Experimental tests of QCD scaling laws at large momentum transfer in exclusive light-meson photoproduction

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Summary

- In the present work [1], we study the energy dependence of the 90^0 light-meson photoproduction off the nucleon.
- We consider practically all available experimental data obtained by the ***CLAS*** Collaboration over more than the last two decades and compare the results with the quark counting rules (*QCR*) predictions.
- We emphasize that in the case of *photoproduction* the *QCR* prediction is not affected by the *Sudakov FF*.
- This fact allows a more direct interpretation of the observed results.

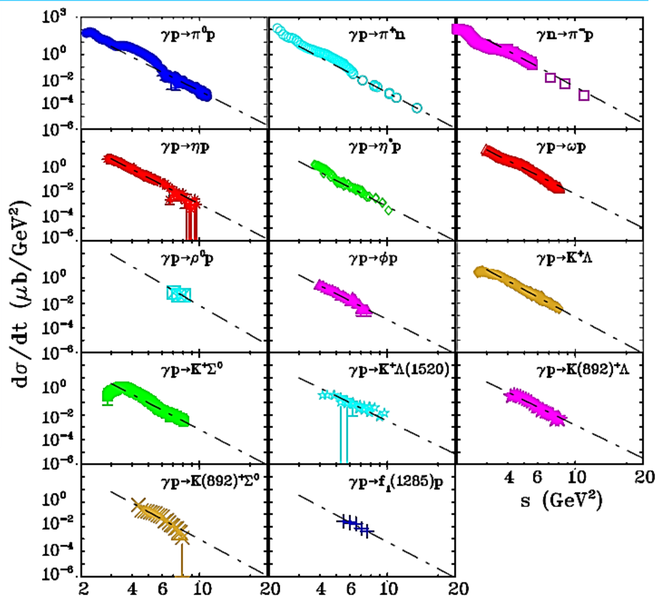
Introduction

- Binary reactions in *QCD* with large momentum transfer involve *quark* and *gluon* exchanges between colliding particles.
- *QCR* of *Brodsky-Farrar* [2] *and Matveev-Muradyan-Tavkhelidze* [3] have simple recipe to predict energy dependence of $d\sigma/dt(s)$ of two-body reactions $a + b \to c + d$ at large *production* or *scattering* angles when t/s is *finite* and is kept *constant.*
- Fixed angle (90^0) for *production* or *scattering* behavior for exclusive processes is expected to be $d\sigma/dt(s) \propto s^{-(n-2)}$, where n is number of constituents: $(n-2) = (n_a + n_b) + (n_c + n_d) - 2$ and $s + t + u = m_a^2 + m_b^2 + m_c^2 + m_d^2$.
- The optimal condition is large s with large $|t|$ & $|u|$ is $\theta = 90^0$.

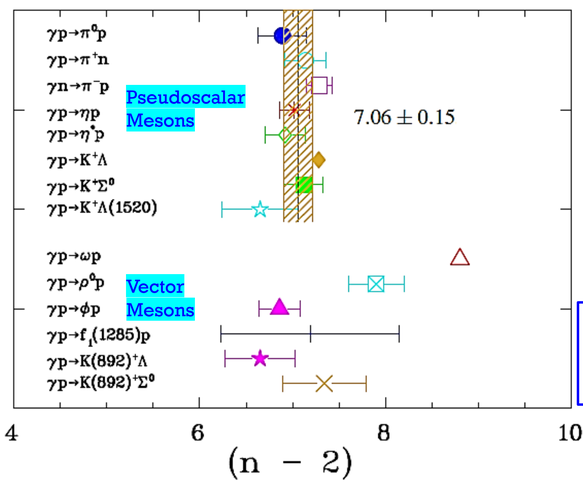
- *QCR* accounts for minimum numbers of elementary hard processes needed to provide large momentum transfer to *hadron*.
- At very large energies, this *QCR* is modified by so-called *Sudakov FF* [4].
- Of course, probability of new *gluon emission* is suppressed by *QCD* coupling constant α_s, but simultaneously it can be enhanced by large $\ln^2 s$.
- *Probability* not to emit any additional *gluons* is called *Sudakov FF*.
- For very large s, we expect that cross section of large angle *hadron-hadron* scattering should fall down with s faster than *QCR* prediction [5].
- Theoretically was shown that due to *point-like* nature of *photon*, *Sudakov FF* is *absent* in case of *large angle meson photoproduction* [6].

