REPORT OF GROUP V

e^+e^- AND $\bar{p}p$ EXPERIMENTS

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ABSTRACT

We have studied the physics possibilities on two super high energy machines. First, we have investigated e^+e^- at 350 GeV and, second, $\bar{p}p$ at 20 TeV.

INTRODUCTION

We have considered experimentation on future e^+e^- and $\bar{p}p$ machines. In particular, we have considered two machines:

(1) 350 x 350 GeV e^+e^-.

(2) 20 x 20 TeV $\bar{p}p$.

In order to investigate both the physics possibilities and technical questions we made a number of physics assumptions. These accelerators go beyond the region that will be explored in the energy region of presently conceived machines (CERN and Fermilab $\bar{p}p$, LEP, etc.). We have assumed that the physics will be very rich on these planned machines and that many of the physics goals of these machines will be realized. We then use this as a starting point in discussing what could be done at still higher energies.

To be specific, we have assumed that the coming generation of machines will accomplish the following ambitious goals:

(1) W will be found

(2) Z° will be found

(3) t-quark will be found

(4) Any Higgs (H) < 100 GeV will be found

(5) Quark, Gluon jet phenomenology will have been studied and understood.

PHYSICS POSSIBILITIES

We have looked at a range of physics possibilities[1] on these very high energy machines and have estimated the rates, detection signatures, etc., for the following processes:

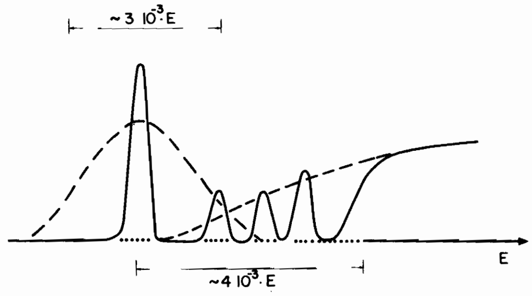
1. More Flavors

Even assuming the t-quark is found, there could be still heavier flavors. These, of course, would give further steps in R, in e^+e^- collisions, and the distributions, decays, etc., can also provide signatures. An interesting point, however, is whether accurate energy resolution in beam energies (for e^+e^-) would be useful in studying "onium" spectroscopy. This is particularly important, since the momentum resolution in colliding linacs is poorer than for storage rings. From simple argument, it appears that the states will be smeared out because of the availability of weak decays $(Q \rightarrow W^+ + q)$,

$$\Gamma(\text{onium}) \sim 6\ 10^{-3} m_Q \qquad (\text{from } \Gamma(Q \rightarrow W_q))$$

$$\text{Binding Energy} \sim 7.5\ 10^{-3} m_Q$$

therefore



we conclude that good energy resolution will not be of the same importance as at lower energies for fermion spectroscopy.

2. Further Z°'s

It is possible that even if the Z° is found, there will be further Z°'s at higher mass. These would be easily detectable as the rate is extremely high

$$\frac{\sigma(e^+e^- \to Z^{\circ\prime} \to \text{all})}{\sigma_{pt}} = 5600.$$

Also, the width would be expected to be a few percent.

Assuming $\frac{\Gamma(Z^{\circ\prime})}{\Gamma(Z^\circ)} = \frac{m_{Z^{\circ\prime}}}{m_{Z^\circ}}$ then $\frac{\Gamma(Z^{\circ\prime})}{m_{Z^{\circ\prime}}} \approx 3\%$

3. Higgs Particles

If there are heavy Higgs Particles they will decay in W-pairs and Z-pairs. As shown by Figure 1 the width of these states will be extremely broad[1].

