Hadronic Physics
Search for New Forms of Femtoscale Matter

Prof. Paul Eugenio

Prof. Volker Credé

Dr. Alexander Ostrovidov

Florida State University

Tallahassee, FL USA

Physics Graduate Student Presentation

FSU Keen 707 October 21, 2016

Hadron Physics Graduate Students
at Florida State University

Hadronic Nuclear Physics Faculty

- Prof. Paul Eugenio
- Prof. Volker Credé

Present Students

- Hussein Al Ghoul*
- Aristeidis Tsaris*
- Bradford Cannon
- Priyashree Roy#
- Zulkaida Akbar
- Chrisopher Zeoli#
- Ashley Ernst

*- graduated Spring 2016 PhD
#- expected Fall 2016 PhD

Recent Graduates

Nathan Sparks (PhD 2013)	PostDoc @ Catholic U./JLAB
Sungkyun Park (PhD 2013)	KAERI Staff Scientist, Korea
Mukesh Saini (PhD 2013)	Intel, Q&R Engineer
Andrew Wilson (PhD 2012)	PostDoc @ UBonn, Germany
Craig Bookwalter (PhD 2012)	PostDoc @ PNNL > Ultimate Software
Charles Hanretty (PhD 2011)	PostDoc @ UVA > JLAB Staff Scientist
Burnham Stokes (PhD 2006)	PostDoc @ GWU > Lead Engineer at GE
Shifeng Chen (PhD 2006)	PostDoc @ DukeU > Professor, UMaryland Med School

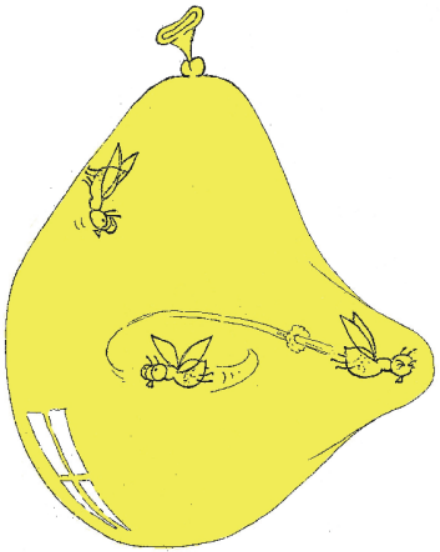
Strong-Coupling Quantum Chromodynamics (QCD)

$$\mathcal{L}_{\mathrm{QCD}} = \sum_q \bar{q}\left(i\gamma_\mu D^\mu - m_q\right) q$$

$$-\frac{1}{4} F^{\mu\nu} F_{\mu\nu}$$

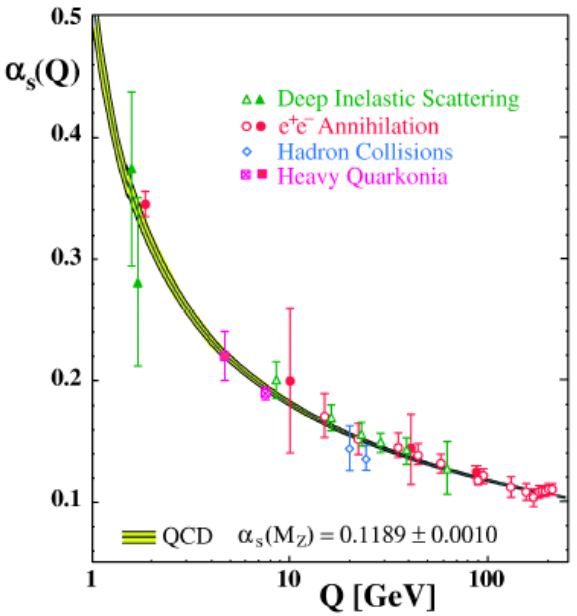
QCD is the theory of the strong nuclear force which describes the interactions of quarks and gluons making up hadrons.

Strong processes at larger distances and at small (soft) momentum transfers belong to the realm of non-perturbative QCD.

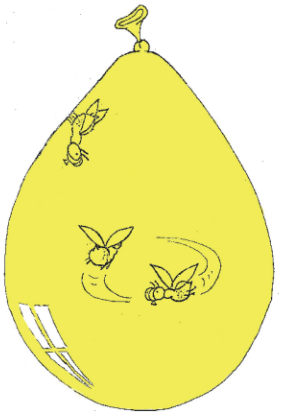


Confinement

"Strong QCD"

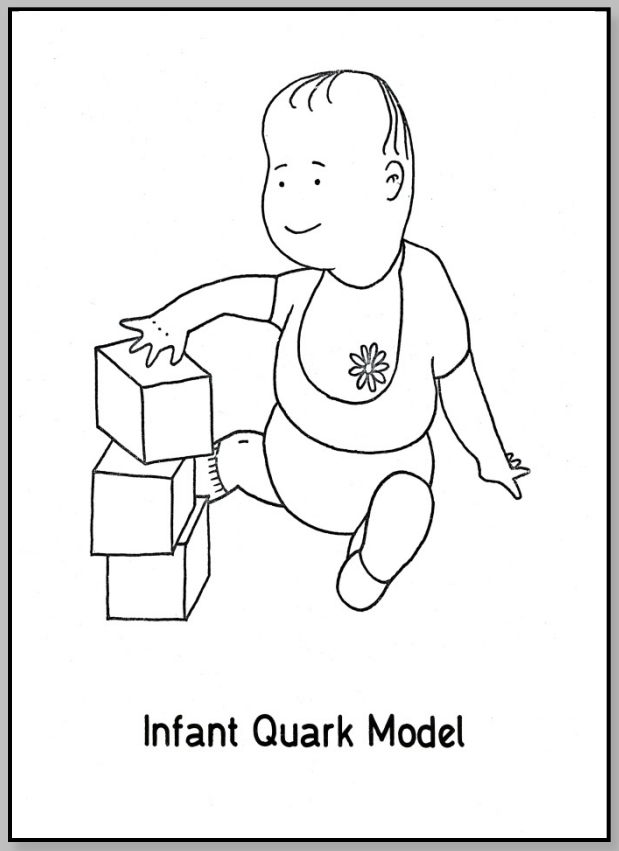


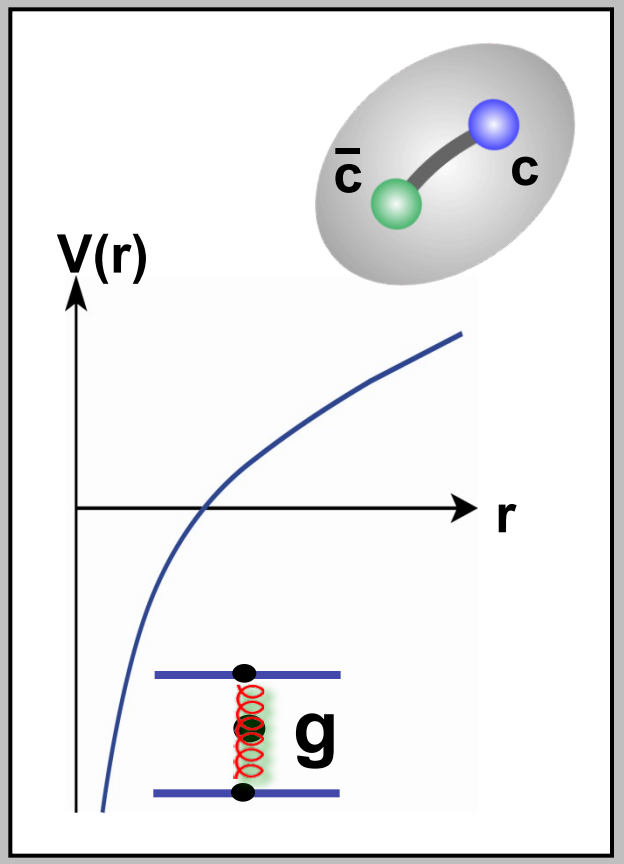
"pQCD"

