Longitudinal Laser Wire for Project X/HINS

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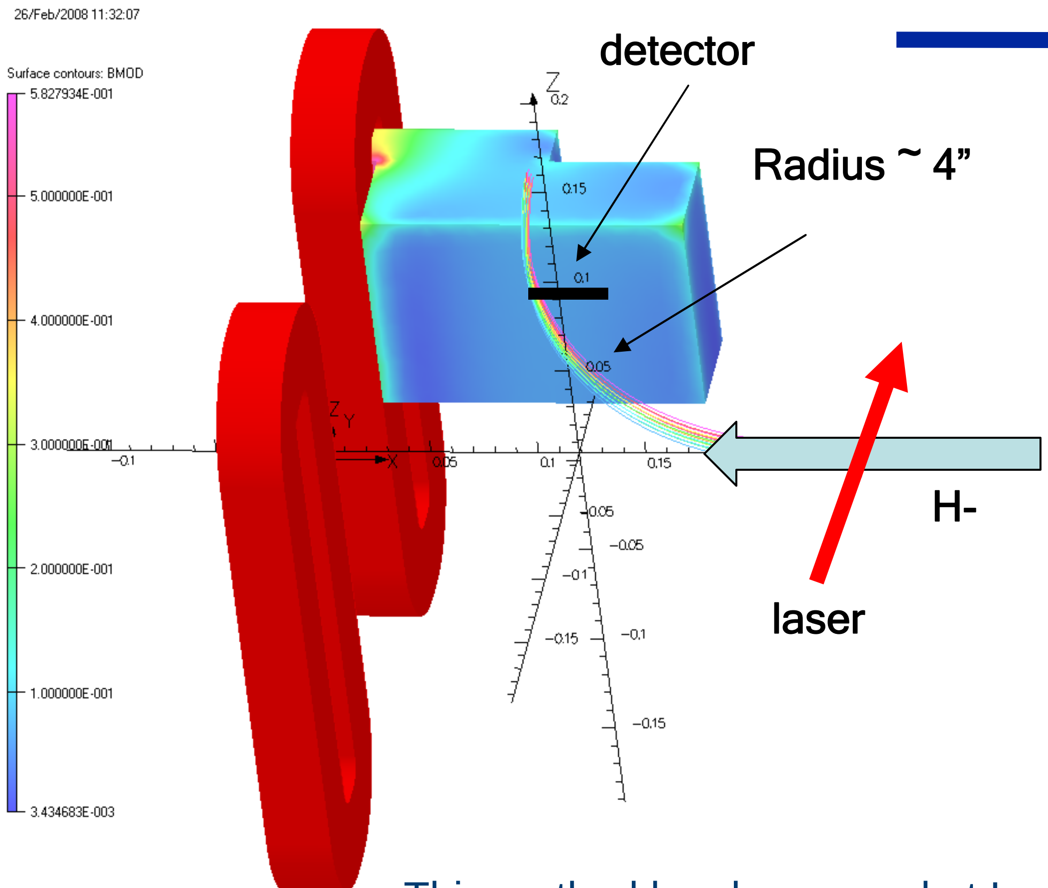
Overview

- Collaboration between LBNL and FNAL on laser wire diagnostics started in August 2009.
- Three main goals:
  - Explore feasibility of single fiber laser with fiber distribution to each station
  - Develop specific case of longitudinal laser wire.
  - Produce a report with findings (and hopefully continue collaboration!)

Laser Neutralization of H^-



- First ionization potential for H^- ions is 0.75eV
- Photons with λ<1500 nm can separate H^- ion into free electron and neutral H
- Deflect and detect low energy electrons

