Hadronic properties of the photon.

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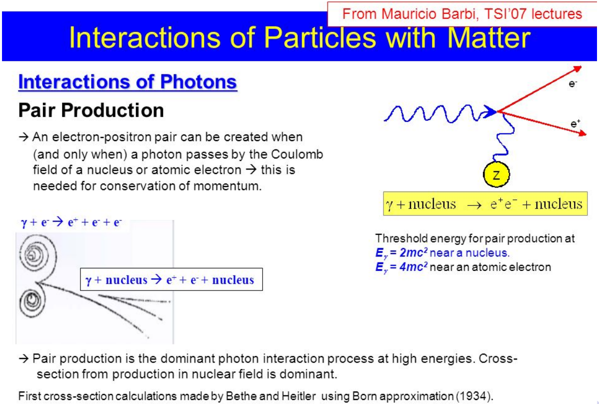
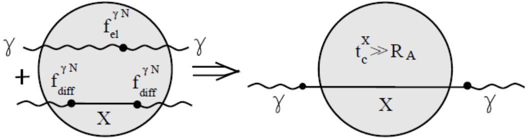
Introduction

At first the photon was regarded as structureless, but with increasing energy it was found that through the interaction with a Coulomb field the photon could materialize as pairs of electrons the effect which is earliest manifestation of photon structure. Lepton pair production $\gamma \leftrightarrows e^+e^-$ and vice versa at any energies is accounted through radiative corrections in QED.



Hadronic structure of photon

At high energy $E_\gamma > 2m_\pi$ the hadronic structure of the photon is manifested. Before the interaction the photon (real or virtual)fluctuate to hadronic state, which then interact with a target. The well example of such approach is the vector dominance model (VDM), where the photon hadronic component is presented as a set of light vector mesons ρ, ω, ϕ. The lifetime of such fluctuation or coherence length grows with energy as $t_c = l_c = \frac{2E}{M^2}$ where M is the mass of hadronic state. The best way to reveal the existence of hadronic component of photon is its interaction with nuclei.
If the hadronic component lifetime is enough long it leads to absorption of photons in their interaction with nuclei. At very high energies ($l_c >> R$) it seems that hadronic component interact with a target.



Total cross section $\sigma(\gamma A)$

$A_{eff} = \frac{\sigma(\gamma A)}{A\sigma(\gamma N)}$ for real and virtual photons.

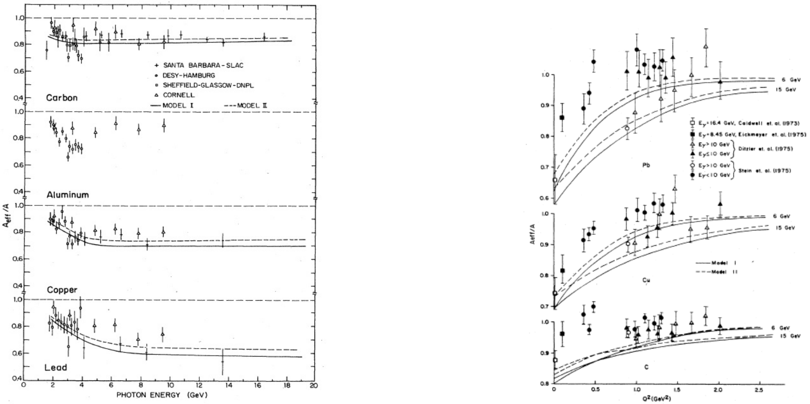


Figure: Left: The energy dependence of A_{eff}. Right: The dependence of A_{eff} on the mass of virtual photon Q^2.

Mesons photoproduction off nuclei.

Gottfried&Yennie 1969. $N_{eff} = \frac{d\sigma(\gamma+A\to M+A')/dt}{d\sigma(\gamma+N\to M+A')/dt}$ should decrease with energy as a result of interference between direct and two step photoproduction in nuclei.

