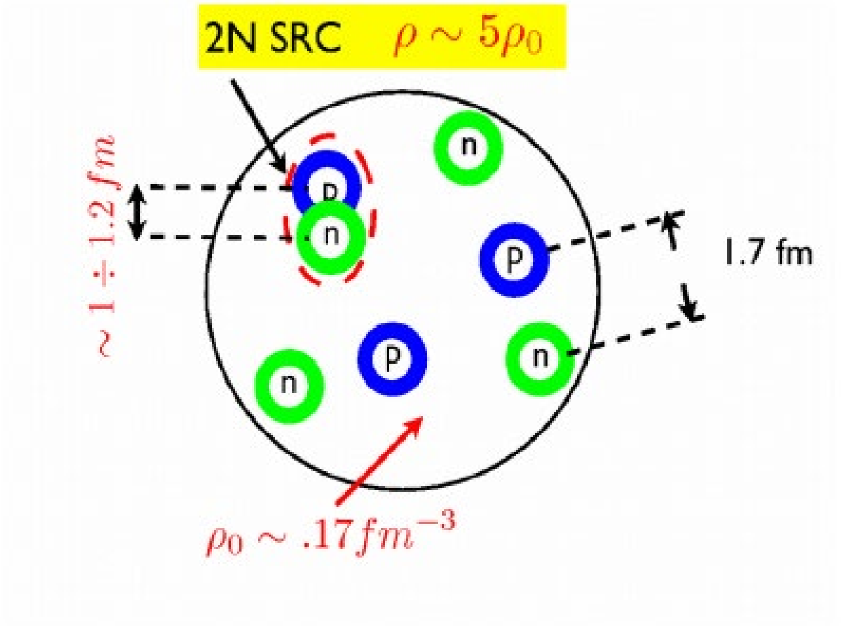
POLARZIATION TEST FOR QUSI-FREE KNOCKOUT OF NUCLEON FROM NUCLEAR SHORT-RANGE CORRELATED NN PAIR

Yu.N. UZIKOV (DLNP, JINR, Dubna)

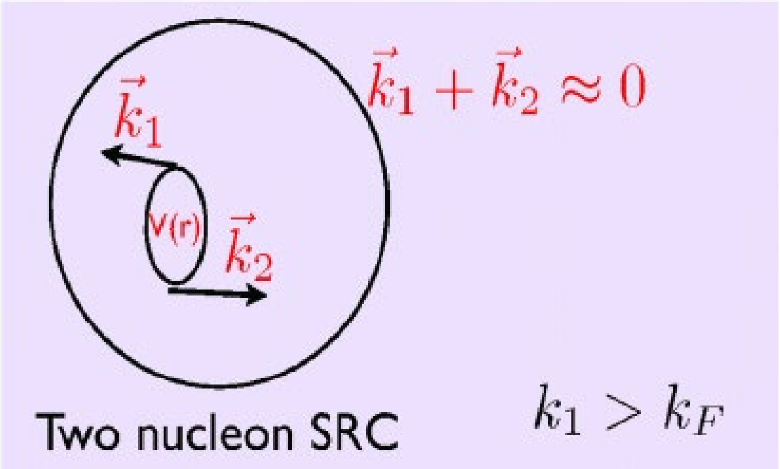
- Main properties of SRC NN pairs in nuclei
- $^{12}C + p \to p + p + N + ^{10}B$ at BM@N NICA
- ISI@FSI in $^{12}C(p,ppN)^{10}A$
- T_{20} in pd-pX, pd-dp, ed-ed in the SRC region
- ISI@FSI in pd->ppn
- Conclusion

24th International Spin Symposium, Matsue (Japan), October 18-22, 2021

- Dubna, M.G. Mesheryakov et al., (1957)
  $p + {}^{12}C \rightarrow d + X$ at 670 MeV; quasi-elastic knock-out of the fast deuterons.
  D.I. Blokhintsev (1957) : **fluctons** in nuclei
  Blokhintsev, Efremov, Lukjanov, Titov, 6q, 1978;
  Strikman, Frankfurt, 1978, SRC



- Two nucleons at short distances r_{NN} <0.5 fm
  with relative momentum $q > 1/r_{NN}$ =0.4 GeV/c;
  Repulsive core in NN-potential →
  high-momentum part
  of the w.f. of NN pair



● Summary of the main results on SRC of BNL, Jlab, SLAC

* High-momentum part ($q > p_F$) accounts for 20% nucleons .

* pn- SRC pairs at 0.3 GeV/c < q < 0.7 GeV/c dominate by factor of 20 as compared to pp and nn due to the tensor forces.

* Factorization $n(p_1, p_2) = C_A n_{c.m.}(k_{cm}) n_{rel}(q)$.

* SRC are connected with **neutrino-nucleus interaction**, **neutron stars** structure, modification of the bound nucleon structure (**EMC effect**).

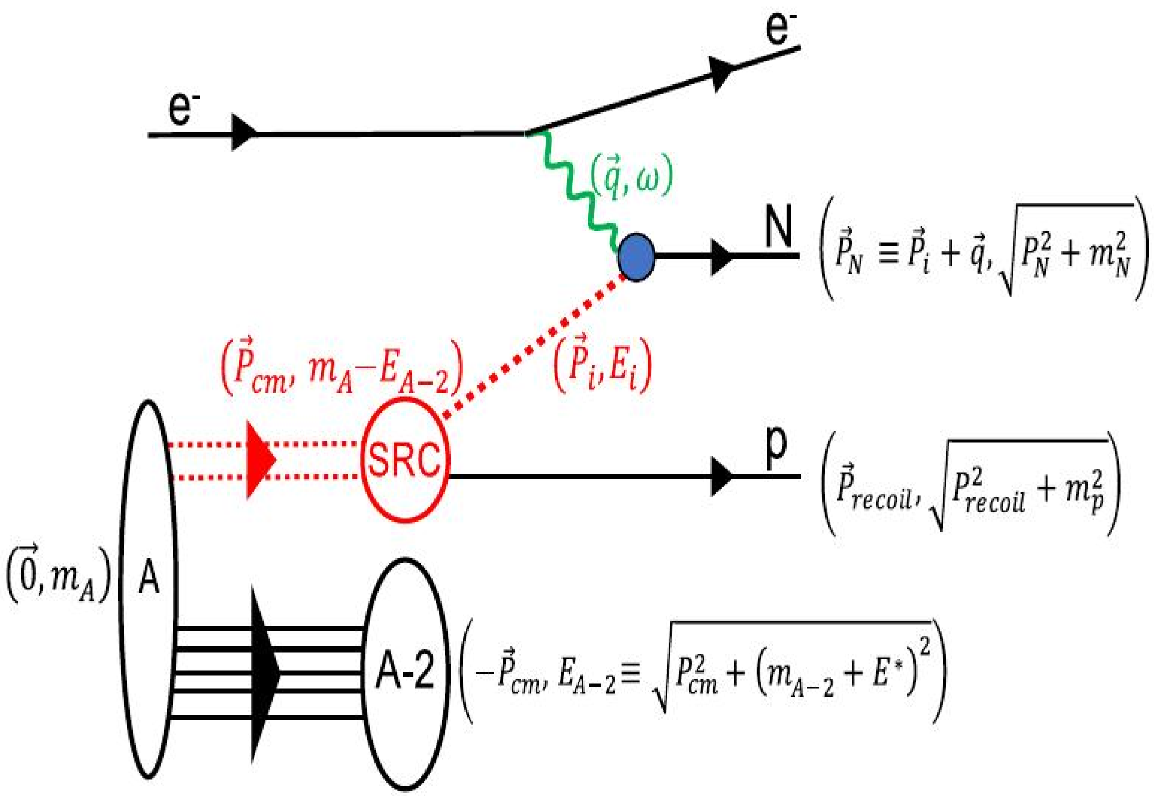
* 3N SRC

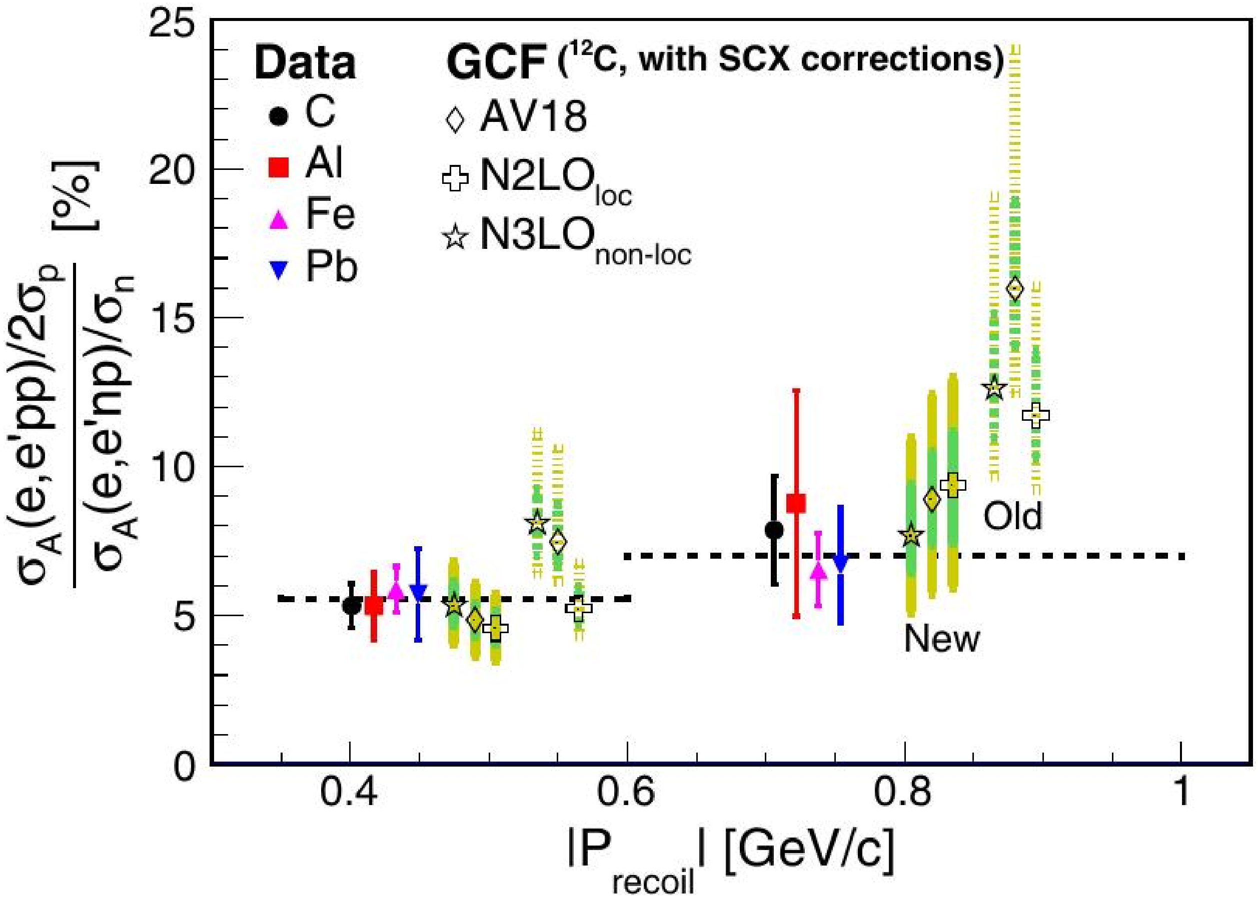
Cioffi degli Atti, Phys. Rep. 590 (2015) 1

