Quark propagation and hadron formation in the nucleus
(progress in analysis of experimental data of CLAS EG2 experiment)

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CLAS collaboration meeting
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Experimental details

EG2 Experiment target in GEANT3
Solid (C, Al, Fe, Sn, Pb) target simultaneously with deuterium target
Schematic diagram describing semi-inclusive Deep Inelastic Scattering of a lepton off a nucleon

One photon exchange reaction

Proton in "A" nucleus

$X = (\pi, \pi, K, ...)$

hadron shower

quarks

gluons
Experimental Variables

\( \nu \) – energy transferred by the electron, = initial energy of struck quark, (2 ~ 4.5) GeV here

\( Q^2 \) – probe, (1 ~ 4) GeV\(^2\) here

\( z_h \) – energy fraction carried by hadron; 0<\( z_h <1 \)

\( p_T \) – hadron momentum transverse to virtual photon direction

\( \Phi \) – hadron azimuthal angle to virtual photon direction

\( E_{\text{BEAM}} = 5 \) GeV (CLAS)
Experimental Observables

Transverse momentum broadening

\[ \Delta p_T^2 = p_T^2(A) - p_T^2(2H) \]

(DIS kinematics)

Hadronic multiplicity ratio

\[
R_M^h(z, \nu, p_T^2, Q^2, \phi) = \left\{ \begin{array}{c}
\frac{N_{h \text{DIS}}(z, \nu, p_T^2, Q^2, \phi)}{N_{e \text{DIS}}(\nu, Q^2)} \\
\frac{N_{h \text{DIS}}(z, \nu, p_T^2, Q^2, \phi)}{N_{e \text{DIS}}(\nu, Q^2)} \\
\end{array} \right\} \frac{A}{D}
\]
Transverse momentum dependence on 1/3 of nuclear mass number (all together in 24 kinematical region)

Acceptance correction less than 14%
Multiplicity Ratio Dependence on $Z_h$ in different $Q^2$ and $\nu$ bins.
3 pions 1 dimensional Multiplicity Ratios distributions paper

People currently involved in the analysis:

William Brooks (coordinator)
Raphael Dupre
Ahmed El Alaoui
Hayk Hakobyan
Taiysia Mineeva
Sebastian Moran
Orlando Soto

Several independent data analysis are performed

Two analysis notes are under review:
“Hadronization studies via pi0 electroproduction off D, C, Fe and Pb”
“Study of the hadronization of the charged pions”
Integrated distribution comparison between Raphael and Hayk analysis

Multiplicity Ratio in function of $z$

For the moment there is $\sim 10\%$ systematic difference
Possible sources for uncertainty in the results

- Different dimensional binning in acceptance correction procedure (5 dim. - Hayk (up to 3% correction) & 4 dim. Raphael (10% correction))
- Tighter particle ID cuts in the case of Raphael's analysis for electrons and for pions.
- Vertex cut
- Different approaches in pion identification: $\Delta t$ – Hayk & $\Delta \beta$ – Raphael
- Etc.
Acceptance correction method?
Comparison 5 dim. acceptance correction vs. 4 dim.

Porcentual Difference in MR between (Q2, Xb, Phi, Pt) and (Q2, Xb, Pt) kinematical bins, for different Vertex Cuts

\[
\frac{\text{Bin}(Q2, Xb, Phi, Pt) - \text{Bin}(Q2, Xb, Pt)}{\text{Bin}(Q2, Xb, Pt)} \times 100
\]
Vertex cut?
Ratio of acceptances for positive pions from the solid target to the liquid target

~2% effect
Comparison of different vertex cuts

Comparison MR for different Vertex Cuts, Si Xf Cut, Acceptance Corrected.
EMC curve with different vertex cuts

EMC Curves, Comparison different Vertex Cuts

$\frac{\sigma_C}{\sigma_D}$ vs $x_B$

- SLAC E139
- CERN MMC
- Jlab E05103

- CC Hayk’s vertex cuts
- RC Hayk’s vertex cuts
- AC Hayk’s vertex cuts
- CC Raphael’s vertex cuts
- RC Raphael’s vertex cuts
- AC Raphael’s vertex cuts

Paper’s Result

externals

Hayk’s Simulations
EMC curve from different analysis

EMC Ratio

Squares: Raphael's Analysis
Circles: Hayk's Analysis

C
Fe
Pb

Acceptance Correction Applied
Normalization factors comparison

\[ MR = \left( \frac{N_{\pi+}^{\text{DIS}_{\text{A}}}}{N_{\pi+}^{\text{DIS}_{\text{D}}}} \right)^{D} A = \frac{N_{\pi+}^{\text{DIS}_{\text{A}}}}{N_{\pi+}^{\text{DIS}_{\text{D}}}} \times \frac{N_{\text{ef}_{\text{D}}}}{N_{\text{ef}_{\text{A}}}} \]

- Hayk
- Krishna
- Orlando
- Raphael

\( \frac{N_{d}(X_{0},Q^{2})_{A}}{N_{d}(X_{0},Q^{2})_{D}} \)
Physics generator code for simulations?
Comparison of different simulation codes

Discrepancy between Orlando's and Hayk's Simulations (\%) , MR Zh, 5D
Conclusions!

