LEP SUMMER STUDY
Organized under the Joint Sponsorship of
ECFA and CERN

Les Houches and CERN
10 to 22 September, 1978

THE PETRA AND PEP PROGRAMMES
A write-up* based on the talks presented by
G. Wolf, DESY, and
R. Schwitters, SLAC

* Written from notes and transparencies by M. Jacob
Copies available upon request from Ch. Redman, CERN/ISR
LEP Summer Study Secretariat
It was deemed appropriate to start the Summer Study at Les Houches with extensive presentations of the PETRA and PEP programmes. These presentations were given by G. Wolf and R. Schwitters, respectively. This paper is written from their transparencies. The reviewer (M. Jacob) is entirely responsible for possible inaccuracies and omissions.

1. The PETRA Programme

1.1 Foreword

PETRA is an acrostic for Positron-Elektron-Tandem Ring Anlage. The circumference of the machine is 2.3 Km. The energy range extends from 10 to 38 GeV (5 to 19 GeV beam energy) but the beam energy could be increased to 23 GeV at a later stage. The design luminosity at 15 GeV is $10^{32}$ cm$^{-2}$ s$^{-1}$. Construction started in December 1975. Beams were stored for the first time in July 1978.

Figure 1 gives the general layout on the DESY site.

1.2 Physics with PETRA

At present, one can classify physics research at PETRA along different lines. They are as follows:

a) $T (b\bar{b})$ spectroscopy and study of the $b\bar{q}$ ($5q$) states. This corresponds to the lower end of the energy range.

b) Search for new narrow states (new quarks) and related spectroscopy.

c) Jet studies with a possible differentiation between quark jets and gluon jets.

d) Search for heavy leptons.

e) Study of $\gamma\gamma$ processes.

f) Study of weak-electromagnetic interference with possible hints at the weak boson(s).

The present review follows them sequentially.

The $T$ Family

In connection with $b$ quark physics a look at the present (experiments at DORIS) is worthwhile. Figure 2.a) gives the $T$ peak as observed in 3 different experiments: DESY-Dortmund-Heidelberg-Lund, in DASP, DESY-Heidelberg-Munich and Aachen-DESY-Hamburg-Seigen-Wuppertal in PLUTO. The value of $R$ off resonance is $5.2 \pm 1$.

* G. Voss presented the machine and discussed its performance by September 1978 in his talk at Les Houches
Figure 1: The PETRA machine. General layout.
The parameters of the resonance are obtained in a (by now) standard way.

The three experiments report respectively:

<table>
<thead>
<tr>
<th></th>
<th>PLUTO</th>
<th>DASP 2</th>
<th>DESY–HD</th>
</tr>
</thead>
<tbody>
<tr>
<td>M(GeV)</td>
<td>9.46 ± 0.01</td>
<td>9.46 ± 0.01</td>
<td>9.46 ± 0.01</td>
</tr>
<tr>
<td>$\Gamma_{ee}$ (KeV)</td>
<td>1.3 ± 0.4</td>
<td>1.5 ± 0.4</td>
<td>1.1 ± 0.3</td>
</tr>
<tr>
<td>$B_{\mu\mu}$ ($10^{-2}$)</td>
<td>2.7 ± 2.0</td>
<td>2.5 ± 2.1</td>
<td>1.0 ± 1.0</td>
</tr>
<tr>
<td>$\Gamma_{tot}$ (KeV)</td>
<td>&gt; 20</td>
<td>&gt; 20</td>
<td>&gt; 15</td>
</tr>
</tbody>
</table>

The mean values, as presented at the Tokyo Conference by G. Flügge are $\Gamma_{tot} = 50$ KeV, $\Gamma_{ee} = 1.3 ± 0.2$ KeV, $B_{\mu\mu} = (2.6 ± 1.4) \times 10^{-2}$.

A prominent and very recent result has been the observation of the $T'$. The variation of the cross-section over the resonance peak is shown in Figure 2.b). The parameters, as reported by the two different groups, are as follows:

<table>
<thead>
<tr>
<th></th>
<th>D–HD–M</th>
<th>DASP 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>M(GeV)</td>
<td>10.016 ± 0.01</td>
<td>10.012 ± 0.01</td>
</tr>
<tr>
<td>$\Delta M$(MeV)</td>
<td>557 ± 5</td>
<td>555 ± 3</td>
</tr>
<tr>
<td>$\Gamma_{ee}$ (KeV)</td>
<td>0.32 ± 0.10</td>
<td>0.5 ± 0.2</td>
</tr>
<tr>
<td>$\Gamma_{ee}(T)/\Gamma_{ee}(T')$</td>
<td>3.4 ± 0.9</td>
<td>= 3</td>
</tr>
</tbody>
</table>

The mass difference $\Delta M$ between the $T'$ and the $T$ ($556 ± 3$) is definitely smaller than the one observed in the $\psi$ family, namely $591 ± 1$ MeV.

