Spin Physics Experiments at NICA- SPD.

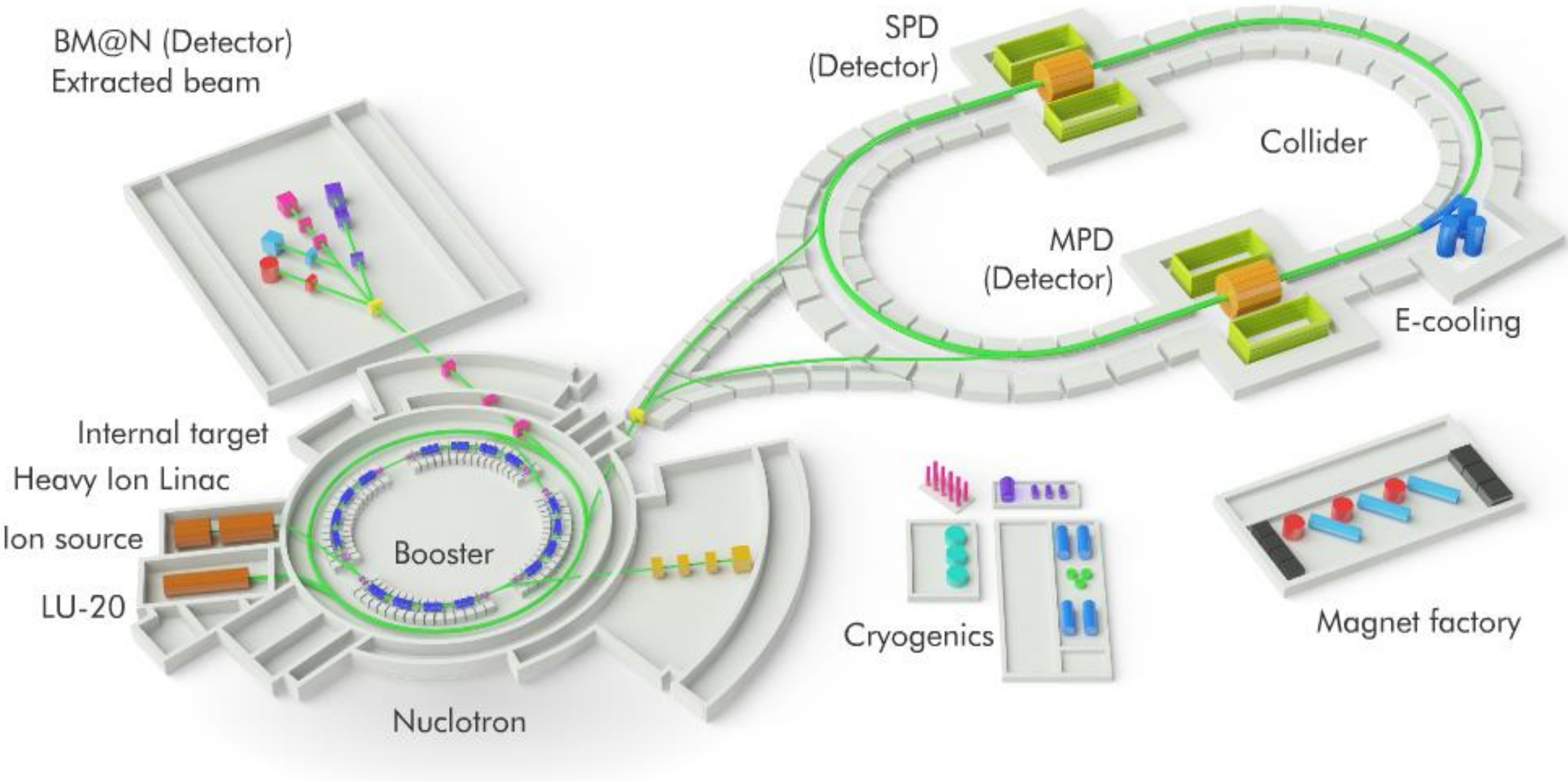
A. Kovalenko, I. Savin, JINR,Dubna.

Talk at the 22-nd International Symposium on Spin Physics held at the University of Illinois at Urbana Champaign, Illinois, USA

OUTLINE

1. Nuclotron based Ion Collider fAcility of JINR.
2. Spin physics program at NICA with polarized beams and Spin Physics Detector.
3. Measurements of the nucleon Parton Distribution Functions.

1. NICA: Nuclotron based Ion Collider fAcilities at JINR



Polarized beams at NICA.

The NICA complex at JINR has been approved in 2008 assuming two phases of construction.

The first phase, realizing now, includes construction of facilities for heavy ion physics program .

The second phase should include facilities for the program of spin physics studies with polarized protons and deuterons.

For deatails of the project status see the talk of A. Kovalenko.

Spin physics requirements to the NUCLOTRON-NICA complex

Beams. The following beams will be needed, polarized and non-polarized:

pp, pd, dd, pp↑, pd↑, p↑p↑, p↑d↑, d↑d↑.

Beam polarizations both at MPD and SPD: longitudinal and transversal. Absolute values of polarizations should be (90-50)%.The life time of the beam polarization should be long enough ≥24h. Measurements of Single Spin and Double Spin asymmetries in *DY* require running in different beam polarization modes: *UU*, *LU*, *UL*,*TU*, *UT*,*LL* ,*LT and TL*.

Beam energies: $p\uparrow p\uparrow(\sqrt{s_{pp}}) = 12 \div \geq 27$ GeV (5 ÷ ≥12.6 GeV kinetic energy),

$d\uparrow d\uparrow(\sqrt{s_{NN}}) = 4 \div \geq 13.8$ GeV (2 ÷ ≥5.9 GeV/u ion kinetic energy).

Asymmetric beam energies should be considered also.

Beam luminosities: in the *pp* mode: $L_{average} \geq 1 \cdot 10^{32}$ cm^{-2}s^{-1} (at $\sqrt{s_{pp}} = 27$ GeV),

in the *dd* mode: $L_{average} \geq 1 \cdot 10^{30}$ cm^{-2}s^{-1} (at $\sqrt{s_{NN}} = 14$ GeV).

LoI on SPD

LoI → arXiv:1408.3959 [hep-ex]

LoI signed by 124 authors representing 23 Institutions from 10 countries.
Armenia (1), Belarus (2), Czechia(3), France(1), Italy(1), Mongolia(1), Poland(2), Russia(6), Ukraine(2) and USA(4)

PAC JINR (DUBNA) Recommendations:

….The PAC heard with interest a report on the preparation of the Letter of Intent "Spin physics experiments at NICA-SPD with polarized proton and deuteron beams" presented by I. Savin. The PAC is pleased to see the first steps toward formation of an international collaboration around the SPD experiment. The PAC regards the SPD experiment as an essential part of the NICA research program and encourages the authors of the Letter of Intent to prepare a full proposal and present it at one of the forthcoming meetings of the PAC. …

Physics motivations for NICA

1. Nucleon spin structure studies using the Drell-Yan mechanism.
2. New nucleon PDFs and J/Ψ production mechanisms.
3. Direct photons.

Various by-product reactions will be studied using dedicated triggers

Basic twist-2 PDFs of the nucleon

(vertical – nucleon, horizontal – quark polarization)

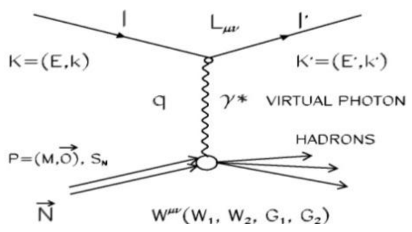
N\q	U	L	T
U	f_1 Number Density		$h_1^\perp$ Boer-Mulders
L		g_1 Helicity	$h_{1L}^\perp$ Worm-gear - L
T	$f_{1T}^\perp$ Sivers	$g_{1T}^\perp$ Worm-gear - T	h_1 Transversity $h_{1T}^\perp$ Pretzelosity

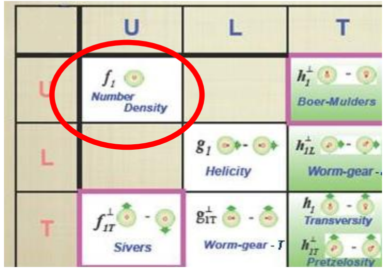
T-odd

chiral-odd

PDFs f_1 and g_1 (> 40 years of measurements)

Measured from Inclusive Deep Inelastic lepton (l)-nucleon (N) Scattering (IDIS) : $l + N \rightarrow l' + X$, nucleon can be polarized .

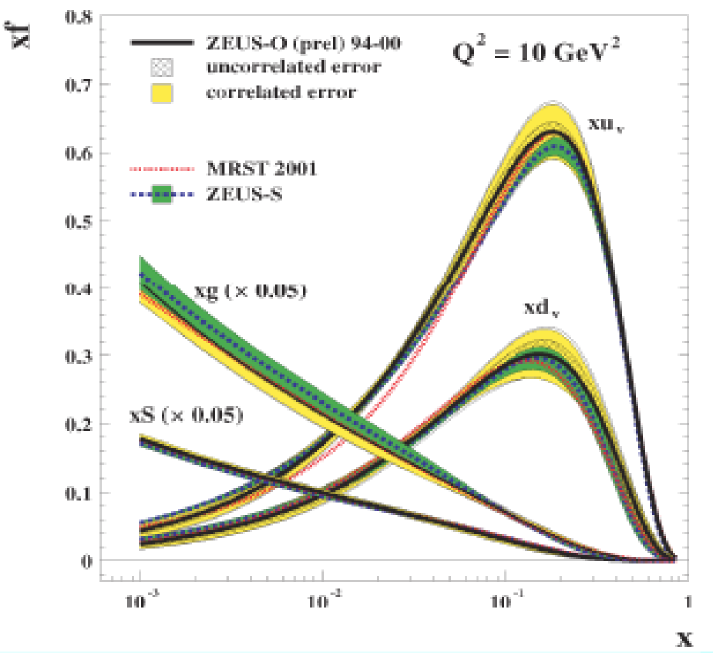




$$\frac{d^2\vec{\sigma}^{S_eS_N}}{d\Omega dE'} = \frac{d^2\sigma^{unp}}{d\Omega dE'} + S_N S_e \frac{d^2\sigma^{pol}}{d\Omega dE'},$$

$$\sigma^{unp} \equiv \frac{d^2\sigma^{unp}}{dxdQ^2} = \frac{4\pi\alpha^2}{Q^4 x} F_2(x,Q^2)\left[1 - y - \frac{y^2\gamma^2}{4} + \frac{y^2(1+\gamma^2)}{2(1+R(x,Q^2))}\right]$$

$R(x,Q2)$ and $F_2(x,Q^2)$ have been measured by the collaborations SLAC, EMC, BCDMS, NMC, ZEUS, H_1 and others. (with JINR participation)

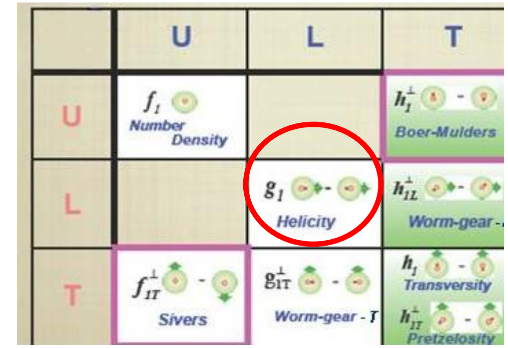


In QCD:

$F_2(x, Q^2) = x\sum_q e^2_q [\mathbf{q}(x, Q^2) + anti\text{-}\mathbf{q}(x, Q^2)]$, $q=u, d, s$.

