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

Taya Chetry
Ken Hicks
Ohio University

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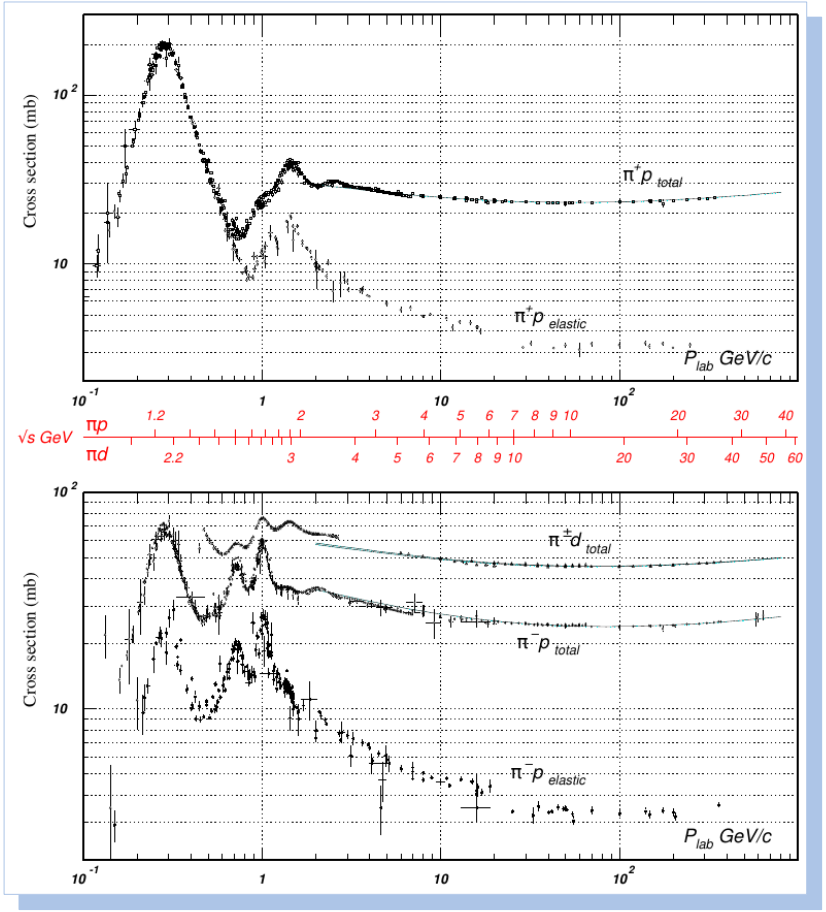
Goal

- 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 ~10^{23} s
  - Vector meson beams cannot be produced in a lab.
- Extract ωN cross section
  - LQCD ($\pi\pi$ - scattering)
  - Physics Models



C. Patrignani et al. (Particle Data Group)
Chin. Phys. C, 40, 100001 (2016) and 2017 update

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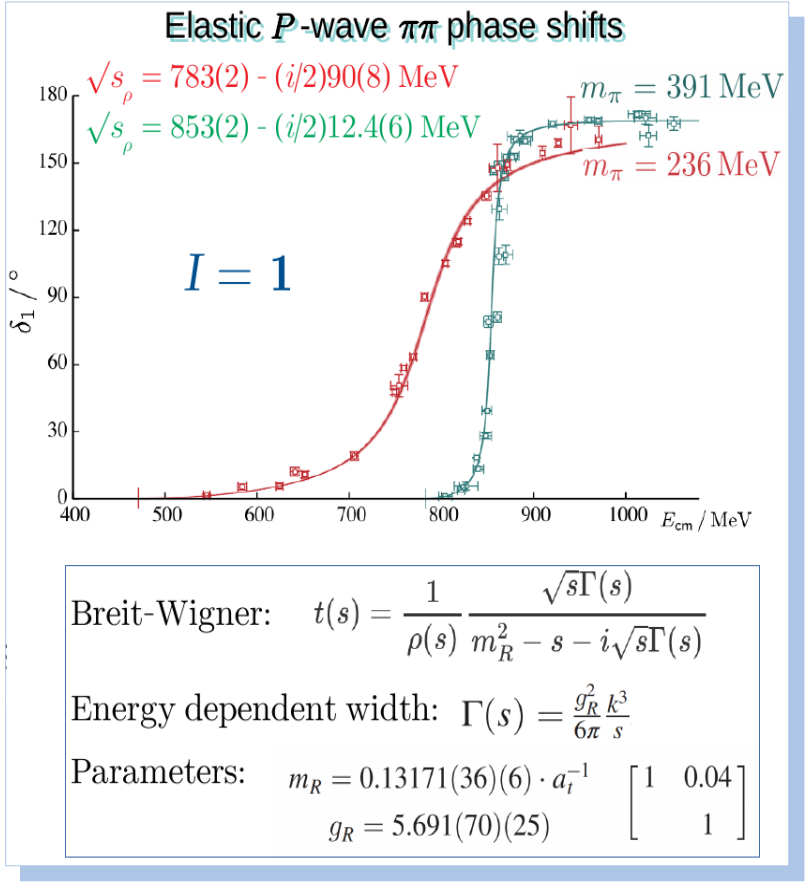
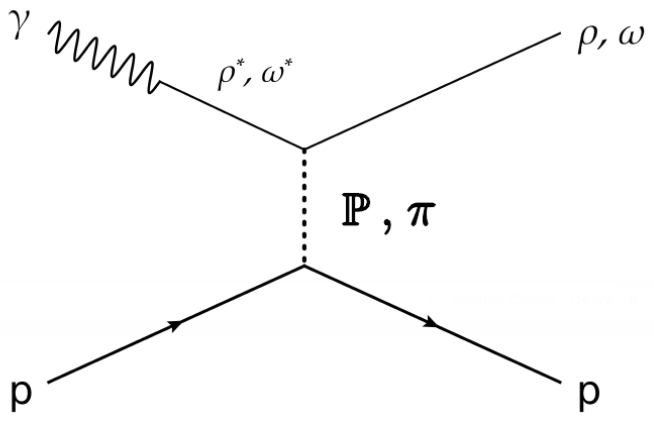


