# *Comparative Analysis of Vector-meson-Proton Scattering Lengths from Threshold Measurements*

*Igor Strakovsky*☆

*The George Washington University*

$J/\psi$ photoproduction is sample of hard processes corresponding to relatively large scale M~(0.5 – 1)*$M_{J/\psi}$.

$J/\psi$ is 'small size' object which can be used to study internal structure of proton (hadron), like in DIS case but now $J/\psi$ feels not electric charge but gluon distribution.

* Supported by DE-SC0016583

# *Outline*

- Vector-meson domestic Zoo.
- Vector-meson - nucleon SL.
- Brief tour through experiments.
- $\sigma_t$ fits.
- Brief tour through SLs.
- Ongoing activities.
- Summary.

# Vector-meson Domestic Zoo

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- Some ***vector-mesons*** can, compared to other mesons, be measured to very high precision.
- This stems from fact that ***vector-mesons*** have **same** quantum numbers as ***photon***.

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| Name | Quark Content | $\Gamma$ (MeV) | |
|---|---|---|---|
| $\rho^+(770)$ | $u\bar{d}$ | 148 | |
| $\rho^0(770)$ | $\frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$ | 149 | |
| $\omega(782)$ | $\frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$ | 8.5 | |
| $K^{*+}(892)$ | $u\bar{s}$ | 51 | |
| $K^{*0}(892)$ | $d\bar{s}$ | 47 | |
| $\phi(1020)$ | $s\bar{s}$ | 4.3 | |
| $D^{*+}(2010)$ | $c\bar{d}$ | 0.083 | *Open Charm* |
| $D^{*0}(2007)$ | $c\bar{u}$ | < 2.1 | |
| $J/\psi(1S)(3097)$ | $c\bar{c}$ | 0.093 | *Charmonium* |
| $\Upsilon(1S)(9460)$ | $b\bar{b}$ | 0.052 | *Quarkonium* |

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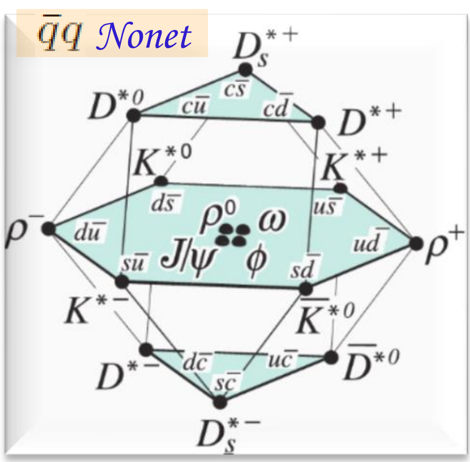


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- I will focus on **3** vector-mesons from $\bar{q}q$ *Nonet* which widths are **narrow** enough to study meson photoproduction @ threshold & where data are available.

# Vector-meson – Nucleon SL

# *Vector-Meson – Nucleon SL Determination*

IS, L. Pentchev, & A.I. Titov, Phys Rev C **101** (2020)

- For evaluation of absolute value of VN SL,
  we apply VMD approach that
  links near-threshold photoproduction *Xsections* of **γp→Vp** & elastic **Vp→Vp**

$$\frac{d\sigma^{\gamma p\to Vp}}{d\Omega}|_{\rm thr} = \frac{q}{k}\frac{1}{64\pi}|T^{\gamma p\to Vp}|^2 = \frac{q}{k}\cdot\frac{\pi\alpha}{g_V^2}\frac{d\sigma^{Vp\to Vp}}{d\Omega}|_{\rm thr} = \frac{q}{k}\cdot\frac{\pi\alpha}{g_V^2}|\alpha_{Vp}|^2$$

**k** is photon CM momentum $k = (s - M^2) / 2\, s^{1/2}$

**q** is *vector-meson* CM momentum

$\mathbf{T}^{\gamma p\to Vp}$ is the invariant amplitude of *vector-meson* photoproduction

$\alpha$ is fine-structure constant

$\mathbf{g_V}$ is VMD coupling constant, related to *vector-meson* **EM** decay width $\Gamma_{V\to e+e-}$

$$g_V = \sqrt{\frac{\pi\alpha^2 m_V}{3\Gamma_{V\to e^+e^-}}}$$

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- Finally, one can express absolute value of SL as product of
  pure **EM** VMD-motivated kinematic factor
  $R_V^2 = \alpha m_V k/12\pi\Gamma_{V\to e^+e^-}$ & $h_{Vp} = \sqrt{b_1}$ ,
  where $b_1$ came from best fit $\sigma_t(q) = b_1 q + b_3 q^3 + b_5 q^5$ ,
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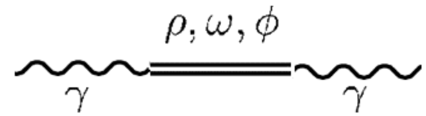
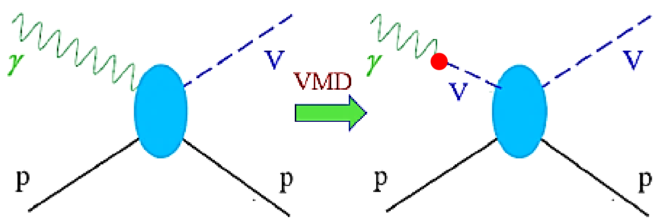
- To avoid theoretical uncertainties, we did not
  - determine sign of SL,
  - separate Re & Im parts of SL,
  - extract Isospin 1/2 & 3/2 contributions.

- Vector-Meson Dominance model relying on transparent current-field identities

M. Gell-Mann & F. Zachariasen, Phys Rev **124**, 953 (1961)
J.J. Sakurai, *Currents and Mesons* (The University of Chicago Press, Chicago, 1969)
N.M. Kroll, T.D. Lee, & B. Zumino, Phys. Rev. **157**, 1376 (1967)

- In VMD, real photon can fluctuate into virtual vector-meson, which subsequently scatters off target proton.




- VMD does not contain *free parameters* & can be used for variety of qualitative estimates of observables in vector-meson photoproductions @ least as first step towards their more extended theoretical studies.

# VMD Approach: EM Factor

VMD coupling constant $g_V = \sqrt{\frac{\pi\alpha^2 m_V}{3\Gamma_{V\to e^+e^-}}}$

EM factor $R_V^2 = \alpha m_V k/12\pi\Gamma_{V\to e^+e^-}$

| V | $m_V$ | $\Gamma_{V\to e+e-}$ | $g_V$ | $R_V$ |
|---|---|---|---|---|
| | (MeV) | (keV) | | ($MeV^{1/2}$) |
| $\omega$ | 782.65 | 0.60±0.02 | 8.53±0.14 | 390.5±6.4 |
| $\phi$ | 1019.461 | 1.27±0.04 | 6.69±0.10 | 342.5±5.3 |
| $J/\psi$ | 3096.916 | 5.55±0.11 | 5.58±0.07 | 454.9±4.1 |
| $Y$ | 9460.30 | 1.340±0.018 | 19.84±0.14 | 2655.0±162.2 |

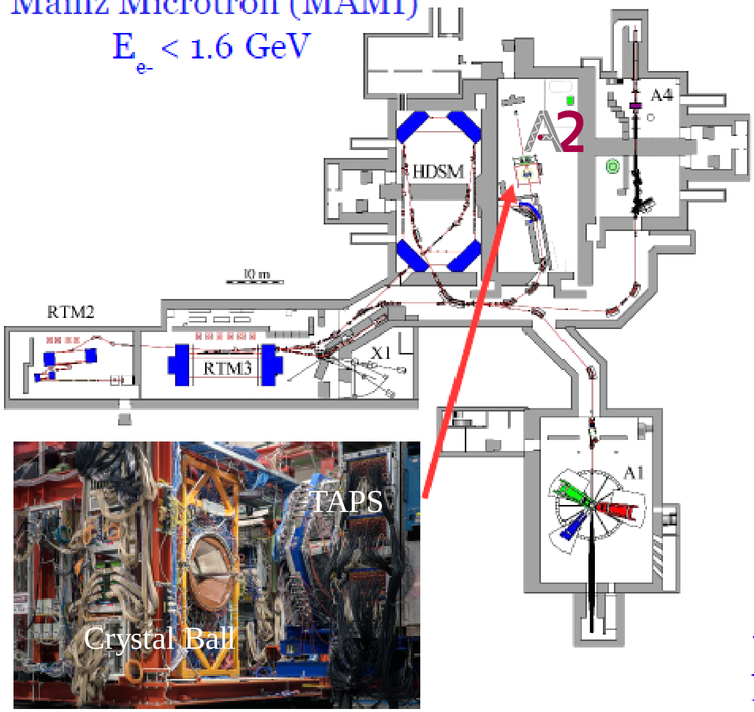
- EM factor $R_V$ for each vector-meson are close to each other.

# Brief Tour through Experiments

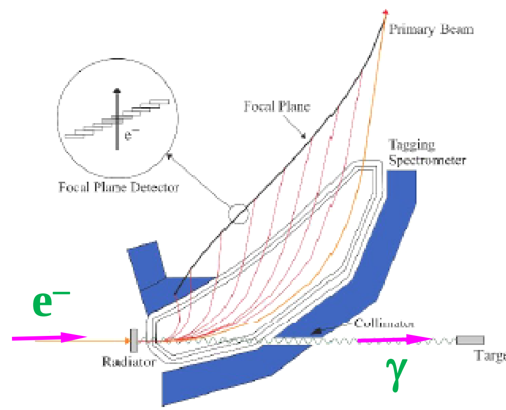
# A2

# *in 2020*

Mainz Microtron (MAMI)
$E_{e-} < 1.6$ GeV



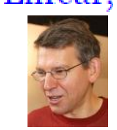

Tagger/End point tagger




$E_\gamma = E_{e-} - E_{tagg}$

Upgrade → experiments with ~4 times higher rates ~~will be~~ possible!

- High-Flux, Tagged, Bremsstrahlung Photon Beam: Unpolarized, Linear, and Circular
- Polarized and Unpolarized Targets
- Recoil polarimeter



# A2 in 2020

- was build @ SLAC & used in $J/\psi$ measurements @ SPEAR3 & b quark physics @ DESY.

Then worked @ BROOKHAVEN NATIONAL LABORATORY for physics of *hadrons* & it is @ MAMI now.

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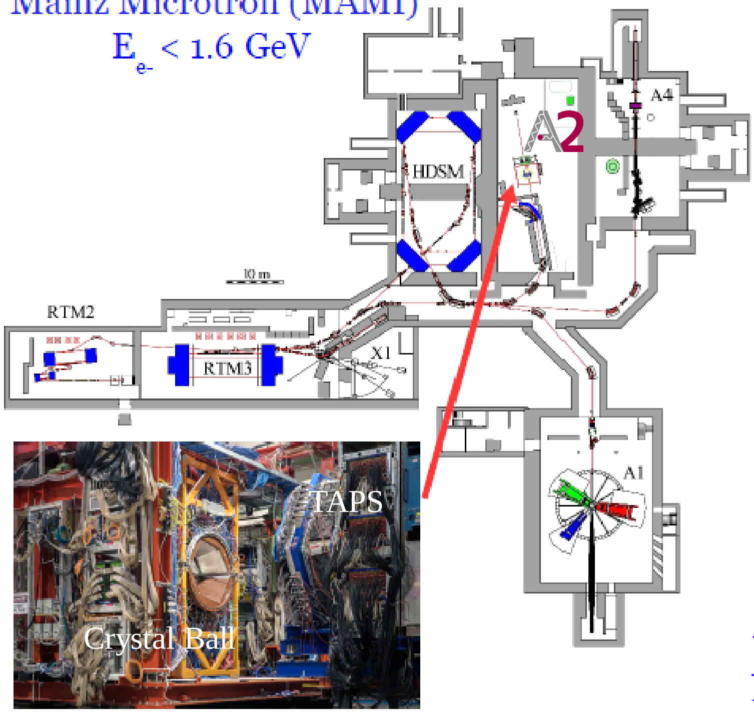


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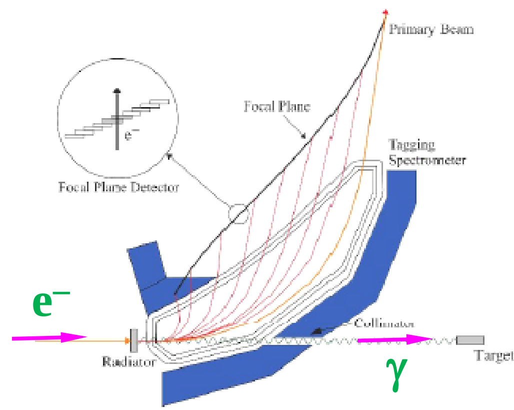


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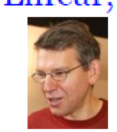
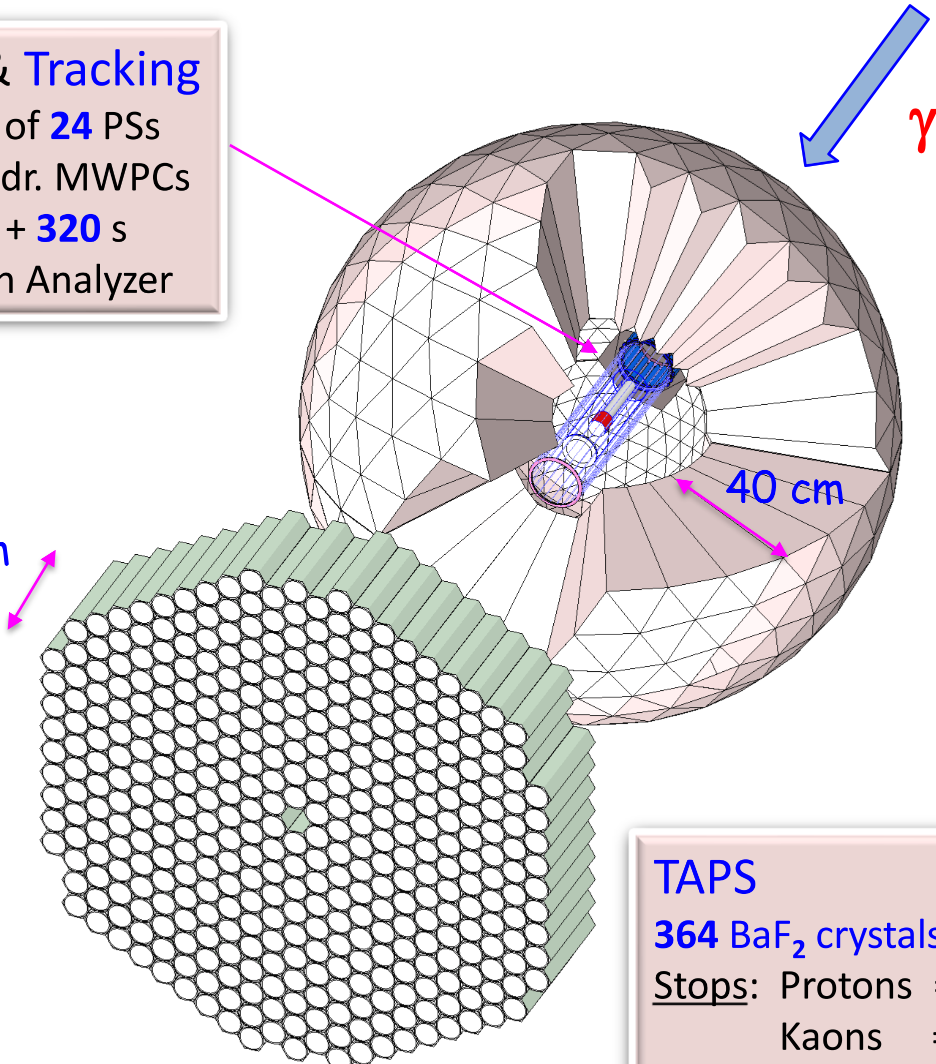


