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ДЕПОНИРОВАННАЯ ПУБЛИКАЦИЯ

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Investigation of Color Transparency and Nucleon Relativistic Motion Effects in the Deuteron

(Letter of Intent)

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The proposed experiment will study the nucleon relativistic motion in the deuteron and Color Transparency using the cryogenic deuteron target for EVA (E850) setup at AGS.

Experimental Equipment

Beamline: C1 line with momenta from 6 to 12 Gev/c
Detector: EVA Spectrometer with cryogenic H2/D2 target
Beamtime: Approximately 200 hours of setup and 800 hours of date taking during the FY 1998 proton run.

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Изучение цветовой прозрачности и эффектов релятивистского движения нуклонов в дейтроне

(Предложение эксперимента)

Н.Кристенсен и др.

Предлагается проект эксперимента по исследованию эффектов релятивистского движения нуклонов и цветовой прозрачности в экспериментах с криогенной дейтериевой мишенью на установке EVA (E850) на AGS.

Работа выполнена при поддержке Российского Фонда Фундаментальных Исследований, Грант N 95-02-05061.

Introduction

The deuteron is the simplest and best understood nuclear system bound by strong interactions. As such it has received an extraordinary amount of attention. The binding energy of the deuteron is rather small compared to the nuclear potential and to the binding energy of heavier nuclei. The average distance between the nucleons in the deuteron is larger than the typical distance in nuclei.

At first glance these facts would seem to discourage one from using the deuteron for studying relativistic effects, nucleons short range correlation, effects due to the difference between a bound and a free nucleon, and color coherence features. These effects, if they exist in nuclei, should be more important in heavy systems at high densities and large binding energies and can be expected to be only of minor importance in the more dilute deuteron system. This is true for inclusive reaction. However, a complete measurement of the kinematics of the $pd \rightarrow pp(n)$ reaction, as can be done using the EVA detector at BNL, makes it possible to focus on different aspects of the nuclear ground state and the reaction mechanisms that we mentioned above, provided that the kinematical parameters are chosen correctly.

We propose to measure the $pd \rightarrow pp(n)$ reaction at bombarding momenta from 6 to 12 GeV/c and at around 90^0 cm scattering angle. The measurement of the scattering angles and momenta of the two emerging high energy protons determines completely the kinematics of the reaction and makes it an exclusive measurement. The large scattering angle and the high momentum ensure the hardness of the process.

In this letter of intend we will focus in more detail on two aspects: the study of nucleon relativistic motion in the deuteron and the possibility to study Color Transparency (CT). There will be other aspects of the deuteron wave function and the reaction mechanism that also be illuminated by the proposed measurements although we will not discuss them here in detail.

The examples we presented are specific cases were theoretical predictions exist. In general, we propose to perform an extensive study of the Large Momentum Transfer $pd \rightarrow pp(n)$ reaction. Different selected kinematical conditions will allow us to focus on different aspects of the reaction mechanism and ground state properties of the deuteron. Our expected sensitivity for 1 week of beam is to phenomena with cross sections as low as $1nb/(GeV/c)^2$.

We will be able to use the data to examine to what extent the impulse approximation is justified, Can we really factorize the hard and soft interaction? Can we assume that the scattering is quasifree on a moving nucleon? What is the correct way to describe the deuteron wave function at short distances? Can we see effects due to difference between bound and free nucleons ? What are the effects due to ISI and FSI and is there an indication of color transparency?

These measurements are part of a choerent experimental and theoretical research program. More details are given in the theoretical papers [1, 2] that discuss the potential study of high momentum transfer pd reaction at BNL energies.

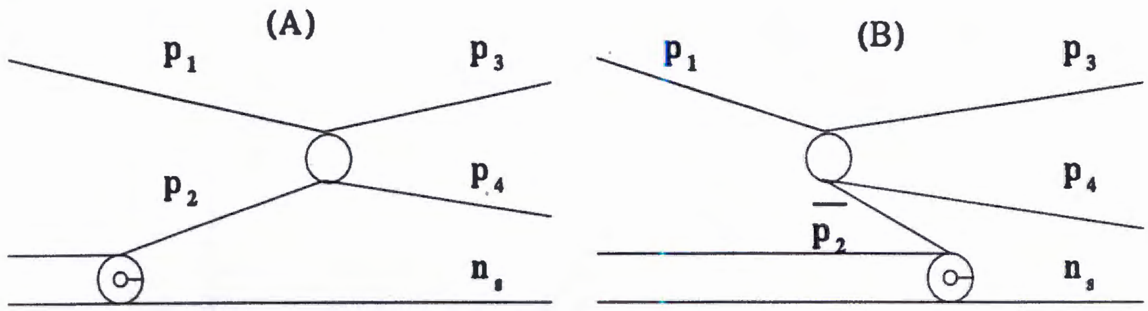

Fig. 1: Time-ordered diagrams representing the impulse approximation contribution (A) and the relativistic (vacuum) contribution (B).

A. Study of the role of relativistic effects in the deuteron wave function

In Fig.1 we show two time-ordered diagrams which represent the standard impulse approximation contribution (A) with on-energy shell NN amplitude and the relativistic contribution (B). To examine the role of the relativistic contribution (diagram B) we compare the results obtained in the light-cone impulse approximation with those of the virtual nucleon formalism (VN). In the LC impulse approximation the contribution of diagram B is included into the definition of the deuteron wave function. By comparing the LC impulse approximation with the VN approximation, where diagram B is included in a different way, we actually can learn about the importance of diagram B. Formally, the main difference between the LC and virtual nucleon formalisms is in the value of the momentum at which the deuteron wave function is calculated [1]. The large sensitivity to the relativistic effects is specific for the deuteron wave functions where the S-wave component becomes zero for spectator momenta of 400 MeV/c.

