QUASI-DEUTERON CLUSTERS IN THE ^{12}C AND SHORT-RANGE NN CORRELATIONS IN THE REACTION $^{12}C+p\to{}^{10}A+pp+N$

Yu.N. UZIKOV (DLNP, JINR)

- Cold dense baryonic matter in nuclei
- $^{12}C(p,pd)^{10}B$ and p<pn>→dp, pd→$\{pp\}_s n$
- Elements of formalism for $p+^{12}C\to p+p+N+^{10}B$ (BM@N)
- SRC c.m. momentum distribution and pp/pn ratio
- ISI@ FSI
- Conclusion

"INFINUM-2023 ", Dubna, 2023, March 3

- ♦ Dubna, 1957, L.S. Azhgirey,…, **M.G. Mesheryakov** et al. ZHETF, **33**
  $p+^{12}C \rightarrow d+X$ at 670 MeV:
  quasi-elastic knock-out of fast deuteron clusters:
  D.I. Blokhintsev (1957) - fluctuations of nuclear density;
  fluctons (6q) in nuclei - **A.V. Efremov** (1976);

  SRC –Short Range Correlations **M. Strikman, L. Frankfurt (1978)**
  NN-pair with almost zero c.m. momentum but large (equal) internal momenta $q_1=-q_2$; at short distances r_{NN} <0.5 fm
  with high relative momentum $q>1/r_{NN}$ =0.4 GeV/c;
  Repulsive NN-core → high-momentum part of the w.f. of NN pair

- ♦ **A.M. Baldin**, Cumulative effect (1971).

- ♦ Search for high-momentum components of the nuclear wave functions

♦ Intensive study of SRC in nuclei during last one-two decades using mainly electron beams (e,ep), (e,epp).

The Main Results:

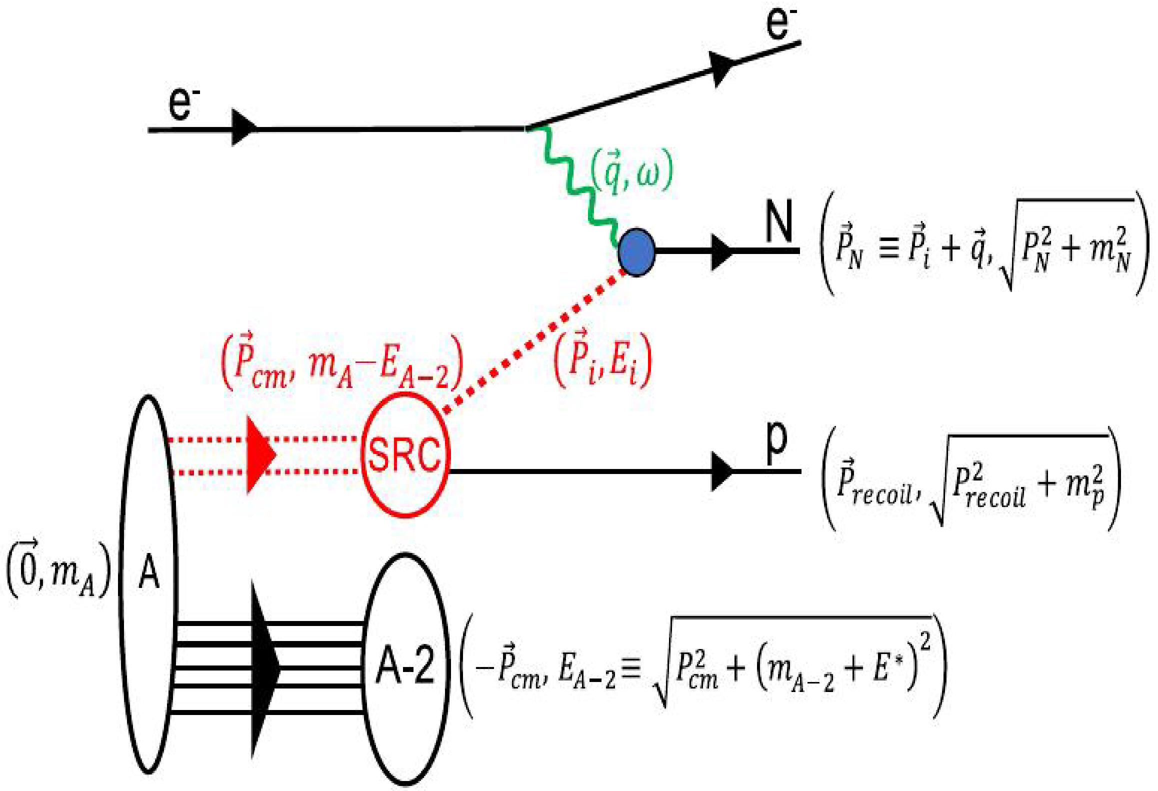
* High-momentum part of the nucleon momentum distribution ($q > p_F \sim$ 250-300 MeV/c) accounts for 20% nucleons .
* pn- SRC pairs dominate by factor of ~20 as compared to pp and nn due to the tensor forces.
* Factorization at high q: $n(p_1, p_2) = n^{A}_{c.m.}(k_{cm}) n_{rel}(q)$
* SRC are connected with neutrino-nucleus interaction, neutron stars structure, modification of the bound nucleon structure (**EMC effect**).

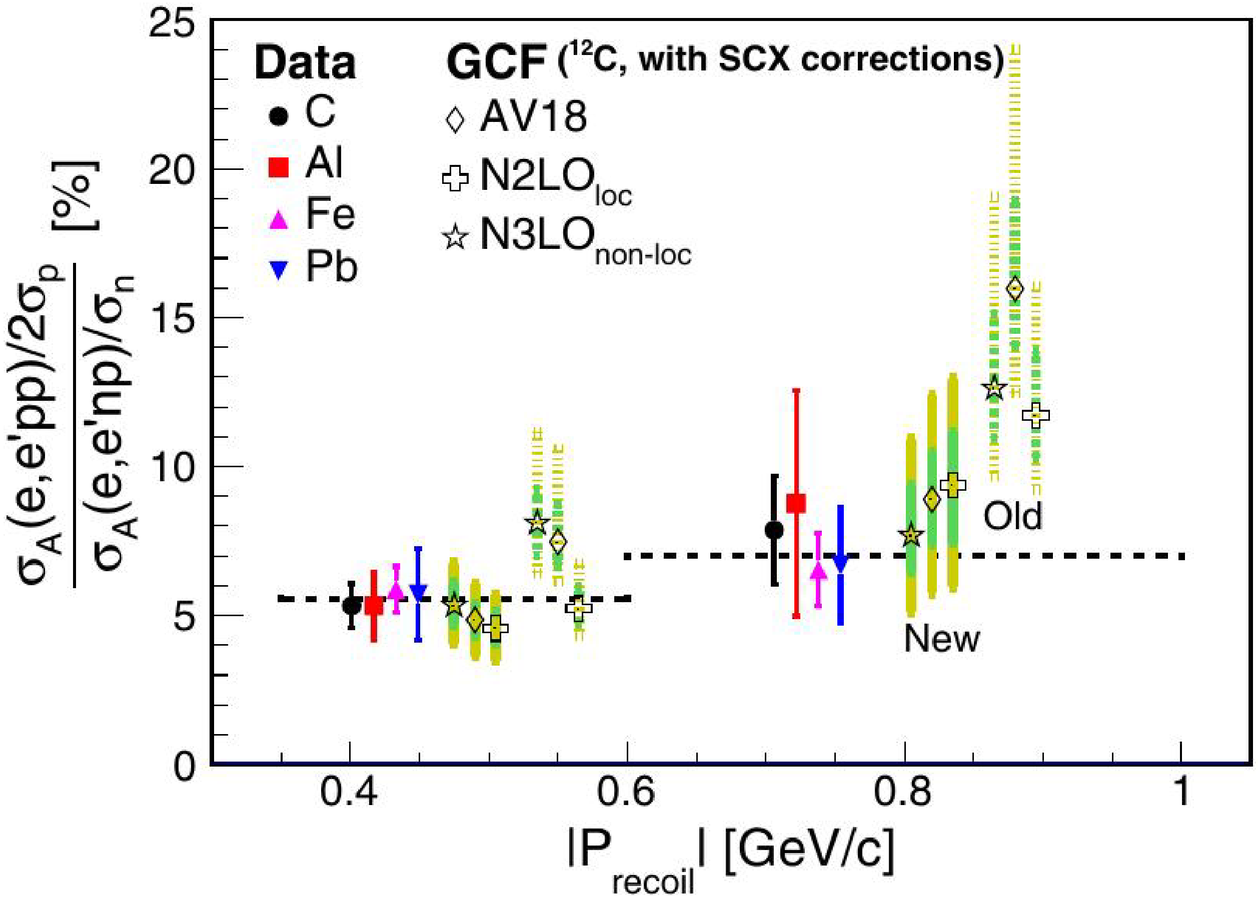
Cioffi degli Atti, Phys. Rep. 590 (2015) 1

O. Hen et al. Rev. Mod. Phys. 89 (2017) 045002.

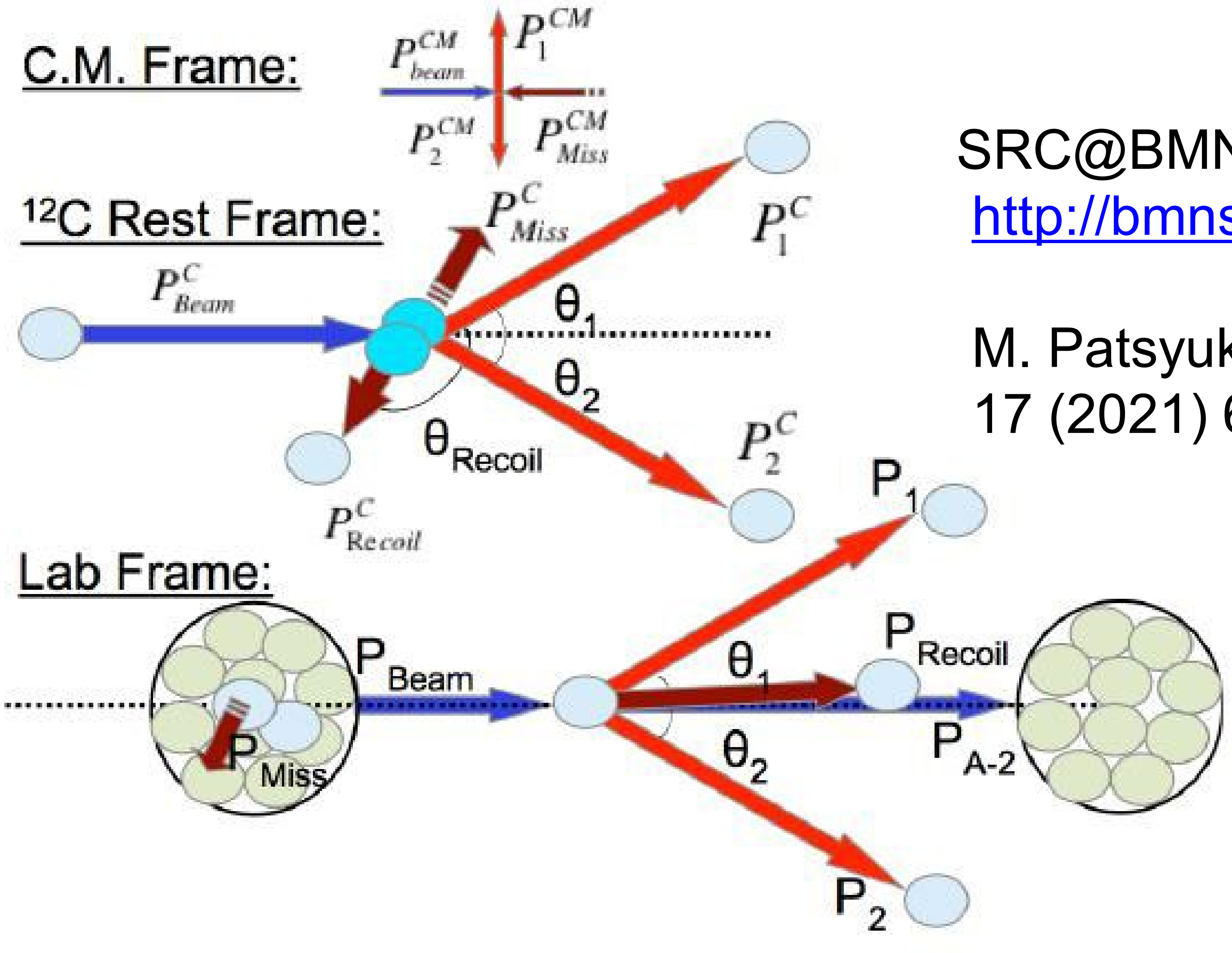
M.Duer et al. PRL 122 (2019) 172502 (CLAS Collabotration)

E_e=5 GeV,
A(e,e'np), A(e,e'pp)





Project of BM@N to study SRC in JINR with 4=GeV/c /nucleon beam of ^{12}C and proton target in Inverse kinematics . **Talk by Maria Patsyuk today**



SRC@BMN proposal
http://bmnshift.jinr.ru/wiki/doku.pho

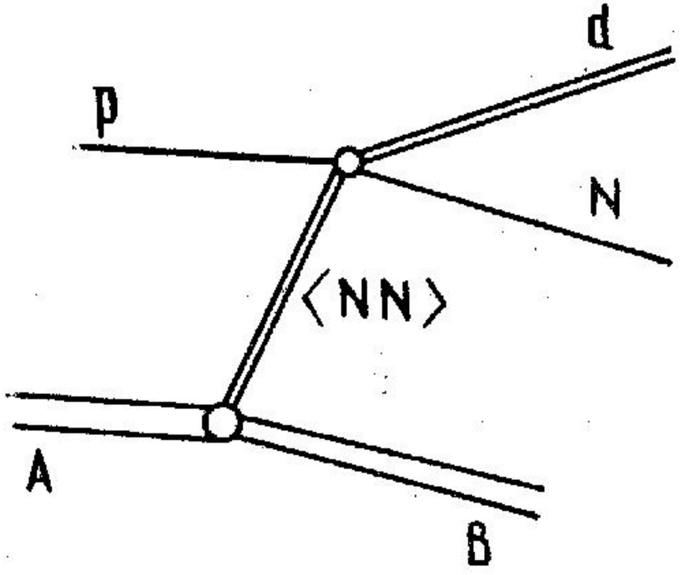
M. Patsyuk et al., Nature Phys. 17 (2021) 693; arXiv:2102.02626 [nucl-ex]

12C(p,2p)11B (g.s.), shell model is OK !

12C(p,2pN)10A , SCR:
10B 23events (pn);
10Be – 2 event (pp)

CONCLUSION: unperturbed by ISI@FSI distributions are measured

Quasi-elastic knockout of fast deuteron clusters $^{12}C(p,pd)^{10}B$ and hard $pd \to dp$



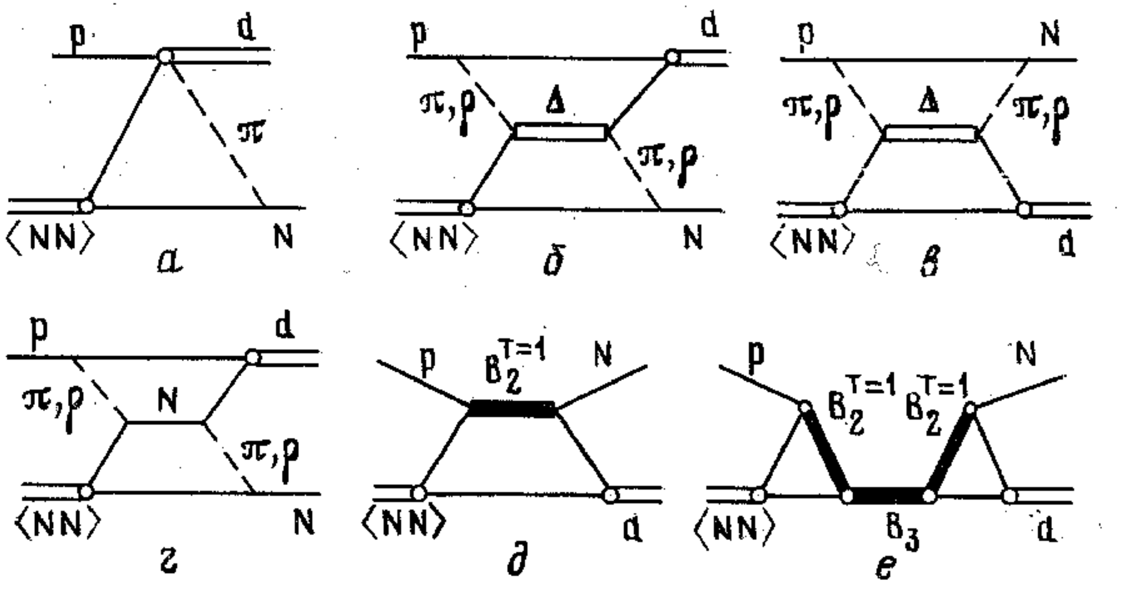


Рис. 5.6: Рис.3 . Механизмы процесса $p < NN > \to Nd$, для которых выполняется соотношение $d\sigma(p < np >_{T=0} \to pd) = 9 d\sigma(p < np >_{T=1} \to pd)$.