# Crystal Ball, TAPS, & Tracking

**PID & Tracking**
Barrel of **24** PSs
**2** cylindr. MWPCs
**480** w + **320** s
Carbon Analyzer



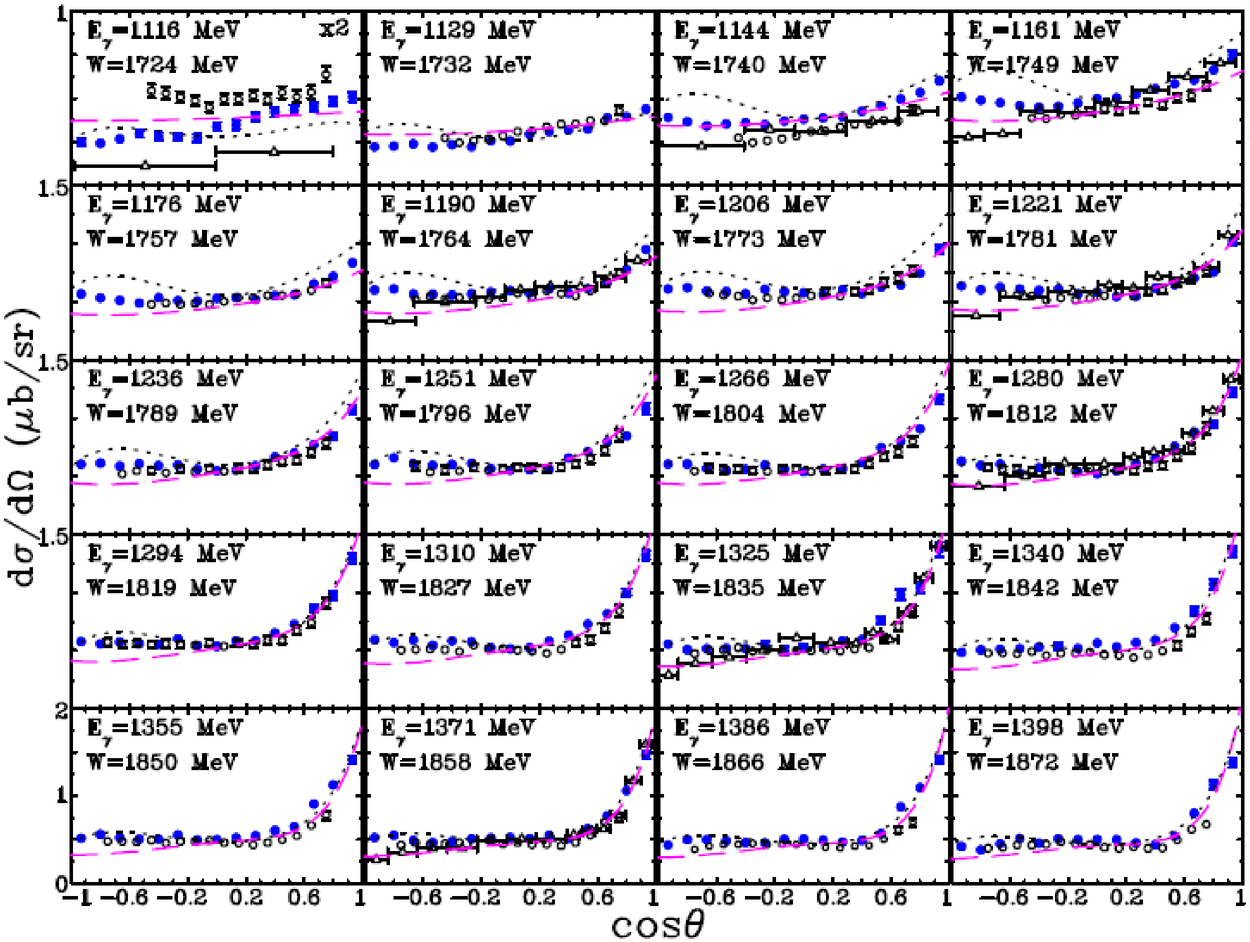

**Crystal Ball**
**672** NaI(Tl) crystals [20°–160°]
Stops: Protons = 420 MeV
Kaons = 340 MeV
Chrg. p = 240 MeV
Chrg. m = 230 MeV

$\sigma(E) = 2$ MeV
$\sigma(\theta) = 2.5^{o}$
$\sigma(\phi) = 2^{o}/\sin\theta$

**TAPS**
**364** $BaF_2$ crystals [0°–20°]
Stops: Protons = 360 MeV
Kaons = 280 MeV
Chrg. p = 180 MeV

# $\gamma p \rightarrow \omega p \rightarrow \pi^0 \gamma p \rightarrow 3\gamma p$ *Measurements*

IS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (2015)



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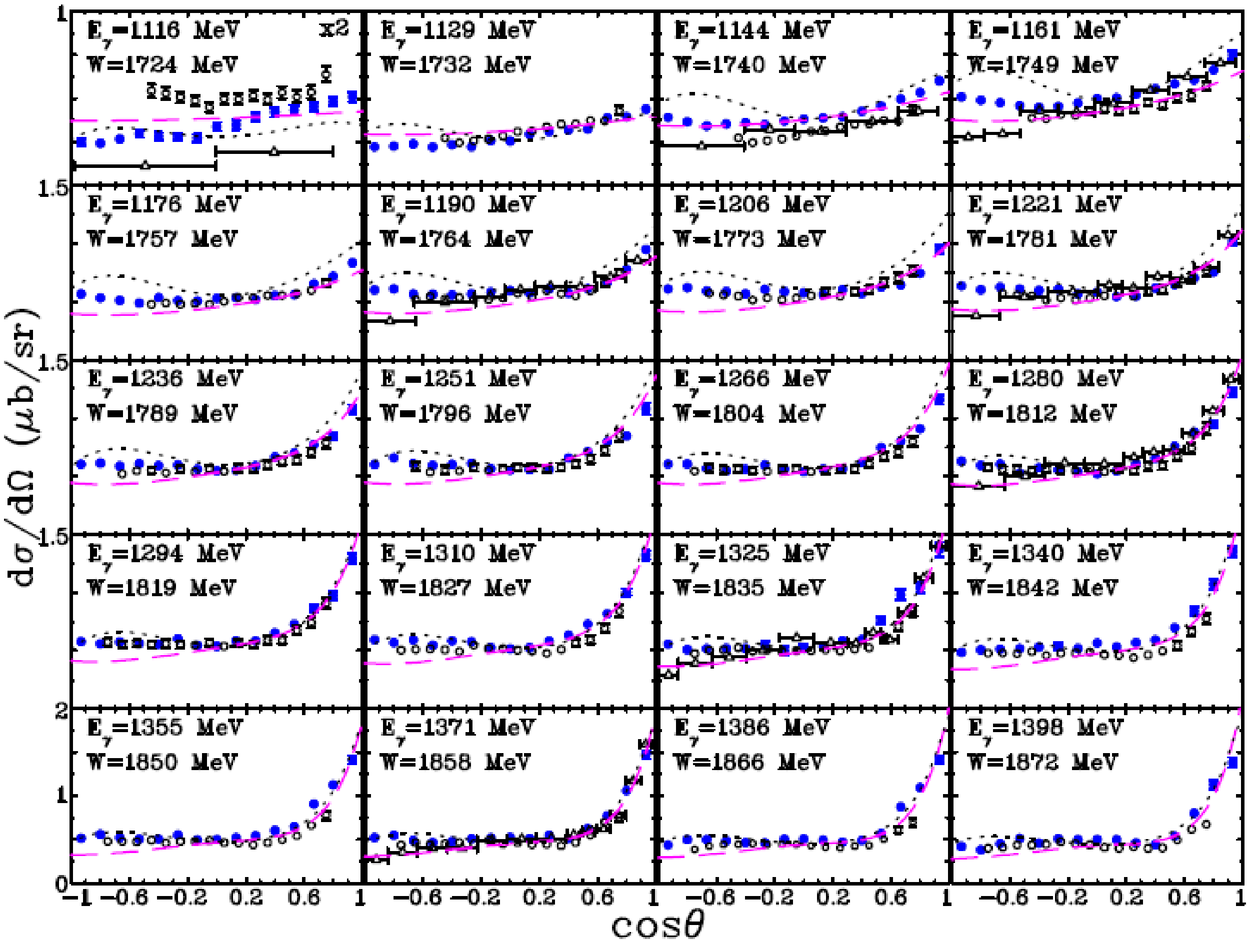
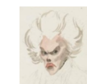



- Full production-angle coverage allows to determine $\sigma_t$.
- Legendre polynomial extension

$$d\sigma/d\Omega(E_\gamma,\cos\theta) = \sum_{j=0} A_j(E_\gamma)P_j(\cos\theta)$$

confirms $\sigma_t$ determination

$$\sigma_t = 4\pi A_0(E_\gamma)$$



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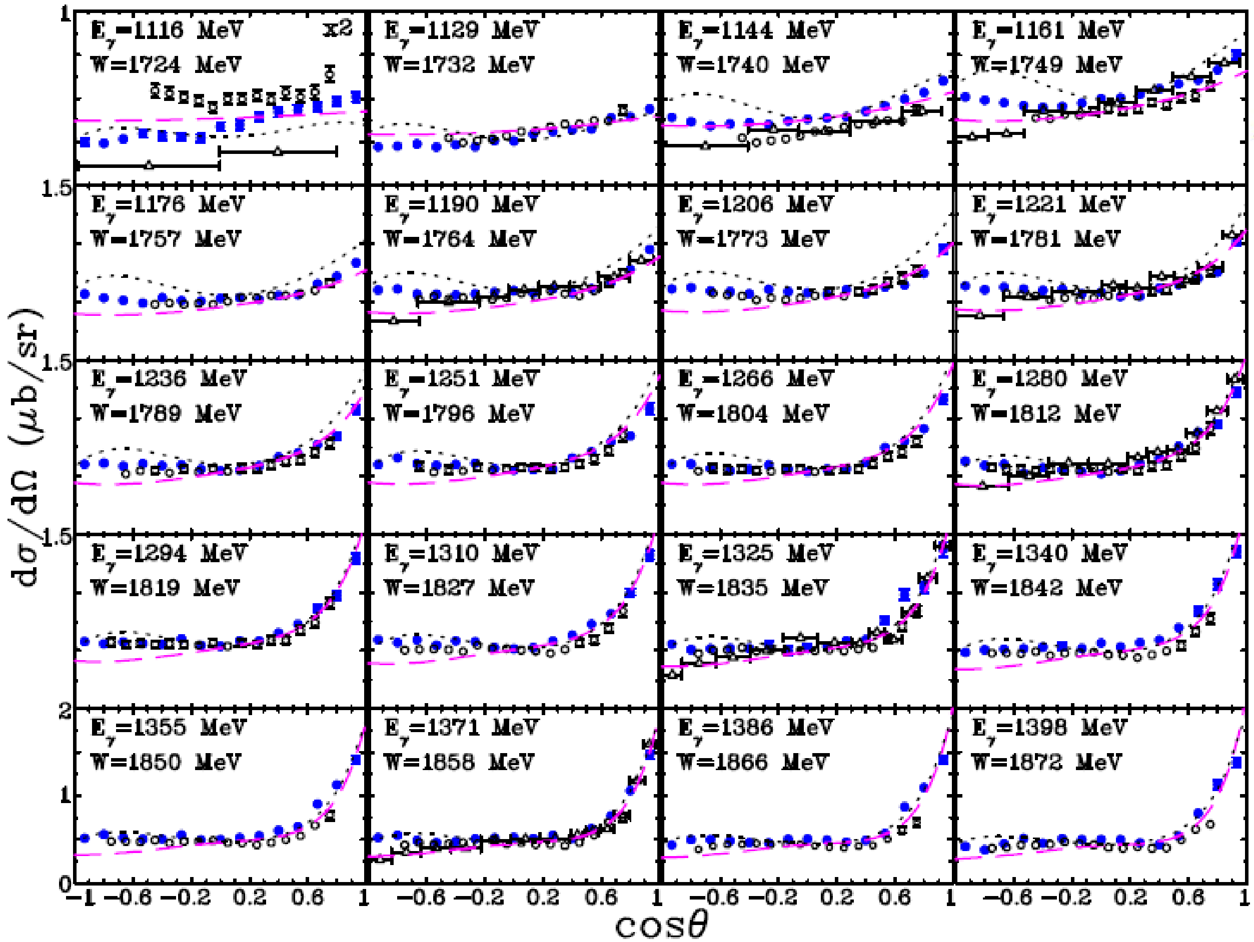


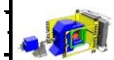

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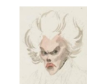

