STRANGE MESON SPECTROSCOPY AT CLAS AND CLAS12

Alessandra Filippi

INFN Torino, Italy

Pion-Kaon Interactions Workshop, JLAB, February 14-15, 2018

Outline

- Introduction
  - Light mesons decaying to $K\bar{K}$ and $K\bar{K}\pi$: open vs hidden strangeness
  - Exotic strangeonia and expected channels

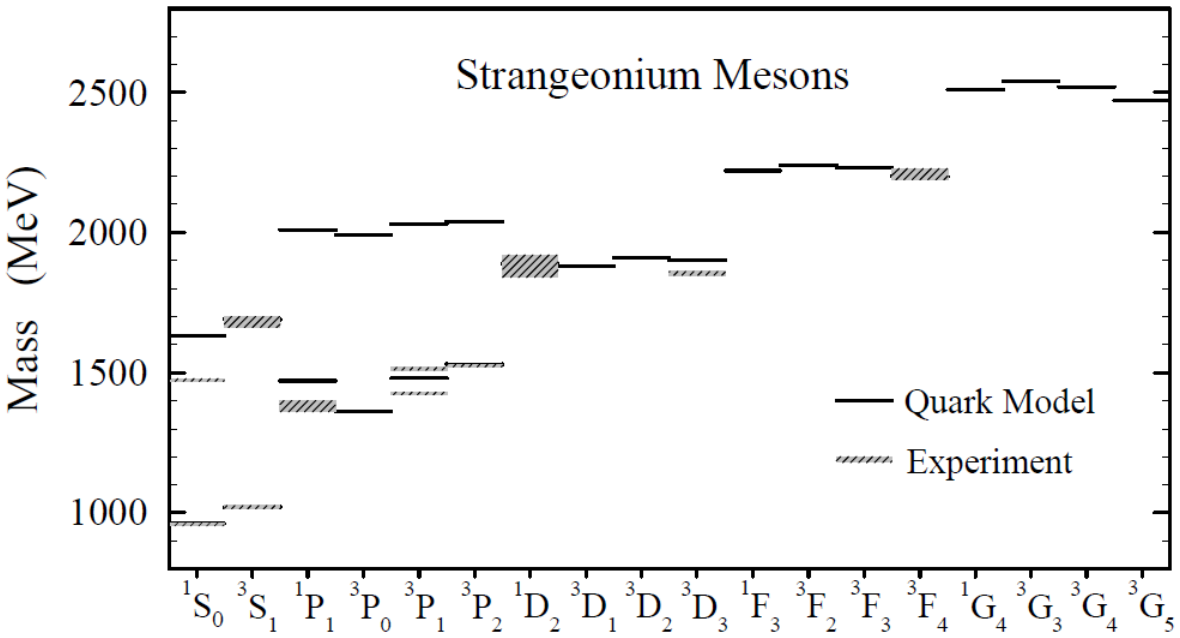
- Studies of photoproduction reactions by real photons: CLAS6
  - The $K\bar{K}$ system: K^+K^- and K_SK_S
  - The $K\bar{K}\pi$ and $K\pi\pi$ systems
  - The $\phi\eta$ system

- Studies of photoproduction reactions by virtual photons: CLAS12

- Summary and Conclusions

Introduction: strange quarkonia

- Light mesons (u,d,s) with at least one strange quark/antiquark in their valence component
  - Kaonia/antikaonia: dominant valence $n\bar{s}/s\bar{n}$ (n= u, d)
    - Of 22 expected states below 2.1 GeV, ~13 have been observed
  - Strangeonia: $s\bar{s}$
    - Of 22 expected states below 2.1 GeV, <10 are steadily established

