Spin Physics Experiments @ NICA-SPD with polarized proton and deuteron beams.

Letter of Intent.

**I.Savin, on behalf of the Drafting Committee*), talk at
EU-Russia-JINR @ Dubna Round Table, Dubna, 3-5 March 2014.**

CONTENT

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Nec sine te, nec tecum vivere possum. (Ovid)*

Spin Physics Experiments at NICA-SPD with polarized proton and deuteron beams.

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1. **Introduction.**

   1.1. Basic PDFs of nucleons.

   1.2. DIS as a microscope for nucleons. The PDF f_1 and g_1.

   1.3. New TMD PDFs.

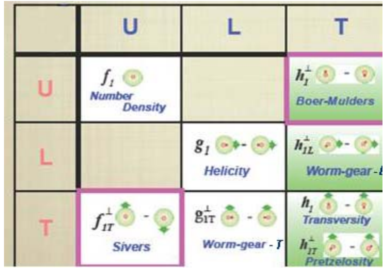
   1.4. Other actual problems of high energy physics.

INTRODUCTION. 1.1. Basic twist-2 PDFs of the nucleons (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



Twist-2 PDFs of nucleons :

f_1 - ***density*** of partons in non-polarized nucleon, *(x, Q^2)*;

g_1 - ***helicity*** **,** longitudinal polarization of quarks in longitudinally polarized nucleon;

h_1 - ***transversity,*** transverse polarization of quarks in transversely polarized nucleon ;

$f^\perp_{1T}$ - ***Sivers,*** correlation between the transverse polarization of nucleon (transverse spin) and the transverse momentum of non-polarized quar

$g^\perp_{1T}$ - ***worm-gear-T,*** correlation between the transverse spin and the longitudinal quark polarization ;

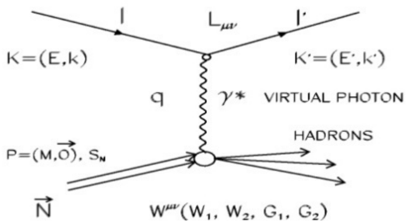
$h^\perp_1$ - ***Boer-Mulders,*** distribution of the quark transverse momentum in the non-polarized nucleon ;

$h^\perp_{1L}$ - ***worm-gear-L,*** correlation between the longitudinal polarization of the nucleon (longitudinal spin) and the transverse momentum of quarks ;

$h^\perp_{1T}$ - ***pretzelosity,*** distribution of the transverse momentum of quarks in the transversely polarized nucleon ;

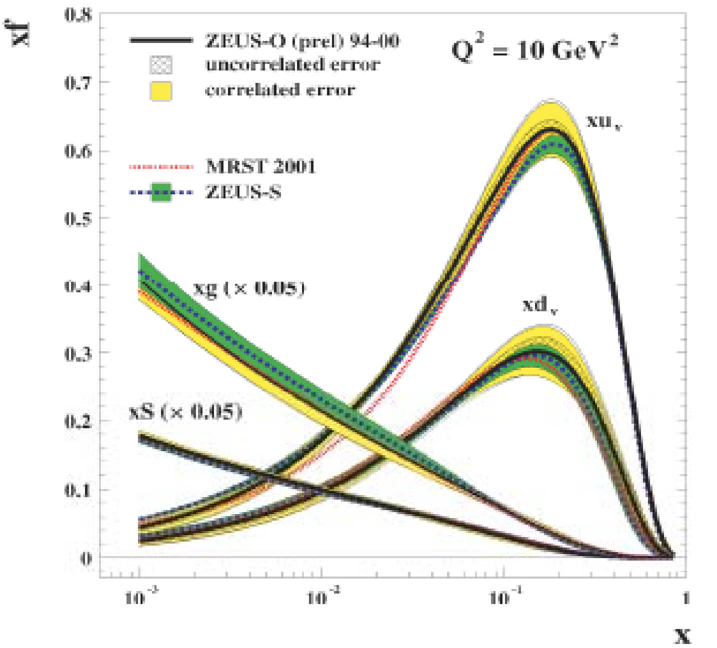
Introduction. 1.2. PDFs f_1 and g_1

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



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

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

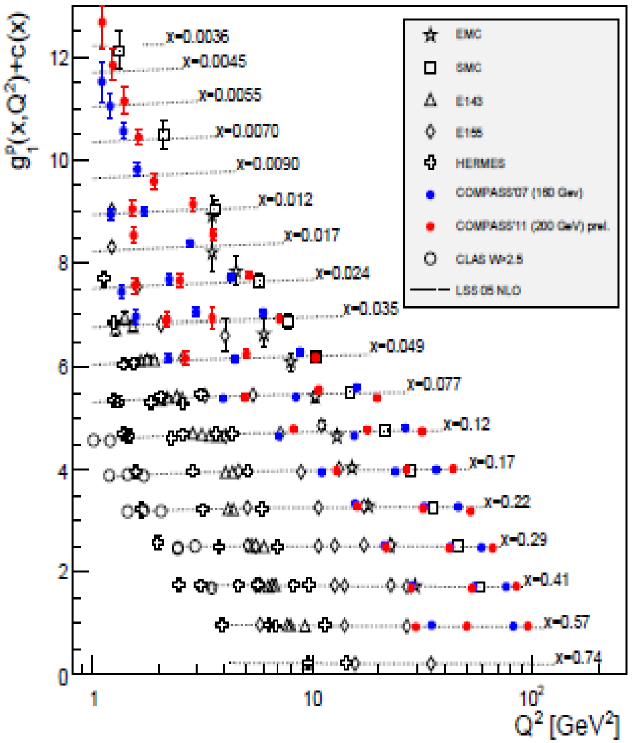


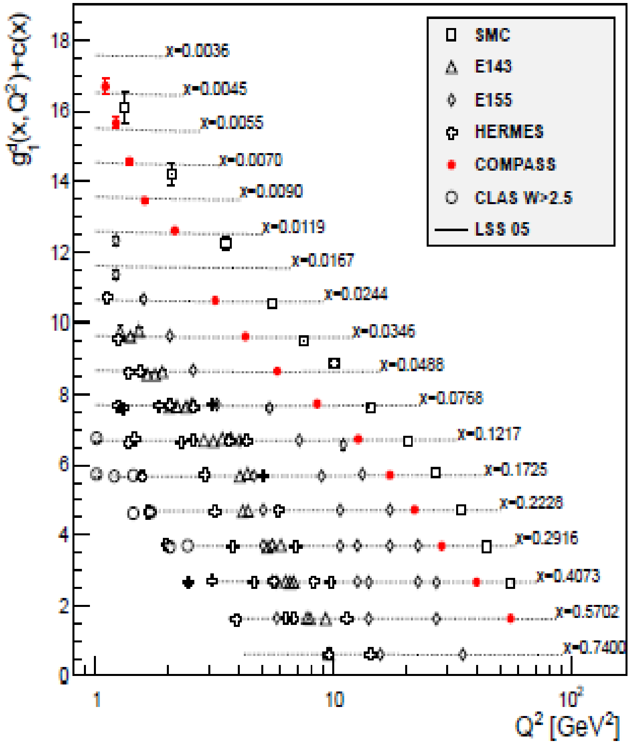
$R(x,Q2)$ and $F_2(x,Q^2)$ have been measured by the collaborations SLAC, EMC, BCDMS, NMC, ZEUS, H_1 and others.