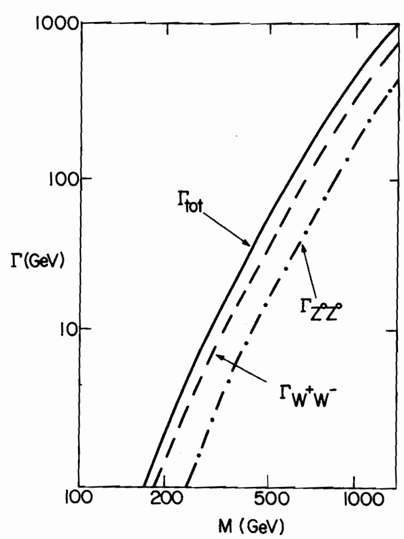


Fig. 1: Decay width for decay of a heavy Higgs particle (Ref. 2). For mass M_H > 200 GeV, decay into W-pairs and Z-pairs dominates.

4. Technicolor

This is the name given to a new exact non-Abelian symmetry (like QCD) giving a new strong interaction. The scale of this new interaction is estimated to be ~ (1000-3000) x QCD. In addition to effects that set in with that scale there would also be technicolor analogs to ρ, Δ ... with masses ~ (0.5-5 TeV). Theoretically, this replaces the Higgs mechanism.

5. Pseudo-Goldstone Bosons

These yield hadrons lighter than the technicolor scale. This is analogous to the existence of the $\pi^{\pm}$ which is lighter than the QCD scale.

An example might be a "techi-K" with estimated mass (M_{Tk}) ≈ 15 GeV.

It would be difficult to distinguish such particles from Higgs particles. The way they are different is that they have structure on a scale of ~ 1 TeV.

6. Supersymmetric Particles

Finally, we have studied the signatures and rates for supersymmetric particles,

Scalar quarks	$\tilde{q}$
Scalar leptons	$\tilde{\ell}$
Wino	$\tilde{W}^{\pm}$
Zino	$\tilde{Z}^{\circ}$
Gluino	$\tilde{g}$

It is possible to search for these particles on the new machines discussed in this report up to ~ 500 GeV. The general technique is to study a process like $e^+e^- \to \tilde{q}\,\tilde{q}$ followed by the decay $\tilde{q} \to q + \nu$. This then yields nearly back-to-back jets, plus missing energy (neutrinos) for a signature.

E^+E^- COLLIDER

In order to evaluate the physics possibilities for e^+e^- we have assumed a machine with the following parameters:

E = 350 x 350 GeV colliding lineac

$\mathcal{L} = 10^{33}\ \mathrm{cm^{-2}\ sec^{-1}}$

$\beta^* = 10$ cm

$P_b = 100$ Mw

$P_s = 4$ Mw

$f = 2\ 10^4$ Hz

$\sigma_t = 0.5\mu$ $\qquad\sigma_\ell = 1$ mm

$\delta = 4\%$

Several features are important to discuss. We have concluded that a luminosity of $\sim 10^{33}\ \mathrm{cm^{-2}\ sec^{-1}}$ is necessary to do physics in this energy region. This is strictly a rate question and as can be seen from Table 1 the new physics which could possibly emerge in the energy regime has a very small rate.

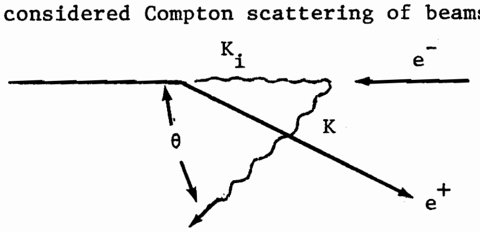
Table 1

Rates for e^+e^- Collider at $\sqrt{s}$ = 700 GeV, $\mathcal{L} = 10^{33}$ cm^{-2} sec^{-1}. For reference, R = 1 yields 15 evts/day, and we have derated by a factor of 2 for experimental reality.

