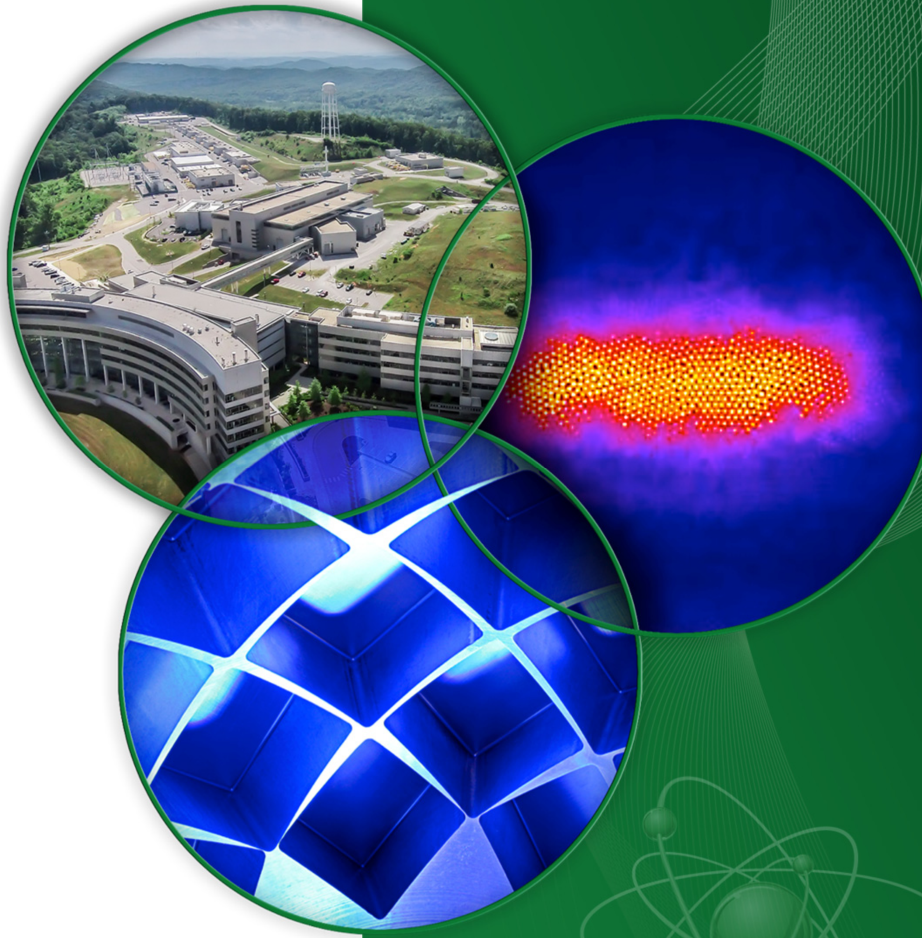
H^- Charge Exchange Injection Issues at High Power



by Mike Plum,
Oak Ridge Spallation Neutron Source

HB2016, July 3-8, 2016
Malmo

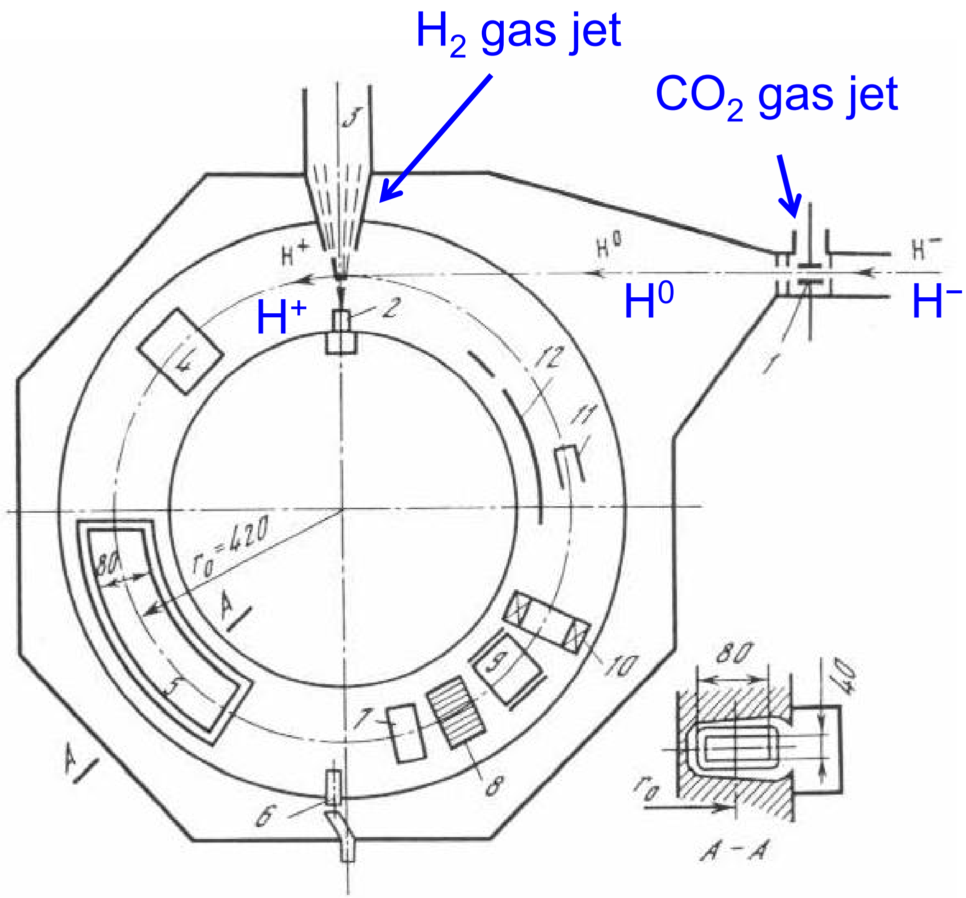
ORNL is managed by UT-Battelle
for the US Department of Energy

Oak Ridge National Laboratory | Spallation Neutron Source

Charge exchange injection – who cares?

- Charge exchange injection (CEI) is the only way to achieve low loss multi-turn injection into a synchrotron or storage ring
  - Best loss achieved without CEI = ~10%
  - Best loss achieved with CEI = ~0.02%
- CEI is the only way to stack many turns without linear growth in emittance
  - $\varepsilon_{TOTAL} < N * \varepsilon_{INJECTED}$
- Only practical way today is to use stripper foils, but these become complicated for high beam powers…
- This talk will focus on H^- charge exchange injection

First charge exchange injection by BINP / Novosibirsk in 1966



1- First stripper
2 - Main stripper pulsed supersonic jet
3 - Gas pumping
4 - Pickup integral
5 - Accelerating drift tube|
6 - Gas luminescent profile monitor
7 - Residual gas current monitor
8 - Residual gas IPM
9 - BPM
10 - Current monitor
11 - FC
12 - Deflector for suppression transverse instability by negative feedback.

Small Radius- High beam density. Revolution 5.3 MHz. 1MeV, 0.5 mA, 1 ms.

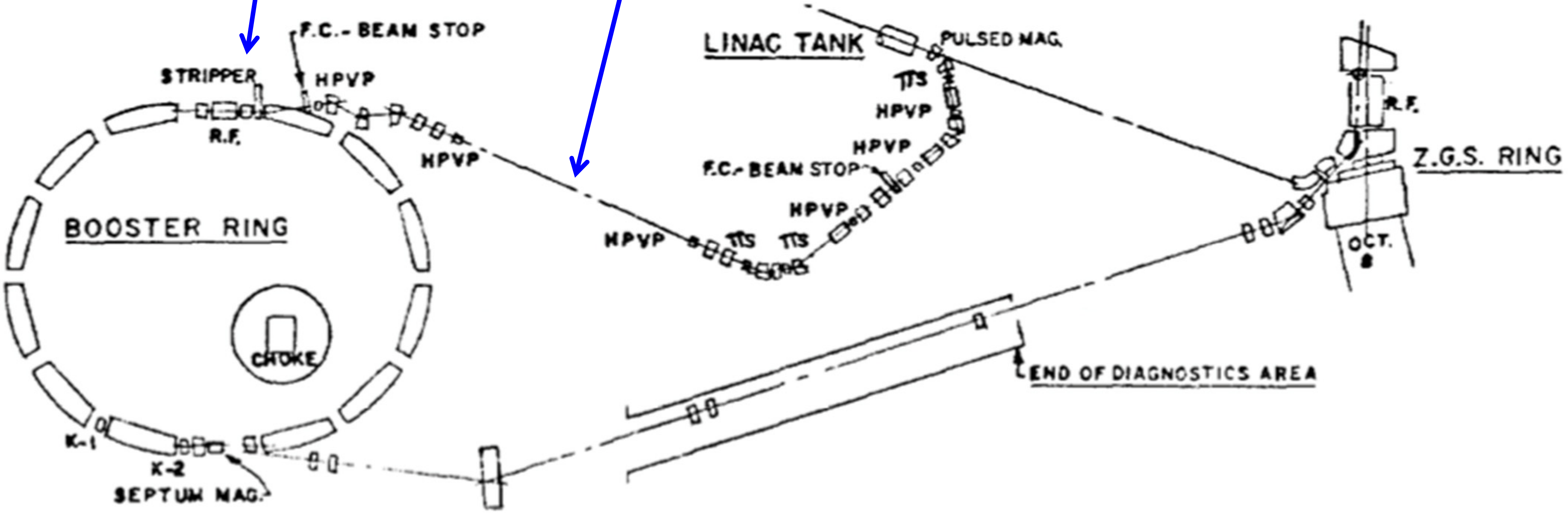
•EXPERIMENTS ON PRODUCING INTENSIVE BEAMS BY MEANS OF THE METHOD OF CHARGE-EXCHANGE INJECTION PROTON, G. I. Budker, G. I. Dimov, and V. G. Dudnikov, Sov. Atomic Energy, 1966.

