Study of the deuteron spin structure at short distances and reactions mechanisms at LHE/LHEP JINR

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VBLHEP, 28 March 2025

Outline

- **Motivation**
- **Review of dA- inclusive breakup in collinear geometry and dp- backward elastic scattering data.**
- **Results on inclusive breakup and pion production at large transverse momenta in dA-interaction.**
- **Discussion of the polarization data for exclusive channel dp→ppn.**
- **Possible continuation at Nuclotron JINR.**
- **Conclusion**

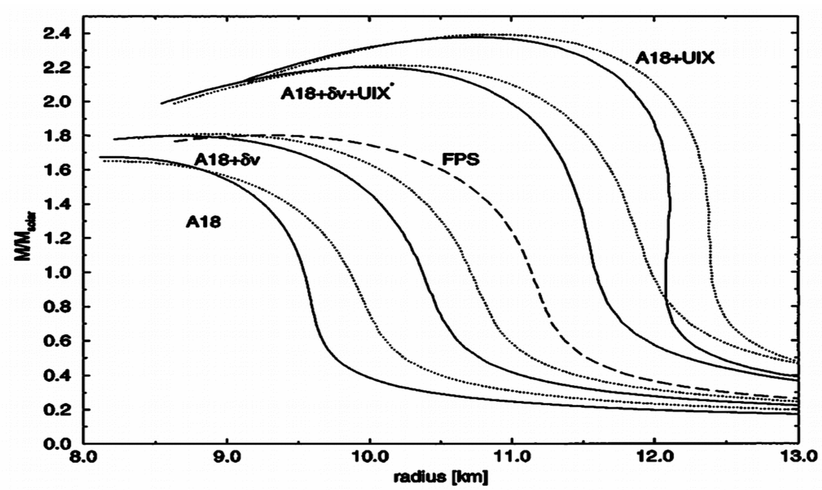
Motivation of the dp interaction studies

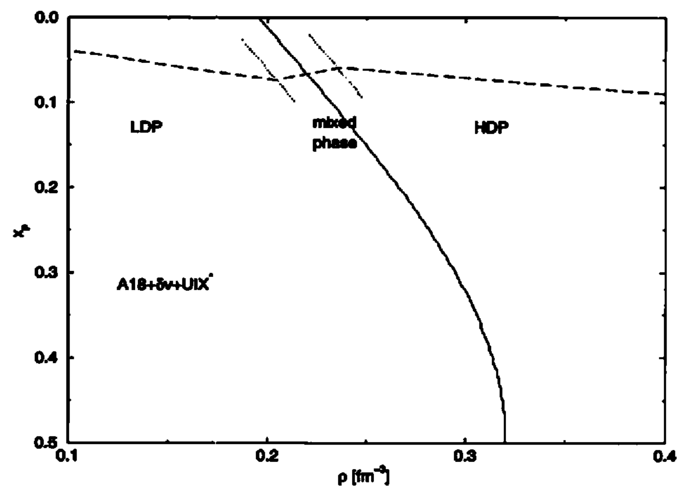
- Nucleon-nucleon interaction at short distances (including its mass off-shell behaviour)
- Relativistic effects
- Transition to the nonnucleonic degrees of freedom
- Contribution of three-nucleon forces (3NFs)

Deuteron : J=1, S=1, I=0

Few nucleons systems as a tool for dense matter studies

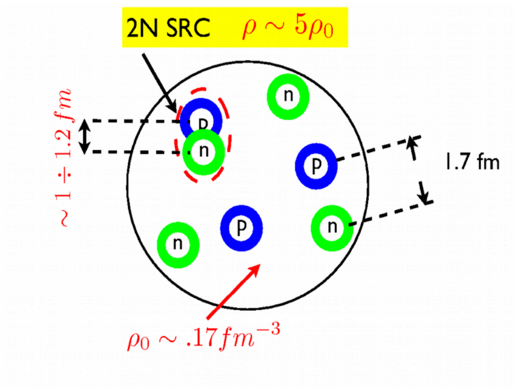
Alternative (to HIC) way to obtain the information on the EOS at extreme densities (neutron stars) is the studies of the few nucleon systems.

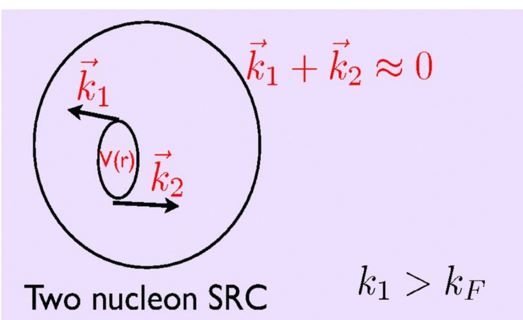




Relativistic effects in 2NF and contribution of 3NF play very important role. (**A.Akhmal et al, Phys.Rev. C58 (1998) 1804**)

Short range correlations (SRCs)





Summary of the theoretical analysis of the experimental findings

practically all of which were predicted well before the data were obtained

- More than ~90% all nucleons with momenta k≥300 MeV/c belong to two nucleon SRC correlations — BNL + Jlab +SLAC
- Probability for a given proton with momenta 600> k > 300 MeV/c to belong to **pn** correlation is ~ 18 times larger than for **pp** correlation — BNL + Jlab
- Probability for a nucleon to have momentum > 300 MeV/c in medium nuclei is ~25% — BNL + Jlab 04 +SLAC 93
- Probability of non-nucleonic components within SRC is small - < 20% - 2N SRC mostly build of two nucleons not 6q, ΔΔ,... — BNL + Jlab +SLAC
- Three nucleon SRC are present in nuclei with a significant probability — Jlab 05

Poor data base on the spin parts of the 2N and 3N short-range correlations. This motivates the necessity to study light nuclei structure at short distances.

Experiments at JINR allowed to reach $p_T \sim 1$ GeV/c

Relativistic effects

- The principal feature of the relativistic quantum mechanics is the impossibility to separate the relative motion of the constituents and motion of the composite system as a whole. This leads to the dependence of the **relativistic** wave function not only on the relative momenta of the nucleons $\vec{\mathbf{q}}$ inside the composite system, but also on the total momentum $\vec{\mathbf{p}}$ of this system

$$\Psi = \Psi(\vec{\mathbf{q}}, \vec{\mathbf{p}})$$

- Therefore, **relativistic** wave function is the function of the relative momentum $\vec{\mathbf{q}}$ in each new reference system.

- However, it is enough to know wave function in the infinite momentum frame, $\vec{\mathbf{p}} \to \inf$, where the structure of the wave function simplifies. Namely, the dependence on $|\vec{\mathbf{p}}|$ disappears, only the dependence on the direction of the vector $\vec{\mathbf{n}} = \vec{\mathbf{p}}/|\vec{\mathbf{p}}|$

$$\Psi = \Psi(\vec{\mathbf{q}}, \vec{\mathbf{n}})$$

Relativization schemes

For the case of the deuteron vertex the internal momentum $\mathbf{k}$:

$$k = \sqrt{\frac{m_p^2 + \mathbf{k}_T^2}{4x(1-x)} - m_p^2},$$
$$x = \frac{E_p + p_{pl}}{E_d + p_d},$$

where $\mathbf{E_d}$ and $\mathbf{p_d}$ are the energy and momentum of the initial deuteron, respectively, $\mathbf{p_{pl}}$ is the longitudinal momentum of the proton, $\mathbf{m_p}$ and $\mathbf{E_p}$ are the mass and energy of the proton, respectively.

- Minimal relativization scheme (Dirac, Weinberg, Frankfurt& Strikman)
- Bete-Salpeter equation solving (Tjon&Keisler, Bondarenko et al.)
- Quasi-potential wave functions (Gross, Braun&Tokarev, Kaptari et al.)
- Covariant theory on the light cone (Karmanov et al.)

Deuteron wave function on the light cone

Relativistic deuteron wave function on light cone is defined by **6** invariant functions $\mathbf{f_1}, ..., \mathbf{f_6}$ (instead of **2** in the non-relativistic case), each of them depends on 2 scalar variables $\mathbf{k}$ and $z = cos(\widehat{\mathbf{kn}})$:

$$\psi(\mathbf{k},\,\mathbf{n}) \;=\; \frac{1}{\sqrt{2}}\sigma f_1 + \frac{1}{2}\left[\frac{3}{k^2}\mathbf{k}(\mathbf{k}\cdot\sigma) - \sigma\right] f_2 + \frac{1}{2}\left[3\mathbf{n}(\mathbf{n}\cdot\sigma) - \sigma\right] f_3 + \frac{1}{2k}[3\mathbf{k}(\mathbf{n}\cdot\sigma) + 3\mathbf{n}(\mathbf{k}\cdot\sigma) - 2\sigma(\mathbf{k}\cdot\mathbf{n})] f_4 + \sqrt{\frac{3}{2}}\frac{i}{k}[\mathbf{k}\times\mathbf{n}] f_5 + \frac{\sqrt{3}}{2k}[[\mathbf{k}\times\mathbf{n}]\times\sigma] f_6,$$

$$(\mathbf{n}\cdot\mathbf{k}) = (\frac{1}{2} - \alpha)\cdot\sqrt{\frac{m_p^2 + \mathbf{p}_T^2}{\alpha(1-\alpha)}}.$$

V.A.Karmanov, J.Carbonell et al.

Dependence of the deuteron structure on 2 internal variables

Non-nucleonic degrees of freedom

When the distances between the nucleons are comparable with the size of the nucleon, the nucleon- nucleon interaction is a non-local.

The fundamental degrees of freedom, quark and gluons in the frame of QCD, begin also to play a role at the internucleonic distances comparable with the size of the nucleon.

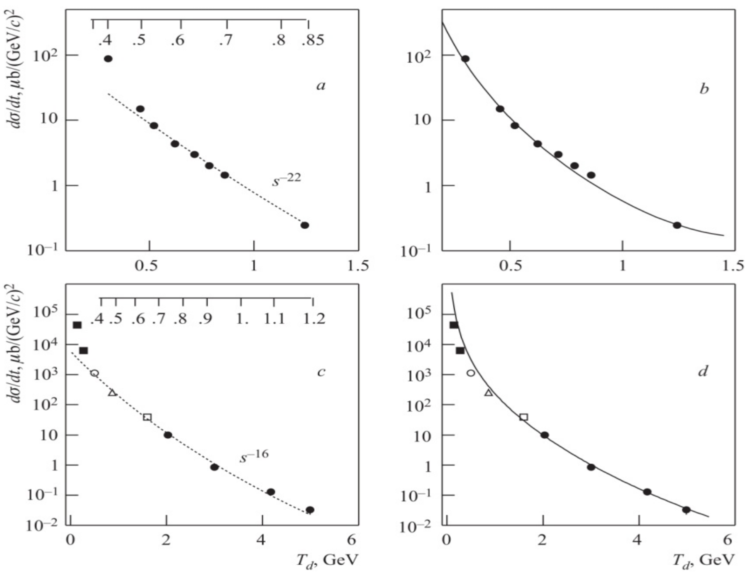
They can manifest as ΔΔ, NN*, N*N*, 6q etc.components.

Fundamental (quark) degrees of freedom

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:

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

Matveev, Muradyan, Tavkhelidze   self- similarity
Brodsky, Farrar, Lepage   pQCD
Polchinski, Strassler   AdS/QCD correspondence



For the reaction **dd → ^{3}Hen**

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

For the reaction **dp → dp**

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

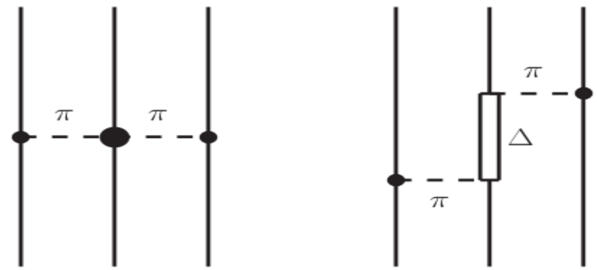
Similar rules for dp-inclusive breakup:
$\sim(1-x)^5$

Picture is taken from

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

Three Nucleon Forces

- **Modern NN potentials (CD-Bonn, AV-18, Njimegen etc.) accurately reproduce the NN data set up to about 350 MeV. However they fail in the description of the triton binding energy and data on unpolarized dp-elastic scattering and breakup.**
- **Incorporation of three nucleon forces (3NF), when interaction depends on the quantum numbers of the all three nucleon, allows to reproduce the binding energy of the three-nucleon bound systems and the data on unpolarized dp- interaction.**

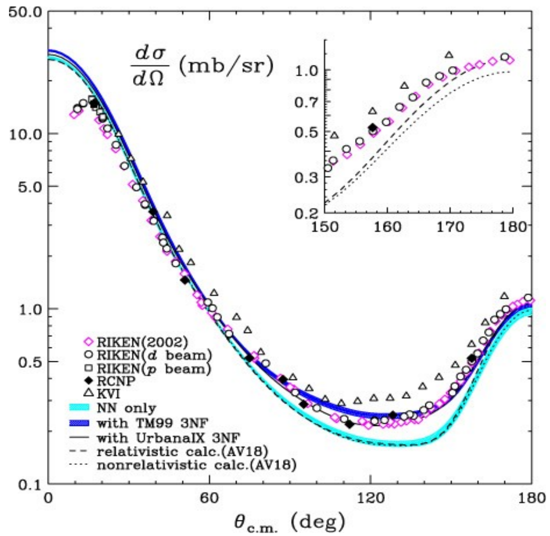


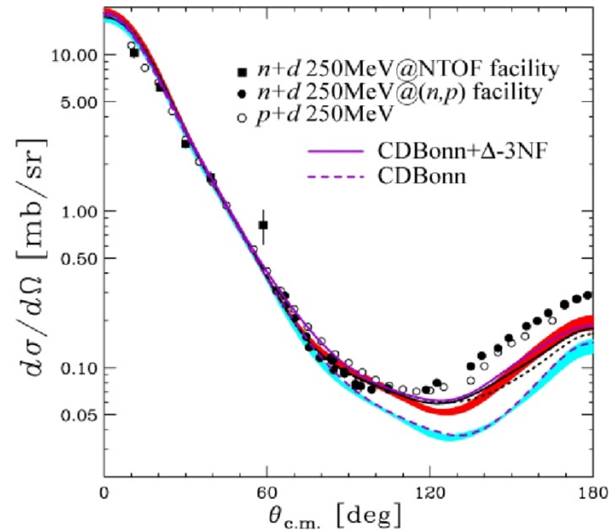
- Tucson-Melbourne
- Brazil
- Urbana-IX
- Fujita-Miyazawa ($N\Delta$)
- Chiral Effective Field Theory

Needs to be very careful: according to the theorem of W.N.Polyzou and W.Gloeckle, Few Body Syst. 9 (1990) 97, off-shell behaviour of 2NF can imitate 3NF effect.

Triton binding energy without 3NF:
Y.Fujiwara et al., Phys.Rev.C66 (2002) 021001(R)

Cross section in dp- elastic scattering at intermediate energies





The differential cross section in elastic Nd scattering at the energy of 135 (left figure) and 250 (right figure) MeV/u.

K. Sekiguchi et al., Phys. Rev. Lett. 95, 162301 (2005)

K. Hatanaka et al., Phys. Rev. C 66, 044002 (2002)

The cross section data for dp- elastic scattering are reproduced well up to 150 MeV taking into account 3NF. Manifestation of three-nucleon forces effect in the cross-section of dp-elastic scattering at this energy: up to 30% in the vicinity of Sagara discrepancy. But the problems in the description are at higher energies. New types of 3NF (short range, s-channel contributions).

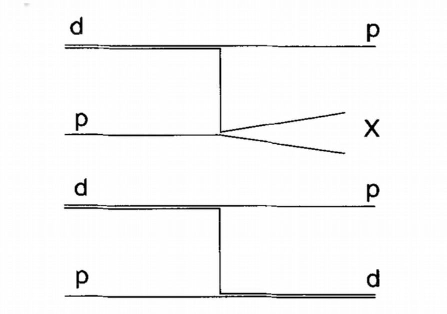
Status to the late 1980s

Two competing scientific centers with polarized deuteron beam: LHE, JINR (Dubna, USSR-RF) and LNS (Saclay, France) with Synchrophasotron and Saturne-2 accelerators, respectively.

Similarity for

dA→p(0°)X **in relativistic impulse approximation (RIA)**

dp→pd **in one-nucleon exchange approximation (ONE)**



Cross section is proportional to

$u^2(k) + w^2(k)$ **for dA→p(0°)X**

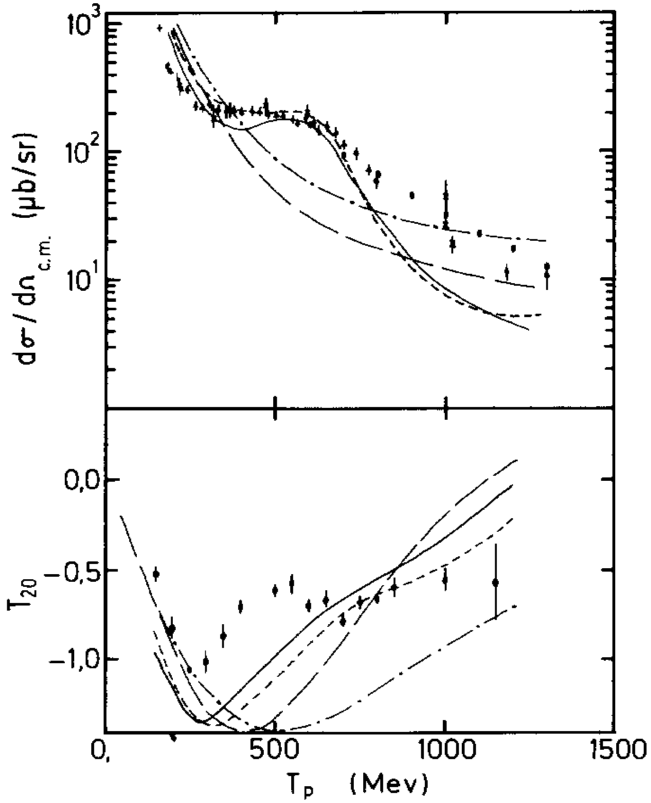
$(u^2(k) + w^2(k))^2$ **for dp→pd**

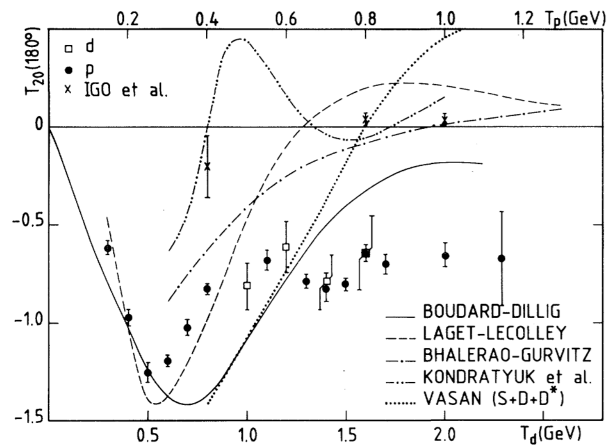
Tensor analyzing power

$$T_{20} = \frac{w(k)}{\sqrt{2}} \frac{2\sqrt{2}u(k) - w(k)}{u^2(k) + w^2(k)}$$

L.L.Frankfurt, M.I.Strikman, PLB76 (1978) 285
S.S.Vasan, PRD8 (1973) 4092; V.A.Karmanov, YF34 (1981) 1020

SATURNE-2 results to the late 1980s

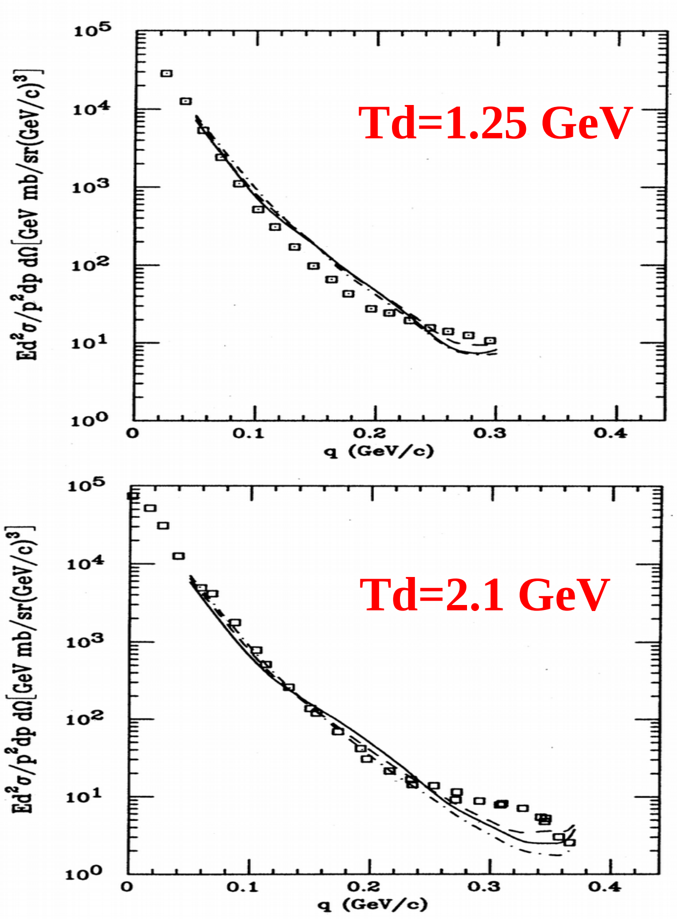


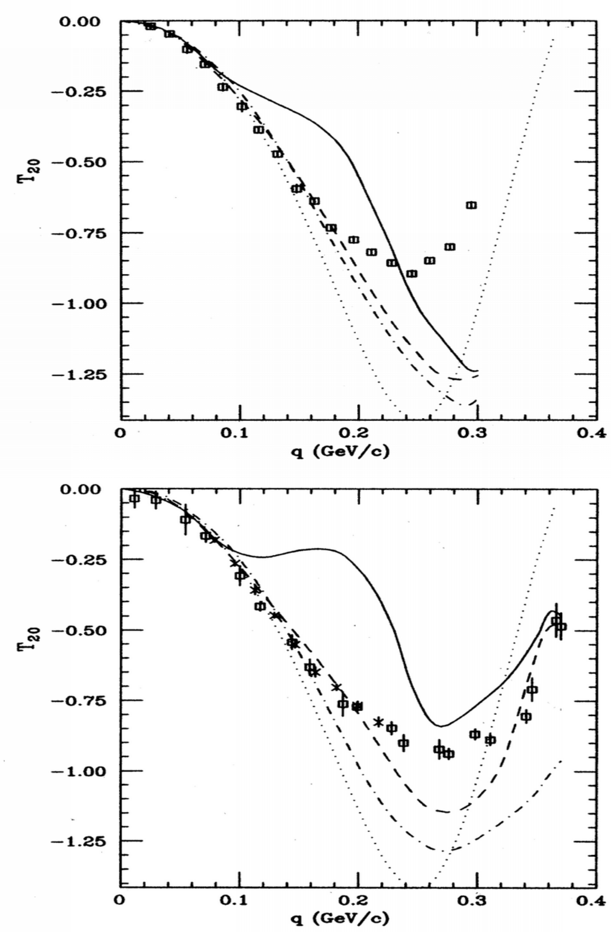


Strong deviation of T_{20} from ONE predictions:
negative value at large k,
smaller than $-\sqrt{2}$ at k=300 MeV/c

J.Arvieux et al., PRL50 (1983) 19
J.Arvieux et al., NPA431 (1984) 613

SATURNE-2 results to the late 1980s

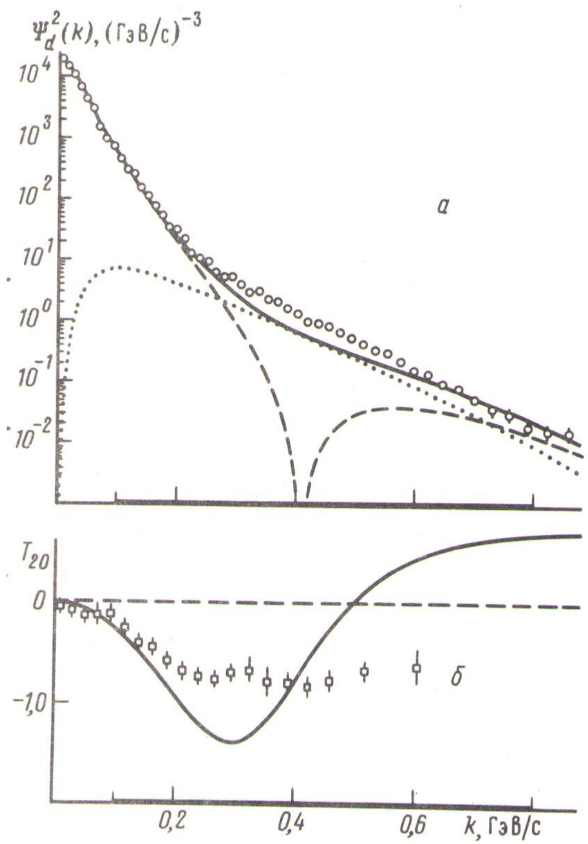




C.F.Perdrisat et al., PRL59 (1987) 2840
V.Punjabi et al., PRC39 (1989) 608

Strong deviation of T_{20} from RIA
Weak dependence on the target A

Synchrophsotron results at the late 1980s



Shoulder in cross section at k=300 MeV/c → New physics (6q component).