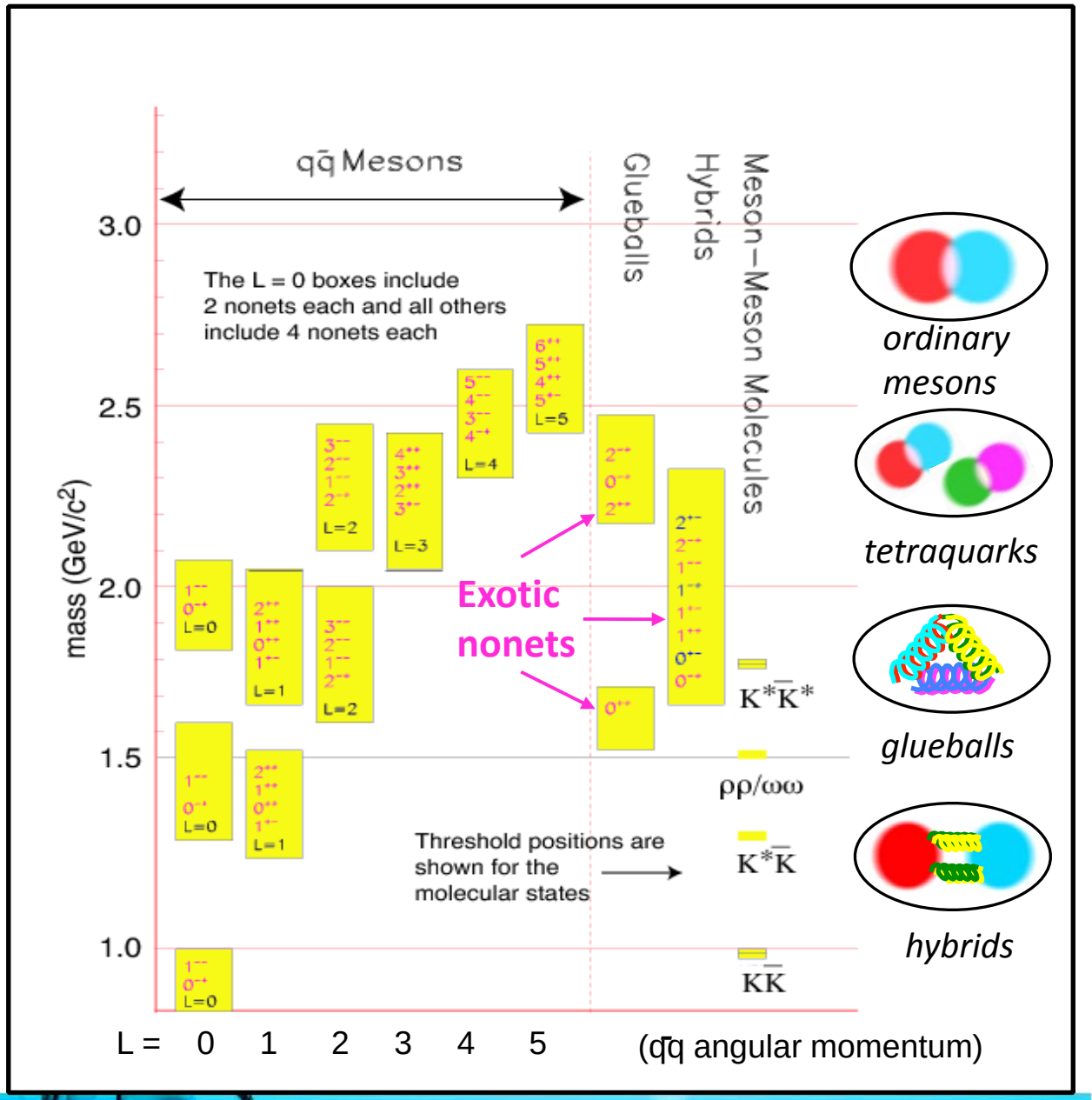


Godfrey, Napolitano, Rev. Mod. Phys. 71 (1999), 1411

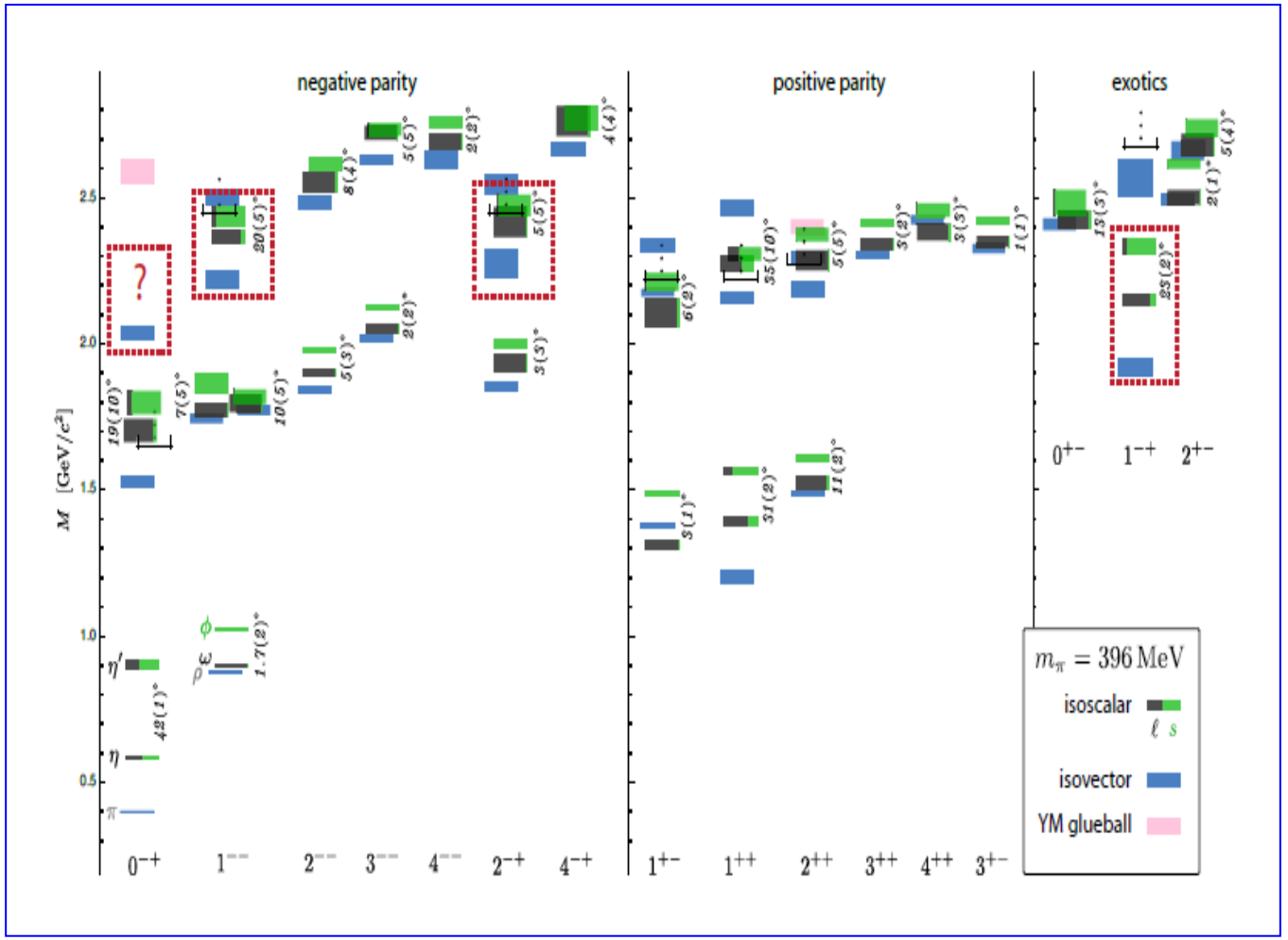
- Strangeonium experimental signatures much less known (and clear) than charmonium
- Large probability of:
  - strong mixing with light mesons & other expected (but still unobserved) structures
  - Overlap of broad states
  - Decay channels shared

The meson spectrum + gluons: exotics

- The meson spectrum bears also the information about gluons, which bind quarks
- Which is the expected signature of gluonic degrees of freedom ?
  - Observation of extra states possibly with quantum numbers not allowed by CQM
- New states with gluonic content:
  - **Glueballs (ggg)**
  - **Hybrids ($q\bar{q}g$)**
  - **Multiquark/molecular states**
    - **EXOTICS**



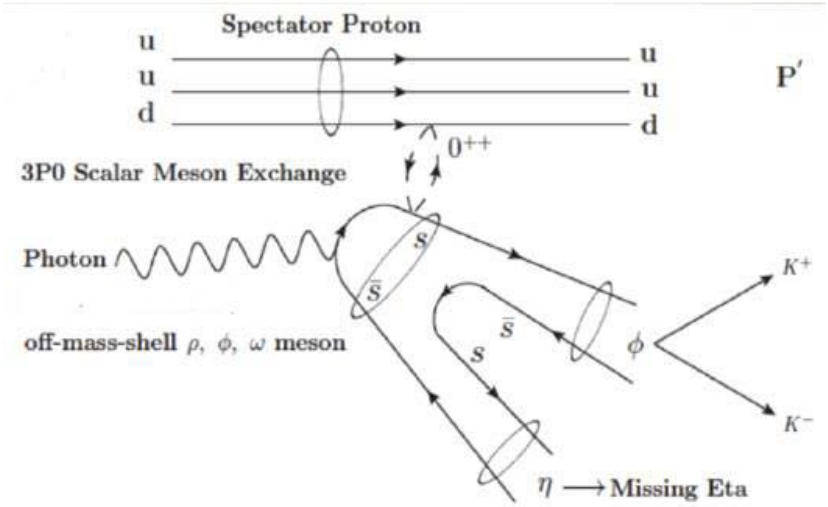
LQCD expectations for the meson spectrum



Remarkable agreement of most recent LQCD calculation with the expected meson spectrum
BUT: the lightest exotic of the spectrum now expected at 1600 MeV (1^{-+}) and 2 GeV (0^{+-})

Strangeonia decay patterns

- **Smoking gun** decay modes for $s\bar{s}$ states: $\eta\phi$, $\eta'\phi$, $\phi\phi$
  - $\eta\phi$: identification of C = -1 $s\bar{s}$ candidates
  - Small branching fraction to non-strange final states

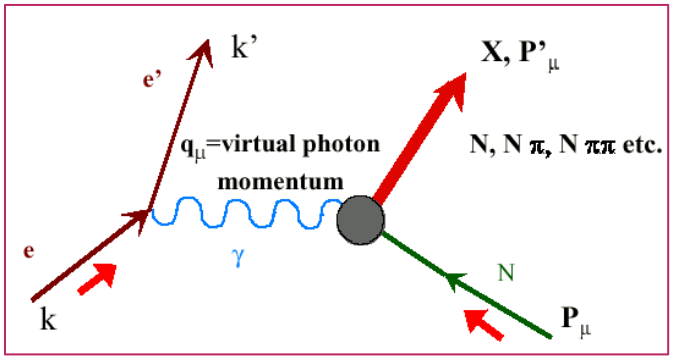


- Other relevant channel for $s\bar{s}$ and exotics ($q\bar{q}g$, $q\bar{q}q\bar{q}$): $\phi\pi^0$
- **Decays to open-strangeness final states do not uniquely identify strangeonia**: $K\bar{K}$, $K\bar{K}^*$ ($K\bar{K}\pi$), $K^*\bar{K}^*$ (+c.c.)
  - Decay channels shared by:
    - **Light quark iso-singlet mesons**
    - **Exotic states**
      - Experimental evidences of significant $n\bar{n} \leftrightarrow$ gluons $\leftrightarrow s\bar{s}$ mixing, especially in the scalar 0^{++}, **pseudoscalar 0^{-+}** and 2^{-+} sectors

OPEN/HIDDEN STRANGENESS IN PHOTOPRODUCTION REACTIONS

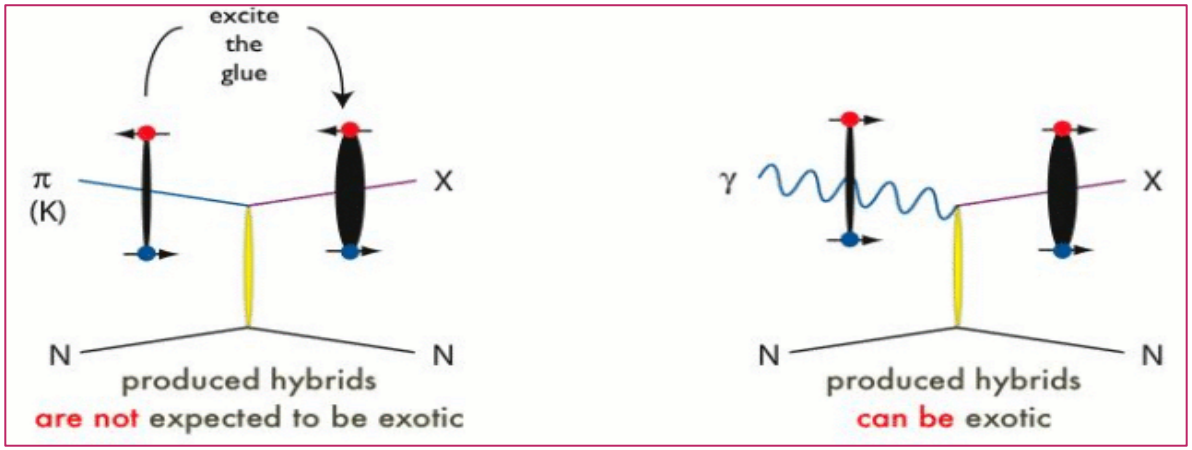
Meson spectroscopy with e.m. probes

- The electromagnetic interaction is weaker than the strong one and can be calculated perturbatively with high precision (based on well-known QED)
  - Scattering: one-photon exchange approximation



- Meson photoproduction: **high probability of spin-1 meson production from photons**

