SNS Laser Stripping

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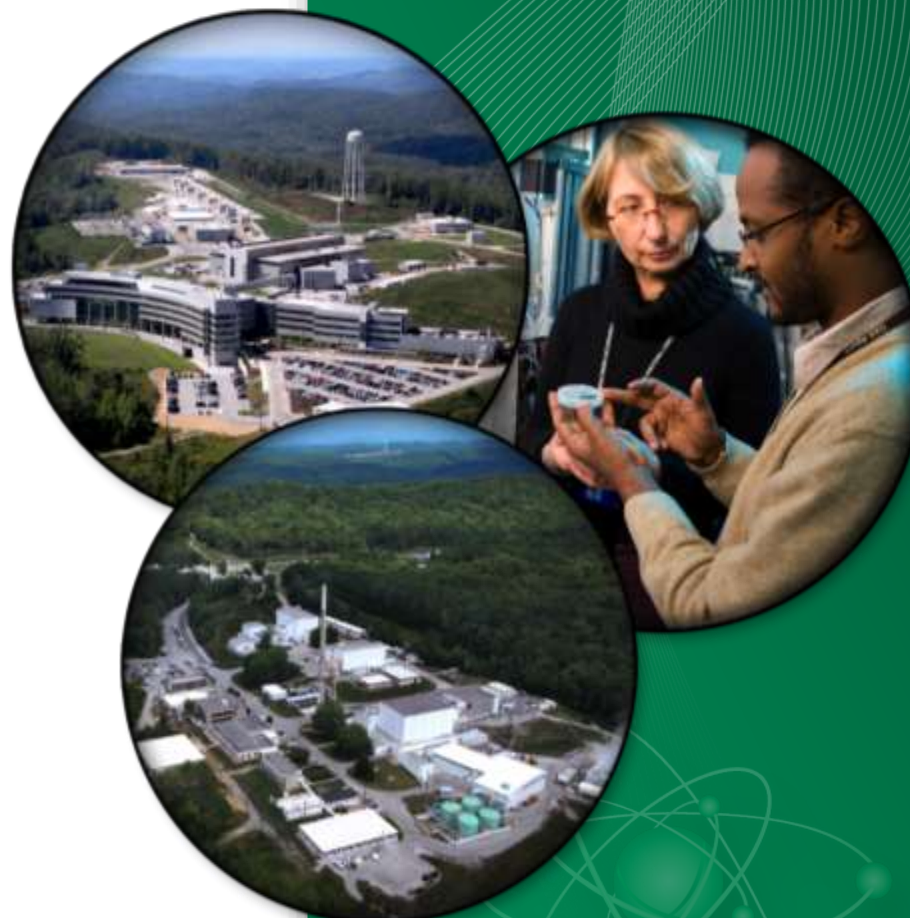
Accelerator Advisory Committee
May 7-9, 2013



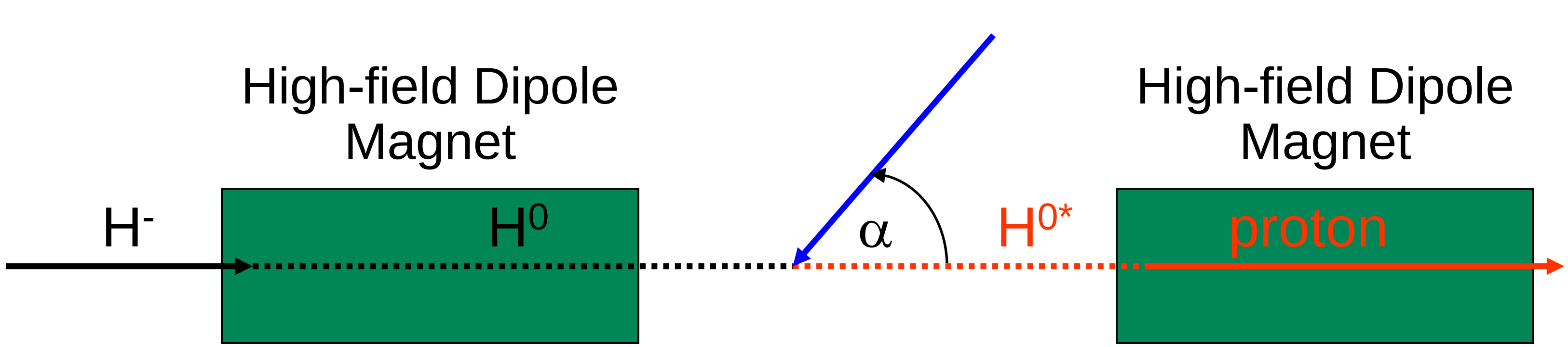
Motivation

- Charge exchange injection is a requirement for high power multi-turn injection
- The only practical way to accomplish this today is with stripper foils, but we are quickly approaching the limit of foil failure due to the high temperatures
- Beam loss due to to foil scattering is also a problem (highest loss point in the SNS accelerator complex)
- Laser stripping can solve both these problems
  - Laser technology is quickly advancing
  - 7 ns stripping demonstrated in 2006, next is 10 us demonstration, eventually full millisecond

Three-Step Stripping Scheme

- Our team developed a novel approach for laser-stripping which uses a three-step method employing a narrowband laser [V. Danilov et. al., Physical Review Special Topics – Accelerators and Beams 6, 053501]

$$f_{\text{rest frame}}(1 \rightarrow 3) = \gamma(1+\beta\cos(\alpha))f_{\text{beam frame}}$$