Courtesy V. Dudnikov

First use of stripper foil for CEI at Argonne, 1972

Stripper foil mechanism located just downstream of C magnet

50 MeV H^- beam from linac

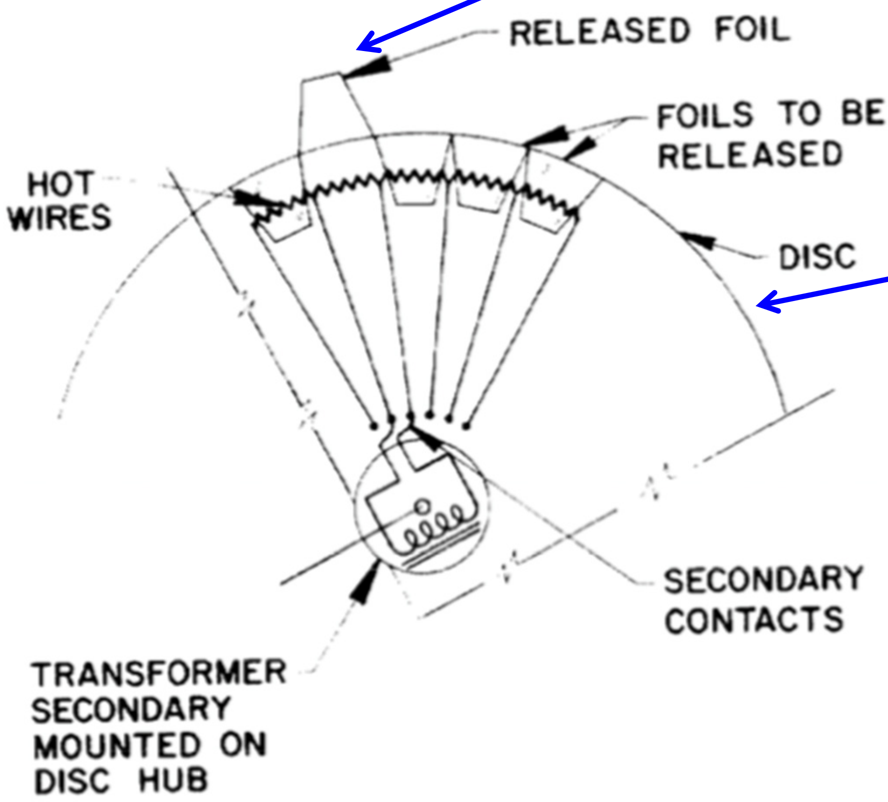


Booster I

J.D. Simpson, PAC’73

Stripper foil assembly used at Argonne test booster for ZGS

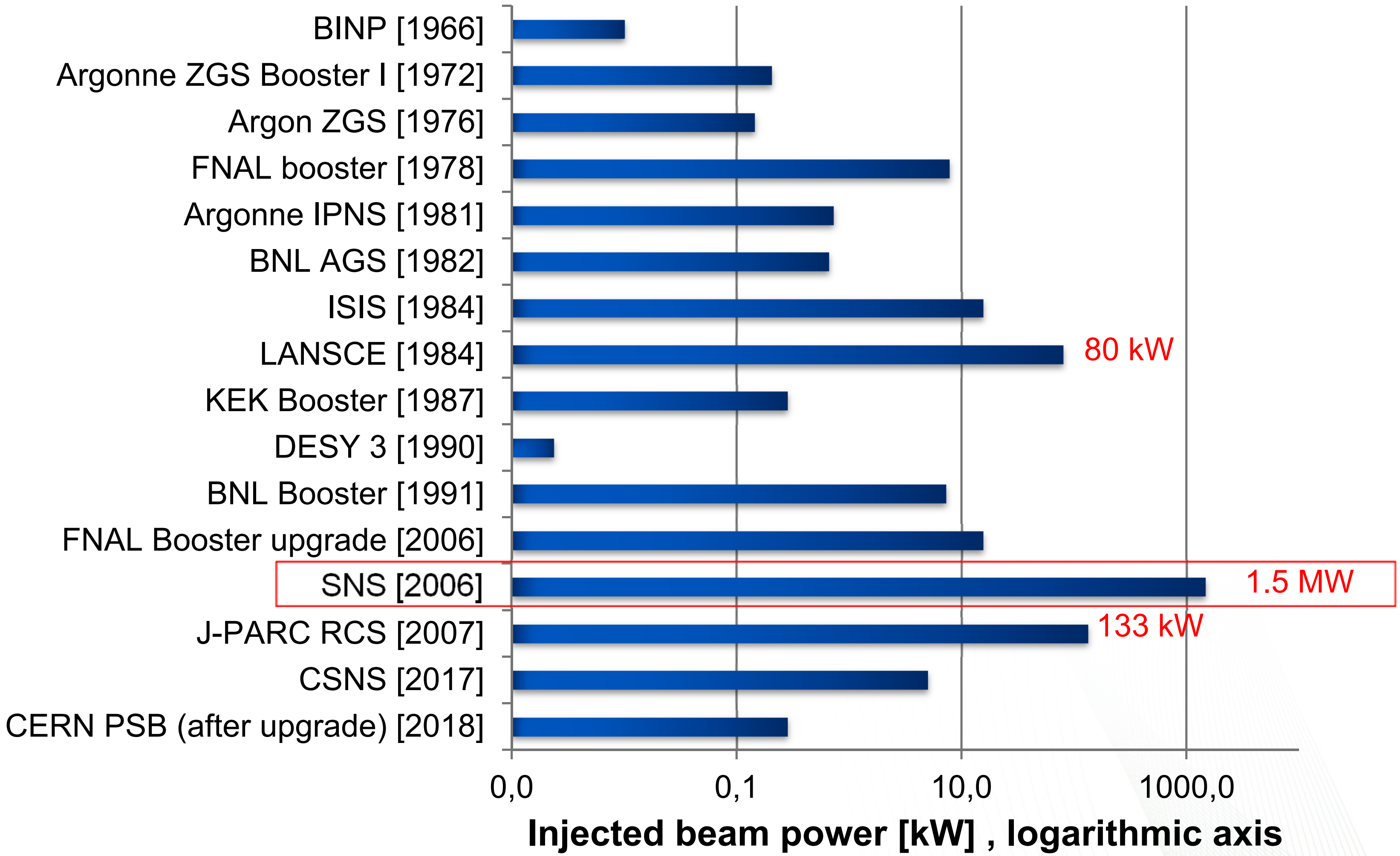
Polyparaxylene foil, 35 μm thick, ~36 x 100 mm^2



