“High $p_T$ physics at $\sqrt{s_{NN}} < 10$ GeV: Fundamental problems and its solution”

*S.S. Shimanskiy (JINR)*
PLAN

1. Fundamental problems and why $\sqrt{S_{NN}} < 10 \text{ GeV}$

2. Unique experimental features

3. How can be resolved these problems
Fundamental problems and why $\sqrt{S_{NN}} < 10\ GeV$
In purely hadronic physics, too, there are tantalizing questions regarding spin dependence. There exists a whole array of semi-inclusive experiments like $pp \rightarrow \pi X$ with a transversely polarized proton beam or target, or $pp \rightarrow \text{hyperon} + X$, with an unpolarized initial state in which huge hyperon spin asymmetries or polarizations — at the 30%-40% level! — are observed. These experiments are very hard to explain within the framework of QCD. The asymmetries all vanish at the partonic level and one has to invoke soft, non-perturbative mechanisms. All such mechanisms predict that the asymmetries must die out as the momentum transfer increases, yet there is no sign in the present data of such a decrease.

In exclusive reactions like $pp \rightarrow pp$ the disagreement between the data on the analysing power at large momentum transfer and the naive QCD asymptotic predictions is even more severe, but here at least there is an escape clause: the theory of exclusive reactions in QCD is horrendously difficult.
SUMMARY

For the past 30 years QCD-based calculations have continued to disagree with the ZGS 2-spin & AGS 1-spin elastic data and the ZGS, AGS, Fermilab & RHIC inclusive data.
* These large spin effects do not go to zero at high-energy or high-$P_{\perp}$ as was predicted.
* No QCD-based model can explain all the large spin effects.

BASIC PRINCIPLE OF SCIENCE:
If a theory does not agree with reproducible experimental data, then the theory must be modified.

These precise spin experiments provide experimental guidance for the required modification of the theory of Strong Interactions.

Elastic $d\sigma/dt$, $A_{nn}$ and $A_n$ experiments at higher energy and $P_{\perp}$ could provide more guidance, just as the RHIC inclusive $A_n$ experiments confirmed the similar Fermilab experiments.
(E-704 Yokosawa et al.).

And extension into non polarized phenomena!
FIG. 3. Plot of the ratio of the spin-parallel to spin-antiparallel differential cross sections, as a function of $P_T^2$, for $p-p$ elastic scattering. The squares are the fixed-angle data at $90^\circ_{c.m.}$, with the incident energy varied. The circles are data (Refs. 5, 11) with the momentum fixed at 11.75 GeV/c while the scattering angle is varied. The dashed and solid lines are hand-drawn possible fits to the $90^\circ_{c.m.}$ data.

$p_T \sim 2$ GeV/c region
Non-polarized particle beams

\[ pp \rightarrow pp (90^\circ) \]

Krisch A. and Leksin G. – non pointlike structure of nucleon

\[ p_T \sim 2 \text{ GeV/c region} \]
Cumulative processes

Leksin G.A.

Fig. 5. Dependence of the slope parameter $T_0$ for the invariant function of the protons escaping under the action of $p, \pi^\pm, K^-, \gamma, \bar{p}$ with various energies $E_0$, the escape angle is $120^\circ$ in the laboratory frame.

$T = \frac{d\sigma}{dt} \left( p + "p" \to p + p \right) / Z \frac{d\sigma}{dt} \left( p + p \to p + p \right)$

$R_{AA}, v_2, p/\pi \ldots$

$p_T \sim 2$ GeV/c region

B. Van Overmeire, J. Ryckebusch, nucl-th/0608040
DIQUARK COMPONENT

Can be as candidate for subcomponent of hadrons
Multiquark states have been discussed since the 1st page of the quark model

A SCHEMATIC MODEL OF BARYONS AND MESONS *

M. GELL-MANN
California Institute of Technology, Pasadena, California

Received 4 January 1964

If we assume that the strong interactions of baryons and mesons are correctly described in terms of the broken “eightfold way” 1-3, we are tempted to look for some fundamental explanation of the situation. A highly promised approach is the purely dynamical "bootstrap" model for all the strongly interacting particles within which one may try to derive isotopic spin and strangeness conservation and broken eightfold symmetry from self-consistency alone 4). Of course, with only strong interactions, the orientation of the asymmetry in the unitary space cannot be specified; one hopes that in some way the selection of specific components of the F-spin by electromagnetism and the weak interactions determines the choice of isotopic spin and hypercharge directions.

