Double Spin Correlations in the Reaction dd->pnpn and in Elastic Proton-Nucleon Scattering at Large Angles

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CONTENT

- Motivation :
  SPD NICA experiment at the first stage (*talk by V. Kim on 22.10.24*)
- Dibaryons, multiquark configuration in interaction of hadrons,
  Color transparency, constituent counting rules
- Data on A_{NN} for pp->pp at $\vartheta_{cm} = 90^o, \sqrt{s} = 3-5$ GeV and theoretical models
- How to get A_{NN} pn->pn from dd->pnpn?
- Conclusion

This work is supported by grant of Scientific program JINR-Republic of Kazakhstan, JINR order № 411, 05.06.2023.

SEARCH FOR ONSET OF THE TRANSITION REGION

$hadrons \to q, g$

"One of the outstanding issues of strong interaction physics is understanding the dynamics of the transition between hadronic to quark-gluon phases of matter".

F. Gross, P. Klempt et al., 50 Years of QCD, *Eur.Phys.J.C* 83 (2023) 1125;
e-print: 2212.11107[hep-ph]

Three remarkable phenomena in the transition region:
COLOR TRANSPARENCY A(p,2p)B
CONSTITUENT COUNTING RULES
MULTIQUARK CONFIGURATIONS

Double polarized pp-elastic scattering at 90° includes all these features $3GeV \leq \sqrt{s_{NN}} \leq 5.5GeV$

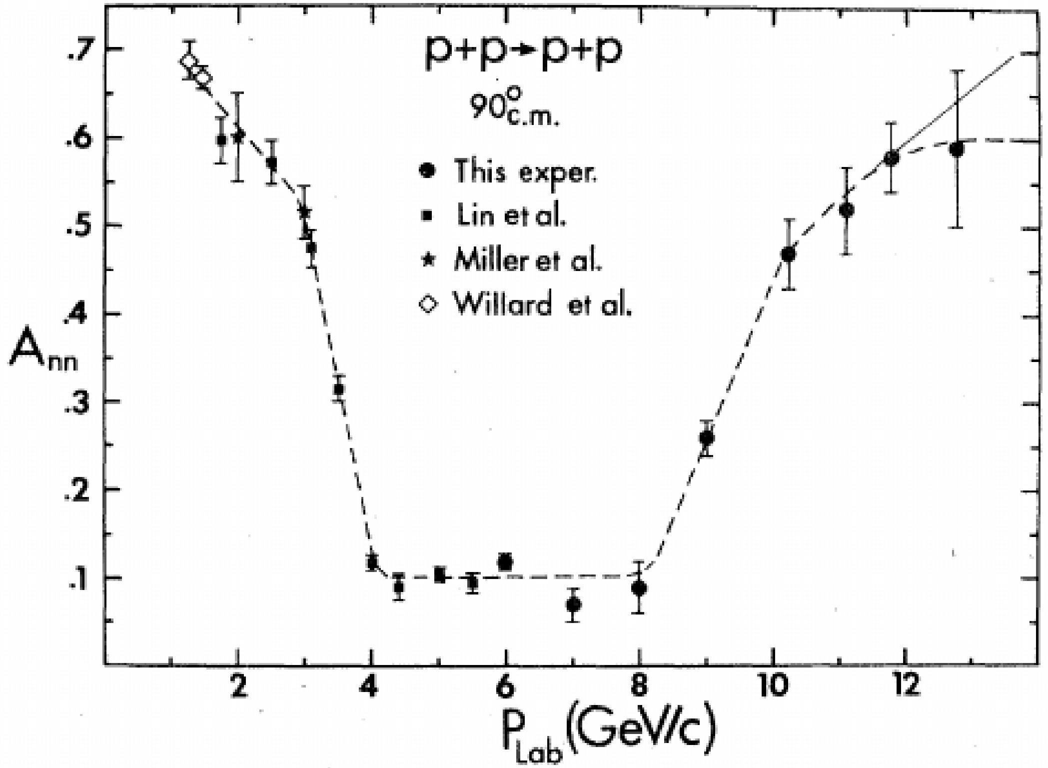
Indication to octoquark configurations in hard double polarized $p^{\uparrow}p^{\uparrow}$-> pp

SPIN-SPIN EFECTS IN HARD pp ELASTIC SCATTERING

PHYSICAL REVIEW D VOLUME 23, NUMBER 3 1 FEBRUARY 1981

Energy dependence of spin-spin effects in *p*-*p* elastic scattering at 90°$_{c.m.}$

E. A. Crosbie, L. G. Ratner, and P. F. Schultz
Argonne National Laboratory, Argonne, Illinois 60439



$$A_{NN} = \frac{d\sigma(\uparrow\uparrow) - d\sigma(\uparrow\downarrow)}{d\sigma(\uparrow\uparrow) + d\sigma(\uparrow\downarrow)}$$

$$\vartheta_{cm} = 90^{\circ}$$

pp(90°)-dynamics at very short distances:

$$\sqrt{s} = 5-7GeV, -t = 5-10GeV^2 : r_{NN} \sim 1/\sqrt{-t} \leq 0.1 fm$$

Three aspects of QCD dynamics in pp(90°)-elastic:

i) $d\sigma^{pp}(s, \vartheta_{cm} = 90^{\circ}) \sim s^{-10}$, but unexpected oscillations at s=10-20 GeV^2

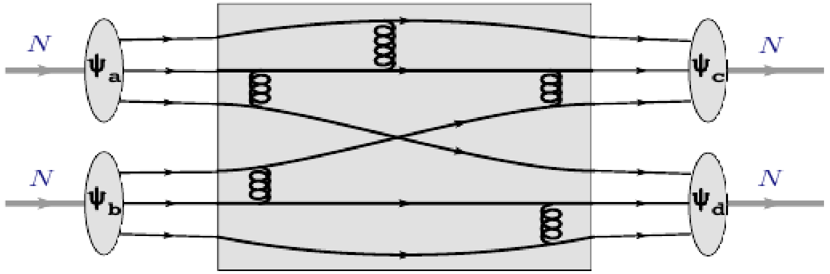
ii) $A_{NN} = \frac{d\sigma(\uparrow\uparrow) - d\sigma(\uparrow\downarrow)}{d\sigma(\uparrow\uparrow) + d\sigma(\uparrow\downarrow)}$ experiment contradicts to **pQCD : A_{NN}=1/3**

iii) Bump in color transparency in A(p,2p) at $4.9GeV \leq \sqrt{s_{NN}} \leq 5.5GeV$

S.Brodsky, de Teramond, PRL 60 (1988) 1924.

