PROPOSALS FOR EXPERIMENTS AT THE FIRST STAGE OF THE SPD PROJECT IN dd COLLISIONS

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Kazakh-British Technical University, Almaty, May 24, 2024

QCD ... and NICA SPD at the 1-st stage

- ♦ Spontaneously broken chiral symmetry $SU_L(3)\times SU_R(3)$: $m_q \to 0$
  Goldstone bosons π,η,K (hadrons = effective degrees of freedom)
- ♦ Asymptotic freedom $\alpha_s(Q^2)\to 0$ (quarks, gluons)

Perturbative theory occurs in two kinematical regions:

- Large s and $Q^2\ (\gg \Lambda^2_{QCD})$ **(pQCD).**
- Small momenta q as compared to $\Lambda_{CSB}\sim 1GeV, q/\Lambda_{CSB}\ll 1,$ **(ChEFT)**

Intermediate energy region (few GeV):

too high for *ChEFT*, not enough high for *pQCD.*

The NICA SPD at lower energies $\sqrt{s_{NN}}=3.5-10GeV$ *is suitable to*

search for onset of transition region $\boxed{hadrons \to q,g}$**:**

CCR, color transparency, multiquarks, dibaryons,SRC...,

*(**V.V. Abramov et al. Phys.Part. Nucl. 51 (2021) 1044)** **pp-,pd-,dd***

dd-collisions at the first stage of SPD $\sqrt{s_{NN}} \leq 10 GeV$

- d↑d↑→ dd
  at small angles – test of ***pN amplitudes*** via spin-dependent Glauber theory
- d↑d↑→ p X
  at large p_T - search for ***6q-configurations*** in deuterons (talk by V. Vechernin)

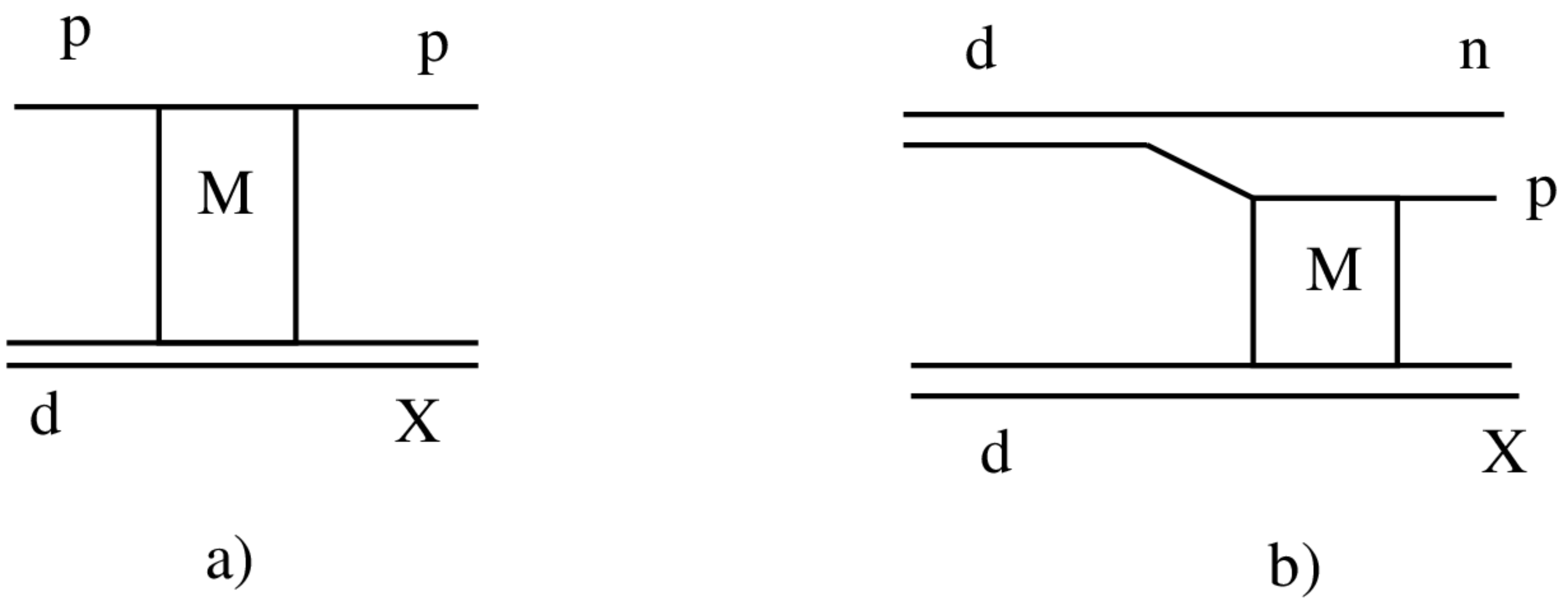
- d↑d↑→ pnpn and p↑ N ↑ →pN (***octoquarks*** in pN- at the *s* and *c*-thresholds)

- dd→ ^{3}Hn at large angles and ***CCR*** (6q in both deuterons and 9q in ^{3}H)

- ***Dibaryons***. Since ***pd→ DY*** will be not accessibly directly at very first phase of SPD, then to use ***dd→ DY+n*** at quasi-free kinematics
- $dd \to {}^4H_{\Lambda\Lambda} + K^+ + K^-$ (S=-2 hypernucleus)

- ...

From pd →pX to dd→npX



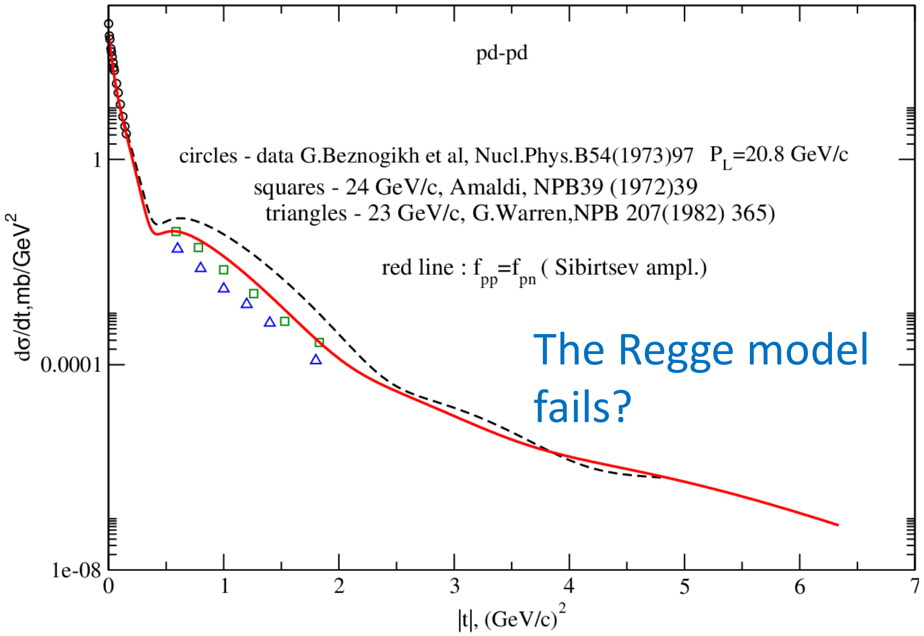
$$T(dd \to n + pX) = \Sigma_{\sigma'} < \sigma_n, \sigma_{p'} \,|\psi_d^{\lambda}(\vec{q}) > T_{\lambda\sigma'}^{M_X \sigma_p}(pd \to pX)$$

The pd→pX amplitude can be extracted from dd→n+pX with minimum distortions, when the final neutron takes one half of the deuteron momentum $\vec{p}_n = \vec{p}_d / 2$

●Test of pN spin-amplitudes in pd (and dd) elastic scattering using the spin-dependent Glauber model

pd→pd

Yu.N. U., J. Haidenbauer, A. Temerbayev,
A. Bazarova, Phys.Part. Nucl. 53 (2022) 419;
NN-Regge: A.Sibirtsev et al. EPJ A(2010)



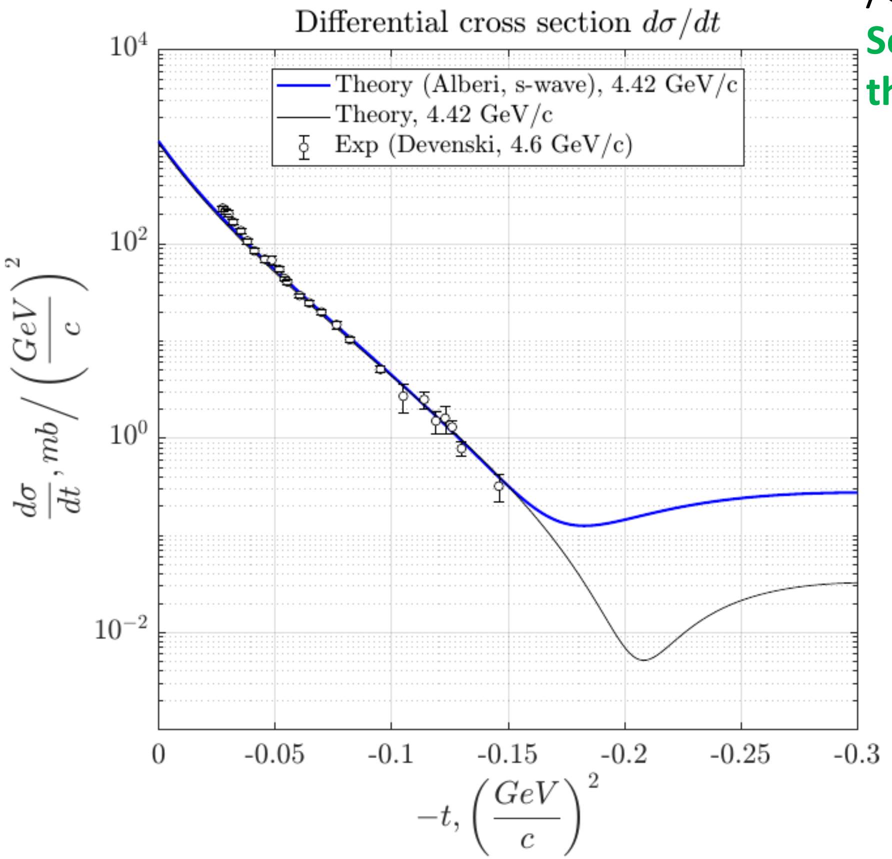
The Regge model fails?