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

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

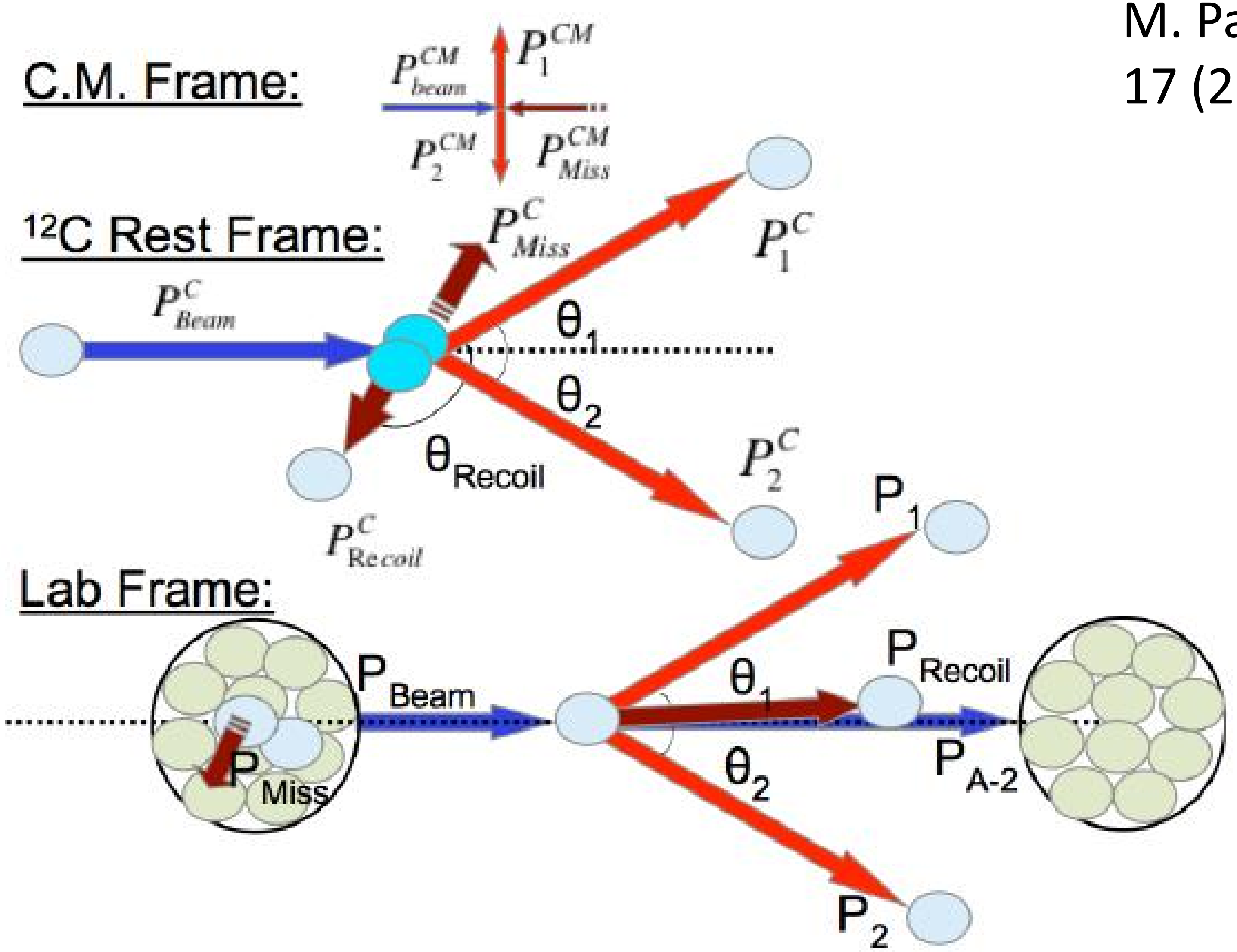
E_e=5 GeV,
A(e,e'np), A(e,e'pp)





Study of SRC at BM@N

4=GeV/c /nucleon beam of ^{12}C and proton target in inverse kinematics



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

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

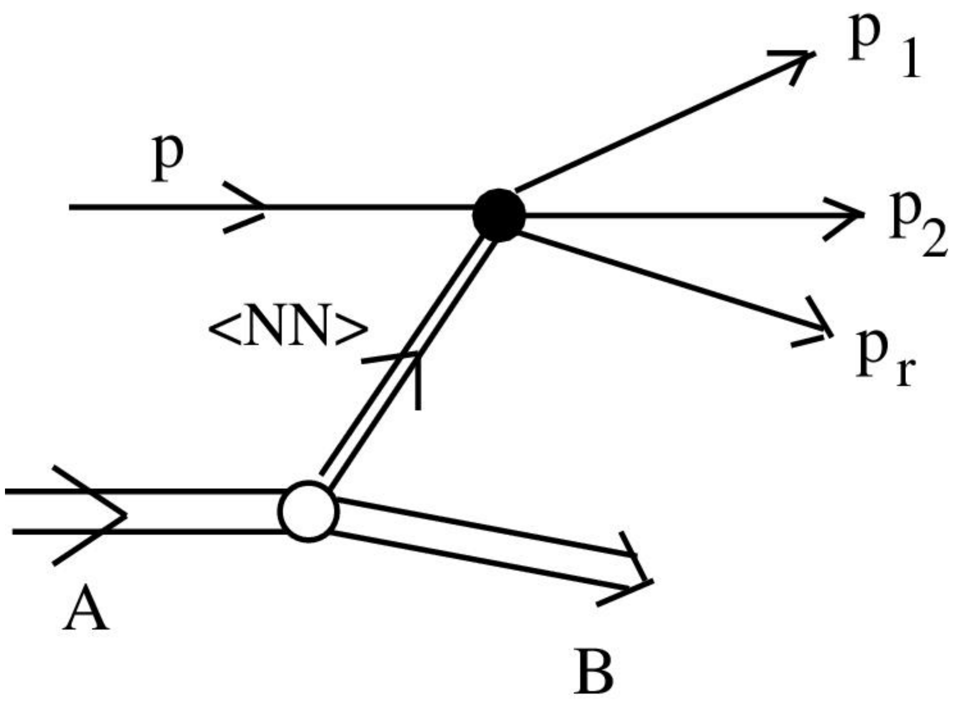
12C(p,2pN)10A , SCR:

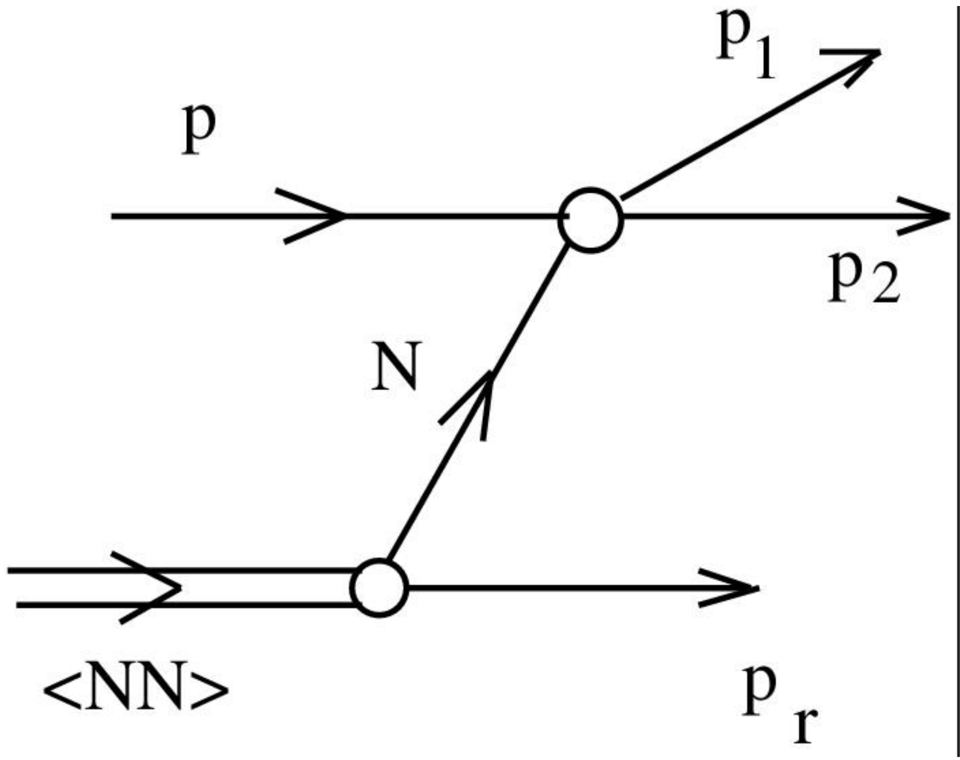
10B 23 events (pn);

10Be – 2 event (pp)

CONCLUSION: unperturbed by ISI@FSI distributions are measured "All measured reactions are well described by theoretical calculations that do not contain ISI/FSI distortions"

