



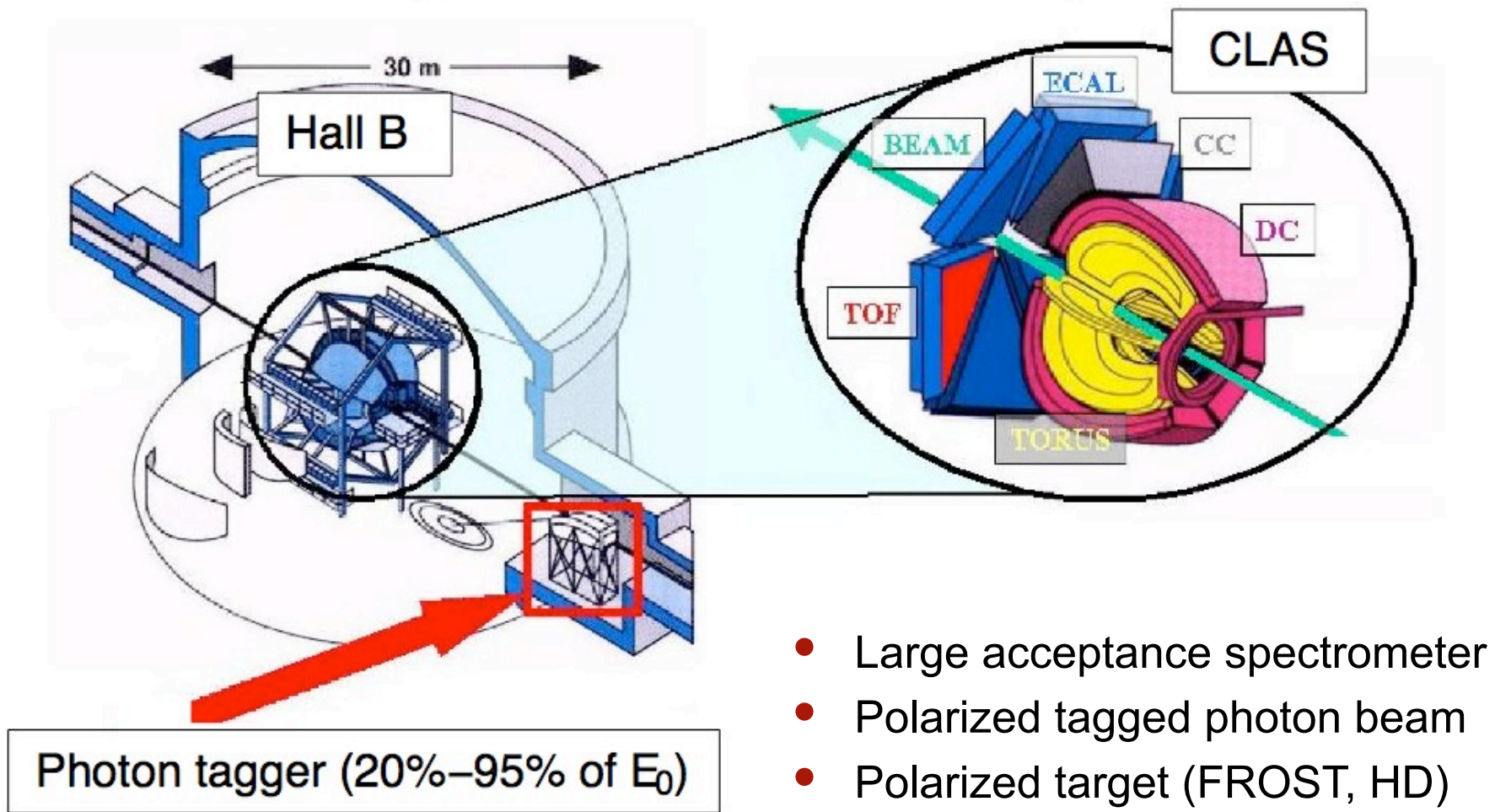
Meson Photoproduction (CLAS)

- Spectroscopy of baryons
- Spectroscopy of mesons
- ρ -mesons in the medium
- Reaction mechanisms

Steffen Strauch (University of South Carolina)
for the CLAS Collaboration

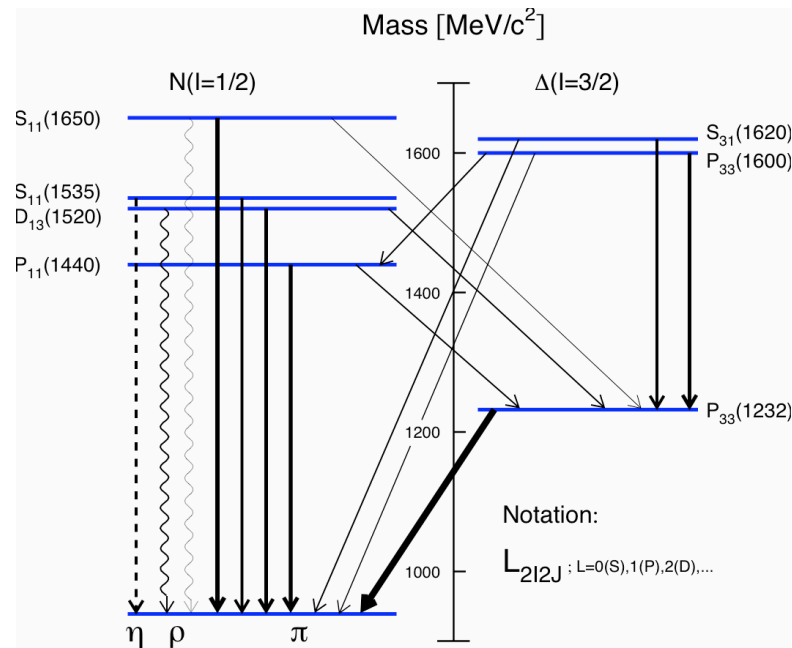


The CEBAF Large Acceptance Spectrometer





Studying the Excited States of the Nucleon

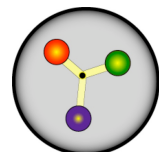
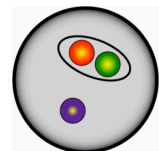
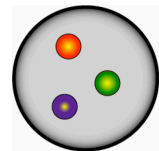


$$\gamma N \rightarrow N\pi, N\pi\pi, N\eta, YK, \dots$$

- The **location** and **properties** of excited states reflect the **dynamics** and **relevant degrees-of-freedom** within the nucleons.