Step 1: Lorentz Stripping

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

Step 2: Laser Excitation

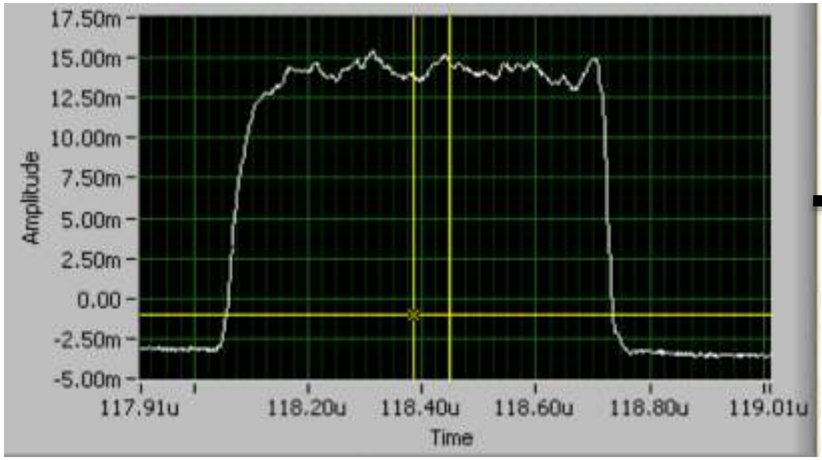
$H^0\ (n=1) + \gamma \rightarrow H^{0*}\ (n=3)$

Step 3: Lorentz Stripping

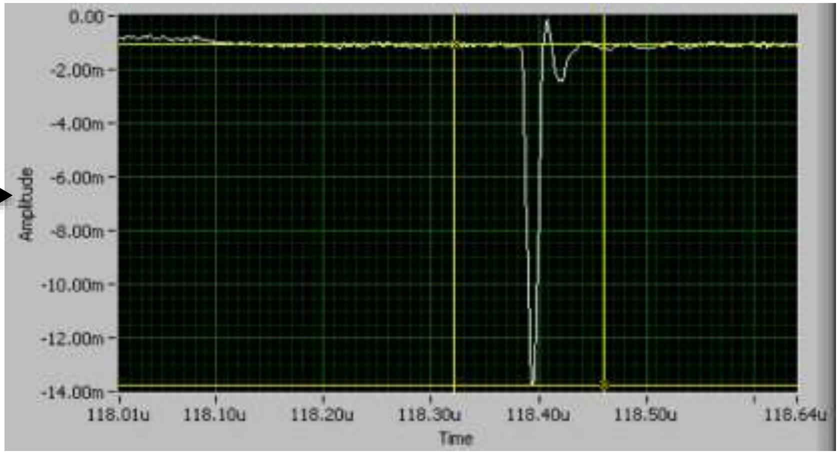
$H^{0*} \rightarrow p + e^-$

Laser stripping demonstrated for first time in 2006

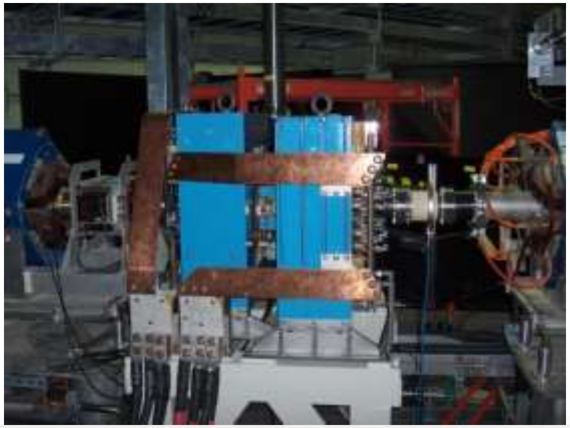
- Demonstrated 90% stripping efficiency for ~7 ns



BCM, laser & magnets off



BCM, laser & magnets on



Magnet assembly in tunnel

Damaged optical window

Laser Stripping Grant

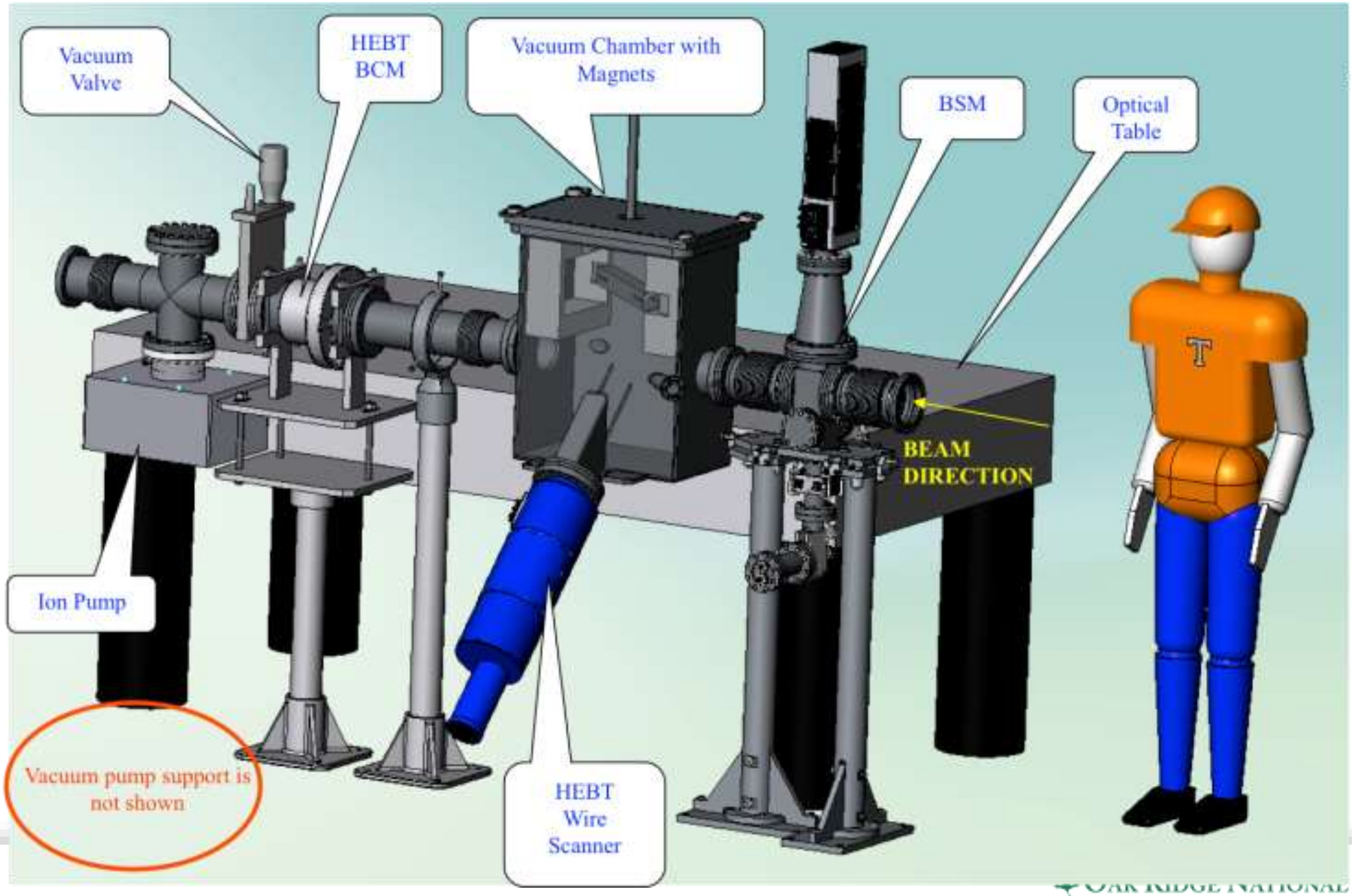
- “Laser Stripping for High Intensity Proton Beam”, submitted last fall to the FY2013 DOE-HEP program. PI is Sarah Cousineau.
- Submitted through UT Office of Research.
- Proposal is a collaboration between SNS, Fermilab, University of Tennessee Department of Physics and Astronomy. Heavily weighted toward educational component
- Notified by program manager in January that proposal will be funded. $825k over 3 years.
- Award has been signed off at DOE in Washington and is awaiting distribution in DOE area office

