

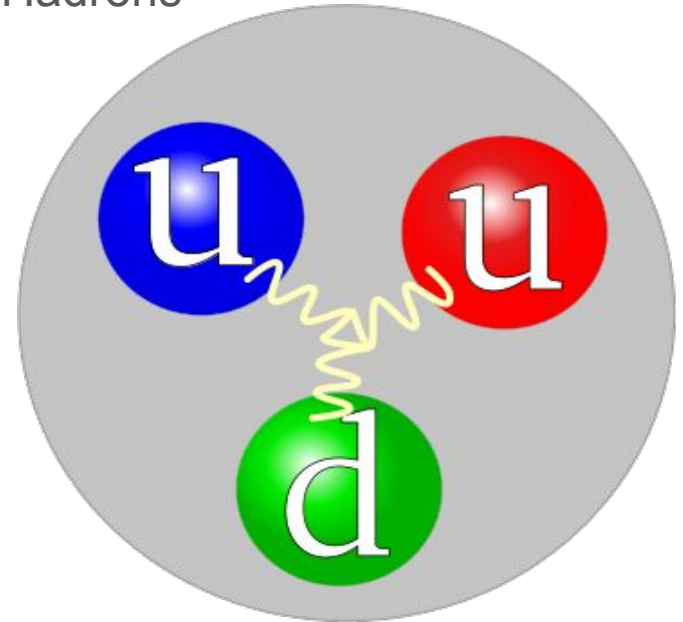
Searching for Exotic Quark Systems

-Looking for new particles to model old systems-

Robert Powel

1964-Quarks First Proposed

- Proposed to better explain behavior of different Hadrons
 - Not widely accepted at first
- Confirmed by deep inelastic scattering in 1969



Quarks making up a proton.

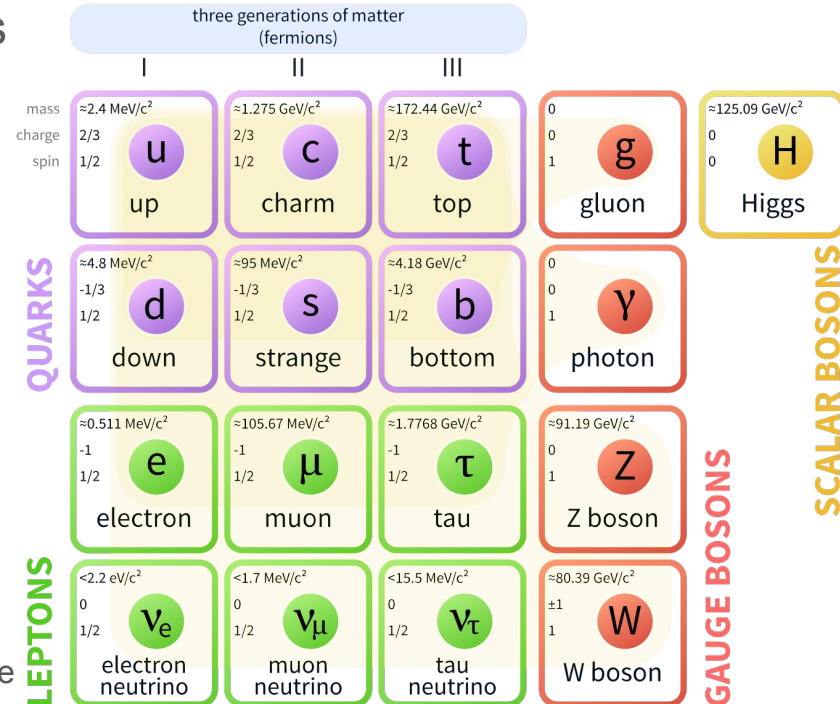
<http://adsabs.harvard.edu/abs/1969PhRvL..23..930B>

<http://www.slac.stanford.edu/pubs/beamline/25/3/25-3-carithers.pdf>

Combinations of Six Quarks make up Baryons and Mesons

- Baryons and Mesons - Standard Hadrons
- Tetraquark and Pentaquark - Exotic Hadrons
- Observed at particle accelerators
- Can help understand astronomical systems

Standard Model of Elementary Particles



Early 2000's - Tetraquark Found

- Belle Experiment found first tetraquark candidate in 2003 (later confirmed)
 - Used KEKB accelerator to primarily study CP violation
- Fermilab finds another candidate in 2009
- BES III Experiment find first confirmed Tetraquark in 2013
- LHCb Finds three more tetraquark candidates in 2016

<https://www.symmetrymagazine.org/breaking/2008/04/13/the-charming-case-of-x3872>

