The Nimrod Era

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3 July 2002

- Nimrod – the machine and facilities
- Particle physics through the Nimrod era
- The Birmingham-Rutherford group
- The Legacy of Nimrod

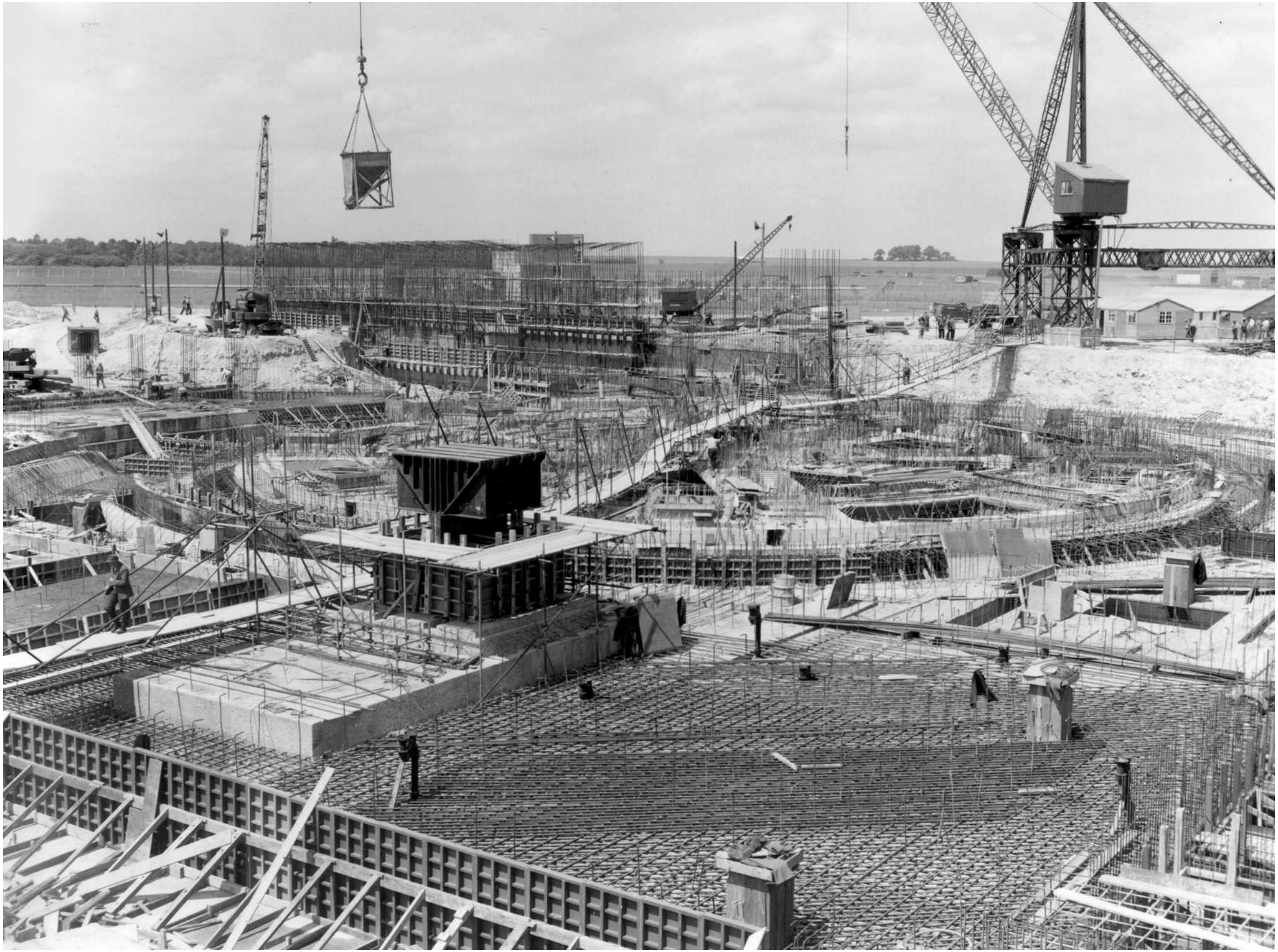
Nimrod
The machine and facilities

