

Analysis of the possibility of studying the asymmetry of pions production in collisions of transversely polarized protons and deuterons on the MPD@NICA

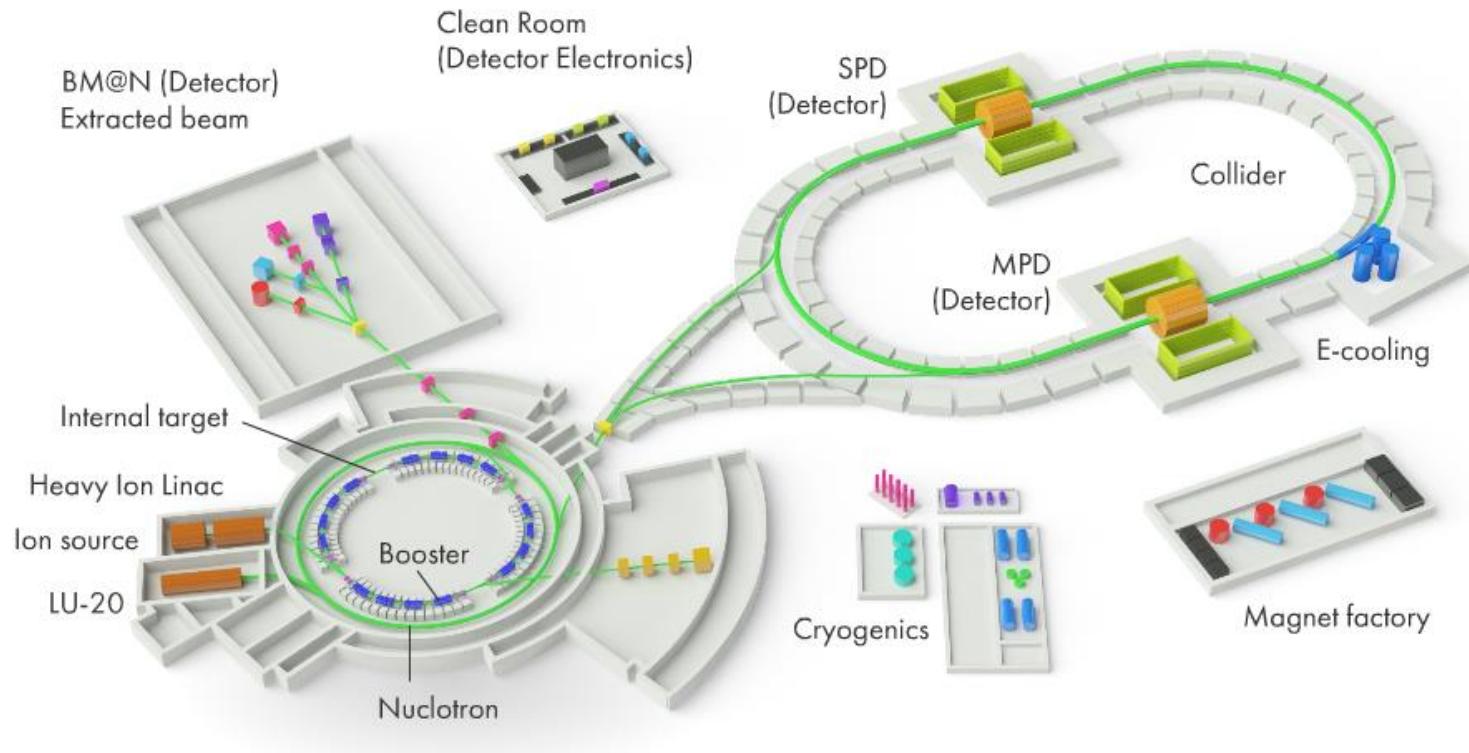
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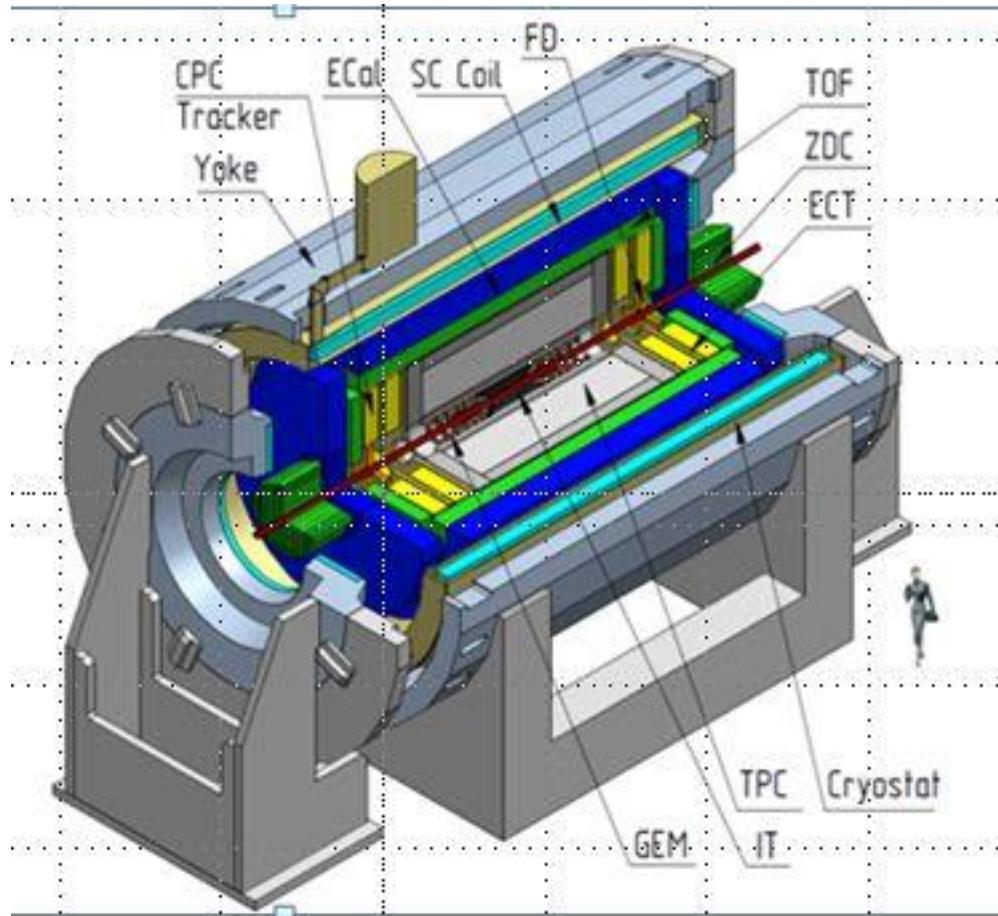
NICA Complex

Nuclotron-based Ion Collider fAcility (NICA)



<http://nica.jinr.ru/complex.php>

Multi Purpose Detector (MPD)



<http://mpd.jinr.ru/mpd/>

Motivation

- ✓ Collisions of polarized beams are part of the NICA project
- ✓ Dubna has unique possibility to collide polarized proton and deuteron
- ✓ At the moment MPD@NICA is oriented to study heavy ion collision and has no proposal to use polarized beams
- ✓ One of the possibilities – to study transverse asymmetry of pion production

