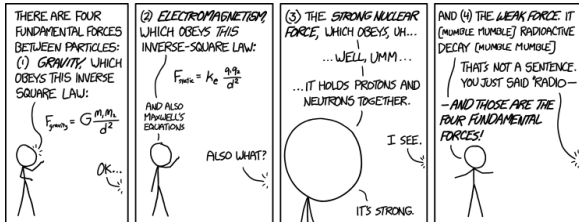


# Hunting for Quarks and Gluons

Jerry Gilfoyle

University of Richmond

- What we know and don't know about the sub-atomic world and its forces.
- What we'll learn with Jefferson Lab (JLab).
- How we measure things - CLAS12.
- What we do.



# What Do We Know About the Structure of Matter?

- The structure of matter.  
→ Table of Elements (TOE)

PERIODIC TABLE OF THE ELEMENTS

1 H Hydrogen	PERIODIC TABLE OF THE ELEMENTS																18 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57 La-Lu Lanthanide series	71 Hf Hafnium	72 Ta Tantalum	73 W Tungsten	74 Re Rhenium	75 Os Osmium	76 Ir Iridium	77 Pt Platinum	78 Au Gold	79 Hg Mercury	80 Tl Thallium	81 Pb Lead	82 Bi Bismuth	83 Po Polonium	84 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89-103 Ac-Lr Actinide series	105 Rf Rutherfordium	106 Db Dubnium	107 Sg Seaborgium	108 Bh Bohrium	109 Hs Hassium	110 Mt Meitnerium	111 Uun Ununennium	112 Uuu Ununbium	113 Uub Ununtrium	114 Uut Ununquadium	115 Uuq Ununpentium	116 Uup Ununhexium	117 Uuh Ununseptium	118 Uus Ununoctium	119 Uuo Ununennium
89 La Lanthanum	90 Ce Cerium	91 Pr Praseodymium	92 Nd Neodymium	93 Pm Promethium	94 Sm Samarium	95 Eu Europium	96 Gd Gadolinium	97 Tb Terbium	98 Dy Dysprosium	99 Ho Holmium	100 Er Erbium	101 Tm Thulium	102 Yb Ytterbium	103 Lu Lutetium			104 Lu Lutetium
101 Ac Actinium	102 Th Thorium	103 Pa Protactinium	104 U Uranium	105 Np Neptunium	106 Pu Plutonium	107 Am Americium	108 Cm Curium	109 Bk Berkelium	110 Cf Californium	111 Es Einsteinium	112 Fm Fermium	113 Md Mendelevium	114 No Nobelium	115 Lr Lawrencium			116 Lr Lawrencium



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$\gamma$ photon	0	0	<b>g</b> gluon	0	0	<b>H</b> Higgs	126	0
<b>W<sup>-</sup></b>	80.39	-1						
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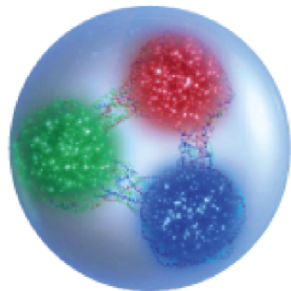
More than 99% of our mass is in quark triplets.

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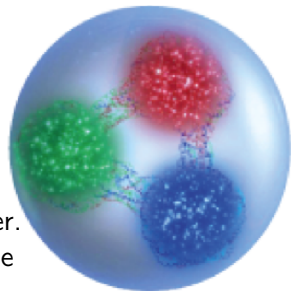
# What is the force that holds us together?

- Quarks are bound by the 'color' force.
- There are three kinds of 'color' charge.
- The quarks are never alone.  
→ confinement
- At high energy the force is weak.  
→ asymptotic freedom



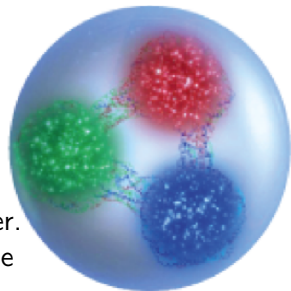
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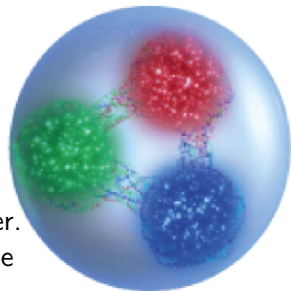
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Yet!



