SEMI-INCLUSIVE PROCESSES

TAGGED STRUCTURE FUNCTIONS

general class of **A(e, e' (A-1))X** processes at low values of the momentum of the residual nucleus

$$|\vec{p}_{A-1}| < 0.3 \text{ GeV/c}$$

AIM

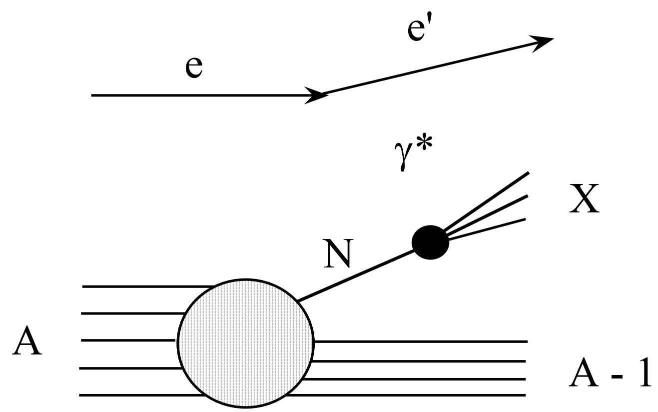
to show that for **A = 2** semi-inclusive $^2H(e, e' p)X$ processes could be an interesting tool to extract model-independent information on:

the **neutron structure function** $F_2^n(x, Q^2)$ both in the deep-inelastic regime and in the nucleon-resonance production regions.

PLB 387 (1996); Proc. of the Workshop "Future Physics at HERA" (nucl-th/9608053); NPA 631 (1998);
Proc. of the Workshop "Exclusive Processes …", JLAB (nucl-th/9910020).

S.Simula – 14/05/02

SPECTATOR MECHANISM



$$\frac{d^4\sigma}{dE_{e'}\; d\Omega_{e'}\; d\vec{p}_{A-1}} = M|\vec{p}_{A-1}|\, n_N^{(0)}(|\vec{p}_{A-1}|)\, \frac{F_2^N(x_{sp}, Q^2)}{x_{sp}}\, D^N(x, Q^2; \vec{p}_{A-1})$$

$\vec{p}_N = -\vec{p}_{A-1} \implies$ tagging of the momentum of the struck nucleon;

$n_N^{(0)}(|\vec{p}_N|)$ = nucleon momentum distribution corresponding to the ground-to-ground state transition;

$F_2^N(x_N, Q^2)$ = struck nucleon structure function;

$D^N(x, Q^2; \vec{p}_{A-1})$ = kinematical factor depending also upon the ratio of longitudinal to transverse cross section off the nucleon, $R_{L/T}^N(x_{sp}, Q^2)$

The variable x_{sp} is defined as

$$x_{sp} = \frac{Q^2}{Q^2 + M^{*2} - M^2} = \frac{Q^2}{Q^2 + (\nu + M_A - E_{A-1})^2 - (\vec{q} - \vec{p}_{A-1})^2 - M^2}$$

with $E_{A-1} \equiv \sqrt{M_{A-1}^2 + |\vec{p}_{A-1}|^2}$, and it is a combination of both electron and hadron variables.

- define:

a) the reduced semi-inclusive nuclear response function as

$$F^{(s.i.)}(x, Q^2; \vec{p}_{A-1}) \equiv \frac{1}{D^N(x, Q^2; \vec{p}_{A-1})\Big|_{R^N_{L/T}=0}} \frac{d^4\sigma}{dE_{e'}\, d\Omega_{e'}\, d\vec{p}_{A-1}}$$

b) the spectator function as

$$F^{(sp)}(x_{sp}, Q^2; |\vec{p}_{A-1}|) \equiv M|\vec{p}_{A-1}|\, n_N^{(0)}(|\vec{p}_{A-1}|) \frac{F_2^N(x_{sp}, Q^2)}{x_{sp}}$$

One gets

$$F^{(s.i.)}(x, Q^2; \vec{p}_{A-1}) = F^{(sp)}(x_{sp}, Q^2; |\vec{p}_{A-1}|)\, \tilde{D}^N(x, Q^2; \vec{p}_{A-1})$$

with the kinematical factor given by

$$\tilde{D}^N(x, Q^2; \vec{p}_{A-1}) \equiv \frac{1}{D^N(x, Q^2; \vec{p}_{A-1})\Big|_{R^N_{L/T}=0}} D^N(x, Q^2; \vec{p}_{A-1})$$

***** SPECTATOR SCALING *****

if $\tilde{D}^N \cong 1$, at fixed value of $|\vec{p}_{A-1}|$ and Q^2 the reduced semi-inclusive nuclear response

$$F^{(s.i.)}(x, Q^2; \vec{p}_{A-1})$$

does not depend on x and the detection angle θ_{A-1} separately, but only on one variable, x_{sp}.

