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EXCLUSIVE AND SEMI-EXCLUSIVE REACTIONS AT A HIGHER ENERGY CEBAF

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1 Old and new initiatives

More energy at CEBAF will provide more opportunity for studies of hadron and nuclear properties. Many of the experiments that could be done are extensions of things already done at lower energies. Others represent new initiatives that could not work or could not theoretically be interpreted at lower energies. I will concentrate on the new initiatives, but do not wish our thinking to neglect what can be learned from continuations of lower energy work. Allow me to begin with a list of some things that should be continued into a new energy regime.

- Baryon and meson spectroscopy of higher mass states. With 4 GeV incoming electron energy, strange mesons are limited to 1.8 GeV in mass and charm is not producible.

- Exclusive reactions, including meson and baryon form factors and reactions on few nucleon systems. The latter includes deuteron photodisintegration, the A and B form factors of the deuteron, and the deuteron tensor polarization T_{20}. (And we should not forget T_{20} in inclusive scattering.)

- Hadrons in the nuclear medium, with such topics as color transparency, electroproduction of ρ mesons, virtual Compton scattering off nuclei,and backward hadrons from e-d reactions.

The very last must be especially important, since it gives the logo used in the advertizing for this conference

All the preceeding are good.

In addition, there are new initiatives that this talk will call attention to, in particular:

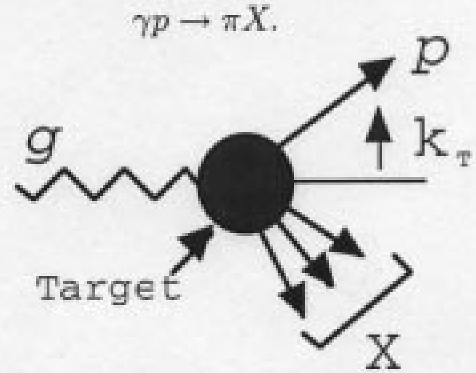
1. Semi-exclusive meson production
2. Duality in semi-exclusive reactions
3. New views of exclusive reactions and perturbative QCD (leading to "off-forward parton distributions")

2 New initiatives

2.1 Semi-exclusive reactions

A semi-exclusive reaction is one where one or a few, but not all, of the hadrons in a final are observed. There are of course many such processes, and we will focus on pion photoproduction [1,2],

$$\gamma p \to \pi X.$$



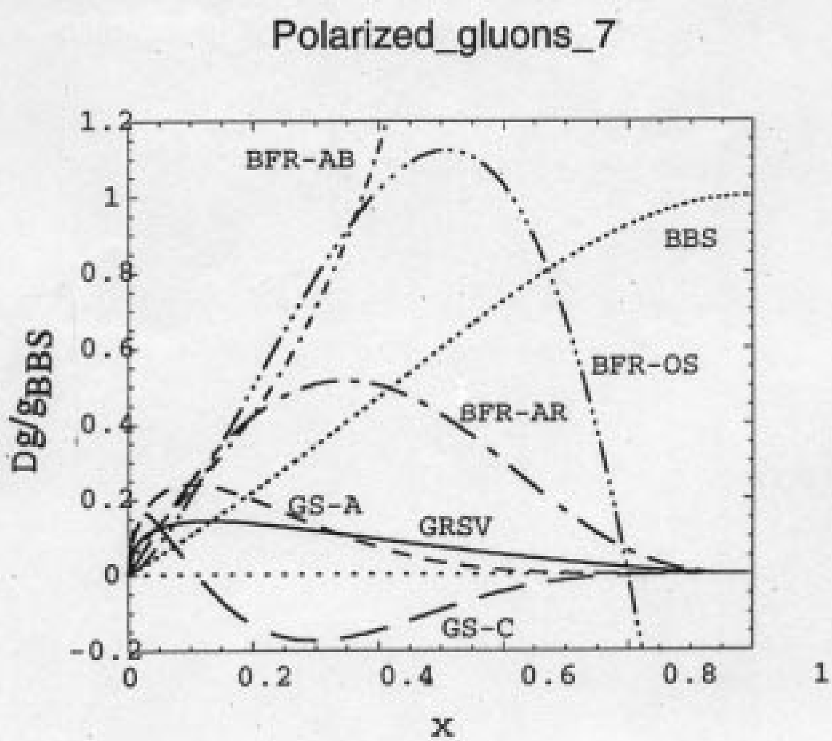
There will be two further provisos: that the transverse momentum of the pion is high, and that the recoil mass m_X is high. These provisos ensure that perturbation theory can be used in the calculations.

