Experimental Overview and Status of the Quark Model

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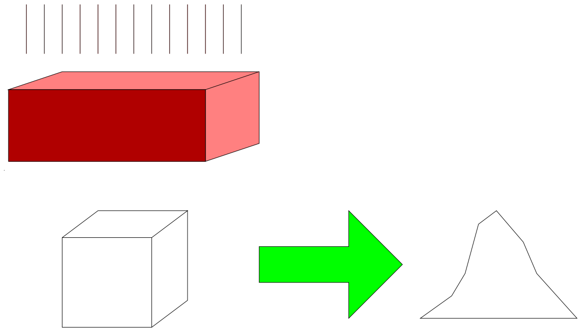
References and Acknowledgements:

- Steve Godfrey and JN,
  hep-ph/9811410 and Rev Mod Phys (Oct, 99)
- Mina Nozar, *et al.*, BNL/E852 Collaboration
- Mike Klusman, *et al.*, JLab/CLAS Collaboration
- Alex Dzierba, *et al.*, JLab/Hall D Collaboration

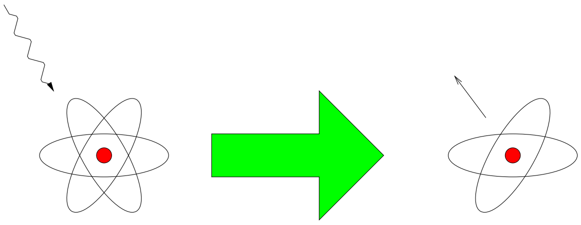
Constituents, Energy, and Size

Macroscopic matter



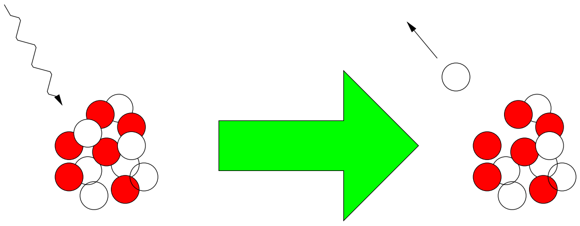
$$\frac{\Delta E}{M} = \frac{0}{\infty}$$

Atoms



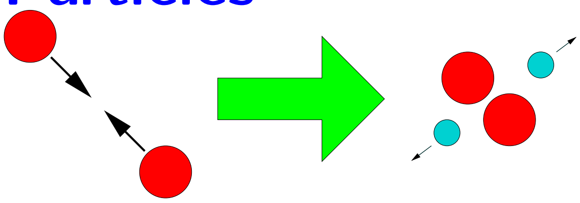
$$\frac{\Delta E}{M} = \frac{10\ \text{eV}}{10\ \text{GeV}} = 10^{-9}$$

Nuclei



$$\frac{\Delta E}{M} = \frac{10\ \text{MeV}}{10\ \text{GeV}} = 10^{-3}$$

Particles



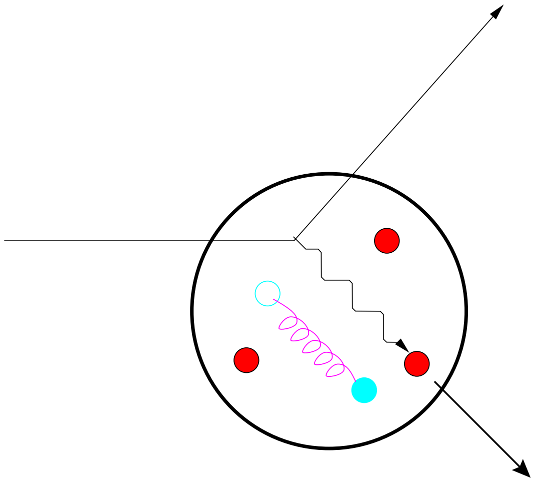
$$\frac{\Delta E}{M} = \frac{2\ \text{GeV}}{2\ \text{GeV}} = 1$$

Quantum Chromodynamics

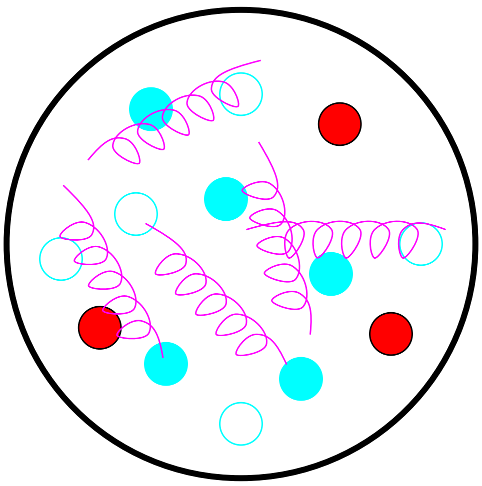
$$\mathcal{L}_{QCD} = \bar{q}_i(i\partial_\mu\gamma^\mu\delta_{ij} - g\frac{\lambda^a_{ij}}{2}A^a_\mu\gamma^\mu - m\delta_{ij})q_j - \frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu}$$

$$F^{\mu\nu}_a = \partial^\mu A^\nu_a - \partial^\nu A^\mu_a - g f_{abc} A^\mu_b A^\nu_c$$

Weak QCD: Perturbation Theory



Strong QCD: Lattice?? Low Energy Theorems??