Goals of the Project

- Scientific Goals:
  - Demonstrate >= 90% stripping efficiency of a 10 μs, 1 GeV H^- beam (>1,000 times longer than before)
  - Perform lab-based development of a power recycling optical cavity to sustain 0.5 MW in-cavity UV wavelength laser peak power over long durations (needed for >10 us stripping)
- Educational goals:
  - Forge a stronger research collaboration between SNS and UT Dept. Physics and Astronomy
  - Strengthen accelerator physics graduate research program at UT

10 μs experiment: Configuration

- Experiment will be placed in drift region of SNS HEBT
- A vacuum insert with custom permanent-magnet assembly and laser window will be fabricated

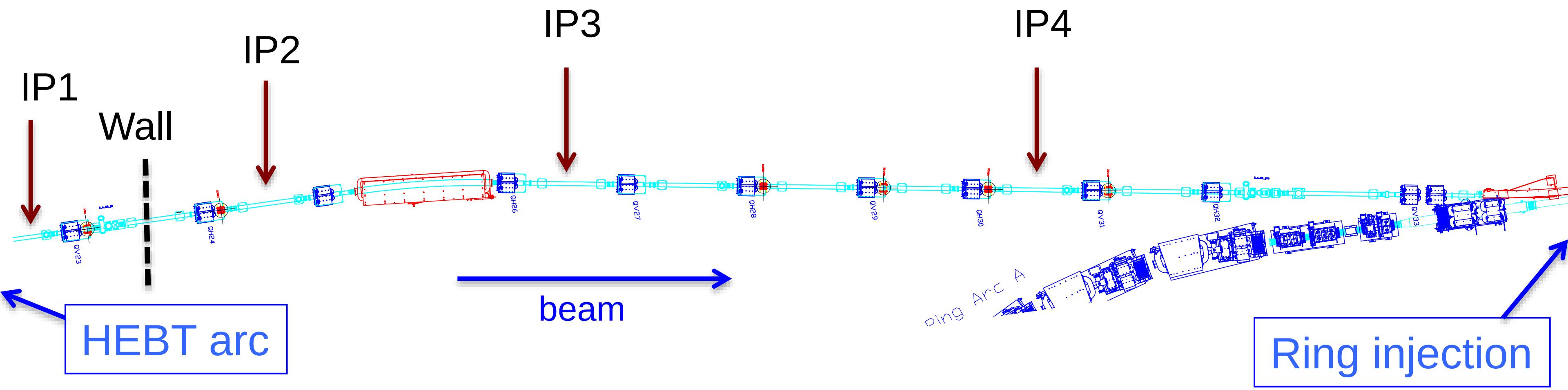


10 μs experiment: Challenges

- **High field gradient** magnets to minimize the induced angular spread of beam
- Minimize **laser power** requirement:
  - Special beam transport optics:
    - Dispersion tailoring at interaction to match beam energy spread to laser angular spread
    - Upright horizontal phase space ellipse to reduce angular spread of beam
    - Minimize vertical beam size at interaction point
  - Temporal match of laser beam to H^- beam pulse
- **Protect** the laser
  - Laser electronics is susceptible to radiation damage
  - Now evaluating possibility of remote placement of laser compared with in tunnel placement

10 μs experiment: Choose interaction pt.

- Currently evaluating candidate interaction points in the HEBT



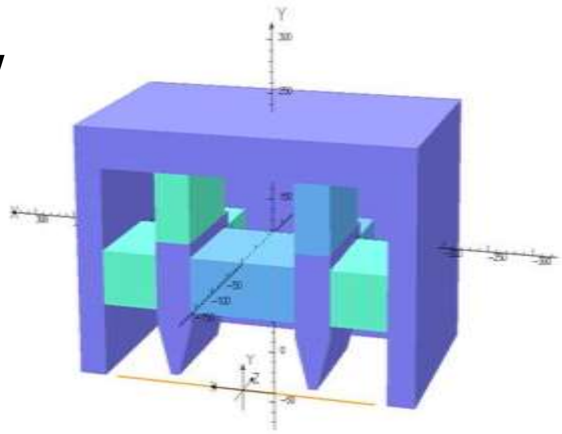
Evaluating these option against:

- Achievability of transverse and longitudinal optics
- Beam loss and radiation
- Waste beam disposal
- Length of laser transport line (for remote laser case)