Machine	Scenario $e^+e^- \rightarrow$	R	SLEP Rate (Evts/day)
PETRA	Present	~ 5	40
LEP	$\rightarrow Z°, W^{\pm}$		
	Hadrons	~ 10	75
	$W^+ W^-$	22	155
	Z°Z°	~ 20	150
SLEP	Z° + H°	0.16	1
	$H^+ + H^-$	0.26	2
	$Z°'$	5600	40,000
	Techni ρ	7	50
	$\tilde{W}^+ \tilde{W}^-$	2	15
	Scalar quark $\tilde{q}$	0.5	4
	Scalar lepton $\tilde{\ell}$	0.26	2
	Wino $W^{\pm}$	2	15
	Zino $\check{Z}°$	0	-

We have investigated the environment around an interaction region and whether a detector can be shielded. Fig. 2 shows a hypothetical layout of an interaction region with an expanded vertical scale. As shown, intense beamstrahlung radiation (~ 2 Mw) will emerge from the interaction point both forwards and backwards. The critical energy of this radiation, ε_c ~ 400 MeV. We placed a beam dump ~ 80 meters downstream (which means you need a clear area for that long). Off the dump, ~ 40 Kw of 1 Mev γ's are backscattered. With the dump so far from the experiments only 40 mw strikes the shielding near the experiments. This seems tolerable.

In addition, we considered Compton scattering of beamstrahlung.



This source could make harder photons which could be a serious problem for experiments. However, it appears (see Fig. 3) that except for very small angles the probability of making such photons is small.

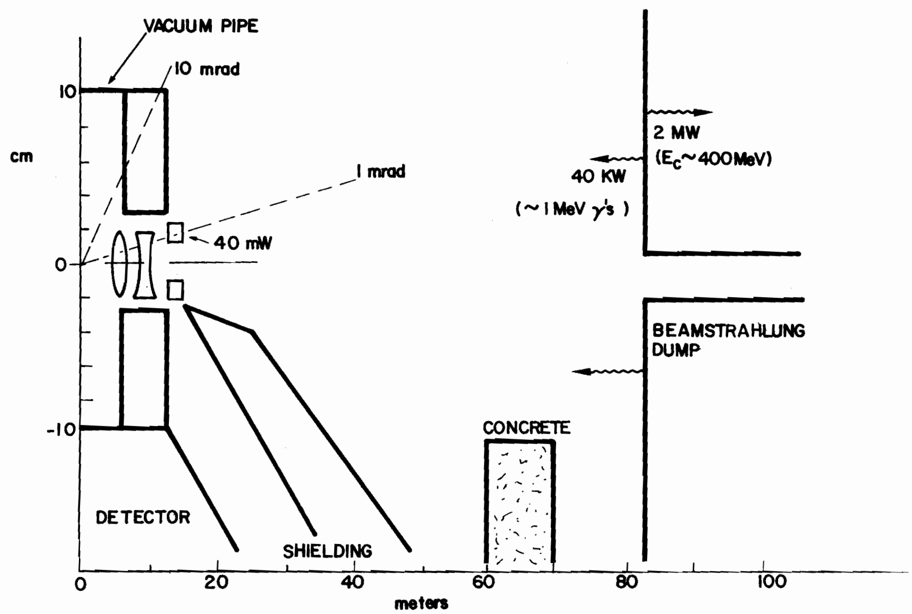


Fig. 2: Possible layout for shielding against beamstrahlung background in 350 GeV x 350 GeV e^+e^- interaction region. (Note the different vertical and horizontal scales.)