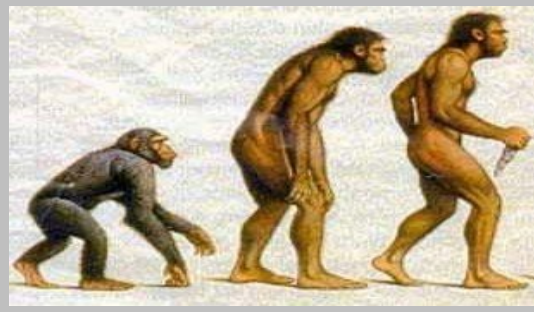


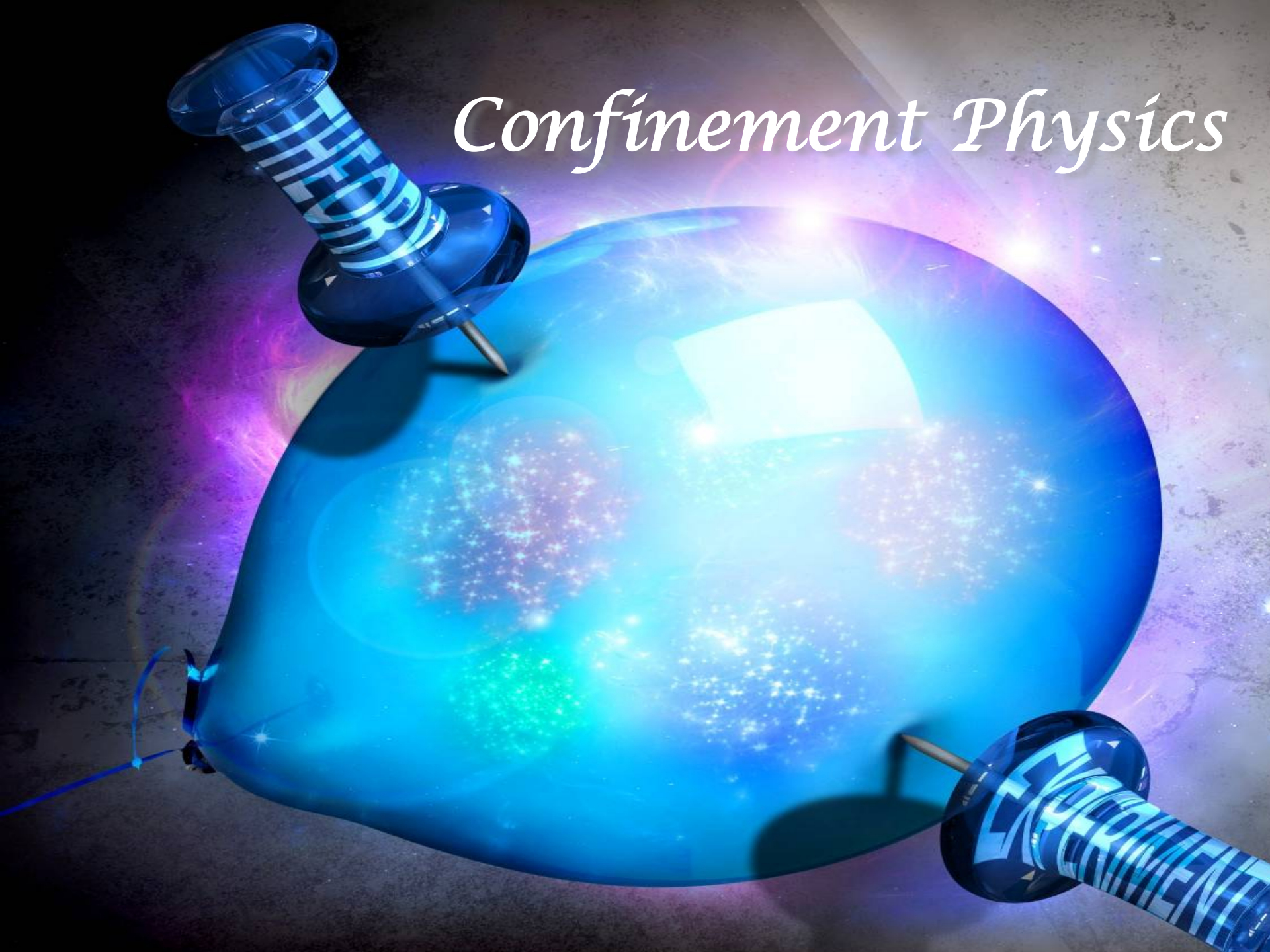
Asymptotic Freedom

Evolution of understanding







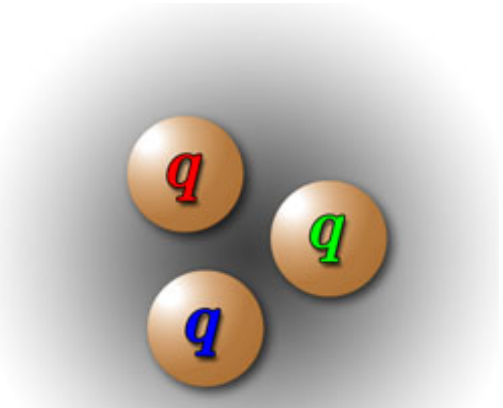

Confinement Physics
THEORY
EXPERIMENT

Hadrons: Baryons & Mesons

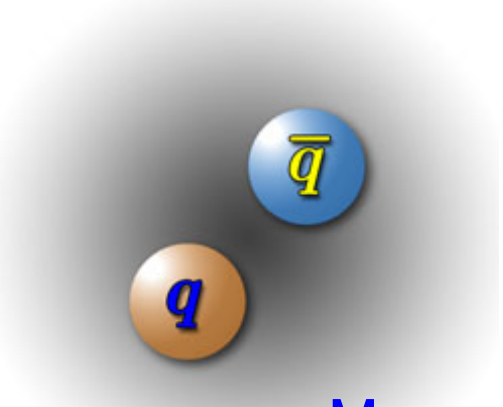
The strong coupling confines quarks and breaks chiral symmetry, and so defines the world of light hadrons.

Baryons are special because

- their structure is most obviously related to the color degree of freedom, e. g. $|\Delta^{++}\rangle = |u^{\uparrow}u^{\uparrow}u^{\uparrow}\rangle$.
- they are the stuff of which our world is made.



Baryons



Mesons

Hadrons: Baryons & Mesons

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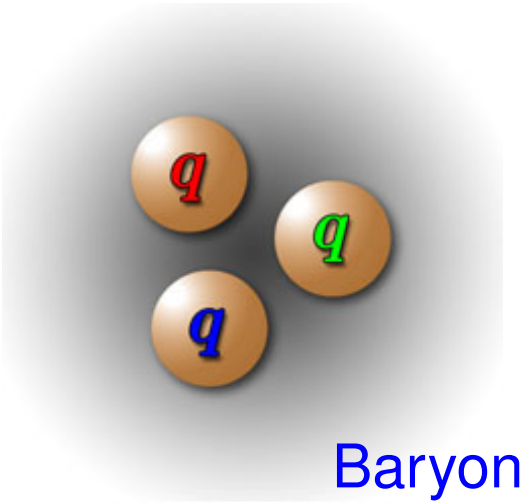
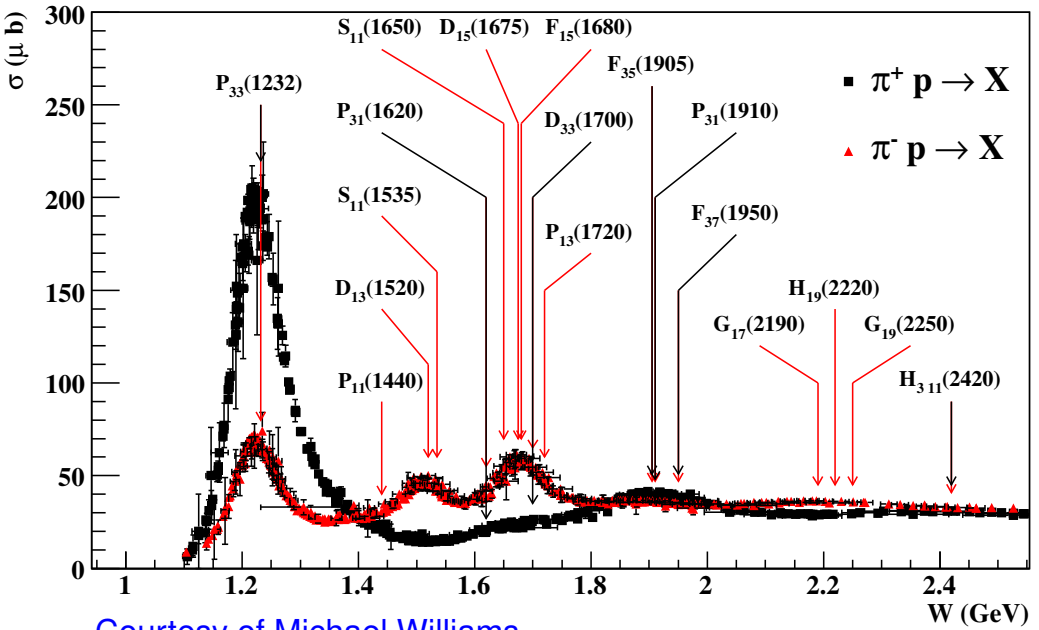


