Overview of Laser Stripping Development

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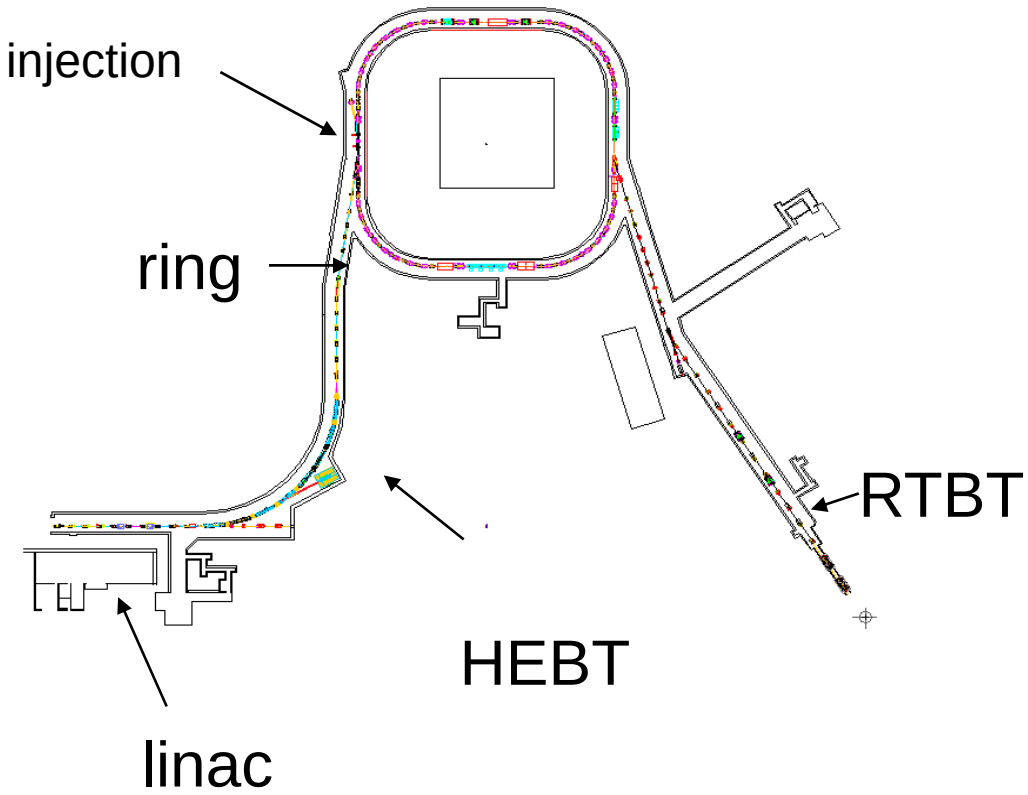
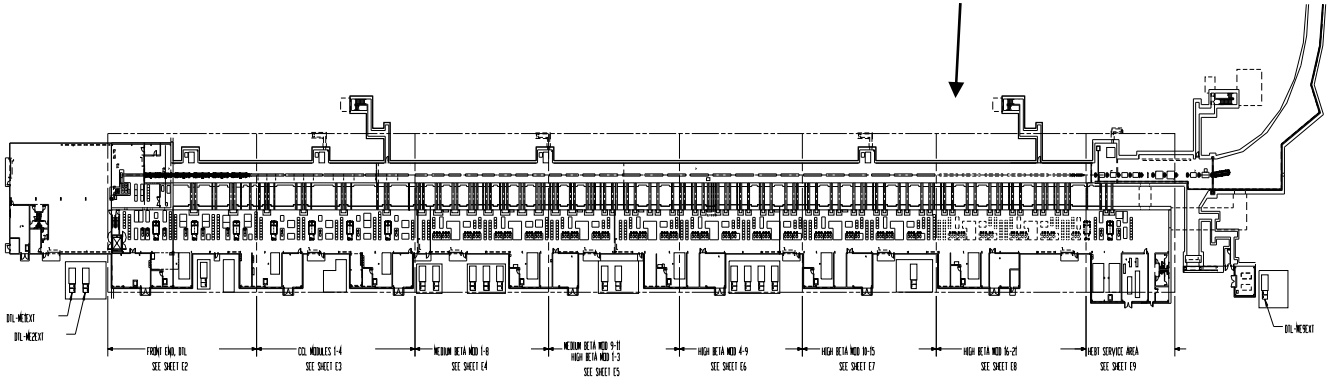
SNS, Oak Ridge, TN

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)

