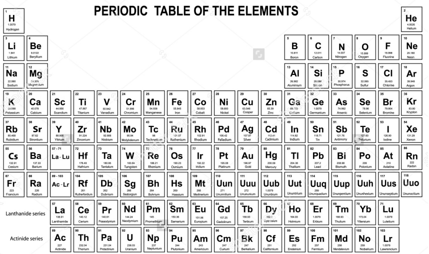
What Do We Know About the Structure of Matter?

- The structure of matter.

  $\rightarrow$ Table of Elements (TOE)



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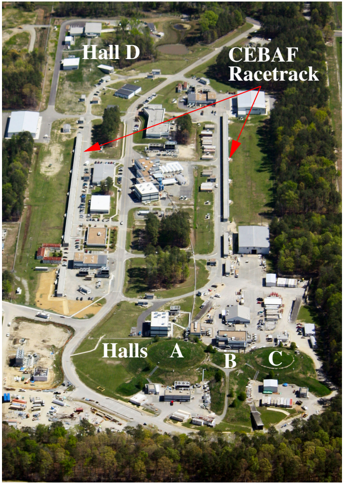
- Worldwide effort to unravel QCD in nuclei.

How Do We Turn on the Lights Inside a Nucleus?

- 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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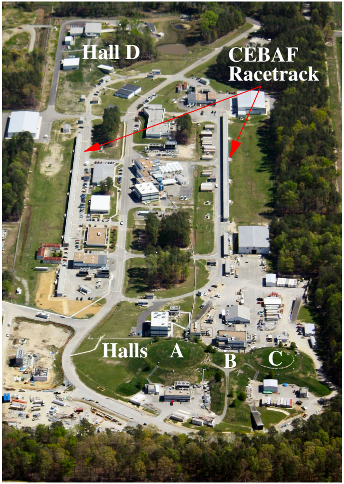
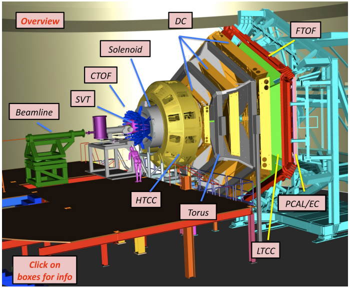
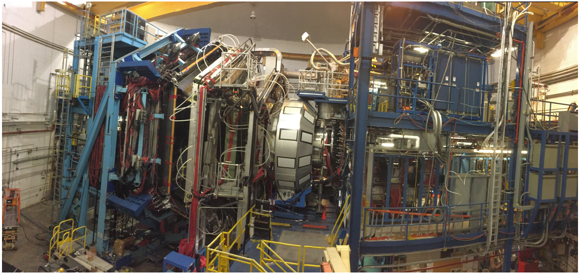


How Do We See Quarks?

- 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 $\approx$ 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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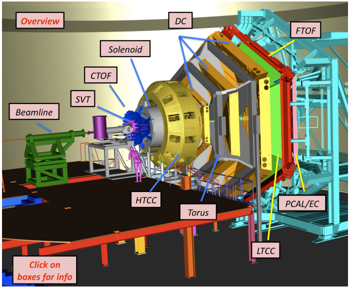
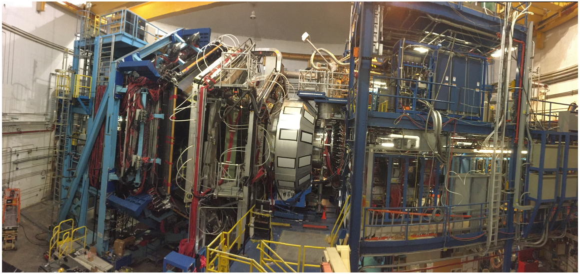


First production data spring, 2018!



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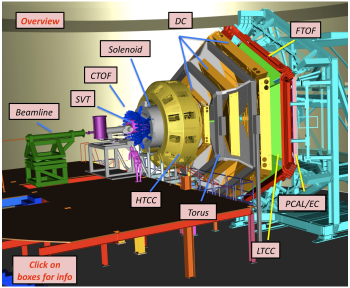

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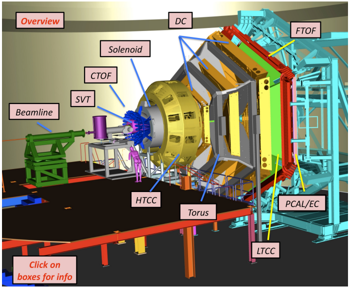

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Additional Slides

Where does mass come from?

