What's Inside the Nucleus?

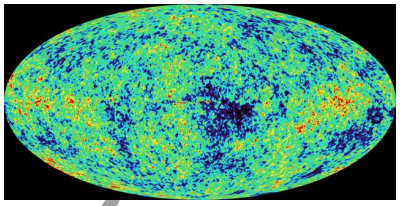
The Frontiers of the Structure of Matter

Jerry Gilfoyle, University of Richmond

"The Periodic Table"

What Do We Know?

From the Edge of the Universe to

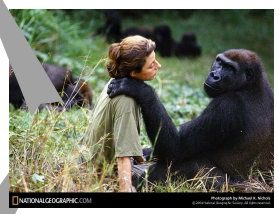


10^{26}m

10^{7} m

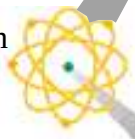
the Earth to ...

hominids to ...



10^{1}m

10^{-10}m



the Atom to...

the nucleus to...

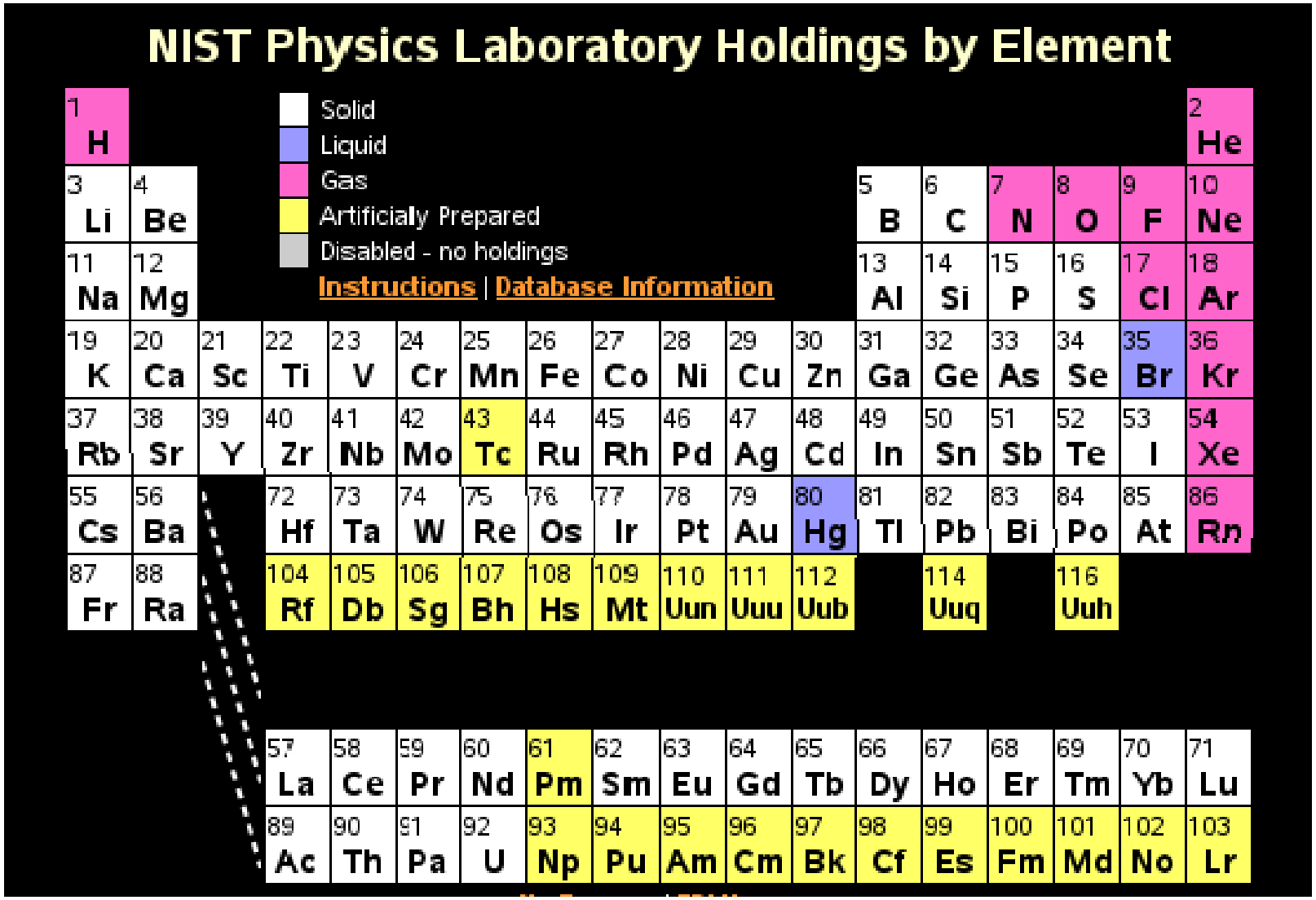
10^{-15}m

Protons and ...

neutrons ...

... are made
of quarks.

The Periodic Chart



What Do We Know?

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

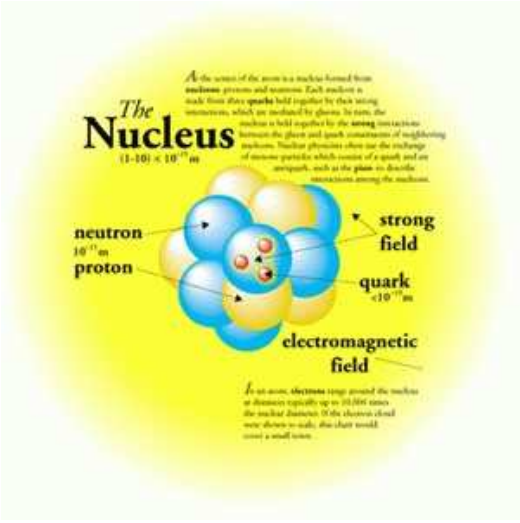
FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c^2	Electric charge	Flavor	Approx. Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	−1	d down	0.006	−1/3
ν_μ muon neutrino	<0.0002	0	c charm	1.3	2/3
μ muon	0.106	−1	s strange	0.1	−1/3
ν_τ tau neutrino	<0.02	0	t top	175	2/3
τ tau	1.7771	−1	b bottom	4.3	−1/3

BOSONS force carriers spin = 0, 1, 2, ...

Unified Electroweak spin = 1			Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge	Name	Mass GeV/c^2	Electric charge
γ photon	0	0	g gluon	0	0
W^-	80.4	−1			
W^+	80.4	+1			
Z^0	91.187	0			

- 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.



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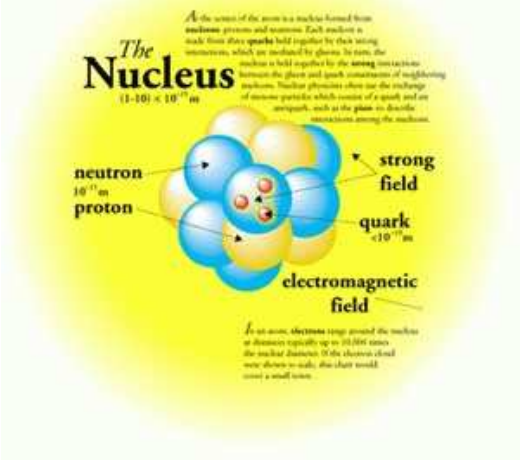

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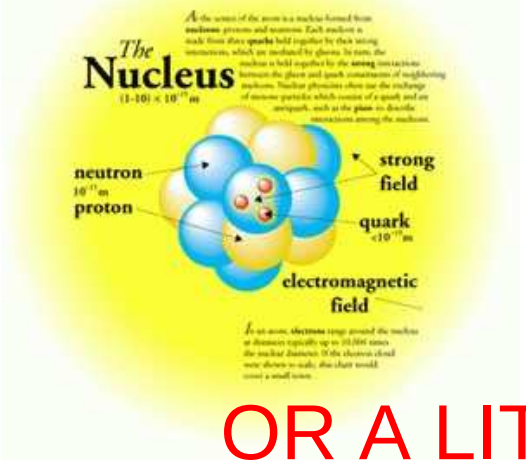

OR A LITTLE?

Is This a Lot (or a Little)?

- Saying this is nuclear and particle physics.

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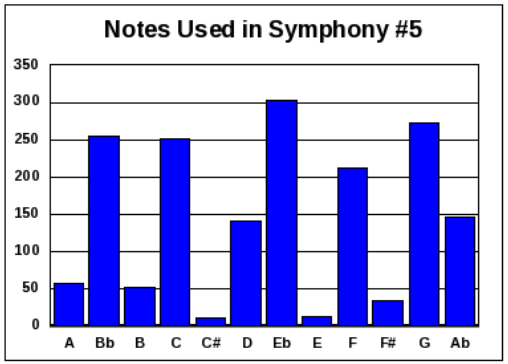

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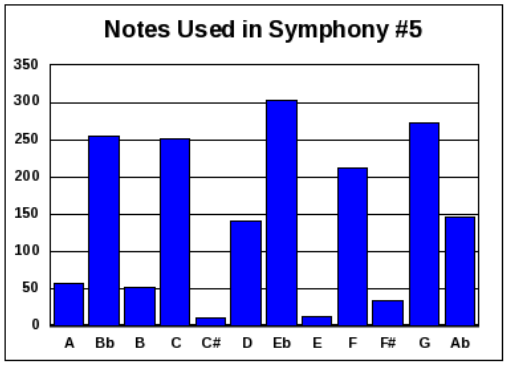


- The Standard Model of nuclear and particle physics has been superbly successful, but is now looking a bit frayed around the edges. And it has never really worked in the world we live in with protons and neutrons and atomic nuclei.

Quantum Chromodynamics

The Nobel Prize in Physics 2004

"for the discovery of asymptotic freedom in the theory of the strong interaction"

David J. Gross

1/3 of the prize

USA

University of California, Kavli Institute for Theoretical Physics
Santa Barbara, CA, USA

b. 1941

H. David Politzer

1/3 of the prize

USA

California Institute of Technology (Caltech)
Pasadena, CA, USA

b. 1949

Frank Wilczek

1/3 of the prize

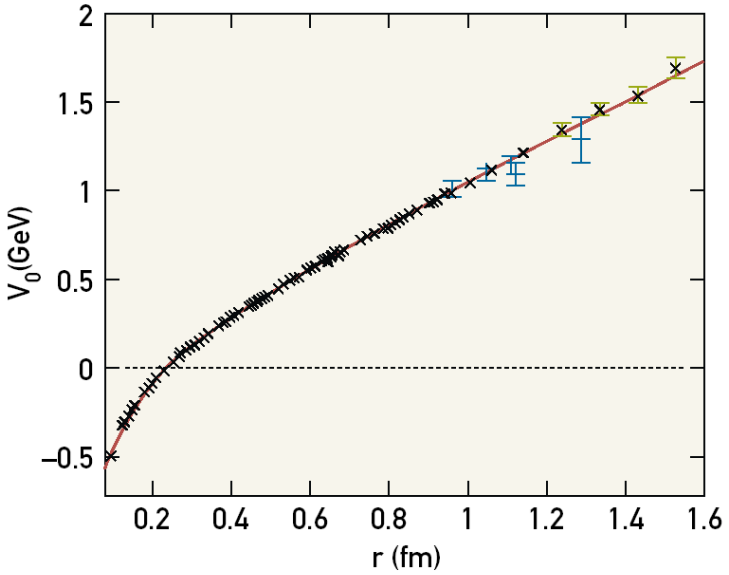
USA

Massachusetts Institute of Technology (MIT)
Cambridge, MA, USA

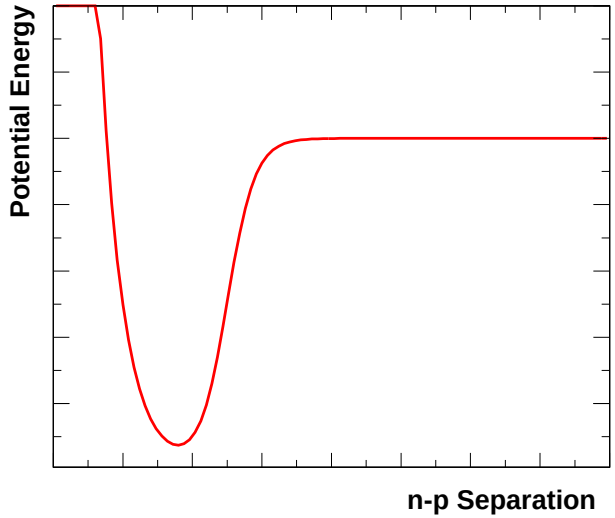
b. 1951

What is the Force?