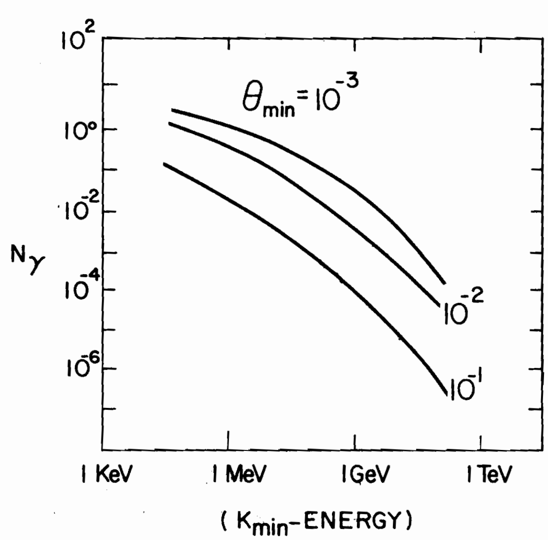


Fig. 3: The background for Compton scattering of beamstrahlung photons with opposing beam for 350 x 350 GeV e^+e^- is shown. The number of photons for $K > K_{min}$, $\theta > \theta_{min}$ per bunch crossing is shown.

We have studied the signatures and detection of the various physics phenomena discussed. We find that almost all phenomena at these energies lead to many jets and/or isolated leptons. The jet-jet effective mass appears to be the way to identify and distinguish Z, W, H°, etc. These topologies are illustrated in Figure 4. A more specific illustration is shown in Figure 5. This shows the production of a Higgs and Z° in e^+e^- annihilation. The two-body kinematics (e.g., Z + Z) reconstruct to the Higgs mass.

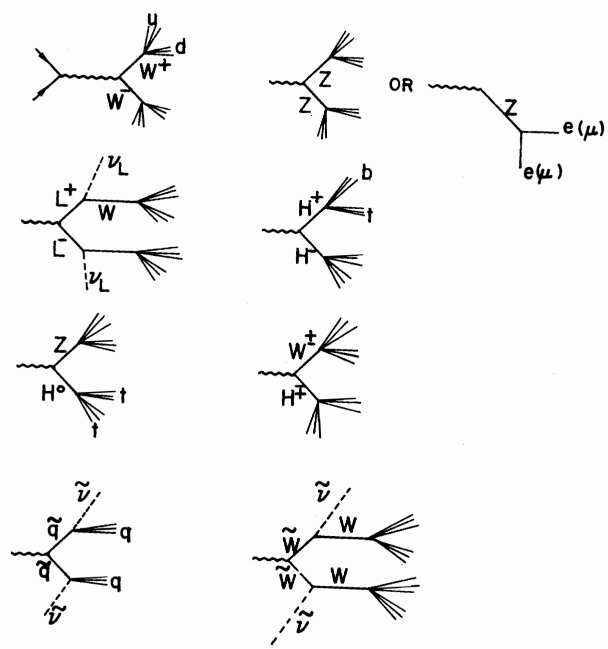


Fig. 4: Shown are various topologies for new phenomena at very high energies. Notice that final states are various combinations of jets and leptons. The jet-jet effective mass must be reconstructed to identify Z, W, H°, etc.

Finally, the basic layout of a possible e^+e^- detector for SLED has been studied. The detector includes a vertex detector, which could identify short-lived particles (e.g., charm), dE/dx measurement which will be useful in determining the multiplicity of jets, electromagnetic and hadronic calorimitry to measure energy and direction of jets and electrons.

