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Proposal for HE3 Probe Head

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Abstract: We propose to develop a prototype of brand new head for the HE3 probe with intent to measure the cyclotron circulating beam vertical distribution and size with largely improved resolution and accuracy.

1 Introduction

We desire to measure, by using HE probe(s), the circulating beam vertical distribution and size with high resolution and good accuracy, as such measurements allow to characterize properties of the beam during acceleration, up to 480 MeV extraction by stripper foil. The existing 7-finger probes, both HE1 and HE2, are flawed in this application because the fingers are too tall in comparison with the beam size. The middle five fingers are the same height of 6.35 mm (0.25 inch) and the two outer ones are 15.875 mm (0.625 inch) each. The beam size is typically 15 mm (full bottom width), making 95% of the beam on just two or three fingers. So the binning is rather coarse, leading to a poorly estimated beam size all over the place. In order to remedy this defect, we propose to build a prototype of brand new head for the HE3 probe.

2 Proposed Vertical Fingers

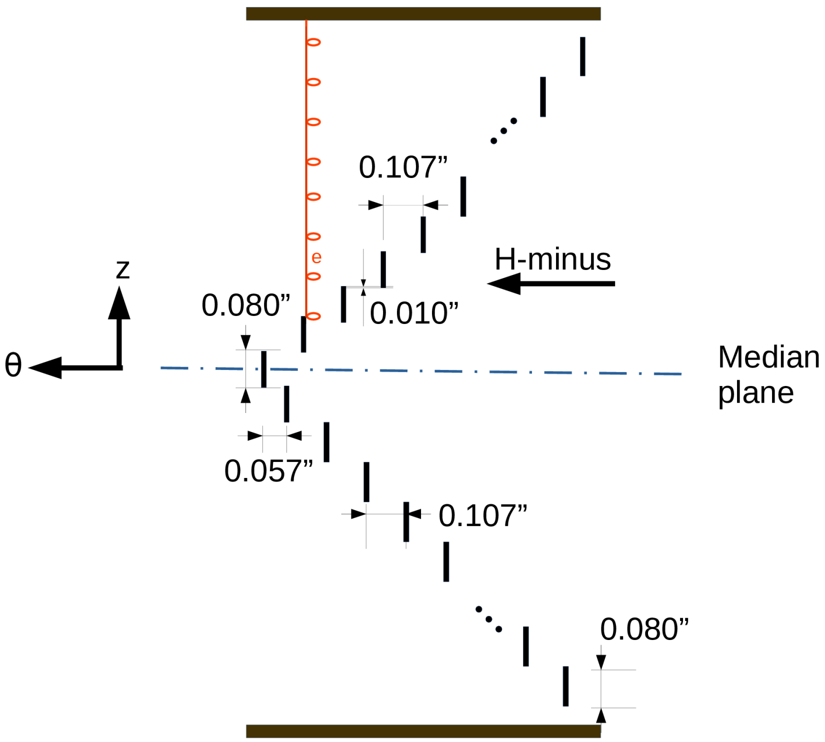

Figure 1: *Schematic diagram showing the proposed 35-finger arrangement in θ-z plane. Note that the finger thickness is 0.007 inch, the lower 17 fingers are displaced from the upper ones by 0.050 inch in the H^- beam direction, while in the vertical direction adjacent fingers overlap by 0.010 inch.*

The existing HE1 probe head shroud has a height of 2.800 inch in vertical direction, and a depth of 1.800 inch in beam direction. We consider these sizes as a reference of the envelope for the HE3 new head.

The HE3 probe travels between inner limit of (301.900 inch, 114.100°) and outer limit of (314.400 inch, 115.547°), where 0° angle is along North-East side dee gap centre-line. This corresponds to H^- energy from 445.3 to 519.8 MeV. Assume that the two electrons of H^- travel in the same speed as H^- (i.e. neglecting orbital modulations), then each electron carries a kinetic energy from 0.242 to 0.283 MeV. Accordingly, the stopping power of the electron in Tantalum varies from 1.390 to 1.321 $\mathrm{MeV\,cm^2/g}$, shown in Fig. 2. If the finger is made of Tantalum foil of thickness 0.003 inch (and density $16.69\,\mathrm{g/cm^3}$), then the electron would escape out of the finger with energy from 0.066 to 0.155 MeV, and spiral around the cyclotron B_z force lines with a radius varying from 2.0 to 3.0 mm as B_z changes from 4.4523 to 4.6912 kG over the probe's travel path. (The B_r component is 3 orders of magnitude smaller than the B_z so the overall field is dominated by the B_z.) While for a foil thickness of 0.004 inch, the escape energy would become 0.008 to 0.059 MeV, and the spiral radius from 0.7 to 1.8 mm. Further, with 0.005 inch thickness, the electron gets almost fully stopped in the finger except at the outer limit of probe travel. See Fig. 3. We must avoid any cross-talk between neighbouring fingers. **Thus, for secured measurement, we choose a thickness of 0.007 inch for every finger. Plus a spacing of 0.100 inch (net) between adjacent fingers**, we could accommodate $1.800/(0.100+0.007) + 1 = 18$ fingers, in the beam direction.