- Quantum chromodynamics (QCD) looks like the right way to get the force at high energy (Nobel Prize in 2004).



- 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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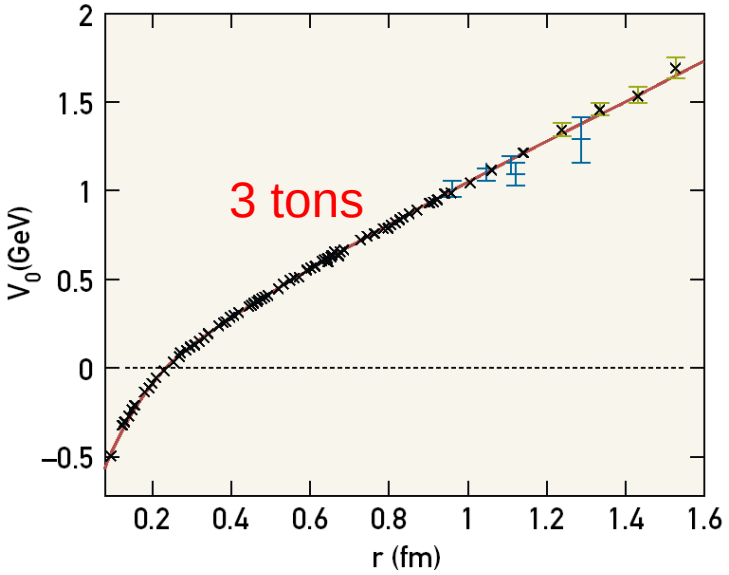

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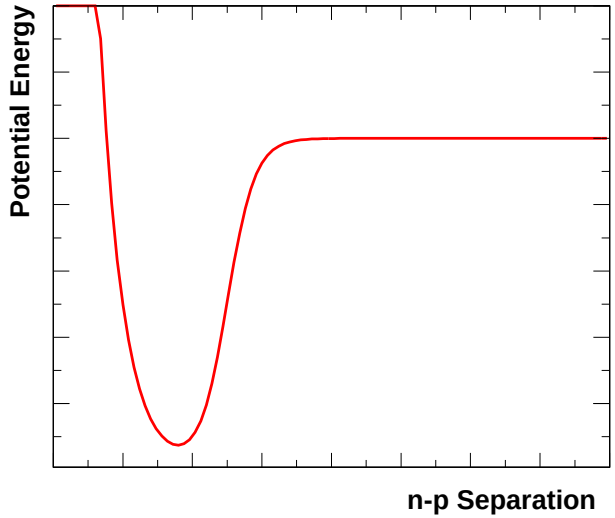
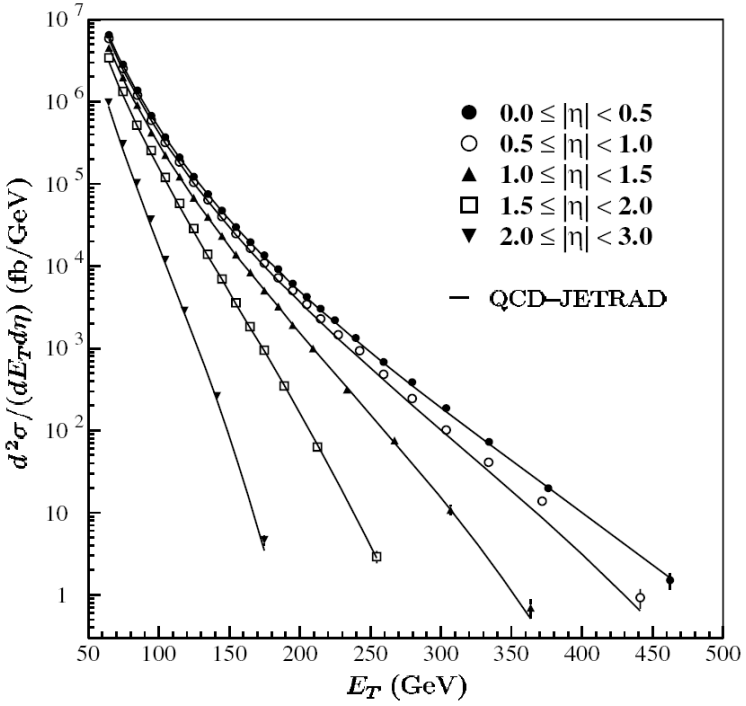
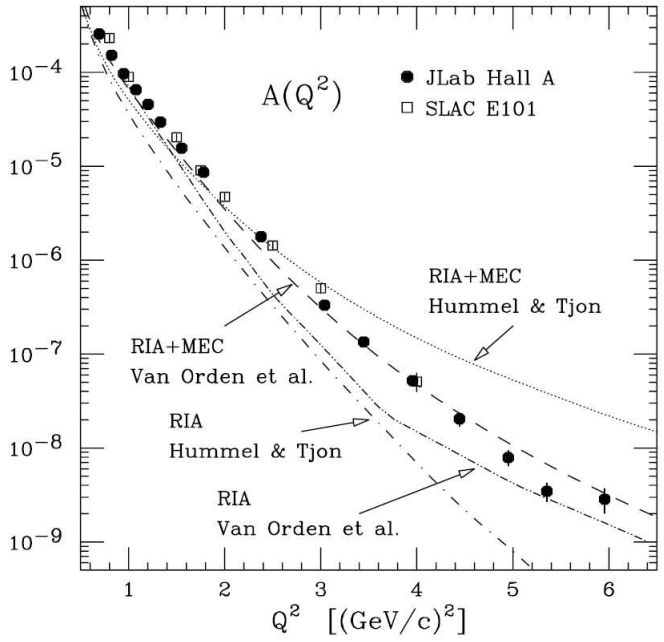


How Well Do We Know It?

- We have a working theory of strong interactions: quantum chromodynamics or QCD (B.Abbott, *et al.*, Phys. Rev. Lett., **86**, 1707 (2001)).

- The coherent hadronic model (the standard model of nuclear physics) works too (L.C.Alexa, *et al.*, Phys. Rev. Lett., **82**, 1374 (1999)).





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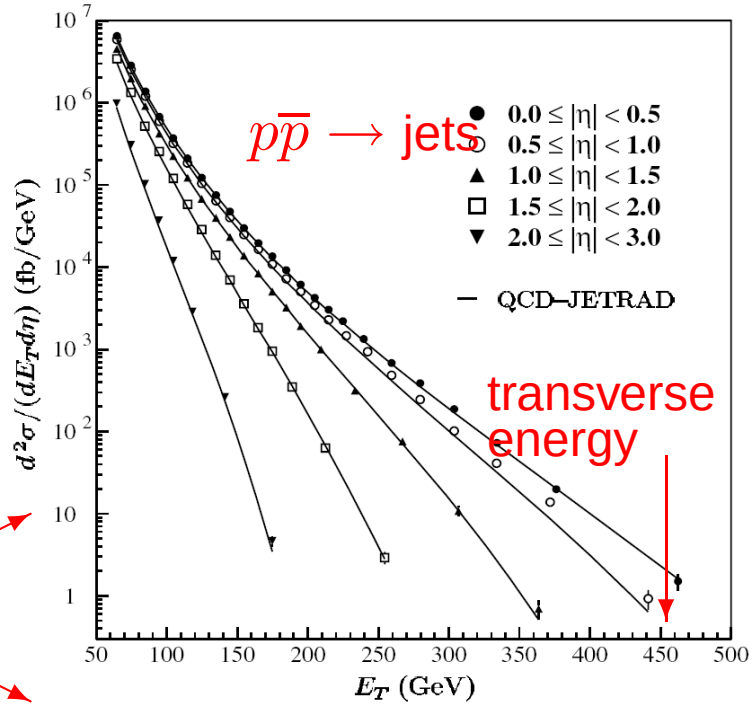
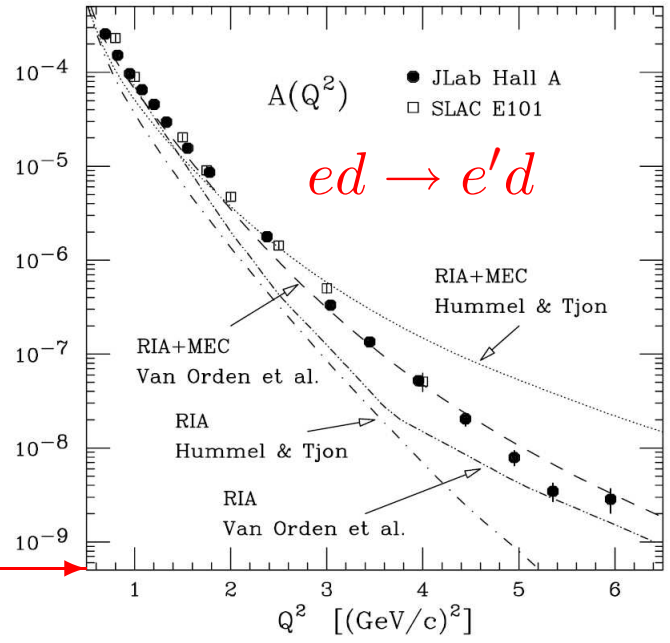


effective target area

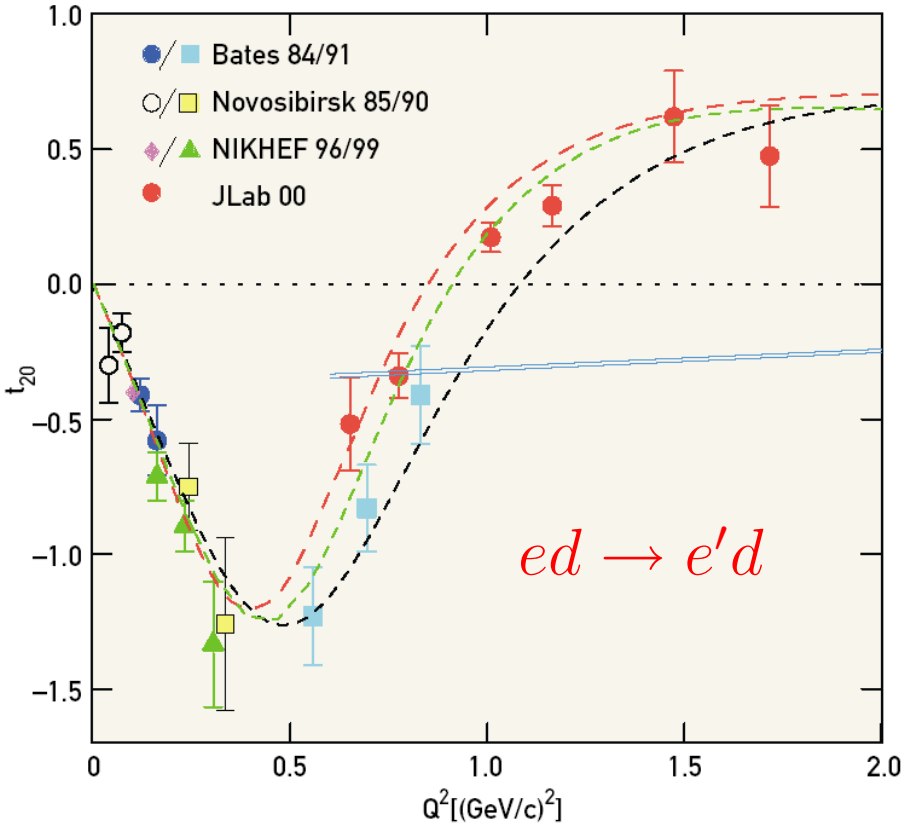


4-momentum transfer squared

What Don't We Know?

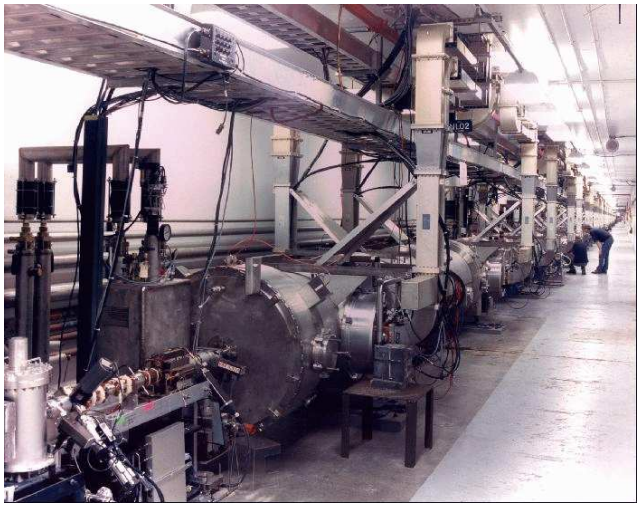
1. We can't get QCD and the hadronic model to line up. D. Abbott, *et al.*, Phys. Rev Lett. **84**, 5053 (2000).

