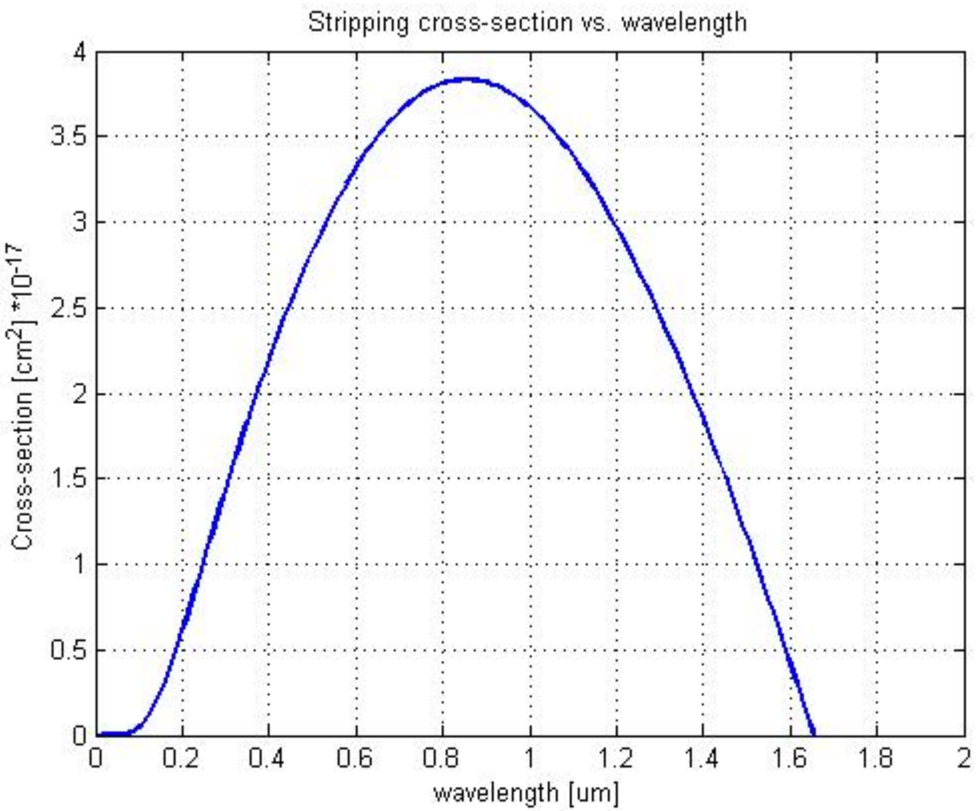
Probes for transverse profile beam measurement

- Solid material (‘wire scanner’)
  - Wire is damage by beam
  - Beam is damaged by wire
- Jets
  - Gas
  - Metal vapor
- Residual Gas
- Charged beam
- Laser
  - Interaction?

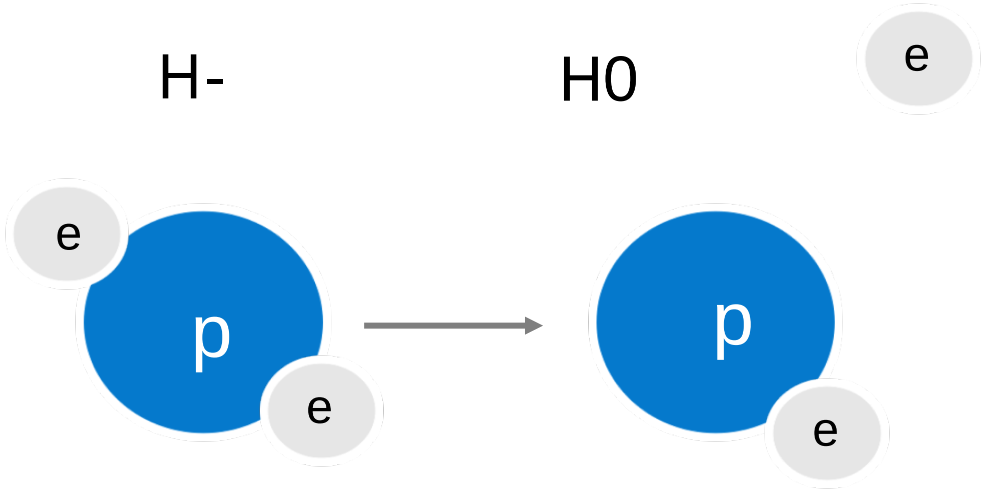




H- Interaction with photon



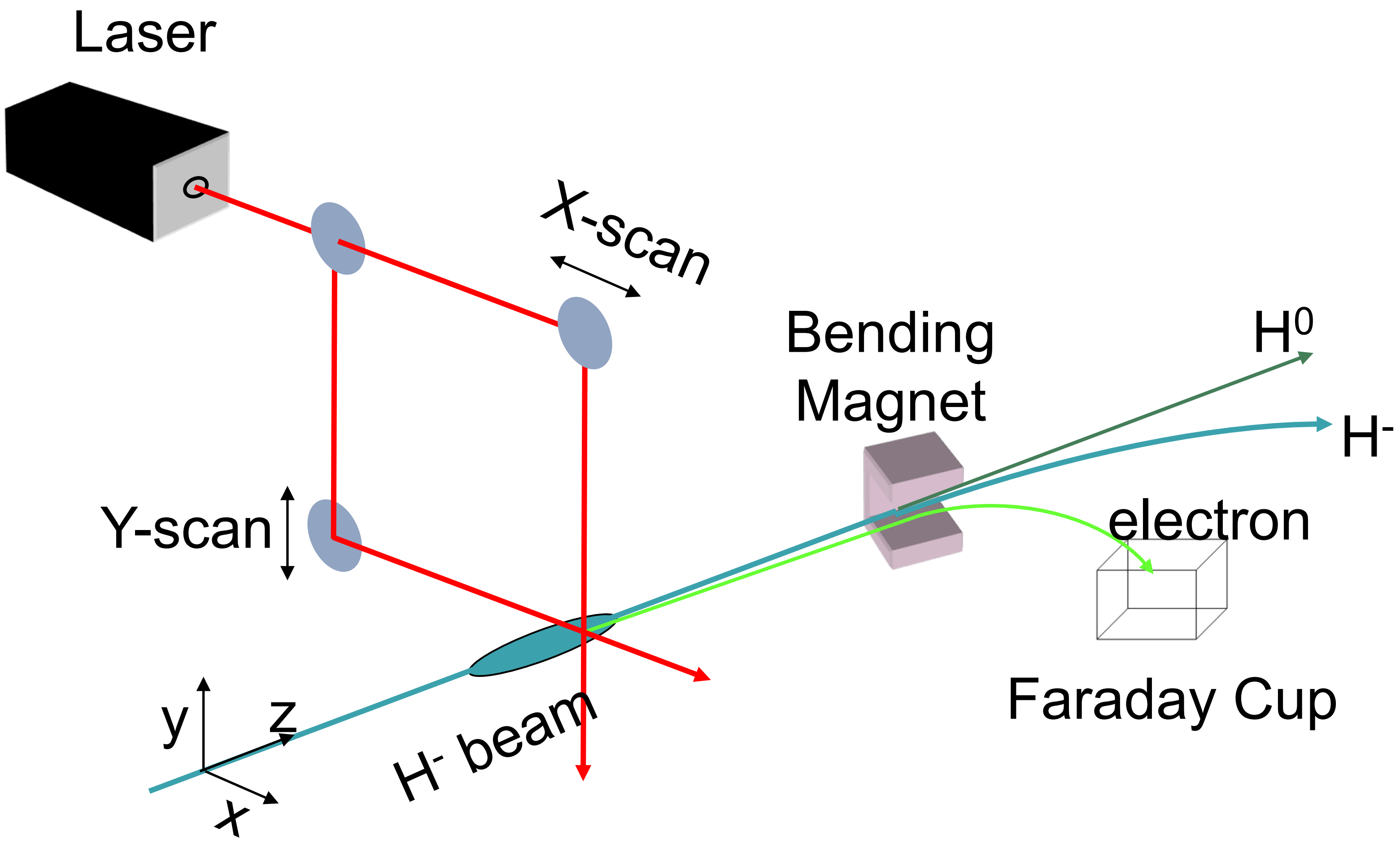
Cross-section of one electron photo-detachment



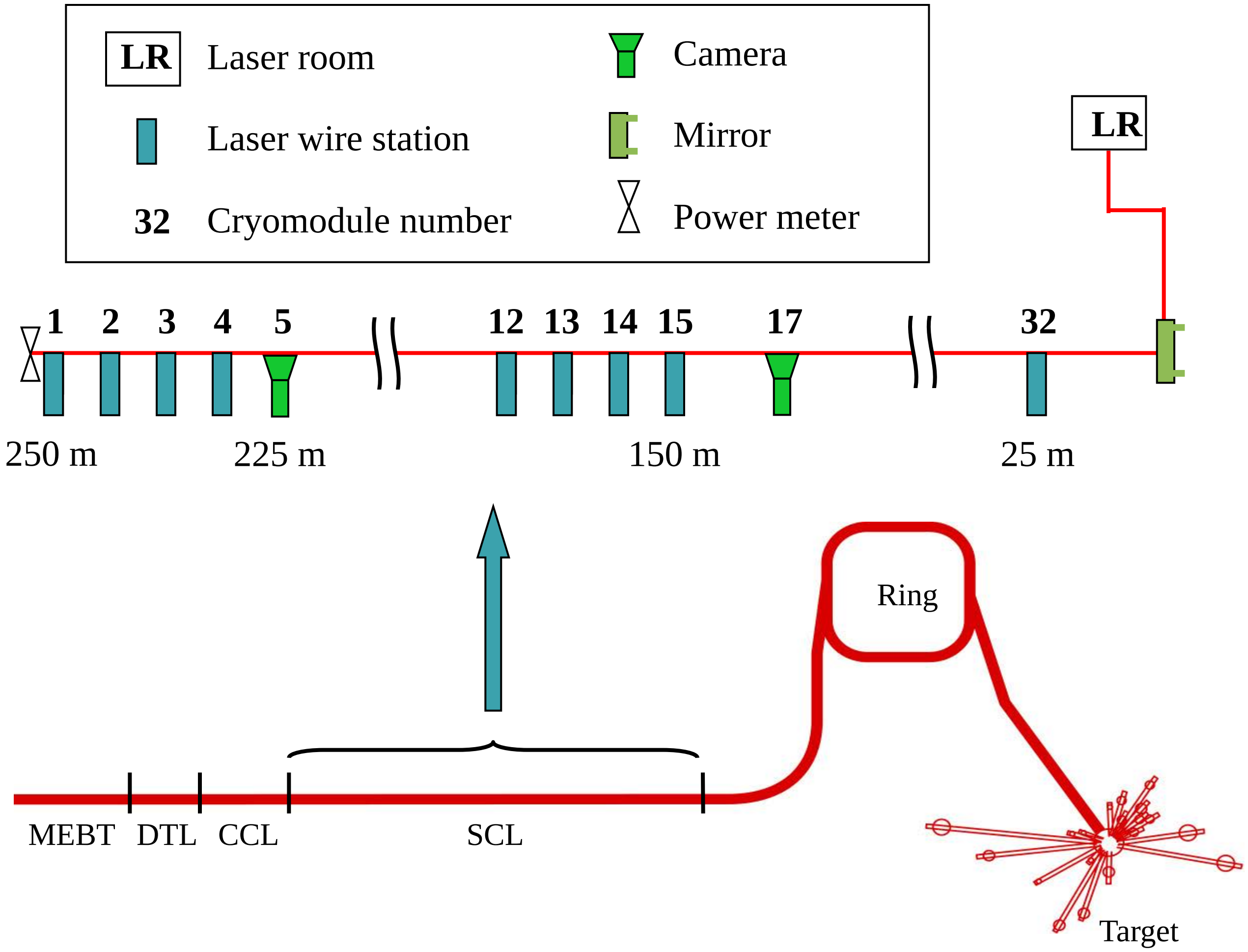
$$H^{-} + \gamma = H^{0} + \mathrm{e}$$

$$f_{\text{Beam Frame}} = \gamma(1 + \beta\cos(\alpha))f_{\text{Lab Frame}}$$

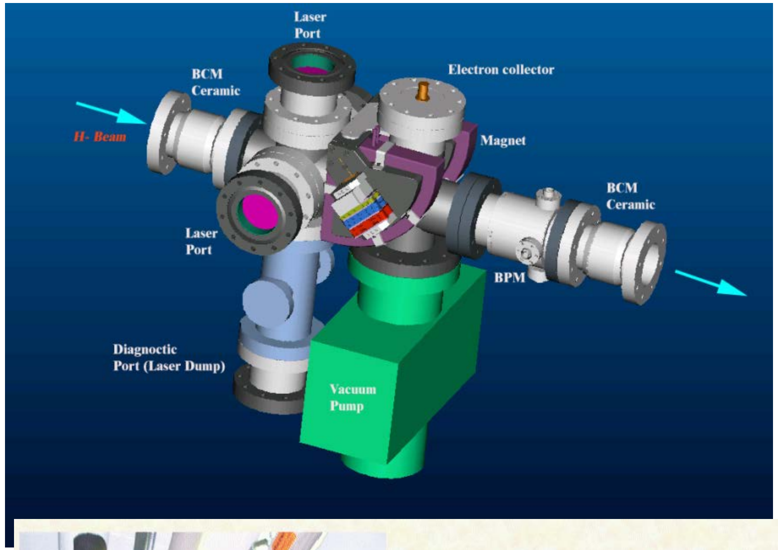
Principle of operation of a transverse “laser wire”