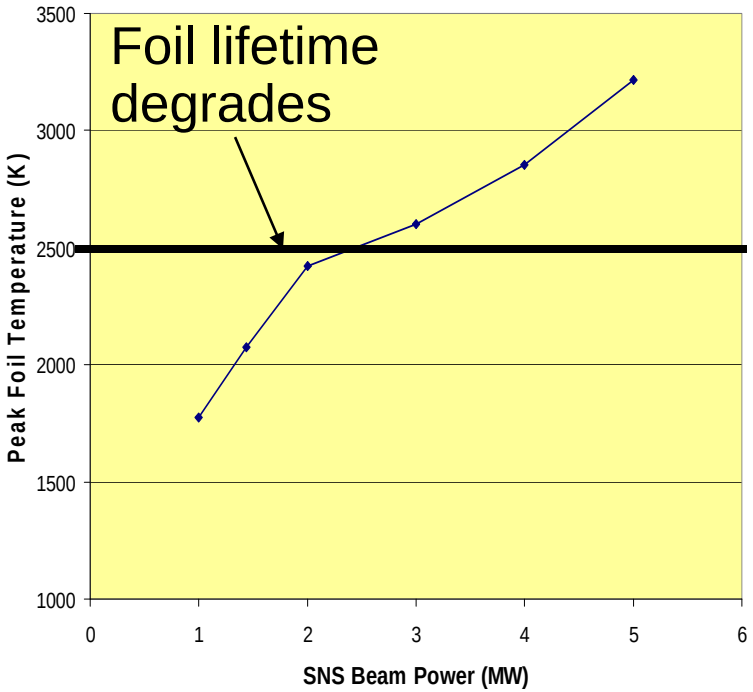




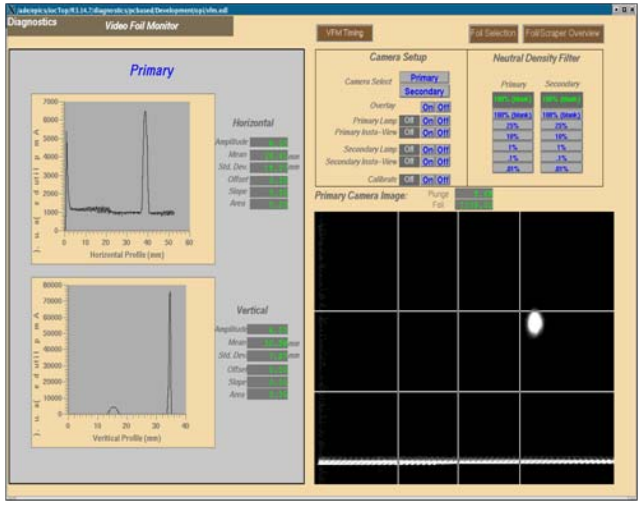
Stripping Foil Limitations

- 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

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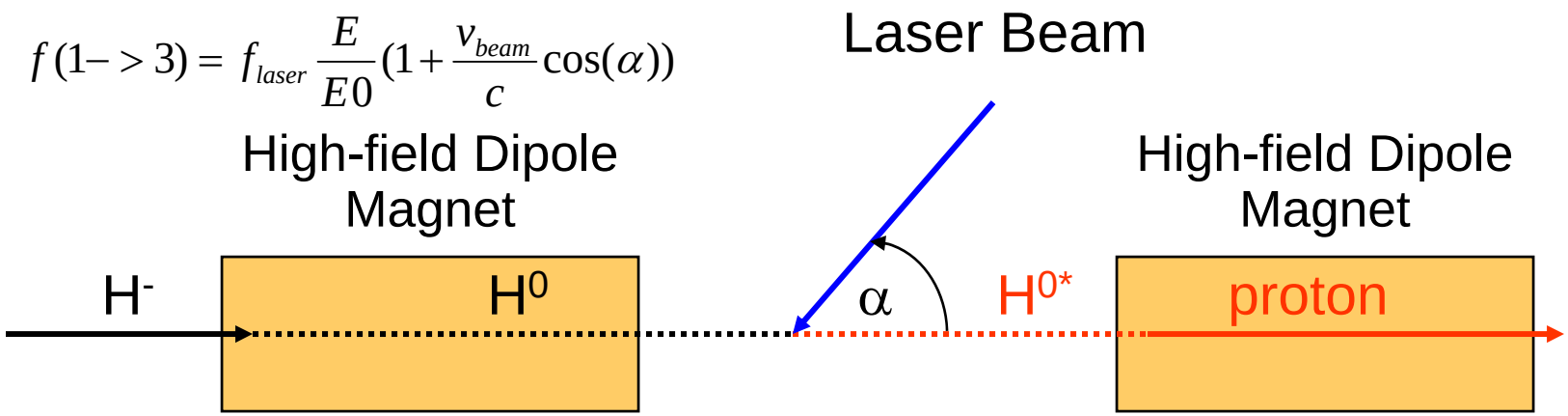
Three-Step Stripping Scheme

- **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

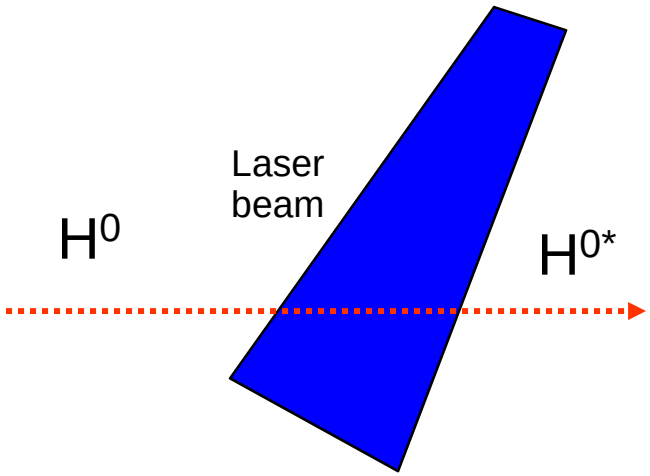
$H^0\ (n=1) + \gamma \rightarrow H^{0*}\ (n=3)$

