Laser Based Beam Instrumentation

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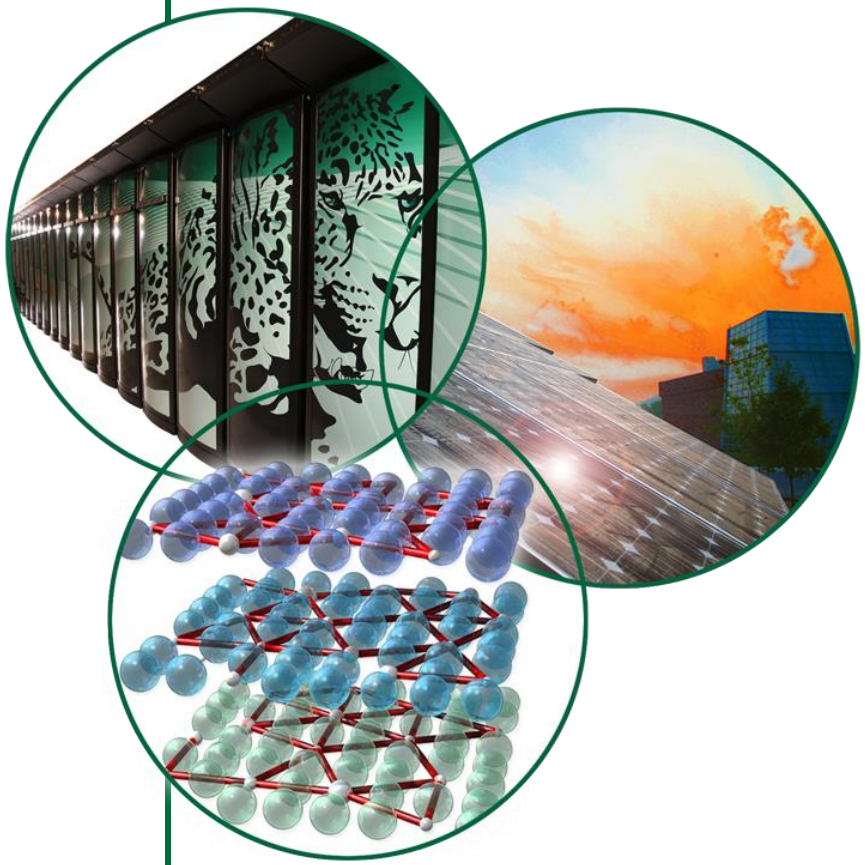
Beam Instrumentation Team



Accelerator Advisory Committee

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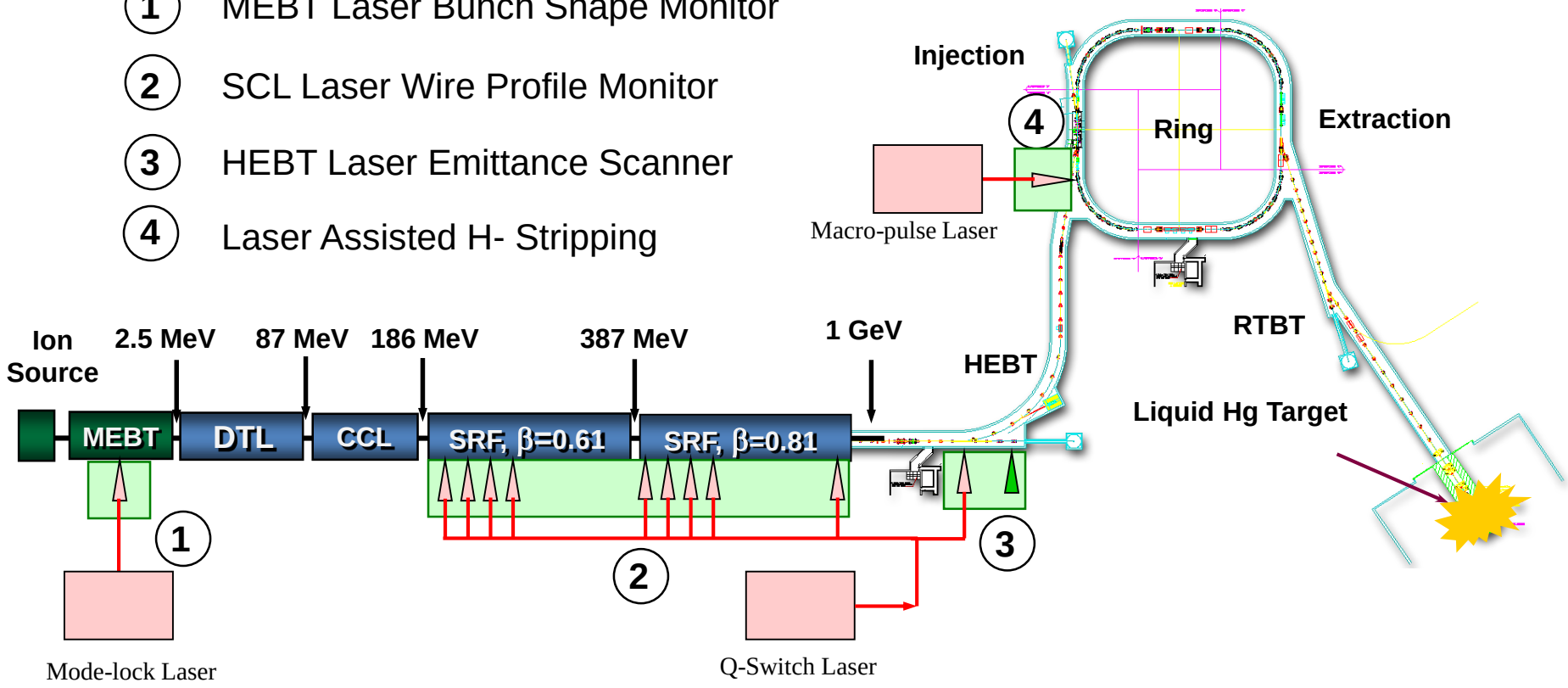
U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

Laser Based Beam Instrumentation at the SNS Accelerator Complex

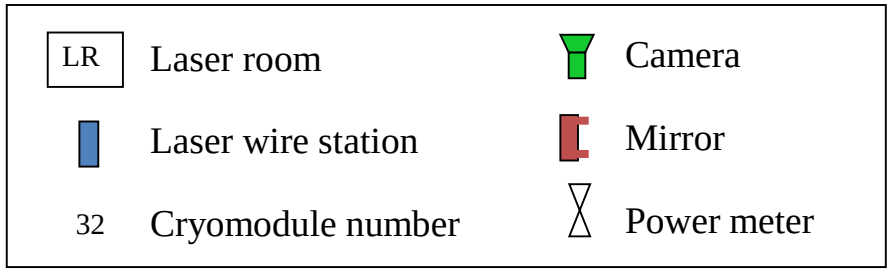
1. MEBT Laser Bunch Shape Monitor
2. SCL Laser Wire Profile Monitor
3. HEBT Laser Emittance Scanner
4. Laser Assisted H- Stripping

