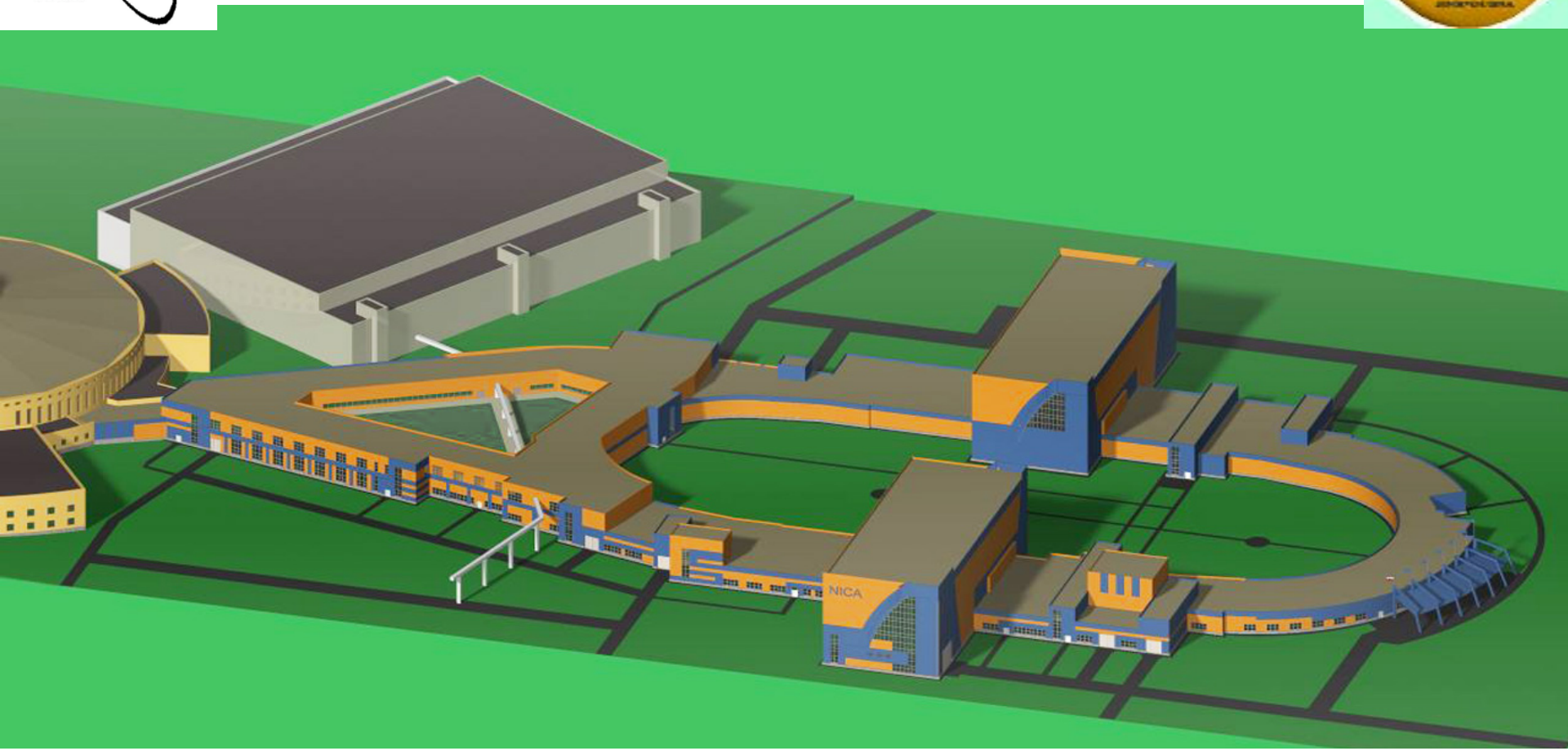
# Opportunities for Spin Physics at NICA

O.Kouznetsov and I.Savin
Veksler & Baldin Laboratory of High Energy Physics,
JINR, Dubna



# NICA ➔ Nuclotron-based Ion Collider fAcility

OUTLINE

- **Spin physics at Dubna: historical remarks**
- **NICA complex**
  - *new Source of Polarized Ions (SPI-project)*
  - *polarization control*
  - *beams parameters*
  - *intersection points and detectors*
- **Drell -Yan process as an example of the spin studies with SPD detector**
- **Conclusion**

# JINR in Spin Studies

***Started*** **in early 50-th from:**

**- experiments at Laboratory of Nuclear Problems with polarized beams and targets at Synchrocyclotron,**

**-pioneering Development of super-frozen polarized targets,**

**-experiments at Serpukhov 70 GeV proton Synchrotron,**

**-experiments at Synchrophasotron with movable polarized target and other fixed target experiments.**

***Continued*** **with JINR participation in**

**Nucleon Spin structure experiments:**

**SMC, COMPASS-I, COMPASS-II (SPS CERN),**

**HERMES (DESY),**

**STAR (BNL).**

***Accompanied*** **by theoretical developments (Lapidus, Ryndin, Kopeliovich, Efremov, Teryaev, Sidorov, Goloskokov…) and**

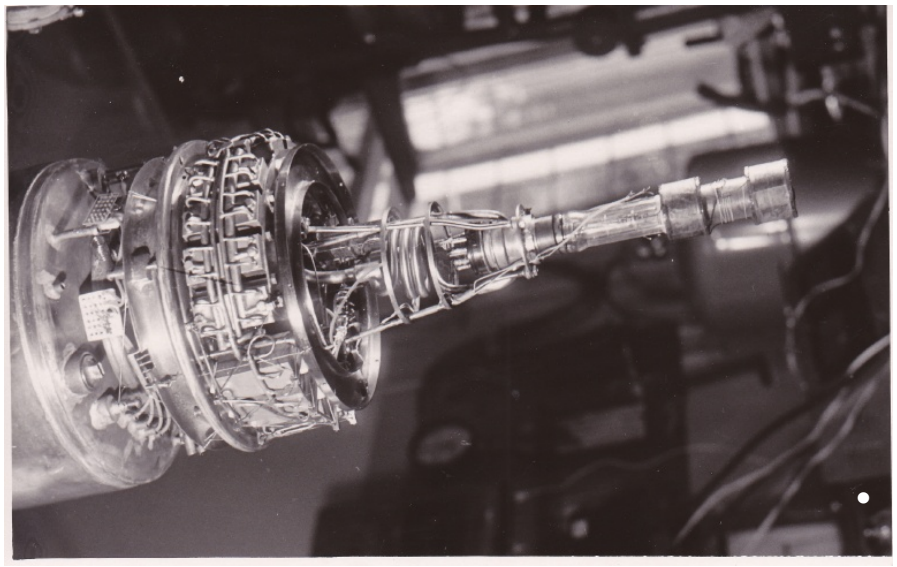
***Organization*** **of biannual International Spin Workshops DSPIN (1981-2013), SPIN2012 conference, DSPIN 2013: http://theor.jinr.ru/~spin/2013/**

