H- Laser Stripping

Bob Zwaska

Laser as Alternative to Foil

- Remove electrons without putting nuclei in beam
- Potentially very attractive:
  - Reduce losses
  - Reduce activation
  - Reduce scattering
  - Avoid foil failure
  - More flexible painting
  - …
- Many questions:
  - Stripping efficiency?
  - Cost?
  - Reliability?

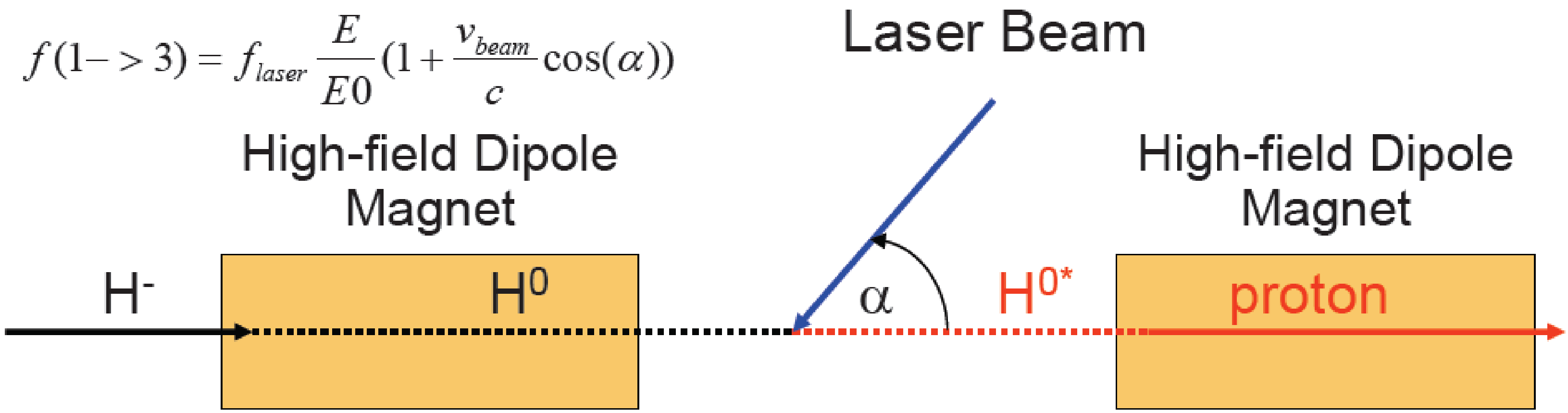
Path is already being explored

- SNS has mature experiments on laser stripping
- 3 step method:
  - Lorentz strip outer electron
  - Excite atom
  - Lorentz strip excited electron
- We'll use their experience as a base
  - Slides and text from Danilov EPAC04
- There are other methods (2-step, 1-step)
  - Examine those in the future

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]**

$$f(1->3) = f_{laser}\frac{E}{E0}(1+\frac{v_{beam}}{c}\cos(\alpha))$$



Step 1: Lorentz Stripping

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

Step 2: Laser Excitation

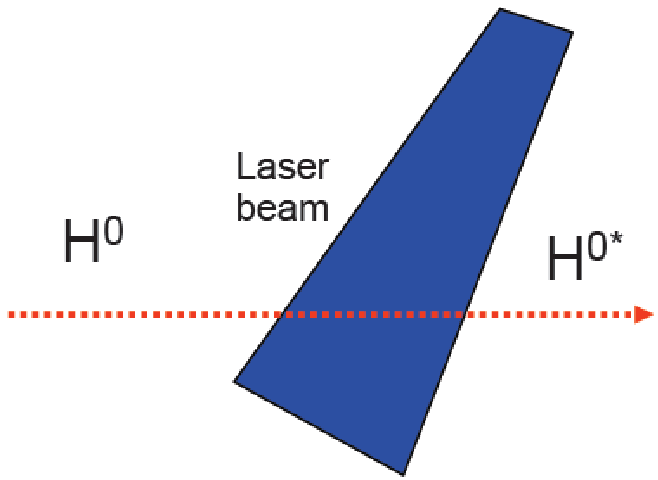
$H^0\ (n=1) + \gamma \rightarrow H^{0*}\ (n=3)$