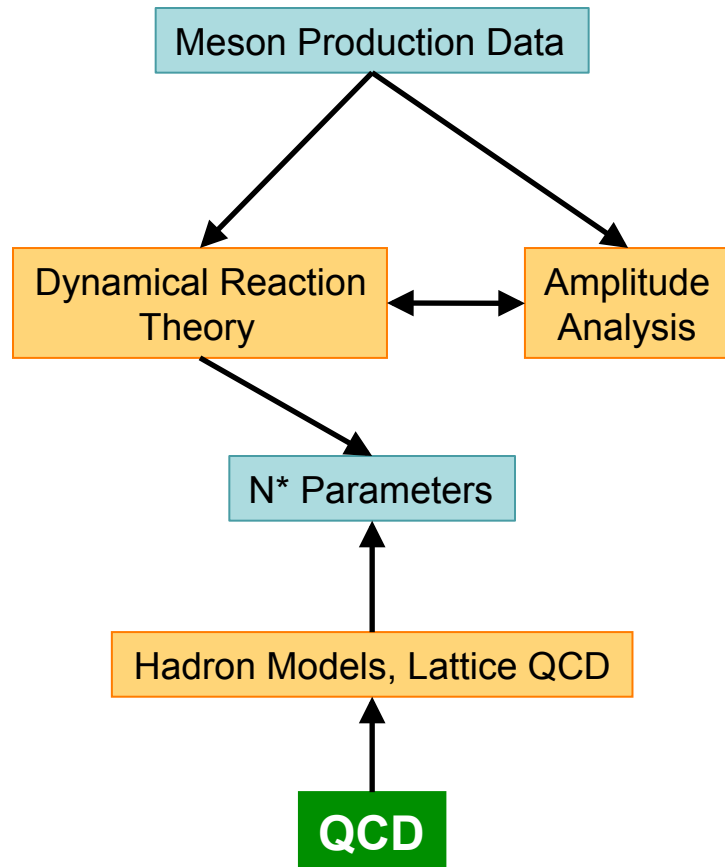
Quark Models

- Symmetric Constituent Quark Models** predict overabundance of excited states (“**missing**” resonance problem)
- Quark-Diquark Models** predict fewer states
- Quark and Flux-Tube Models** predict increased number of states





Extraction of Resonance Parameters

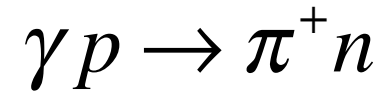
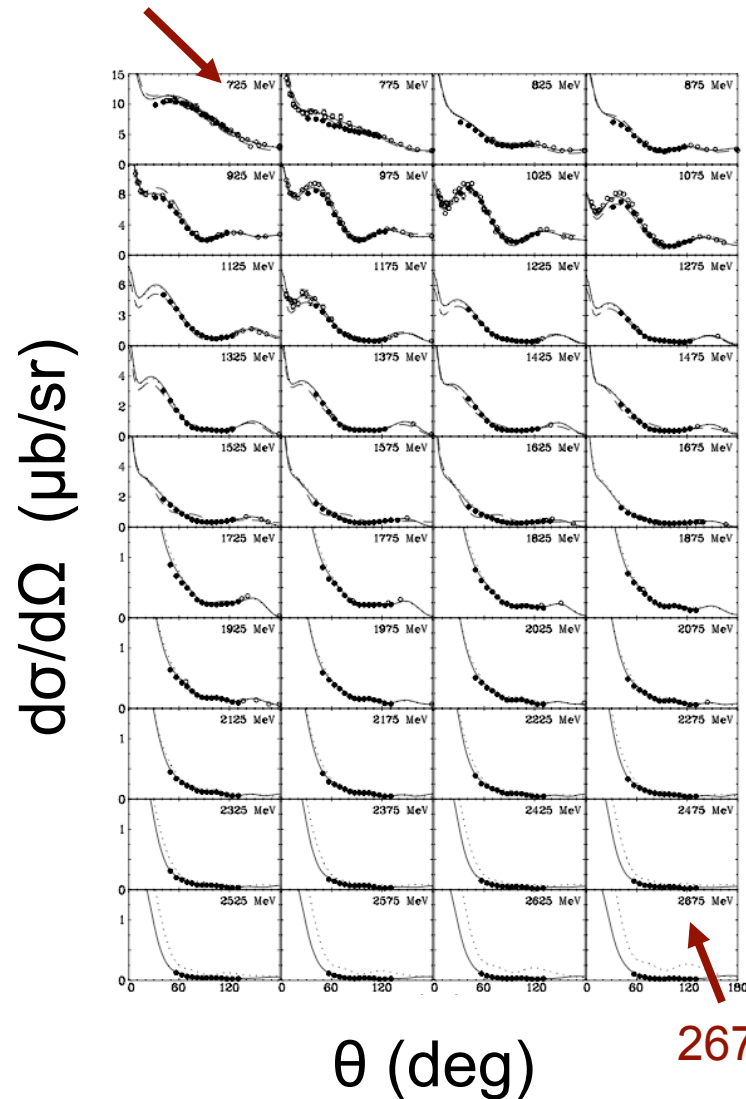