The observed values for the $e^+e^-$ partial width, for both the $T$ and the $T'$ clearly favours $Q = 1/3$, or the $b$ quark assignment. It is then interesting to note that this is an assignment which gives a constant value for the quantity $\Gamma_{ee}/|\Sigma c_i Q_i|^2$ for all $1^3S_1$ vector states. This is shown in Figure 2.c).

The spectroscopy of the $J/\psi$ family is displayed in Figure 3.a). The established states and the still expected ones are shown as solid and dashed lines respectively. The $T$ family should show a similar pattern.

Figure 3.b) gives the excitation energies as measured for the $J/\psi$ family and calculated by the Cornell group for the $T$ family.

Next to the $T$ family, states with $b$ quarks should be produced in pairs. They correspond to the quark assignments

$$B_{-0}^0 = b\bar{u} \quad B_{00}^0 = b\bar{d} \quad B_{0-}^0 = b\bar{s} \quad B_{-0}^- = b\bar{c}$$

They will decay weakly.
Figure 2.a: The $T$ as observed at DORIS
Figure 2.b): The T' as observed at DESY
Figure 2.c): The quantity $\Gamma_{vee}/|\Sigma_{q_{\pi}}|^2$ (in KeV) for the vector mesons corresponding to the fundamental $^3S_1$ states
Figure 3.a) : The J/ψ spectroscopy with established states (solid lines) and still expected ones (dashed lines)
Figure 3.b) : Excitation energies (in MeV) for a $q\bar{q}$ system as functions of the quark mass $M$
The weak coupling at the quark level is defined through a Cabibbo matrix which is written as follows:

\[
A = \begin{pmatrix}
    c_1 & s_1 c_3 & s_1 s_3 \\
    -s_1 c_2 & c_1 c_2 c_3 - s_1 s_2 e^{i\delta} & c_1 c_2 s_3 + s_1 c_3 e^{i\delta} \\
    s_1 s_2 & -c_1 s_2 c_3 - c_2 s_3 e^{i\delta} & -c_1 s_2 s_3 + c_2 c_3 e^{i\delta}
\end{pmatrix}
\]

with \( c_1 = \cos \theta_1 \), \( s_1 = \sin \theta_1 \)

The Cabibbo angle proper corresponds to \( \theta_C = \arg \cos \theta_1 \). The values of \( \theta_2 \) and \( \theta_3 \) are bounded by 20° and 160° respectively, when \( \theta_C = 130° \). The CP violating phase \( \delta \) is such that \( \sin \delta > 5 \times 10^{-3} \).

The weak coupling induces second order transitions between the \( B_0 \) and \( \bar{B}_0 \) states. As a result a \( B_0 \bar{B}_0 \) primordial configuration, which should lead through semi-leptonic decays to final states of the type \( (e^+\nu X)(e^-\bar{\nu}X') \), with yields referred to as \( N^+ (N^-) \) should, through \( B_0 \bar{B}_0 \) mixing, also give final state configurations of the type \( (e^+\nu X)(e^-\bar{\nu}X') \) and \( (e^-\bar{\nu}X)(e^+\nu X') \), with yields referred to as \( N^{++} \) and \( N^{--} \). It will be important to study such a mixing, measuring

\[
\gamma_2 = (N^{++} + N^{--})/(N^{++} + N^{--} + N^{++} + N^{--})
\]

for which theoretical estimates (Ellis et al., Ali et al.,) are at the level of \( \gamma_2 \approx 0.1 \) (non strange) and \( \gamma_2 = 0.5 \) (strange).

The \( N^{++} \) and \( N^{--} \) yields should actually differ. This is a CP violating effect associated with the phase \( \delta \). The asymmetry is given by

\[
a = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} \approx 4 \tan \delta
\]

Estimates for the asymmetry \( a \) are at the level of \( 5 \times 10^{-3} \) (non strange) and \( 2 \times 10^{-3} \) (strange).

Similar effects, but now associated with closed loops with Higgs bosons, could possibly be one order of magnitude larger. This is however very model dependent.

