Beam Matching to a Plasma Through a Thin Scattering Element
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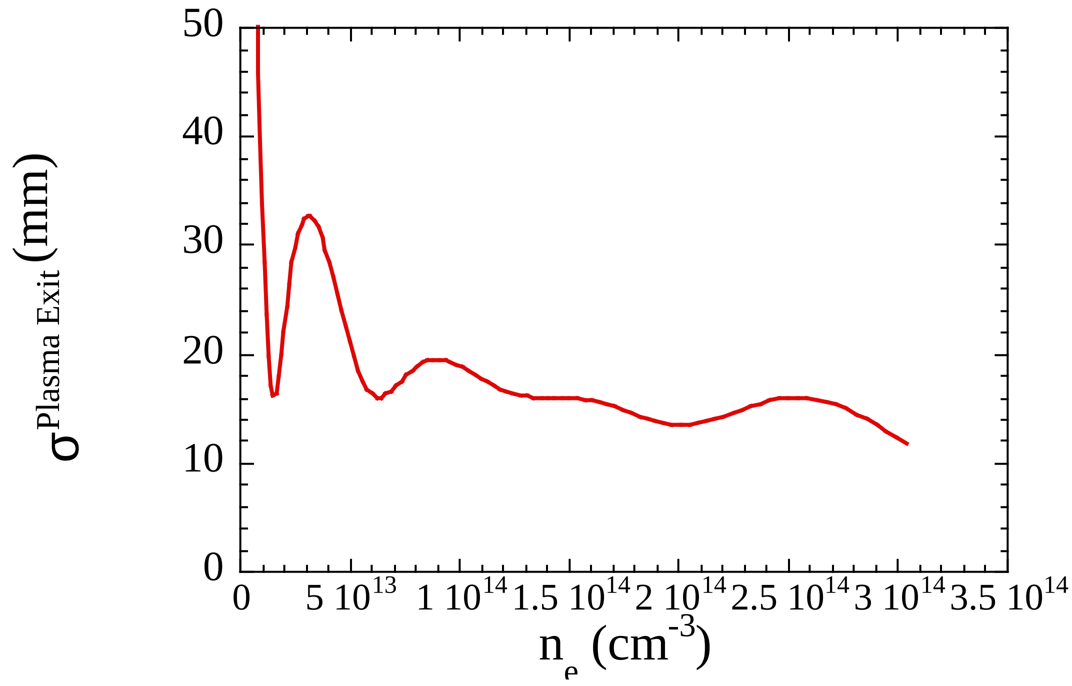
Motivation

As discussed in the new E-162 proposal we plan to move the experiment up to IP-0 in order to beta match the beam to the plasma. This will have several advantages. First, as shown by Patrick and me, there will be no betatron oscillations over a broad range of plasma density near the wake field resonance. See Fig. 1. Similarly, the beam will be nearly matched for all the energies we expect to see. Second, it will allow easier operation of the imaging spectrometer, since there will be only small beam size changes at IP-2. Third this should give us better energy resolution by reducing head tail offset effects.



The Question

The question is what set of beam parameters would be needed to do the matching? Normally it would be a fairly easy task to match the beam to the plasma because the necessary beta can be produced at IP-0. Scattering from the pellicle makes the problem more difficult but not untractable. I have calculated the matching conditions including the effect of the pellicle.

A Solution

In a paper written by J. B. Rosenzweig he calculated the change in Twiss parameter due scattering. The method I used to find the desired beam parameters was to start at the plasma entrance with a matched beam (i.e. $\beta_{focus}=\beta_{plasma}=1/k$, $k=\omega_p/c(2\gamma)^{1/2}$). Then propagate those parameters back to the pellicle. I then calculated what would be the corresponding beam parameters at the pellicle before scattering. From there I propagated the beam back to the upstream OTR. The downstream OTR beam parameters were also calculated starting from the matched beam condition. Finally I started with the matched upstream OTR beam parameters to get the beam parameters downstream with the pellicle removed.

The solution presented here is only for illustration and will need more refinement as discussed later.

The following equations were used for the calculations. The change in Twiss parameters due to scattering are given by;

$$\alpha^2=\alpha_0^2\varepsilon_0/(\varepsilon_0+\beta_0\theta^2)$$
$$\beta^2=\beta_0^2\varepsilon_0/(\varepsilon_0+\beta_0\theta^2)$$
$$\varepsilon^2=\varepsilon_0(\varepsilon_0+\beta_0\theta^2)$$

The beam propagation equations are given by;

$\beta(z)=\beta_f(1+z^2/\beta_f^2)$, where β_f is at focus.

$\alpha(z)=-1/2\beta(z)'=-z/\beta_f$

$\sigma^2=\beta\varepsilon$

The results are in tables below for the following conditions.

β_f(match)=.15 m

ε_0=5x10^{-10} (m-r)

θ= 27 urad

The plasma density is 1.43x10^{14} cm^{-3}

Matched condition with pellicle.

	US OTR	Pellicle	Focus	DS OTR
α	22.5	3.6	0	-15.33
ß (m)	24.3	2.1	.15	35.4
ε (m-r)	5x10^{-10}	1.7x10^{-9}	1.7x10^{-9}	1.7x10^{-9}
σ (um)	110	59	15.8	243
z (m)	-.94	-.54	0	2.3

Beam parameters with pellicle removed.

	US OTR	Pellicle	Focus	DS OTR
α	22.5	12.1	0	-47
ß (m)	24.3	7.0	.048	106.8
ε (m-r)	5x10^{-10}	5x10^{-10}	5x10^{-10}	5x10^{-10}
σ (um)	110	59	4.9	231
z (m)	-.94	-.54	.04	2.3

Some important points and observations.

1) The solutions have a weak dependence on the initial emittance because the final emittance is due mainly to scattering by the pellicle. I did not include the scattering effect of the OTR foils and Be windows, but they will be important when we get closer to the final solution. For now I recommend that we keep the foils as thin as possible and consider replacing the titanium with aluminum. The full solution including all the foils will be looked at using PBO Lab Transport.
2) It is important to have the same beam size in x and y for the optimum wake and so we will need the correct initial beam parameters to get the same emittance in x and y at the plasma.
3) The solutions have a strong dependence on scattering angle and so this will need to be measured precisely. There is some discrepancy in the literature as to the correct scattering angle formula.
4) Precise measurements at the OTR's will be required along with quad scans to measure the beam parameters at the upstream OTR's.
5) The beam parameters with the pellicle removed can be used to confirm we have the correct beam set up.
6) As Tom pointed out beam loading is a concern for small beams. This will reduce the wake amplitude, but give us plenty of accelerated electrons.
7) Beam induced ionization may once again be a concern due to the large beam density. I have read the papers by E-150 but I cannot understand how they measured the amount of beam ionization or how to calculate the ionization cross section based on their results.