The Quark Model

A Manifestation of Strong QCD

Massive, Weakly Bound, “Pointlike” Quarks

NO GLUONS: Hamiltonian Potential model

$$V^{\mathsf{RADIAL}}(r) = -\frac{a}{r} + br$$

Elements from QCD

$$V^{\mathsf{HYPERFINE}}(q_1 q_2) = \frac{k}{m_1 m_2} \vec{S}_1 \cdot \vec{S}_2$$

Some Relativistic Effects Included

It is better to have the right degrees of freedom moving at the wrong speed, than the wrong degrees of freedom moving at the right speed.

Status of The Quark Model

Are Failures more Interesting than Successes?

Baryons: Half Integer Spin

- Combinations and excitations of qqq
- **Red Flag:** Not enough excited states??

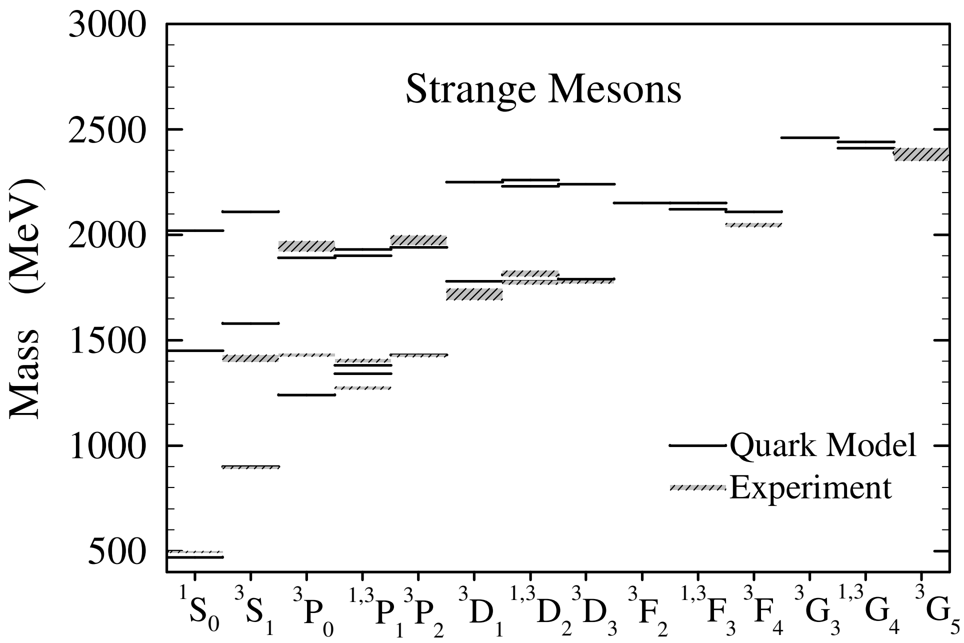
Mesons: Integer Spin

- Combinations and excitations of $q\bar{q}$
- **Red Flag:** Too many excited states!!
  Some with the wrong quantum numbers!!!