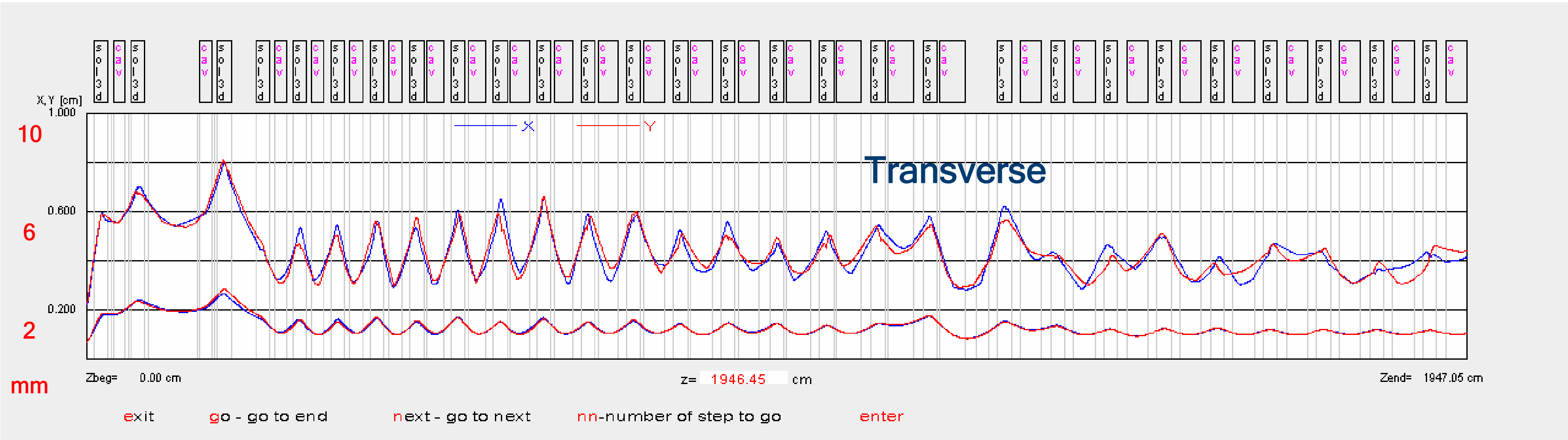
This method has been used at Los Alamos for transverse and longitudinal emittance measurements

Routinely used in SNS for measurement of transverse beam profiles

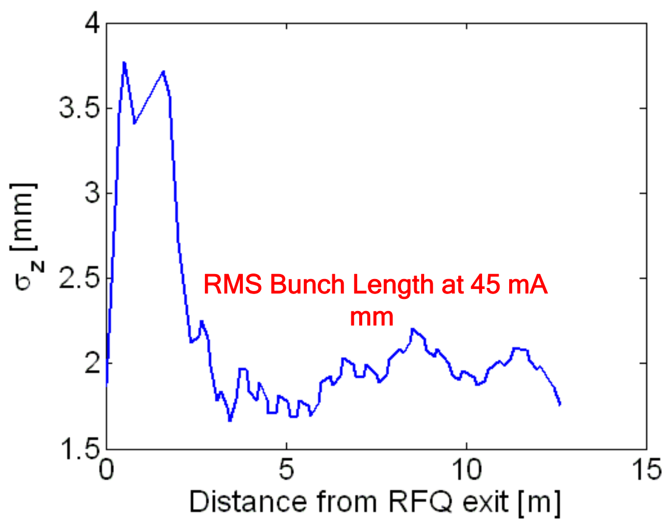
HINS Parameters

	Proton Driver Phase 1 Design	Proton Driver Phase 2 Design	HINS capability	Project X Design	
Particle	H-	H-	H+ then H-	H-	
Nominal Bunch Frequency/Spacing	325 3.1	325 3.1	325 3.1	325 3.1	MHz nsec
Particles per Pulse	15.6	15.6	37.5 *	5.6	E13
Pulse Length	3	1	3/1	1	msec
Average Pulse Current	8.3	25	~20	9	mA
Pulse Rep. Rate	2.5	10	2.5/10	5	Hz
Chopping -6% @ 89KHz and 33% @ 53MHz	37.5%	37.5%	0 - 37.5%	37.5%	
Bunch Current	13.3	39.8	32	14.3	mA
Bunch Intensity	2.5 41	7.6 122	6.1 98	2.7 ** 44	E8 pCoul

