The purpose of this note is to speculate on some of the physics that might require energies higher than those planned for PEP. The large size of the NAL site (5 km x 5 km) could possibly accommodate a 30-GeV electron-(positron) ring colliding in four interaction regions with 2000-GeV protons or 30-GeV positrons.

1. Probing the Proton Structure with Electrons
   a. "Scaling" Continues
   Figure 1 summarizes the e-p kinematics for 30-GeV electrons on 2000-GeV protons and shows how the electron is knocked backwards with energies ranging from 100 GeV to 2000 GeV. Figure 2 shows the number of electron events one would obtain in a 10-day run if the proton continues to display its spin-1/2 parton structure, namely that "scaling" continues. Figure 3 is the corresponding number of neutrino events obtainable in a 10-day run. Here, a luminosity of 10^{32} (cm^2 sec)^{-1} is assumed.

   b. "Scaling" Breakdown in Inelastic Electron Scattering
   One possible model for breaking scaling is the Weinberg model. I choose it because of its very massive intermediate vector mesons. To infer their existence demands the most out of the accelerator and emphasizes dramatically the value of high energy (s = 24 x 10^4 GeV^2 for Super-PEP versus s = 9000 GeV^2 for PEP). The Weinberg model predicts the existence of a neutral intermediate boson (NIB) of mass M_Z and coupling constant g' as well as an intermediate vector boson (IVB) of mass M_W and coupling constant g. (The model also predicts an intermediate scalar boson ISB but makes no prediction of its mass.) The relation between these two objects that are responsible for the weak neutral and charged lepton currents is represented parametrically as follows in terms of a mixing angle, \theta_W:
   \[ \theta_W = \tan^{-1} \frac{g'}{g} \]
   \[ M_W = 37.3 \text{ GeV}/\sin \theta_W \]
   \[ M_Z = 2(37.3) \text{ GeV}/\sin 2\theta_W \]

   Figure 4 (Fig. 7 of PEP Note 16) summarizes this relationship between the masses M_W, M_Z, and \theta_W showing that both masses are infinite for \theta_W = 0^\circ. I shall concentrate mostly on this "worst case" possibility primarily to demonstrate how powerful an experimental tool a Super-PEP can be.

   If a "massive photon" of mass M_Z exists it will contribute an additional amplitude to

*Positron-Electron-Proton colliding beam facilities: 15-GeV electron-positrons incident on 150 GeV (70 GeV) protons. (For physics, see "Particle Physics with Positron-Electron-Proton Colliding Beams, LBL-750, SLAC-146.

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inelastic electron scattering and will lead to an "enhancement factor"* (or a scale breaking factor) in the inelastic electron scattering rate. The differential cross section becomes

\[
\frac{d^2\sigma}{dx dy} = 4\pi\alpha^2 \frac{v_\perp^2}{s} \left( \frac{1}{4} \left( 1 - x \right) \right) \left( \frac{1}{2} + \frac{1 - y}{y^2} \right) \left( 1 + \left( \frac{e_Z}{e} \right)^2 \right) \frac{1}{M_Z^2 + s xy} \]

The factor, \( \left\{ 1 + \left( \frac{e_Z}{e} \right)^2 \right\} \), is defined as the "enhancement factor," where

\[
Q^2 = s xy, \quad s = 4E_\perp E_p
\]

\[
e_Z/e = (3/4) \tan \theta_W - (1/4) \cot \theta_W
\]

\[
\theta_W = \tan^{-1} \left( \frac{g'/g}{g} \right)
\]

g' is the coupling constant of the NIB to the neutral lepton current and \( g \) is the coupling constant of the IVB to the charged lepton current.

The "enhancement factor," \[ \left\{ 1 + \left( \frac{e_Z}{e} \right)^2 \right\} \frac{1}{M_Z^2 + (s xy - Q^2)} \]

for \( (x = Q^2/2M_\perp^2) = (y = v/v_{\text{max}}) = 1 \) for PEP (I) \( (s = 4200 \text{ GeV}^2) \) is shown in Fig. 4. Figure 5 shows the dramatic increase in this enhancement factor for Super-PEP. Figure 6 (Fig. 7 of the LBL-750, SLAC-146 Physics Document) shows that for \( \theta_W = 0 \) this effect is hardly observable at PEP (I) energies. For Super-PEP it is easily observable. Figure 7 summarizes the electron events obtainable with \( \theta_W = 0^\circ \) \( (M_Z = \infty) \) in a 10-day run. Comparison with Fig. 2, particularly at high \( Q^2 \), emphasizes how important the weak neutral current becomes as \( s \) increases, even for the case where \( M_Z = \infty \).