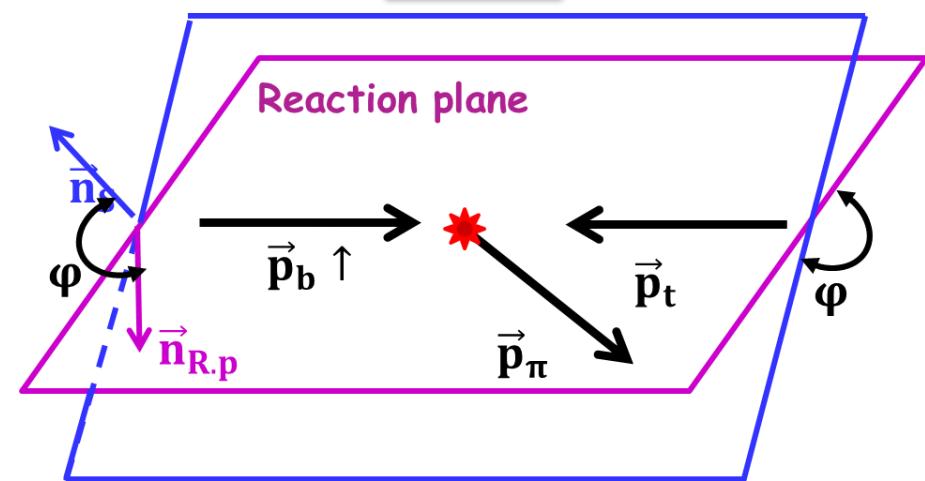
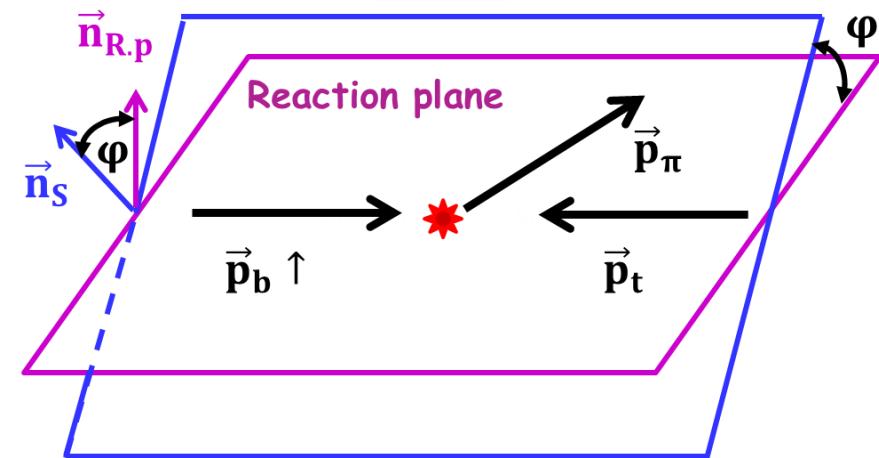
Reaction

$$\mathbf{p} \uparrow + \mathbf{p(A)} = \pi + X$$

Geometry

Left

Right



$$(\vec{n}_S \vec{p}_b) = 0$$

$$\vec{n}_{R.p} = [\vec{p}_b \vec{p}_\pi] / |[\vec{p}_b \vec{p}_\pi]|$$

R. Machleidt, K. Holinde, and Elster. Phys. Rep., 149, 1, (1987).

Description and variables

$$E \frac{d\sigma}{d\vec{p}} = E \frac{d\sigma_0}{d\vec{p}} + (\vec{S} \vec{N}) E \frac{d\sigma_S}{d\vec{p}}$$

$$E \frac{d\sigma}{d\vec{p}} = d\sigma_0(x_F, p_T, s) (1 + A_N(x_F, p_T, s) P \cos \varphi)$$

W. Haeberli. Ann. Rev. Nucl. Sci., 17, 373, (1967)

A_N - Single-Spin Asymmetry (analyzing power)

Feynman variable x_F

$$x_F = p_{c,l}/p_{c,max}$$

$p_{c,i}$ – momentum in c. m.

R.P. Feynman. Phys. Rev. Lett., 23, 1311, (1969).

Kinematic region

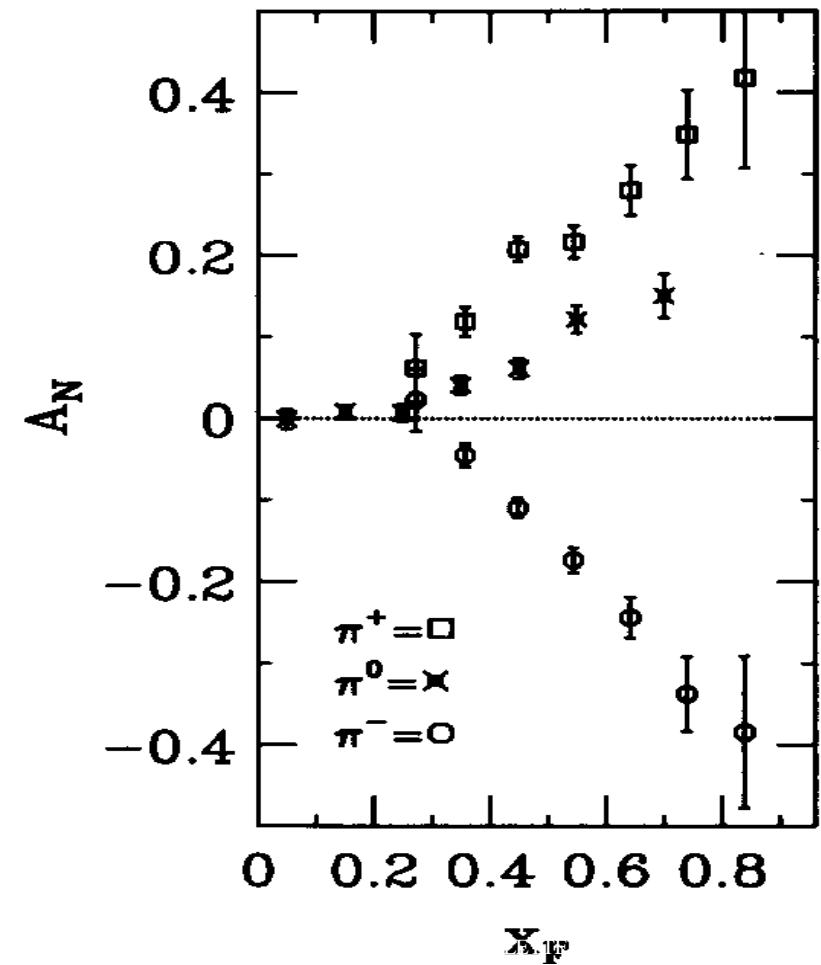
$$\mathbf{p}^\uparrow + \mathbf{p}(A) = \pi + X$$

We are considering pion production in
the fragmentation region of a polarized
proton $x_F > 0$

The experiments indicates a large asymmetry
(A_N up to 40 %) in a wide range of collision energies

High energy data

$(p \uparrow)_b(200 \text{ GeV}) + A_t = \pi + X; A_t = p; \sqrt{s} = 19.4 \text{ GeV}$

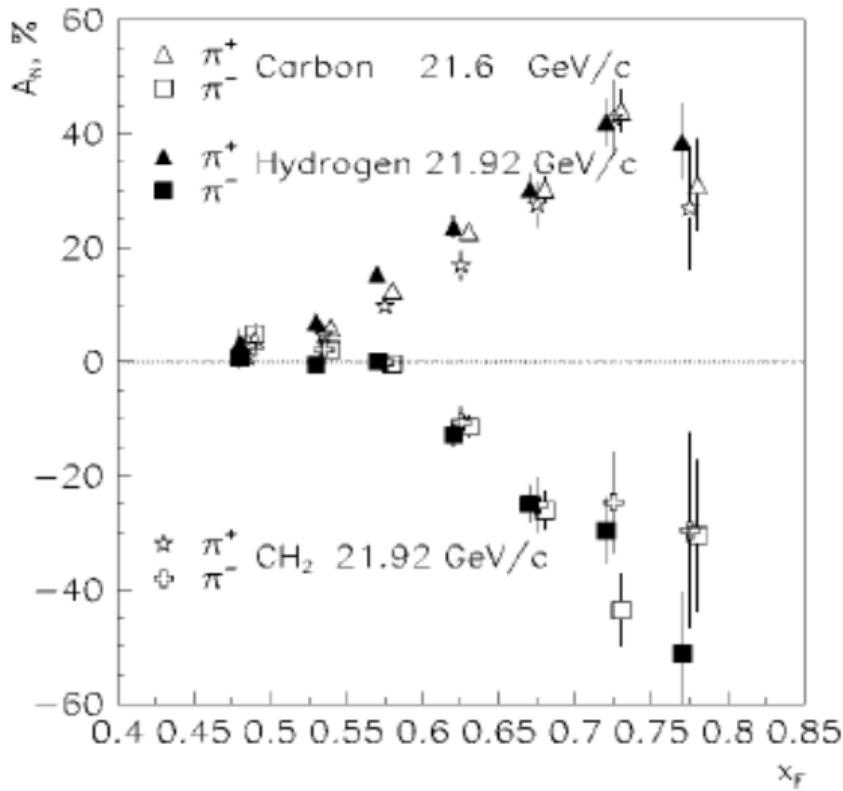


FNAL E704, Phys. Lett. B 264, 462 (1991)