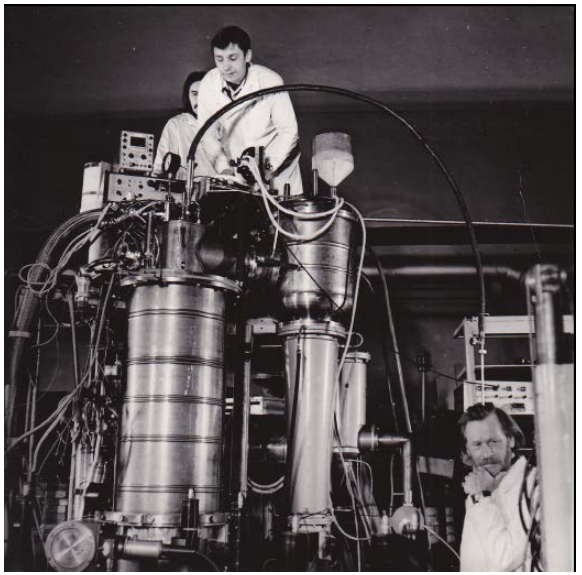
B.S.Neganov
1928-2012

# JINR in Spin Studies: polarized targets

**Pioneering development of frozen targets**
**by group of B.Neganov at Dubna in 1965**
**has reached the required super low temperature of ~20 mK.**
**Based on his idea of dilution of $He^3$ in $He^4$**
**(the dilution refrigerator)**

***B.Neganov, N.Borisov and M.Liburg, Sov.Phys. JETP23 (1966)959***





**The first frozen polarized target in the experiments at the Synchrocyclotron**

# Future spin physics facility at JINR.

**JINR *developing the new accelerator facility* "NICA Complex"**

***providing intensive beams of relativistic ions up to Au with max energy up to*** $\sqrt{S_{NN}}$ ***= 11 GeV (*** $Au^{79+}$***) and polarized protons and deuterons .***