Besides, there are secondary electrons, kicked out of the finger surface. These electrons have a typical energy of 5 eV. Even if it's tripled to 15 eV, the electron's spiral radius around B_z is only about 30 µm, way smaller than the finger gap of 0.100 inch (2540 µm). But they spiral upward and downward in 50:50 probability.

In the vertical direction, we assume a uniform height of 0.080 inch (2 mm) for all the fingers, so we could accommodate $2.800/0.080 = 35$ fingers. Furthermore, we have to take into consideration the particle's incident angles, both the coherent and the incoherent. The coherent angle (due to vertical oscillation of static equilibrium orbit) is ≤ 4.0 mrad over the probe travel path, while the incoherent angle is ≤ 3.0 mrad (4rms). Summing them up gives an overall angle of ≤ 7.0 mrad. We can choose to overlap adjacent fingers vertically by 0.010 inch. This is more than enough (as 0.100 inch × 7 mrad=0.0007 inch).

Thus, we propose 35 fingers in total, 17 up and 17 down, the lower 17 fingers are displaced from the upper ones by 0.050 inch in the beam direction, and the adjacent fingers overlap vertically by 0.010 inch. The finger thickness is 0.007 inch. This is shown in the schematic diagram Fig. 1.

It should be mentioned that with 0.007 inch Tantalum foil, the total energy deposit in the finger by a single H^- ion (i.e. 2 electrons and 1 proton) is no more than $0.283\times2 + 0.437=1.003$ MeV over the probe's entire travel path. If we limit the circulating beam current to 1 µA for the probe, then the maximum power deposit is 1.0 W. This should be acceptable concerning the temperature rise.

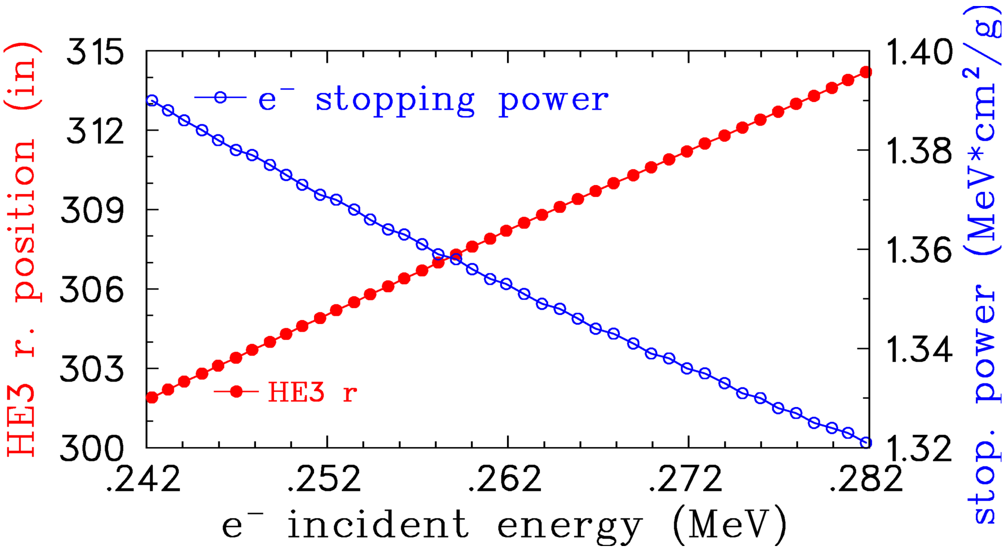

Figure 2: *Kinetic energy of H^- electrons as a function of probe radial position (red), and the corresponding stopping power of the electrons in Tantalum (blue).*