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





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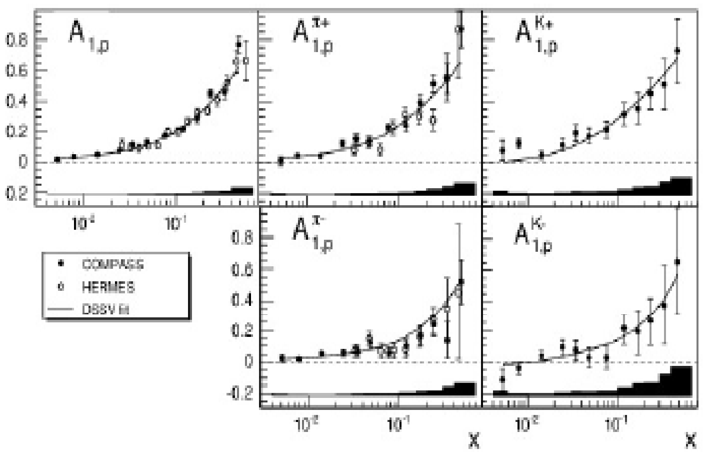
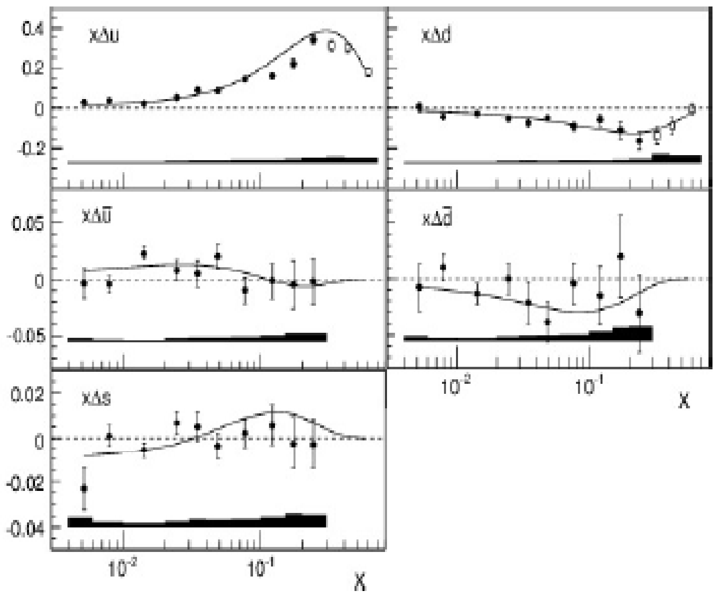
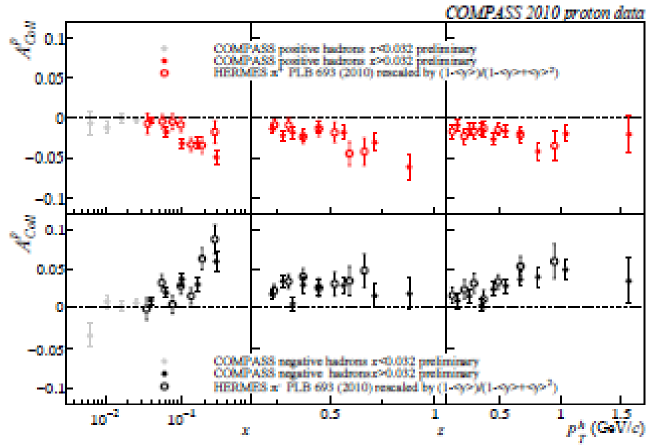
DSSV, Phys. Rev. D **80** (2009) 034030

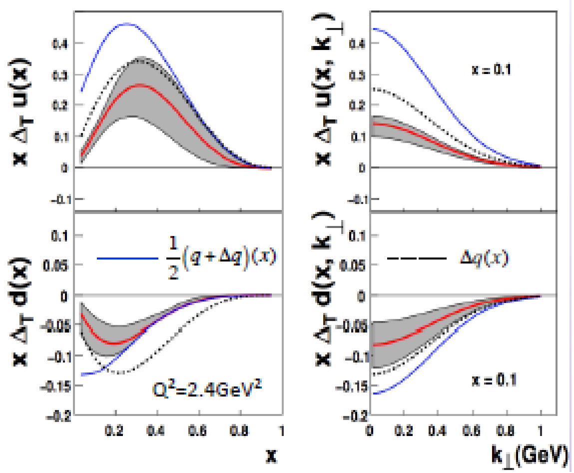




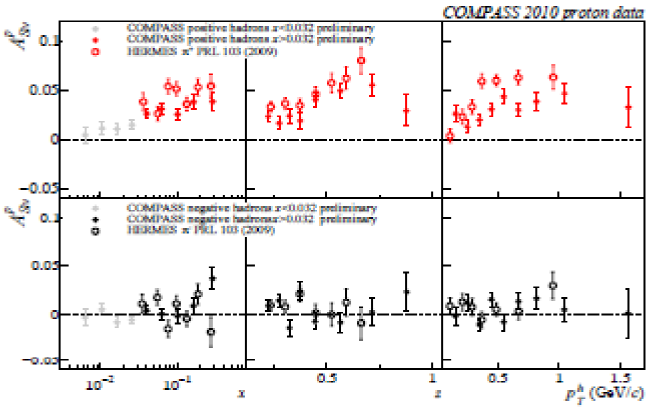
INTRODUCTION. 1.3. TMD PDFs

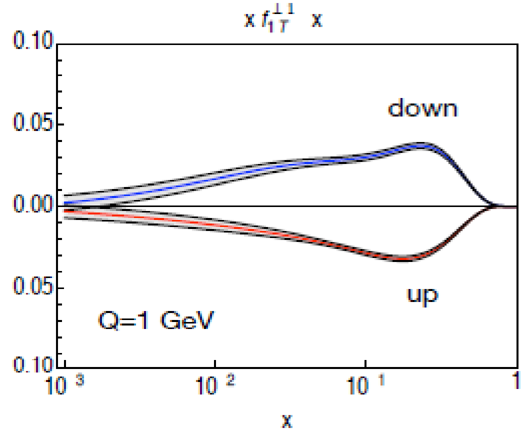
Transversity PDF h_1





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





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

2. Physics motivations

2.1. Nucleon spin structure studies using the Drell-Yan mechanism. (AE)

2.2. New nucleon PDFs and *J/Ψ* production mechanisms. (OSh)

2.3. Direct photons. (AG)

2.4. Spin-dependent high-p_T reactions. (SSh)

2.5. Spin-dependent effects in elastic *pp* and *dd* scattering. (OT)

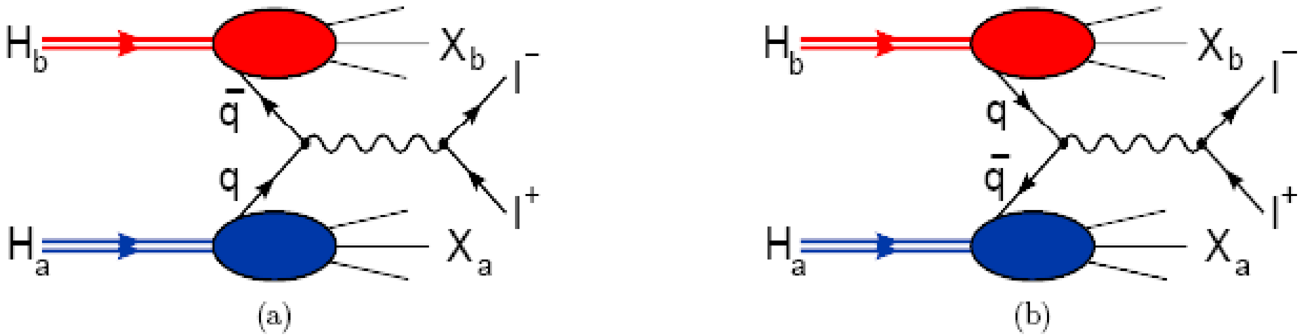
2.6. Spin-dependent reactions in heavy ion collisions. (OT)

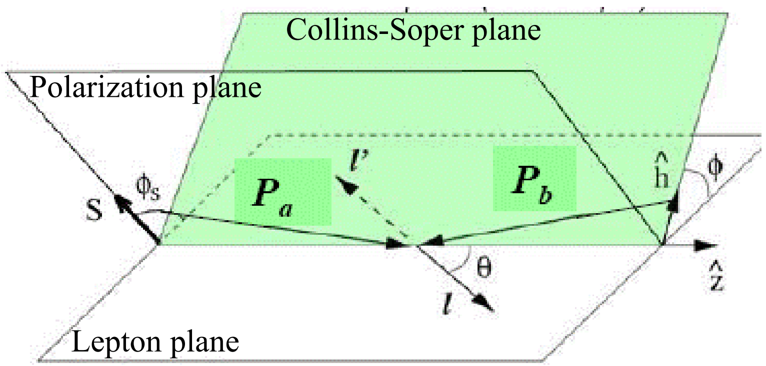
2.7. Future experiments on nucleon structure in the world. (AN)

Physics motivations.

2.1. Nucleon structure studies using the Drell-Yan mechanism.

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





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

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

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

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

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

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

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

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

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

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

$F_j^{\,i}$ 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.