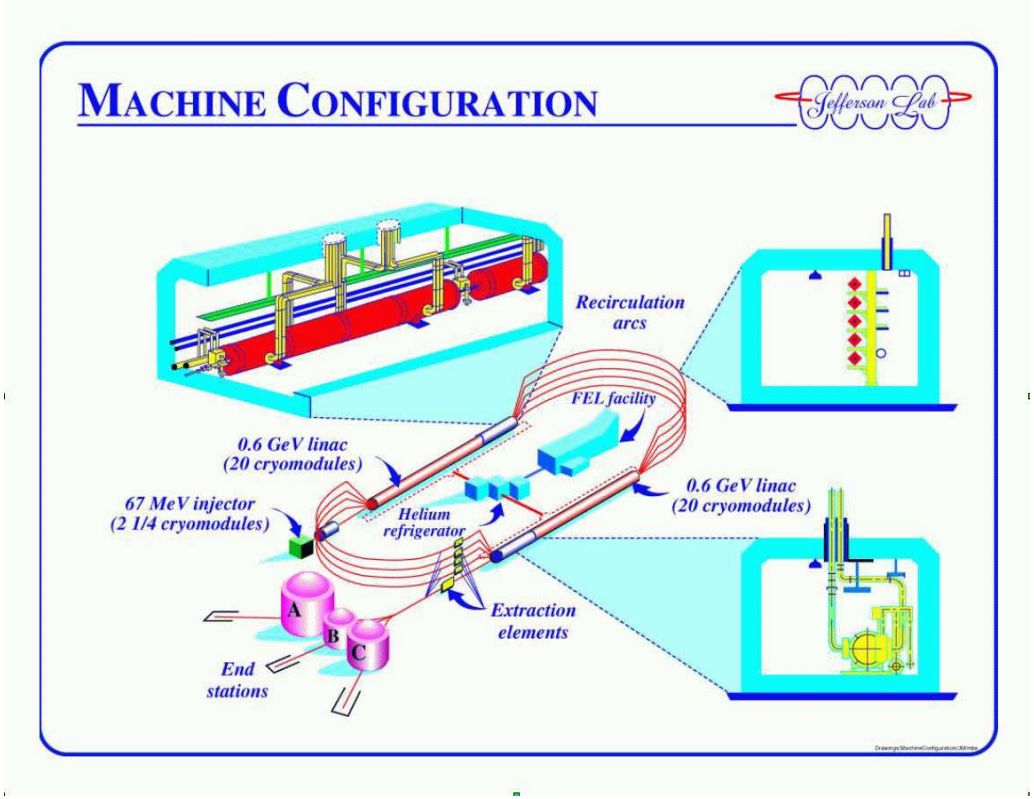
2. NEED TO FIGURE OUT QCD AT THE ENERGIES OF NUCLEI!!



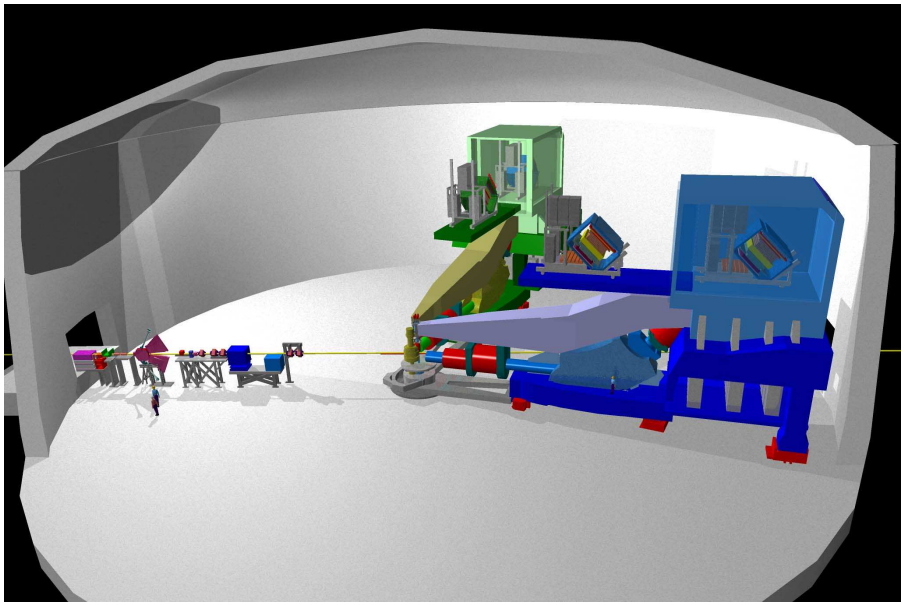
A Laboratory for the Strong Force.

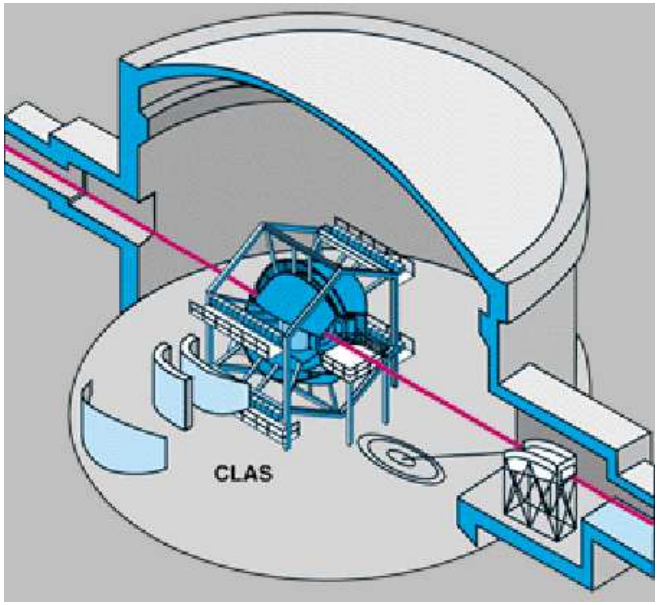
Thomas Jefferson National Accelerator Facility (JLab)

