First Results of SNS Laser Stripping Experiment

Viatcheslav Danilov

On behalf of the ORNL Laser Stripping Team

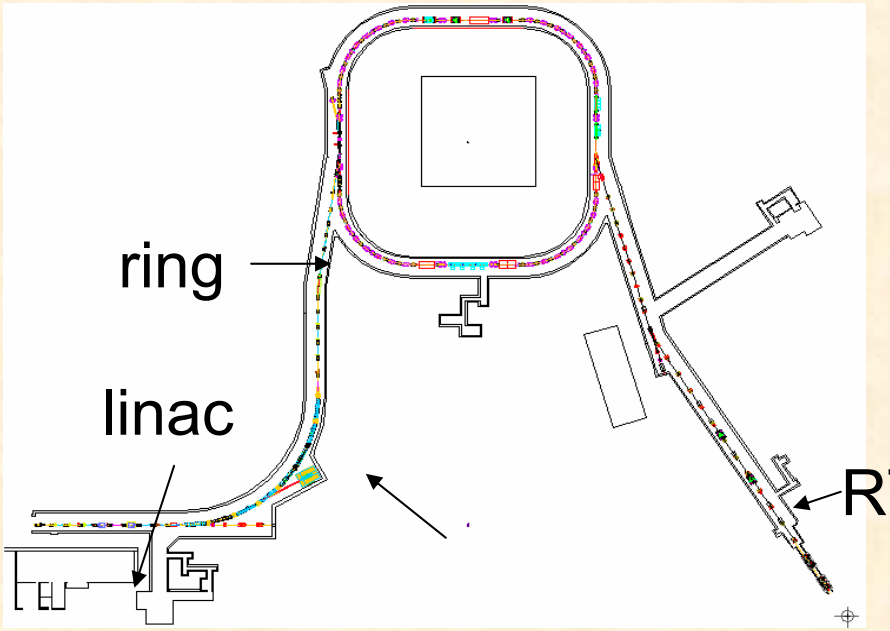
EPAC, Edinburgh, UK, 26-30 June 2006

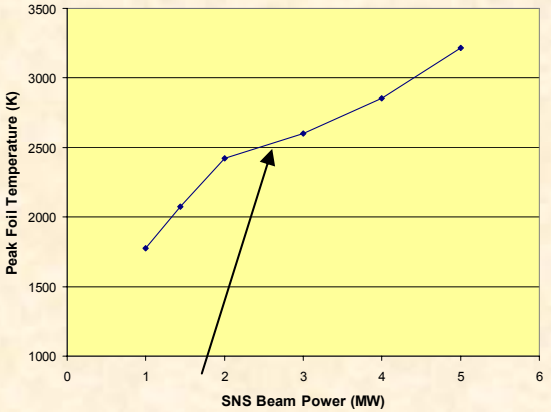
OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

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
- The ring design was low-loss high intensity oriented
- Foils used to get high density beams (nonliuvillian injection)
- Drawbacks – short lifetime, activation, high loss





Foil degrades

History and Directions

- Initially was proposed by Zelensky, *et al (*NIM A, 227 1984).

  This paper described 3-step stripping method – H^- conversion to H^0, H^0 excitation from ground to upper state and then H^0->p conversion using photo ionization.

- Main problem arise – energy spread of ions too large to get excitation of all beam. Variety of methods were proposed to overcome the difficulty. Two of them are foundations for described below POP experiments:

  1) Froissart-Stora excitation. V. Danilov *et al*, SNS TechNote (April 2002), Phys. Rev. ST Accel. Beams 6, 053501 (2003)

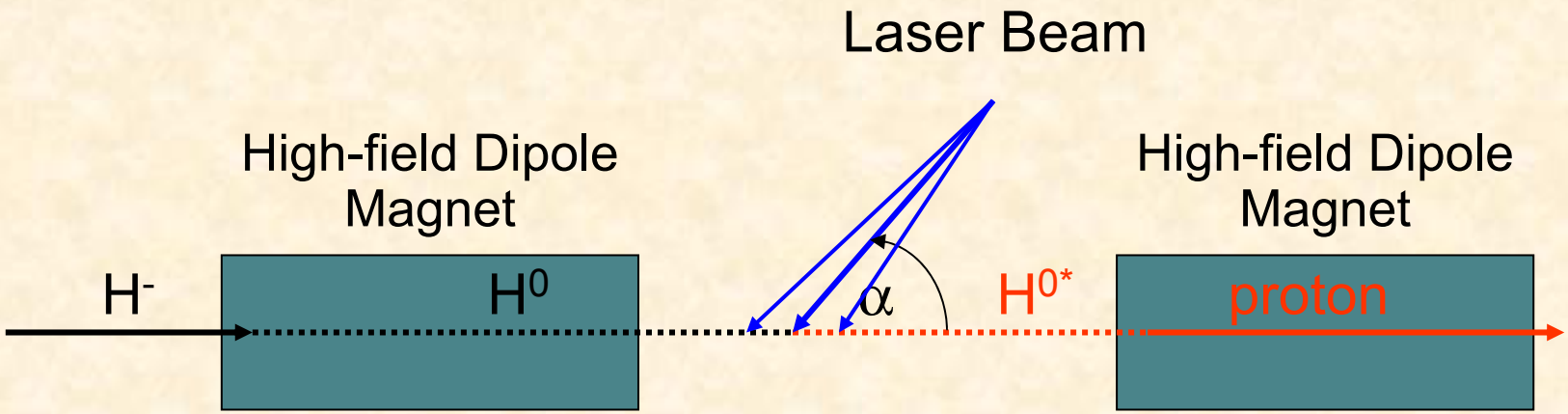
  2) Broadening the upper levels by electric field (I. Yamane *et al*, KEK Preprint, July 2002)

