Plasma Window for Gas Charge Stripping of Heavy Ion Beams

Andrew LaJoie

9/2/2019

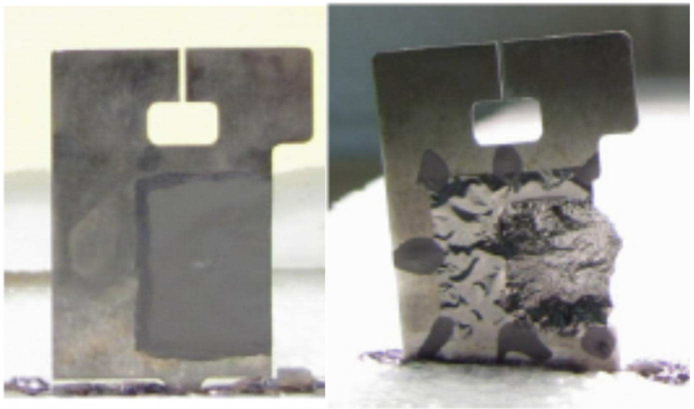
NAPAC2019

Outline

- Motivation behind plasma window for gas charge stripper
- Structure of plasma window
- Considerations for accelerator inclusion
- Results
  - Flow rate reduction
  - Plasma diagnostics
- Moving forwards
- Conclusions

Motivation

- Solid charge strippers can suffer rapid damage from high intensity heavy ion beam
  - Sources: Sublimation & radiation damage
  - e.g. power density of 30 MW/cm^3 in carbon at FRIB
- Gas or liquid alternatives
  - Can flow to remove heated stripper material to cool
  - FRIB will use liquid lithium film as charge stripper
- Gas stripper challenges
  - No solid barriers + wide aperture for beam passage + high pressure = high escape flow rate
  - High gas flow rate → differential pumping back to beamline pressure
  - Lower charge states than solid



Carbon foil damage by ~5×10^{14} $^{208}Pb^{27+}$ ions. Equivalent of 8 seconds of FRIB beam exposure.

J. A. Nolen and F. Marti, *Rev. of Accel. Sci. and Tech.*, **6** (2013), pg 221-236.

Equilibrium Charge States in Gases

- Helium
  + gives highest equilibrium charge state (Q_e)
  - light, so highest escape flow rate

- Argon
  + heavier, easier to contain
  - doesn't provide as high of Q_e

RIKEN data:

Material	Q_e for $^{238}U^{35+}$ at 11 MeV/u
He	66+
Ar	56.6+
N_2	56+
CO_2	55.7+
C (solid)	72+

- Need to mitigate high gas flow from charge stripper → Plasma Window

H. Kuboki et al, *J. Radioanl. Nucl. Chem.*, **299**, 2014
H. Okuno et al, *Phys. Rev. Spec. Topics - Accel. and Beams*, **14**, 2011