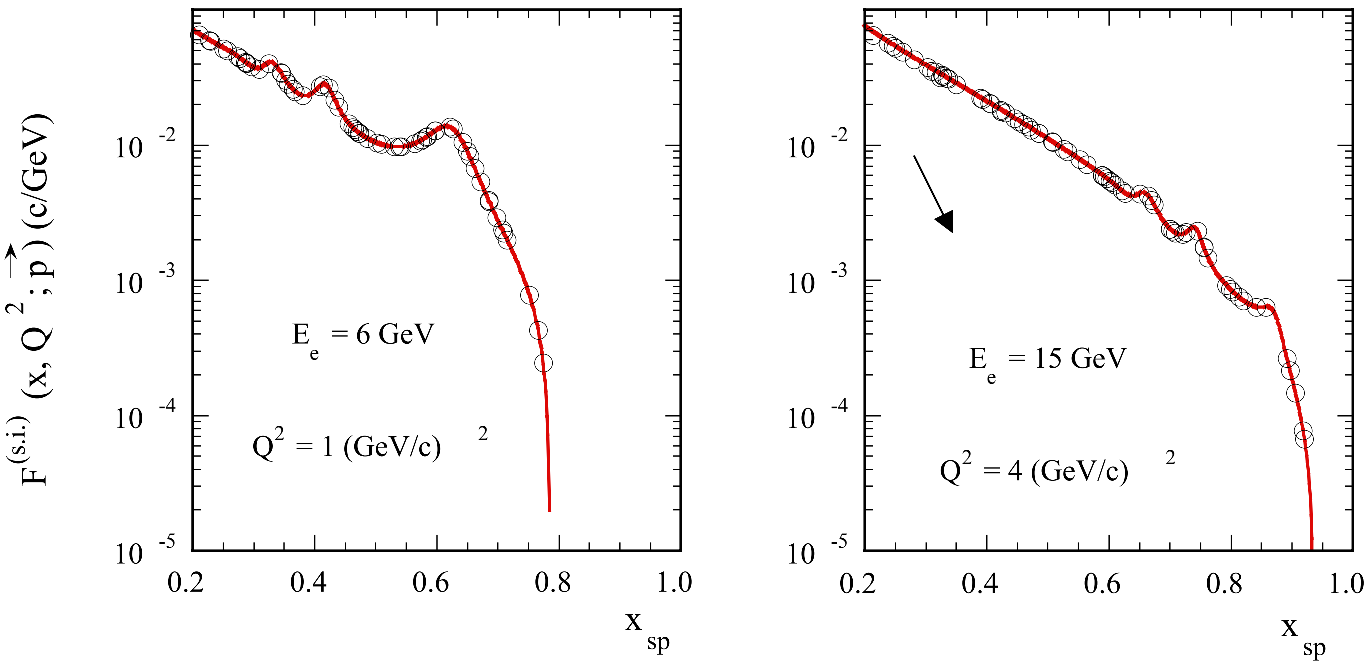
- **Bj limit**: $R^N_{L/T} \xrightarrow[Bj]{} 0 \quad \Rightarrow \quad \tilde{D}^N \xrightarrow[Bj]{} 1$

- **finite Q2**: calculations have been performed for several semi-inclusive processes, like

  - ^{2}H(e, e' p)X and ^{2}H(e, e' n)X;
  - ^{4}He(e, e' ^{3}He)X and ^{4}He(e, e' ^{3}H)X; $\Leftarrow$
  - ^{12}C(e, e' ^{11}C)X and ^{12}C(e, e' ^{11}B)X.

parametrization of SLAC data used as input for $F_2^N(x, Q^2)$

$^{2}H(e, e' p)X$



- spectator scaling fulfilled within few % at finite Q2; ———— $F^{(sp)}(x_{sp}, Q^2; |\vec{p}|)$

- little model dependence in $n^{(^2H)}(|\vec{p}|)$ when $|\vec{p}| < 0.3$ (GeV/c) (one-pion-exchange tail in the NN interaction)

- spectator scaling works both in deep-inelastic and in the nucleon-resonance production region;

reaction mechanism ⇔ scaling property

- the observation of the spectator scaling represents a model-independent test of the dominance of the spectator mechanism (see also later on);

the occurrence of a scaling property does not depend on the particular value of the scaling function;

- in the spectator-scaling regime the neutron structure function can be extracted with small uncertainty due to nuclear effects.