10 μs experiment: Magnet Status

Requirements:

- Magnet requires 1.5 T and 100 T/m gradient. Has 30 mm gap (compare to HEBT beam pipe ~110 mm)
  - Permanent magnet chosen for cost and simplicity
  - Magnet will be retractable



Status:

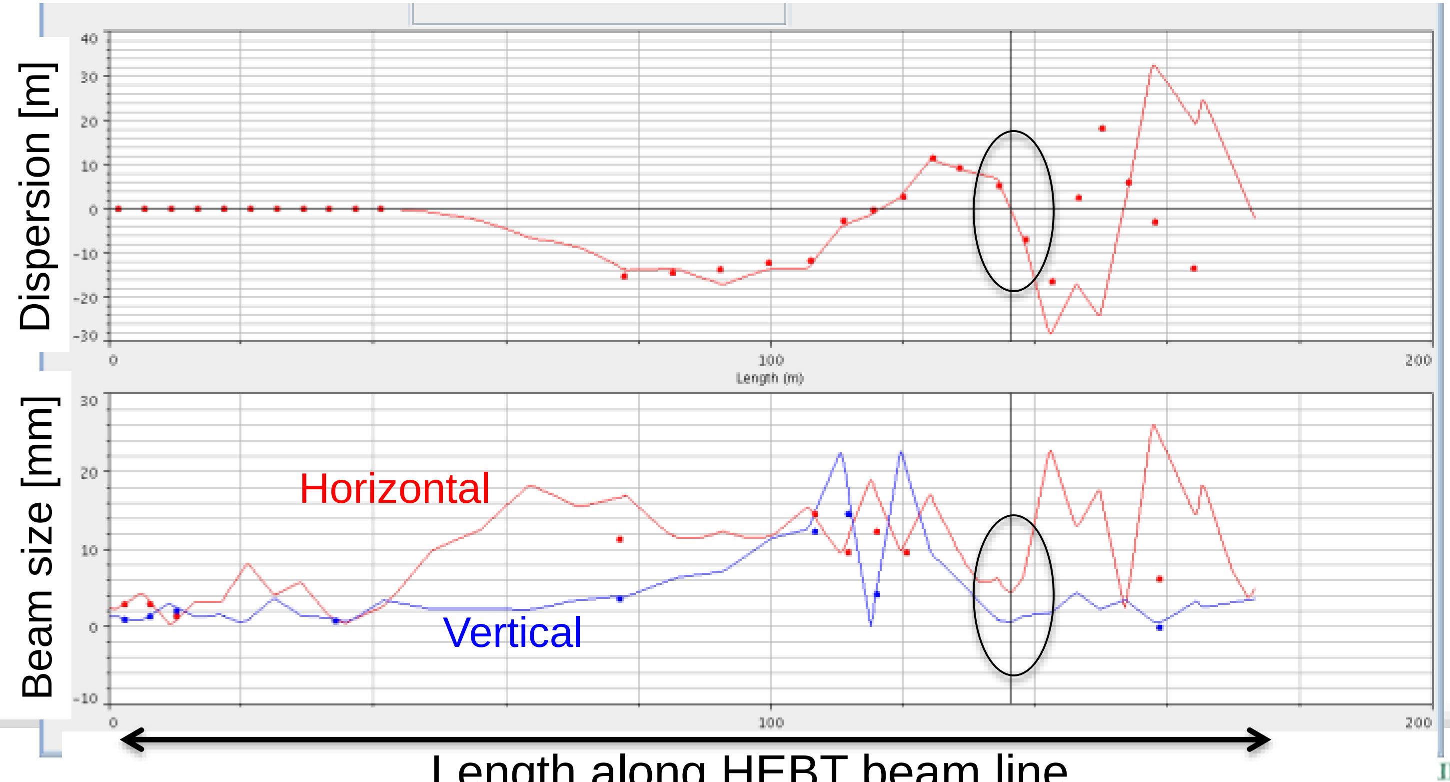
✓ Design completed by J. Volk, Fermilab

✓ Fabrication contracted to SABR Enterprises, LLC. Recent visit by A. Aleksandrov to site to finalize design.

✓ Delivery date estimated for August 2013

10 μs experiment: Transverse optics

- Desire $D_x = 0$, $D_x' = 2.5$, $\alpha_x = 0$, small σ_y
- Successfully demonstrated feasibility for achieving required optics in both planes. Working on repeatability, lower losses.
- Measured emittance and dp/p for stripping beam configuration



