

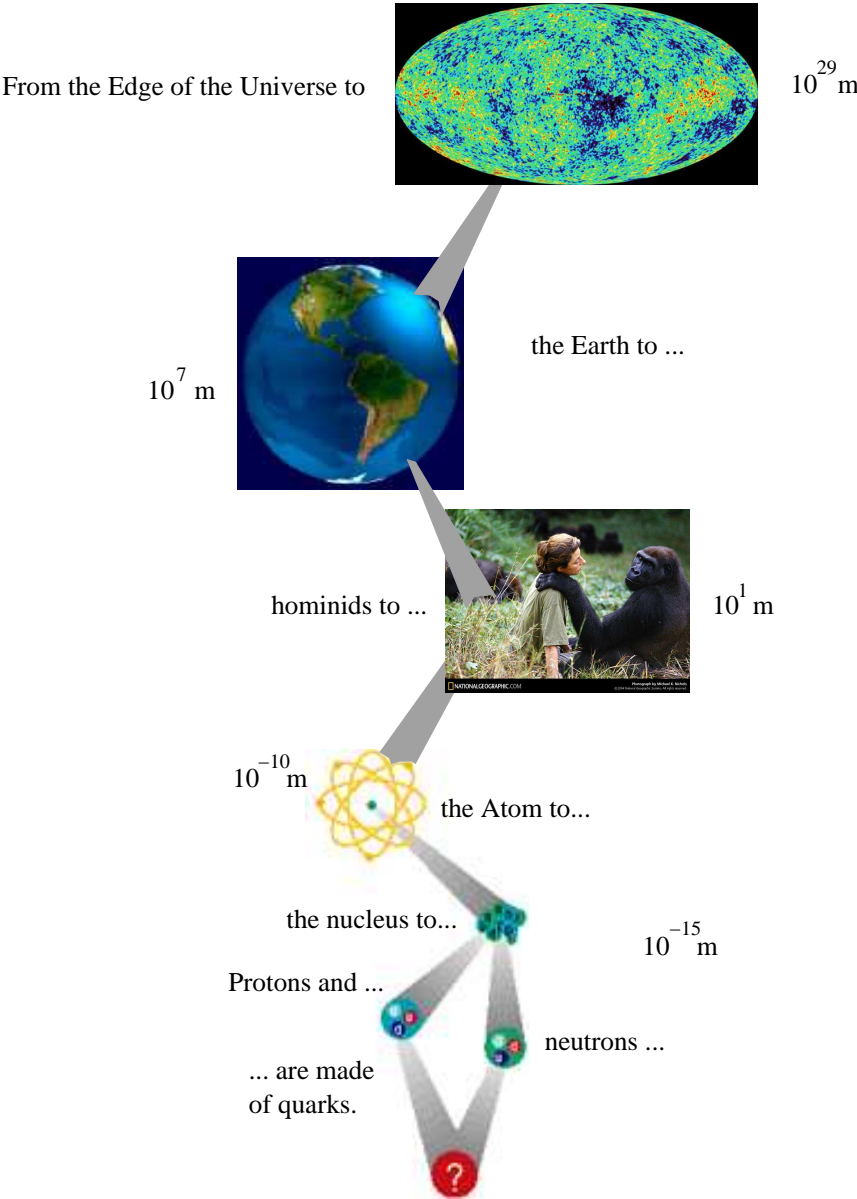
Chasing Quarks in Virginia: Nuclear Physics at JLab

Jerry Gilfoyle, University of Richmond

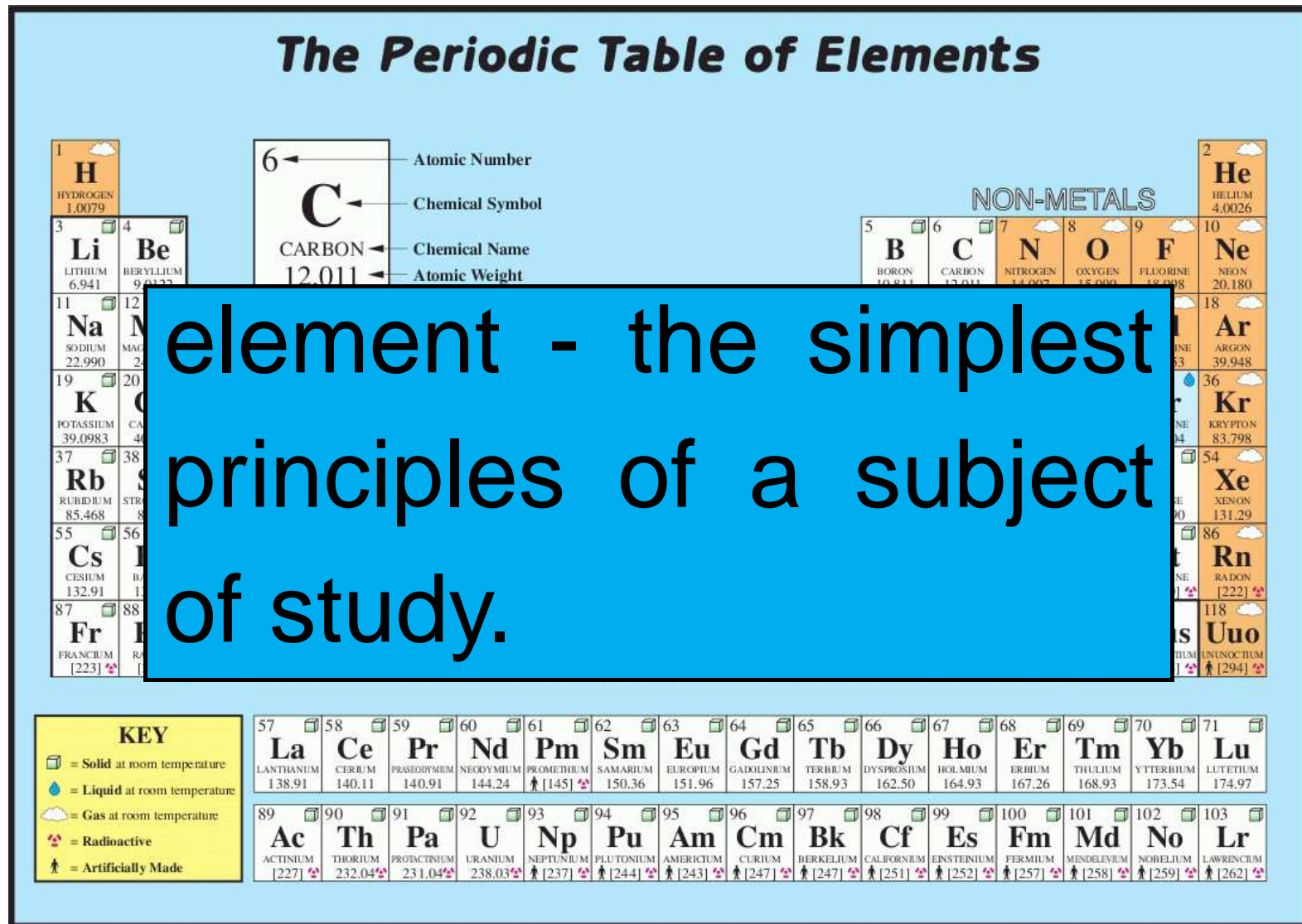


"The Periodic Table"

Chasing Quarks - What Do We Know?



The Periodic Chart



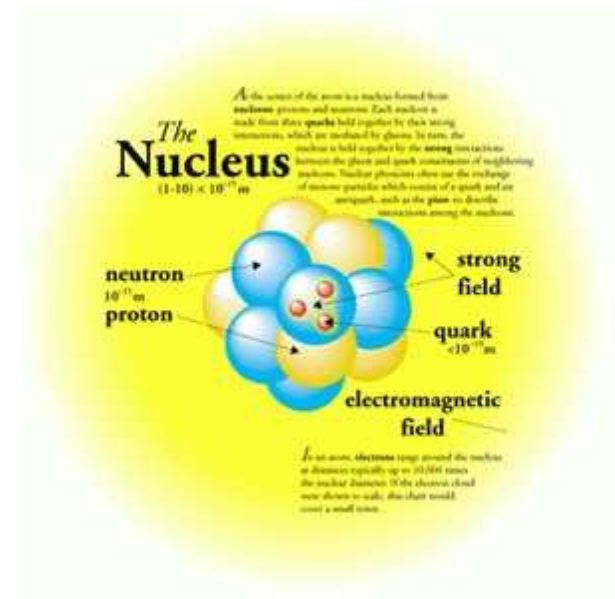
What Do We Know?