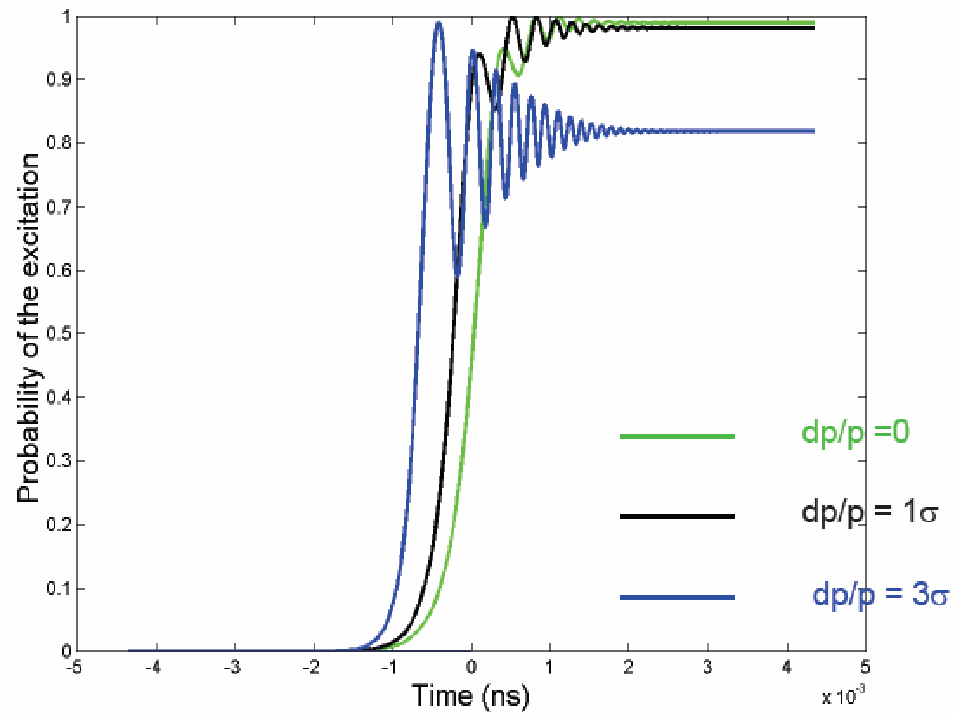
Step 3: Lorentz Stripping

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

Approach that Overcomes the Doppler Broadening

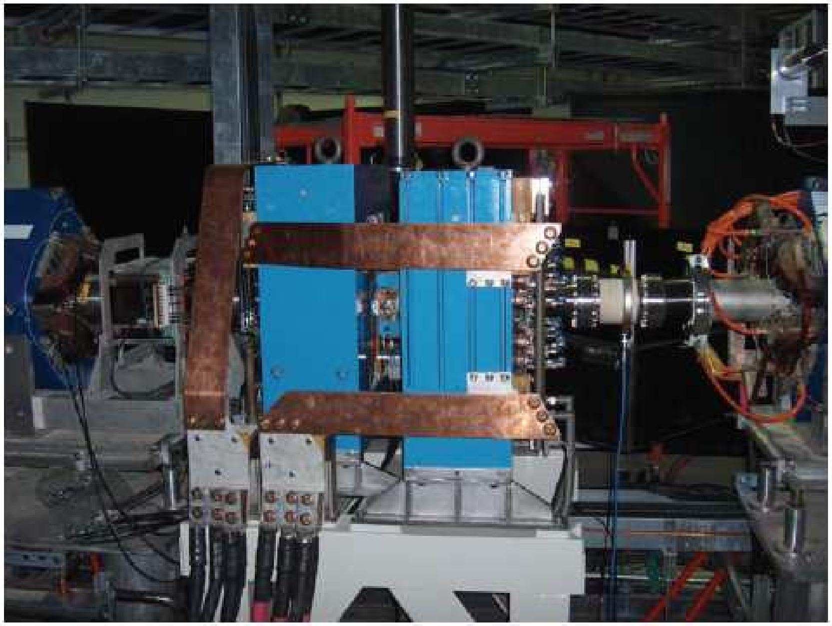
- **By intersecting the H^0 beam with a *diverging* laser beam, a frequency sweep is introduced:**



