Extension of E137

Fermilab

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23 October 1982

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P. O. Box 4349
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Dear Pief:

This is a formal request on behalf of my colleagues that E-137 be granted 5 coulombs of running in the SLED mode at 33 GeV. As you know, we have essentially made this request in the past. As we know, the request is not easily granted inasmuch as SLAC must expend effort, however modest, in upgrading the A beam line.

The physics goals underlying this request are outlined in the enclosed document. The gains in sensitivity from running at higher energy are not overwhelming, but they are significant. In that document is also described the sensitivity of the present experiment and proposed extension to the existence of the now-fashionable photino. We ask that this document be distributed to EPAC.

Given the readiness of the E-137 apparatus and the wish of both proponents and laboratory to complete the experiment in a timely fashion, we ask that the A-line upgrade be carried out as soon as possible.

With best regards,

Yours,

J. D. Bjorken

cc: G. Fischer

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Extension of E-137: Search for Photinos

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Higher Energy for E137?

There are of course visceral reasons for wanting to have a short look--even given the luminosity penalty--at the highest incident energy. Beyond the viscera, there is also the mundane practical advantage of seeing how the beam-associated background (target-in running) varies as energy is increased. But beyond the viscera and the mundane, there is some physics advantage as well.

We have examined in some detail the advantage of higher energy for three hypothetical cases. The first case is production of axions resonantly coupled to e^+e^-. The next case is the production of unstable "heavy" neutrinos ν_h via $e^+e^- \rightarrow Z^\circ \rightarrow \nu_h\bar{\nu}_h$. These cases can already be found in the original proposal. The third case is production, again in e^+e^- annihilation, of photino pairs, one of which subsequently decays into photon plus goldstino. This case was not discussed in the original proposal, and is therefore, the case chosen for detailed discussion here. However, the results in all cases are rather transparent and general. Therefore, we give them here in general terms first.

The new hypothetical particles for which we search will, in general, be described by at least two parameters: (1) the strength of coupling to electrons and/or photons and (2) the mass. For fixed coupling strength, the typical rates tend to rise rapidly with mass, because of the rapid decrease in lifetime with increasing mass. Then one reaches, quite abruptly, the kinematic limit, where the rate drops to zero (Fig. 1). This gives rise to the region of experimental sensitivity shown schematically in Fig. 2. SLED running only extends the range of available mass and not of coupling stength, and the extension is modest. Evidently the increase in mass range scales with available center-of-mass energy; hence with the square root of laboratory energy:

$$\frac{\Delta m}{m} \approx \left(\frac{33}{20}\right)^{1/2} - 1 = 30\%$$

The SLED advantage is likewise greatest for cases in which, at fixed mass, the lifetime limited (minimum) coupling strength is much larger than the rate-limited (maximum) coupling stength. For cases we have examined, we may estimate the number of order of magnitude of coupling strength available for the 30% extension of mass-sensitivity. This is shown in the table below:

Hypothetical Particle	Relevant range of coupling strength
"Axion" coupled only to photon	Factor ∿5-10 in F_χ
"Axion" resonantly produced in e^+e^-	Factor ∿30 in $g^2/4\pi$
Neutral $\nu_h\bar{\nu}_h$ produced in e^+e^-	Factor ∿100 in lifetime
Pair-produced photinos in e^+e^-	Factor ∿100 in the supersymmetric scale parameter d if selectron mass M is 20 GeV; factor ∿4 in d if M is 100 GeV.

This is not an enormous range of parameter space, but it nevertheless is not negligible. All we can say is--remember ADONE!

Photinos

The photino γ_s is a conjectured supersymmetric spin 1/2 partner of the photon. Its mass may be small. A production mechanism is shown in Fig. 3. The exchanged scalar electron (selectron) is, if it exists, heavier than 15 GeV. The coupling constant at the vertices is ∼e, and the total cross-section is[1]

$$\sigma(e^+e^- \to \gamma_s\bar{\gamma}_s) = \frac{2\pi\alpha^2 s}{3M^4}\sqrt{1-\frac{4\mu^2}{s}}\left(1+\frac{2\mu^2}{s}\right)$$

Here μ is the photino mass and M the selectron mass.

The photino decays into photon plus spin-1/2 goldstino. We assume the goldstino has a mass which is negligible in comparison to the photino. In this case the photino decay width is given by[2]

$$\Gamma = \frac{\mu^5}{8\pi d^2}$$

Here d is the "goldstino decay constant", analogous to the pion decay constant, and is a measure of the scale of supersymmetry breaking. $\sqrt{d}$ might be hoped to be of order 100 GeV, although excursions of an order of magnitude either way are easily tolerable. While one naturally associates the mass M of the selectron with the value of $\sqrt{d}$, there is no strict connection.