$0.2 \text{ GeV}/c \leq p_T \leq 2 \text{ GeV}/c$

Low energy data

$$(p \uparrow)_b(22 \text{ GeV}) + A_t = \pi + X; A_t = p; \sqrt{s} = 6.6 \text{ GeV}$$



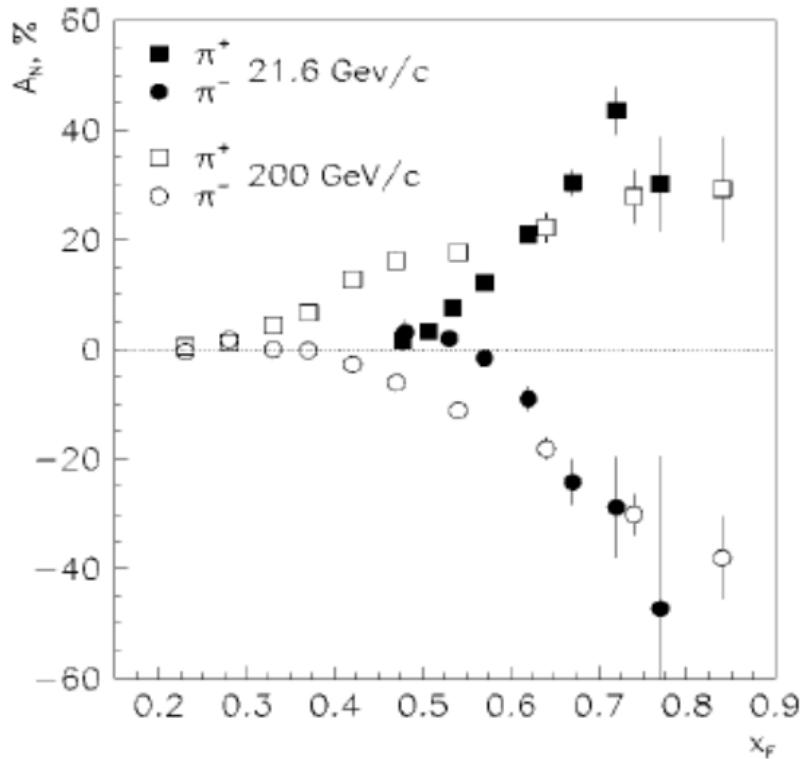
E925 Collaboration (AGS BNL)
Phys. Rev. D 65 , 092008, (2002)

there is no dependence
on the target for data in
the fragmentation region
of the polarized beam

$$0.2 \text{ GeV}/c \leq p_T \leq 2 \text{ GeV}/c$$

High and Low energy data

$$p_b \uparrow + A_t = \pi + X$$



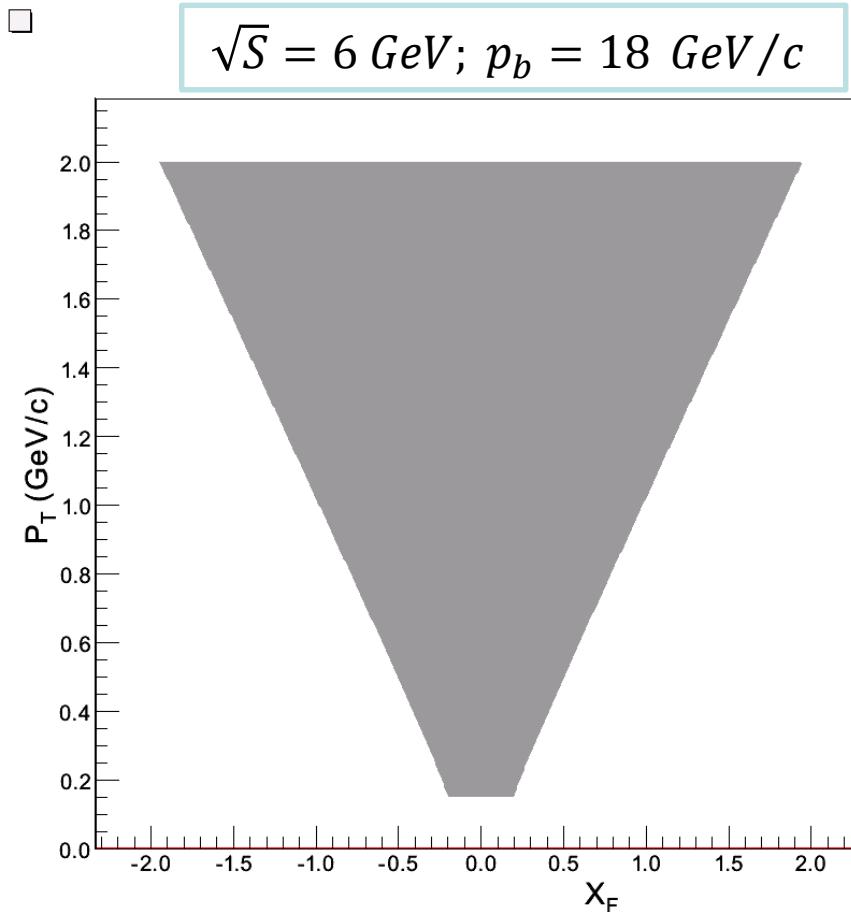
D.L. Adams et al., Phys. Lett. B 264, 462
(1991) 200 GeV

C.E. Allgower et al., Phys. Rev. D 65
, 092008, (2002) (22 GeV)

$0.2 \text{ GeV}/c \leq p_T \leq 2 \text{ GeV}/c$

MPD pion acceptance (x_F , p_T)

