Program - to resolve SRC nuclear structure using high energy high momentum transfer probes.

Mark Strikman

Objects which enter into consideration are often new at least on the computation level.

Nonrelativistic formulation

Relativistic effects

light cone dominance in hard processes - approximations maybe more transparent if LC formulation for the wave function is used

momentum density: $n(k)$
not observable directly

LC momentum density: $\rho^N_A(\alpha, k_t)$
observable

formally connection with LC projection of $P(k,E)$

Spectral function: $P(k,E)$
observable directly, theoretical calculations for A=3, nuclear matter

Spectral function: $\rho^N_A(\alpha, k_t, p\_)$
observable directly

Decay function: $D(k_1,k_2, E)$
observable directly, theoretical calculations for A=3. Pair correlation model (~ 30 years old). Connection to double momentum distribution?

Decay function: $D(\alpha_1,\alpha_2, k_t,p\_)$
observable directly

$k_1+k_2=0$ $\neq$ $\alpha_1+\alpha_2=2$

Consensus of the 70's: it is hopeless to look for SRC experimentally

NO GO theorem: high momentum component of the nuclear wave function is not observable (Amado 78)

Theoretical analysis of F&S (75) : results from the medium energy studies of short-range correlations are inconclusive due to insufficient energy/momentum transfer leading to complicated structure of interaction (meson exchange currents,...), enhancement of the final state contributions.

Way out - use processes with large energy and momentum transfer:

$$q_0 \geq 1 GeV \gg |V_{NN}^{SR}|, \vec{q} \geq 1 GeV/c \gg 2\ k_F$$

Adjusting resolution scale as a function of the probed nucleon momentum allows to avoid Amado theorem. Standard trick in QCD.

Hence for probing momenta < 400 MeV/c lower energy & momentum transfer should be sufficient than those used at BNL

Actually it is now a standard trick in atomic (10 eV vs 1000 eV) and solid state physics (0.2 eV vs 30 eV) scales.

Can one check whether indeed the tail is due to SRCs?

Consider distribution over the residual energies, E_R, for A-1 nucleon system after a nucleon with momentum k was instantaneously removed -

nuclear spectral function

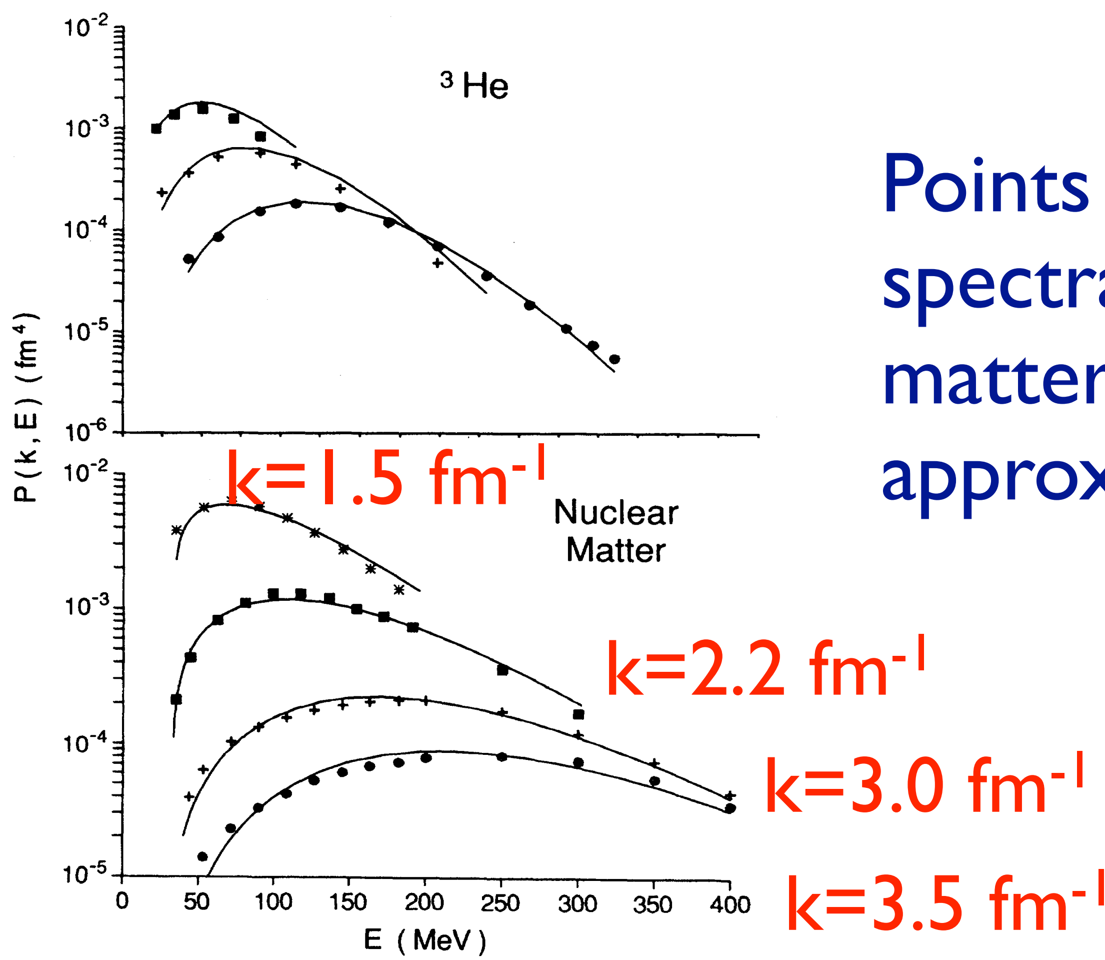
$$P_A(k,E_r), n_A(k) = \int dE_R P_A(k,E_r)$$

