Differential Cross Section for $\gamma d \rightarrow \omega d$ using CLAS at Jefferson Lab

Taya Chetry
Ken Hicks
Ohio University

APS April Meeting
15 April 2018
Goal

- $\pi-N$ scattering provides access to fundamental questions
  - Baryon spectrum of QCD
  - Chiral dynamics of QCD
  - Study of isospin violation
  - Internal structure of the nucleon

- Just imagine the possibilities with other mesons, say a vector meson!

- Experimental challenges:
  - Short lifetimes $\sim 10^{23}$ s
  - Vector meson beams cannot be produced in a lab.

- Extract $\omega N$ cross section
  - LQCD ($\pi\pi$ - scattering)
  - Physics Models
Goal

- **π-N** scattering provides access to fundamental questions
  - Baryon spectrum of QCD
  - Chiral dynamics of QCD
  - Study of isospin violation
  - Internal structure of the nucleon

- Just imagine the possibilities with other mesons, say a vector meson!

- **Experimental challenges:**
  - Short lifetimes \( \sim 10^{23} \text{s} \)
  - Vector meson beams cannot be produced in a lab.

- **Extract** \( \omega N \) cross section
  - LQCD (\( \pi\pi \) - scattering: \( \rho \) resonance)
  - Physics Models

**Motivation**

- \( \sqrt{s} = 783(2)-(i/2)90(8) \text{ MeV} \)
- \( \sqrt{s} = 853(2)-(i/2)12.4(6) \text{ MeV} \)
- \( m_\pi = 391 \text{ MeV} \)
- \( m_\pi = 236 \text{ MeV} \)

\[ I = 1 \]

\[ t(s) = \frac{1}{\rho(s)} \frac{\sqrt{8} \Gamma(s)}{m_R^2 - s - i \sqrt{8} \Gamma(s)} \]

Energy dependent width:
\[ \Gamma(s) = \frac{g_R^2 k^3}{6\pi s} \]

Parameters:
\[ m_R = 0.13171(36)(6) \cdot a_i^{-1} \begin{bmatrix} 1 & 0.04 \\ 1 & 1 \end{bmatrix} \]
\[ g_R = 5.691(70)(25) \]
**Vector Meson Dominance**

**Theory**

Phenomenologically:

\[
\frac{d\sigma}{dt} \propto e^{-bt}
\]

- Deuteron acts as an Isospin filter for \( I = 0 \) only.
- Vector Meson off deuterium simplifies theoretical interpretations of the data.

- Two processes:
  - \( \gamma N \rightarrow \omega N \)
  - \( \omega N \rightarrow \omega N \)

- Slope parameters:
  - \( b_{\gamma N} \) and \( b_{\omega N} \)

- Ratio of Re(A) and Im(A):
  - \( \alpha_{\gamma N} \) and \( \alpha_{\omega N} \)
CLAS @ JLab

- Jefferson Lab: Newport News, VA;
- CEBAF: accelerated electrons up to 6 GeV;
- Experimental Halls: A, B, C and D;
- Hall B: electron or photon beam;

- Data from $g10$ run period (Spring, 2004);
- Target: 24 cm long liquid deuterium at $Z = -25$ cm;
- Electron beam energy 3.778 GeV;
Vector Mesons off Deuteron in CLAS

Motivation

Highlights:
- $g_{10}$ data
- A rescattering model is used.
- Within VMD, data is consistent with $\sigma_{\phi N}$ at about 10 mb.
- In the model, larger $\sigma_{\phi N}$ is possible by taking $b_{\gamma N} > b_{\phi N}$
Previous results

Limited World Data

- Mostly from Bubble Chamber experiments.
- Missing double scattering effect.