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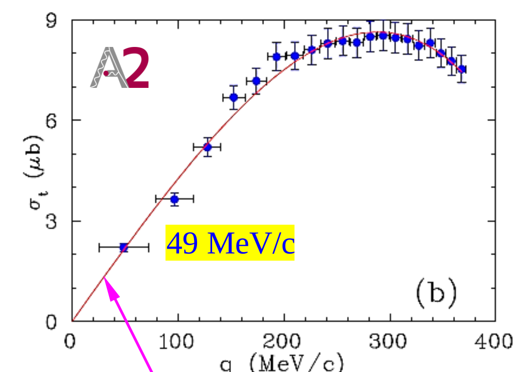
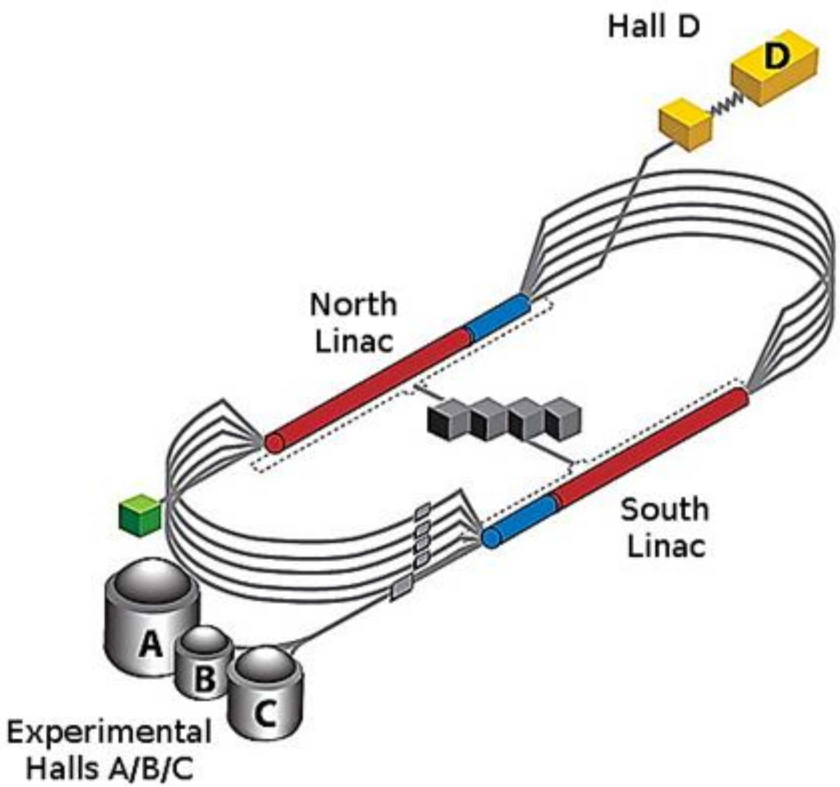
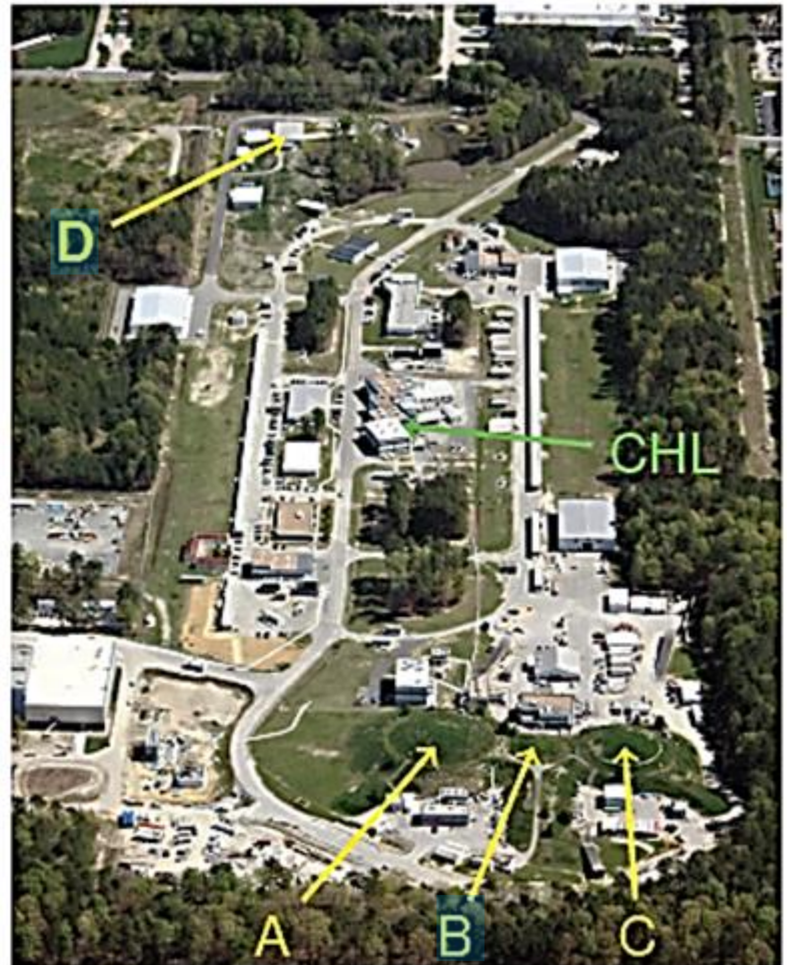



$$\sigma_t(q) = b_1 q + b_3 q^3 + b_5 q^5$$

# Jefferson Lab *in 2020*

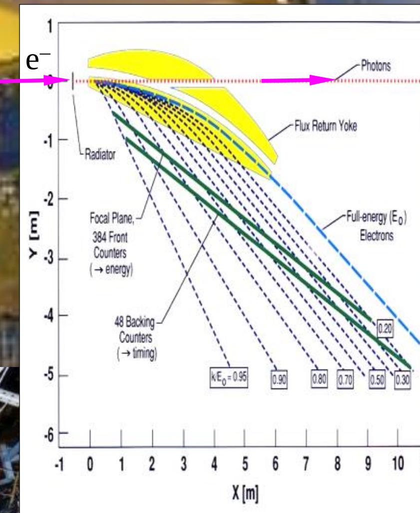



- Accelerator: 2.2 GeV/pass
- Halls A,B,C: $e^-$ 1-5 passes $\leq$11 GeV
- Hall D: $e^-$ 5.5 passes 12 GeV $\Rightarrow$ $\gamma$-beam
- Runs 2017-2018: 5.5 passes 11.7 GeV

# CEBAF Large Acceptance Spectrometer 1997-2012

Bremsstrahlung Photon Tagger
384 E & 61 T Counters

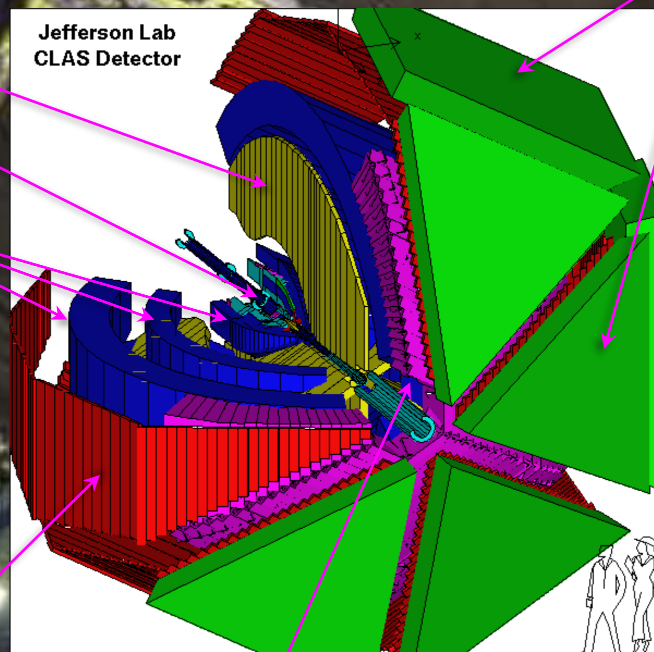


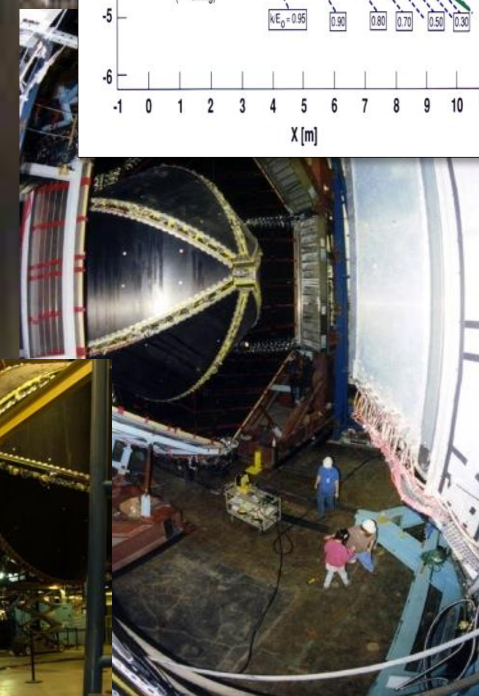

Electromagnetic Calorimeters
Lead/Scintillator, 1296 PMTs

Torus Magnet
6 Superconducting Coils

Target + Start Counter

Drift Chambers
35,000 cells



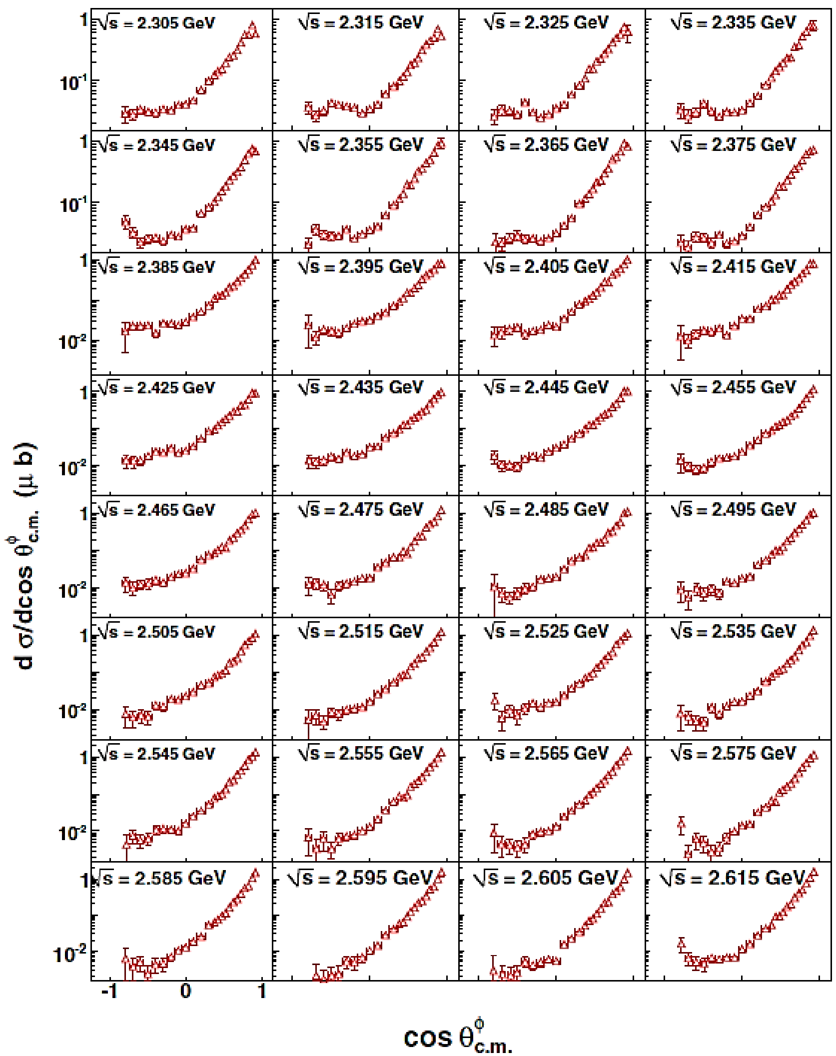
Time-of-Flight Counters
Plastic Scintillators, 684 PMTs

Gas Cherenkov Counters
e/π separation, 256 PMTs

B.A. Mecking *et al*. Nucl Inst Meth A **503**, 513 (2003)

# $\gamma p \to \phi p \to K^+K^-p$ *Measurements*

B. Dey *et al*, Phys Rev C **89**, 055208 (2014)



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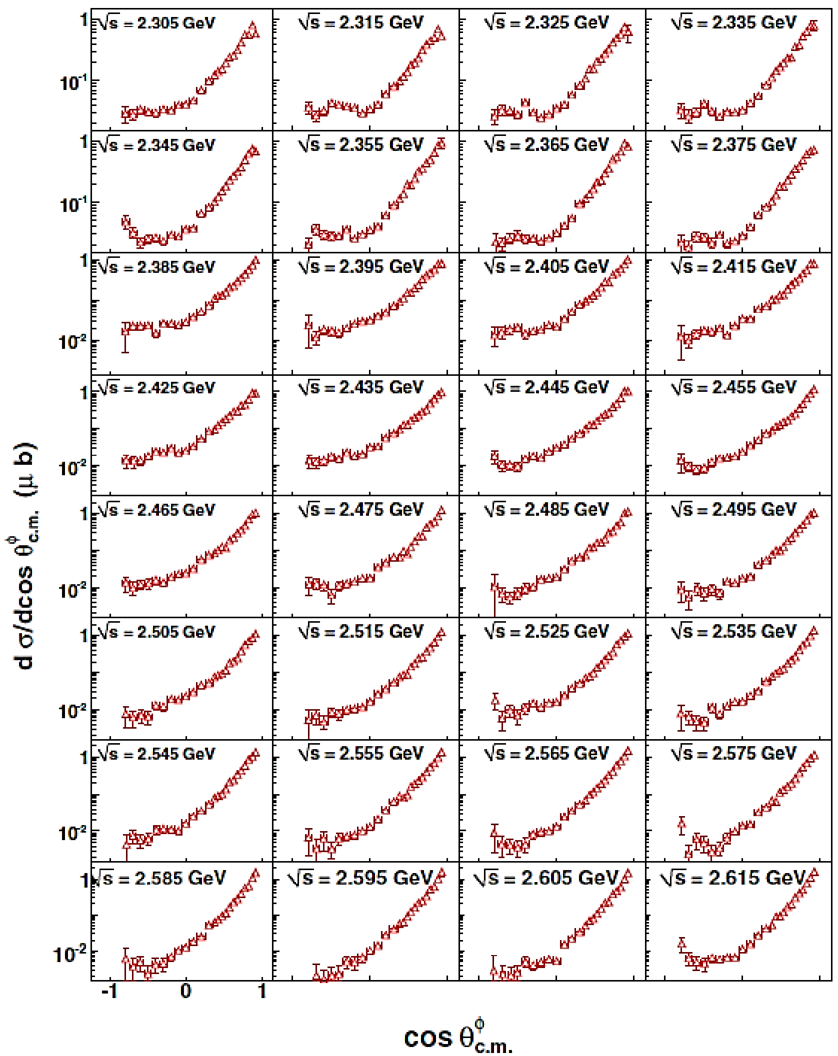


- **cosθ** of CLAS spans from -0.80 to 0.93.
- Legendre polynomial extension

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is way to determine $\sigma_t$ $\quad \sigma_t = 4\pi A_0(E_\gamma)$

IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (2020)

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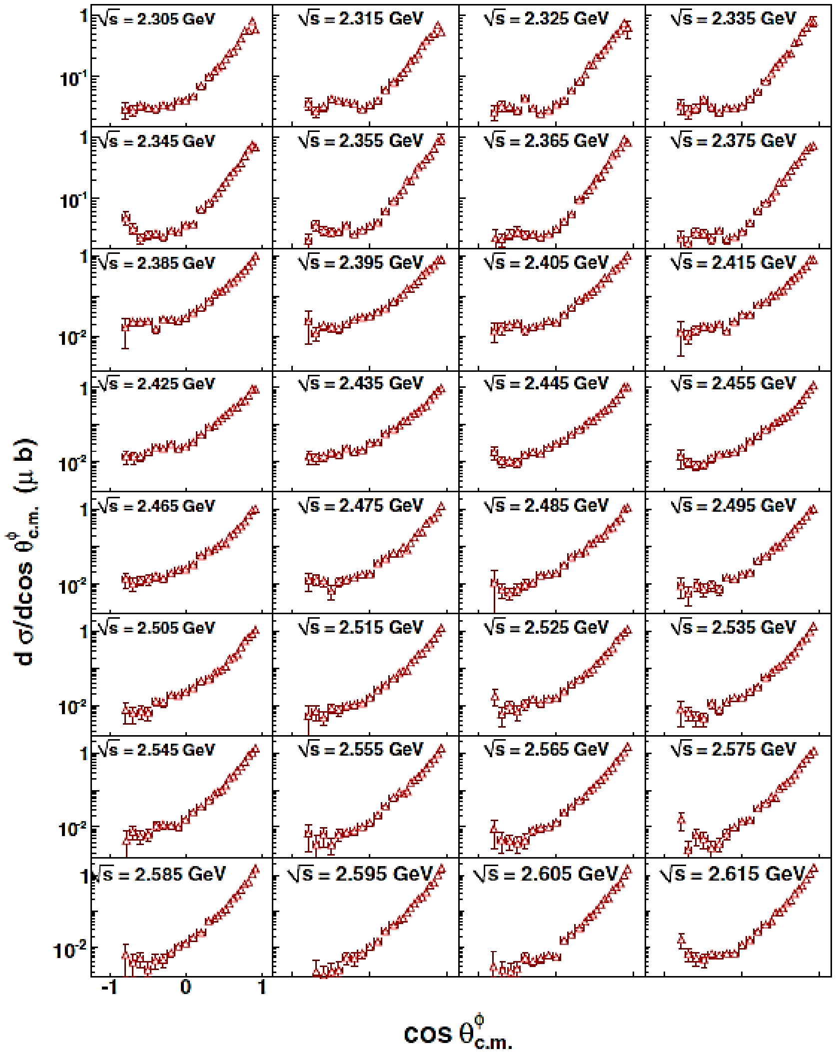


