Interpreting SRCs: FSI in x>1, from (e,e') to (e,e'NN)

17 min —-> selected issues

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OUTLINE

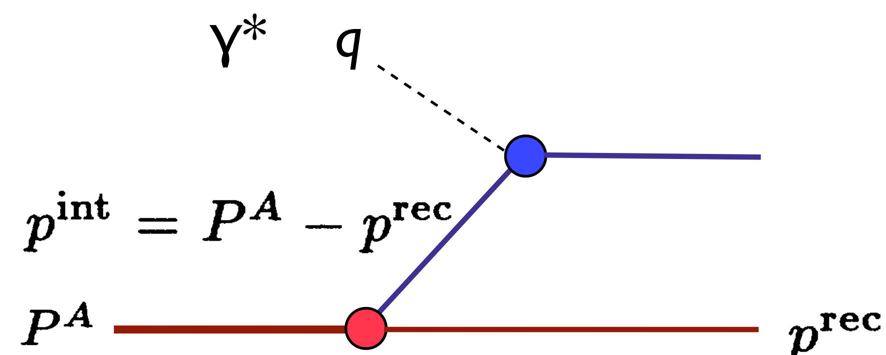
(e,e') : onset of light cone dominance and locality of FSI

FSI and quenching at large Q

FSI & looking backward

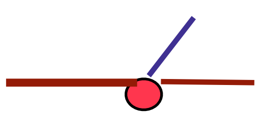
Onset of LC dominance in high Q^2A (e,e') processes

Consider high Q^2 (e,e') process at fixed large x >1 in the many nucleon approximation for the nucleus



The on-shell condition for the struck nucleon

$$(p^{\rm int} + q)^2 = m^2$$

 (Vertex function)^2 is the spectral function of the nucleus

$$P_A(k,E) = \langle \psi_A | a^+_{\rm N}(k) \delta(E + E_{\rm R} - E_{\rm fX}) a_{\rm N}(k) | \psi_A \rangle,$$

QCD analog - fully unintegrated parton density -

$$\tilde{m}^2 + q_+ p_-^{int} + q_- p_+^{int} + q^2$$

$$= \tilde{m}^2 + q_+ \frac{M_A}{A}\alpha + q_- \left(\frac{\tilde{m}^2 + p_t^2}{\alpha(M_A/A)}\right) + q^2 = m^2$$

Use the nucleus rest frame

$$\alpha \equiv A\frac{p_-^{int}}{P_-^A}$$ light-cone fraction scaled to A

$$P_+^A = P_-^A = M_A.$$

$$\Rightarrow \quad \frac{\partial \alpha}{\partial \tilde{m}^2} = -\left(\frac{1 + (q_-/\alpha)(M_A/A)}{(q_+ M^A/A) - [q_-(\tilde{m}^2 + p_t^2)]/\alpha^2 M_A/A}\right) \longrightarrow 0 \quad \propto 1/q_+$$

$Q^2 \rightarrow \infty, x = const$

$\Rightarrow$ In high energy limit σ depends only on the spectral function integrated over all variables but α - LC dominance, in particular no dependence on the mass of the recoil system. Relevant quantity is LC nucleon density matrix - $\rho_A^N(\alpha)$

$$\rho_A^N(\alpha) = \int \prod_{i=1}^{i=A} \frac{d\alpha_i}{\alpha_i} d^2 p_{t\,i} \psi_A^2(\alpha_i, p_{t\,i}) \delta(\alpha_1 - \alpha)$$

LC nuclear many nucleon wave function

Expectation: $\rho_A^N(\alpha, k_t) \approx a_2(A)\rho_D^N(\alpha, k_t)$ for$1.3 \leq \alpha \leq 1.6$

For larger α three nucleon correlations decreases slower with increase of α. Effects of 3N correlations can be seen in $P_A(k,E)$ but no simple relation is known (exists?) with $\rho_A(\alpha > 1.6, p_t)$

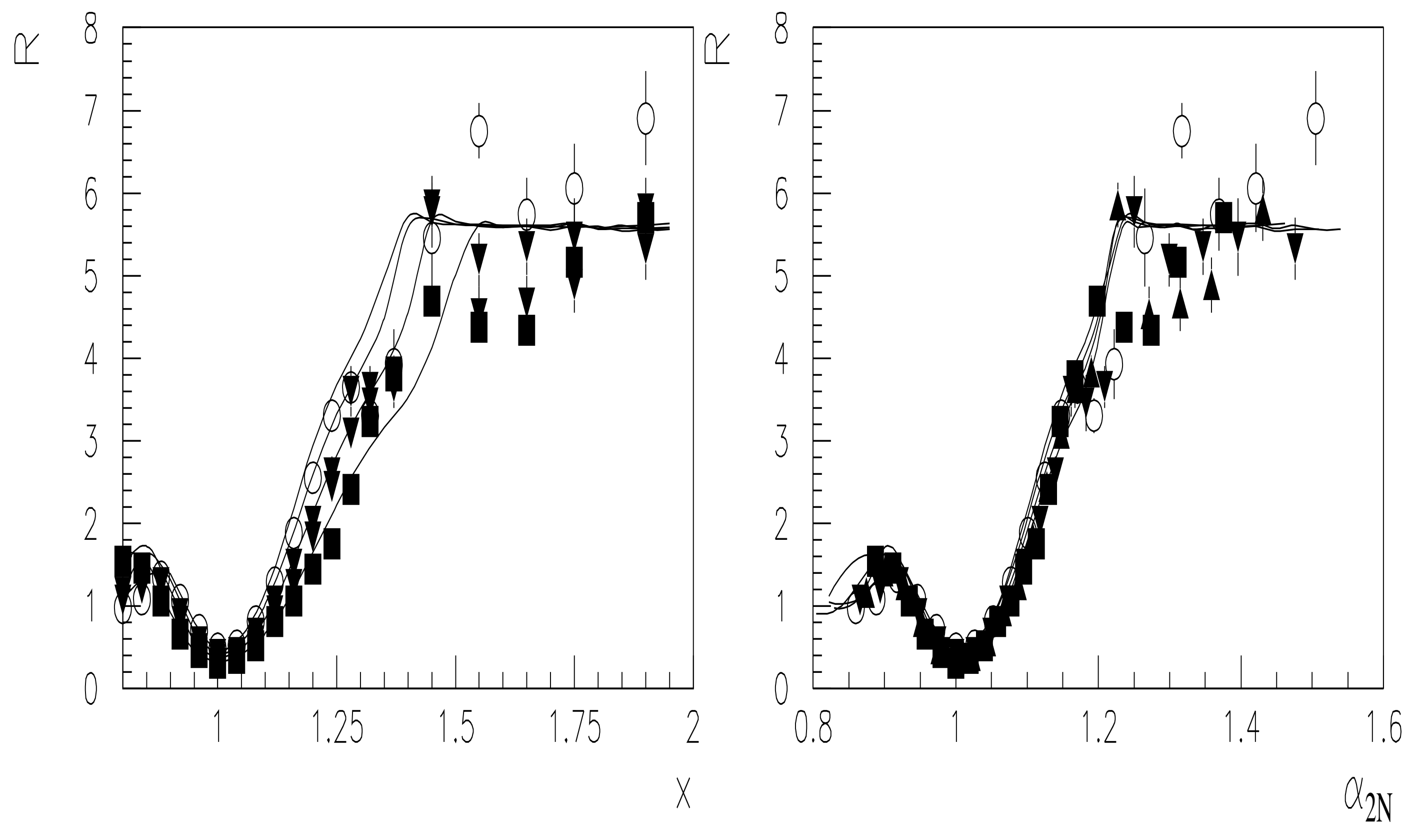
Determine $\alpha(x,Q)$ based on dominance of two nucleon correlations in the recoil