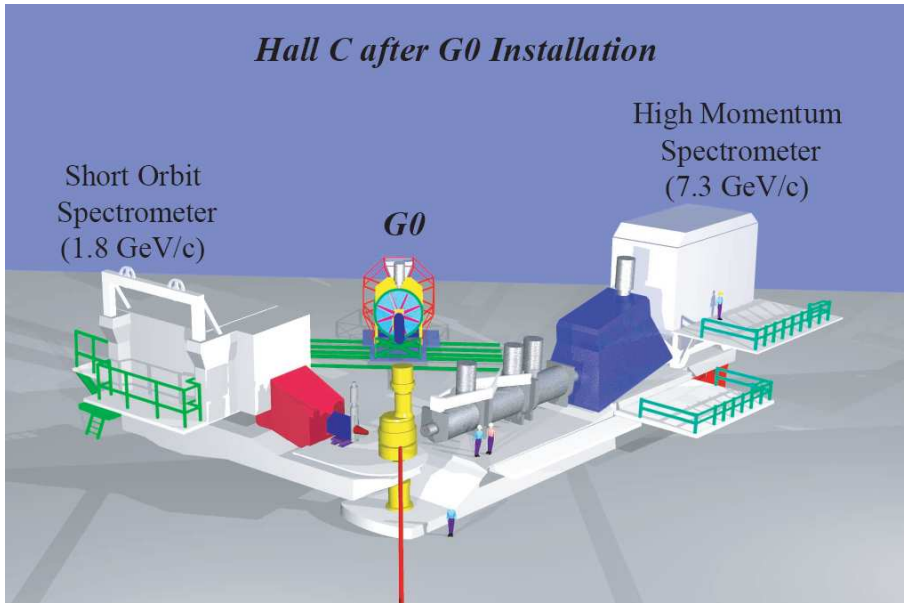




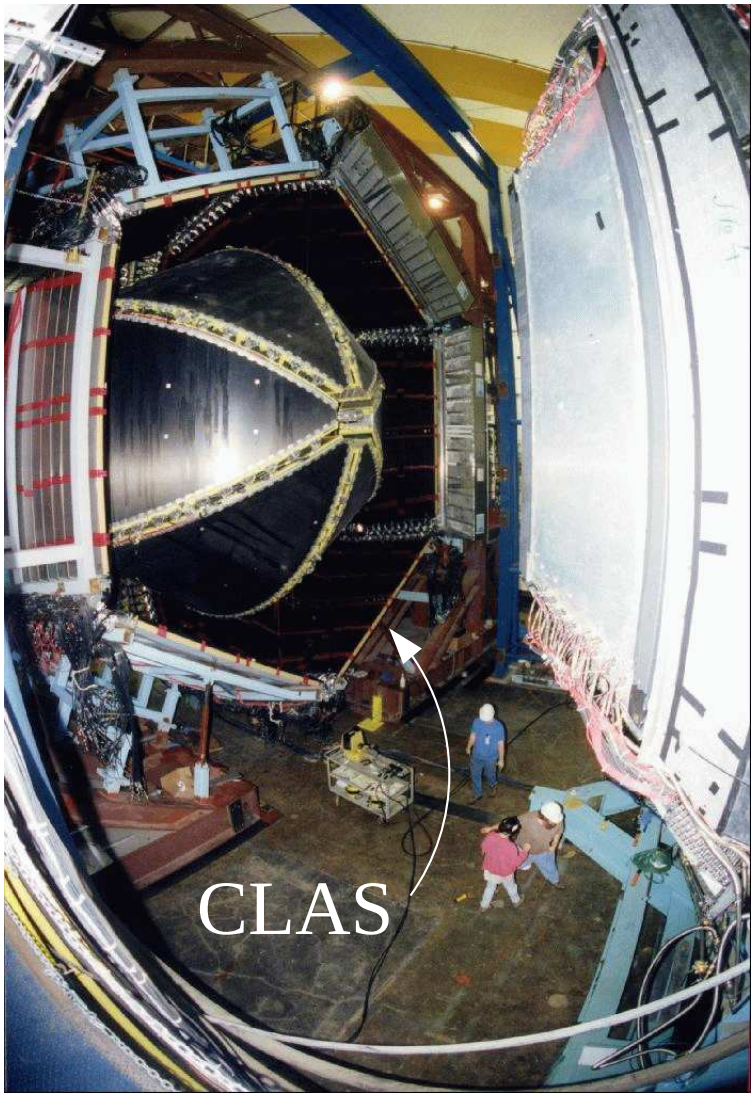
Halls A, B, C

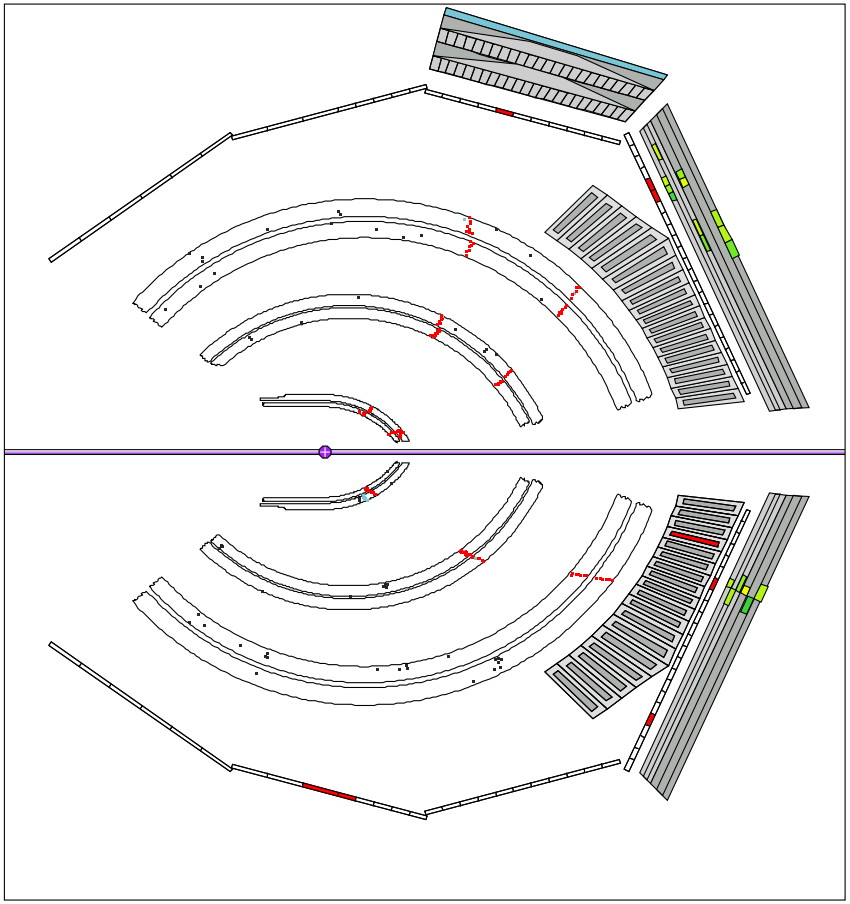



CLAS

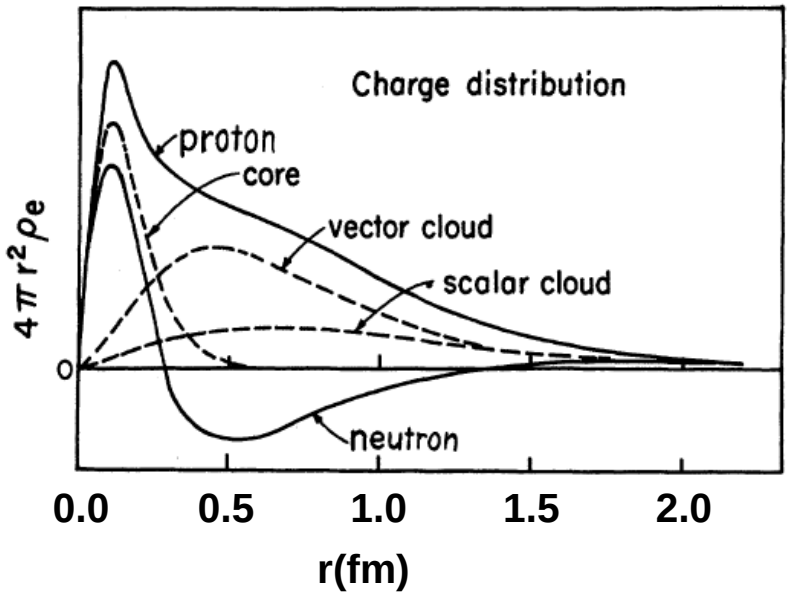

Hall C after G0 Installation
High Momentum
Spectrometer
(7.3 GeV/c)
Short Orbit
Spectrometer
(1.8 GeV/c)
G0

The CEBAF Large Acceptance Spectrometer (CLAS)





What We Knew and Now Know About the Neutron.



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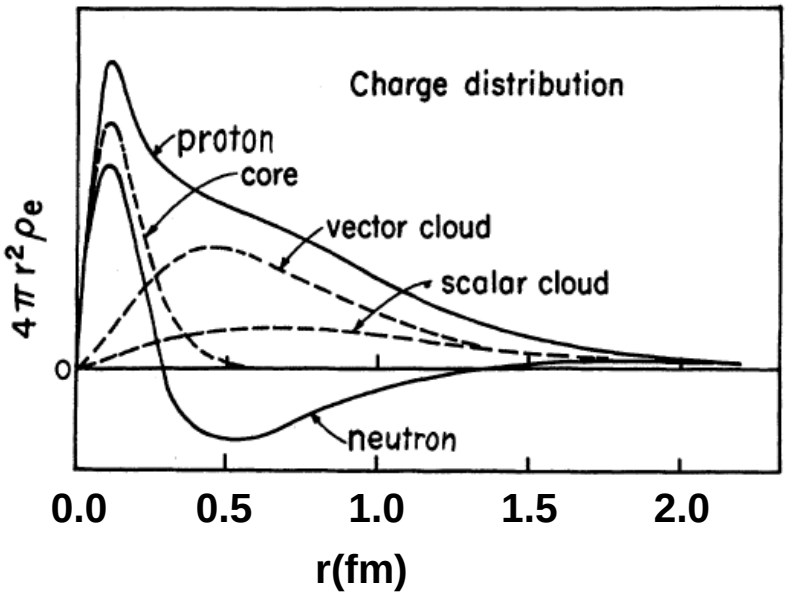

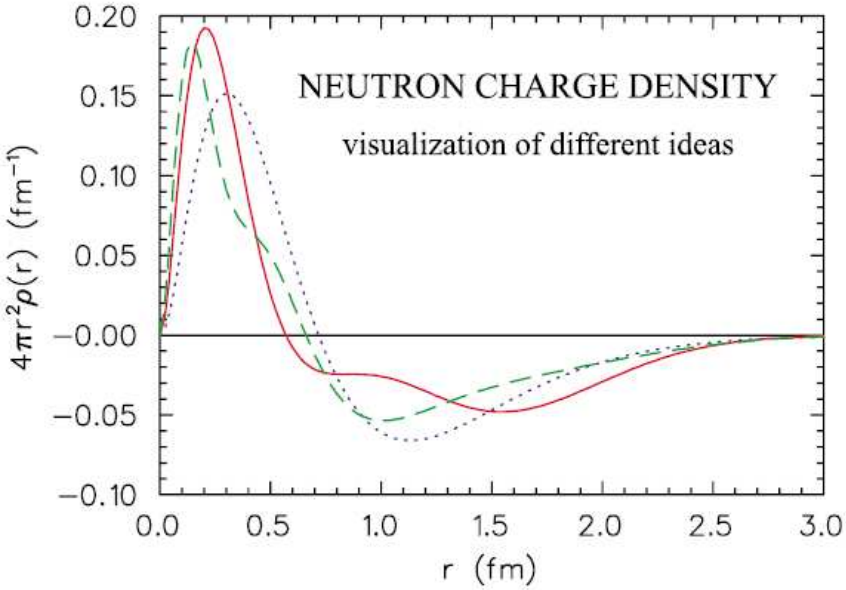

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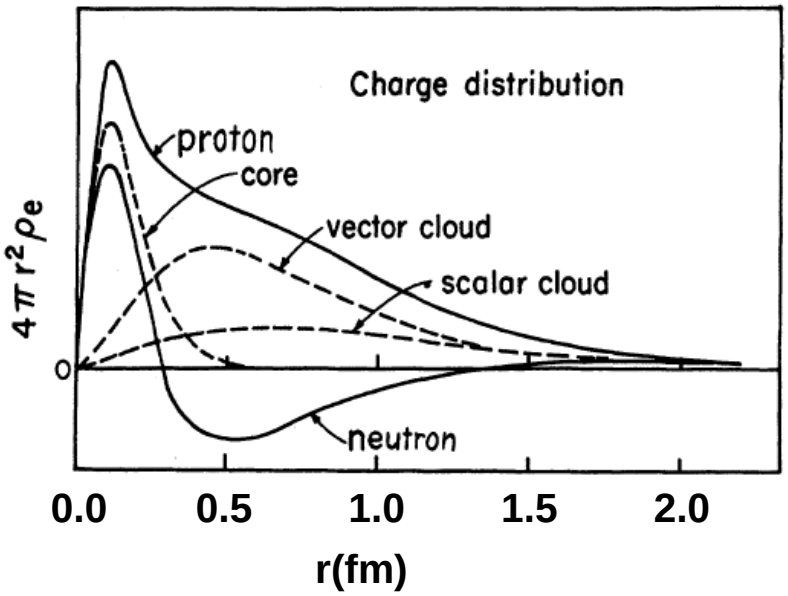

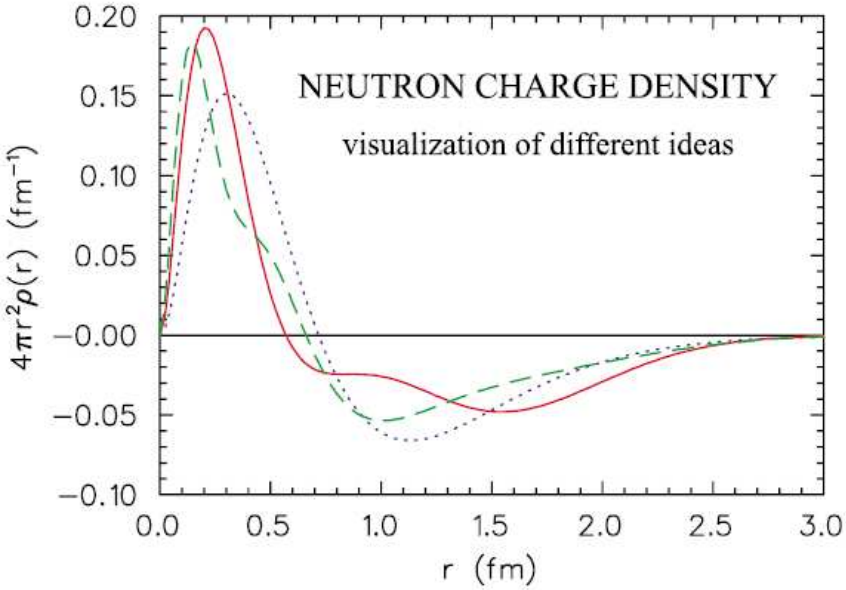

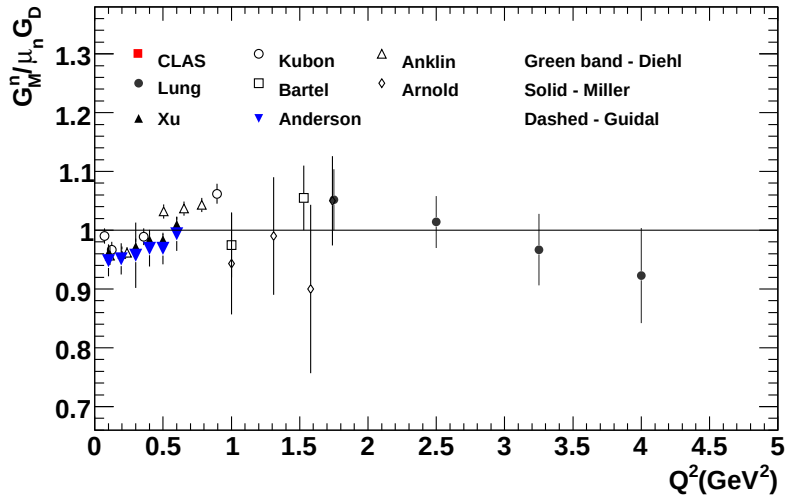

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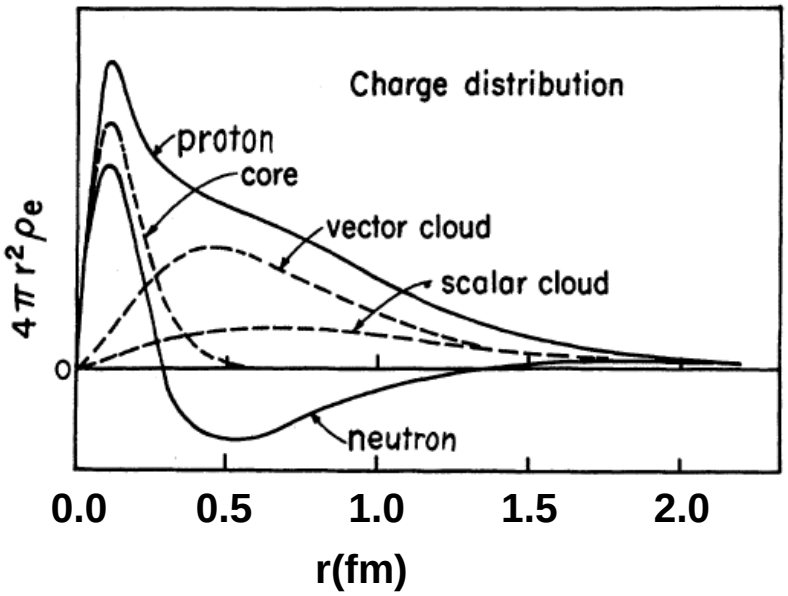