REACTION $^{12}C+p \rightarrow {}^{10}B+P+P+N$

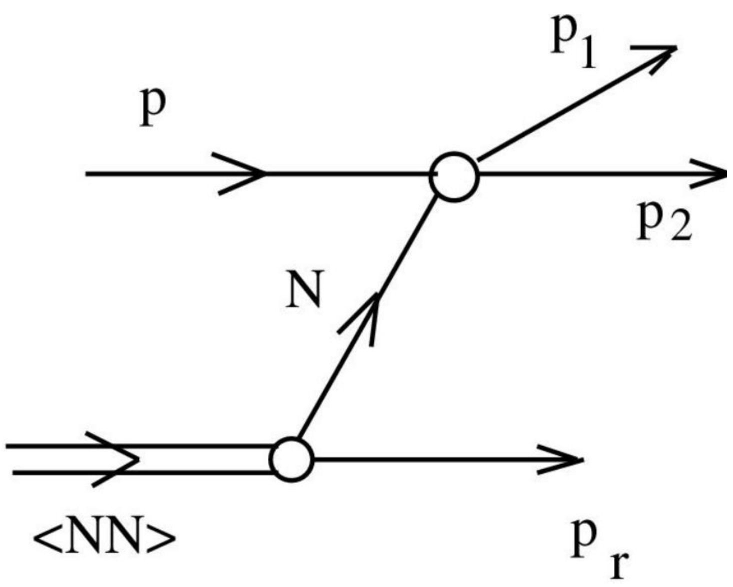




Matrix element of the $p+ < NN > \to p + p + N$

In the Light front dynamics

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



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

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

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

SRC

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

Transition matrix element

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

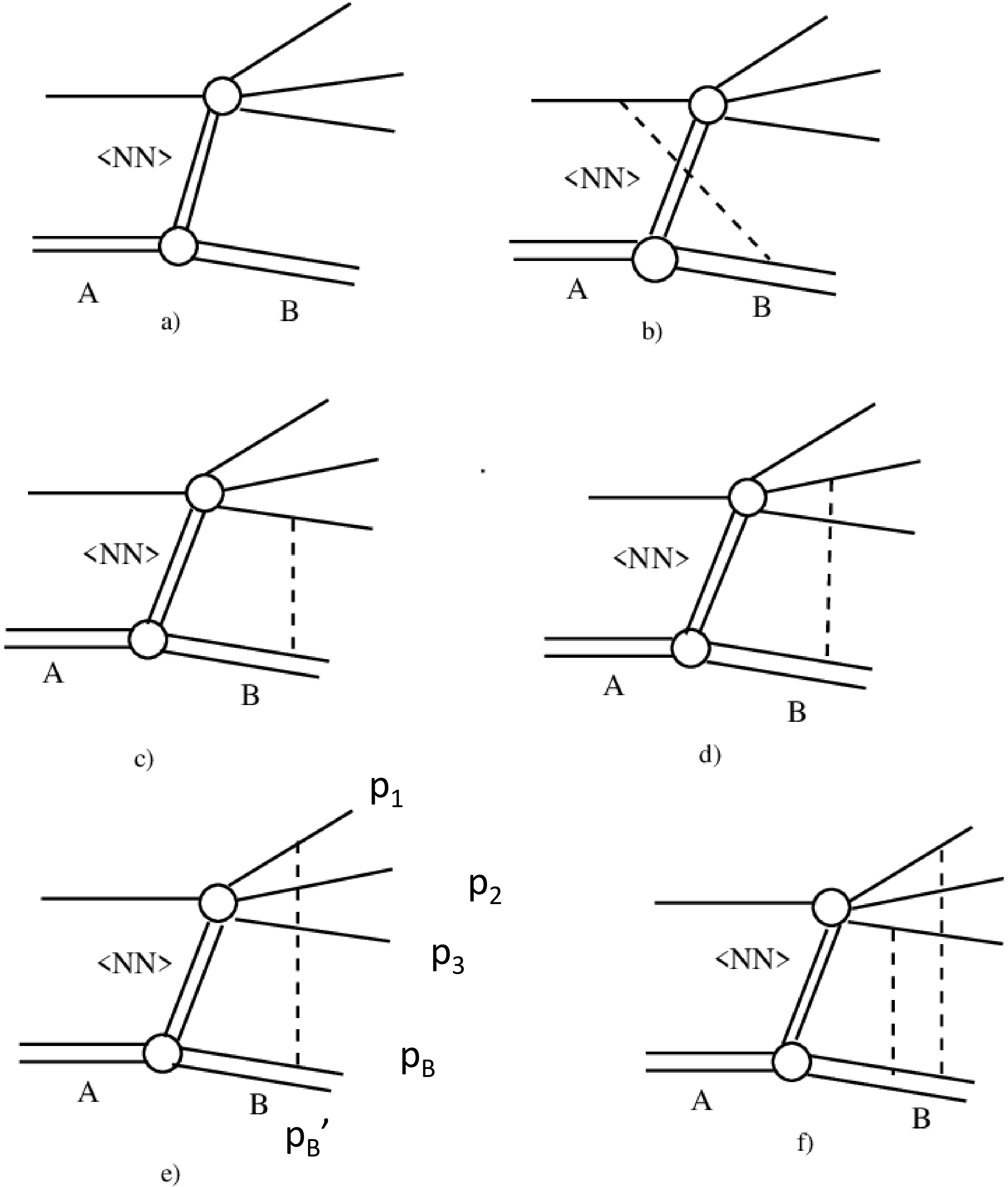
$$T^{px' \to Nx} =< \mathbf{k}_N \mathbf{k}_x \chi_N \psi_x | \tau(px' \to Nx) | \mathbf{k}_p, -\mathbf{k}_B \chi_p \psi_{x'} >$$

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

Yu.N. Uzikov, Izv. RAN. Ser. Fiz. 84 (2020) 580;
EPJ Web Conf. 222 (2019) 03027;
Phys. Part. Nucl. 52 (2021) 652

How to take into account ISI and FSI?

ISI@FSI
ELASTIC RESCATTERINGS



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

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

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)

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

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

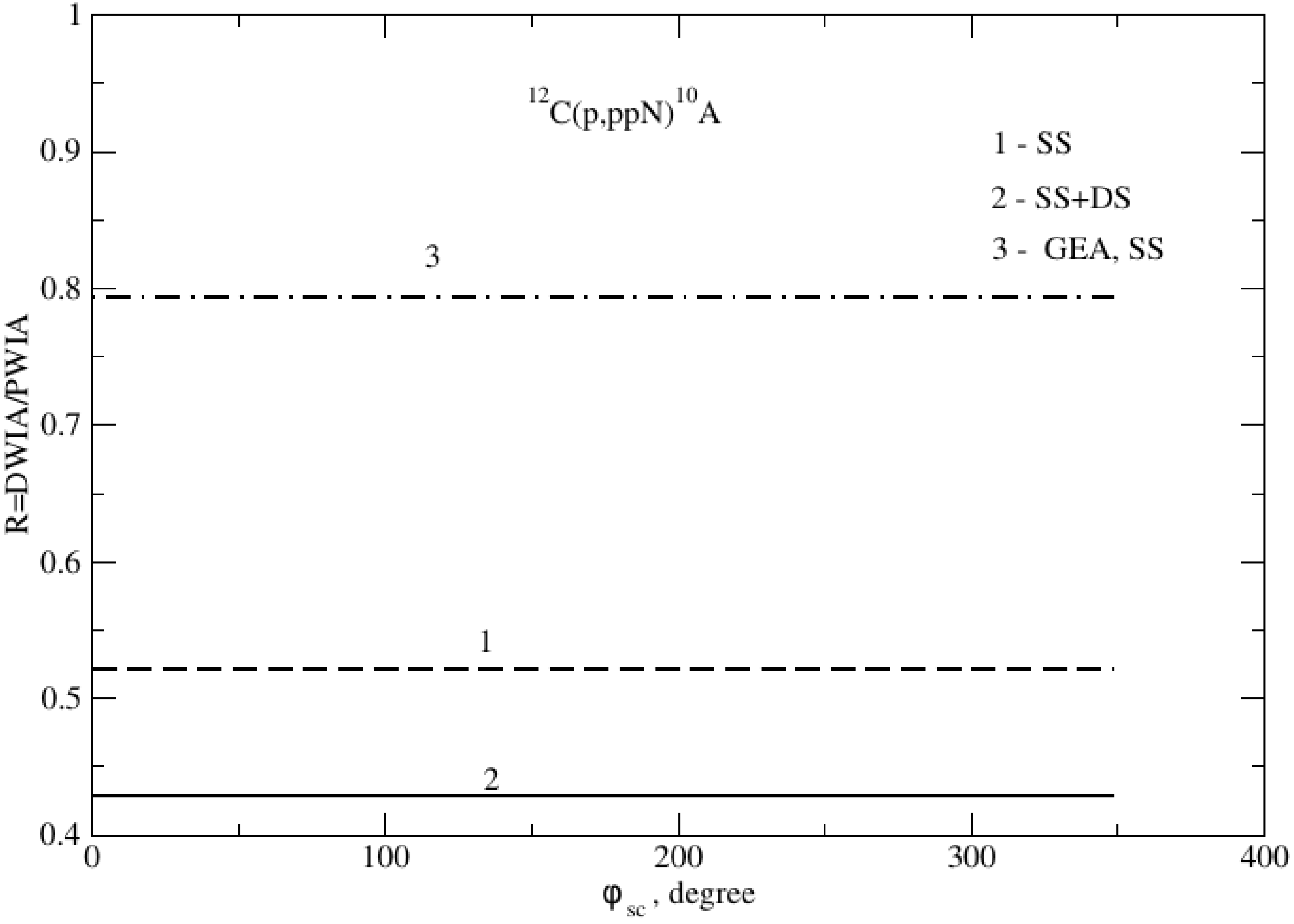
$$-\frac{1}{(4\pi)^2 k_{pA}\ k_{NB}} \int d^2\mathbf{q}_p\ d^2\mathbf{q}_N F_{pB}(\mathbf{q}_p)\ F_{NB}(\mathbf{q}_N)\ \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_N - \mathbf{q}_p) -$$

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

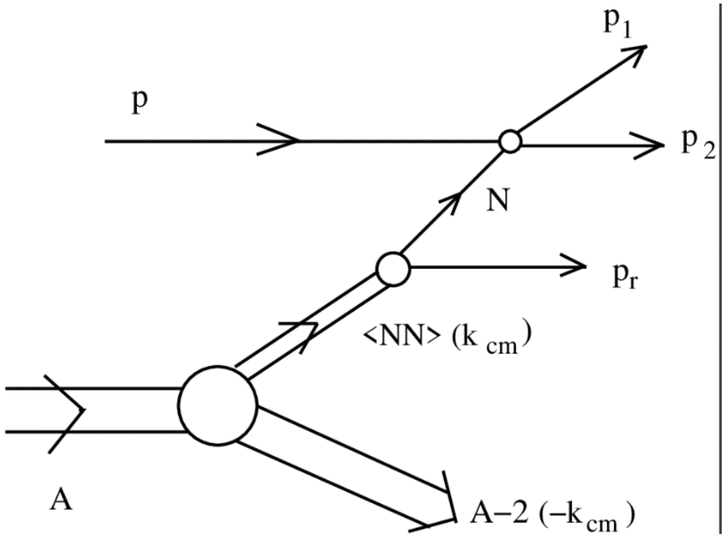
$$-\frac{1}{(4\pi)^2 k_{xB}\ k_{NB}} \int d^2\mathbf{q}_x\ d^2\mathbf{q}_N F_{xB}(\mathbf{q}_p)\ F_{NB}(\mathbf{q}_N)\ \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_p - \mathbf{q}_N) -$$