Search for New Quarks

The first approach is to look for narrow states. The cross-section at the peak depends directly on the energy resolution of the beam \( \Delta E \). It increases as \( S \) at fixed radius and decreases as \( \rho^{-\frac{1}{2}} \), where \( \rho \) is the magnetic radius. The cross-section at the peak is given in practice by

\[
\sigma = \frac{12\pi \Gamma_{ee}}{S} \frac{e}{\Delta E}
\]

One may then compare the resolution at PETRA and at DORIS, giving also the corresponding value for a LEP machine (at 100 GeV per beam).
where $S$ is in $(\text{GeV})^2$.

The signal over noise ratio can then be estimated (taking $Q = 2/3$ and $\Gamma_{\text{vee}} = 5$ KeV) as a function of the mass of the resonance. This gives for the PETRA range

<table>
<thead>
<tr>
<th>$M_{\nu}$ (GeV)</th>
<th>Integrated cross section (nb GeV)</th>
<th>Signal over Noise ratio (PETRA)</th>
<th>Events/day ($L = 10^{31}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>0.44</td>
<td>16</td>
<td>$32 \times 10^3$</td>
</tr>
<tr>
<td>20</td>
<td>0.24</td>
<td>8</td>
<td>$8 \times 10^3$</td>
</tr>
<tr>
<td>30</td>
<td>0.11</td>
<td>4</td>
<td>$2 \times 10^3$</td>
</tr>
</tbody>
</table>

This is manageable but one is far below the values which are typical of $J/\psi$ spectroscopy.

A schematic picture for the variation of parameter $R$ as a function of the centre-of-mass energy is given in Figure 4. Next to $b\bar{b}$ states one should expect $t\bar{t}$ states ($Q = 2/3$). There is however no solid prediction for the $t$ mass. The expected precision on $R$ should be at the level of 0.1. The increase associated with the $b\bar{b}$ threshold ($Q = 1/3$) may then be hardly detectable.

**Jet Studies**

As first shown by the SLAC-LBL study in the 3 - 7.4 GeV range, the final state hadrons organized themselves into two jets, as expected from a primordial quark anti-quark system. This leads to a decrease of the sphericity with increasing energy as the jet structure becomes more and more pronounced. As is now well known, the jets follow the $1 + \cos^2 \theta$ distribution associated with the primordial quarks of spin $\frac{1}{2}$. PLUTO, at DORIS, has now extended this analysis up to 9.5 GeV. The jet picture has thus been further confirmed. Also, the jet axis, whether defined from charged particles or neutrals, is found to be the same. The variation of the mean observed sphericity as a function of energy is shown in Figure 5. It combines SLAC results (open dots) and DORIS results (full dots). There is an obvious departure from the phase space model which matches data as well as the jet model at 3 GeV, and full agreement with the jet model. At 5 GeV half of the energy is found within a cone of $33^\circ$. At 9.4 GeV it is within a cone of $28^\circ$ only. Going further in energy is of great potential interest. One may
Figure 4: An artist's impression of what could be the behaviour of $R$ as a function of energy. The shaded region is still terra incognita.
Figure 5: Variation of the observed sphericity as a function of energy
then differentiate between the "naive" jet picture, whereby jet members have a fixed transverse momentum with respect to the jet axis, from expectations based on QCD according to which gluon emission leads to a widening of the jet with increasing centre-of-mass energy. A possible limiting behaviour could then correspond to a fixed opening angle within which a fixed and large fraction of the energy should be confined for a fixed and large fraction of all hadronic events. In the model of Sterman and Weinberg for instance, one gets a limiting angle which should be almost reached as the centre-of-mass energy gets beyond 20 GeV.

Jet fragmentation is interesting to study and particles near the limit of phase space should have quantum numbers strongly correlated with those of the primordial hadron constituent. In $e^+e^-$ annihilations, this should lead to important correlations among secondaries of high energy, taking one on each side so that they could be readily associated with the primordial quark and antiquark respectively. At present, available information refers to charge correlations only. Figure 6 shows SPEAR results with a particle with $x > 0.5$ (0.7) required in order to better define the jet. There is an important correlation on the same side. Two fast particles on the same side tend to balance out their charge. The expected quark-antiquark correlation on the away side appears only in the latter case or only when the two particles are required to take a very large fraction of the available energy.

