Discovery of Gluon

An overview

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Historical Background - Theoretical

1964: Gell-Mann postulated quarks as the fundamental constituents of strongly-interacting particles. [1]

Questions: How are these forces mediated? Gluons? What was their spin? What charge did they couple to? Color charge was postulated, which explained the apparent symmetry of baryon wavefunctions, and the decay rate of $\pi^0 \to 2\gamma$. Why were individual quarks not seen? Can individual colors be seen?

1968: Results from deep inelastic electron-proton scattering experiments in SLAC interpreted in terms of quasi-free point-like particles called partons, by James Bjorken and Richard Feynman. Partons $\leftrightarrow$ Quarks

1971: Chris Llewellyn-Smith showed that from the deep inelastic scattering experiments, we can measure the total proton momentum carried by the quark partons (or charged partons), which was turned out to be about half the total. This suggests that the other half is carried by neutral partons - Gluons? This was the earliest circumstantial evidence for gluons.

Historical Background - Theoretical

1971: Gerardus ‘t Hooft showed that unbroken (massless) non-Abelian gauge theories were renormalizable.

It was known at the time that asymptotic freedom is key to the near scaling behavior of strong interactions (Giorgio Parisi). ‘t Hooft was aware that non-Abelian gauge theories are asymptotically free.

1973 (QCD): The connection between non-Abelian gauge theories and strong interactions was made by David Politzer, and by David Gross and Frank Wilczek. Gross and Wilczek also proposed non-Abelian gluons interacting via an unbroken SU(3) color group.

QCD calculations predicted logarithmic deviations from scaling in deep-inelastic scattering. Early results from Fermilab in 1974 were qualitatively consistent with these predictions (structure functions increase at low momentum fractions and decrease at high momentum fractions). In 1974, unexpected (from QCD) cross-sections of $e^+e^- \longrightarrow$ hadrons at CoM energies > 4 GeV was explained by the discovery of charm quark.

By mid 1970s, QCD was the major candidate theory for strong interactions

PETRA collider at DESY, Hamburg

Positron-Elektron-Tandem-Ring-Anlage (Ring accelerator for positrons and electrons)
Circumference: 2304 m
Max. energy/beam: 23.4 GeV   Luminosity: 2×10^{31} cm^{-2} s^{-1}

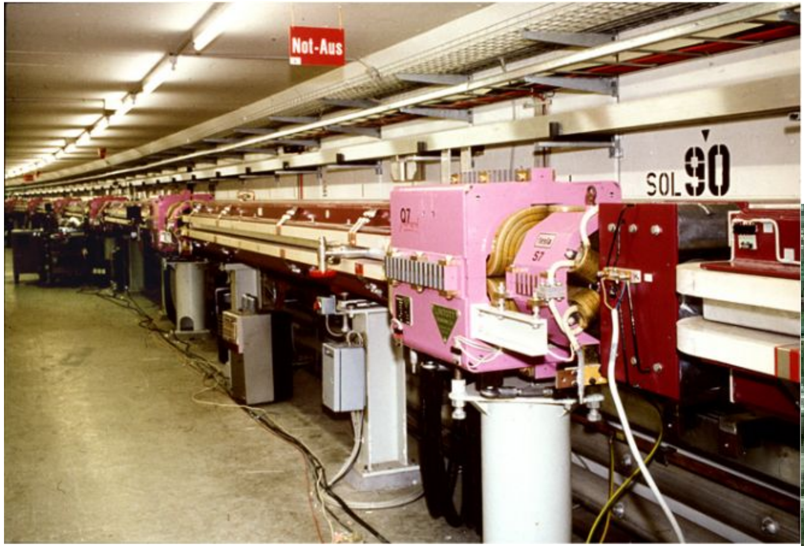
Proposed: 1974   Approved: Oct. 1975   End of construction: 1978   End of operations: 1986
PETRA was ready at 90% of the cost and almost one year ahead of schedule.