Baryons

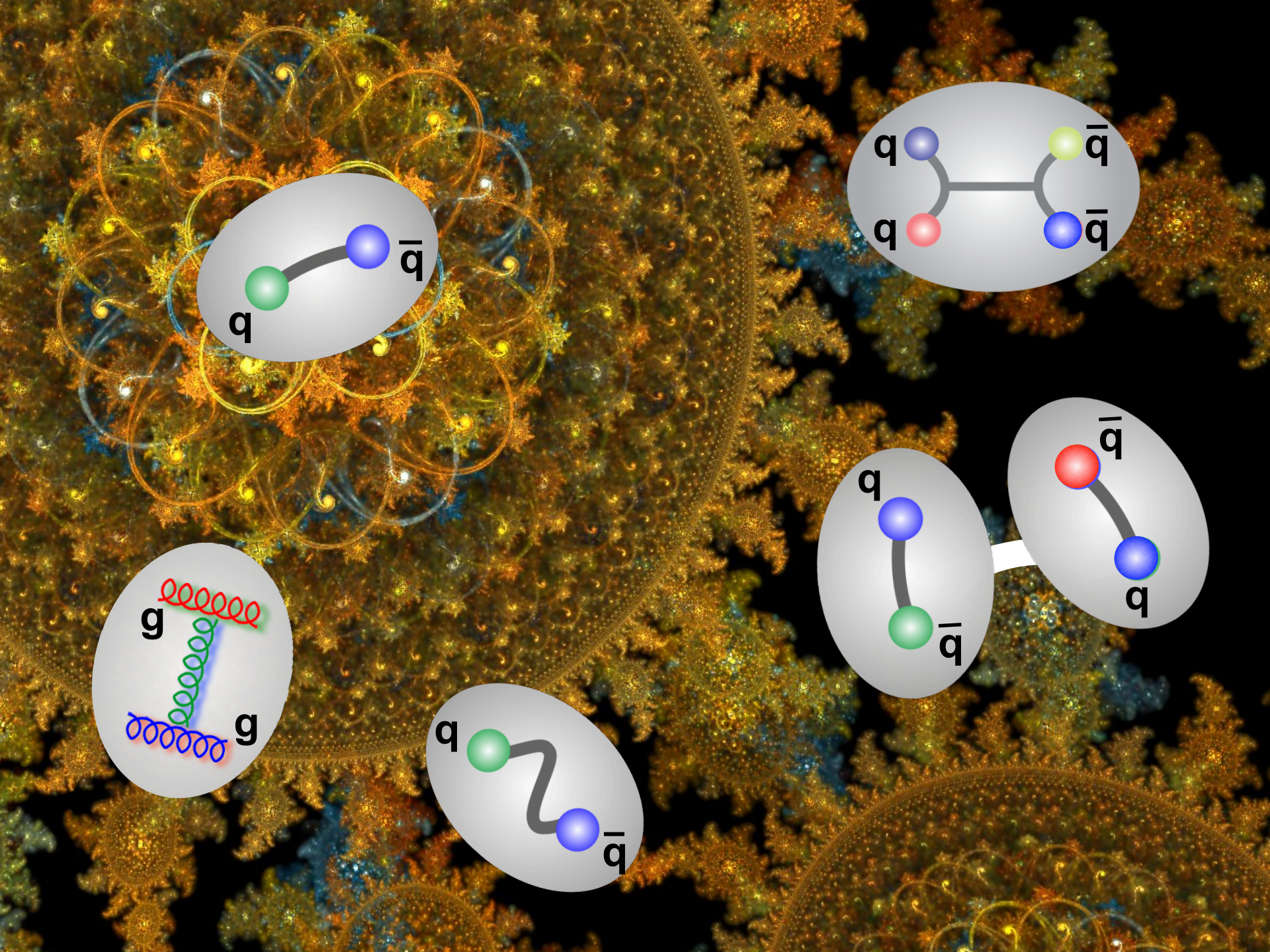


Courtesy of Michael Williams

➜ PDG 2010, J. Phys. GG 37.

Great progress in recent years:

➜ $\underline{\gamma N}$ & πN data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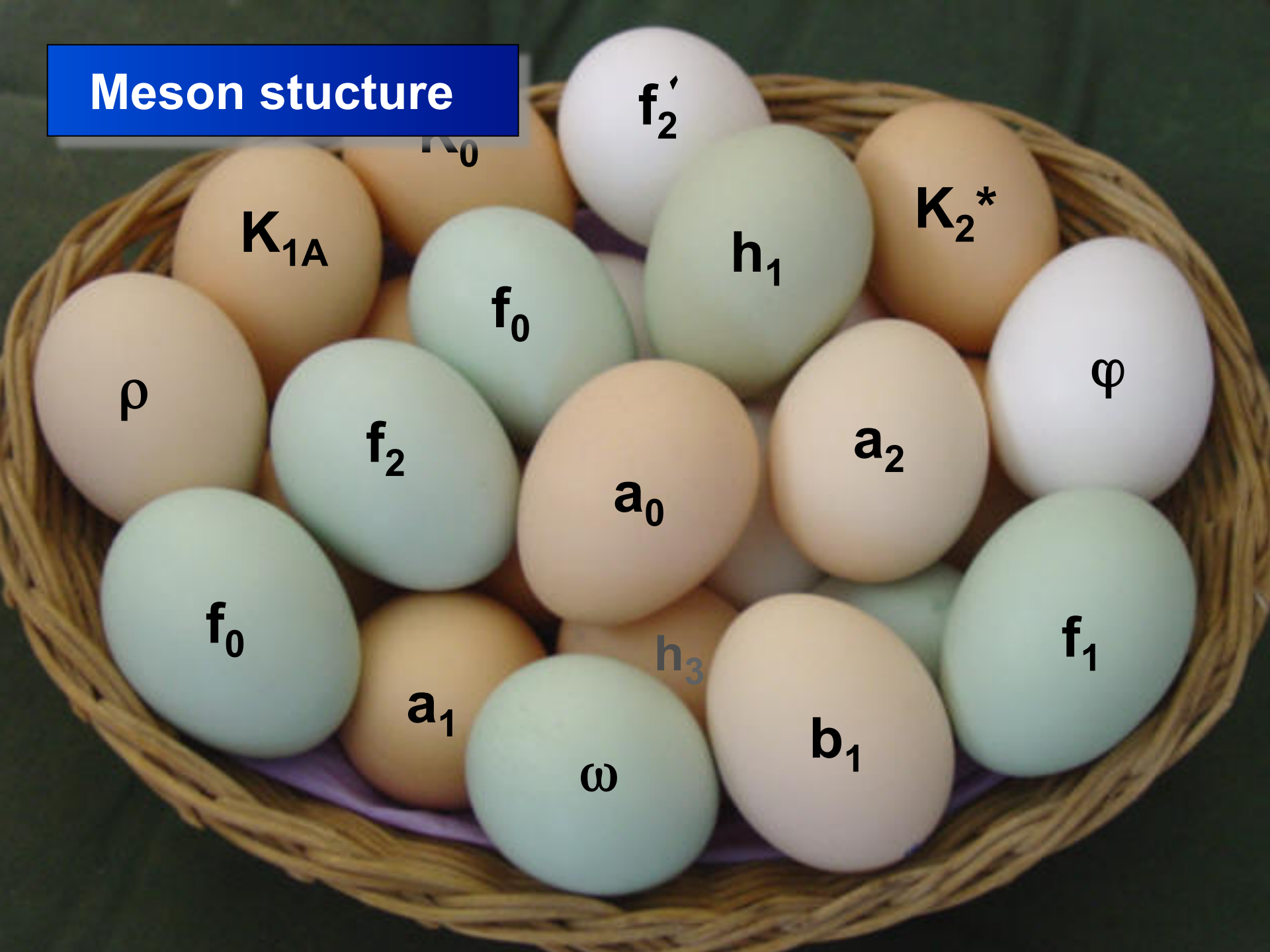
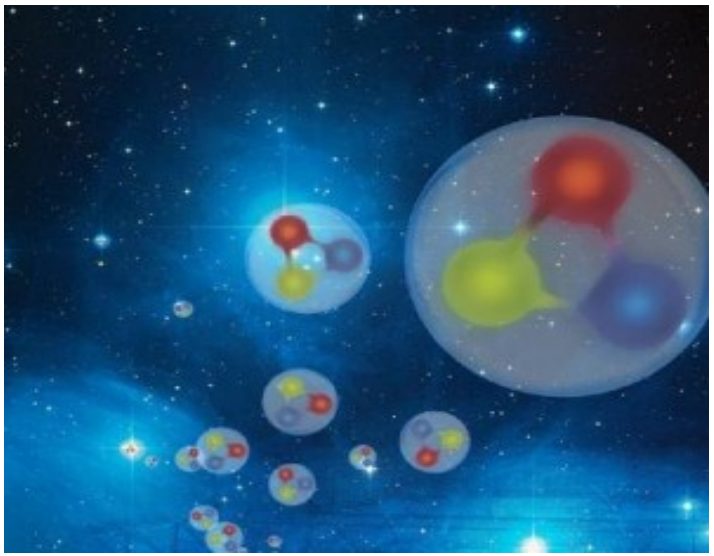

Meson stucture
f_2'
K_{1A}
h_1
K_2^*
f_0
ρ
φ
f_2
a_2
a_0
f_0
h_3
f_1
a_1
b_1
ω

More Surprising States?

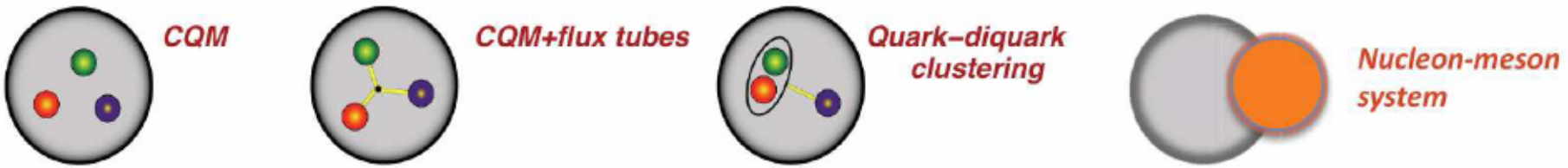
Non-Perturbative QCD



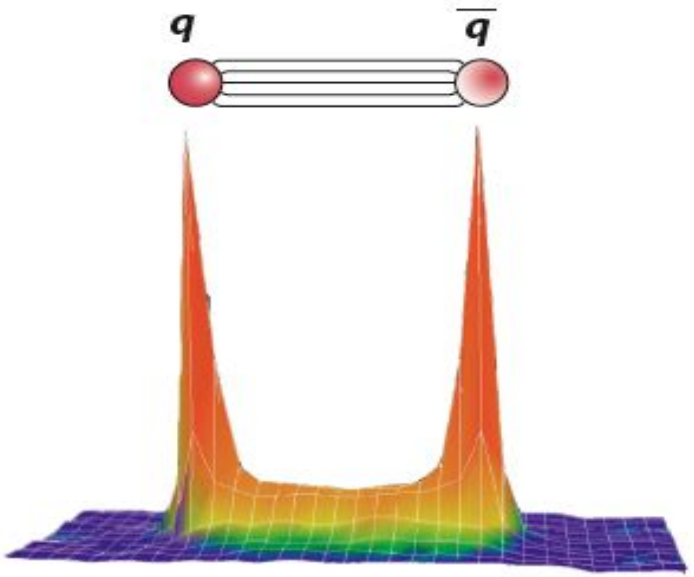
How does QCD give rise to excited hadrons?

1. What is the origin of confinement?
2. How are confinement and chiral symmetry breaking connected?
3. What role do gluonic excitations play in the spectroscopy of light mesons, and can they help explain quark confinement?

Baryons: What are the fundamental degrees of freedom inside a nucleon? Constituent quarks? How do the degrees change with varying quark masses?



Non-Perturbative QCD



How does QCD give rise to excited hadrons?

1. What is the origin of confinement?
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Mesons: What are the properties of the predicted states beyond simple quark-antiquark systems (hybrid mesons, glueballs, ...)?

➜ Gluonic Excitations provide a measurement of the excited QCD potential.

Hybrid baryons are possible but do not carry “exotic” quantum numbers.