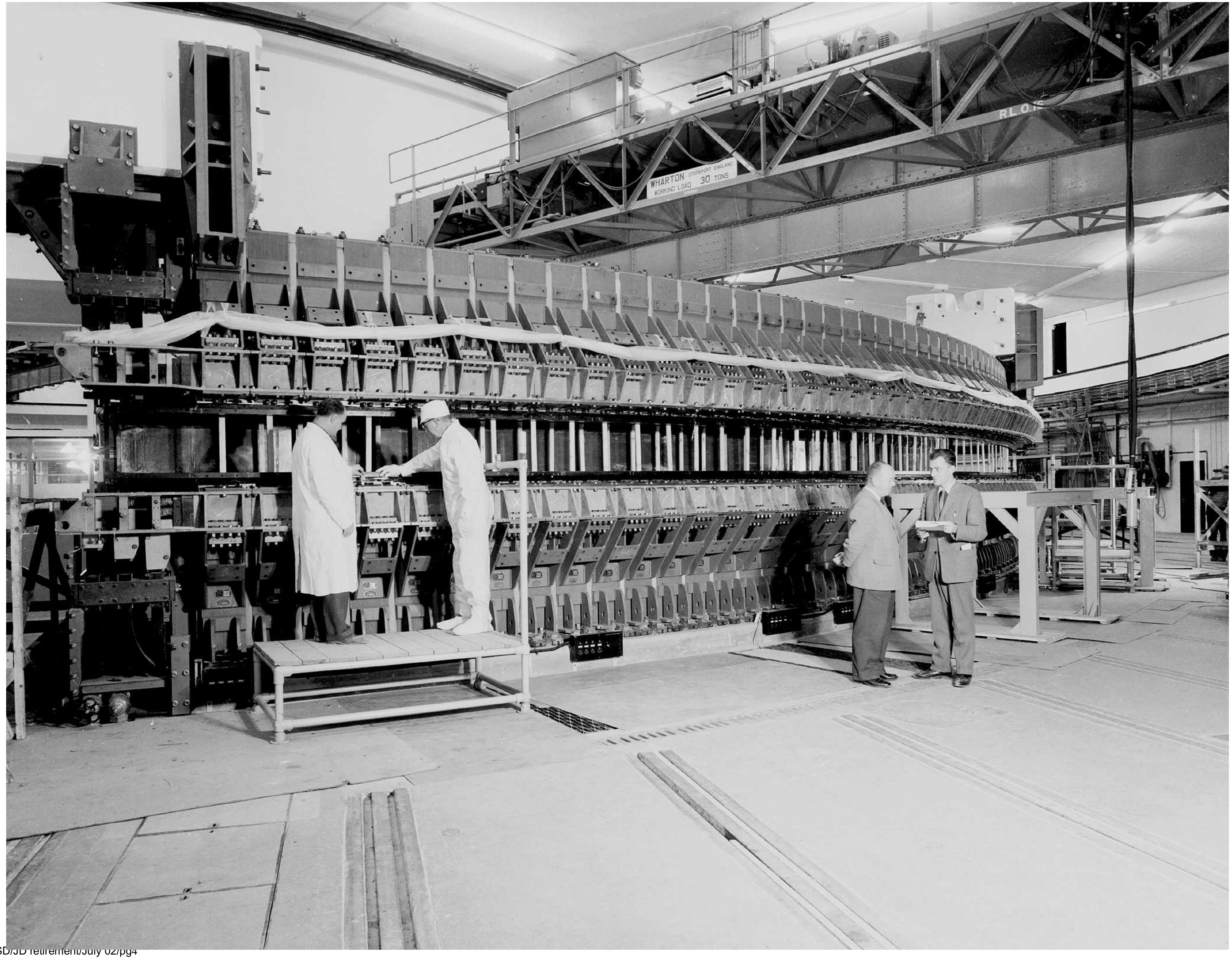
- Predecessors:

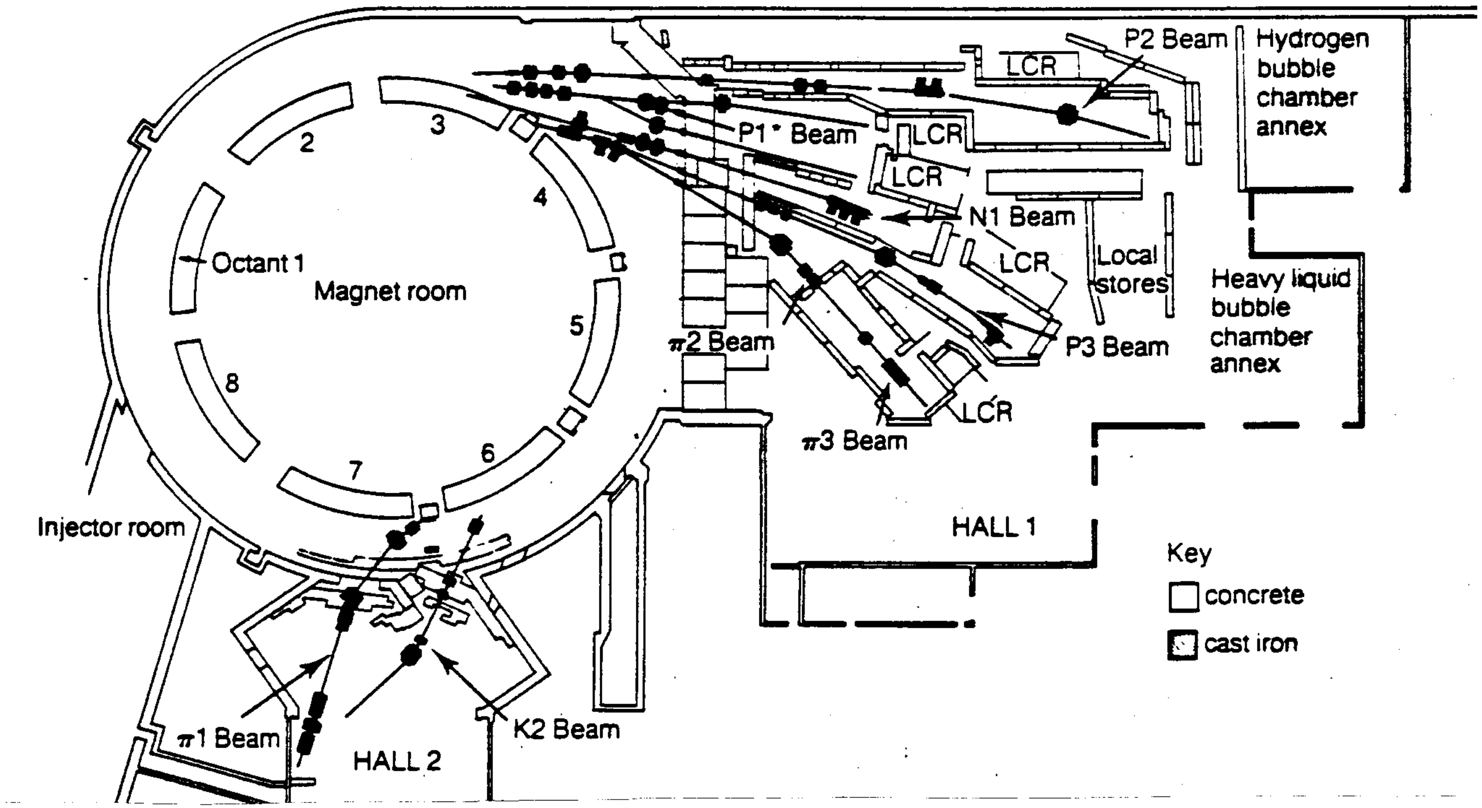
  1 GeV proton synchrotron (Birmingham University) 1953
  400 MeV proton synchrotron (Liverpool University) 1954
  450 MeV electron synchrotron (Glasgow University) 1954