A way to confront the VN and the LC approaches to the description of relativistic motion of nucleons in the deuteron is by measuring the asymmetry between the cross sections for parallel and antiparallel geometries at light-cone momentum fractions α and $2-\alpha$. Since the light-cone formalism is invariant under exchange of α and $2-\alpha$ this assumption predicts that the asymmetry will be zero. That is true even when FSI and ISI are taken into account. In contrast, in the virtual nucleon description the interacting nucleon is off-shell while the spectator is on the mass shell. As a result the symmetry with respect to the α, $2-\alpha$ transposition is lost. Fig.2 shows the asymmetry predicated in the VN approximation case. As will be argued in the next section the difference between the two predictions can be checked experimentally in the proposed experiment.

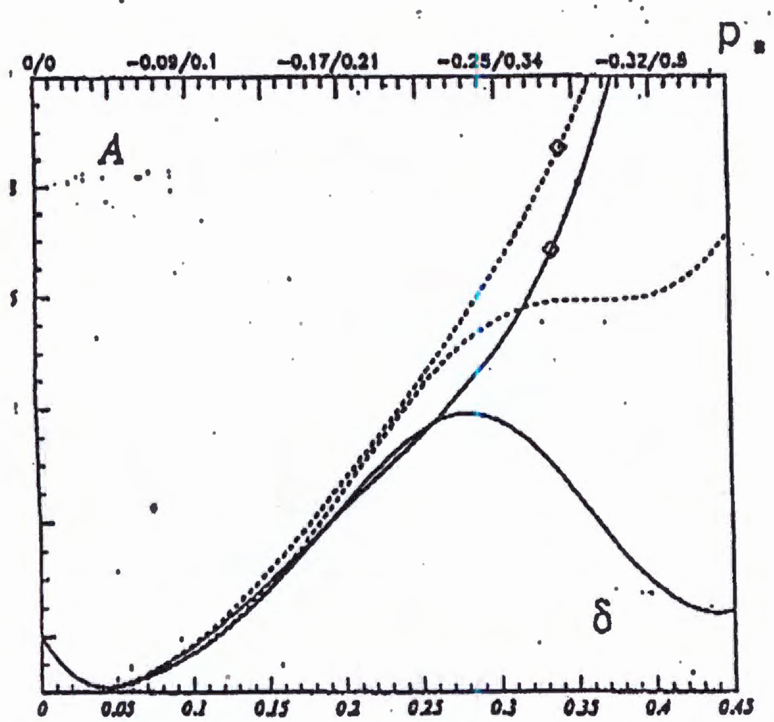

Fig 2: The asymmetry between the cross sections for parallel and antiparallel geometries at light-cone momentum fractions α *and* $2-\alpha$ *defined as:*

$$A(\delta) = \frac{f(1-\delta) - f(1+\delta)}{[f(1+\delta) + f(1-\delta)]/2} \qquad (1)$$

where $f = \frac{\alpha^2\sigma^{pd}}{(s^2-4m^2s)\cdot\sigma^{pp}}$ *and* $\alpha = 1 - \delta, 2 - \alpha = 1 + \delta$*. The top scale represents the corresponding values of the longitudinal component of the spectator momenta (Ps) calculated for* $\alpha = 1 - \delta$ *(negative Ps) and* $\alpha = 1 + \delta$ *(positive Ps) at* δ *= 0.1, 0.2 and 0.3.*

The solid line in Fig.2 is for the PWIA calculation with the "Paris" deuteron wave function. The dashed line is for the PWIA calculation with the "Bonn" wave function. The curves with "Diamond" correspond to the calculation with ISI and FSI. The calculation in this figure [1] corresponds to an incident momentum of 12 GeV/c and was carried out in the VN approximation. In the LC formalism the asymmetry is zero.

The covariant approach in light-cone variables to describe deuteron is developed in [43]. In the approach relativistic deuteron wave function (RDWF) is expressed via the dnn vertex function $\Gamma_\alpha(x, k_\perp)$ with one nucleon on-mass shell. The RDWF is automatically dependent in single variable-virtuality of active nucleon. In the approach the RDWF is not symmetric under replacement $x \leftrightarrow 1 - x$.

We also propose to study the forward-backward asymmetry of the $p+d \to (pp) + n$ process

$$A = \frac{N_+ - N_-}{N_+ + N_-}$$

where $N_\pm = Ed^3\sigma(k_1, \pm q_z)/dq^3$, k_1 is the momentum of incident proton. The asym-