Barrel part



$$p_\pi (\max) \approx \sqrt{s}/2$$

$$x_F \approx (2p_L)/\sqrt{s}$$

Variables; distributions

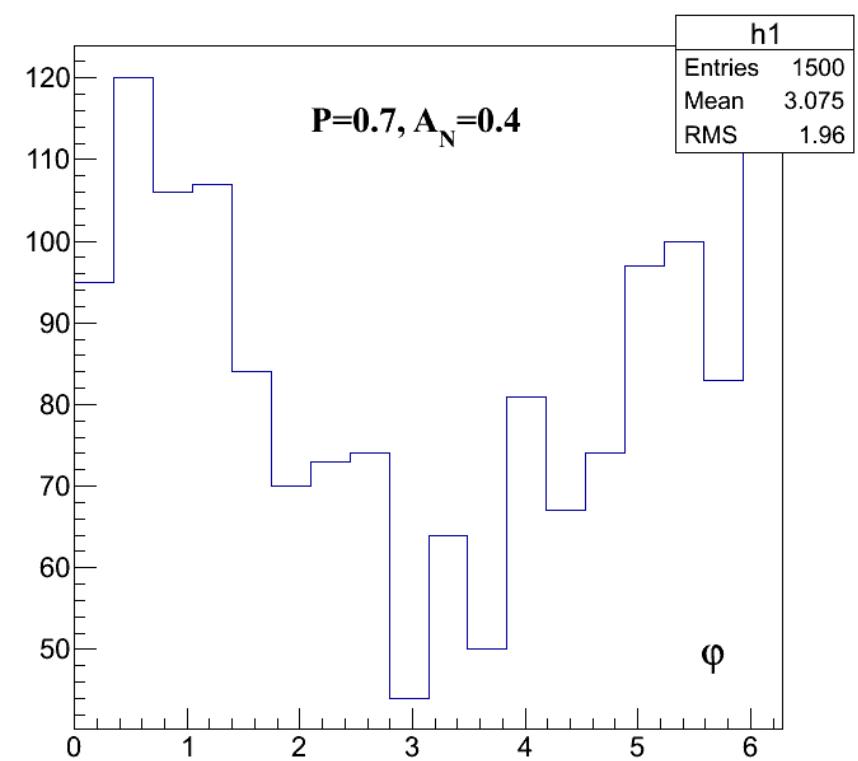
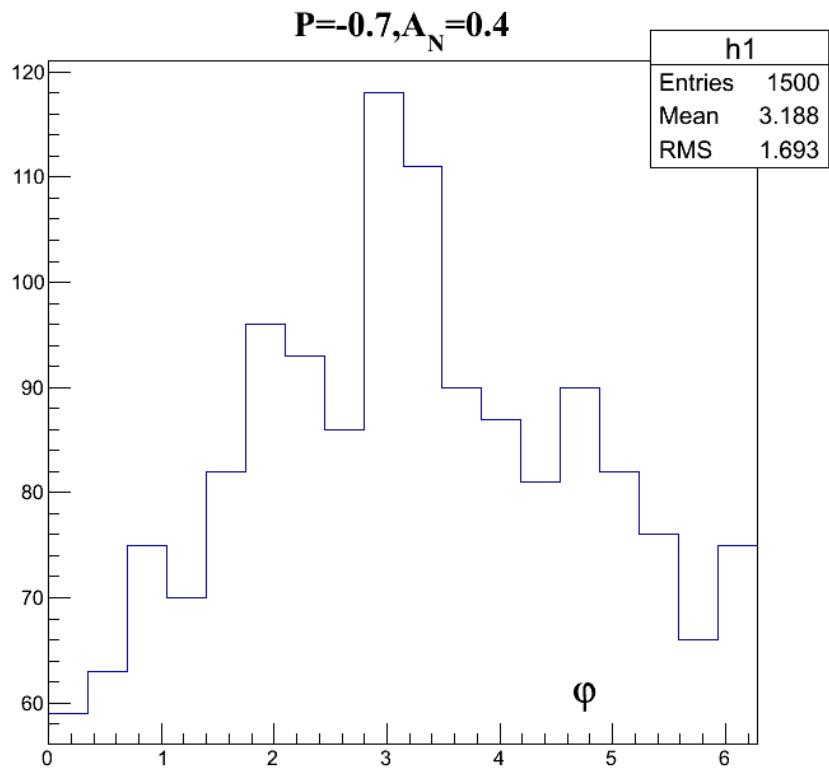
- measurements with three polarization values $P_+ > 0; P_- < 0; P_0 \equiv 0$
- number of recorded pions per azimuthal angle interval
 $dN_+/d\varphi; dN_-/d\varphi; dN_0/d\varphi;$
- corresponding luminosities $L_+; L_-; L_0$
- normalized distributions along azimuthal angle $n_i(\varphi) = (dN_i/d\varphi)/L_i$

$$n_i(\varphi) = \sigma_0(1 + P_i A_N \cos\varphi)$$

$$\langle n_i \rangle = \int_0^{2\pi} n_i(\varphi) d\varphi = \sum_{j=1}^{N_\varphi} n_i(\varphi_j) = 2\pi \sigma_{0,i}$$

$$\langle n_i \cos\varphi \rangle = \int_0^{2\pi} n_i(\varphi) \cos\varphi d\varphi = \sum_{j=1}^{N_\varphi} n_i(\varphi_j) \cos\varphi_j = \pi \sigma_{0,i} A_N P_i$$

Polar angle distribution



Asymmetry and experimental data

$$A_N = \frac{3}{P_+ P_-} \frac{P_- \langle n_+ \cos\varphi \rangle + P_+ \langle n_- \cos\varphi \rangle}{\langle n_- \rangle + \langle n_0 \rangle + \langle n_+ \rangle}$$

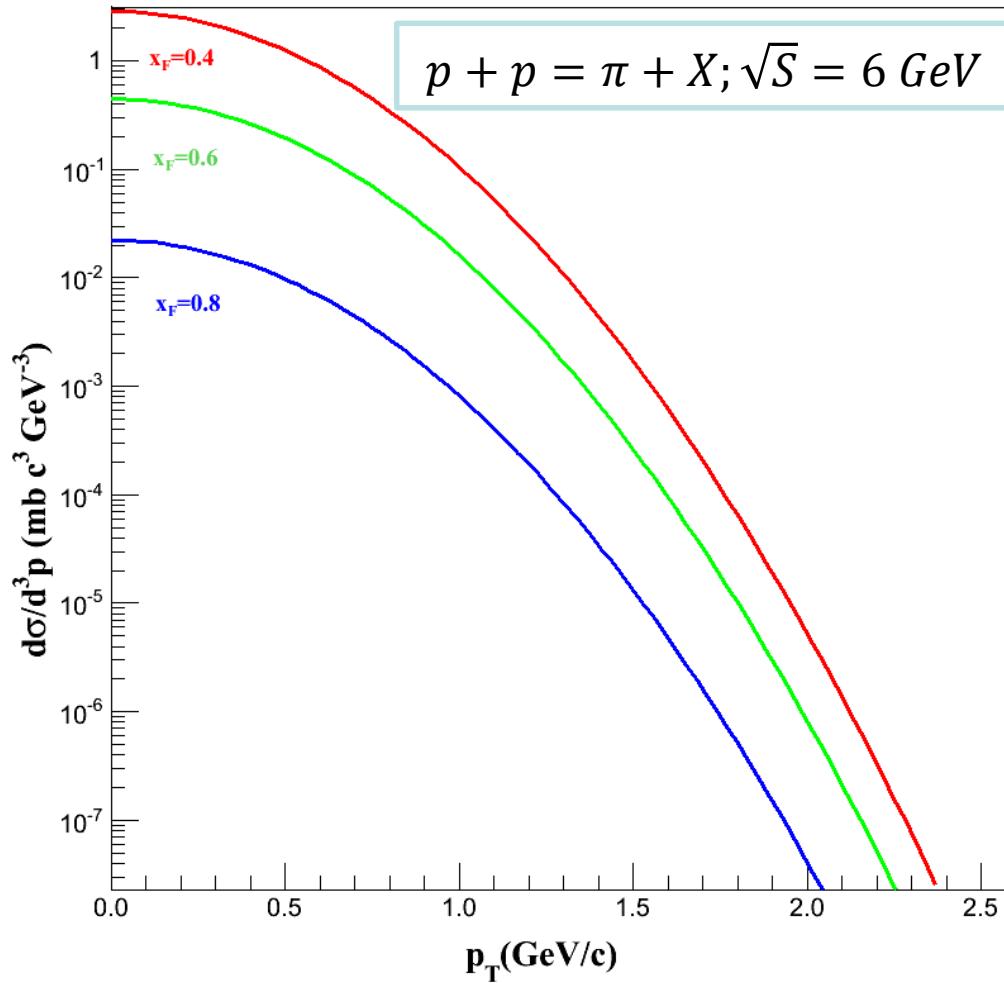
for simplicity

$$P_+ = -P_- = P$$

$$A_N = \frac{3}{P} \frac{\langle n_+ \cos\varphi \rangle - \langle n_- \cos\varphi \rangle}{\langle n_- \rangle + \langle n_0 \rangle + \langle n_+ \rangle}$$

