First Steps Toward Laser Stripping Implementation

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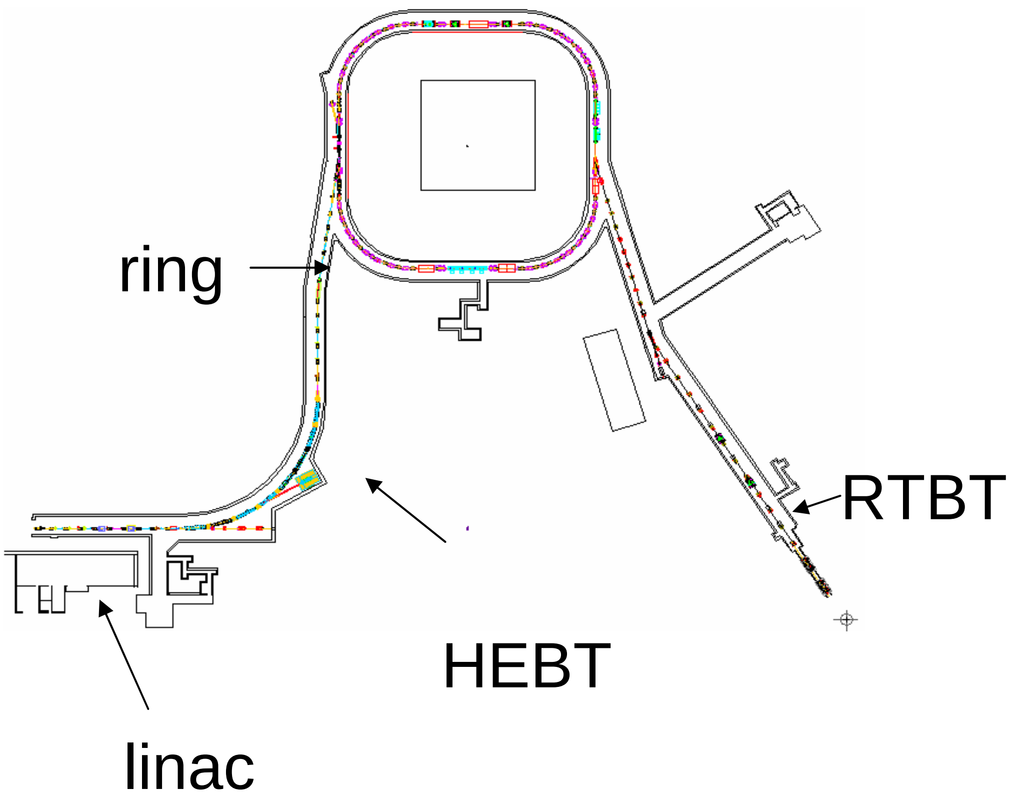
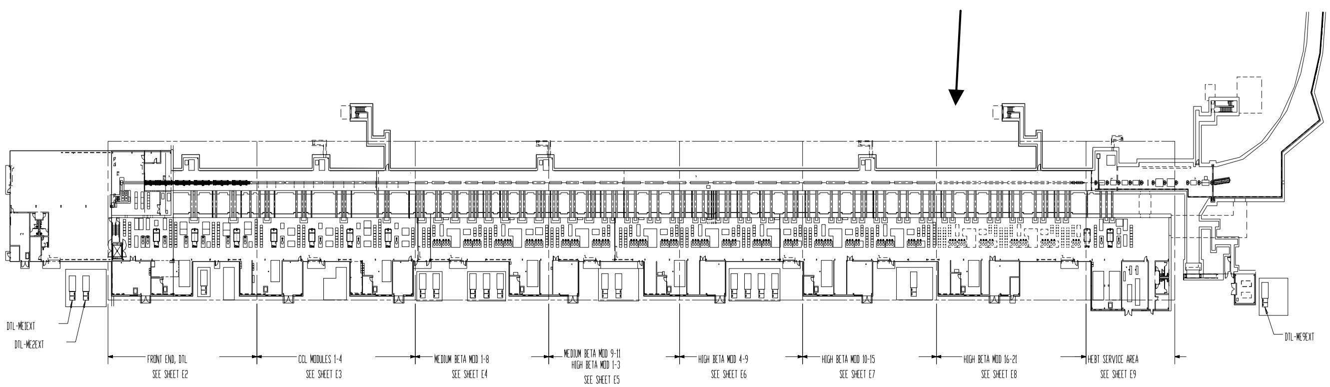
Powerful Facilities Motivation (SNS Example)

