

What's Inside the Neutron?

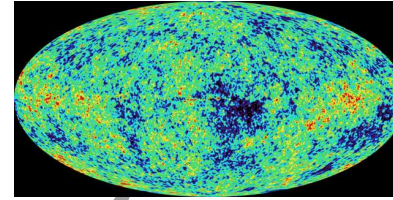
Jerry Gilfoyle, University of Richmond



"The Periodic Table"

What Do We Know?

From the Edge of the Universe to



10^{26} m

the Earth to ...

10^7 m



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

NIST Physics Laboratory Holdings by Element

1																		2																	
1	H																	2	He																
3	Li	4	Be											5	B	6	C	7	N	8	O	9	F	10	Ne										
11	Na	12	Mg											13	Al	14	Si	15	P	16	S	17	Cl	18	Ar										
19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr
37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe
55	Cs	56	Ba			72	Hf	73	Ta	74	W	75	Re	76	Os	77	Ir	78	Pt	79	Au	80	Hg	81	Tl	82	Pb	83	Bi	84	Po	85	At	86	Rn
87	Fr	88	Ra			104	Rf	105	Db	106	Sg	107	Bh	108	Hs	109	Mt	110	Uun	111	Uuu	112	Uub			114	Uuq			116	Uuh				
						57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu
						89	Ac	90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Md	102	No	103	Lr

- Solid
- Liquid
- Gas
- Artificially Prepared
- Disabled - no holdings

[Instructions](#) | [Database Information](#)

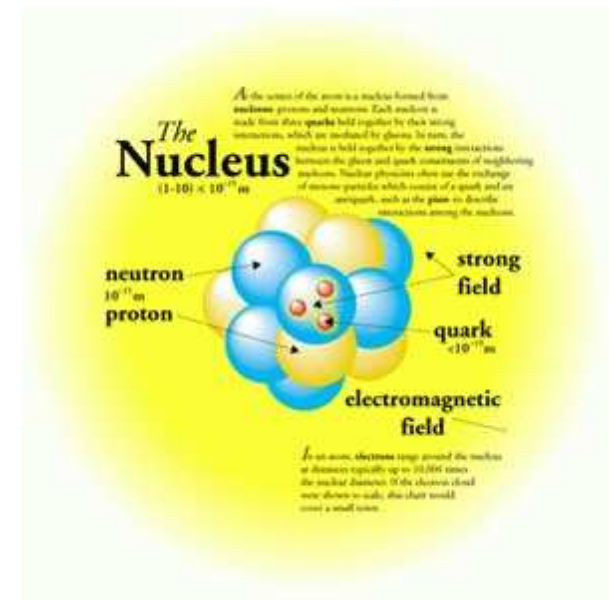
What Do We Know?

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

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			
Z⁰	91.187	0			

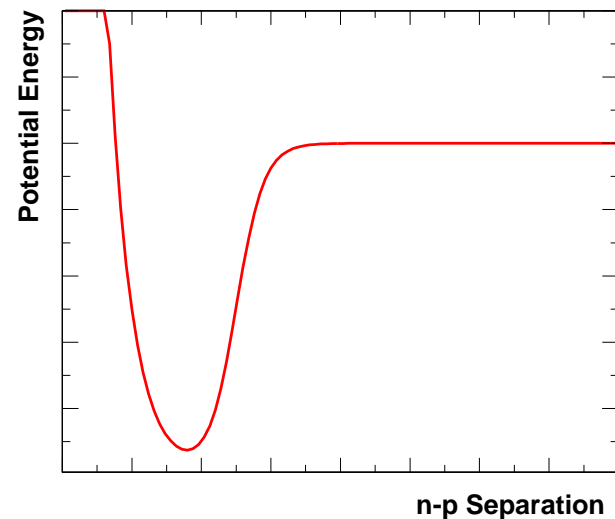
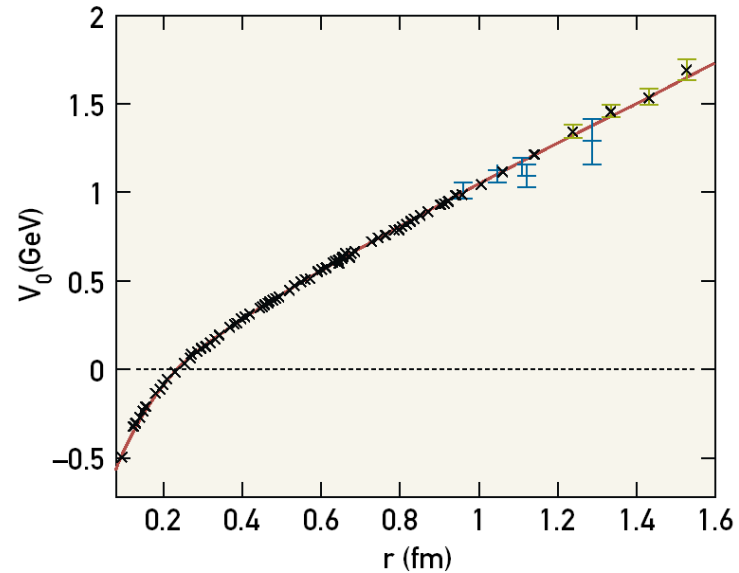
FERMIONS			matter constituents spin = 1/2, 3/2, 5/2, ...		
Leptons spin = 1/2			Quarks spin = 1/2		
Flavor	Mass GeV/c ²	Electric charge	Flavor	Approx. Mass GeV/c ²	Electric charge
ν_e electron neutrino	$<1 \times 10^{-8}$	0	u up	0.003	2/3
e electron	0.000511	-1	d down	0.006	-1/3
ν_μ muon neutrino	<0.0002	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

- 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.



