Data mining - directions for the further studies - theorist's view

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Data mining meeting, MIT, August 9, 14

Outline

- *Towards quantitative measurements of 2N correlations*
- *How to observe directly of 3N correlations*
- *Discovering nonnucleonic degrees of freedom in nuclei*

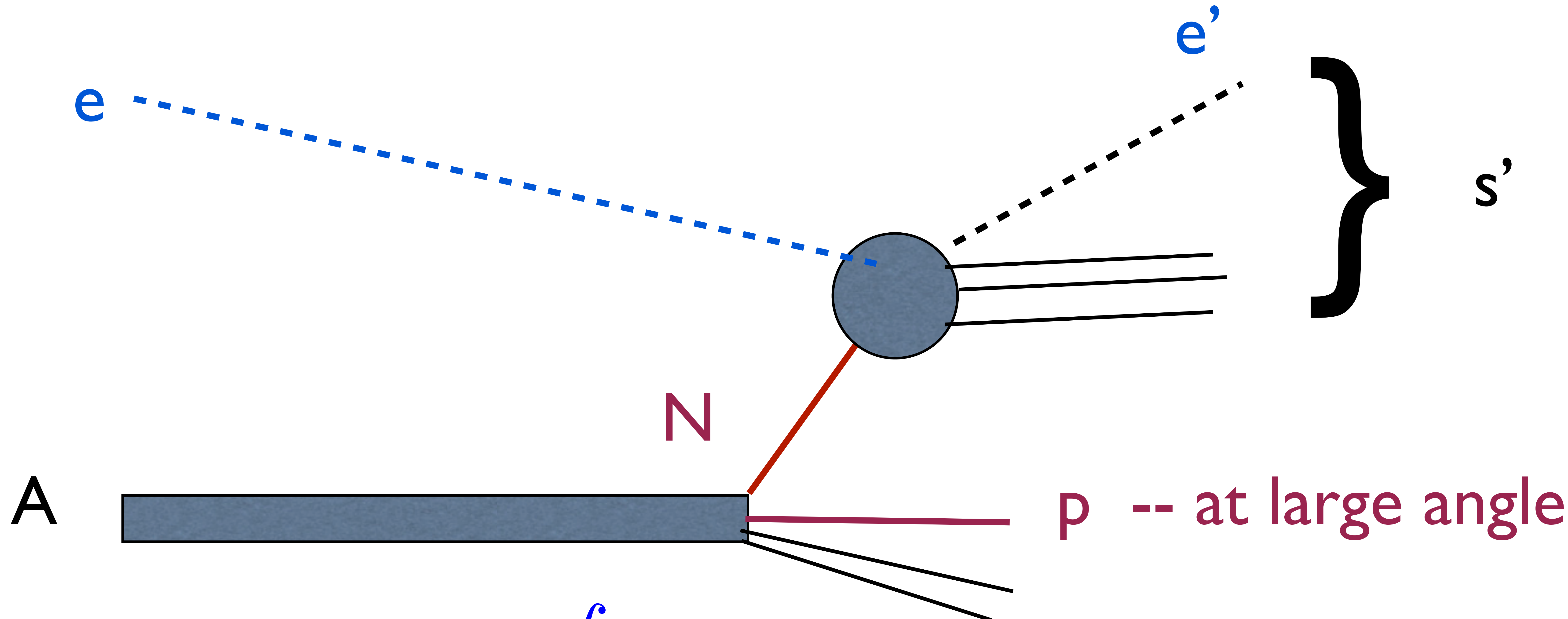
Towards more quantitative studies of 2N correlations

a_2 is known from (e,e') & dominance of (pn) SRC is established

How close are a_2's determined using two methods?

Modeling distortion, 3N effects, contribution of secondary hadron interactions...
Ultimately - upper limit on non-nucleonic contribution to SRC : < 10--15%?

Are SRC dominate in the inclusive backward nucleon production $\gamma(\gamma^*) A \to N+X$ reaction? We described inclusive data on backward production as sum of scattering of 2N, 3N SRCs. e' constrains picture strongly. More sensitive to relative strength of 2N and 3N & motion of pair.



$$\sigma(\alpha_p, p_t, Q^2, \nu) = \int d\alpha_N dp_{tN} D(\alpha_p, p_t, \alpha_N, p_{tN})\sigma(Q^2, s')$$

where D is the decay function which was studied in (e,e'pN). Check universality, A dependence (secondary interactions of hadrons produced in eN scattering). May try also to look at the forward particles produced in the eN scattering (e.g. Delta's). Shift of quasielastic peak due to $\alpha_p + \alpha_N \sim 2$

Medium/ heavy nuclei two QE peaks - shifted from electron scattering of SRC and at standard position from secondary break up of 2N by knocked out nucleon

First A(e,e'p) experiment with detection of protons in backward hemisphere was performed by Kim Egyan's group in 1986 - previous (e,e'p) experiments measured knocked out protons which are emitted forward along $\vec{q}$.