- **consistency check**:

$^{2}H(e, e' n)X$:

$$F^{(s.i.)} \cong F^{(sp)} = M|\vec{p}|\, n^{(^2H)}(|\vec{p}|) \frac{F_2^p(x_{sp}, Q^2)}{x_{sp}}$$

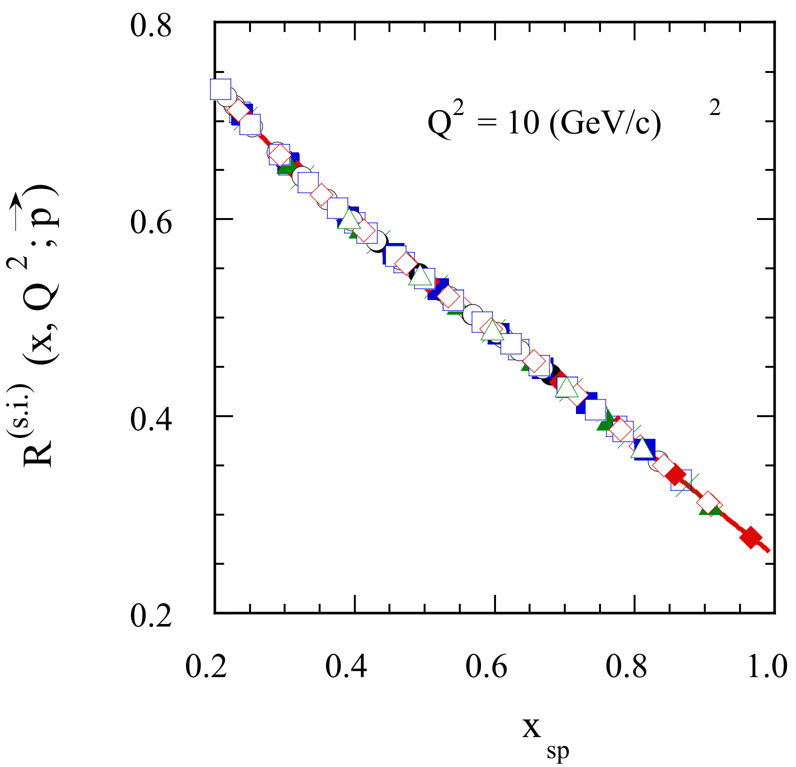
little model dependence for $|\vec{p}| < 0.3$ (GeV/c)

known from experiments

RATIO OF SEMI-INCLUSIVE CROSS SECTIONS

$$R^{(s.i.)}(x, Q^2; \vec{p}) = \frac{d^4\sigma[{}^2H(e, e' p)X]}{d^4\sigma[{}^2H(e, e' n)X]} \xrightarrow[\text{spect. scal.}]{} \frac{F_2^n(x_{sp}, Q^2)}{F_2^p(x_{sp}, Q^2)}$$

- more general scaling property $\Longrightarrow$ at fixed Q^2 the ratio of semi-inclusive cross sections does not depend upon x and $\vec{p}$ separately, but only on one variable, x_{sp}, and it is independent of $n^{({}^2H)}(|\vec{p}|)$