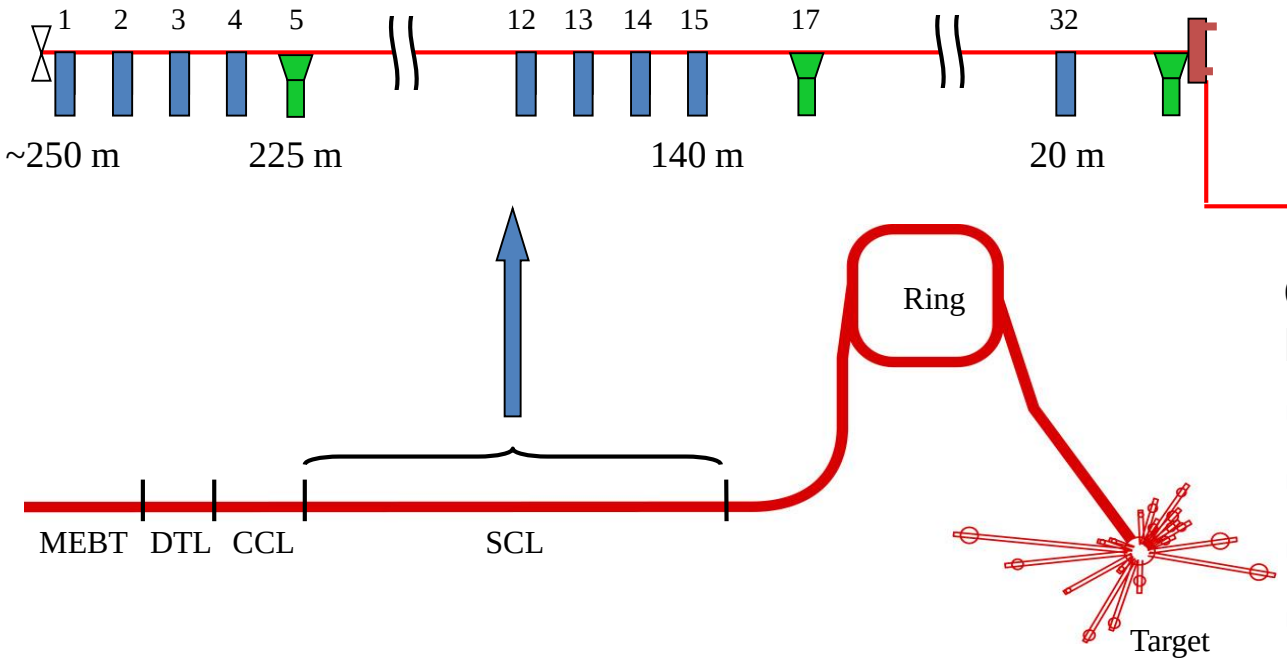


SCL Laser Wire Profile Monitors

Total of 9 laser wire stations commissioned

- **4 LWs from 200 MeV**
- **4 LWs from 450 MeV**
- **1 LW at 1 GeV**

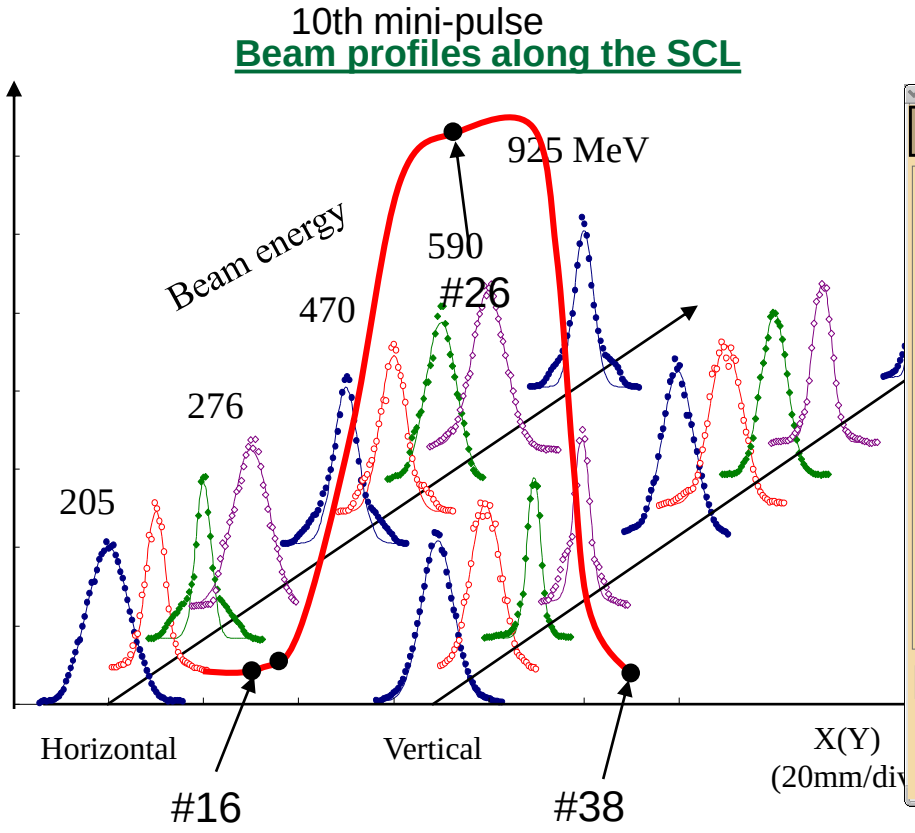




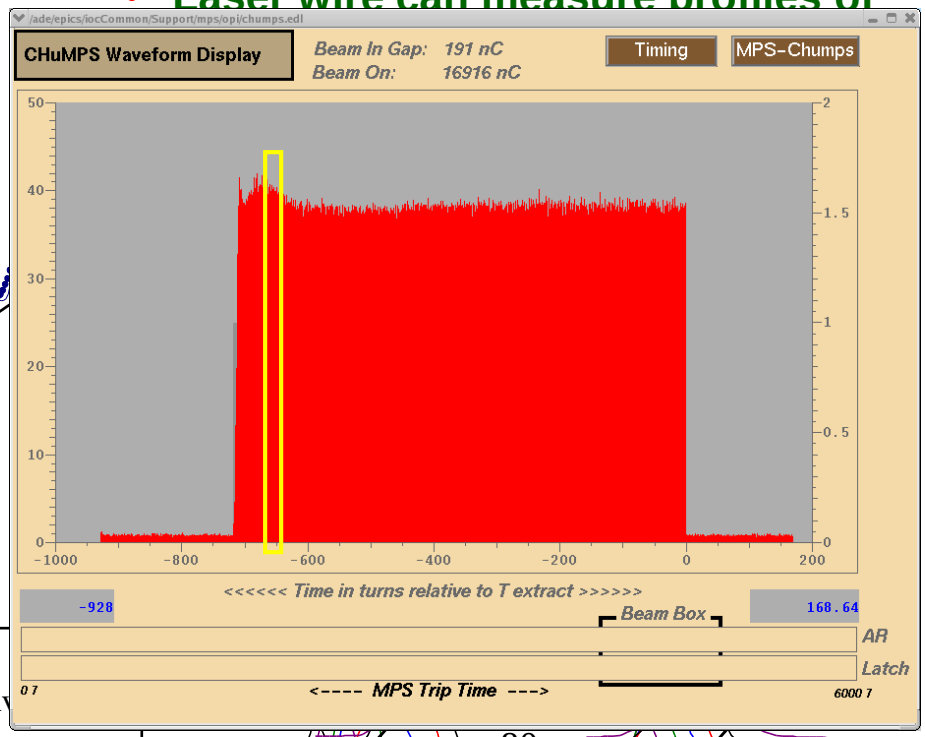
Q-switched Nd:YAG Laser

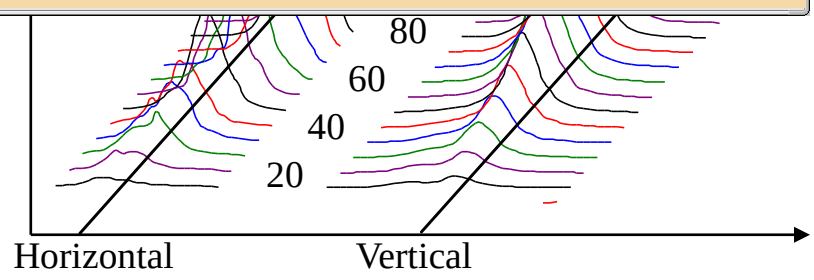
- λ = 1.06 μm
- f_{rep} = 30 Hz,
- T_w = 7 ns
- E_p = 1 J