D.J. Wilson, R.A. Briceño, J.J. Dudek, R.G. Edwards, C.E. Thomas
The Hadron Spectrum Collaboration
Phys. Rev. D 92, 094502 (2015)

Vector Meson Dominance

Theory

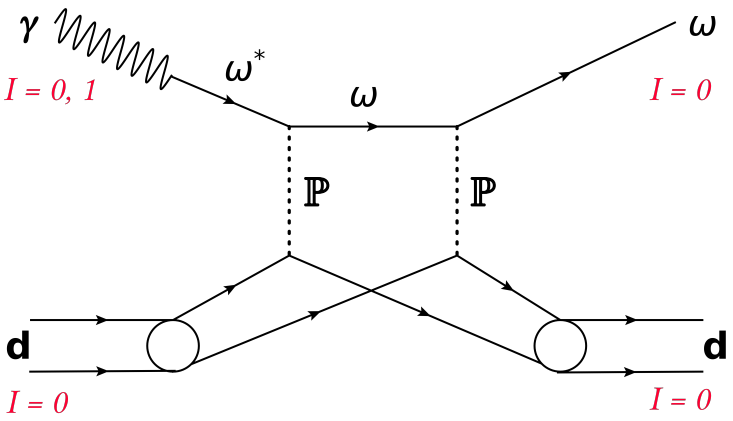


Phenomenologically:

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

b is the slope parameter

$t = (P_\gamma - P_{\rho,\omega})^2$

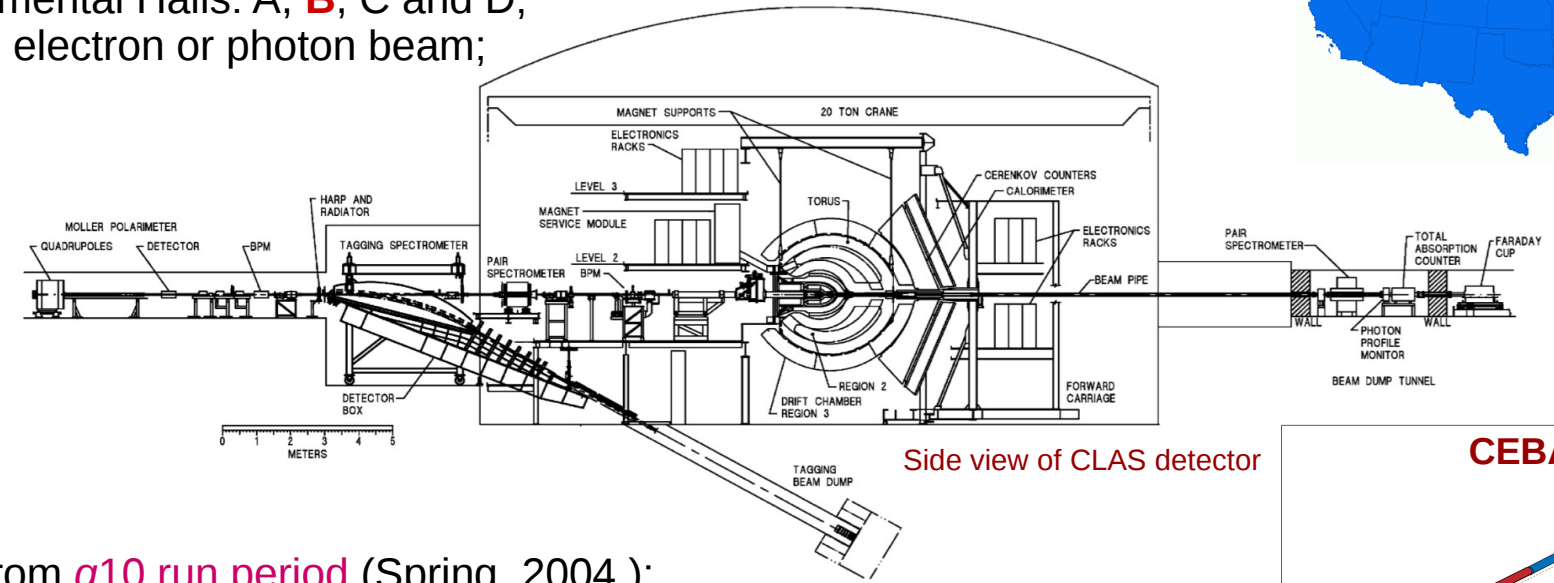


- Two processes:
  - $\gamma N \rightarrow \omega N$
  - $\omega N \rightarrow \omega N$
- Slope parameters:
  - $b_{\gamma N}$ and $b_{\omega N}$
- Ratio of Re(A) and Im(A):
  - $\alpha_{\gamma N}$ and $\alpha_{\omega N}$

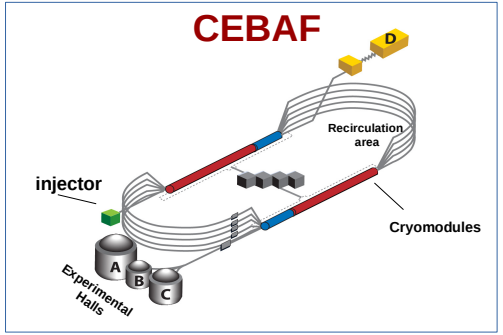
- Deuteron acts as an Isospin filter for $I = 0$ only.
- Vector Meson off deuterium simplifies theoretical interpretations of the data.

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;



Side view of CLAS detector

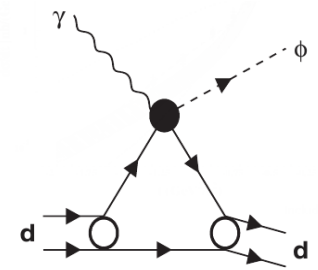


- Data from *g*10 run period (Spring, 2004);
- Target: 24 cm long liquid deuterium at Z = -25 cm;
- Electron beam energy 3.778 GeV;

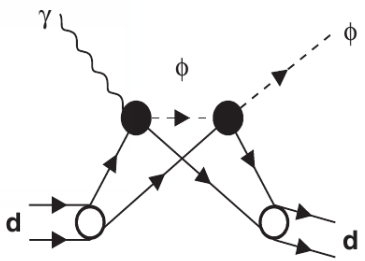
Vector Mesons off Deuteron in CLAS

Motivation

Single scattering

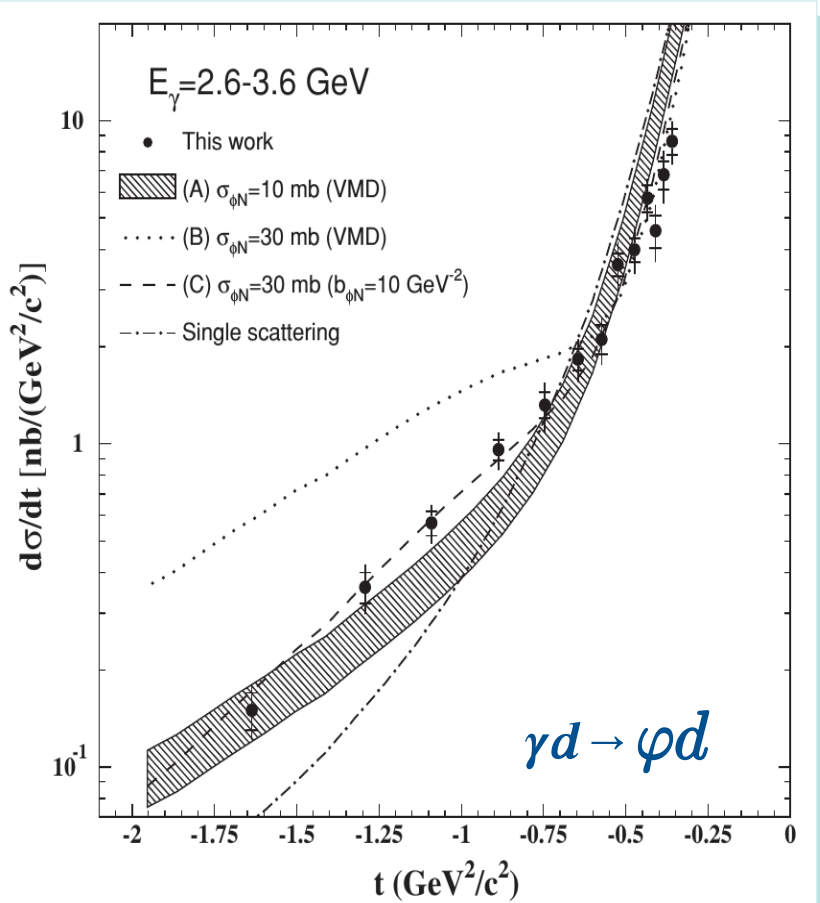


Double scattering



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 $b_{\gamma N} > b_{\phi N}$



