# The possibility of studying polarization observables in reactions of the production of pions by polarized beams of protons and deuterons at the JINR LHEP

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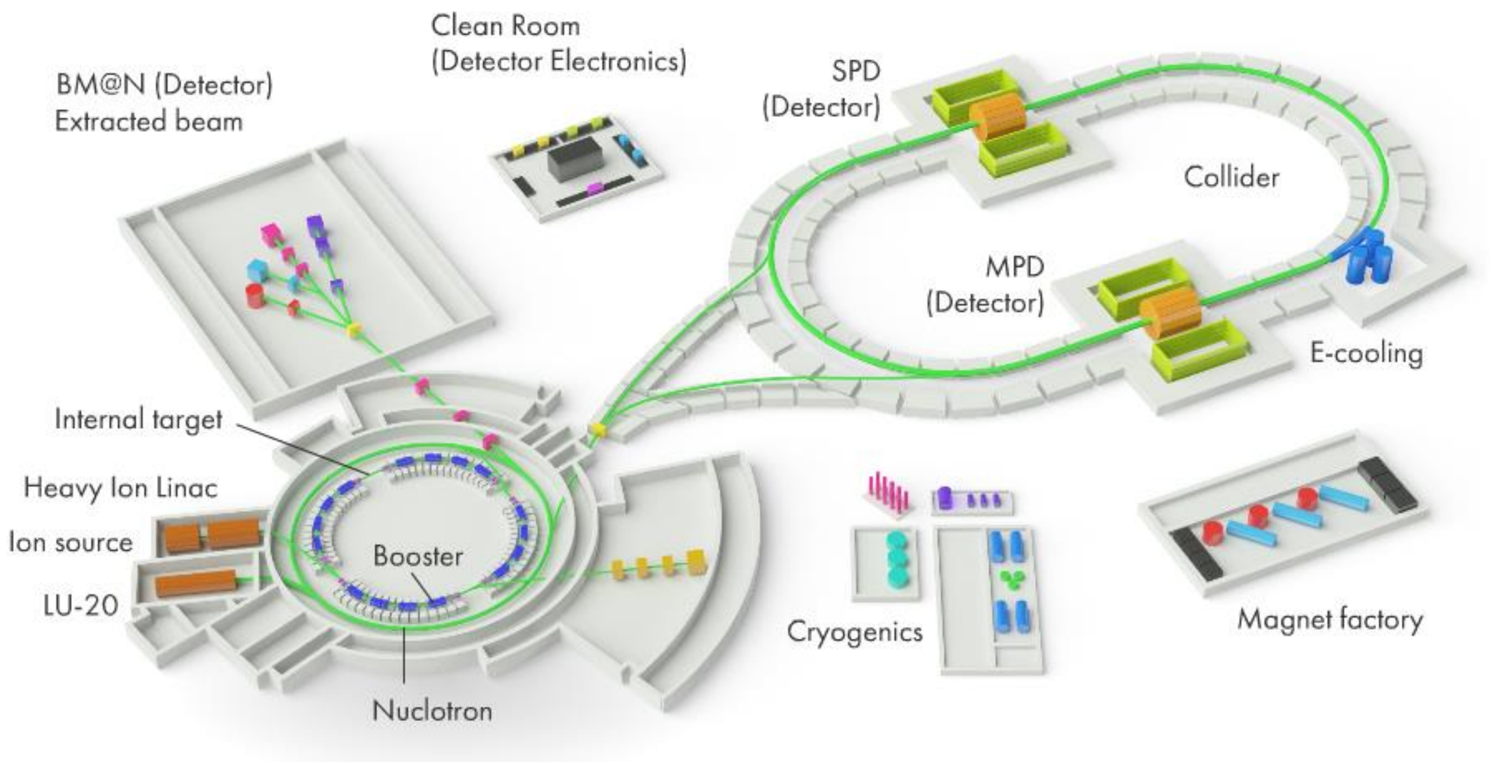
# NICA Complex

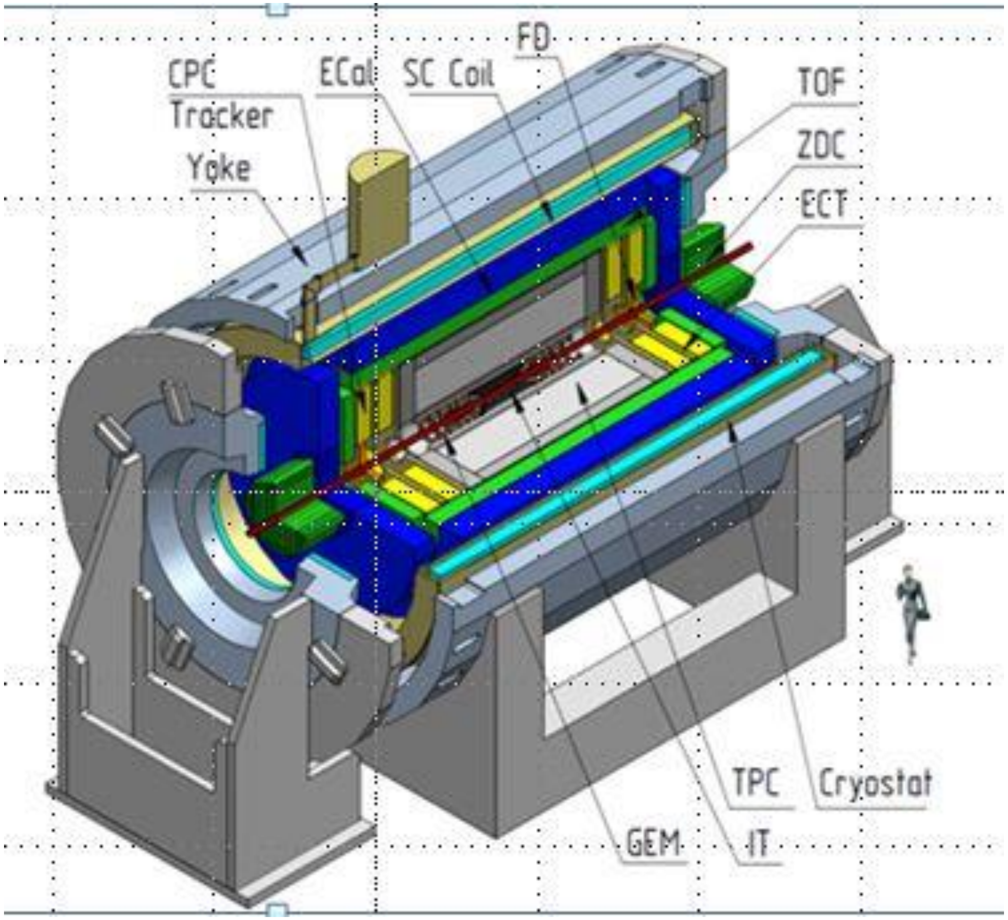
***N**uclotron-based **I**on **C**ollider f**A**cility (**NICA**)*




**http://nica.jinr.ru/complex.php**

# MPD

## Multi Purpose Detector (MPD)




http://mpd.jinr.ru/mpd/

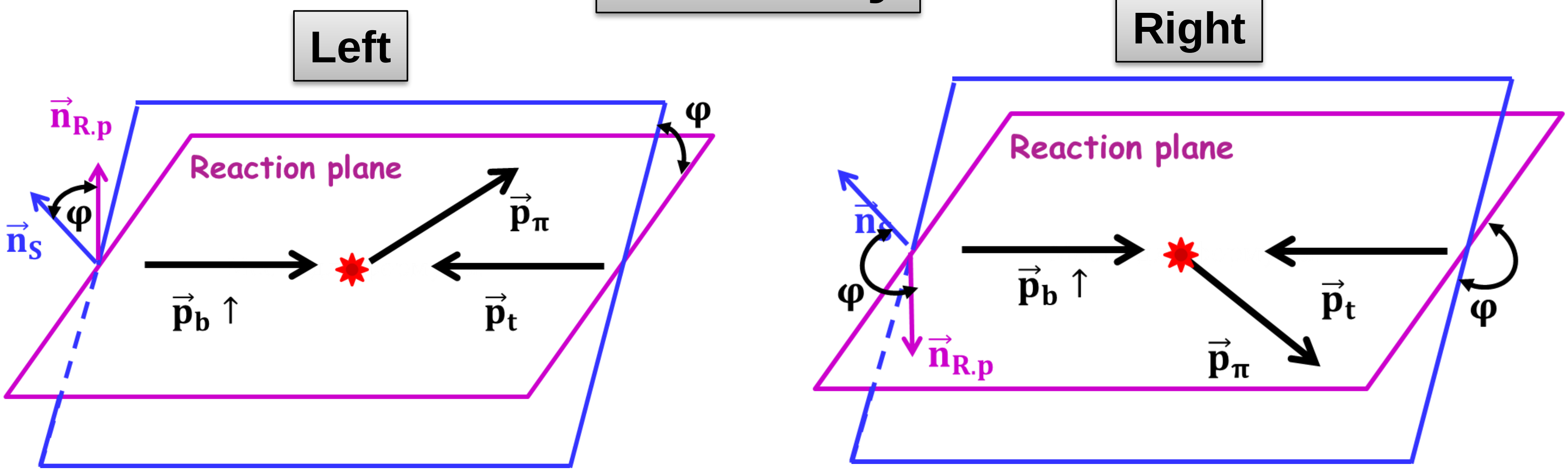
# Motivation

- ✓ 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

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

# Geometry




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

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

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

# Description and variables

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

$$\mathbf{Ed\sigma/d\vec{p}} \;= \boldsymbol{d\sigma_0}(\mathbf{x_F, p_T, s})\,(\mathbf{1} + \boldsymbol{A_N}(\mathbf{x_F, p_T, s})\boldsymbol{Pcos\varphi})$$

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

**$A_N$ - Single-Spin Asymmetry (analyzing power $A_y$)**

**Feynman variable $\mathbf{x_F}$**

$$\mathbf{x_F} = \boldsymbol{p_{c,l}/p_{c,max}}$$

$$\boldsymbol{p_{c,l}} - \textbf{momentum in c. m.}$$

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

# Kinematic region

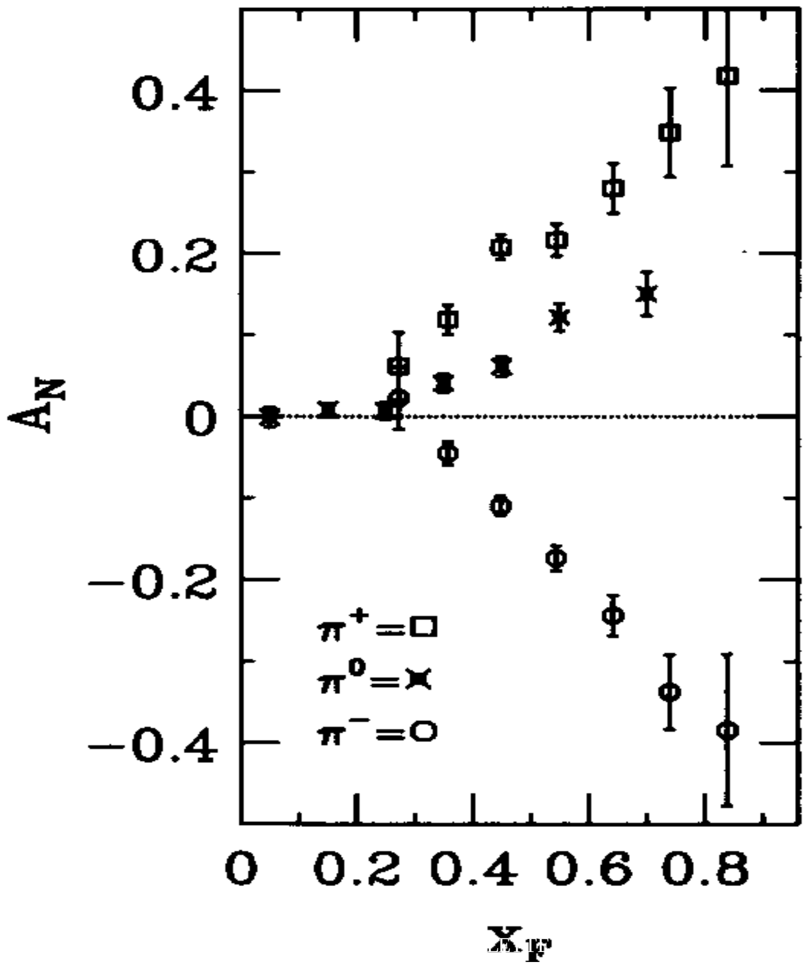
$$\mathbf{p}\uparrow\ +\mathbf{p}(\mathbf{A}) = \boldsymbol{\pi} + \mathbf{X}$$