We may now write down the expression for the event rate in the detector:

$$dN = \int_0^{E_-} \frac{dE_+}{E_-}\, \phi\left(\frac{E_+}{E_-}\right) \cdot \sigma(E_+) \cdot \Gamma \cdot \ell \cdot \left(\frac{\mu}{E_+}\right) \cdot Eff(E_+)$$

Here

E_- = energy of incident electron beam

E_+ = energy of annihilating positron

$\phi(E_+/E)$ = track-length distribution of positrons in the dump

ℓ = length of decay region

The factor (μ/E_+) roughly takes care of the γ^{-1} time-dilation inhibition of the photino decay width. The efficiency factor $Eff(E_+)$ includes not only the residual correction to this, but also detection-efficiency corrections due to the finite energy threshold E_{min} for the decay photon to be observed in the detector. (The efficiency factor should also include the geometrical acceptance; the correction is unimportant for positrons of energy in excess of 10 GeV, and we do not include it.) The formula for $Eff(E_+)$ is

$$Eff(E_+) = E_+ \int_0^{E_+/2} dE\, f(E) \left[\frac{\theta(E - E_{min})}{E}\, \epsilon(E) + \frac{\epsilon(E_+ - E)}{E_+ - E}\right]$$

Here $f(E)$ is the (normalized) momentum distribution of the <u>slowest</u> photino, and E_{min} ($\gtrsim 2$ GeV) is the minimum detected photon energy. The detection efficiency $\epsilon(E)$ for observing the decay-product of a photino of energy E is

$$\epsilon(E) = 1 - \frac{E_{min}}{E}$$

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appropriate for a uniform decay-photon laboratory momentum spectrum. For photinos of negligible mass, f(E) is a constant[3] while for photinos of maximal mass (produced near threshold) f(E) peaks near $E_+/2$.

Numerical evaluation gives the result shown in Fig. 4. Since we shall be interested mainly in annihilating positrons of energy >10-15 GeV, we shall set this efficiency factor equal to a constant:

$$\mathrm{Eff}(E_+) = 3.2 \pm 0.5$$

We now put all this together. Defining

$$s_{max} \approx 2m_e E_- = 4\mu^2_{max}$$

we have for the number of events per incident electron

$$N = (3.2 \pm 0.5)\frac{\alpha^2\mu^6(2m_e\ell)}{6M^4d^2}F\left(\frac{\mu^2}{\mu^2_{max}}\right)$$

where

$$F(\varepsilon) = \int_\varepsilon^1 dx\, \phi(x)\sqrt{1-\frac{\epsilon}{x}}\left(1+\frac{\epsilon}{2x}\right)$$

The form factor depends only upon the positron track-length spectrum (cf. Fig. 3 of the proposal) and can be numerically integrated. The result is shown in Fig. 5. This implies (for fixed M and d) a dependence of yield on mass as shown in Fig. 6. It exemplifies the general argument made in the preceding section.

Finally we may estimate the region of parameter-space for which the E137 experiment is sensitive. We choose a selectron mass of 20 GeV, near the lower bound, and plot in Fig. 7 the event-rate (per coulomb) as function of $\sqrt{d}$ and μ. For the record, useful formulae are

$$N = 0.15\left(\frac{100\,\mathrm{GeV}}{M}\right)^4\left(\frac{\mu}{10\,\mathrm{MeV}}\right)^6\left(\frac{100\,\mathrm{GeV}}{\sqrt{d}}\right)^4 F\left(\frac{\mu^2}{\mu^2_{max}}\right)\mathrm{events/coulo}$$

where F is read directly from Fig. 5. Also the photino lifetime is[2]

$$\tau = 15.5\left(\frac{\sqrt{\alpha}}{100\,\mathrm{GeV}}\right)^4\left(\frac{10\,\mathrm{MeV}}{\mu}\right)^5 \mu\mathrm{sec}.$$

For a selectron mass M of 100 GeV, the excluded region becomes rather minimal, as shown in Fig. 8. Values of M higher than 300 GeV do not lead to constraints on photino properties in this experiment.

We shall not compare these limits with those obtained in other experiments. In particular, photino production in hadron collisions is dominated by (virtual) $q\bar{q}$ annihilation via squark exchange. (Squarks are the scalar supersymmetric partners of quarks.) The sensitivity again depends upon the fourth power of the squark mass, which is greater than 15 GeV but otherwise unknown. It might even be expected to be larger than the selectron mass.

Request

We request that SLAC grant us an opportunity to search for photinos. This proposal requests that the laboratory upgrade the maximum energy of the A beam line from 20 GeV to 30 GeV, which will allow us to take advantage of the SLEDed mode of operation of the accelerator. It is our understanding that all necessary magnets already exist. Effort has to be taken by the laboratory to install them.

Furthermore, we request that the experiment be run with 10 Coulombs of integrated charges of 30 GeV electrons. By comparing the nominal parameters of the SLEDed mode (200 mA x 0.15 μsec) and the conventional mode (50 mA x 1.6 μsec) and operation of the accelerator this request is approximately equivalent to that of the approved running on the axion searches. Based on our running experience in January of 1982, this request will take six weeks to execute at 180 pps, assuming 100% efficiency.

Since the photino search experiment is going to be executed on the same detector as the axion search experiment, there will be no additional request to the laboratory for new equipment, but we would like to request some time (of the order of ∿ 3 weeks) to use the electron test beam to calibrate a fraction of the detector.

REFERENCES

1. P Fayet; preprint LPTENS82-12. The amplitude is pure J = 1 in the s-channel The kinematic factors for finite mass, while not cited by Fayet, are typical for this kind of process. See also P. Fayet, Physics Letters 86B. 272 (1979)
2. N. Cabibbo, G. Farrar, and L. Maiani, Physics Letters 105B, 155 (1981).
3. Actually the distribution in $y = \frac{E}{E_+}$ is $\{1+(1-y)^2\}$. We ignore here this nuance.

