Differential cross sections and spin density matrix elements for $\gamma p \rightarrow \phi p$ from the CLAS g11a experiment

Biplab Dey
1 Introduction and Event Selection

2 Signal-background separation

3 Acceptance Calculation, $d\sigma/dt$, and the SDME’s
   - Data-driven acceptance calculation
   - Spin structure for vector mesons
   - Results

4 Features of the data
   - Forward-angle “bump” structure
   - $g_{\phi NN}$ and strangeness content in the nucleon
   - SCHC/TCHC and Pomeron coupling

5 Summary
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5 Summary
Vector meson photo- and electro-production

- Vector mesons $V \in \{\rho, \omega, \phi, J/\psi, \ldots\}$ have played an important role in our understanding of photo-hadro reactions (QED and QCD).

- $\gamma^{(*)}$ has both $I = 0$ and $I = 1$, and same $J^{PC} = 1^{--}$ as $V$. It can fluctuate into a virtual $V$ during interactions with hadrons.

- Vector-meson dominance (Feynman), photon beam acts like a beam of polarized hadrons:

$$A_{\gamma p \rightarrow V' p'} = \sum_V \frac{e}{\gamma_V} A_{\gamma V p \rightarrow V' p'},$$

Diagram:

- $\gamma^{(*)}$
  - exch. of Reggeons, Pomeron, ...
  - $V \rightarrow V'$
  - $p \rightarrow p'$
**Special role of the $\phi(1020)$**

- In SU(3), almost pure $s\bar{s}$ state (simplest $^3S_1$ “strangeonuem”) – OZI rule suppresses quark/meson exchanges during interaction with ordinary nucleons.

- Chief attraction – very “clean” system to study gluonic exchanges; gluonic structure of the Pomeron, for example.

- Near threshold and forward angles, access to the scalar glueball $J^P = 0^+$ expected (LQCD predicts mass $\approx 1.73$ GeV).
**Special role of the $\phi(1020)$**

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Wide interest in this channel, but very little world data!
**Charged- and neutral-mode topologies**

- $\phi$ predominantly decays to two kaons:
  - $\phi \rightarrow K^+K^-$ is the “charged-mode” ($bf = 0.491$)
  - $\phi \rightarrow K^0_SK^0_L$ is the “neutral-mode” ($bf = 0.34$).

- Charged-mode: kinematic fit to $\gamma p \rightarrow \phi p \rightarrow K^+(K^-)p$.

- Neutral-mode: kinematic fit to $\gamma p \rightarrow \phi p \rightarrow K^0_S(K^0_L)p \rightarrow \pi^+\pi^-(K^0_L)p$.

- Event selection: 10% confidence level cut from kinematic fit, timing cuts for particle-identification.

- $K^0_S$ selection cut (neutral-mode): $M(\pi^+\pi^-) \in [0.488, 0.508]$ GeV.
Charged-mode and $\phi p - K^+ \Lambda(1520)$ overlap

- Phase-space overlap with $\gamma p \rightarrow K^+ \Lambda(1520) \rightarrow K^+ K^- p$ between 2 and 2.2 GeV in $\sqrt{s}$.
- Hard $|M(pK^-) - 1.52| < 0.015$ GeV cut
- Only for the charged-mode (important!).
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   - Results

4. **Features of the data**
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5. **Summary**
**Lineshape issue**

- The basic problem is that the $\phi$ has non-negligible width ($\sim 4$ MeV) and a mass close to the $KK$ threshold
  - What is the signal lineshape for a channel opening near the threshold?
  - What are the background (PID) lineshapes + “other” (eg. $f_0(980)$) channels opening near the threshold?
  - Side-band subtraction ineffective since nothing on the low-mass side

- Having a high statistics dataset is awesome, but greater demand on reducing systematic uncertainties

- With $g_{11a}$ statistics, we are very sensitive to lineshape systematics!
YIELD EXTRACTION FOR THIS ANALYSIS

- Start with a phenomenological ansatz – mass-dependent non-rel. BW (true lineshape) convoluted with Gaussian (detector resolution).

- Blatt-Weisskopf barrier term gives typical asymmetric lineshape with long tail. Gaussian parameters kept floating.

- Neutral is a 3-track \((p\pi^+\pi^- (K_L))\) topology while charged is 2-track \((pK^+(K^-))\) topology. Resolution, and thereby lineshapes are inherently different.
Yield extraction for this analysis (cntd)

- Keep the *functional form* for signal fixed, and keep the local background shape completely floating.