Even if we consider the scattering amplitudes of strongly interacting particles on the mass shell only and treat the matrix elements of the weak, electromagnetic, and gravitational interactions by means of $n_t - n_f$ would be zero for all known baryons and mesons. The most interesting example of such a model is one in which the triplet has spin $\frac{1}{2}$ and $z = -1$, so that the four particles $d^-$, $s^-$, $u^0$ and $b^0$ exhibit a parallel with the leptons.

A simpler and more elegant scheme can be constructed if we allow non-integral values for the charges. We can dispense entirely with the basic baryon $b$ if we assign to the triplet $t$ the following properties: spin $\frac{1}{2}$, $z = -\frac{1}{2}$, and baryon number $\frac{3}{2}$. We then refer to the members $u^3_t$, $d^3_t$, and $s^3_t$ of the triplet as "quarks" 6) $q$ and the members of the anti-triplet as anti-quarks $\bar{q}$. Baryons can now be constructed from quarks by using the combinations $(qqq)$, $(qqq)$, etc., while mesons are made out of $(q\bar{q})$, $(qqq)$, etc. It is assuming that the lowest baryon configuration $(qqq)$ gives just the representations 1, 8, and 10 that have been observed, while the lowest meson configuration $(q\bar{q})$ similarly gives just 1 and 8.

that it would never have been detected. A search for stable quarks of charge $-\frac{1}{2}$ or $+\frac{1}{2}$ and/or stable di-quarks of charge $-\frac{1}{2}$ or $+\frac{1}{2}$ or $+\frac{3}{2}$ at the highest energy accelerators would help to reassure us of the non-existence of real quarks.
Hadrons from diquarks?

Still an open question!

Role of diquarks in building hadrons?

Light and heavy baryon spectroscopy is sensitive to this question

Additional motivation for existence of tetra- and penta-quarks.

Exotic Hadrons,
Dubna, Sep.18,2018
Tomasz Skwarnicki

Does effective mechanism to suppress rapid fall-apart exist?
All these phenomena are happened in the $\sqrt{S_{NN}} < 10 \text{ GeV}$

No explanations up to now!
Unique experimental features
That will open possibility to provide unique experiments
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.
Some unique features for NICA

- Spin transparency mode in the NICA collider provide unique opportunity for efficient spin manipulation of any particle species ($p$, $d$, $^{3}$He, ...) in any orbit place without affecting of the collider orbital characteristics.

- Both vertical and longitudinal directions of the beam polarization in MPD and SPD detectors are available.

- Spin flipping system allows one to carry out high quality experiments with polarized proton and deuteron beams.
Some unique features for NICA

Working with spin-flippers at NICA

a) new ring fill modes (all bunches with the same polarization in both rings) and the work (sequential switching-on of the spin-flippers in the rings):

1st ring

+++... | xxx | - - -... | ---- | - - -... | xxx | +++ | ---- | +++...

2nd ring

+++... | ---- | +++... | xxx | - - -... | ---- | - - - | xxx | +++...

(+ +)  (- +)  (- -)  (+ -)  (+ +)

|xxx| - spin-flipper switching-on, no data taking

|----| - spin-flipper switching-off, no data taking

b) there is no problem with measuring interbunch luminosity, no problem with different polarization for different modes of the source!
Some unique features for NICA

NICA Collision place for SPIN physics
(deuteron and other beams, the first time all isotope states for NN system: \(pp, pn,nn\).)