While quark jets should be the common feature, search for gluon jets is of great importance. An a priori interesting hunting ground is offered by the narrow vector resonances since, in the framework of QCD, they should decay into 3 primordial gluon jets. The mass of the $T$ could be enough for the corresponding structure to emerge with, in particular, a coplanar but not collinear structure. An obvious consequence is that the mean observed sphericity should increase. This is indeed the case as shown in Figure 7. The sphericity is much higher on the $T$ peak than just outside the peak and it takes a value in agreement with QCD expectations. On the $T$ peak the mean observed sphericity is found to be $0.38 \pm 0.02$ for charged particles (Figure 7 from PLUTO results), and $0.37 \pm 0.02$ for neutrals (DESY-Hamburg-Heidelberg-Munich). Off resonance the corresponding values are $0.27 \pm 0.015$ and $0.19 \pm 0.02$, respectively.

The mean multiplicity also increases on the resonance, as "naively" expected from gluon jets. It rises from $4.9 \pm 0.1$ off resonance to $5.9 \pm 0.1$ on resonance.

Further studies are much needed on the $T$ peak. Another a priori interesting hunting ground for gluon jets is opened by $\gamma$ triggers. In such a case the high energy photon should be produced together with two primordial gluon jets rather than with a quark-antiquark pair in a positive C configuration. The latter
Figure 6: Charge correlations among jet fragments
Figure 7: Increase in sphericity on the $T$ resonance
configuration should rather correspond to soft photons. A particular case of special interest is $\chi$ state production, the $\chi$ recoiling from the $T'$ ($T''$) with $\gamma$ emission. The angular distribution of the jet axis with respect to the photon direction should then change from $1 + \cos^2\theta$ to $1 - 3/2 \cos^2\theta$, depending on whether one considers a two-gluon system or a quark-antiquark pair. The angular distribution is then defined with respect to the photon direction, in the $\chi$ rest frame.

Search for Heavy Leptons

Charged heavy leptons can be produced through the one-photon annihilation process. The production cross-section is then given by

$$\sigma_{L^+L^-} = \sigma_{\mu^+\mu^-} \beta \left(1 + \frac{1 - \beta^2}{2}\right)$$

where $\beta = p/E$. When $s \gg 2M_L$ the cross-section corresponds to the point-like value and contributes for one unit of $R$. The decay depends on the nature of $L$.

If the $L$ lepton corresponds to the sequential series or is of the ortho type its decay modes will be of the type $L^- \rightarrow \nu_L + (e\nu, \mu\nu, \tau\nu$ or $q\bar{q})$.

The expected branching ratios (as estimated by Y. Tsai) depend on the mass. Keeping the $\tau$ as a reference ($M_{\tau} = 1.8$ GeV), one can list for instance what is then expected for $M_L = 6$ GeV. It is as follows:

<table>
<thead>
<tr>
<th>Mode</th>
<th>$B(1.8)$</th>
<th>$B(6)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e\bar{\nu}$</td>
<td>0.18</td>
<td>0.23</td>
</tr>
<tr>
<td>$\mu\bar{\nu}$</td>
<td>0.18</td>
<td>0.23</td>
</tr>
<tr>
<td>$\tau\bar{\nu}$</td>
<td>--</td>
<td>0.20</td>
</tr>
<tr>
<td>$\pi\nu$</td>
<td>0.10</td>
<td>0.01</td>
</tr>
<tr>
<td>$p\nu$</td>
<td>0.22</td>
<td>0.05</td>
</tr>
<tr>
<td>$A_\tau\nu$</td>
<td>0.1</td>
<td>0.02</td>
</tr>
<tr>
<td>Hadrons, $\nu$</td>
<td>0.08</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Other types of leptons can a priori exist. One may consider leptons with charges normally associated with anti-particles, or (and) with no specific neutrino of their own. This leads to decay modes which may indicate some apparent violation of the $\mu e$ universality.

There may also be heavy neutral leptons, as those (right handed) which can be advocated in order to suppress parity violation effects in atomic experiments. In this case $E$ and $M$ neutral leptons could be the partners of the $e$ and $\mu$ respectively, in right-handed doublets. The mass eigenstates could be linear combinations of $E$ and $M$. Such leptons could be produced through $W$ exchange in the $t$ channel, hence together with a neutrino $e^+e^- \rightarrow E\nu$, or in pairs through $Z^0$ (s channel) or $W$ (t channel) exchange. Production rates can then be estimated to be at the level of about $10^{-34}$ and $10^{-35}$ cm$^2$ respectively, provided that they
exist at all, and, assuming a mass of the order of 3 GeV say. The production rate is large enough for experimentation, with 100 to 10 events per day at 15 GeV beam energy.