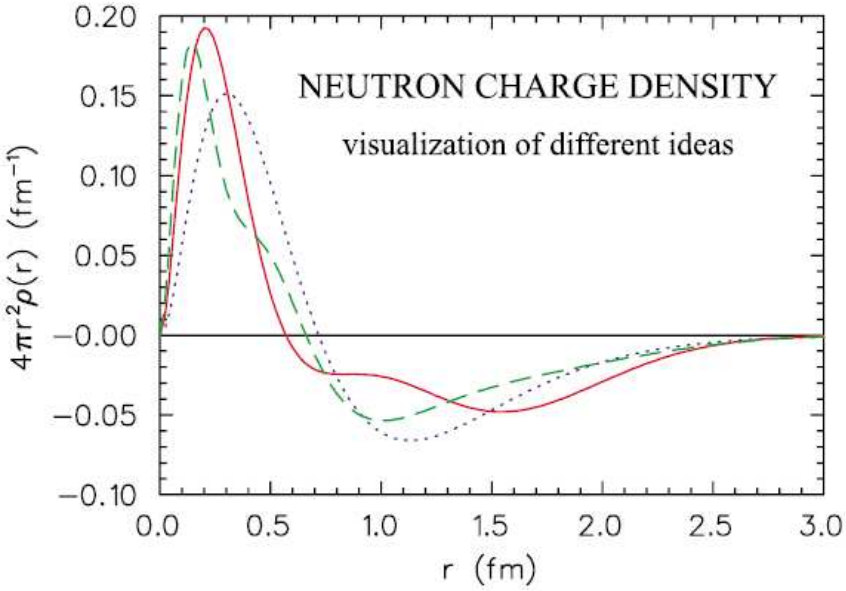

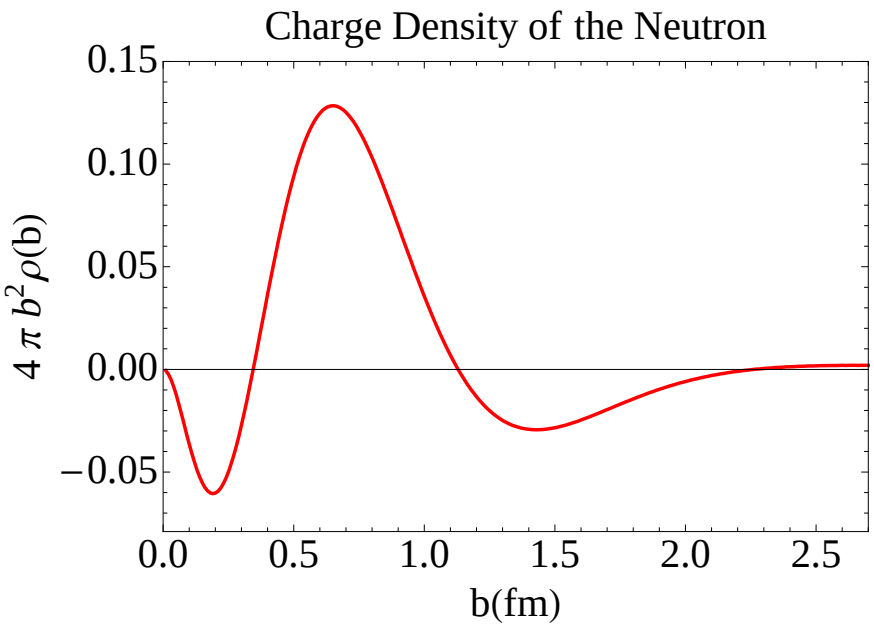

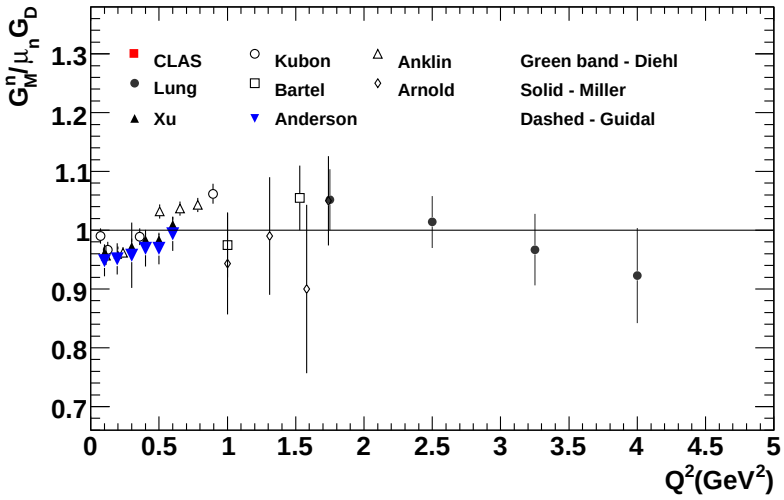

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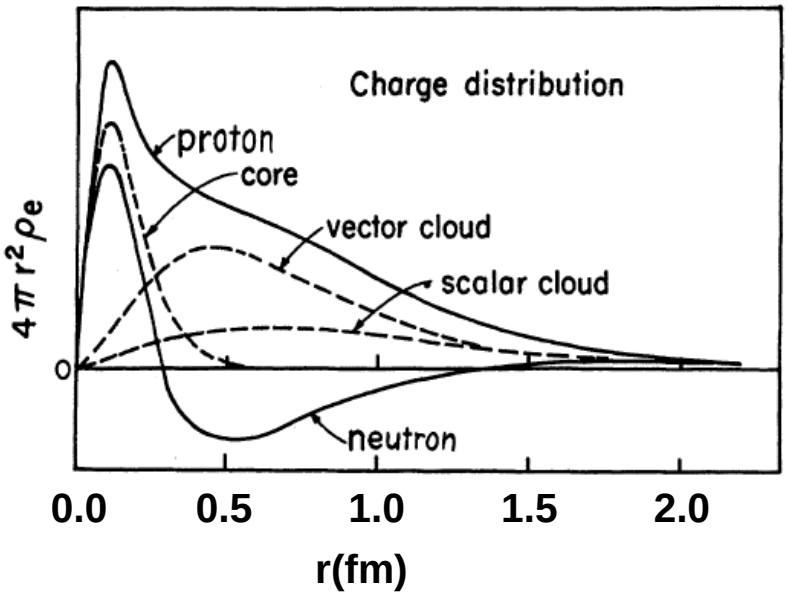

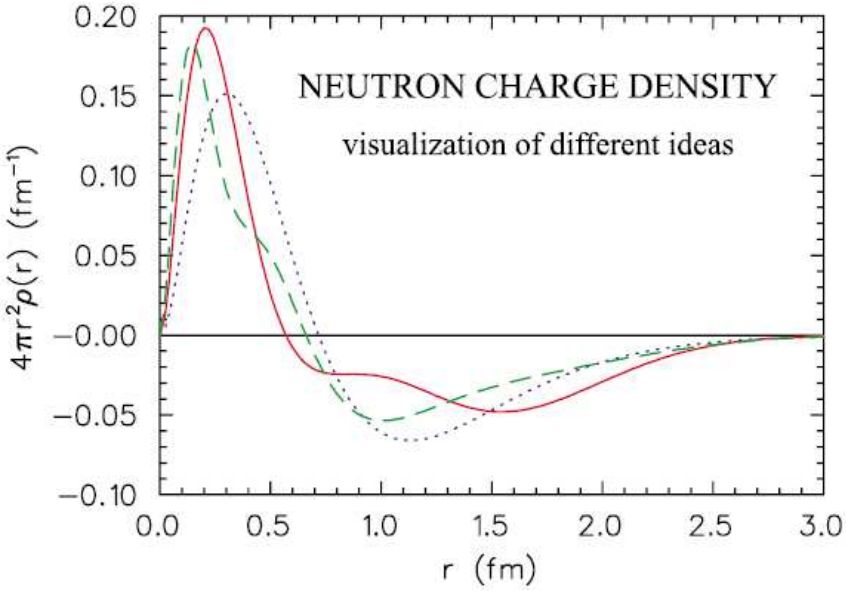

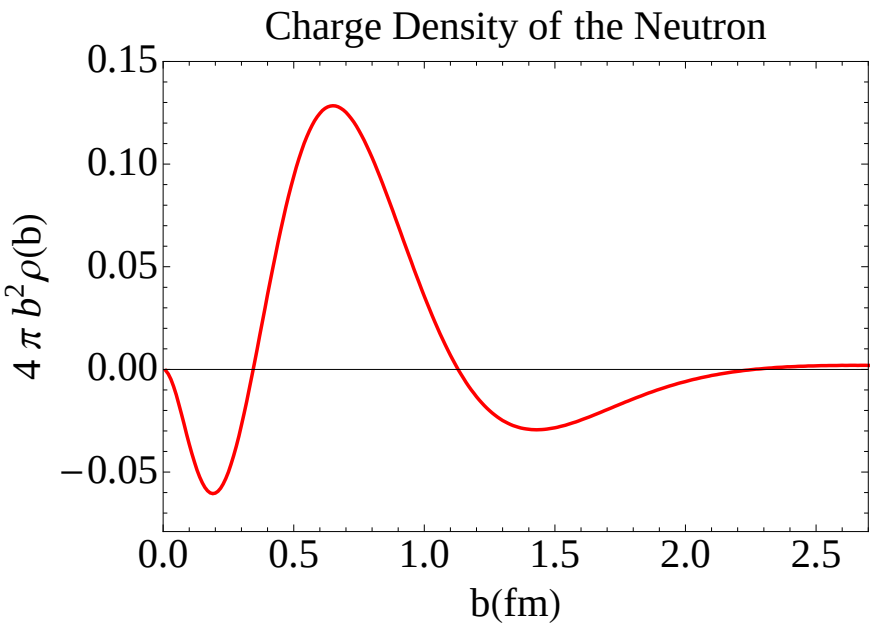

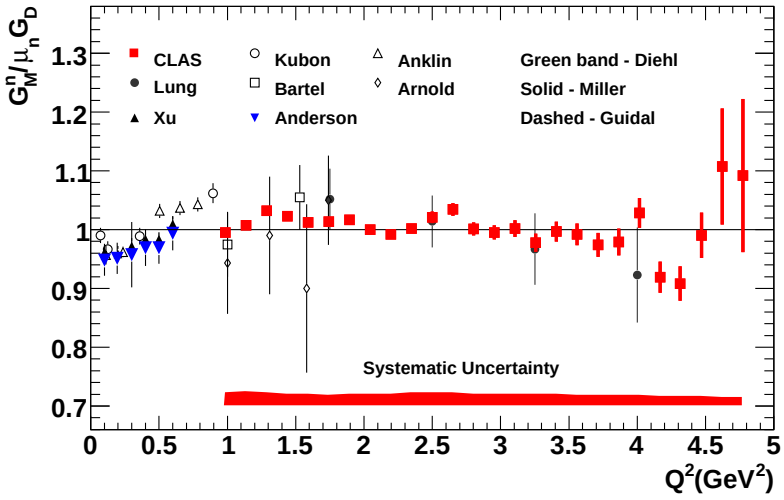

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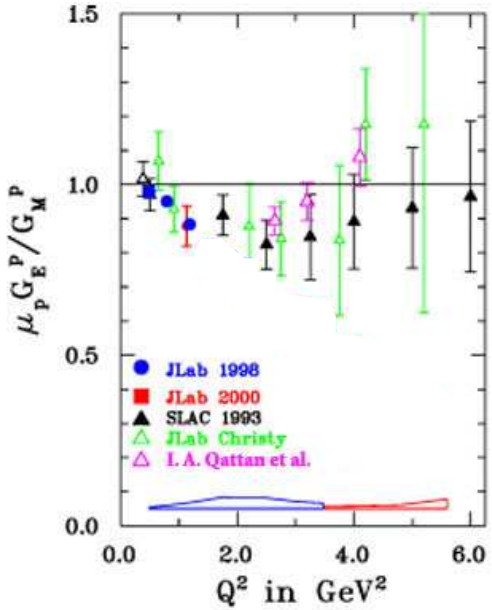
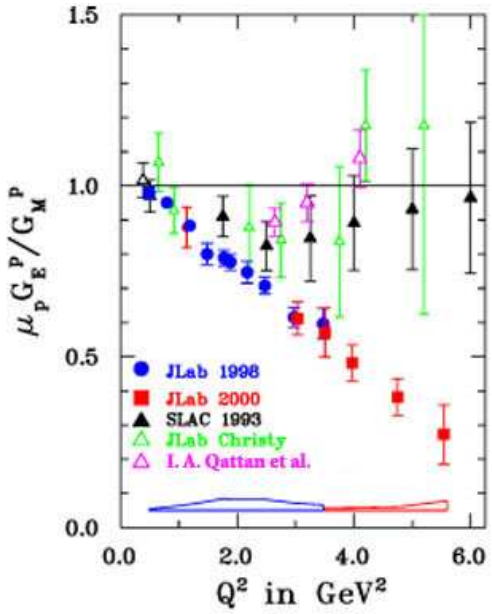


Figure 1: The ratios $\mu_p G_E^p / G_M^p$ from the two JLab recoil polarization experiments, compared to the Rosenbluth separation data.