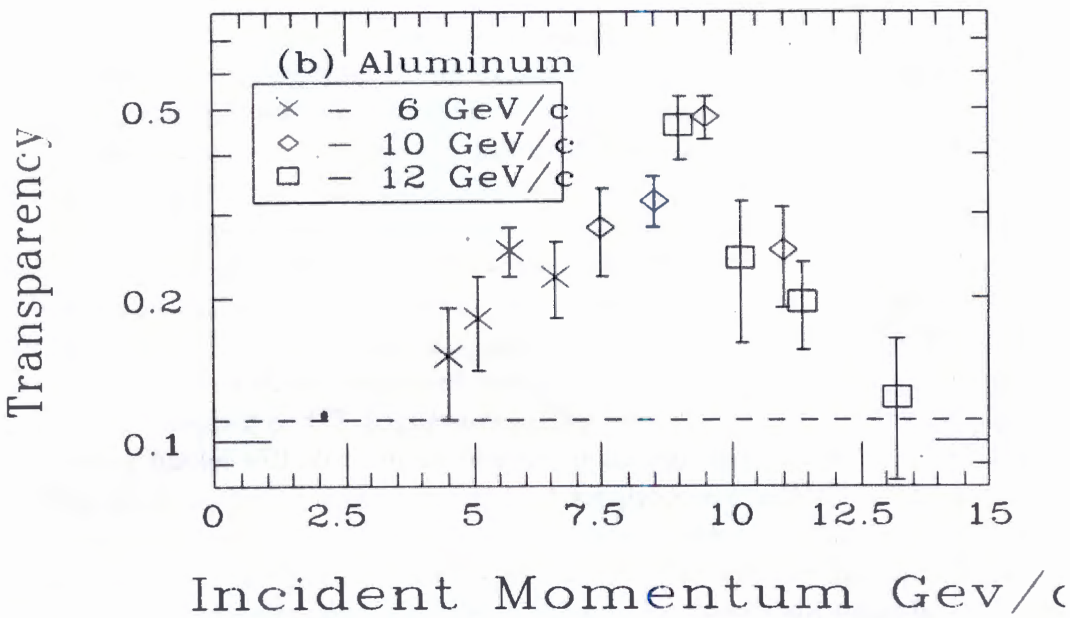

Fig.3: The transparency vs. incident beam momentum for various nuclear targets. Results are from Ref 1.

metry is sensitive to both soft rescattering and hard scattering mechanisms. The investigation of the dependence of the asymmetry on nucleon momentum $| q_z |$ in the deuteron rest frame allow to obtain information on the high momentum component of deuteron, hard scattering amplitude of elastic p – N collision and contributions of secondary processes (for example FSI).

B. Study of Color Transparency (CT)

A pioneering experiment at BNL [3] measured the ratio of the cross section for high momentum transfer quasi-exclusive proton scattering on a nucleus to the cross section for a 'free' hard proton-proton scattering. The measurement was performed with incident proton energies of 6, 10 and 12 GeV/c and on Li, C, Al, Cu, and Pb targets. The acceptance of the two arm spectrometer was limited to about 90^0 cm scattering which means $Q^2 = -t = -u = s/2 = m_N E_{in}$ which satisfied the conditions for hard scattering.

In an impulse approximation picture this ratio, corrected for the nucleon Fermi motion and normalized to the number of protons in the nuclei, indicates the amount of soft scattering of the particles before and after the hard scattering and is known as nuclear transparency.

The measured ratio was unexpected. It was measured to be about the same as the standard Glauber calculation at 6 GeV/c and increased to about three times the Glauber prediction at 10 GeV/c after which it fell again (see Fig. 3).

These experimental results provoked a large number of theoretical studies in the last few years [8]-[34]. They based on our knowledge of the strong interaction and on our ability to apply the calculations to the description of realistic experimental circumstances. The large number of calculations and models create quite a controversial picture. Basic questions related to the role played by the nucleon correlations in nuclei [33], the relation of the in-medium to free-space scattering amplitudes [34], the space/time description of the expansion of the small object [7], the reason for the measured momentum dependence of the transparency [11, 15, 16, 22, 27], the interplay between soft and hard, small and large components [14, 17] and many other problems are left open for future investigation.

The diversity of ideas and the widely different interpretations call for more measurements that will allow to settle some of the issues that are being discussed. We propose to measure the hard proton scattering on a deuteron target in the very same energy range where the quasi-exclusive process was measured [3]. We will pinpoint observables that can be measured and are predicted to be much different when calculated in Glauber or CT frameworks. The very different structures of the deuteron and heavy nuclei will allow us to deduce important experimental information.

The fully exclusive measurement that we proposed will allow kinematical restrictions to a region where the contribution from the deuteron wave function is well established and where the major contributions come from soft rescattering of the produced quark-gluon wave package. The proposed measurement will provide complementary information to what was (and will be) measured on heavier nuclei. We will try to emphasize this complementary point of view that the proposed measurement on the deuteron offers.

The deuteron is the best understood nuclear system, with a wave function constrained by detailed experimental data over a very wide range of momenta [35]. The fact that we can use the deuteron wave function will allow us to shed new light on the role of nucleon correlations in CT, better than can be achieved for heavy nuclei with much lesser known wave functions.

For heavy nuclei the study of CT is done by looking at cases where the particles do not suffer from ISI/FSI. There the CT predicts an increase in events with no ISI/FSI. In the case of the deuteron we measure the complementary case where we look for an increase in events that *did* undergo ISI/FSI.

Another important difference between the semi-exclusive measurements on heavier nuclei and the measurement on the deuteron has to do with the ability to reduce the obscure effects related to the expansion of the wave function as it propagates through the nucleus. The relevant distance for the expansion of the small object to normal nucleon size in heavy nuclei is the radius of the nucleus (a few Fermi). In case of the deuteron, by employing kinematical constraints, it will be possible to study the rescattering at distances from the hard collision which are about one Fermi. Models that predict rapid and slow expansion will give very different results which can than be contrasted.