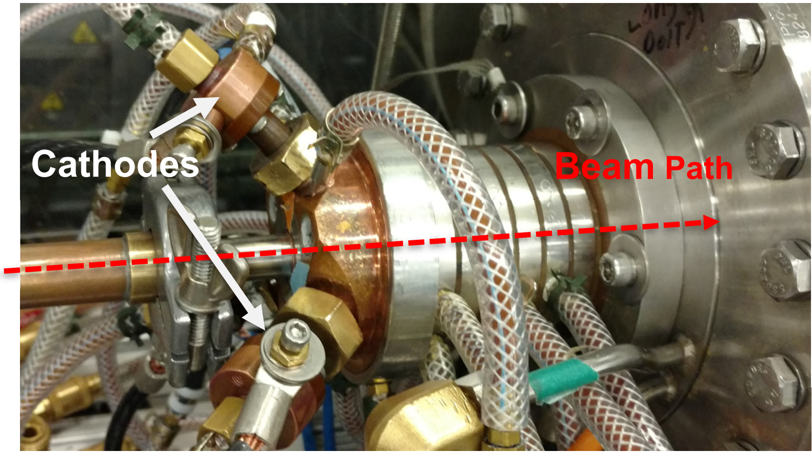
Plasma Window (PW) Concept

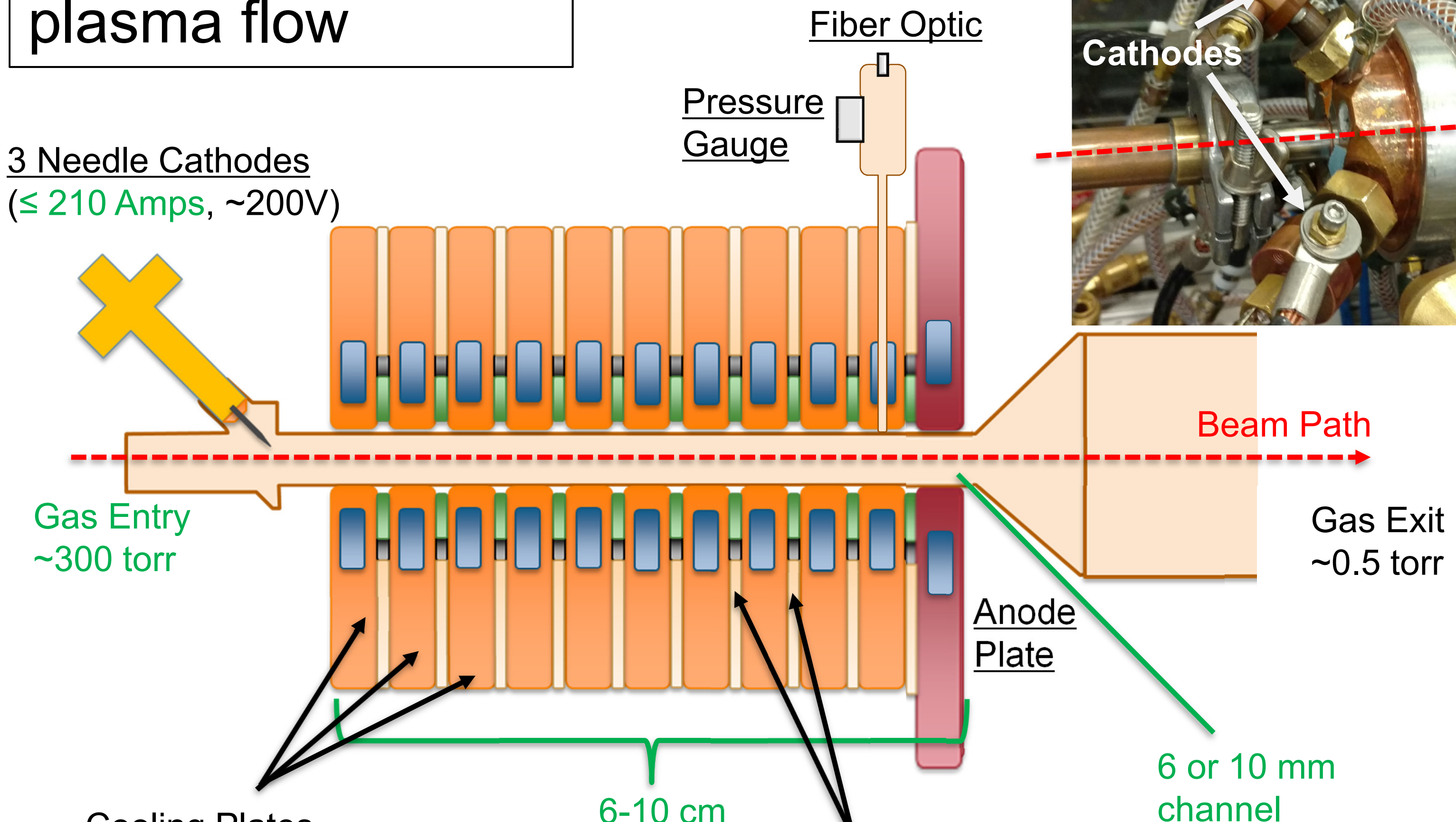
Plasma Window is DC cascaded arc in flowing gas

Gas Charge Stripper → Escaping gas flow is converted to plasma → Substantially heated → Increased viscosity, reduced gas flow