M.A.Zhusupov, Yu.N.U. PEPAN 18 (1987) 323

$$p+ < np >_{T=0} \rightarrow p + d,$$

$$p+ < np >_{T=1} \rightarrow p + d,$$

$$p+ < nn >_{T=1} \rightarrow n + d.$$

$$R = d\sigma(p, nd)/d\sigma(p, pd)$$

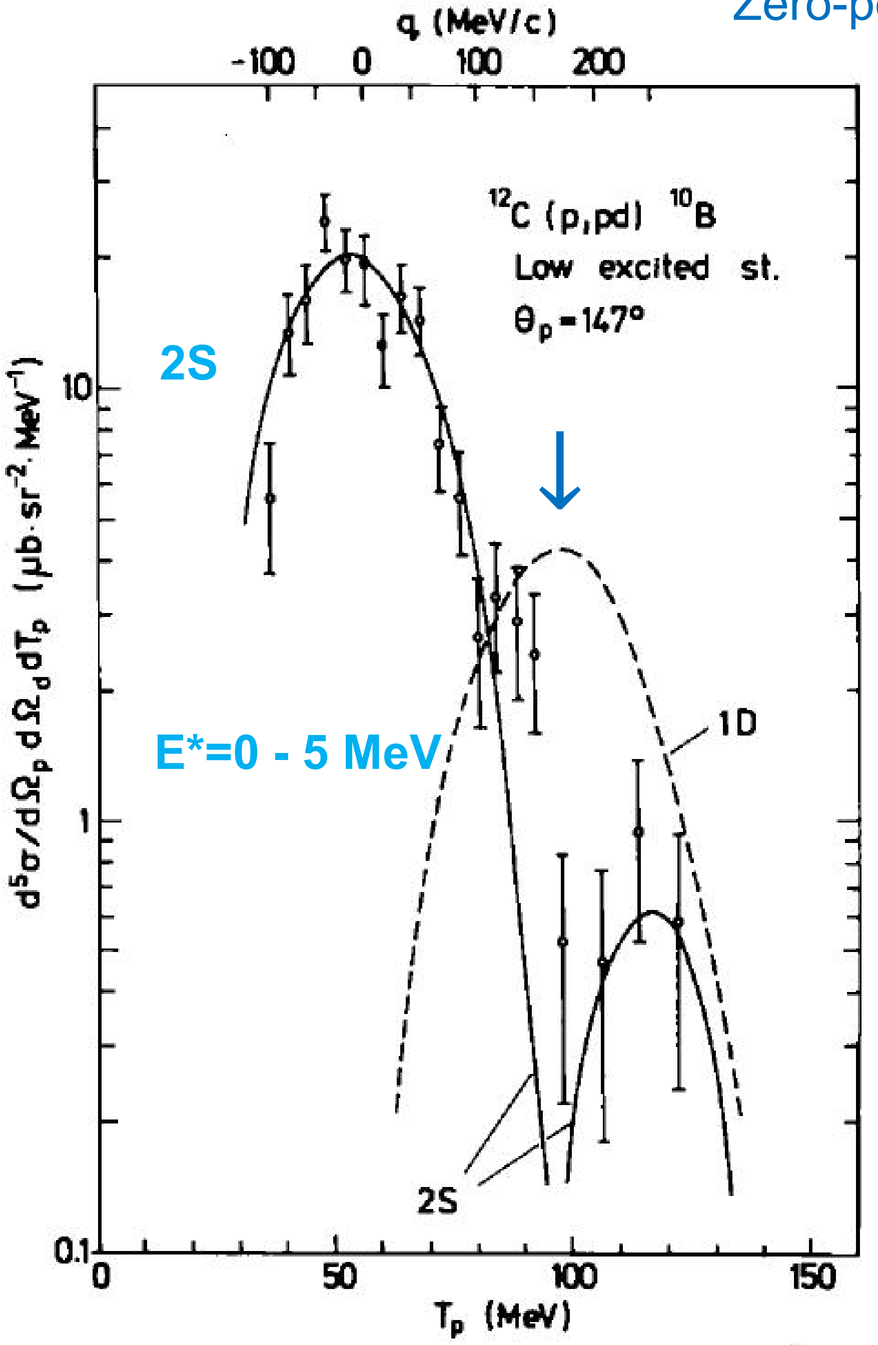
Таблица 5.3.2. Отношение дифференциальных сечений $[d\sigma(p, nd)/d\sigma(p, pd)]10^2$

Ядро-мишень	События					
	"низкоэнергетические"			"высокоэнергетические"		
	эксп.	Теория		эксп.	Теория	
		$R_0 = 9$	$R_0 = 1$		$R_0 = 9$	$R_0 = 1$
^7Li	$6,1 \pm 0,9$	13,7	80,0	$9,1 \pm 1,5$	6,1	42,8
^6Li	$0,30 \pm 0,16$	0	0	$8,1 \pm 1,5$	6,9	48,6

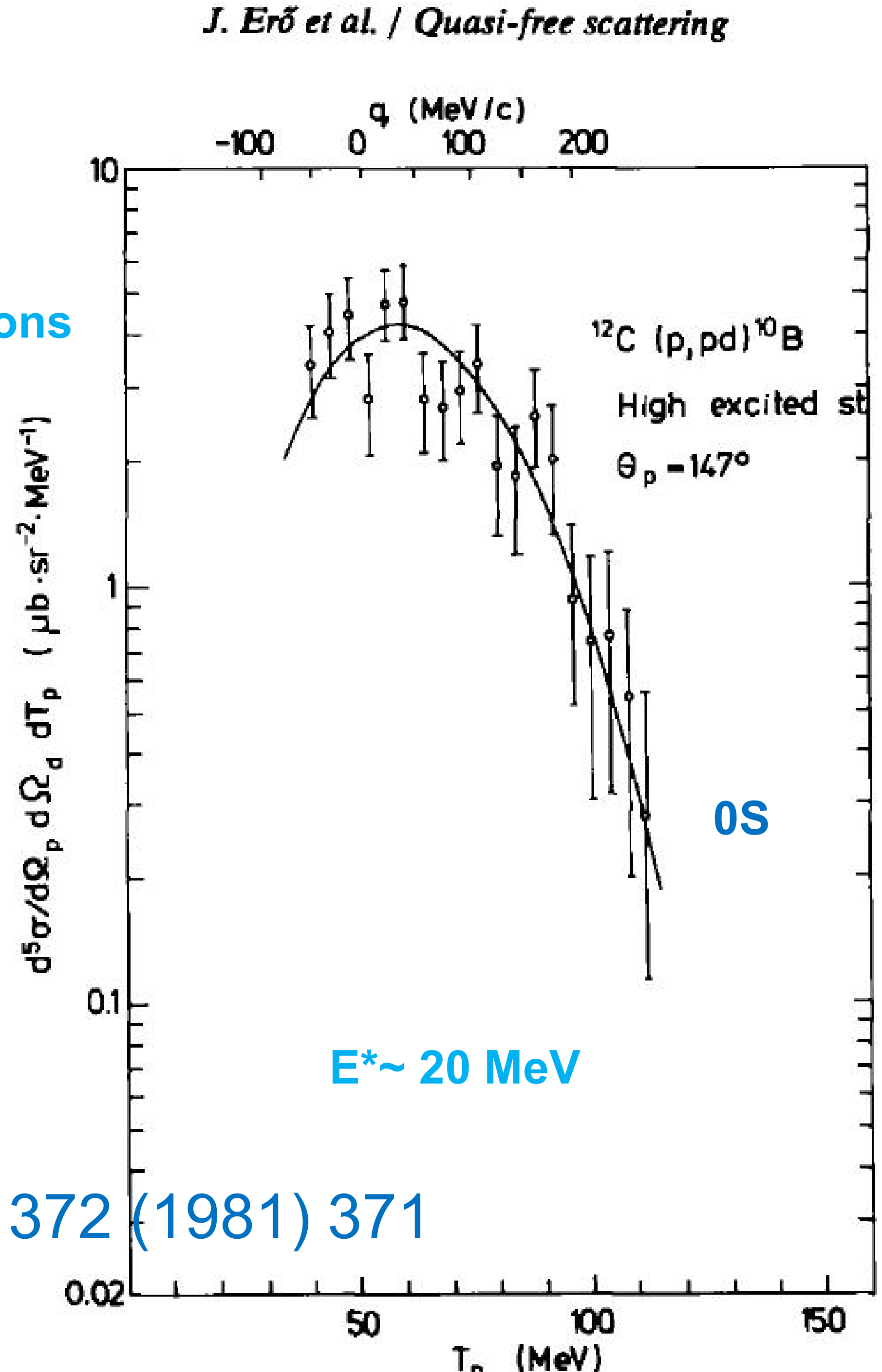
D. Albrecht et al. Nucl. Phys. A 322 (1979) 525; exp. **^{6,7}Li(p,nd) 670 MeV**

O. Imambekov, Yu.N. U., Izv. Akad. Nauk SSSR, Ser. Fiz., **51** (1987) 947- (theor. model)

Zero-point at q ≈180 MeV/c



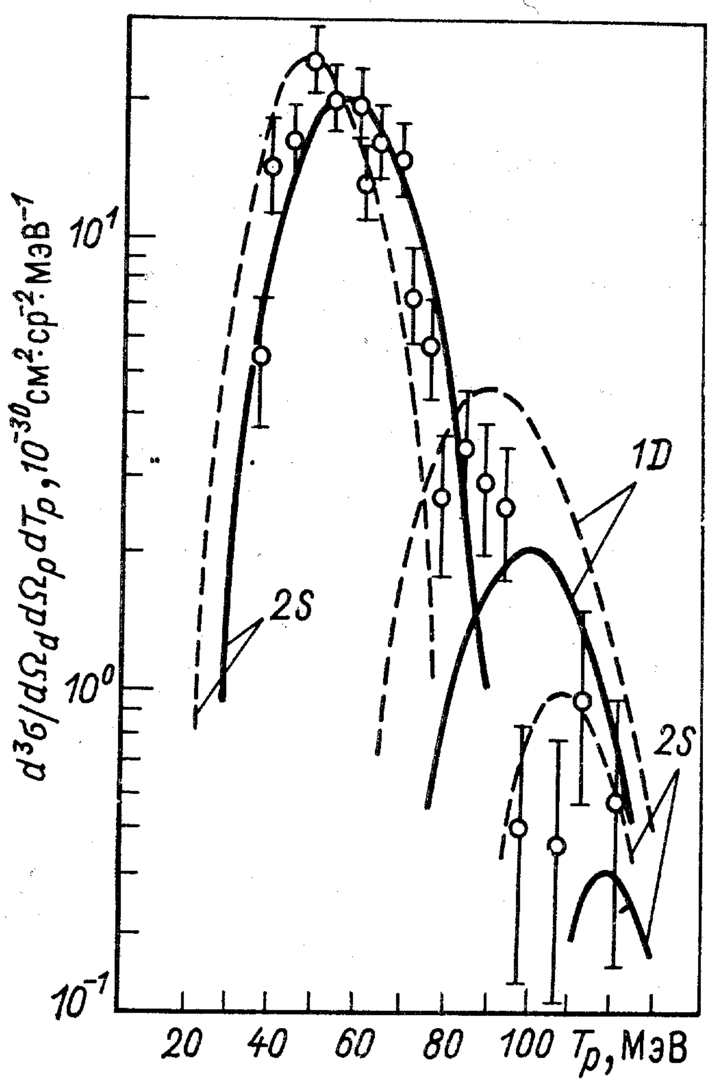
Different <NN>c.m.s. momentum distributions



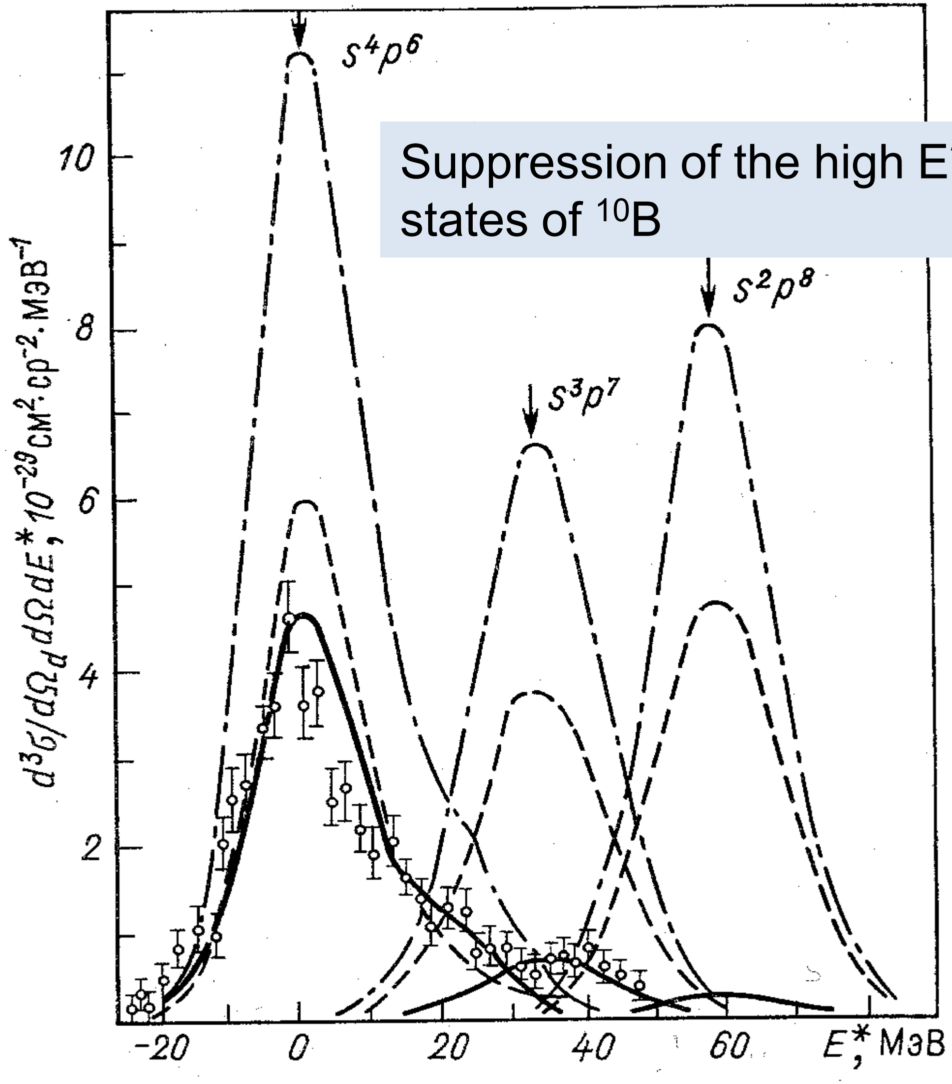
J.Ero et al. NPA 372 (1981) 371

M.A.Zhusupov,O.Imambekov, Yu.N.U. Izv.AN SSSR (1986)

FSI- strong absorption



$^{12}C(p,pd)^{10}B$ (s^4p^6)



Suppression of the high E* states of ^{10}B

$^{12}C(p,pd)^{10}B$(exited states)

