Hunting for Quarks

Jerry Gilfoyle, University of Richmond

"The Periodic Table"
What Do We Know?

- Protons and neutrons are made of quarks.
- The Atom
- The nucleus
- ... are made of quarks.
- ... are made of quarks.
- Neutrons ...
- ... are made of quarks.
- ... are made of quarks.
- Hominids to ...
- Red blood cells.
- The Earth to ...

- $10^{-10}$ m
- $10^{-6}$ m
- $10^{-15}$ m
- $10^1$ m
- $10^7$ m
- $10^{-6}$ m
What Else Do We Know?

- The Universe is made of quarks and leptons and the force carriers.

<table>
<thead>
<tr>
<th>Bosons</th>
<th>Force Carriers</th>
<th>Spin = 0, 1, 2, ...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name</td>
<td>Mass GeV/c²</td>
<td>Electric Charge</td>
</tr>
<tr>
<td>γ photon</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>W⁻</td>
<td>80.4</td>
<td>-1</td>
</tr>
<tr>
<td>W⁺</td>
<td>80.4</td>
<td>+1</td>
</tr>
<tr>
<td>Z⁰</td>
<td>91.187</td>
<td>0</td>
</tr>
<tr>
<td>g gluon</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- The atomic nucleus is made of protons and neutrons bound by the strong force.

- The quarks are confined inside the protons and neutrons.

- Protons and neutrons are NOT confined.
What is the Force?

- Quantum chromodynamics (QCD) looks like the right way to get the force at high energy.

- The hadronic model uses a phenomenological force fitted to data at low energy. This ‘strong’ force is the residual force between quarks.
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How Well Do We Know It?

- We have a working theory of strong interactions: quantum chromodynamics or QCD.

- The coherent hadronic model (the standard model of nuclear physics) works too.
How Well Do We Know It?


What Don’t We Know?

1. We can’t get QCD and the hadronic model to line up.

2. We have to find the hadronic model ‘baseline’ to see the transition to QCD.
Experiments at Jefferson Lab

- Jefferson Lab is a US Department of Energy national laboratory and the newest ‘crown jewel’ of the US.
- The centerpiece is a 7/8-mile-long, racetrack-shaped electron accelerator that produces unrivaled beams.
- The electrons do up to five laps around the Continuous Electron Beam Accelerator Facility (CEBAF) and are then extracted and sent to one of three experimental halls.
- All three halls can run simultaneously.
The CEBAF Large Acceptance Spectrometer (CLAS)

- CLAS is a 45-ton, $50-million radiation detector.
- It covers almost all angles.
- It has about 40,000 detecting elements in about 40 layers.
- Drift chambers map the trajectory of the collision. A toroidal magnetic field bends the trajectory to measure momentum.
- Other layers measure energy, time-of-flight, and particle identification.
- Each collision is reconstructed and the intensity pattern reveals the forces and structure of the colliding particles.
Life on the Frontiers of Knowledge
Some Results and Conclusions

- Measuring the deuteron wave function.

- We are hunting for quarks (and gluons) hidden inside the nucleus.

- Strong physics motivation to test the nuclear ‘coherent hadronic model’ in a new energy range and push it past its limits and break it.