We hope to learn a lot from these studies, including information about:

- the polarized and unpolarized gluon distributions of the target,
- the quark distributions for high x, and
- the pion wave function at short range.

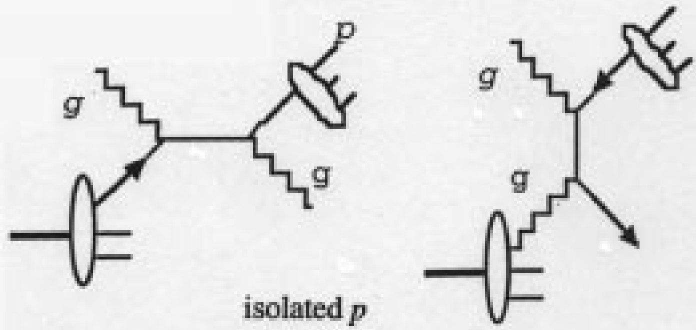
To quickly say something about one of these learning goals, consider the gluon distributions, especially w/ polarization. Deep inelastic scattering does not measure gluons to LO, since the gluons are electrically neutral. Analyzing the scaling violations of the quark distributions does imply information about the gluon distributions, but for the polarized case there is not sufficientdata over a sufficient range of x and Q^2 to get definitive results. In fact, the spread among published results is striking, as one can see from the figure on thenext page.

In this figure, g is the gluon distribution function for the proton, $\Delta g \equiv g_{\uparrow} - g_{\downarrow}$, and initials GS, BFR, GRSV, and BBS refer to the authors of the distributions (and are decoded in [2]). Clearly Δg remains to be learned.

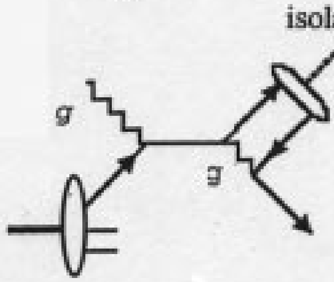


To proceed we need to consider the mechanisms for $\gamma p \to \pi X$. There are four, and they go under the names fragmentation process, direct pion production, resolved photon production, and vector meson dominance production. Some representative diagrams for each case are,

