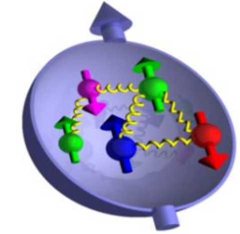
SPD at NICA.



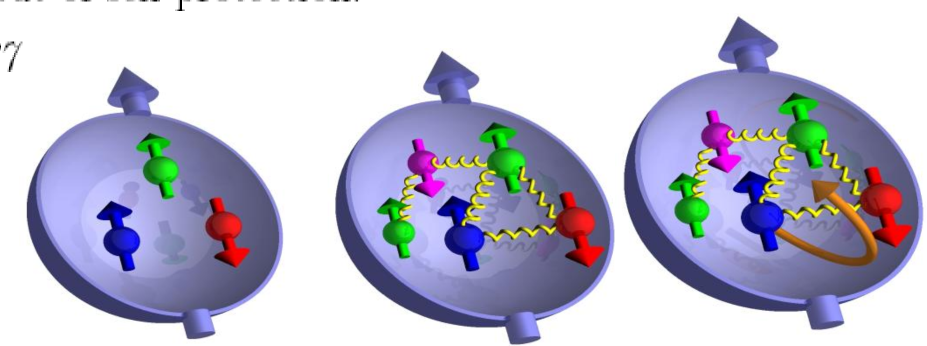
Polarization data has often been the graveyard for fashionable theories. If theorists had their way they might well ban such measurements altogether out of self-protection.

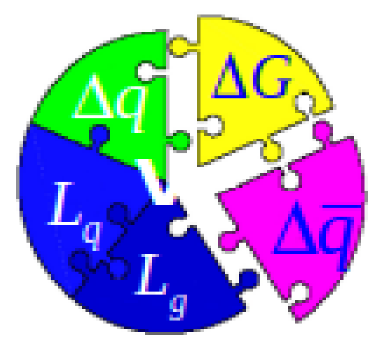
J.D. Bjorken, 1987

«Spin Physics Experiments at NICA-SPD with polarized proton and deuteron beams», EPJ Web Conf. 85 (2015) 02039,
submitted Aug 2014

NICA White Paper (http://mpd.jinr.ru/wp-content/uploads/2016/04/WhitePaper_10.01.pdf
NICA White Paper, EPJ A, vol. 52 (2016) No.8.

20-22 International Symposiums on Spin Physics,
Dubna, Russia
Beijing, China
Champaign, USA





Spin Physics in White Book.

Polarization effects in heavy ion collisions

The conversion of the huge initial angular momentum available in a heavy ion collision into the angular momentum carried by dense matter, and possibly by the spins of produced particles is an extremely interesting problem. Understanding it will undoubtedly allow to penetrate deeper into the collision dynamics. A number of observables are proposed in this section – most of them have never been studied before in heavy ion experiments. The physics issues include the dynamics of the collision, the chiral properties of the produced medium, and of the possible local violation of P and CP symmetries.

Spin program with polarized beams

The spin program is an important and integral part of the NICA project. Indeed, ever since the “spin crisis” of 1987, the composition of the nucleon spin in terms of the fundamental constituents – quarks and gluons – remains in the focus of attention of many physicists. The highlights of the NICA spin program include measurements of Drell-Yan processes with longitudinally polarized proton and deuteron beams, spin effects in inclusive and exclusive production of baryons, light and heavy mesons and direct photons, and studies of helicity amplitudes and double spin asymmetries in elastic scattering. The SPD detector at NICA would allow to contribute significantly to the current and planned international program in spin physics.

Spin Physics in White Book.

Polarization effects in heavy ions collisions at NICA
A. Efremov, O. Teryaev V. Toneev

Spin physics
A. Efremov, A. Nagaytsev, I. Savin, O. Shevchenko and O. Teryaev .

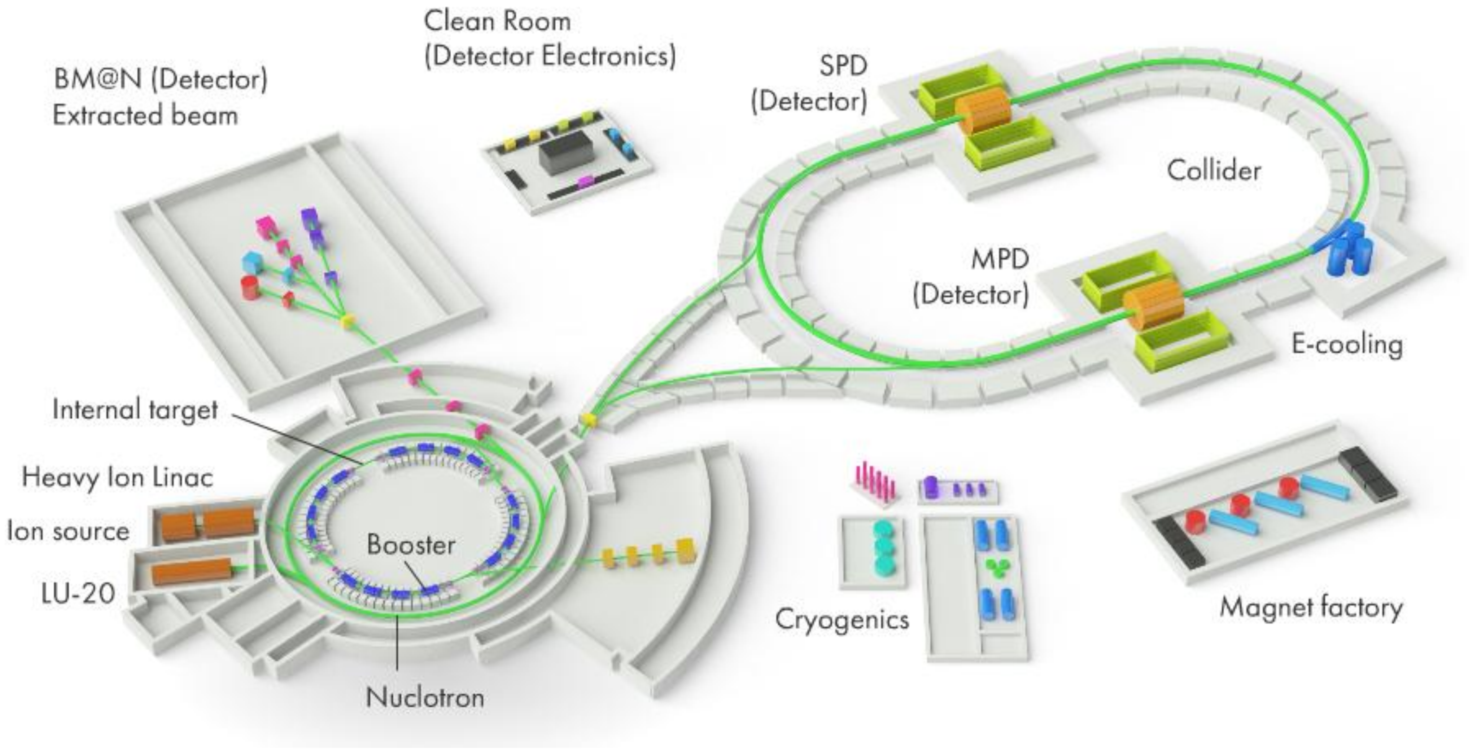
Polarization of Λ^0 hyperons in nucleus-nucleus collisions at MPD
V. Ladygin, A. Jerusalimov and N. Ladygina

Possible effect of mixed phase and deconfinement upon spin correlations in the Λ -antiΛ pairs generated in relativistic heavy-ion collisions
V.L. Lyuboshitz and V.V. Lyuboshitz

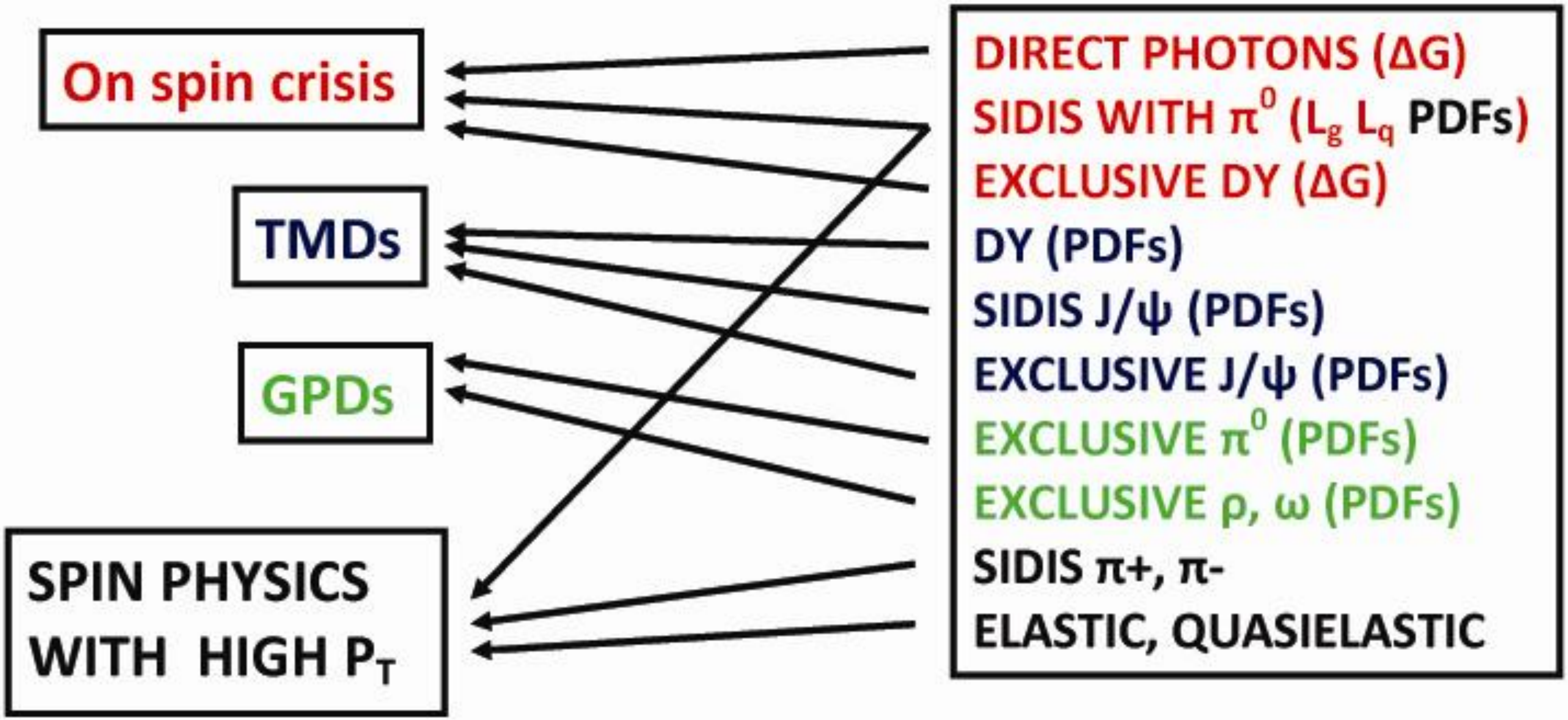
Spin Physics at NICA. Main tasks.