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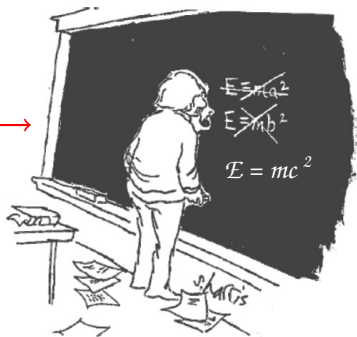
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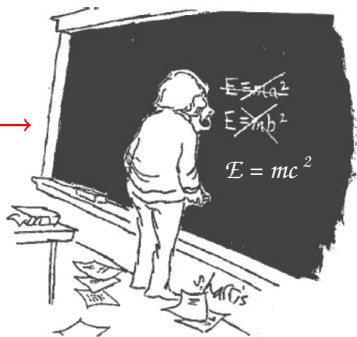
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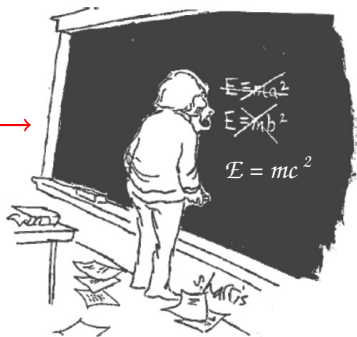
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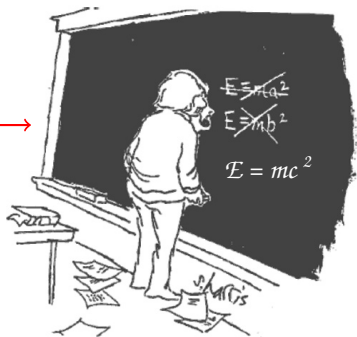
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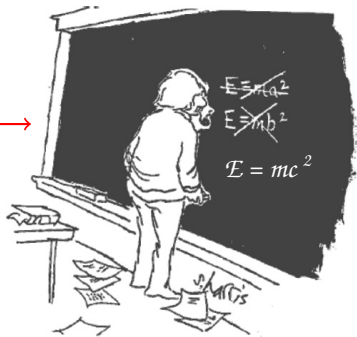
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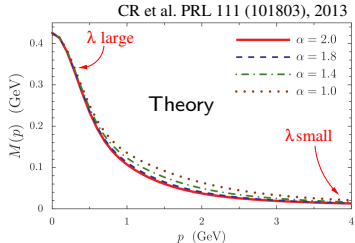


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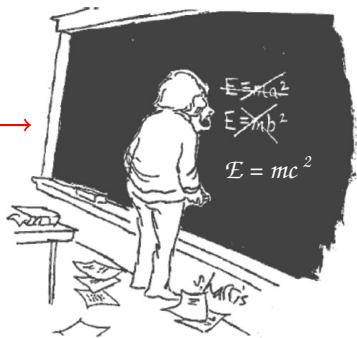


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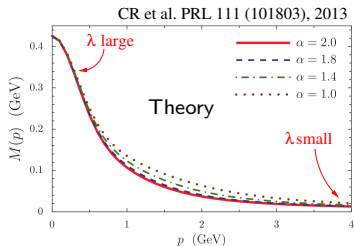


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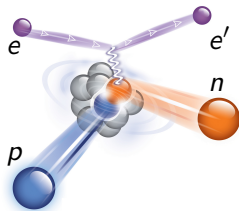