- Perform independent fits in small phase-space regions.

- Very different from employing global background “template” shapes!
**SAMPLE BACKGROUND SEPARATION FROM CLAS g6a**

- Cumulative $E_\gamma \in [3.3, 3.6]$ GeV, $\sim 1000 \phi$-skimmed events
Sample fit-quality checks, this analysis

- For $\sqrt{s} \in [2.12, 2.15]$ GeV, $|\cos_{\text{c.m.}}| < 0.33$ (mid-angles), charged-mode.

- $\zeta$ and $\varphi$ are the $\phi \rightarrow KK$ breakup angles.

- Enough statistics to look at small ($\sqrt{s}, \cos \theta_{\text{c.m.}}, \zeta, \varphi$) regions.

- Note the strong phase-space dependence of background.
Caveats I

- At forward-most angles, lots of statistics, but hardly any events below $\phi$ peak.

- Impossible to do side-band subtraction if a peak arises right at the threshold

$$\sqrt{s} \in [2.59, 2.63] \text{ GeV}, \cos_{c.m}^\phi = 0.8 \text{ and } 0.9$$

- We currently quote the charged/neutral difference as the systematic uncertainty, but inputs from theory will help here.

- Affects Pomeron characterization – one of our chief goals
Caveats II – S-P wave interference

- $S$-wave ($f_0$) exists and has to interfere with the $P$-wave ($\phi$)

- $KK$ angular distribution bears this out – FB asymmetry flips sign at $M(KK) = 1.019$ GeV

- Our background method puts the interference to zero “by hand”

- $g_{11a}$ is an excellent resource to investigate this
Final $\phi$ data yields and binning

- **Charged-mode:** $\sim 0.475$ million $\phi$ events. $\sqrt{s} = 10$-MeV-wide energy bins.

- **Neutral-mode:** $\sim 0.101$ million $\phi$ events. $\sqrt{s} \approx 30$-MeV-wide energy bins.

- Angular binning is always $0.1$ in the center-of-mass production angle, $\cos \theta^{\phi}_{c.m.}$.
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5 SUMMARY
Acceptance Calculation

100 million flat phase-space “Raw” Monte Carlo events generated for each topology and passed thru GSIM to give a set of “Accepted” (Acc) Monte Carlo events.

Acc. MC underwent same set of analysis cuts as actual Data.

Expand the scattering amplitude using a large number (almost complete basis) of $s$-channel $J^P$ waves:

$$\mathcal{M}(\sqrt{s}, \cos \theta_{c.m.}) \sim \sum_{J^P} \alpha_{MP,LS}^{J^P} \mathcal{A}_{\gamma p \rightarrow J^P \rightarrow \phi p, MP, LS}^{\gamma p \rightarrow J^P \rightarrow \phi p, MP, LS}(\sqrt{s}, \cos \theta_{c.m.})$$

Perform a unbinned extended maximum likelihood partial-wave analysis (PWA) fit independently in each $\sqrt{s}$-bin.
Charged-mode, center-of-mass production-angle:

$$\sqrt{s} = 2.155 \text{ GeV}$$

- PWA-fit weighted Monte Carlo matched the Data in all distributions for both modes.
Acceptance from PWA-fit results

- PWA-fit-weighted acceptance is: \( \eta_{wtd.} = \frac{\left( \sum_{i}^{N_{acc}} l_{i} \right)}{\left( \sum_{j}^{N_{raw}} l_{j} \right)} \) where

  \[
l_{i} = \sum_{m_{incoh.}} \left| \sum_{m_{coh.}} M_{m_{coh.},m_{incoh.}} \right|^2.
\]

- Note that this PWA-fit result is \emph{not} to be interpreted as \emph{physics} (in terms of resonances). We have simply expanded the production amplitude in a semi-complete basis of \( s \)-channel \( J^{P} \) waves in order to best fit the data.

- Applied in previous CLAS \( \omega p \) (PRC 80, 06528 (2009)), \( \eta p/\eta' p \) (PRC 80, 045213, (2009)), \( K^+\Lambda \) (PRC 81, 025201 (2010)) and \( K^+\Sigma^0 \) (PRC 82, 025202 (2010)) analyses, with excellent results.
Structure of Spin Information Content

- Consider the general case $\vec{\gamma} \vec{p} \rightarrow \vec{V} \vec{p}'$. There are $2 \times 2 \times 3 \times 2 = 24$ complex amplitudes $A$ tagged by helicities.