The proposed measurement will also make contact with experimental efforts [36]-[40] at CEBAF and HERMES in the study of CT effects in electron deuteron interactions at intermediate to large momentum transfers. As in the past, the combined knowledge from the electromagnetic and hadronic probes can yield a better insight to the problem.

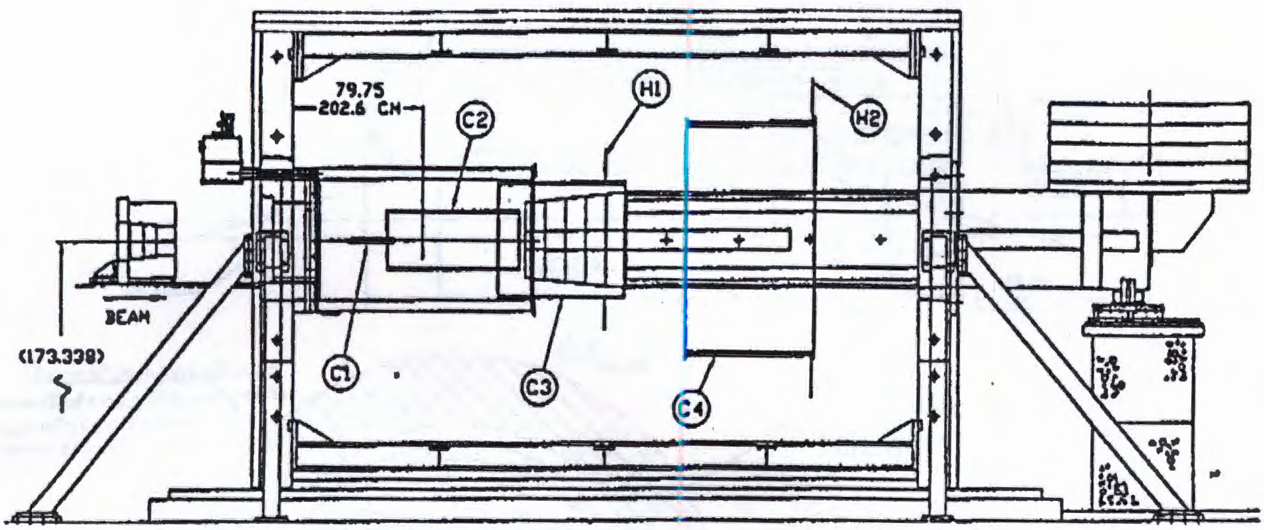

Fig. 4: Cross section of the EVA detector at BNL. The detector has cylindrical symmetry around the beam axis. The magnetic field lines emerging from the downstream end of the solenoid are collected and returned through the long steel pole piece. The entrance plug at the upstream end of the spectrometer is normally rolled into the upstream end wall.

C. Experimental Details

C.1 Setup

The experiment will make use of the Exclusive Variable Apparatus (EVA) spectrometer (see Fig.4) which is now operational at the AGS of Brookhaven National Laboratory (BNL) [41]. The detector consists of a re-engineered solenoidal magnet with a field of nearly 1 Tesla and 4 cylindrical tracking straw chambers (C1-C4) consisting of nearly 6000 straw drift tubes. Each cylinder has four layers of straw tubes. With charge division, each independent chamber provides enough information to determine space points and tangent directions of the tracks. Two fan-shaped arrays of scintillator hodoscopes (H1 and H2) are used for fast pre-triggering. The EVA spectrometer was constructed in order to expand earlier measurements by Carroll et al. [3] which we mentioned in the introduction.

A dedicated cryogenic deuteron target that can be installed in the center of the solenoid (inside the smallest straw tube cylinder C1) has been designed by Leonid Golovanov from Dubna. The solid target track will be removed and the cryogenic target installed. The target cell consists of an inner vessel surrounded by a vacuum jacket and a thermal insulation in between. The vessel has a cylindrical shape of 70 mm diameter, 500 mm length and 50 mm diameter entrance window. The vessel is made of 175 μm thick A-type mylar. The vacuum jacket, also cylindrical, is made of Rohacell-70 plastic foam with specific weight of 0.071 g/cm^3. The outer diameter of the vacuum jacket is 130 mm and the thickness of the wall is 17.5 mm. The thermal insulation of the inner vessel consists of 20 alternation layers of metallized mylar 10 μm thick and glasswool ($15 \cdot 10^{-4}$ g/cm^2).