:

$$\alpha_{tn} = 2 - \frac{q_- + 2m}{2m_N}\left(1 + \frac{\sqrt{W^2 - 4m_N^2}}{W}\right) \qquad where\ q_- = q_0 - q_3,\ W^2 = 4m_N^2 + 4q_0 m_N - Q^2$$

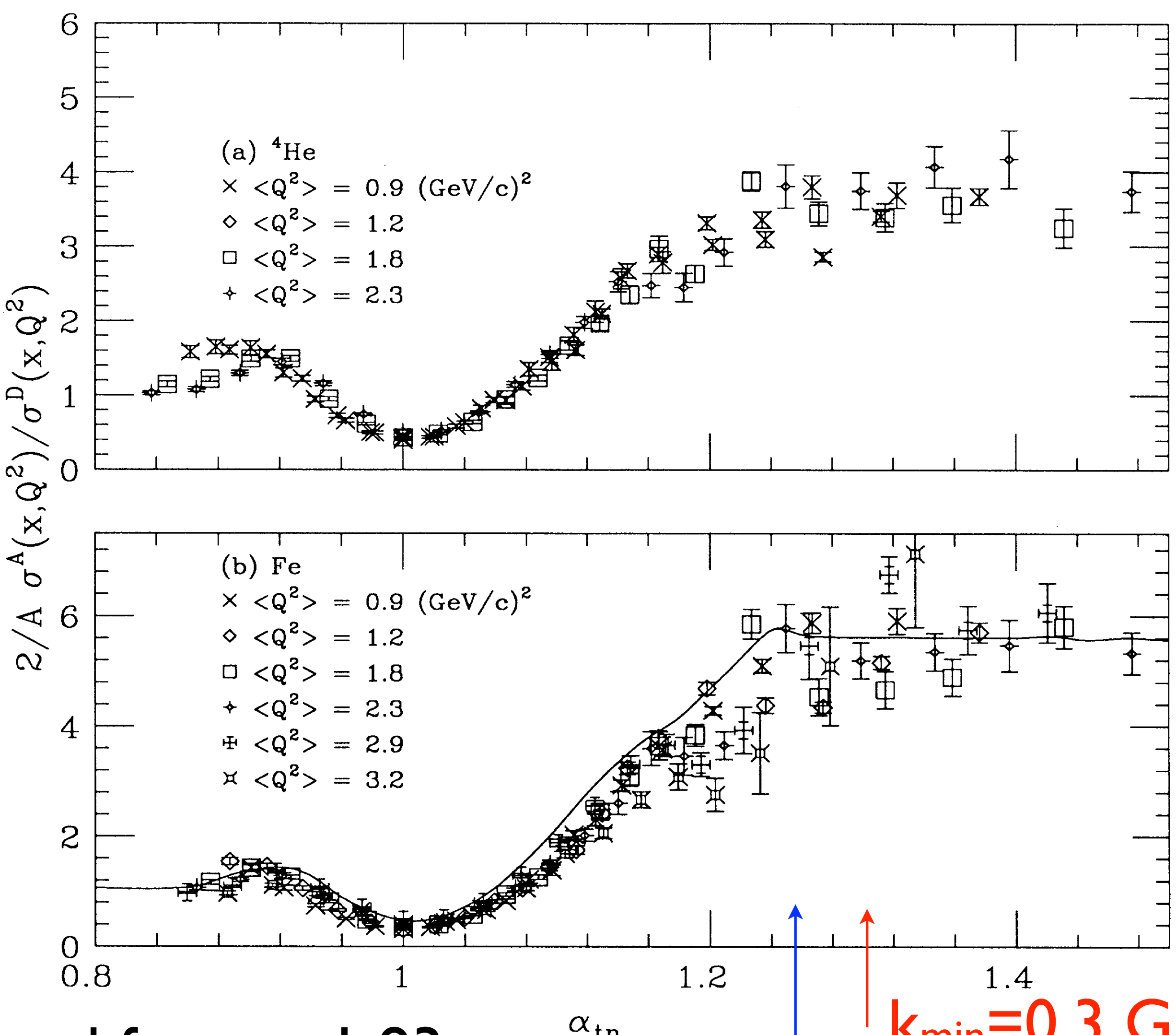
Used observation that distribution over α_{NN} around $\alpha_{NN} = 2$ is symmetric function of $\alpha_{NN} - 2$. Allows to take $\tilde{m}^2$ in average point corresponding to

$\alpha_{NN} = 2$. Maximum of the spectral function distribution over E_{rec}.



The x and α_{2n} dependence of the ratio $R = \frac{2\sigma^{56}}{56\sigma^{d}}$ for different values of $Q^2 = 1.2 \div 2.9$ GeV^2.

$$\Rightarrow \frac{\sigma_{A_1}(x,Q^2)}{\sigma_{A_2}(x,Q^2)} = \frac{\int \rho_{A_1}(\alpha_{tn},p_t)d^2p_t}{\int \rho_{A_2}(\alpha_{tn},p_t)d^2p_t} = \frac{a_2(A_1)}{a_2(A_2)}\Big|_{1.6>\alpha\geq 1.3}$$