T. Mibe *et al.*, CLAS Collaboration
Phys. Rev. C 76, 052202(R) (2007)

Previous results

Limited World Data

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

Experiment	Energy	Target	Measured quantities	$\lvert T_0^N \rvert^2$ (μb/GeV^2)	$\sigma_{\omega N}$ (mb)	$\hat{f}_\omega^2/4\pi$	Assumptions	Comments
SLAC–Berkeley Ballam *et al.* (1973)	9.3	H	$\left.\frac{d\sigma}{dt}\right\|_\omega$	11.4 ± 2.1	...	25.3 ± 4.7	$\sigma_{\omega N} = 27$ mb $\alpha_\omega = -0.24$ $\left.\frac{d\sigma}{dt}\right\|_{t=0} = \lvert T_0^N \rvert^2$	No correction for A_2 exchange
Rochester Abramson *et al.* (1976)	8.3	D, Be, C, Al Cu, Pb	$\left.\frac{d\sigma}{dt}\right\|_{t=0}$	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	$\left.\frac{d\sigma}{dt}\right\|_\omega$	11.2 ± 2.5		25.7 ± 6.5	$\sigma_{\omega N} = 27$ $\alpha_\omega = -0.24$	
Tel Aviv Alexander *et al.* (1975)	7.5	D	$\left.\frac{d\sigma}{dt}\right\|_{\rho,\omega}$ $\left.\frac{d\sigma}{dt}\right\|_\rho \Big/ \left.\frac{d\sigma}{dt}\right\|_\omega = 7.1^{+2.0}_{-1.2}$	...	...	$15.5^{+7.0}_{-2.8}$	$\hat{f}_\omega^2/\hat{f}_\rho^2 = \left.\frac{d\sigma}{dt}\right\|_\rho \Big/ \left.\frac{d\sigma}{dt}\right\|_\omega$ $\hat{f}_\rho^2/4\pi = 2.18$	The rho cross section was anomalously low
Pisa–Bonn Braccini *et al.* (1970)	5.7	C, Al, Zn, Ta, Ag, Pb	Smeared cross section	13.5 ± 3.3	$27.0^{+6.0}_{-5.5}$	22.0 ± 5.4	$\alpha_{\omega N} = -0.3$	Poor t resolution and uncertainties in background correction