c. "Scaling" Breakdown in Neutrino Reactions

Here the existence of a massive "IVB" diminishes the \( d^2\sigma/dx dy \) distribution by the factor \[ \left( \frac{M_\perp^2}{M_\perp^2 + Q^2} \right)^2 \]. For the \( \theta_W = 0^\circ \) case the "diminution factor" is unity for all \( x \) and \( y \). However, for \( \theta_W = 16.5^\circ \) with \( M_\perp = 137 \text{ GeV} \), the diminution factor can be determined. This is displayed in Fig. 8 along with the percentage accuracy with which it could be determined vs \( x \) and \( y \) in a 20-day run.

9. Where Do the Hadrons Go?

One possible model assumes that \( 1 - x \) of the proton merely behaves as a spectator in the interaction and thus produces a hadron jet in the direction of the incident proton. The remaining part, \( x \), of the proton receives a momentum transfer \( q \) and produces a jet in the appropriate direction. Figure 8' summarizes the momentum vectors of these jets for various regions of the \( x \) vs \( y \) space.

e. A Possible Detector

During the ISABELLE Summer Study a conceptual design of a solenoid-quantameter-calorimeter (hadrometer) detector that would provide an adequate detector for nearly all of the PEP-type physics discussed here was proposed. The need for the magnetic field was to be able to make corrections for the electron members of Dalitz pairs that could masquerade as the

*Includes only the vector part, no axial part included.
scattered electrons. The ISABELLE-PEP solenoidal field provided at least 10% momentum accuracy to 200-GeV electrons. For the 2000-GeV electrons of Super-PEP it could determine the sign of the charge.

2. Some $e^+e^-$ Physics

$e^+e^-\rightarrow \mu^+\mu^-$

Here again is a reaction in which the presence of a massive photon coupled to the weak neutral lepton current can make itself manifest. M. Suzuki has modified the formulas of Cung, Mann, and Paschos (C-M-P) to be consistent with the ordinary gauge models, in particular the Weinberg model. Equation (3) of (C-M-P) is modified as follows:

$$\frac{d\sigma}{dt} = \frac{\alpha^2}{4\pi} \left\{ [2 - \sin^2 \theta(1 + |P_+| |P_-| \cos 2\phi)] + \\
+ \epsilon(s)[1 - \frac{g_R^+ + g_L}{g_R^+ g_L} F] [2 - \sin^2 \theta(1 + |P_+| |P_-| \cos 2\phi) + 2 \cos \theta] + \\
+ \epsilon(s)[1 - \frac{g_R^+ + g_L}{g_R^+ g_L} P] (1 + \cos \theta)^2 \right\},$$

where $\theta$ and $\phi$ are the polar and azimuthal angles. $P_+$, $P_-$, $P$ are the polarizations of the initial state and the muon helicity, respectively.

The values of $g_R$ and $g_L$ are summarized in Bjorken and Llewellyn Smith as follows:

$$\epsilon(s) = \frac{\sqrt{Z} G_0}{4\pi} \frac{1}{M_Z^2} \frac{s}{s - M_Z^2},$$

$$G_0 = \frac{4}{\sqrt{2}} \frac{(g_R^+ g_L^-)^2}{M_Z^2} \frac{G}{\sqrt{2}} = \frac{g^2}{4M_W^2}.$$
The form of the unmodified distribution (dashed line) is plotted in Fig. 1t with modifi­
cators (solid lines) for PEP and Super-PEP. The unmodified total cross section is

\[ \sigma = \frac{4\pi \alpha^2}{3s} = \frac{87 \times 10^{-33}}{s(\text{GeV}^2)} \text{ cm}^2 = 2.41 \times 10^{-35} \text{ cm}^2 \text{ for Super-PEP.} \]

In a 10-day run with a luminosity of \(10^{32} \text{(cm sec)}^{-1}\) one would obtain \(N_0 = 2100\) events. The statistical error in \(\varepsilon\) for a detector that covers \(|\cos \theta| < \cos \theta_m\) is

\[ \delta \varepsilon = \left(3N_0 \left(\cos \theta_m - \tan^{-1}(\cos \theta_m)\right)\right)^{-\frac{1}{2}}. \]