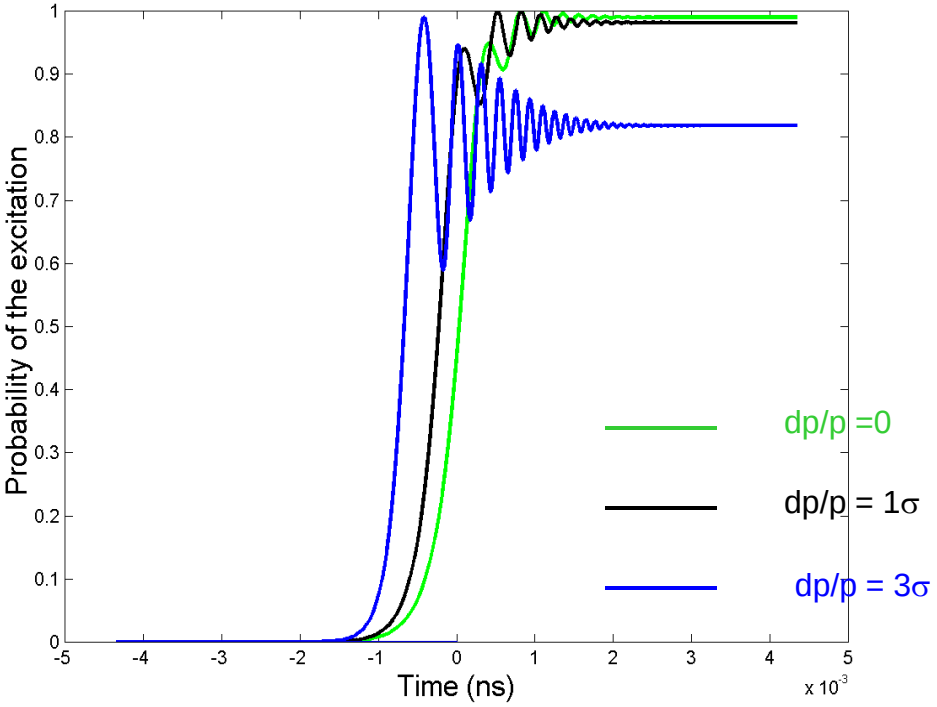
Step 3: Lorentz Stripping

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

Approach that Overcomes the Doppler Broadening

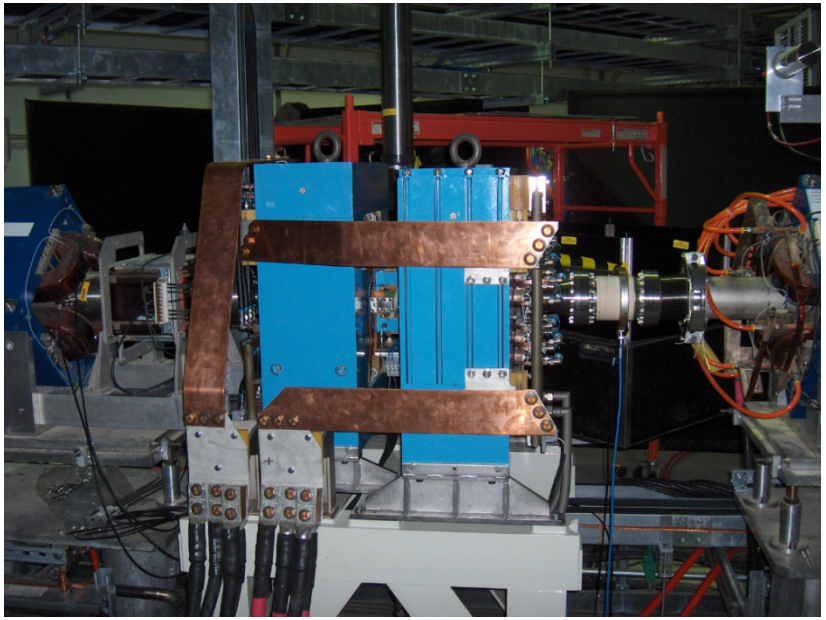
- **By intersecting the H^0 beam with a *diverging* laser beam, a frequency sweep is introduced:**

