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SOME COMMENTS ON FORWARD CALORIMETERS

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In contemplating the problems presented by the extremely high single-particle rates expected at ISABELLE, one quickly discovers that calorimeters are particularly hard to deal with. Since hadronic showers are of finite size, the favorite trick of making increasingly smaller counters in order to reduce individual counting rates does not work once the counters are of smaller size than the hadronic showers -- one can only go farther away from the intersection region.

To put these comments onto a more quantitative scale, we remark that the formula

$$dN/d\Omega = 3 \times 10^{-27} L/\theta \quad (1)$$

gives a reasonable fit to the 400x400 single-particle rates predicted by Paige (ISABELLE 1977 Summer Workshop, p. 202, BNL 50721), where L is the luminosity and θ the polar angle. We take the individual shower counter areas to be of order a^2 , where a is the mean hadronic shower radius. Then, at luminosities of $2 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$, we would predict individual counting rates of

$$\Delta N = 6 \times 10^8 a^2/r^2 \theta \quad (\text{counts/sec}) \quad (2)$$

where r is the distance of the counter from the intersection region. If we think we can tolerate at most, say, 600-kilocycle rates, we must have $a^2/r^2 \theta \sim 10^{-3}$, which, for $a \sim 20 \text{ cm}$, implies

$$r \geq 7.3/\sqrt{\theta} \quad (\text{meters}). \quad (3)$$

Thus, for $\theta = 10 \text{ mrad}$ we have already far exceeded the dimensions of the largest proposed experimental hall. Clearly, calorimeters to be used in the forward directions at ISABELLE must be able to service rates of several megacycles. Rewriting Eq. (2), we see that the minimum distance (meters) from the intersection that a counter may be placed at $L = 2 \times 10^{32}$ is determined simply from its maximum counting rate, f (megacycles), and the polar angle, θ (radians):

$$r \sim 5 \text{ meters}/\sqrt{f\theta} \quad (\theta \ll 1) \quad (4)$$

Apparently, the most forward angles are totally unfeasible for present detectors. In order to discover what sort of forward angles might be of physics interest, we have considered a specific

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experiment. We defined the minimum forward scattering angle of interest by requiring that the acceptance for Drell-Yan di-leptons extend to $X_F \approx 2p_L/\sqrt{s} \approx 0.5$ in the laboratory, and $135^\circ \leq \theta^* \leq 45^\circ$ in the di-lepton rest frame. Such a capability affords a comparison of X_F and angular distributions on the resonances and in the continuum. For a di-lepton the more forwardly emitted particle has a laboratory angle θ given by (neglecting P_t)

$$\tan \theta = \frac{\sin \theta^*}{\sqrt{1 + (X_F^2 s / 4M^2)(\beta + \cos \theta^*)}} \quad (5)$$

where M is the di-lepton mass, $c\beta$ is its lab velocity, and θ^* is the center-of-mass emission angle. For $\sqrt{s} = 800$ GeV and $M = M_Y$ this requires electron or muon identification and measurement down to 20 mrad (Fig. 1).

Figure 2 shows one possible arrangement of calorimeters achieving coverage down to 20 mrad. One cylindrical calorimeter covers the polar angles $3\pi/4 \geq \theta \geq \pi/4$, and two conical forward calorimeters are placed according to the following constraints:

1. Each calorimeter is placed as close as possible to the intersection region, subject to the restriction that no cell experience counting rates > 10 megacycles; from Eq. (2), $a \approx 0.2$ m.

Fig. 1. Lepton angle vs X_F .

Fig. 2. Calorimeters arranged to achieve coverage down to 20 mrad.

2. Only two forward (i.e., $\theta < \pi/4$) calorimeters can be used, and they are arranged to minimize the total mass of the device. (All three units, A, B, and C, are assumed to have the same azimuthal coverage.)

The solid lines in Fig. 2 show the positions where a counter of $(20 \text{ cm})^2$ surface normal to intersection would experience a 10-megacycle singles rate at $L = 2 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ as given by Eq. (1). The 10-megacycle rate requirement is indeed optimistic; if this rate must be reduced, the total mass will increase proportionally. If these calorimeters are of total depth 1 m Fe with 2π azimuthal coverage, then calorimeter A comprises 250 metric tons and calorimeters B and C are 289 and 156 tons, respectively.

It might be possible to get the same coverage with low mass by increasing the number of individual zones; however, even as it is, the region at $\theta = 180 \text{ mrad}$ is very unpleasant as particles grazing calorimeter B will spray onto C, greatly confusing matters. Since this edge has been carefully placed to intercept the greatest flux, it would seem undesirable to have more such regions.

For experiments in which electrons are of interest, the vacuum chamber also presents a special problem. At grazing angles of 20 mrad the effective vacuum chamber wall is $2.8X_0$ (steel) per 1 mm of nominal pipe wall thickness perpendicular to the beam. Clearly a specific vacuum chamber has to be designed to avoid this problem.

Note that "windows" in the chamber imply large radial discontinuities and special care (J.C. Herrera, in 1976 ISABELLE Workshops, p. 236, BNL 50611).

One final comment on the $p_{\perp}$ resolution of a forward calorimeter is that, since

$$p_{\perp} = p \sin\theta \quad ,$$

we have

$$(\Delta p_{\perp}/p_{\perp})^2 \approx (\Delta\theta/\theta)^2 + (\Delta p/p)^2 \quad . \quad (6)$$

Because $\langle p \rangle$ increases dramatically in the forward direction (Paige, op. cit.), and $\Delta p/p$ falls as $1/\sqrt{p}$, the $\Delta\theta/\theta$ contribution can eventually dominate the $p_{\perp}$ resolution:

$$\Delta\theta/\theta \sim a/r\theta \quad . \quad (7)$$

Taking, again, $a \sim 0.20$ m, one might desire $\Delta\theta/\theta \sim 0.1$, so that $r\theta = 2$ m. Such considerations would lead to an even more elongated and massive device than that shown in Fig. 2.