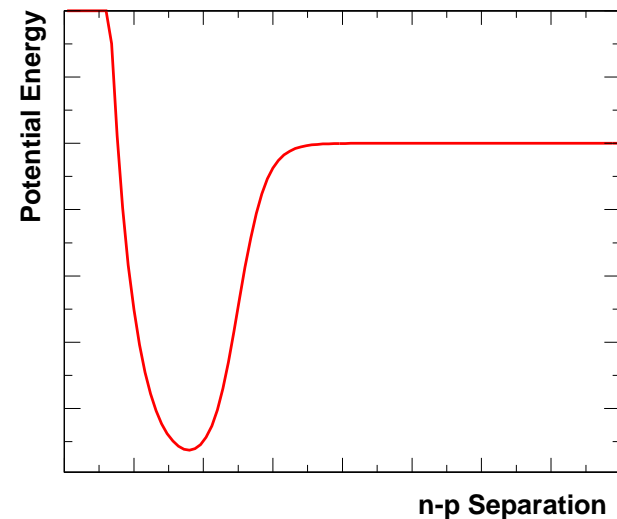
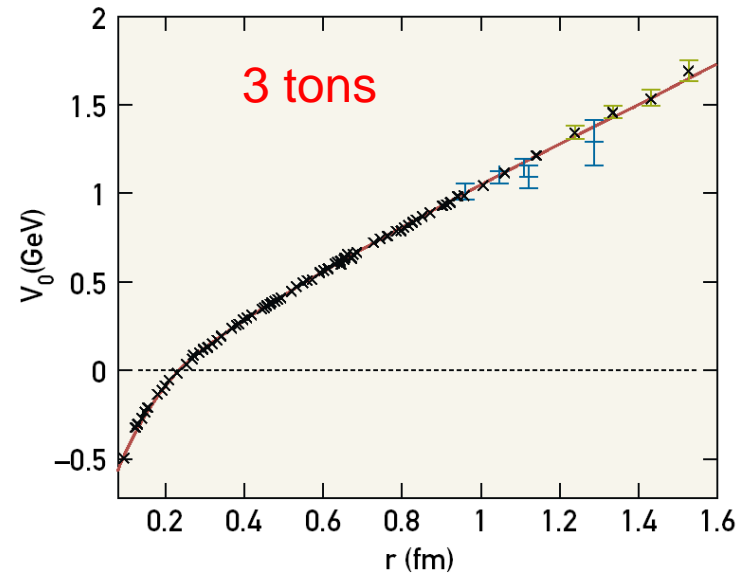
What is the Force?

- 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.



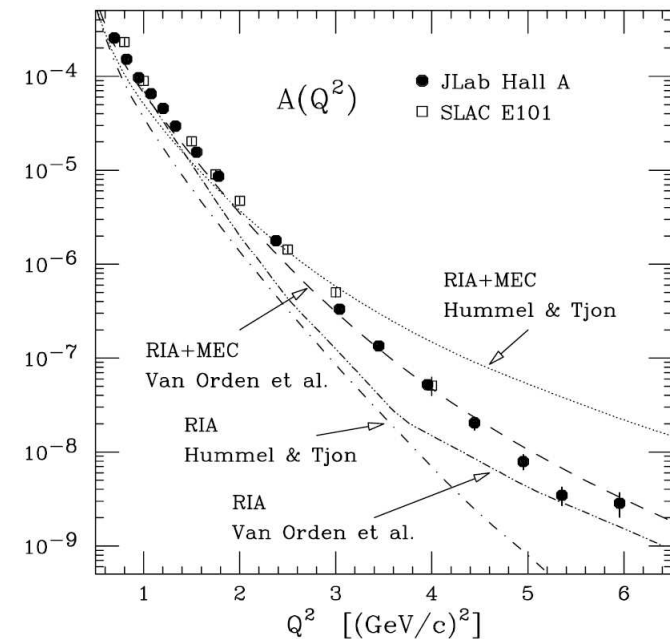
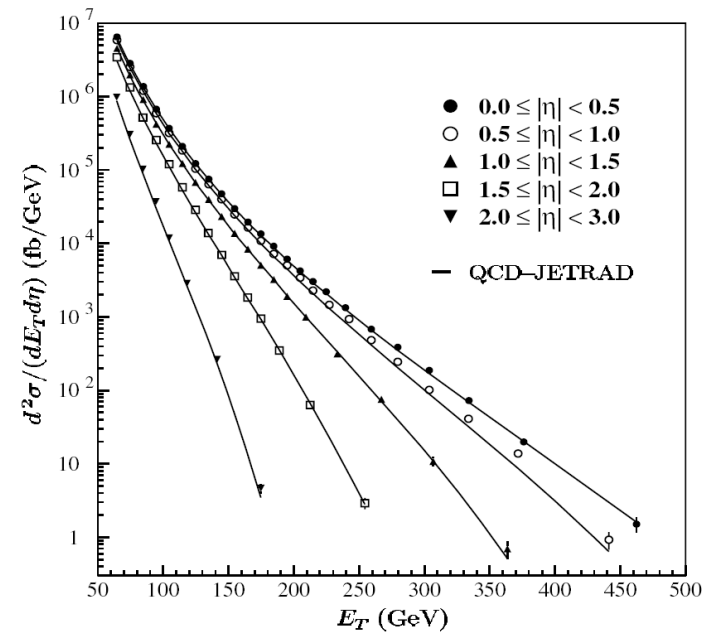
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How Well Do We Know It?