Once produced, such leptons should decay leptonically (eeν, eνν, μνν) about 50% of the time, the remaining decay modes associating charged leptons with hadrons.

Study of 2γ Processes

This can be well studied at PETRA and the PLUTO detector in particular could soon contribute important results. A detailed discussion of the 2γ process is to be found elsewhere in the proceedings of the Summer Study, in LEP Summer Study/1-13 and this will therefore not be reviewed here.

Weak Contributions

Weak effects should manifest themselves as the energy increases. At present energies the electromagnetic cross-section (one-photon exchange) decreases as \( \alpha^2/s \) whereas the weak cross-section increases as \( G^2s \) (point-like four fermion coupling). At higher energies extrapolation of such behaviour gives an increasing role to weak interactions, with eventually \( s^2 > \alpha^2 / G^2 \). Nevertheless, what is expected is rather some damping of the weak interaction effect, the point-like interaction being only a low energy approximation to \( Z^0 \) exchange. This may however occur with both couplings playing a competing rôle, as predicted in gauge theories.

In the PETRA energy range, the emergence of weak contributions should lead to:

(i) A change in the behaviour of the cross-section.
(ii) Forward-backward asymmetry.
(iii) Changes in the differential cross-section according to beam polarization.

The weak coupling of the \( Z^0 \) to a quark-antiquark pair or lepton pair \( ff \) is written

\[
G^f \tilde{f} \mu u (v_f - a_f \gamma_5) f
\]

With a forward-backward asymmetry for quark

\[
A = \frac{F - B}{F + B} = \frac{3}{2} g_a \frac{2 - \alpha_e}{\alpha_e} \frac{s m_q^2}{s - m_q^2}
\]

The ratio \( \frac{a}{\alpha_e} \) is 3/2 for the u, c and t quarks and 3 for the d, s and b quarks.

It is 1 for a muon pair.

One may thus expect asymmetries at the level of 18% at 30 GeV and 36% at 40 GeV, when studying jet production. We have used \( g = \frac{G}{8\sqrt{2}\pi a} \approx 4.4 \times 10^{-5} \text{ GeV}^{-2} \).
For lepton pair production, the cross-section divided by the one-photon exchange contribution reads

\[
1 - v_e v_\mu g \frac{s}{(\frac{s}{m_Z^2} - 1) + \frac{1}{s - m_Z^2}}
\]

with \(v_e = v_\mu = -1 + 4 \sin^2 \theta_W = 0\)

\[a_e = a_\mu = -1\]

in the standard model of Weinberg-Salam.

The forward-backward asymmetry is then given by

\[
\frac{F - B}{F + B} \approx -\frac{3}{8} a_e a_\mu \frac{s m_Z^2}{s - m_Z^2}
\]

which, with \(m_Z\) beyond the PETRA energy range, can be approximated as

\[
\frac{F - B}{F + B} \approx 7 \times 10^{-5} s \text{ with } s \text{ in GeV}^2.
\]

This gives 6% at \(\sqrt{s} = 30 \text{ GeV}\) and 12% at \(\sqrt{s} = 40 \text{ GeV}\).

Figure 8.a) gives the ratio between the full cross-section for muon pair production and the cross-section calculated from one-photon exchange, as obtained for different values of \(a\) and \(v\). Figure 8.b) shows the related variation of the forward-backward asymmetry. Although some specific effects should occur over the PETRA energy range in its first stage (up to 30 GeV), the expected effects remain small and cannot provide any definite test of the Weinberg-Salam model used for calculating these effects.

1.3 The PETRA Detectors

At present there are 5 main detectors, all resulting from large collaborations. They are respectively:

- **CELLO** (DESY-Karlsruhe-Munich-Orsay-Paris-Saclay)
- **JADE** (DESY, Hamburg-Heidelberg-Lancaster-Manchester-Tokyo)
- **MARK J** (Aachen-DESY-MT-NIKHEF, Amsterdam)
- **PLUTO** (Aachen-DESY, Hamburg-Bergen-Maryland-Siegen-Wuppertal)

Four of them use a solenoid field configuration. The respective diameters \(D\), lengths \(L\) and Field strength \(B\) are (in metres and Tesla):