- Parity halves this to 12 independent $A$'s, $12 \times 12 = 144$ bilinears.

- 290 single-, double- triple- and quadruple correlations, but lots of redundancies as well!

- What is the least number of polarizations observables to make a complete measurement?
  - Recall, answer is 7 for the pseudo-scalar case ($\vec{\gamma} \vec{p} \rightarrow K^+ \bar{\Lambda}$).
Consider the general case $\bar{\gamma}\vec{p} \rightarrow \vec{V}\vec{p}'$. There are $2 \times 2 \times 3 \times 2 = 24$ complex amplitudes $A$ tagged by helicities.

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- Recall, answer is 7 for the pseudo-scalar case ($\bar{\gamma}\vec{p} \rightarrow K^+\bar{\Lambda}$).
- For vector-mesons, still an open question.
Spin Density Matrix Elements (SDME’s)

- Average over the (unobserved) $p$ and $p'$ spins and look at $\gamma p \rightarrow \nabla p'$. Transfer of spin information from initial to final vector-particle.

- Spin info encoded in the density matrix. Massive $V$ has 8 real elements:

$$\rho = \frac{1}{3} \left[ I + \frac{3}{2} \vec{S} \cdot \vec{P} + \sqrt{3} \tau \cdot T \right]$$

- $\vec{S}$ is the pure spin-1 operator and $\vec{P}$ is the vector polarization. $\tau$ is a tensor operator containing correlations of the type $S_i S_i$. $T$ is the tensor polarization.

- For $\phi \rightarrow KK$, $\rho \rightarrow \pi\pi$, $\omega \rightarrow \pi\pi\pi$: $\vec{P}$ fully inaccessible and only 3 out of 5 $T$ elements available in $\rho^V$. 
SDME’s cntd.

- General structure:
  \[
  \rho^V_{mVm'} = \left( \sum_{m_pm_{\gamma}m'_{\gamma}} A_{mVm_p'm_i m_{\gamma}} (\rho^\gamma)_{m_{\gamma}m'_{\gamma}} A^*_{mVm_p'm_p'm_{\gamma}} \right) / \text{norm}
  \]

- If \( P^S \) is the Stokes’ vector for beam, \( \rho^V = \rho^0 + P^S_i \rho^i \)
  - \( \rho^0 \) for unpolarized beam (\( \Rightarrow g11a \), 3 elements).
  - \( \rho^1 \) and \( \rho^2 \) for linearly polarized beam (\( g8 \), 6 elements).
  - \( \rho^3 \) for circularly polarized beam (\( g1c \), 3 elements).

- Note: \( \rho \)'s are not Lorentz invariants, choice of frame “inspired by” production mechanism under study (important!)
\( \rho_{mm'}^0 \) ELEMENTS

- Spin quantitation axis as the beam dirn. \( \hat{z}_{CM} \) (Adair frame).

- \( \phi \) rest frame decay angles: \( \theta_{Ad} \) and \( \varphi_{Ad} \).

Conventional Schilling’s method: fit to an \( \phi \rightarrow KK \) decay angular intensity distribution:

\[
I(\sqrt{s}, \cos \theta^{c.m.}) \sim \frac{1}{2} (1 - \rho^{00}) + \frac{1}{2} (3 \rho^{00} - 1) \cos^2 \theta_{Ad} - \rho^{1-1}_1 \sin^2 \theta_{Ad} \cos 2 \varphi_{Ad} \\
- \sqrt{2} \text{Re} \rho^{10}_0 \sin 2 \theta_{Ad} \cos \varphi_{Ad}
\]

Equivalently, direct construction of the \( \phi \) density matrix using PWA fit results:

\[
\rho_{mm'}^0 = \frac{\sum A^m A^{m'}*}{\sum |A^m|^2 + |A^{m'}|^2},
\]

where \( m, m' \) are \( \phi \) spin-projections and incoherent sum is over the spins of \( \gamma, p, \) and \( p' \).
Acceptance Calculation, $d\sigma/dt$, and the SDME's

$\sqrt{s}$-bin-wise $d\sigma/d\cos\theta^c.m.$ and Adair frame SDME's

**Charged-mode:**

- $10$-MeV-wide, $87$ $\sqrt{s}$ bins
- $1530$ kinematic points

**Neutral-mode:**

- $30$-MeV-wide, $26$ $\sqrt{s}$ bins
- $461$ kinematic points
Angular-binned \(d\sigma/dt\) results