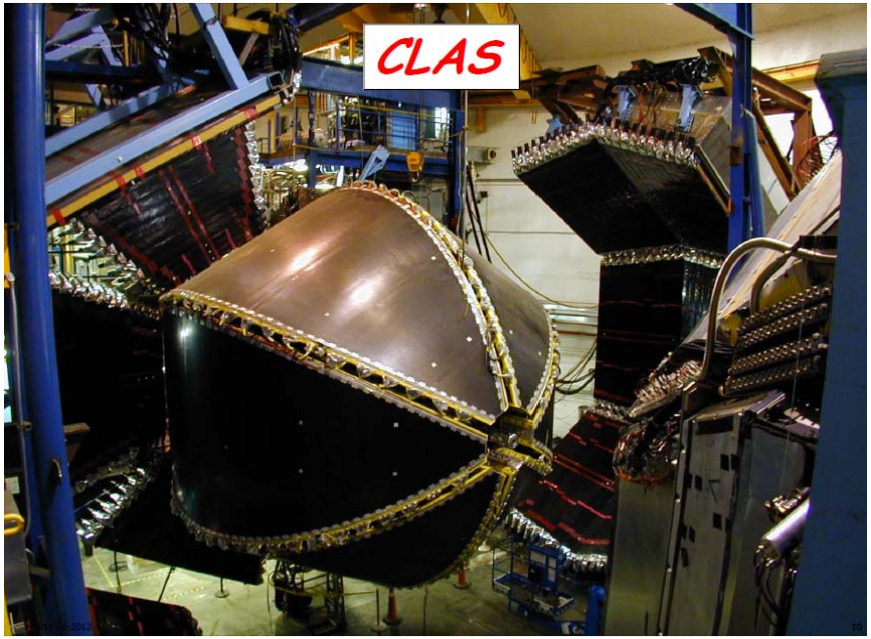
π (K)N: Need spin-flip for exotic quantum number

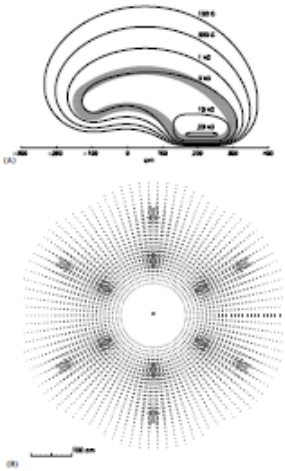


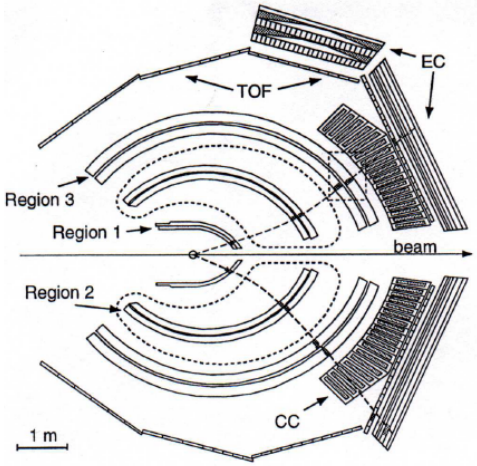
γN: No spin-flip for exotic quantum number

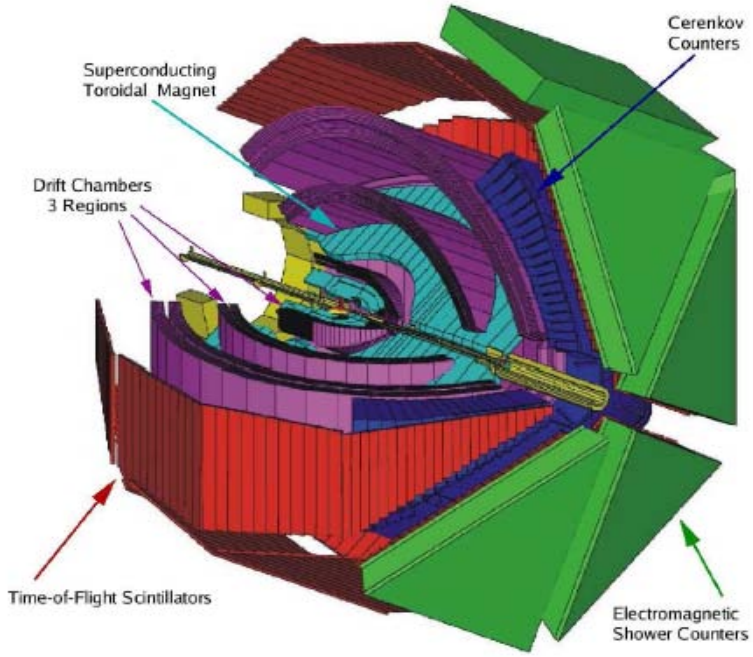
  - Expected production rate for exotics and conventional mesons: comparable
- **$\bar{s}s$ coupling to the photon relatively large (beam spin vector)**

CLAS @ 6 GeV


CLAS




EC
TOF
Region 3
Region 1
beam
Region 2
CC
1 m


Cerenkov
Counters
Superconducting
Toroidal Magnet
Drift Chambers
3 Regions
Time-of-Flight Scintillators
Electromagnetic
Shower Counters

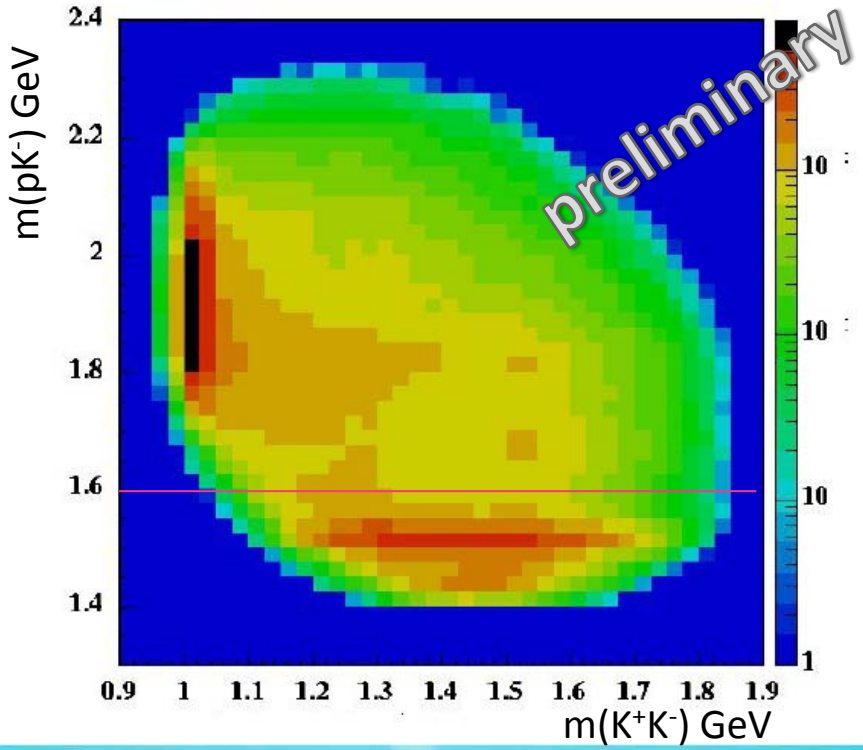
The K^+K^- system: $\gamma p \rightarrow pK^+K^-$

S. Lombardo, UCornell, 2016

Physics case: investigation of light meson resonance spectrum

- $\phi(1020)$ main decay mode
- possible sub-threshold decay of $f_0(980)$ and $a_0(980)$ scalars
- issues: σ production? Other scalars? $f_0(980)$ coupling to $\pi\pi/K\bar{K}$?

- CLAS6 g11 data set:
  - E_γ = (3-3.8) GeV
  - -t: (0.6-1.3) GeV^2
  - p and K^+ detected in CLAS, K^- reconstructed by missing mass
    - π/K misidentification: 10-15%
- Low mass region selected
  - $m_{pK^-} > 1.6$ GeV
  - Baryonic resonance contributions ($\Lambda(1520)$) removed, no overlap



The K^+K^- system: $\gamma p \rightarrow pK^+K^-$

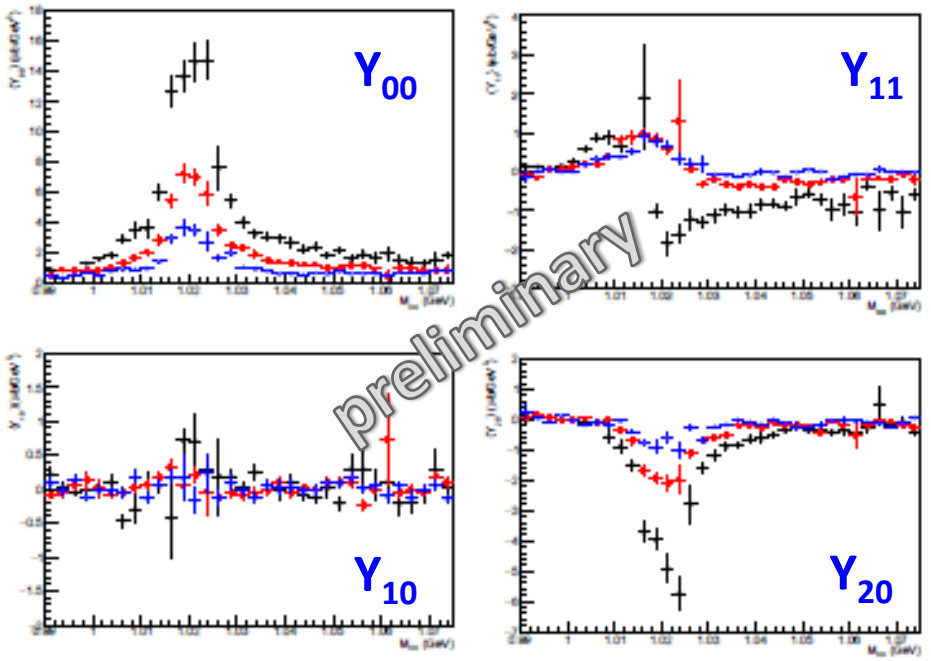
- Study of S-P wave interplay in the $K\bar{K}$ system
  - Cross-sections extraction in each partial wave through likelihood fits

