POSSIBLE PHYSICS STUDIES AT THE FIRST STAGE OF THE NICA SPD PROGRAMME

Yu. N. Uzikov

DLNP JINR, Dubna

on behalf of the coauthors of the paper

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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

V. V. Abramov[a], A. Aleshko[b], V. A. Baskov[c], E. Boos[b], V. Bunichev[b], O. D. Dalkarov[c], R. El-Kholy[d], A. Galoyan[e], A. V. Guskov[f], V. T. Kim[g, h], E. Kokoulina[e, i], I. A. Koop[k, l, m], B. F. Kostenko[m], A. D. Kovalenko[e, †], V. P. Ladygin[e], A. B. Larionov[o, n], A. I. L'vov[c], A. I. Milstein[j, k], V. A. Nikitin[e], N. N. Nikolaev[p, z], A. S. Popov[j], V. V. Polyanskiy[c], J.-M. Richard[q], S. G. Salnikov[j], A. A. Shavrin[r], P. Yu. Shatunov[j, k], Yu. M. Shatunov[j, k], O. V. Selyugin[n], M. Strikman[s], E. Tomasi-Gustafsson[t], V. V. Uzhinsky[m], Yu. N. Uzikov[f, u, v, *], Qian Wang[w], Qiang Zhao[x, y], and A. V. Zelenov[g]

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

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

[a] NRC "Kurchatov Institute"—IHEP, Protvino, Moscow oblast, 142281 Russia
[b] Skobeltsyn Institute of Nuclear Physics, MSU, Moscow, 119991 Russia
[c] Lebedev Physical Institute, Moscow, 119991 Russia
[d] Astronomy Department, Faculty of Science, Cairo University, Giza, 12613 Egypt
[e] Veksler and Baldin Laboratory of High Energy Physics, Joint Institute for Nuclear Research, Dubna, Moscow oblast, 141980 Russia
[f] Dzhelepov Laboratory of Nuclear problems, Joint Institute for Nuclear Researches, Dubna, Moscow oblast, 141980 Russia
[g] Petersburg Nuclear Physics Institute, NRC KI, Gatchina, Russia
[h] St. Petersburg Polytechnic University, St. Peterburg, Russia
[i] Sukhoi State Technical University of Gomel, Gomel, 246746 Belarus
[j] Budker Institute of Nuclear Physics of SB RAS, Novosibirsk, 630090 Russia
[k] Novosibirsk State University, Novosibirsk, 630090 Russia
[l] Novosibirsk State Technical University, Novosibirsk, 630092 Russia
[m] Laboratory of Information Technologies, Joint Institute for Nuclear Research, Dubna, Moscow oblast, 141980 Russia
[n] Joint Institute for Nuclear Researches, BLTP, Dubna, Moscow oblast, 141980 Russia
[o] Institut für Theoretische Physik, Justus-Liebig-Universität, Giessen, 35392 Germany
[p] Landau Institute for Theoretical Physics, Chernogolovka, 142432 Russia
[q] Université de Lyon, Institut de Physique des 2 Infinis de Lyon, UCBL-IN2P3-CNRS, 4, rue Enrico Fermi, Villeurbanne, France
[r] St. Petersburg State University, St. Peterburg, Russia
[s] Pennsylvania State University, 104 Davey Laboratory, University Park, PA, 16802 USA
[t] DPhN, IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette Cedex, 91191 France
[u] Dubna State University, Dubna, Moscow oblast, 141980 Russia
[v] Department of Physics, M.V. Lomonosov State University, Moscow, 119991 Russia
[w] Guangdong Provincial Key Laboratory of Nuclear Science, Institute of Quantum Matter, South China Normal University, Guangzhou, 510006 P.R. China
[x] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, 100049 P.R. China
[y] University of Chinese Academy of Sciences, Beijing, 100049 P.R. China
[z] Moscow Institute of Physics and Technology (National Research University), Dolgoprudny, 141701 Russia
**e-mail: uzikov@jinr.ru*

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NICA SPD at energies $\sqrt{s_{NN}} = 3.5 - 10$ GeV (1st stage)

TOPICS /PLAN

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

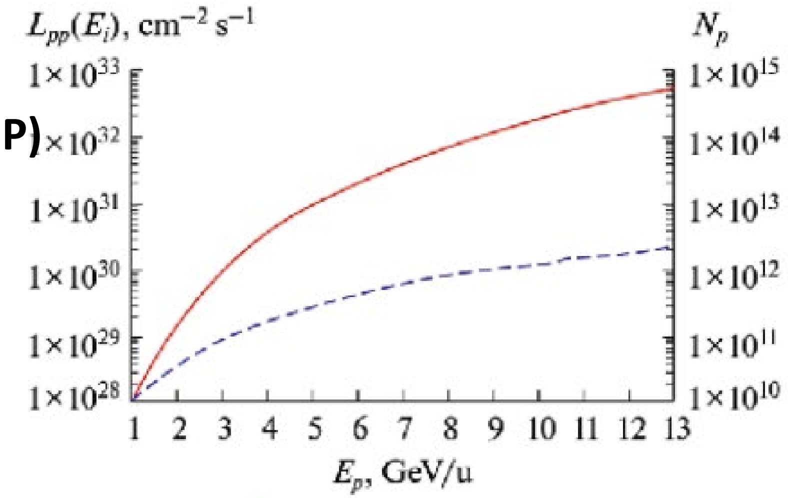
SPD AT NICA

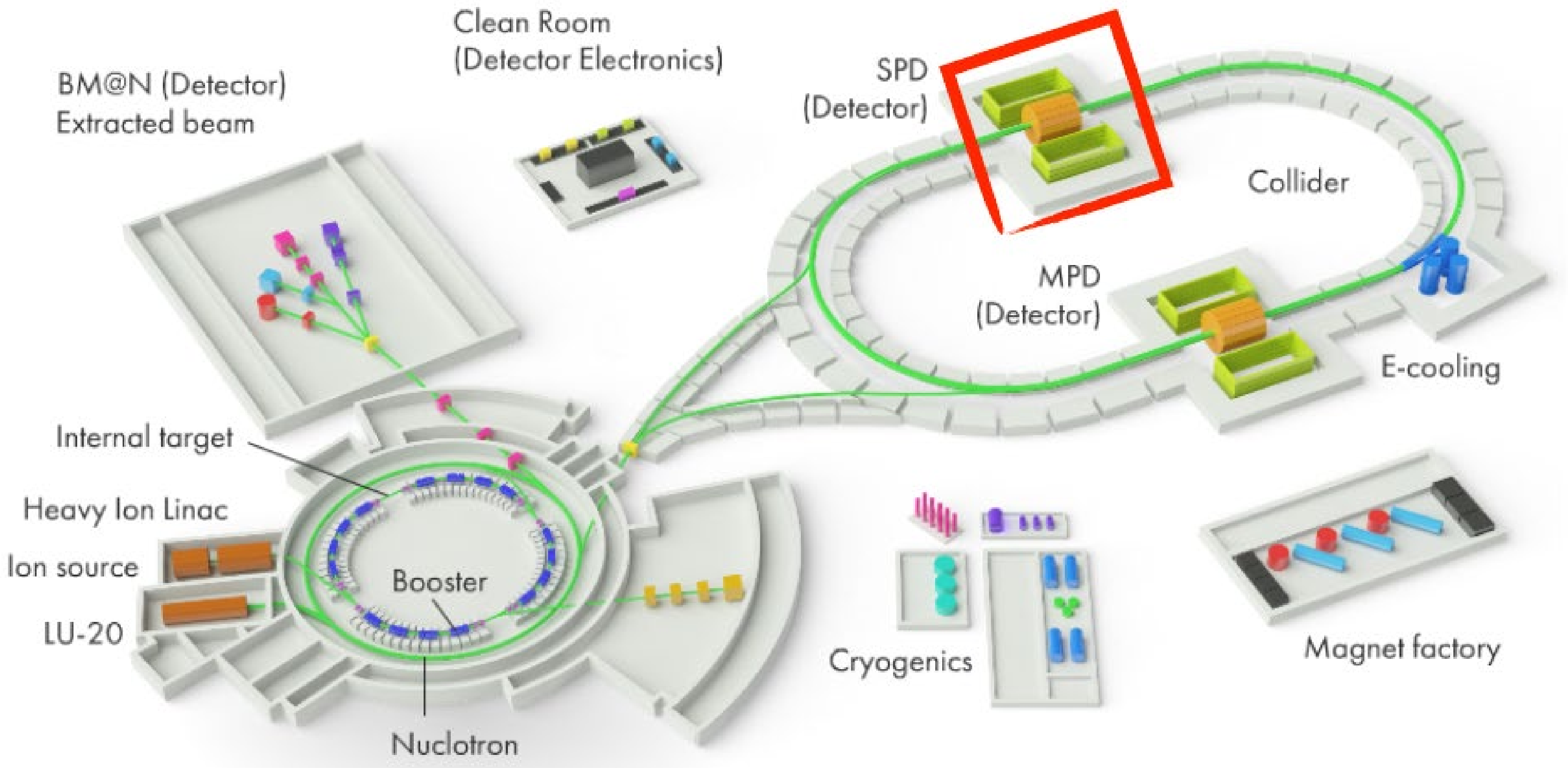
Spokesmen:
A. Guskov (JINR), V. Kim (PINP)

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

U, L, T

$|P| > 70\%$





See talk by I.N. Meshkov on Monday

$d^{\uparrow}d^{\uparrow}$ ***mode is unique***:

$p^{\uparrow}n^{\uparrow} \rightarrow pn$

$n^{\uparrow}n^{\uparrow} \rightarrow nn$

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

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

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

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

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

Tensor polarized deuterons

• The second stage of the SPD (after2032)

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 $g + q \rightarrow \gamma + q$

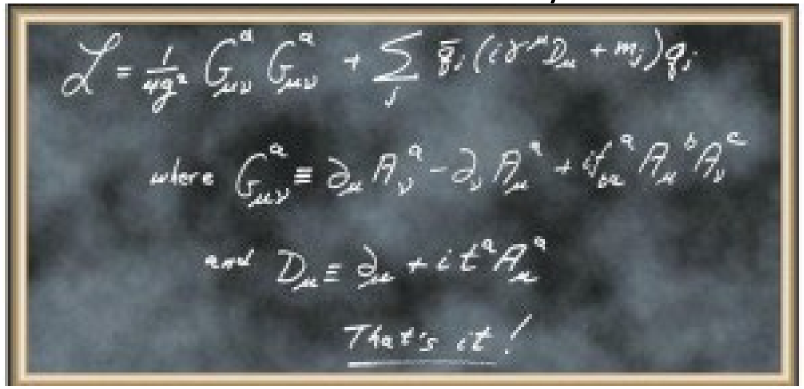
Basics of QCD …

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

Asymptotic freedom $\alpha_s(Q^2) \to 0$

Spontaneously broken chiral symmetry $SU_L(3) \times SU_R(3)$ $m_q \to 0$:

Goldstone bosons π, η, K

Perturbative description occurs in two kinematical regions:

- Large s and Q^2 **(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 energies $\sqrt{s_{NN}} = 3.5 - 10GeV$ *is suitable to*

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

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

and some other aspects of hadron physics.

● 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 scarce at T_n> 1 GeV, T_p> 3 GeV.
Measurement/test of spin amplitudes of NN elastic scattering in soft and hard NN- collisions is important.

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

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

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

5 – pp, 6 – pn, TV gives additional 2

Complete polarization experiment :

One need 9 independent observables for pp-elastic at each energy.
Too complicated task.

Available parametrizations (fit) to pp-data:

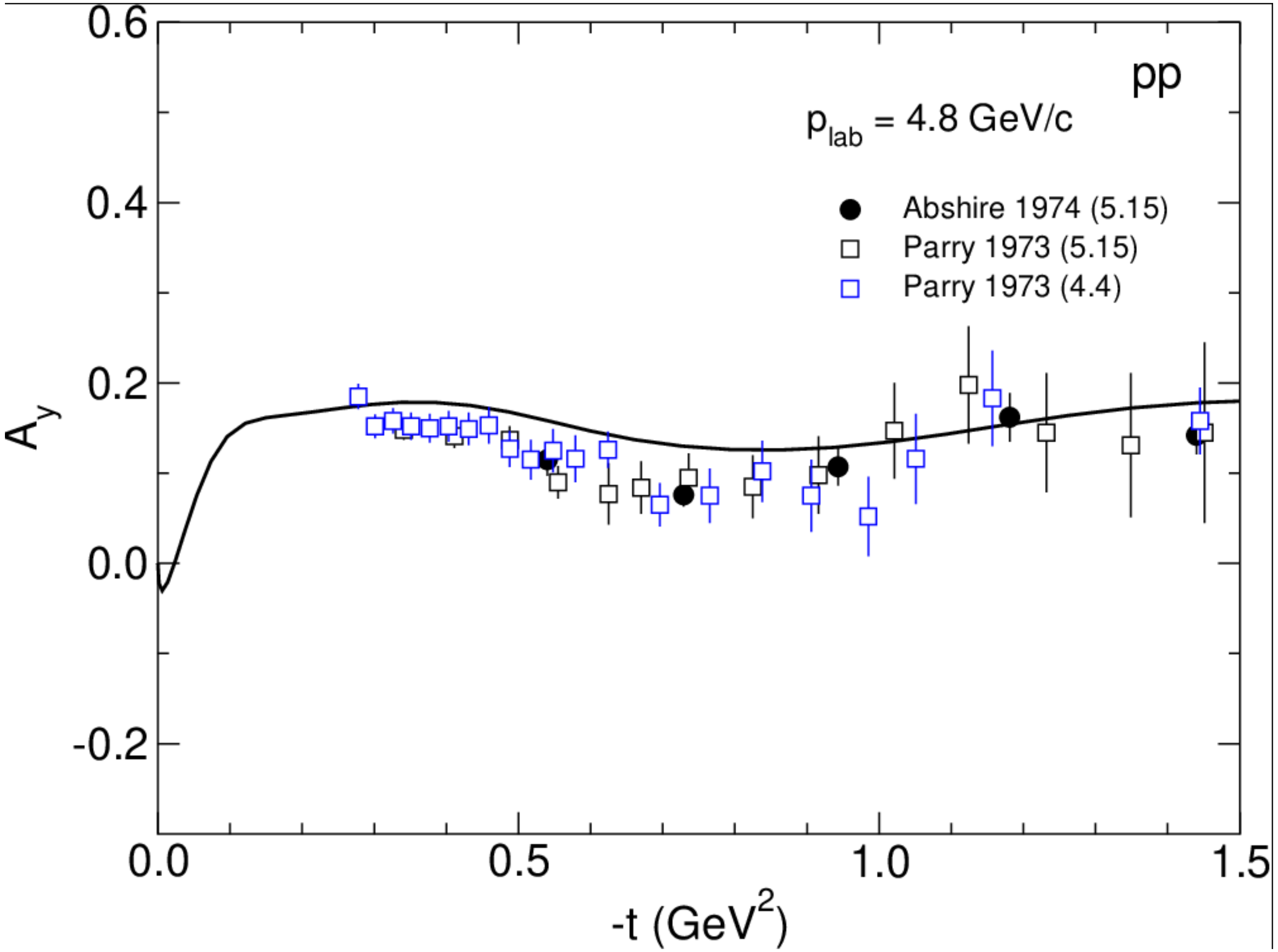
Regge: W.P. Ford, J.W. van orden. Phys Rev.C 87 (2013) 014004;

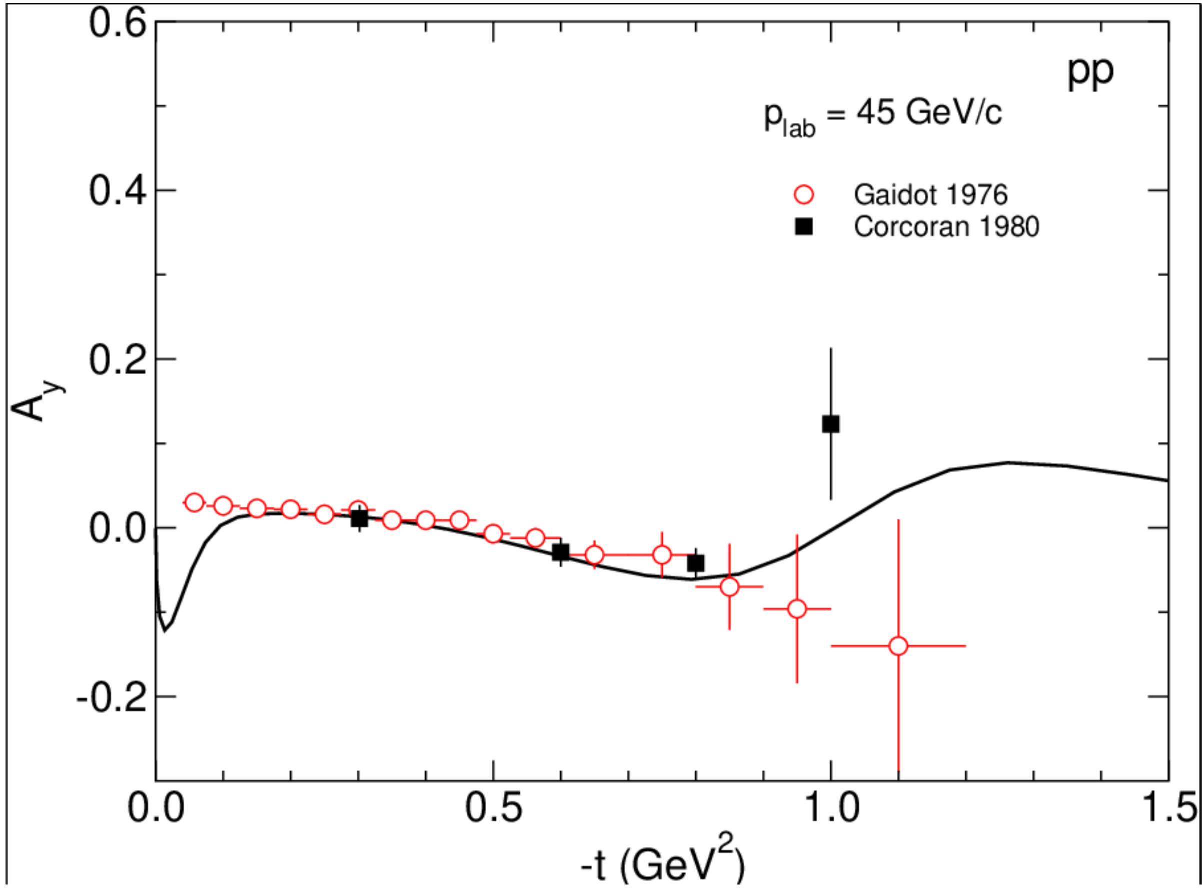
A. Sibirtsev et al. Eur. Phys. J. A 45 (2010) 357; P=4-50 GeV/c