for 2N SRC: $$\langle E_R(k)\rangle = k^2/2m_N$$ FS81-88

Confirmed by numerical calculations

Numerical calculations in NR quantum mechanics confirm dominance of two nucleon correlations in the spectral functions of nuclei at k> 300 MeV/c - could be fitted by a motion of a pair in a mean field (Ciofi, Simula,Frankfurt, MS - 91). However numerical calculations ignored three nucleon correlations - 3p3h excitations.

Relativistic effects maybe important rather early as the recoil modeling does involve k^2/m_N^2 effects.



Points are numerical calculation of the spectral functions of ^{3}He and nuclear matter - curves two nucleon approximation from CSFS 91

In addition to 2N correlations higher order correlations

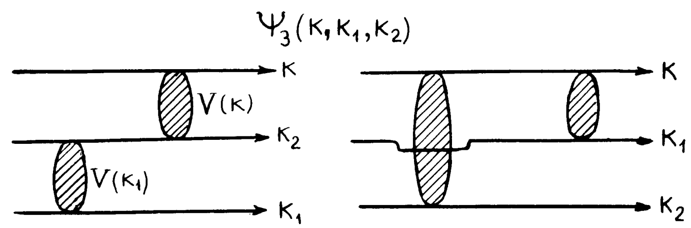
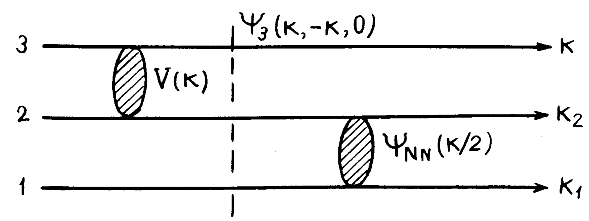


FIG. 8.8:

$$P_A(k,E)\Big|_{E<\text{const.},\ k\to\infty} \sim \left(\frac{V(k/2)}{(k/2)^2}\right)^4 \sim n_A^2(k/2).$$