Possible main tasks:

- **‘Spin crisis’.**
- **Transverse Momentum Distributions (TMDs).**
- **Generalized Parton Distributions (GPDs).**
- **Spin effects in reactions with high p_T .**



Spin Physics at NICA.
Main tasks and measurements.



Spin Physics at NICA. Main tasks and measurements.

Leading twist TMD distribution functions (left) and GPDs (right).
The U,L,T correspond to Unpolarized, Longitudinally polarized and Transversely polarized nucleons (rows) and quarks (columns)

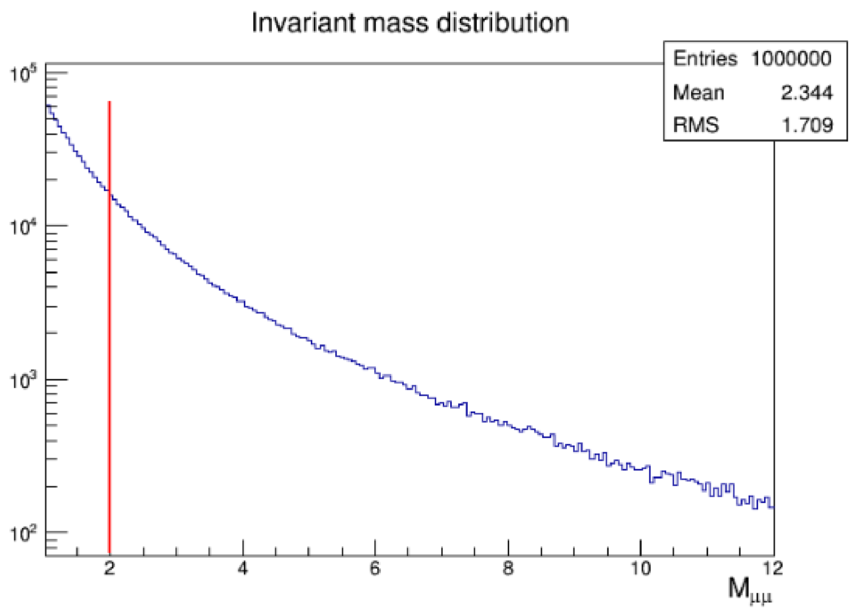
N/q	U	L	T
U	f_1		$h_1^{\perp}$
L		g_{1L}	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	h_1 , $h_{1T}^{\perp}$

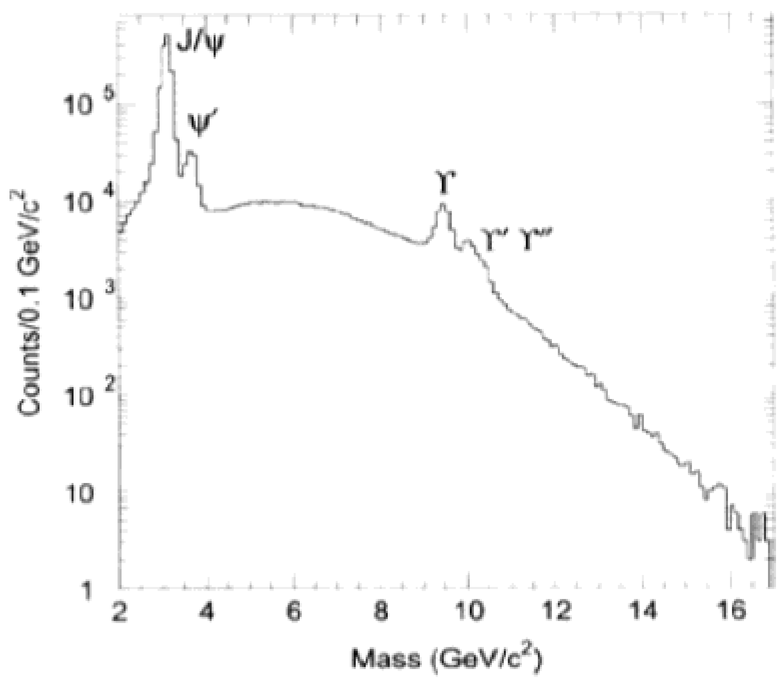
	U	L	T
U	$\mathcal{H}$		$\mathcal{E}_T$
L		$\widetilde{\mathcal{H}}$	$\widetilde{\mathcal{E}}_T$
T	$\mathcal{E}$	$\widetilde{\mathcal{E}}$	$\mathcal{H}_T, \widetilde{\mathcal{H}}_T$

TMD and GPD distributions describe partons with certain polarizations in nucleons with another polarization state. The diagonal elements of TMD and GPD tables are the momentum, longitudinal and transverse spin distributions of partons and after integration over transverse degrees of freedom represent the well known PDFs related to the leading-twist light-cone wave functions squared: the momentum ($f_1(x, k^2_T)$), the helicity ($g_1(x, k^2_T)$) and the transversity (h_1 (x, k^2_T)) distributions. They are the only ones that survive after integration over the intrinsic transverse momentum k_T , and are all needed for a complete description of the collinear nucleon structure.

Main tasks and measurements. DY studies

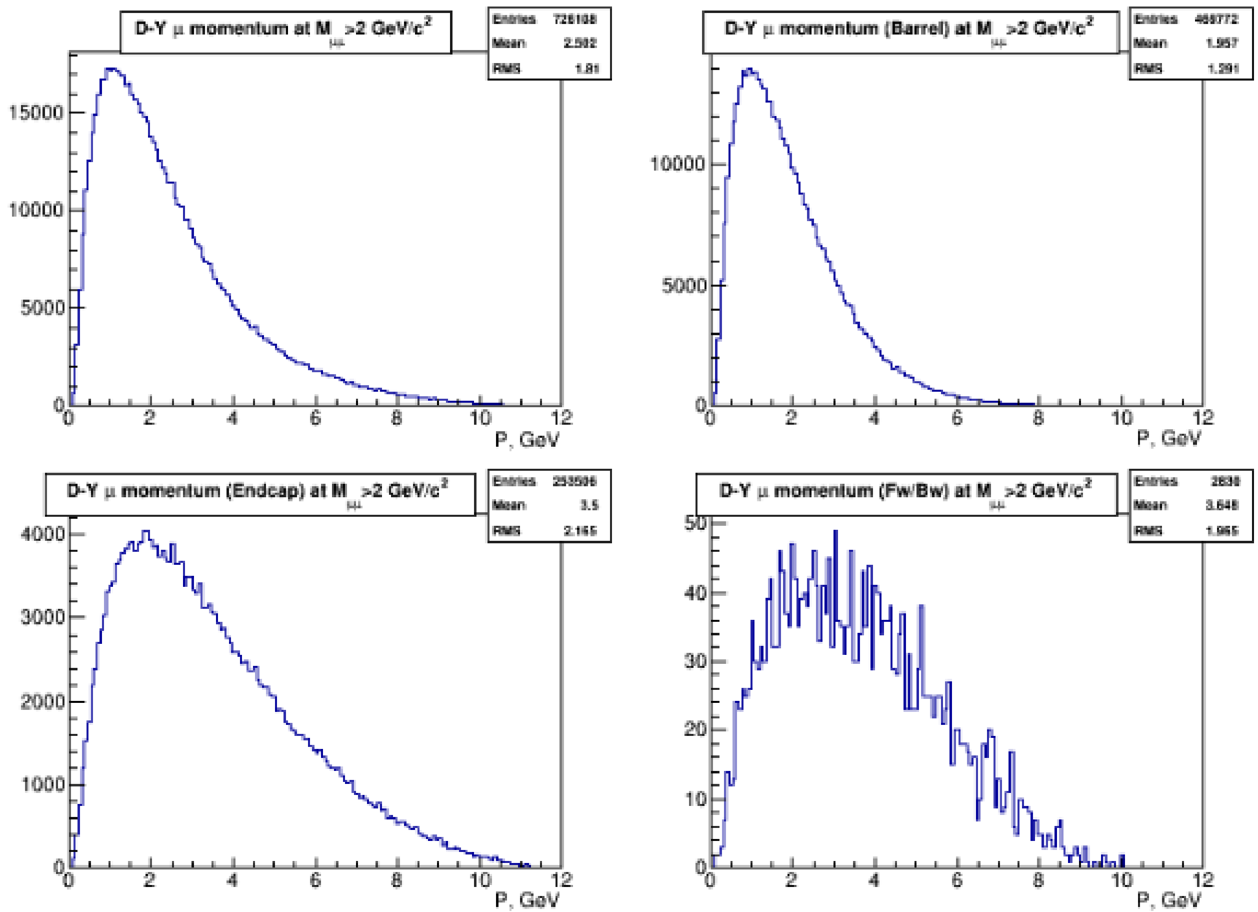
DY pairs (muons) were generated by MC method using the PYTHIA 6.4 code. The center of the coordinate system was put at the beams intersection point (Z=0, the Z axis is along the beams). The generated reaction is pp →(μ- , μ+) +X at √s =24 GeV, which includes the leading order 2-2 quark level hard scattering sub-processes q anti-q →γ* →(μ- , μ+). The initial-state radiation (ISR) and final-state radiation (FSR) were switched on. The GRV 94L parameterization of parton distributions was used.



