Adone

Asymptotic Freedom QCD

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Plan of the Talk:

- The Adone Intersecting storage ring.
- The theory at the beginning of the sixties.
- The impact of the theory on the design of experimental apparatus.
- Partons: back to field theory.
- The crucial role of Adone experiments in the formulation of QCD.
- A new paradigm: Asymptotic freedom and quark confinement.

I will not cover in detail the Physics at Frascati with Ada and Adone. Mario Greco tomorrow will speak about this point.

I started to be interested in Adone physics in 1970 and I was a researcher at Frascati from 1971 to 1981.

THE FRASCATI STORAGE RINGS

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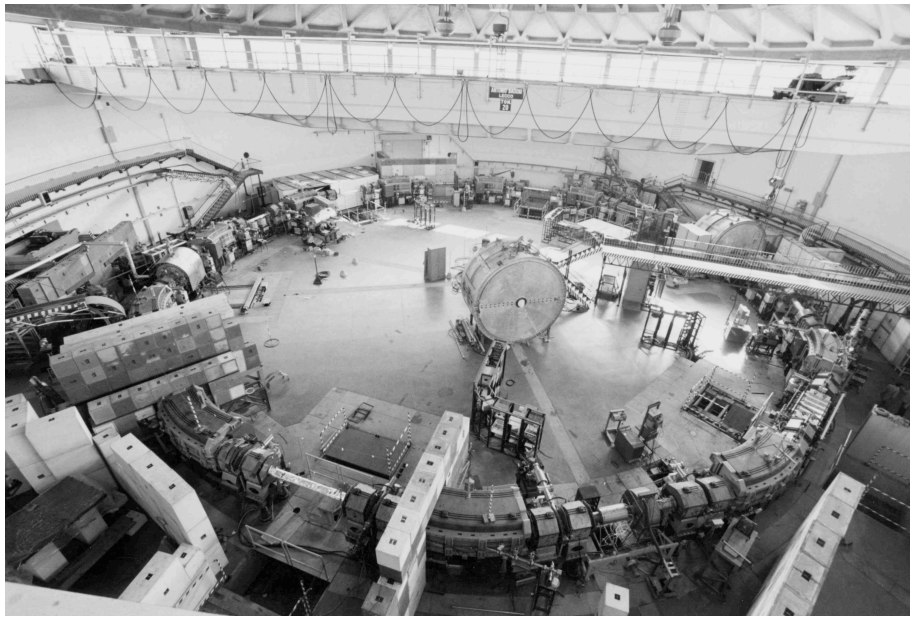
Frascati is developping two storage rings. The first (code name AdA = anello d'accumulazione = storage ring) designed for storing electrons and positrons of up to 250 MeV is actually undergoing the first tests, the second (code name Adone) a storage ring for electrons and positrons of up to 1.5 GeV, is still being planned.

The AdA team consists of C. Bernardini, G.F. Corazza, G. Ghigo, R. Querzoli and myself. The magnet was planned by Dr. Sacerdoti and built in Terni, the radiofrequency by Dr. Puglisi.

Adone is a national effort. A design team headed by Dr. Amman has the task of arriving at a specific design proposal by the beginning of 1962. Simultaneously a committee is preparing the experiments to be carried out with the machine. If by the beginning of 1962 it is found that the project has a reasonable chance of success from a technical point of view; it is expected that the machine should be working late in 1964.

Let me be very brief on the Adone project : electrons and positrons circulate in a magnetic ring designed to contain particles of up to 1.5 GeV energy. The energy losses are replaced by R.F. Injection is effected by means of a low energy (of between 50-200 MeV). The final energy is reached by raising the magnetic field to the desired value.



Adone

The beams of electrons and positrons, each of energy 1.5 GeV, circulated in a ring 105 m long, divided into 12 equal sectors composed of a bending dipole, followed by a pair of quadrupoles and a straight section of 2.5 m.

Four of the 12 straight sections available allowed the intersection of the beams, resulting in available in four points of interaction for the installation of experimental apparatus.

Four experimental apparatus have been constructed.

The remaining 8 sections housed the radio-frequency cavities and the equipment for beam injection and diagnostics.

Serendipity

I remember that some one told me that during the construction of Adone, Bruno and others had to take irreversible decisions without no hints.

In all the cases the decisions were the right ones, otherwise Adone could have had years of delay.

A personal memory

Around 1971 a preprint arrived where it was claimed that the cross-section for the process

$$e^+e^- \to 2e^+2e^-$$

was or order

$$1/m_e^2 \qquad \text{and not } 1/E^2$$

I remember that I and some one else were in Nicola's room were Nicola was presenting his ideas on the subject, Bruno entered in the room saying

I do not understand how a grown-up man can write such a nonsence.