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



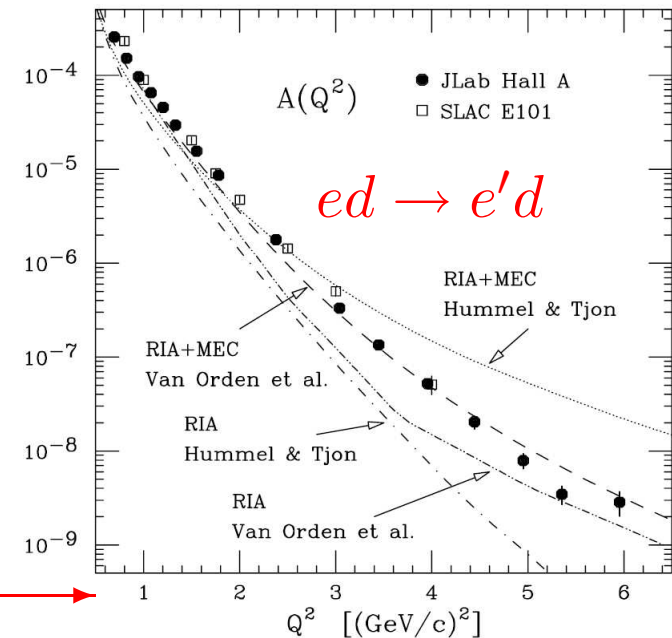
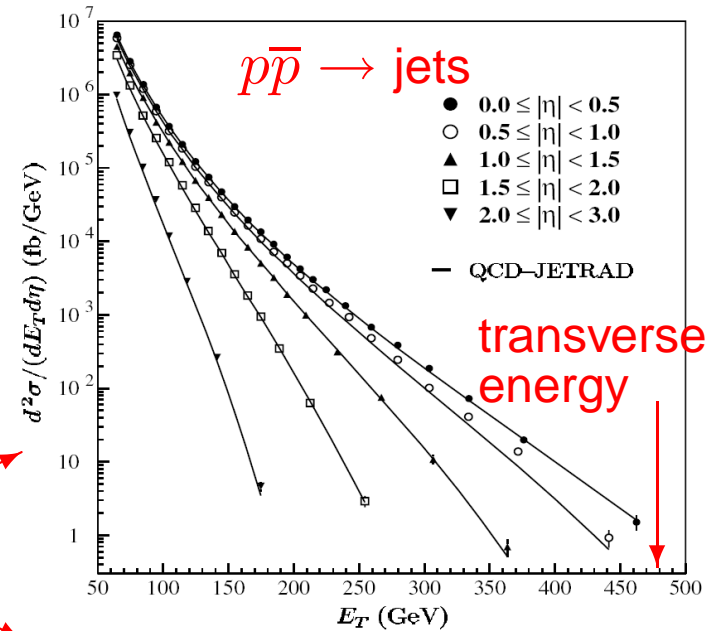
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effective target area