**pion is detected in the fragmentation region of a polarized proton** $\mathbf{x_F > 0}$

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

# High energy data

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

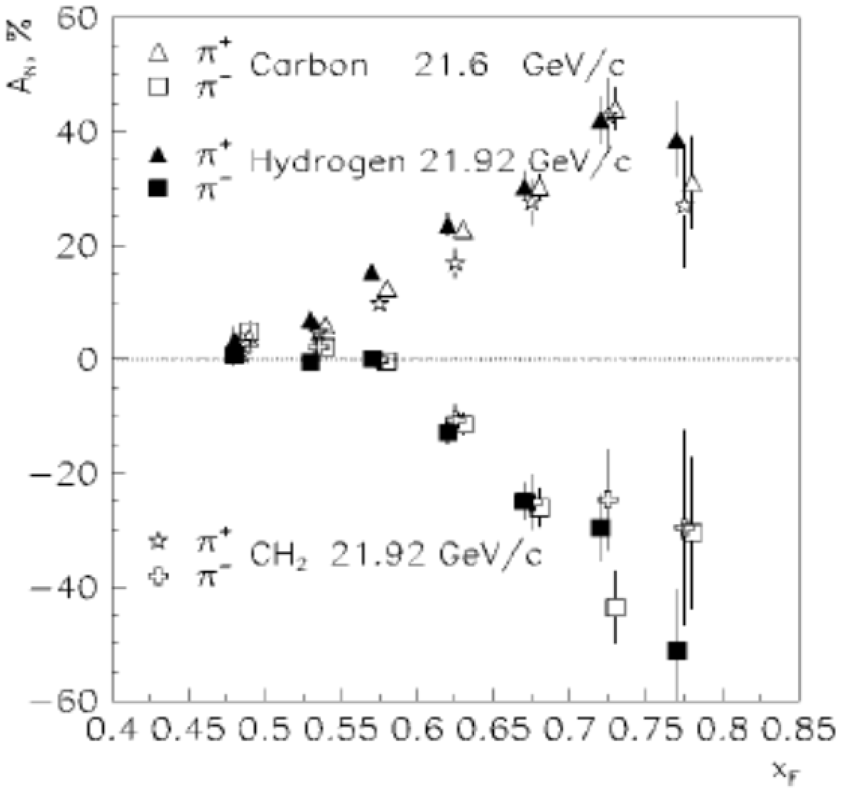



*FNAL E704, Phys. Lett. B 264, 462 (1991)*

$0.2\ \mathrm{GeV/c} \le p_T \le 2\ \mathrm{GeV/c}$

# Low energy data

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



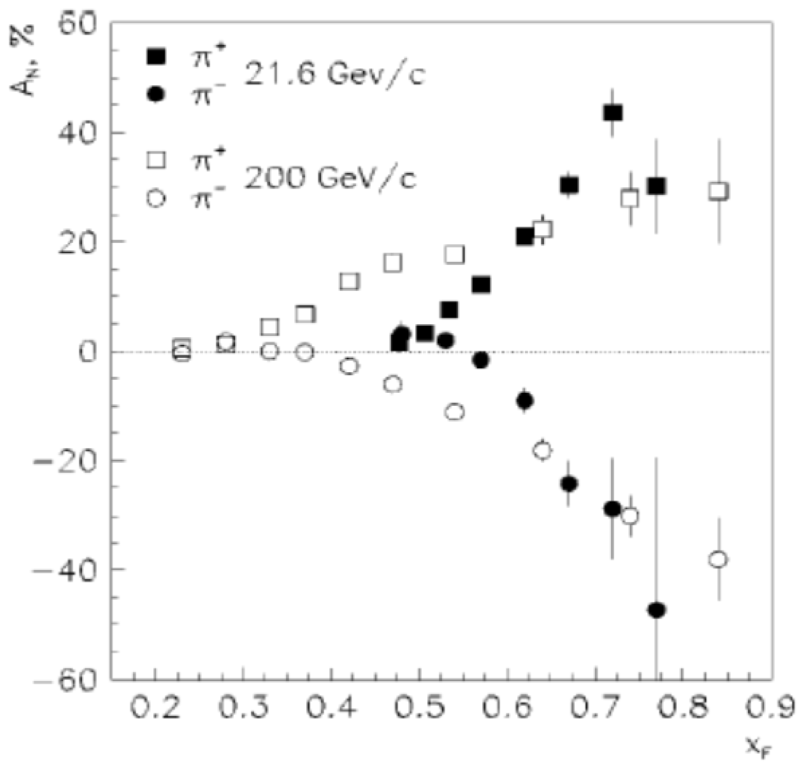

*E925 Collaboration (AGS BNL)*
*Phys.Rev. D 65 ,092008, (2002)*

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

$$0.2\ GeV/c \le p_T \le 2\ GeV/c$$

# 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)*

$$\mathbf{0.2}\, GeV/c \leq p_T \leq \mathbf{2}\, GeV/c$$

# Variables; distributions

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

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

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

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

# Asymmetry and experimental data

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

**for simplicity**

$$\mathrm{P_+} = -\mathrm{P_-} = \mathrm{P}$$

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

# Errors estimations

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

$$\mathbf{N_0 \approx N_+ \approx N_-}$$

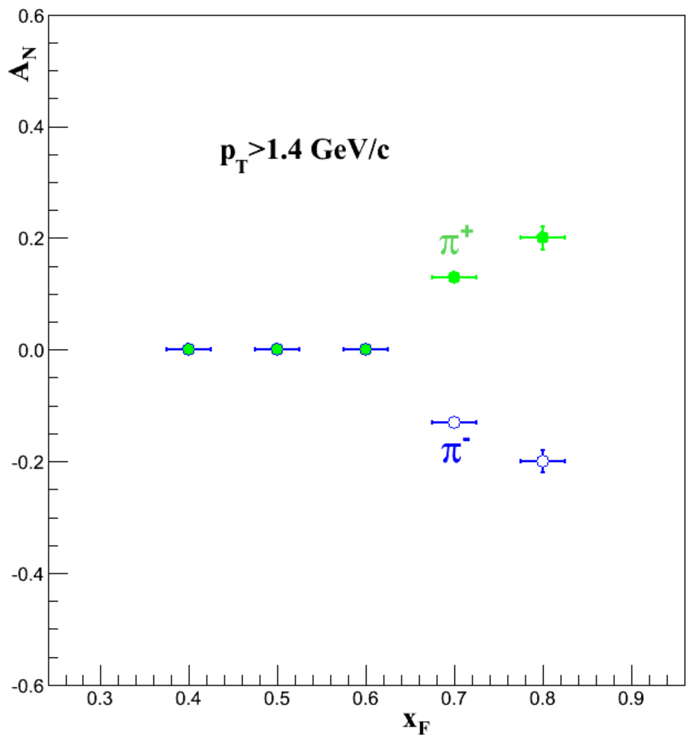
$$\Delta \mathbf{A_N} \approx \frac{\sqrt{2}}{\mathbf{P}} \sqrt{\left((\delta \mathbf{N_0})^2 + (\delta \mathbf{L_0})^2\right)}$$

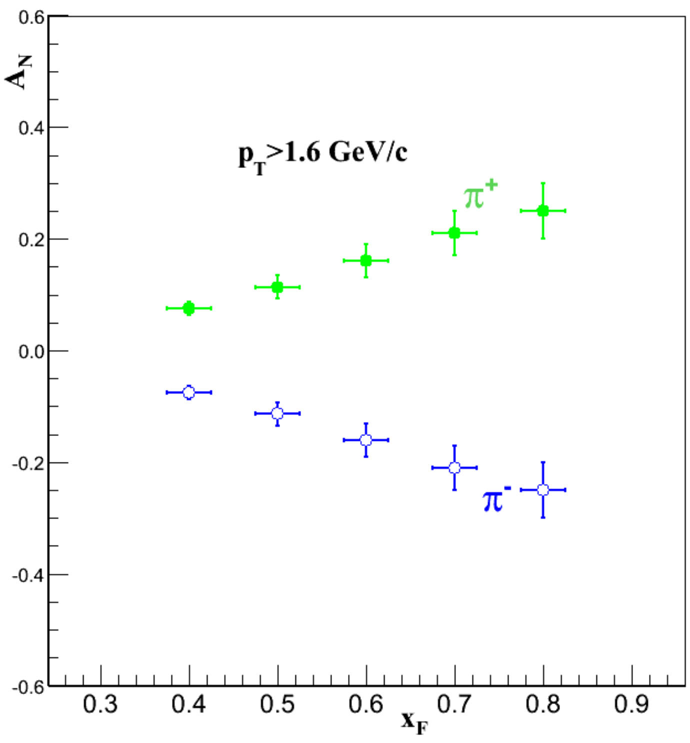
$$\Delta \mathbf{A_N} \approx A_N \delta P$$

# Asymmetry for $p\uparrow p \to \pi X$ at MPD

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

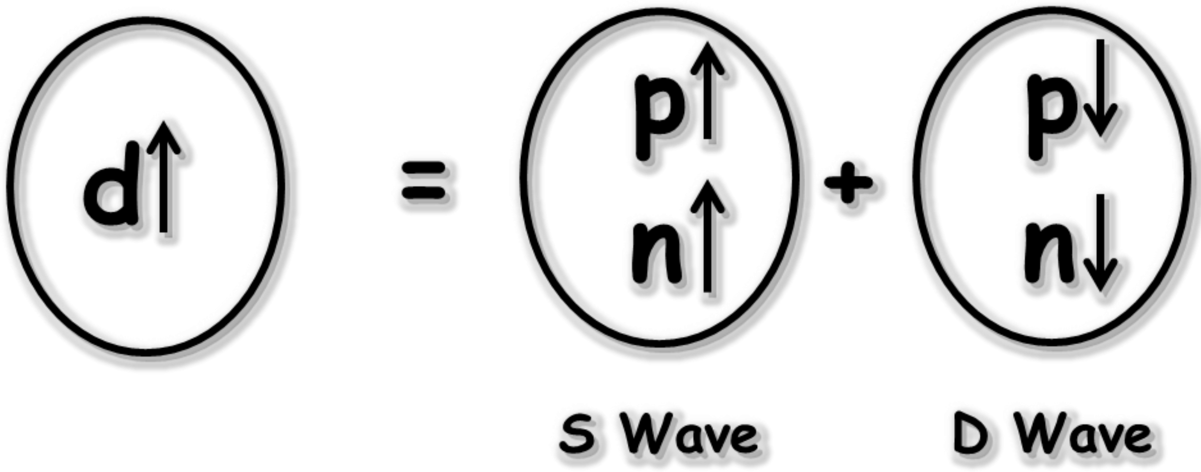
$$\mathbf{p\uparrow + p = \pi + X;\ \sqrt{s} = 4\ GeV, E_b = 7.6\ GeV}$$



