SUGGESTIONS FOR STUDIES AT THE FIRST STAGE OF THE NICA SPD PROGRAMME

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on behalf of the coauthors of the paper

V.V. Abramov et al., Phys. Part. Nucl. **52**, 1044 (2021); arXiv:2102.08477 [hep-ph]

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Physics of Particles and Nuclei, 2021, Vo. 51, N 6, pp. 1044-1119

(NICA SPD workshop, October 5-6, 2020; https://indico.jinr.ru/event/1525/)

Possible Studies at the First Stage of the NICA Collider Operation with Polarized and Unpolarized Proton and Deuteron Beams

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ФИЗИКА ЭЛЕМЕНТАРНЫХ ЧАСТИЦ И АТОМНОГО ЯДРА
2021. Т. 52. ВЫП. 6. С. 1392–1529

35 coauthors from 24 Institutions, Russia, France, Egypt, USA, China

NICA SPD at energies $\sqrt{s_{NN}} = 3.5 - 10$ GeV / the first stage/

TOPICS

- Helicity amplitudes of elastic NN scattering & spin observables in p-d and d-d elastic
- Polarized large angle pN elastic scattering
- Single spin observables in p+p->h X, p+A-> h X
- Charmed vector meson production of pN- collisions
- Color transparency, constituent counting rules, multiquark configurations
- Exclusive hard process with the deuteron: CT, SRC
- Exotic Hypernuclei , dibaryons
- Hadron formation in ^{12}C-^{12}C, ^{40}Ca-^{40}Ca
- PDF and polarized tau-leptons production
- Search for physics beyond the Standard Model

S. J. Brodsky, Novel QCD Physics at NICA,

Eur. Phys. J. A, **52** (2016) 220

- Charm and bottom physics at threshold.
- Intrinsic strange and charm distribution at large x.
- Exclusive reactions pQCD counting rules.
- Hidden- colour of nuclear wave functions

$$|d> = |NN> + |\Delta\Delta> + |C\bar{C}>$$

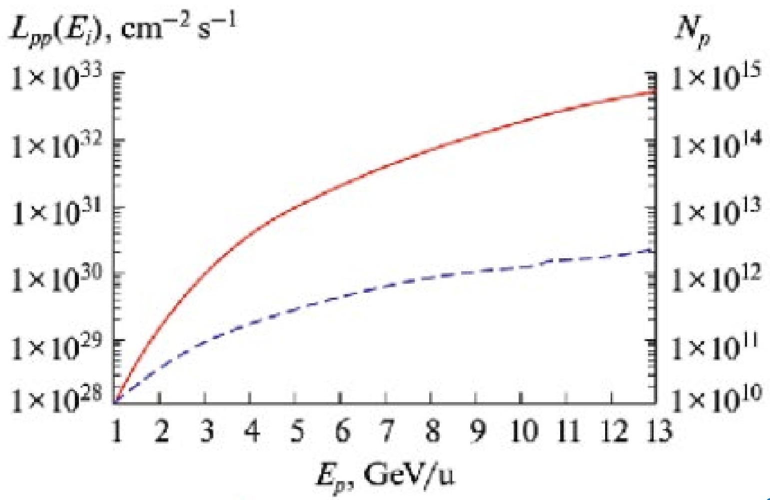
- Odderon (C=-1, three-gluon exchange) $pp \to D^+ D^- pp$

SPD AT NICA

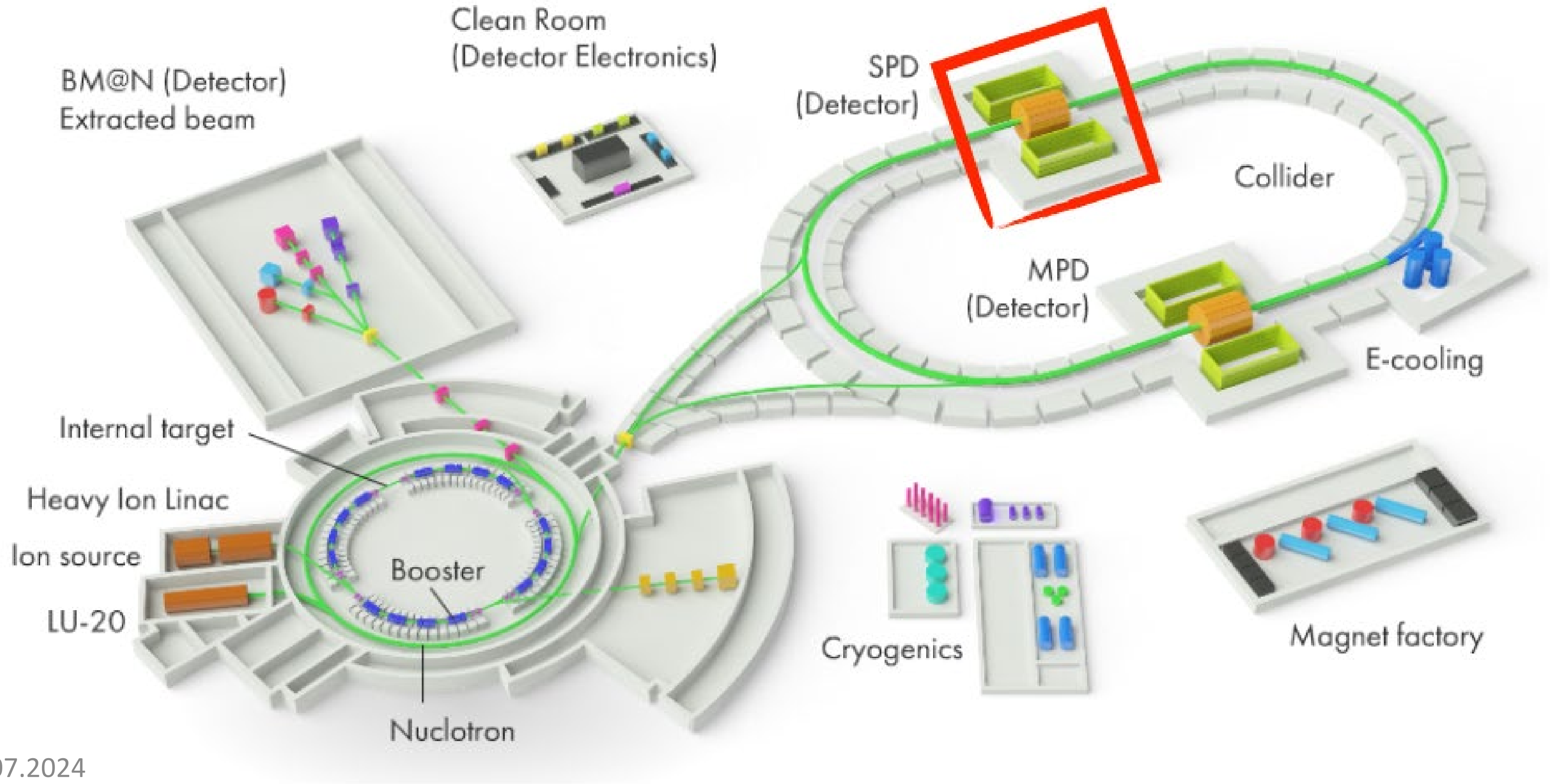
$p^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 27\ GeV$
$d^{\uparrow}d^{\uparrow} : \sqrt{s} \leq 13.5\ GeV$
$d^{\uparrow}p^{\uparrow} : \sqrt{s} \leq 19\ GeV$

U, L, T

$|P| > 70\%$



See previous talk



$\vec{d}\vec{d}$ **mode is unique**:

$\vec{p}\vec{n} \rightarrow pn$

$\vec{n}\vec{n} \rightarrow nn$

• The first stage of the SPD (2028-2030)

Polarized and non-polarized phenomena at lower energies and reduced luminosity

$\vec{p}\vec{p}, \vec{d}\vec{d}, \vec{p}\vec{d}$ LL, TT, TL and LT; **dd- double polarized mode is unique**

$\sqrt{s_{NN}} < 9.4 GeV, L \le 10^{31} cm^{-2} s^{-1}$ **For protons**

$\sqrt{s_{NN}} < 4.5 GeV, L \le 10^{30} cm^{-2} s^{-1}$ **For deuterons**

Tensor polarized deuterons

• The second stage of the SPD (>2032)

The main task of the SPD: study of polarized gluon content in the proton and deuteron via charm production from 2-gluon fusion and prompt photons $g + q \rightarrow \gamma + q$

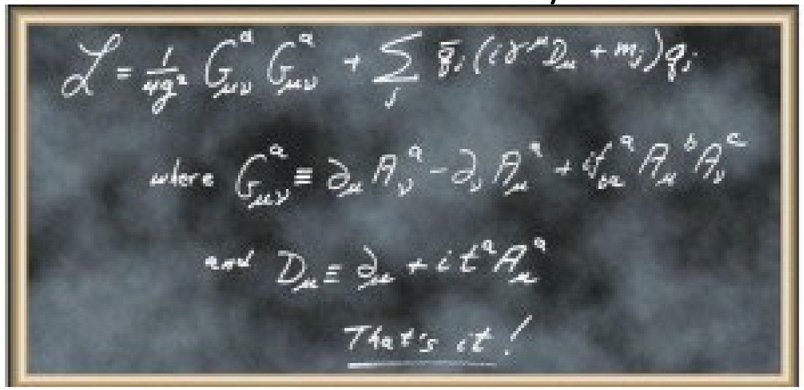
Basics of QCD …

F. Wilczek, QCD Made Simple
Physics Today **53N8** 22-28, (2000)

C.Roberts, NUCLEUS-2020

Quantum Chromodynamics

$SU_c(3)$



- Quite possibly, the most remarkable theory we have ever invented
- One line and two definitions are responsible for the
  origin, mass and size of (almost) all visible matter!

…. and NICA SPD at 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 theories occurs in two kinematical regions:

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

Intermediate energy region (few GeV):
too high for *ChEFT*, not enough high for *pQCD.*
The NICA SPD at lower energies $\sqrt{s_{NN}} = 3.5-10 GeV$ *is suitable to*
search for onset of transition region $hadrons \to q, g$**:**
CCR, color transparency, SRC, multiquarks, dibaryons,…,

pN ELASTIC SCATTERING

NN forces is a basis of nuclear and hadronic physics.
NN-> NN is still not well understood, knowledge of spin dependence of NN forces is very noncomplete at T> 1 GeV.
Measurement/test of spin amplitudes of NN elastic scattering in soft and hard NN- collisions is important.

$$\phi_1(s,t) = \langle + + |M| + + \rangle,$$
$$\phi_2(s,t) = \langle + + |M| - - \rangle,$$
$$\phi_3(s,t) = \langle + - |M| + - \rangle,$$
$$\phi_4(s,t) = \langle + - |M| - + \rangle,$$
$$\phi_5(s,t) = \langle + + |M| + - \rangle.$$

$$\frac{d\sigma}{dt} = \frac{2\pi}{s^2}\{|\phi_1|^2 + |\phi_2|^2 + |\phi_3|^2 + |\phi_4|^2 + 4|\phi_5|^2\}.$$

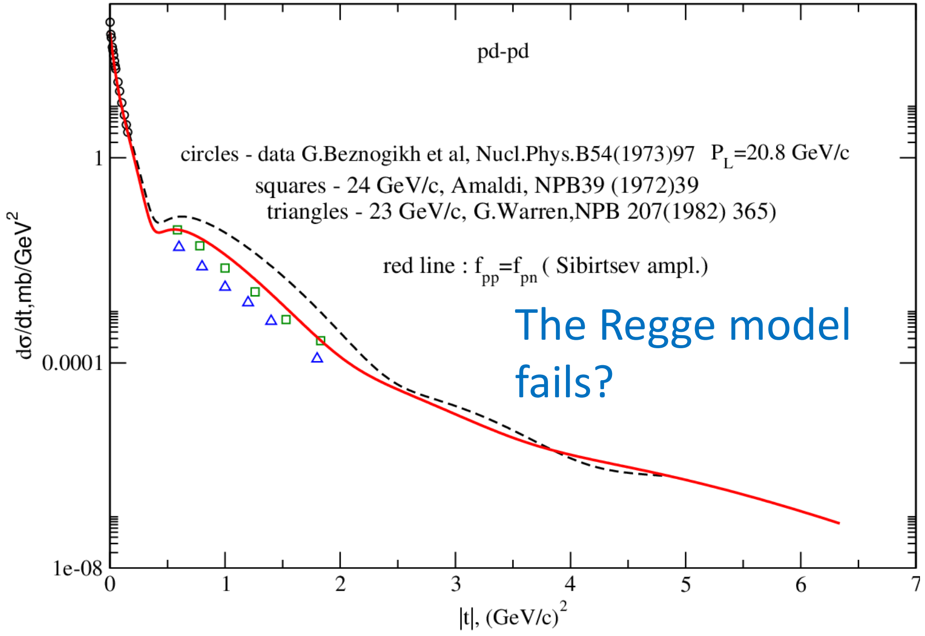
$$A_N \frac{d\sigma}{dt} = -\frac{4\pi}{s^2}\,\mathrm{Im}\{\phi_5^*(\phi_1 + \phi_2 + \phi_3 - \phi_4)\},$$
$$A_{NN} \frac{d\sigma}{dt} = \frac{4\pi}{s^2}\{2|\phi_5|^2 + \mathrm{Re}(\phi_1^*\phi_2 - \phi_3^*\phi_4)\},$$