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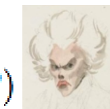

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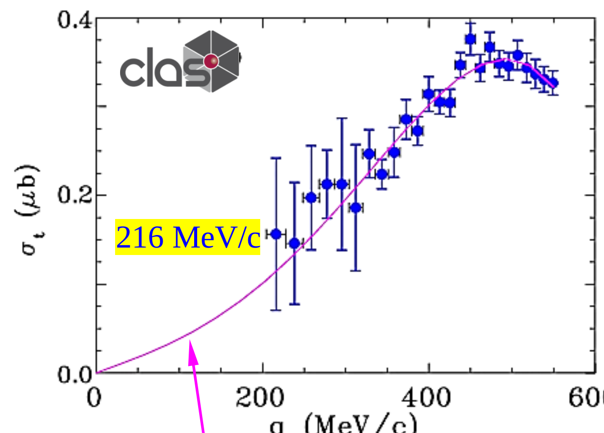


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IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (2020)

PHYSICAL REVIEW LETTERS **123**, 072001 (2019)

Editors' Suggestion

*2nd paper*

First Measurement of Near-Threshold $J/\psi$ Exclusive Photoproduction off the Proton

(GlueX Collaboration)

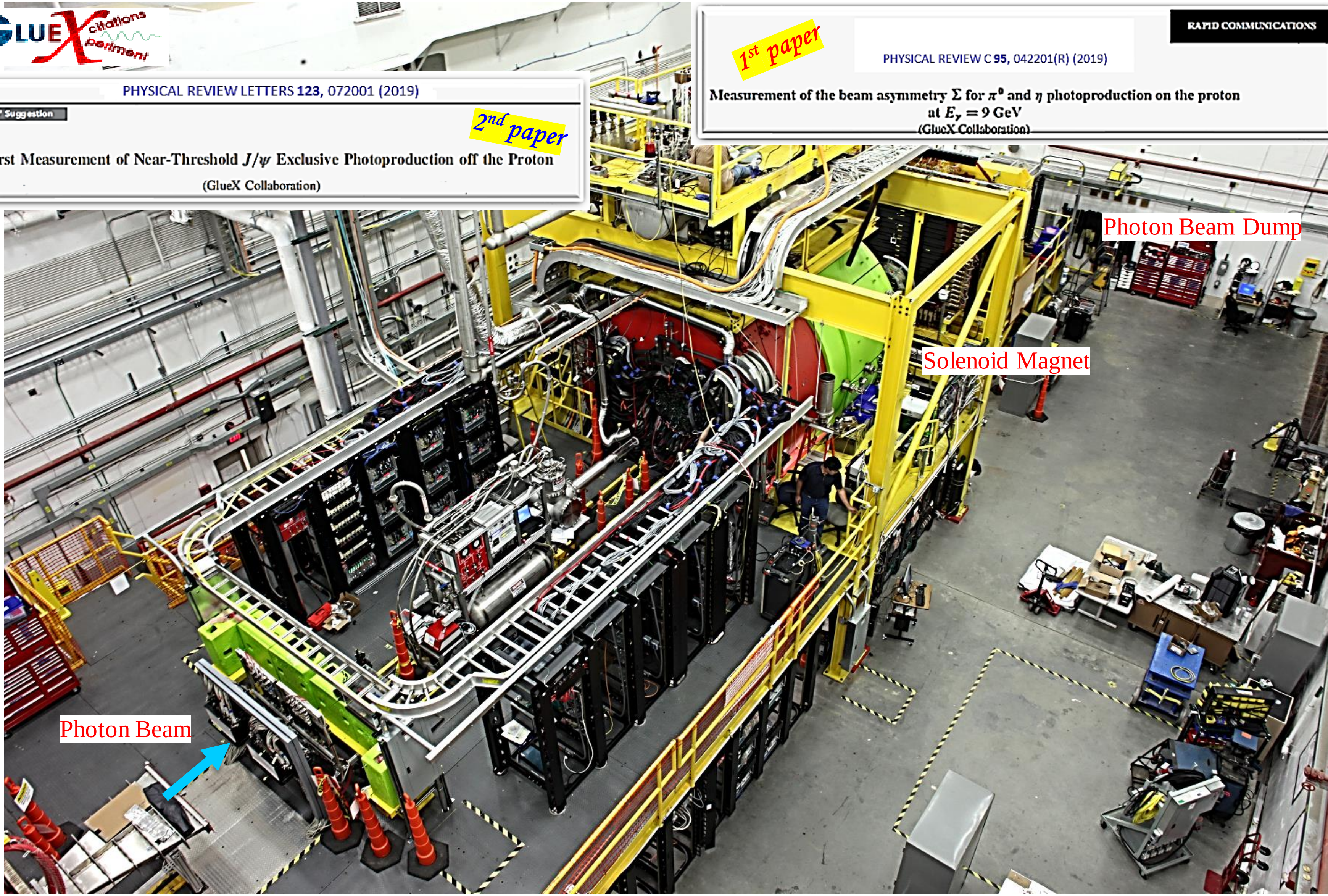
*1st paper*

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **95**, 042201(R) (2019)

Measurement of the beam asymmetry $\Sigma$ for $\pi^0$ and $\eta$ photoproduction on the proton at $E_\gamma = 9$ GeV

(GlueX Collaboration)



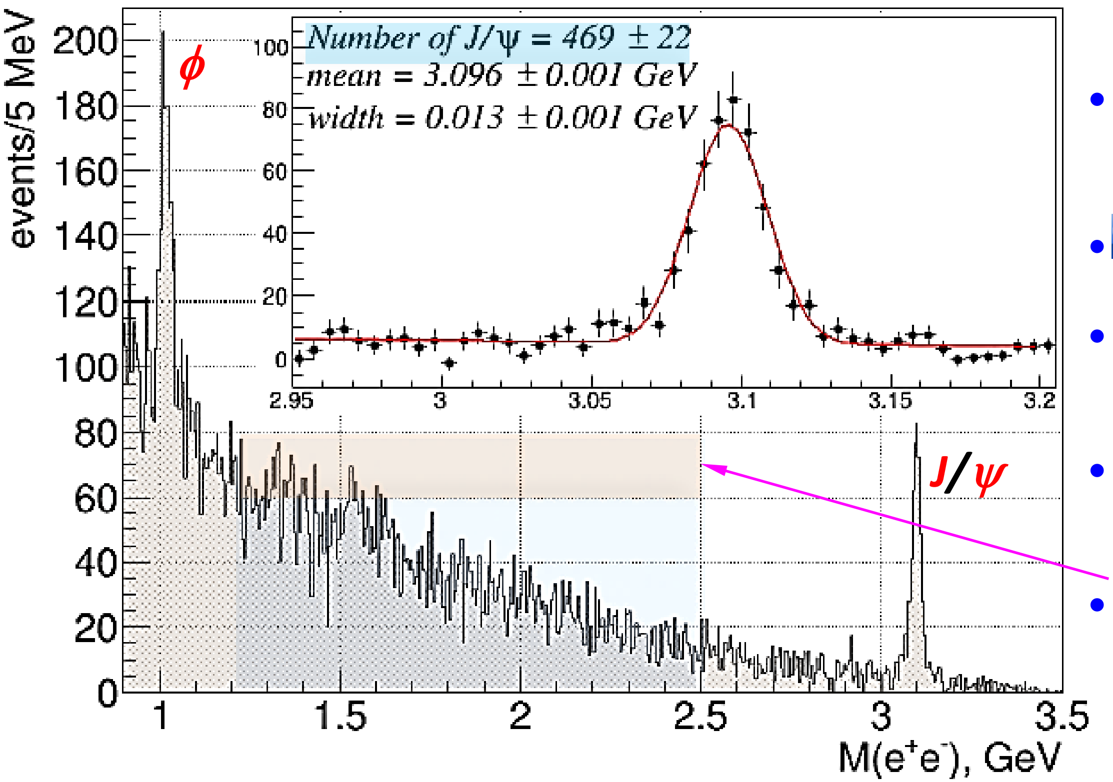

GlueX Statistics: above 8.2 GeV

Spring 2016: 10 pb$^{-1}$
Spring 2017: 58 pb$^{-1}$

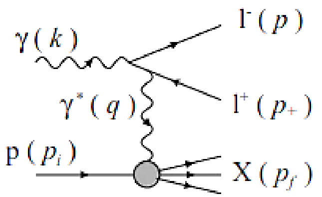
25% of total statistics (2016-2018) up to date.

# $e^+e^-$ Invariant Mass Spectrum

A. Ali *et al*, Phys Rev Lett **123**, 072001 (2019)




- Tagged photon beam (**0.2%** energy resolution) & exclusivity reaction: $\gamma p \rightarrow J/\psi p \rightarrow e^+e^- p$.
- PDG BR($J/\psi \rightarrow e^+e^-$) = (5.971±0.032)%.
- Pion contamination ~50% in continuum (using E/p fits to estimate it).
- Kinematic fit (constrained mostly recoil proton): **13** MeV mass resolution; no rad tail.
- BH [M($e^+e^-$) = 1.2 – 2.5 GeV] used for normalization.

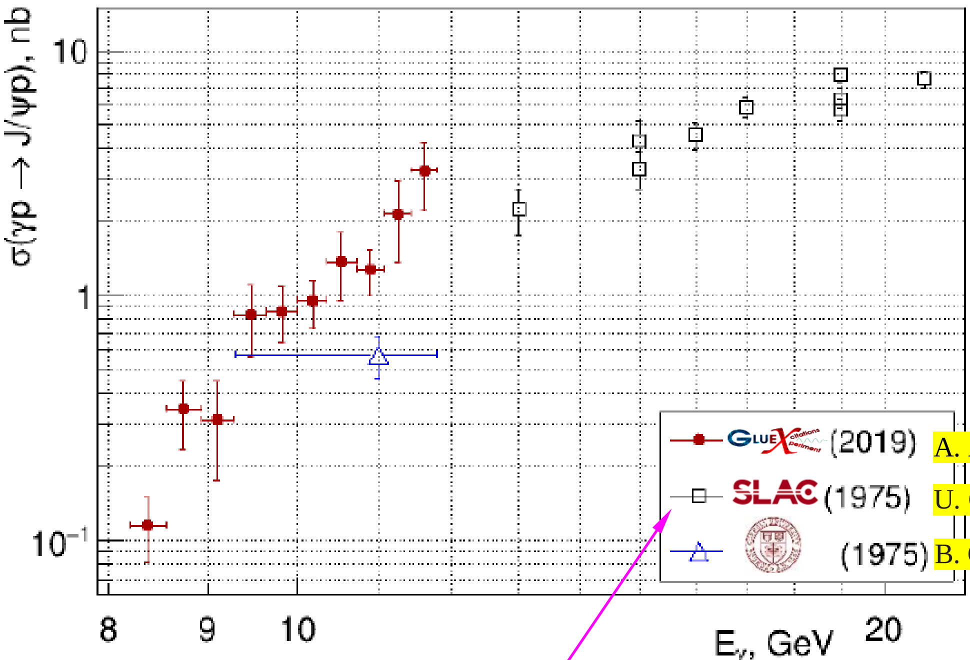



- Overall normalization error is 27%.

# *Total Xsection for $\gamma p \to J/\psi p \to e^+e^- p$ @ $J/\psi$ Threshold*

A. Ali *et al*, Phys Rev Lett **123**, 072001 (2019)

$$\sigma_{J/\psi}(E_\gamma) = \frac{N_{J/\psi}(E_\gamma)}{N_{BH}(E_\gamma)} \frac{\sigma_{BH}(E_\gamma)}{\mathcal{B}_{J/\psi}} \frac{\varepsilon_{BH}(E_\gamma)}{\varepsilon_{J/\psi}(E_\gamma)}$$




A. Ali *et al*, Phys Rev Lett **123**, 072001 (2019)

U. Camerini *et al*, Phys Rev Lett **35**, 483 (1975)

B. Gittelman *et al*, Phys Rev Lett **35**, 1616 (1975)

- Yields [**N**($J/\psi$) & **N**(BH)] extracted from fits of **M**($e^+e^-$) & **E**/**p** in bins of energy.
- **σ**(BH) calculated using analytical & numerical results of **EM** tree level diagrams.
- Syst errors of individual data points assigned to max deviation when varying fitting methods.
- Errors dominated by statistics.

- SLAC experiment measured $d\sigma/dt$ at $t = t_{min}$ as function of $E_\gamma$.
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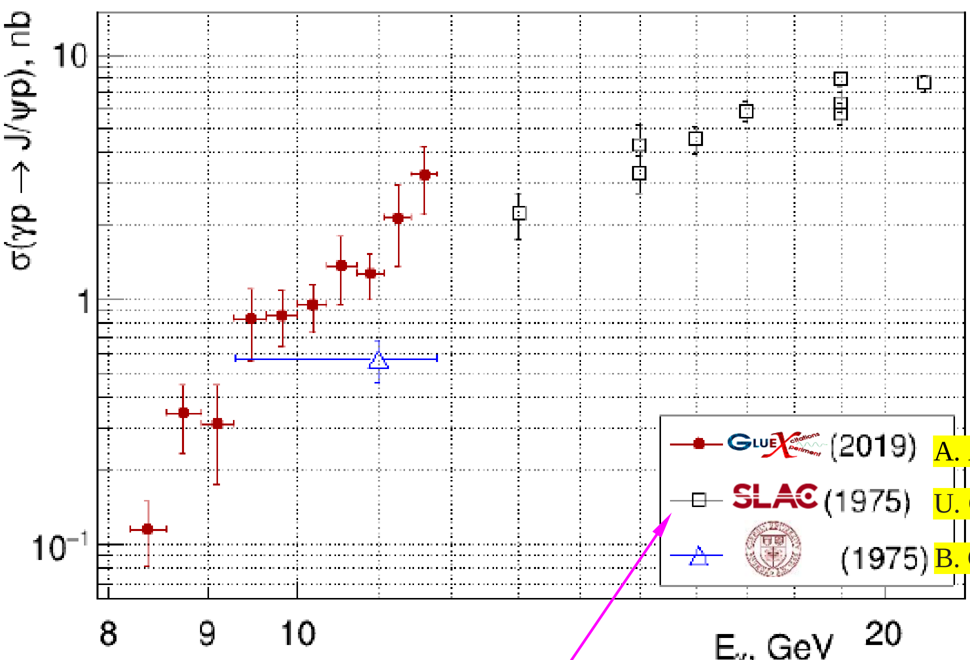


A. Ali *et al*, Phys Rev Lett **123**, 072001 (2019)

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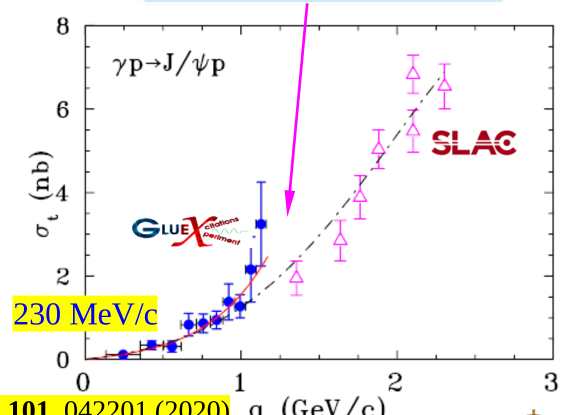
- To determine $\sigma_t$ from SLAC data, GlueX used dipole **t**-dependence.