<table>
<thead>
<tr>
<th>Detector</th>
<th>(D)</th>
<th>(L)</th>
<th>(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CELLO</td>
<td>1.5</td>
<td>3.5</td>
<td>1.5</td>
</tr>
<tr>
<td>JADE</td>
<td>2</td>
<td>3.6</td>
<td>0.5</td>
</tr>
<tr>
<td>PLUTO</td>
<td>1.4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>TASSO</td>
<td>2.7</td>
<td>4.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Figure 8.a) : The expected cross-section divided by the one-photon exchange cross-section
Figure 8.b) : The forward-backward asymmetry
MARK J has a toroidal field configuration. It uses shower counters and magnetized iron. Figure 9 shows each of them. PLUTO, which recently moved away from DORIS, should eventually be replaced by CELLO in the interaction area where it is installed at present. One may rightfully be impressed by the sophistication of all these detectors and perhaps also surprised by some redundancy among them. Nevertheless, this simply reflects a physics where each event is a priori valuable and where there is only one most interesting process, namely the one-photon annihilation. This is very different from hadron physics where detectors usually try to focus on special types of processes, selecting one among many a priori interesting ones. As already mentioned, no detector is yet dedicated to the study of $2\gamma$ processes, though PLUTO can probably explore them rather far already.

CELLO (Figure 9.a)) has a $4\pi$ coverage for charged particles and neutral detection. It can separate photons from electrons with a high precision and can well distinguish between electrons, muons and hadrons. JADE (Figure 9.b)) has drift chambers and track sampling. Electrons, muons, pions, protons and kaons are separated over the 3 to 15 GeV/c range. The PLUTO detector (Figure 9.c)) has $4\pi$ coverage for charged particles and photon detection. It separates electrons, muons and hadrons. The TASSO detector (Figure 9.d)) which uses aerogel and Cerenkov detectors has full particle identification. The MARK J detector (Figure 9.e)) is specialized for muon and lepton pair detection ($\mu$, $\mu^+\mu^-$, $e\mu$, $e^+e^-$).

Apart from these large detectors, there is a monopole search experiment installed in the present PLUTO area. It uses capton foils inside the beam pipe and is based on a $dE/dx$ measurement. It should be sensitive to a production cross-section two orders of magnitude lower than the point-like (muon pair) cross-section.

This concludes the survey of the PETRA programme.

2. The PEP Programme

2.1 The Machine

The layout of the machine is sketched in Figure 10. The length of the circumference is 2.2 Km. The beam energy can vary between 4 and 18 GeV (with foreseen extension up to 29 GeV). The designed luminosity varies as $L = 10^{32} (E/15)^2 \text{cm}^{-2} \text{sec}^{-1}$ below 15 GeV. It then decreases and equals $10^{31}$ at 18 GeV.

The machine should be ready for first beams in October 1979 and the experimental areas will be ready for occupancy in the spring of '79. It is hoped that area 6 will be completed with building and crane by beam turn on time.
MARK J has a toroidal field configuration. It uses shower counters and magnetized iron. Figure 9 shows each of them. PLUTO, which recently moved away from DORIS, should eventually be replaced by CELLO in the interaction area where it is installed at present. One may rightfully be impressed by the sophistication of all these detectors and perhaps also surprised by some redundancy among them. Nevertheless, this simply reflects a physics where each event is a priori valuable and where there is only one most interesting process, namely the one-photon annihilation. This is very different from hadron physics where detectors usually try to focus on special types of processes, selecting one among many a priori interesting ones. As already mentioned, no detector is yet dedicated to the study of \(2\gamma\) processes, though PLUTO can probably explore them rather far already.

CELLO (Figure 9.a)) has a \(4\pi\) coverage for charged particles and neutral detection. It can separate photons from electrons with a high precision and can well distinguish between electrons, muons and hadrons. JADE (Figure 9.b)) has drift chambers and track sampling. Electrons, muons, pions, protons and kaons are separated over the 3 to 15 GeV/c range. The PLUTO detector (Figure 9.c)) has \(4\pi\) coverage for charged particles and photon detection. It separates electrons, muons and hadrons. The TASSO detector (Figure 9.d)) which uses aerogel and Cerenkov detectors has full particle identification. The MARK J detector (Figure 9.e)) is specialized for muon and lepton pair detection \((\mu, \mu^+\mu^-, e\mu, e^+e^-)\).

Apart from these large detectors, there is a monopole search experiment installed in the present PLUTO area. It uses capton foils inside the beam pipe and is based on a \(dE/dx\) measurement. It should be sensitive to a production cross-section two orders of magnitude lower than the point-like (muon pair) cross-section.