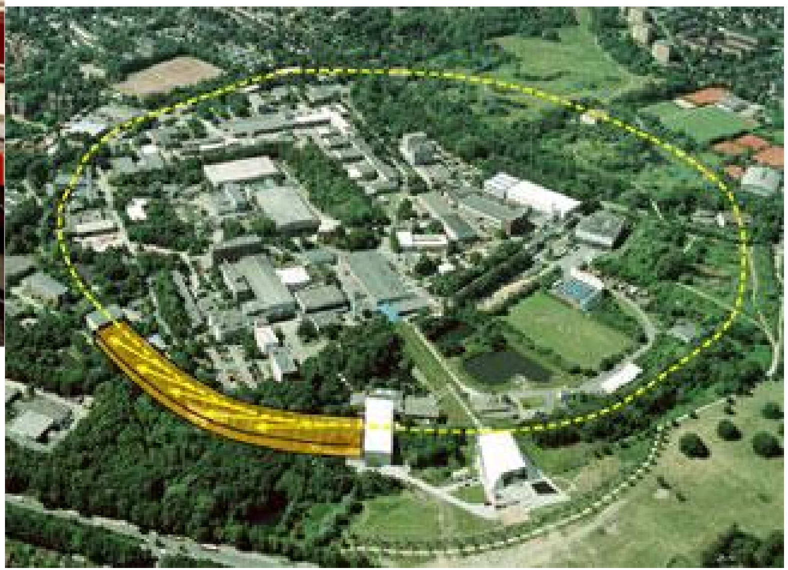
Detector collaborations on PETRA: CELLO/PLUTO, JADE, MARK-J, TASSO

Primary motivation behind the construction was to discover new quarks. But the top quark turned out to be beyond the reach of this collider.

Next phases:
PETRA II (1987-2007): Pre-accelerator for HERA and X-ray radiation source
PETRA III (Since 2009): “Most brilliant storage-ring-based X-ray source in the world.”