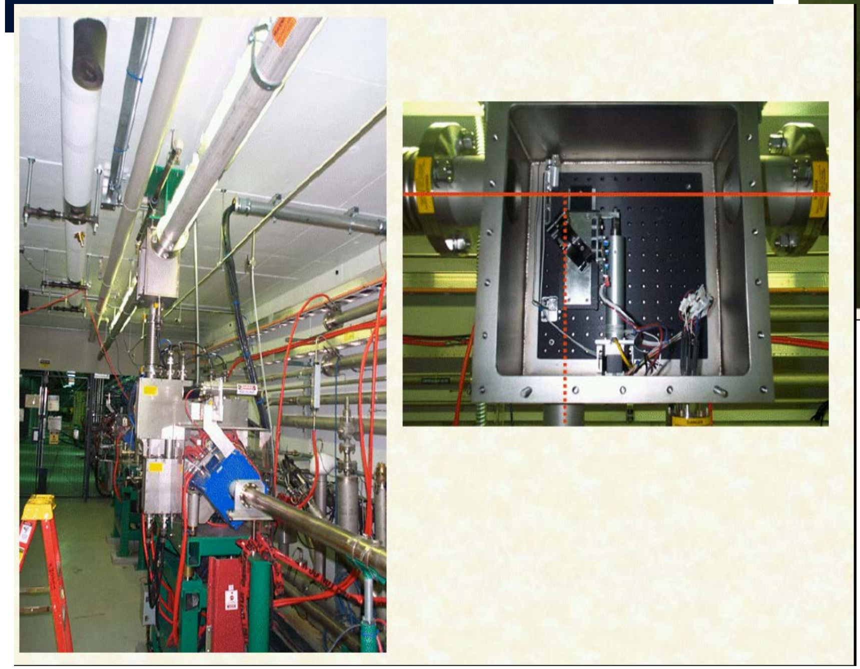


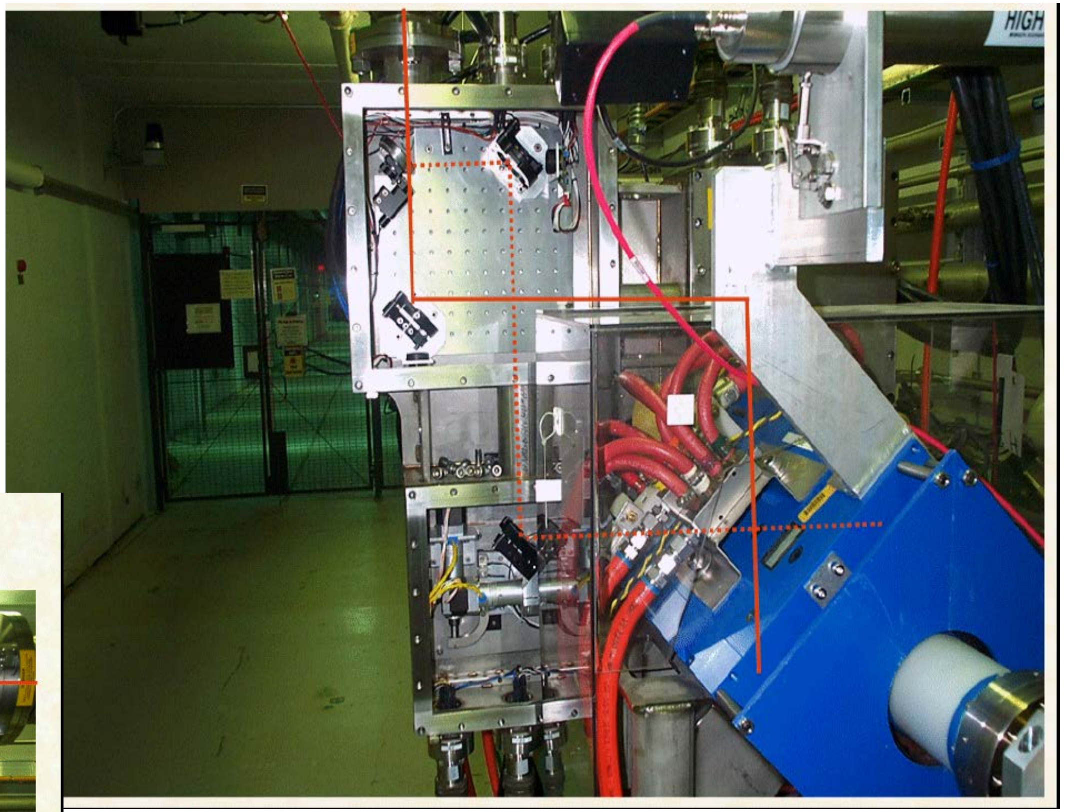
Layout of the SNS laser wire system



SNS Laser wire hardware

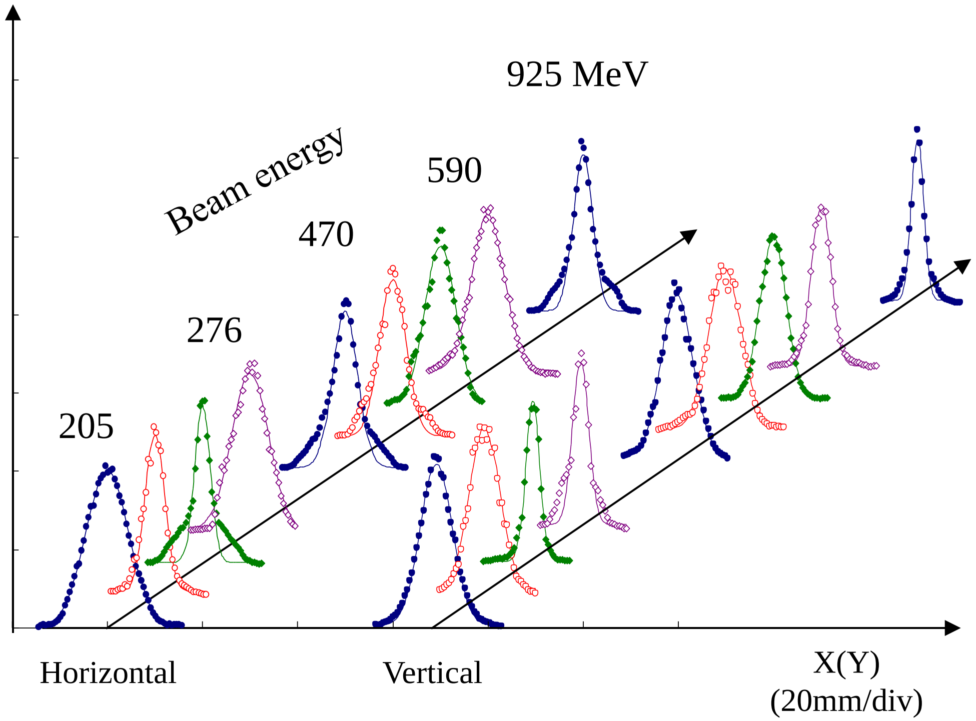






Laser Wire Measurement Output

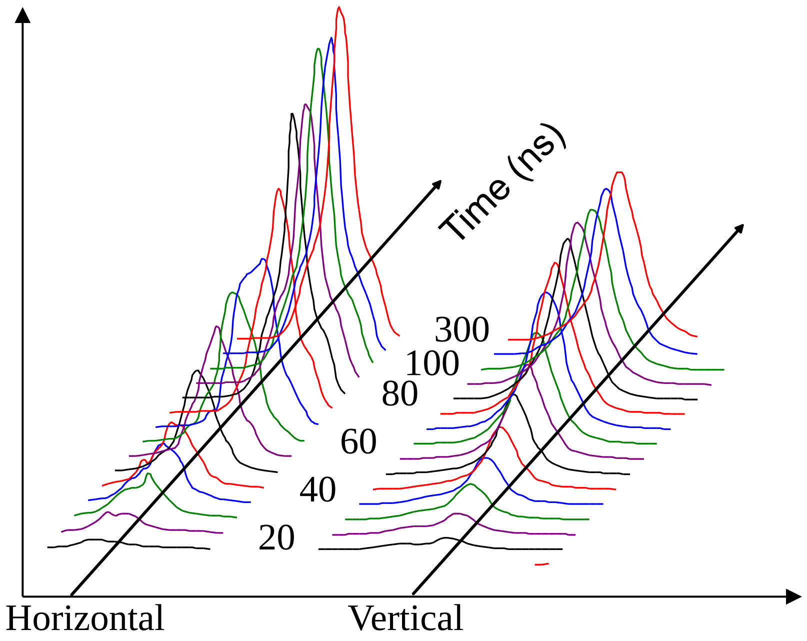
Beam profiles along the SCL



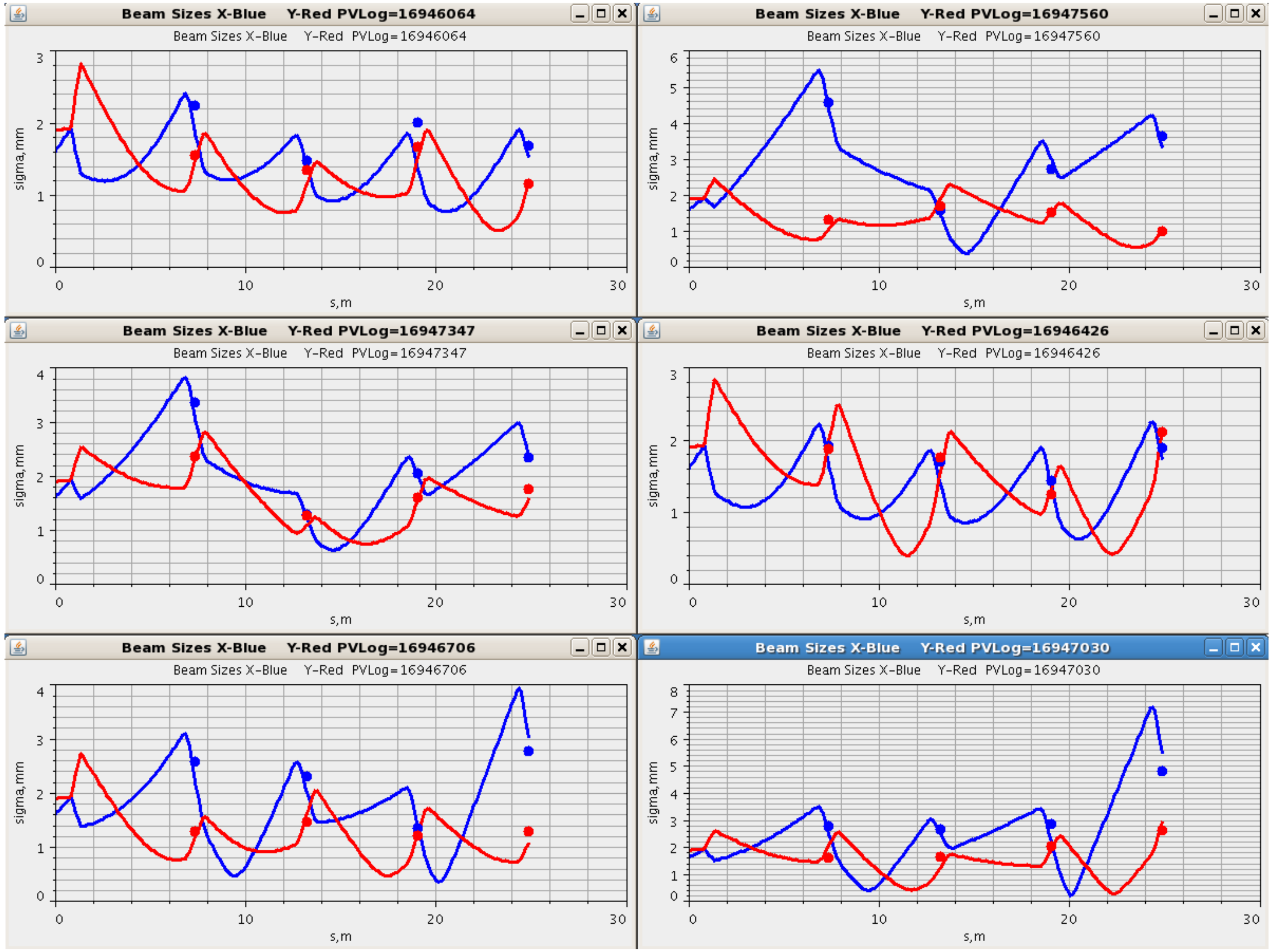
- Profiles measured at all 9 stations (200 – 925 MeV)
- Measurement has been conducted on 1 MW neutron production beam

- Laser wire can measure profiles at each mini-pulse (~ 1 us long) or different segments within a single mini-pulse