Eikonal: S. Wakaizumi, M. Sawamoto, Prog. Theor. Phys. V.64 (1980) 1699

An effective test: data on pd-elastic scattering in forward hemisphere to compare with the Glauber calculations

A. Sibirtsev et al, EPJA (2010); Regge parametrization of pp amplitudes at p_L=4 - 50 GeV/c
Soft region



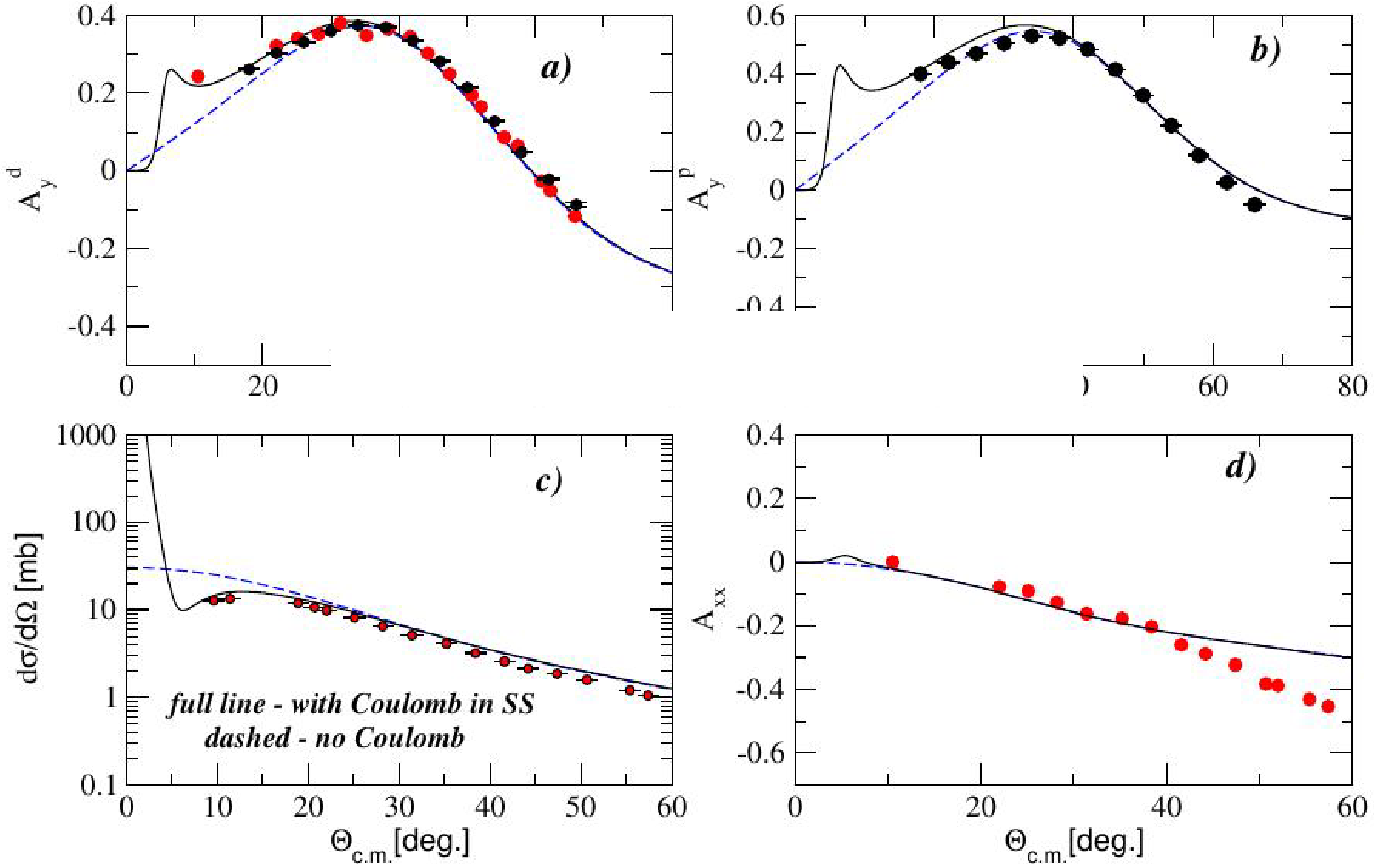


Five helicity pp –amplitudes of pp- scattering for complete polarization experiment $\phi_1, \ldots, \phi_2 \Rightarrow$ > 9 (!) observables

pd elastic scattering at 135 MeV

A.A. Temerbayev, Yu.N.Uzikov, Yad. Fiz. **78** (2015) 38

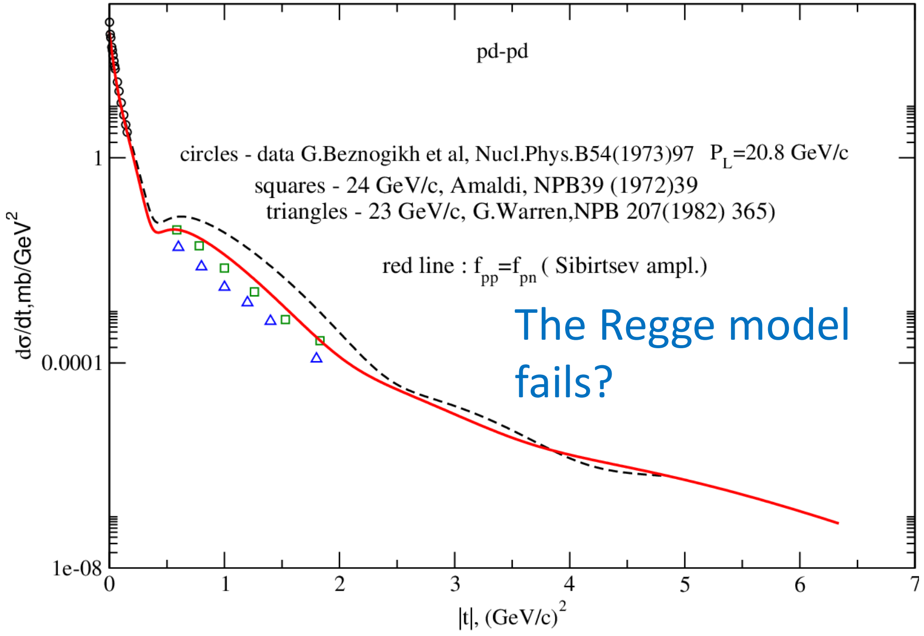
Glauber: single+ double pN scattering



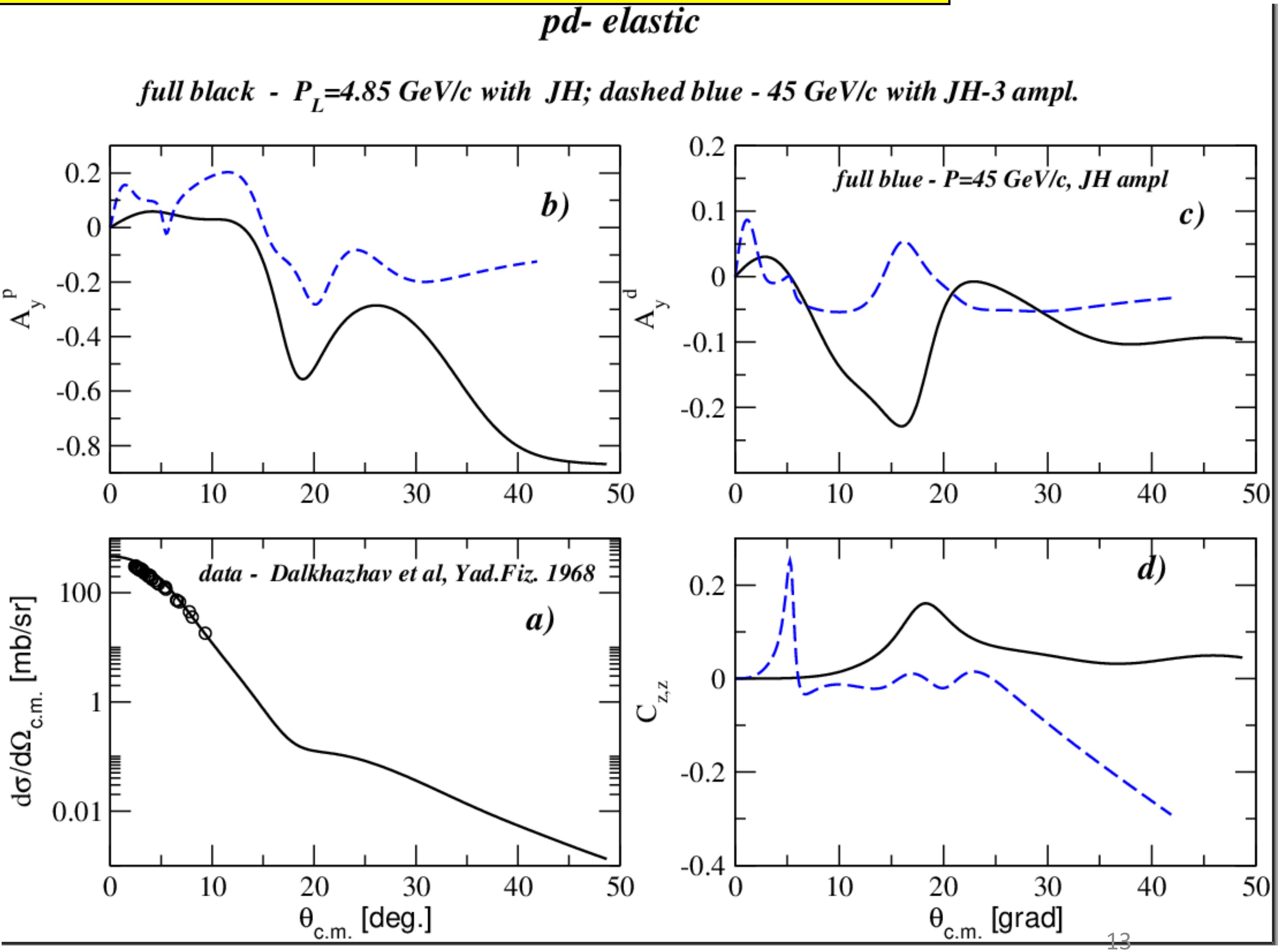
Data: K. Sekiguchi et al. PRC (2002); B. von Przewoski et al. PRC (2006)
See also Faddeev calculations: A.Deltuva, A.C. Fonseca, P.U. Sauer, PRC 71 (2005) 054005.

For 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?



Quasielastic pd scattering

$$p + d \rightarrow \{pp\}(^1S_0) + n$$

pn->pn: $f_{12}^{collin} = \alpha + \beta(\boldsymbol{\sigma}_1 \cdot \boldsymbol{\sigma}_2) + (\varepsilon - \beta)(\boldsymbol{\sigma}_1 \cdot \mathbf{k})(\boldsymbol{\sigma}_2 \cdot \mathbf{k}).$

$$d\sigma_0 = \frac{1}{3}\mathcal{K}\left\{|\varepsilon|^2 + 2|\beta|^2\right\},$$

$$T_{20} = \frac{1}{\sqrt{2}}A_{zz} = \sqrt{2}\frac{|\beta|^2 - |\varepsilon|^2}{|\varepsilon|^2 + 2|\beta|^2},$$

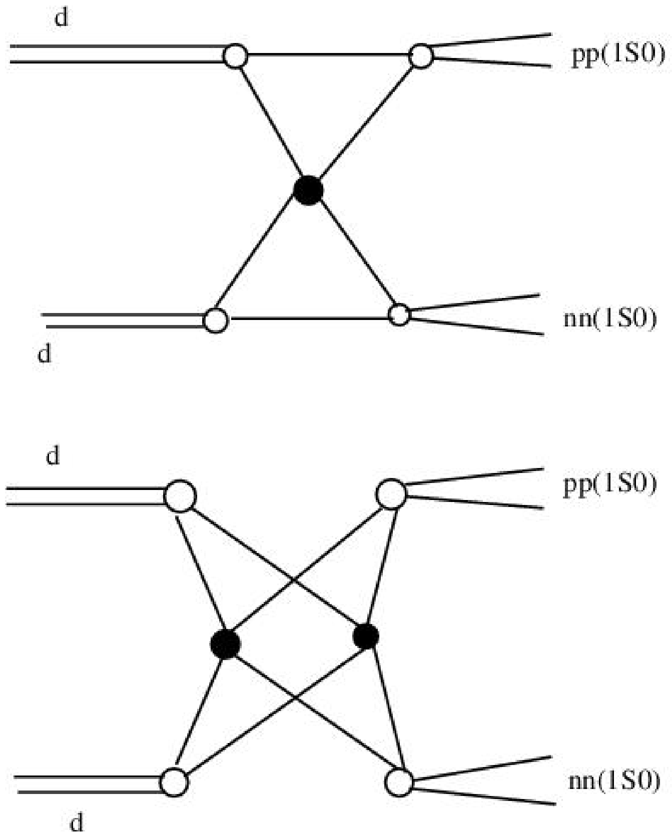
$$C_{x,x} = C_{y,y} = -2\frac{Re\varepsilon\beta^*}{|\varepsilon|^2 + 2|\beta|^2},\ C_{xz,y} = -C_{yz,x} = 3\frac{Im\beta\varepsilon^*}{|\varepsilon|^2 + 2|\beta|^2}.$$

Complete polarization experiment in collinear kinematics (Yu.N.U):

$$|\varepsilon|, |\beta|, \mathrm{Re}\,\varepsilon\beta^*, \mathrm{Im}\,\varepsilon\beta^*$$

Also dd-elastic and dd->pp($^1S_0$)+nn($^1S_0$)

dd- elastic and quasi-elastic scattering



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

Knowledge of helicity pN amplitudes is absolutely necessary

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

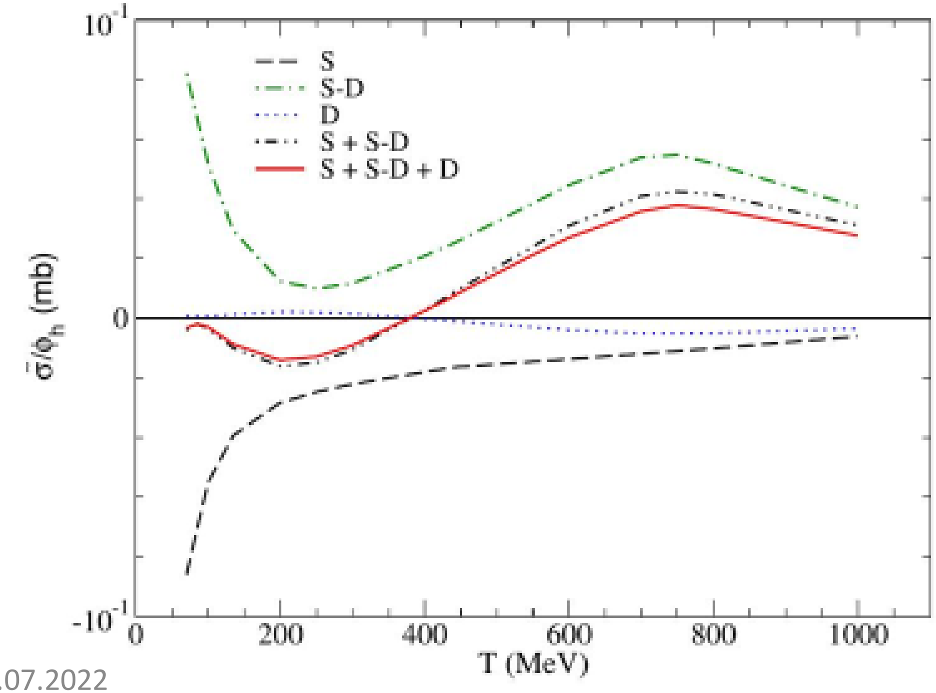
$$C' \approx i\phi_5 + iq/2m(\phi_1 + \phi_3)/2$$

Helicity pN amplitudes and deuteron FF modulate the TVPC signal !