>10 Observables is required

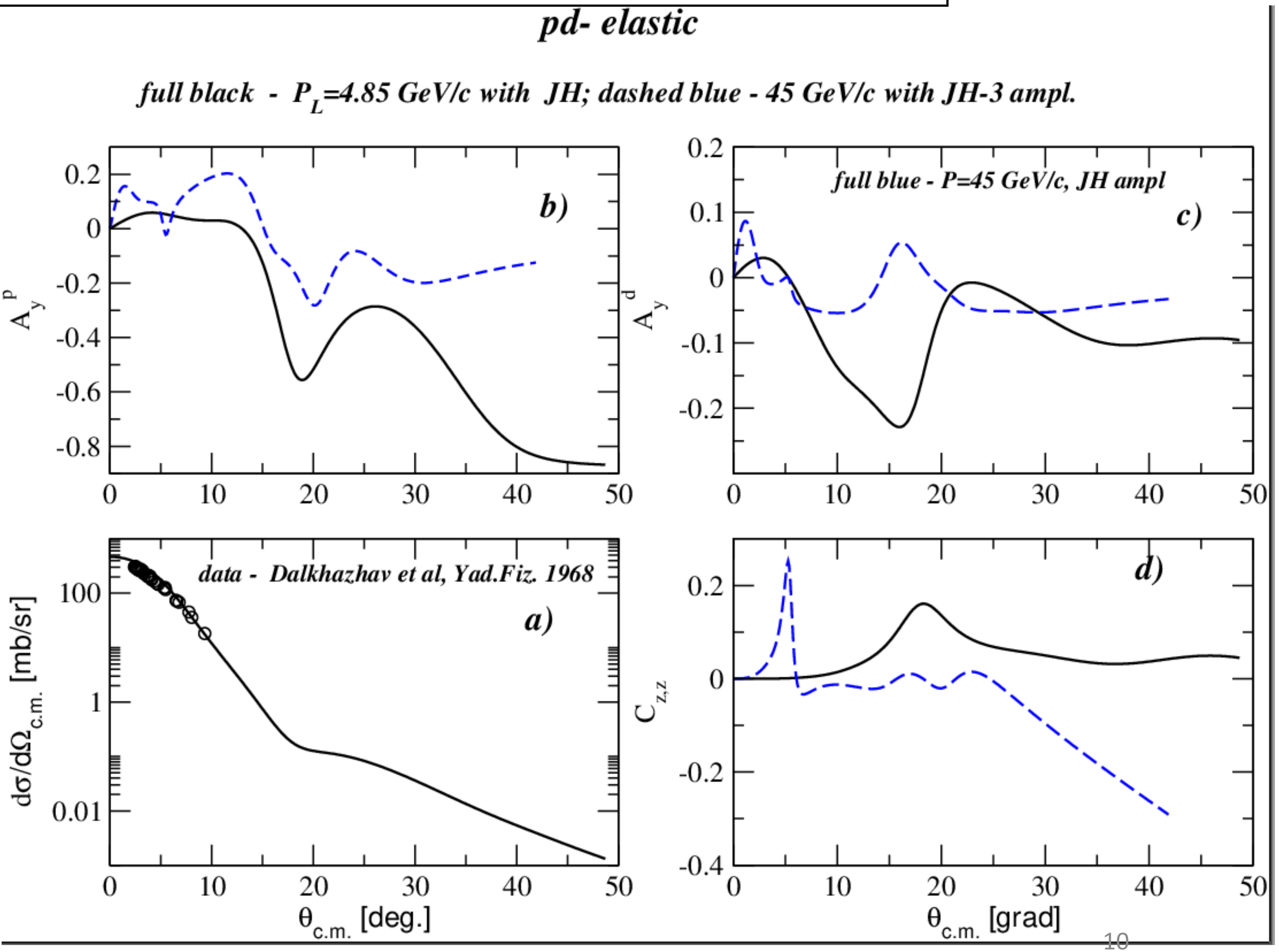
5 – pp, 6 – pn, TV gives additional 2

Test of pN amplitudes: in *pd* elastic scattering within the Glauber model

Yu.N. U., J. Haidenbauer, A. Temerbayev, A. Bazarova, Phys.Part. Nucl. 53 (2022) N2, p.419; arXiv:2011.04304 [nucl-th]



The Regge model fails?



Search for T-invariance violation in doble polarized pd scattering.

Knowledge of helicity pN amplitudes is absolutely necessary

See below section by N. Nikolaev et al. on a new method of measurement of TVPC and PV signal

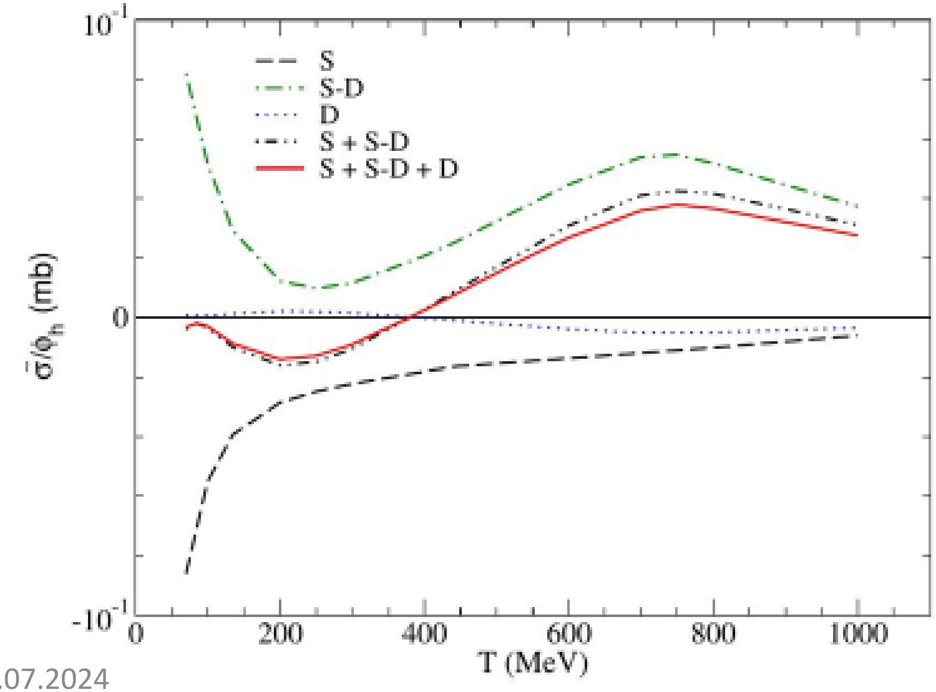
$$C' \approx i\phi_5 + iq/2m(\phi_1 + \phi_3)/2$$

Yu.N.U., A.A. Temerbayev, PRC 92 (2015) 014002;
Yu.N.U., J. Haidenabuer, PRC 94 (2016) 035501.

Helicity pN amplitudes are absolutely necessary !

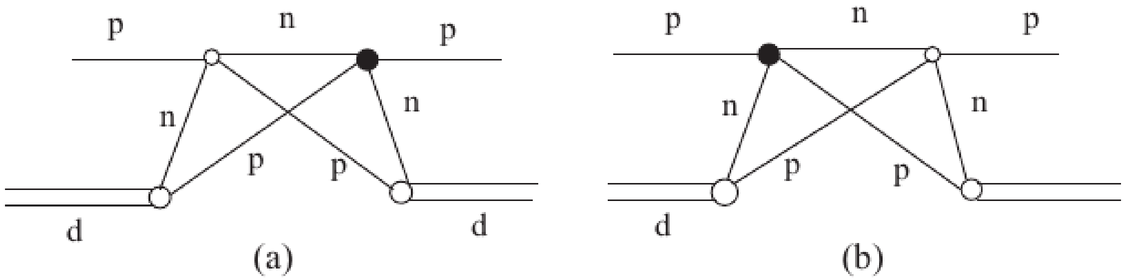
$$\sigma_{tot} = \underbrace{\sigma_0 + \sigma_1 \mathbf{p}^p \cdot \mathbf{P}^d + \sigma_2(\mathbf{p}^p \cdot \hat{\mathbf{k}})(\mathbf{P}^d \cdot \hat{\mathbf{k}}) + \sigma_3 P_{zz}}_{T-even, P-even} + \underbrace{\widetilde{\sigma}_{tvpc} p_y^p P_{xz}^d}_{T-odd, P-even}$$

TVPC. The S- and D- wave contributions-I



Yu.N. Uzikov, J.Haidenbauer, PRC 94 (2016) 035501

$$\tilde{\sigma}_{tvpc} \Leftrightarrow g_{tvpc} C'$$



Search for T-invariance violation in double polarized pd – scattering (see below “Search for physics BSM” .)

SEARCH FOR ONSET OF THE TRANSITION REGION

$hadrons \to q, g$

COLOR TRANSPARENCY (p,2p)
CONSTITUENT COUNTING RULES
MULTIQUARK CONFIGURATIONS

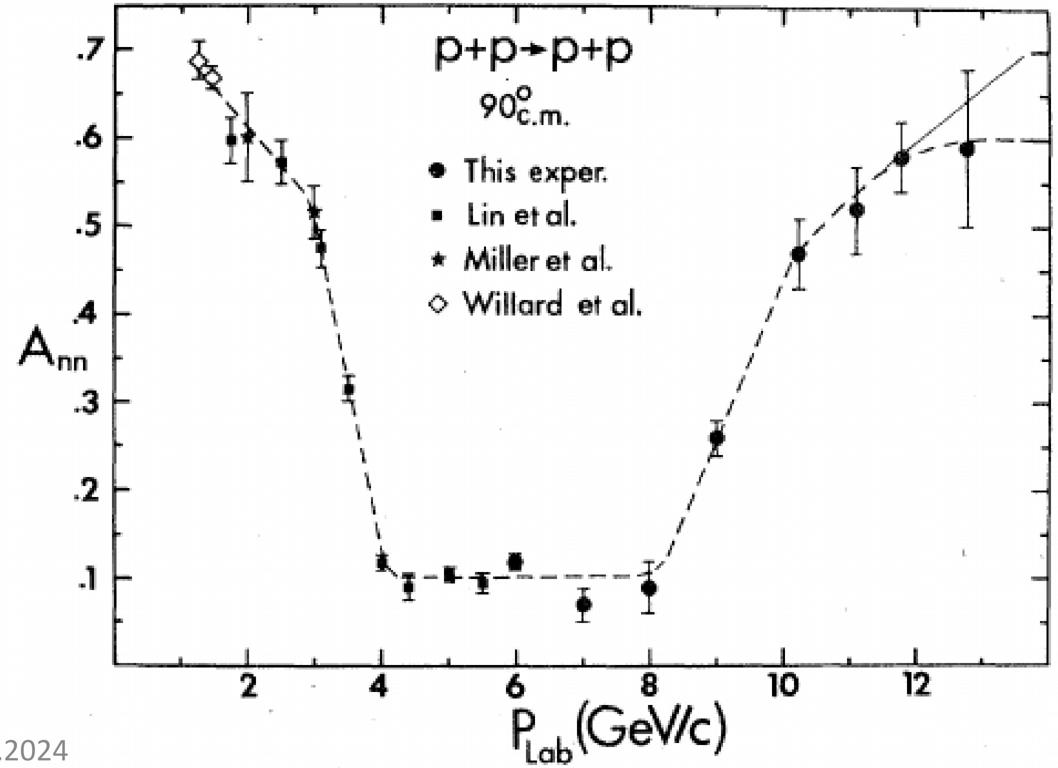
Double polarized pN-elastic scattering at 90°
includes all these aspects $3GeV \leq \sqrt{s_{NN}} \leq 5.5GeV$

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 $90^\circ_{\text{c.m.}}$

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) $A_{NN} = \dfrac{d\sigma(\uparrow\uparrow) - d\sigma(\uparrow\downarrow)}{d\sigma(\uparrow\uparrow) + d\sigma(\uparrow\downarrow)}$ 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:
assume octoquarks at the thresholds $s\bar{s}, c\bar{c}$

$$\phi_2^{PQCD} = \phi_5^{PQCD} = 0; \phi_1^{PQCD} = 2\phi_3^{PQCD} = -2\phi_4^{PQCD}$$

$$\sigma A_{NN} = |\phi_3|^2; \sigma = 3|\phi_3|^2; A_{NN}^{pQCD} = \frac{1}{3}$$

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

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

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

Another explan. of pp-oscillations and CT bump: J. Ralston, B. Pire PRL 49 (1982)1605

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

This can be done at NICA SPD.

What is relation to LHCb pentaquarks from decay of $\Lambda_b \to J/\psi\, p$ **?**

COLOR TRANSPARENCY

Color transparency (CT) is an unique prediction of QCD:
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

100% CT: $$\sigma(h+A \to h+N+(A-1)) = A\sigma(hN \to hN)$$

- 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: $\lim_{b\to 0} \sigma(b^2) \propto b^2$
- **PLC will expand** as it moves and will get a normal hadron size after pass of **coherence length L_h**. At enough large s , $L_h > 2R_A$