PhD of M.Amaryan

First results: YERPHI-1351-46-91, Jul 1991

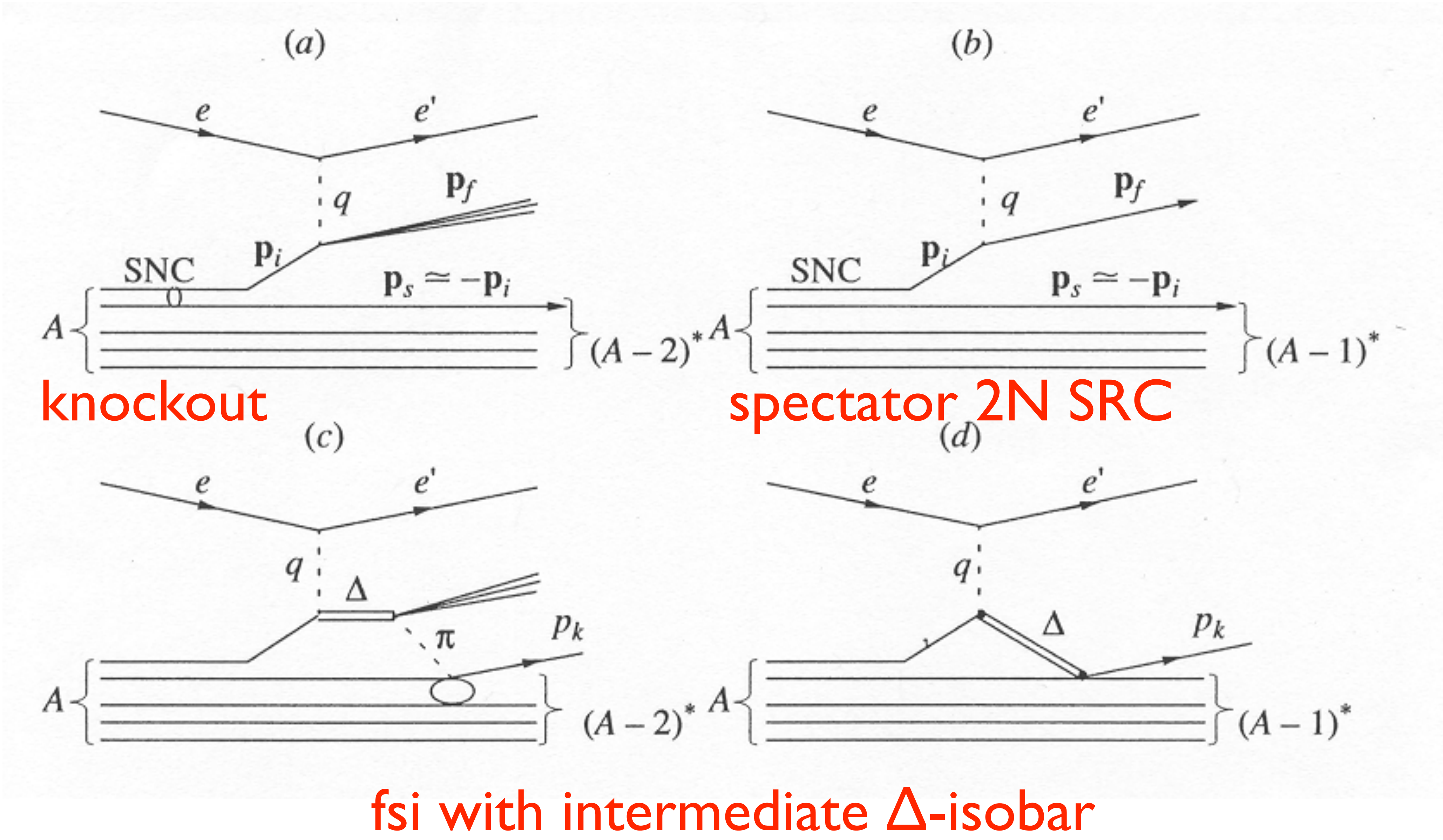
$\Downarrow$

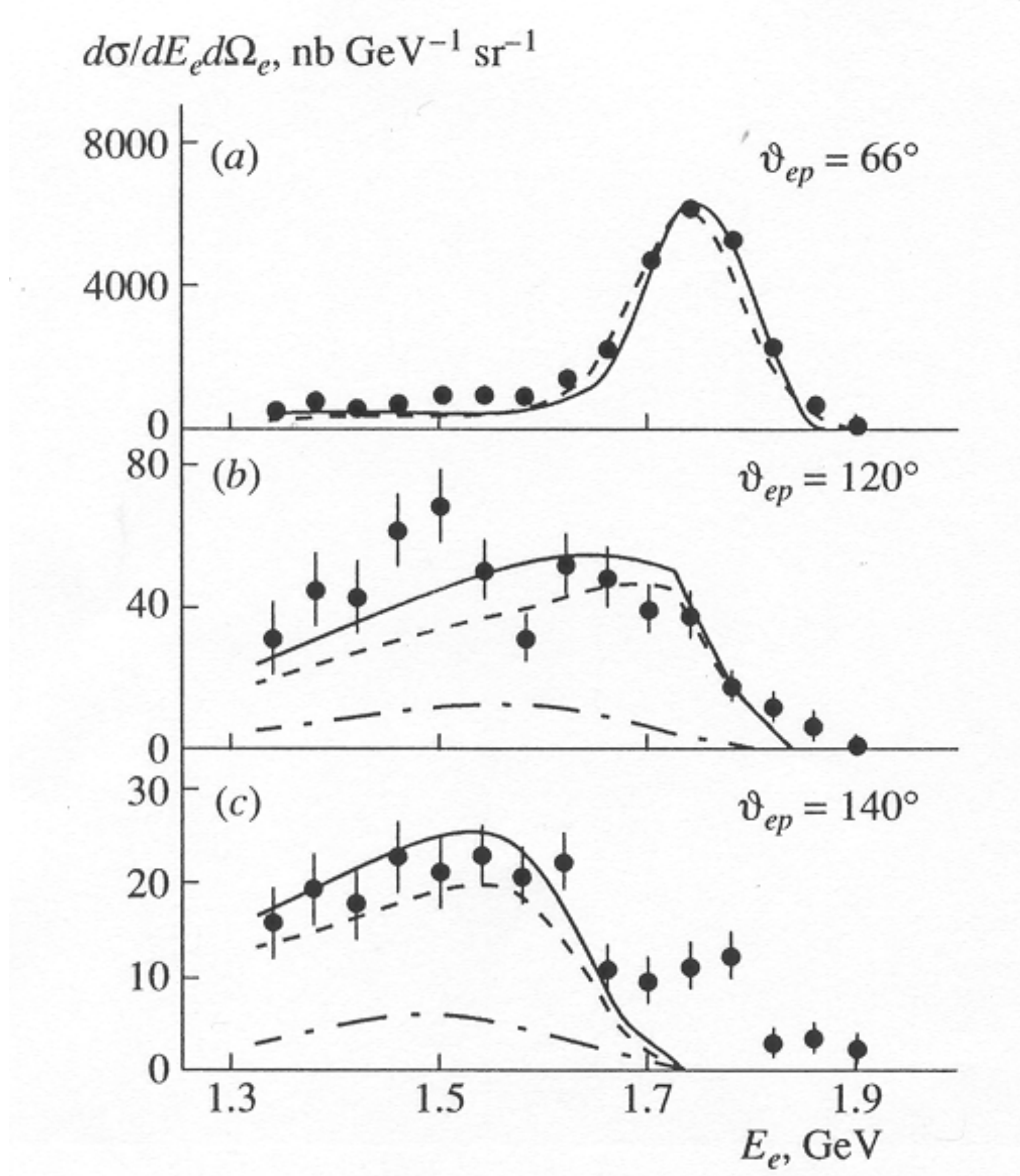
Emission of Cumulative Protons in the Reaction $^{12}C(e, e'p)$

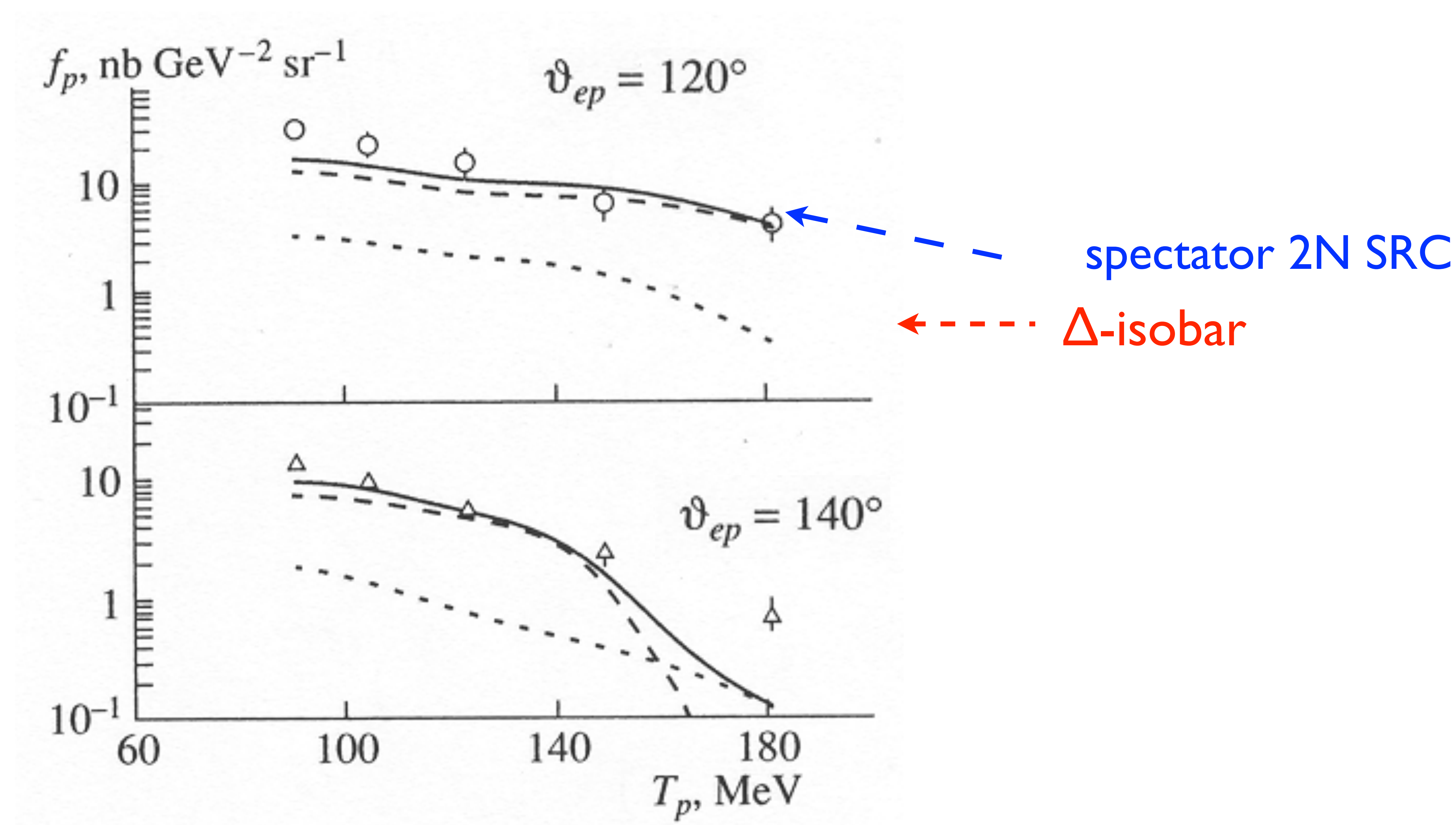
K. V. Alanakyan, M. J. Amaryan, G. A. Asryan, R. A. Demirchyan, K. Sh. Egiyan, M. S. Ohanjanyan, M. M. Sargsyan, S. G. Stepanyan, and Yu. G. Sharabyan

Yerevan Physics Institute, ul. Brat'ev Alikhanian 2, Yerevan, 375036 Armenia

Published: Phys.Atom.Nucl.61:207-213,1998,


(a)
(b)
(c)
(d)
e
e'
q
$\mathbf{p}_f$
$\mathbf{p}_i$
SNC
$\mathbf{p}_s \simeq -\mathbf{p}_i$
A
$(A-2)^*$
$(A-1)^*$
Δ
π
p_k
knockout
spectator 2N SRC
fsi with intermediate Δ-isobar


$d\sigma/dE_e d\Omega_e$, nb GeV^{-1} sr^{-1}
(a)
$\vartheta_{ep} = 66°$
(b)
$\vartheta_{ep} = 120°$
(c)
$\vartheta_{ep} = 140°$
8000
4000
0
80
40
0
30
20
10
0
1.3
1.5
1.7
1.9
E_e, GeV

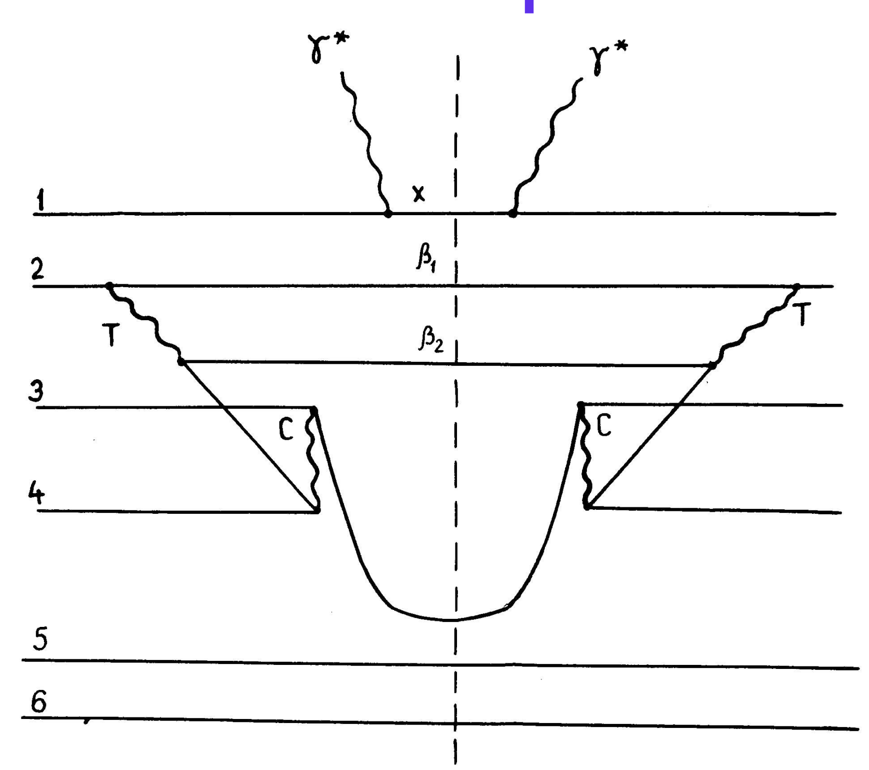

f_p, nb GeV^{-2} sr^{-1}
$\vartheta_{ep} = 120°$
$\vartheta_{ep} = 140°$
10
1
10^{-1}
10
1
10^{-1}
60
100
140
180
T_p, MeV
spectator 2N SRC
Δ-isobar

How to observe directly of 3N SRC

Note - 3N/2N should grow with nuclear density - important for central region of neutron stars where $\rho/\rho_{nuc} \gtrsim 2$

Structure of the light cone density matrix.

In principle one can start from calculating many body LC wave function based on many body bound state equation (involves three body potential to keep rotational invariance satisfied). We use cluster expansion and analog of quark counting rules.