One more substantial trick to reduce power, applicable to all the methods:

dispersion function tailoring to eliminate Dopler spread of transition frequencies - V. Danilov *et al*, Phys. Rev. ST Accel. Beams 6, 053501 (2003)

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, 053501,2003]**



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

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

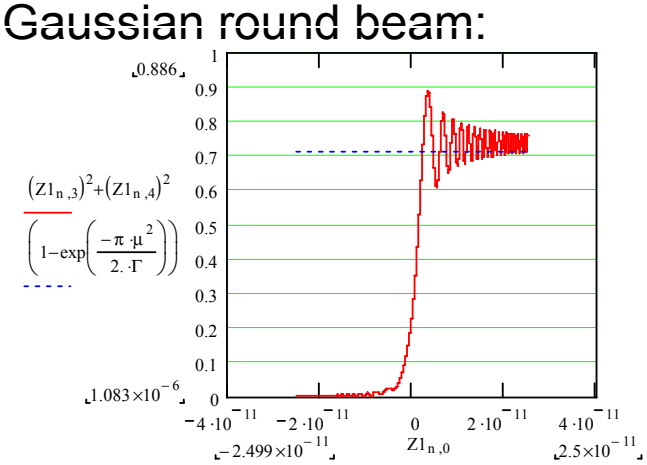
Froissart – Stora Solution

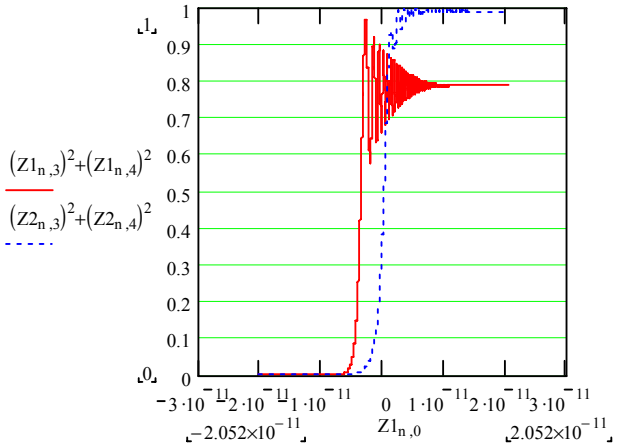
- Linear in Time Frequency Change – Two State Quantum Resonant System. Ideal case from t=- ∝ to t=+ ∝
- Asymptotic probability of excitation C_n^2 is expressed via Rabi frequency Ω and light frequency derivative with respect to time Γ=dω/dt

$$C_n^2 = 1 - \exp\left(-\frac{\pi\Omega^2}{2\Gamma}\right)$$

Principles Behind Simulations

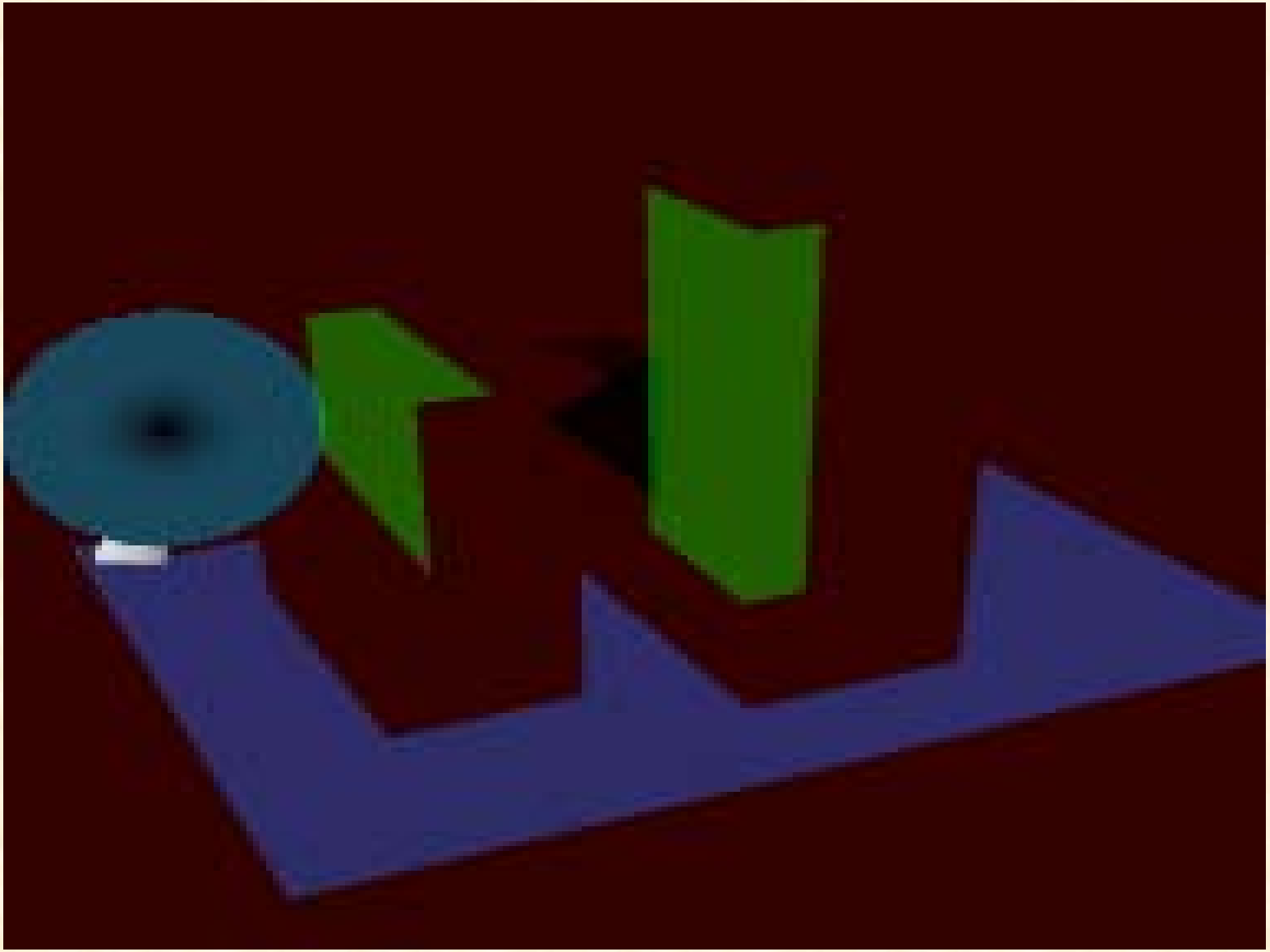
- Two level approximation (n=1 -> n=3,l=1,m=0).
- Benchmark – constant electric field density is in very good agreement with Froissart-Stora formula
- Two examples – constant laser power density with sharp edges (left) and Gaussian round beam:





