Vector-Meson Photoproduction @ Threshold

*Igor Strakovsky**
The George Washington University

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

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

* Supported by DE-SC0016583

Sources

PHYSICAL REVIEW LETTERS 123, 072001 (2019)

Editors' Suggestion

First Measurement of Near-Threshold J/ψ 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 ω 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 ωp, ϕp, and $J/\psi p$ scattering lengths from A2, CLAS, and GlueX threshold measurements

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

Rapid Communications

J/ψ p scattering length from GlueX threshold measurements

Igor I. Strakovsky,[1,*] Denis Epifanov,[2,3] and Lubomir Pentchev[4]
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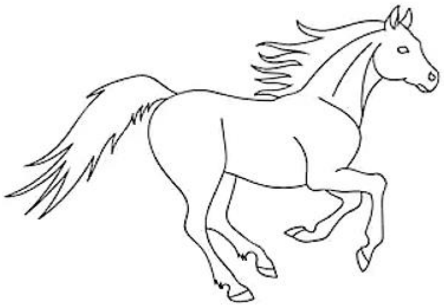
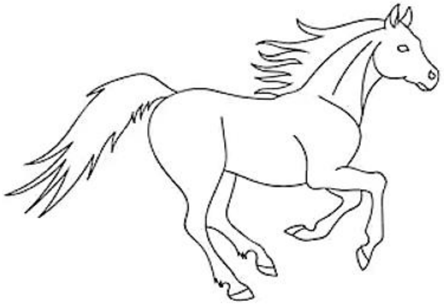
Outline



- Vector-Meson domestic Zoo.
- Vector-Meson - nucleon SL.
- Brief tour through experiments.
- σ_t fits.
- Brief tour through V-M 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***.

$$I^G(J^{PC}) = 0^-(1^{--})$$

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Name PDG	Quark Content	Γ (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*
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$J/\psi(1S)(3097)$	$c\bar{c}$	0.093	*Charmonium*
$\Upsilon(1S)(9460)$	$b\bar{b}$	0.052	*Quarkonium*

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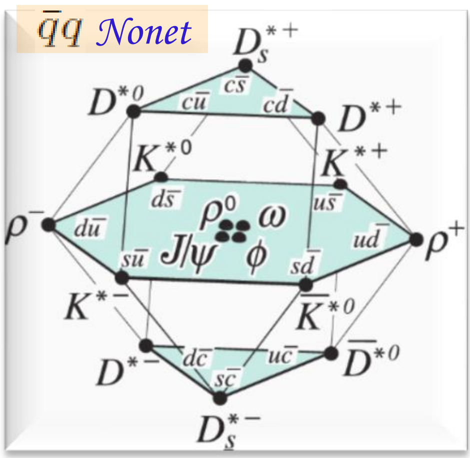

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- I will focus on **3** vector-mesons from $\bar{q}q$ ***Nonet*** which widths are **narrow** enough to study meson photoproduction @ threshold & where data are available.

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

α is fine-structure constant

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 $\sigma_t(q) = b_1 q + b_3 q^3 + b_5 q^5$,
  that is determined by interplay of strong (hadronic) & EM dynamics as

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

Vector-Meson – Nucleon SL Determination

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

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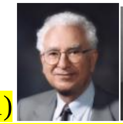
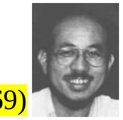
  that is determined by interplay of strong (hadronic) & EM dynamics as

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

- To **avoid** theoretical uncertainties, we did not
  - determine sign of **SL**,
  - separate **Re** & **Im** parts of **SL**,
  - extract Isospin **1/2** & **3/2** contributions.

VMD Approach

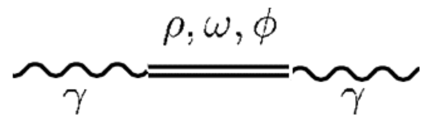


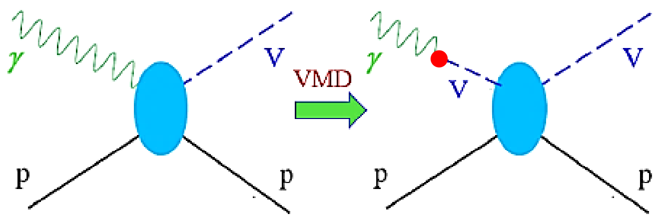


- Vector-Meson Dominance model relying on transparent current-field identities

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

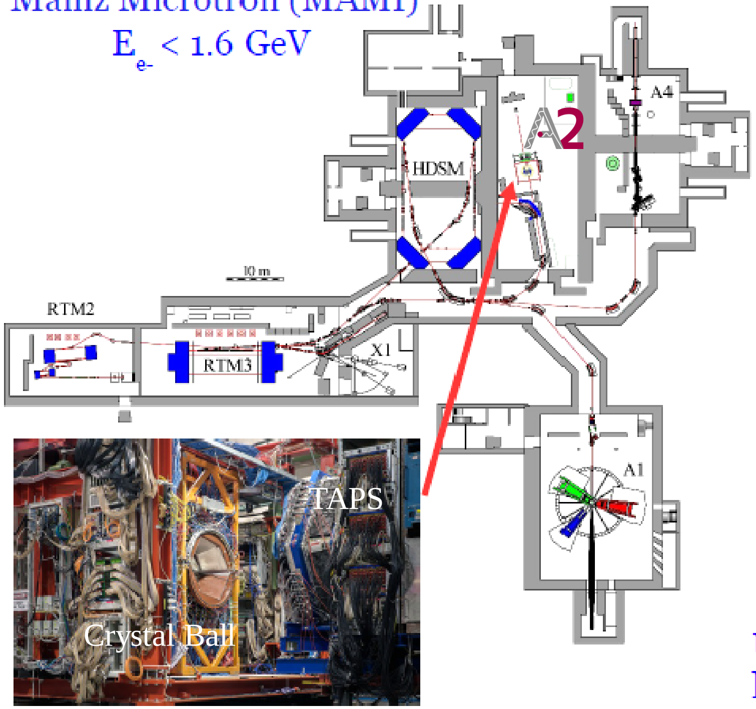
PDG particle data group	V	m_V	$\Gamma_{V\to e+e-}$	g_V	R_V
		(MeV)	(keV)		($MeV^{1/2}$)
	ω	782.65	0.60±0.02	8.53±0.14	390.5±6.4
	ϕ	1019.461	1.27±0.04	6.69±0.10	342.5±5.3
	J/ψ	3096.916	5.55±0.11	5.58±0.07	454.9±4.1
	Υ	9460.30	1.340±0.018	19.84±0.14	2655.0±162.2

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

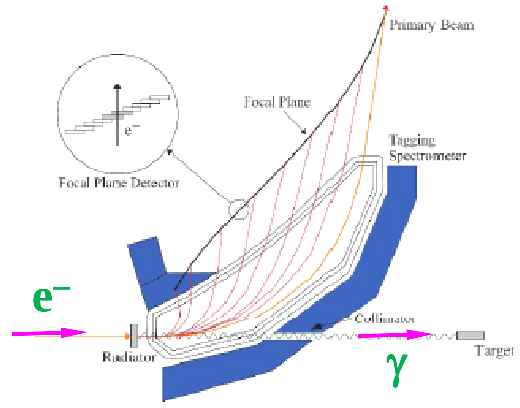
Brief Tour through Experiments

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/ψ* measurements @ SPEAR3 & b quark physics @ DESY.

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

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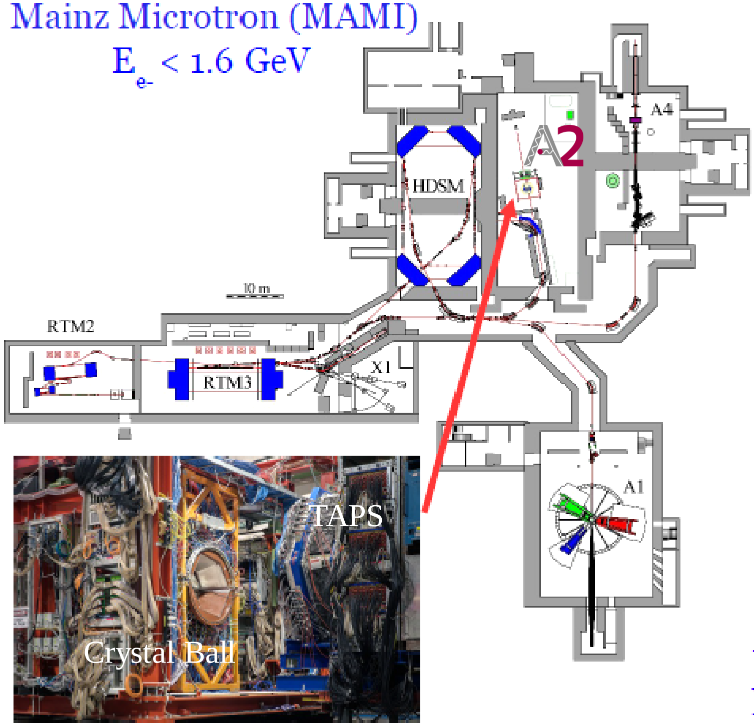

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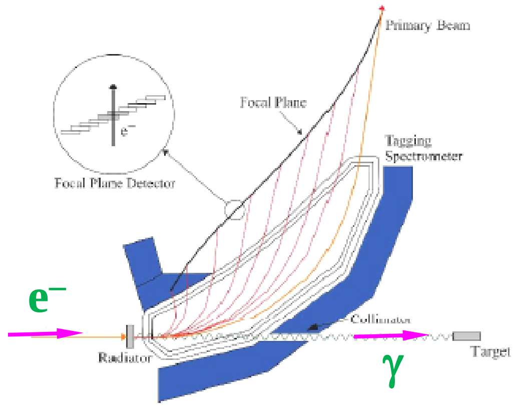

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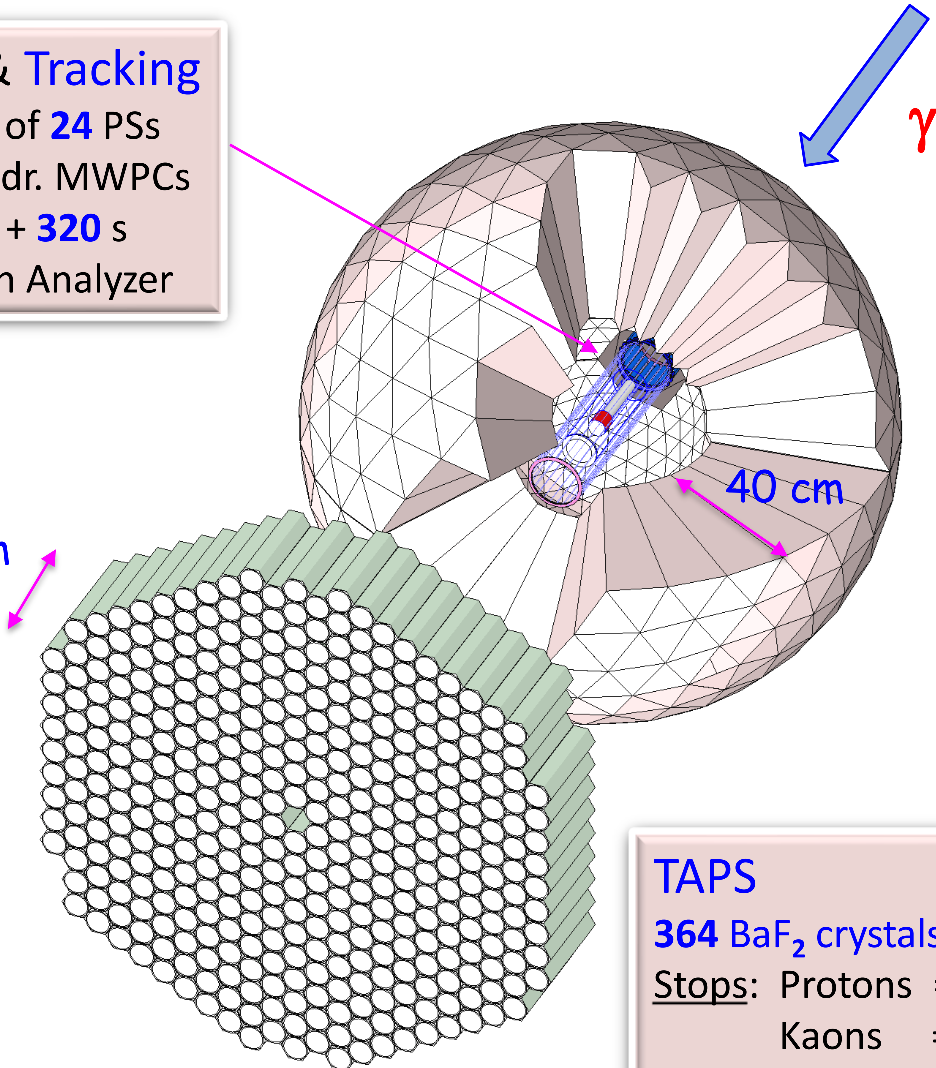
Crystal Ball, TAPS, & Tracking