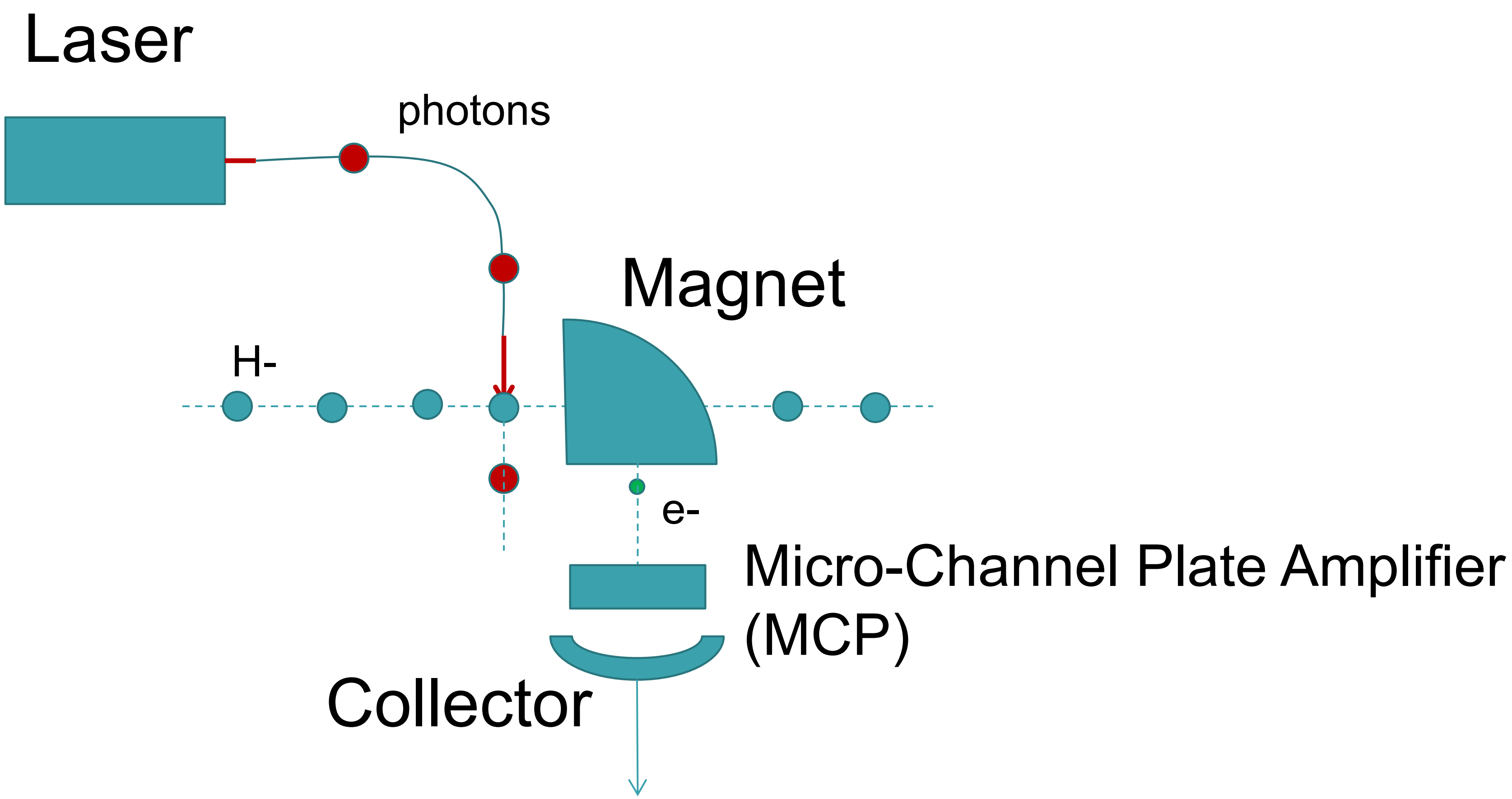
Beam profiles within single mini-pulse



Physics Study - LW Sizes   Measured/ Calculated

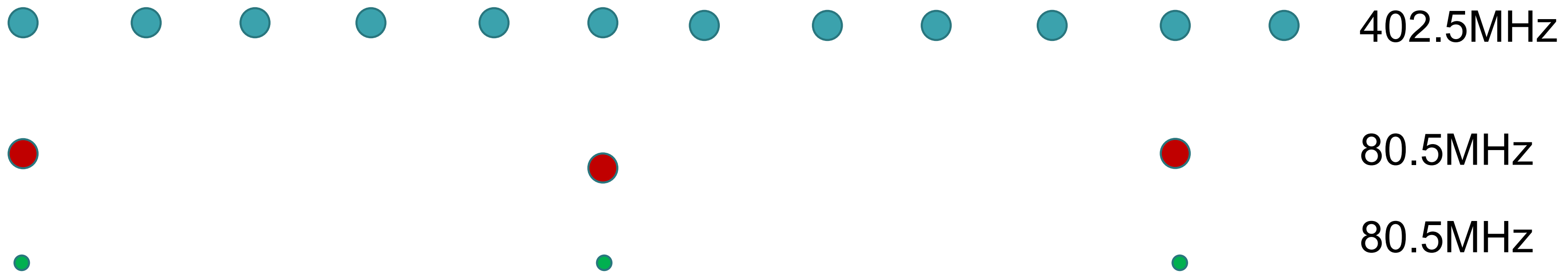


Longitudinal Laser Wire Principle of Operation

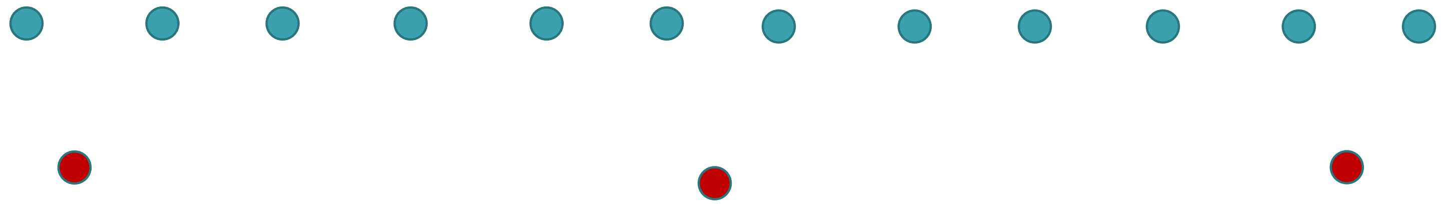


Time relations

Maximum signal when photons and ions overlap in time

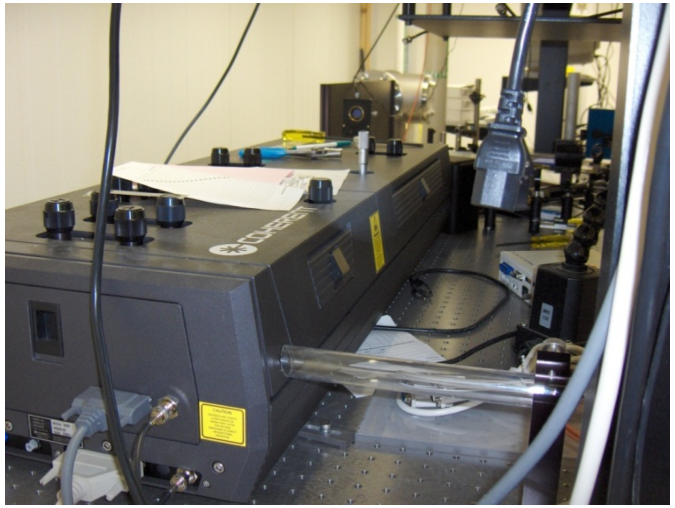


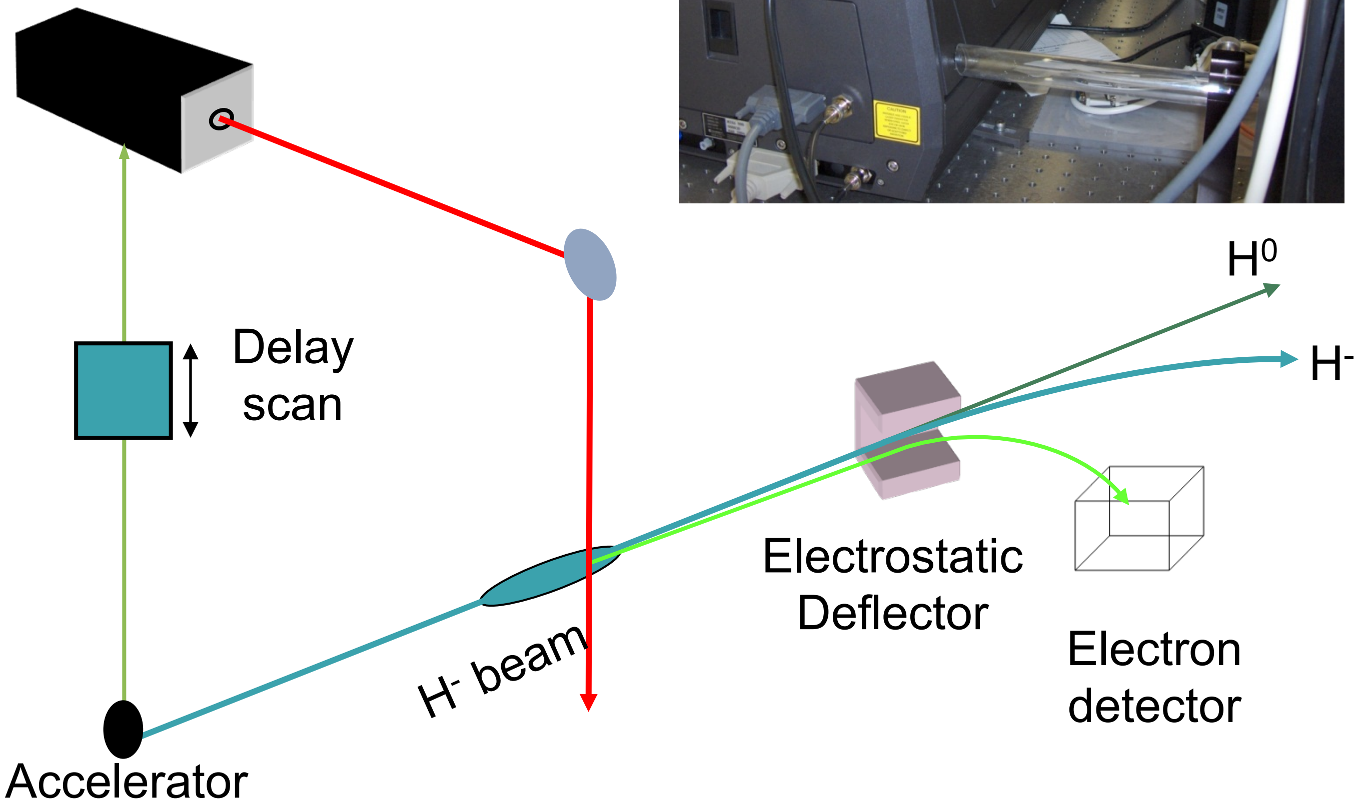
No signal when photons and ions do not overlap

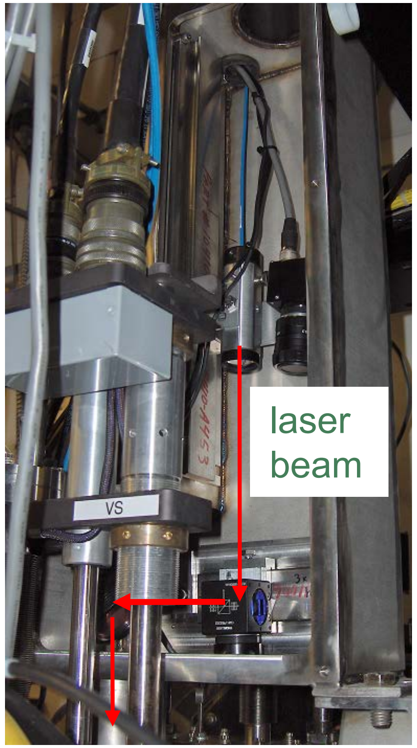


Scanning delay between photons and ions and measuring output electrons gives longitudinal ion bunch profile

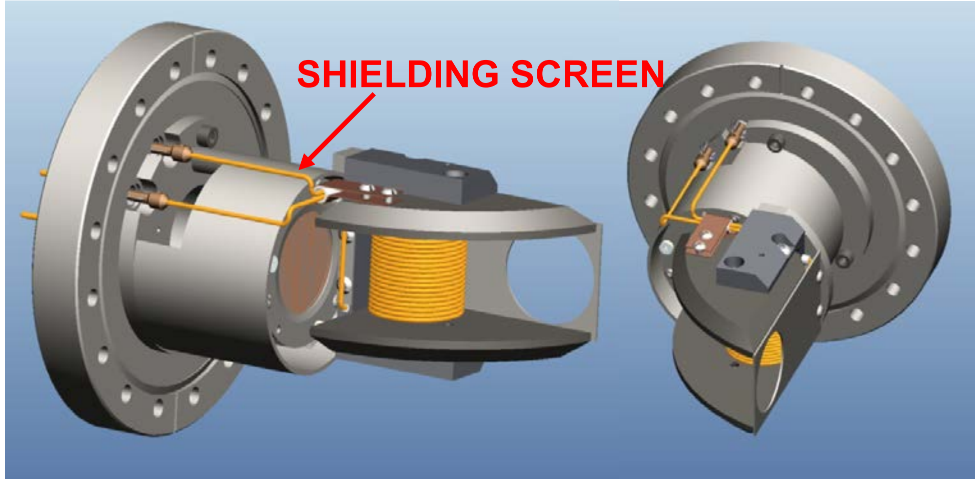
SNS 2.5MeV Longitudinal Profile Measurements