The Eq. (2.1.2) includes 24 leading twist SFs. Each of them is expressed through a weighted convolution, C, of corresponding leading twist TMD PDF in the transverse momentum space,

$$C\left[w(\vec{k}_{aT},\vec{k}_{bT})f_1\bar{f}_2\right] \equiv \frac{1}{N_c}\sum_q e_q^2 \int d^2\vec{k}_{aT} d^2\vec{k}_{bT} \delta^2(\vec{q}_T - \vec{k}_{aT} - \vec{k}_{bT}) w(\vec{k}_{aT},\vec{k}_{bT}) \times$$
$$\left[f_{1q}(x_a,\vec{k}_{aT}^2)\bar{f}_{2q}(x_b,\vec{k}_{bT}^2) + \bar{f}_{1q}(x_a,\vec{k}_{aT}^2) f_{2q}(x_b,\vec{k}_{bT}^2)\right],$$

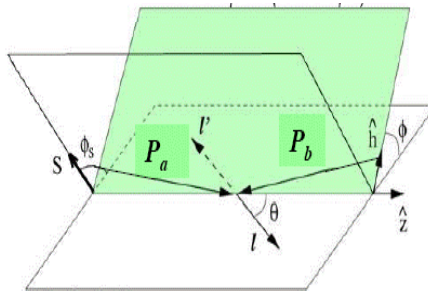
where k_{aT} (k_{bT}) is the transverse momentum of quark in the hadron H_a (H_b) and f_1 (f_2) is a TMD PDF of the corresponding hadron.

Expressions for all leading twist SFs of **quarks** and **antiquarks** entering Eq. (2.1.2) are given in the text of LoI. F.e. in unpolarized case:

$$F_{UU}^1 = C\left[f_1\bar{f}_1\right], \quad F_{UU}^{\cos 2\phi} = C\left[\frac{2(\vec{h}\cdot\vec{k}_{aT})(\vec{h}\cdot\vec{k}_{bT}) - \vec{k}_{aT}\cdot\vec{k}_{bT}}{M_a M_b} h_1^{\perp}\bar{h}_1^{\perp}\right],$$

where $\boldsymbol{h^{\perp}{}_1}$ is the Boer-Mulders PDF for quarks & anti-quarks.

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



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

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

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

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

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

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

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

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

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

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

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

In above expressions: cross section σ^{pq} with superscripts:
horizontal arrows - for positive (negative) longitudinal beam polarizations,
vertical arrows - for transversal beam polarization ,
0 - for the non-polarized hadrons .

$$D = \sin^2\theta / (1+\cos^2\theta)$$

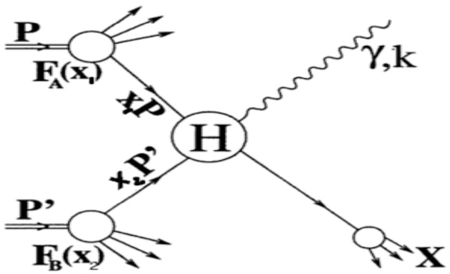
$A^i_{jk} = F^i_{jk} / F^1_{UU}$ --amplitude of SF modulation

Applying the Fourier analysis to the measured asymmetries, one can separate each of all ratios $A^i_{jk} = F^i_{jk} / F^1_{UU}$ entering Eq. 2.1.10.

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.

Physics motivations. 2.3. Direct photons.

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

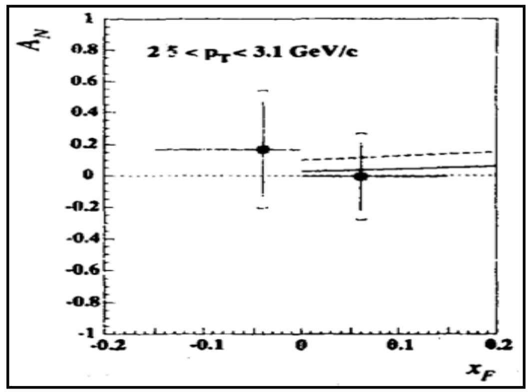


Vertex H corresponds to
q + qbar →γ+g   or   g+q→γ+q hard processes.

One can show that the polarized gluon distribution (Sivers gluon function) can be extracted from measurement of the transverse single spin asymmetry $A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$ of order few %.

Via double spin asymmetry A_{LL} one can measure a gluon polarization in the nucleon:

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



3. Requirements to the NUCLOTRON-NICA complex. (IS)

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

$pp, pd, dd, pp\uparrow, pd\uparrow, p\uparrow p\uparrow, p\uparrow d\uparrow, d\uparrow d\uparrow.$

Beam polarizations both at MPD and SPD: longitudinal and transversal. Absolute values of polarizations should be ≥ 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* (spin flipping for every bunch or group of bunches should be considered).

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

$d\uparrow d\uparrow(\sqrt{s_{NN}}) = 4 \div \geq 13.8$ GeV ($2 \div \geq 5.9$ 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).

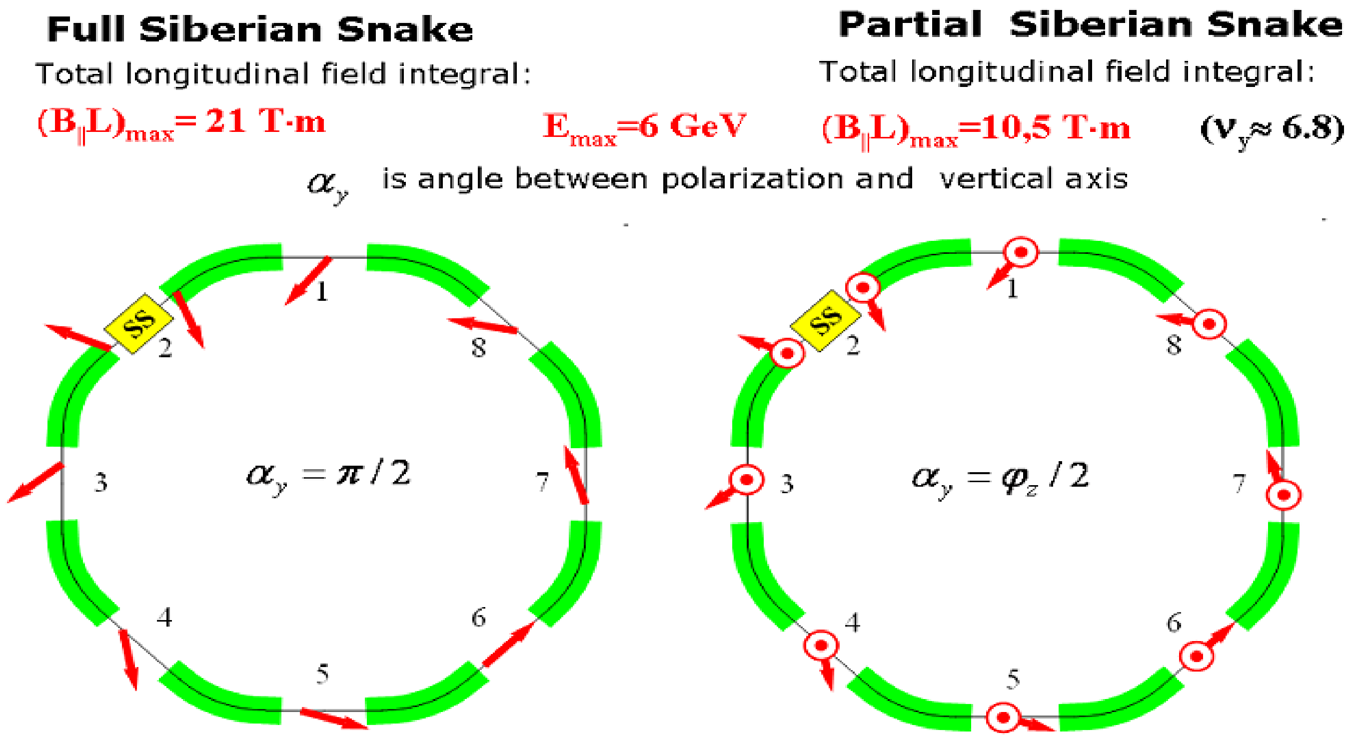
4. Polarized beams at NICA. (TO BE UPDATED)

