• Quark propagation and hadronization
  • Parton Energy loss
  • Transverse momentum broadening

  - Present status
  - Jlab measurements at 12 GeV

• Talks: Brooks, Ciofi degli Atti, Kopeliovich, Mosel, Muccifora, Peng
SIDIS and hadronization distance scales

Determine the scale of hadronization using nuclei

Nucleus acts as an ensemble of targets: reduction of multiplicity of fast hadrons due to both hard partonic and soft hadron interaction.

Interactions with the medium during $l_f \rightarrow$ space-time picture of hadronization

$$R_M(z,\nu) = \frac{\frac{N_{h}(z,\nu)}{N_{\text{DIS}}}}{\frac{N_{h}(z,\nu)}{N_{\text{DIS}}}} = \frac{1}{\sigma_{\text{DIS}}} \frac{d^2\sigma_h}{dzd\nu} \bigg|_A = \frac{\Sigma e_f^2 q_f(x) D_f^h(z)}{\Sigma e_f^2 q_f(x) D_f^h(z)}$$
Indications from models and data suggest $dE/dx$ may be of measurable size, ~1 GeV/fm. There is an associated quark-gluon correlation function (Guo and Qiu, PRD61, 096003, 2000). Energy loss is proportional to the gluon density of the medium. Struck quark emits gluons in vacuum because of confinement. In nuclear medium, multiple scattering will stimulate additional gluon radiation; may vary as $L^2$ - QCD LPM effect connected to transverse observable:

$$L$$

$\Delta x$ may be of measurable function (Guo and Qiu, of the medium).

$\Delta(p_t^2) \equiv \langle p_t^2 \rangle(A) - \langle p_t^2 \rangle(cH)$ versus $A$ for the DY process from E772 (123; PL McGaughey, JM Moss, JC Peng, unpublished data). Solid curve corresponds to $0.027((A/2)^{1/3} - 1)$. 

Figure 15
Multiplicity ratio for identified hadrons vs $\nu, z$

HERMES, PLB 577 (2003) 37
Multiplicity ratio vs $Q^2$

Dependence on $1 < Q^2 < 10$ GeV$^2$: stronger at small $\nu$, weaker at high $\nu$
**$P_t$ dependence for identified hadrons**

**Nucl-ex/0403029**

Dependence of the Cronin effect on the hadron species. Cronin effect for protons larger than for pions.
Hadrons and Pions @ $E_{\text{beam}}=12 \ & \ 27 \ \text{GeV}$

Extension of the $\nu$ range down to 2 GeV

- Measurements are in progress at HERMES
  $2<\nu<23 \ \text{GeV} \ Q^2<10 \ \text{GeV}^2$
  He, N, Ne, Kr, Xe
Jefferson Lab Experiments: Next 7 Years

• E02-104 (Brooks, CLAS EG2) in Hall B
  – Took part of data in January-February this year
  – Hadronization, transverse momentum broadening surveyed over a wide kinematic range

• E04-002 (Chen, Norum, Wang) in Hall A
  – Hadronization in narrow kinematic bins with good particle ID for charged K and $\pi$
  – Waiting to get on the schedule

• Interest in Hall C (Ent, Gaskell, Keppel, Kinney)
  – Transverse momentum broadening in narrow kinematic bins with good particle ID for charged K and $\pi$
  – Proposal under discussion
CLAS EG2, very preliminary, 5% of total data set
DIS kinematics, $Q^2>1$, all $\nu$

No acceptance correction (small, two targets in the beam)
Not final calibrations (should be nearly irrelevant, bins are huge)
No fiducial cuts (probably ok, two targets in beam)
No radiative correction (effect primarily cancels in ratios)
No correction for $\pi^+$ from rho (need full statistics to correct for this)***
Few-percent kaon contamination in region 2-2.7 GeV
No isospin correction for heavy targets (~5%?)
No acceptance correction (small, two targets in the beam)
Not final calibrations (should be nearly irrelevant, bins are huge)
No fiducial cuts (probably ok, two targets in beam)
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No correction for pi+ from rho (need full statistics to correct for this)***
Few-percent kaon contamination in region 2-2.7 GeV
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No xF cuts
transverse momentum square broadening of leading π⁺