- There is no discrepancy between GlueX & SLAC data.

| $a_i$ | GlueX | GlueX & SLAC |
|---|---|---|
| $a_1$ [nb/(GeV/c)] | $0.46 \pm 0.16$ | $0.53 \pm 0.12$ |
| $a_3$ [nb/(GeV/c)$^3$] | $0.83 \pm 0.91$ | $0.78 \pm 0.16$ |
| $a_5$ [nb/(GeV/c)$^5$] | $0.28 \pm 0.87$ | $-0.06 \pm 0.03$ |
| $\chi^2$/dof | 0.67 | 0.98 |

$\sigma_t(q) = b_1 q + b_3 q^3 + b_5 q^5$




IS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (2020)

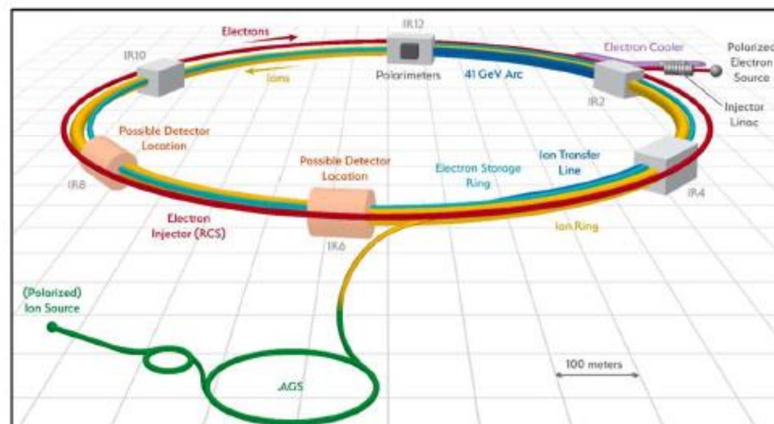
# Electron Ion Collider Receives CD-0 Approval

- EIC Panel evaluated proposals from JLAB and BNL (Aug – Oct, 2019)
- CD-0 approved Dec. 19, 2019
- DOE announced selection of Brookhaven National Lab to host EIC Jan. 9, 2020

**U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility**

January 9, 2020

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory will provide crucial infrastructure for the new Electron Ion Collider.




Courtesy of S. Henderson, JLUO, June 2020

11

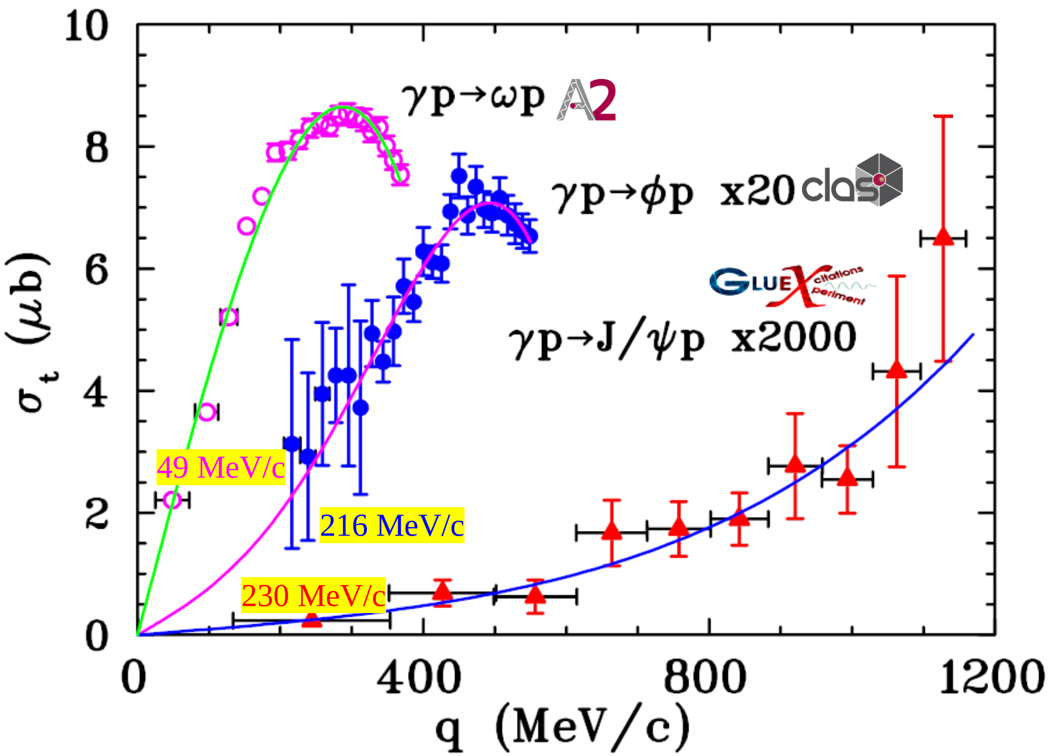
Jefferson Lab

# Total Cross Section Fits

# Total Cross Sections for Vector-Meson Photoproduction off Proton

- Traditionally, $\sigma_t$ behavior of near-threshold binary inelastic reaction $m_a + m_b < m_c + m_d$ is described as series of odd powers in $q$ (even powers in case of elastic).

$$\sigma_t(q) = b_1 q + b_3 q^3 + b_5 q^5$$



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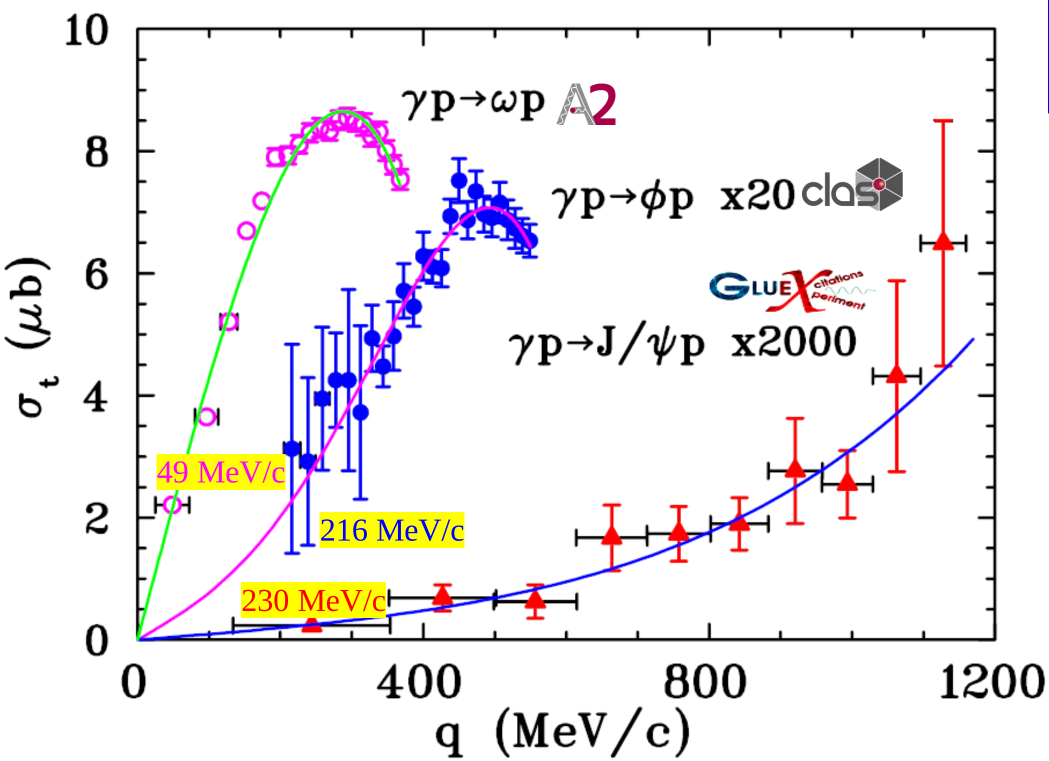
$$\sigma_t(q) = b_1 q + b_3 q^3 + b_5 q^5$$

- Linear term is determined by two independent *S*-waves only with total spin *1/2* &/or *3/2*.
- Contributions to cubic term come from both *P*-wave amplitudes & **W** dependence of *S*-wave amplitudes,
- Fifth-order term arises from *D*-waves & **W** dependencies of *S*- & *P*-waves.



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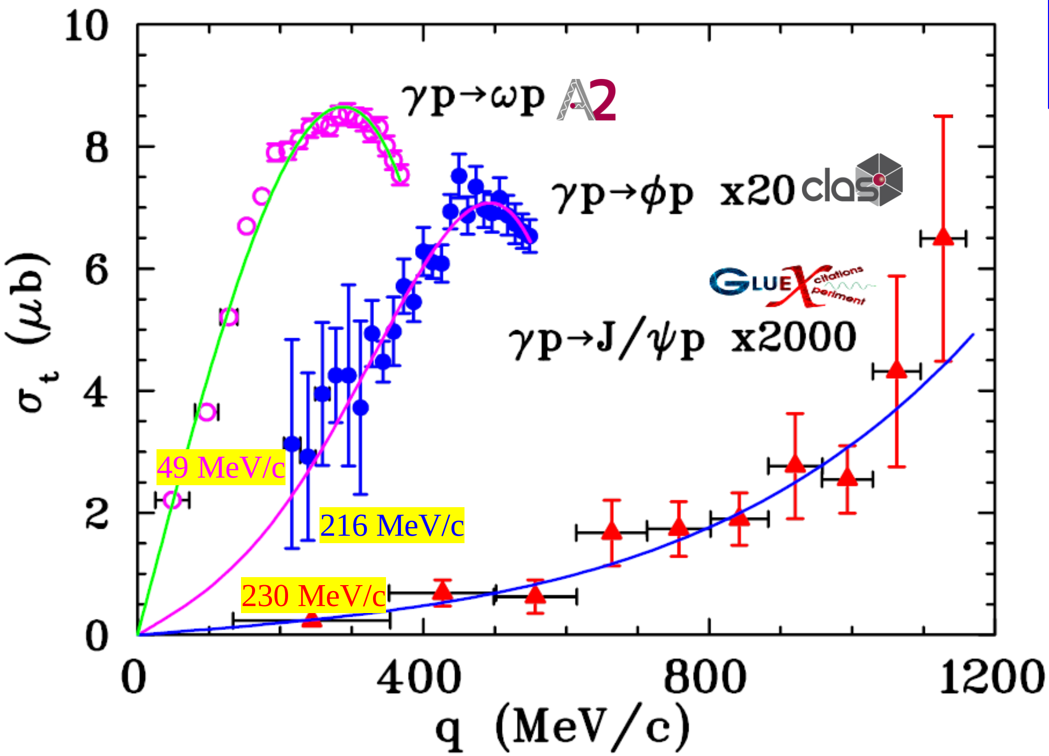


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A2: $b_1$ = (**4.42**±0.14) x $10^{-2}$ μb/(MeV/c)
IS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (2015)

CLAS: $b_1$ = (**3.40**±1.15) x $10^{-4}$ μb/(MeV/c)
IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (2020)

GlueX: $b_1$ = (**0.46**±0.16) x $10^{-6}$ μb/(MeV/c)
IS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (2020)

- Dramatic differences in hadronic factors $h_{Vp} = (b_1)^{1/2}$, as slopes ($b_1$) of $\sigma_t$ @ threshold as function of $q$ varies significantly from $\omega$ to $\phi$ to $J/\psi$.

- Therefore, such big difference in SL is determined mainly by hadronic factor $h_{Vp}$.

# Brief Tour through SLs

# *What is Known for $\omega N$ Scattering Length*

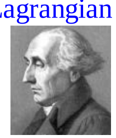
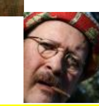
A2 $|\alpha_{\omega p}| = (0.82 \pm 0.03)$ fm from phenomenology — IS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (2015)


$\alpha_{\omega p} = (-0.97 \pm 0.16 \pm 0.03 + i0.07 \pm 0.15 \pm 0.19)$ fm from phenomenology — T. Ishikawa *et al*, Phys Rev C **101**, 052201(R) (2020)

$\alpha_{\omega p} = (-0.026 + i0.28)$ fm from coupled-channel analysis of $\omega$ production in $\pi N$ & $\gamma N$ — V. Shklyar *et al*, Phys Rev C **71**, 055206 (2005)


$\alpha_{\omega p} = (-0.41 \pm 0.05)$ fm from the QCD sum-rule — Y. Koike & A. Hayashigaki, Prog Theor Phys **98**, 631 (1997)

$\alpha_{\omega p} = (1.6 + i0.30)$ fm from effective Lagrangian approach based on chiral symmetry — F. Klingl, T.Waas, & W.Weise, Nucl Phys A **650**, 299 (1999)

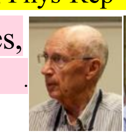




$\alpha_{\omega p} = (-0.44 + i0.20)$ fm from coupled-channel unitary approach — M.F.M. Lutz, G. Wolf, & B. Friman, Nucl Phys A **706**, 431 (2002); **765**, 495 (2006)

$\alpha^{1/2}_{\omega N} = (-0.0454 - i0.0695)$ fm from dynamical coupled-channel analysis
$\alpha^{3/2}_{\omega N} = (-0.180 - i0.0597)$ fm
— M.W. Paris, Phys Rev C **79**, 025208 (2009)

$|\alpha_{\omega N}| = (0.81 \pm 0.41)$ fm from meson-nucleus optical potential — E. Friedman & A. Gal, Phys Rep **452**, 89 (2007)

- That turned out to be in agreement, within uncertainties, with estimate made using A2 & ELPH data.




- Theoretical approaches lead to ImSL << ReSL.

# *What is Known for $\phi N$ Scattering Length*

$|\alpha_{\phi p}|$ = (0.063 ± 0.010) fm from phenomenology

IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (2020)

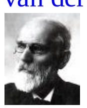
0.15 fm from forward coherent $f$-meson photoproduction from deuterons near threshold

W.C. Chang *et al*, Phys Lett B **658**, 209 (2008)

(–0.15 ± 0.02) fm from QCD sum rule analysis on spin-isospin averaged $\rho$, $\omega$, & $\phi$ meson-$N$ scattering

Y. Koike & A. Hayashigaki, Prog Theor Phys **98**, 631 (1997)

~2.37 fm from QCD van der Waals attractive $\phi N$ potential for analysis of $\phi$-nucleus bound states



H. Gao, T.S.H. Lee, & V. Marinov, Phys Rev C **63**, 022201 (2001)

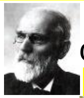
- This value is more than order of magnitude greater than results using clas exp data & provides problem for this particular potential model.

A.I. Titov *et al*, Phys Rev C **76**, 048202 (2007)

- There's less known about $N\phi$ couplings.