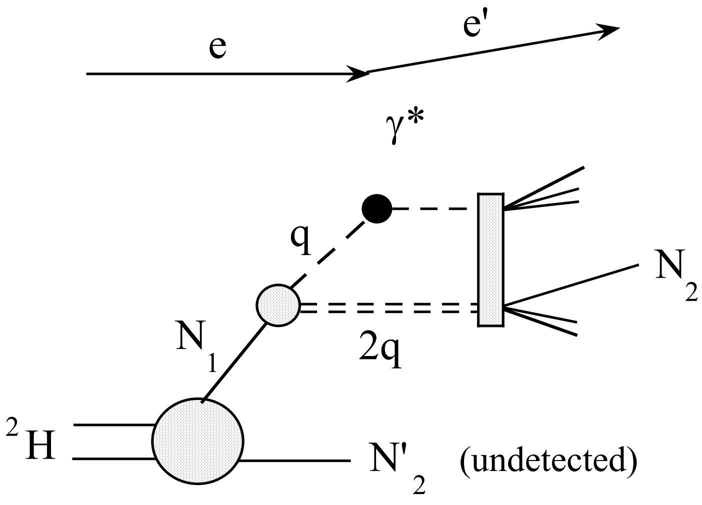
COMPETITIVE REACTION MECHANISMS

- nucleon production from fragmentation processes;
- effects from exotic components (6q bags);
- breaking down of the impulse approximation;
- off-shell deformation of F_2^N.

MAIN RESULTS

- backward nucleon production ($\theta_p > 90^o$) suitable for extracting almost model-independent information on the neutron structure function;
- the semi-inclusive cross section ratio $R^{(s.i.)}$ can yield almost model-independent information on F_2^n / F_2^p provided $|\vec{p}| \sim 0.1 \div 0.2$ GeV/c , while possible off-shell deformation of F_2^N can be investigated at $|\vec{p}| > 0.3$ GeV/c.

NUCLEON PRODUCTION FROM FRAGMENTATION PROCESSES



current fragmentation $\Longrightarrow$ mainly fast particles

target fragmentation $\Longrightarrow$ slow particles

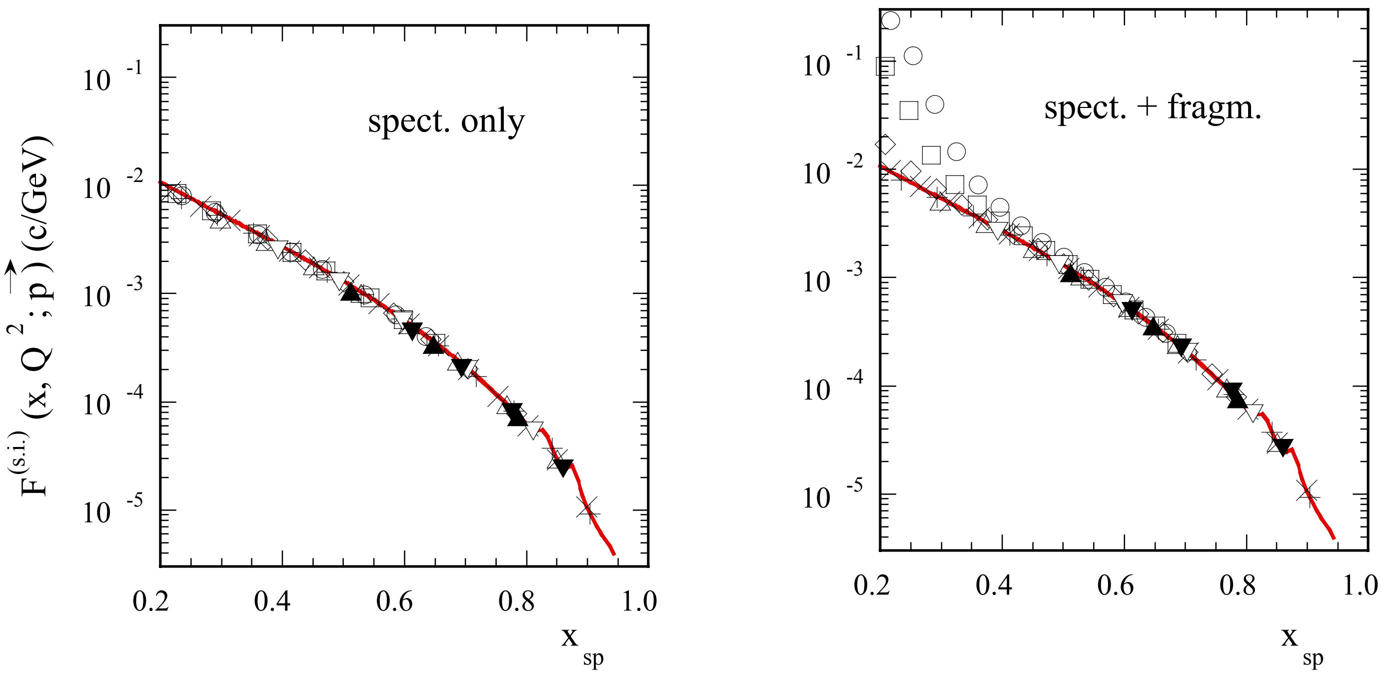
$$F_2^{(^2H)}\left(x, Q^2; \vec{p}_2\right)\Big|_{frag.} \xrightarrow[Bj]{} \sum_{N_1=n,p} \int_x^2 dz_1\, z_1 f^{N_1}(z_1)\, F_2^{N_1(N_2)}\left(\frac{x}{z_1}, \frac{z_2}{z_1 - x}; \vec{p}_{2\perp}\right)$$