- Measurement of **eight observables** needed to unambiguously determine the **four amplitudes** of single meson photoproduction:
 - differential cross section: $d\sigma/d\Omega$
 - single polarization observables: P, T, Σ
 - double polarization observables
- CLAS experiments with
 - polarized **beam**
 - polarized **target** (FROST, HD)
 - **recoil** polarization (weak decay of hyperons)



π^+ Photoproduction on the Proton

725 MeV

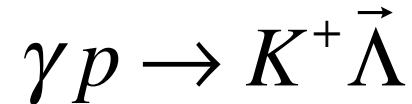


- π^+n data up to 2675 MeV
- SAID multipole analysis:
 - significant new constraints at high energies
 - no significant change of resonance parameters
- need measurements of **spin observables**

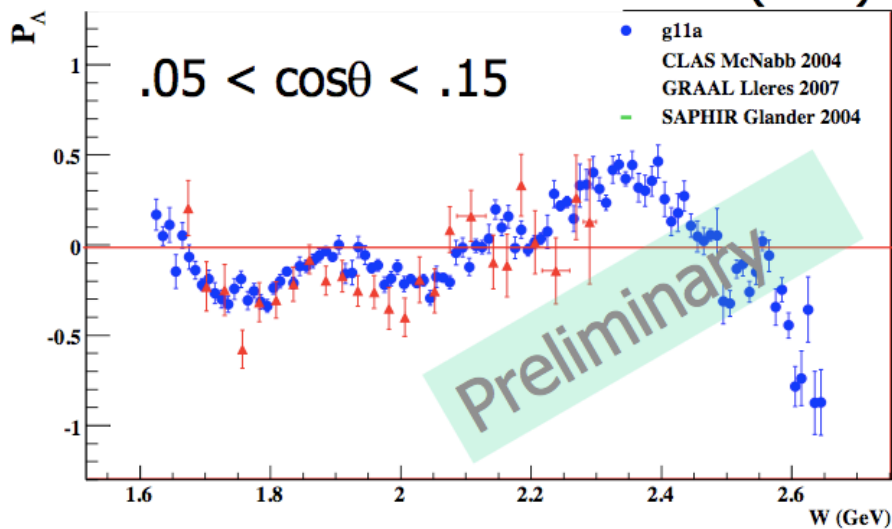
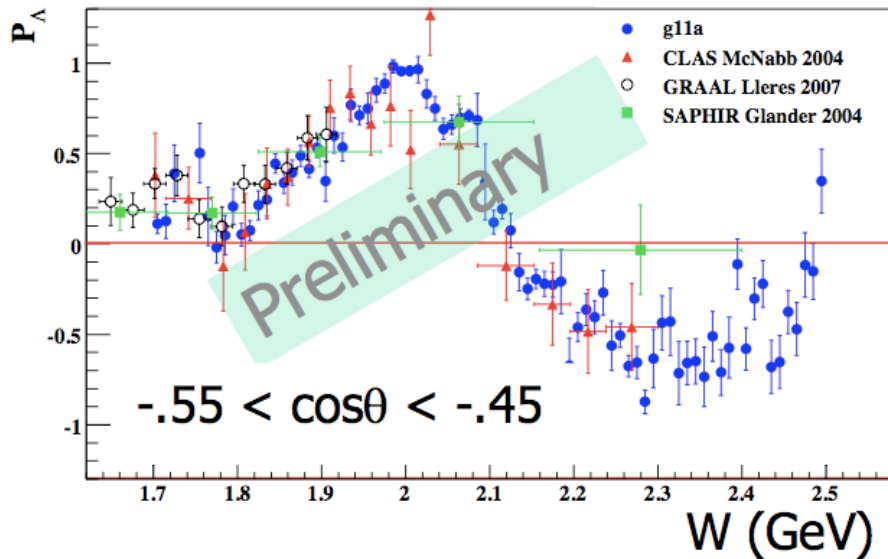
M. Dugger *et al.*, arXiv:0903.1110v1 [hep-ex]



Hyperon Recoil Polarization P_{Λ}



- Induced polarization P_{Λ}
- Preliminary CLAS'09 data has best coverage yet
- Good agreement with previous data
- CLAS PWA in progress