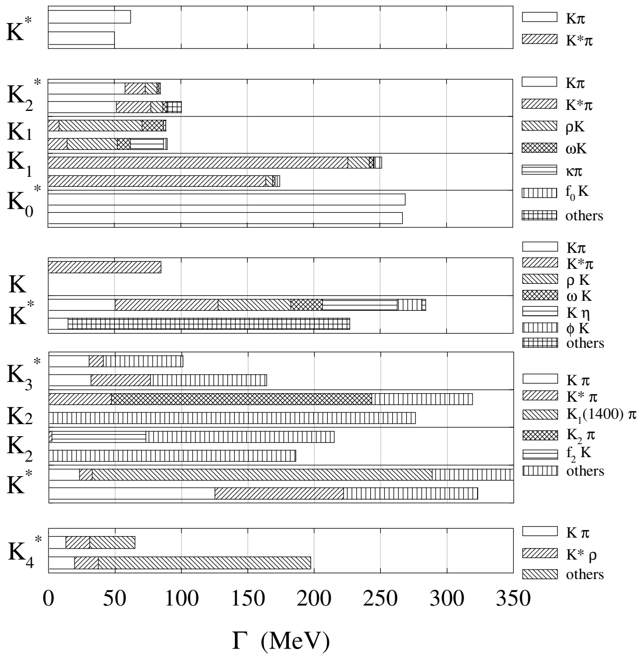
Example: The Strange Mesons

Comparison of Experiment and Theory

Masses

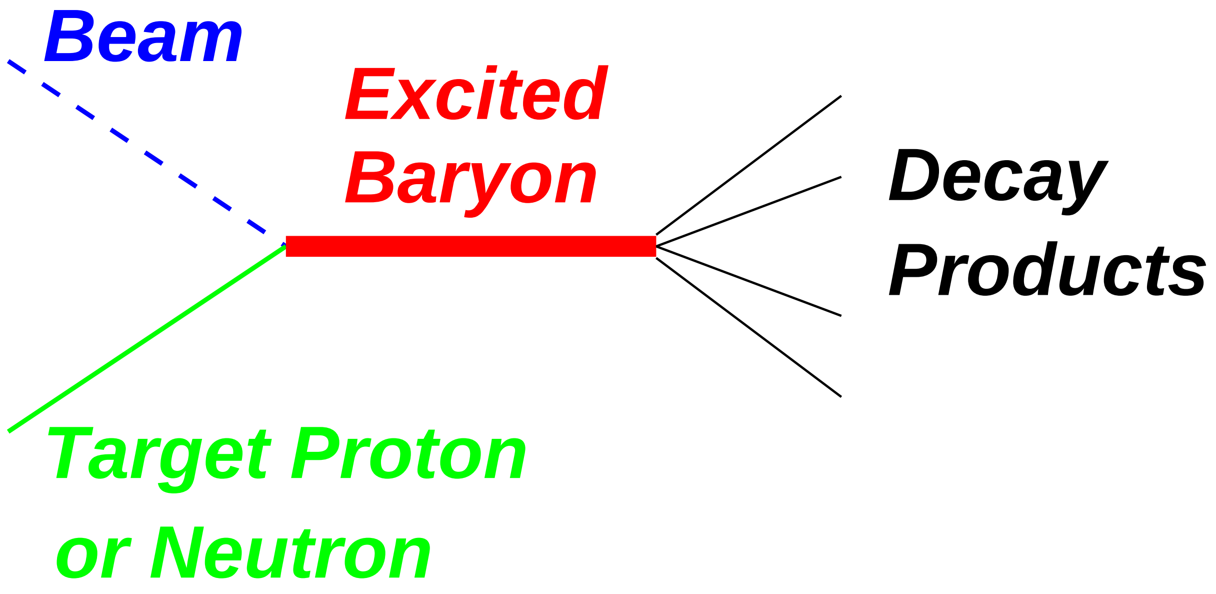


Decay Patterns

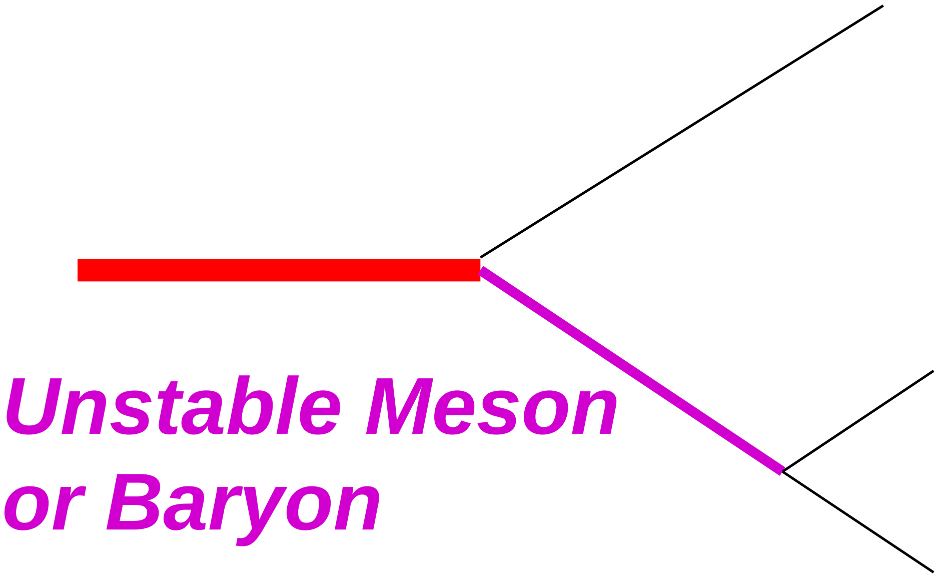


Status of the Non-Strange Baryons
(From Mike Klusman)

Experiments:
Baryon Formation and Decay



Multibody Decays:
Handled as "Quasi-Two Body"



Until recently, almost all experiments done with pion beams. Photon beams are now, finally, available.

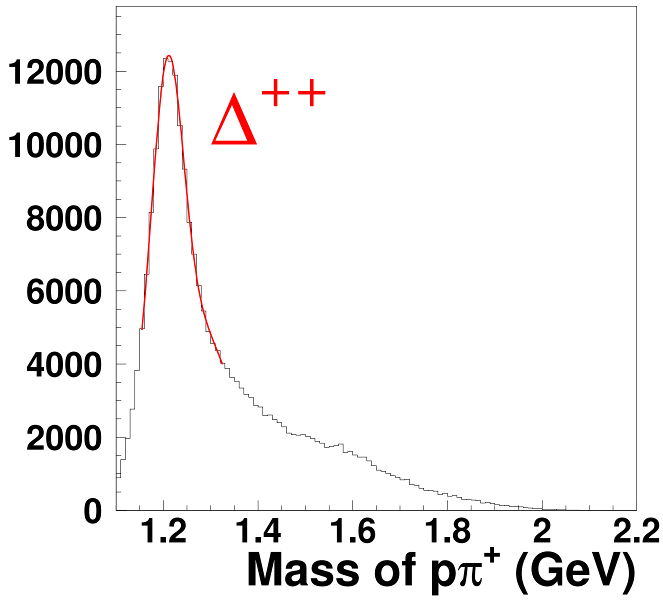
Overlay for Diquark Model and Non-Strange Baryons
(From Mike Klusman)