$f^{N_1}(z_1)$ = light-cone momentum distribution of the struck nucleon;

$F_2^{N_1(N_2)}$ = nucleon fragmentation structure function.

- fixed value of $|\vec{p}|$ = 0.5 GeV/c and Q^2 = 10 $(GeV/c)^2$;
- x varies in 0.20 ÷ 0.95 and θ_p in 10° ÷ 170°.

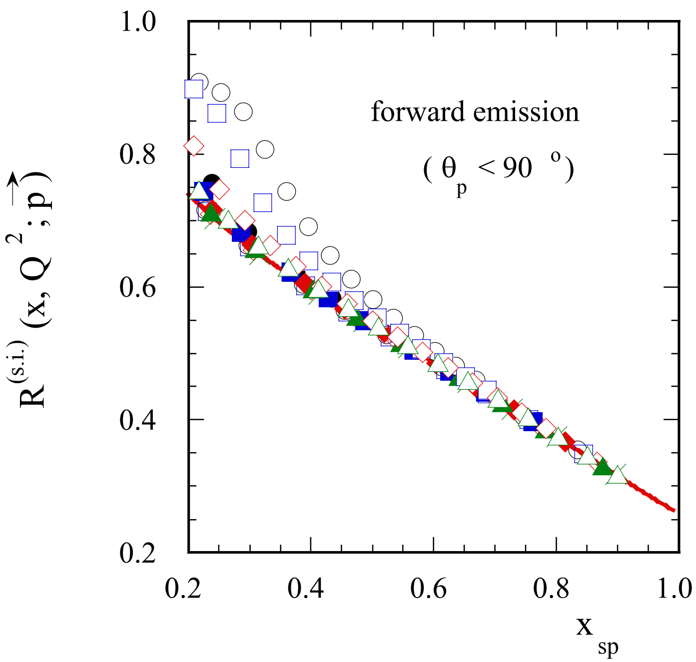
$^2H(e, e' p)X$

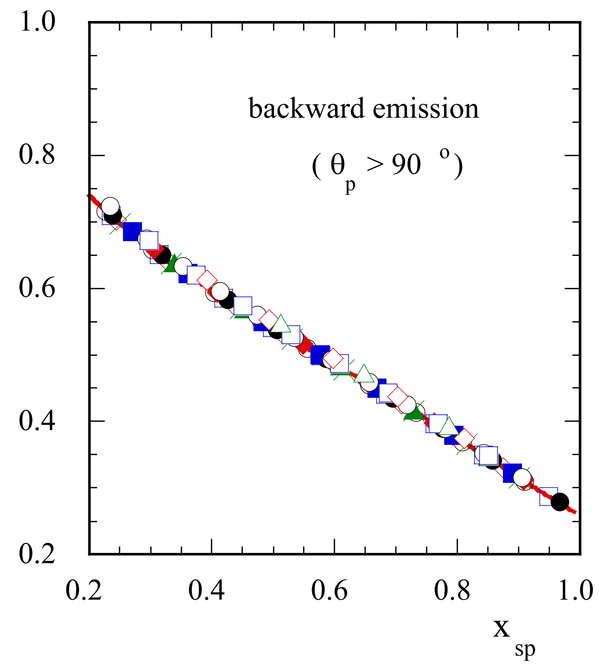


markers : $F^{(s.i.)}(x, Q^2; \vec{p})$ —— $F^{(sp)}(x_{sp}, Q^2; |\vec{p}|)$

- fixed value of $Q^2 = 10\ (\mathrm{GeV}/c)^2$ and $|\vec{p}| = 0.1, 0.3, 0.5$ GeV/c;
- x varies in $0.20 \div 0.95$ and θ_p in $10^o \div 170^o$