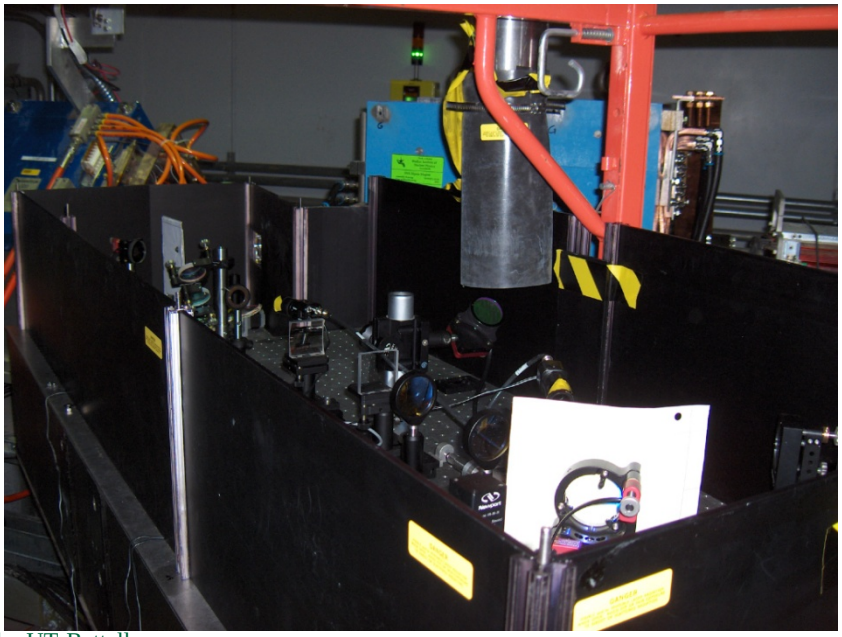




- The quantum-mechanical two-state problem with linearly ramped excitation frequency shows that the excited state is populated with high efficiency
- Estimations for existing SNS laser (10 MW 7 ns) gave 90% efficiency

Laser Stripping Assembly



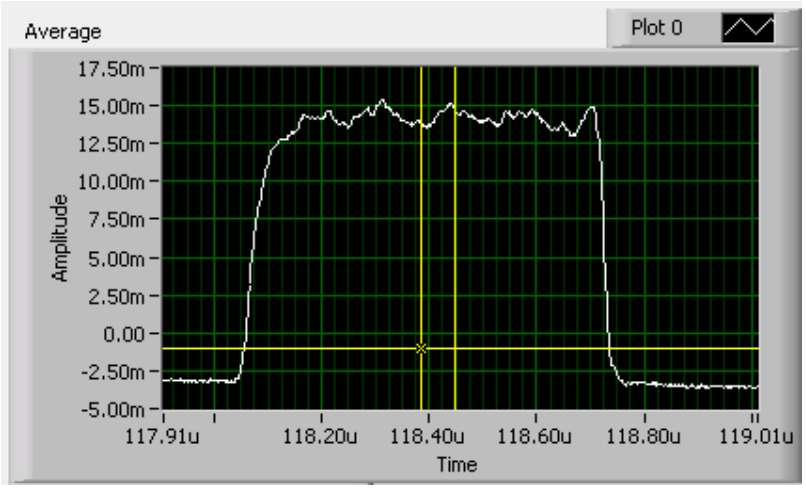


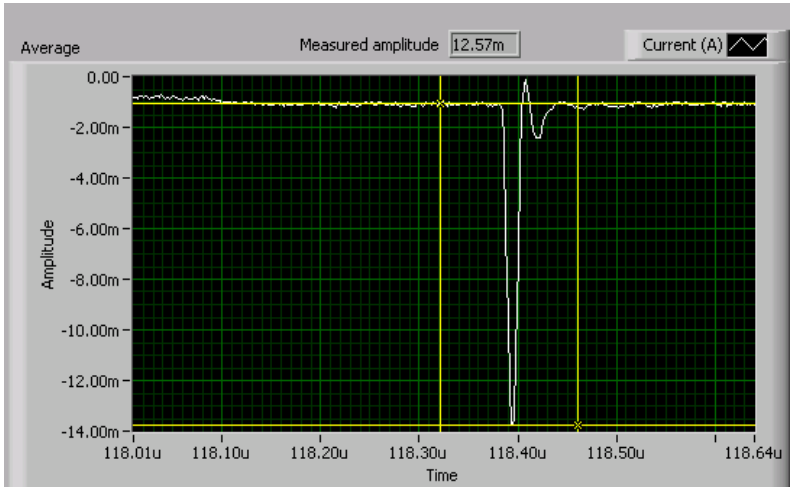
Magnets
(BINP production)

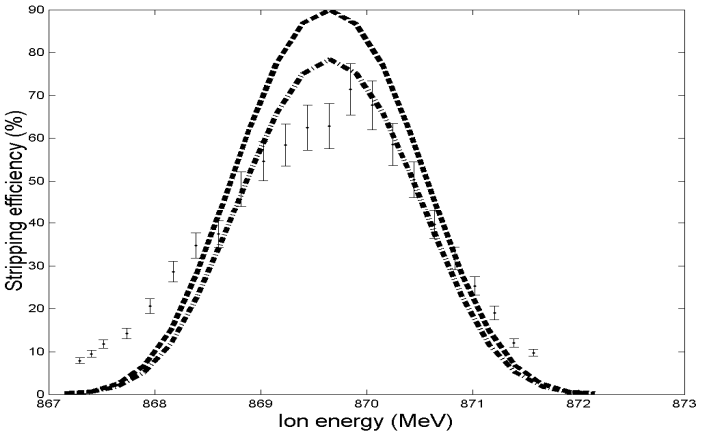
Optics table (1st experiment)
1st experiment – failed
2nd 50% efficiency achieved
(v. chamber failure afterwards)
3rd – 85% achieved
4th – 90 % achieved

