# Short-Range Structure of the deuteron with tagging

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Workshop:Short-Range Structure with Tagging

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# tagging with (tensor) polarized deuterons:

- Probing deuteron on the level of nucleonic degrees of freedom: light cone vs virtual nucleon approximations

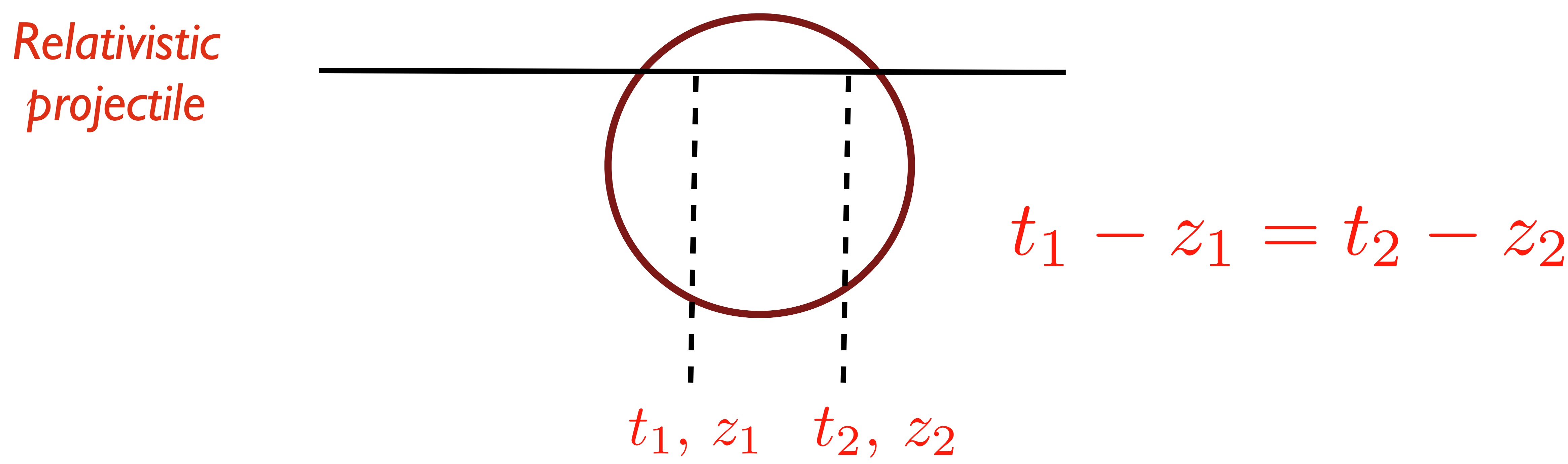
- Probing spin/isospin quark structure of bound nucleons

- Direct observation of non-nucleonic degrees of freedom in deuteron

To resolve short-range structure of nuclei *on the level of nucleon/hadronic constituents* one needs processes which transfer to the nucleon constituents both energy and momentum larger than the scale of the NN short range correlations $q_0 \geq 1 GeV, \vec{q} \geq 1\, GeV$

$\Rightarrow$ Need to treat the processes in the relativistic domain. The price to pay is a need to treat the nucleus wave function using light-cone quantization - - One cannot use (at least in a simple way) nonrelativistic description of nuclei.

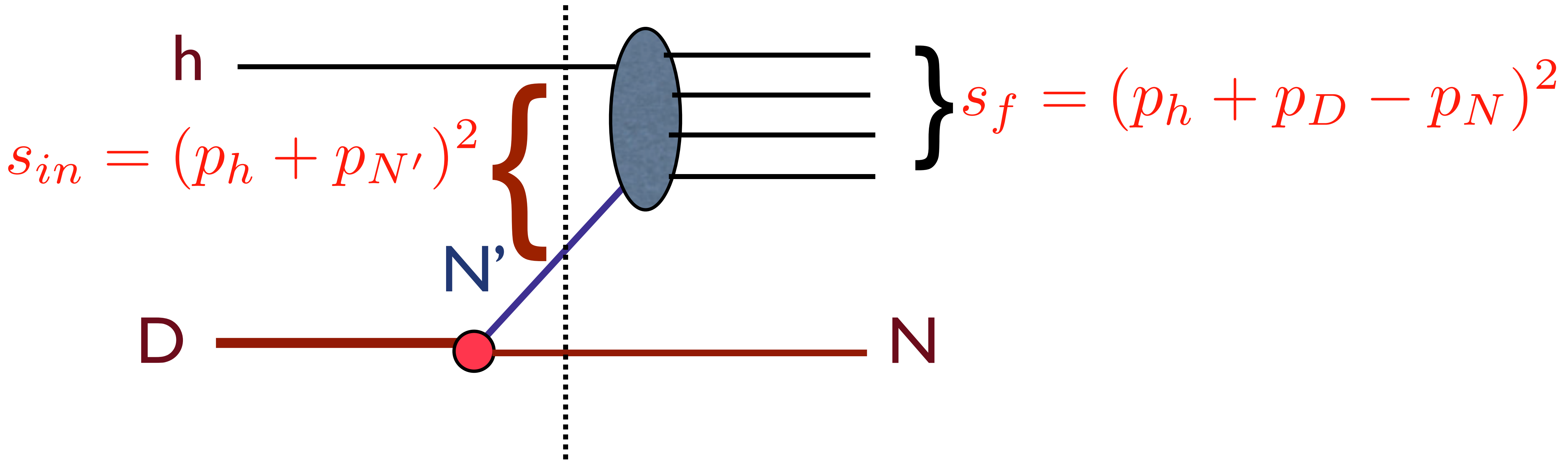
⇒ High energy process develops along the light cone.




Similar to the perturbative QCD the amplitudes of the processes are expressed through the wave functions on the light cone. *Note: in general no benefit for using LC for low energy processes.*

*LC quantization is uniquely selected in high energy processes if one tries to express cross section through elementary amplitudes near energy shell.*

Consider the break up of the deuteron in the impulse approximation:
$h+D \to X+N$, for $E_h \to \infty$




In quantum mechanical treatment energy in the $D \to NN$ vertex is not conserved. As a result

$$\Delta \equiv (s_{in} - s_f) \to 2\,E_h(2\sqrt{m_N^2 + p_N^2} - m_D)\,|_{\,E_h \to \infty}$$

is infinite at high energies. Amplitude is far off energy shell.

# *In case of LC quantization along reaction axis*

$$\Delta = (p_{\rm NN} + p_{\rm h})^2 - (p_{\rm D} + p_{\rm h})^2 = M_{\rm NN}^2 - M_{\rm D}^2 + (p_{\rm h})_+(p_{\rm NN} - p_{\rm D})_- + (p_{\rm h})_-(p_{\rm NN} - p_{\rm D})_+$$
$$= M_{\rm NN}^2 - M_{\rm D}^2 + \frac{1}{2}(m_{\rm h}^2/E_{\rm h})(M_{\rm NN}^2/M_{\rm D} - M_{\rm D}) \simeq M_{\rm NN}^2 - M_{\rm D}^2$$

Here $M^2_{NN}$ is invariant mass squared of the two nucleon system

Δ is fine and hence amplitude is close to the mass shell

Requirement of finite Δ uniquely fixes quantization axis for the high energy limit to be according to LC prescription

Often ignored - elementary "hN" amplitude is off "-" shell

$$\mu^2 = (p_D - p_N)^2 - m_N^2 < 0$$

and elementary amplitude can depend on it and in some cases on $p_{tN}$ as well. For average configurations in nucleon small parameter is $\mu^2/m_\rho^2$

Hard processes - different energy scales: functions of x, flavor,,,

LC dynamics for two body case -
more technical discussion - connected to Millers talk

## Decomposition over hadronic states could be useless if too many states are involved in the Fock representation

$$|D\rangle = |NN\rangle + |NN\pi\rangle + |\Delta\Delta\rangle + |NN\pi\pi\rangle + ...$$

***Problem*** - we cannot use a guiding principle experience of the models of NN interactions based on the meson theory of nuclear forces - *such models have a Landau pole close to mass shell and hence generate a lot of multi meson configurations*. (On phenomenological level - problem with lack of enhancement of antiquarks in nuclei)

Instead, we can use the information on NN interactions at energies below few GeV and the chiral dynamics combined with the following general quantum mechanical principle - *relative magnitude of different components in the wave function should be similar to that in the NN scattering at the energy corresponding to off-shellness of the component.*

Geometric reasoning - internucleon distance in 2N SRC < 2 $r_N$ suggests 2N SRC is actually quark soup or has many non-nucleonic hadronic components.