PDFs f^a_1 ($a \equiv q$) are determined from the QCD analysis of all IDIS data

Polarized PDFs from the NLO-QCD fits to the g_1d and g_1p data



$Q^2 = 3\ \mathrm{GeV}^2$

integrals:

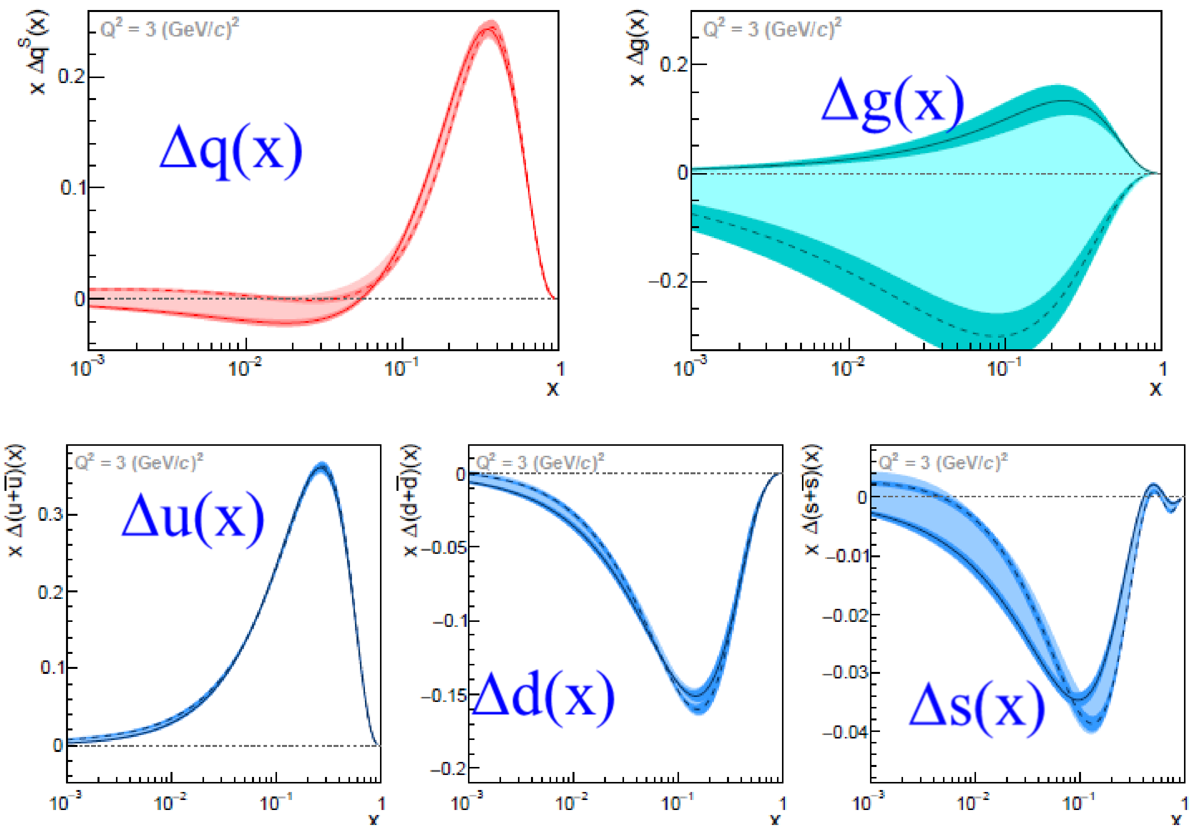
$0.27 \leq \Delta\Sigma \leq 0.39$

$-1.6 \leq \Delta G \leq 0.5$

$0.82 \leq \Delta U \leq 0.85$

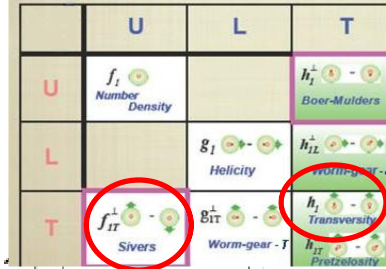
$-0.45 \leq \Delta D \leq -0.42$

$-0.11 \leq \Delta S \leq -0.08$



Parton helicity distributions in the longitudinally polarized nucleon at Q^2=3 GeV^2 as a function of x.

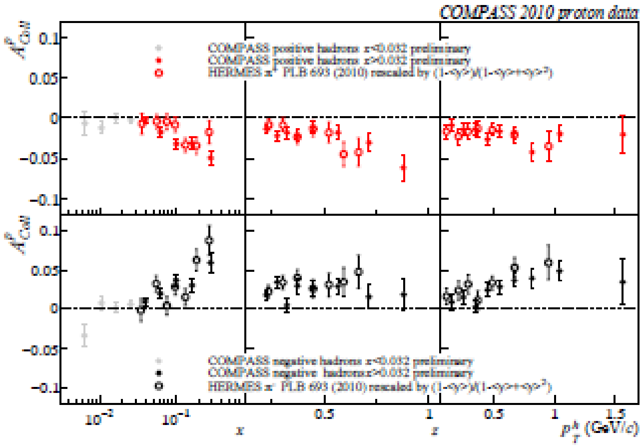
COMPASS: PLB 753(2016)18

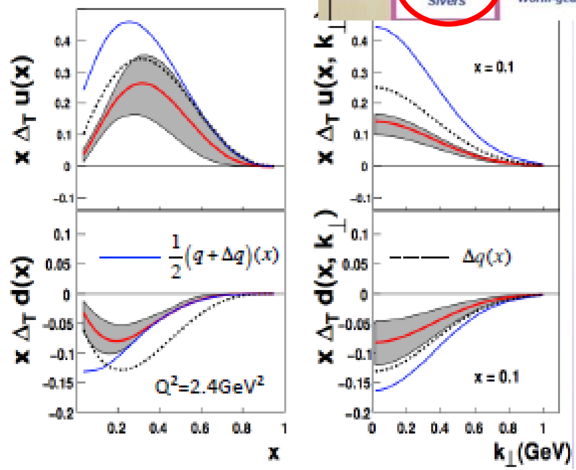


Transverse Momentum Dependent (TMD) PDFs

Transversity PDF h_1 ,

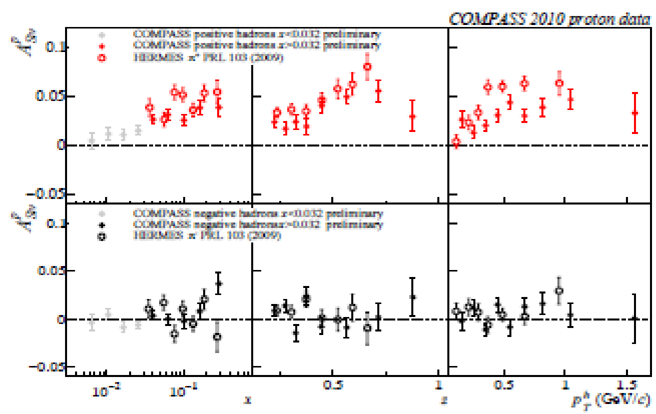
Measured recently

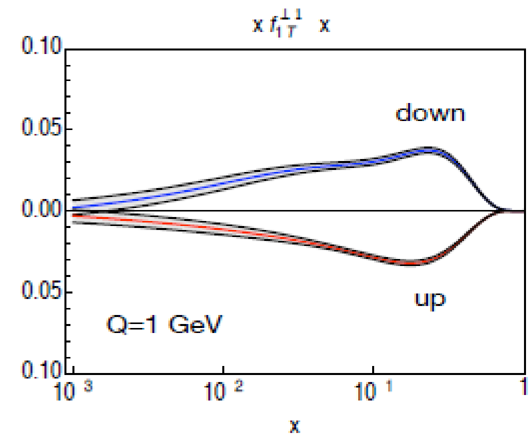




Sivers PDF $f^{\perp}_{1T}$.

Measured recently



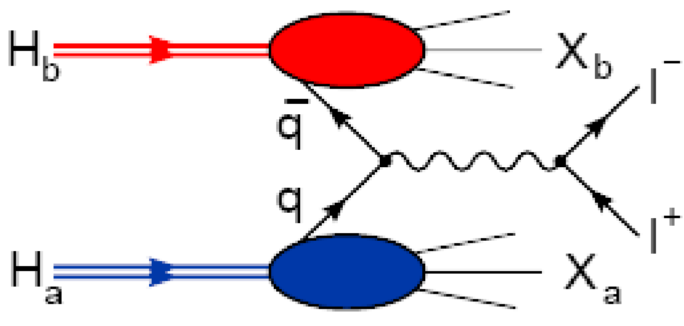


No data : Pretzelosity PDF $h^{\perp}_{1T}$,Worm-gear-L $h^{\perp}_{1L}$, Worm-gear-T $g^{\perp}_{1T}$,Boer-Mulders $h^{\perp}_{1}$

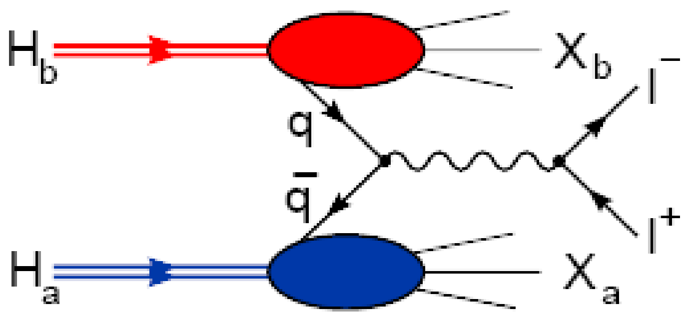
Nucleon structure studies using inclusive Drell-Yan*) mechanism

$$H_a(P_a, S_a) + H_b(P_b, S_b) \rightarrow l^-(l, \lambda) + l^+(l', \lambda') + X \ ,$$

where $\boldsymbol{P_a}$ ($\boldsymbol{P_b}$) and $\boldsymbol{S_a}$ ($\boldsymbol{S_b}$) are the momentum and spin of the hadron H_a (H_b), while $\boldsymbol{l}$ ($\boldsymbol{l'}$) and $\boldsymbol{\lambda}$ ($\boldsymbol{\lambda'}$) are the momentum and spin of the lepton, respectively.