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

BOSONS			force carriers		
spin = 0, 1, 2, ...			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			
W^+	80.39	+1			
W bosons					
Z^0	91.188	0			
Z boson					

FERMIONS			matter constituents		
spin = 1/2			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_L lightest neutrino*	$(0-0.13)\times 10^{-9}$	0	u up	0.002	2/3
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μ muon	0.106	-1	s strange	0.1	-1/3
ν_H heaviest neutrino*	$(0.04-0.14)\times 10^{-9}$	0	t top	173	2/3
τ tau	1.777	-1	b bottom	4.2	-1/3

- The atomic nucleus is made of protons (uud) and neutrons (udd) bound by the strong force.
- The quarks are confined inside the protons and neutrons.
- Protons and neutrons are NOT confined.



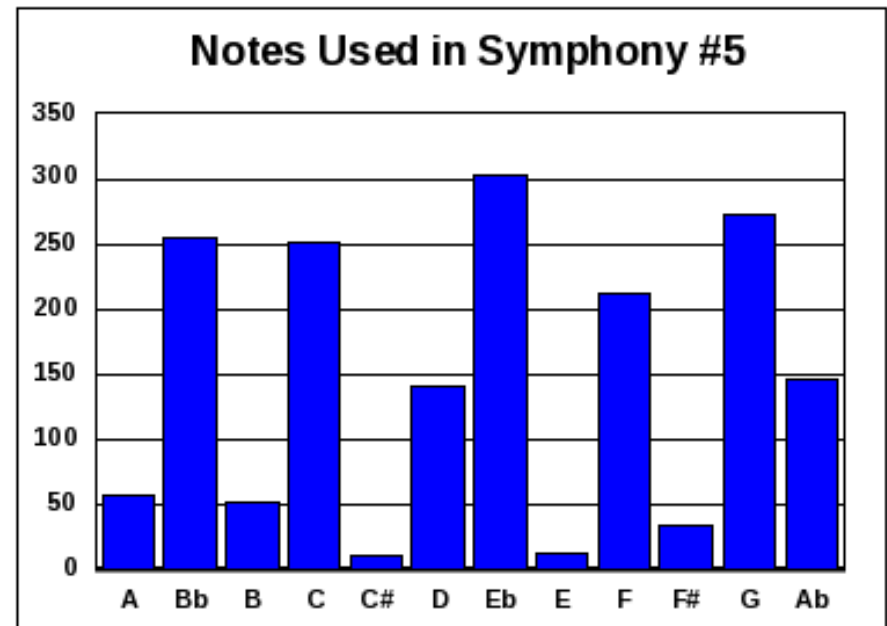
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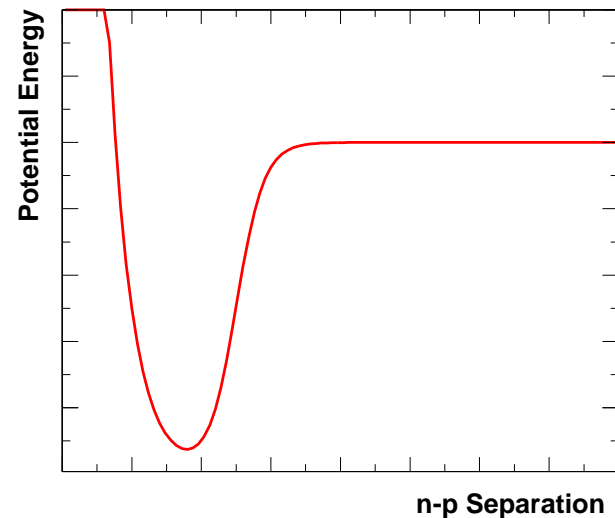
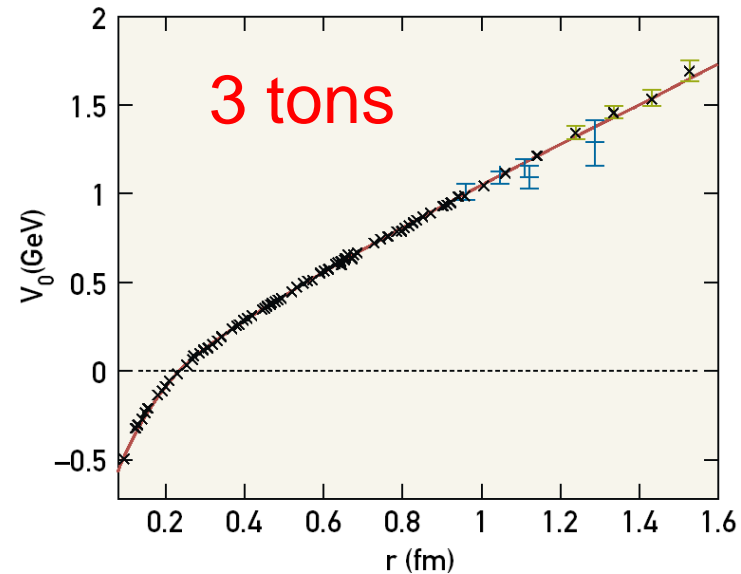
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What is the Force?

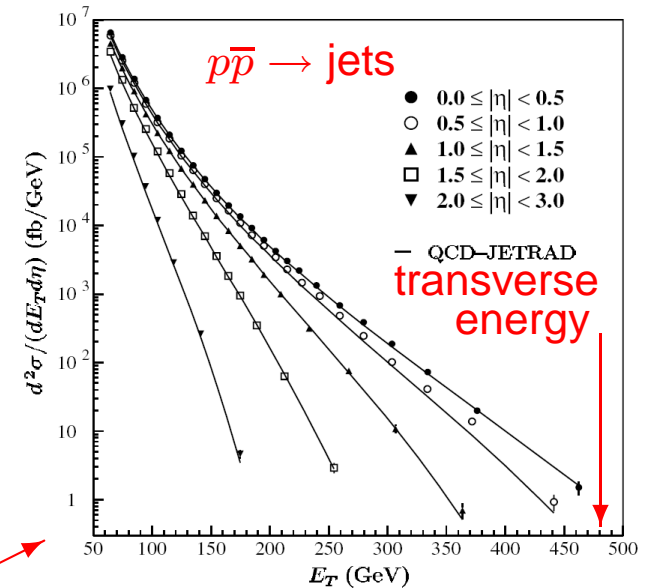
- Quantum chromodynamics (QCD) gets the force among quarks and gluons right at high energy (Nobel Prize in 2004).
- The hadronic model uses protons and neutrons (nucleons) to describe data at low energy. This 'strong' force is the residual force between quarks.



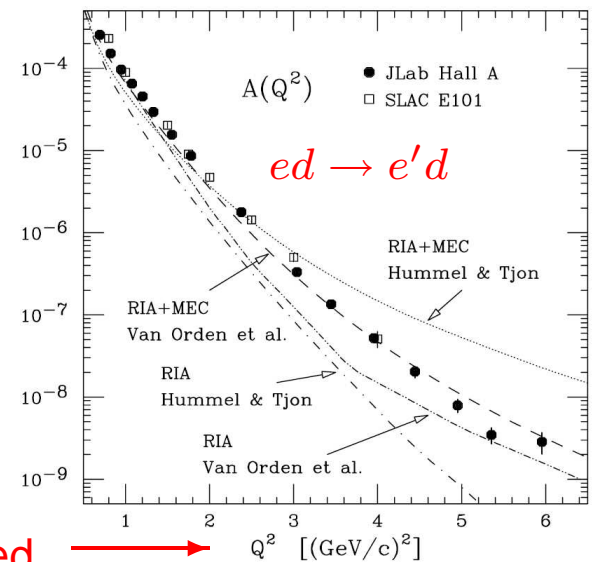
How Well Do We Know It?

● QCD works real good!
(B.Abbott, *et al.*, Phys. Rev. Lett., **86**, 1707 (2001)).

● So does the hadronic model
(L.C.Alexa, *et al.*, Phys. Rev. Lett., **82**, 1374 (1999)).



effective target area



4-momentum transfer squared



What Don't We Know?

- Matter comes in pairs of quarks or triplets.
- We are made mostly of the triplets (protons and neutrons).
- More than 99% of our mass is in nucleons.
- The proton is 2 ups + 1 down; the neutron is 1 up + 2 downs.
- How much does the proton weigh?

