

Hunting for Quarks and Gluons

Jerry Gilfoyle

University of Richmond

- What we know about the sub-atomic world and its forces - background.
- We're about to learn more at the upgraded Jefferson Lab (JLab) - physics motivation.
- How we measure things - technical details.
- Summary and Conclusions.

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																	2 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	58 Hf Hafnium	59 Ta Tantalum	60 W Tungsten	61 Re Rhenium	62 Os Osmium	63 Ir Iridium	64 Pt Platinum	65 Au Gold	66 Hg Mercury	67 Tl Thallium	68 Pb Lead	69 Bi Bismuth	70 Po Polonium	71 At Astatine	72 Rn Radon
73 Fr Francium	74 Ra Radium	75 Ac-Lr Actinide series	76 Rf Rutherfordium	77 Db Dubnium	78 Sg Seaborgium	79 Bh Bohrium	80 Hs Hassium	81 Mt Meitnerium	82 Uun Ununennium	83 Uuu Ununbium	84 Uub Ununtrium	85 Uut Ununquadium	86 Uuq Ununpentium	87 Uup Ununhexium	88 Uuh Ununseptium	89 Uus Ununoctium	90 Uuo Unundecium
Lanthanide series		La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	
Actinide series		Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

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Leptons spin = 1/2			Quarks spin = 1/2					
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e electron	0.000511	-1	d down	0.005	-1/3			
ν_M middle neutrino*	$(0.009-2) \times 10^{-9}$	0	c charm	1.3	2/3			
μ muon	0.106	-1	s strange	0.1	-1/3			
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→ protons and neutrons
→ the nucleons

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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⁻	80.39	-1	Higgs Boson spin = 0		
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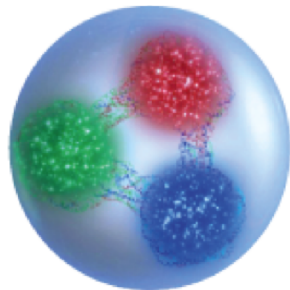
More than 99% of our mass is in quark triplets.

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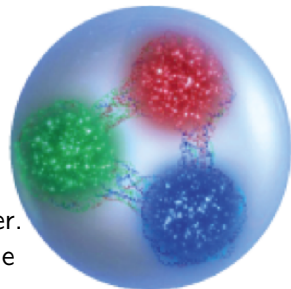
What is the force that holds us together?

- The color force binds quarks together via gluon exchange.
- The quarks are never alone.
→ confinement
- At high energy the force is weak.
→ asymptotic freedom



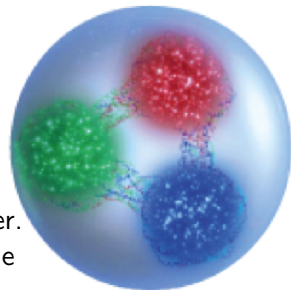
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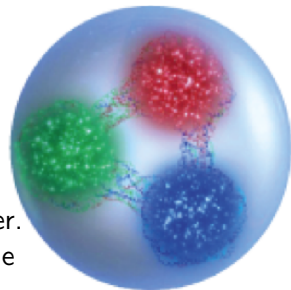
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Yet!

Where does mass come from?

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How do we get out of this?