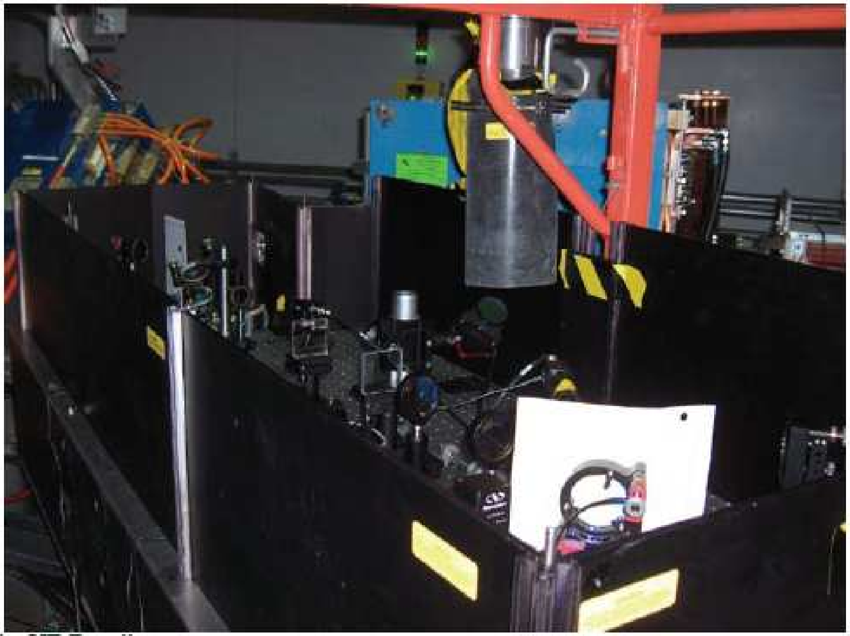


- The quantum-mechanical two-state problem with linearly ramped excitation frequency shows that the excited state is populated with high efficiency
- Estimations for existing SNS laser (10 MW 7 ns) gave 90% efficiency

Laser Stripping Assembly



Magnets
(BINP production)



Optics table (1st experiment)

1st experiment – failed
2nd 50% efficiency achieved
(v. chamber failure afterwards)
3rd – 85% achieved
4th – 90 % achieved

multiple problems were overcome
(e.g., windows broken by powerful laser)

↓

Laser power reduction – follow-up intermediate experiment

- Matching laser pulse time pattern to ion beam one by using mode-locked laser instead of Q-switched

  ~ x25 gain

- Using dispersion derivative to eliminate the Doppler broadening due to the energy spread