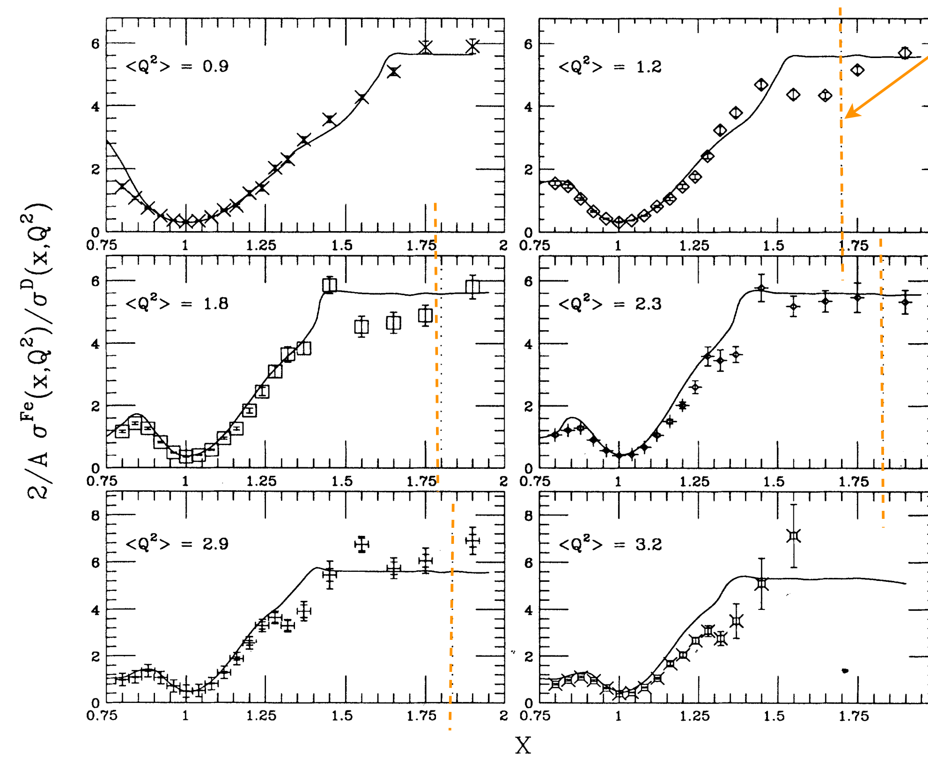


Frankfurt et al, 93 extracted ratios from SLAC data

k_{min}=0.3 GeV

k_{min}=0.25 GeV

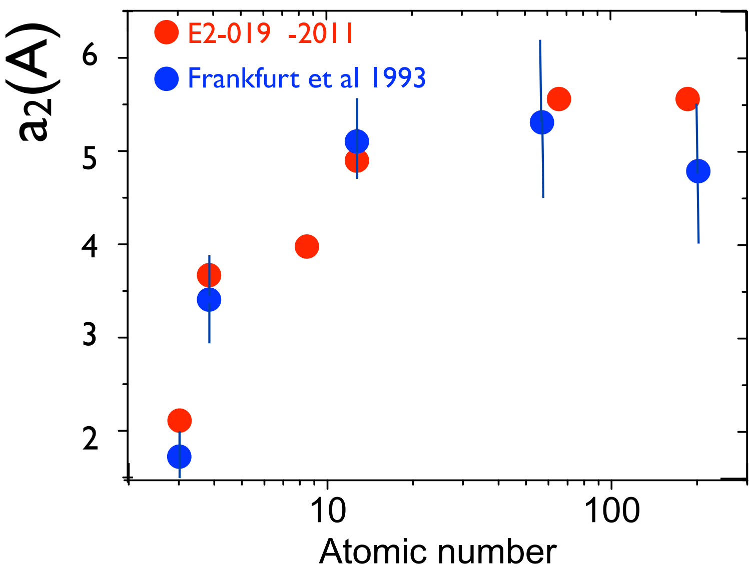
$W - M_D \leq 50\,MeV$



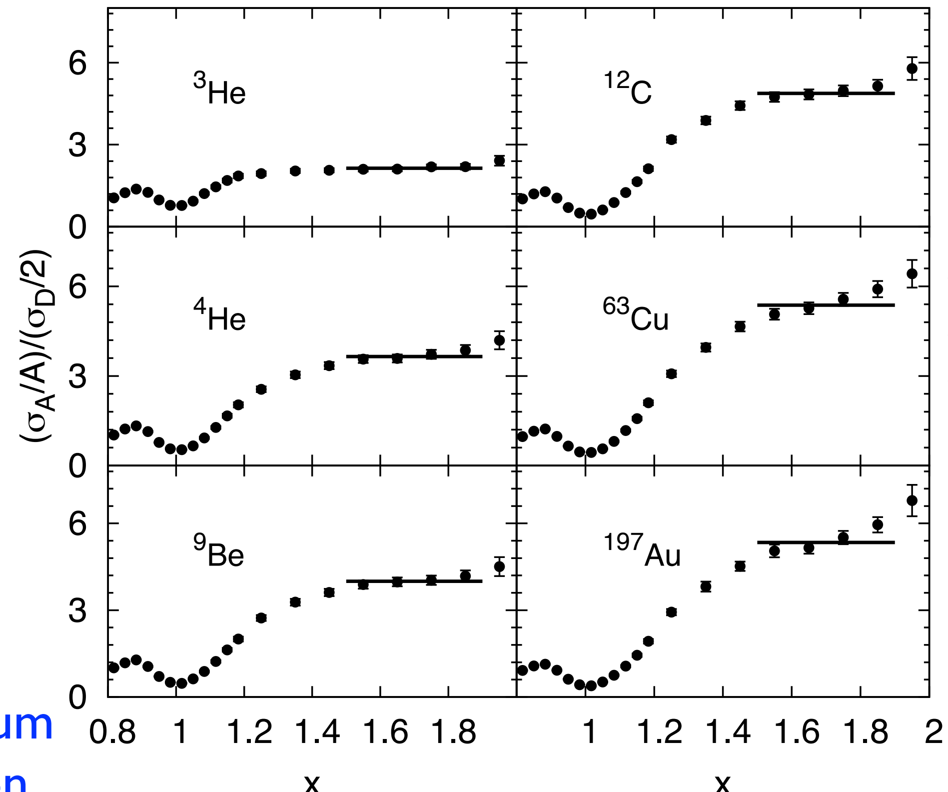
Masses of NN system produced in the process are small - strong suppression of isobar, 6q degrees of freedom.

Right momenta for onset of scaling of ratios !!!