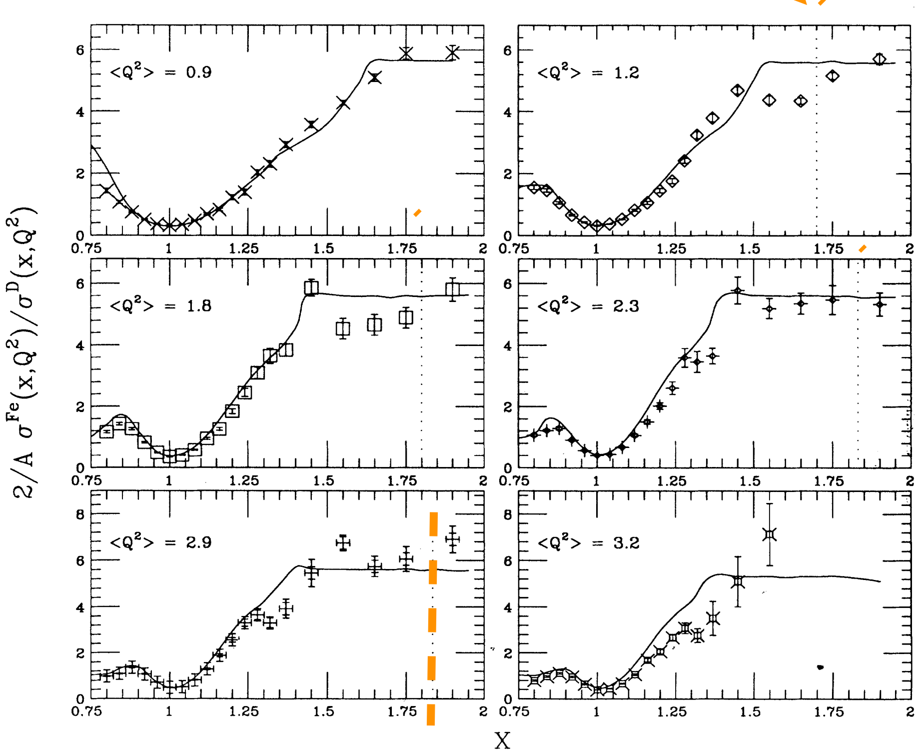
$$P_A(k,E_R(k))_{|k>k_F} = \sum_{j=2}^{A} P_j(k,E_R(k))$$

In NR formalism 3N,.. correlations show up only via recoil cuts. In LC α> 2 cut --> 3N in density matrix

3N effects requires more careful analysis of relativistic kinematics - Misak’s talk

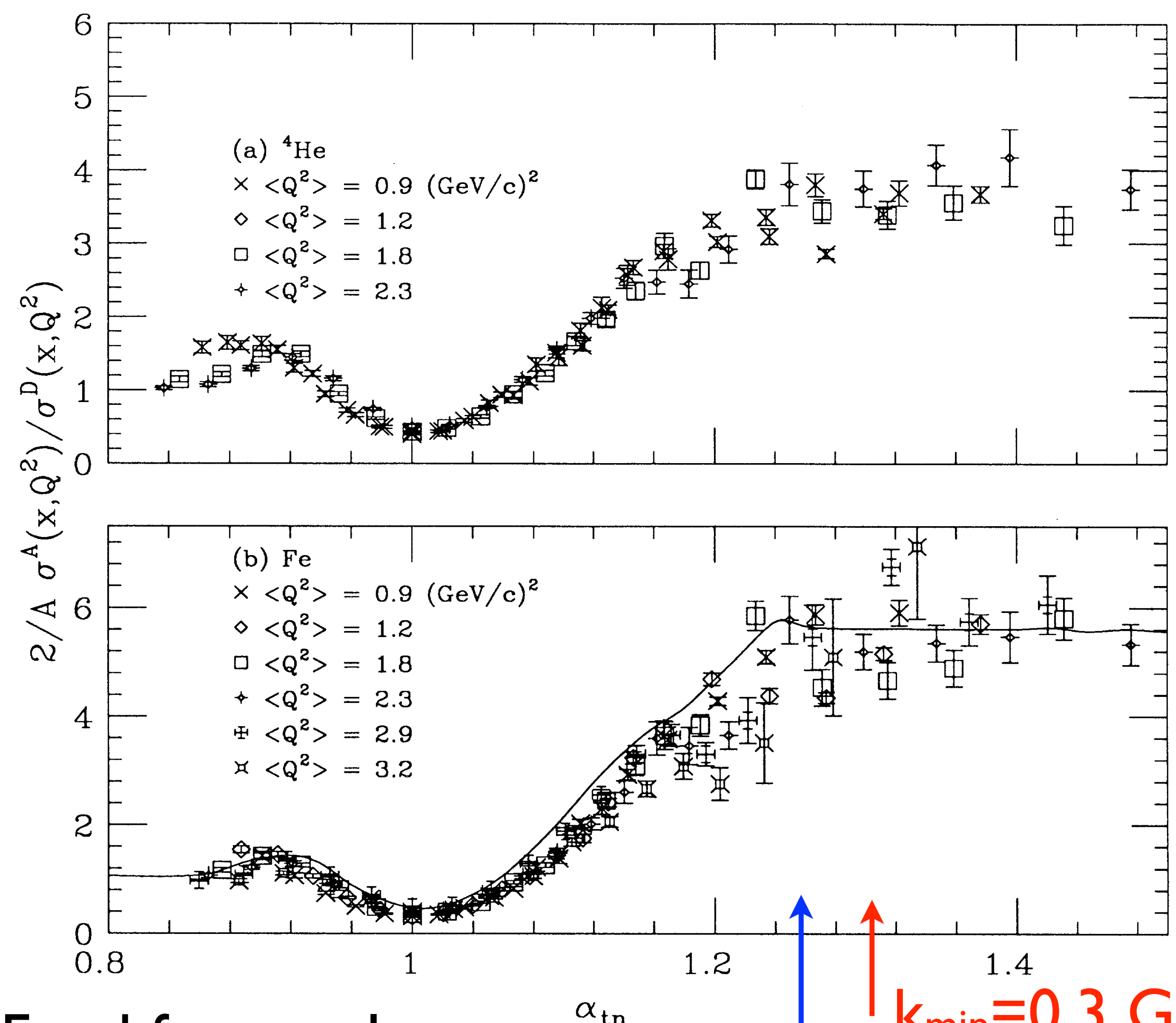
$$\frac{\sigma_{A_1}(x,Q^2)}{\sigma_{A_2}(x,Q^2)} = \frac{\int \rho_{A_1}(\alpha_{tn},p_t)d^2p_t}{\int \rho_{A_2}(\alpha_{tn},p_t)d^2p_t} \cdot \frac{a_2(A_1)}{a_2(A_2)}\Big|_{1.6>\alpha\geq 1.3} =$$