  3 GeV Cosmotron (BNL) (1954)
  6.3 GeV Bevatron (LBL) (1954)
  25-30 GeV CERN PS (1959)
  25-30 GeV AGS (BNL) (1960)

- March 1957 UK Government set up the National Institute for Research in Nuclear Sciences
- The initiative to build Nimrod was resisted by many in the universities, but their suspicions were gradually overcome
- The machine: 7 GeV, 10^{12} protons per pulse, 0.5 Hz pulse rate
- Construction period 1957-27 August 1963, just ahead of the ZGS at Argonne
- These were the last of the weak focusing proton synchrotrons




WHARTON STOCKPORT ENGLAND
WORKING LOAD 30 TONS



Throughout its life, physics programme was directed mainly to studying *baryon resonances*

- Nimrod beamlines in 1964
- First generation experiments measured $\pi^{\pm}p$, $K^{\pm}p$ and pp total cross-sections, differential cross-sections and polarisation
- Also $K^{\pm}d$ total cross-section, $\pi^{-}p \rightarrow \pi^{0}n$ and ηn and $np \rightarrow pn$ charge exchange processes

Gerry Pickavance and Godfrey Stafford shutting Nimrod down

6 July 1978

- Nimrod was operational 1964-1978
- In those 14 years, the facilities were used by several hundred physicists and graduate students (125 PhD theses)
- Users came from about 20 UK universities and a dozen overseas institutions
- A generation of physicists received their training at Nimrod, and can now be found at major HEP laboratories around the world
- The physics was important, and the community built up was at least as important
- None of this would have happened without the hard work, warmth and dedication of the entire staff of the Rutherford Laboratory, following the example set by Gerry Pickavance and Godfrey Stafford.

Particle Physics through the Nimrod Era

1964

Strong Interactions

~ 100 particles

hadron dynamics?

particles made of all other particles

~~Field Theory~~

QED

Lamb shift calculated to 1 part in 10^7

Quantum Field Theory
Feyman diagrams

Weak Interactions

4 leptons

weak interaction dynamics?

"V-A theory"
(limited to low energy)

1978

The Standard Model

6 quarks* gluon	6 leptons γ, W, Z
QCD	Electroweak Theory

Quantum Field Theory – Feynman Diagrams

[Experimental discovery of *W*, *Z* and top quark came later]

Quarks: real or fictitious?

- View from one of the foot-soldiers (grad student then post-doc) caught up in a 'paradigm shift' in scientific thinking.

- For the strong interactions, the overriding issues was what (if any) substructure lay within the 100-odd mesons and baryons.

- 1961: *'These notes are intended for students who wish to participate actively in particle physics research: a knowledge of the basic principles of quantum mechanics and special relativity is taken for granted. It is however unnecessary to be conversant with the subtleties of field theory, and a certain innocence in this respect is perhaps even desirable. Experts in field theory seem to find current trends in S-matrix research more baffling than do nonexperts.'*

(Chew, 'S-matrix Theory of Strong Interactions')

- 1963: *'Each particle helps to generate other particles, which in turn generate it. In this circualr and violently nonlinear situation, no free parameters appear and the only self-consistent set of particles is the one we find in Nature.'*

(Chew)

- 1963: *Building the 200 BeV machine (and by inference Nimrod or any other accelerator) would be a waste of taxpayers' money. The bootstrap theory is on the verge of calculating everything.*

(Chew, lecture at Oxford U)

[Despite this Corbett and I continued to glue together our spark chambers ...]

- 1963: George Zweig's paper on 'aces' was repeatedly rejected by referees, and languished unpublished till reprinted in a historical collection almost two decades later.

- 1964: *'Hadrons are all mutual composites of each other that haul themselves into existence by their bootstraps.'*

(Chew)

- *'When first proposed in 1964, quarks were ridiculed by all but a few eccentrics who went searching for them. After these efforts failed to unearth anything unusual, most physicists thought the matter settled for good.'*

(Riordan, 1987)

- 1964: Greenberg's suggestion of 'paraquarks' (later called colour) to satisfy the spin-statistics theorem *'reeked of artifice'*; the possible existence of quarks was in serious doubt by early 1965.

- 1965 *'If the present ideas are valid, the quarks should exist; they should not be only mathematical entities.'*

(Morpurgo)

- 1966 *'We must face the likelihood that quarks are not real.'*

(Gell-Mann)

- 1966 *'The idea that mesons and baryons are made primarily of quarks is difficult to believe, since we know that they are mostly, if not entirely, made up out of one another.'*

(Gell-Mann, 'State of Particle Physics' overview at Rochester Conf Berkeley)

- 1966 (Riordan, referring to the Rochester Conf Berkeley) Dalitz, supposed to talk about abstract symmetries, presented a detailed discussion of his nonrelativistic quark model. Gell-Mann left abruptly during the first part of his talk. By the end, the audience was reduced to one third.