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



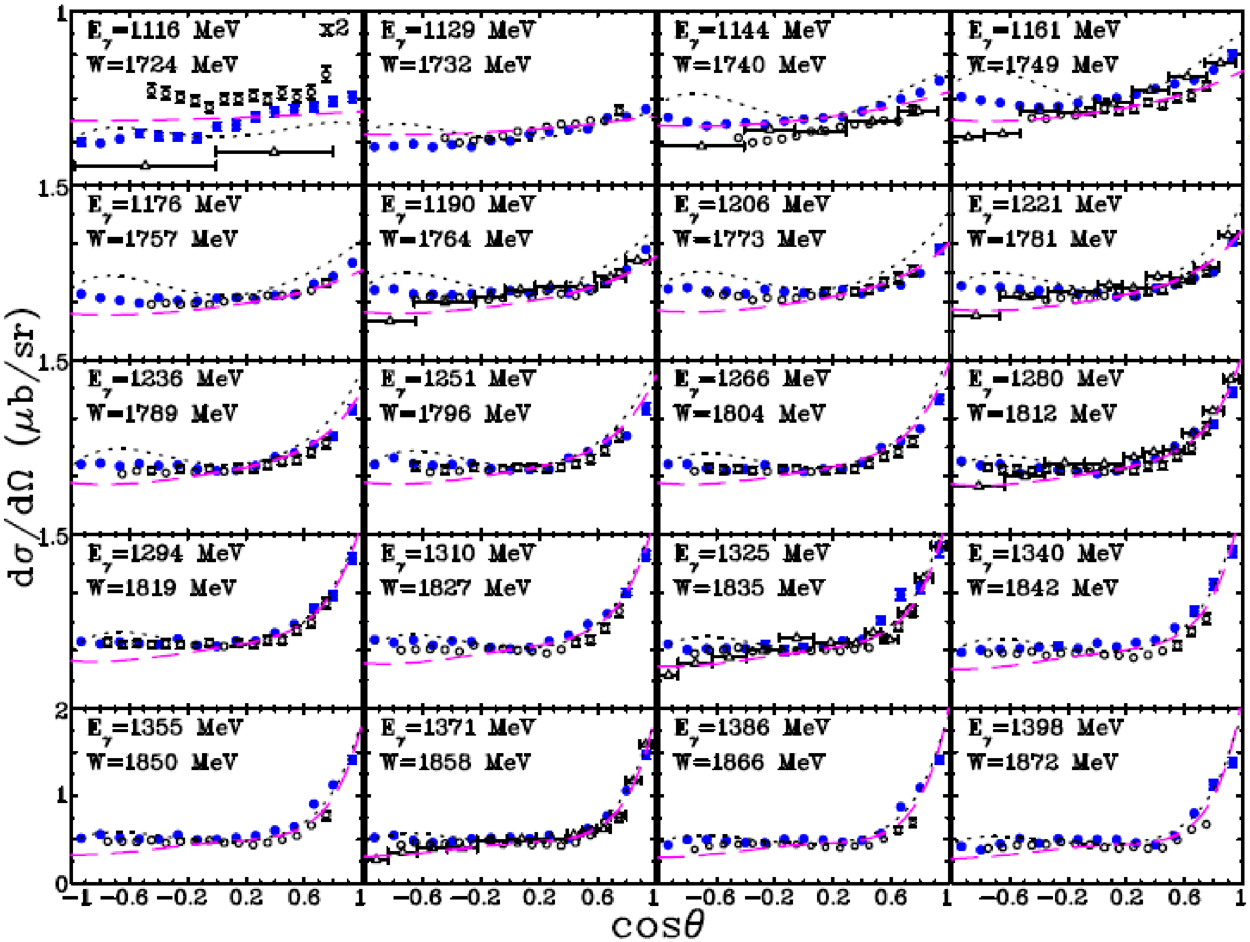
Crystal Ball
672 NaI(Tl) crystals [20°–160°]
Stops: Protons = 420 MeV
Kaons = 340 MeV
Chrg. p = 240 MeV
Chrg. m = 230 MeV

$\sigma(E)$ = 2 MeV
$\sigma(\theta)$ = 2.5°
$\sigma(\phi)$ = 2°/sinθ

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

$\gamma p \to \omega p \to \pi^0 \gamma p \to 3\gamma p$ Measurements

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



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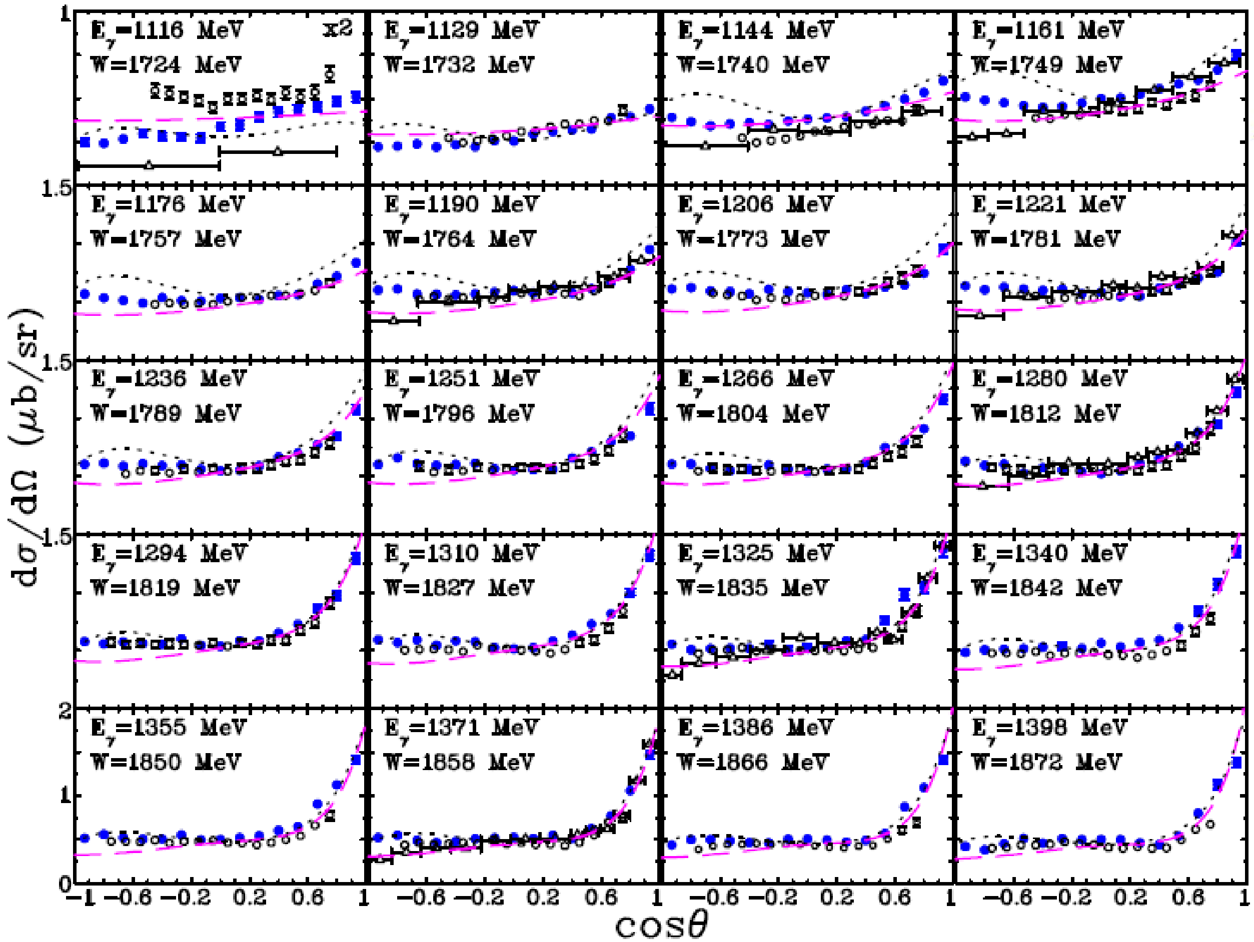


- Full production-angle coverage allows to determine σ_t.
- Legendre polynomial extension

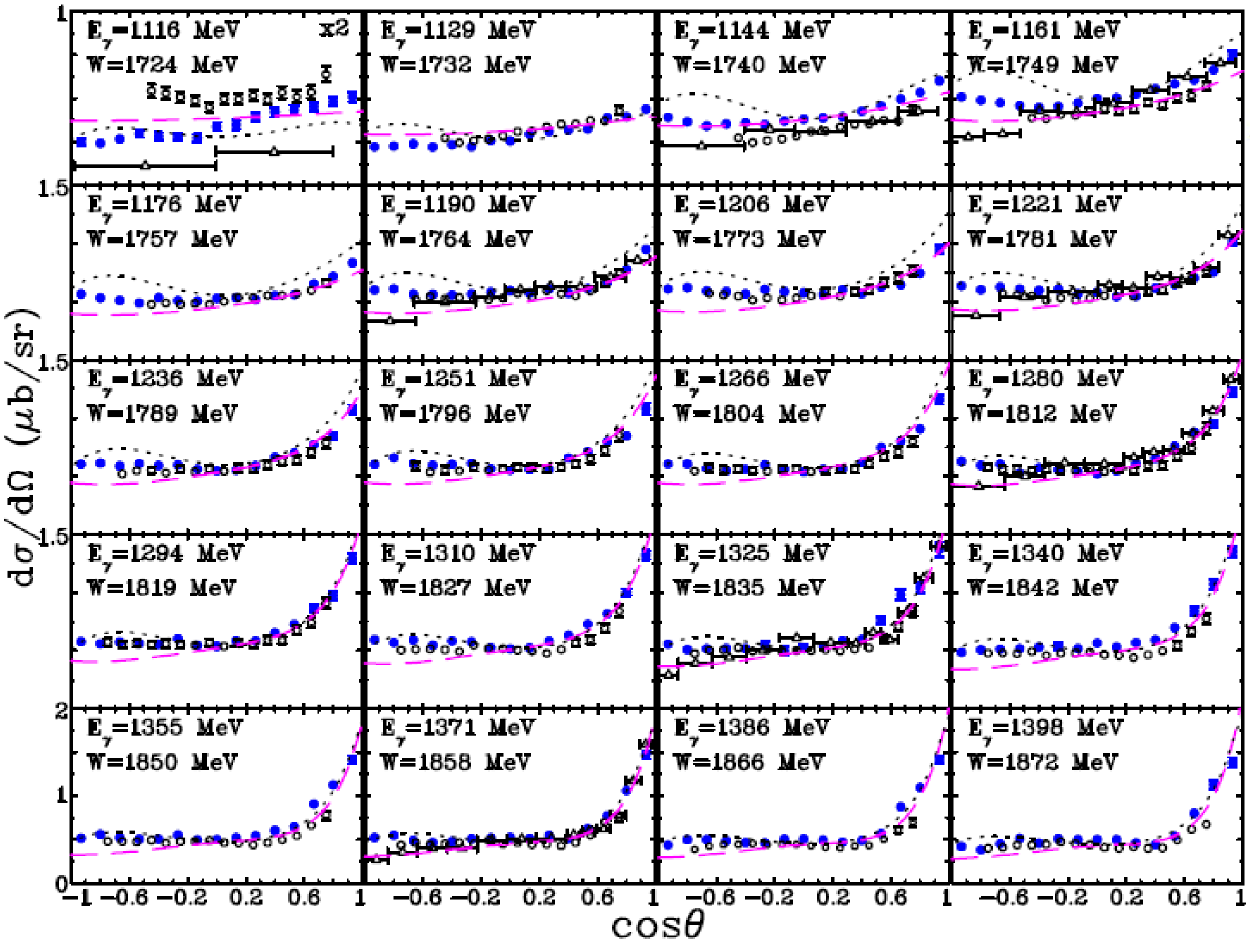
$$d\sigma/d\Omega(E_\gamma,\cos\theta) = \sum_{j=0} A_j(E_\gamma) P_j(\cos\theta)$$