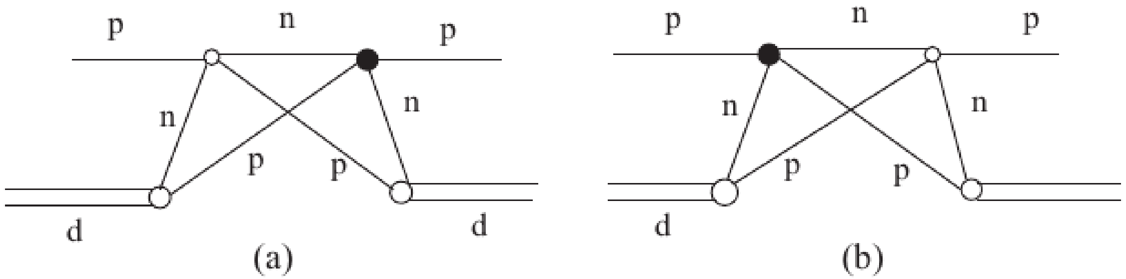
Yu.N.U., A.A. Temerbayev, PRC 92 (2015) 014002;
Yu.N.U., J. Haidenabuer, PRC 94 (2016) 035501.

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

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



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

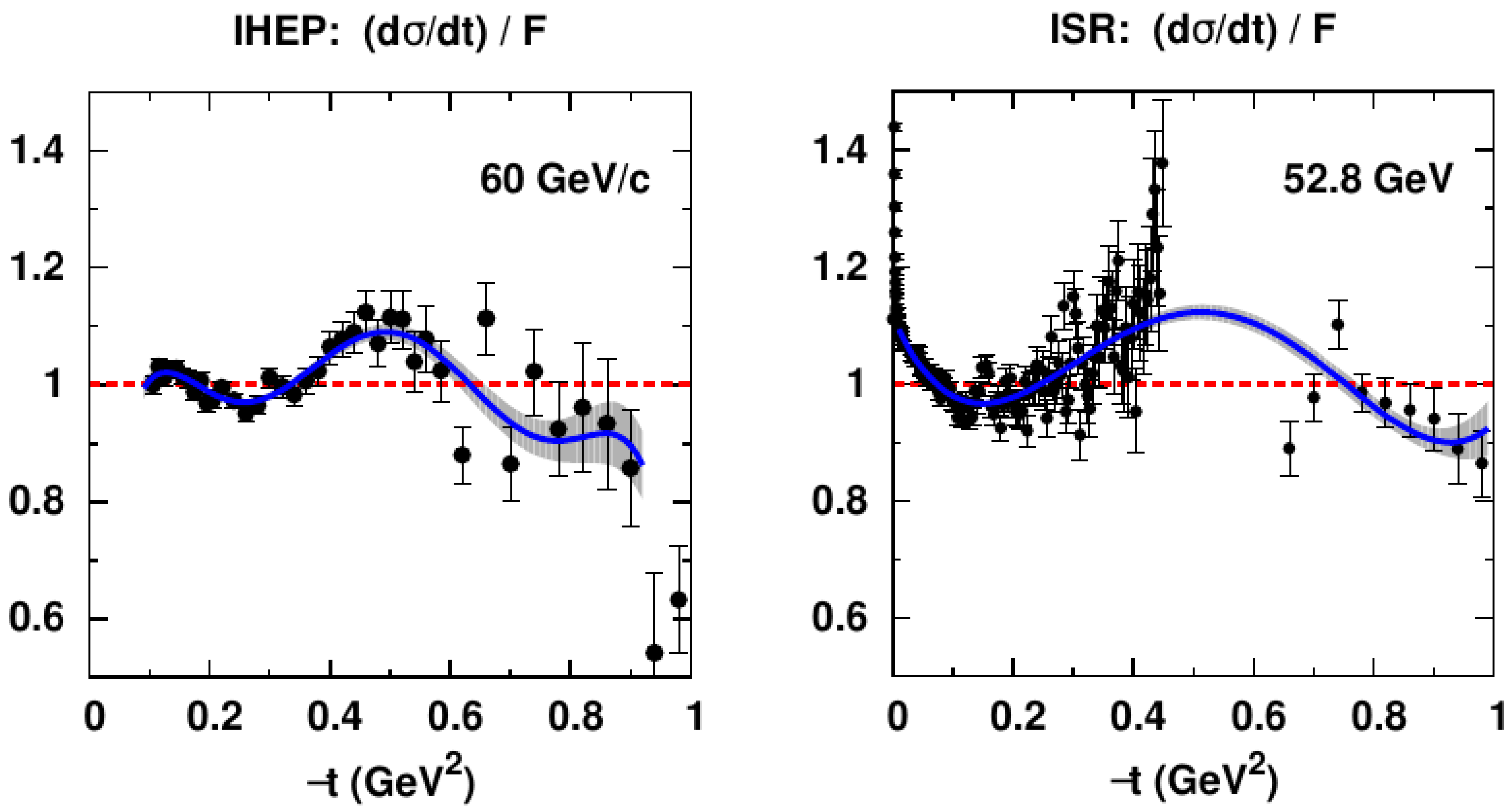


Search for T-invariance violation in double polarized pd – scattering (see below “Search for physics BSM” .)

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

● *Periphery of nucleon in diffractive pp scattering*

V.A. Baskov, O. D. Dalkarov A. I. L'vov et al.



$$F(t) = Ae^{Bt+Ct^2}$$

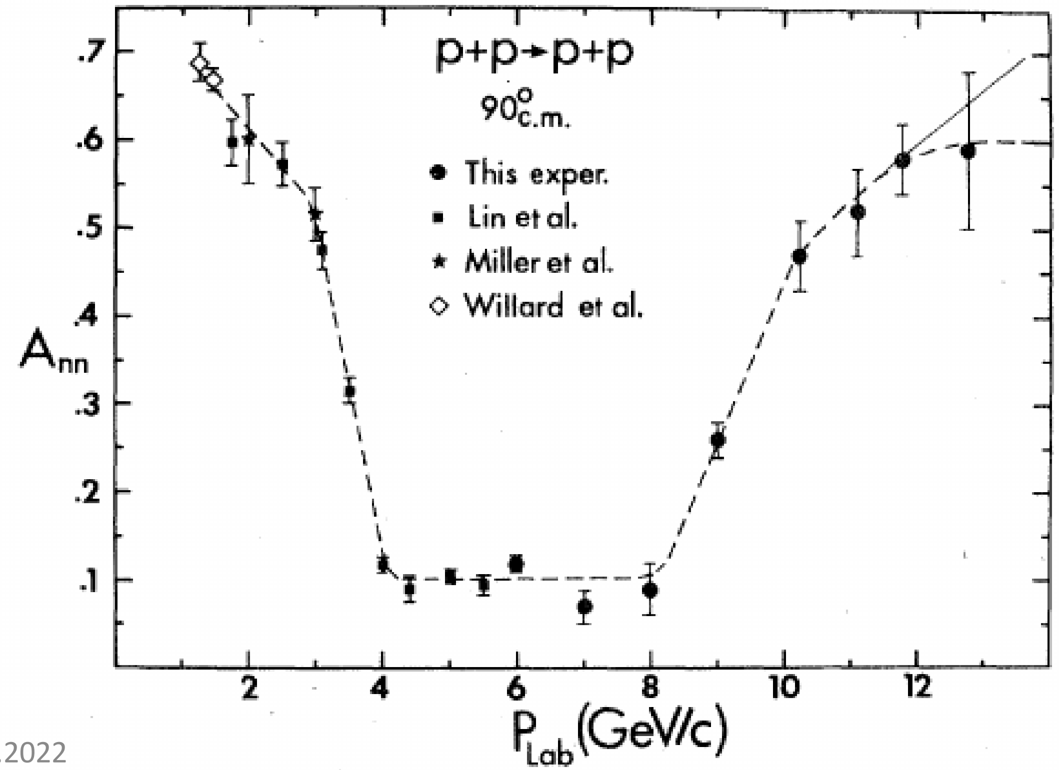
Pion cloud effect,
A.Anselm, V. Gribov,
PLB 1973

Spin-spin effects 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



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

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

Brodsky@de Teramond, PRL 60 (1988) 1924

Spin correlations and hard pp elastic scattering

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

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

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

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

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

Possible explanation for all three observations:
octoquarks at the thresholds: $6qs\bar{s}, 6qc\bar{c}$

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

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

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 view on 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

- At high transferred momentum the exclusive 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 : $T = \sigma^A(a, aN) / \sigma^A_{PWIA}$

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

CT for mesons production is well established

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

$E_{\gamma} = 2.25 GeV$

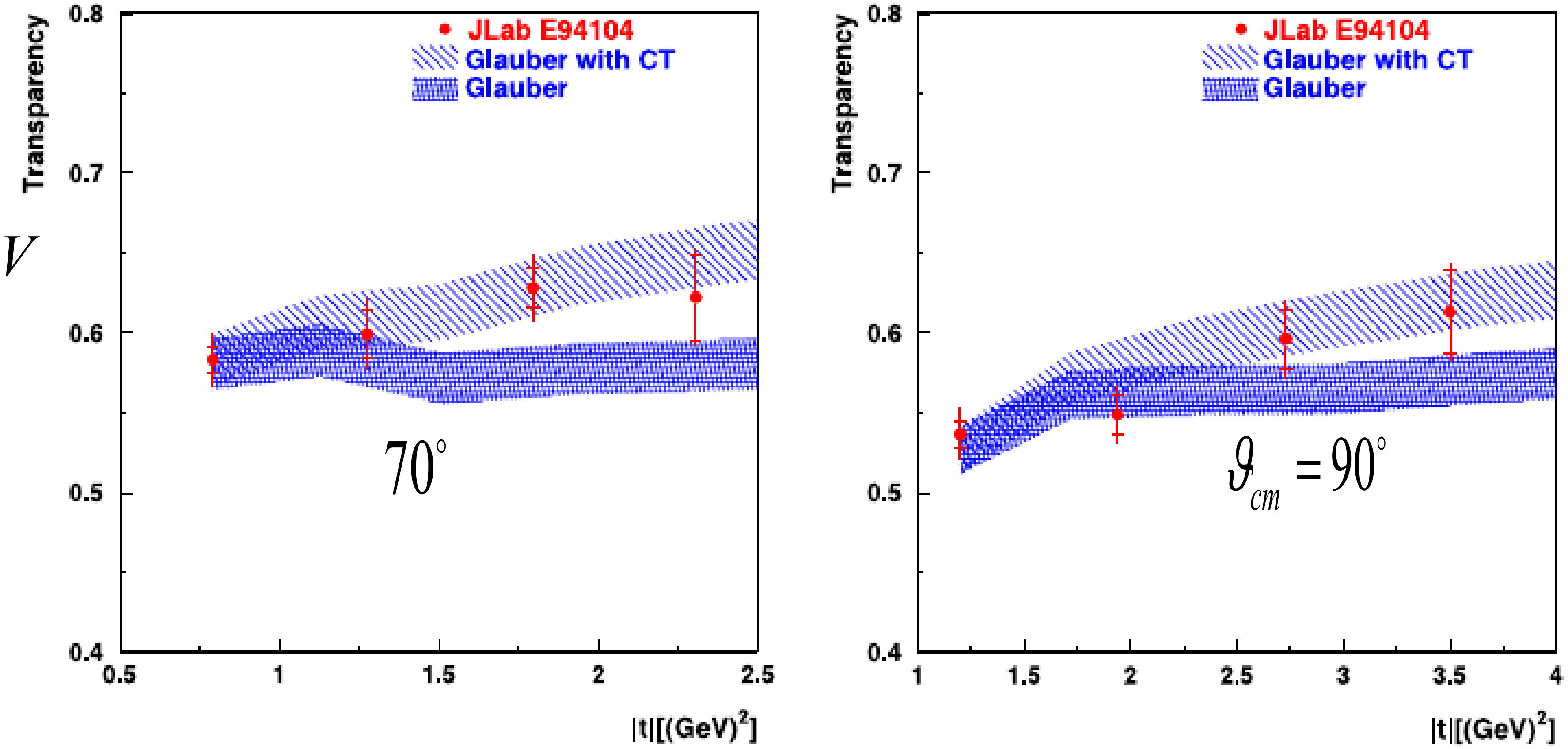
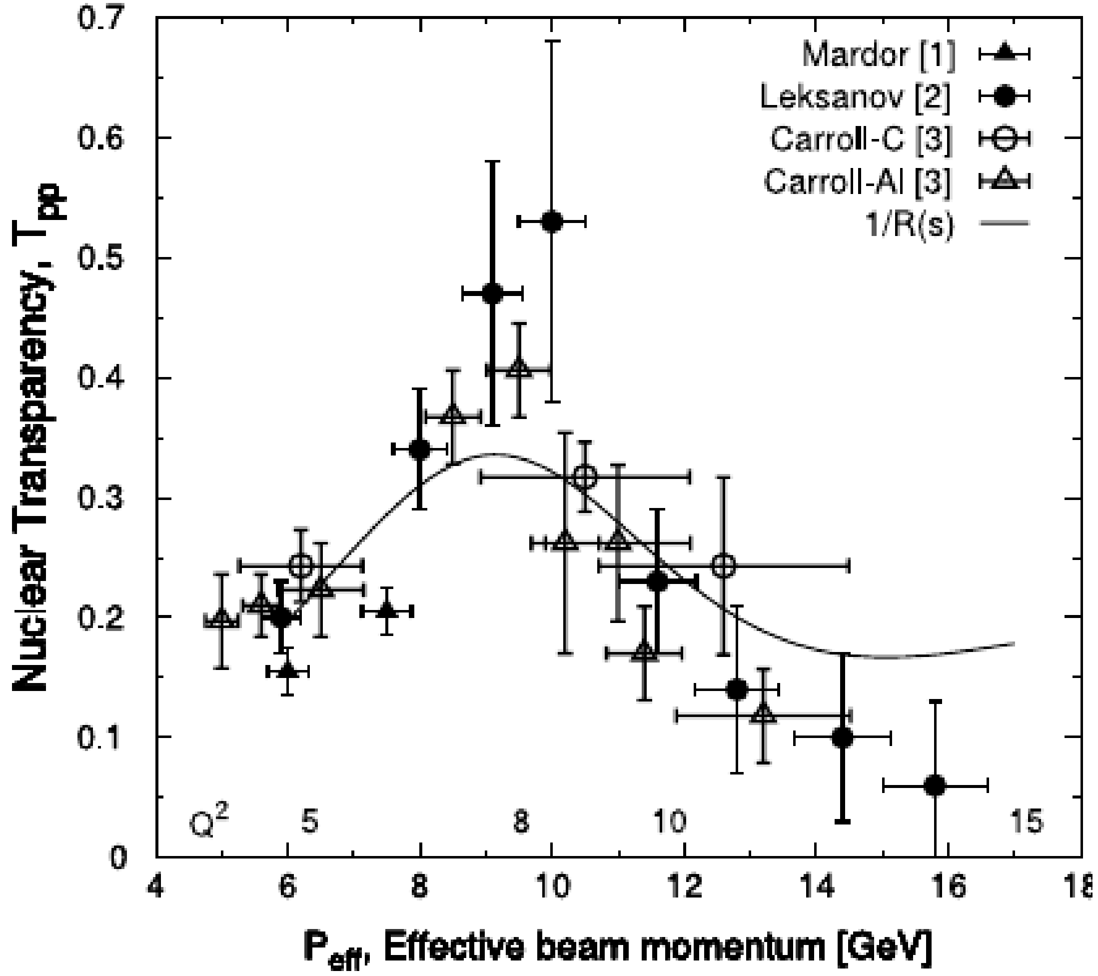


Fig. 13. The nuclear transparency of ^{4}He(γ, $p\pi$) at $\theta^{\pi}_{cm} = 70^{\circ}$ (left) and $\theta^{\pi}_{cm} = 90^{\circ}$ (right), as a function of momentum transfer square $|t|$ [80]. The inner error bars shown are statistical uncertainties only, while the outer error bars are statistical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

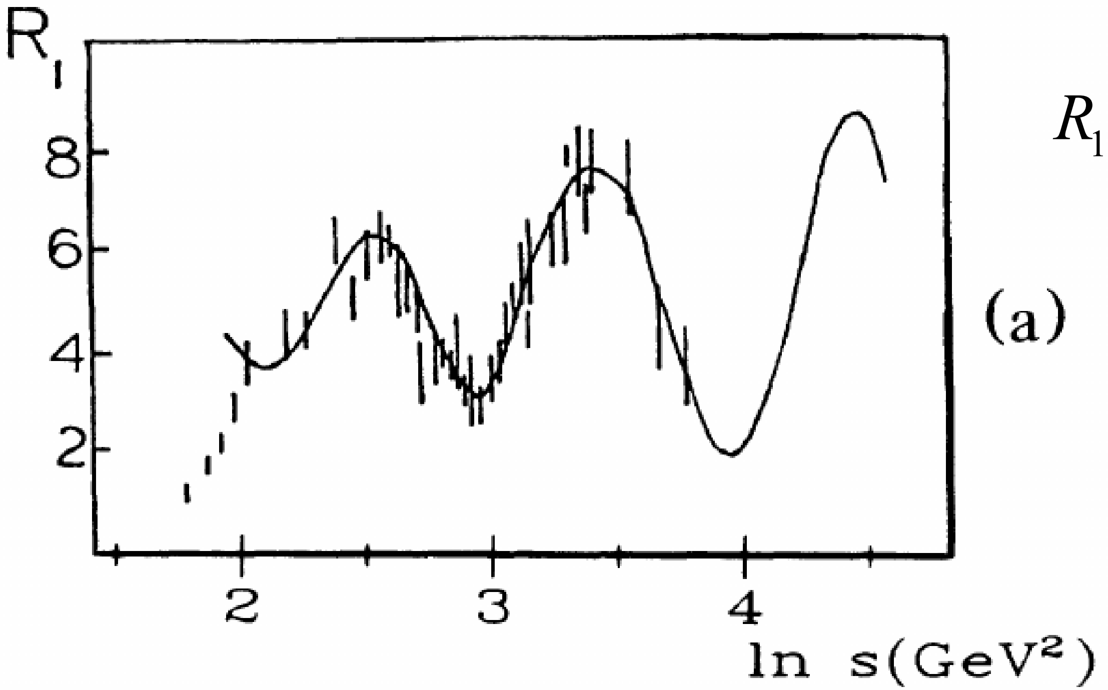
  f_{QC} - quark counting (PLC -size);