This concludes the survey of the PETRA programme.

2. The PEP Programme

2.1 The Machine

The layout of the machine is sketched in Figure 10. The length of the circumference is 2.2 Km. The beam energy can vary between 4 and 18 GeV (with foreseen extension up to 29 GeV). The designed luminosity varies as \(L = 10^{32} (E/15)^2 \text{ cm}^{-2} \text{ sec}^{-1}\) below 15 GeV. It then decreases and equals \(10^{31}\) at 18 GeV.

The machine should be ready for first beams in October 1979 and the experimental areas will be ready for occupancy in the spring of 79. It is hoped that area 6 will be completed with building and crane by beam turn on time.
Figure 9.a) : The Detector CELLO
Figure 9.b) : The JADE Detector
Figure 9.c) : The PLUTO Detector
Figure 9.d) : The TASSO Detector
2.2 The Approved Experiments

No specific request for time or energy have been considered as yet. During a "first round" approvals for several "facilities" have been given. During a "second round" smaller experiments were also included in the programme. A third round just considered DELCO and discussed the programme status.

At present 7 experiments have been approved. They are as follows:

- **PEP 5** Mark II detector
- **PEP 4** Using TPC chambers
- **PEP 9** Study of 2γ processes
- **PEP 6** MAC detector
- **PEP 12** High resolution spectrometer
- **PEP 14** Search for free quarks
- **PEP 2** Monopole search

It is also expected that one experiment will use the DELCO detector (Stanford, Caltech, SLAC).
Figure 11.a) shows a general view of the Mark II detector. It is a detector weighing 1500 tons. The magnet has an inner radius of 1.59 m and a length of 4.18 m. The field strength is 0.5 T and the thickness corresponds to 1.2 radiation lengths. The drift chambers cover 90% of the full solid angle with 3204 cells and 16 layers. The shower counters cover 90% of the full solid angle. There are 8 barrel counters. There are 18 layers with a thickness of 14 radiation lengths. The expected resolution is $0.1/E$. There is a stored read-out for position resolution.

The muon detector system covers 60% of the full solid angle. It is a 4 layer system. At average incidence their iron thickness corresponds to 47, 70, 101 and 132 cm respectively. The detector proper has 3808 triangular proportional tubes. The wire spacing is 2.5 cm.

The time of flight system covers 75% of the full solid angle with 48 double-ended counters. The expected time resolution is 250 psec. There is also a small angle tagging system.

Figure 11.b) shows a layout of the detector of Experiment PEP 4 with TPC's, while Figure 11.c) shows a schematic diagram of the TPC proper. In this set-up the TPC has a length of about 1 m with an inner and outer radius of 0.1 and 1 m respectively. The gas mixture at 10 atmospheres contains 80% Argon and 20% Methane. The drift voltage is 200 KV/m and the wire gain is $10^3$. There are 1200 wires per end cap and altogether $10^4$ "pads". The digital system uses an analogue CCP storage at 50 psec per bucket. The expected $dE/dx$ resolution is less than 3% and the expected spatial resolution is 100 - 150 microns.

The magnet (Figure 11.b) has a radius of 1.1 m and a length of 3.8 m. The field strength is 1.5 T and the thickness corresponds to 0.6 radiation lengths. This includes the vessel of the TPC.

Figure 11.d) gives a layout of experiment PEP 9 with emphasis on $2\gamma$ processes.

Figures 11.e) and 11.f) show the MAC detector of Experiment PEP 6. The magnet has an inner radius of 0.5 m and a length of 2 m. The field strength varies from 0.5 to 1 T. The thickness corresponds to one radiation length. The drift chambers have 1,200 channels with a double sense wire system, with 10 layers. The shower counters are set up in a hexagonal array with 13,000 wires and 32 layers. There are 1200 read-out channels.

The hadron calorimeter has 30 layers of steel and proportional tubes with a total thickness of about 1 m. It includes approximately 50,000 wires with read-out in 3,600 channels. The total weight is 550 tons. It is toroidally magnetized for $\mu^+\mu^-$ determination. The time-of-flight system uses counters just
Figure 11.a) : The Mark II detector
Figure 11.b) : Layout of Experiment PEP 4
Figure 11.c: Schematic view of the Time Projection Chamber (TPC)
Figure 11.d) : The $2\gamma$ detector of experiment PEP 9
Figure 11.f) : The MAC detector. Blown-up view
the steel with a conventional system. There are three sets of drift chambers. The first one is just outside the shower counters. The second and third ones are outside the steel and determine the muon direction. The total number of channels is 4,800. The overall expected resolution, using tracking, shower counters and calorimeter, is the order of 0.5/$\sqrt{E}$.