- 1966 Gasciorowicz published 'Elementary Particle Physics' (600 pages) which became a widely used text. It contained only a single paragraph on quarks, which ended *'... we will not discuss the quark model further.'*

- 1967-1972 *eN* inelastic scattering at SLAC and *νN* inelastic scattering at CERN (Gargamelle) yielded data of generally increasing precision (but there were some glitches). Initially consistent with the bootstrap model (Chew, Gell-Mann), vector dominance (Sakurai) and quark-partons (Feynman, Bjorken) by the time of the Rochester Conference at FNAL in 1972,

'The data provide an astonishing verification of the Gell-Mann-Zweig quark model of hadrons.' (Perkins)

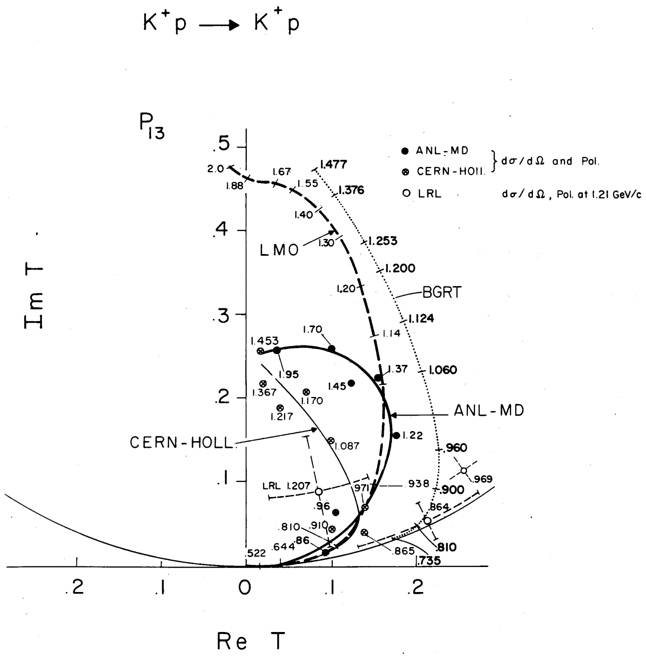
- The S-matrix theory and nuclear democracy were dead and rapidly buried.

Throughout this period, experiments on meson and baryon resonances (again, apart from some glitches) built up evidence in favour of the quark model, rather than the more general predictions of the 'Eightfold Way'. In this, experiments at Nimrod played an important role.

Resonance Physics

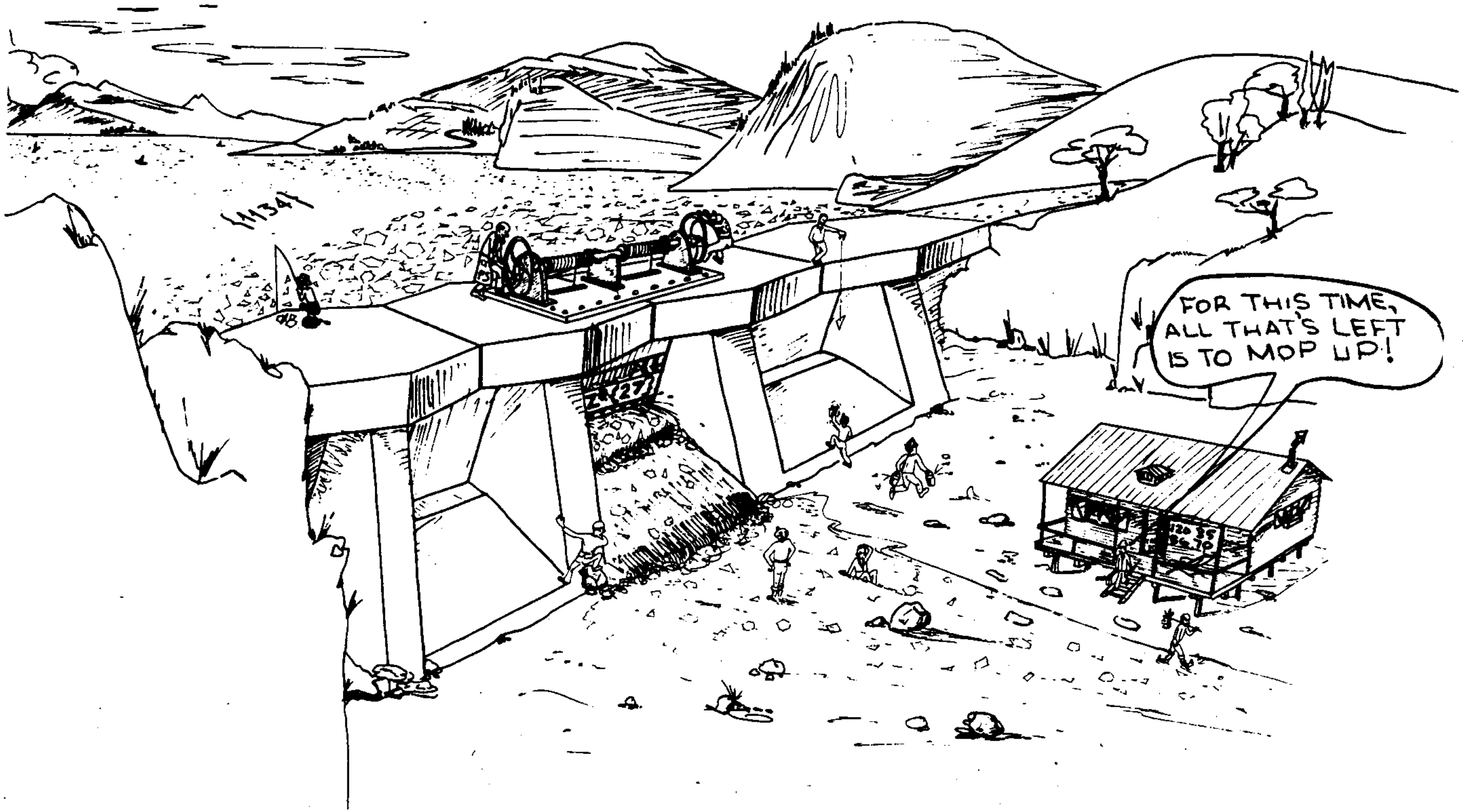
- Most Nimrod experiments provided input to the partial wave analyses which slowly established the full picture of non-strange and strange baryon resonances to be in conformity with the expectations of the quark model.