Ring parameters:

- ~ 1GeV (860-931 MeV in our studies)
- Design intensity – 1.4×10^{14} protons
- Power on target – 1.4 MW at first stage
- Foils used to get high density beams (non Liouvillian injection)

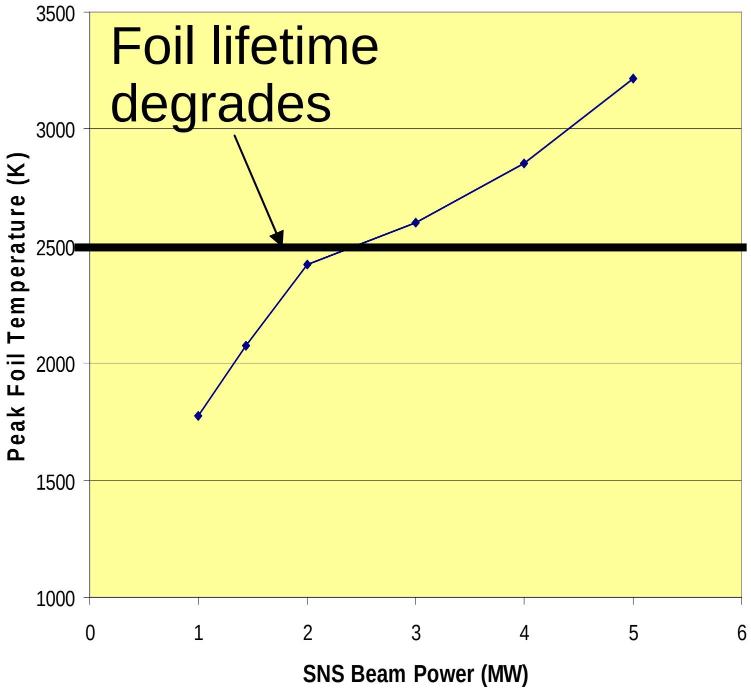




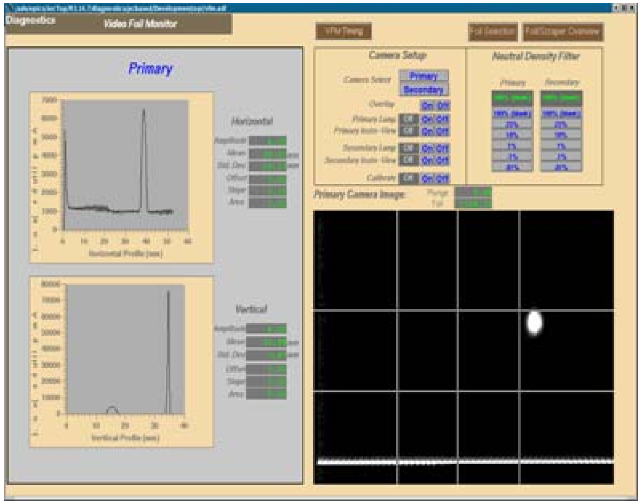
Stripping Foil Limitations

- The SNS will use 300-400 $\mu g/cm^2$ Carbon or Diamond foils
- Two important limitations:
  1. Foil Lifetime: tests show rapid degradation of carbon foil lifetime above 2500 K, yet we require lifetime > 100 hours
  2. Uncontrolled beam loss: Each proton captured in the ring passes through foil 6-10 times: leads to uncontrolled loss of protons