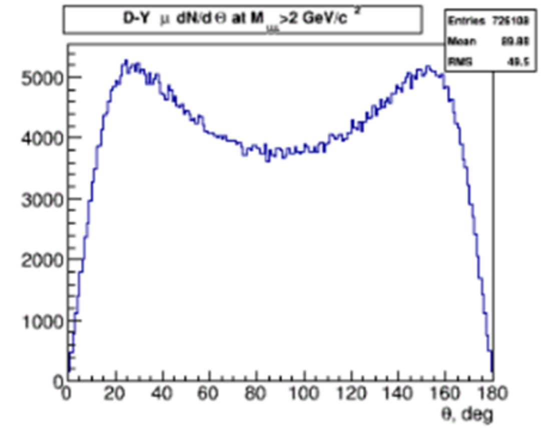


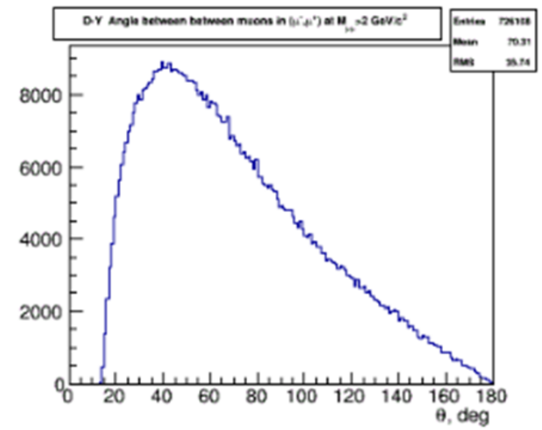
Main tasks and measurements.
DY studies

The average muon momentum is equal to 2.5 GeV /c for all angles,
1.95 GeV/c – for the central angular region (35 – 145 deg.) ,
3.5 GeV/c - for the forward/backward region (3 -35 deg.).
So, the momentum of particles to be measured in SPD is in the range ~ 0.5 - 12 GeV/c.

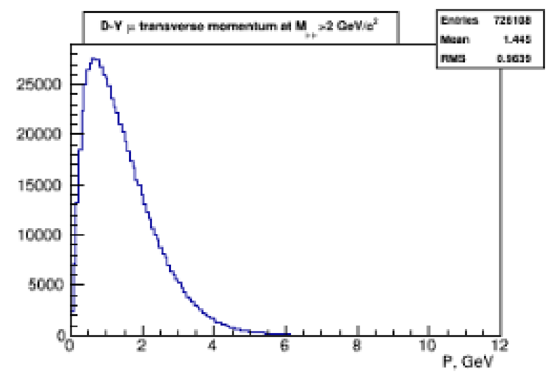


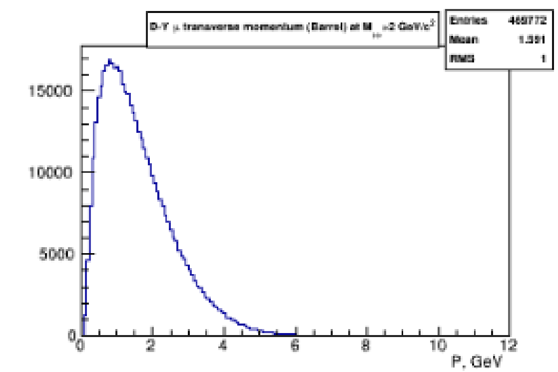
Main tasks and measurements. DY studies

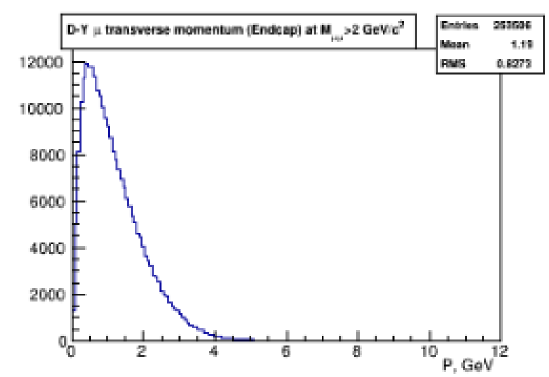


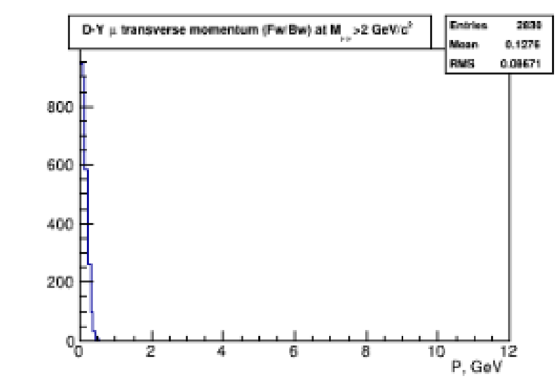


Most of the single muons are within the central angular region part of the volume. The minimal and maximal opening angles between muons are 20 deg. and 180 deg., respectively. These types of angular distributions require almost 4π geometry for the SPD.









The distributions of the muon transverse momentum

Main tasks and measurements. DY studies

Estimations of DY total cross sections and numbers of events

lower cut on Q, GeV	2.0	3.1	3.5	4.0
$\sqrt{s} = 20$ GeV $(L \simeq 0.5 \cdot 10^{32}$ cm^{-2}s$^{-1})$				
σ_{DY} total, nb	0.86	0.13	0.07	0.03
N events for a month, 10^3	120	18	9.7	4.6
$\sqrt{s} = 22$ GeV $(L \simeq 0.7 \cdot 10^{32}$ cm^{-2}s$^{-1})$				
σ_{DY} total, nb	1.01	0.16	0.09	0.05
N events for a month, 10^3	200	33	18	9.0
$\sqrt{s} = 24$ GeV $(L \simeq 1.0 \cdot 10^{32}$ cm^{-2}s$^{-1})$				
σ_{DY} total, nb	1.15	0.20	0.12	0.06
N events for a month, 10^3	300	52	30	15
$\sqrt{s} = 26$ GeV $(L \simeq 1.2 \cdot 10^{32}$ cm^{-2}s$^{-1})$				
σ_{DY} total, nb	1.30	0.24	0.14	0.07
N events for a month, 10^3	415	77	45	24

Possible DY statistics for NICA – p. 4

Month – 30 days of data taking

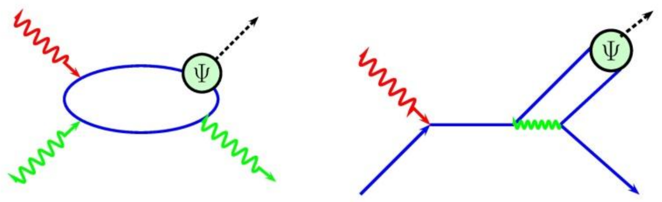
Main tasks and measurements. GPD studies

Short remarks: «GPDs studies at NICA with polarized beams» by S.V.Goloskokov

At NICA detector it is proposed to have a fullidentificationof the final particles. In this case it is possible to detect exclusive reactions like $pp \to ppM$ where M is a some meson state.

At NICA we shall be able to extract hard photon-proton scattering with hadron recoil $W \sim 5\text{-}12$ GeV in the γp system.

At large photon virtuality Q^2 the meson photoproduction amplitude can be presented in a factorized form as a convolution of hard scattering part which can be calculated perturbatively and Generalized Parton Distributions (GPDs).



Typical lowest order Feynman graphs for the $\gamma^* g \to Vg$ (left) and $\gamma^* q \to Vq$ (right) subprocesses of meson electroproduction.

In the case of vector meson production M= ρ, ω one can obtain information on *GPDs H* for gluon, sea and valence quark distributions. Exploiting transversely polarized proton beam, the information on *GPD E* can be obtained.

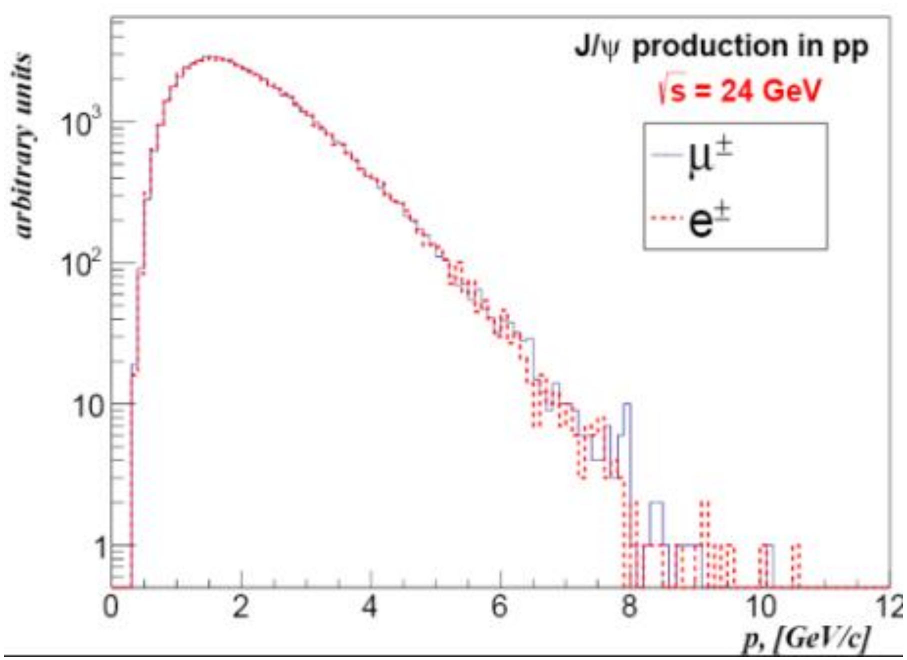
The J/ψ production is dominated by gluon fusion. Thus by measuring the $A_{//}$ asymmetry one can the determined *tilda-H* effects and Δg.