Strong deviation of T_{20} from RIA predictions:
negative value at large k,
smaller than $-\sqrt{2}$ at k=300 MeV/c

1-st JINR award in 1989
HZDR (Rossendord) award in 1989

V.G.Ableev et al., NPA 393 (1983) 491
V.G.Ableev et al., JETP Lett.47 (1988) 649

New polarization observable

Experiments performed at both facilities demonstrated the following results.

1. $u^2(k) + w^2(k)$ extracted from the cross section data for the both reactions (dA→pX and dp→pd) within RIA have the same behaviour: shoulder at k=300 MeV/c

2. strong deviation of T_{20} from RIA and ONE predictions: negative value at large k, smaller than $-\sqrt{2}$ at k=300 MeV/c

Transverse polarization transfer from vector polarized deuteron to proton for dA→ pX

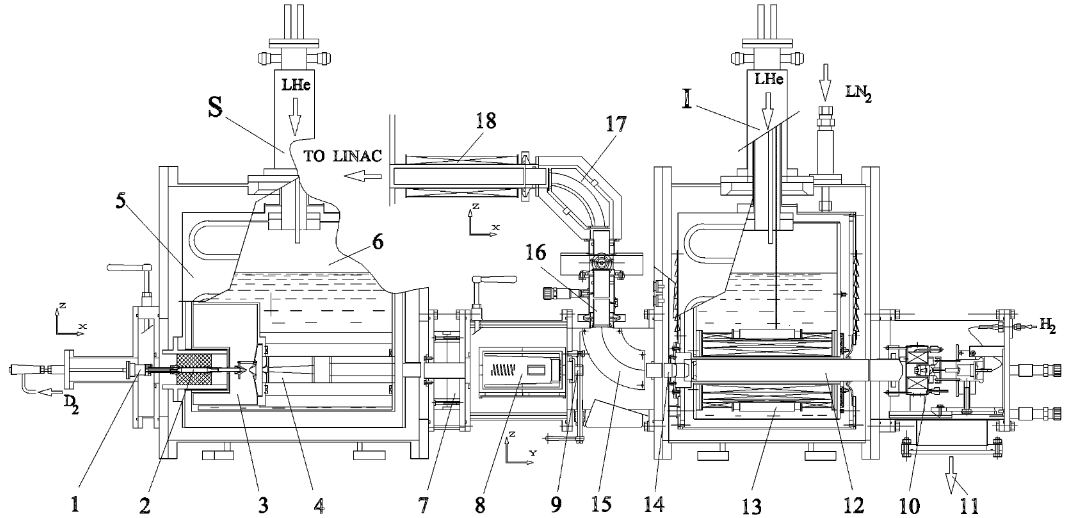
$$\kappa_0 = \frac{u(k)^2 - w(k)^2 - u(k) \cdot w(k)/\sqrt{2}}{u^2(k) + w^2(k)}$$

L.L.Frankfurt, M.I.Strikman, NPA 405 (1983) 557
A.Boudard, C.Wilkin, J.Phys.G:Nucl.Phys. 11 (1985) 583

1989

36=3*12 years ago I began my work at JINR

Polarized ion source POLARIS

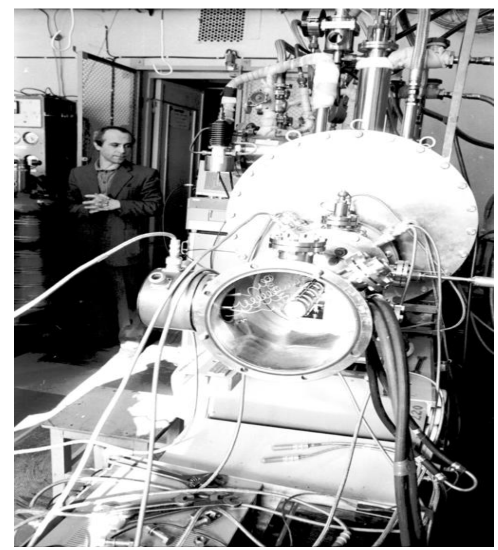


Yu.K.Pilipenko

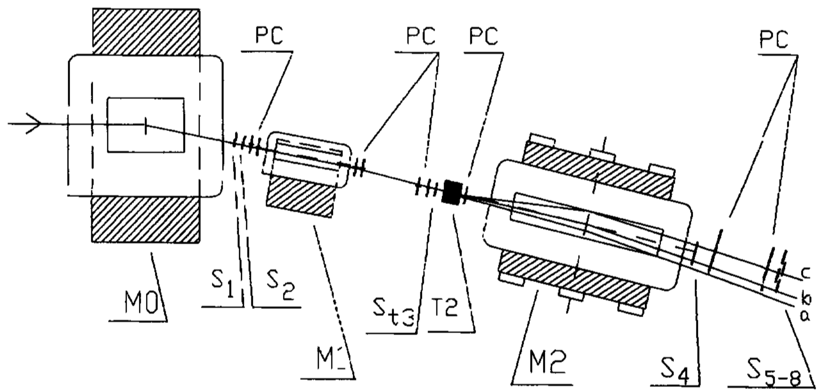
Intensity up to $3 \cdot 10^9$ d/pulse (peak)

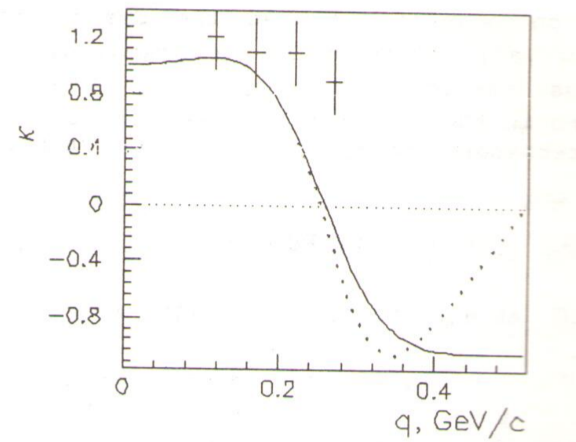
Pyy= ±0.75-0.80
Py = ±0.50-0.57

Yu.K.Pilipenko et al., NIM A536 (2005) 237



First measurements of κ_0 at ALPHA setup





I.M.Sitnik – leader

B.Kuehn – Live target

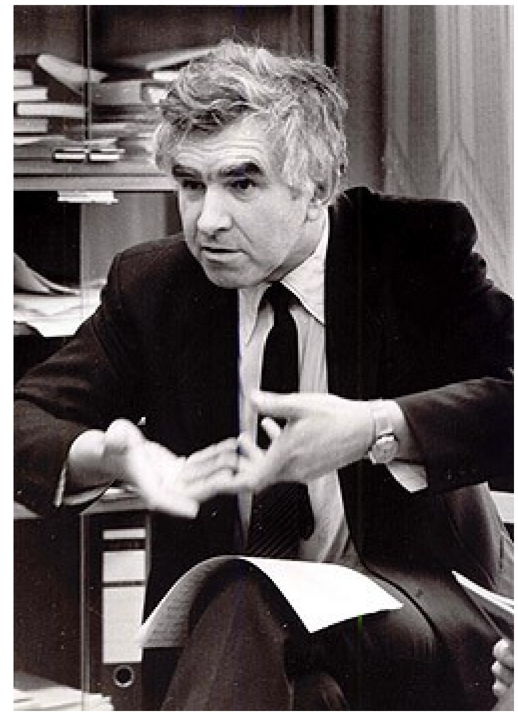
Very exotic behaviour!
QCD?
Enormous deuteron D-state behaviour?

Presented at 7th Conf. On Polar.Phen.in Nucl.Phys., July 1990, Paris

First measurements of κ_0 at ANOMALON setup

Quite low experiment luminosity (FOM) at ALPHA
Possible problems with analyzing powers for proton polarimetry

L.N.Strunov



V.A. Sviridov

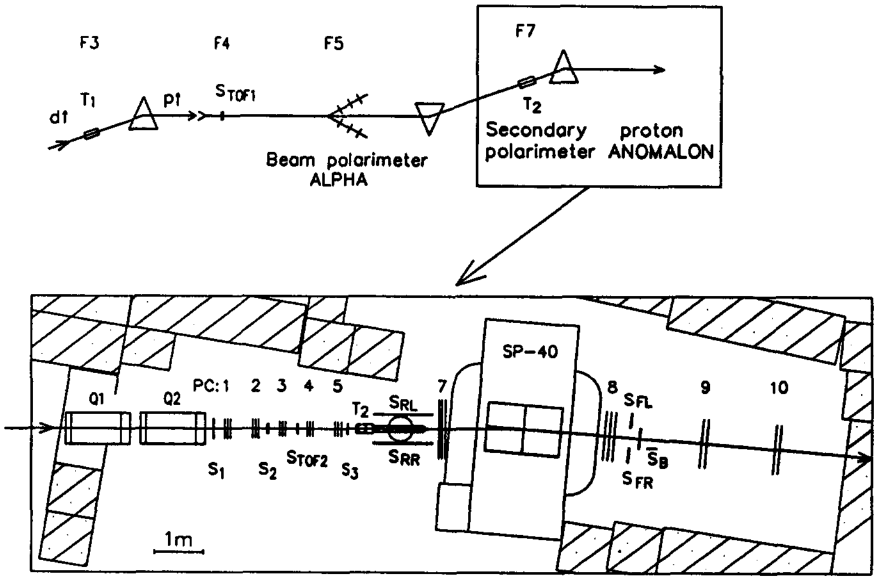
1m hydrogen target

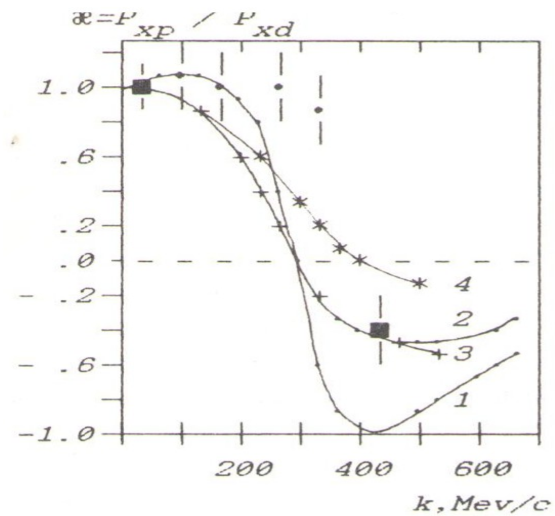
Detection of pp-elastic scattering

Close to 2π acceptance

ANOMALON setup!

First measurements of κ_0 at ANOMALON setup



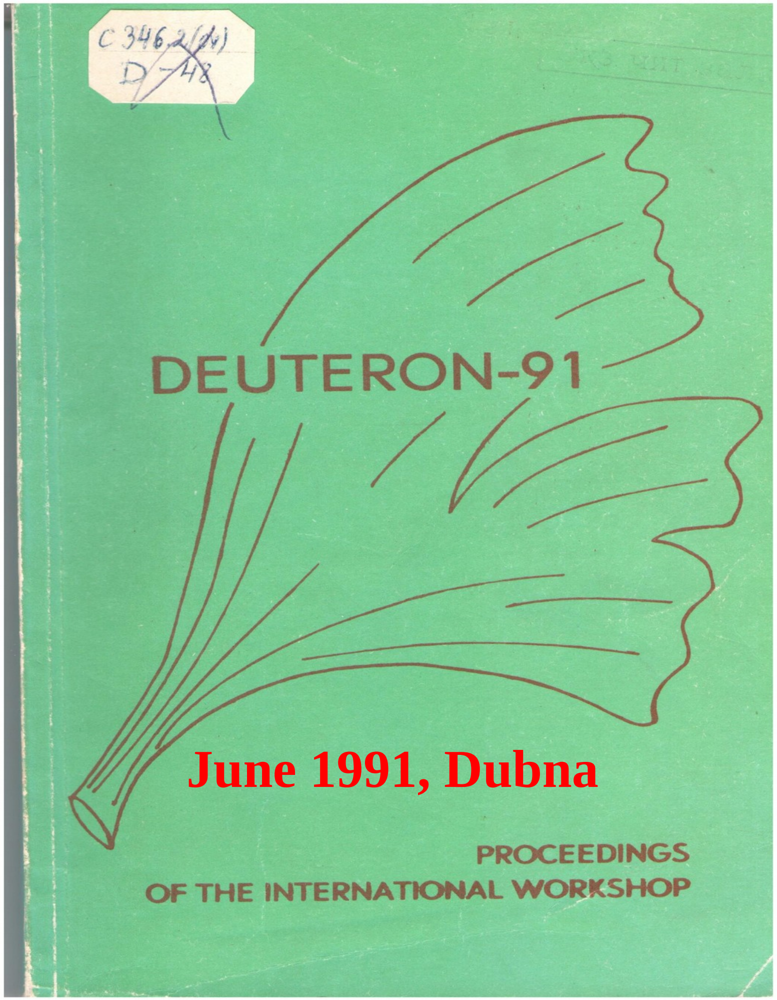


A.V.Zarubin -leader

V.V.Perelygin
ANOMALON team

ALPHA-team
L.S. Zolin&Co
B.Morozov &Co

Negative value of κ_0 at k=400 MeV/c consistent with traditional approaches



B. Kuehn - chairman
S.Shimansky – scientific secretary.

Start of several collaborations

Dubna-Saclay-Virginia

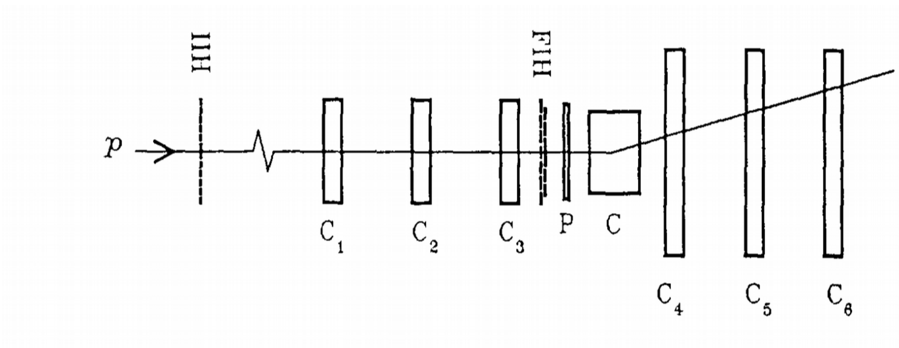
(Sitnik, Tomasi-Gustaffson, Perdrisat)

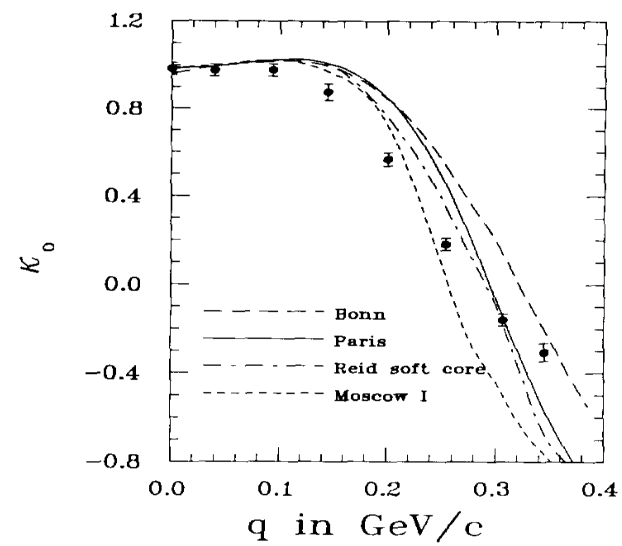
ANOMALON
(Zarubin, Strunov, Belostotsky, Horikawa)

First steps toward Delta-Sigma (Strunov, Lehar)

First motivation of polarization effects in meson production

Measurements of κ_0 in $dp \to pX$ at SPES4-POMME





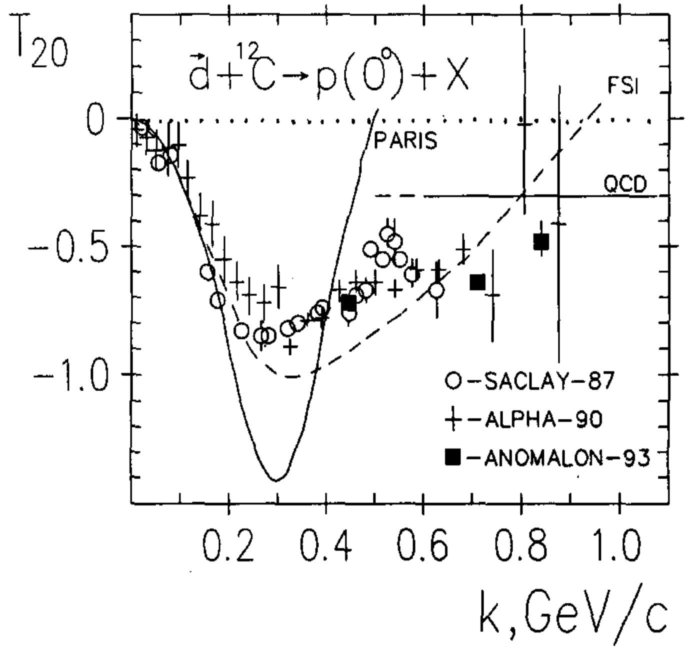
SATURNE-2

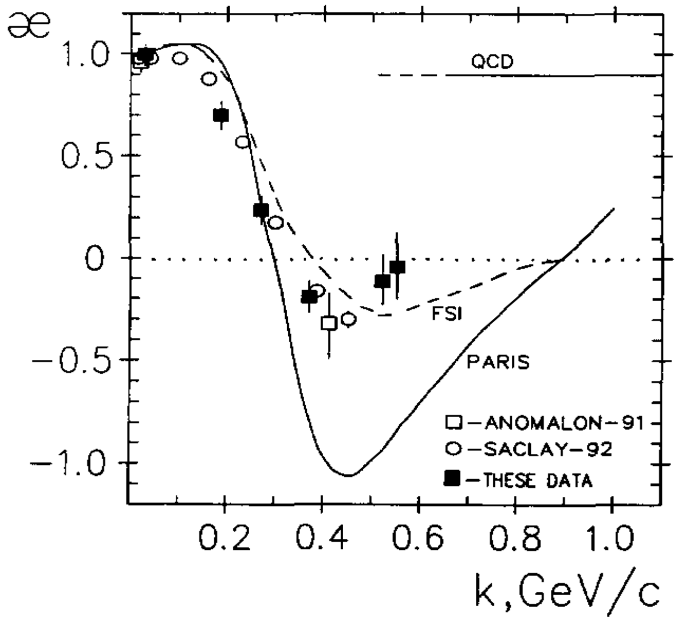
SPES4 spectrometer
POMME calibrated proton polarimeter with carbon analyzer

E.Cheung et al., PLB284 (1992) 210

Behaviour of κ_0 is consistent with the traditional approaches

Measurements of κ_0 in $dC \rightarrow pX$ at ANOMALON

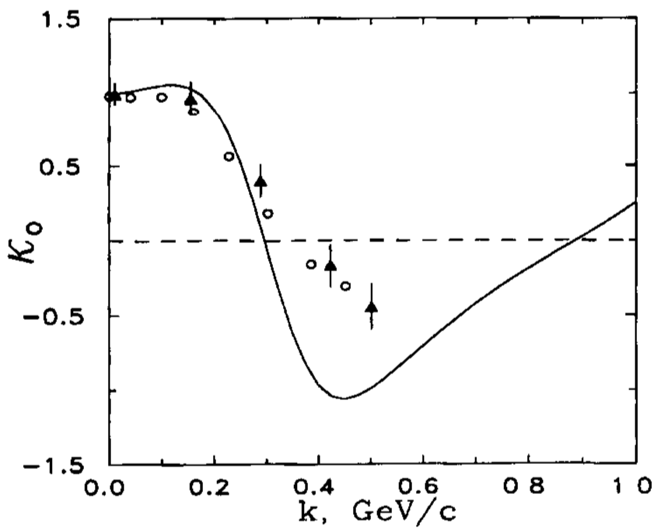


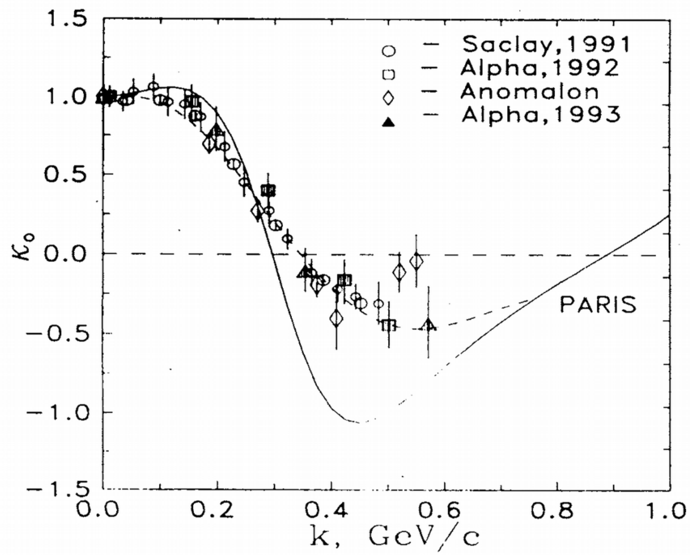


A.A.Nomofilov et al., PLB325 (1994) 327

Behaviour of κ_0 is consistent with the traditional approaches taking into account pion production, while behaviour of T20 is not!