Presently, injection area is the most activated at SNS



SNS Foil Glowing 160 kW

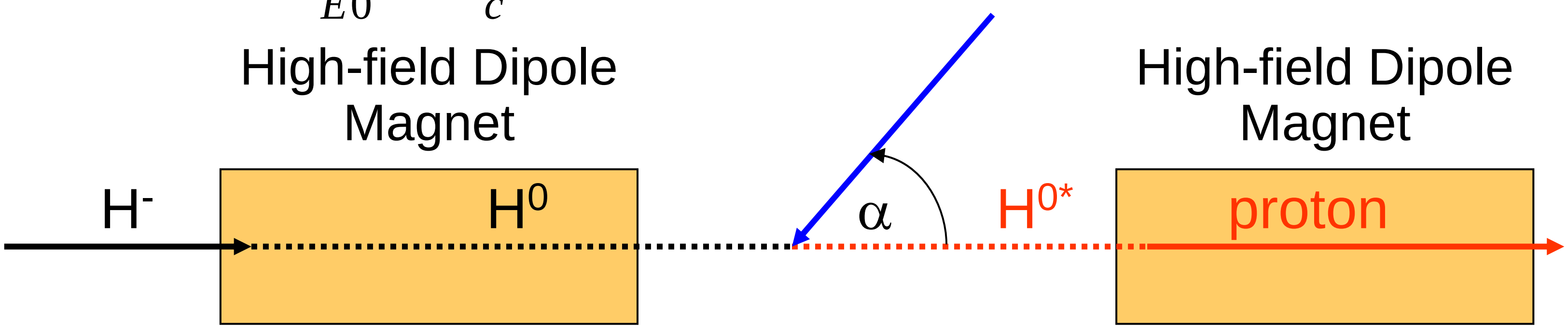


Damaged PSR Foil

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]**

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



Step 1: Lorentz Stripping

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

Step 2: Laser Excitation

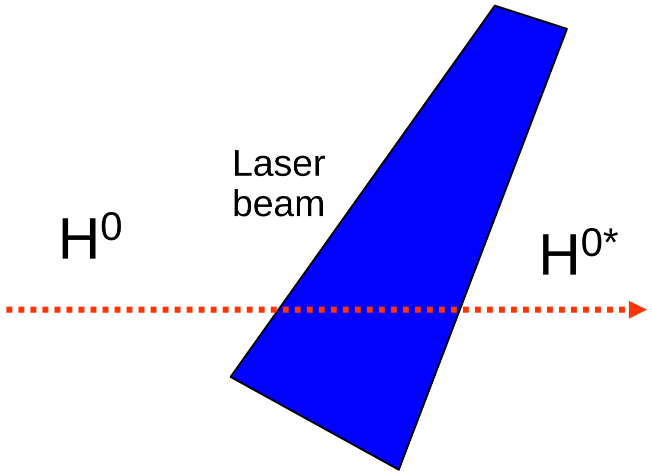
$H^0\ (n=1) + \gamma \rightarrow H^{0*}\ (n=3)$

