Update on VM Photoproduction @ Threshold

Igor Strakovsky*

The George Washington University

- Proposed experiments with  that are aimed to study *Charmonium* & *Quarkonium* in Photo- & Electro-Production off proton & nuclei @ threshold.

- They will allow further studies of J/ψ–N and Y–N interactions & will also give access to variety of other interesting physics aspects that are present in near-threshold region.

- There is special interest to study J/ψ–N & Y-N interaction because of ***small size*** of *Charmonium* & *Quarkonium* that can be used to probe internal structure of nucleon & nuclei.

- This is *Hard Process* (with scale defined by charm quark mass) with some similarity to DIS, however, J/ψ–N & Y–N are not sensitive to *EM* but *Gluonic* distribution.

- Experimentally, *Charmonium*–N & *Quarkonium*–N interaction can be investigated using J/ψ & Y Photo-& Electro-Production within *VMD* model.

- Moreover, ***VM***s can, compared to other mesons, be measured to very high precision. This stems from fact that ***VM***s have same quantum numbers as ***Photon*** $I^G(J^{PC}) = 0^-(1^{--})$.

*Supported by DE-SC0016583

VM–Nucleon SL Determination

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

- For evaluation of *absolute* value of *VM–N SL*,
  we apply *VMD* approach that
  links near-threshold photoproduction *Xsections* of ***γp→VMp*** & elastic ***VMp→VMp***

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

k is **photon** CM momentum $k = (s - M^2) / 2\sqrt{s}$
q is *VM* CM momentum
$T^{\gamma p\to Vp}$ is the invariant amplitude of *VM* PhotoProduction
α is fine-structure constant, $e^2/4\pi \sim 1/137.$
g_V is VMD coupling constant, related to *VM* **EM** decay width $\Gamma_{V\to e^+e^-}$

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

- 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

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

- 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: 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)		($MeV^{1/2}$)
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
Y	9460.30	1.340±0.018	19.84±0.14	2655.0±162.2

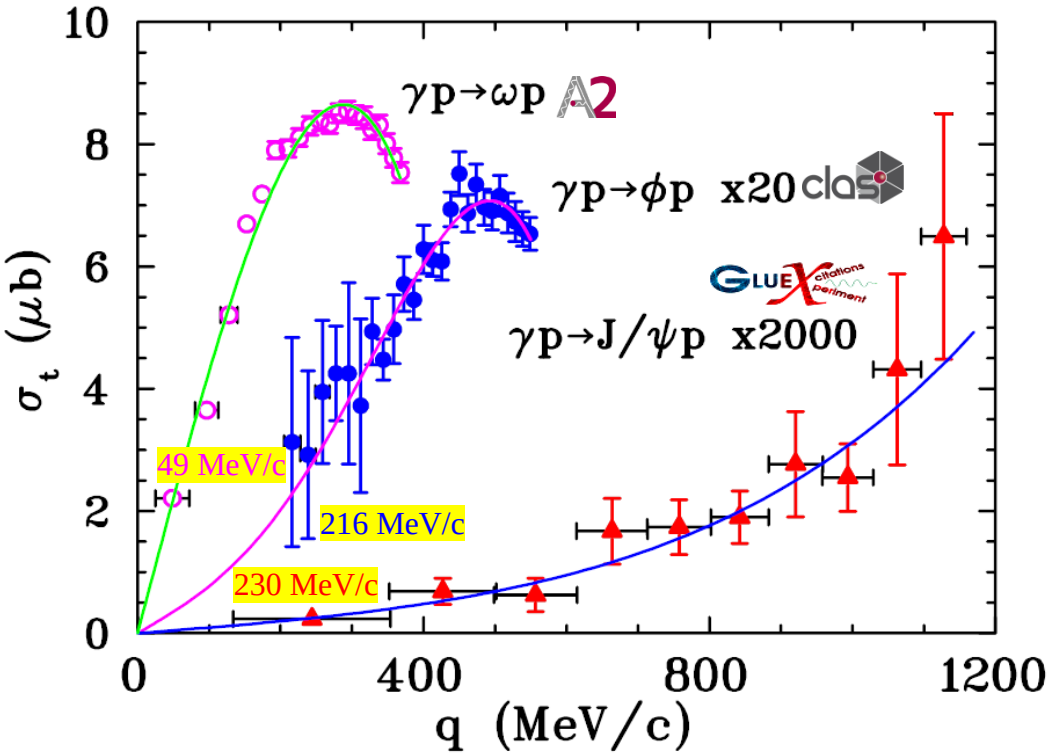
- *EM* factor R_V for *each* VM are close to each other, except Y.