The tagging stations can be used as polarimeter!
DIQUARK DYNAMIC MANIFESTATION
FIG. 2: (Color online) Ratio of the $pn \rightarrow pn$ to $pp \rightarrow pp$ elastic differential cross sections as a function of $s$ at $\theta_{c.m.}^N = 90^0$. 
MASS ANALYSIS OF THE SECONDARY PARTICLES PRODUCED
BY THE 25-GEV PROTON BEAM OF THE CERN PROTON SYNCYCHROTRON

V. T. Cocconi,* T. Fazzini, G. Fidecaro, M. Legros,† N. H. Lipman, and A. W. Merrison
CERN, Geneva, Switzerland

(a) POSITIVE PARTICLES
emitted at \( \theta_{LS} = 15.9^\circ \)
and measured at 61 m
from the target

(b) NEGATIVE PARTICLES
emitted at \( \theta_{LS} = 15.9^\circ \)
and measured at 61 m from the target

(c) RATIO DEUTERONS/PROTONS
as a function of momentum
for particles emitted at \( \theta_{LS} = 15.9^\circ \)

\[ \frac{D}{P} \]

\[ \frac{P}{\pi^+} \]

\[ \frac{K^+}{\pi^+} \]

\[ \frac{P}{\pi^-} \]

\[ \frac{K^-}{\pi^-} \]

\( p/\pi \) ratio

+ d/p problem
In the framework of a diquark model of the nucleon, the strong scaling violation of the $p/\pi^+$-ratio in the $pp$-collisions from $\sqrt{s} = 11.5$ GeV (IHEP, Serpukhov) to $\sqrt{s} = 23.4$ GeV (FNAL) and to $\sqrt{s} = 62$ GeV (CERN ISR) is described. A fairly good description of the magnitude of cross sections for single protons and for symmetric-proton-pairs with large-$p_\perp$ is obtained. In the model with the dominating scalar $(ud)$-diquark, the yield relation $\Lambda^0/p \approx K^+/\pi^+$ is predicted.

![Graph](image-url)

**Fig. 1.** $R = p/\pi^+$ is the particle yield ratio in the $pp$-collisions.

a) $\theta_{CM} = 90^\circ$: • the FNAL data at $\sqrt{s} = 23.4$ GeV ($E = 300$ GeV); ▲ the IHEP (Serpukhov) data at $\sqrt{s} = 11.5$ GeV ($E = 70$ GeV).

b) $\theta_{CM} = 45^\circ$: • the CERN ISR data at $\sqrt{s} = 62$ GeV ($E \approx 1900$ GeV).
The dotted curve shows the contribution of the $qq$-subprocess, the dashed one shows the contribution of the $qd$-subprocess. The total contribution of the $qq$, $qd$- and $dd$-subprocesses is denoted by the solid lines. The dashed-dotted curves show the calculations with the diquark function $G_2(x) \sim (1 - x)/x$ at 70 GeV (curve 1) and at 300 GeV (curve 2).
Kim's mechanisms in exclusive reactions

$pp \rightarrow pp + X, \ pp \rightarrow D(H) + X$

reactions with diquarks

Double $qd$-scattering

Diquark proof
How can be resolved these problems?
NN – interactions mainly

From the inclusive experiments to the correlations and the exclusive experiments. We haven’t the theory but we will have new experimental set ups.
NN Elastic scattering with polarized deuteron beams at NICA:

\[
\begin{align*}
    p &\uparrow \quad + \quad p \uparrow \quad \rightarrow \quad p + p \\
    p &\uparrow \quad + \quad n \uparrow \quad \rightarrow \quad p + n \\
    n &\uparrow \quad + \quad n \uparrow \quad \rightarrow \quad n + n
\end{align*}
\]

for calibration

New data!

By the way we will have the counting rules verification!

pd, nd and dd – too!
Exclusive NN study at $x_T \sim 1$

Hadron reactions when all particles in high $p_T$ region

$N \uparrow + N \uparrow \rightarrow BB + MM$

$B (p, n, \Lambda, \Delta \ldots), M (\pi, K, \mu \ldots)$

Mechanisms of hyperons polarization

$N \uparrow N \uparrow \rightarrow NN$

isotopic symmetry (quark universality) studies, $p_T \sim 2$ GeV/c anomaly

$N \uparrow N \uparrow \rightarrow BB + \pi\pi (KK)$

$N \uparrow N \uparrow \rightarrow \Delta\Delta$

Detail vertexes studies and spin structure of the interaction vertex:

$q + (q) - (quark - quark)$

$q + (qq) - (quark - diquark)$

$(qq) + (qq) - (diquark - diquark)$
High $p_T$ exclusive inelastic reactions $\rightarrow$ MPI

$$p \uparrow + p \uparrow \rightarrow B + B + \overline{M}M$$

$$p \uparrow + p \uparrow \rightarrow p + p + \pi^0\pi^0(\pi^+\pi^-)$$

$$R = \frac{N(\pi^+\pi^-)}{N(\pi^0\pi^0)} \rightarrow \frac{2}{7} \quad \text{Without diquark}$$

$$R = \frac{N(\pi^+\pi^-)}{N(\pi^0\pi^0)} \rightarrow 0 \quad \text{diquark}$$

Diquark ($S=0$)

$$A_{n(pp)} \rightarrow 0$$

With out $q\overline{q}$ pair $A_{(\Delta^+)(\Delta^+)}$
\[ pp \rightarrow D(H + \Lambda N + \Sigma N) + \ldots \text{ reactions with diquarks} \]

Double \textit{qd-scattering}

Diquark proof

\[ \Lambda \Lambda + \Lambda N + \Sigma N + \ldots \]
Exotic states and flavor universality
Exotic states production

pp - reactions with pentaquarks production

Diagram showing reactions involving quarks and pentaquarks.
Exotic states production

pp - reactions with tetraquarks production
PANDA

Direct reaction to tetraquarks production in $pp$

Diquark proof

Exotic states production

tetraquarks
$\overline{p}d$ - reaction with tetraquarks + pentaquark production

PANDA
Exotic states production

$D$ $d$ $d$ $d$ $d$ $d$ $d$ $d$ $d$

$d+d\text{-bar}$

tetraquarks

$q\text{-bar}$ $d\text{-bar}$

$p$ $p$ $p$ $p$ $p$ $p$ $p$ $p$ $p$
MULTIQUARK(MULTINUCLEON) COMPONENT
CUMULATIVE PROCESSES
+ d/p problem, cum. Region ~0.25

p/π ratio ~ 20

Fig. 2. Momentum spectrum of particles emitted at 90° from a beryllium target struck by 30-Bev protons. The ordinate is the number of particles produced at the target per steradian per Bev/c per circulating proton. The dashed portions of the curves indicate regions where the corrections due to multiple scattering exceed 15%. At the time these data were taken no effort was made to detect He³.
$p + A \rightarrow c \left(35^\circ_{\text{lab}}\right) + X$

$E_p = 50$ GeV

**SPIN data**


---

*Invariant function found for positive pion, proton, deuteron and triton.*

The vertical dashed lines indicate the kinematical limit for elastic nucleon–nucleon scattering. The upper horizontal scale shows values of the transverse momentum $p_T$. 
**Ratio d/p**

\[ p + A \rightarrow c \left(35^0_{\text{lab}}\right) + X \]

\[ E_p = 50 \text{ GeV} \]

**FODS data**

ФОДС В.В.Абрамов и др., ЯФ 45(5) (1987), 845–851

\[ p + A \rightarrow c \left(90^0_{\text{cms}}\right) + X \]

\[ E_p = 70 \text{ GeV} \]
Knot out cold dense nuclear configurations

**SRC configuration**

\[ \langle B \rangle \sim 1 \]

\[ \langle B \rangle \sim ? \]

**Flucton configuration**

\[ p \] at PANDA
Flucton case

Knock out of a nuclear fragment

\[ \langle B \rangle > 1 \]

\[ \sigma_h \sim P_K \cdot \frac{d \sigma_{el}(K)}{dt} \]

Collision with hot flucton - small explosion

\[ \langle B \rangle < 1 \]

\[ \sigma_h \sim P_K \cdot \frac{d \sigma_{inel}(K)}{dt} \]
Flucton case

Knock out of a flucton in an excited state

$\langle B \rangle > 1 \ (?)$

? for SPD and PANDA
Average baryon number $\langle B \rangle$
Knockout of Deuterons and Tritons with Large Transverse Momenta in $pA$ Collisions Involving 50-GeV Protons