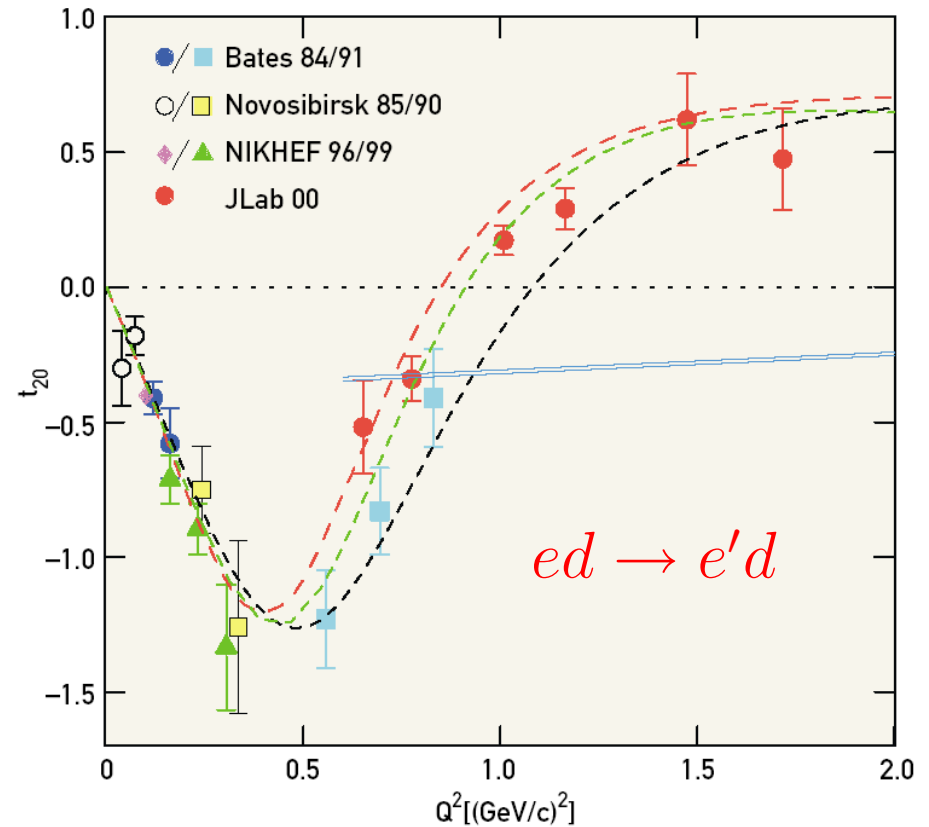
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4-momentum transfer squared



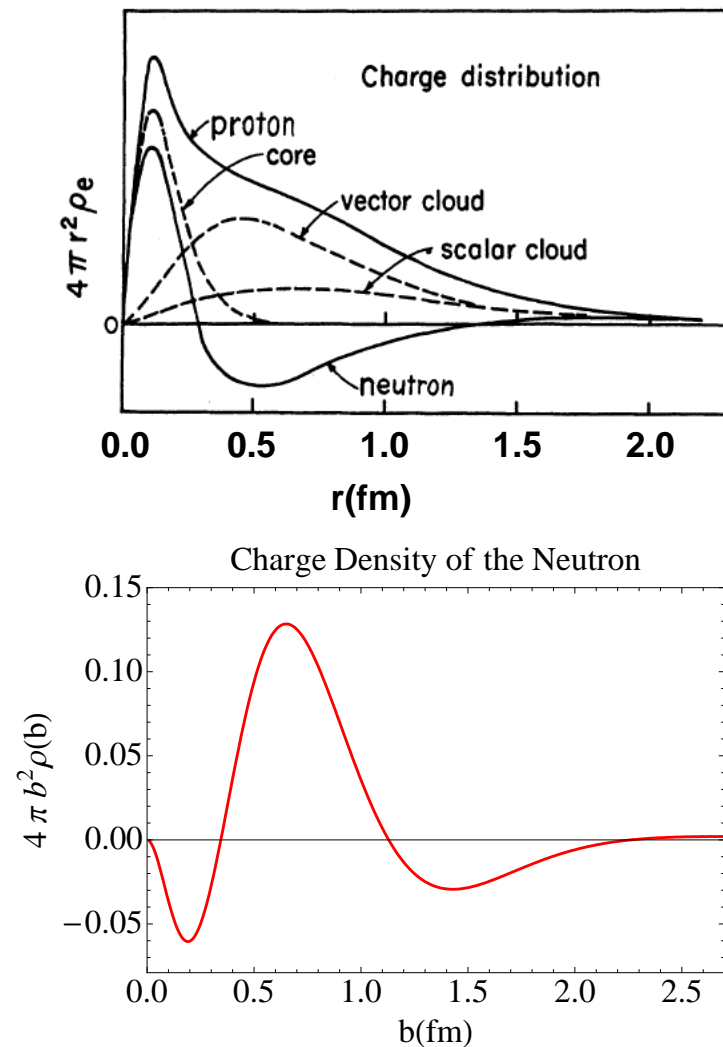
What Don't We Know?

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!!