confirms σ_t determination

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

$\gamma p \to \omega p \to \pi^0 \gamma p \to 3\gamma p$ Measurements

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



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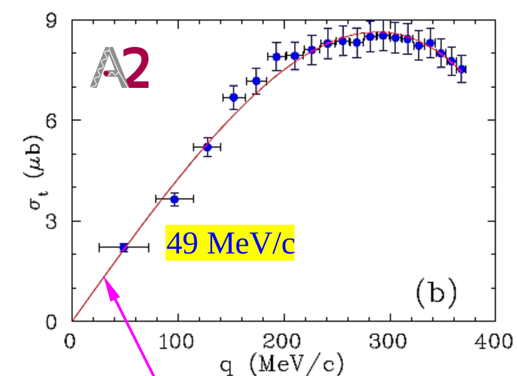
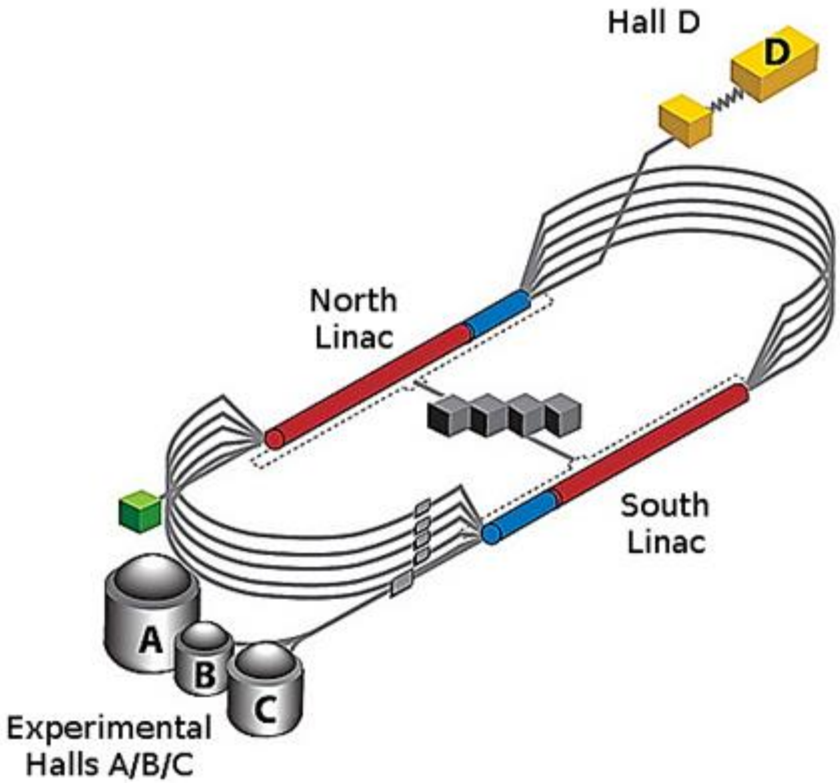
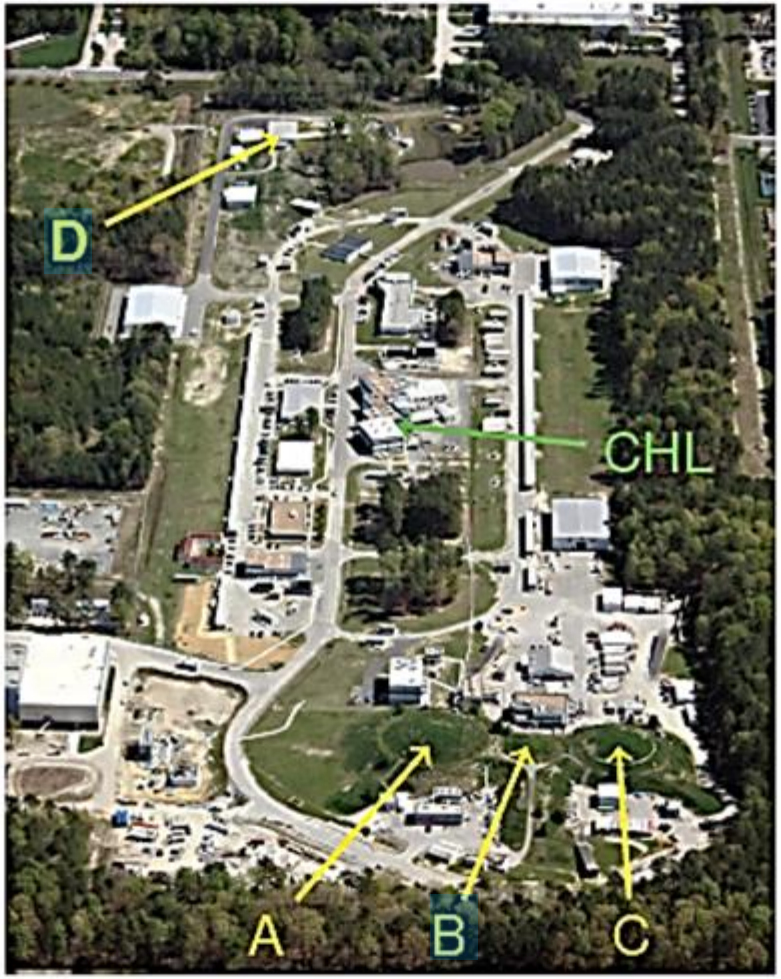


$$\sigma_t(q) = b_1 q + b_3 q^3 + b_5 q^5$$

Jefferson Lab *in 2020*

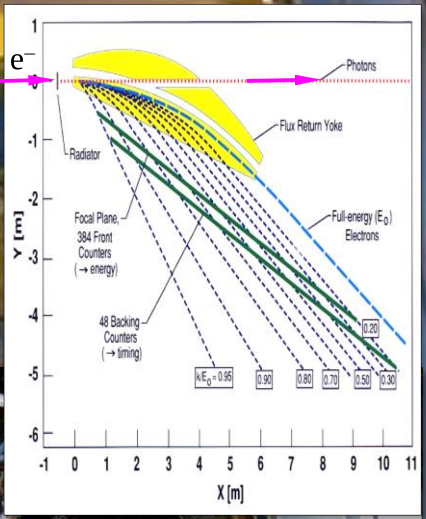




- Accelerator: 2.2 GeV/pass
- Halls A,B,C: e^- 1-5 passes $\leq$11 GeV
- Hall D: e^- 5.5 passes 12 GeV $\Rightarrow$ γ-beam
- Runs 2017-2018: 5.5 passes 11.7 GeV

CEBAF Large Acceptance Spectrometer 1997-2012

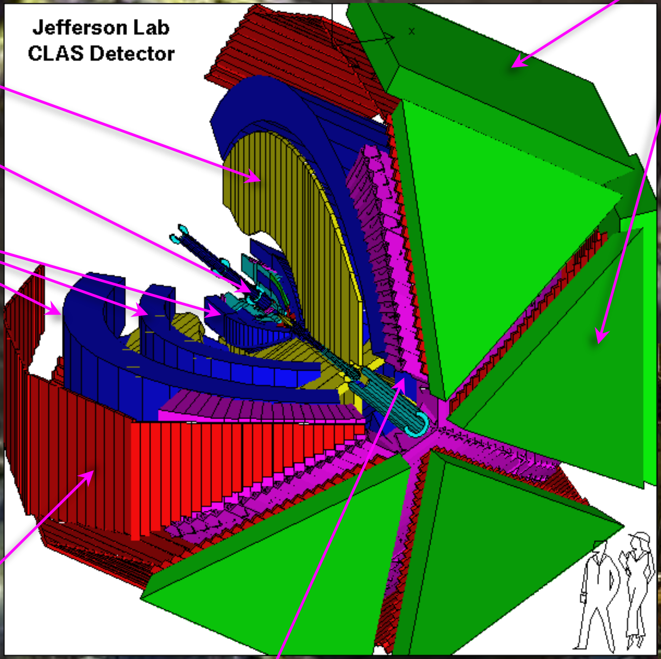
Bremsstrahlung Photon Tagger
384 E & 61 T Counters



Electromagnetic Calorimeters
Lead/Scintillator, 1296 PMTs

Torus Magnet
6 Superconducting Coils

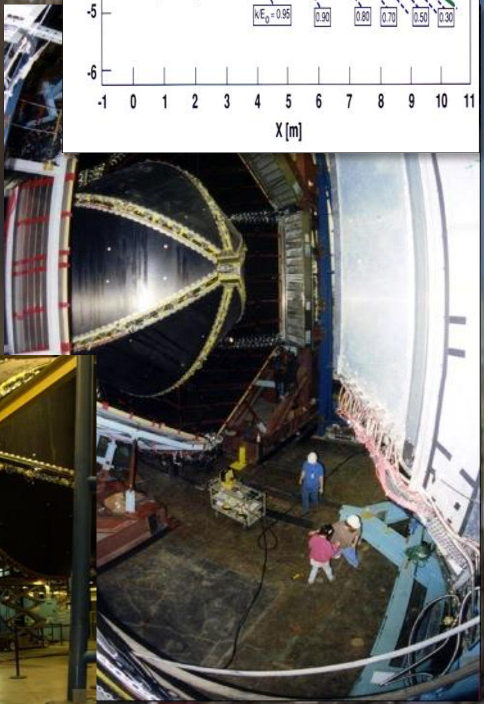
Target + Start Counter



Drift Chambers
35,000 cells

Time-of-Flight Counters
Plastic Scintillators, 684 PMTs

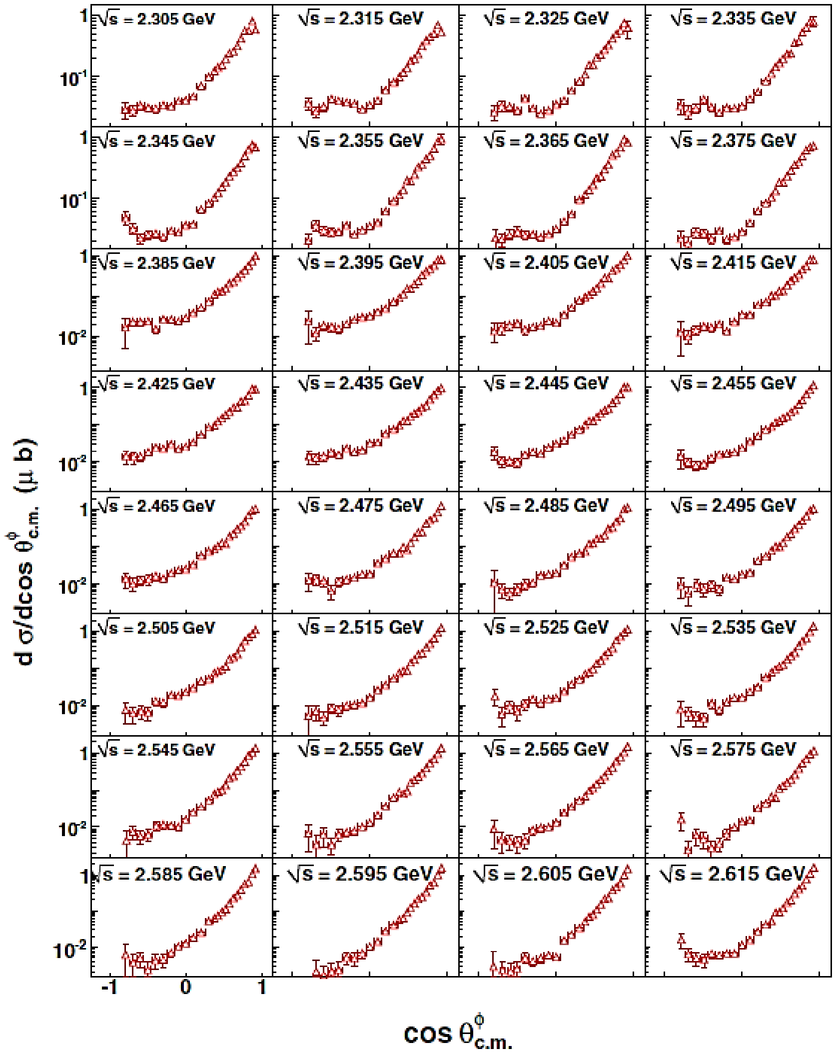
Gas Cherenkov Counters
e/π separation, 256 PMTs



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

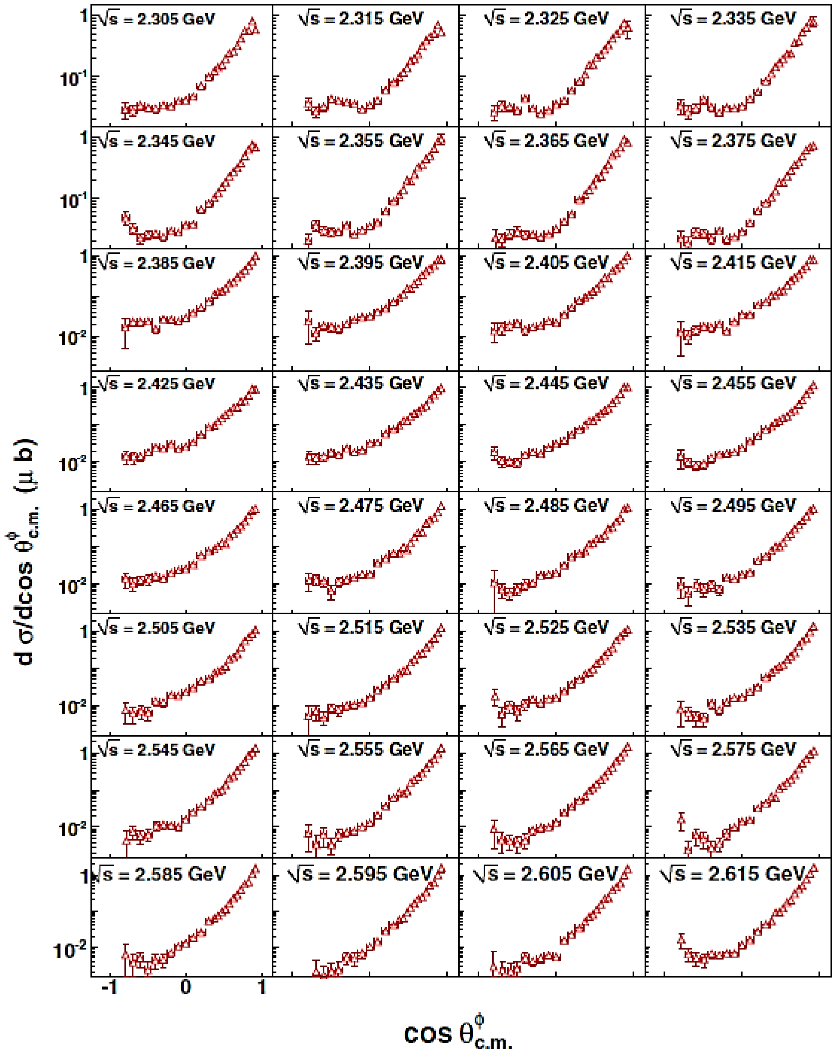
$\gamma p \rightarrow \phi p \rightarrow K^+K^-p$ Measurements