F1

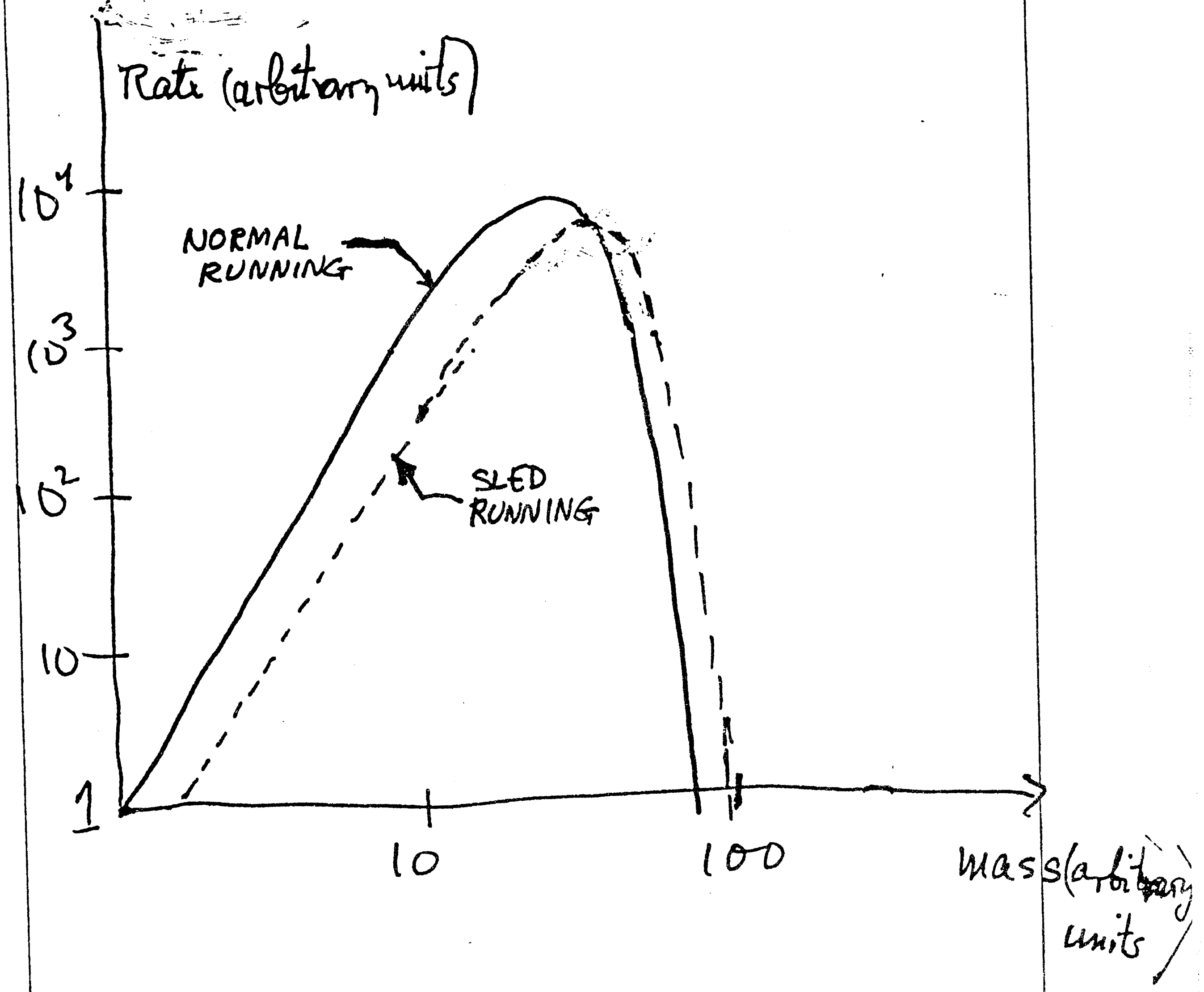

Fig. 1: Typical behavior of calculated rate of observation of hypothetical particle versus mass at fixed coupling strength.