(a)

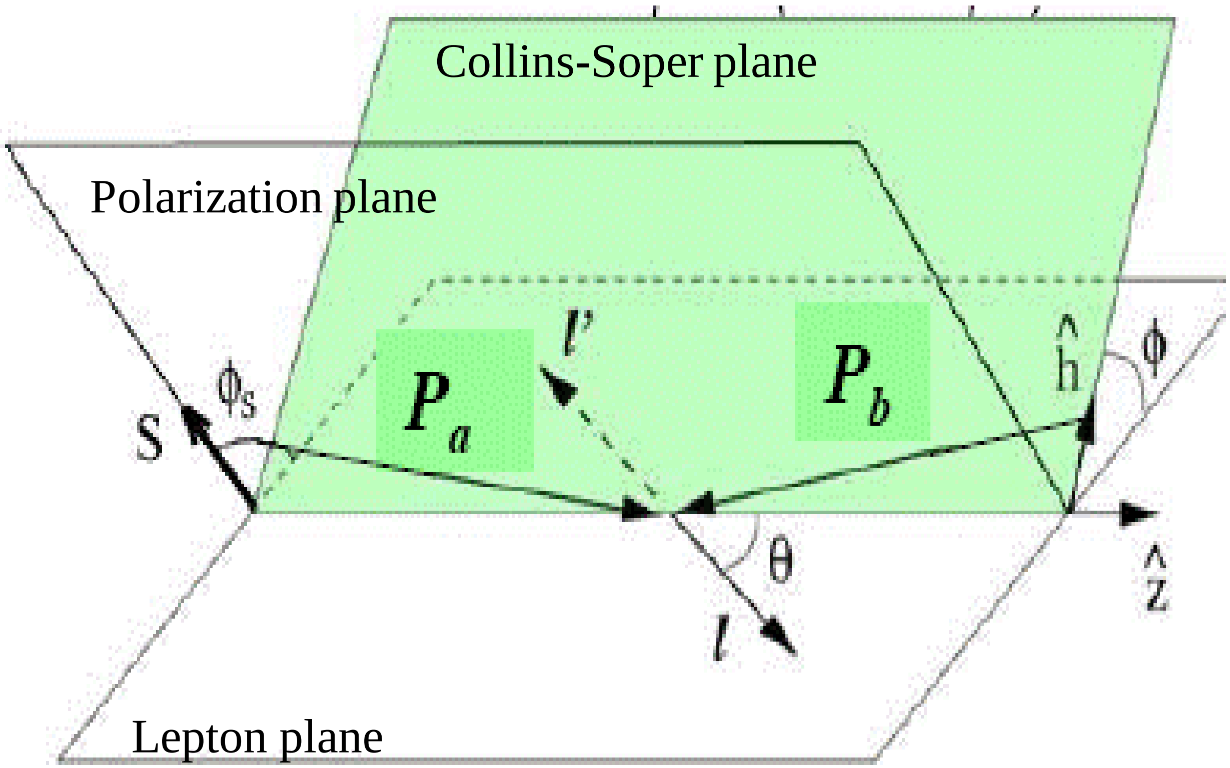


(b)

The constituent quark (anti-quark) of the hadron H_a annihilates with constituent anti-quark (quark) of the hadron H_b producing the virtual photon which decays into a pair of leptons $l^{\pm}$ (electron-positron or $\mu^{\pm}$). The hadron spectator systems X_a and X_b are usually not detected. Both diagrams have to be taken into account.

(*Exclusive DY will be considered in the Proposal*), A. Pivovarov and O. V. Teryaev, POS, (Baldin ISHEPP XXII) 090, 2014 http://pos.sissa.it

The kinematics of the Drell-Yan process is considered usually in the Collins-Soper (CS) reference frame [J.C. Collins, D.E. Soper, and G. Sterman, Nucl. Phys. B250, 199 (1985).]



Results of the most complete theoretical analysis of this process [S. Arnold, A. Metz and M. Schlegel, Phys.Rev. D79 (2009) 034005 [arXiv:hep-ph/0809.2262] are used .

The X-section of the DY pair's production in the QPM via LO PDFs is rewritten by us in the more convenient variables with a change of notations of the azimuthal angles corresp. to CS rf.

$$\frac{d\sigma}{dx_a dx_b d^2 q_T d\Omega} = \frac{\alpha^2}{4Q^2} \times$$

$$\Big\{\Big((1+\cos^2\theta)F_{UU}^{1} + \sin^2\theta\cos 2\phi F_{UU}^{\cos 2\phi}\Big) + S_{aL}\sin^2\theta\sin 2\phi F_{LU}^{\sin 2\phi} + S_{bL}\sin^2\theta\sin 2\phi F_{UL}^{\sin 2\phi}$$

$$+\left|\vec{S}_{aT}\right|\Big[\sin(\phi-\phi_{S_a})\big(1+\cos^2\theta\big)F_{TU}^{\sin(\phi-\phi_{S_a})} + \sin^2\theta\Big(\sin(3\phi-\phi_{S_a})F_{TU}^{\sin(3\phi-\phi_{S_a})} + \sin(\phi+\phi_{S_a})F_{TU}^{\sin(\phi+\phi_{S_a})}\Big)\Big]$$

$$+\left|\vec{S}_{bT}\right|\Big[\sin(\phi-\phi_{S_b})\big(1+\cos^2\theta\big)F_{UT}^{\sin(\phi-\phi_{S_b})} + \sin^2\theta\Big(\sin(3\phi-\phi_{S_b})F_{UT}^{\sin(3\phi-\phi_{S_b})} + \sin(\phi+\phi_{S_b})F_{UT}^{\sin(\phi+\phi_{S_b})}\Big)\Big]$$

$$+S_{aL}S_{bL}\Big[\big(1+\cos^2\theta\big)F_{LL}^{1} + \sin^2\theta\cos 2\phi F_{LL}^{\cos 2\phi}\Big] \qquad (2.1.2)$$

$$+S_{aL}\left|\vec{S}_{bT}\right|\Big[\cos(\phi-\phi_{S_b})\big(1+\cos^2\theta\big)F_{LT}^{\cos(\phi-\phi_{S_b})} + \sin^2\theta\Big(\cos(3\phi-\phi_{S_b})F_{LT}^{\cos(3\phi-\phi_{S_b})} + \cos(\phi+\phi_{S_b})F_{LT}^{\cos(\phi+\phi_{S_b})}\Big)\Big]$$

$$+\left|\vec{S}_{aT}\right|S_{bL}\Big[\cos(\phi-\phi_{S_a})\big(1+\cos^2\theta\big)F_{TL}^{\cos(\phi-\phi_{S_a})} + \sin^2\theta\Big(\cos(3\phi-\phi_{S_a})F_{TL}^{\cos(3\phi-\phi_{S_a})} + \cos(\phi+\phi_{S_a})F_{TL}^{\cos(\phi+\phi_{S_a})}\Big)\Big]$$

$$+\left|\vec{S}_{aT}\right|\left|\vec{S}_{bT}\right|\Big[\big(1+\cos^2\theta\big)\Big(\cos(2\phi-\phi_{S_a}-\phi_{S_b})F_{TT}^{\cos(2\phi-\phi_{S_a}-\phi_{S_b})} + \cos(\phi_{S_b}-\phi_{S_a})F_{TT}^{\cos(\phi_{S_b}-\phi_{S_a})}\Big)\Big]$$

$$+\left|\vec{S}_{aT}\right|\left|\vec{S}_{bT}\right|\Big[\sin^2\theta\Big(\cos(\phi_{S_a}+\phi_{S_b})F_{TT}^{\cos(\phi_{S_a}+\phi_{S_b})} + \cos(4\phi-\phi_{S_a}-\phi_{S_b})F_{TT}^{\cos(4\phi-\phi_{Sa}-\phi_{S_b})}\Big)\Big]$$

$$+\left|\vec{S}_{aT}\right|\left|\vec{S}_{bT}\right|\Big[\sin^2\theta\Big(\cos(2\phi-\phi_{S_a}+\phi_{S_b})F_{TT}^{\cos(2\phi-\phi_{S_a}+\phi_{S_b})} + \cos(2\phi+\phi_{S_a}-\phi_{S_b})F_{TT}^{\cos(2\phi+\phi_{S_a}-\phi_{S_b})}\Big)\Big]\Big\}$$

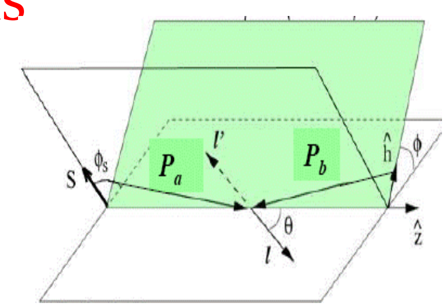
F_j^i are the SFs, depend on four variables $P_a \cdot q$, $P_b \cdot q$, $\boldsymbol{q_T}$ and q^2 or on $\boldsymbol{q_T}$, q^2 and the Bjorken variables of colliding hadrons, x_a, x_b,

$$x_a = \frac{q^2}{2P_a\cdot q} = \sqrt{\frac{q^2}{s}}e^{y},\ x_b = \frac{q^2}{2P_b\cdot q} = \sqrt{\frac{q^2}{s}}e^{-y},\ q_T \text{ and } q^2$$

, y is the *cm* rapidity.