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



$\gamma p \rightarrow \phi p \rightarrow K^+K^- p$ Measurements

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



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

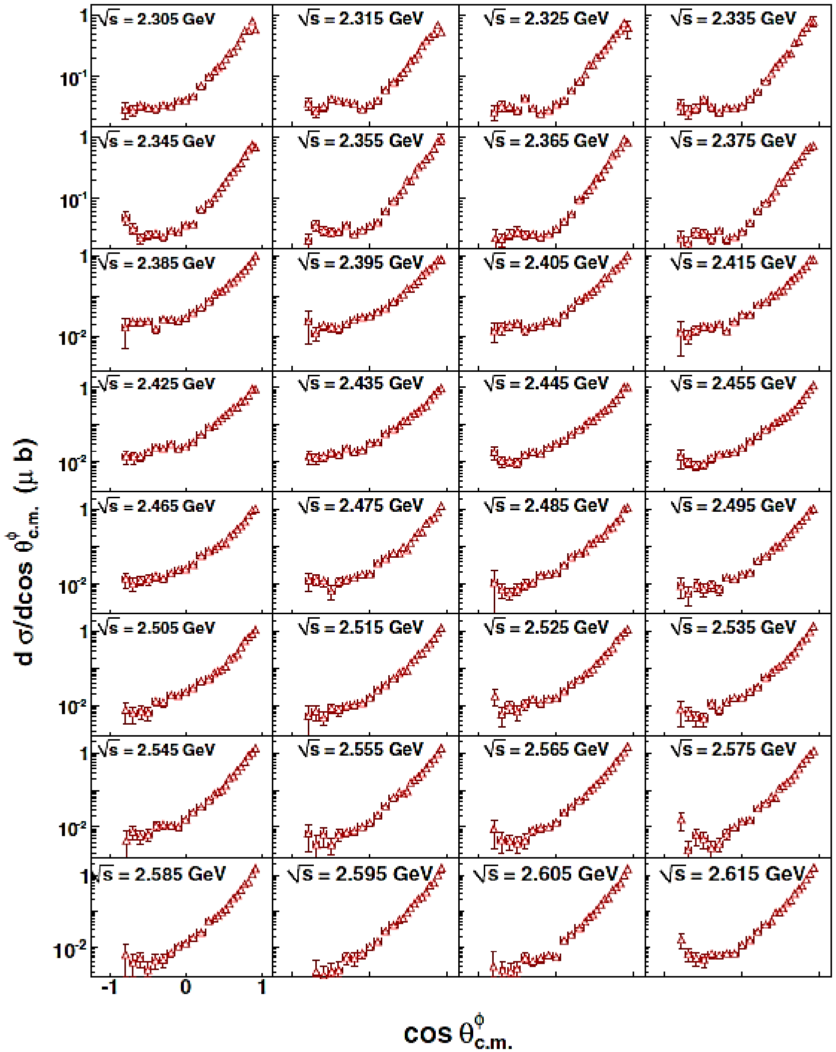
$$d\sigma/d\Omega(E_\gamma, \cos\theta) = \sum_{j=0} A_j(E_\gamma) P_j(\cos\theta)$$

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

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

$\gamma p \rightarrow \phi p \rightarrow K^+K^- p$ *Measurements*

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



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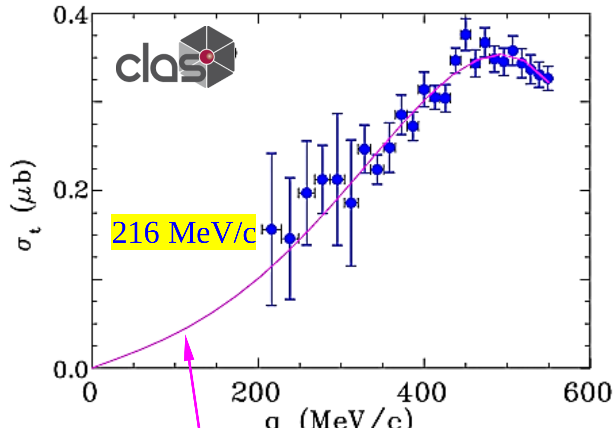

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IS, L. Pentchev, & A.I. Titov, Phys Rev C **101**, 045201 (2020)

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

Editors' Suggestion

2nd paper

First Measurement of Near-Threshold J/ψ Exclusive Photoproduction off the Proton

(GlueX Collaboration)

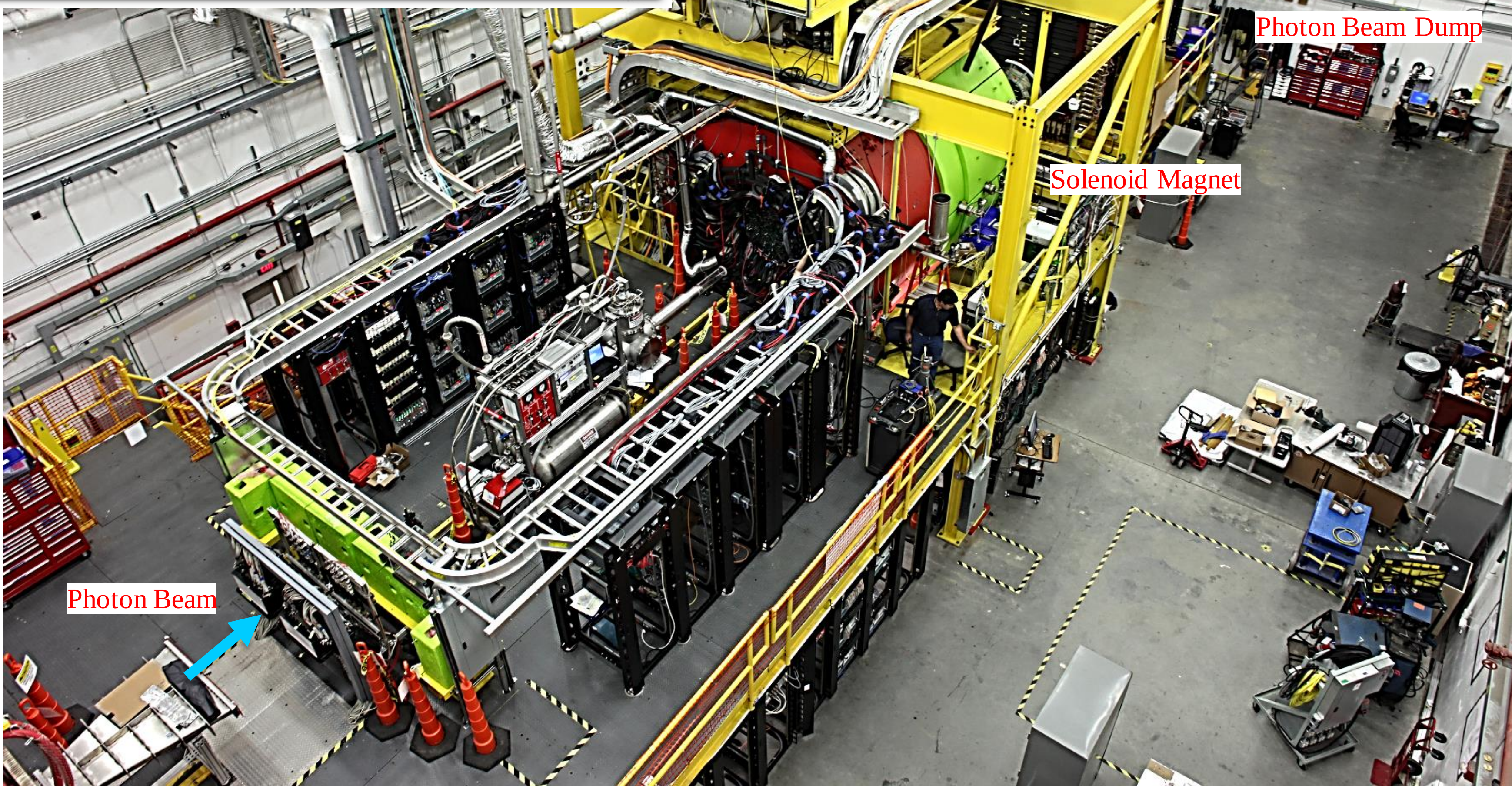
RAPID COMMUNICATIONS

1st paper

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

Measurement of the beam asymmetry Σ for π^0 and η photoproduction on the proton at $E_\gamma = 9$ GeV

(GlueX Collaboration)



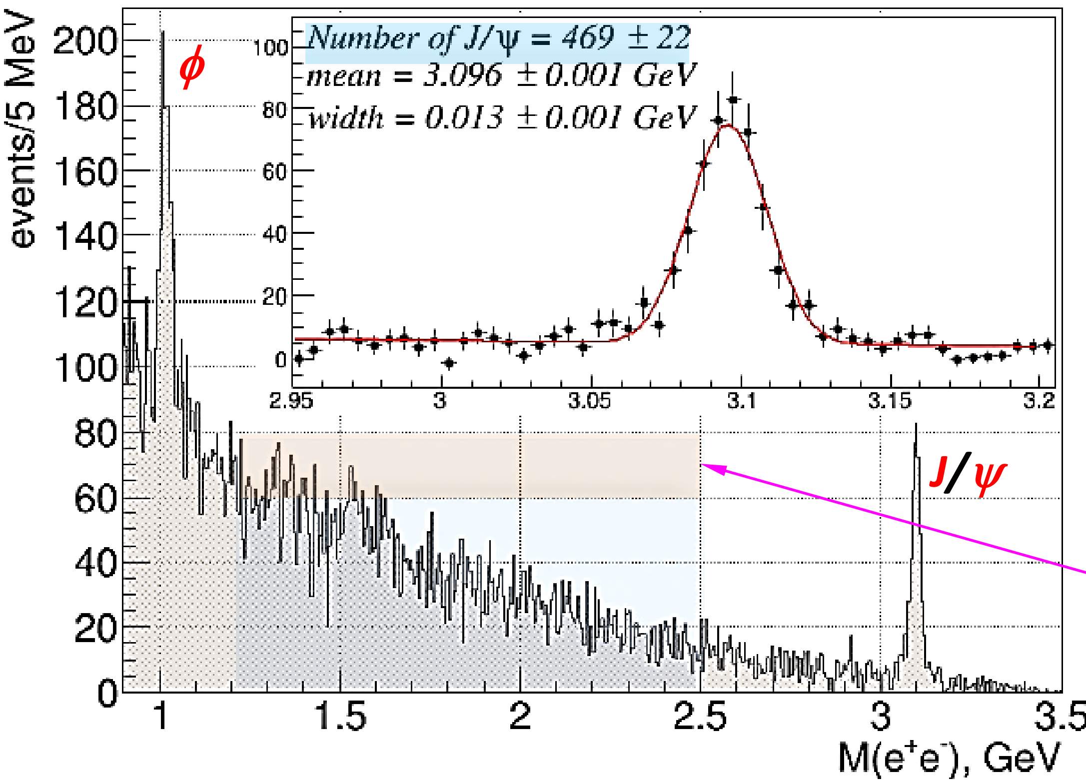
GlueX Statistics: above 8.2 GeV

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

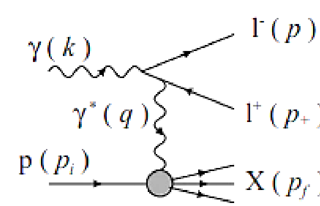
25% of total statistics (2016-2018) up to date.

e^+e^- Invariant Mass Spectrum

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



- Tagged photon beam (**0.2%** energy resolution) & exclusivity reaction: $\gamma p \to J/\psi p \to e^+e^-p$.
- PDG BR($J/\psi \to e^+e^-$) = (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.

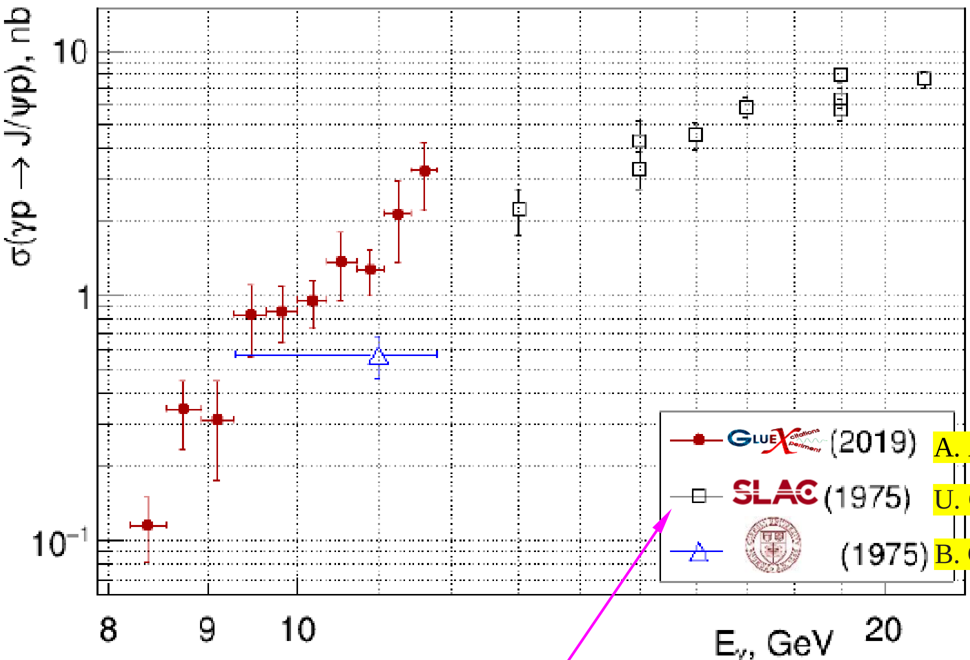


- Overall **normalization** error is **27**%.