**Main targets of "NICA Complex" studies:**

***- hot and dense baryonic matter,***

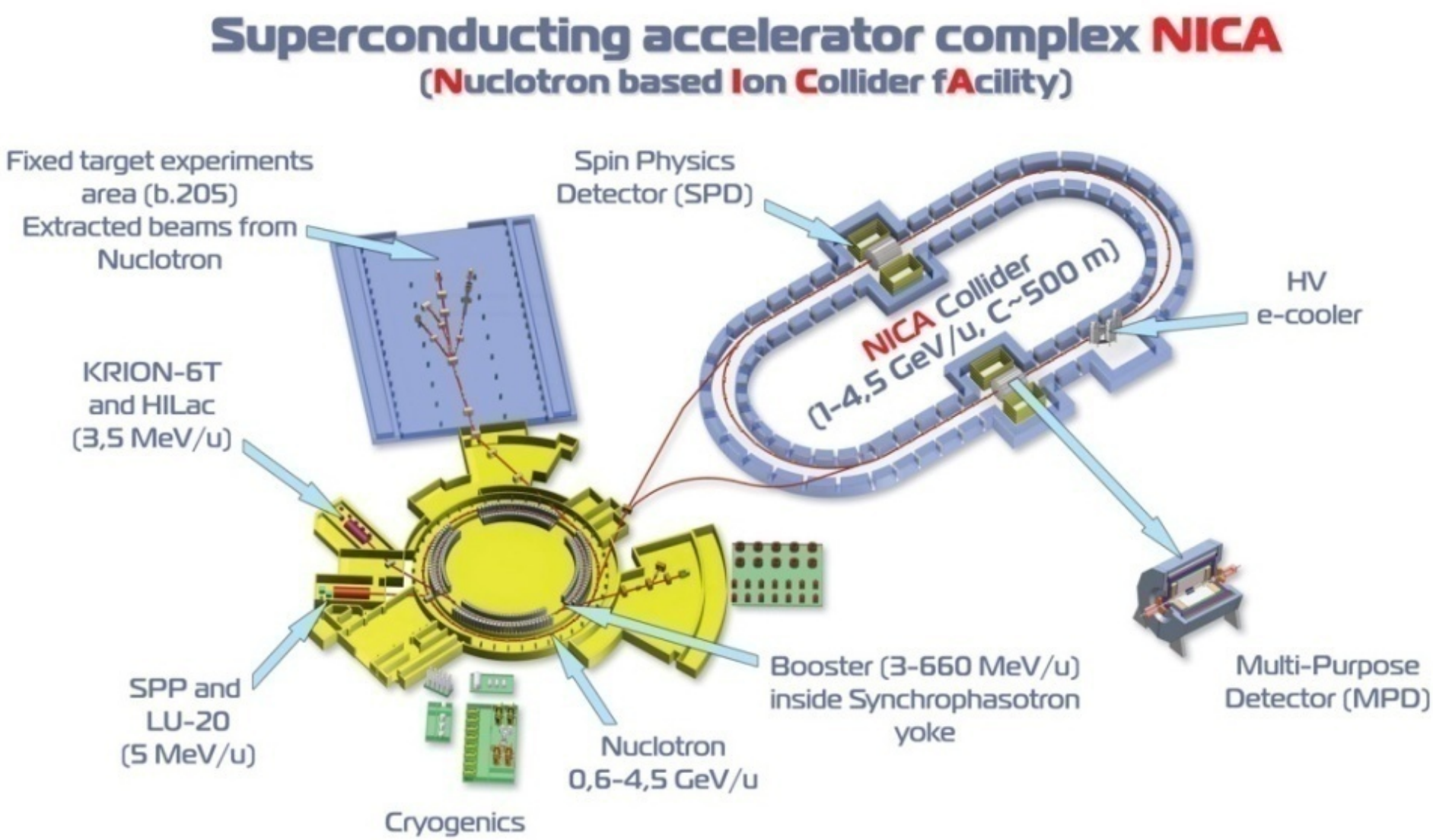
***- nucleon spin structure,***

***- polarization phenomena in heavy ion collisions***

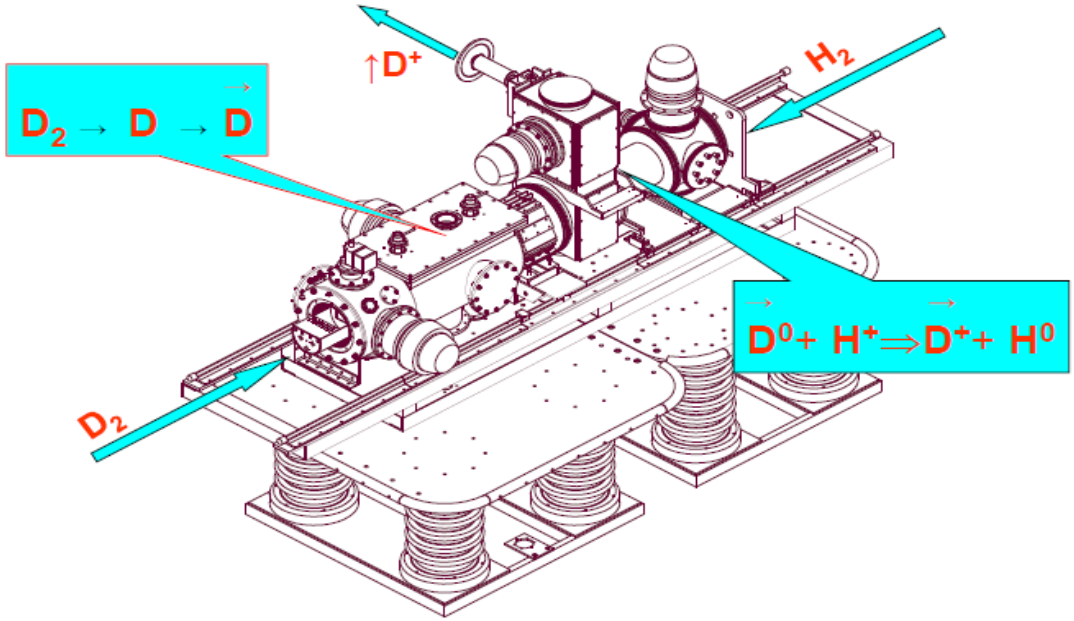
***in fixed target and collider experiments. For last ones:***

- **p↑p↑** $\sqrt{s_{pp}}$ **= 12 ÷ 27 GeV (5 ÷ 12.6 GeV kinetic energy )**
- **d↑d↑** $\sqrt{s_{NN}}$ **= 4 ÷ 13.8 GeV (2 ÷ 5.9 GeV/u ion kinetic energy )**
- $L_{average} \geq 1 \cdot 10^{32}\ cm^{-2}s^{-1}$ **(at** $\sqrt{s_{pp}}$ **= 27 GeV)**

# The NICA Complex



# New Polarized Ions Source (SPI-project)

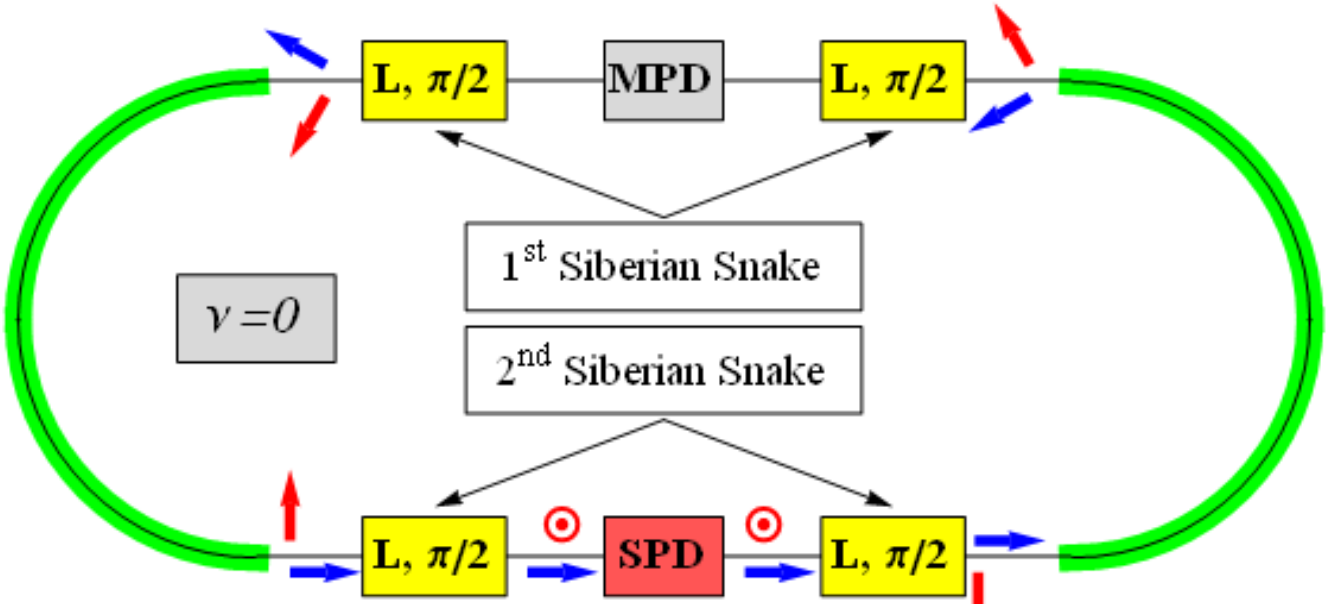



**The SPI-project assumes the development of the source of Polarized Deuterons (Protons) using a charge-exchange plasma ionizer. Nearly resonant charge-exchange reactions for production of polarized protons & deuterons are:**

$$H^0\uparrow + D^+ \Rightarrow H^+\uparrow + D^0$$
$$D^0\uparrow + H^+ \Rightarrow D^+\uparrow + H^0 \qquad \sigma \sim 5 \cdot 10^{-15}\ cm^2$$

**The output $\uparrow D^+$ ($\uparrow H^+$) current of the source is expected to be at a level of 10 mA. The $D^+$ polarization will be up to 90% of the maximal vector (±1) for $\uparrow D^+$ ($\uparrow H^+$) and tensor (+1,-2) for $\uparrow D^+$ polarization.**

# Polarization control scheme in the Collider with spin tune ν = 0




The novel scheme of proton and deuteron polarization control in the NICA collider is proposed (A.Kondratenko et al., to be confirmed).

By means of two Siberian Snakes with solenoid magnetic field, the beam spin tune is shifted to the “zero” spin resonance vicinity, whereas manipulation of the polarization is realized by “weak” field solenoids. The scheme makes it possible to obtain any desired direction of the polarization in the both MPD and SPD detectors.

# NICA complex beams

*Heavy ion colliding beams up to* $^{197}Au^{79+}$ x $^{197}Au^{79+}$

at $\sqrt{s_{NN}} = 4 \div 11$ GeV, $L_{average} = 1 \times 10^{27}\ cm^{-2} \cdot s^{-1}$

*Light-Heavy ion colliding beams of the same energy range and L*

*Polarized beams of protons and deuterons in collider mode:*

$p\uparrow p\uparrow$ $\sqrt{s_{pp}} = 12 \div 27$ $L_{average} \geq 1 \times 10^{32}\ cm^{-2} \cdot s^{-1}$