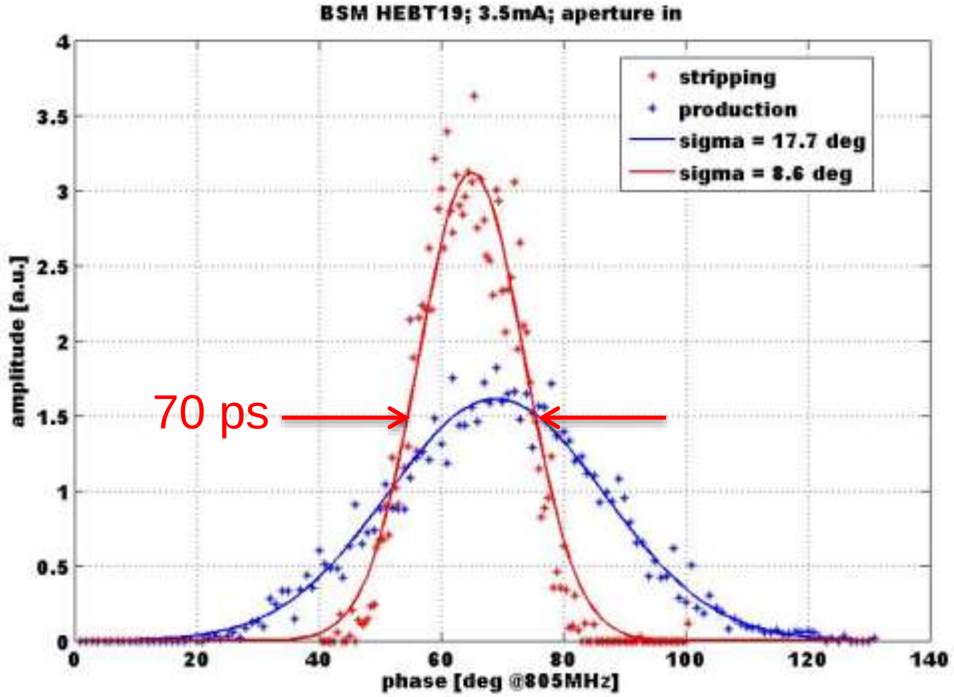
✓ $D_x = 0$
✓ $D_x' = 2.5$

✓ $\alpha_x = 0$
✓ Small vert. size

Courtesy T. Gorlov

10 μs experiment: Longitudinal optics

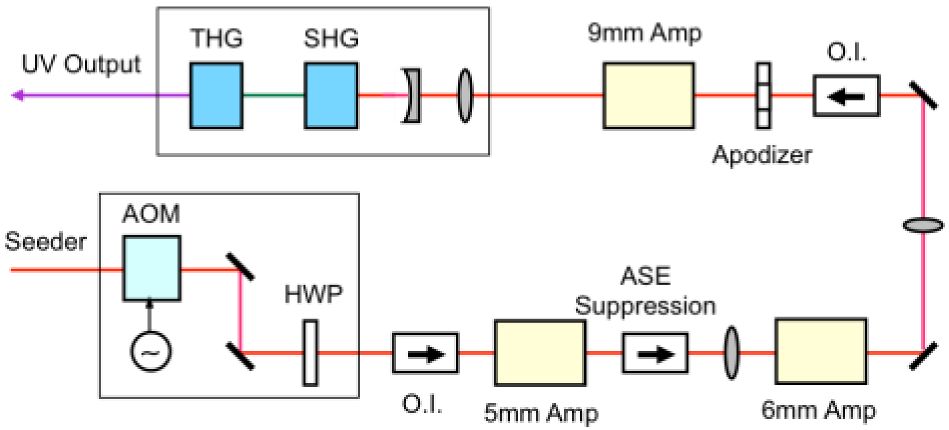
- Desire <50 ps FWHM micropulses at 1 GeV
- Measured max linac energy to be ~1.07 GeV for short beam pulses
- Need to minimize SCL energy reduction required to achieve desired longitudinal beam parameters
- Need to demonstrate simultaneous transverse and longitudinal optics



Single micropulse length measurement on April 9, 2013; cost ~60 MeV of energy loss due to SCL cavity rephasing. FWHM = 70 ps (desire < 50 ps).

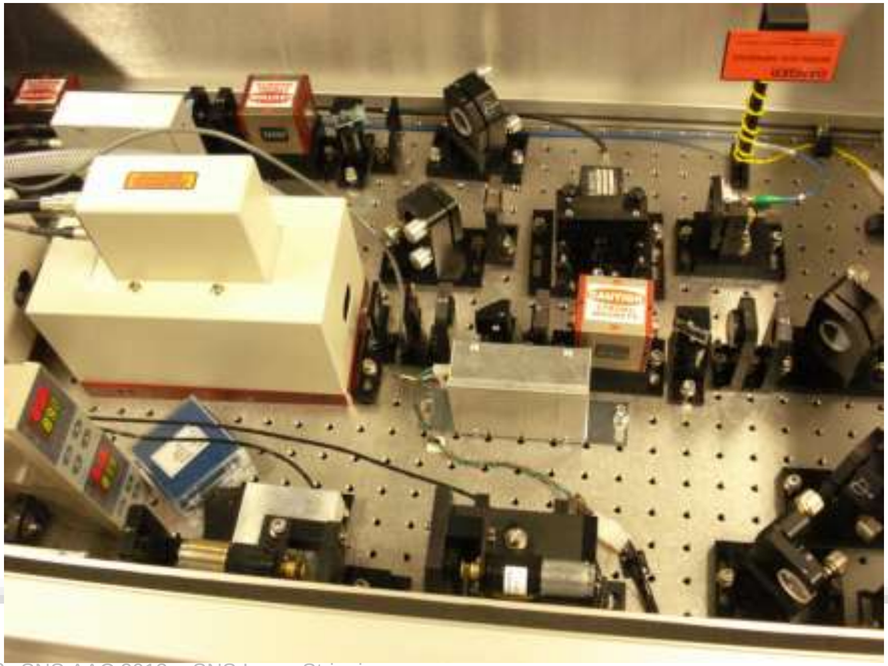
Courtesy A. Aleksandrov

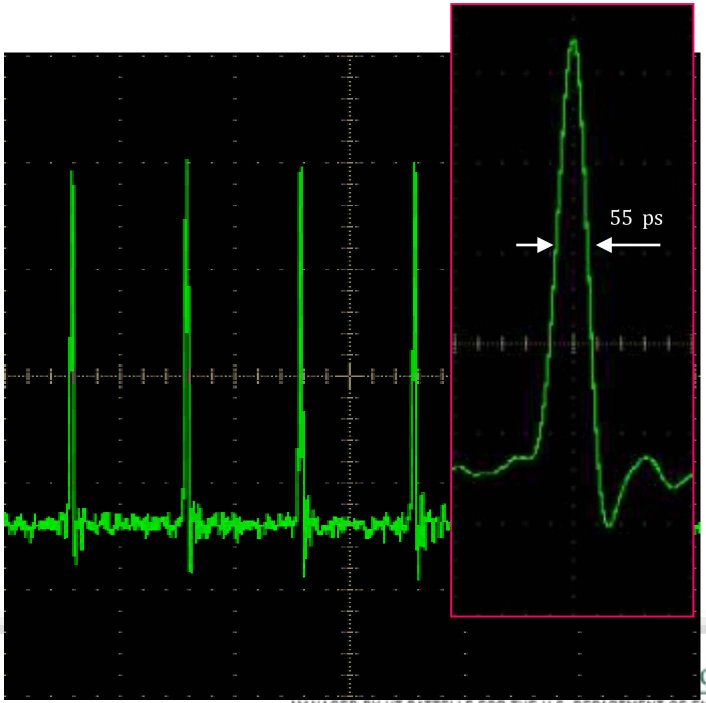
Macropulse laser system for laser stripping