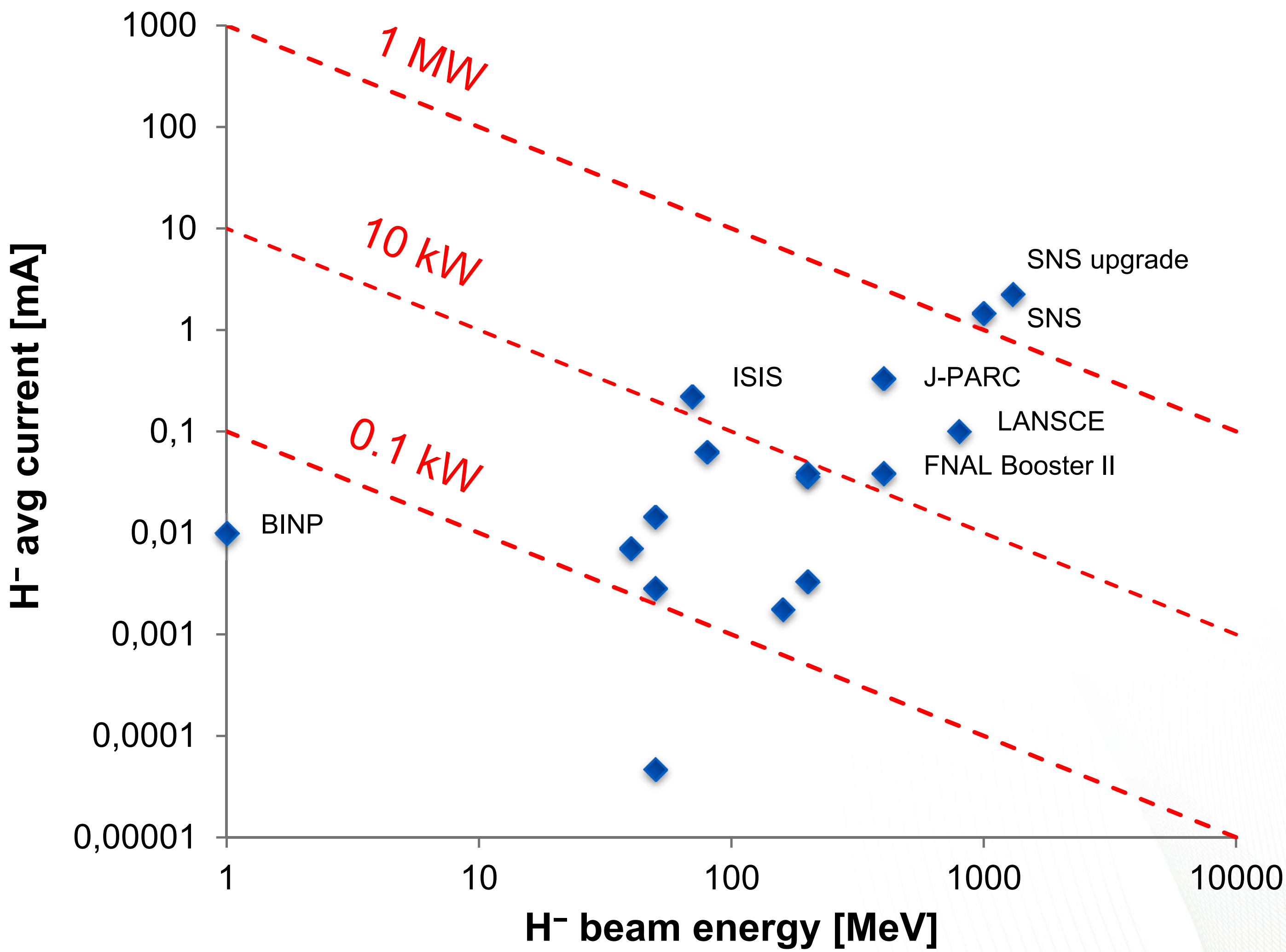
- Rotating disk, ~0.9 m dia.,1800 rpm, synchronized with 30 Hz booster cycle
- Foil is only in path of beam during injection
- Expected foil lifetime 2 hours

A. J. Gorka, PAC'73

Brief history of H^- injected beam power



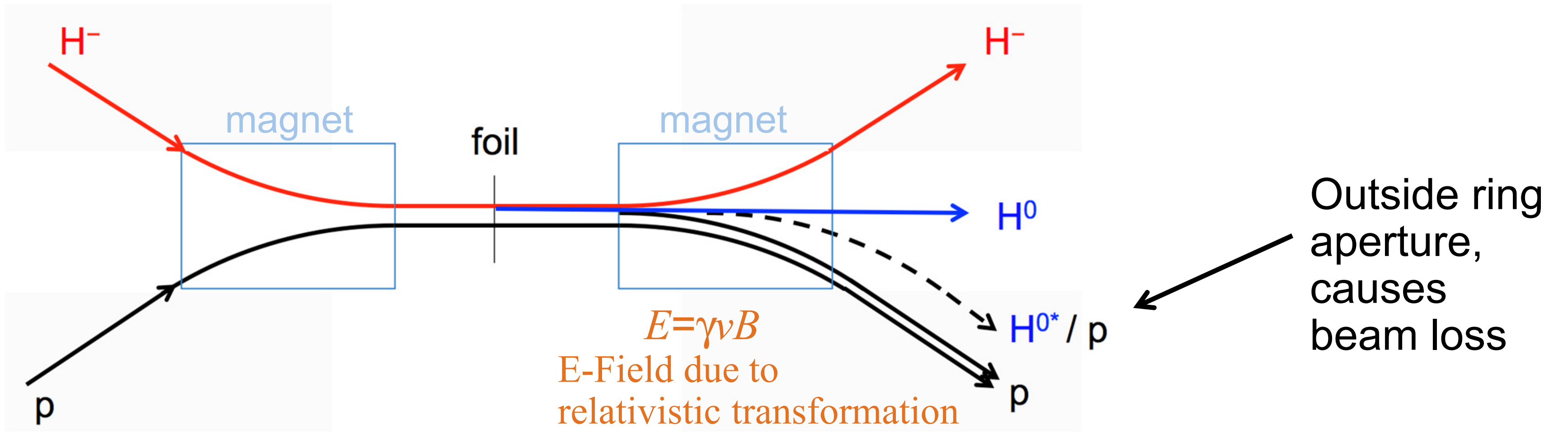
H^- injected beam power



Complications of CEI at high power

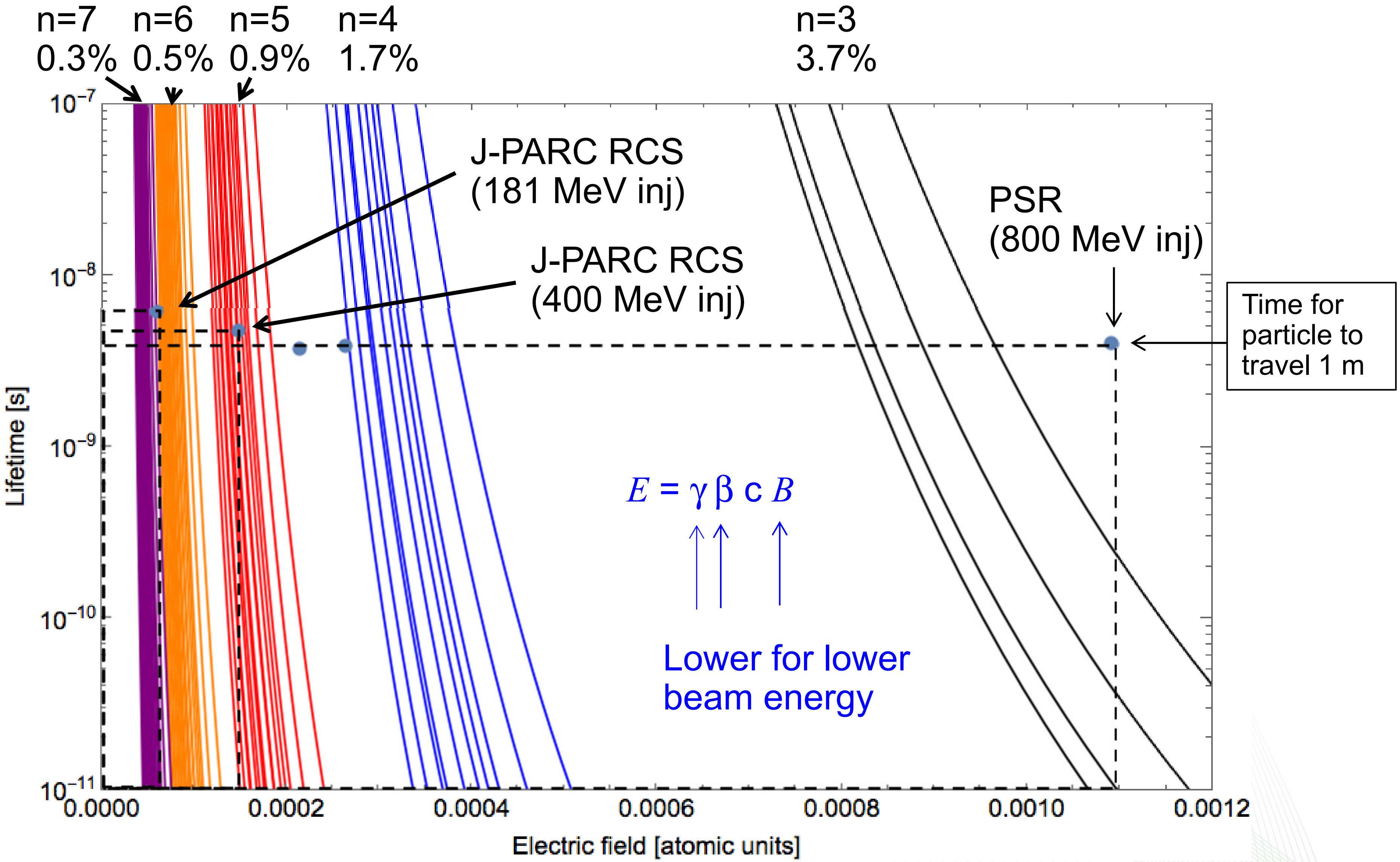
- Beam loss caused by foil scattering
- Stripper foil lifetime
- Control and disposal of un-stripped and partially stripped beam
- Beam loss caused by H^0 excited states
- Stripped (convoy) electrons must be controlled too
- Damage caused by reflected convoy electrons