dd→dd, Glauber model

A. Kornev , START program

/G. Alberi et al. NPB 17 (1970) /

So far without spins in pN , that should be included



• *SEARCH FOR 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, e-print: 2212.11107[hep-ph];

Eur. Phys. J. C 83 (2023) 1125

Three remarkable phenomena:
COLOR TRANSPARENCY A(p,2p)B
CONSTITUENT COUNTING RULES
MULTIQUARK CONFIGURATIONS
…

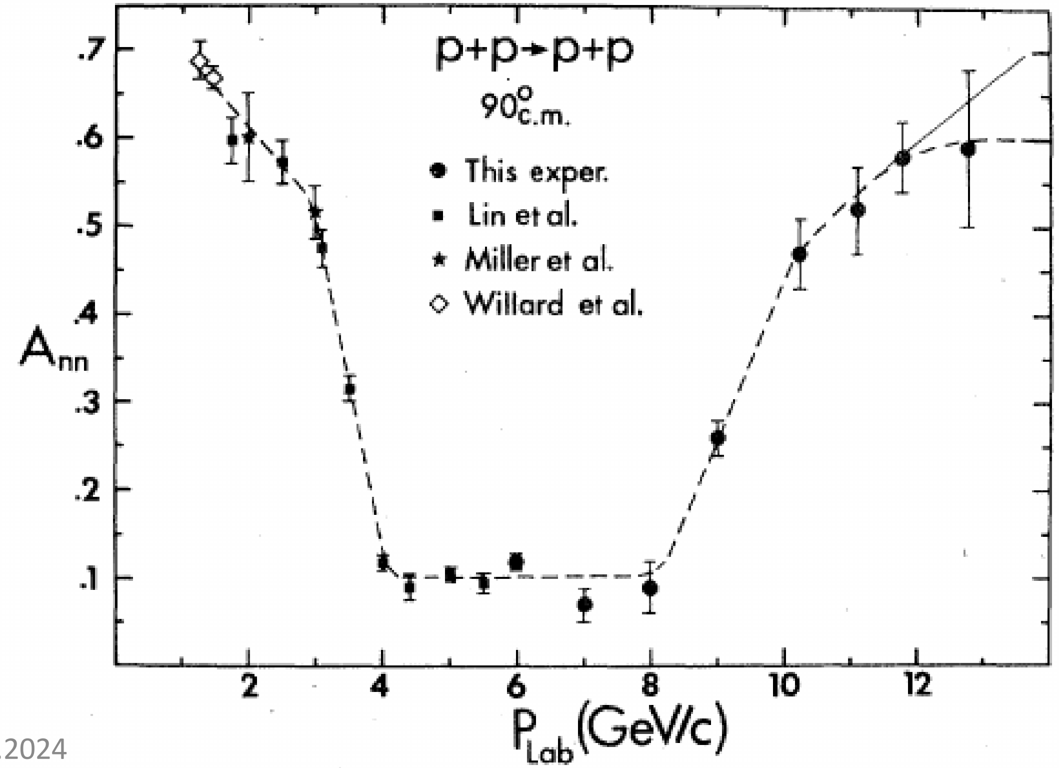
Double polarized pN-elastic scattering at 90°
includes all these features $3GeV \le \sqrt{s_{NN}} \le 5.5GeV$

SPIN-SPIN ASYMMETRY 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^o) -> dynamics at very short distances:

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

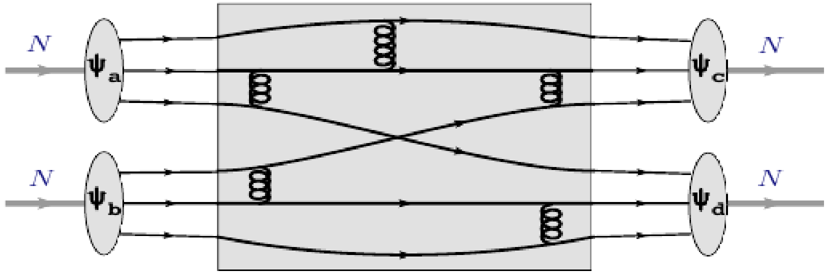
Three aspects of QCD dynamics in pp(90^o)-elastic at these energies:

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

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

iii) Puzzle : 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 $s\bar{s}, c\bar{c}$



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

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

pQCD QIM

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

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

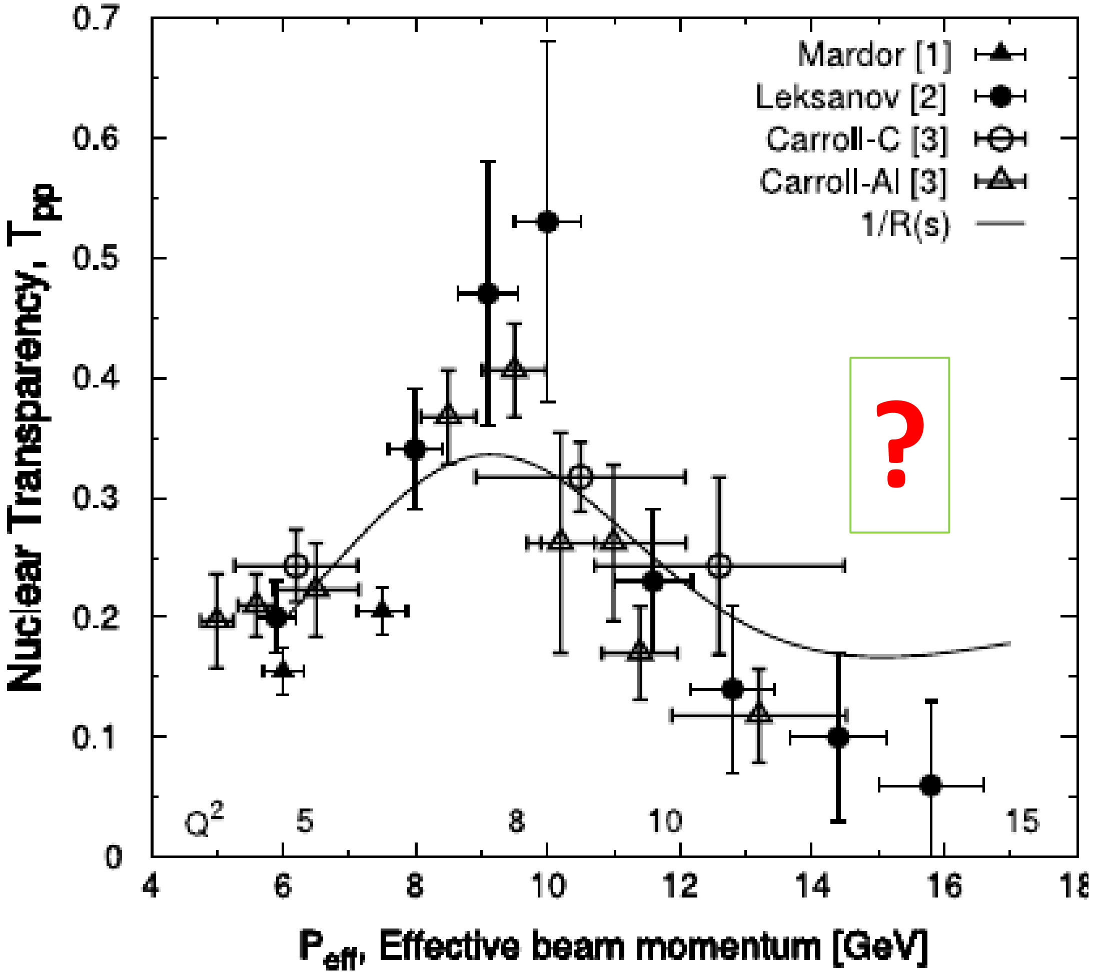
Octoquark resonances: $J = L = S = 1$ $\quad uuds\bar{s}uud$ $\quad \sqrt{s} = 3GeV$

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

CT for baryons
A(p,2p)

CT 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);

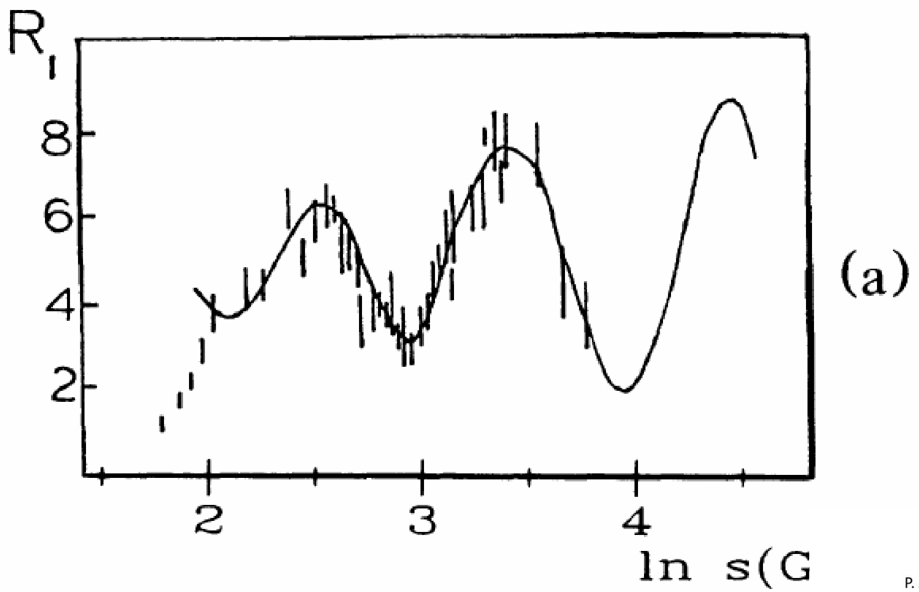
f_L - Landshoff (normal size);

Attenuation for f_L in nuclear medium

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

Another explanation of pp-oscillations in $d\sigma / dt$ at 90^o and CT bump (but not for A_{NN}):