SRC in A(p,3N)B

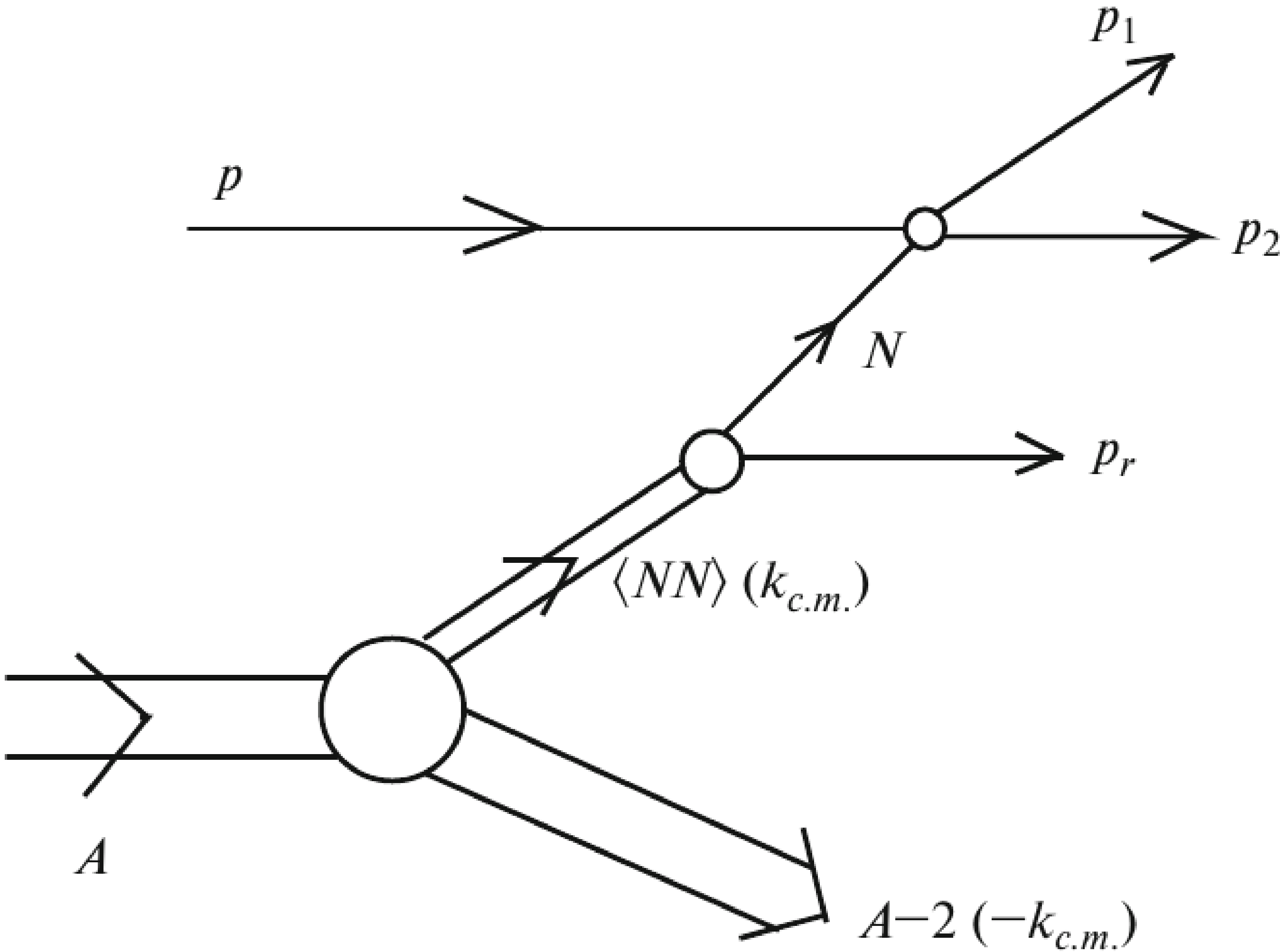


Fig. 1. The pole mechanisms of the reaction $A(p, 2pN)A-2$.

SRC from ab initio quantum Monte Carlo calculations

R.Cruz-Torres et al. Nature Phys. 17 (2021) 306 (and references therein)

NN: =AV18+UX, AV4'+UIX, N^2LO, NV2+3+Ia ; Generalized Contact Formalizm

Factorization at small r or high q:

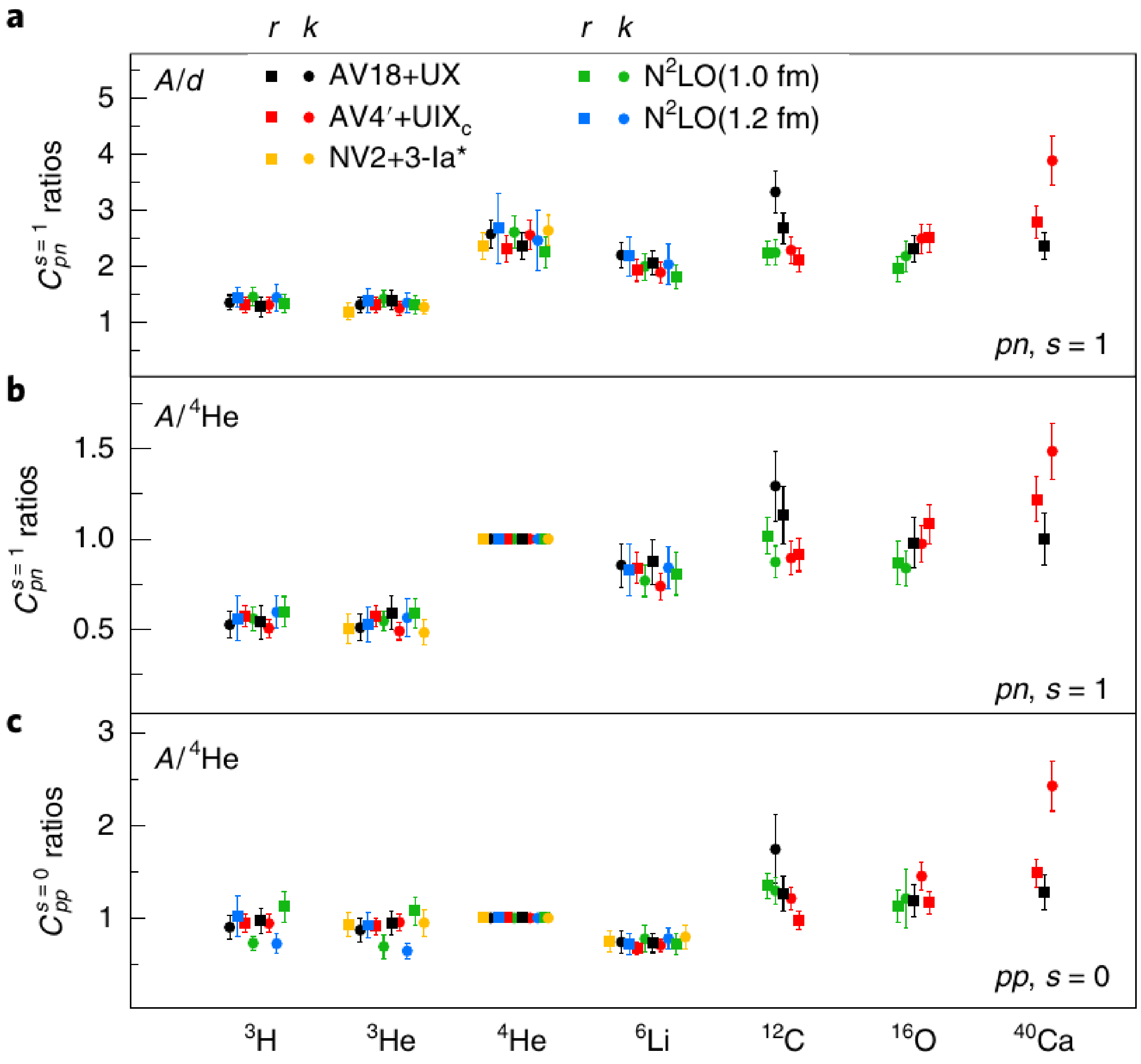
$$\rho^A_{\alpha,NN}(R,r) = C^A_{\alpha,NN}(R)\times|\varphi^\alpha_{NN}(r)|^2,$$
$$n^A_{\alpha,NN}(Q,q) = \tilde{C}^A_{\alpha,NN}(Q)\times|\tilde{\varphi}^\alpha_{NN}(q)|^2,$$

Nuclear contact coefficients:

$$C^A_{\alpha,NN} \equiv \int d\mathbf{R}\ C^A_{\alpha,NN}(\mathbf{R}),$$
$$\tilde{C}^A_{\alpha,NN} \equiv \frac{1}{(2\pi)^3}\int d\mathbf{Q}\ \tilde{C}^A_{\alpha,NN}(\mathbf{Q}),$$

"NN models with very different short-range physics all lead to the same contact term ratios A/d … Relative abundance of SRC pairs in nuclei is a long-range (that is mean-field) quantity that is insensitive the short-distance nature of the nuclear force"

Thus, at the first step, one may apply a shell model (h.o.TISM=ТИМО) with NN-correlators for the SRC analysis like it was done for the $^{12}C(p,pd)B$,



R.Cruz-Torres et al.,
Nature Phys. 17 (2021) 306

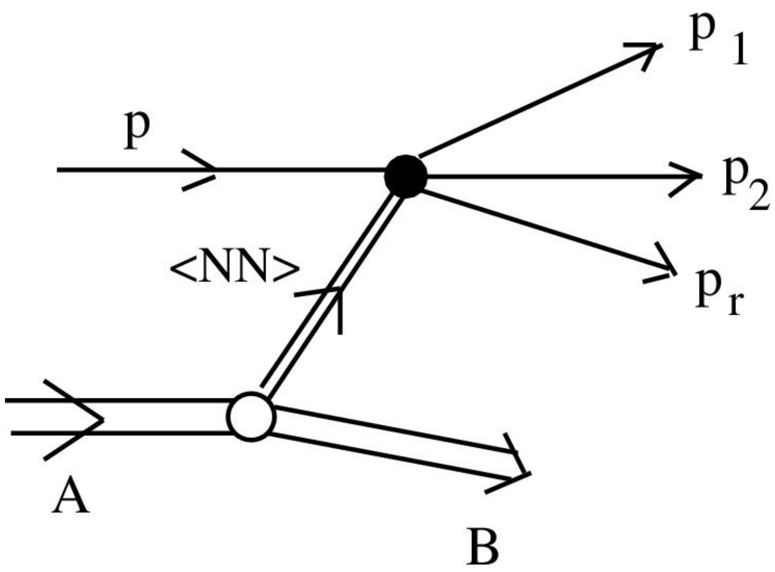
Matrix element

$$M_{fi} = M(A \to B + <NN>) \frac{1}{p_{NN}^2 - M_{NN}^2 + i\varepsilon} M(p <NN> \to ppN),$$

$$d\sigma = (2\pi)^4 \delta^4(P_i - P_f) \frac{1}{4I} |M_{fi}|^2 \Pi_{j=1}^n \frac{d^3 p_j}{2E_j (2\pi)^3}$$

In the rest frame of A:

$$M(^{12}C \to {}^{10}B + <NN>) = -\begin{pmatrix} A \\ 2 \end{pmatrix}^{1/2} < \Psi_A | \Psi_B, \Psi_{NN}, \Psi_{\nu\Lambda} >$$



$$\times (\varepsilon_A^{B+<NN>} + \frac{q^2}{2\mu}) \Psi_{\nu\Lambda M_\Lambda}(\mathbf{q}) \sqrt{2m_A 2m_B 2m_{<NN>}},$$

$$\varepsilon_A^{B+<NN>} = m_B + m_{<NN>} - m_A,$$

$$\mu = m_B m_{<NN>} / (m_B + m_{<NN>}),$$

$$\mathbf{q} = \frac{m_B \mathbf{p}_{<NN>} - m_{<NN>} \mathbf{p}_B}{m_B + m_{<NN>}}$$

Yu.N. U., Izv. RAN. Ser. Fiz. 84 (2020) 580

Spectroscopic factors within the translationally-invariant shell model (TISM)

/For future: ab initio microscopic calculations of A=12 system/

$$S^x{}_A = \binom{A}{x}^{1/2} < \psi_A | \psi_B \psi_{\nu\Lambda}(\mathbf{R}_{A-x} - \mathbf{R}_x) \psi_x >$$

$$\psi_A^{TISM} = |AN[f](\lambda\mu)\alpha LSTJMM_T >$$

Oscillator rule:

$$N_A - N_B = N_x + \nu$$

Mixing shell-model configurations:

$$\psi_{J,T}^A = \sum_{[f]LS} \alpha_{[f]LS}^{A,JT} \, |AN[f](\lambda\mu)\alpha LSTJMM_T >$$

$$|AN_A\alpha >= \sum_{\beta\gamma\Lambda M_\Lambda N_B N_x \nu} < AN_A\alpha | A - xN_B\beta, \nu\Lambda M_\Lambda, xN_x\gamma >$$

$$|BN_B\beta > |xN_x\gamma > |\nu\Lambda M_\Lambda > .$$

– *Matrix element for* $p +^{12} C \to p + p + N +^{10} B$

$$M_{fi}(pA \to ppNB) = \begin{pmatrix} A \\ 2 \end{pmatrix}^{1/2} \sum_{M_{J_d}, \bar{J}, \bar{M}, M_\Lambda} \sum_{\alpha_i, \alpha_f, N, \Lambda, \mathcal{L}} \alpha_i^{AJ_iT_i} \alpha_f^{A-2J_fT_f}$$

$$< A\alpha_i | A-2\,\alpha_f, N\Lambda; d' > (\Lambda M_\Lambda J_{d'} M_{J_{d'}} | \bar{J}\bar{M})(J_f M_{J_f} \bar{J}\bar{M} | J_i M_i)$$

$$(T_f M_{T_f} T_{d'} M_{T_{d'}} | T_i M_{T_i}) U(\Lambda L_{d'} \bar{J} S_{d'}; \mathcal{L} J_{d'}) \begin{Bmatrix} L_f & S_f & J_f \\ \mathcal{L} & S_{d'} & \bar{J} \\ L_i & S_i & J_i \end{Bmatrix}$$

$$[(2L_i+1)(2S_i+1)(2J_f+1)(2\bar{J}+1)]^{1/2} \Psi^{dist}_{N\Lambda M_\Lambda}(\mathbf{k}_B)$$

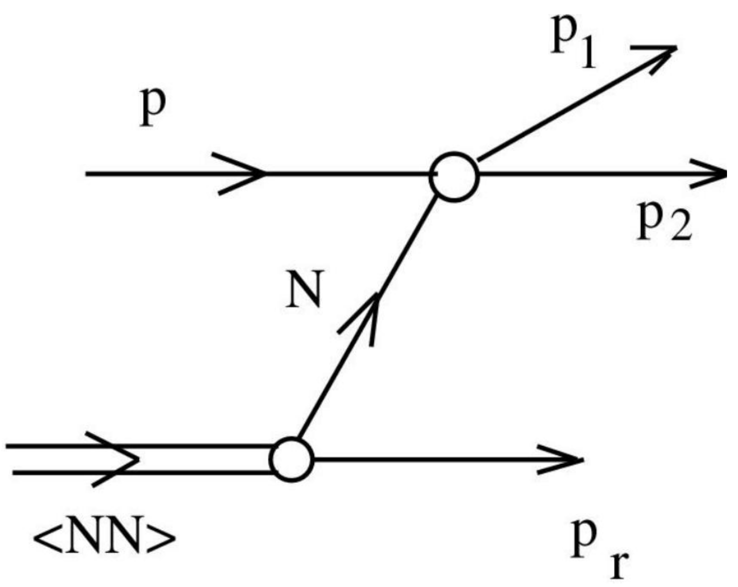
$$\times < \mathbf{p}_1\sigma_1, \mathbf{p}_2\sigma_2, \mathbf{p}_r\sigma_r | \hat{M}(p < NN > \to p_1 p_2 p_r) | \mathbf{p}\sigma_p, -\mathbf{k}_B \Psi_{NN} >$$

^{12}C: $L_i = S_i = J_i = 0, T_i = 0;\ |10B >= |s^4 p^6 >$

– Matrix element of the $p+ < NN > \rightarrow p + p + N$

In the Light front dynamics

$$M_{fi}^{LFD}(p < NN > \rightarrow p_1 p_2) = \frac{\Psi_d^{LFD}(\mathbf{k}_\perp, \xi)}{1-\xi} M_{fi}(pN \rightarrow p_1 p_2),$$



$$\xi = \frac{p_r^+}{p_r^+ + p_N^+}, \quad \mathbf{q}_\perp = (1-\xi)\mathbf{p}_{r\perp} - \xi \mathbf{p}_{N\perp},$$

$$M_{pN}^2 = \frac{m_p^2 + \mathbf{p}_{N\perp}^2}{\xi(1-\xi)}.$$

$$\Psi_d^{LFD}(\mathbf{q}) = \sqrt{\varepsilon(\mathbf{q})}\varphi_d^{nonrel}(\mathbf{q})$$