  ~ x10 gain

- Recycling laser pulse

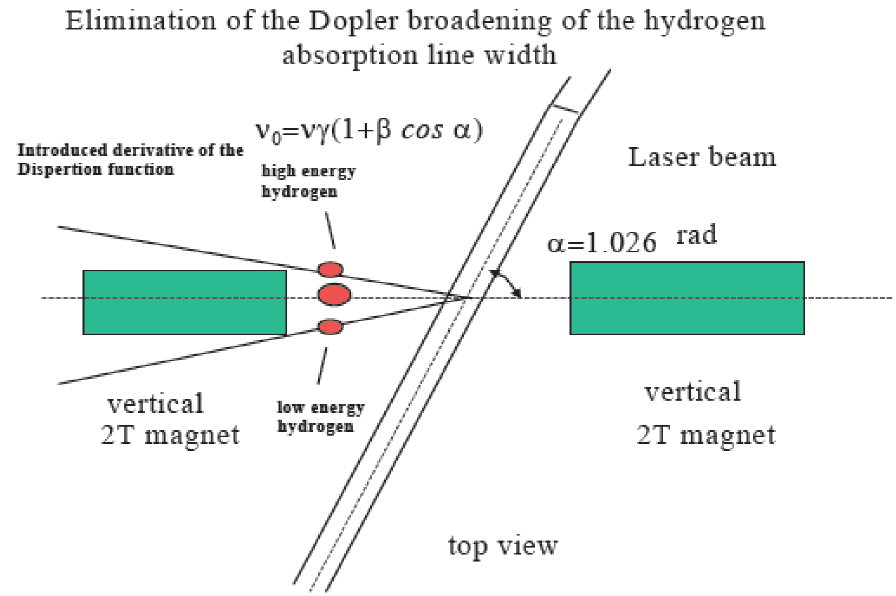
  ~ x10 gain

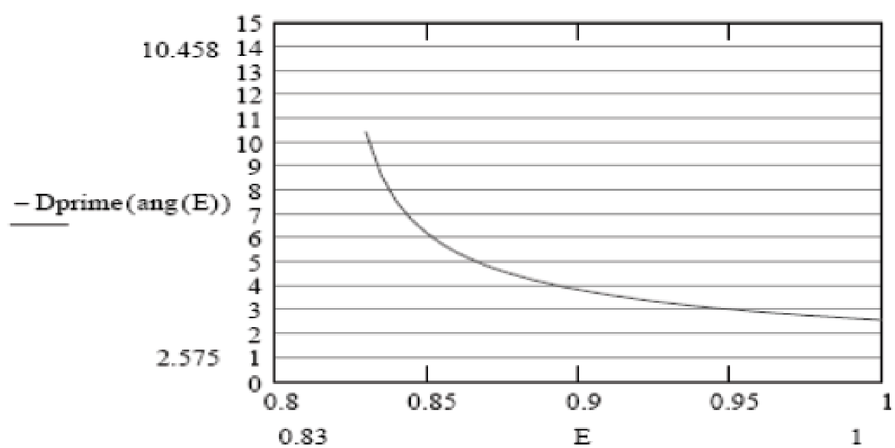
- Vertical size and horizontal angular spread reduction

  ~ x2-5 gain

By combining all factors the required average laser power can be reduced to 50 – 120W, which is within reach for modern commercial lasers.

Dispersion function tailoring



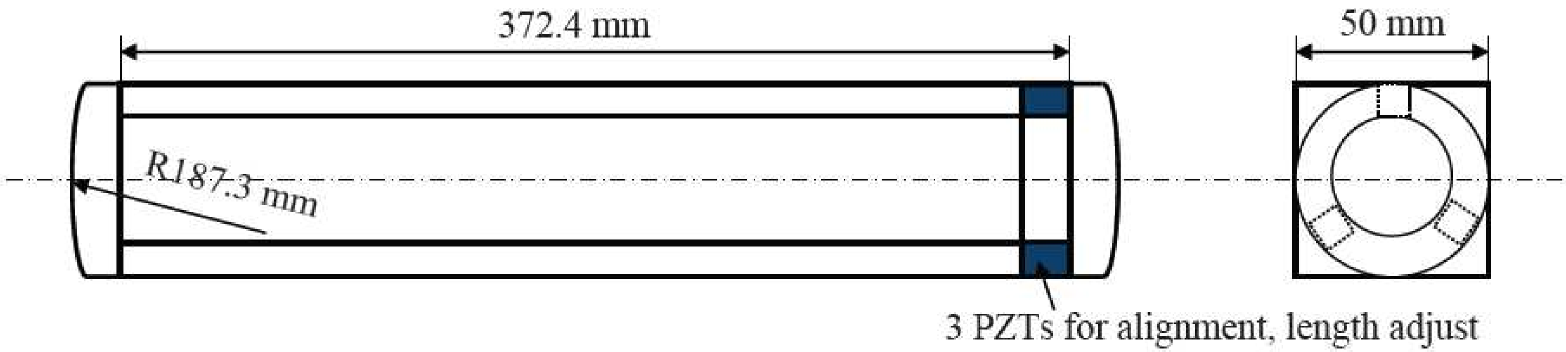


Introducing dispersion derivative at IP results in ion angle dependence on energy.

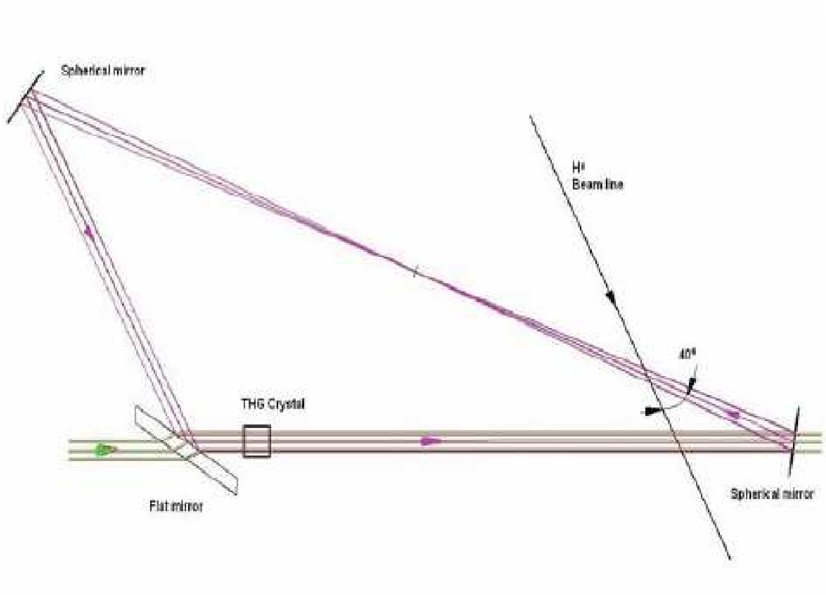
For 1 GeV SNS beam D'=2.58 is sufficient for full elimination of Doppler spread

Required dispersion is a very nonlinear function of energy. Higher energy is much preferable.