For this example, with \(N_0 = 2100\), \(\cos \theta_m = 1\),

\[ \delta \varepsilon = \frac{\left(3(2100)(1 - 0.788) = (0.644)(2100)\right)^{-\frac{1}{2}}}{\varepsilon = 0.079} = 0.344. \]

In general, the fractional error in \(\varepsilon\) is proportional to \(1/\sqrt{s}\). By doubling the electron energy from PEP to Super-PEP one halves the fractional error.

b. \(e^+ + e^- \rightarrow \gamma^+ + \gamma^-\)

Several of the gauge theories propose heavy leptons whose production would be copious. Generally their masses are less than the 15 GeV that PEP would be designed for. It would be prudent to plan for energies in excess of this value. Since the excessive radiation loss of the \(e^+e^-\) rings \(=E^4/R\) per turn) provides an essential energy barrier beyond which an accelerator of fixed radius cannot go, one should plan for the maximum radius possible. For this reason I have chosen 30 GeV for the electron energy and would propose compromises in the pp options to allow larger bending radii.

c. \(e^+ + e^- \rightarrow \gamma + \gamma + \text{Hadrons: A Reaction for Probing the Structure of Nearly Real Photons:} \)

One of the electrons provides a cloud of virtual photons for the other. A fast moving electron behaves like \(1/137\) of a real photon whose energy distribution is

\[ N(E)\,dE = \frac{2\alpha}{\pi} \ln \frac{E}{m} \frac{dE}{E} \left(1 - \frac{E}{E_0} + \frac{1}{2} \frac{E_0^2}{E^2}\right) \text{ where,} \]

\[ \frac{2\alpha}{\pi} \ln \frac{E}{m} = 0.0510 \text{ for Super-PEP} \]

\[ = 0.0478 \text{ for PEP.} \]

This distribution is displayed in Fig. 12. If one assumes the photon to have the same structure function, \(\frac{d^2W}{d^2Q}\), as the proton one can predict the number of events vs \(Q^2\) and \(y\) to be expected for intervals in \(E_0\) from 0 to \(E\). The numbers of events predicted for a 10-day run for five equal intervals of \(E_0/E\) are summarized in Fig. 13, according to the following:

\[ 1. \quad \frac{d^3\sigma}{dE\,dx\,dy} = N(E) \frac{\pi\alpha^2}{s} \left(\frac{1-x}{x} \left(\frac{1}{2} + \frac{1-y}{y^2}\right)\right) \text{ assuming} \]
\[ vW_2 = \frac{1}{4}(1-x) \text{ and } W_2 / W_1 = v^2 / Q^2 \]

2. \( 0.04 \leq x \leq 1 \) and \( y \geq 1 \)
3. Detection efficiency = 100%
4. Luminosity = \( 10^{32} \text{(cm}^2\text{sec)}^{-1} \)

From an experimental point of view it is implied that \( E_y \) is measurable either by observing all final hadrons or the other electron that provided the nearly real photon. The kinematics for \( e + \gamma \rightarrow e^+ + \text{hadrons} \) is summarized in Fig. 14 using the following relations

Loci of equal final electron energy, \( E_e' \)

\[ Q^2 = 4E_e E_e' - 4E_e^2 (1-y) \]

\[ Q^2 / s_{\text{max}} = \frac{E_e'}{E_e} (1-y), \text{ an expression that is independent of } E_y \]

Here, \( y = \frac{\nu}{\nu_{\text{max}}} = 1 - \frac{E_e'}{E_e} \cos^2 \theta / 2 \), which is also independent of \( E_y \).

Loci of equal electron scattering angle, \( \theta_e \)

\[ Q^2 = 4E_e^2 (1-y) \tan^2 \theta_e / 2, \text{ or } \]

\[ Q^2 / s_{\text{max}} = (1-y) \tan^2 \theta_e / 2, \text{ again an expression independent of } E_y \]

From Fig. 13 one observes that there will be substantial information about the photon electromagnetic structure over \( s \) values from 100 GeV\(^2\) to 3600 GeV\(^2\) for \( Q^2 \) values up to 400 GeV\(^2\). Beam-gas background can be calculated assuming that a 3-meter long column of gas at \( 10^{-9} \) torr is a target for the electron beams. If the electron beam current is 200 mA this corresponds to an effective luminosity of \( 2.0 \times 10^{29} \text{(cm}^2\text{sec)}^{-1} \). The \( s \) for beam gas scattering is \( 2ME_e = 56.3 \) GeV\(^2\) which is \( 56.3/3600 = 0.0156 \) of the maximum \( s \) for \( e^+ e^- \) events. The kinematic boundary for the beam-gas events corresponds to the \( E_y / E_e = 0.0156 \) line of Fig. 14. The number of background events in this region can be scaled from Fig. 4 of PEP-Note 16 by the factor,

\[ \frac{4200}{56.3} \times \frac{2 \times 10^{29}}{1.0 \times 10^{32}} \times 10 \text{ days} = 1.49. \]