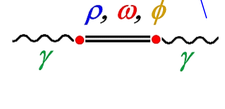
QCR for Light-Meson Photoproduction

- Two decades of JLab6 *Era* has ended leaving in its wake plethora of cross section measurements for light meson photoproduction off nucleon.
- Most of them by ***CLAS*** Collaboration (**26** papers for **2001 - 2021**) and $s < 11$ GeV^2.
- There is *unique* opportunity to *bridge resonance* & *high-energy* regions, in particular, that encompassing region in which *Regge* theory is applicable, and evaluate *QCR* phenomenology with differential cross sections above resonance energies.



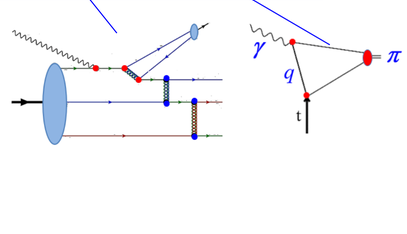
- There are *three* options of how one can consider *photon* in γN interaction:
  * No constituents ($n_\gamma = 0$) & $d\sigma/dt(s) \propto s^{-6}$.
  * Photon is *point-like particle* which participated in strong interaction ($n_\gamma = 1$) & $d\sigma/dt(s) \propto s^{-7}$.
  * There is *q-bar-q* configuration which participated in interaction ($n_\gamma = 2$) & $ds/dt(s) \propto s^{-8}$.



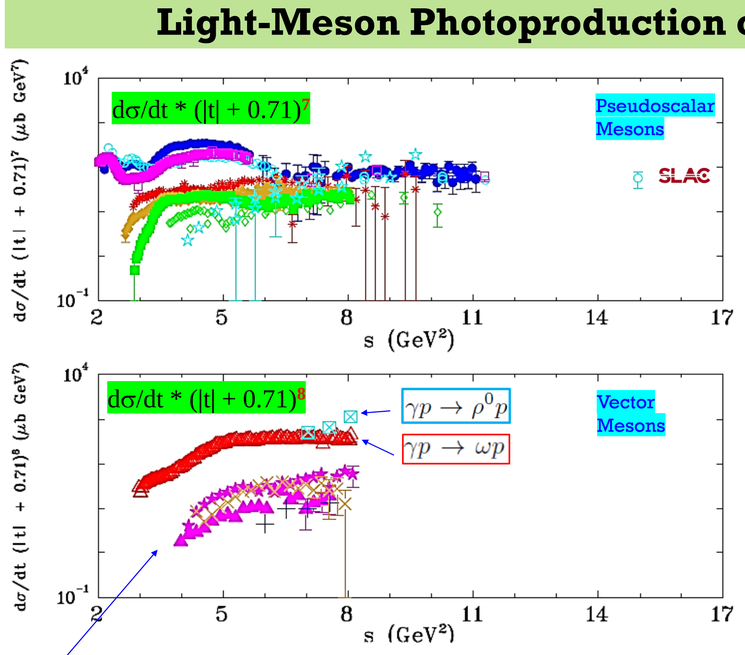


- Thanks to *point-like* nature of photon in high energy large angle scattering, there is no *Sudakov FF* in these processes[1].

- Due to *vector* nature of ω & ρ mesons in order to form spin part of corresponding wave function, we have to ***violate*** *s-channel helicity conservation*.
- Therefore, we have to expect additional suppression of 90^0 high energy photoproduction.
- For case of ω & ρ mesons:
  * Without *s-channel helicity non-conservation*, expected $n_\gamma = 1$ & $(n-2) = 7$
  * Accounting for *helicity non-conservation*, expected $n_\gamma = 2$ & $(n-2) = 8$
  * Accounting for *helicity non-conservation*, expected $n_\gamma = 3$ & $(n-2) = 9$
- Thus, one can say that observed energy dependence of ω and ρ cross section behavior at larger s is consistent with *QCR*.