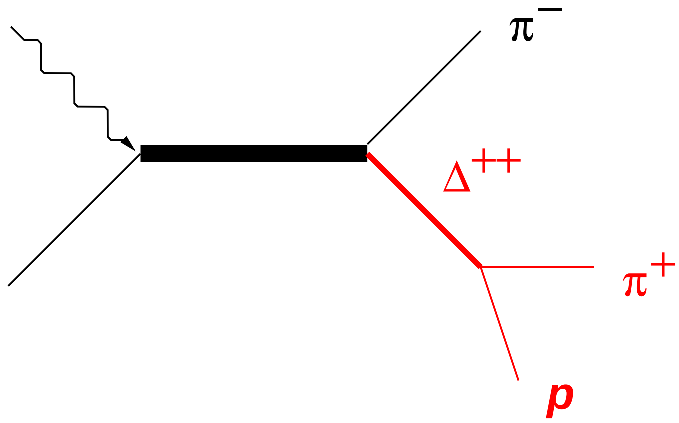
The CLAS: Diagram from Jefferson Lab

Preliminary Data from CLAS

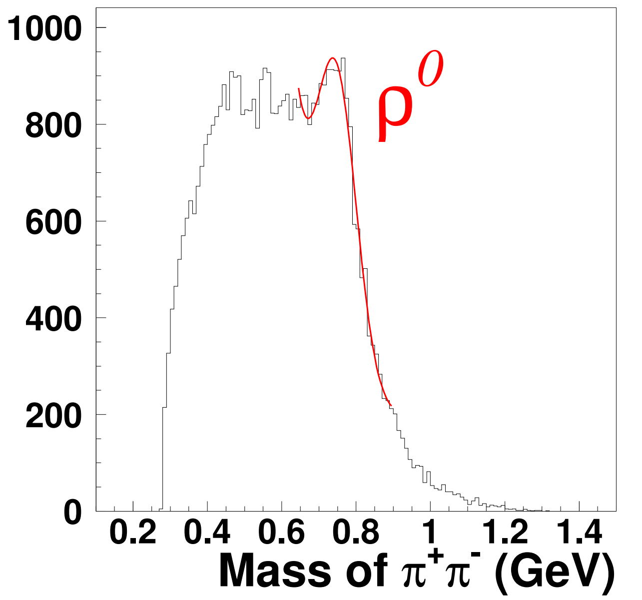
$$\gamma p \rightarrow p\pi^+\pi^-$$

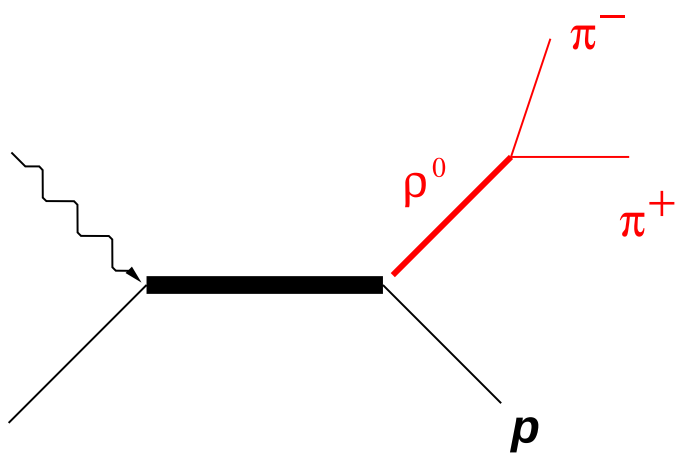
$\gamma p \rightarrow \Delta^{++}\pi^- \rightarrow p\pi^+\pi^-$