Measurements of κ_0 in $dC \rightarrow pX$ at ALPHA setup





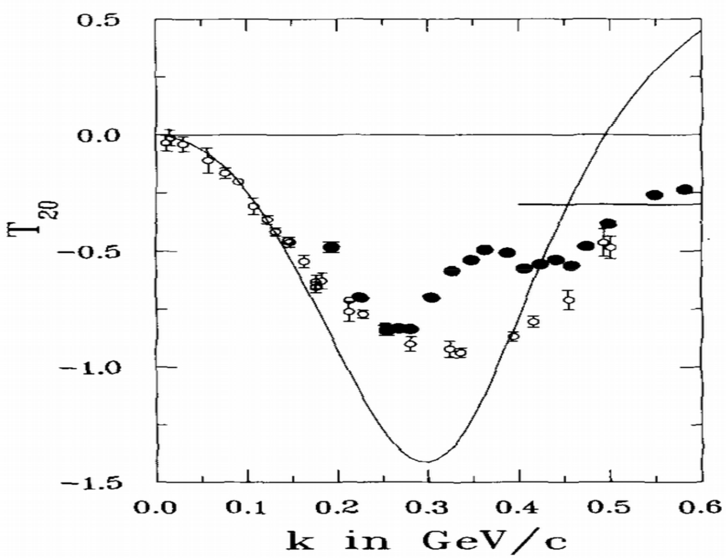
Behaviour of κ_0 is consistent with the traditional approaches taking into account pion production.

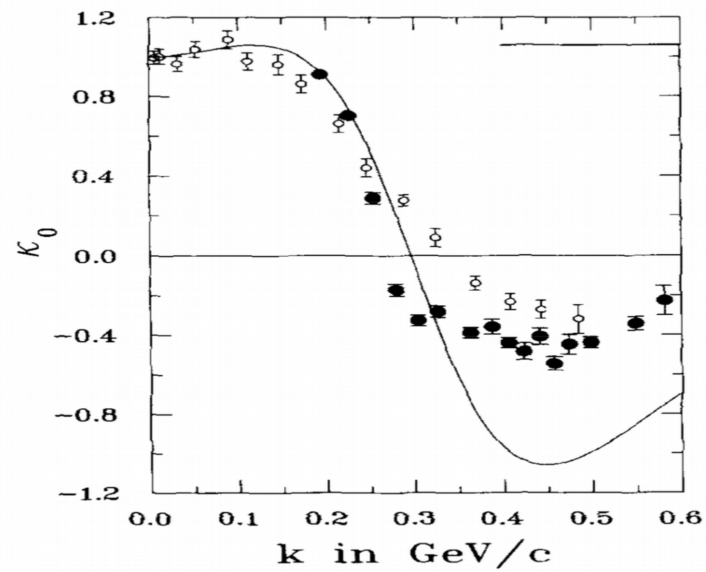
B.Kuehn et al., PLB334 (1994) 298

L.S.Azhgirey et al., JINR RC3[77](1996) 23

pCH_2 analyzing power is higher than pCH analyzing power at 4.5 GeV/c.

Measurements of T_{20} and κ_0 in $dp \to pd$ at SATURNE2





C.F.Perdrisat, V.Punjabi - leaders

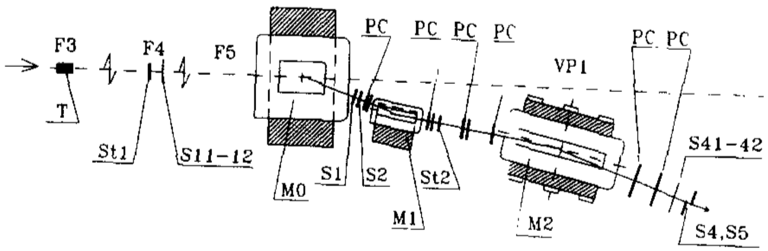
$$\kappa_0 = \frac{u(k)^2 - w(k)^2 - u(k)\cdot w(k)/\sqrt{2}}{u^2(k) + w^2(k)}$$

V.Punjabi et al., PLB350 (1995) 178

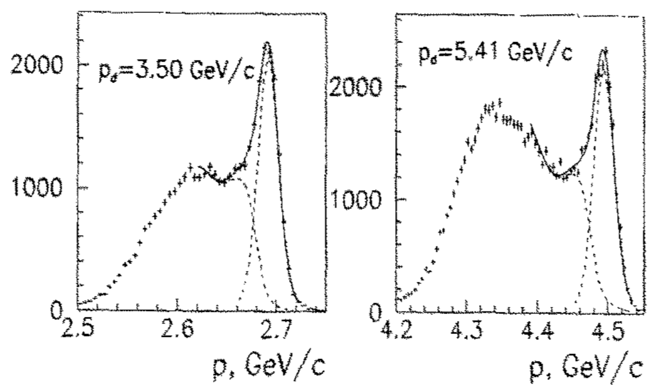
VPL -1992
I.M.Sitnik,V.P.Ladygin,M.P.Rekalo,PAN57(1994)2170

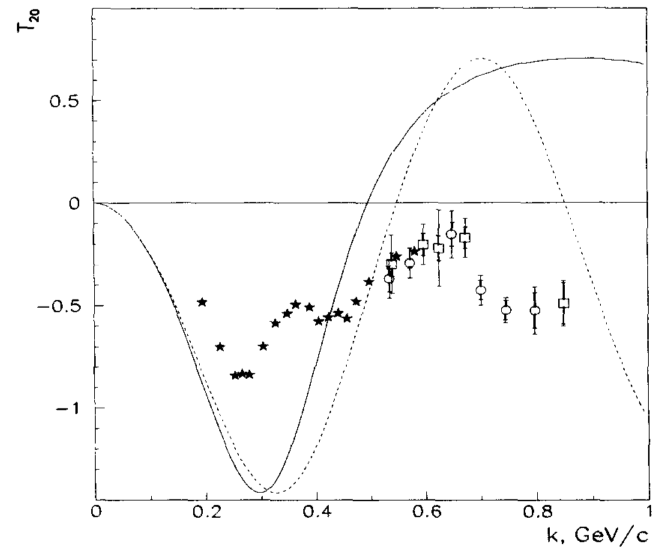
Behaviour of T_{20} and κ_0 is completely different for $dp \to pd$ and $dp \to pX$.
Unexpected structures in T_{20} for $dp \to pd$
Different reaction mechanisms, different degrees of freedom(?)

Measurements of T_{20} in $dp \rightarrow pd$ at ALPHA



dp/p =0.3%



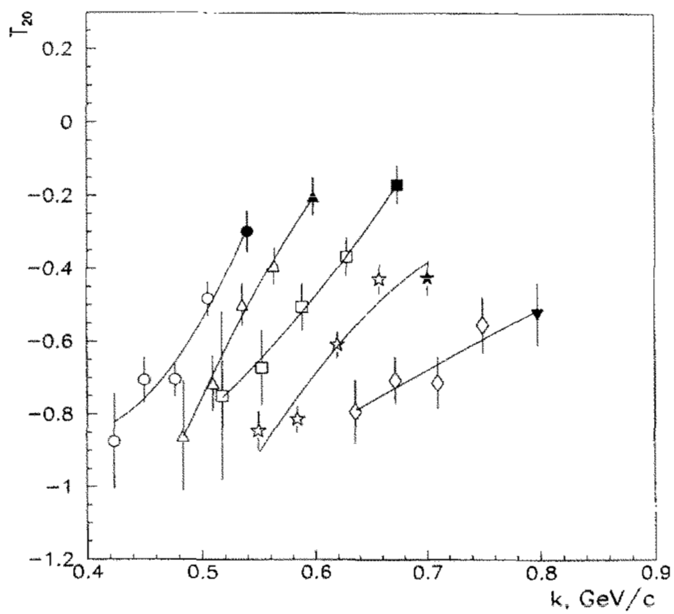


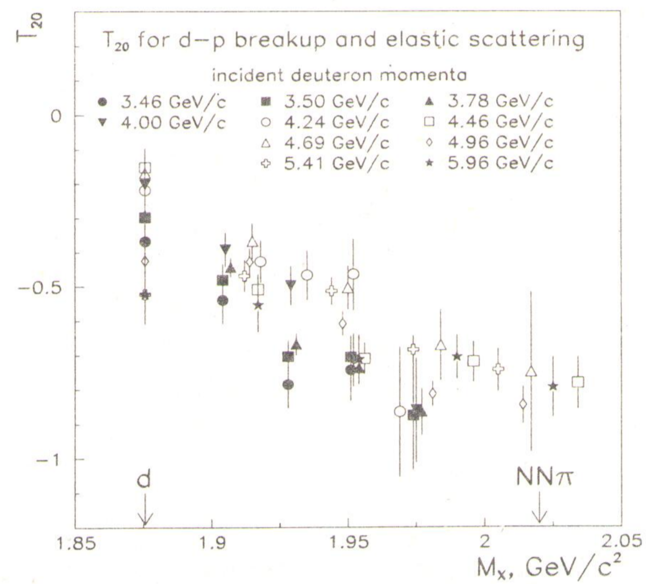
I.M.Sitnik -leader

L.S.Azhgirey et al., PLB 391(1997) 22

Behaviour of T_{20} is completely different from ONE predictions.
New unexplained structure at k=600 MeV/c.
Negative T_{20} value at k>700 MeV/c.

Measurements of T_{20} in $dp \to p\ (pn)$ at ALPHA



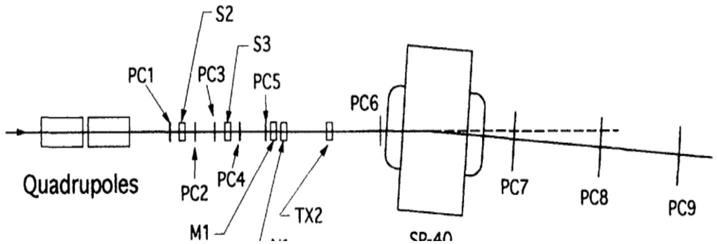


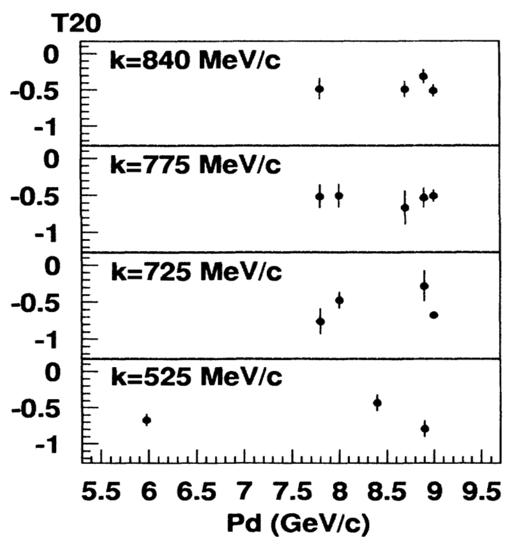
I.M.Sitnik -leader
L.S.Azhgirey and S.Nedev -leading role in the data treatment.

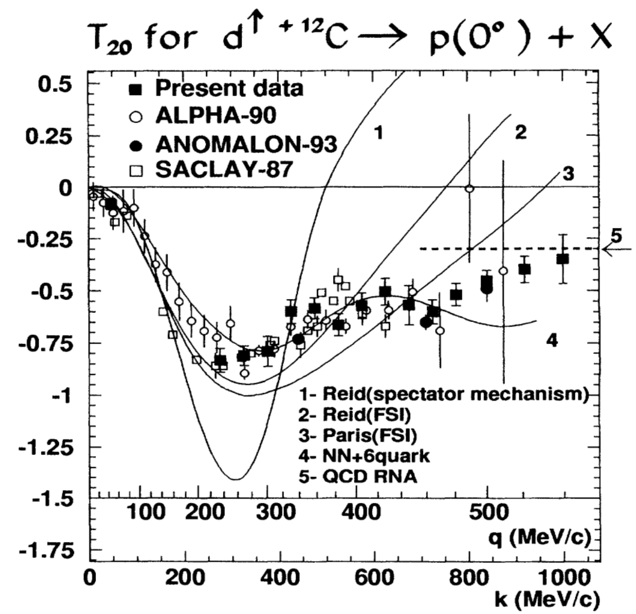
L.S.Azhgirey et al., PLB 391(1997) 22
L.S.Azhgirey et al., PAN 61 (1998) 494

Absence of k-scaling in T_{20} behaviour for $dp \to p\ (np)$.
Significant role of FSI.
Dependence on k and Mx $\to$ first hint on dependence on 2 variable

Measurements of T_{20} in $dC \rightarrow pX$ at ANOMALON





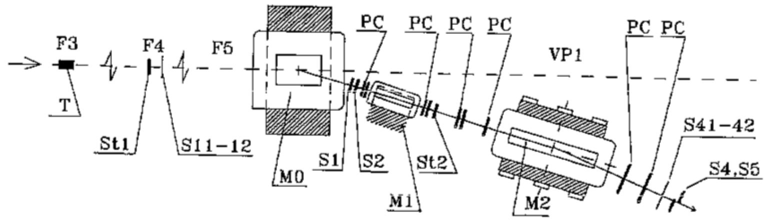


T_{20} at large k has large negative value inconsistent with the traditional approaches predictions.

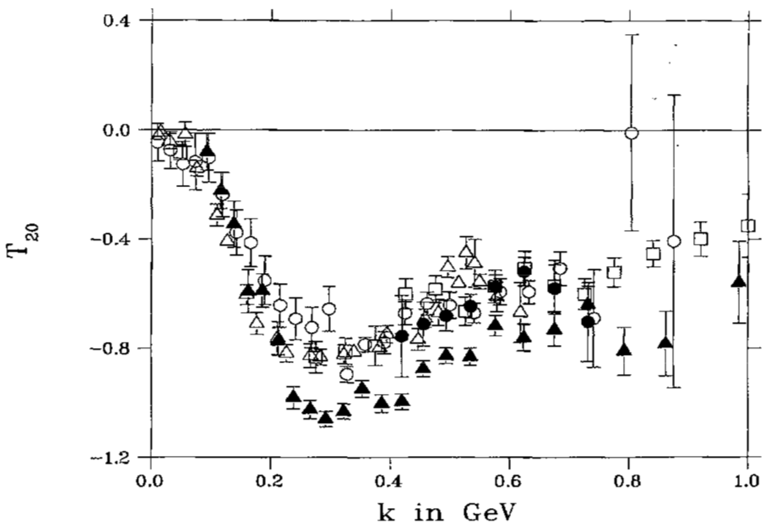
T.Aono et al., PRL74 (1995) 4997

Model dependent values of T_{20} ("RIA" is used)

Measurements of T_{20} in $dA \to pX$ at 9 GeV/c at ALPHA

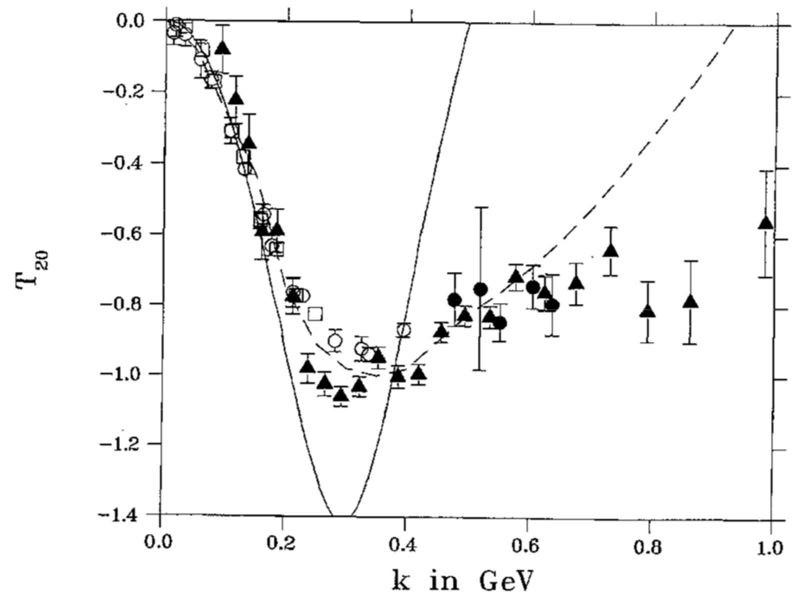


dp/p=1%



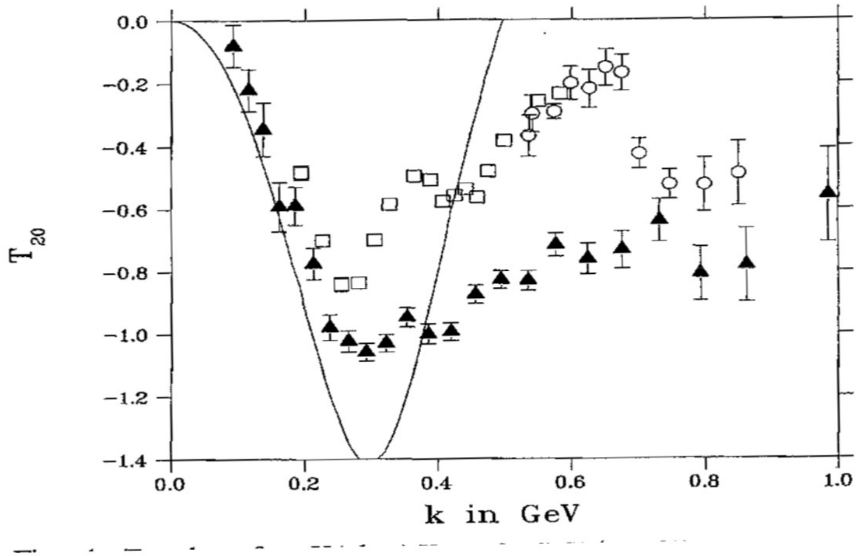
N.M.Piskunov – leader

L.S.Azhgirey et al., PLB387 (1996) 37



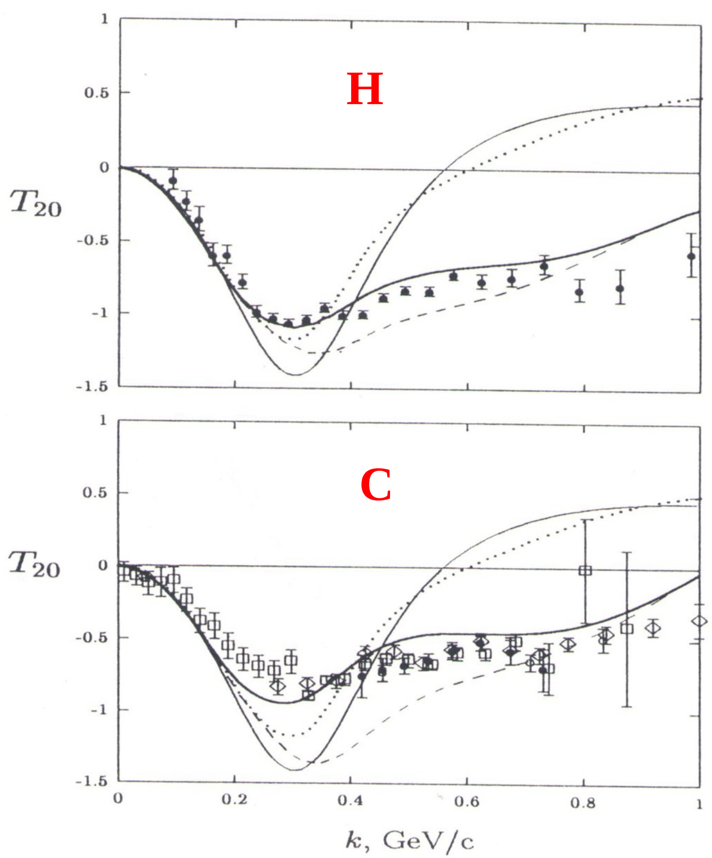
T_{20} at large k (>700 MeV/c) has large negative value inconsistent with the traditional approaches predictions.
T_{20} weakly depends on the energy.
$|T_{20}|$ for carbon target is 30-40% less than for hydrogen target.

