Beam Transport Effects in Helium

K. A. Marsh, P. Muggli, B. Blue, M. Hogan, C. O'Connell

During the E-162 experiments in June 2001 we looked at the transport of the beam in helium, nitrogen and argon. Since helium is used as a buffer gas for the lithium oven we were concerned about how the gas might effect the beam transport. We were especially concerned about plasma formation due to impact ionization.

In this note we discuss the results for helium. The results for argon and nitrogen will be discussed in future publications.

Measurements
To test the effect, the beam line volume between the beryllium windows was filled with helium and the beam size was monitored on the downstream optical transition radiator (DSOTR) as a function of helium fill pressure. The results are plotted below in figure 1.

Theory and analysis
The results can be modeled using the usual beam envelope equation and taking into account the effect of impact ionization. Since the beam envelope parameters are not the same in x and y we solve two coupled envelope equations for x and y. The general beam envelope equation for beam transport in a plasma, is given by,

$$\sigma''_{x,y} + k\sigma_{x,y} = \epsilon^2/\sigma^3_{x,y} \qquad (1)$$

where $k = 2\pi r_e n_e/\gamma$, assuming complete blowout of the plasma electrons. The plasma density is formed by impact ionization and is given by,

$$dn_e/dt = n_b n_g \sigma_i c \qquad (2)$$

The beam peak density on axis for an asymmetric Gaussian beam is,

$$n_b = N_0/((2\pi)^{3/2}\sigma_x \sigma_y \sigma_z). \qquad (3)$$

The resulting equations for beam transport with impact ionization are given by,

$$\sigma''_x + K/\sigma_y = \varepsilon^2/\sigma^3_x \qquad\qquad (4)$$

$$\sigma''_y + K/\sigma_x = \varepsilon^2/\sigma^3_y$$

Where $K = 2 r_e N_0 n_g \sigma_i/((2\pi)^{3/2})$

$r_e = 2.8 \times 10^{-15}$ m
$N_0 = .72 \times 10^{10}$ beam charge
$n_g = 3.3 \times 10^{22}$ atoms/m^3/Torr
$\sigma_i = .26 \times 10^{-22}$ m^2 impact ionization cross section
$\gamma = 2 \times 28500$

The equations are coupled due to the fact that the plasma density depends on the beam density and therefore the beam size in x and y. Note that the charge used for these measurements was $.72 \times 10^{10}$ electrons.

The focusing on the beam is not uniform in time. Each time slice of the beam further ionizes the gas and the next slice further pushes out the plasma electrons to form the ion channel. Each succeeding slice feels a stronger focusing force. To model the beam size at the DSOTR we look at the force on the center or peak of the beam pulse. We calculate the plasma density at the peak of the beam pulse according to equation 2, and assume that 70% of those plasma electrons are expelled to form the ion channel. Refinement of the model is needed for looking at all the slices and summing them to create a time integrated image.

The helium atoms also scatter the beam causing emittance growth. This can be ignored for now because the emittance growth is small for the case we considering. For the argon and nitrogen cases the emittance growth is significant and should not be ignored.

The coupled envelope equations (4) were solved using <u>Mathematica</u>. For a symmetric parallel beam, that enters the helium, the beam will pinch at 100 Torr as seen in figure 2. However this does not describe our experiment because the beam was initially focused into the gas and the x and y beam parameters were not equal. The initial x and y beam envelopes in vacuum

are shown in figure 3. The initial conditions are $_x(0)$=160 µm, $'_x(0)$=-200 µm/m, $_y(0)$=118 µm, $'_y(0)$=-75 µm/m. The beam emittance was calculated to be 25×10^{-10} m-r. The large emittance was due to scattering from the beryllium window and the USOTR titanium foil.

The beam envelopes at 100 Torr are shown in figure 4. The theoretical beam sizes as a function of helium pressure is shown in figure 5, and agree well the measured beam sizes in figure 1.