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

CT for mesons production is well established

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

$E_{\gamma} = 2.25 GeV$

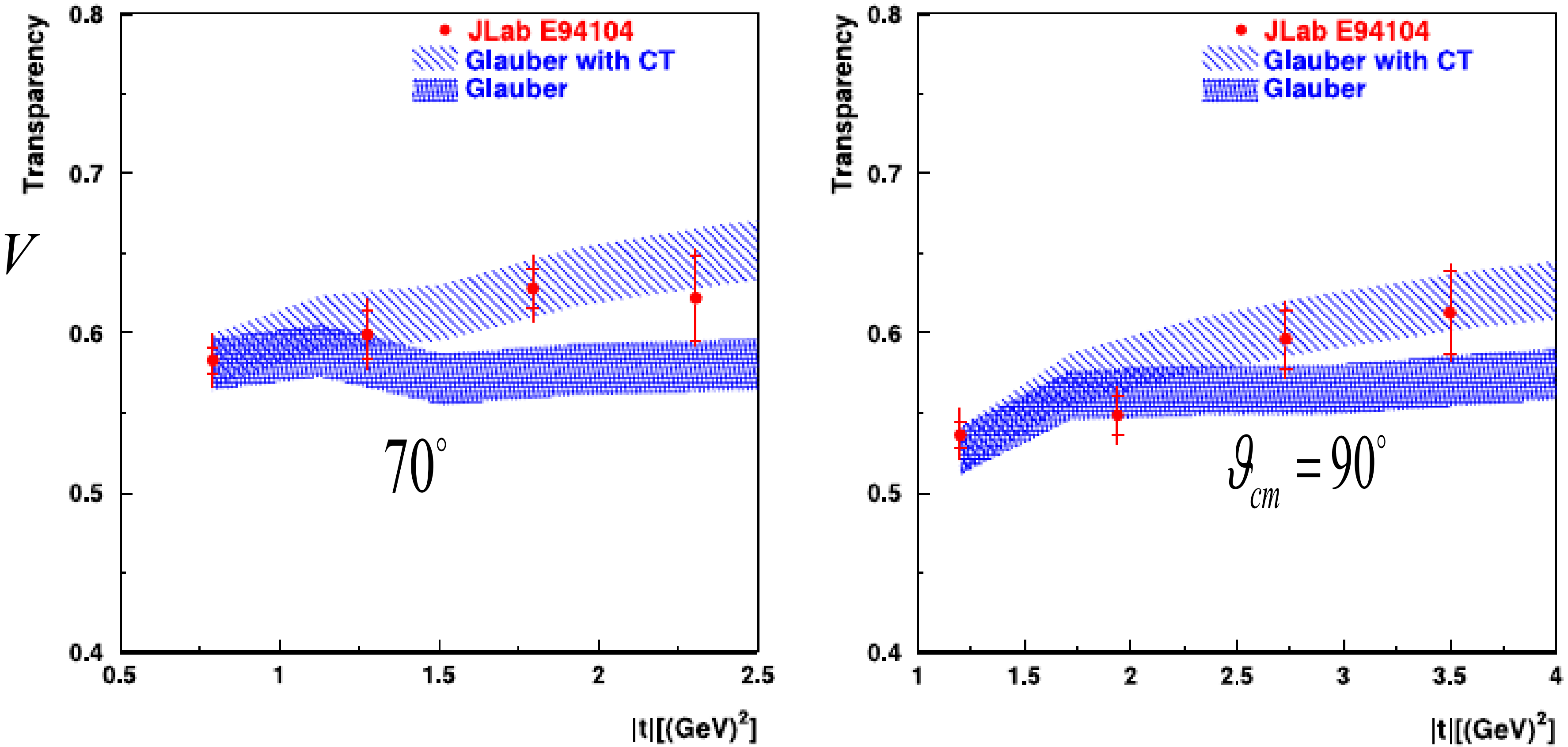
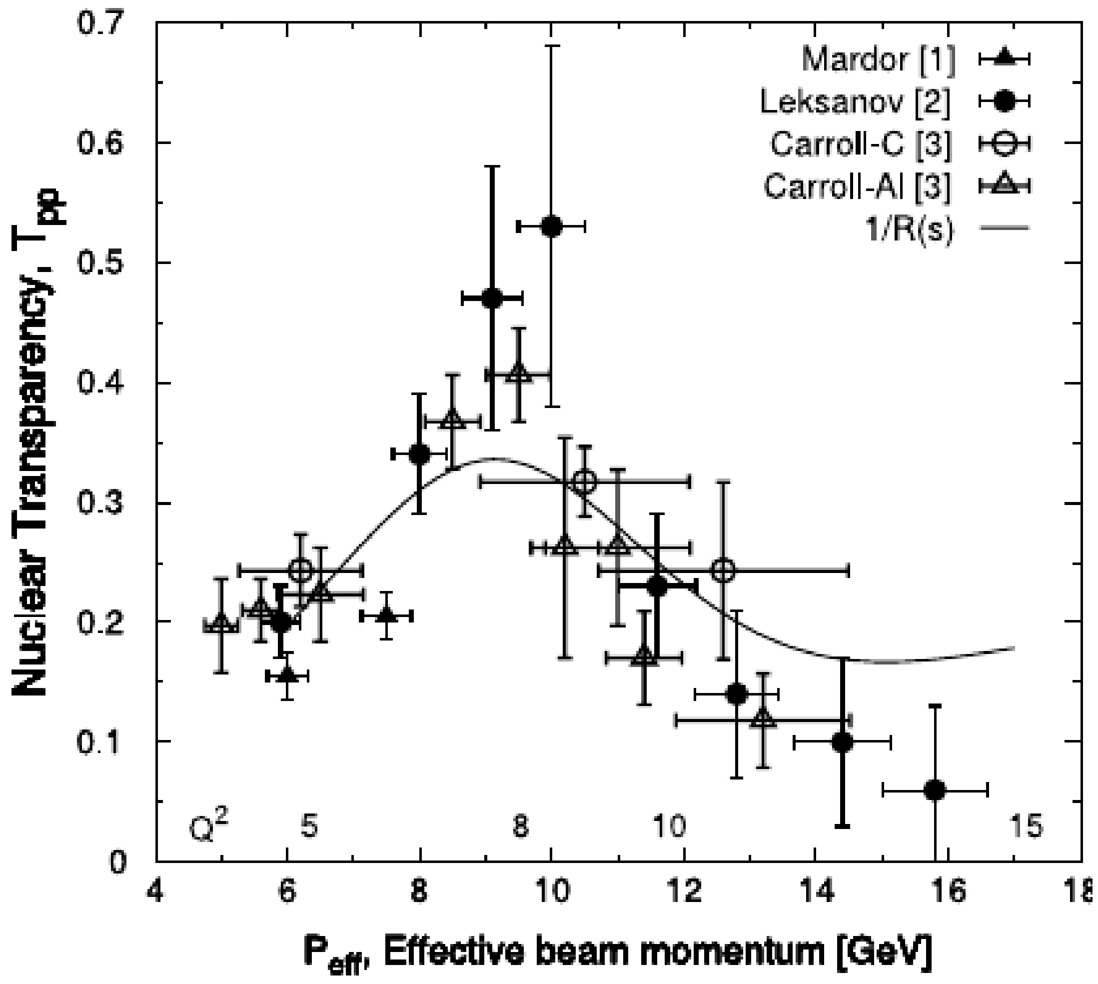


Fig. 13. The nuclear transparency of ^{4}He(γ, $p\pi$) at $\theta^{\pi}_{cm} = 70^{\circ}$ (left) and $\theta^{\pi}_{cm} = 90^{\circ}$ (right), as a function of momentum transfer square $|t|$ [80]. The inner error bars shown are statistical uncertainties only, while the outer error bars are statistical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

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

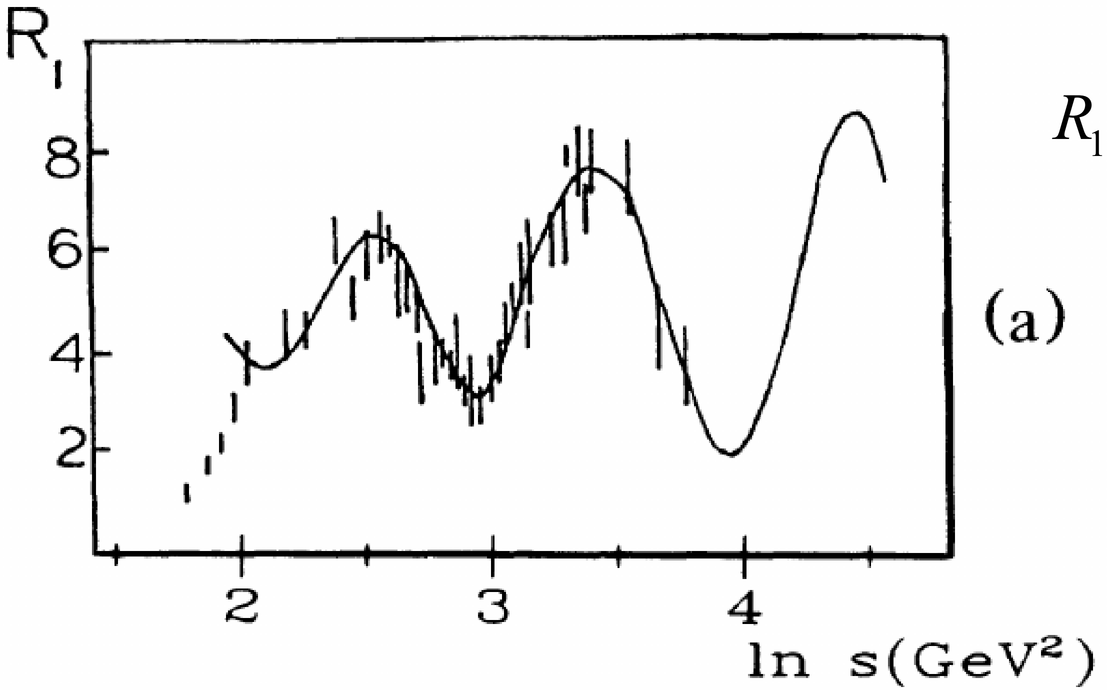
f_{QC} - quark counting (PLC -size);

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

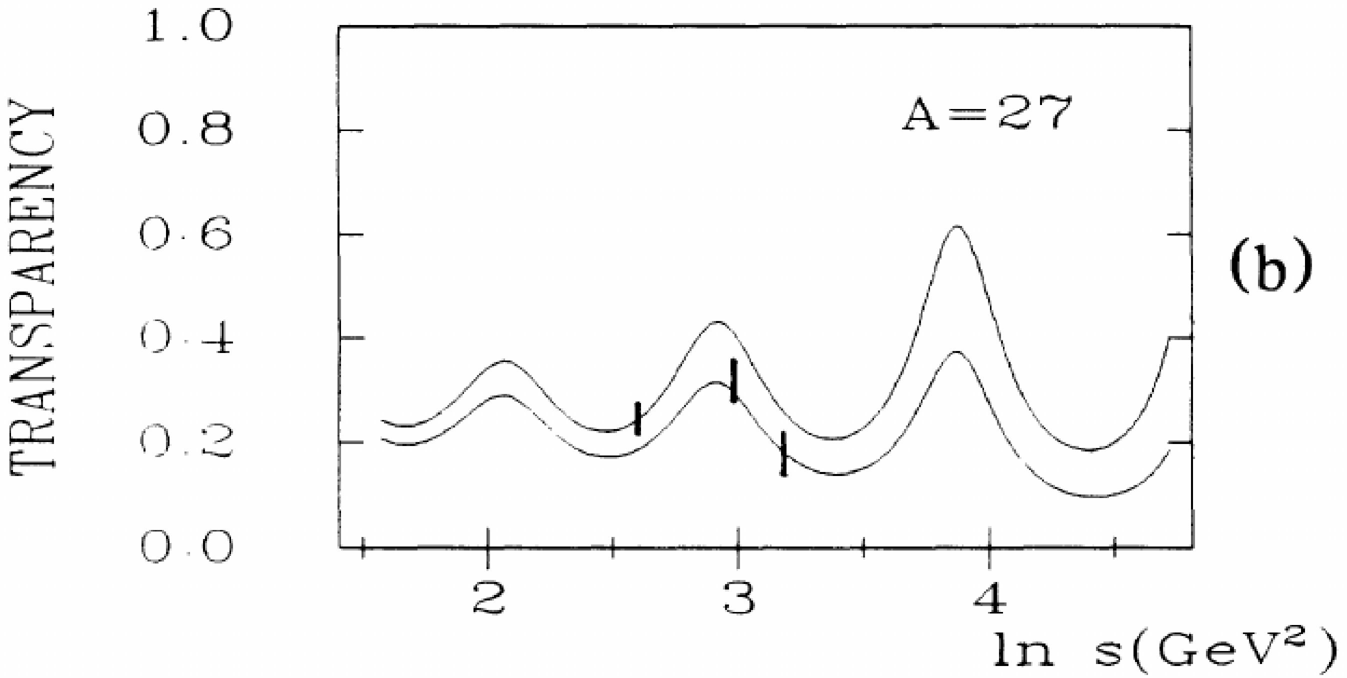
J.P. Ralston, B. Pire.
PRL 61 (1988) 1823;
PRL 49 (1982) 1605



(a)

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

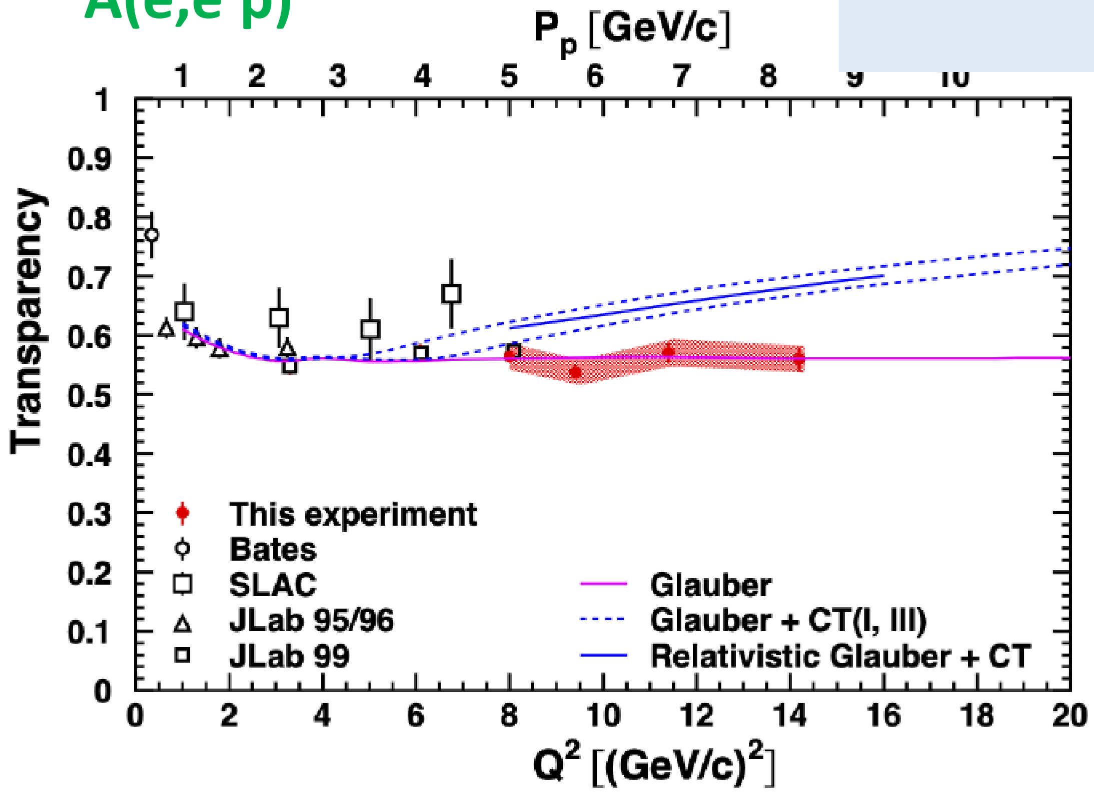
$$T = \frac{d\sigma^{pA}/dt}{A\,d\sigma^{pp}/dt}$$



(b)