SRC

Yu.N. U., EPJ Web Conf. 222 (2019) 03027

– *Momentum distribution in* $< NN > -^{10}B_5$

TISM(ТИМО)

$N\Lambda = 20, 22$ for $|s^4p^6>$

$$R_{20}^2 = \frac{6}{\sqrt{\pi}\ p_0^3}\left[1 - \frac{2}{3}\left(\frac{p}{p_0}\right)^2\right]^2 exp\left\{-\left(\frac{p}{p_0}\right)^2\right\}, \quad (1)$$

$$R_{22}^2 = \frac{16}{15\sqrt{\pi}\, p_0^3}\left(\frac{p}{p_0}\right)^4 exp\left\{-\left(\frac{p}{p_0}\right)^2\right\} \quad (2)$$

$N\Lambda = 00$ for $|s^2p^8>$

$$R_{00}^2 = \frac{4}{\sqrt{\pi}\, p_0^3} exp\left\{-\left(\frac{p}{p_0}\right)^2\right\}$$

where $p_0 = \sqrt{\mu}/r_0 = \sqrt{\mu} p_0^{h.o.}$;
$\mu = \frac{m_1 m_2}{m_1 + m_2} = \frac{5}{3}$ – the reduced mass of the $d -^{10} B$ system in m_N;
r_0 is the h.o. shell model parameter;
$p_0^{h.o.} = \hbar/r_0$

The <NN> c.m. distribution in mean-field model

(Cioffi degli Atti, Simula, PRC, 1996)

$$\langle (\Sigma_{i=1}^{A} \vec{k}_i)^2 \rangle = 0, \qquad < k^2_{c.m.} >= \frac{2(A-2)}{A-1} < k^2 >$$

$$n_{c.m.}(k_{c.m.}) = C \exp(-\alpha_{c.m.} k^2_{c.m.}) \qquad < k^2_{c.m.} >= 3/2\alpha_{c.m.}$$

Antisymmetrization effects are not taken into account;
s-shape is assumed.

$$\alpha_{c.m.} = \frac{3(A-1)}{4(A-2)} \frac{1}{2M < T >}$$

$$T_s = \frac{3}{2} \frac{p_0^2}{2M} \text{ and } T_p = \frac{5}{2} \frac{p_0^2}{2M}$$

$$< T >= \frac{4T_s + 8T_p}{12} = \frac{13}{6} \frac{p_0^2}{2M}$$

$$p_0 = ?$$

Charge form factor of the ^{12}C

$$\rho(r) = 2R_{00}^2(r) + 4R_{11}^2(r)$$

$$= \frac{8}{r_0^3\sqrt{\pi}}\left[1 + \frac{4}{3}\left(\frac{r}{r_0}\right)^2\right]\exp\left(-\frac{r^2}{r_0^2}\right),$$

where $r_0 = \hbar/p_0$. Then the charge form factor is

$$F(q) = \int d^3r\rho(r)\exp\left(i\frac{A-1}{A}\mathbf{qr}\right).$$

F_{ch} fit: p_0=109 MeV/c;

$$R_{00}^2(p_{cm}) = C\exp\left\{\frac{p_{cm}^2}{P_0^2}\right\};$$

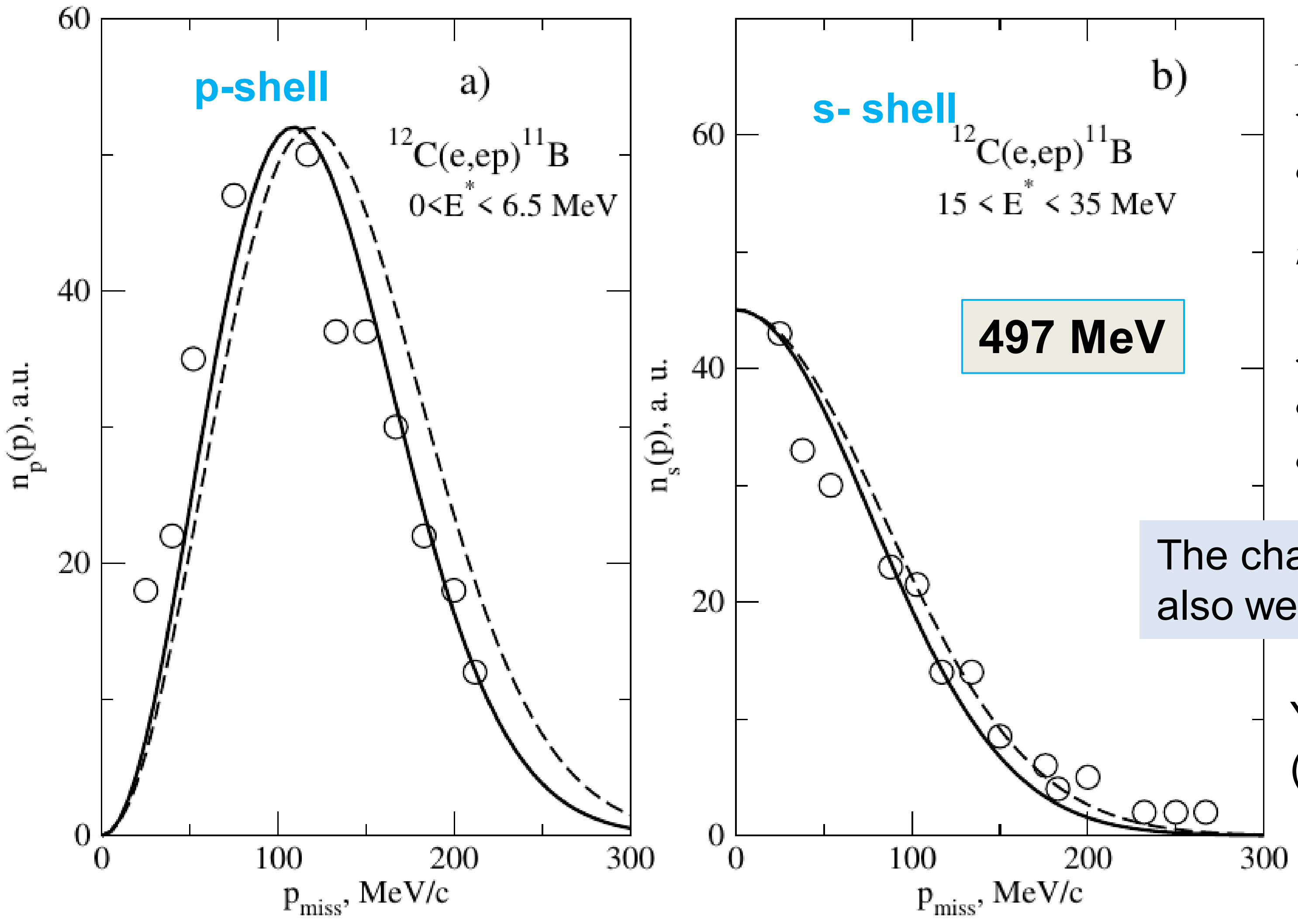
$$\tilde{p}_0 = \sqrt{\frac{12}{11}}p_0 = 113.8MeV/c, \langle T \rangle = 15MeV$$

$$TISM: P_0^2 = \frac{5}{3}\tilde{p}_0^2$$

$$P_0 = 146.8MeV/c$$

Talmi-Moshinsky for ^{10}A - 2 relative motion

^{12}C(e,ep) ^{11}B: Data – A. Dieperink, T. Forest, Ann. Rev. Nucl. Part. Sci. 25 (1975) 1.



$Mean - field - model, C. - \circ\, deg. - \circ\, Atti, Simula(1996$

$< T >= 16.9 MeV; \alpha_{c.m.} = 1.0 fm^2;$

$\sigma = 142.8 MeV / c;$

$$n(p_{cm}) = C \exp\left\{-\frac{p_{cm}^2}{2\sigma^2}\right\} = C \exp(-\alpha_{cm} p_{cm}^2);$$

$fit - \circ\, to - \circ\, ^{12}C(e,ep)^{11}B - \circ\, ^{12C} F_{ch} : - \circ < T >= 14.9 Me$

$\sigma^{TISM} = 103 MeV / c$

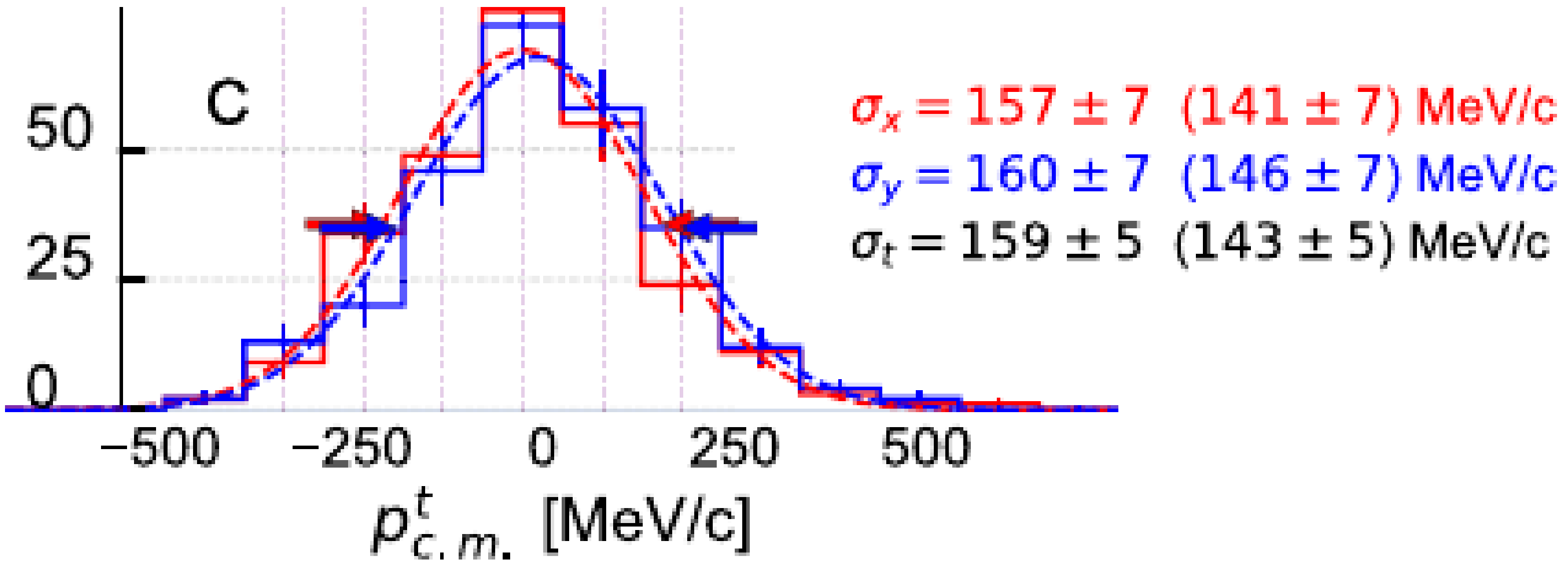
$\sigma_{exp.}(e,epp) = (143 \pm 6) MeV / c$

The charge form factor of ^{12}C is also well described

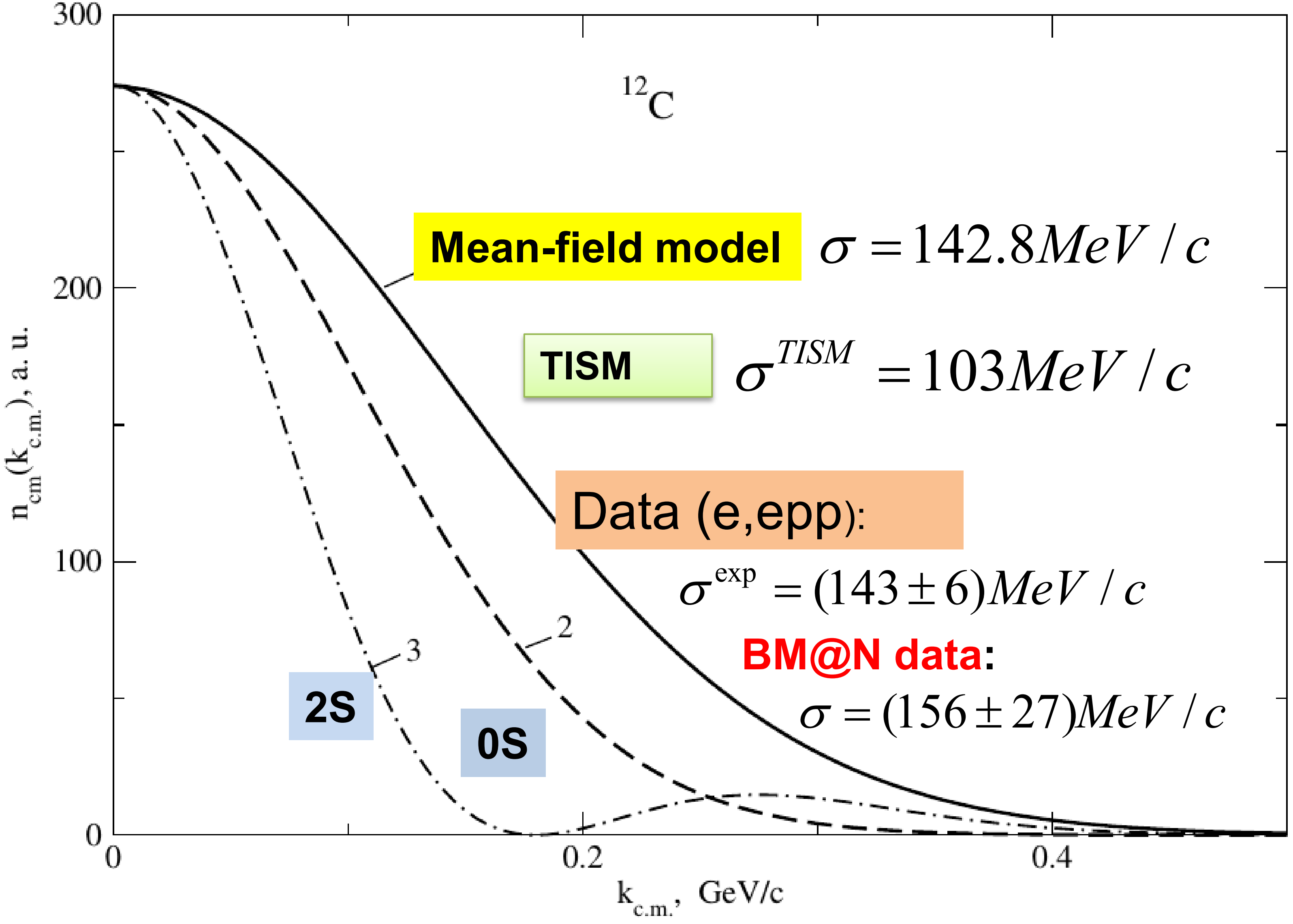
Yu.N.U. Phys. Part. Nucl. 52 (2021)652

Fig. 2. Single nucleon momentum distribution in the reaction $^{12}C(e,ep)^{11}B$ at electron beam energy 497 MeV for the p-shell (a) and s- shell nucleons (b) corresponding to transitions to the states of the residual nucleus ^{11}B with excitation energy $0 < E^* < 6.5$ MeV and $15 < E^* < 35$ MeV, respectively. The curves show the results of our calculations in the plane wave impulse

E. Cohen et. al. PRL 121 (2018) 092501



Comparison with calculations appears to show that the SRC pairs are formed from mean-field nucleons in specific quantum states.