Figure 11.g) gives the layout of the high resolution spectrometer of experiment PEP 12. The magnet has an inner radius of 2.3 m and a length of 4 m. The field strength is 1.7 T. The thickness is very large. There are two sets (inner and outer) of drift chambers. The inner set is similar to the one used in Mark II. The outer layer consists of a double set of cylindrical tube drift chambers.

The shower (and trigger) counters are set as a band with two layers. They are of the lead scintillator sandwich type.

A second phase development should include additional muon counters outside the magnet using the magnet steel as absorber. It should also include photoionization Cerenkov counters between the inner and outer drift chambers.

Figure 11.h) shows the layout of the free quark detector of experiment PEP 14. In this case, the $dE/dx$ and time-of-flight counters are set in 8 layers. They altogether use 400 phototubes. 32 lucite Cerenkov counters are set behind the time-of-flight counters. Finally, 14 multiwire proportional chambers are used to track charge 1/3 particles.

2.3 Progress of Detectors

At beam turn on, in October, 1979, Mark II (PEP 5) should be running and occupy one of the interaction areas (Area 12 on Figure 10). The area next to it (anti-clockwise) will be used for machine study, while accommodating the monopole detector of experiment PEP 2. Either of the two following areas could accommodate the DELCO detector together with either the high resolution spectrometer or the free quark experiments which will be in 6 and 8 respectively. The next area around (Area 4) will be used for the MAC detector of experiment PEP 6. The last intersection area will house the TPC detector of experiment PEP 4 together with the $2\gamma$ detector of experiment PEP 9.

The present status of Mark II is such that runs should take place from mid-October 1978 to June 1979, for 25 weeks altogether. The detector will then be moved to PEP in June 1979 to start up in October 1979.

Figures 12 and 13 illustrate partially the performance of the detector with recent physics results and Figure 14 gives the efficiency for neutral detection.
Figure 11.g) : Layout of the high resolution spectrometer of experiment PEP 12
Figure 11.h) : Free quark search experiment - experiment PEP 14
Figure 12.b) : 7-prong hadron
Preliminary Mk II
$K_s^0 \rightarrow \pi^+ \pi^-$ Invariant Mass
$E_{\text{c.m.}} = 4.16$ GeV

Figure 13.a)
Preliminary MK II
$K^-\pi^+ + K^+\pi^-$ Invariant Mass
$E_{c.m.} = 4.16$ GeV
\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure13c.png}
\caption{\textit{D}^0 \textit{Recoil Mass}
\textit{E}_{c.m.} = 4.16 \text{ GeV}}
\end{figure}
Figure 13.d)
Figure 14: 
(a) photon detection efficiency
(b) $\pi^0\eta^0$ detection efficiency
Figure 15: Second Moment vs. Mean, for the truncated dE/dx energy loss distribution in the prototype TPC chamber for particles at 800 MeV/c momentum.
Studies with TPC are progressing. A prototype chamber with 200 dE/dx samples and 8 "pads" is being tested. At present the precision on the measurement of dE/dx is at the 2.7% level. The precision on the "pads" is 140 μ. The CCD tests have been successful. Figure 15 shows the separation between pions, electrons and protons thus obtained.

A prototype magnet 0.7 m long is being tested. Results are satisfactory.

At present the coil of the TPC detector is under construction. It should be completed in January 1979. Design for the iron is completed and magnetic measurements should begin in August 1979. The construction of the TPC is beginning. The construction of the cylindrical calorimeter is delayed due to funding reasons. The detector should be sufficiently advanced for check-up in the beam in the spring of 1980.

The MAC detector is well into production for all components. It should be ready by October 1979. The high resolution spectrometer should be ready before the spring of 1980. At present, the iron is starting to arrive from Argonne while the coil is being modified. Work is beginning on the other components.

Equipment for the free quark search experiment should be ready by October 1979.

Delays with the 2γ experiment are mainly due to the NaI crystal part of the detector. 60 elements should be available by mid 1979. The remaining 60 should be ready early in 1980 only.

2.4 Future Possibilities

They are summarized in Figure 16 which gives the expected luminosity as a function of energy for different possible stages of development. They correspond to an increasing amount of radio frequency power and to the possible use of superconducting cavities.

This concludes the survey of the PEP programme.