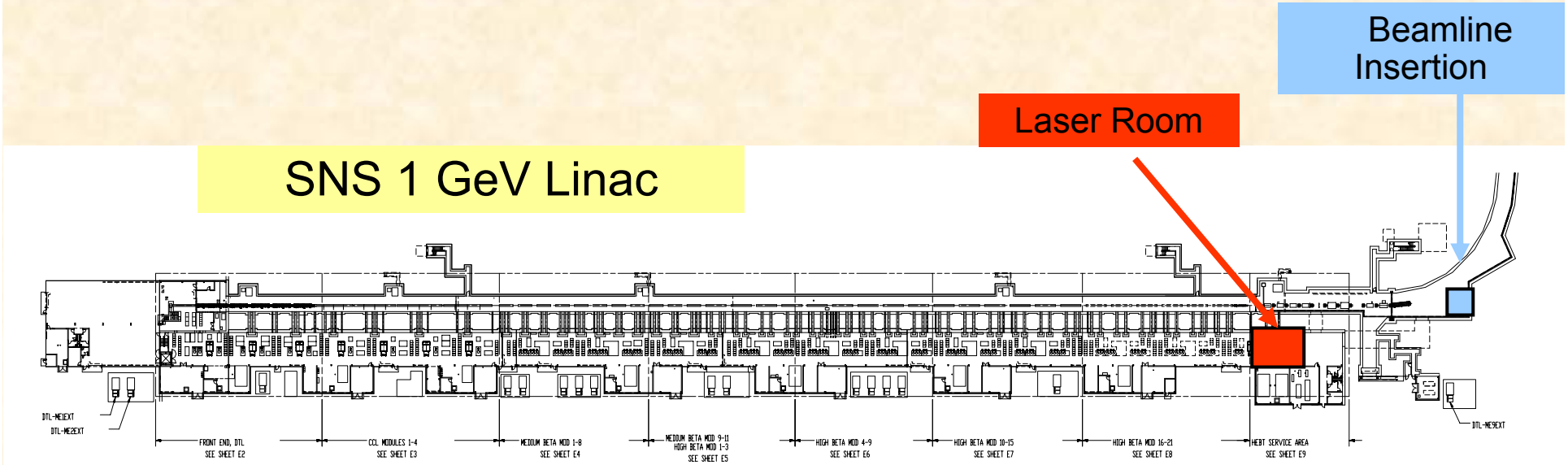
Our case (10 MW laser power) – around 90 %, without divergence (Rabi oscillations) – 0.1%. It was worth to check the new approach – led to POP experiment