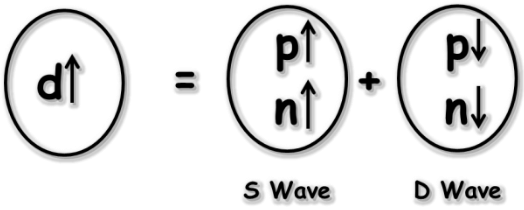
**Unique possibility to obtain asymmetry of collision of polarized neutron from collision of polarised deuteron**

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



# Structure of the cross section

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




## cross section

$$d\sigma(d + p \to \pi X) = w_S d\sigma(d_S + p \to \pi X) + w_D d\sigma(d_D + p \to \pi X)$$

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

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

$\alpha \approx 0.85$ – shading factor

# Reid DWF

## Deuteron Wave Function (DWF)

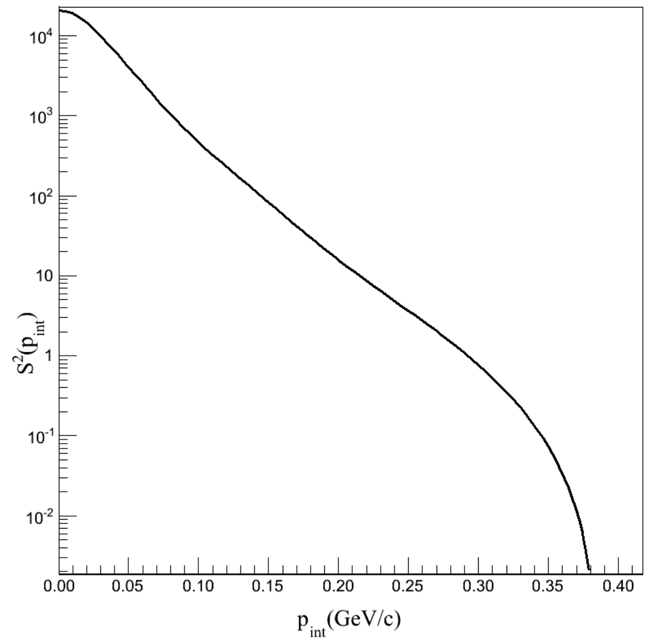
$$\sigma_p = \sqrt{\langle p^2 \rangle} = 0.09\ \mathrm{GeV/c}$$

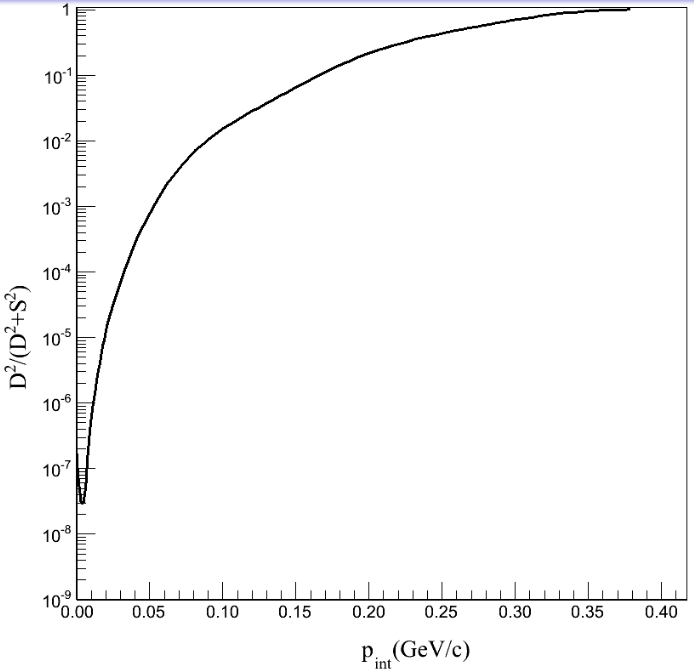
→

$$\Delta x_F \approx 0.004$$

$$w_S = \frac{\int S^2(p)p^2\mathrm{dpd}\Omega}{\int\left(S^2(p)+D^2(p)\right)p^2\mathrm{dpd}\Omega} = 0.953$$

$$w_D = \frac{\int D^2(p)p^2\mathrm{dpd}\Omega}{\int\left(S^2(p)+D^2(p)\right)p^2\mathrm{dpd}\Omega} = 0.047$$






*R.V.Reid. Ann.Phys. (N.Y.), 50, 411, (1968)*

## Thus, we can ignore D-wave in cross section

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

$$d\sigma_{+,d}(\varphi) = d\sigma_{0,d}\left(1 + P_{+} A_N(d) \cos\varphi\right) =$$
$$+\alpha d\sigma_{0,p}\left(1 + P_{+} A_N(p) \cos\varphi\right) +$$
$$+\alpha d\sigma_{0,n}\left(1 + P_{+} A_N(n) \cos\varphi\right)$$

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

## Asymmetry $\mathbf{A_N(n)}$ for $\mathbf{n\uparrow + p = \pi + X}$

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

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

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

# Conclusion I

The report shows that the study of transverse asymmetry at MPD@NICA allows to obtain new data like $A_N$ for $n\uparrow + p(A) = \pi + X$.
But you need to know the absolute luminosity.

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

# Fixed target - luminosity

$$L(cm^{-2}s^{-1}) = \mathrm{N_{bm}} \cdot \mathrm{N_A} \frac{\rho_t(\mathrm{g \cdot cm^{-3}})\mathrm{l_t(cm)}}{\mathrm{A_t}} \mathrm{f(s^{-1})}$$

$\mathrm{N_{bm}}$ –the number of particles in the burst
$\mathrm{N}_A = 6 \cdot 10^{23}$ – Avogadro number
$\rho_t$ –the density of the target
$\mathrm{l_t}$ –target length along the beam
f – repetition rate

**estimations**

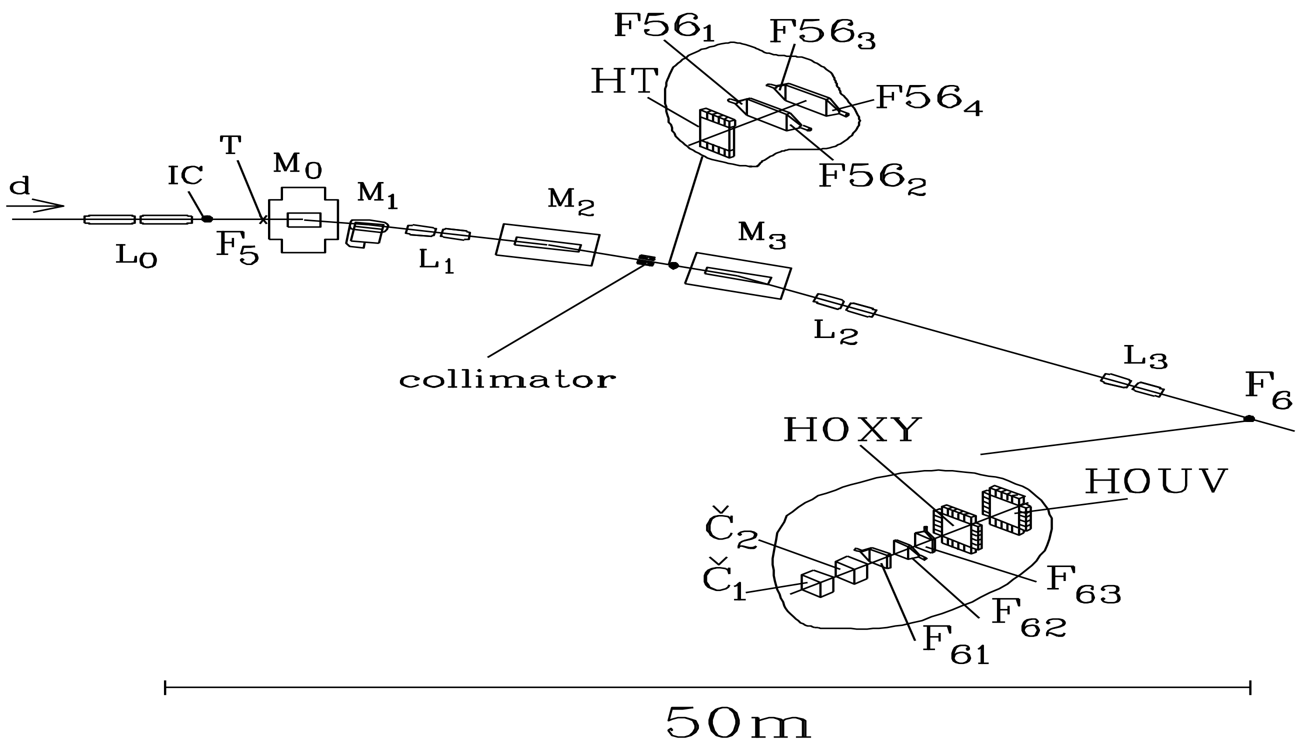
✓ **carbon target**

$\{\mathbf{N_{bm}} = \mathbf{10^{10}; l_t = 10\ cm, f = 0.1\ s^{-1}}\} \rightarrow \mathbf{L \approx 10^{33} cm^{-2} s^{-1}}$

✓ **beryllium target**

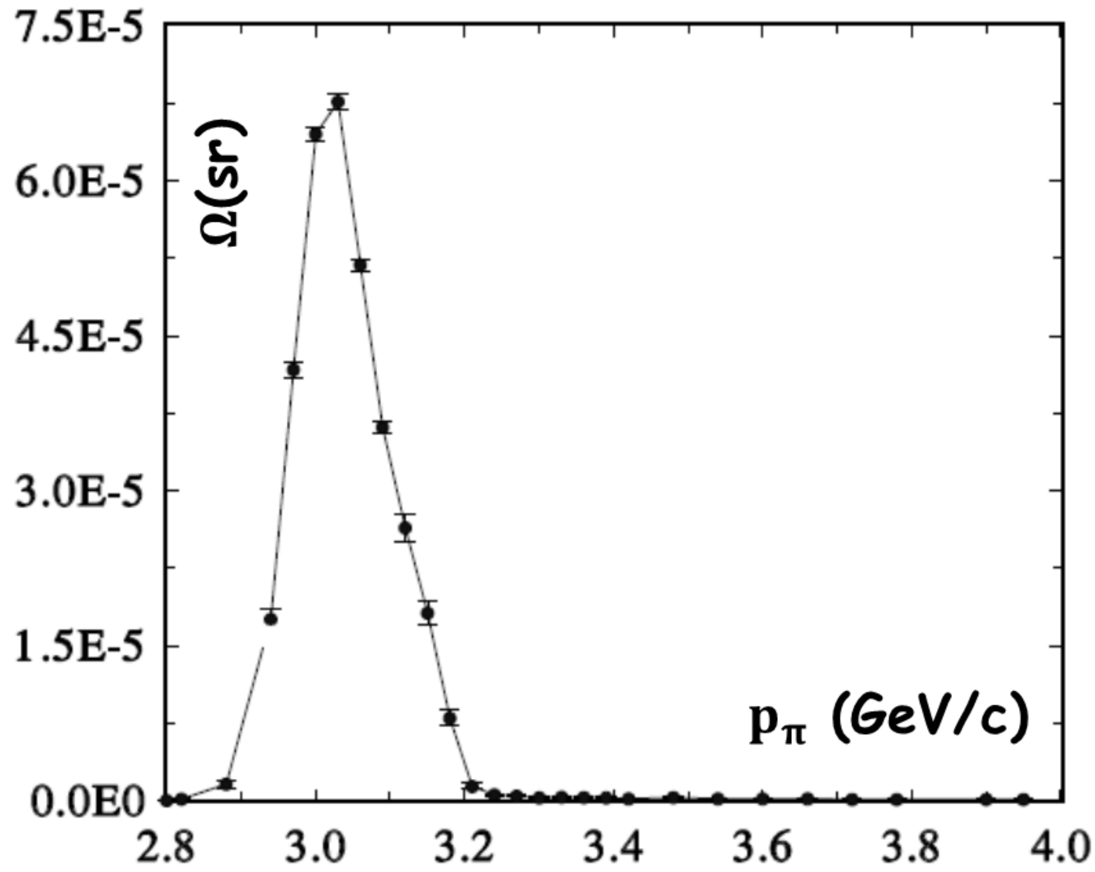
$\{\mathbf{N_{bm}} = \mathbf{10^{10}; l_t = 10\ cm, f = 0.1\ s^{-1}}\} \rightarrow \mathbf{L \approx 10^{33} cm^{-2} s^{-1}}$