CLAS EG2 Preliminary
5% of data

No acceptance correction (small, two targets in the beam)
Not final calibrations (should be nearly irrelevant, bins are huge)
No fiducial cuts (probably ok, two targets in beam)
No radiative correction (effect primarily cancels in ratios)
No correction for π⁺ from ρ (need full statistics to correct for this)***
Few-percent kaon contamination in region 2-2.7 GeV
No isospin correction for heavy targets (~5%?)
No xF cuts

transverse momentum square broadening of leading π⁺

Catherine Silvestre (Nantes)
No clear $Q^2$ dependence seen

Multiplicity ratio of different $Q^2$ strips for pion+ with energy smaller 2 GeV:
• 6 GeV beam: $Q^2 < 4 \text{ GeV}^2$, $\nu < 5 \text{ GeV}$.
12 GeV beam: $Q^2 < 9 \text{ GeV}^2$, $\nu < 9 \text{ GeV}$. 
Examples of Experimental Data and Theoretical Predictions

Bins in yellow are accessible at 6 GeV
<table>
<thead>
<tr>
<th>hadron</th>
<th>$c\tau$</th>
<th>mass (GeV)</th>
<th>flavor content</th>
<th>detection channel</th>
<th>production rate per 1k DIS events</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0$</td>
<td>25 nm</td>
<td>0.13</td>
<td>$u\bar{u}d\bar{d}$</td>
<td>$\gamma\gamma$</td>
<td>1100</td>
</tr>
<tr>
<td>$\pi^+$</td>
<td>7.8 m</td>
<td>0.14</td>
<td>$ud$</td>
<td>direct</td>
<td>1000</td>
</tr>
<tr>
<td>$\pi^-$</td>
<td>7.8 m</td>
<td>0.14</td>
<td>$d\bar{u}$</td>
<td>direct</td>
<td>1000</td>
</tr>
<tr>
<td>$\eta$</td>
<td>0.17 nm</td>
<td>0.55</td>
<td>$u\bar{u}d\bar{d}s\bar{s}$</td>
<td>$\gamma\gamma$</td>
<td>120</td>
</tr>
<tr>
<td>$\omega$</td>
<td>23 fm</td>
<td>0.78</td>
<td>$u\bar{u}d\bar{d}s\bar{s}$</td>
<td>$\pi^+\pi^-\pi^0$</td>
<td>170</td>
</tr>
<tr>
<td>$\eta'$</td>
<td>0.98 pm</td>
<td>0.96</td>
<td>$u\bar{u}d\bar{d}s\bar{s}$</td>
<td>$\pi^+\pi^-\eta$</td>
<td>27</td>
</tr>
<tr>
<td>$\phi$</td>
<td>44 fm</td>
<td>1.0</td>
<td>$u\bar{u}d\bar{d}s\bar{s}$</td>
<td>$K^+K^-$</td>
<td>0.8</td>
</tr>
<tr>
<td>$K^+$</td>
<td>3.7 m</td>
<td>0.49</td>
<td>$u\bar{s}$</td>
<td>direct</td>
<td>75</td>
</tr>
<tr>
<td>$K^-$</td>
<td>3.7 m</td>
<td>0.49</td>
<td>$\bar{u}s$</td>
<td>direct</td>
<td>25</td>
</tr>
<tr>
<td>$K^0$</td>
<td>27 mm</td>
<td>0.50</td>
<td>$d\bar{s}$</td>
<td>$\pi^+\pi^-$</td>
<td>42</td>
</tr>
<tr>
<td>$p$</td>
<td>stable</td>
<td>0.94</td>
<td>$ud$</td>
<td>direct</td>
<td>1100</td>
</tr>
<tr>
<td>$\bar{p}$</td>
<td>stable</td>
<td>0.94</td>
<td>$\bar{u}\bar{d}$</td>
<td>direct</td>
<td>3</td>
</tr>
<tr>
<td>$\Lambda$</td>
<td>79 mm</td>
<td>1.1</td>
<td>$uds$</td>
<td>$p\pi^-$</td>
<td>72</td>
</tr>
<tr>
<td>$\Lambda(1520)$</td>
<td>13 fm</td>
<td>1.5</td>
<td>$uds$</td>
<td>$p\pi^-$</td>
<td>-</td>
</tr>
<tr>
<td>$\Sigma^+$</td>
<td>24 mm</td>
<td>1.2</td>
<td>$us$</td>
<td>$p\pi^0$</td>
<td>6</td>
</tr>
<tr>
<td>$\Sigma^0$</td>
<td>22 pm</td>
<td>1.2</td>
<td>$uds$</td>
<td>$\Lambda\gamma$</td>
<td>11</td>
</tr>
<tr>
<td>$\Xi^0$</td>
<td>87 mm</td>
<td>1.3</td>
<td>$us$</td>
<td>$\Lambda\pi^0$</td>
<td>0.6</td>
</tr>
<tr>
<td>$\Xi^-$</td>
<td>49 mm</td>
<td>1.3</td>
<td>$ds$</td>
<td>$\Lambda\pi^-$</td>
<td>0.9</td>
</tr>
</tbody>
</table>
The essential reaction mechanism has not been isolated: Hadron forms inside nucleus or outside? or both?