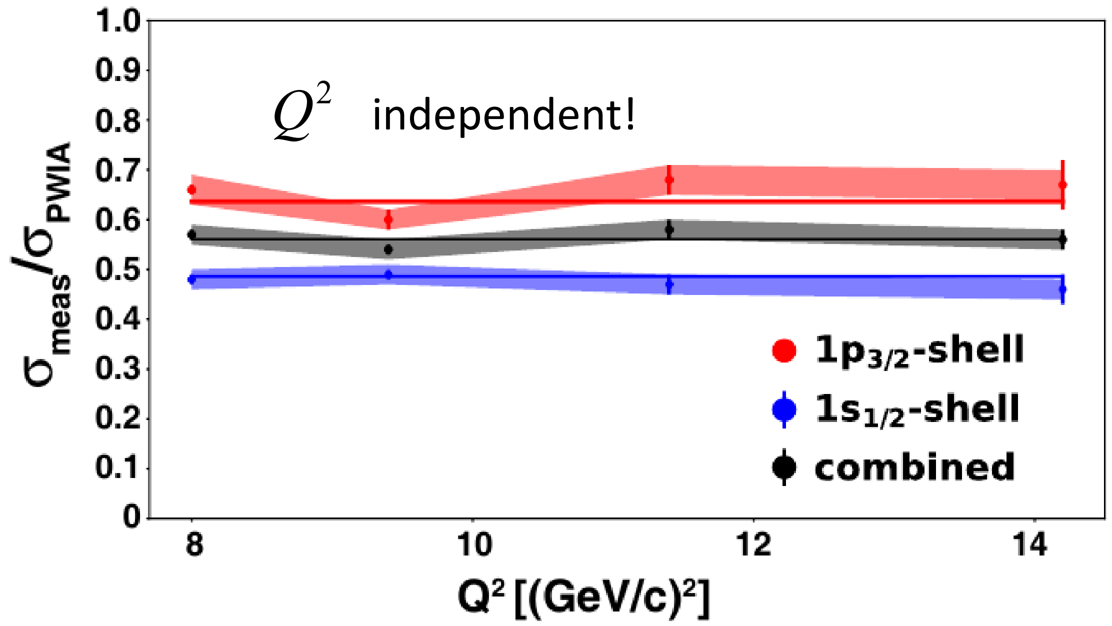
A NEW PROBLEM

CT for baryons
A(e,e'p)



D. Bhetuwal et al (Hall C), PRL 126 (2021) 082301
"Ruling out color transparency in quasi-elastic $^{12}C(e,e'p)$ up to Q^2 =14.2 $[GeV/c]^2$"

In contrast:
A(p,2p) data show a rise of transparency T in this reqion.



D. Bhetuwal et al, arxiv:2205.13495 [nucl-ex]
26 May 2022

- **S. J. Brodsky, G.F. de Teramond, Physics 2022, 4, 633-646;**

"Onset of Color Transparency in Holographic Light-Front QCD"

CT is predicted to occur at significantly higher momentum transfer Q^2

$Q^2 \geq 14 GeV^2$ for proton,

$Q^2 \geq 22 GeV^2$ for neutron,

as compared with mesons $Q^2 \geq 4 GeV^2$.

For SPD **pd->ppn** at: $\sqrt{s_{pp}} = 5 - 7 GeV^2, Q^2 = 11.7 - 22.8 GeV^2$

Expansion effects are strongly suppressed, because of $r^d{}_{NN} \sim 1 fm$

- **P.Jain, B. Pire, J. P. Ralston, Physics 2022, 4 , 578-589**

"Short-distance model of CT is ruled out?"

"Not-So-Short-Distance Processes"

"Old pp-scattering data at fixed angle have never been repeated"

Nuclear filtering and the ratio σ_L / σ_T

THE REACTION pd →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, arXiv:2208.08832 [nucl-th]/

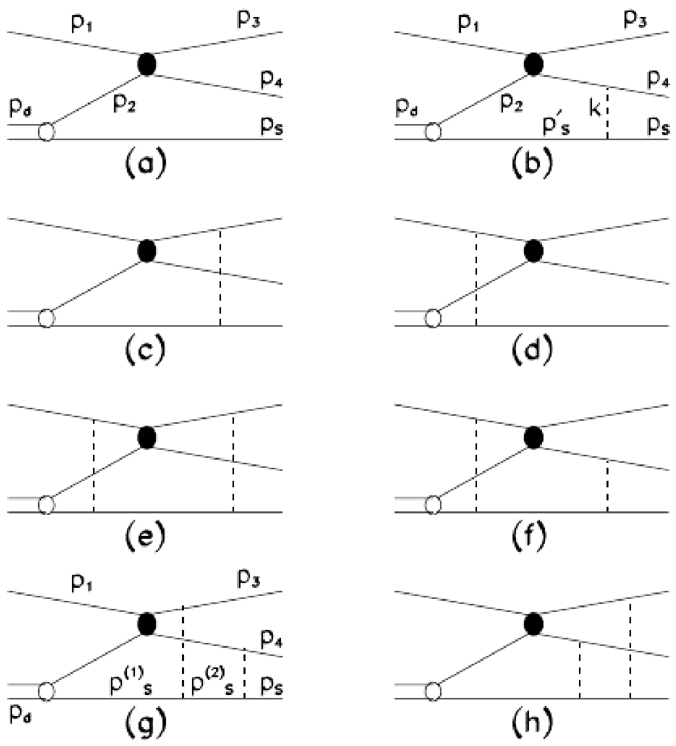
  or

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

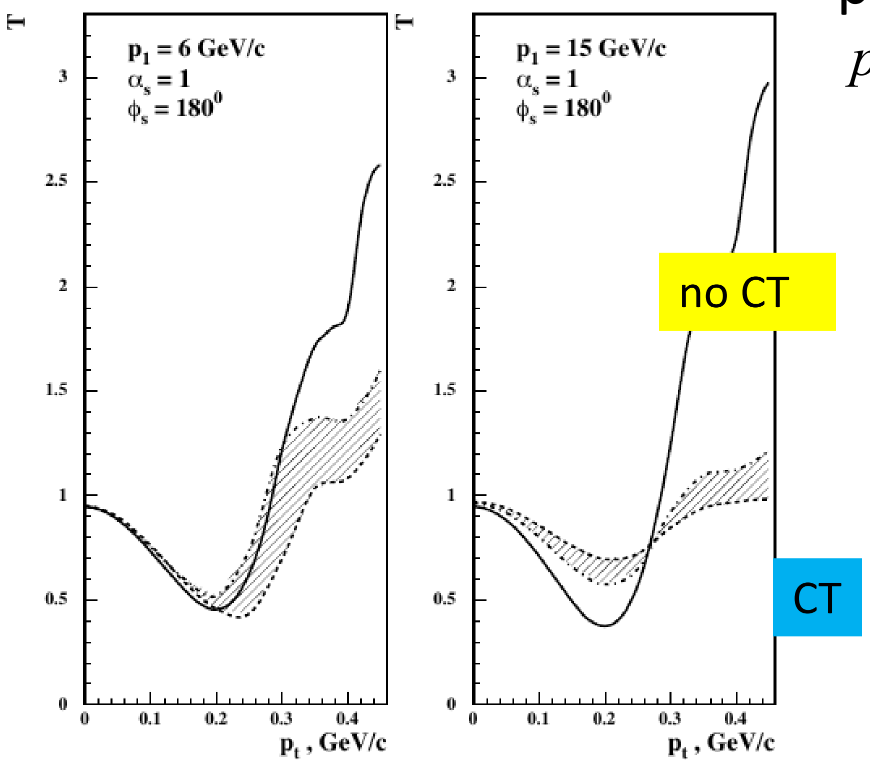
/L. Frankfurt et al. PRC 51 (1995) 890/

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

L.L. Frankfurt et al. PRC 56 (1997) 2752; **A.B. Larionov, arXiv:2208.08832 [nucl-th], A_yy**



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

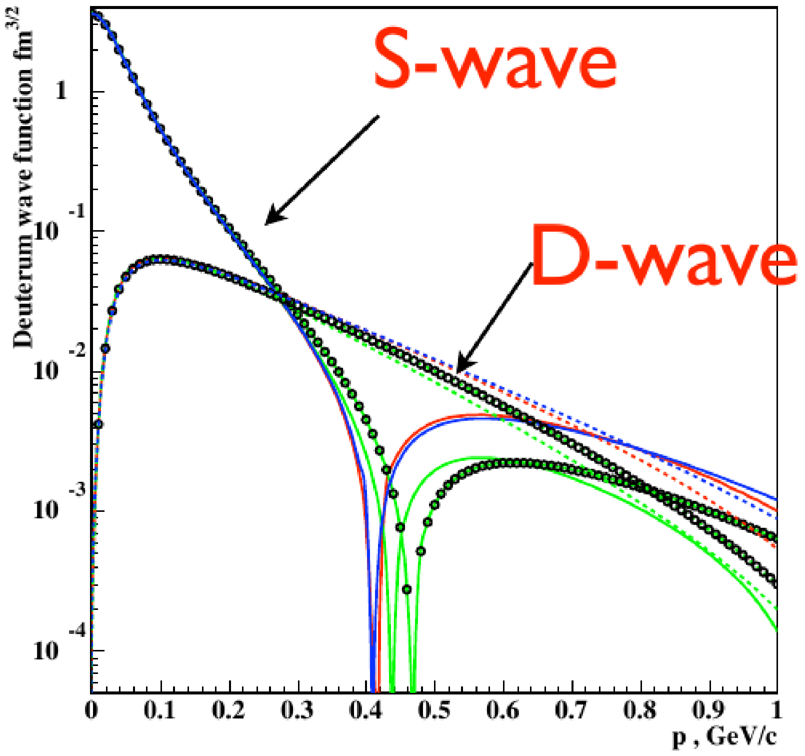


pd->ppn with hard $pp \rightarrow pp(\vartheta_{cm} \approx 90^{\circ})$

Transverse momentum of spectator

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

SHORT-RANGE NN CORRELATIONS IN NUCLEI



$$\psi_D^2(k)_{|k\to\infty} \propto \frac{V_{NN}^2(k)}{k^4}$$

D-wave dominates in the Deuteron wf for 300 MeV/c < k < 700 MeV/c

D-wave is due to tensor forces which are much more important for pn than pp

$$n_A(k)_{|k\to\infty} \propto \frac{V_{NN}^2(k)}{k^4}$$

$$\Longrightarrow n_A(k) \approx a_2(A)\psi_D^2(k)_{|k\to\infty}$$

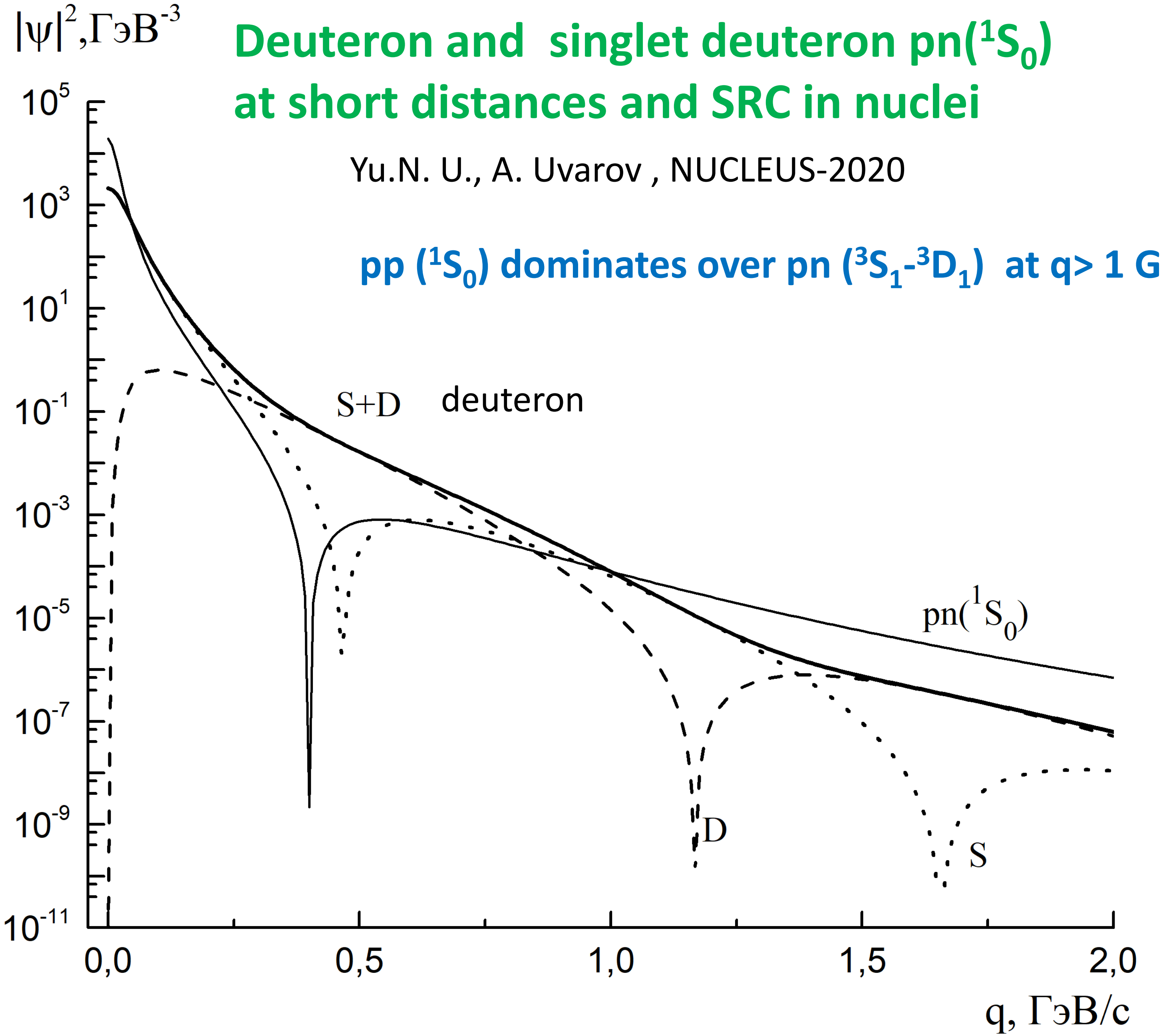
O. Hen, G. Miller, E. Piasetzky, Rev. Mod. Phys. 89 (2017)

pp ($^1S_0$) dominates over pn ($^3S_1$-$^3D_1$) at q> 1 GeV/c

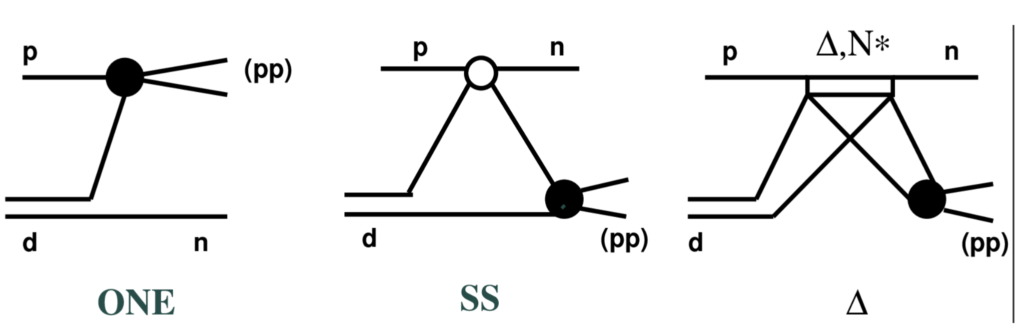
Deuteron and singlet deuteron pn($^1S_0$) at short distances and SRC in nuclei