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

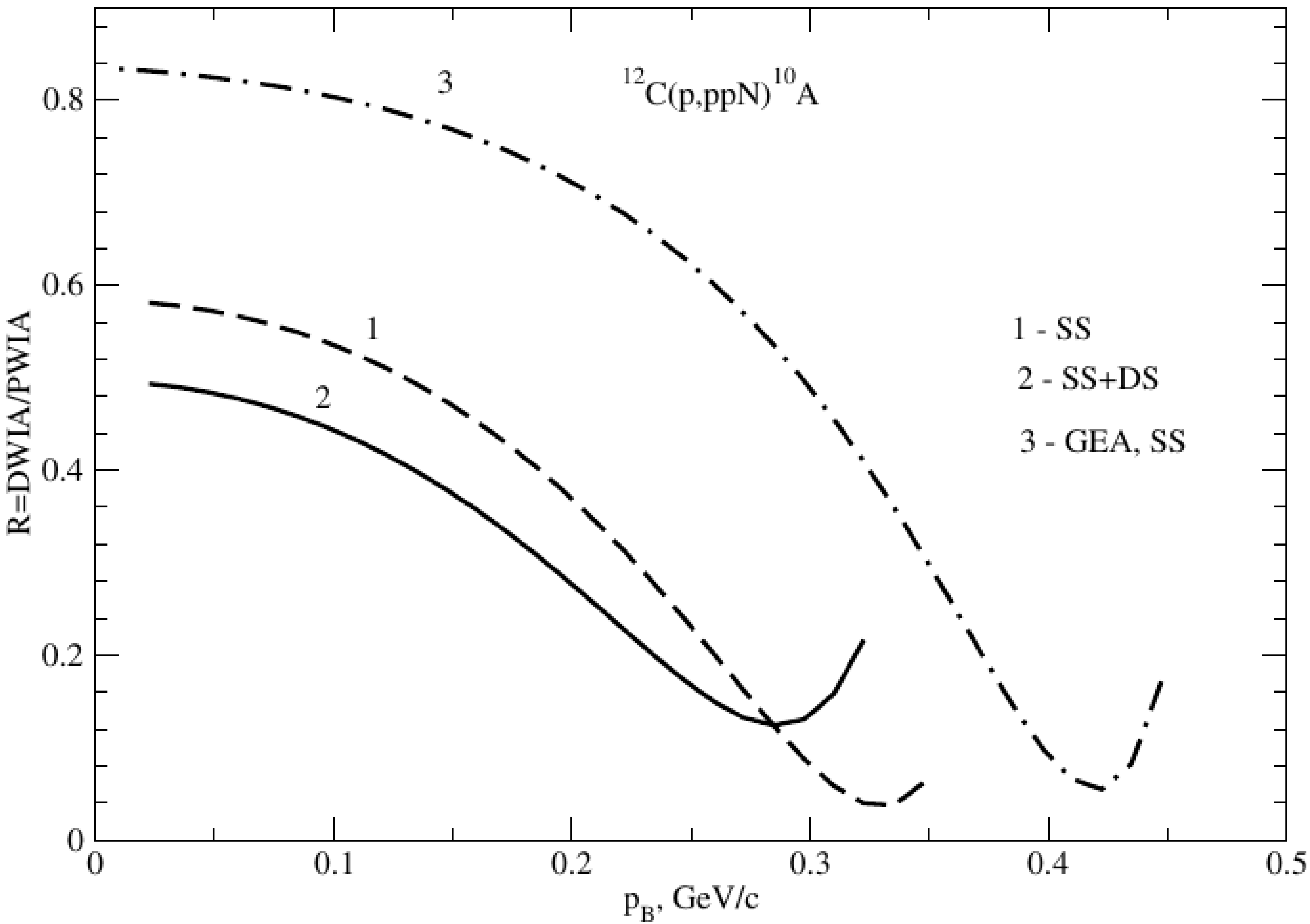
$$\times F_{pB}(\mathbf{q}_p)\ F_{NB}(\mathbf{q}_N)\ F_{xN}(\mathbf{q}_x)\ \psi_{\nu\Lambda}(\mathbf{k}_B - \mathbf{q}_N - \mathbf{q}_p - \mathbf{q}_x).$$



$^{12}C(p,ppN)^{10}A$
1 - SS
2 - SS+DS
3 - GEA, SS
3
1
2
R=DWIA/PWIA
φ_{sc} , degree
1
0.9
0.8
0.7
0.6
0.5
0.4
0
100
200
300
400

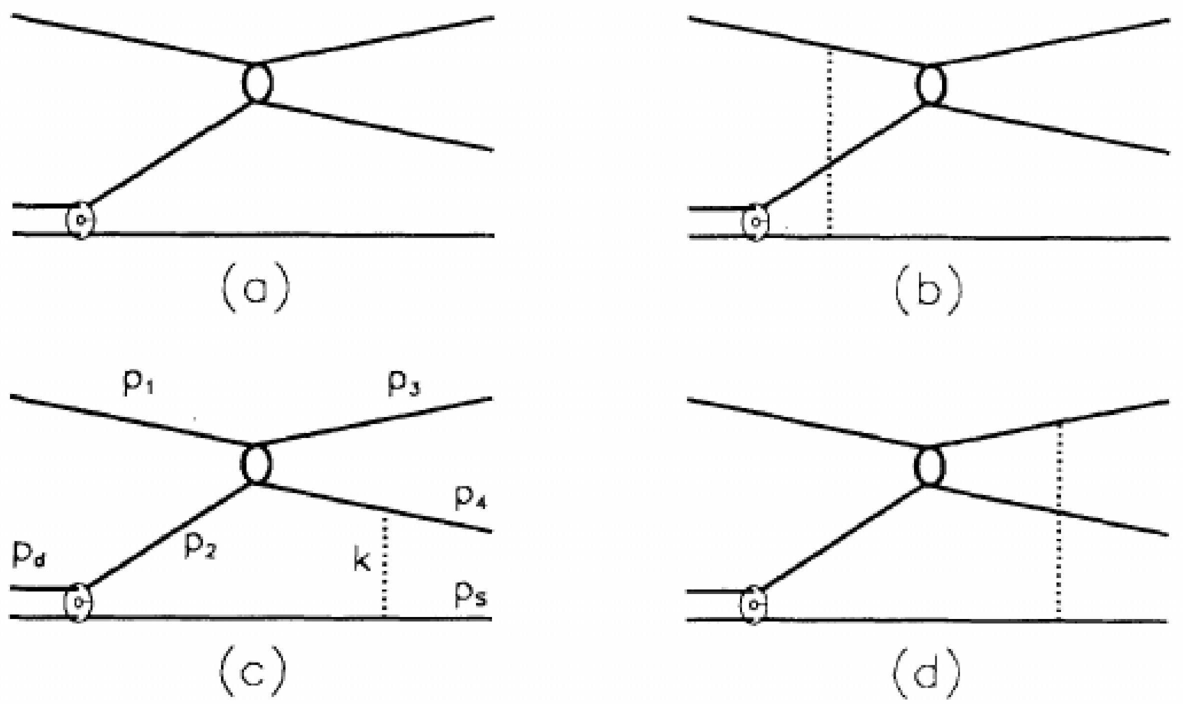


p
p_1
p_2
N
p_r
<NN> (k_{cm})
A
A−2 ($-k_{cm}$)



$^{12}C(p,ppN)^{10}A$
3
1
2
1 - SS
2 - SS+DS
3 - GEA, SS
R=DWIA/PWIA
p_B, GeV/c
0
0.2
0.4
0.6
0.8
0
0.1
0.2
0.3
0.4
0.5

What about ISI@FSI in p<NN>-> p+N+N?