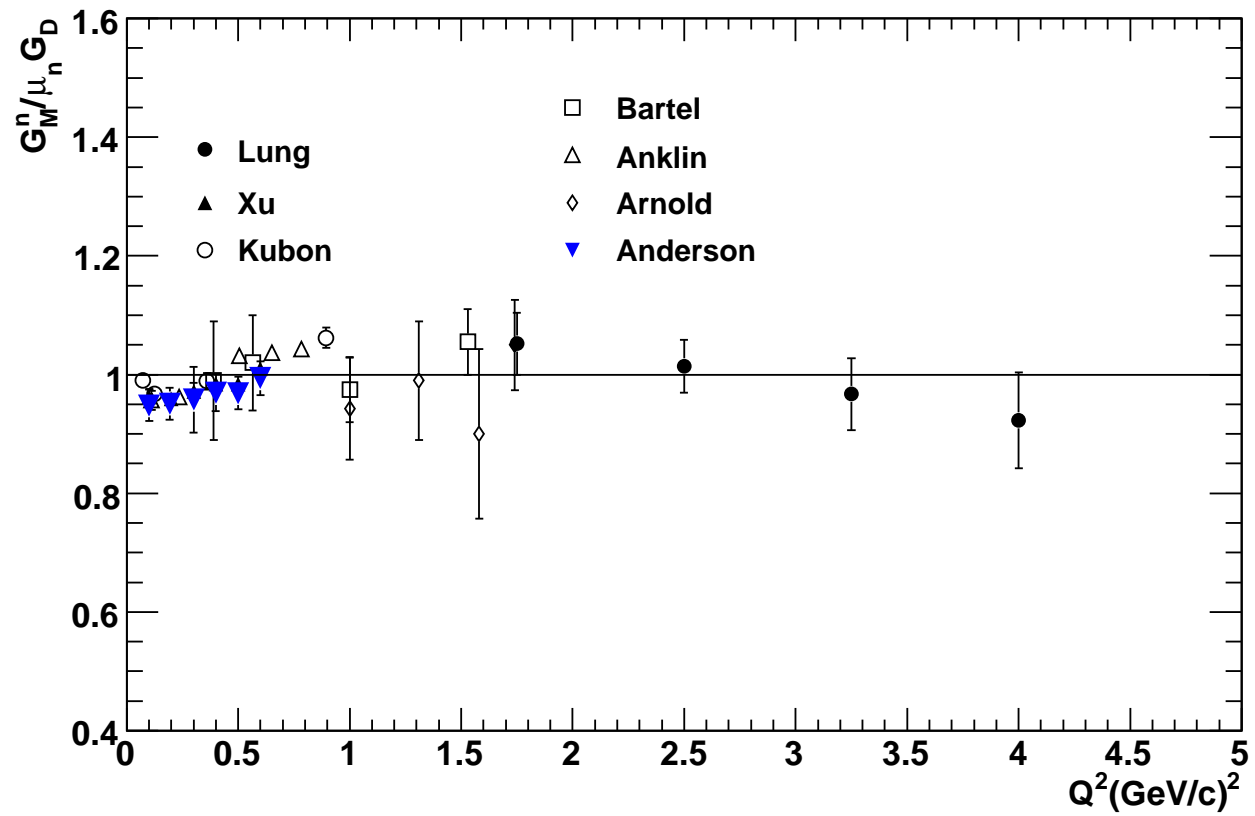


What We Knew and Now Know About the Neutron.

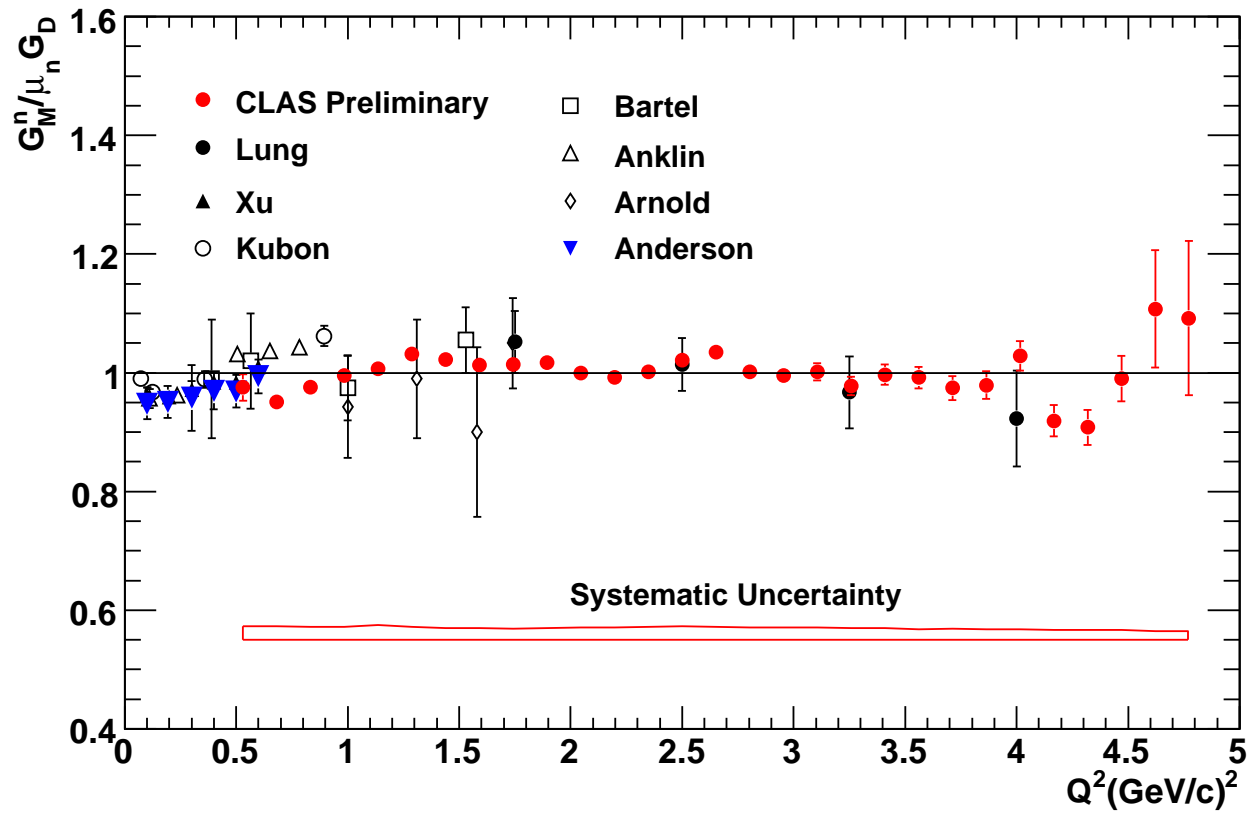
- Comparison with previous results. Note that b and r are conceptually different.