FS76-81: *geometry reasoning is misleading* and nucleon degrees of freedom make sense for momenta well above Fermi momentum due to presence in QCD of

**a hidden parameter** (FS 75-81) : in NN interactions: direct pion production is suppressed for a wide range of energies due to chiral properties of the NN interactions:

$$\frac{\sigma(NN \to NN\pi)}{\sigma(NN \to NN)} \approx \frac{k_\pi^2}{16\pi^2 F_\pi^2}, \; F_\pi{=}94MeV$$

⇒ Main inelasticity for NN scattering for $T_p \leq 1$ GeV is single Δ-isobar

in the deuteron channel only 2 Δ's allowed = threshold: $k_N = \sqrt{m_\Delta^2 - m_N^2} \approx 800\ MeV$ !!

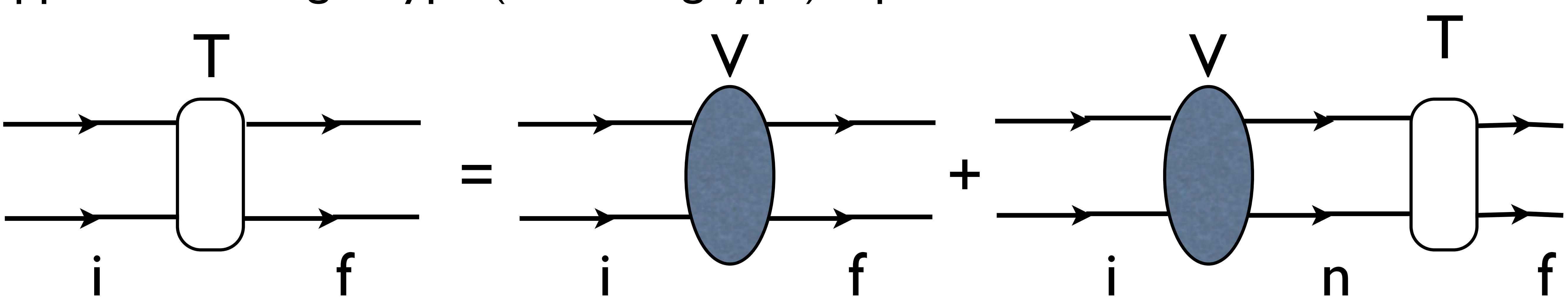
***Correspondence argument: wave function - continuum ⇒ Small parameter for inelastic effects in the deuteron/nucleus WF, while relativistic effects are already significant since*** $p_N/m_N \leq 1$

# Light-cone Quantum mechanics of two nucleon system

Due to the presence of a small parameter (inelasticity of NN interactions) it makes sense to consider two nucleon approximation for the LC wave functio of the deuteron.

Key point is presence of the unique matching between nonrelativistic and LC wave functions in this approximation. Proof is rather involved.

*First step:* include interactions which do not have two nucleon intermediate states into kernel V (like in nonrel. QM) to build a Lippman-Schwinger type (Weinberg type) equation.



The LC "energy denominator" is $1/(p_{n_+} - p_{f_+})$

Using explicit expression for the propagator in terms of the LC variables and using corresponding expressions for the two-body phase volume on LC we obtain:

$$T(\alpha_i, k_{it}, \alpha_f, k_{ft}) = V(\alpha_i, k_{it}, \alpha_f, k_{ft}) + \int V(\alpha_i, k_{it}, \alpha', k'_t) \frac{d\alpha'}{4\alpha'(1-\alpha')} \frac{d^2k'_t}{(2\pi)^3}$$

$$\times \frac{T(\alpha', k'_t, \alpha_f, k_{ft})}{[(m^2 + k'^2_t)/\alpha'(1-\alpha') - (m^2 + k^2_{ft})/\alpha_f(1-\alpha_f)]/2}$$

## ***Second step: Impose condition that master equation should lead to the Lorentz invariance of the on-energy-shell amplitude of NN scattering***

Introduce three- vector $\vec{k} = (k_3, k_t)$ with

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

Invariant mass of two nucleon system is $M_{NN}^2 = \frac{m^2 + k_t^2}{\alpha(1-\alpha)} = 4m^2 + 4k^2$

$$T(k_{\rm i}, k_{\rm f}, k_{\rm i3}, k_{\rm f3}) = V(k_{\rm i}, k_{\rm f}, k_{\rm i3}, k_{\rm f3}) + \int V(k_{\rm i}, k', k_{\rm i3}, k'_3) \frac{{\rm d}^3 k'}{\sqrt{k'^2 + m^2}} \frac{1}{4(2\pi)^3} \frac{T(k', k_{\rm f}, k'_3, k_{\rm f3})}{k'^2 - k_{\rm f}^2}.$$

On-mass-shell

$$T(k, k_3, k_{\rm f}, k_{\rm f3}) = T(k^2, k_{\rm f}^2, kk_{\rm f})$$

$$V(k, k_3, k_{\rm f}, k_{\rm f3}) = V(k^2, k_{\rm f}^2, kk_{\rm f})$$

For rotational invariance of T it is sufficient that the same relation is satisfied for V off-mass-shell. The proof that this condition is also necessary is much more complicated (FS + Mankievich 91) . At the same time it is obvious that it would be very difficult to satisfy the highly nonlinear equation for the on-shell amplitude if this condition were violated.

The proof uses methods of complex angular momentum plane and assumption that the amplitude is decreases sufficiently fast with momentum transfer (actually rather slow decrease was sufficient).

$$T(k,k_{\mathrm{f}}) = V(k,k_{\mathrm{f}}) + \int V(k,k') \frac{\mathrm{d}^3k'}{4\sqrt{k'^2+m^2}} \, \frac{1}{k'^2-k_{\mathrm{f}}^2} \, \frac{1}{(2\pi)^3} \, T(k',k_{\mathrm{f}})$$

Very similar structure for the equation for the scattering amplitude in NR QM and for LC. If a NR potential leads to a good description of phase shifts the same is true for its LC analog. Hence simple approximate relation for LC and NR two nucleon wave function

# Spin zero /unpolarized case

rescale $\alpha \rightarrow 2\alpha$ so that $0<\alpha<2$ with $\alpha=1$ corresponds to a nucleon at rest ( more convenient when generalizing to $A>2$)

# Relation between LC and NR wf.

$$\int \Psi_{NN}^2\left(\frac{m^2+k_t^2}{\alpha(2-\alpha)}\right)\frac{d\alpha d^2k_t}{\alpha(2-\alpha)}=1 \qquad \int \phi^2(k)d^3k=1$$

$$\Psi_{NN}^2\left(\frac{m^2+k_t^2}{\alpha(2-\alpha)}\right)=\frac{\phi^2(k)}{\sqrt{(m^2+k^2)}}$$

Similarly for the spin 1 case we have two invariant vertices as in NR theory:

$$\psi_\mu^D\epsilon_\mu^D=\bar{u}(p_1)\left(\gamma_\mu G_1(M_{NN}^2)+(p_1-p_2)_\mu G_2(M_{NN}^2)\right)u(-p_2)\epsilon_\mu^D$$

hence there is a simple connection to the S- and D- wave NR WF of D

For two body system in two nucleon approximation

***the biggest difference between NR and virtual nucleon approximation and LC is in the relation of the wave function and the scattering amplitude***

Let us illustrate this for the high energy deuteron break up $h(e) + D \to X + N$ in the impulse approximation with nucleon been in the deuteron fragmentation region - spectator contribution.