"Particles" and "Resonances"

We are discussing quantum mechanical states:

$$|qqq>, |q\bar{q}>, \ldots$$

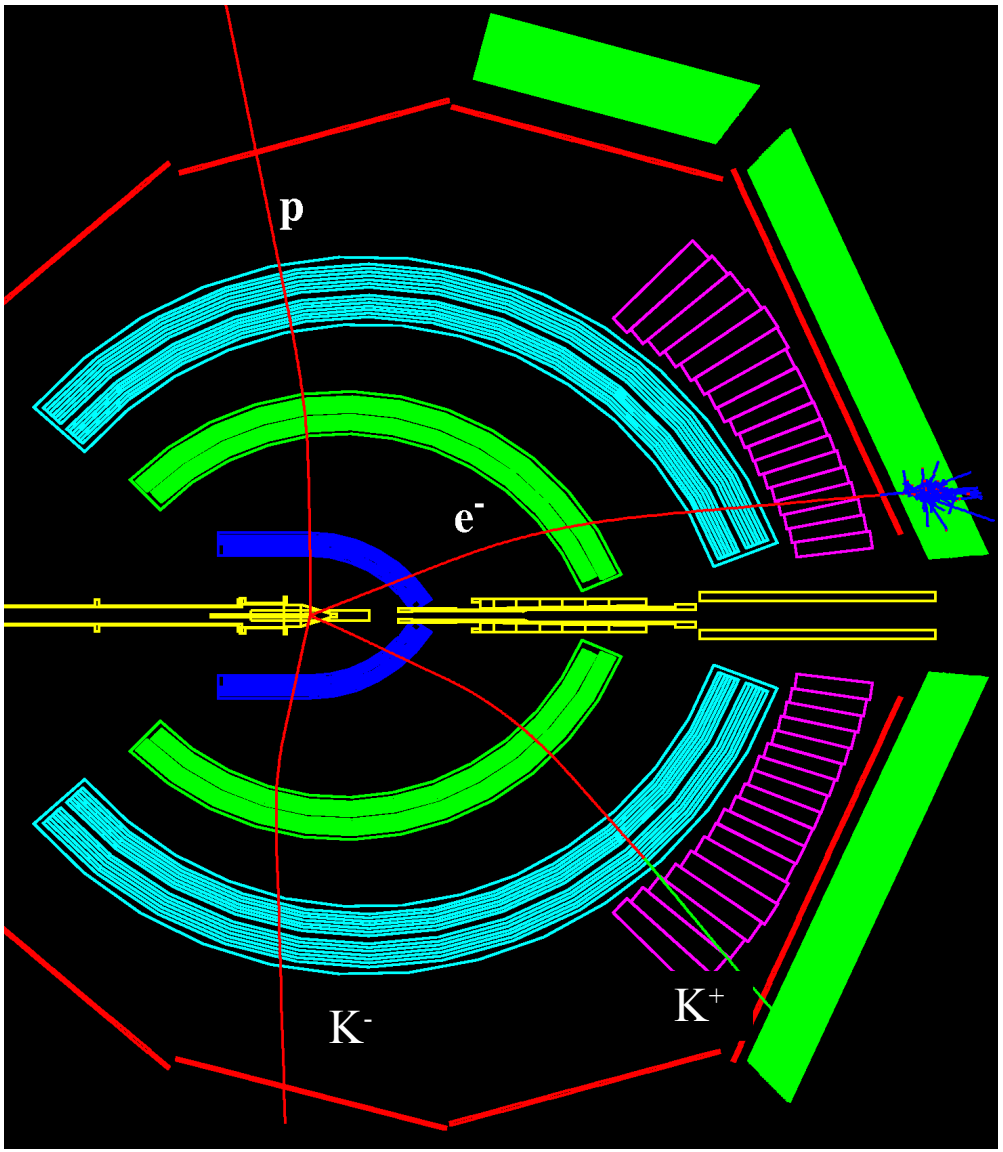
The lowest lying states are "particles". If they decay, they do so through something other than QCD-powered interactions. Therefore they live a long time.

Hadronic Matter which does decay through QCD live a very short time.

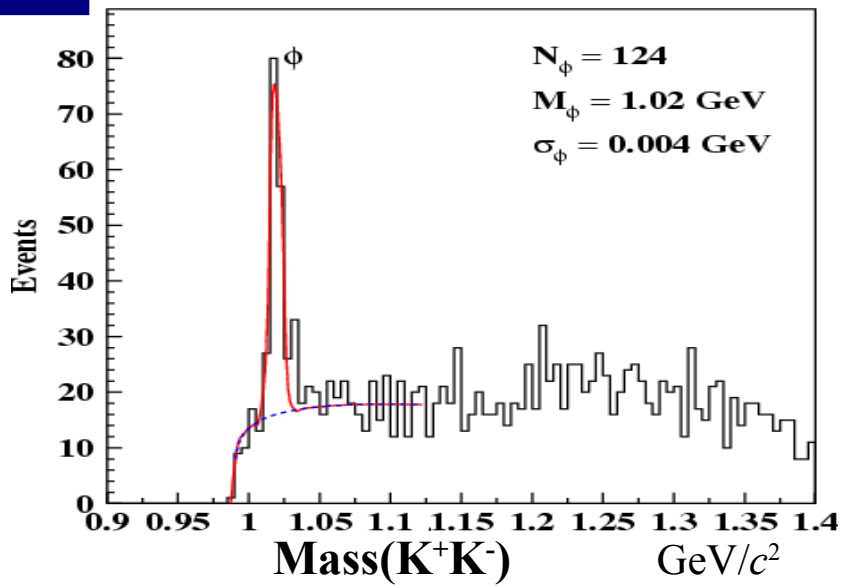
Very short lived states are observed as quantum mechanical "resonances". They can only be studied statistically, not one by one.

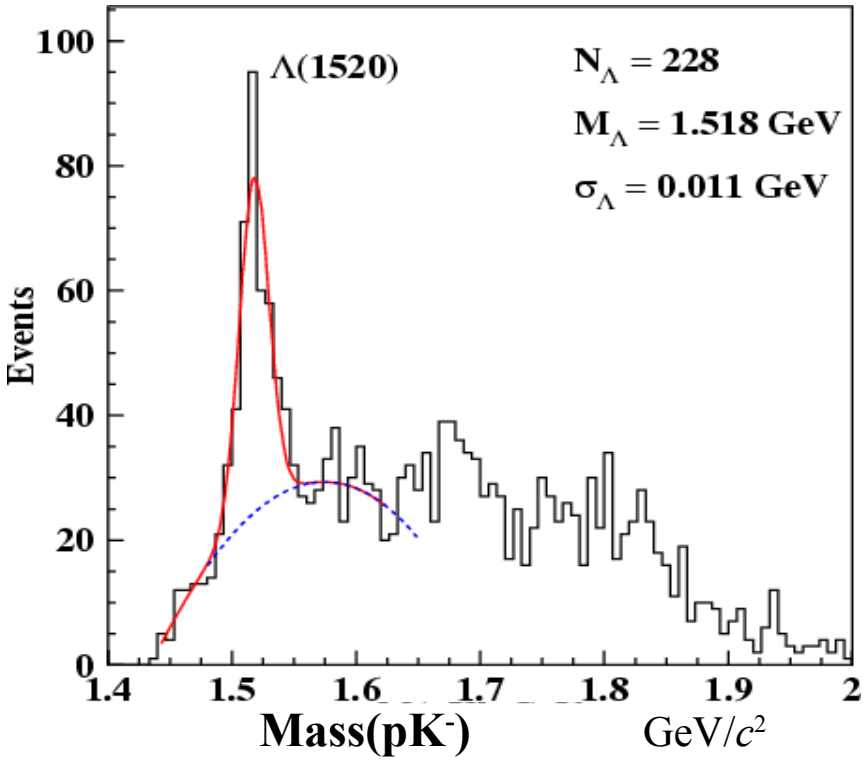
Examples

$e\,p \rightarrow e'\,p\,K^+\,K^-$



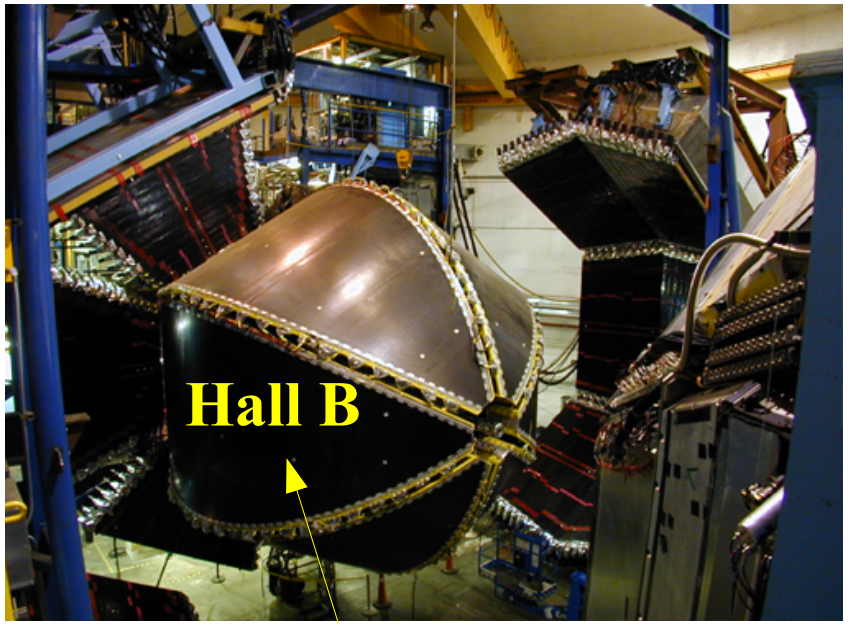
2 particles in, 4 particles out
one "event"