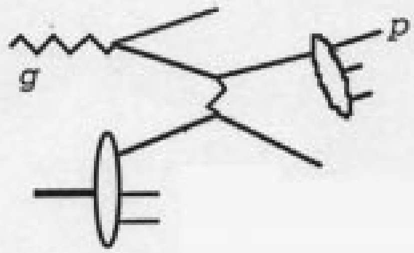
Fragmentation



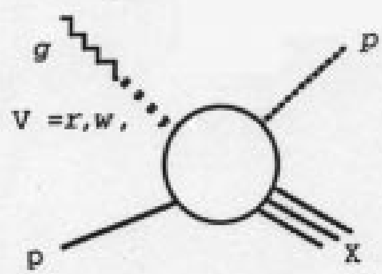
Direct Pion



Resolved Photon



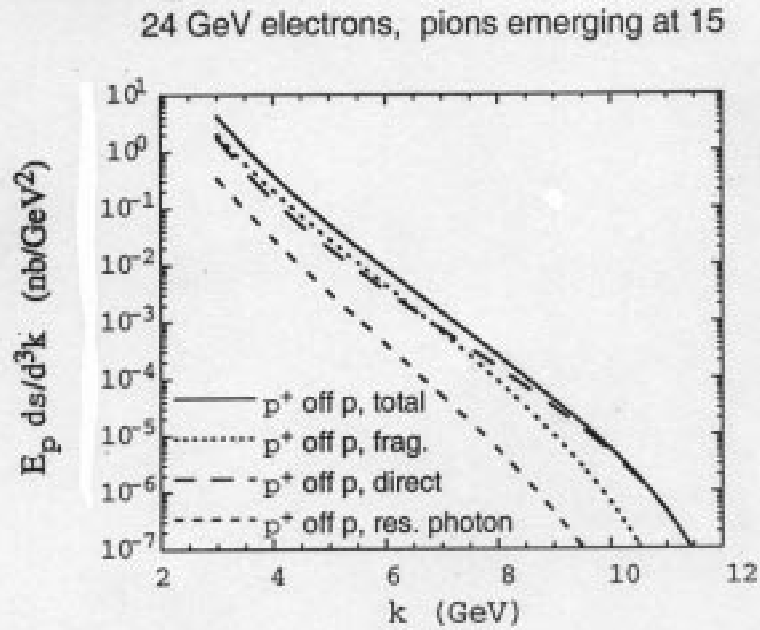
VMD



At lowish energy—but not lowish $k_\perp$—pions come from fragmentation and from direct production. This can be seen in the following plot, where we have calculated the fragmentation, direct pion, and resolved photon contributions for one energy (a plot at 12 GeV or 48 GeV would be qualitatively similar) and angle.

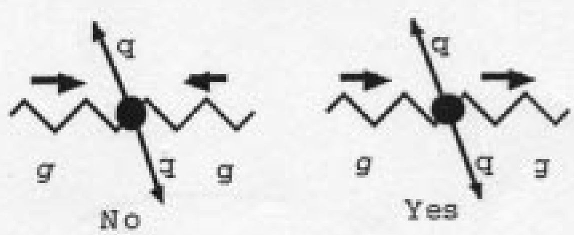
VMD is not included in the calclation, but is important for $k_\perp$ <

1.5 GeV. At the highest momenta, there is a region where direct pion production dominates, and below that a region where the fragmentation process is the most important.



Where, fragmentation dominates, about 1/3 to 1/2 of rate comes from gluon targets in the proton. Note the importance of the high pion transverse momentum, and not just for allowing perturbative calculations. There has to be a recoiling particle, hence the process must be higher order. Then it is possible for the gluon target process, the second one illustrated on the preceeding page, to be of the same order of magnitude as a quark target process.

Also, it is very useful that the polarization asymmetry of $\gamma g \to q\bar{q}$ is (−)100%, as illustated in the figure.



The corresponding asymmetry for $\gamma q \to gq$ is of the order of 50%. Hence there is good sensitivity to the polarized gluon distribution.

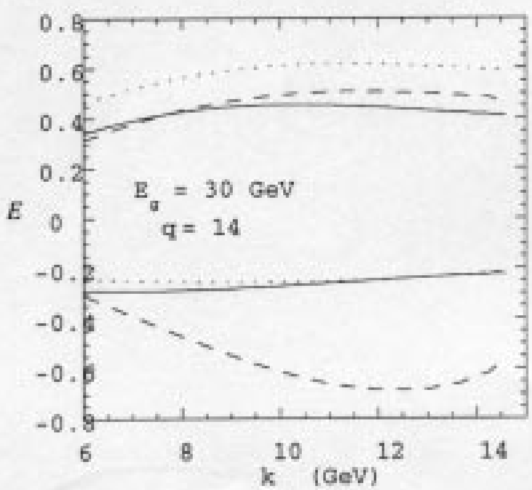
On the next page is a plot of

$$E \equiv A_{LL} \equiv \frac{d\sigma_{R+} - d\sigma_{R-}}{d\sigma_{R+} + d\sigma_{R-}}$$