F2

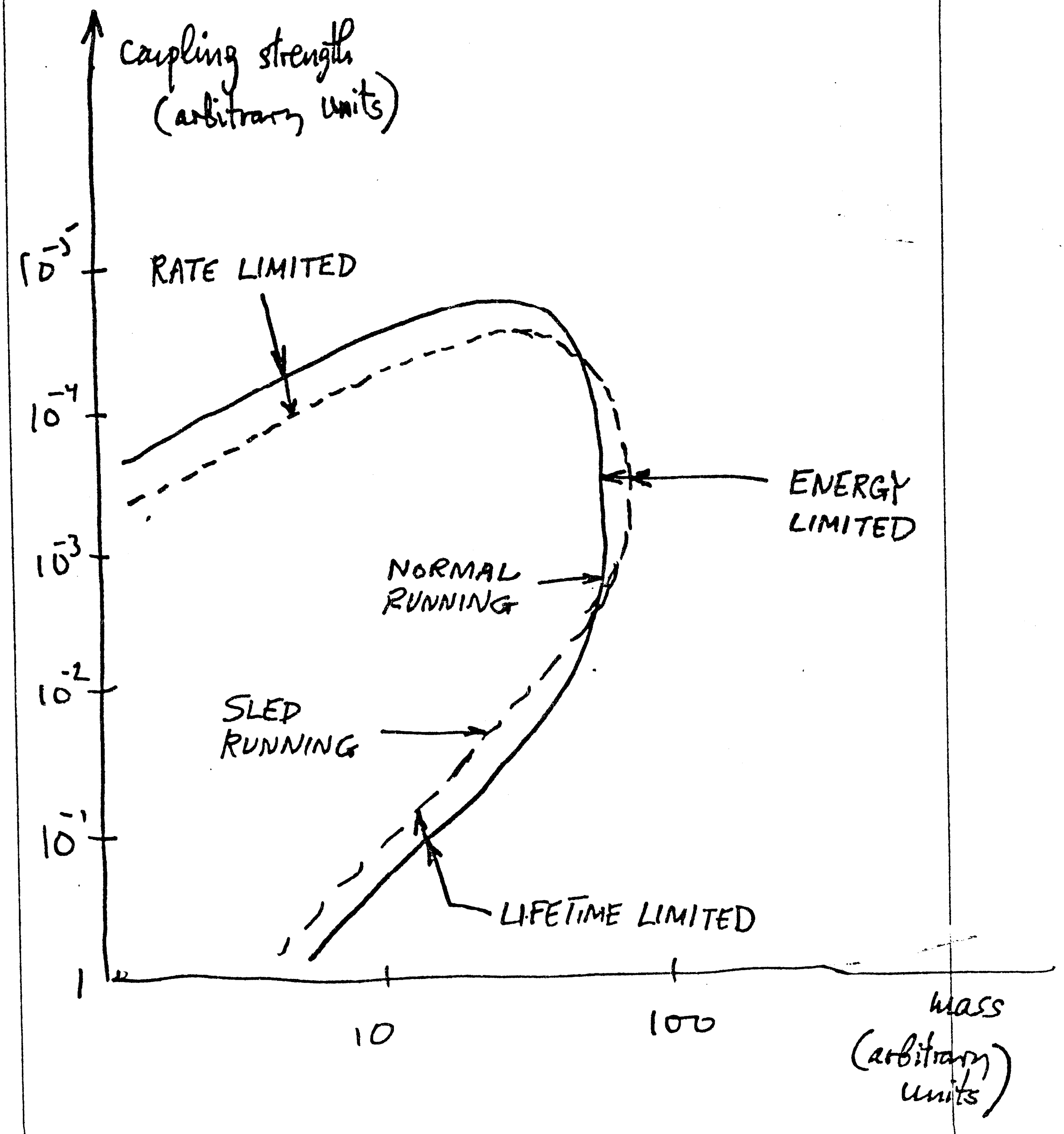

Fig. 2: ~~Generic~~ region of parameter space excluded by E137 running.

F3

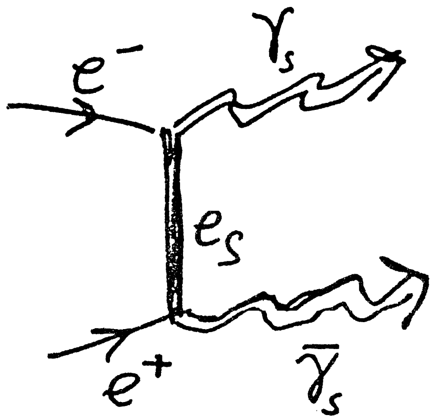

Fig. 3: Electron - positron annihilation into photino pairs. The exchanged particle is the selectron.