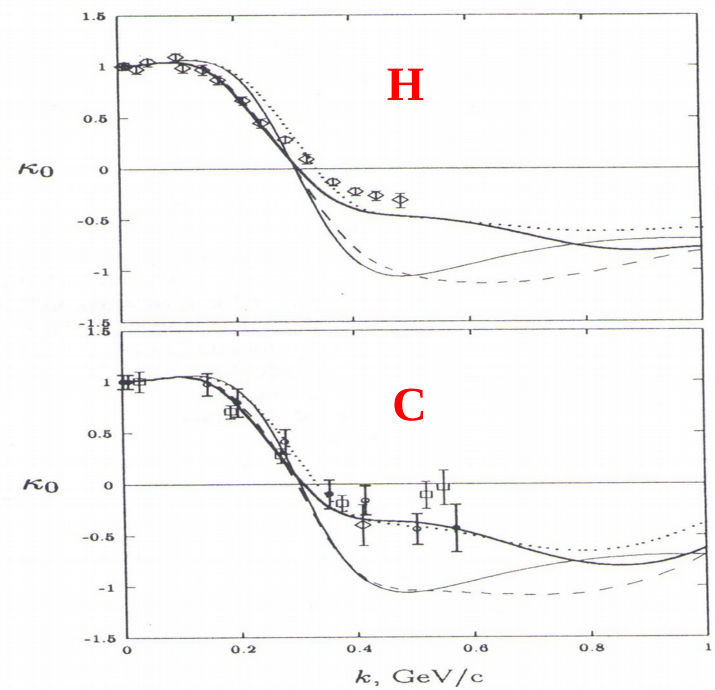
Results on T_{20} in $dA \rightarrow pX$ and $dp \rightarrow pd$



1. T_{20} in both processes at large k (>700 MeV/c) has large negative value inconsistent with the traditional approaches predictions.
2. Reaction mechanisms are very important.
3. Unexpected structures in are observed in T_{20} behaviour in $dp \rightarrow pd$.
4. Best in the world results for $dA \rightarrow pX$:
T_{20} (H) = -0.558 ±0.150 at k=985 MeV/c
T_{20} (C) = -0.351 ±0.116 at k=1000 MeV/c

Theory for description of dp → pX and dC → pX

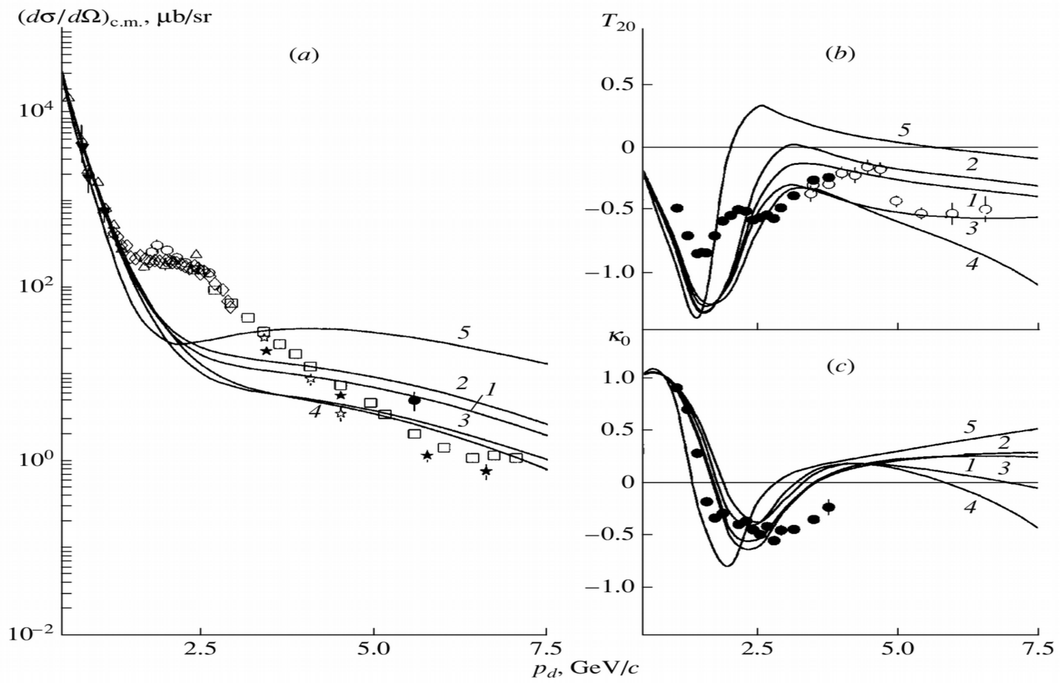




Quark Exchange + NIJM93
Minimal scheme of relativization
Glauber-Sitenko approach

A.P.Kobushkin, PLB 421 (1998) 53

Theory for description of dp → pd



L.S.Azhgirey, N.P.Yudin, PAN 63(2000) 2184

One Baryon Exchange with
1% total probability of
N*(1520),N*(1535),N*(1650),N*(1675)
Effective P-waves.

Reaction mechanisms!
L.Kaptari et al., PRC57(1998)1097
N.B.Ladygina, SciPost Phys.Proc.3(2020)053

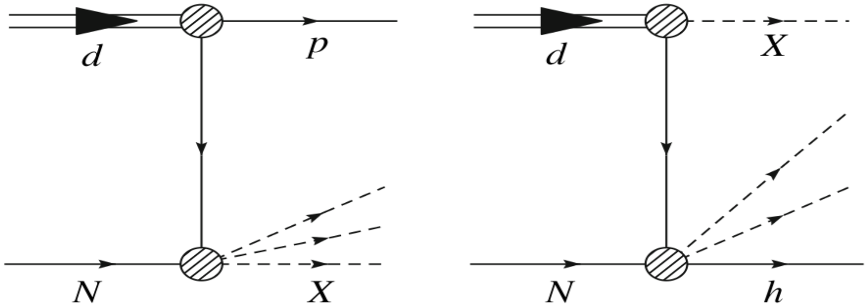
Structures in T_{20} cannot be reproduced

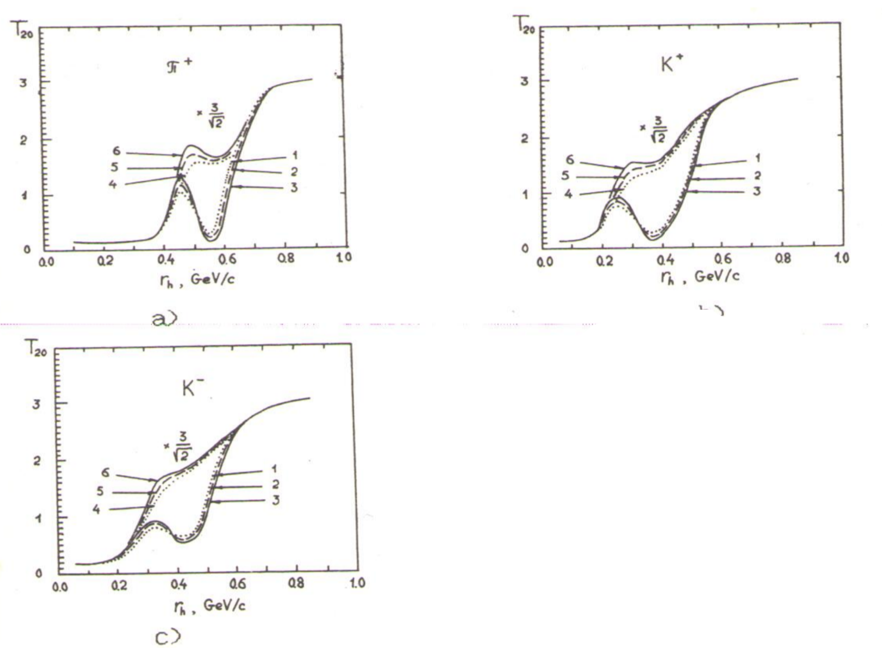
What to do?

N.G. Chernyshevsky

with polarized deuteron beam of $2\text{-}3 \cdot 10^9$ ppp ?

T_{20} in cumulative meson production





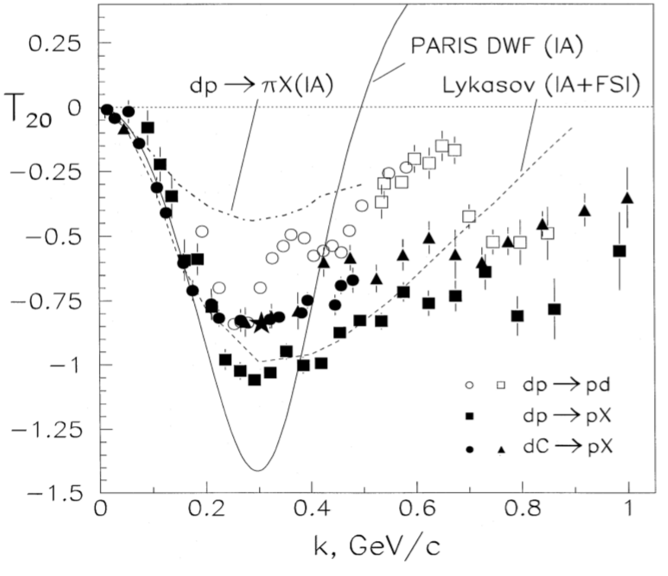
M.A.Braun, M.V.Tokarev,
In Proc. of Deuteron-91

Fiz.Elem.Chast.Atom.Yadra 22 (1991) 1237

T_{20} in cumulative meson production at SPHERE

L.S.Zolin

A.G.Litvinenko



Leaders:
L.S.Zolin,
A.G.Litvinenko

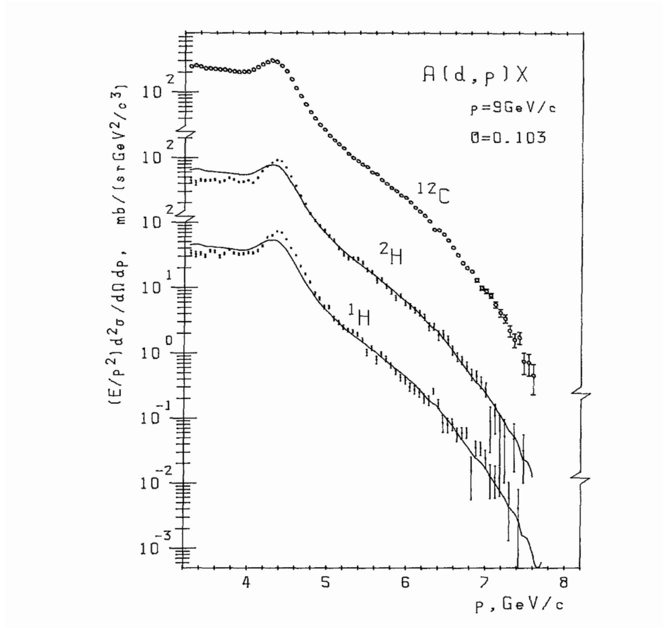
Spectrometer: VP1,4V

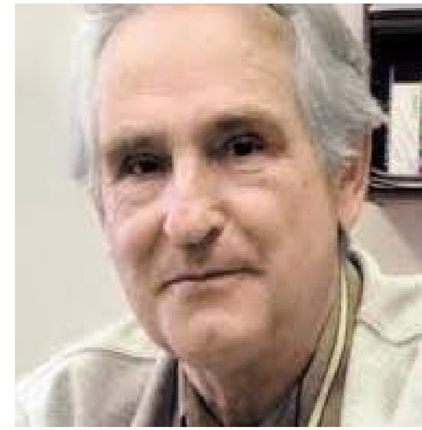
PID: TOF& aerogel

First measurements in 1995

A(d,p)X reaction at large transverse momenta (up to 1 GeV/c) of protons at MASPIK

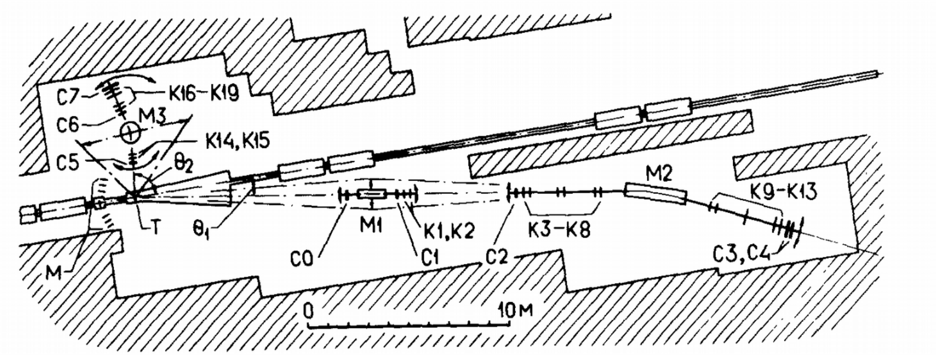
L.S.Azhgirey





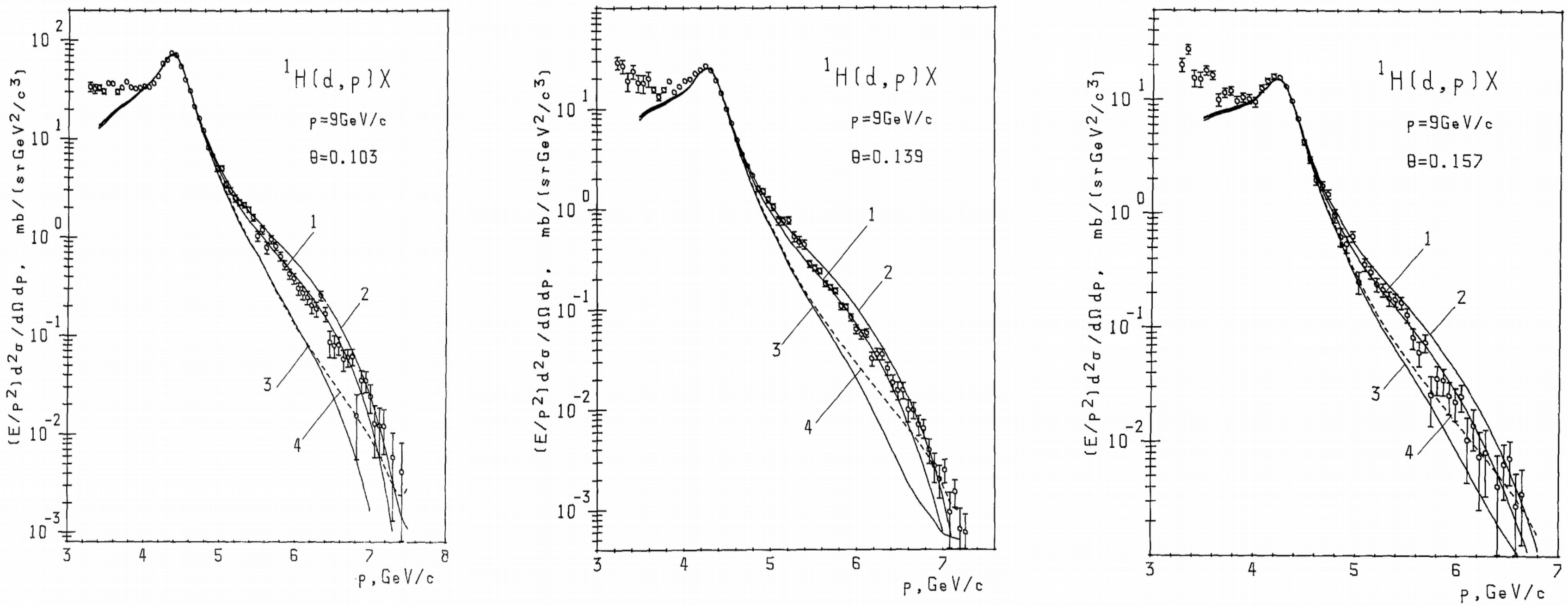
N.P.Yudin

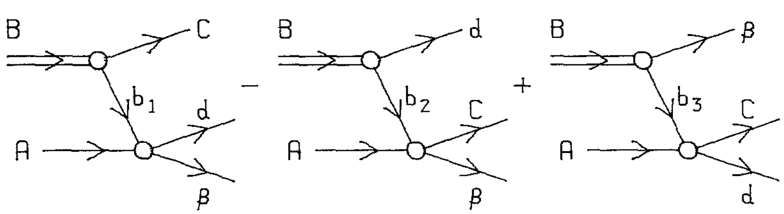
L.S.Azhgirey et al., NPA528(1991)621



H,D,C targets
Deuteron momenta 9 GeV/c
3 proton emission angles

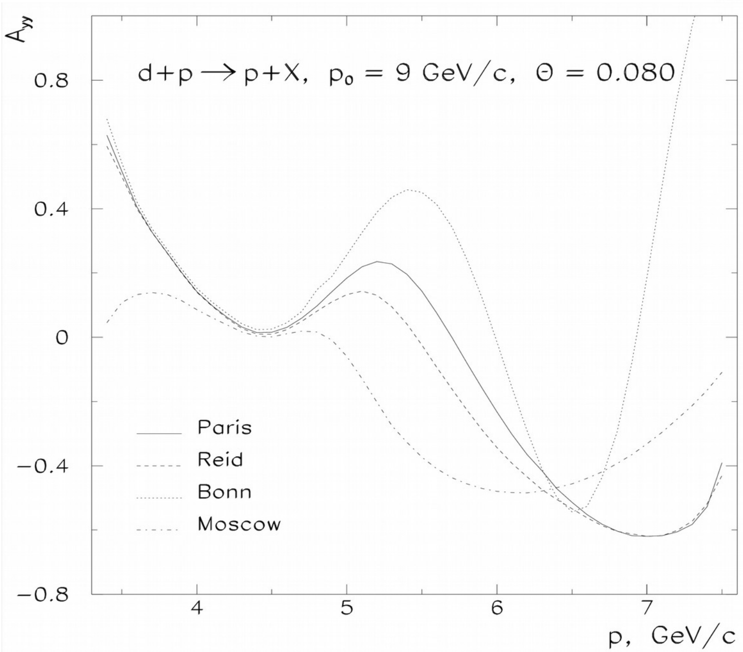
dp → pX at large transverse momenta (up to 1 GeV/c) of protons at MASPIK

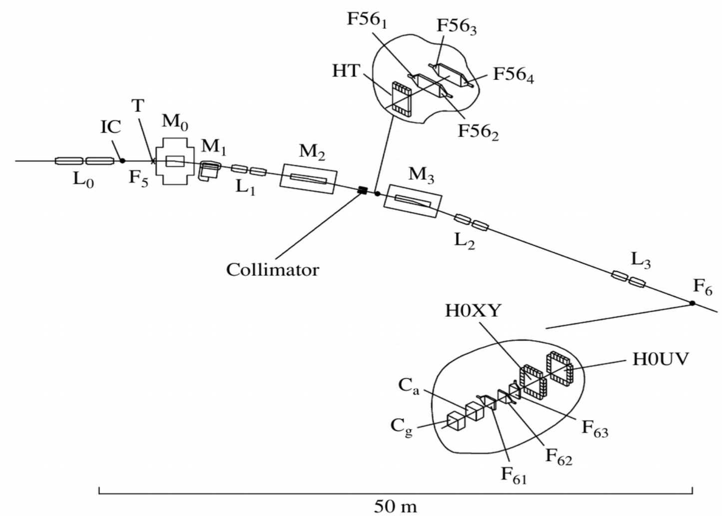




Relativistic hard scattering (RHS) model desribes dp → pX reaction up to p_T ∼1 GeV/c using standard DWF (Paris)
Meson production is negligiable

A_{yy} in A(d,p)X reaction at large transverse momenta of protons at SPHERE





Based on idea:
L.S.Azhgirey, N.P.Yudin, PAN 57(1994)160

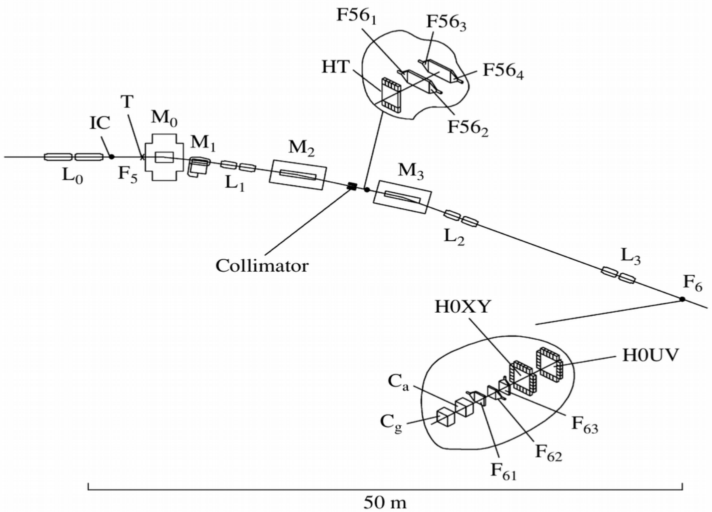
The idea is to change the polarity of the field in M0 magnet (P.A.Rukoyatkin) to select the proton emission angle

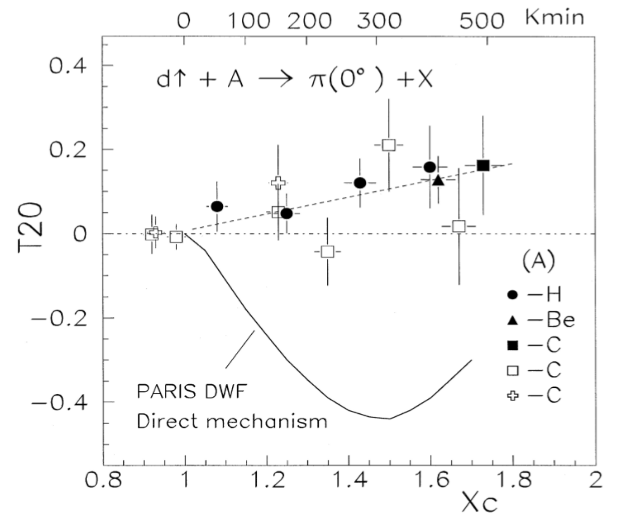
PID: TOF (3 independent values)