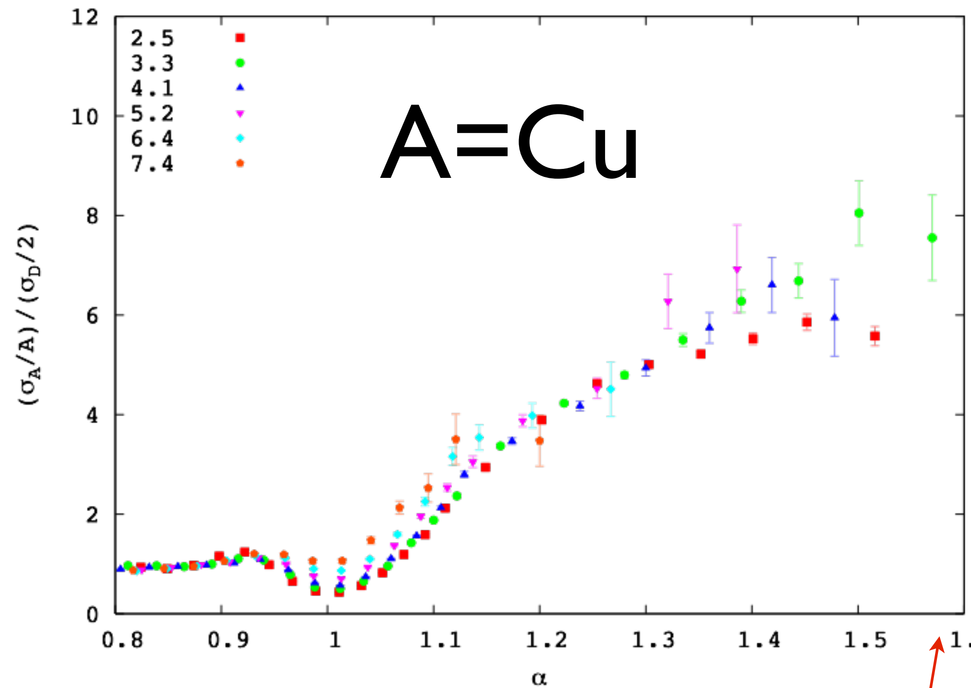
Universality of 2N SRC is confirmed by Jlab experiments



Probability of the high momentum component in nuclei per nucleon, normalized to the deuteron wave function



Per nucleon cross section ratio at Q^2=2.7 GeV^2 - E2-019-2011



From N.Fomin thesis

E2-019-2011

k=700 MeV/c

Very good agreement between three (e,e') analyses for a_2 (A)

FSI and the scaling of rations

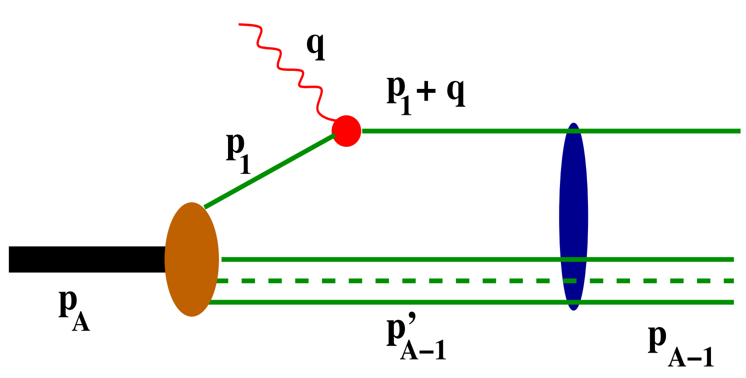
Two types - FSI interaction within SRC and knockout of low momentum nucleon with FSI with the whole nucleon.

FSI of first type maybe large up to a factor of 2 for σ(e,e'), cancels in the ratio of σ's

next slide

Second - is few % . One would come to an opposite if one does does not take into account off mass- shell effects

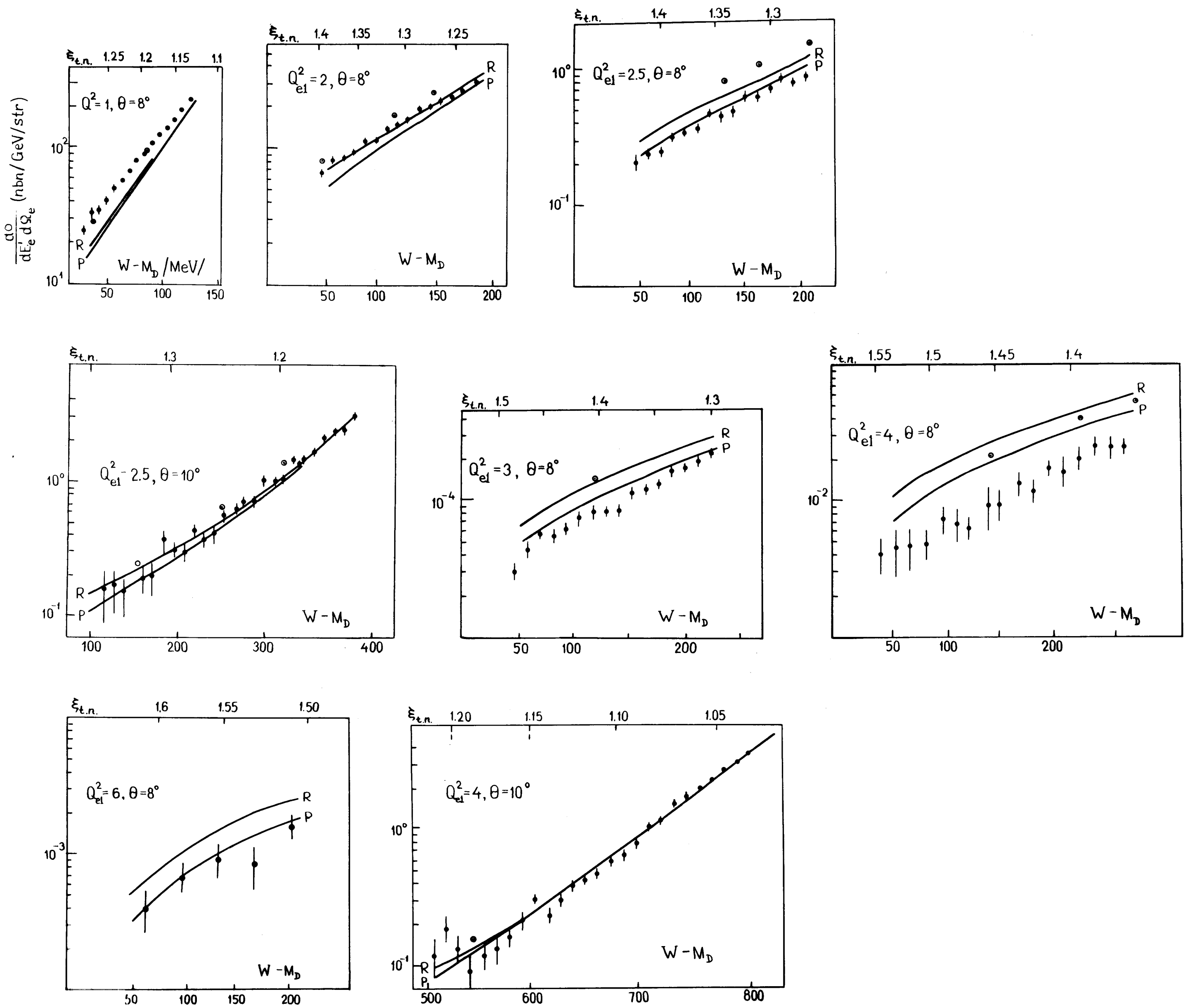
Sargsian, Frankfurt, MS 2008.