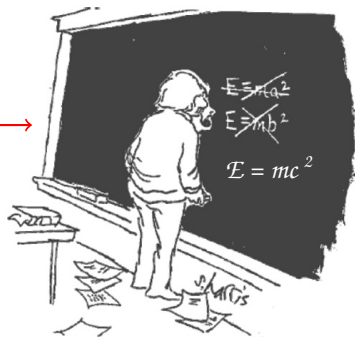
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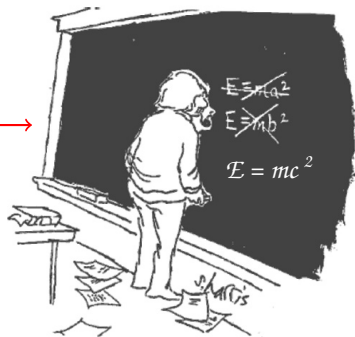
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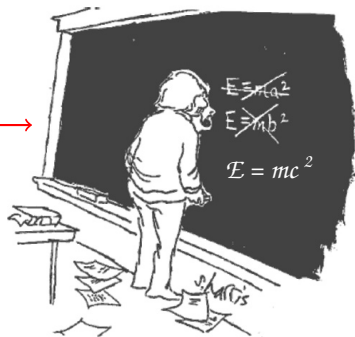
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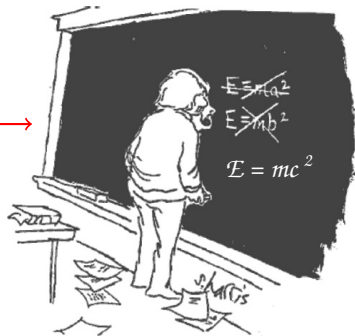
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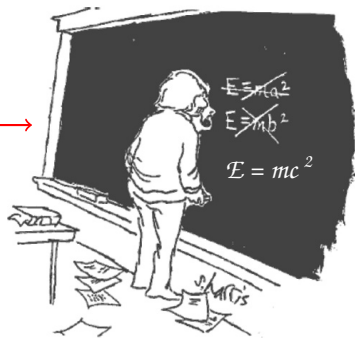
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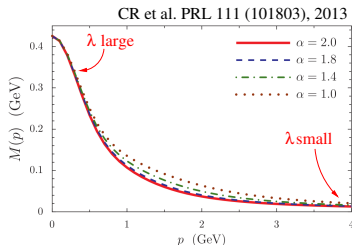
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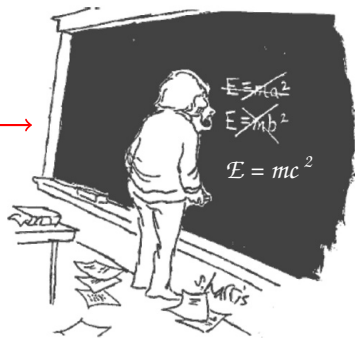


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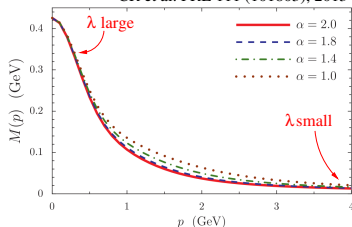
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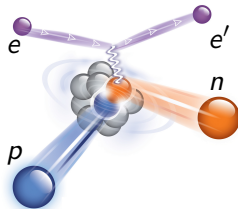
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CR et al. PRL 111 (101803), 2013



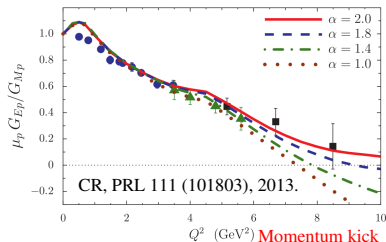
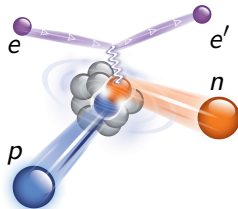
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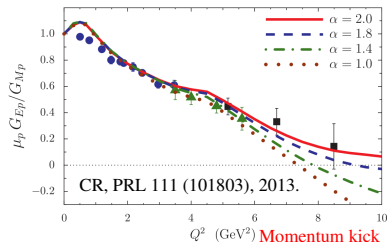
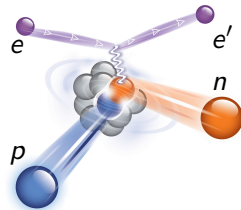
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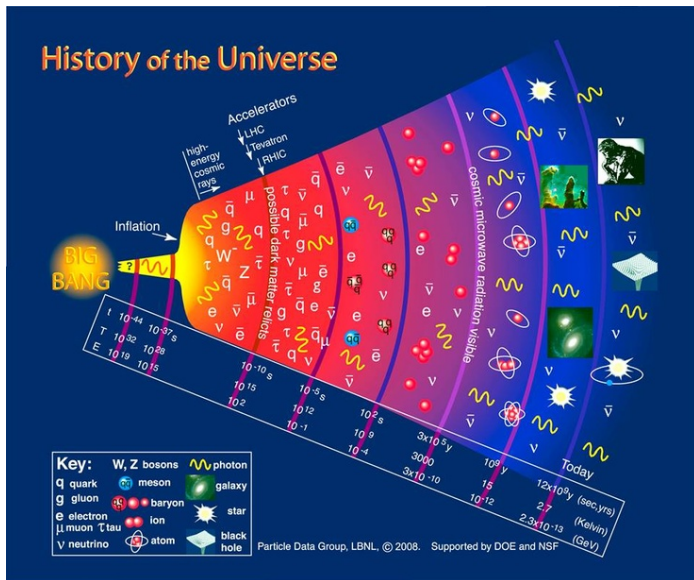
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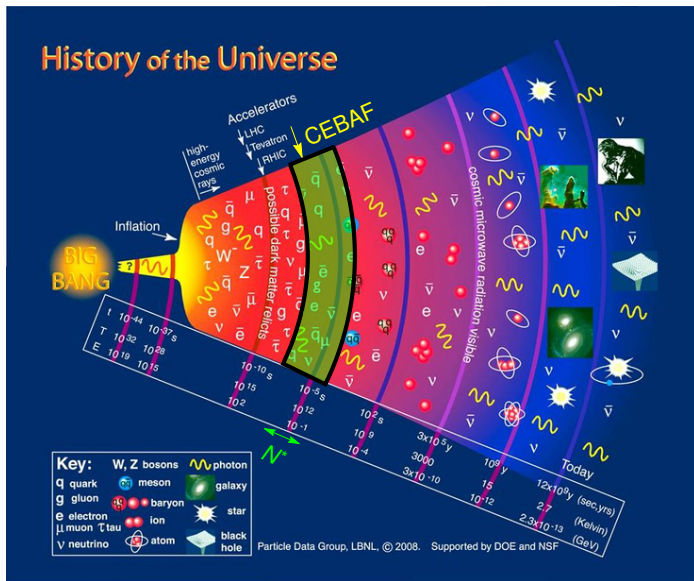