Measured UV light output parameters

- Wavelength: 355 nm
- Macropulse: 10 μs @ 10 Hz
- Micropulse: 55 ps @ 402.5 MHz
- Peak power: 1 MW





Courtesy Y. Liu & C. Huang

10 μs experiment: Laser Placement

- Remote placement of laser in ring service building:
  - Protects laser (e.g. rad damage due to beam loss)
  - No moving laser in & out of tunnel for every measurement
- Challenges:
  - Space availability
  - Transport issues (vibration, power loss in mirrors)
  - Cost
  - Longitudinal optics achievability

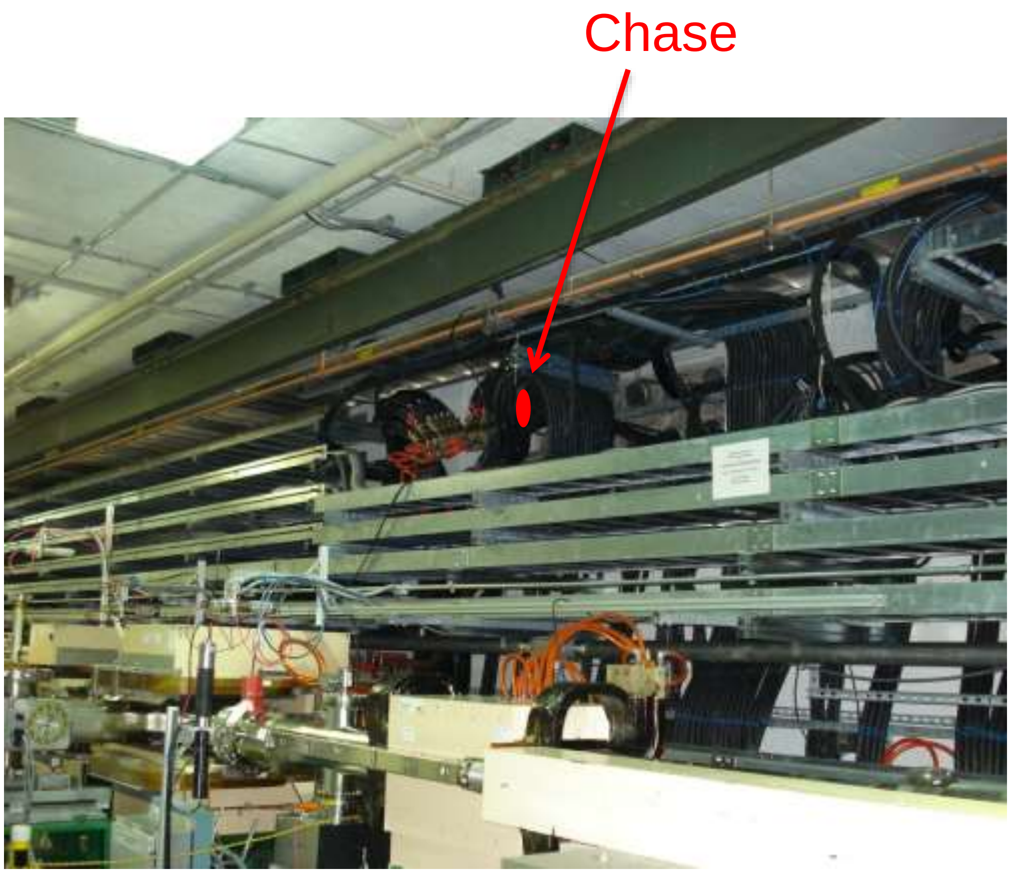
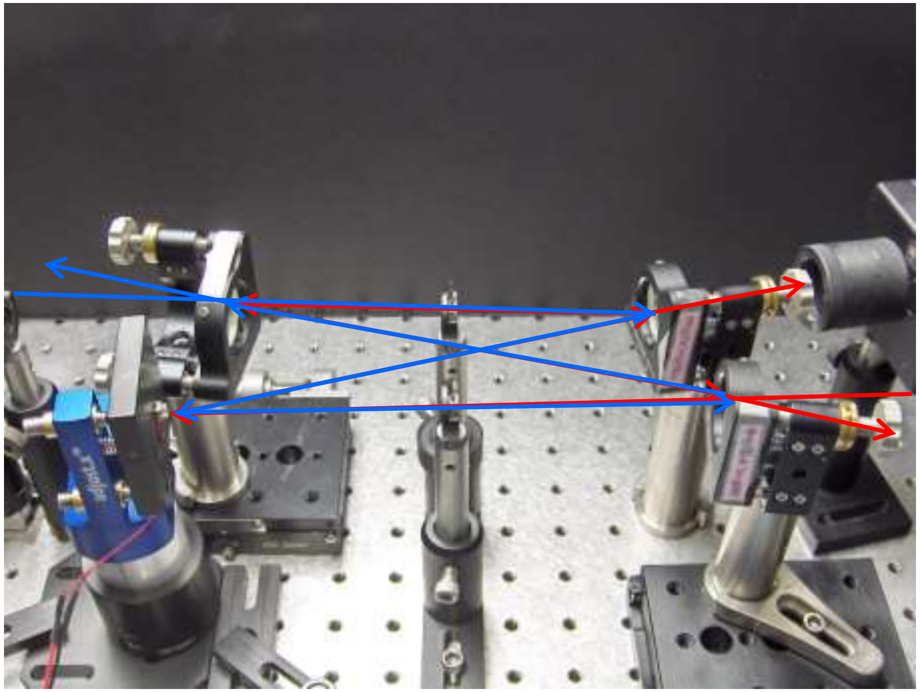