If |p^int| is small, the struck nucleon has large virtuality

$$\Delta M^2 = m^2 - p^2 \approx m_N^2 - Q^2(-1 + \frac{1}{x}) - p_{int}^2$$

LC collinear method calculation (FS88) , data from SLAC experiments.



Upper curves include fsi as calculated by Arenhovel

We used non-covariant technique where energy is not conserved and momentum is conserved to determine what longitudinal distances, r, fsi can contribute

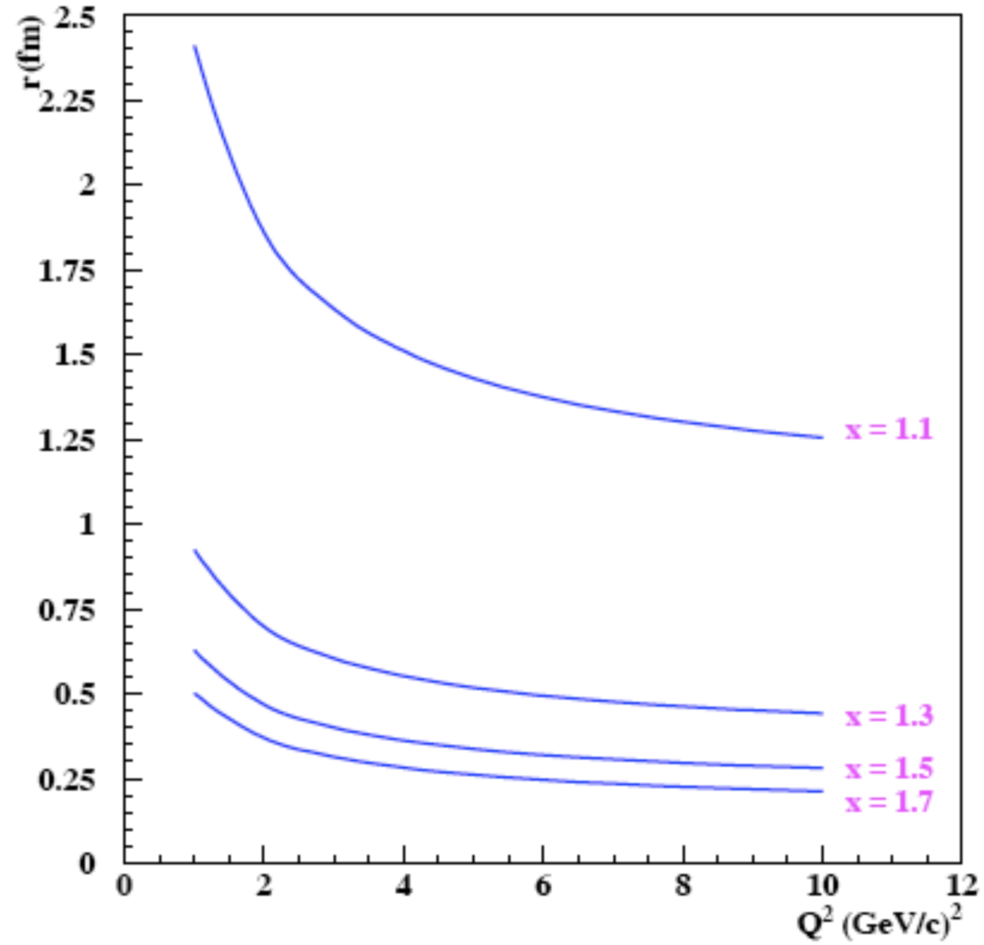
$$A^{FSI,\mu}(eA \to eX) \sim \int d^3p_1 \psi_A(p_1) J^{\mu}_{em}(p_1, q) \frac{1}{\Delta E + i\epsilon} t_N(p_1 + q, p_f),$$

J_μ is the electromagnetic current, tN represents the rescattering amplitude of struck nucleon and ΔE is the energy difference between intermediate and initial states:

$$\Delta E = -q_0 - M_A + \sqrt{m^2 + (q + p_1)^2} + \sqrt{\tilde{M}^2_{A-1} + p_1^2}.$$

Within this representation we can estimate the characteristic distances that struck nucleon propagates as:

$$r \approx \frac{v}{\Delta E},$$



At x> 1.3, $Q^2 > 1$ GeV^2 fsi is local (r < 1fm) and hence should cancel in the A/D ratios if one neglects pp SRC.

Other way to probe locality of FSI is to consider the correlator of the two e.m. currents.

$$2m_A q_3 \sigma^{(r)} = \int e^{iqy} \langle A \mid [J_\mu(y), J_\lambda(0)] \mid A\rangle \epsilon_\mu^{(r)} \epsilon_\lambda^{(r)} d^4 y.$$

where $q_3 = \sqrt{Q^2 + Q^4/4m^2x^2}$,

Strong oscillations in the exponential lead to the condition that in the discussed kinematic range y_0 and y_z are small. For example for Q^2=1.5 GeV^2, x=1.5