Possible explanation for all three observations:

assumes octoquarks at the thresholds $s\bar{s}\,, c\bar{c}$



$$\phi_1^{\rm PQCD} = 2\phi_3^{\rm PQCD} = -2\phi_4^{\rm PQCD} = 4\pi C F(t) F(u)[(t-m_d^2)/(u-m_d^2)+(u\leftrightarrow t)]e^{i\delta}.$$

$$\phi_3 = M(+-,+-) \quad \sigma A_{NN} = |\phi_3|^2; \sigma = 3|\phi_3|^2; A_{NN}^{pQCD} = \frac{1}{3}$$

pQCD QIM

$$\phi_3^{\rm res} = 12\pi \frac{\sqrt{s}}{p_{\rm c.m.}} d^{\,1}_{1,1}(\theta_{\rm c.m.}) \frac{(1/2)\Gamma^{pp}(s)}{M^* - E_{\rm c.m.} - \frac{1}{2} i\Gamma},$$

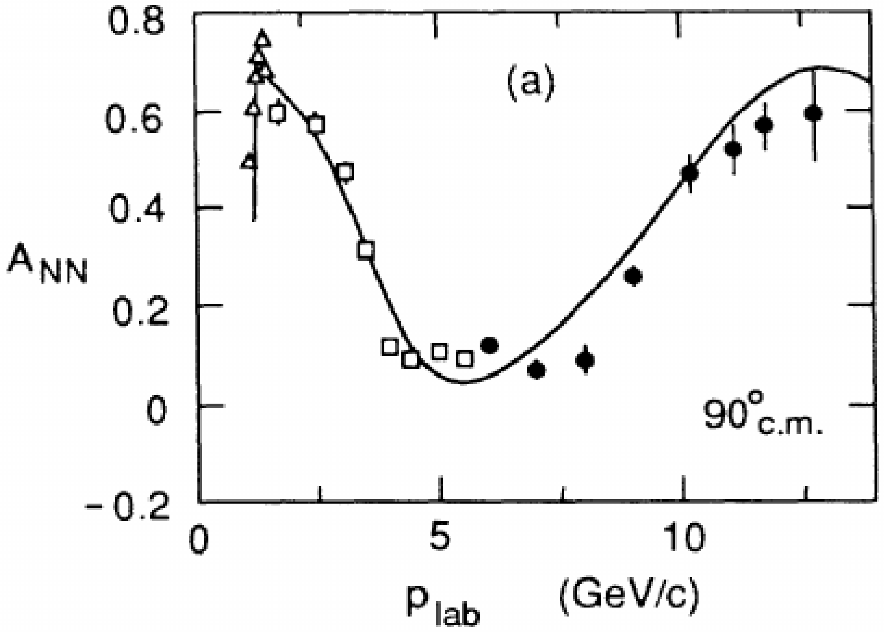
Interference of pQCD term and non-perturbative resonance term allows one to explain all three above features

Octoquark resonances: $J = L = S = 1$ $\quad uuds\bar{s}uud \quad \sqrt{s} = 3GeV$

$uudc\bar{c}uud \quad \sqrt{s} = 5GeV \quad pp \to p[J/\psi\, p]$

Spin Correlations, QCD Color Transparency, and Heavy-Quark Thresholds in Proton-Proton Scattering

Stanley J. Brodsky and Guy F. de Teramond
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 14 January 1988)



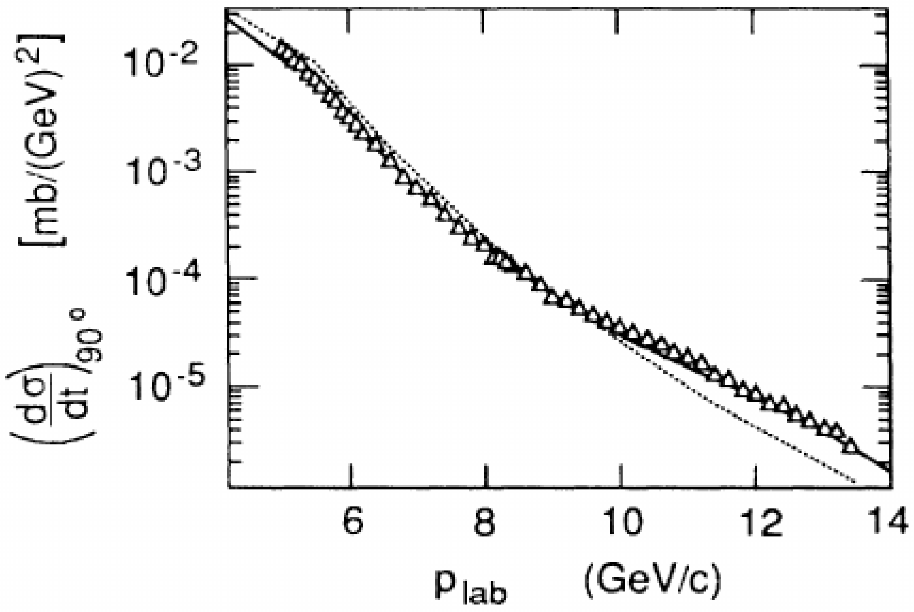


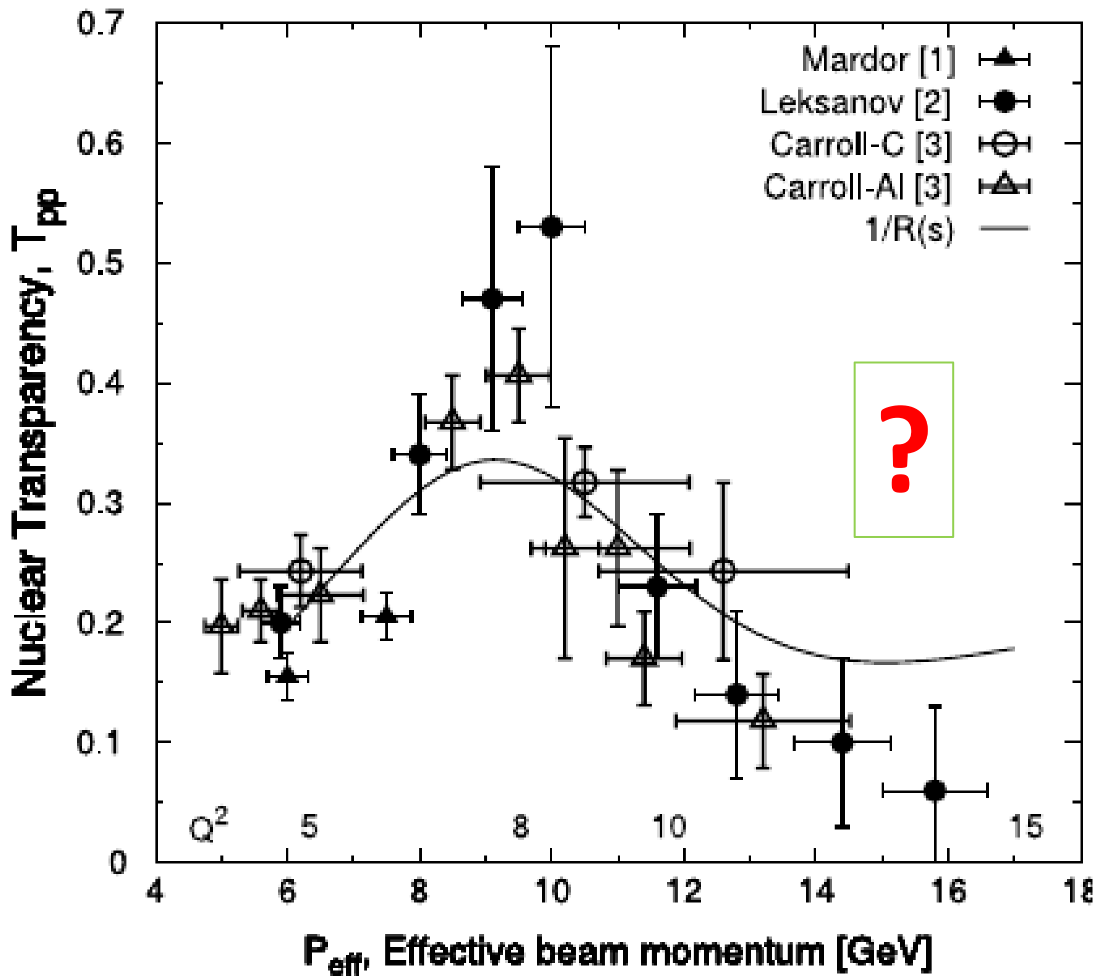
FIG. 1. Prediction (solid curve) for $d\sigma/dt$ compared with the data of Akerlof *et al.* (Ref. 16). The dotted line is the background PQCD prediction.