# Possible set up | 4B channel (building#205)



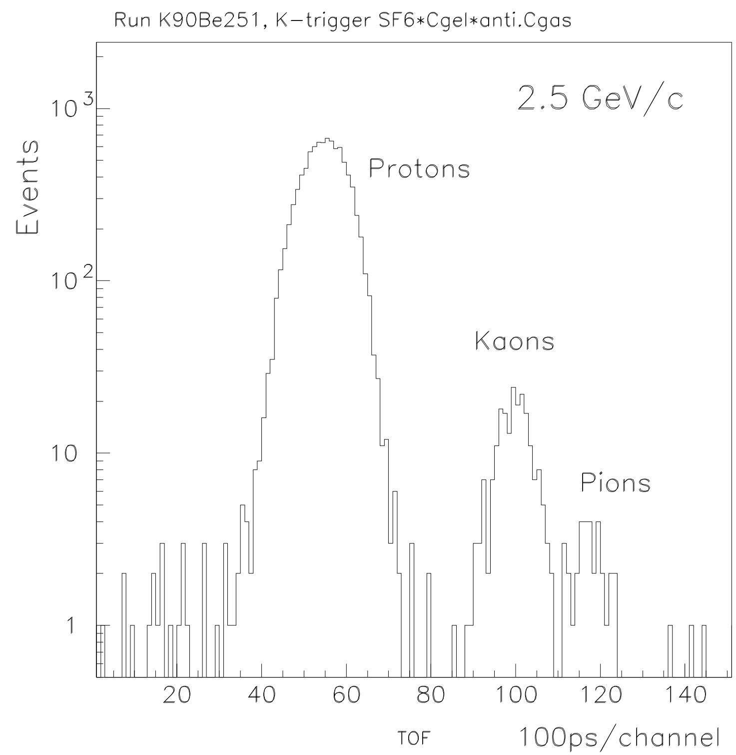

| | |
|---|---|
| $F_i$, $F_{i,j}$ | the scintillation counters |
| $\check{C}_1$, $\check{C}_2$ | the threshold Cherenkov counters |
| HT, H0XY, H0UV | the scintillation hodoscope |
| $M_i$ | the bending magnets |
| $L_i$ | a doublet of quadrupole lenses |
| IC | ionization chamber |
| T | target |

# Acceptance




$$\mathbf{Acc(4.5\ GeV/c)} = \int \mathbf{\Omega(p)dp} = \mathbf{1.8 \cdot 10^{-5} sr \cdot GeV/c};\ \mathbf{\Delta p/p = 2}\ \%$$

# Time-of-Flight spectrum




**protons are suppressed by using aerogel Cherenkov counter (n=1.035) and pions are suppressed by gas Cherenkov counter (anticoincidences, $\mathbf{CO_2, P = 12\ at.}$)**

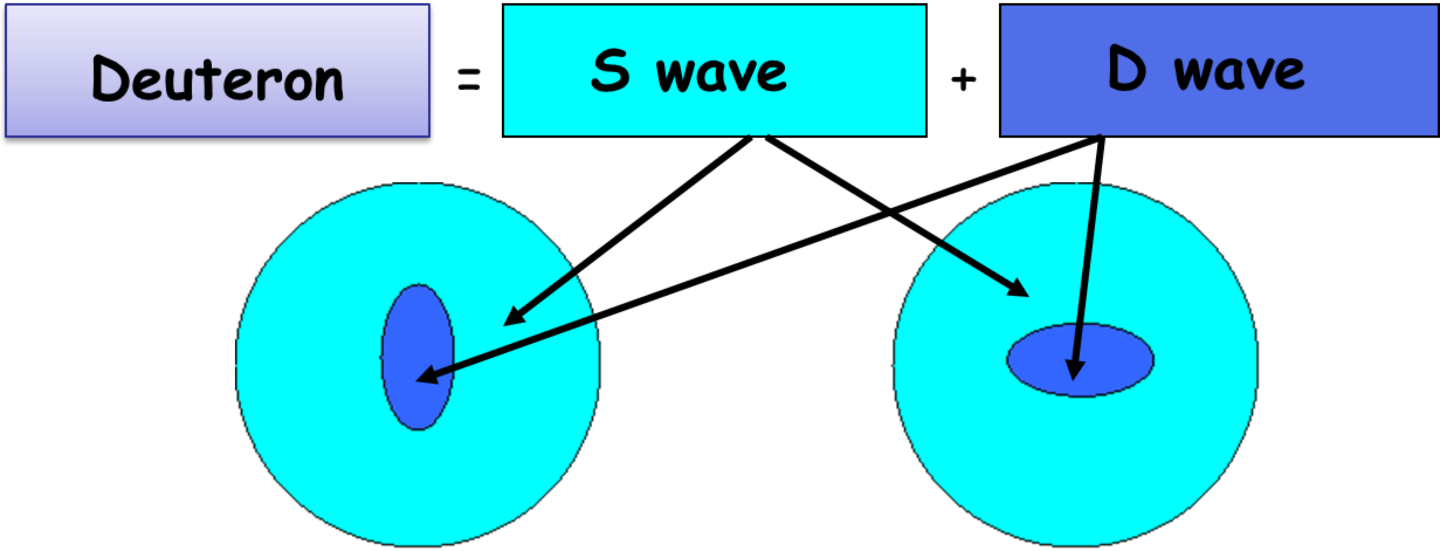
# Deuteron Tensor polarization

$$\mathbf{N_{+1} + N_0 + N_{-1} = 1}$$

$$\boldsymbol{\tau_{20} = \frac{1}{\sqrt{2}}(1 - 3N_0) \rightarrow -\sqrt{2} \leq \tau_{20} \leq \frac{1}{\sqrt{2}}}$$

$$\mathbf{p_{yy} = (1 - 3N_0) \rightarrow -2 \leq \tau_{20} \leq 1}$$

$$\boldsymbol{\tau_{20} = \frac{1}{\sqrt{2}} p_{yy}}$$



# Deuteron fragmentation into cumulatve pions

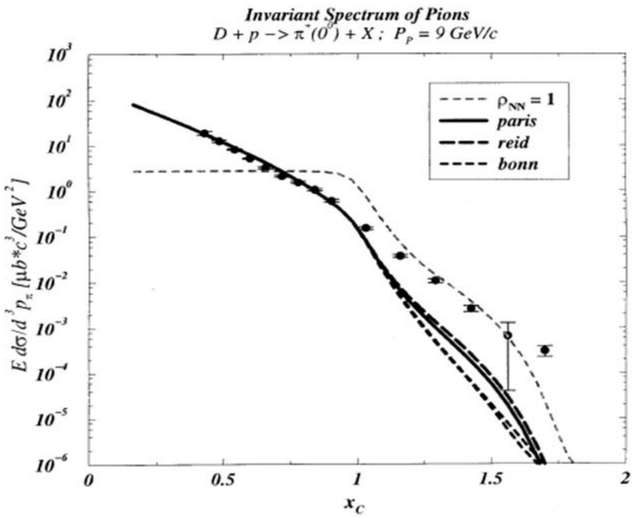
$$\mathbf{D\uparrow\ + p(A) = \pi(\theta) + X}$$

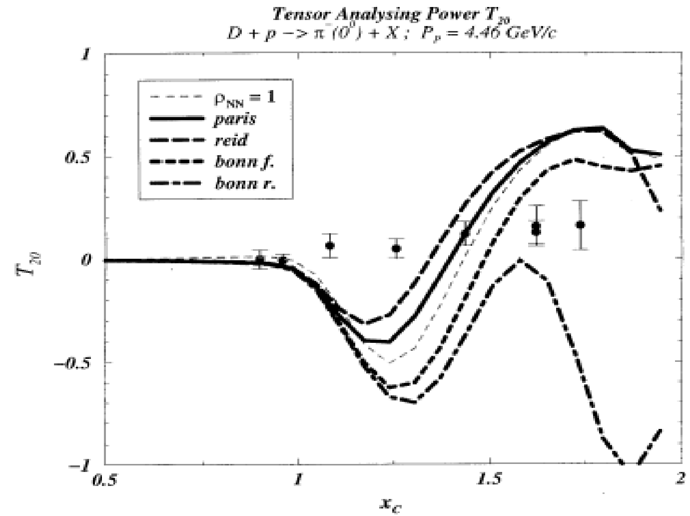
$$\mathbf{d\sigma = d\sigma_0\left(1 + \frac{3}{2}A_y p_y + \frac{1}{2}A_{yy} p_{yy}\right)}$$

$$\mathbf{T_{20} = -\frac{1}{\sqrt{2}}A_{yy}}$$

# Deuteron fragmentation into cumulatve particle Polarization observables

$$\vec{D} + \mathbf{p} = \boldsymbol{\pi}^{-}(\mathbf{0}^{O}) + \mathbf{X}$$



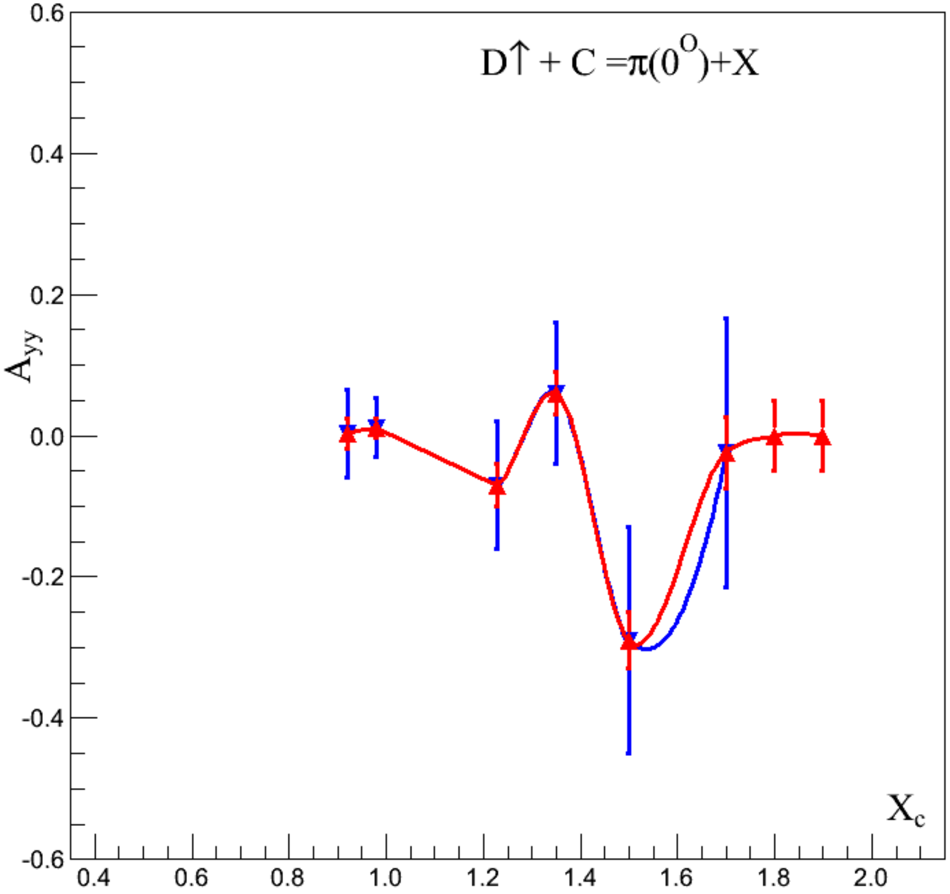

In Impulse Approximation $\mathbf{d\sigma}$ depends strongly on $\boldsymbol{\rho}_{\mathbf{NN}} = \mathbf{d\sigma}(\mathbf{NN} \to \mathbf{c})$

In Impulse Approximation $\mathbf{T_{20}}$ depends weakly $(\Delta T_{20} < 0.2)$ on $\boldsymbol{\rho}_{\mathbf{NN}} = \mathbf{d\sigma}(\mathbf{NN} \to \mathbf{c})$

A.Yu.Illarionov, A.G.Litvinenko, and G.I.Lykasov. Eur.Phys.J., **A 18**,313, (2003).