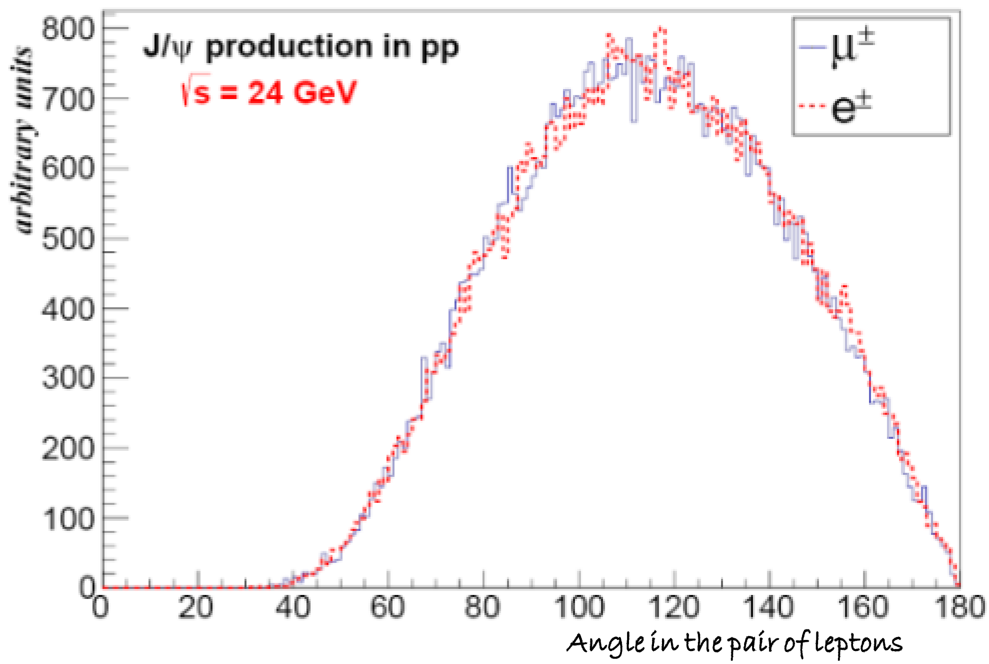
The transversity effects , which were studied for the first time in the SIDIS reactions, can be investigated with the pseudoscalar meson $M=\pi^0$ in the final state to get data on:

- *GPDs* H_T and E_T ;
- π^0 cross section.

Main tasks and measurements.
J/ψ studies.

The J/Ψ mesons produced in pp collisions at √ s =24 GeV and decayed into the charged lepton pairs have been simulated by MC with the PYTHIA 6.4 generator for the direct production mechanism . This mechanism includes the J/Ψ production via gluon-gluon, gluon-quark and quark-quark fusion including production of intermediate states and its subsequent decays into the J/Ψ. The CTEQ 5L, LO parameterization is used for the PDFs.

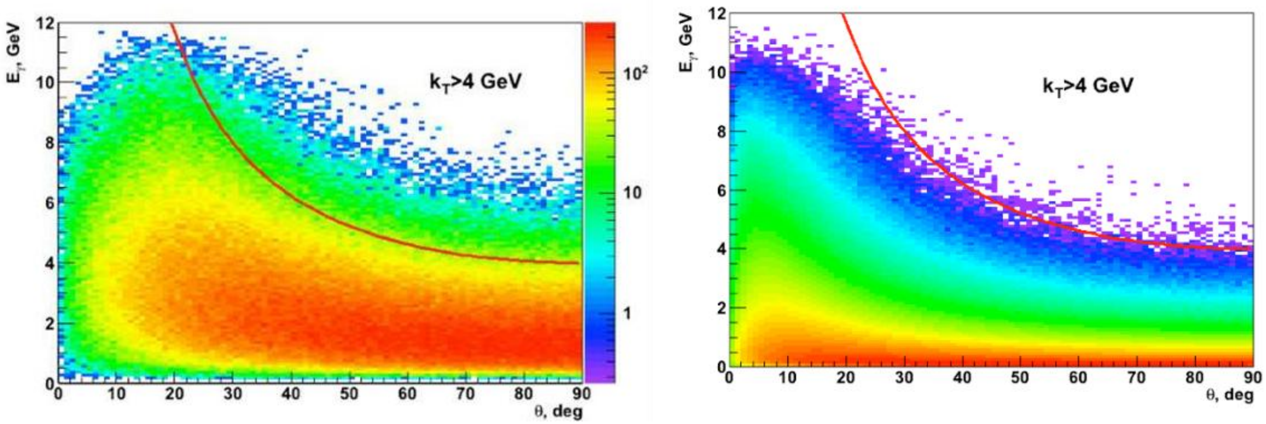




Main tasks and measurements. Direct photons.

A sample of direct photons produced in pp collisions at $\sqrt{s}$=24 GeV has been generated by the MC method using the PYTHIA 6.4.2 code. The five hard processes with direct photons in the final state were used: q+g→q+γ, q+q→g+γ, g+g→g+γ, q+q→γ+γ and g+g→γ+γ. Relative probabilities of the first two processes are ~ 85% and 15%, respectively, while the contribution of all others is less than ~ 0.2%. CTEQ 5L is used for the set of PDFs. No special kinematic cuts are applied.

The right part of this Figure shows the corresponding plot for minimum bias photons (mainly from π^0 decay). The MC simulations show that for p_T > 4 GeV signal-to-background ratio is about 5% that is in good agreement with the data of the UA6 experiment for non-polarized protons at $\sqrt{s}$ =24.3 GeV.



left - direct photons,
right - minimum bias photons.

For the effective registration and identification of direct photons, SPD should have:

- an electromagnetic calorimeter (ECAL)
- a tracking system capable to distinguish between clusters from neutral and charged particles in ECAL. It also should be capable to reconstruct the beam intersection point;
- a trigger system should include ECAL. Since for asymmetry measurements quite energetic photons are needed only, for the main trigger one can require an energy of above 2-3 GeV deposited in any cell of ECAL;
- a DAQ system with a bandwidth up to 100 kHz;
- a luminosity monitor.

Main tasks and measurements. High p_T studies

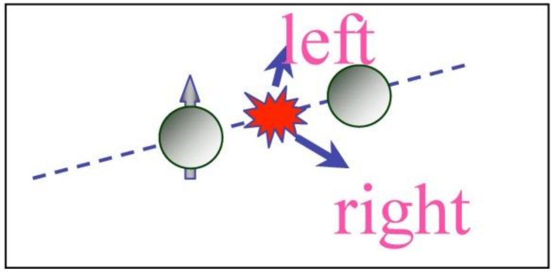
Many final state probes are studied at RICH: Jets, π^0 , $\pi^\pm$, η, Direct photons etc.
Large transverse Single Spin Asymmetries found at low energies and the effect do not disappear with energy growth

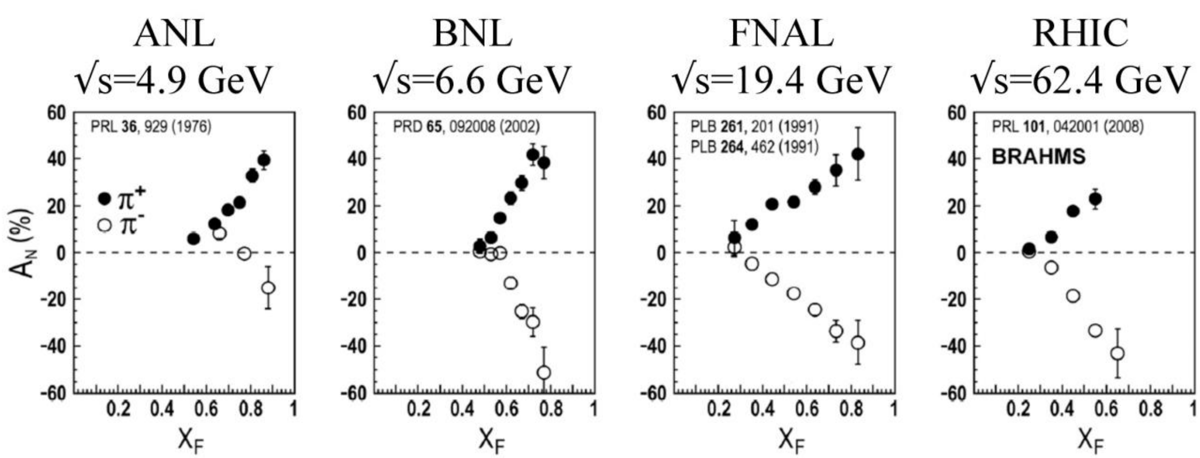
- Large single spin transverse spin (~40%) found at low energies

→ soft physics effect.