8 asymmetries to be measured: A_{LU}, A_{UL}, A_{TU}, A_{UT}, A_{LL}, A_{TL}, A_{LT}, A_{TT}

which include 23 modulations with amplitudes $A^{i}_{jk} = F^{i}_{jk} / F^{1}_{UU}$ normalized to unpolarized one.



$$A_{UU} \equiv \frac{\sigma^{00}}{\sigma^{00}_{\text{int}}} = \frac{1}{2\pi}\left(1 + D\cos 2\phi A^{\cos 2\phi}_{UU}\right)$$

$$A_{LU} \equiv \frac{\sigma^{\rightarrow 0} - \sigma^{\leftarrow 0}}{\sigma^{\rightarrow 0}_{\text{int}} + \sigma^{\leftarrow 0}_{\text{int}}} = \frac{|S_{aL}|}{2\pi} D \sin 2\phi A^{\sin 2\phi}_{LU}$$

$$A_{UL} \equiv \frac{\sigma^{0\rightarrow} - \sigma^{0\leftarrow}}{\sigma^{0\rightarrow}_{\text{int}} + \sigma^{0\leftarrow}_{\text{int}}} = \frac{|S_{bL}|}{2\pi} D \sin 2\phi A^{\sin 2\phi}_{UL}$$

$$A_{TU} \equiv \frac{\sigma^{\uparrow 0} - \sigma^{\downarrow 0}}{\sigma^{\uparrow 0}_{\text{int}} + \sigma^{\downarrow 0}_{\text{int}}} = \frac{|\vec{S}_{aT}|}{2\pi}\left[A^{\sin(\phi-\phi_{S_a})}_{TU} \sin(\phi - \phi_{S_a}) + D\left(A^{\sin(3\phi-\phi_{S_a})}_{TU} \sin(3\phi - \phi_{S_a}) + A^{\sin(\phi+\phi_{S_a})}_{TU} \sin(\phi + \phi_{S_a}) \right)\right]$$

$$A_{UT} \equiv \frac{\sigma^{0\uparrow} - \sigma^{0\downarrow}}{\sigma^{0\uparrow}_{\text{int}} + \sigma^{0\downarrow}_{\text{int}}} = \frac{|\vec{S}_{bT}|}{2\pi}\left[A^{\sin(\phi-\phi_{S_b})}_{UT} \sin(\phi - \phi_{S_b}) + D\left(A^{\sin(3\phi-\phi_{S_b})}_{UT} \sin(3\phi - \phi_{S_b}) + A^{\sin(\phi+\phi_{S_b})}_{UT} \sin(\phi + \phi_{S_b}) \right)\right]$$

$$A_{LL} \equiv \frac{\sigma^{\rightarrow\rightarrow} + \sigma^{\leftarrow\leftarrow} - \sigma^{\rightarrow\leftarrow} - \sigma^{\leftarrow\rightarrow}}{\sigma^{\rightarrow\rightarrow}_{\text{int}} + \sigma^{\leftarrow\leftarrow}_{\text{int}} + \sigma^{\rightarrow\leftarrow}_{\text{int}} + \sigma^{\leftarrow\rightarrow}_{\text{int}}} = \frac{|S_{aL} S_{bL}|}{2\pi}\left(A^{1}_{LL} + D A^{\cos 2\phi}_{LL} \cos 2\phi \right)$$

$$A_{TL} \equiv \frac{\sigma^{\uparrow\rightarrow} + \sigma^{\downarrow\leftarrow} - \sigma^{\downarrow\rightarrow} - \sigma^{\uparrow\leftarrow}}{\sigma^{\uparrow\rightarrow}_{\text{int}} + \sigma^{\downarrow\leftarrow}_{\text{int}} + \sigma^{\downarrow\rightarrow}_{\text{int}} + \sigma^{\uparrow\leftarrow}_{\text{int}}} = \frac{|\vec{S}_{aT}| S_{bL}}{2\pi}\left[A^{\cos(\phi-\phi_{S_a})}_{TL} \cos(\phi - \phi_{S_a}) + D\left(\begin{array}{l} A^{\cos(3\phi-\phi_{S_a})}_{TL} \cos(3\phi - \phi_{S_a}) \\ + A^{\cos(\phi+\phi_{S_a})}_{TL} \cos(\phi + \phi_{S_a}) \end{array} \right)\right]$$

$$A_{LT} \equiv \frac{\sigma^{\rightarrow\uparrow} + \sigma^{\leftarrow\downarrow} - \sigma^{\rightarrow\downarrow} - \sigma^{\leftarrow\uparrow}}{\sigma^{\rightarrow\uparrow}_{\text{int}} + \sigma^{\leftarrow\downarrow}_{\text{int}} + \sigma^{\rightarrow\downarrow}_{\text{int}} + \sigma^{\leftarrow\uparrow}_{\text{int}}} = \frac{S_{aL} |\vec{S}_{bT}|}{2\pi}\left[A^{\cos(\phi-\phi_{S_b})}_{LT} \cos(\phi - \phi_{S_b}) + D\left(\begin{array}{l} A^{\cos(3\phi-\phi_{S_b})}_{LT} \cos(3\phi - \phi_{S_b}) \\ + A^{\cos(\phi+\phi_{S_b})}_{LT} \cos(\phi + \phi_{S_b}) \end{array} \right)\right]$$

$$A_{TT} \equiv \frac{\sigma^{\uparrow\uparrow} + \sigma^{\downarrow\downarrow} - \sigma^{\uparrow\downarrow} - \sigma^{\downarrow\uparrow}}{\sigma^{\uparrow\uparrow}_{\text{int}} + \sigma^{\downarrow\downarrow}_{\text{int}} + \sigma^{\uparrow\downarrow}_{\text{int}} + \sigma^{\downarrow\uparrow}_{\text{int}}} = \frac{|\vec{S}_{aT}||\vec{S}_{bT}|}{2\pi}\Big[A^{\cos(2\phi-\phi_{S_a}-\phi_{S_b})}_{TT} \cos(2\phi - \phi_{S_a} - \phi_{S_b}) + A^{\cos(\phi_{S_b}-\phi_{S_a})}_{TT} \cos(\phi_{S_b} - \phi_{S_a})$$

$$+ D\Big(A^{\cos(\phi_{S_b}+\phi_{S_a})}_{TT} \cos(\phi_{S_a} + \phi_{S_b}) + A^{\cos(4\phi-\phi_{S_a}-\phi_{S_b})}_{TT} \cos(4\phi - \phi_{S_a} - \phi_{S_b})$$

$$+ A^{\cos(2\phi-\phi_{S_a}+\phi_{S_b})}_{TT} \cos(2\phi - \phi_{S_a} + \phi_{S_b}) + A^{\cos(2\phi+\phi_{S_a}-\phi_{S_b})}_{TT} \cos(2\phi + \phi_{S_a} - \phi_{S_b}) \Big)\Big] \qquad (2.1.10)$$

Applying the Fourier analysis to the measured asymmetries, one can separate each of all ratios $A^{i}_{jk} = F^{i}_{jk} / F^{1}_{UU}$.

Extraction of different TMD PDFs from these ratios is a task of the global analysis since each of the SFs is a result of convolutions of different TMD PDFs in the quark transverse momentum space. For this purpose one needs either to assume a factorization of the transverse momentum dependence for each TMD PDFs, or to transfer them to impact parameter representation and to use the Bessel weighted TMD PDFs.

The large number of independent SFs to be determined from the polarized DY processes at NICA (24 for identical hadrons in the initial state) **is sufficient to map out all eight leading twist TMD PDFs for quarks and anti-quarks**.

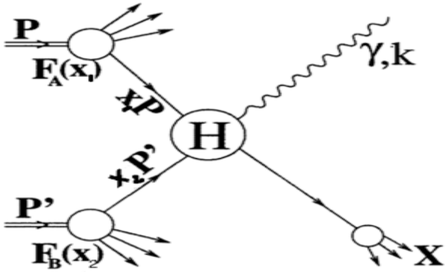
This fact indicates the high potential of the polarized DY process for studying new PDFs. This process has also a certain advantage over SIDIS which also capable of mapping out the leading twist TMD PDFs but requires knowledge of fragmentation functions.

The transverse single spin asymmetries depending on the Structure Functions F^1_{UT} F^1_{TU}

are of the particular interests. The both SFs contain the Sivers PDF which was **predicted to have the opposite sign in DY as compared to SIDIS.** As the sign reversal is at the core of our present understanding of transverse single spin asymmetries in hard scattering processes, the experimental check of this prediction is of the utmost importance.

2.4. Direct photons.

Direct photon productions in the non-polarized and polarized *pp (pd)* reactions provide information on the gluon distributions in nucleons



Vertex H corresponds to parton-parton interaction

q + qbar →γ+X (15%) or g+q→γ+X (85%)

hard processes.

No fragmentation functions

One can show that the polarized gluon distribution (Sivers gluon function) can be extracted from measurement of the transverse single spin asymmetry A_N

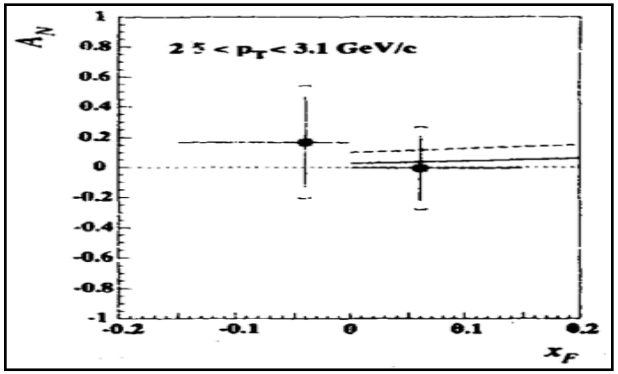
Via double spin asymmetry A_{LL}

$$A_{LL} = \frac{(\sigma_{++} + \sigma_{--}) - (\sigma_{+-} + \sigma_{-+})}{(\sigma_{++} + \sigma_{--}) + (\sigma_{+-} + \sigma_{-+})}$$

a gluon polarization in the nucleon:

$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \cdot \left[\frac{\sum_q e_q^2 [\Delta q(x_2) + \Delta \bar{q}(x_2)]}{\sum_q e_q^2 [q(x_2) + \bar{q}(x_2)]} \right] \cdot \hat{a}_{LL}(gq \to \gamma q) + (1 \leftrightarrow 2),$$

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$ of order few %.



SPD layout.