- As one small example, evidence for exotic Z^{*}s (pentaquark states) from BNL σ_{tot} measurements (1966) was shown by Birmingham/RAL and other experiments to reflect the opening of nonresonant inelastic scattering amplitudes.



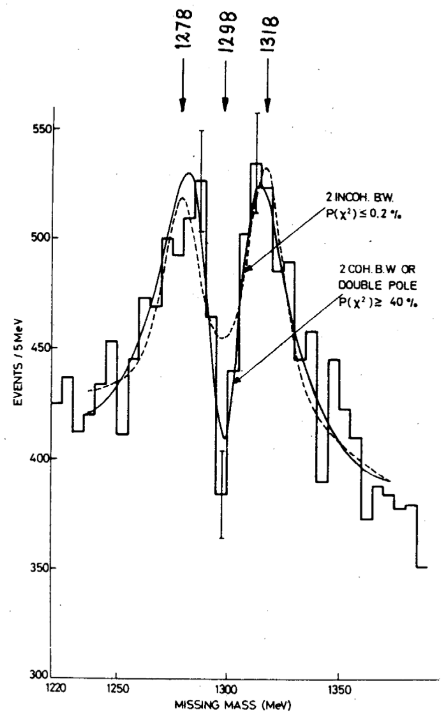
Levi Setti: Lund Conference 1969

Strange baryon resonances

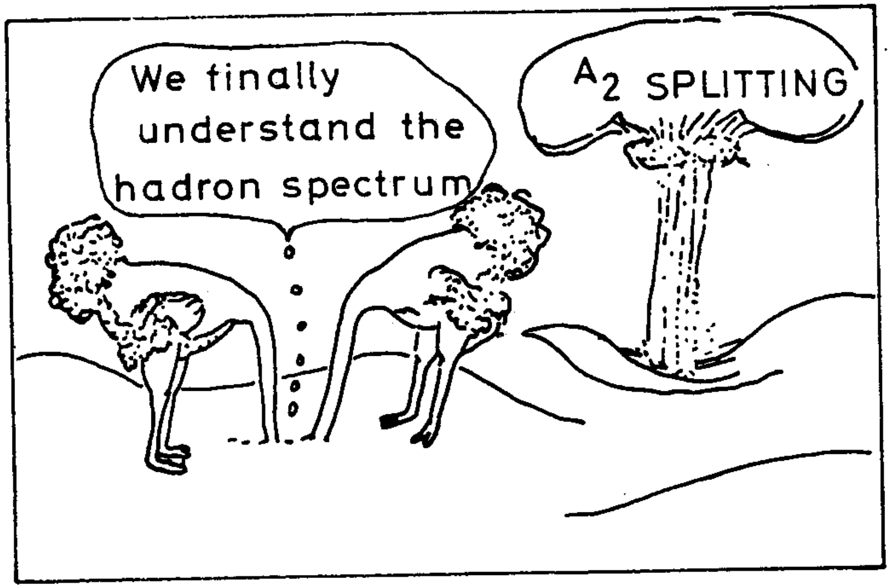


§ ‘A2 splitting’

Evidence by the Magli$\breve{c}$ group that a_2(1320) mass had anomalous fine structure



FITS TO THE TOTAL(MMS+CBS)A2 DATA



- Followed by at least a dozen confirmations from low statistics experiments, which also started to see splitting of other well established resonances…

- Rochester Conference, London 1-10 July 1974

- B Richter skipped the resonance physics sessions, but the rising value of $R = \sigma_{tot} / \sigma_{\mu\mu}$ in $e^+e^- \to$ hadrons was a major mystery.

- In a 12-page paper on the '*R*-crisis', J Ellis devoted two sentences to the possibility of a fourth quark. Theoretical estimates of *R* ranged from 0.36 to 70,383.

- Over the following year or two, the J/ψ, ψ', ψ'' and χ_c states provided a wealth of data on resonance physics, which were analysed with finesse by experts on this subject within the Mark I collaboration (G Goldhaber et al).

- Charmonium became the equivalent of positronium for QCD, the newly conceived field theory of quarks and gluons. Asymptotic freedom was the unexpected key to all this.

- With the discovery of the tau lepton (1976) and the upsilon (1977), the major structure of the Standard Model was revealed (with three building blocks still to be found).