→ Generated theoretical work to find mechanism

- – Initial (Siver's) and Final (Collin's) state effects



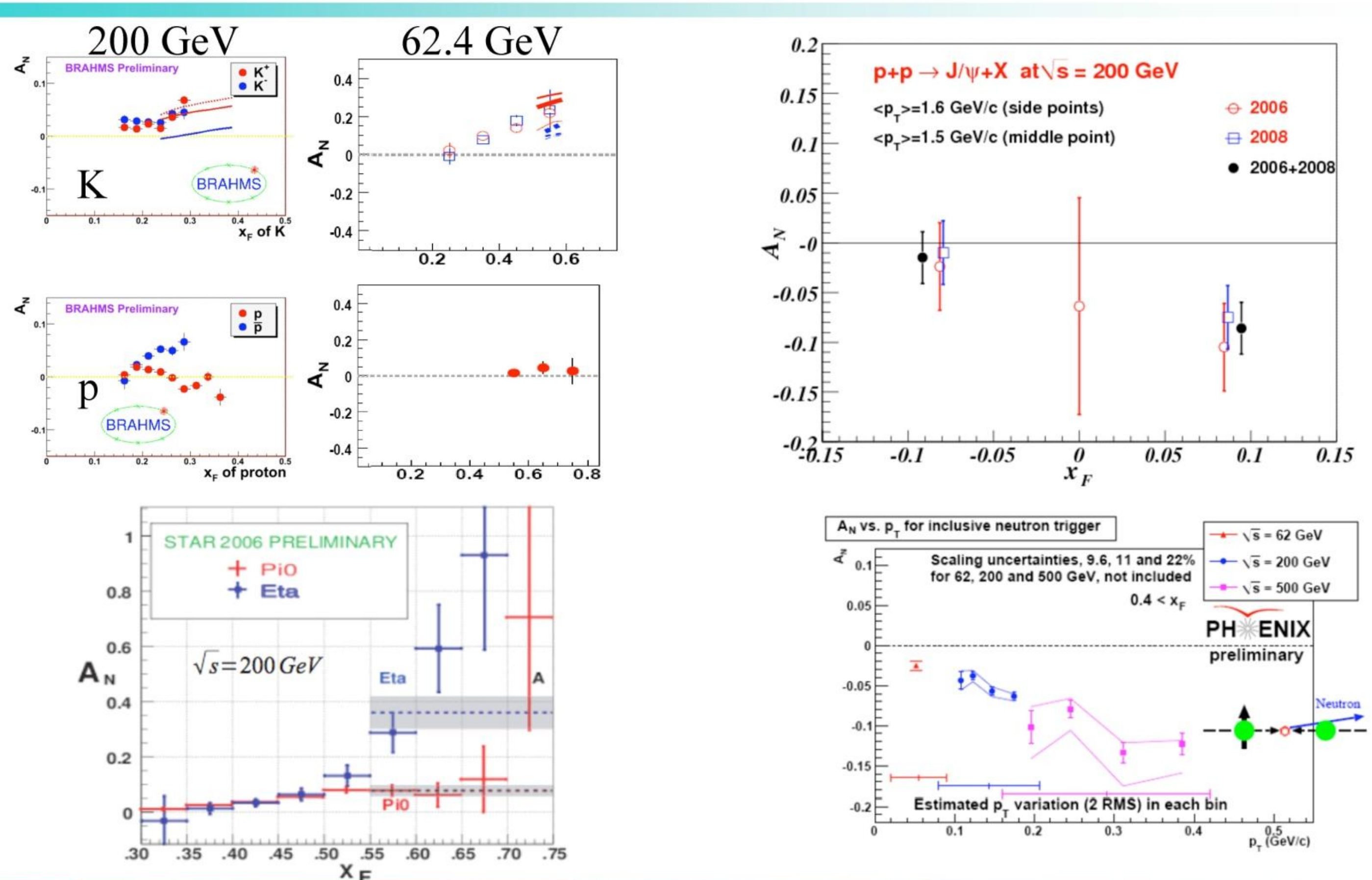


$$x_F = 2p_{long} / \sqrt{s}$$

K.Boyle, Spin Physics at RHIC, EQCD 2011

Main tasks and measurements. High p_T studies

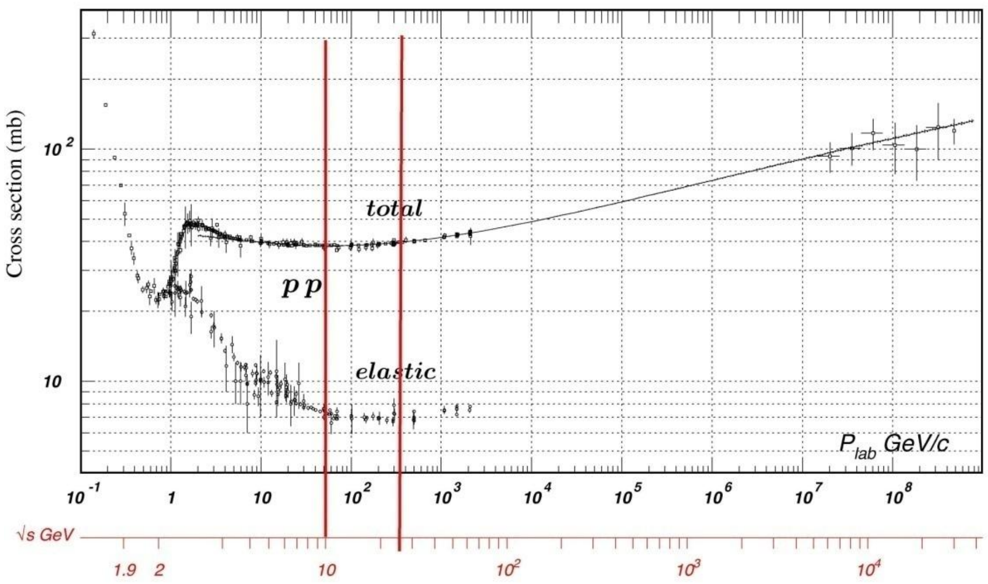
More transverse spin results (surprises)



K.Boyle, Spin Physics at RHIC, EQCD 2011

See talks by S.Shimansky and A.Krisch givne in SPIN-2012, Dubna

Main tasks and measurements. Rates.



At NICA luminosity (~ 2 10 ^{30} sm^{-2} s^{-1}) pp interaction rate is of about 80 K per second (with elastic processes contribution around 15 K).

Charged particles	13.5
Neutral particles	22.5
π+	4.6
π -	3.9
π0	4.8
K+	0.4
K -	0.3
K0	0.7

The main task of the trigger system is to provide identification the reactions with:

- **two muons in the final state;**
- **various types of hadrons (π+/-, K, p, …);**
- **photons (π^0, ω, η..);**
- **elastic scattering.**

Different triggers should run in parallel to collect data for several physics processes simultaneously and for calibration as well.

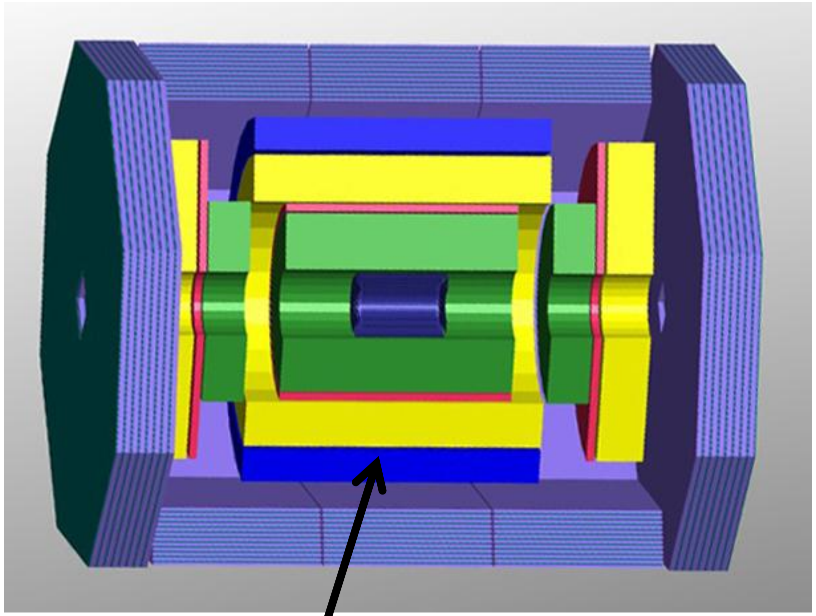
Possible layout of the SPD.

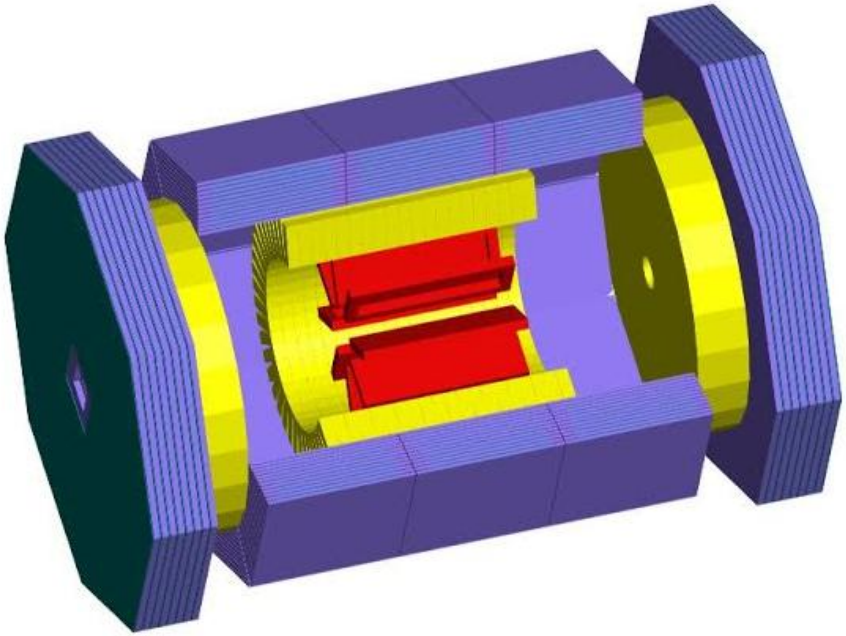
Требуемые характеристики экспериментальной установки :

- геометрия близкая к 4π ;
- высокоточный (лучше 50 *мкм*) и быстрый вершинный детектор ;
- трековая система, обеспечивающая высокую точность (лучше 200 *мкм*) по треку,
- скорость сбора данных для светимости > 10^{32} ,
- минимум материала;
- измерение нейтральных (π^0) вторичных частиц;
- Идентификация заряженных частиц с эффективностью близкой к 100%;
- быстрая и современная триггерная система;
- модульность и доступность к элементам установки, что позволит модернизировать, дополнять и изменять детекторы для выполнения новых исследований.

