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INTERSECTING STORAGE ACCELERATOR NOTES

Conceptual Design of a Hybrid Detector for Electron Physics at ISABELLE
and PEP: Solenoid + Quantameter + Hadrometer (Calorimeter)

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CONCEPTUAL DESIGN OF A HYBRID DETECTOR FOR ELECTRON PHYSICS AT ISABELLE

AND PEP: SOLOINOID + QUANTAMETER + HADROMETER (~~CALORIMETER~~)

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I - Introduction

The most striking feature of the electron kinematics for the colliding $e - p$ beams in ISABELLE and PEP is the accessibility of the electron for easy measurement. Figures 1, 2, and 3 summarize the electron kinematics for PEP (I; 15 GeV electrons, 70 GeV protons), PEP (II; 15 GeV electrons, 200 GeV protons), and ISABELLE (I; 5 GeV electrons, 200 GeV protons)*. A summary of the kinematical relations is contained in the appendix.

The simplest detector would be one which surrounds the interaction region with a Quantameter^a capable of measuring simultaneously the energy and position of the electron induced shower. Such a device will be an essential component of any electron detector and will probably be the primary part of the trigger system. It is best located immediately beyond the coil of a superconducting Solenoid as well as on the end - caps of such a magnet.

The magnet provides redundant electron information and will help in identifying stray electrons or positrons (e.g., from π^0 Dalitz pairs) that masquerade as the scattered electron. For example, the experimenters at SIAC frequently reverse the polarity of the single arm spectrometer so

* It is not clear at this time what the energy of the ISABELLE electrons will be. The actual kinematics will lie somewhere between the latter two figures.

as to determine the Dalitz pair contribution to the electron counting rate.

In Section II the measurement accuracy of the solenoid is discussed. Section III contains a brief description of the Quantameter and in Section IV arguments are given for surrounding the Quantameter with a Hadrometer.

II - The Solenoid Magnet

The length of the magnet (2 ℓ) is chosen to be 15 meters so that as few electrons as possible will pass out the end caps and yet not be so long that one cannot provide compensating Solenoidal coils (of smaller radius) at both ends to insure that $\int B \, d\ell$ of the circulating beams is zero through the device.

The magnetic field is chosen as 30 kilogauss because it is easily obtainable with existing superconducting technology where the superconducting material is embedded in aluminum. This allows the coil thickness to be held to approximately one radiation length. The radius is chosen so as to provide a sagitta of at least ≈ 1 centimeter for most electrons that would pass through the cylindrical coil. From the kinematics of Figures 1, 2, and 3 one notices that the electron receives nearly the full energy of the incident proton for scattering angles approaching 180 degrees to the initial direction of the electron. For this reason it is necessary to increase the radius of the solenoid from 1.5 meters for PEP (I) to 2 meters for PEP (II) and ISABELLE. Figures 4, 5 and 6, respectively are plots of the reciprocal of the electron sagitta measured in inverse millimeters. If the sagitta measurement accuracy is

1mm then this number is numerically equal to the fractional transverse momentum error.*

Figure 7 superimposes the information contained in Figure 4 on the Q^2 vs ν (or x vs y) plot to demonstrate that the solenoid provides accurate transverse momentum measurement over most of the kinematic region. The detector volume inside the coil being filled with MWPCs provides longitudinal information so Q^2 is determined to nearly the same fractional accuracy as the transverse momentum.† Only electrons with angles beyond 170 degrees must have their energies determined primarily by the Quantameter.

III - The Quantameter

For showers generated by energetic electrons and photons most of the shower energy is developed beyond the first few radiation lengths. Therefore, the photons and electrons that pass through the walls of the solenoidal magnet can still have their energies well determined provided the shower detector is immediately outside the coil. Figure 8 shows the result of a shower energy measurement using a series of multiwire proportional chambers (MWPC), exposed to a 9 GeV electron beam at SIAC. These chambers measured simultaneously the energy and the position of the showers. From these tests it has been determined that with 15 chambers interspersed within 15 radiation lengths of Pb one could determine the shower energy to,

* For a smaller magnet of $2\ell = 10m$, "accurate coverage" will be correspondingly smaller. The vertical broken lines of Figures 4, 5 and 6 indicate where the abrupt increase in error will begin for this smaller solenoid.