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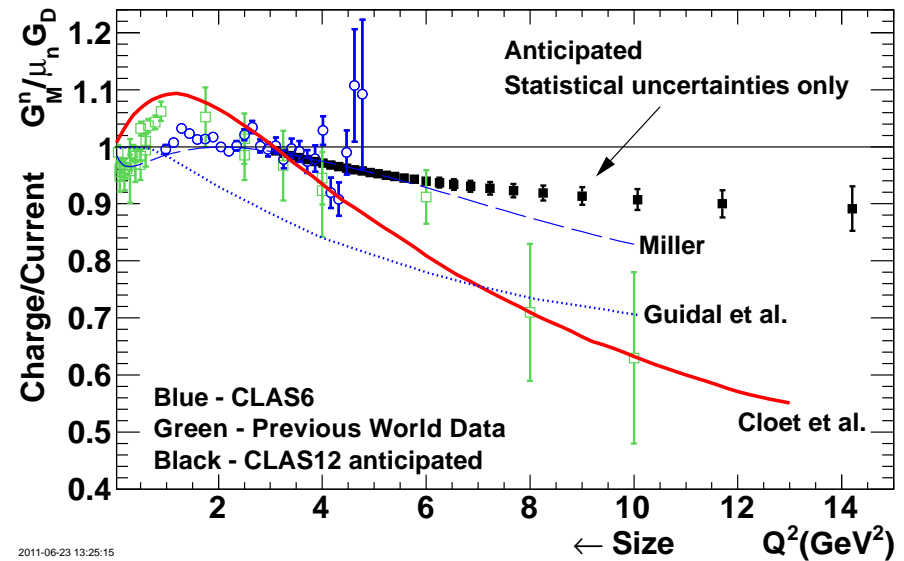
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$$m_p = 2m_{up} + m_{down} = 2(0.002 \text{ GeV}/c^2) + 0.005 \text{ GeV}/c^2$$

$$= 0.939 \text{ GeV}/c^2 \quad \text{OOOPS!!!????}$$

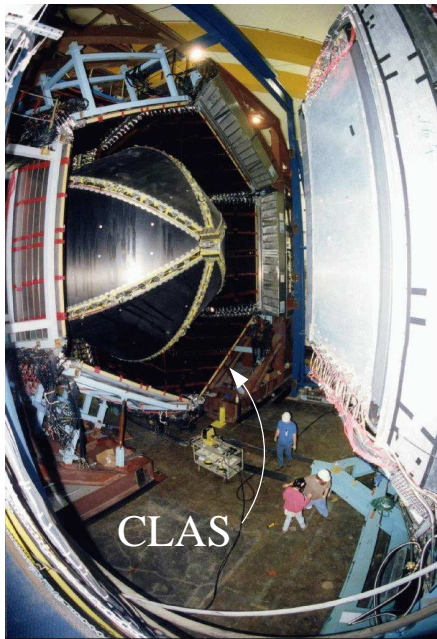
What's Up? Or Down?

- The strong force produces an intense field that stores a huge amount of energy. Remember the 3 tons.
- That intense, high-energy field has mass!
 $\rightarrow E = mc^2$
- We know the missing mass is in there, but don't yet have a working theory.
- Maybe soon (after the 12 GeV Upgrade at Jefferson Lab)!



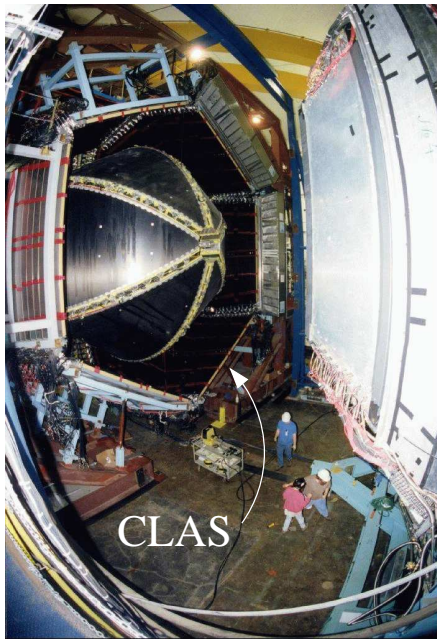
How Do We See Inside a Nucleus?

- High-energy electrons can throw a diffraction pattern when they shine on atomic nuclei.
- Need a big accelerator!
- And a big detector!
- And lots of help.