Beam loss caused by H^0 excited states



- First discovered ~1993 by R. Hutson and R. Macek at the Los Alamos Proton Storage Ring
  - Causes 15 - 20% of the total beam loss today at PSR (i.e. causes 23 – 40 W beam loss)
- If SNS design did not account for H^{0*} beam loss, it would have caused up to ~2,850 W of beam loss
- J-PARC RCS has only <8 W of H^{0*}, not enough to require special treatment

H^0 excited states lifetime vs E-field



H^0 excited states – SNS solution

- Concern over H^0 excited state beam loss drove SNS design team to place the stripper field inside a strong magnetic field
- B-field immediately strips the $n \geq 5$ H^{0*} states
- Also directs convoy electrons to an electron catcher
- At SNS, H^0 excited state beam loss is too low to accurately measure

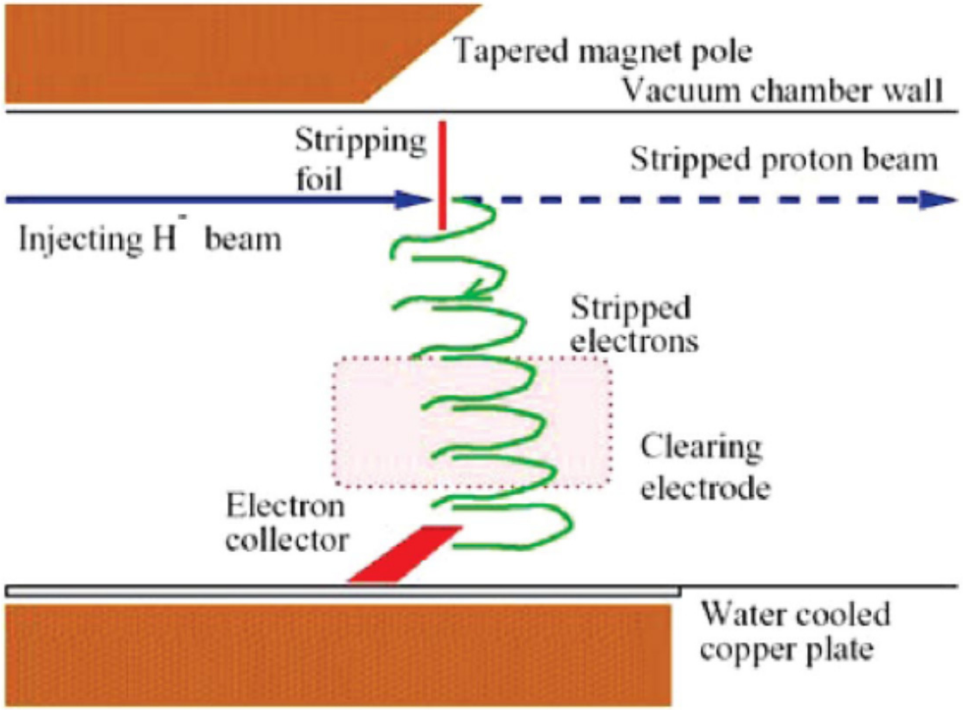
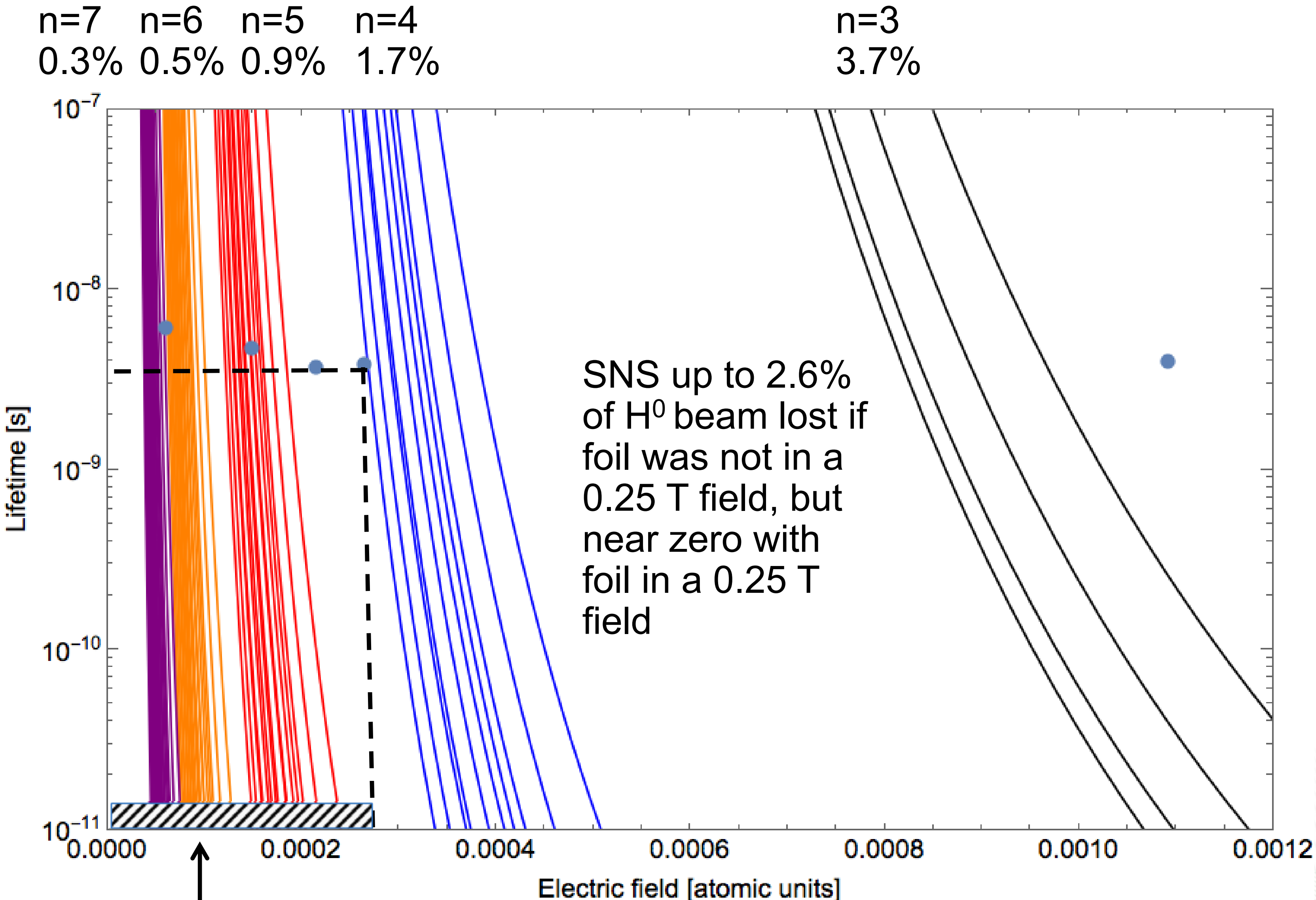