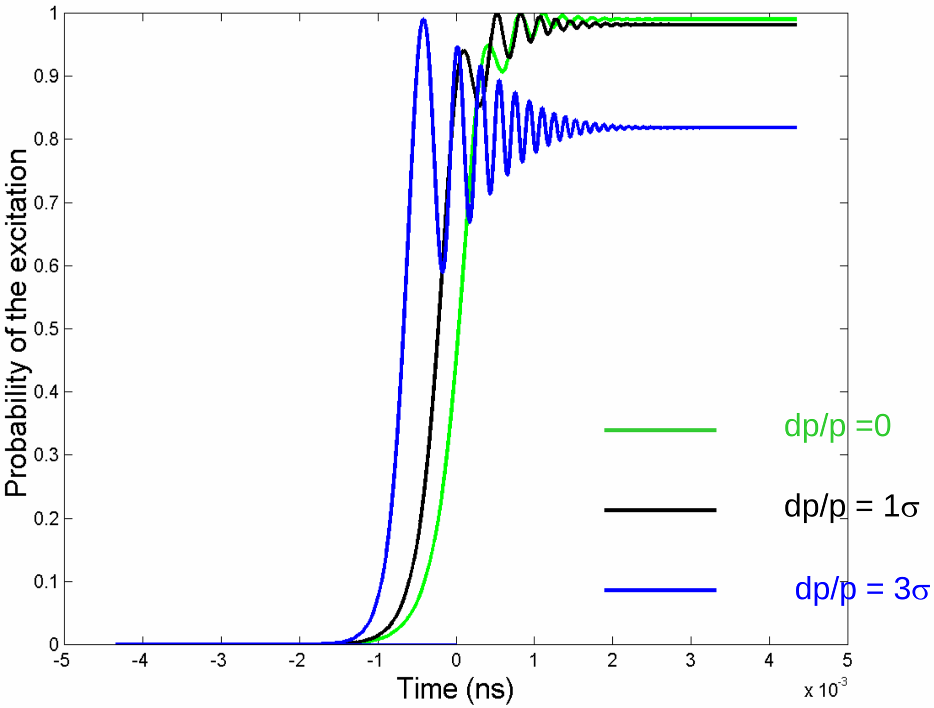
Step 3: Lorentz Stripping

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

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

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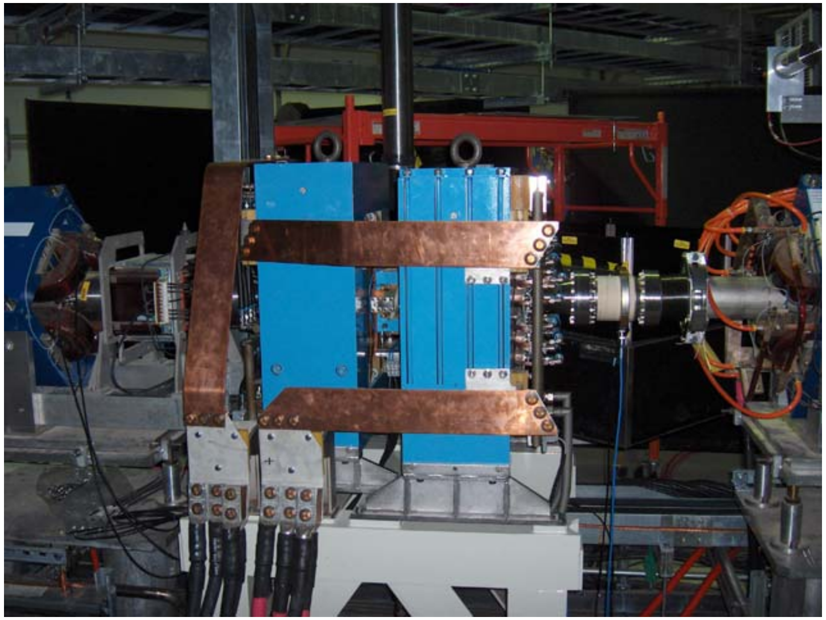
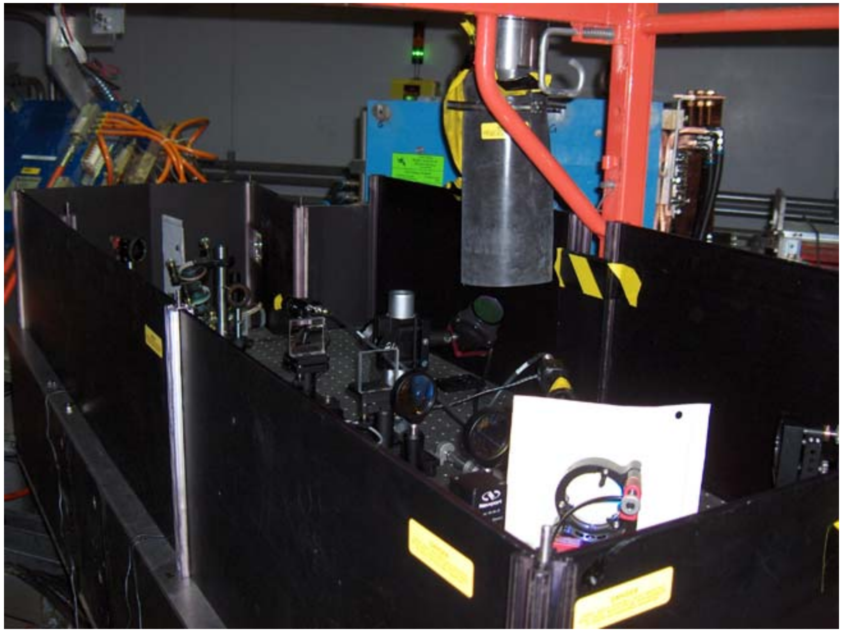
Laser Stripping Assembly



Magnets
(BINP production)



Optics table (1st experiment)

1st experiment – failed

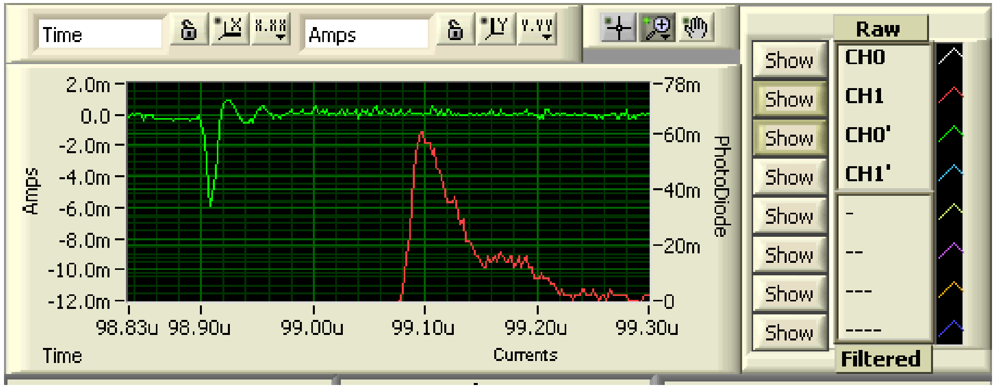
2nd 50% efficiency achieved
(v. chamber failure afterwards)