Backward-angles

\[-0.55 < \cos\theta_{\text{c.m.}} < -0.45\]

\(\sqrt{s}\) (GeV)

\(d\sigma/dt\) (\(\mu\text{b}/\text{GeV}^2\))

- Charged-mode
- Neutral-mode
Angular-binned $d\sigma/dt$ results

Mid-angles

$0.05 < \cos\theta_{c.m.} < 0.15$

- Charged-mode
- Neutral-mode
Angular-binned \( \frac{d\sigma}{dt} \) results

Forward-angles

\( 0.85 < \cos \theta_{c.m.} < 0.95 \)

- Charged-mode
- Neutral-mode

\( \sqrt{s} \) (GeV)

\( \frac{d\sigma}{dt} \) (\( \mu b/GeV^2 \))
Angular-binned SDME results (charged-mode)
Comparison with LEPS (charged-mode)

- Previous SDME measurements: *highly* statistics limited, wide energy bins.

- Often averaged over angular variables in Schilling’s intensity expression, *without* proper acceptance correction.

- Latest forward-angle LEPS results (Chang PRC 82, 015205 (2010)) incorporates several improvements and are in overall *good agreement* with us.

Gottfried-Jackson frame:

<table>
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<tr>
<th>E_γ = 1.87 GeV</th>
<th>E_γ = 2.07 GeV</th>
<th>E_γ = 2.27 GeV</th>
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<td>-0.2 0 0.2 0.4</td>
<td>-0.5 0 0.5 1</td>
</tr>
</tbody>
</table>

- CLAS (2011)  
- LEPS (2010)
In all ...

- Roughly **8000 individual data points** for $\phi$

- Together with the published $g_{11a} \omega$ (PRC 80, 065208 (2009)) results, the most **extensive** world-dataset on **vector mesons**
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Features of the data

Forward-angle “bump” structure

$\phi - \Lambda(1520)$ OVERLAP

- "Classic" Dalitz problem involving multiple channels (see Kei Moriya's CLAS g11a analysis)
“Classic” Dalitz problem involving multiple channels (see Kei Moriya’s CLAS $g_{11a}$ analysis), but overlaps are $E_\gamma$ dependent.

For $\phi$-$\Lambda(1520)$, need to look at only the narrow $E_\gamma \sim 2.2$ GeV region (if statistics can afford it).
What about on the $\Lambda(1520)$ side?

- Compare $\Sigma^+\pi^-$ and $pK^-$ decay modes of $\Lambda(1520)$.
- Note *strong gradient* for $pK^-$ around $E_\gamma \sim 2.2$ GeV, $t \rightarrow t_{min}$

Currently, the $\Sigma^+\pi^-$ binning is too wide to make a statement, but ...
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Currently, the $\Sigma^+\pi^-$ binning is too wide to make a statement, but ...

- Hard to believe $\Sigma^+\pi^-$ will track $pK^-$ with finer binning $\Rightarrow$ “real” physics issue here
Features of the data  
Forward-angle “bump” structure

**Resonance Interpretation – \( \phi(1020) \) Side**

- Work by Kiswandhi *et al.*, arXiv:1112.6105v2: fits to forward-angle LEPS data shows prominence of \( J^P = \frac{3}{2}^\pm \), mass around 2080 MeV.

![Graph showing resonance interpretation](image)

\[ \cos \theta_\text{c.m.} = 0.9 \]
Work by Kiswandhi et al., arXiv:1112.6105v2: fits to forward-angle LEPS data shows prominence of $J^P = \frac{3}{2}^\pm$, mass around 2080 MeV.

But “bump” only at forward-angles. With a single resonance, impossible to get a structure only at forward-angles. Even a set of resonances must be highly tuned to do this.

New CLAS data: resonance(s) interpretation looks unlikely
Charged/neutral comparisons

After a lot of effort, charged and neutral mostly agree now,

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<th>√s (GeV)</th>
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<th>2.4</th>
<th>2.6</th>
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<td>ρ</td>
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<td>φ</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>0.9</td>
</tr>
</tbody>
</table>
After a lot of effort, charged and neutral mostly agree now, except at forward-angles, especially for $\sqrt{s} \in [2, 2.2]$ GeV:

- **Pomeron slope**

- $\phi$-$\Lambda(1520)$ coupled-channel analyses (Ozaki et al., PRC 80, 035201 (2009)), an interesting prospect but we need $\Lambda(1520)$ data of comparative binning as well.
In SU(3), the $\phi$-$\omega$ mixing angle is $\theta_V \approx 35^\circ$.