Figure courtesy L. Wang

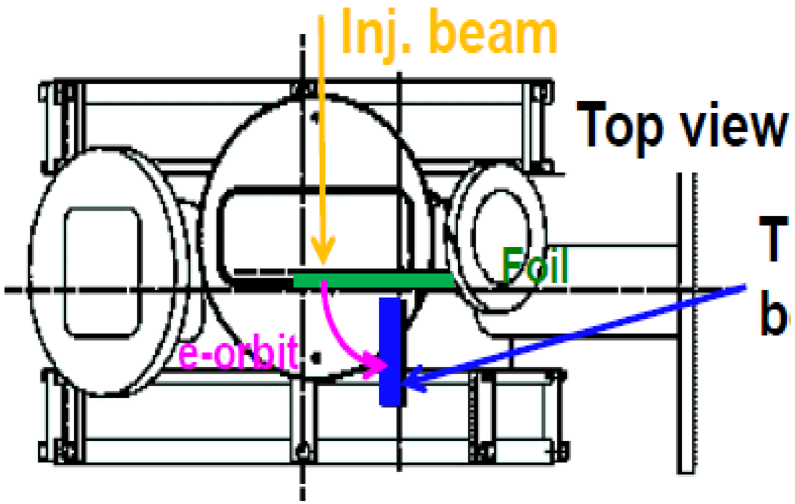
H^0 excited states for SNS



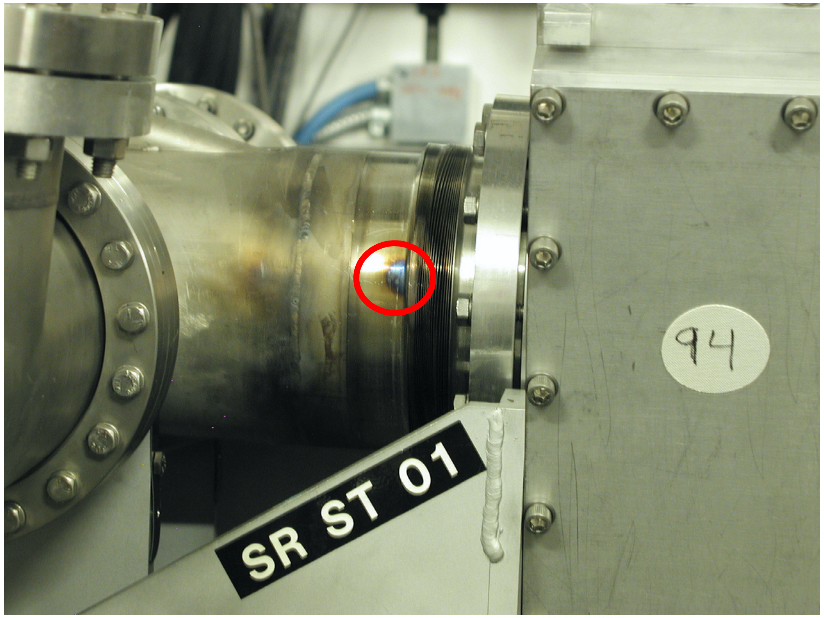
Stripped within a few mm because foil is inside a magnet

Control of convoy electrons

- At SNS design power, the convoy electrons carry 1.6 kW of power. This amount of power must be properly controlled.



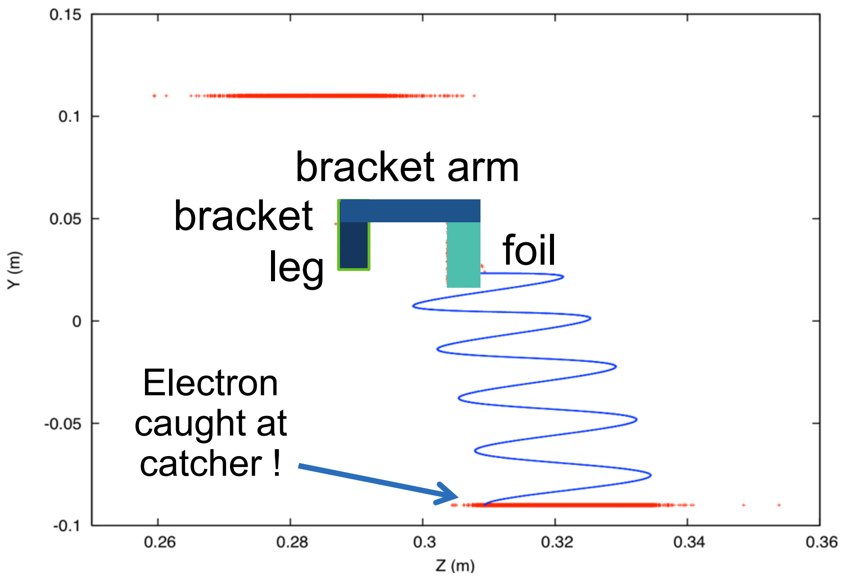
J-PARC intercepts convoy electrons (~145 W) after ¼ turn in chicane magnet fringe field. (Courtesy P. Saha)



Un-controlled convoy electron burn spot at PSR, due to ~85 W of electron power.

(Courtesy R. Macek)

Reflected convoy electrons at SNS



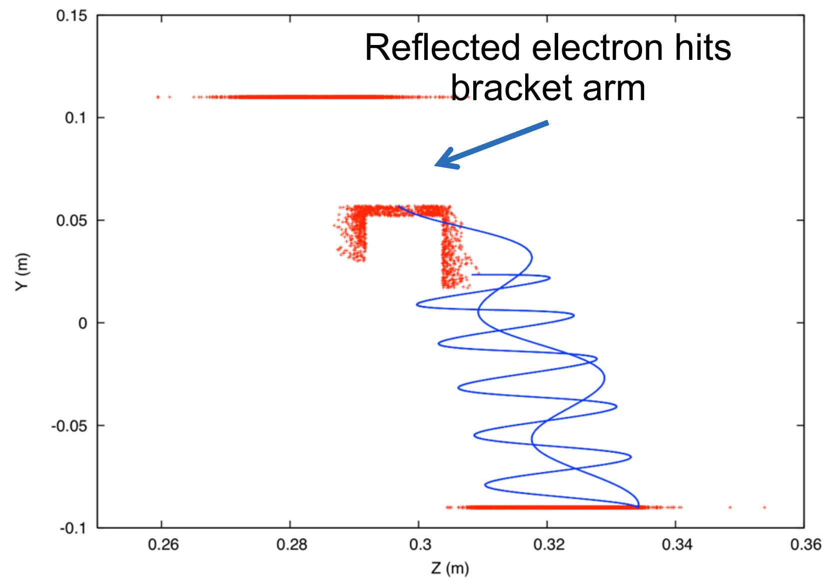
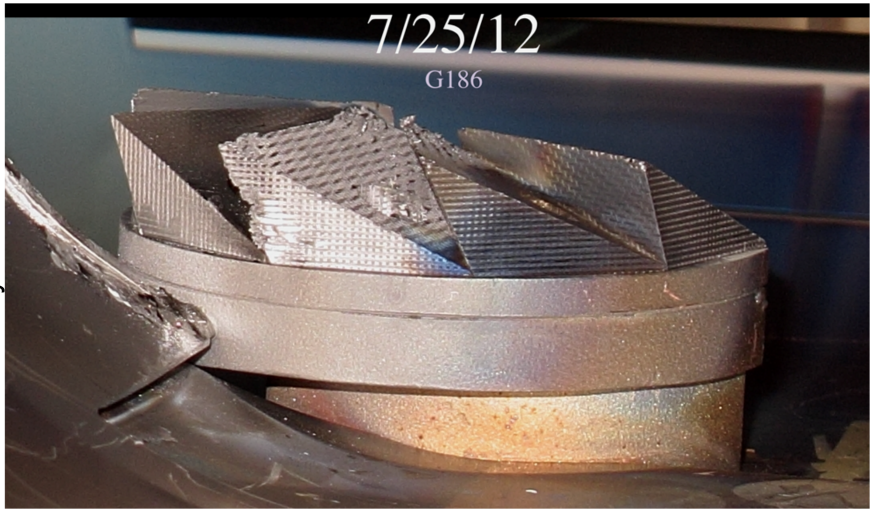