$W - M_D \leq 50\,MeV$



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

The local FSI interaction, up to a factor of 2, cancels in the ratio of σ's



Frankfurt et al, 93

k_{min}=0.3 GeV

k_{min}=0.25 GeV

Right momenta for onset of scaling

Nuclear Decay Function

Provides a much better way to determine what SRCs are made of

What happens if a nucleon with momentum k belonging to SRC is instantaneously removed from the nucleus (hard process)? Our guess is that associated nucleon from SRC with momentum ~ -k should be produced.

Formal definition of a new object - nuclear decay function (FS 77-88) - probability to emit a nucleon with momentum k_2 after removal of a fast nucleon with momentum k_1, leading to a state with excitation energy E_r (nonrelativistic formulation)

$$D_A(k_2, k_1, E_r) = \left|\langle\phi_{A-1}(k_2, ...)\,|\delta(H_{A-1} - E_r)a(k_1)|\,\psi_A\rangle\right|^2$$

General principle (FS77): to release a nucleon of a SRC - it is necessary to remove nucleons from the same correlation - perform a work against potential $V_{12}(r)$

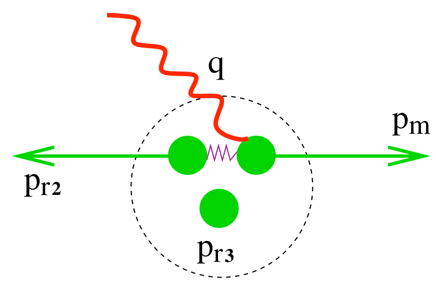
For 2N SRC can model decay function as a decay of a NN pair moving in mean field (like for P_A) Piasetzky et al 06

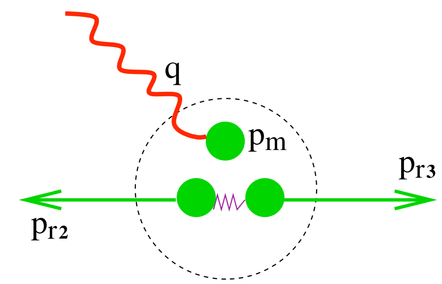
Accuracy?

Operational definition of the SRC: nucleon belongs to SRC if its instantaneous removal from the nucleus leads to emission of one or two nucleons which balance its momentum: includes not only repulsive core but also tensor force interactions. Prediction of back - to - back correlation.