Experimental deviation $\Delta \theta_V \approx 4^\circ$, $g_{\phi NN} = -\tan(\Delta \theta_V) \chi_{OZI} g_{\omega NN}$, where $\chi_{OZI}$ is the OZI evading parameter denoting strangeness content in the nucleon.

CLAS 2000 $g6a$ data first showed a $u$-channel rise (large $|t|$) for $\phi \Rightarrow$ larger values of $g_{\phi NN}$

CLAS 2011 $g11a$ confirms this. Coupled channel $\phi$-$\omega$ fits can shed light on strangeness in the nucleon.
Helicity conservation in $\gamma p \rightarrow Vp$

- $\rho_{00}^0 \sim |A_{m_V=0, m_\gamma=1}|^2 + |A_{m_V=0, m_\gamma=-1}|^2$ measures spin flip. But, in which frame?
Helicity conservation in $\gamma p \rightarrow Vp$

- $\rho_{00}^0 \sim |A_{m_V=0,m_\gamma=1}|^2 + |A_{m_V=0,m_\gamma=-1}|^2$ measures spin flip. But, in which frame? Depends on mechanism of interest.

- Pomeron ($IP$) – “universal”, exchange of vacuum quantum numbers ($?^{++}$), spin-$1$ energy-behavior (Regge trajectory $\alpha(0) \sim 1$).
Helicity conservation in $\gamma p \rightarrow Vp$

- $\rho_{00}^0 \sim |A_{m_V=0,m_\gamma=1}|^2 + |A_{m_V=0,m_\gamma=-1}|^2$ measures spin flip. But, in which frame? Depends on mechanism of interest.

- Pomeron ($IP$) – “universal”, exchange of vacuum quantum numbers (??++), spin-1 energy-behavior (Regge trajectory $\alpha(0) \sim 1$).

- If coupling as $0^{++}$, expect $\rho_{00}^0 = 0$ in GJ ($t$-channel) frame. Not seen in data. TCHC is broken.

- Instead, high-energy data (ZEUS, SLAC, etc.) show $\rho_{00}^0 \approx 0$ in Hel ($s$-channel) frame, SCHC is observed.
**How does the Pomeron couple to hadrons?**

- Odd that a $t$-channel process preserves helicity in the $s$-channel. DL $\mathcal{I}P$ is isoscalar $1^{++}$ photon ($\gamma^{\mu}$ coupling) and predicts SCHC.

- Phenomenological explanation by Gilman et al. (PLB 31, 387 (1970)). However, no fundamental reason for SCHC.
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- New CLAS results show $\rho_{00}^0 \neq 0$: both TCHC and SCHC violation at all angles (both $\phi$ and $\omega$ channels, in fact).

- We need to better understand the structure of the $IPqq$ coupling.
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First ever extensive world data for the $\phi$ channel. Corresponding $\omega$ results already published.

Detailed $d\sigma/dt$ and $^{0}_{\rho_{mm'}}$: coverage from near threshold to $\sqrt{s} = 2.84$ GeV and $-0.85 \leq \cos \theta^{\phi}_{c.m.} \leq 0.95$.

Access to both charged- and neutral-modes results is a very useful tool.

“Structure” around $\sqrt{s} \sim 2.1$ GeV needs careful study. Present results will provide detailed information towards this.

Lots of interesting features visible in the new data – SCHC violation, finite value of $g^{NN}_{\phi}$, Pomeron slope etc.

Full partial-wave analysis on both $\phi$ and $\omega$. CLAS $\Lambda(1520)$ results from the same dataset soon to be available as well for coupled-channel analysis.
**Event-selection: Timing cuts**

- 2-D calculated mass cut on $p, K^+$ (charged-mode)

- 2-D $\Delta$ time-of-flight ($tof_{\text{meas}} - tof_{\text{calc}}$) cut on $p, \pi^+$ (neutral-mode)
Event-selection contd.

- $K_S^0$ selection cut (neutral-mode): $0.488 \text{ GeV} \leq M(\pi^+, \pi^-) \leq 0.508 \text{ GeV}$. 

![Graph of invariant mass vs missing mass off p](image)

Missing Mass Off p (GeV)

- accepted, rejected
**Lineshape**

- $\phi$ width is $\Gamma_0 \approx 4$ MeV, however, its mass being so close to the $KK$ threshold ($\approx 0.99$ GeV) leads to an unsymmetric lineshape.