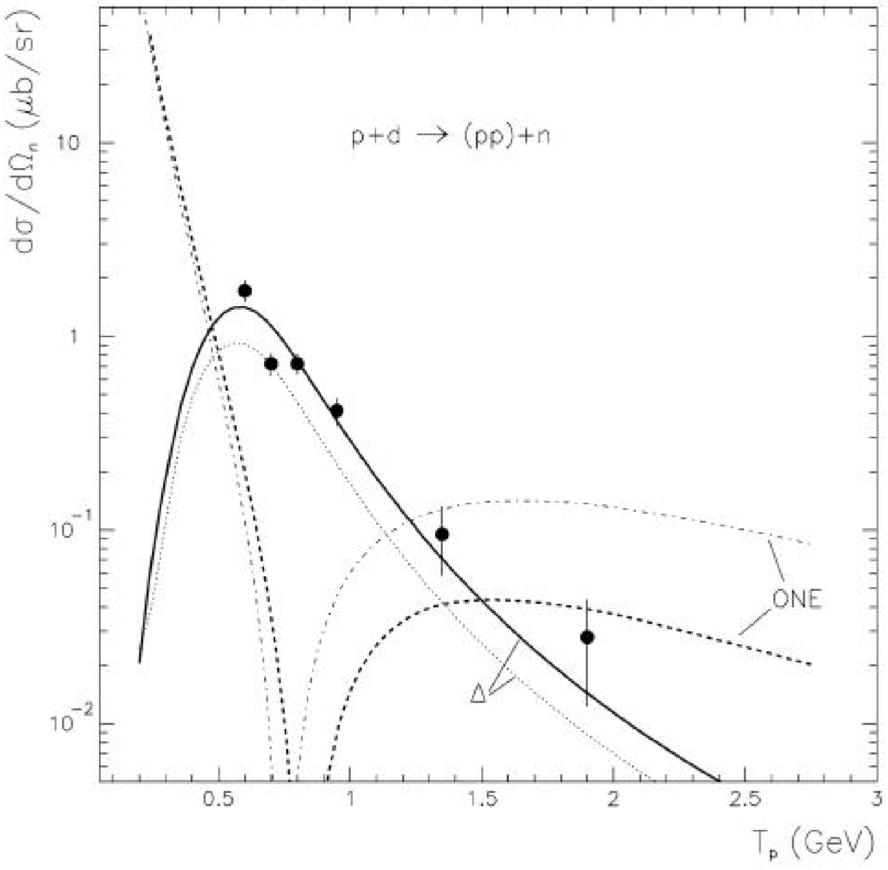
Yu.N. U., A. Uvarov , NUCLEUS-2020

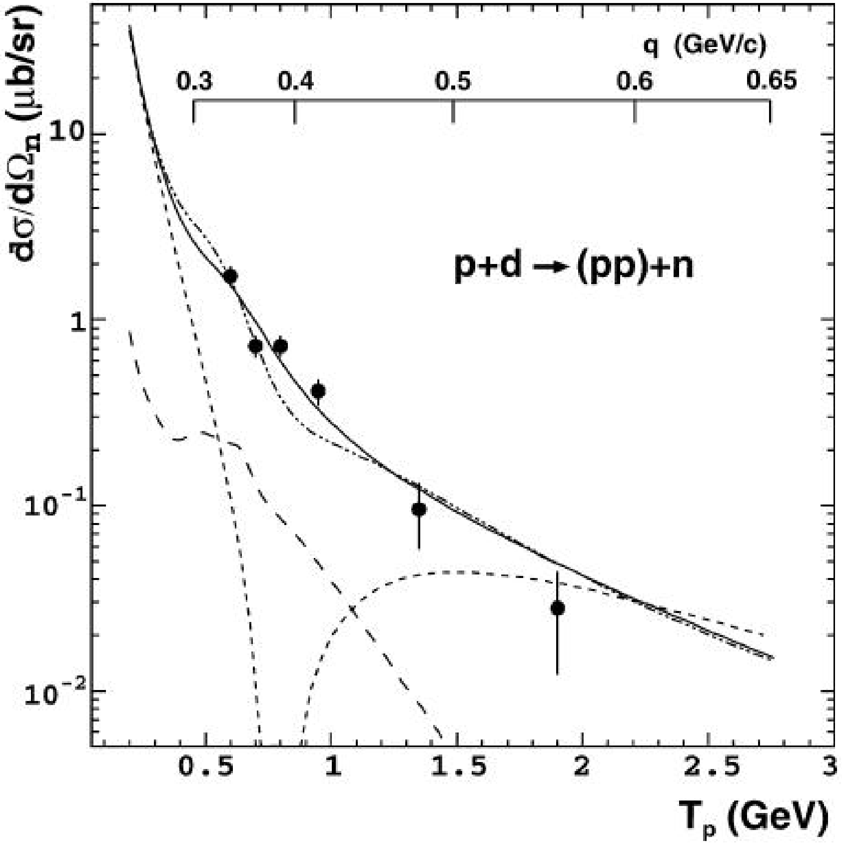
pp ($^1S_0$) dominates over pn ($^3S_1$-$^3D_1$) at q> 1 GeV/c



V.Komarov et a.l PLB 553 (2003);
J.Haidenbauer, Yu.N. U. PLB 562 (2003)







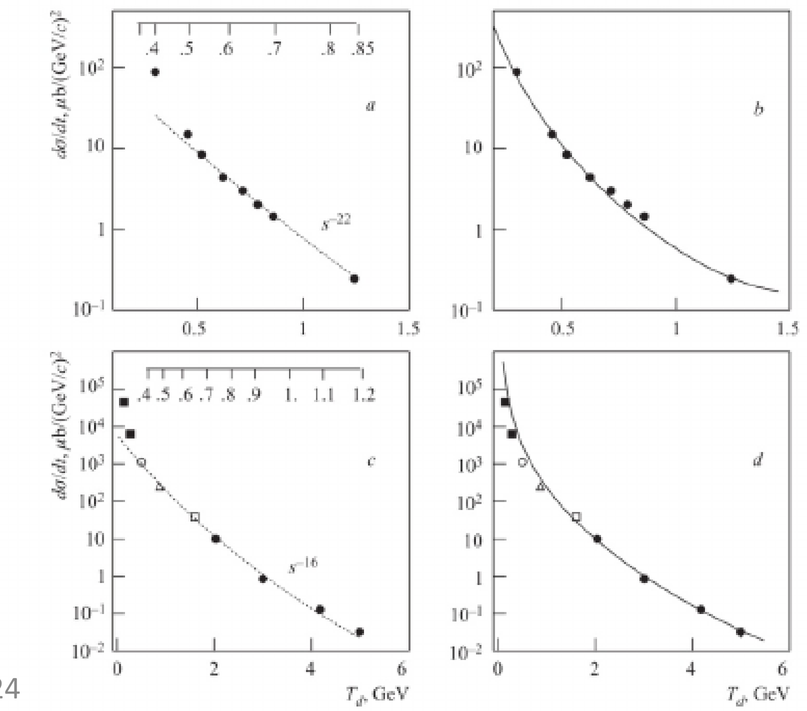
Constituent Counting Rules

At high energy s and large transverse momenta p_t the constituent counting roles (CCR) predict the following behavior of the differential cross section for the binary reactions:

$$\frac{d\sigma}{dt}(ab \rightarrow cd) = \frac{f(t/s)}{s^{n-2}} \quad ; \quad n = N_a + N_b + N_c + N_d$$

Matveev, Muradyan, Tavkhelidze **-self similarity**
Brodsky, Farrar et al. **-perturbative QCD**
J. Polchinski, M.J. Strassler **-AdS/QCD correspondance**

$$\gamma d \rightarrow pn, E_\gamma \geq 1 GeV$$



Yu. N. Uzikov , JETP Lett, 81 (2005) 303-306

For the reaction **dd → ³Hen**

$$N_A + N_B + N_C + N_D - 2 = 22$$

For the reaction **dp → dp**

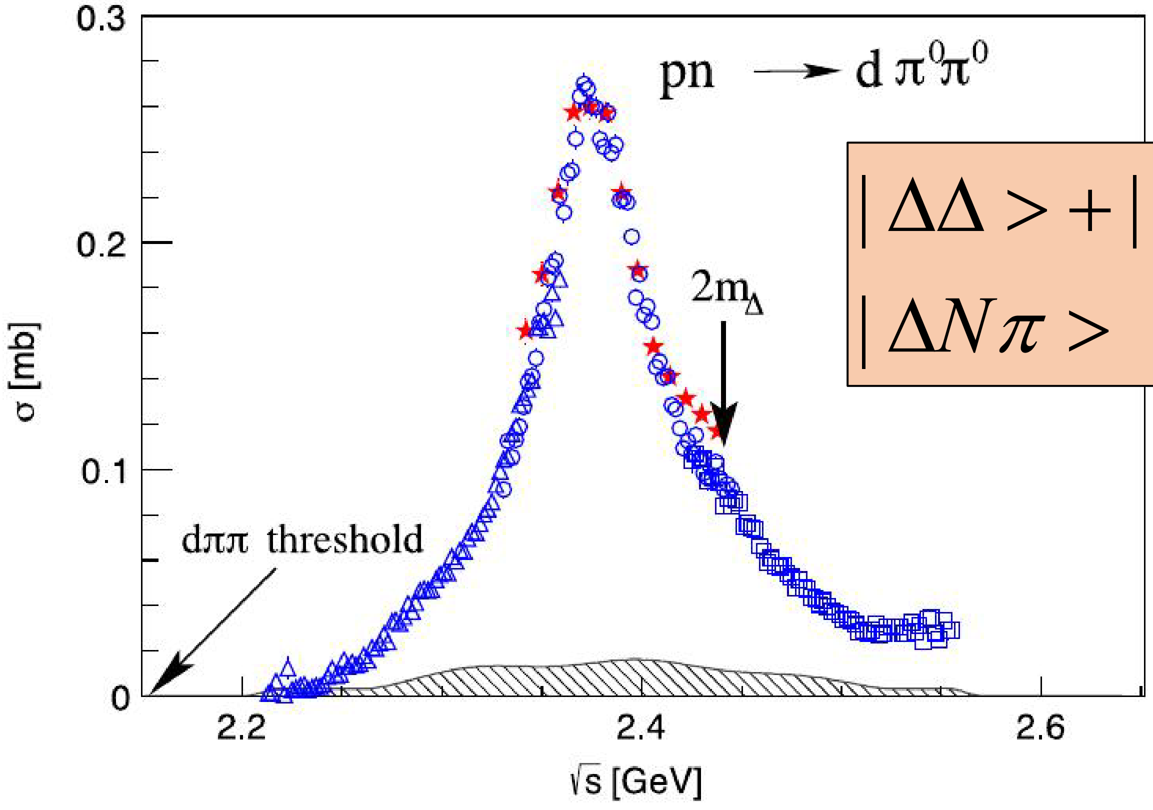
$$N_A + N_B + N_C + N_D - 2 = 16$$

Unexpectedly Early!

The regime corresponding to CCR can occur already at T_d ~ 500 MeV (!?)

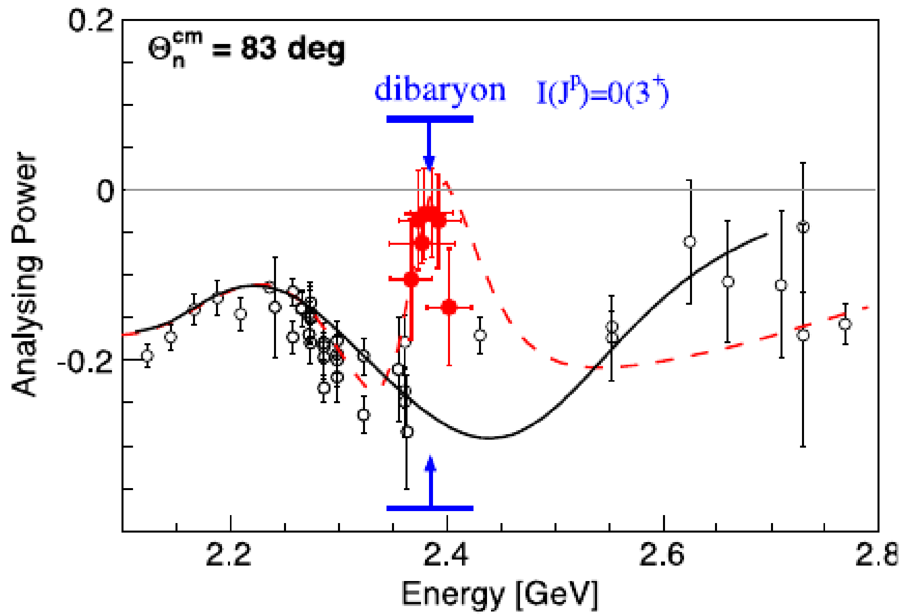
DIBARYON RESONANCES

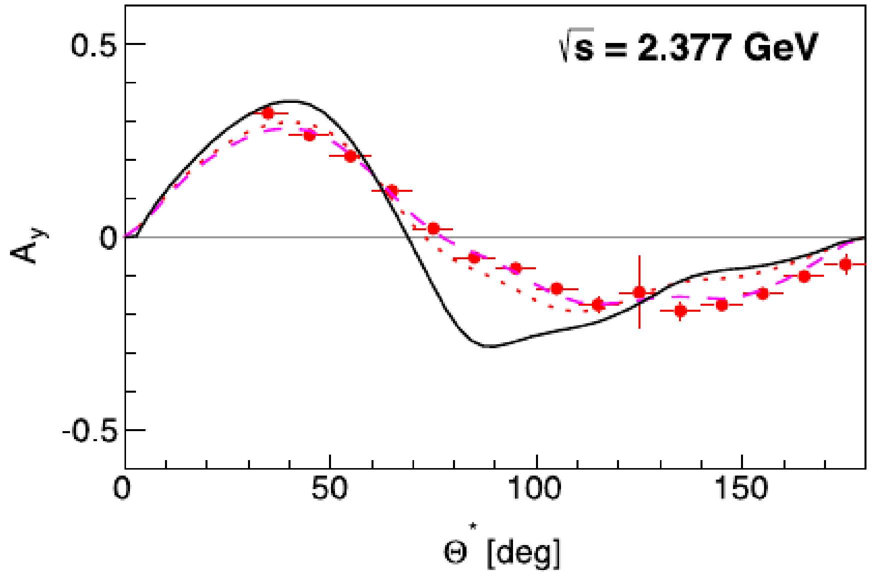
H. Clement / Progress in Particle and Nuclear Physics 93 (2017) 195–242