The dominant QCD diagram for the process $\ell + \mathrm{D} \rightarrow \ell' + \mathrm{N} + \mathrm{X}$

at fixed $x \sim \frac{1}{3}$ and $\alpha \rightarrow 2 - X$ in the 6q model of the deuteron

$$\rho^{\mathrm{N}}_{\mathrm{D}}(\alpha, k_\perp = 0) \sim (2-\alpha)^3 \quad \text{at } 1.5 < \alpha < 1.8.$$

FS79

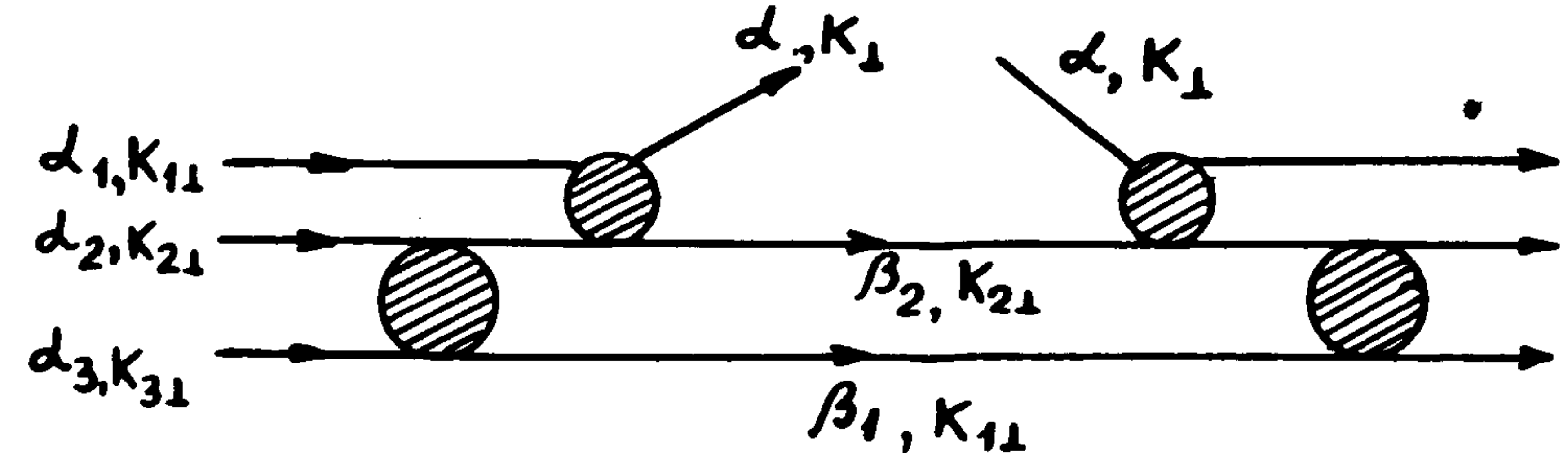


FIG. 2.8: A typical diagram for the three-nucleon correlation.

$$\rho_3(\alpha, k_\perp = 0) = \int \frac{d\beta_1}{\beta_1} d^2k_{1\perp} \frac{d\beta_2}{\beta_2} d^2k_{2\perp} \delta(\beta_1 + \beta_2 + \alpha - 3) \times \delta(k_{1\perp} + k_{2\perp} + k_\perp) \psi^2(2 - \beta_1, k_{1\perp}) \psi^2\left(\left(2 - \frac{2\beta_2}{\alpha}\right), k_{2\perp}\right).$$

Assuming that $\psi^2(2 - \beta_1, k_\perp)_{\beta_1 \to 0} \sim (2 - \beta_1)^{n+1} f(k_\perp^2)$ we obtain

$$\rho_3(\alpha, k_\perp = 0) \sim (3 - \alpha)^{2n+1}.$$

$$\rho_j(\alpha, k_\perp = 0) \sim (j - \alpha)^{n(j-1)+j-2}$$

$$\rho_A^N(\alpha, k_\perp = 0) = \sum_{j=2}^{A} a_j C j \left(1 - \frac{\alpha - 1}{j - 1}\right)^{n(j-1)+j-2}$$

$$\rho_A^j(\alpha, k_\perp) \propto (1 - \frac{\alpha - 1}{j - 1})^{n(j-1)+j-2}$$

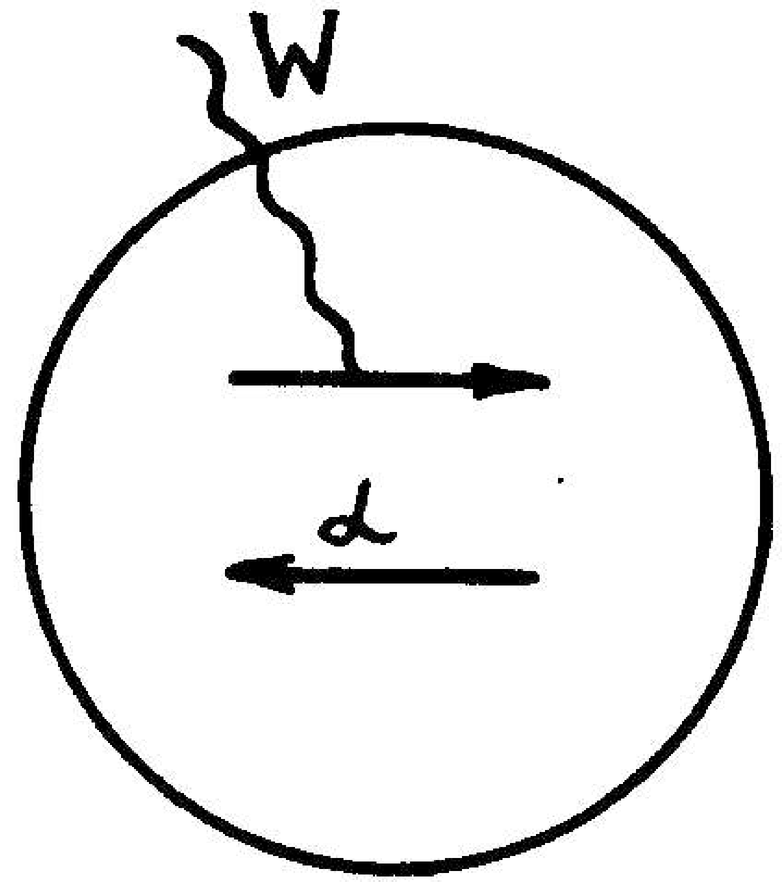
a remarkable property for n~ 3

$$\rho_A^{(3)}(\alpha, k_\perp)/\rho_A^{(2)}(\alpha, k_\perp) \approx const$$

with accuracy 10% for $1.3 \leqq \alpha < 1.6$

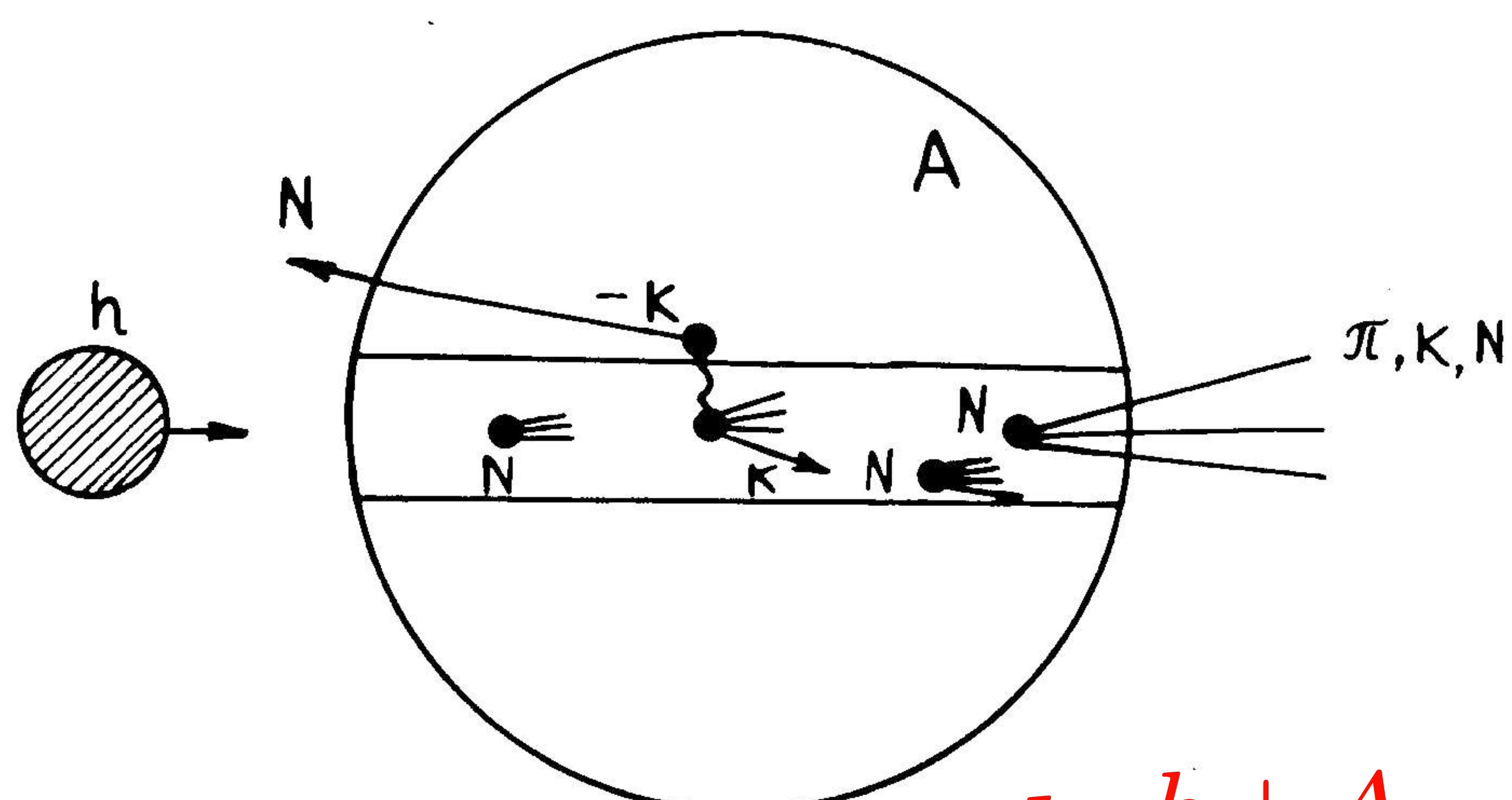
and increasing rapidly for $\alpha \geq 1.6$

hence j> 2 SRCs may contribute significantly to ρ^N_A already at $\alpha \geq 1.3$ but don't lead a strong dependence of ρ^N_A / ρ^N_D for $\alpha \leqq 1.6$. However the recoil "+" component is *in average* smaller for j> 2 but the distribution could be broader than for j=2. May impact scaling of the ratios at x> 1 and large Q.