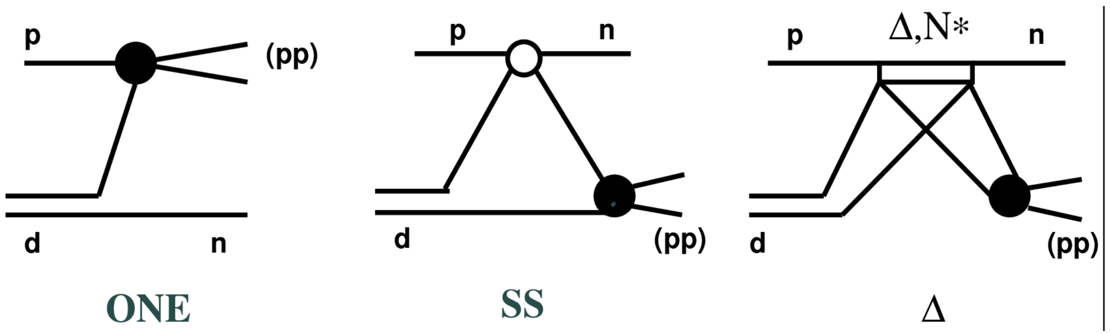


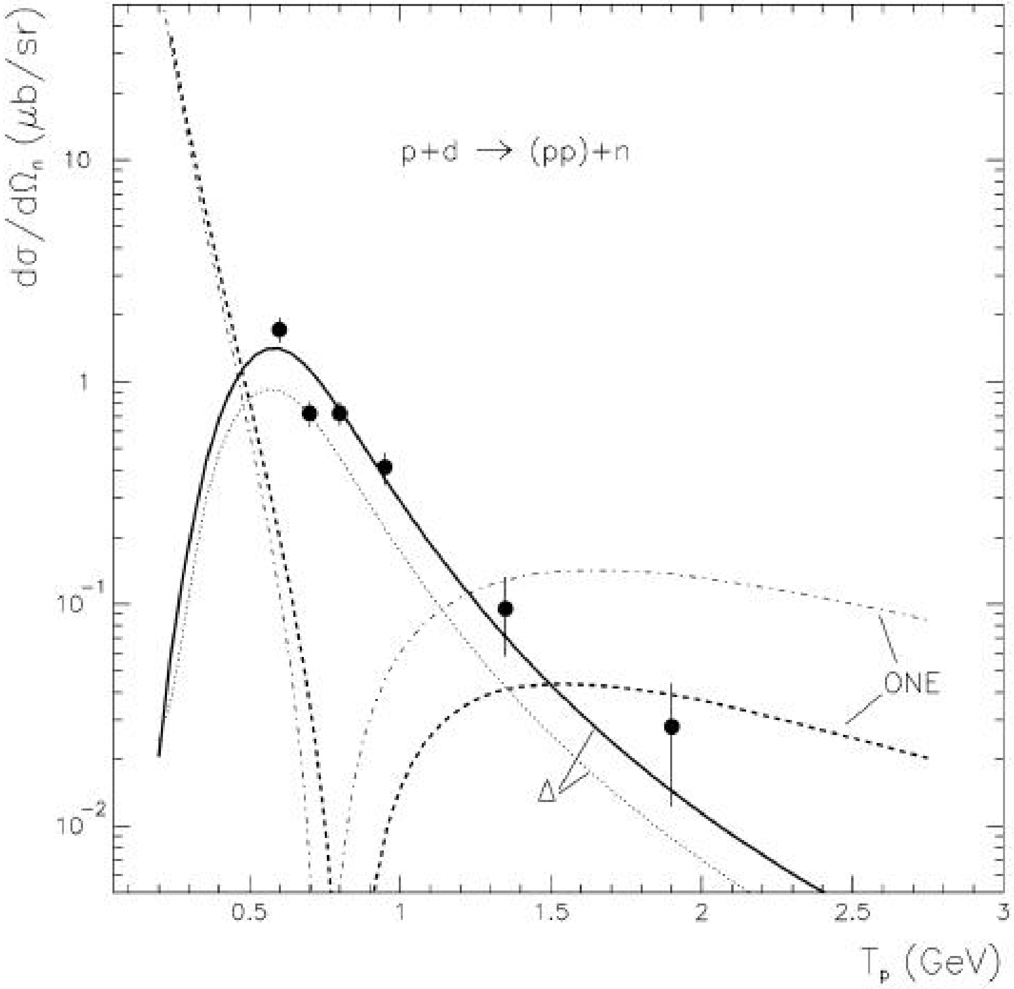
L. Frankfurt et al, PRC 51 (1995) 890

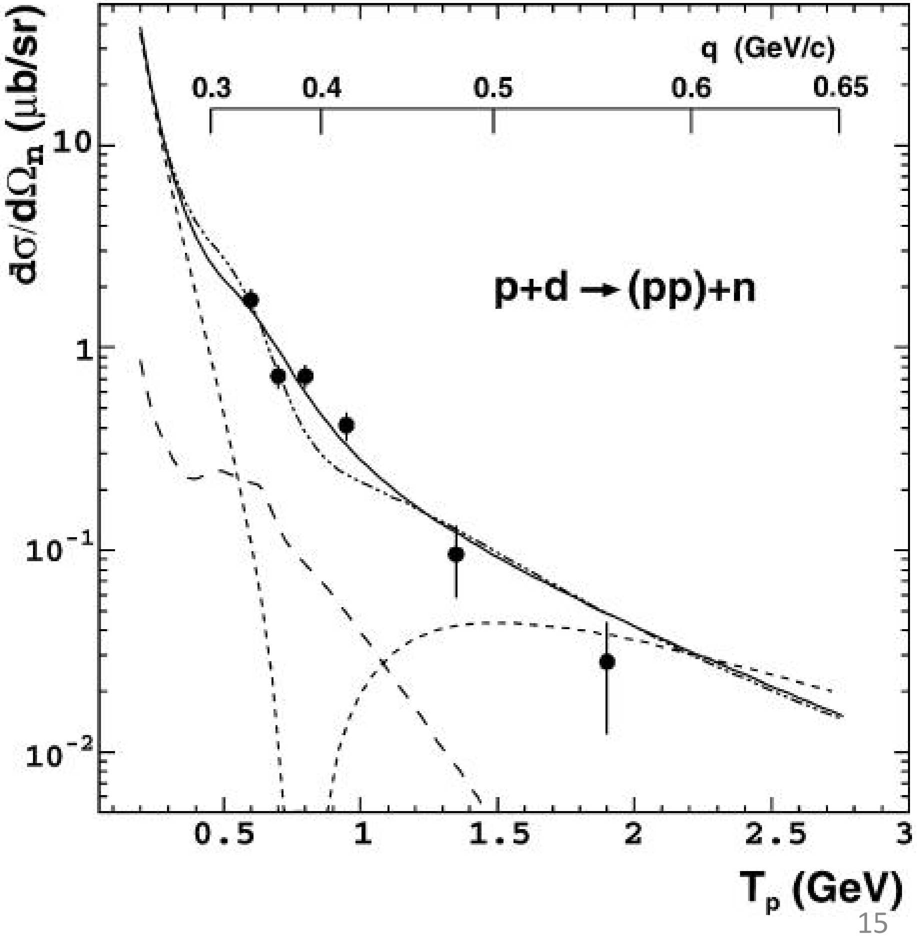
Backward pd-> {pp)($^1S_0$)n and Δ excitation

V.Komarov et a.l PLB 553 (2003);

J.Haidenbauer, Yu.N. U. PLB 562 (2003)







• Polarization test for the IA in p<NN>->pNN and measurement of $n_{rel}(q_{rel})$

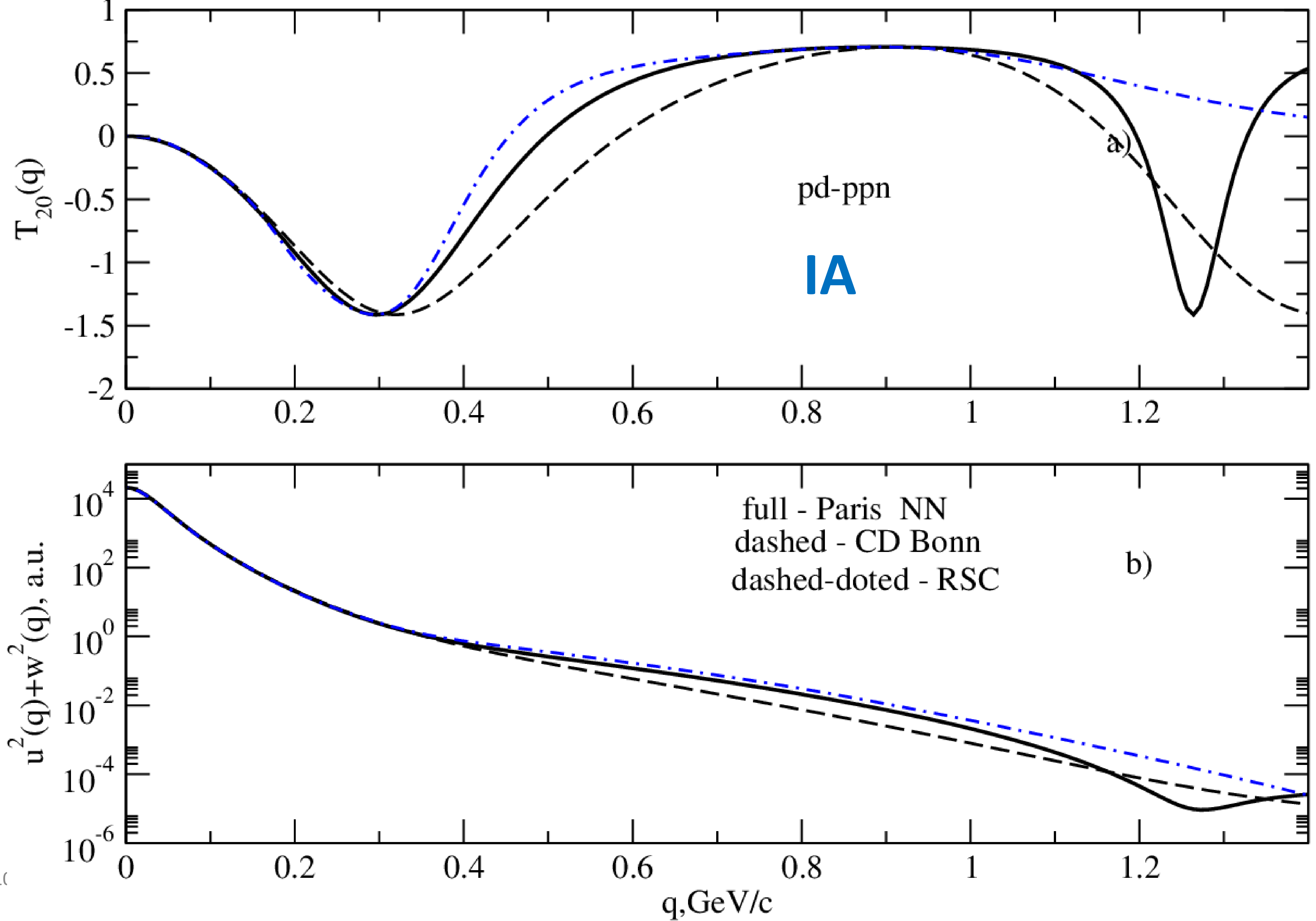
$$p < NN > \to p + N + N;$$

$$p + \vec{d} \to p + p + n;$$

$$T_{20} - measurement$$

IA for T_{20} $\Longrightarrow$ n_{rel} (q)

A similar test was suggested for
mechanisms of backward pd->{pp}s+n at 0.5-2 GeV at COSY(1999)



T20(q)
pd-ppn
IA
a)
0.5
0
-0.5
-1
-1.5
-2
1
0
0.2
0.4
0.6
0.8
1
1.2
u2(q)+w2(q), a.u.
full - Paris NN
dashed - CD Bonn
dashed-doted - RSC
b)
10^4
10^2
10^0
10^-2
10^-4
10^-6
q,GeV/c