3rd – 85% achieved

4th – 90 % achieved

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

First Observation of Laser Stripping



The first signal of stripping observed in March, 2006

5 minutes later

Sasha Aleksandrov

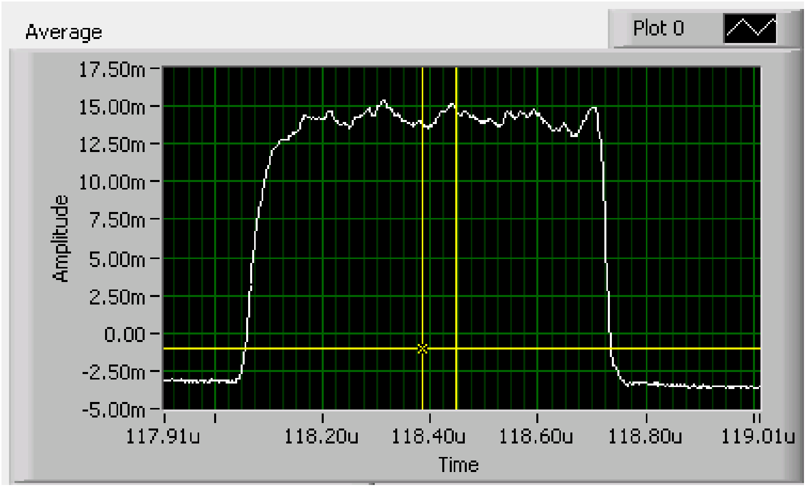
Wim Blokland

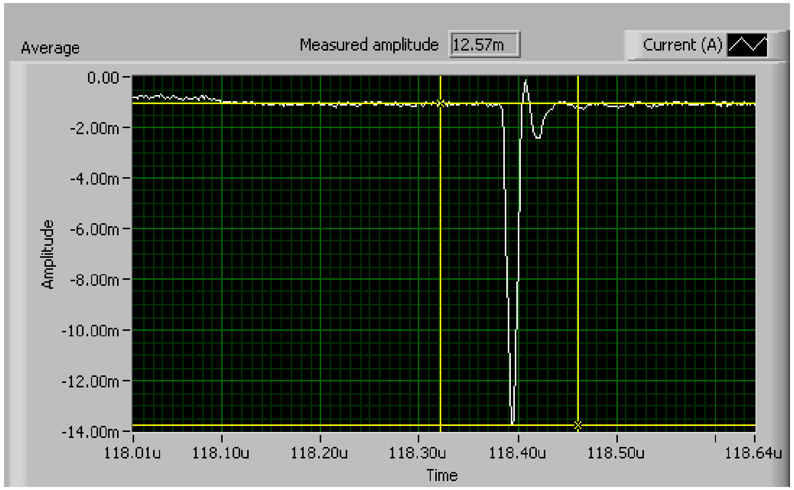
Andrei Shishlo

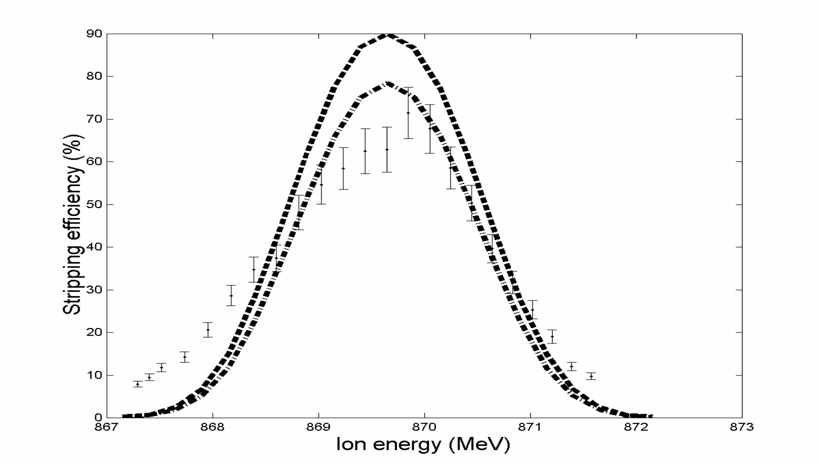
The first people to see the laser stripping signals