Production of a fast backward nucleon in the W* scattering from the two-nucleon correlation spectator mechanism.

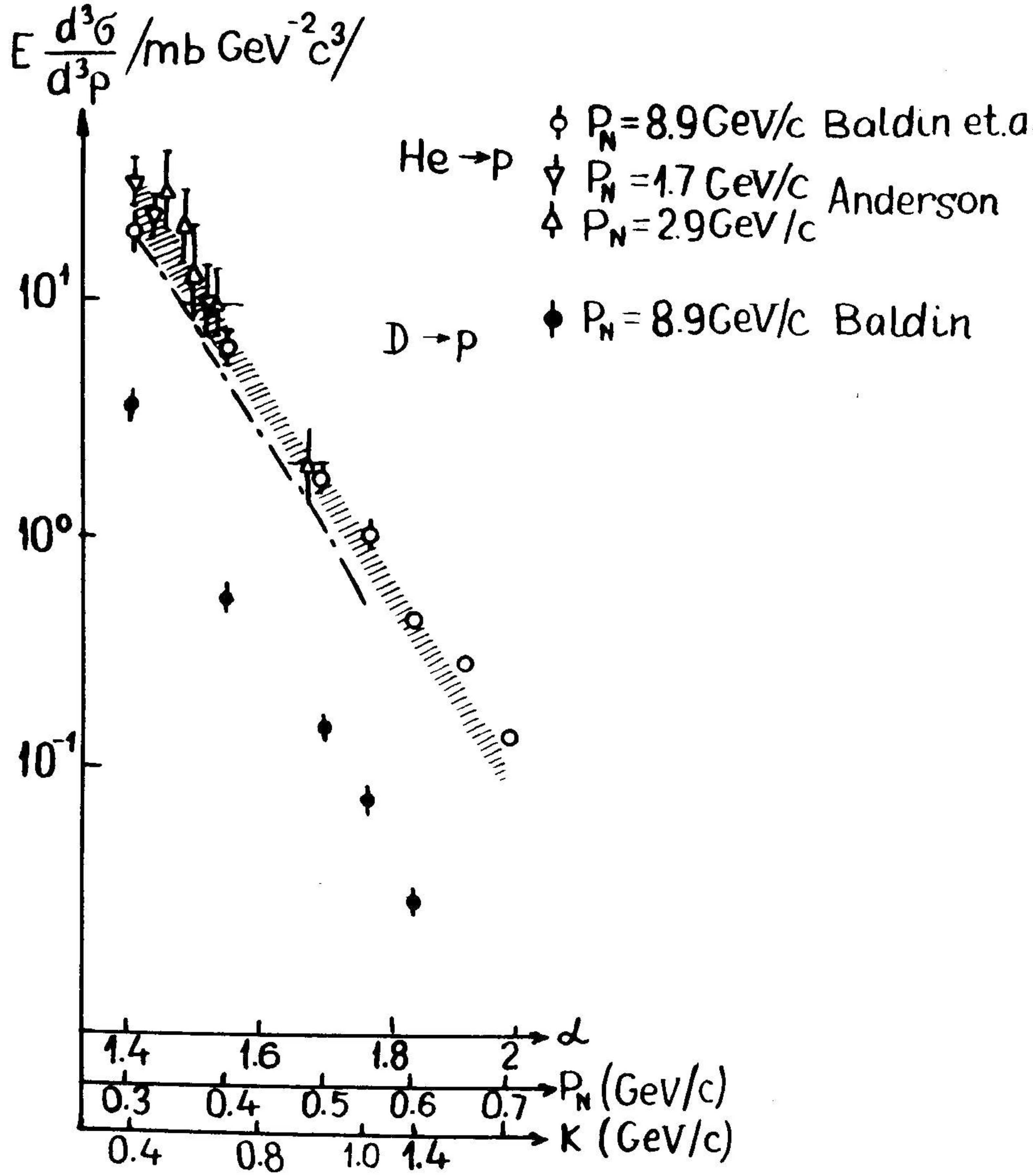
x -- α correlation observed for neutrino scattering off Ne (CERN and FNAL)



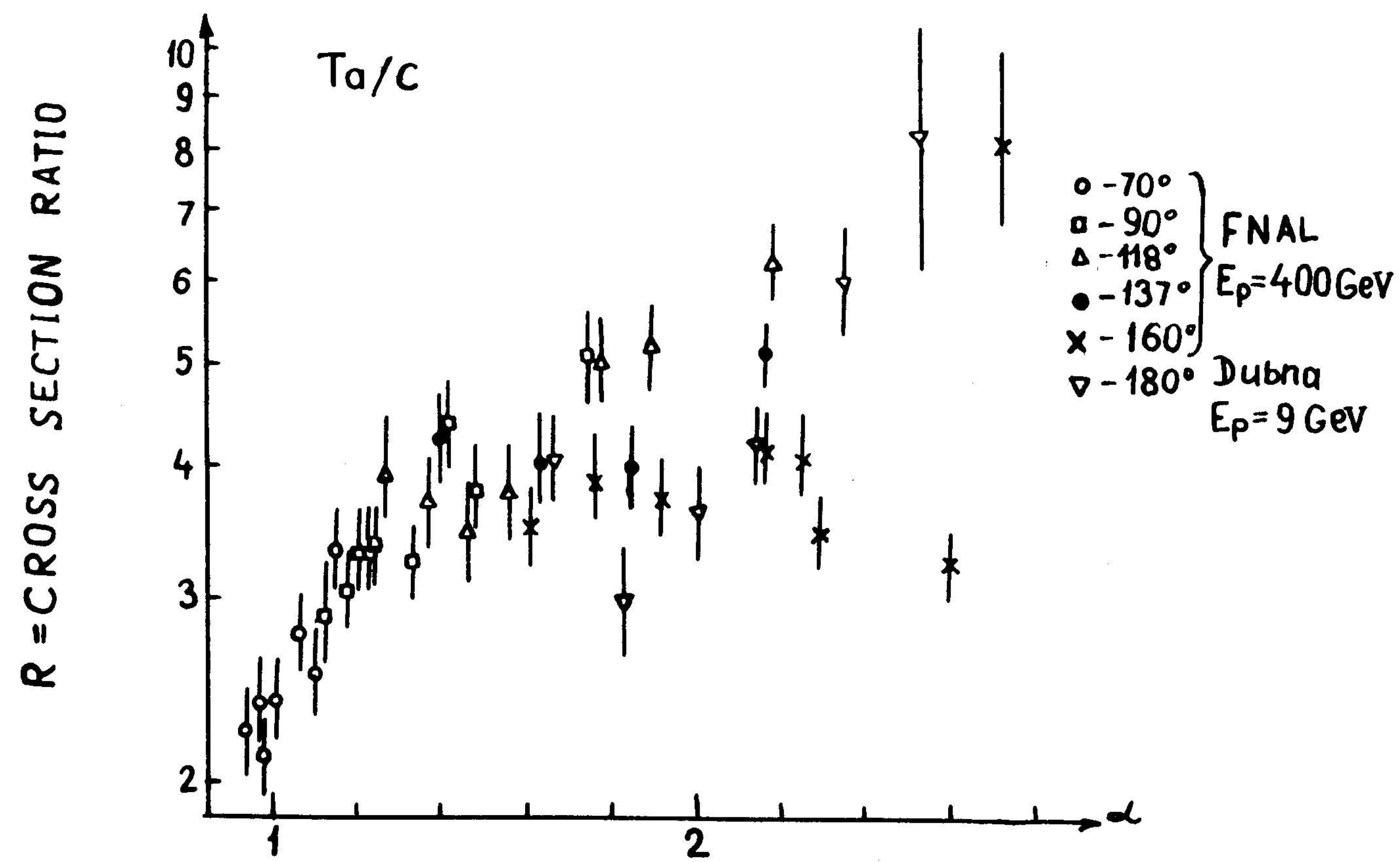
Production of a fast backward nucleon in the pA scattering

$$G_h^{A/N}(\alpha, p_t) \equiv \frac{d\sigma^{h+A\rightarrow N+X}}{\frac{d\alpha d^2 p_t}{\alpha}} = \kappa_h A \sigma_{in}^{hN} \rho_A^N(\alpha, p_t)$$

where factor κ_h accounts for local screening effects



E d³σ/d³p /mb GeV⁻²c³/
He → p
P_N = 8.9 GeV/c Baldin et.al
P_N = 1.7 GeV/c
P_N = 2.9 GeV/c
Anderson
D → p
P_N = 8.9 GeV/c Baldin
α
P_N (GeV/c)
K (GeV/c)



R = CROSS SECTION RATIO
Ta/C
- 70°
- 90°
- 118°
- 137°
- 160°
- 180°
FNAL
Ep=400GeV
Dubna
Ep=9 GeV
α