  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

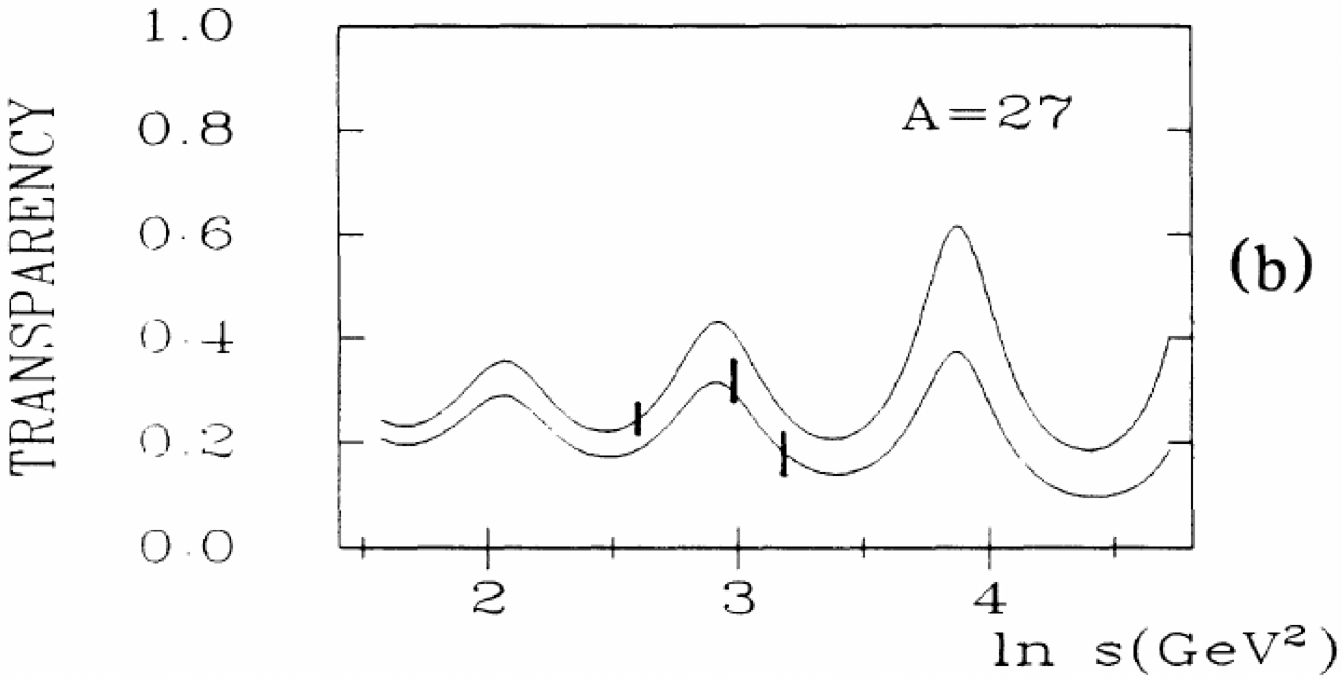
J.P. Ralston, B. Pire.
PRL 61 (1988) 1823;
PRL 49 (1982) 1605



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

(a)

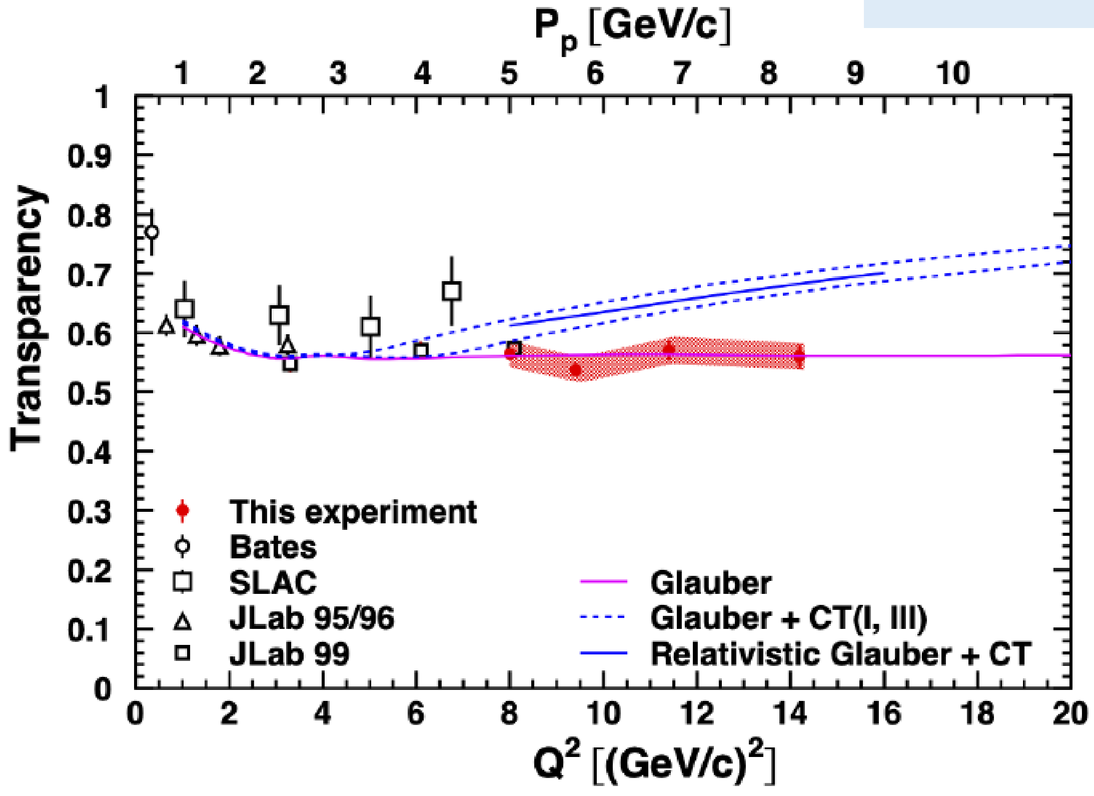
$$T = \frac{d\sigma^{pA} / dt}{A d\sigma^{pp} / dt}$$



(b)

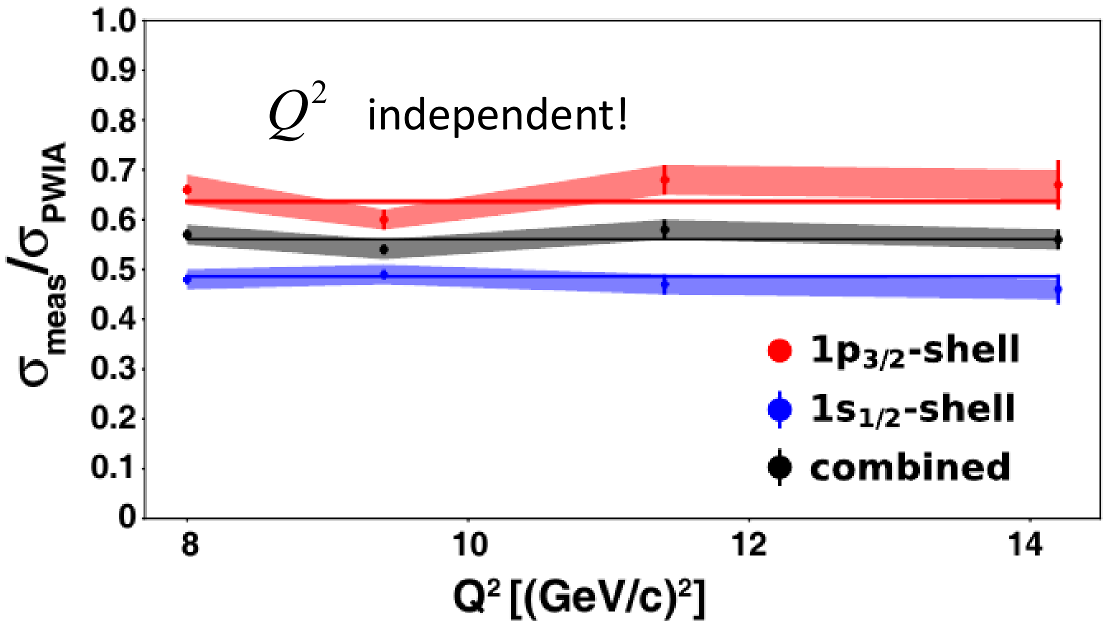
CT for baryons: A(e,e'=p)

A NEW PROBLEM



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"

A(p,2p) data show a rise of transparency T in this region.



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/

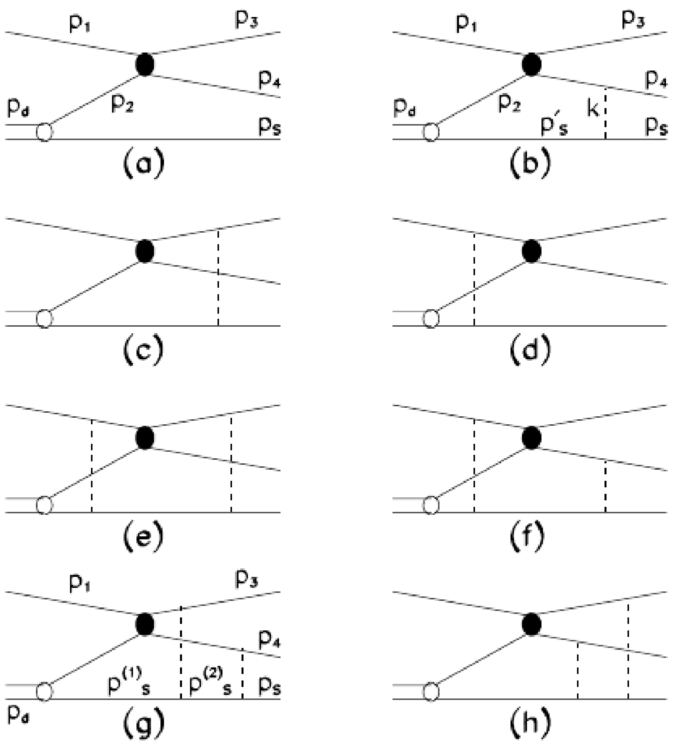
  or

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

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

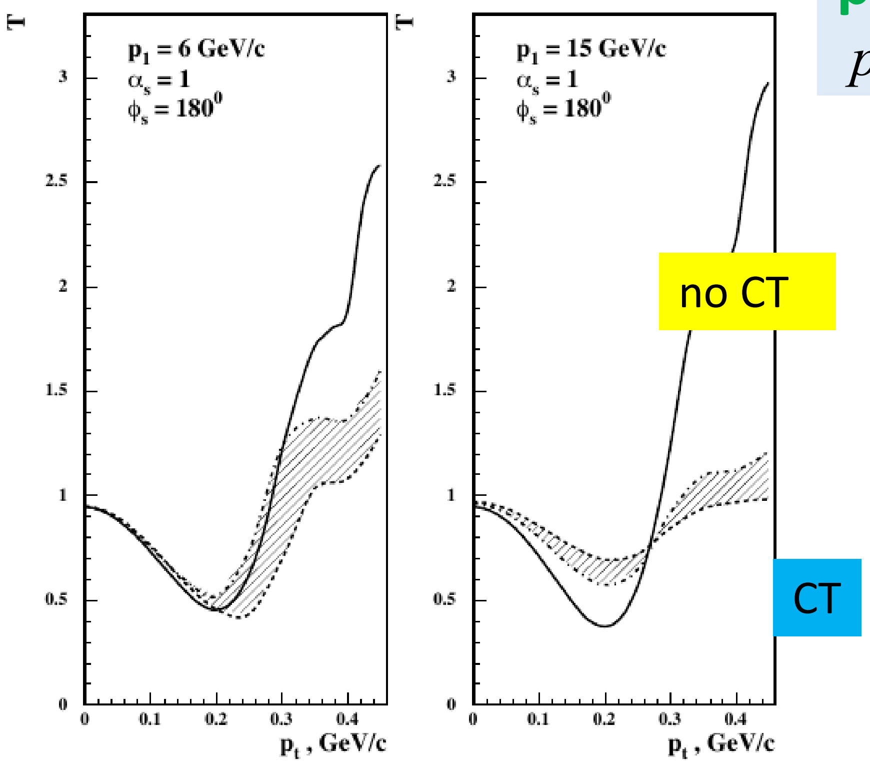
Testing rescattering dynamics (including color transparency effects - dashed curves)

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



A.B. Larionov (in progress)

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



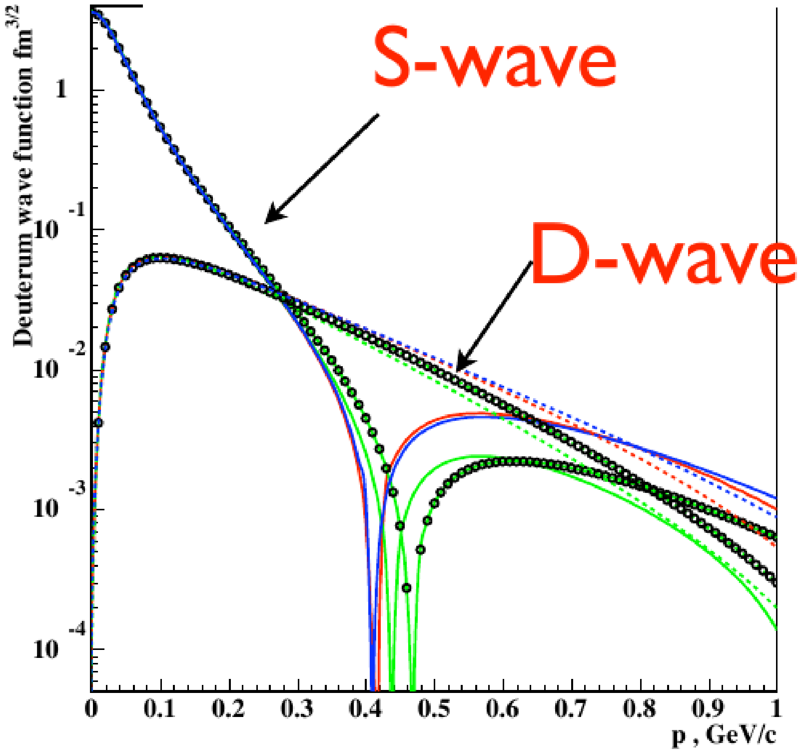
Transverse momentum of spectator

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

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

• *Deuteron structure at short distances and SRC in nuclei*

Deuteron is a hydrogen atom of short range nuclear structure studies



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

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

$i=1$

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

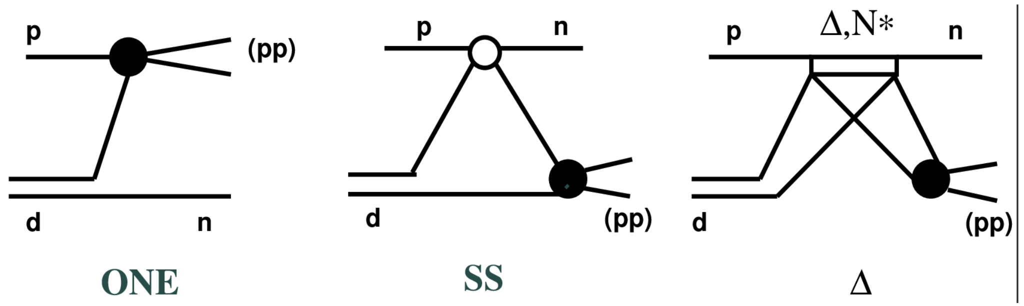
$$\Longrightarrow n_A(k) \approx a_2(A)\psi_D^2(k)_{|k\to\infty}$$

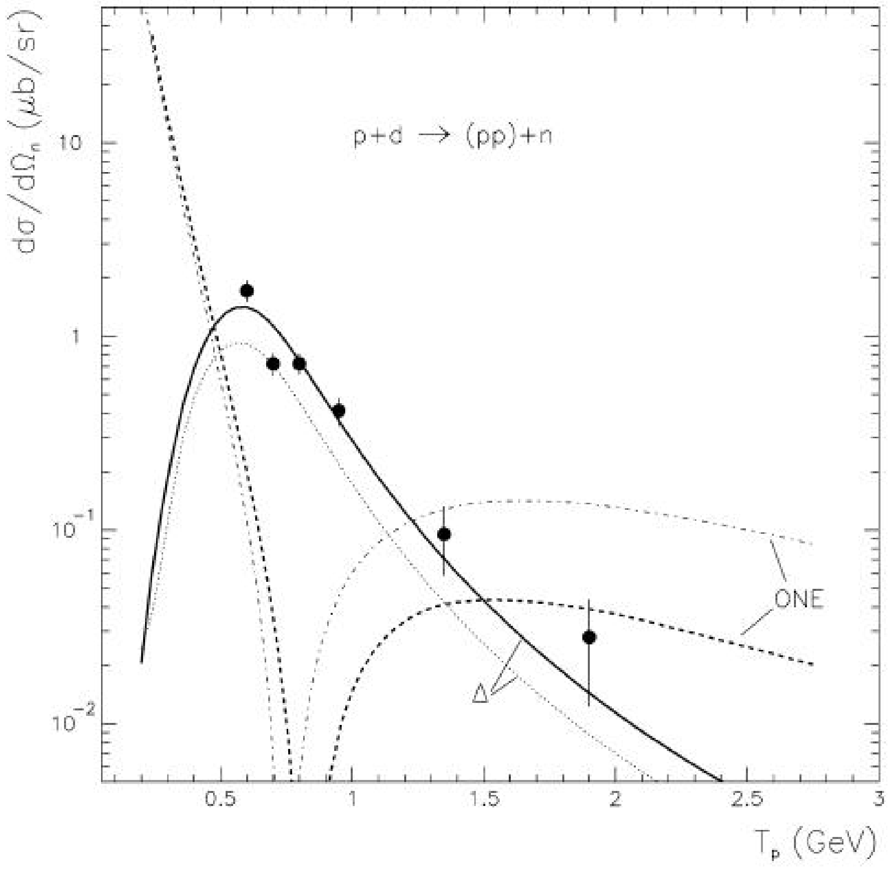
O. Hen, G. Miller, E. Piasetzky,
Rev. Mod. Phys. 89 (2017)