NSCL Plasma Window

Beam coaxial with plasma flow



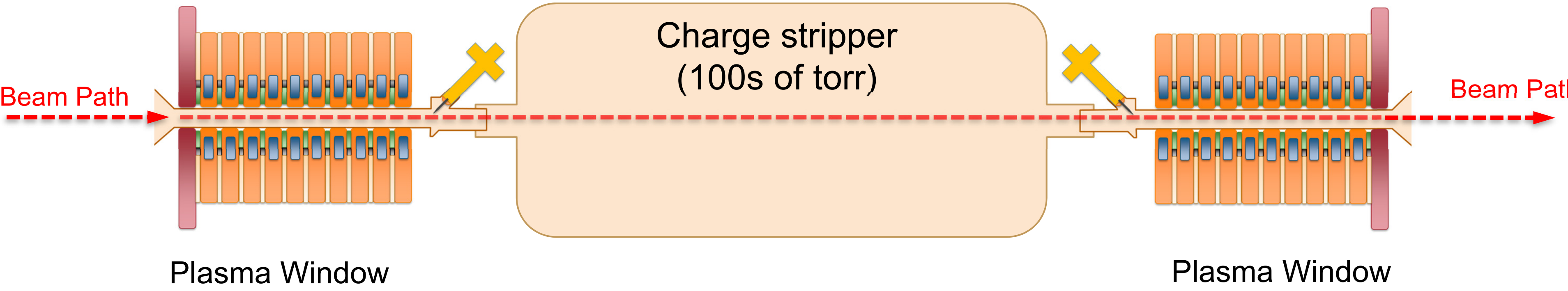


Cooling Plates
Six to Ten 7 mm thick metal plates (water cooled) separated by 2 mm insulated spacers

Design options

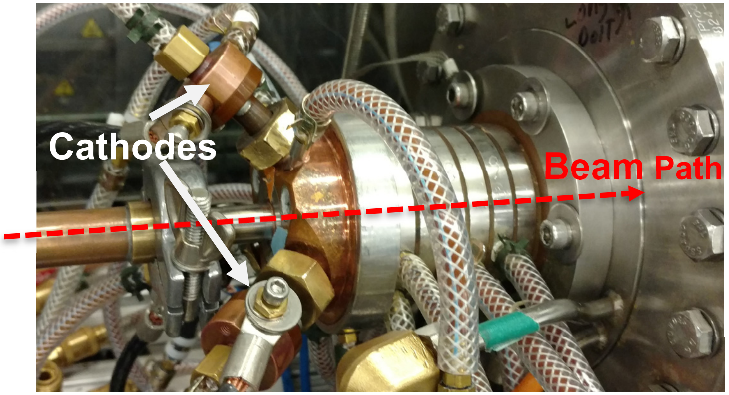
Plasma Window (PW) Structure

In Accelerator:



NSCL Test Stand (half system):

Charge stripper
(not shown in photo)