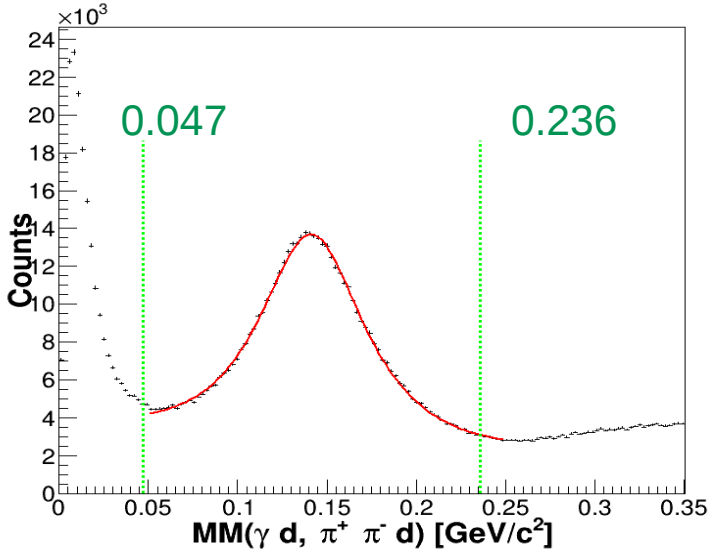
Previous results

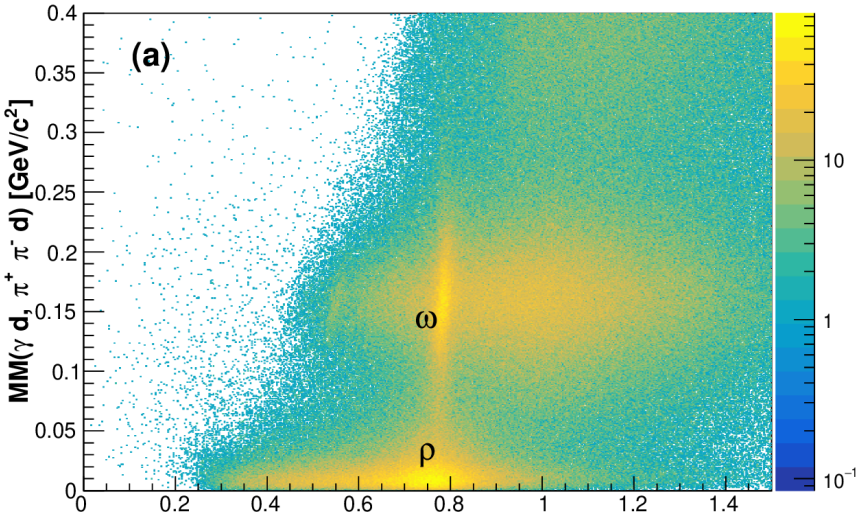
Limited World Data

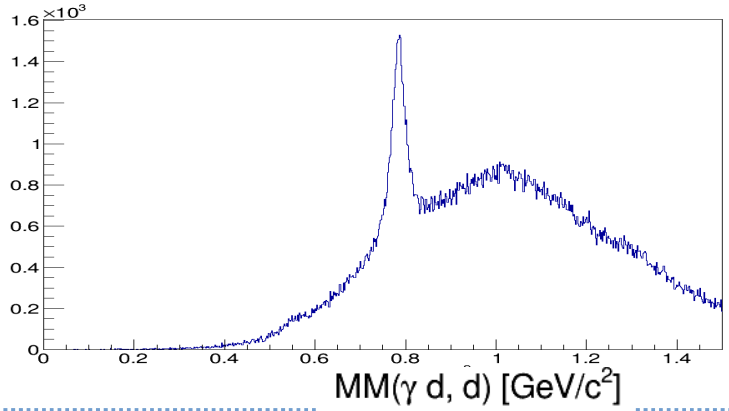
- Best data till date is from the Weizman Institute of Science
- $E_\gamma = 4.3$ GeV and $|t| < 0.2$ GeV$^2/c^2$

Experiment	Energy	Target	Measured quantities	$\lvert T_0^N \rvert^2$ (μb/GeV^2)	$\sigma_{\omega N}$ (mb)	$\hat{f}_\omega^2/4\pi$	Assumptions	Comments
Weizmann Eisenberg *et al.* (1976)	4.3	D	$\left.\frac{d\sigma}{dt}\right\|_\omega$	18.5 ± 4.5	...	15.6 ± 3.8	$\sigma_{\omega N} = 27$ mb $\alpha_{\omega N} = -0.24$	
Weizmann Eisenberg *et al.* (1976)	4.3	D	$\left.\frac{d\sigma}{dt}\right\|_\rho$ $\left.\frac{d\sigma}{dt}\right\|_\rho \Big/ \left.\frac{d\sigma}{dt}\right\|_\omega = 6.7^{+2.1}_{-1.3}$	...	...	$14.6^{+4.9}_{-3.0}$	$\hat{f}_\omega^2/\hat{f}_\rho^2 = \left.\frac{d\sigma}{dt}\right\|_\rho \Big/ \left.\frac{d\sigma}{dt}\right\|_\omega$ $\hat{f}_\rho^2/4\pi = 2.18$	
Harvard–CEA Gladding *et al.* (1973)	4.2	H	$\left.\frac{d\sigma}{dt}\right\|_{\rho,\omega}$ $\left.\frac{d\sigma}{dt}\right\|_\rho \Big/ \left.\frac{d\sigma}{dt}\right\|_\omega = 7.7 \pm 0.12$			16.8 ± 2.8	$\hat{f}_\omega^2/\hat{f}_\rho^2 = \left.\frac{d\sigma}{dt}\right\|_\rho \Big/ \left.\frac{d\sigma}{dt}\right\|_\omega$ $\hat{f}_\rho^2/4\pi = 2.18$	No correction for OPE or A_2 exchange
ABHHM Benz *et al.* (1974)	1.3–5.3	D	$\sigma_{\rho,\omega}$ $\frac{\sigma(\rho)}{\sigma(\omega)} = 7.2^{+2.7}_{-1.6}$			$15.7^{+6.2}_{-3.7}$	$\hat{f}_\omega^2/\hat{f}_\rho^2 = \frac{\sigma(\gamma d \rightarrow \rho d)}{\sigma(\gamma d \rightarrow \omega d)}$ $\hat{f}_\rho^2/4\pi = 2.18$	
Lancaster Morris *et al.* (1976)	3.9	D	$\left.\frac{d\sigma}{dt}\right\|_{\rho,\omega}$	14.5 ± 5.4		15.3 ± 6.4	$\hat{f}_\omega^2/\hat{f}_\rho^2 = \frac{\sigma(\gamma d \rightarrow \rho d)}{\sigma(\gamma d \rightarrow \omega d)}$ $\hat{f}_\rho^2/4\pi = 2.18$	Poor-resolution experiment
Colliding beams						18.4 ± 1.8		