We are probing how mass emerges from QCD color fields.

A Connection With Ted



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How Do We Measure the Form Factors? - 1

- Build the newest US national lab Jefferson Lab (JLab) in Newport News, VA
- The accelerator CEBAF is a mile-long, racetrack-shaped, superconducting linear accelerator.
- Rapidly varying electric fields push electrons to 12 GeV.
- Electron beam distributed to four halls.
- Just completing a \$330M Upgrade.



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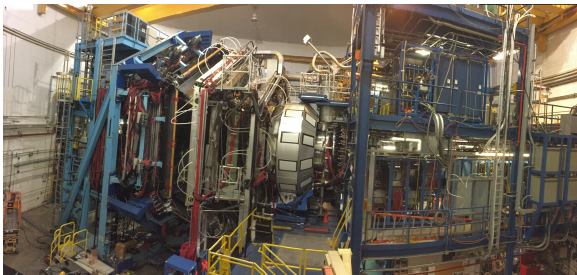
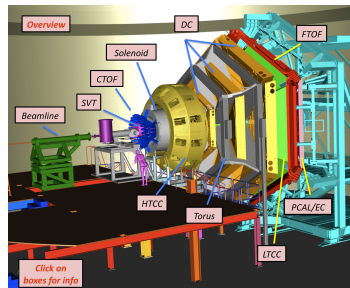
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It's a QCD laboratory!



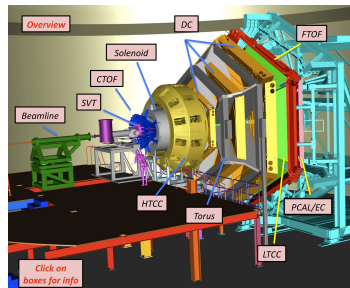
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- Build a large (3-story, 45-ton) particle detector called CLAS12 in Hall B.
- Many layers measure the debris from electron-target collisions.
- Over 100,000 readouts in ≈ 40 layers.
- Large magnet bends charged particles to measure 4-momenta of the debris.
- Will write 5-10 TByte to disk each day.

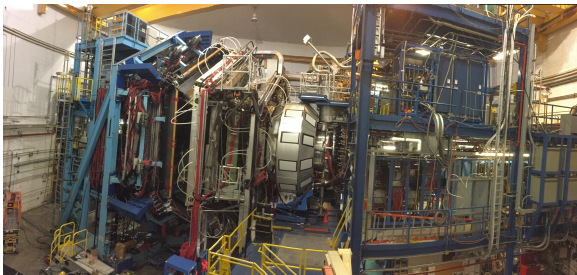


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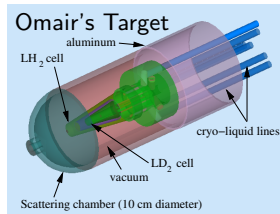


First production data
spring, 2018!