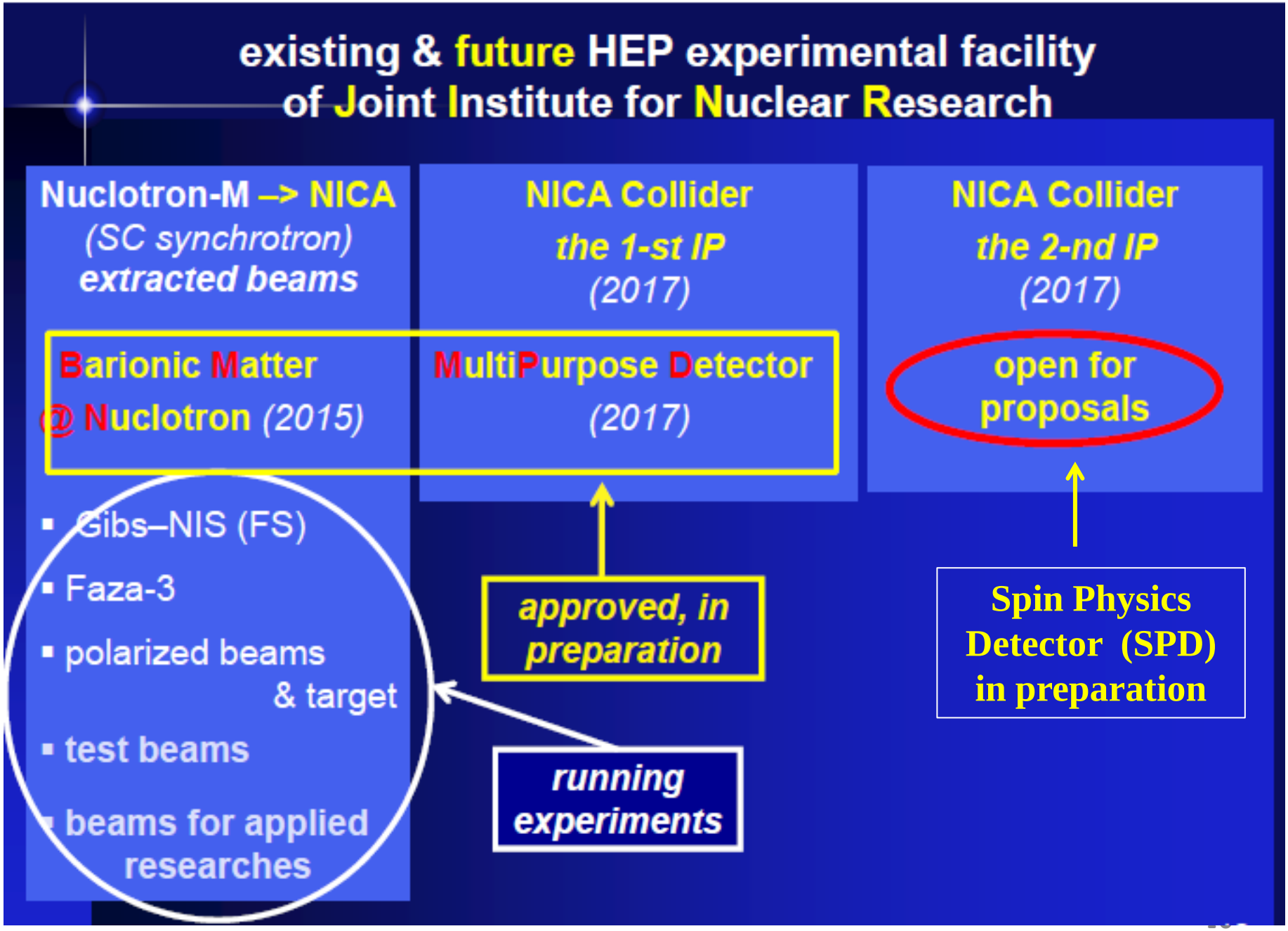
$d\uparrow d\uparrow$ $\sqrt{s_{NN}} = 4 \div 13.8$ GeV

*Extracted beams of light ions and polarized protons and deuterons for fixed target experiments:*

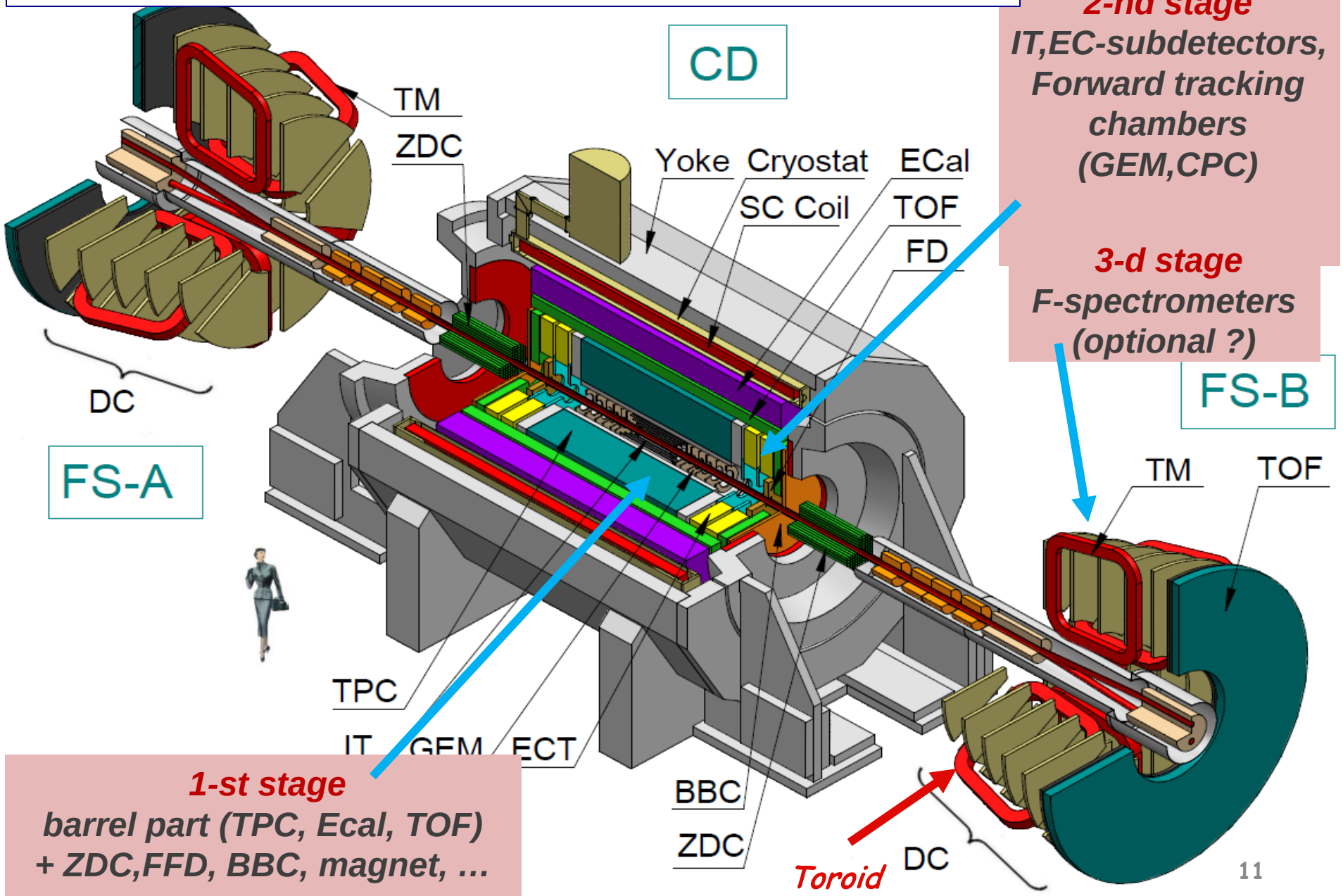
| | |
|---|---|
| $Li \div Au = 1 \div 4.5$ GeV /u | ion kinetic energy |
| $p, p\uparrow = 5 \div 12.6$ GeV | kinetic energy |
| $d, d\uparrow = 2 \div 5.9$ GeV/u | ion kinetic energy |