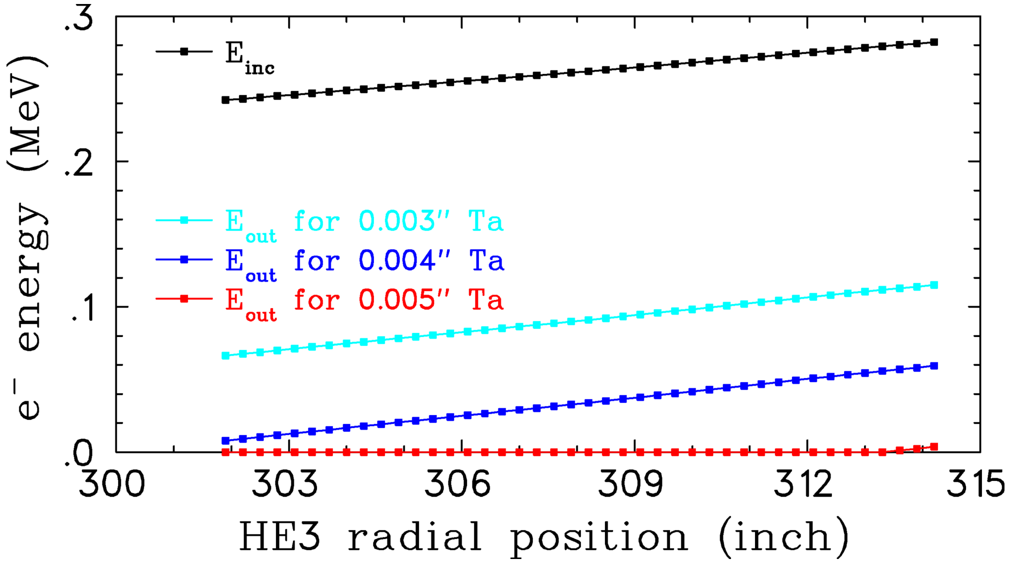

Figure 3: *Incident energy (black) and outgoing energy (color) of the electrons as a function of probe radial position, for different thicknesses of Tantalum foil. Notice that for 0.005 inch thickness, the electrons get almost fully stopped in the foil.*

3 Probe Head Orientation

Horizontally, the circulating beam orbit has to perpendicularly hit the probe head. To this end, the probe head needs to rotate by an angle relative to the travel line of the probe, shown in diagram Fig. 4.

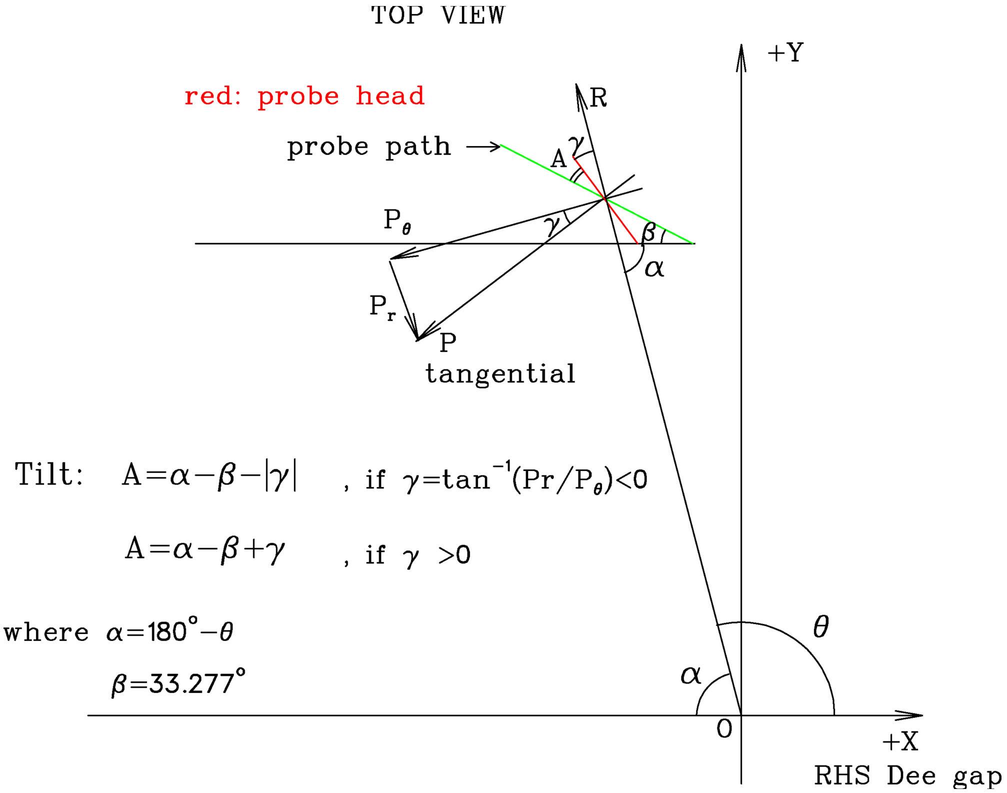

Figure 4: *Schematic diagram showing the plan view of HE3 probe head (red line), travel path (green line) and beam direction, where A denotes a rotation angle that is required for the probe head so that the beam perpendicularly hits the probe head.*