Laser Wire Measurement Performance



- Laser wire can measure profiles of





- **Measurements can be conducted parasitically during neutron production**

Laser-beam interaction location (unit: sub-rev turn, ~30 ns)

Recent Progress

- Simultaneous profile scans can be performed at multiple stations
- EPICS software developed to make laser wire measurement operation more convenient
- User can measure profiles at any single or a group of locations by simple clicks

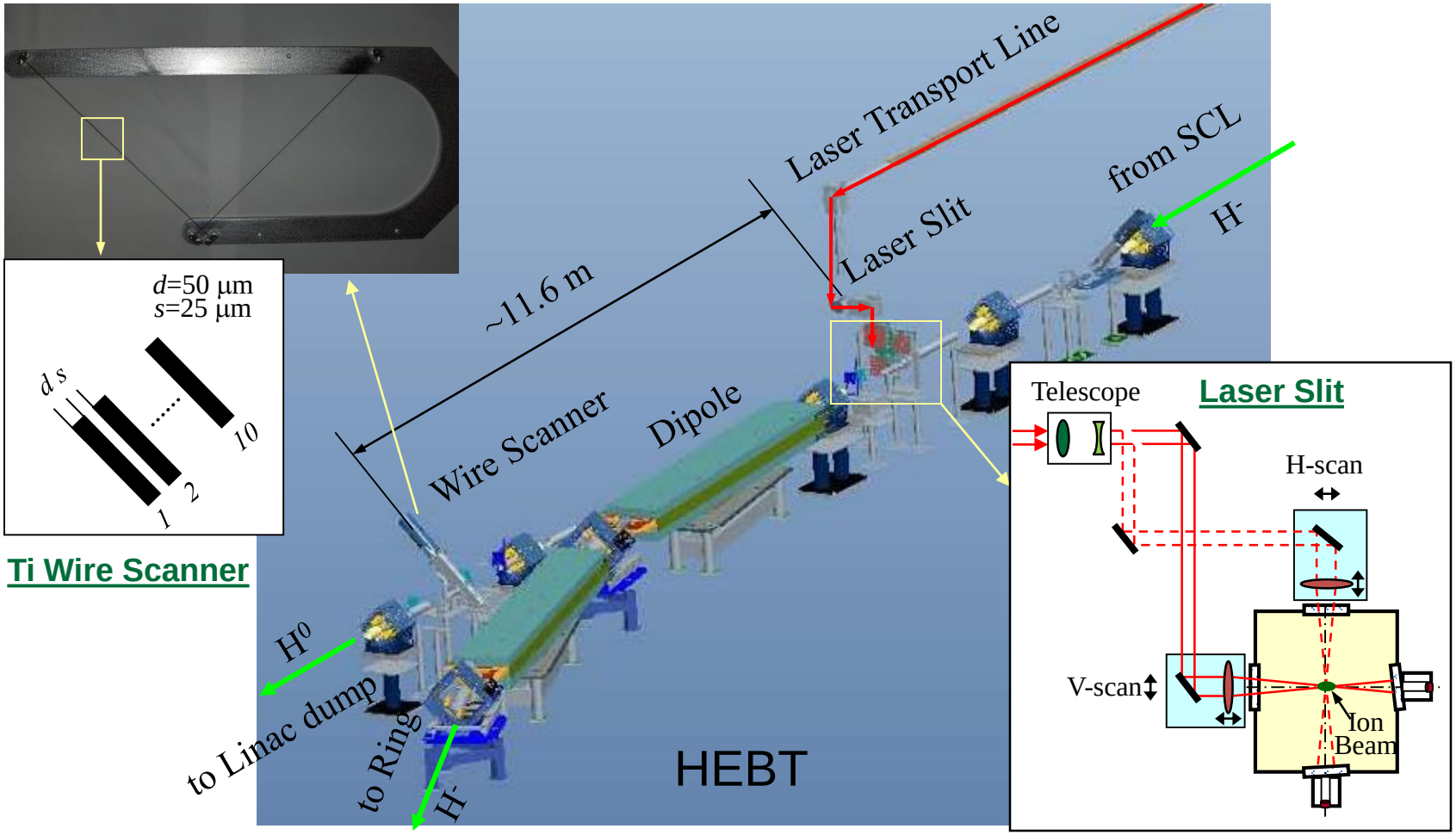
From EPICS, user can select one, multiple, or all scanners

Laser Wire Transfer Line

Label	Description	Retract	mm	Insert	Command		
LW_01	Station 01		-0.037		Rtn Lim	Set Pt	Ins Lim
LW_02	Station 02		0.042		Rtn Lim	Set Pt	Ins Lim
LW_03	Station 03		-0.058		Rtn Lim	Set Pt	Ins Lim
LW_04	Station 04		0.138		Rtn Lim	Set Pt	Ins Lim
LW_12	Station 12		-0.016		Rtn Lim	Set Pt	Ins Lim
LW_13	Station 13		0.069		Rtn Lim	Set Pt	Ins Lim
LW_14	Station 14		-0.021		Rtn Lim	Set Pt	Ins Lim
LW_15	Station 15		-0.016		Rtn Lim	Set Pt	Ins Lim
LW_32	Station 32		0.021		Rtn Lim	Set Pt	Ins Lim
LW_EMIT	Beam Block		0.000		Rtn Lim	Set Pt	Ins Lim

LW1 LW2 LW3 LW4

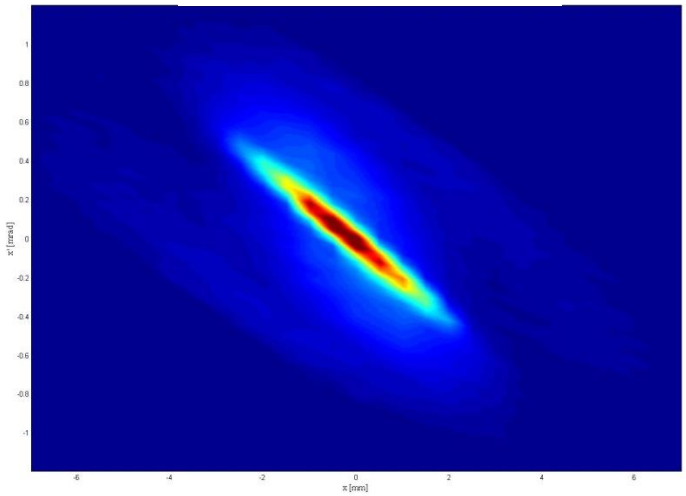
HEBT Laser Emittance Scanner



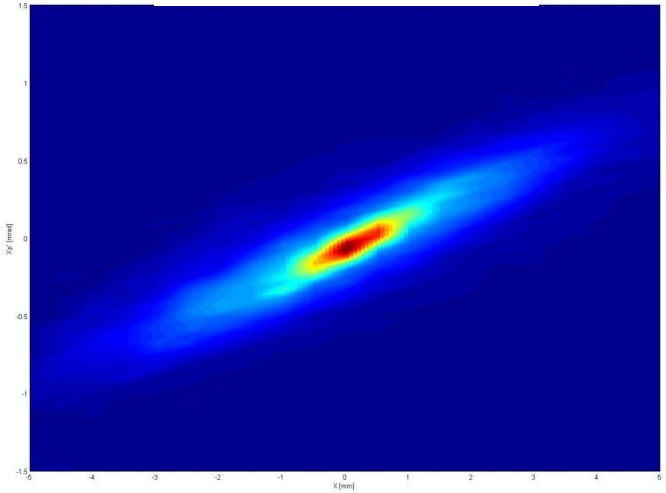
- **Laser wire scanner converts a narrow channel of H^- beam into H^0 beam**
- **Titanium wire scanner measures divergence of the H^0 beam released from laser slit**
- **Measurement is nonintrusive.**