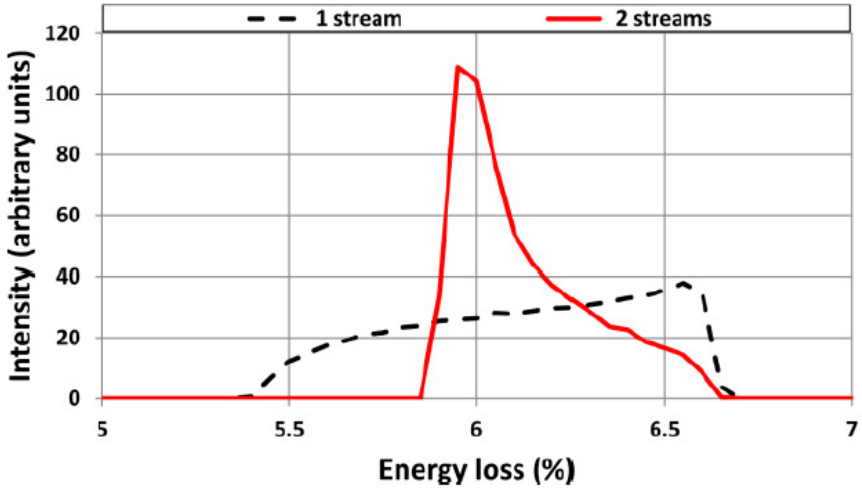
Implementation in Accelerator

- Large power deposition from beam heats gas locally

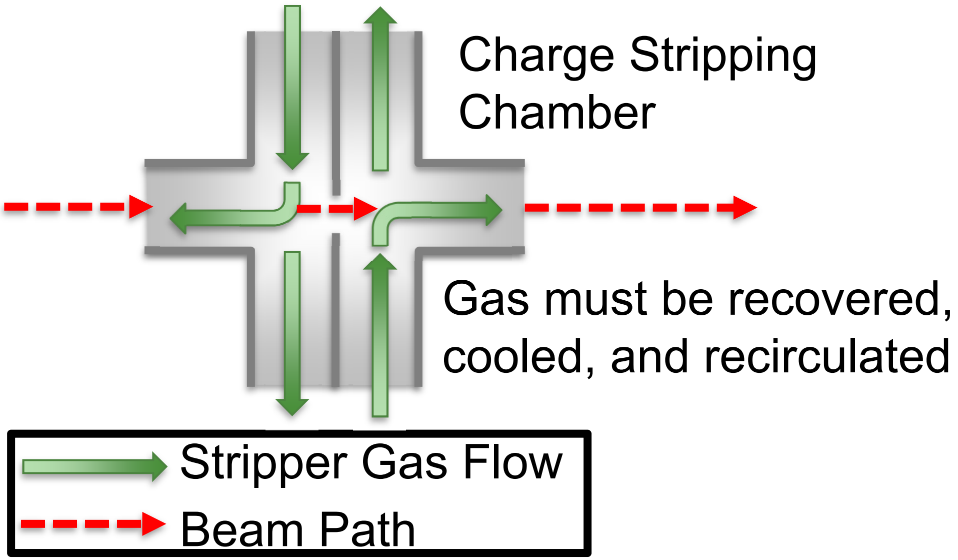
  Heating → lower density → lower target thickness → lower charge state dist.

- To avoid excessive heating, must flow gas perpendicular to beam path

  Can use 2 opposing gas flows (~100 m/s) to reduce energy spread to beam



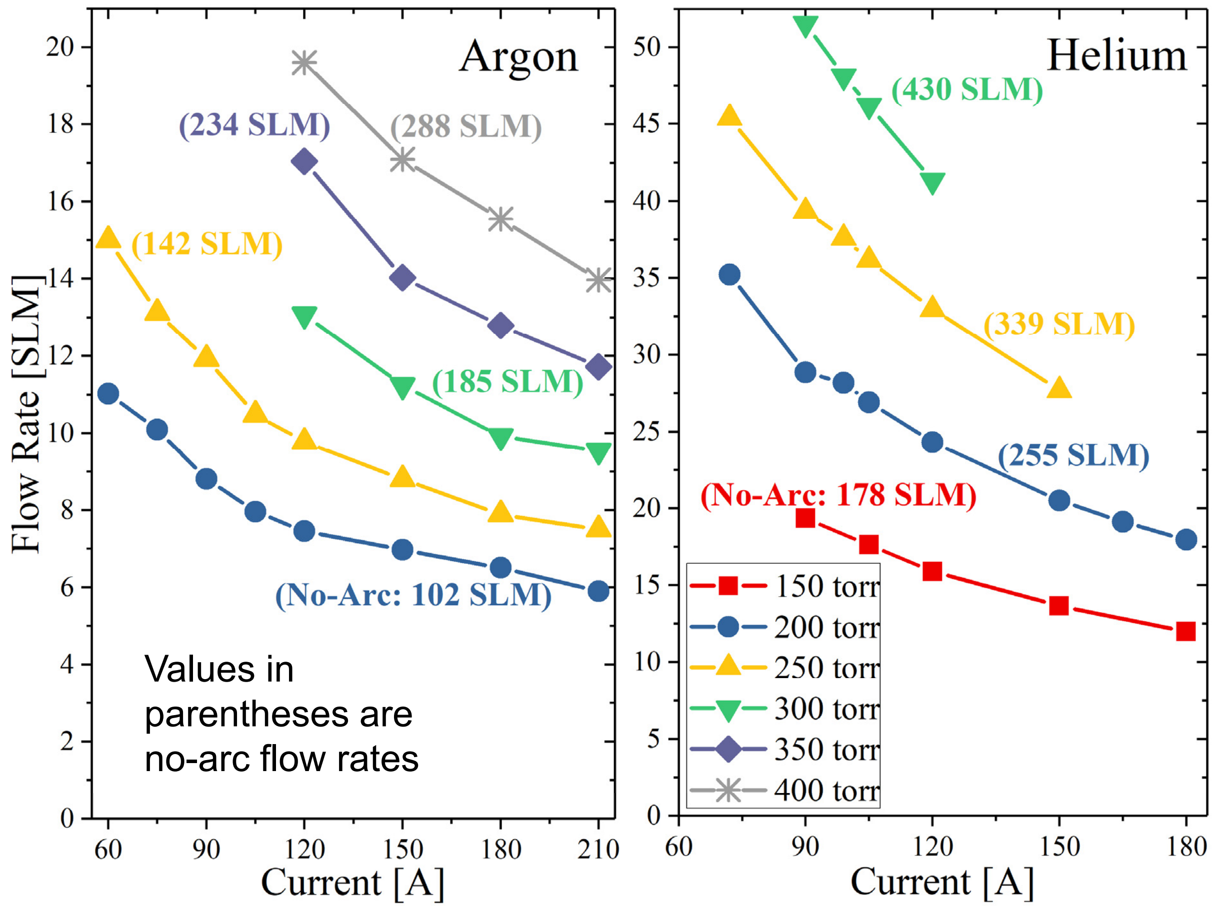
Calculation showing Variation in energy loss of a 16.5 MeV/u U beam in a He gas stripper using a single gas stream and counter-flowing double stream (P. Thieberger, BNL).