For any particle, b, in the final state in the target fragmentation region the light cone fractions are conserved under longitudinal boosts

$$\alpha_{\rm b}/2 = (E_{\rm b} + p_{{\rm b}Z})/(E_{\rm D} + p_{{\rm D}Z})$$

Hence in the rest frame

$$2 > \alpha_{\rm b} \equiv \left(\sqrt{m_{\rm b}^2 + p_{\rm b}^2} - p_{{\rm b}Z}\right)/M_{\rm D}$$

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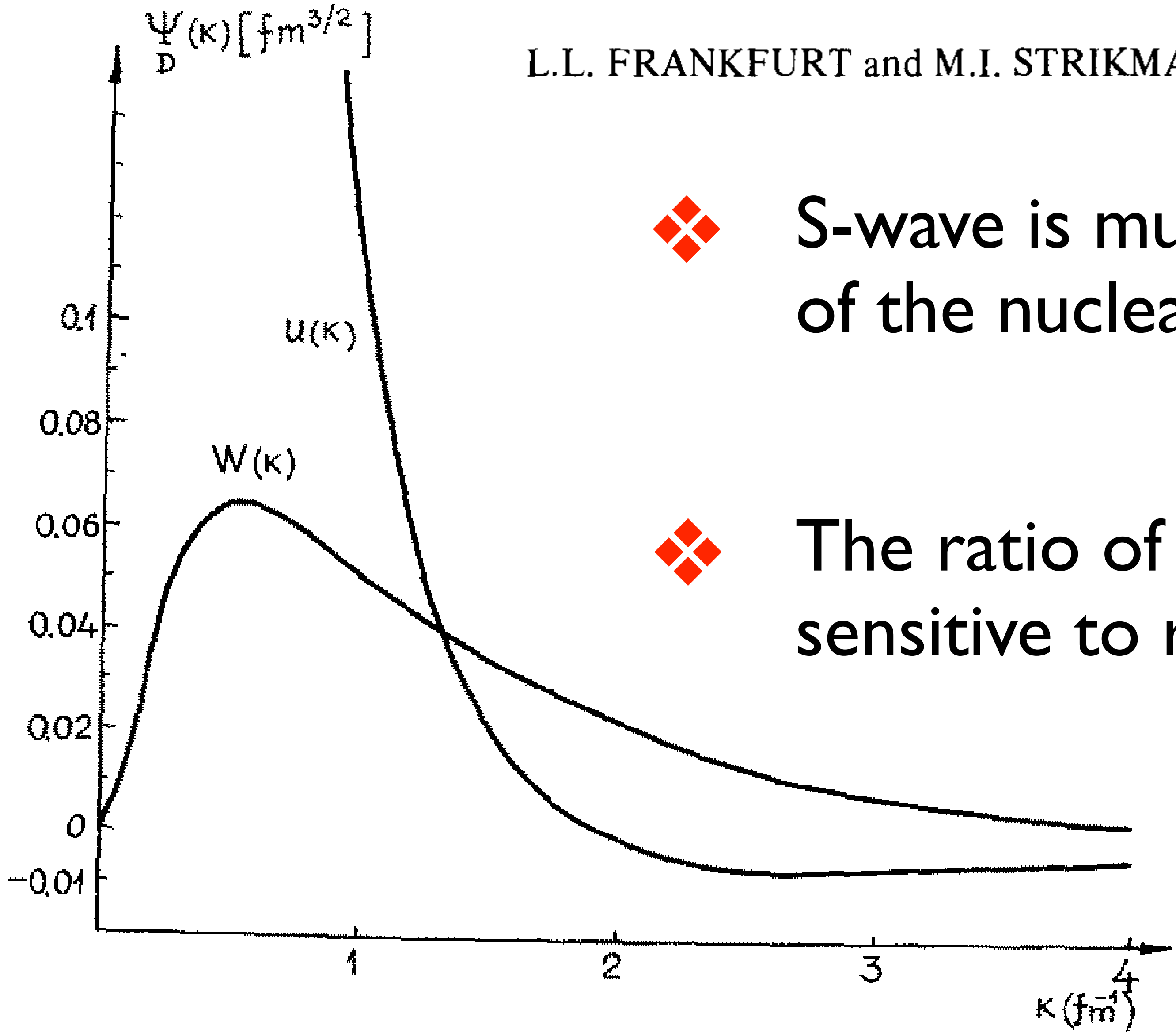
**NEW DIRECT WAY OF CHECKING THE NUCLEAR CORE HYPOTHESIS IN INCLUSIVE HADRON SCATTERING OFF THE POLARIZED DEUTERON**

L.L. FRANKFURT and M.I. STRIKMAN




- S-wave is much more sensitive of the presence of the nuclear core than $\psi^2_D(\kappa)$
- The ratio of S and D - waves is much more sensitive to relativistic effects than $\psi^2_D(\kappa)$

Fast variation of w(k)/u(k) with k $\Longrightarrow$

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

$$\frac{d\sigma(e + D_\Omega \to e + N + X)}{(d\alpha/\alpha)\, d^2 p_t} \Bigg/ \frac{d\sigma(e + D \to e + N + X)}{(d\alpha/\alpha)\, d^2 p_t}$$

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

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

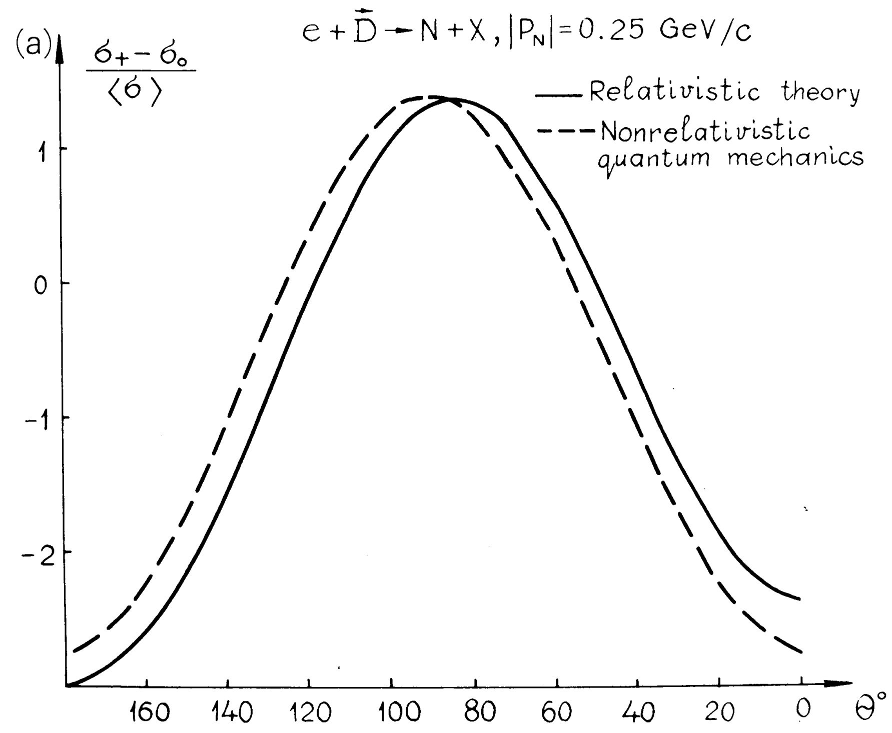
## Consider

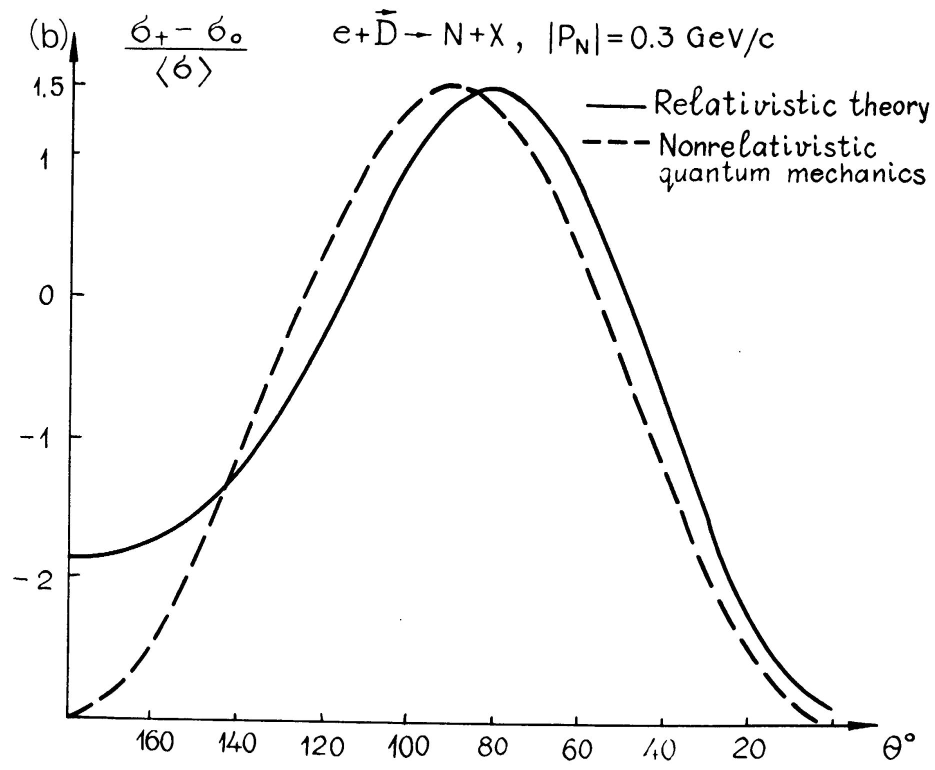
$$R = T_{20} = \left[\frac{1}{2}(\sigma_+ - \sigma_-) - \sigma_0\right] \Big/ \langle\sigma\rangle$$