PETRA collider at DESY, Hamburg

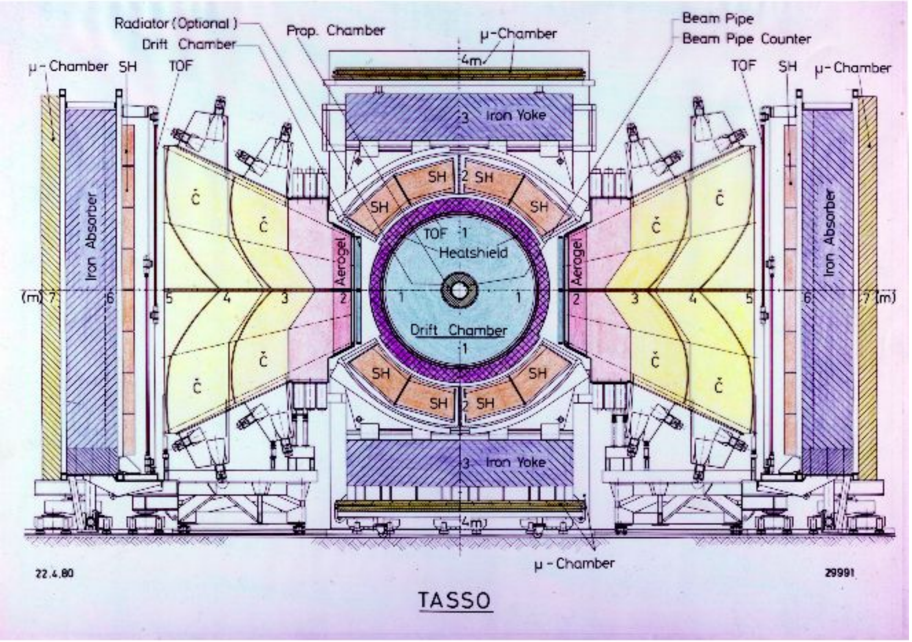




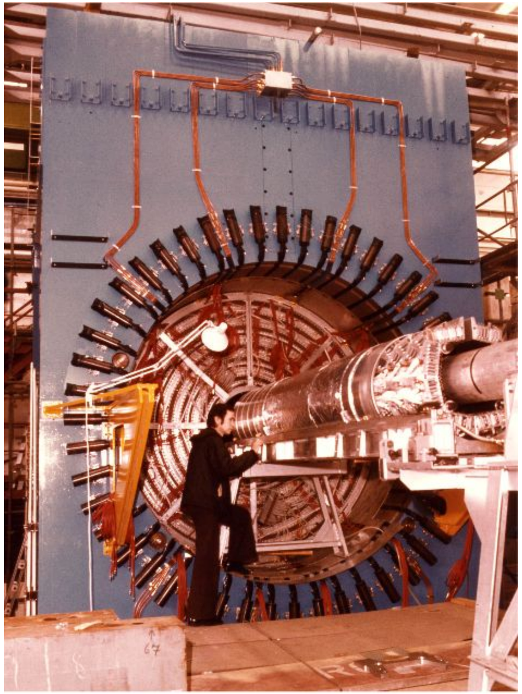
TASSO detector collaboration

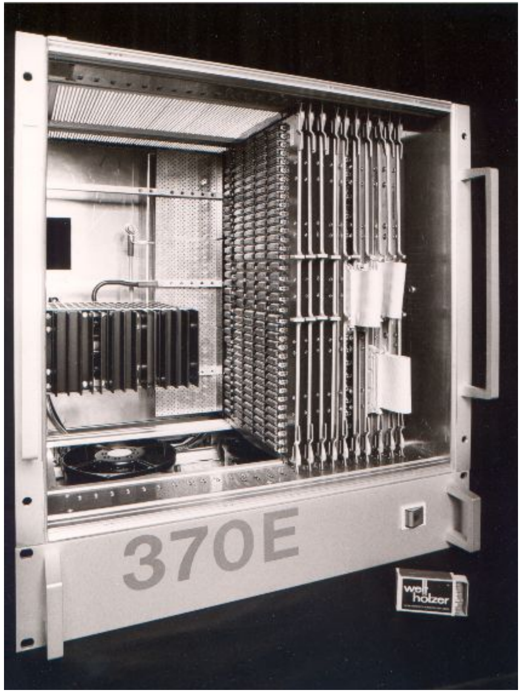
A large 4π (hermetic) magnetic detector for PETRA.

Approximately 100 researchers from RWTH Aachen, Universität Bonn, DESY, Universität Hamburg, Imperial College London, Universität Mainz, Oxford University, Rutherford Laboratory, and Weizmann Institute.



TASSO detector collaboration





Search for gluons - phenomenology

1969: Bjorken, Cabibbo, Drell discussed jets as possible signatures for quarks.

1975: Jets were observed at the electron-positron collider SPEAR at SLAC for the process $e^+e^- \longrightarrow q\bar{q} \longrightarrow$ jet jet.

Jets were yet to be observed in hadron colliders (CERN’s Intersecting Storage Rings collider), and leptons don’t interact with gluons.

1976: John Ellis, Mary K. Gaillard and Graham Ross proposed 3-jet events as a signature for gluon emission by quarks through hard-bremsstrahlung. From asymptotic freedom, they argued that hard-gluon bremsstrahlung will be the dominant source of a third jet (jet broadening) transverse to the main jet axis.

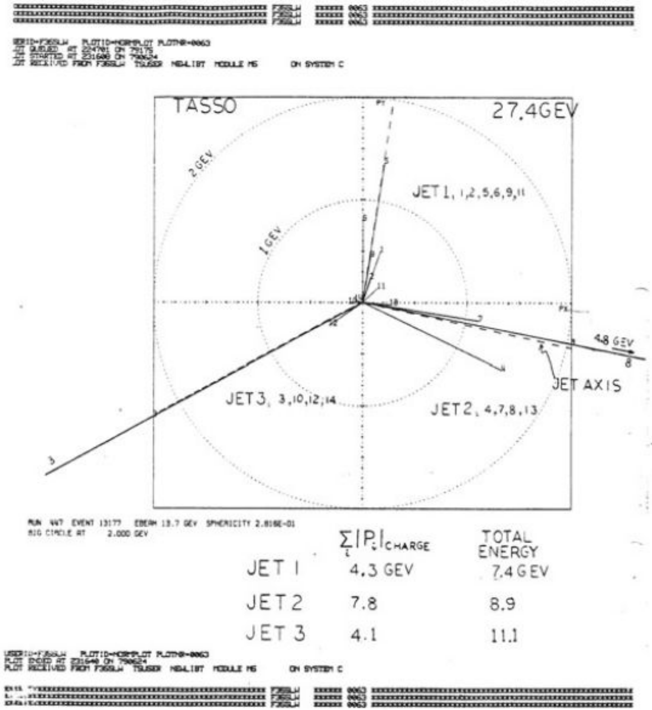
$$e^+e^- \longrightarrow q\bar{q}g \longrightarrow \text{jet jet jet}$$

The authors got in touch with TASSO.

1977: George Sterman and Steve Weinberg carefully treated infrared and collinear singularities. Their work led to systematic study of variables describing jet broadening and multijet events.

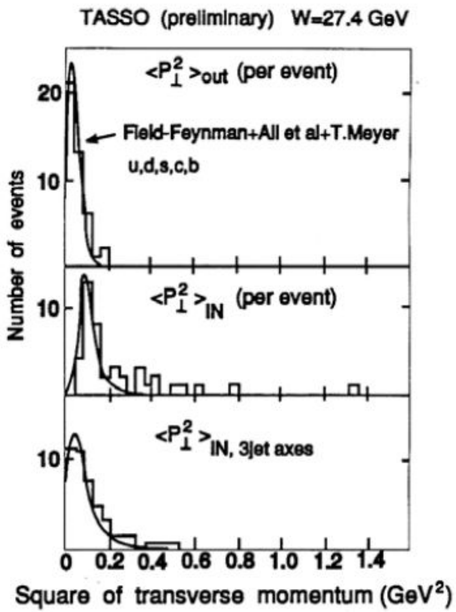
Discovery of gluons

June 1979: First planar three jet event was observed by TASSO, with PETRA operating at a CoM energy of 27.4 GeV.