- Acceptance correction method (5 dim vs 4 dim) doesn't reproduce the observed uncertainty between different analyses.

- Vertex cut doesn't reproduce the observed uncertainty between different analyses.

- Further studies are necessary (currently on progress).
$\pi^0$ analysis status update (1):

radiative correction for the electron off nuclear targets

Taisiya Mineeva
Inclusive electron radiative corrections in DIS

Code: EXTERNALS from D.Gaskell & al (based on the code originating in SLAC in 80s)

- First Born approximation + next-to leading order QED processes
- Mo & Tsai formalism for handling of IR divergencies: angular peaking approximation equivalent radiator method
- New: full 3D integration of radiative tails in elastic, quasielastic and dis regimes
- Nuclear dependencies are accounted via global parametrization to structure fnc

\[ f_{EMC}(x') = c(x') A^{\alpha(x')} \]

* P.Bosted, V.Mamyan “Empirical fit to electron-nucleus scattering”
  arXiv:1203.2262v2

Mo&Tsai(1969):

Y.S.Tsai (1971):
Radiative correction (RC) factors for D, C, Fe, Pb

\[ \delta_{RC} = \frac{\sigma_{Rad}}{\sigma_{Born}} \]

\[ N_{e_{corr}} = \frac{N_{e_{meas}}}{\delta_{RC}} \]
Radiative correction (RC) factors normalized to D

\[ R_{\text{corr}}^e \sim \frac{(N_{\text{meas}}/\delta_{RC})_D}{(N_{\text{meas}}/\delta_{RC})_A} \sim N \times \frac{(\delta_{RC})_A}{(\delta_{RC})_D} \]
Coulomb correction for C, Fe, Pb

Code: the same code EXTERNALS from D.Gaskell & al
Formalism: effective momentum approximation + focusing factor

$k_i' = k_i + \Delta k, \quad k_f' = k_f + \Delta k,$

$k_{i,f}' = |\vec{k}_{i,f}'|, \quad \Delta k = -V_0/c,$

$V_0 = (1.5) \times (Z/R) \times (\hbar c) \times \alpha \times 0.775$

Coulomb correction factor is normalized by the square of focusing factor:

$f(0) = \left(1 - \frac{\beta}{R}\right)^{-2} \sim \left(1 - \frac{V(0)}{E}\right)^2 \sim \left(\frac{k_{i,f}'}{k_i}\right)^2$

Coulomb correction (CC) for C, Fe, Pb

\[ \delta_{CC} = \frac{\sigma_{QE}}{\sigma_{Coul}} \]

\[ N_{e \text{corr}} = N_{e \text{meas}} \cdot \delta_{CC} \]
Consensus on electron radiative corrections

- Inclusive electron RC are now calculated with EXTERNAL code for all three pion analysis
- Charged pion analysis carried by Raphael Dupré previously used RADGEN

### Comparison of $(\delta_{RC})_{Pb}/(\delta_{RC})_{D}$ between two codes, in bins of $\nu$ (color) vs $x_B$

Note: EXTERNALS does exact calculations, while RADGEN is based on MC and has statistical fluctuations

The average difference between EXTERNAL and RADGEN over all bins is 0.75%
π⁰ analysis status update (2):

systematic uncertainties

Taisiya Mineeva
### Summary table of the current status on systematic uncertainties

<table>
<thead>
<tr>
<th>Systematic uncertainty</th>
<th>$\Delta_{RMS}^C$ (%)</th>
<th>$\Delta_{RMS}^{Fe}$ (%)</th>
<th>$\Delta_{RMS}^{Pb}$ (%)</th>
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<tbody>
<tr>
<td><strong>Normalization type</strong></td>
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<tr>
<td>Target vertex cut</td>
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<td>Target leakage</td>
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<td>EC time (beta) cut</td>
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<td>Electron radiative corrections</td>
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<td>SIDIS radiative corrections</td>
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<td><strong>Bin-by-bin basis</strong></td>
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<td>Background shape</td>
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<td>Signal shape</td>
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<td>Acceptance in finite bin width</td>
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<td>Total in $(\nu, z, p_T^2)$</td>
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<td>5.6</td>
<td>6.9</td>
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