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



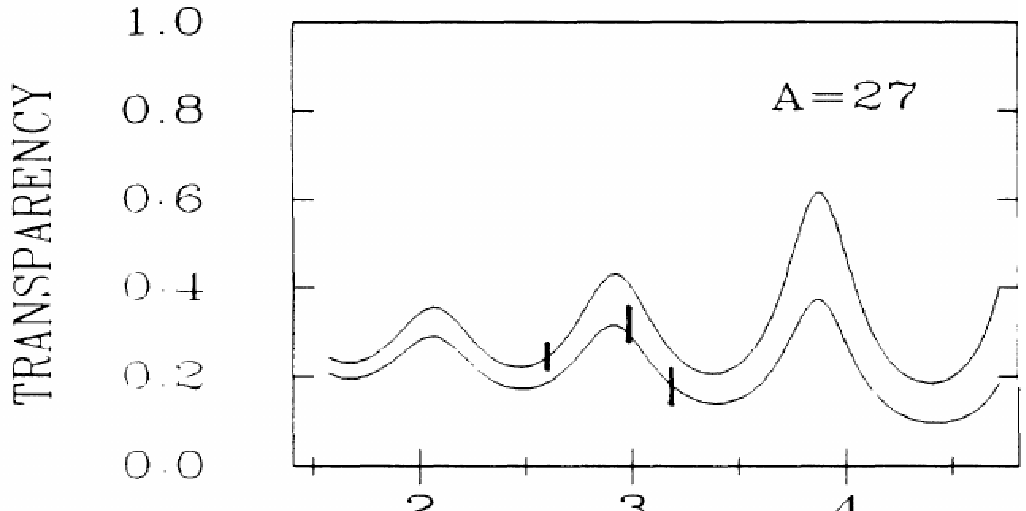
$$R_1 = s^{10} \frac{d\sigma^{pp}}{dt}$$

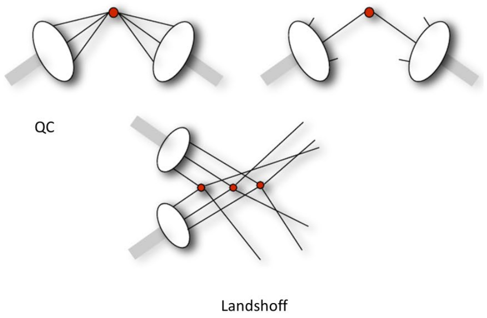
Nuclear filtering mechanism for CT

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

Landshoff + QC mehanisms -> oscillations

P. Jain, B. Pire, J.P. Ralston, Physics 2022, 4, 579-589





Landshoff

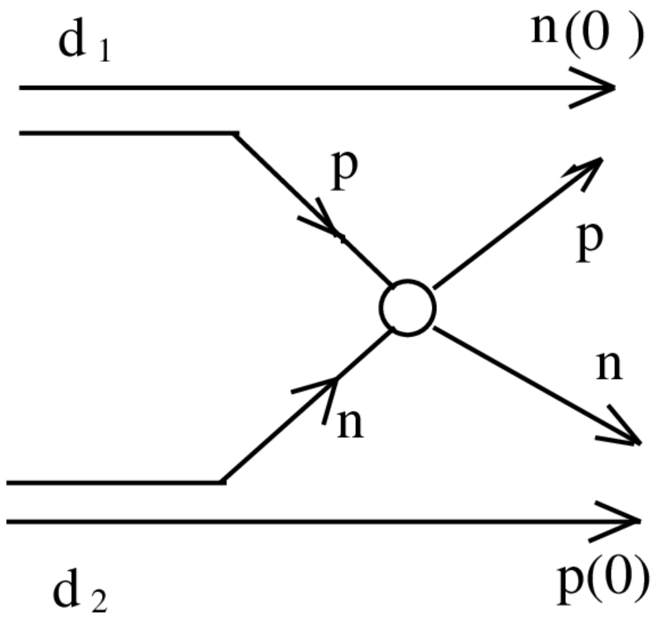
There are two different explanations for pp-oscillations and CT bump:

J. Ralston, B. Pire PRL 49 (1982)1605 ♦ S. Brodsky , G. F. de Teramond, PRL 60(1988) 1924

New independent data on A_{NN} in **pn-pn** elastic scattering will 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.

$$d^{\uparrow}d^{\uparrow} \rightarrow p(90^\circ) + n(90^\circ) + p_s(0) + n_s(0)$$



Transversaly 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 :

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

$$A^{dd}_{\vec{N}\vec{N}} \Rightarrow A^{pn}_{\vec{N}\vec{N}}(\theta^{pn}_{cm} = 90^\circ) \qquad (2)$$

(for any ON)

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

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

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

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

Yu. N. U., A.A. Temerbayev, e-Print: 2311.12605 [nucl-th]
(accepted by Phys. Elem. Part. Nucl.)

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 $\theta_{cm} = 90°$ is $\sim 10^{-2}\mu b/sr$ [2]. For the luminosity $\sim 10^{29} cm^{-2} sec^{-1}$ in pp-collision [24] this corresponds to $N \sim 10^{-3}/sec$. However, for the scattering angle $\theta_{cm} = 50°$ this number increases by two orders of magnitude [20].

N=3.6/hour at $\vartheta_{cm} = 90^\circ, \sqrt{s} = 5 GeV$

N=360/hour at $\vartheta_{cm} = 50^\circ$

(From A. Larionov, PRC 2023)

COLOR TRANSPARENCY (CT)

Color transparency (CT) is an unique prediction of QCD:
the interaction of hadrons with nuclear medium must vanish for exclusive processes at high momentum transfer

(A. Mueller, S. Brodsky; 1982)

- At high transferred momentum the excusive reaction is **dominated by point-like configurations (PLC)**, **color- singlets**, minimal Fock-space terms;

- Small object (b →0 transverse separation, **color multipoles vanish**) has small interaction cross sections: $\lim_{b\to 0}\sigma(b^2)\propto b^2$

CT is necessary condition for factorization in exclusive hard processes

Nuclear transparency: $T=\sigma^{A}(a,aN)/\sigma^{A}_{PWIA}(a,aN)$

CT is well established for meson production, but not for baryons

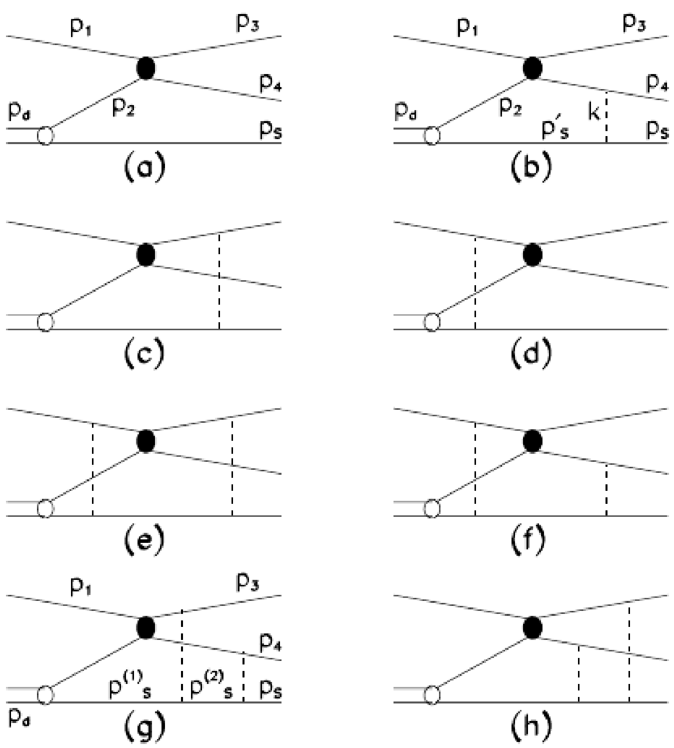
pd→ ppn

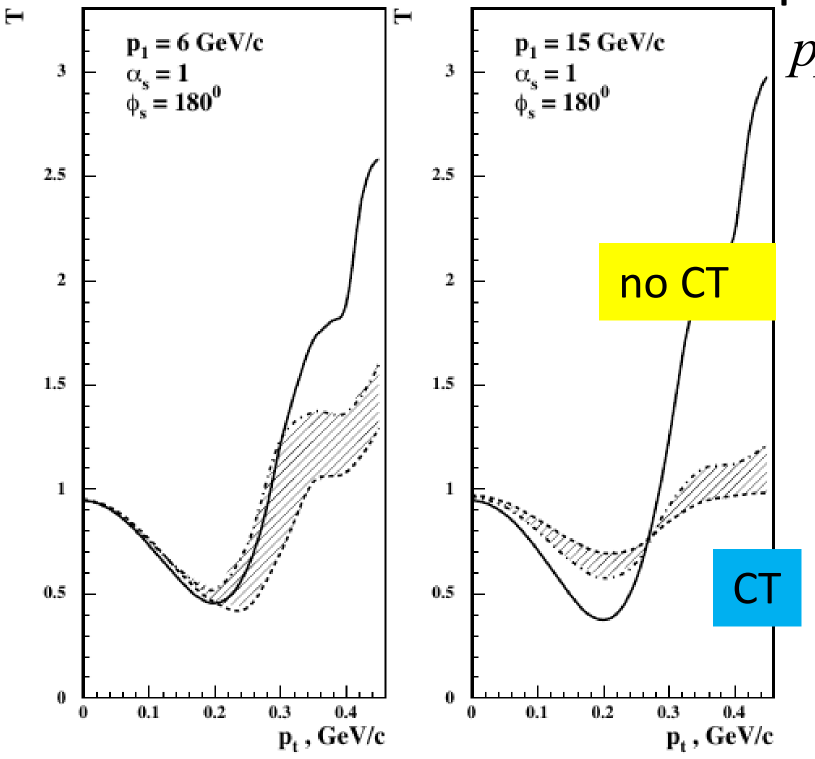
Testing rescattering dynamics (including color transparency effects - dashed curves)

L.L. Frankfurt et al. PRC 56 (1997) 2752; **A.B. Larionov, PRC 107 (2023) ,014695;** $d\sigma / d\Omega, A_{yy}$