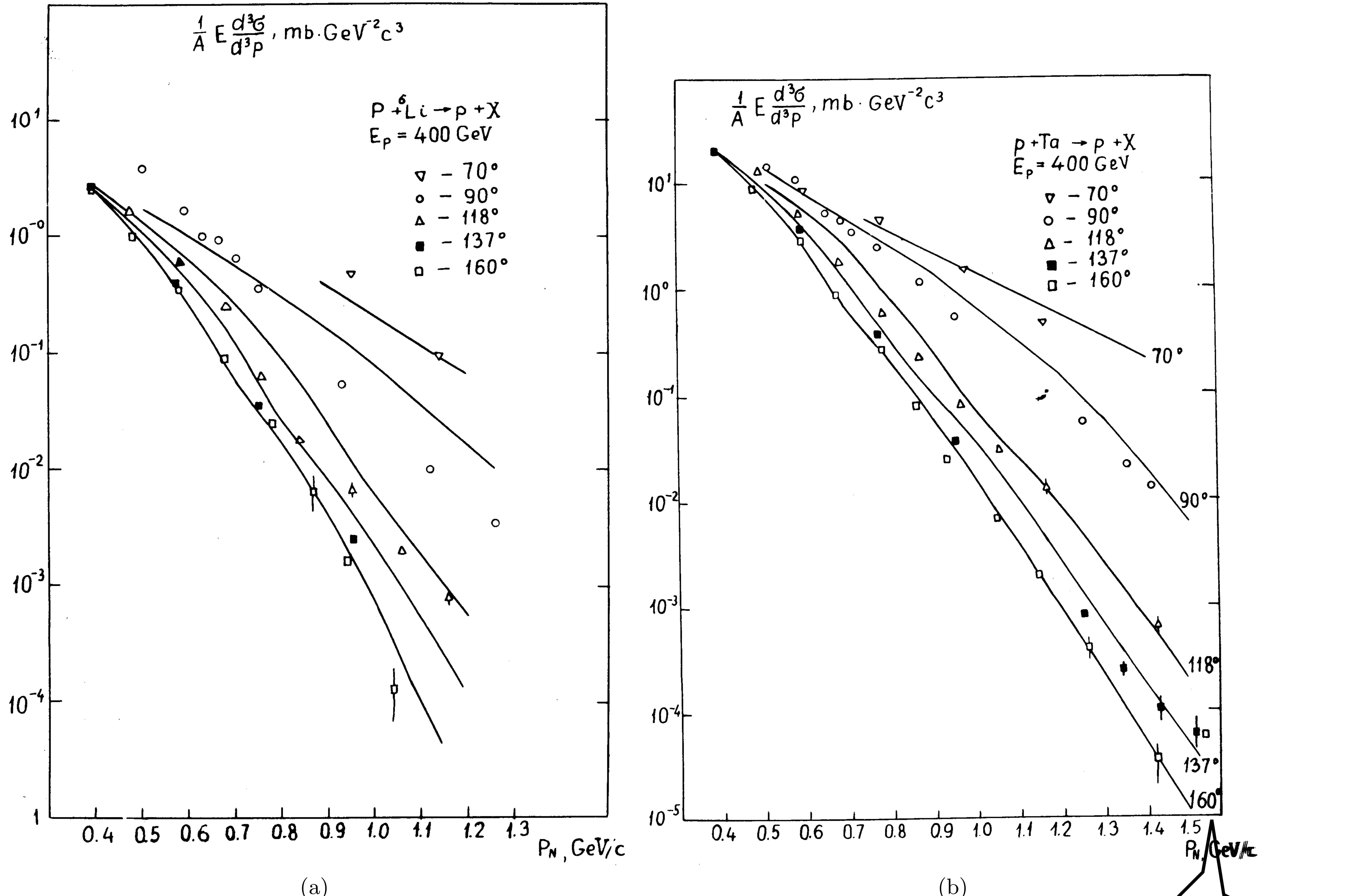
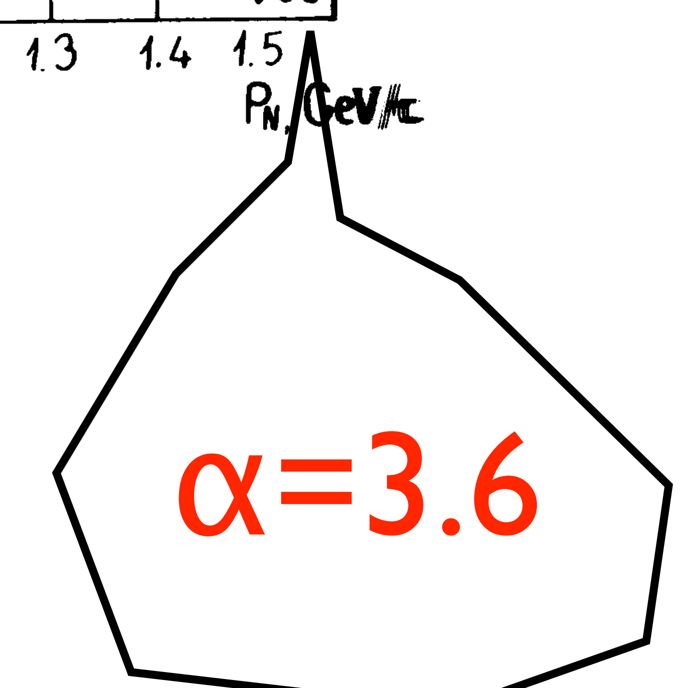


FIG. 8.4: Comparison of the FNC model with the 400 GeV data [35, 36].



Evidence from NR calculations? *3N SRC can be seen in the structure of decay of ^3He* (Sarsgian et al).

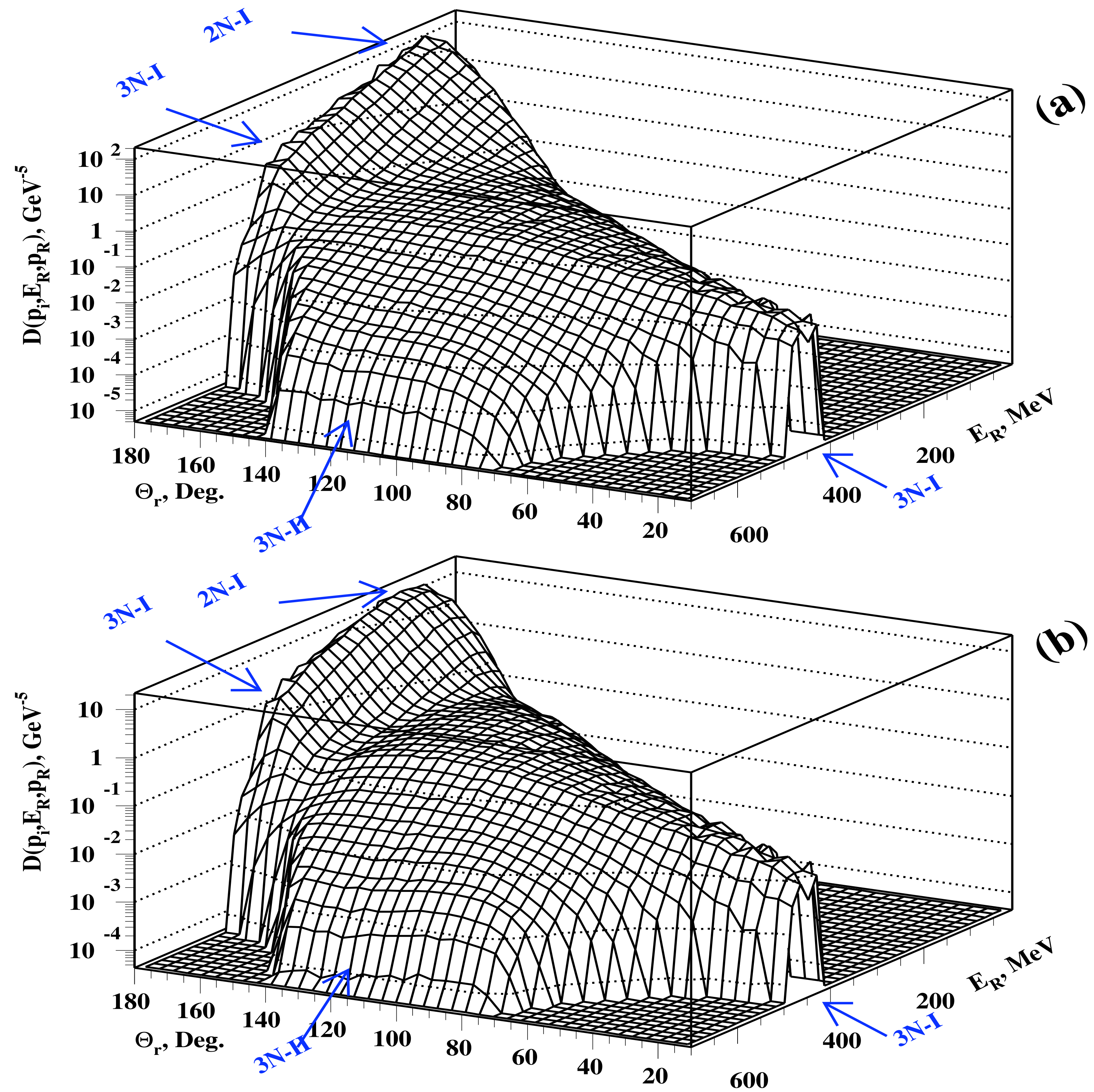
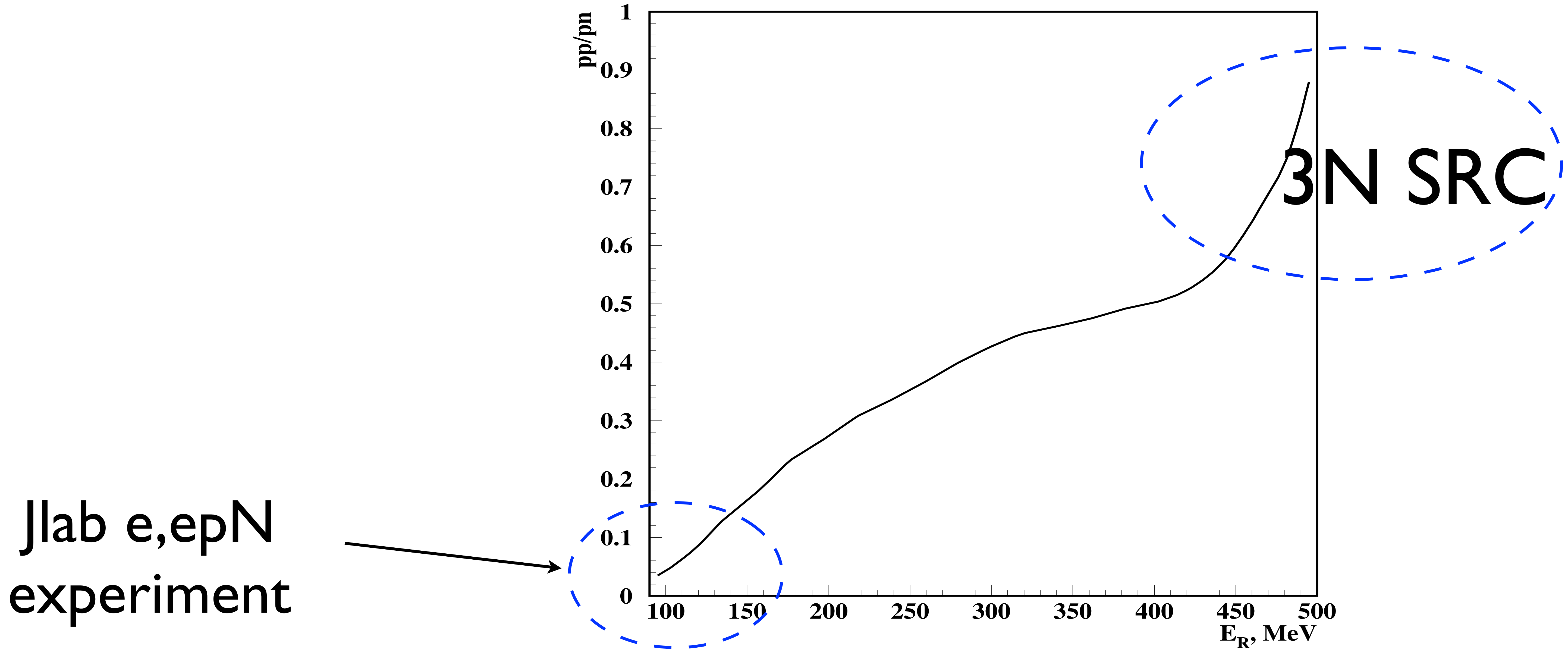


Figure 8: Dependence of the decay function on the residual nuclei energy and relative angle of struck proton and recoil nucleon. Figure (a) neutron is recoiling against proton, (b) proton is recoiling against proton. Inital momentum of the struck nucleon as well as recoil nucleom momenta is restricted to $p_{in}, p_r \geq 400$ MeV/c.