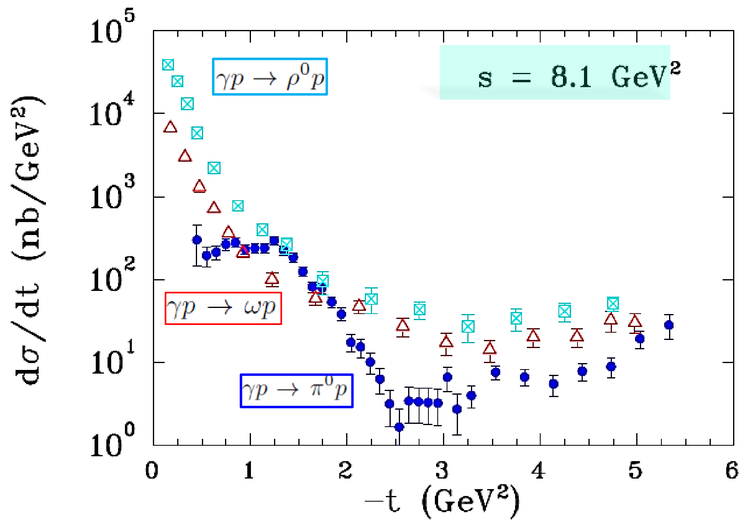
Light-Meson Photoproduction off Nucleon with CLAS



- Since we consider not very large s, we have to discuss possible power corrections to *QCR*.
- Unfortunately, corresponding power corrections are closely related to *nonPerturbative* structure of incoming hadrons.
- Therefore, we evaluate possible role of power corrections based on well known dipole behavior of proton QED *FF*, $G(t) = 1 / (1 - t/0.71)^2$ which describes all four-momentum dependencies of both ***electric*** & ***magnetic*** *FF*s of proton quite well, where constant **0.71 GeV^2** determines scale of correction in comparison with asymptotic behavior $G(t) = 1/t^2$.

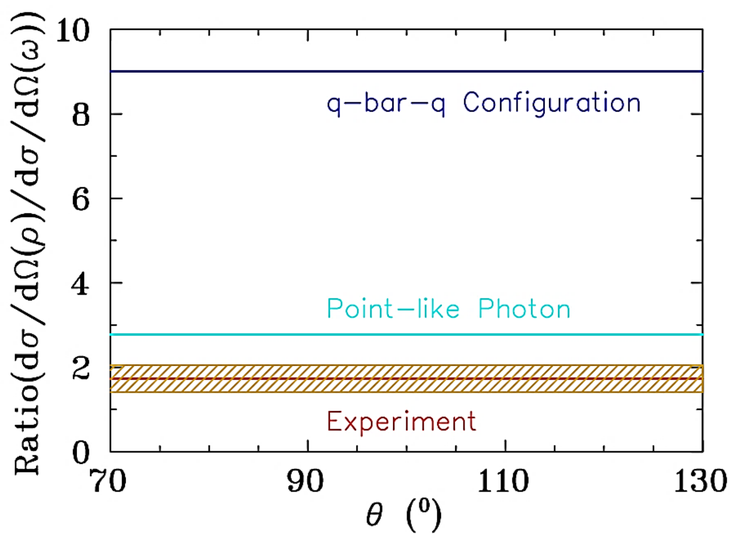
- It demonstrates possible role of "infrared cutoff" $(t - 0.71)$ in this energy interval.

- ϕ, $f_1(1285)$, and $K(892)^+$ cross sections are close to each other and lie significantly below other mesons plateau.
- It may indicate common mechanism of their production.



- For lower values of $|t|$, $d\sigma/dt$ of ω and ρ^0 photoproduction is order of magnitude higher than that of π^0.
- For higher values of $|t|$, ω, and ρ^0 photoproduction $d\sigma/dt$ is little bit higher.
- $d\sigma/dt(t)$ for light meson photoproduction off nucleon @ 90^0 is *minimal*.

- We evaluate *light mesons* photoproduction & **it was not evident** whether in this situation photon acts like *q-bar-q* pair (*VDM* contribution) or *no constituent* object.



- Vertex is *quark electric charged* \times wave function.
- Cross section is ~ (vertex)^2.
  $|\rho^0\rangle = |uu\rangle - |dd\rangle \Rightarrow$
  vertex($\gamma\rho$) = 2/3 − (−1/3) = 1
  $|\omega\rangle = |uu\rangle + |dd\rangle \Rightarrow$
  vertex($\gamma\omega$) = 2/3 + (−1/3) = 1/3
  Ratio is $(1/(1/3))^2 = 9$
- Analogous calculation & accounting for *proton* wave function.
  Ratio is $(5/3)^2 = 2.8$

- From $s = 11$ GeV^2 to $s = 21$ GeV^2, $d\sigma/dt(90^0)$ drops down by factor of 10^4.
- Within JLab12 program, **Hall C** (π^0 will come), GlueX (η & ω are coming), & CLAS12 can extend measurements up to $s \simeq 21$ GeV^2.

Stay Tuned. Coming Soon!

References

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Acknowledgments

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