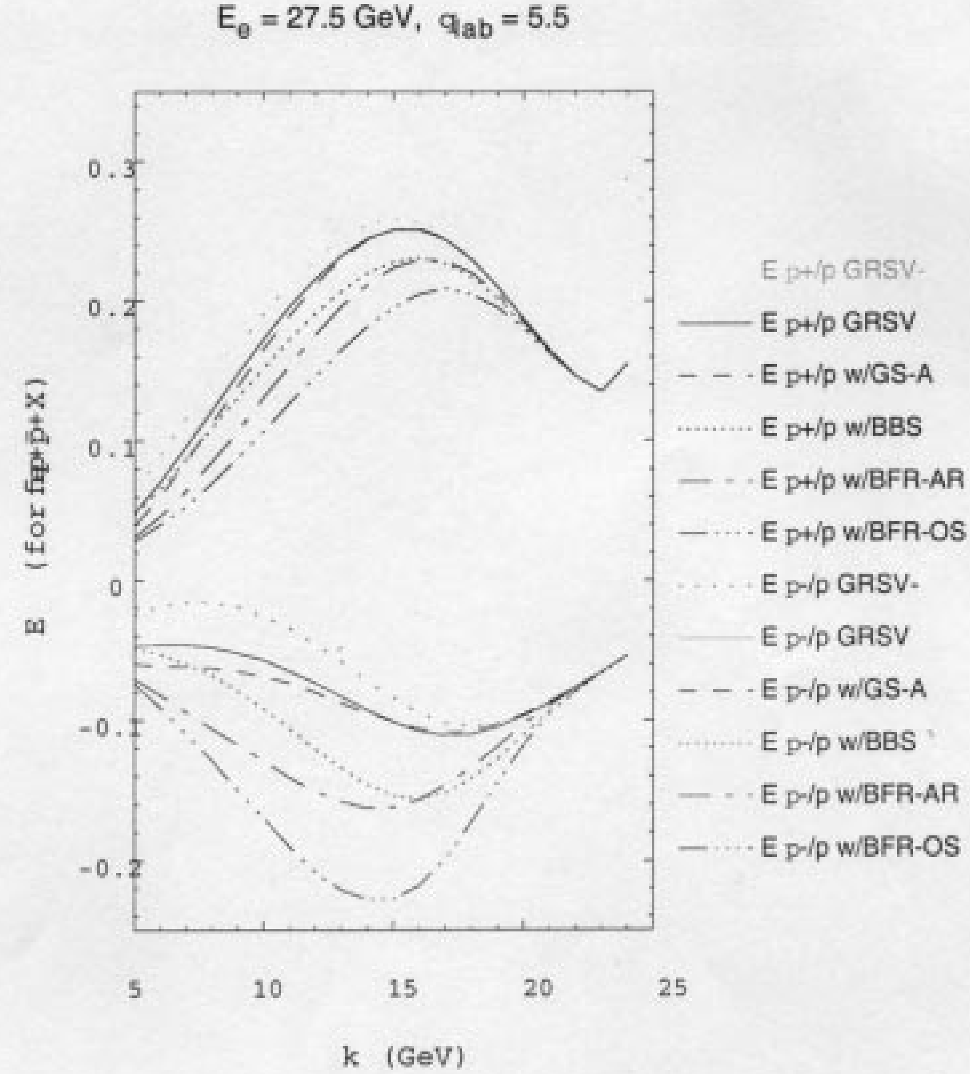
vs. k the momentum of the outgoing pion for $ep \to e'\pi X$ at the idicated energy and angle. The R above refers to the right handed polarization of the photon, and the "±" gives the helicity of the target proton. The plot is not as complicated as it first appears.

All curves use the same quark distributions, in this case those of GRSV. The six curves above are all for π^+ production. The bottom six curves are correspondingly for the π^-. One of each set of curves is a benchmark, with Δg set to zero. The others show what happens when various different model Δg's are used. One sees, as promised, quite a dispersion in the curves, indicating that this is a possible way to verify a correct Δg model.