For 2N SRC we can model decay function as decay of a NN pair moving in mean field (like for spectral function in the model of Ciofi, Simula and Frankfurt and MS91), Piasetzky et al 06

Spectator is released





Emission of fast nucleons "2" and "3" is <u>*strongly suppressed due to FSI*</u>

resembles 2N momentum distribution

does not resemble 2N momentum distribution -

<u>Studies of the spectral and decay function of ^{3}He reveal both two nucleon and three nucleon correlations</u>

Sargsian et al 2004

Factorization (analogy with pQCD)

Same decay and density matrix for different processes

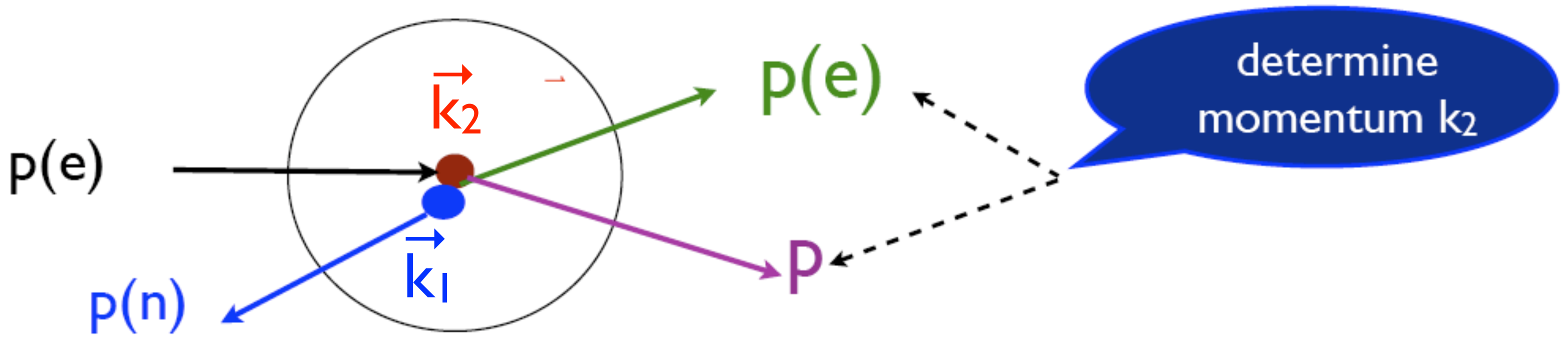
Impulse approximation

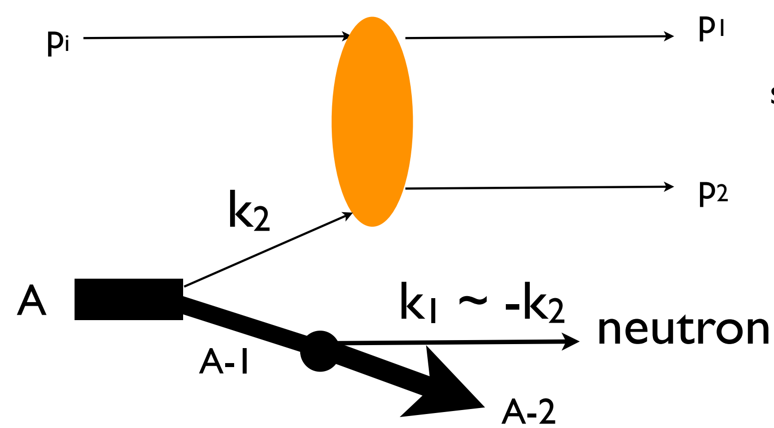
$$\sigma(H + A \to h' + N_1 + N_2 + (A-2)) = \sigma(H + A \to h' + N_1) \times D(\alpha_i, k_t, ...)$$

GEA - to correct for rescattering and absorption

simplification - LC fraction conservation in elastic rescatterings

electron, vs photon vs proton beams





$s' = (p_1 + p_2)^2$

$t = (p_1 - p_p)^2$

$k_2 = p_1 + p_2 - p_i$

Collider frame
$s' = \alpha s_{NN}$, $\alpha < 1$
neutron momentum $(2-\alpha)p$

From measurement of p_1, p_2 $p_{neutron}$ choose small excitation energy of A-2 (< 100 MeV)

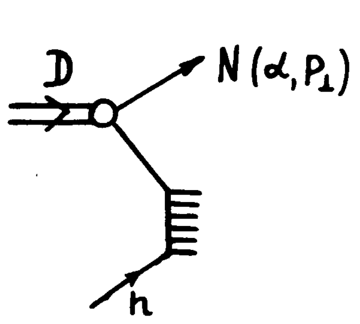
$\sigma = d\,\sigma^{pp \to pp}/dt(s',t)$ * (Decay function)

Test of Factorization: $\sigma / d\,\sigma^{pp \to pp}/dt(s',t)$ independent of s', t