CT for baryons

A(p,2p)

PUZZLE

D. Dutta et al. / Progress in Particle and Nuclear Physics 69 (2013) 1–27



Unexpected drop of T in A(p,2p) at high P_L is not understood:

- J. Ralston, B.Pire, PRL 61 (1988) 1823

  Nuclear filtering : $f_{pp} = f_{QC} + f_L$

  f_{QC} - quark counting (PLC -size);

  f_L - Ladshoff (normal size);

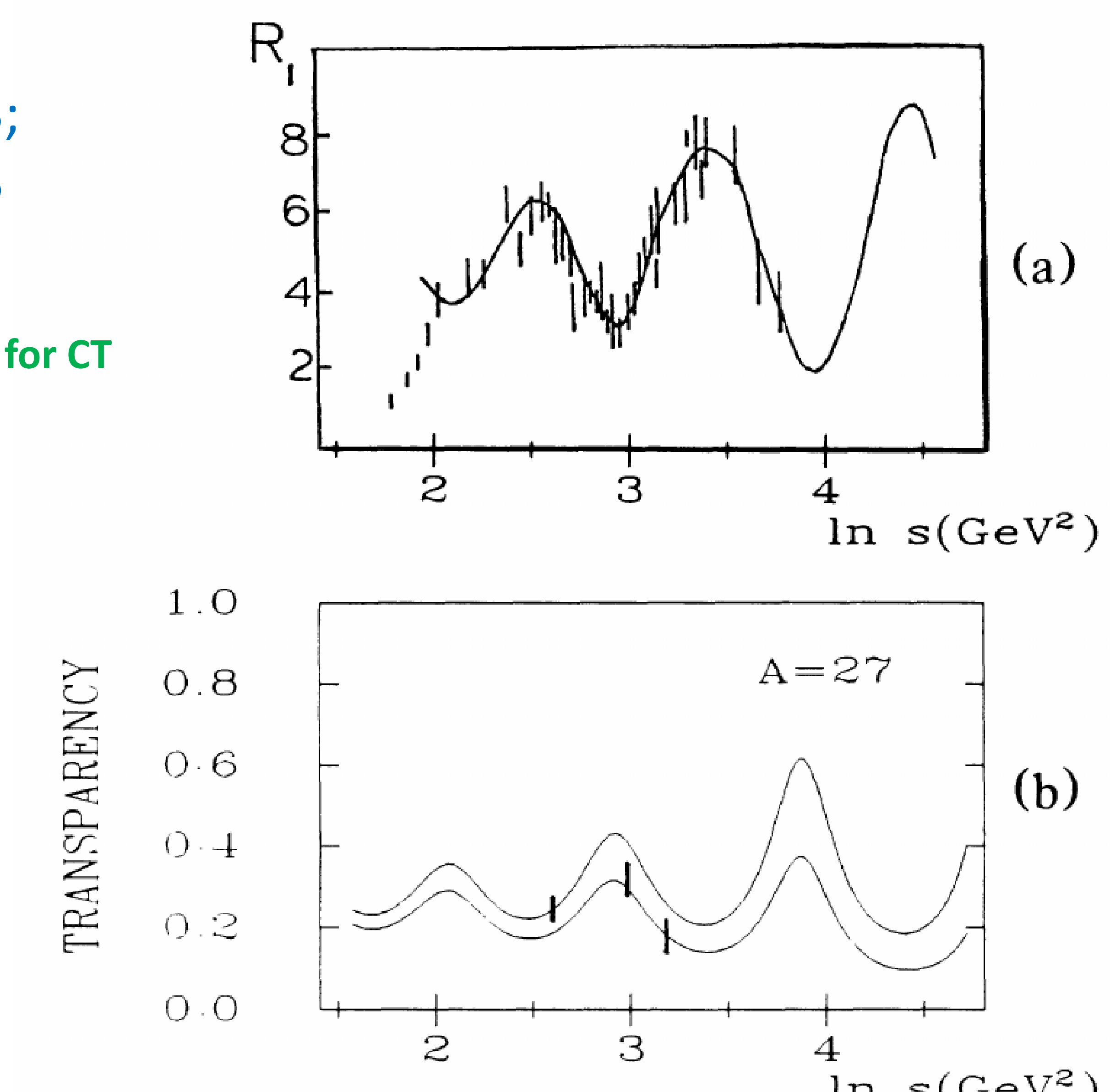
  Attenuation for f_L in nuclear medium

- due to intermediate (very broad, $\Gamma \sim 1 GeV$) $6qc\bar{c}$ resonance formation at the charm threshold , S. Brodsky , G. F. de Teramond, PRL 60(1988) 1924

D. Bhetuwal et al. (Hall C), PRL 126 (2021) : CT is excluded in $^{12}C(e,e'p)$ for Q^2 up to 14 GeV^2

Another explanation of pp-oscillations and CT bump:

J.P. Ralston, B. Pire.
PRL 61 (1988) 1823;
PRL 49 (1982) 1605



$$R_1 = s^{10}\frac{d\sigma^{pp}}{dt}$$

Nuclear filtering mechanism for CT

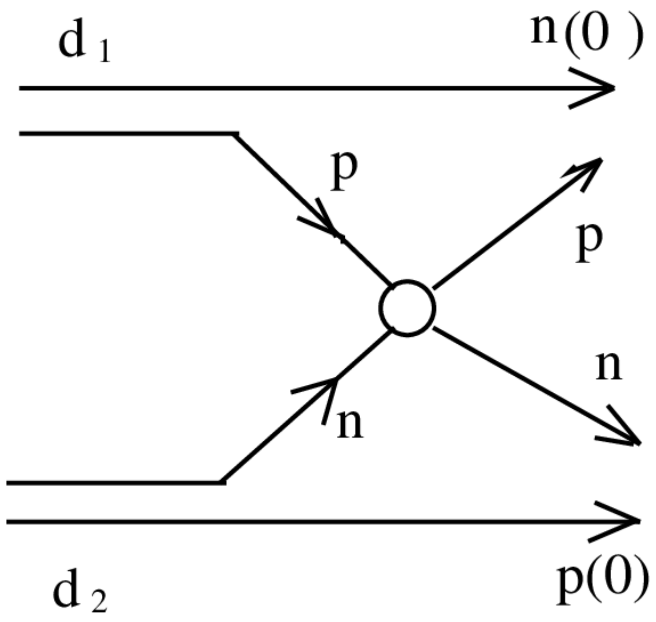
$$T = \frac{d\sigma^{pA}/dt}{A\,d\sigma^{pp}/dt}$$

Similar data on A_{NN} in pn-pn elastic scattering would be very valuable due to different spin-isospin dependence of p-n (T=0) as compared to p-p.

