Hunting for Quarks

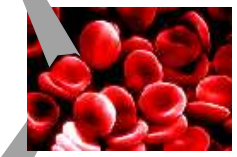
Jerry Gilfoyle, University of Richmond

"The Periodic Table"

What Do We Know?

The Earth to ... 10^{7} m

10^{1} m  hominids to ...

red blood cells.  10^{-6} m

10^{-10} m  The Atom

The nucleus 10^{-15} m

Protons and ...  neutrons ...

... are made of quarks. 

What Else 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		
Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	−1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1		
Name	Mass GeV/c^2	Electric charge
g gluon	0	0

FERMIONS matter constituents spin = 1/2, 3/2, 5/2, ...

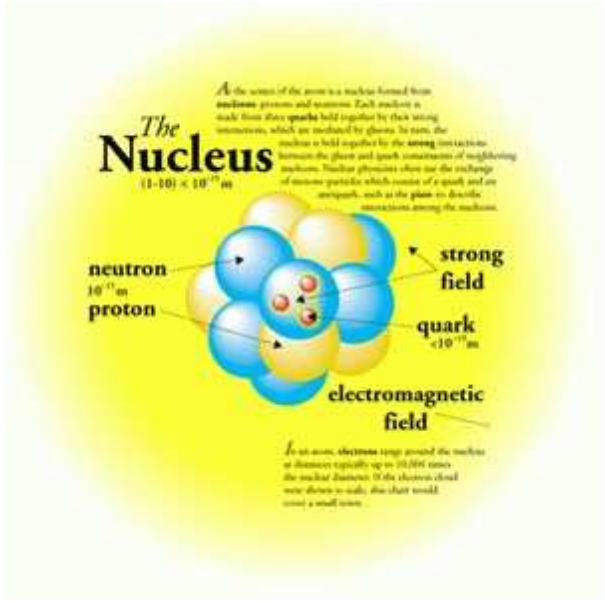
Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	−1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	−1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	−1

Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	−1/3
c charm	1.3	2/3
s strange	0.1	−1/3
t top	175	2/3
b bottom	4.3	−1/3

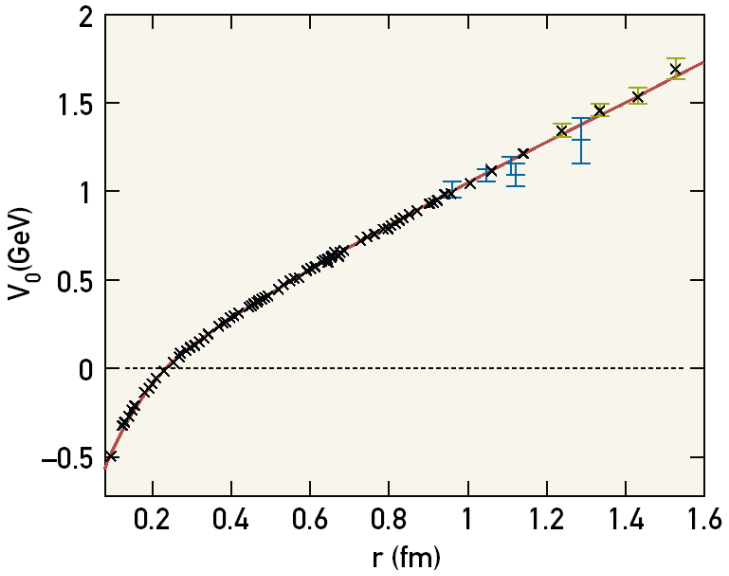
- The atomic nucleus is made of protons and neutrons bound by the strong force.



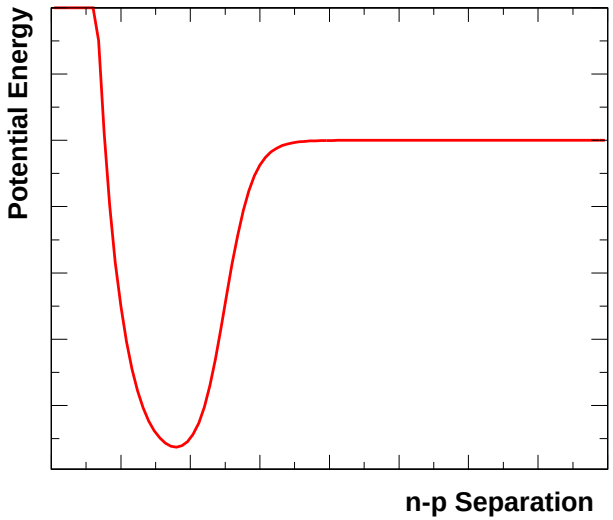
- The quarks are confined inside the protons and neutrons.
- Protons and neutrons are NOT confined.

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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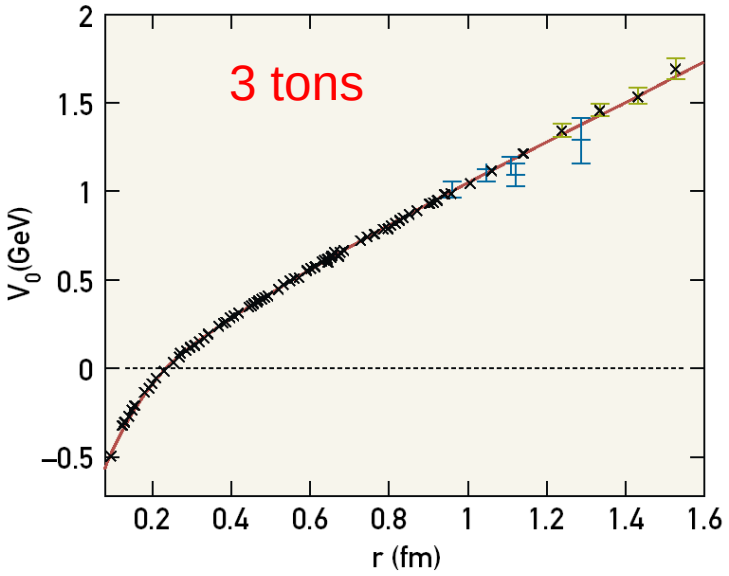