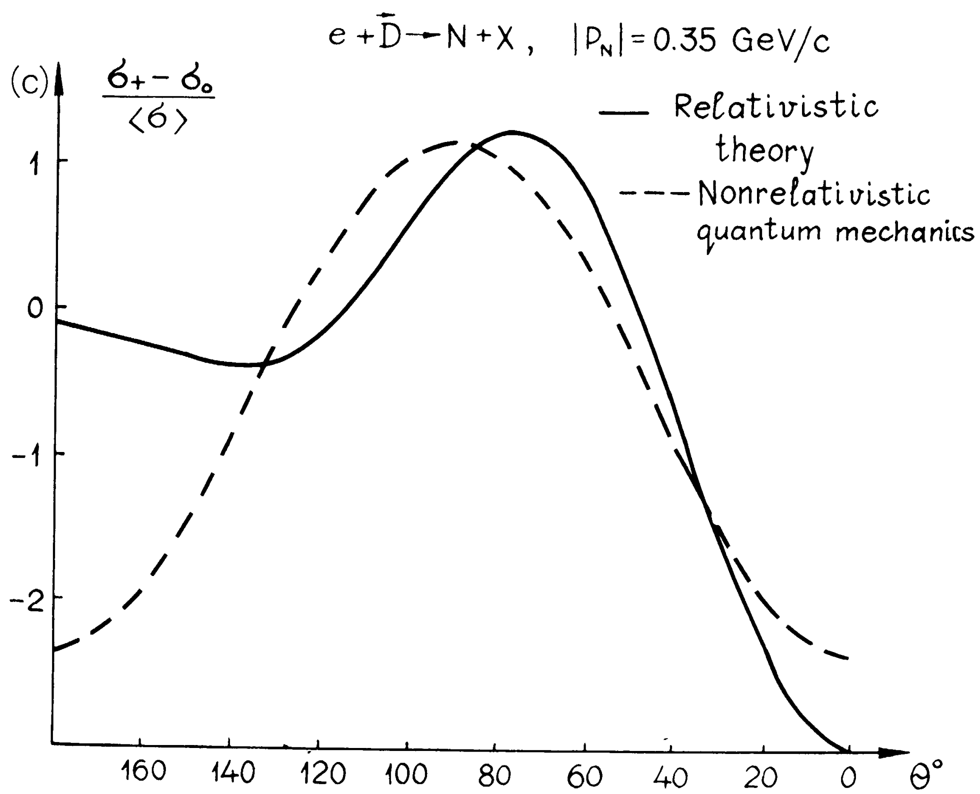
$$R^{lc}(p_s) = \frac{3(k_t^2/2 - k_z^2)}{k^2}\, \frac{u(k)w(k)\sqrt{2} + \frac{1}{2}w^2(k)}{u^2(k) + w^2(k)}$$

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

trivial angular dependence for fixed p



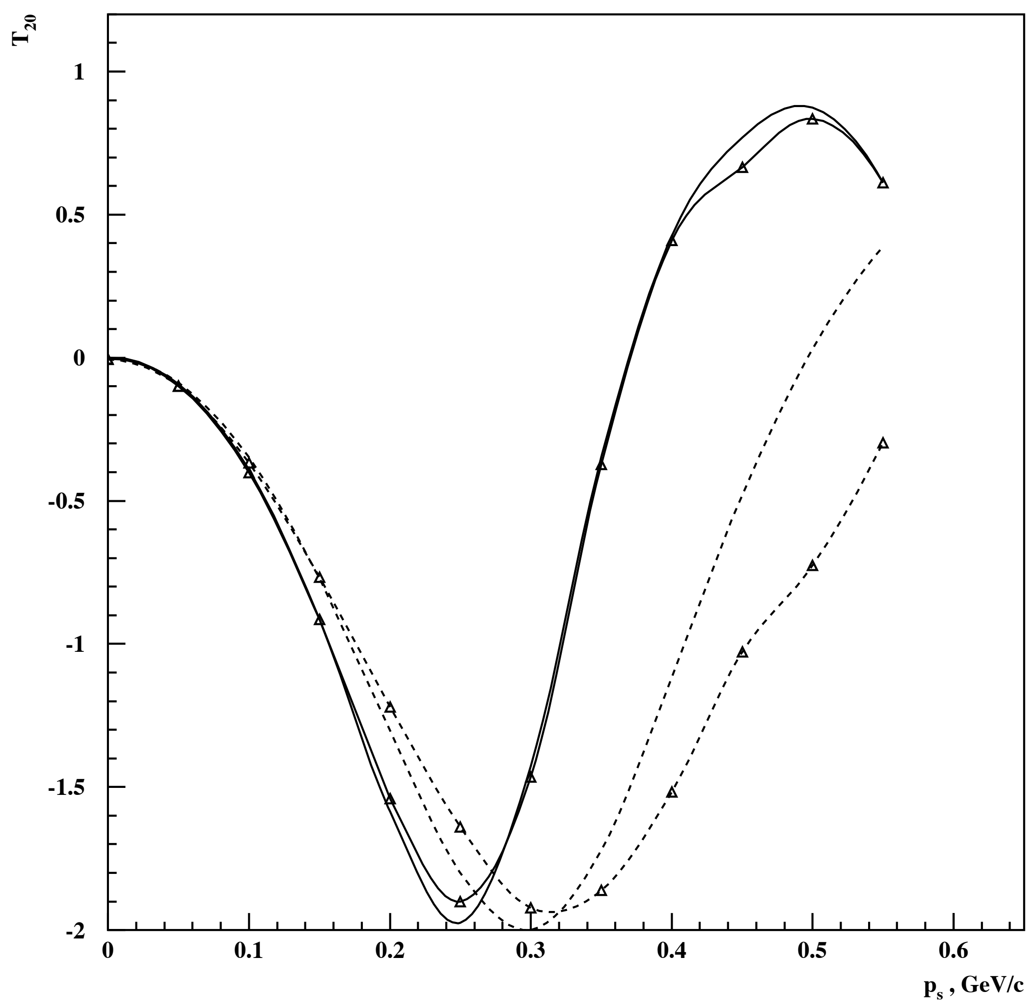




Factorization test: $T_{20}$ should be universal - the same for various hard inclusive and exclusive processes

Mechanisms of violation of factorization: fsi, nonnucleonic degrees of freedom in D

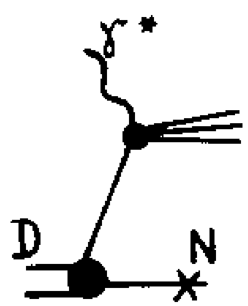
# Effect of FSI may differ on LC and NR - because of light cone fraction conservation



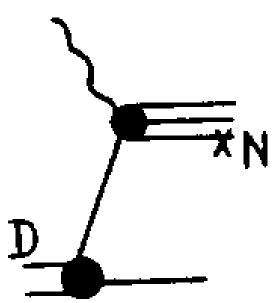

Sargsian and MS 96

$p_s$ dependence of the(e,e'p) tensor polarization at $\vartheta$=180°. Solid and dashed lines are PWIA predictions of the LC and VN methods, respectively. Marked curves include FSI.

# Tagging - direct vs spectator mechanism




The spectator mechanism for the $\ell + D \rightarrow \ell' + p + X$ reaction.




The direct mechanism for the $\ell + D \rightarrow \ell' + p + X$.

# Special properties of fragmentation in DIS - FS 77

DIS reaction $e + N \to e + h + X$

vs hadronic reaction H + N ⟶ h +X

$\alpha_h = (E_h - p_{3\,h})/m_N$ light-cone fraction of N's p_ carried by h

$\alpha_h = x_F$ for hadronic reaction; Feynman scaling: $\frac{1}{\sigma_{inel}(HN)} \frac{d\sigma(H + N \to h + X)}{dx_F} = f^{H \to h}(x_F)$

DIS kinematics: $\alpha_h \leq (1 - x)$

Smooth - hard - soft connection? Possible only for $x \ll 1, \alpha_h \ll 1 - x$

Indeed diffraction, neutron production are similar, as well as $f_g^{p \to n}(x_F) \approx f_q^{p \to n}(x_F)$

Finite x - new interesting physics of what happens with the system when one of the "essential" partons is removed.