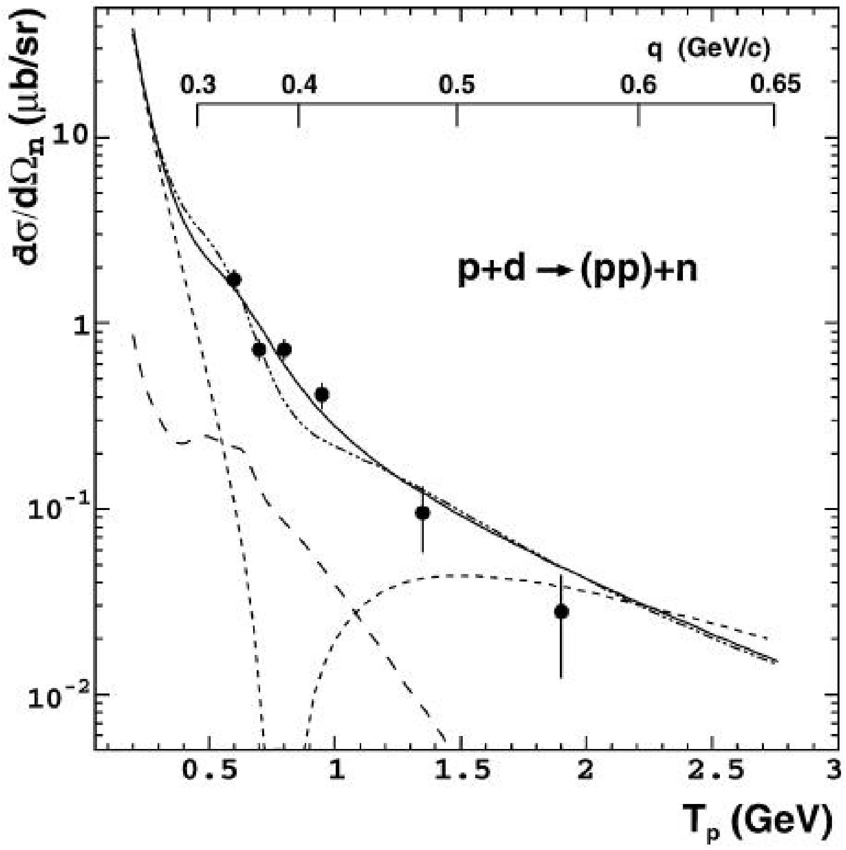
pp ($^1S_0$) dominates over pn ($^3S_1$-$^3D_1$) at q> 1 GeV/c

pp (1S0) diproton formation

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







Constituent Counting Rules

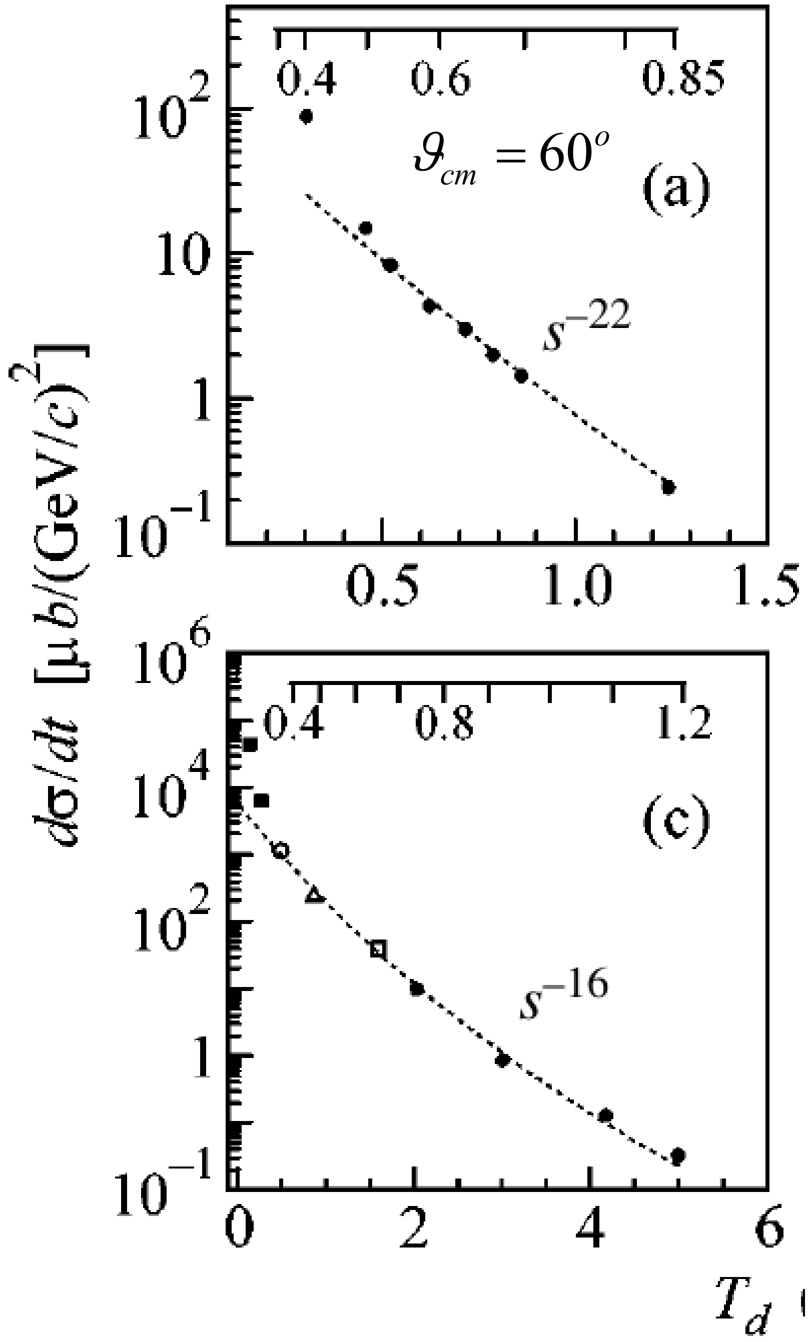
At high energy s and large transverse momenta –t, the constituent counting rules (CCR) predict the following behavior of the differential cross section of the binary reaction:

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

Matveev, Muradyan, Tavkhelidze (1973) – self similarity,
Brodsky, Farrar (1973) - pQCD
J. Polchinski, M.J. Strassler (2002) - Ads/CFT correspondence

CCR behaviour observed in many reactions with free mesons and baryons, and also in the reactions with the lightest nuclei:

$$\gamma d \to pn, E_\gamma \geq 1GeV; d\sigma / dt \sim s^{-11}$$



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

For the reaction $dd \to {}^3He n$

$$N_a + N_b + N_c + N_d - 2 = 22$$

For the reaction $dp \to dp$

$$N_a + N_b + N_c + N_d - 2 = 16$$

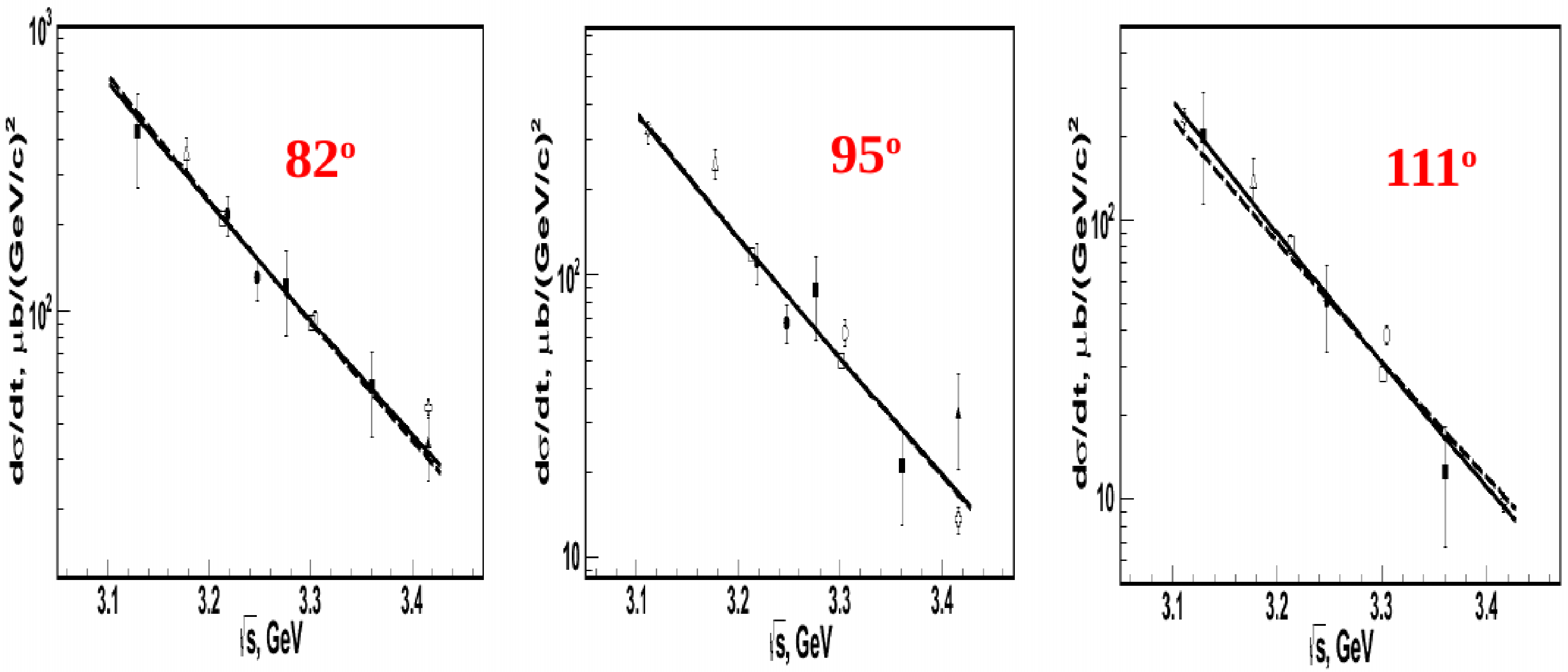
CCR regime at unexpectedly low energies, T_d=500 MeV.

Is it the onset of the transition region?

Spin observables in the CCR region?

How spin observables can help to identify the CCR region?

CCR for dp- elastic scattering cross section



Pictures are taken from A.A.Terekhin et al., Eur.Phys.J, A55 (2019) 129

Lines are the results of the fit by the S^{-16} (dashed) and S^{-n}(solid) dependencies.

Other suggestions, not all directly related to QCD

Single-spin observables in pp and in pA are not explained by pQCD. Model of Chromo-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. 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 collisions

$^{12}C-^{12}C$, $^{40}Ca-^{40}Ca$

A.B. Larionov

Pair production of polarized tau leptons in SPD experiments

PDF from polarized Drell-Yan process $\sqrt{s} = 24 GeV$

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)

TO CONCLUSION

QCD Lagrangian after proper work will allow one to get the proton mass, proton spin, q-g structure of hadrons, genuine hadron-hadron interaction potential and … all properties of any hadronic system.

However, so far at intermediate energies (few GeV to ten GeV) **we do not have good understanding of the most fundamental processes as pN elastic scattering at large angles, single-spin asymmetries in meson and hyperon production, and their relation to QCD aspects of hadron interactions like CT, CCR.**

Systematic experimental study of hadronic processes including polarization observables is necessary to get deeper understanding of these problems.

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, TVPC, PV)

Usage of polarized beams is crucial in this study.

Thank you for your attention!

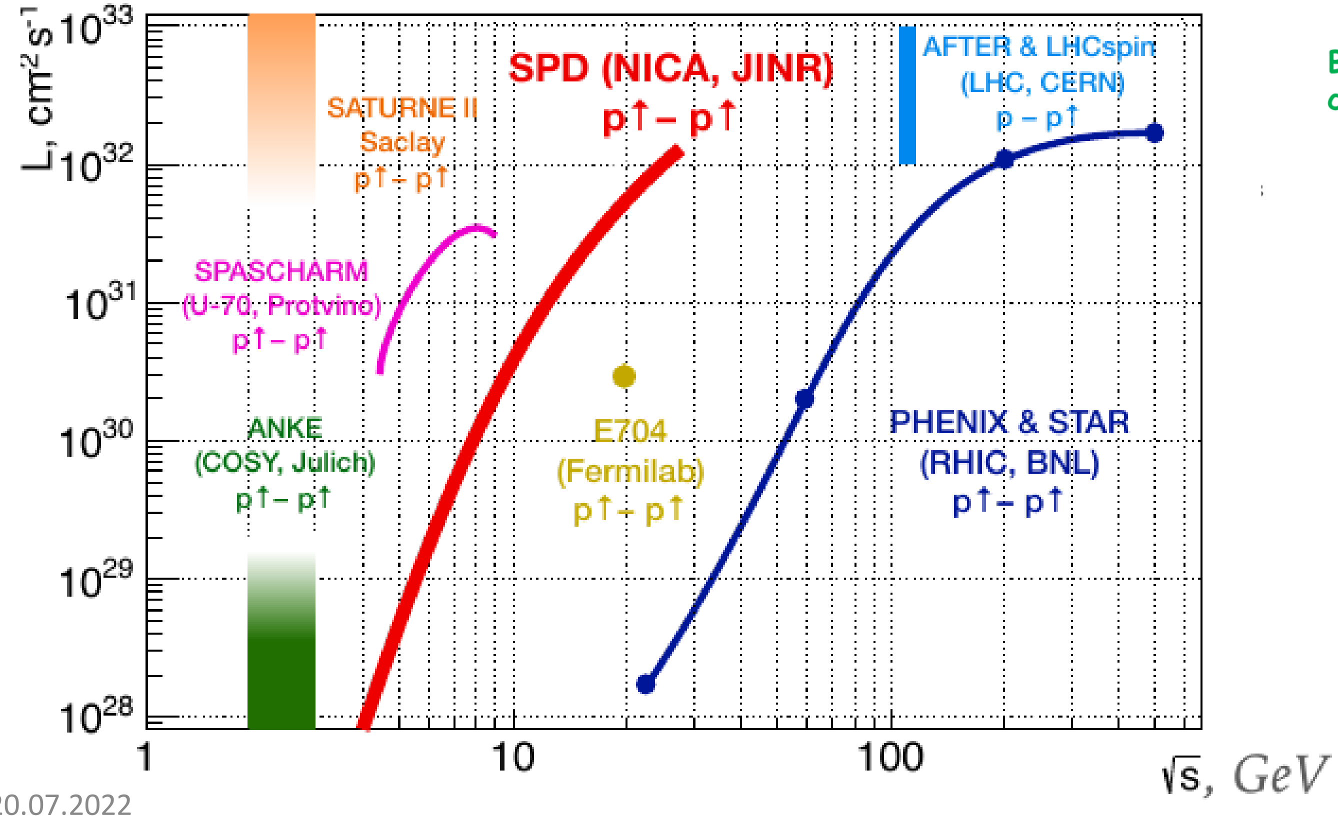
NICA aerial view, April 2022

BACKUP

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 Δp/p up to 10^{-5}.

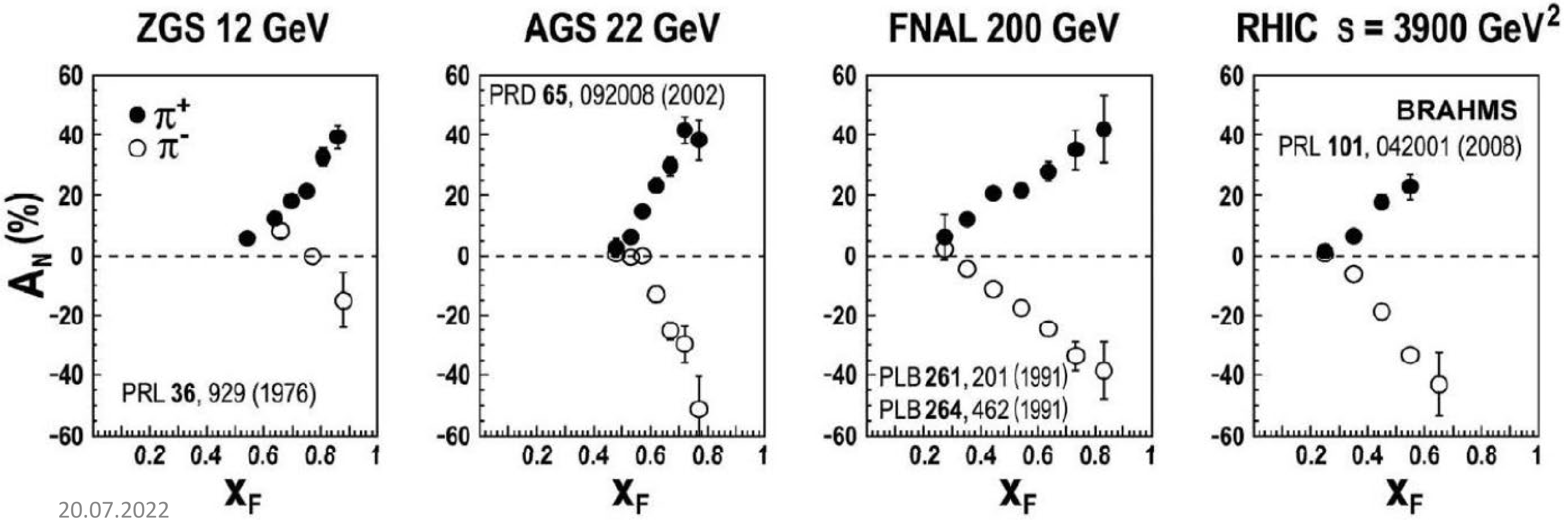
The unique detectors: ΔΩ ~ 4π (exclusive reactions, correlations, backward range); detection all kinds of particles (especially neutron); working at luminosity up to 10^{30} - 10^{32} cm^{-2} s^{-1} (the rare event can be investigated); PID – close to full energy range.

