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Résumé. - Les principaux développements de la physique des particules élémentaires, des origines à 1965, sont présentés en une liste chronologique à trois volets : théories, découvertes expérimentales et moyens techniques. L'attention est portée principalement sur la période 1930-1965, pour laquelle nous donnons les références des articles originaux.

Abstract. - The main developments in elementary particle physics, from the origins to 1965, are presented in a chronological list with three columns : theories, experimental discoveries and technical means. Our work mainly focuses on the period 1930-1965, for which we give the references of the original papers.

1. Introduction.- This work was undertaken on the occasion of the International Colloquium on the History of Particle Physics (Paris, July 21-23, 1982).

It appeared interesting to establish a chronological list of the most important discoveries -theoretical, experimental and technical- in this field and to present it in the form of a comparative table. This presentation may serve to visualize the development of this research but, of course, supposes the reader to be familiar with this field.

We divided the history of particle physics into three periods :

- Period before 1930 : "Early steps in corpuscular physics".
- Period from 1930 to 1965 : "From neutron to quarks".
- Period after 1965.

We did not treat the third, too recent, period and focused our historical work on the second one. The years 1930-1933 see the advent of neutron, neutrino, and positron and, in 1964, quarks emerge. This is the reason why we chose for our study the limits 1930-1965, which correspond roughly to the period analyzed in this conference.

However, for reasons of continuity, it seemed necessary to give an outlook of the discoveries made before 1930, in particular those related to the emergence of "corpuscular" physics. Thus, a list of the most relevant discoveries is given for this period with the names of the authors (table I). This table is conceived as a simple guide-line and no references to publications are given. However, we respected the chronological order for discoveries made within a particular year. We referred for that to the dates of submission of the papers as we did for the second period (cf. below).

2. Presentation of the second period.- For the second period, we established a list of various topics with the corresponding references. With such a program arose certain difficulties.

First, a list of the most important topics had to be established. However, it is impossible to draw a clear demarcation line. The very rich world of particles and resonances is a good example. We chose to mention all resonances found in the years 1960-1961, but only some typical ones in the following years. Apart the f^0 which played a role in the works on the pomeron trajectory, we mentioned only the resonances which allowed to complete the 0^- and 1^- octets of mesons and the $3/2^+$ decuplet of baryons. In the same manner, we did not cover all the works devoted to the determination of the quantum numbers of these resonances. In order to make the table as clear as possible, we also preferred to keep together some important works made in a definite domain. We indicated, in that case, date limits rather than a specific year (see, for example, topic 86 : dispersion relations 1952-1958). We also omitted some topics which seemed important, but whose paternity is difficult and, perhaps, impossible to establish (for example : the idea that the electron cannot exist in the nucleus, the concepts of peripherism, bootstrap ...). A crude list of discoveries may also lead to oversimplified ideas. To obviate this inconvenience, we often judged useful to add informations or historical notes to the references.

Another difficulty lies in the choice of the references. We tried to retain the first and the next important ones according to the influence they have had. It is out of the scope of this work to give a complete bibliography which may be found in specialized review articles devoted to a restricted subject.

We apologize for involuntary omissions and errors which may have escaped our attention.

3. Choice of the dates.- The list of reference numbers of the topics follows, in principle, the chronology (explained below) of the first publications. However, in the case of some technical developments we chose a more appropriate date than that given by the publications. Topics with date limits are another exception. In that case, we chose the beginning year, but put this topic in the last position of the topics belonging to the same year and the same column.

The data chosen for a paper is indicated in brackets after the reference, and is, in principle, the date of submission of that paper. If a date does not appear (i.e. Review of Modern Physics), we indicate only the month of publication. We have also included, as references, talks given at conferences, if they are published in the corresponding proceedings, as well as notes written for Academies of Science. In these cases we have retained the dates of the oral presentations. We have also retained references on talks given at Conferences of the American Physical Society, although the papers referred to give only abstracts of the talks. In that case we mention in brackets, APS and the meeting dates.

4. <u>Bibliography</u>.- We have been considerably helped in our work by some existing attempts of this kind in particular :

- D. Halliday : Introduction to Nuclear Physics p.2, (John Wiley and Sons, New York, 1955).
- R. Omnès : Introduction à l'étude des particules élémentaires, p.421-430 (Ediscience, Paris, 1970).
- B. Pontecorvo : Fifty years of neutrino physics : a few episodes (Dubna report E1 81-117, 1981).

We have also profited from some books reproducing published papers on a restricted subject, in particular :

- R.T. Beyer : Foundations of nuclear physics (Dover, New York, 1949)
- J. Schwinger : Selected papers on QED (Dover, New York, 1958).
- R. Hofstadter : Nuclear and Nucleon Structure (W.A. Benjamin, New York, 1963).
- P.K. Kabir : The development of weak interaction theory (Gordon and Breach, New York, 1963).
- M. Gell-Mann and Y. Ne'eman : The eightfold way (W.A. Benjamin, New York, 1964).