Cross section

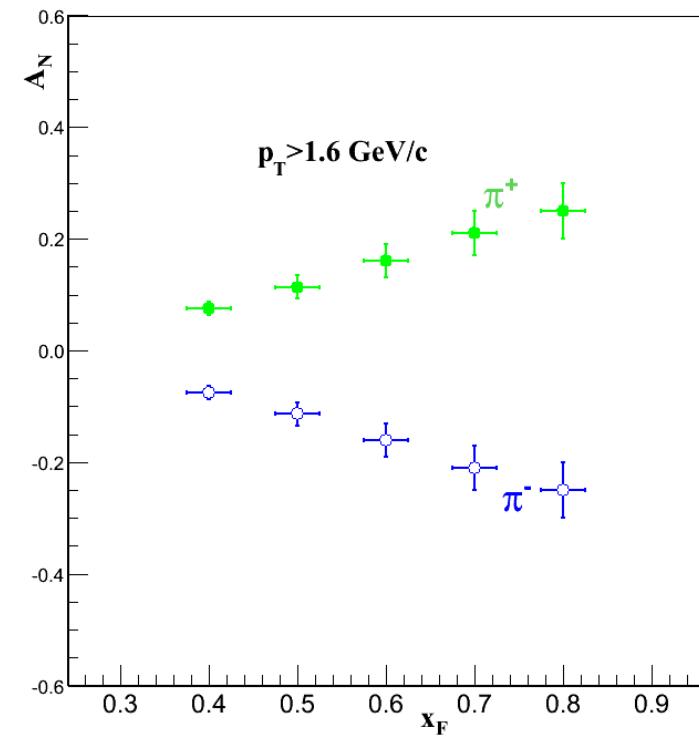
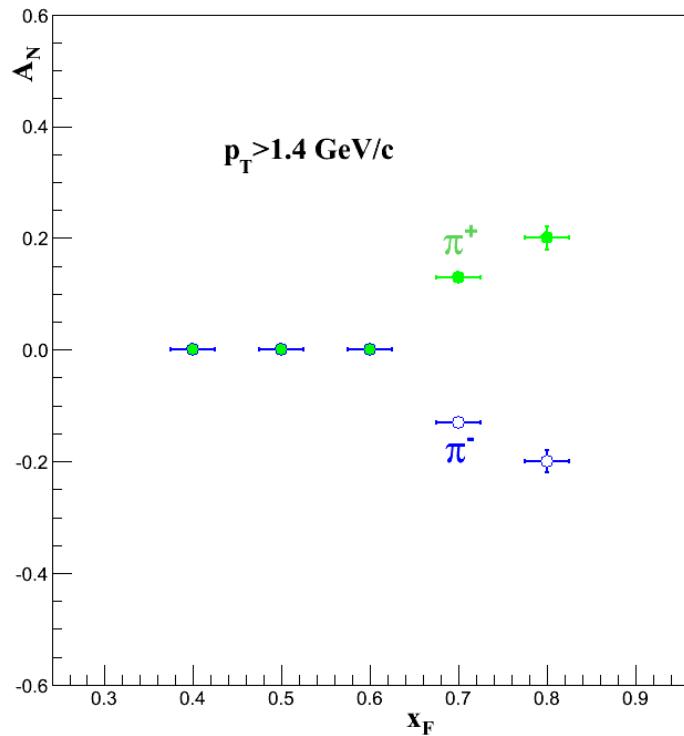
V.S.Barashenkov, N. V.Slatin, PEPAN, v.15, p.997, (1984)



Asymmetry for $p \uparrow p \rightarrow \pi X$ at MPD

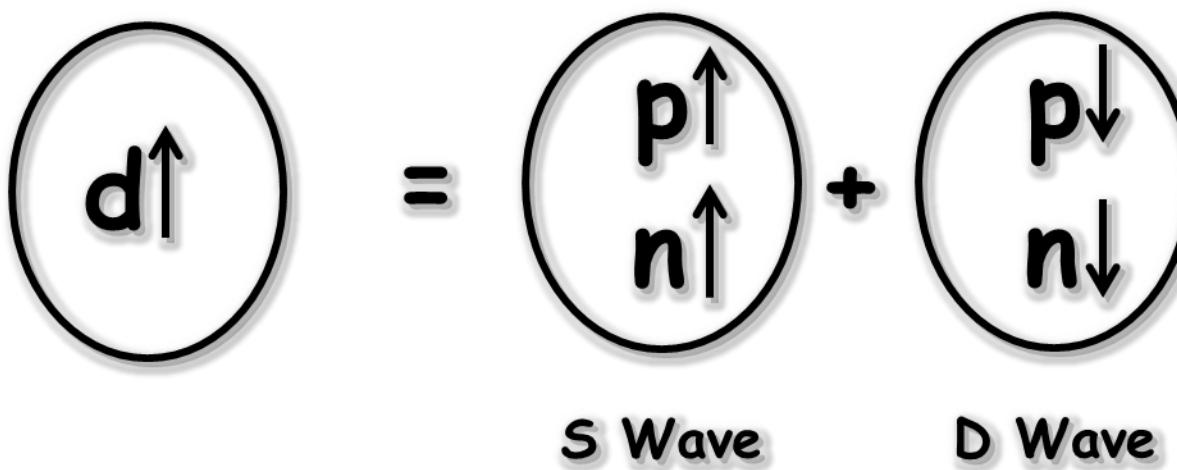
$L = 10^{31} \text{ cm}^{-2}\text{s}^{-1}$; $T = 1 \text{ Month}$

$p \uparrow + p = \pi + X$; $\sqrt{s} = 6 \text{ GeV}$, $E_b = 18 \text{ GeV}$



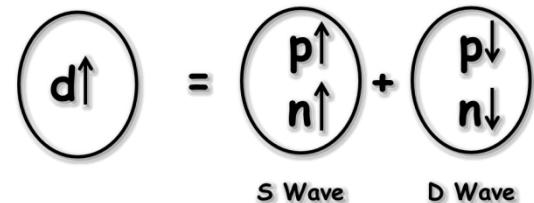
Unique possibility to obtain asymmetry
of collision of polarized neutron
from collision of polarised deuteron

$$d\uparrow + p(A) = \pi + X$$



Structure of the cross section

$$D \uparrow + p = \pi + X$$



cross section

$$d\sigma(d + p \rightarrow \pi X) = w_s d\sigma(d_S + p \rightarrow \pi X) + w_D d\sigma(d_D + p \rightarrow \pi X)$$

$$d\sigma(d_S \uparrow + p \rightarrow \pi X) = \alpha [d\sigma(p \uparrow + p \rightarrow \pi X) + d\sigma(n \uparrow + p \rightarrow \pi X)]$$

$$d\sigma(d_D \uparrow + p \rightarrow \pi X) = \alpha [d\sigma(p \downarrow + p \rightarrow \pi X) + d\sigma(n \downarrow + p \rightarrow \pi X)]$$

$\alpha \approx 0.85$ – shading factor

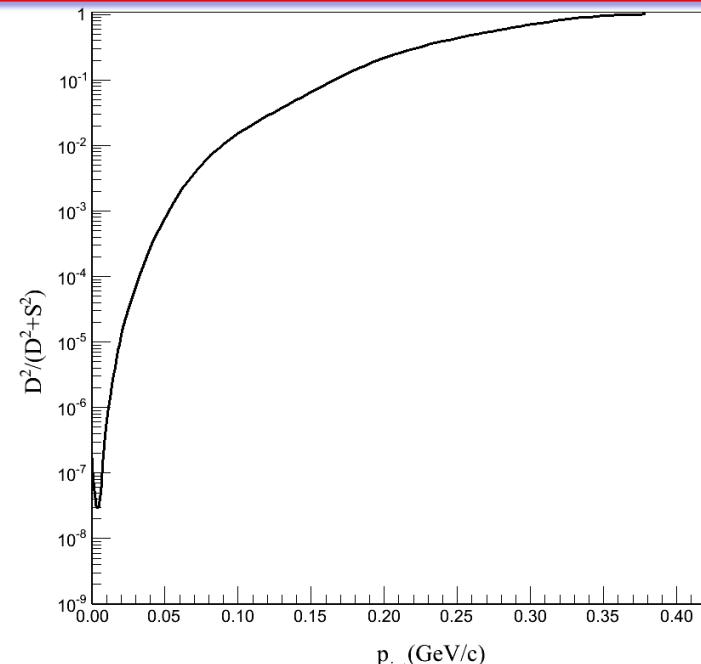
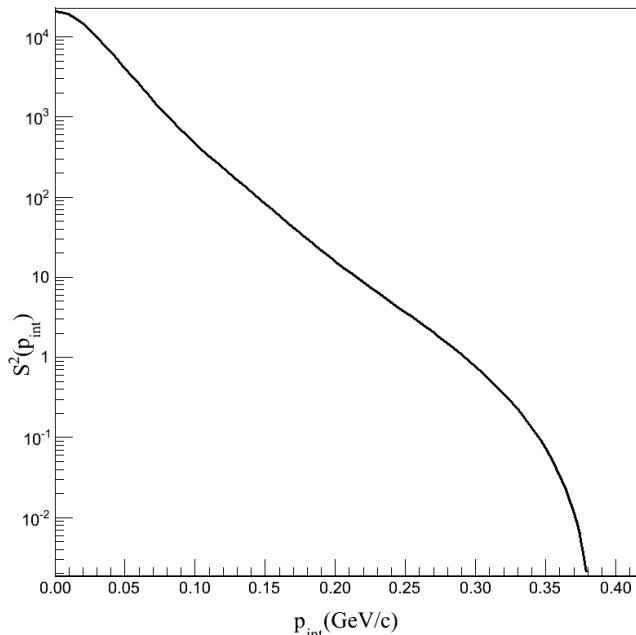
Deuteron Wave Function (DWF)

$$\sigma_p = \sqrt{\langle p^2 \rangle} = 0.09 \text{ GeV/c}$$

$$\Delta x_F \approx 0.004$$

$$w_S = \frac{\int S^2(p) p^2 dp d\Omega}{\int (S^2(p) + D^2(p)) p^2 dp d\Omega} = 0.953$$

$$w_D = \frac{\int D^2(p) p^2 dp d\Omega}{\int (S^2(p) + D^2(p)) p^2 dp d\Omega} = 0.047$$