Total Cross Sections for VM 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).

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

- *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.



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)

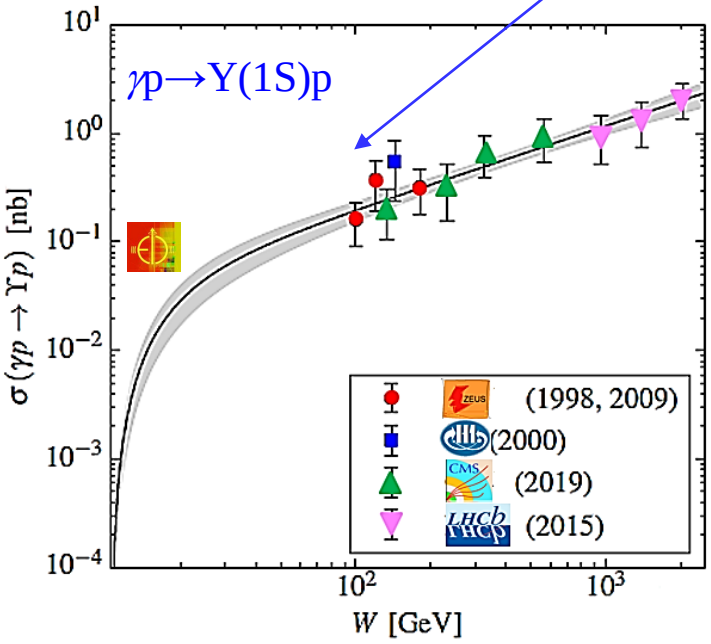
GlueX b_1 = (0.46±0.16) x 10^{-6} μb/(MeV/c)
IS, D. Epifanov, & L. Pentchev, Phys Rev C **101**, 042201 (2020)

- Dramatic differences in hadronic factors $h_{Vp} = (b_1)^{1/2}$, as slopes (b_1) of σ_t @ threshold as function of q varies significantly from ω to ϕ to J/ψ.

- Big difference in *SL* of *VM*s is determined mainly by hadronic factor h_{Vp}.

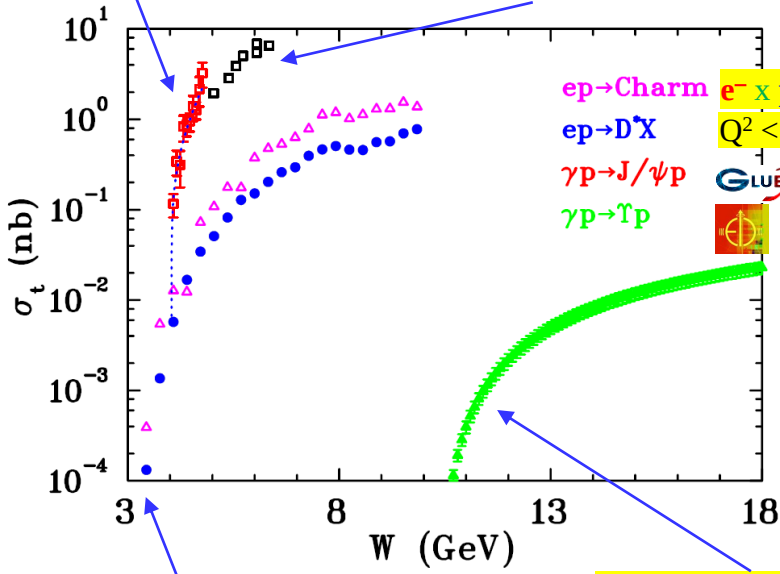
Expectation from 

- For simulations,
  - One assumed total integrated luminosity of **100** $\mathbf{fb^{-1}}$ for  , which corresponds to **116 days @** $\mathbf{10^{34}}$ $\mathbf{cm^{-2}\,s^{-1}}$.
  - Extrapolation goes down from **100 GeV**.