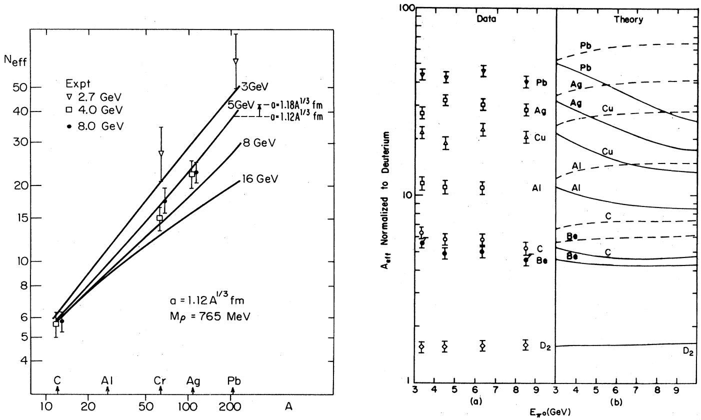


Figure: Left: The A dependence of N_{eff} for ρ^0 photoproduction.Right: The energy dependence of N_{eff} for π^0 photoproduction off nuclei.

Color dipole model

It is no doubt that the photon has a hadronic component which leads to it shadowing in nuclei.The vector dominance model predicts more shadowing and stronger suppression of nuclear transparency than existing experimental data. Currently the best way to describe the hadronic photon structure is the color dipole model widely discussed in literature which was first applied to production by real (Gevorkyan,Kotzinian,Jaloyan Phys. Lett. B212,251, 1988) and virtual (Nikolaev& Zakharov,Zeitshrift fur Physics C53,331, 1992) photons. The idea is that before interaction the photon fluctuates to colorless quark-anti-quark pair which interacts with a target as a color dipole $\sigma(r) \sim r^2 log(r)$. Such generalization of vector dominance model allows one to correctly account besides elastic (Glauber) multiple scattering all inelastic (Gribov) corrections.

$$\sigma_{L(T)}(\gamma A) = \int |\Psi^{\gamma}_{L(T)}(Q^2, r, \alpha)|^2 \sigma(r) d^2 r d\alpha$$

$r \equiv x_{\perp}$ - the transverse distance in $q\bar{q}$ pair; α- the partition of light cone momentum carried by quark; $(1-\alpha)$-anti-quark

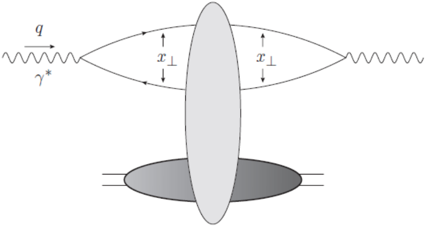


Figure: The virtual photon interaction with a target.

Has vector meson polarization impact on interaction?

The vector meson $V(\rho, \omega, \varphi)$ can be transversely (*helicity* $\lambda = \pm 1$) or longitudinally ($\lambda = 0$) polarized.

$\sigma_{L(T)}(VA) = \int |\Psi^V_{L(T)}(r, \alpha)|^2 \sigma(r) d^2 r d\alpha$

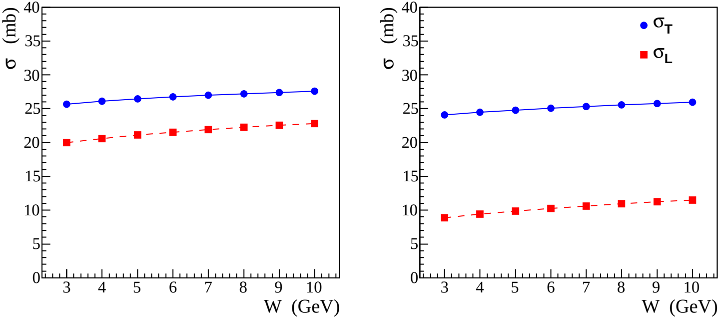


Figure: Left: Boosted Gaussian. Right: Relativistic light cone model.