Many review articles exist also on various subjects and can be found in different reviews (Physics Reports, Annual Review of Nuclear Science ...).

The various talks given at this Conference were also fruitful and enabled us to complete our bibliography. Finally, we have the pleasure of thanking people who made remarks about the preliminary version of this work given in July 1982 during the Paris Conference. We would also like to thank M. Conversi, M. Gell-Mann, P. Hamamdjian, F. Netter, K. Nishijima, C. Peyrou, B. Pontecorvo, G.D. Rochester, H. Schnewly and F. Selleri for remarks we received after the Conference.

Table I - Early steps in corpuscular physics

Year	Theoretical Advances	Name	Year	Experimental Results	Name	Year	Technical Developments	Name
1811 - 1814	Introduction of atoms and molecules	Avogadro Ampère						
1820	Electrodynamical theory of magnetism	Ampère						
						∼1833	First studies of electrical discharges in gazes	Faraday
1868 - 1881	Maxwell equations	Maxwell						
1869	Classification of elements	Mendeleev						
						1876	Development of electrical discharges in vacuum	Crookes
1880 - 1900	Statistical thermodynamics	Boltzmann Gibbs	1881	Measurement of elementary charge (Q/N)	Helmotz			
			1887	Velocity of light is constant	Michelson Morley			
			1895	Cathode rays are negatively charged	J.B. Perrin			
				Discovery of X-rays	Röntgen			
			1896	Discovery of radioactivity	Becquerel			
1897	Explanation of the Zeeman effect	Lorentz	1897	Zeeman effect	Zeeman			
				Identification of the electron (e/m)	J.J. Thomson			
			1898 - 1902	Isolation of radium	M. et P. Curie			
1900	Black body radiation theory (quantum h)	Planck						
1905	Quantum of light and photoelectric effect	Einstein	1905	Rules of spectral lines	Balmer Ritz			
	Theory of Brownian motion	Einstein						
	Theory of relativity	Einstein						

Year	Theoretical Advances	Name	Year	Experimental Results	Name	Year	Technical Developments	Name
						1908	Particle counting by proportionnal counters	Geiger and Rutherford
			1909	α rays = He_4 nuclei	Rutherford			
			1910	Electron charge measurement	Millikan			
			1910 -1911	Discovery of cosmic rays	Gockel Hess			
			1911	Evidence of the atomic nucleus	Rutherford			
						1912	Wilson chamber	CTR Wilson
1913	Planetary model of the atom	Bohr	1913	Stark effect	Stark			
	Concept of isotopism	Fajans Soddy						
			1914	Atomic excitation by electrons	Franck and Hertz			
				Continuous β spectrum	Chadwick			
						1909 -1920	Improvements of ionisation chamber for cosmic rays	Wulf Millikan
1916	Development of Bohr atom	Sommerfeld						
			1919	First nuclear transmutation and evidence for proton ($^{14}_{7}N + \alpha \rightarrow {}^{17}_{8}O + p$)	Rutherford			
1920	Hypothesis of "neutrons" in nuclei	Rutherford						
						1919 -1924	Ion mass spectrograph	Aston
			1922	Stern-Gerlach experiment	Stern and Gerlach			
			1923	Corpuscular nature of X-rays	Compton			

Year	Theoretical Advances	Name	Year	Experimental Results	Name	Year	Technical Developments	Name
1924	Wave aspect of matter	L. de Broglie						
	Light quanta statistics	Bose						
	Generalization of Bose statistics	Einstein						
1924-1925	Exclusion principle	Pauli						
1925	Electron spin hypothesis	Uhlenbeck and Goudsmit						
1925-1926	Matrix mechanics	Heisenberg Born Jordan						
1926	Fermi-Dirac statistics	Fermi Heisenberg Dirac						
	Wave mechanics	Schrödinger						
	Statistical interpretation of QM	Born						
1927	Quantum theory of radiation	Dirac	1927	Measurement of energy release in β decays. β decays have definitely continuous spectrum	Ellis and Wooster			
	Uncertainty relations	Heisenberg						
	Concept of parity	Wigner						
	Quantization of bosons	Klein and Jordan		Verification of electron diffraction	Davisson and Germer			
1927-1928	Introduction of group theory in QM	Weyl Wigner				1928	Geiger-Müller counter	Geiger and Müller
1928	Relativistic equation for electron	Dirac					Linear accelerator principle	Wideröe
	Quantization of fermions	Jordan and Wigner						
	α decay of nucleus explained by tunnel effect	Gamow				1929	Coincidence method for particle detection	Böthe and Kolhörster