F4

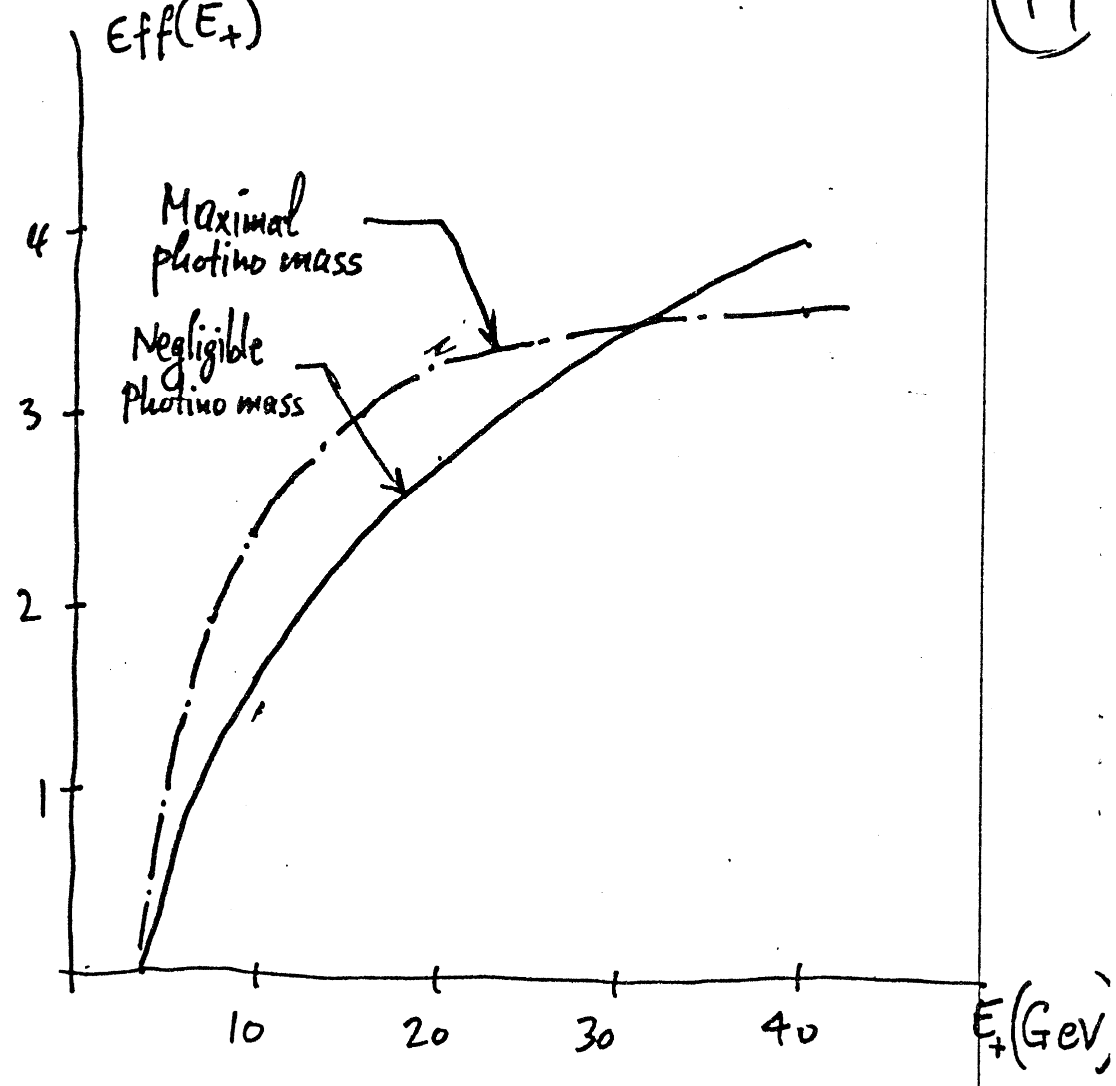

Fig. 4: ~~Positron [illegible]~~ Decay-Photon "detection efficiency" as function of positron energy

F5

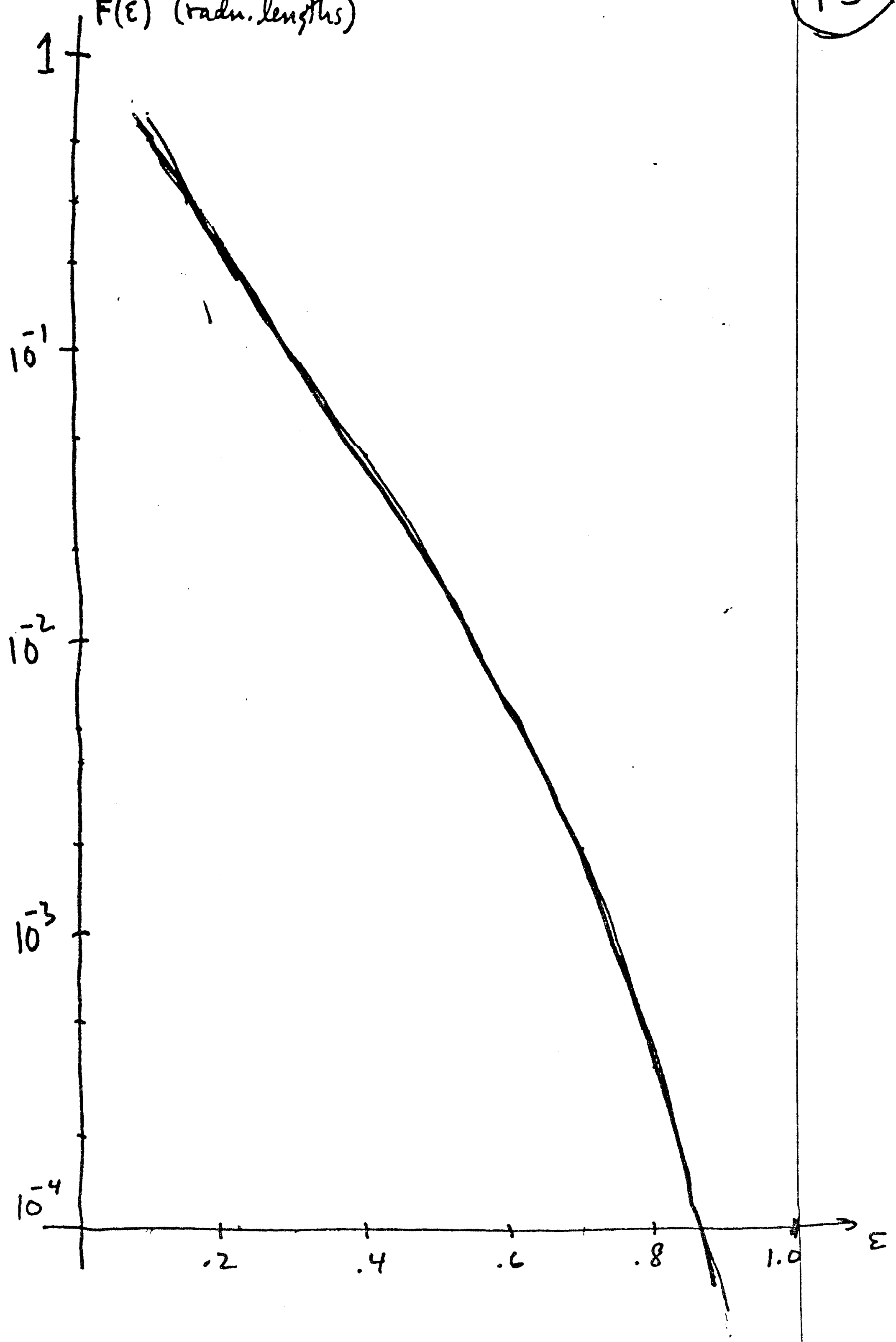

Fig. 5: "Luminosity-function" for photino production.
1 radiation length $\simeq 2 \times 10^{25}$ cm^{-2}.