**Gluon bremsstrahlung** (Kopeliovich)
- Gluon radiation of colored quark
- Formation of color singlet pre-hadron
- Color transparency modulates pre-hadron (color dipole) attenuation
- Hadron attenuates in medium

**Twist-4 pQCD model** (Wang)
- Medium-induced gluon radiation modifies F. F
- No hadronization
- Non-abelian LPM effect predicted

- Can extrapolate to predict jet quenching in RHIC collisions

\[
\frac{dE}{dL} \approx 0.5 \text{ GeV/fm}
\]
Connections to Relativistic Heavy Ions

Nuclear SIDIS is related to parton propagation in AA collisions

- \( P_T (A-A) \approx E_h z \nu (DIS) \) → the relevant energies are few – few tens of GeV.
- Jet quenching (suppression of high \( P_T \) hadrons) and depletion of the Cronin effect at RHIC:

Jet quenching, ascribed to radiative energy loss, would be an indication of high partonic density, e.g. QGP.

(Pre-)hadron interaction in the nuclear medium might give alternative explanation.

Summary

• A unified picture is starting to emerge from the study of quark energy loss in Drell-Yan, SIDIS, and hadron production in d+Au collision. The 12 GeV upgrade provides an opportunity to further study the SIDIS.

• Future Drell-Yan, SIDIS, and p-A data will provide quantitative information on the propagation and hadronization of quarks in cold and hot nuclear medium.
Perturbative hadronization

Although hadronization is usually considered as a manifestation of confinement, it also may be a perturbative process.

\[
\begin{align*}
\text{Positronium production} \\
\varepsilon^- \overline{e}^+ \rightarrow \gamma \\
\varepsilon^- \overline{e}^+ \rightarrow \gamma
\end{align*}
\]

Of course, formation of the wave function is always nonperturbative.

Inclusive production of leading hadrons has a limiting case of exclusive process.
\[ Z_h = \frac{P_{h+}}{P_{g-}} \]

Slower \( q\bar{q} \) pairs are produced earlier.

The less \( Z_h \) is, the more \( q\bar{q} \) pairs is produced, the longer it takes.

The pre-hadron (a \( q\bar{q} \) dipole) is produced perturbatively with a size \( \bar{r}(Q^2,Z_h) \) controlled by \( Q^2 \) and \( Z_h \).

In the limit \( Z_h \to 1 \) \( \bar{r} \sim \frac{1}{Q} \)

The string model contradicts data on \( CT \) at large \( Z_h \).
The production time distribution function

\[ t_p = \langle t \rangle \text{ shrinks at } z_h \to 1 \]
Gluon Bremsstrahlung

FF modification: Nuclear Suppression + Induced Radiation

Nuclear suppression: interaction of the $q\bar{q}$ in the medium.
Energy loss: induced gluon radiation by multiple parton scattering in the medium.
Gluon Bremsstrahlung

Q^2-dependence: mainly due to Induced Radiation.

Good description of ν, z, Q^2 and P_t -dependence.
FSI in BUU Transport model

\( \gamma \)-A eA reaction splitted in 2 parts:

- \( \gamma^*N \to X \) using PYTHIA & FRITIOF

- propagation of final state X within BUU transport model.