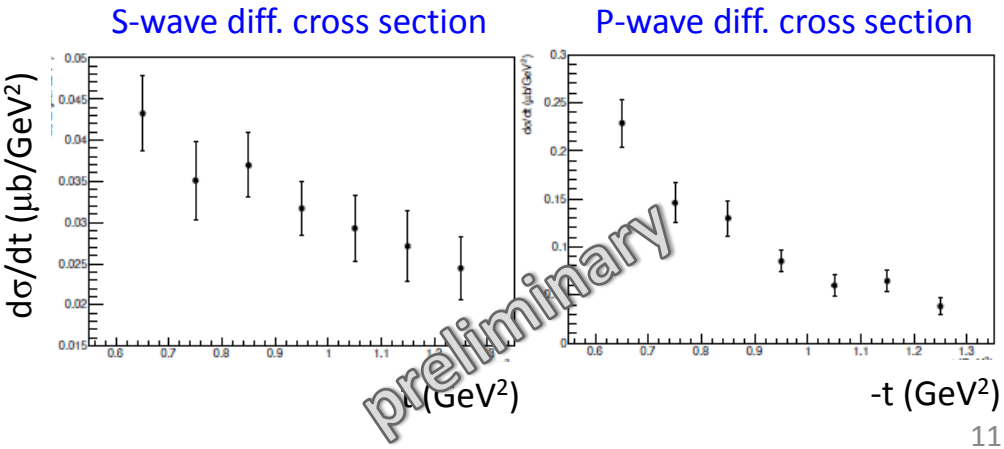
- Method: moments analysis

$$\langle Y_{LM} \rangle = 4\pi \int d\Omega_K \frac{d\sigma}{dt dM_{KK} d\Omega_K} Y_{LM}(\Omega_K)$$

  - Moments can be expressed as bilinear combination of partial waves, depending on L, M and photon and proton helicities
  - Amplitude parameterizations:
    - S wave: ρ, ω exchange in t-channel
    - P-wave: Pomeron exchange

S. Lombardo, 2016





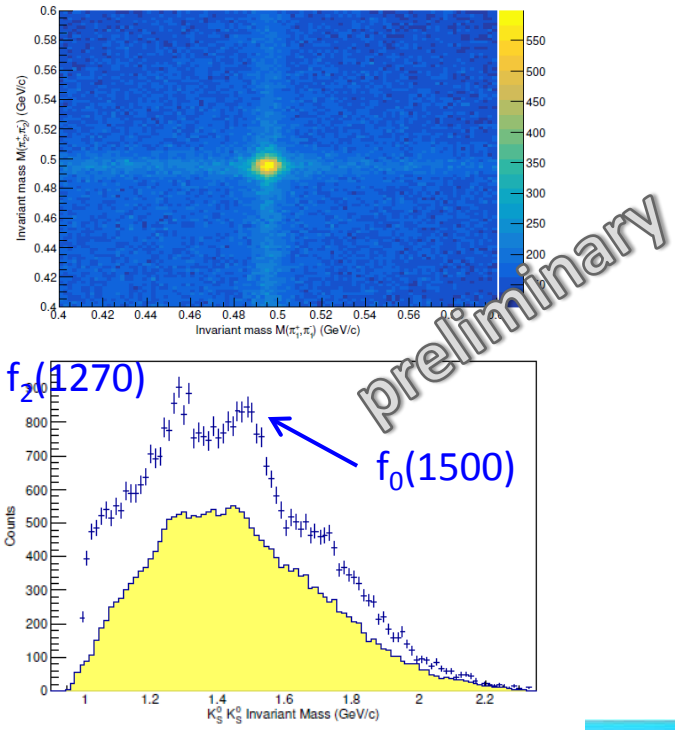
The K_SK_S system: $\gamma p \rightarrow pK_SK_S$

S. Chandavar, UOhio, 2017
arXiv: 1712.02184

Physics case: search for a scalar glueball in its kaonic decay

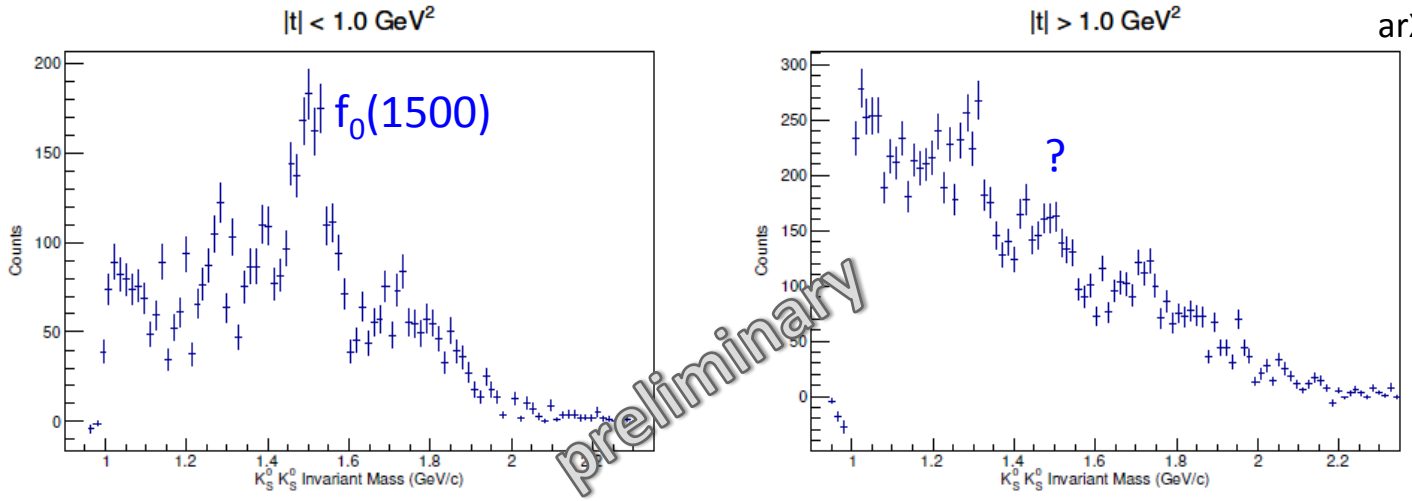
- K_SK_S system: $J^{PC} = (\text{even})^{++}$
- light scalar sector: several candidates, too many states for the nonet
  - $f_0(600)$, $f_0(980)$, $f_0(1370)$, **$f_0(1500)$**, $f_0(1700)$, …
- no study yet in photoproduction reactions

- CLAS6 g12 data set:
  - E_γ = (2.7-3) && (3.1-5.1) GeV
  - 4π detected in CLAS, p reconstructed by missing mass
  - High correlation between K_S pairs
- Selection in t ranges
  - Low t: resonance production in t-channel
  - Wider t range for s-channel production

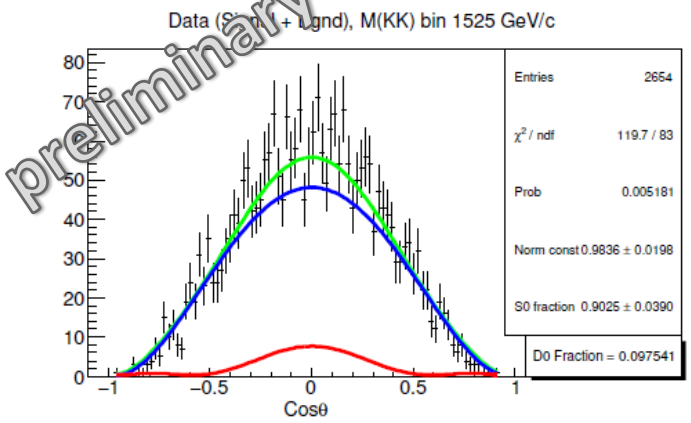


The K_SK_S system: $\gamma p \rightarrow pK_SK_S$

S. Chandavar, UOhio, 2017
arXiv: 1712.02184



- Clean signal of $f_0(1500)$ for $|t| < 1$ GeV^2, no indication for $|t| > 1$ GeV^2
  - t-channel process
  - Good glueball candidate??
- Low acceptance at fw/bw angle: no PW analysis possible
- Angular analysis of Gottfried-Jackson distributions, comparison with simulations
  - S-wave dominance, small D-wave contribution above 1550 MeV