Photo by Chris Luck

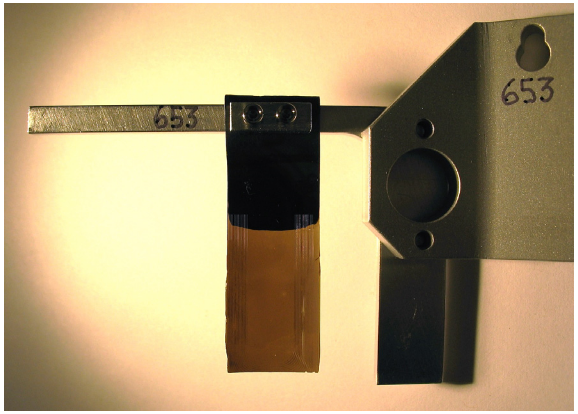


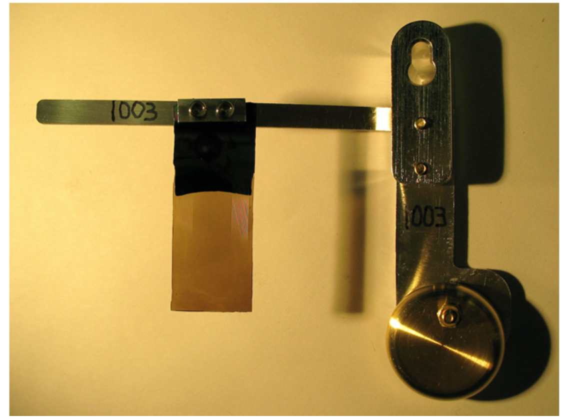
The convoy electrons are ideally trapped by this electron catcher mounted in the bottom of the vacuum chamber

But, location of catcher is not ideal due to component fabrication error and changes to foil mount position

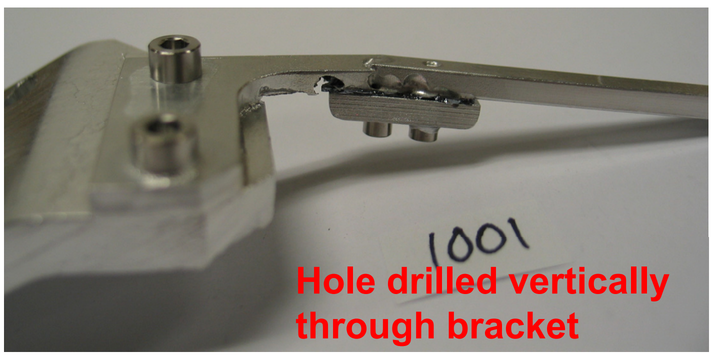
Simulations by S. Cousineau

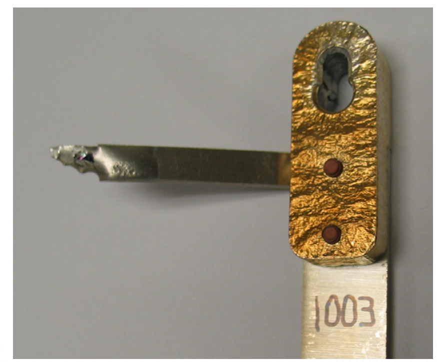
From HB2010





NEW STRIPPER FOILS





USED STRIPPER FOILS

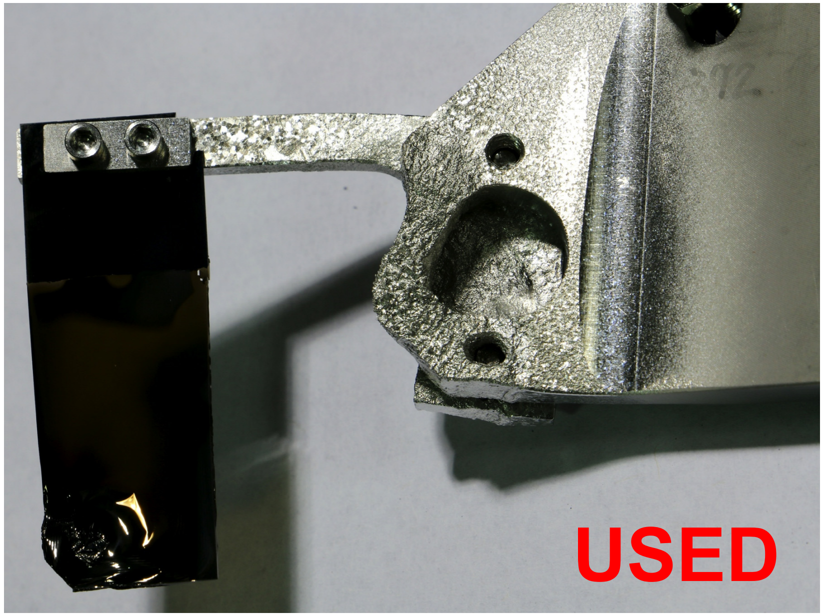
Foils began to fail after increasing beam power to ~840 kW

Solution: Change bracket material from aluminum to titanium, and move stripper foil 1 cm further out along bracket arm

Photos by Chris Luck

SNS stripper foils 2009 - present

Photos by Chris Luck



Typical foil in use since 2009
Nanocrystalline diamond 0.350 mg/cm^2
Titanium bracket

Worked very well until 2014, at beam powers less than 1.2 MW

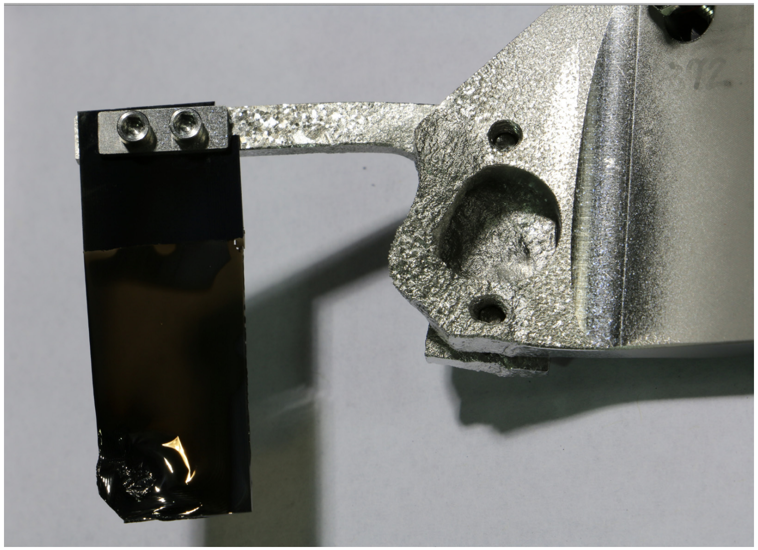
Stripper foil removed July 2014, used at beam powers up to 1.4 MW

Threshold for damage is ~1.2 MW

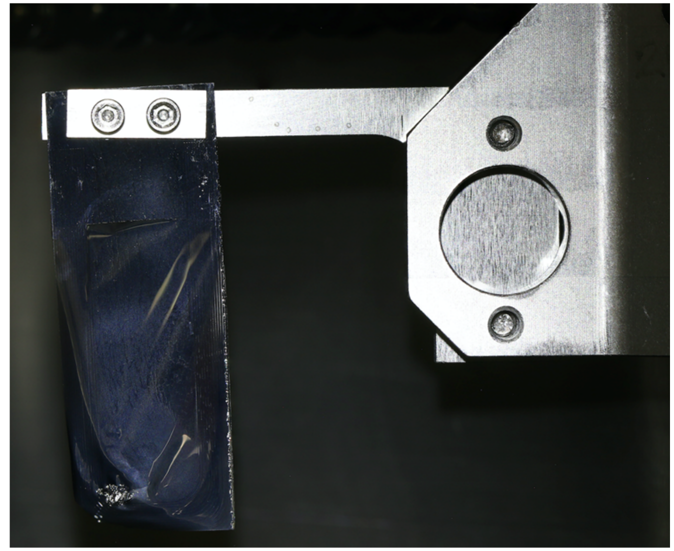
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

Mitigation for convoy electron damage

Photos by C. Luck



#1872, 3 months at 1.1 to 1.4 MW
(~20 days at 1.3 – 1.4 MW)



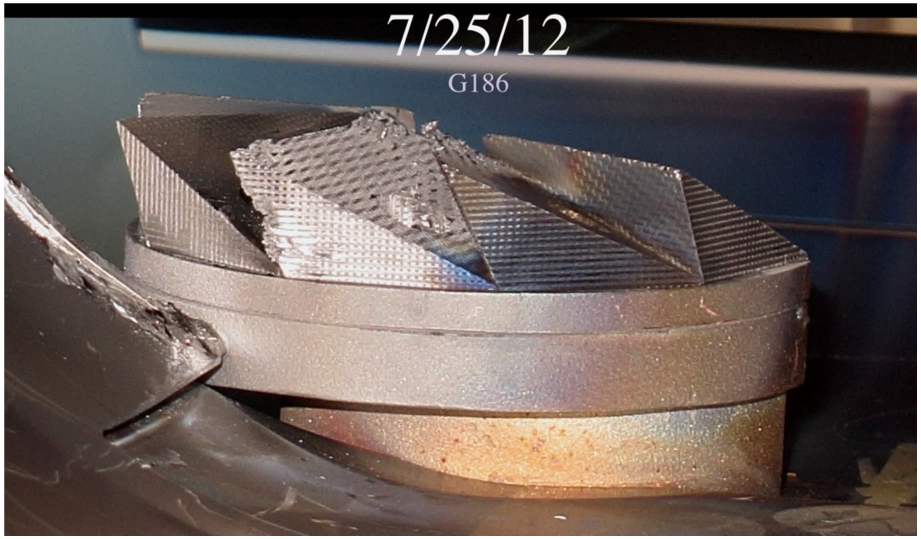
#2199, TZM bracket,
~16 days at 1.3 – 1.4 MW

