

REMARKS ON EXPERIMENTAL UTILITY OF ELECTRON AND POSITRON ACCELERATORS

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General

With the advent of high-intensity electron accelerators such as the Stanford Linear Accelerator, secondary beams from these machines have moved into a competitive position relative to those of proton synchrotrons of similar energy. For example, beams of muons, pions, and kaons are in continual use at SLAC for experiments which might otherwise be done at proton accelerators; and, in some cases, the SLAC secondary beams, being initiated by leptons and occurring in short bursts at potentially high repetition rates, provide distinct experimental advantages. For example, the beam flux permissible through a conventional bubble chamber is limited usually to some value below the capability of the accelerator feeding it. With current typical bubble-chamber expansion times and synchrotron repetition rates and duty cycles, the chamber can be expanded only once each beam spill, in which case the data rate is determined entirely by the synchrotron repetition rate. With a fast-cycling accelerator (as most electron accelerators are) which is capable of sufficient secondary beam intensity to reach the limiting flux in one pulse, the same bubble chamber can be operated at its maximum potential data rate and without diversion of substantial amounts of beam from other experiments. On the other hand, the spill time of some proton synchrotrons is, or soon will be, sufficiently long so that two, or occasionally even three, bubble chamber expansions are possible in one pulse with only minor deterioration of quality. This will, to some extent, offset the advantage of the high repetition rate possible when the electron linear accelerator is used.

There are two bubble chambers at SLAC, and 5,100,000 bubble chamber pictures were produced there in the last year—a greater output than at any other laboratory in the world.

In using a wire spark chamber on-line with a computer, the wire chamber must be read out and the event logged after each event trigger. This process typically takes about 10 milliseconds with present equipment for a fairly large experiment. Thus events can be accepted at the

rate of about 100 per sec. For the class of experiments for which the SLAC accelerator is capable of producing average trigger rates equal to that figure and for which trigger logic is not limited by accidentals, the data rate is the maximum possible with the apparatus because the accelerator repetition rate is greater than that of the spark chamber. At a (slow-cycling) proton synchrotron, on the other hand, events occur only during the spill and the data rate is reduced by the duty factor. Pion fluxes at SLAC, while somewhat lower than those at present proton accelerators, are adequate for many pion-reaction experiments which fall in this class.

The foregoing cases are examples of the fact that many important experiments cannot utilize the full secondary-beam intensities available from present-day accelerators, electron or positron; and for these experiments, details of the accelerator's performance, the cleanliness or definition of the secondary beam or some other consideration will be overriding. For example, the time structure and other special characteristics of an electron linear accelerator makes possible several singular technical advantages which can be utilized in secondary beams. Among these are:

1. Flexibility in "chopping" the electron beam by a transverse deflector operating at a subharmonic frequency of the main accelerator. This method permits introduction of a time structure into the beam which, in its extreme form, permits filling only one RF bucket of the accelerating wave corresponding to a pulse length of the order of 10^{-11} second. This capability is of great value for making time-of-flight measurements.

2. The use of a microwave separator is much simpler in connection with a microwave linear accelerator since the beam has intrinsic microwave structure.

3. The pulsed nature of an electron linear accelerator beam permits production of a polarized monoenergetic gamma-ray beam by exploiting collisions between the fast electrons and photons in a high-power pulsed laser beam.

4. High-intensity positron beams are available.

5. The mix of neutrinos and antineutrinos is almost totally symmetrical in a neutrino beam originating from an electron machine since the primary source of such neutrinos comes from rho mesons.

There remains of course a large class of experiments in which particle flux is the primary consideration. From that point of view, the electron accelerators excel in electron and gamma-ray beams, and the proton accelerators generally excel in hadron and neutrino beams. Studies have been made recently at SLAC of the experimental potential of a two-mile superconducting linear electron accelerator on the SLAC site. In the course of these studies comparisons were made between secondary beams available from 100 GeV electrons and those available from 200 GeV protons. A brief review of these comparisons may be illuminating.

For orientation, Table 1 gives a comparison of primary intensities of various accelerators at their maximum energies

Table 1

Primary Intensity at Maximum Energy and Duty Cycle.

Accelerator	Energy (GeV)	Average Intensity (Part/sec)	Average Beam Power (kW)	Maximum Duty Cycle	Repetition Rate (sec ⁻¹)
AGS (Improved)	33	5×10^{12}	25	0,5	0,5
NAL	200	$1,5 \times 10^{13}$	500	0,25	0,25
SLAC	21	$1,5 \times 10^{14}$	500	6×10^{-4}	360
Superconducting SLAC	100	2×10^{13}	300	6×10^{-2}	0,25-0,06

Generally speaking, neither electron nor proton accelerators can compete in the production of the primary particles of the other. Thus, we shall compare only secondary hadron beams and muon beams. (Neutrinos, coming from meson decays, follow meson intensities.)