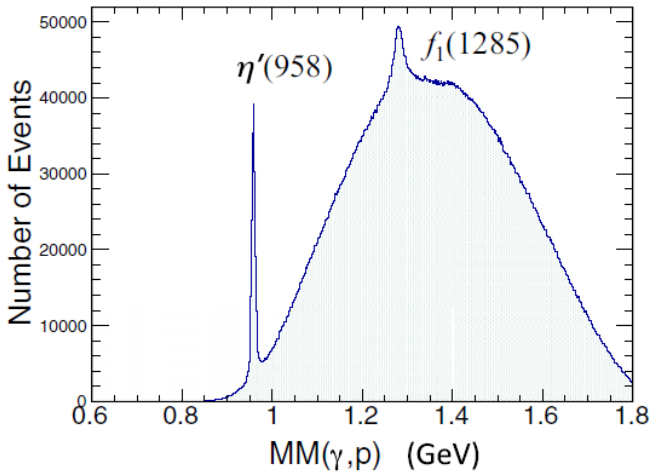
The $K\bar{K}\pi$ system: $\gamma p \rightarrow pK^0K^{\pm}\pi^{\mp}$

CLAS Collaboration, PRC93, 065202 (2016)

Physics case: superimposition of several axial/scalar states in the 1.3-1.5 GeV mass range with decay in $K\bar{K}\pi$

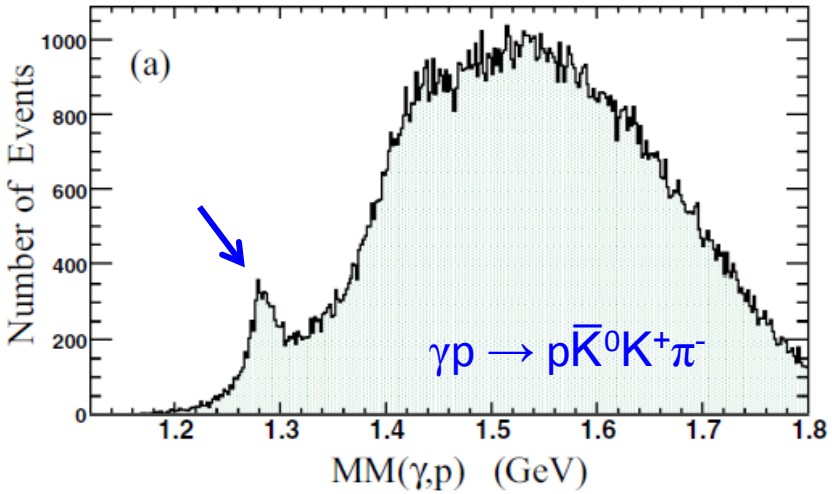
- $J^P = (odd)^+$ or $J^P = (even)^-$
- η-like pseudoscalars $\mathbf{0^{-+}}$: all of them decay to $K\bar{K}\pi$, K^*K, $a_0(980)\pi$
- axial states $\mathbf{1^{++}}$:
  - $f_1(1285)$: not seen in K^*K
  - $f_1(1420)$: favored candidate as hybrid $q\bar{q}g$, or 4q state, or K^*K molecule
  - other: $f_1(1510)$, isovector $a_1(1420)$…

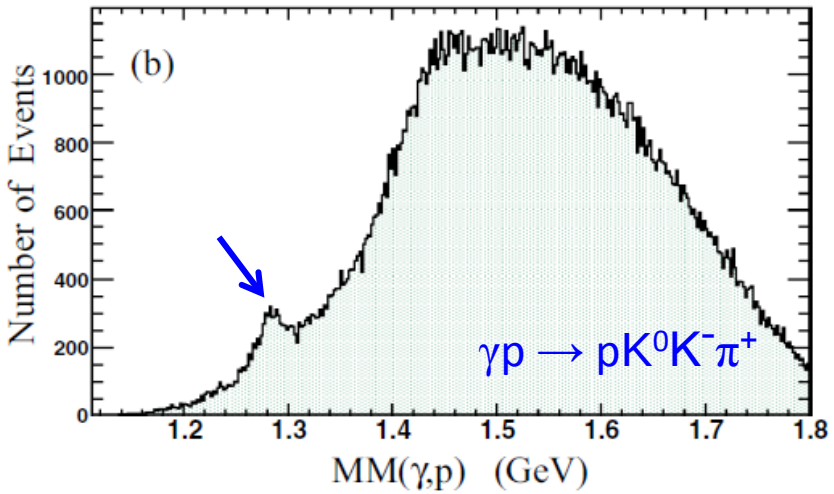
- CLAS6 g11a data set:
  - E_γ = (3-3.8) GeV
  - p, $K^{\pm}$, $\pi^{\mp}$ detected in CLAS, K^0 from missing mass
  - Kaon identification by TOF
  - Study of the $p\pi^+\pi^-\eta$ and $p\pi^+\pi^-\gamma$ channels on the same sample



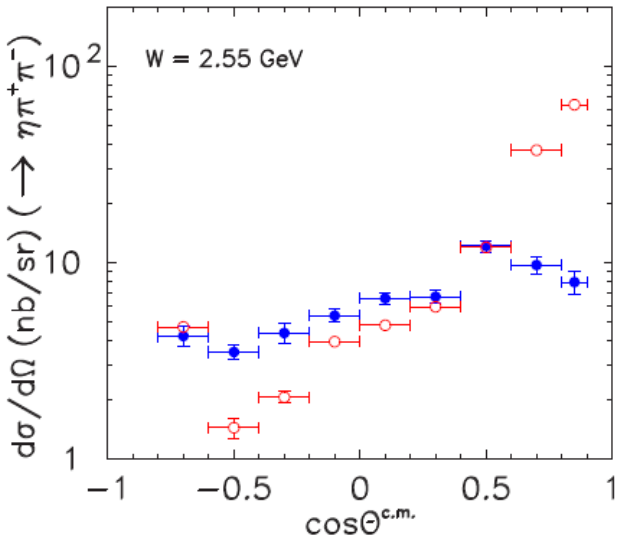
The $K\bar{K}\pi$ system: $\gamma p \rightarrow pK^0K^{\pm}\pi^{\mp}$

CLAS Collaboration, PRC93, 065202 (2016)



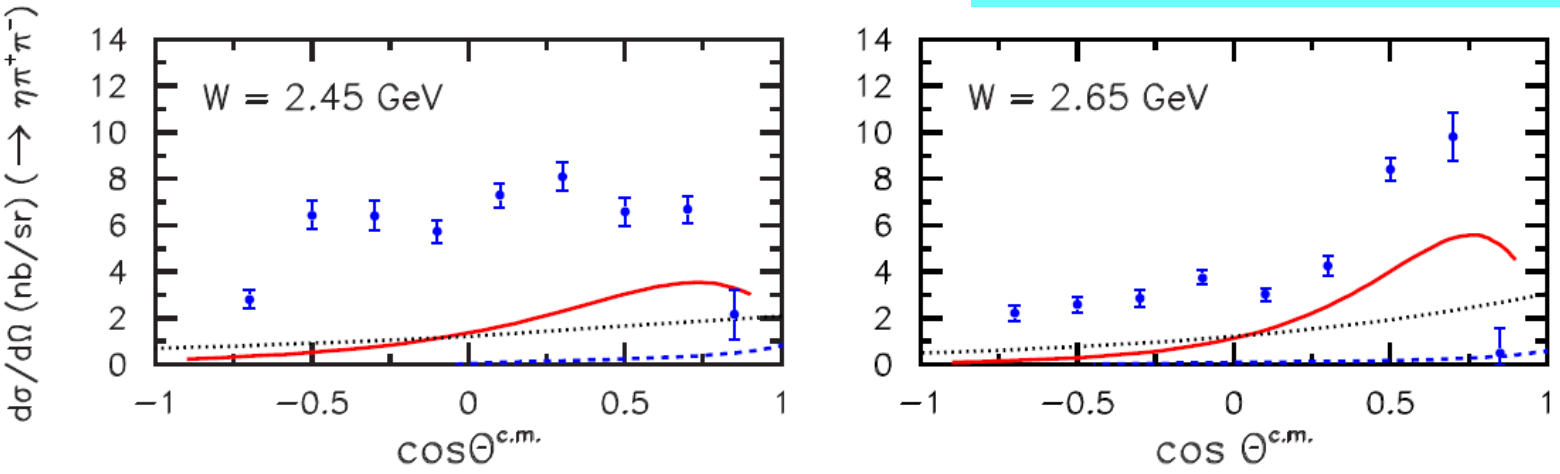


- No evidence found for higher mass $\eta(1405)$, $\eta(1470)$, $f_1(1420)$, $f_1(1510)$
- First observation in photoproduction at ~1280 MeV, studied in $\pi^+\pi^-\eta$
  - $M = (1281.0 \pm 0.8)$ MeV
  - $\Gamma = (18.4 \pm 1.4)$ MeV
    - More compatible with $f_1(1285)$ than $\eta(1295)$
  - Differential cross sections: flatter trend as compared to $\eta'(958)$