Experiment Animation

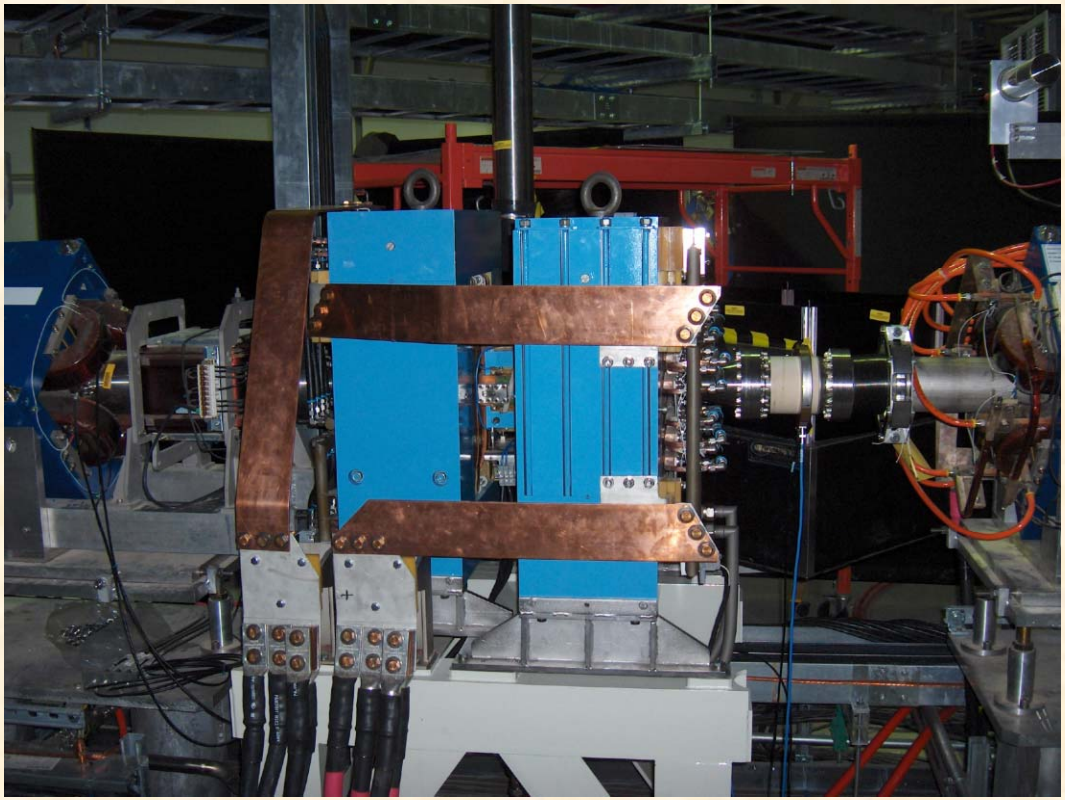


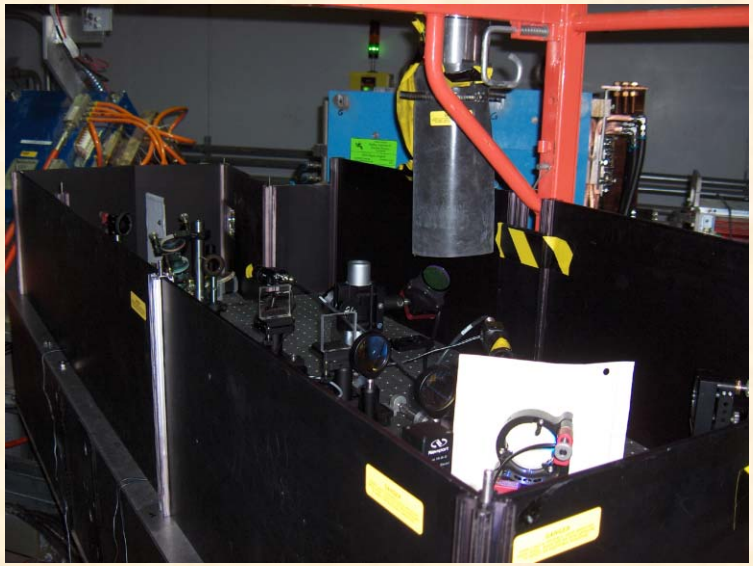
Proof-of-Principle Experiment

- **We added beamline hardware between two quadrupoles in the transport line at the exit of the SNS Linac**
- **We used frequency tripled light from an existing Nd:YAG laser installed for SNS linac diagnostics**



Laser Stripping Assembly





Two Sets of Experiments Description

- 1st experimental run (December 2005)-no stripping seen. We wish we could get the answer to this puzzle
- 2nd experimental run preparation – laser moved to the table. It trippled the laser beam power
- Laser beam incident angle and beam parameters (energy of the ions) were more carefully measured
- Second run (march 2006) led to a first success!!!