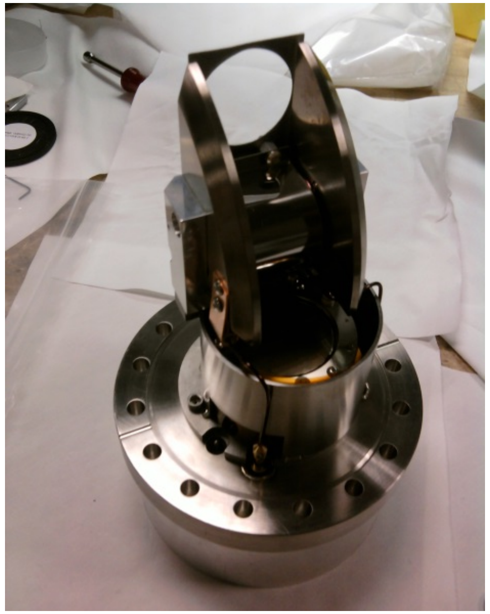


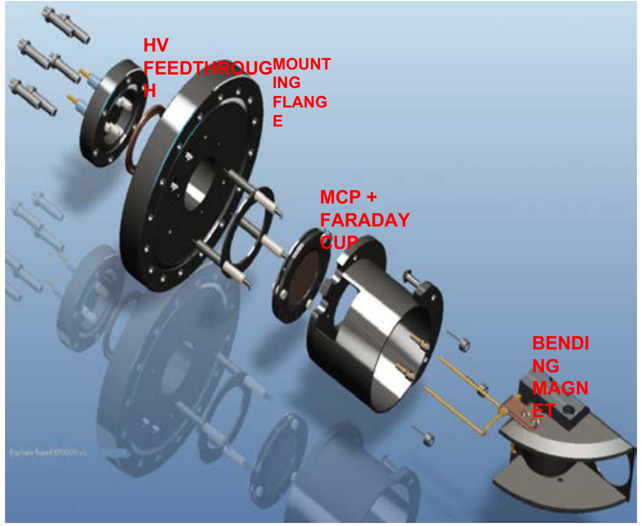


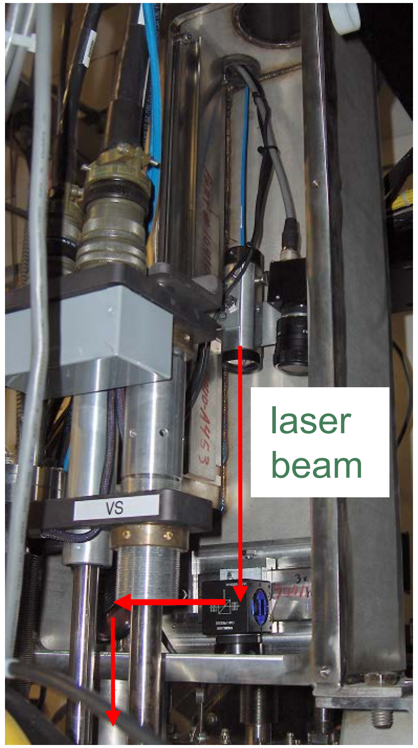


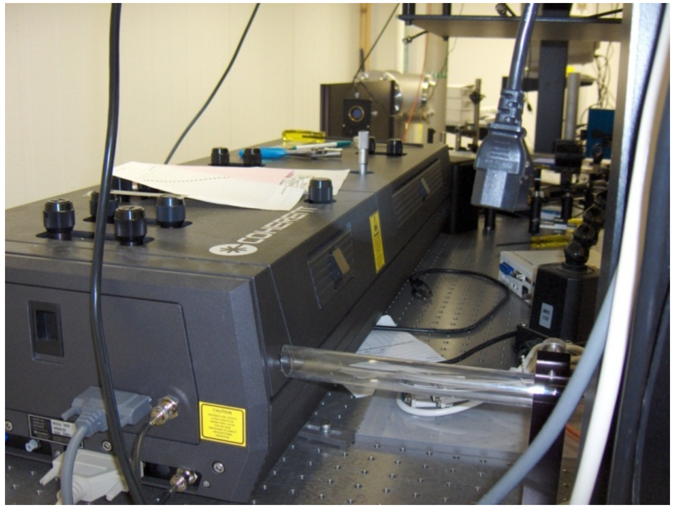
SNS Longitudinal Laser Wire Hardware





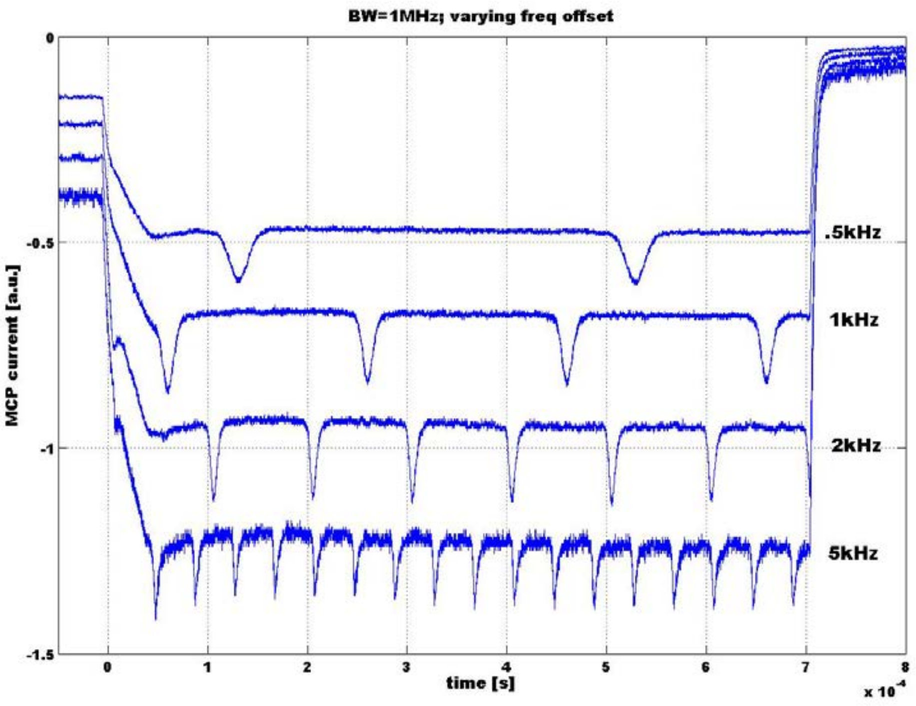




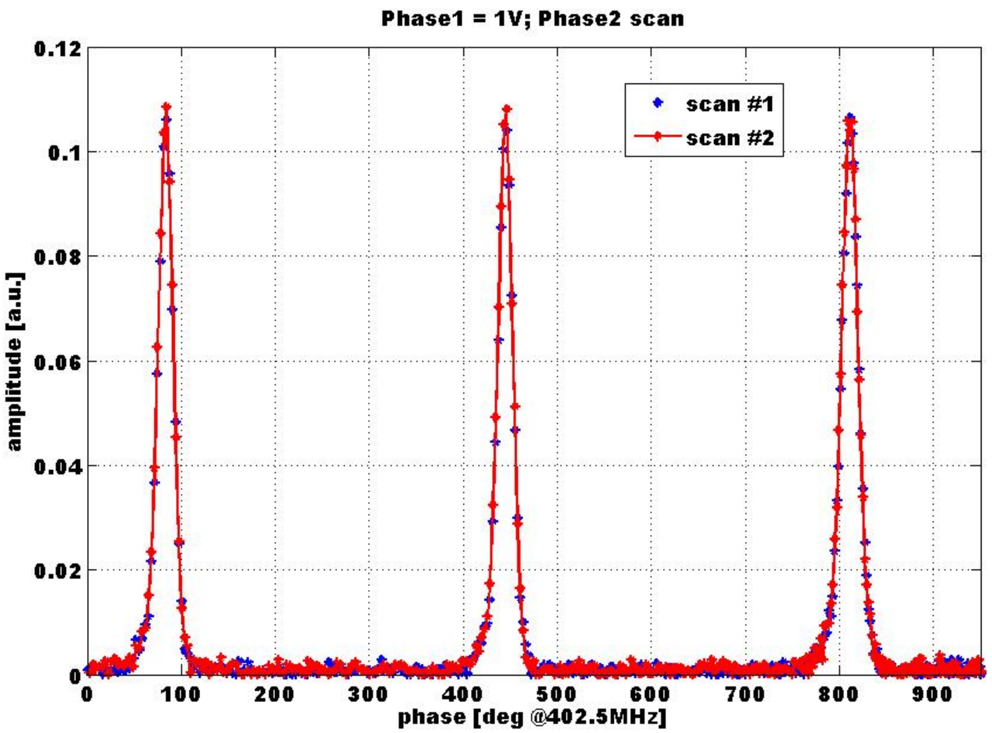


Longitudinal profiles measured in two modes

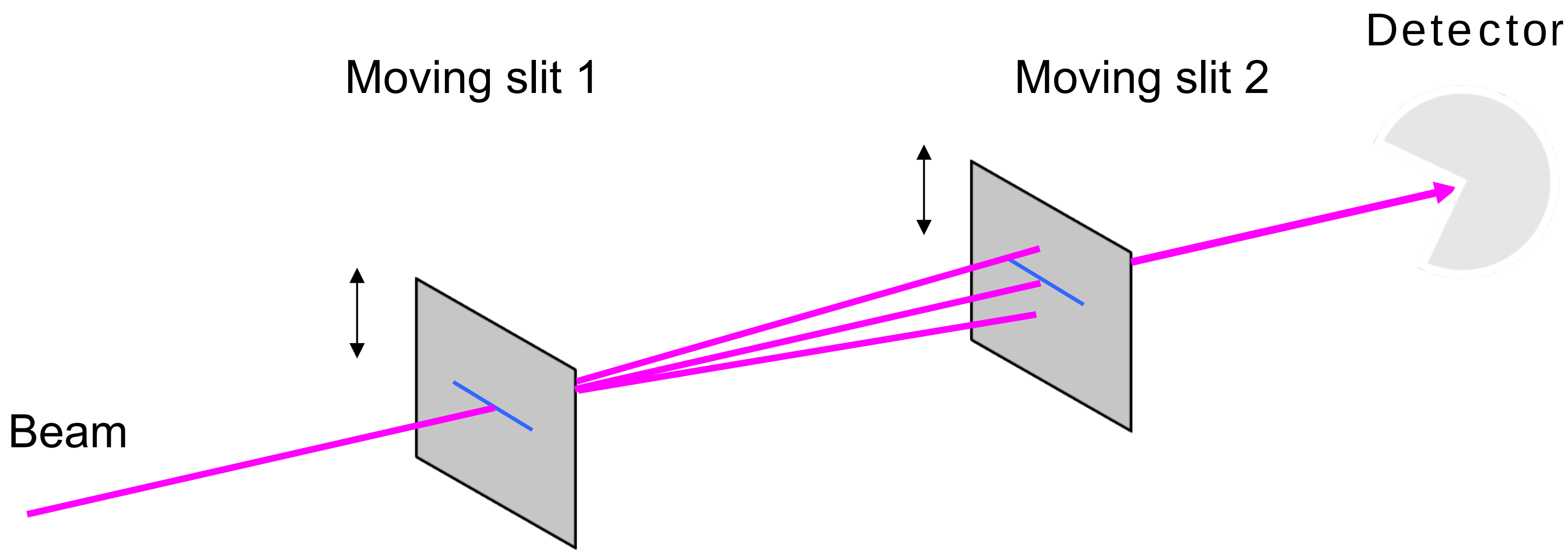
Frequency offset

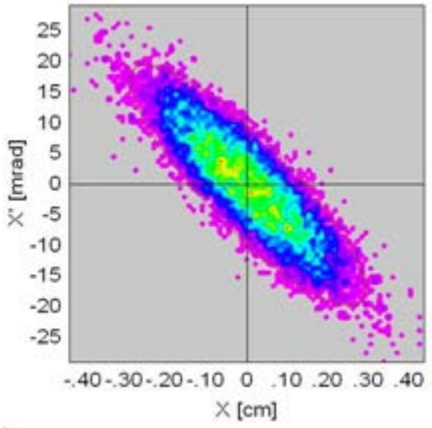