- Feynman diagrams were now all-pervasive. In his own words,

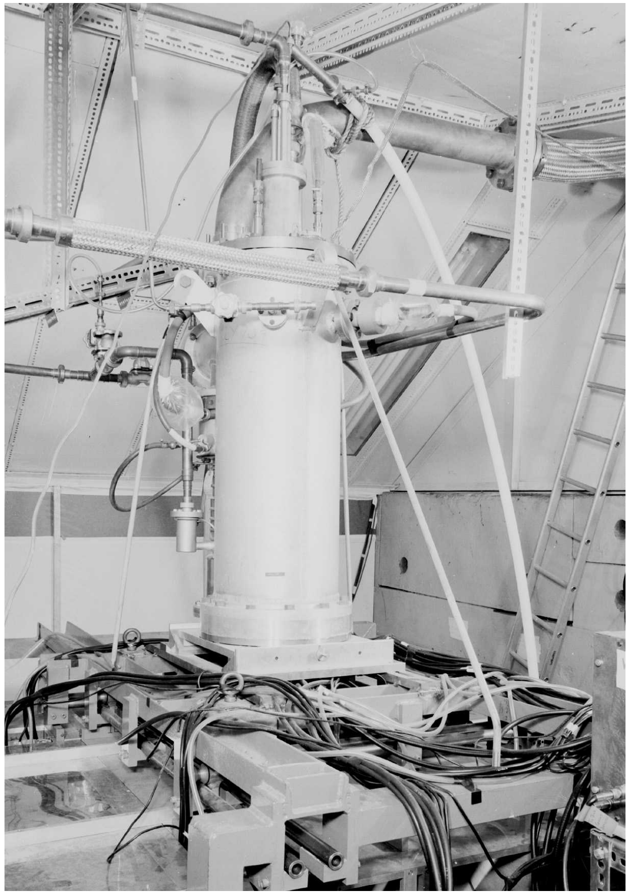
"I was delighted when something esoteric could be made to look so simple."

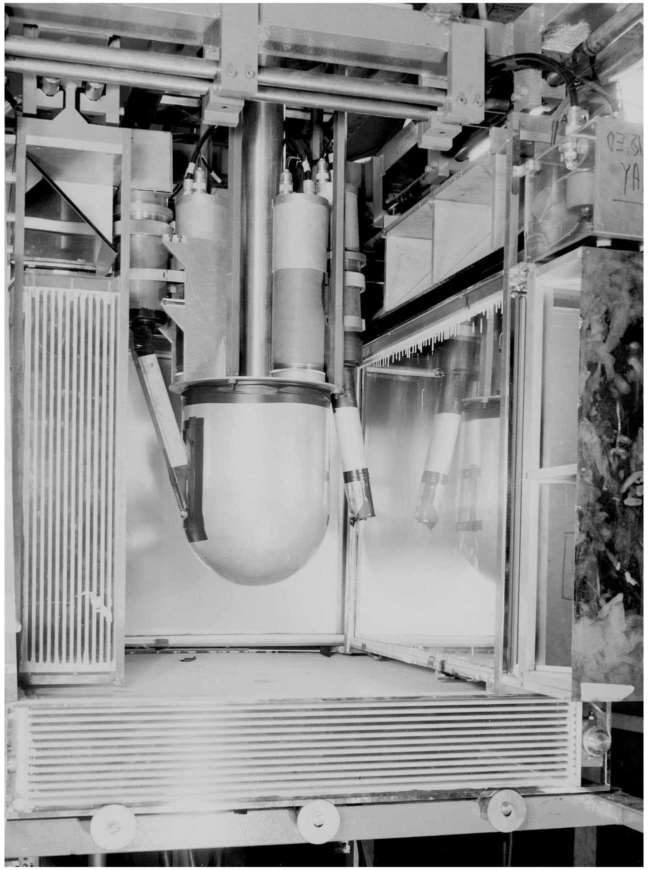
———————————————————

The Birmingham-Rutherford Group

- Preceded by Birmingham-Cambridge-Rutherford total cross-sections
  $\pi^{\pm}p$, $\pi^{\pm}d$, $K^{\pm}p$ and $K^{\pm}d$ 600-2700 MeV/*c*. Extremely accurate!

- First experiments were often hybrid: part university and part Rutherford engineering





- 1967-1971 Birmingham-RAL group measured differential cross-sections for K^+p and K^+n elastic scattering

  Rapid escalation in technology, notably spark chambers:
  optical $\rightarrow$ acoustic, magnetostrictive and capacitive readout
  small $\rightarrow$ large and extra large (possible only at Rutherford Lab)