<u>Conclusion</u>
The model equations give good agreement with the observed beam size at the DSOTR. The model could be used to estimate the effect of propagating the beam through 25 meters of helium at 2.5 Torr with a charge of 2×10^{10} electrons. The result is shown in figure 6. If, as considered in the E-164 proposal, we fill the imaging spectrometer with helium, the imaging properties could be compromised.
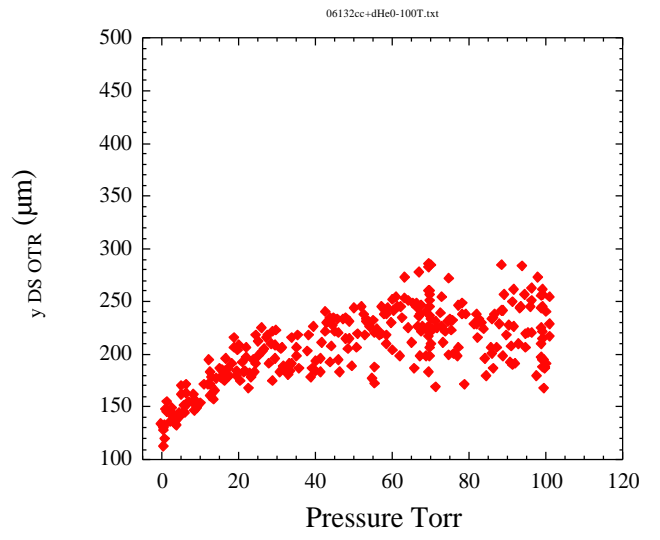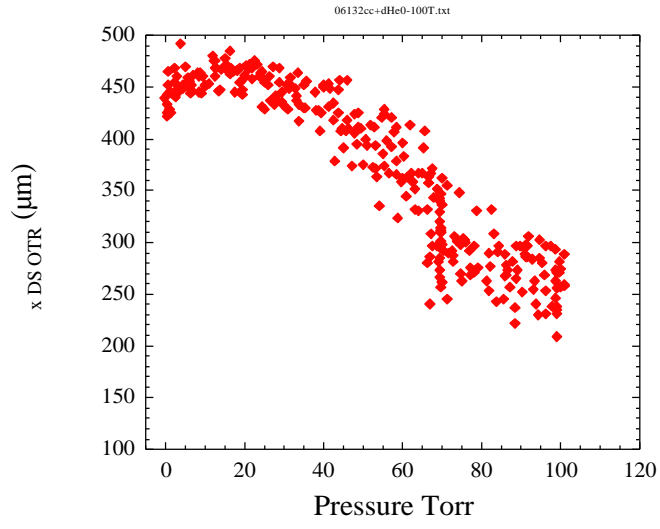
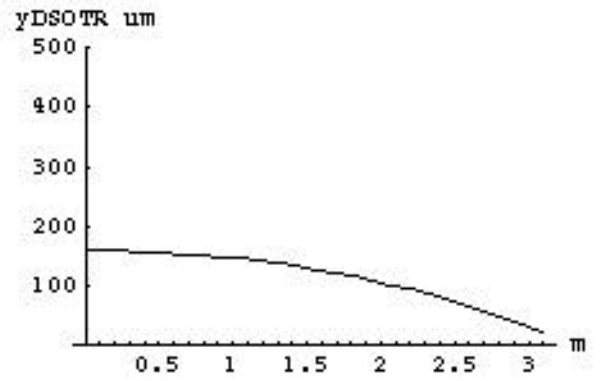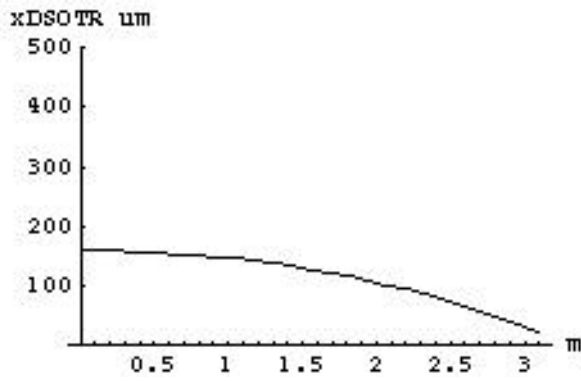Figure 1. Measured DSOTR beam size as function of helium pressure.