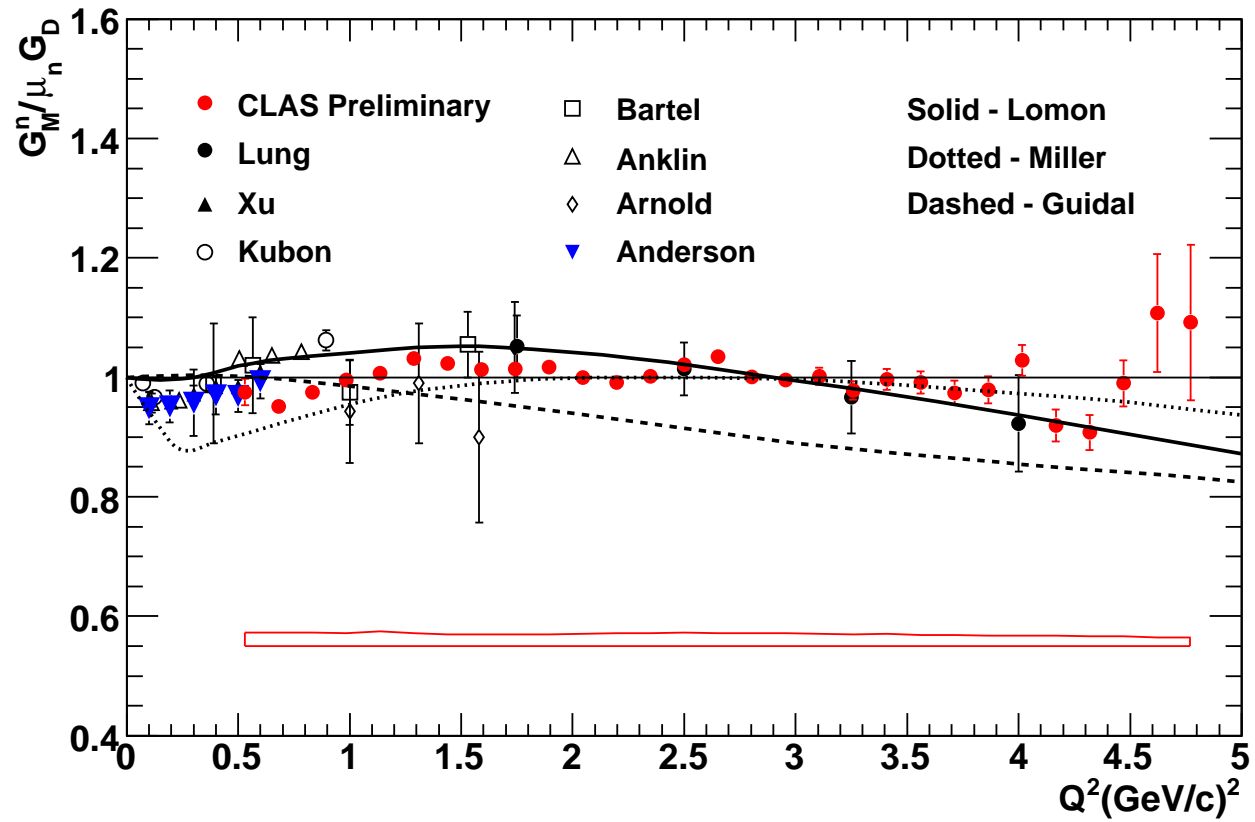
Results - Comparison with Existing Data and Theory