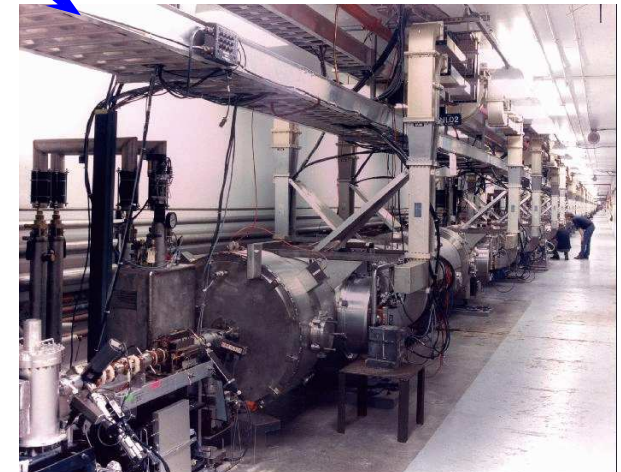
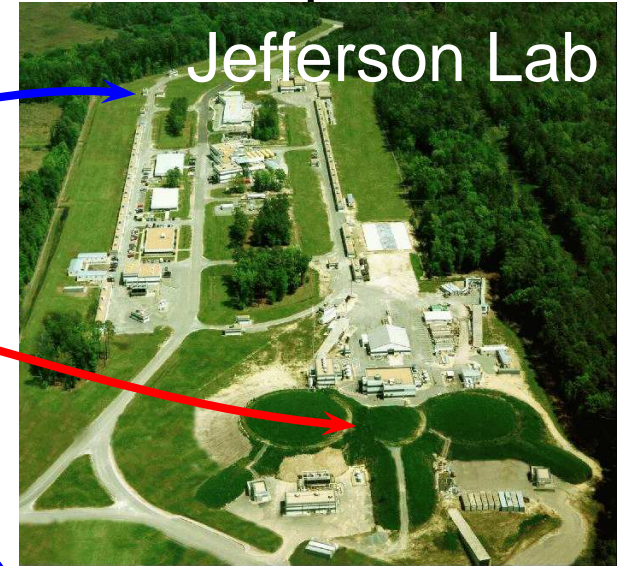
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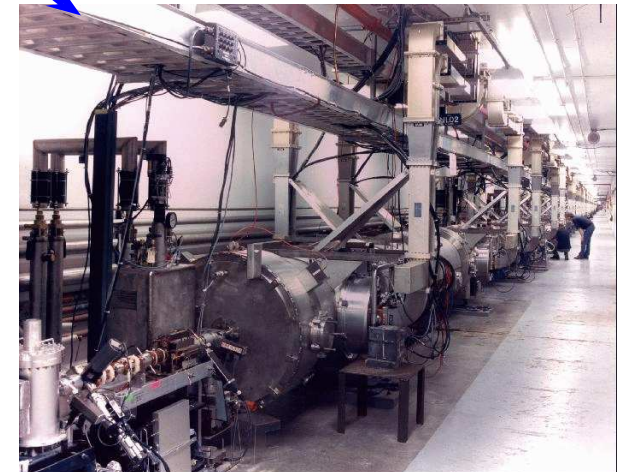
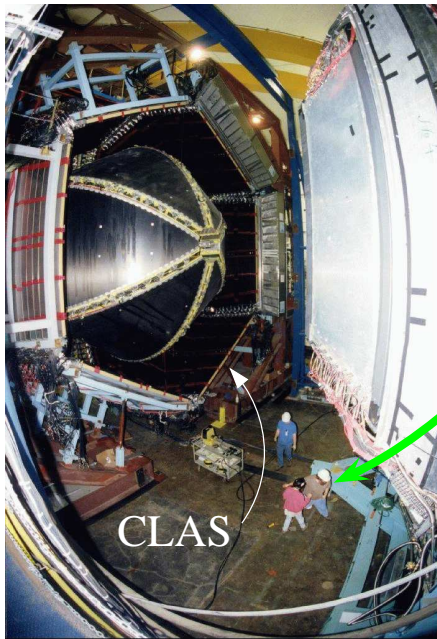
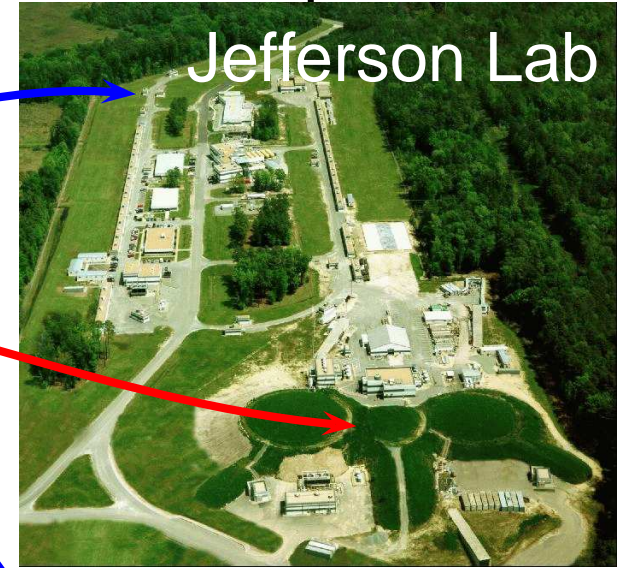
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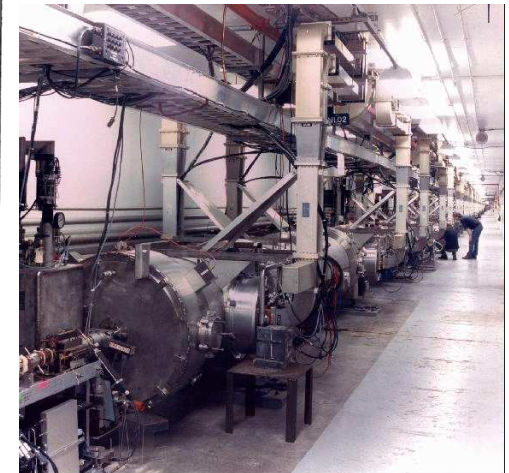
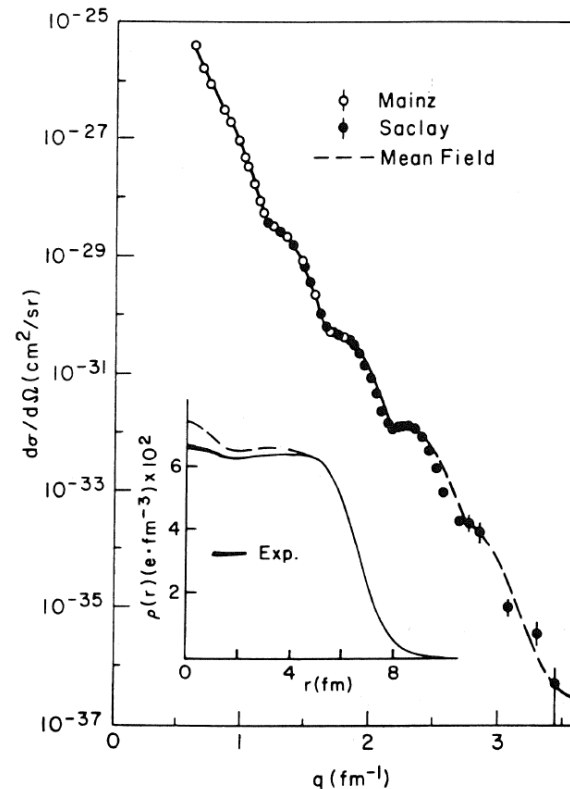
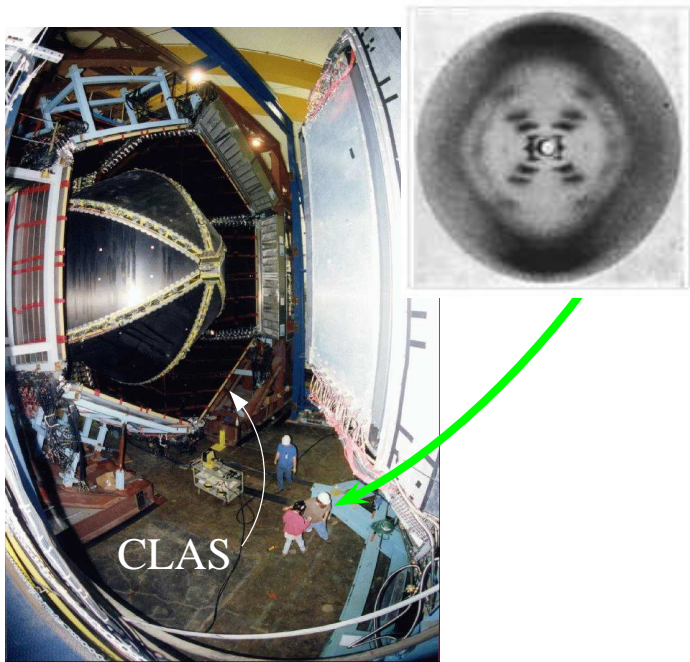
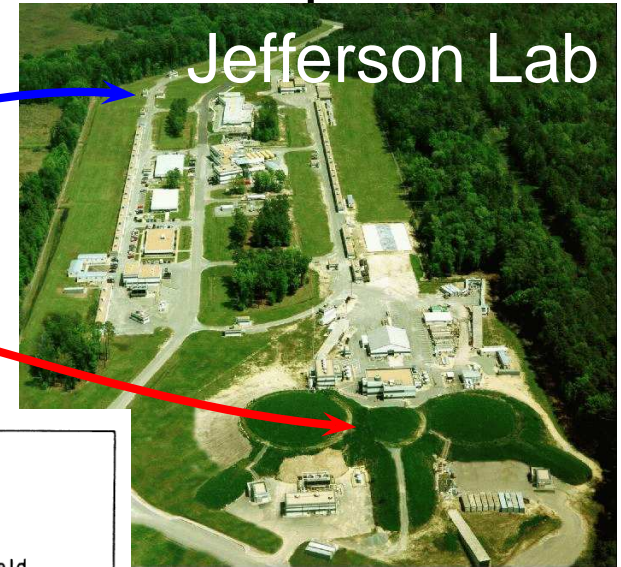
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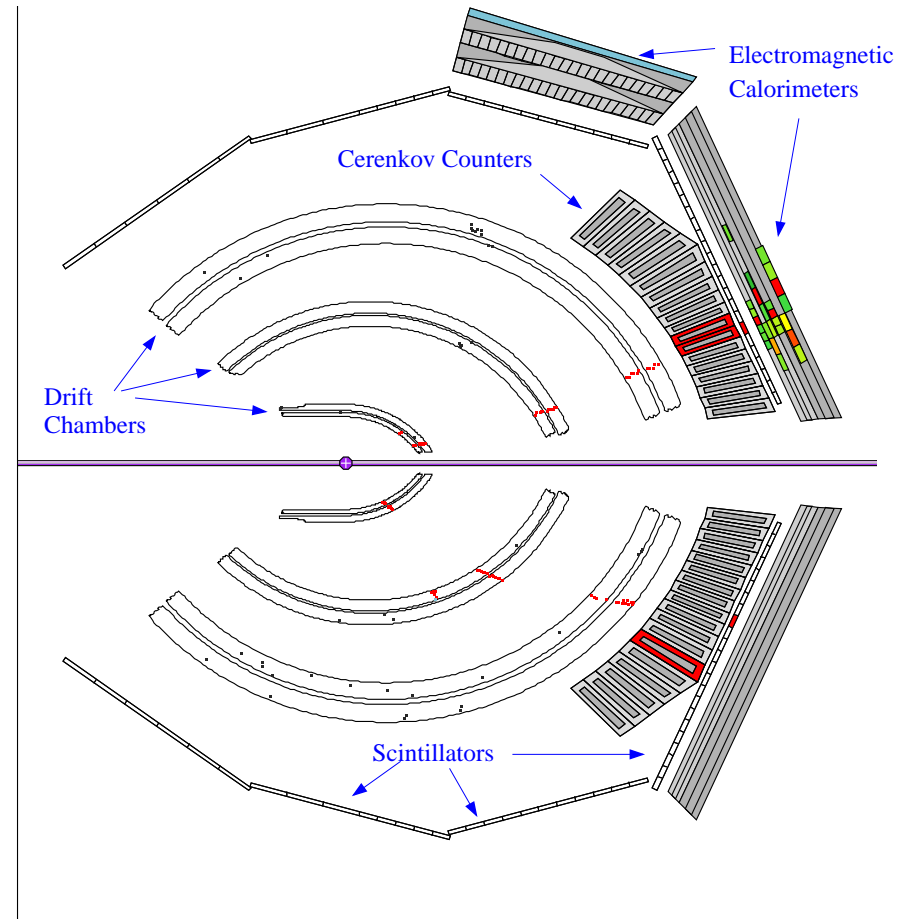
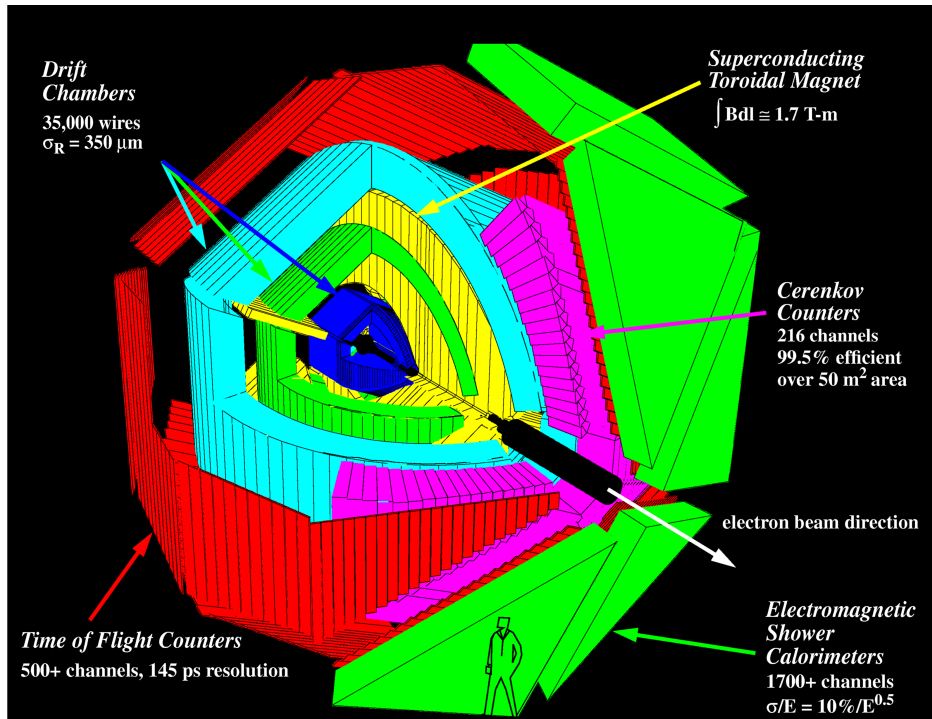