Table II - Steps in particle physics from 1930 to 1965

Year	Theoretical Advances	Year	Experimental Results	Year	Technical Developments
1928 - 1936	Applications of QED to electromagnetic processes[1]				
1930	Concept of antiparticle[2]			1930 - 1932	Cockroft-Walton accelerator[3]
	Neutrino hypothesis[5]			1930 - 1932	First cyclotrons (4 and 11")[4]
1931	Introduction of the magnetic monopole[6]	1931 -1932	Identification of the deuterium[7]	1931	Electrostatic accelerator (Van de Graaff)[8]
1932	Hypothesis of neutron as a particle[10]	1932	Identification of the neutron[9]		
	Introduction of the isospin[11]				
	First theories of nuclear exchange forces[12]		Discovery of the positron[13]	1932	Triggering of Wilson chamber by Geiger counters[14]
	Validity of QED in cosmic-ray physics[15]				
	Introduction of T invariance[16]	1933 -1934	Measurement of the magnetic moment of the proton and of the deuteron[17]		
1933	Vacuum polarization and charge renormalization[18]				
	β decay theory[19]				
1934	Distinction between "strong" and "weak" interactions[22]	1934	Discovery of artificial radioactivity and of β^+ decay[20]	1934 -1949	*Čerenkov effect and* corresponding detectors[21]
	Quantization of the scalar field[23]				
	Meson theory of nuclear forces[24]				

Year	Theoretical Advances	Year	Experimental Results	Year	Technical Developments
1936	Extension of Fermi interaction and Gamow-Teller selection rules [25]				
	Problem of the increase of the weak interaction with energy [26]				
	Isospin invariance for nucleus [27]	1936	Charge independance of nuclear forces [27]		
	Super multiplet theory [28]	1937	Evidence of the "mesotron" (μ) in penetrating cosmic rays [29]	1937 - 1939	Magnetic resonance method for determination of nuclear magnetic moments [30]
1937	Majorana neutrino [31]				
	Treatment of the infrared divergence [32]				
	Principle of mass renormalization [33]				
	Particle states in the Poincaré group [34]				
1938	Hypothesis of a π° [35]				
	Concept of baryonic charge [36]	1938	K capture of orbital electron by weak process [37]		
*	Energy production in stars by Bethe's cycle [38]	*	Discovery of nuclear fission [39]		
		1939 *	Emission of neutrons in the fission process [40]	1939	The 60 inch medical cyclotron at Berkeley [41]
1939	Demonstration of spin statistics connexion [42]				
			Direct measurement of neutron's magnetic moment [43]		
			First observation of the mesotron decay [44]		

* Important topic but at the limit of the field.

Year	Theoretical Advances	Year	Experimental Results	Year	Technical Developments
				1940 -1943	(First electronic computers)
		1941	Lifetime of the mesotron [45]		
1942	General formalism of the S-matrix [46]			1942 *	First nuclear reactor [47]
				1940 -1945	(Developments in microwave technics)
1943 -1949	Covariant formalism of quantum electrodynamics [48]	1944	First observation of the K^+ [49]	1945	Principle of phase stability for accelerators [50]
				1945 -1946	Development of nuclear emulsion [51]
		1946	Mesotron is not the Yukawa meson [53]	1946	The 184 inch synchrocyclotron 380 MeV α at Berkeley [52]
		1947	Discovery of the π meson and the decay $\pi \rightarrow \mu$ [54]		
1947	Explanation and calculation of the Lamb Shift [55]		Measurement of the Lamb Shift [55]	1947	Scintillation counters [56]
	First calculation of (g-2) for electron [57]		Measurement of (g-2) for electron [57]		
			Absence of $\mu \rightarrow e\gamma$ [58]		
1947 -1949	Universal Fermi interaction [60]		Discovery of V° particles [59]		
		1947 -1949	$\mu \rightarrow e + 2\nu$ [61]	1948	Production of π by accelerator [62] (Synchrocyclotron, Berkeley)
1948	Path integral formalism in quantum mechanics [63]				
		1948	Identification of the neutron decay [64]		
*	Big Bang theory [65]				
1949	First composite model of the π [67]	1949	Discovery of the $(K^+ \rightarrow \pi^+ \pi^+ \pi^-)$ [66]		
			Identification of $\pi^\circ \rightarrow 2\gamma$ [68]		
	ρ Michel parameter for the e spectrum of the μ decay [69]				
				1949	Semi-conductor detectors [70]
				1949 -1950	Liquid scintillation counters [71]

* Important topic but at the limit of the field

Year	Theoretical Advances	Year	Experimental Results	Year	Technical Developments
		1950	Evidence for the production of "jets" in NN collision at high energies [72]		
			Parity of the π^- and $\pi^- - \pi^\circ$ mass difference [74]	1950 -1952	Strong focusing principle for accelerators [73]
				1950 -1953	1 GeV electron Linac at Stanford [75]
		1951	Two types of V° particles ($\Lambda^- \to p\pi^-$, $K^\circ \to \pi^+\pi^-$) [76]		
			Charge distribution in the nucleus [77]		
			Decay modes of K^+ different from the τ [78]		
1951	Hypothesis of associated production of V° particles [79]			1951	Development of the diffusion Cloud chamber [80]
		1952	Discovery of the Ξ^- [81]	1952	Invention of bubble chamber [82]
					The Cosmotron (3 GeV) at Brookhaven [83]
			First hyperfragment [84]		
		1952 -1953	Discovery of the Δ^{++}(First resonance in particle physics) [85]		
1952 -1958	Dispersion relations [86]				
1953	Introduction of the G invariance [87]	1953	Discovery of the Σ^+ [88]		
			K° has same mass as K^+ [89]		
	Renormalization group [90]			1953	Production of V° by Cosmotron [91]
	Concept of lepton number [92]		Associated production of strange particles and discovery of the Σ^- [94]		
	CPT theorem [93]				
1953 -1955	Strangeness and classification of particles [95]	1953	Structure of nucleus explored by electrons from 100 to 700 MeV [96]		