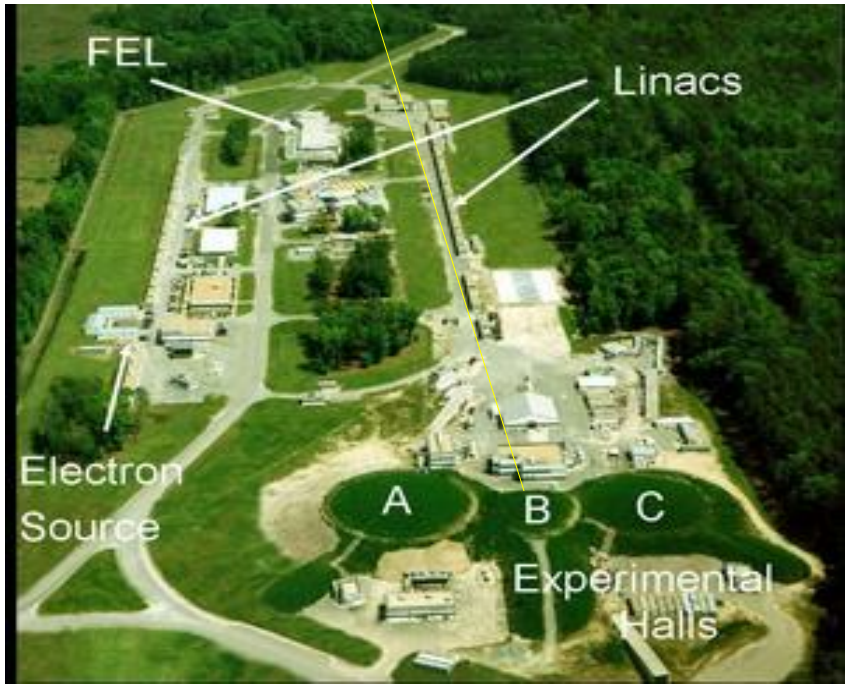




2 "histograms" of many events

CLAS: CEBAF Large Acceptance Spectrometer



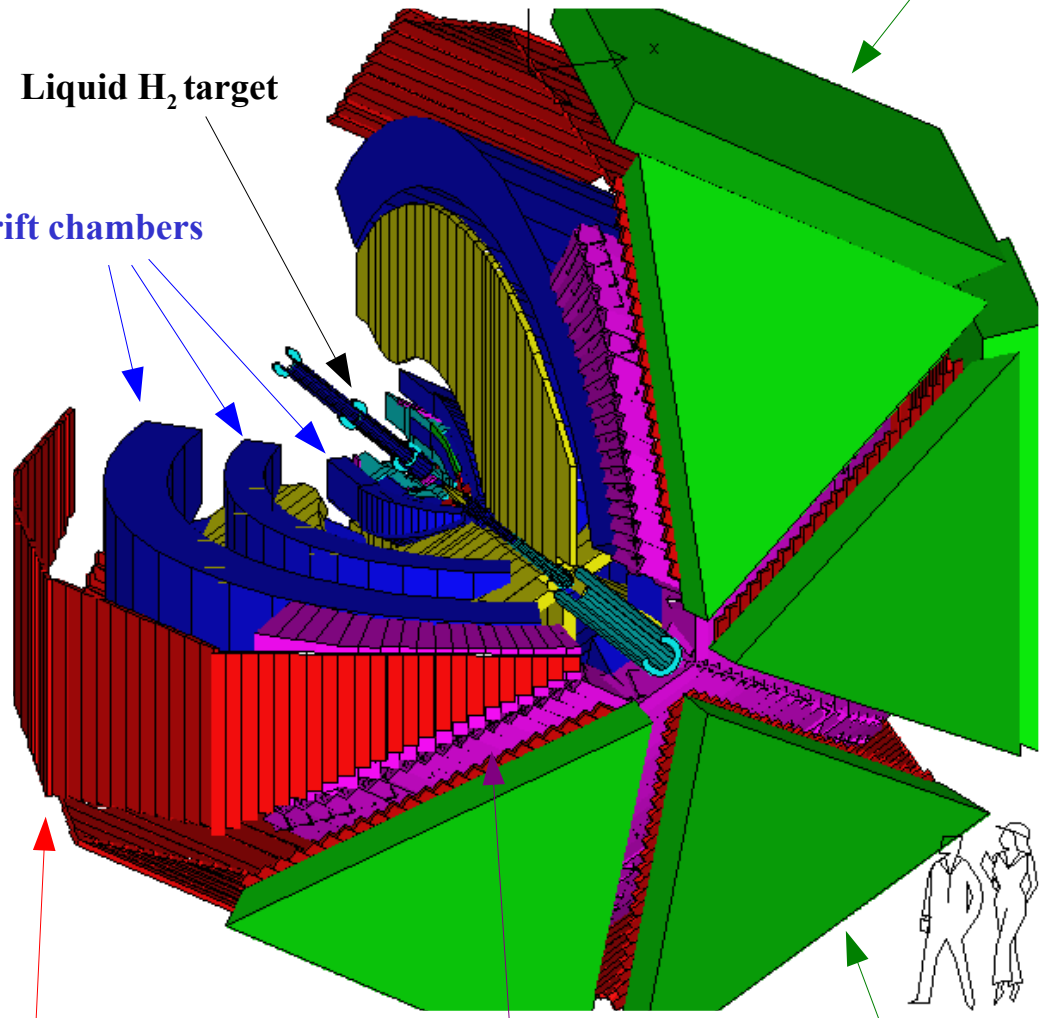


Torus magnet
6 superconducting coils

Large angle calorimeters

Liquid H_2 target

Drift chambers



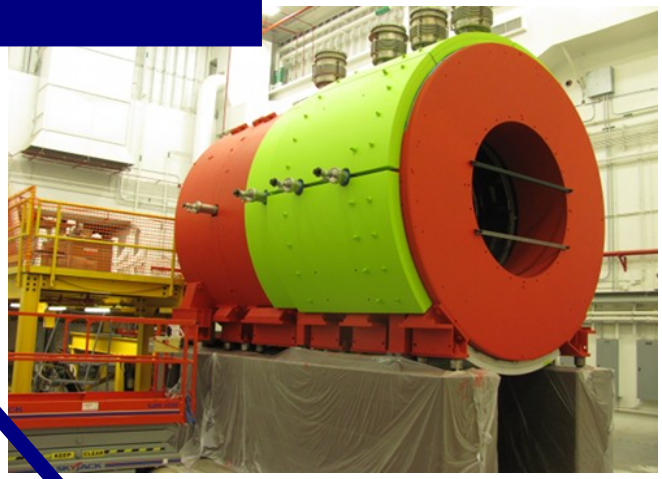
Gas Cherenkov counters

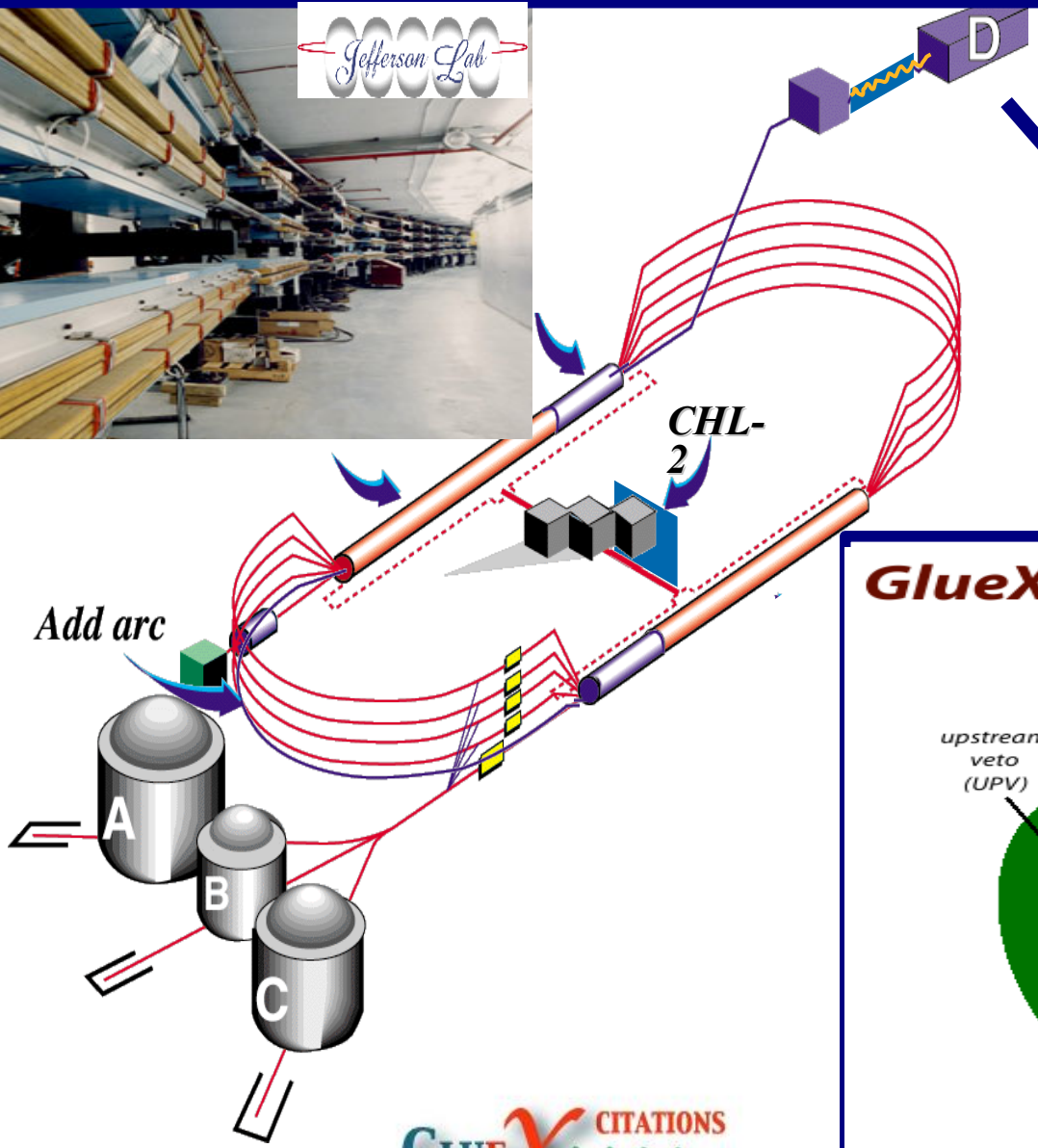
Time-of-flight counters

Electromagnetic calorimeters

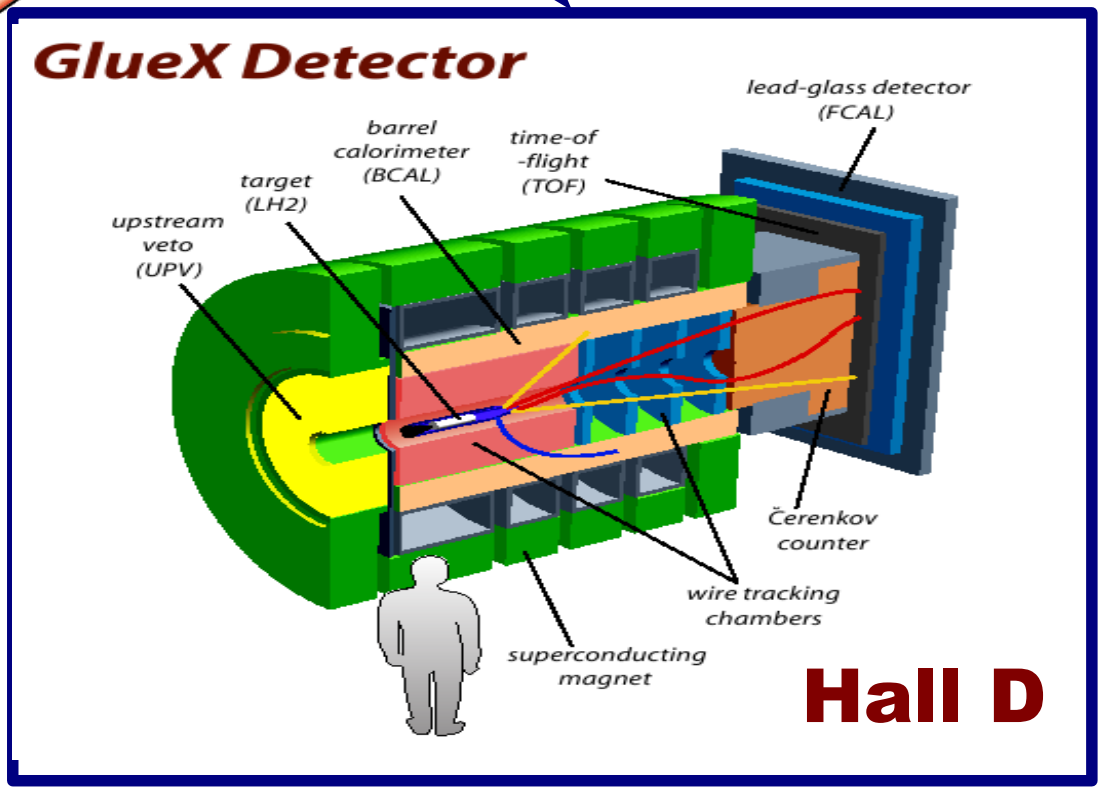
Future Program

Jefferson Lab 12 GeV Upgrade



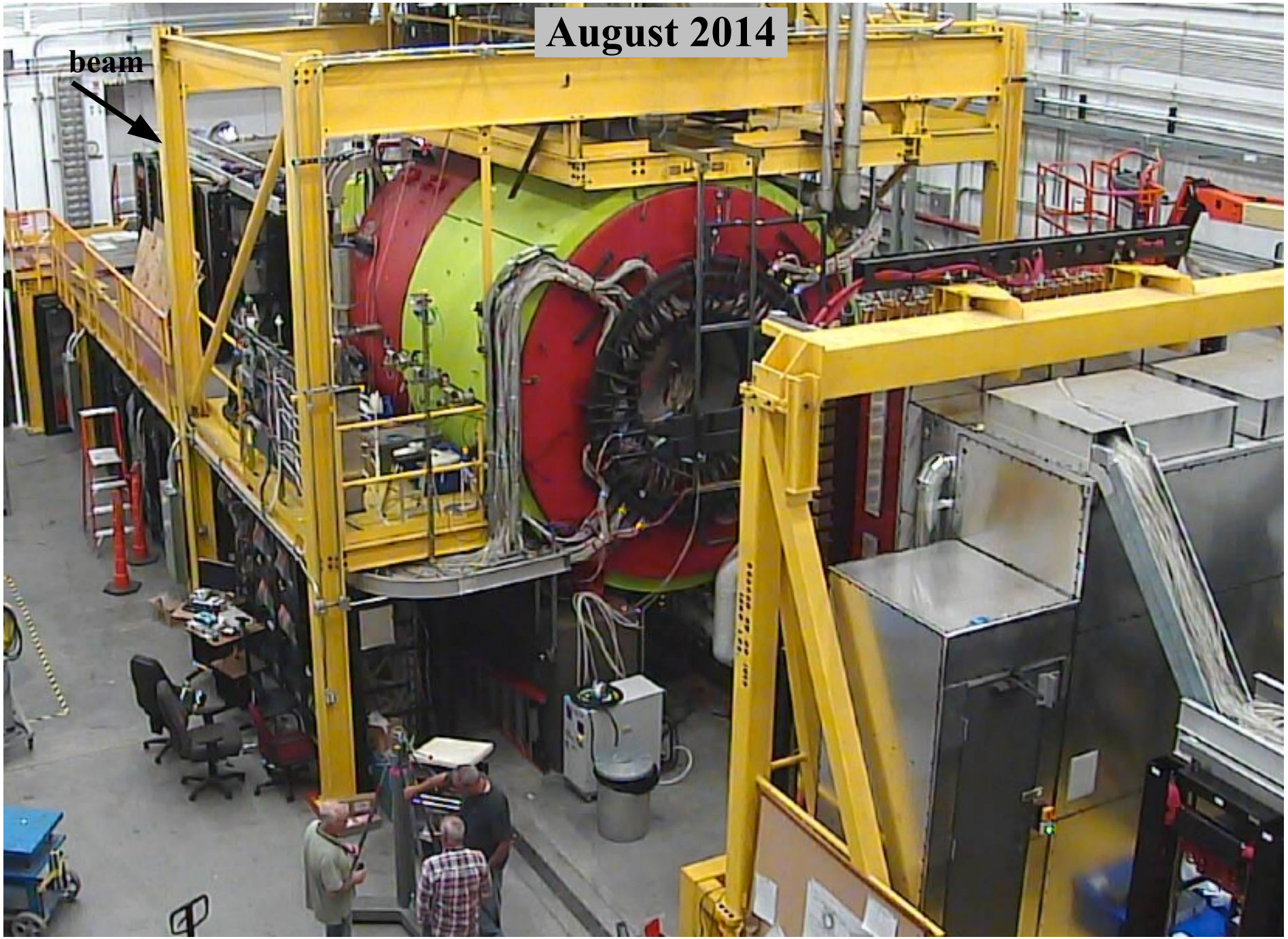


GLUEX CITATIONS PERIMENT



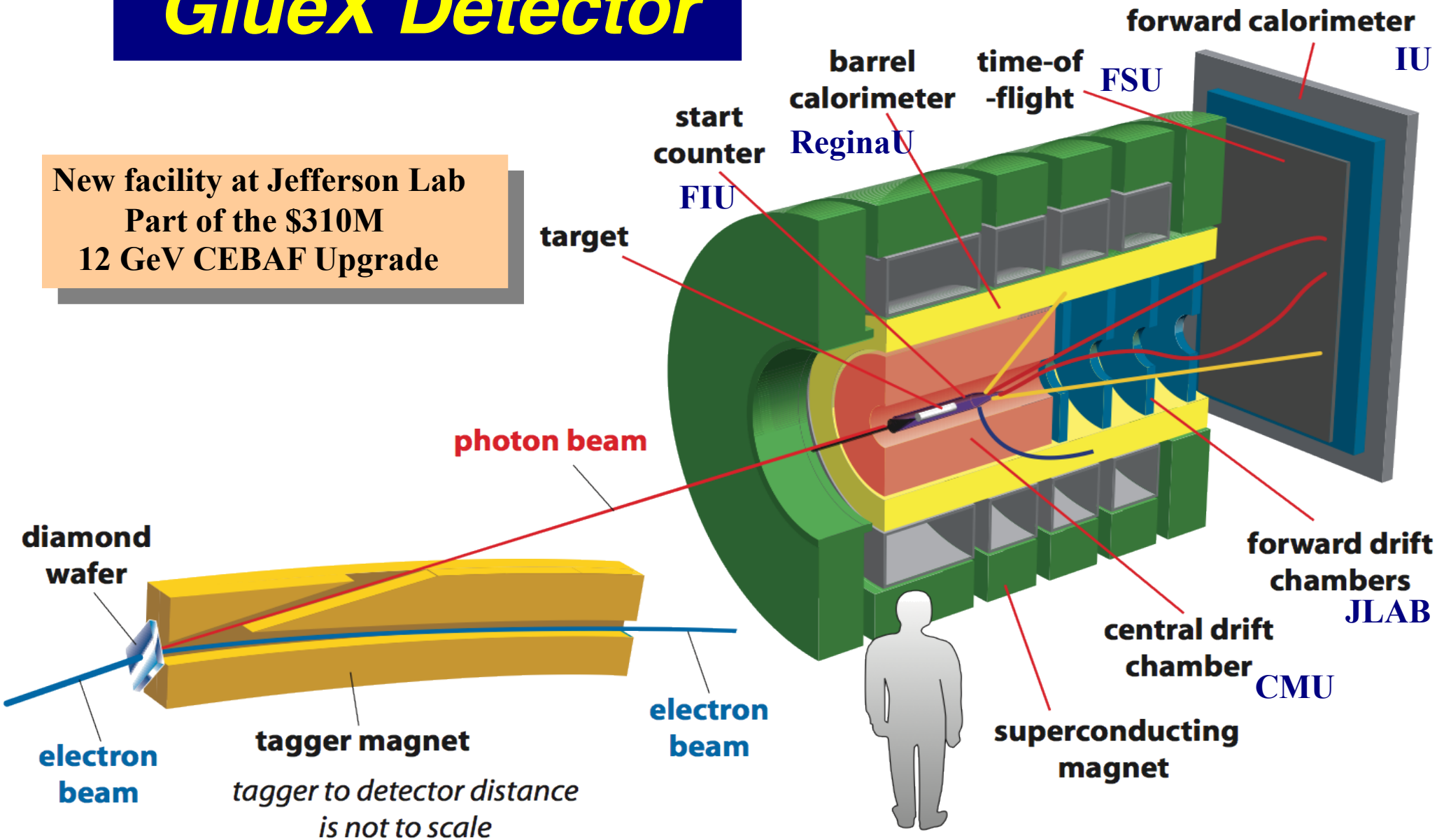