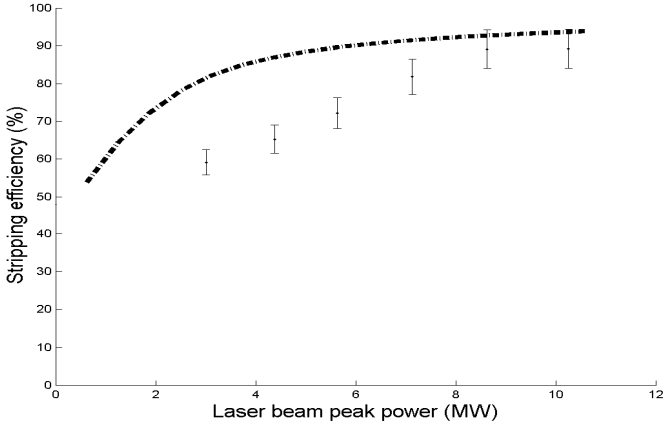
multiple problems were overcome
(e.g., windows broken by powerful laser)

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

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**

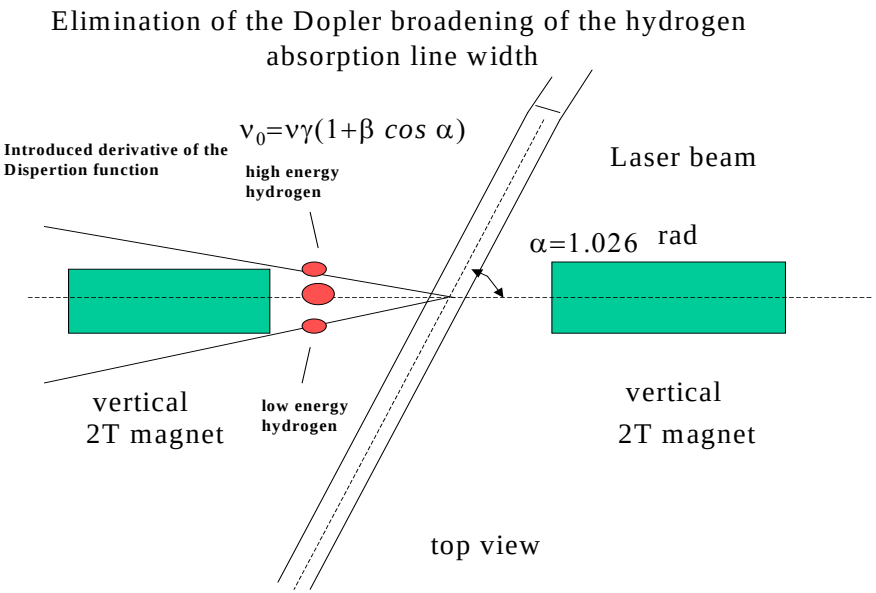
  ~ x10 gain

- **Vertical size and horizontal angular spread reduction**

  ~ x2-5 gain

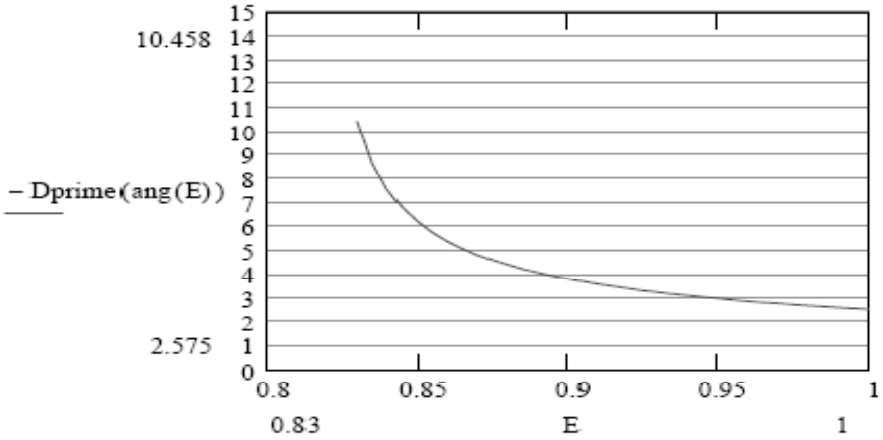
By combining all factors the required average laser power can be reduced to 50 – 120W, which is within reach for modern commercial lasers.