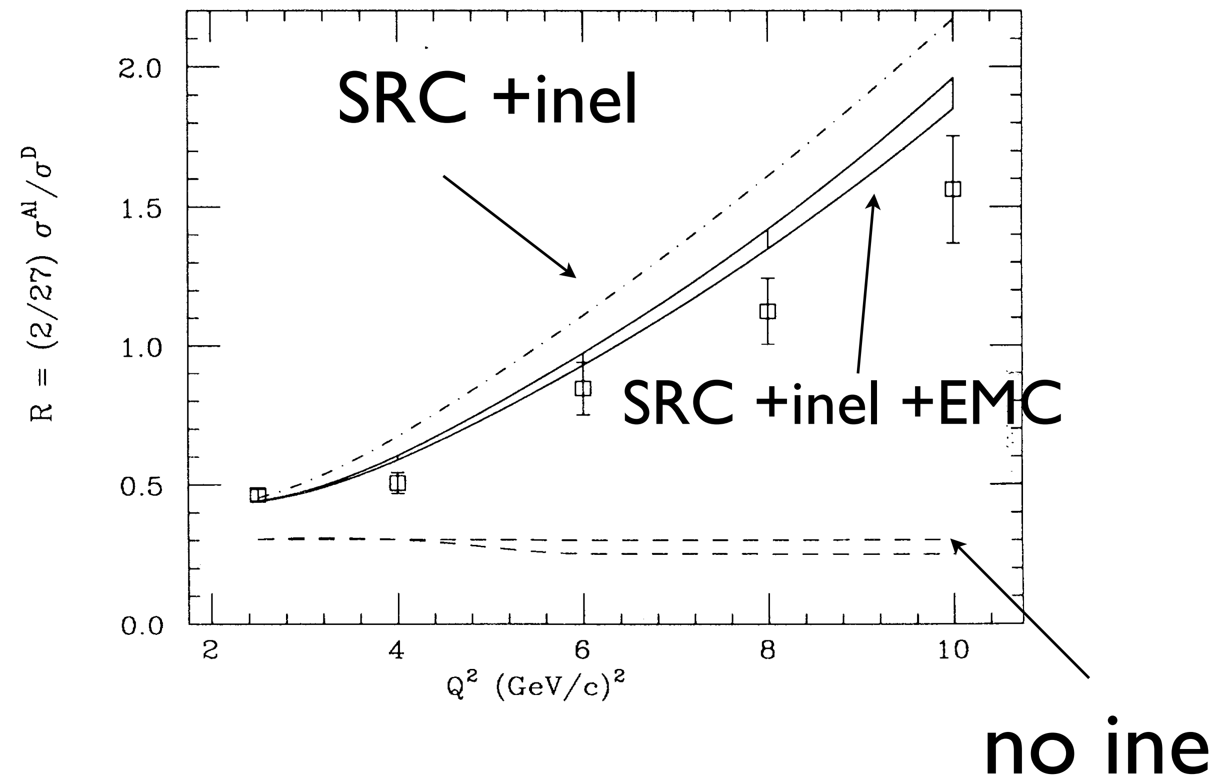
$$y_- = \frac{1}{q_+} \sim 0.1 \text{ fm}, y_+ = \frac{1}{q_-} \sim 0.3 \text{ fm},$$

Open questions:

$x < 2$

- testing scaling of ratios for larger $Q^2 \sim 6$ GeV^2- graduate onset of new regime where inelastic contribution becomes significant (dominates - outside 12 GeV range?)

R(x=1)=5 in DIS limit



- differential Isotopic structure of correlations (pn vs pp)

- onset of α_{2N} scaling - plot ratios at fixed α_{2N} as a function of Q^2.

- Testing tensor structure of SRC: $e\vec{D} \to e + X, e + p + n$

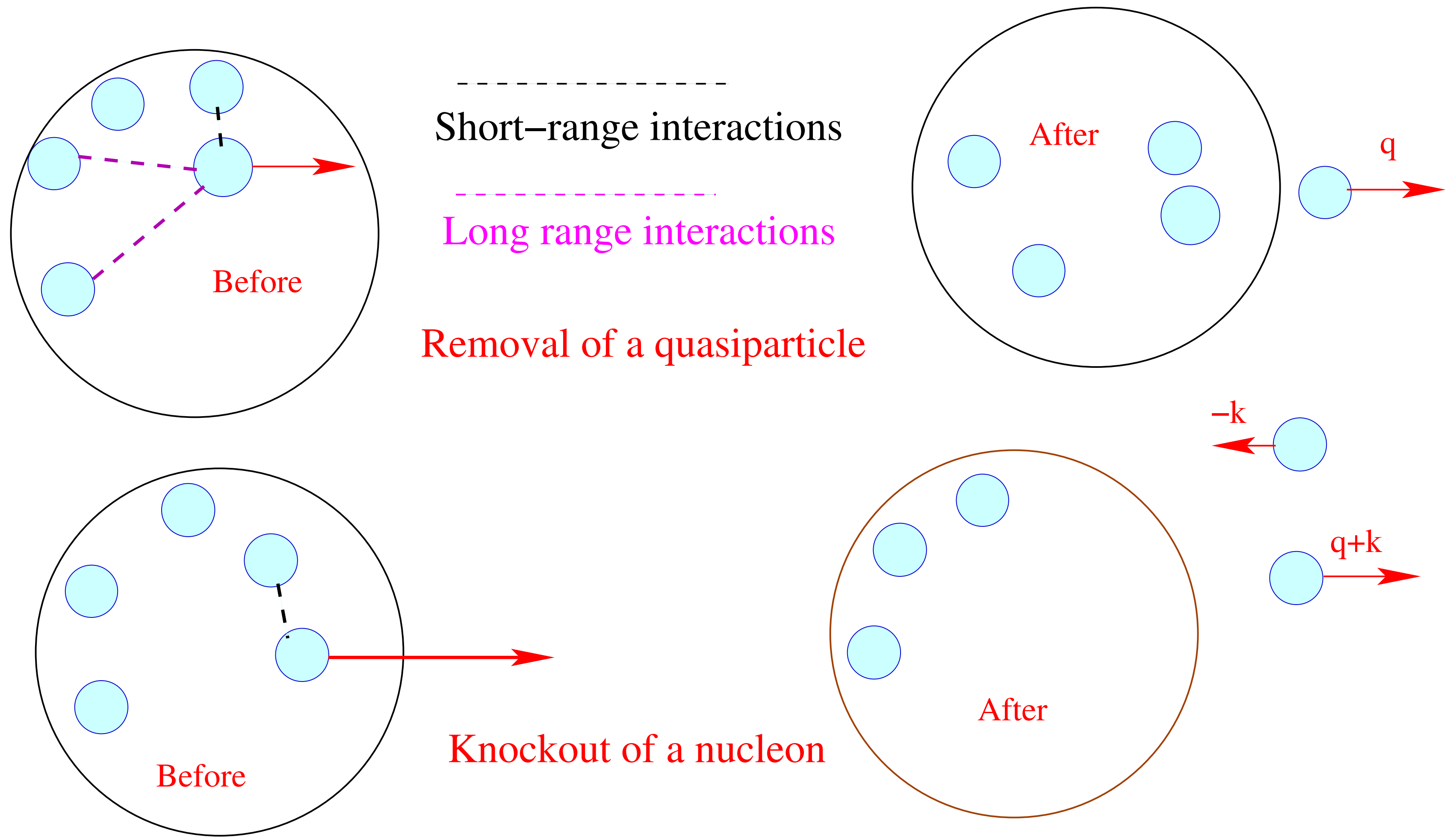
$$\gamma + \vec{D} \to \pi^- + p + \text{slow proton}$$