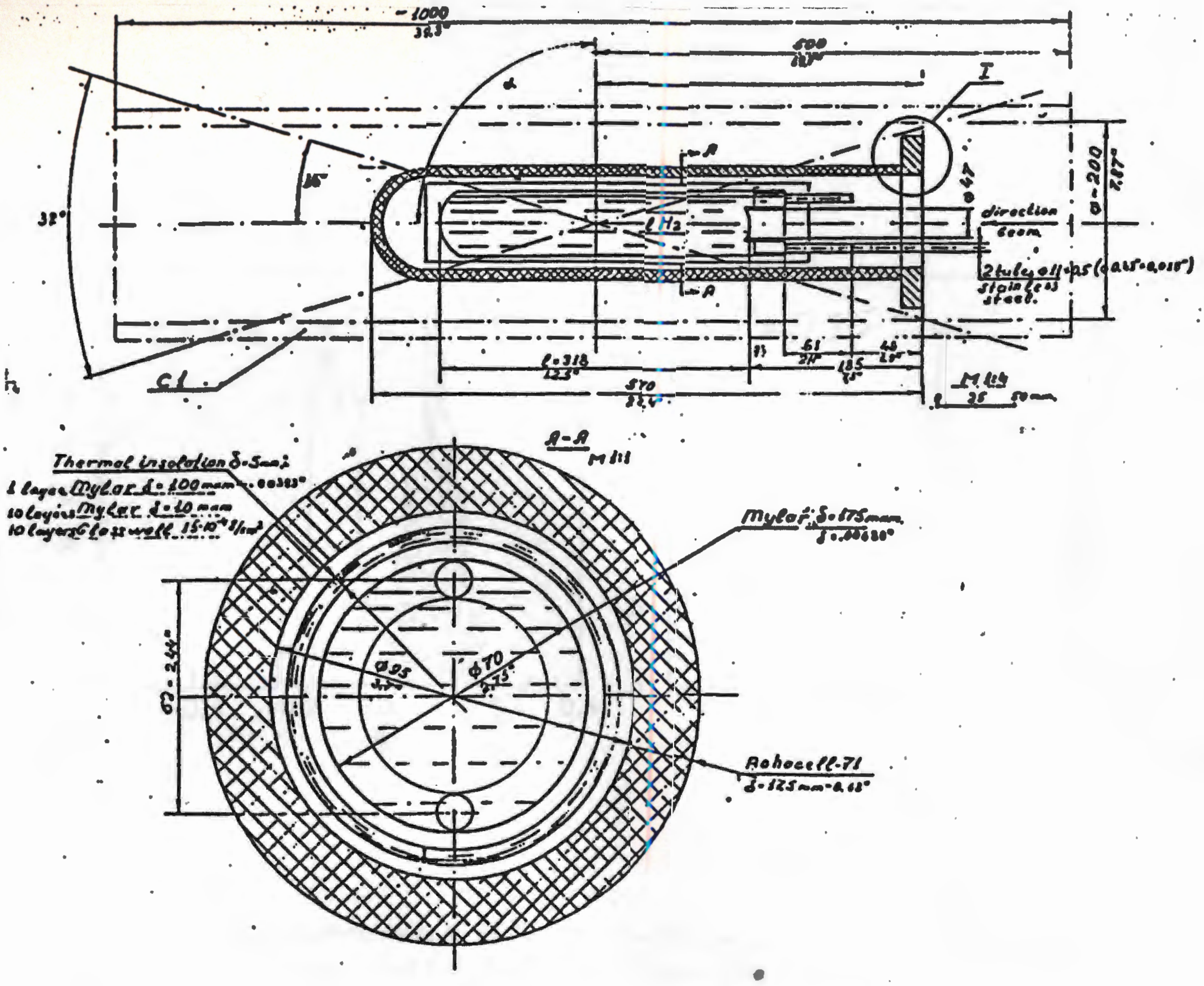

Fig. 5: A schematic drawing of the cryogenic target to be built for this measurement.
Parameters of the target are:
1. Volume of the liquid H_2 in the target - 1.2 litre
2. Quantity of the lH_2 along the beamline - 2.25 g/cm^2
3. Quantity of the material for vecoil particles:
$0.435 g/sm^2$ ($\alpha = 90^o$) $\div$ 1.582 g/cm^2 ($\alpha = 16^o$)

A schematic view of the target is given in Fig 5.

The target will use an existing helium refrigerator to condense either deuterium or hydrogen for calibration purposes. Heavier gases such as neon, nitrogen or argon may also be condensed for A dependent studies.

C.2 Beam time request

To demonstrate our experimental ability to measure the required effects we will calculate the expected rate for a measured cross section of $1nb/(GeV/c)^2$. For the designed deutron target the number of scatters is 2×10^{24}. With a beam of 2×10^7 particles/spill and 100 beam hours a week, we expect 10^{12} protons to hit the target per week. Our acceptance at 6 GeV/c is about $\Delta t = 1(GeV/c)^2$. The acceptance grows with energy s so the value for 6 GeV/c gives a conservative estimate for all other energies. For the rate estimate we will also assume an effective solid angle