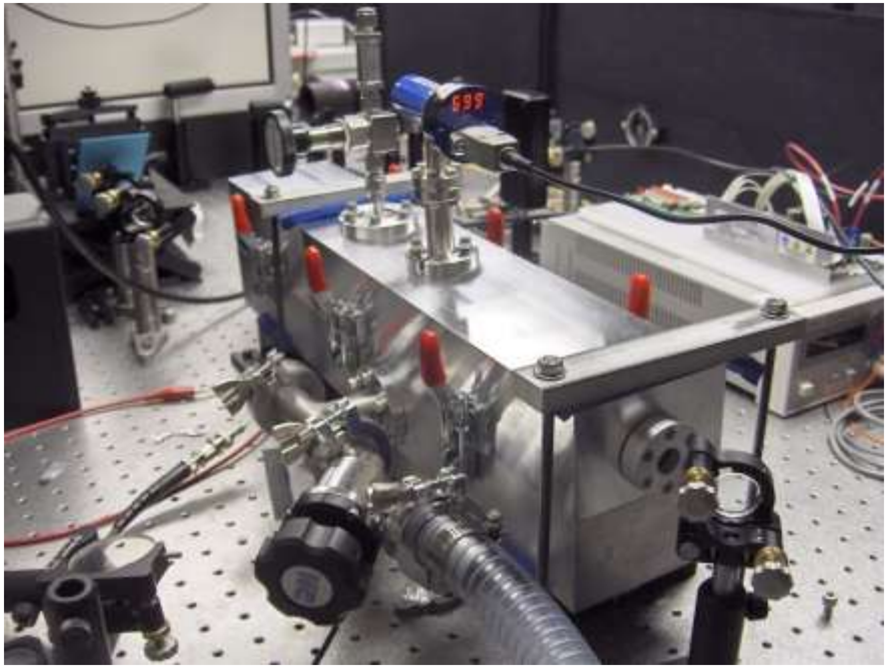
Photo of ring injection area

Power recycling optical cavity development

- Needed for stripping more than 10 μs pulse lengths at 10 Hz
- Both Fabry-Perot and Ring configurations have been developed
- Experiment is ongoing to raise the cavity coupling efficiency – goal is to obtain a power enhancement factor of 10 – 20 for 100 μs pulse width



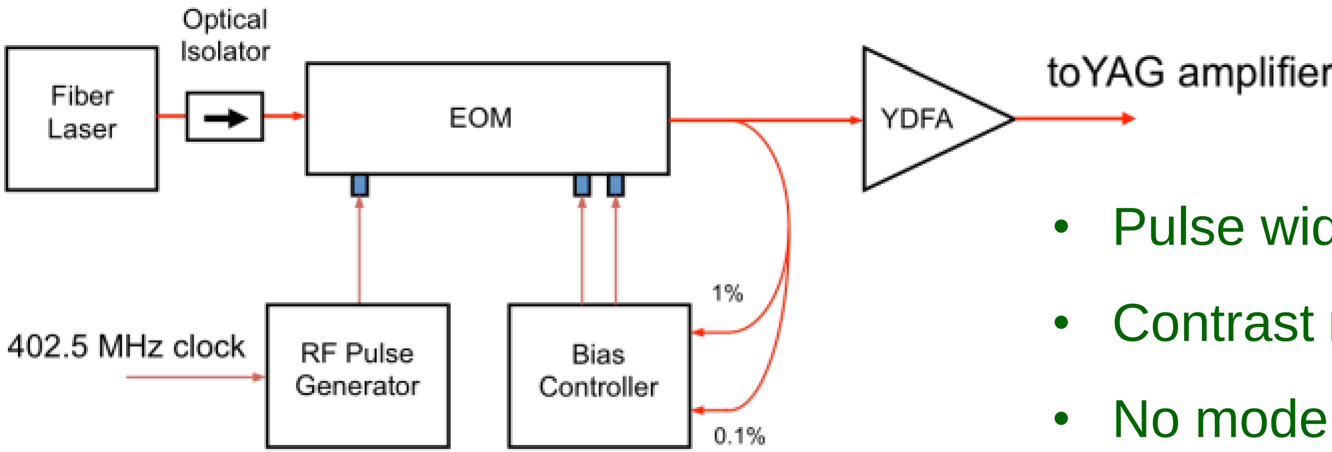
Ring cavity



Fabry-Perot cavity

Courtesy Y. Liu & C. Huang

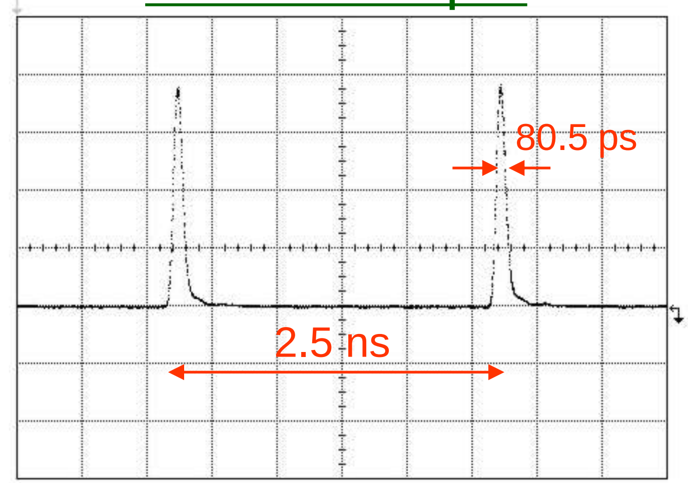
New picosecond seeder has been developed – important for recycling cavity



- Pulse width (~80 ps)
- Contrast ratio (>40 dB)
- No mode hopping
- Narrow line width (~140 KHz)