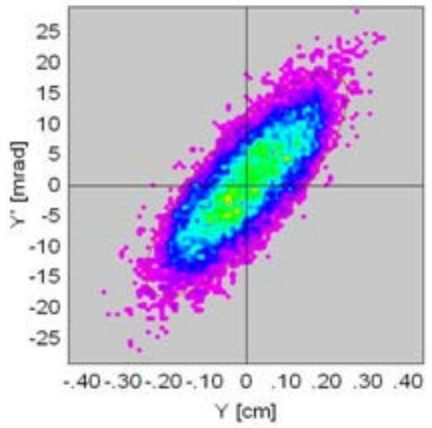
Phase Scan



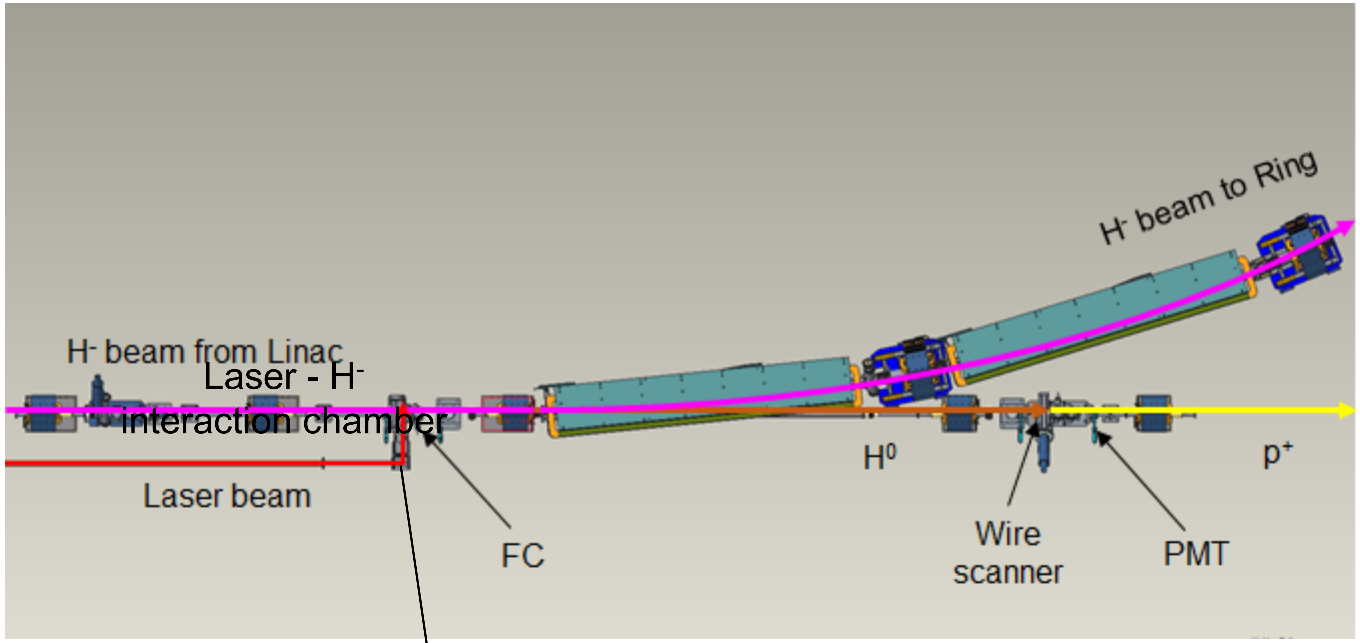
Schematic of emittance measuring system

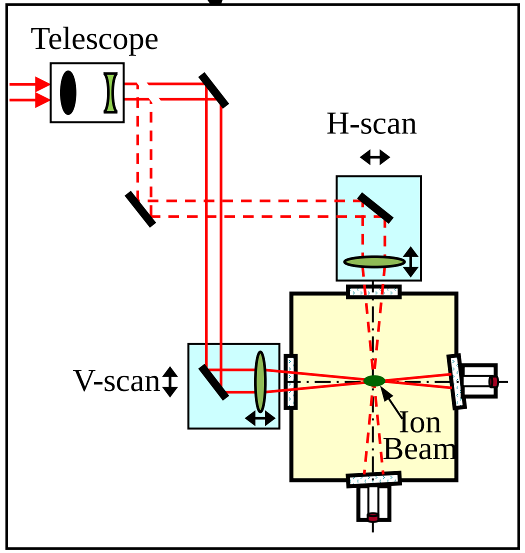


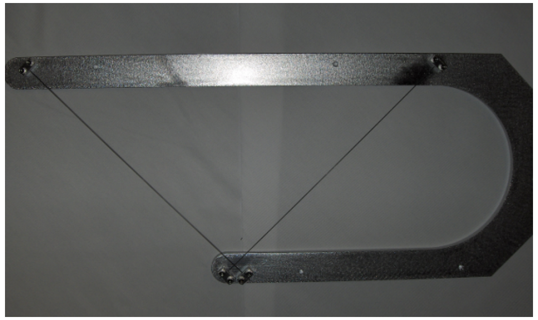


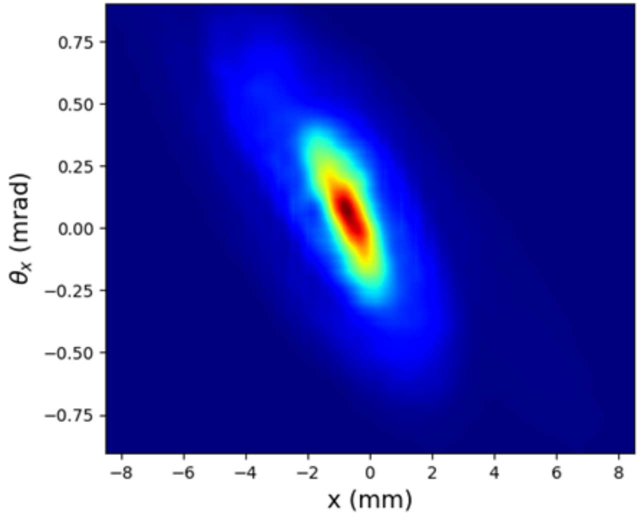


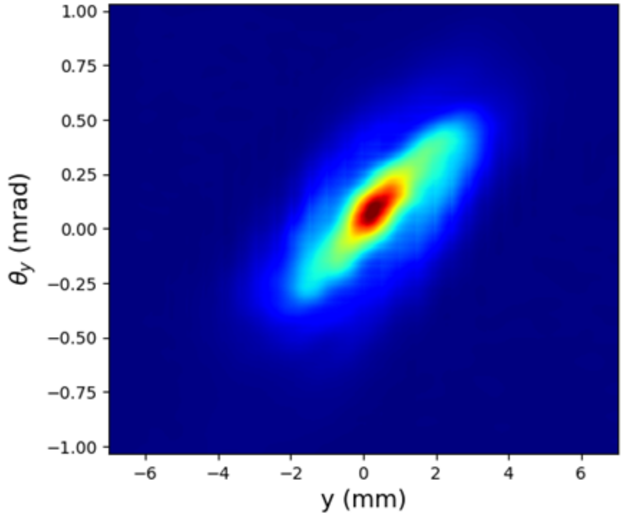
SNS Laser Emittance Scan Layout



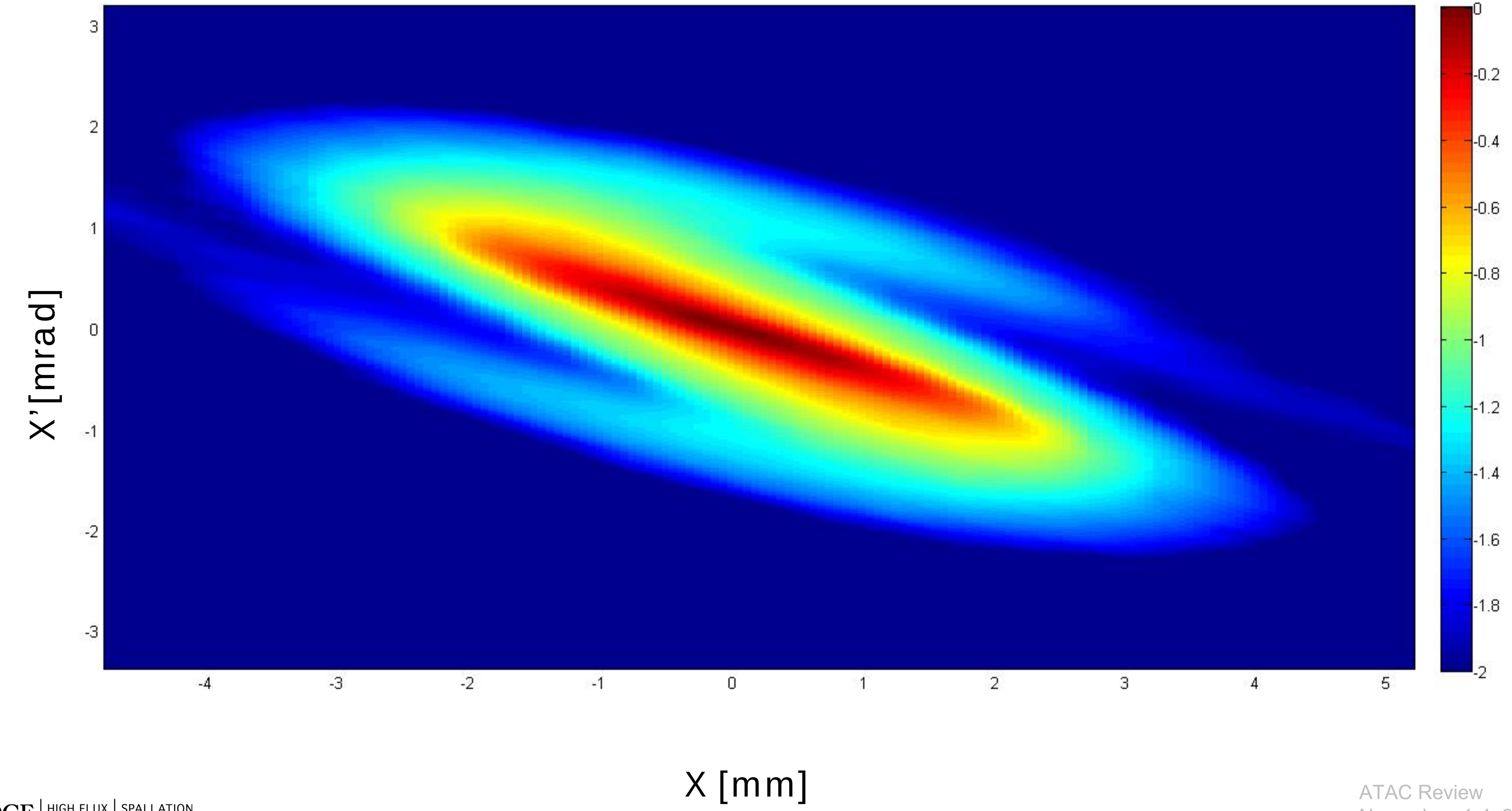




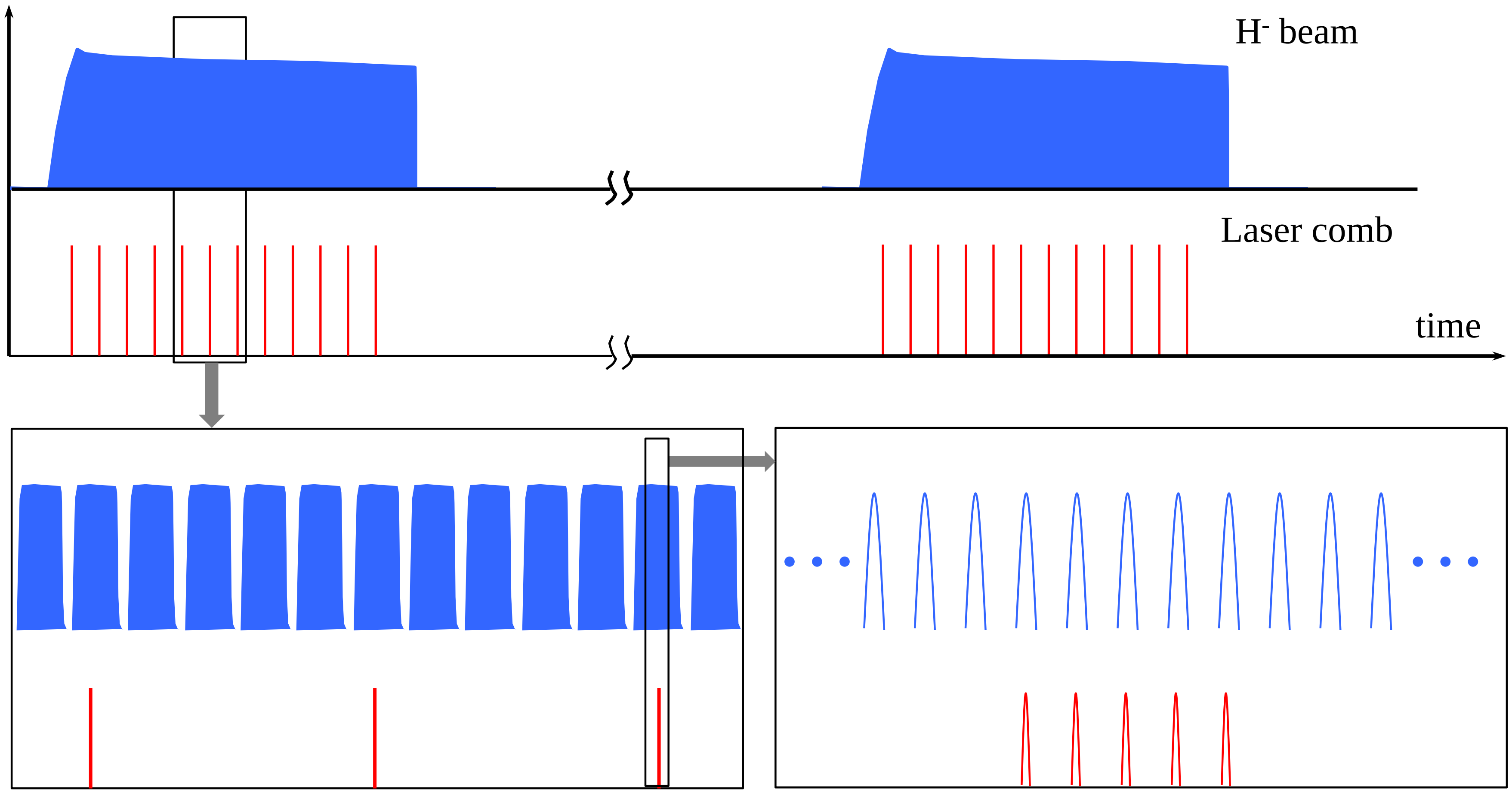




Horizontal x-x’ distribution (intensity in log scale)