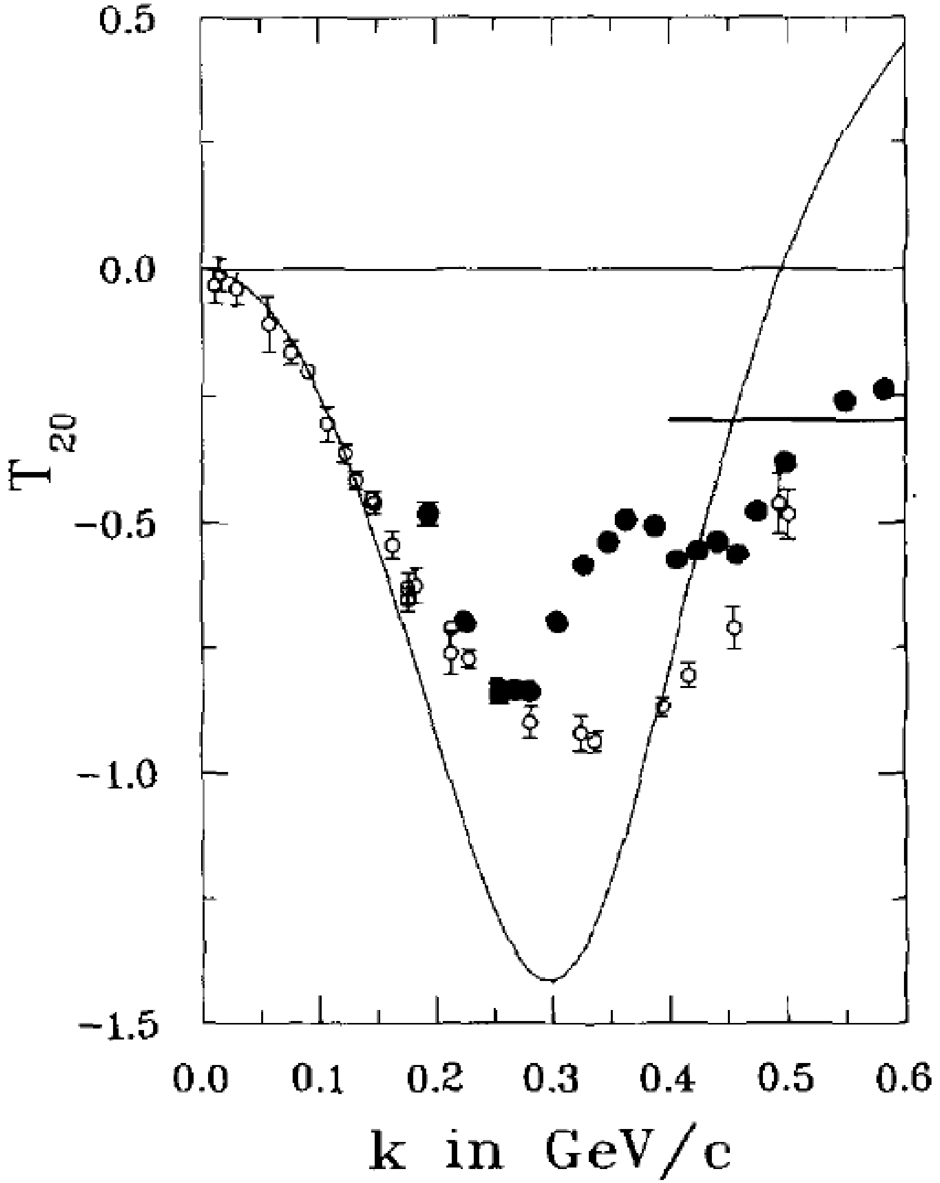
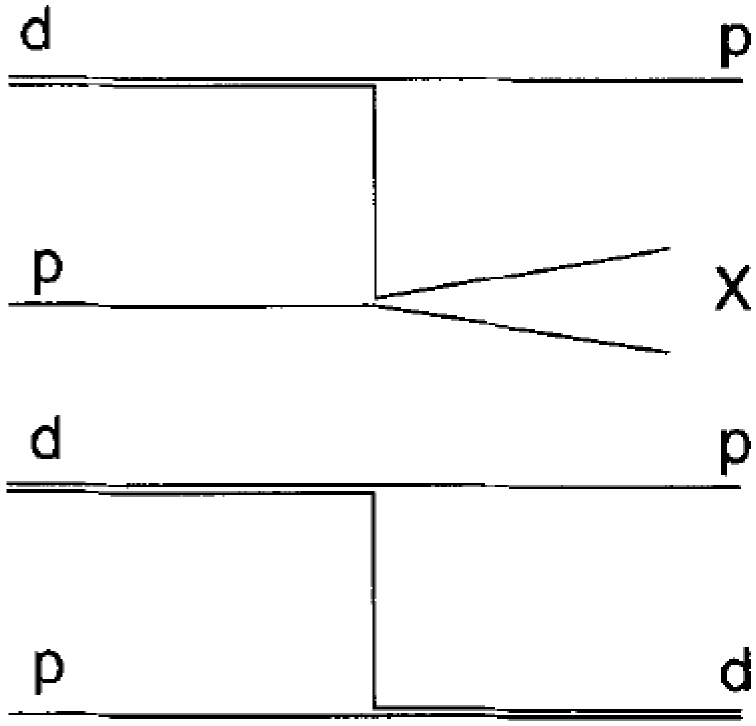


Fig. 2. T_{20} versus k; (•) for backward elastic dp and (○) for inclusive breakup. Solid curve is IA using Paris deuteron wave function; straight line is asymptotic prediction [24].



$$T_{20} = \frac{1}{\sqrt{2}} \frac{\sqrt{8}uw - w^2}{u^2 + w^2}$$

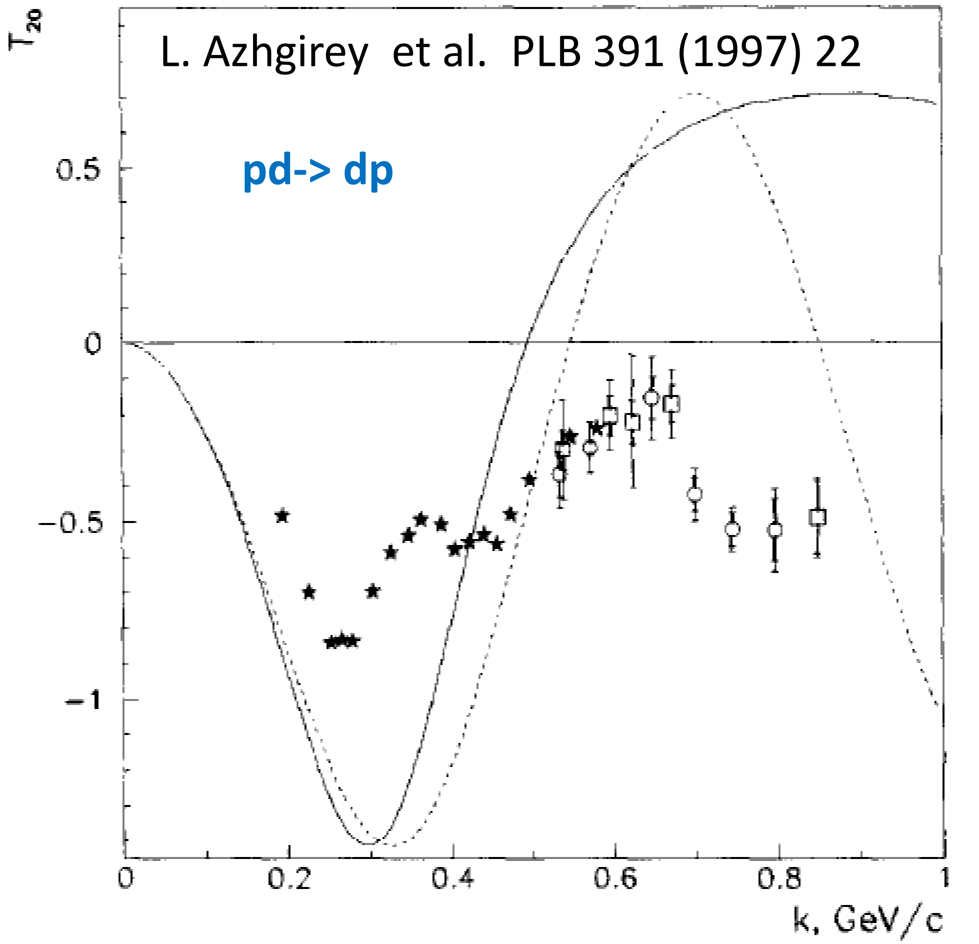


Fig. 3. Tensor analyzing power T_{20} for the backward elastic dp scattering versus k; (⋆) Saclay data [2], (∘) 93-run (□) 94-run: this experiment. Solid and broken curves are the ONE predictions