Permanent monitoring of the vector polarization component

Leaders:
L.S.Azhgirey, V.P.Ladygin

Results on T_{20} in cumulative pion production





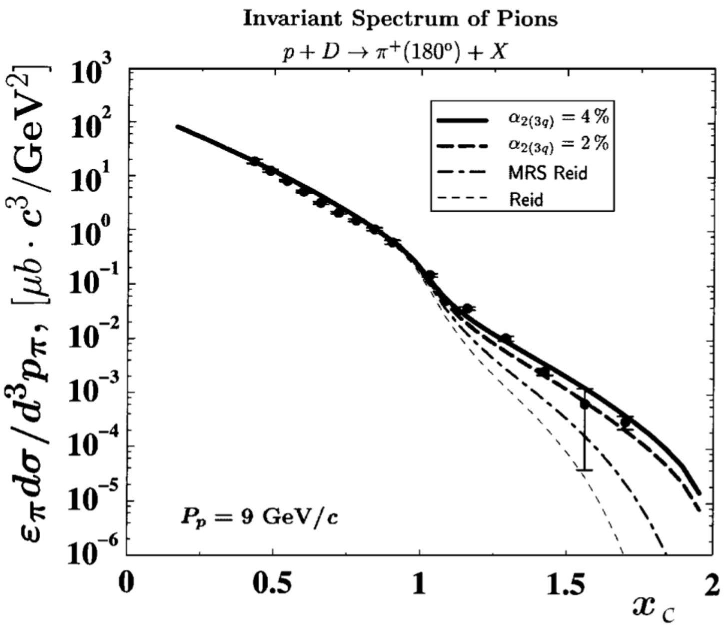
Leaders: L.S.Zolin, A.G.Litvinenko

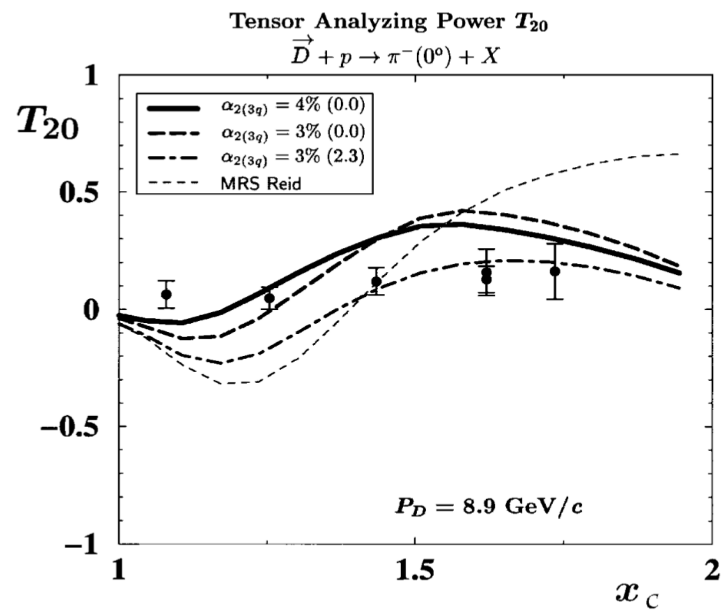
S.Afanasiev et al.,NPA625(1997)817
S.Afanasiev et al.,PLB445(1998) 14

T_{20} sign is positive being opposite to RIA predictions.
T_{20} value is independent on the target A-value.

Non-nucleonic degrees ($\Delta\Delta$ -component) ?

Description of T_{20} in cumulative pion production



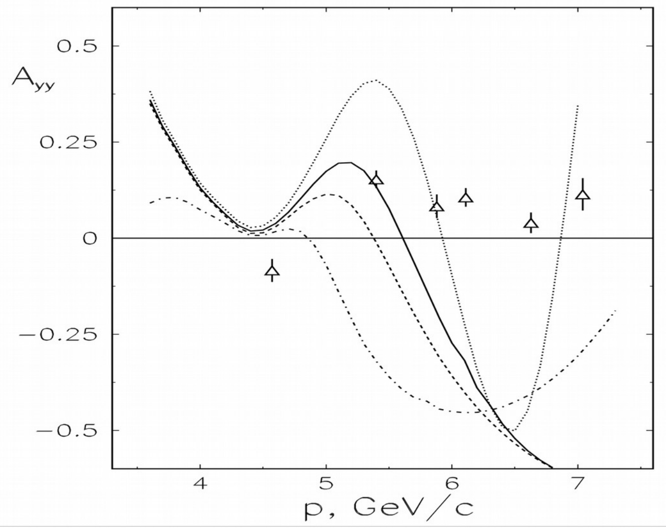


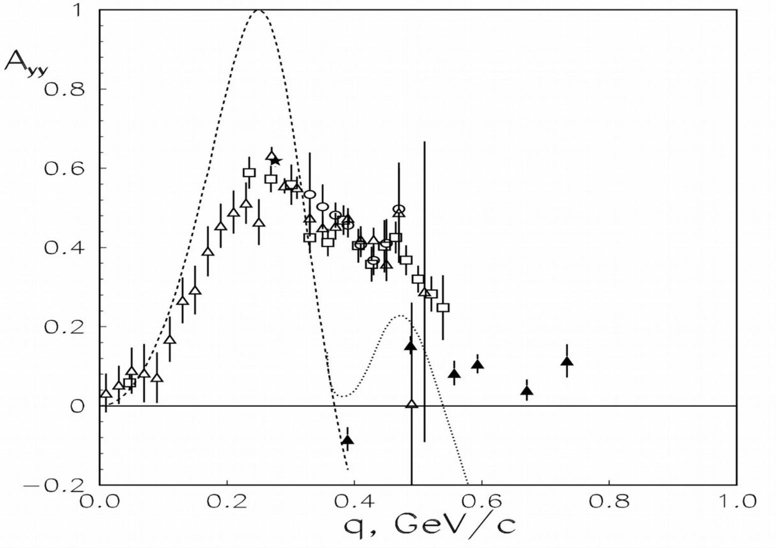
A.Yu.Illarionov, A.G.Litvinenko, G.I.Lykasov, EPJA14(2002)247

Data on T_{20} in cumulative pion production is described only with the use of ~4% 6q component.

Xc - cumulative number (~α/2).

First results on A_{yy} in C(d,p)X at 9 GeV/c and 85 mr of the proton emission angle





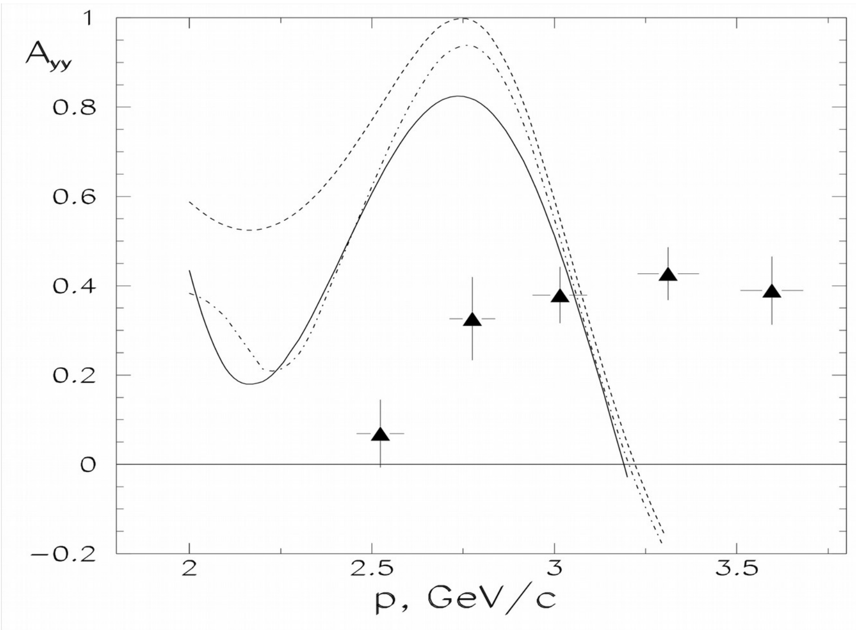
A_{yy} sign is positive being opposite to RHS predictions.

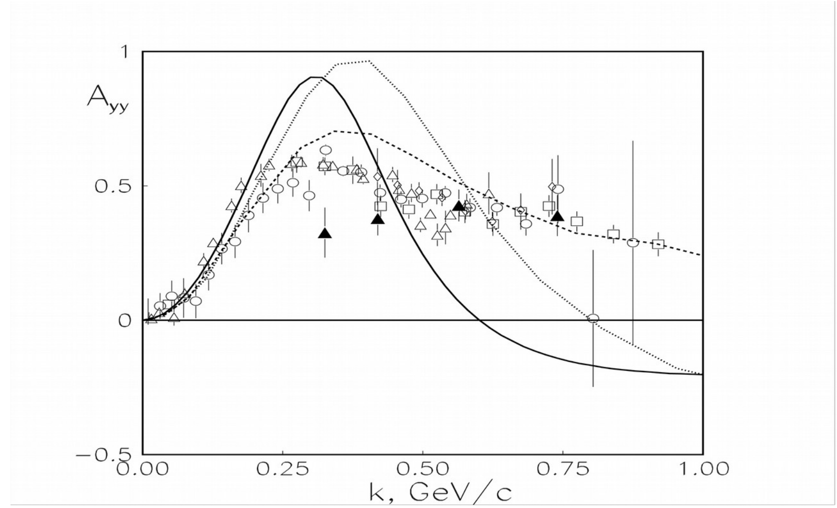
Indication of the dependence on the emission angle.

Leaders: L.S.Azhgirey, V.P.Ladygin

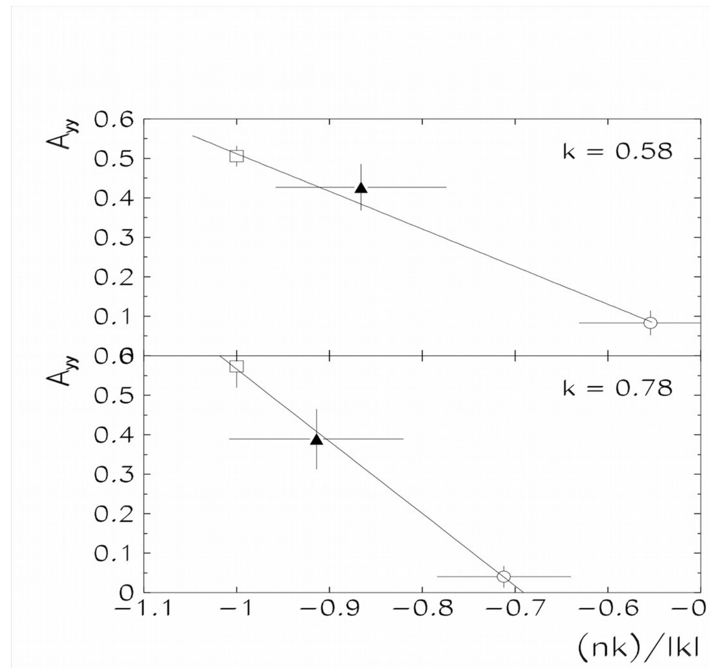
S.V.Afanasev et al.,PLB434(1998)21

A_{yy} in Be(d,p)X at 4.5 GeV/c and 80 mr



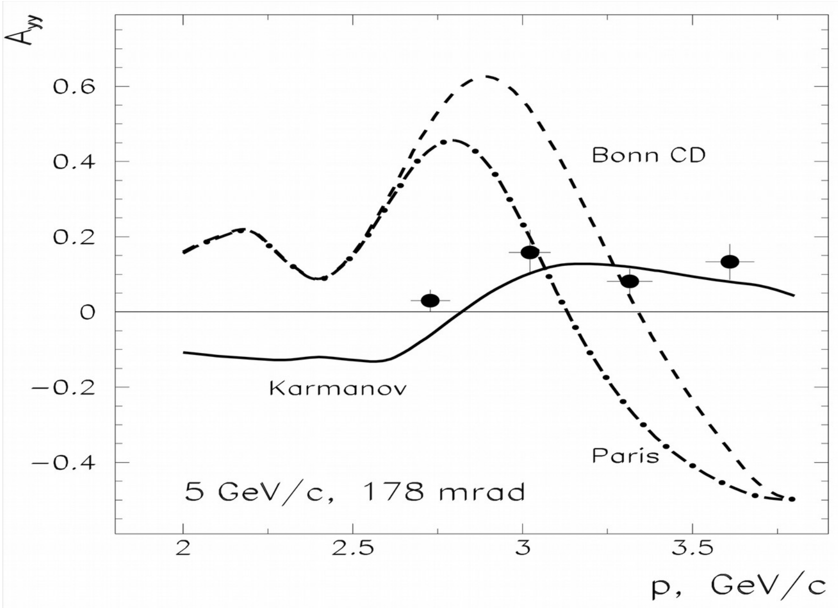


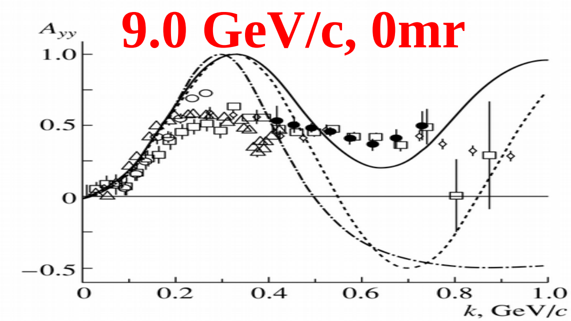
V.P.Ladygin et al., FBS32(2002)127

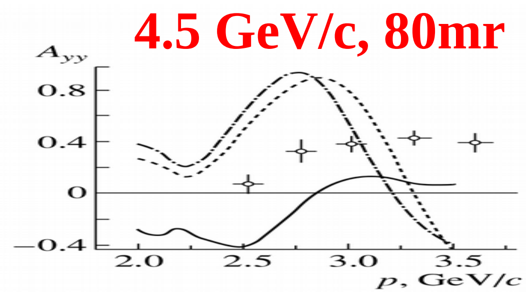


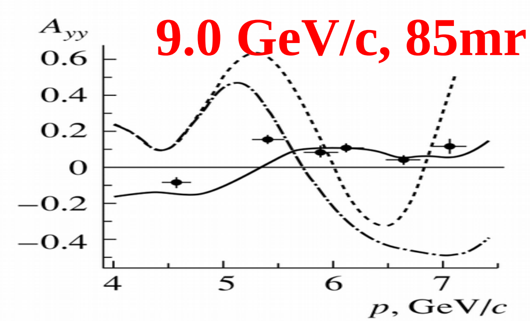
A_{yy} sign at large momenta is positive being opposite to RHS predictions.
Variable k can be used as a scaling one up to P_T ~300 MeV/c.
Dependence on the 2-nd variable !

A_{yy} in Be(d,p)X at 5.0 GeV/c and 178 mr







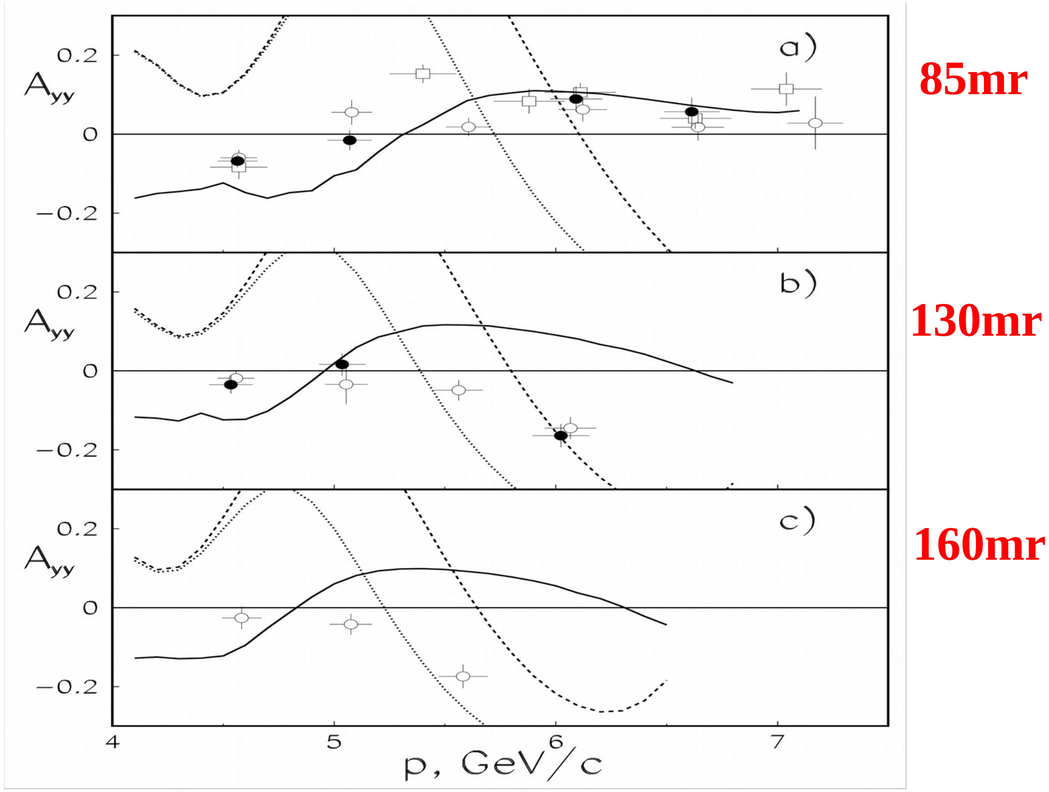


L.S.Azhgirey et al., PLB595(2004)151
Theory:
L.S.Azhgirey,N.P.Yudin, PAN68(2005)160
L.S.Azhgirey,N.P.Yudin, PPN37(2006)535

A_{yy} is in agreement with RHS using Karmanov DWF at 5.0 and 178 mr

Some problems in description at other energies and proton emission angles.

Angular dependence of A_{yy} in H(d,p)X and C(d,p)X

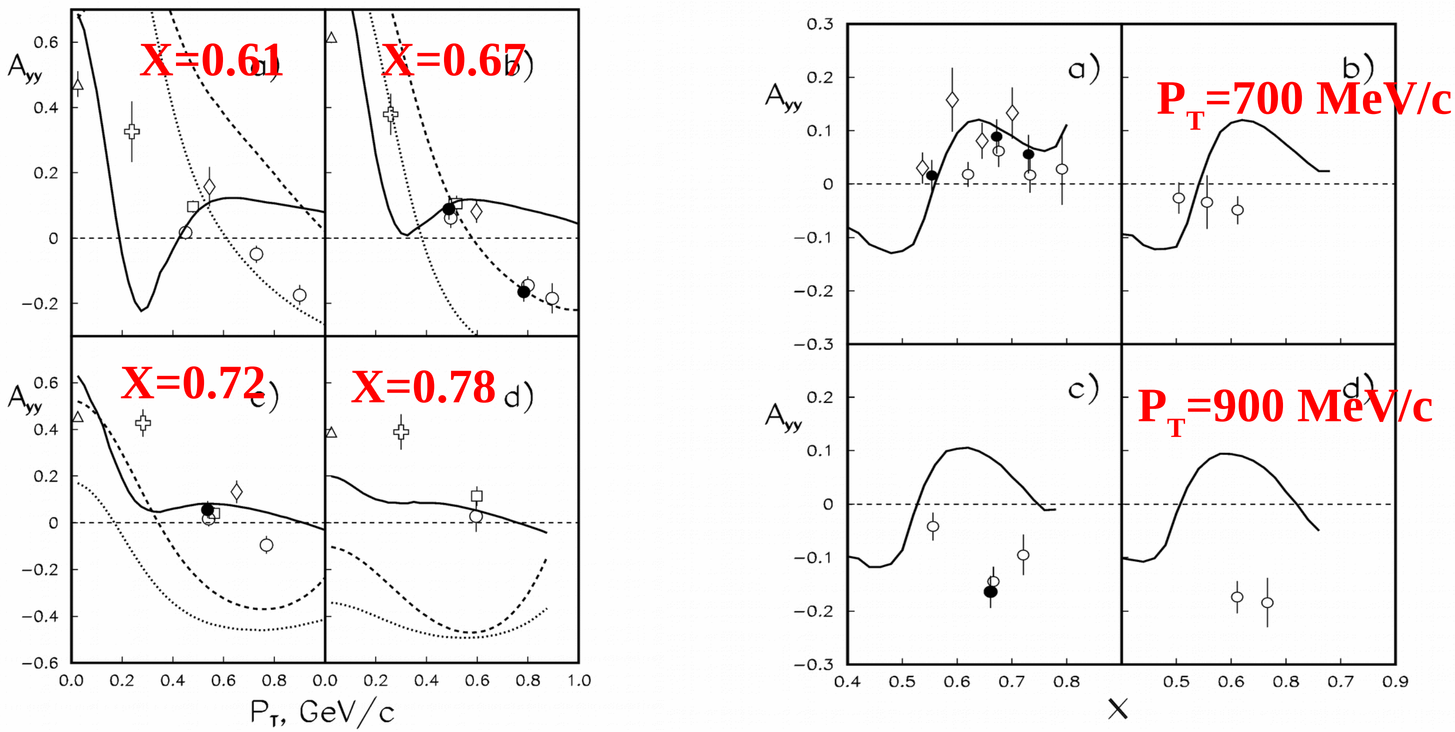


A_{yy} demonstrates independence on the target A-value.

RHS model with Karmanov DWF describes A_{yy} only at 85mr.