Year	Theoretical Advances	Year	Experimental Results	Year	Technical Developments
1954	Yang-Mills field [98]	1954	Evidence for $K^+ \to \mu + \nu$ [97]	1954	First operation of Bevatron (6 GeV) at Berkeley [99]
	$K_1^\circ K_2^\circ$ mixture theory [101]		Evidence for $K^+ \to \pi^+\pi^\circ$ [100]		
	Axiomatic field theory [102]				
1955	Hypothesis of conserved vector current (CVC) [103]			1955	Flash tube chambers [104]
		1955	Branching ratios of the K^+ [105]		
			Identification of the $\bar{p}$ [106]		
			θ-τ puzzle [107]		
	The static model of πN interaction [108]				
1956	$\Delta S = \Delta Q$ rule for semi-leptonic weak decays of strange particles [109]				
	Hypothesis of parity violation in weak interactions [110]	1956	First observation of ν reactions [111]		
			Identification of long-lived neutral V particles (K_0^2) [112]		
	Two-component theory of neutrino [114]		Identification of $\Sigma^\circ \to \Lambda^\circ \gamma$ [113]		
	Hypothesis of CP violation [115]				
1957	Description of e.m structure of nucleons by form factors [116]	1957	Limited transverse momentum in jets [117]		
	σ models [119]		Violation of parity and charge conjugation in weak interactions [118]		
	Revival of intermediary boson in weak interactions [120]				
	Universal (V-A) weak interaction [121]				
	Pomeranchuk theorem [122]		The neutrino is left handed [123]		

Year	Theoretical Advances	Year	Experimental Results	Year	Technical Developments
1958	Goldberger-Trieman relation [124]	1958	Failure of Universal Fermi Interaction in β decay of hyperons [125]		
	Method for extracting ππ cross sections [127]		K_S-K_L mass difference [126]		
			Verification of (V-A) theory in $\pi \to e\nu$ [128]	1949 - 1958	Spark chambers [129]
		1959	First observation of Ξ° [130]	1959	Feasibility of ν reactions with accelerators [131]
1960	Introduction of Regge pole [132]			1960	CERN proton synchrotron (25 GeV) [133]
	Partially conserved axial current (PCAC) [134]				AGS (30 GeV) at Brookhaven [135]
	Goldstone theorem [136]	1960	Discovery of Y^* (1385) [137]		
		1961	Precise measurement of (g-2) factor for the μ [138]		
1961	SU_3 and classification of particles. (The eightfold way) [139]		Discovery of K^* (890) [140]		
	Current algebra [141]		Measurement of π° lifetime ($\sim 10^{-16}$ sec) [142]		
			Discovery of ρ meson [143]		
			Indication of a $Y_o^*(1405)$ [144]		
	Froissart bound on cross sections [146]			1961	First e^+e^- storage rings [145]
	Multiperipheral model [148]		Discovery of ω° meson [147]		
	Application of Regge poles to resonances and particles [149]		Discovery of η° meson [150]		
		1962	Identification of two neutrinos (ν_e and ν_μ) [151]		
			Discovery of $\Xi^*(1530)$ [152]		
			Discovery of f^o meson [153]		
			Discovery of φ meson [154]		

Year	Theoretical Advances	Year	Experimental Results	Year	Technical Developments
1963	SU_3 and weak interactions. Introduction of the Cabibbo angle[155]			1963	(Integrated electronic circuity)
				1963 - 1964	Streamer chamber [156]
1964	First introduction of quarks[157]	1964	Observation of the Ω^- [158]		
			Discovery of $\eta'(958)$ meson [159]		
			Discovery of CP violation [160]		
	SU(6) and classification of particles [161]				
	Higgs mechanism for spontaneous symmetry breaking [162]				
	Superweak theory [163]				
	Introduction of colour for quarks [164]				
		1965 *	Discovery of cosmic black body radiation [165]		

* Important topic but at the limit of the field

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Phys. Rev. 52(1937)1107 ‹Aug. 11›. The interest for this
formalism became generalized since about 1955.

47) E. Fermi, Internal report (1943) for the Metallurgical Laboratory of University of Chicago, reproduced in Am. J. of Physics
20(1952)536 (First divergence of the pile in Dec. 1942).