The $K\bar{K}\pi$ system: $\gamma p \rightarrow pK^0K^{\pm}\pi^{\mp}$

CLAS Collaboration, PRC93, 065202 (2016)



- Poor match of the differential cross sections with expectations from t-channel models
  - s-channel substantial contribution?
  - Dynamically produced state via s-channel involving N* excitations or KK* molecular interactions?
  - Larger support for $f_1(1285)$ identification
- First determination of the relative branching ratio: $\Gamma(K\bar{K}\pi)/\Gamma(\eta\pi\pi) = 0.216 \pm 0.032$
  - Consistent with PDG value : 0.171 ± 0.013
  - Not known for η(1295)

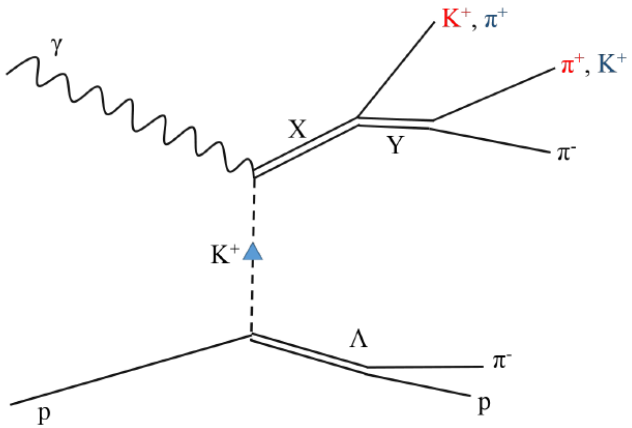
The Kππ system: $\gamma p \rightarrow \Lambda K^+\pi^+\pi^-$

M. Al Ghoul, FSU, 2016

Physics case: search for excited strange mesons

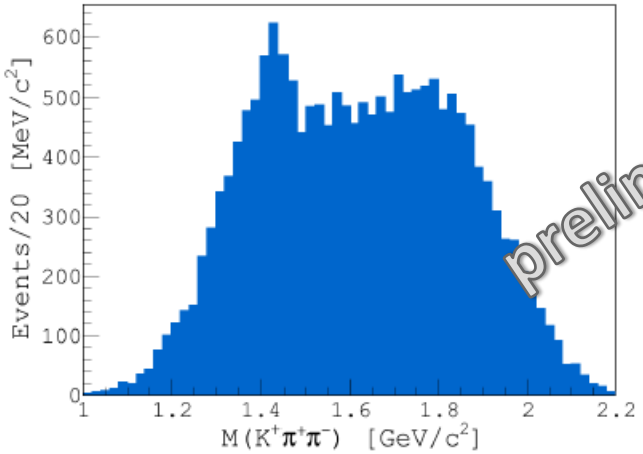
- Low mass region (1-1.5 GeV) extensively studied in past diffractive experiments: $K_1(1270)$, $K_1(1400)$, $K^*(1410)$
- Little is known in the (1.5-2) GeV mass range: $K(1630)$, $K_1(1650)$
- None of these states ever observed in photoproduction (peripheral production: low momentum transfer events)

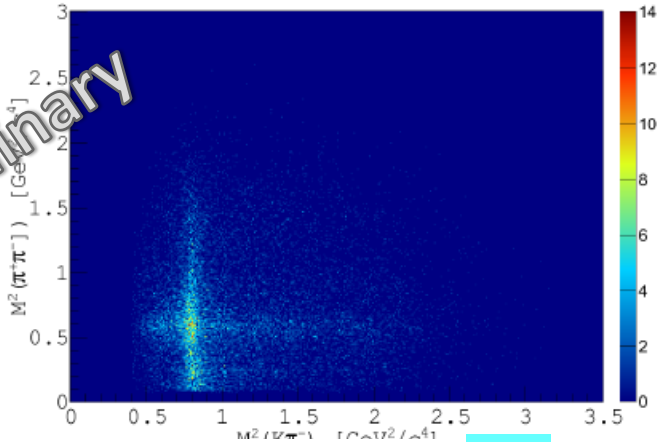
- CLAS6 g12 data set:
  - E_γ = (4.40-5.45) GeV
  - Selection of $pK^+\pi^+\pi^-\pi^-$ exclusive final state
  - $\Lambda \rightarrow \pi^- p$ selection by invariant mass
  - Background from $\Sigma^-(1385) \rightarrow \Lambda\pi^-$ decay removed
  - Background from π/K misidentification removed



The Kππ system: γp → ΛK⁺π⁺π⁻

M. Al Ghoul, FSU, 2016

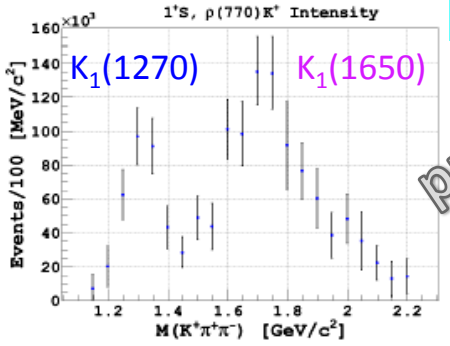


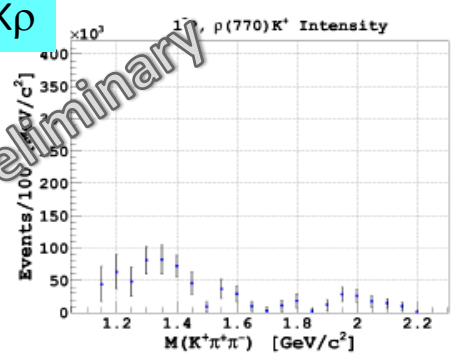


Partial wave analysis 16K evts

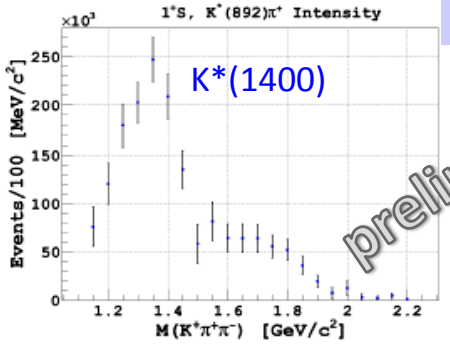
- **1^+S:**
  - →Kρ: observation of $K_1(1270)$ and $K_1(1650)$
  - →K*π: observation of $K_1(1400)$
- **1^-P:**
  - →Kρ: observation of K*(1650)?
  - →K*π: observation of K*(1410)