- pre-hadron \( \tau_F = 0.5 \) fm,
- \( \sigma^* \) by costituent quark model:
  \( \sigma^*_\text{meson} = \frac{\#q_{\text{orig}}}{2} \sigma_{\text{meson}} \)

- purely absorbitve FSI
FSI in BUU Transport model

HERMES @ 12 GeV (\(\tau_f=0.5 \text{ fm/c}\))

Model seems to work also at lower energy
FSI in BUU Transport model

Jefferson Lab ($\tau_f = 0.5$ fm/c)

- CLAS detector
  larger geometrical acceptance
  - detects more secondary particles from FSI

- CEBAF
  lower energy
  - strong effect of Fermi-motion
Quark energy loss from semi-inclusive DIS

- No initial-state interaction
- Energy loss of quarks and hadrons in nuclei
- Need to avoid the target fragmentation region
- Complementary to Drell-Yan
Energy loss from DIS
due to multiple parton scattering and induced parton energy loss
(without hadron rescattering)
pQCD approach: LPM interference effect $\rightarrow A^{2/3}$ dependence

- 1 free parameter $C\equiv$ quark-gluon correlation strength in nuclei.
- From $^{14}$N data $C=0.0060$ GeV$^2$:
  \[ \Delta E = n <\Delta z_g> \propto C \alpha_s^2 m_N R_A^2 \]
  \[ <dE/dL> \approx 0.5 \text{ GeV/fm} \]
Absorption Models:

Important role of the pre-hadron formation and interaction. Hadron formation mainly outside the nucleus. Induced radiation smaller contribution compared to absorption.
⇒ Strong dependence on the pre-hadron interaction cross section.

Energy loss models:

Energy loss mechanism mainly, competing processes play a modest role.
⇒ Strong dependence on the gluon transport coefficient that reflects the medium gluon density
⇒ Observables sensitive to models assumptions
3. THE SEMI-EXCLUSIVE DIS \( A(e,e'\,B)X \) PROCESS

PWIA : The debris propagates through the nucleus freely

Melnitchouk, Sargsian, Strikman, 
Z. Phys. A356(97)99
Simula, Phys. Lett. B387(96)245
CdA, Kaptari, Scopetta, EPJA 5(99)181

\[
\frac{d\sigma^A}{dx \, dQ^2 \, dP_{A-1}} = K^A(x, Q^2, y_A, z_1^{(A)}, z_1^{(A)}) F_2^{N/A}(x_A, Q^2, p_1^2) P^A(E, |\vec{P}_{A-1}|)
\]
• The hadronizing quark interacts with the spectator nucleons via $\sigma_{eff}(t)$
• The survival probability of (A-1) is reduced depending on the features of $\sigma_{eff}(t)$.

CdA, Kopeliovich, EPJA17(2003)133
$^3\text{He}(e,e'D)X$

\[ \theta_D = \Phi_p D \]

(After CdA, Kaptari unpublished)

C. Ciofi degli Atti  
Jlab-1, Nov 04
\[ F_{\text{eff}} \equiv P_A^D(\alpha, p_T^2, 2/A, x_B, P_T, Q^2) \quad \alpha = \frac{E-p_\parallel}{m_N} \]

**Experiment (PRELIMINARY):**
Jlab 94-102 S. E. Kuhn, K. A. Griffioen, co-spokespersons, *Inelastic electron scattering off a moving nucleon in deuterium*

**Theory** (After CdA, Kaptari, unpublished)

C. Ciofi degli Atti

Jlab-1, Nov 04
4. HADRONIZATION MECHANISM AND GREY TRACKS

- The whole jet inelastically interacts with spectators nucleons, which recoil and form Grey Tracks (GT). GT production covers the main bulk of inelastic events.

Calculation of GT production (CdA, Kopeliovich, hep-ph/0409077)
• Theory: debris-nucleon cross section;

• Experiment: Fermilab E665(μ – Xe and μ – D processes at 490 GeV beam energy; GT- protons with momentum 200 – 600 MeV/c).

• Empirical relation: between the mean number of collisions, \( \langle \nu_c \rangle \), and the mean number of GT \( \langle n_g \rangle \)

\[
\langle n_g \rangle = \frac{\langle \nu_c \rangle - (2.08 \pm 0.13)}{3.72 \pm 0.14}
\]

• The Model: DIS on a bound nucleon at coordinate \((\vec{b}, z)\). The hadronizing quark (The debris) propagates through the nucleus interacting with spectator nucleons via \( \sigma_{eff}(z - z') \). The number of collisions, (plus the recoiling nucleon formed in the hard \( \gamma^* - N \) act) is

\[
\langle \nu_c \rangle = \int d^2 b \int_{-\infty}^{\infty} dz \rho_A(b, z) \int dz' \rho_A(b, z') \sigma_{eff}(z - z') + 1.
\]
The mean number of grey tracks $\langle n_g \rangle$ produced in the $\mu X e$ DIS vs $Q^2$ in the non-shadowing region ($x_{Bj} = 0.07$) (full). The solid curve includes the $Q^2 - x_{Bj}$ correlation.