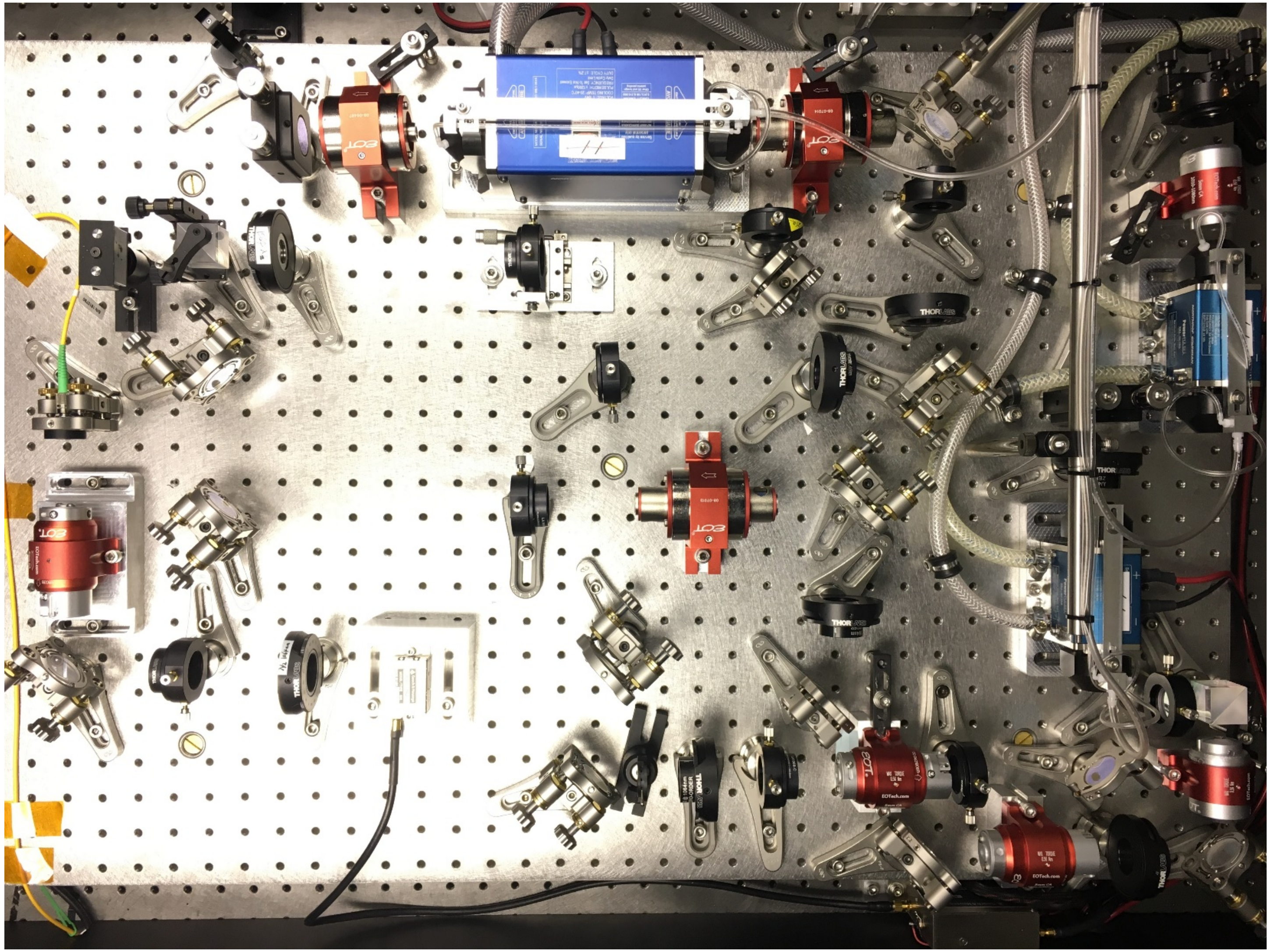


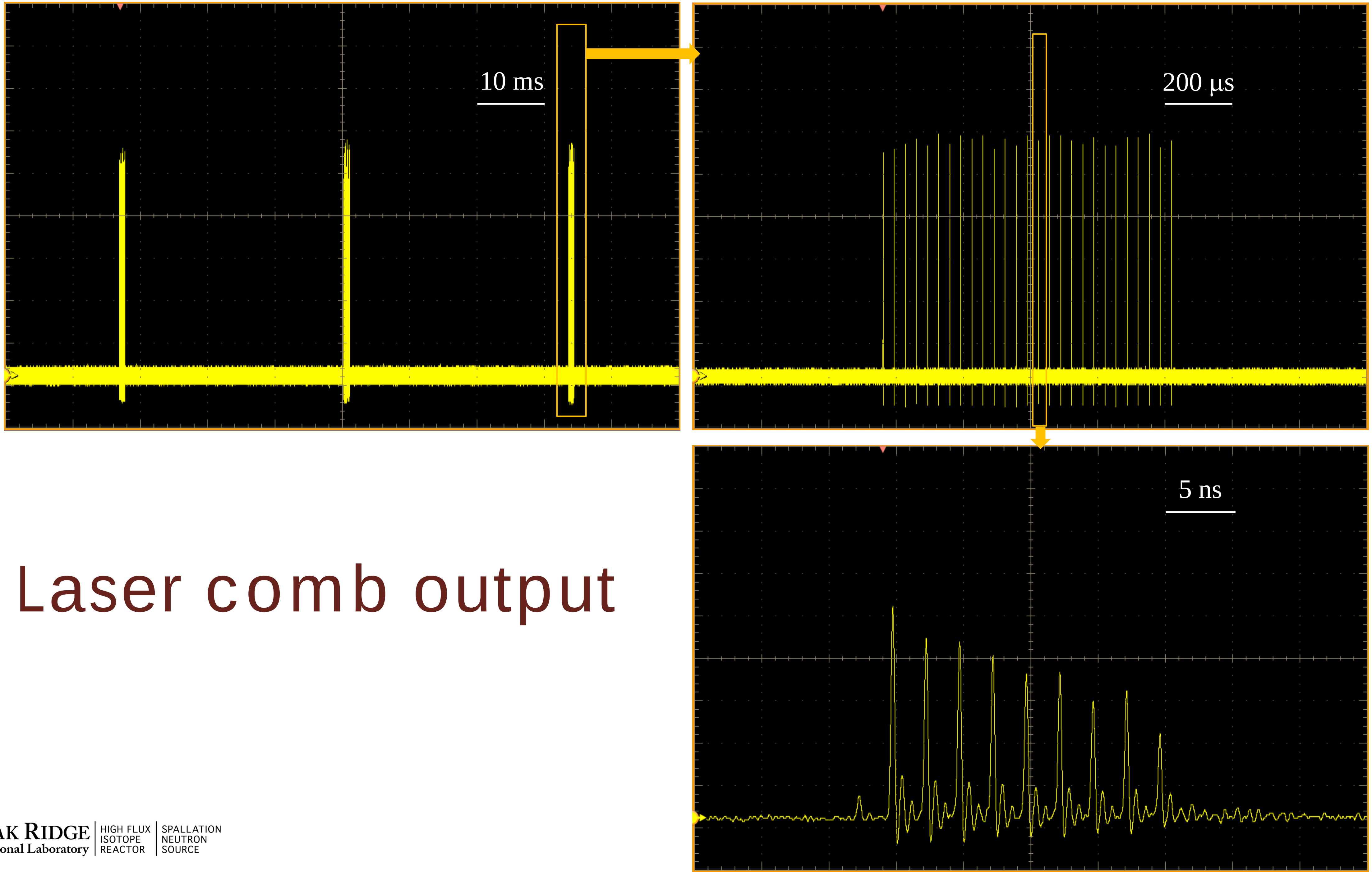
H^- beam diagnostics using a laser comb



Continuous development of light source with additional amplifier and pico-second pulsed seeder

New seeder: 9 ps (FWHM, vendor data), 13 ps (FWHM, in-house measurement)

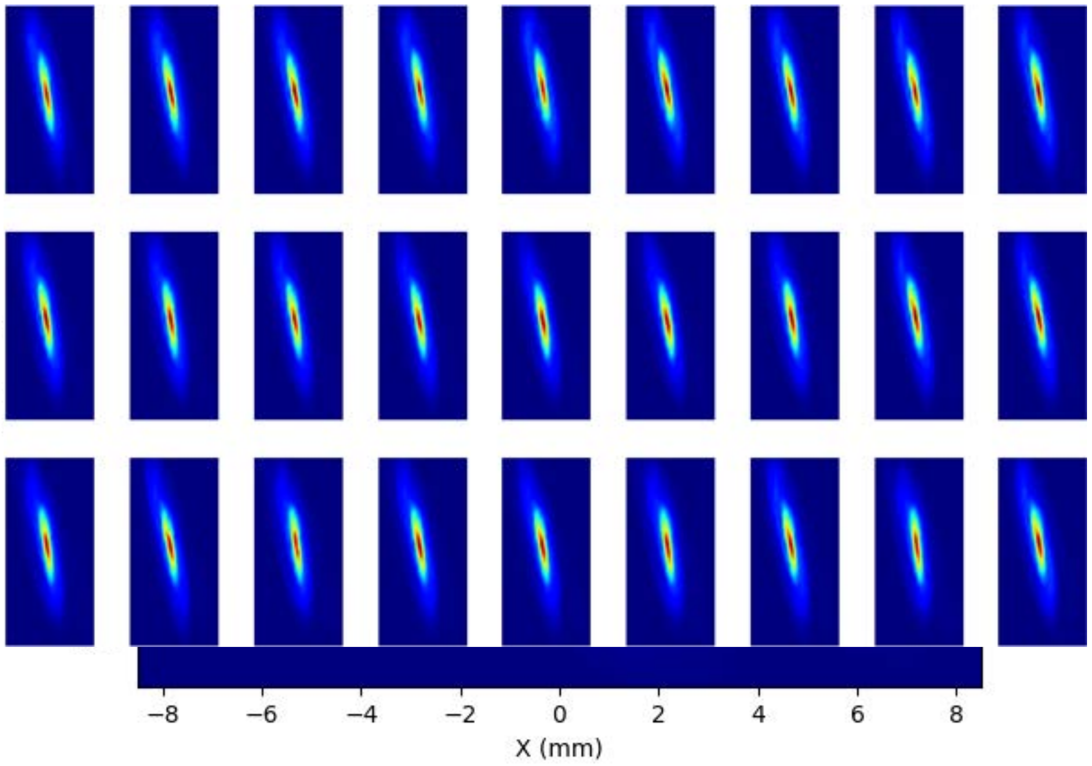




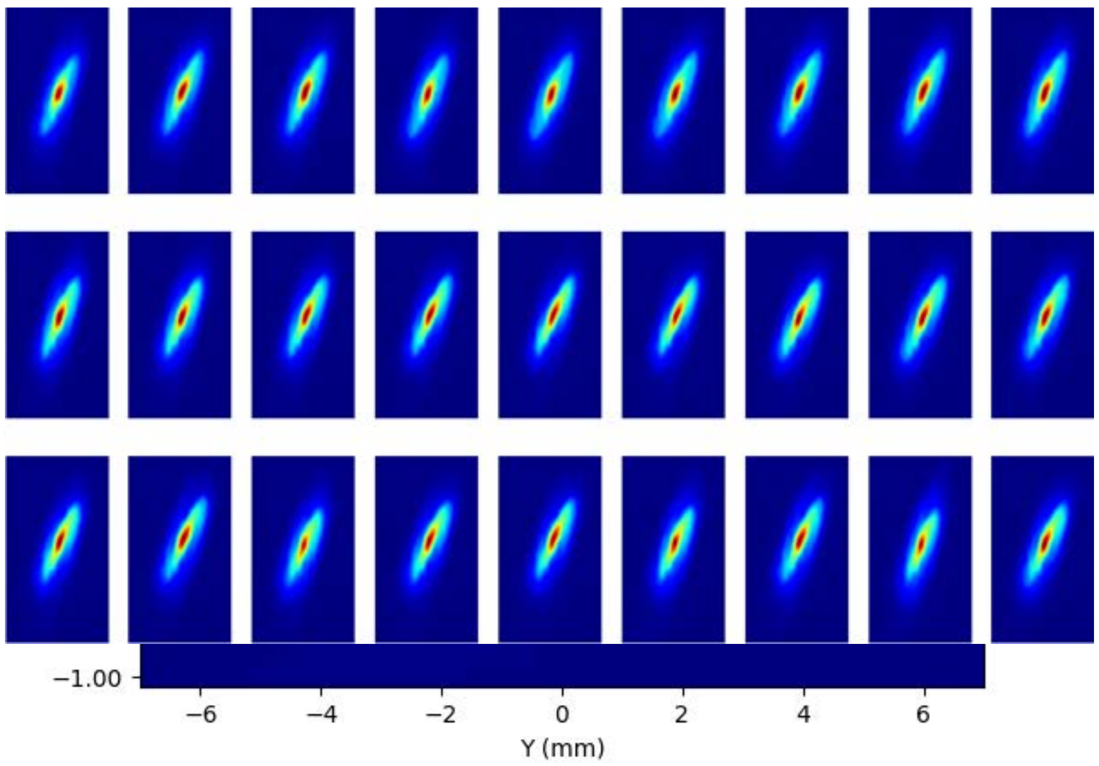
Laser comb output

Scan over H$^-$ beam macro-bunch (N_c = 27, T_s = 35us)