TISM

$$\nu = N_A - N_x - N_{A-x}$$

$$N_x = 0, N_A = 8$$

$$R_{\nu\Lambda}(k_{c.m.})$$

$$s^4 p^6, \nu = 2$$

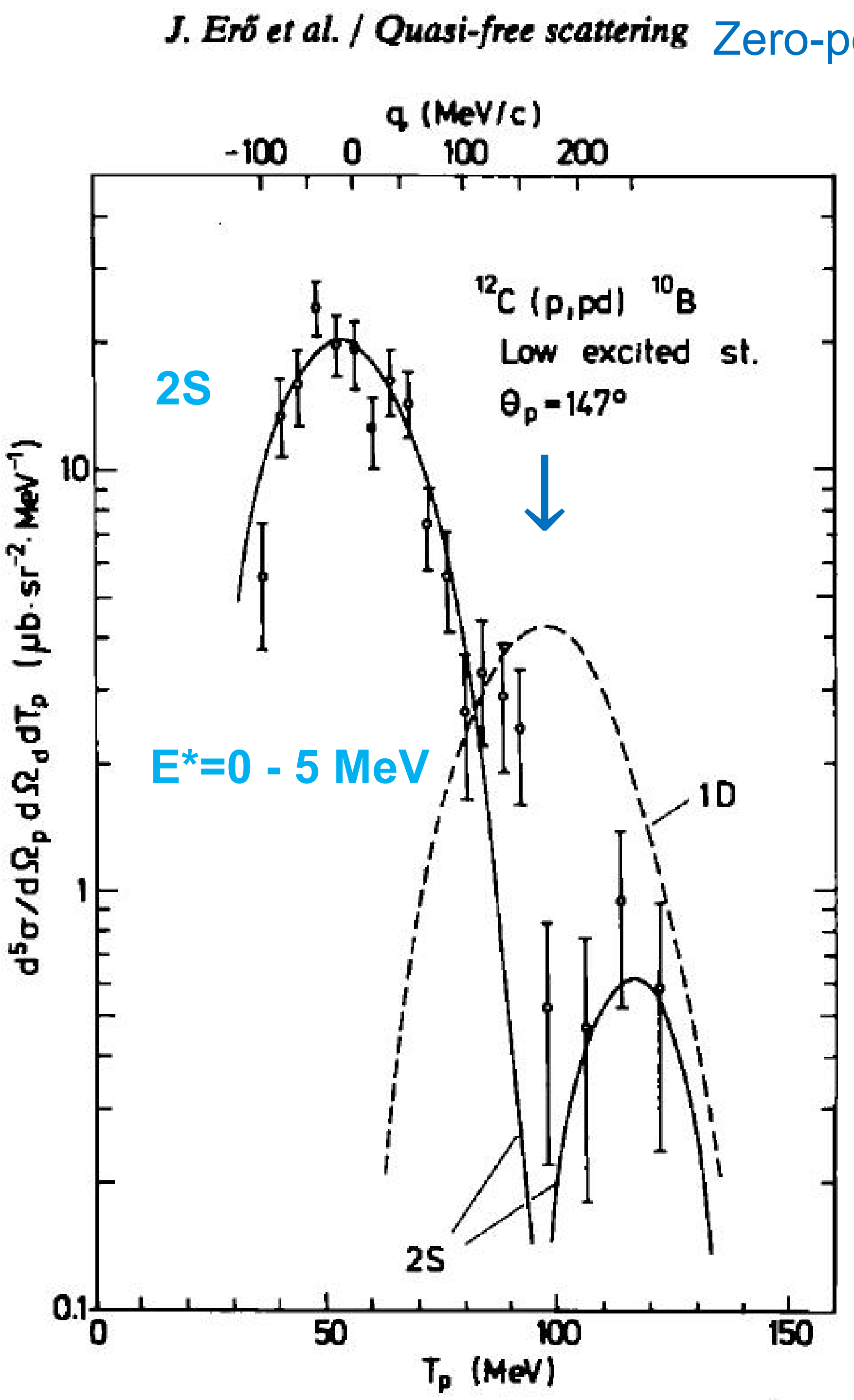
$$s^2 p^8, \nu = 0$$

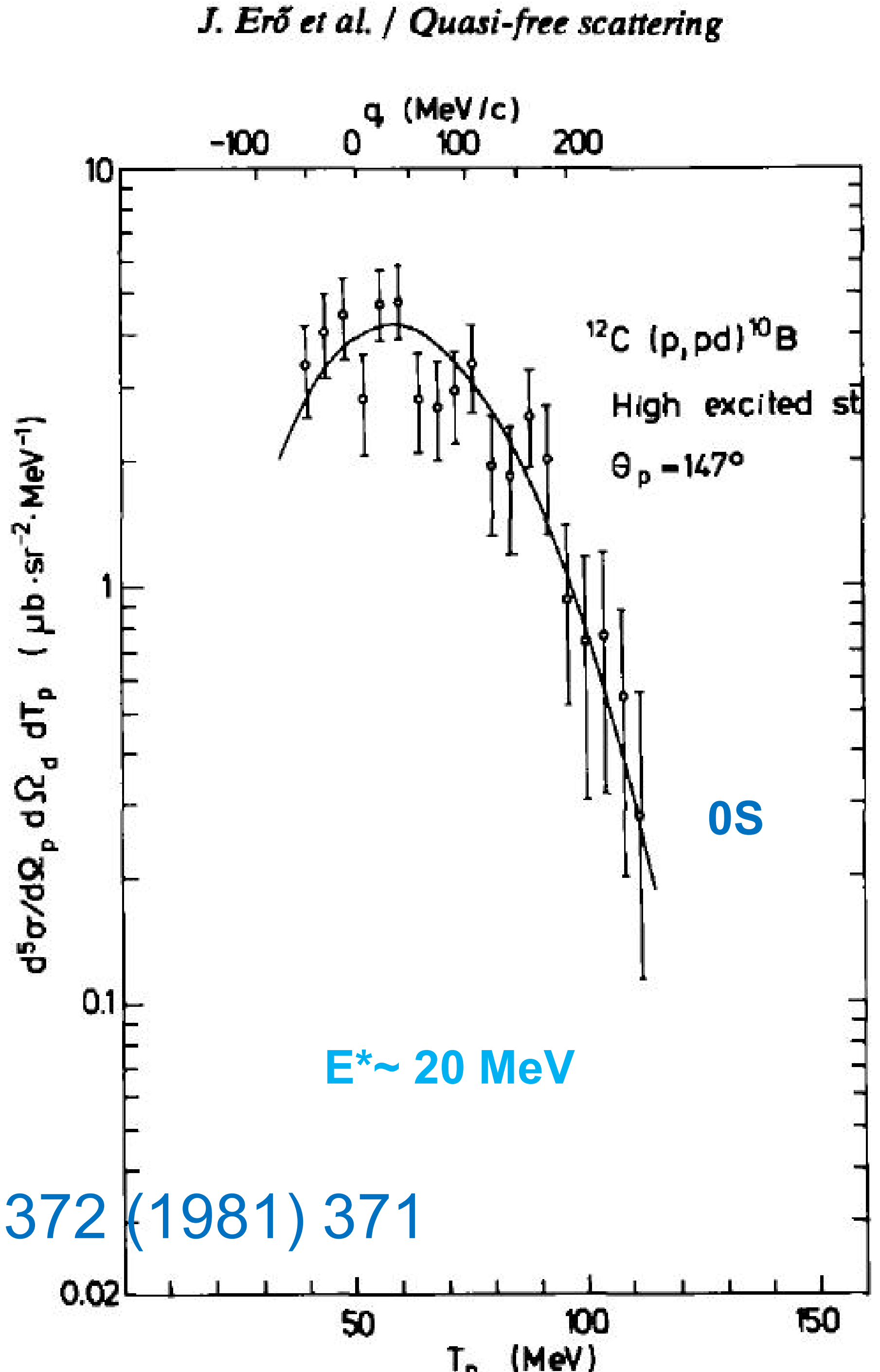
$k_{c.m.}$- PUZZLE

Fig. 3. Distribution over the c.m. momentum of the SCR pair $p_{c.m.}$ in the ^{12}C for the mean-field model with $\alpha_{c.m.} = 0.95\ fm^2$ (full line) and the TISM wave function squared with $p_0 = 146.9$ MeV/c for the 0S-type (dashed), and 2S-type (dashed-dotted). All distributions are arbitrary normalized at $p_{c.m.} = 0$ to the same value.

Zero-point at q ≈180 MeV/c

12C(p,pd)10B
670 MeV





J.Ero et al. NPA 372 (1981) 371

pp/pn ratio

$$S_A^x = \binom{A}{2}^{1/2} \frac{1}{\sqrt{2T+1}} PC(S,T)$$

$$|M_{fi}(A(p,2pN)B)|^2 \propto \frac{1}{2T+1} n_{cm}(k_{c.m.}) n_{NN}(q_{rel}) |M^{pN}|^2 [I_{pN} PC(s,T)]^2$$

$$R = \frac{pp}{pn} = \frac{(pp)_{S=1,T=1}}{(pn)_{S=1,T=0} + (pn)_{S=0,T=1}} = \frac{1}{2} R_{rel}$$

$$^{12}C : |[444], L_i = 0, S_i = 0, T_i = 0, J_i = 0 >$$

$$PC(S=1,T=0) = PC(S=0,T=1)$$

pp to pn pairs ratio of the spectroscopic factors: 1/2

GCF: Contact terms ratio $C_{S=0}(pp)/C_{S=1}(pn)$~ 1/14

R. Cruz-Torres, et al. Nature Phys. 17 (2021) 306; R.Weiss et al. PLB 780 (2018) 211

pp/pn ratio

$$R_{rel} = \int_{q_{\min}}^{q_{\max}} dq q^2 \psi^2{}_{pp;ST=01}(q) / \int_{q_{\min}}^{q_{\max}} dq q^2 \psi^2{}_{d;ST=01}(q);$$

$$\psi_{10}^2(q) = u^2(q) + w^2(q); \psi_{01}(q), pp(^1S_0) - scattering;$$

$$\int_0^{\infty} dq q^2 \psi_{ST}^2(q) = 1;$$

Table 1. The $(ST = 01)/(ST = 10)$ ratio R_{rel} versus q_{min} at $q_{max} = 1.0 \div 2.0$ GeV/c

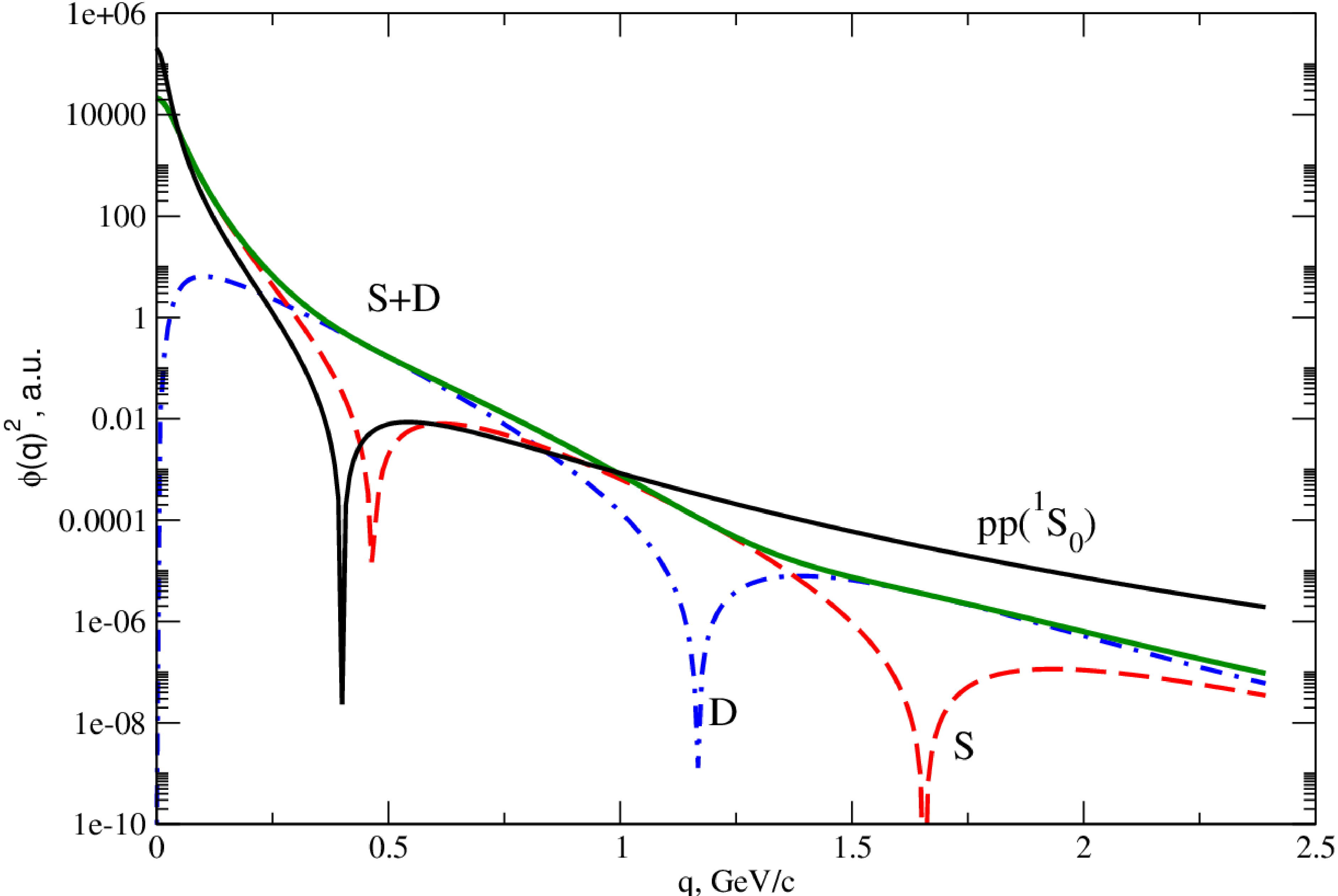
q_{min}, GeV/c	R_{rel}	q_{min}, GeV/c	R_{rel}
0.2	0.15	0.6	0.27-0.3
0.3	0.06-0.07	0.7	0.39-0.54
0.4	0.09 -0.10	0.8	0.55-0.88
0.5	0.17-0.2	0.9	0.78-1.5

$$R = \frac{pp}{pn} = \frac{pp}{(pn)_{S=1,T=0} + (pn)_{S=0,T=1}} = \frac{1}{2} R_{rel}$$

M.Duer et al. (CLAS coll.) PRL 122 (2019) 172502

R_{rel}=0.06-0.07 at q_{min}=0.3 GeV/c, q_{max}=1-2 GeV/c
pp/pn=0.03-0.035
R_{exp}=5% (that is 3% with account for charge-exchange in the final state)

pp and deuteron internal momentum distribution



pp(1S0) scattering
Lensky V. et al.,
EPJ A 26 (2005)107
CD – Bonn NN

Yu. Uzikov, A. Uvarov, Phys. Part. Nucl. **53** , №2, 426 (2022).

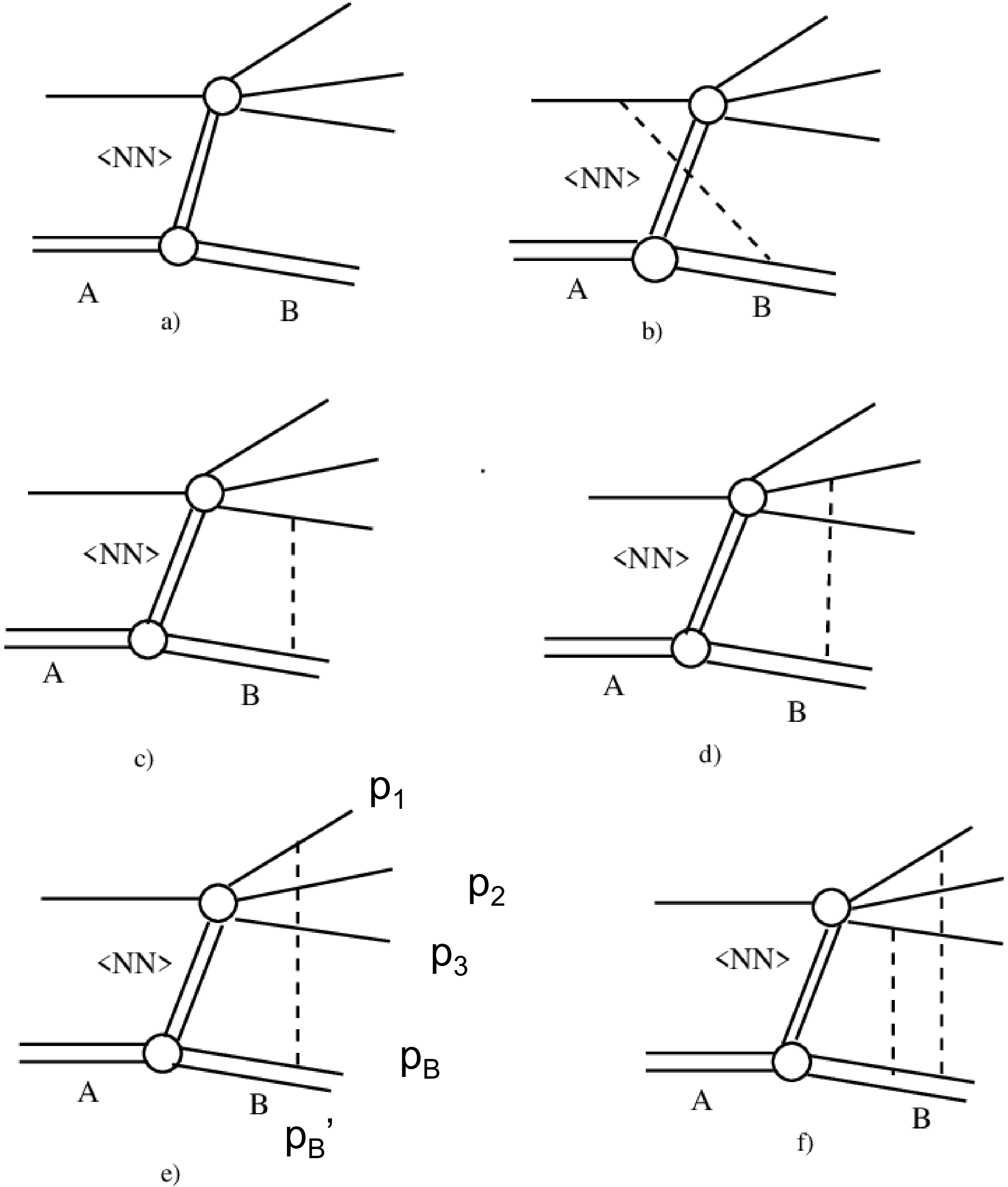
How to take into account ISI and FSI?