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

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





EXOTIC HYPERNUCLEI

中国科学院高能物理研究所 Institute of High Energy Physics 中国科学院 CHINESE ACADEMY OF SCIENCES

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

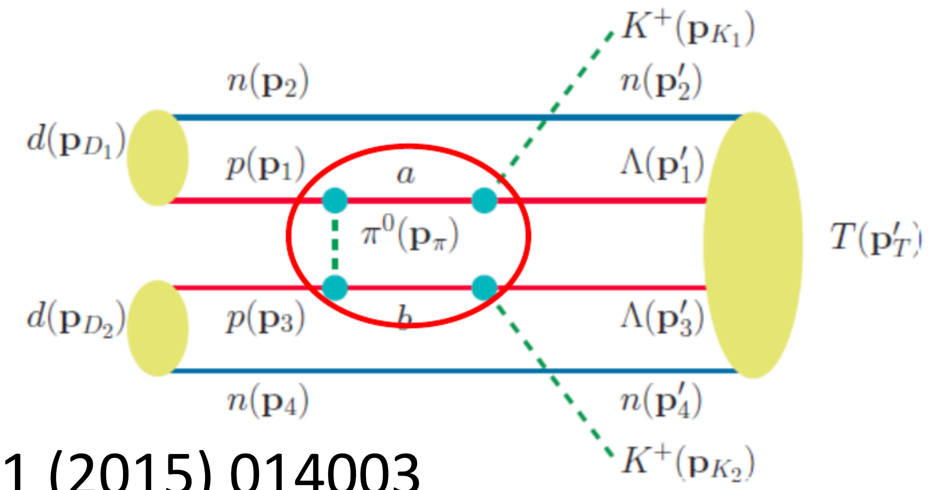
Tetraneutron is observed

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

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



Other channels pd->2K+(nΛΛ)

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

Other suggestions

Single-spin observables in pp and in pA are not explained by pQCD. Model of Choromo-magnetic polarization of quarks.

(V. Abramov) $pp \to \pi X, p(A) \to \vec{\Lambda} X$

Vector meson production in NN collisions: $\frac{\sigma(np \to npJ/\psi)}{\sigma(pp \to ppJ/\psi)} = 5$

(F.E. Tomasi-Gustafsson)

Multiquark correlations, fluctons, diquarks in collisions of particles and nuclei $pp \to d(\vartheta_{cm} = 90^o) + X$

(V.Kim, A. Shavrin, A. Zelenov)

Production of hyper-nucleus ${}^{4}_{\Lambda\Lambda}n$ in $dd \to {}^{4}_{\Lambda\Lambda}n + K^+ + K^+$

(Q. Zhao, J.-M. Richard, Q. Wang)

Soft Photon study in pp, pA and AA proton

E.Kokoulina, V. Nikitin

Problems of soft PP interactions

A. Galoyan and V. Uzhinsky

Hadron formation effects in heavy ions collisons ^{12}C-^{12}C, ^{40}Ca-^{40}Ca

A.B. Larionov

Pair production of polarized tau leptons in SPD experiments

A. Aleshko, E. Boos, V. Bunichev

Search for light dibaryons in inelastic d-d and p-d

B.F. Kostenko

- **Search for physics beyond the Standard Model**

Measuring Antiproton-Production Cross Sections in pp and pd in favour of search for Dark Matter WIMPs (**R. El-Kholy**)

For analysis of PAMELA and AMS-02 data.

Test of the SM via parity violation in $\vec{p}N$ and in $\vec{p}A$ scattering up to $\leq 10^{-7}$

Search for CP(T) violation beyond the SM in double polarized pd scattering down to $10^{-(5-6)}$.

Principal novelty: precessing polarization of stored particles

(I.A. Koop, A.I. Milstein, N.N. Nikolaev, A.S. Popov, S.G. Salnikov, P.Yu. Shatunov, Yu.M. Shatunov)

OUTLOOK

Detailed study of pp-, dd- and pd-collisions at NICA SPD at energies $\sqrt{s_{NN}}$ <10 GeV offer a possibility to

- test models for spin-effects in NN elastics scattering and reactions of meson and hyperon production;
- get more insight into QCD properties of the transition region from hadron to quark- gluon degrees of freedom in hadronic systems (CT, CCR, multiquarks);
- and give a valuable contribution to search for physics BSM (DM, TV, PV)

Usage of polarized beams is crucial in this study.

Thank you for your attention!

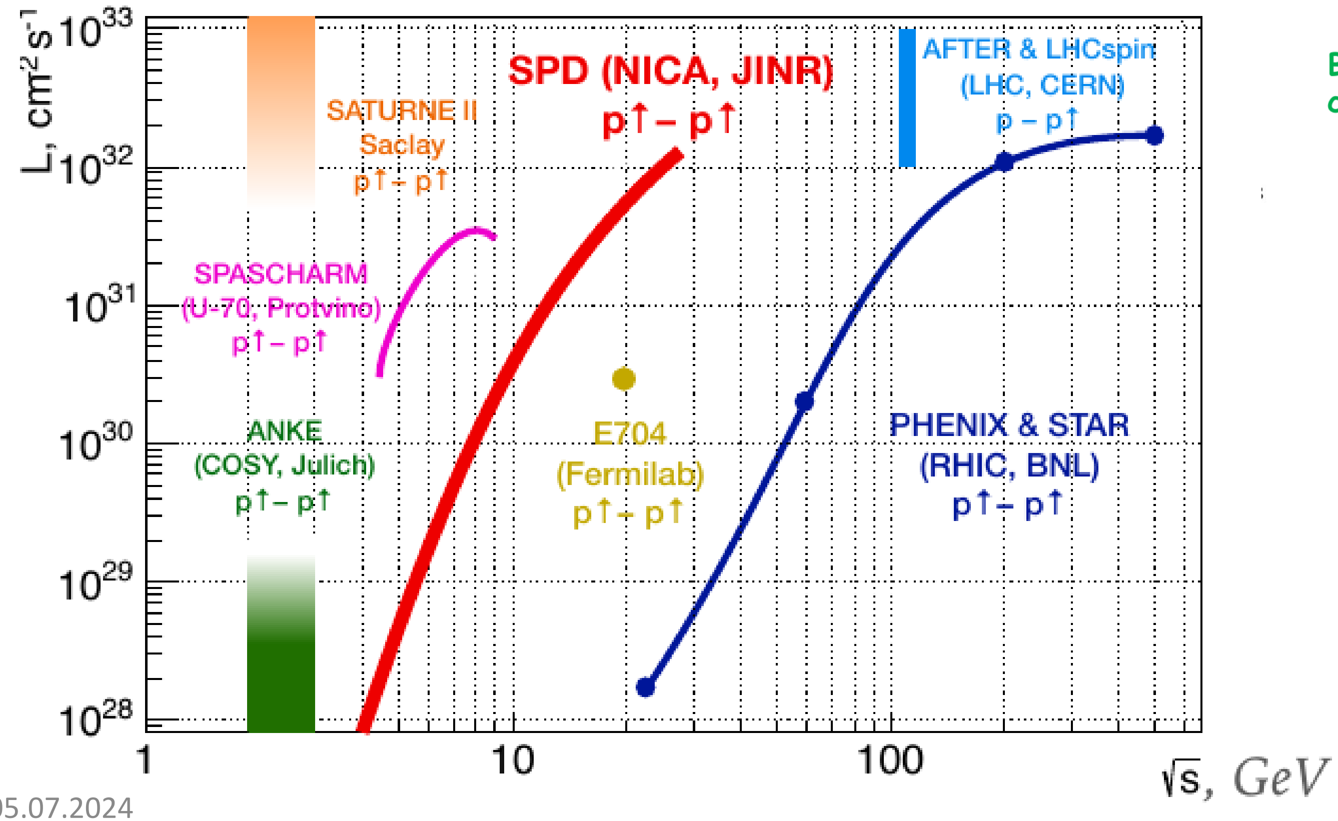
NICA aerial view, April 2022

BACKUP-I

SPD – VS OTHERS

In the $d^{\uparrow}d^{\uparrow}$ mode we are unique

In the $p^{\uparrow}p^{\uparrow}$ mode:



NN Elastic scattering with polarized deuteron beams :

$p\uparrow + p\uparrow \rightarrow p + p$ for calibration

$p\uparrow + n\uparrow \rightarrow p + n$

$n\uparrow + n\uparrow \rightarrow n + n$

New data!

By the way we will have the counting rules verification!

pd, nd and dd – too!

Main advantages

The unique beams: – wide range of kind of the beam particles (especially antiproton and polarization) and $\Delta p/p$ up to 10^{-5}.

The unique detectors: $\Delta\Omega \sim 4\pi$ (exclusive reactions, correlations, backward range); detection all kinds of particles (especially neutron); working at luminosity up to 10^{30} - 10^{32} $cm^{-2}\ s^{-1}$ (the rare event can be investigated); PID – close to full energy range.

T-even P-even

$$M_N(\mathbf{p},\mathbf{q};\boldsymbol{\sigma},\boldsymbol{\sigma}_N)$$
$$= A_N + C_N\boldsymbol{\sigma}\hat{\mathbf{n}} + C'_N\boldsymbol{\sigma}_N\hat{\mathbf{n}} + B_N(\boldsymbol{\sigma}\hat{\mathbf{k}})(\boldsymbol{\sigma}_N\hat{\mathbf{k}})$$
$$+ (G_N + H_N)(\boldsymbol{\sigma}\hat{\mathbf{q}})(\boldsymbol{\sigma}_N\hat{\mathbf{q}}) + (G_N - H_N)(\boldsymbol{\sigma}\hat{\mathbf{n}})(\boldsymbol{\sigma}_N\hat{\mathbf{n}})$$

T-odd P-even

$$t_{pN} = h_N[(\boldsymbol{\sigma}\cdot\mathbf{k})(\boldsymbol{\sigma}_N\cdot\mathbf{q}) + (\boldsymbol{\sigma}_N\cdot\mathbf{k})(\boldsymbol{\sigma}\cdot\mathbf{q})$$
$$- \tfrac{2}{3}(\boldsymbol{\sigma}_N\cdot\boldsymbol{\sigma})(\mathbf{k}\cdot\mathbf{q})]/m_p^2$$
$$+ g_N[\boldsymbol{\sigma}\times\boldsymbol{\sigma}_N]\cdot[\mathbf{q}\times\mathbf{k}][\boldsymbol{\tau}-\boldsymbol{\tau}_N]_z/m_p^2$$
$$+ g'_N(\boldsymbol{\sigma}-\boldsymbol{\sigma}_N)\cdot i\,[\mathbf{q}\times\mathbf{k}][\boldsymbol{\tau}\times\boldsymbol{\tau}_N]_z/m_p^2.$$

Null-test signal:

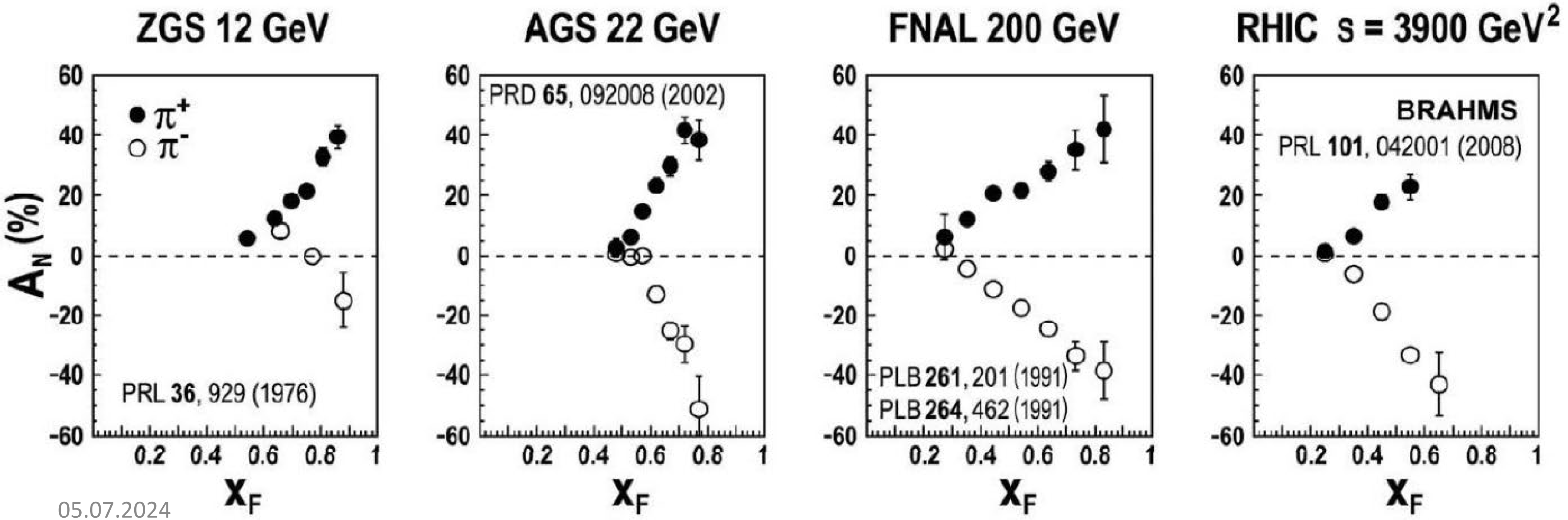
$$\widetilde{g} = \frac{i}{4\pi m_p}\int_0^\infty dq q^2\Big[S_0^{(0)}(q) - \sqrt{8}S_2^{(1)}(q) - 4S_0^{(2)}(q)$$
$$+\sqrt{2}\frac{4}{3}S_2^{(2)}(q) + 9S_1^{(2)}(q)\Big][-C'_n(q)\,h_p + C'_p(q)(g_n - h_n)]$$