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Tomonaga method :
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Z. Koba, T. Tati and S. Tomonaga, Prog. Theor. Phys. 2(1947)101,198
‹Nov. 6, 1946›.
T. Tati and S. Tomonaga, Prog. Theor. Phys. 3(1948)391 ‹May 23›.
Schwinger method :
J. Schwinger, Phys. Rev. 74(1948)1439 ‹July 29› ; 75(1949)651
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Feynman method (Feynman diagrams) :
R.P. Feynman, Phys. Rev. 76(1949)749 ‹April 8› ; 76(1949)769
‹May 9›.
Equivalence between the Schwinger-Tomonaga method and the Feynman method and generalization :
F.J. Dyson, Phys. Rev. 75(1949)486 ‹Oct. 6, 1948› ; 75(1949)1736
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49) L. Leprince-Ringuet et M. Lhéritier, Comptes Rendus Acad.
Sc. Paris 219(1944)618 ‹Dec. 13›.

50) E.M. Mac Millan, Phys. Rev. 68(1945)143 ‹Sept. 5› ; 70(1946)800 ‹APS July 20›.
V. Veksler, Journ. Phys. (USSR) 9(1945)153 ‹March 1› ;
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It is recalled that already in 1896 Becquerel used photographic emulsion as a detector. Howewer, slow progresses were made on that technique until 1945.

52) W.M. Brobeck, E.O. Lawrence, K.R. Mac Kenzie, E.M. Mac Millan, R. Serber, D.C. Sewell, K.M.Simpson, R.L.Thornton, Phys. Rev. 71(1947)449 ‹Feb. 26› (First operation in Nov. 1946).

53) M. Conversi, E. Pancini, O. Piccioni, Phys. Rev. 71(1947)209 ‹Dec. 31, 1946›.

54) Discovery of π^- mesons producing nuclear disintegrations :
D.H. Perkins, Nature 159(1947)126 ‹Jan. 25›.
G.P.S. Occhialini and C.F. Powell, Nature 159(1947)186 ‹Feb. 8›.
Decay of π in μ :
G.M.G. Lattes, H. Muirhead, G.P.S. Occhialini and C.F. Powell, Nature 159(1947)694 ‹May 24›.
Evidence for two body decay $\pi \rightarrow \mu + \nu$ and π mass measurement :
C.M.G. Lattes, G.P.S. Occhialini, C.F. Powell, Nature 160(1947)453 ‹Oct. 4›.

55) Experimental discovery :
W.E. Lamb Jr., R.C. Retherford, Phys. Rev. 72(1947)241 ‹June 18›.
The existence of the "Lamb shift" was suspected from earlier experiments made in 1938.
Theoretical calculation in non-relativistic QED :
H.A. Bethe, Phys. Rev. 72 (1947) 339 ‹June 27›.
After this first calculation, many authors calculated the Lamb shift in a relativistic QED. Similarly, other experiments were made. With the (g-2) factor (see topics 57 and 138), the Lamb shift is one of the most precise tests of the QED theory (see topic 48).

56) F. Marshall and J.W. Coltman, Phys. Rev. 72(1947)528 ‹APS, June 20›.
H. Kallmann, Natur und Tecknik ‹Berlin Dahlem Colloquium, July 1947›
The detection of particles by scintillation fluorescence was known from early days (see i.e. Rutherford's experiments). The progress in this technique refers here to the introduction of organic crystal counters which are transparent for particles and give short scintillation pulses which can be recorded by photomultiplier technique.
NaI for γ detection :
R. Hofstadter, Phys. Rev. 74(1948)100 ‹May 20›.

57) Experiment :
P. Kusch and H.M. Foley, Phys. Rev. 72(1947)1256 ‹Nov. 3›.
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J. Schwinger, Phys. Rev. 73(1948)416 ‹Dec. 30, 1947›.

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R. Sard and E. Althauss, Phys. Rev. 73(1948)1251 ‹Jan. 30›.
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59) G.D. Rochester, C.C. Butler, Nature 160 (1947) 855 ‹Dec. 20›.
A.J. Seriff, R.B. Leighton, C. Hsiao, E.W. Cowan and C.D. Anderson, Phys. Rev. 78(1950)290 ‹March 6›.

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O. Klein, Nature 161(1948)897 ‹June 5›.
G. Puppi, Nuovo Cimento 5(1948)587 ‹Nov. 2›.
T.D. Lee, M. Rosenbluth, C.N. Yang, Phys. Rev. 75 (1949)905 ‹Jan. 7›.
J. Tiomno and J.A. Wheeler, Rev. of Mod. Phys. 21(1949)144, 153 ‹Jan.›.
The first papers compared the μ^- decay or the μ^- capture to the electron β decay or the K capture. At that time the mode of the μ decay was unknown. The last mentioned paper introduces the doublets (p,n) (μ,μ_o) (e,ν) at a time where the three body decay $\mu \to e2\nu$ or $\mu \to e\mu_o\nu$ was strongly favored (see Topic 61).