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

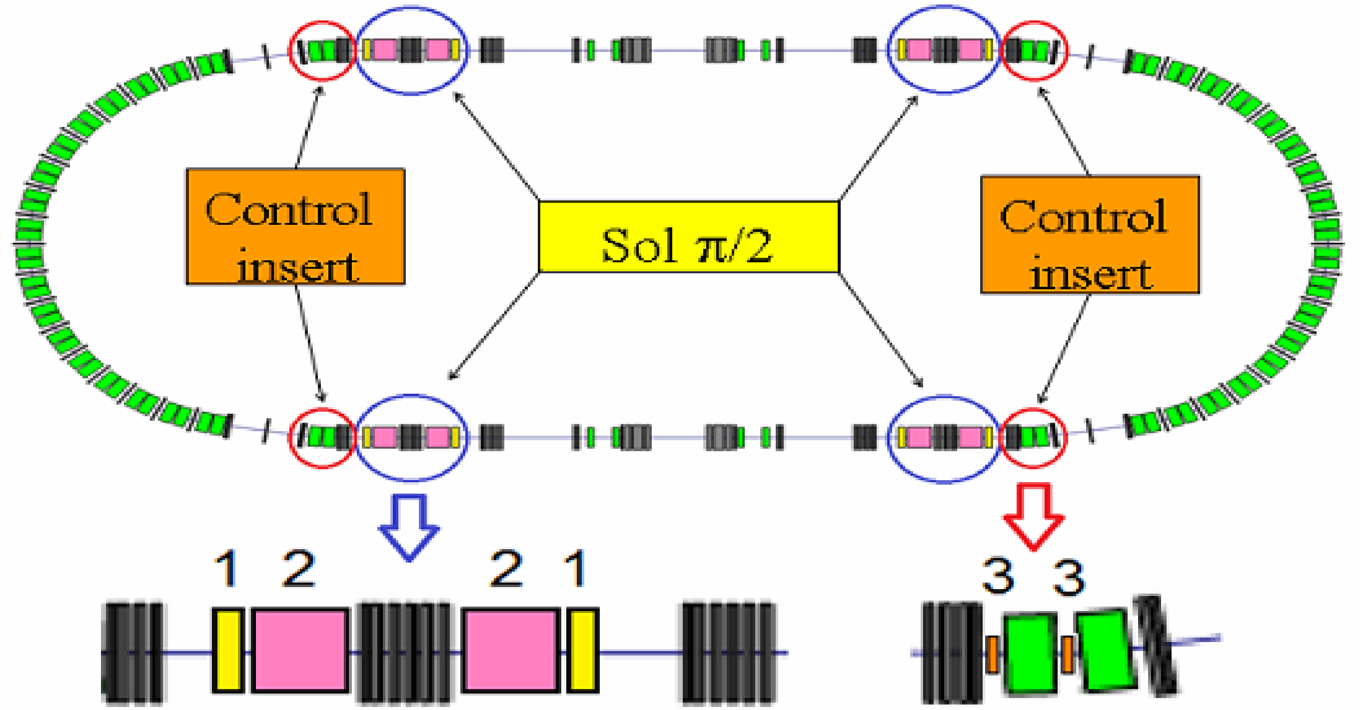
The first phase, realizing now, includes construction of facilities for heavy ion physics program .

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

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

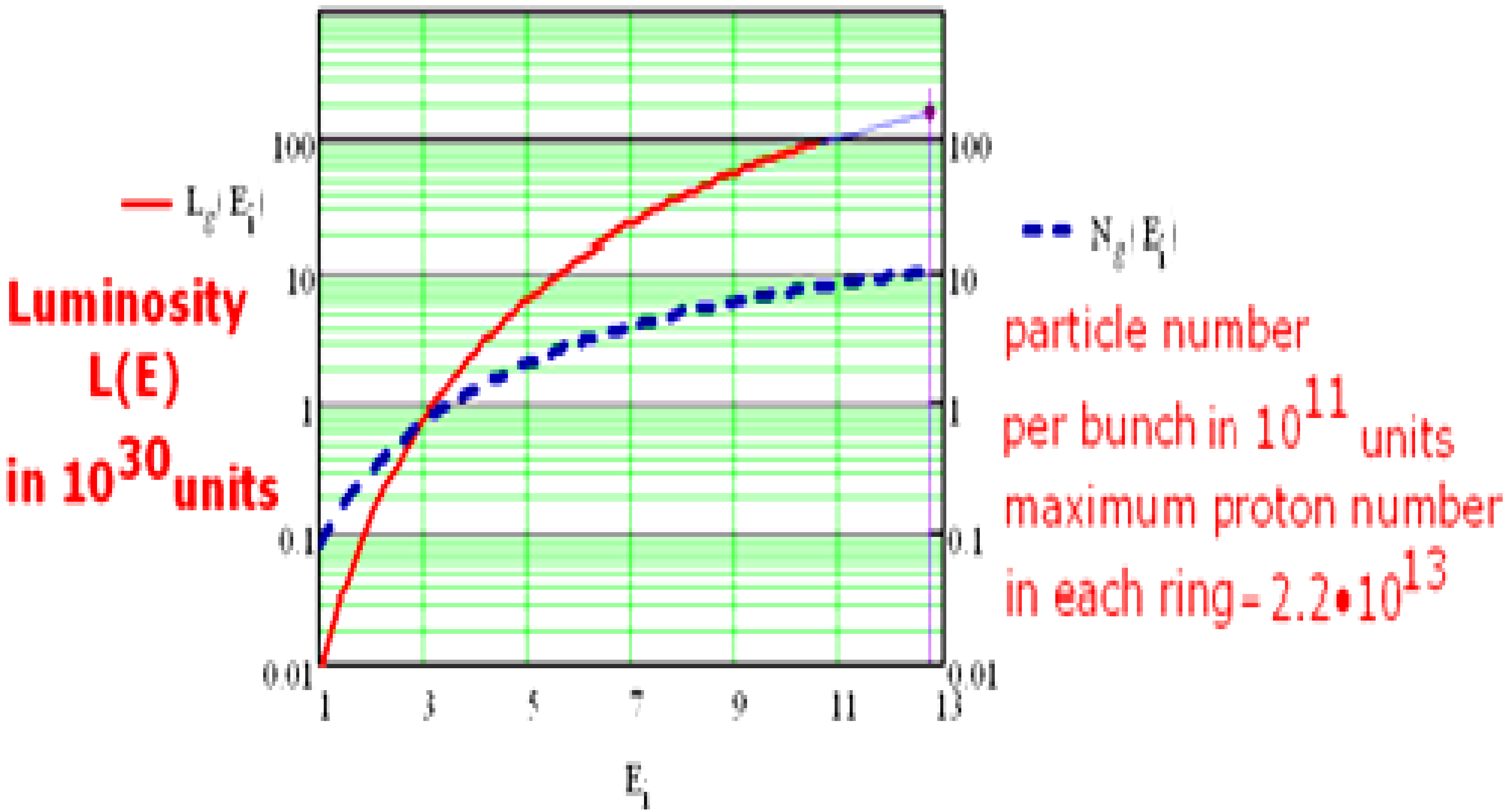


Polarized deuterons acceleration in Nuclotron is possible up to the energy of 5.6 GeV/u



	Type of solenoid	B_{max}	L, m	BL, T·m
1	Pulse	±4	1.25	-5÷5
2	Stationary	9	4	0÷36
3	Weak pulse	±0.5	0.5	-0.25÷0.25

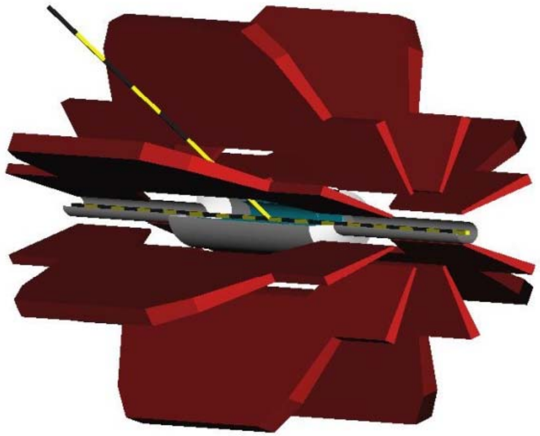
Feasible schemes of manipulations with polarized protons and deuterons at Nuclotron and NICA are suggested. The final scheme will be approved at the later stages of the project.