L. Azhgirey et al. PLB 387 (1996) 37

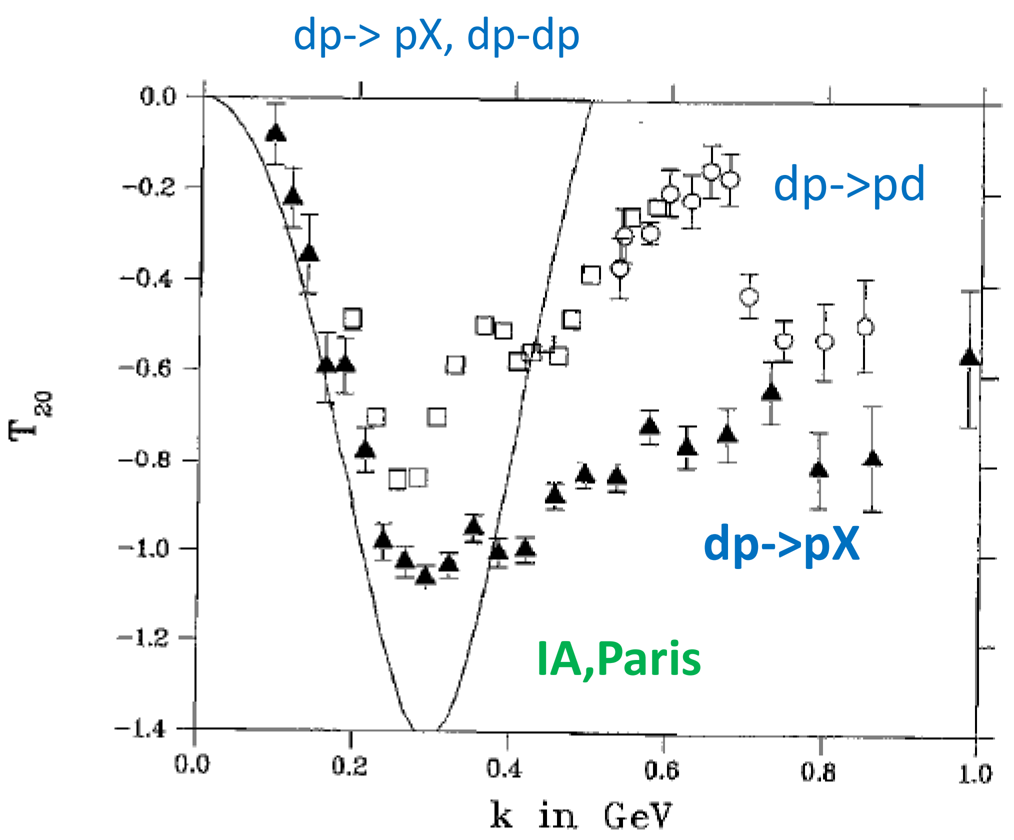
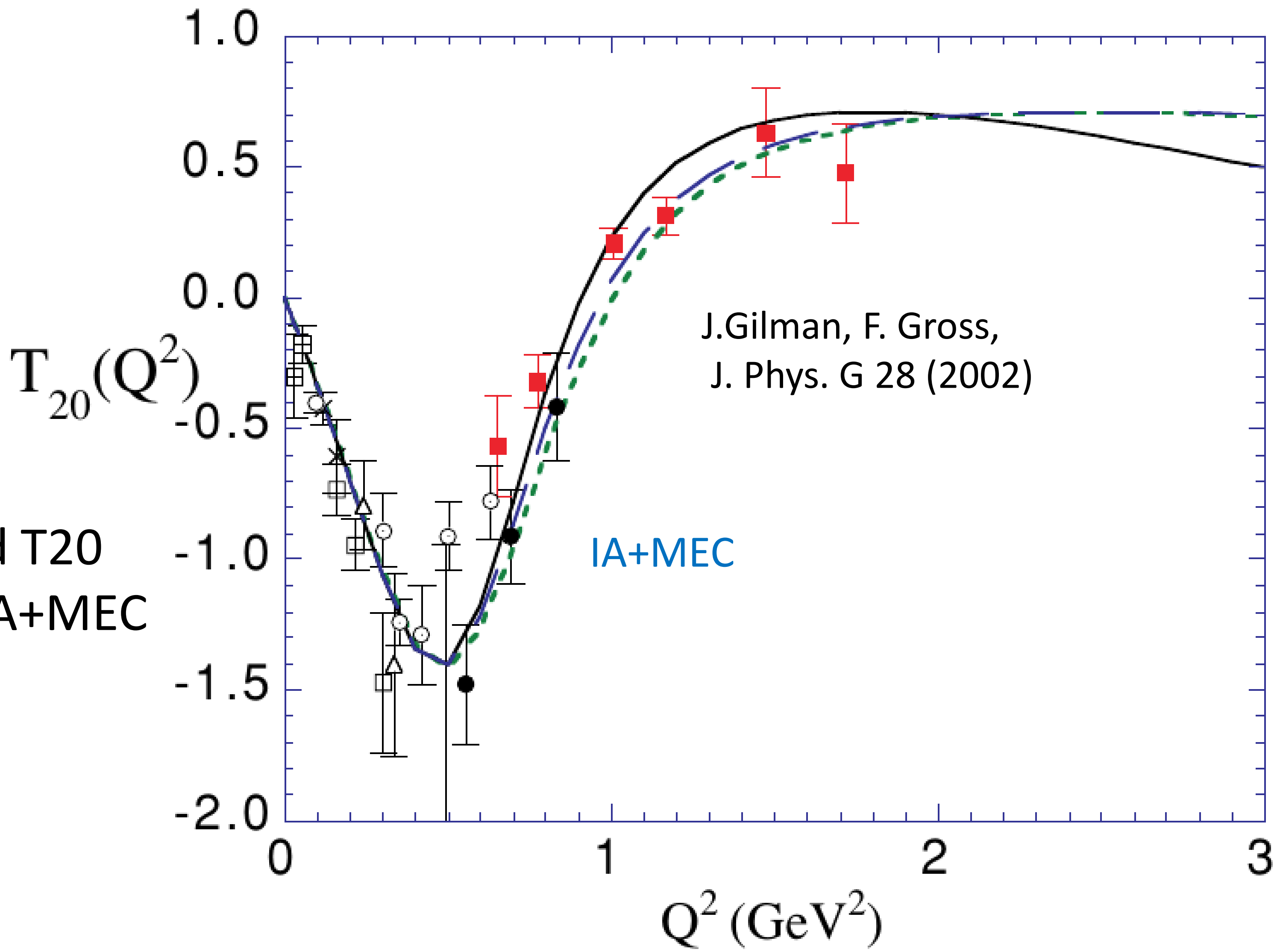
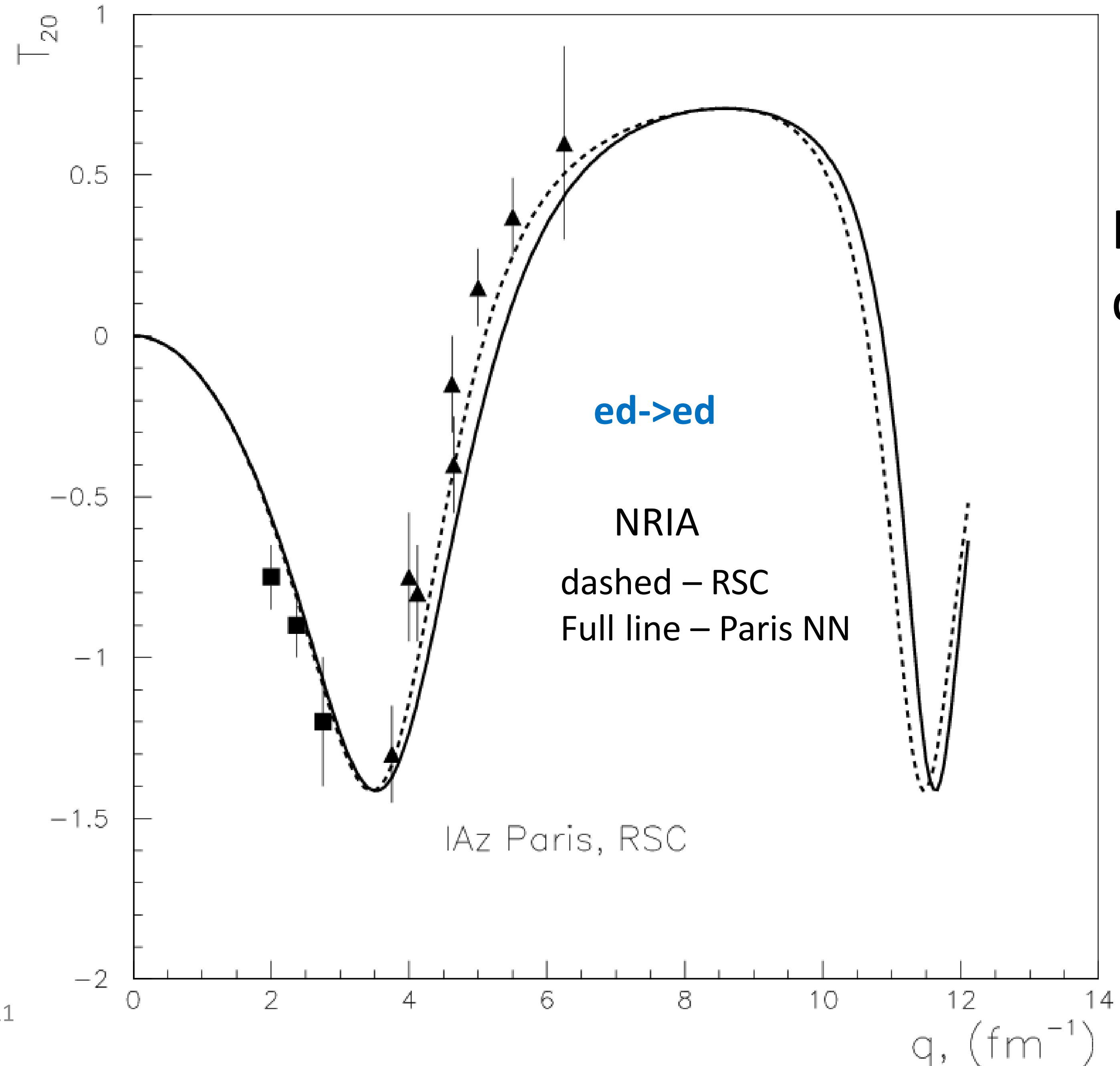


Fig. 4. T_{20} data for $H(d,p)X$ at 9 GeV/c (filled triangles), compared with T_{20} data for backward elastic $dp \to pd$ from refs [19] (empty circles) and [22] (empty squares). The IA prediction that both reactions are closely related is not validated by these data. The curve represents the IA, as in Fig. 2.

ed-> ed



In ed scattering measured T20 is in agreement with the IA+MEC calculations



Impulse approximation dominates!

SUGGESTION for BM@N or SPD NICA: In order to check validation of the IA for the quasi-elastic knock out of the nucleon from SRC NN pair

p+<NN>-p+N+N, (1)

it is of importance to measure the T_{20} for the free reaction

p+d-> p+p+n (2)

at the same kinematics as in the subprocess (1) of the reaction

$^{12}C+p \to p+N+N+ {}^{10}A$

BM@N result : 23 event for pn, and 2 for pp , while was expected ~400;
for free deuteron one may expect ~ 100.

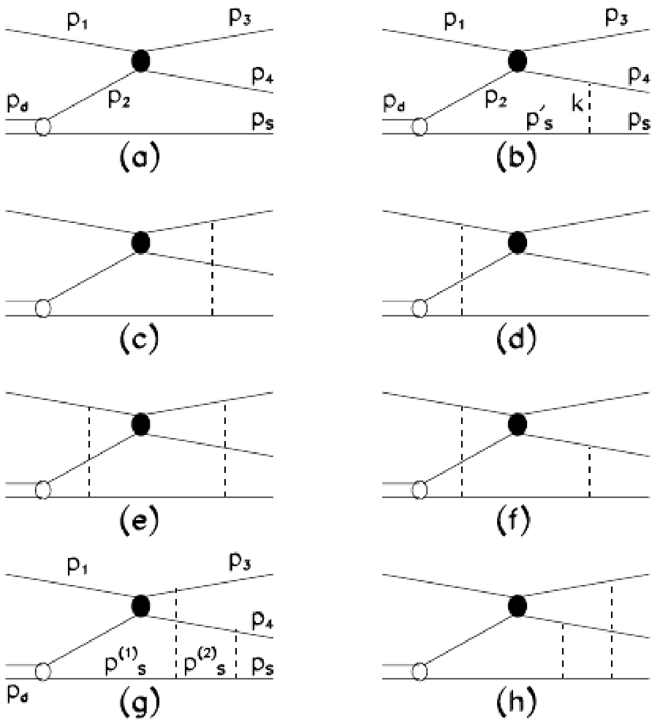
In addition:

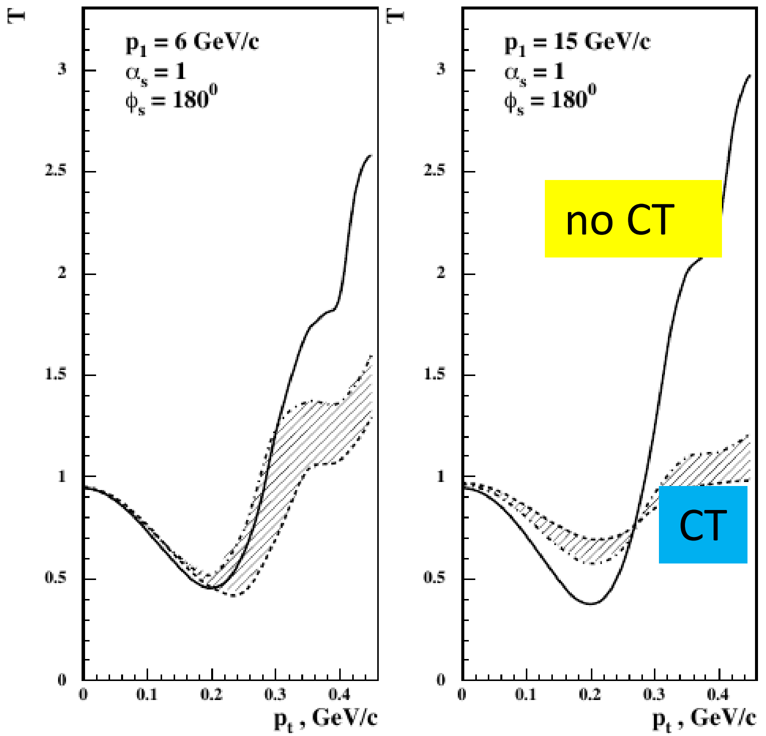
Testing rescattering dynamics (including color transparency effects - dashed curves)