Onset of high energy picture and nuclear transparency

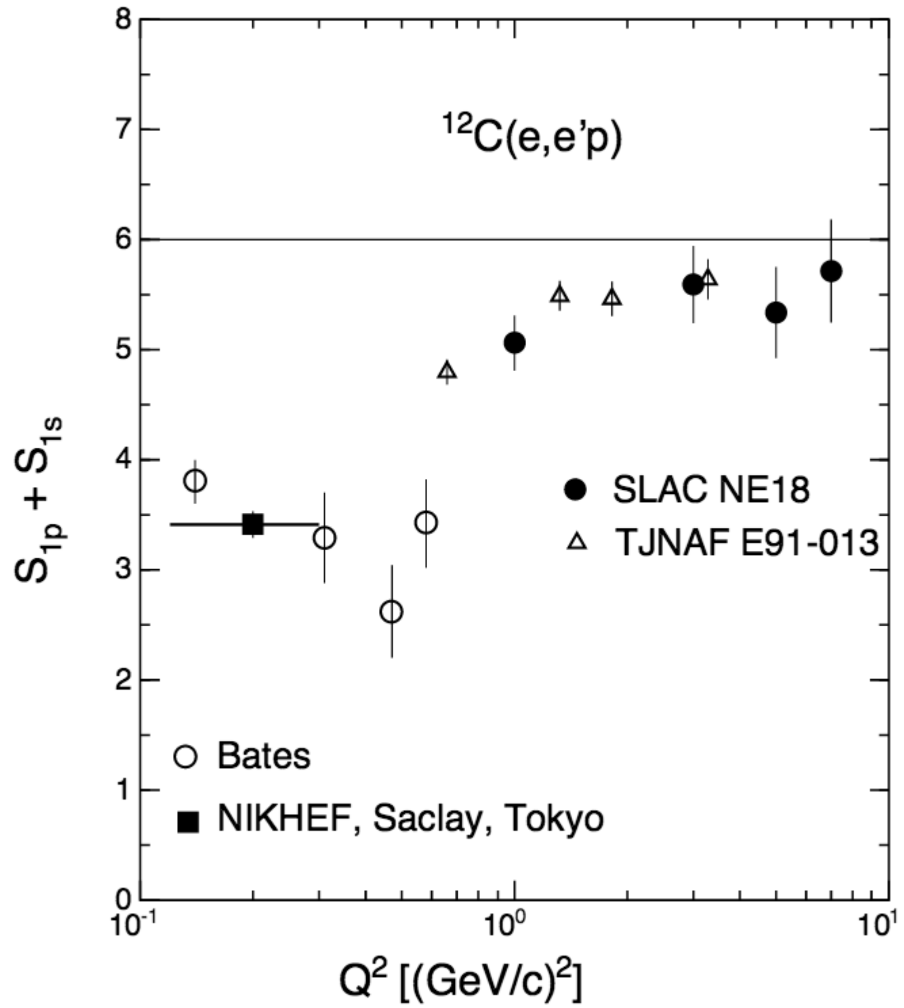
Experience of quantum field theory - interactions at different resolutions (momentum transfer) resolve different degrees of freedom - renormalization,.... No simple relation between relevant degrees of freedom at different scales.

Low Q^2 scale

High Q^2 scale



Possible to describe low energy nucleon-nucleon (nucleus) interactions, main characteristics of nuclei (radii, binding,...) using effective interactions where high momentum interactions are absent - Landau - Migdal Fermi liquid logic, Effective Field theory



Lapikas, van der Steenhoven, Frankfurt, MS Zhalov, Phys.Rev. C, 2000

Q^2 dependence of the spectroscopic factor

Rather rapid transition from regime of interaction with quasiparticles to regime of interaction with nucleons

$Q^2_{transition} \approx 0.8$ GeV^2

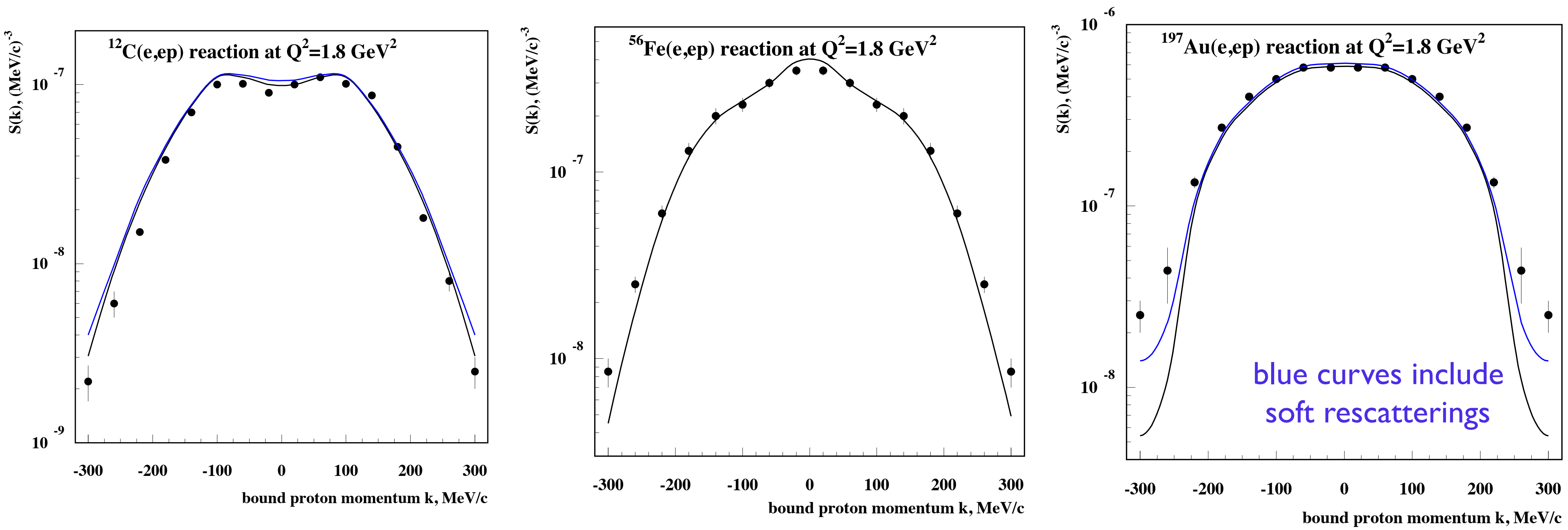
Still need to study transition in a single experiment.