- The proton is 2 ups + 1 down; the neutron is 1 up + 2 downs.

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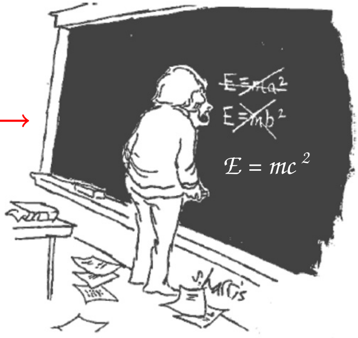

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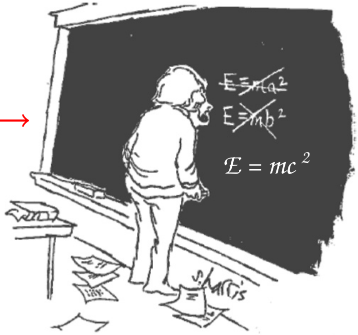

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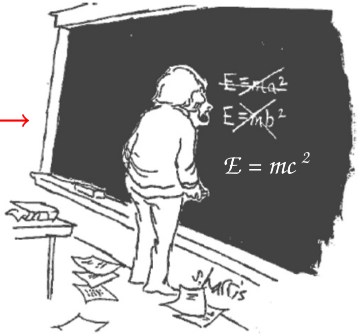

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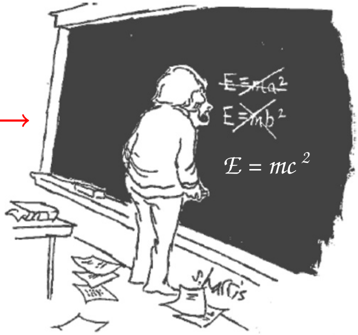

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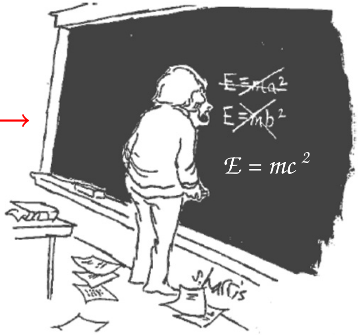
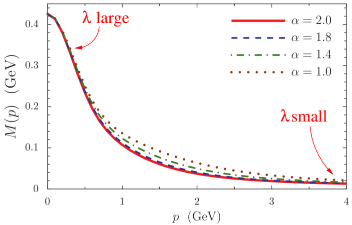


CR et al. PRL 111 (101803), 2013



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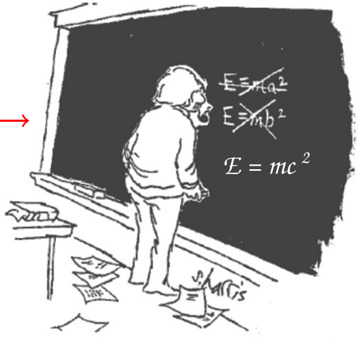
- At low momentum you probe the whole cloud.



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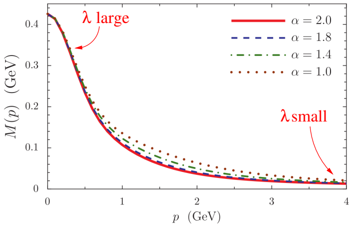

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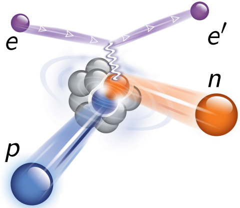

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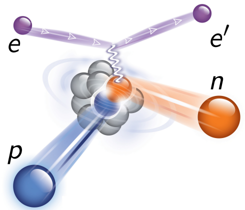
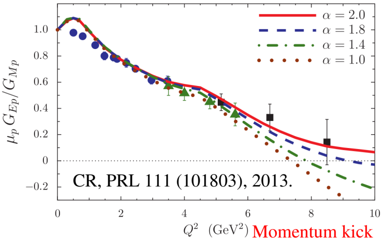
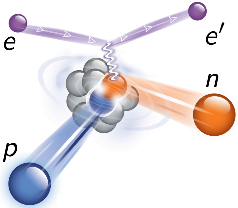


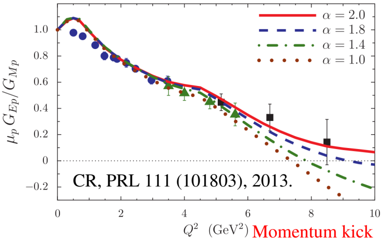


But is it real?