Figure 2. Calculated beam envelope of an initially symmetric parallel beam propagating in 100 Torr of helium.
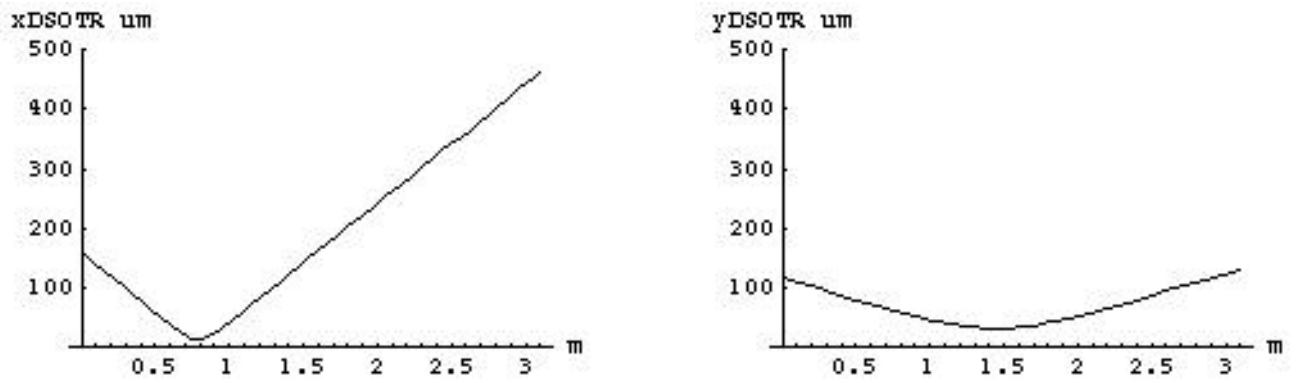
Figure 3. Initial beam envelope in vacuum used to model the experiment.
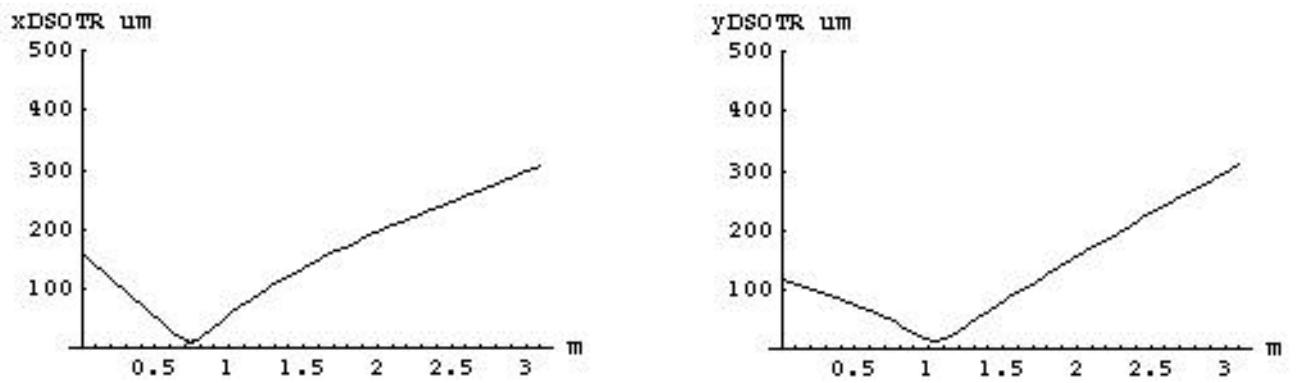