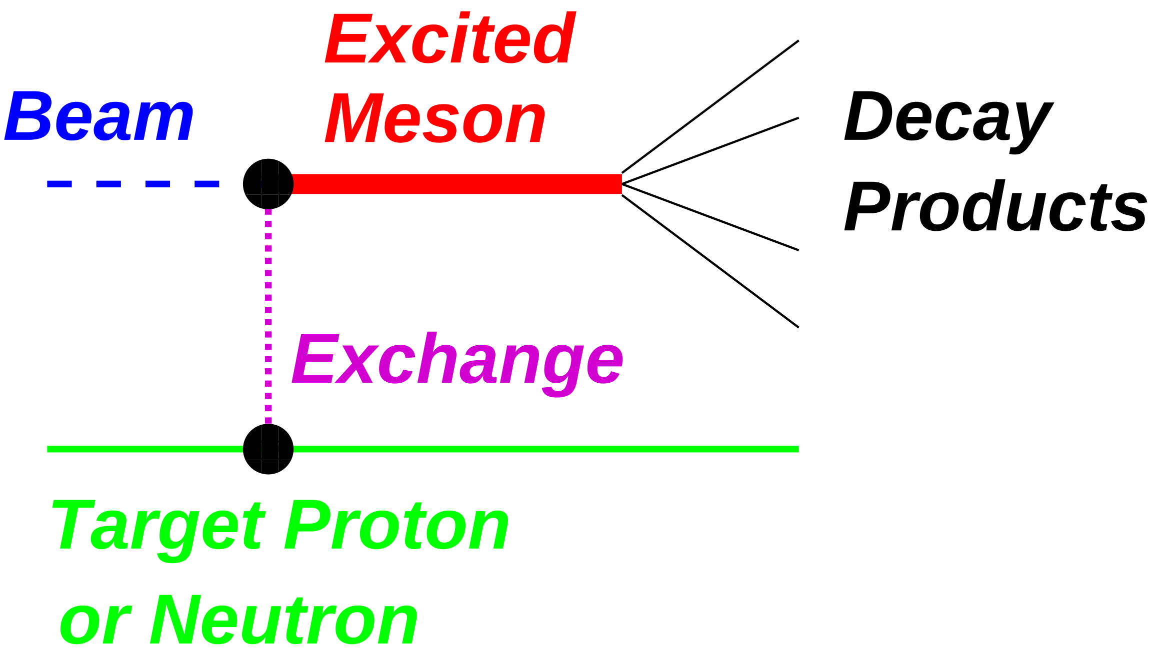


$\gamma p \rightarrow p\rho^0 \rightarrow p\pi^+\pi^-$





Experiments:
Meson Production and Decay



"Peripheral Production"

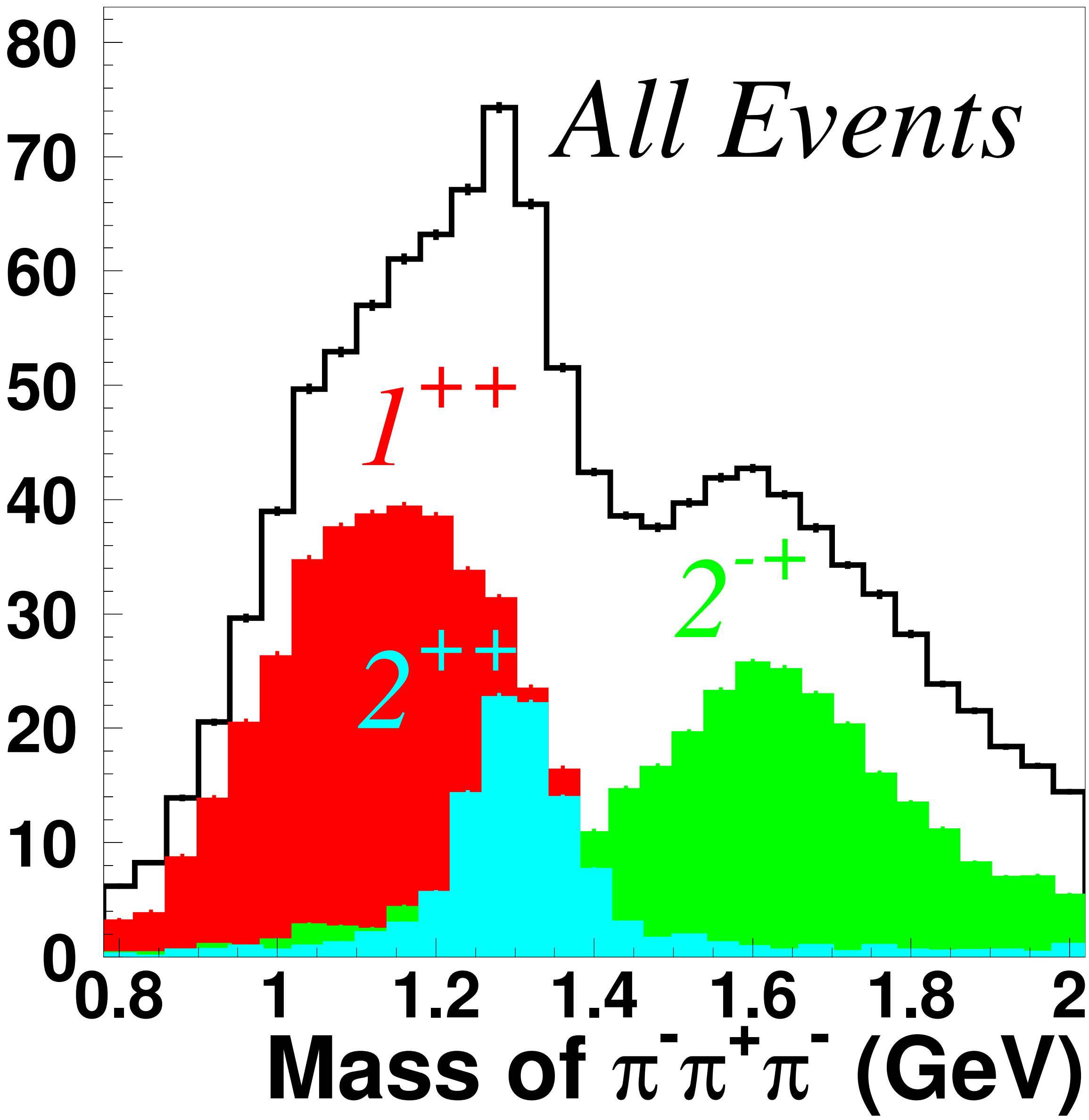
Multibody Decays Handled as "Quasi-Two Body" as for Baryons

Until recently, almost all experiments done with pion beams. Photon beams are now, finally, available.