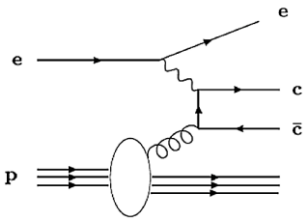
A. Ali *et al*, Phys Rev Lett **123**, 072001 (2019)

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



Courtesy of Sylvester Joosten, Sept 2020

O. Gryniuk *et al*, Phys Rev D **102**, 014016 (2020)

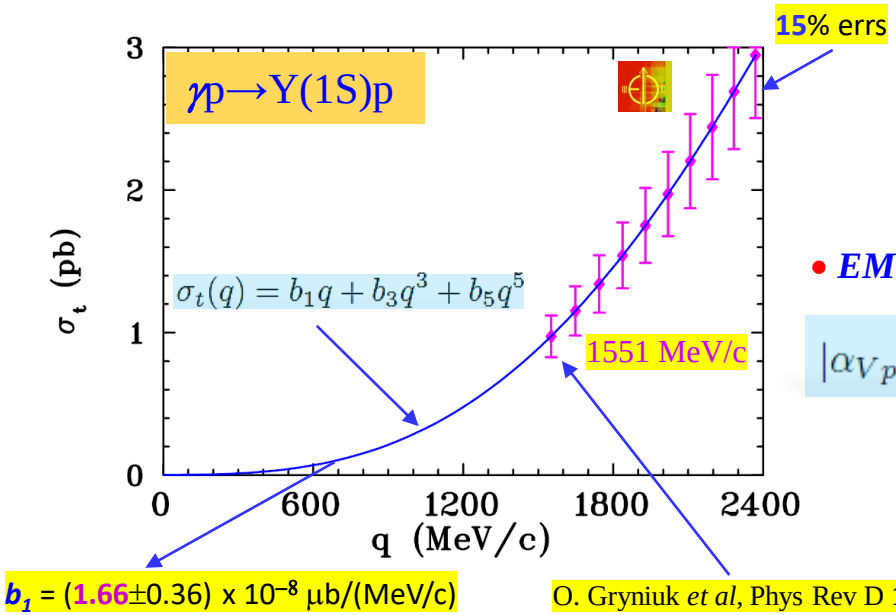


Courtesy of Sergey Furletov, July 2020

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

For Photoproduction - FMNR: S. Frixione P. Nason, & G. Ridolfi, Nucl Phys B **454**, 3 (1995)

Expectation from



***b*$_1$** = (1.66±0.36) x 10^{-8} μb/(MeV/c)

O. Gryniuk *et al*, Phys Rev D **102**, 014016 (2020)

- ***EM*** factor R_V for each ***VM*** are close to each other.

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

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

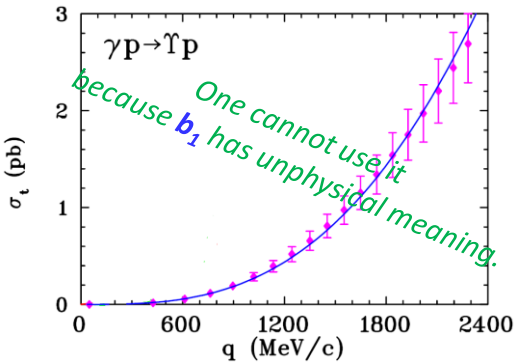
$|\alpha_{Yp}|$ = **0.000108**±0.000011 fm