Horizontal



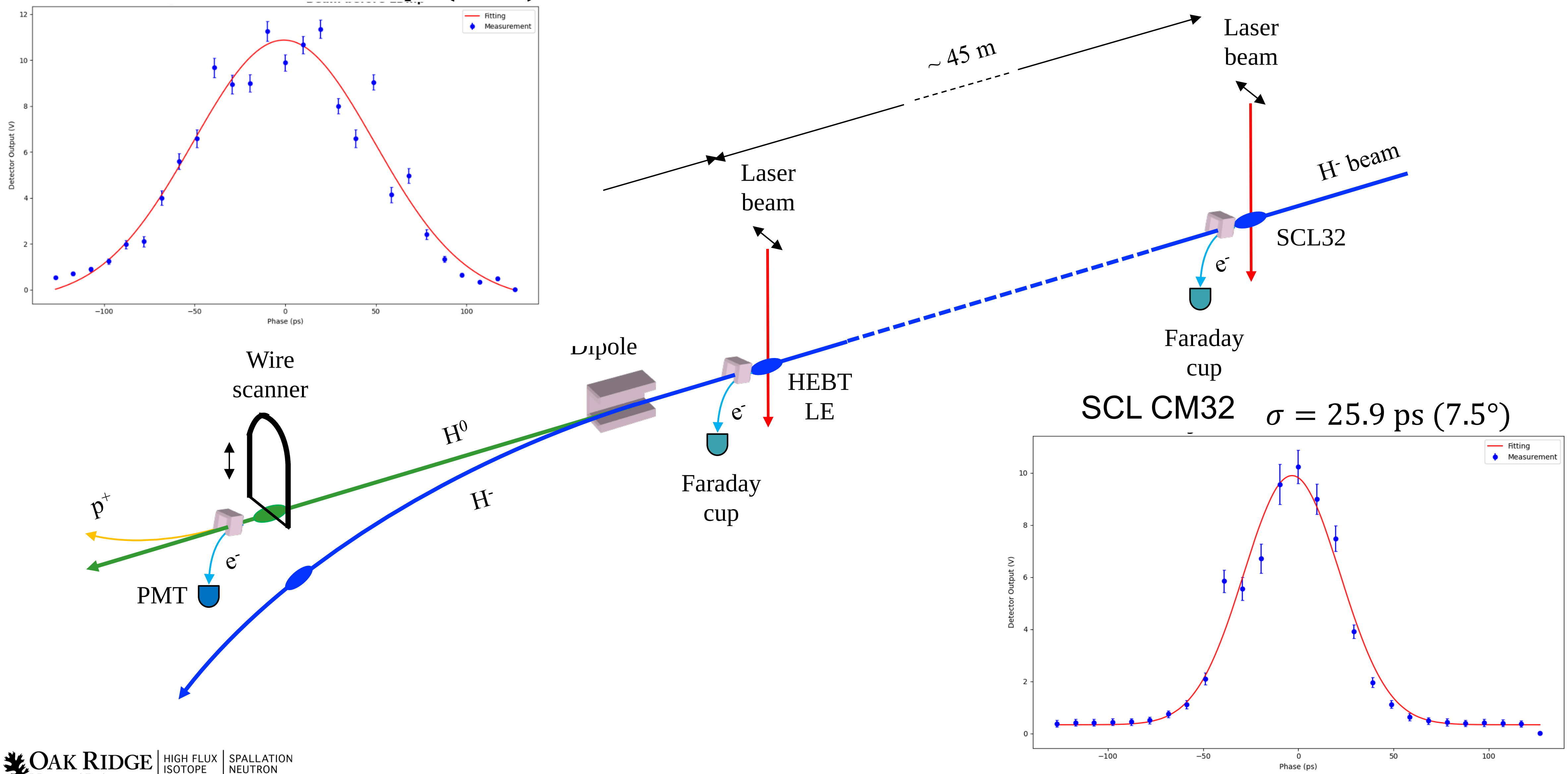
Vertical



Bunch shape and energy spread measurement

Linac Dump $\sigma = 62.6 \text{ ps } (17.2°)$

SCL CM32 $\sigma = 25.9 \text{ ps } (7.5°)$

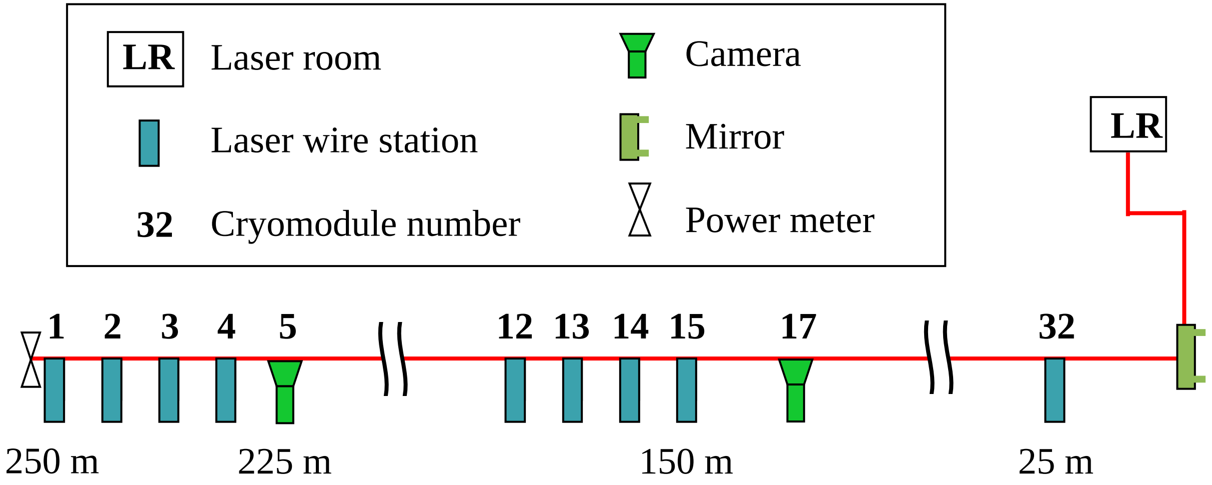


Beam energy calibration with lasers

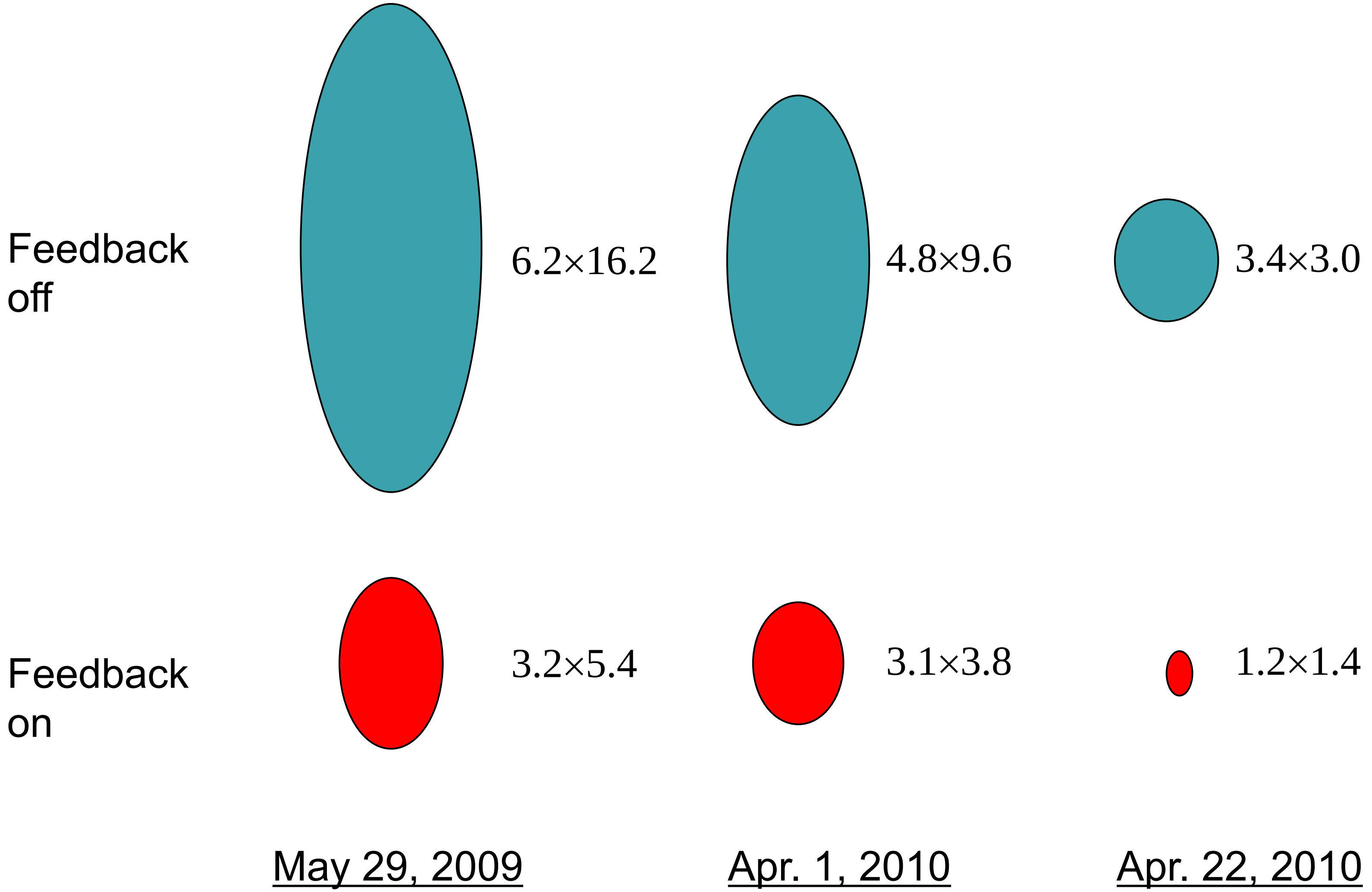
- Feshbach resonance
  - Photo - detachment to H0(n=2) +e-
- Hydrogen atom spectroscopy
  - Excitation between bound energy levels
  - Detection of level decay (luminescence)

Implementation challenges

- Laser beam delivery
  - Stability
  - Power density on vacuum windows
- Electron collection
- Measurement Dynamic Range

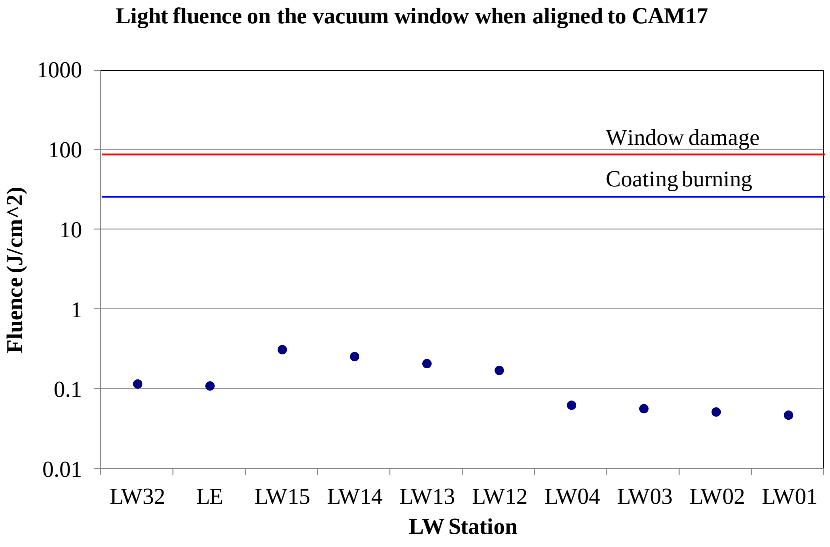


Laser pointing stability improvement

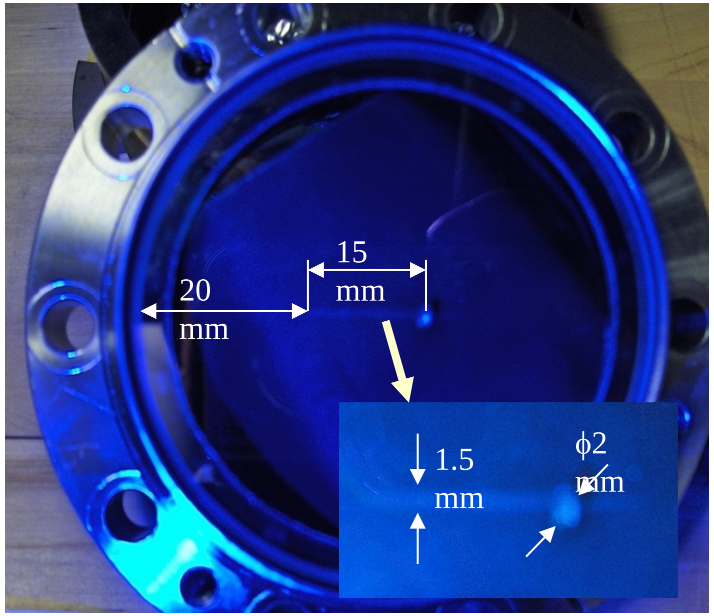


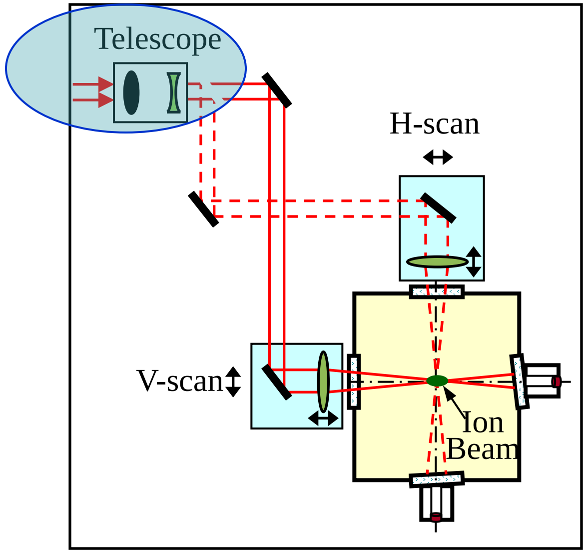
Laser power density on vacuum window is major design constraint