This can be done at NICA SPD.

How to get a double – spin correlations A^{pn}_{yy} in $pn \rightarrow pn$ from $dd \rightarrow pnpn$?

At NICA SPD $d^{\uparrow} d^{\uparrow} \to p(90^{\circ}) + n(90^{\circ}) + p_s(0) + n_s(0)$



Transversally polarized deuterons. Hard pn elastic scattering at 90°. Nucleons p (0) and n(0) are spectators.
The S-wave dominates in the deuterons at $\vec{q}_1 = \vec{q}_2 = 0$

S-waves :

$$\vec{p}_s = \vec{d}_1 / 2; \vec{n}_s = \vec{d}_d / 2 \quad (1)$$

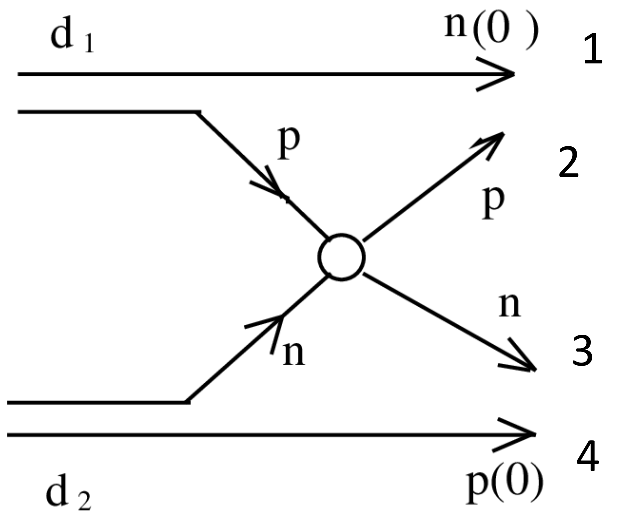
$$A^{dd}_{\vec{N}\vec{N}} \Rightarrow A^{pn}_{\vec{N}\vec{N}}(\theta^{pn}_{cm} = 90^{\circ}) \quad \text{(for any OZ)} \quad (2)$$

S+D-waves: $\vec{q}_1 \neq 0 \uparrow\uparrow OZ, \vec{q}_2 \neq 0 \uparrow\downarrow OZ$ **OZ || beam**

$$A^{dd}_{Z,Z} \Rightarrow A^{NN}_{Z,Z} = \frac{\sigma_{\nearrow\nearrow} - \sigma_{\nearrow\swarrow}}{\sigma_{\nearrow\nearrow} + \sigma_{\nearrow\swarrow}} \quad (3)$$

ISI@FSI and deviation from the conditions of Eq. (1) are under estimation

Elements of formalism for dd->pnpn



$$M_{fi} = \sum_{\sigma_2'\sigma_3'} \frac{M(d_1 \to 12')iT_{NN}(2'3' \to 23)iM(d_2 \to 3'4)}{(p_{2'}^2 - m_N^2 + i\epsilon)(p_{3'}^2 - m_N^2 + i\epsilon)}$$

$$M(d_1 \to 12') = -(\varepsilon + q_1^2/m) < \chi_1\chi_2|\phi_\lambda > \sqrt{2m_p 2m_n 2m_d}$$
$$= -(\varepsilon + q_1^2/m)u(q_1)\frac{1}{\sqrt{4\pi}}(\frac{1}{2}\sigma_1\frac{1}{2}\sigma_{2'}|1\lambda_1)\sqrt{2m_p 2m_n 2m_d}$$

$$M_{fi} = \sum_{\sigma_2'\sigma_3'} 2m_d < \chi_1\chi_2'|\phi_{\lambda_1} >< \chi_3'\chi_4|\phi_{\lambda_2} > T_{NN}(2'3' \to 23)$$

$$d\sigma_{\lambda_1\lambda_2} = \frac{1}{9}\sum_{\sigma_1\sigma_2\sigma_3\sigma_4} M^{\sigma_1\sigma_2\sigma_3\sigma_4}_{\lambda_1\lambda_2}(dd \to pnpn)(M^{\sigma_1\sigma_2\sigma_3\sigma_4}_{\lambda_1\lambda_2}(dd \to pnpn))^* =$$

$$= \frac{1}{9}\sum_{\sigma_1\sigma_2\sigma_3\sigma_4} | < \chi_{\sigma_2}(2)\chi_{\sigma_3}(3)|t_{pn}|\chi_{\sigma_p=\lambda_1-\sigma_1}(p)\chi_{\sigma_n=\lambda_2-\sigma_4}(n) > |^2$$

$$\times(\frac{1}{2}\sigma_1\frac{1}{2}\lambda_1 - \sigma_1|1\lambda_1)^2(\frac{1}{2}\sigma_4\frac{1}{2}\lambda_2 - \sigma_4|1\lambda_2)^2 u(q_1)^2 u(q_2)^2.$$

$\lambda_1 = +1, \lambda_2 = \pm 1$

$$d\sigma_{\lambda_1=+1\lambda_2=+1} = \sum_{\sigma_2\sigma_3} u(q_1)^2 u(q_2)^2 | < \chi_{\sigma_2}(2)\chi_{\sigma_3}(3)|t_{pn}|\chi_{\sigma_p=+\frac{1}{2}}(p)\chi_{\sigma_n=+\frac{1}{2}}(n) > |^2$$

$$d\sigma_{\lambda_1=+1\lambda_2=-1} = \sum_{\sigma_2\sigma_3} u(q_1)^2 u(q_2)^2 | < \chi_{\sigma_2}(2)\chi_{\sigma_3}(3)|t_{pn}|\chi_{\sigma_p=+\frac{1}{2}}(p)\chi_{\sigma_n=-\frac{1}{2}}(n) > |^2$$

Using R_3–invariance

$$d\sigma_{0,1} = d\sigma_{0,-1} = d\sigma_{-1,0} = d\sigma_{1,0} = d\sigma_{0,0}. \qquad d\sigma_{-1,0} = d\sigma_{0,+1}$$

Polarization of the beam

$$m = \pm 1, 0$$

Unpolarized deuteron beam

$$N_+ = N_- = N_0 \equiv n$$

Vector and tensor polarizations:

$$P_Y = \frac{\mathcal{N}_{m=+1} - \mathcal{N}_{m=-1}}{\mathcal{N}_{m=+1} + \mathcal{N}_{m=-1} + \mathcal{N}_{m=0}},$$

$$P_{YY} = \frac{\mathcal{N}_{m=+1} + \mathcal{N}_{m=-1} - 2\mathcal{N}_{m=0}}{\mathcal{N}_{m=+1} + \mathcal{N}_{m=-1} + \mathcal{N}_{m=0}}$$

$m = +1$	$m = -1$	$m = 0$
$N_+=2n$	0	$n \Rightarrow P_Y = \frac{2}{3}, P_{YY} = 0$
0	$N_-=2n$	$n \Rightarrow P_Y = -\frac{2}{3}, P_{YY} = 0$