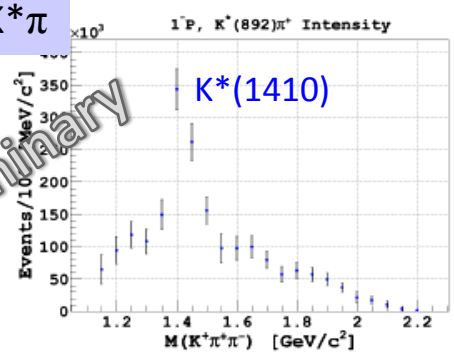
Kρ





K*π

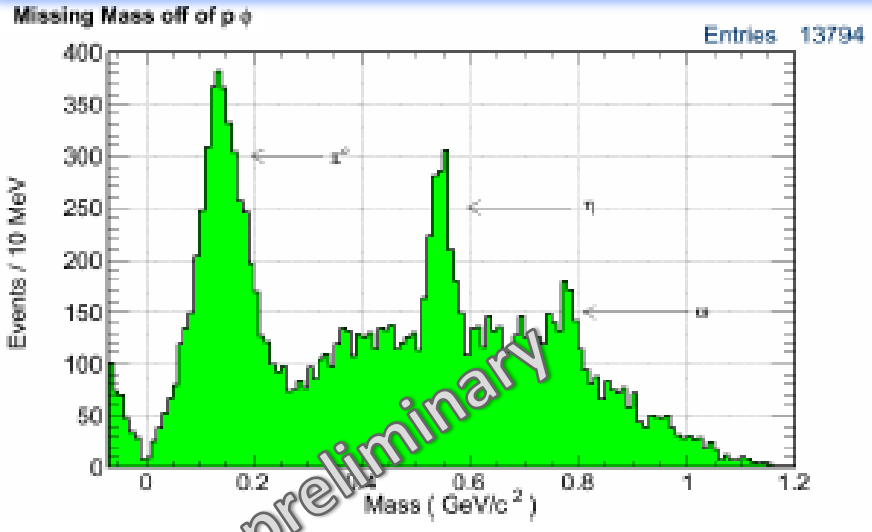


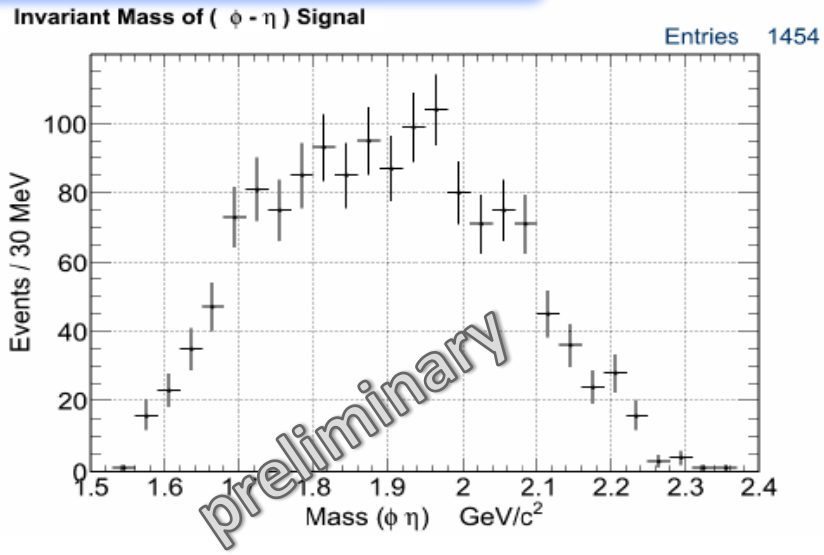


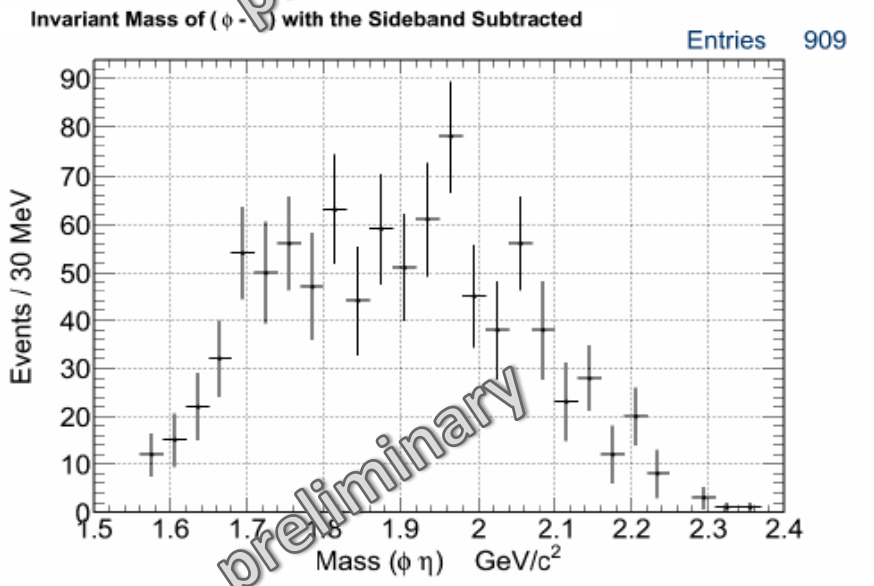
The $\eta\phi$ decay channel: $\gamma p \rightarrow pK^+K^-\eta$

Physics case: search for a 1^{-+} strangeonium hybrid

M. Saini, FSU, 2012







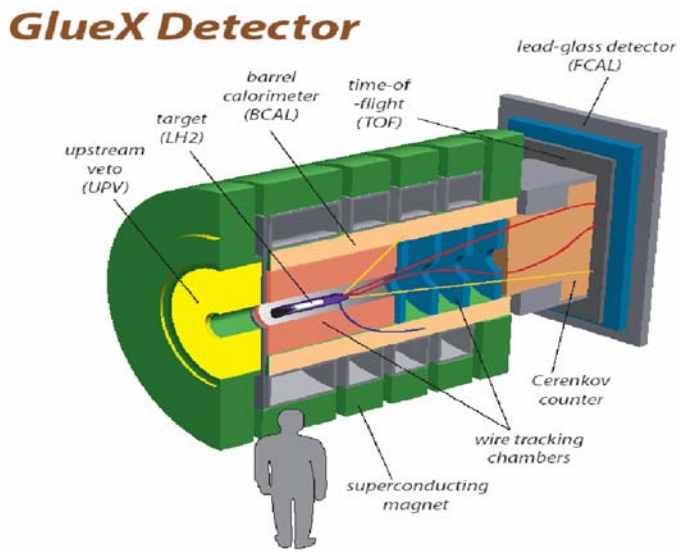
- g12 dataset analysis:
  - $\gamma p \rightarrow pK^+K^-\eta_{miss}$
  - real photons up to 5.45 GeV/c
- Largest sample collected for final state (909 events)

STRANGE MESON SPECTROSCOPY WITH VIRTUAL PHOTONS IN CLAS12

Photoproduction experiments at JLAB today

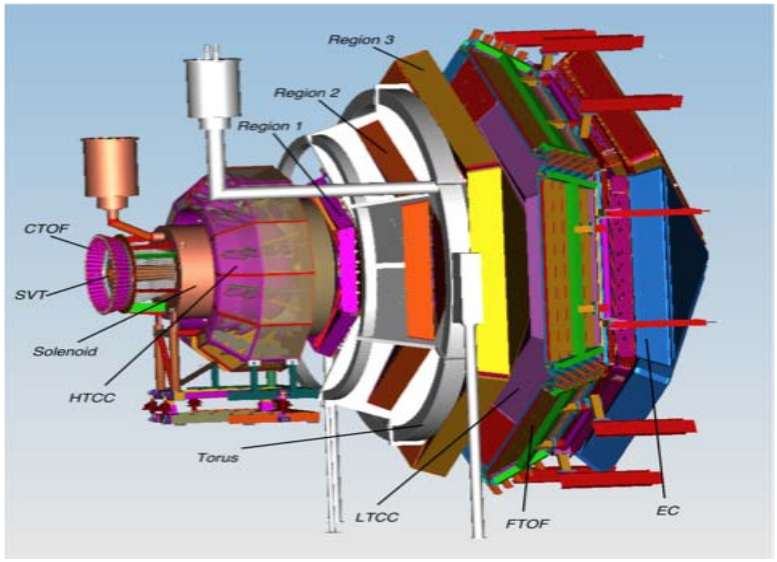
- High intensity real and virtual photon beams
- Able to measure exclusively the production reactions and the decays of the emitted particles
- Requirements:
  - Good acceptance, momentum resolution, particle id capabilities

Hall-D - GlueX Detector



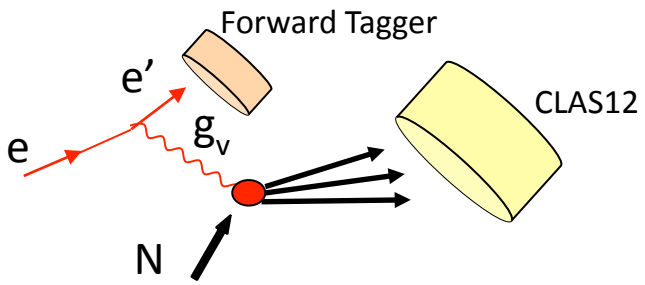
- Good hermeticity
- Uniform acceptance
- Limited resolution
- Limited pID

Hall-B - CLAS12 Detector

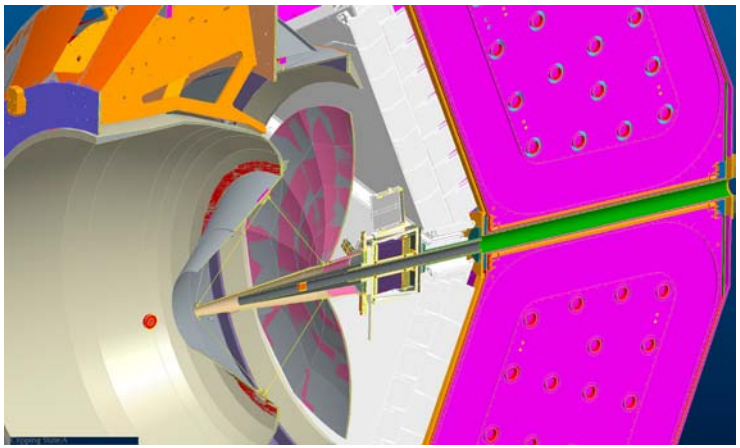


- Good resolution
- Good pID
- Resonable hermeticity
- NON-Uniform acceptance

Low Q^2 quasi-real photoproduction



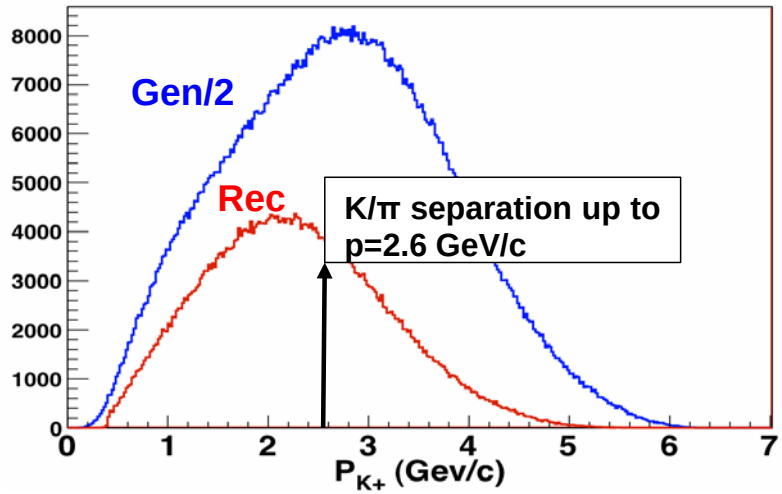
$E_{scattered}$	0.5 - 4.5 GeV
θ	2.5^o - 4.5^o
ϕ	0^o - 360^o
ν	6.5 - 10.5 GeV
Q^2	0.01 - 0.3 GeV^2 ($< Q^2 > 0.1$ GeV^2)
W	3.6 - 4.5 GeV