To remove trivial kinematic effect of $\alpha_h \leq (1-x)$ define

$$z \equiv x_F = \alpha_h/(1-x), max(z) = 1$$

Expectations (FS77, 81): faster decrease with z with increase of x

$$f_q^{p\to n(\Delta)}(z,x) \propto (1-z)^{n(x)}$$

| | |
|---|---|
| diffraction | $n(x < 0.01) \sim -1$ |
| constituent $qq\bar{q}q$ | $n(0.01 < x < 0.15) \sim 0$ |
| constituent qq | $n(0.15 < x < 0.4) \sim 1$ |
| perturbative qq | $n(0.4 < x) > 1(?)$ |

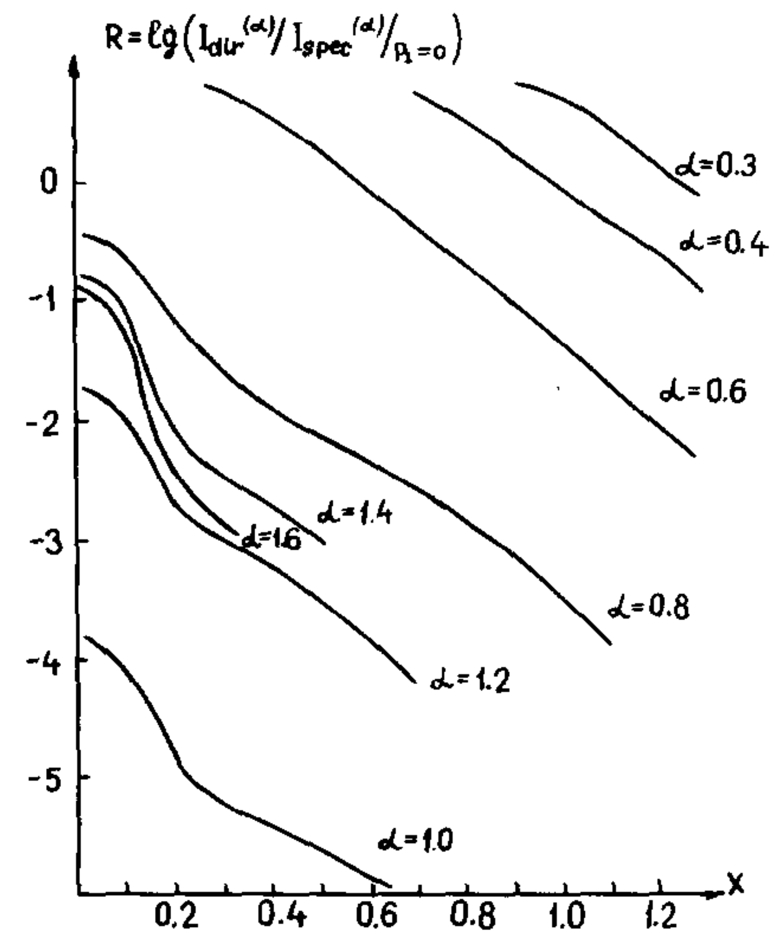
# Important implications for tagging in eD / eA

*Nucleons produced in eN scattering at x > 0.25 have large longitudinal momenta in the target rest frame.*

*Consider x=0.3. Expectation* $\langle z \rangle \leq 0.5$ ➠ $\langle\alpha\rangle = (1-x)\langle z\rangle \sim 0.35$

$$\langle p_N(longit.)\rangle = m_N \frac{1-\alpha^2}{2\alpha} \geq 1.2 GeV/c$$

Nucleus fragments dominate for backward region and for large enough x even in a part of the forward region !!!



Deuteron — Searching for non-nucleonic effects

## Tagged structure functions

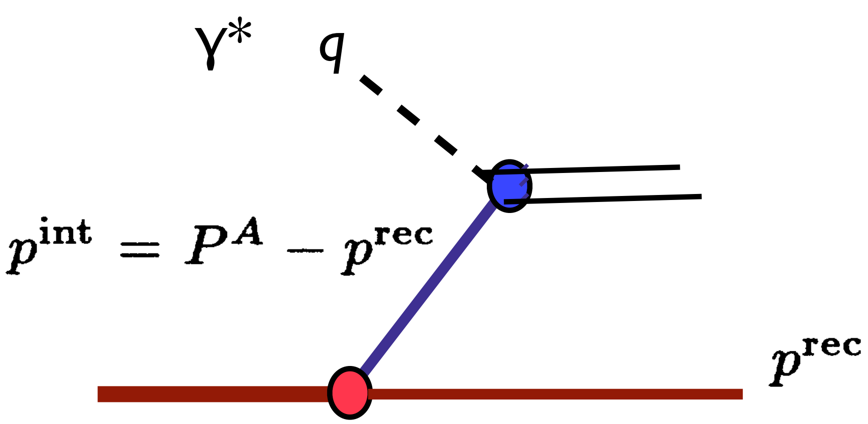
$$e + D \to e + \text{"}backward\,proton\text{"} + X$$

$$F_{2\,bound\,neutron}(x/(2-\alpha_{spect}), \Delta m^2)$$

off shellness of interacting nucleon

$$\Delta m^2 = p_{int}^2 - m^2 = (m_A - p_{spect})^2 - m^2.$$

$$\delta(p, E_{exc}) = \left(1 - \frac{p_{int}^2 - m^2}{2\Delta E}\right)^{-2}$$




EMC effect $\propto p^2_{spect}$ and significant for $x/(2-\alpha_{spect}) \geq 0.5$

# *DIS: EMC effect and x > 1*

EMC effect cannot be explained in many nucleon approximation without introducing baryon charge and /or momentum non-conservation using convolution approximation:

$$F_{2A}(x,Q^2)=\int \rho_A^N(\alpha,p_t)F_{2N}(x/\alpha)\frac{d\alpha}{\alpha}d^2p_t$$

Since spread in α due to Fermi motion is modest ⇒ do Taylor series expansion in convolution formula in (1- α): α= 1+ (α-1)

Fermi motion

$$R_A(x,Q^2)=1-\frac{\lambda_A x F_N'(x,Q^2)}{F_N(x,Q^2)}+\frac{xF_{2N}'(x,Q^2)+(x^2/2)F_{2N}''(x,Q^2)}{F_{2N}(x,Q^2)}\cdot\frac{2(T_A-T_{^2H})}{3m_N}$$

$$F_{2N}\propto(1-x)^n, n\approx 2(JLAB) \qquad R_A(x,Q^2)=1-\frac{\lambda_A n x}{1-x}+\frac{xn\left[x(n+1)-2\right]}{(1-x)^2}\cdot\frac{(T_A-T_{^2H})}{3m_N}$$

$$n\approx 3(Leading\, twist)$$

small negative for x <(n+1)/2
> 0 and rapidly growing for x > (n+1)/2

EMC effect is unambiguous evidence for presence of non nucleonic degrees of freedom in nuclei. The question - what are they?

Possible scenario of the EMC effect (FS83): large deformations for rare configurations of nucleons responsible for large x with deformation mostly for large nucleon momenta

Combination of two ideas:

(a) Quark configurations in a nucleon of a size << average size (PLC) should interact weaker than in average. Application of the variational principle indicates that probability of such configurations in nucleons is suppressed.

(b) Quarks in nucleon with $x>0.5$ --0.6 belong to small size configurations (3 q) with strongly suppressed pion field - while pion field is critical for SRC especially D-wave.