L.L. Frankfurt et al. PRC 56 (1997)

$$T = \sigma^{DWIA} / \sigma^{IA}$$

pd->ppn





P_L=6 GeV/c is accessible at BM@N

α_s =1 optimal for testing dynamics of multinucleon rescatterings

TO CONCLUSION

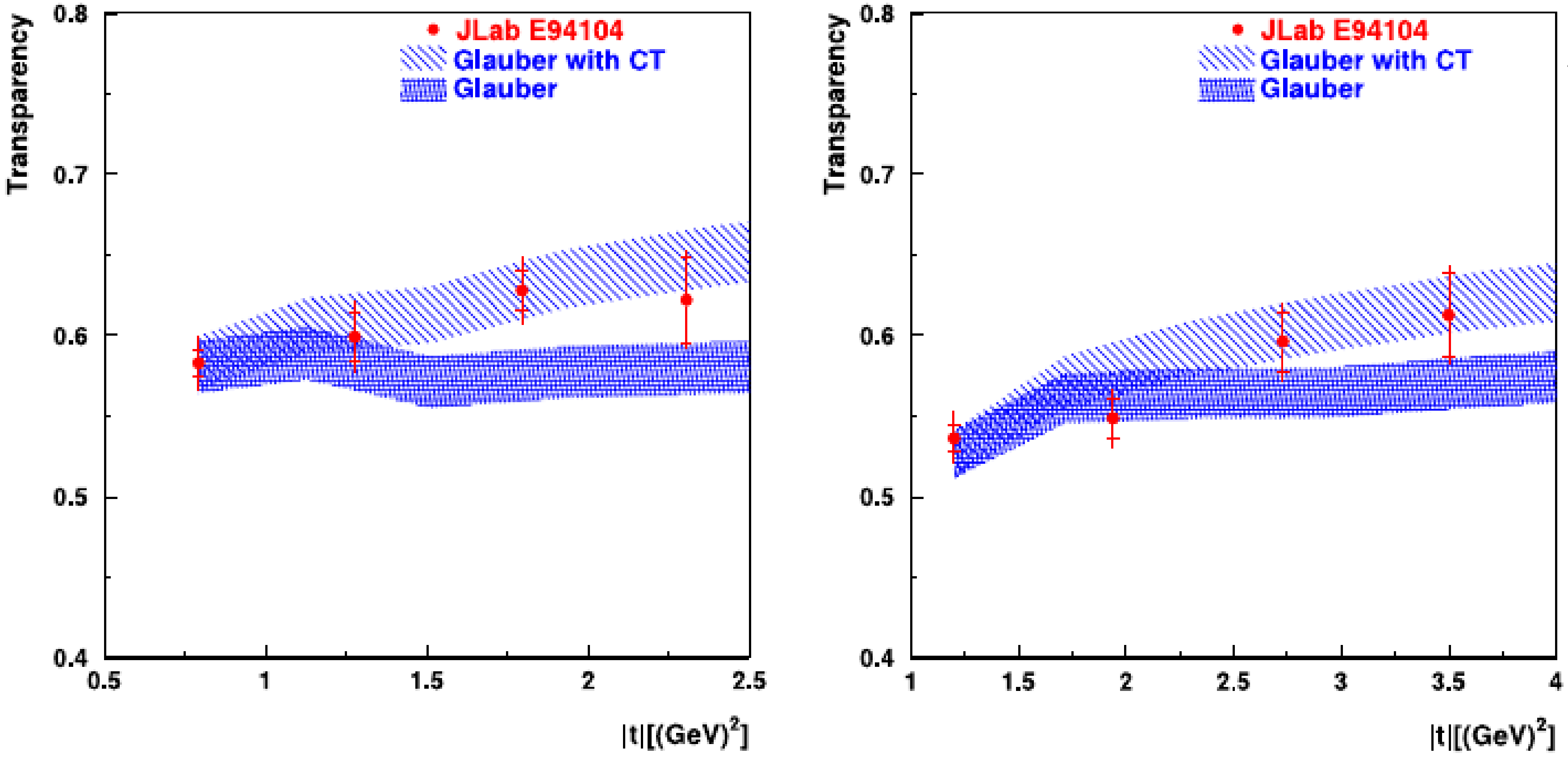
The reaction p+d →p+p+n has two aspects :

(i) Study of the deuteron wave function, u(q) and w(q) waves at high q
(ii) Study of wave packets evolution over distances < 2 fm under interference between IA, single and double rescatterings. One can choose kinematics with minimal and maximal FSI-> CT.

THANK YOU FOR ATTENTION!

SUPPLEMENTARY SLIDES

$$T = \sigma(\gamma A) / \sigma(\gamma p)$$

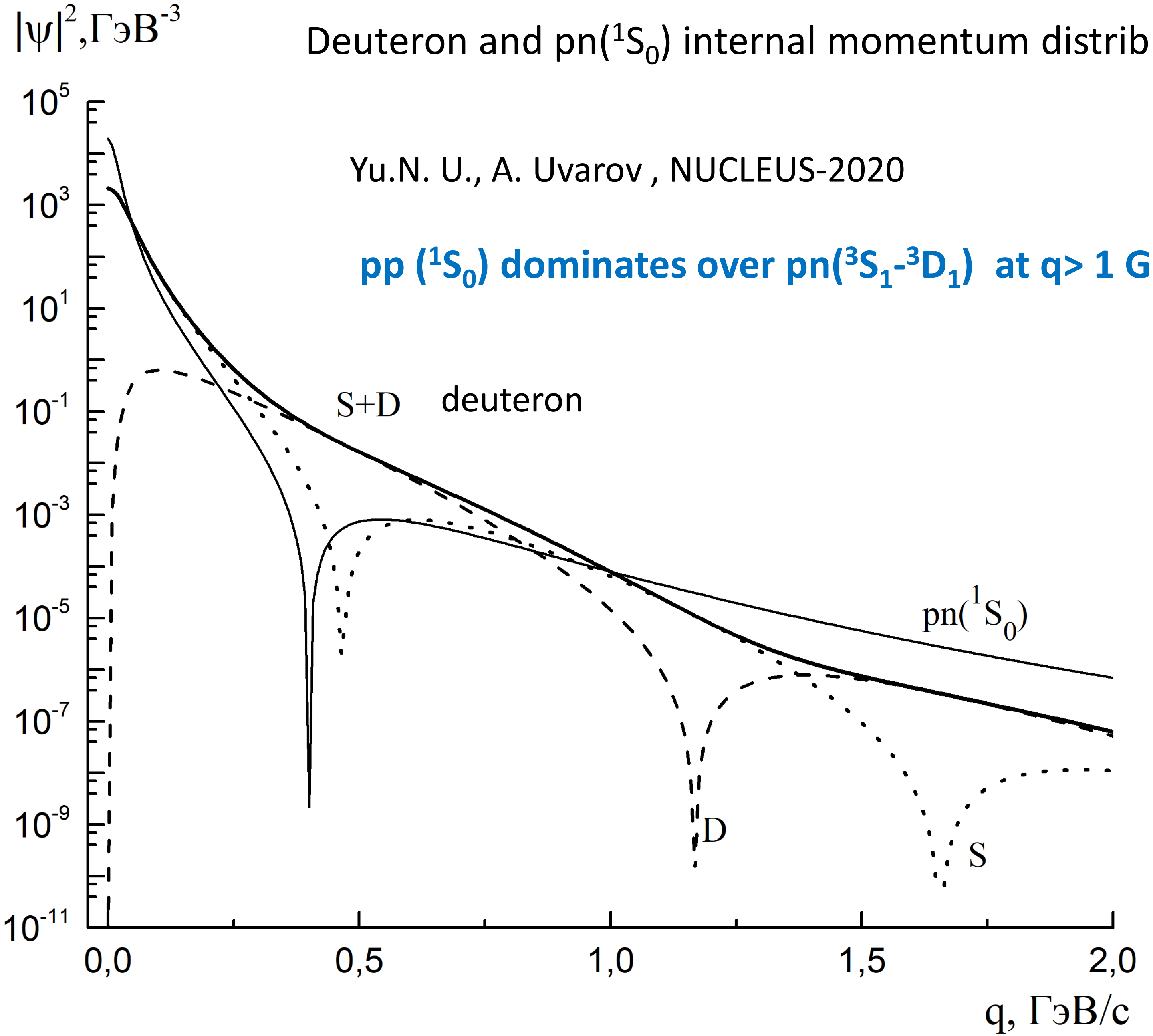


CT is observed for A(e,e ρ^0).

For baryons CT observations are less clear – bump.

Fig. 13. The nuclear transparency of ^{4}He(γ, $p\pi$) at $\theta^\pi_{cm} = 70^\circ$ (left) and $\theta^\pi_{cm} = 90^\circ$ (right), as a function of momentum transfer square $|t|$ [80]. The inner error bars shown are statistical uncertainties only, while the outer error bars are statistical and point-to-point systematic uncertainties (2.7%) added in quadrature. In addition there is a 4% normalization/scale systematic uncertainty which leads to a total systematic uncertainty of 4.8%.

Deuteron and pn($^1S_0$) internal momentum distribution



arXiv:2102:08477 [hep-th]

Prepared for Physics of Elementary Particles and Atomic Nuclei. Theory

Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams

V.V. Abramov[1], *A. Aleshko*[2], *V.A. Baskov*[3], *E. Boos*[2], *V. Bunichev*[2], *O.D. Dalkarov*[3], *R. El-Kholy*[4], *A. Galoyan*[5], *A.V. Guskov*[6], *V.T. Kim*[7,8], *E. Kokoulina*[5,9], *I.A. Koop*[10,11,12], *B.F. Kostenko*[13], *A.D. Kovalenko*[5], *V.P. Ladygin*[5], *A. B. Larionov*[14,15], *A.I. L'vov*[3], *A.I. Milstein*[10,11], *V.A. Nikitin*[5], *N. N. Nikolaev*[16,26], *A. S. Popov*[10], *V.V. Polyanskiy*[3], *J.-M. Richard*[17], *S. G. Salnikov*[10], *A.A. Shavrin*[18], *P.Yu. Shatunov*[10,11], *Yu.M. Shatunov*[10,11], *O.V. Selyugin*[14], *M. Strikman*[19], *E. Tomasi-Gustafsson*[20], *V.V. Uzhinsky*[13], *Yu.N. Uzikov*[6,21,22,*], *Qian Wang*[23], *Qiang Zhao*[24,25], *A.V. Zelenov*[7]

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