Transition matrix element

$$T_{fi} = \binom{A}{x}^{1/2} \sum_{x' \ \nu\Lambda} < \psi_A | \psi_B \psi_{x'}, \psi_{\nu\Lambda} > \Phi_{\nu\Lambda}(\mathbf{k}_B) T^{px' \to Nx}.$$

$$T^{px' \to Nx} = < \mathbf{k}_N \mathbf{k}_x \chi_N \psi_x | \tau(px' \to Nx) | \mathbf{k}_p, -\mathbf{k}_B \chi_p \psi_{x'} >$$

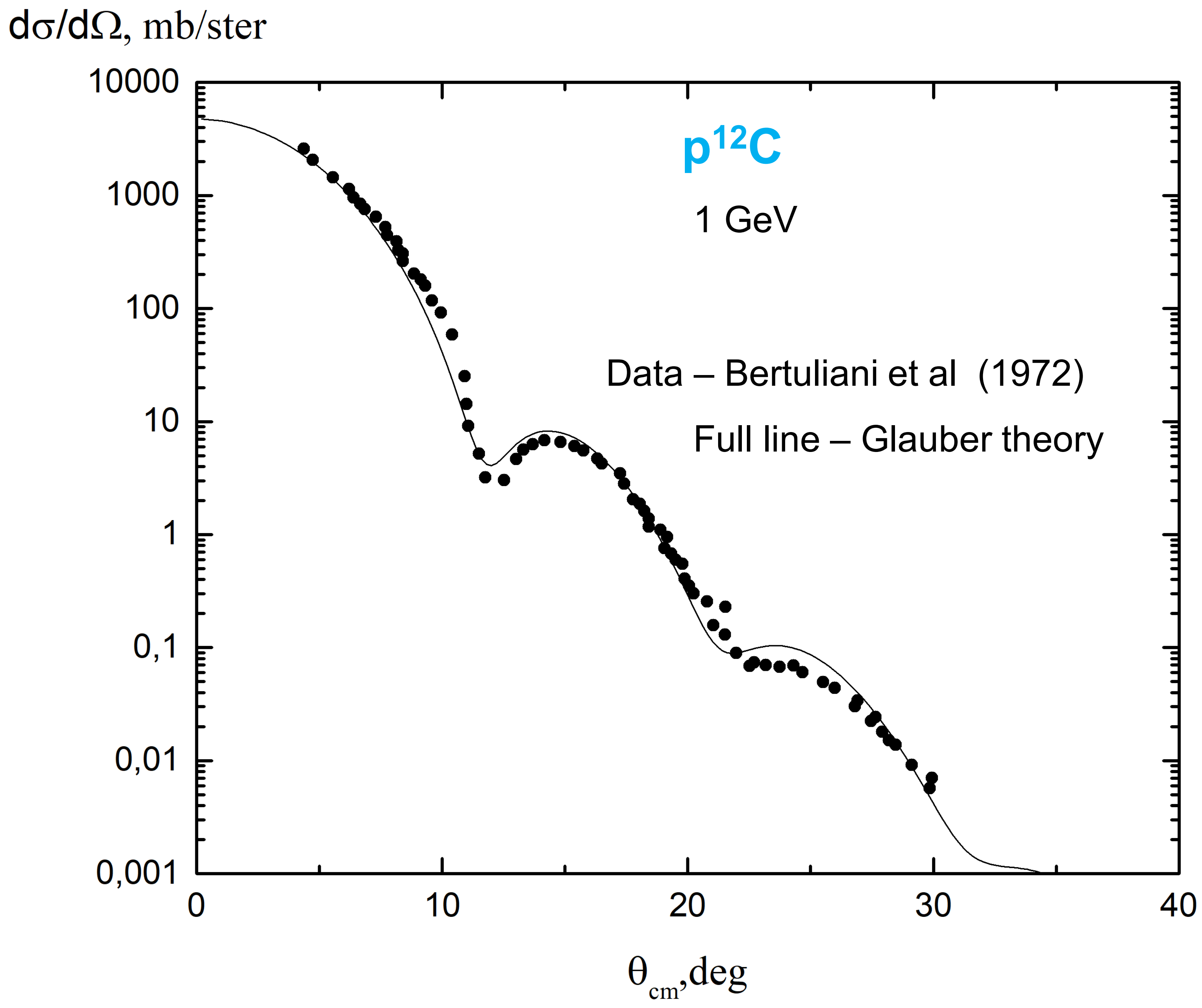
$$N_A - N_B = N_x + \nu$$



ISI@FSI ELASTIC RESCATTERINGS

Feynman graphs + generalized eikonal appr.
L.L. Frankfurt et al. PRC 56(1997) 2752

T-operator formalism with eikonal appr.
kollinear kinematics.
M.A. Zhusupov, Yu. N. Uzikov ,
Fiz. Elem. Chast. At. Yadr. 18(1987) 323



dσ/dΩ, mb/ster
10000
1000
100
10
1
0,1
0,01
0,001
0
10
20
30
40
θcm,deg
p12C
1 GeV
Data – Bertuliani et al (1972)
Full line – Glauber theory

Feynman graphs + generalized eikonal approximation (GEA)
L.L. Frankfurt et al. PRC 56(1997) 2752

$$\frac{1}{(p_1 + p_B - p_{B'})^2 - m^2 + i\varepsilon} \cong \frac{1}{2p_{1z}} \frac{1}{p_{B'_z} - p_{B_z} + \Delta_1 + i\varepsilon};$$

$$\Delta_1 = -\frac{\vec{p}_{1t}}{p_{1z}}(\vec{p}_{Bt} - \vec{p}_{B'_t}) + \frac{E_1}{p_{1z}}(E_B - E_{B'});$$

$$\Delta_1 \neq 0 -> GEA$$

T-operator formalism, eikonal appr.; kollinear kinematics. M.A. Zhusupov, Yu.N.U. Sov.J.Part.Nucl 18 (1987)

$$\Phi_{\nu\Lambda}(\mathbf{k}_B) = \psi_{\nu\Lambda}(\mathbf{k}_B) + \frac{i}{4\pi k_{pA}} \int d^2\mathbf{q}_p F_{pB}(\mathbf{q}_p) \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_p) +$$

$$+ \frac{i}{4\pi k_{xB}} \int d^2\mathbf{q}_x F_{xB}(\mathbf{q}_x) \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_x) + \frac{i}{4\pi k_{NB}} \int d^2\mathbf{q}_N F_{NB}(\mathbf{q}_N) \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_N)$$

$$- \frac{1}{(4\pi)^2 k_{pA}\ k_{NB}} \int d^2\mathbf{q}_p\ d^2\mathbf{q}_N F_{pB}(\mathbf{q}_p)\ F_{NB}(\mathbf{q}_N)\ \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_N - \mathbf{q}_p) -$$

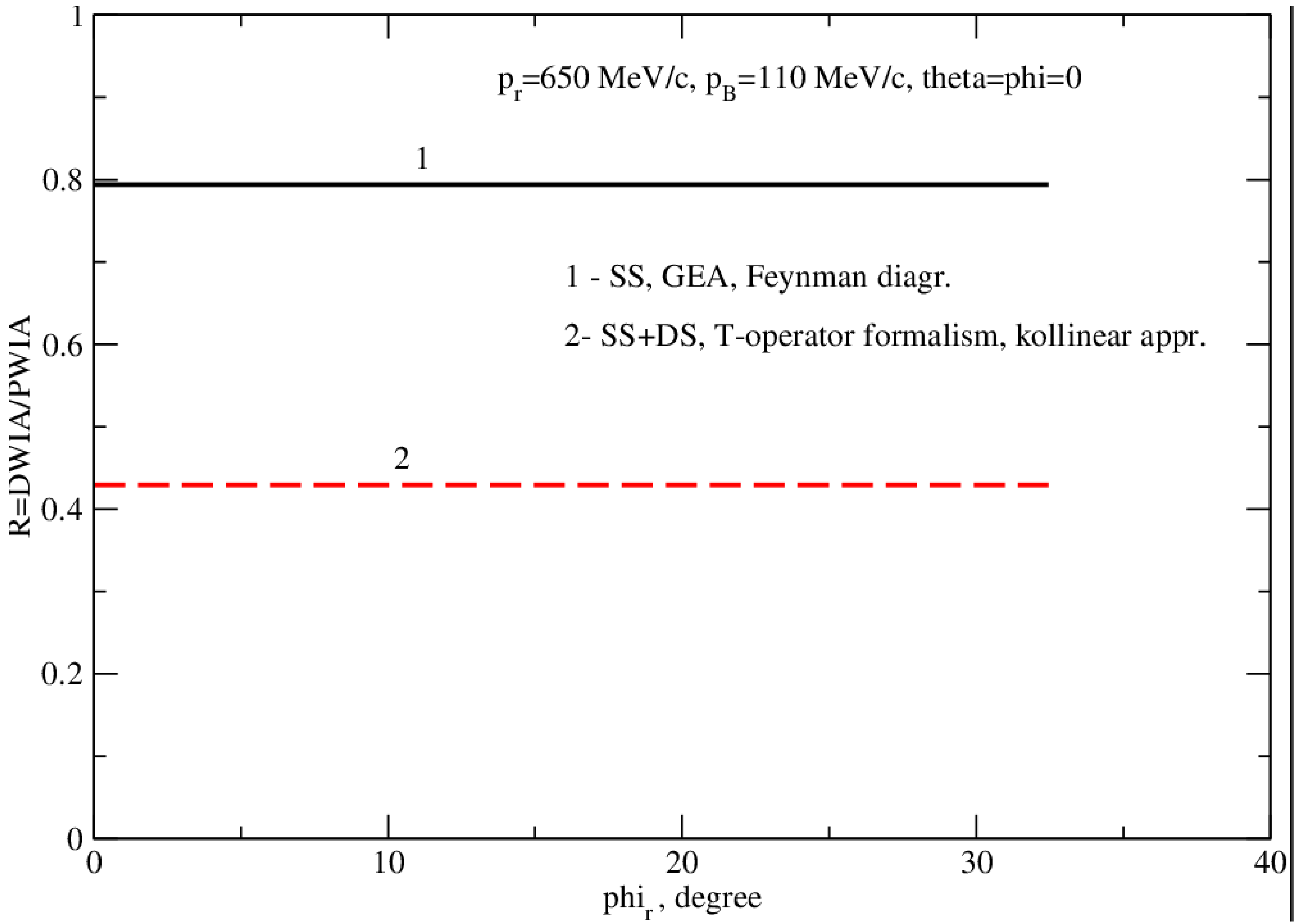
$$- \frac{1}{(4\pi)^2 k_{pA}\ k_{xB}} \int d^2\mathbf{q}_p\ d^2\mathbf{q}_x F_{pB}(\mathbf{q}_p)\ F_{xB}(\mathbf{q}_x)\ \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_p - \mathbf{q}_x) -$$

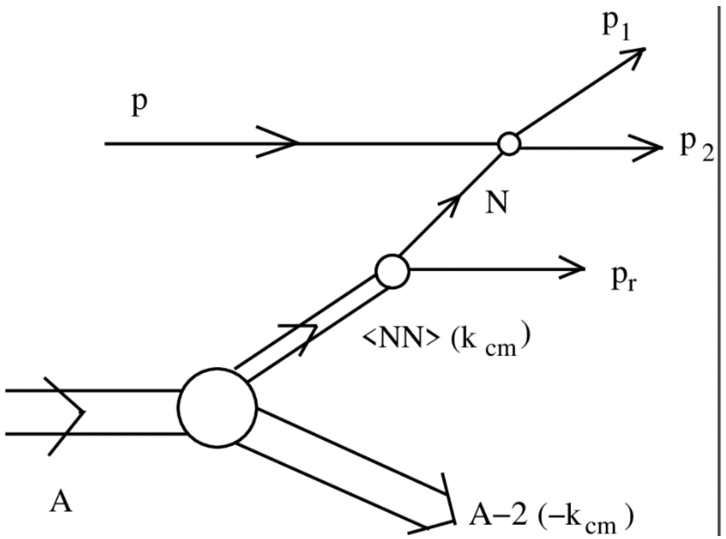
$$- \frac{1}{(4\pi)^2 k_{xB}\ k_{NB}} \int d^2\mathbf{q}_x\ d^2\mathbf{q}_N F_{xB}(\mathbf{q}_p)\ F_{NB}(\mathbf{q}_N)\ \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_p - \mathbf{q}_N) -$$

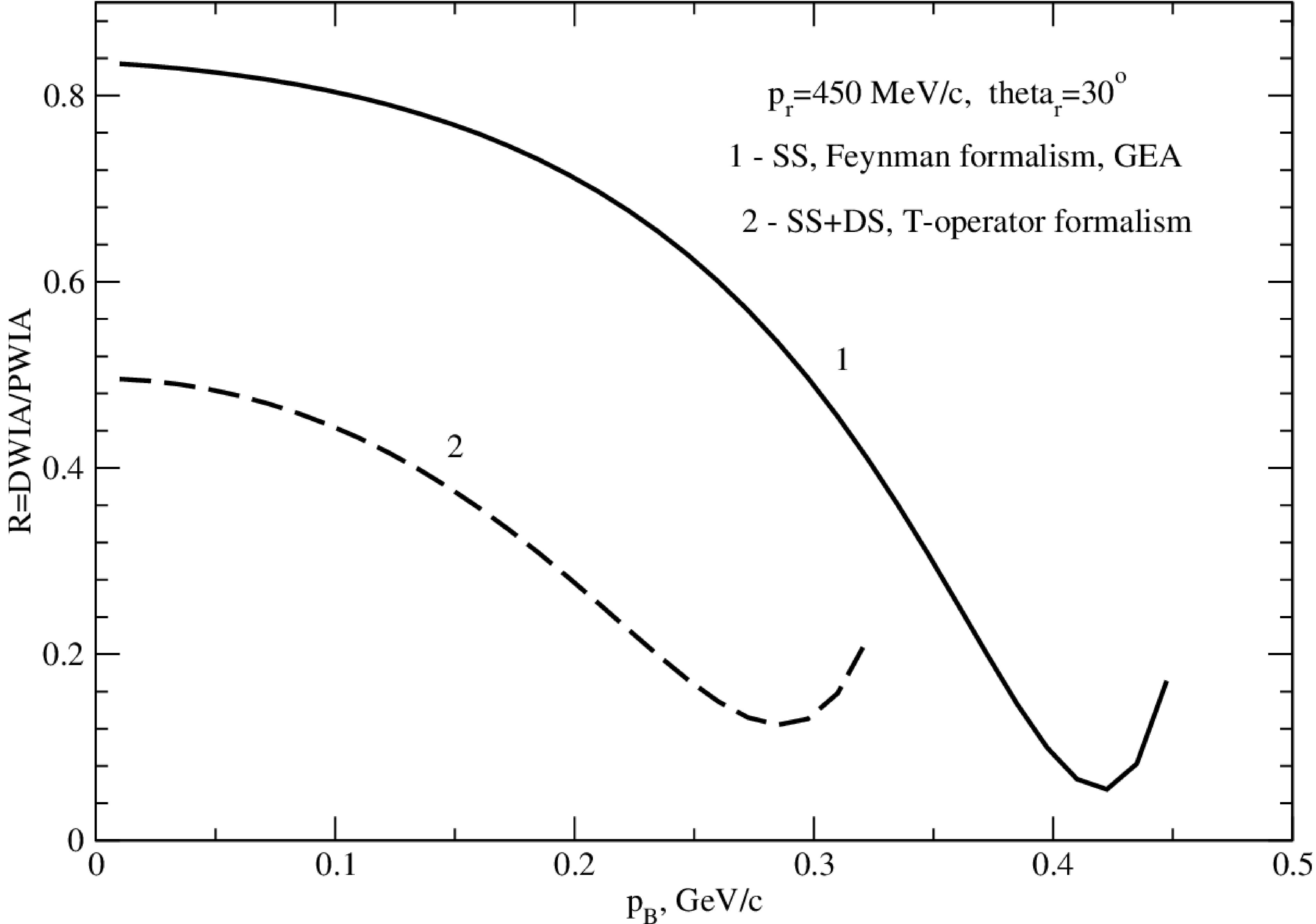
$$- \frac{i}{(4\pi)^3 k_{pA}\ k_{NB}\ k_{xB}} \int d^2\mathbf{q}_p\ d^2\mathbf{q}_N d^2\mathbf{q}_x \times$$

$$\times F_{pB}(\mathbf{q}_p)\ F_{NB}(\mathbf{q}_N)\ F_{xN}(\mathbf{q}_x)\ \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_N - \mathbf{q}_p - \mathbf{q}_x).$$