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A CLAS Event



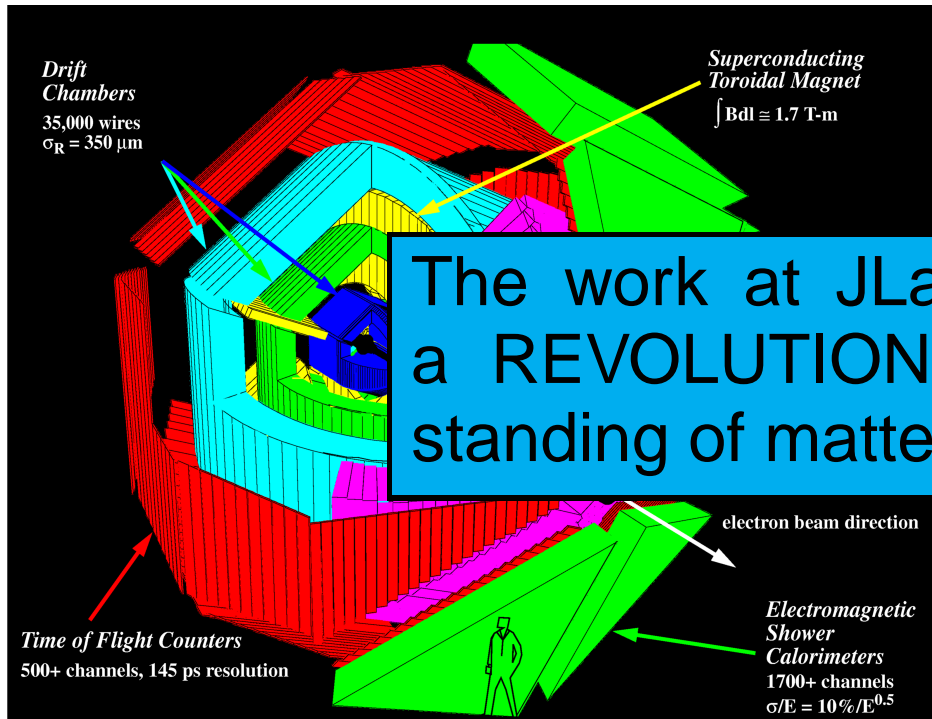
Drift chambers - Charged particle trajectories.

Cerenkovs - Separate electrons from pions.

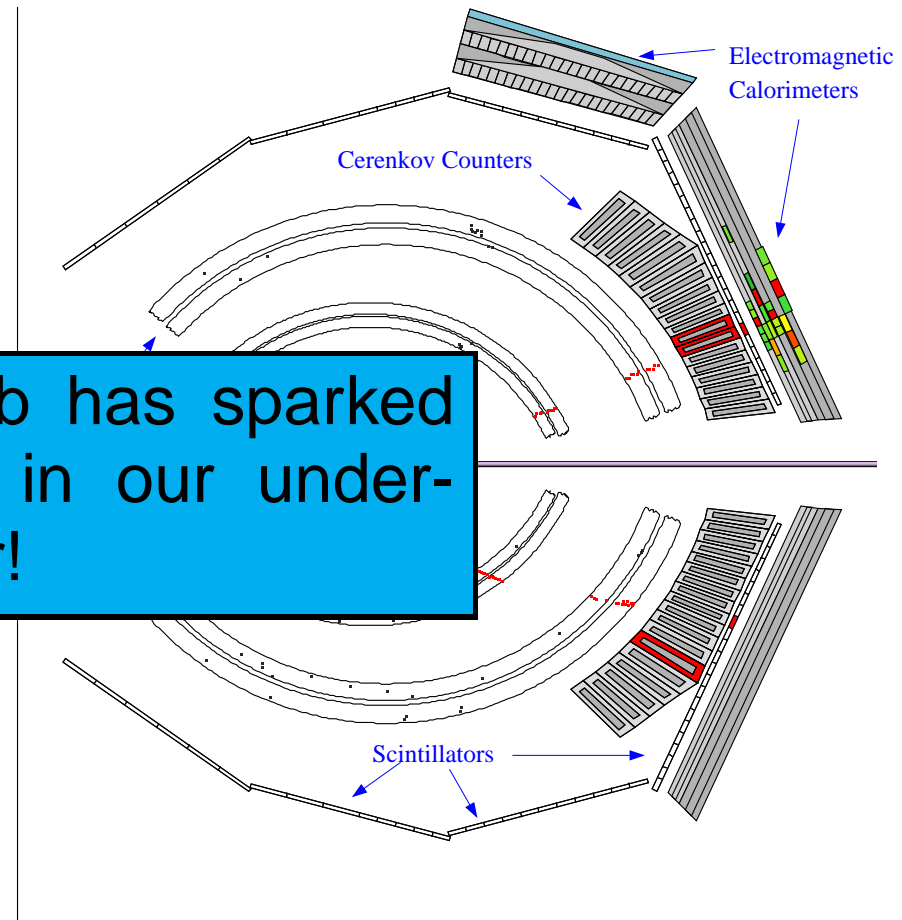
Scintillators - Light produced by particles.

Calorimeters - Energy.

A CLAS Event



The work at JLab has sparked a REVOLUTION in our understanding of matter!