HINS Beam Sizes



At 2.5 MeV,
RMS transverse beam size 2 mm
RMS bunch length 3.5 mm



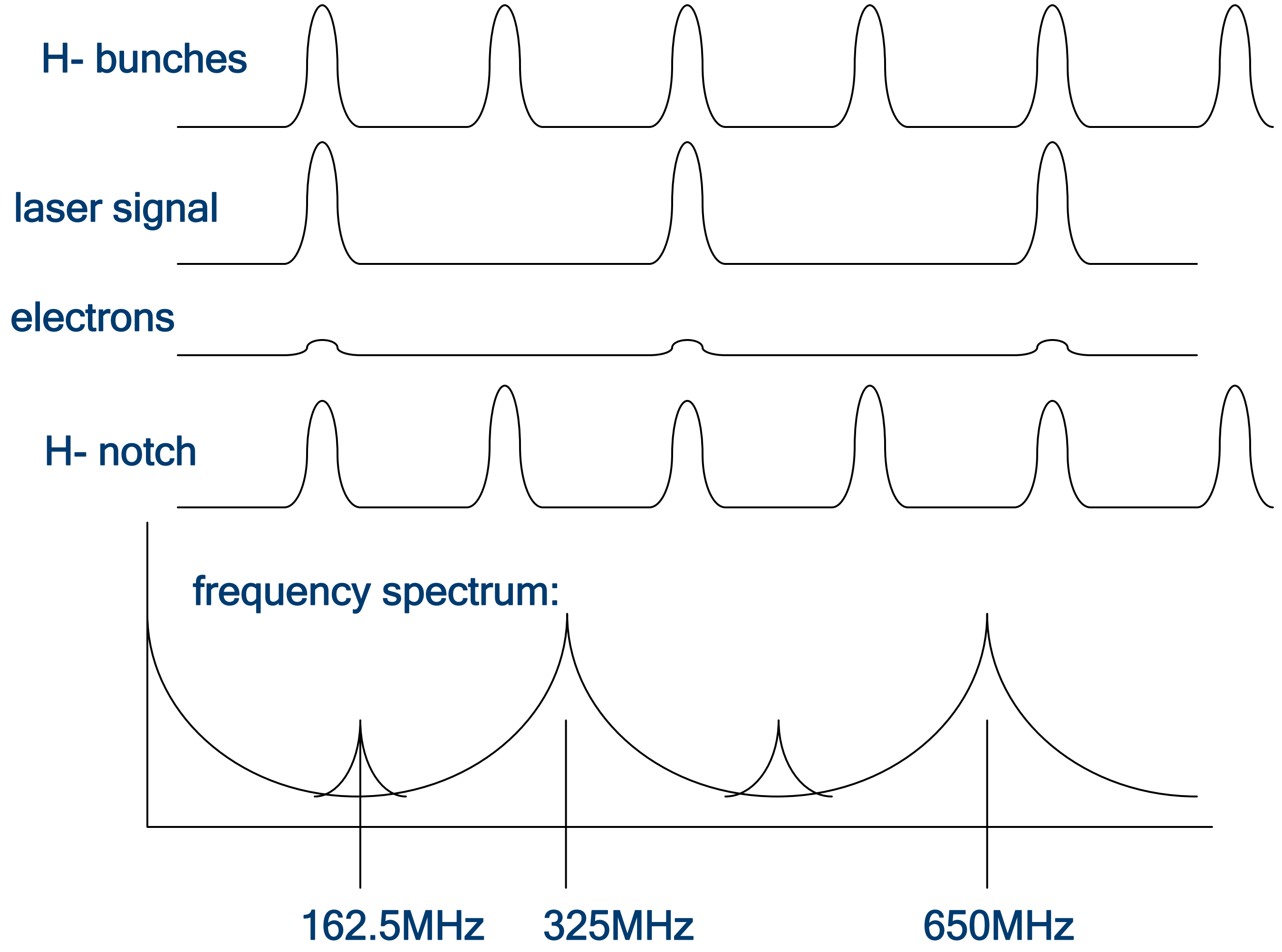
Laser Design Considerations

- Need to minimize required laser power for a given signal-to noise ratio
  - Reduce Laser power
    - Lower cost, more reliable
    - Higher power lasers break more often
- Produce continuous train of pulses
  - Lower peak power reduces damage, enables fiber delivery
  - Continuous signal allows fast scans, even within 1ms pulse
- Possible fiber delivery of laser to diagnostic
  - Easier to maintain alignment
  - Laser can be far from radiation
  - One laser can be used for multiple stations

Laser Design Considerations (2)

