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ELECTRON BEAM DIAGNOSTICS IN THE FERMILAB ELECTRON COOLING EXPERIMENT

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Abstract

Successful electron cooling of antiproton beams requires a precisely aligned and high quality electron beam. Mean e⁻ momentum and energy are to be held within 0.25 mrad and $\frac{1}{2}$ eV respactively. In addition the e⁻ "temperature" about this mean (rest frame velocity spread) should be held to $\leq \frac{1}{2}$ eV. The diagnostics required to align the beam in angle and energy are rather straightforward. The temperature measuring diagnostics (one for $T_\perp$; one for $T_\parallel$) are more exotic.

Position and Angle Alignment

The cooling process requires a proper overlap of the cold e⁻ beam on the warm antiproton beam. In angle the beams should not be locally diverging by more than 0.25 mrad. Our electron beam is confined on a solenoidal magnetic field (~1 kG; 0.002 cm gyroradius). Therefore this guide field must be extremely smooth and its overall direction must be adjustable to high precision.

The solenoid is 5 m in length, comprising 5 one meter segments. Each segment has sufficiently uniform field by construction (foil wrapped on precision hubs). Subsequent tests have confirmed this feature. Each 1 m segment mounts on independent adjustments within the unit 5 m flux return tube. Gap correction windings circle the ~ 1/8 in. gaps between 1 m segments. The challenge was to align the 5 segments and pick up their mean magnetic axis with external survey instrumentation.

A small, total immersion, TWT e⁻ gun was mounted on axis ~ 20 cm inside one end of the solenoid. a phosphor screen was mounted on a longitudinal motion rail in such a way that the small e⁻ beam (~ 0.5 mm ϕ) could be intercepted at any position along the solenoid. This interception spot could be viewed through a coaxial port mounted off the other end of the solenoid. With a precision alignment telescope we were able to adjust each segiment and the gap correctors such that the e⁻ beam deviated no more than ± 0.002 in. from a true line throughout the 5 m length. The mean line so define was easily referred to the mechanical structure and storage ring orbit coordinates.

Overall tilt of the e⁻ beam is accomplished by weak dipole windings; one pair for vertical, and one for horizontal tilting. These run the length of the solenoid and are just outside the solenoid windings. Again, the small TWT beam was used to accurately calibrate the tilting strength of these windings.

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Energy Measurements

We do not need an absolute precision monitor of e⁻ beam energy (voltage). If the beam is otherwise properly adjusted then the cooling process itself will be the appropriate indicator of e⁻ beam mean energy. However we have designed and constructed a precision 10^4:1 HV divider to monitor relative beam voltage. The stability of this device is at least 20 ppm which will allow meaninful shifts of beam voltage on the scale to which cooling is sensitive (~ $\frac{1}{2}$ eV). The divider is additionally A. C. compensated to allow study of transient HV phenomena (e. g. , ripple).

Longitudinal Temperature

The spread of longitudinal velocities in the 110 keV e⁻ beam may be characterized by an effective $T_\parallel$ The true statistical spread is extremely small (equivalent to $T_\parallel \sim 10^{-4}$ eV).[1] However our beam, if unneutralized, will have a large systematic space charge depression (1300 V edge to center). This will result in a ~ 7 eV longitudinal temperature spread profile. An important study will therefore be to investigate neutralization of this effect.[2] In order to monitor such studies we have developed a Compton scatter probe to measure the systematic longitudinal velocity spread (Fig. 1).[3]

A cw Q switched YAG laser (1.06μ) has its output injected through a port into the vacuum chamber. The beam is aligned parallel to the oncoming e⁻ beam in the 5 m straight section. The laser beam may also be translated parallel such that it can illuminate any ~ 1 mm ϕ portion of the 6 cm ϕ e⁻ beam profile. Backscattered photons (0.29μ) are collected by the same injection optics but split off from the laser path by a specially coated mirror and directed to a Fabry-Perot analyser. The Fabry-Perot is arranged to have a FSR of ~ 20Å which corresponds to the backscatter wavelength shift calculated to correspond to a ~ 7 eV difference in e⁻ energy. Resolution is limited to ~ $\frac{1}{2}$ Å by the laser beam width and the finite backscatter collection cone. With a 20 watt cw laser we expect a signal of ~ 10 counts/s from the phototube. Even at this signal level we expect virtually no background: 1. The system is highly frequency selective, 2. the low level light is shifted far from, and to the UVfrom, the high intensity laser light and 3. Q switching the laser allows very low duty cycle operation.

