Transport and Stripping of 8 GeV H^- Ions (TM-2285): An Overview

Jean-Francois Ostiguy
Accelerator Division
FNAL

Object of this Talk

Provide a rapid overview of the issues that have been identified and documented in TM-2285. The talk is intentionally somewhat superficial.

Subsequent talks will go into the details of most of what is presented here.

Acknowledgements

We are greatly indebted to our external collaborators for sharing their expertise and experience with us. Without them, we most likely would not have been able to identify and understand many of the issues surrounding 8 GeV H- injection in such a relatively short period of time.

Background

The Proton Driver Project, in a nutshell:

- An 8 GeV, Superconducting linac-based machine
- 0.5 MW, upgradable to 2.0 MW beam power
- 2.0 MW: 1 ms RF pulse, 10 Hz rep rate, 26 micro C, 1.5 x 10^{14} protons (0.5 MW: 3 ms, 2.5 Hz)
- Beam power in the MI: 133 kW @ 8 GeV
  2 MW @ 120 GeV
  (1.5 s cycle time)
- 1 ms = 90 MI turns
- H- injection with striping foils into the Main Injector.
- Primary mission: "super beams" used for Neutrino production, pbar production etc …

Two Key Technical Issues for the 8 GeV SCL PD

RF power distribution:

Especially in low energy (beta < 1) cavities.
To keep costs down, RF power from 1 klystron to be distributed to ~8 cavities. A fast, high power phase shifter is required accomplish this. Such a device was designed (1965) for application to phased array radar. SNS also considered it. R&D program is under way; progress is very encouraging.

8 GeV H- transport and injection [This Workshop]:

- Higher energy and higher intensity imply better control of transport and injection losses than what FNAL is accustomed to.
- H- are delicate
- MI Ring momentum acceptance is finite.
- Striping efficiency is not 100%
- **How do the relevant physical processes scale with energy ?**
- Collimation, protection

H- are delicate !

- Magnetic Field Stripping
- Residual Gas Stripping
- Blackbody Radiation Stripping

Magnetic Field Stripping

- An ion traveling at the speed of light in a transverse magnetic field B experiences, in its own reference frame, an electric field of magnitude
  E [MV/cm] = 3.197 p[GeV/c] B [T]
- In theory, *any* electric field applied to an H-ion makes it unstable since its wave function is free asymptotically.
- Theory predicts that H^- lifetime is an exponentially decreasing function of the electric field.
- H- lifetime has been experimentally measured at many laboratories. There is –unfortunately- no data available above 800 MeV. The theoretical scaling with energy fits the available data below 800 MeV rather well; this is reassuring.
- By extrapolation (conservative), we find that at 8 GeV, for B=600 G, the lifetime is on the order of 1 ms in the lab frame. This corresponds roughly to a length L = 3000 km (fractional loss rate 3×10^{-7}). 600 G is used as a practical bending field limit.

Detailed presentation : W. Chou

Residual Gas Stripping

- Electron detachment cross-section can be computed theoretically. Once again, there is no data available at 8 GeV and one needs to resort to extrapolation. The predicted cross-section scaling w/r to energy is $1/\beta^2$. The agreement with experimental data at low energy is good.
- Assuming residual gas pressure of 10^{-7} torr and a composition of 50% H_2, 25% N_2, 25% O_2, the predicted loss rate from residual gas is (in terms of collision length)

$$L = 3000 \text{ km}$$

Detailed presentation: W. Chou

Blackbody Radiation Stripping

- The walls of the beam enclosure randomly emit thermal photons (blackbody radiation).
- In the frame of the ion, the radiation is blue-shifted to energies that are above the electron affinity of H^0. The photo-detachment cross-section at these energies is large.
- For E = 8 GeV, T= 300 K, one gets L = 1300 km
i.e. the fractional beam loss rate is about 10^{-6} per meter.
For a beam intensity of 10^{14} particles/sec, the corresponding particle loss rate would be 10^8 particles/[s-m] ~10^{-1} W/m
This loss level is problematic [Details: M. Kostin].
- Loss due to blackbody radiation (a.ka. thermal photo detachement) is expected to be more significant than residual gas or magnetic field.
- **It is likely that special measures will need to be taken to reduce and/or control those losses.**