The Shape of Things We Thought We Knew.



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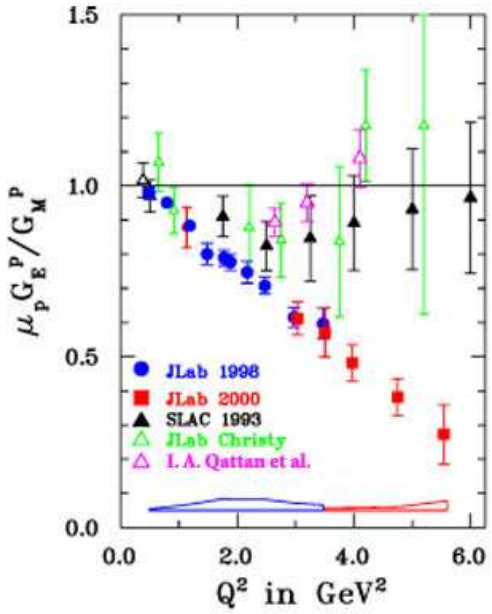

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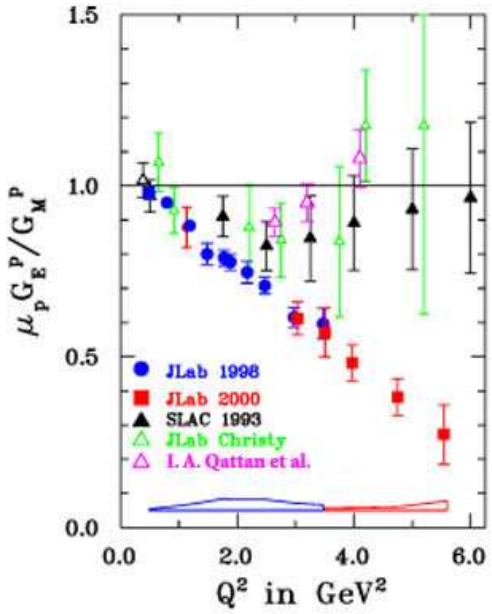

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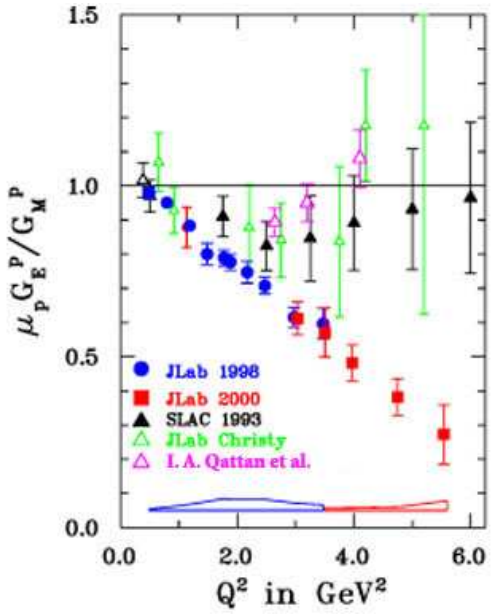

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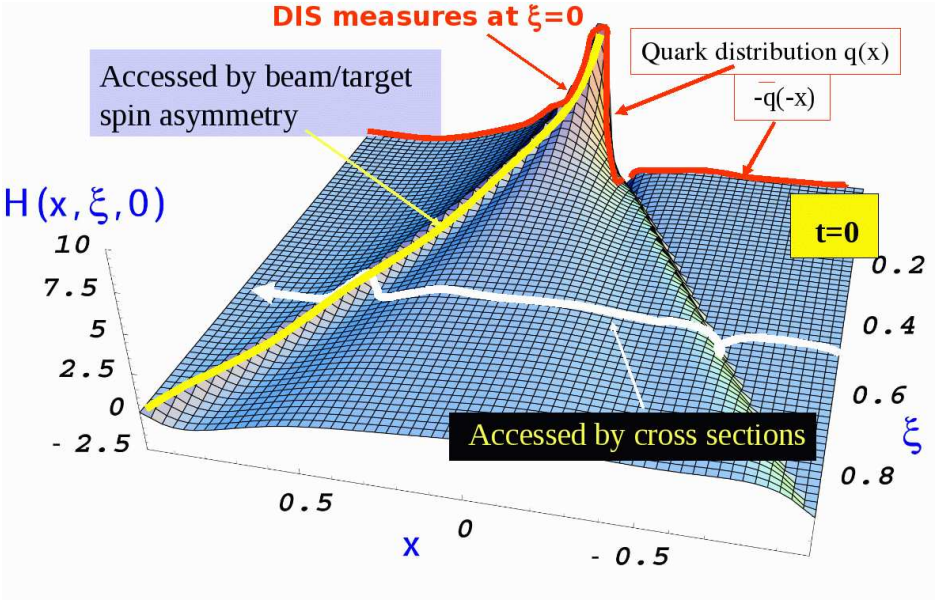

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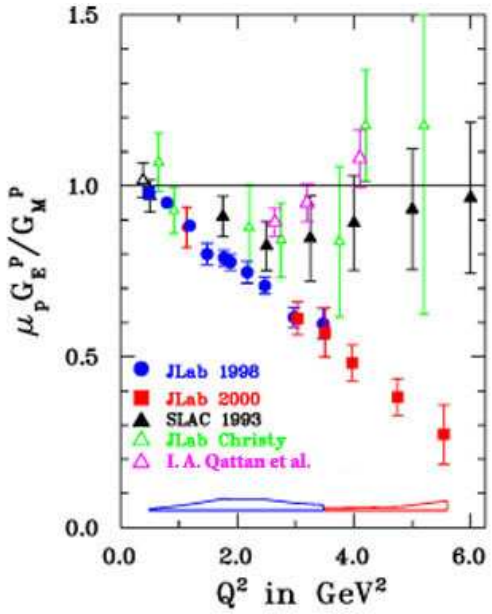

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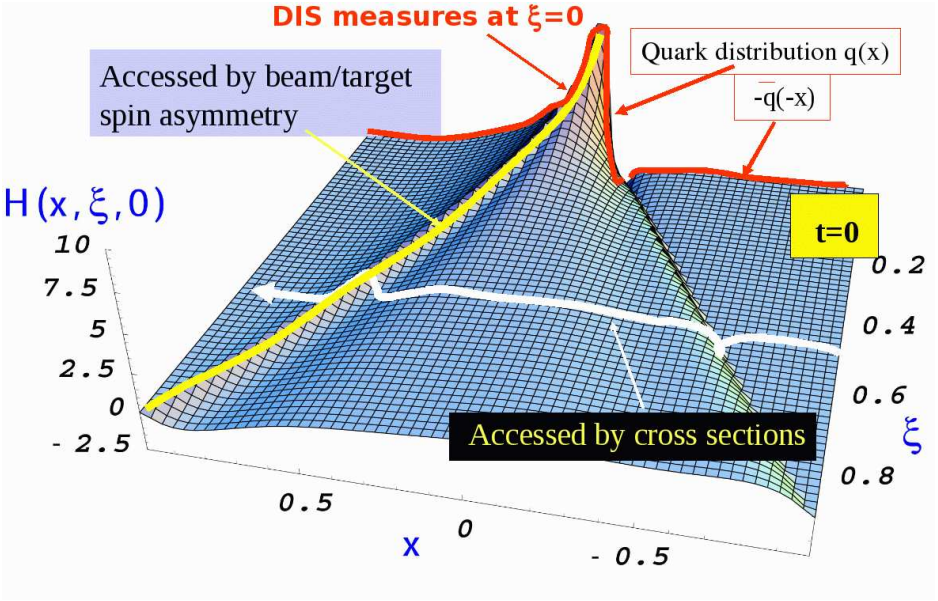

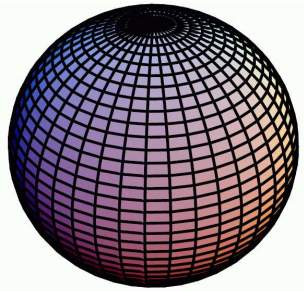

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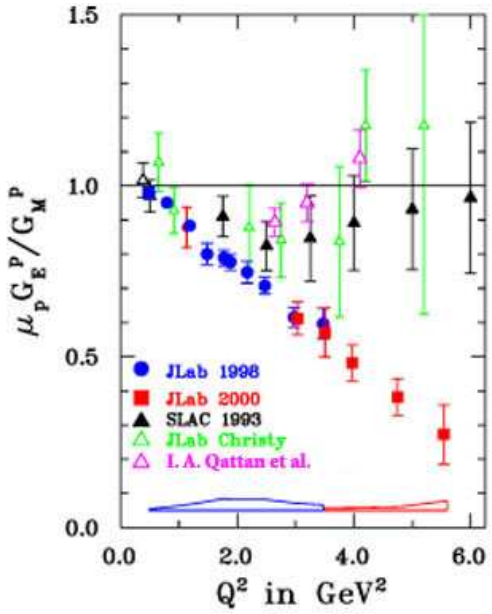

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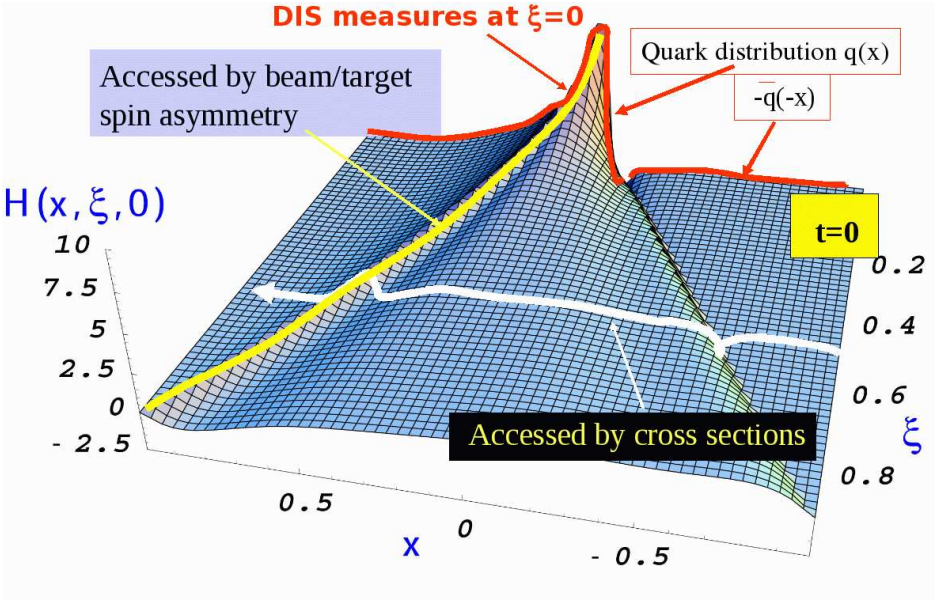

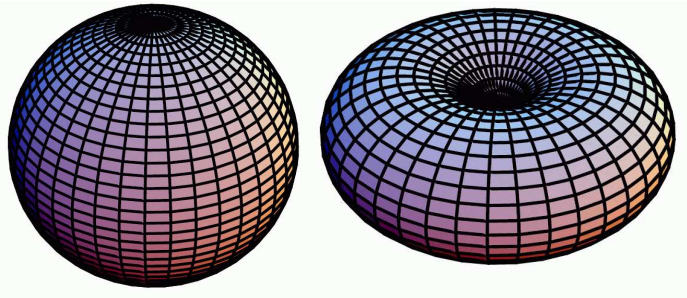

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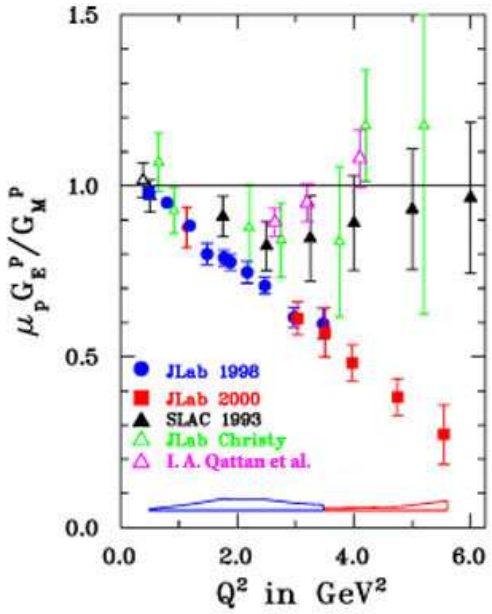