Possible layout of the SPD. Magnet

There are two options: toroid or solenoid.





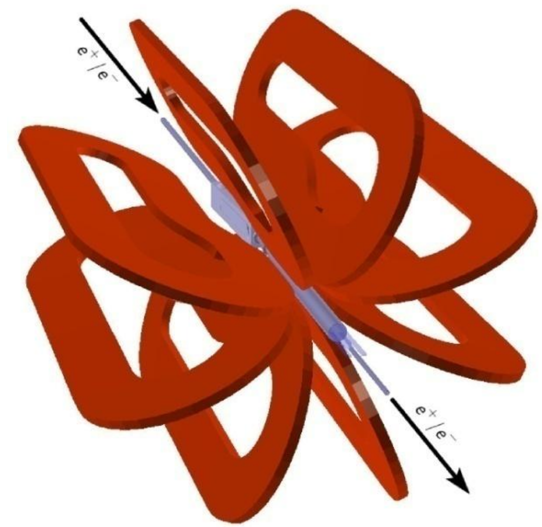
The magnet part of SPD, usually called “barrel”, contains inside a vertex detector, tracking detectors and electromagnetic calorimeters (ECAL). Outside of the barrel one needs to have muon and hadron detectors. The end-cap part of SPD could contain a tracking, ECAL, and muon range systems.

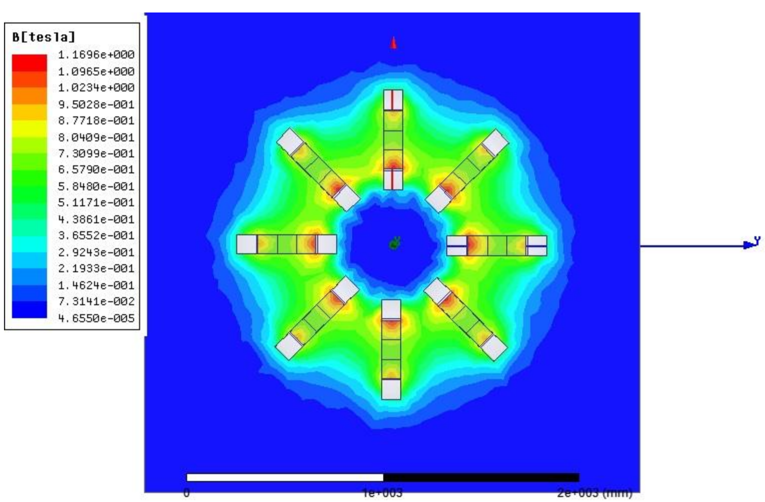
SOLENOID:

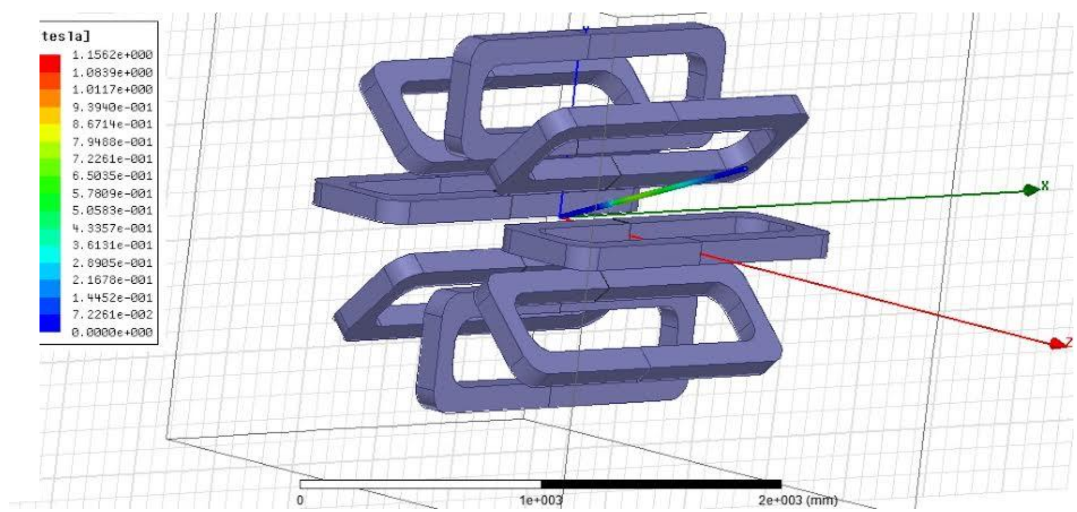
The solenoid SPD version could have almost 100% azimuthal acceptance, which is important, for example, for detection of some exclusive reactions. Disadvantage of the solenoid option is a 40 presence of the magnetic field in the beam pipe region. This field will disturb beam particle trajectories and change polarization. Screening of this field should be studied.

Possible layout of the SPD. Magnet.

Конструкция магнита должна обеспечить аксептанс установки не менее 85 %, и интеграл поля не менее 1.5 Тм. Важным свойством тороидального магнита является отсутствие влияния по пучки коллайдера, что позволяет иметь широкие возможности по использованию различных спиновых состояний пучков.



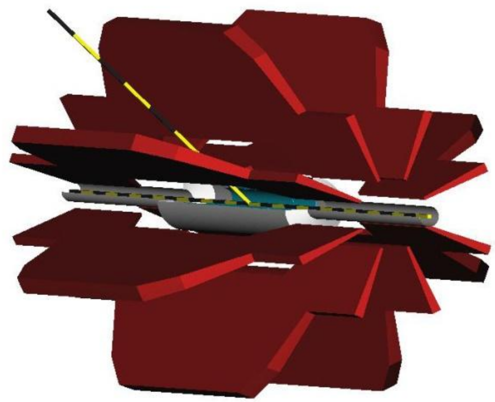


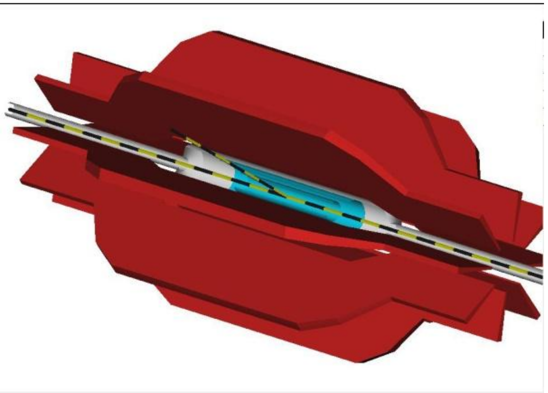


Possible layout of the SPD. Magnet.

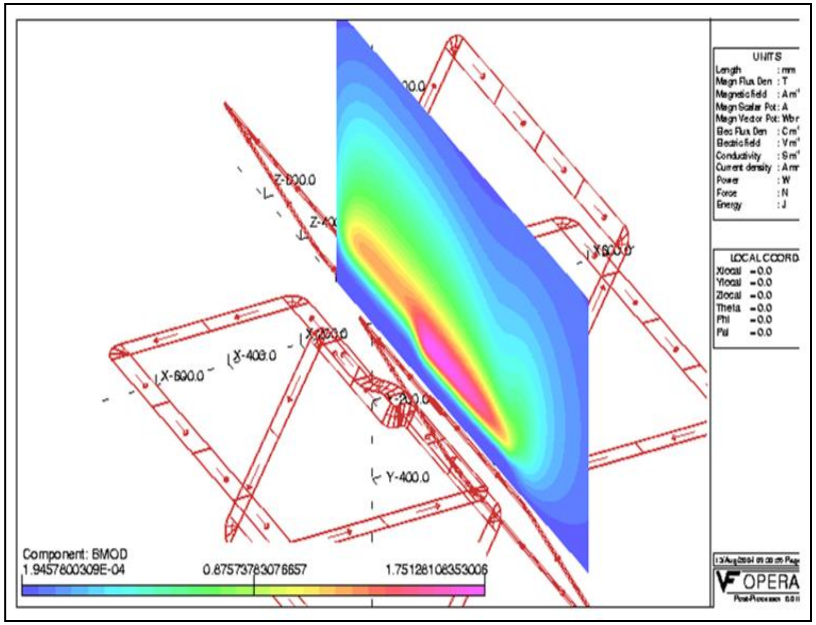
SPD Toroid Magnet (preliminary)

- 8 coils
- ~100 x 60 cm coils
- average integrated field: ~ 1.0-1.5 Tm
- acceptance ~ 80-85 %