• 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

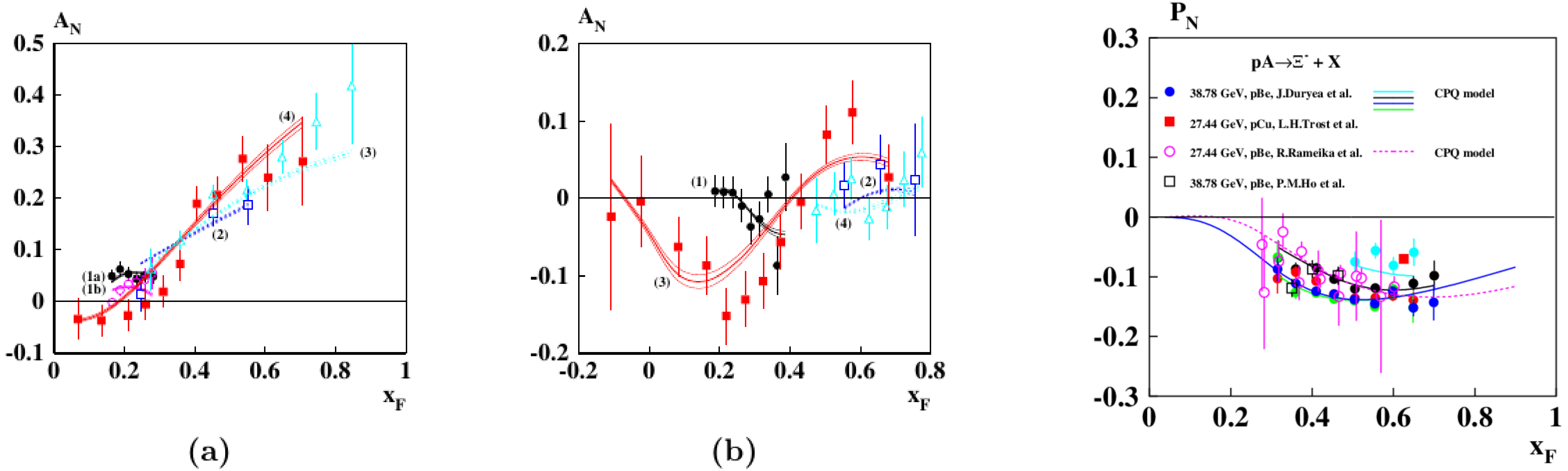


V. Abramov, 2009-2020

The model of chromomagnetic polarization of quarks (CPQ)

Shtern-Gerlach chromomagnetic forces@ quark structure of hadrons.

Global fit of 3600 exp.points from 85 different reactions



$A_N(x_F)$ 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)

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

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

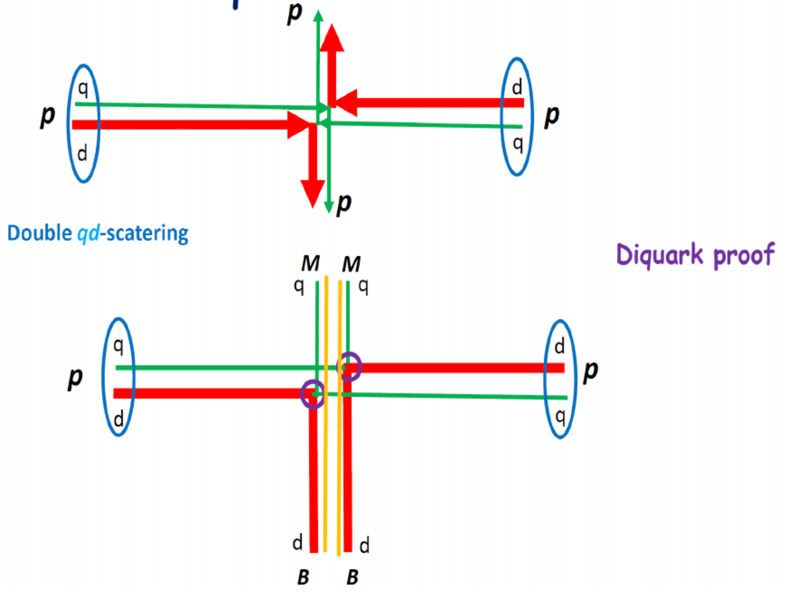
B. Kostenko: d+d->d+d*

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

Ratio d/p

Kim's mechanisms in exclusive reactions

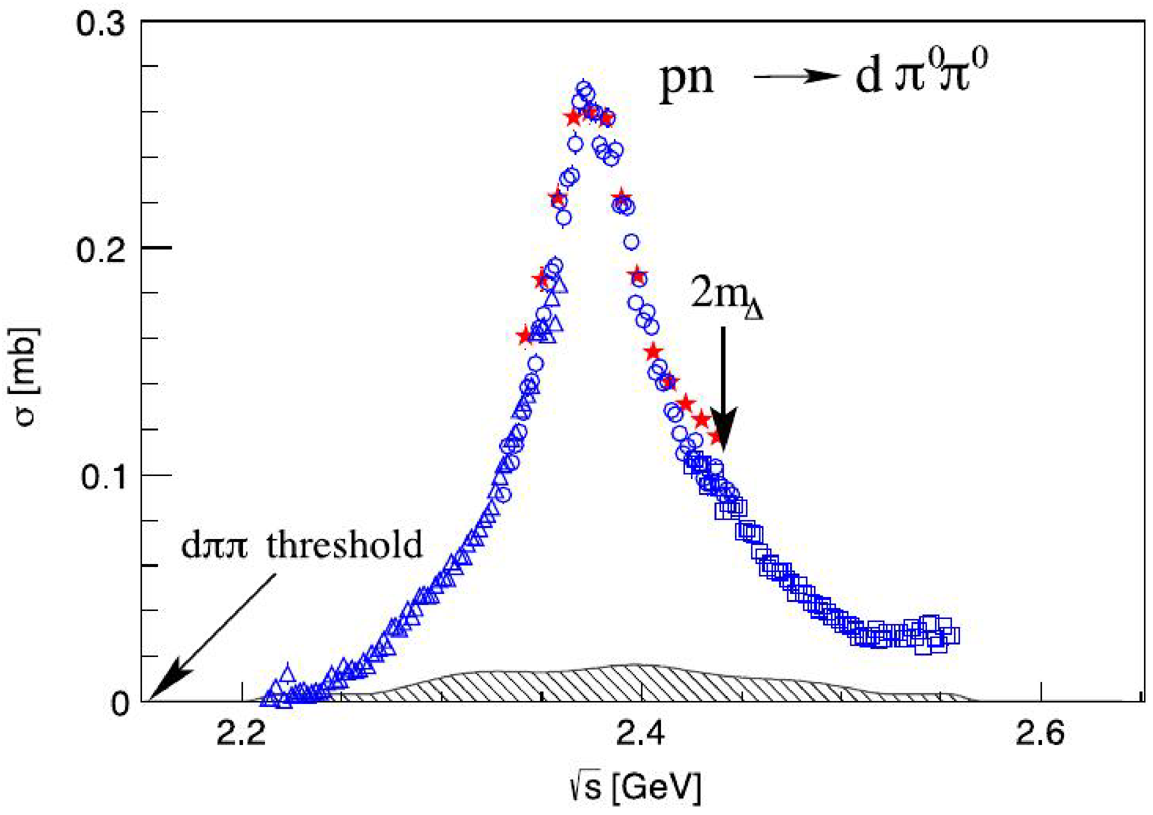
pp - > pp + X, pp -> D(H) + X
reactions with diquarks



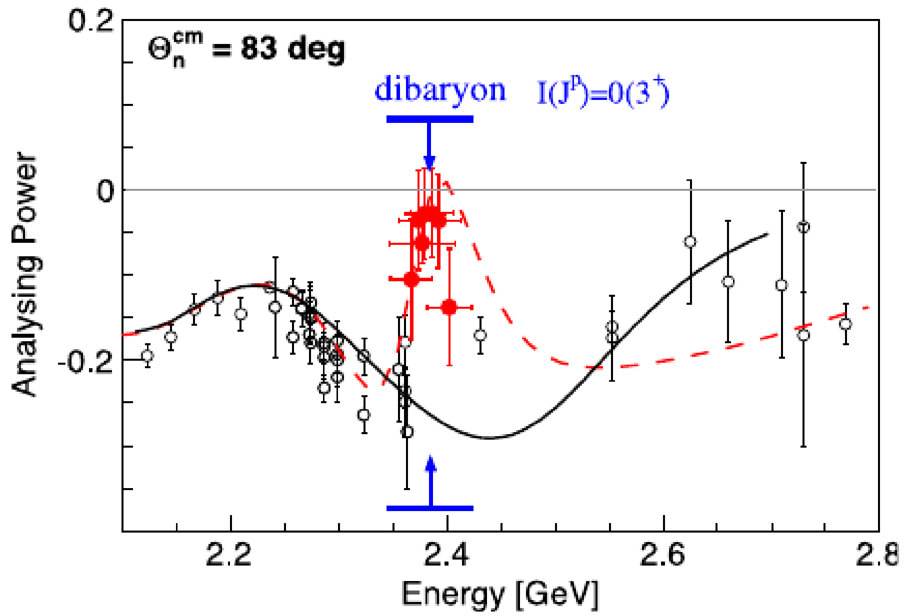
d(2380) dibaryon

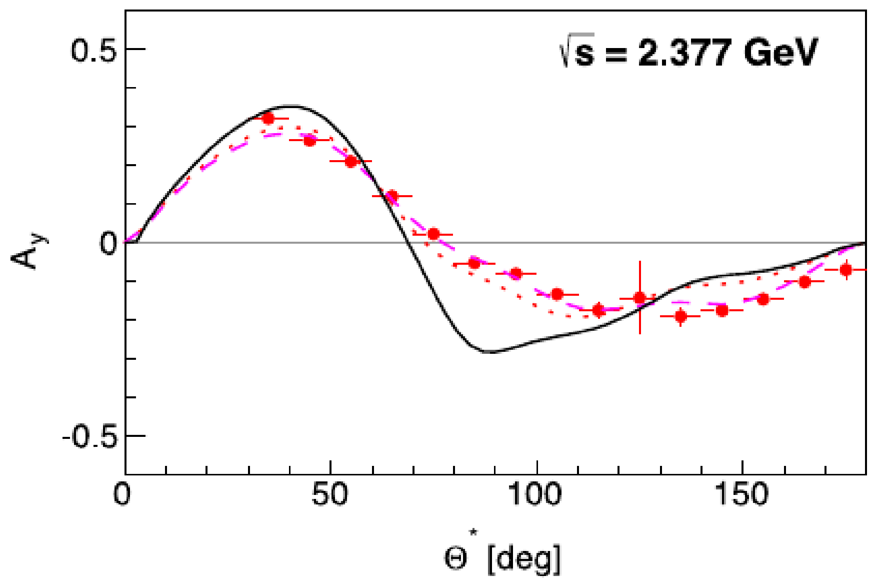
$$I,J^P = 0,3^+$$

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



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



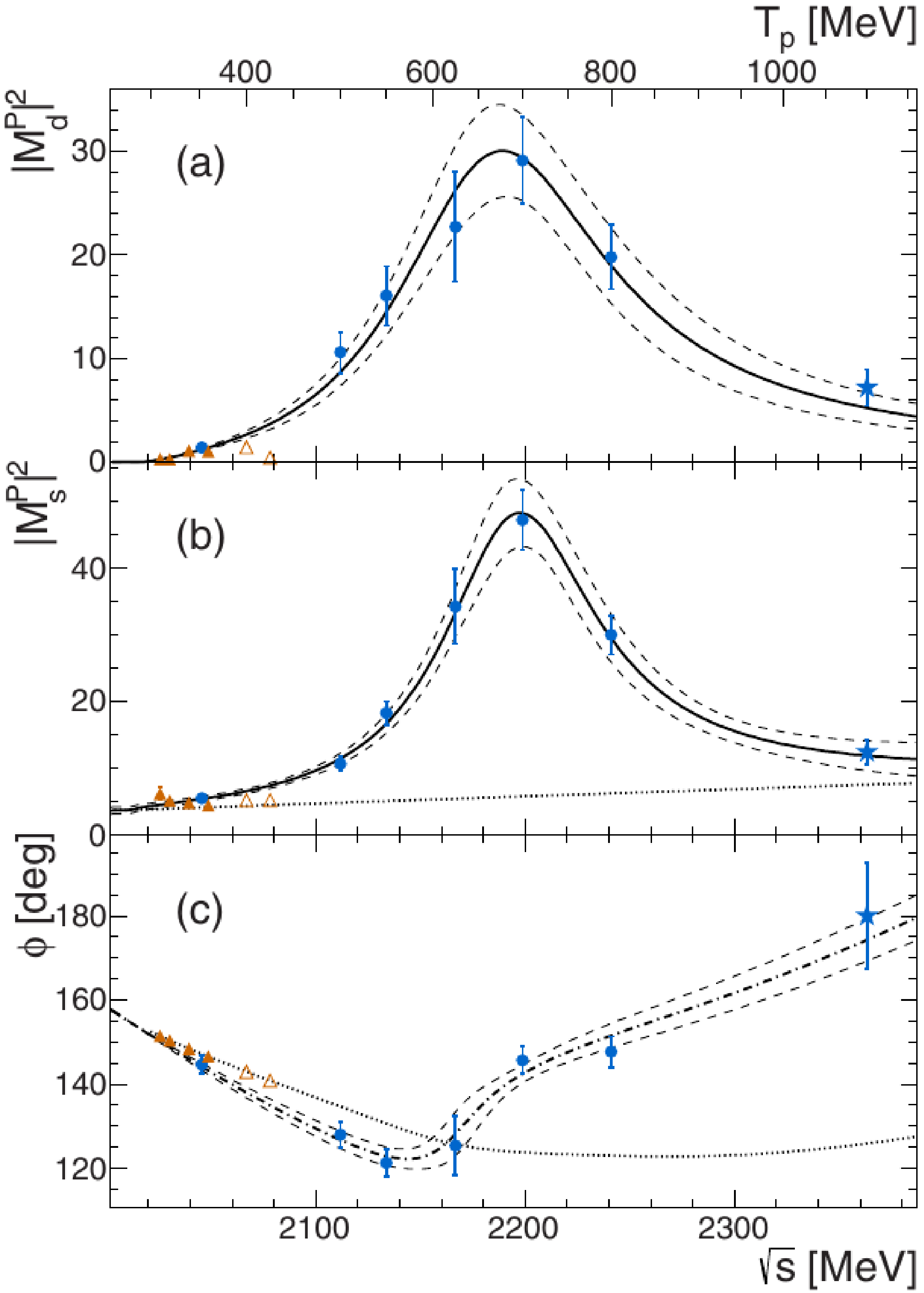


Resonances in the reaction

$$pp \to \{pp\}_s(^1S_0) + \pi^0$$

$$M = 2200, \Gamma \sim 100 MeV, I = 1$$

V.I. Komarov et al. (for ANKE coll) PRC (2016)



• *VECTOR MESONS PRODUCTION IN NN COLLISIONS*

(E. Tomasi-Gustafsson)

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

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

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

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

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)

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

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

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

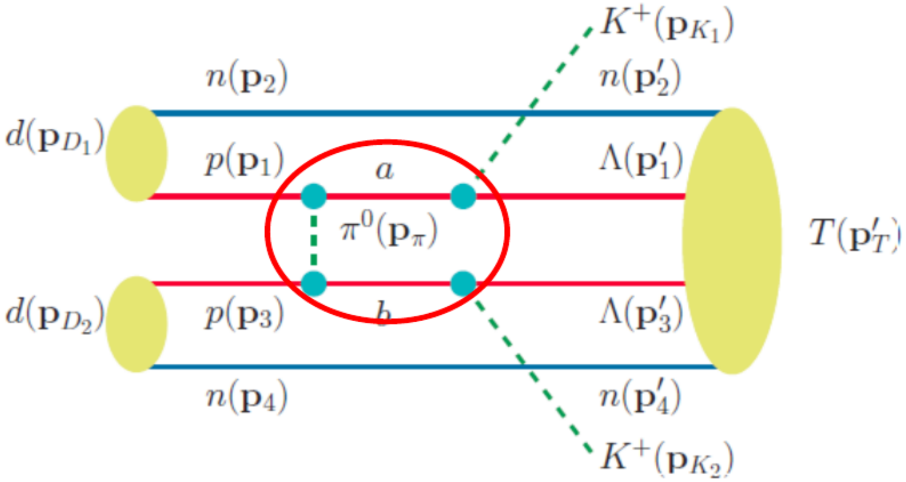
中国科学院
CHINESE ACADEMY OF SCIENCES

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

Qiang Zhao

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

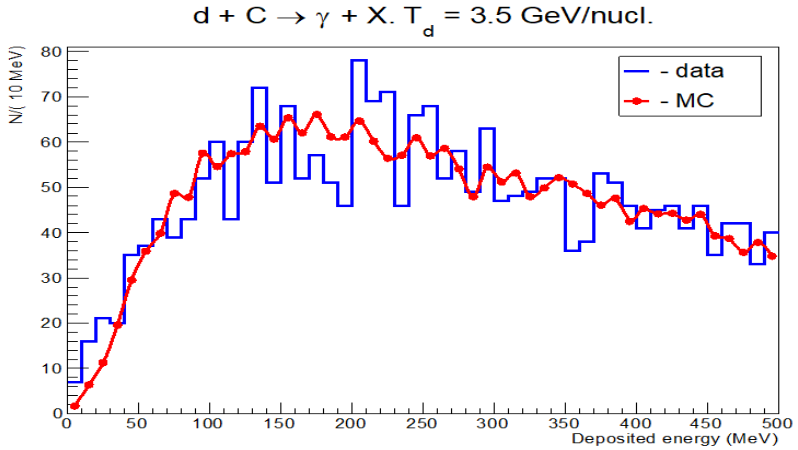
E X O T I C S

Soft Photon (SP) study yield in proton and light nuclei interactions at SPD-NICA setup

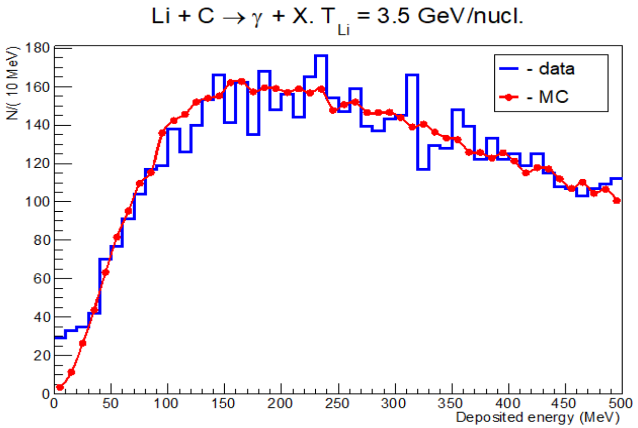
E.Kokoulina, V. Nikitin

SP have energy smaller than 50 MeV. The main mechanism of their formation is Compton scattering of soft gluons on valence quarks at the final stage of hadronization with the photon radiation: q + g -> γ + q.