- 'Harwell Electronics' replaced by 'tunnel logic' in late '60s

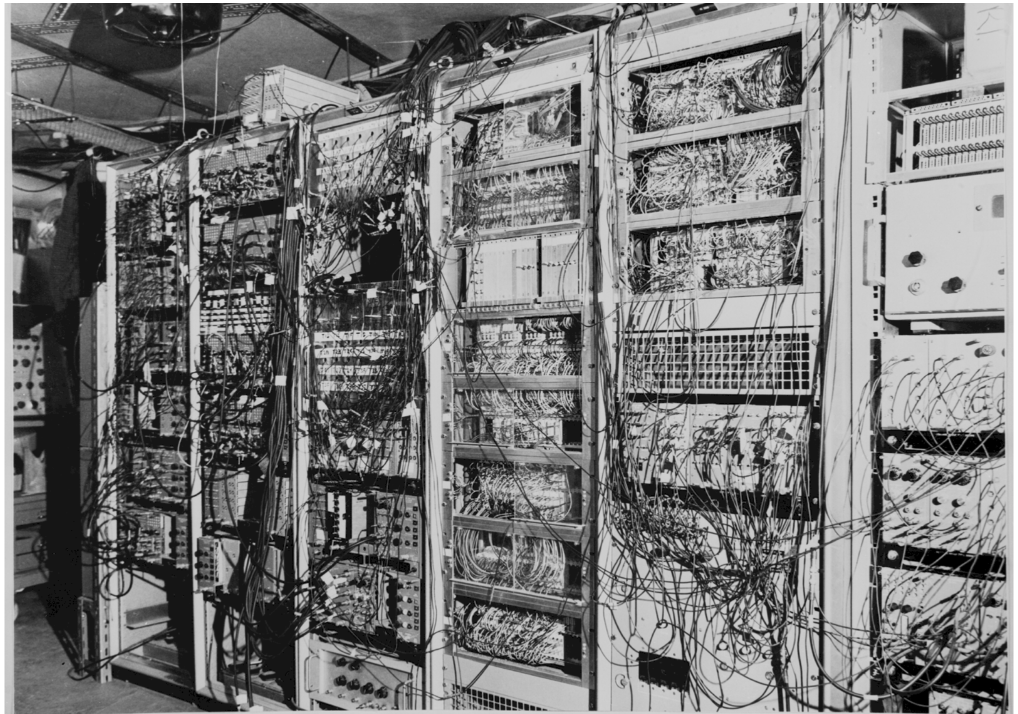
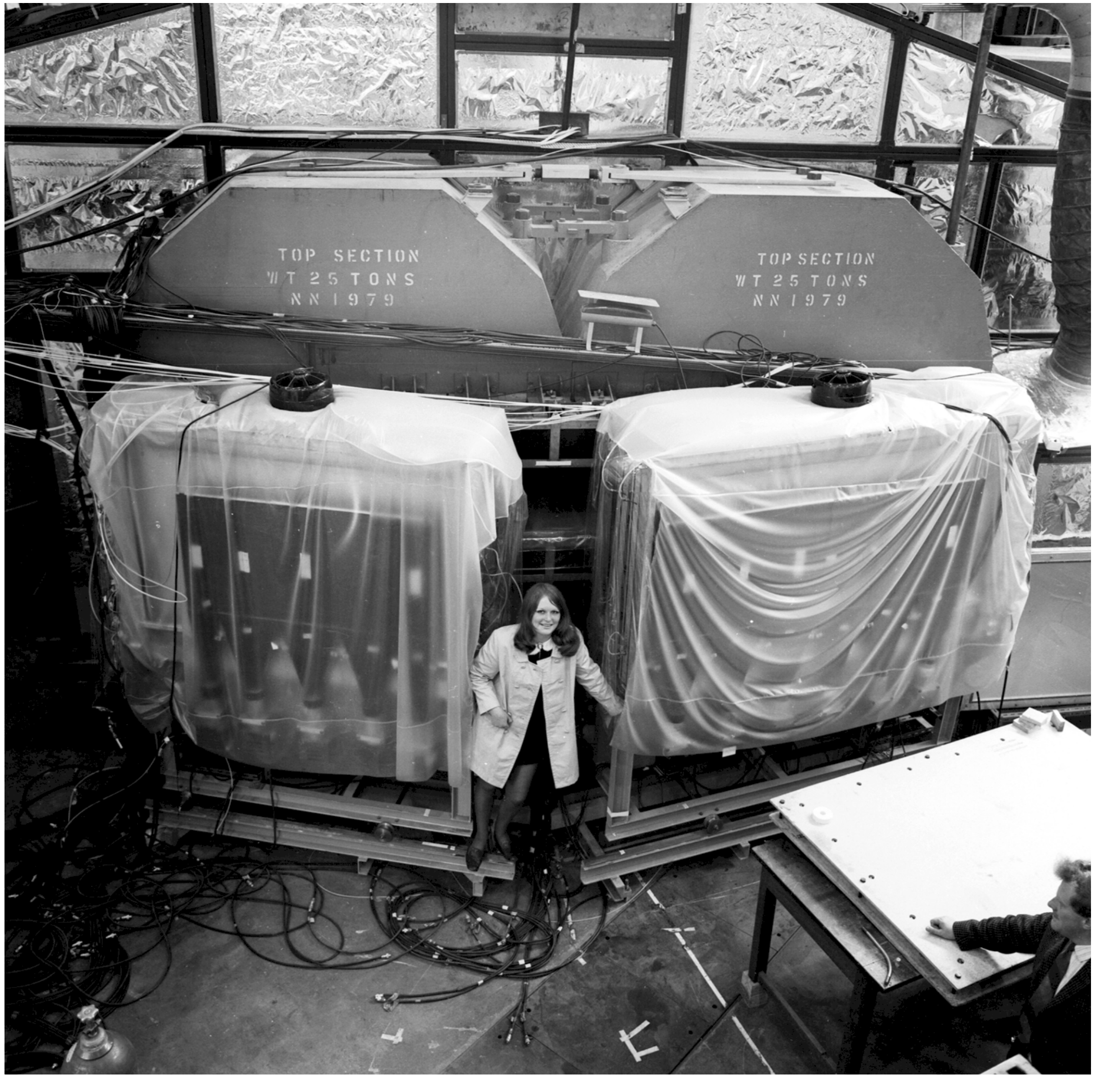
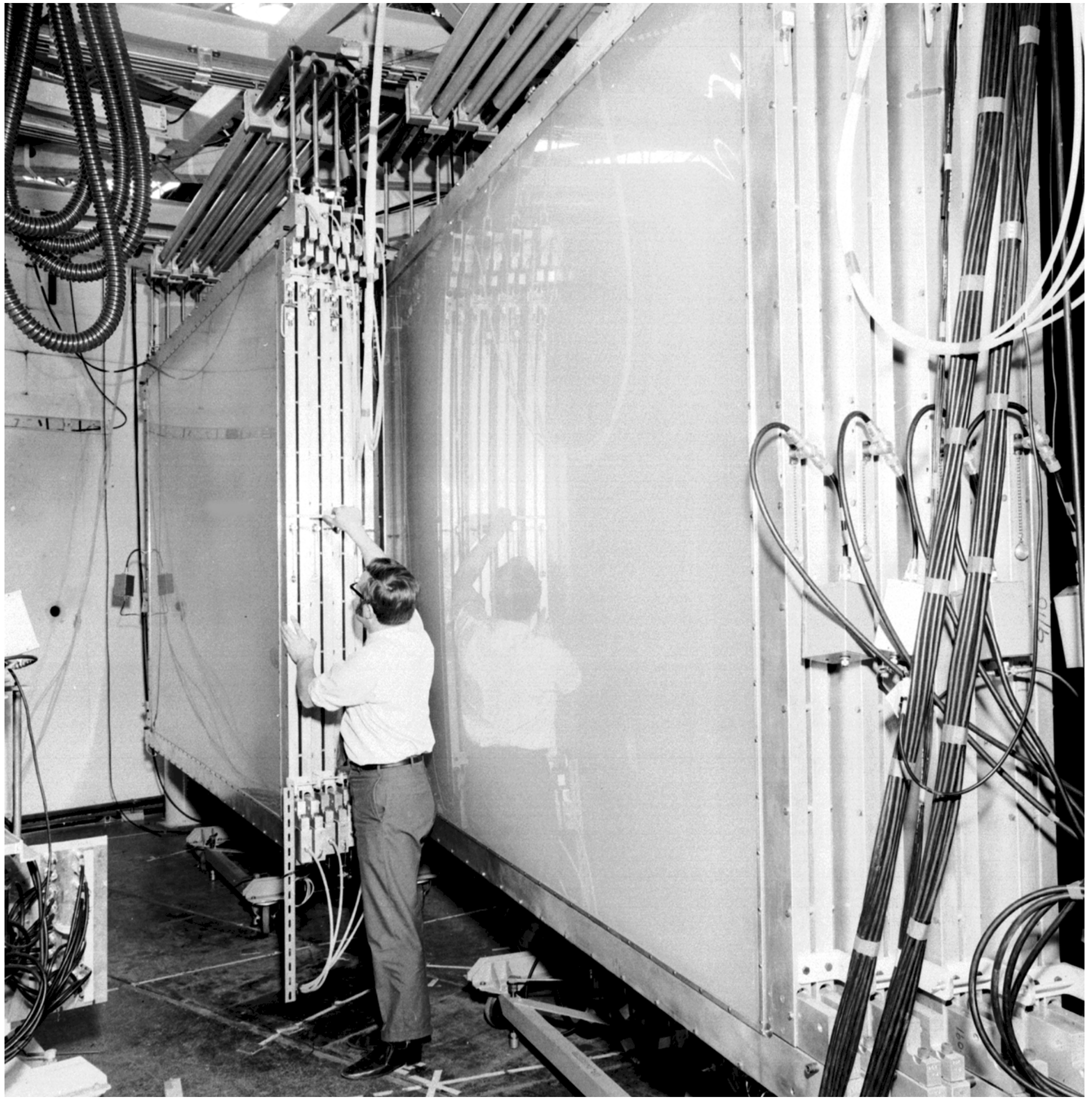