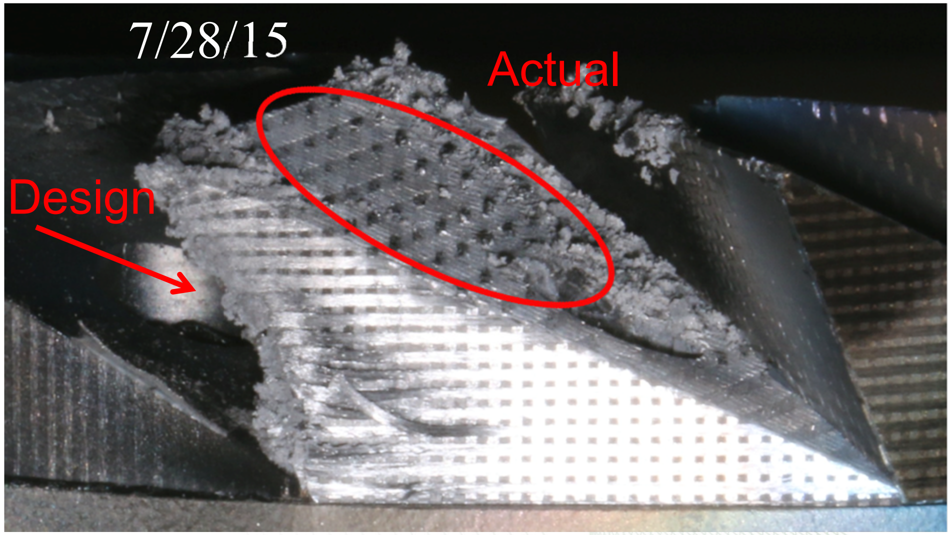
- New TZM bracket tested Nov. – Dec. 2015
- Advantages: high sublimation temperature, low sputtering yield, high sputtering threshold
- Disadvantages: Heavy, long-lived radio-activation

TZM bracket shows almost zero damage

SNS Electron Collector damage

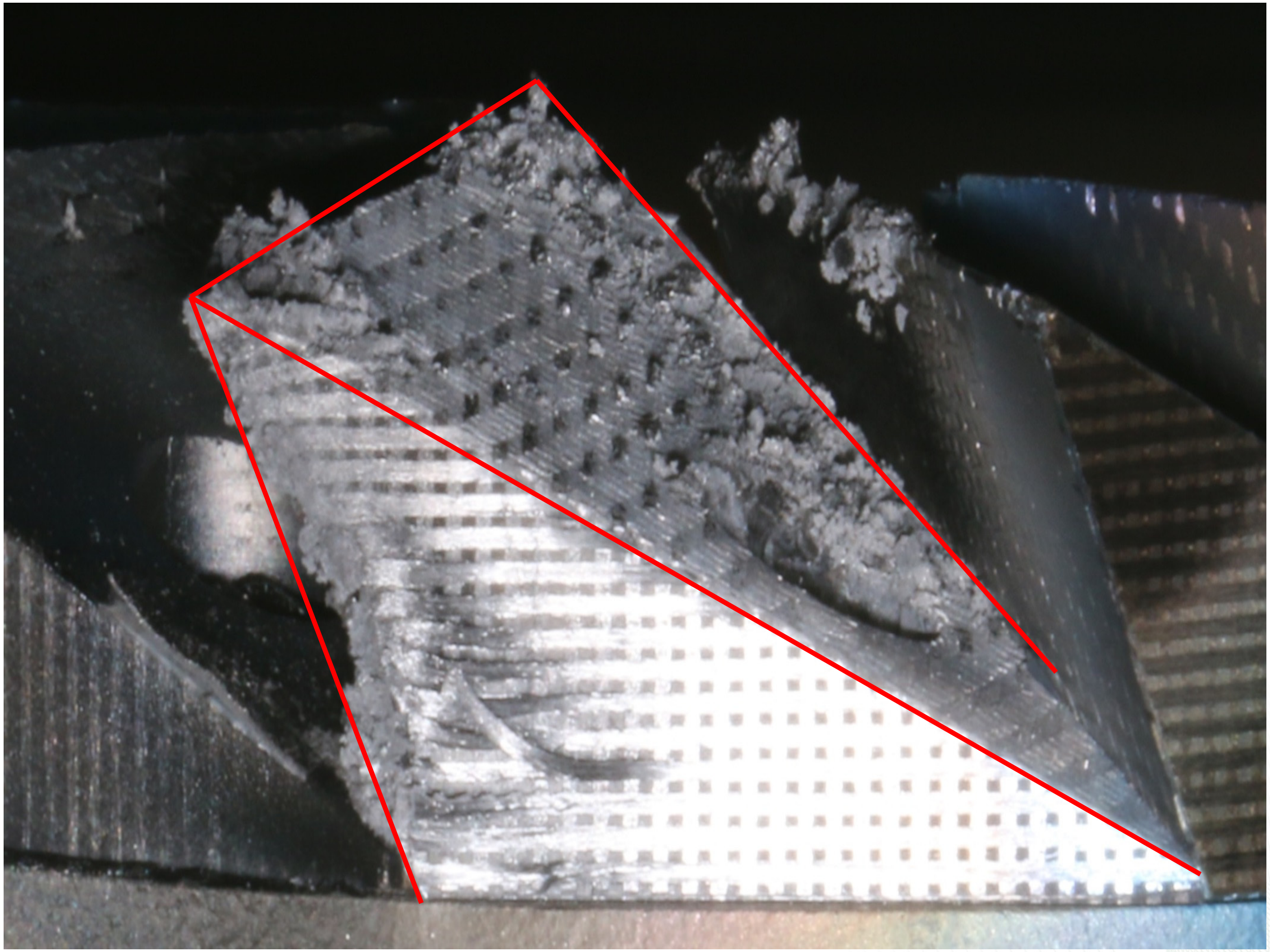
- Electron collector is becoming eroded away due to impact of convoy electrons
- Convoy electrons should strike undercut face of wedge, but due to misalignment they instead strike the top of the wedge.
- Electrons are more likely to reflect when they strike the top of the wedge
- Redesign is now in progress