Detailed presentation: Howard Bryant, UNM

Foil Physics

- Interaction cross-section decreases as energy increases. The physics (and scaling with energy) is similar to that of residual gas stripping. [details: W. Chou]

- Foil thickness needs to be increased to compensate for reduced cross-section and minimize partial striping (H^0) [details: A. Drozhdin]

- Increased foil thickness results in higher thermal stresses and reduced foil life. [**details: Z. Tang and M. Kostin**]

- SNS foil life is expected to be ~10s of hours. PD has lower beam power than SNS but foil is thicker, so foil life expected to be of the same order. This is a concern. Diamond foil may be an attractive alternative [**details: R.W. Shaw, SNS**]

Foil: Multiple and Large Angle Scattering

- Emittance growth due to multiple scattering: expected to be negligible (assuming a few foil hits for ~100 turn injection, L=600 micro g/cm^2, Lrad = 42 g/cm^2 and Beta = 58 m) .
- Large angle scattering: known not to be negligible in PSR. Likely not to be a problem because of small no of foil hits, but issue is unresolved.

Detailed presentations: W. Chou and
R. Macek (LANL)

Collimation

It is necessary to collimate the tails of the momentum distribution in order for the injected beam distribution to be within the momentum acceptance of the ring (i.e. the MI). This is accomplished with spatial collimators at sufficiently dispersive locations.

Issues:

- With max bend field allowable about 600 G, the injection transfer line must be at minimum a few 100 m long.
- Physical constraints on the FNAL site (wetlands, etc)
- Collimated beam absorber blocks must be able to survive an "incident"
  (e.g. : 1 time full beam pulse energy dumped into an absorber block)

Detailed Presentation: A. Drozhdin

Energy Jitter

Issue:

Need a "narrow" brush for controlled longitudinal phase space painting. Energy jitter increases the effective longitudinal energy spread of the beam and therefore the size of the "brush". To cross transition in MI, control must be better than +/- 15 MeV.

Q1: How well should/can jitter be controlled/corrected ?

Q2: Can we take advantage of our understanding of the sources of jitter ?

Energy jitter sources (M. Huening) :

- Beam loading different in each cavity
- Microphonics detuning
- Lorentz detuning
- arrival phase dependent on upstream acceleration
- Source and front end jitter
- …

Energy Jitter Correction

SNS approach:

Use a drift to convert energy offset into phase offset into an energy correction cavity.

Problem: at 8 GeV, a very long drift would be necessary to establish energy-phase correlation necessary to allow correction by a cavity.

$$d\,\text{beta}/d\,\text{gamma} = 1/(\text{beta} * \text{gamma}^3)$$

While the typical distance involved at 1 GeV is on the order of 10s of meters, for an 8 GeV beam, it becomes many km !

A different approach is needed at 8 GeV !

Assumptions:

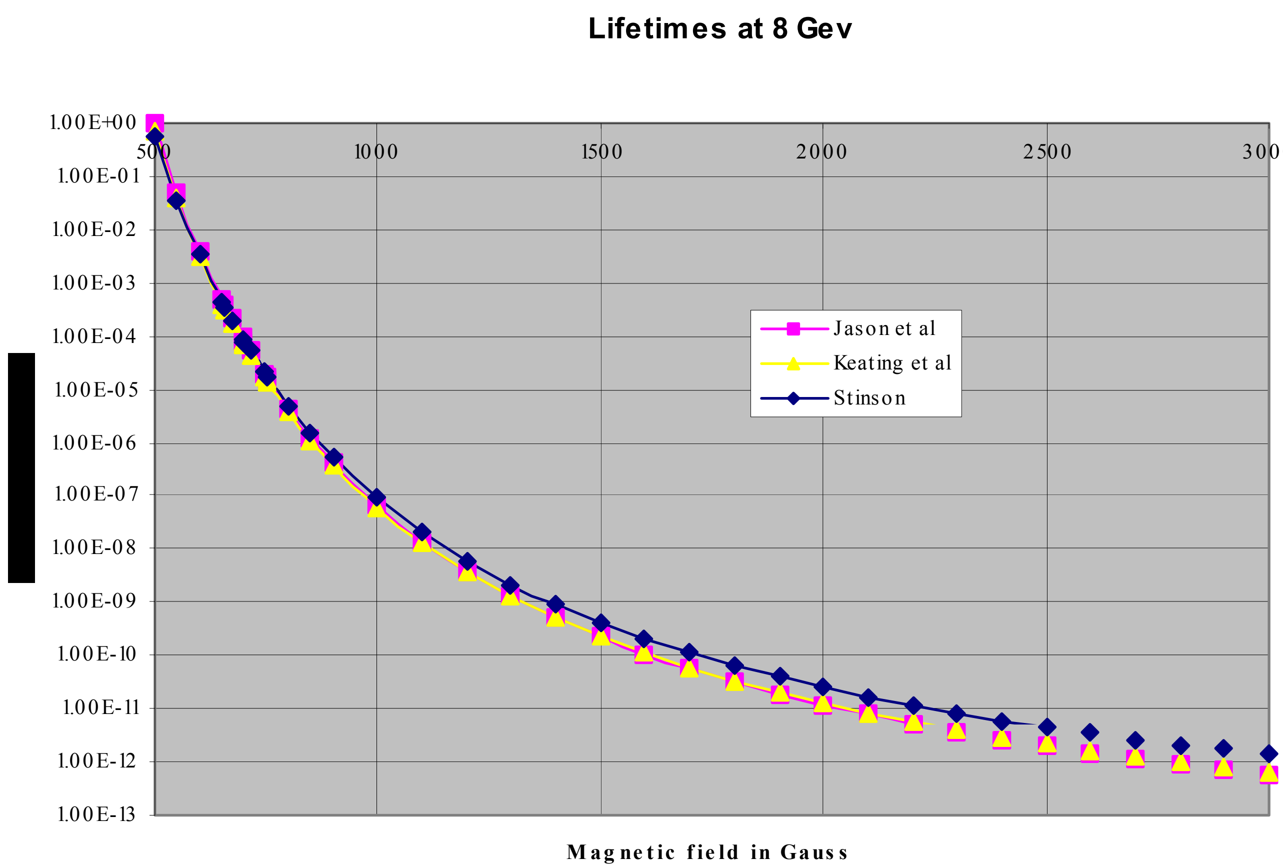
- individual bunch energy spread from the linac is acceptable, without correction. It is mostly the mean energy deviation that needs to be corrected.
- The dispersion in the momentum collimating arc of the transport line can be used to measure the mean energy deviation. It can then be corrected by an RF structure phased accordingly.

Detailed Presentations: J. Wei, P. Ostroumov and J. Maclachlan

Status

- We believe the relevant physical mechanisms at play have been identified and that their scaling with energy is reasonably well understood.
- Momentum collimation requires a ~1 km line (to avoid magnetic field stripping). The line has been designed.
- Surprisingly, blackbody radiation appears to be an important effect. Special measures may need to be taken.
- Foils: (graphite) foil life is a concern. Diamond may be an alternative.
- Energy jitter compensation:
  - *A posteriori* correction with a cavity (a la SNS) is not a practical solution. We need to use our knowledge of the source and nature of the phase jitter to devise a better solution. Numerical simulations required to validate this solution!

Predicted H- Lifetime at 8 GeV



Cross Section of H- Incident on C Foil

	800 MeV (measured)	200 MeV (measured)	200 MeV (scaled)	400 MeV (scaled)	8 GeV (scaled)
$\sigma_{-1,\,0}$	0.676 ± 0.009	1.56 ± 0.14	1.49	0.942	0.484
$\sigma_{0,\,1}$	0.264 ± 0.005	0.60 ± 0.10	0.584	0.368	0.189
$\sigma_{-1,\,1}$	0.012 ± 0.006	–0.08 ± 0.13	0.026	0.0167	0.0086

H0 Yield at Different Energies