The Hall D Complex at Jefferson National Lab
CEBAF Accelerator
photon beam
12 GeV electron beam

GlueX Detector in Hall D



GlueX Detector

New facility at Jefferson Lab
Part of the $310M
12 GeV CEBAF Upgrade

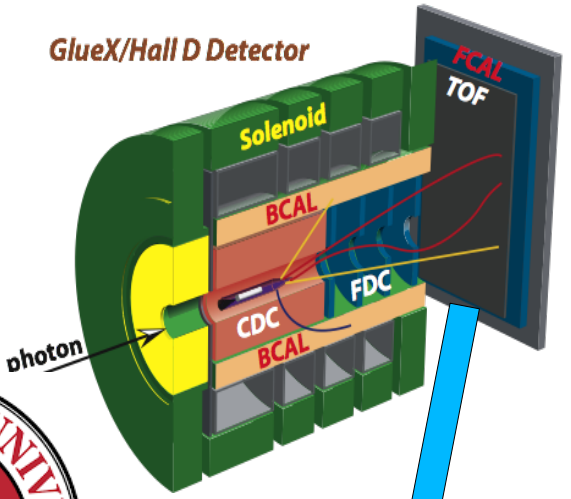


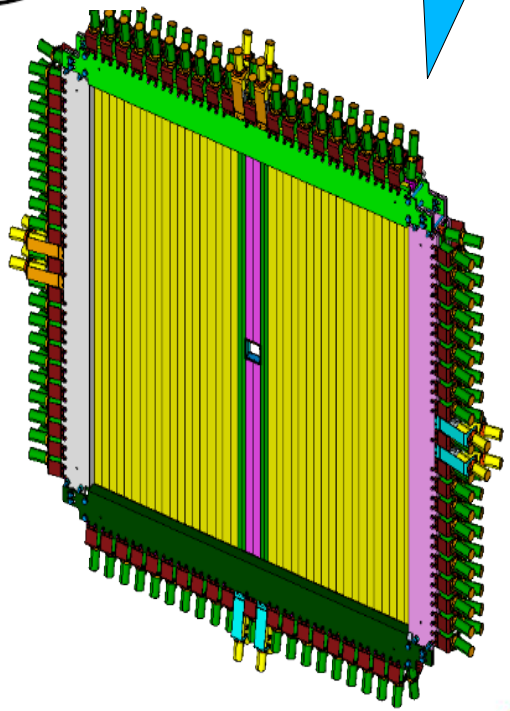
GlueX Collaboration
founded around 1998
~100 physicists; 21 institutions

Time-of-Flight Wall

TOF Detector Overview

- Particle id (π/K/p) up to 2–3 GeV/c at 4σ
- Two independent TOF planes: horizontal and vertical (~3m x 3m)
- 92 modules with 176 H10534 Hamamatsu PMTs
- 176 fADC (250 MHz) and TDC (25 psec) readout channels
- Angular coverage $2^{o} < \theta < 11^{o}$