J. A. Nolen and F. Marti, *Rev. of Accel. Sci. and Tech.*, Vol. 6 (2013), pg 221-236.

Flow Rate Reduction

- Plasma window of six 6 mm aperture plates (total length 6 cm)
- Flow rate reduced from no-arc case by up to
  - 20 in argon
  - 12 in helium
- Higher current = lower flow rate (at expense of greater strain on cooling system)



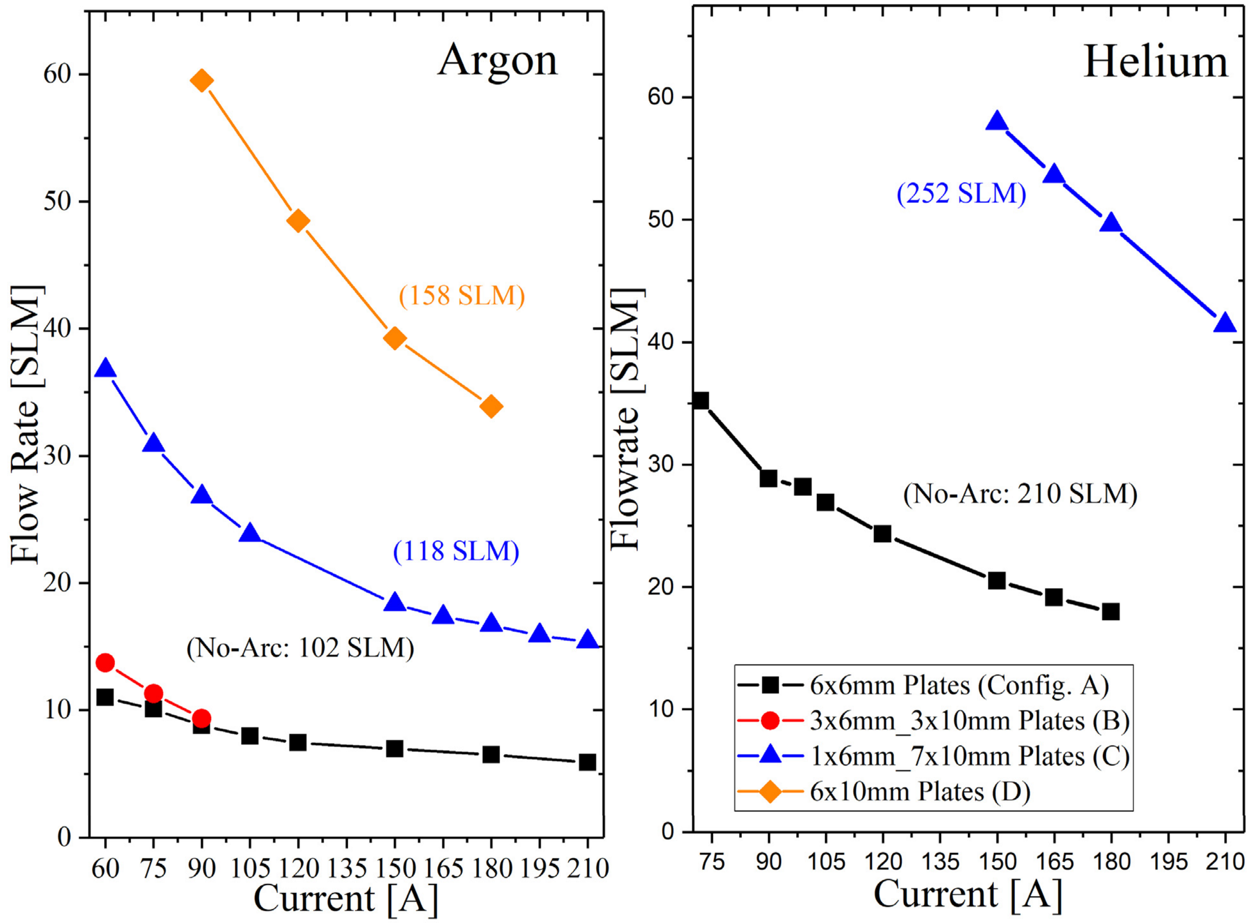
Arc heats gas → greater viscosity → lower flow rate