Total Xsection for $\gamma p \to J/\psi p \to e^+e^- p$ @ J/ψ 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/ψ) & **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_γ.
- To determine σ_t from SLAC data, GlueX used dipole t-dependence.

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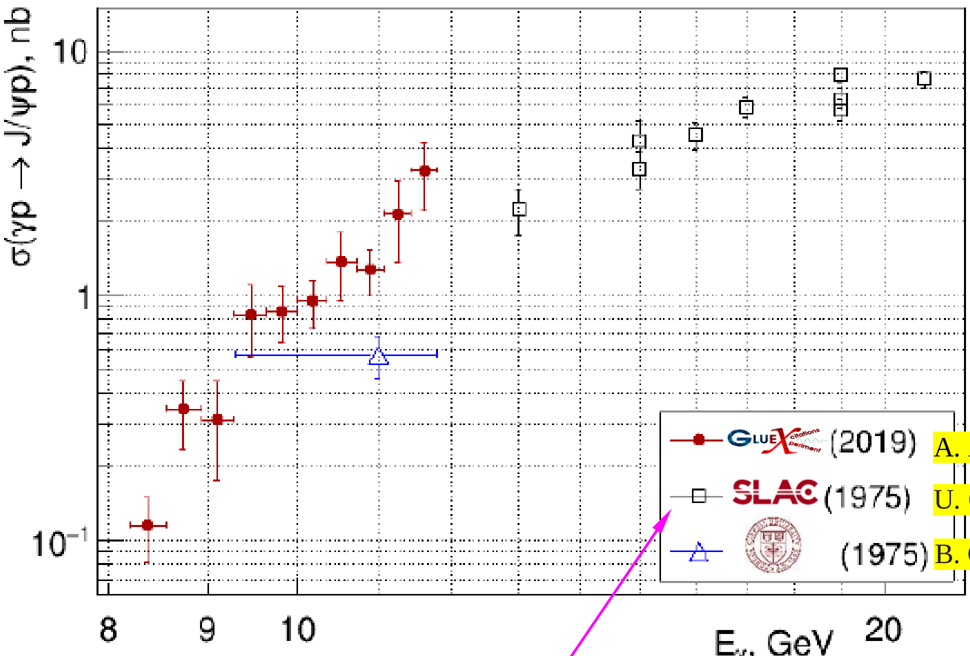

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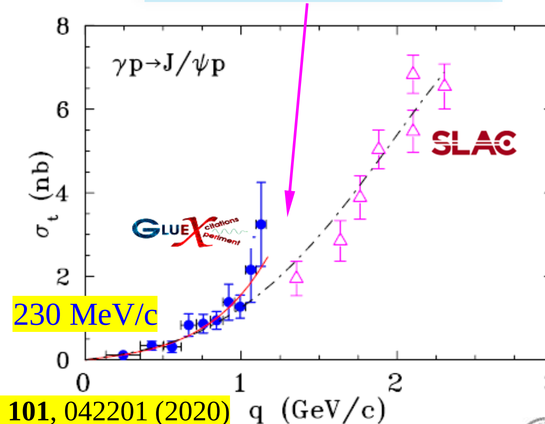
- SLAC experiment measured $d\sigma/dt$ at $t = t_{min}$ as function of E_γ.
- To determine σ_t from SLAC data, GlueX used dipole t-dependence.

- There is no discrepancy between GlueX & SLAC data.

a_i	GlueX	GlueX & SLAC
a_1 [nb/(GeV/c)]	0.46 ± 0.16	0.53 ± 0.12
a_3 [nb/(GeV/c)^3]	0.83 ± 0.91	0.78 ± 0.16
a_5 [nb/(GeV/c)^5]	0.28 ± 0.87	-0.06 ± 0.03
χ^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) in 2020

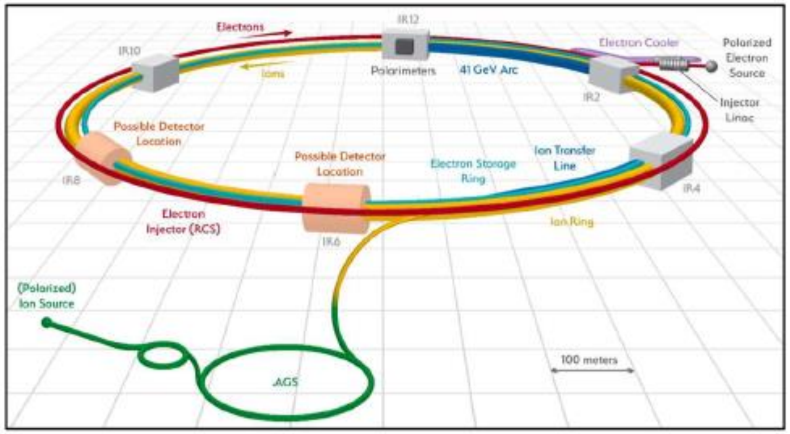
Electron Ion Collider Receives CD-0 Approval

- 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

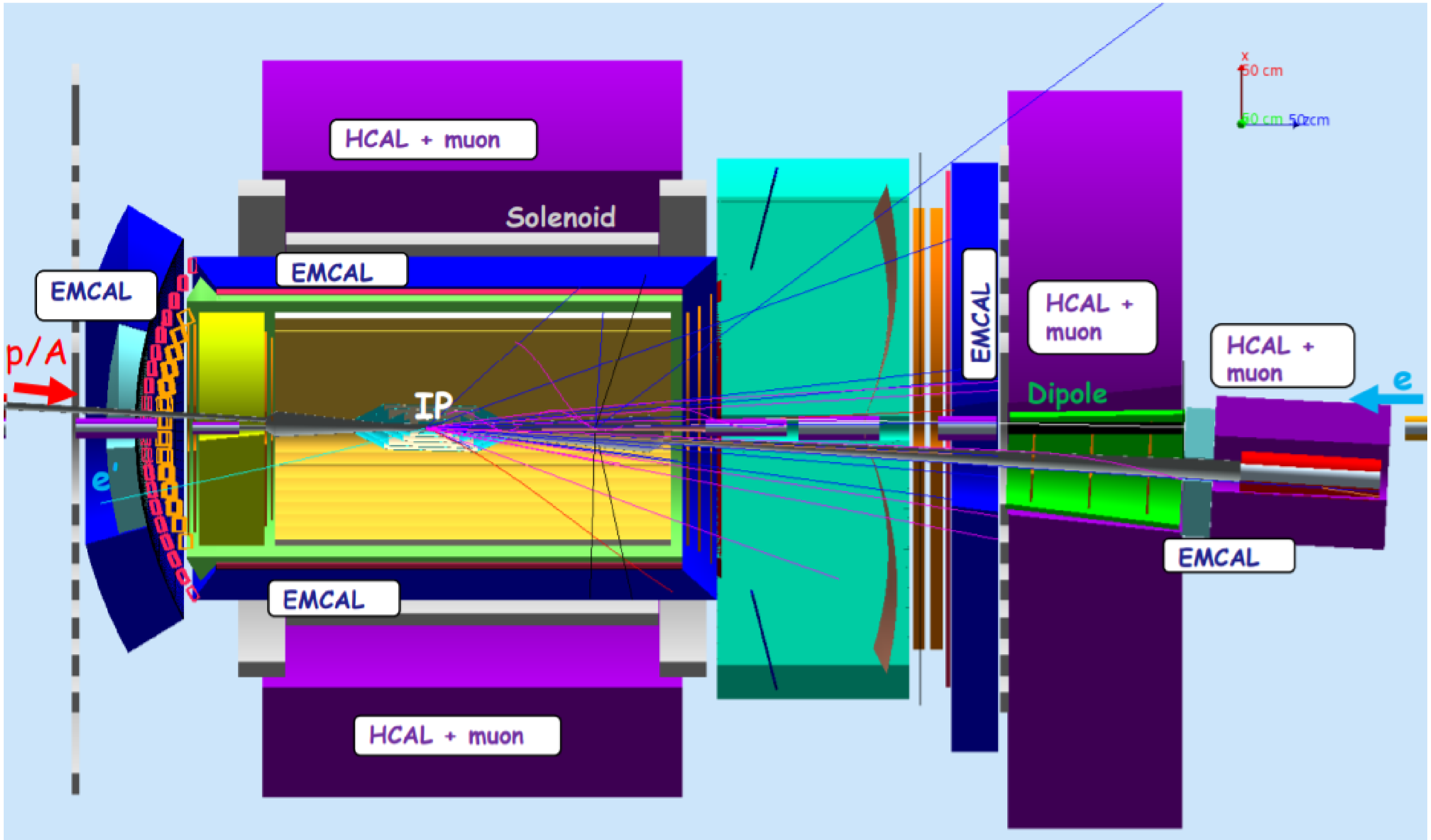


Courtesy of Stuart Henderson, JLUO, June 2020

11

Jefferson Lab

EIC Central detector overview



Modular design of the central detector

Yulia Furletova

47

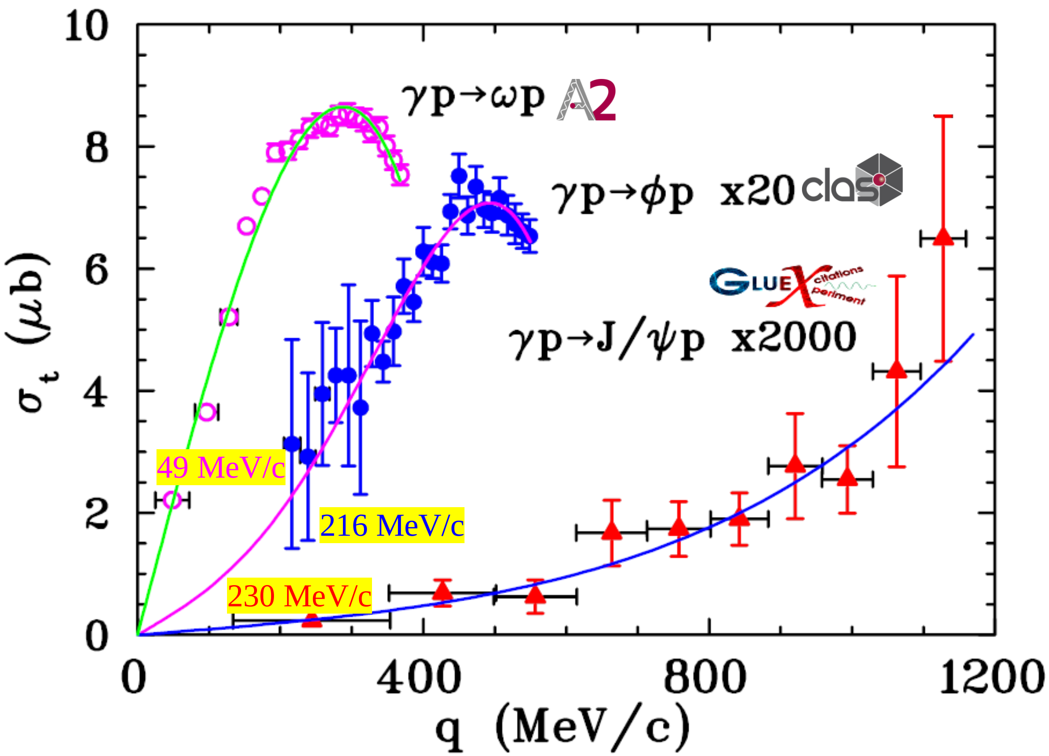
Courtesy of Yulia Furletova, June 2020

Total Cross Section Fits

Total Cross Sections for Vector-Meson Photoproduction off Proton

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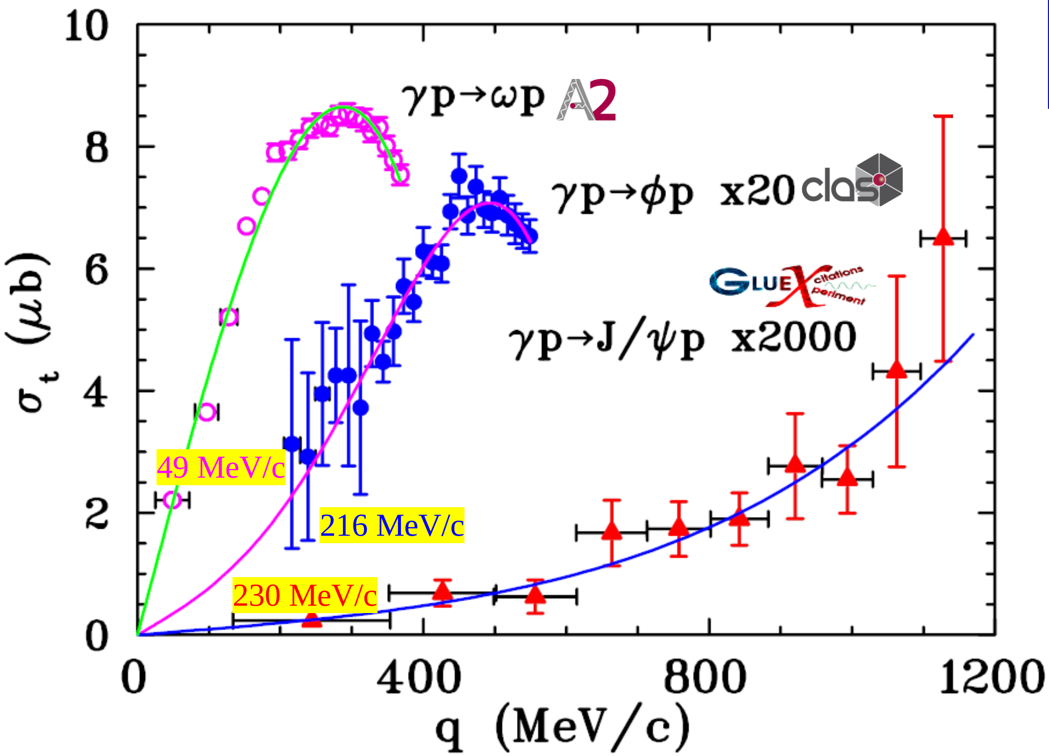
- Linear term is determined by two independent *S*-waves only with total spin *1/2* &/or *3/2*.
- Contributions to cubic term come from both *P*-wave amplitudes & **W** dependence of *S*-wave amplitudes,
- Fifth-order term arises from *D*-waves & **W** dependencies of *S*- & *P*-waves.