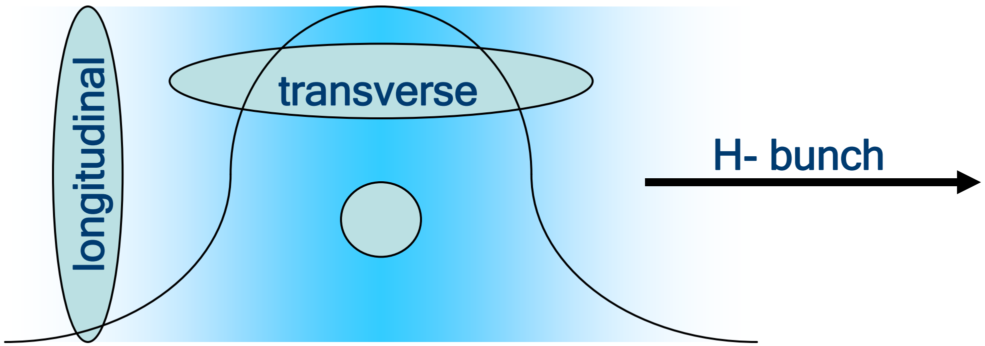
- Use synchronous detection to locate signal in low noise area
  - Modulation of signal can be simply a lower rep rate for laser or an amplitude modulation
  - Demodulate signal at detector, filter out background signal
- Main question: what is the background signal?
  - Experiments with fast detectors are needed
  - Estimates of background signal, from gas stripping etc.

Every other bunch is hit, for ~1ms



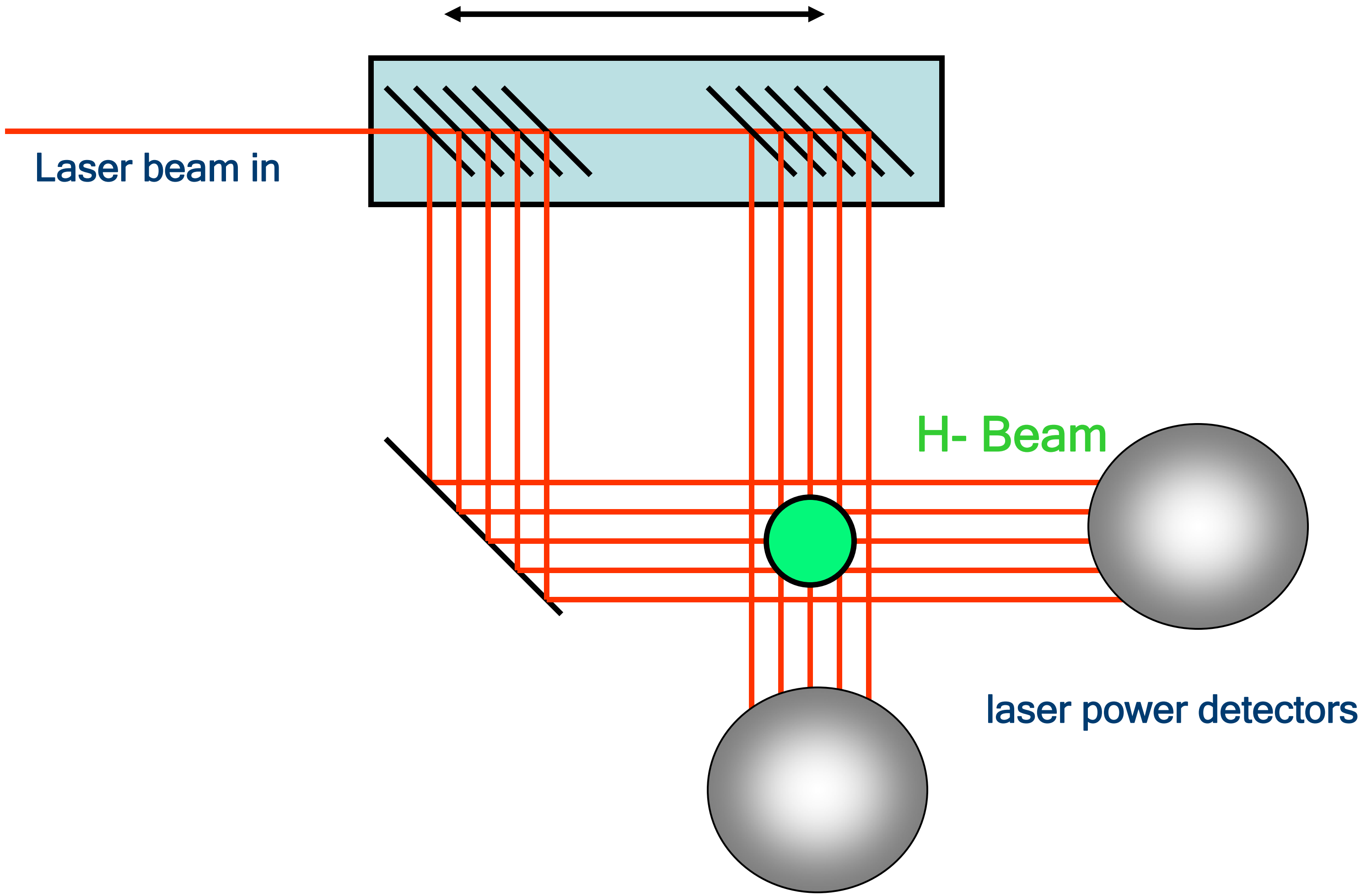
- Laser rep rate can be modulated to appear at lowest noise area, once it's found