PHYSICAL REVIEW C **82**, 014003 (2010)

Vector and tensor analyzing powers in deuteron-proton breakup at 130 MeV

E. Stephan,[1,*] St. Kistryn,[2] R. Sworst,[2] A. Biegun,[1] K. Bodek,[2] I. Ciepał,[2] A. Deltuva,[3] E. Epelbaum,[4] A. C. Fonseca,[5] J. Golak,[2] N. Kalantar-Nayestanaki,[6] H. Kamada,[7] M. Kiš,[6] B. Kłos,[1] A. Kozela,[8] M. Mahjour-Shafiei,[6,†] A. Micherdzińska,[1,‡] A. Nogga,[9] R. Skibiński,[2] H. Witała,[2] A. Wrońska,[2] J. Zejma,[2] and W. Zipper[1]

TABLE I. Set of the polarization states used in the $^1H(\vec{d},pp)n$ breakup experiment. The maximum polarizations P_Z, P_{ZZ} (for 100% efficiency of transitions in the ion source) and corresponding combinations of the magnetic fields are shown. The x indicates that the magnetic field is switched on, whereas the—indicates that the magnetic field is switched off. I_f denotes the full beam intensity. In the case of transitions with medium field on, the beam intensity is reduced to 2/3 of I_f in the case of 100% efficient transitions.

Polarization states		Magnetic fields				Beam intensity
P_Z	P_{ZZ}	SF1	SF2	MF	WF	
0	0	–	–	–	–	I_f
$+\frac{1}{3}$	+1	x	–	–	–	I_f
$+\frac{1}{3}$	−1	–	x	–	–	I_f
0	+1	x	–	x	–	$\frac{2}{3}I_f$
0	−2	–	x	x	–	$\frac{2}{3}I_f$
$+\frac{2}{3}$	0	x	x	–	–	I_f
$-\frac{2}{3}$	0	–	–	–	x	I_f

P_{yy}=0 for P_y=+2/3, -2/3

Comment by N.M. Piskunov

In this case measurement of A_{yy} in dd->pnpn seems to be similar to that for pp->pp (See Crabb et al. PRL 1978)

Two sets of deuterons beams:

$P_1 = +\frac{2}{3}, P_2 = +\frac{2}{3}$

$P_1 = +\frac{2}{3}, P_2 = -\frac{2}{3}$

N$_1$

N$_2$

$$A_{YY}^{dd} = \frac{\mathcal{N}_1 - \mathcal{N}_2}{\mathcal{N}_1 + \mathcal{N}_2}$$

In terms of $d\sigma_{\lambda_1\lambda_2}$

$$A_{YY}^{dd} = \frac{2\cdot 2d\sigma_{++} + 2d\sigma_{+0} + 2d\sigma_{0+} + d\sigma_{00} - (2\cdot 2d\sigma_{+-} + 2d\sigma_{+0} + 2d\sigma_{0-} + d\sigma_{00})}{2\cdot 2d\sigma_{++} + 2d\sigma_{+0} + 2d\sigma_{0+} + d\sigma_{00} + (2\cdot 2d\sigma_{+-} + 2d\sigma_{+0} + 2d\sigma_{0-} + d\sigma_{00})}$$

Using R_3–invariance

$$A_{YY}^{dd} = \frac{d\sigma_{+1,+1} - d\sigma_{+1,-1}}{d\sigma_{+1,+1} + d\sigma_{+1,-1} + \frac{5}{2} d\sigma_{0,0}} = \frac{4}{9} A_{YY}^{NN}$$

Yu.N. Uzikov, A.A. Temerbayev, Phys. Part. Nucl. 55 (2024) 895;
e-Print: 2311.12605 [nucl-th]

OUTLOOK

- We do not have good understanding of the most fundamental process, as hard elastic NN-scattering , in particularly at $\sqrt{s} = 3 - 10 GeV$ and their relation to QCD (CT,CCR…)

- Available data on double spin correlation in hard pp->pp are intriguing. Theoretical interpretation is questionable.

- A similar data on A_{NN} in hard pn->pn will provide important independent information on the short-range NN-dynamics

- Measurement of A^{dd}_{yy} in $d^{\uparrow}d^{\uparrow} \to p(90^{\circ}) + n(90^{\circ}) + p_s(0) + n_s(0)$ will provide A^{pn}_{yy} in case of the S-wave d.w.f. dominance

THANK YOU FOR ATTENTION!

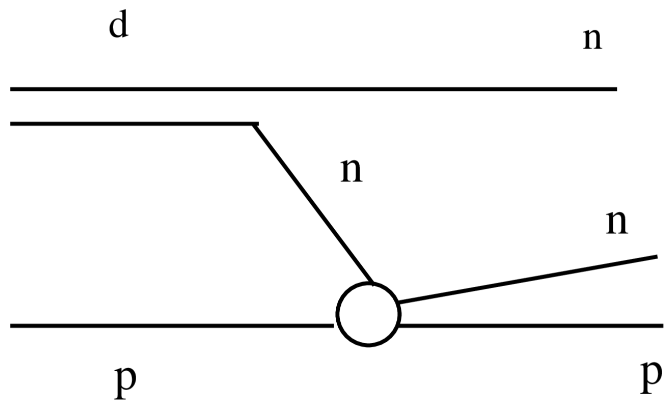
VOLUME 43, NUMBER 14 PHYSICAL REVIEW LETTERS 1 OCTOBER 1979

Spin-Spin Forces in 6-GeV/*c* Neutron-Proton Elastic Scattering

D. G. Crabb, P. H. Hansen, A. D. Krisch, T. Shima, and K. M. Terwilliger
Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan 48109

$$d^{\uparrow} p^{\uparrow} \rightarrow pnp$$

Measurement was made of $d\sigma/dt$ for $n_{\uparrow} + p_{\uparrow} \rightarrow n + p$ at $P_{\perp}^2 = 0.8$ and 1.0 $(\mathrm{GeV}/c)^2$ at 6 GeV/c. The 6-GeV/c 53%-polarized neutrons from the 12-GeV/c polarized deuteron beam at the Argonne zero-gradient synchroton were scattered from our 75%-polarized proton target. Both spins were oriented perpendicular to the scattering plane. We found large unexpected spin-spin effects in n-p elastic scattering which are quite different from the p-p spin-spin effects.



onance by a factor of 12.5. By carefully tuning the pulsed quadrupoles, the ZGS staff was able to jump this $0-\nu_y$ resonance and obtain a beam of 12-GeV/c deuterons with a neutron polarization of $P_B = (53 \pm 3)\%$.