At higher pion momenta we have direct pion production, and target gluons not important. However, since π^+'s come mainly from u, and π^-'s from d, we have a way to measure u and d distributions. They are not as well known at high x as one might think[4]. Here is a plot of E (equvalently, A_{LL}) vs. pion momentum k for high k and three polarized quark models.

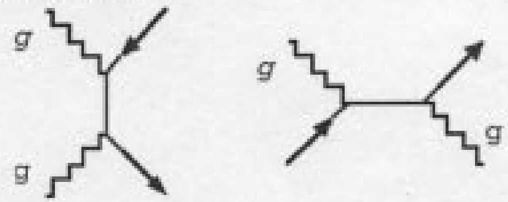


The π^+'s are above, the π^-'s below and the solid curves are GRSV; the dashed, GS; the dotted, CTEQ/Soffer (decoded in [2]).



Hence we have shown two things that can be learned from semi-exclusive pion production.

We will close this section with one more comment. As lower energies it is harder to find a fragmentation region between the direct pion production and VMD regions. Help may be available in fishing out gluon target events by looking two jets or two hadrons 180° apart in azimuth angle. Think of the two parton level diagrams,



Fragmenting q's give faster hadrons than fragmenting glue. This leads to $q\bar{q}$ final state giving harder hadron pairs than qg or $\bar{q}g$.

It may be that two pions with some cuts like $m_{\pi\pi}$ above 2 GeV or each $k_\perp$ above 1.5 GeV suffices to ensure that the ratio of gluon fusion to quark Compton is several to one even at CEBAF with 12 GeV.

2.2 *New initiative: Duality in semi-exclusive reactions*

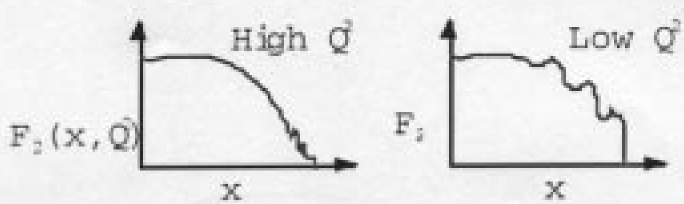
We can begin by reminding ourselves of Bloom-Gilman duality in deep inelastic scattering. The differential cross section can be written as some known kinematic factors times the structure function $F_2(x, Q^2)$,

$$\frac{d\sigma}{dE'\,d\Omega} = \ldots \times F_2(x, Q^2)$$

.

No final hadrons are observed,but their mass W is determined from measured quantities, as $W^2 = m_N^2 + Q^2(1-x)/x$.

For W out of the resonance region, we have Bjorkenscaling, meaning that F_2 depends mainly on x and only weakly on Q, and there is a smooth scaling curve for F_2. In the resonance region, a plot of F_2 vs. x shows the expected bumps at values that depend on Q^2 according to the above formula,



The "duality" between the bumps and the scaling curve can be summarized in two statements.

1. The scaling curve from high Q^2 is decent average over resonance bumps seen at the same x at lower Q^2. (This is true for all resonances.)

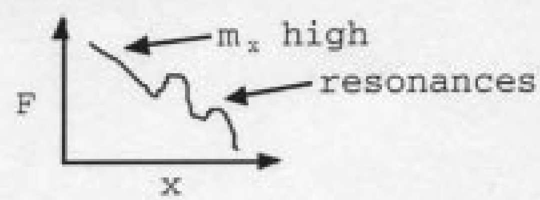
2. Resonance bumps do not disappear. They move. But the ratio of bump to continuum is constant. (This is true for most resonances, but fails for the $\Delta(1232)$.)

It appears tha at low Q^2, where final state interactions modify the structure function, the OA scale is still set by 1-quark interaction.