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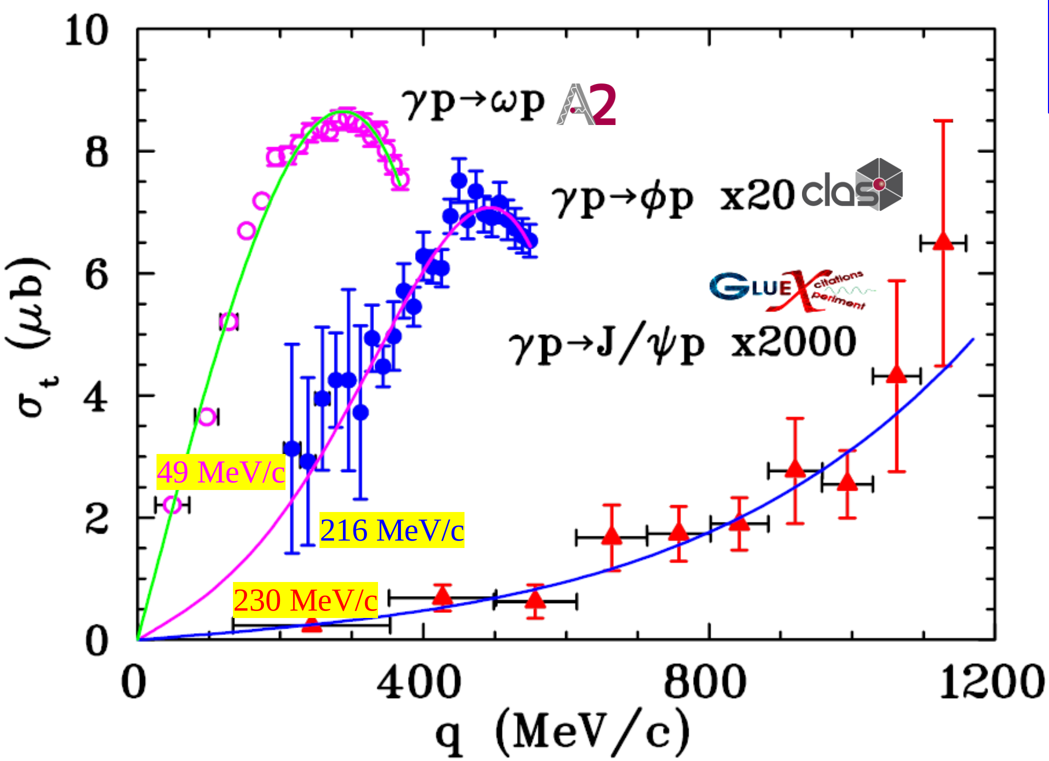


A2 $b_1 = (4.42 \pm 0.14) \times 10^{-2}$ μb/(MeV/c)
IS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (2015)

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

GlueX $b_1 = (0.46 \pm 0.16) \times 10^{-6}$ 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 σ_t @ threshold as function of q varies significantly from ω to ϕ to J/ψ.

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

Brief Tour through SLs

What is Known for ωN SL

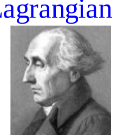
$|\alpha_{\omega p}| = (0.82 \pm 0.03)$ fm from phenomenology — IS, S. Prakhov, Ya. Azimov *et al*, Phys Rev C **91**, 045207 (2015)

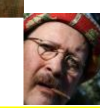
$\alpha_{\omega p} = (-0.97 \pm 0.16 \pm 0.03 + i0.07 \pm 0.15 \pm 0.19)$ fm from phenomenology — T. Ishikawa *et al*, Phys Rev C **101**, 052201(R) (2020)

$\alpha_{\omega p} = (-0.026 + i0.28)$ fm from coupled-channel analysis of ω production in πN & γN — 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 ϕN SL

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

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

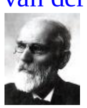
0.15 fm from forward coherent f-meson photoproduction from deuterons near threshold

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 ρ, ω, & ϕ meson-N scattering

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

~2.37 fm from QCD van der Waals attractive ϕN potential for analysis of ϕ-nucleus bound states



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

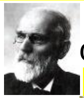
- This value is more than order of magnitude greater than results using . exp data & provides problem for this particular potential model.

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

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

What is Known for $J/\psi N$ SL

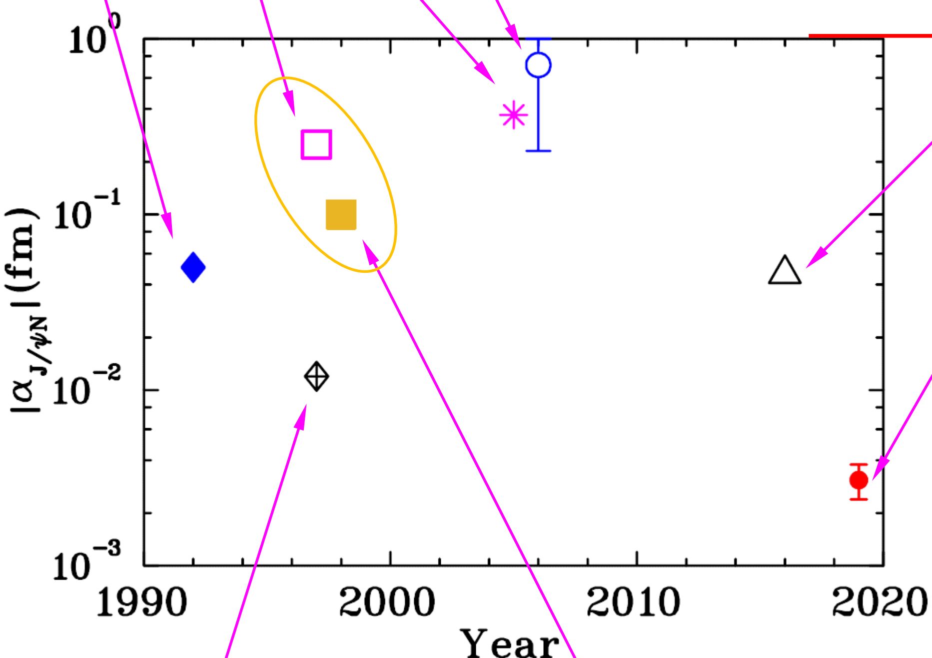
Heavy-quarkonia gluonic interactions, LE QCD theorem
A.B. Kaidalov & P.E. Volkovitsky, Phys Rev Lett. **69**, 3155 (1992)



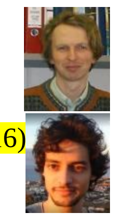
Gluonic van der Waals interaction
S.J. Brodsky & G.A. Miller, Phys Lett B **412**, 125 (1997)

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)

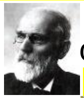
Gauge-invariant q-bar-q Green's function
V.I. Shevchenko, Phys Lett B **392**, 457 (1997)

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

What is Known for J/ψN SL

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

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



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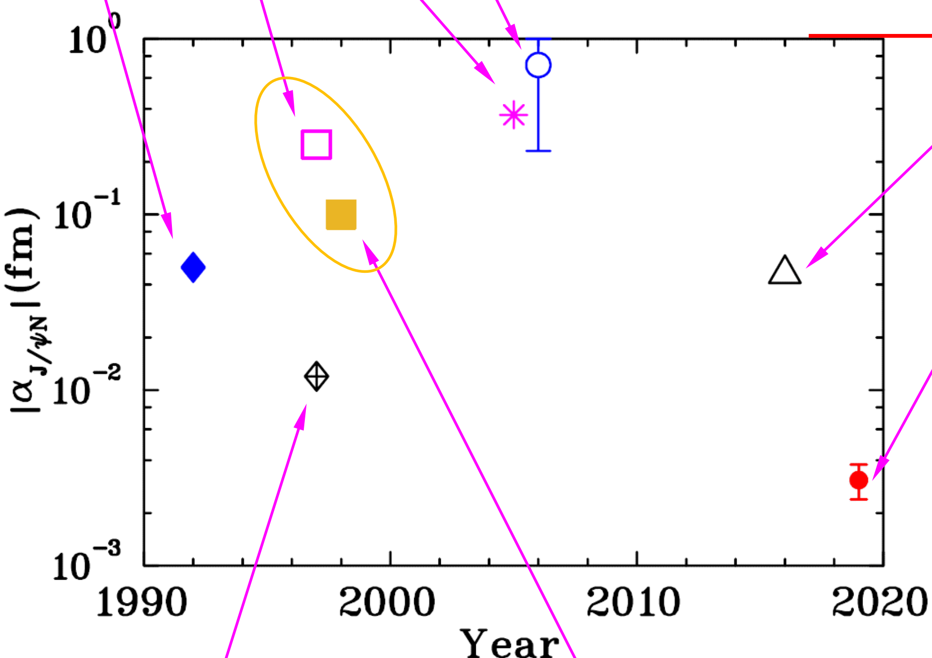

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IS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (2020)

- 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)

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

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/ψN Interaction

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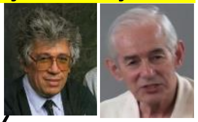
Courtesy of A. Vainshtein & M. Ryskin, July 2020



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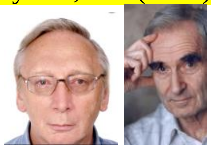
K.G. Boreskov & B.L. Ioffe, Sov J Nucl Phys **25**, 331 (1977)



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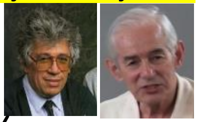

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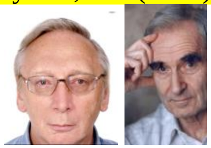
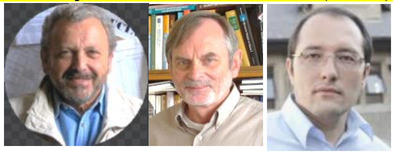


- **Color** factor for *charmonium* is **1**/**9** while for *open charm* is **8**/**9**.

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



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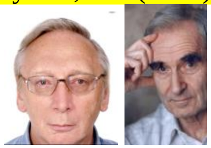

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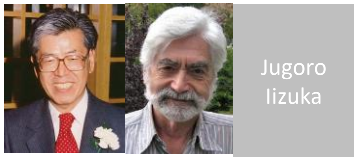
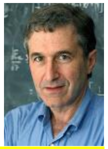
- Additional suppression factor for *J/ψN* interaction @ threshold is **OZI** rule. **OZI** suppressed processes have larger number of independent fermion loops compared with non-suppressed processes.

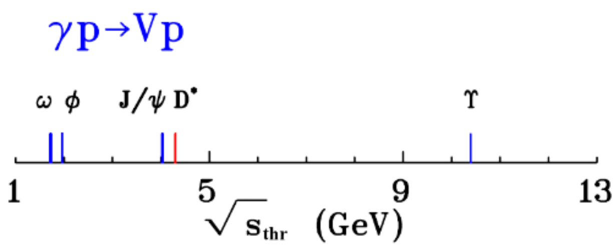




Courtesy of B. Kopeliovich & R. Jaffe, June 2020

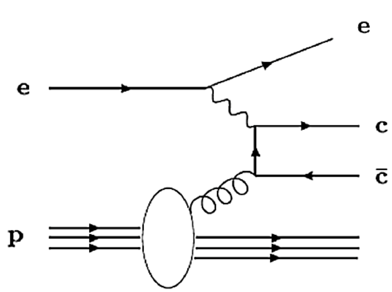
Open Charm

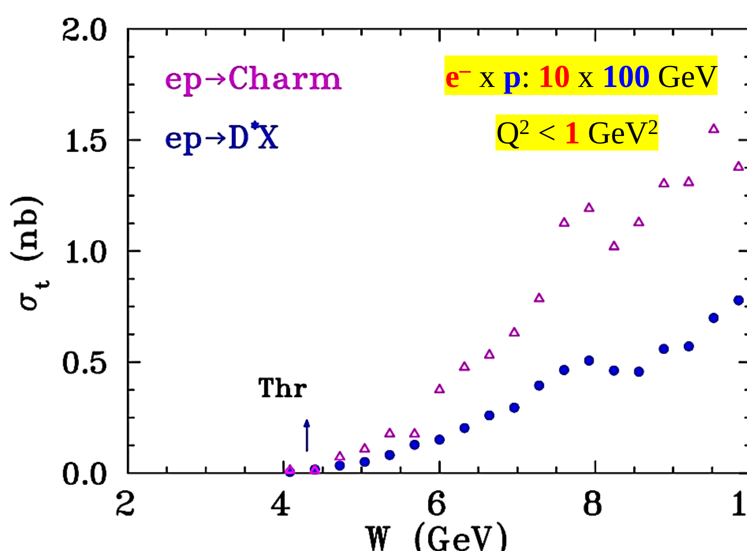
- It was shown that fluctuation of **photon** into open charm $\gamma p \rightarrow \bar{D}^0 \Lambda_c^+$ is preferable than into charmonium J/ψ.
  Suppression is just available phase space: W_{thr}(open charm) = **4.30** GeV while
  W_{thr}(charmonium) = **4.03** GeV).