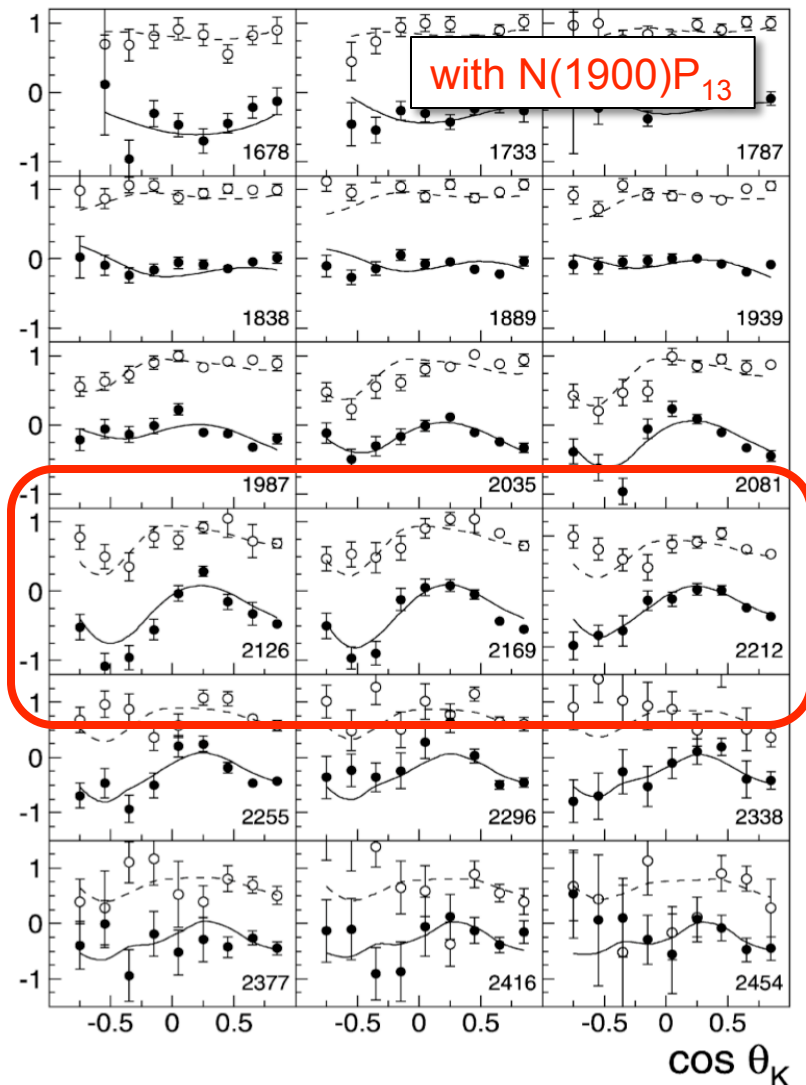
Figures from: R. Schumacher, NSTAR 2009; M. McCracken (CMU) Ph.D. work; J. McNabb *et al.*, Phys. Rev. C **69**, 043302 (2004).



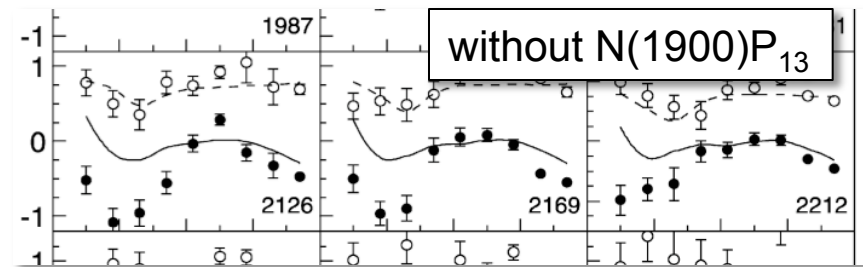
Polarization Transfer Observables C_x , C_z

C_x (\bullet), C_z (\circ) for $K^+\Lambda$ channel

$$\vec{\gamma} p \rightarrow K^+ \vec{\Lambda}$$



- $N(1900)P_{13}$ needed in PWA of Nikonov et al.



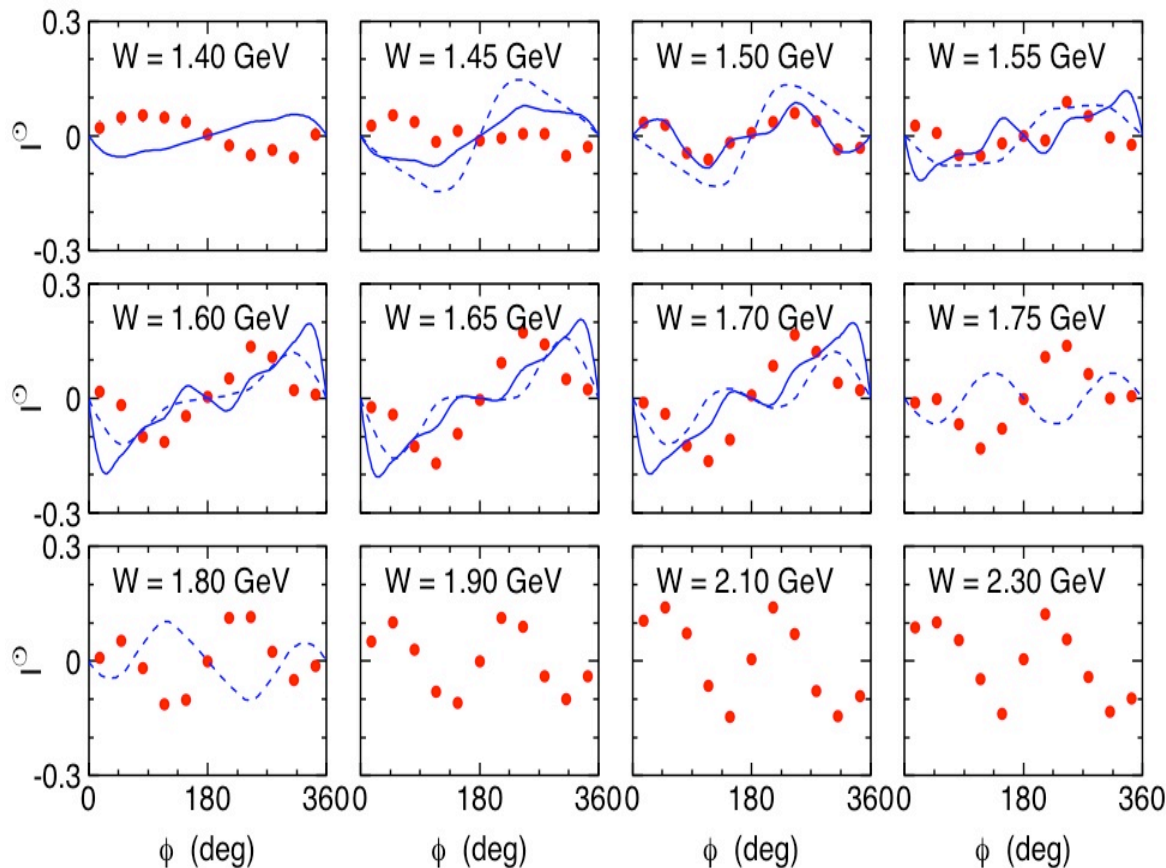
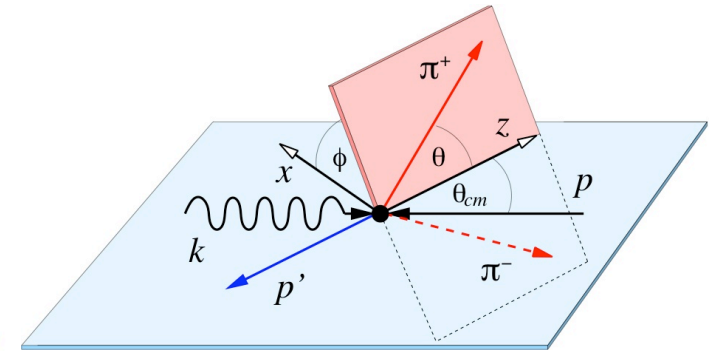
- $N(1900)P_{13}$ found in qqq models, not in quark-diquark models.