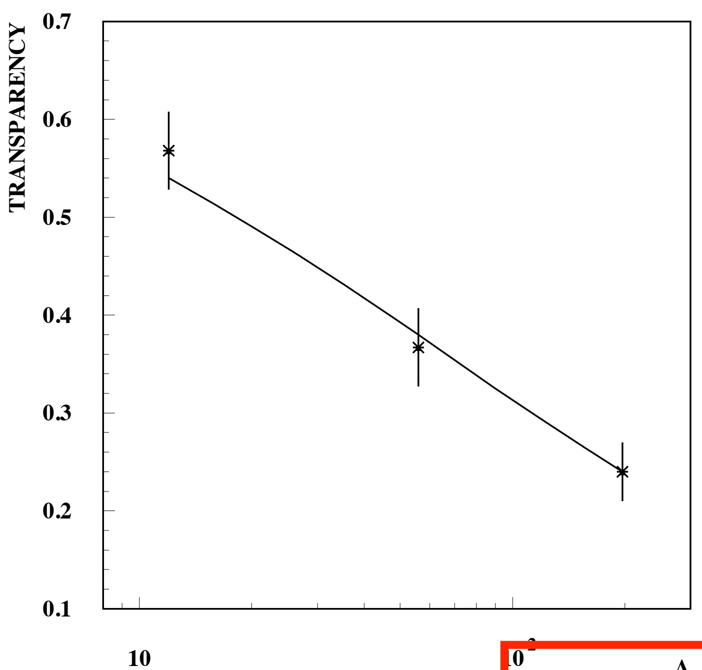
Glauber model (Frankfurt, MS, Zhalov) with HFS wave function

: very small suppression at large Q^2 :

Quenching factor Q > 0.9

Confirms conclusion of Lapikas et al of Q^2 dependence of Q factor





Comparison of transparency calculated using HFS spectral function with the data. No room for large quenching, though 10-15% effect does not contradict to the data.

Small quenching is consistent with a small strength at large excitation energies for the momentum range of the NE-18 experiment (R. Milner - private communication)

Need data on (e,e'p) for small k and large E_r and Q^2 ~ 2 GeV^2

Alternative possibility - 10-15% chiral transparency effect

In the calculation we checked that normalization of the spectral function is correct using (e,e') data at x=1 and moderate Q^2. classical mechanics calculation of transparency gives similar result.

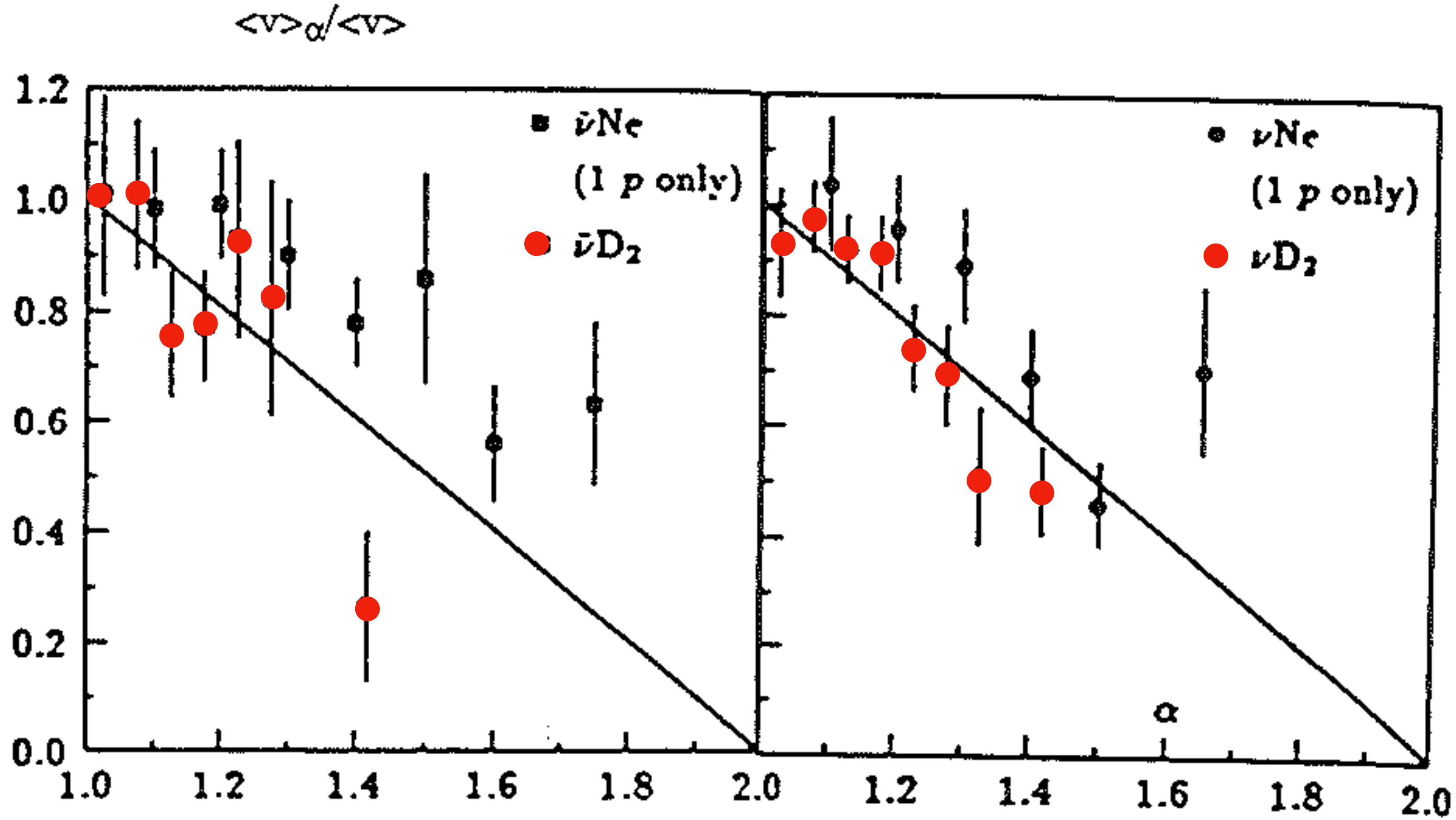
So in (e,e'p) one can use QM for 2N fsi (Misak's talk) and classical for the nucleons at distances > 1.5 fm.

Also, elastic rescaterings produce via elastic rescattering forward nucleons with relatively large p_T - mimic SRCs with larger internal momenta.

Open question: how much down in Q one can go in calculation of transparency? - Glauber approximation for pA elastic scattering had problems at T_p ~ 600 MeV (LAMPF) - (straight line geometry breaks down) expect similar problems for GEA.

Evidence for 2N SRC from (anti) neutrino scattering (BEBC, 1988)

v=xy - related to muon angle, measured better than x &y



Solid curve is "Doppler effect"prediction (FS77) $\langle V \rangle_\alpha / \langle V \rangle = 2 - \alpha$

Data with selection of events with one proton (to suppress two step processes). In early FNAL data where all events were included, the effect is a factor of two smaller - 1/2 protons from two step processes.

Studies of (eA->e' backward +X) are necessary at the very least to understand possible role of the fsi in the tagged structure function search for the EMC effect,
Is it still the best experiment (FS 85) for revealing origin of the EMC effect?