*Applied research in ion beams at kinetic energy*

*starting from from 0.3 GeV/u*


existing & future HEP experimental facility
of Joint Institute for Nuclear Research
Nuclotron-M –> NICA
(SC synchrotron)
extracted beams
NICA Collider
the 1-st IP
(2017)
NICA Collider
the 2-nd IP
(2017)
Barionic Matter
@ Nuclotron (2015)
MultiPurpose Detector
(2017)
open for
proposals
Gibs–NIS (FS)
Faza-3
polarized beams
& target
test beams
beams for applied
researches
approved, in
preparation
running
experiments
Spin Physics
Detector (SPD)
in preparation

# MultiPurpose Detector (MPD) @ 1st IP




***2-nd stage***
***IT,EC-subdetectors, Forward tracking chambers (GEM,CPC)***

***3-d stage***
***F-spectrometers (optional ?)***

***1-st stage***
***barrel part (TPC, Ecal, TOF) + ZDC,FFD, BBC, magnet, …***

# Spin physics with SPD at NICA

**Letter of Intent on spin physics experiments and requirements to SPD detector is under the way**

SPD at NICA project has all chances to stay in near future as major player in the spin physics domain due to the high intensity polarized light nuclear beams. Both proton and deuteron beams can be effectively polarized, with a polarization degree not less than 50%. The facility under construction will propose unique opportunity to collide the polarized protons and polarized deuterons.

The studies of polarized Drell-Yan process in collisions of transversely polarized protons and deuterons provide access to the very important and still poorly known sea and valence, Boer-Mulders and Sivers PDFs in the proton. To determine Boer-Mulders and Sivers PDFs, The following measurements must be performed: unpolarized and single polarized DY processes with pp and pD collisions; J/ Ψ production processes with unpolarized and single polarized pp and pD collisions, which can not be completely duplicated by other experiments (COMPASS, RHIC, PAX and J-PARC ).

# Spin physics with SPD at NICA

**Working Group has started the preparation of the spin physics program to operate with polarized pp, pD & DD beams**

## Preliminary topics

- Drell-Yan processes with L&T polarized p & D beams
- extraction of unknown (poor known) PDF
- PDFs from J/Ψ production processes
- Direct photons
- Spin effects in various exclusive & inclusive reactions
- Diffractive processes
- Cross sections, helicity amplitudes & double spin asymmetries (Krisch effect) in elastic reactions
- Spectroscopy of quarkoniums

# Spin Physics at NICA

**Extraction of unknown (poor known) parton distribution functions (PDFs):**

$p(D)\,p(D) \to \gamma^* X \to l^+ l^- X$ — **Boer-Mulders PDF**

$p^{\uparrow}(D^{\uparrow})\,p(D) \to \gamma^* X \to l^+ l^- X$ — **Sivers PDFs (Efremov,… PLB 612 (2005), PRD 73(2006));**

$p^{\uparrow}(D^{\uparrow})\,p^{\uparrow}(D^{\uparrow}) \to \gamma^* X \to l^+ l^- X$ — **Transversity PDF (Anselmino, Efremov, …)**

$p^{\uparrow}(D^{\uparrow})\,p(D) \to \gamma^* X \to l^+ l^- X$ — **Transversity and first moment of Boer-Mulders PFDs**

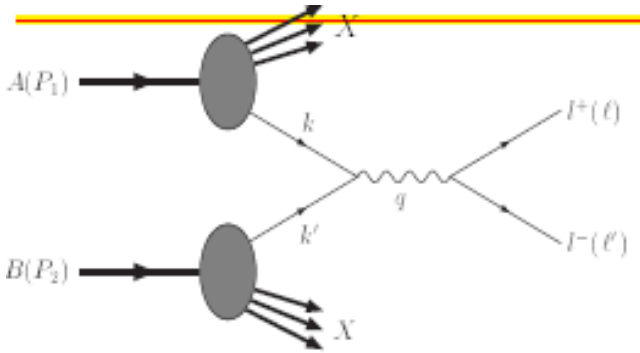
$p(D)\,p(D) \to \gamma^* X \to l^+ l^- X$ — **(Sissakian, Shevchenko, Nagaytsev , Ivanov, PRD 72(2005), EPJ C46 ,2006 C59, 2009)**

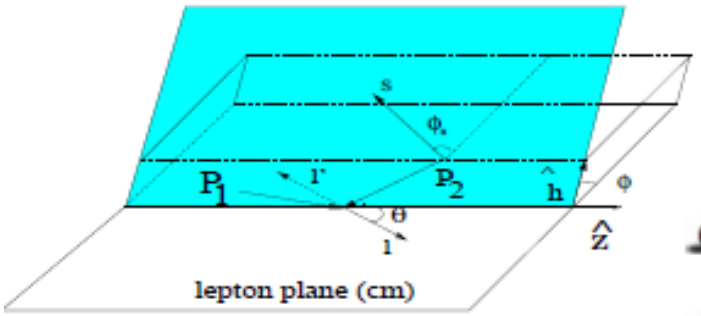
$p^{\rightarrow}(D^{\rightarrow})\,p^{\leftarrow}(D^{\leftarrow}) \to \gamma^* X \to l^+ l^- X$ — **Longitudinally polarized sea and strange PDFs and tenzor deuteron structure (Teryaev, …)**

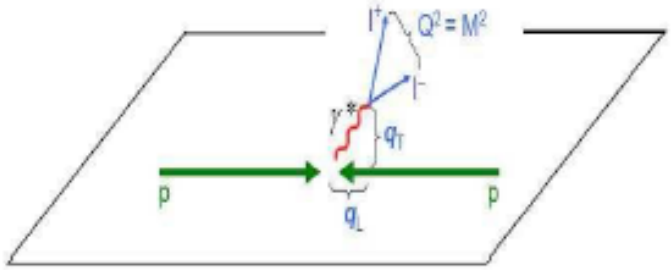
**The same PDFs from J/ψ production processes ( $\sqrt{s} \le 10 GeV$).**