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

pd->ppn with hard $pp \to pp(\vartheta_{cm} \approx 90^{\circ})$





The next is dd->pnpn

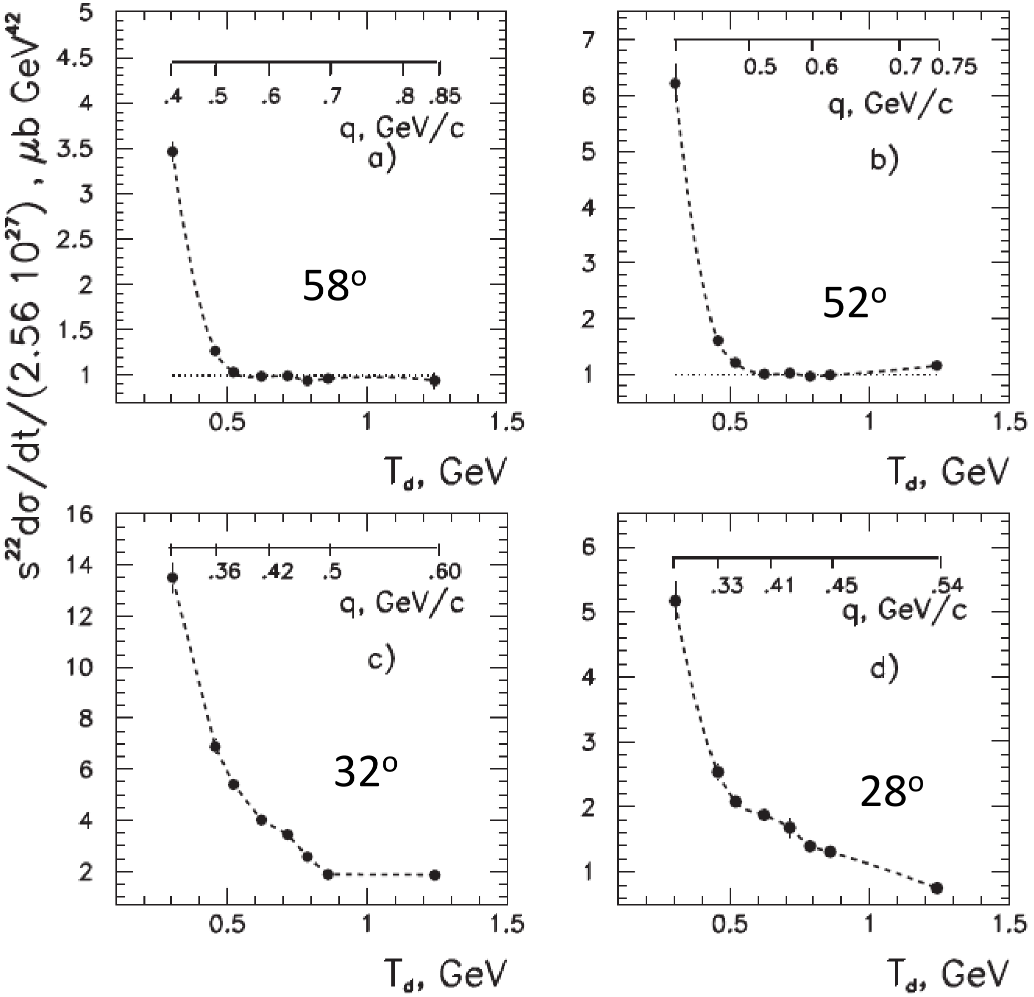
Transverse momentum of spectator

α_s =1 optimal for testing dynamics of multinucleon rescatterings $\alpha_s = 2(E_s - p_s^z) / m_d$

CONSTITUENT COUNTING RULES (CCR) IN d+d→³H+n

$$d\sigma / dt = f(t/s) s^{-(n-2)};$$

$$ab \rightarrow cd, n = N_a + N_b + N_c + N_d$$



SATURNE data (1980)

d+d→^{3}H+p
n=22

Unexpectedly low energy

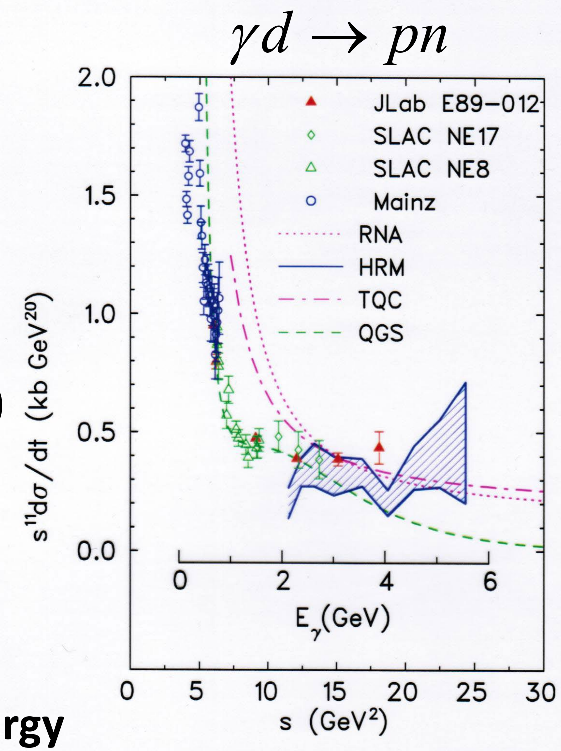


Figure 1: From S.J. Brodsky et al. Phys.Lett. **B578** (2004) 69

$s^{11}(d\sigma/dt)$ for $\theta_{c.m.} = 90°$

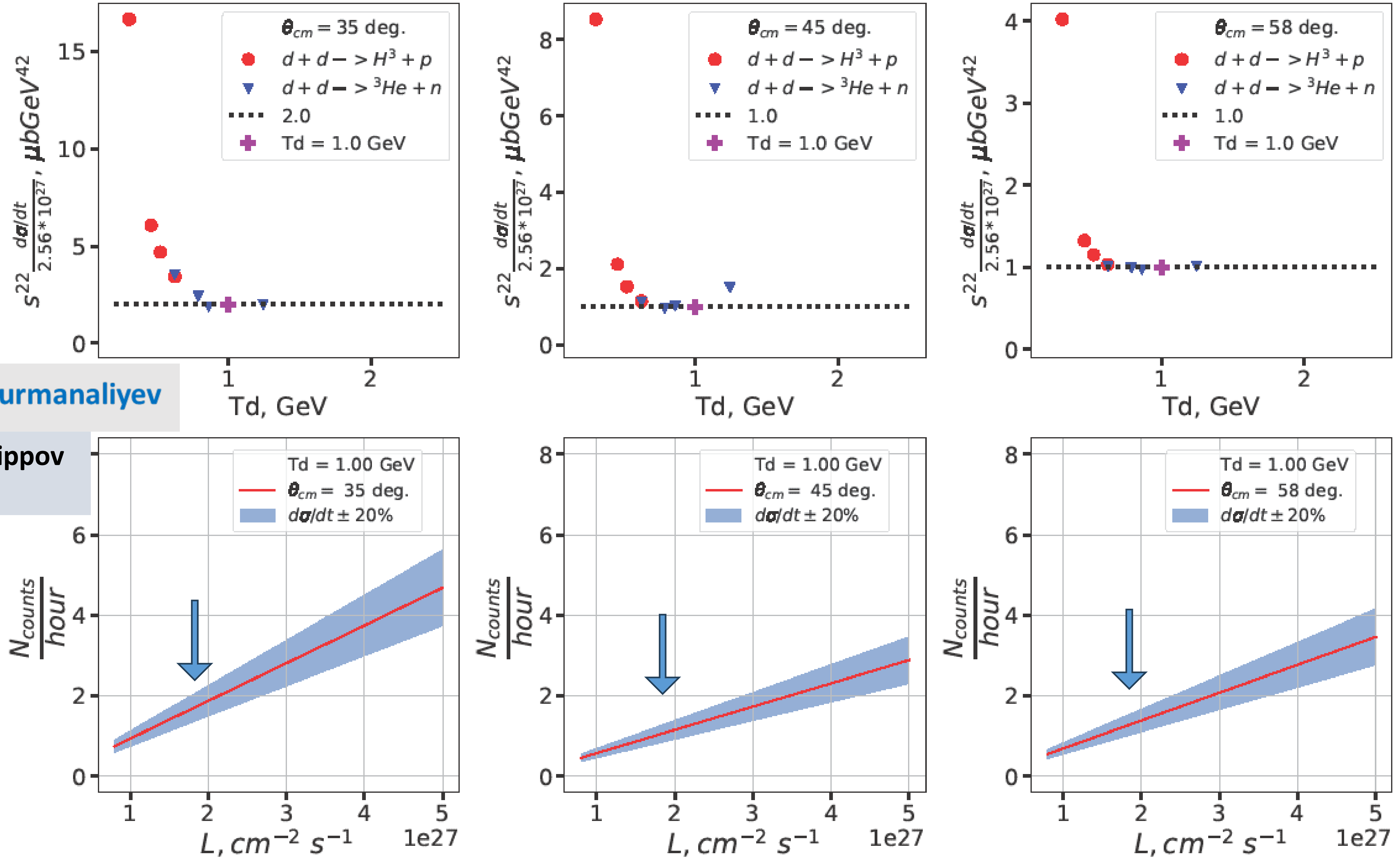
In pp->dπ^+ at the same p_T=1 - 1.5 GeV/c CCR ~ $s^{\{-12\}}$ was not observed!

What about pp->dp$^+$?