Thus, we can ignore D-wave in cross section

$$(w_S > w_D) \rightarrow d\sigma(dp \rightarrow \pi X) = \alpha d\sigma(d_S p \rightarrow \pi X)$$

$$\begin{aligned} d\sigma_{+,d}(\varphi) &= d\sigma_{0,d}(1 + P_+ A_N(d) \cos\varphi) = \\ &+ \alpha d\sigma_{0,p}(1 + P_+ A_N(p) \cos\varphi) + \\ &+ \alpha d\sigma_{0,n}(1 + P_+ A_N(n) \cos\varphi) \end{aligned}$$

And we can obtain $A_N(n)$ from $A_N(d)$ and $A_N(p)$

Asymmetry $A_N(n)$ for $n \uparrow + p = \pi + X$

$$\sigma_0(d/p) = \frac{1}{3 \cdot 2\pi} [\langle n_+(d/p) \rangle + \langle n_0(d/p) \rangle + \langle n_-(d/p) \rangle]$$

$$A_N(p/d) = \frac{3}{P_+ P_-} \frac{P_- \langle n_+(p/d) \cos\varphi \rangle + P_+ \langle n_-(p/d) \cos\varphi \rangle}{\langle n_-(p/d) \rangle + \langle n_0(p/d) \rangle + \langle n_+(p/d) \rangle}$$

$$A_N(n) = \frac{\sigma_0(d) A_N(d) - \alpha \sigma_0(p) A_N(p)}{\sigma_0(d) - \alpha \sigma_0(p)}$$

Errors estimations

$$n_i = (N_i)/(L_i)$$

$$N_0 \approx N_+ \approx N_-$$

$$\Delta A_N \approx \frac{\sqrt{2}}{P} \sqrt{((\delta N_0)^2 + (\delta L_0)^2)}$$

$$\Delta A_N \approx A_N \delta P$$

Conclusion

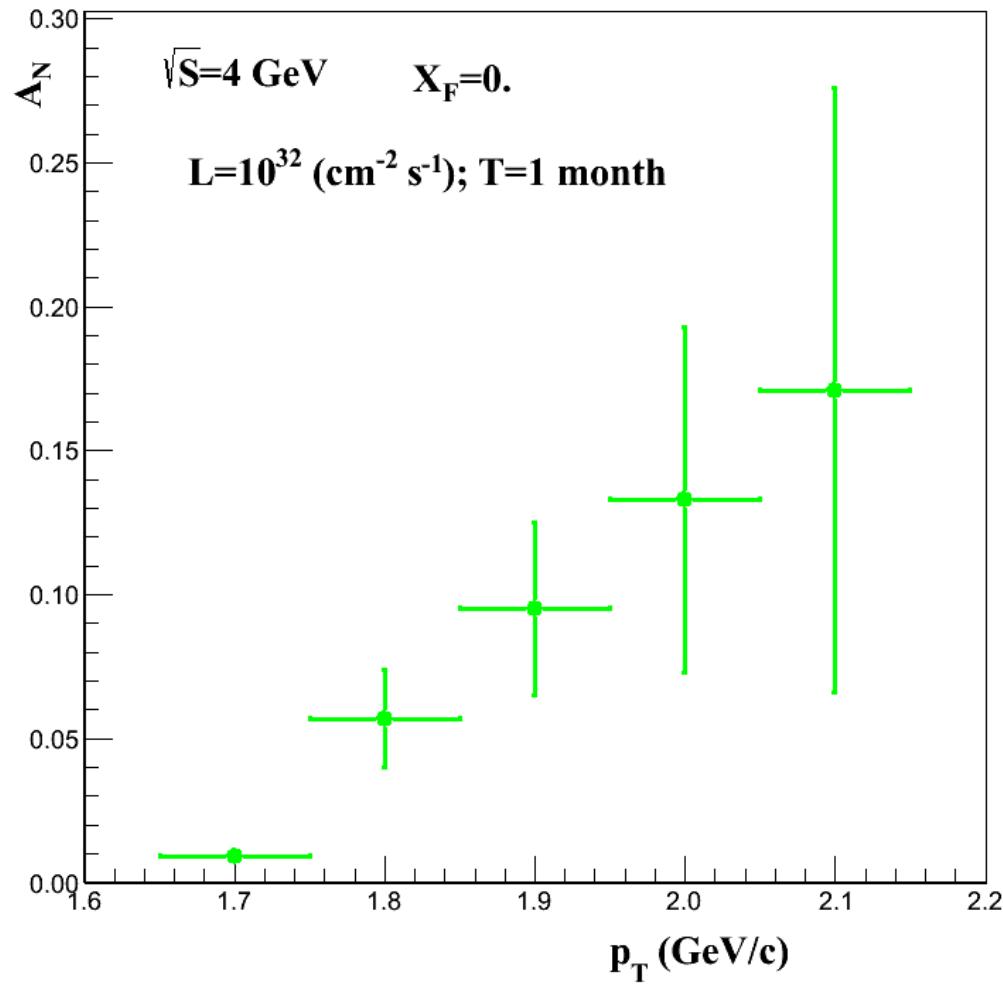
The main idea of my proposal is to use unique possibility of the beams of polarized neutrons and protons

The report shows that the study of transverse asymmetry at MPD@NICA allows to obtain new data like $A_N(n)$.