Introducing in the wave function of the nucleus explicit dependence of the internal variables we find for weakly interacting configurations in the first order perturbation theory using closer we find

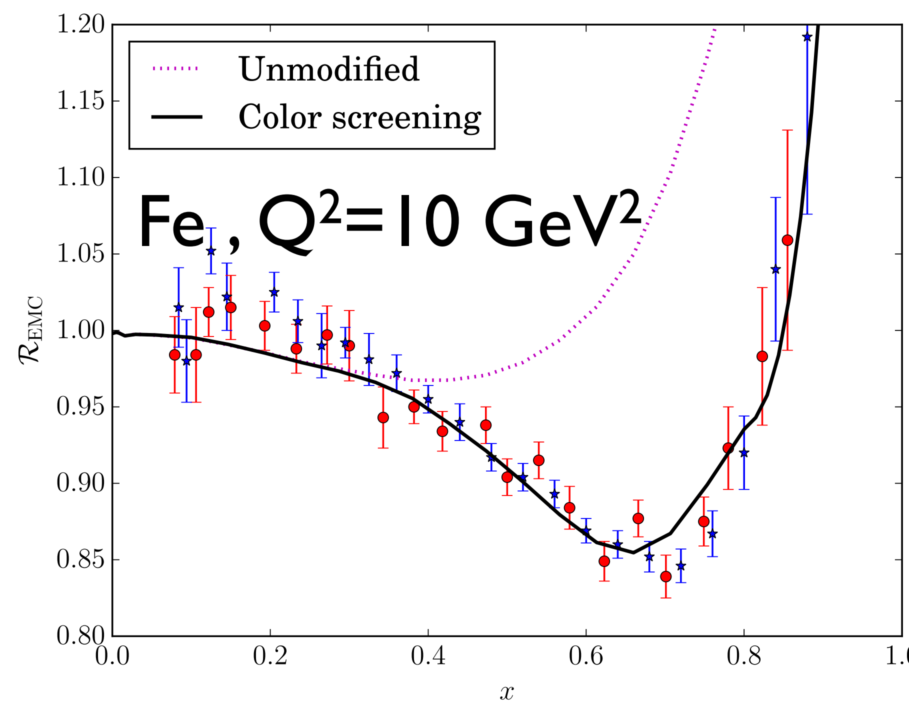
$\tilde{\psi}_A(i) \approx \left(1 + \sum_{j\neq i} \frac{V_{ij}}{\Delta E}\right) \psi_A(i)$ where $\Delta E \sim m_{N^*} - m_N \sim 600 - 800\, MeV$ average excitation energy in the energy denominator. Using equations of motion for $\psi_A$ the momentum dependence for the probability to find a bound nucleon, $\delta_A(p)$ with momentum $p$ in a PLC was determined for the case of two nucleon correlations and mean field approximation. In the lowest order

$$\delta_A(p) = 1 - 4(p^2/2m + \epsilon_A)/\Delta E_A$$

After including higher order terms we obtained for SRCs and for deuteron:

$$\delta_D(\mathbf{p}) = \left(1 + \frac{2\frac{\mathbf{p}^2}{2m} + \epsilon_D}{\Delta E_D}\right)^{-2}$$

Simple parametrization of suppression: no suppression $x \leq 0.45$, by factor $\delta_A(k)$ for $x \geq 0.65$, and linear interpolation in between




Freese, Sargsian, MS 14

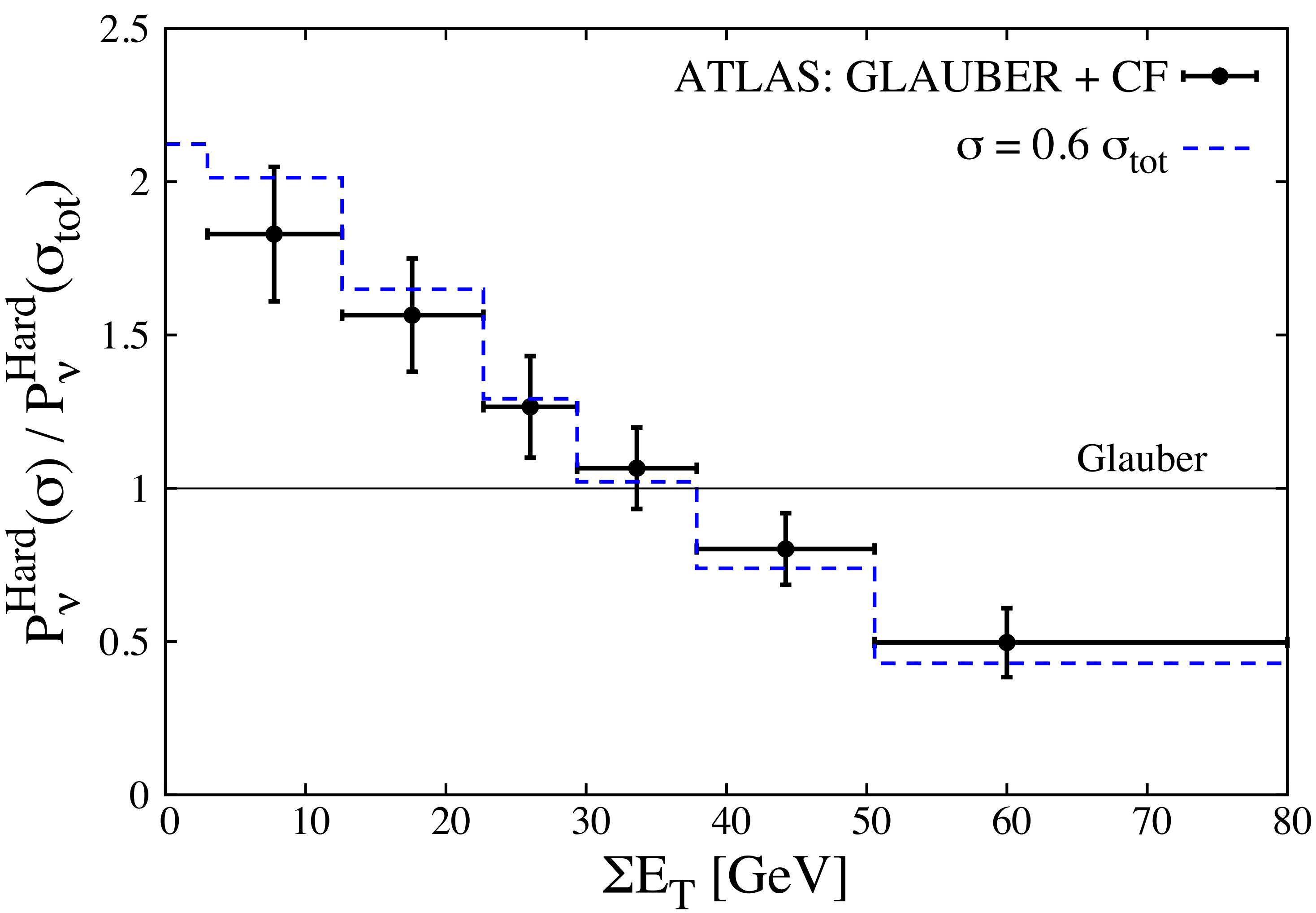
Dependence of suppression we find for small virtualities: $1-c(p^2_{int}-m^2)$

seems to be very general for the modification of the nucleon properties. Indeed, consider analytic continuation of the scattering amplitude to $p^2_{int}-m^2=0$ . In this point modification should vanish.
Our quantum mechanical treatment automatically took this into account. So similar dependence e.g. for $G_E/G_M$ for bound nucleon (consistent with Jlab data)

# *Critical test we suggested in 1983:*

pA scattering with trigger on large x hard process. If large x corresponds to small sizes hadron production will be suppressed. In other words - trigger for large activity - suppression of events with large x.

ATLAS and CMS report the effect of such kind. Our analysis (M.Alvioli, B.Cole. LF, . D.Perepelitsa, MS) suggests that for x~ 0.6 the transverse size of probed configurations is a factor of 2 smaller than average.