N. N. Antonov$^a$, A. A. Baldin$^b$, V. A. Viktorov$^c$, V. A. Gapienko$^d$, G. S. Gapienko$^e$, V. N. Gres$^a$, M. A. Ilyushin$^d$, V. A. Korotkov$^d$, A. I. Mysnik$^d$, A. F. Prudkovlyad$^d$, A. A. Semak$^a$, V. I. Terekhov$^c$, V. Ya. Uglekov$^c$, M. N. Ukhanov$^a$, B. V. Chuiko$^a$, and S. S. Shimanski$^b$

$$\frac{E_d}{\sigma_{inel}} \frac{d^5\sigma_A}{dp_A^3} = B_A \times \left(\frac{E_p}{\sigma_{inel}} \frac{d^3\sigma_p}{dp_p^3}\right)^A$$

Mean values of the $B_2$ parameter

<table>
<thead>
<tr>
<th>Target</th>
<th>C</th>
<th>Al</th>
<th>Cu</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_2 \times 10^2$, GeV$^2$/c$^3$</td>
<td>$1.41 \pm 0.10$</td>
<td>$1.56 \pm 0.08$</td>
<td>$1.51 \pm 0.07$</td>
<td>$1.41 \pm 0.06$</td>
</tr>
</tbody>
</table>
ON THE FLUCTUATIONS OF NUCLEAR MATTER

D. I. BLOKHINTSEV

Joint Institute for Nuclear Research

Submitted to JETP editor July 1, 1957


It is shown that the production of energetic nuclear fragments in collisions with fast nucleons can be interpreted in terms of collisions of the incoming nucleon with the density fluctuations of the nuclear matter.

1. INTRODUCTION

The motion of nucleons in nuclei can result in short-lived tight nucleon clusters, in other words, in density fluctuations of nuclear matter. Since such clusters are relatively far removed from the other nucleons of the nucleus, they become atomic nuclei of lower mass in a state of fluctuating compression. In their study of the scattering of 675-Mev protons by light nuclei, Meshcheriakov and coworkers observed recently certain effects which confirm the existence of such fluctuations, at least for the simplest nucleon-pair fluctuations, which lead to the formation of a compressed deuteron.
1. **Cold** - exists inside ordinary nuclear matter as a quantum component of the wave function (with some probability and life time).

2. **superDense** - several nucleons can be in a volume less than the nucleon volume. The mass will be several nucleon masses. The small size means that the multinucleon (multiquark) configuration seeing as point like objects in processes with high transfer energy.

3. **Baryonic Matter** - enhancement of baryonic states and suppression of sea and gluon degrees of freedom (mesons and antiparticles production).
HIGH $p_T$ ISSUES at SPD, PANDA and J-PARC-HI

1. Flavor universality (pp- and nn-interactions).
2. Diquark properties.
3. Exotic states.
4. Nature of the spin effects.
5. FSI (with $s,c$-quarks participation).
6. $\Lambda N$ – hypernuclei.
7. ...

NN – interactions mainly

NA- and AA – interactions

8. Nature of CsDBM and CT.
10. The Deuteron spin structure.
11. np(nn) dilepton anomaly.
12. ...
Thank you!
B. Van Overmeire, J. Ryckebusch, nucl-th/0608040


$p_T \sim 2 \text{ GeV/c region}$
VIII. SUGGESTIONS FOR FUTURE EXPERIMENTS

Clearly there remain a number of interesting investigations involving nuclear transparency of protons and other hadrons. A revival of the AGS fixed target program [44], or the construction of the 50-GeV accelerator as part of the J-PARC complex in Japan [55], would provide excellent opportunities to expand the range of these nuclear transparency studies. Some of the remaining questions are the following.

1. What happens at higher incident momentum? Does nuclear transparency rise again above 20 GeV/c, as predicted in the Ralston-Pire picture [56]?

2. A-dependent studies in the 12 to 15 GeV/c range; will the effective absorption cross section continue to fall after the nuclear transparency stops rising at \( \sim 9.5 \text{ GeV/c} \) [56]?

3. At the higher energy ranges of these experiments the spin effects are expected to be greatly diminished. However, they continue to persist, as shown in both single and double spin measurements [34,57]. So it is important to see, in quasielastic scattering inside a nucleus, whether a relatively pure pQCD state is selected, and if the spin dependent effects are attenuated.

4. Measurements of nuclear transparency with antiprotons, pions, and kaons will be informative. These particles have widely different cross sections at 90° \(_{\text{cm}}\). For instance, the \( pp \) differential cross section at 90° \(_{\text{cm}}\) is 50 times larger than the \( \bar{p}p \) differential cross section [19]. How should this small size of the \( pp \) cross section affect the absorption of \( \bar{p} \)'s by annihilation?