Over 30 years several experiments have confirmed the increased yield of SP compared to theoretical calculations, but there is still no comprehensive understanding and explanation of this phenomenon.

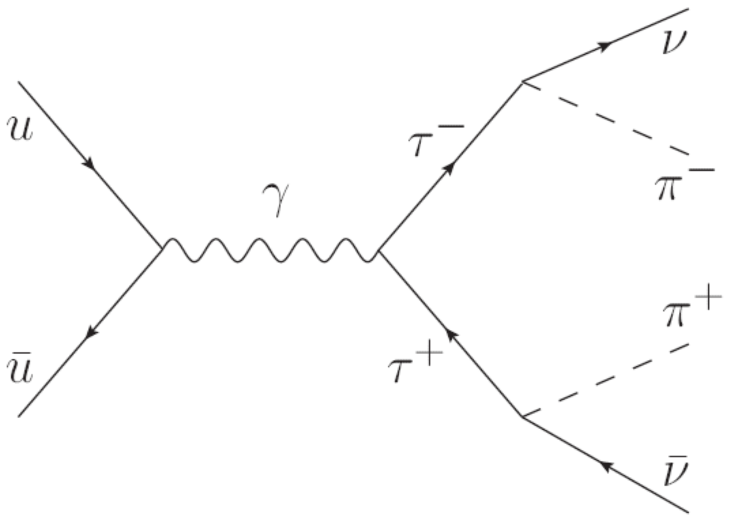


50th and 51st Nuclotron's runs.



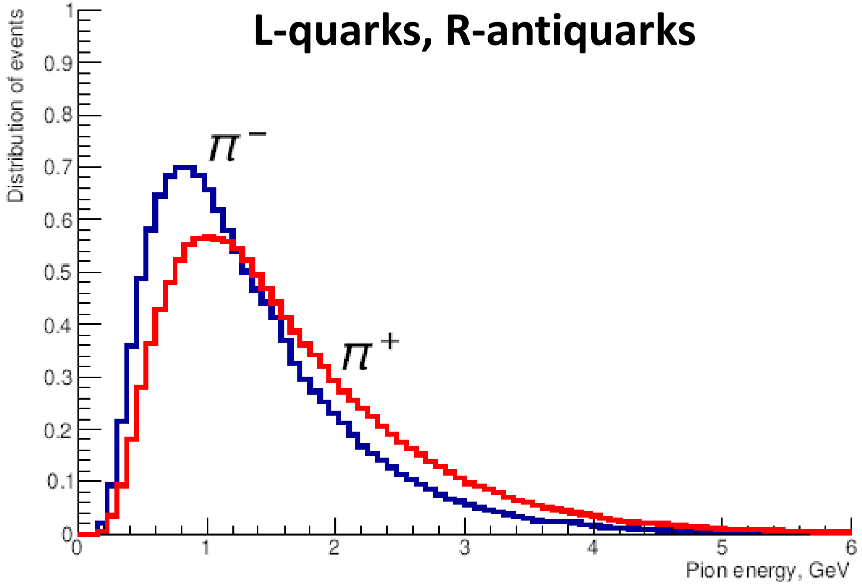
PDF and polarized tau-leptons production

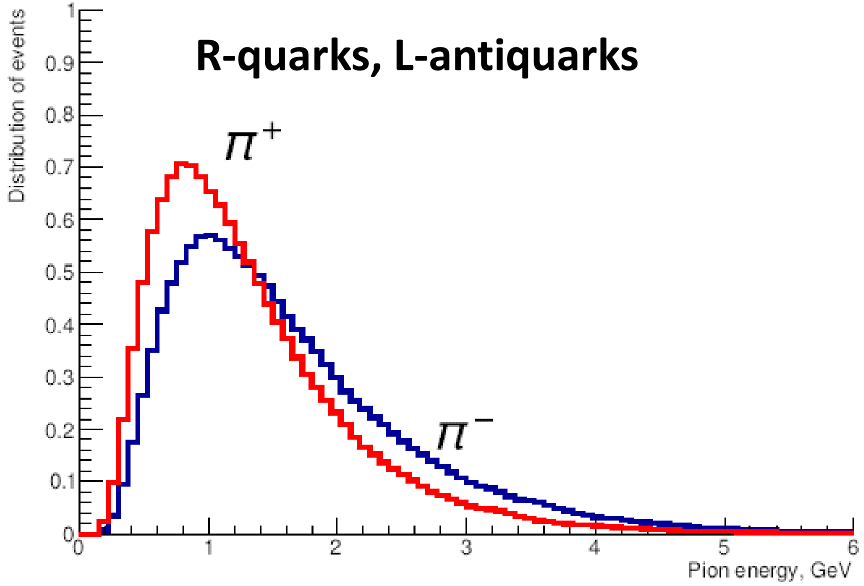
A. Aleshko, E. Boos, V. Bunichev



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

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

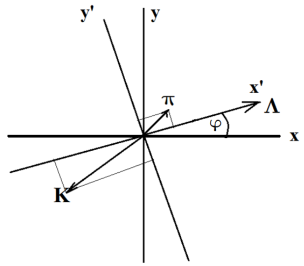




Problems of soft PP interactions

A. Galoyan and V. Uzhinsky

New Two-particle P_T correlations



two-particle P_T correlation function can be determined as:

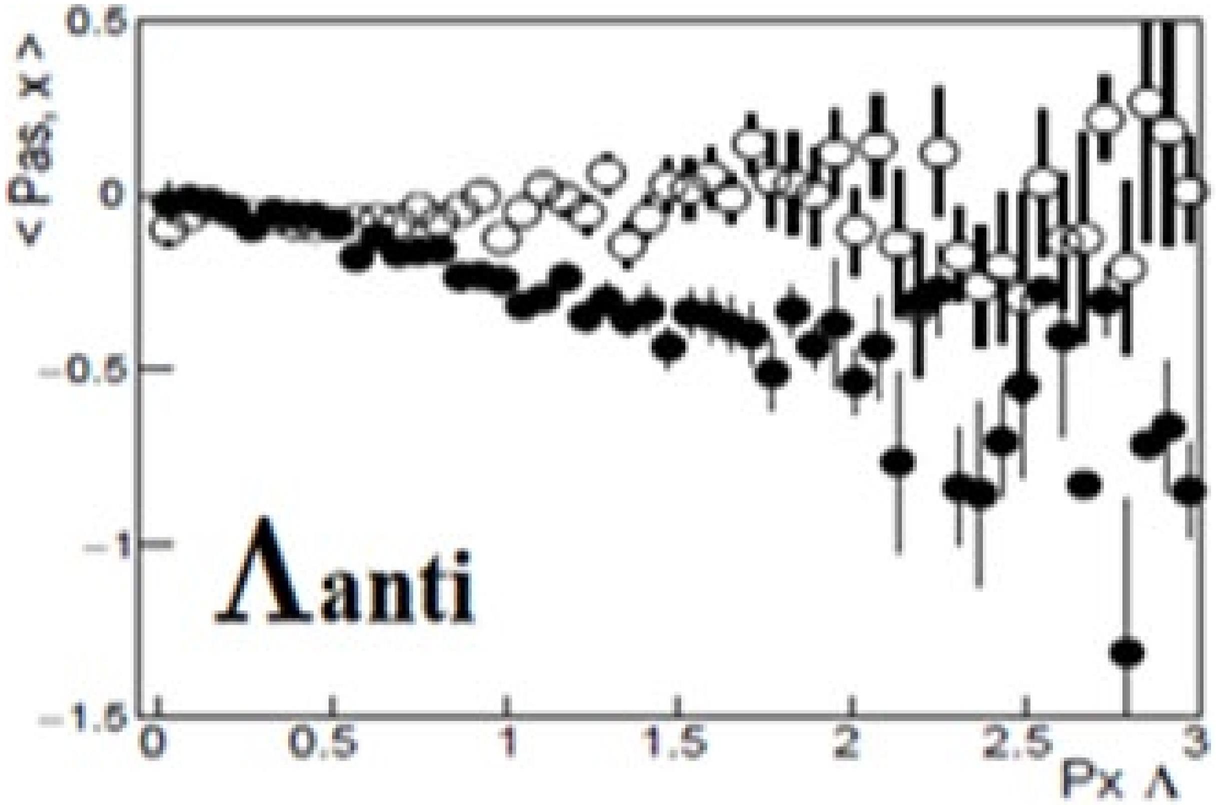
$$C(\vec{P}_T^{tr}, \vec{P}_T^{as}) = \frac{1}{N_{tr}} \frac{d\ N(tr, as)}{d^2 P_T^{tr}\ d^2 P_T^{as}},$$

The function C is a function of 4 independent variables. Though, accounting azimuthal symmetry of interactions of unpolarized particles there must be only 3 independent variables.

We propose to use as the variables the module of transverse momentum of the trigger particle ($|\vec{P}_T^{tr}|$), and 2 projections of the vector $\vec{P}_T^{as}$ on the direction of the vector $\vec{P}_T^{tr}$, and on the direction perpendicular to $\vec{P}_T^{tr}$ In Fig. we choose Λ as a trigger particle, and K-meson or π-meson as associated particles.

$$P_{T,L}^{as} = \vec{P}_T^{as} \cdot \vec{P}_T^{tr} / |\vec{P}_T^{tr}|,$$

$$P_{T,T}^{as} = |\vec{P}_T^{as} \otimes \vec{P}_T^{tr}| / |\vec{P}_T^{tr}|$$



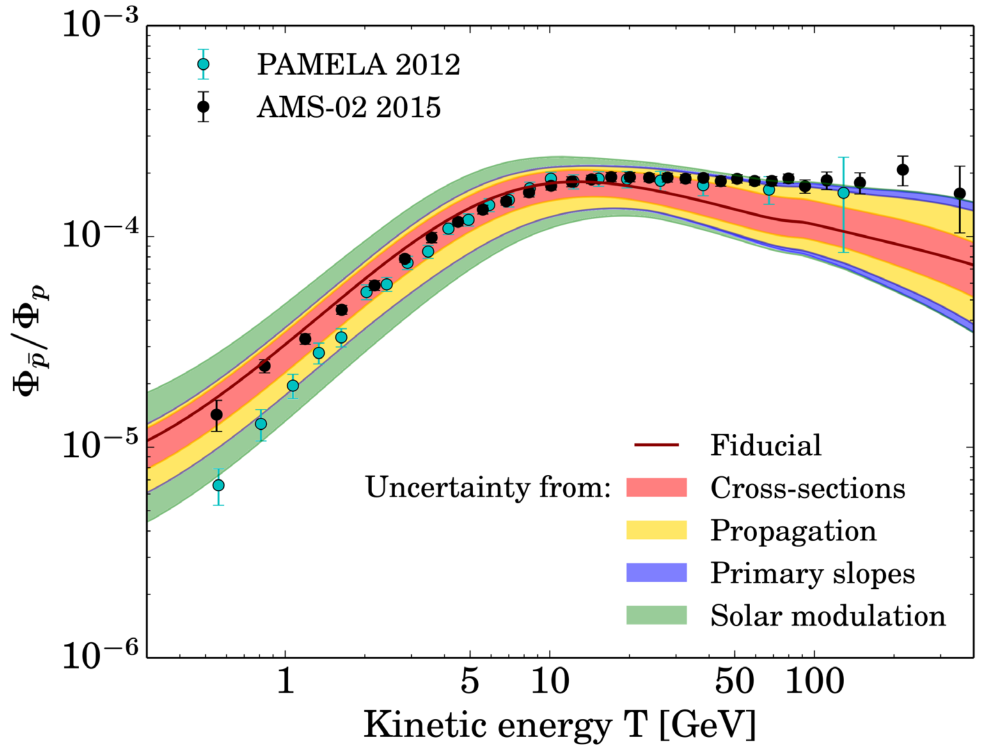
Averaged projections of associated particle momentum (Pass,x) on trigger particle momentum (Px Λ) in pp interactions at Ecms=10 GeV. Open points – Pythia 6.4 calculations. Closed ones are FTF calculations.

There is a big difference between model predictions!

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}~80 GeV
- High theoretical uncertainties: 20-50%[1]
- Stat. sig.: from (> 5σ) to (~ 1.1σ)

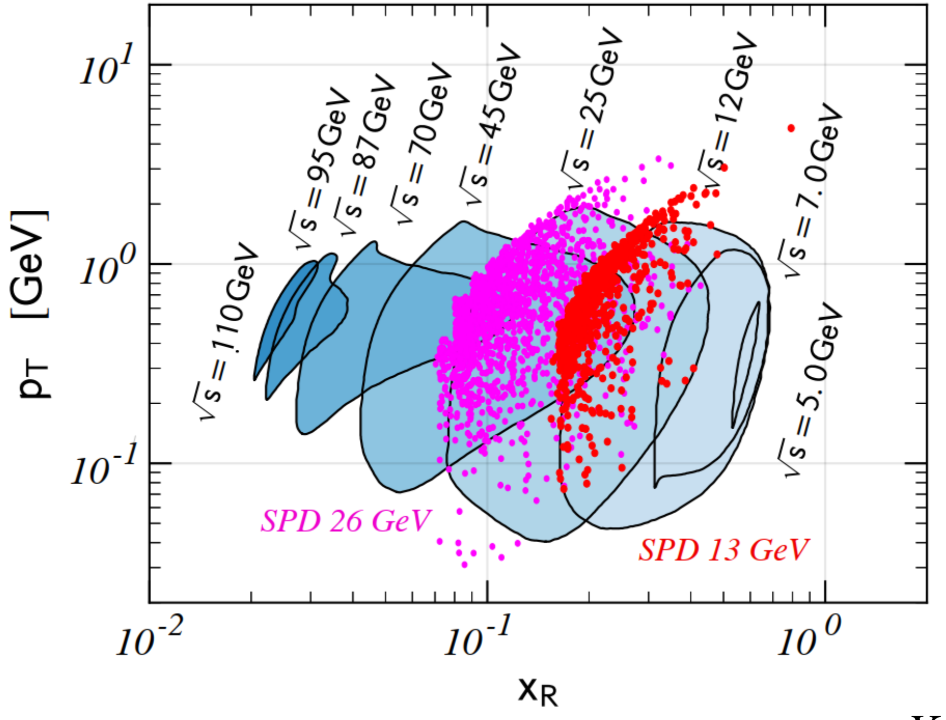


Potential Coverage by NICA SPD

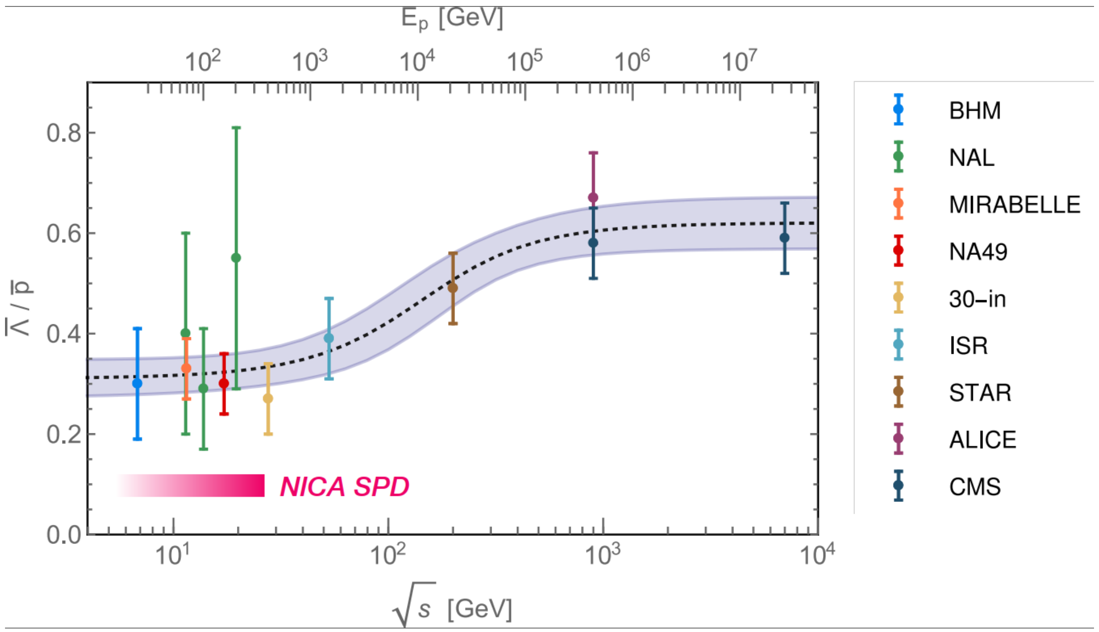
Necessary parameter-space coverage[1] to match AMS-02 precision:

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

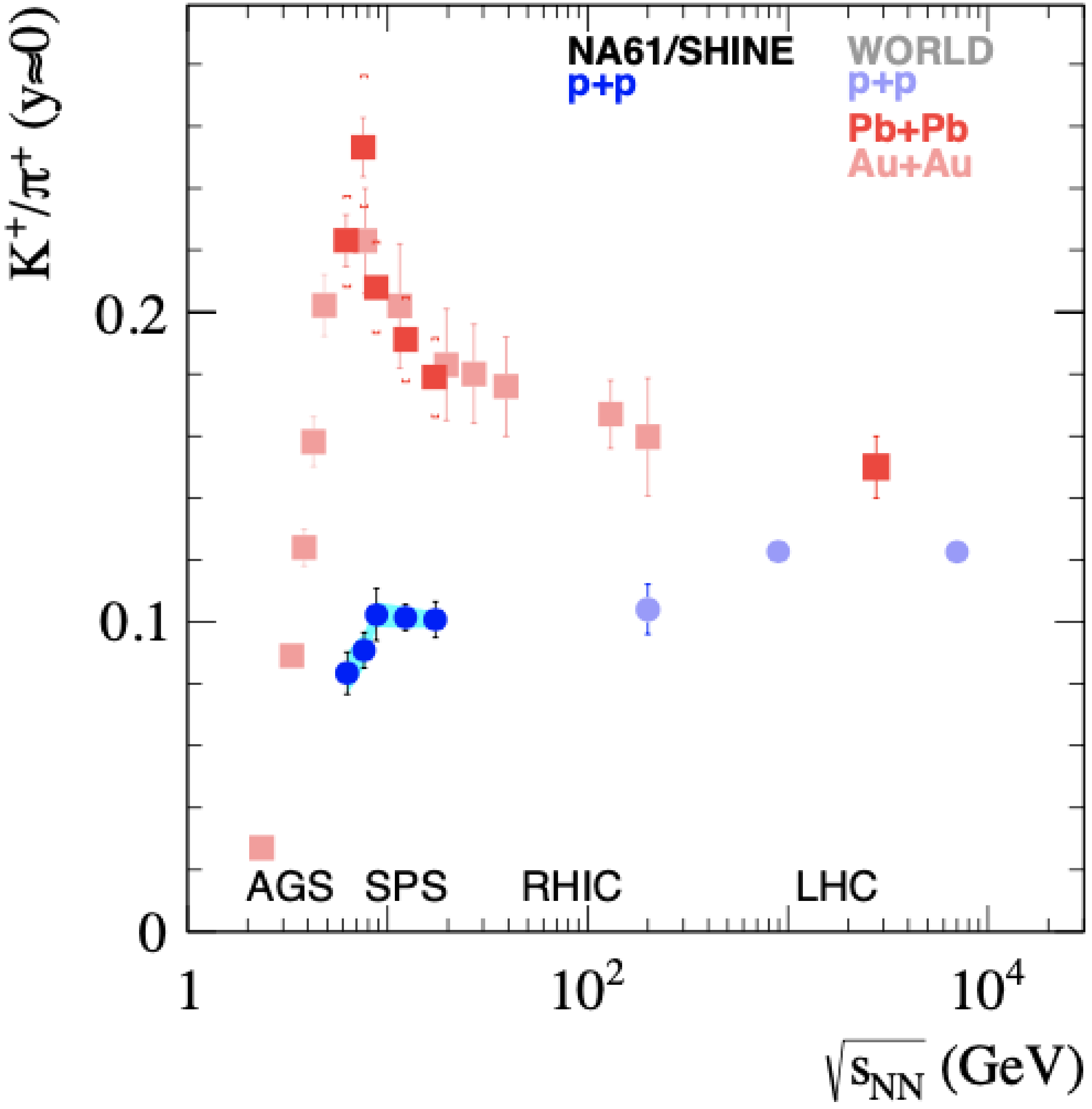
$$+ \sigma_{\rm TVPV}\left(\mathbf{k}\cdot\left[\mathbf{P}^{\rm d}\times\mathbf{P}^{\rm p}\right]\right)$$ TVPV

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



NA61/SHINE: pp->$K^+(\pi^+)X$

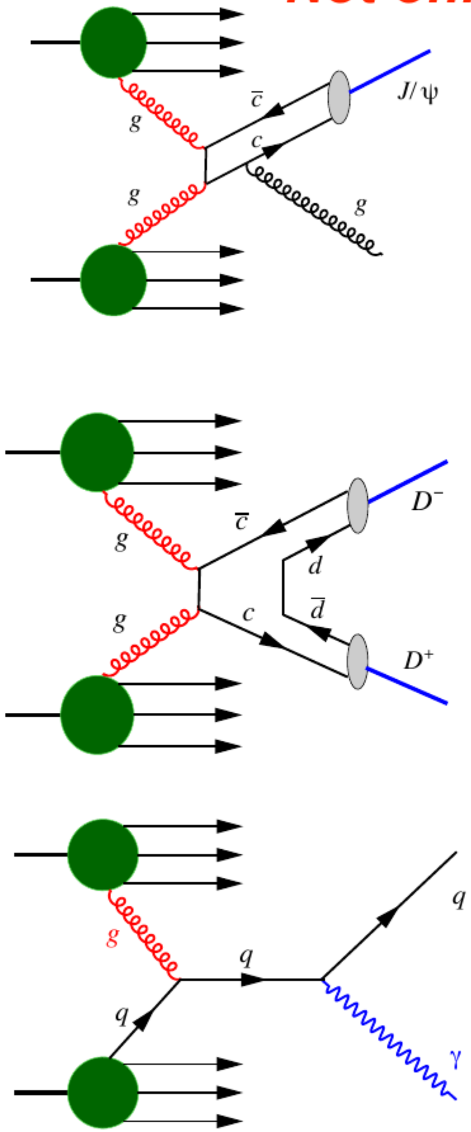
A.Aduszkiewicz et al. PRC 102 (2020)

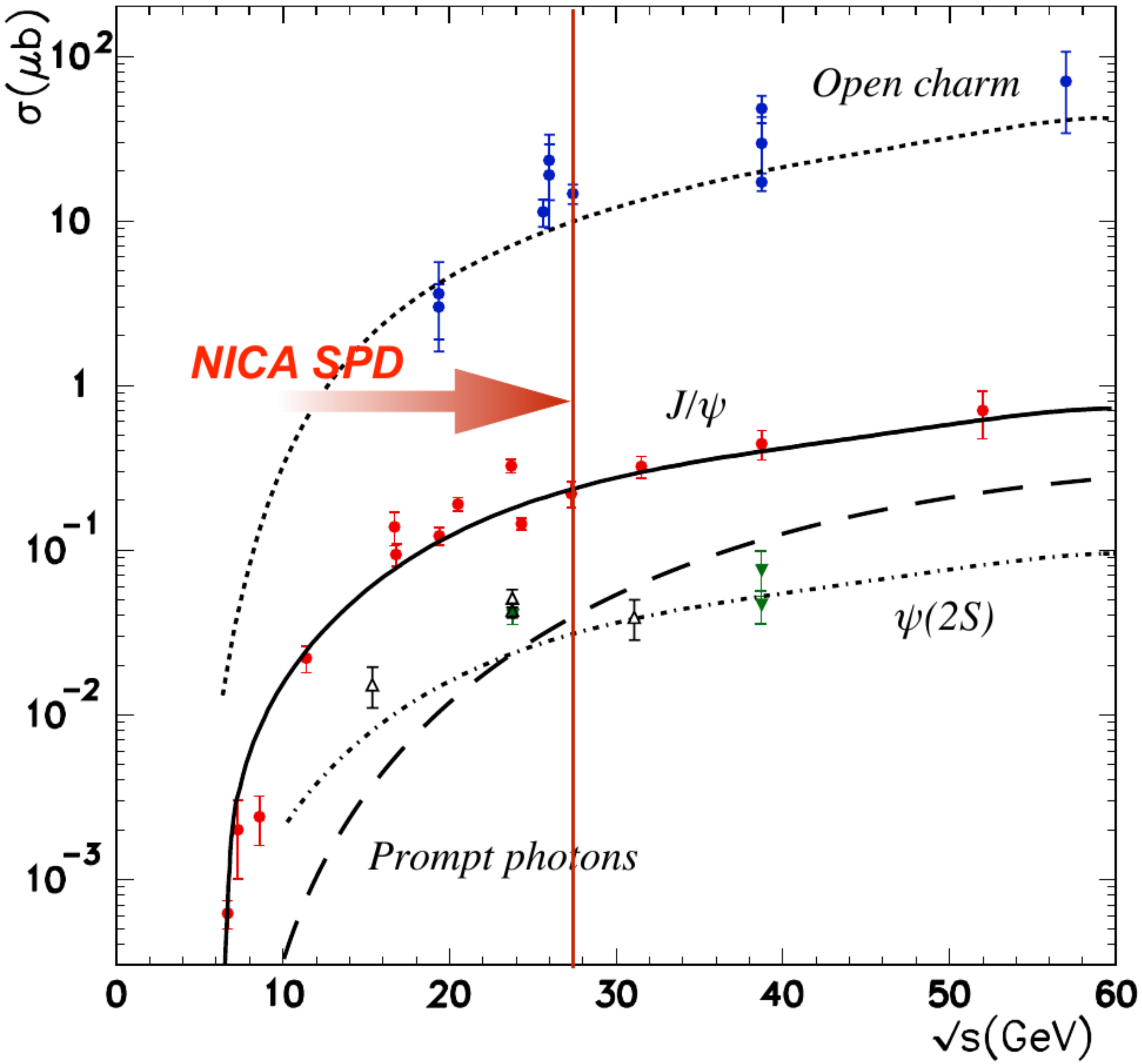
The horn in the region of SPD NICA ?

What about the pn-channel?

SPD and gluon structure of nucleon

Not only J/ψ!

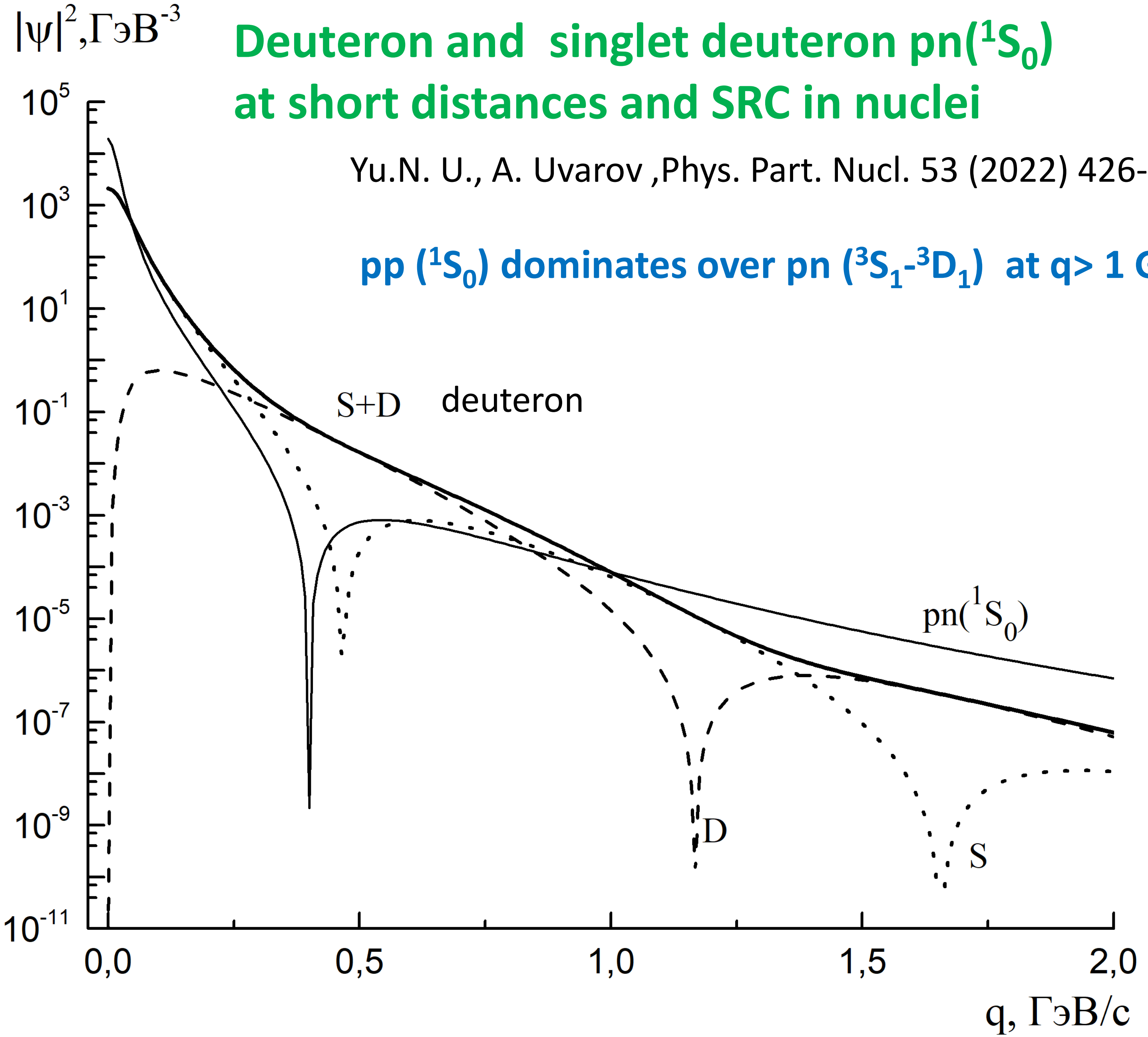


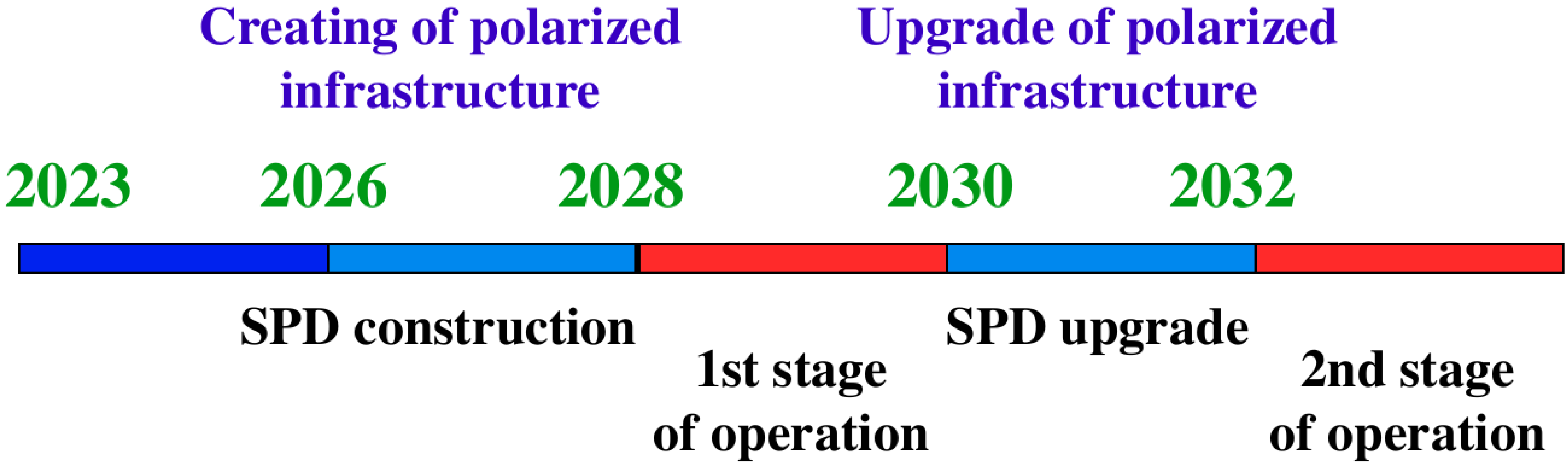


Deuteron and singlet deuteron pn($^1S_0$) at short distances and SRC in nuclei

Yu.N. U., A. Uvarov ,Phys. Part. Nucl. 53 (2022) 426-432.

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





Tentative operating plan of the SPD project