Benchmarking Signals

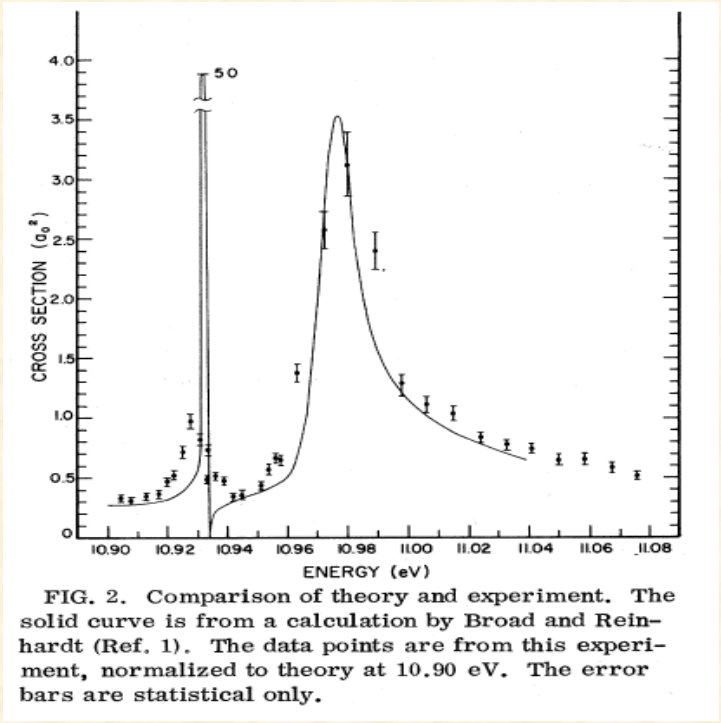
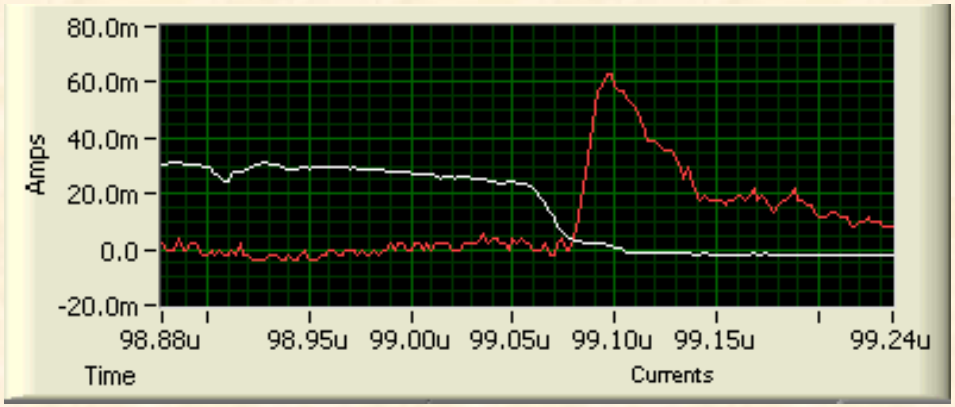


FIG. 2. Comparison of theory and experiment. The solid curve is from a calculation by Broad and Reinhardt (Ref. 1). The data points are from this experiment, normalized to theory at 10.90 eV. The error bars are statistical only.

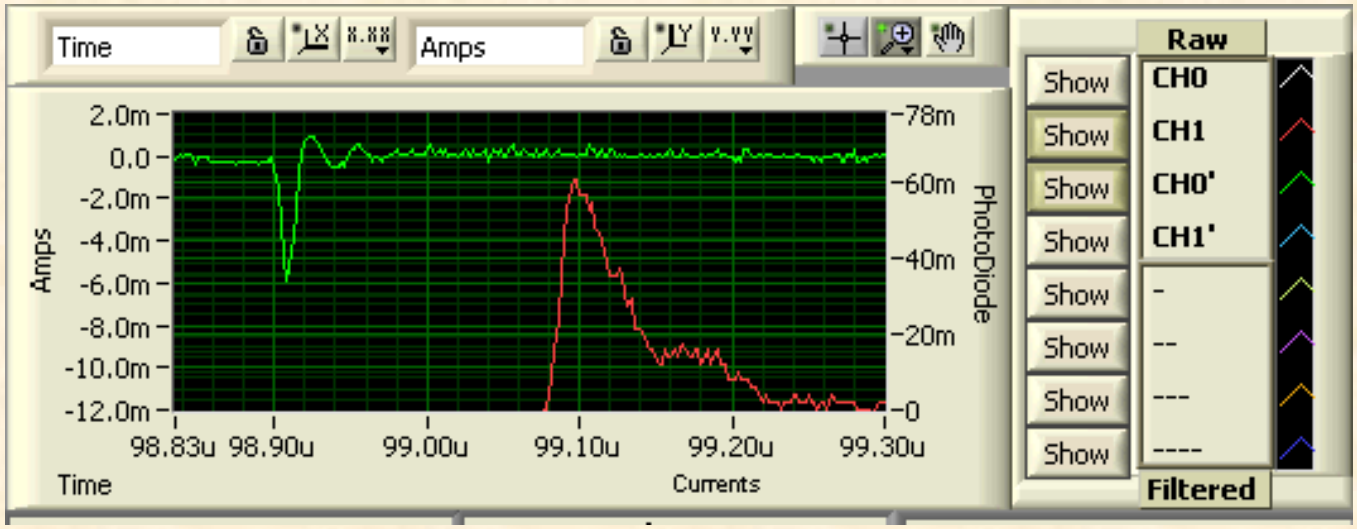
One electron photodetachment cross section vs photon energy. Data from H.C. Bryant, *et al* paper **Phys. Rev. Lett. 38, 228–230 (1977)**

This measured cross section was used to gauge the laser power. Estimation for our laser power – around 10-20% of atoms should be stripped