<https://arxiv.org/abs/0911.2178>

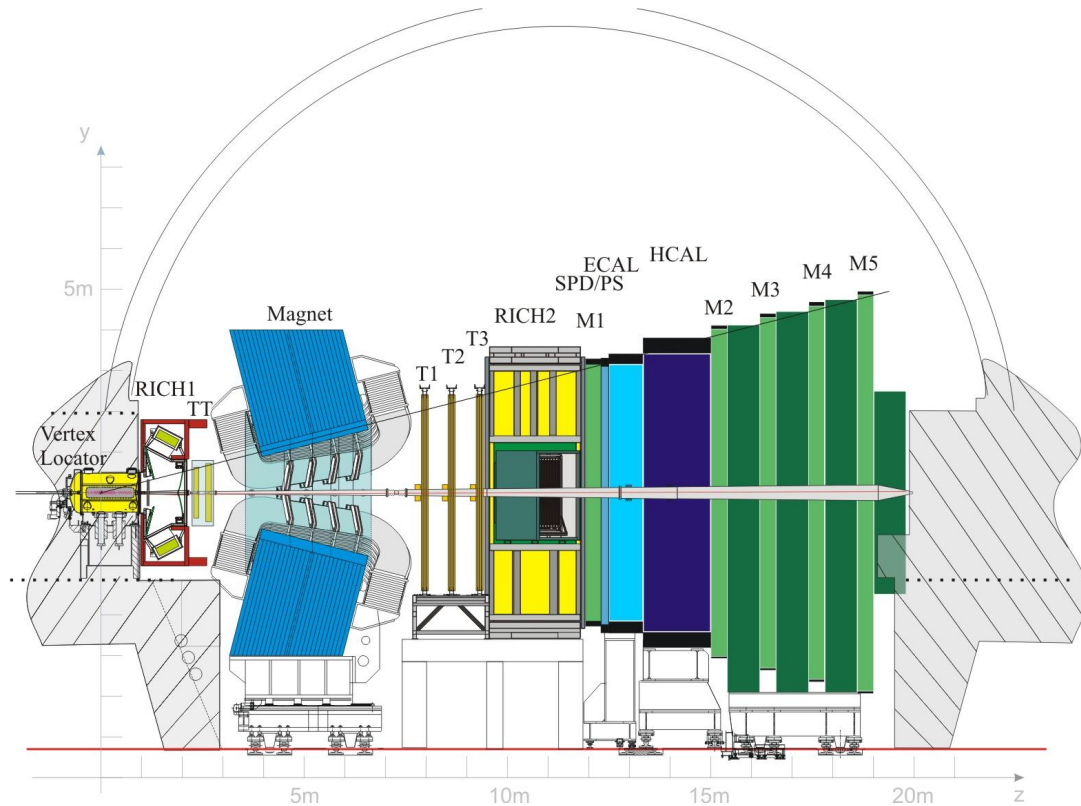
<https://www.universetoday.com/27394/new-particle-throws-monkeywrench-in-particle-physics/>

<https://physics.aps.org/articles/v6/69>

<https://arxiv.org/abs/1606.07895>

Pentaquark

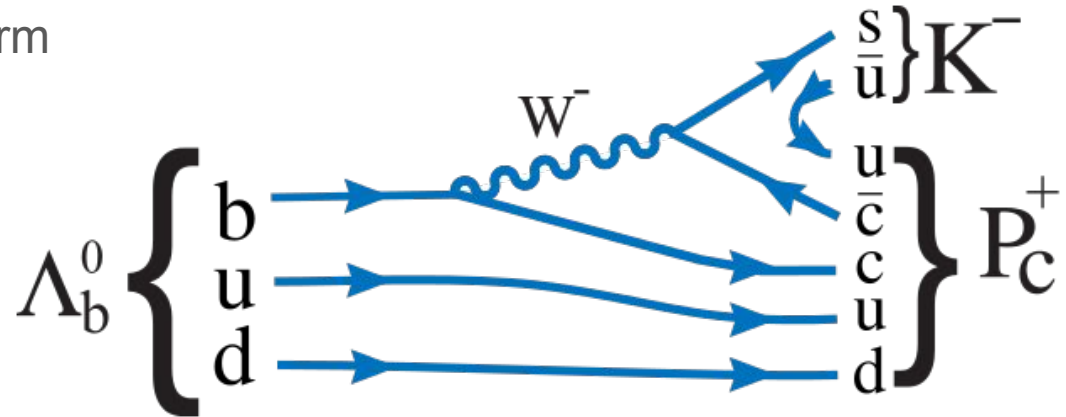
- 4 Quarks and an Antiquark
 - At first searched for limited classes of pentaquarks
- Many rejected candidates in 2000's
 - LEPs in 2003
 - Belle and LEPs
- LHCb found 2 pentaquarks in 2015
 - “cannot be described by a model that contains only excited kaon states decaying into ϕK^+ , and four $J/\psi \phi$ structures are observed



LHCb-Detector

Lambda-b Decay

- Primarily decays into J-psi+proton+kaon
- Can also decay to 2 different 5-quarks particles Pc(4450)+ and Pc(4380)+
- Both have 2 up, 1 down, 1 charm and 1 anti-charm



Feynman diagram of decay to pentaquark.

Further Search for Exotic Hadrons

- Higher energy resolution of detectors
- Higher energy collisions
- Increased statistics
- Matching models to observations
- Maybe observe hexaquarks