What at $\vartheta_{cm} = 90^0$? in dd>^{3}Hn

Zh. Kurmanaliyev

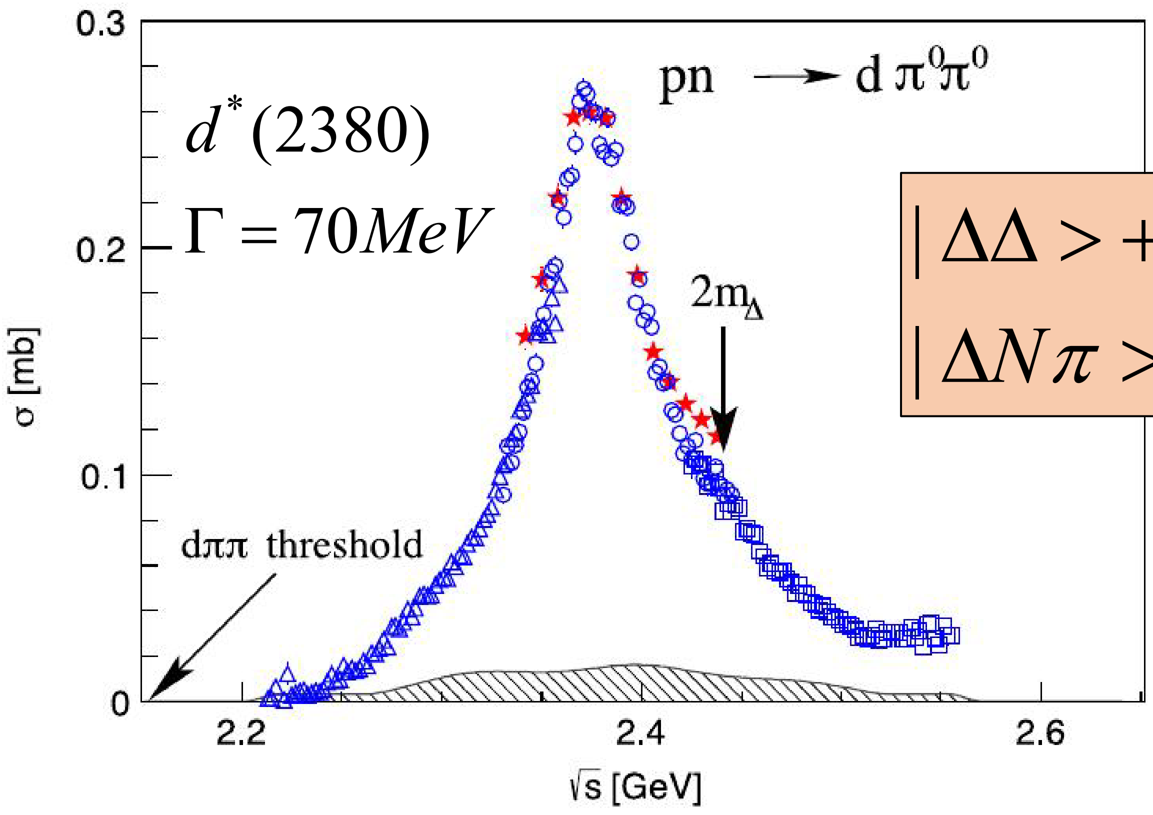
A. Filippov



DIBARYON RESONANCES

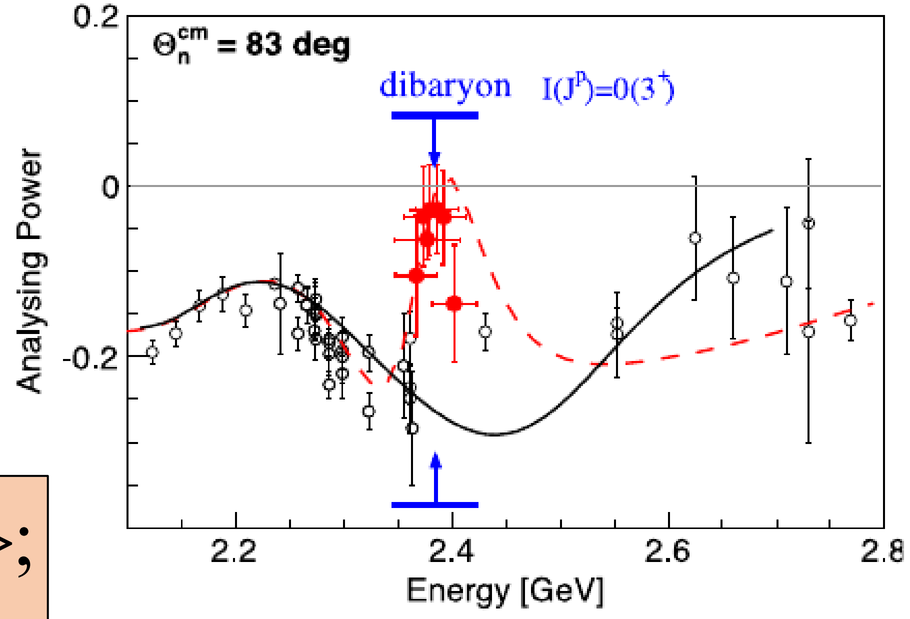
WASA@COSY

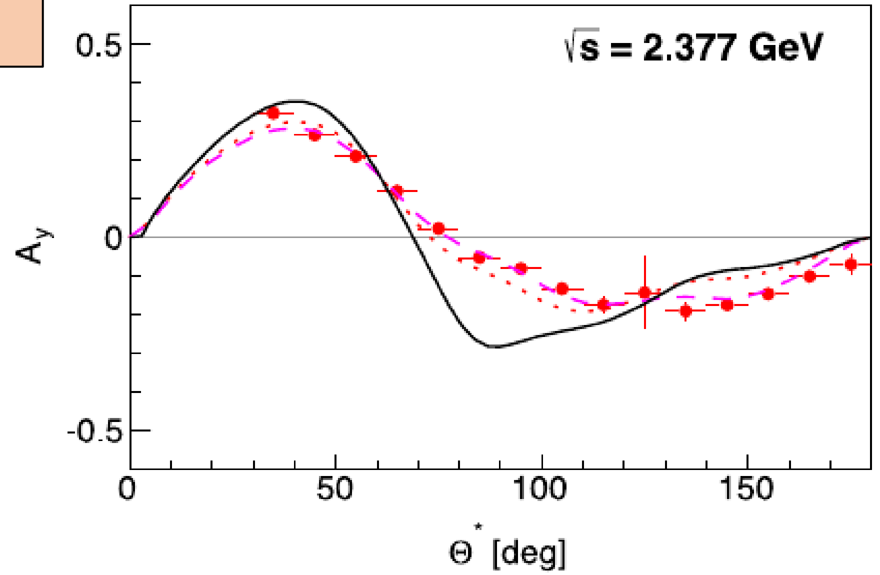
H. Clement / Progress in Particle and Nuclear Physics 93 (2017) 195–242



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

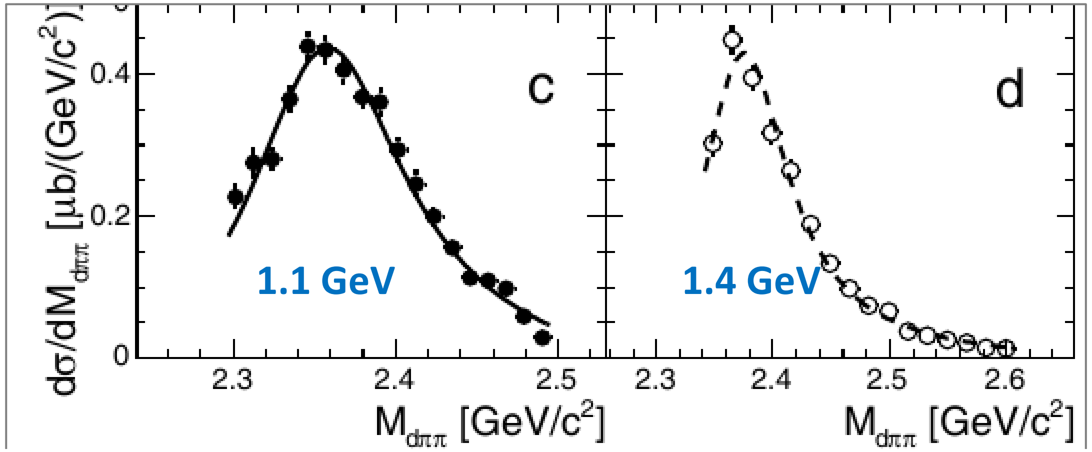
H. Clement / Progress in Particle and Nuclear Physics 93 (2017) 195–242





Compact 6q or quasi-moleculas?

t-channel excitation of the deuteron to the D_{03} in pd→pd*(2380)



Eur. Phys. J. A (2018) **54**: 206
DOI 10.1140/epja/i2018-12641-0

THE EUROPEAN PHYSICAL JOURNAL A

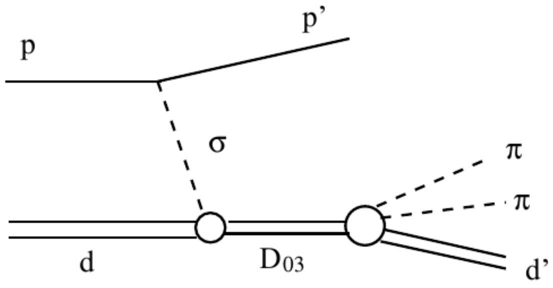
Regular Article – Experimental Physics

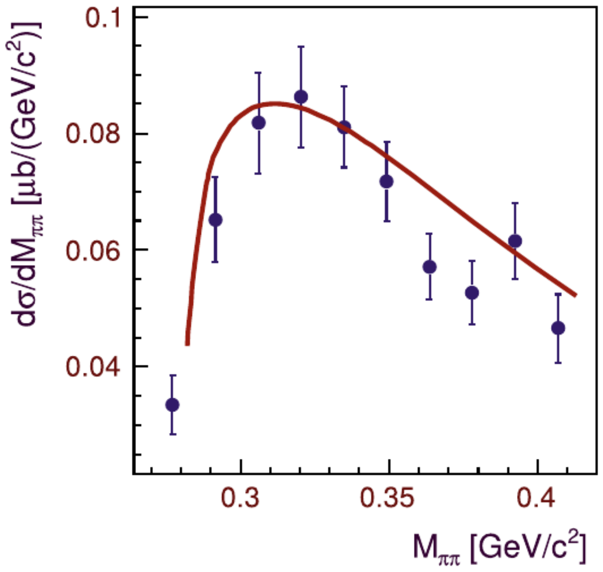
Resonance-like coherent production of a pion pair in the reaction pd → pd$\pi\pi$ in the GeV region

V.I. Komarov[1], D. Tsirkov[1,a], T. Azaryan[1], Z. Bagdasarian[2,3], B. Baimurzinova[4,5], S. Barsov[6], S. Dymov[1,2], R. Gebel[2], M. Hartmann[2], A. Kacharava[2], A. Khoukaz[7], A. Kulikov[1], A. Kunsafina[1,4,5], V. Kurbatov[1], Zh. Kurmanaliyev[1,4,5], B. Lorentz[2], G. Macharashvili[3], D. Mchedlishvili[2,3], S. Merzliakov[2], S. Mikirtytchiants[2,6], M. Nioradze[3], H. Ohm[2], F. Rathmann[2], V. Serdyuk[2], V. Shmakova[1], H. Ströher[2], S. Trusov[2,8], Yu. Uzikov[1,9,10], Yu. Valdau[2,6], and C. Wilkin[11]