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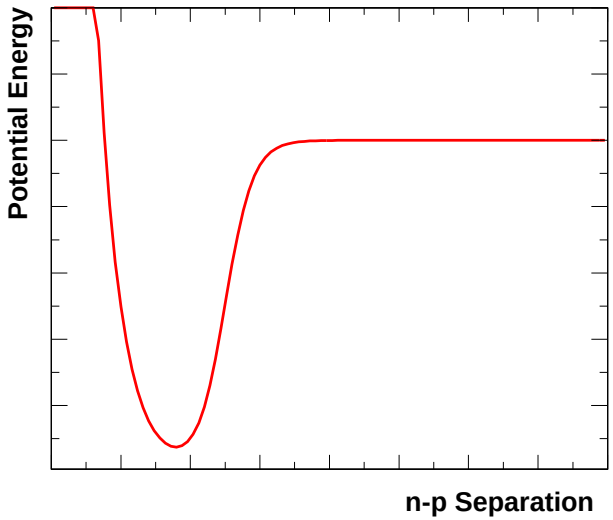
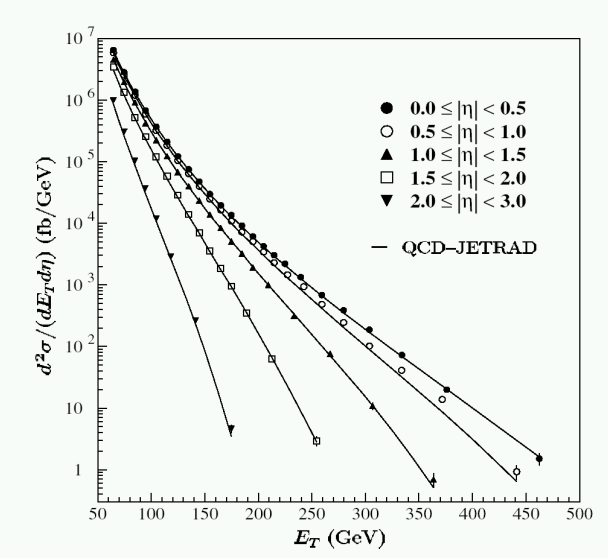


How Well Do We Know It?

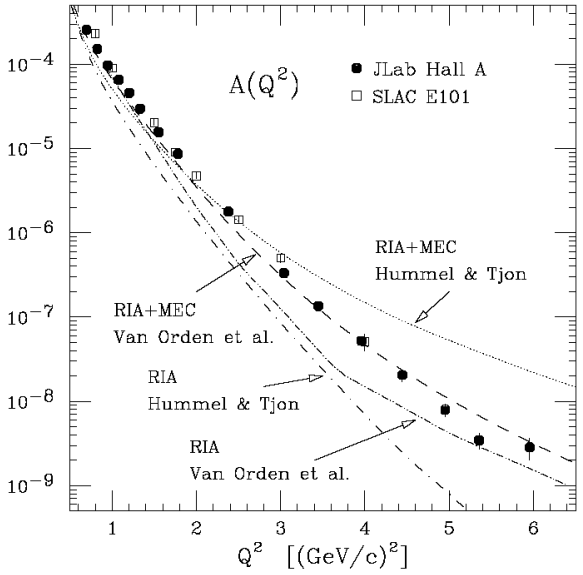
- We have a working theory of strong interactions: quantum chromodynamics or QCD.

  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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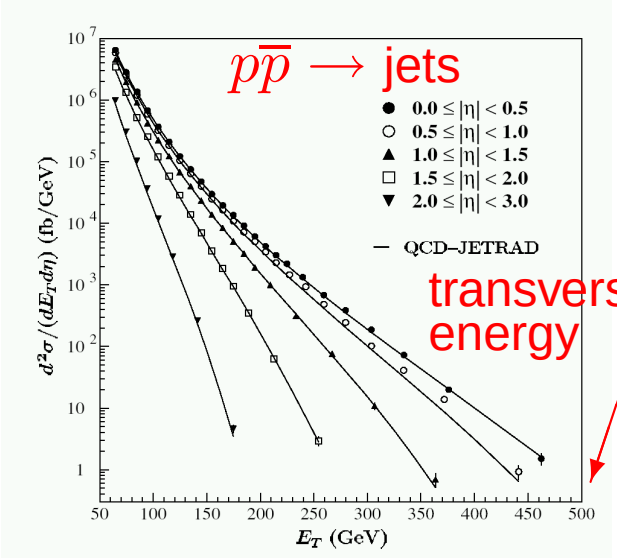

effective area of the target

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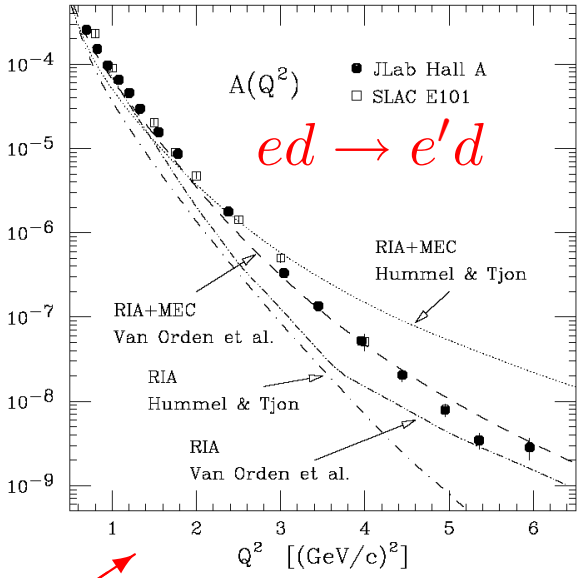


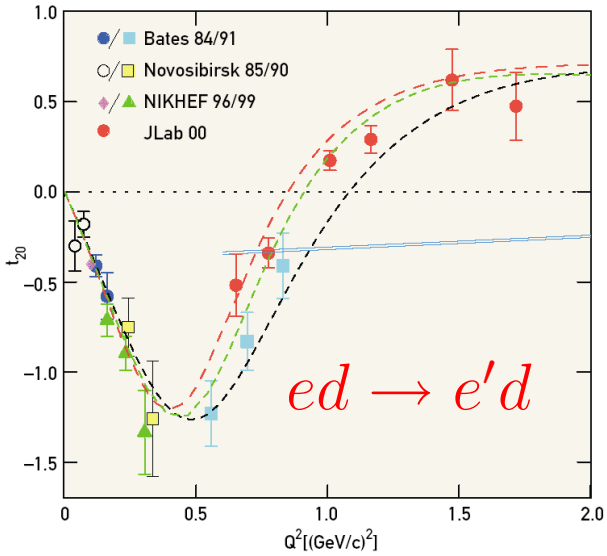
4-momentum transfer squared

What Don't We Know?

1. We can't get QCD and the hadronic model to line up.

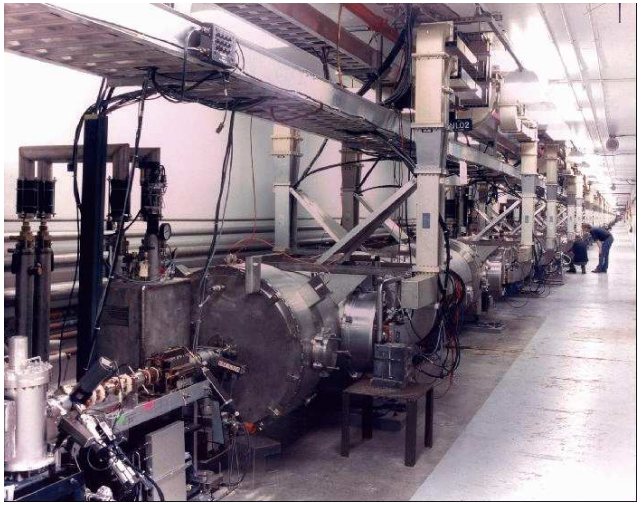
   D. Abbott, *et al.*, Phys. Rev Lett. **84**, 5053 (2000).