Emittance Measurement Results

Horizontal

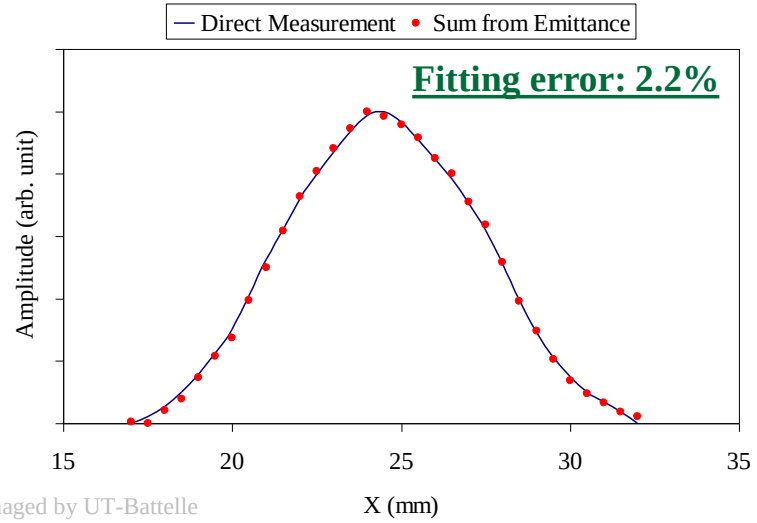


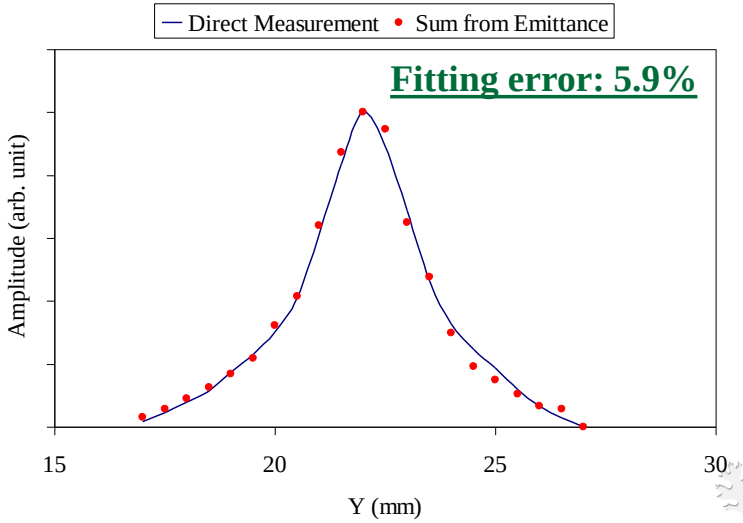
Vertical



Measured emittance: ~ 0.5 mm·mrad

Self-consistency check – comparison between the integration of the emittance (over the angle) with the directly measured profiles

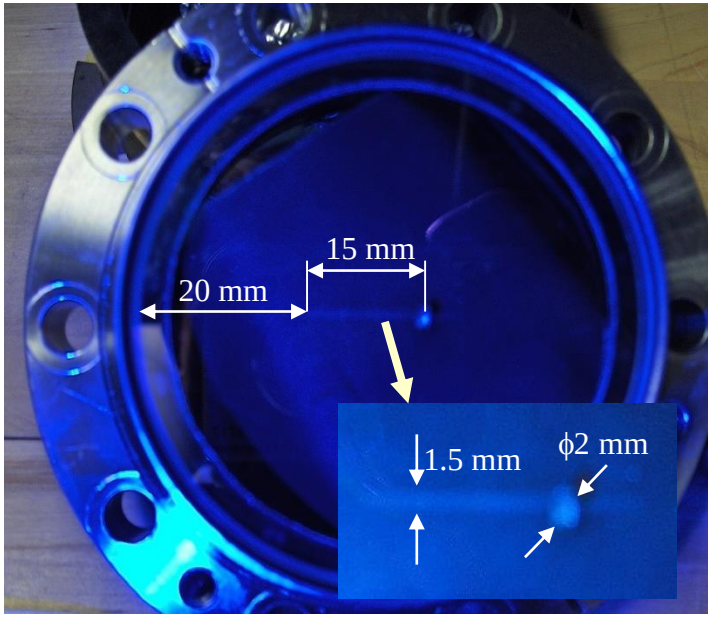




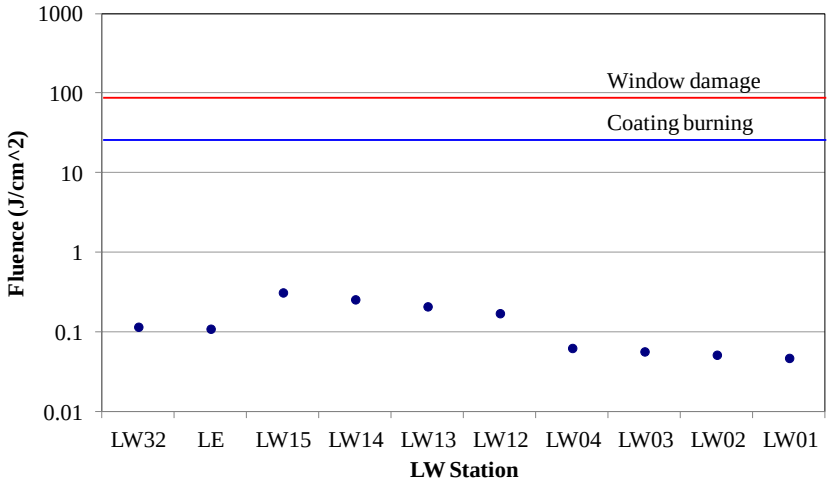
Event of Laser Induced Vacuum Failure

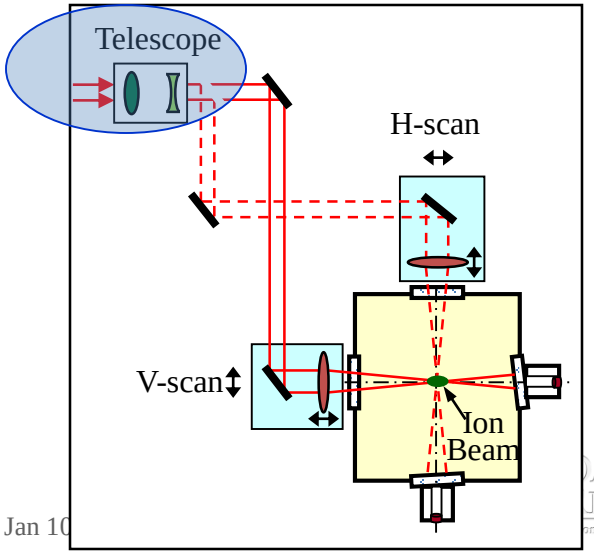
- On Nov. 18, 2011, a laser beam induced vacuum failure occurred during laser emittance measurement
- Cracks on the vacuum window were caused by the over focusing of the laser beam by the telescope in the measurement station
- Vendor specified threshold of optical breakdown has been re-confirmed in the lab
- Optical design has been modified to ensure optical fluence on the vacuum window below 10% of the optical breakdown threshold