Yu. U., Acta Phys. Pol. B Proc. Suppl. 14 , № 4, (2021) 793.







p_r=450 MeV/c, $theta_r$=30^o
1 - SS, Feynman formalism, GEA
2 - SS+DS, T-operator formalism
1
2
R=DWIA/PWIA
p_B, GeV/c
0
0.1
0.2
0.3
0.4
0.5
0.2
0.4
0.6
0.8

SUMMARY

- TISM applied for the $k_{c.m}$ distribution of <NN> clusters works quite well in the case of $^{12}C(p,pd)^{10}B$ reaction at separation of s^4p^6 and s^2p^8 states of the ^{10}B.

- TISM allows oneto **explains** **pp/pn** ratio for SRC in ^{12}C, but **fails** to describe data on the $k_{c.m}$ – distribution (whereas a simple **mean–field** model is OK).

- ISI@FSI effects in differential cross sections of the reaction $^{12}C(p,2pN)^{10}A$ in kinematics of the BM@N SRC experiment are **not negligible**:
  - suppression factor R=DWIA/PWIA ~ 0.4-0.8;
  - smooth dependence on all scattering angles and momenta except of p_B –dependence

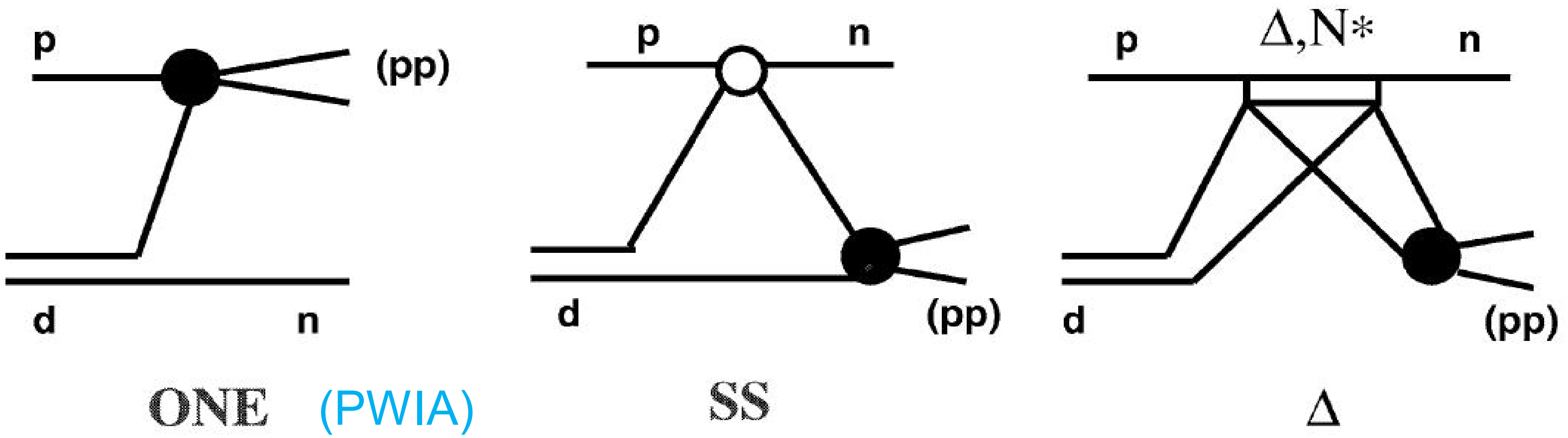
- A study of SRC pairs in A(p,3N)B with separation of the final states of the residual nucleus and BM@N conditions will be very important.

- Is TISM it too simple for SRC?
  Further study using the ^{12}C w.f. based on microscopic ab initio calculations /M.Piarulli et al.PRC 107 (2023)/ **is necessary**

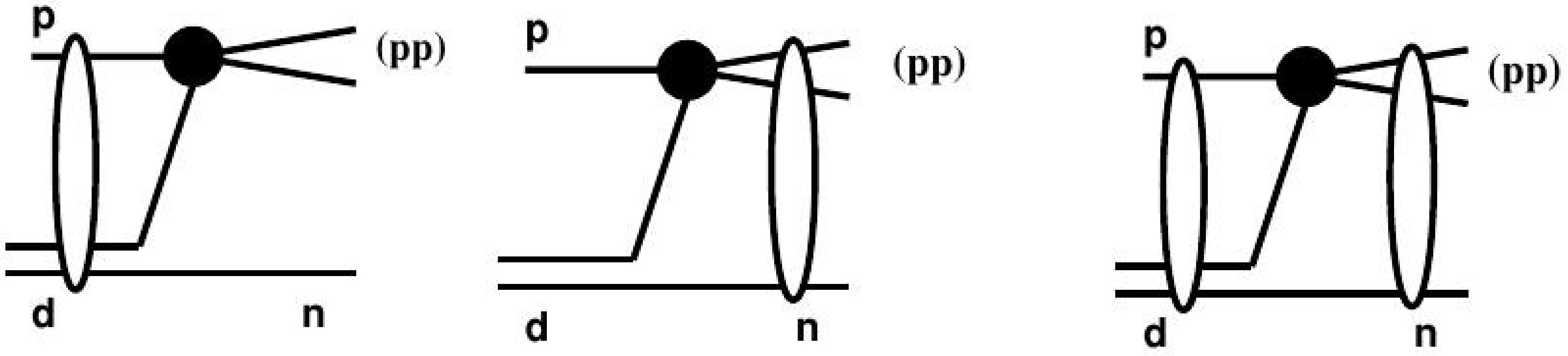
THANK YOU FOR ATTENTION!

BUCKUP

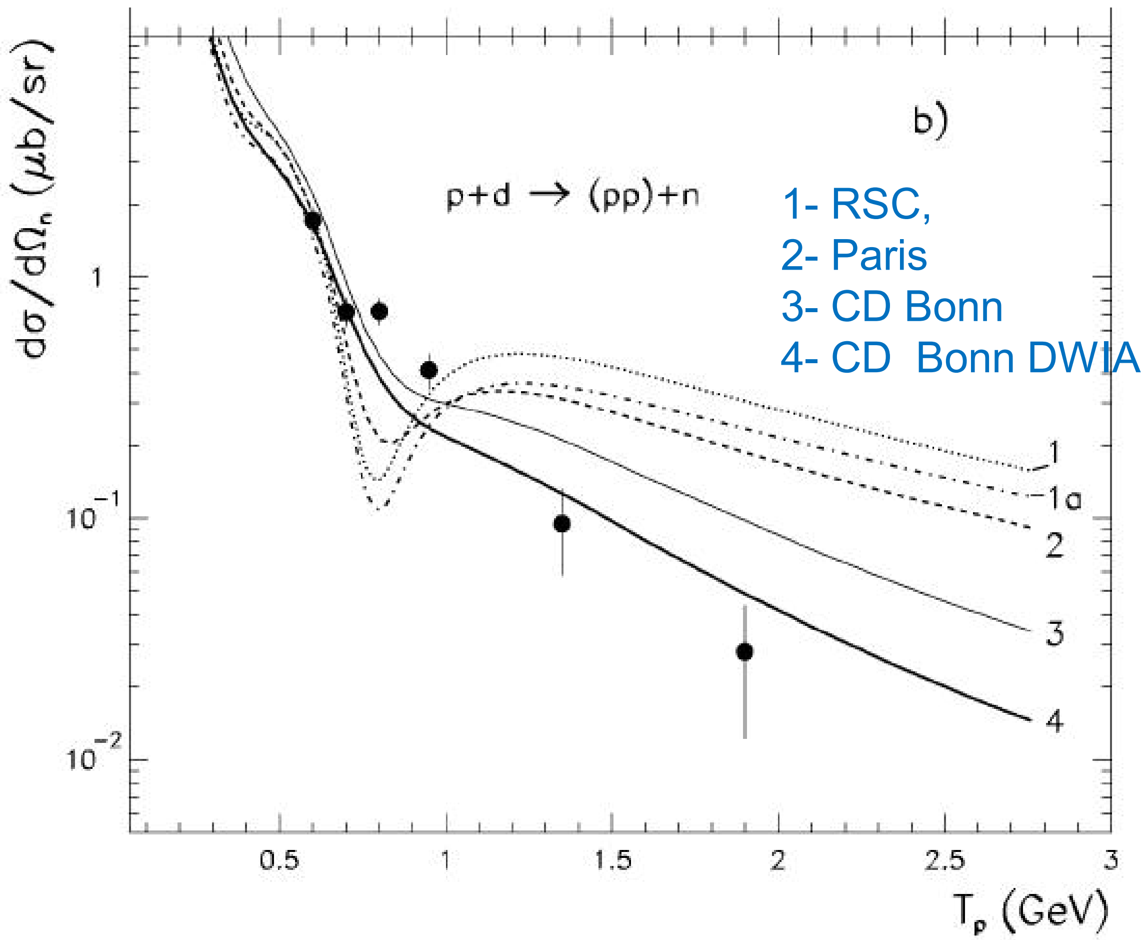
J. Haidenbauer, Yu.N. Uzikov / Physics Letters B 562 (2003) 227–233



Mechanisms of the breakup reaction $pd \to (pp)n$. The same mechanisms are used for the reaction $pd \to dp$.

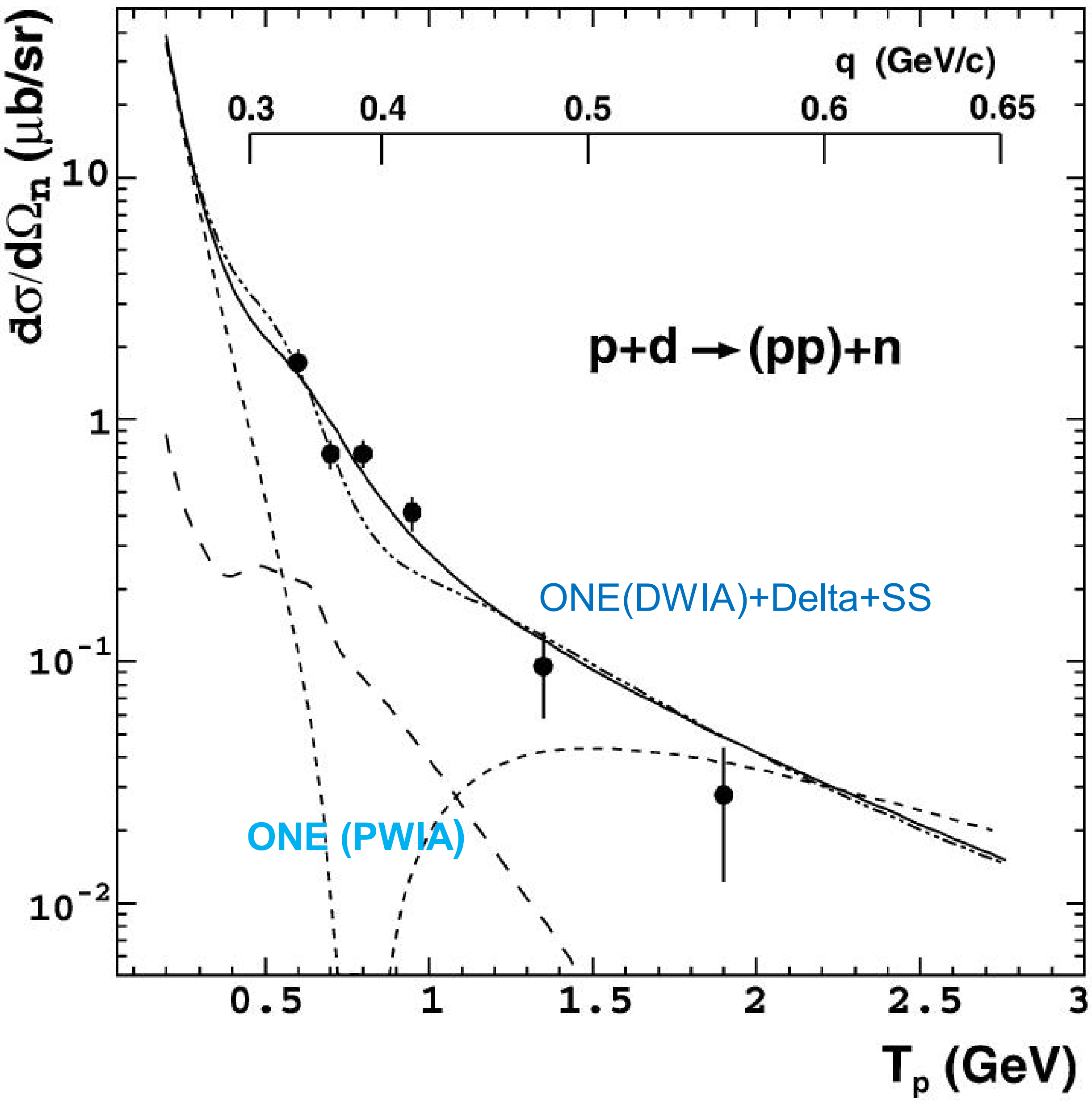


ONE (DWIA)



ONE+Delta+SS

J. Haidenbauer, Yu.N. Uzikov / Physics Letters B 562 (2003) 227–233



PARENTAGE COEFFICIENTS of TISM

$$< AN_i = 8[f_i](\lambda_i\mu_i)\alpha_i L_i S_i T_i | A{-}2 N_f [f_f](\lambda_f\mu_f)\alpha_f L_f S_f T_f, \nu\Lambda; N_x L_x S_x T_x : L_i S_i T_i >$$

N_f	6							
$[f_f]$	[442]							
$(\lambda_f\mu_f)$	(22)							
$\nu\Lambda$	00				22			
$N_x L_x$	22				00			
$^{2T_f+1\,2S_f+1}L_f$	$^{13}D_I$	$^{31}D_I$	$^{13}D_{II}$	$^{31}D_{II}$	$^{13}D_I$	$^{31}D_I$	$^{13}D_{II}$	$^{31}D_{II}$
PC	$\sqrt{\frac{1}{264}}$	$\sqrt{\frac{1}{264}}$	$-\sqrt{\frac{35}{792}}$	$\sqrt{\frac{35}{792}}$	$-\sqrt{\frac{3}{550}}$	$\sqrt{\frac{3}{550}}$	$-\sqrt{\frac{7}{110}}$	$\sqrt{\frac{7}{110}}$