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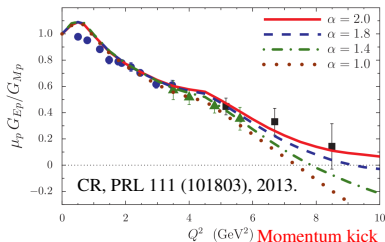
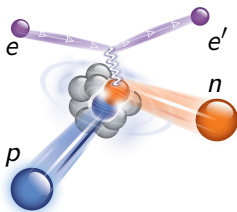
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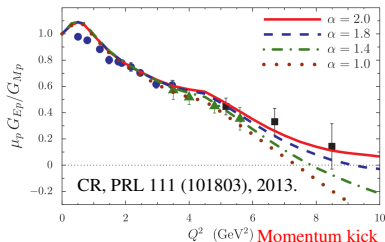
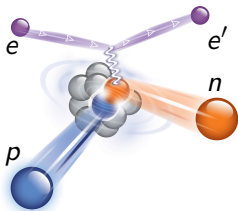
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We are probing how mass emerges from QCD color fields.





# How Do We Measure the Form Factors? - 1

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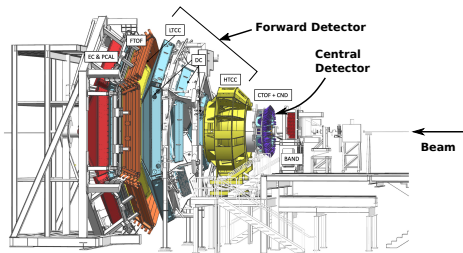
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It's a QCD laboratory!



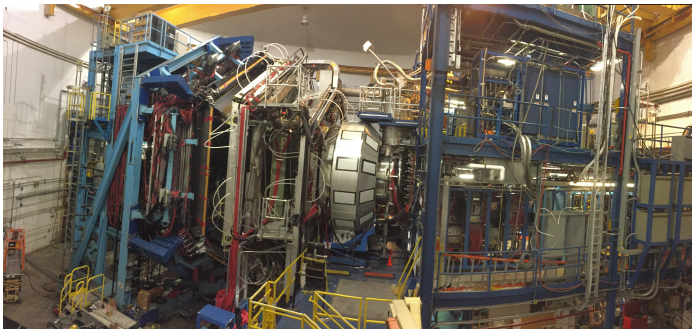
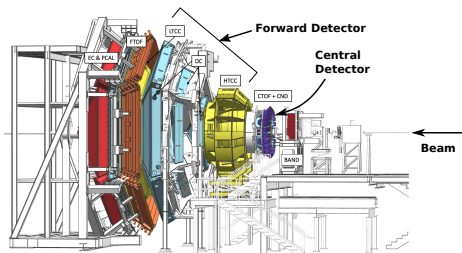
# How Do We Measure the Form Factors? - 2

- Build a large (3-story, 45-ton) particle detector called CLAS12 in Hall B.
- Many layers measure debris from electron-target collisions.
- Over 100,000 readouts in  $\approx 40$  layers.
- Large magnets bend charged particles to measure 4-momenta.
- Will collect 10-30 TByte each day.



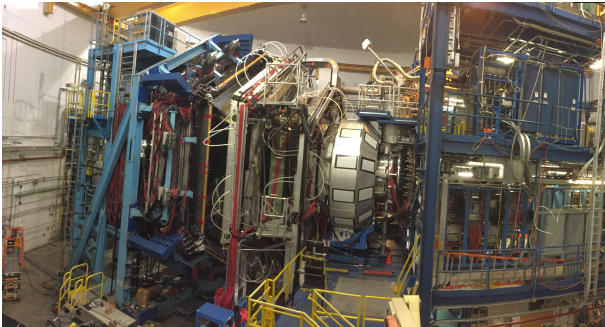
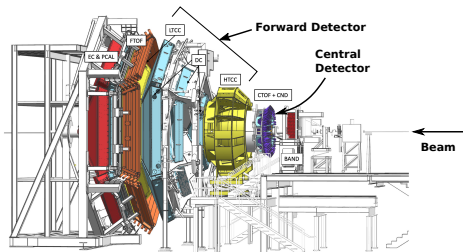
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- Build a large (3-story, 45-ton) particle detector called CLAS12 in Hall B.
- Many layers measure debris from electron-target collisions.
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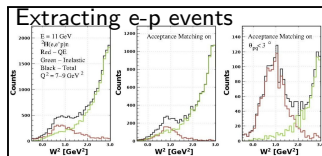
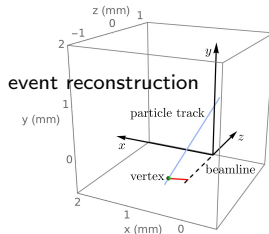
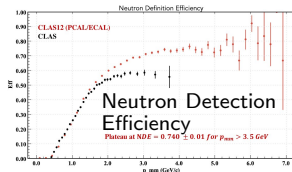
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# Some of the Nuclear Physics at the University of Richmond