Schematic Diagram of E852 Detector

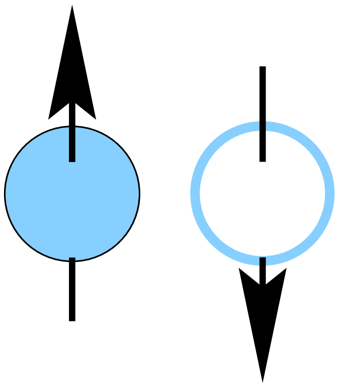
Data from BNL Experiment E852

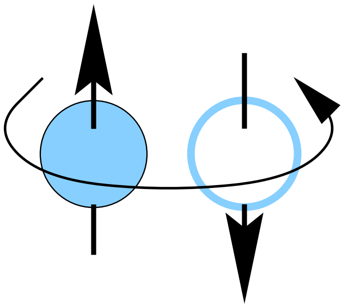
$\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$ at 18 GeV/c



Broad Overlapping States!

D/S in $b_1(1235)$ Decay

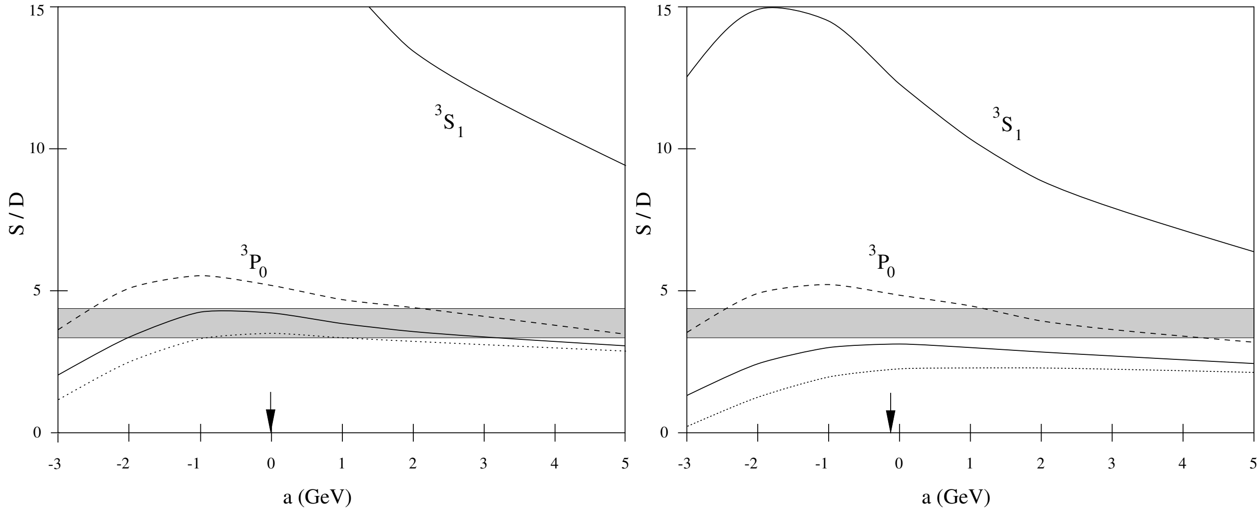
Pion 135 MeV $L = 0$ 

b_1 1235 MeV $L = 1$ 

$b_1(1235) \to \omega\pi$ and $J_\omega = 1$

$\Rightarrow$ S $(\ell = 0)$ or D $(\ell = 2)$ decays are possible!