**A. Sissakian, O. Shevchenko, O. Ivanov, (Dubna, JINR). arXiv:0710.1791**

# Drell-Yan kinematics




- $x_1 = \frac{Q^2}{2p_1 q}, \quad x_2 = \frac{Q^2}{2p_2 q}$ – Bjorken variables
- $s = (p_1 + p_2)^2 \simeq 2p_1 p_2$
  $Q^2 = M^2 \simeq x_1 x_2 s \equiv \tau s$
  $y = \frac{1}{2} \ln \frac{x_1}{x_2}$
  $x_F = x_1 - x_2$
  $x_1 = \frac{\sqrt{x_F^2 + 4\tau} + x_F}{2} = \sqrt{\tau} e^{y}$
  $x_2 = \frac{\sqrt{x_F^2 + 4\tau} - x_F}{2} = \sqrt{\tau} e^{-y}$
- $\theta$ – Polar angle of lepton pair
- $\phi$ – azimutal angle of lepton pair
- $\phi_S$ – angle of hadron polarization measured with respet to lepton plane

# Drell-Yan cross sections

QPM: (D. Boer, PRD 60 (1999) 014012 )

unpolarized: $H_1 H_2 \to l^+ l^- X$

$$\frac{d\sigma^{(0)}(H_1H_2\to l\bar{l}X)}{d\Omega dx_1 dx_2 d^2\mathbf{q}_T} = \frac{\alpha^2}{12Q^2}\sum_{q,q} e_q^2 \Big\{ (1+\cos^2\theta)\mathcal{F}[\bar{f}_{1q} f_{1q}] + \sin^2\theta\cos(2\phi)\mathcal{F}\left[(2\hat{\mathbf{h}}\cdot\mathbf{k}_{1T}\,\hat{\mathbf{h}}\cdot\mathbf{k}_{2T} - \mathbf{k}_{1T}\cdot\mathbf{k}_{2T})\frac{h_{1q}^{\perp} h_{1q}^{\perp}}{M_1 M_2}\right]\Big\}$$

single polarized: $H_1 H_2^{\uparrow} \to l^+ l^- X$

PAX, COMPASS: $\bar{p}p^{\uparrow} \to l^+ l^- X$ COMPASS: $\pi^- p^{\uparrow} \to \mu^+ \mu^- X$

RHIC, NICA, J-PARC: $pp^{\uparrow} \to l^+ l^- X$

$$\frac{d\sigma^{(1)}(H_1H_2^{\uparrow}\to l\bar{l}X)}{d\Omega dx_1 dx_2 d^2\mathbf{q}_T} = \frac{\alpha^2}{12Q^2}\sum_{q,q} e_q^2 \Big\{ (1+\cos^2\theta)\mathcal{F}[f_1 \bar{f}_1]$$

$$+\sin^2\theta\cos(2\phi)\mathcal{F}\left[(2\hat{\mathbf{h}}\cdot\mathbf{k}_{1T}\,\hat{\mathbf{h}}\cdot\mathbf{k}_{2T} - \mathbf{k}_{1T}\cdot\mathbf{k}_{2T})\frac{h_1^{\perp} \bar{h}_1^{\perp}}{M_1 M_2}\right]$$

$$+ (1+\cos^2\theta)\sin(\phi-\phi_S)\mathcal{F}\left[\hat{\mathbf{h}}\cdot\mathbf{k}_{1T}\frac{f_{1T}^{\perp}\bar{f}_1}{M_1}\right] - \sin^2\theta\sin(\phi+\phi_S)\mathcal{F}\left[\hat{\mathbf{h}}\cdot\mathbf{k}_{2T}\frac{h_1\bar{h}_1^{\perp}}{M_2}\right]$$

$$-\sin^2\theta\sin(3\phi-\phi_S)\mathcal{F}\left[\left(4\hat{\mathbf{h}}\cdot\mathbf{k}_{2T}(\hat{\mathbf{h}}\cdot\mathbf{k}_{1T})^2 - 2\hat{\mathbf{h}}\cdot\mathbf{k}_{1T}\mathbf{k}_{1T}\cdot\mathbf{k}_{2T} - \hat{\mathbf{h}}\cdot\mathbf{k}_{2T}\mathbf{k}_{1T}^2\right)\frac{h_{1T}^{\perp}\bar{h}_1^{\perp}}{2M_1^2 M_2}\right]\Big\}$$

$$\hat{h} \equiv \mathbf{q}_T/|\mathbf{q}_T|; \qquad \mathcal{F}[f\bar{f}] \equiv \int d^2\mathbf{k}_{1T}\, d^2\mathbf{k}_{2T}\, \delta^2(\mathbf{k}_{1T}+\mathbf{k}_{2T}-\mathbf{q}_T) f_q(x_1,\mathbf{k}_{1T}^2)\bar{f}_q(x_2,\mathbf{k}_{2T}^2)$$

# SSA in pp↑ collisions

$$x_p \gg x_{p\uparrow}$$

$$A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}\Big|_{x_p\gg x_{p\uparrow}} \simeq 2\frac{\bar{f}_{1T}^{\perp(1)u}(x_{p\uparrow})f_{1u}(x_p)}{\bar{f}_{1u}(x_{p\uparrow})f_{1u}(x_p)} = 2\frac{\bar{f}_{1T}^{\perp(1)u}(x_{p\uparrow})}{\bar{f}_{1u}(x_{p\uparrow})}$$

$$A_{UT}^{\sin(\phi+\phi_S)\frac{q_T}{M_N}}\Big|_{x_p\gg x_{p\uparrow}} \simeq -\frac{h_{1u}^{\perp(1)}(x_p)\bar{h}_{1u}(x_{p\uparrow})}{f_{1u}(x_p)\bar{f}_{1u}(x_{p\uparrow})}$$

$$x_p \ll x_{p\uparrow}$$

$$A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}\Big|_{x_p\ll x_{p\uparrow}} \simeq 2\frac{f_{1T}^{\perp(1)u}(x_{p\uparrow})\bar{f}_{1u}(x_p)}{f_{1u}(x_{p\uparrow})\bar{f}_{1u}(x_p)} = 2\frac{f_{1T}^{\perp(1)u}(x_{p\uparrow})}{f_{1u}(x_{p\uparrow})}$$

$$A_{UT}^{\sin(\phi+\phi_S)\frac{q_T}{M_N}}\Big|_{x_p\ll x_{p\uparrow}} \simeq -\frac{\bar{h}_{1u}^{\perp(1)}(x_p)h_{1u}(x_{p\uparrow})}{\bar{f}_{1u}(x_p)f_{1u}(x_{p\uparrow})}$$

Restriction because of acceptance (fixed target)

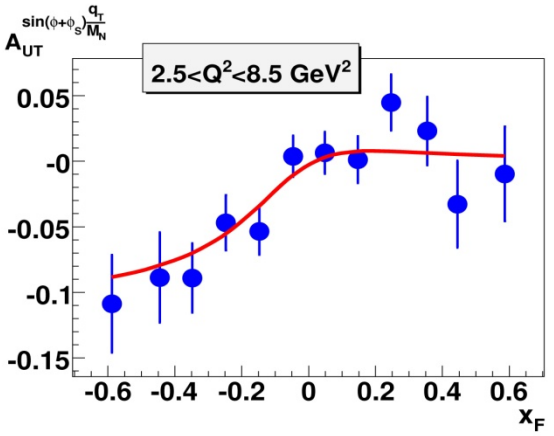
$$x_F \equiv x_{beam} - x_{target} \geq 0$$