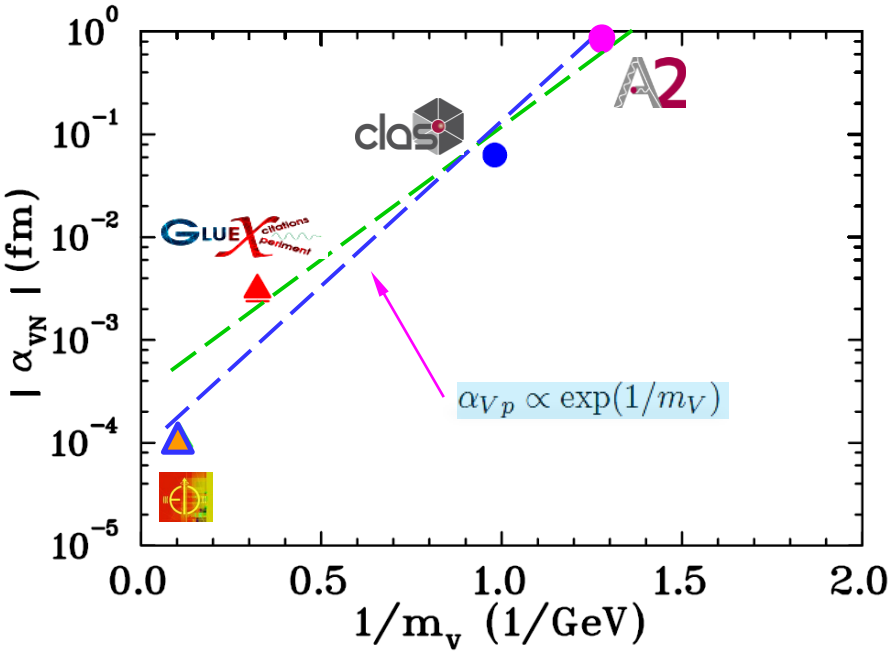
$|\alpha_{Yp}|$ = **0.066**±0.001 fm

or

$|\alpha_{Yp}|$ = **0.016**±0.001 fm

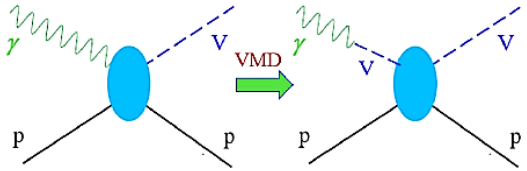
Difference factor is 600 or 150





- Such small value of ϕp *SL* compared to typical ***hadron*** size of **1 fm**, indicates that proton is more transparent for ϕ-meson compared to ω-meson, & is much less transparent than for J/ψ-meson.

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



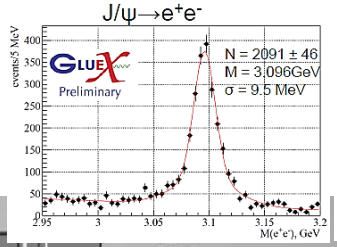
- $p \to V$ coupling is proportional to α_s & *separation* of corresponding quarks.
- This *separation* (in zero approximation) is proportional to $1/m_V$.

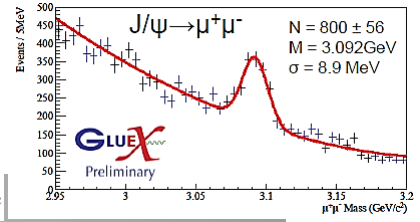
Courtesy of Michael Ryskin, July 2020

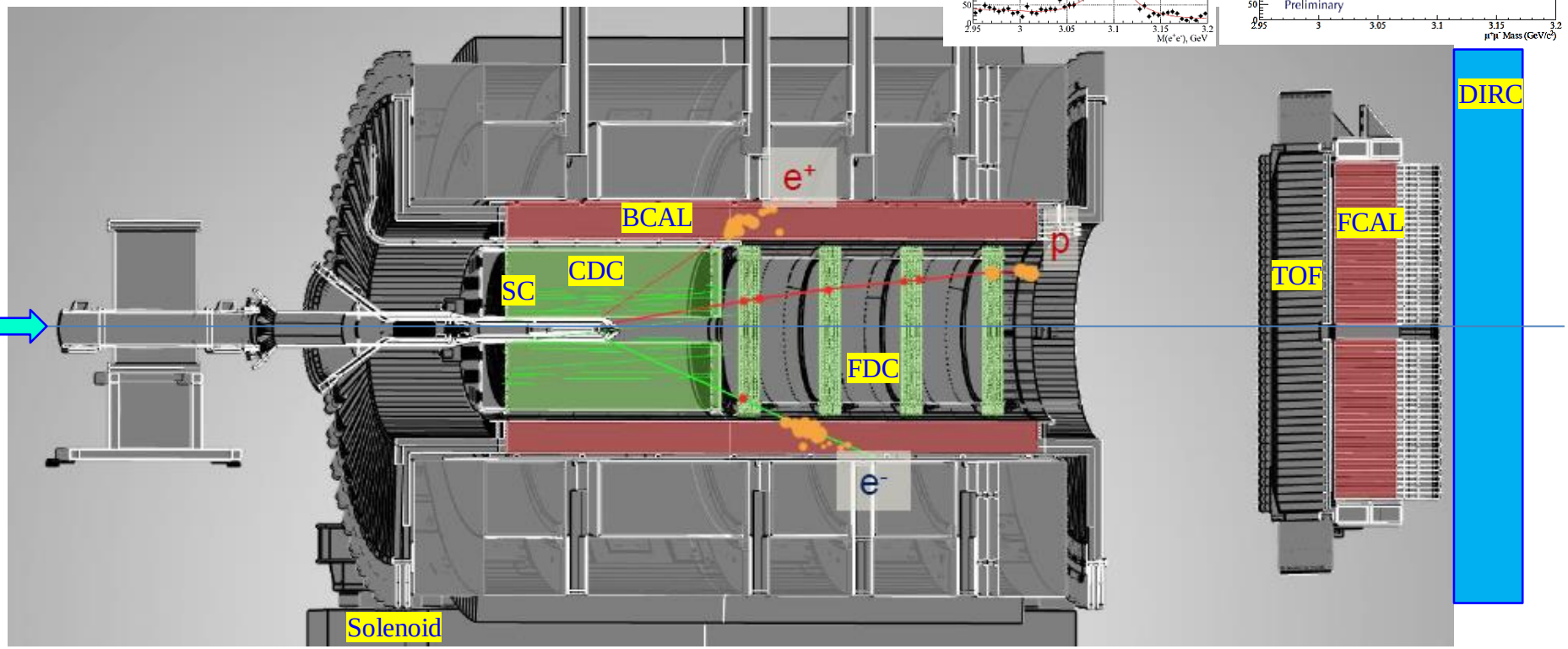
Exclusive Reaction $\gamma p \rightarrow J/\psi p \rightarrow e^+e^- p$ @ J/ψ Threshold