- The Debris-Nucleon cross section, \textit{with no readjustment of the parameters} correctly predicts the $Q^2$ dependence, thanks to the $Q^2$ and $x_{Bj}$-dependent gluon radiation mechanism;
Extend 'traditional' EMC effect measurements:
Improve the data at large \( x \) and \( A \)-dependence
EMC effect for separated structure functions
Flavor dependence

Structure functions of nuclei at \( x>1 \):
Information about the high momentum components
\( \to \) SRC's in nucleus

Space-time characteristics of hadronization:
- Multivariate measurements of nuclear multiplicity vs \( \nu, z, Q^2, p_t \)
Measurements of the \( p_t \) broadening.
Connections to the fundamental process of gluon emission.
- Complementary analysis of Grey Tracks
High-density configurations: quark distributions at $x>1$

The EMC effect compares light nuclei to heavy nuclei in order to see the effect of changing the *average* density (0.06-0.15 nucleons/fm$^3$).

Probing the quark structure of SRCs allows us to see the effect of changing *local* density. Densities can be several times larger in the region where nucleons overlap.

Need the following:
- A way to isolate high density configurations
- Understanding of SRCs in terms of nucleonic degrees of freedom

* DIS ($e,e'$): Measure *quark* distributions at $x>1$.
  - Structure of SRCs: Superfast quarks
    - At $x>1$, contributions from mean-field momentum distributions are negligible, and we probe the distribution of SRCs
  
  - Look for deviations from simple convolution model
    $$ q_A(x) = q_{p/m}(x) \otimes n_A(k) $$

    10-20% for EMC effect measurements
    Possibly much higher when probing high-density configurations
Summary I: Nuclear Structure

1) \( A(e,e') \): \( x > 1.5, \ Q^2 \sim 5-10\ GeV^2 \):
   - A-dependence of 2N SRCs
   - Isolate multi-nucleon SRCs
   - Map out size of 2N, 3N SRCs in nuclei

2) Exclusive \( A(e,e'p) \) and \( A(e,e'NN) \) reactions,
   ‘tagged’ SRCs
   - Provide much more detailed information on SRCs, but with reduced
     kinematic range, larger issues with reaction mechanism (FSIs, MECs,...)

3) \( x \sim 1.0-1.5, \ Q^2 > 15\ GeV^2 \):
   - Measure PDFs for \( x > 1 \)
   - Look for excess superfast quarks - beyond contribution
     from quarks in ordinary (but high momentum) nucleons
   - Isolate and identify non-hadronic contributions to nuclear structure
Summary II: EMC effect

Average nuclear densities are quite low - well below expected phase transition

Extend traditional measurements of the EMC effect
  Measure at larger x values
  Separated structure functions
  Flavor dependence
  $^3$H vs. $^3$He to separate nuclear effect, neutron excess

Test models that assume non-hadronic explanation more directly
  Modified in-medium nucleon form factors
  Probe SRCs to look for non-hadronic components in SRCs

  * SRCs provide a small high-density component in nuclei
  * Several times higher than average nuclear densities
  * Tightly packed nucleons could deform, swell, or even merge
  * May be origin of EMC effect, medium modifications

J. Arrington
No enhancement/ Suppression of antiquarks at $0.15 \leq x$
(Drell-Yan process - FNAL)

$\frac{q_A}{q_N}$

$Q^2 = 15 \text{ GeV}^2$

A-dependence of antiquark distribution, data are from FNAL nuclear Drell-Yan experiment, curves - pQCD analysis of Frankfurt, Liuti, MS 90

A.Bruell
Figure 10: The calculated scale evolution of $F_2^\text{Sn}(x, Q^2)/F_2^\text{Cl}(x, Q^2)$ compared with the NMC data [3] at different fixed values of $x$. The data are plotted with statistical errors only.
Connections to Relativistic Heavy Ions

Nuclear SIDIS is related to parton propagation in AA collisions

\[ P_T(A-A) \approx E_h = z \nu (DIS) \rightarrow \text{the relevant energies are few few tens of GeV.} \]

• Jet quenching (suppression of high \( P_T \) hadrons) and depletion of the Cronin effect at RHIC:

Jet quenching, ascribed to radiative energy loss, would be an indication of high partonic density, e.g. QGP.

(Pre-)hadron interaction in the nuclear medium might give alternative explanation.