† $Q^2 = 4E_e E'_e \sin^2 \frac{\theta'}{2} = 2E_e (E'_e \sin \theta'_e = P_t) \tan \frac{\theta'}{2}$

$$\delta E/E = 0.2 / \sqrt{E_e (\text{GeV})},$$

the position to ≤ 5 mm, and the direction of the shower axis to a few degrees. Figure 9 summarizes the fractional error of the shower energy for PEP (I).

For PEP (II) and ISABELLE the fractional accuracy for those electrons that have angles between 170 and 180 degrees ($E'_e \geq 160$ GeV) is,

$$\delta E/E = 0.016, \text{ (say } 2\%).$$

Where the solenoid does poorly the Quantameter does well.

IV - Hadrometer (Calorimeter)

One might consider the curvature measurement of the electron to be typical of single hadrons. But one must deal also with those hadrons that are neutral or those that strike the end caps. For these reasons a hadrometer is added to the device. Figure 10 shows how the solenoid and quantameter (which together are about 1 collision length thick) are surrounded by a hadrometer (which is ≈ 15 collision lengths thick as seen from the interaction region). It would have three dimensional granularity. The steel sandwich of the hadrometer would also serve as a return yoke for the magnetic field.

Hopefully, the hadrometer may help to identify the final state nucleon by capitalizing on the relatively low inelasticity of energetic nucleon interactions compared with energetic meson interactions.

Where do the hadrons go? If the virtual photon exchanged in elastic electron scattering continues to behave like a hadron one would suspect that in the "Q" + incident proton center-of-mass there would

be two outgoing "fire balls" each moving in nearly the same direction as their respective incident hadrons. When transformed back into the FEP frame the jet associated with the incident proton would continue down the beam pipe direction while the other one would be in a direction near the $\vec{Q}$ direction. The hadrons associated with the $\vec{Q}$ -core will emerge generally at large angles and will be readily detected. The "beam - pipe" hadrons will pose more of a problem. One might engage in some "worst-case analysis" here by assuming that a typical pion of this group is moving with the longitudinal velocity of the incident proton and has a typical transverse momentum of ≈ 0.4 GeV. This meson would then be emitted at an angle of,

$$\theta_{\pi} \approx \frac{0.4 \text{ GeV}}{(\eta = 200) (M_{\pi} c^2 \approx \frac{1}{7} \text{ GeV})} = 14 \text{ Milliradians}$$

relative to the proton direction and would be only $14 \times 10^{-3} \times 7.5 \text{ m} = 10 \text{ cm}$ from the beam axis as it exits from the Solenoid. It would very likely pass down the beam pipe.

Provisions will probably be provided to detect some of these beam-pipe particles further downstream. For example, the very low momentum transfer processes require such equipment for the diffracted electrons.

Appendix:Electron kinematics in electron proton colliding beams

I. Kinematics

Briefly the kinematic relations are as follows:^b

Momentum transfer squared

$$Q^2 = 2M \nu + M^2 - W^2, \quad (1)$$

Energy transfer

$$\nu = \mathbf{P}_p \cdot \mathbf{q} / M = \frac{2E_p}{M} \left\{ E_e - E'_e \cos^2 \frac{\theta'_e}{2} \right\}, \quad (2)$$

Loci of Equal Final Lepton Energy E'_e (on Q^2 vs ν plot)

$$Q^2 = 4E_e (E'_e - E_e) + 2M \nu \left(-\frac{E_e}{E_p} \right). \quad (3)$$

Loci of Equal Final Lepton Scattering angle, θ'_e

$$Q^2 = \frac{2ME_e}{E_p} (\nu_{\max} - \nu) \tan^2 \frac{\theta'_e}{2} \quad (4)$$

$$\nu_{\max} = \frac{s \left(\frac{P_e}{E_e} + \frac{P_p}{E_p} \right)^2}{2M} = 2E_p (E_e/M) \quad (5)$$

where E_e and E_p are the initial energies and M^2 and W^2 are initial and final hadron invariant mass-squareds, resp.