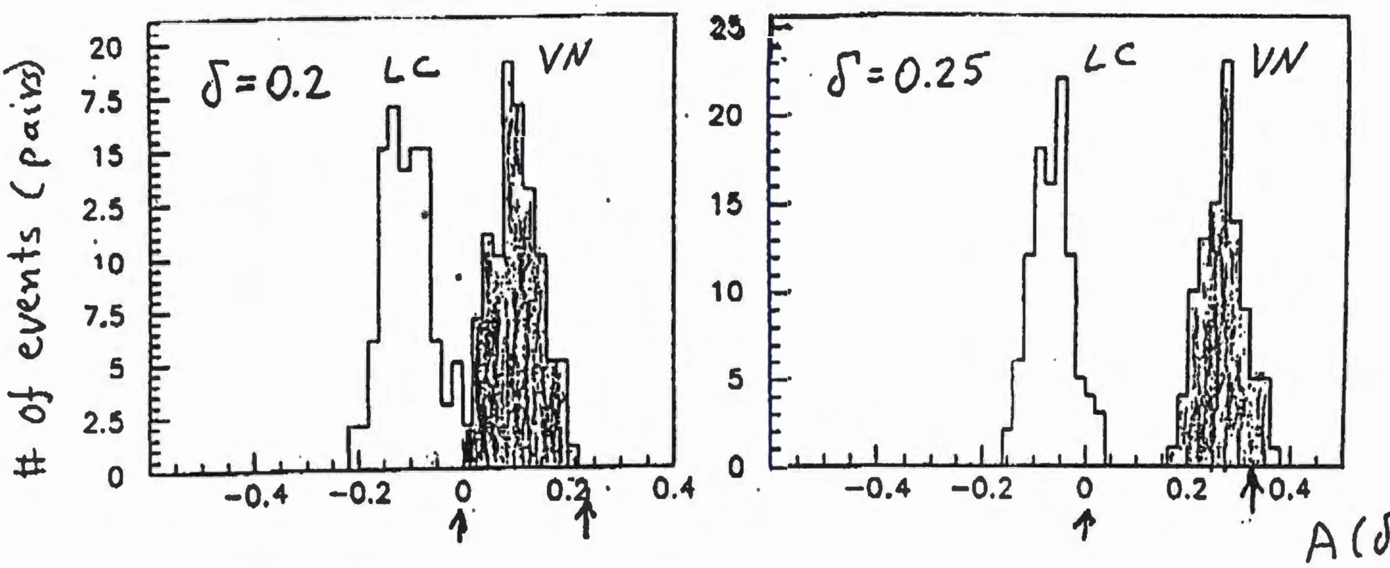

Fig. 6: Simulated measurements of the asymmetry parameter $A(\delta)$. The calculation was done assuming $d\alpha/\alpha = 1\%$. One peak correspond the expected reasults in the LC formalizm and the other to the VN prediction. The theoretical predictions are shown by arrows.

which is about conservatively estimated at 0.1 of the geometrical one due to straw tube inefficiencies, reconstruction inefficiencies etc. Under all these assumption the expected rate is:

$200 events/week/nb/GeV/c^2$.

To demonstrate the ability to address the physics issue we discussed we show in figure 6 a simulation of the expected measured asymmetry (as defined in figure caption of fig 2.). The simulation shows the expected $A(\delta)$ measurements obtained with a device which has a $d\alpha/\alpha$ resolution of 1 %. The calculation is done for 100 pair measurements at $\alpha = 1.2/0.8$ and $\alpha = 1.25/0.75$. The geometry of the measurements in the $\alpha = 1.2/0.8$ case is shown in fig. 7.

The calculations were done for the LC, assuming A=0 and for the VN assuming the calculated value for 6 GeV/c incident beam [42]. The symmetric geometry of the events makes them ideal for study with the EVA detector. The cross section for the proposed measurements (α = 1.2/0.8 and 0.75/1.25) are $0.3 - 10\mu b/sr/GeV^4$. We need less than a day to obtain data as shown in Fig. 6 which shows clearly the difference between the two models.

The effects due to CT are predicted to be more pronounced as the incident energy increases. However, the cross sections drop fast as a function of the incident energy.

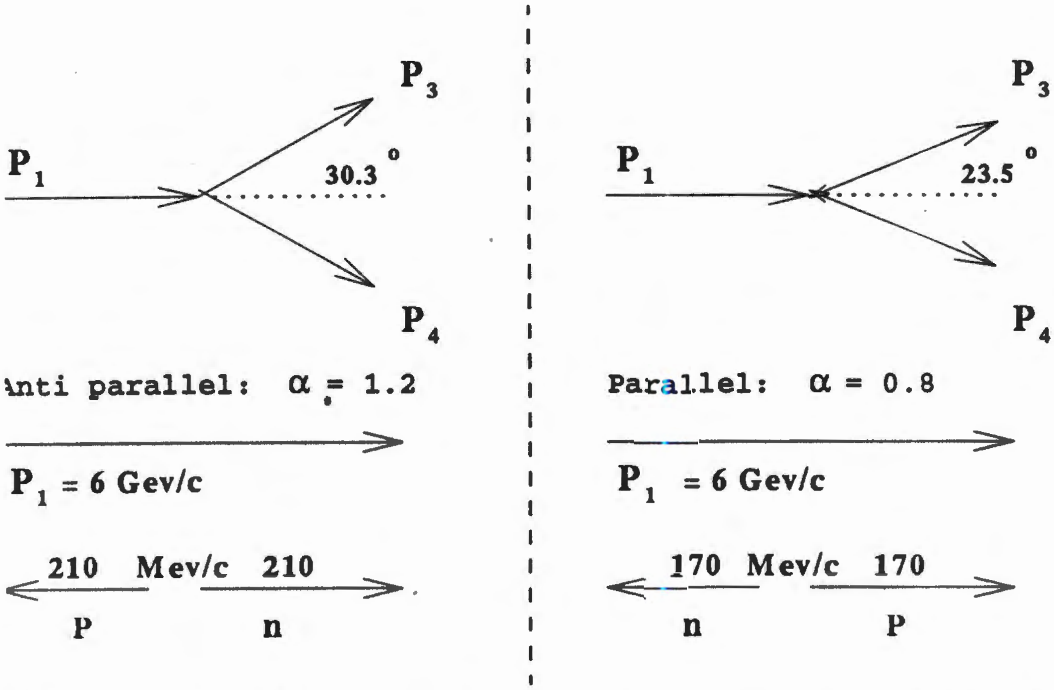

Fig. 7: The kinematics for the pair of measurements required to measure the $\delta = 0.2$ $\alpha = 0.8/1.2$ *point in Figs. 2.,6.*

An incident momentum of 9 GeV/c seems to be an optimized compromise. The calculations of the expected cross section as a function of p_t for this energy and $\alpha = 1$ are shown in Fig 8. It is clear from the figure that, to gain maximum sensitivity to CT, one should look at the ratio of the cross sections at high and low p_t. The ratio will also reduce some systematic errors.