Charged Hadron Beams

Table 2 gives a comparison of hadron fluxes from a 100 GeV superconducting accelerator and the NAL accelerator. The solid angle of acceptance of the secondary beam is taken to be 10^{-5} steradian and the momentum acceptance 1 GeV/c. The NAL accelerator yields are taken from curves on the Hagedorn-Ranf estimates, while those for the superconducting electron accelerator are based on the Dufner-Tsai predictions. The momentum range over which the figures apply is from 20% to 70% of the primary energy.

Table 2

Charged Secondary Hadron Yields.
Assumes Proton target efficiency of 1/3, $\Omega=10^{-5}$; $\Delta p=1$ GeV/c

Particle	Yield from 100 GeV Superconducting SLAC (part/sec)	Yield from NAL (part/sec)
π^{\pm}	10^8	5×10^8
k^{\pm}	4×10^4	5×10^7
\bar{p}	5×10^3	5×10^6

Neutral Hadron Beams

In the production of neutral secondary hadron beams, the electron accelerator enjoys the advantage that the neutron contamination is **much less** than at the proton accelerator. Thus, although the predicted fluxes

of K_L^0 's and \bar{n} 's are lower by about 1000 at the superconducting linac the beams are much purer. Contamination ratios are as follows: K^0/n (SLAC) ~ 1 ; \bar{n}/n (SLAC) $\sim 0, 2$; K^0/n (NAL) $\sim 0,1$ \bar{n}/n (NAL) $\sim 0,01$.

Muon beams

Muons are produced from electrons predominantly by electromagnetic pair production and, with optimum targeting, very high-quality muon beams result. Moreover, much less background accompanies the muon beam than at a proton accelerator. It is estimated that a 75 GeV muon beam with $\Delta p/p = 10^0/0$ and a phase-space volume of $0,7 \times 10^{-6} \text{ cm}^2$ steradian can be produced at the superconducting accelerator with a rate of 2×10^6 muons/sec. The flux at NAL is expected to be about 2×10^8 muons/sec with same momentum bite but a phase-space volume of 10^{-3} cm^2 steradian and a much more severe shielding problem.

ДИСКУССИЯ

Орлов — Из спектров образования π^- — мезонов на электронных и протонных ускорителях видно, что при больших импульсах спектр пионов, образованных протонами, падает более резко, чем спектр пионов, образованных электронами. В связи с этим можно ожидать, что при еще больших энергиях разница в „выходах“ может еще уменьшиться.

Rees — The difference between the absolute yields is very significant and the difference between the slopes of the spectra is very small. So I cannot agree with Orlov.

Исприян — С экспериментальной точки зрения важно также угловое распределение частиц, образованных при e и p столкновениях. Сравнились ли угловые распределения вторичных частиц?

Rees — The difference between the angular distribution of the secondary particles is not so large.

Орлов — У меня три замечания: 1) необходимо сравнивать выходы от кольцевых электронных ускорителей с соответствующими данными от протонных ускорителей, 2) не надо забывать, что сечения слабых взаимодействий растут с энергией.

Так например, при энергии $100 \text{ ГэВ} \times 100 \text{ ГэВ}$ сечения процессов $e-e^+ \begin{matrix} \nearrow \mu^-\mu^+ \\ \searrow e^-e^+ \end{matrix}$ становятся порядка 10^{-36} см^2 (если нет нейтральных токов). Эти обстоятельства говорят в пользу электронных ускорителей. 3) γ — пучки, получаемые на протонных ускорителях, не могут быть использованы для измерения процессов с малыми сечениями.

Rees — I agree with Orlov that at the same energy the γ -beams from electron accelerators are better than the ones obtained from proton accelerators. But the detection of the weak processes with such small cross-sections will be very difficult.

Орлов — Приведенные мной величины поперечных сечений оценены с большой осторожностью и запасом. Кроме того, для ускорителя, о проекте которого я докладываю на конференции, e^-e^+ столкновения можно осуществлять в режиме ускорения (а не при максимальной энергии), когда еще нет времени для роста нестабильностей.

Wideroe — Will the synchrotron radiation of the electron accelerators at high energies be used?

Орлов — В нашем докладе на конференции приведены оценки по исследова-

нию фундаментальной реакции $\gamma\gamma \rightarrow \gamma\gamma$ с использованием синхротронного излучения встречных пучков.

Wideroe — I should like to know whether there is any synchrotron which is used only for its synchrotron radiation.

Rees — I think the Wisconsin synchrotron is such a machine.

Lofgren — Out of this discussion it seems that the difference between points of view on the comparative experimental abilities of the future electron and proton accelerators shows that the problem is not clear. So I think that it is necessary to have accelerators of both types.