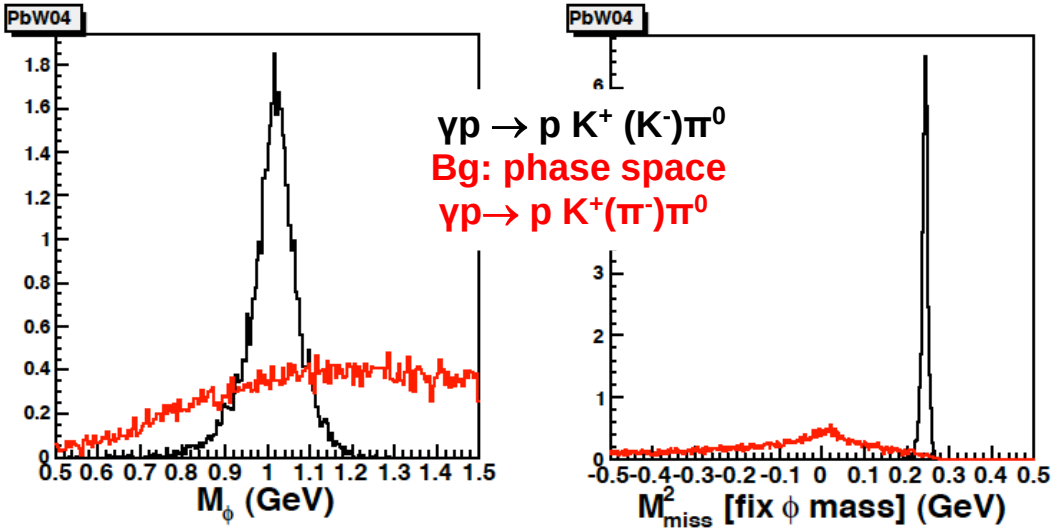
- Electron scattering at "0" deg (2.5°-4.5°)
  - **Low Q^2 virtual photon ⇒ quasi real**
- Photon tagging: detection of electron at small angles
  - High energy photons: 6.5 - 10.5 GeV
  - To be accomplished by a "Forward Tagger"

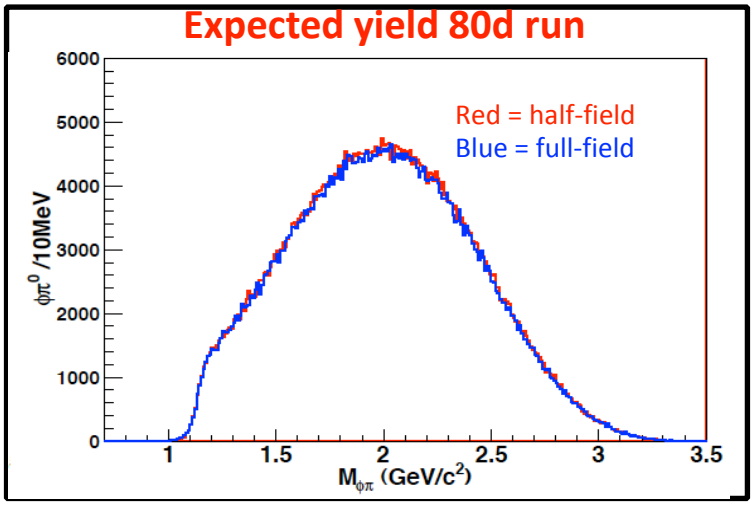
- **Quasi real photons: linearly polarized**
  - Polarization: 70%-10%, measured event by event
- **High luminosity**: $N_\gamma \sim 5\times10^8$, $L \sim 10^{35}$ $cm^{-2}s^{-1}$ on 5 cm LH_2 target
  - Thin targets can be used

Search for strange hybrids with CLAS12: $\gamma p \rightarrow p\phi\pi^0$



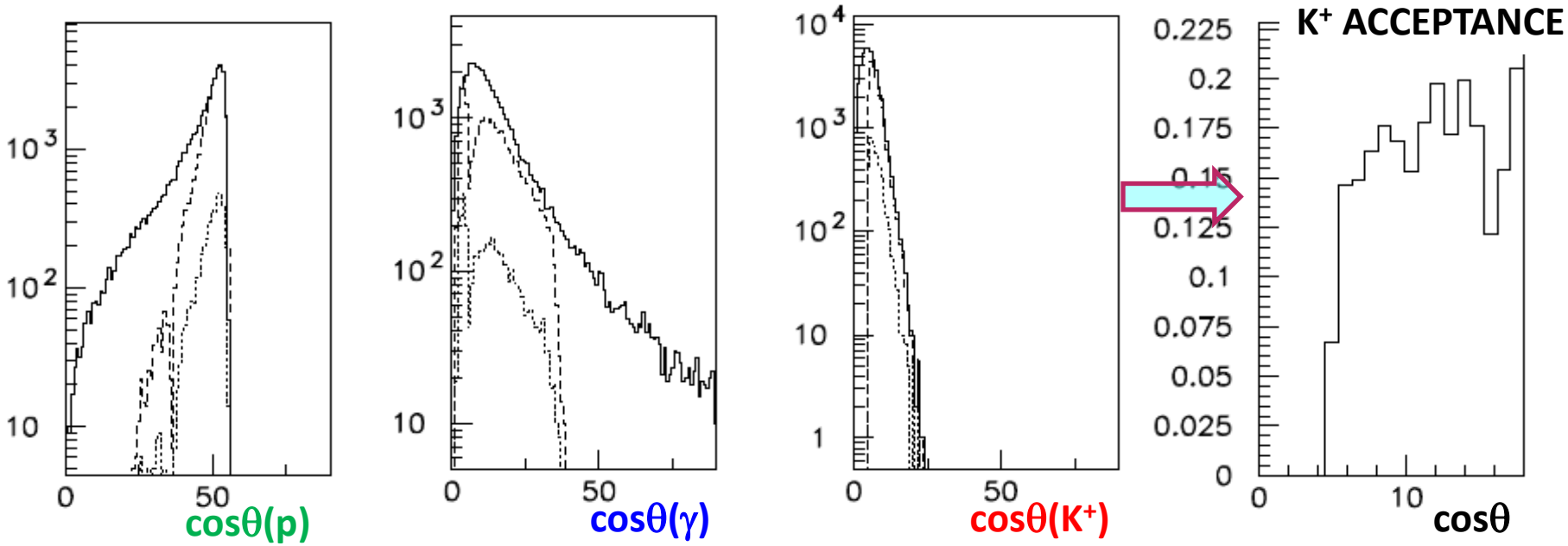
- Production cross section: 10 nb
- CLAS12 acceptance: ~10%
- Good π/K separation power required for momenta up to 2.6 GeV/c
- Simulation: **good background rejection capabilities using kin. fit and pid** of CLAS12
- Expected events in 80 data taking days @ full luminosity: ~ 3000 evts/mass bin
- Expected trigger rate: < 10 kHz





$\gamma p \rightarrow \varphi\pi^0 p$

Search for strange hybrids with CLAS12: $\gamma p \rightarrow p\phi\eta$



- Acceptance evaluation of $\gamma p \rightarrow p\phi(1850) \rightarrow p\eta\phi \rightarrow pK^+(K^-)_{miss}\gamma\gamma$ events with CLAS12 (lab emission angle distribution)
  - Good acceptance for neutrals, sizeably increased by FT calorimeter: overall acceptance > 10%
- Expected cross secton for strangeonia production: O(10 nb)
  - About half of BR(K^+K^-)

Summary and Conclusions

- Light meson spectrum with open and hidden strangeness still to be fully understood
  - Many observations in different reactions
  - Many confirmations, many disagreements
  - Too many states observed to be arranged in available CQM slots
  - Too few ordinary states (radial excitations) observed where expected

- Photoproduction reactions can be studied now with intense beams at new generation experiments. Expected to be an efficient source of:
  - **$s\bar{s}$ pairs,** due to the spin vector nature of the photon beam
    - Open and hidden strangeness (strangeonia) mesons
  - **spin-1 hybrid states**

- Photoproduction: ideal place to study benchmark decay channels
  - Promising outlook for smoking –gun decay channels: $\eta\phi$, $\eta'\phi$, $\phi\phi$, $\phi\pi$
    - $BR(\eta\phi)/BR(K^+K^-) = 0.5$
  - Limited outcome from other spectroscopy experiments in the last decade