# production of π under a zero angle

$$X_c = \frac{m_N E_\pi - {m_\pi}^2/2}{p_\pi p_b cos\theta_\pi - E_\pi E_b + E_b m_N - (m_N)^2}$$



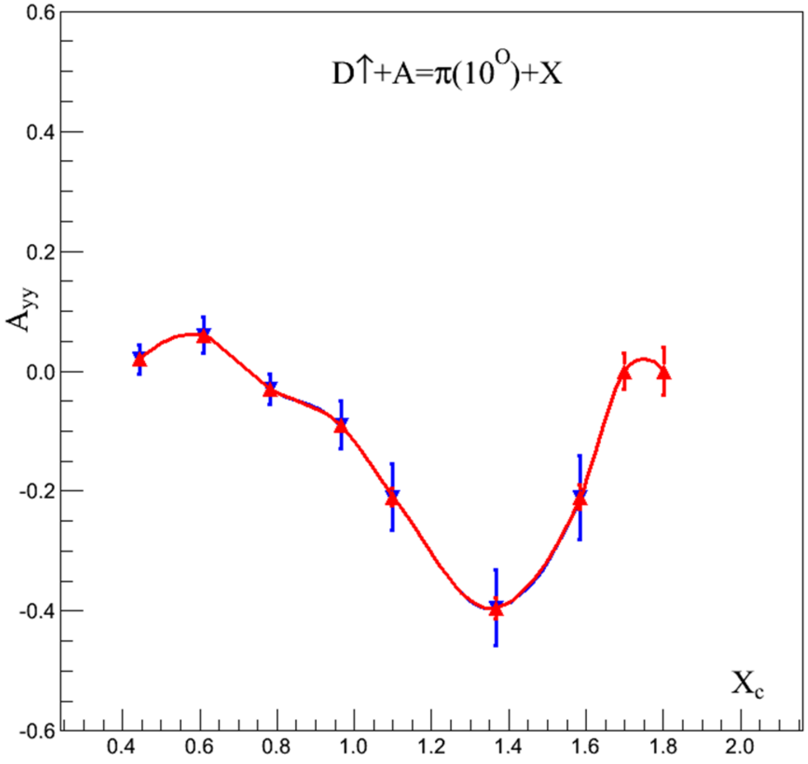

blue - exp. data;
one week; **$I = 10^9$ per burst**

*S.V.Afanasiev et al., Nucl.Phys. A(625),p.817,(1997)*

red –red available in two weeks
for **$I = 10^{10}$ per burst**

# production of π under a zero angle

$$X_c = \frac{m_N E_\pi - m_\pi{}^2\ /2}{p_\pi p_b cos\theta_\pi - E_\pi E_b + E_b m_N - (m_N)^2}$$




blue – exp. data;
one week; $\mathbf{I = 10^9}$ **per burst**

*S.V.Afanasiev et al., Phys.Lett.B, p.445,(1998)*

red – available in two weeks for $\mathbf{I = 10^{10}}$ **per burst**

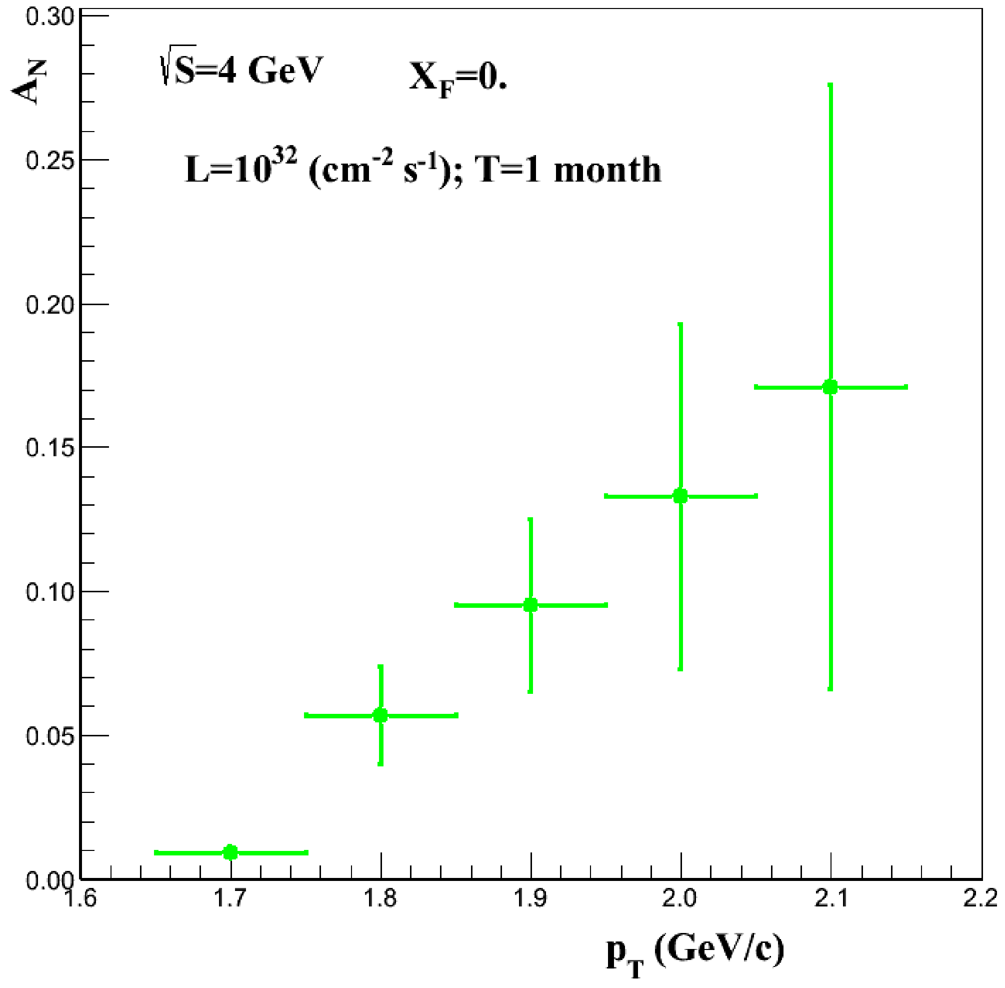
# Conclusion II

The study of tensor analyzing power with the beam intensity $10^{10}$would allow us:

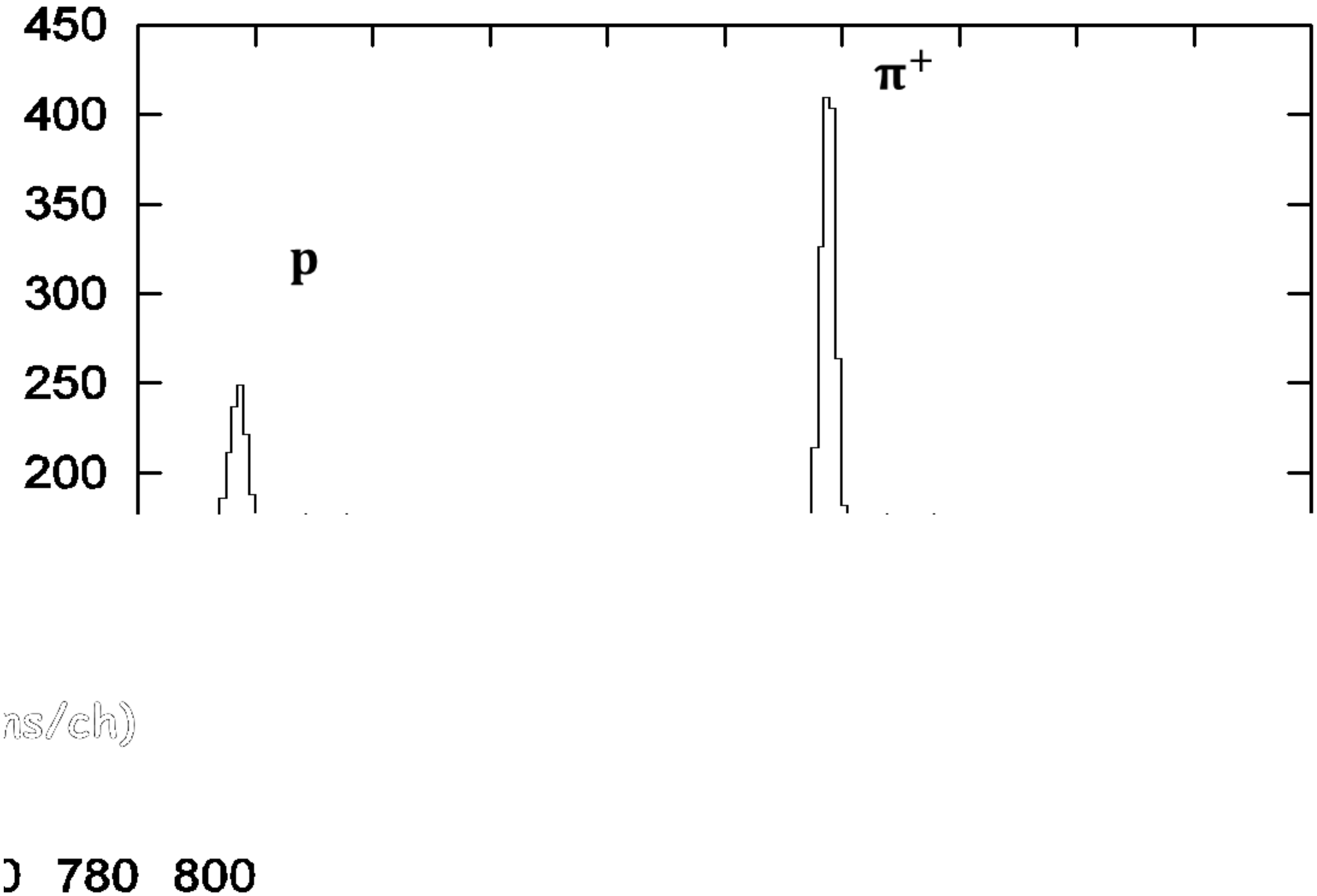
1. to obtain more accurate data (in factor 3)
2. to reach to the region of higher internal momentum $p_{int}$ up to 0.75 GeV/c ($l_{NN} \cong 0.3\ fm$)
3. to include into study new particles (positive and negative kaons)