- All previous world data relied on a Gaussian $\phi$ lineshape for yield extraction fits.

- We've tried to employ a better approximation by taking a mass-dependent width:

$$\Gamma(m) = \Gamma_0 \left( \frac{q}{q_0} \right)^{2L+1} \left( \frac{m}{m_0} \right) \left( \frac{B_0}{B} \right)$$

- $L = 1$ for $P$-wave $\phi \rightarrow KK$ decay.

- Break-up momentum $q(m) = \sqrt{m^2 - m_K^2}/2$ for a $\phi$ mass $m$.

- Barrier-factor $B_{L=1} = \sqrt{2z/(1+z)}$ with $z = q/d$, $d \sim 1$ fm ($\approx 0.1973$ GeV).

- Subscript 0 denotes evaluation at the $\phi$ mean mass $m_0 = 1.01946$ GeV.

- Final signal-function in background fits: Voigtian with Breit-Wigner width taken as $\Gamma(m)$.
FIG. 1. (a) Missing mass distribution for the $p(\gamma, K^+K^-)X$ reaction in $KK$ mode. (b) Missing mass distribution for the $p(\gamma, K^0\bar{p})X$ reaction in $Kp$ mode. (c) and (d) are the $K^+K^-$ invariant mass distributions after the cut on the missing mass for $KK$ and $Kp$ modes, respectively. The hatched histograms are the simulated background.
**Fig. 3.** $\Phi$ separation from the background in the $K^+K^-$ mass spectrum.

**Fig. 4.** Contributions of phase space, $\Lambda(1520)$ and $\Phi$ production to the $K^+K^-$ mass spectrum for photon energies between 2.1 and 2.4 GeV.
Charged-mode

$\sqrt{s} = 2.155$ GeV

Data
Acc MC (unweighted)
Acc MC (weighted)

$\sqrt{s} = 2.155$ GeV

Data
Acc MC (unweighted)
Acc MC (weighted)
Neutral-mode

\[ \sqrt{s} = 2.135 \text{ GeV} \]
Comparison between PWA and Schilling’s methods

\[ \rho_{00}^0 (PWA) \quad \rho_{00}^0 (Schil) \quad \rho_{1-1}^0 (PWA) \quad \rho_{1-1}^0 (Schil) \quad \rho_{10}^0 (PWA) \quad \rho_{10}^0 (Schil) \]

\[ \sqrt{s} = 2.105 \text{ GeV} \quad \sqrt{s} = 2.325 \text{ GeV} \quad \sqrt{s} = 2.615 \text{ GeV} \]

\[ \cos \theta_{c.m.} \]
Ozaki et al. (PRC 80, 035201 (2009)): $K\Lambda(1520)$ and $\phi p$ channels couple:
The $\sqrt{s} \approx 2.1$ GeV “structure” (contd.)

$\gamma p \rightarrow K^+ \Lambda(1520)$:

Work of R. De Vita et al.
Yield extraction is complicated since $\phi$ is so close to $KK$ threshold. Physics model in MC could also make a difference, since forward-angle “bump” around $\sqrt{s} \sim 2.1$ GeV shows that simple diffractive Pomeron phenomenology is no longer valid.
**Comparison with Daresbury ’84 and CLAS ’00**

- $E_\gamma = 3.3$ GeV

![Graph](image1.png)

- $E_\gamma = 3.6$ GeV

![Graph](image2.png)

- $E_\gamma$ bin-widths were 1 GeV (Daresbury-84) and 600 MeV (CLAS-00). Systematics of background subtraction/yield extraction in older $\phi$ results seem questionable.

- CLAS-2000 backward-angle rise confirmed by CLAS-2010: non-negligible $g_{\phi NN}$ for $u$-channel exchange at high $\sqrt{s}$. 

- Biplab Dey (UCR/CMU)

2012 JLab Thesis Prize June 6th, 2012
$R_{\phi/\omega}$ AND FLAVOR-INDEPENDENCE


\[ R_{\phi/\omega} \text{ as a function of } (\cos\theta_{c.m.}, \sqrt{s}): \]

- $R_{\phi/\omega}$ is generally small (*OZI*-suppression).
- In the diffractive limit where Pomeron dominates, $R_{\phi/\omega} \sim O(1)$. Qualitatively agrees with Donnachie-Landshoff model: quark-quark-Pomeron coupling $\sim \beta_u \beta_s \bar{u}' \gamma_\mu u$. Couplings $\beta$ almost flavor-independent.