| Experiment                   | Energy | Target     | Measured quantities | $|T|^2$ (mb/GeV$^2$) | $\sigma_{\omega N}$ (mb) | $\gamma^2/4\pi$ | Assumptions | Comments                  |
|------------------------------|--------|------------|---------------------|----------------------|-------------------------|----------------|-------------|----------------------------|
| SLAC–Berkeley Ballam et al. (1973) | 9.3    | H          | $\frac{d\sigma}{dt}|_{\omega}$ | 11.4 ± 2.1           | 25.3 ± 4.7             | $\gamma^2/4\pi$ | $\alpha_{\omega N} = 0.27$ | No correction for $A_2$ exchange |
| Rochester Ballam et al. (1976) | 8.3    | D, Be, C, Al, Cu, Pb | $\frac{d\sigma}{dt}|_{t=0}$ | 7.4 ± 0.5           | 25.4 ± 2.7             | 30.4 ± 4.8 | $\alpha_{\omega N} = -0.24$ | Corrected for $A_2$ exchange |
| Tel Aviv Alexander et al. (1975) | 7.5    | D          | $\frac{d\sigma}{dt}|_{\omega}$ | 11.2 ± 2.5           | 25.7 ± 6.5             | $\alpha_{\omega N} = 0.27$ | $\alpha_{\omega N} = -0.24$ |
| Tel Aviv Alexander et al. (1975) | 7.5    | D          | $\frac{d\sigma}{dt}|_{p,\omega}$ | ...                 | ...                      | 15.8 ± 3.8 | $\gamma^2/\gamma^2 = \frac{d\sigma}{dt}|_{t=0} / \frac{d\sigma}{dt}|_{\omega}$ | The rho cross section was anomalously low |
| Pisa–Bonn Braccini et al. (1970) | 5.7    | C, Al, Zn, Ta, Ag, Pb | $\frac{d\sigma}{dt}|_{\omega}$ | 13.5 ± 3.3           | 27.0 ± 6.5             | 22.0 ± 5.4 | $\alpha_{\omega N} = -0.3$ | Poor $t$ resolution and uncertainties in background correction |

Differential Cross Section for $\gamma d \rightarrow \omega d$

T. Chetry, Ohio University

APS April Meeting 2018
## Previous results

### Limited World Data
- Best data till date is from the Weizman Institute of Science
- $E_γ = 4.3$ GeV and $|t| < 0.2$ GeV$^2/c^2$

| Experiment          | Energy | Target | Measured quantities | $|T|^2$ (µb/GeV$^2$) | $σ_ω$ (mb) | $P_ω/4π$ | Assumptions | Comments |
|---------------------|--------|--------|---------------------|----------------------|------------|----------|-------------|----------|
| Weizmann Eizensberg et al. (1970) | 4.3    | D      | $\frac{dσ}{dt}_ω$  | 18.5 ± 4.5           | ...        | 15.6 ± 3.8 | $σ_ω$ = 27 mb, $α_ω$ = -0.24 |          |
| Weizmann Eizensberg et al. (1970) | 4.3    | D      | $\frac{dσ}{dt}_ω$  | ...                 | ...        | 14.6 ± 1.2 | $P_ω/P_ω^*$ = $\frac{dσ}{dt}_ω$ / $\frac{dσ}{dt}_ω^*$ |          |
|                      |        |        | $\frac{dσ}{dt}_ω$ | $6.7^{+4.1}_{-2.3}$ |            |          | $P_ω/4π$ = 2.18 |          |
| Harvard–CEA Gladding et al. (1973) | 4.2    | H      | $\frac{dσ}{dt}_ω$  | 16.8 ± 2.8           | ...        | 14.6 ± 1.2 | $P_ω/P_ω^*$ = $\frac{dσ}{dt}_ω$ / $\frac{dσ}{dt}_ω^*$ | No correction for OPE or $A_2$ exchange |
|                      |        |        | $\frac{dσ}{dt}_ω$ | $7.7 ± 0.12$         |            |          | $P_ω/4π$ = 2.18 |          |
| ABHIM Benz et al. (1974) | 1.3−5.3| D      | $σ_ω$              | 15.7 ± 2.7           | ...        | 14.5 ± 5.4 | $P_ω/P_ω^*$ = $\frac{σ(d \rightarrow ωd)}{σ(d \rightarrow ωd)}$ | Poor-resolution experiment |
|                      |        |        | $\frac{dσ}{dt}_ω$ | $7.2^{+3.1}_{-1.8}$ |            |          | $P_ω/4π$ = 2.18 |          |
| Lancaster Morris et al. (1978) | 3.9    | D      | $\frac{dσ}{dt}_ω$  | 15.3 ± 6.4           | ...        | 14.5 ± 5.4 | $P_ω/P_ω^*$ = $\frac{σ(d \rightarrow ωd)}{σ(d \rightarrow ωd)}$ | Poor-resolution experiment |
|                      |        |        | $\frac{dσ}{dt}_ω$ | 18.4 ± 1.8           |            |          | $P_ω/4π$ = 2.18 |          |

---

Differential Cross Section for $γd \to ωd$

T. Chetry, Ohio University

APS April Meeting 2018
Global Spectrum: $g10$ Data

- Basic cuts to reduce background:
  - $z$-vertex cut
  - Fiducial cut
- Minimum Momentum cut, etc.