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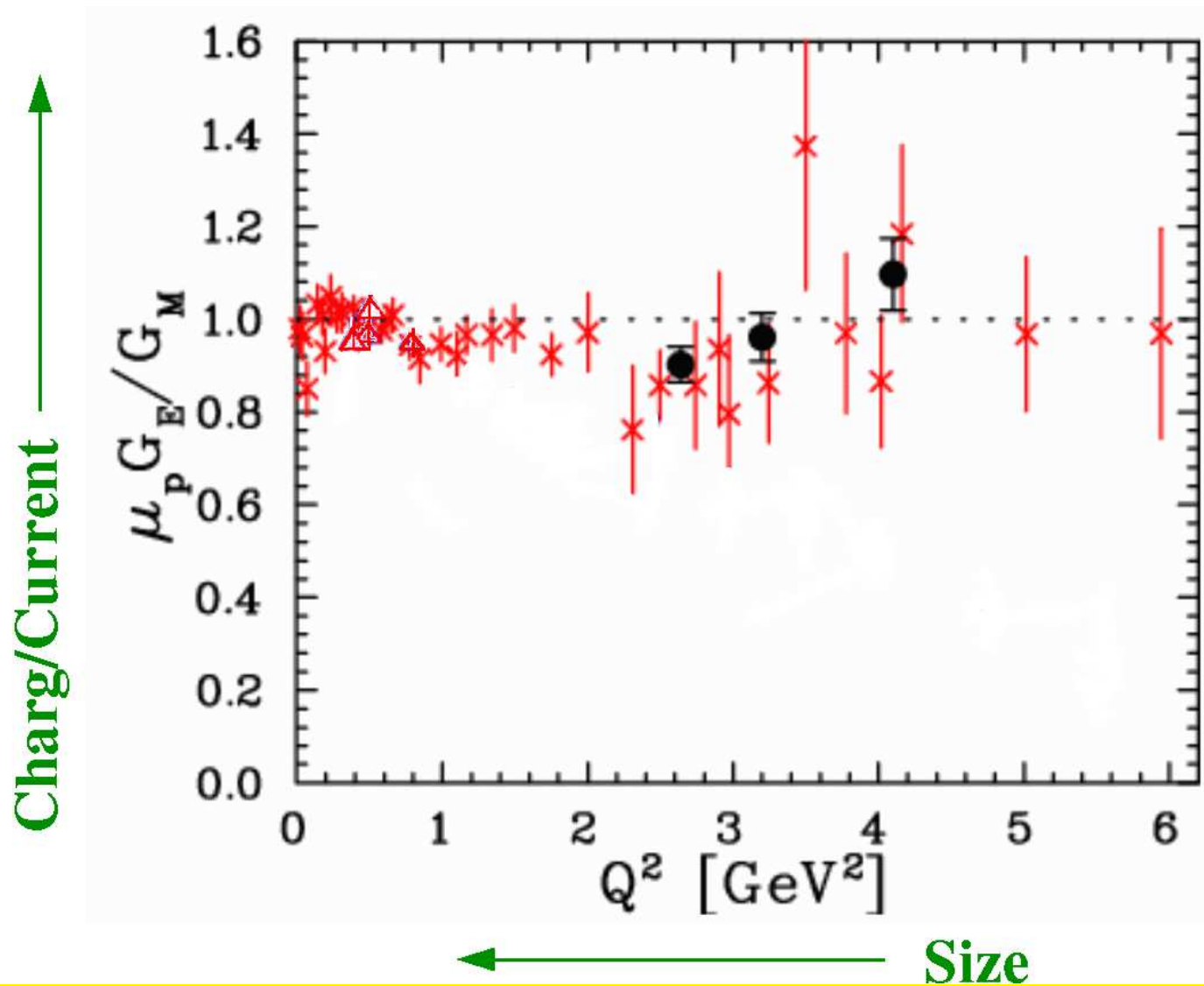
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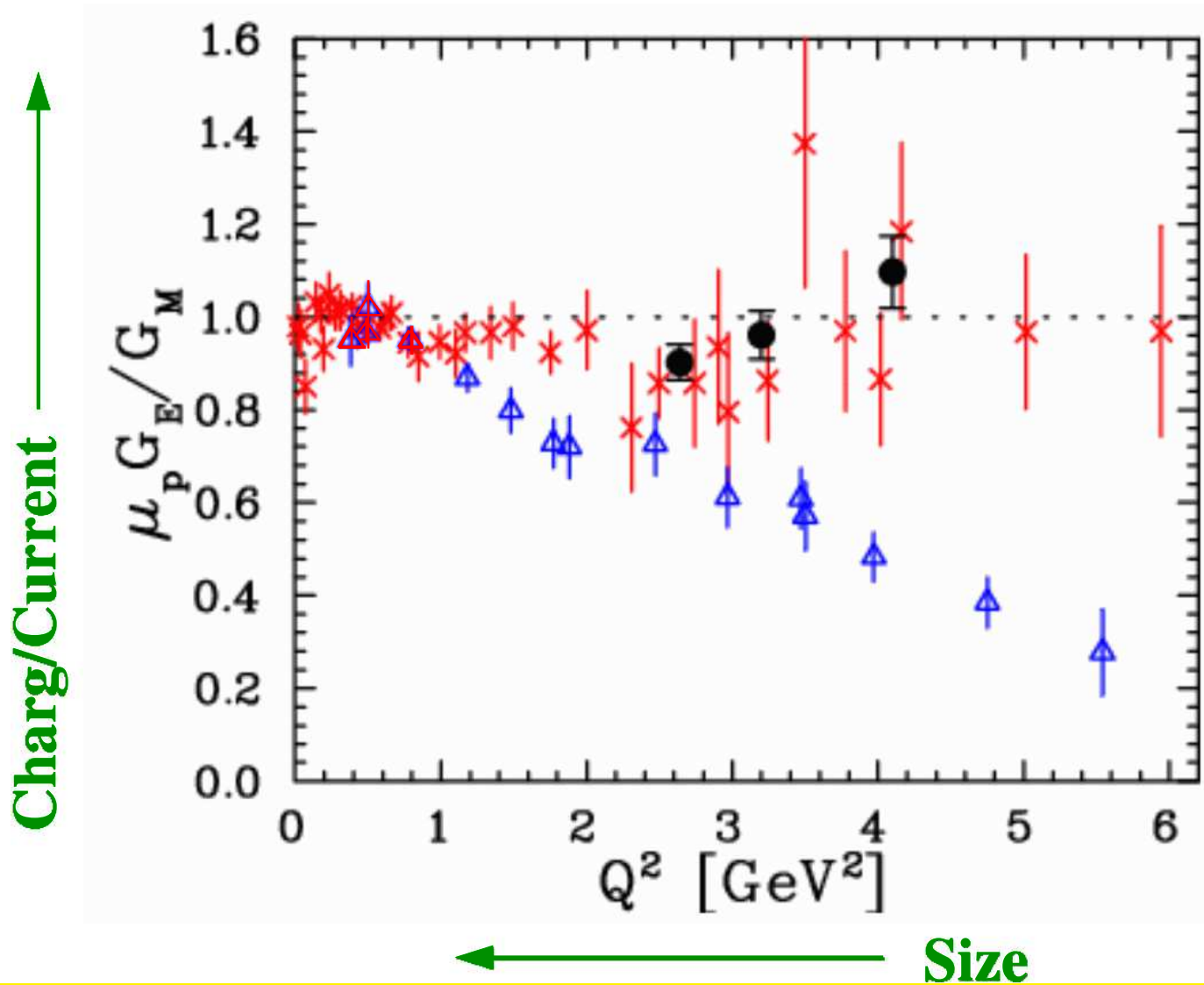
What Do We See?

Where are the charges and the currents?