ANKE@COSY

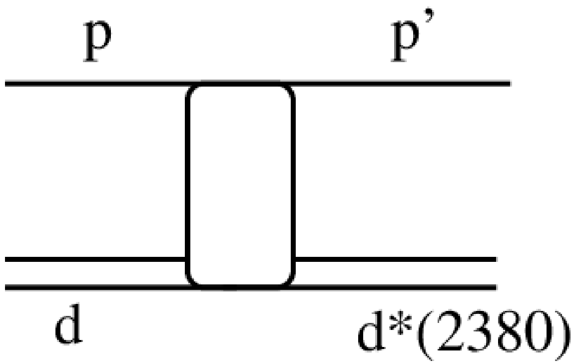
$\pi^+\pi^-$ gives the T=1 contribution, non-resonant

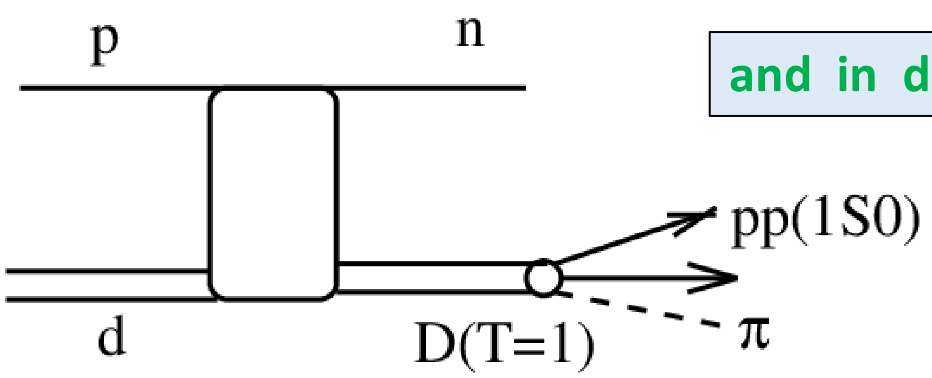




N.Tursunbaeyv, Y. U. in: Recent Prog.in Few-Body Physics, (Eds. N.A. Orr et al.,2018) Chapt.76, p. 467-470

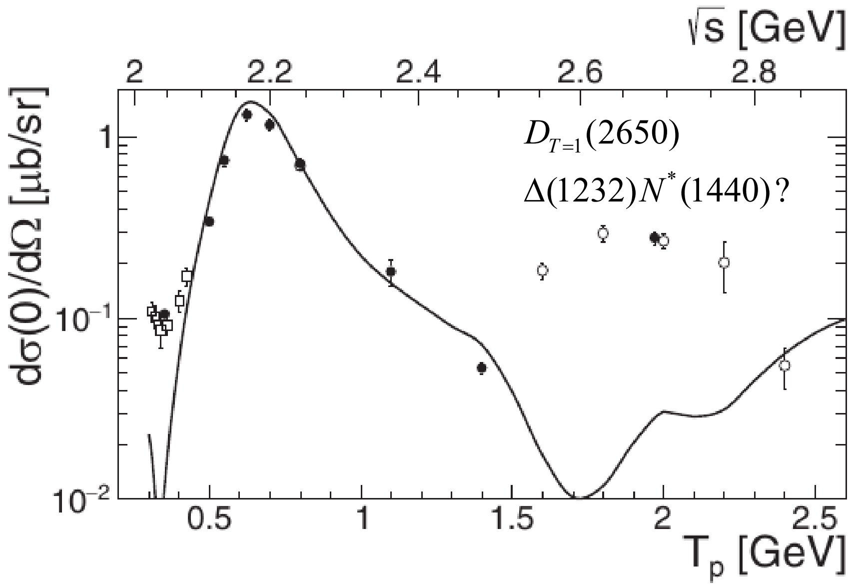
Search for other dibaryons (T=1) from $pp \to D_{T=1} \to \{pp\}_s \pi^0$

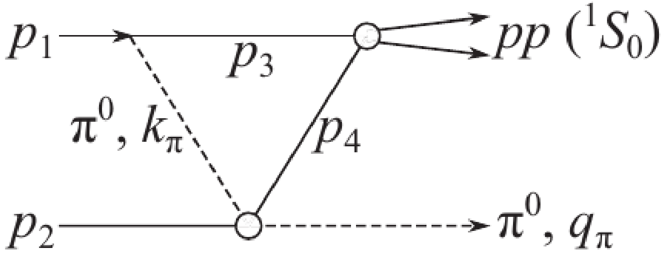




and in dd-> (nn)+(pp)

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





$E_{pp} \le 3MeV$

ANKE@COSY

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

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]

V. Komarov et al. Phys.Rev.C 93 (2016) 6, 065206 $\sqrt{s} = 2.2GeV$

EXOTIC HYPERNUCLEI

Production of the neutral hyper-nucleus ${}^{4}_{\Lambda\Lambda}n$ at SPD NICA

Qiang Zhao

Institute of High Energy Physics, CAS

and Theoretical Physics Center for Science Facilities (TPCSF), CAS

zhaoq@ihep.ac.cn

Tetraneutron is observed

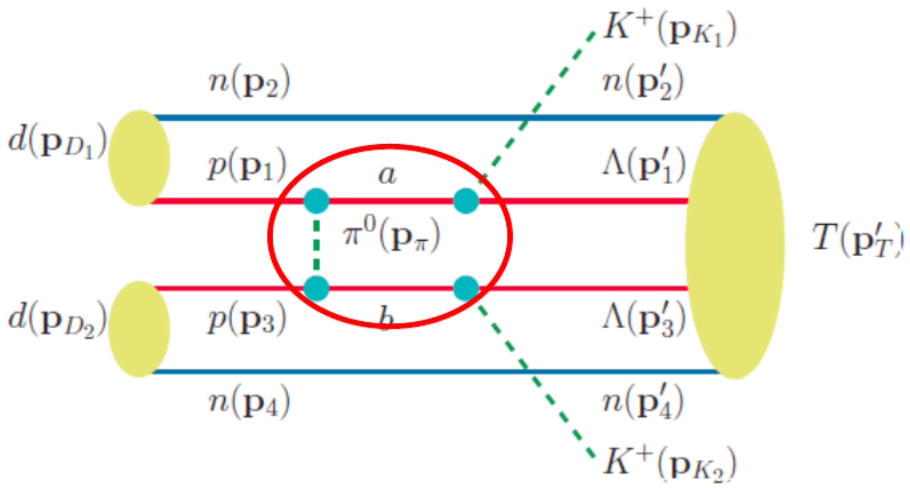
M. Duer et al, Nature 606 (2022)

${}^{8}He(p,p{}^{4}He)$, 2.37 MeV; Gamma=1.75 MeV

Production mechanism for (ΛΛnn) in deuteron-deuteron collision

$$d + d \to K^{+} + K^{+} + T.$$

J.M. Richard, Q. Wang, Q. Zhao, PRC 91 (2015) 014003



Other channels pd->2K+(nΛΛ)

MC Simulations by A. Datta and M. Davydov (Summer, 2022) at E_cm= 5.2 - 5.4 GeV, N=6000/year, but the K^+K^+ background has to be estimated

TO CONCLUSION

So far we do not have good understanding of the most fundamental processes, like hard elastic pN scattering and their relation to QCD aspects of hadron interactions like CT, CCR.

Detailed study of $d^{\uparrow}d^{\uparrow}$-collisions at SPD offer a possibility to get more insight into these problems.

THANK YOU FOR ATTENTION!

BACKUP

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

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

Sort-range correlations (SRC) in the reaction pd →ppn / dd→n +ppn

Deuteron breakup **pd->ppn** can be studied **in two different region of kinematics,** allowing to investigate either

- **CT** – one hard pN- scattering + rescatterings with a soft nucleon-spectator ;

  /L. Frankfurt et al. PRC 56 (1997) 2752; A.B. Larionov, PRC 107 (2023) , 3014695

  or

- **SRC** - *hard nucleon-spectator;high momentum components of d.w.f.; Relativistic eff, polarization observables to separate the S- and D-waves.*

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

BAU - **Baryon Asymmetry of the Universy**:
CP-violation (or T-violation under CPT) is required beyond the SM

$$\eta_{\exp} = \frac{n_B - n_{\bar{B}}}{n_\gamma} = 10^{-10} \gg \eta_{SM} \sim 10^{-19}$$

Null-test signal of Time Violating Parity Conserving (TVPC) effects is a total cross section of double polarized pd-, ^{3}Hed-, dd- scattering with one colliding particle being vector polarized (p_y) and another one tensor polarized (P_{xz}).

Advantages:

- Not necessary to measure two small observables (A_y and P_y) and their difference (for T-invariance $A_y = P_y$).
- Cannot be imitated by ISI@FSI.
- Not equivalent to spin-correlation in elastic scattering $C_{y,zx}$
- Requires to suppress / exclude the contribution of the P_y^d

To compare: EDM (electric dipole moment) of particles and nuclei is a signal of T- and P-violation.