Cracks on the vacuum window



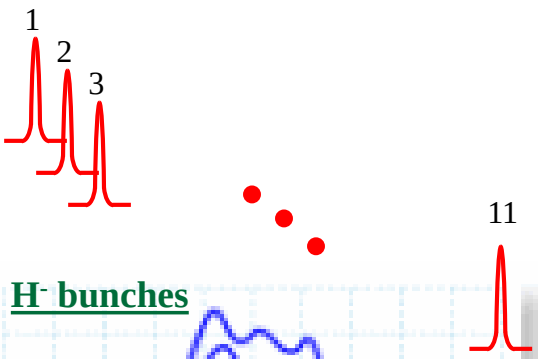
Maximum optical fluence on vacuum windows



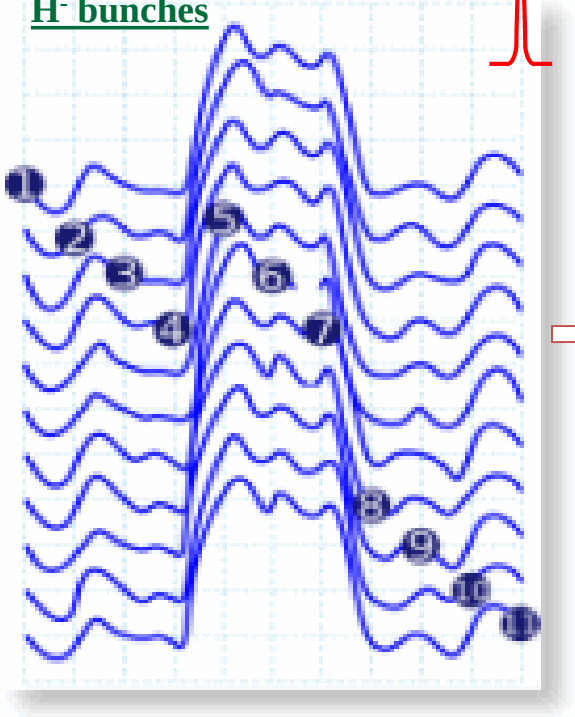


Laser Based Bunch Shape Monitor

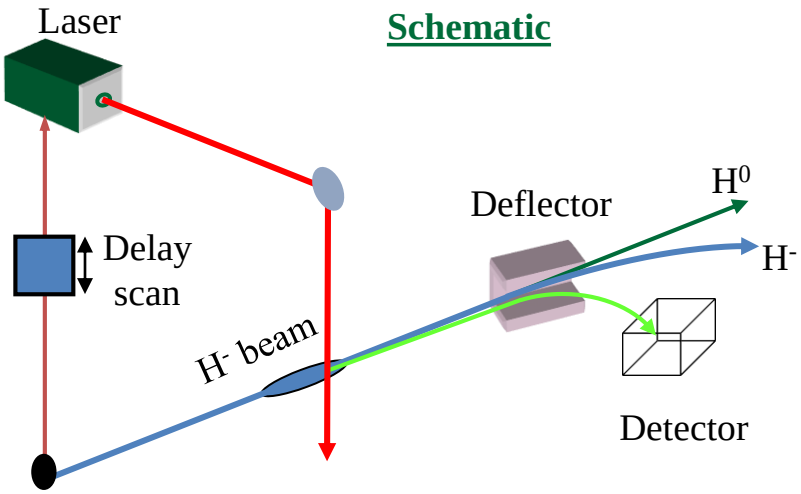
Pico-second laser pulses



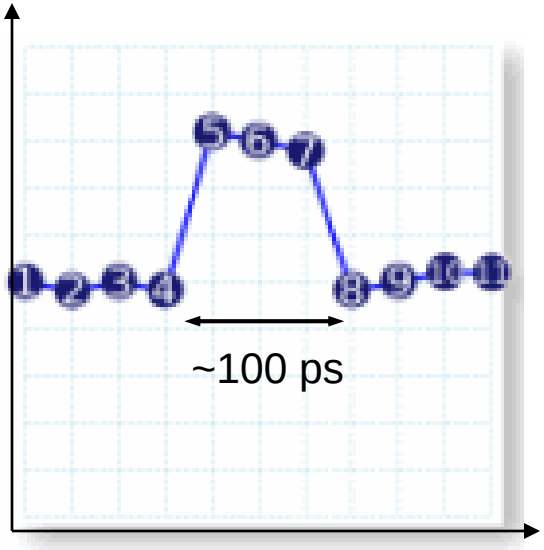
H⁻ bunches



Schematic

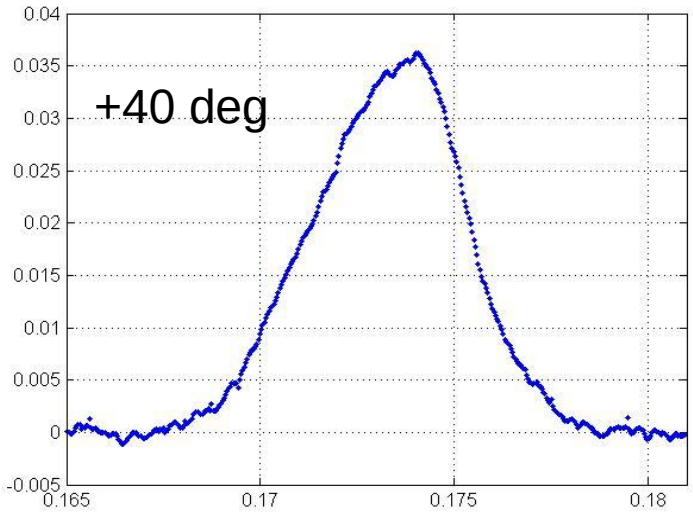


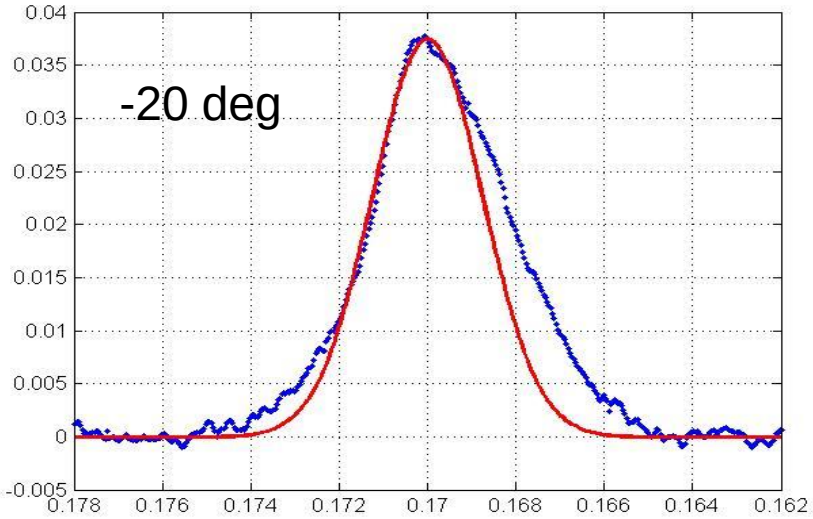
Measurement

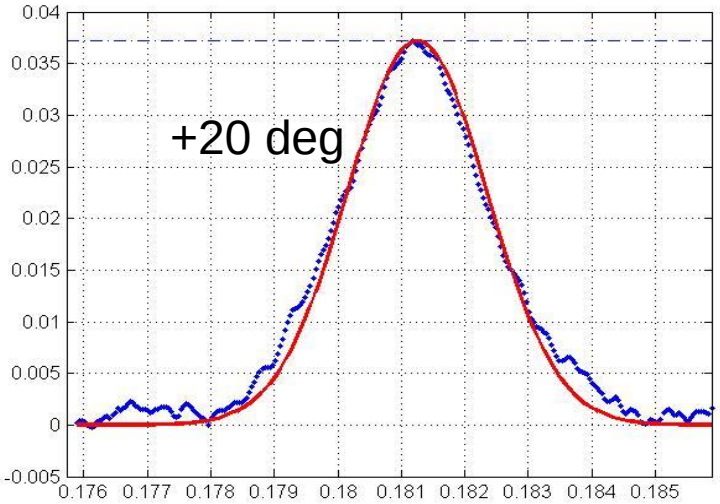


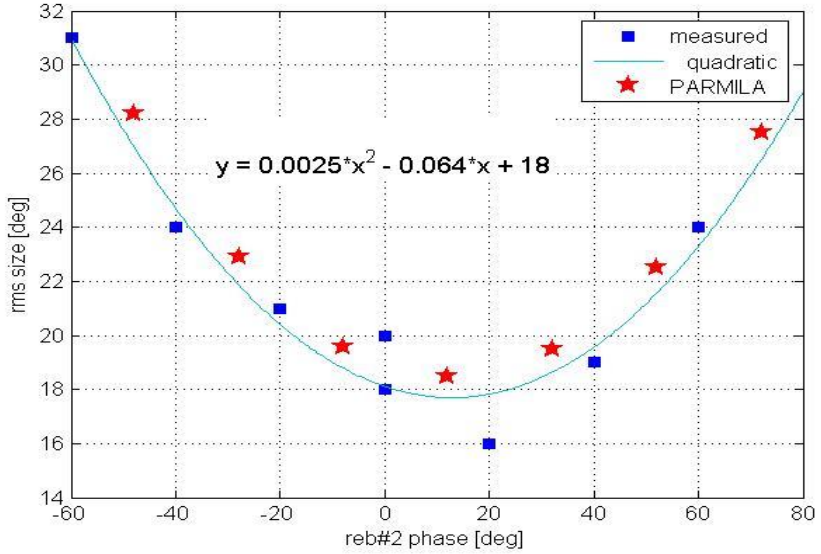
- **Laser source: Ti:Sapphire mode-locked laser**
- **Externally locked to accelerator clock**