# Backup slides

# Asymmetry in the central region

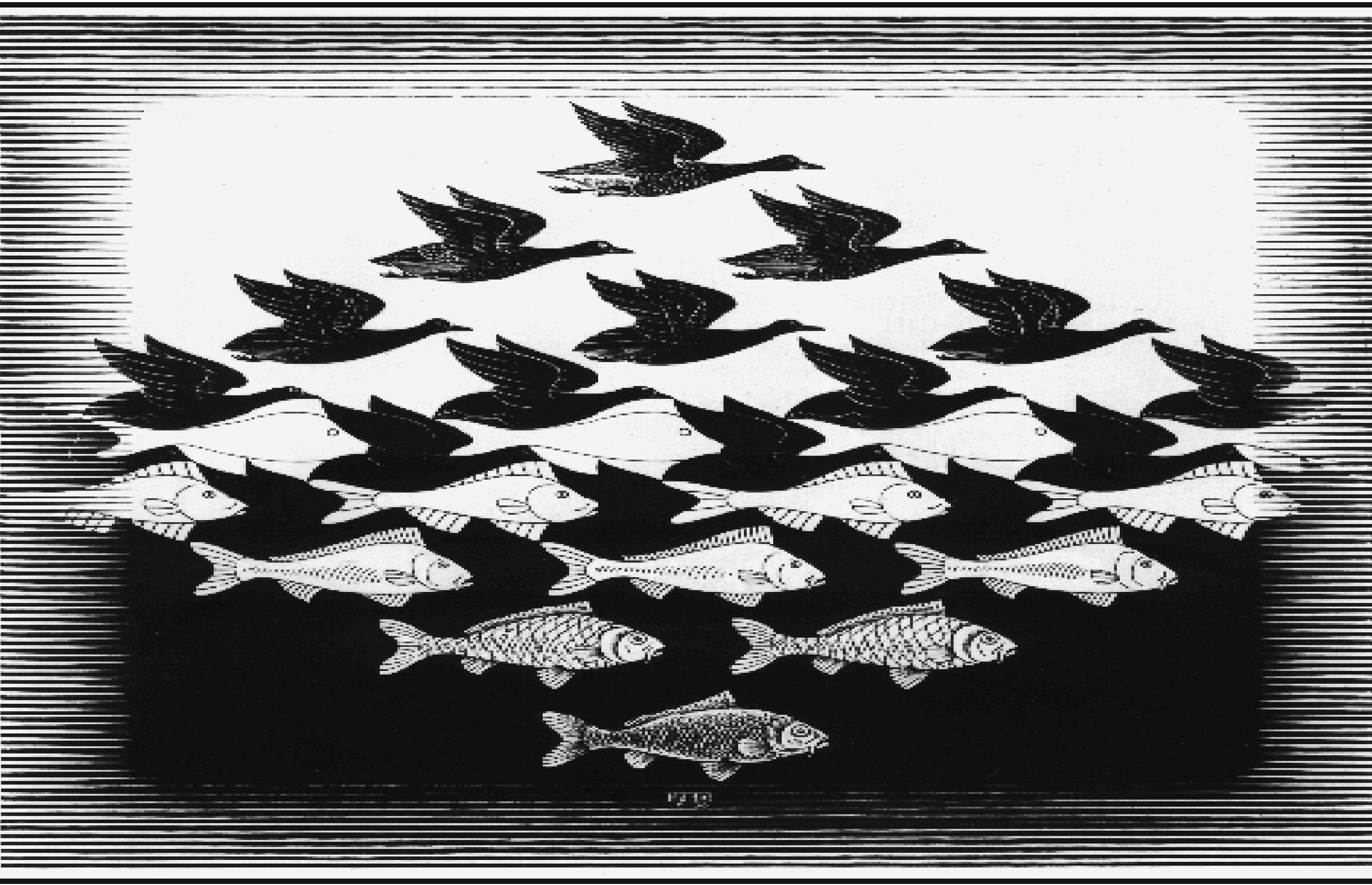


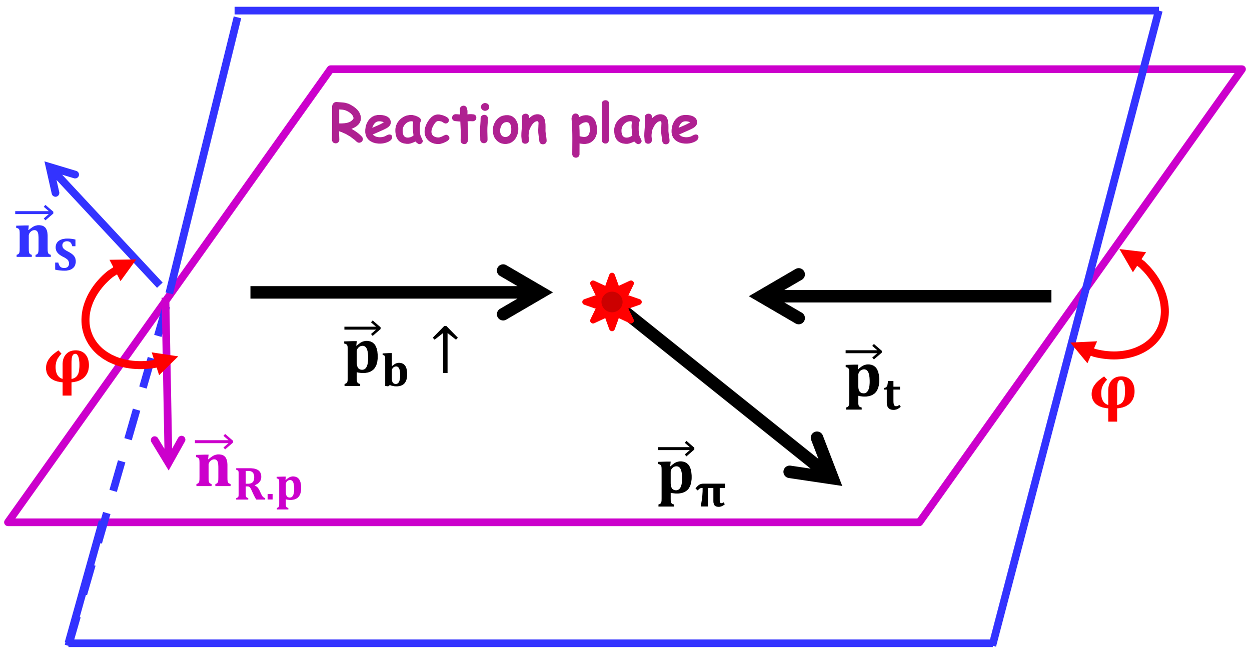
# Time-of-Flight spectrum




protons are suppressed by 100 times
using aerogel Cherenkov counter

# DUALITY – HOW  IT IS LOOKS LIKE






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

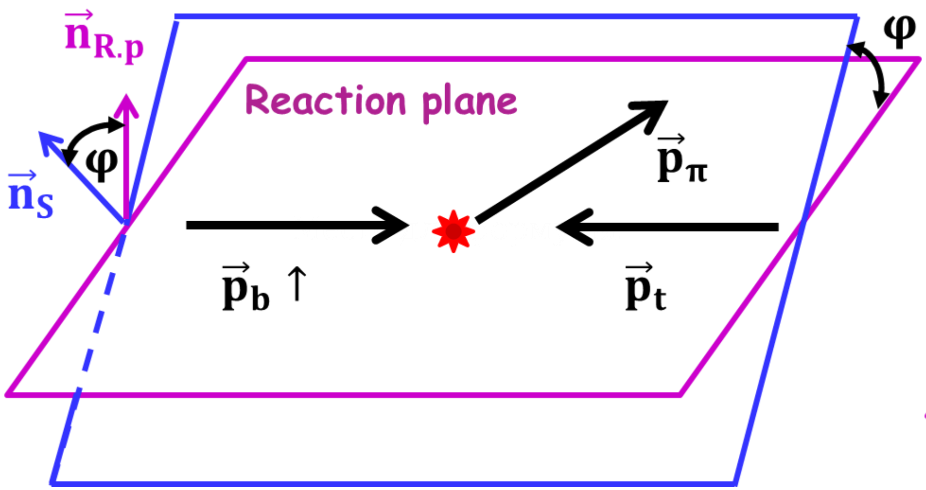
$\vec{n}_{R.p} = [\vec{p}_b \vec{p}_\pi] / |[\vec{p}_b \vec{p}_\pi]|$

# Reaction

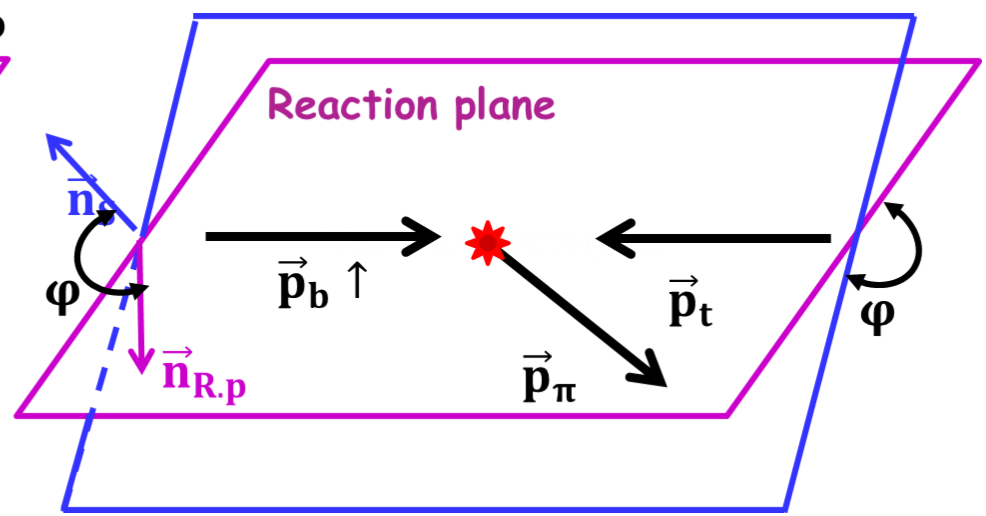
$$\mathbf{p}\uparrow\ +\mathbf{p(A)} = \boldsymbol{\pi} + \mathbf{X}$$

## Geometry

### Left




### Right




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

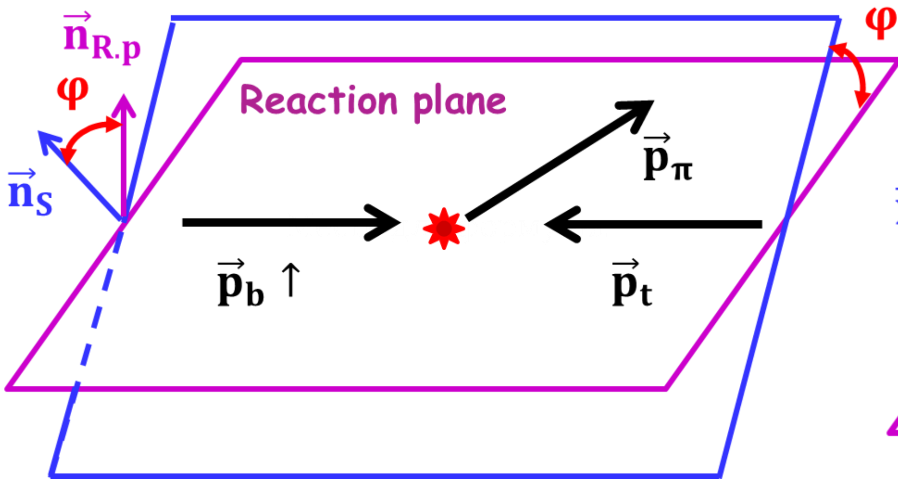
$$\vec{n}_{R.p} = [\vec{p}_b \vec{p}_\pi] / \left| \overrightarrow{[\vec{p}_b \mathbf{p}_\pi]} \right|$$