Introducing the scaling variable,

$$X = Q^2 / 2M \nu.$$

One can re-express equations (3) and (4) as

$$E'_e = E_e \frac{1 + \tan^2 \frac{\theta'_e}{2}}{1 + \frac{E_e}{xE_p} \tan^2 \frac{\theta'_e}{2}} \quad (6)$$

Equation (6) allows one to calculate the radius ρ of the helical trajectory of an electron of energy E'_e emitted at an angle θ'_e to the 30 kilogauss magnetic field lines of the solenoid,

$$\rho(\text{meters}) = \frac{E'_e (\text{GeV})}{0.9} \sin \theta'_e \quad (7)$$

From this one can calculate the sagitta of the helical trajectory for two cases:

a) The track passes through the coils of radius r_0

$$\text{Sagitta} = 2\rho \sin^2 \left\{ \frac{1}{2} \sin^{-1} \left(\frac{r_0}{2\rho} \right) \right\} \quad (8)$$

b) The track passes through the end cap a distance l away from the interaction

$$\text{Sagitta} = 2\rho \sin^2 \left\{ \frac{l \tan \theta'_e}{4\rho} \right\} \quad (9)$$

For case b) the distance of the particle from the axis of the Solenoid as it passes through the end cap is,

$$r = 2\rho \sin \left\{ \frac{l \tan \theta'_e}{2\rho} \right\} \quad (10)$$

References

- a Energy Resolution of a Multiwire Proportional Quantameter,
LBL-795, UM511-111-72, and NAL document TM 357, T. Katsura,
V. Z. Peterson, D. E. Yount, University of Hawaii, S. Parker,
and M. L. Stevenson, LBL.
- b See also PEP Notes 3 and 16 "The Kinematics and Possible Dynamics
of Inelastic Lepton Scattering in PEP", M. L. Stevenson.

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MLS

$10^{-3} Q^2 (\text{GeV}^2)$

PEP(II)

$E_e = 15 \text{ GeV}$ $E_p = 200 \text{ GeV}$

$s = 4 E_e E_p = 12,000 \text{ GeV}^2$

$\theta_e' = 150^\circ$

$E_d' (\text{GeV})$

$x = 0.2$

Fig. 2

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HLS

4000
3000
2000
1000
0

ISABELLE (C) E_e
 $E_e = 5.6 \text{ GeV}$ $E_p = 200 \text{ GeV}$

$s = 4 E_e E_p = 4500 \text{ GeV}^2$

$Q^2 (\text{GeV}^2)$

2000
1000
0

Fig 3

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Measurement Accuracy of Solenoidal Magnet 30 kgauss, 3m diameter x 2 x 7.5m

(Sagitta)⁻¹ (mm)⁻¹ ≈ fractional error for 1mm resolution

For PEP(I)
15 GeV electrons
70 GeV protons

Fig 4

(Sagitta) (mm)

fractional error in p/mms for mm resolution

Measurement Accuracy of Solenoidal Magnet 30kgauss, 4m diam. x 2 x 7.5m long

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For PEP(II)
15 GeV electrons
200 GeV protons

.335
at $N75^\circ$

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Measurement Accuracy of Solenoidal
Magnet, 30 kgauss, 4m diam x 2 x 7.5 m long

For ISABELLE (I)
56 GeV electrons
200 GeV protons

$(Sagitta)^{-1} (mm)^{-1}$

Fig 6

Fig. 8

DEPENDENT
 OF SHOWER
 PEAK
 CRACK ENERGY
 CRACK ENERGY

0.1