5. The production of exclusively produced resonances provides a large testing ground for nuclear transparency effects. This is especially true for those resonances that allow the determination of final state spin orientation, such as \( \rho \)'s or \( \Lambda \)'s [19,36]. Will the interference terms that generate asymmetries disappear for reactions which take place in the nucleus?

6. Measurements in light nuclei that determine the probability of a second hard scatter after the first hard interaction are an alternative way to study nuclear transparency effects. With the proper kinematics selected, the probability of the second scatter is dependent on the state of the hadrons at the first hard interaction [58].
J.W. Cronin et al., Production of hadrons at large transverse momentum at 200, 300, and 400 GeV, Phys.Rev. D, v.11, N 11, 3105-3123 (1975)

**p_T ~ 2 GeV/c region**

**Fig. 20.** Comparison of the cross-section ratio \( p/\pi^+ \) measured on tungsten at \( \sqrt{s} = 23.7 \) GeV (closed circles), with that obtained by extrapolation to \( A = 1 \) (open circles). Ratios obtained from the British–Scandinavian collaboration (Ref. 23) at \( \sqrt{s} = 23.4 \) GeV are also plotted (closed squares).

**Baryon anomaly in Pb-Pb**

- $p_T \sim 2$ GeV/c region

**Highlights**

- Baryon to meson ratio increasing with centrality for $p_T < 8$ GeV/c.
  - Enhancement at moderate $p_T$ is consistent with radial flow
  - May be explained by quark recombination from QGP (coalescence model)
- For $p_T > 8$ GeV/c no dependence on centrality and collision system
  - Consistent with fragmentation in vacuum
Resume
XII Advanced research Workshop on High Energy Spin Physics
(DUBNA-SPIN-07)

The spin physics attracts great attention since the 70th when at the energy of beams ~ 10 GeV in reactions with hadrons in complete contradiction with predictions of QCD that polarization characteristics must disappear at high energies the huge spin effects were discovered. The began detailed studies with the higher energies showed that the observed spin effects do not disappear even at energies of hundreds GeV. The deep inelastic lepton scattering on polarized targets in 80th and 90th of the past century led to the problem named "spin crisis". Until now the spin effects have not found complete physical explanation in the framework of QCD. The situation when there is no adequate understanding of polarization phenomena at the energies ~ 10 GeV is real challenge to nowadays theoretical models. This energy region becomes especially important in connection with the increasing interest to the astrophysical problems, where enormous magnetic fields up to ~ 10^18 Gs have been discovered. Strong magnetic fields can be as indication to an enormous role of the spin effects in processes of the massive star evolution, the nucleosynthesis of heavy elements and the solution of the mystery of the supernova explosions. One of the most important problem for high-energy physics remains until now is understanding the nature of the spin and, in particular, skill to calculate the spin of hadrons from constituent spins.

In the program of the international conference D5PIN07 the results of activity with polarized beams of the LHE JINR accelerator complex have been presented. These reports have reflected: the development of new methods to preservation of polarization in the nucleon for polarized protons and the lightest nuclei; the project to create new polarized ions source (in plan to use components from IUClF CIPIOS source); the proposals of further spin research with polarized beams of modernized nucleon-M and in a future with NICA-collider beams. All these proposals are actually the substantiation of the project for creation on nucleon-M the center for spin studies in the region of energies ~ 10 GeV. The acceleration of the lightest polarized nuclei will make possible for the first time studies of the polarized nuclear matter collisions (d^n d, d^7 He^n and ^7 He^n He^n), for the first time study of the complete set of the isotopic states of the nucleon-nucleon interactions (p^n p, n^n p and n^n n) and study of the of orbital angular momentum contribution to the nucleon spin. Accelerator complex with such possibilities will not have a concurrence from other activities which will lead polarization studies and obtained data will help to resolve the riddles of the spin, which do not have the solution since 70th. Materials which have been presented on D5PIN07 confirm high level and urgency of JINR polarization studies and the undoubted realizability of the proposed project of creation of a unique center for polarization studies. Spin community (presented on D5PIN07) expresses their complete interest in realization of polarization project on nucleon-M and future development the spin program on NICA-collider.