Beam shape options



- Longitudinal is short pulse, sampling entire cross-section
  - Must have narrow horizontal diameter as well as in time
- Two transverse options
  - short pulse with wide horizontal diameter, narrow vertical
  - long pulse with small or wide horizontal diameter, narrow vertical
- Longer pulse has smaller peak power for lower nonlinearity

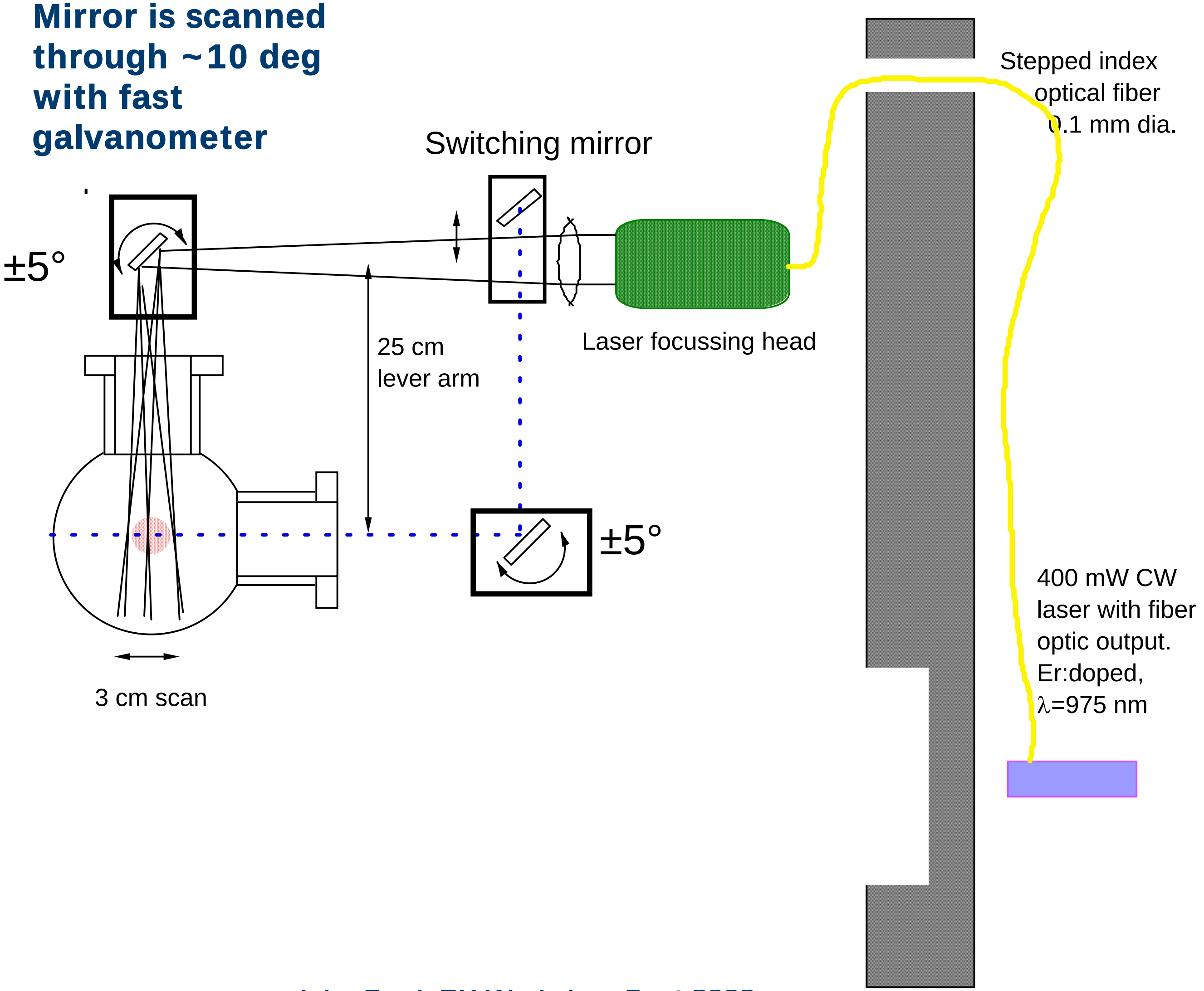
A slow scanning option



- Alternate method is fast scanning mirrors on each axis

Transverse Scanning

Mirror is scanned through ~10 deg with fast galvanometer