The Antifact: Theories in the sixties

Boostrap: No elementary constituents. Also, Murray Gell-Mann was not taking quarks seriously.

Hadrons were soft: very fast decay of the proton form factor. Exponential suppression of particle productions at large momentum transfer.

Field theory was discredited.

A different view point

In electromagnetism, we have currents, In weak interactions we have the four fermion Fermi interaction and V-A theories.

Current algebra: local commutators. Mostly European Physics (Triangular Meetings Paris-Rome-Utrecht).

Expectations

The productions of 2 particles like $\pi^+\pi^-$ or three particles like $\pi^+\pi^-\pi^0$ should be the dominant process.

The cross-section was supposed to be small (correct!).

Most of the interesting physics was supposed to be the discovery of new resonances like $\rho^{'}$, or the search for exotic objects like the heavy electron (τ in modern language).

Consequently, the four experimental apparatus had a small fraction of solid angle that was enough for collinear and planar events: theoretical controlled cross-sections.

The unexpected reality: multi-hadron productions

Adone started to work in 1969.

From 1970 it was clear that the total hadron production was quite high, higher than the $\mu^+\mu^-$ cross-sections and many events had a charged multiplicity greater than 2 (multi-prong events).

It was a mess to be sure of the value of the cross-section for hadron production as far as the efficiency depends on the production model. After some time it was clear that the ratio

$$R = \frac{e^+e^- \to hadrons}{e^+e^- \to \mu^+\mu^-}$$

was around 2 and R did not have a great dependence on the energy.

Progresses in the mean while

In 1968 experiments at SLAC showed a large cross-section for the process (deep inelastic scattering)

$$e^+ + \text{proton} \to e^+ + \text{hadrons}$$

Bjorken showed that these large cross-sections are a consequence of current algebra sum rules.

Feynman introduces the idea of partons (i.e. field theory under disguised form).

Partons at Adone

In 1970 Nicola Cabibbo, G.P. and Massimo Testa derived the formula

$$R = \frac{e^+e^- \to hadrons}{e^+e^- \to \mu^+\mu^-} = \sum_i Q_i^2 + \frac{1}{4}\sum_i B_i^2 \,.$$

Q_i are the charges of the spin 1/2 partons and B_i are the charges of the spin 0 parton.

In the conventional quark model

$$R = \frac{2}{3}$$

For partons that are $SU(3) \times SU(3)$ mesons $R = 1$.

QCD

Around 1971 Fritzsch and Gell-Mann suggested that the correct theory is given by colored quarks interacting via an octet of colored gluons.

I remember a seminar of Gell-Mann (1972?) in Aula Conversi where he proposed QCD arguing that in QCD

$$R = 2$$

and this result was in agreement with Frascati data.

Asymptotic Freedom

Landau noticed in 1955 that all theories had a divergent effective coupling at high energy (Landau ghost), but it was not clear for gauge Yang-Mills theory were the computation was not done.

Around 1966 a Russian physicist (name forgotten) computed the beta function for Yang-Mills theory in a very elegant way and he found the correct result!

In 1971 Symanzik noticed that the $g\phi^4$ theory is asymptotic free for negative g.

In 1971 Coleman did a systematic study of all Yukawa-type theories: no asymptotic freedom.

Asymptotic Freedom for QCD

In 1972 t'Hooft presented to the Marseille conference his result on the negative sign of the beta function for small coupling constant in Yang-Mills theory (a five-minute remark).

In 1973 Politzer and Gross & Wilczek computed the beta function and showed that QCD is asymptotically free.

At the end of 1973 the first evaluation of the running strong coupling constant was obtained from violations of Bjorken scaling.

Asymptotic Freedom for QCD

In 1974 the discovery of J/ψ at Brookhaven and SLAC, immediately reconfirmed at Frascati, proved the existence of charm.

The widths for the processes

$$\psi \to hadrons \qquad \psi \to \mu^+\mu^-$$

(measured also at Adone) were in good agreement with the theoretical prediction using the charmonium model.

The same model gave good prediction for the width for the process

$$\psi \to \eta_c\gamma$$

and for the decays of its pseudo scalar partner η_c.

Conclusions

Summarising there were two crucial contributions of Adone to QCD:

• The measurement of R: it was a strong evidence for the colored quark model.

• The measurement of the decay widths of the ψ. They were crucial in establishing directly the correctness of the colored gluon model with a small coupling constant.