1. Bunee Gerry (BNL, Brookhaven, USA)
2. Soffer Jacques (Temple Univ. Philadelphia, USA)
3. Belotostski Stanislav (PNPI Gatchina, Russia)
4. Dodge Gail (Old Dominion Univ. Norfolk, USA)
5. Sivers Dennis (Portland Phys. Inst. USA)
6. Vasilev Alexander (IHEP, Protvino, Russia)
7. Ramsey Gordon (Loyola Unive. Chicago, USA)
8. Crabb Donald G. (Univ. of Virginia, Charlottesville, USA)
9. Troshin Sergey (IHEP, Protvino, Russia)
10. Nurushev Sandibek (IHEP, Protvino, Russia)
11. Ginzburg Ilja (DSBRAN Novosibirsk, Russia)
12. Grosse Perdekamp Matthias (Univ. of Illinois, Upton, USA)
РАССЕЯНИЕ ЧАСТИЦ ВЫСОКОЙ ЭНЕРГИИ
КАК МЕТОД ИССЛЕДОВАНИЯ
МАЛОНУКЛОННЫХ КОРРЕЛЯЦИЙ В
ДЕЙТОНЕ И ЯДРАХ

М. И. Стрикман, Л. Л. Франкфурт

Ленинградский институт ядерной физики им. Б. П. Константинова, Ленинград

малых расстояний в ядрах и о способе их описания представляет самостоятельный интерес. Цель обзора — показать, что отбор событий, содержащих кумулятивные частицы, увеличивает относительный вклад от конфигураций в волновой функции ядра, содержащих несколько нуклонов (два, три) на малых относительных расстояниях *. (Кумулятивными частицами мы, следуя [6], называем вторичные частицы, образующиеся в кинематической области, запрещенной для рассеяния на свободном нуклоне. Независимо от теоретической интерпретации этот термин удобен для обозначения указанной кинематической области.)

Status of the pentaquark problem

• 1\textsuperscript{st} relatively certain theoretical suggestion of mass $\sim 1530$ MeV and width $< 15$ MeV:


• Experiment: \textit{about ten} papers with positive evidences;
  \textit{about ten} papers with negative results
  (some of them with higher statistics).

• Common opinion and PDG position

  (since edition of 2008):

  \textbf{Pentaquark is dead!}

  (Note, at the same time, great enthusiasm
  in searches for tetraquarks!)

Ya.I.Azimov, PNPI Winter School 2013
The rate for L~ $10^{30}$ cm$^{-2}$c$^{-1}$:

- $\sim 0.2$ c$^{-1}$
- $\sim 0.01$ c$^{-1}$
Tetraquarks in the light meson sector

Light meson sector: scalars!

Pentaquark

Glueball

Tetraquark

Hybrid

Christian S. Fischer (University of Gießen)

X(3872) as a four-quark state
Study of feasibility to detect pentaquark $\Theta^+ (\bar{\Theta}^-)$ in PANDA

S. Belostotski, S. Manaenkov, V. Petrov, D. Veretennikov

PANDA collaboration meeting 19/3,
November 4-8, 2019, GSI
Exclusive $\theta^+ (\bar{\theta}^-)$ production in p anti-p collision

Pentaquark production by K-meson exchange

Differential cross-section

\[
\frac{d\sigma}{dt} = \frac{g^4 [(M_\theta - m_N)^2 - t]^2}{16\pi s(s - 4m_N^2)(M_K^2 - t)^2}
\]

$m_N$ is nucleon mass
$M_K$ is $K^0$ mass
$M_\theta$ is pentaquark mass
$s, t$ are the Mandelstam variables

Total cross-section

\[
\sigma_{tot} = \frac{g^4}{16\pi s(s - 4m_N^2)} \left\{ [(M_\theta - m_N)^2 - M_K^2]^2 \left[ \frac{1}{M_K^2 - \tau_{\max}} \right] \right\}
\]

$\theta^+$ total width

\[
\Gamma_{tot} = \frac{g^2 P_0^3}{\pi [(M_\theta + m_N)^2 - M_K^2]}
\]

$P_0$ is momentum of $K^0$ in $\theta^+$ rest system