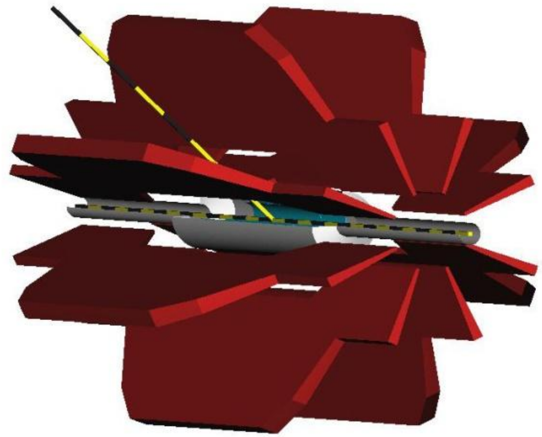
Preliminary considerations of the event topologies have required SPD to be equipped with the sub-detectors covering ~4π angular region around the beams intersection point:

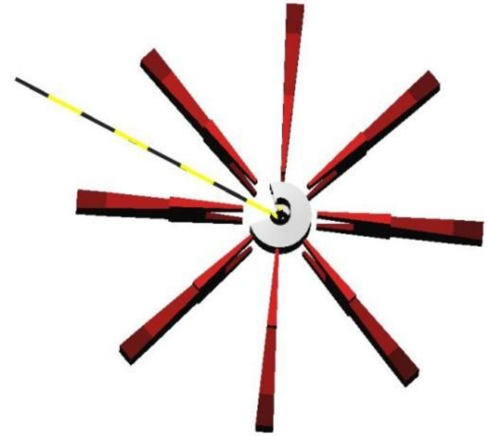
vertex detectors (VD),
tracking detectors (TD),
electromagnetic calorimeters (ECAL),
hadron detectors (HD) and
muon detectors (MD).

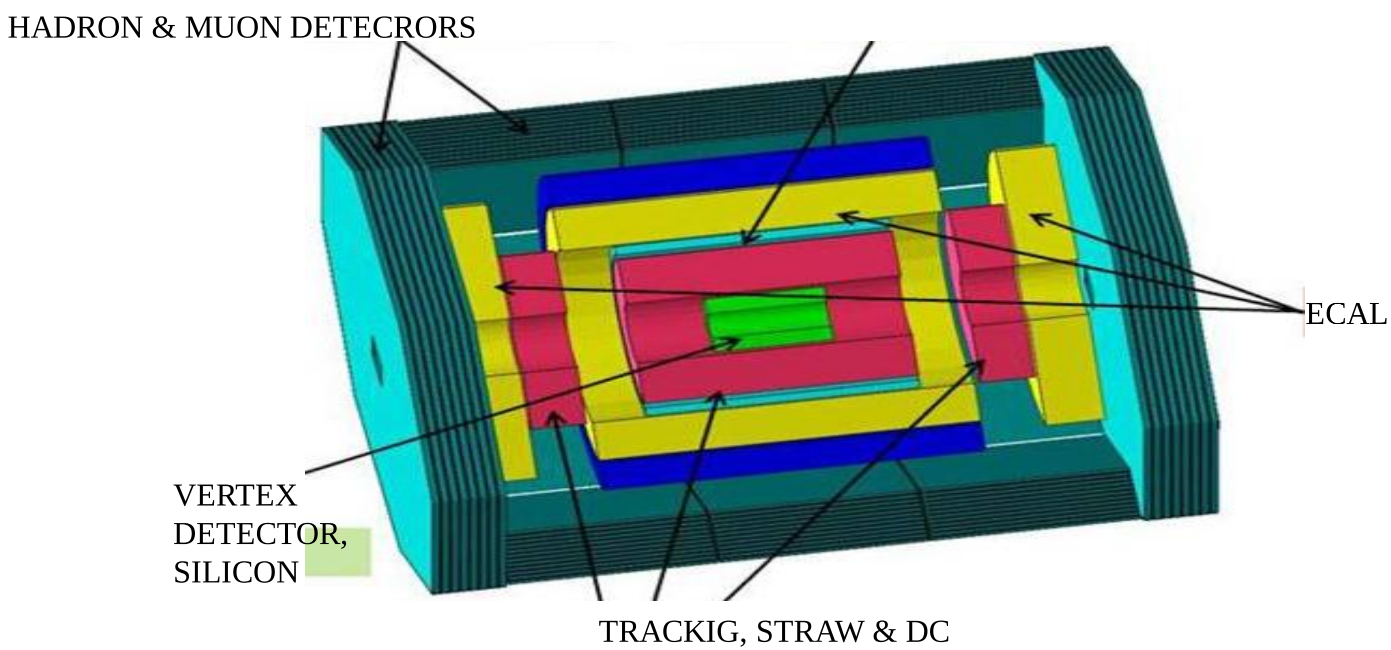
VD, TD and ECAL must be in the magnetic field.

Prototypes of all sub-detectors exist or under development.

There are two options for the magnet: toroid or solenoid.







The “almost 4π geometry” requested by DY and direct photons can be realized in the solenoid version of SPD if it has overall length of about 6 m.

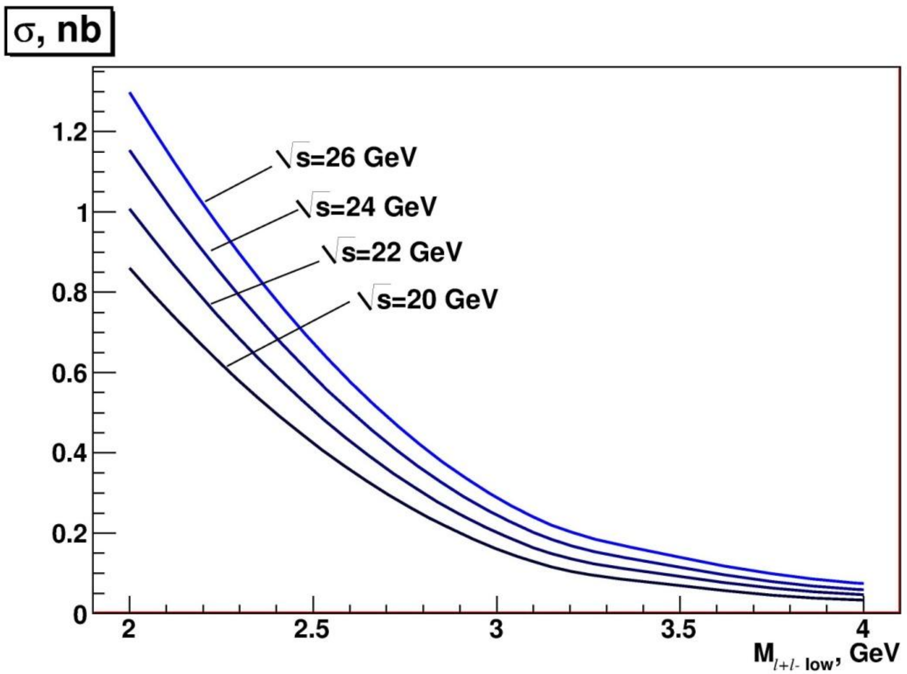
Proposed measurement with SPD.

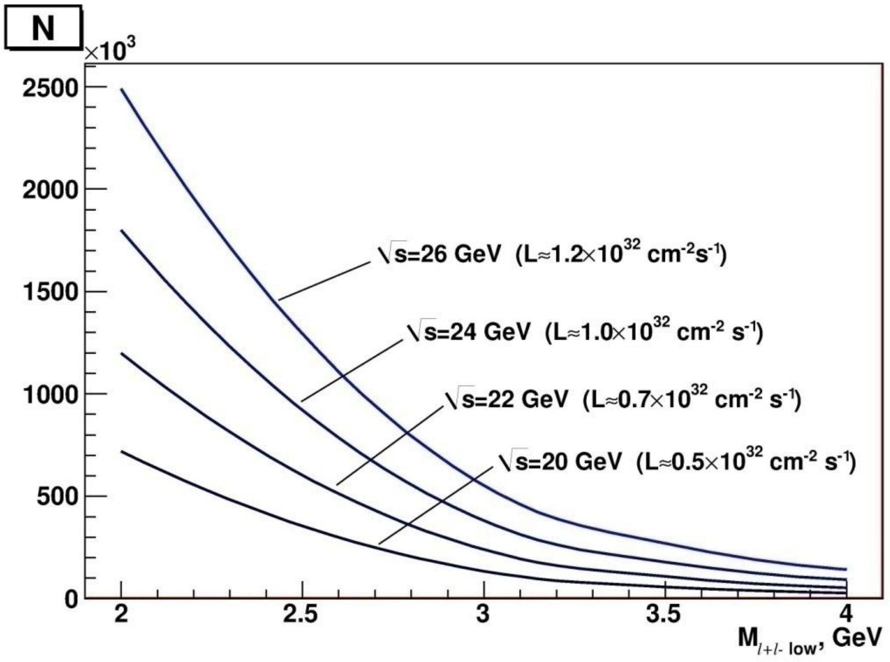
We propose to perform measurements of asymmetries of the DY pairs production in collisions of polarized protons and deuterons which provide an access to all collinear and TMD PDFs of quarks and anti-quarks in nucleons in the single experiment.

The measurements of asymmetries in production of J/Ψ and direct photons will be performed simultaneously with DY using dedicated triggers.

Estimations of *DY* production rates

To estimate the precision of measurements, the set of original software packages for MC simulations, including generators for Sivers , Boer-Mulders and transversity PDFs were developed. With these packages we have generated a sample of 100K D-Y events (~ 1 year of data taking) for comparison with expected asymmetries.

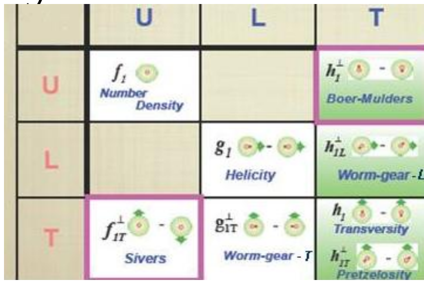




Cross section (left) and number of DY events (right) versus the minimal invariant mass of lepton pair for various proton beam energies.