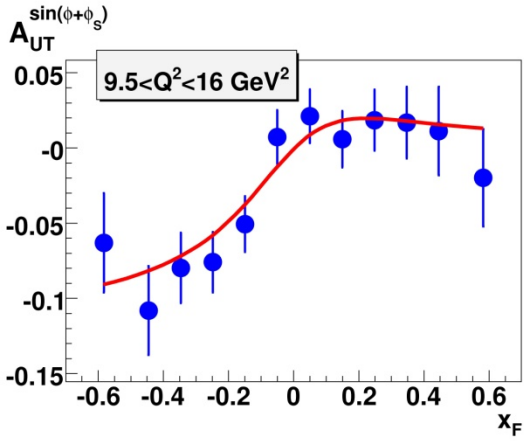
$A_{UT}^{\sin(\phi-\phi_S)} \neq 0$ only if $x_p - x_{p\uparrow} > 0$

$A_{UT}^{\sin(\phi+\phi_S)} \neq 0$ only if $x_p - x_{p\uparrow} < 0$

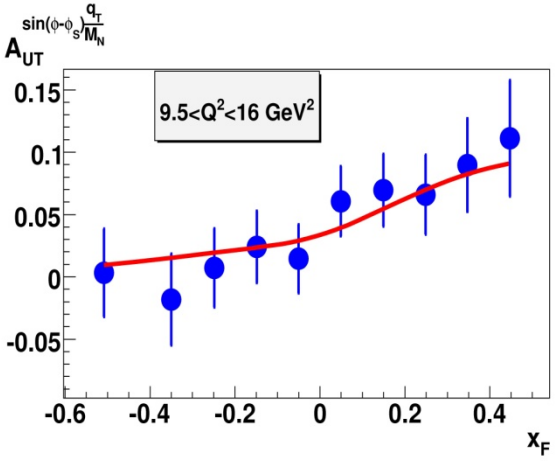
advantage of collider mode!

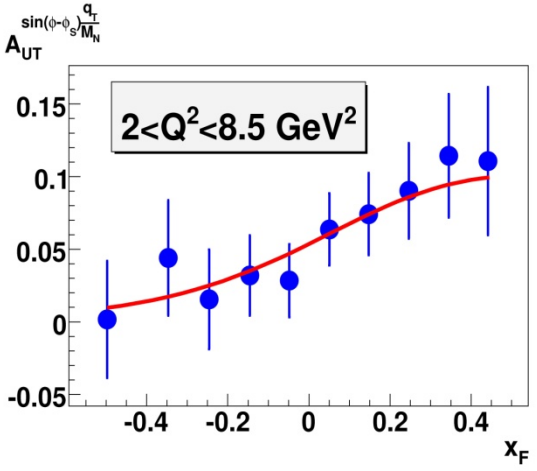
# The SSA asymmetries (preliminary estimations)




**Access to transversity and Boer-Mulders PDFs.**
**A.N.Sissakian, O.Yu.Shevchenko, A.P.Nagaytsev,PRD 72 (2005), EPJ C46 (2006)**




**Access to Sivers PDFs.**
**A.V.Efremov et al., PLB 612(2005), PRD 73(2006)**
**A.N. Sissakian, O.Yu. Shevchenko, A.P. Nagaytsev, O.N. Ivanov, Phys.Part.Nucl.41,(2010)**

# Conclusion

**JINR is developing the new accelerator facility NUCLOTRON M-NICA: ”NICA COMPLEX”.**

The facility under construction will provide unique opportunity to collide the polarized protons and polarized deuterons. The studies of Drell-Yan process in collisions of transversely polarized protons and deuterons provide access to the very important and still poorly known sea and valence transversity, Boer-Mulders and Sivers PDFs.

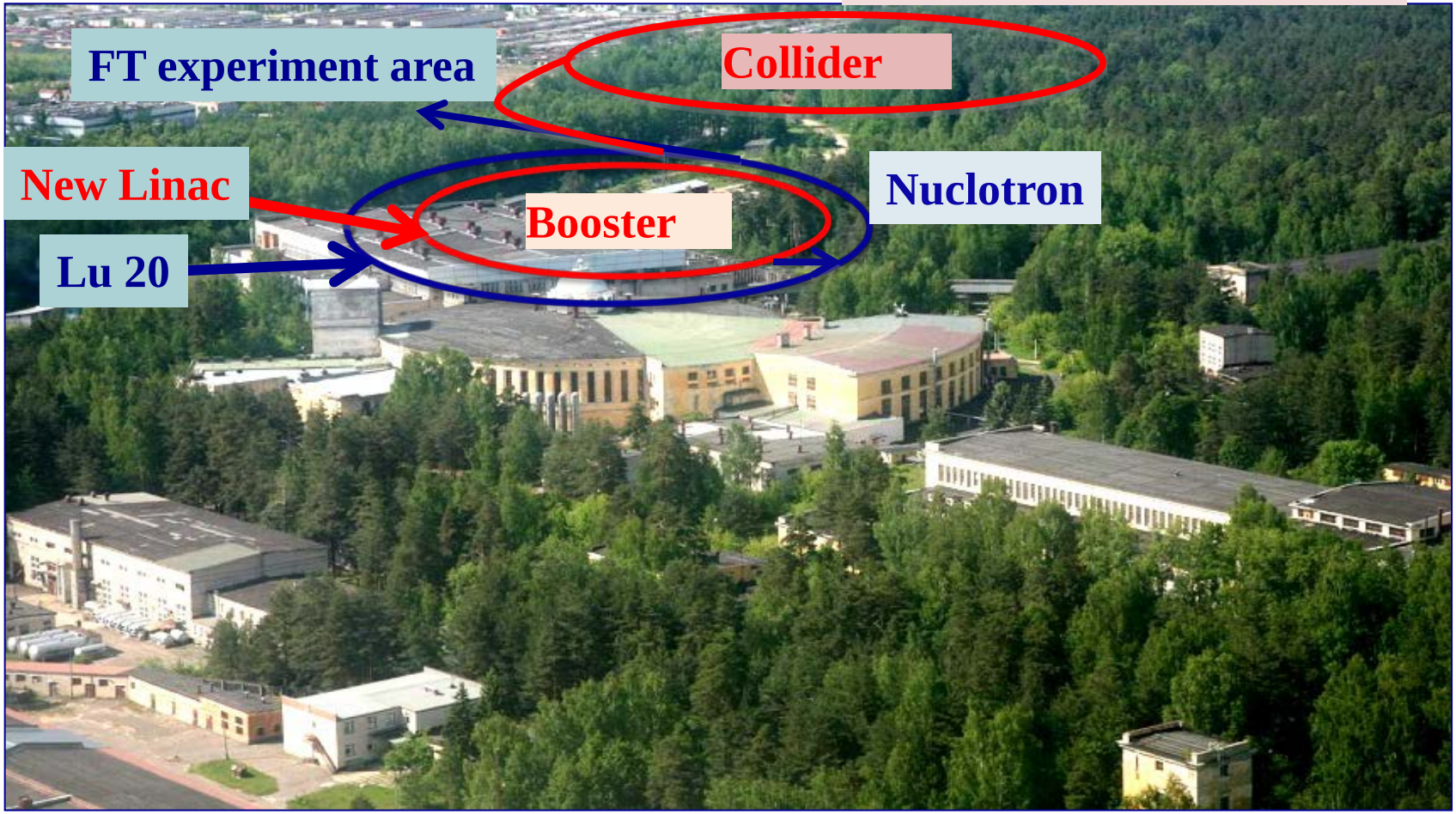
**LoI** for spin physics experiments at NICA is under preparation. Several international workshops **NICA-SPIN 2013** are organized. The first workshop was in Dubna (see **http://nica.jinr.ru/files/Spin_program/NICA-SPIN2013/program.html),** the second will be in Prague **( http://thsun1.jinr.ru/~praha/2013),** the third one will be at Dubna during the DSPIN2013 workshop (**http://theor.jinr.ru/~spin/2013**).