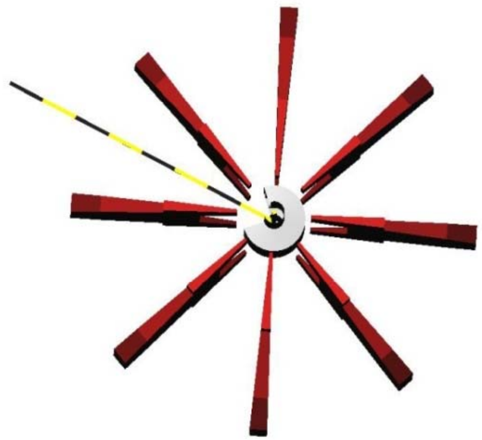


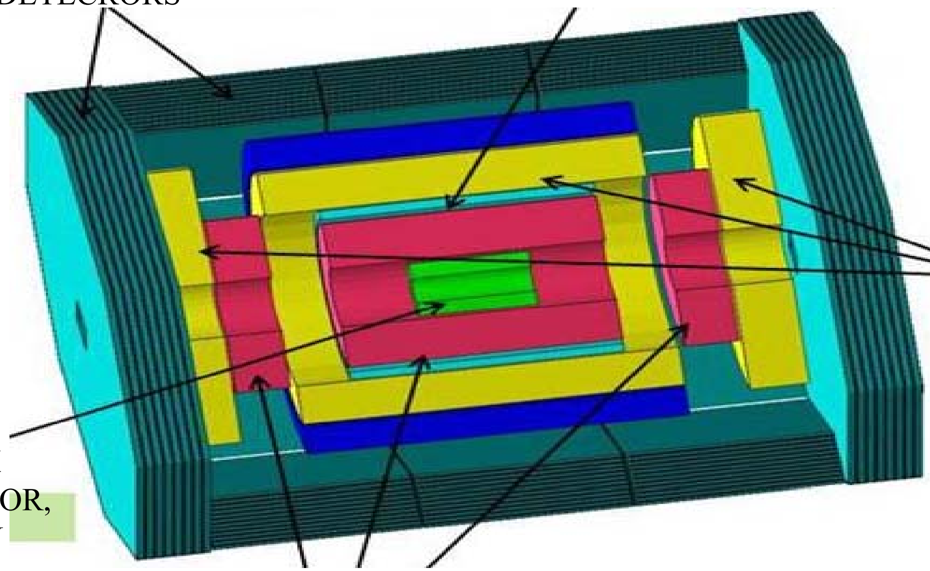
The number of particles reaches a value about $2.2 \cdot 10^{13}$ in each ring and the peak luminosity $L_{peack} = 2 \cdot 10^{32}$ $cm^{-2}s^{-1}$ at 12.7 GeV.

5. Requirements to the spin physics detector (SPD). (AN, IS)

5.1. Event topologies.
5.2. Possible layout of SPD.
5.3. Trigger system.
5.4. Local polarimeters and luminosity monitors.
5.5. Engineering infrastructure.
5.6. DAQ.
5.7. SPD reconstruction software.
5.8. Monte Carlo simulations.
5.9. Slow control.
5.10. Data accumulation, storing and distribution.

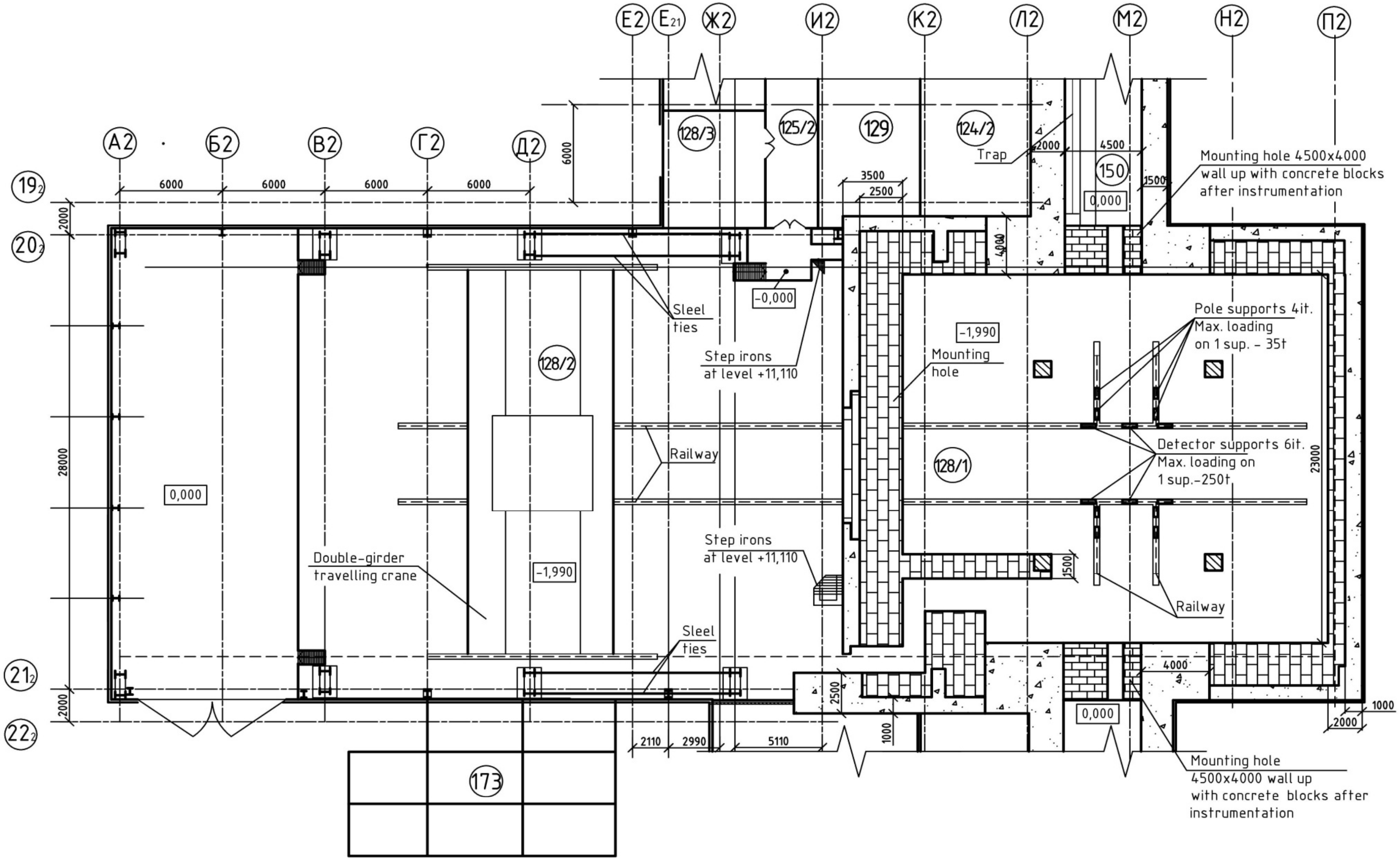






The “almost 4π geometry” requested by DY and direct photons can be realized in the solenoid version of SPD if it has overall length and diameter of about 6 m.

SPD experimental area



6. Proposed measurements with SPD.

6.1. Estimations of *DY* and *J/Ψ* production rates. (AN, OSh)
6.2. Estimations of direct photon production rates. (AG)

6.3. Rates in high-p_T reactions. (SSh)
6.4. Rates in elastic *pp* and *dd* scattering.
6.5. Feasibility of the spin-dependent reaction studies in heavy ion collisions.

We propose to perform measurements of asymmetries of the DY pairs production in collisions of polarized protons and deuterons (Eqs.2.1.0) which provide an access to all collinear and TMD PDFs of quarks and anti-quarks in nucleons.

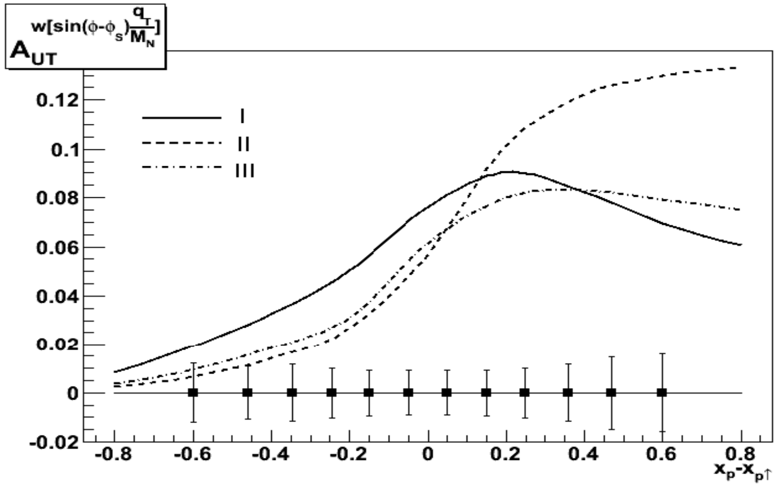
The measurements of asymmetries in production of J/Ψ and direct photons will be performed simultaneously with DY using dedicated triggers.

The set of these measurements will supply complete information for tests of the quark-parton model of nucleons at the twist-two level with minimal systematic errors.