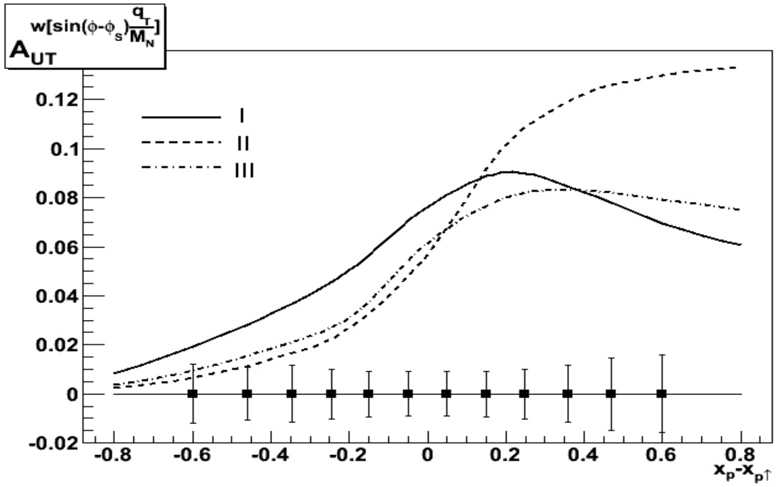
Estimations of required precisions

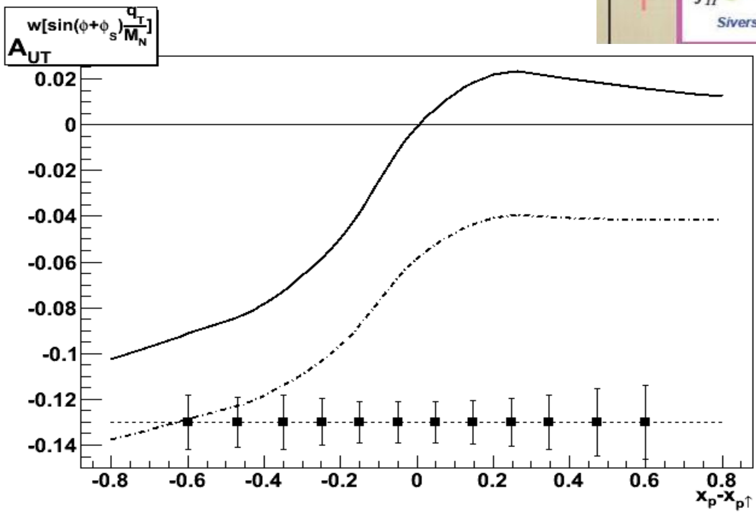
To estimate the precision of measurements, the set of original software packages for MC simulations, including generators for Sivers , Boer-Mulders and Transversity PDFs were developed. With these packages we have generated a sample of 100K DY events (~ 1 year of data taking) for comparison with expected asymmetries.



Sivers

Boer-Mulders





Estimations of direct photon production rates

A_N and A_{LL} could be measured at SPD with statistical accuracy ~0.11% and ~0.18%, respectively, in each of 18 x_F bins (-0.9< x_F < +0.9).

$\sqrt{s}$=24 GeV $L = 1.0 \times 10^{32}$, $cm^{-1}s^{-1}$	σ_{tot}, nbarn	$\sigma_{P_T>4\ GeV/c}$, nbarn	Events/year, 10^6	Events/year, 10^6 ($P_T > 4\ GeV/c$)
All processes	1290	42	3260	105
$qg \to q\gamma$	1080	33	2730	84
$q\bar{q} \to g\gamma$	210	9	530	21

$\sqrt{s}$=26 GeV $L = 1.2 \times 10^{32}$, $cm^{-1}s^{-1}$	σ_{tot}, nbarn	$\sigma_{P_T>4\ GeV/c}$, nbarn	Events/year, 10^6	Events/year, 10^6 ($P_T > 4\ GeV/c$)
All processes	1440	48	4340	144
$qg \to q\gamma$	1220	38	3680	116
$q\bar{q} \to g\gamma$	240	10	660	28

Large statistics of events provide opportunities to measure the asymmetries as a function of x_F and p_T.

CONCLUSION

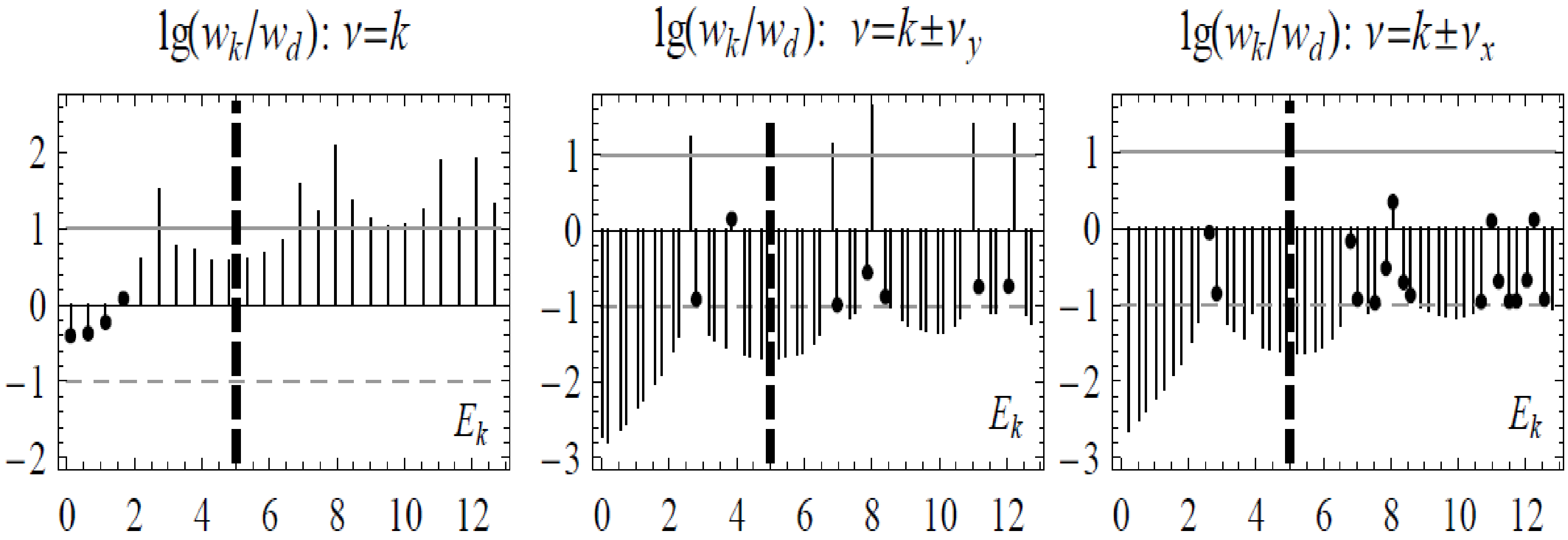
1. The comprehensive program of the spin nucleon structure and other spin dependent reactions study is suggested. It can be realized at NICA using the polarized proton, deuteron and heavy ion beams and specialized SPD detector.
2. Interesting spin program can be suggested for fixed target experiments.
3. The program is supported by a number of Laboratories and the world leading experts from 10 countries.
4. The International collaboration should be organized for preparations of the Proposal.

N.B. Russian government has released this year a first tranche of money to participate in construction of the NICA facility.