Based on the results of calculation for the acceleration orbit which we assume to be well centred radially, we obtain, over the probe's entire travel range, a series of geometrical parameters shown in Fig. 4, namely,

(X, Y) coordinates along the travel line;
(R, θ) coordinates along the travel line;
E: kinetic energy of the orbit at the corresponding coordinate;
$\alpha = 180^\circ - \theta$;
β: angle that the travel line makes with X axis;
$\gamma = tan^{-1}(P_r/P_\theta)$; and
A: the rotation angle that is required for perpendicular hit.

These parameters are listed in Table 1. We notice that the rotation angle required for perpendicular incident barely changes. **We specify an rotation angle of 31.6°, with an overall inaccuracy of** $\leq\pm 0.2^\circ$, taking into account the error of angles arising from various sources.

Table 1: (X, Y; R, θ) coordinates, orbit energy E, and rotation angle A along the travel path.

X (in.)	Y (in.)	R (in.)	θ (deg)	E (MeV)	α (deg)	β (deg)	γ (deg)	A(deg)
-123.275	275.585	301.900	114.100	445.313	65.900	33.277	-0.979	31.6
-123.573	275.780	302.200	114.136	447.034	65.864	33.277	-0.941	31.6
-123.870	275.976	302.500	114.173	448.768	65.827	33.277	-0.903	31.6
-124.168	276.171	302.800	114.209	450.510	65.791	33.277	-0.866	31.6
-124.465	276.366	303.100	114.245	452.255	65.755	33.277	-0.828	31.6
-124.762	276.561	303.400	114.281	453.993	65.719	33.277	-0.791	31.7
-125.060	276.756	303.700	114.317	455.725	65.683	33.277	-0.754	31.7
-125.357	276.951	304.000	114.353	457.450	65.647	33.277	-0.718	31.7
-125.653	277.146	304.300	114.389	459.170	65.611	33.277	-0.682	31.7
-125.950	277.341	304.600	114.424	460.889	65.576	33.277	-0.646	31.7
-126.247	277.535	304.900	114.460	462.613	65.540	33.277	-0.611	31.7
-126.543	277.730	305.200	114.496	464.345	65.504	33.277	-0.576	31.7
-126.840	277.925	305.500	114.531	466.083	65.469	33.277	-0.541	31.7
-127.136	278.119	305.800	114.566	467.826	65.434	33.277	-0.507	31.6
-127.432	278.314	306.100	114.602	469.567	65.398	33.277	-0.473	31.6
-127.728	278.508	306.400	114.637	471.308	65.363	33.277	-0.439	31.6
-128.024	278.702	306.700	114.672	473.048	65.328	33.277	-0.406	31.6
-128.320	278.896	307.000	114.707	474.788	65.293	33.277	-0.373	31.6
-128.616	279.090	307.300	114.742	476.534	65.258	33.277	-0.340	31.6
-128.912	279.284	307.600	114.777	478.290	65.223	33.277	-0.308	31.6
-129.207	279.478	307.900	114.812	480.062	65.188	33.277	-0.276	31.6
-129.503	279.672	308.200	114.847	481.852	65.153	33.277	-0.244	31.6
-129.798	279.866	308.500	114.881	483.659	65.119	33.277	-0.212	31.6
-130.093	280.060	308.800	114.916	485.481	65.084	33.277	-0.180	31.6
-130.388	280.253	309.100	114.950	487.316	65.050	33.277	-0.149	31.6
-130.683	280.447	309.400	114.985	489.161	65.015	33.277	-0.117	31.6
-130.978	280.640	309.700	115.019	491.010	64.981	33.277	-0.085	31.6
-131.273	280.834	310.000	115.053	492.866	64.947	33.277	-0.053	31.6
-131.567	281.027	310.300	115.087	494.729	64.913	33.277	-0.022	31.6
-131.862	281.221	310.600	115.121	496.602	64.879	33.277	0.010	31.6
-132.156	281.414	310.900	115.155	498.482	64.845	33.277	0.041	31.6
-132.451	281.607	311.200	115.189	500.365	64.811	33.277	0.072	31.6
-132.745	281.800	311.500	115.223	502.250	64.777	33.277	0.103	31.6

4 Acknowledgements

Useful discussions with Beam Diagnostics group and Beam Physics group are greatly appreciated.