Flow Reduction in Different PW Channels

- Config. D flow is 6x larger than Config. A

- Config. C vs. D
  - Significantly lower flow
  - Likely not all from 2 extra plates

<u>Single 6mm plate at beginning brings large improvement</u>

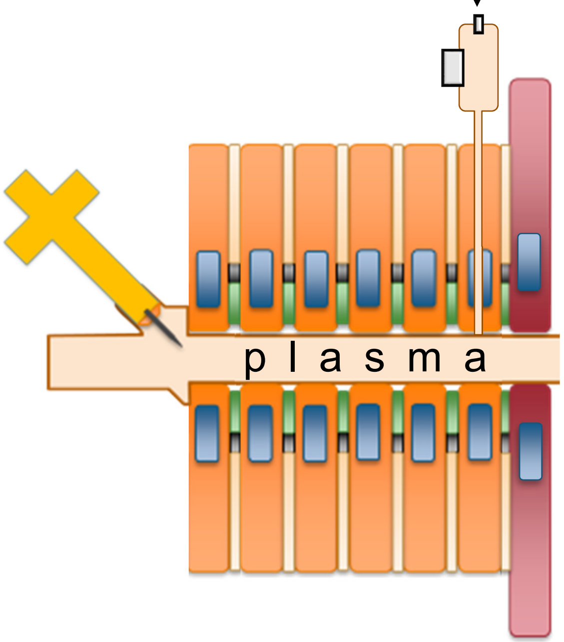


All plot points at Stripper Pressure 200 torr

Plasma Diagnostics

Config. A (6x6mm)

Fiber Optic Feedthrough at Plate 6 → Optical Emission Spectroscopic Measurements → Plasma Electron Density and Temperature



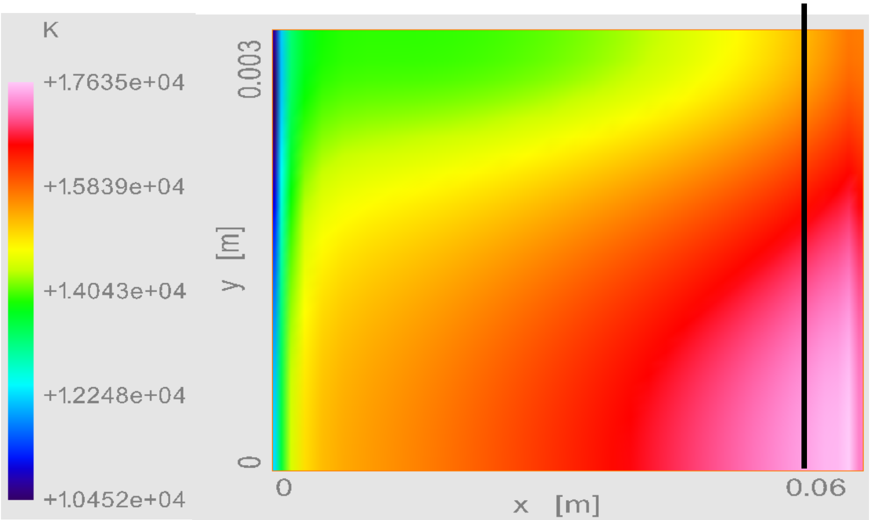
- Use plasma arc modeling code PLASIMO, compare to PW spectral measurement:
  - Electron density (from Stark broadening)
  - Electron temperature (from emission line intensity ratios)
- Can use to model other geometries not tested