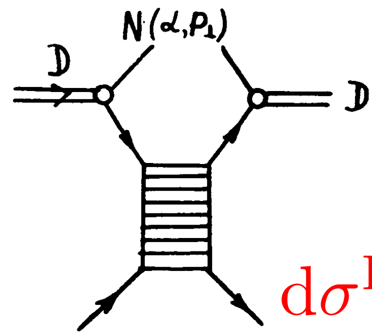
GEA - to correct for rescattering and absorption

simplification - LC fraction conservation in elastic rescatterings

electron, vs photon vs proton beams; violation of factorization due to EMC like effects (off shellness - Sunday session)



(a)

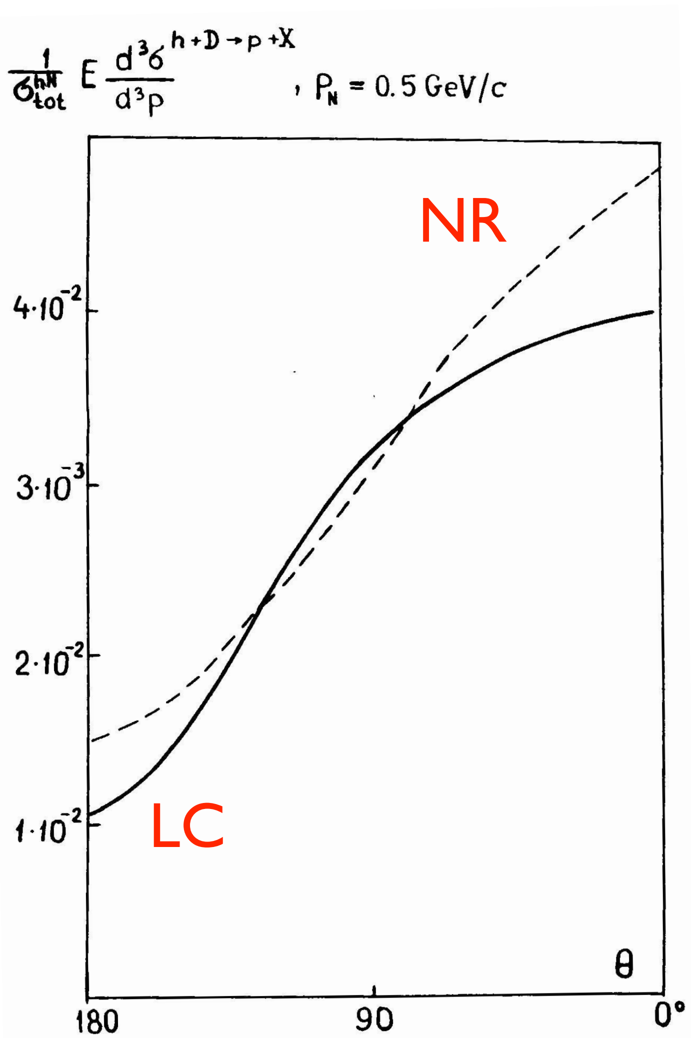


(b)

$$\left.\frac{\mathrm{d}\sigma^{\mathrm{D+h\to N+\cdots}}}{(\mathrm{d}\alpha/\alpha)\mathrm{d}^2p_\perp}\right|_{\text{LC imp.approx.}} = \sigma^{\mathrm{hN}}_{\mathrm{inel.}}[(2-\alpha)s_{NN}]\cdot\frac{[U^2(k)+W^2(k)]}{(2-\alpha)}\sqrt{k^2+m^2}$$

$$\left.\frac{\mathrm{d}\sigma^{\mathrm{D+h\to N+\cdots}}}{(\mathrm{d}\alpha/\alpha)\mathrm{d}^2p_\perp}\right|_{\text{NR imp.approx.}} = \sigma^{\mathrm{hN}}_{\mathrm{inel.}}[(2-\alpha)s_{NN}]\cdot(2-\alpha)[U^2(p)+W^2(p)]\sqrt{p^2+m^2}$$