Measuring the polarization of these neutrons was also a new problem. A fast "uncalibrated"

Polarization: 53% for n, 75% for p

Double spin correlations in pn->pn

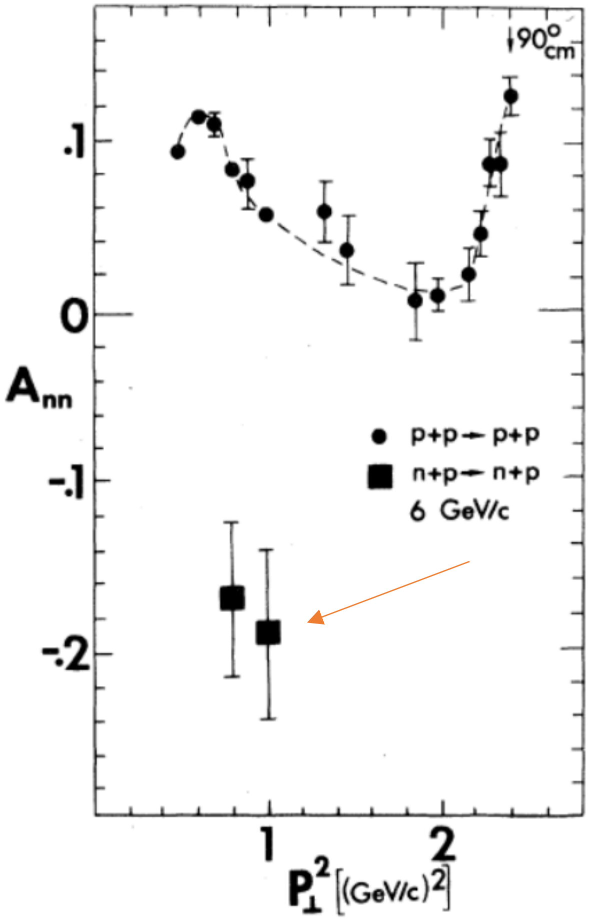


FIG. 2. The spin-spin correlation parameter, A_{nn}, for pure-initial-spin-state nucleon-nucleon elastic scattering at 6 GeV/c is plotted against the square of the transverse momentum. The proton-proton and neutron-proton data are quite different.

NUMBER 14 PHYSICAL REVIEW LETTERS 1 OCTOBER 1979

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Randall Laboratory of Physics, The University of Michigan, Ann Arbor, Michigan 48109

$$(d\sigma/dt)_{\uparrow\uparrow} = \langle d\sigma/dt\rangle(1 + 2A + A_{nn}),$$

$$(d\sigma/dt)_{\downarrow\downarrow} = \langle d\sigma/dt\rangle(1 - 2A + A_{nn}),$$

$$(d\sigma/dt)_{\uparrow\downarrow} = (d\sigma/dt)_{\downarrow\uparrow} = \langle d\sigma/dt\rangle(1 - A_{nn}).$$

A -> 0

$$\frac{(d\sigma/dt)_{\uparrow\uparrow}}{(d\sigma/dt)_{\uparrow\downarrow}} \equiv \frac{(d\sigma/dt)_{\uparrow\uparrow} + (d\sigma/dt)_{\downarrow\downarrow}}{(d\sigma/dt)_{\uparrow\downarrow} + (d\sigma/dt)_{\downarrow\uparrow}} = \frac{1 + A_{nn}}{1 - A_{nn}}.$$

Concerning the counting rate N of this process one should note that differential cross section of the pp-elastic scattering at $\sqrt{s_{NN}} = 5$ GeV and $\theta_{\rm cm} = 90°$ is $\sim 10^{-2}\,\mu\text{b/sr}$ [2]. For the luminosity $\sim 10^{29}\,\text{cm}^{-2}\,\text{s}^{-1}$ in pp-collision [24] this corresponds to $N \sim 10^{-3}/\text{s}$. However, for the scattering angle $\theta_{\rm cm} = 50°$ this number increases by two orders of magnitude [20].

$$I = I_0\left(1 + \frac{3}{2}P_y A_y + \frac{3}{2}P_y^T A_y^T + \frac{9}{4}P_y P_y^T C_{y,y}\right)$$

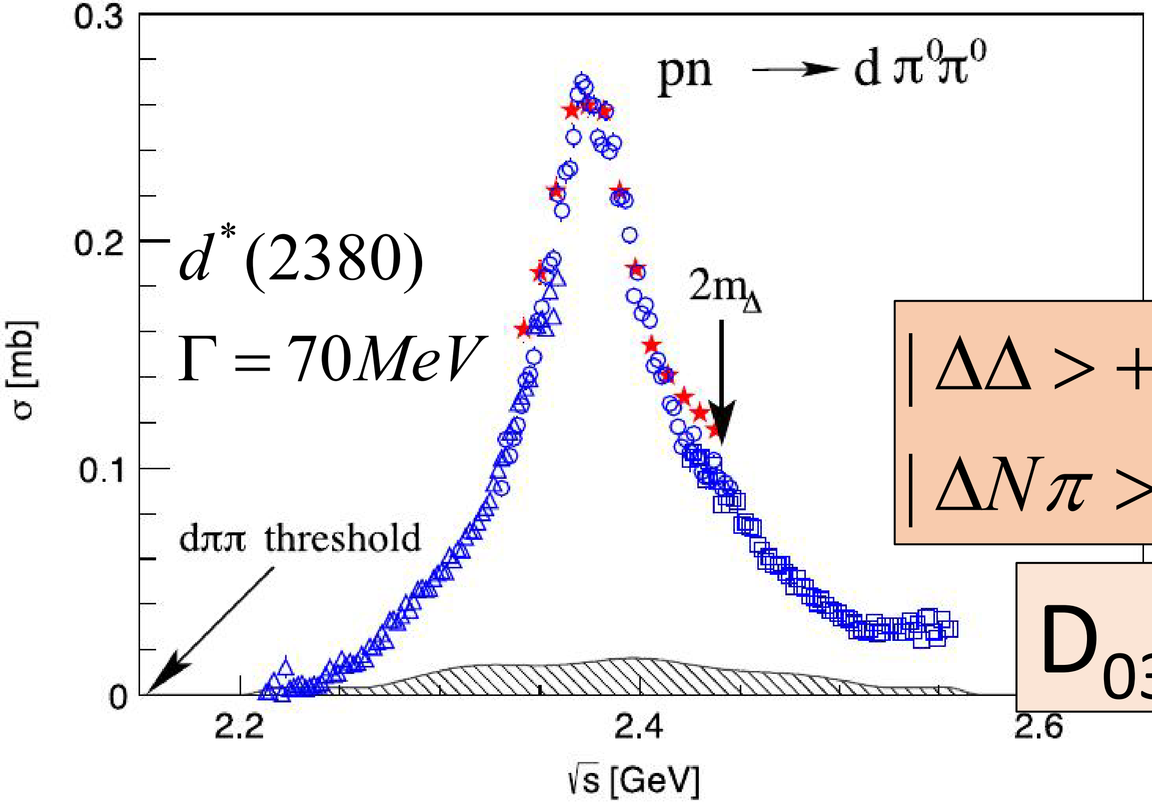
$$P_y = P_y^T = \frac{2}{3};$$

$$N_{\uparrow\uparrow} = L(2\times 2d\sigma_{++} + 2d\sigma_{+0} + 2d\sigma_{0+} + d\sigma_{00}),$$
$$N_{\uparrow\downarrow} = L(2\times 2d\sigma_{+-} + 2d\sigma_{+0} + 2d\sigma_{0-} + d\sigma_{00}),$$