Global Spectrum: *g*10 Data

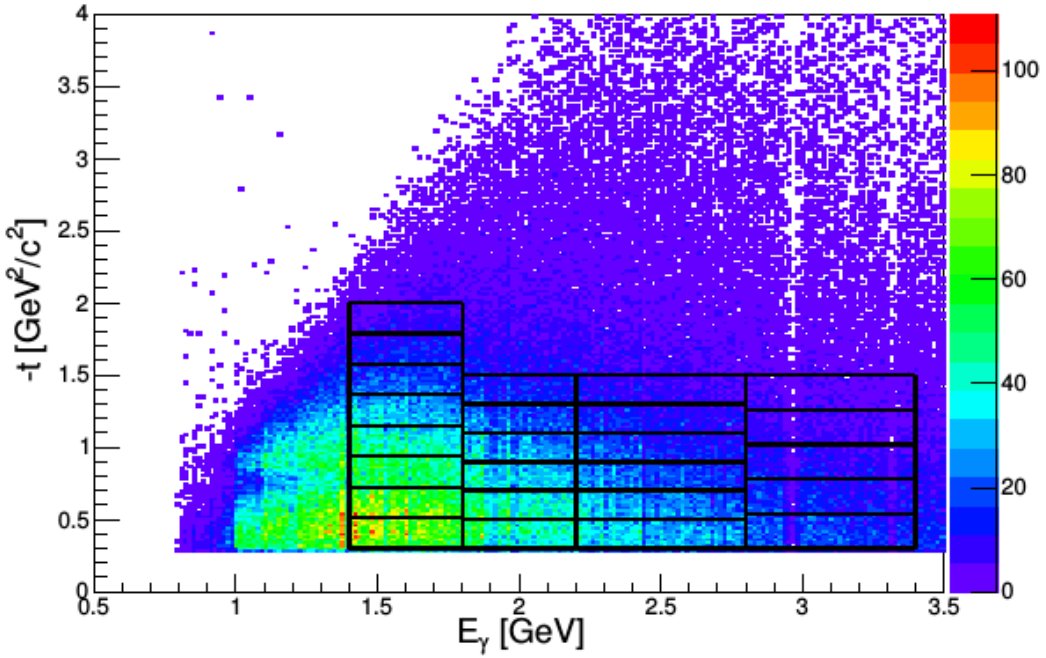






- Basic cuts to reduce background:
  - z-vertex cut
  - Fiducial cut
- Minimum Momentum cut, etc.
- Corrections applied:
  - Momentum corrections
  - Energy loss corrections
- Signal over smooth background.

Binning



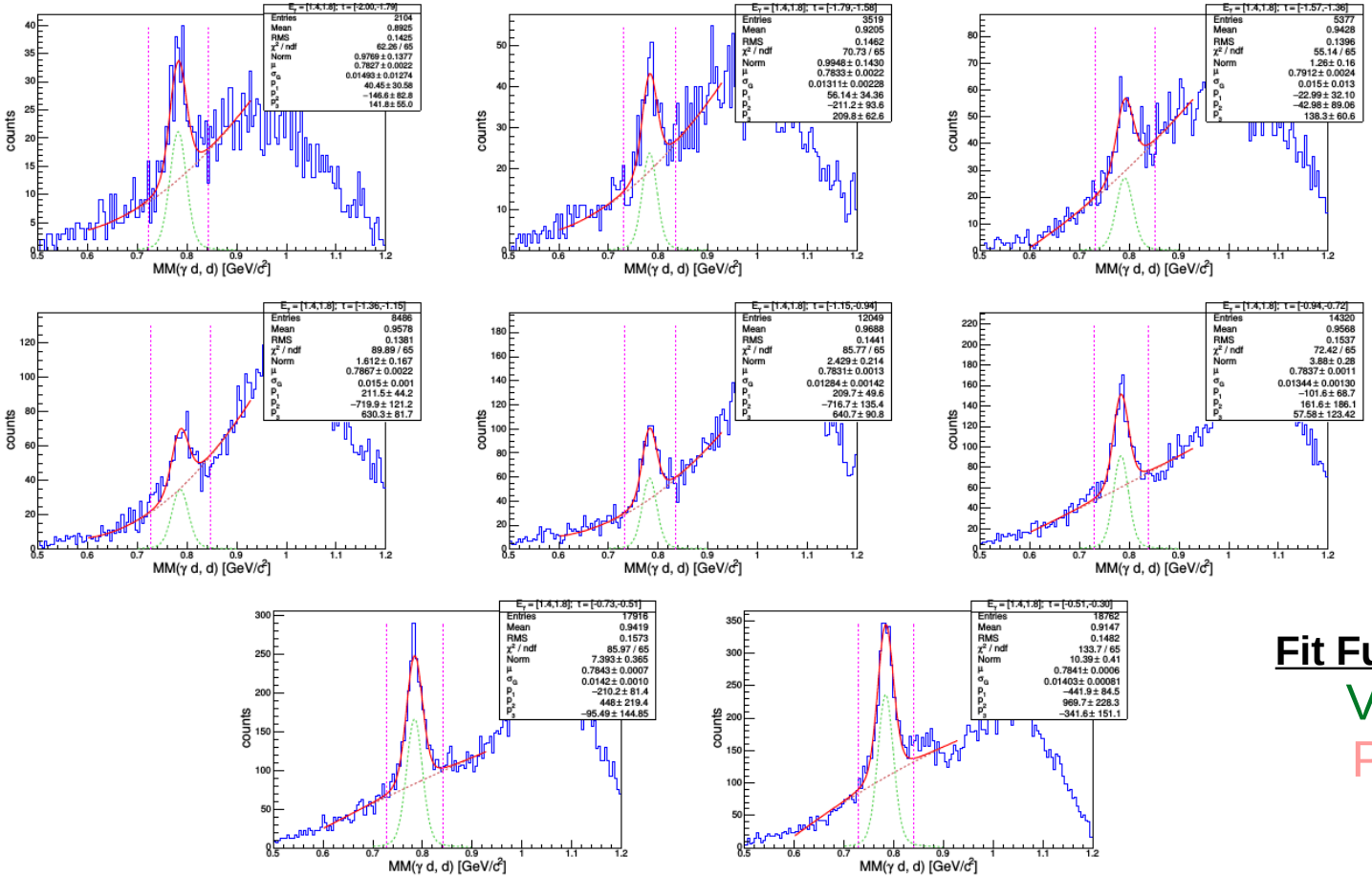
E_γ [GeV]	*t*-bins	$-t_{min}$ [GeV^2/c^2]	$-t_{max}$ [GeV^2/c^2]
1.4-1.8	8	2.0	0.3
1.8-2.2	6	1.5	0.3
2.2-2.8	6	1.5	0.3
2.8-3.4	5	1.5	0.3