Modulator and RF Source

Seeder Output

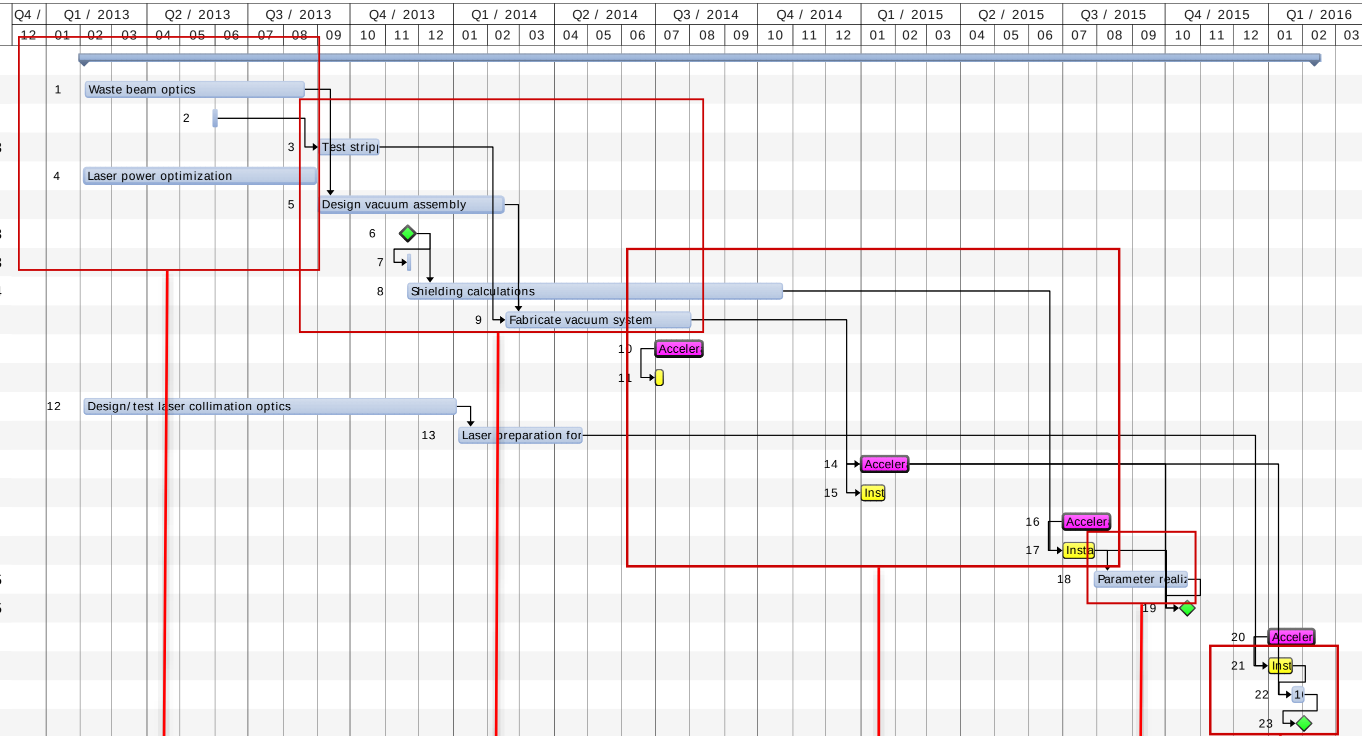


Courtesy Y. Liu & C. Huang

C. Huang, C. Deibele, and Y. Liu, "Narrow linewidth picosecond UV pulsed laser with mega-watt peak power," Optics Express Vol. 21, No. 7, 4 April 2013.

Project Schedule

#	Title	Given Work	Expected Start	Expected End
0	**Laser Stripping Project**		**2/4/13**	**2/11/16**
1	**Waste beam optics**	**7m**	**2/5/13**	**8/19/13**
5	Receive stripping magnet	1d	5/31/13	5/31/13
6	Test stripping magnet in lab	2m	9/2/13	10/25/13
7	**Laser power optimization**	**8m**	**2/4/13**	**8/30/13**
11	Design vacuum assembly	6m	9/2/13	2/14/14
12	Vacuum system conceptual design		11/21/13	11/21/13
13	Order cabel pull material	1d	11/21/13	11/21/13
14	Shielding calculations	1y	11/21/13	10/22/14
15	Fabricate vacuum system	6m	2/17/14	8/1/14
16	Accelerator Shutdown	6w	7/1/14	8/11/14
17	**Installation**	**6w**	**7/1/14**	**7/7/14**
19	**Design/test laser collimation optics**	**12m**	**2/4/13**	**1/3/14**
23	**Laser preparation for installation**	**9m**	**1/6/14**	**4/25/14**
28	Accelerator shutdown	6w	1/1/15	2/11/15
29	**Installation**	**6w**	**1/1/15**	**1/21/15**
32	Accelerator shutdown	6w	7/1/15	8/11/15
33	**Installation**	**6w**	**7/1/15**	**7/28/15**
37	Parameter realization experiments	3m	7/29/15	10/20/15
38	Ready for final demonstration		10/20/15	10/20/15
39	Accelerator shutdown	6w	1/1/16	2/11/16
40	Install final laser	3w	1/1/16	1/21/16
41	10us demonstration	7d	1/22/16	2/1/16
42	10us demonstration complete		2/1/16	2/1/16



Finalize beam optics, IP location, laser window specs (now – 09/ 2013)

Installation period (7/2014 – 7/2015)

Final experiment 01/2016

Design and fabricate vacuum assembly (09/2013 – 09/2014)

Parameter realization experiments (8/2015 – 10/2015)

Courtesy S. Cousineau

Status of Educational Front

- Two UT undergraduates will join us for laser stripping projects for summer
  1. Develop a computer controlled optical correlator that measures the pulse width of the laser based on nonlinear optical technology
  2. Evaluate waste beam transport scenarios through simulations of beam loss and radiation deposition calculations
- Currently have postdoc (C. Huang)
- Search for UT graduate student ongoing

Summary

- We are working on a laser stripping demonstration for a 10 μs H^{-} beam, 1000x longer pulse length than before
- Magnet fabrication will start soon, expect delivery August 2013
- Required beam optics is being tested and refined
- Beam line insert design will start soon
- Plan to install 2014 – 2015, and first measurements in 2015
- Stay tuned…