The numbers in the \( x \) vs \( y \) bins are

<table>
<thead>
<tr>
<th>( x )</th>
<th>1.0</th>
<th>.8</th>
<th>.6</th>
<th>.4</th>
<th>.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>( y )</td>
<td>1.653,900</td>
<td>34,240</td>
<td>9476</td>
<td>4112</td>
<td>2286</td>
</tr>
<tr>
<td>.8</td>
<td>2,318</td>
<td>48.0</td>
<td>13.3</td>
<td>5.77</td>
<td>3.19</td>
</tr>
<tr>
<td>.6</td>
<td>7,691</td>
<td>159</td>
<td>44.1</td>
<td>19.1</td>
<td>10.6</td>
</tr>
<tr>
<td>.4</td>
<td>32,483</td>
<td>672</td>
<td>186</td>
<td>80.8</td>
<td>44.7</td>
</tr>
<tr>
<td>.2</td>
<td>483</td>
<td>10.00</td>
<td>2.76</td>
<td>1.20</td>
<td>.664</td>
</tr>
</tbody>
</table>

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By comparing these numbers with those of the lowest value of \( \frac{E_y}{E_e} \) of Fig. 13, one realizes the background poses no problem. Furthermore, if any of the final-state hadrons are detected one can determine the location of the interaction and rule out any event that does not fall within the 30-cm long beam-crossing region. The background would then be a factor of ten lower than that given in the previous table.

References

6. B. Sadoulet, see A Proposal for Measuring the Charge Asymmetry of \( e^+ e^- \rightarrow \mu^+ \mu^- \) and Equipping the Endcaps of the SPEAR Magnetic Detector (Draft July 6, 1973), G. Knies, A. M. Litke, D. Neuffer, B. Sadoulet, M. L. Stevenson, and S. Parker.
e-p KINEMATICS at NAL

Fig. 1
NUMBER OF ELECTRON EVENTS PER 10 DAYS

ASSUMING,

1) \( \frac{d^2\sigma}{dx\,dy} = \frac{\pi Q^2}{s} \left( \frac{1-x}{x^2} \left( \frac{1}{2} + \frac{1-y}{y^2} \right) \right) \)

(ASSUMING \( \nu W_2 \approx \frac{1}{4}(1-x) \) AND \( W_1/W_2 = \nu^2/Q^2 \))

2) \( 0.01 \leq x \leq 1 \)

3) 100% DETECTION EFFICIENCY

4) LUMINOSITY = \( 10^{32} \text{ (cm}^2\text{ sec)}^{-1} \)

\( y = \nu/\nu_{\text{max}} \)

\( x = Q^2/2M\nu \)

Fig. 2
SUPER PEP AT NAL

NUMBER OF NEUTRINO EVENTS PER 10 DAYS

ASSUMING,

1) $\sigma_{\nu N} = 0.8 \ \nu_{\text{MAX}} 10^{39} \text{cm}^2$
2) $\nu(\beta_2=W_2) \alpha(1-X)$
3) $\sigma_R = \sigma_S = 0$, i.e. SPIN 1/2 PARTON MODEL
4) 100% DETECTION EFF
5) LUMINOSITY $= 10^{32} (\text{cm}^2 \text{sec})^{-1}$

FIG. 3
FIG. 4

\[ \theta_W(\text{DEG}) = \tan^{-1}(g'/g) \]

ENHANCEMENT FACTOR (RIGHT HAND SCALE)

\[ M_Z \]

\[ M_W \]
WEINBERG MODEL & SUPER PEP
ELECTROMAGNETIC
"ENHANCEMENT FACTOR" AT x=y=1

SUPER PEP
(s = 24 x 10^4 GeV^2)

PEP(I)
(s = 4200 GeV^2)

\[ \theta_w (\text{DEG}) = \tan^{-1}(g'/g) \]