РНФ грант № 23-22-00123 : **Search for T-invariance violation in scattering of polarized protons, ^{3}He nuclei and deuterons on polarized deuterons**.
https://www.rscf.ru/project/23-22-00123

Double spin correlations in pn->pn

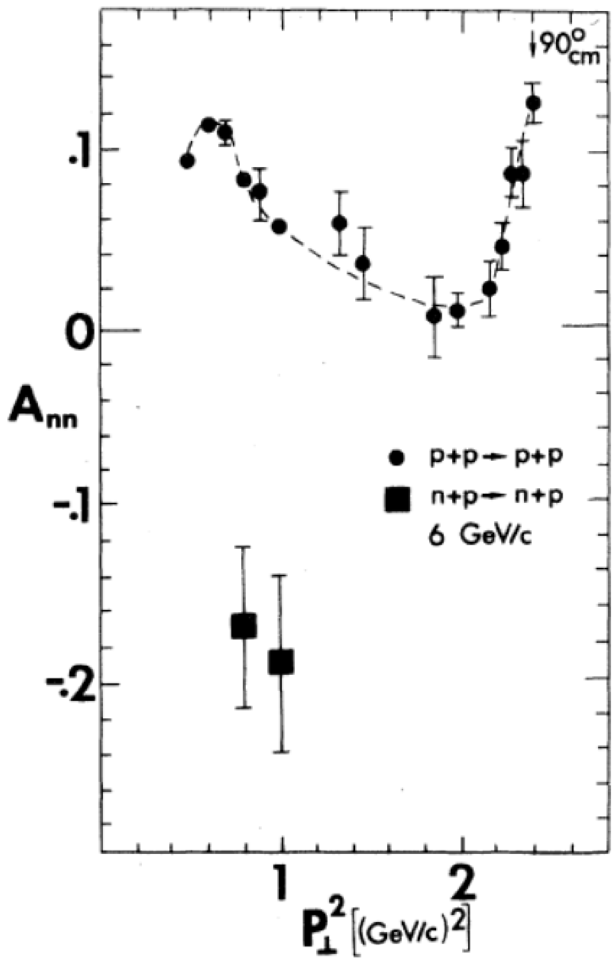


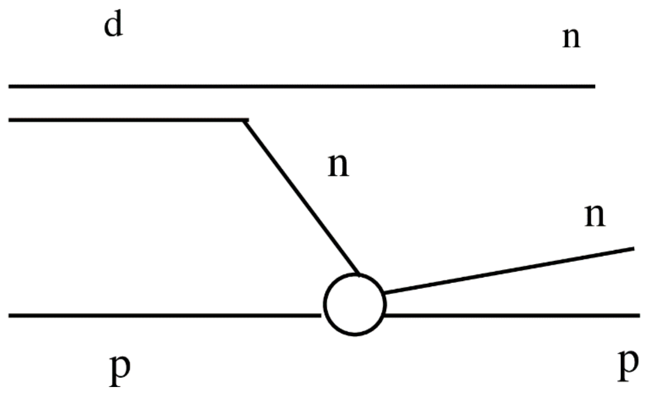
FIG. 2. The spin-spin correlation parameter, A_{nn}, for pure-initial-spin-state nucleon-nucleon elastic scattering at 6 GeV/c is plotted against the square of the transverse momentum. The proton-proton and neutron-proton data are quite different.

VOLUME 43, NUMBER 14 PHYSICAL REVIEW LETTERS 1 OCTOBER 1979

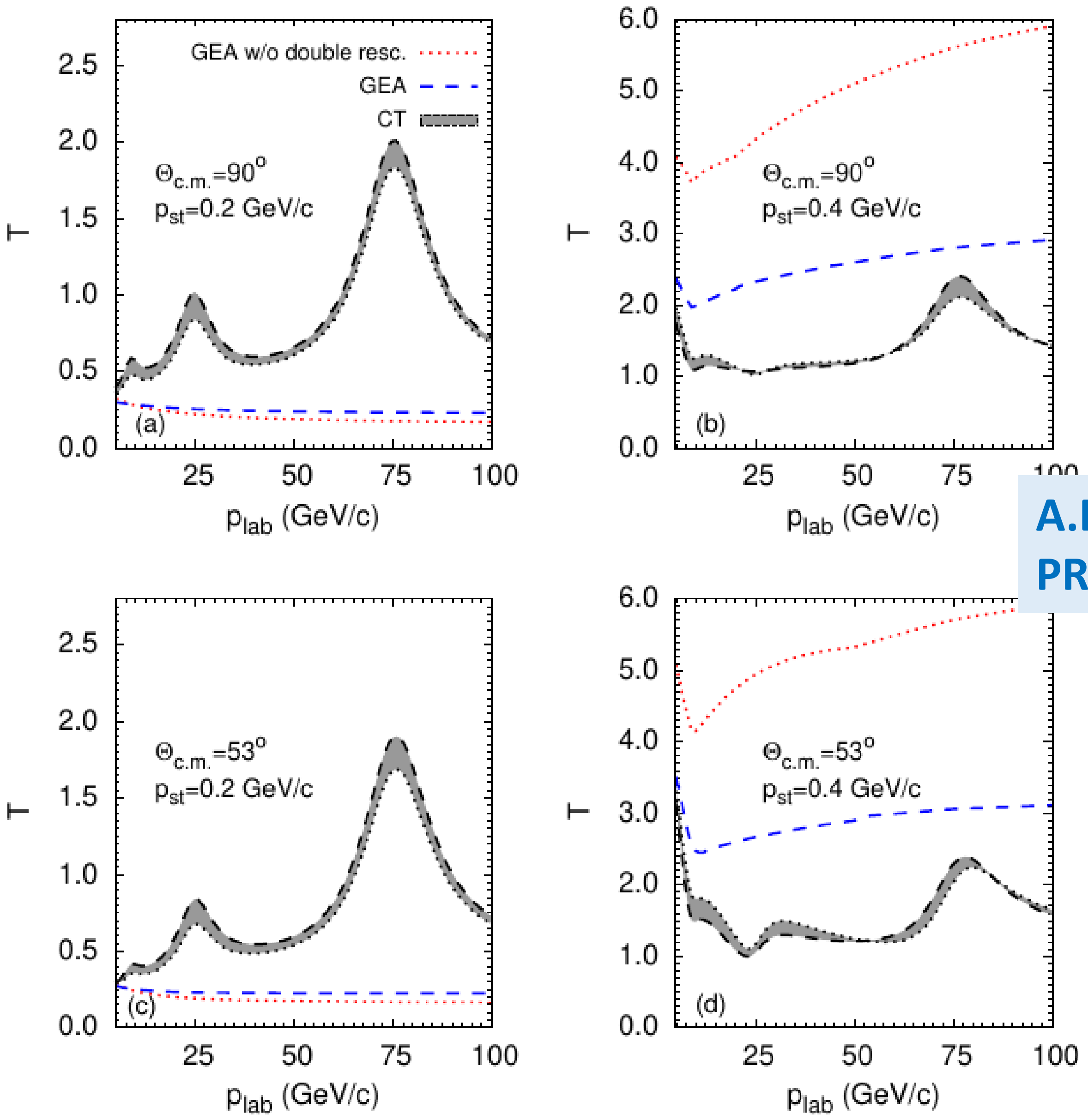
Spin-Spin Forces in 6-GeV/c Neutron-Proton Elastic Scattering

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

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



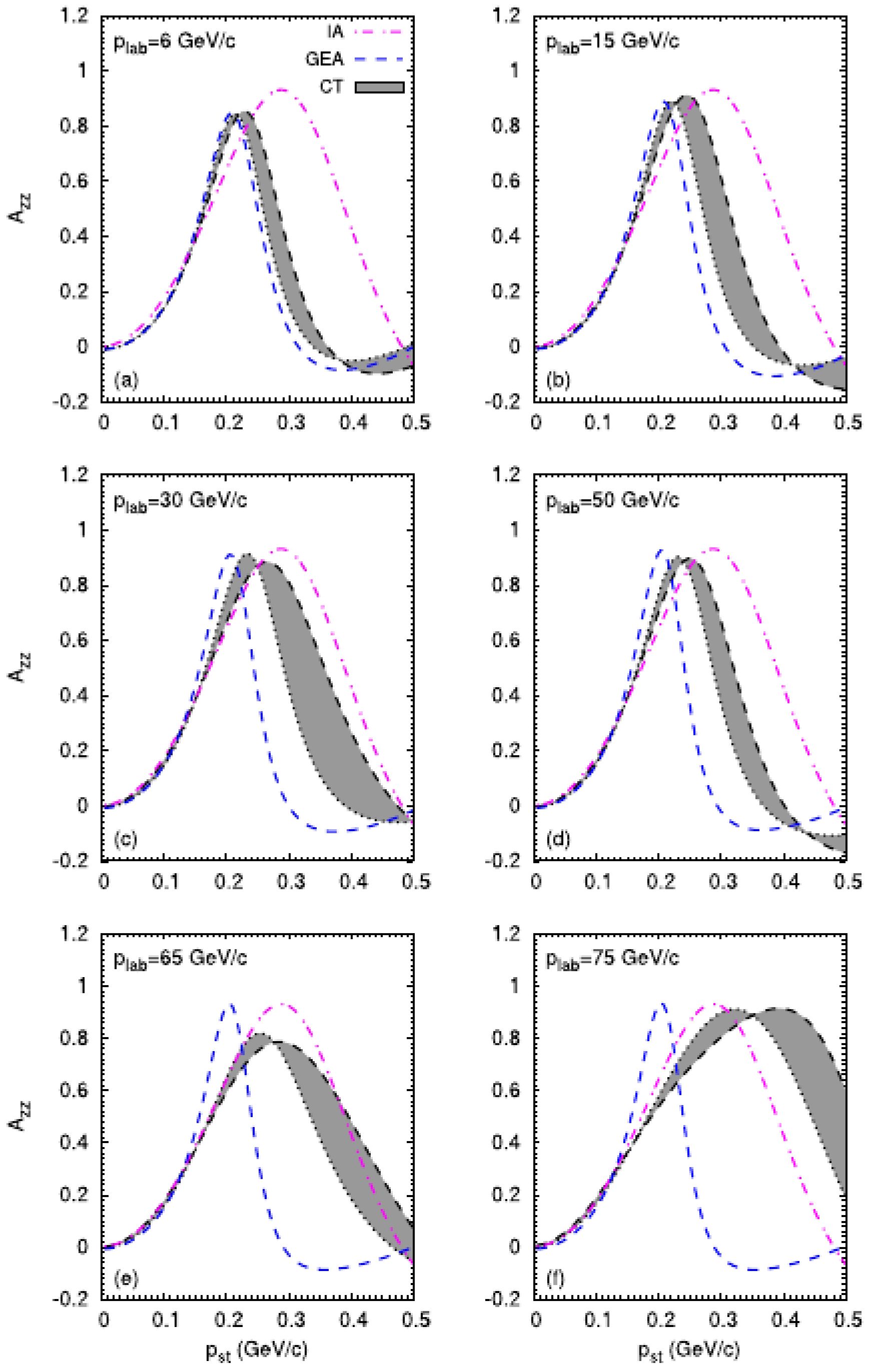
Polarization: 53% for n, 75% for p



$$l_c = \frac{2p}{\Delta M^2}$$

0.7-3 GeV^2

A.B.Larionov, PRC, 107 (2023)