● SINGLE-SPIN OBSERVABLES

pQCD does not explain single and double spin asymmetries in $pp \to \pi^+(\pi^-)X$

INCLUSIVE PION ASYMMETRY IN PROTON-PROTON COLLISIONS

C. Aidala SPIN 2008 Proceeding and CERN Courier June 2009

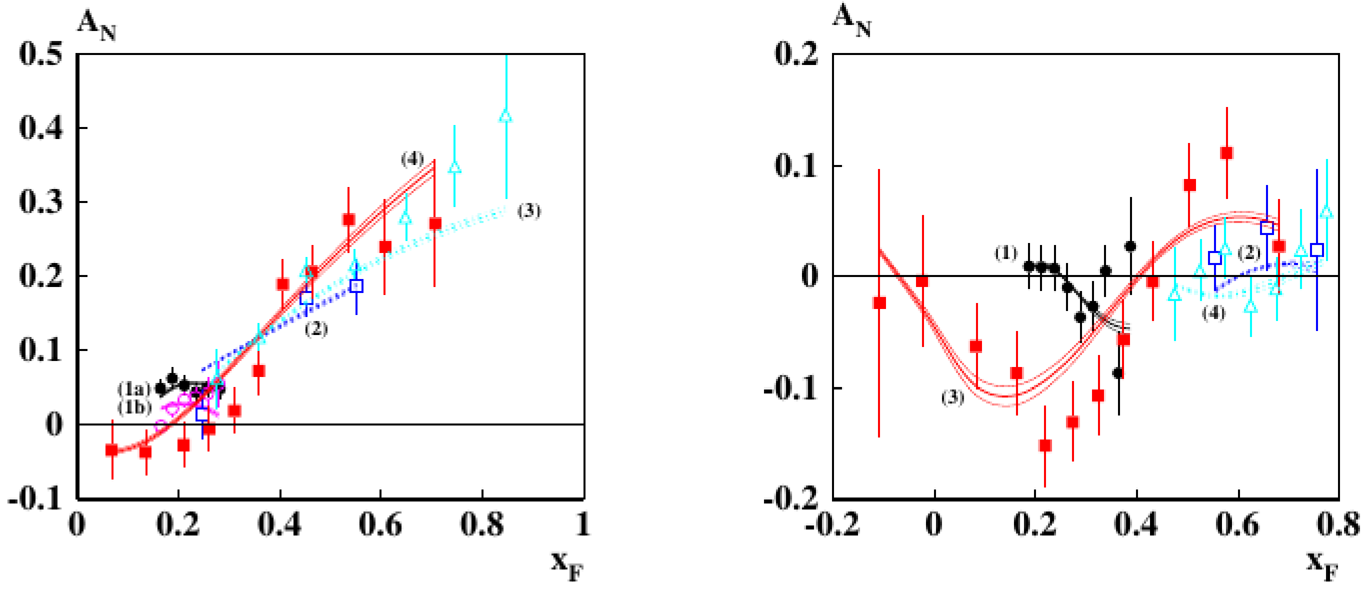


V. Abramov, 2009-2020

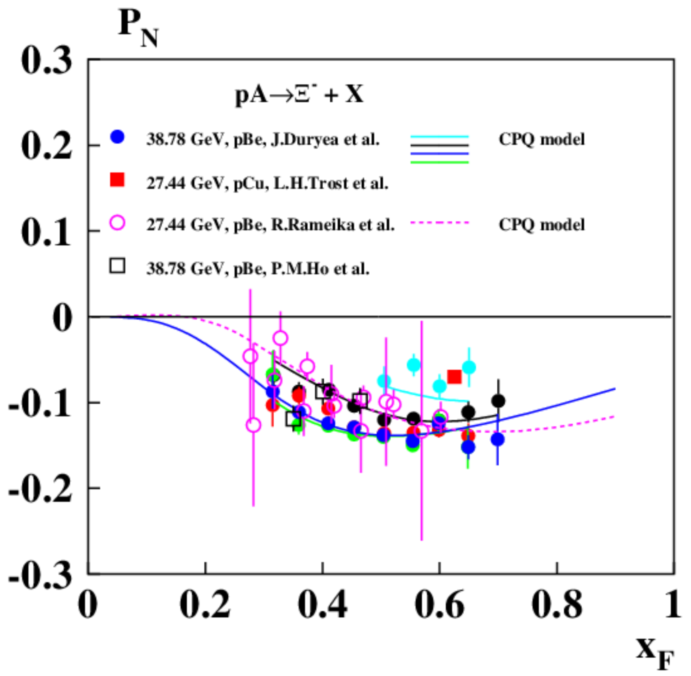
The model of chromomagnetic polarization of quarks (CPQ)

Shtern-Gerlach chromomag-mag forces, quark structure of hadrons.

Global fit of 3600 exp.points from 85 different reactions



(a) (b)



$A_N(x_F)$ for the reaction $p^\uparrow + p(A) \to \pi^+ + X$ **(a)** and $p^\uparrow + p(A) \to p + X$ [102] **(b)** [102].

$$\lambda \approx -|\psi_{qq}(0)|^2/|\psi_{q\bar{q}}(0)|^2 = -1/8 = -0.125.$$

Oscillations and resonance behavior for A_N, P_N are predicted.

A wide program of new measurements is suggested for NICA SPD

Fit=-0.136 \pm 0.0003

Multiparton interaction and exotic resonance production

Victor Kim

Petersburg Nuclear Physics Institute (NRC KI - PNPI), Gatchina
St. Petersburg Polytechnic University (SPbPU)

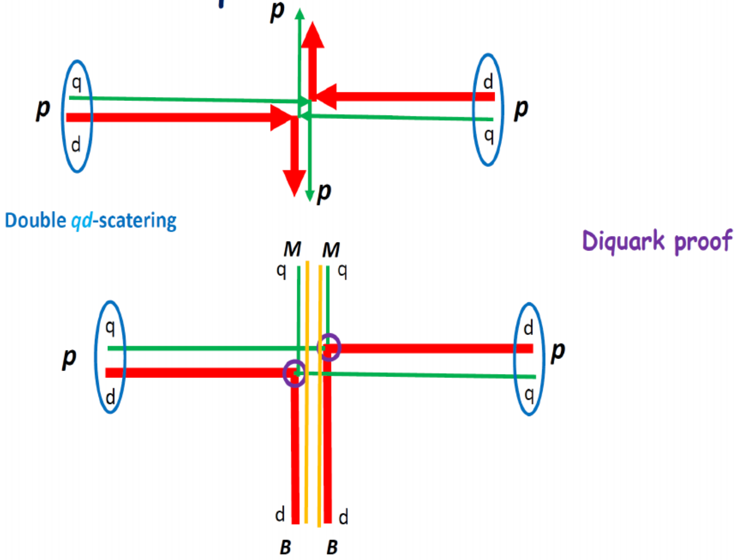
in collaboration with A.A. Shavrin (SPbSU) and A.V. Zelenov (NRC KI - PNPI)

Ratio d/p

Kim's mechanisms in exclusive reactions

pp - > pp + X, pp -> D(H) + X
reactions with diquarks

$$pp \to d(\vartheta_{cm} = 90^o) + X$$



Search for dibaryon resonances
V.I. Komarov (2018)

B. Kostenko: d+d->d+d*

$$q_0 = \frac{M_*^2 - M_d^2}{4E_d^{lab}}, M_* = M_d + n\varepsilon$$

• VECTOR MESONS PRODUCTION IN NN COLLISIONS

(E.E. Tomasi-Gustafsson)

$$N+N\to N+N+V,\ V=\rho,\omega,\phi,\ J/\Psi\ldots$$

General Considerations for threshold production
(the threshold region may be quite wide : $q< m_c$)

$$S_i=1,\ \ell_i=1\ \to\ j^P=1^-\to S_f=0,$$
$$\mathcal{M}(\mathrm{pp})=2f_{10}[\tilde{\chi}_2\sigma_y\vec{\sigma}\cdot(\vec{U}^*\times\hat{\vec{k}})\chi_1]\,(\chi_4^\dagger\sigma_y\,\tilde{\chi}_3^\dagger),$$

$$S_i=1,\ell_i=1\to j^P=1^-\to S_f=0,$$
$$S_i=0,\ell_i=1\to j^P=1^-\to S_f=1,$$
$$\mathcal{M}(\mathrm{np})=f_{10}[\tilde{\chi}_2\sigma_y\vec{\sigma}\cdot(\vec{U}^*\times\hat{\vec{k}})\chi_1](\chi_4^\dagger\sigma_y\,\tilde{\chi}_3^\dagger)+f_{01}(\tilde{\chi}_2\,\sigma_y\chi_1)[\chi_4^\dagger\vec{\sigma}\cdot(\vec{U}^*\times\hat{\vec{k}})\sigma_y\tilde{\chi}_3^\dagger],$$

The dynamical information is contained in the amplitudes that are different for the different vector mesons

M.P. Rekalo, E.T.-G.. New J. Phys., 4,68(2002).

Large isotopic effect at threshold (model independent)

$$\frac{\sigma(np\to npJ/\psi)}{\sigma(pp\to ppJ/\psi)}=5$$

See also Yu.N.U. Yad. Fiz. 77 (2014) 681

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Qiang Zhao

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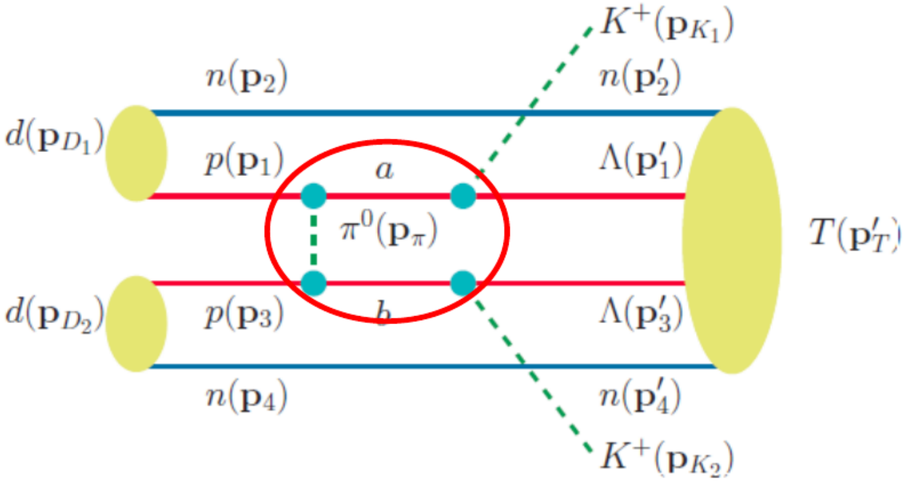
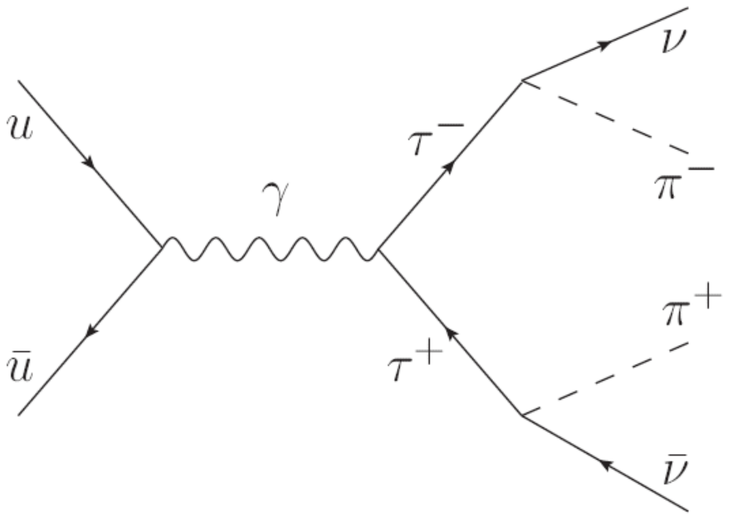


J.M. Richard, Q. Wang, Q. Zhao, PRC 91 (2015) 014003

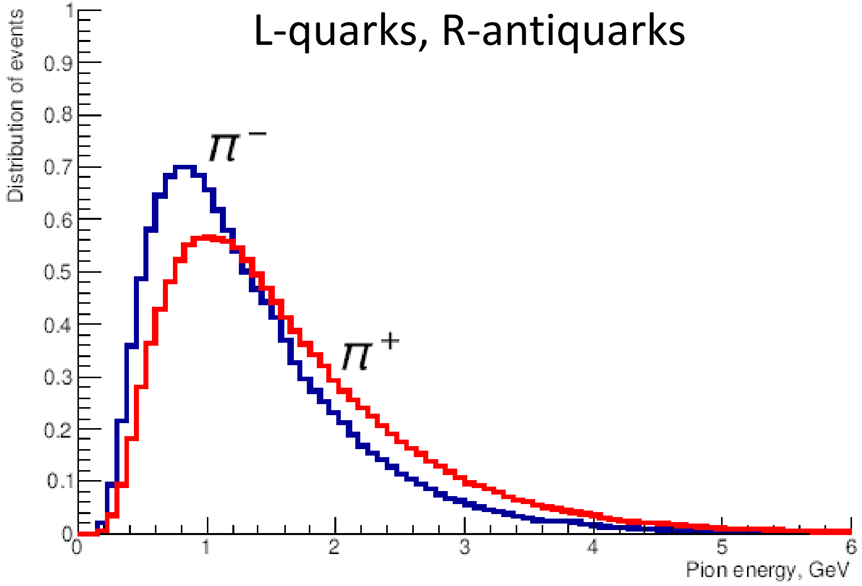


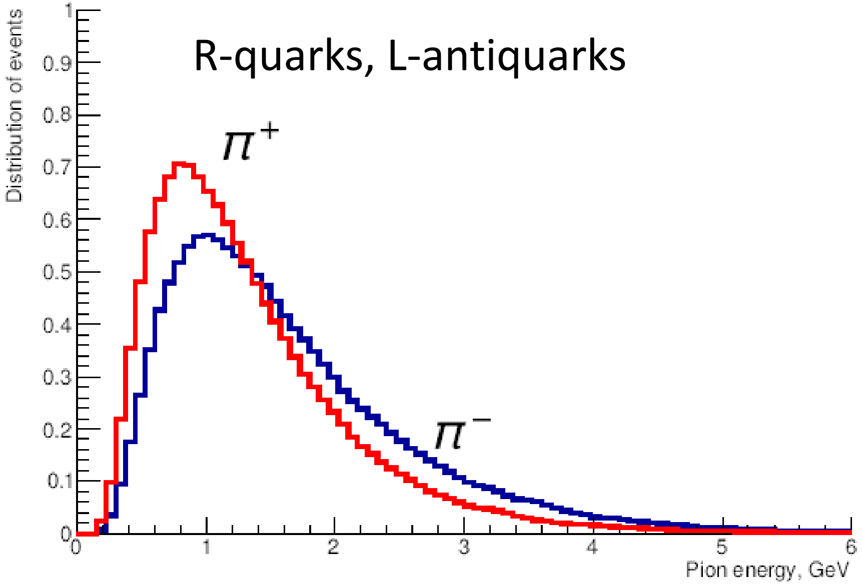
PDF and polarized tau-leptons production