Dispersion function tailoring



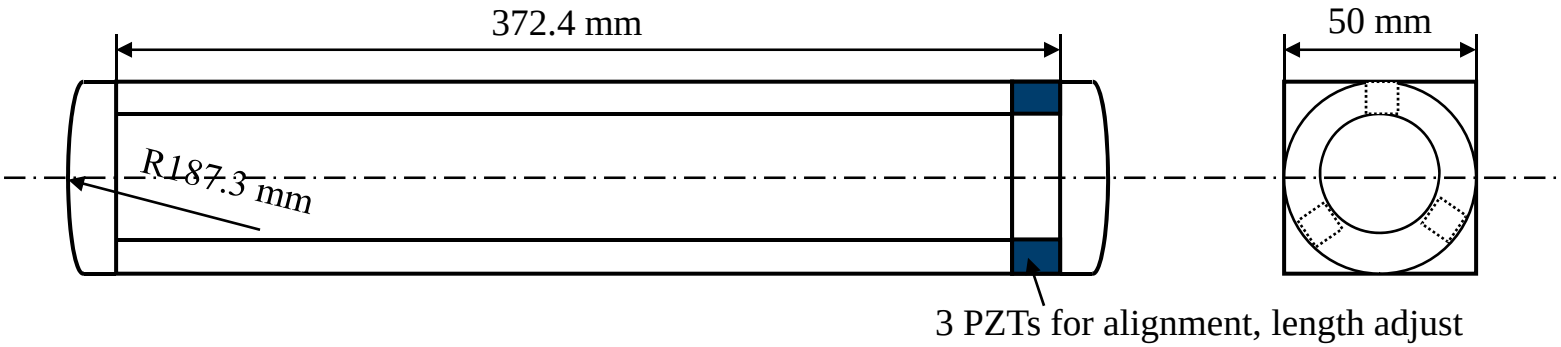
Introducing dispersion derivative at IP results in ion angle dependence on energy.

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

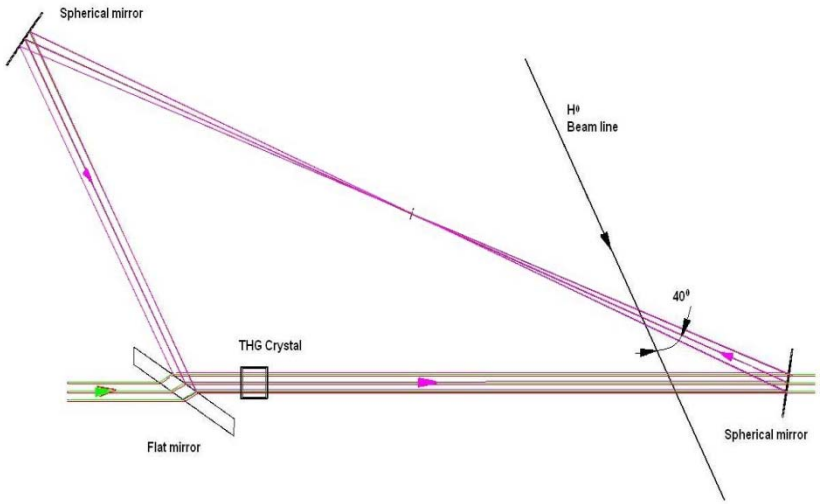


Required dispersion is a very nonlinear function of energy. Higher energy is much preferable.

Fabri-Perot and Inside Crystal Conversion Schemes



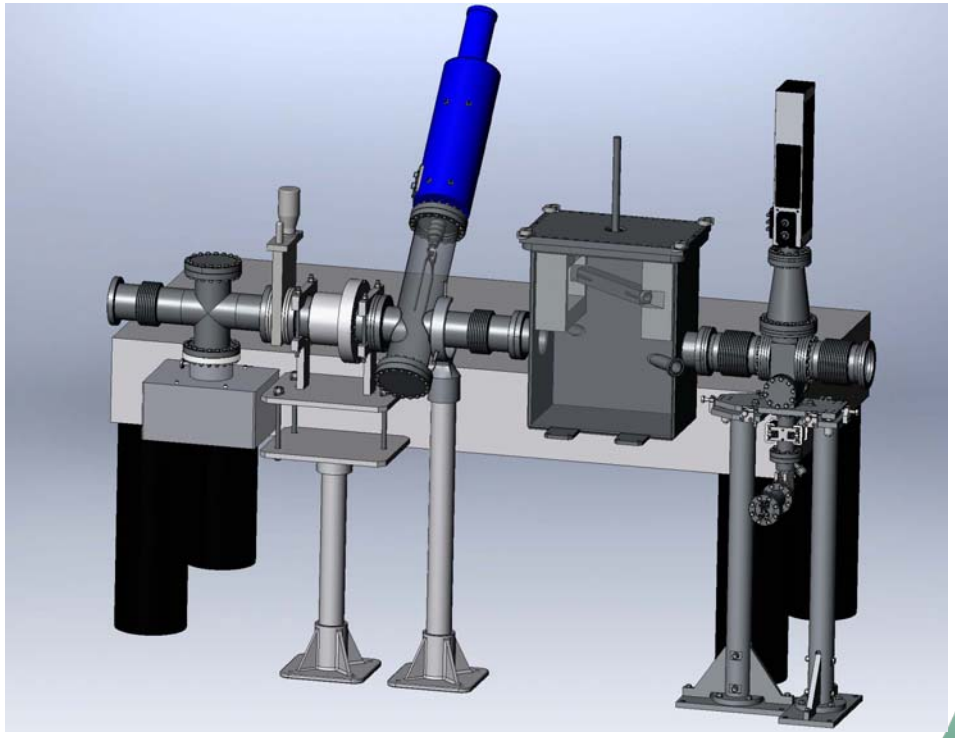
Design and production: Light Machinery
Finesse: ~ 37
Designed power amplification factor: ~ 10
R > 92% at 355 nm