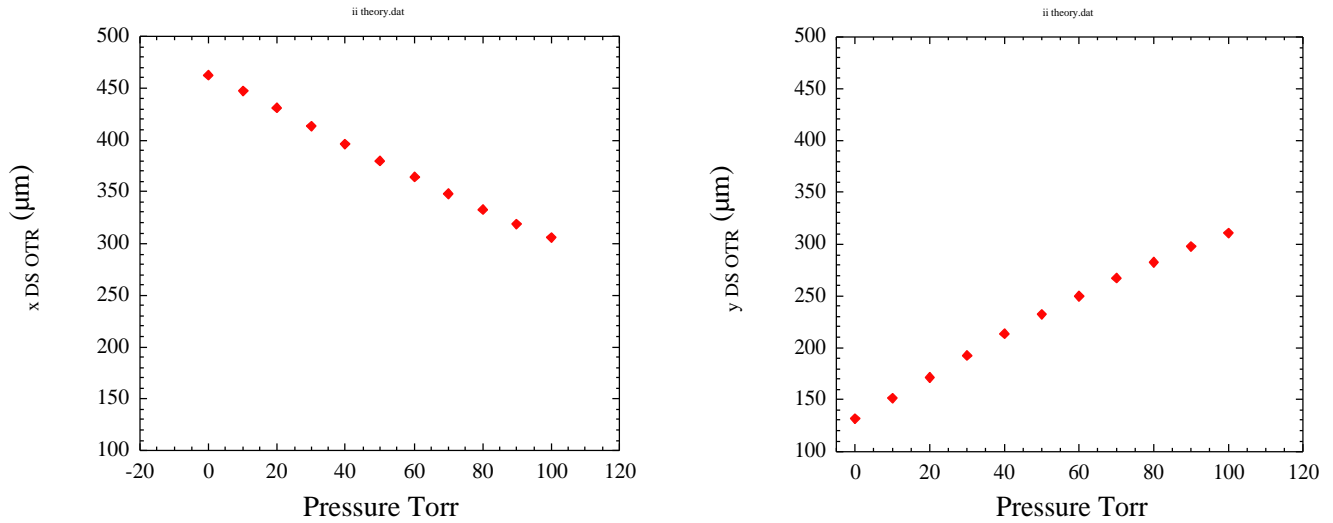Figure 4. Same initial beam parameters as figure 3, in 100 Torr of helium.

Figure 5. Theoretical beam size at DSOTR as a function of helium pressure.
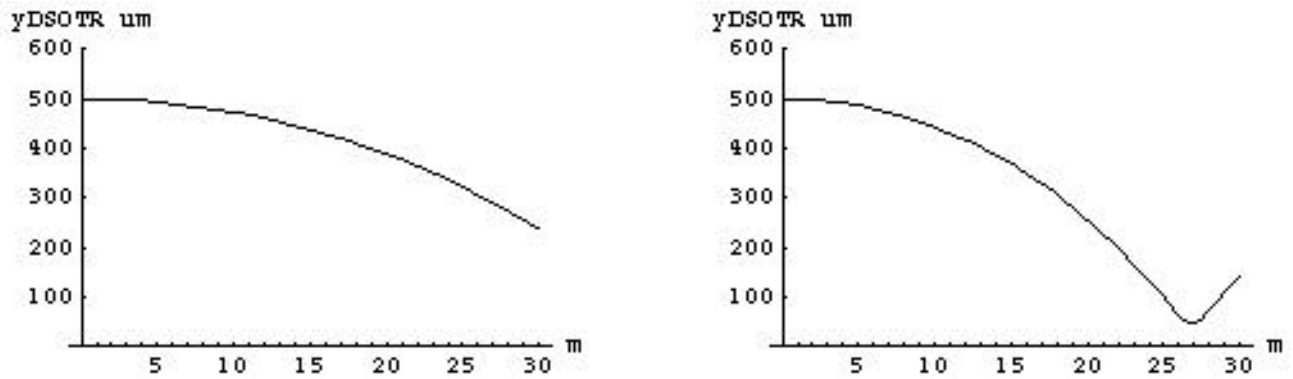

Figure 6. Beam envelope when propagating through 25 meters of helium at 2.5 Torr.   The first figure shows the envelope of the center of the beam and the second figure shows the envelope of the tail of the beam. The beam is initially parallel and has a charge of 2×10^{10} electrons. If the imaging spectrometer is filled with helium the imaging properties could be compromised.