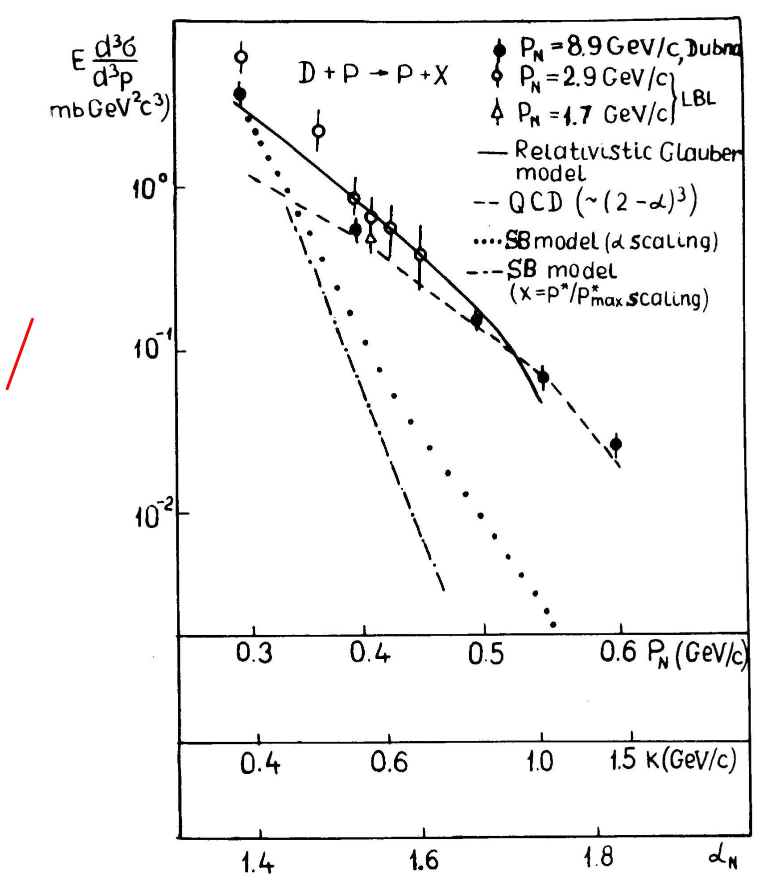
LC nucleon: nonlinear relation between internal momentum k and observed momentum p (see next slide). Asymptotic behavior at $\alpha\to 2$ is determined by WF at $k\to\infty$. Similar to particle physics.



Numerical rel. effect is modest for unpolarized case

$$\alpha = (\sqrt{p^2+m^2} - p_3)/(m_D/$$

$$\alpha = 1 - \frac{k_3}{\sqrt{k^2+m^2}}$$



The best way to look for the difference between LC and NR/Virtual nucleon seems to be scattering off the polarized deuteron

$$\frac{\mathrm{d}\sigma(\mathrm{e}+\mathrm{D}_\Omega \to \mathrm{e}+\mathrm{N}+\mathrm{X})}{(\mathrm{d}\alpha/\alpha)\,\mathrm{d}^2 p_\mathrm{t}} \Bigg/ \frac{\mathrm{d}\sigma(\mathrm{e}+\mathrm{D} \to \mathrm{e}+\mathrm{N}+\mathrm{X})}{(\mathrm{d}\alpha/\alpha)\,\mathrm{d}^2 p_\mathrm{t}}$$

$$= 1 + \left(\frac{3k_i k_j}{k^2}\,\Omega_{ij} - 1\right) \frac{\frac{1}{2}w^2(k) + \sqrt{2}u(k)w(k)}{u^2(k)+w^2(k)} \equiv P(\Omega, k)$$

