Possibility of focusing of charged particles in experiments with colliding beams

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Oriented crystal film is proposed as a focusing system. Colliding-beam reaction yields may be increased 1 to 2 orders of magnitude due to effect of spatial regrouping of channeled particles.

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One of the most important problems in experiments with colliding beams is the enhancement of reaction yield. This is achieved by establishing intersection regions where the beams are focused by means of magnetic systems. In this work we further propose placement of oriented crystal films at the intersection regions through which the particles pass in the channeling mode.

During particle channeling substantial redistribution of particle flux occurs within the channel cross section and in depth.[1] Output oscillations are observed near the surface,[2] which are adequately explained by theory.[3] In particular, approximately an order of magnitude increase in the flux density may be attained at the channel center for a small beam divergence. In this case, the reaction yield in an experiment with colliding beams will be proportional to that product of flux densities of the colliding beams, i.e., in principle, two-orders of magnitude increase may be attained for the reaction yield. Moreover, it is good to remember that the information concerning spatial-temporal characteristics of events under study is substantially upgraded since the interaction point is known with high accuracy.

Figure 1 schematically shows trajectories of colliding positive particles in a plane channel (trajectories of the negative particles will differ from those shown in Fig. 1).

The highest flux density is attained at the first maximum, i.e., at the quarter length of the spatial trajectory period. At great depths, the flux density diminishes the oscillations.[3] Therefore, we shall calculate the value of flux density in the region of the first maximum.

Particle motion in a channel under the condition of multiple scattering is described by the Planck-Fokker equation. Multiple scattering at the small depths under consideration may be neglected. The problem then reduces to the solution of the

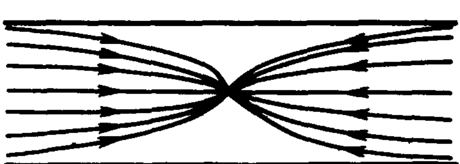

FIG. 1. Focusing of particles in a plane channel.

Liouville equation:

$$\frac{\partial f}{\partial z} + \theta \frac{\partial f}{\partial x} - \frac{U'(x)}{Mv^2} \frac{\partial f}{\partial \theta} = 0, \tag{1}$$

where f is the particle coordinate and angular distribution function, z is depth, x is distance from the center of the plane channel, θ is the angle between particle trajectory and channel direction, $Mv^2/2$ is particle energy and U' is potential gradient in a channel.

Subsequently, we shall assume the potential to be harmonic:

$U(x) = V_0 x^2$.

In the case of beam divergence $\overline{\Delta\theta}$ when the initial angle of beam injection into a channel is zero, the flux density at the channel center is:

$$\gamma(x = 0, \theta_0 = 0, z) = \int_{-l}^{+l} dx_0 \int_{-\infty}^{+\infty} d\theta f(x, \theta, z, x_0, \theta_0)$$

$$= \frac{1}{2\cos\omega z}\left[\Phi\left(\frac{l\omega\cos\omega z}{\overline{\Delta\theta}\sin\omega z}\right) - \Phi\left(-\frac{l\omega\cos\omega z}{\overline{\Delta\theta}\sin\omega z}\right)\right], \tag{2}$$

where l is channel halfwidth, x_0 are injection points, $\omega = (2V_0/E)^{1/2}$, E is the particle energy and Φ is the error integral.

As we pointed out, the yield enhancement in a colliding beam experiment is γ^2.

Figure 2 (curve 1) shows the value of γ^2 for the case where beams collide in a tungsten channel (110) at $E = 10$ GeV with $\overline{\Delta\theta} = 2\times10^{-5}$ rad (these conditions correspond to experiments at SLAC). Clearly, a 70-fold increase in the reaction yield may be attained under these conditions. As the beam divergence increases, $\overline{\Delta\theta} = 5\times10^{-5}$, γ^2 falls (Fig. 2, curve 2).

In addition to beam divergence, potential anharmonicity also affects the value of γ^2. Calculations show that γ decreases by ~10%, i.e., γ^2 decreases by ~20%.

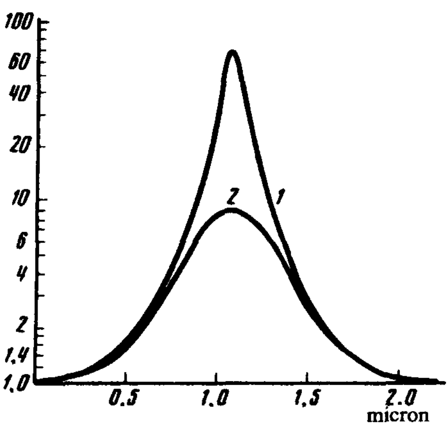

FIG. 2. Calculation of enhancement of colliding-beam reaction yield in the (110) tungsten channel at $E = 10$ GeV for positions: 1—$\overline{\Delta\theta} = 2\times10^{-5}$ rad; 2—$\overline{\Delta\theta} = 5\times10^{-5}$ rad.

Another factor that may decrease γ^2 is the initial beam energy dispersion. Figure 2 (curve 1) shows the curve halfwidth, $\overline{\Delta x}$, is approximately 10^{-5} cm. Therefore, it is desirable that $\Delta E / E \lesssim 10^{-2}$ (where ΔE is initial energy dispersion). This condition is comparatively simple to satisfy. Constraints placed on ΔE at higher divergence levels (Fig. 2, curve 2) are relaxed further.

It is also evident that the thickness of film should be achieved with accuracy considerably exceeding $\overline{\Delta x}$, i.e., of the order of 100 Å. This condition is also satisfiable. Finally, it is essential that the colliding beams are injected into the crystal from both ends in-phase. Dispersion of injection points should be less than $\overline{\Delta x}$ so that γ^2 remains sufficiently large.

As is evident from Fig. 2, at $E \sim 10$ GeV 2-μm thick films are required (as the energy increases the film thickness is $\sim E^{1/2}$). These thin films have no significant effect on the beam characteristics, especially if we take into account the fact that nuclear scattering is suppressed for approximately 90% of beam particles involved in the channeling. That is to say that beams in these experiments may transit through a crystal many times without a substantial loss of intensity.

[1]M.A. Kumakhov, Usp. Fiz. Nauk **115**, 427 (1975); [Sov. Phys. Usp. **18**, 203 (1975)].
[2]E. Bøgh, Radiat, Eff. **12**, 261 (1972).
[3]M.A. Kumakhov and R. Vedel', ibid. **26**, 43 (1975); **30**, 1 (1976).