N.B.B. Text of the LoI is at http://arxiv.org/abs/1408.3959

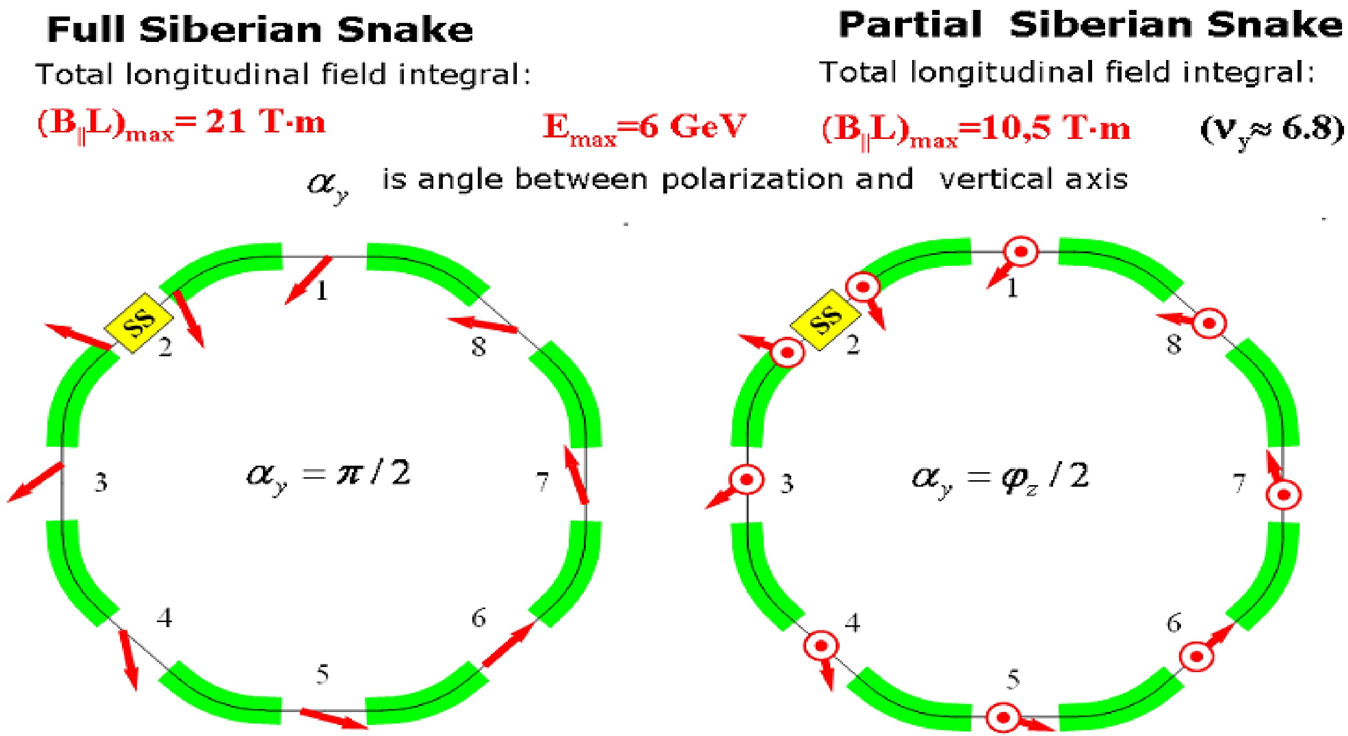
backup

Proton spin resonances in the Nuclotron



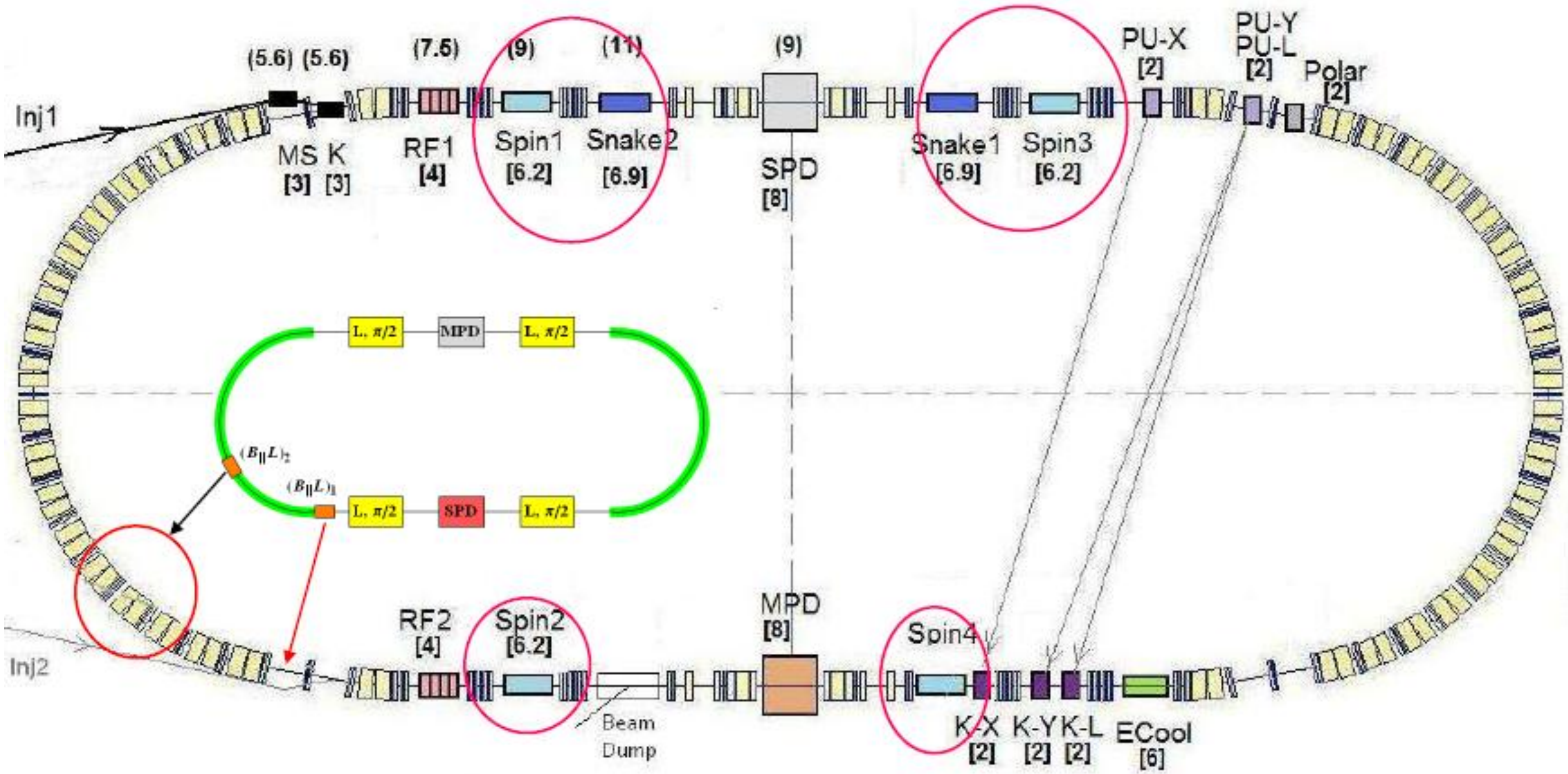
Possible solution is found in the energy range up to 5-6 GeV. Further acceleration can be done at NICA.

Proton spin dynamics in the Nuclotron ring in the case of a full or partial snake working synchronously with accelerating cycle



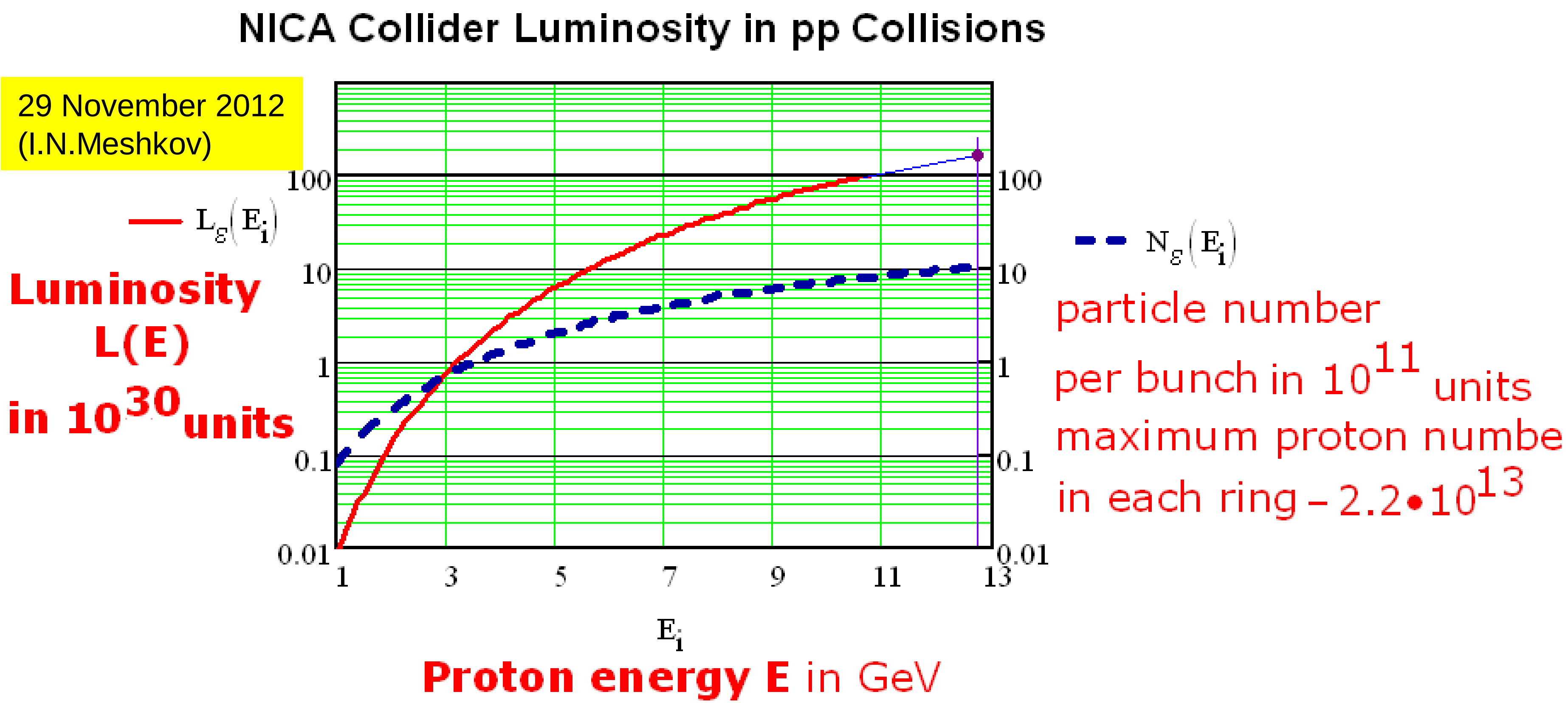
Polarized deuterons acceleration in Nuclotron is possible up to the energy of 5.6 GeV/u

Possible NICA structure for polarized proton and deuteron beams



NICA pp-collisions peak luminosity

29 November 2012
(I.N.Meshkov)



The number of particles reaches a value about $2.2 \cdot 10^{13}$ in each ring and the peak luminosity reaches $L_{peack} = 2 \cdot 10^{32}$ $cm^{-2}s^{-1}$ at 12.7 GeV

Outline (LoI)

1. Introduction

2. Physics motivations

2.1 Twist-2 PDFs of the nucleon
2.2. Nucleon spin structure studies using the Drell-Yan mechanism
2.3. New nucleon PDFs and *J/Ψ* production mechanisms.
2.4. Direct photons.
2.5. Spin-dependent high-p_T reactions.
2.6. Spin-dependent effects in elastic *pp* and *dd* scattering.
2.7. Spin-dependent reactions in heavy ion collisions.

3. Requirements to the NUCLOTRON-NICA

4. Requirements to the Spin Physics Detector (SPD)

4.1. Event topologies.
4.2. Possible layout of SPD.
4.3. Trigger system.
4.4. Local polarimeters and luminosity monitors.
4.5. Engineering infrastructure.
4.6. DAQ.
4.7. SPD reconstruction software.
4.8. Monte Carlo simulations.
4.9. Slow control.
4.10. Data accumulation, storing and distribution.

5. Proposed measurements with SPD

5.1. Estimations of *DY* and *J/Ψ* production rates.
5.2. Estimations of direct photon production rates.
5.3. Rates in high-p_T reactions.
5.4. Rates in elastic *pp* and *dd* scattering.
5.5. Feasibility of the spin-dependent reaction studies in heavy ion collisions.

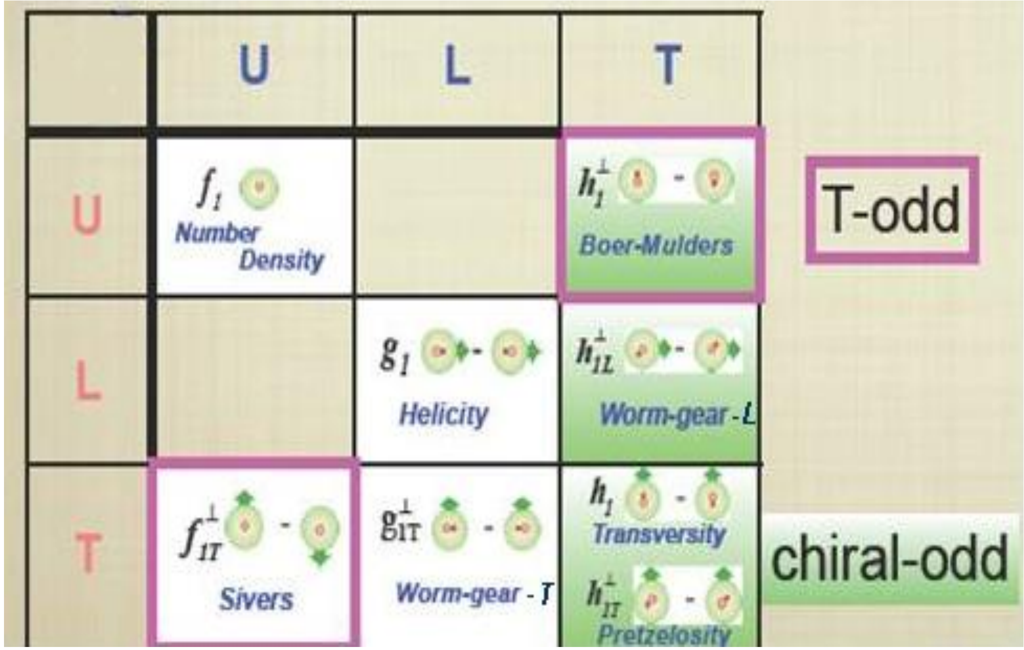
6. Time scale of the Project

7. Conclusion

Possible data taking scenario.