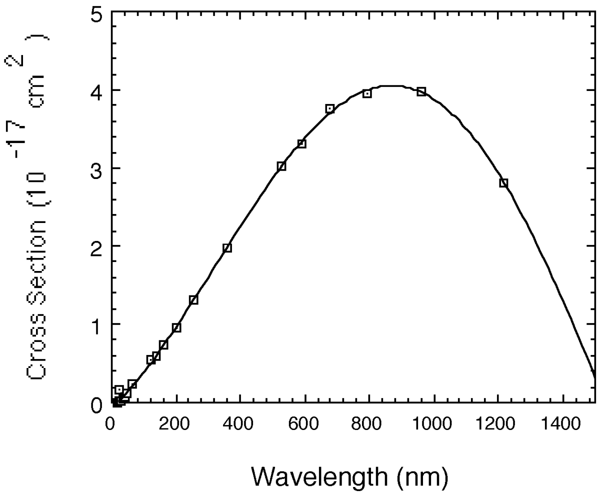


Laser Ionization

Photo detached ions

$$N_{PD} \ll N_{i,Volume}, \quad N_{PD} = \frac{I_b N_L}{\sqrt{2\pi} e \beta c} \frac{1-\beta \cos\theta}{\sin\theta} \frac{\sigma_d(E_{cm})}{\sqrt{2}\sigma_b}$$

- where
  - σ_b = laser size
  - σ_d = photodetachment cross section
  - N_L = n. of photons in laser pulse
  - θ = Laser incident angle



- Laser optics can help maximizing efficiency
- Mode locked 1-10 MW low DF class laser are commercially available and should yield enough ionization for a good reading