Data: R. Bradford, et al., Phys. Rev. C **75**, 035205 (2007). Analysis: V.A. Nikonov *et al.*, Phys. Lett. B **662**, 245 (2008)



Beam-Helicity Asymmetries in Double-Pion Photoproduction on the Proton

- Dominant nucleon-resonance decay channels $W > 1.6$ GeV: $\pi\pi N$



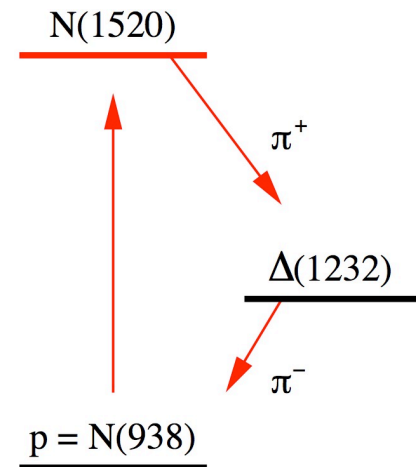
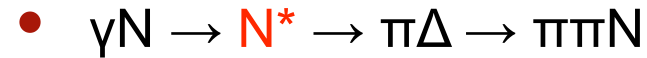
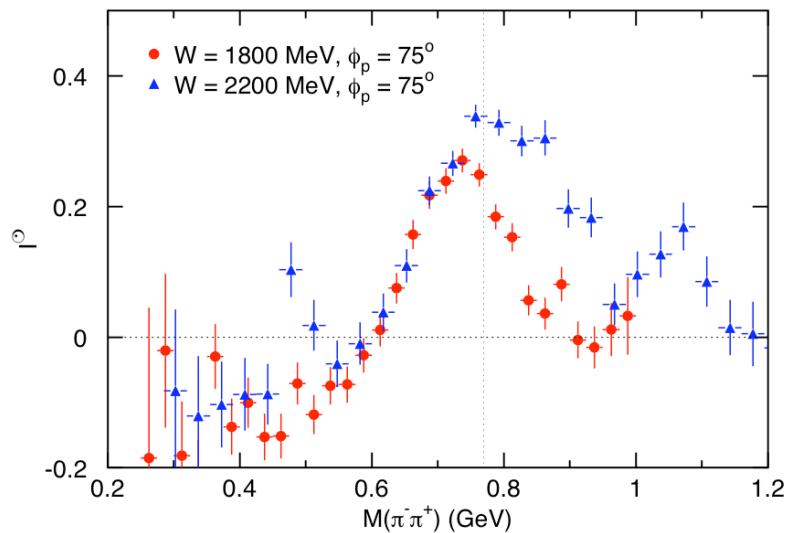
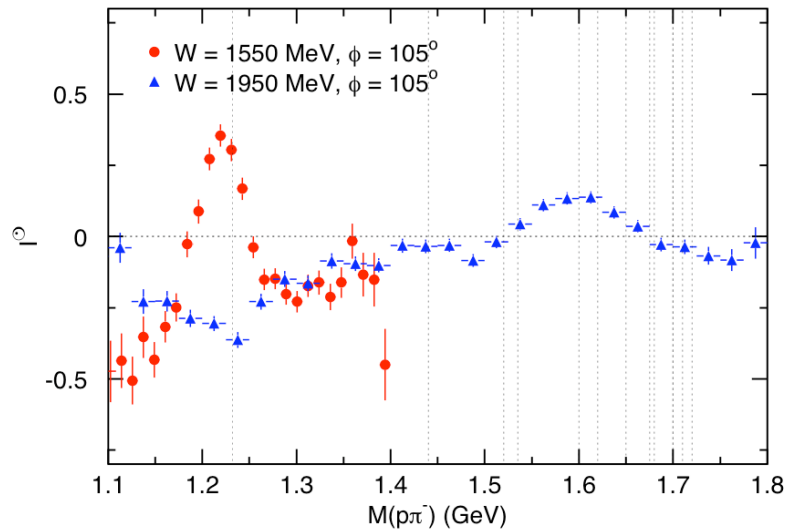
- New observables: helicity asymmetry

$$I^{\otimes}(\phi) = \frac{1}{P} \frac{N^+ - N^-}{N^+ + N^-}$$

Models: V. Mokeev (dashed),
A. Fix (solid); W. Roberts and
T. Oed, Phys. Rev. C **71**,
055201 (2005);
Data: S. Strauch *et al.*, Phys.
Rev. Lett. **95**, 162003 (2005)