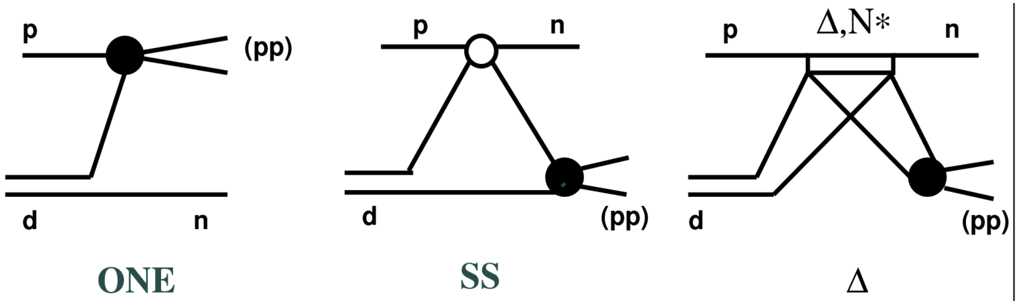
The next step is dd-> n+ppn

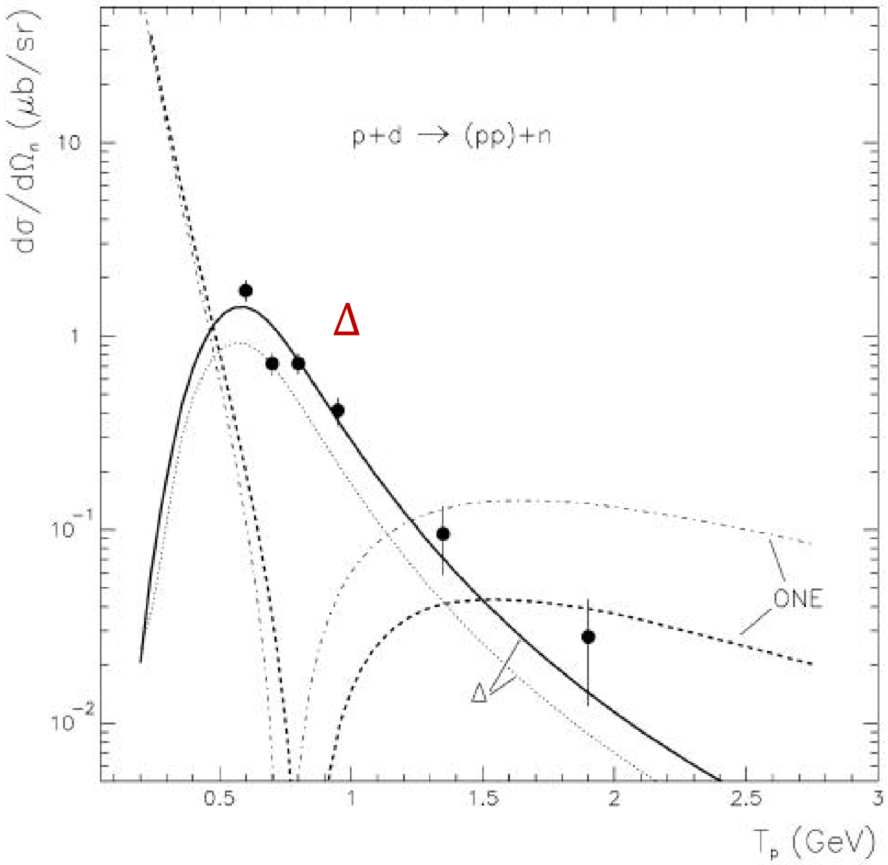
FIG. 7. Beam momentum dependence of the transparency T at $\alpha_s = 1$, $\varphi = 180^\circ$ for different values of p_{st} and $\Theta_{c.m.}$ as indicated on the panels. Notations are the same as in Fig. 5

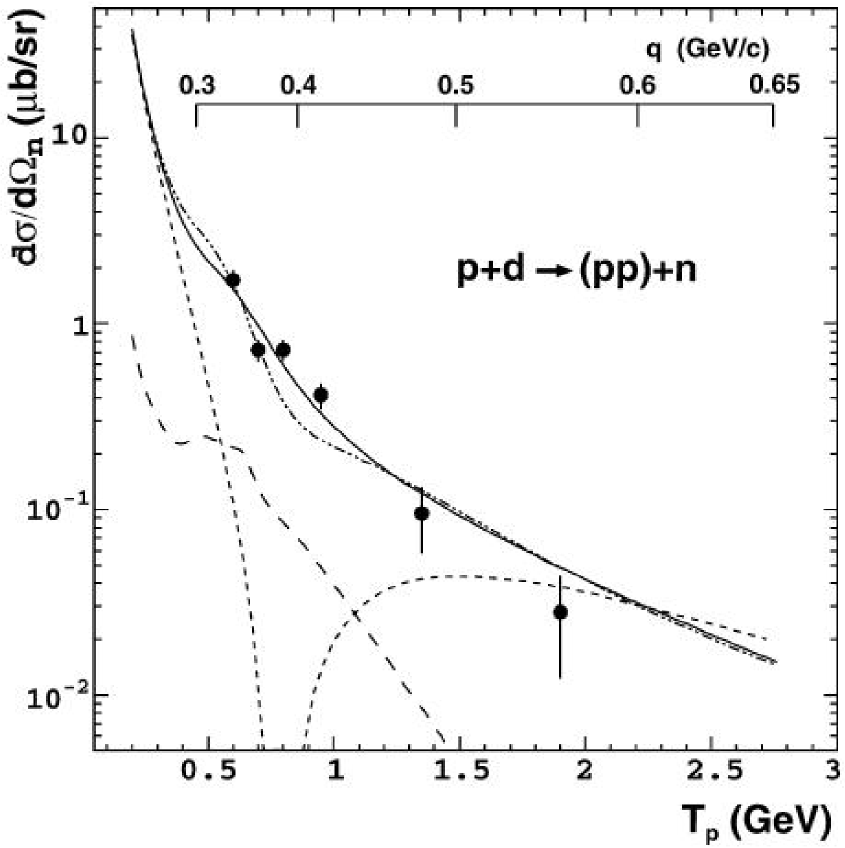
O.Imambekov, Yu.N. U. Yad.Fiz. 52 (1990)

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

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







Delta-mechanism is suppressed by factor 1/9 for the pp($^1S_0$) as compared to d: impact to T_{20} (?)

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->pp$\pi^+\pi^-$
at 1 GeV

41

V. Kurbatov, B. Kostenko. **Search for narrow dibaryons in dd->dd* ,**
Talk at the SPD meeting, 2024
Resolution for the mass measurement M^*_d at SPD is ~3 MeV,

M.Sargsian (2014)

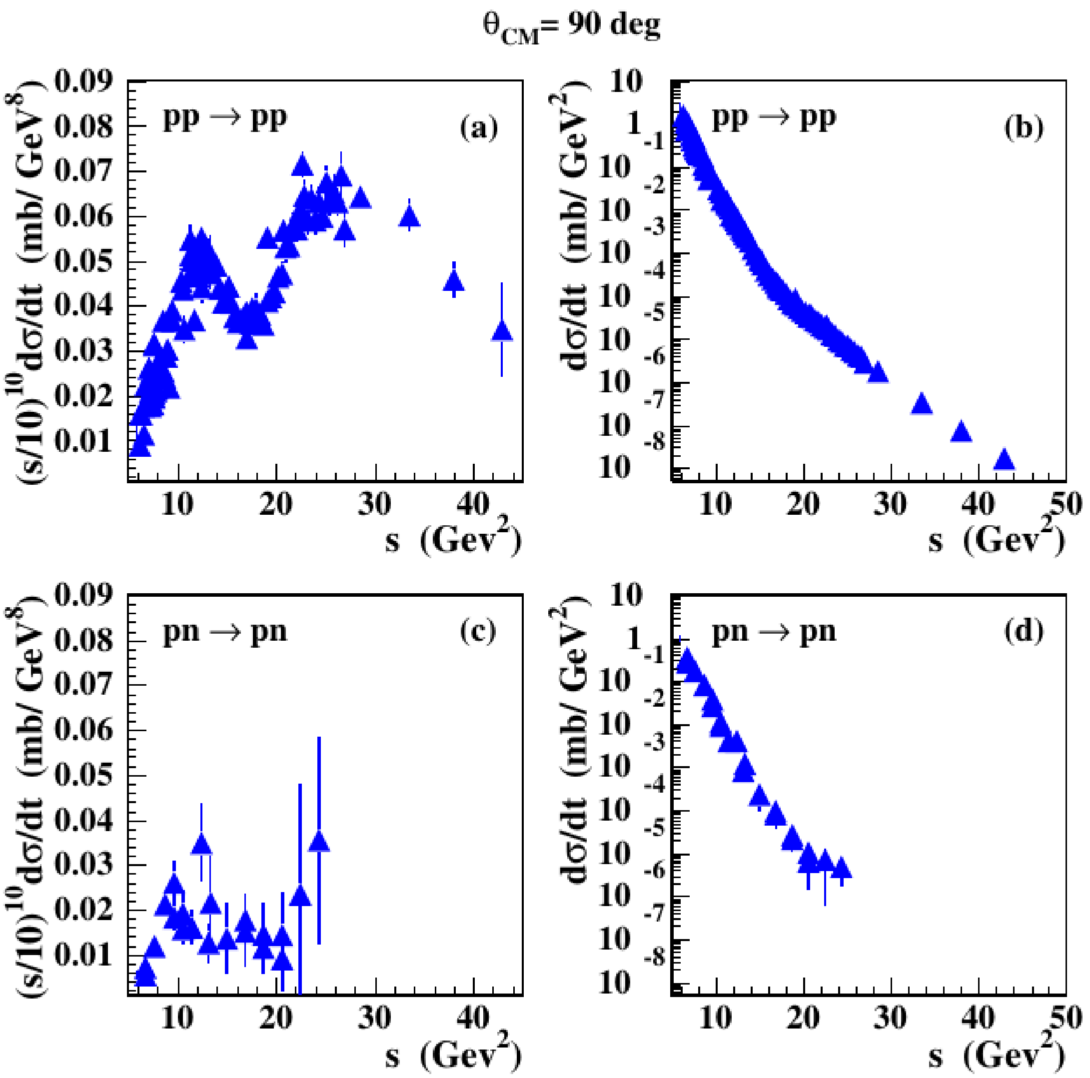


Figure 1. The invariant energy dependence of elastic pp and pn differential cross sections unweighted (b) (d) and weighted by s^{10} factor (a), (c). The experimental data are from Ref. [50, 51, 52, 53, 54].