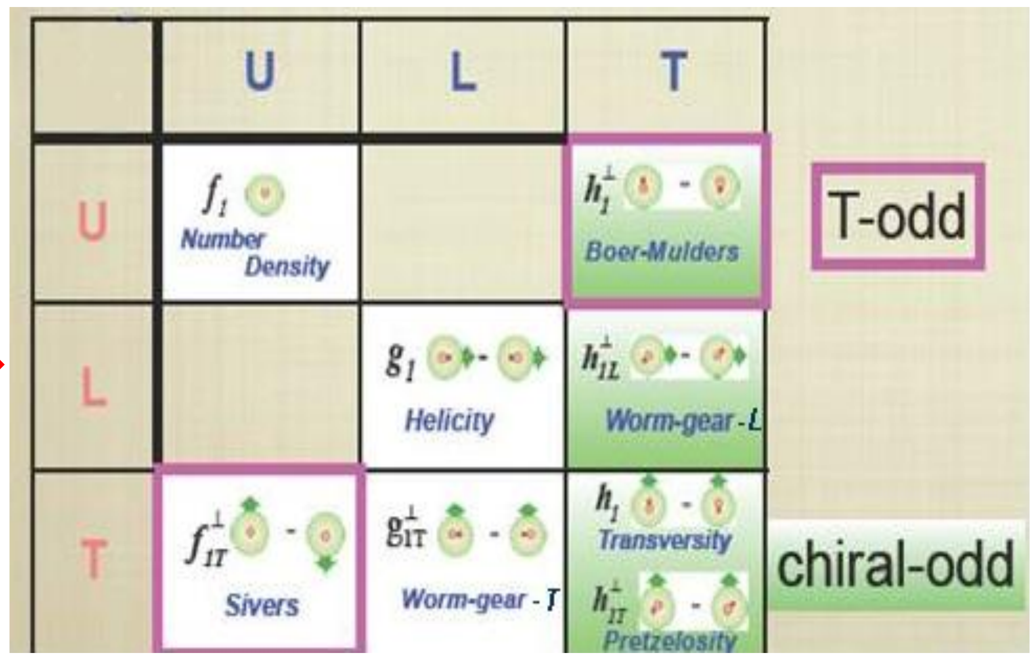
At the first step of the project it is reasonable to start measurements with non-polarized protons (*pp*) and with non-polarized deuterons (*dd*), (*pd*). These data would provide a cross checks of our results with very precise world data on f_1 PDFs. At the same time new data on the Boer-Mulders PDF will be obtained.

First step →



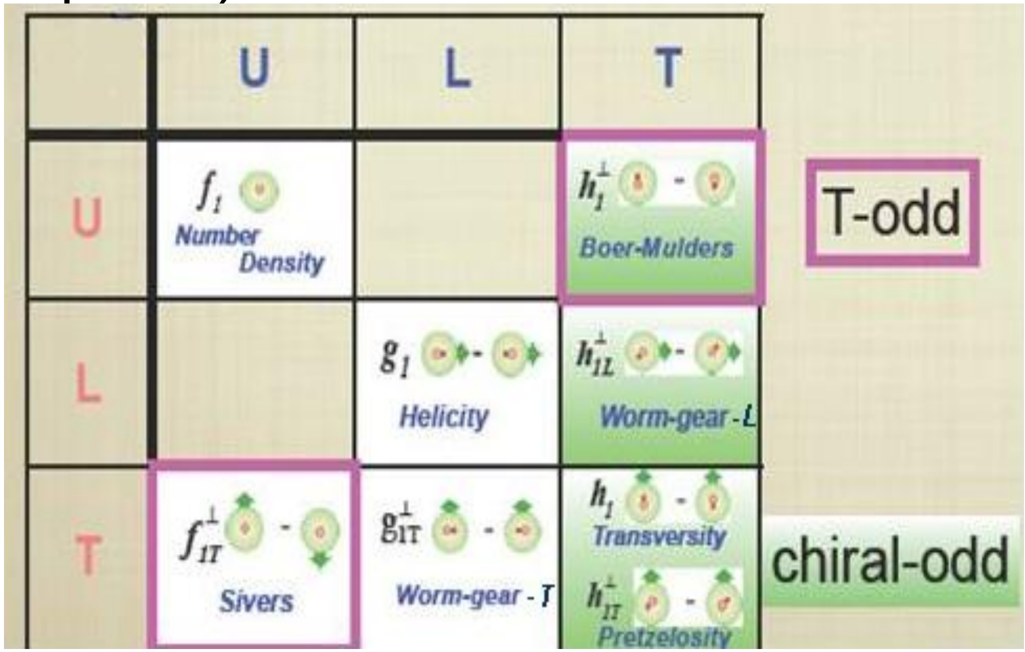
At the second step the measurements should be performed with longitudinally polarized protons and deuterons in *pp*, *pd* and *dd* collisions with the beam polarizations *UL*, *LU*, *LL* to obtain asymmetries A_{LU}, A_{UL} and A_{LL} (Eqs.2.1.10) in each case. These data will be cross checked by existing data on g_1 PDF and provide new information on the Worm-gear-L PDF in proton and neutron (*u* & *d* quarks).

Second step →



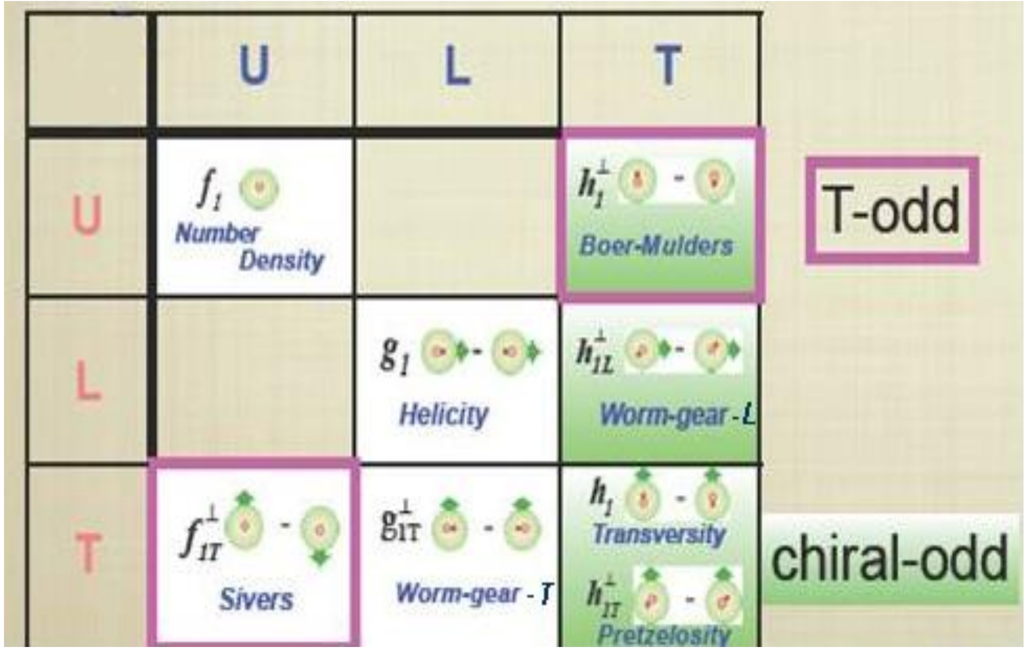
At the third step (the most important) measurements should be performed with transverse beam polarization in *pp*, *pd* and *dd* collisions (*UT*, *TU* and *TT*) to obtain asymmetries A_{UT}, A_{TU} and A_{TT} in each case. These data will be cross checked by existing data on Transversity PDF and provide new information on the Sivers, Worm-gear-T and Pretzelosity PDFs in proton and neutron (*u* & *d* quarks).

Third step →



Finally, at the fourth step (the most difficult) measurements should be performed with *pp*, *pd* and *dd* beams when one beam polarized longitudinally while other – transversally in order to measure asymmetries A_{LT} and A_{TL} in each case. These data will provide new information and cross checks of our results on Transversity, Worm-gear-L, Pretzelosity and Worm-gear-T PDFs

The fourth step [



List of LoI participants (124) still is open for interested people

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+

Expressed of Interest:
INFN Italy (Torino), Belorussia (Gomel States University), Moscow States University, St. Petersburg (Gatchina), ITEP Moscow

NICA-SPD vs Others

An advantage of NICA is the beams

Experiment	CERN, COMPASS-II	FAIR, PANDA	FNAL, E-906	RHIC, STAR	RHIC-PHENIX	NICA, SPD
mode	*fixed target*	*fixed target*	*fixed target*	*collider*	*collider*	*collider*
Beam/target	*π- , p*	*anti-p, p*	*π- , p*	*pp*	*pp*	*pp, pd,dd*
Polarization:b/t	*0; 0.8*	*0; 0*	*0; 0*	*0.5*	*0.5*	*0.9*
Luminosity	$2\cdot10^{33}$	$2\cdot10^{32}$	$3.5\cdot10^{35}$	$5\cdot10^{32}$	$5\cdot10^{32}$	10^{32}
√s , GeV	*14*	*6*	*16*	*200, 500*	*200, 500*	*10-26*
$x_{1(beam)}$ *range*	*0.1-0.9*	*0.1-0.6*	*0.1-0.5*	*0.03-1.0*	*0.03-1.0*	*0.1-0.8*
q_T, *GeV*	*0.5 -4.0*	*0.5 -1.5*	*0.5 -3.0*	*1.0 -10.0*	*1.0 -10.0*	*0.5 -6.0*
Lepton pairs,	*μ-μ+*	*μ-μ+*	*μ-μ+*	*μ-μ+*	*μ-μ+*	*μ-μ+, e+e-*
Data taking	*2015*, 2018	*>2020*	*2014-2017*	*>2018*	*>2021*	*>2021*
Transversity	YES	NO	NO	YES	YES	YES
Boer-Mulders	YES	YES	YES	YES	YES	YES
Sivers	YES	YES	YES	YES	YES	YES
Pretzelosity	YES (?)	NO	NO	NO	YES	YES
Worm Gear	YES (?)	NO	NO	NO	NO	YES
J/Ψ	YES	YES	NO	NO	NO	YES
Flavour separ	NO	NO	YES	NO	NO	YES
Direct γ	NO	NO	NO	YES	YES	YES