$^2H(e, e'\, p)X\ /\ ^2H(e, e'\, n)X$





markers : $R^{(s.i.)}(x, Q^2; \vec{p})$

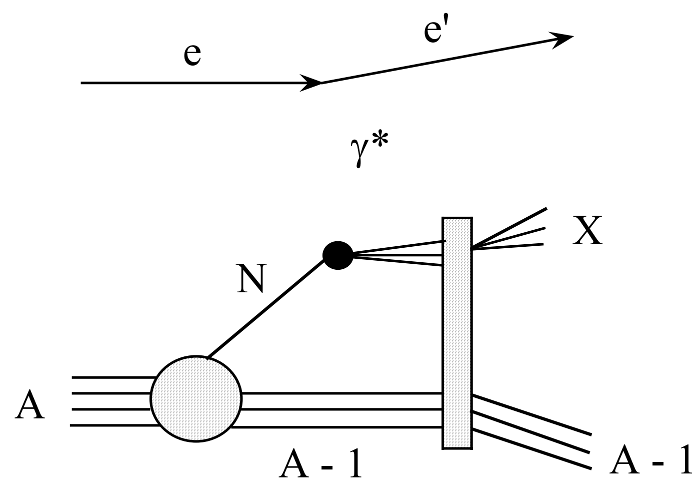
——— $F_2^n(x_{sp}, Q^2) / F_2^p(x_{sp}, Q^2)$

- fragmentation processes violate the spectator scaling;

- nucleon production from fragmentation relevant only at $x_{sp} < 0.4$ and for forward nucleon emission ($\theta_p < 90^o$);

- backward nucleon production ($\theta_p > 90^o$) suitable for extracting the neutron to proton structure function ratio F_2^n / F_2^p .

FINAL STATE INTERACTIONS



distortion of the energy spectrum and angular distribution of the emitted fragments $\Longrightarrow$ loss of the tagging of the momentum of the struck nucleon;

$\Rightarrow$ • the choice of backward kinematics ($\theta_p > 90^o$) and low-momentum detected nucleon, i.e. the probe of large n-p interdistances in the deuteron, is expected to minimize FSI effects;

• FSI effects are expected also to cancel out (at least partially) in the cross section ratio $R^{(s.i.)}$;

CONCLUSIONS

- emission of slow nuclear fragments in semi-inclusive processes A(e, e' (A-1))X can provide relevant information on the nucleon structure function;

- within the spectator mechanism the semi-inclusive cross section exhibits a peculiar property, the spectator scaling:

at fixed value of $|\vec{p}_{A-1}|$ and Q^2 the semi-inclusive cross section does not depend on *x* and the detection angle θ_{A-1} separately, but only on one variable, x_{sp}

$$\frac{\sigma[A(e,e'(A-1)X)]}{kinem.\quad factor} \xrightarrow{spect.\quad scal.} M|\vec{p}_{A-1}|\, n_N^{(0)}(|\vec{p}_{A-1}|)\, \frac{F_2^N(x_{sp},Q^2)}{x_{sp}}$$

- the spectator variable x_{sp} is a combination of both electron and hadron variables:

$$x_{sp} = \frac{Q^2}{Q^2 + M^{*2} - M^2} = \frac{Q^2}{Q^2 + (\nu + M_A - E_{A-1})^2 - (\vec{q} - \vec{p}_{A-1})^2 - M^2}$$

- the experimental observation of the spectator scaling is a model-independent test of the dominance of the spectator mechanism;

- spectator scaling can hold both in the DIS regime and in the nucleon-resonance production regions as well as in the quasi-elastic regime;

- within the spectator scaling information on the nucleon structure function can be extracted with small uncertainty due to nuclear effects;

- competitive processes:

- fragmentation (only for A=2);

- final state interactions;

$\Longrightarrow$ expected to be negligible for **backward** emission ($\theta_{A-1} > 90^o$);

- the semi-inclusive cross section ratio $R^{(s.i.)}$ can yield almost model-independent information on F_2^n / F_2^p provided $|\vec{p}_{A-1}| \sim 0.1 \div 0.2$ GeV/c, while possible off-shell deformation of F_2^N can be investigated at $|\vec{p}_{A-1}| > 0.3$ GeV/c.