61) Evidence that the secondary charged particle has not a discrete energy :
See review of the first experiments (1947-1948) in : J. Tiomno and J.A. Wheeler, Rev. of Mod. Phys. 21(1949)144 ‹Jan.›.
Evidence that the emitted particle is an electron :
E.P. Hincks and P. Pontecorvo, Phys. Rev. 75(1949)698 ‹Jan. 3›.
Energy spectrum of the decay electrons in favor of $\mu \to e + 2\nu$:
P.B. Leighton, C.D. Anderson and A.J. Seriff, Phys. Rev. 75(1949)1432 ‹March 11›.

62) E. Gardner and C.M.G. Lattes, Science 107(1948)270 ‹March 12›.
J. Burfening, E. Gardner and C.M.G. Lattes, Phys. Rev. 75(1949)382 ‹Oct. 11, 1948›.

63) R.P. Feynman, Rev. Mod. Phys. 20(1948)367 ‹April›.

64) A.H. Snell and L.C. Miller, Phys. Rev. 74(1948)1217 ‹APS, April 29›.
A.H. Snell, F. Pleasonton and R.V. McCord, Phys. Rev. 78(1950)310 ‹March 6›.
J.M. Robson, Phys. Rev. 78(1950)311 ‹March 13›.
The instability of the neutron was expected since the discovery of the neutron, found heavier than the $(p+e^-)$ mass (cf. topic 10).

65) G. Gamow, Phys. Rev. 74(1948)505 ‹June 21›.

66) First example of 3 charged prongs decay of the K^+ :
R. Brown, U. Camerini, P.H. Fowler, H. Muirhead, C.F. Powell, D.M. Ritson, Nature 163(1949)82 ‹Jan. 15›.
Evidence for $K^+ \to \pi^+\pi^+\pi^-$:
P.H. Fowler, M.G.K. Menon, C.F. Powell and O. Rochat, Phil. Mag. 42(1951)1040 ‹July 15›.

67) E. Fermi and C.N. Yang, Phys. Rev. 76(1949)1739 ‹Aug. 24›.

68) R. Bjorklund, W.E. Crandall, B.J. Moyer and H.F. York, Phys. Rev. 77(1950)213 <Sept. 19, 1949>.
J. Steinberger, W.K.H. Panofsky, J. Steller, Phys. Rev. 78(1950)802 <April 28>.
A.G. Carlson, J.E. Hopper and D.T. King, Phil. Mag. 41(1950)701 <May 24>.

69) L. Michel, Proc. Phys. Soc. A63(1950)514, 1371 <Sept. 28, 1949>.

70) K.G. Mac Kay, Phys. Rev. 76(1949)1537 <Sept. 29>.
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71) M. Ageno, M. Chiozzoto and R. Querzoli, Accad. Naz. Lincei 6(1949)626.
G.T. Reynolds, F.B. Harrisson and G. Salvini, Phys. Rev. 78(1950)488 <March 24>.
H. Kallmann, Phys. Rev. 78(1950)621 <April 12>.
This technique opened the way to large scintillation counters.

72) J.J. Lord, J. Fainberg and M. Schein, Phys. Rev. 80(1950)669 <Aug. 18>.
During 1947-1950, many cosmic ray experiments show an indication of multiple pion production. The referred paper gives a clear event obtained in emulsion where the interaction occured probably on a light nucleus (no evaporation track) and gives many particles in a forward cone and a few particles outside this cone.

73) Christophilos, Private Report (1950).
E.D. Courant, M.S. Livingston, H.S. Snydler, Phys. Rev. 88(1952)1190 <Aug. 21>.

74) W.K.H. Panofsky, R.L. Aamodt, J. Hadley, Phys. Rev. 81(1951)565 <Oct. 6, 1950>.

75) M. Chodorow, E.L. Ginzton, W.W. Hansen, R.L. Kyhl, R.B. Neal, W.K.H. Panofsky and the staff, Rev. Sc. Instr. 26(1955)134 <Dec. 2, 1954>.
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76) R. Armenteros, K.H. Barker, C.C. Butler, A. Cachon, A.M. Chapman, Nature 167(1951)501 <March 31>.
R.B. Leighton, S.D. Wandass and W.L. Alford, Phys. Rev. 83(1951)843 <July 5>.
R. Armenteros, K.H. Barker, C.C. Butler and A. Cachon, Phil. Mag. 42(1951)1113 <Aug. 15>.
R.W. Thomson, A.V. Buskirk, L.R. Etter, C.J. Karzmark and R.H. Rediker, Phys. Rev. 90(1953)329 <March 5>.
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77) First results coming from electron nuclei experiment :
E.M. Lyman, A.O. Hanson and M.B. Scott, Phys. Rev. 84(1951)626 ‹July 3›.
The possibility of investigating the internal structure of nuclei with high energy particles was known since a long time. The first explicit theoretical paper is :
M.E. Rose, Phys. Rev. 73(1948)279 ‹Nov. 3›.