Recoil energy dependence of the ratio of decay function calculated for the case of struck and recoil nucleons - p_s & p_r for struck proton and recoil proton and neutron for p_s & $p_r > 400$MeV/c & $180^\circ > \theta(\widehat{p_s\ p_r}) > 170^\circ$

Evidence for 3N correlations from the scaling of ratios observed in A(e,e') for x >2 starting with ^{4}He/^{3}He analysis in FS 88

Warnings:

(i) $\alpha < 2$ in the discussed kinematics - selection of small recoil masses for relatively modest momenta

(ii) W in (e -- 3N) interaction at x > 2 and studied Q range is rather close to the threshold - hence f.s.i. is likely to be important for absolute (e,e') cross section (less so for ratios)

Correlations in p A→ p (backward) + p (backward) +X

measurements of Bayukov et al 86

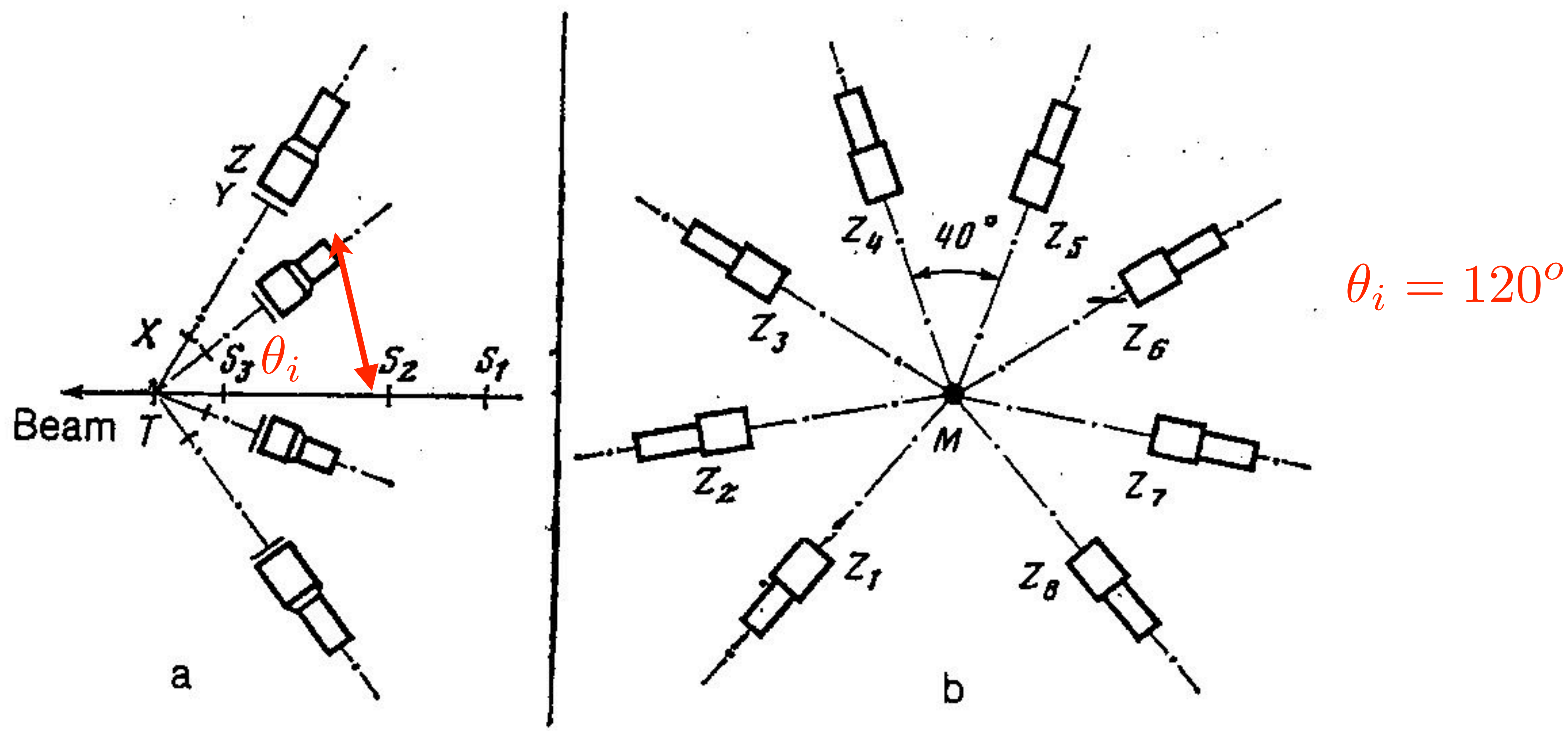
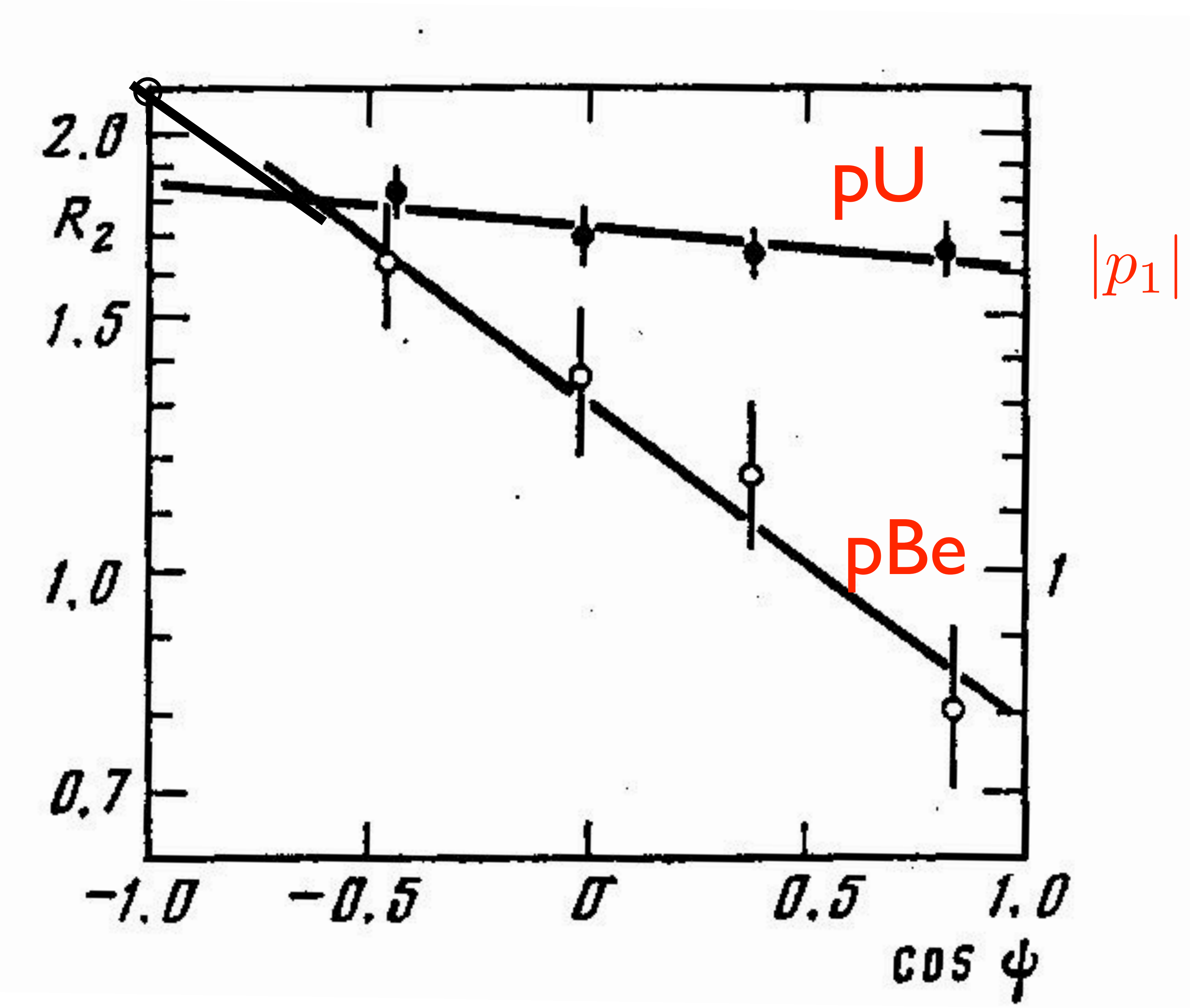
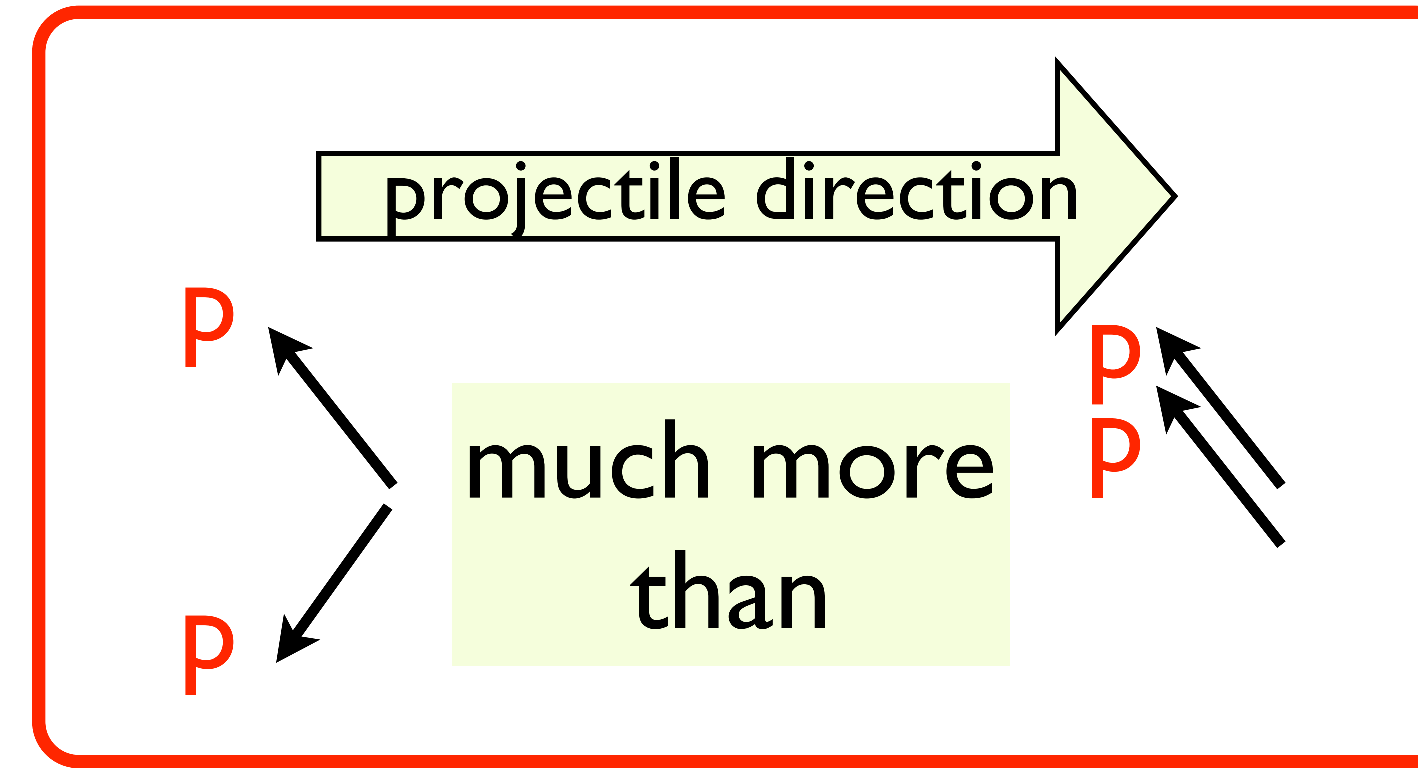


