THE INSTITUTE OF PHYSICS AND THE PHYSICAL SOCIETY

AMALGAMATED 1960

South Western Branch

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Dr. J.M. Valentine,
Rutherford High Energy Laboratory,
Chilton,
Didcot,
Berks.

3rd. October, 1963.

Dear Dr. Valentine,

I thank you for your letter dated 30/9/63, and for your suggested title "Organisation and Machines for High Energy Physics" which will suit admirably.

I look forward to contacting you again about final details shortly before the lecture date.

Yours sincerely,

W.E. Laker.

W.E. LAKER.

Accelerators and Organizations for High Energy Physics

The accelerator story really starts in 1928 when Gamow and also Condon and Gurney showed how wave mechanics could be used to describe the penetration of nuclear potential barriers by charged particles and made it seem ~~possible that~~ probable that energies of 400 keV would be sufficient to cause disintegration of light nuclei. This seemed a much more possible goal with the technology of the time than the artificial production of 5 to 8 MeV α-particles similar to those from naturally radio-active materials which had been used by Rutherford. Once this fact was known the accelerator race was on; as everyone knows the first heat was won by Cockcroft and Walton when they reported the disintegration of lithium by 400 keV protons in 1932. But in a sense the accelerator race has been going on ever since.

The Cockcroft-Walton generator was based on a simple voltage multiplier principle. The major invention in the accelerator field came shortly afterwards, also in 1932, with the invention by Lawrence of the cyclotron. Since then the really big accelerators of their day have been circular machines of one sort or another. Some idea of the rate of progress can be obtained by plotting the diameter of the accelerator ~~against~~ (on a log scale) against the year at which it first operated. I believe that this idea was first put forward by Fermi in an after dinner speech he made at an accelerator conference shortly after the war ~~#~~ so it should not be taken too seriously. Using only data from the most advanced accelerators of their time ~~which~~ we get the ~~four~~ five points shown on the first slide (These are presumably the ones which Fermi used). Making a wild extrapolation on a straight line basis one gets an accelerator with the same diameter as the earth ~~shortly~~ (a natural limit for terrestial machines!) shortly after the end of this century. I believe that Fermi also extrapolated costs and man power figures and showed that such an accelerator would cost the same as the gross national product of the United States and would take the whole male population of the US to build it. This is quite a good joke which gets better if one plots the points which relate to the leading accelerators which have been built since 1946. These are shown on the second slide. They are still on the same straight line and so is the new machine proposed for 1972.

Obscured text reads:

... against the year at which it first operated. I believe that this idea was first put forward by Fermi in an after-dinner speech he made ...

A plot of the energy of the accelerators shows a similar story. The __third slide__ is a simple ~~plot~~ graph with most of the well known accelerators named on it. The energy increases by a factor of 10 every 5 or 6 years from 1932. ~~The~~ The __fourth slide__ is a more subtle variation of the same graph. It shows how the different varieties of machine have contributed to the energy rise. At this stage I should say a few words about the different types of proton accelerator.

(1) __Cyclotron__

~~Constant~~ Magnetic resonance accelerator. Constant magnetic field, fixed frequency. Limited by relativistic mass increase, practical energy limit ~ 25 MeV for protons

$$\frac{mv^2}{r} = evB$$ pole face diameter of ~ 60 ins.

$$f = \frac{v}{2\pi r} = \frac{eB}{2\pi m}$$ fixed if m is constant

(2) __Synchrocyclotron__ (frequency modulated cyclotron)

The maximum energy limitation can be removed and the ions can be accelerated indefinitely if the applied frequency is varied to match exactly the ion revolution frequency. Frequency is varied cyclically so that a short bunch of ions accelerated to high energy each frequency sweep. ∴ Pulsed machine ~1% output of cyclotron. First machine of this sort was Berkely 184 inch synchrocyclotron in 1946. A list of others is shown in fifth slide (Livingston & Blewitt p 354 table 11.1). Note weight of magnet.

(3) Proton synchrotron.

With a synchrocyclotron a solid core magnet is required. At relativistic energies magnet weights and costs increase roughly with the cube of pole-face diameter. For GeV range the magnet is impractically large. ∴ Use a ring magnet covering only a narrow annular band and synchrotron principle of acceleration at constant radius.
A fixed orbit radius is chosen and a ring-shaped magnet produces a magnetic field normal to the doughnut-shaped vacuum chamber enclosing the orbit. The magnetic field increases with time as the protons gain energy to maintain constant orbit radius. Ions are injected into the orbit at low energy when magnetic field is small and energy is supplied by

an accelerating electric field applied across a gap at one ~~or~~ more points in the orbit. The applied electric field must synchronize with the changing orbital frequency of the particle requiring frequency modulation over a wide range during acceleration.