78) C.O'Callaigh, Phil. Mag. 42(1951)1032 ‹July 15›.
H.S. Bridge and M. Annis, Phys. Rev. 82(1951)445 ‹March 12›.
M. Annis, H. Bridge, H. Courant, S. Olbert and B. Rossi, Nuovo Cimento 9(1952)624 ‹June 14›.

79) H. Miyazawa, Prog. Theor. Phys. 6(1951)631 ‹July 15›.
A. Pais, Phys. Rev. 86(1952)663 ‹Jan. 22›.

80) Principle of diffusion cloud chamber :
A. Langsdorf, Rev. Sci. Instr. 10(1939)91 ‹Dec. 20, 1938›.
Development of this detector for physics with accelerators
D.H. Miller, E.C. Fowler and R.P. Schutt, Rev. Sci. Instr. 22(1951)280 ‹Oct. 21›.
The results of experiments given in topics 91 and 94 were obtained with this technique.

81) R. Armenteros, K.H. Barker, C.C. Butler, A. Cachon, C.M. York, Phil. Mag. 43(1952)597 ‹March 11›.
C.D. Anderson, E.W. Cowan, R.B. Leighton and V.A.G. Van Lint, Phys. Rev. 92(1953)1089 ‹Sept. 3›.

82) D.A. Glaser, Phys. Rev. 87(1952)665 ‹June 12›, 91(1953)762 ‹May 20›.

83) M.H. Blewett and the Cosmotron Staff, Rev. Sc. Instr. 24(1953)723 ‹Sept.›. (First operation of the Cosmotron at $\sim$ 2 GeV in June 1952).

84) M. Danysz and J. Pniewski, Phil. Mag. 44(1953)348 ‹Dec. 1, 1952›.

85) Increasing πP cross section (below resonance) :
H.L. Anderson, E. Fermi, E.A. Long, R. Martin and D.E. Nagle, Phys. Rev. 85(1952)934 ‹Jan. 21›.
First phase shift analysis :
H.L. Anderson, E. Fermi, R. Martin and D.E. Nagle, Phys. Rev. 91(1953)155 ‹March 6›.
Decreasing πP Cross Section (above resonance) :
S.J. Lindenbaum and L.C.L. Yuan, Phys. Rev. 92(1953)1578 ‹Aug. 14›.

86) The dispersion relations existed already in classical optics, known as Kramers-Kronig relations (1926-1927). Here are given references on the application to particle physics.
Forward dispersion relations for photons :
J.S. Toll, Princeton, Thesis (1952).
Forward dispersion relations for massive particles :
M. Gell-Mann, M.L. Goldberger and W.E. Thirring, Phys. Rev. 95(1954)1612 ‹May 24›.
R. Karplus and M.A. Ruderman, Phys. Rev. 98(1955)771 ‹Jan. 31›.
M.L. Goldberger, Phys. Rev. 99(1955)979 ‹April 7›.
M.L. Golberger, H. Miyazawa and R. Oehme, Phys. Rev. 99(1955)986 ‹April 20›.
Derivation of dispersion relations in field theory :
K. Symanzik, Phys. Rev. 105(1957)743 ‹Oct. 8, 1956›.
N.N. Bogoliubov, B.V. Medvedev, M.K. Polivanov, Fortschritte der Physik 6(1958)169 ‹no date› (these two papers were presented at the Seattle Conference, Sept. 1956).
Dispersion relations in two variables :
S. Mandelstam, Phys. Rev. 112(1958)1344 ‹June 27›.

87) L. Michel, Nuovo Cimento 10(1953)319 ‹Jan. 24›.
C.N. Yang and T.D. Lee, Nuovo Cimento 3(1956)749 ‹Jan. 30›.

88) A. Bonetti, R. Levi-Setti, M. Panetti and G. Tomasini, Nuovo Cimento 10(1953)345 ‹Jan. 28›.
A. Bonetti, R. Levi-Setti, M. Panetti and G. Tomasini, Nuovo Cimento 10(1953)1736 ‹Nov. 3›.
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92) Ja. Zel'dovitch, Dokl. Akad. Nauk. USSR 91(1953)1317 ‹July 2›.
E.J. Konopinski and H.M. Mahmoud, Phys. Rev. 92(1953)1045 ‹July 24›.

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W. Pauli, in : Niels Bohr and the development of Physics Pergamon Press (1955).

94) W.B. Fowler, R.P. Shutt, A.M. Thorndike, W.L. Whitemore, Phys. Rev. 93(1954)861 ‹Nov. 10, 1953›.

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a) hypothesis of a isotopic spin 1/2 for $K(K^+,K°)$ and $\bar{K}$ and integer isotopic spin for $V^{\pm}$, V° particles :
M. Gell-Mann, Phys. Rev. 92(1953)833 ‹Aug. 21›.
T. Nakano and K. Nishijima, Prog. Th. Phys. 10(1953)581 ‹Nov. 16›.
b) classification of strange particles with prediction of $\Sigma°$ and $\Xi°$:
K. Nishijima, Prog. Th. Physics 12(1954)107 ‹July 13›.
M. Gell-Mann and A. Païs, Proc. of Glasgow Conf. on Nucleon and Meson Physics (1954)342 ‹July 13-17›.
K. Nishijima, Prog. Th. Physics 13(1955)285 ‹Feb. 11›.
M. Gell-Mann, Suppl. Nuovo Cimento 4(1956)848 (Proc. of Pisa Conference ‹June 1955, 12-18›.