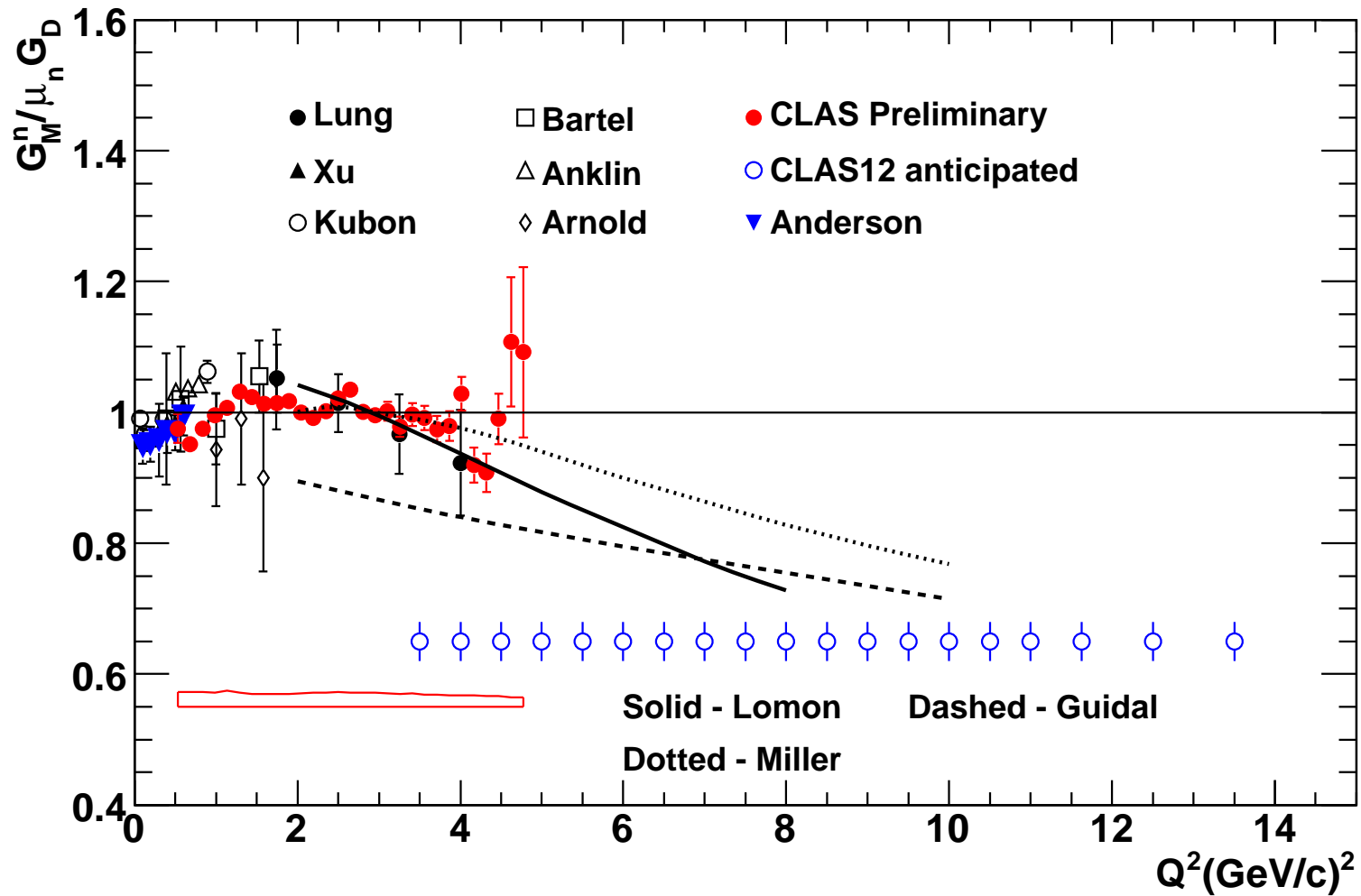
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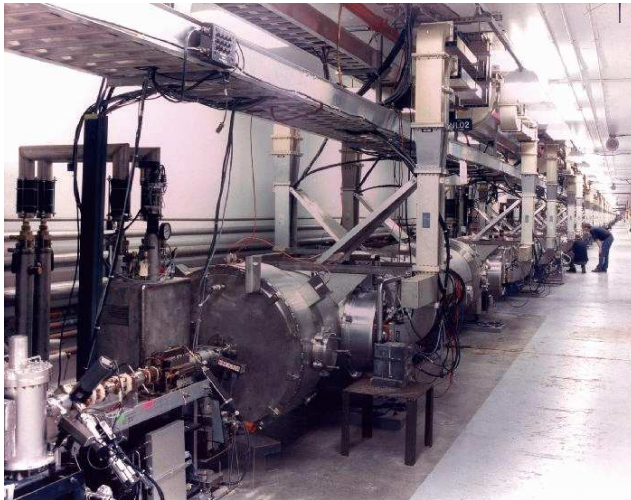
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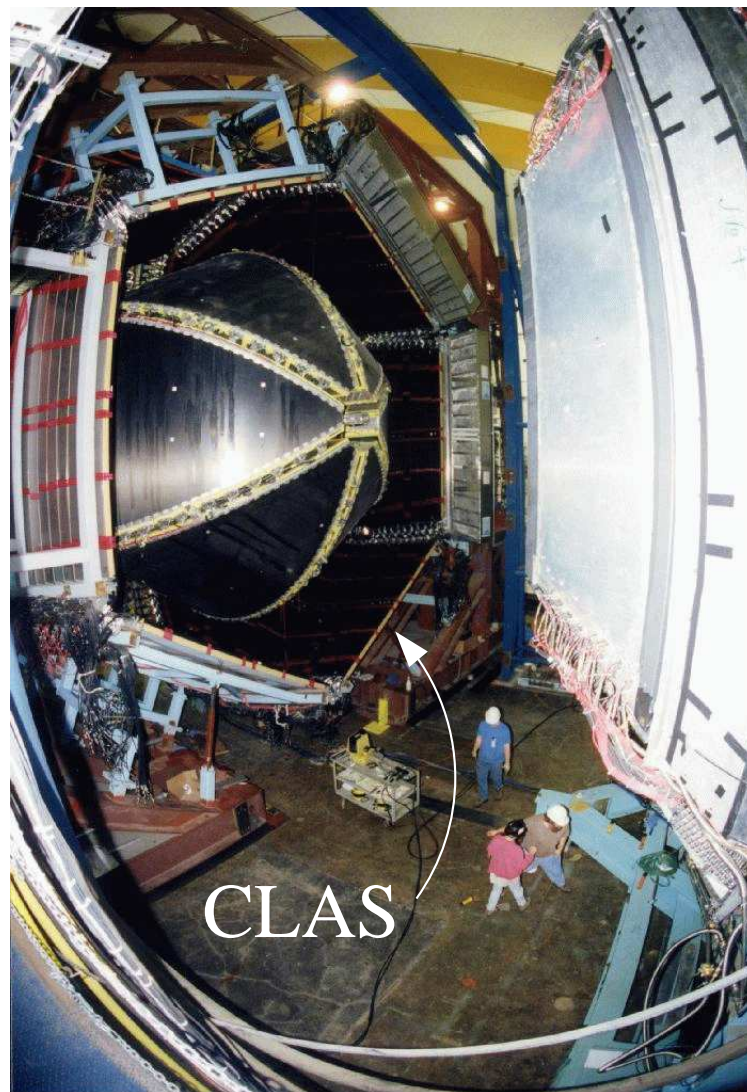
More To Come