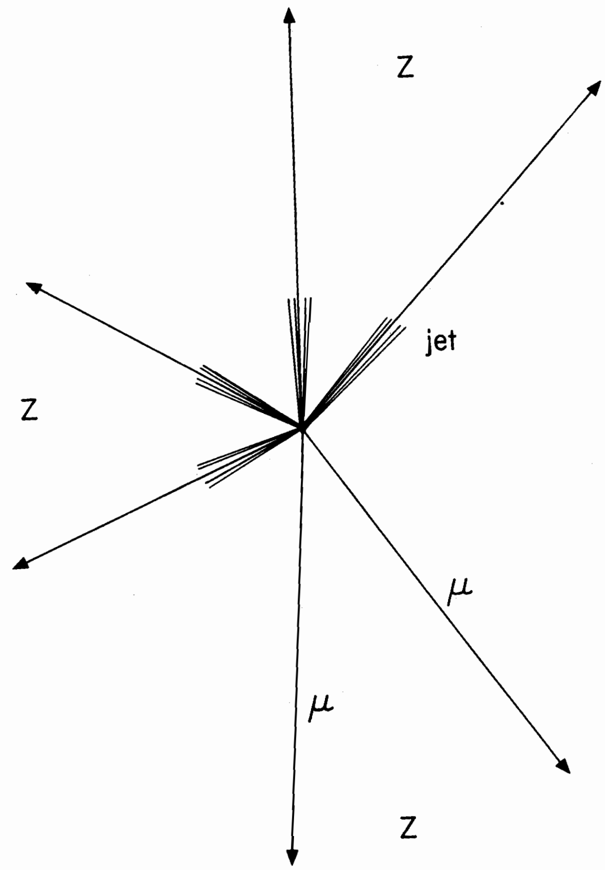


Fig. 5: A specific example of the reaction e^+e^- (700 GeV) $\rightarrow$ Z(90 GeV) + H(500 GeV) with subsequent decays Z $\rightarrow q\bar{q}$ and H $\rightarrow$ ZZ $\rightarrow q\bar{q}+\mu\bar{\mu}$ is shown. The invariant mass of pairs give Z mass and invariant mass of two Z's give H mass.

PROTON-ANTIPROTON

For evaluating the physics possibilities on a very high energy $\bar{p}p$ machine we assumed the following machine parameters:

$E_p = E_{\bar{p}} = 20$ TeV

$\mathcal{L} = 10^{32}$ cm^{-2} sec^{-1}

$N_{bunches} = 1000$

$n_{\bar{p}}$/bunch = 5 10^9

$\mathcal{L}_{bunch} \cdot \sigma_{hadronic} \cdot \tau = 2 \ \frac{\text{Interactions}}{\text{Bunch crossing}}$

Bunch interaction length ~ 1m

Time between bunches ~ 0.2 μsec

Beam size ~ 10 μm

It is important to note that the interaction rate is so high that it is necessary to distribute the beam in many bunches around the ring. For our example, we chose 1000 bunches around the 70 km ring with a resulting separation of ~ .2 μsec between bunches. Even with this distributed beam there are several interaction/per crossing.

As shown in Figure 6 the physics of a 20 TeV x 20 TeV machine can essentially be divided into angular regions. It is interesting that the physics more or less divides into angular regions. For example, elastic scattering is typically at ~ 5 μr, the characteristic angle for W-production is ~ 20 mr, and much larger angles provides a probe to very short distances (possibly enabling a study of quark structure). In a sense, this divides the physics interest chronologically and therefore we call this an "archeological" plan.

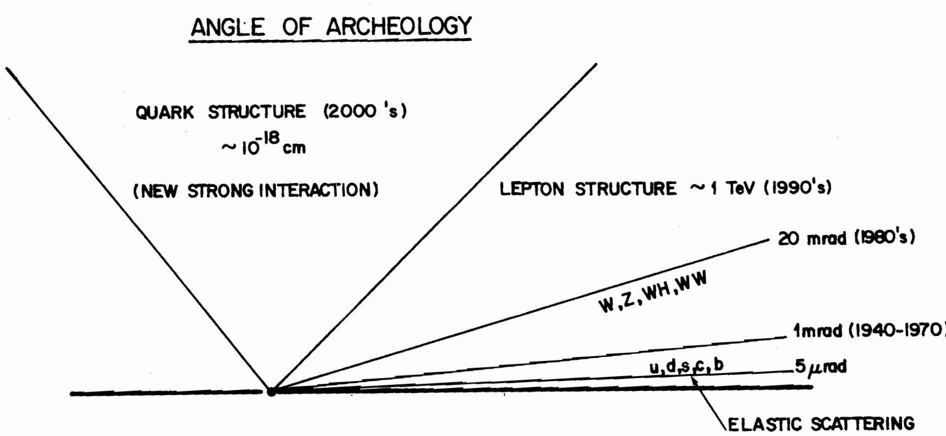


Fig. 6: Plot showing the kinematic regions for various physics phenomena for 20 TeV $\bar{p}p$. The small angles represent physics studied on present machines and at larger angles to future physics.