2. We have to find the hadronic model 'baseline' to see the transition to QCD.

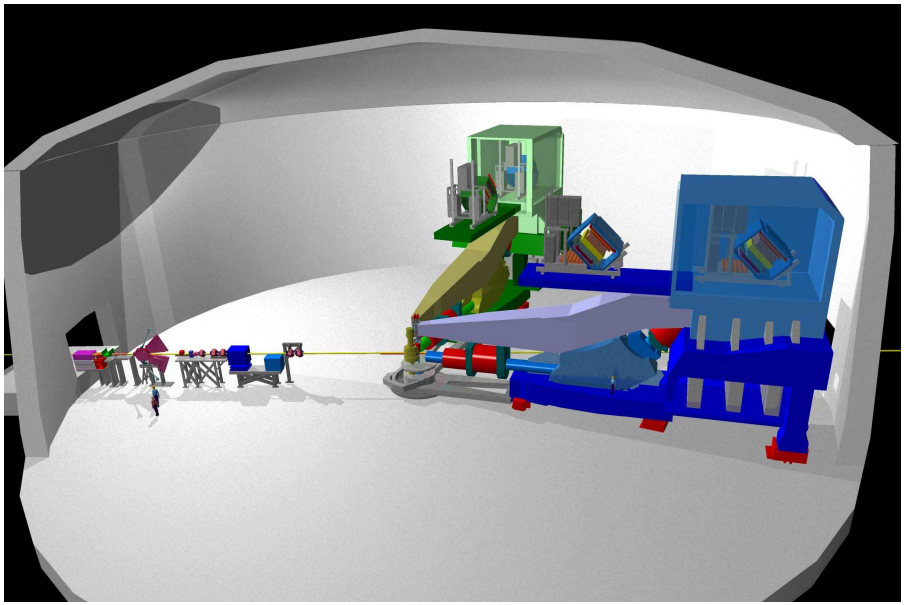


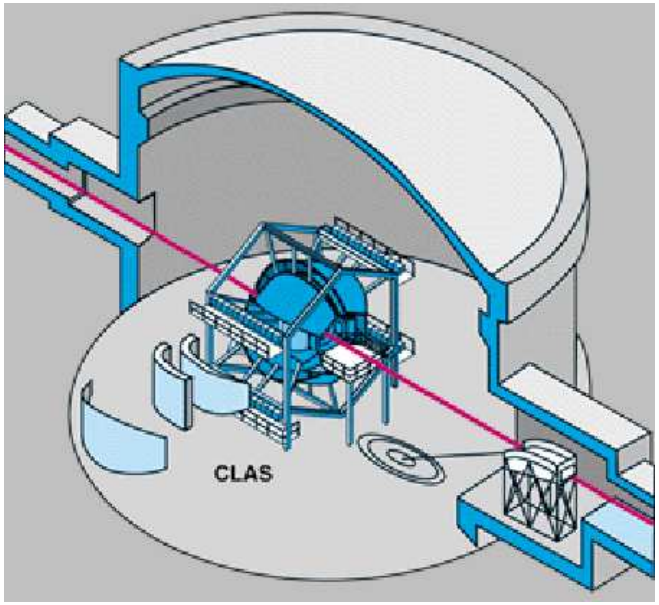
Experiments at Jefferson Lab

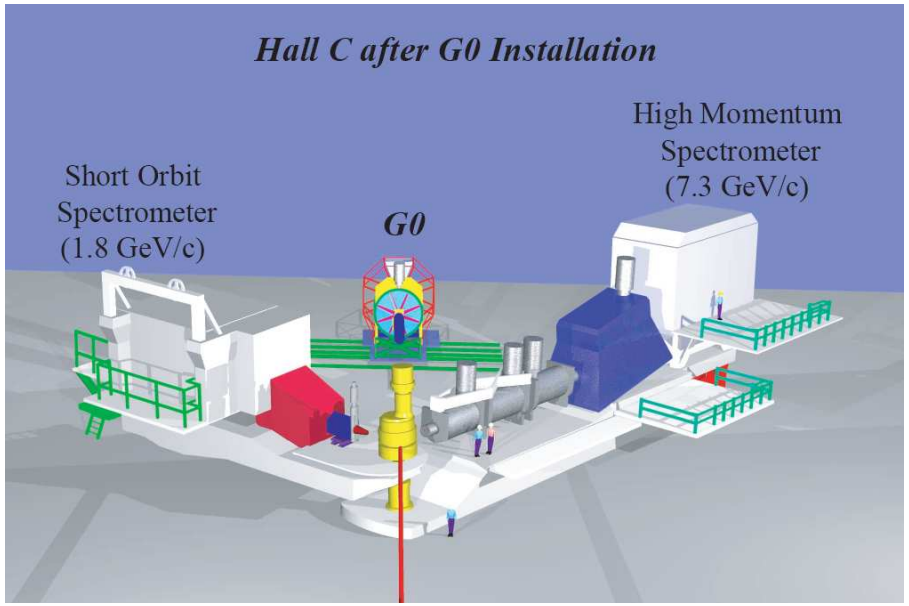
- Jefferson Lab is a US Department of Energy national laboratory and the newest ‘crown jewel’ of the US.
- The centerpiece is a 7/8-mile-long, racetrack-shaped electron accelerator that produces unrivaled beams.
- The electrons do up to five laps around the Continuous Electron Beam Accelerator Facility (CEBAF) and are then extracted and sent to one of three experimental halls.
- All three halls can run simultaneously.



Halls A, B, C

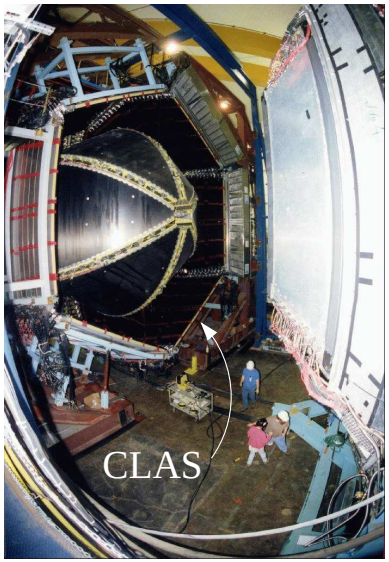


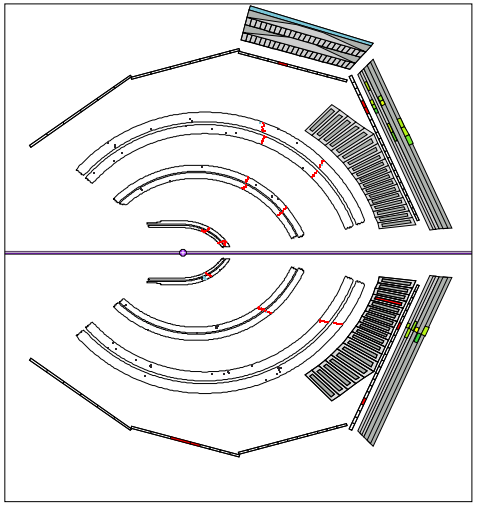

CLAS


Hall C after G0 Installation
High Momentum
Spectrometer
(7.3 GeV/c)
Short Orbit
Spectrometer
(1.8 GeV/c)
G0