Ω is the spin density matrix of the deuteron, $\mathrm{Sp}\Omega = 1$

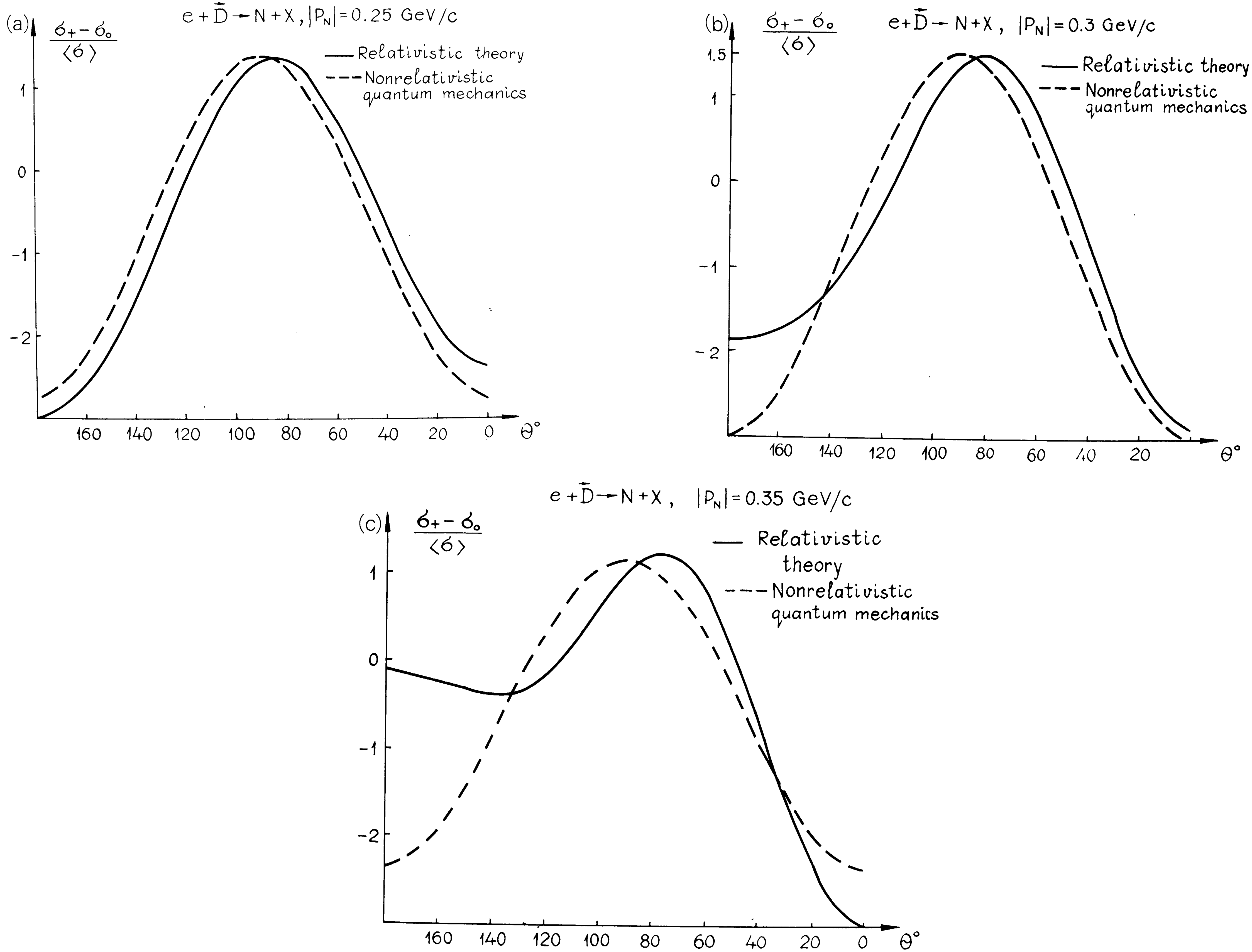
Consider

$$R = T_{20} = \left[\frac{1}{2}(\sigma_+ - \sigma_-) - \sigma_0\right] \Big/ \langle\sigma\rangle$$

$$R^{lc}(p_\mathrm{s}) = \frac{3(k_\mathrm{t}^2/2 - k_z^2)}{k^2}\,\frac{u(k)w(k)\sqrt{2} + \frac{1}{2}w^2(k)}{u^2(k)+w^2(k)}$$

trivial angular dependence for fixed p

$$R^{\mathrm{nonrel}}(p_\mathrm{s}) = \frac{3(p_\mathrm{t}^2/2 - p_z^2)}{p^2}\,\frac{u(p)w(p)\sqrt{2} + \frac{1}{2}w^2(p)}{u^2(p)+w^2(p)}$$


(a)
$\frac{\sigma_+ - \sigma_0}{\langle \sigma \rangle}$
$e + \vec{D} \to N + X, |P_N| = 0.25$ GeV/c
Relativistic theory
Nonrelativistic quantum mechanics
1
0
-1
-2
160 140 120 100 80 60 40 20 0
θ°
(b)
$\frac{\sigma_+ - \sigma_0}{\langle \sigma \rangle}$
$e + \vec{D} \to N + X, |P_N| = 0.3$ GeV/c
Relativistic theory
Nonrelativistic quantum mechanics
1.5
1
0
-1
-2
160 140 120 100 80 60 40 20
θ°
$e + \vec{D} \to N + X, |P_N| = 0.35$ GeV/c
(c)
$\frac{\sigma_+ - \sigma_0}{\langle \sigma \rangle}$
Relativistic theory
Nonrelativistic quantum mechanics
1
0
-1
-2
160 140 120 100 80 60 40 20 0
θ°