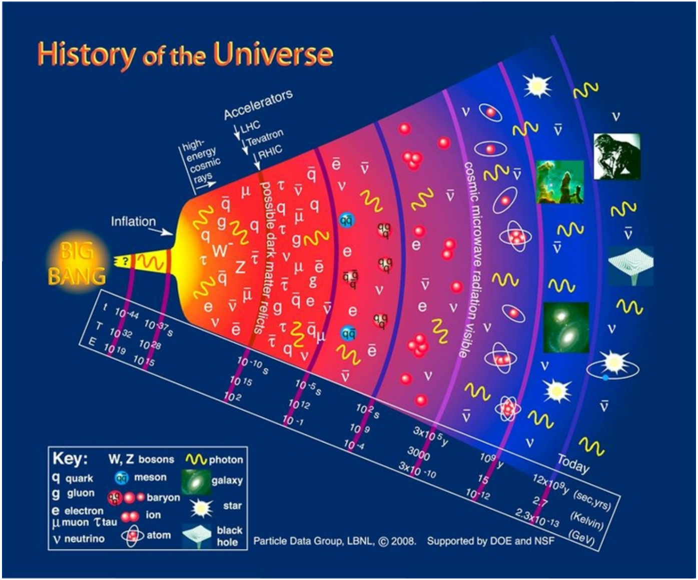
- The cross section reflects the effective size of the target in a scattering experiment.
- The form factors G_E and G_M are two components of the cross sections we measure.
- The ratio of the form factors G_E/G_M for the proton is sensitive to the shape of the mass function.

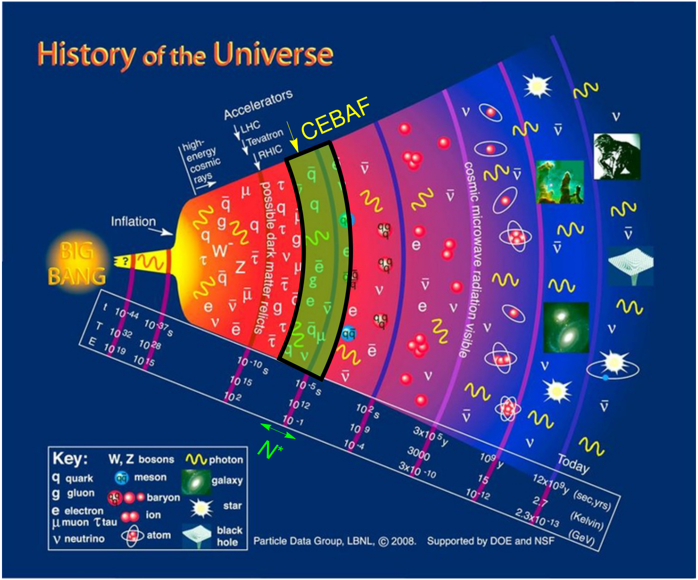
We are probing how mass emerges from QCD color fields.





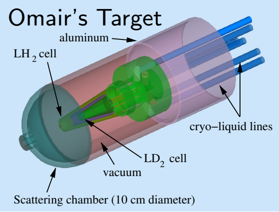
A Connection With Ted



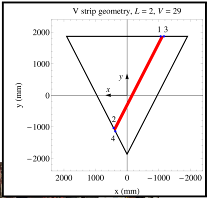

History of the Universe
Accelerators
LHC
Tevatron
RHIC
CEBAF
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
Today
N^*
Key:
q quark
g gluon
e electron
μ muon τ tau
ν neutrino
W, Z bosons
meson
baryon
ion
atom
photon
galaxy
star
black hole
Particle Data Group, LBNL, © 2008. Supported by DOE and NSF