Data show a $p_t$ enhancement similar to that observed in pA scattering at $p_t \sim 1-2$ GeV.

In DIS neither multiple scattering of the incident particle nor interaction of its constituents → FSI contribution to the Cronin.

V. Muccifora
FF modification + formation time effect

F. Arleo et al., NPA715(2003)899

- Gluon transport coefficient fixed from Drell-Yan
  \[ \hat{q} = 0.14 \text{ GeV}^2 / \text{fm} \]

\[ \langle -dE / dL \rangle_{\text{cold} \text{ final}} \approx 0.6 \text{ GeV / fm} \]

With formation time effect

Without formation time effect
dE/ dL and Gluon density at RHIC


\[ \frac{dE}{dL} \bigg|_{\text{Au}} \] predictions determined by using \( C = 0.0060 \) GeV\(^2\) from HERMES data.

PHENIX: hot, expanding system.
HERMES: cold, static system.

\[ \Delta E_{\text{sta}} \propto \rho_0 R_A^2; \quad \rho_0 \text{ gluon density and } R_A \approx 6 \text{ fm} \]

\[ \Delta E_{\text{exp}} \approx \Delta E_{\text{sta}} (2\tau_0/R_A); \quad \tau_0 \text{ initial formation time of dense medium} \]

• Gluon density in Au+Au \( \sim 15 \) times higher than in cold matter
Observables sensitive to the model assumptions.

• Investigation of the $Q^2$-dependence of the nuclear effects.

• $p_t$-broadening and its $z$-dependence.

• Investigation of the $Q^2$-dependence of “grey tracks” (GT) in SIDIS:
  $A(e,e'B)X$ where the recoil nucleus $B$ does not survive, but breaks in fragments (predominantly protons) with few-hundred MeV/c momenta.

• Double/single hadron production
Models based on (pre-)hadronic absorption

T. Falter et al.,: nucl-th/0406023.

Models based on partonic energy loss


→ Observable sensitive to the model assumption
HERMES vs. Jlab data

Using inclusive A1p and A1n Jlab data
Add fragmentation process to SIMC

Input parameters:

- **Pdf’s** \((q_i, q_i)\): CTEQ5M
- **FF’s** \((D_{qi})\): Binnewies et al., given as \((D^+ + D^-)\)
- **D^-/D^+**: from HERMES
- **\(P_t (b)\)**: from HERMES
- \(\phi\): assume no \(\phi\) dep.

\(x \sim 0.3\)
Fascination with Hadronization

- $\nu$: energy transferred by the electron (initial energy of struck quark)
- $Q^2$: four-momentum transferred by the electron (initial size of struck quark)
- $z_h = E_{\text{hadron}}/\nu$, fraction of struck quark energy carried by hadron; $0 < z_h < 1$
- $p_T$: quark/hadron momentum transverse to virtual photon direction; results from initial quark transverse momentum, multiple scattering in-medium, intrinsic gluon emission, other hadronization dynamics.
Motivation

color transparency (CT): phenomenon where hadron produced inside nucleus at large momentum transfer experiences little final state interaction

if CT occurs then cross section should scale $\sim A$

pert. QCD has been successful in qualitative description of form factors at large $\Delta^2_{\perp}$

pert. QCD also predicts CT at large $\Delta^2_{\perp}$

exp: no clear evidence for CT @Jlab

Can GPDs shed some light on physics of form factors and CT? (Can CT shed some light on physics of GPDs?)
Summary

- GPDs provide decomposition of form factors w.r.t. the momentum of the active quark
- GPDs could clarify mechanism for form factor at large $\Delta^2$
- discussed how hadron configurations with size $R \sim 1/\Lambda$ can contribute significantly to form factor
- contribution to nucleon form factor can be $\sim \frac{1}{\Delta^4}$ until suppression of PDFs due to higher order corrections sets in
- could provide additional explanation for lack of CT @JLab
- large $x$ behavior of PDFs & GPDs critical for contribution from large size configurations to form factor
  - how rapidly does $q(x)$ go to zero as $x \to 1$
  - how does $\perp$ size $d_{\perp}(x)$ behave for $x \to 1$
- JLab@12GeV could illuminate physics of form factors from three different angles: CT, PDFs@large $x$, and GPDs.
Multiplicity ratio on He, Ne, Kr

Data suggest $\alpha \sim 2/3$

nuclear attenuation: $1-R_A^h = A^\alpha$

V. Muccifora