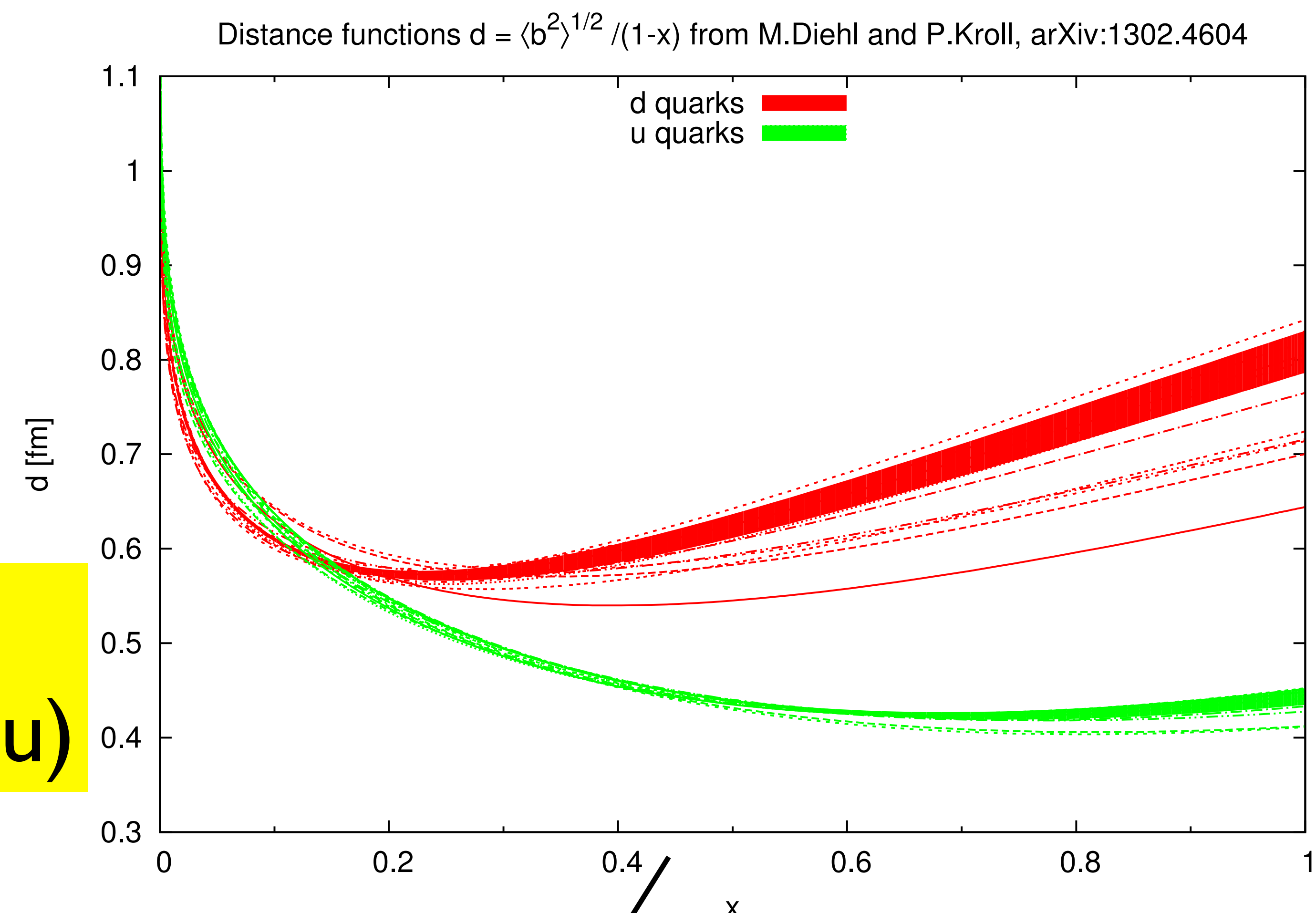



Relative probability of hard processes corresponding to a small σ selection as a function of $\Sigma E_T$ .ATLAS data are for x = 0.6 with black crosses taking into account the difference between number of wounded nucleons calculated in the Glauber and CF approaches

# Separating EMC effect using flavor tagging using forward $\pi^+$ and $\pi^-$

## Is effect the same for u and d quarks in the bound proton/neutron?

Analysis of Diehl and Kroll of nucleons GPDs based on the data on nucleon form factors



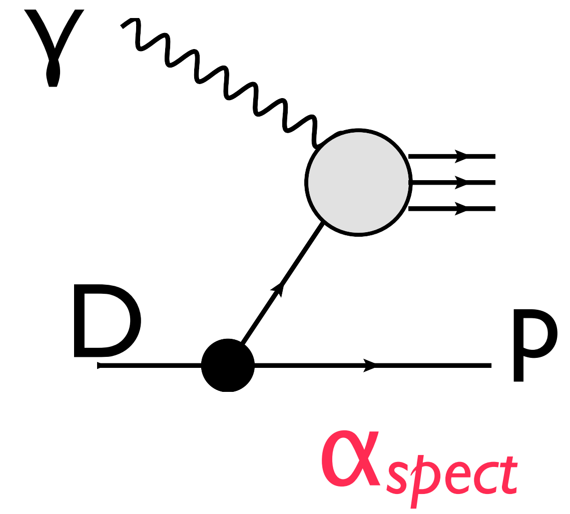

u(x>0.4) (ud) transverse size is much smaller than for d(x>0.4) (uu)

Color screening model of the EMC effect (LF83-85): smaller configurations, larger EMC effect.

For neutron EMC only for d - quarks , hence effect for $F_{2n}$ is smaller than for $F_{2p}$

*Critical test of the origin of EMC effect in DIS (FS85)*

*Tagging of proton and neutron in* $e+D \rightarrow e+ N_{\alpha_{spect}>1} + X$.




EIC - nucleon along deuteron or fixed target-- backward nucleon

*modification is expected to increase quadratically with tagged nucleon momentum. It is applicable for searches of the form factor modification in (e,e'N) as well.*

$$1 - F_{2N}^{bound}(x/\alpha, Q^2)/F_{2N}(x/\alpha, Q^2) = f(x/\alpha, Q^2)(m^2 - p_{int}^2)$$

Here $\alpha = 2 - \alpha_{spect}$

Expect large effect only for $x/\alpha \geq 0.5$.

# Additional handles

EMC effect for u and d quarks in proton/ neutron - best using forward pions - natural kinematics for collider. No EMC effect for d -quarks in protons?

Deuteron polarization

EMC effect may differ for S and D waves - different role of single and two pion exchange - which couple to small configurations differently

Different EMC effect for

$$\lambda_u = \lambda_D/2 \qquad \lambda_d = \lambda_D/2$$

$$\lambda_u = -\lambda_D/2 \qquad \lambda_d = -\lambda_D/2$$

Since x are large, moderate collider energies are preferable.

*Interesting possibility - EMC effect maybe missing some significant deformations which average out when integrated over the angles*

A priori the deformation of a bound nucleon can also depend on the angle φ between the momentum of the struck nucleon and the reaction axis as

$$d\sigma/d\Omega/ < d\sigma/d\Omega >= 1 + c(p,q).$$

Here <σ> is cross section averaged over φ and dΩ is the phase volume and the factor c characterizes non-spherical deformation.

Such non-spherical polarization is well known in atomic physics *(discussions with H.Bethe, V.Gribov)*. Contrary to QED detailed calculations of this effect are not possible in QCD. However, a qualitatively similar deformation of the bound nucleons should arise in QCD. One may expect that the deformation of bound nucleon should be maximal in the direction of radius vector between two nucleons of SRC.

# Looking for Δ 's, 6q....

electron beams - SIDIS - Advantage - cross section for e Δ can be estimated with a reasonable accuracy in difference from

$$e+^2H \rightarrow e+ \; forward \; \Delta^{++} + \; slow \; \Delta^{-}$$

spectator mechanism

$$\sigma(e^2H \rightarrow e+\Delta+X) = \sigma(x' = \frac{x}{(2-\alpha)}, Q^2)\frac{\Psi^2_{\Delta\Delta}(\alpha, k_t)}{(2-\alpha)}$$

$$\alpha_\Delta = \frac{\sqrt{m_\Delta^2 + p^2} - p_3}{m_d/2}$$

p is target rest frame momentum of isobar

$\alpha$=1, $p_t$=0 corresponds to $p_3$ ~ 300 MeV/c forward - for good acceptance need to detect slow protons and pions. Easy for collider.

Competing mechanism - Δ's from nucleons=direct mechanism

$$\left.\frac{\sigma^{1D/\Delta}}{dx\, dy\, \frac{d\alpha}{\alpha}\, d^2k_t}\right|_{direct} = \int \frac{d\beta}{\beta}\, d^2p_t\, \rho_D^N(\beta, p_t) \times \tag{18}$$

$$\times \frac{d\sigma^{1N/\Delta}}{dx\, dy\, d\alpha/\alpha\, d^2k_t}\left(\beta E_1, x/\beta, y, Q^2, \frac{\alpha}{\beta - x}, k_t - \frac{\alpha}{\beta}\, p_t\right)$$

For scattering of stationary nucleon

$$\alpha_\Delta < 1 - x$$

*Also there is strong suppression for production of slow Δ's - larger x stronger suppression*

$$x_F = \frac{\alpha_\Delta}{1-x} \qquad \sigma_{eN\to e+\Delta+X} \propto (1-x_F)^n, n \geq 1$$

Numerical estimate for $P_{\Delta\Delta}$ =0.4%

$$\left. \frac{\sigma^{1D/\Delta}}{dx\ dy\ \frac{d\alpha}{\alpha}\ d^2k_t} \right|_{direct} \Bigg/ \left. \frac{\sigma^{1D/\Delta}}{dx\ dy\ \frac{d\alpha}{\alpha}\ d^2k_t} \right|_{spect} < 0.1$$