- **Pulse width: 2.5 ps**
- **Repetition rate: 80.5 MHz (5th subharmonic of RF frequency)**

Longitudinal Bunch Size Measured at MEBT (2005)



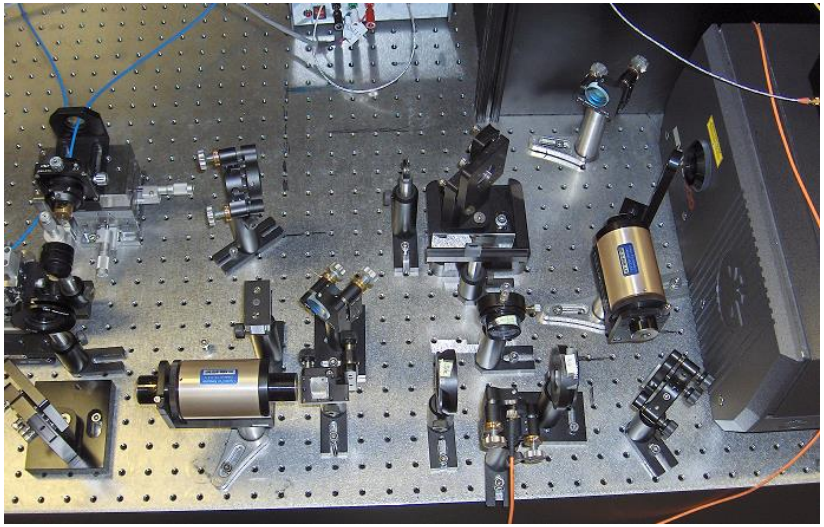






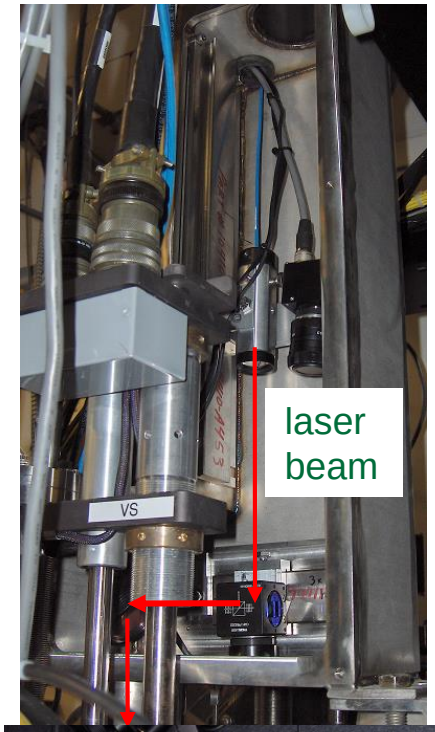
Laser Bunch Shape Monitor at MEBT

Laser and fiber launching optics

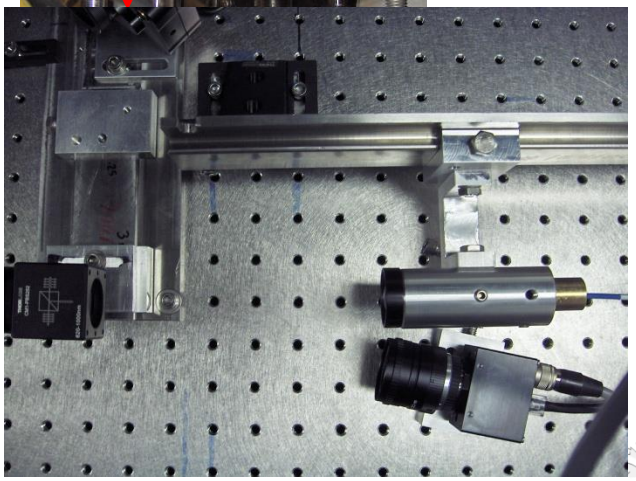


- **Picosecond pulse transmission through fiber has been studied**
- **Fiber transmission line has been installed**
- **Measurement station has been modified and tested**
- **Detection part is being designed and will be installed in the summer**