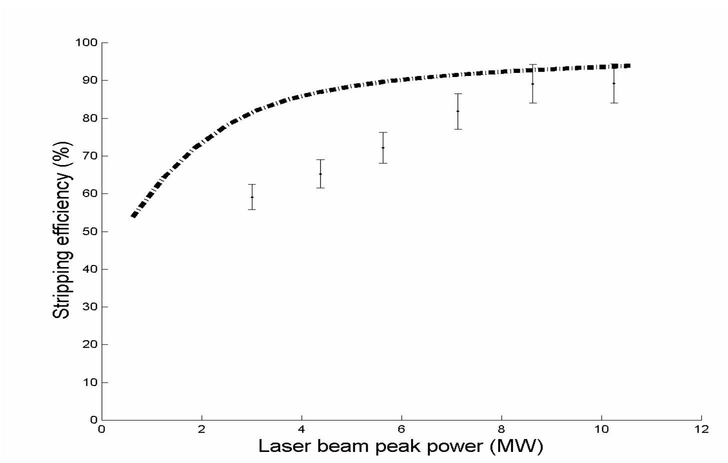
Self-organized criticality of luck

Experimental results









The maximal achieved efficiency: 0.85±0.1 (3rd run) and 0.9 ±0.05 (4th run)
Straightforward use is costly – laser power needed is 10 MW*0.06=.6 MW

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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

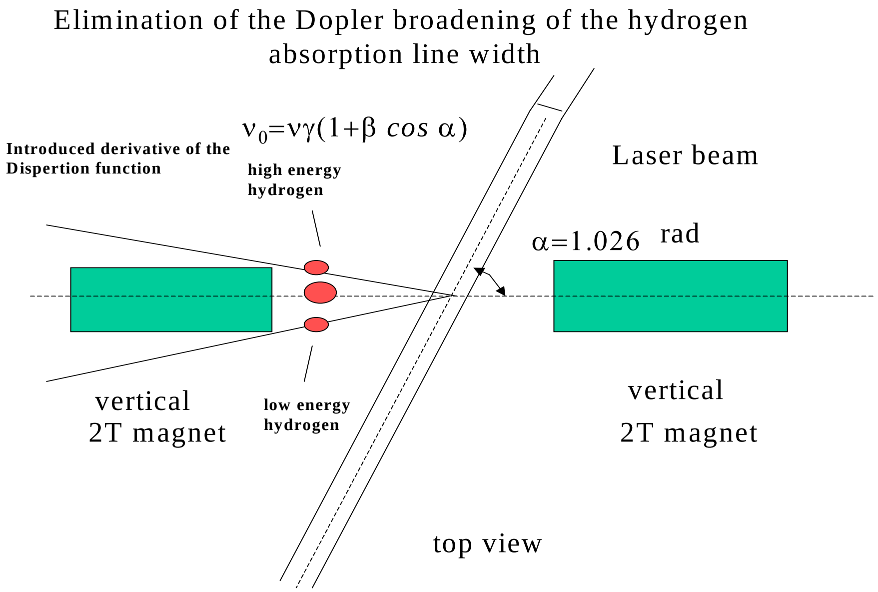
  ~ x10 gain

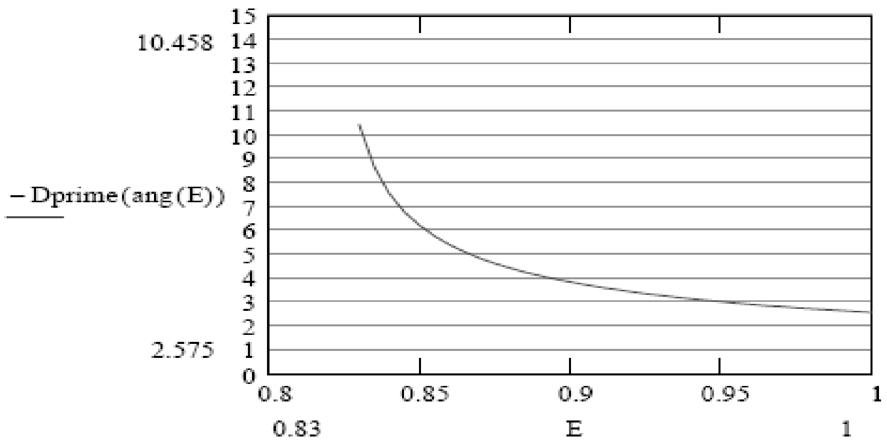
- Vertical size and horizontal angular spread reduction