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R. Hofstadter, F. Bumiller, M. Yearian, Rev. Mod. Phys. 30(1958)482 ‹April›.
See also R. Hofstadter, Nuclear and Nucleon Structure, W.A. Benjamin, New York, 1963.

97) B.P. Gregory, A. Lagarrigue, L. Leprince-Ringuet, F. Muller and C. Peyrou, Nuovo Cimento 11(1954)292 ‹Jan. 30›.
H.S. Bridge, H. Destaebler Jr., B. Rossi and B.V. Sreekantan, Nuovo Cimento 1(1955)874 ‹March 18›.
R. Armenteros, B. Gregory, A. Hendel, A. Lagarrigue, L. Leprince-Ringuet, F. Muller and C. Peyrou, Nuovo Cimento 1(1955)915 ‹April 12›.

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99) W.M. Brobeck, UCRL-3912 (Sept. 1957) (first operation in 1954).

100) Evidence for a two body decay, π^+ + neutral :
M.G.K. Menon and C. O'Ceallaigh, Proc. Roy. Soc. A221(1954)292 ‹july 1, 1953› (revised version of a discussion talk, Jan. 29,1953).
Evidence for $K^+ \to \pi^+\pi^o$:
A.L. Hodson, J. Ballam, W.H. Arnold, D.R. Harris, R.R. Rau, G.T. Reynolds and S.B. Treiman, Phys. Rev. 96(1954)1089 ‹Aug. 11›.

101) M. Gell-Mann, A. Païs, Phys. Rev. 97(1955)1387 ‹Nov. 1, 1954›.

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A.S. Wightman, Phys. Rev. 101(1956)860 ‹July 18, 1955›.

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CVC and symmetry between electromagnetism and weak interaction :
R.P. Feynman and M. Gell-Mann, Phys. Rev. 109(1958)193 ‹Sept. 16, 1957›.
The first mention of a possible unification of electromagnetic and weak interactions has been given by Klein (1939).

104) M. Conversi and A. Gozzini, Nuovo Cimento 2(1955)189 ‹June 17›.

105) G. Stack Collaboration :
J.H. Davis, D. Evans, P.E. François, M.W. Friedlander, R. Hillier, P. Iredale, D. Kerfe, M.G.K. Menon, D.H. Perkins, C.F. Powell, J. Boggild, N. Brene, P.H. Fowler, J. Hooper, W.C.G. Ortel, M. Scharff, L. Crane, R.H.W. Johnston, C. O'Ceallaigh, F. Anderson, G. Lawlor, T.E. Nevin, C. Alvial, A. Bonetti, M. Di Corato, C. Dilworth, R. Levi-Setti, A. Millone, O. Occhialini, L. Scarsi, G. Tomasini, M. Ceccarelli, M. Grilli, M. Merlin, G. Salandin, B. Sechi, Nuovo Cimento 2(1955)1063 ‹Oct. 2›.
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106) O. Chamberlain, E.G. Segré, E.C. Wiegand, T. Ypsilantis, Phys. Rev. 100(1955)947 ‹Oct. 24›.

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Spin parity of the τ by the Dalitz plot
R.H. Dalitz, Phil. Mag. 44(1953)1068 ‹July 1› ;
Phys. Rev. 94(1954)1046 ‹Feb. 9›.
J. Orear, G. Harris, S. Taylor, Phys. Rev. 100(1955)932 ‹Aug. 22›.
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L.W. Alvarez and S. Goldhaber, Nuovo Cimento 2(1955)344 ‹July 7›.
V. Fitch and R. Motley, Phys. Rev. 101(1956)496 ‹Nov. 9, 1955›.
L.W. Alvarez, F.S. Crawford, M.L. Good, M.L. Stevenson, Phys. Rev. 101(1956)503 ‹Nov. 4, 1955›.
θ and τ masses are equal :
R.W. Birge, J.R. Peterson, D.H. Stork, M.N. Whitehead, Phys. Rev. 100(1955)430 ‹July 25›.

108) G.F. Chew and F.E. Low, Phys. Rev. 101(1956)1570 ‹Nov. 28, 1955›.

109) M. Gell-Mann, Proc. Rochester Conference 1956, part 8, p.26 ‹April 3-7›.
M. Gell-Mann and R.P. Feynman, Phys. Rev. 109(1958)193 ‹Sept. 16, 1957›.

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Soon after this paper, it was shown that an asymmetry of the form $\vec{\sigma}\vec{p}$ would mean not only the violation of parity but also of charge conjugation.
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