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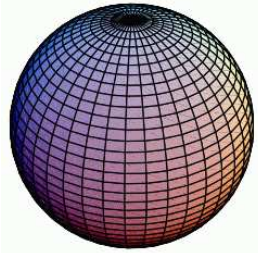
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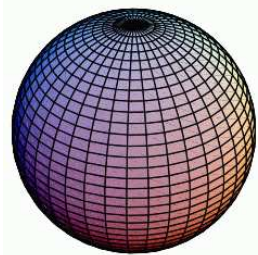
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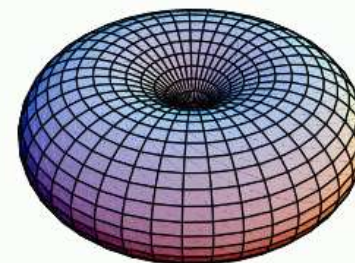
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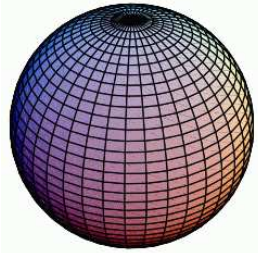
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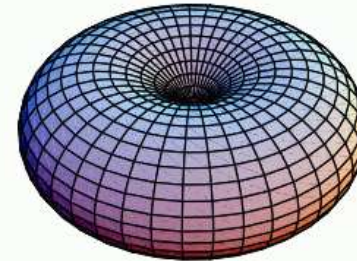
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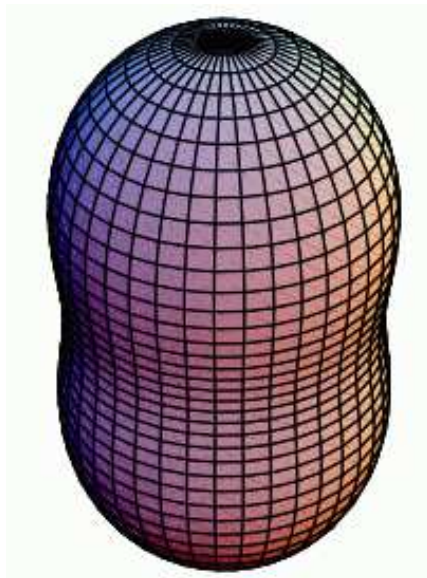
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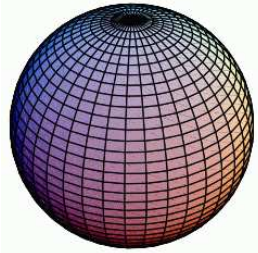
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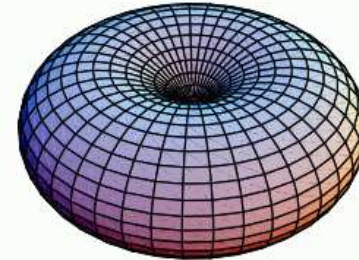
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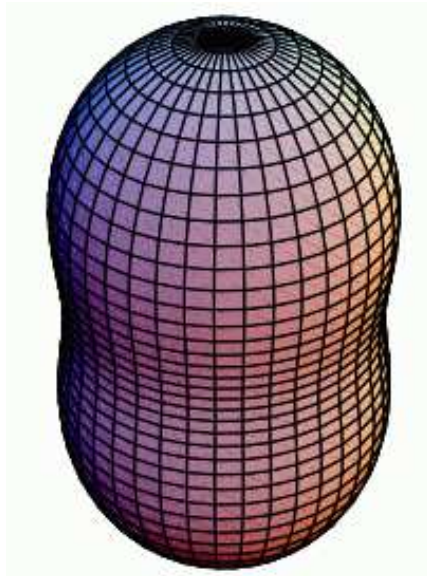
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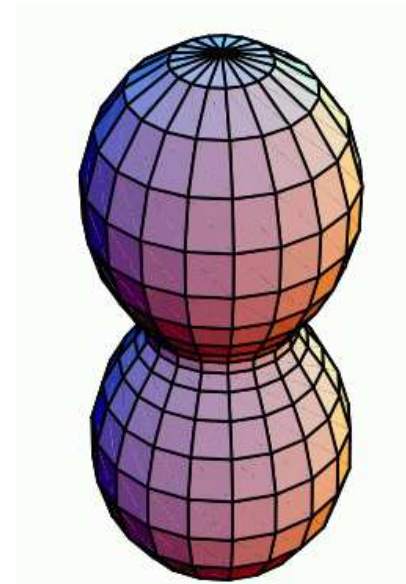
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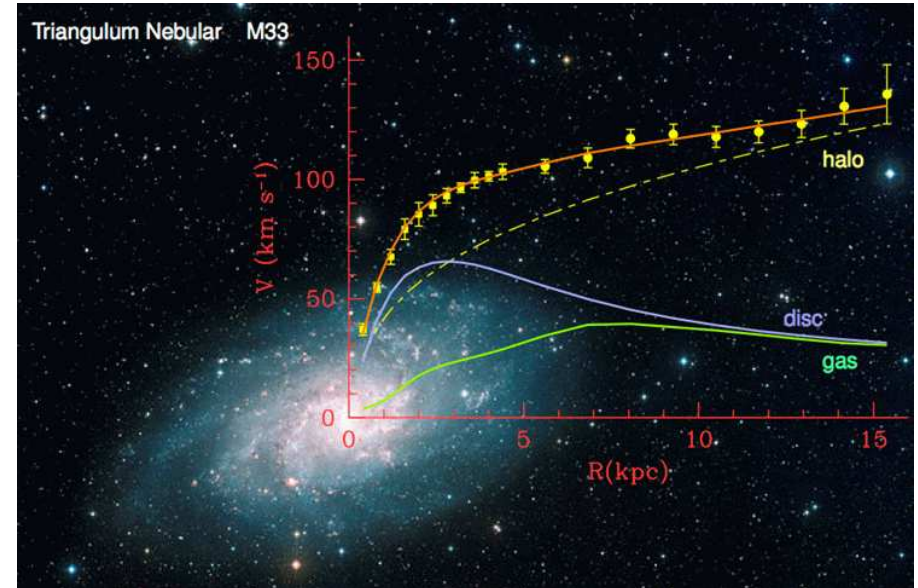


Not your mama's proton!

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Maybe we can see stuff we can't see!!

Some of the matter in the Universe is invisible or 'dark'.

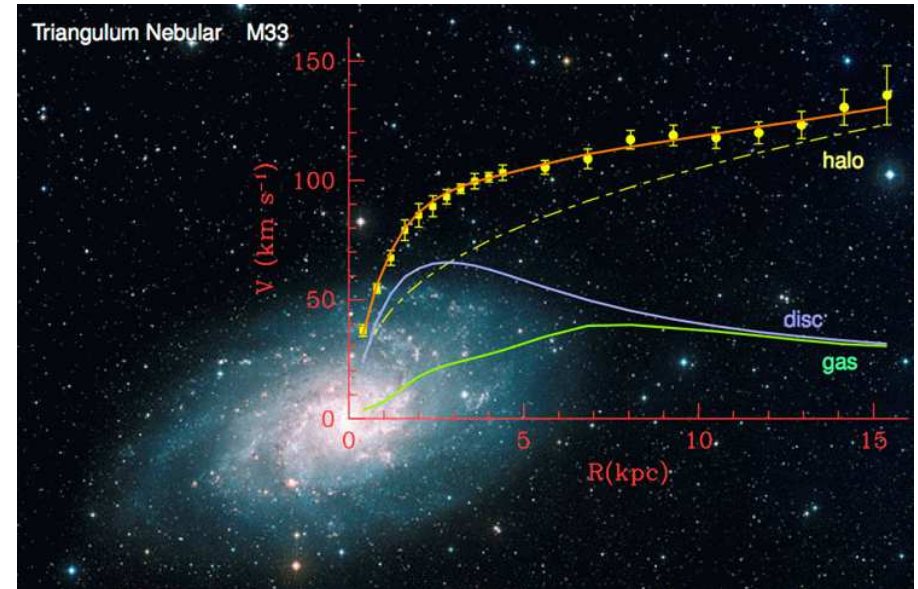
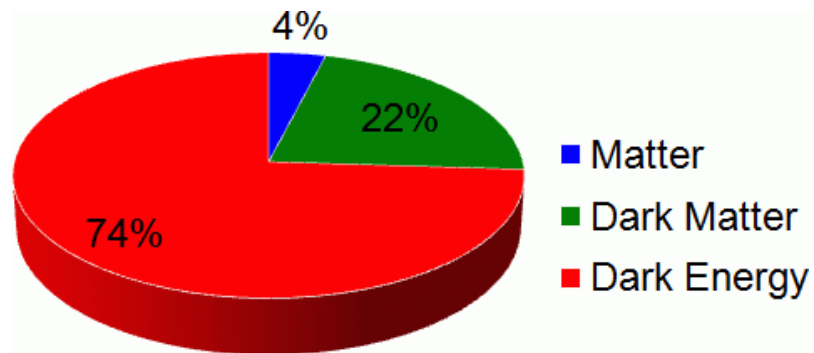