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

Yield extraction

$\gamma d \rightarrow \omega d$

E_γ = [1.4, 1.8] GeV



Yield is extracted by taking integral of the Voigt function

Fit Functions

Voigt

Pol2

Differential Cross Section

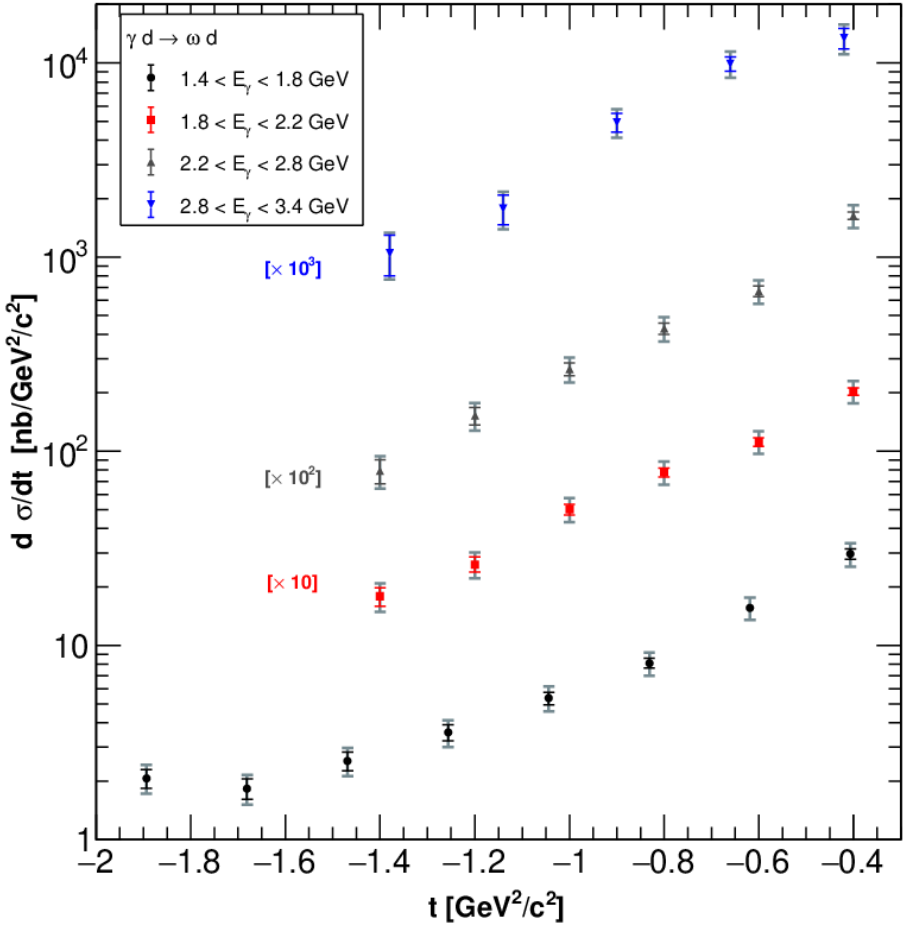
$$\frac{d\sigma}{dt} = \frac{Y_D}{\Delta t A \mathscr{L}} \times \frac{\Gamma_\omega}{\Gamma_{\omega\to\pi^+\pi^-\pi^0}} \times \gamma_{corr}$$