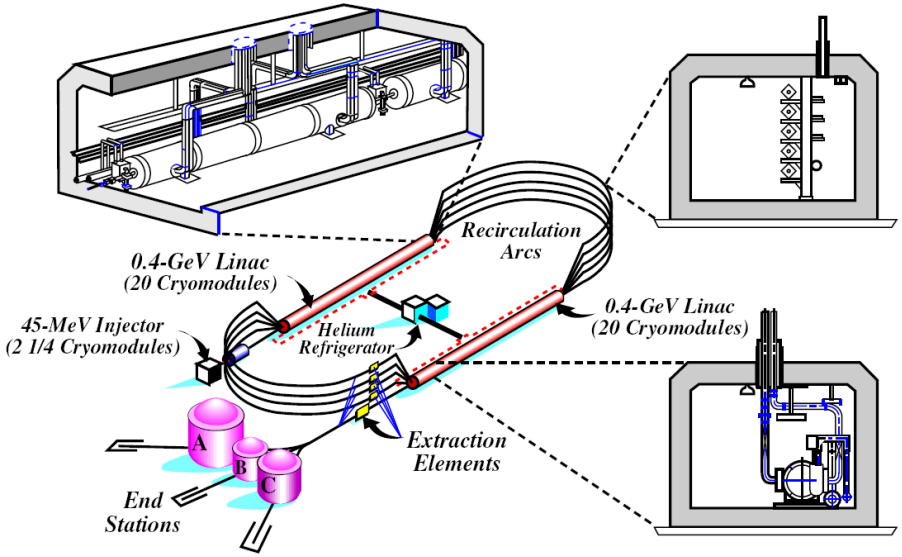
The CEBAF Large Acceptance Spectrometer (CLAS)

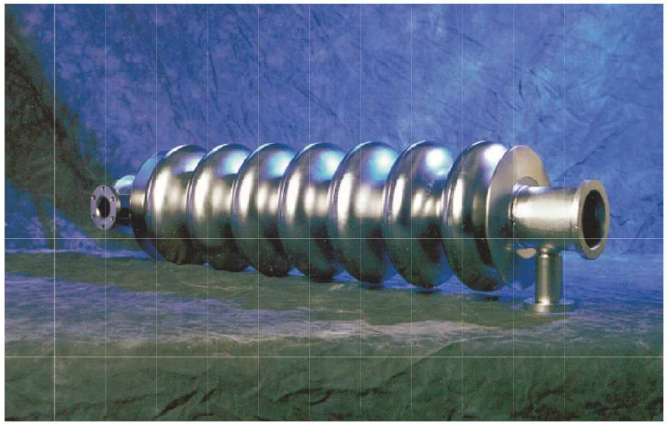
- CLAS is a 45-ton, $50-million radiation detector.
- It covers almost all angles.
- It has about 35,000 detecting elements in about 40 layers.
- Drift chambers map the trajectory of the collision. A toroidal magnetic field bends the trajectory to measure momentum.
- Other layers measure energy, time-of-flight, and particle identification.
- Each collision is reconstructed and the intensity pattern reveals the forces and structure of the colliding particles.





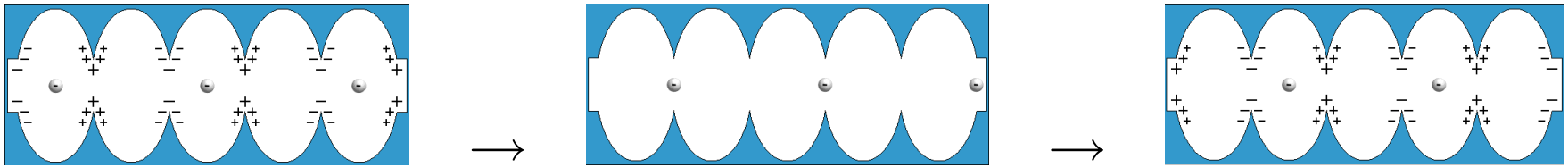
How Does CEBAF Work?





Cavity

What happens inside the cavity? Feed it with oscillating, radio-frequency power at 1.5 GHz! In each hall beam buckets are about 2 picoseconds long and arrive every 2 nanoseconds.

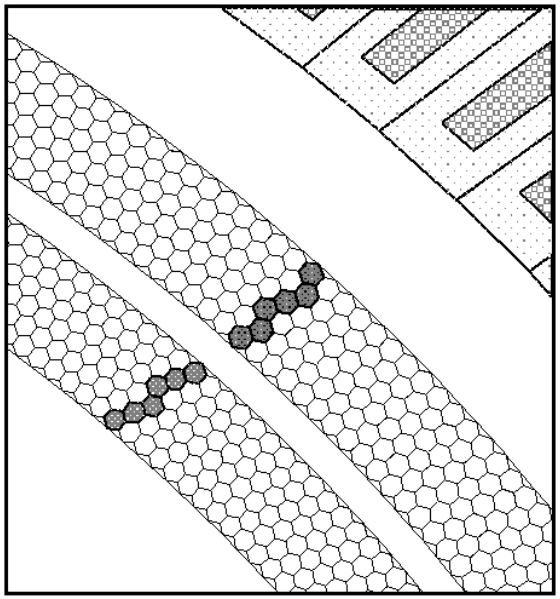


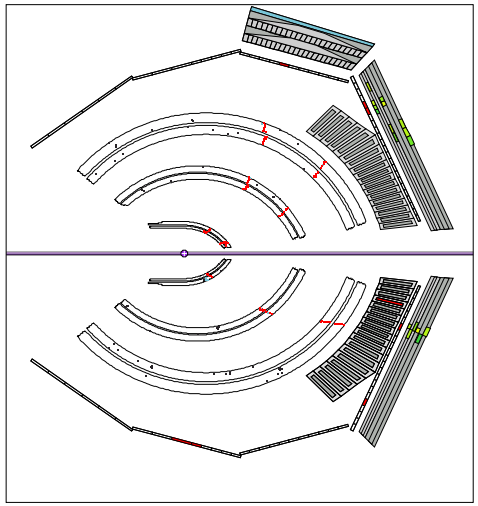
A. B. C.

How Does CLAS Work? - 1

Beam hits target.