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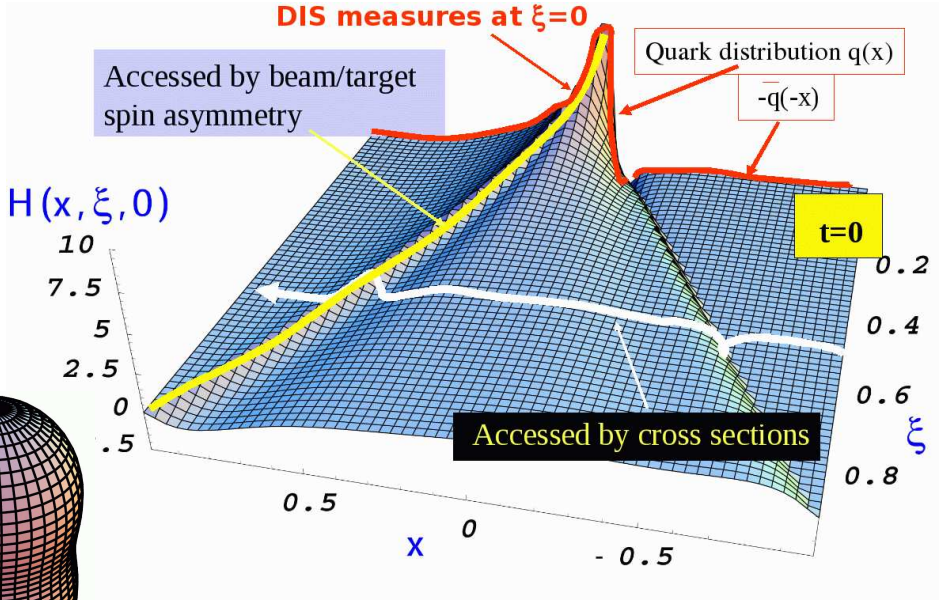

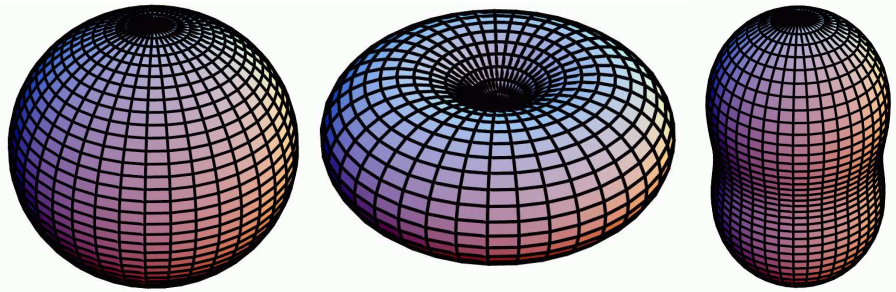

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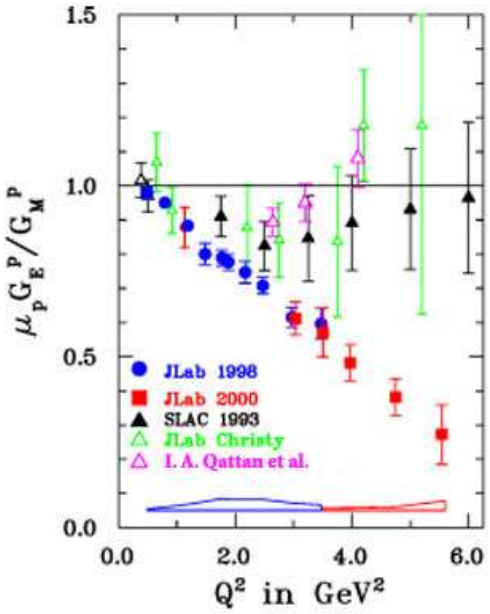

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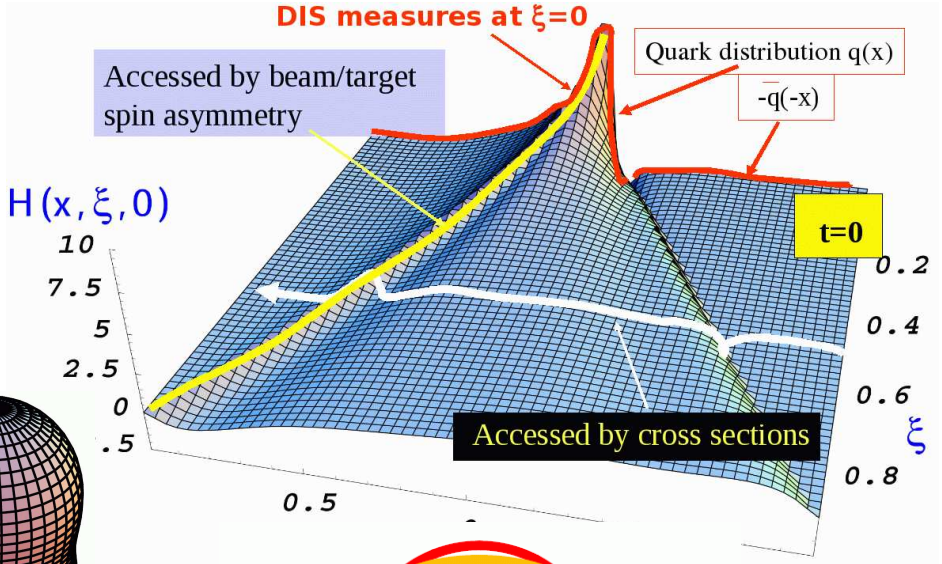
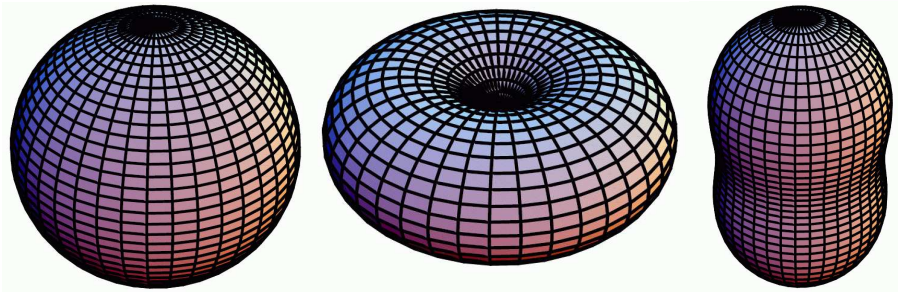
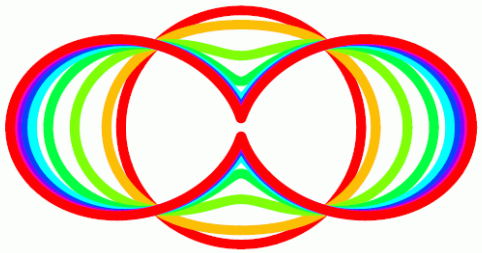
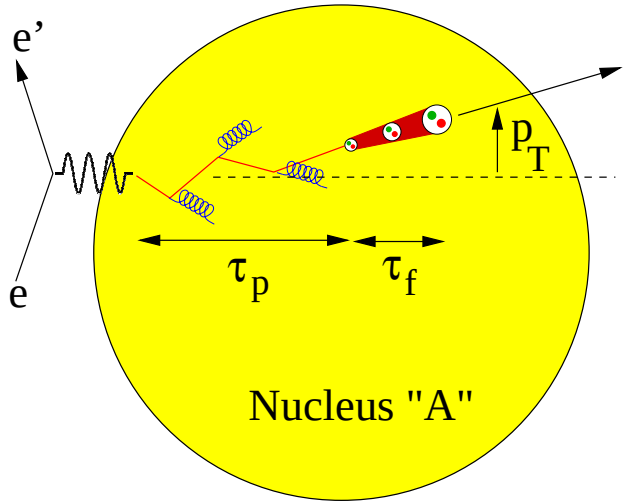






Quark Propagation and Hadron Formation

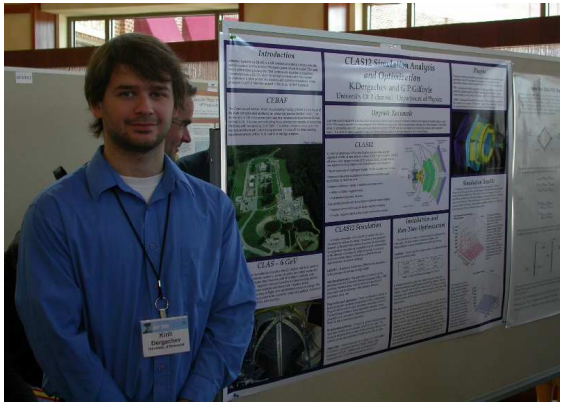
- Probe space-time properties of hadronization in nuclear DIS.
- Struck quark is deconfined and loses energy by multiple scattering and/or gluonic radiation (production time τ_p).
- The quark is finally 'dressed' to form a hadron (formation time τ_f).

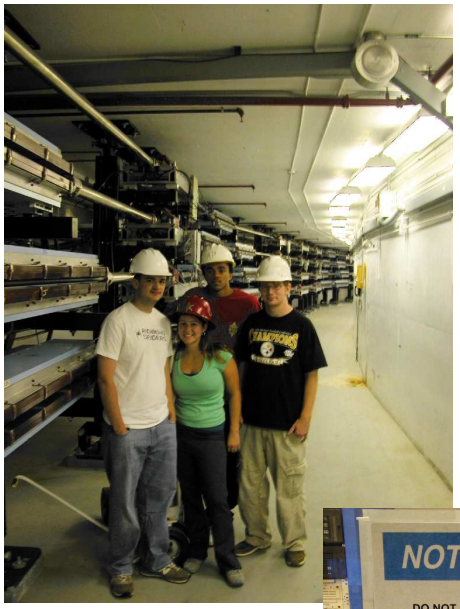


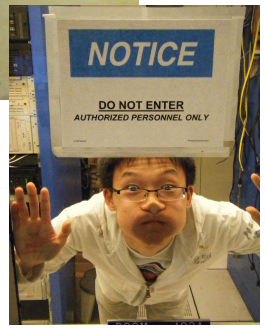
- Direct confrontation of QCD and confinement in the nuclear environment.

- How long can a light quark be deconfined?
- How long does it take to form the color field of a hadron?

Life on the Frontiers of Knowledge







The LHC or JLab - Why should YOU pay for it?