Tests possible to exclude rescattering mechanism: πN→Δ FS90

*For the deuteron one can reach sensitivity better than 0.1 % for* ΔΔ especially with quark tagging *(FS 80-90)*

Δ-isobars are natural candidate for most important nonnucl. degrees of freedom

Large energy denominator for NN →NΔ transition ➡ Δ's **predominantly in SRCs**

Δ 's in 3He on 1% level from Bjorken sum rule for A=3 - Guzey &F&S 96

## Expectations during EMC effect rush

TABLE II. Pion excess and Δ fraction in nuclear matter (NM) and nuclei.

| | $\langle \delta n^{\pi} \rangle / A$ | $\langle n^{\Delta} \rangle / A$ |
|---|---|---|
| NM, $k_F = 0.93$ | 0.08 | 0.03 |
| NM, $k_F = 1.13$ | 0.12 | 0.04 |
| NM, $k_F = 1.33$ | 0.18 | 0.06 |
| $^2$H | 0.024 | 0.005 |
| $^3$He | 0.05 | 0.02 |
| $^4$He | 0.09 | 0.04 |
| $^{27}$Al | 0.11 | 0.04 |
| $^{56}$Fe | 0.12 | 0.04 |
| $^{208}$Pb | 0.14 | 0.05 |

ruled out by Drell - Yan data

Friman, Pandharipande, WIringa 1983

$$\frac{P(\Delta)}{P_{SRC}(N)} \sim \frac{0.04}{0.2}$$ ~ 0.2

Too much ?

for x> 0.1 very strong suppression of two step mechanisms (FS80)

is confirmed by neutrino study of $\Delta$-isobar production off D

Best limit on probability of $\Delta^{++}\Delta^{-}$ component in the deuteron $< 0.2\%$

Polarized deuteron extra bonus: $\Delta^{++}\Delta^{-}$ mostly in D-wave -- hence large spin effects

An analysis has been made of 15 400 $\nu$–d interactions in order to find a $\Delta^{++}(1236)$–$\Delta^{-}(1236)$ structure of the deuteron. An upper limit of 0.2% at 90% CL is set to the probability of finding the deuteron in such a state.

**SEARCH FOR A Δ(1236)–Δ(1236) STRUCTURE OF THE DEUTERON**

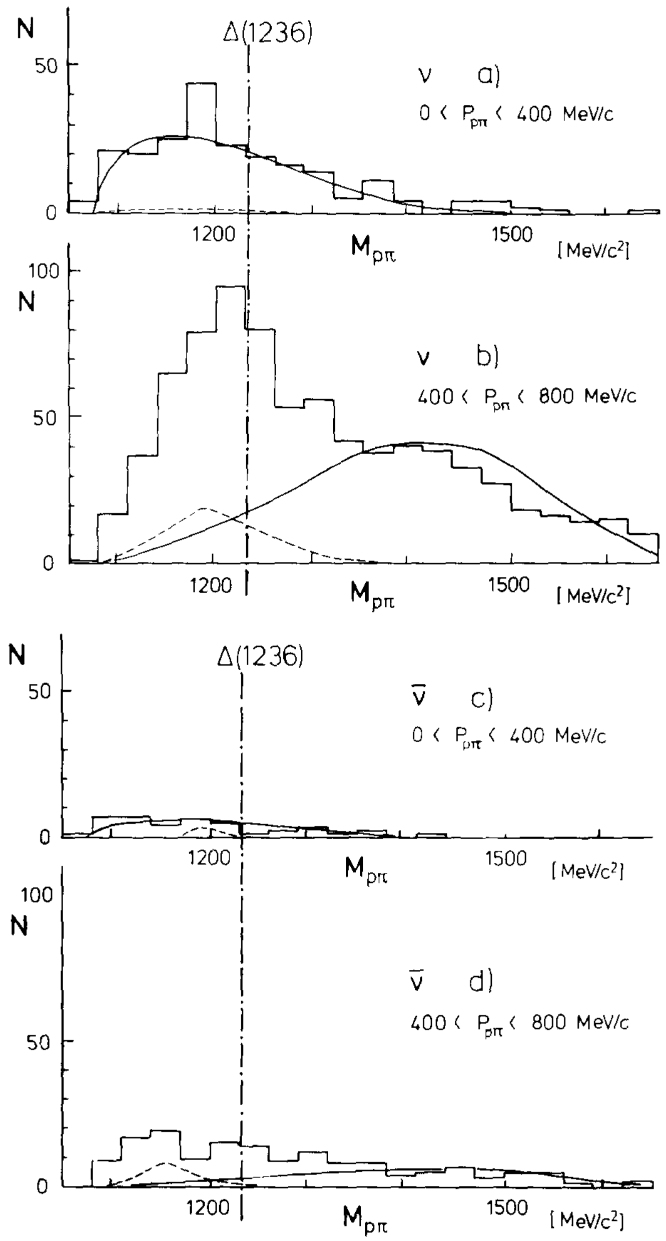



Fig. 1. Effective mass distributions of $p\pi^+$ combinations for $\nu$ (top) and $\bar{\nu}$ (bottom) interactions. The distributions are presented for two intervals of the combined $p\pi^+$ momentum: 0–400 and 400–800 MeV/$c$. The chosen bin size is 30 MeV/$c^2$ = $\Gamma(1235)/4$. The solid lines show the calculated background of combinations of a pion with a spectator proton. The dotted lines show prompt $p\pi^+$ production as obtained from $\nu/\bar{\nu}$–hydrogen data.

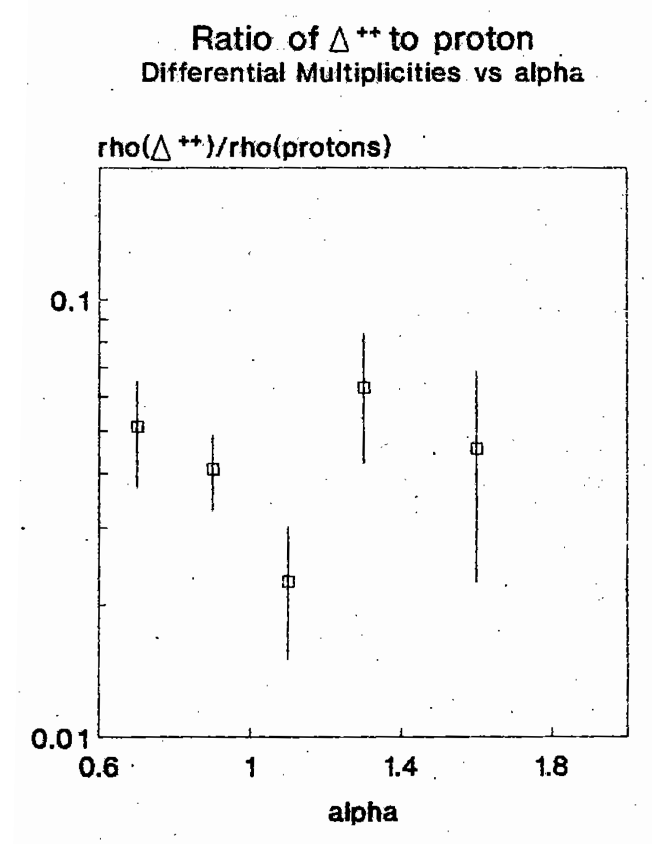
# Is there a positive evidence for Δ's in nuclei?

- Indications from DESY AGRUS data (1990) on electron - air scattering at $E_e$=5 GeV (Degtyarenko et al).

  Measured $\Delta^{++}/p$, $\Delta^0/p$ for the same light cone fraction alpha.

$$\frac{\sigma(e+A\to\Delta^0+X)}{\sigma(e+A\to\Delta^{++}+X)}=0.93\pm0.2\pm0.3$$

$$\frac{\sigma(e+A\to\Delta^{++}+X)}{\sigma(e+A\to p+X)}=(4.5\pm0.6\pm1.5)\cdot10^{-2}$$




- Bjorken sum rule for A=3

  One needs to include Δ's in the A=3 system on the level of 1% to remove the discrepancy with 3N model (Guzey, FS 94)

Perfect kinematics for EIC studies - Δ's along nucleus

# Conclusions

Hard inclusive/ exclusive experiments  with polarized deuteron can

- Critical test 2 nucleon dynamics description - LC vs VN
- Understanding of isospin &  spin dependence of the EMC effect
- Discovering /putting limits on baryonic nonnucleonic degrees of freedom in SRCs