BCM signal (white) and photodiode signal (red). Observed dip was around 20%

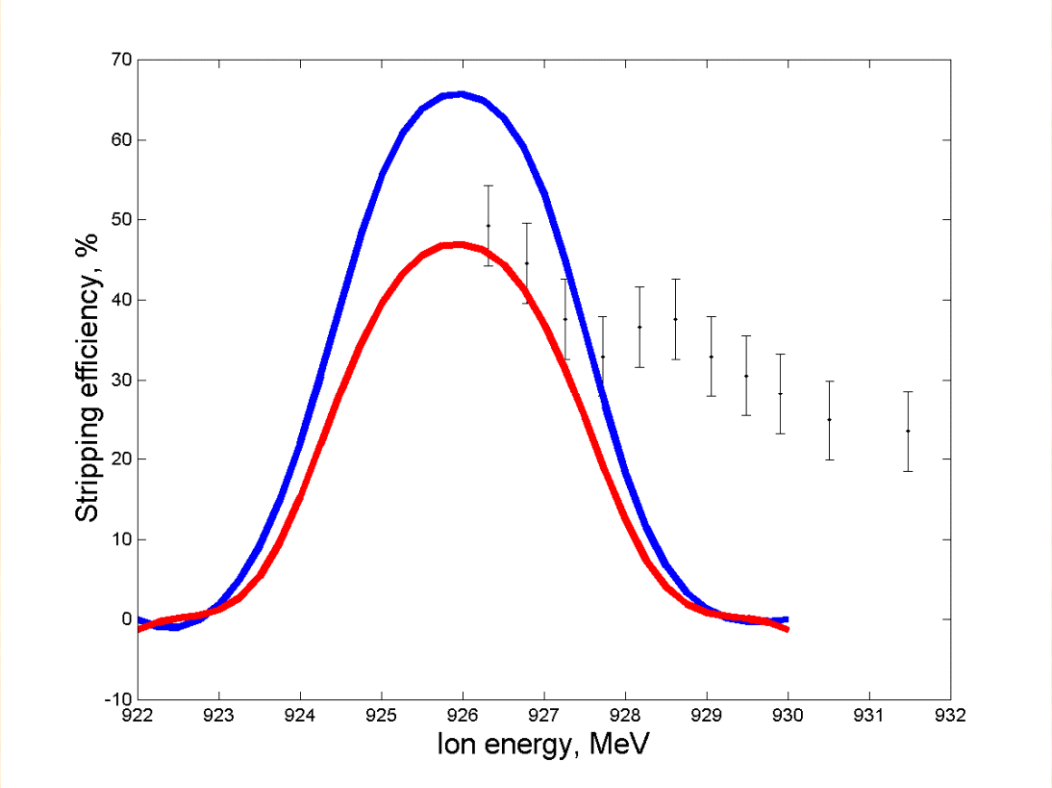
First Observed Stripping !!!



One of the first proton signals (green line)

Signal duration is around 10 ns – little longer than the laser one (7 ns)
This was taken into account to estimate the actual stripping percentage. One hour experiment produced one (the only) set of data. Then the vacuum chamber got a leak

Comparison with Simulations



Experimental data (dots with error bars) and two calculated efficiency vs energy curves for 0.8 mm (blue line) and 1.2 mm (red line) vertical sizes of the ion beam. Ion beam energy spread was 0.5 MeV in calculations. It seems that it was larger (see the experimental width is 2.5 larger).

The energy spread was once measured – the value was 0.8 MeV. The measured vertical sizes were from 0.8 to 2.4 mm. The knob Was created to minimize the sizes and maximize the stripping, but we didn't have time to engage in optimization

Summary of First Experiments

- The first substantial (about 50%) stripping was observed at SNS
- The results are roughly about what we expected from calculation.
- We believe disagreements are related to our limited knowledge of the beam parameters.
- More accurate beam data could not be obtained due to the sudden leak in the vacuum chamber, which stopped the linac operation.

Plans for the Future Development

- Reach 90% in present scheme (this year)

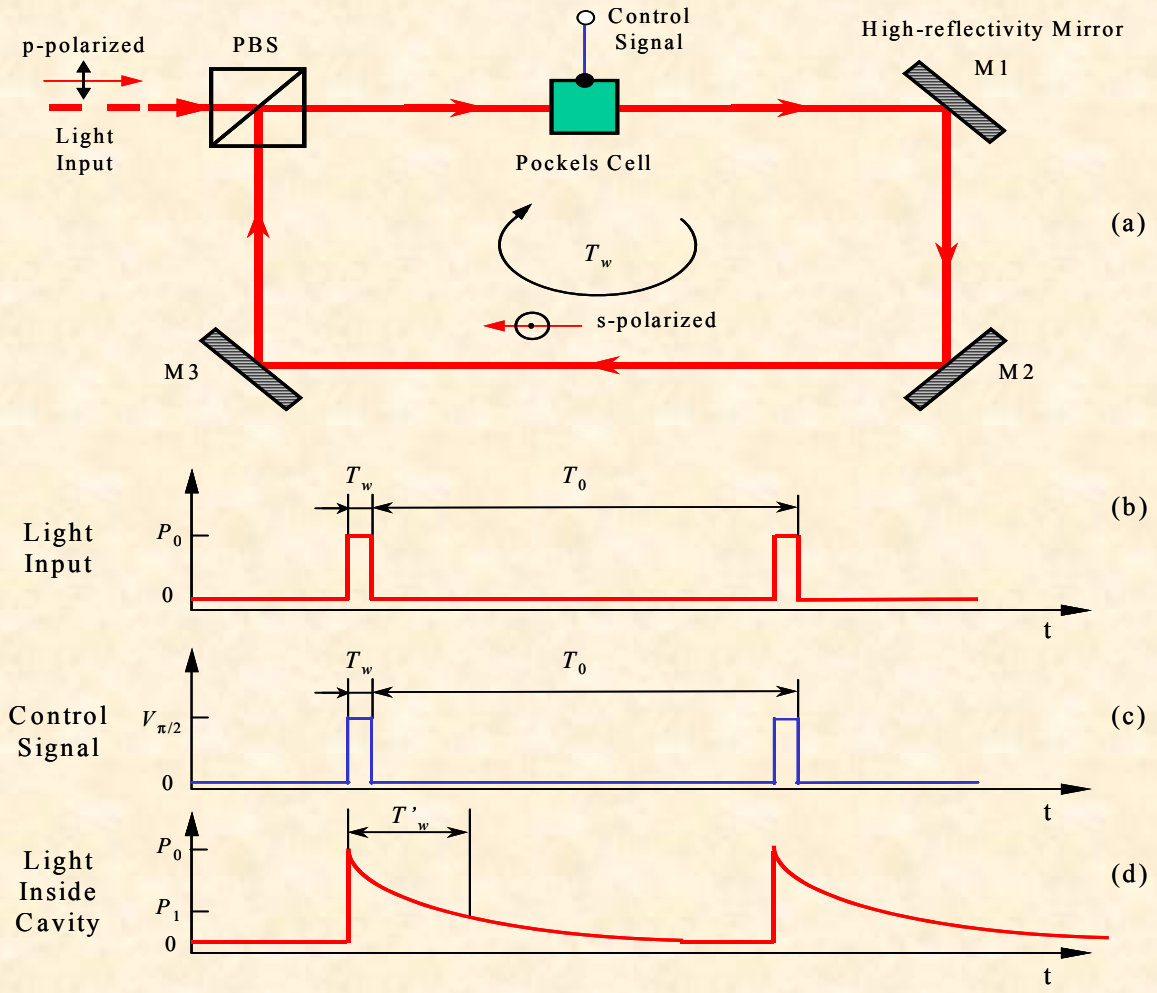
  Laser beam power reduction:

1) Recycling (factor 1000 of reduction anticipated)

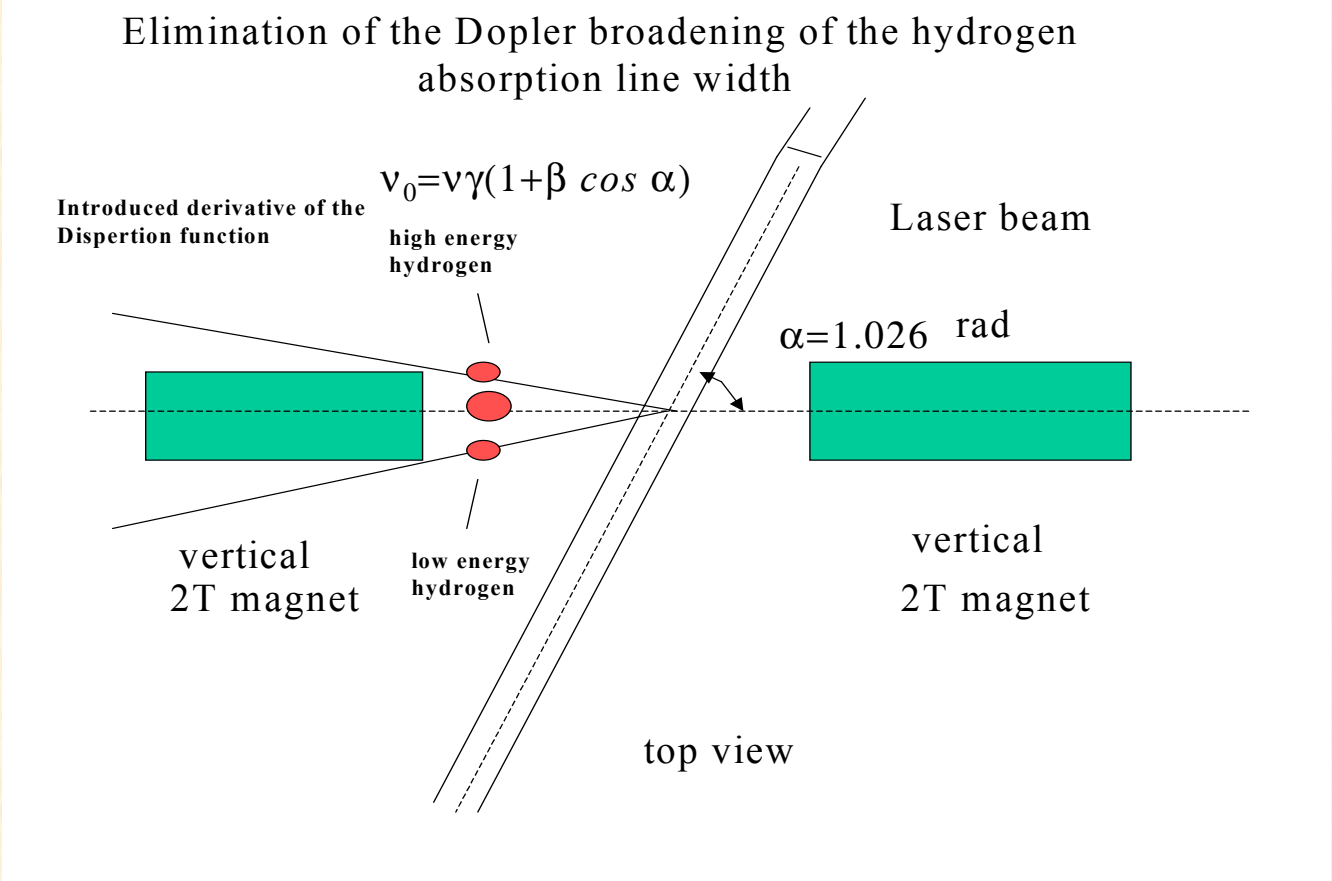
2)Dispersion derivative to eliminate the Dopler broadening of the absorption line (factor 10 of reduction)