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

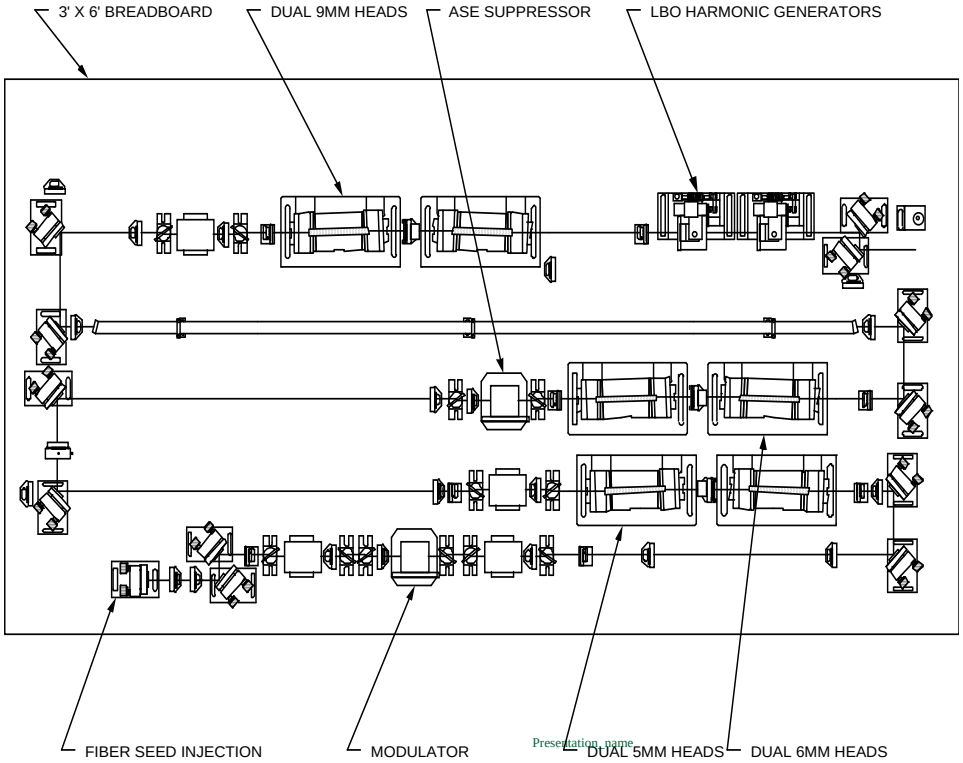
New experiment place

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



Mode locked laser parameters

Parameter	Offered	Comment
Wavelength	355nm	
Energy	30 uJ	
Pulse Duration	10 μs	>10μs possible with programmable waveforms
SLM Oscillator	mode locked	
Temporal Profile	flat envelope	
Beam Diameter	~5mm	
Spatial Profile	Like Powerlite	Harmonics at laser
Beam Divergence	Like Powerlite	
Repetition Rate	10 Hz/402.5 MHz	Macropulse rate / micropulse rate
Shot to Shot Stability	3% RMS	for pulse envelope
Polarization	Vert	
Jitter	<50ns	Macropulse envelope
Interface	GUI	
Laser Head size	3' x 6' x 13"	Larger table available for upgrades
Cabinets	CAB35	
Electrical Requirements	30A 1 phase 220V	
Water Requirements	2 X Powerlite	