FIG. 1. Diagram of apparatus. (a)—Side view, (b)—view along the beam direction. Only the Z counters are shown.

$$R_2 = \frac{1}{\sigma^{in}_{pA}} \frac{d\sigma(p+A \to pp+X)/d^3p_1 d^3p_2}{d\sigma(p+A \to p+X)/d^3p_1 d\sigma(p+A \to p+X)/d^3p_2}$$



$|p_1| = |p_2| \approx 500 MeV/c$



Curves are experimental fit.

We can reasonably reproduce the pattern of ψ dependence of R_2 as due to correlated contributions of scattering off 3N SRC and uncorrelated term due to scattering of spacially separated 2N SRC.

ψ dependence of R_2 for (virtual) photons - should be at least as pronounced. Would be interesting to look at such correlation already for p > 300 MeV/c. Also study a shift of quasielastic peak for 2p events: $\alpha_{p\,1} + \alpha_{p\,2} + \alpha_N \sim 3$

Discovering nonnucleonic degrees of freedom in nuclei

Expectations

- pionic component is small due to chrial symmetry
- closest inelastic intermediate state is Δ- isobar - due to strong attraction potential enhancement as compared to a naive estimate
- non-nucleonic degrees of freedom are predominantly in SRC

< 10- 15 % of SRC

⬇

< 2 - 3 % per nucleon

Intermediate states with Δ -isobars.

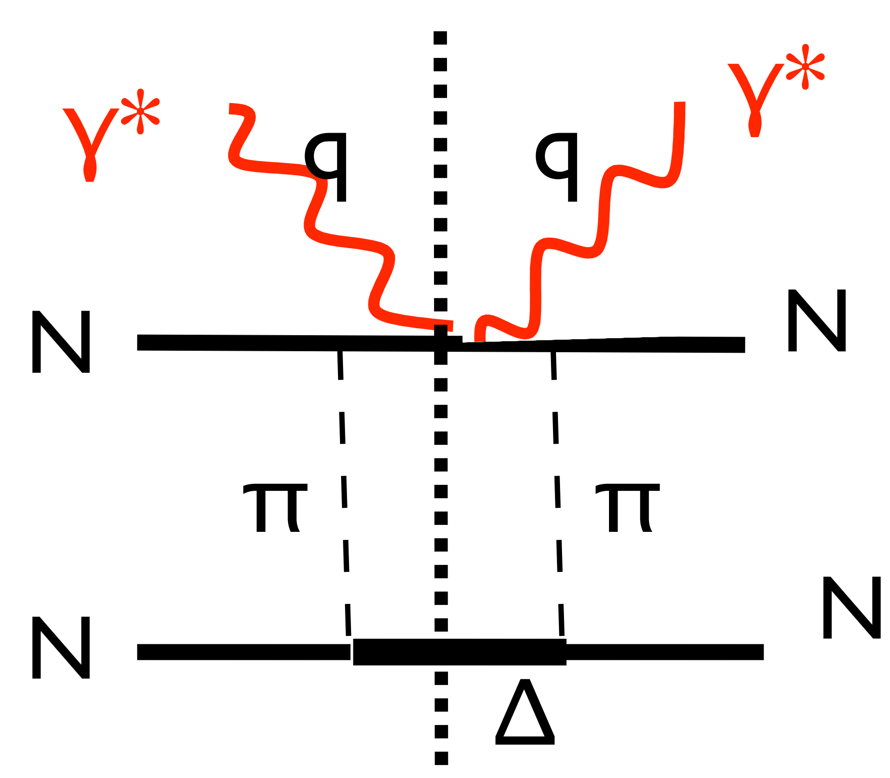
Often hidden in the potential. Probably OK for calculation of the energy binding, energy levels. However wrong for high Q^2 probes.

Explicit calculations of B.Wiringa - ~1/2 high momentum component is due to ΔN correlations, significant also ΔΔ . Tricky part - match with observables - momentum of Δ in the wf and initial state

Large Δ admixture in high momentum component

⇓

- Suppression of NN correlations in kinematics of BNL experiment
- Presence of large E_R tail (~ 300 MeV) in the spectral function



I do not discuss N*'s but they may contribute as well

Generic feature: distribution of ***ΔΔ over relative momenta in the deuteron wave function is broad*** .

$$\frac{1}{2E_\Delta - m_d} = \frac{1}{2\sqrt{m_\Delta^2 + k^2} - m_d}$$

Reason: the energy denominator in difference from NN state is practically constant up to k ~ ***m_Δ/2***

The same in the light cone formalism

$$\left[\frac{m_\Delta^2 + k_t^2}{\alpha(2-\alpha)} - m_d^2\right]^{-1}$$

α/2 is the light-cone fraction carried by isobar

Since difference is large small sensitivity to change of α: change of α from 1 to 1.3: α(2-α) --- 1 to 0.91

ΔΔ is off shell by huge factor on nuclear scale ~ 600 MeV. Need relativistic framework. Difficult with virtual particles - need violates symmetry between the particles. One obtained $P_{\Delta\Delta}$ up to 6%

More recent quantum mechanics estimates on the scale of a fraction of %.
3He - 1% (ΔNN)

LC consideration of energy denominators - if $|\alpha - 1| > 0.3$ the ratio of Δ and N yield for the same α is a weak function of α. A simple minded quark exchange (FS80): Δ/N ~ 1/7

Starting from nonrelativistic QM description it is possible to establish relation between LC and nonrelativistic wf's in the case of D= NN + Δ Δ

Spin zero /unpolarized case

Relation between LC and NR wf.

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

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

The same relation between $\Psi_{\Delta\Delta}(\alpha_\Delta, k_t)\, and\, \phi_{\Delta\Delta}(k)$

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

$$\psi^{\rm D}_\mu \varepsilon^{\rm D}_\mu = \bar{U}(p_1)\{\gamma_\mu \Gamma_1(M^2_{\rm NN}) + (p_1-p_2)_\mu \Gamma_2(M^2_{\rm NN})\}U(-p_2)\varepsilon^D_\mu .$$

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

Looking for non-nucleonic degrees of freedom (a sample of processes)

electron beams - SDIS - Advantage - cross section for e Δ can be estimated with a reasonable accuracy

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 $p_3 \sim 300$ MeV/c forward

Competing mechanism - Δ's from nucleons=direct mechanism

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

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

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: $\pi N \to \Delta$ FS90

For the deuteron one can reach sensitivity better than 0.1 % for ΔΔ especially with quark tagging *(FS 80-90)* for $x > 0.1$ very strong suppression of two step mechanisms (FS80)

is confirmed by neutrino study of Δ-isobar production off deuteron

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

An analysis has been made of 15 400 ν–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