# What is known for $J/\psi p$ Scattering Length

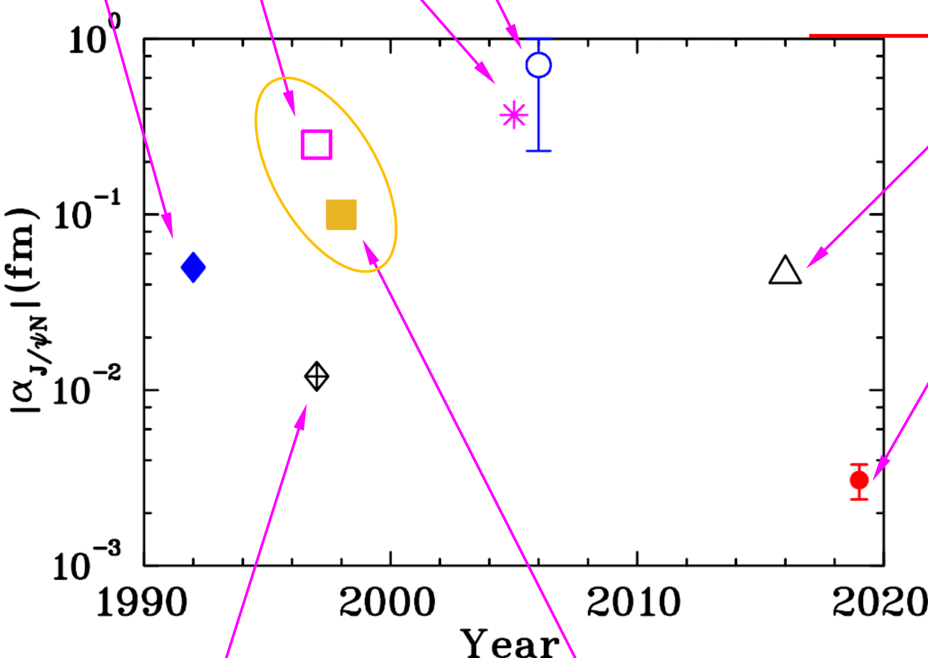
Heavy-quarkonia gluonic interactions, LE QCD theorem
A.B. Kaidalov & P.E. Volkovitsky, Phys Rev Lett. **69**, 3155 (1992)



Gluonic van der Waals interaction
S.J. Brodsky & G.A. Miller, Phys Lett B **412**, 125 (1997)

Multipole expansion & low-energy theorems in QCD
A. Sibirtsev & M.B. Voloshin, Phys Rev D **71**, 076005 (2005)

Lattice QCD
K. Yokokawa *et al*, Phys Rev D **74**, 034504 (2006)




Hadron size

Global fit to SLAC previous diff & total cross section data
O. Gryniuk & M. Vanderhaeghen, Phys Rev D **94**, 074001 (2016)

Fit GlueX total threshold cross sections
IS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (2020)

Gauge-invariant q-bar-q Green's function
V.I. Shevchenko, Phys Lett B **392**, 457 (1997)

QCD sum rules
A. Hayashigaki, Prog Theor Phys **101**, 923 (1999)

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- Following D. Kharzeev *et al*, Eur Phys J C **9**, 459 (1999)
  ImA << ReA

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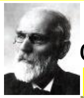
A.B. Kaidalov & P.E. Volkovitsky, Phys Rev Lett. **69**, 3155 (1992)



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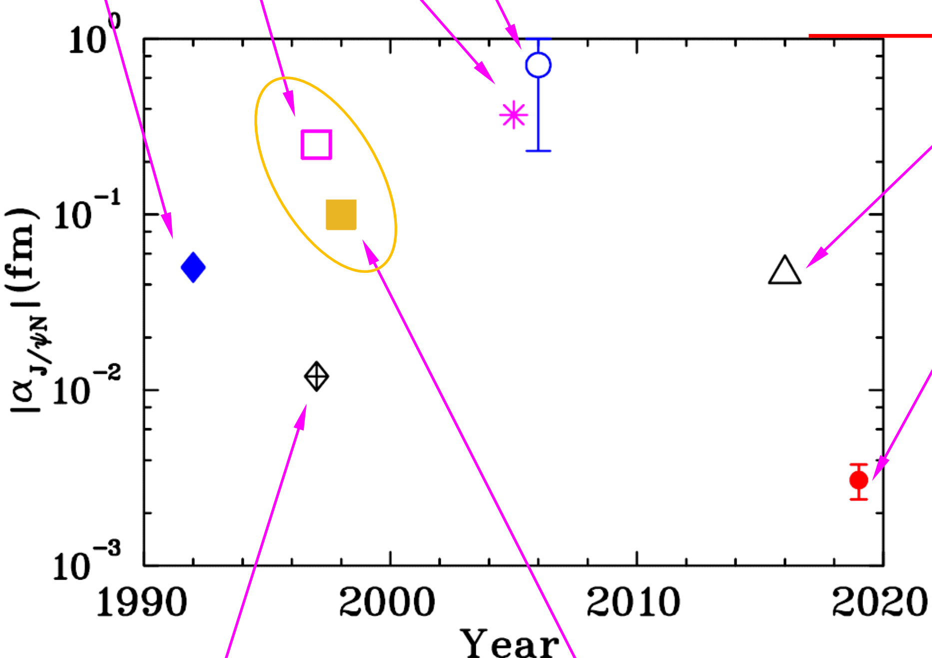


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- Our result for $J/\psi p$ **SL disagrees** with previous theoretical predictions individually, though it is within wide range of these predictions.

Gauge-invariant q-bar-q Green's function
V.I. Shevchenko, Phys Lett B **392**, 457 (1997)

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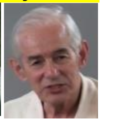
# *VMD for J/ψN Interaction*

- There is no alternative VMD to get ***J/ψ p*** SL from meson photoproduction.

Courtesy of A. Vainshtein & M. Ryskin, July 2020

# *VMD for $J/\psi N$ Interaction*

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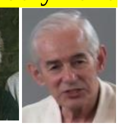
Courtesy of A. Vainshtein & M. Ryskin, July 2020

- To estimate theoretical uncertainty related to VMD model, one refer to estimation of cross section of $J/\psi$ photoproduction in *peripheral model* & found strong energy dependence close to threshold because non-diagonal $\gamma p \to Vp$ & elastic $Vp \to Vp$ must have larger transfer momenta vs elastic scattering. This result in violation of VMD by factor of **5**.

K.G. Boreskov & B.L. Ioffe, Sov J Nucl Phys **25**, 331 (1977)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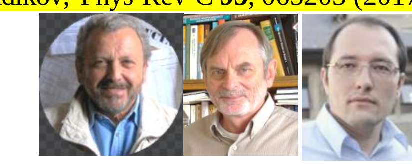
- **Color** factor for *charmonium* is **1**/**9** while for *open charm* is **8**/**9**.

B.Z. Kopeliovich, I. Schmidt, & M. Siddikov, Phys Rev C **95**, 065203 (2017)



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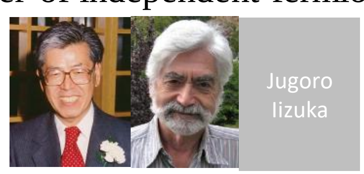
- Additional suppression factor for $J/\psi N$ interaction @ threshold is **OZI** rule. **OZI** suppressed processes have larger number of independent fermion loops compared with non-suppressed processes.

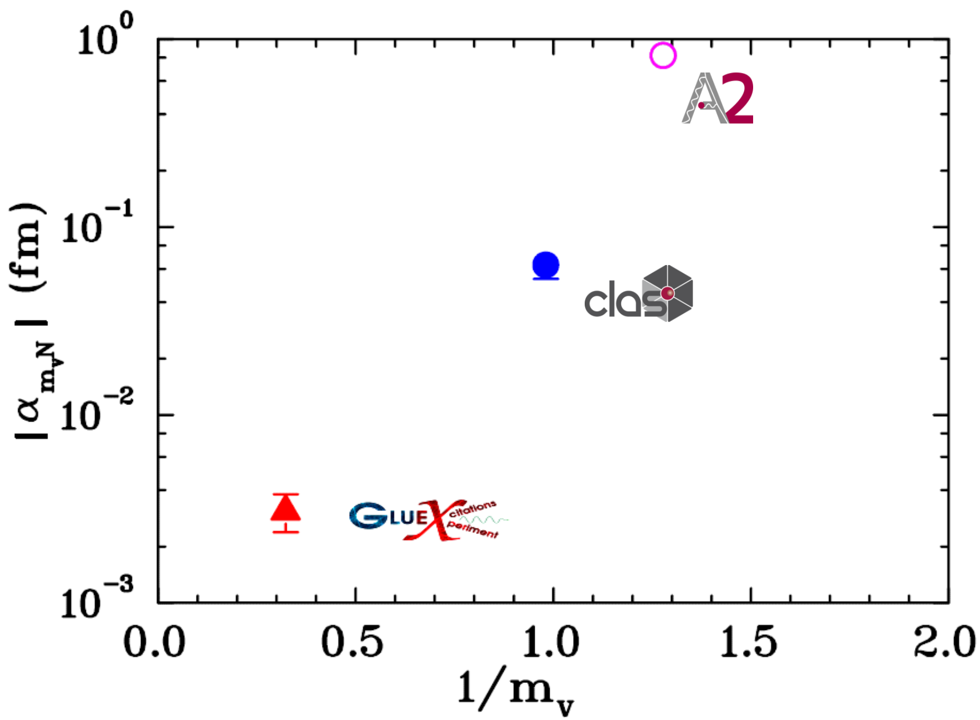



Courtesy of B. Kopeliovich & R. Jaffe, June 2020

# *Vector-Meson – Nucleon SL*

- **EM** factor $R_V$ for each vector-meson are close to each other.
- Therefore, such big difference in SL is determined mainly by **hadronic** factor $h_{Vp}$.

$$|\alpha_{Vp}| = R_V h_{Vp}$$



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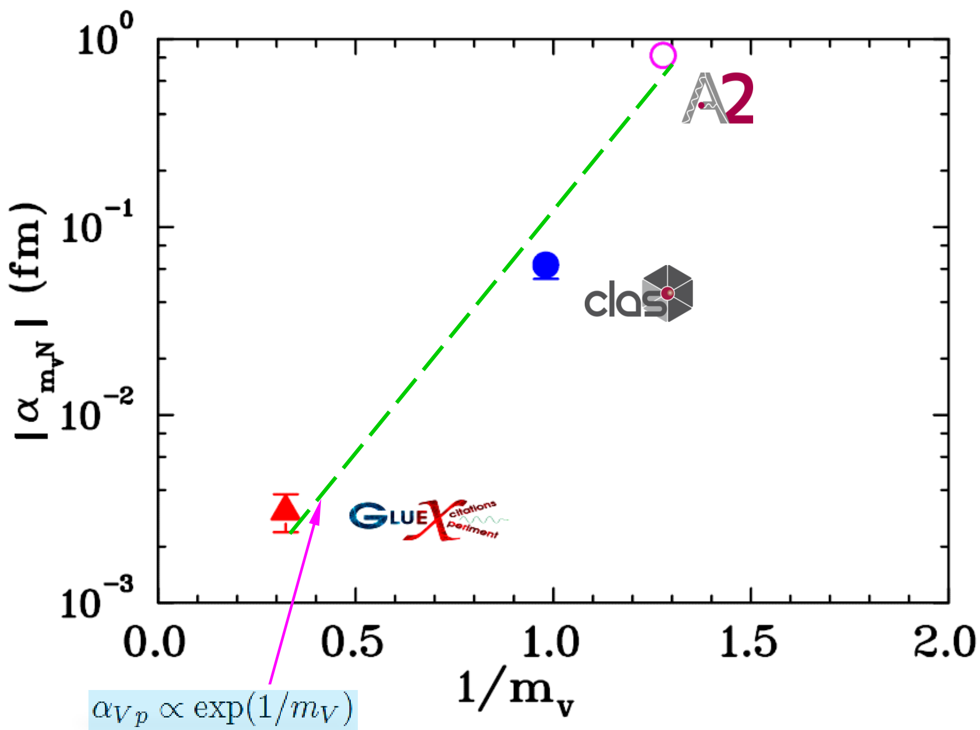


$$\alpha_{Vp} \propto \exp(1/m_V)$$

- Such small value of $\phi p$ SL compared to typical hadron size of **1 fm**, indicates that proton is more transparent for $\phi$-meson compared to $\omega$-meson, & is much less transparent than for $J/\psi$ -meson.

$$|\alpha_{J/\psi p}| \ll |\alpha_{\phi p}| \ll |\alpha_{\omega p}|$$

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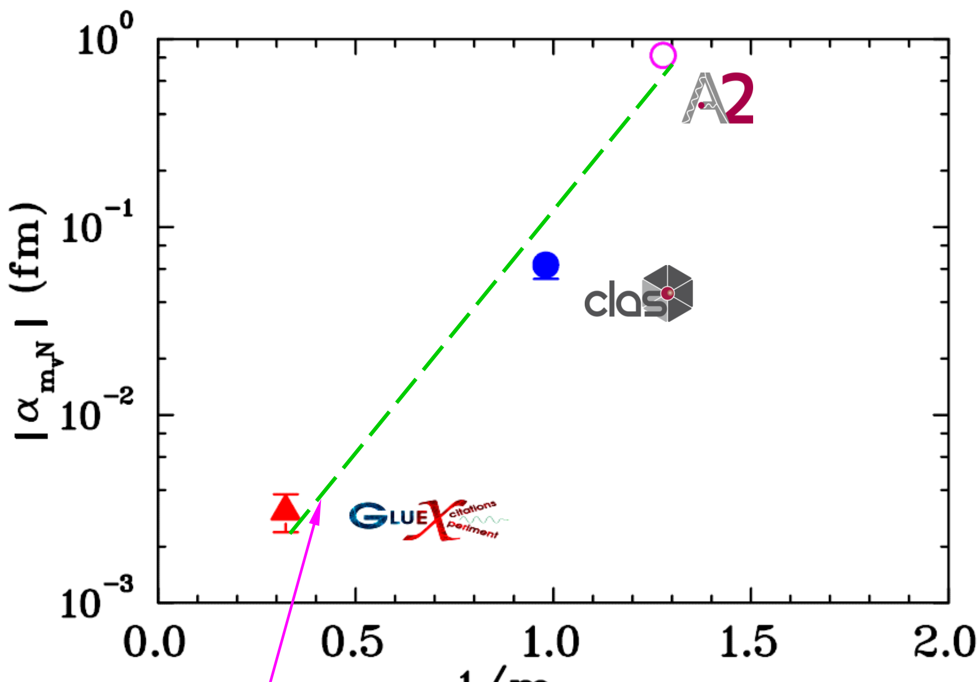


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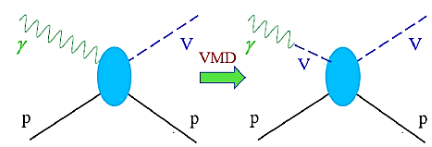


- p→V coupling is proportional to $\alpha_s$ & *separation* of corresponding quarks. This *separation* (in zero approximation) is proportional to $1/m_V$.

# Ongoing Activities

# *Expectation from* Jefferson Lab

- Present & future experiments @ CLAS12 & 007$^{J/\psi}$ that are aimed to measure charmonium production on proton & nuclei will allow further studies of $J/\psi N$ interaction & will give also access to variety of other *interesting* physics aspects that are present in near-threshold region.

- $\sigma_t$ is unmeasurable in both cases & requires extraction from $d\sigma/dt$.
- Critical factor is how close to threshold both experiments will go .

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- In particular, low-energy $J/\psi$ photoproduction $d\sigma/dt$ data can be used to extract fraction of *nucleon's mass* arising from gluons, & corresponding ***spatial distribution***.