Maximum optical fluence on vacuum windows

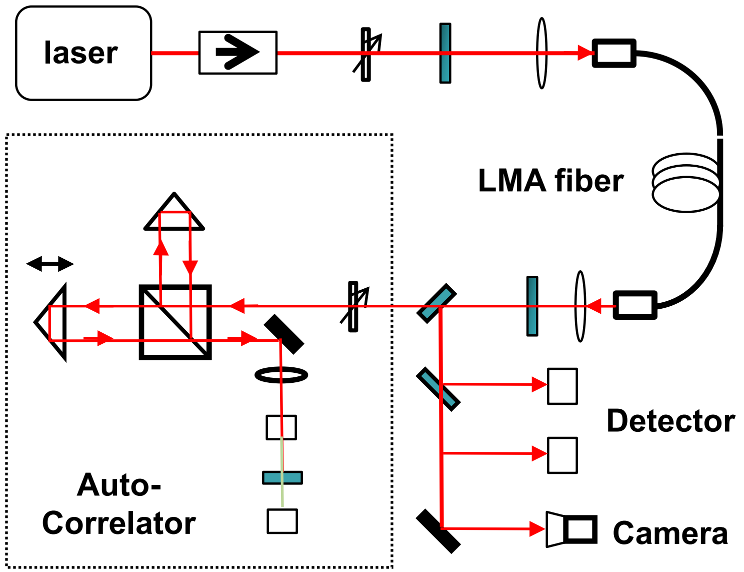


Cracks on the vacuum window

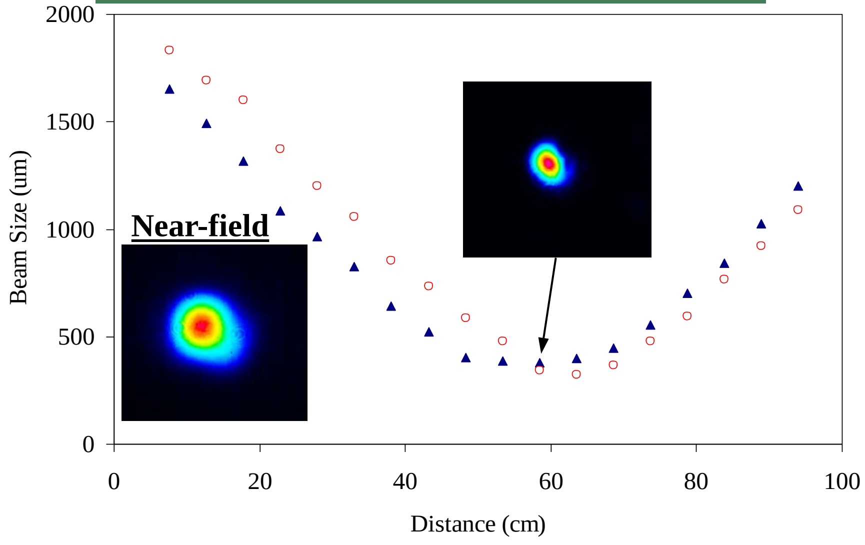




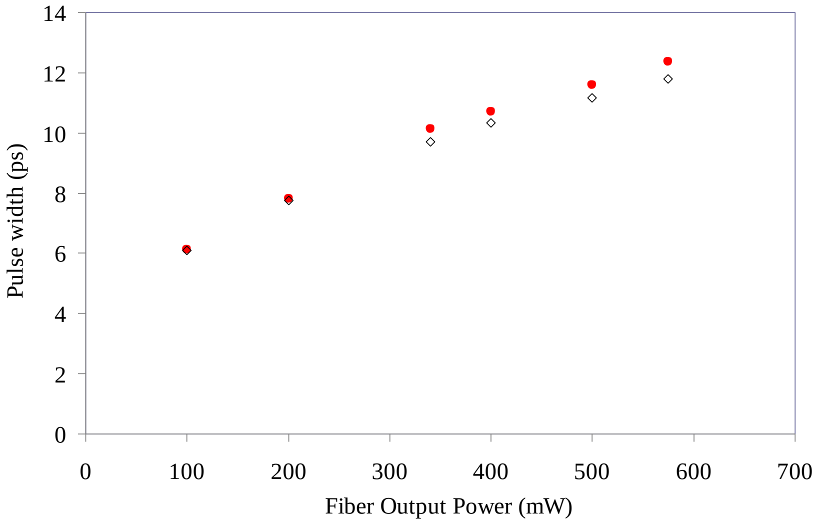
R&D Activity: Fiber Transmission of Picosecond Pulses



Beam profiles after fiber transmission

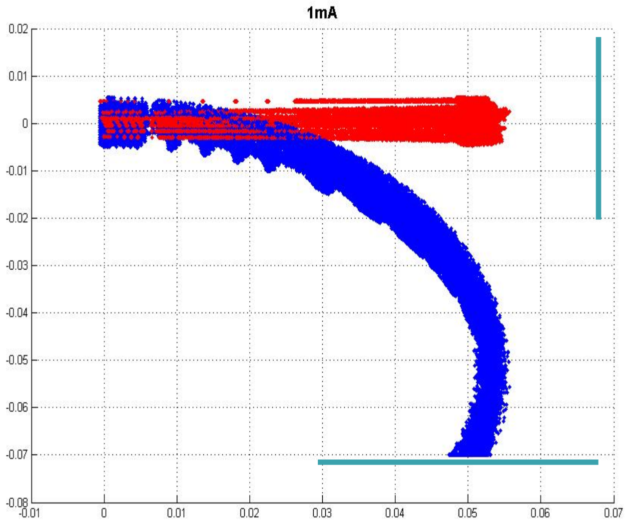


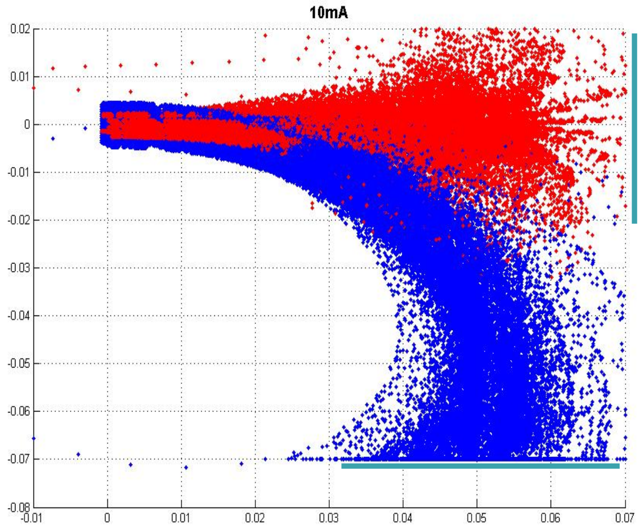
Pulse width broadening

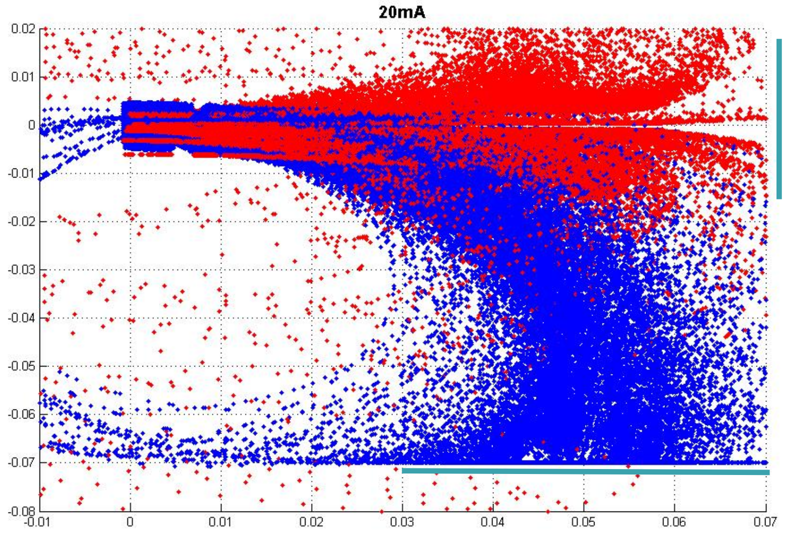


- **Optical fiber transmission has advantages of stability, easy maintenance, and safety**
- **A 100-ft large mode area (LMA) fiber was used to transmit picosecond KW laser pulses**
- **Beam profiles and pulse width variation are studied as a function of launching optics, fiber length, and transmission power**

Space charge effect on electron collection at 2.5MeV



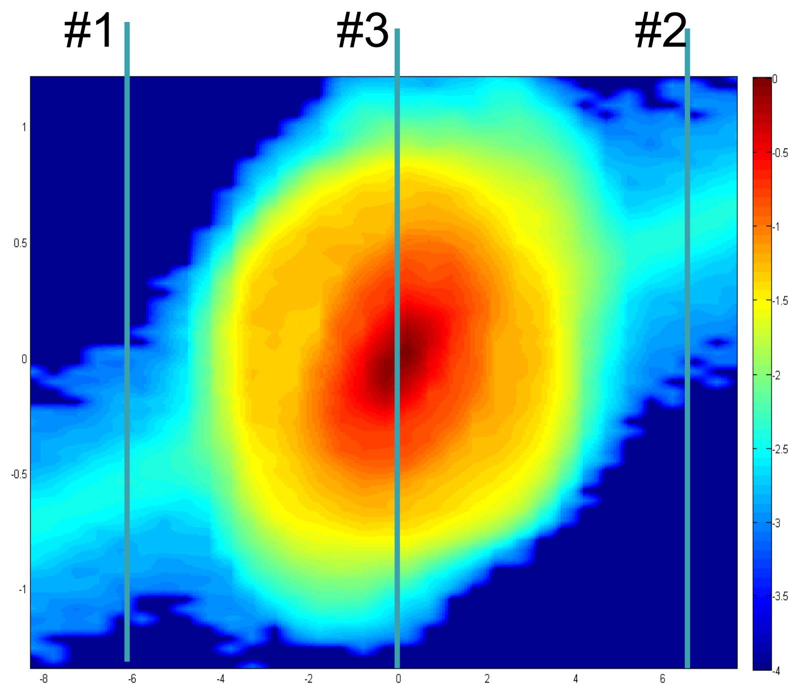


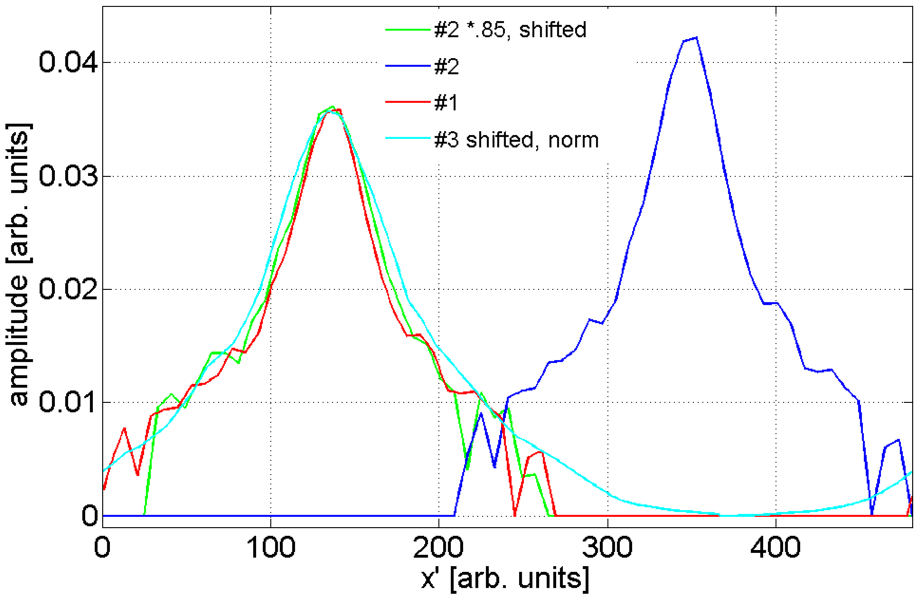


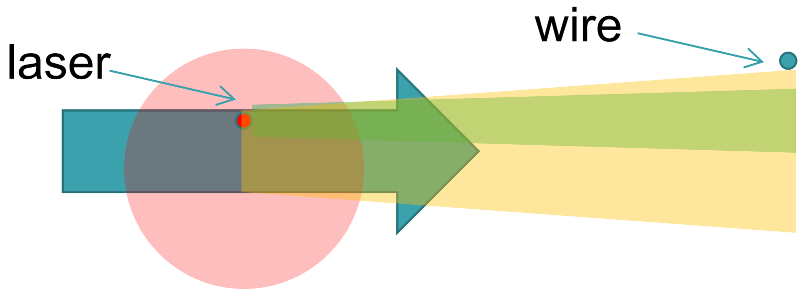
Simulated motion of stripped electrons in the collection system

Space charge at nominal current creates ~50% energy spread in addition to transverse deflection

High Dynamic Range Limits







Observation is fully consistent with presence of uniform stripping media near the IP.

Confirmed by simulations

Thank You for Attention!