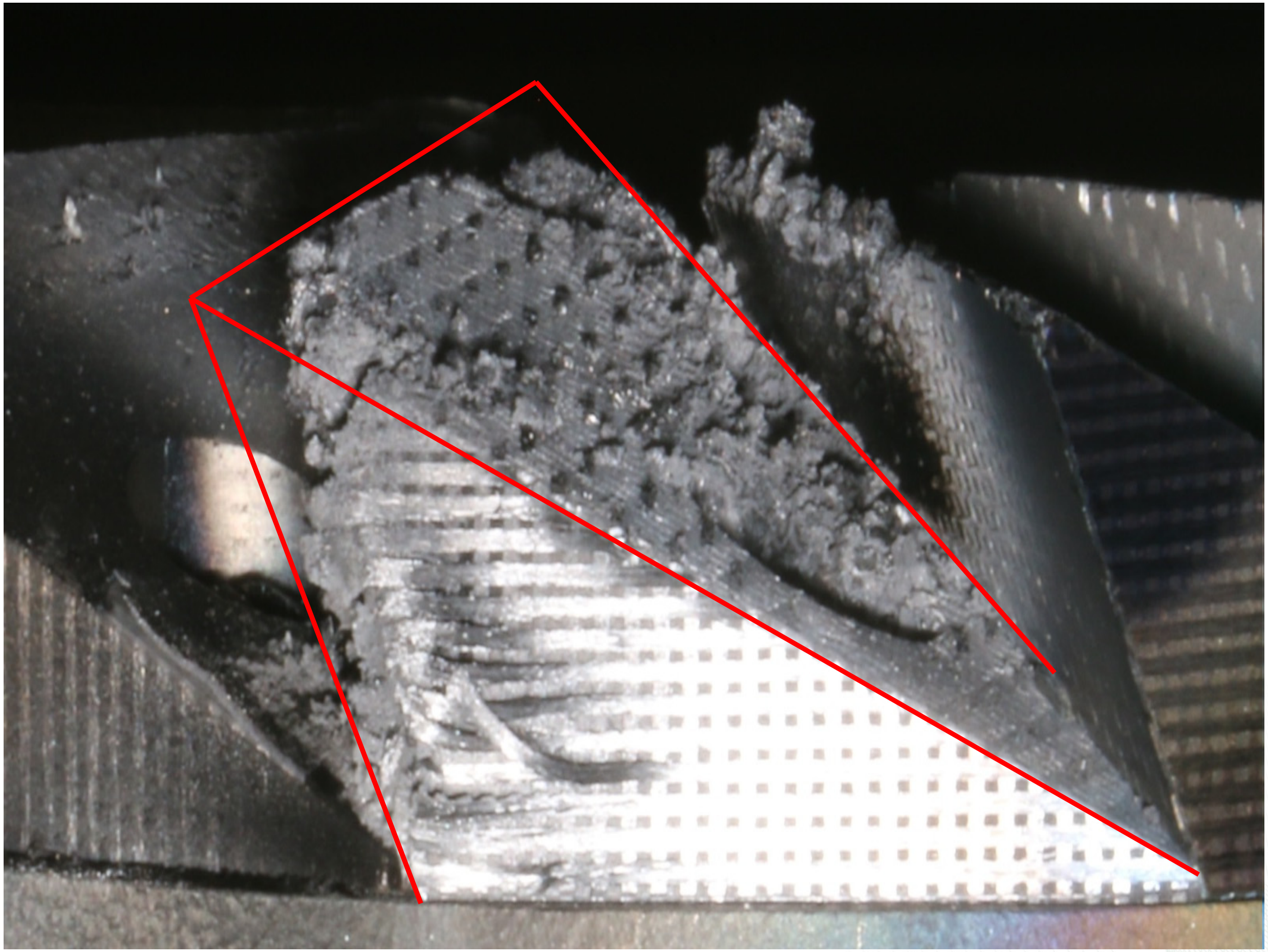
Photos by C. Luck

Electron Catcher on 7/28/15



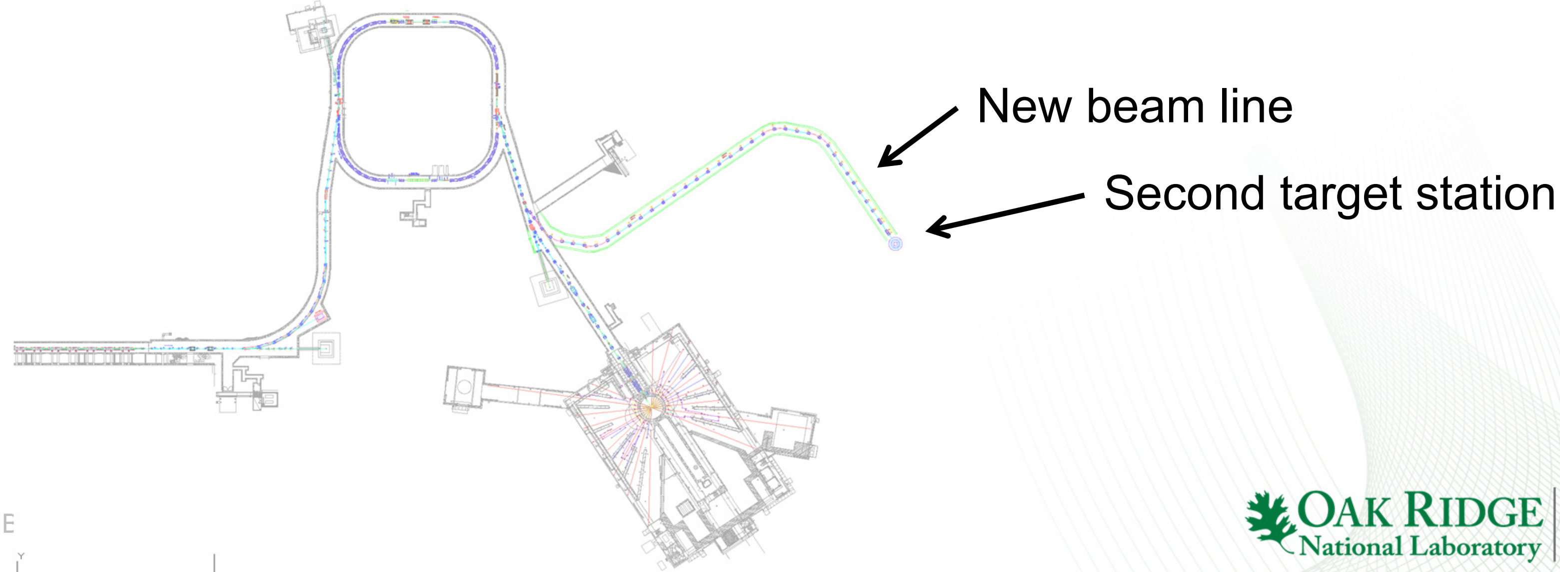
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

Electron Catcher on 1/15/16



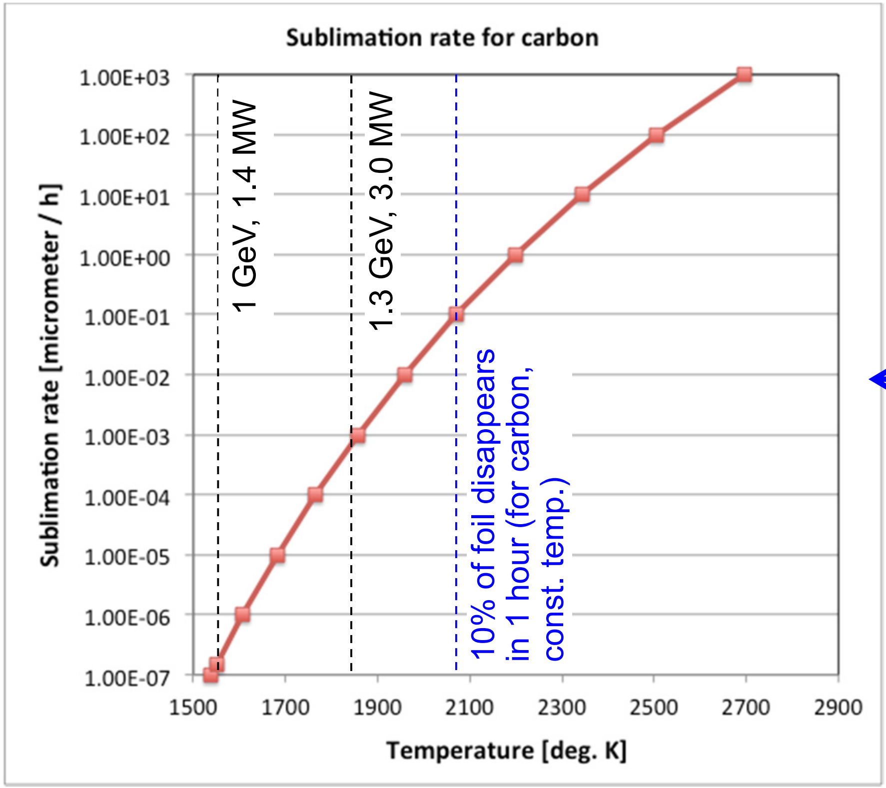
Second target station upgrade

- At SNS we plan to increase the beam power to 2.8 MW @ 1.3 GeV (today SNS is capable of 1.4 MW at 957 MeV)
  - Convoy electron power will double
  - Stripper foils must be thicker to achieve the same stripping efficiency at a higher beam energy
  - Chicane B-fields must be lower for H^{0*} states
  - Foil temperature will increase by ~300 K



Stripper foil lifetime

- Biggest risk to stripper foil lifetime is sublimation
- A small temperature increase makes a big change in foil lifetime



Sublimation rate increases by factor of 10,000 for 300 K temperature increase.

Note: Big error bars on predicted foil temperatures! Lots of assumptions.

Measurement of absolute foil temperature is in progress

Summary

- Charge exchange injection at high power has challenges with beam loss, stripper foil survival, and convoy electron damage
- Today’s machines have addressed these issues, but complications continue to arise as beam powers are increased
- The Second Target Station project at SNS will provide further interesting challenges

Thank you for your attention!