- The usual suspects: Sarah Hu, Jessie Hess, Matthew Hayrich, Ryan Sanford, Alexander Balsamo, Chris Childs, Ben Weinstein, Michael Armstrong, Adrian Saina, Lamya Baashen, old gray-haired guy.
- Software is important! We are writing code for:
  - analyzing CLAS12 data and simulations.
  - extracting the neutron magnetic form factor  $G_M^n$  from the  $eD \rightarrow e'p(n)$  and  $eD \rightarrow e'n(p)$  reactions.
  - measuring the neutron detection efficiency (NDE) needed for  $eD \rightarrow e'n(p)$  with  $ep \rightarrow e'\pi^+n$ .
  - determine the CLAS12 NDE *in situ*.
  - establish benchmarks for the CLAS12 event reconstruction resolution.
  - install reconstruction unit tests.
  - build CLAS12 subsystem geometry.
- Ten students over last three years.
- Seven presentations at national meetings.

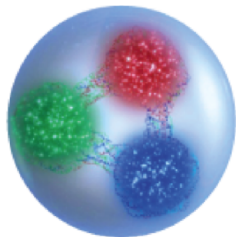


## Summary and Conclusions

- JLab is at the frontier of our understanding of the basic properties of matter including most of the known mass.
- Putting QCD on a precise quantitative basis in the nuclear energy regime.
- CLAS12 is a large, complex particle detector. Software is the key element to bring it all together.
- Our group is feverishly working to understand the deluge of data that has arrived!
- Students are using and developing essential tools for handling complex systems with large data sets.

# What is the force that holds us together?

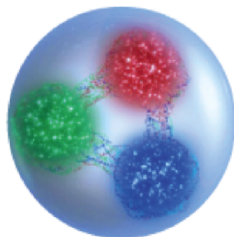
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- The quarks are never alone.
  - confinement
- At high energy the force is weak.
  - asymptotic freedom





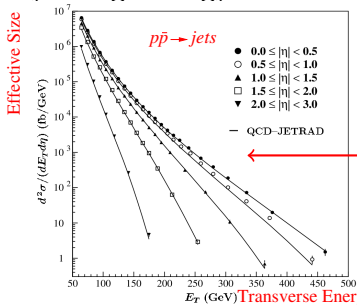
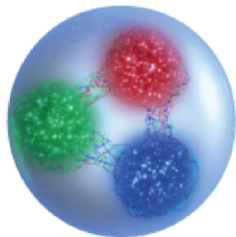
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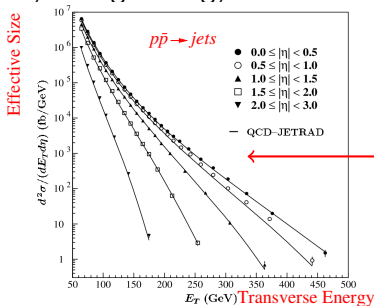
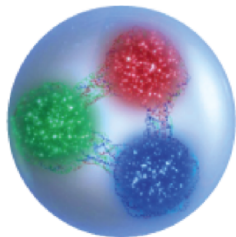
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But can't be solved at nucleon energies. Yet!