Geiger and Swanson, Phys.Rev.D50:6855-6862,1994



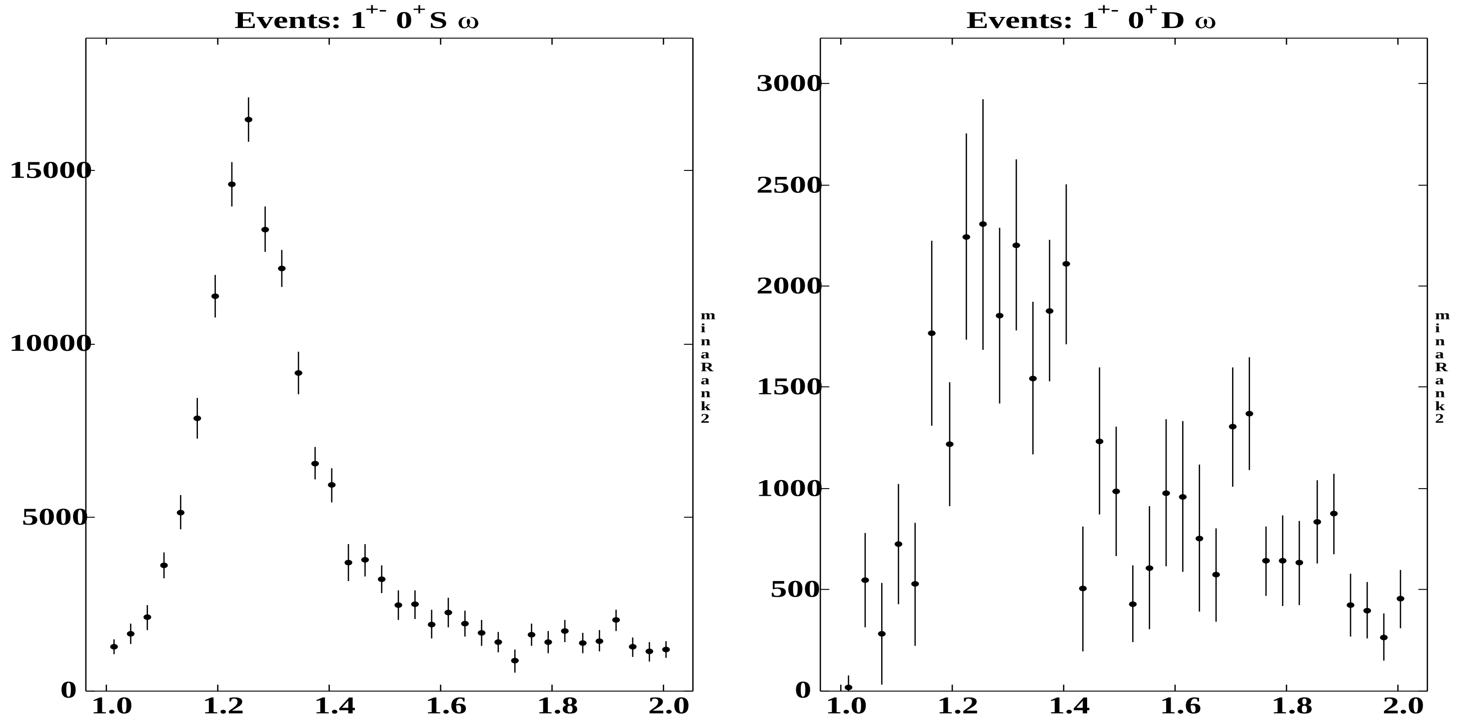
Previous Results

- 0.23 ± 0.03 CBAR 1994 in $\bar{p}p \rightarrow \omega\eta\pi^0$
- 0.45 ± 0.04 CBAR 1993 in $\bar{p}p \rightarrow \omega\pi^0\pi^0$
- 0.25 ± 0.05 $\Omega\gamma$ 1984 in $\gamma p \rightarrow \omega\pi^0 p$
- 0.40 ± 0.10 Bubble Chamber 1977 $\pi^- p \rightarrow \omega\pi^- p$

Preliminary Data from E852

$$\pi^- p \rightarrow \omega\pi^- p$$

$\ell = 0$ $\ell = 2$



$\omega\pi^-$ Mass (GeV)

The Isovector Vector Mesons

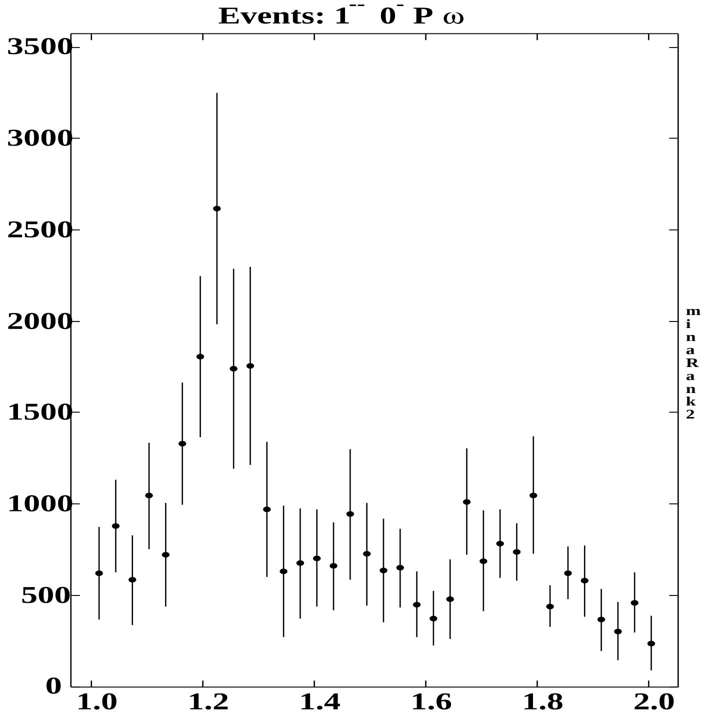
Quark Model Predicts *Two* Excited ρ Mesons:

- ρ_S: A Radial Excitation
  $\Rightarrow \rho(1450)$ with $\Gamma = 310 \pm 60$
- ρ_D: An Orbital Excitation
  $\Rightarrow \rho(1700)$ with $\Gamma = 240 \pm 60$

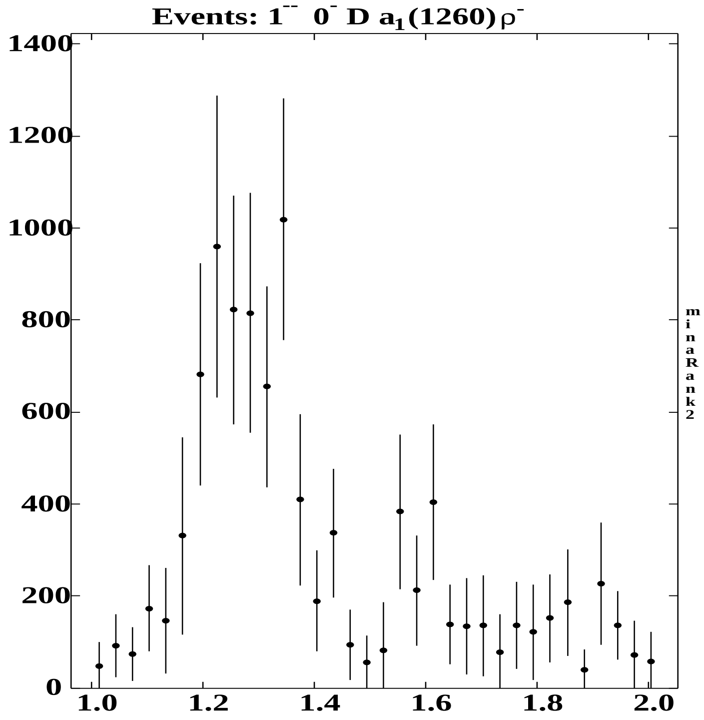
Preliminary Data from E852

A surprise in $\pi^- p \rightarrow \pi^+\pi^-\pi^0\pi^- p$?