1. Over the last 100 years, at least 50% of the growth in our standard of living is due to technological change.

2. Technological spinoffs: NMR$\longrightarrow$MRI, WWW, transistors, computers, ...

3. Production of trained scientists, engineers, technicians. ....

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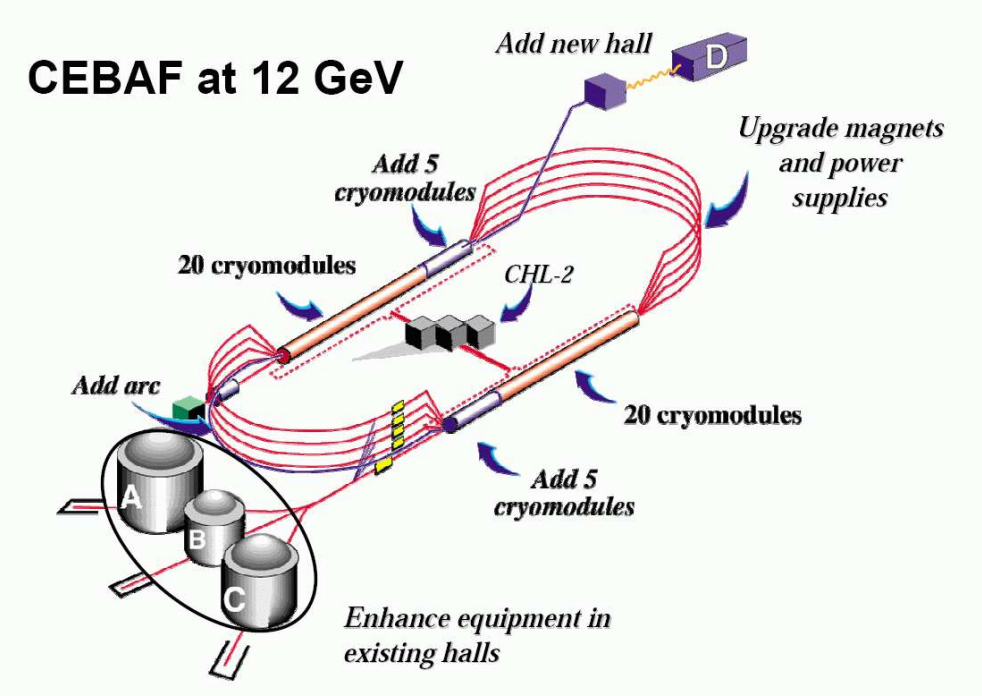
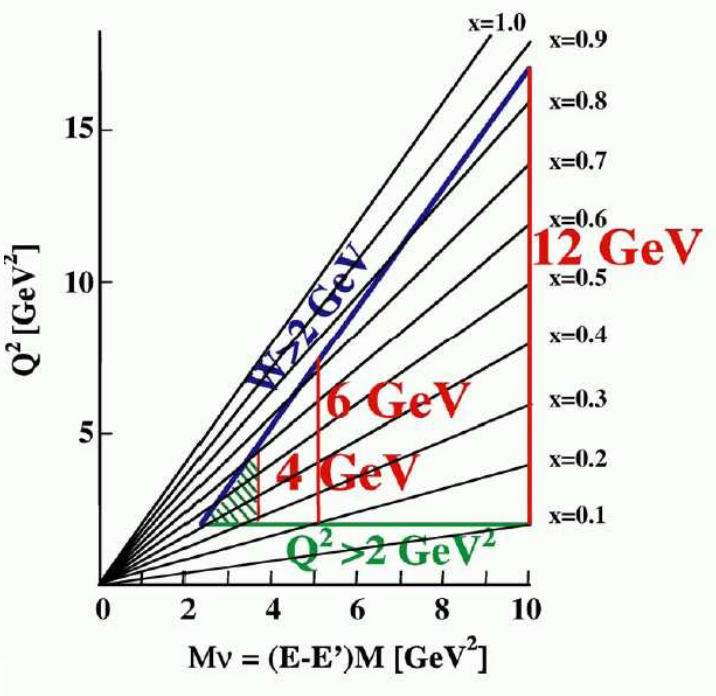
Unknown questioner to Franklin:	Sir, what's the use of flying in the air?
Ben Franklin's answer:	Sir, what's the use of a newborn baby ?

The Future: JLab 12-GeV Upgrade

- The electron beam energy at JLab (CEBAF) will be doubled from 6 GeV to 12 GeV.
- Halls A, B and C will be upgraded to accommodate the new physics opportunities.
- A new hall (Hall D) will house a large-acceptance detector built around a solenoidal magnet for photon beam experiments.
- All of the physics discussed here will be extended to 12 GeV.





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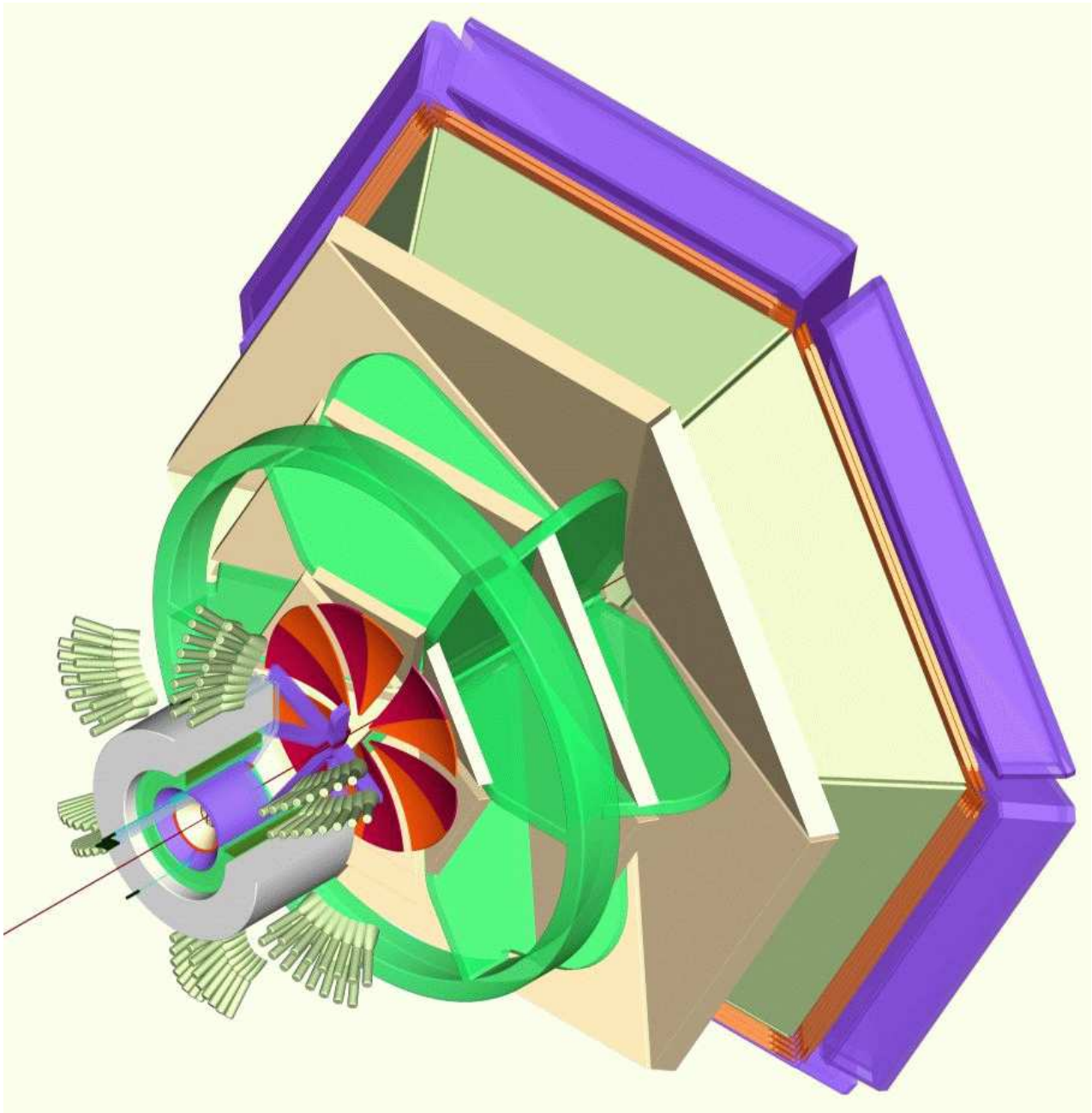

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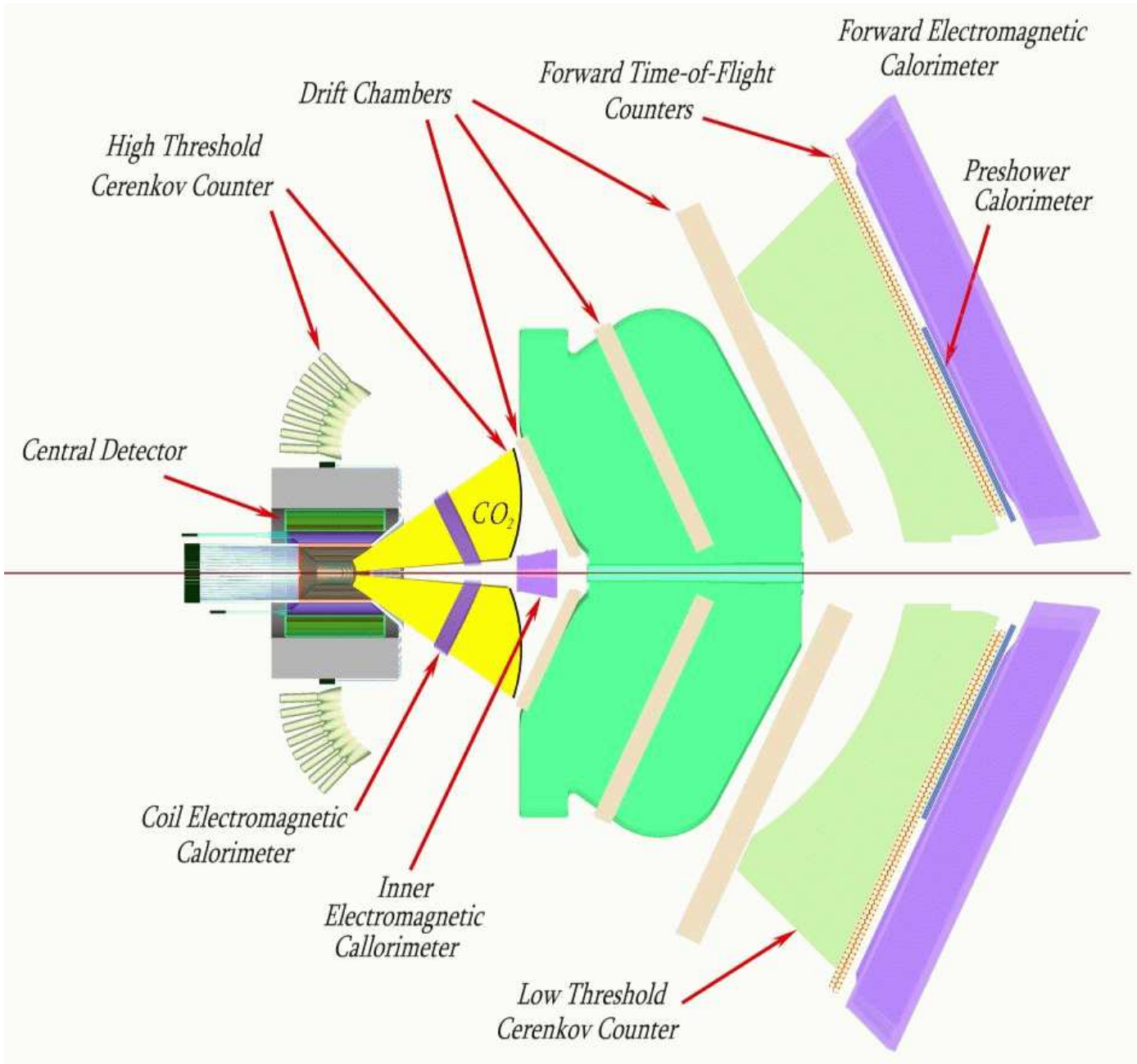

Additional Slides

More Life on the Frontier - the Large Hadron Collider

1. The Large Hadron Collider (LHC) is the largest and highest-energy particle accelerator, colliding opposing beams of protons at 99.999999% of the speed of light.

2. Will test various predictions of high-energy physics, including the existence of the Higgs boson and other new particles.

3. 27 kilometres around, beneath the Franco-Swiss border, built by over 10,000 scientists and engineers from over 100 countries and hundreds of universities and laboratories.

4. On 10 September 2008, the proton beams were successfully circulated in the main ring of the LHC for the first time.

The LHC - It Won't Eat You!

- No danger of creating a black hole that will suck in the Earth despite what some people say.

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Lawsuit: Huge Atom Smasher Could Destroy World

Monday, March 31, 2008

By Paul Wagenseil
FOX NEWS

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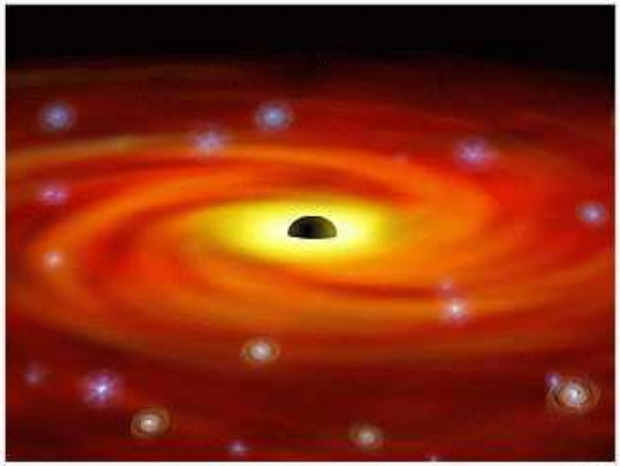

AP

Black holes can be such a drag.

Stop the scientists before they destroy us all!

That's what a Hawaii man with a background in nuclear physics is asking a court to do.

Walter F. Wagner and his colleague Luis Sancho have filed a federal lawsuit seeking to stop work on the Large Hadron Collider, a gigantic atom smasher on the Franco-Swiss border that's set to start operations in May.

• Click here to visit FOXNews.com's Natural Science Center.

Physicists hope its incredible energies will form briefly-lived new particles that could shed light on the origins of the universe, among other marvels.

- It may be responsible for other surprising effects.

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http://www.comedycentral.com/colbertreport/full-episodes/index.jhtml?episodeId=209851

http://www.youtube.com/watch?v=j50ZssEojtM