V.P.Ladygin et al., PLB629 (2005) 60

Relativistic effects in deuteron from A(d,p)X



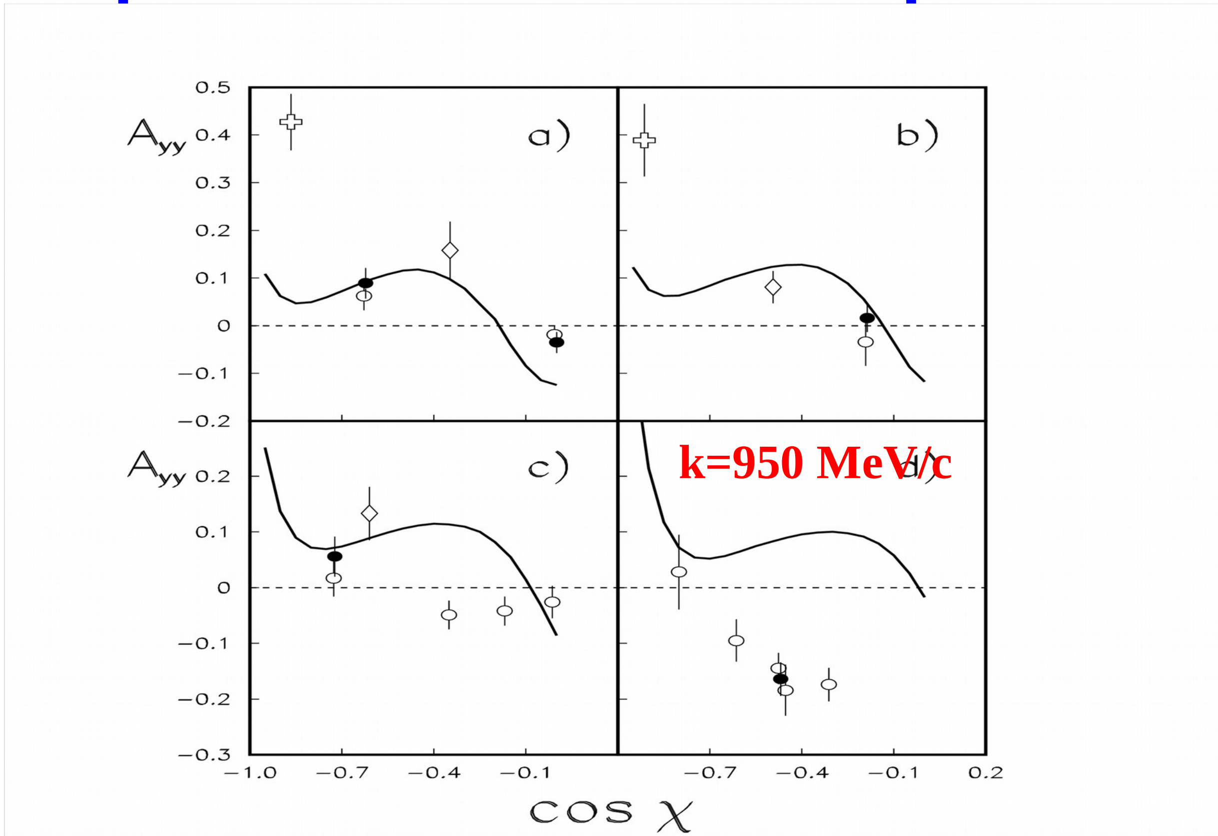
A_{yy} in deuteron inclusive breakup demonstrates the dependence on 2 internal variables: p_T and x_F.

A_{yy} changes the sign at p_T of about 600 MeV/c independently on x_F.

A_{yy} demonstrates negative asymptotic at large p_T .

V.P.Ladygin et al., PLB629 (2005) 60

Dependence of the deuteron spin structure on (n,k)/|k|

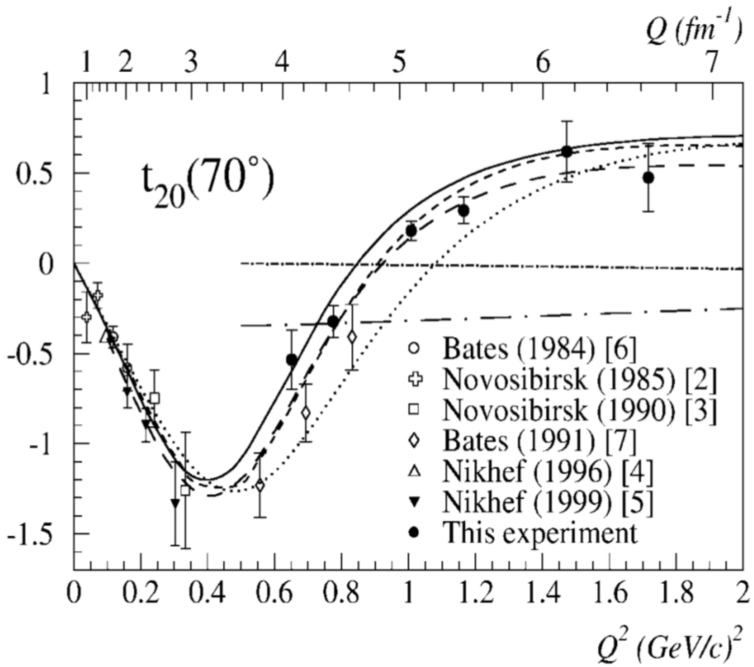


A_{yy} in deuteron inclusive breakup at fixed k demonstrates strong dependence on 2-nd internal variable (n,k)/|k|.

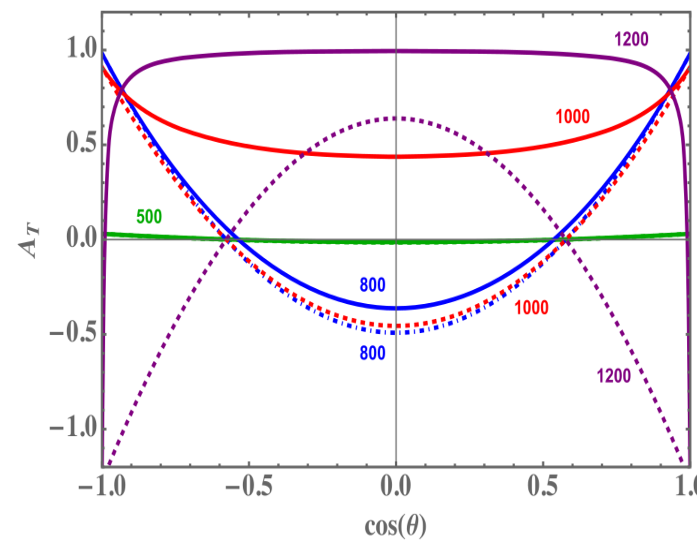
RHS with Karmanov DWF fails to reproduce the data at large k.

V.P.Ladygin et al., PLB629 (2005) 60

Deuteron spin structure from the world data



D.Abbott et al., PRL84(2000)5053



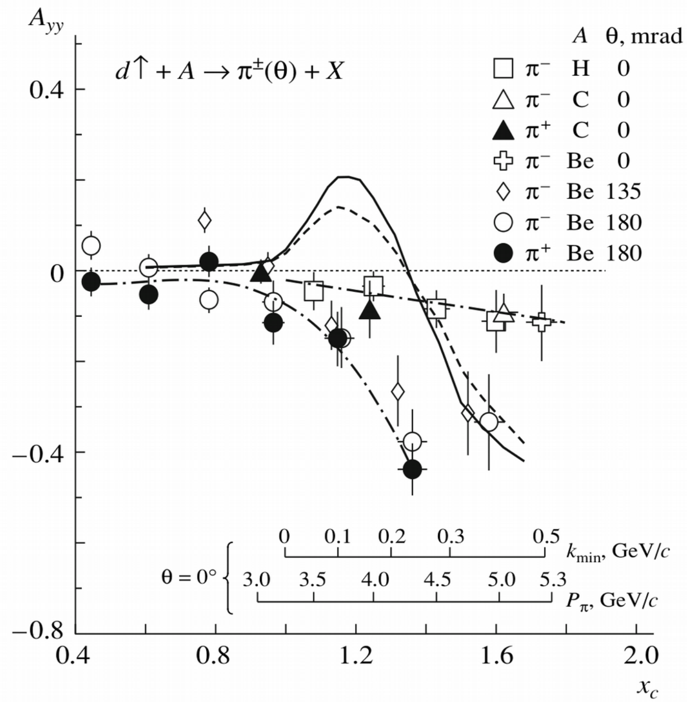
M.M.Sargsian, F.Vera, PRL130(2023)112502

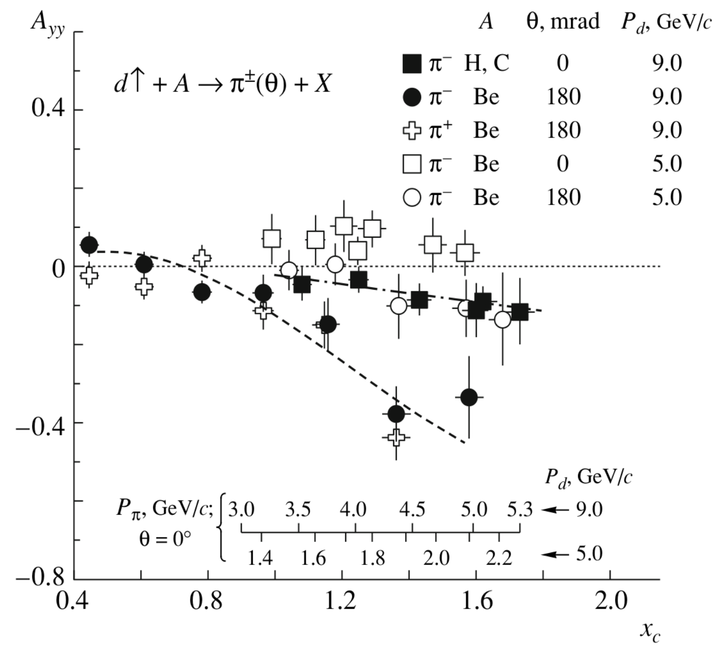
1. Best description of t_{20}(ed) is obtained with Karmanov DWF.

f_5 term plays very significant role (instead of MEC).

2. Calculations on A_{zz} in ed → e pn for upcoming experiment at JLAB demonstrate significant dependence on (n,k)/|k| variable at large k.

Results on A_{yy} in cumulative pion production



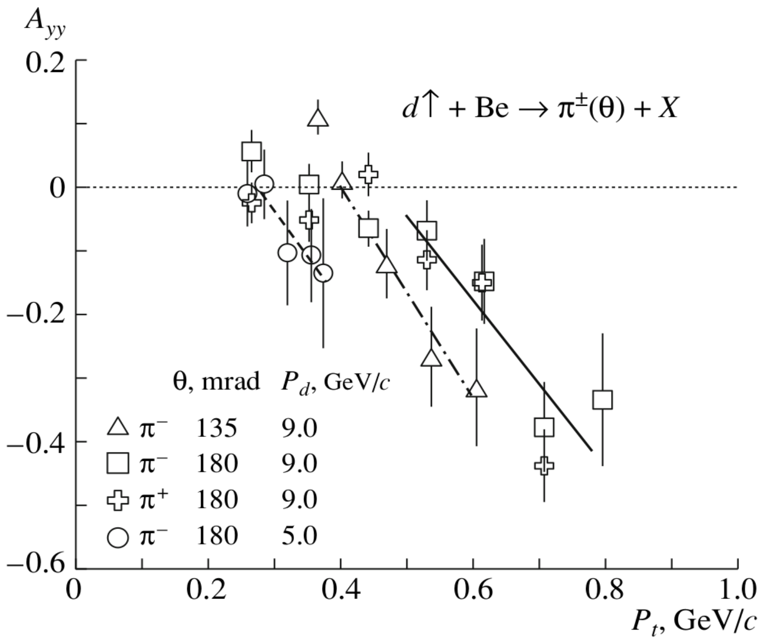


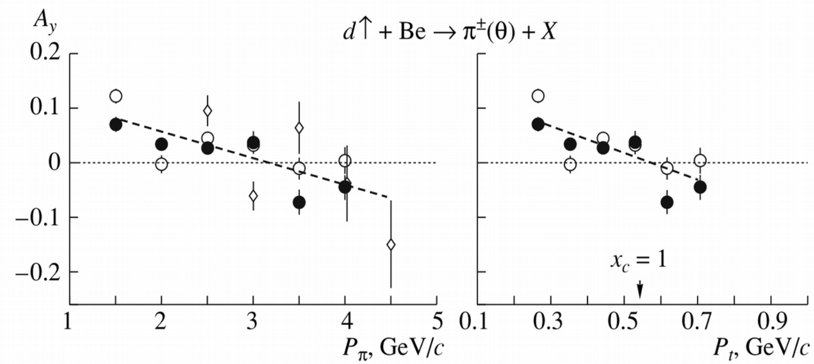
Leaders: L.S.Zolin, A.G.Litvinenko

L.S.Azhgirey et al.,PAN74(2011)1392

A_{yy} has negative values at non-zero emission angles.

Results on A_{yy} in cumulative pion production





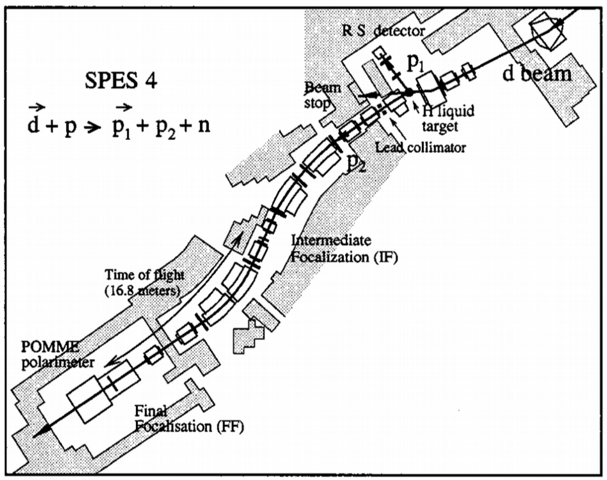
A_{yy} has negative values at large tranverse pion momenta P_T.
A_{yy} demonstrates linear dependence on P_T, but there is no scaling on P_T.
A_y has non zero value in non-cumulative region.

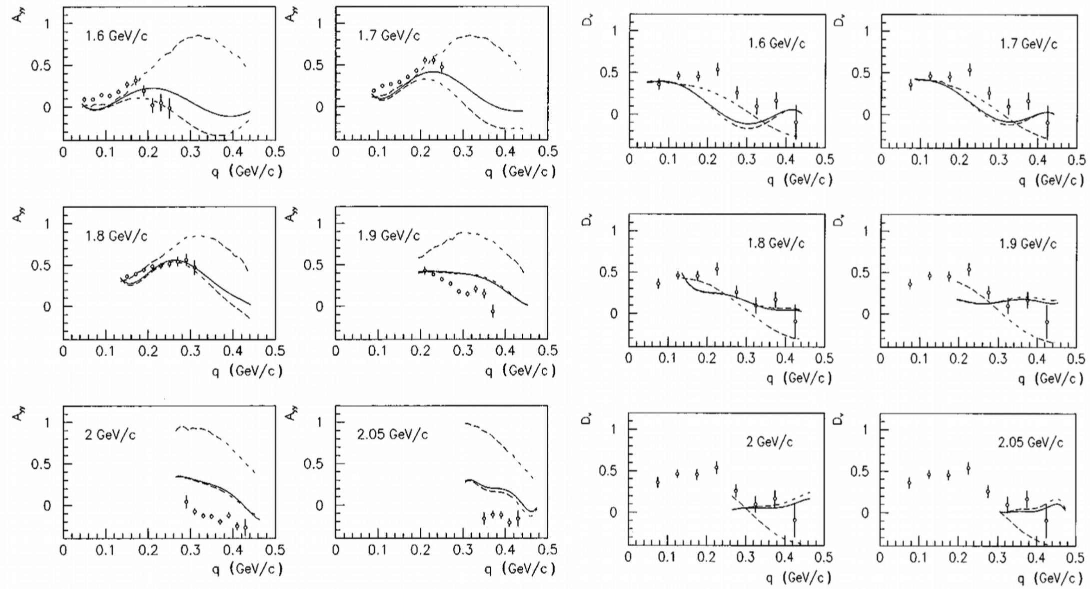
Leaders: L.S.Zolin, A.G.Litvinenko

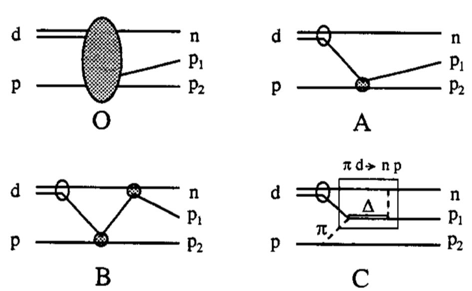
L.S.Azhgirey et al.,PAN74(2011)1392

Data are still waiting for the theory!

Polarization observables in dp→ppn at 1.0 GeV/n from SATURNE-2.





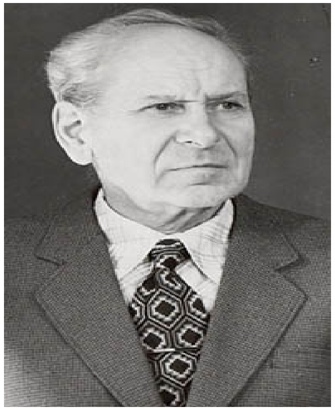


Several polarization observables (A_{yy}, A_y, P_o, D_v has been measured) at 1.0 GeV/n.

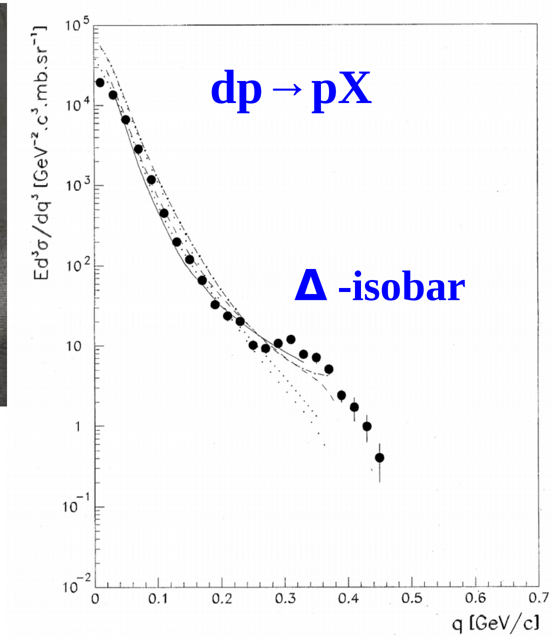
Importance of the additional to IA mechanisms (Δ -isobar excitation in the intermediate state) is demonstrated.

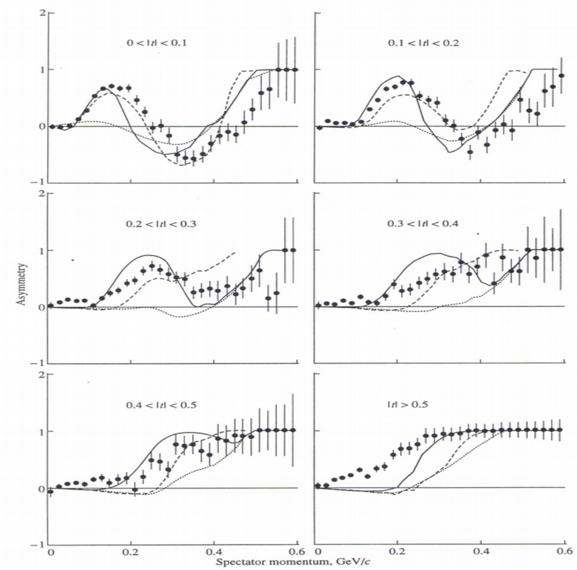
S.L.Belostotski et al.,PRC56(1997)50

dp → ppn at 1.0 GeV/n from LHE BC



R.M.Lebedev





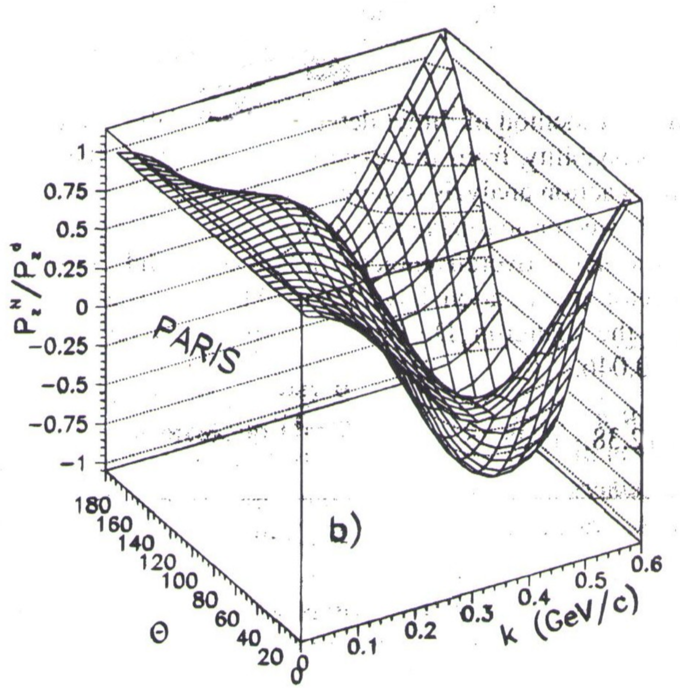
V.V.Glagolev

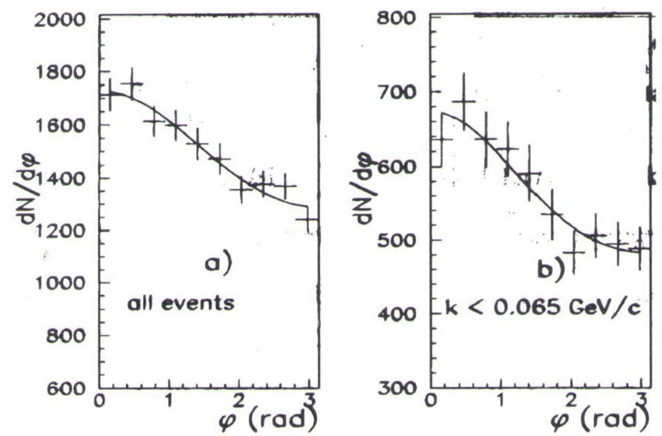
$$A = \frac{N(\alpha < 90^\circ) - N(\alpha > 90^\circ)}{N(\alpha < 90^\circ) + N(\alpha > 90^\circ)} \qquad \cos\alpha = \mathbf{q}\cdot\mathbf{p_s}/|\mathbf{q}||\mathbf{p_s}|$$

V.V.Glagolev et al.,ZPA357(1997)107
V.V.Glagolev et al.,PAN59(1996)2125

Inclusive proton spectra and spatial correlations demonstrated the importance of the additional to IA mechanisms (FSI, Δ-isobar excitation).