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

- There are no σ_t for open charm @ threshold.





Boson Gluon Fusion LO & NLO

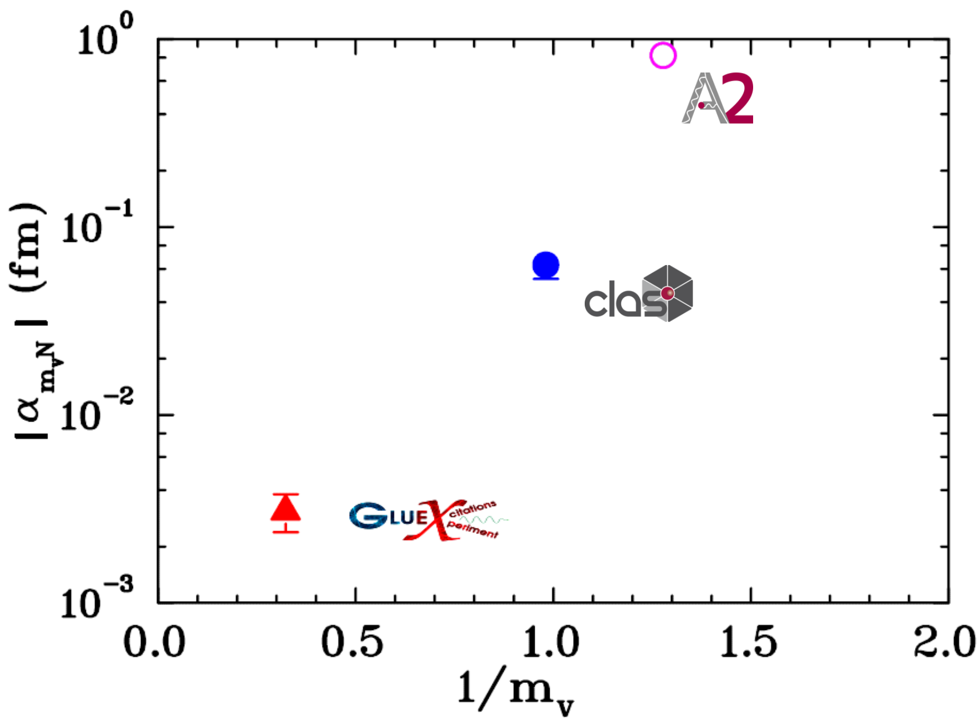
Courtesy of Sergey Furletov, July 2020

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

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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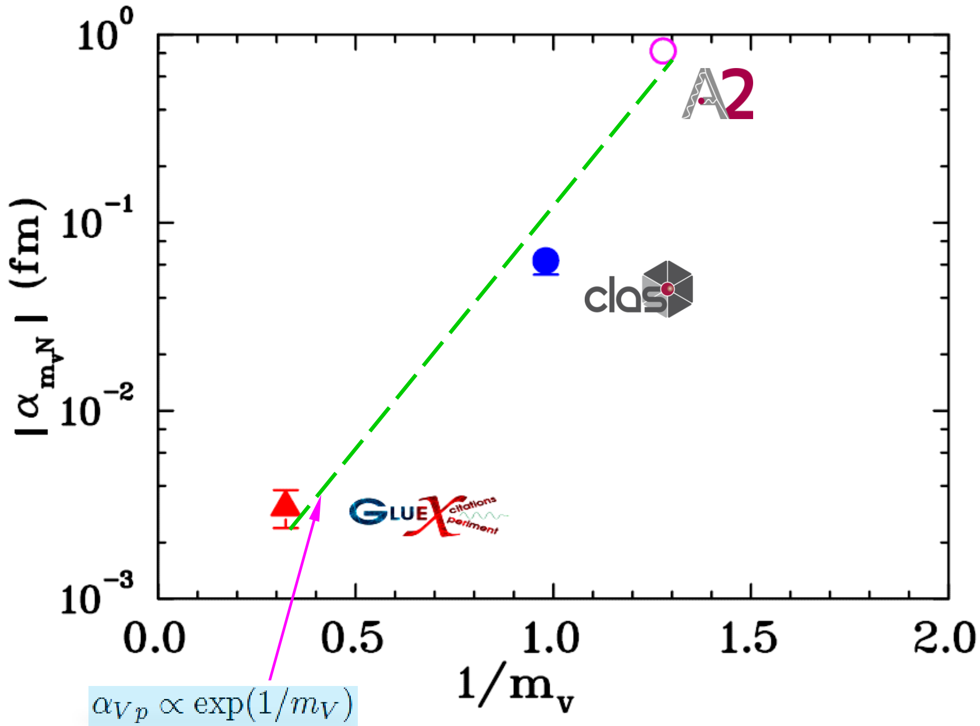

$$\alpha_{Vp} \propto \exp(1/m_V)$$

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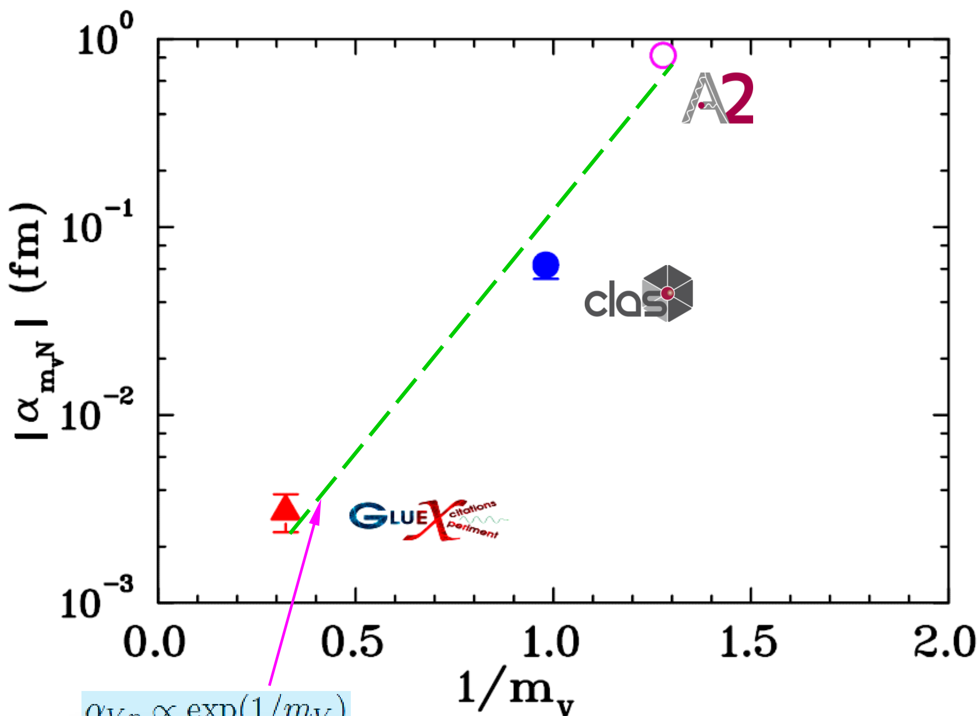

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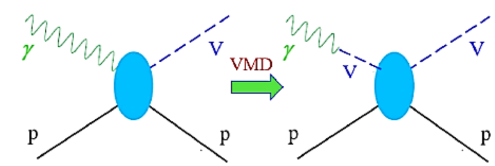

- $p \to V$ coupling is proportional to α_s & *separation* of corresponding quarks. This *separation* (in zero approximation) is proportional to $1/m_V$.

Courtesy of Michael Ryskin, July 2020

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.

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- In particular, low-energy J/ψ 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)

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Fall 2018 dataset

Time-like Compton Scattering &
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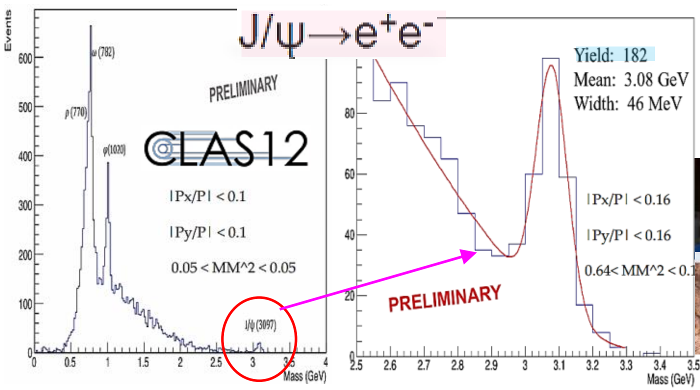

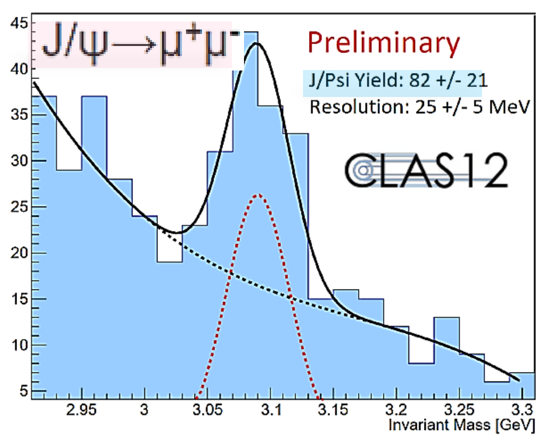

Courtesy of Joseph Newton & Richard Tyson, CLAS Collab meeting, July 2020

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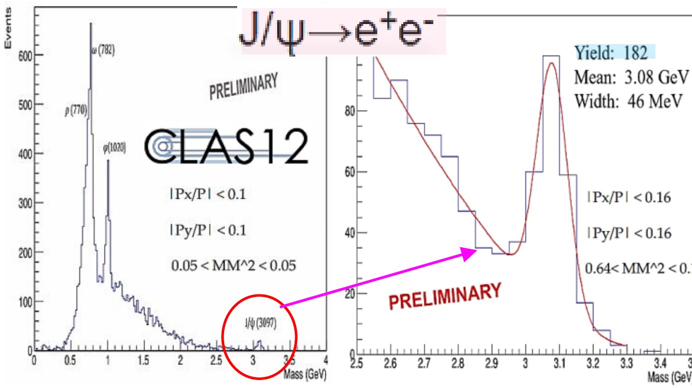
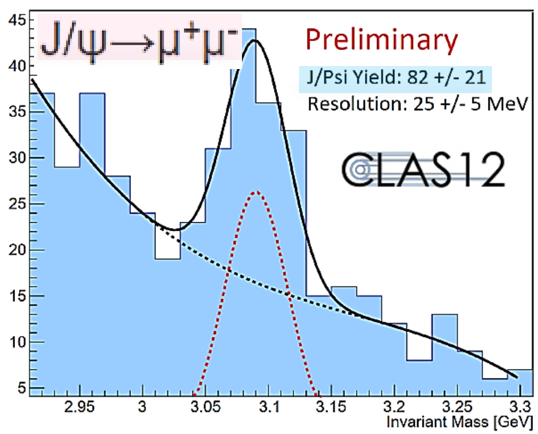
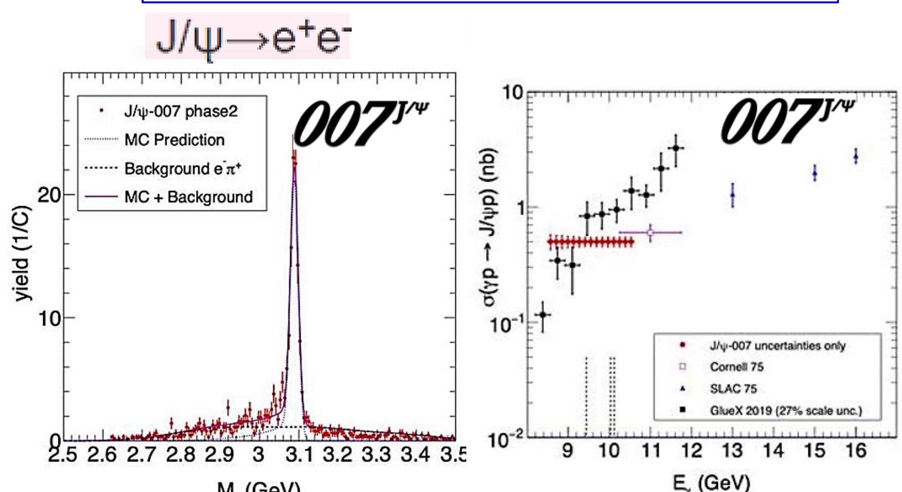




Search for LHCb Charmed "Pentaquark" using Photoproduction of J/ψ @ Threshold in Hall C @ Jefferson Lab (E12-16-007)



Courtesy of Joseph Newton & Richard Tyson, CLAS Collab meeting, July 2020

Courtesy of Burcu Duran & Sylvester Joosten, APS April 2020

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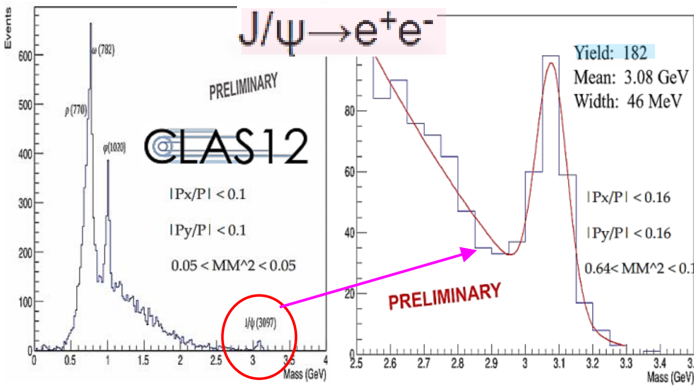

- σ_t is unmeasurable in both cases & requires extraction from $d\sigma/dt$.
- Critical factor is how close to threshold both experiments will go .