D. Kharzeev *et al*, Eur Phys J C **9**, 459 (1999)

# *Expectation from* Jefferson Lab

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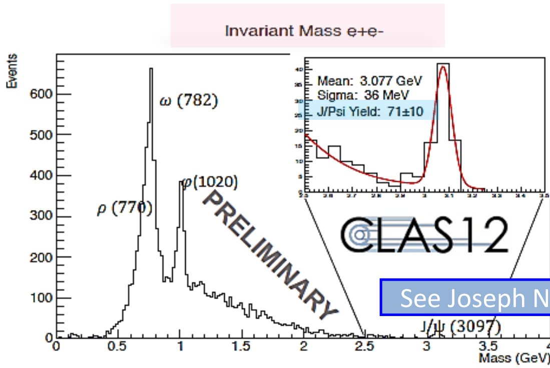
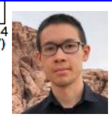
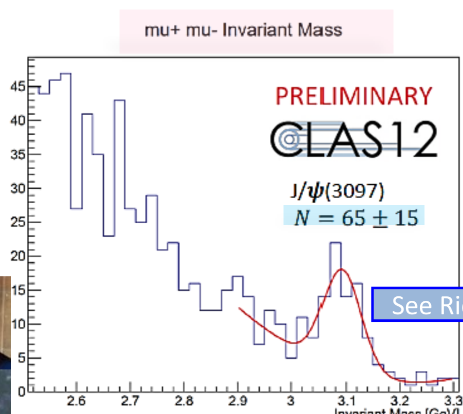
*Time-like Compton Scattering &*
*$J/\psi$ Photoproduction (E12-12-001A)*

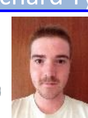



See Joseph Newton's talk






See Richard Tyson's talk



CLAS12 Run Group A Jeopardy PAC48

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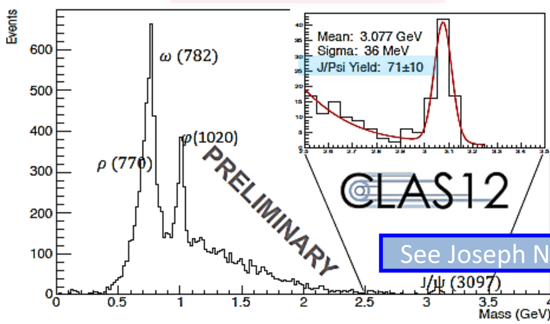
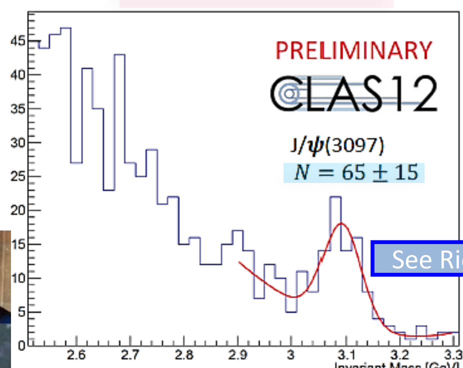
- Critical factor is how close to threshold both experiments will go .

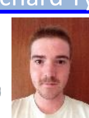
*Time-like Compton Scattering & $J/\psi$ Photoproduction (E12-12-001A)*

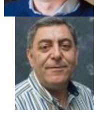



See Joseph Newton's talk



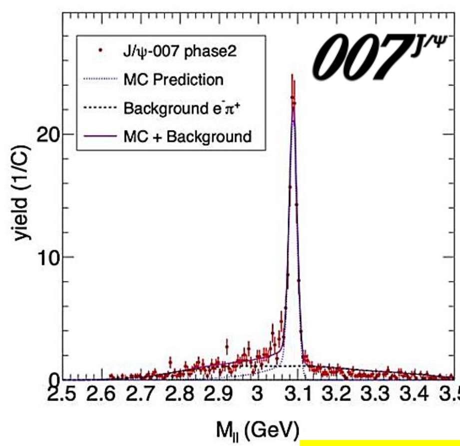

See Richard Tyson's talk

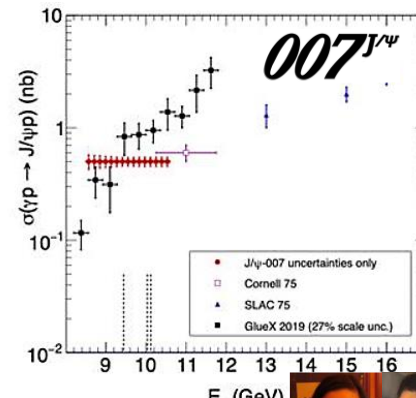




CLAS12 Run Group A Jeopardy PAC48

*Search for LHCb Charmed "Pentaquark" using Photoproduction of $J/\psi$ @ Threshold in Hall C @ Jefferson Lab (E12-16-007)*

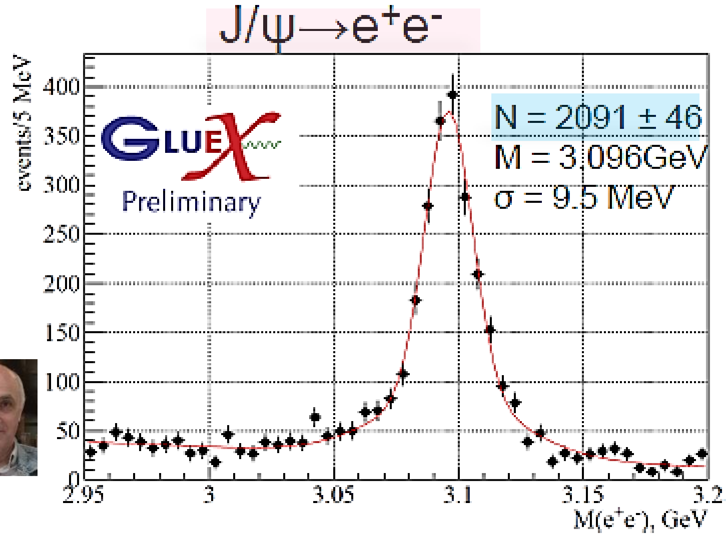


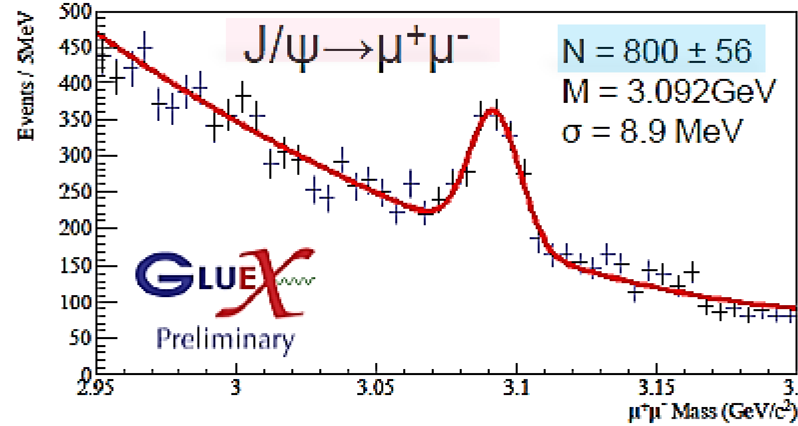



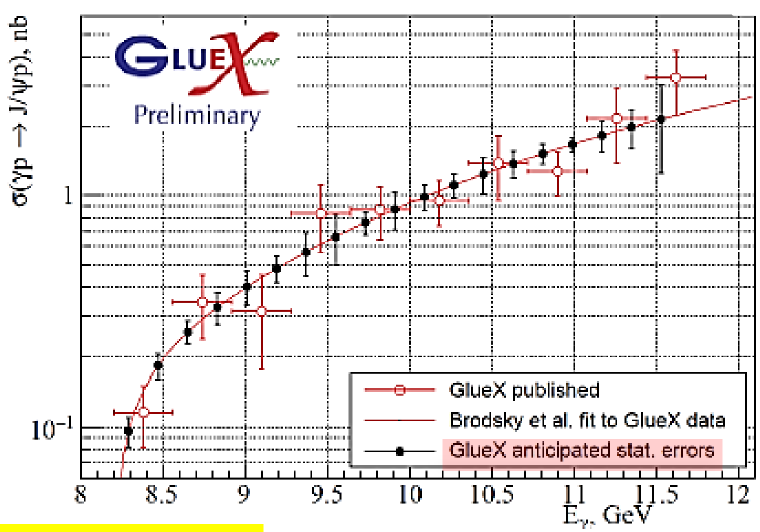

B. Duran & S. Joosten, APS April 2020

# *Expectation from* Jefferson Lab

- Total GlueX statistics for 2016–2018



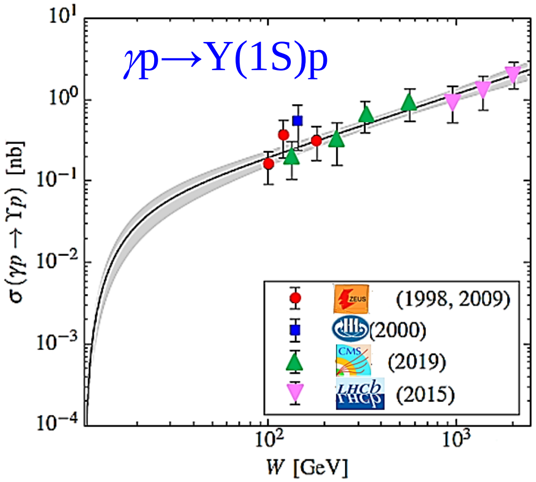





Courtesy of A. Austeregesilo, JLUO, June 2020

# *Expectation from*

- Such small value of $\phi p$ SL compared to typical hadron size of **1 fm**, indicates that proton is more transparent for $\phi$-meson compared to $\omega$-meson, & is much less transparent than for $J/\psi$ -meson.




$\sigma_t(\gamma p \to \Upsilon(1S)p) \sim 0.01 \times \sigma_t(\gamma p \to J/\psi p)$

O. Gryniuk *et al*, arXiv:2005.09293 [hep-ph]

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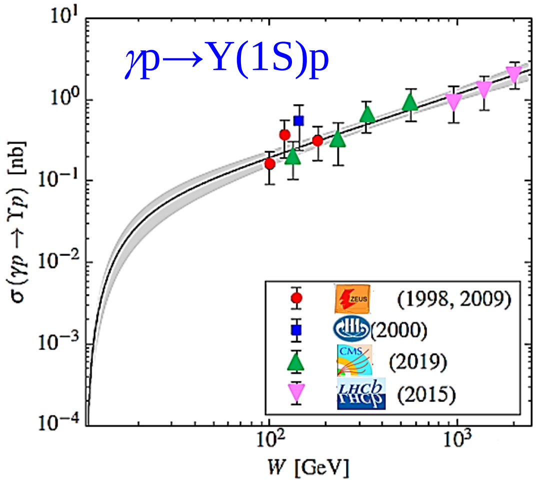
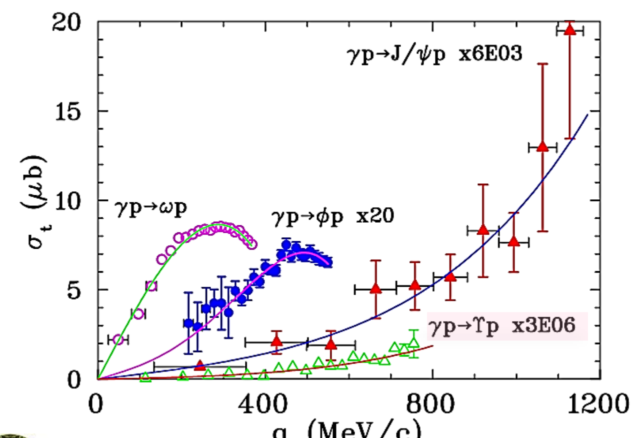



$\sigma_t(\gamma p \rightarrow Y(1S)p) \sim 0.01 \times \sigma_t(\gamma p \rightarrow J/\psi p)$

O. Gryniuk *et al*, arXiv:2005.09293 [hep-ph]

- GlueX threshold experiment projects on measurements for *Y(1S)p*.



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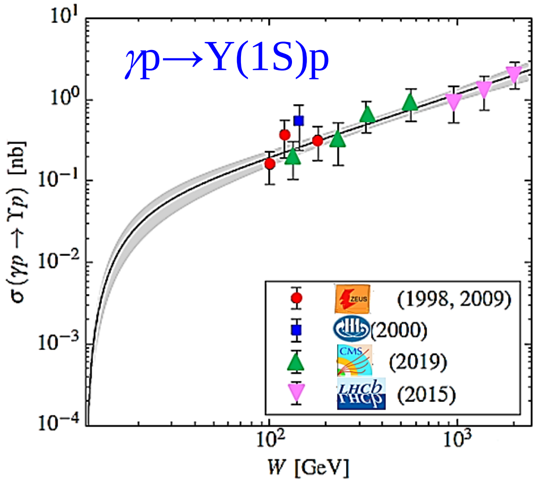


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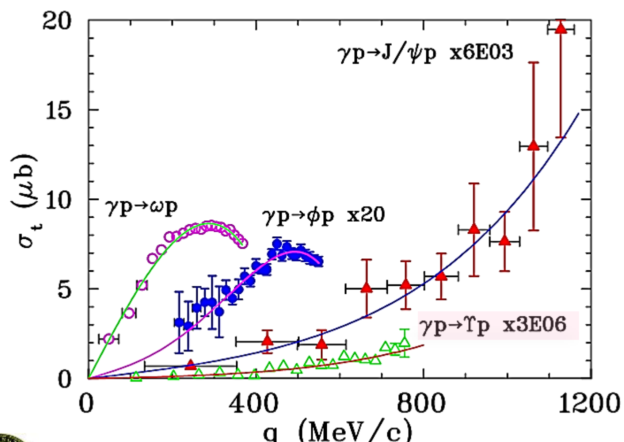
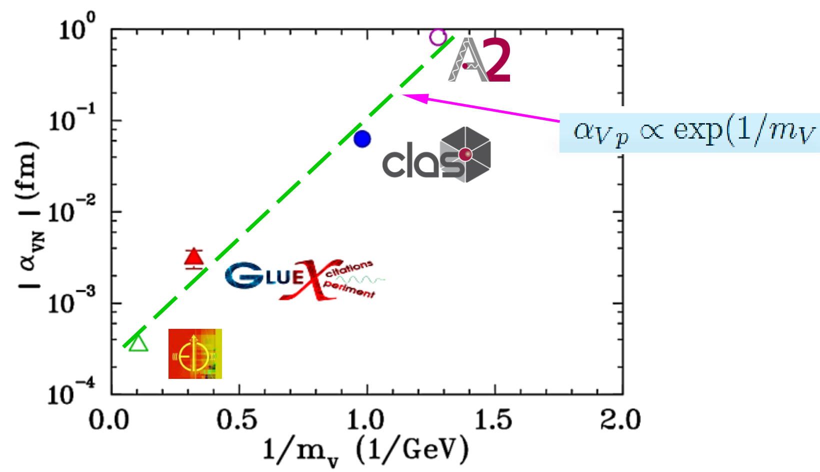



$|\alpha_{Yp}| << |\alpha_{J/\psi p}| \ll |\alpha_{\phi p}| \ll |\alpha_{\omega p}|$



# Summary


- High accurate measurements near-threshold by A2, clas, & GlueX allow to determine $\sigma_t$ of reactions $\gamma p \to Vp$ & to estimate absolute value of $Vp$ SLs within **VMD** model.

| | |
|---|---|
| A2 | $\lvert\alpha_{\omega p}\rvert$ = (0.82 ± 0.03) fm |
| clas | $\lvert\alpha_{\phi p}\rvert$ = (0.063 ± 0.010) fm |
| GlueX | $\lvert\alpha_{J/\psi p}\rvert = (3.08 \pm 0.55(\text{stat.}) \pm 0.42(\text{syst.}))$ mfm. |

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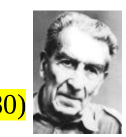
- Due to small size of 'young' $J/\psi$, measured **SL** is very small. $J/\psi$ crated by photon then most probably $J/\psi$ is not formed completely & its radius is smaller than that for normal $J/\psi$. Therefore, one observe stronger suppression.