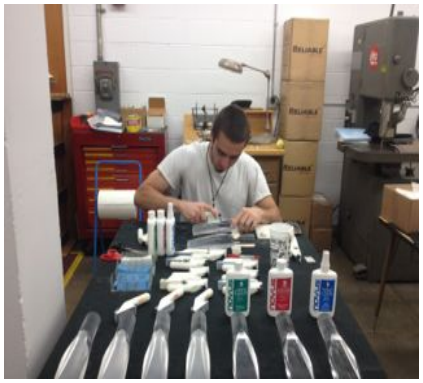




FLORIDA STATE UNIVERSITY
VIRES ARTES MORES
1851

GlueX CITATIONS PERIMENT

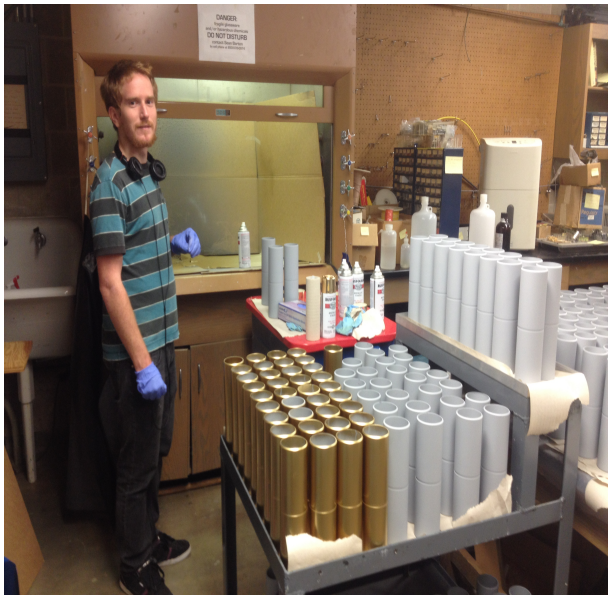
Time-of-Flight Construction at FSU

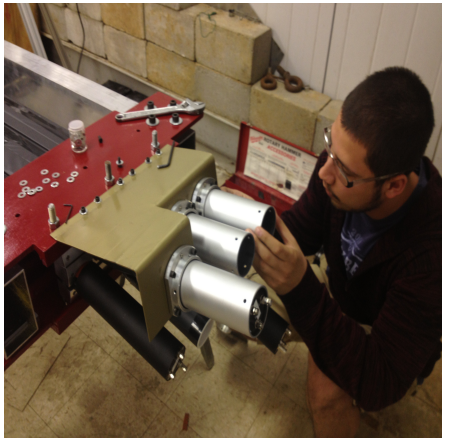


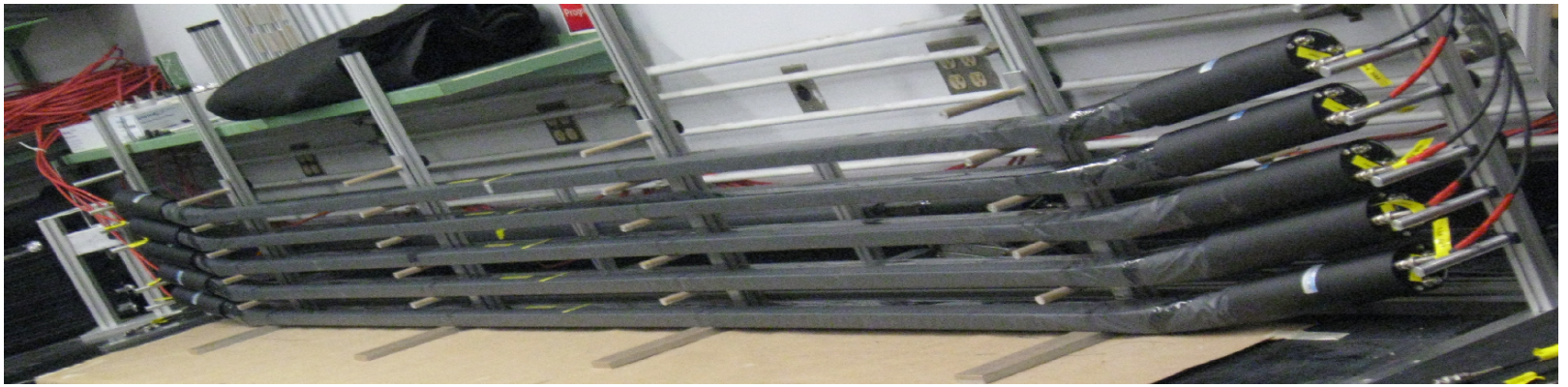
TOF construction

Fall 2013 completion of modules

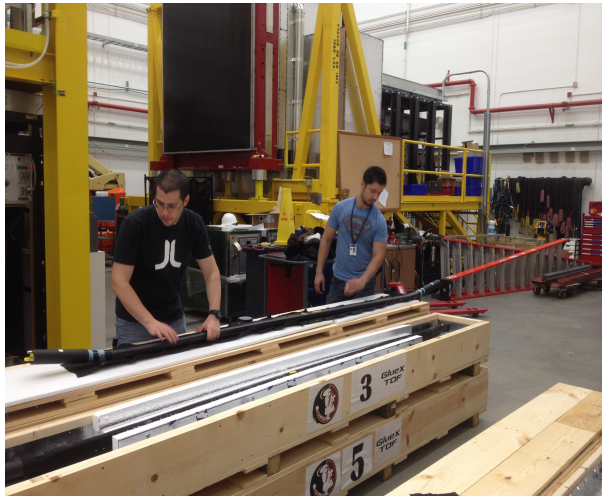
Spring 2014 assembly & installation

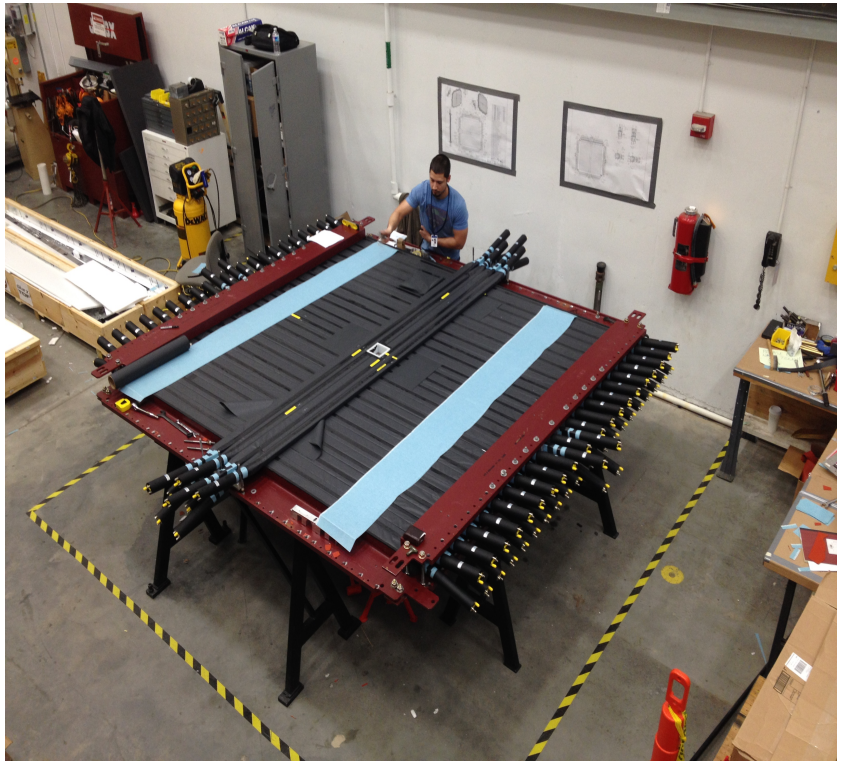


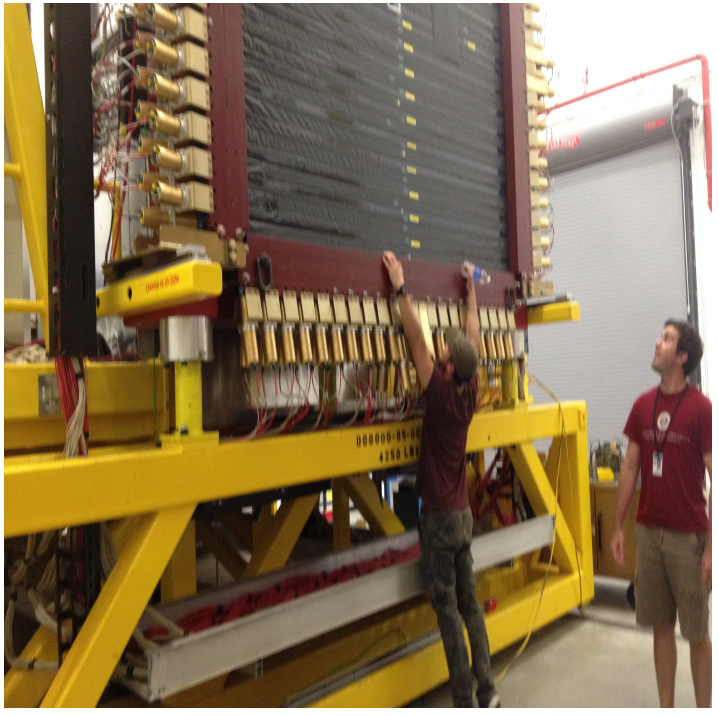




Time-of-Flight Assembly & Installation by FSU



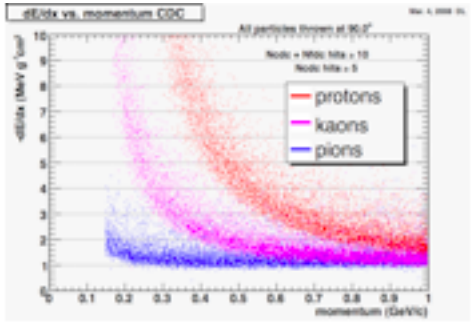




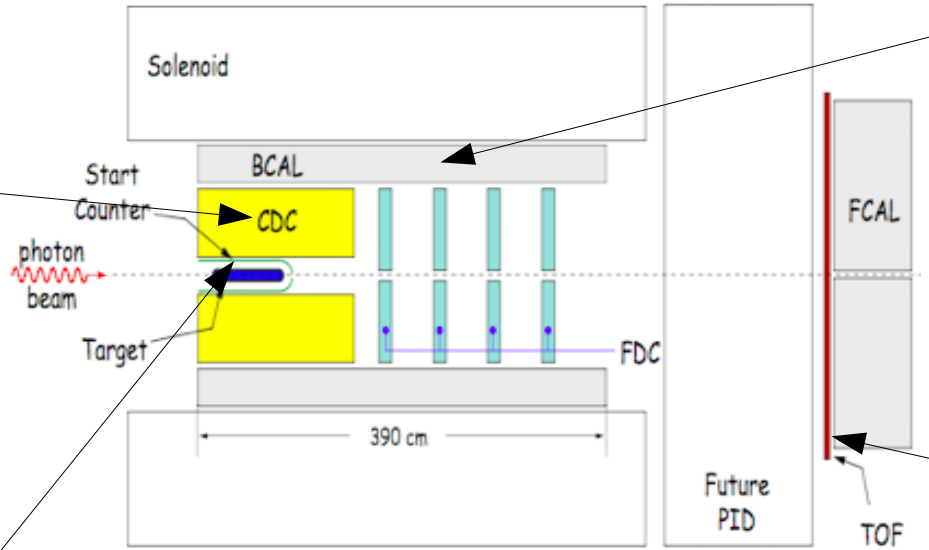
Particle Identification

Time-of-flight & dE/dx

CDC dE/dx