A = Acceptance
Δt = Width of t-bin
Y_D = Signal Yield
γ_{corr} = Photon Multiplicity Correction factor

Luminosity,

$$\mathscr{L}(E_\gamma) = \frac{\rho_T N_A l_T}{M_d} N_\gamma(E_\gamma)$$

$\rho_d = 0.169\, gcm^{-3}$
$l_d = 24\, cm$
$M_d = 2.014\, g\, mole^{-1}$
$N_\gamma(E_\gamma) =$ Photon Flux



Model based on VMD

$$f^{\gamma N \to \omega N} = \sigma_{\gamma^* \omega}(i + \alpha_{\gamma N}) e^{\frac{-b_{\gamma N}}{2} t}$$

b → p, d: $b_{\gamma N} = b_{\omega N}$

σ → p, d: $d\sigma/dt|_{t=0;\gamma N}$, $\sigma_{\omega N}$

$\alpha = \frac{Re(A)}{Im(A)}$ → p, d: $\alpha_{\gamma N}$, $\alpha_{\omega N}$

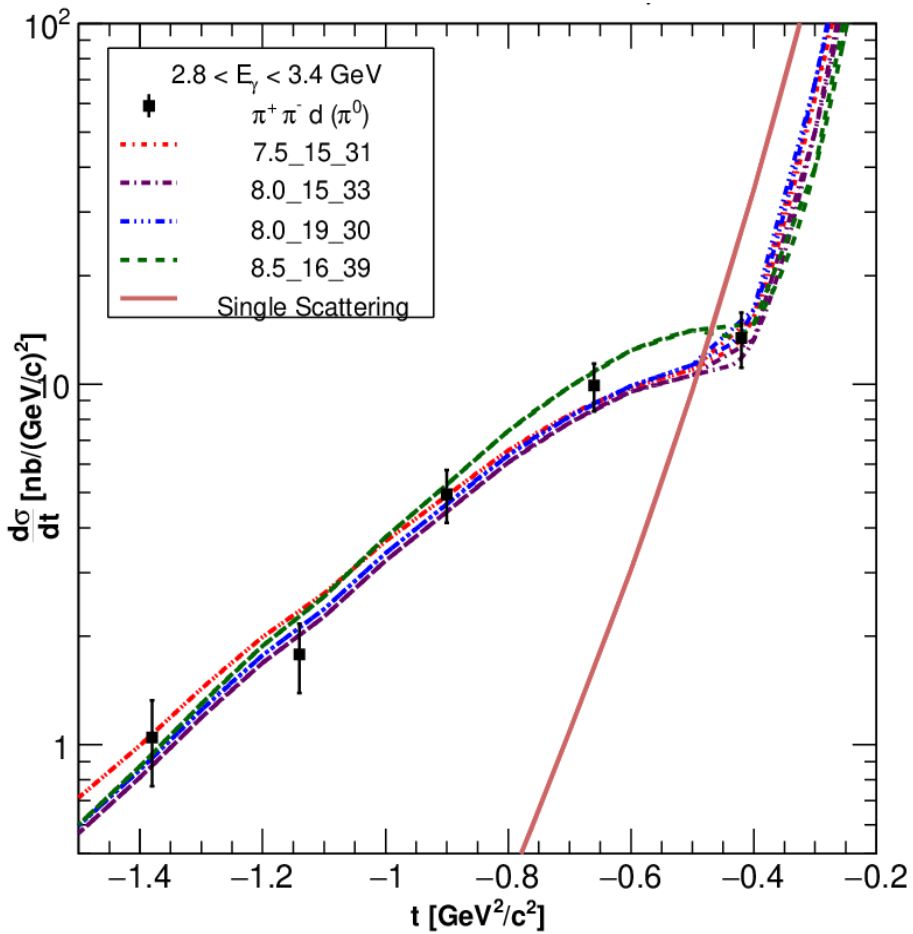
Calculation based on VMD
(provided by M. Sargsian, FIU)*

$\frac{d\sigma}{dt}$

Comparison with Data → $\sigma_{\omega N}$

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

Results



$b_{\gamma N} = b_{\omega N}$ $[GeV^{-2}/c^{-2}]$	$\left.\frac{d\sigma}{dt}\right\|_{t=0,\gamma N}$ $[\mu b/(GeV^2/c^2)]$	$\sigma_{\omega N}$ $[mb]$	χ^2/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 ω-N scattering.
- First high statistics world data for the reaction: $\gamma\,\mathrm{d} \rightarrow \omega\,\mathrm{d}$. Extracted $30 < \sigma_{\omega\mathrm{N}} < 40$ mb using a rescattering model based on VMD for E_γ = [2.8, 3.4] 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