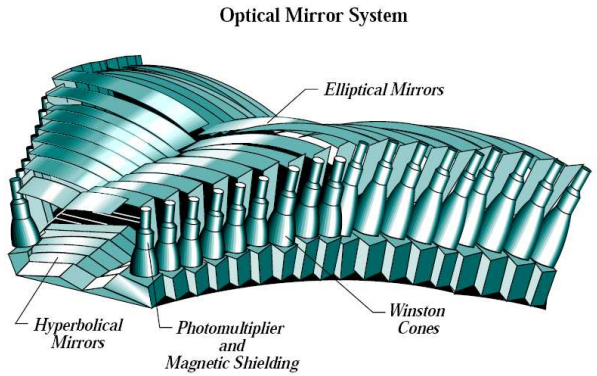
Hits in the drift chambers

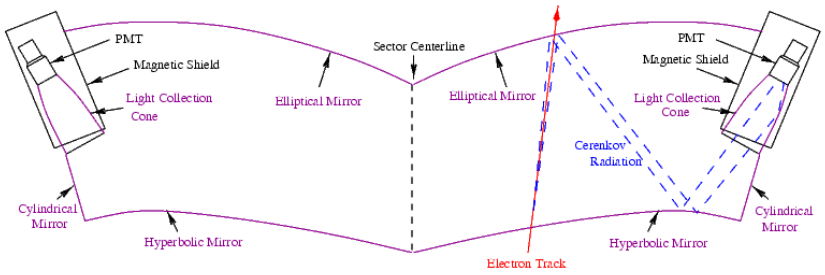




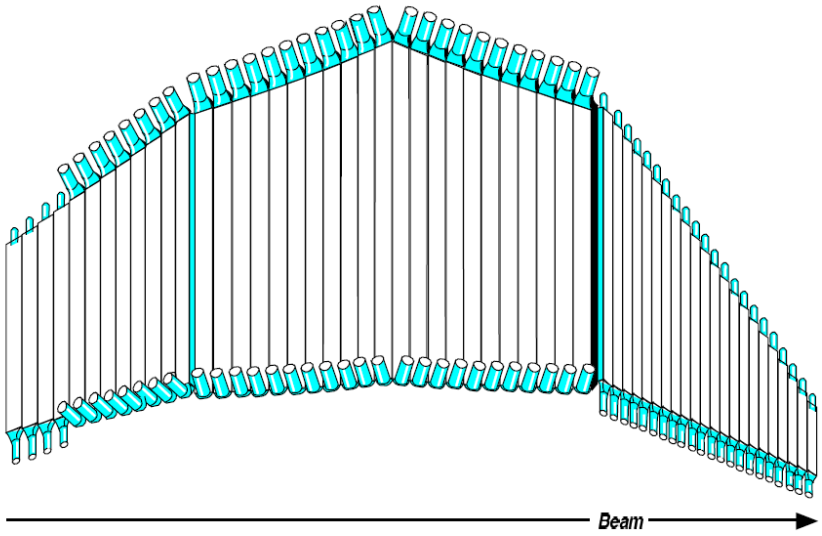
How Does CLAS Work? - 2

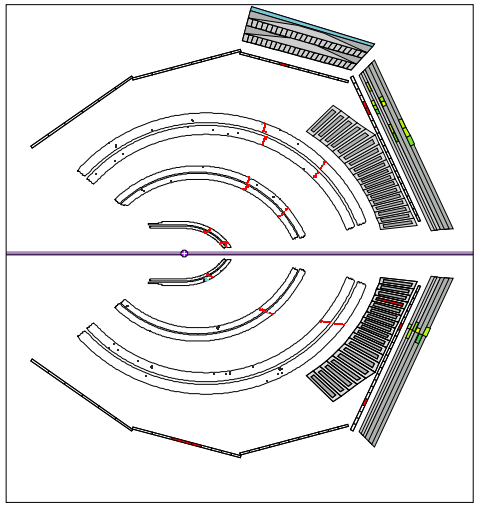
Cerenkov counters separate electrons from heavier, slower particles.





Hits in the plastic scintillators produce fast, timing signals.

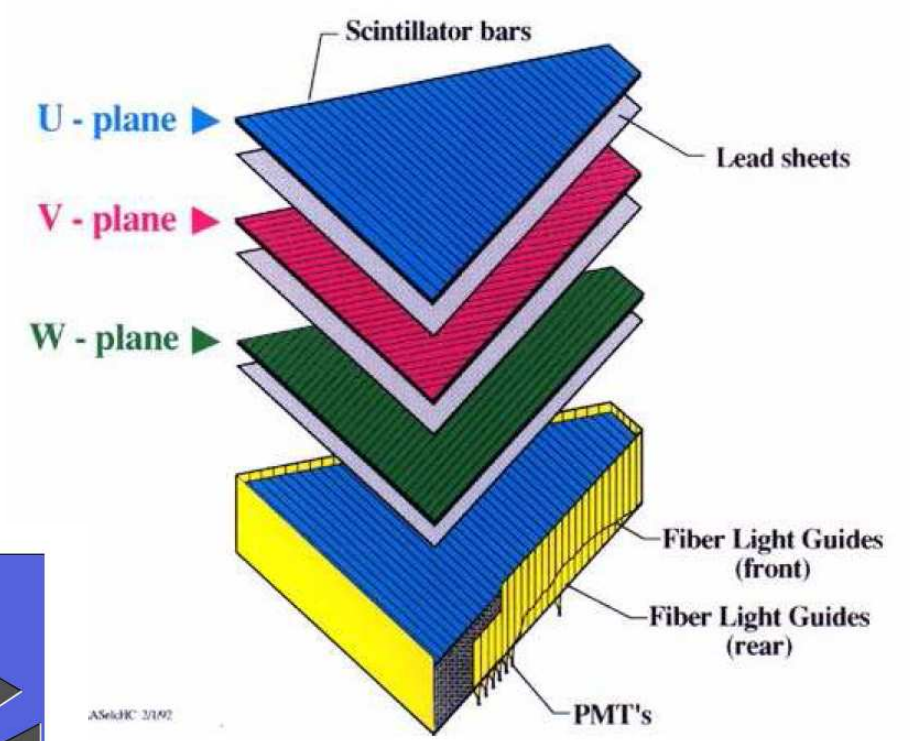


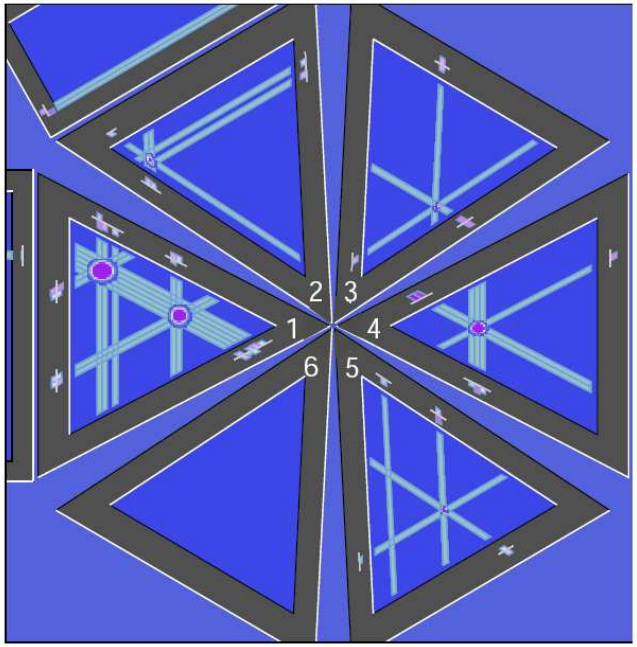


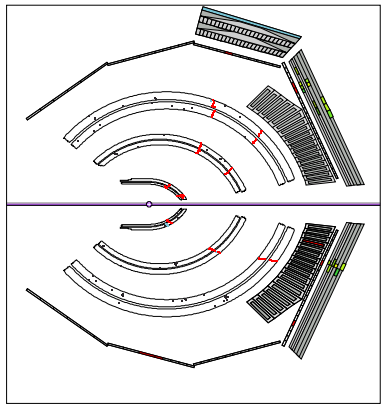
How Does CLAS Work? - 3

Calorimeters stop the particles and measure the energy

Signals from the different layers localize the hit.