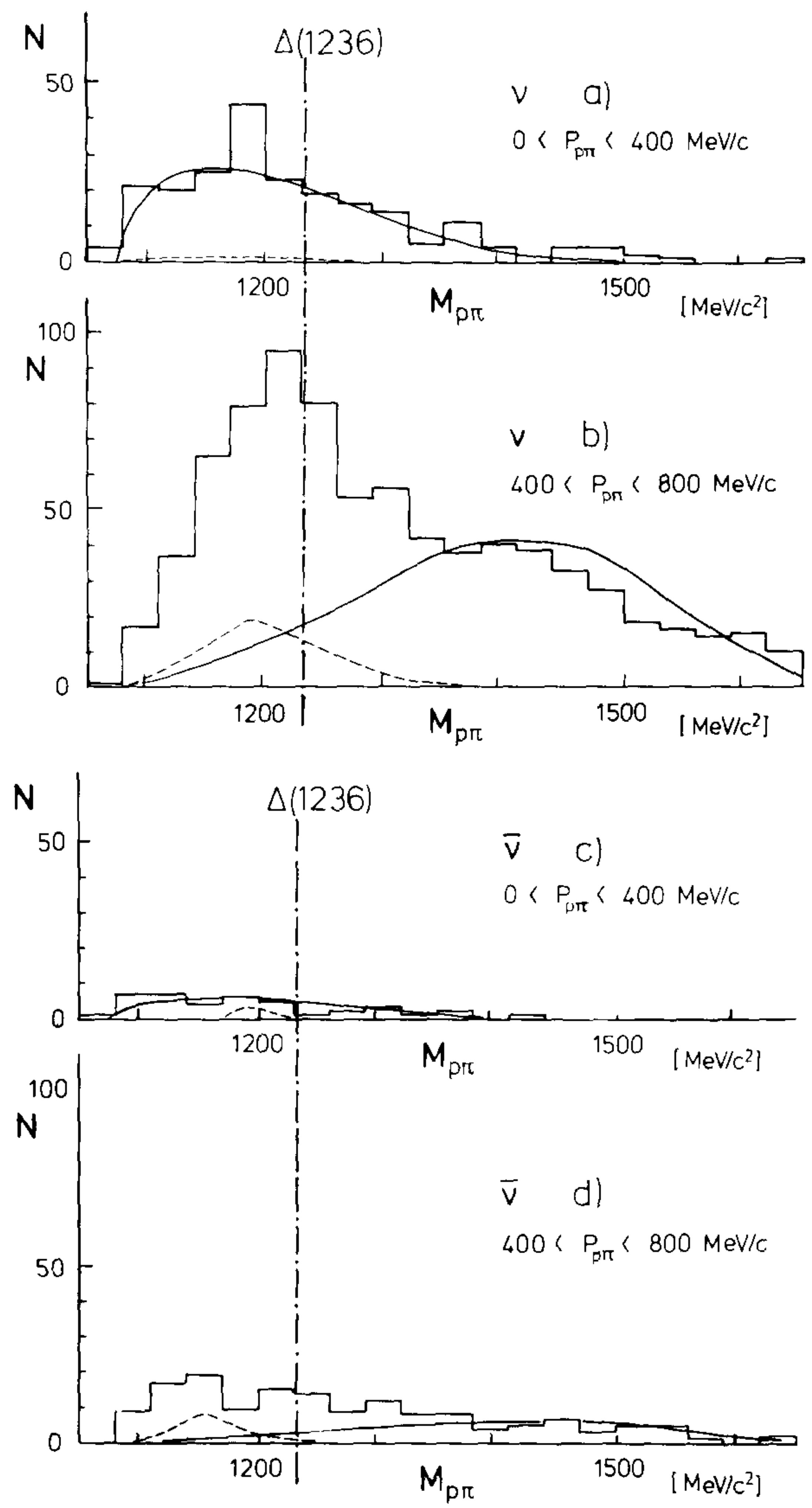


Fig. 1. Effective mass distributions of $p\pi^+$ combinations for ν (top) and $\bar{\nu}$ (bottom) interactions. The distributions are presented for two intervals of the combined $p\pi^+$ momentum: 0–400 and 400–800 MeV/c. The chosen bin size is 30 MeV/c^2 = Γ(1235)/4. The solid lines show the calculated 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.

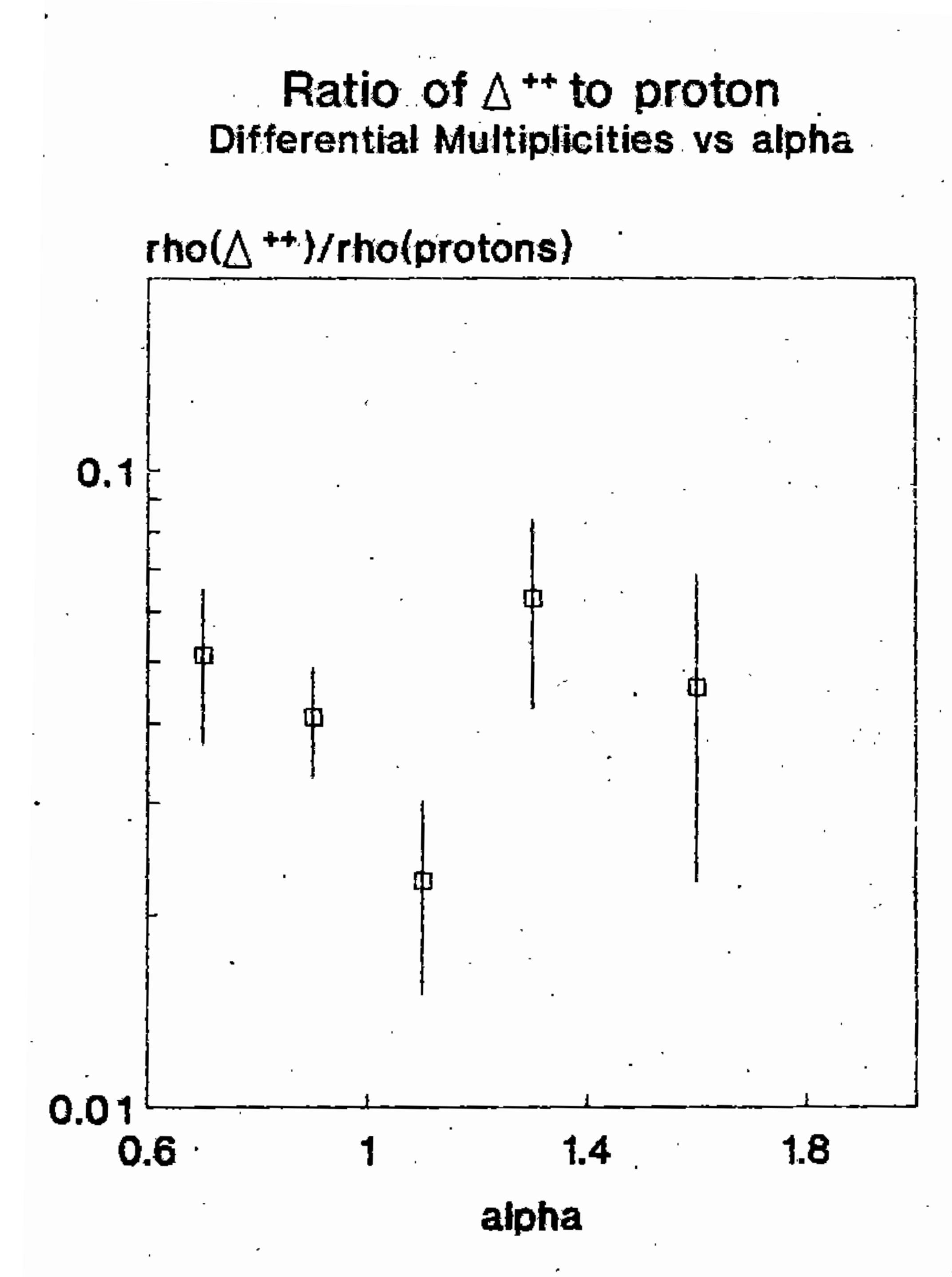
Is there a positive evidence for Δ's in nuclei?

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

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

$$\frac{\sigma(e + A \to \Delta^0 + X)}{\sigma(e + A \to \Delta^{++} + X)} = 0.93 \pm 0.2 \pm 0.3$$

$$\frac{\sigma(e + A \to \Delta^{++} + X)}{\sigma(e + A \to p + X)} = (4.5 \pm 0.6 \pm 1.5) \cdot 10^{-2}$$



It seems that there are data in the CLAS archive to do this much better.

☞ *Semiexclusive approaches toSearching/discovering baryonic nonnucleonic degrees of freedom in nuclei*

(a) Knockout of Δ^{++} isobar in $e+^{2}H \rightarrow e+\ forward\ \Delta^{++} +\ slow\ \Delta^{-}$

$e+^{3}He \rightarrow e+\ forward\ \Delta^{++} +\ slow\ nn$

Sufficiently large Q are necessary to suppress two step processes where Δ^{++} isobar is produced via charge exchange. Can regulate by selecting different x - rescatterings are centered at x=1.

(b) Looking for slow (spectator) Δ's in exclusive processes with ^{3}He

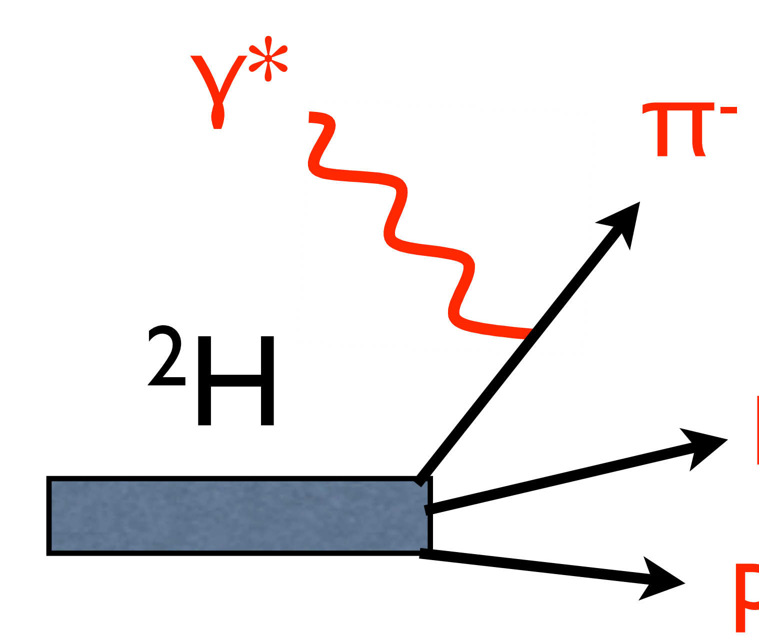
Another possibility for 12 GeV, study of $x_F \geq 0.5$ *production of* Δ− *isobars in* e+D(A)→e+ Δ +X. *For the deuteron one can reach sensitivity better than 0.1 % for* ΔΔ especially with quark tagging *(FS 80-89)*

(c) $e+^{2}H \rightarrow e+\ forward\ N +\ slow\ N^{*}$

☞ *Searching/discovering mesonic degrees of freedom in nuclei*

$e+^{2}H \rightarrow e+\ forward\ \pi^{-}(along\ \vec{q}) + p(forward)\ +\ p(forward)$

$p_N \sim 0.3 - 0.4\ GeV/c$



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Conclusions

Opportunities for study of two nucleon short-range correlations with backward nucleon in $e+A \rightarrow e$ +backward proton + X starting at low Q^2. Need to strengthen studies of f.s.i. like production of pions with secondary interactions off SRC.

Two backward protons - promising way for study of three nucleon short-range correlations in nuclei

Observation of $\Delta\Delta$ on .2 % level seems possible, but one needs to find optimal kinematics to reduce combinatoric background. Preliminary step - study acceptance of CLAS to slow Delta's. For semiinclusive and exclusive channels are worth exploring.

For heavier nuclei looking for forward Δ^{++} knockout at $Q^2 > 1.5 \div 2$ GeV^2. and for control Δ^0 (or even better Δ^-) which should be much smaller than Δ^{++} .

Deuteron is the stepping stone - allows to normalize production of Δ's off heavier nuclei.