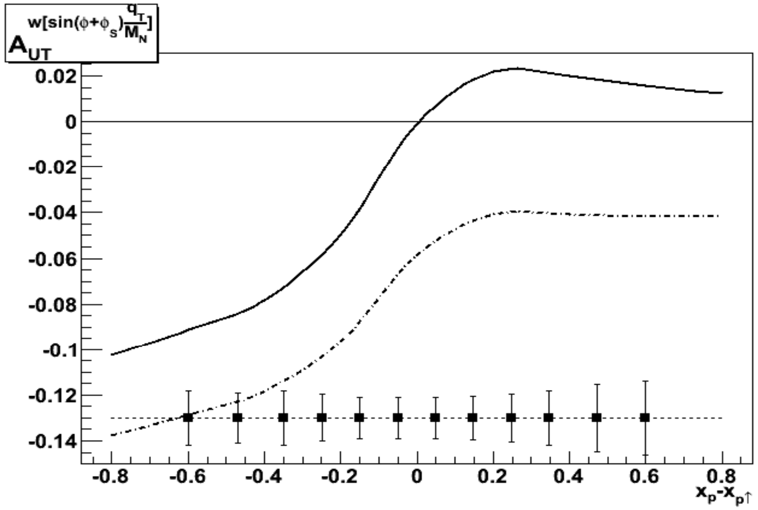
6.1. Estimations of *DY* production rates

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.

Sivers



Boer-Mulders



6.2. 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

7. Time lines of the Project

The participants of the LoI are planning to submit the document for discussions at the JINR and outside during the year 2014.

If it will be approved at JINR by the end of 2014, the corresponding Proposal could be prepared by the end of 2015.

CONCLUSIONS

1. The comprehensive program of the nucleon structure study is suggested. It can be realized at NICA using the polarized proton and deuteron beams.The text of LoI is almost complete.

2. It will be updated and finalized after the presentations at seminars and NTS.

3. Presentation of LoI at the JINR PAC on particle physics is planned for 24-25 June 2014.

4. The list of participants is open for interested people.

5. The draft of LoI is available on request.

Back up slides

Twist-2 PDFs of nucleons :

f_1 - ***density*** of partons in non-polarized (U) nucleon, *(x, Q²)*;

g_1 - ***helicity*** **,** longitudinal polarization of quarks in longitudinally polarized (L) nucleon;

h_1 - ***transversity*****,** transverse polarization of quarks in transversely polarized (T) nucleon ;

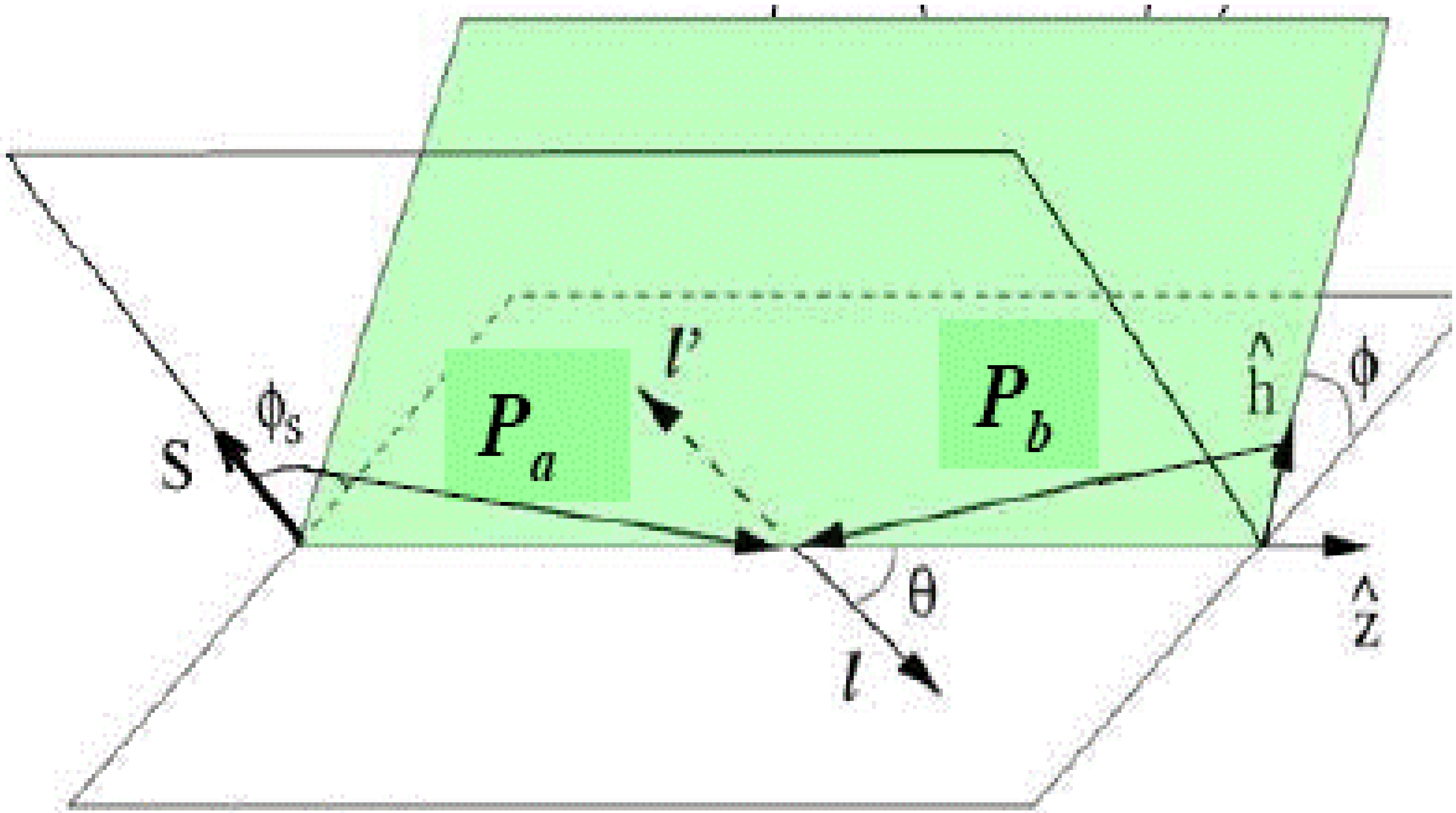
$f^{\perp}_{1T}$ - ***Sivers*** **,** correlation between the transverse polarization of nucleon (transverse spin) and the transverse momentum of non-polarized quar

$g^{\perp}_{1T}$ - ***worm-gear-T*** **,**correlation between the transverse spin and the longitudinal quark polarization ;

$h^{\perp}_{1}$ - ***Boer-Mulders*** **,** distribution of the quark transverse momentum in the non-polarized nucleon ;

$h^{\perp}_{1L}$ - ***worm-gear-L*** **,** correlation between the longitudinal polarization of the nucleon (longitudinal spin) and the transverse momentum of quarks ;

$h^{\perp}_{1T}$ - ***pretzelosity*** **,**distribution of the transverse momentum of quarks in the transversely polarized nucleon ;



ϕ_S
S
P_a
l'
P_b
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Introduction. 1.2. PDFs f_1 and g_1

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Measured from σ^{pol} separated off σ^{tot} in so-called *asymmetries.*

g_1 The cross sections difference, $\Delta\sigma_{//}$, for two opposite longitudinal target polarizations is given by the expression:

$$\Delta\sigma_{//} \equiv \Delta\left(\frac{d^2\sigma_{//}^{pol}}{dxdQ^2}\right) = \frac{16\pi\alpha^2 y}{Q^4}\left[\left(1-\frac{y}{2}-\frac{y^2\gamma^2}{4}\right)g_1 - \frac{y\gamma^2}{2}g_2\right],$$