1. DIBARYON RESONANCES

WASA@COSY

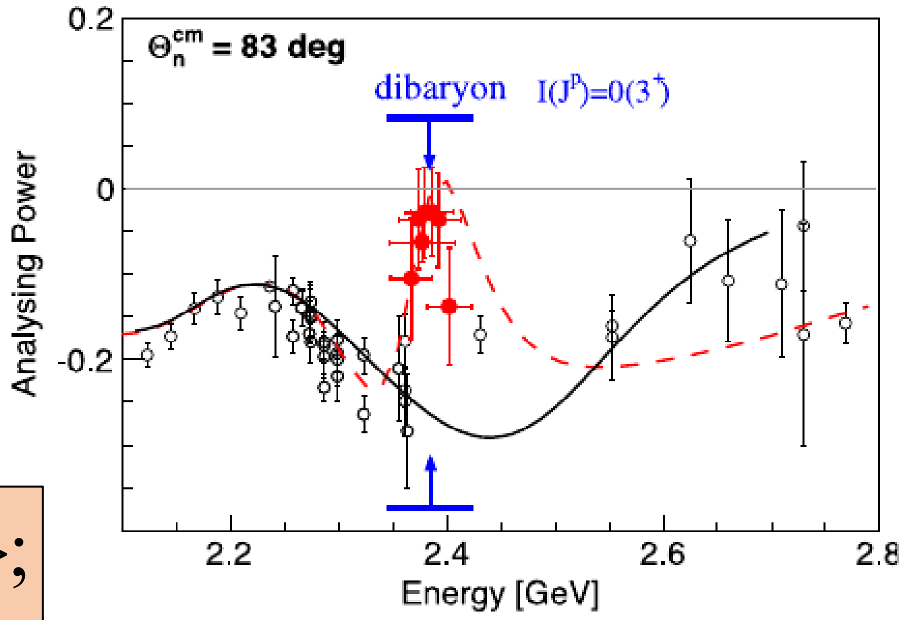
H. Clement / Progress in Particle and Nuclear Physics 93 (2017) 195–242

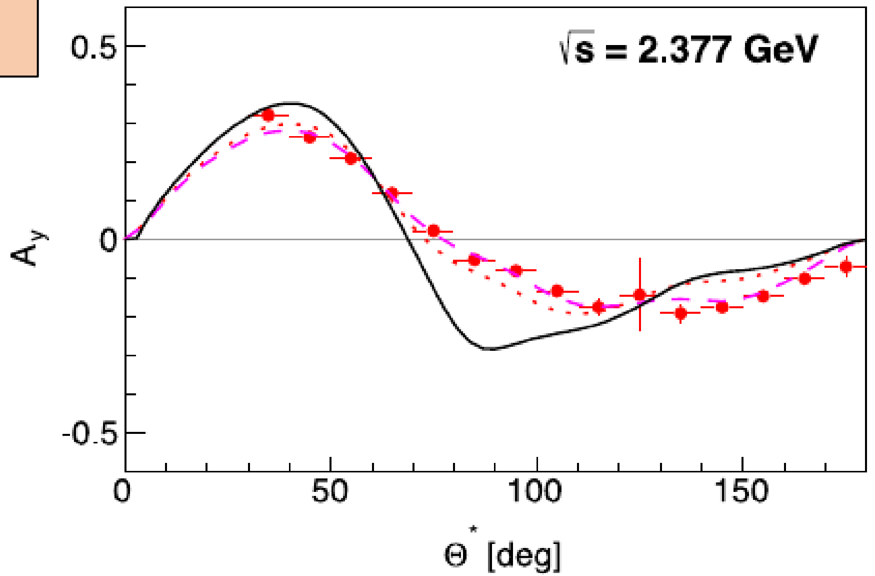


$$|\Delta\Delta> + |C\bar{C}>;$$
$$|\Delta N\pi>$$

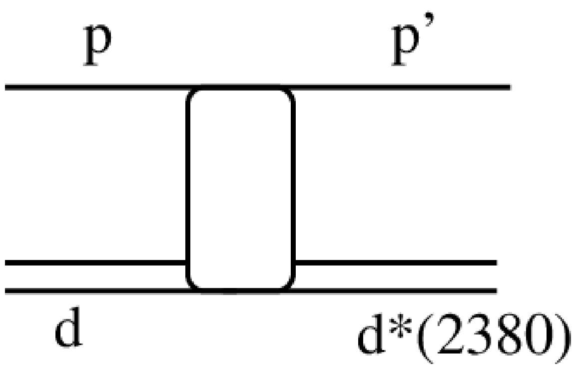
D_{03}

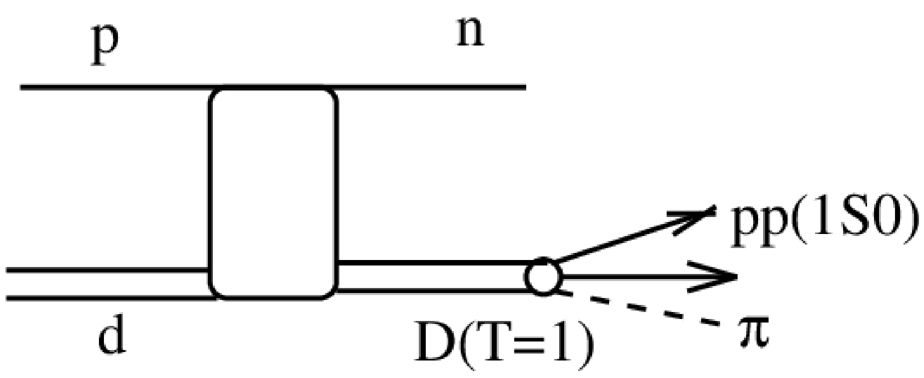
H. Clement / Progress in Particle and Nuclear Physics 93 (2017) 195–242



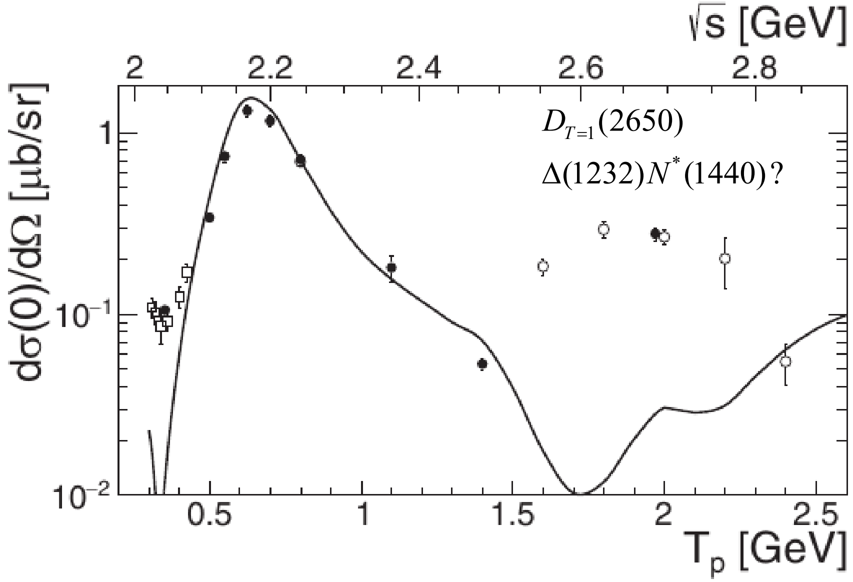


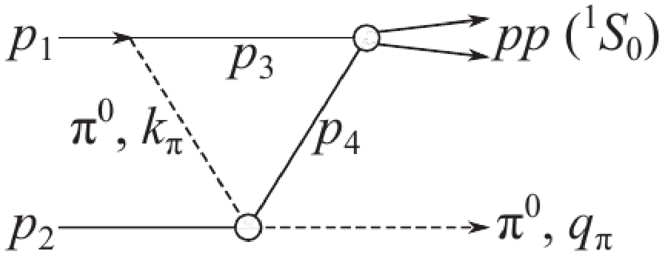
DIBARYONS IN pp and pd collisions





PHYSICAL REVIEW C **107**, 015202 (2023)