Measurement site



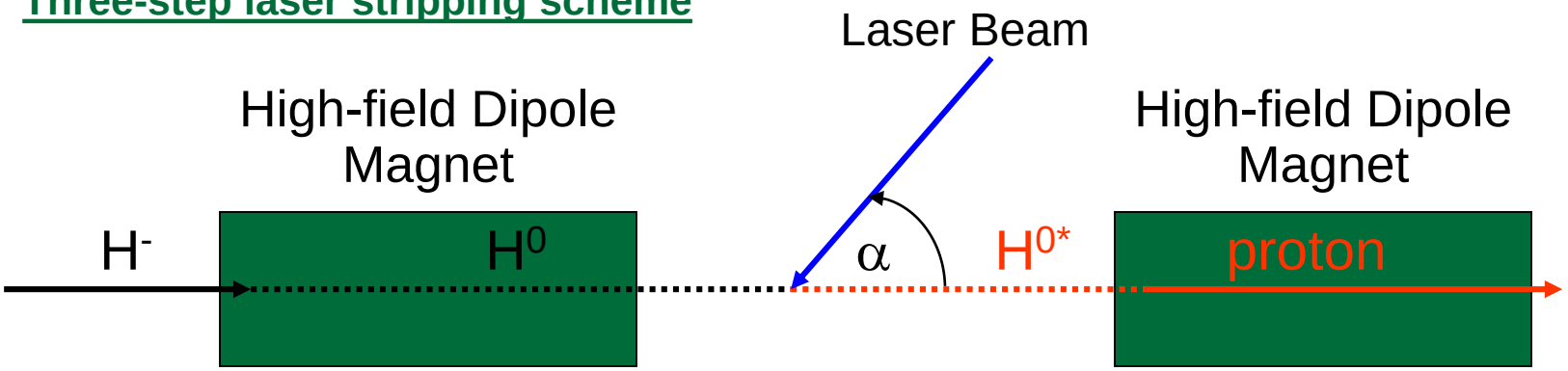
Fiber output



Laser Assisted H^- Beam Stripping

- Our team has developed a novel approach of "foil-less" stripping for charge-exchange injection in high intensity proton facilities
- The approach uses a three-step method employing a narrowband laser beam
- Proof-of-principle experiment demonstrated a stripping efficiency of 90%

Three-step laser stripping scheme



Step 1: Lorentz Stripping

$H^- \rightarrow H^0 + e^-$

Step 2: Laser Excitation

$H^0 (n=1) + \gamma \rightarrow H^{0*} (n=3)$

Step 3: Lorentz Stripping

$H^{0*} \rightarrow p + e^-$

Next Stage Laser Stripping Experiment Plan

New experiment site

Macro-pulse laser system

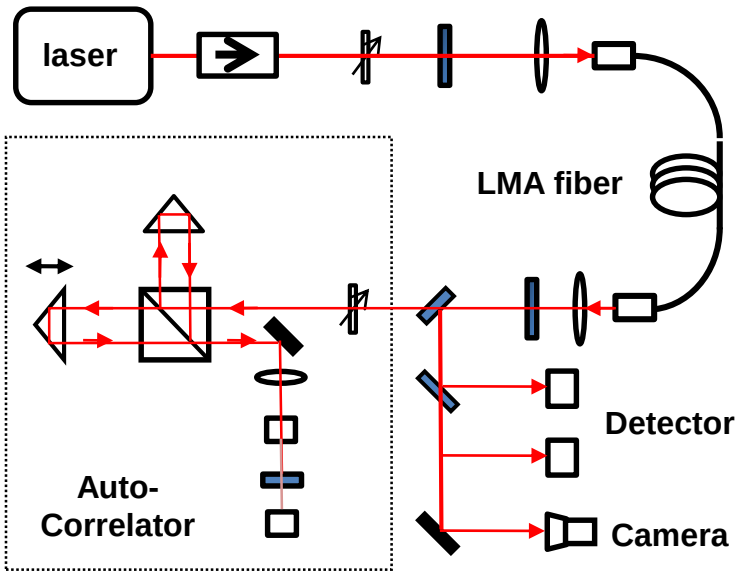
- Optimization of beam parameters has been investigated to minimize the laser power requirement
- Macro-pulse laser system has been designed, fabricated and tuned
- The laser can deliver 1 MW / 50 ps / 402.5 MHz micro-pulses at 355 nm. Micro-pulses are bunched to 10 us macro-pulses at 10 Hz.
- Laser is ready for experiment on actual SNS H^- beam
- Vacuum vessel and stripping magnets have to be designed and manufactured

Laser Optics Capabilities at SNS

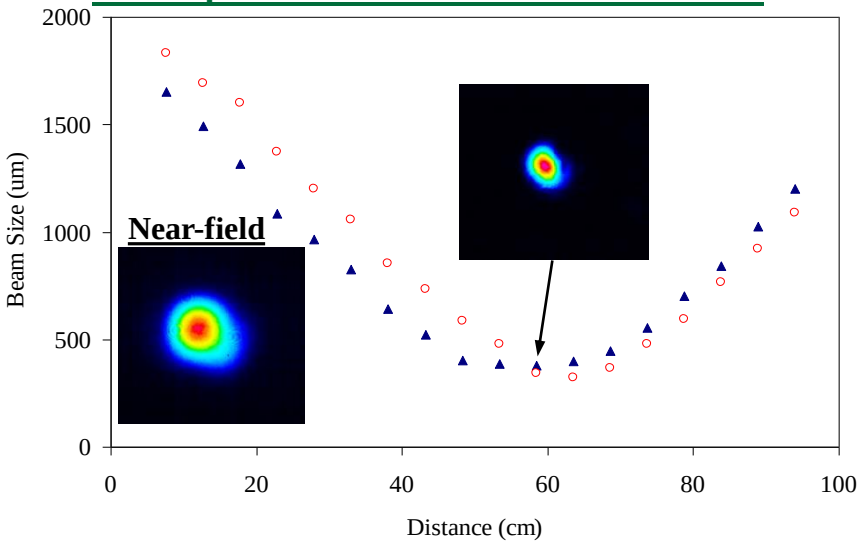
- **Laser Rooms**
  - **HEBT laser room – light source for SCL laser wire scanner and HEBT laser emittance scanner**
  - **Mezzanine laser room – light source for MEBT laser bunch shape monitor**
  - **Front end laser room – light source and optical cavity R&D development for laser assisted H^- beam stripping**
- **Lasers**
  - **Nd:YAG Q-switched lasers with pulse widths of 7-10 ns and peak powers of 100 MW**
  - **Ti-Sapphire mode locked laser with pulse width of 2.5 ps and rep. rate of 80.5 MHz**
  - **Master oscillator power amplifier (MOPA) system providing macro-pulses with 1MW/50ps/402.5MHz at 355 nm**
- **Expertise**
  - **High sensitivity high dynamical range signal detection**
  - **Motion control and optical sensing with high radiation resistance**
  - **Laser beam pointing stabilization**
- **Collaboration with DOE SBIR funded project is vital for supporting a PostDoc and R&D activity**