In semi-exclusive process it is also possible to find a duality like a Bloom-Gilman-like inclusive-exclusive connection. Again focusing on pion photoproduction, there is a Bjorken-like scaling in region where direct pion production dominates. Here the cross section can be written as a function of x times known kinematic factors, and x is totally fixed by qunatities that are experimentally measureable.

$$\frac{d\sigma}{dx\ dt} = \sum_q q(x)\frac{d\sigma}{dt}(\gamma q \to \pi q) \quad \to F(x) \times \text{known kinematic factor}$$

As m_X gets into resonance region, will see bumps above smooth curve. Changing the photon-pion momentum transfer variable t is analogous to changing Q^2 in deep inelastic scattering. At a fised t,F vs. x will look like,



With changeing t, we can ask [3]

- Does Bjorken scaling work in this case?
- Does duality version 1 (the averaging) work?
- Does duality version 2 (constancy of the resonance to continuum ratio) work? (It does not need to fail for the Δ this time even though it failed before.)

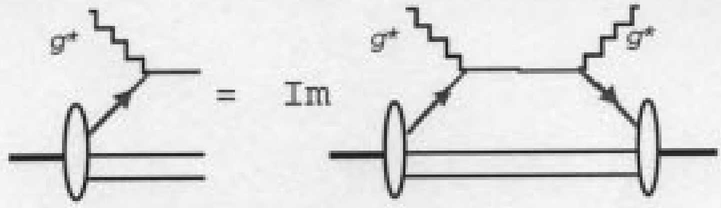
For duality version 2 to be true, a smooth curve going like $(1-x)^3$ at high x would be dual to a resonance production cross section

$$\frac{d\sigma}{dt}(\gamma + p \rightarrow \pi + R) \propto \frac{1}{s^7}$$

for fixed t/s and for a given resonance R. This is precisely the same as the counting rule prediction (and the data for $\gamma p \rightarrow \pi^+ n$).

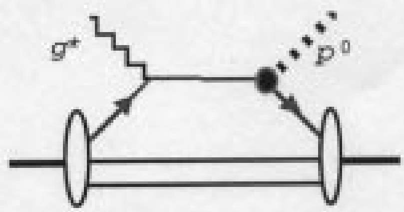
2.3 New initiative: Off forward parton distributions

By way of background, recall that deep inelastic scattering can be thought of as the imaginary part of forward Compton scattering, as in the following diagram:



The parton that returns to the hadron has the same momentum as the one that left. Its momentum distribution is given in terms of squares of wave functions, and is in today's language the "forward parton distribution."

Now consider instead quasi-elastic (exclusive) scatterings, such as virtual Compton scattering, $\gamma^* + p \rightarrow \gamma + p$, or $\gamma^* + p \rightarrow \pi^0(\text{or } \rho^0) + p$. A diagram, as relevant to high Q^2 incoming photon, looks somewhat like the previous one:



but the parton leaving and the parton entering the baryon have different momenta. The relevant distribution is the "off-forward parton distribution," which is related to products of wave functions with different incoming and outgoing momentum fractions. Learning what it is will provide new and more detailed information about hadron structure [6].

For CEBAF, studies indicate that the π^0 or ρ^0 reactions should be feasible and useful, although virtual Compton scattering may have strong Bethe-Heitler contributions [7].

3 Finis

John Ralston has commented that "Deep inelastic scattering mixes all manner of quark wave functions. If we want to learn about hadron structure directly, we should study exclusive reactions."

With more energy at CEBAF, there are many new opportunities for study of exclusive and semi-exclusive reactions. Some of these fall into the category of "more of the same but better," and some are opportunities for new studies not possible or not interpretable at lower energy.

This talk listed some of the former, and discussed possibilities for the latter, in particular

- Semi-exclusive meson production,
- Duality in semi-exclusive reactions, and
- Exclusive meson photoproduction and off-forward distributions,

and gave some inkling of what could be learned about the parton distribution within hadrons from each.

I look forward to learning of still more possibilities as the workshop proceeds.

Short list of references

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2. A. Afanasev, C. Carlson and C. Wahlquist, Phys. Lett. B **398**, 393 (1997) and Phys. Rev. D **58**, 054007 (1998).
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