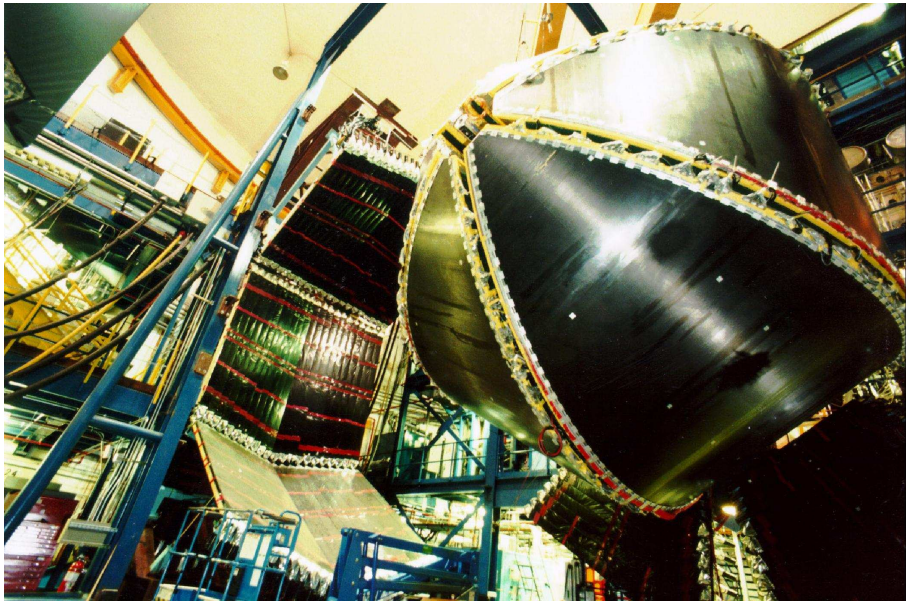


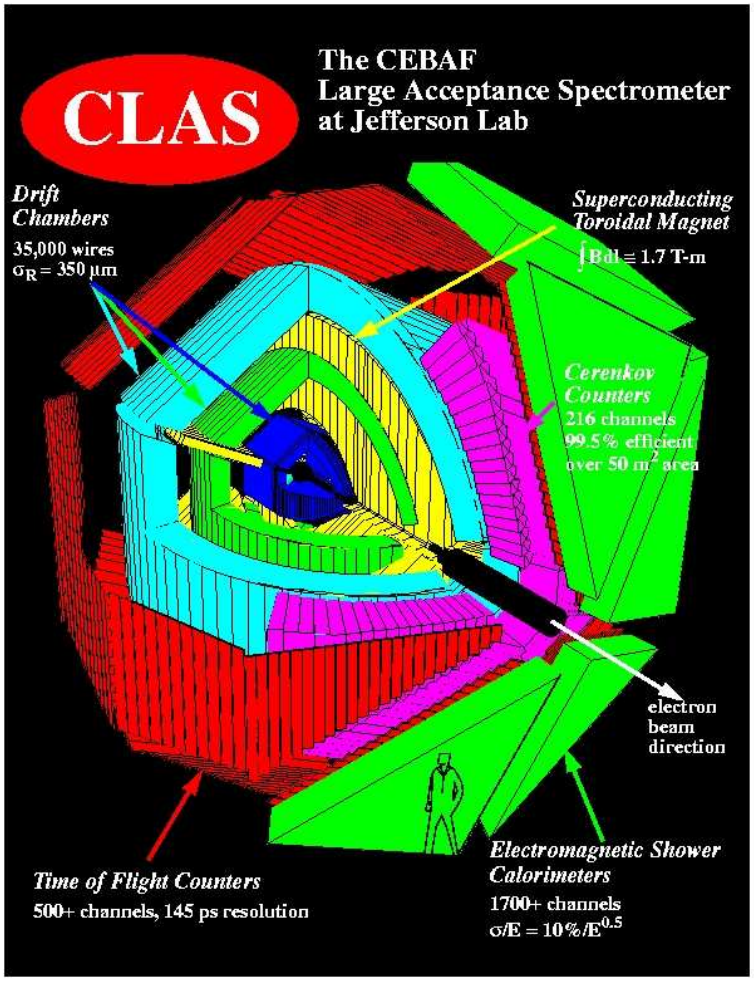




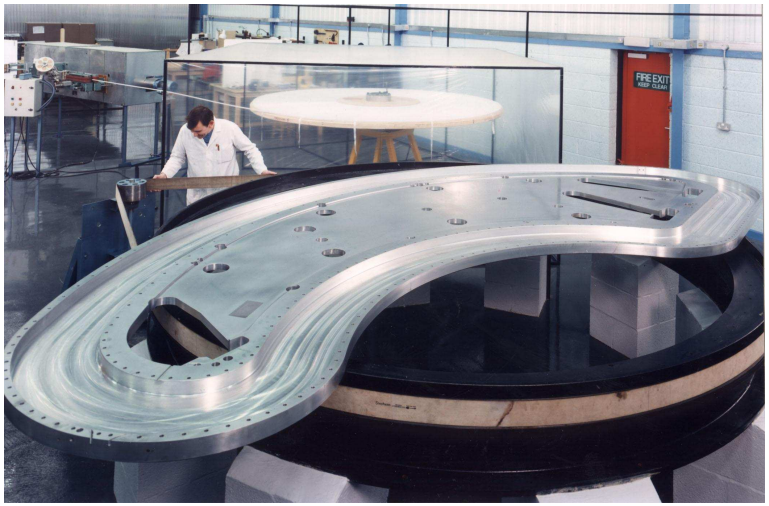
How Does CLAS Work? - 4

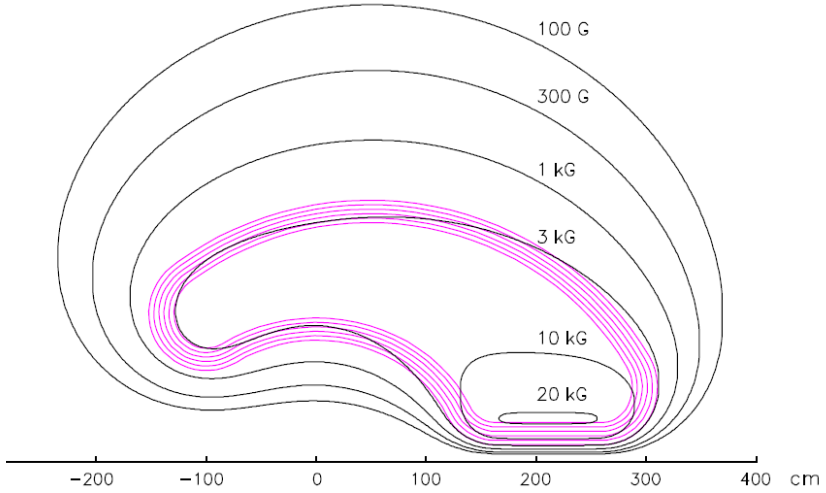
The final detector configuration.