connected with the longitudinal asymmetry, $A_{//}$, defined as

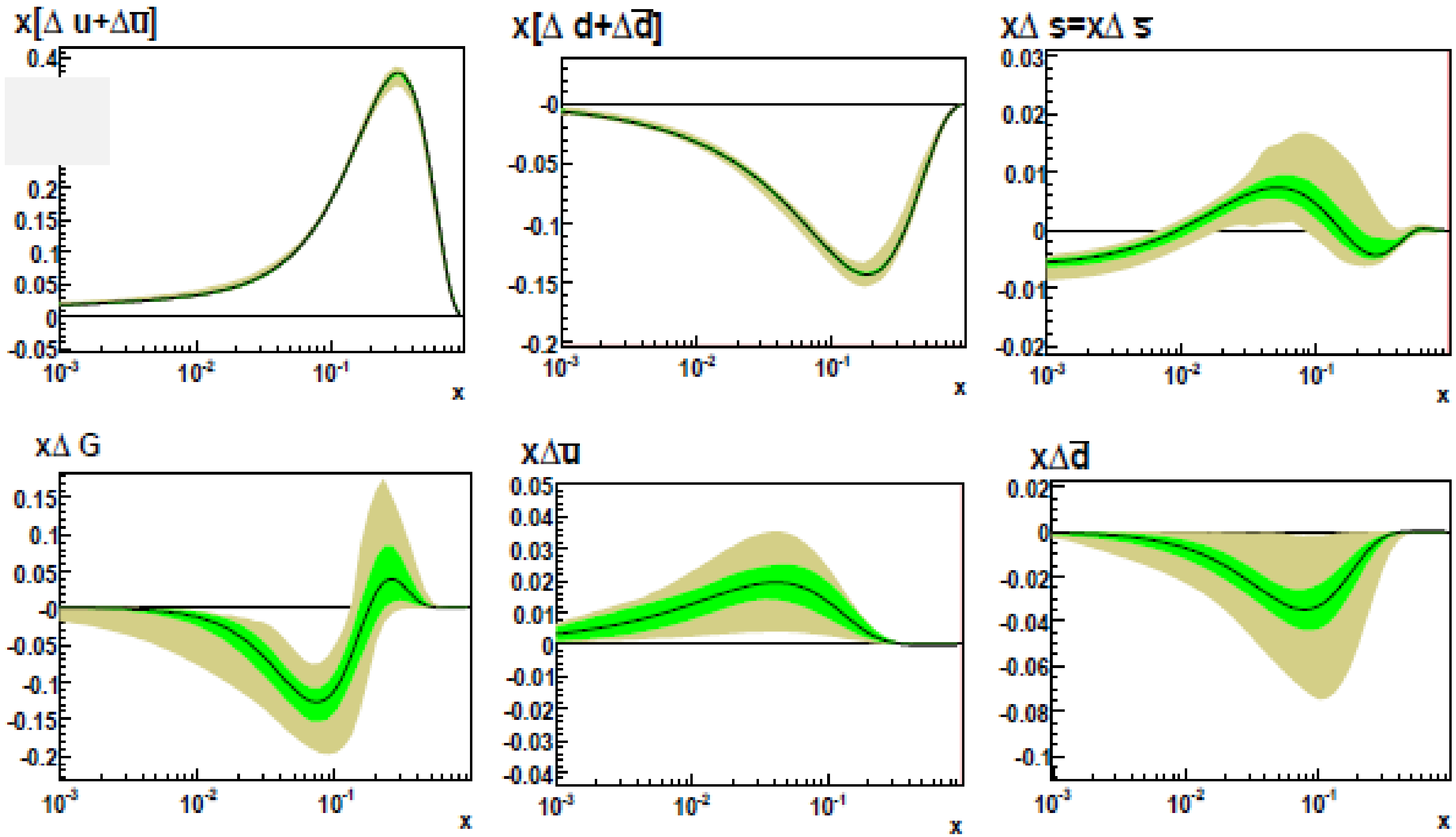
$$A_{//} = \frac{\Delta\sigma_{//}}{2\sigma^{unp}} = \frac{\sigma^{\rightarrow\Rightarrow} - \sigma^{\rightarrow\Leftarrow}}{\sigma^{\rightarrow\Leftarrow} + \sigma^{\rightarrow\Rightarrow}}$$

which, in the first approximation, related to g_1:

$$A_{//}/D \approx A_1 \approx (g_1 - \gamma^2 g_2)/F_1 \approx g_1/F_1,$$

The QPM expression for virtual photon asymmetry A_1:

$$A_1^p = \frac{\sigma_{1/2}^p - \sigma_{3/2}^p}{\sigma_{1/2}^p + \sigma_{3/2}^p} = \frac{\sum e_i^2\left[q_i^{\uparrow}(x) - q_i^{\downarrow}(x)\right]}{\sum e_i^2\left[q_i^{\uparrow}(x) + q_i^{\downarrow}(x)\right]} \qquad g_1(x) = \sum_i e_i^2\left[q_i^{\uparrow}(x) - q_i^{\downarrow}(x)\right]$$



x[Δ u+Δū]
x[Δ d+Δd̄]
xΔ s=xΔ s̄
xΔ G
xΔū
xΔd̄
x

INTRODUCTION. 1.4. Other actual problems of high energy physics

2-SPIN PROTON-PROTON ELASTIC CROSS SECTIONS

12 GeV ZGS

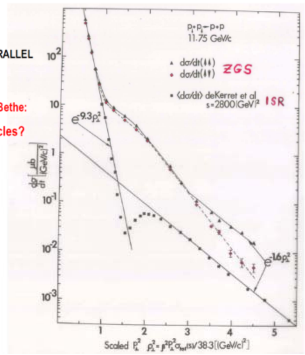
1977-1978

SPINS PARALLEL 4X SPINS ANTIPARALLEL

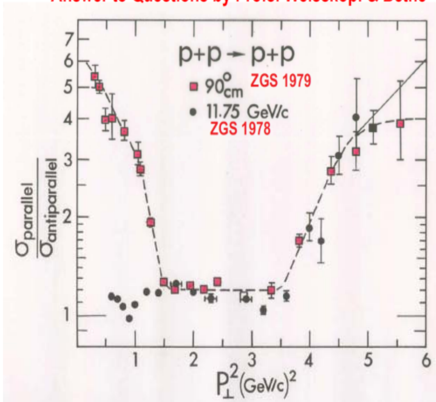
TOTALLY UNEXPECTED

Questions by Profs. Weisskopf & Bethe:

High P_t or 90°_{cm} Identical Particles?



Answer to Questions by Profs. Weisskopf & Bethe



AGS 1985-1990 A_n

PERTURBATIVE QCD ⇒

$A_n = 0$ at HIGH $P_\perp^2$ and HIGH ENERGY

$A_n \neq 0$ ⇒

PROBLEM with PQCD?

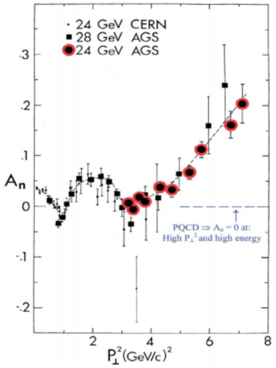
NO MODEL can EXPLAIN ALL

HIGH-$P_\perp^2$ SPIN EFFECTS (A_n & A_{nn})

GOAL

MEASURE A_n (and A_{nn})

up to $P_\perp^2$ = 12 (GeV/c)