  ~ 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



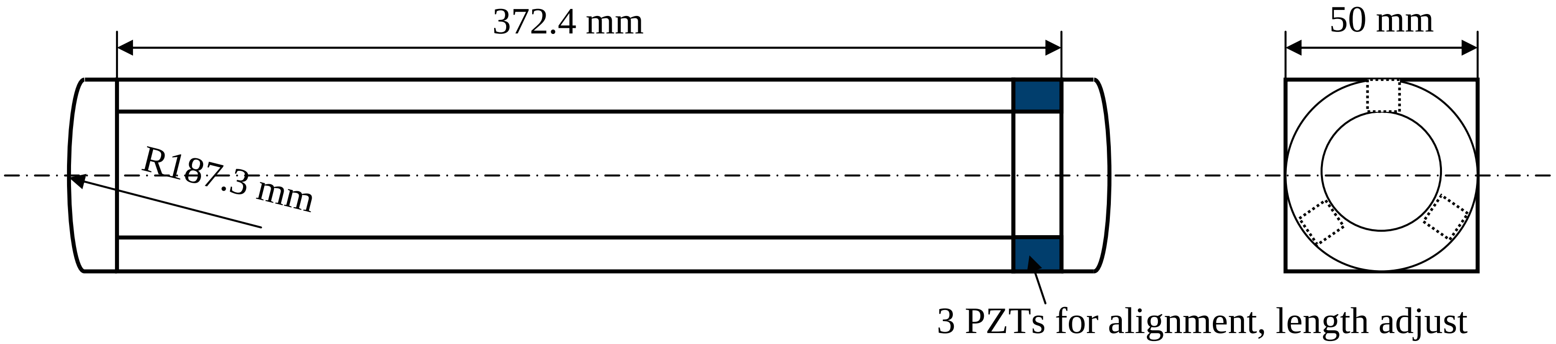


Introducing dispersion derivative at IP results in ion angle dependence on energy.

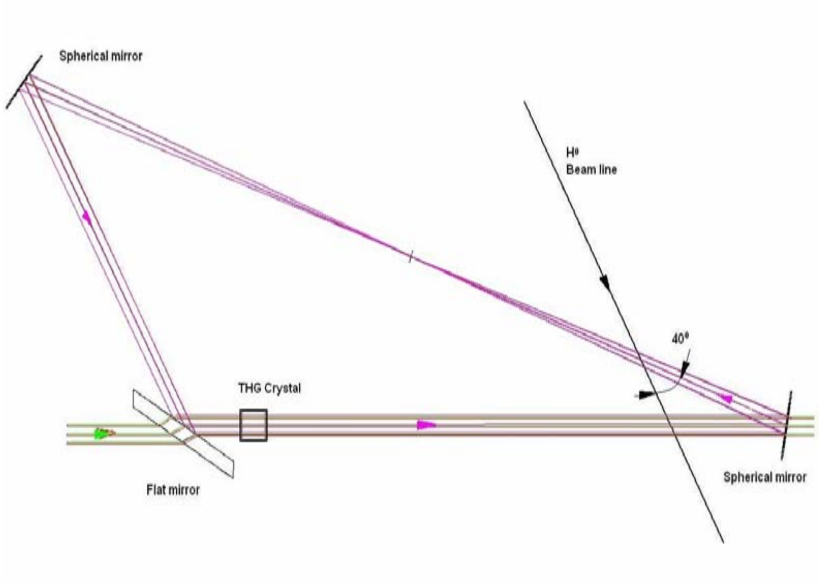
For 1 GeV SNS beam D'=2.58 is sufficient for full elimination of Doppler spread