- πp separation <450MeV/c
- πK separation <275MeV/c

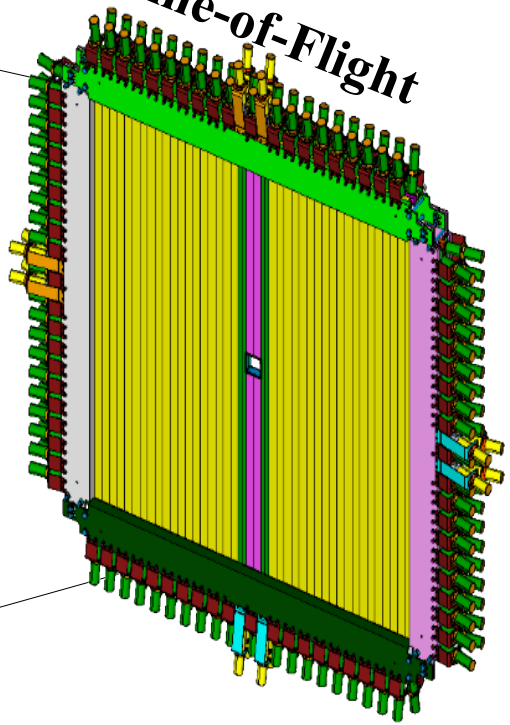


Detector is cylindrically symmetric about the beamline

$BCAL_{TOF}$

- $\sigma_t = 74ps/\sqrt{E} + 33ps$
- πp separation <450MeV/c
- πK separation <275MeV/c

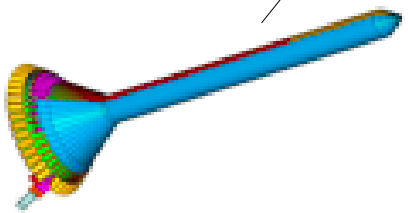
Time-of-Flight



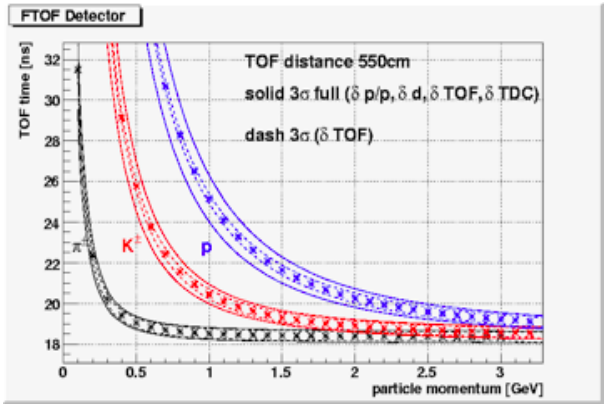
- 176 readout channels
- $\sigma_{TOF} < 80/\sqrt{2}$ ps
- 4σ K/π separation < 2GeV/c

Future PID upgrade with a Forward DIRC

Start Counter

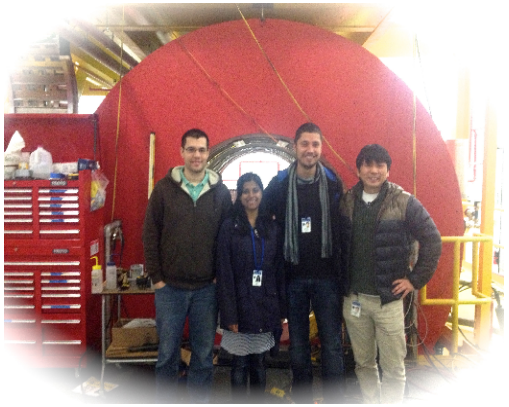


- 40 scintillators
- 300 ps (w/tracking)
- Used for start-up



GlueX Experiment

The Excitement is Just Beginning



Time to take DATA

&

Graduate Students