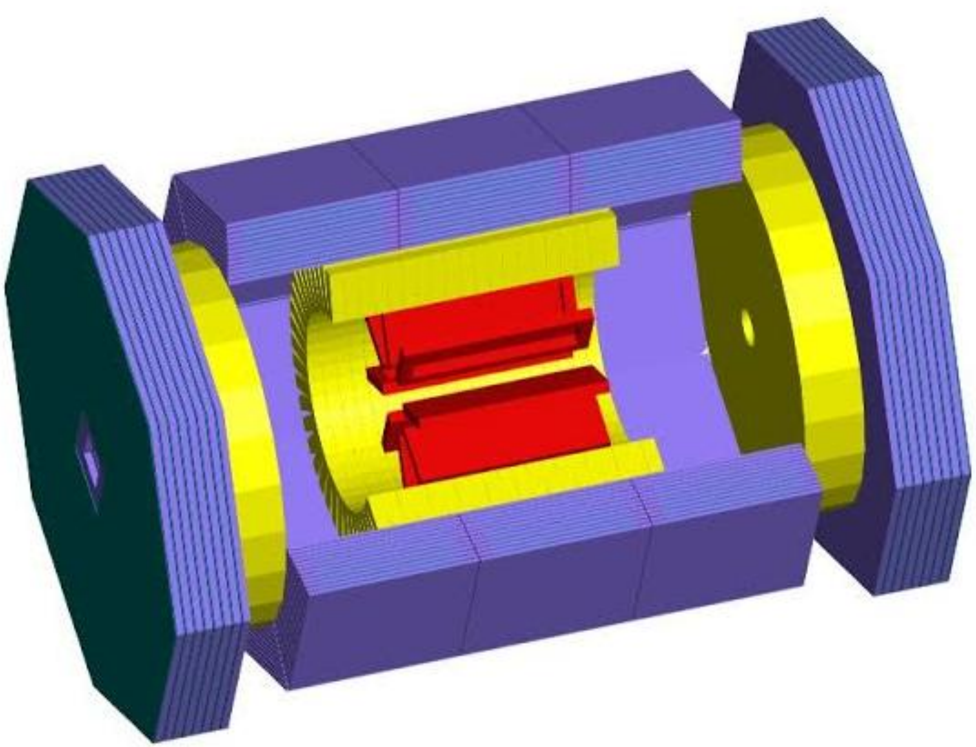
PAX Toroid Magnet

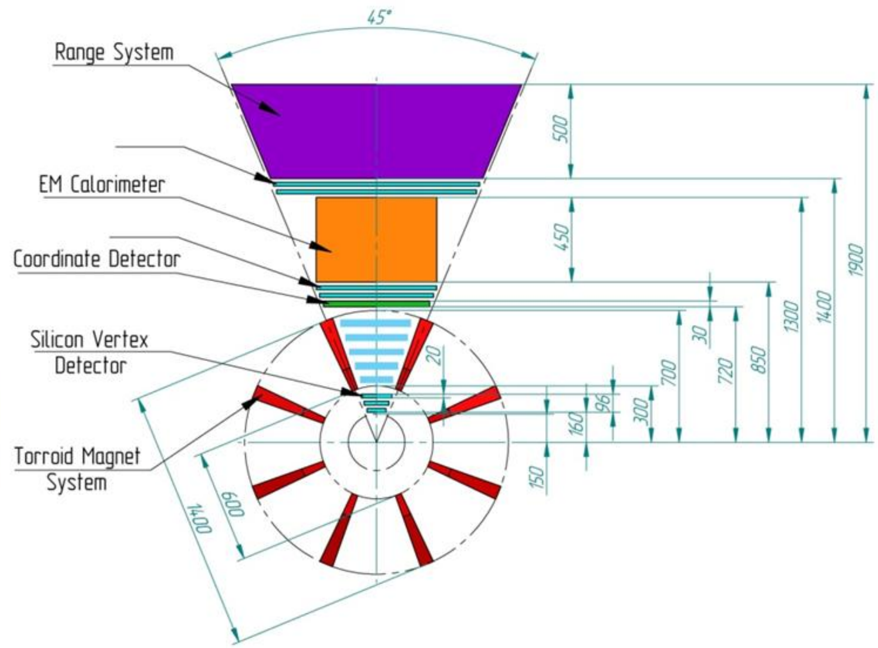


- 800 x 600 mm coils
- 3 x 50 mm section (1450 A/mm^2)
- average integrated field: 0.6 Tm
- free acceptance > 80 %

Possible layout of the SPD.

Установка может состоять из 3-х основных частей: баррельной и двух торцевых.
Длина установки – около 6 м, диаметр – до 4 м.





Показаны основные детекторы установки:
красным – торроидальный магнит,
желтым – электромагнитный калориметр,
мюонная система - выделена синим цветом.

Possible layout of the SPD.

<u>Трековые детекторы могут быть созданы из следующих элементов</u>:
- вершинный детектор - несколько координатных кремниевых слоев с разрешением порядка 30 мкм;
- центральный и торцевые трековые детекторы – несколько групп слоев тонких строу трубок;
- дополнительно можно использовать пространство между обмотками тороидального магнита для дрейфовых камер. Разрешение по треку ~ 300 мкм

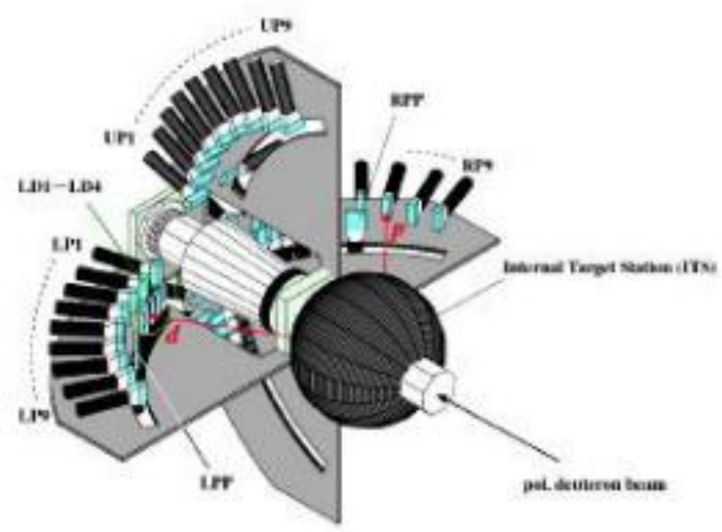
<u>Триггерные детекторы могут состоять из:</u>
- сигналы от электромагнитного калориметра (шашлык – как для КОМПАСС);
- сцинтилляционные пластины.
Необходимо организовать различные типы триггеров.

<u>Для идентификации частиц:</u>
- время-пролетная система из - RPC плоскостей;
- электромагнитный калориметр;
- мюонная система.

Polarimetry at Linac, Nuclotron and NICA.

Requirements to the polarization monitoring and measurements at NICA are the following:
- **polarimeters should be installed after Linac, inside the Nuclotron ring, at the beam transportation line to the collider and in both rings of the collider;**
- **evaluation of the polarization should be at the standard level for deuterons and protons;**
- **absolute calibration of the beam polarization should be possible;**
- **optimal use of the same experimental equipment at different places is desirable;**
- **permanent monitoring of the beam polarization.**

The <u>dp elastic scattering</u> at large angles (> 60 deg. in CM system) is often used for the deuteron beam polarization measurements in the energy range 200-2000 MeV. Analyzing powers of this reaction have large values and were measured with high accuracy.



The proton beam polarization measurement in the energy range of NICA can be done using <u>pC (proton-carbon) and CNI (Coulomb-Nuclear Interference) polarimeters.</u> Since the hadronic spin-flip part of the amplitude at NICA energies is not negligible, CNI polarimeter is not an absolute one. To improve the systematic errors and to calibrate it, the polarimeter based on polarized <u>pp elastic scattering</u> can be designed. The place for polarized jet target is reserved at the collider.

The system of such measurements is designed at the LHEP in the framework of the project DSS (Deuteron Spin Structure).

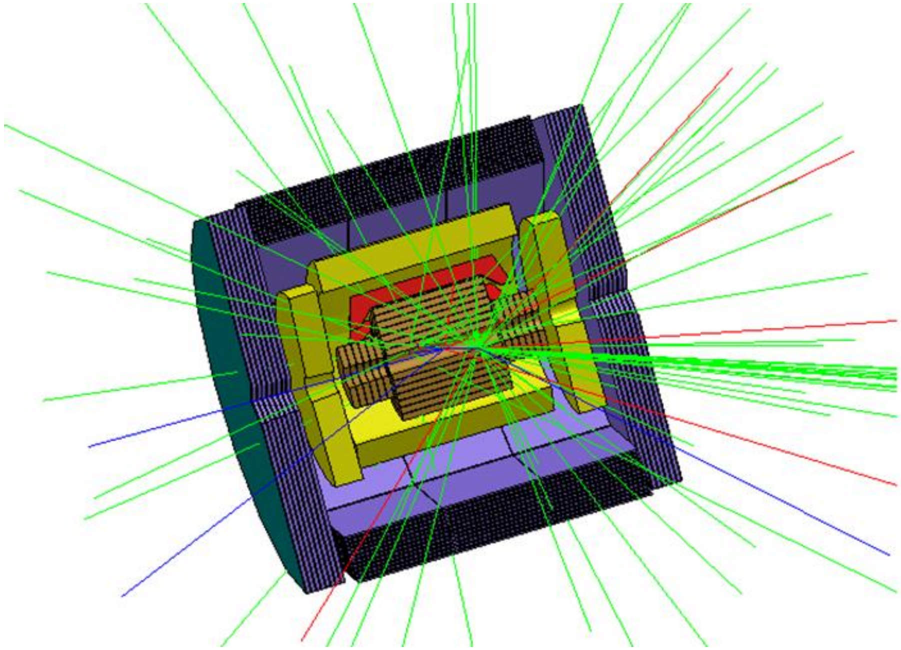
From talks and contributons from V. Ladygin

Outlook.

Proposed measurements using the specialized Spin Physics Detector (SPD) can provide an access to all leading twist collinear GPDs and TMDs of quarks and anti-quarks in nucleons.

The set of these measurements permits to tests the quark-parton model of nucleons at the QCD twist-2 level with minimal systematic errors.

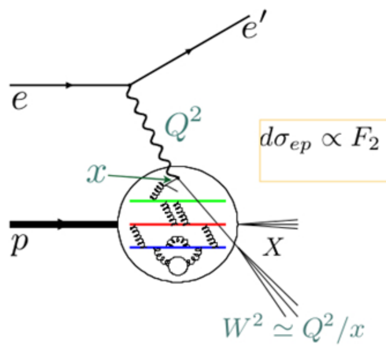
One is also could contribute in «spin crisis» solving.