$\omega\pi^-$ with $\ell = 1$



$a_1\pi$ with $\ell = 2$



$\pi^+\pi^-\pi^0\pi^-$ Mass (GeV)

Exotic Mesons Published from E852

Comparison of peripheral pion and photoproduction

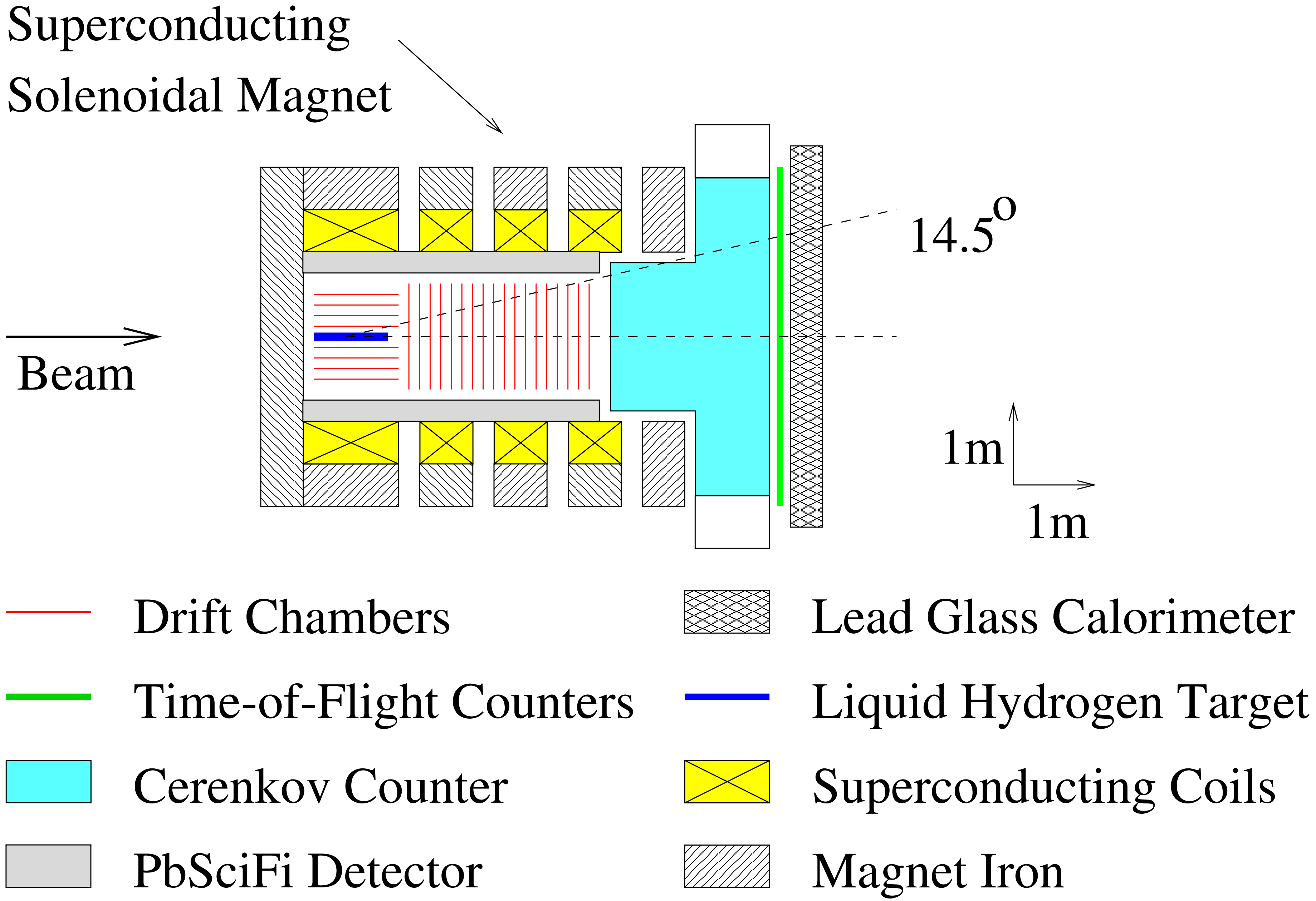
Pion and photoproduction of 3pi data

The Jefferson Lab Hall D Project

- Linked to major energy upgrade at CEBAF: $E_\gamma \sim$ 12 GeV
- Workshops over the past two years: Physics & Instrumentation
- Experimental facility in design stages
- First beams on target in $\geq$ 2002
- Collaboration Meeting: August 5,6 at Jefferson Lab

http://anthrax.physics.indiana.edu/~dzierba/Eightplus/
http://www.phys.cmu.edu/halld/

The Hall D Detector



The CEBAF and Hall D Site
(Aerial Photograph)