	6						7				8	
	[442]				[433]		[442]		[433]		[442]	
	(22)				(03)		(13)		(13)		(04)	
	00		20		11		11		00		00	
	20		00		11		00		11		00	
	^{31}S	^{13}S	^{31}S	^{13}S	$^{13}D_I$	$^{31}D_I$	$^{13}D_{II}$	$^{31}D_{II}$	$^{13}D_I$	$^{31}D_I$	$^{13}D_{II}$	$^{31}D_{II}$
	$-\sqrt{\frac{2}{99}}$	$\sqrt{\frac{2}{99}}$	$-\sqrt{\frac{8}{275}}$	$\sqrt{\frac{8}{275}}$	$\sqrt{\frac{1}{55}}$	$\sqrt{\frac{9}{55}}$	$-\sqrt{\frac{21}{275}}$	$\sqrt{\frac{21}{275}}$	$\sqrt{\frac{3}{110}}$	$\sqrt{\frac{27}{110}}$	$\sqrt{\frac{3}{110}}$	$-\sqrt{\frac{3}{110}}$

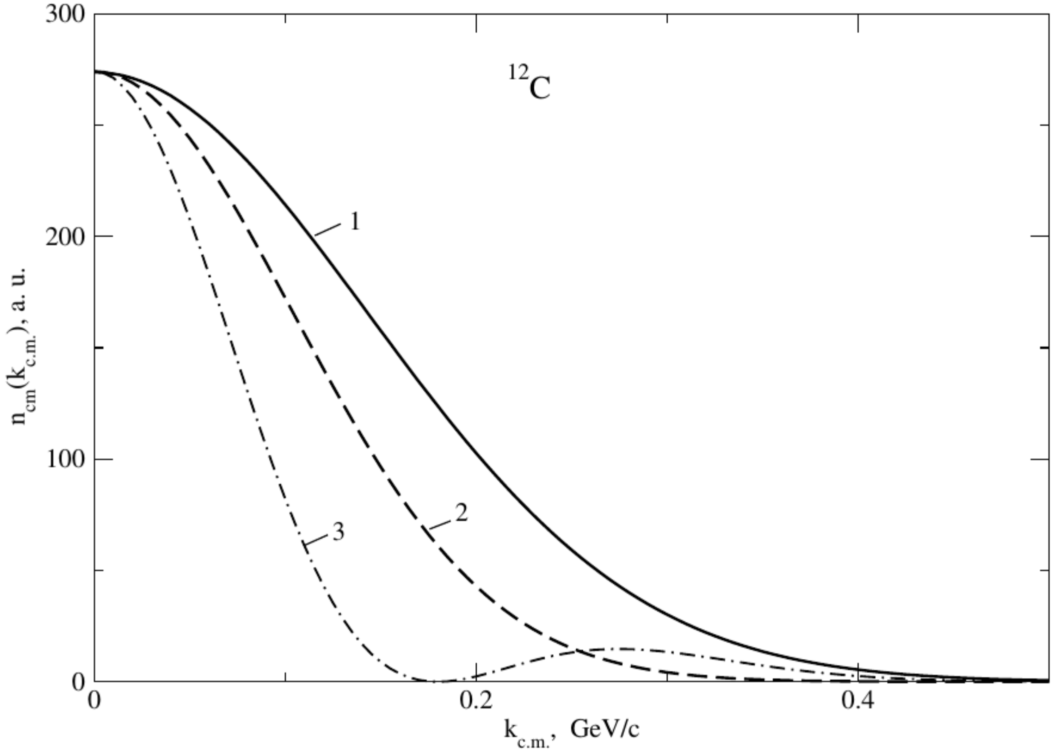
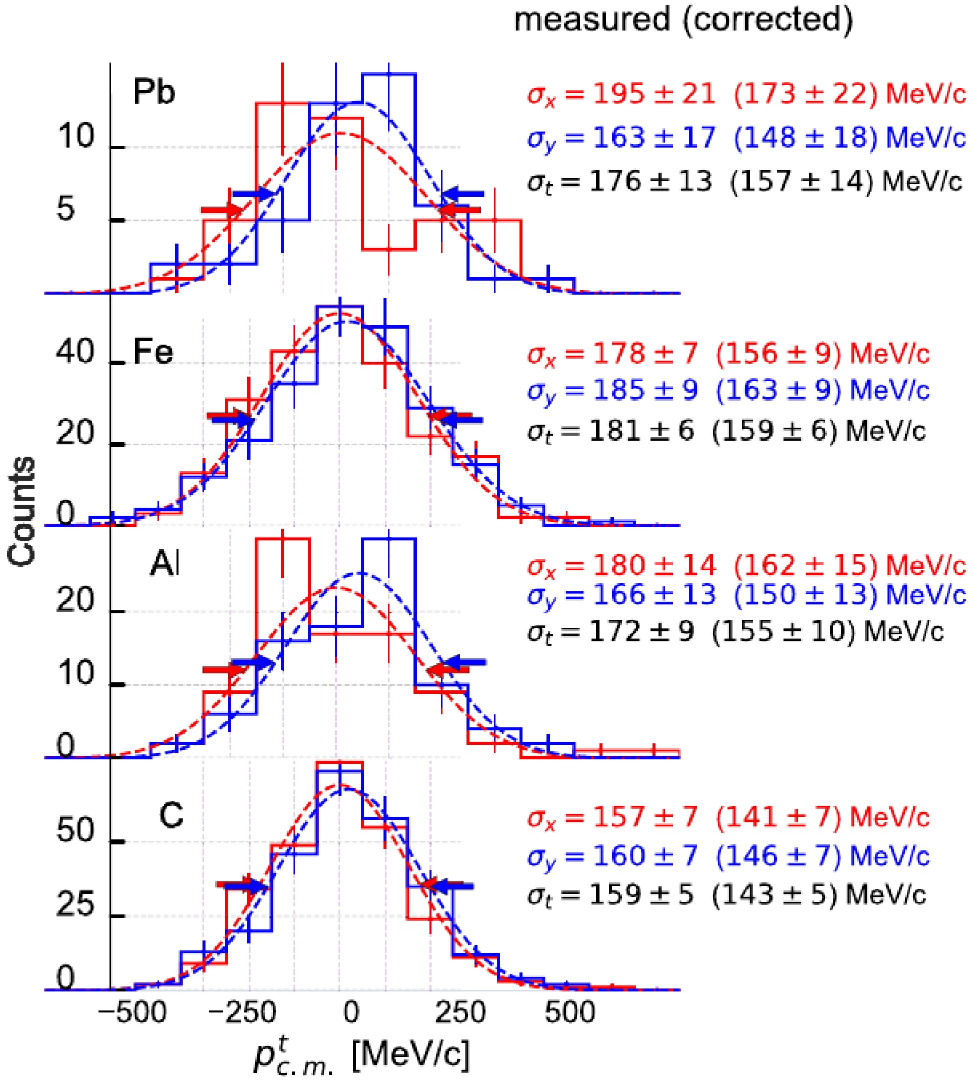


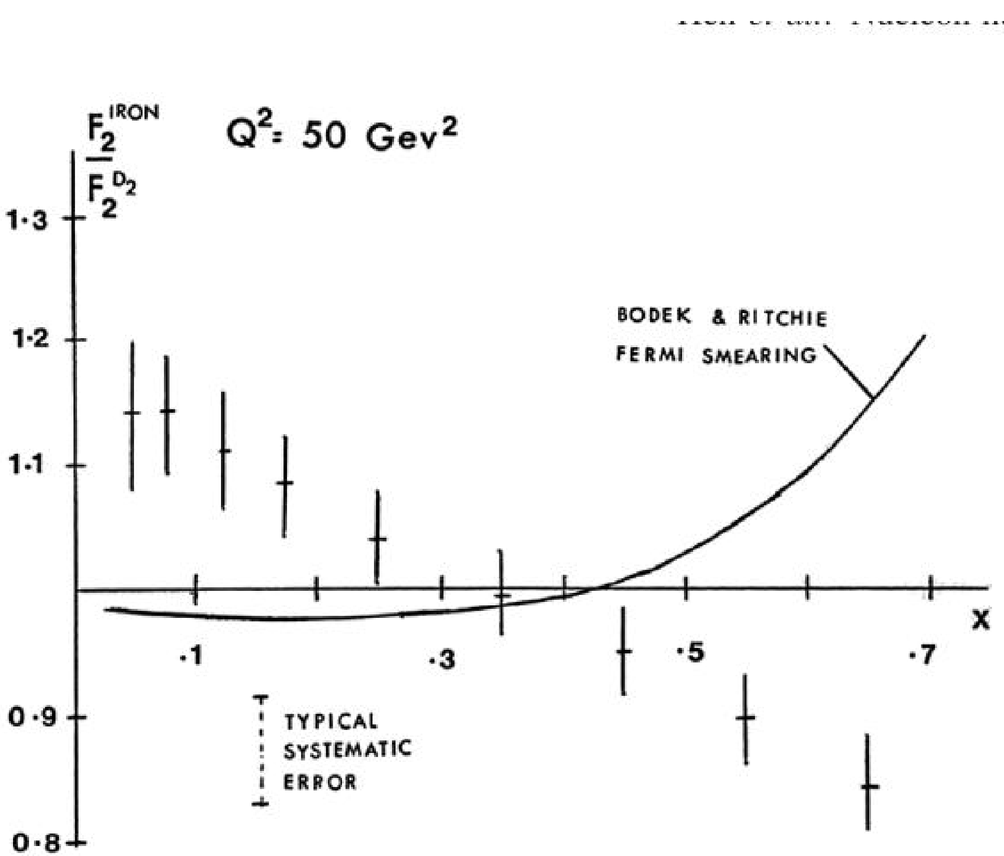
Fig. 3. Distribution over the c.m. momentum of the SCR pair $p_{c.m.}$ in the ^{12}C for the mean-field model with $\alpha_{c.m.} = 0.95\, fm^2$ (full line) and the TISM wave function squared with $p_0 = 146.9$ MeV/c for the 0S-type (dashed), and 2S-type (dashed-dotted). All distributions are arbitrary normalized at $p_{c.m.} = 0$ to the same value.

E. Cohen et. al. PRL 121 (2018) 092501



EMC- effect and SRC

O. Hen et al. Rev. Mod. Phys. 89 (2017) 045002



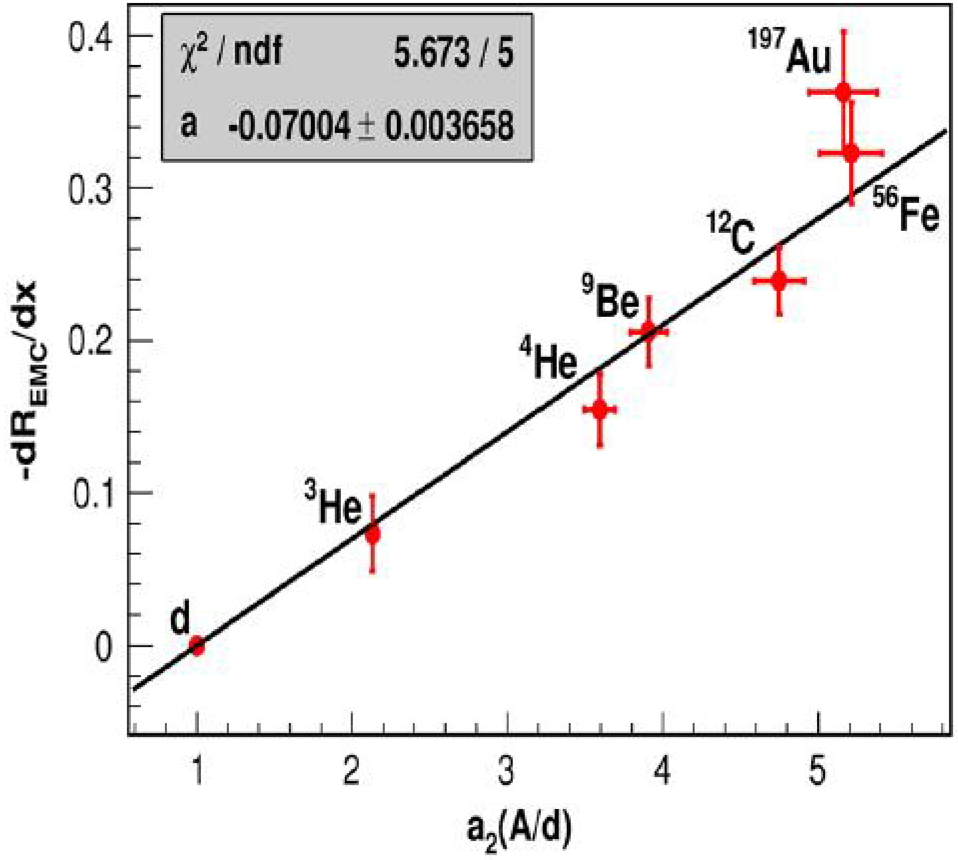


FIG. 34. The slope of the EMC effect (R_{EMC}, ratio of nuclear to deuteron cross section) for $0.35 \leq x_A \leq 0.7$ plotted vs $a_2(A)$, the SRC scale factor (the relative probability that a nucleon belongs to an SRC *NN* pair) for a variety of nuclei. The fit parameter $a = -0.070 \pm 0.004$ is the intercept of the line constrained to pass through the deuteron (and is therefore also the negative of the slope of that line). From Hen *et al.*, 2013.

Center mass motion of SRC NN pairs in nuclei

E.O. Cohen et al. Phys.Rev.Lett. **121** (2018) 092501

Hard breakup of a pp-SRC pair in a hard two-nucleons knockout $A(e,e'pp)$ reactions at recoil proton momentum $p_{rec} \geq 350$ MeV/c assuming factorization

$$d\sigma(e,e'pp) \sim n_{SRC}(\vec{p}_1,\vec{p}_2) \approx n^A_{c.m.}(\vec{p}_{c.m.}) n^{NN}_{rel}(\vec{p}_{rel})$$

$n^A_{c.m.}(\vec{p}_{c.m.})$ is approximated by the 3-D Gaussian $g(x)g(y)g(z)$,

$g(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{x^2}{2\sigma^2}\right]$

$\underline{^{12}C}$:

$\sigma_x \approx \sigma_y \approx \sigma_z = (145 \pm 5) MeV/c$

i.e. $p_0 = \sqrt{2}(145 \pm 5)$MeV/c=$(205 \pm 7)$MeV/c

$$S_A^x = \binom{A}{x}^{1/2} \sum_{\mathcal{L}\,\overline{J}\,\overline{M}} (J_B M_B \overline{J}\ \overline{M} | J_A M_A)(\Lambda M_\Lambda J_x M_x | \overline{J}\ \overline{M})$$

$$(T_B M_{T_B} T_x M_{T_x} | T_A M_{T_A}) U(\Lambda L_x J S_x; \mathcal{L} J_x)$$

$$[(2L_A+1)(2S_A+1(2J_B+1)(2\overline{J}+1)]^{1/2} \left\{ \begin{array}{ccc} L_B & S_B & I_B \\ L & S_x & \overline{J} \\ L_A & S_A & I_A \end{array} \right\}$$

$$< AN_A[f_A](\lambda_A \mu_A)\alpha_A L_A S_A T_A|$$

$$|A - xN_B[f_B](\lambda_B \mu_B)\alpha_B L_B S_B T_B; \nu\Lambda, xN_x[f_x](\lambda_x \mu_x)\alpha_x L_x S_x T_x(\mathcal{L}) : L_A S_A T_A >$$

Theoretical model: C.Ciofi degli Atti, S.Simula, PRC 53 (1996) 1689

$$n_{cm}(p) = (\frac{\alpha}{\pi}) \exp\left[-\alpha p^2\right] \qquad (3)$$

$\alpha = 1$ fm^2 or $p_0 = \hbar/\sqrt{\alpha} = 197$ MeV/c

From the deuteron knock-out $^{12}C(p,pd)^{10}B$ from p-shell
($|^{10}B >= |s^4p^6>$) (J.Erö et al., 1981) one has
$\mathbf{p_0 = 155 MeV/c}$
(**not for 1S-wave distribution in Eq.(3), but for 2S Eq.(1)!**)

$\underline{^4He}$: $\alpha = 2.4$ fm^2 or $p_0 = \hbar/\sqrt{\alpha} = 127.3$ MeV/c,
that is compatible with $p_0 = (144.6 \pm 18.2)$ MeV/c from the deuteron knockout $^{12}C(p,pd)^{10}B$ from the α-core, (J.Erö et al., NPA 372, 1981),
$|^{10}B >= s^2p^8>$