The deuteron D-state probability from dp→ppn at 1.0 GeV/n from LHE BC





Azimutal angle distributions for vector polarized dp→ ppn reaction in quasielastic kinematics were analyzed.
pp- and np- elastic scattering analyzing powers at 1 GeV were used (k<65 MeV/c).

V.V.Glagolev et al.,ZPA356(1996)183

$$\omega_D = 0.078 \pm 0.046$$

General View of SPI

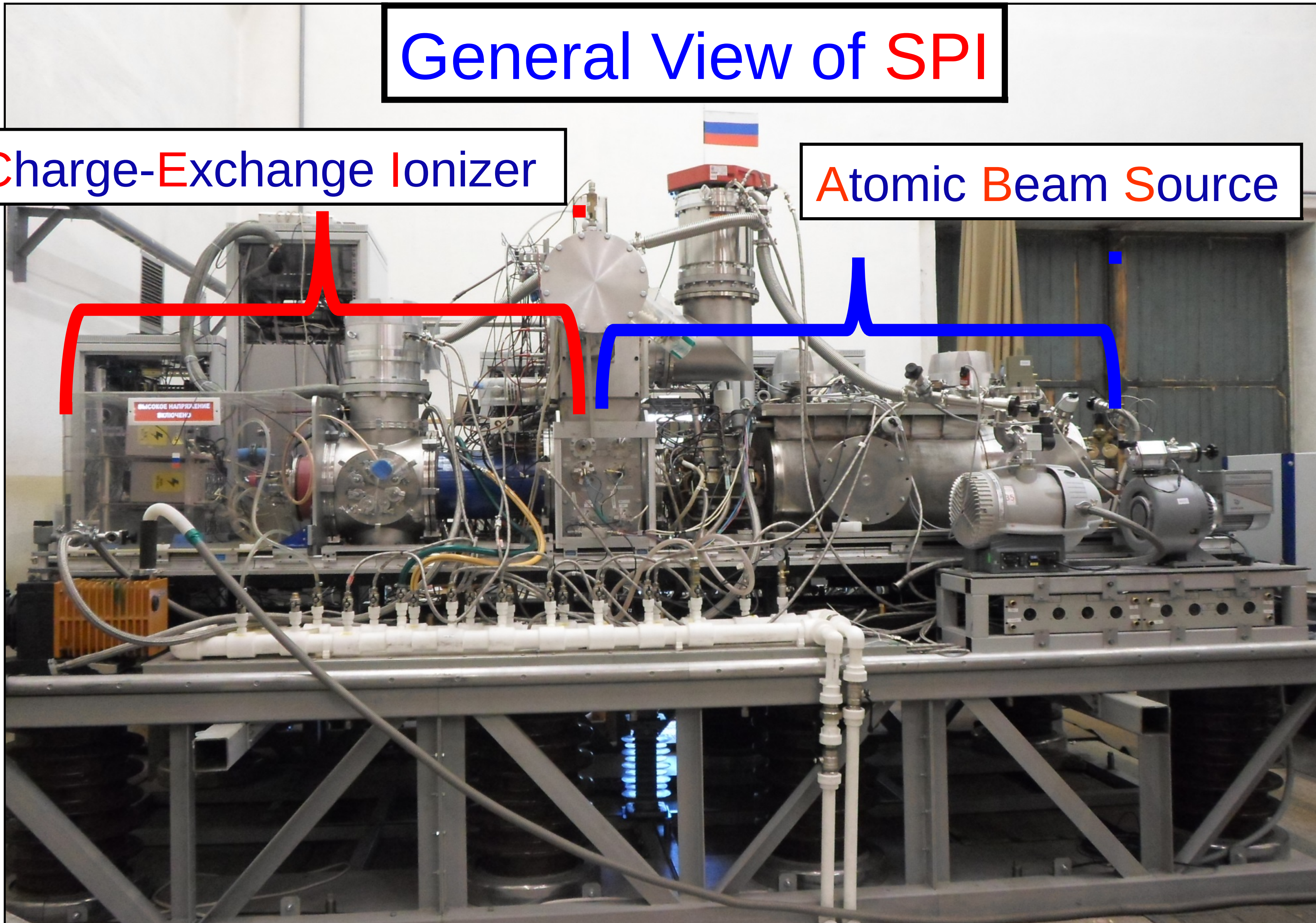


Figure of merit will be increased in future by a factor ~10^3

Possible continuation at Nuclotron: inclusive

1. Measurements of the tensor analyzing power A_{yy} in $dA \to pX$ at large transverse momenta in order to reach k=1200 MeV/c

First depolarizing resonance for deuterons at Nuclotron is at 5.8 GeV.

10^{10} polarized deuteron beam with Pd=12-14 GeV/c
Carbon target at F5
Spectrometer 4V + tracking with HyperNIS (optionally).
Emission angle by 2SP40
PID MRPCs (70-80 ps)

2. Measurements of vector transverse polarization transfer κ_0 in $dA \to pX$ at large transverse momenta

5-6·10^{10} polarized deuteron beam with Pd=10-6 GeV/c
Focal plane proton polarimeter at fixed momentum 4.5-5.0 GeV/c
Spectrometer 4V + tracking with HyperNIS (optionally).

Possible continuation at Nuclotron: exclusive

1. Measurements of the tensor analyzing power A_{yy} in $dp \rightarrow \Delta\Delta N$ as a tool for "hidden color" search

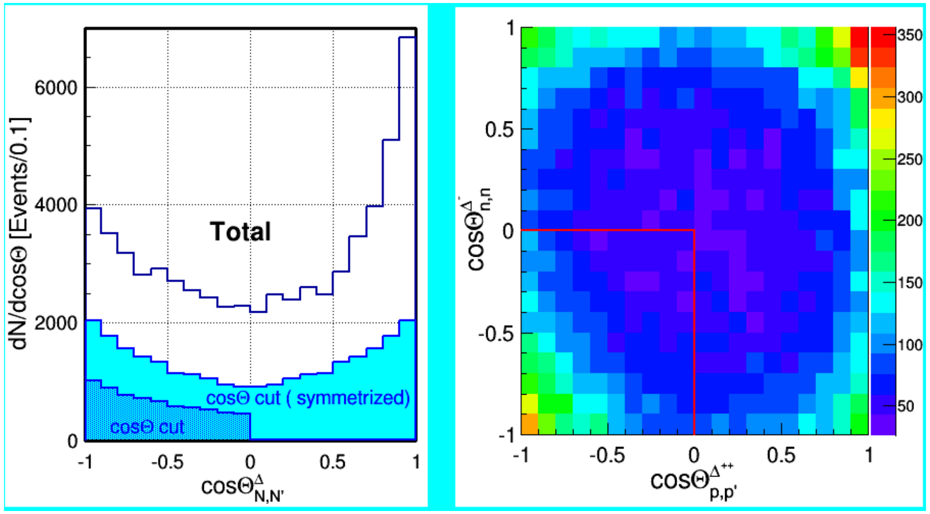
10^{6-7} polarized deuteron beam with Pd=4.5-6.0 GeV/c
LH_2 target at F6
Tracking with HyperNIS +PID
Detection of protons and pions within aperture of SP40.

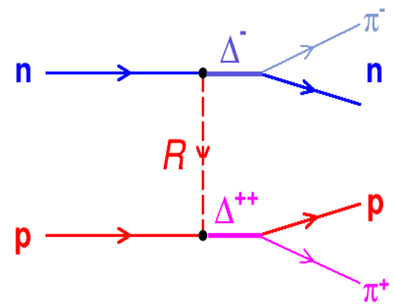
2. Measurements of the tensor analyzing power A_{yy} in $dp \rightarrow ppn$ in SRC region

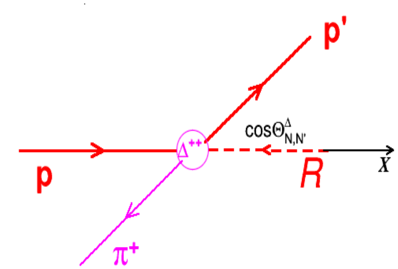
HyperNIS-SRC is not very suited to reach large k-values,
but still can be used to estimate experimental D-state probability in deuteron (?).

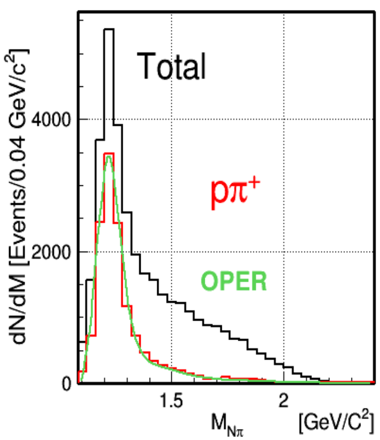
Ways:
to use F5 point with 4V for fast proton+ TOF-arm for slow proton
to build "new MASPIK"

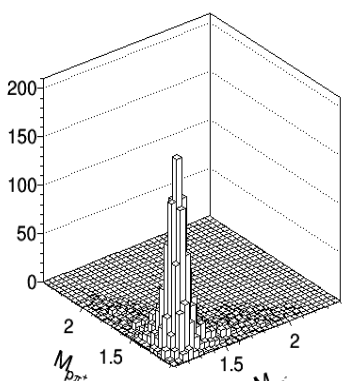
Selection of dp → $\Delta^{++}\Delta^{-}$ p and “n”p → $\Delta^{++}\Delta^{-}$

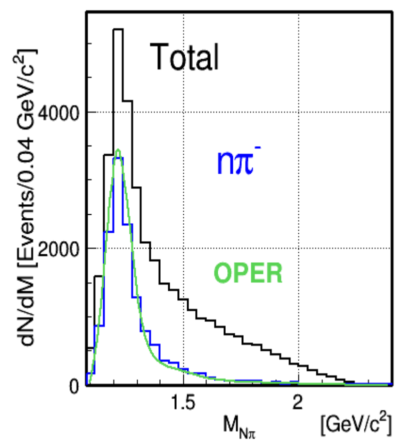








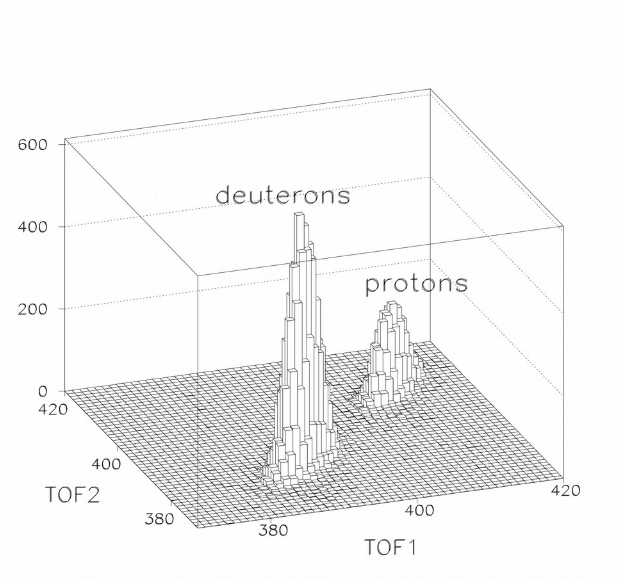


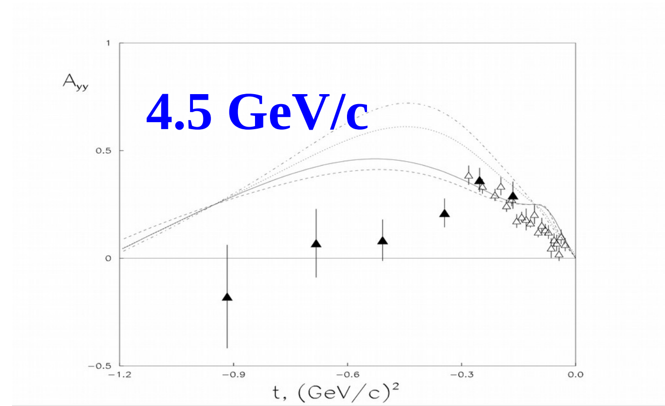


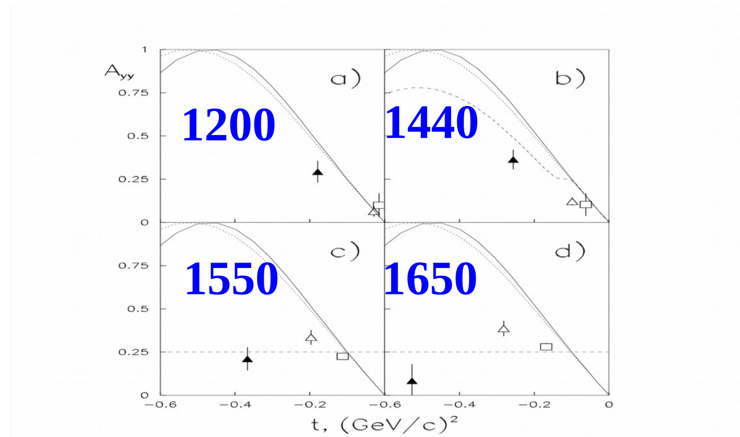
Needs to measure proton- spectator

A.P.Jerusalimov: seminar LHEP 31.01.25

Study of inclusive and exclusive dp → dX







Deuterons are the main background for dA → pX studies at large k:
Spin effects in dA → dX - by free.

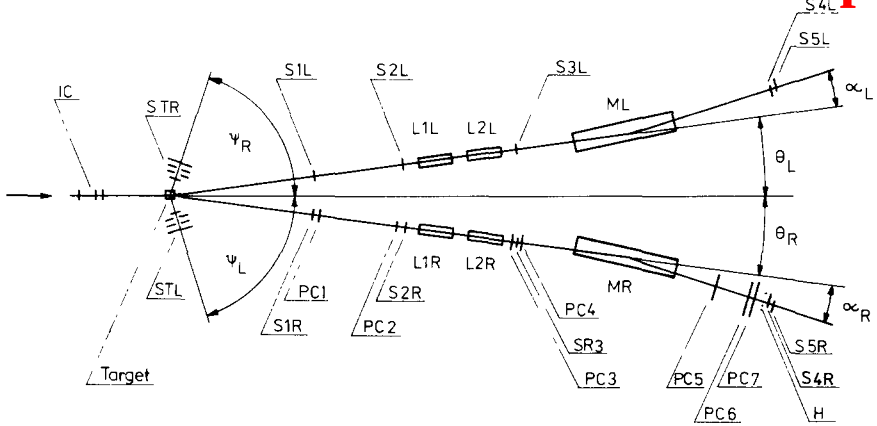
Saclay idea is to measure spin-flip probabilites S0, S1, S2 for region of Roper N*(1440) resonance excitation in dp → dX reaction (**M.Morlet, C.Djalali -LNS E250**)

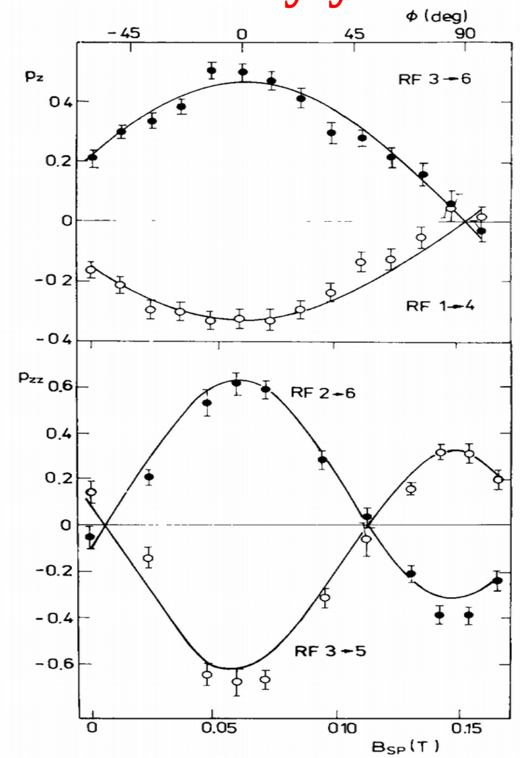
Theory:
VPL&NBL:PAN65(2002)182

L.S.Azhgirey et al., PLB361(1995)21, leader E.A.Strokovsky
V.P.Ladygin et al., EPJA8 (2000) 409, leader V.P.Ladygin

Polarimetry: ALPHA polarimeter

Main HE deuteron tensor-vector polarimeter for many years

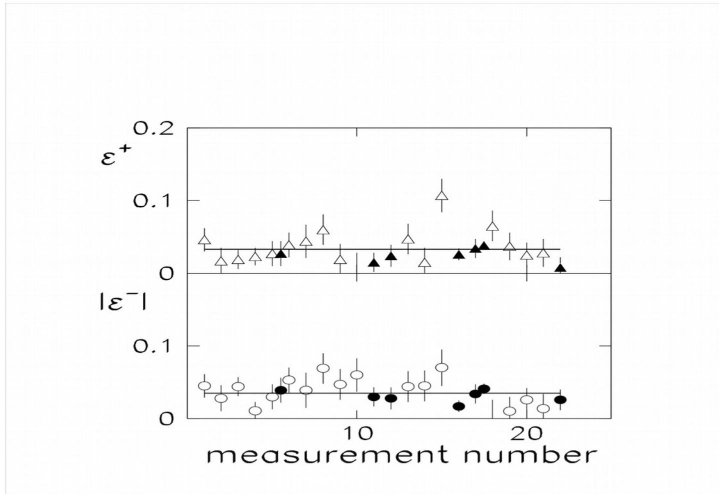


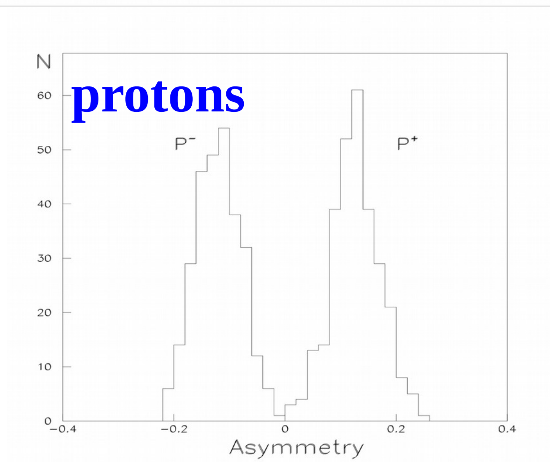


V.I.Sharov
L.N.Strunov
A.A.Nomofilov

V.G.Ableev et al., NIM306(1991)73

Polarimetry: Vector deuteron and proton polarimeter F4/F3

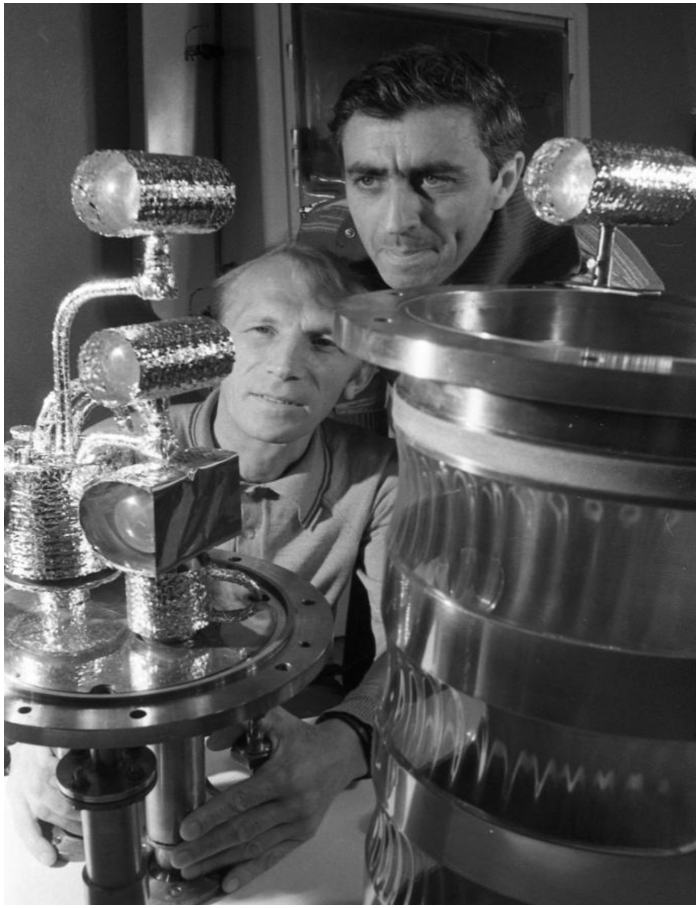


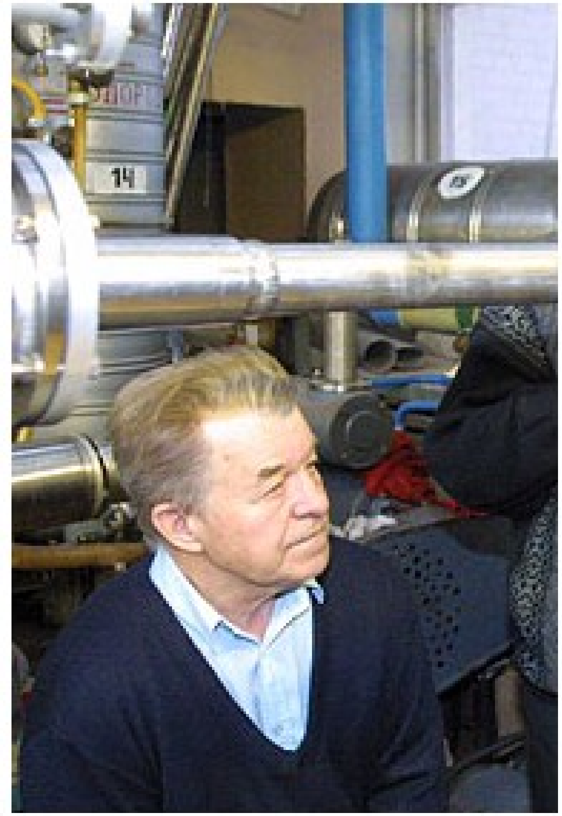


L.S.Azhgirey
G.D.Stoletov
F.Lehar
L.Budkin
V.N.Zhmyrov
A.N.Prokofiev&Co

L.S.Azhgirey et al., NIM497(2003)340

Liquid hydrogen targets





L.B.Golovanov
Yu.T.Borzunov
A.P.Tsvinev

Conclusions

The study of the short-range deuteron spin structure at LHE/LHEP has a long and glorious history.