INCLUSIVE HYPERON POLARIZATION

Devlin, Pondrum, Bunce, Heller *et al.* 1976-80

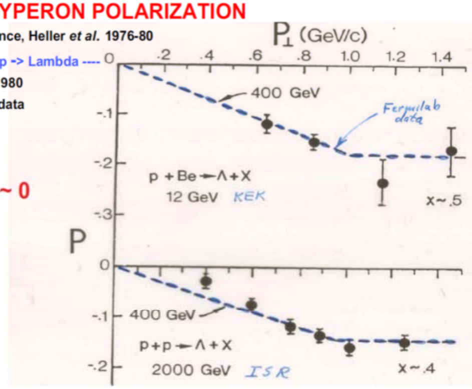
Fermilab 400 GeV p+p -> Lambda ----

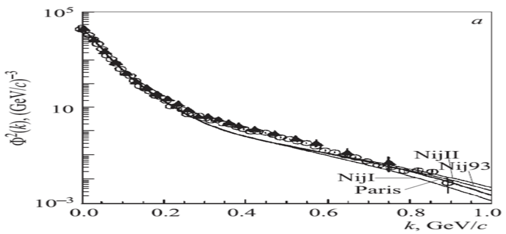
Plot by Heller ~1980

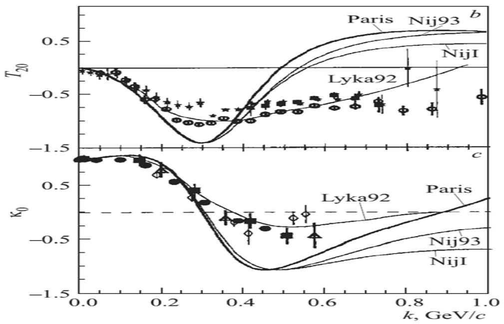
with KEK & ISR data

P ~ 15-20 %

QCD says P ~ 0





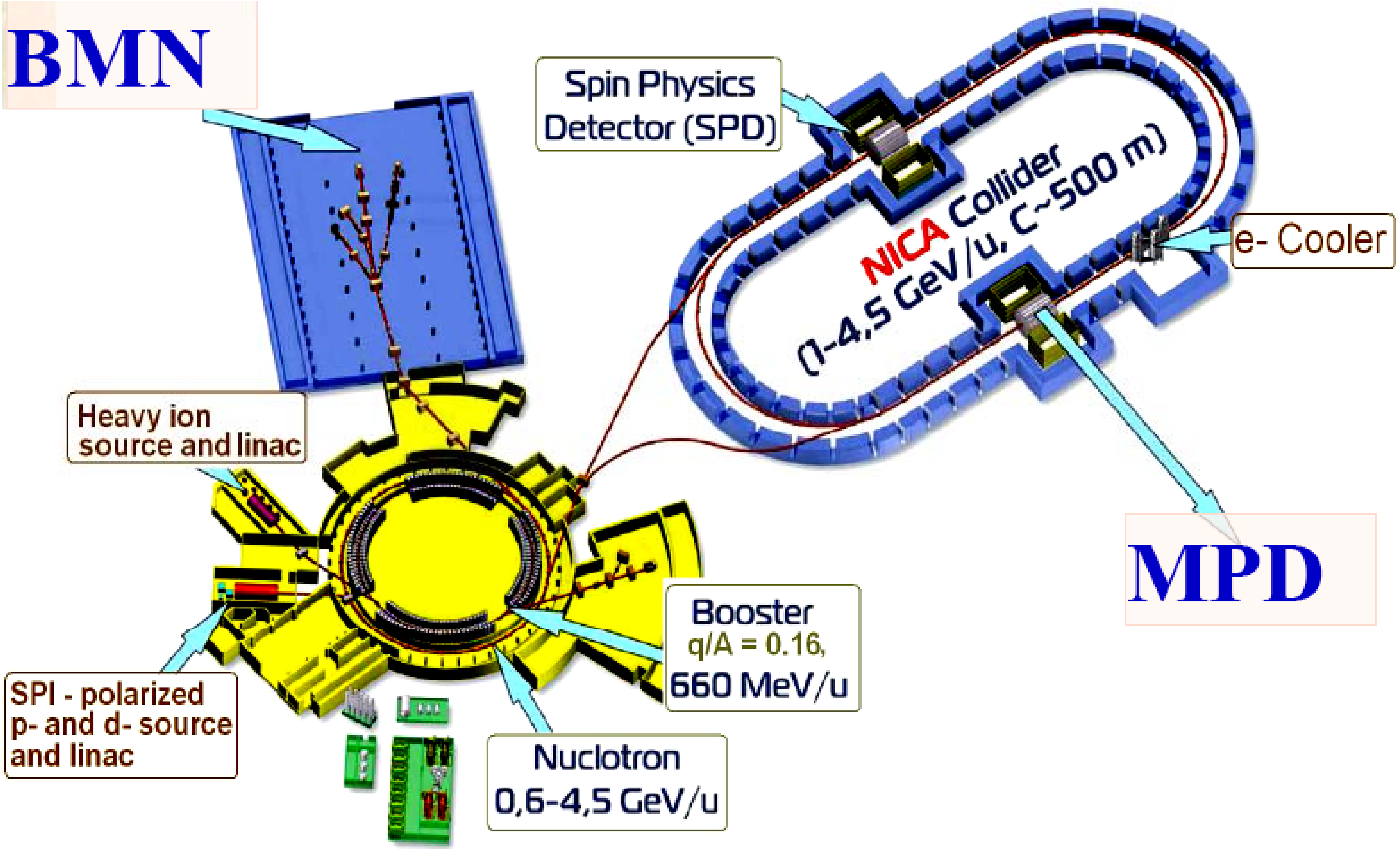


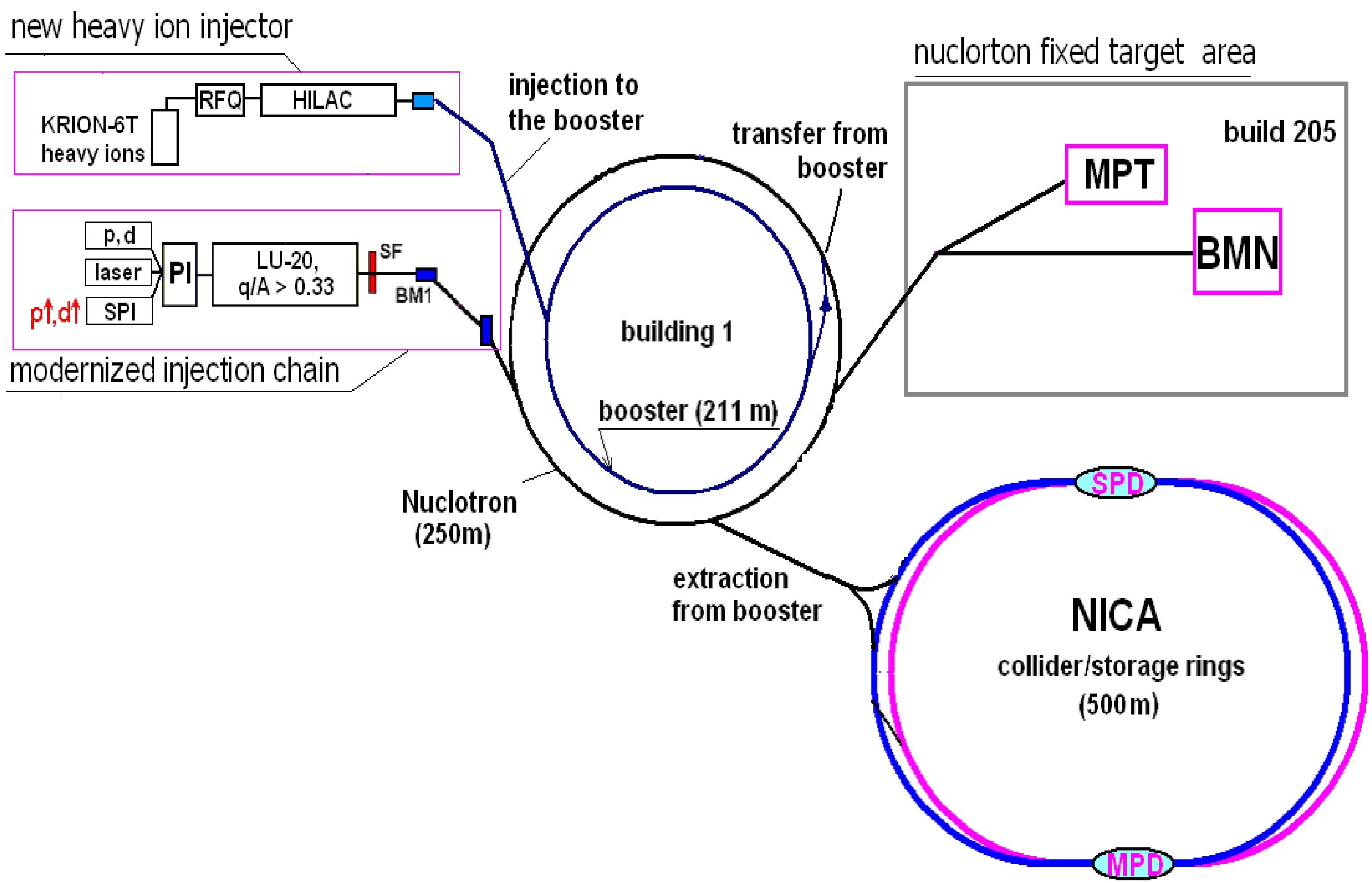
Infrastructure**.** The infrastructure of the Nuclotron-NICA complex should include:

- a source(s) of polarized (non-polarized) protons and deuterons,
- a system of polarization control and absolute measurements (3-5%),
- a system of luminosity control and absolute measurements,
- a system(s) of data distribution on polarization and luminosity to the experiments.

The infrastructure tasks should be subjects of the separate project(s).

Beams intersection area**.** The area of ± 3m along and across of the beams second intersection point, where the detector for the spin physics experiment will be situated, must be free of any collider elements and equipment. The beam pipe diameter in this region should be minimal, 10 cm or less, to guaranty the angular detector acceptance close to 4π. The walls of the beam pipe in the region ± 1m of the beams intersections should have a minimal thickness and made of the low-Z material (Be?).


BMN
Spin Physics
Detector (SPD)
NICA Collider
(1-4,5 GeV/u, C~500 m)
e- Cooler
MPD
Heavy ion
source and linac
Booster
q/A = 0.16,
660 MeV/u
SPI - polarized
p- and d- source
and linac
Nuclotron
0,6-4,5 GeV/u


new heavy ion injector
KRION-6T
heavy ions
RFQ
HILAC
injection to
the booster
transfer from
booster
nuclorton fixed target area
build 205
MPT
BMN
p,d
laser
SPI
pↂ,dↂ
PI
LU-20,
q/A > 0.33
SF
BM1
modernized injection chain
building 1
booster (211 m)
Nuclotron
(250m)
extraction
from booster
SPD
NICA
collider/storage rings
(500m)
MPD