F6A

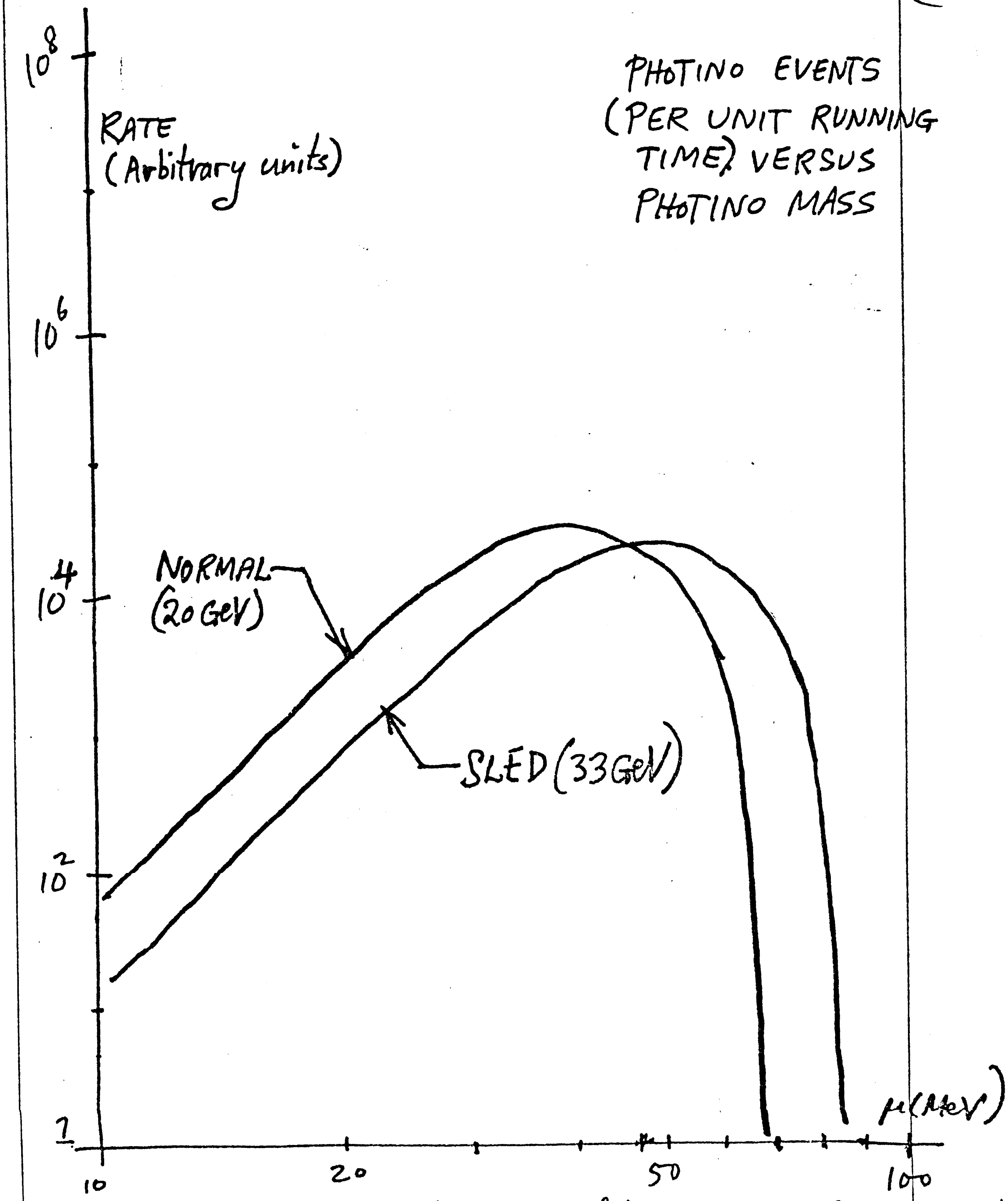

Fig. 6a Photino event-rate versus photino mass. We have take the ratio of normal beam intensity to SLED intensity to be a factor ~5.