E.L. Feinberg, Sov Phys Usp, **23**, 629 (1980)

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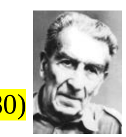

- Light vector-meson can be 'young' as well. This depends on particular kinematics. Another point is that for slow heavy quark, we need more time to reach equilibrium, i.e., to form final (long-living/static) vector-meson.


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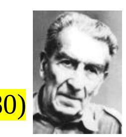

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- will open new window in solving $VN$ SL puzzle. It will allow to make deal with `young' $\Upsilon$ as well.

# *Acknowledgements*

I thank

| | |
|---|---|
| *Yakov Azimov* | *Konstantin Boreskov* |
| *Stanley Brodsky* | *Daniel Carman* |
| *Eugene Chudakov* | *Michael Eides* |
| *Denis Epifanov* | *Sergey Furletov* |
| *Takatsugu Ishikawa* | *Robert Jaffe* |
| *Dmitry Kharzeev* | *Boris Kopeliovich* |
| *Jerry Miller* | *Lubomir Pentchev* |
| *Michael Ryskin* | *Alexander Titov* |
| *Arkady Vainstein* | *Michael Voloshin* |

for useful remarks & continuous interest in project.

# Backup

# Sources

PHYSICAL REVIEW LETTERS 123, 072001 (2019)

Editors' Suggestion

## First Measurement of Near-Threshold $J/\psi$ Exclusive Photoproduction off the Proton

A. Ali,[10] M. Amaryan,[22] E. G. Anassontzis,[2] A. Austregesilo,[3] M. Baalouch,[22] F. Barbosa,[14] J. Barlow,[7] A. Barnes,[3] E. Barriga,[7] T. D. Beattie,[23] V. V. Berdnikov,[17] T. Black,[20] W. Boeglin,[6] M. Boer,[4] W. J. Briscoe,[8] T. Britton,[14] W. K. Brooks,[24] B. E. Cannon,[7] N. Cao,[11] E. Chudakov,[14] S. Cole,[1] O. Cortes,[8] V. Crede,[7] M. M. Dalton,[14] T. Daniels,[20] A. Deur,[14] S. Dobbs,[7] A. Dolgolenko,[13] R. Dotel,[6] M. Dugger,[1] R. Dzhygadlo,[10] H. Egiyan,[14] A. Ernst,[7] P. Eugenio,[7] C. Fanelli,[16] S. Fegan,[8] A. M. Foda,[23] J. Foote,[12] J. Frye,[12] S. Furletov,[14] L. Gan,[20] A. Gasparian,[19] V. Gauzshtein,[25,26] N. Gevorgyan,[27] C. Gleason,[12] K. Goetzen,[10] A. Goncalves,[7] V. S. Goryachev,[13] L. Guo,[6] H. Hakobyan,[24] A. Hamdi,[10] S. Han,[29] J. Hardin,[16] G. M. Huber,[23] A. Hurley,[28] D. G. Ireland,[9] M. M. Ito,[14] N. S. Jarvis,[3] R. T. Jones,[5] V. Kakoyan,[27] G. Kalicy,[4] M. Kamel,[6] C. Kourkoumelis,[2] S. Kuleshov,[24] I. Kuznetsov,[25,26] I. Larin,[15] D. Lawrence,[14] D. I. Lersch,[7] H. Li,[3] W. Li,[28] B. Liu,[11] K. Livingston,[9] G. J. Lolos,[23] V. Lyubovitskij,[25,26] D. Mack,[14] H. Marukyan,[27] V. Matveev,[13] M. McCaughan,[14] M. McCracken,[3] W. McGinley,[3] J. McIntyre,[5] C. A. Meyer,[3] R. Miskimen,[15] R. E. Mitchell,[12] F. Mokaya,[5] F. Nerling,[10] L. Ng,[7] A. I. Ostrovidov,[7] Z. Papandreou,[23] M. Patsyuk,[16] P. Pauli,[9] R. Pedroni,[19] L. Pentchev,[14,*] K. J. Peters,[10] W. Phelps,[8] E. Pooser,[14] N. Qin,[21] J. Reinhold,[6] B. G. Ritchie,[1] L. Robison,[21] D. Romanov,[17] C. Romero,[24] C. Salgado,[18] A. M. Schertz,[28] R. A. Schumacher,[3] J. Schwiening,[10] K. K. Seth,[21] X. Shen,[11] M. R. Shepherd,[12] E. S. Smith,[14] D. I. Sober,[4] A. Somov,[14] S. Somov,[17] O. Soto,[24] J. R. Stevens,[28] I. I. Strakovsky,[8] K. Suresh,[23] V. Tarasov,[13] S. Taylor,[14] A. Teymurazyan,[23] A. Thiel,[9] G. Vasileiadis,[2] D. Werthmüller,[9] T. Whitlatch,[14] N. Wickramaarachchi,[22] M. Williams,[16] T. Xiao,[21] Y. Yang,[16] J. Zarling,[12] Z. Zhang,[29] G. Zhao,[11] Q. Zhou,[11] X. Zhou,[29] and B. Zihlmann[14]

PHYSICAL REVIEW C 91, 045207 (2015)

## Photoproduction of the $\omega$ meson on the proton near threshold

I. I. Strakovsky,[1,*] S. Prakhov,[1,2,3,†] Ya. I. Azimov,[4] P. Aguar-Bartolomé,[2] J. R. M. Annand,[5] H. J. Arends,[2] K. Bantawa,[6] R. Beck,[7] V. Bekrenev,[4] H. Berghäuser,[8] A. Braghieri,[9] W. J. Briscoe,[1] J. Brudvik,[3] S. Cherepnya,[10] R. F. B. Codling,[5] C. Collicott,[11,12] S. Costanza,[9] B. T. Demissie,[1] E. J. Downie,[1,2] P. Drexler,[8] L. V. Fil'kov,[10] D. I. Glazier,[5,13] R. Gregor,[8] D. J. Hamilton,[5] E. Heid,[1,2] D. Hornidge,[14] I. Jaegle,[15] O. Jahn,[2] T. C. Jude,[13] V. L. Kashevarov,[2,10] I. Keshelashvili,[15] R. Kondratiev,[16] M. Korolija,[17] M. Kotulla,[8] A. Koulbardis,[4] S. Kruglov,[4,‡] B. Krusche,[15] V. Lisin,[10] K. Livingston,[5] I. J. D. MacGregor,[5] Y. Maghrbi,[15] D. M. Manley,[6] Z. Marinides,[1] J. C. McGeorge,[5] E. F. McNicoll,[5] D. Mekterovic,[17] V. Metag,[8] D. G. Middleton,[2,14] A. Mushkarenkov,[9] B. M. K. Nefkens,[3,‡] A. Nikolaev,[7] R. Novotny,[8] H. Ortega,[2] M. Ostrick,[2] P. B. Otte,[2] B. Oussena,[1,2] P. Pedroni,[9] F. Pheron,[15] A. Polonski,[16] J. Robinson,[5] G. Rosner,[5] T. Rostomyan,[15] S. Schumann,[2] M. H. Sikora,[1,3] A. Starostin,[3] I. Supek,[17] M. F. Taragin,[1] C. M. Tarbert,[13] M. Thiel,[8] A. Thomas,[2] M. Unverzagt,[2,7] D. P. Watts,[13] D. Werthmüller,[15] and F. Zehr[15]

PHYSICAL REVIEW C 89, 055208 (2014)

## Data analysis techniques, differential cross sections, and spin density matrix elements for the reaction $\gamma p \to \phi p$

B. Dey,[1,*] C. A. Meyer,[1] M. Bellis,[1,†] M. Williams,[1,‡] K. P. Adhikari,[28] D. Adikaram,[28] M. Aghasyan,[17] M. J. Amaryan,[28] M. D. Anderson,[36] S. Anefalos Pereira,[17] J. Ball,[7] N. A. Baltzell,[3] M. Battaglieri,[18] I. Bedlinskiy,[21] A. S. Biselli,[11] J. Bono,[12] S. Boiarinov,[34] W. J. Briscoe,[14] W. K. Brooks,[35,34] V. D. Burkert,[34] D. S. Carman,[34] A. Celentano,[18] S. Chandavar,[27] L. Colaneri,[19] P. L. Cole,[15] M. Contalbrigo,[16] O. Cortes,[15] V. Crede,[13] A. D'Angelo,[19,31] N. Dashyan,[38] R. De Vita,[18] E. De Sanctis,[17] A. Deur,[34] C. Djalali,[33] D. Doughty,[8,34] M. Dugger,[4] R. Dupre,[3] A. El Alaoui,[3] L. El Fassi,[3] L. Elouadrhiri,[34] G. Fedotov,[33] S. Fegan,[36] J. A. Fleming,[10] M. Garçon,[7] N. Gevorgyan,[38] Y. Ghandilyan,[38] G. P. Gilfoyle,[30] K. L. Giovanetti,[22] F. X. Girod,[7,§] D. I. Glazier,[10] J. T. Goetz,[27] R. W. Gothe,[33] K. A. Griffioen,[37] M. Guidal,[20] K. Hafidi,[3] C. Hanretty,[13] N. Harrison,[9] M. Hattawy,[20] K. Hicks,[27] D. Ho,[1] M. Holtrop,[25] C. E. Hyde,[28] Y. Ilieva,[33,14] D. G. Ireland,[36] B. S. Ishkhanov,[32] D. Jenkins,[40] H. S. Jo,[20] K. Joo,[9,35] D. Keller,[27] M. Khandaker,[26] A. Kim,[23] W. Kim,[23] A. Klein,[28] F. J. Klein,[6] S. Koirala,[28] V. Kubarovsky,[34,29] S. E. Kuhn,[28] S. V. Kuleshov,[35,21] P. Lenisa,[16] K. Livingston,[36] H. Lu,[1] I. J. D. MacGregor,[36] N. Markov,[9] M. Mayer,[28] M. E. McCracken,[1,2] B. McKinnon,[36] T. Mineeva,[9] M. Mirazita,[17] V. Mokeev,[32,34] R. A. Montgomery,[17] K. Moriya,[1,‖] H. Moutarde,[7] E. Munevar,[14] C. Munoz Camacho,[20] P. Nadel-Turonski,[34] S. Niccolai,[20] G. Niculescu,[22] I. Niculescu,[28] M. Osipenko,[18] L. L. Pappalardo,[16] R. Paremuzyan,[38] K. Park,[33,23,¶] E. Pasyuk,[34,4] P. Peng,[39] J. J. Phillips,[36] S. Pisano,[17] O. Pogorelko,[21] S. Pozdniakov,[21] J. W. Price,[5] S. Procureur,[7] D. Protopopescu,[36] A. J. R. Puckett,[9] D. Rimal,[12] M. Ripani,[18] B. G. Ritchie,[4] A. Rizzo,[19] P. Rossi,[34,17] P. Roy,[13] F. Sabatié,[7] M. S. Saini,[13] D. Schott,[12] R. A. Schumacher,[1] E. Seder,[9] I. Senderovich,[4] Y. G. Sharabian,[34] A. Simonyan,[38] E. S. Smith,[34] D. I. Sober,[6] D. Sokhan,[20] S. S. Stepanyan,[23] P. Stoler,[29] I. I. Strakovsky,[14] S. Strauch,[33] V. Sytnik,[35] M. Taiuti,[27] W. Tang,[27] S. Tkachenko,[33] M. Ungaro,[9,29] B. Vernarsky,[1] A. V. Vlassov,[21] H. Voskanyan,[38] E. Voutier,[24] N. K. Walford,[6] D. P. Watts,[10] N. Zachariou,[33] L. Zana,[10] J. Zhang,[28] Z. W. Zhao,[33] and I. Zonta[19]

PHYSICAL REVIEW C 101, 045201 (2020)

## Comparative analysis of $\omega p$, $\phi p$, and $J/\psi p$ scattering lengths from A2, CLAS, and GlueX threshold measurements

Igor I. Strakovsky,[1,*] Lubomir Pentchev,[2] and Alexander I. Titov[3]
[1]Department of Physics, Institute for Nuclear Studies, The George Washington University, Washington DC 20052, USA
[2]Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA
[3]Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna 141980, Russia

PHYSICAL REVIEW C 101, 042201(R) (2020)

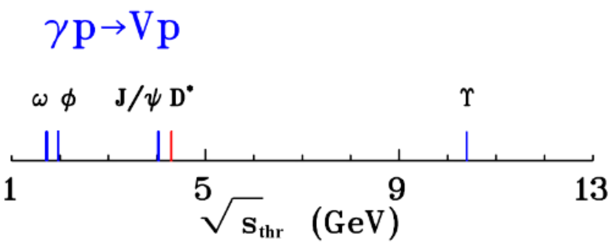
Rapid Communications

## $J/\psi\ p$ scattering length from GlueX threshold measurements

Igor I. Strakovsky,[1,*] Denis Epifanov,[2,3] and Lubomir Pentchev[4]
[1]Department of Physics, Institute for Nuclear Studies, The George Washington University, Washington, D.C. 20052, USA
[2]Budker Institute of Nuclear Physics SB RAS, Novosibirsk 630090, Russia
[3]Novosibirsk State University, Novosibirsk 630090, Russia
[4]Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA

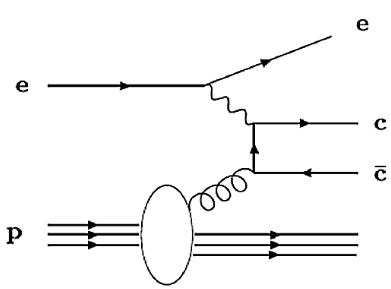
# *Open Charm*

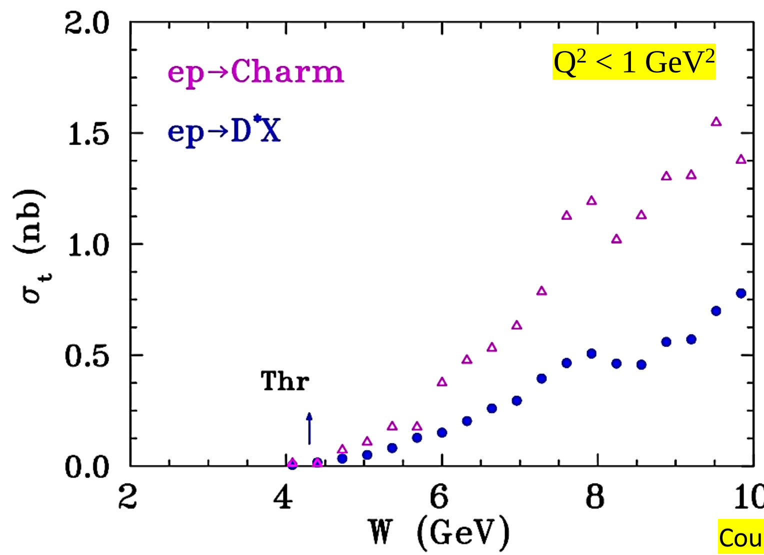
- It was shown that fluctuation of photon into open charm $\gamma p \to \bar{D}^0 \Lambda_c^+$ is preferable than into charmonium $J/\psi$. Suppression is just available phase space: $W_{thr}$(open charm) = **4.30** GeV while $W_{thr}$(charmonium) = **4.03** GeV).




K. Boreskov *et al*, Phys Rev D **47**, 919 (1993)

- There are no $\sigma_t$ for open charm @ threshold.




Courtesy of S. Furletov, July 2020

**HVQDIS**: B.W. Harris & J. Smith, Phys Rev D **57**, 2806 (1998)