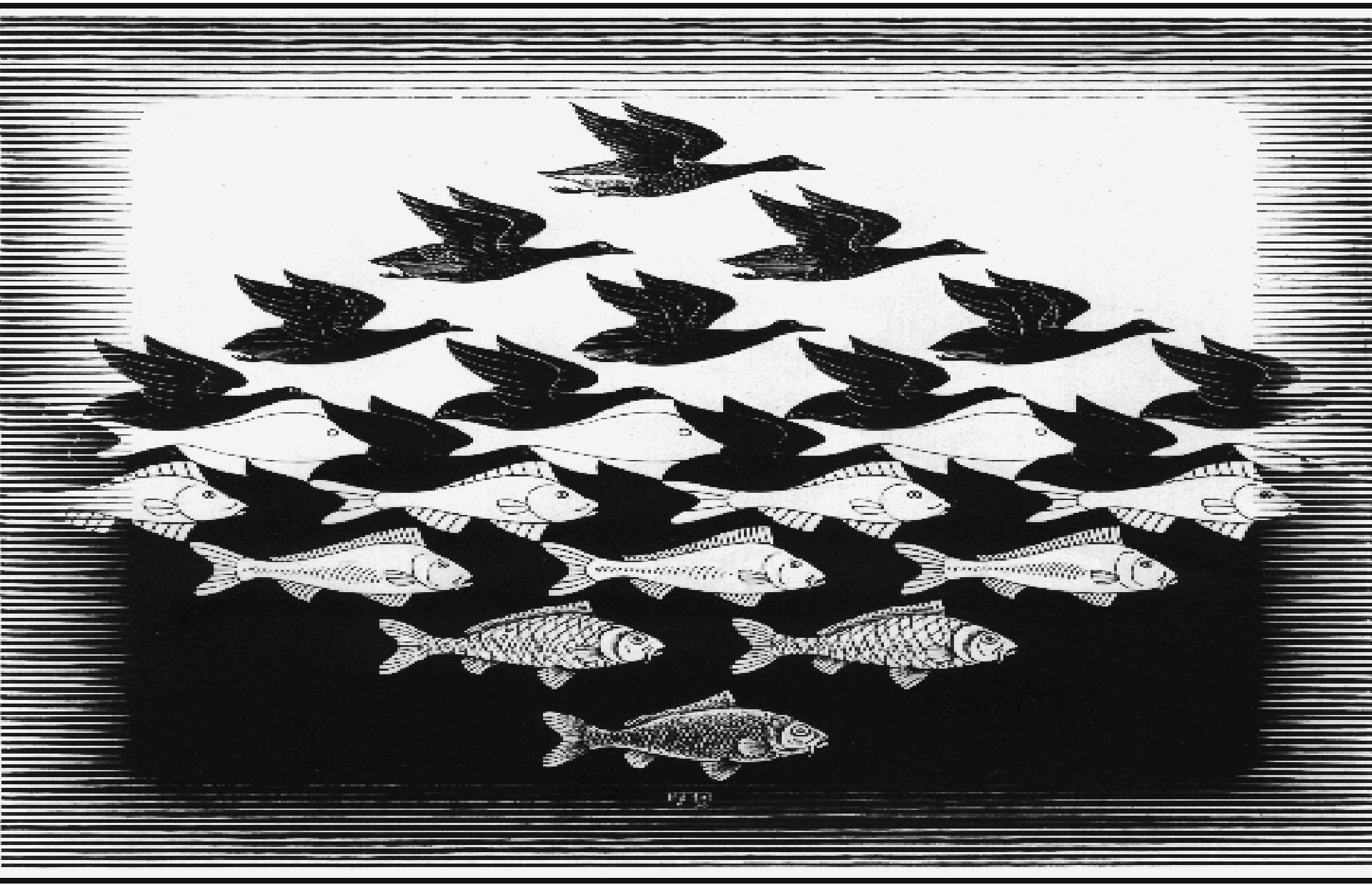
Further studies can be connected with the central region and spin correlation measurements.

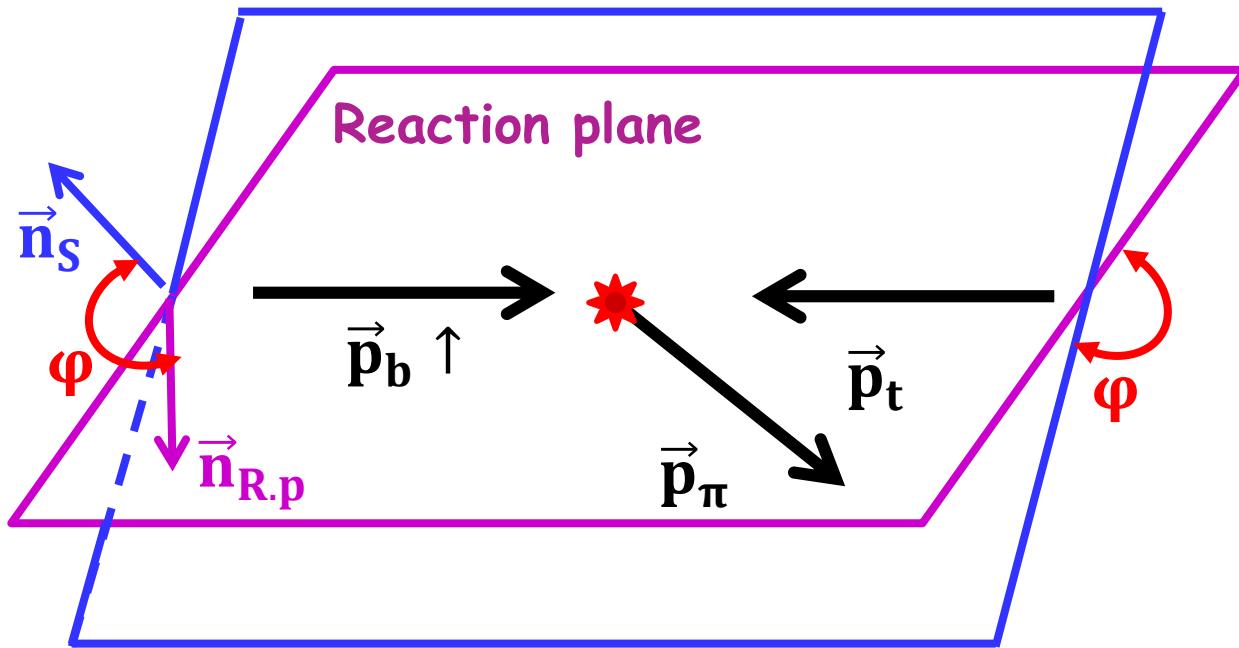
Backup slides

Asymmetry in the central region



DUALITY – HOW IT IS LOOKS LIKE





$$(\vec{n}_s \vec{p}_b) = 0$$

$$\vec{n}_{R.p} = [\vec{p}_b \vec{p}_\pi] / \|[\vec{p}_b \vec{p}_\pi]\|$$

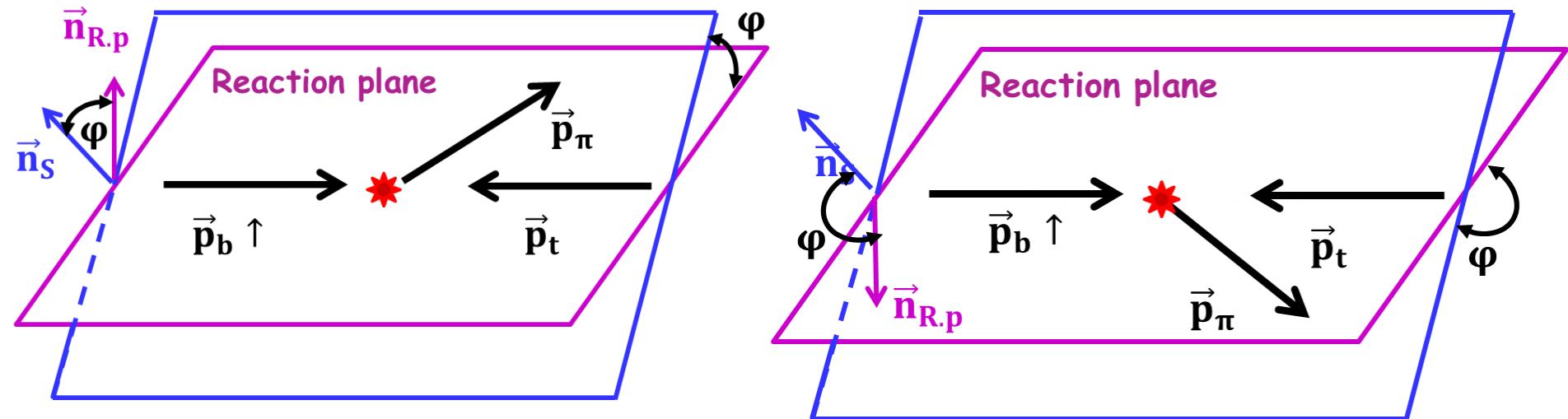
Reaction



Left

Geometry

Right



$$(\vec{n}_S \vec{p}_b) = 0$$

$$\vec{n}_{R.p} = [\vec{p}_b \vec{p}_\pi] / \left| [\vec{p}_b \vec{p}_\pi] \right|$$