F6B

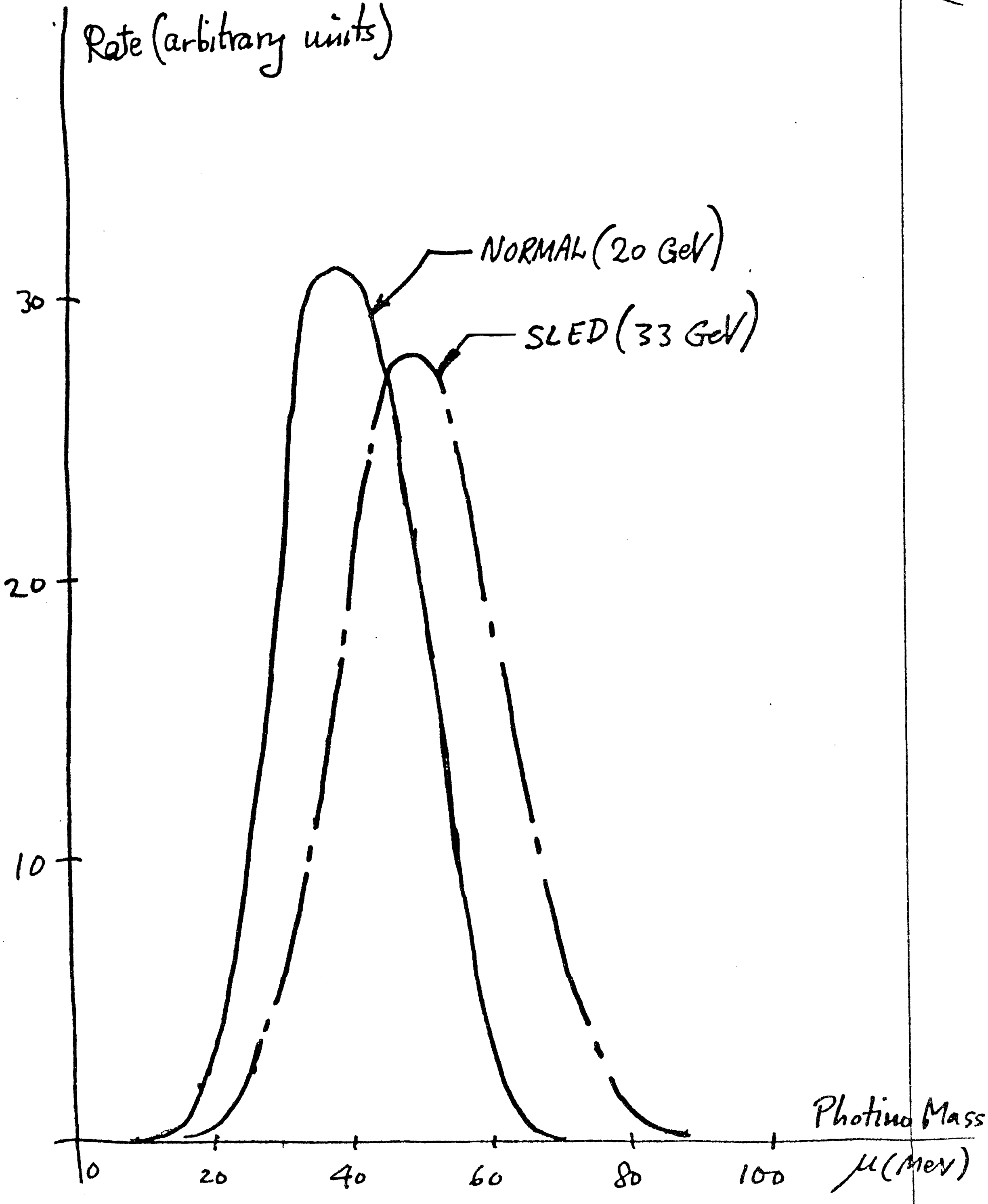

Fig. 6b Photino event-rate versus photino mass, at fixed coupling strength α and selectron mass M.