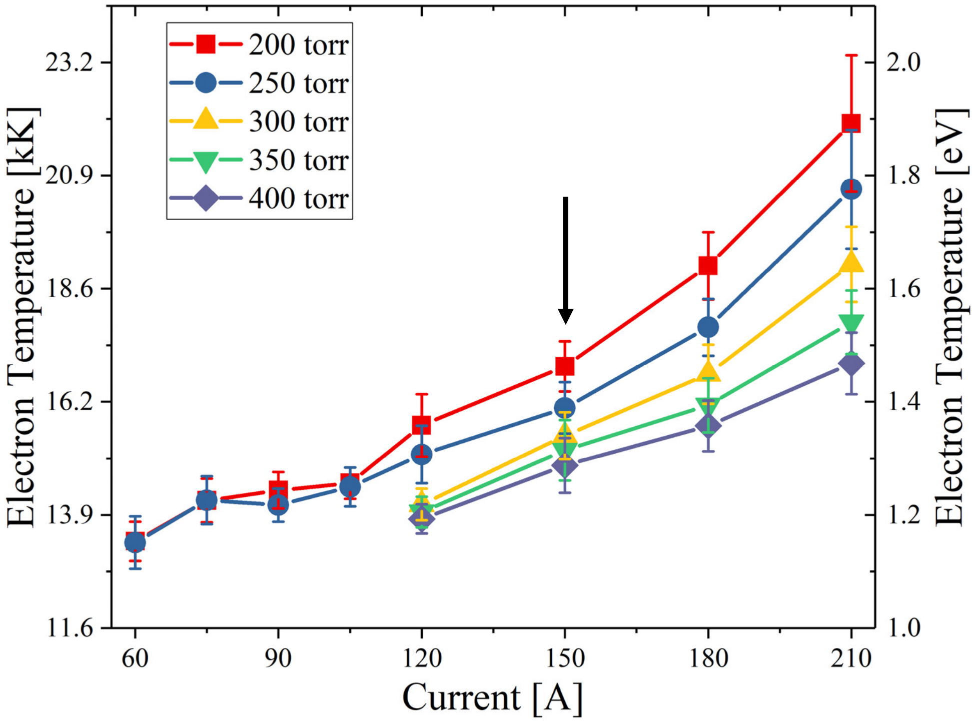
G M Janssen et al, *Plasma Sources Sci. Technol.*, **8** (1999) pg 1-14

Comparison with Model (PLASIMO) in Argon

Plasma temperature with 200 torr, 150 A

Simplified geometry in model





PLASIMO Radial average (over black line in contour plot)	Measurement (black arrow in rightmost plot)
15.6 kK	17.0(±0.5) kK

Observe similar agreement with other plasma properties

Config. A (6x6mm), Argon gas

Looking Forward

- Study effect of increased plasma window length on flow rate
  - 8 and 10 plates
- Cathode longevity studies
  - unattended 140 hour He PW operation successful (discussed in WEPLM56)
  - Aim is ~ 2 weeks (330 hours)
- New geometries with PLASIMO, validating with measurements

Conclusions

- Gas charge strippers are a viable solution to the problem of limited lifetime of solid charge strippers
- Plasma window greatly restricts flow escaping from gas charge stripper
  - Argon easier to manage in plasma window
  - Helium provides better charge states
- Plasma parameters from PLASIMO model are comparable to measured values in studied plasma window configuration
- Lesson from comparing different plasma window configurations:
  - Configuration with all plates of 10 mm aperture results in large flow rate
  - This can be significantly reduced by substituting even a single 6 mm plate at front