Sequential Decay



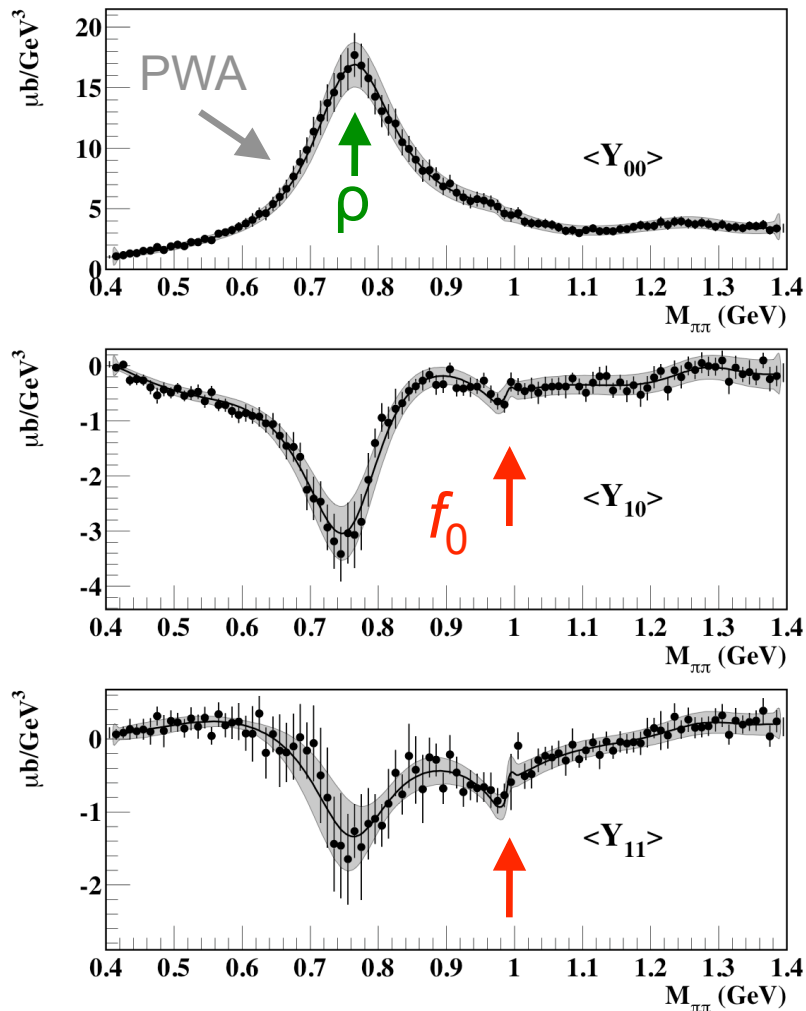
- Helicity asymmetries allow detailed study of the $\pi N \rightarrow \pi\pi N$ reaction (e.g., **sequential decay**)

- Extension of these studies in E06-013 (FROST).



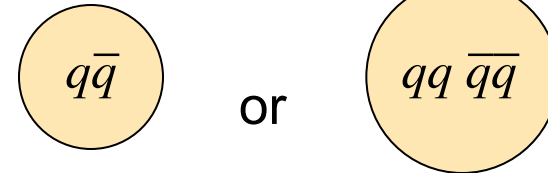
Measurement of Direct $f_0(980)$ Photoproduction on the Proton

Moments of dipion angular distribution



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

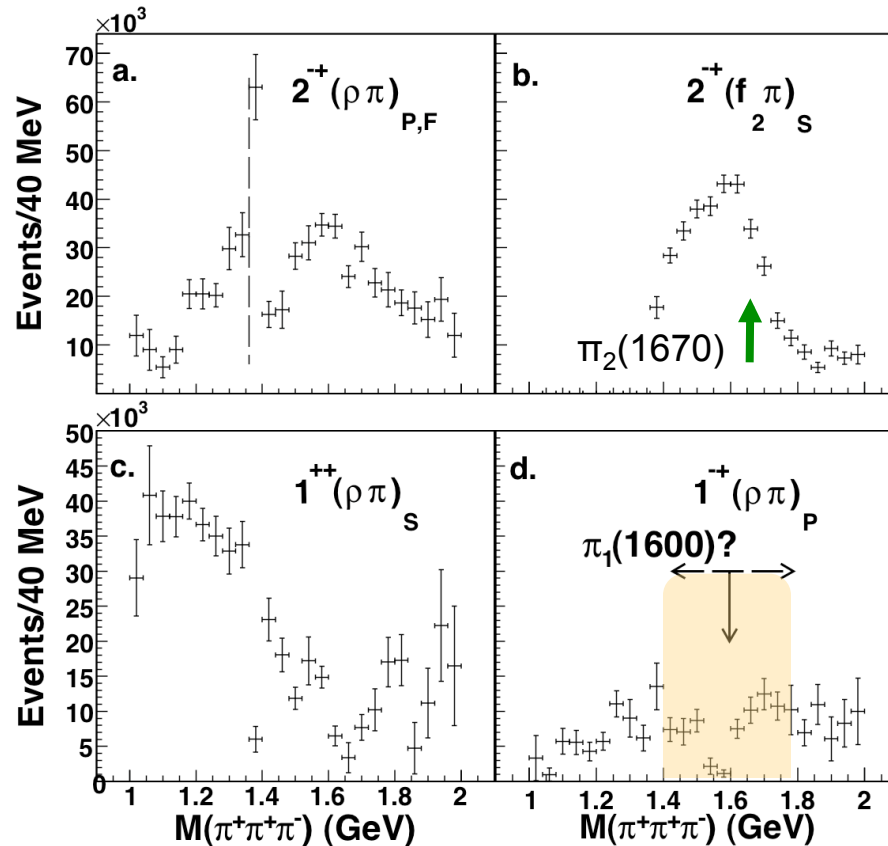
- Low lying scalar mesons: quark-antiquark or diquark-antidiquark bound states?