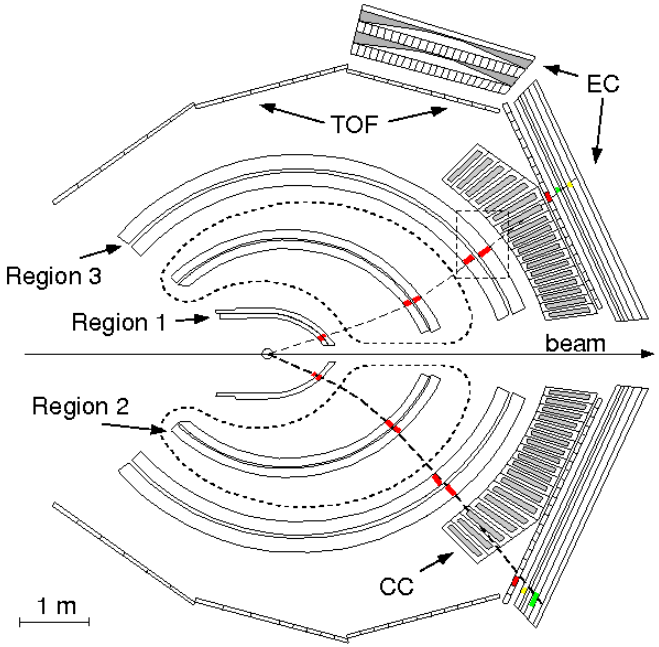




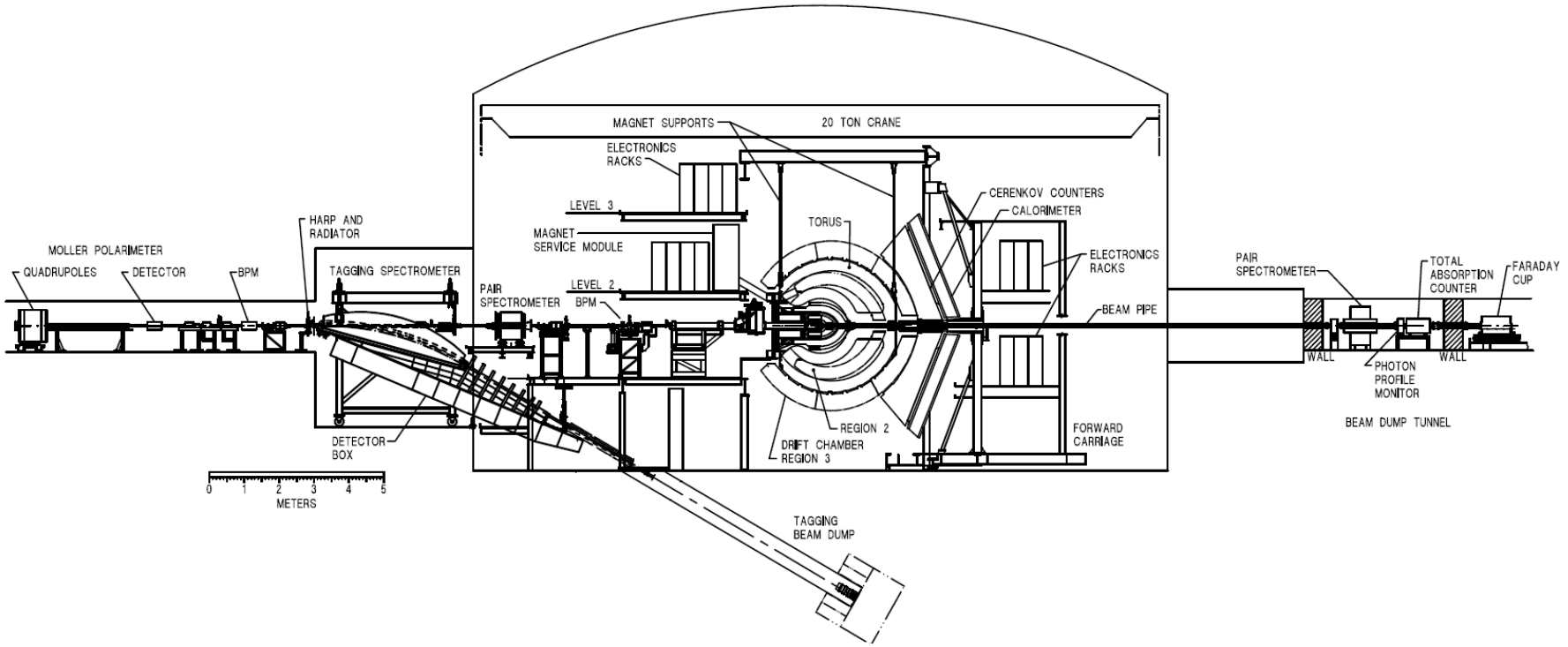
How Does CLAS Work? - 5



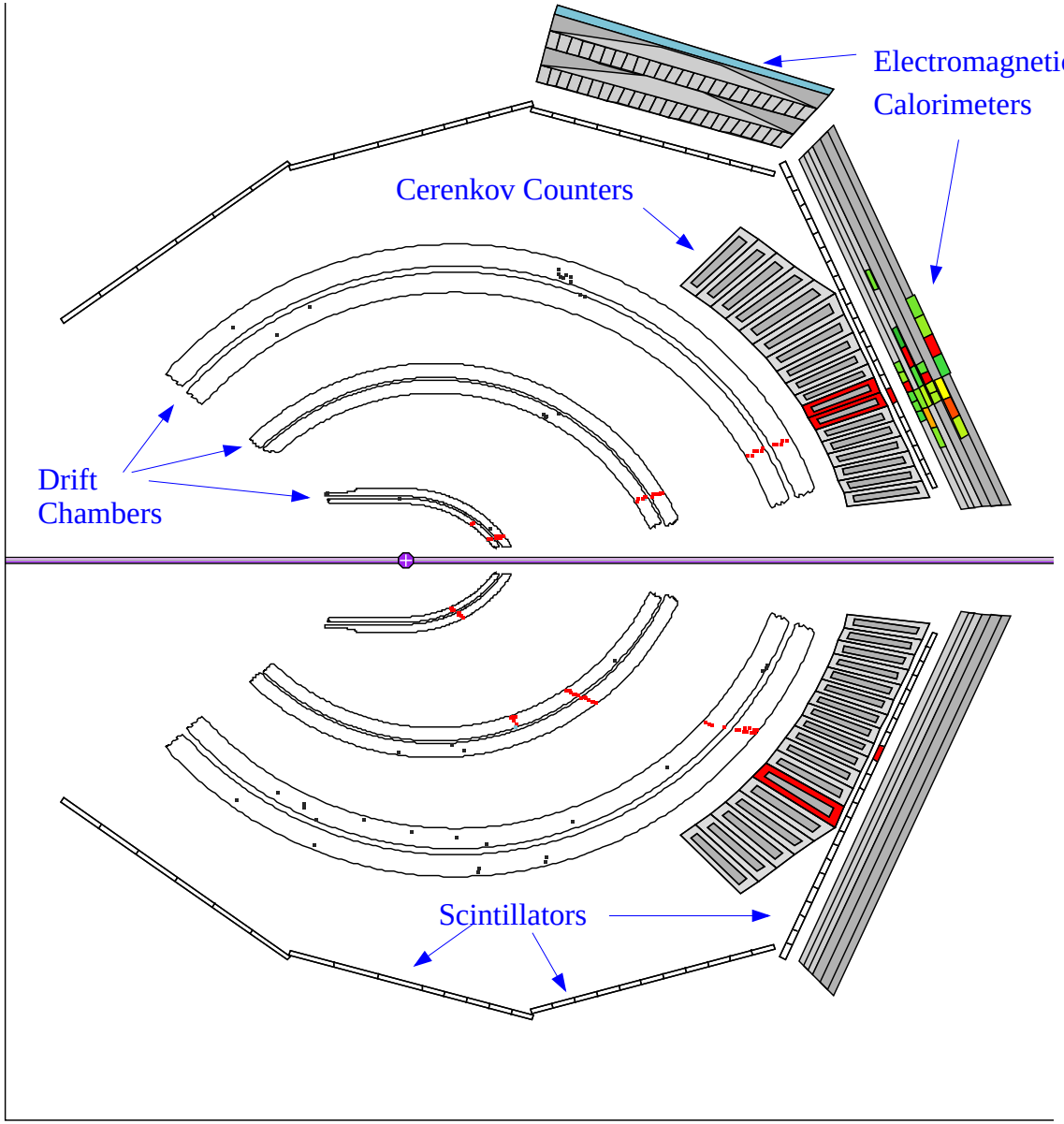




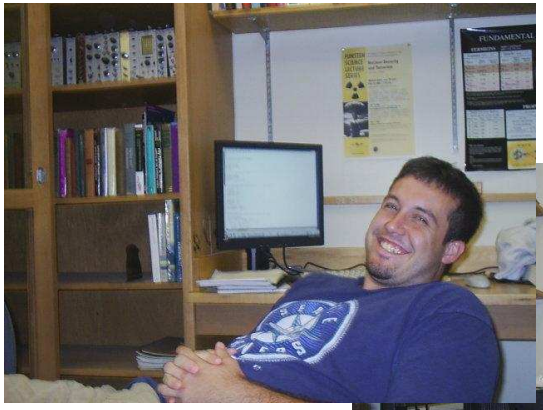
How Does CLAS Work? - 6

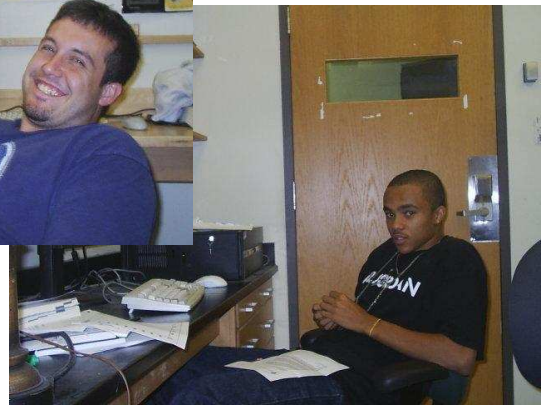


A CLAS Event

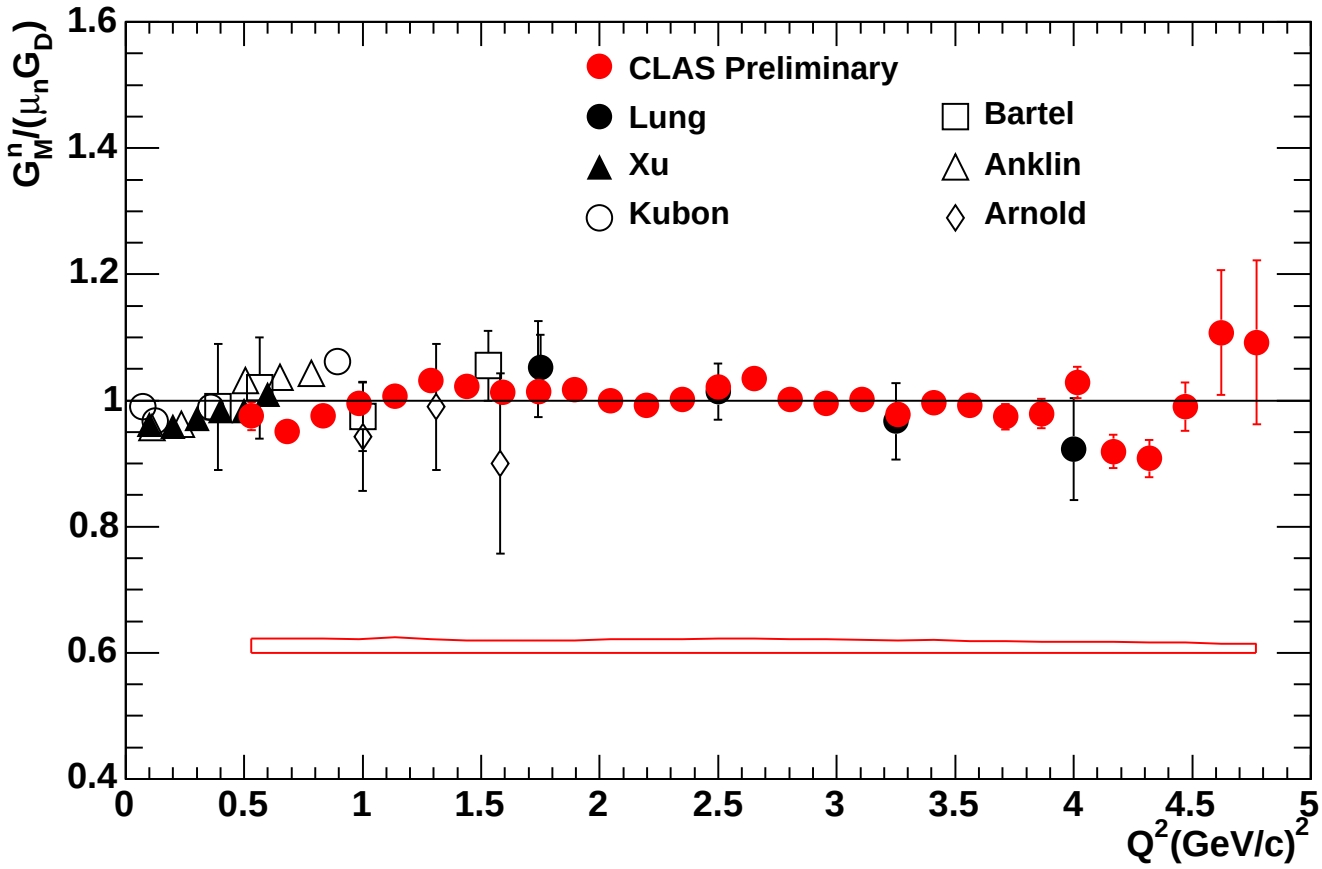

Electromagnetic
Calorimeters
Cerenkov Counters
Drift
Chambers
Scintillators

Life on the Frontiers of Knowledge





What Do the Data Look Like? - A non-objective example.



The magnetic form factor of the neutron G_M^n (above) tells us where the electric charge and currents are located inside the neutron. The CLAS data is in red. The rest of the world's data is in black.