A. Ali *et al*, Phys Rev Lett **123**, 072001 (2019)
L. Pentchev *et al*, in progress

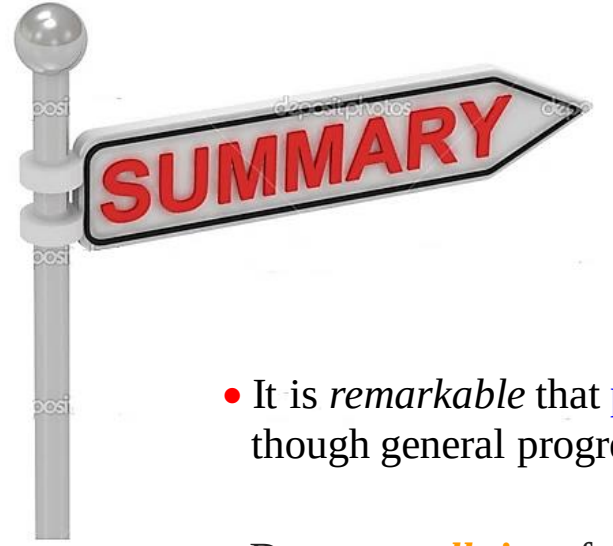
PDG BR($J/\psi \rightarrow e^+e^-$) = (5.971±0.032)% BR($Y \rightarrow e^+e^-$) = (2.38±0.11)%
BR($J/\psi \rightarrow \mu^+\mu^-$) = (5.961±0.033)% BR($Y \rightarrow \mu^+\mu^-$) = (2.48±0.05)%







- *Electrons* separated from *pions* by **E/p** – energy deposition in calorimeters over measured momentum (*pions* >10^3 times more than *electrons*) .



- It is *remarkable* that proton is quite so *transparent* to J/ψ & more to Υ, though general progression from ω to ϕ to J/ψ to Υ.

- Due to ***small size*** of '***young***' J/ψ (Υ) vs '***old***' J/ψ (Υ), measured ***SL*** is very small. J/ψ (Υ) crated by photon @ threshold then most probably J/ψ (Υ) are not formed completely & its radius is smaller than that for normal ('***old***') J/ψ (Υ). Therefore, one observe stronger suppression for J/ψ-***p*** (Υ-***p***) interaction.

- It was observed that J/ψ-N (Υ-N) cross section measured via J/ψ (Υ) re-scattering/absorption inside **nucleus** is anomaly small in case of low energy photoproduction. This can be explained by fact that we dealt with `***young***' J/ψ (Υ) of too small radius. Υ-photoproduction on both proton & nucleus will extend our J/ψ study.

- In case of J/ψ (even Υ) **Electro-Production**, we deal with the `***young***' J/ψ (Υ) for larger Q^2 & we will have smaller formation time & correspondingly smaller radius of heavy *Charmonium* & *Quarkonium*.