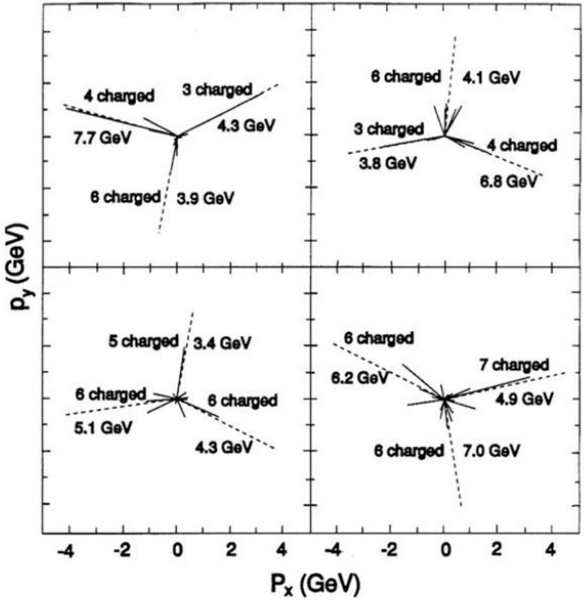
Discovery of gluons

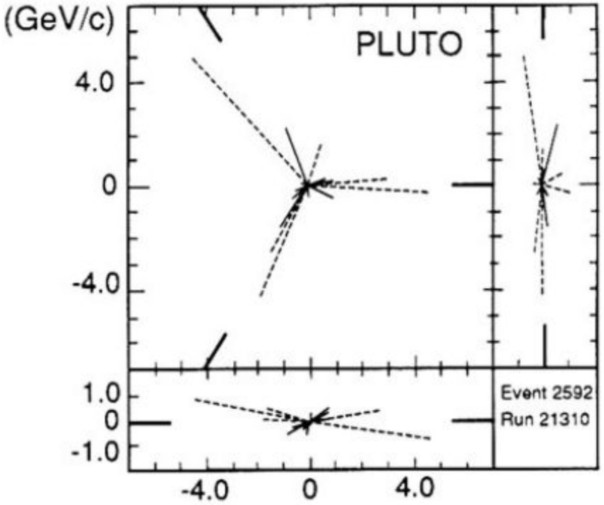
TASSO data from June 1979 was consistent in the entire kinematic region with the Field-Feynman jet model including QCD, and was inconsistent with two-jet production without gluon radiation (jet broadening with rising energy, owing to increasing probability of gluon radiation).



Discovery of gluons

In the kinematic region where one of the jets has a large transverse momentum along the Thrust axis of the event, the gluon-less background is much less than 1, that even individual events have high significance. Also, it will be appropriate to call one of the jets to have originated in a gluon, leaving us with a “smoking gluon”, a direct detection.





Public announcement

JADE, MARK-J and PLUTO corroborated TASSO's findings in the next few weeks, and the discovery of gluons was announced in the Lepton/Photon Symposium held at Fermilab in August 1979.

The first publication titled "Evidence for Planar events in e^+e^- annihilation at high energies" was published in September 1979.

References

[1] M. Gell-Mann, A Schematic Model of Baryons and Mesons, Phys. Lett. 8, 214 (1964)

[2] J. Ellis, The Discovery of the Gluon, Int. J. Mod. Phys. A 29 (2014) 1430072, 50 years of quarks, pp.189-198 (2014)

[3] R. Brandelik et al. [TASSO Collaboration], Evidence for Planar Events in e^+e^- Annihilation at High-Energies, Phys. Lett. B 86, 243 (1979).

[4] P. Soding [DESY], On the discovery of the gluon, Eur.Phys.J. H35 (2010) 3-28 (2010).

[5] G. Sterman and S. Weinberg, Jets from Quantum Chromodynamics, Phys. Rev. Lett. 39, 1436 (1977).

[6] https://www.physics.ox.ac.uk/dwb/tasso.pdf

[7] http://ppewww.physics.gla.ac.uk/~doyle/SaxonFest/talks/3.Lohrmann-Saxon-talk.pdf