The integrated cross section over 2π for the azimuthal angle and for $\alpha = 1 \pm 0.1$ can be measured with good statistics and be compared to theoretical predictions [42]. The calculated ratios are:

with no Color transparency:

$$R_{noCT} = \frac{\sigma(p_t = 50 - 250\ MeV/c)}{\sigma(p_t = 250 - 450\ MeV/c)} = \frac{0.5\mu b/sr}{1.08 \cdot 10^{-3}\mu b/sr} = 518 \qquad (2)$$

with CT (QDM $\Delta M^2 = 0.7$ GeV^2):

$$R_{CT} = \frac{\sigma(p_t = 50 - 250\ MeV/c)}{\sigma(p_t = 250 - 450\ MeV/c)} = \frac{0.64\mu b/sr}{0.68 \cdot 10^{-3}\mu b/sr} = 914 \qquad (3)$$

$$\frac{R_{noCT}}{R_{CT}} = \frac{941}{518} = 1.8 \qquad (4)$$

With the liquid deuteron target and an optimal incident energy we will be able to measure this ratio with sufficiently small statistical and systematic errors to be able to distinguish between these two predictions.

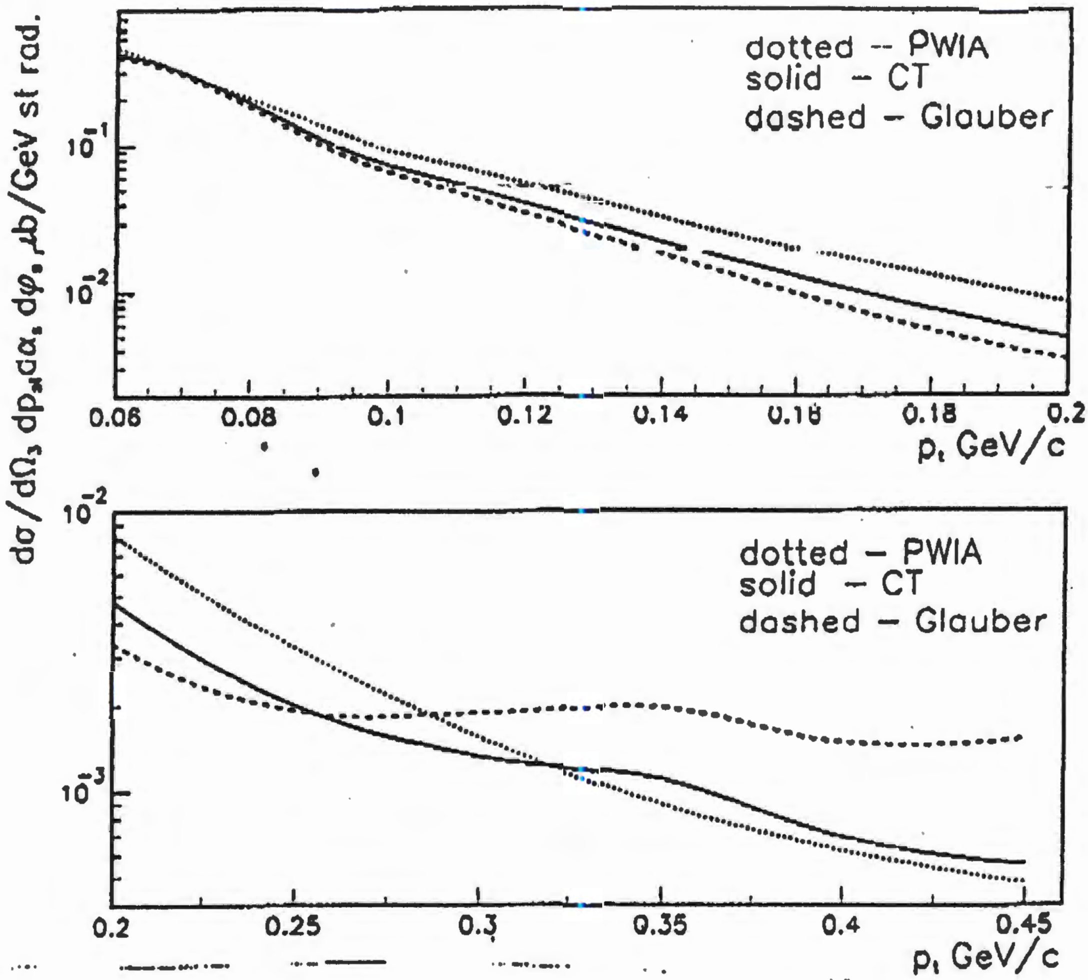

Fig. 8: Calculation of the cross section for pd → ppn at $\alpha = 1$ as a function of p_t in PWIA, Glauber (no CT), and QDM (with $\Delta M^2 = 0.7$ GeV^2).

C.3 Request from BNL

We trust that the solenoidal magnet of the EVA detector will be running reliably later this year following the extensive improvements. smooth operation of the solenoid is obviously essential to the success of any experiments with this detector.