# Reaction

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

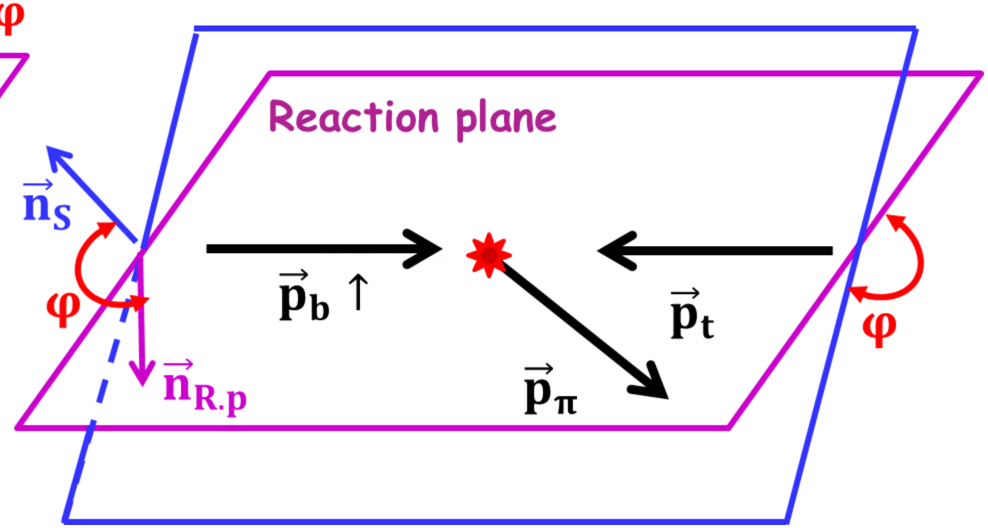
## Geometry

### Left




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

### Right

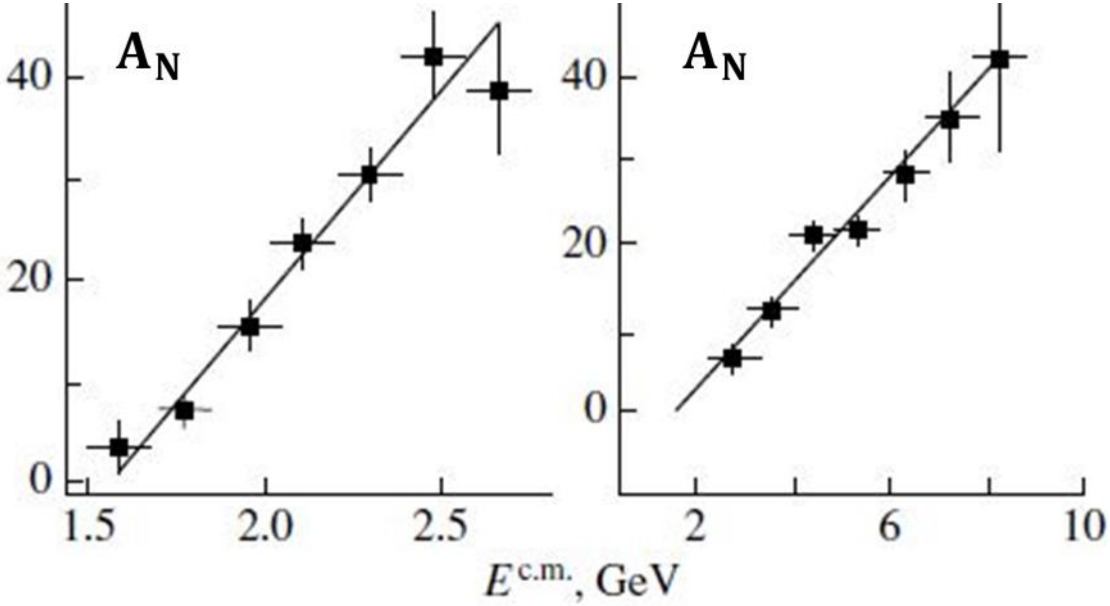



$$\vec{n}_{R.p} = [\vec{p}_b\vec{p}_\pi]/\left|\overrightarrow{[\vec{p}_b\mathbf{p}_\pi]}\right|$$

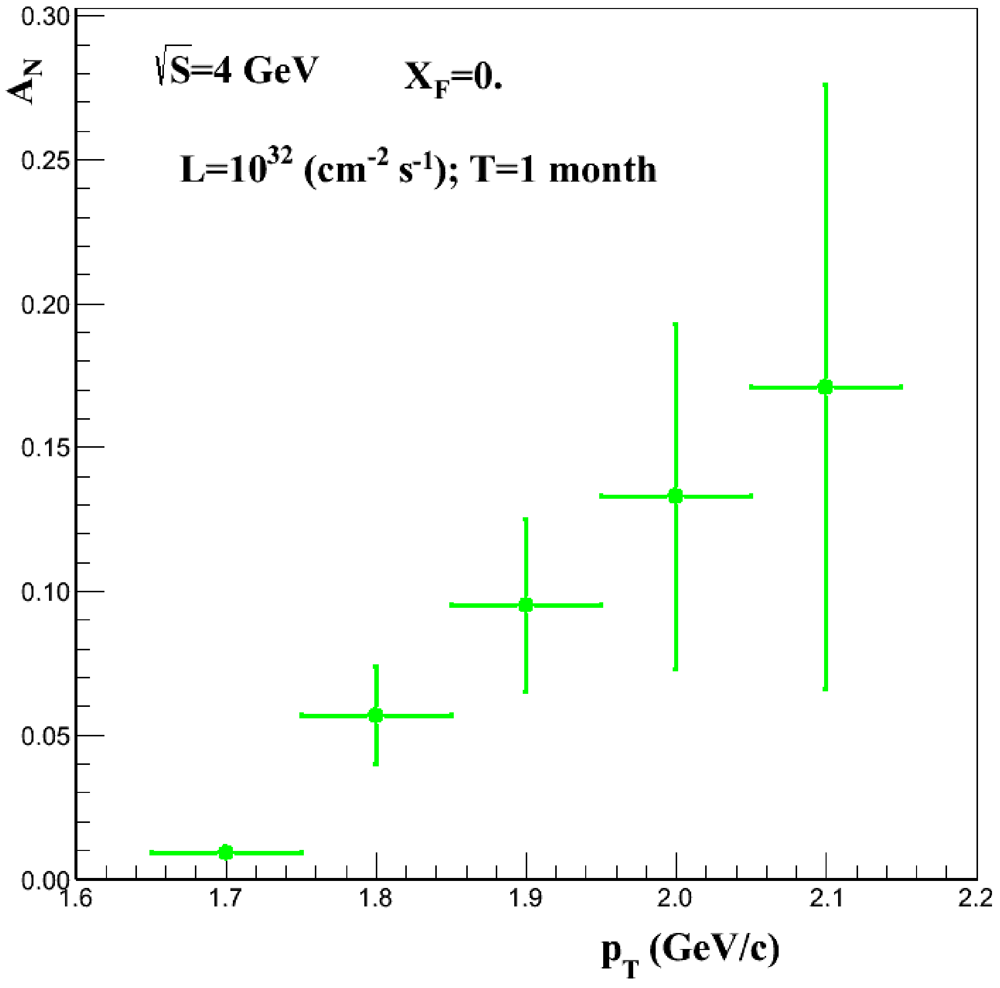
# Approximation from energy at the center of mass

*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

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

**for simplicity and clarity**

$$\mathbf{P_+ = -P_- = P}$$

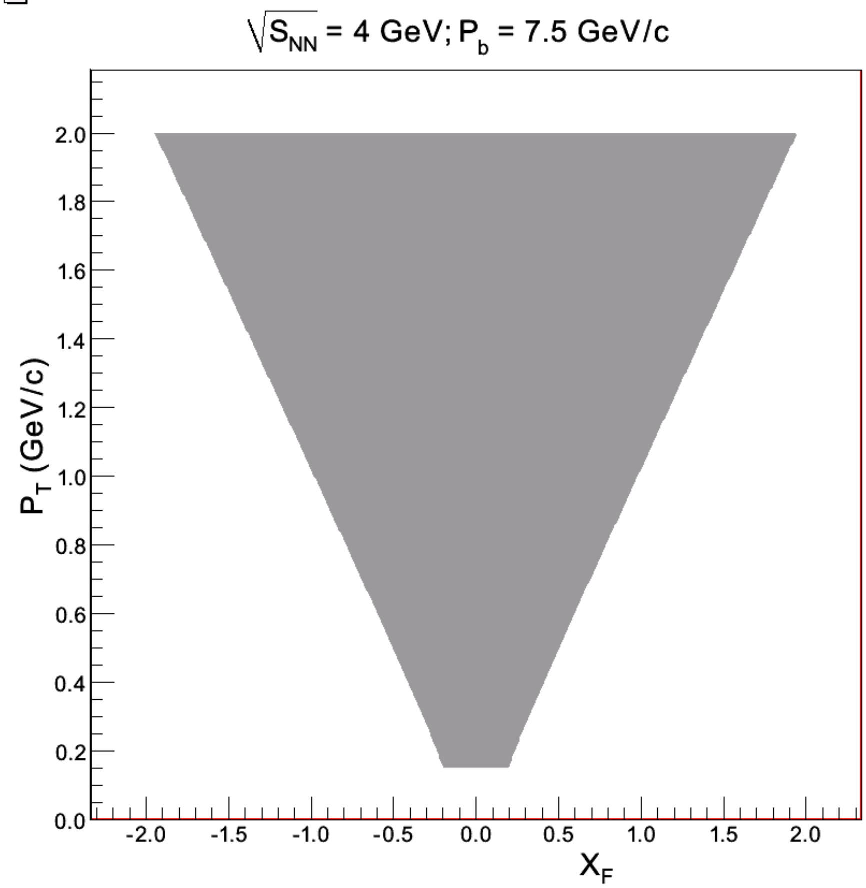
$$\mathbf{A_N} = \frac{3}{P} \frac{\int_0^{2\pi} \left( \left( \mathbf{n_+(\varphi) - n_-(\varphi)} \right) \mathbf{cos\varphi} \right) \mathbf{d\varphi}}{\int_0^{2\pi} \left( \mathbf{n_+(\varphi) + n_0(\varphi) + n_-(\varphi)} \right) \mathbf{d\varphi}}$$