# Cooperation @ Nuclotron-M / NICA MPD experiments

- **Joint Institute for Nuclear Research**
- Institute for Nuclear Research, RAS, **RF**
- Nuclear Physics Institute of MSU, **RF**
- Institute Theoretical & Experimental Physics, **RF**
- St.Petersburg State University, **RF**
- Bogolyubov Institute for Theoretical Physics, NAS, **Ukraine**
- Institute for Scintillation Materials, Kharkov, **Ukraine**
- State Enterprise Scientific & Technology Research Institute for Apparatus construction, Kharkov, **Ukraine**
- Institute of Applied Physics, AS, **Moldova**
- Particle Physics Center of Belarusian State University, **Belarus**
- Physics Institute Az.AS, **Azerbaijan**
- Institute for Nuclear Research & Nuclear Energy BAS, Sofia, **Bulgaria**
- Aristotel University of Thessaloniki, **Greece**
- GSI, **Germany**
- Institute of Physics & Technology of MAS, University of **Mongolia**
- Department of Engineering Physics, Tsinghua University, Beijing, **China**
- University of Science and Technology of China, Hefei, **China**
- Osaka University, **Japan**
- RIKEN, **Japan**
- The University of Sidney, **Australia**
- TJNAF (Jefferson Laboratory), **USA**
- University of Cape Town, **RSA**

# New collaborators, welcome!

**accelerator facility NICA**



# Back up slide

# NICA polarized pp-collisions scenario and average luminosity

| Parameter | Value |
|---|---|
| Nuclotron Dipole Field Ramp up, T/s<br>Nuclotron Dipole Field Ramp down, T/s | 0.6<br>1.0 |
| Magnet field flat top duration, s | 0.5 |
| Total useful cycle duration, s | 3.17 |
| Dipole Magnetic Field at 6 GeV protons, T<br>Acceleration time, s | ~ 1<br>1.67 |
| Number of accelerated protons per pulse | $5 \cdot 10^{10}$ |
| Number of cycles to store $2 \cdot 10^{13}$ particles<br>Collider filling time at cycle duration 5s, s | 400<br>2000 |
| Collider filling time at cycle duration 7s, s | 2800 |
| Preparation of the beam in the collider (cooling, bunching emittance formation), s | 1000 |
| Magnetic field ramp in the collider, T/s | 0.6 |
| Acceleration time from 6 GeV to 12.6 GeV | ~ 1.7 |
| Luminosity life time (30% polarization | 5400 |
| Total cycle duration, s<br>Working part, % | ~ 8400/9200<br>64.3/58.7 |

- **Average luminosity**

**at E = 12.6 GeV:**

**$\langle L \rangle = (1.1\text{-}1.3)10^{32}$**

**$1/(cm^2 \cdot s)$.**

**(to be confirmed)**

# NICA-SPIN 2013

## International Workshop

JINR, Dubna, Russia
March 17 - 19, 2013

NICA



## Scientific Program

| | | |
|---|---|---|
| 10.00 | Opening | Yu.Potrebenikov |
| 10.10 | Nucleon spin structure and Drell-Yan | A.Efremov |
| 10.40 | Polarized protons and deuteron at NICA | A.Kovalenko |
| 11.10 | Polarised proton beam acceleration | Yu.Filatov |
| 11.40 | Coffee break | |
| 12.00 | Control of beam polarisation | A.Kondratenko |
| 12.20 | Injector for Nuclotron/NICA polarised beams | A.Butenko |
| 12.40 | Status of Polarised Ions Source | V.Fimushkin |
| 13.00 | The engineering equipment and systems for NICA | N.Topilin |
| | Lunch (13.30 - 14.30) | |
| 14.30 | The deuteron beam polarization measurements at Nuclotron | P. Kurilkin |
| 14.50 | Polarimetry for proton beam | V.Ladygin |
| 15.10 | Use of the deuteron breakup reaction for polarimetry tensor polarized beam | E.Strokovsky |
| 15.30 | High pT spin physics | S.Shimanski |
| 16.00 | Cofee break | |
| 16.20 | Final state spin physics at NICA | O.Teryaev |
| 16.50 | Drell-Yan studies at NICA | O.Shevchenko |
| 17.20 | Remarks on DY program at COMPASS and NICA | O.Denisov |
| 17.40 | Future Drell-Yan experiments | A.Nagaytsev |
| 18.00 | Closing remarks | I.Savin |

# ADVANCED STUDIES INSTITUTE
# SYMMETRIES AND SPIN

*(SPIN-Praha-2013 and NICA-SPIN-2013)*

**Prague, July 7 - 13, 2013**





## OVERVIEW

Advanced Studies Institute (ASI), **SPIN-Praha-2013**, is the 29th in the series of International meetings on Spin Research Program, that began with the first meeting of this series at Joint Institute for Nuclear Research, Dubna, in 1975, and continued after that from 1976 on regular basis at Czech Republic. Prague spin physics meetings cover topics related to symmetry and polarization phenomena in particle and nuclear physics and astrophysics.

Special attention at this Prague meeting will be given to the physical program on spin physics at the collider NICA. The meeting will be the second in the series International Workshops: "NICA-SPIN 2013". The first meeting was held in March 17-19 (NICA-SPIN2013), the third one will be held as a separate session: "Proposals for spin physics experiments at NICA" during the DSPIN-2013 (Dubna, September 17-22).

Characteristic feature of these meetings is:

- to take the broadest possible view of the discipline by inviting distinguished speakers both theoreticians and experimentalists from different collaborations aiming at the research of symmetry phenomena in various physics disciplines;
- to promote contacts among researchers with different background of physics to review and discuss present status and perspectives of their research;
- to help to form new collaborations;
- to help young researchers and students to take active part in the respective international research programmes.

**PRAGUE PHOTOS**