PHYSICAL REVIEW C **107**, 015202 (2023)

ANKE@COSY

Resonant behavior of the $pp \to \{pp\}_s\pi^0$ reaction at the energy $\sqrt{s} = 2.65$ GeV

D. Tsirkov,[1] B. Baimurzinova,[1,2,3,*] V. Komarov,[1] A. Kulikov,[1] A. Kunsafina,[1,2,3] V. Kurbatov,[1]
Zh. Kurmanalyiev,[1,2,3] and Yu. Uzikov[1,4,5]

Tetraquarks, pentaquarks at LHCb … Octoquarks(?)

2.COLOR TRANSPARENCY

Color transparency (CT) is an unique prediction of QCD:
in the final (and/or initial) state interaction of hadrons with nuclear medium must vanish for exclusive processes at high momentum transfer (A. Mueller, S. Brodsky; 1982)

CT is necessary condition for factorization in exclusive hard processes

For latest review of CT see:

D. Dutta, K. Hafidi, M. Strikman, Prog. Part. Nucl. Phys. 69 (2013) 1;
50 Years of QCD (2022), G. Sterman, P. 5.10

CT is well established for meson production,
for baryons is questionable (see A.B. Larionov, PRC (2023) and references therein).

CT for mesons production is well established

$^{4}He(\gamma,\pi p)$

D. Dutta et al. / Progress in Particle and Nuclear Physics 69 (2013) 1–27 15

$E_{\gamma} = 2.25 GeV$

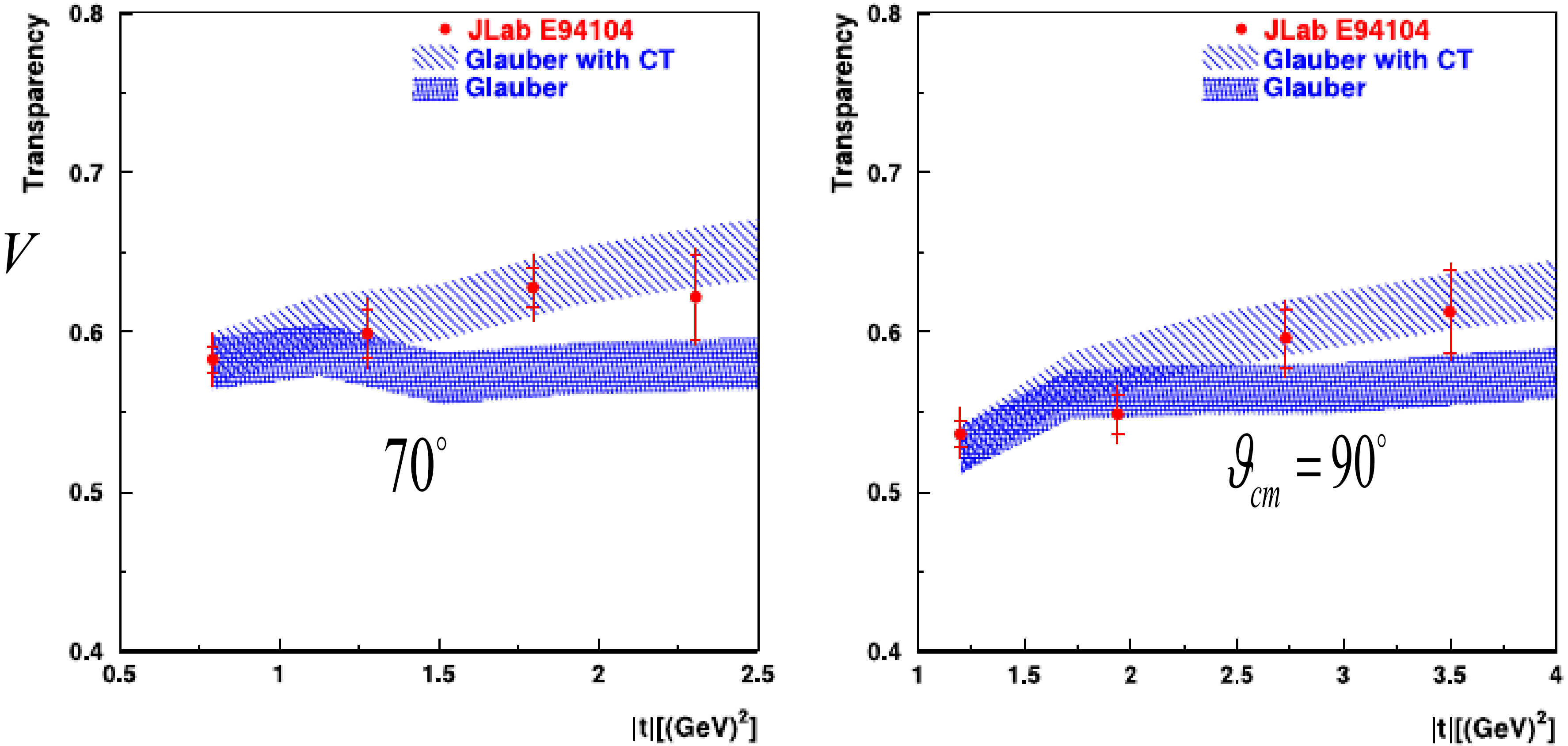


Fig. 13. The nuclear transparency of ^{4}He($\gamma, p\pi$) at $\theta^{\pi}_{cm} = 70^{\circ}$ (left) and $\theta^{\pi}_{cm} = 90^{\circ}$ (right), as a function of momentum transfer square $|t|$ [80]. The inner error bars shown are statistical uncertainties only, while the outer error bars are statistical 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%.

DIBARYON RESONANCES

D_{IJ}

F.J. Dyson, N.-H. Xuong,
PRL **13**, 815 (1964):

Search for non-strange isovector (I=1) and isotensor (I=2) dibaryons.

TABLE III. The mass of non-strange dibaryons (MeV).

	Y	S	I	J	$[f]$	M	$M_{exp.}$
D_{01}	2	0	0	1	[33]	1876	1876
D_{10}	2	0	1	0	[42]	1883	1878?
D_{03}	2	0	0	3	[33]	2351	2380
D_{30}	2	0	3	0	[6]	2394	?
D_{12}	2	0	1	2	[42]	2168	2148?
D_{21}	2	0	2	1	[51]	2182	2140?

Indication to the D_{21}:

P. Adlarson et al. PRL **121** (2018)

in $pp \to pp\pi^+\pi^-$ at 1 GeV