A. Aleshko, E. Boos, V. Bunichev

Energy of pi-meson depends on polarization of tau-lepton

$$\sqrt{s} = 24GeV^2$$

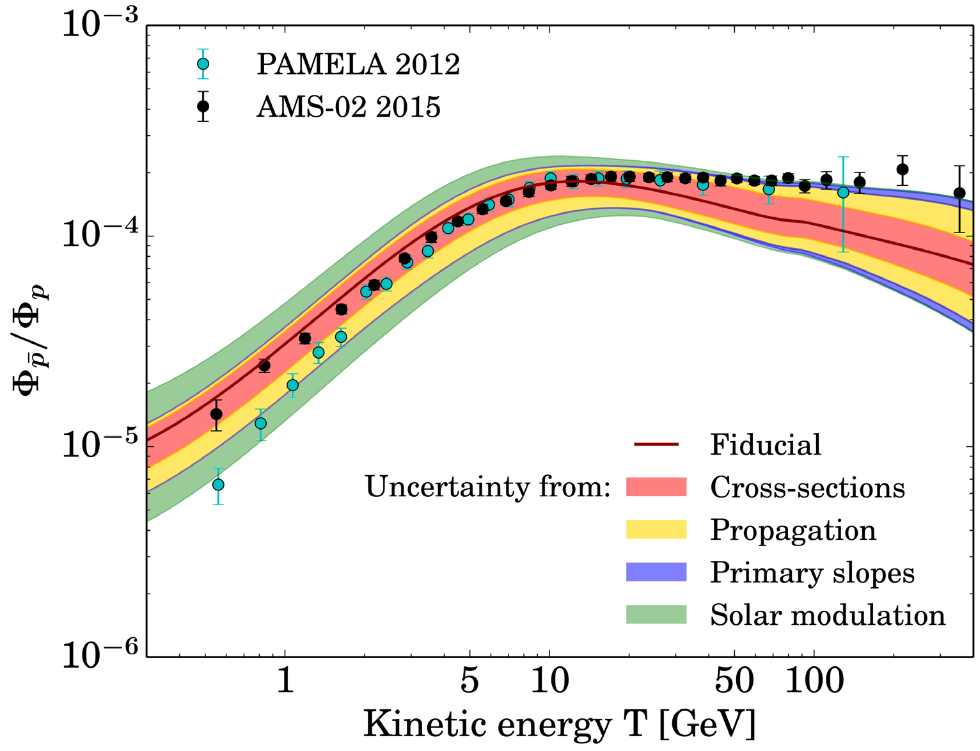




Measuring Antiproton-Production Cross Sections for Dark Matter Search (R. El-Kholy)

DM in light of AMS-02 measurements

- Dark matter > 26%
- AMS-02: Potential signal at $m_{DM} \sim 80$ GeV
- High theoretical uncertainties: 20-50%[1]
- Stat. sig.: from (> 5σ) to (~ 1.1σ)

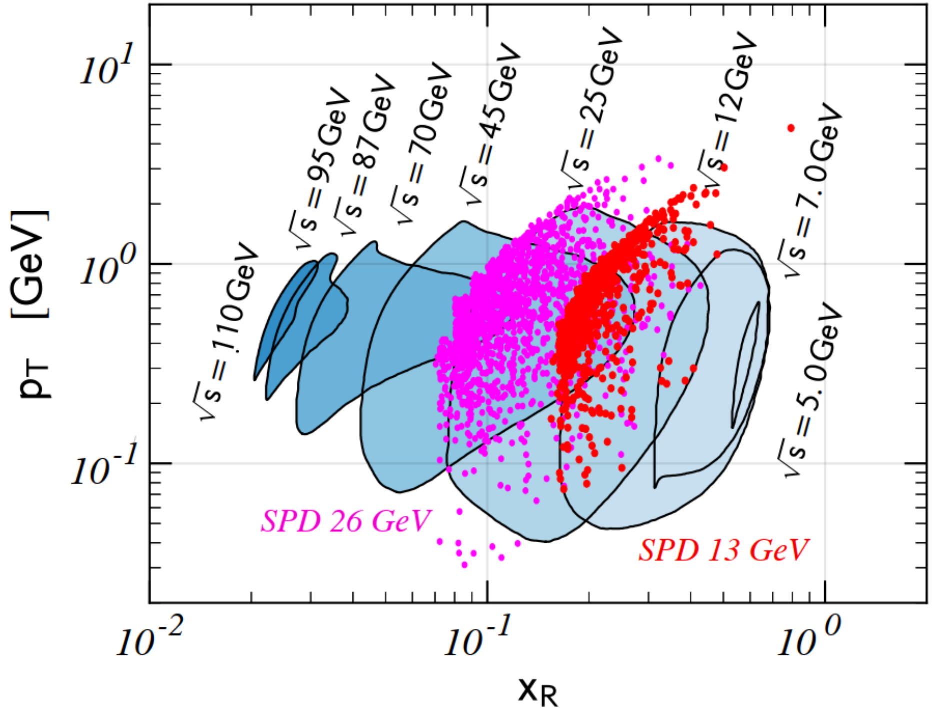


Potential Coverage by NICA SPD

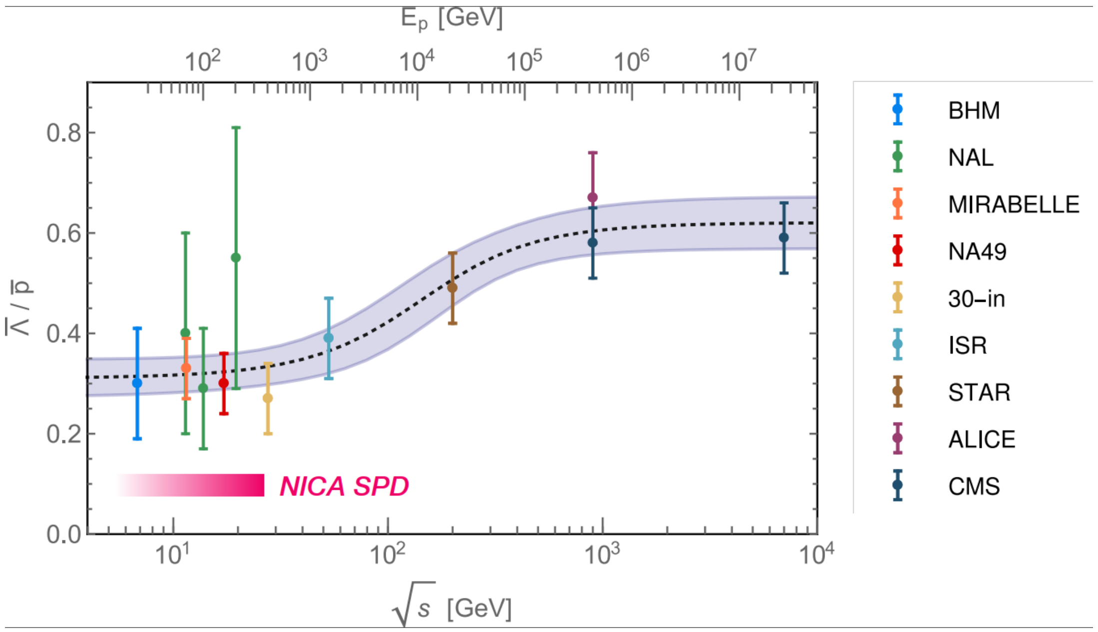
Necessary parameter-space coverage[1] to match AMS-02 precision:

3% within contours

30% outside contours



Accounting for hyperon-induced antiprotons via reconstruction of secondary vertices[2]



$$X_R = \frac{E_p^*}{E_{p\max}^*}$$

Tests of Fundamental Discrete Symmetries at NICA Facility: addendum to the spin physics programme

I. Koop, A. Milstein, N. Nikolaev, A. Popov, S.Salnikov, P. Shatunov and Yu.Shatunov

RFBR grant NICA 18-02-40092 Meg

New approach to spin physics at NICA as a high-intensity source of polarized protons and deuterons

- Test of the Standard Model (SM) via parity violation in single-spin pN and pA scattering: search for the PV asymmetry $< 10^{-7}$
- Beyond SM semistrong CP(T)-violation in double polarized pD scattering: search for T-forbidden vector-tensor asymmetry down to $10^{-\{5-6)}$
- Principal novelty: in the ring-plane precessing polarization of stored particles and Fourier analysis of oscillating vector and tensor asymmetries

Decomposition of the pd total X-section (k = collision axis)

$$\sigma_{\rm tot} = \sigma_0 + \sigma_{\rm TT}\left[\left(\mathbf{P}^{\rm d}\cdot\mathbf{P}^{\rm p}\right) - \left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right)\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right)\right]$$ PC TT

$$+\,\sigma_{\rm LL}\left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right)\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) + \sigma_{\rm T} T_{mn} k_m k_n$$ LL & PC tensor

$$+\,\sigma^{\rm p}_{\rm PV}\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) + \sigma^{\rm d}_{\rm PV}\left(\mathbf{P}^{\rm d}\cdot\mathbf{k}\right)$$ PV single spin at NICA

$$+\,\sigma^{\rm T}_{\rm PV}\left(\mathbf{P}^{\rm p}\cdot\mathbf{k}\right) T_{mn} k_m k_n$$ PV tensor

$$+\,\sigma_{\rm TVPV}\left(\mathbf{k}\cdot\left[\mathbf{P}^{\rm d}\times\mathbf{P}^{\rm p}\right]\right)$$ TVPV

TVPC $$+\,\sigma_{\rm TVPC} k_m T_{mn}\epsilon_{nlr} P^{\rm p}_l k_r\,.$$ (TRIC Proposal in Juelich)

$$k_m T_{mn}\epsilon_{nlr} P^{\rm p}_l k_r = T_{xz} P^{\rm p}_y - T_{yz} P^{\rm p}_x$$

05.10.2020 13

N. Nikolaev, F. Rathman, A. Silenko, Yu. Uzikov, PLB 811 (2020) 135983

Spontaneously (Dynamically) Broken Chiral Symmetry [DBCS]

$$m_\pi^2 = -\frac{2(m_u + m_d)}{f_\pi^2} < 0 | \bar{q}q | 0 >;$$

$$f_\pi = 131 MeV, < 0 | \bar{q}q | 0 > = -(257 MeV)^3;$$

M. Gell-mann, R.J. Oakes, B. Renner, Phys. Rev. 175(1968)2195 (PCAC) 2105 refs.

$$m_p = [-2(2\pi)^2 < 0 | \bar{q}q | 0 >]^{1/3}$$

B.L. Ioffe, Nucl.Phys. B 188 (1981) 317; 911 refs.

$$< 0 | \bar{q}q | 0 > \to 0, T \uparrow, \rho \uparrow$$

- ## Constituent counting rules (CCR)

$$a + b \to c + d$$

At fixed θ_{cm} angle

$$\frac{d\sigma}{dt}(ab \to cd) = \frac{1}{s^{n-2}} f(\theta_{cm}) \qquad (3)$$

$$n = N_a + N_b + N_c + N_d$$

V.A. Matveev, R.M. Muradyan and A.N. Tavkhelidze, Lett. Nuovo Cim. 7, 719 (1973).
S.J. Brodsky and G.R. Farrar, Phys. Rev. Lett. 31, 1153 (1973).
S.J. Brodsky and G.R. Farrar, Phys. Rev. D 11, 1309 (1975).

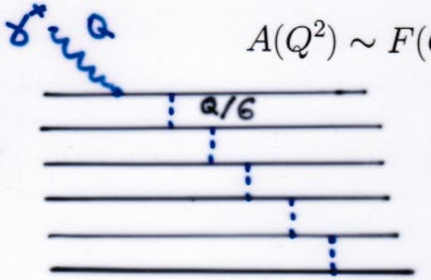
AdS/CFT:
J. Polchinski, A. Strassler, Phys. Rev. Lett. 88 (2002) 03601
CCR without pert. theory

$ed \to ed$

n =1+6+1+6=14, $t = Q^2$
$dt \sim Q^2 d\Omega,$

$$\frac{1}{Q^2}\frac{d\sigma}{d\Omega} \sim \frac{g(\theta_{cm})}{Q^4} A(Q^2) \sim f(\theta_{cm}) \left(\frac{1}{Q^2}\right)^{14-2}$$

$$A(Q^2) \sim F(Q^2)^2 \sim Q^{-20}$$



pQCD

$10! \approx 380000$

$F(Q^2) \sim \left[\frac{1}{Q^2}\right]^5 \sim \frac{1}{Q^{10}}$

hard Q^2-dependence
$Q^{10} F(Q^2) \to const$

$\gamma d \to p + n$

n =1+6+6=13, $t \sim s$

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{11}} \qquad (4)$$