Plate 3. K 12 COUNTER ELECTRONICS

- Dowell immediately guessed why we lacked coincidences!



K12 spectrometer magnet and downstream acoustic spark chambers



John Dowell makes adjustments to the K12A spark chambers

Physicists were incompetent typists – and machines with golf-balls and daisy-wheels were complex!

Instead, we made frequent visits to the typing pool – a lot more enjoyable than TeX!

Our part-time taxi driver was a source of amazement to many

He was not the only one with hidden talents…

The Nimrod complex became heavily populated with Beatles ...

The Legacy of Nimrod

- Nimrod was one of the generation of machines which helped establish the Standard Model.
- With Nina, Nimrod provided a long term stimulus for a national programme in accelerator physics (ISIS, SRS, diamond, ESS, ...)
- Rutherford Lab nurtured detector expertise.
  One example: first-rate engineering support allowed us to turn a dream of micron-precision tracking detectors into reality, once the discovery of charm and *b* quarks established the need:

SCIENTIFIC PROGRAMME SUB-COMMITTEE

New Developments in Particle Detection

Introduction

The literature contains descriptions of many unusual particle detection systems, some of which are of value for special applications. The general importance of a detector is a function not only of its precision, cost, size limitations etc., but also (and most strongly) of the current needs in high energy physics. We shall concentrate on two proposed detectors which look most promising on the basis of this criterion.

The requirements for current accelerators are reasonably well met by the present techniques. Clearly a major breakthrough in timing resolution would be of inestimable [illegible] SLAC, and one could quote othe[illegible] the fact remains th[illegible]eresting experiments c[illegible]s by u[illegible] same woul[illegible]

Conclusion

The devices described fall far short of the 10^{-8} cm limit on spatial resolution previously mentioned. They even fall short of the resolution of order 0.1μ which has been obtained for many years in nuclear emulsions. There is no reason why further progress should not be made, and the prospects are very exciting. For example, a momentum resolution of 1 MeV/c could be obtained on a 100 GeV/c particle in a 20 K Gauss field if we could measure the position of the particle to $\sim 10^{-8}$cm on three thin films separated by a few cm along the trajectory. The developments currently being pursued may make rapid strides towards this more-or-less ultimate goal.

C J S DAMERELL

2 February 1970

- Organisational and social:
  Ops2 meetings (brought the accelerator and particle physics experimentalists together)
  PPESP (brought the UK experimentalists and theorists together)

- Lessons for our future developments:

  Complexity requires a multi-pronged approach: If SUSY or other beyond SM physics is round the corner, LHC and LC will need to work together to unravel the picture

  How can we best maintain the unity of our community? (Working at Boulby, CERN, Fermilab, ILL, Minnesota, SLAC, and so on is wonderful, but….)

  Would multi-way video-conferencing be useful to engage our geographically scattered community in the PPRP open sessions and similar national meetings?

  The Global Accelerator Network provides a bright future in which the UK can play a major role in the Linear Collider and other international projects.

  Just as the transition from a university-based to a national HEP programme required skill, diplomacy and leadership, so will the next step to full internationalisation.

  We can learn important lessons from earlier paradigm shifts in our science and in the means of carrying it out, both of which took place with outstanding success during the Nimrod era.