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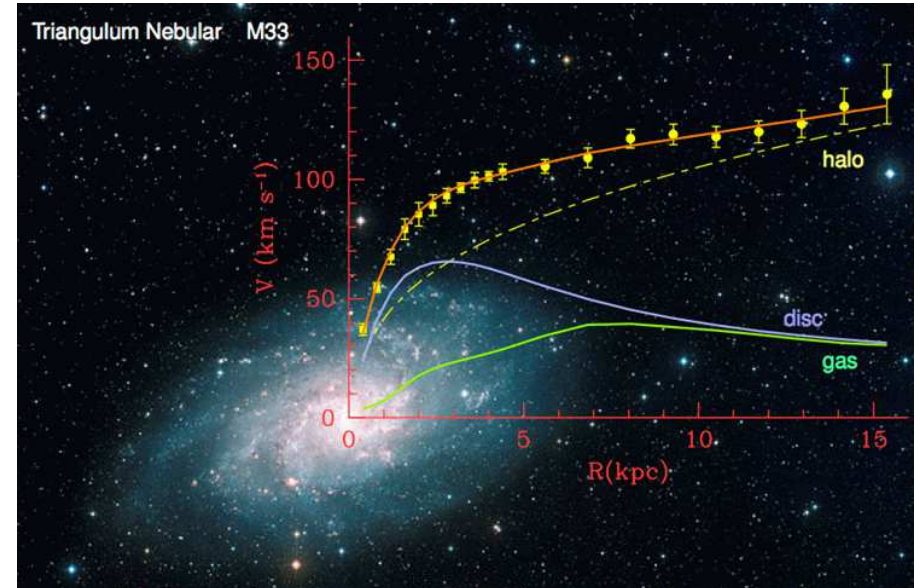
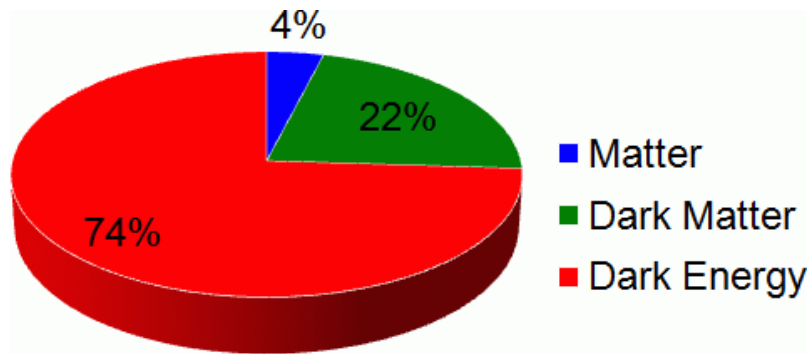


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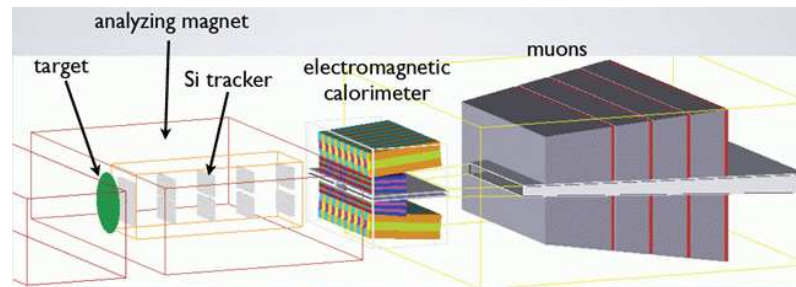
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Heavy Photon Search at JLab

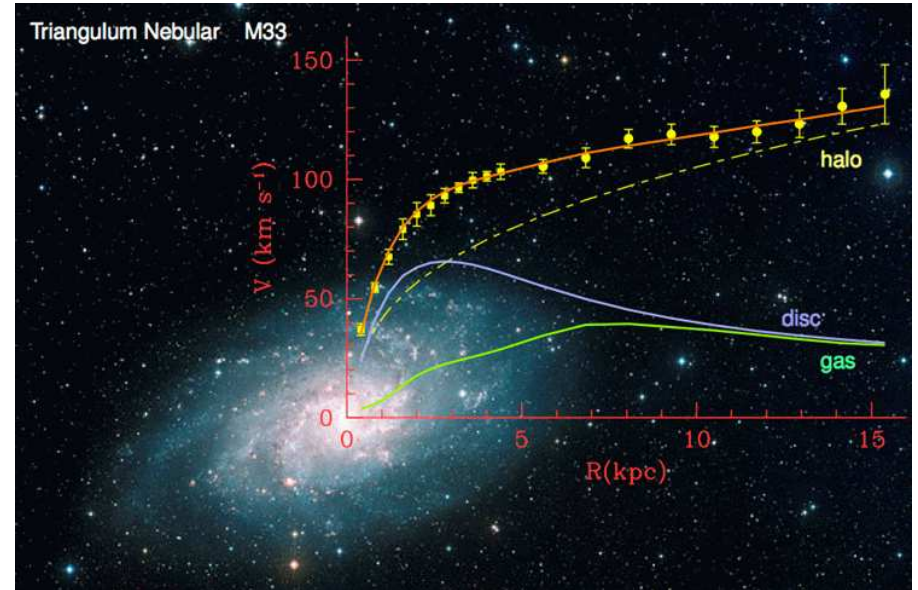
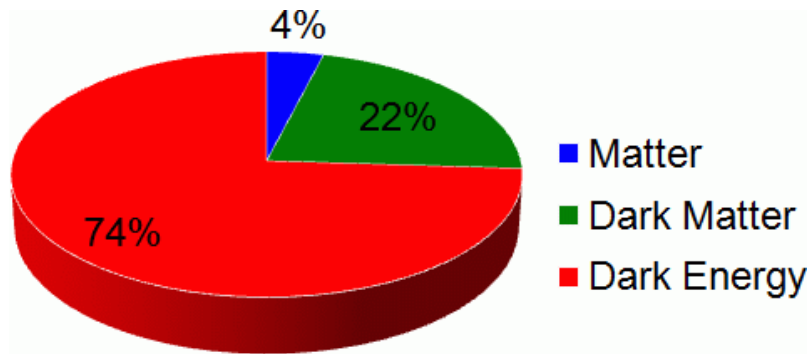


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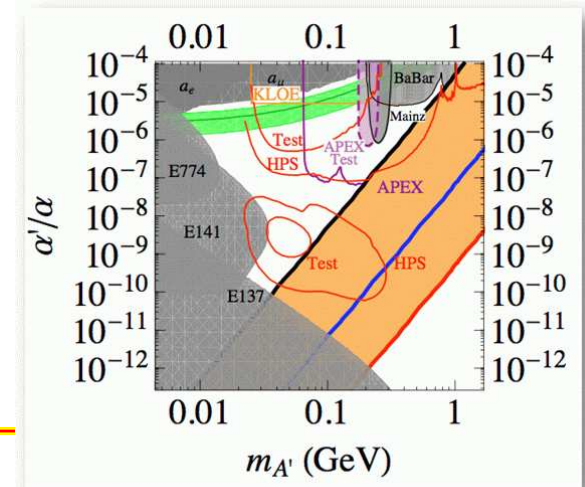
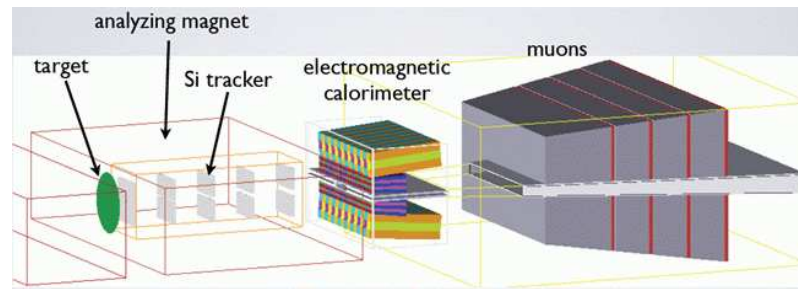
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4. Production of trained scientists, engineers, technicians. all from basic physics research.
About 200 doctoral theses have come out of JLab.



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In Paris in 1783 Benjamin Franklin watched with amazement one of the first hot-air balloon flights. The following exchange was said to occur.

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 ?

3. Technological spin
computers, ...

At JLab about 100

4. Production of train
from basic physics

About 200 doctora



W, transistors,

tented.

s, technicians. all

t of JLab.

To Learn More ...

- Including things to do in the classroom go to education.jlab.org.
- Science activities for elementary and middle school teachers.
- Physics Fest.
- High school student honors program.
- Teacher night.
- Open House.
- ...


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