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

Fabri-Perot and Inside Crystal Conversion Schemes



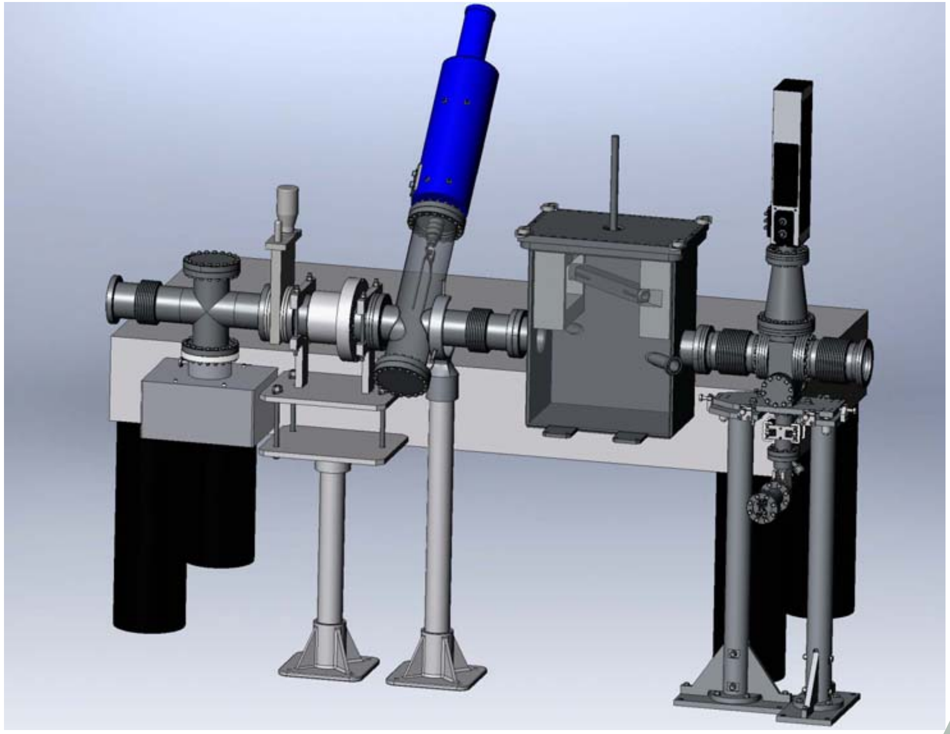
Design and production: Light Machinery
Finesse: ~ 37
Designed power amplification factor: ~ 10
R > 92% at 355 nm



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

New experiment place

Experimental assembly to replace HEBT straight section before the last bending magnet



New projects with possible Laser Stripping Applications

- **SNS have to use UV (355 nm) light due to low (1GeV) energy – it complicates development. Also it is hard to use n=2 level – it requires superconducting stripping magnets**
- **LHC (CERN) Upgrade – 4 GeV linac. Due to higher energy n=2 can be used. 1064nm (most convenient) light is applicable**
- **Project X (Fermilab) – 8 GeV linac. Again 1064 nm laser can be used**

This projects are good next choices for laser stripping device

Summary

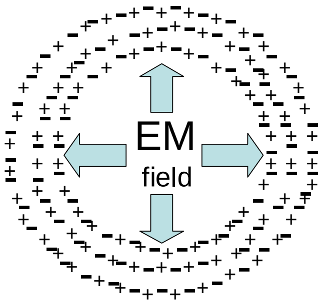
- **Laser stripping project was a successful collaboration of two ORNL labs**
- **It opened the road to full-scale laser stripping device**
- **Follow-up development is underway**

If final stage is successful, the device can be used at all powerful proton accelerators in the world

Unexpected Physics – from laser Stripping to Self-Sustained Formations

Model for self-consistent formation:

1) Dense ion beams fully reflect light in resonance with transition levels;
2) Light can be trapped in the resonant- atom medium;
3) Induced dipoles interact strongly with each other – gas becomes liquid with surface tension counteracting field pressure;
4) The field can be excited by discharge like in gas lasers.



Cross section of torroidal formation

V. Danilov, “Resonant Atom Traps for Electromagnetic Waves**”,** arXiv: 0708.4055 (2007)
V. Danilov, “On Electromagnetic Wave Interaction with Dense Resonant Atom Medium**”,** arXiv: 0806.1526 (2008)

Acknowledgements

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My wife

My long-term supervisors:
Yuri Shatunov, Norbert Holtkamp, Stuart Henderson

My numerous colleagues and friends from
Budker INP, Fermilab, ORNL

Frank Sacherer (1940-1978)

El Captain, 7569ft, Yosemite Park, CA
One of the route free-climbed first
by Sacherer in summer , 1964
(Sacherer Summer – he was first
in 11 out of total 12 first-free-climbed
Highest Grade routs in Yosemite)