Just as in e^+e^- physics, we find that the physics signatures are mainly jets and/or leptons. Below in Table 2 is a summary of the signature and detector requirement for the various physics goals.

Again, from these signatures it is clear that a detector for $\bar{p}p$ must concentrate on detecting leptons and quarks (via jets). The measurements and separation of jets must be good enough to reconstruct invariant masses, etc. From Table 3 we see that rates are very high for W production, Z production and even Higgs production. However, to experiment at very short distances to explore possible quark structure, etc., will require the full design luminosity.

Table 2

$\bar{p}p$ Event Signatures and Detector Requirements

Process $\bar{p}p \rightarrow$	Signature	Detector Requirement
1. $W^+ + X$, $\hookrightarrow u\bar{d}$; $Z^\circ + X$, $\hookrightarrow u\bar{u}$	Two fast forward jets	Good Energy Resolution $\frac{\Delta E}{E} \approx$ few %
2. $W^+ W^- X$, $\hookrightarrow u\bar{d}$, $\searrow \bar{d}u$	Four fast jets	$\frac{\Delta E}{E} \approx$ few %
3. $pp \rightarrow {W \atop Z}$ HX, $\hookrightarrow t\bar{t}$		
a) M_H < 200 GeV	W – 2 narrow jets H – 2 wider jets	$\frac{\Delta E}{E} \approx$ few %
b) M_H > 200 GeV H → $Z^\circ Z^\circ$, → WW	Six narrow jets	$\frac{\Delta E}{E} \approx$ few %
4. $L\bar{L}X$	μe pairs in 20-100 mr region (P_t imbalance)	Good Lepton Identification
5. $Q\bar{Q}X$, q + q' + q"	6 to 10 jets	
6. Supersymmetric particle + scalar quark + $\tilde{\nu}$	Missing P_t	Good Energy Resolution

Table 3

Event Rates/Day for $\bar{p}p$ at 20 FeV Assuming $\mathcal{L} = 10^{32}$ dm^2 sec^{-1}

Process $\bar{p}p \longrightarrow$	Rate	Remarks
$W^+ + X$	$1.6 \ 10^6$	
$Z^\circ + X$	$\sim 4 \ 10^5$	
$W^\pm$ + Higgs	1 - 1000	$M_H \sim$ 15-500 GeV
$W^+ + W^- + X$	~ 1000	
$\ell + \bar{\ell} + X$ $m_{\ell\bar{\ell}} \sim 1$ TeV	$\sim 1 - 10$	Probe Lepton Structure
jet + jet + X $m_{jet-jet} \simeq 10$ TeV	$\sim 1 - 10$	Probe Quark Structure
Heavy Quark $+ \bar{Q} + X$ $\rightarrow W + Q'$ $m_Q \sim 500$ GeV	$\sim 1 - 10$	Super Massive Fermions

Finally, Figure 7 shows a hypothetical quark (jet) and lepton detector for $p\bar{p}$ and Figure 8 gives the resolution for jets and electrons attainable by present shower techniques at these energies.