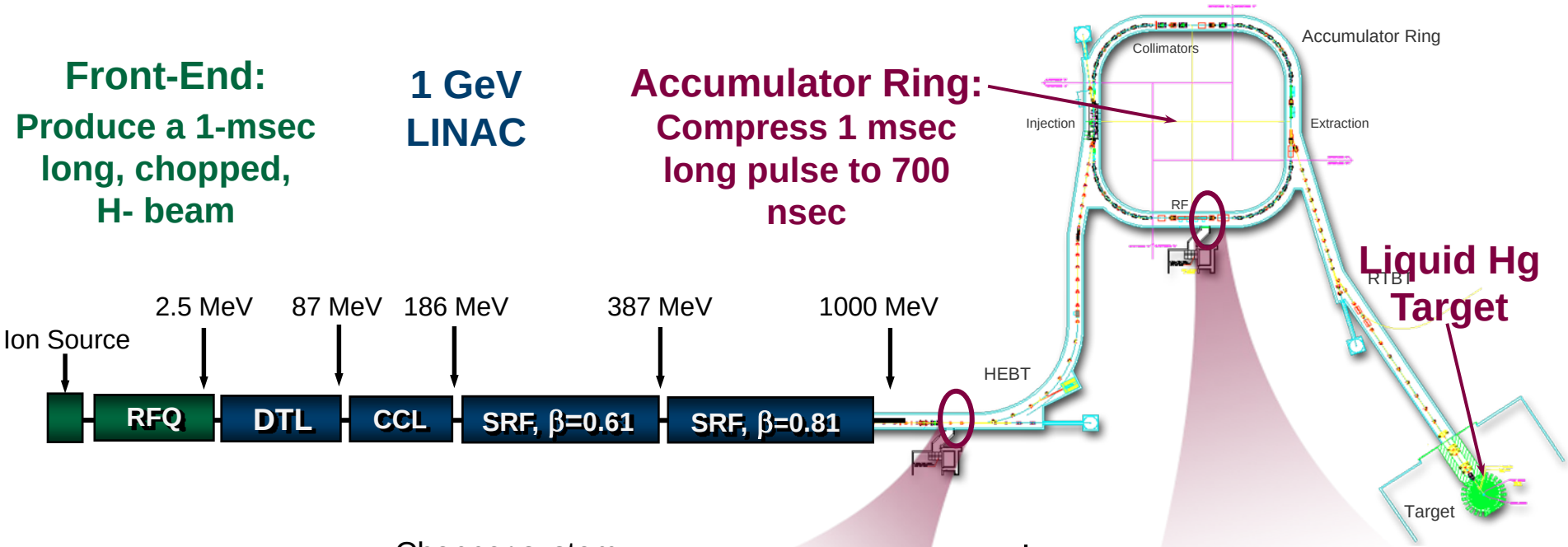


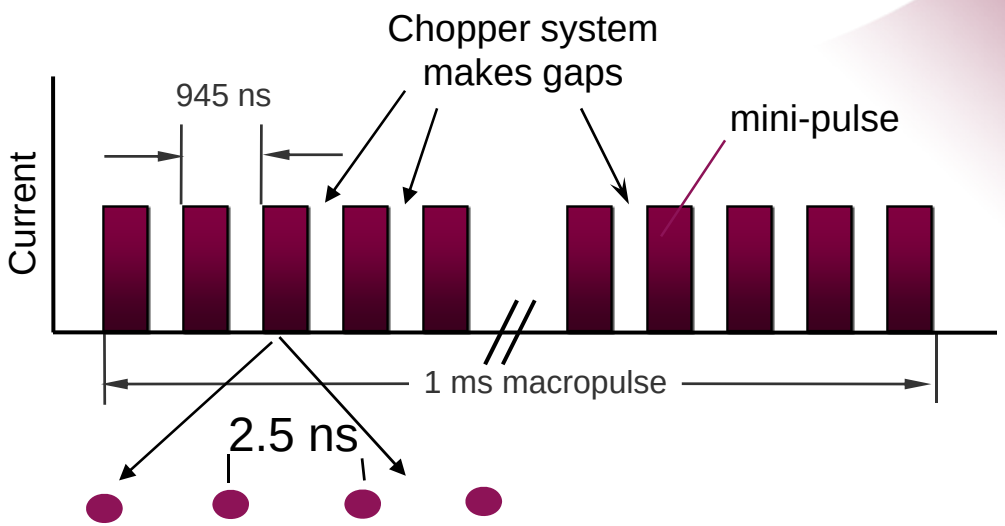
SNS Accelerator Complex

Front-End:
Produce a 1-msec long, chopped, H- beam

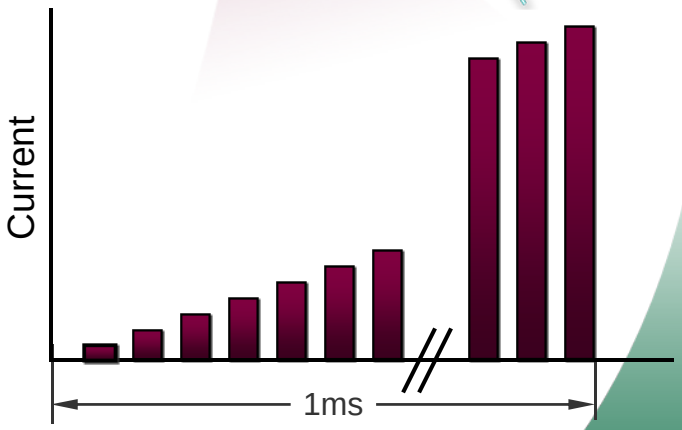
1 GeV LINAC

Accumulator Ring:
Compress 1 msec long pulse to 700 nsec





H- bunches, 402.5 MHz 5-150 ps long



SNS – 60 Hz
Project X, LHC Booster
0.5 – 5 Hz

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List of Requirements to the LS Lasers

- **Wavelength – 355nm (SNS), 532-1064 or more (CERN, Fermilab)**
- **Micro bunch length FWHM – 50-100 ps**
- **Peak power ≈ 1 MW**
- **Rep. rate of micro bunches – 402.6 MHz (SNS), 352.2 MHz (CERN, Fermilab)**
- **Macro pulse duration ≈ 1 ms**
- **Rep. rate of the macro pulse – 0.5 Hz – 60 Hz (SNS)**
- **Question to participants – what is the optimal way to build this laser?**
- **The other question – how to arrange the injection area?**