F7

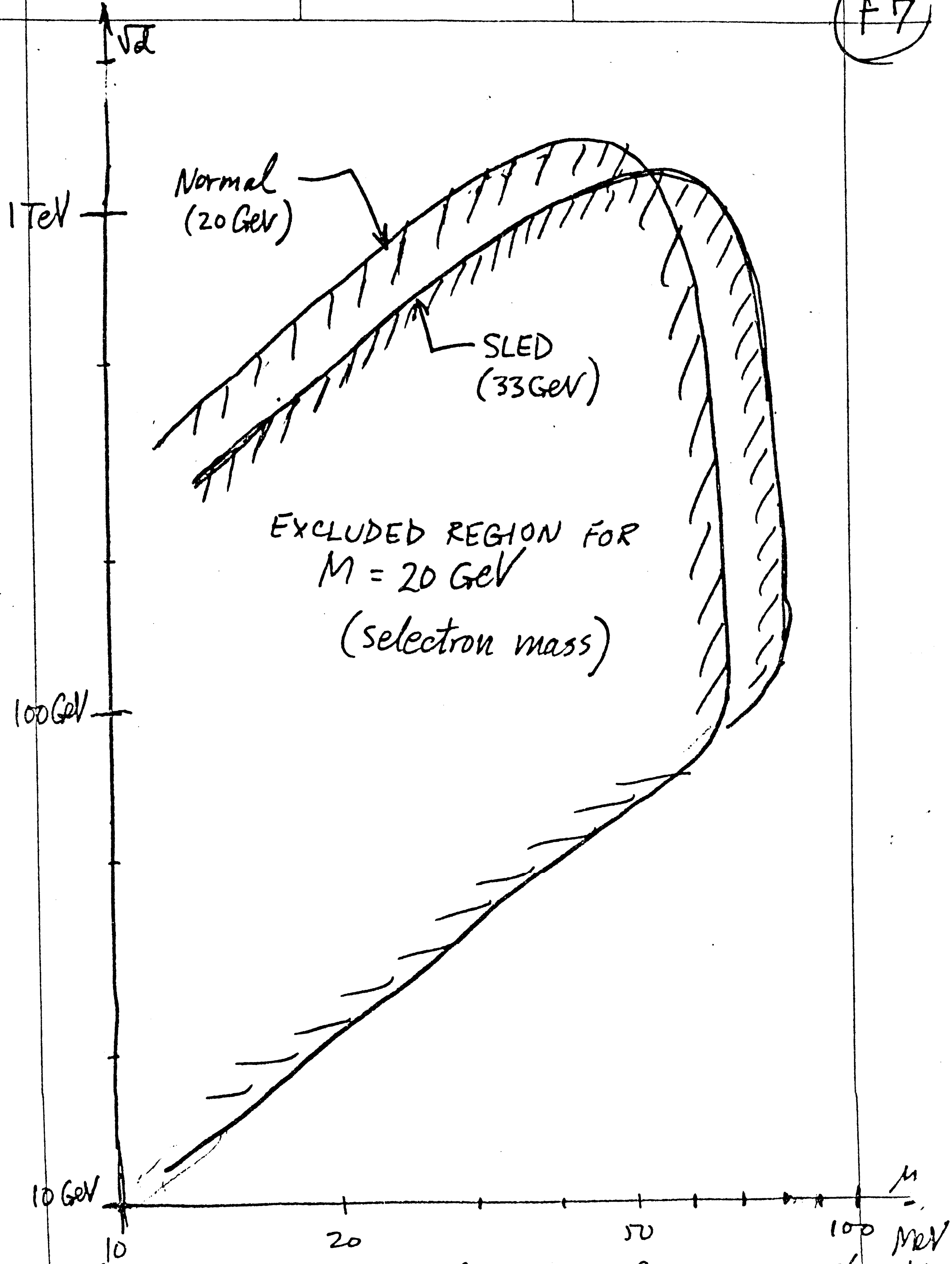

Fig 7: Excluded region of $\sqrt{\alpha}$-μ space for $M = 20$ GeV/1event/coulom

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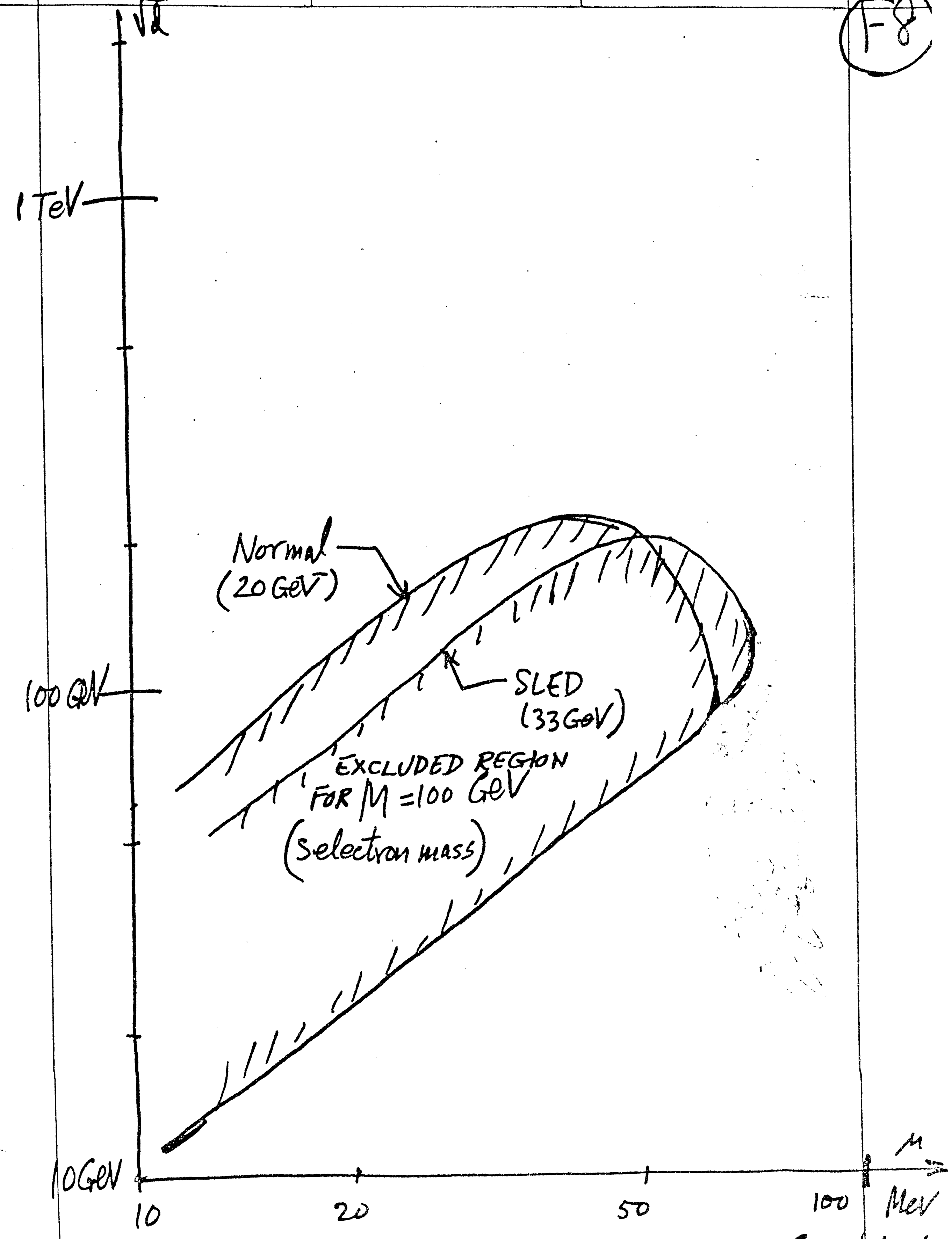

Fig. 8: Excluded region of $\sqrt{a}-\mu$ space for M = 100 GeV / 1 event/coulomb