FIG. 5
\[ \begin{align*}
\theta_W & = 0^\circ \\
\left( \begin{array}{c}
\theta_W \\
m_Z \\
m_W
\end{array} \right) & = \left( \begin{array}{c}
\alpha \\
\alpha \\
\alpha
\end{array} \right)
\end{align*} \]

\[ s = 4200 \text{ GeV}^2 \]

\[ \text{PEP (I)} \]

\[ \begin{align*}
\theta_W & = 90^\circ \\
\left( \begin{array}{c}
\theta_W \\
m_Z \\
m_W
\end{array} \right) & = \left( \begin{array}{c}
\alpha \\
37.3 \text{ GeV} \\
\alpha
\end{array} \right)
\end{align*} \]

\[ \text{y} = \frac{y}{y_{\text{max}}} \]

\[ \text{x} = \frac{x}{x_{\text{max}}} \]

\[ x_0 = 0.2, 0.4, 0.6, 0.8, 1.0 \]

\[ y_0 = 0.2, 0.4, 0.6, 0.8, 1.0 \]

\[ x_{\text{max}} = 1.0 \]

\[ y_{\text{max}} = 1.0 \]

\[ \text{FIG. 6} \]

---
SUPER PEP AT NAL

NUMBER OF NEUTRINO EVENTS PER 10 DAYS

<table>
<thead>
<tr>
<th>30 GeV ELECTRONS</th>
<th>2000 GeV PROTONS</th>
</tr>
</thead>
</table>

SCALING BROKEN WITH THE WEINBERG MODEL ($\theta_w=0^\circ$)

($s=24\times10^4$ GeV$^2$)

![Graph showing number of neutrino events per 10 days for different energies and $Q^2(TeV^2)$ values.]
NEUTRINO EVENTS

DIMINUTION FACTOR = \left( \frac{1}{1 + \frac{\text{SKV} M^2}{M_z^2}} \right)^2

EFFECT OF 137 GeV "IVB" REDUCES "SCALED TOTAL CROSS SECTION" BY A FACTOR 0.28

FIG. 8
POSSIBLE JET-LIKE HADRONIC STATE IN EP INTERACTIONS

30 GeV  2000 GeV
electron  proton

$Q^2$

$x = \frac{Q^2}{2M\nu}$

$y/y_{\text{max}}$

FIG. 8
FORWARD-BACKWARD ASYMMETRY,
\[ \varepsilon(s) \]
\[ e^- + e^+ \rightarrow \mu^+ + \mu^- \]

FIG. 9
\frac{g_R + g_L}{g_R - g_L} \quad \text{POLARIZATION FACTOR}

\text{IN } e^+e^- \rightarrow \mu^+\mu^-

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig10.png}
\caption{FIG. 10}
\end{figure}
MODIFICATION FACTOR ("MF") OF THE 1 + \cos^2 \theta ANGULAR DISTRIBUTION OF \(e^+e^- \rightarrow \mu^+\mu^-\)

**Figure 11**

"MF": MODIFICATION FACTOR

PEP \((15+15)^2=s\)

SUPER PEP \((30+30)^2=s\)

UNMODIFIED ANGULAR DISTRIBUTION
EQUIVALENT PHOTON APPROXIMATION

\[ e^+e^- \rightarrow e^+e^- + \text{HADRONS} \]

\[ N(E_\gamma)(\Delta E_\gamma=0.2E)=\frac{2\alpha}{\mu} \ln \frac{E}{m} \left( \frac{\Delta Z=0.2}{Z} \right) (1-Z+\frac{1}{2}Z^2) \]
INELASTIC ELECTRON-PHOTON SCATTERING WITH SUPER PEP

NUMBER OF EVENTS PER 10 DAYS

FIG. 13
KINEMATICS FOR $e^+\gamma \to e^+\text{HADRON}$

$E_e = 30 \text{ GeV}$
$s_{\text{max}} = 3600 \text{ GeV}^2$
$s = 120 E_\gamma \text{(GeV)}$

$E_\gamma / E_e = 1.0$, "KB"

$E_\gamma / E_e = 0.8$, "KB"

$E_\gamma / E_e = 0.6$,

$E_\gamma / E_e = 0.4$,

$E_\gamma / E_e = 0.2$

$y = \nu / \nu_{\text{max}} = 1 - \frac{E'_e}{E_e} \cos^2 \frac{\theta_e}{2}$

(*-KINEMATIC BOUNDARY OF BEAM-GAS SCATTERING)

FIG. 14