3)Vertical size reduction (factor 3 available)

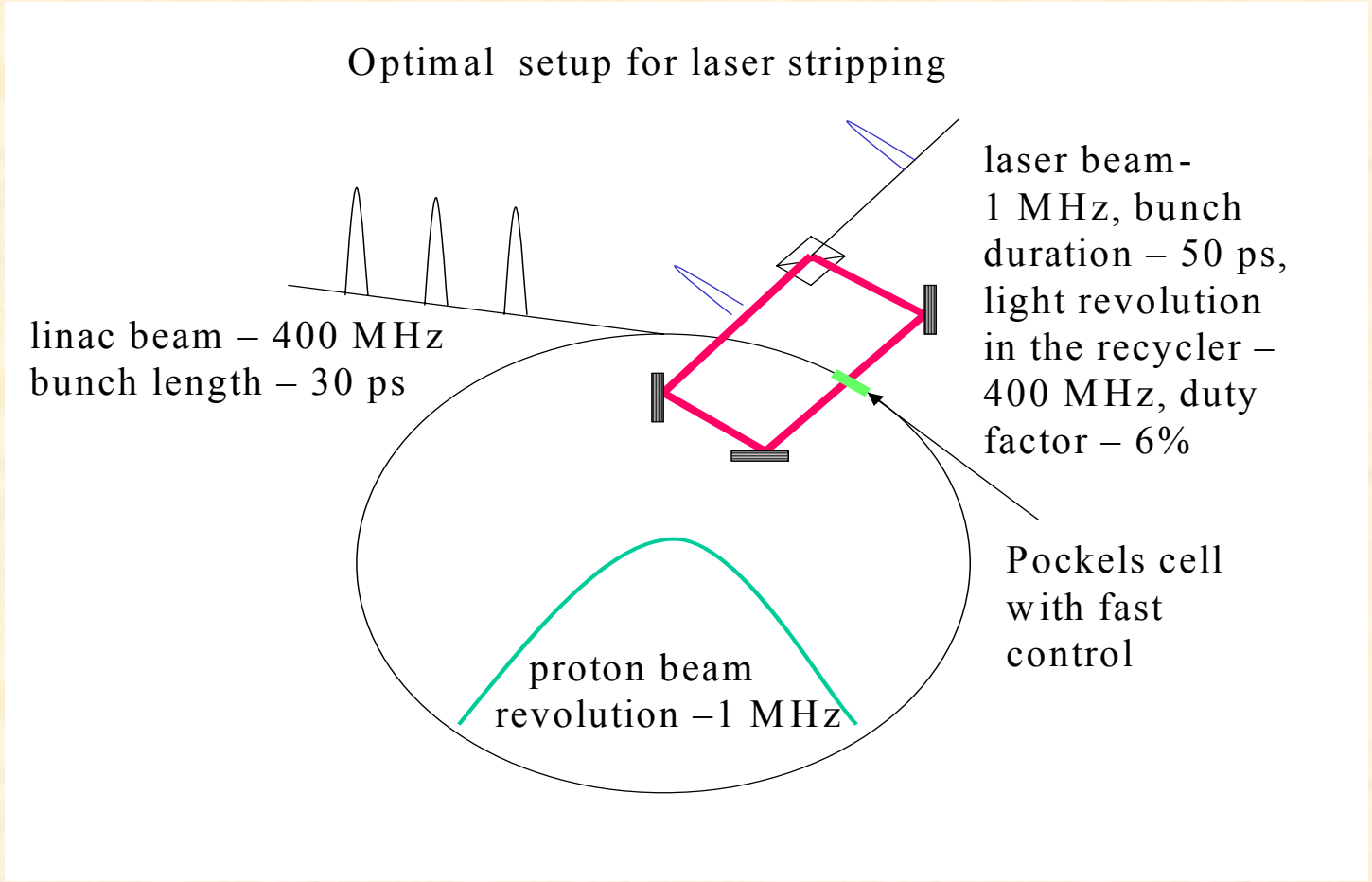
Laser Beam Recycling Scheme



Simple Trick to Reduce Laser Beam Power – Elimination of the Doppler Broadening of the Absorption Line Width



Ideal Stripping Scheme



Acknowledgements

Collaborators:

ORNL: S. Aleksandrov[2],S. Assadi[2],Y. Braiman[1], J. Barhen[1],V. Danilov[2],W. Grice[1], M. Hechler[2], J. Holmes[2], Y. Liu[1], B.Lang[2], G. Murdoch[2], K. Potter[2], A. Shishlo[2]

[1]Computer Science and Mathematics Division

[2]Accelerator Systems Division, Spallation Neutron Source Project

BINP: D. Berkaev, V. Kobets, I. Koop, V. Kuz'minyh, Yu. Shatunov, D. Shvartz

KEK: I. Yamane

Special thanks to our leaders
Norbert Holtkamp and Stuart Henderson
for their support