Experiments at Jefferson Lab

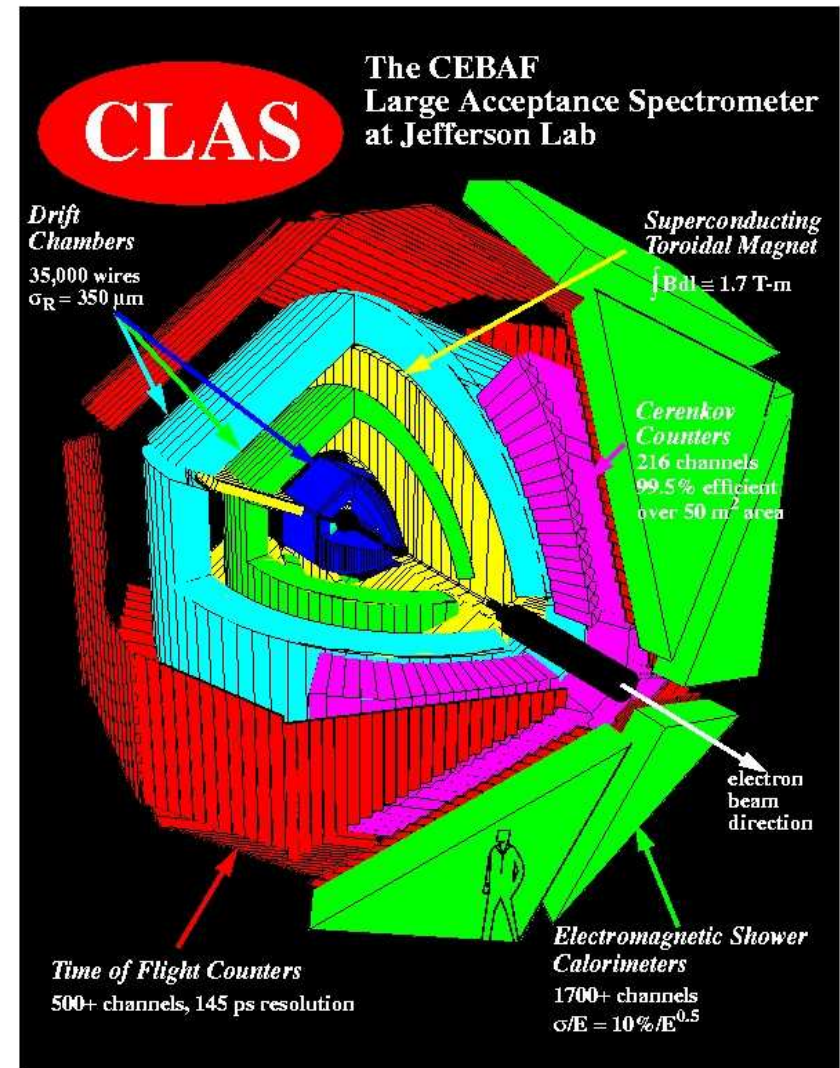


The CEBAF Large Acceptance Spectrometer (CLAS)



More on The CEBAF Large Acceptance Spectrometer (CLAS)

- 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