Transverse Temperature

Since the beam electrons are magnetically confined, transverse velocity of individual electrons seen in the mean rest frame will appear as cyclotron motion at a characteristic ν_c = 2.8 GHz (1 kG field). Such transverse motion can be of two types: First of true Maxwellian character (incoherent angular positions). For instance our 1000°C cathode e⁻ source creates an 0.1 eV $T_\perp$ of this type. Second, imperfections in

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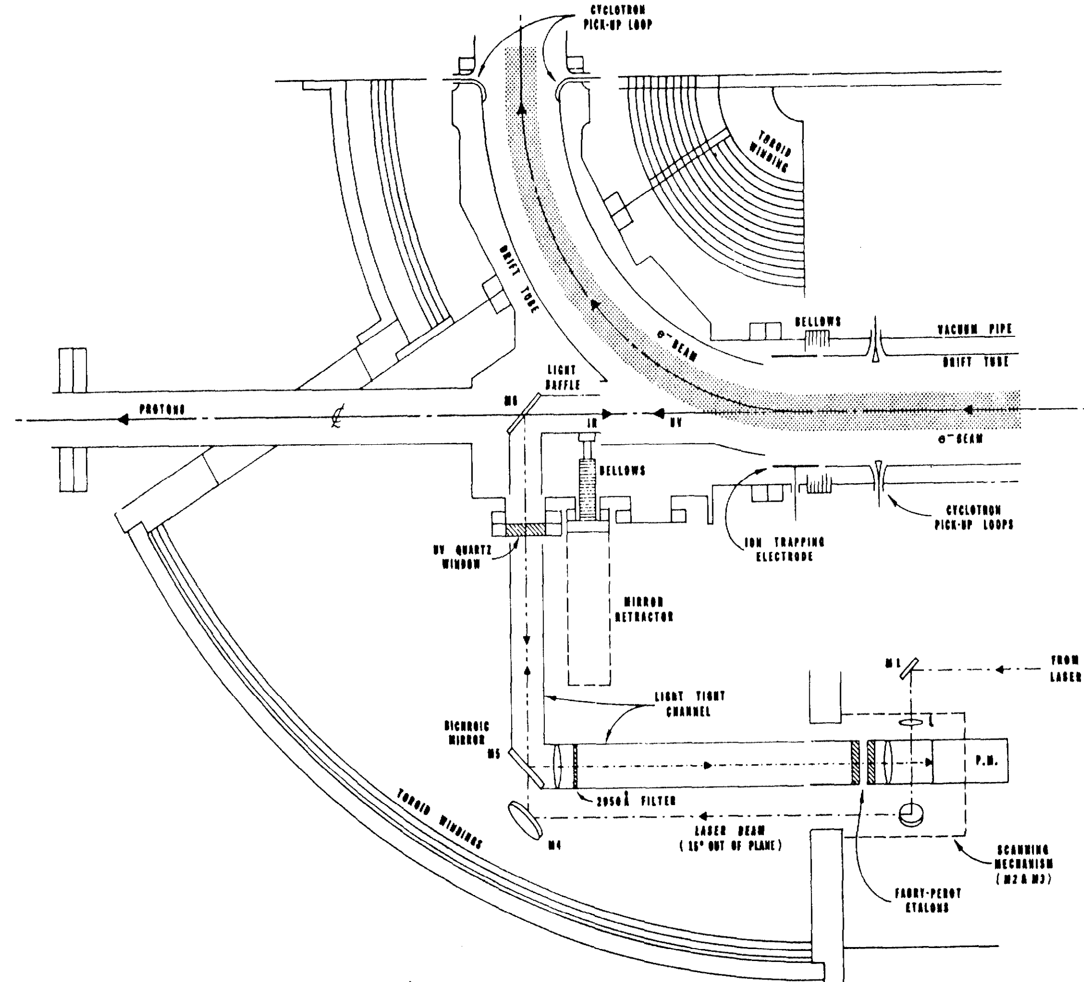

Fig. 1 Electron Beam Diagnostic Devices.

elements of the electron gun or guide field may kick the beam transversely, imparting a coherent $T_\perp$ component. It has been our object to design and then tune elements of the e^- gun and magnetic structure to minimize these $T_\perp$ sources. In fact, we have numerous magnetic and electrostatic elements built into the system to accomplish this.

To monitor this tuning, we shall pick up the cyclotron radiation of the beam electrons. The e^- beam is surrounded by a 15 cm ϕ copper drift tube. We have studied the mechanism of e^- beam cyclotron motion coupling to the waveguide modes of a surrounding tube.[4] In free space the rest frame radiation at 2.8 GHz would be hopelessly smeared out by doppler shift when observed in the lab. However, a surrounding guide is only excited discretely at two frequencies per mode. We use this principal as the basis for monitoring an identifiable signal.

Only TE Modes are excited. For various reasons only excitation and pickup of three particular modes, TE_{11}, TE_{12}, and TE_{01}, is feasible.[4] We have designed pairs of loop pickups which are compatible with coupling to each of these modes. In addition the couplers are designed to surpress pickup of e^- beam induced Schottky noise (broad band noise), which is expected to be the principal background. Actual signal to noise performance is hard to predict since it is background dominated (amplifier Johnson noise is negligible). However our design goal is to detect signals with 1:1 S/N for e^- beams with 1 eV incoherent $T_\perp$. Since our main concern will be with coherent tuning, even better performance may be anticipated.

References

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