Experimental data. Photoproduction off nuclei.

In the late 60's and early 70's many experiments on vector mesons photoproduction off nuclei have been done at SLAC, DESY, Cornell etc . to check the predictions of vector dominance model (VDM) and quark model. The challenge of polarization impact on strong interaction at that time does not even considered.

Why!!! The reasons look as follows:

1) In the naive quark model the total cross sections considered as independent of vector meson polarization $\sigma_T(VN) = \sigma_L(VN)$.

2) In the coherent photoproduction only transverse vector mesons can be produced. As the coherent photoproduction is huge and has clear and unique theoretical predictions the extraction of $\sigma(VN)$ has been done from this part of the cross section.

3) As to the incoherent region to extract $\sigma_L(VN)$ one has to pick out the process, where the bulk of longitudinally vector mesons produced. As was shown in our work Chudakov, Gevorkyan,Somov Phys. Rev.C93,,203,2016. the information on σ_L can be obtained from the incoherent photoproduction of ω mesons on nuclei at JLAB energies $5GeV < E_\gamma < 10GeV$, where due to pion exchange longitudinally polarized ω's can be produced.

Vector mesons electroproduction off nuclei

Why the knowledge of $\sigma_T(VN)$ and $\sigma_L(VN)$ is important ?
Color transparency: According to QCD hard exclusive processes select configurations,where the quarks are close together forming a color neutral object with transverse size $r \sim 1/Q$.
Such effect is well known in QED in photoproduction of e^+e^- pairs (Chudakov effect). The effect of color transparency is seen in electroproduction of vector mesons off nuclei as a grows of nuclear transparency $T_A = \frac{d\sigma_A}{Ad\sigma_N}$ with the mass of virtual photon Q^2.

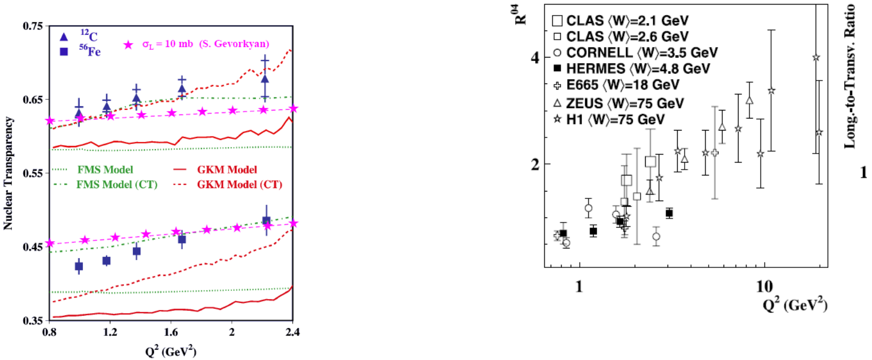


Figure: Left: Nuclear transparency A^{eff} as a function of photon virtuality Q^2. Right:The ratio $R = \frac{\sigma(\gamma^* + N \to V_L + N)}{\sigma(\gamma^* + N \to V_T + N)}$ as a function of Q^2.

The considered effect has to be separated from the effect of color transparency as it is not small and exhibit the same behavior. Thus the challenge of the impact of vector meson polarization on it interaction with nuclei and nucleon can be crucial for determination of such fundamental effect as color transparency!!!

Vector meson production of nuclei by pion and kaon beams.

In charge exchange reactions $\pi^- + N \rightarrow V + N; \quad K^- + N \rightarrow V + N$ many longitudinally polarized vector mesons can produced.
There is proposal (Denisov,Letter of Intend at CERN SPS ArXiv: 1808.00848) to measure vector mesons production off nuclei by pion and kaon beams to extract their transverse and longitudinal interaction cross sections with nucleon as a result of different absorption.