Fabri-Perot and Inside Crystal Conversion Schemes



Design and production: Light Machinery
Finesse: ~ 37
Designed power amplification factor: ~ 10
R > 92% at 355 nm



Inside Crystal Conversion
Flat mirror is transparent to fundamental harmonics and reflects 355 nm light

LASER STRIPPING FOR OTHER PROJECTS

Future projects with H^- beams tend to have higher energy than that of the SNS. This is driven by the need to reduce space charge effects at the ring injection energy. We focus on two future projects: the 4 GeV linac for the LHC new booster, and the Fermilab Project X with 8 GeV beams.

Both projects can build the laser stripping device with the existing technology. The reason for this is the following: for the LHC new linac with 4 GeV beam energy, and for Fermilab Project X with 8 GeV, the level n=2 can be excited by most common 1064 nm laser with incident angle equal to 47.5 and 95 degrees, respectively. The magnetic stripping of the n=2 level is described in detail in the first section. The required peak laser power for these projects is also much lower than that needed for the SNS laser stripping. This comes from two facts: higher dipole transition coefficients for n=2 as compared with the n=3 level, and relativistic amplification of the laser power in the rest frame of the hydrogen beam. A 1 MW peak power beam could do the excitation even without the dispersion derivative introduction. The levels can be achieved in, e.g., Fabri-Perot cavity with high degree of confidence and the overall average laser power could be reduced to the few-watt level.

Guidance from SNS

- They are considering making an operational system for the SNS
- They think a PrX stripper would be even simpler
  - Little to no D’ matching
  - Higher excitation cross section
  - Smaller beam cross section
  - …

Expanding

- They suggest a Nd:YAG at 95º
  - ➢ I think this is unrealistic
    - Tough angle
    - Can't really use Fabry-PerotCavity
- Better, I think, may be a Ho:YAG (Holmium)
  - ➢ 2100 nm instead of 1040
  - ➢ 35º instead of 95º
- Fiber lasers are also a apossibility

Holmium Lasers

- Industrialized for endocrinology
    - Treating stones
- Maybe not as mature as Nd:YAG, but availability is not a problem
- Also, longer wavelength is generally safer

LUMENIS
Enhancing Life. Advancing Technology.

Laser Power

- Turnkey 100 W lasers are available
  - ➢ 3.5 J over 0.5 ms

Models	Single Wavelength: Holmium		
	20 Watt	60 Watt	100 Watt
Wavelengths	2.1 microns	2.1 microns	2.1 microns
Repetition Rate	5-20 Hz	5-40 Hz	5-50 Hz
Energy per Pulse	0.5 - 2.5J	0.2–3.5J	0.2–3.5J
Max. Tissue Effect Setting	2J/10 Hz	1.5J/40 Hz	2J/50 Hz
Electrical	110V/15A & 220V/10A 50/60 Hz Single Phase	230V, 50/60 Hz 20/30A Single Phase	230V, 50/60 Hz 20/30A Single Phase
Dimensions	19" x 24" x 45" (48 cm x 61 cm x 114 cm)	18" x 36" x 39" (46 cm x 91 cm x 99 cm)	18" x 36" x 39" (46 cm x 91 cm x 99 cm)
Aiming Beam	0.8 mW at 650 nm, 3 intensity settings, constant and blinking modes	2.5 mW at 650 nm, 3 intensity settings, constant mode	2.5 mW at 650 nm, 3 intensity settings, constant mode
Treatment Data Output	Printer Output	None	None
Weight	185 lbs/84 kg	340 lbs/155 kg	340 lbs/155 kg
Pulse Duration	Up to 500 microseconds		
Cooling	Self-contained water-to-air exchanger		
Delivery Systems	More than 20 reusable and single-use, flexible and rigid, with standard SMA connector		
Warranty	One year parts and labor.		

Near-Term Plan

- Generate strawman designs based on SNS scheme
  - Nd:YAG and HO:YAG
- Get real estimates for laser power
- Understand requirements on beam parameters
- Get more guidance from SNS