- Interference between P and S waves at $M_{\pi\pi} \sim 1$ GeV indicates presence of $f_0(980)$ resonance (first time in a photoproduction experiment).

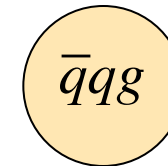


Search for the Photoexcitation of Exotic Mesons in the $\pi^+\pi^+\pi^-$ System



$$\gamma p \rightarrow \pi^+ \pi^+ \pi^- (n)$$

- Lowest lying $(\bar{q}qg)$ state predicted to have $J^{PC} = 1^{-+}$



hybrid meson

- CLAS: No resonant structure observed in the exotic $1^{-+}(\rho\pi)_P$ partial wave
- Upper limit $\sigma \leq 13.5$ nb for the exotic $\pi_1(1600)$, smaller than expected.
- Calculated photo-production cross section overestimated or $\pi_1(1600)$ not exotic?



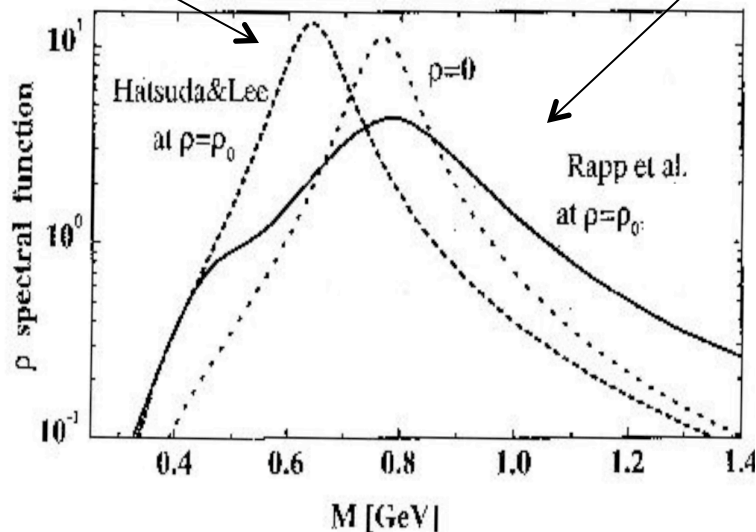
In-Medium Properties of Vector Mesons

$$\frac{m_V^*}{m_V} \approx 1 - \alpha \frac{\rho_B}{\rho_0}$$

Mass shift

?

Broadening



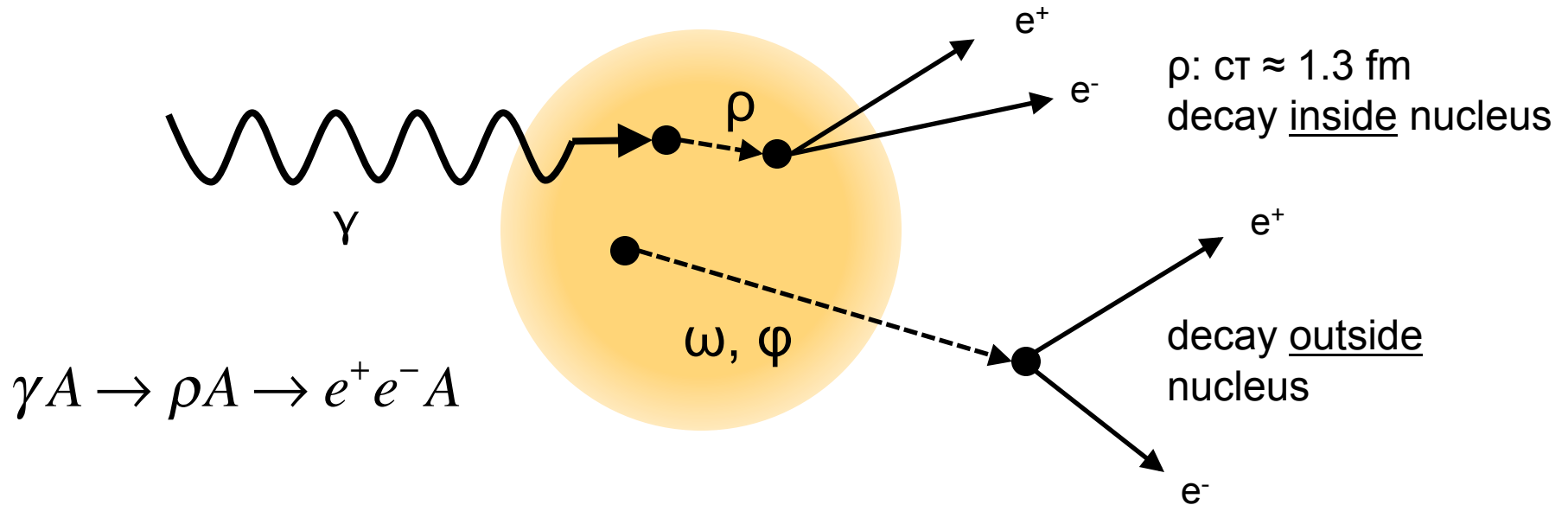
ρ -meson spectral function
(possibly momentum dependent)

- The **dynamical breaking of chiral symmetry** has large impact on the masses of hadrons.
- **Restoration of chiral symmetry** in hot and/or dense nuclear matter is predicted.