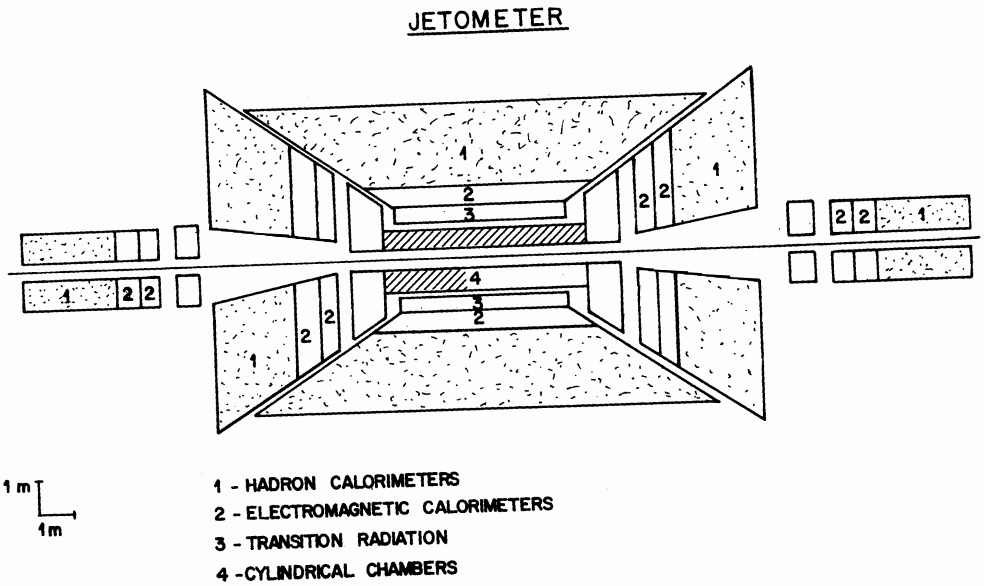


Fig. 7: The Jetometer - a rather simple detector designed for the physics goals discussed in this report. Note, the detector has no magnetic field. The shower counters are arranged in ~ 10 cm x 10 xm towers and a transition radiation detector has been added for particle identification.

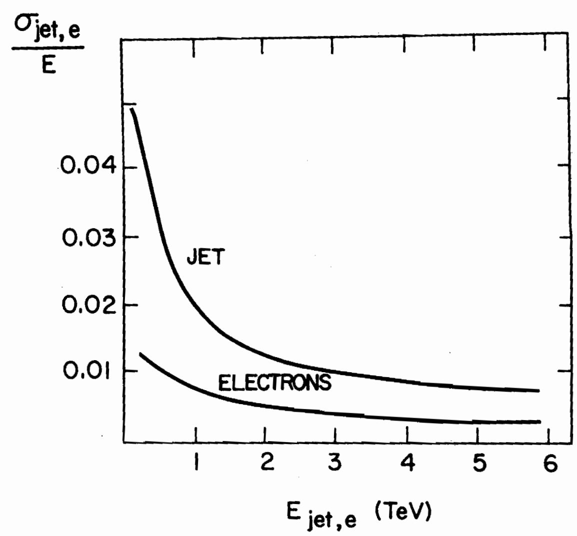


Fig. 8: Expected resolution for high energy jets and electrons. The resolution for jets (hadronic cascades) is $\frac{\sigma}{E} = \frac{0.5}{\sqrt{E}}$ and for electrons (electromagnetic cascades) is $\frac{\sigma}{E} = \frac{0.13}{\sqrt{E}}$.

CONCLUSIONS

From this study we conclude that both e^+e^- and $\bar{p}p$ could be very exciting and open new frontiers in these super high energy machines. This seems true even if much rich physics is doscovered in the LEP energy region rather than beyond. Experimentally we find that it should be possible to work around these machines using present-day techniques. No new technical breakthroughs appear necessary for experiments concentrating on leptons and jets. Studying the rates we find that an e^+e^- machine at such high energies will require $\mathcal{L} \sim 10^{33}$ cm^2 sec^{-1}. For $\bar{p}p$ we note that the beam must be dispersed around the machine in $\sim$ 1000 bunches in order to handle the rates at forward angles where much of the physics is concentrated. Overall, from an experimental point of view, both of these machines are extremely attractive.

* * *

REFERENCES

1. For a more complete discussion, see e^+e^- Physics Beyond LEP, Contribution to this Workshop.
2. Lee, Quigg, Thacker - PR D/6, 1516 (1977).