- Corrections applied:
  - Momentum corrections
  - Energy loss corrections
- Signal over smooth background.
Binning

4 incident photon energy and variable 4-momentum transfer bins.
Yield extraction

$$E_\gamma = [1.4, 1.8] \text{ GeV}$$

Yield is extracted by taking integral of the Voigt function

Fit Functions

Voigt

Pol2
Differential Cross Section

\[ \frac{d\sigma}{dt} = \frac{Y_D}{\Delta t A L} \times \frac{\Gamma_\omega}{\Gamma_{\omega \rightarrow \pi^+\pi^-\pi^0}} \times \gamma_{corr} \]

- \( A \) = Acceptance
- \( \Delta t \) = Width of t-bin
- \( Y_D \) = Signal Yield
- \( \gamma_{corr} \) = PhotonMultiplicity
  Correction factor

Luminosity,

\[ L(E_\gamma) = \frac{\rho_T N_{AT}}{M_d} N_\gamma(E_\gamma) \]

- \( \rho_d = 0.169 \text{ gcm}^{-3} \)
- \( l_d = 24 \text{ cm} \)
- \( M_d = 2.014 \text{ g mole}^{-1} \)
- \( N_\gamma(E_\gamma) = \text{ Photon Flux} \)
Model based on VMD

\[ f_{\gamma N \rightarrow \omega N} = \sigma_{\gamma^* \omega} (i + \alpha_{\gamma N}) e^{-b_{\gamma N} t} \]

\[ \alpha = \frac{Re(A)}{Im(A)} \]

Calculation based on VMD (provided by M. Sargsian, FIU)*

\[ \frac{d\sigma}{dt} \]

Comparison with Data

\[ \sigma_{\omega N} \]

* Frankfurt et al.
  Nucl. Phys. A622 (1997) 511-537
Results

\[ 2.8 < E_t < 3.4 \text{ GeV} \]

\[ \pi^+ \varpi d (\pi^0) \]

\[ 7.5 \_ 15 \_ 31 \]

\[ 8.0 \_ 15 \_ 33 \]

\[ 8.0 \_ 19 \_ 30 \]

\[ 8.5 \_ 16 \_ 39 \]

Single Scattering

| 2.8 < E_t < 3.4 GeV |
|---------------------|
| \( \pi^+ \varpi d (\pi^0) \) |
| 7.5 15 31 |
| 8.0 15 33 |
| 8.0 19 30 |
| 8.5 16 39 |

\( b_{\gamma N} = b_{\omega N} \)

\[ \frac{d\sigma}{dt}_{t=0;\gamma N} \]

\[ [\text{mb}/(\text{GeV}^2/c^2)] \]

\[ \sigma_{\omega N} \]

\[ \chi^2/\text{NDF} \]

| 7.5 | 15 | 31 | 1.13 |
|-----|----|----|------|
| 8.0 | 14 | 34 | 1.15 |
| 8.0 | 15 | 33 | 1.01 |
| 8.0 | 16 | 32 | 0.96 |
| 8.0 | 17 | 31 | 1.00 |
| 8.0 | 18 | 30 | 1.15 |
| 8.0 | 19 | 30 | 0.91 |
| 8.0 | 19 | 31 | 0.87 |
| 8.0 | 20 | 30 | 1.03 |
| 8.5 | 16 | 35 | 1.11 |
| 8.5 | 16 | 39 | 1.00 |
| 8.5 | 17 | 34 | 1.05 |
| 8.5 | 18 | 33 | 1.07 |
| 9.0 | 19 | 39 | 0.89 |
| 9.0 | 20 | 38 | 0.87 |

\[ |\chi^2/F - 1.0| < 0.15 \]

\[ 30 < \sigma_{\omega N} < 40 \text{ mb} \]

This range is typical of hadronic cross-sections in the energy range!
Summary

- Access to lower energy and larger momentum transfer to investigate $\omega$-$N$ scattering.
- First high statistics world data for the reaction: $\gamma d \rightarrow \omega d$. Extracted $30 < \sigma_{\omega N} < 40 \text{ mb}$ using a rescattering model based on VMD for $E_{\gamma} = [2.8, 3.4] \text{ GeV}$.
- The cross-section data provides sensitivity to the nucleon-scattering data in the energy and momentum transfer range mentioned.

Submitted to PLB, arXiv:1802.06746
Outline

- Physics Motivation
- Vector Meson Dominance
- CLAS Detector @ JLab
- Differential Cross Section
- Results
- Summary