R&D: Fiber Transmission of ps Laser Pulses

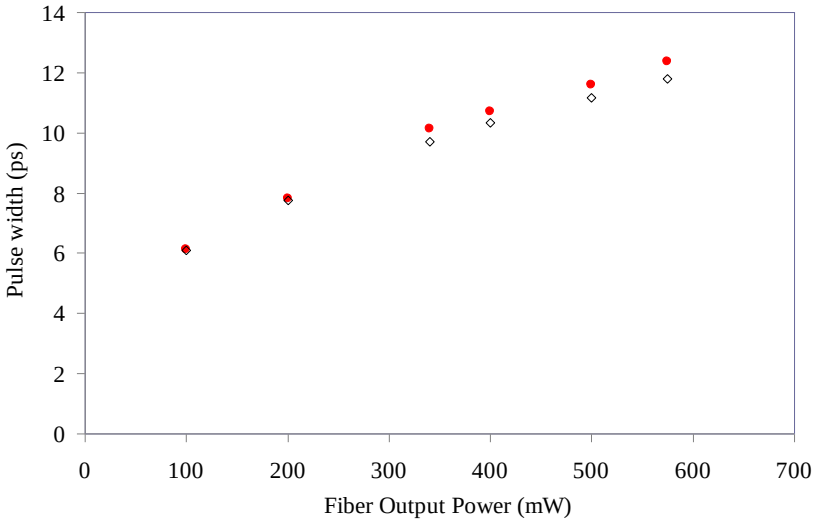
Optical setup



Beam profiles after fiber transmission



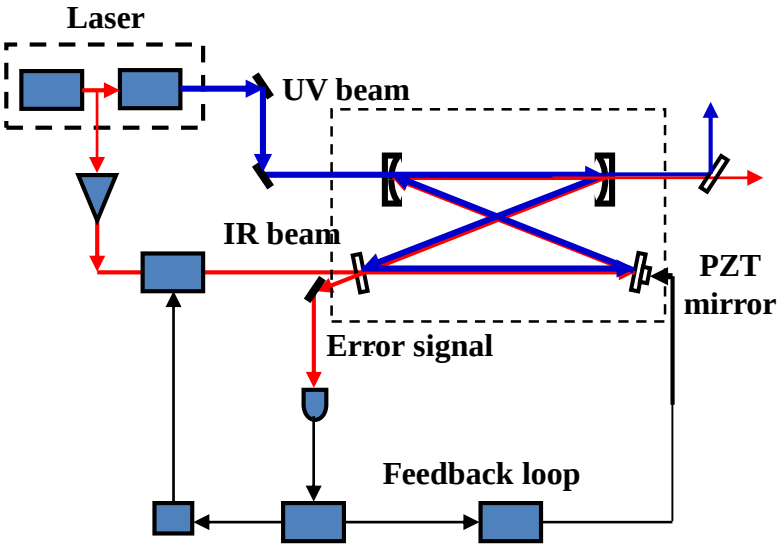
Pulse width broadening

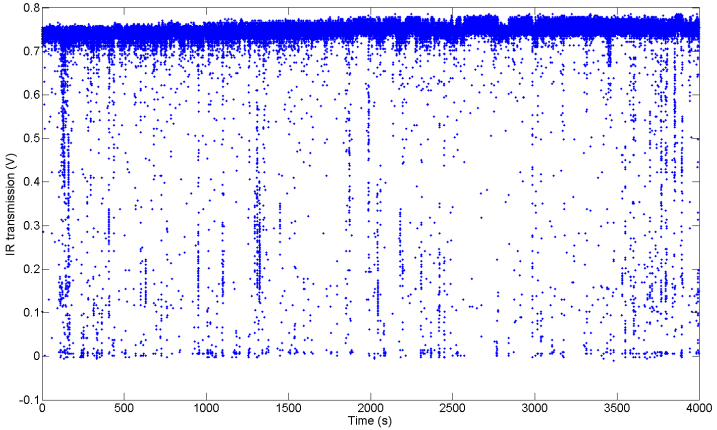


- Optical fiber transmission has advantages of stability, easy maintenance, and safety
- A 100-ft large mode area (LMA) fiber was used to transmit picosecond KW laser pulses
- Beam profiles and pulse width variation are studied as a function of launching optics, fiber length, and transmission power

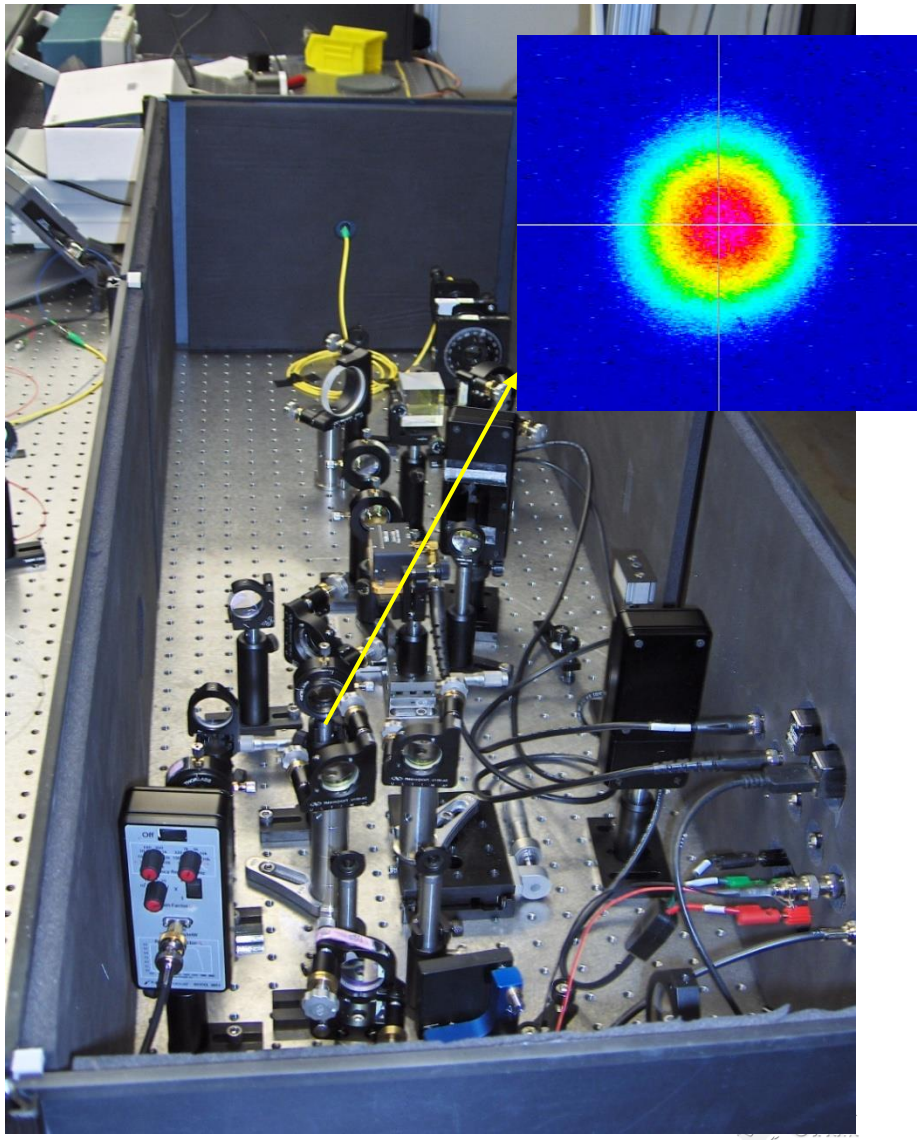
R&D: Beam Recycling Optical Cavity

Dual color optical cavity





Experiment setup



Summary

- World-first large scale, operational laser wire system has been implemented at SNS-SCL. Profile measurement has been conducted on 1 MW, neutron production beam.
- Laser emittance scanner has been commissioned at SNS HEBT.
- Laser based bunch shape monitor is being developed at SNS MEBT using optical fiber transmission.
- Laser assisted H^- beam stripping – proof of principle experiment was demonstrated. Next stage experiment using macro-pulsed laser is being developed.
- Significant infrastructure and expertise on laser based beam instrumentation have been acquired at SNS