Significant progress in understanding of this problem has been achieved together with LNS (France), Jlab(USA).

The main achievements are:

- systematic precise measurements of the tensor analyzing power T_{20} in $dA \rightarrow p(0^{o})X$:

T_{20} (H) = -0.558 ±0.150 at k=985 MeV/c
T_{20} (C) = -0.351 ±0.116 at k=1000 MeV/c

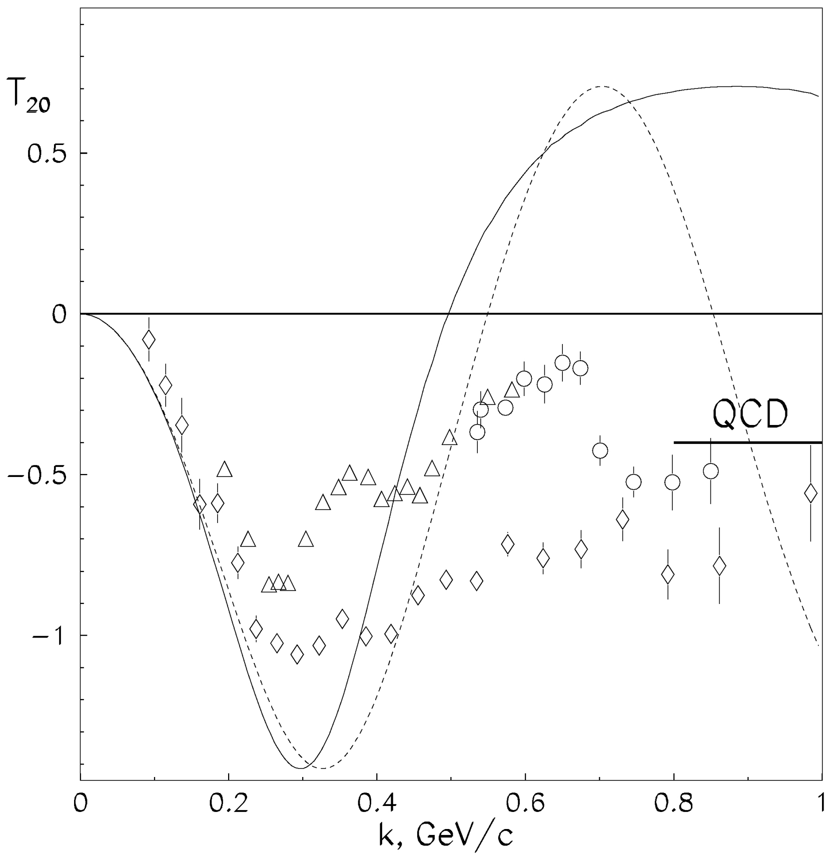
- observation of the A_{yy} (relativistic deuteron tensor structure) dependence on 2 internal variables.

New SPI with high intensity and high values of the tensor and vector polarization is able to provide new stage in the short-range deuteron spin structure studies.

However, new experiments generation has to be based on the existing experimental achievements and experience.

Thank you for the attention!

Non-nucleonic degrees of freedom



When the distances between the nucleons are comparable with the size of the nucleon, the nucleon-nucleon interaction is a non-local.

The fundamental degrees of freedom, quark and gluons in the frame of QCD, begin also to play a role at the internucleonic distances comparable with the size of the nucleon.

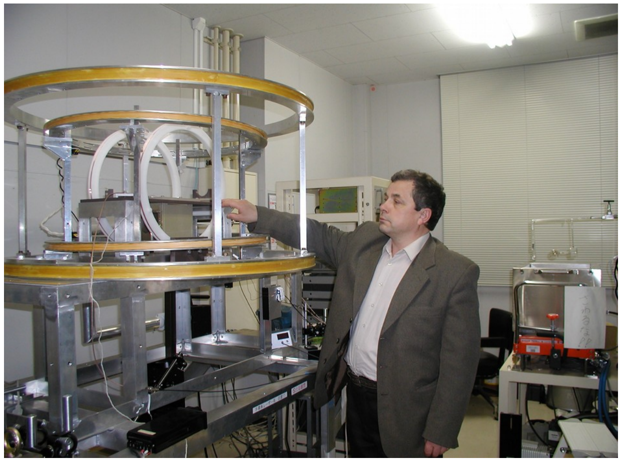
They can manifest as ΔΔ, NN*, N*N*, 6q etc.components.

Data:

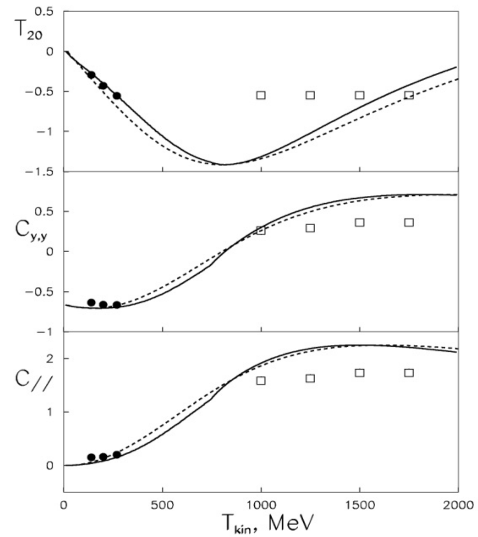
V.Punjabi et al., Phys.Lett.B350 (1995) 178
L.S.Azhgirey et al., Phys.Lett.B391 (1997) 22
L.S.Azhgirey et al., Phys.Lett.B387 (1996) 37

Polarization observables for polarized deuteron induced reactions

Target position is in F5

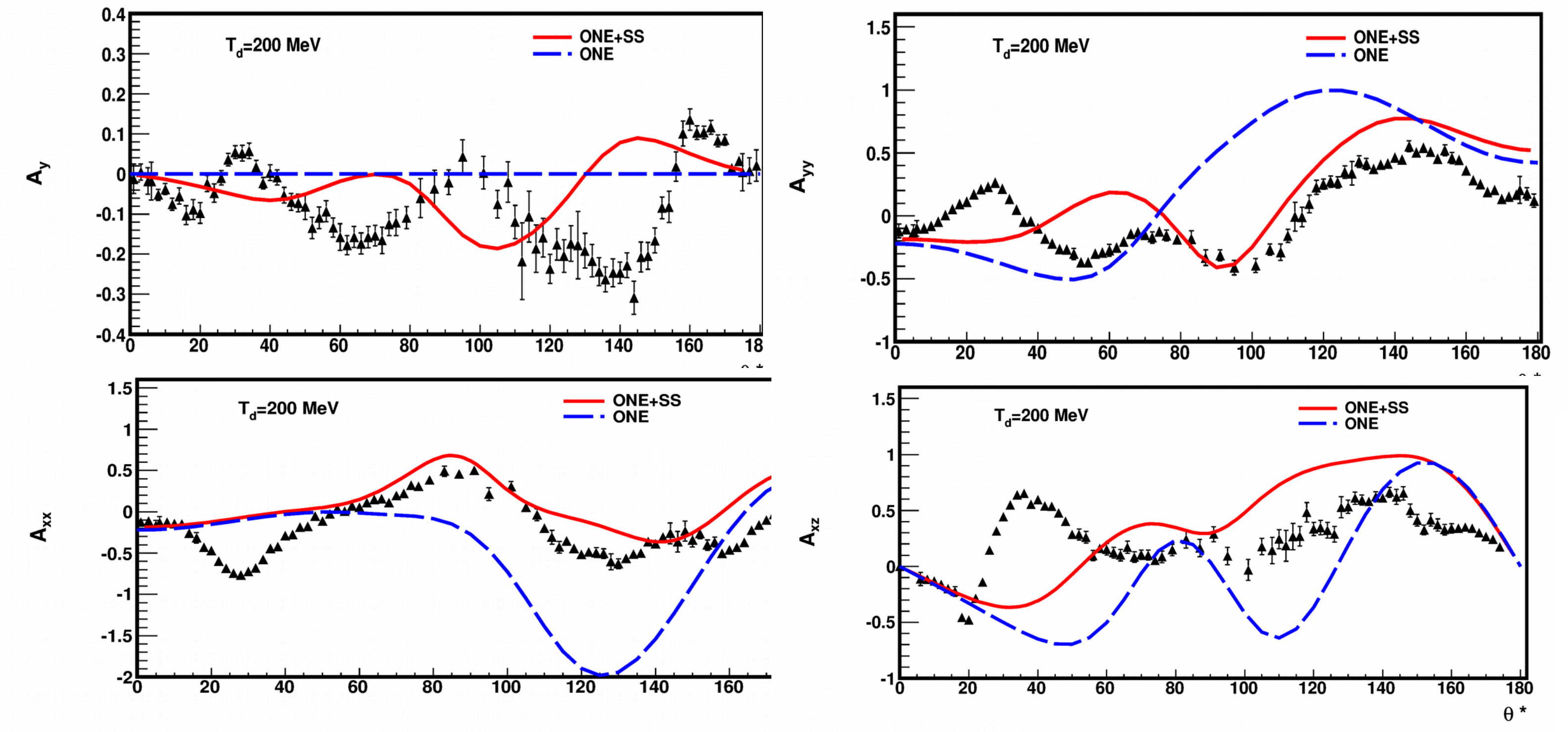


$^{3}He(d,p)^{4}He$



- The measurements of the tensor analyzing power T_{20} and spin correlation $C_{y,y}$ in the $^{3}He(d,p)^{4}He$ reaction in the kinetic energy range between 1.0 and 1.75 GeV can be performed at the BM@N area.
- The polarization observables for the p(d,p)d, d(d,p)t and $d(A,p(0^{o}))X$ at intermediate and high energies also can be studied.
- Non-nucleonic degrees of freedom and baryonic resonances properties can be studied in the $d(A,d(0^{o}))X$ and $d(A,\pi^{-}(0^{o}))X$ reactions at different energies.
- The tensor analyzing power T_{20} can be studied for the meson production in the $d(A,3He(0^{o}))X$ reactions.

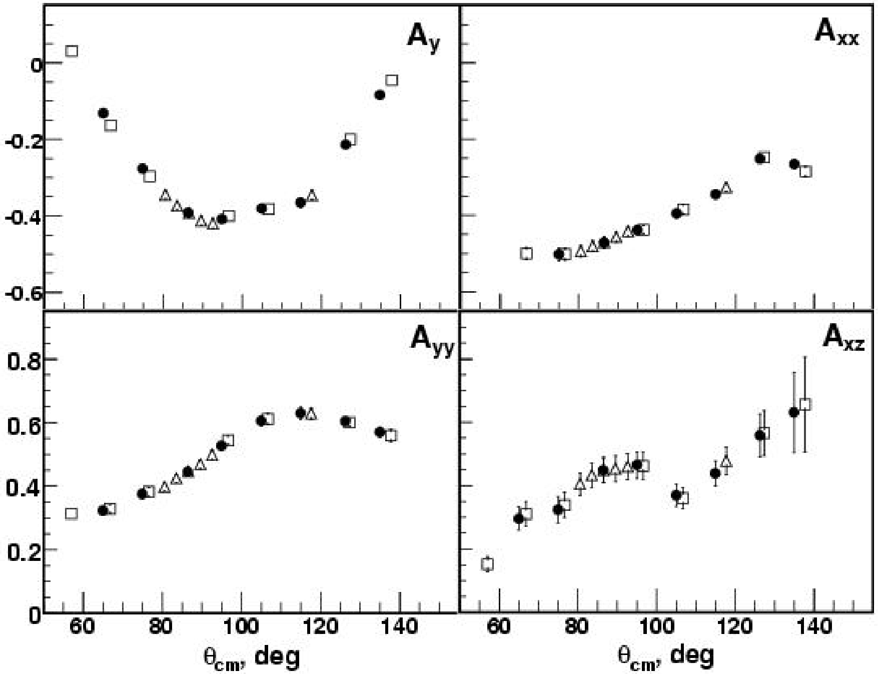
Polarization effects in the $dd \to {}^3He\,n\,({}^3H\,p)$ reactions at Nuclotron energies



The relativistic multiple scattering model was successfully used to describe the $dd \to {}^3He\,n\,({}^3H\,p)$ reactions in a GeV region at the Nuclotron.
The calculations require a large amount of CPUs.
The results were published in FBS, PRC, PPN.

N.Ladygina - theory
A.Kurilkin – experiment

Measurement of the deuteron beam polarization at ITS using DSS detection system at 270 MeV



Vector Ay and tensor analyzing powers A_{yy}, A_{xx} and A_{xz} of dp- elastic scattering as a function of deuteron scattering angle in c.m.s. at deuteron beam energy of 270 MeV. □, Δ- the world data. Extrapolated values of the analyzing powers are marked by ●.

Cubic spline interpolation:

(x_i,y_i) на $[A,B]$

$f(x) = ax^3 + bx^2 + cx + d$

$f''(A) = f''(B) = 0$

K.Sekiguchi et al.,

Phys. Rev. C65 (2002) 034003

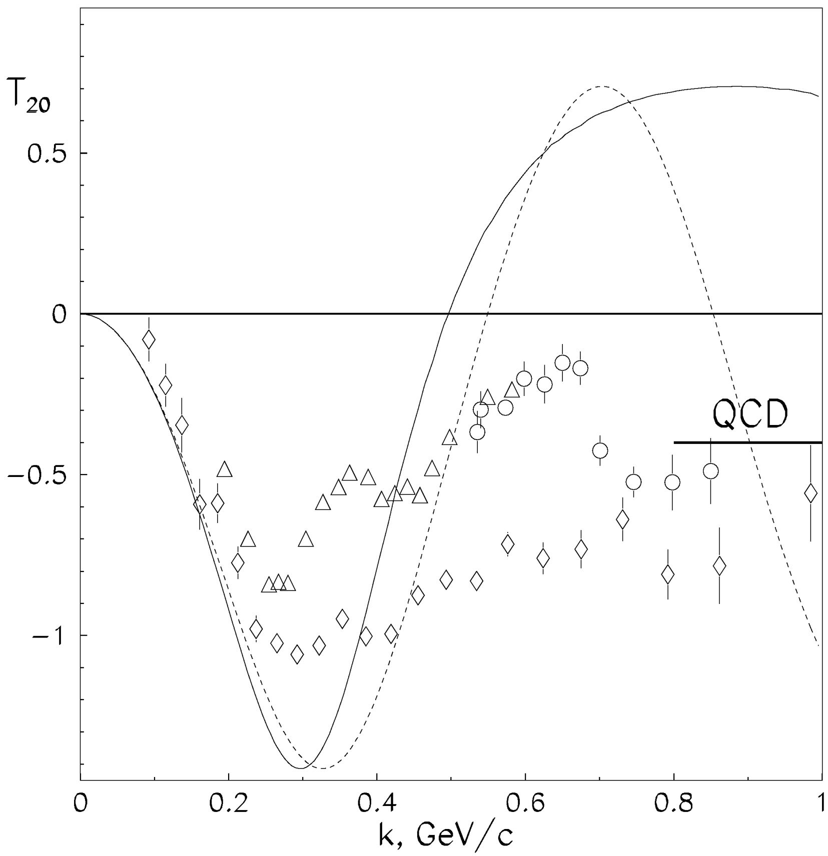
K.Sekiguchi et al.,

Phys. Rev.C70 (2004) 014001

K.Suda, et al.,

Nucl. Instr. Meth. in Phys. Res. A572 (2007) 745

Non-nucleonic degrees of freedom



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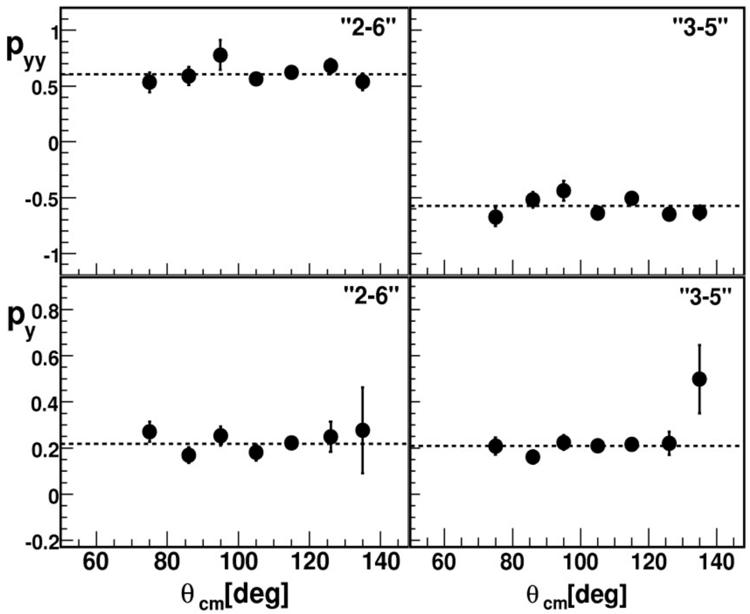
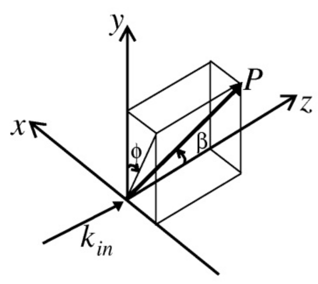


Tensor p_{yy} and vector p_y polarization of the beam for "2-6" and "3-5" spin modes of PIS POLARIS as a function of the deuteron scattering angle in the cms.

$$ß = -90.3^o \pm 1.2^o$$



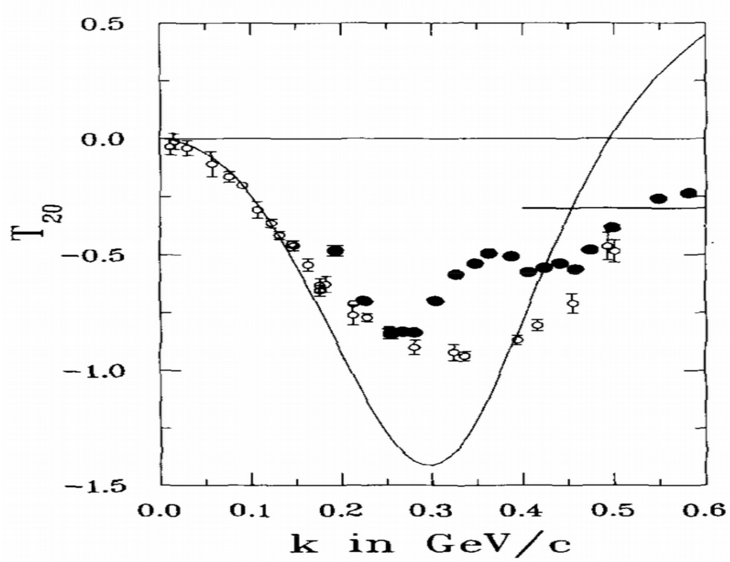
$$F_i^2 = \int \varepsilon A_i^2 d\Omega$$

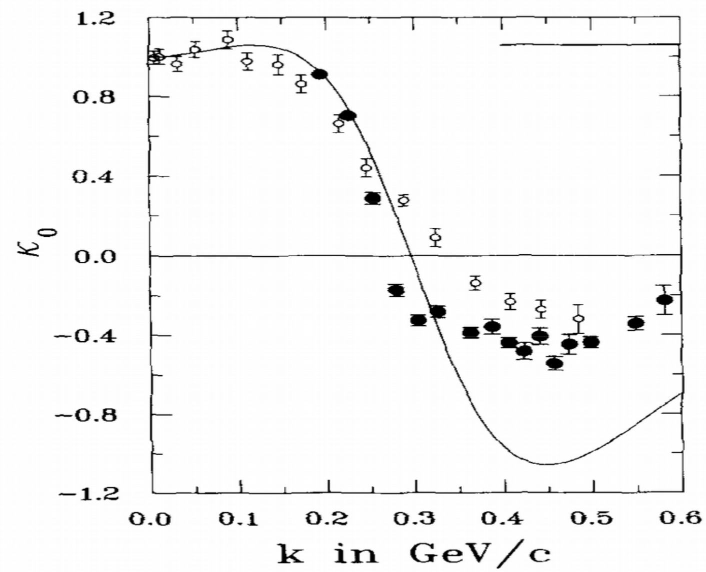
$F_y \sim 1.0 * 10^{-4}$, $F_{yy} \sim 1.8*10^{-4}$, $F_{xx} \sim 0.8*10^{-4}$

- **Reference deuteron beam polarimeter at Nuclotron.**

P.K.Kurilkin et al., Nucl. Instr. and Meth. A 642 (2011) 45

Measurements of T_{20} and κ_0 in $dp \rightarrow pd$ at SATURNE2





C.F.Perdrisat, V.Punjabi - leaders

$$\kappa_0 = \frac{u(k)^2 - w(k)^2 - u(k) \cdot w(k)/\sqrt{2}}{u^2(k) + w^2(k)}$$

V.Punjabi et al., PLB350 (1995) 178

VPL -1992
I.M.Sitnik,V.P.Ladygin,M.P.Rekalo,PAN57(1994)2170

Behaviour of T_{20} and κ_0 is completely different for $dp \rightarrow pd$ and $dp \rightarrow pX$.
Unexpected structures in T_{20} for $dp \rightarrow pd$
Different reaction mechanisms, different degrees of freedom(?)

Summary of the deuteron spin structure studies

$u^2(k) + w^2(k)$ Extracted from dA→pX and dp→pd cross section data were found to be in agreement showing wide shoulder at k=300 MeV/c

T_{20} Strong deviation from RIA and ONE predictions: negative value at large k, smaller than $-\sqrt{2}$ at k=300 MeV/c

New observable:
Transverse vector polarization transfer in dA→pX

$$\kappa_0 = \frac{u(k)^2 - w(k)^2 - u(k) \cdot w(k)/\sqrt{2}}{u^2(k) + w^2(k)}$$

L.Frankfurt, M.Strikman, NPA405(1983)557
A.Boudard, C.Wilkin, JPG:NP11(1985)583