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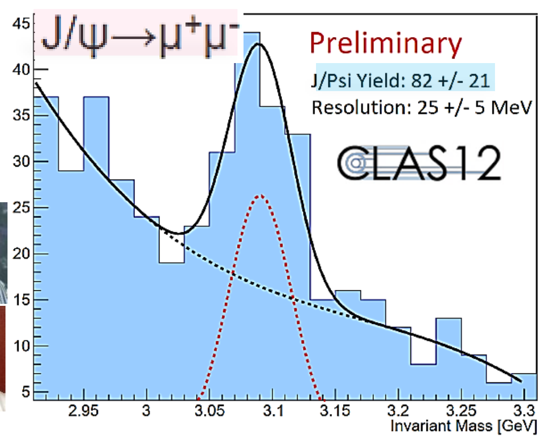

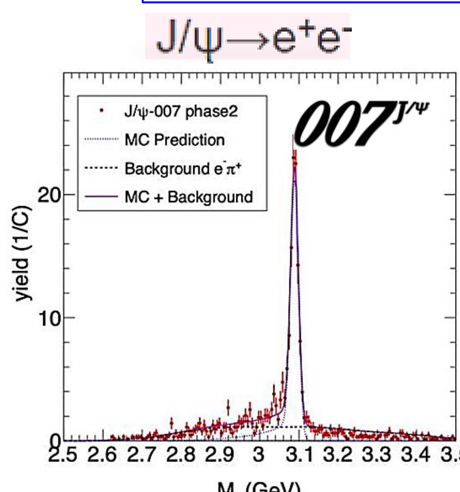

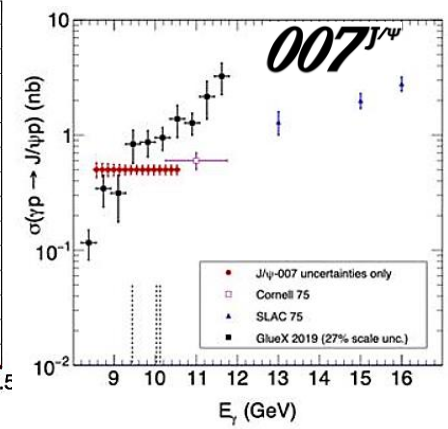

Courtesy of Joseph Newton & Richard Tyson, CLAS Collab meeting, July 2020

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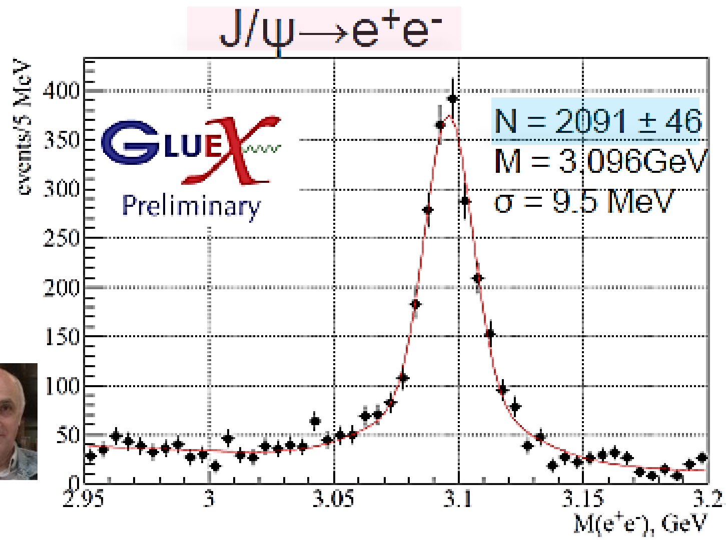
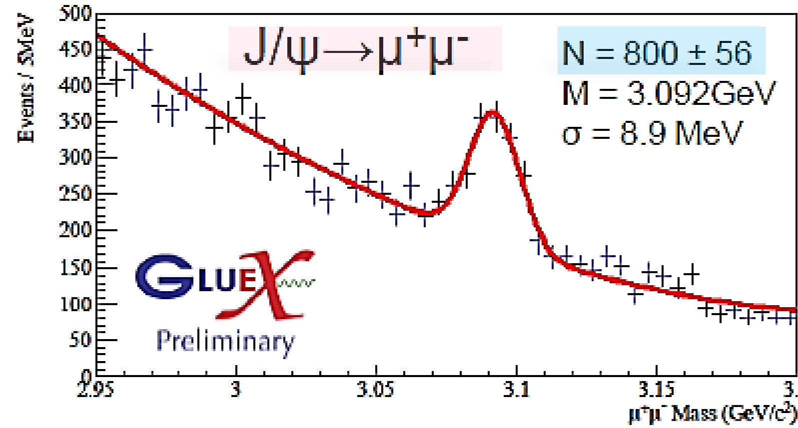
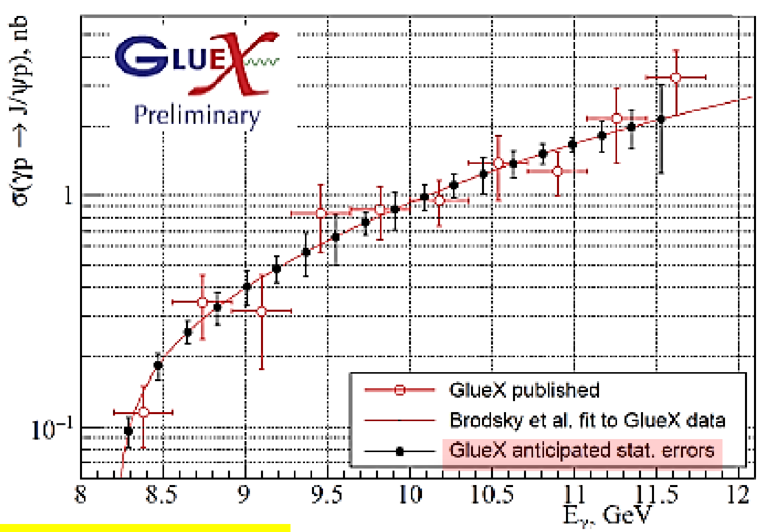
Expectation from Jefferson Lab

- Total GlueX statistics for 2016–2018







Courtesy of Alex Austeregesilo, JLUO, June 2020

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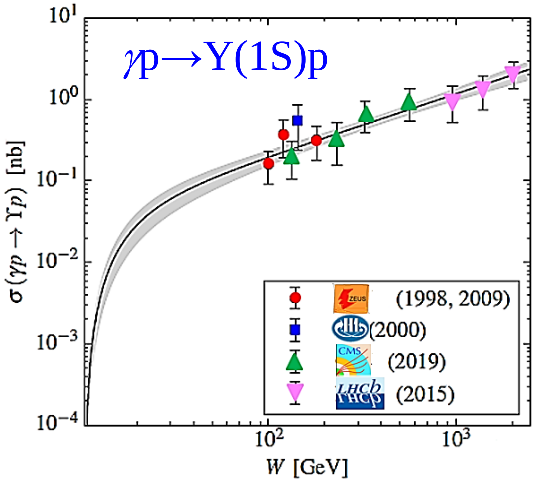

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O. Gryniuk *et al*, arXiv:2005.09293 [hep-ph]

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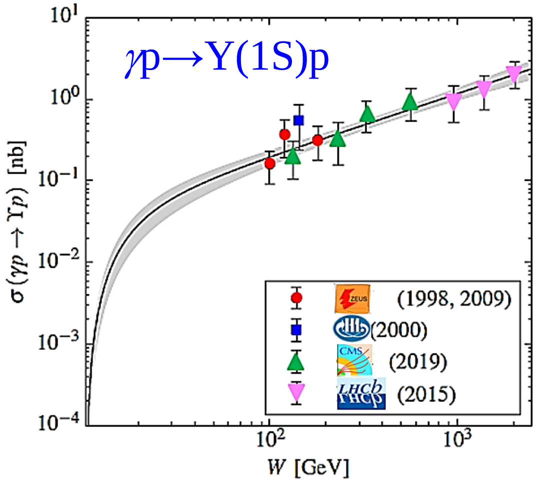

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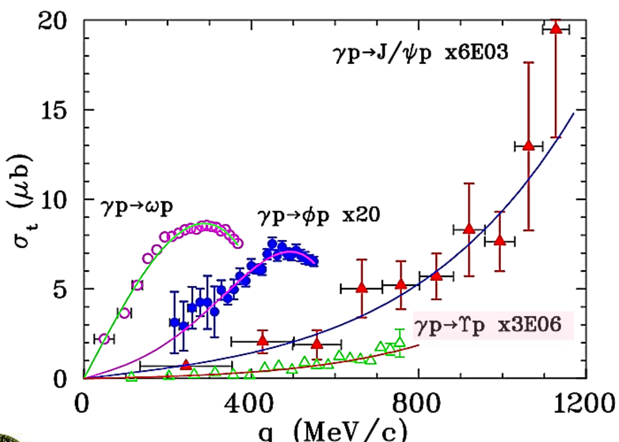

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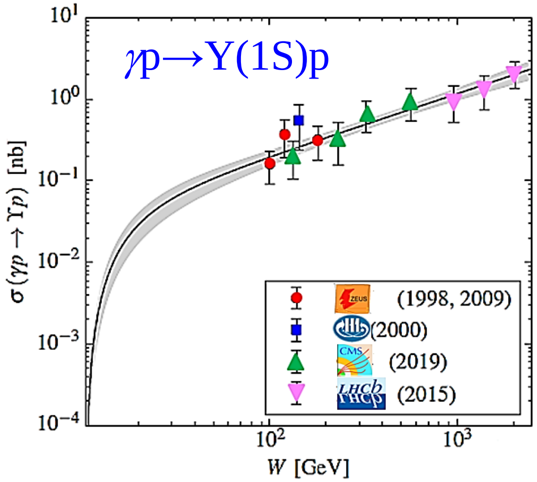

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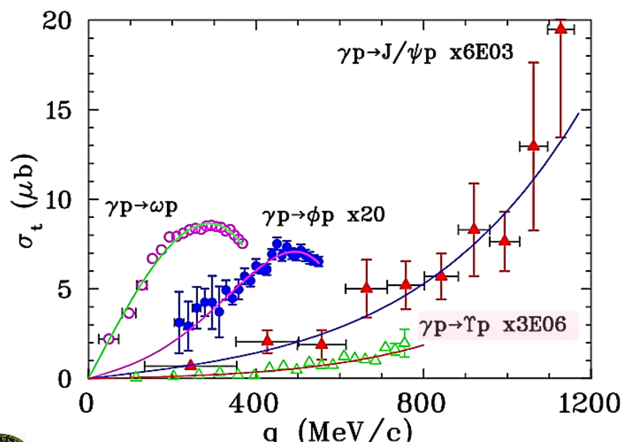
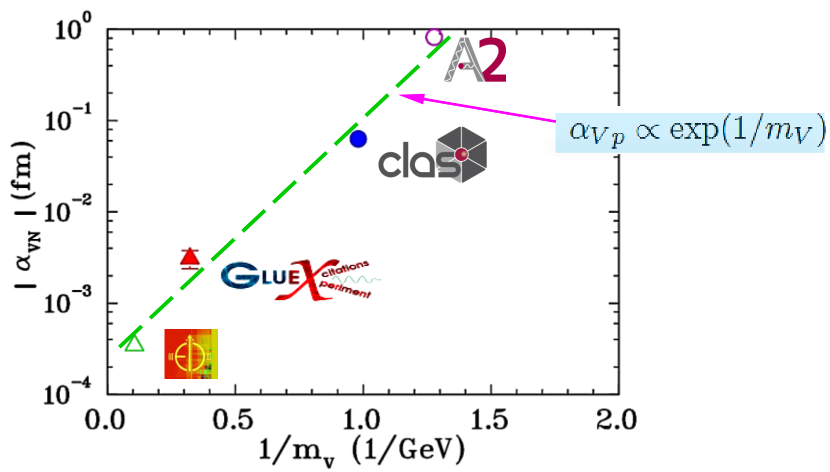


$$|\alpha_{Yp}| << |\alpha_{J/\psi p}| \ll |\alpha_{\phi p}| \ll |\alpha_{\omega p}|$$



Summary

SUMMARY

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A2	$\lvert\alpha_{\omega p}\rvert = (0.82 \pm 0.03)$ fm
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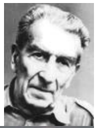

E.L. Feinberg, Sov Phys Usp, **23**, 629 (1980)

Courtesy of Michael Ryskin, July 2020

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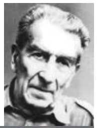

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- **Light** vector-meson can be 'young' as well. This depends on particular kinematics. Another point is that for slow **heavy** quark, one need more time to reach equilibrium, i.e., to form final (long-living/static) vector-meson.

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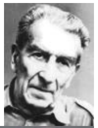
Therefore, one observe stronger ($r_{J/\psi}^2/R_{J/\psi}^2 < 100$) suppression for ***J*/*ψ*-*p*** interaction.

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



Courtesy of Michael Ryskin, July 2020

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

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

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