Finding small signals

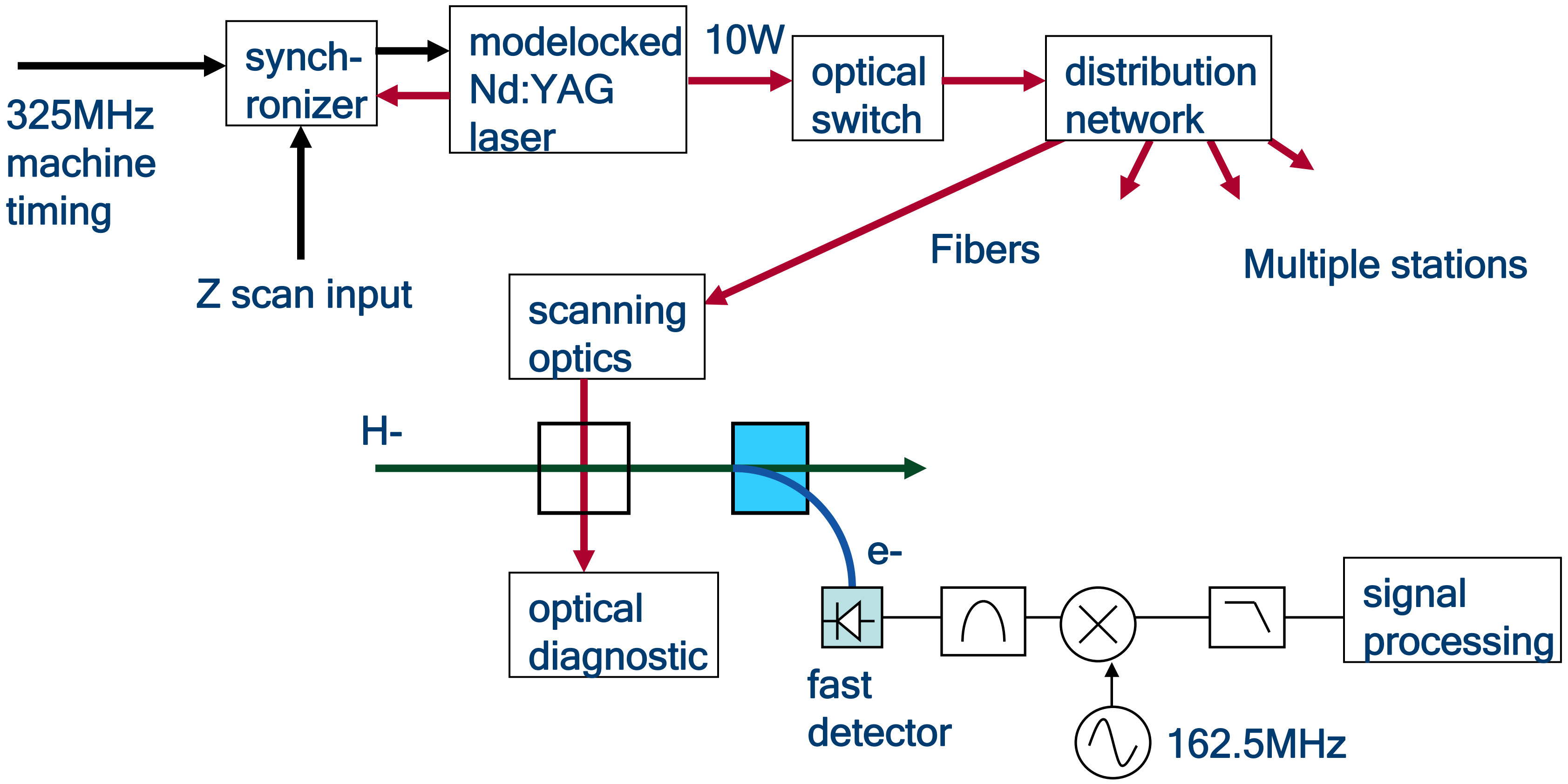
With relatively low laser power (mode-locked fiber laser), a relatively low signal is expected.
Example: for 3 psec 50 microJ/pulse yields about 2.5e14 photons/pulse.
For HINS parameters:
T=2.5 MeV, N=6e8

Signal is ~1e6 electrons/pulse at bunch peak. Lower as the laser probes the tails.

For such a low signal, it may be useful to use lock-in techniques. For example, the laser pulses can be amplitude modulated and the signal can be detected at the modulation frequency. This would allow detection at the lowest noise frequency response. Commercial lock-in techniques available up to several hundred MHz.

Lock-In Amplifier *SR844 – 200 MHz RF lock-in amplifier*

Block diagram of scanning system



- Signal analysis is analog, digital or combination
- Longitudinal scanning is done by adjusting synchronizer

Backgrounds

- H- stripping happens naturally due to three effects
  - Ion Gas interaction
  - Black body radiation
  - Magnetic fields
- The expected contribution from gas stripping is dominant and can cause a substantial background level
  - Time gating is an option to reduce background levels during the measurement
- Electron clouds
  - Bias detector
- RF background
  - Beam signal
    - Must have excellent RF screening of beam signal within beam pipe
    - Signal cables

Plan

- Goals
  - Understand minimum laser pulse energy and rep rate (i.e. power) for acceptable S/N
    - Study frequency dependence of backgrounds
    - Explore lock-in techniques
  - Understand maximum laser pulse energy and laser peak power that can be transmitted over 50-100 m of fiber.
  - Determine measurement bandwidth
  - Explore techniques for measuring tails
    - Very low signal expected
    - Counting techniques probably needed
    - Separate detection scheme?
- Schedule
  - Oct 09, determine laser power capabilities over fiber
  - Nov 09, visit SNS for background study
  - Dec. 09, determine expected S/N for HINS.
  - Jan 09, deliver report.