⇒ expected changes of in-medium properties of hadrons



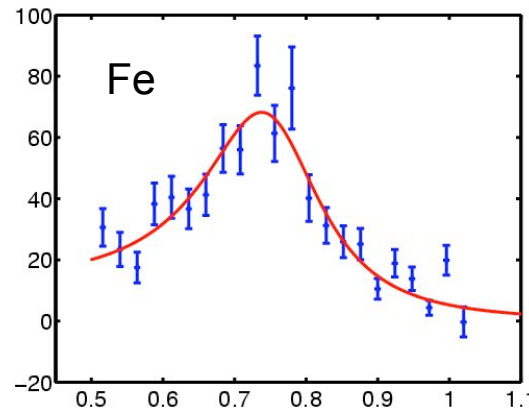
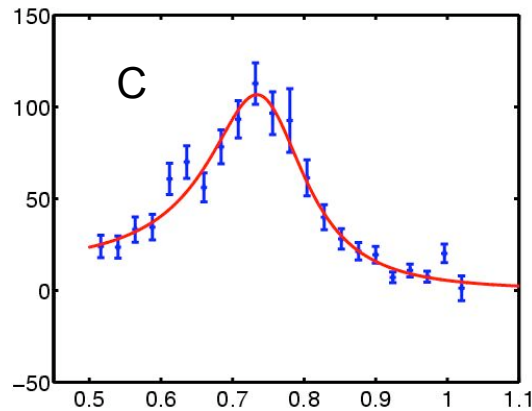
Medium Modification of Vector Mesons



- CLAS g7a Experiment (medium modification at $T = 0$):
 - Targets: LD2, C, Ti, Fe, (Pb)
 - Leptonic decay with almost **no final state interaction**; $\Gamma_{e^+e^-}/\Gamma_{\text{tot}} \sim 5 \times 10^{-5}$
 - Momentum of ρ between 0.8 and 2 GeV (> 0.5 GeV with g7b)
 - Study invariant mass distribution, $m(e^+e^-)$



The ρ -Mass Spectra



Extraction of ρ -mass spectra after subtraction of ω and ϕ contributions and combinatorial background.

e^+e^- Invariant Mass (GeV)

| Target | Mass (MeV/c ²) CLAS data | Width (MeV/c ²) CLAS data | Mass (MeV/c ²) Giessen BUU | Width (MeV/c ²) Giessen BUU |
|------------------------------------|---|--|---|--|
| ¹² C | 762.5 ± 3.7 | 176.4 ± 9.5 | 773.8 ± 0.9 | 177.6 ± 2.1 |
| ⁴⁸ Ti- ⁵⁶ Fe | 779.0 ± 5.7 | 217.7 ± 14.5 | 773.8 ± 5.4 | 202.5 ± 11.6 |

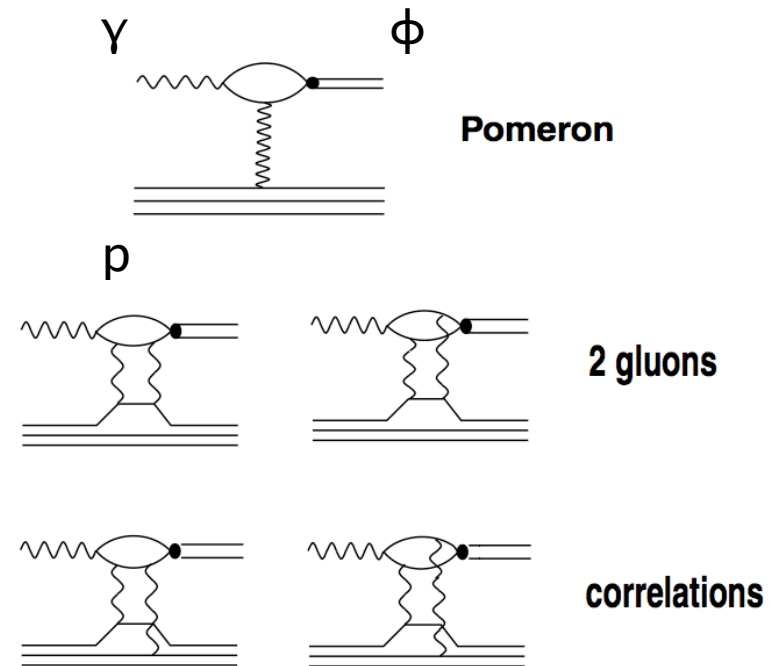
- The vacuum properties of the ρ meson are: $m=770$ MeV/c² and $\Gamma=150$ MeV.
- **No mass shift; broadening of the width is consistent with many-body effects.**

C. Djalali, PANIC 2008; R. Nasseripour *et al.*, Phys. Rev. Lett. **99**, 262302 (2007); M.H. Wood *et al.*, Phys. Rev. C **78**, 015201 (2008).



$\phi(1020)$ Meson Photoproduction

- Photoproduction of ϕ -mesons on the proton at large momentum transfer
[E. Anciant *et al.*, Phys. Rev. Lett. **85**, 4682 \(2000\)](#)
- Tensor polarization of the ϕ -meson photoproduced at high t
[K. McCormick *et al.*, Phys. Rev. C **69**, 032203\(R\) \(2004\)](#)
- Measurement of coherent ϕ -meson photoproduction from the deuteron at low energies
[T. Mibe *et al.*, Phys. Rev. C **76**, 052202\(R\) \(2007\)](#)
- Extensive analysis of ϕ -meson photoproduction from g11 data
[D. Tedeschi, Diffraction 2008](#)





Summary

- Spectroscopy of baryons
 - high precision unpolarized and polarized photoproduction data with various decay channels, covering large angular and energy ranges provide needed input for partial wave analyses in the search for new baryon states
- Spectroscopy of mesons
- ρ -mesons in the medium
 - no significant mass shift observed; width consistent with expected collisional broadening
- Reaction mechanisms