As mentioned above, a conceptual design for the cryogenic target and support has been worked out by L.Golovanov of the JINR, in cooperation with the AGS Cryogenics Group. We assume that a satisfactory arrangement to construct a target to BNL safety standards can be worked out to minimize the load and cost to BNL since JINR is very experienced in this area.

References

[1] L.L. Frankfurt,E. Piasetzky, M.M Sargsyan,and M. Strikman, Phys. Rev. C51 (1995), 890.

[2] L.L. Frankfurt,E. Piasetzky, M.M Sargsyan,and M. Strikman, to be published.

[3] A.S. Carroll et al., Phys. Rev. Lett. 61 (1988) 1698; S. Heppelmann, in *Nuclear Physics on the Light Cone*, M.B. Johnson, and L.S. Kisslinger, eds. (World Scientific, Singapore 1989).

[4] A.H. Mueller Proceeding of the 7th Rencontre de Moriond on elementary Particle Physics, Les Arcs, France (1982); S.J. Brodsky, in Proceeding of the 13th International Symposium on Multiparticle Dynamics, Volendam, The Netherlands, 1982.

[5] S. Nussinov, Phys. Rev. Lett. 34 (1975) 1286.

[6] F.E. Low, Phys. Rev. D 12 (1975) 163.

[7] G.R. Farrar et al., Phys. Rev. Lett. 61(1988) 686.

[8] L.L. Frankfurt and M.I Strikman Phys. Rep. 160(1988),235

[9] S.J. Brodsky, and A.H.Mueller, Phys. Lett. B 206, 685 (1988).

[10] B.Pire, and J.P. Ralston Phys. Rev. Lett. 61,1823 (1988).

[11] S.J. Brodsky and G. de Terramond Phys. Rev. Lett. 60,1924 (1988).

[12] G.R. Farrar, H. Liu, L.L Frankfurt, and M.I.Strikman Phys. Rev. Let. 62, 1095 (1989).

[13] S.J.Brodsky and P.Hoyer Phys. Rev. Lett. 63, 1566, (1989).

[14] B.Pire, and J.P. Ralston Phys. Rev. Lett. 65,2343 (1990).

[15] B.K. Jennings and G.Miller, Phys. Lett. B 236 , 209 (1990).

[16] B.K. Jennings, and G.A. Miller Phys. Rev. D44, 692 (1991).

[17] J.P. Ralston, Phys. Lett. B 269 439, (1991).

[18] J. Botts, Phys. Rev. D44, 2768 (1991).

[19] B.Z.Kopeliovich and B.G.Zakharov, Phys. Rev. D44(1991),3466

[20] B.Z.Kopeliovich and B.G.Zakharov, Phys.Lett.,B264(1991),4343

[21] L.L. Frankfurt and M.I Strikman, Prog. Part. and Nucl. Phys.27(1991),135

[22] B.K. Jennings, and G.A. Miller Phys. Lett. B274 (1992),442

[23] T.S.H Lee and G.A. Miller Phys. Rev. C 45 , 1863 (1992).

[24] I. Mardor et al. Phys.. Rev. C46, 761 (1992).

[25] O. Benhar et al. Phys. Rev. Lett. 69, 1156, (1992).

[26] A.Kohama, K.Yazaki, and R.Seki Nucl. Phys. A536 , 716 (1992).

[27] B.K. Jennings, and G.A. Miller,Phys. Lett. B318(1993),7

[28] P.Jain and J.P.Ralston, Phys. Rev. D48(1993), 1104

[29] L. Frankfurt, M. Strikman, G.A. Miller, Phys. Lett. B 304 (1993) 1.

[30] L. Frankfurt, G. A. Miller, and M. Strikman, Ann. Rev. Nucl. Part. Phys. 44 (1994) 501.

[31] S.J. Brodsky, L. Frankfurt, J.F. Gunion, A.H. Mueller, and M. Strikman, Phys. Rev. D 50 (1994) 3134.

[32] L. Frankfurt, M.I.Strikman, and M.Zhalov Phys. Rev. C 50 (1994) 2189.

[33] L. Frankfurt, E.J. Moniz, M.M. Sargsyan, and M. Strikman, Phys. Rev. C51(1995), 3435.

[34] P.Jain, B. Pire, and J.P.Ralston, submitted to Physics Report (1995).

[35] G.E. Brown , A.D. Jackson: The Nucleon-Nucleon Interaction North-Holland Publish. Comp., 1976.

[36] K. Sh. Egiyan, L.L. Frankfurt, W.R. Greenberg, G.A. Miller, M.M Sargsyan, and M. Strikman, Nucl. Phys. A580 (1994) 365.

[37] L.L. Frankfurt, W.R. Greenberg, G.A. Miller, M.M Sargsyan, and M. Strikman, Z. Phys. A352 (1995) 97.

[38] Summary talk by B. Filippone, BARYONS'95, Santa Fe, Oct. 1995.

[39] Workshop on CEBAF at Higher Energies, Editors N.Isgur and P. Stoler, CEBAF (1994).

[40] Proceeding from Workshop on options for CT studies at CEBAF, CEBAF (1995).

[41] EVA, A Solenoidal Detector for Large Exclusive Reactions, Proposal to BNL (unpublished); Additional Material, Proposal to BNL 1989 (unpublished).

[42] M.M Sargsyan, private communication.

[43] M.A.Braun, M.V.Tokarev, Sov.J.Part.Nucl.22(1991) 601.