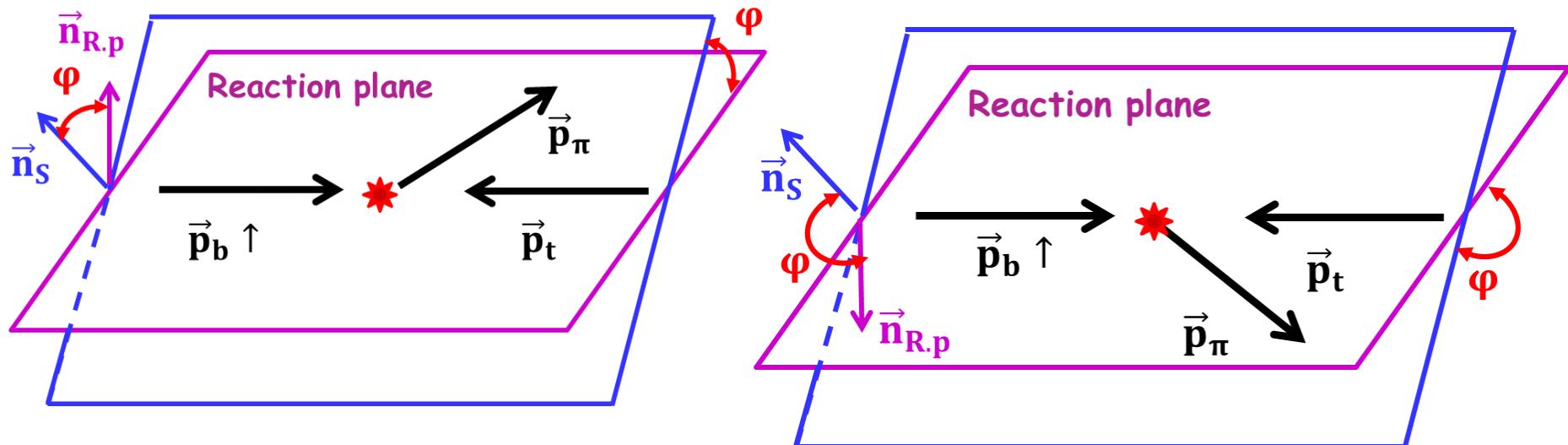
Reaction



Left

Geometry

Right



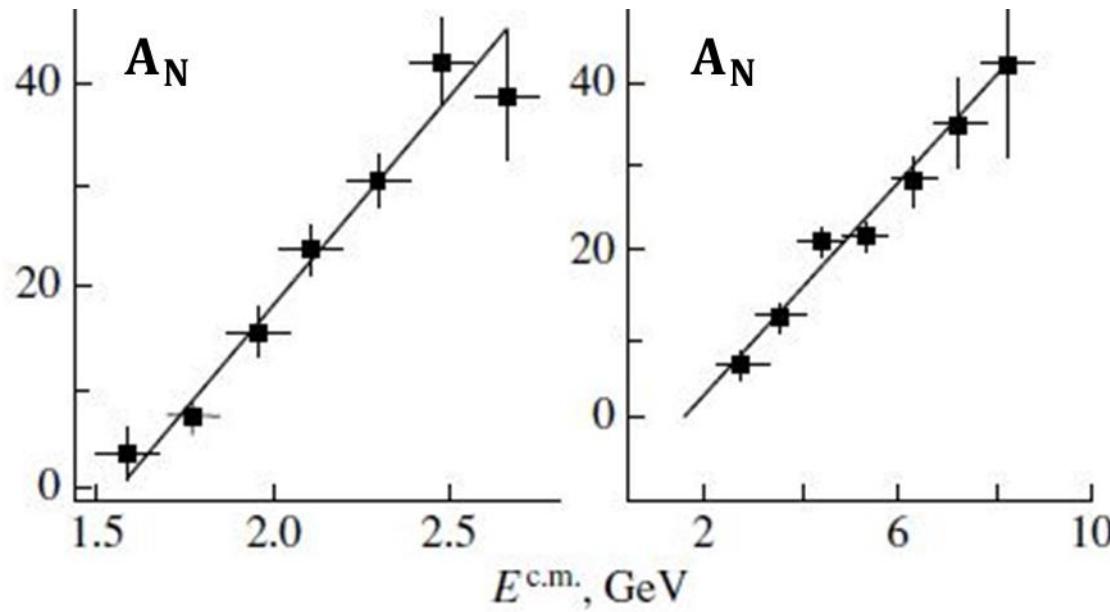
$$(\vec{n}_S \vec{p}_b) = 0$$

$$\vec{n}_{R,p} = [\vec{p}_b \vec{p}_\pi] / \left| [\vec{p}_b \vec{p}_\pi] \right|$$

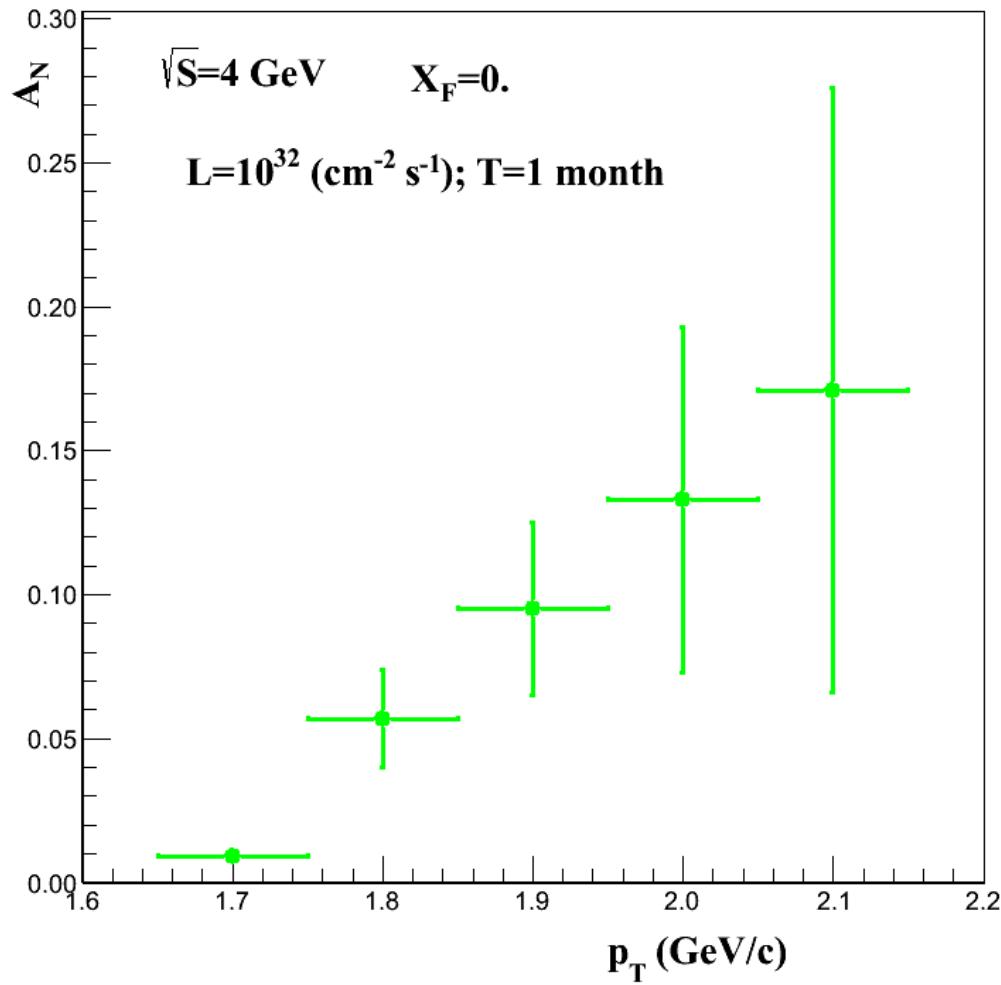
Approximation from energy at the center of mass

A.N. Vasiliev and V. V. Mochalov,
Physics of Atomic Nuclei, Vol. 67, p. 2169 (2004)

$$A_N = \begin{cases} = 0, E_{c.m.} < E_0; \\ = k(E_{c.m.} - E_0) \end{cases}$$



Asymmetry in the central region



Asymmetry and experimental data

$$A_N = \frac{3}{P_+ P_-} \frac{\int_0^{2\pi} ((P_- n_+(\varphi) + P_+ n_-(\varphi)) \cos \varphi) d\varphi}{\int_0^{2\pi} (n_+(\varphi) + n_0(\varphi) + n_-(\varphi)) d\varphi}$$

for simplicity and clarity

$$P_+ = -P_- = P$$

$$A_N = \frac{3}{P} \frac{\int_0^{2\pi} ((n_+(\varphi) - n_-(\varphi)) \cos \varphi) d\varphi}{\int_0^{2\pi} (n_+(\varphi) + n_0(\varphi) + n_-(\varphi)) d\varphi}$$