Quark propagation and hadron formation in the nucleus
(results of CLAS EG2 experiment)

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Schematic diagram describing semi-inclusive Deep Inelastic Scattering of a lepton off a nucleon

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

One photon exchange reaction

Proton in “A” nucleus

Quarks

Gluons

Hadron shower
Experimental Variables

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

Q – 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

Φ – hadron azimuthal angle to virtual photon direction

$E_{BEAM} = 5$ GeV (CLAS)
Experimental details

**Solid target**

Carbon fiber

**Rohacell foam scattering chamber**

Liquid $D^2$

EG2 Experiment target in GEANT3

Solid (C, Al, Fe, Sn, Pb) target simultaneously with deuterium target
Experimental Observables

Transverse momentum broadening

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

Hadronic multiplicity ratio

\[ R_M^h(z, \nu, p_T^2, Q^2, \phi) = \left\{ \frac{N_{h}^{DIS}(z, \nu, p_T^2, Q^2, \phi)}{N_{e}^{DIS}(\nu, Q^2)} \right\}_A \left\{ \frac{N_{h}^{DIS}(z, \nu, p_T^2, Q^2, \phi)}{N_{e}^{DIS}(\nu, Q^2)} \right\}_D \]

(DIS kinematics)
Data analysis procedure

- Particle Identification Scheme for electrons and pions. Fiducial Cuts.
- PYTHIA 6.319 Adaptation to the EG2 Experiment phase-space.
- EG2 Target implementation in the GSIM.
- Acceptance Correction in 5 dimensional binning (up to 3% correction on Multiplicity Ratio).
- Radiative corrections using HAPRAD2 (up to 3% correction on Multiplicity Ratio).
- Momentum correction.
3 pions 1 dimensional Multiplicity Ratios distributions paper

Coordination – William Brooks

Positive Pions – Raphael Dupre, Hayk Hakobyan, Rodrigo Mendez

Negative Pions – Raphael Dupre, Ahmed El Alaoui

Neutral Pions – Taiysia Mineeva, Orlando Soto

Two analysis notes are under review
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 discrepancies

- 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.
- Different approaches in pion identification: $\Delta t$ – Hayk & $\Delta \beta$ – Raphael
- Raphael doesn't have the Radiative Corrections implemented yet.
- Hayk doesn't have Isospin correction implemented
Fitting function: \( f(\phi_{q\pi^+}) = A + B \cos(\phi_{q\pi^+}) + C \cos(2 \cdot \phi_{q\pi^+}) \)

1.64 < \( Q^2 < 2.28 \), 2.62 < \( \eta < 3.04 \), 30.00 < \( \theta_p \) < 40.00, sector = 3, \( \chi^2 = 9.934133 \)

\( \chi_1 = 1.42 \)

1.64 < \( Q^2 < 2.28 \), 2.62 < \( \eta < 3.04 \), 40.00 < \( \theta_p \) < 50.00, sector = 3, \( \chi^2 = 6.030747 \)

\( \chi_1 = 0.86 \)

1.64 < \( Q^2 < 2.28 \), 2.62 < \( \eta < 3.04 \), 50.00 < \( \theta_p \) < 60.00, sector = 3, \( \chi^2 = 8.861233 \)

\( \chi_1 = 1.24 \)

1.64 < \( Q^2 < 2.28 \), 2.62 < \( \eta < 3.04 \), 60.00 < \( \theta_p \) < 70.00, sector = 3, \( \chi^2 = 9.949191 \)

\( \chi_1 = 1.35 \)

GOOD
Fitting function: \( f(\phi_{q\pi^+}) = A + B \cos(\phi_{q\pi^+}) + C \cos(2 \cdot \phi_{q\pi^+}) \)
Radiative corrections with HAPRAD2

68.8% of bins has $\chi^2 < 2$

$\langle\chi^2\rangle = 2.96$

RMS: $\chi^2 = 4.08$
Radiative corrections with HAPRAD2

Correction factor for phi
Further pi+ multi-bin publications
Transverse momentum dependence on $1/3$ of nuclear mass number (all together in 24 kinematical region)

Acceptance correction less than 14%
CLAS Data: binning

Only a fraction of the many bins of CLAS Data
Multiplicity Ratio Dependence on $Z_h$ in different $Q^2$ and $\nu$ bins
Multiplicity Ratio Dependence on $\nu$ in different $Q^2$ and $Z_h$ bins

\begin{align*}
1.0 < Q^2 < 1.3 & \quad 0.4 < z_{\pi^-} < 0.5 \quad | \quad \pi^+ \\
1.0 < Q^2 < 1.3 & \quad 0.5 < z_{\pi^-} < 0.6 \quad | \quad \pi^- \\
1.3 < Q^2 < 1.8 & \quad 0.4 < z_{\pi^-} < 0.5 \quad | \quad \pi^- \\
1.3 < Q^2 < 1.8 & \quad 0.6 < z_{\pi^-} < 0.7 \quad | \quad \pi^+
\end{align*}
Multiplicity Ratio Dependence on $Q^2$ in different $Z_h$ and $\nu$ bins
Cronin effect in different $\nu \bar{\nu}$ Q $(0.4 < Z^h < 0.7)$ kinematical regions

Cronin Effect – Dependence on $A^{1/3}$, $x_B$, and $Q^2$

- **Dependence for different solid targets**: 
  - $0.10 < x_B < 0.18$, $Z > 0.2$
  - $2.2 < Q^2 < 3.2$, $Z > 0.2$ for Carbon
  - $3.7 < Q^2 < 4.3$, $Z > 0.2$ for Iron

- **X$_B$ dependence for Pb**

- **Carbon**

- **Iron**

- **Lead**

- **Pb**