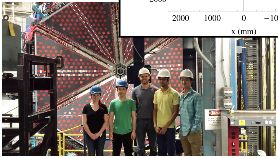
Some of the Nuclear Physics at the University of Richmond

- The usual suspects: Keegan Sherman, Omair 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 μm.
  - extracting the magnetic form factor G_M^n from the $eD \to e'p(n)$ and $eD \to e'n(p)$ reactions.
  - measuring the neutron detection efficiency needed for $eD \to e'n(p)$ with $ep \to e'\pi^+ n$.
  - monitoring and operating a cryogenic $\mathrm{LD_2}$ – $\mathrm{LH_2}$ target.
- Rely now on simulation of CLAS12 and cosmic ray data until 2017.
- Four student posters in Vancouver in October.



Keegan's geometry



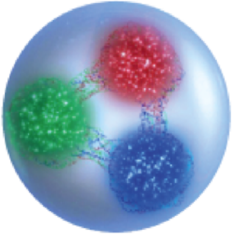


Summary and Conclusions

- 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.
  $\rightarrow$ confinement
- At high energy the force is weak.
  $\rightarrow$ asymptotic freedom



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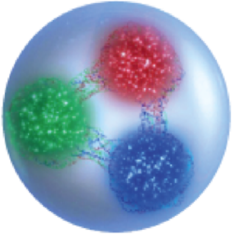

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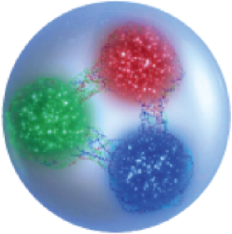

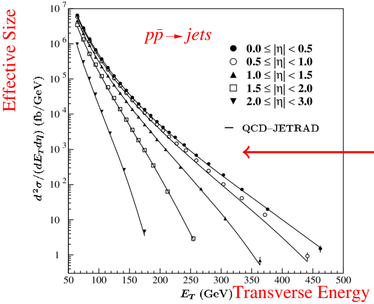

QCD is wildly successful!

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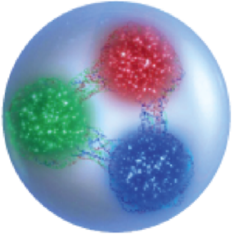
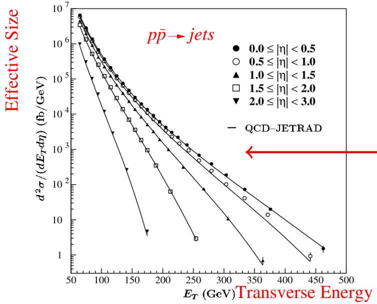


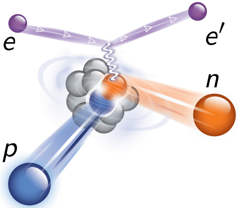


QCD is wildly successful!

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

But is it real?

- The cross section reflects the effective size of the target in a scattering experiment.



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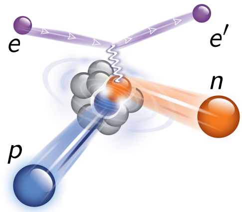

$$\frac{d\sigma}{d\Omega} = \frac{\sigma_{Mott}}{\epsilon(1+\tau)} \left(\epsilon G_E^2 + \tau G_M^2 \right)$$

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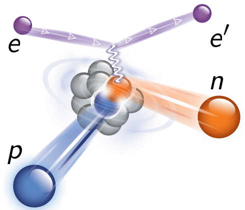

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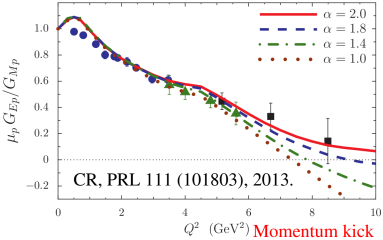
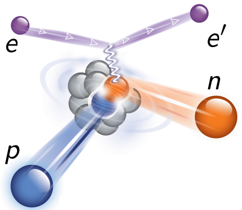


- The cross section reflects the effective size of the target in a scattering experiment.
- This cross section can be expressed here in electric and magnetic form factors G_E and G_M.
- The ratio G_E/G_M for the proton has a zero crossing sensitive to the shape of the mass function.
- So does G_E/G_M for the neutron.



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