First p-s. proposal by Oliphant. First p-s. started was Birmingham machine. First p-s working was Brookhaven cosmotron in May 1952. Max energy was 3.0 GeV ~~&~~ beam intensity of 2×10^{10} protons / pulse. (1954)

List of p-s of "cosmotron" type is shown on sixth slide (Livingston e Blewitt p 445 table 13.1)

(4) Proton synchrotron — strong focussing

Alternating gradient (AG) or strong focussing — ~~1952~~ 1952
In the AG system the passes alternately through strong focussing and defocussing lenses. Net focussing force.

Reduction in radial spread of equilibrium orbits.
∴ Transverse dimensions of magnetic region between polefaces can be made much smaller ∴ Smaller magnets, smaller vacuum vessels.

1959 Cern – 28 GeV ~ 3×10^{11} protons / pulse
1960 Brookhaven – 33 GeV

Early accelerators were of course built in university departments. As the machines became bigger the amount of money involved required government support on a large scale. Since the war all accelerators have been built with government money. The amount of money involved is not the only problem, however, there are others,

(i) The organization to spend the money including the build up of the necessary technical and administrative supporting staff. A large industrial effort is required and that is not always compatible with the sort of organization that exists in most British Universities. (Different in the U.S.) Example of Birmingham with 1 GeV p-s. First started but ~~always~~ very slow. Lack of manpower?

(2) When machine is finished a huge effort is still required to mount experiments (£ 0.25 M for the b.c.). At the same time a very large experimental facility is available — probably too large for an individual university.

Some sort of co-operative venture is required.
Two examples — national NIRNS
— international CERN.

NIRNS

The NIRNS was founded in 1957 and received its Royal Charter in 1958. The Charter is worded rather broadly — deliberately so, so as not to be restricting in the future — but the main reason for its existence is to enable universities to use expensive research facilities which can only be provided centrally.

The first laboratory of the NIRNS was the RHEL. It has two main research programmes, based on two accelerators: a 50 MeV proton linear accelerator which has been in use since 1960 and a 7 GeV proton synchrotron (Nimrod) completed in the autumn of 1963. Also Atlas computer laboratory as part of RHEL. Just started DNPL with 4 GeV electron synchrotron as the second main laboratory of the NIRNS.

Slides of RHEL & Nimrod.

(7a)

Nimrod — vital statistics

Choice of machine — see TGP's paper

Organization (at present!)

The Institute having a Royal Charter is an independent entity ; coming under the Minister for Science. The Governing body of the Institute, chairman Lord Bridges, has part time honorary members representing the universities, UGC, RS, AEA DSIR. Being part-time it is policy forming and not executive. Executive action is delegated to the permanent officers ~~under~~ two Directors RHEL and DNPL and their staffs.

Money comes from Treasury as part of the AEA vote ∴ Money side is supervised by AEA. and subject to Treasury rules. — annual accounting, capital ; non-capital distinction etc.

RHEL

Just passing from building to using phase.

Support of university work.

(i) provision of facilities — accelerators etc.

(ii) provision of money through university agreements. EMR or experimental.

Universities pay for ~~the~~ (most of) their own staff and support them in the university departments.

Experiments for Nimrod are ~~based~~ selected on the basis of their value as physics expts. Four experiments have been chosen for the first half of 1964 and the installation of targets and beam lines.

~~(i) p-p scattering. (AERE & QM Coll. London)~~
~~(ii) polarization in scattering of $\pi^{\pm}$ mesons by protons (RL)~~
~~(iii) charge exchange scattering of neutrons by protons (AERE, Birmingham, Bristol)~~

Universities of Oxford, Cambridge, Birmingham, Bristol Southampton Manchester, 4 colleges of London AERE and RL.

The use of the machine is going to be limited by finance. On a limited budget Nimrod can not be fully exploited. eg. electricity bill ~ £350 K / year ~~for~~ if limitations are put on daytime working during winter — full out ~ £600 K / year. Difficulty of too many customers all of whom have a theoretically equal right. Select on basis of physics — but rejects come back with better experiments etc.

Present 1964/65.

No. of university physicists supported ~ 170.
by programme

Total number of nuclear + HEP physicists ~ 210.

Other research workers ~ 70

(Nimrod + PLA could support about 300
nuclear and HEP. — Robbins?)

~~Should~~

"Scientific inflation" ~ 4% per annum.

This means ~ £2M ~~p/year~~ on RL budget to support same number of research workers in 1969/70 than now.

Present recurrent cost per visiting scientist ~ £6000/year

Gross annual cost per research worker ~ £ 20,000.

Cern

Founded. 1952.
General information from sheet.
Member states pay defined fractions of budget.
Britain 24·6%. (largest)
Part time council
Director - General. — Weisskopf.

600 MeV synchro-cyclotron.
25 - 30 GeV proton synchrotron.

University scientists work at Cern financed by DSIR.

Proposed new accelerator for Europe.

300 GeV p-s. strong focussing. 10^{13} proton / second circulating
2·4 km diameter site area 20 sq. kilometres.
To be built by 1972?