# MPD pion acceptance $(x_F, p_T)$

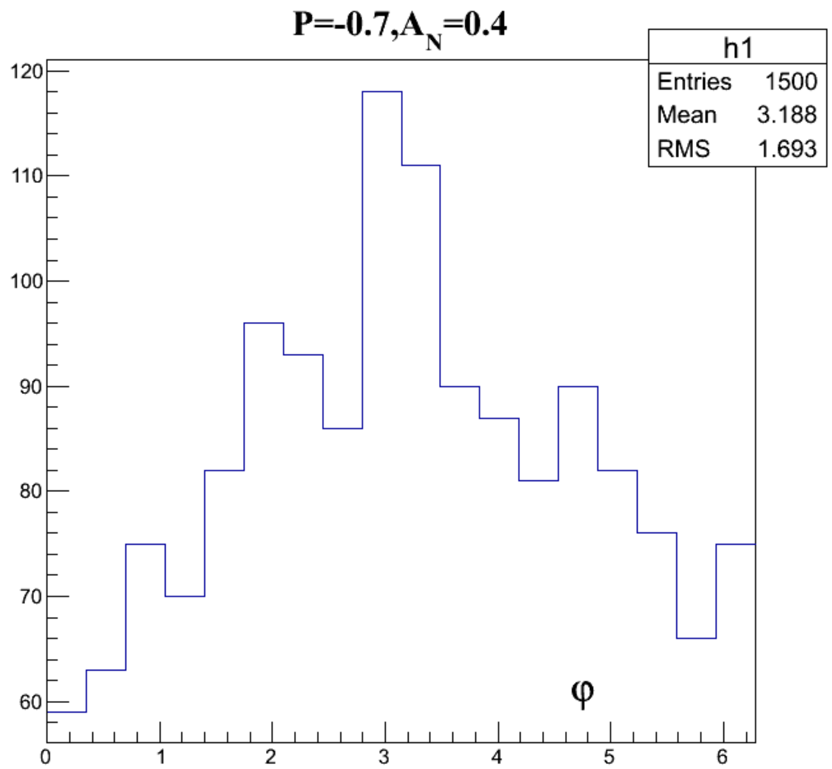
*Barrel part*

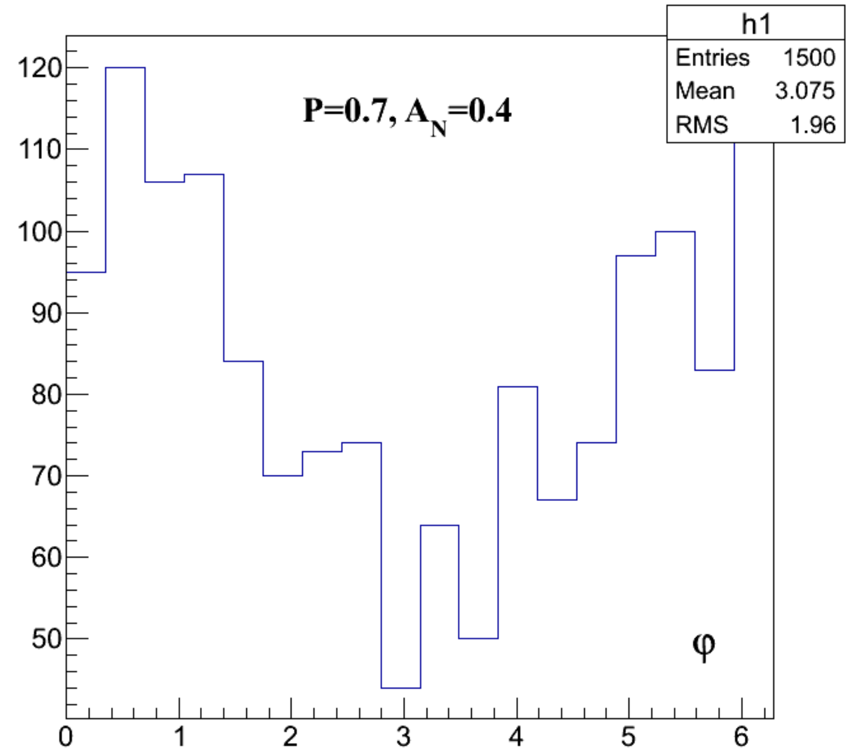
$$p_\pi\,(max) \approx \sqrt{s}/2$$

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



# Polar angle distribution

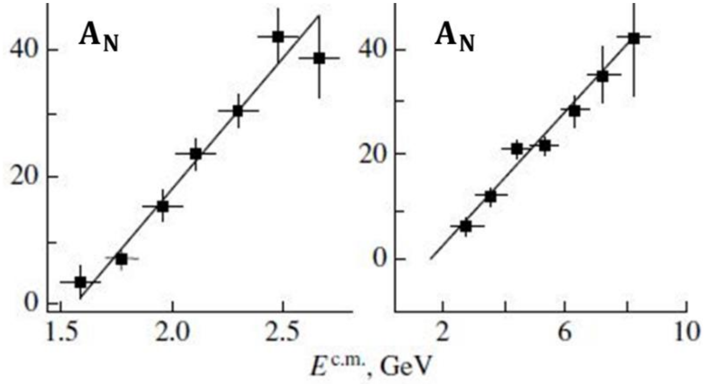


# Approximation from energy at the center of mass

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

$$A_N = \begin{cases} = 0, E_{cm} < E_0(\approx 1.6\text{ GeV}); \\ = k(E_{cm.} - E_0(\approx 1.6\text{ GeV})) \end{cases}$$




**NICA energy (http://nica.jinr.ru):**

- Collider mode (ions A>1) $\sqrt{S_{NN}} \leq 11$ GeV ⟺ Fix.targ. $E_b \leq 5.5$ GeV/N
- Collider mode (protons) $\sqrt{S_{NN}} \leq 22$ GeV ⟺ Fix.targ. $E_b \leq 11$ GeV

**Fix.targ**

$E_b \leq 5.5$ GeV/N ⟺ $\sqrt{S_{NN}} \leq 3.5$ GeV ⟹ $E_{cm,\pi} \leq 1.25$ GeV; $A_N = 0$

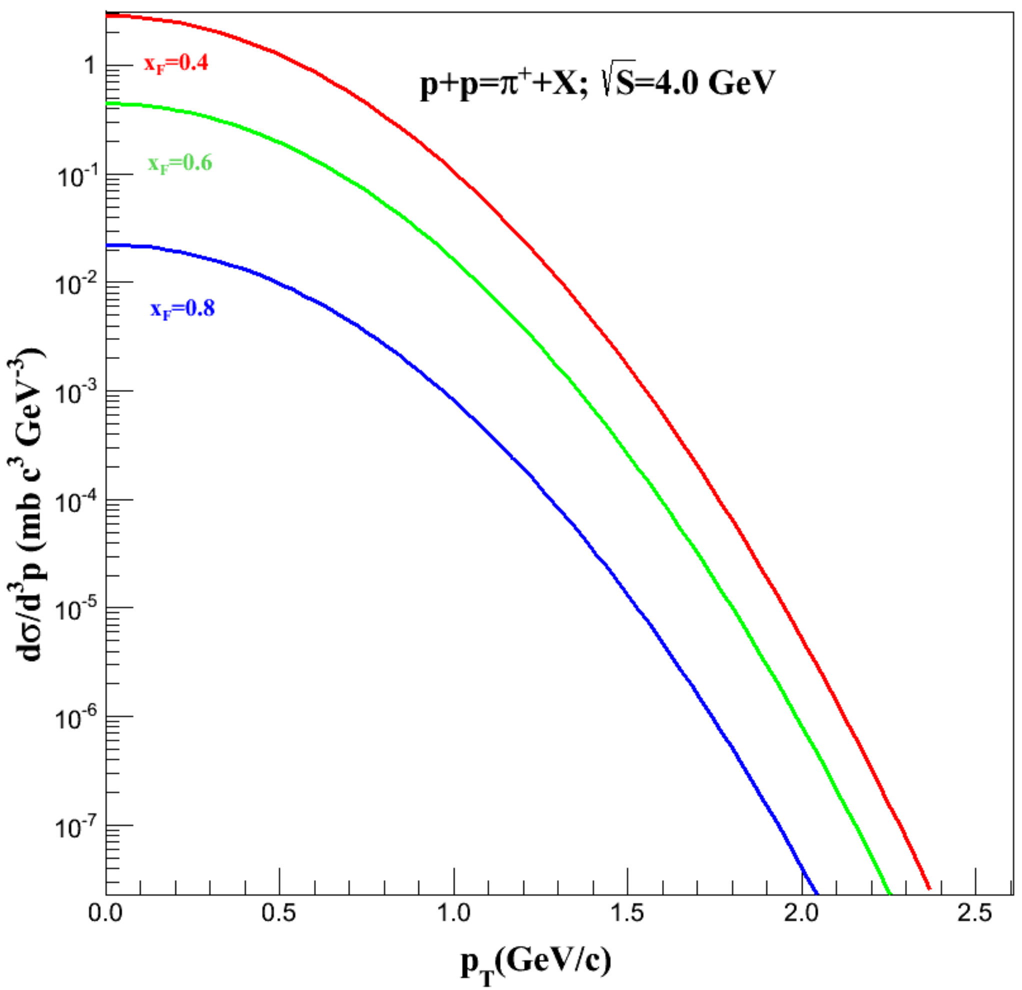
$E_b \leq 11$ GeV ⟺ $\sqrt{S_{NN}} \leq 4.7$ GeV ⟹ $E_{cm,\pi} \leq 2.0$ GeV; $A_N \leq 0.13$

# Conclusion II

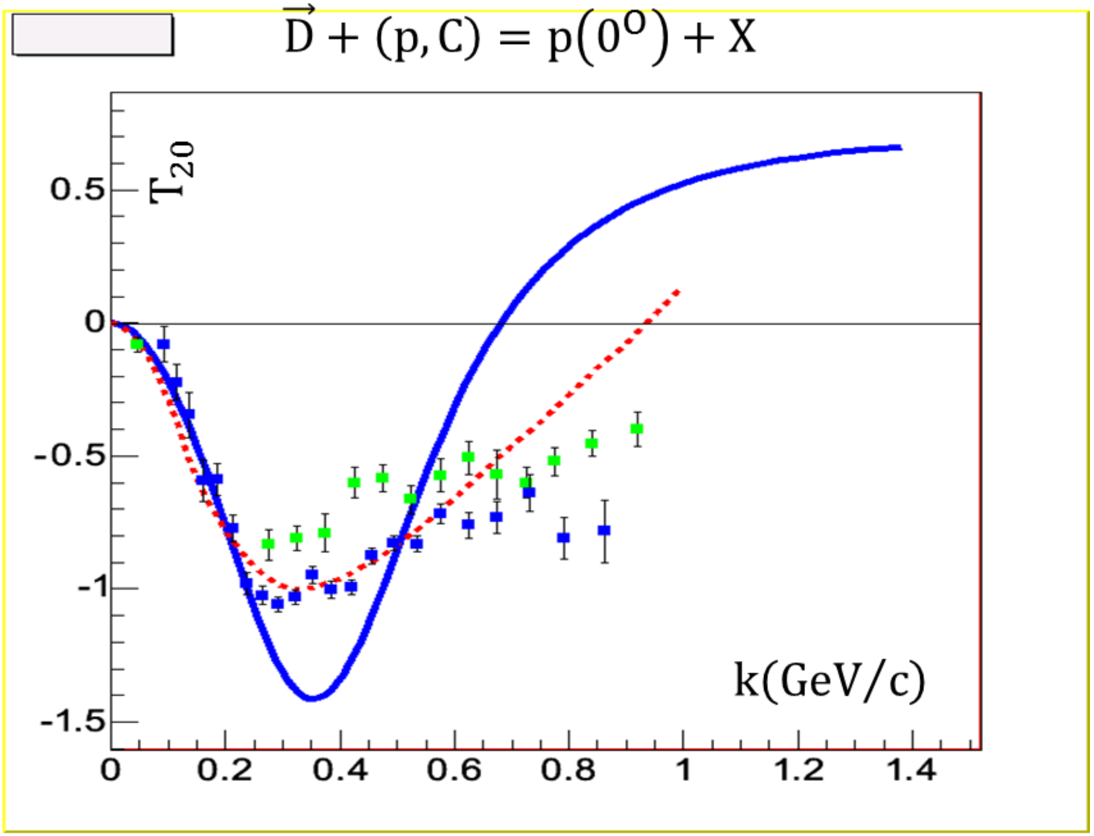
**There is no obvious reason why the study of transverse asymmetry in the fixed target experiment is interesting both for a beam of transversely polarized protons and deuterons. (proton beam $A_N \equiv A_y \leq 0.13$, deuteron beam $A_N \equiv A_y \equiv 0$).**

# Cross section

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



# Deuteron fragmentation into cumulatve particle
# Polarization observables



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**«Monitoring of the Tensor Polarization of High Energy Deuteron Beams»**