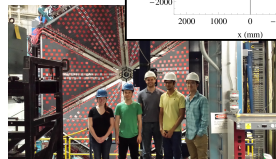
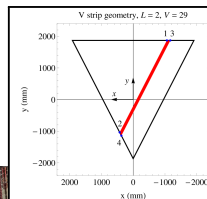


Some of the Nuclear Physics at the University of Richmond

- The usual suspects: Keegan Sherman, Omar Alam, Alexander Balsamo, David Brakman, Peter Davies, old gray-haired guy.
- Software is important! We are writing code for:
 - methods to align the 33,792 elements of the silicon vertex tracker to within $40 - 50 \mu\text{m}$.
 - extracting the 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 needed for $eD \rightarrow e'n(p)$ with $ep \rightarrow e'\pi^+n$.
 - monitoring and operating a cryogenic $\text{LD}_2 - \text{LH}_2$ target.
- Rely now on simulation of CLAS12 and cosmic ray data until 2017.
- Four student posters in Vancouver in October.



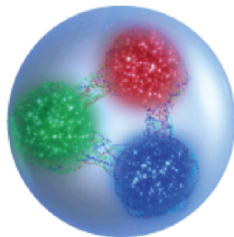
Keegan's geometry



- JLab is at the frontier of our understanding of the basic properties of matter including most of the known mass.
- First measurement of the nucleon mass curve?
- CLAS12 is a large, complex particle detector about to see first beam.
- Our group is preparing feverishly to understand the deluge of data that is coming - first beams in April!

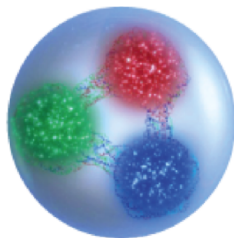
What is the force that holds us together?

- The color force binds quarks together via gluon exchange.
- The quarks are never alone.
 - confinement
- At high energy the force is weak.
 - asymptotic freedom



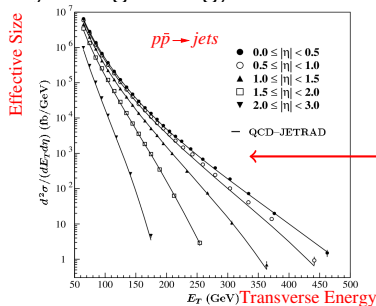
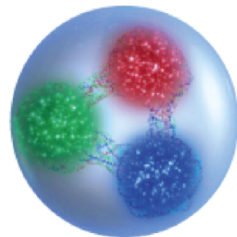
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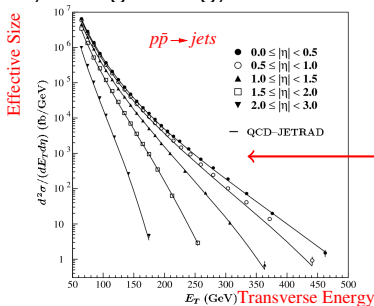
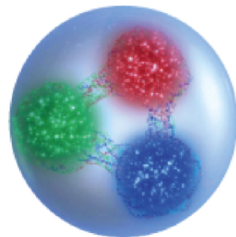
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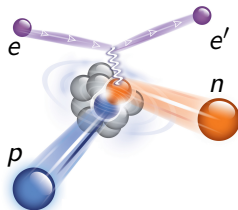


QCD is wildly successful!

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

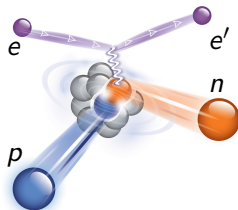
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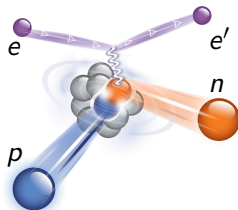
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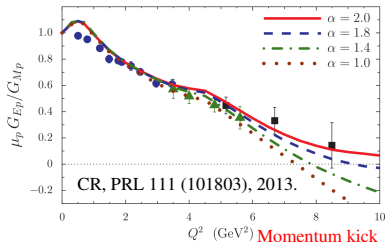
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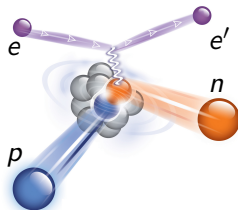


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- The ratio G_E/G_M for the proton has a zero crossing sensitive to the shape of the mass function.
- So does G_E/G_M for the neutron.



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