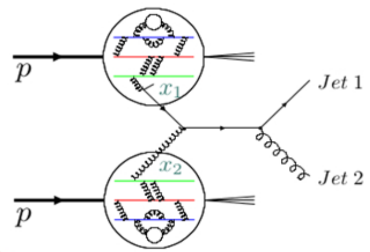
Backup slides

Spin Physics at NICA.
Main tasks and measurements.

- How do we probe the structure and dynamics of matter in ep vs. pp scattering?

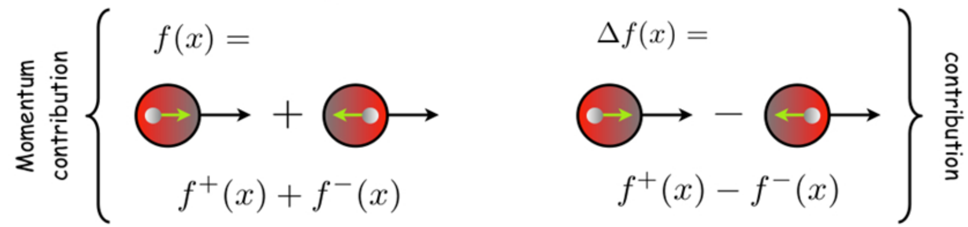


$$d\sigma_{ep} \propto F_2 = \sum_q x e_q^2 f_q(x)$$



Universality

$$d\sigma_{pp} \propto f_1 \otimes f_2 \otimes \sigma_h \otimes D_f^h$$ Factorization



- Spin sum rule:

$$\frac{1}{2} = \underbrace{\langle S_q \rangle}_{\frac{1}{2}\Delta\Sigma} + \underbrace{\langle S_g \rangle}_{\Delta G} + \langle L_q \rangle + \langle L_g \rangle$$

(R.L. Jaffe and A. Manohar, Nucl. Phys. B337, 509 (1990))

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$

$$\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2)dx \qquad \Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx$$

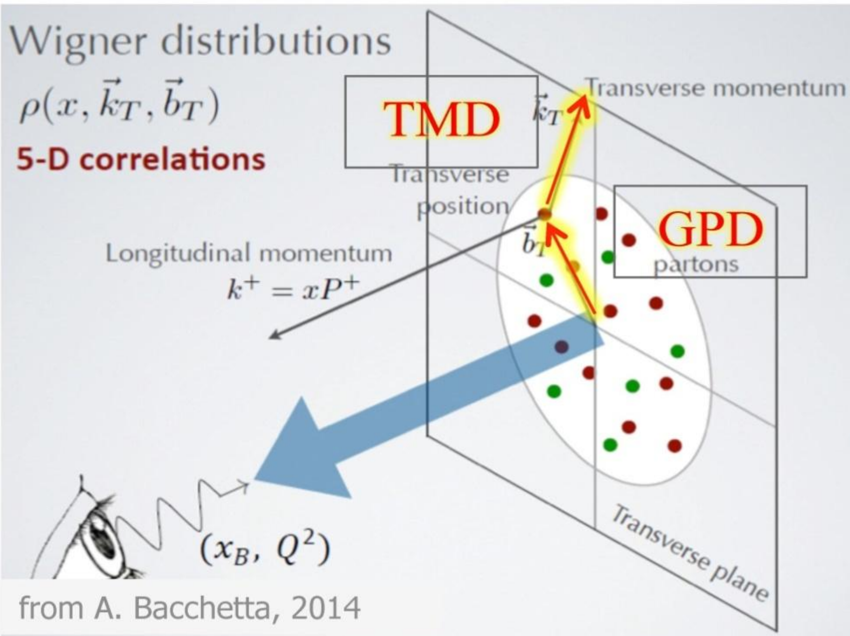
- Current status:
  - Data only from fixed-target experiments (Limited reach in x and Q^2) mostly at lower energy
  - Quark spin contribution is small (~25%):

$$\Delta\Sigma = 0.242 \; (Q^2 = 10\,\mathrm{GeV}^2) \qquad \frac{1}{2}\Delta\Sigma = 0.121$$

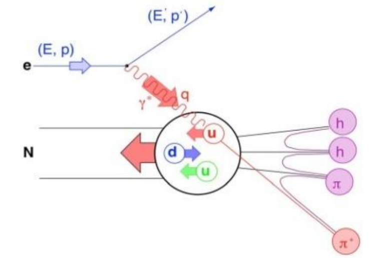
(D. deFlorian et al., Phys. Rev. D80, 034030 (2009))

  - Δg - from scaling violations - unconstrained so far!

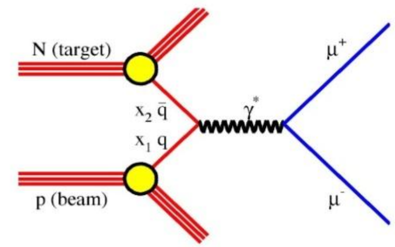
Spin Physics at NICA. Main tasks and measurements.



Semi-Inclusive DIS



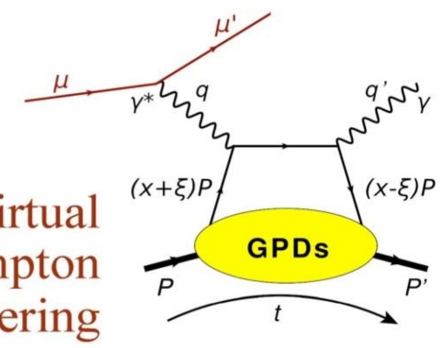
Drell-Yan process



Transversity Momentum Distributions: TMD (x,k_T): probe the transverse parton momentum dependence

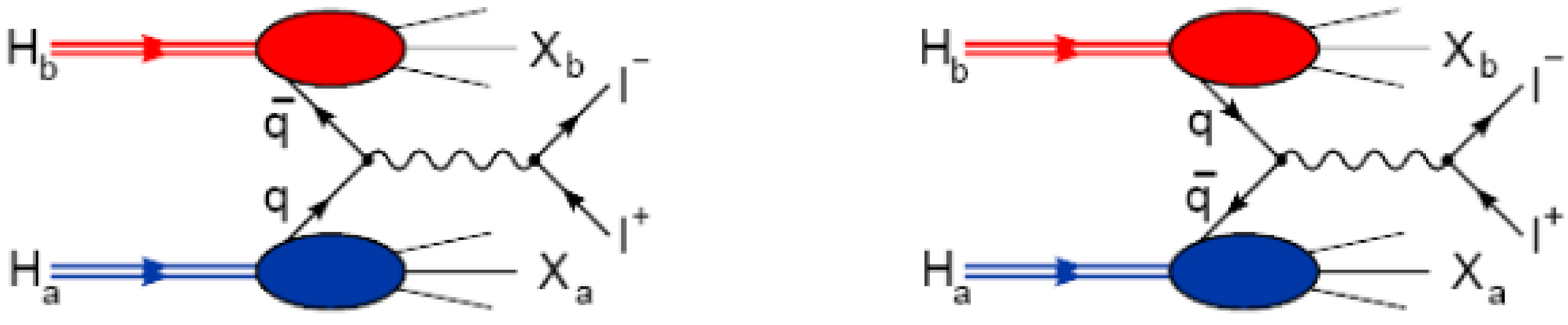
Generalized Parton Distributions : GPD (x,b_T): probe the transverse parton distance dependence

Deeply Virtual Compton Scattering

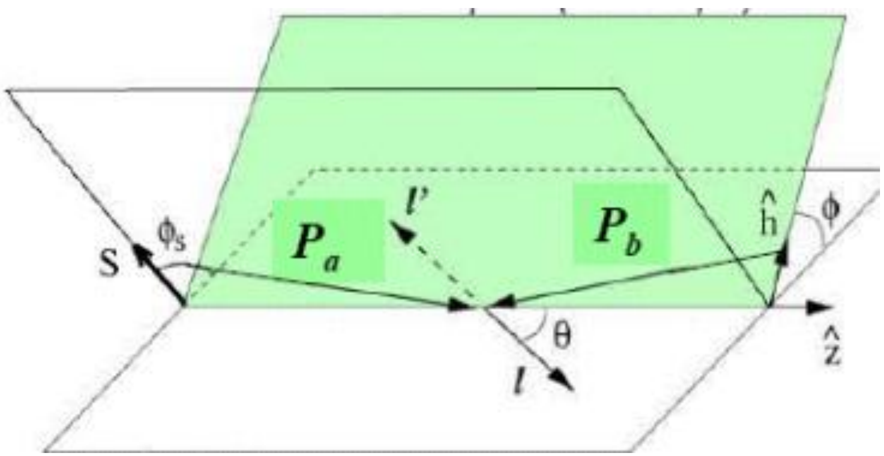


Main tasks and measurements. DY studies

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



(a) (b)



- Transversity: $A_{UT}^{\sin(\phi_h+\phi_S)} \propto h_1 \otimes H_1^{\perp}$
- Sivers: $A_{UT}^{\sin(\phi_h-\phi_S)} \propto f_{1T}^{\perp} \otimes D_1$
- Pretzelosity: $A_{UT}^{\sin(3\phi_h-\phi_S)} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$
- Boer-Mulders: $A_{UU}^{\cos(2\phi_h)} \propto h_1^{\perp} \otimes H_1^{\perp}$
- Worm-Gears: $A_{UL}^{\sin(2\phi_h)} \propto h_{1L}^{\perp} \otimes H_1^{\perp}$; $A_{LT}^{\cos(\phi_h-\phi_S)} \propto g_{1T}^{\perp} \otimes D_1$

Main tasks and measurements. DY studies

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, …)

$p^{\uparrow}(D^{\uparrow})p(D) \to \gamma^* X \to l^+ l^- X$

$p(D)p(D) \to \gamma^* X \to l^+ l^- X$

Transversity and first moment of Boer-Mulders PFDs (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, …)

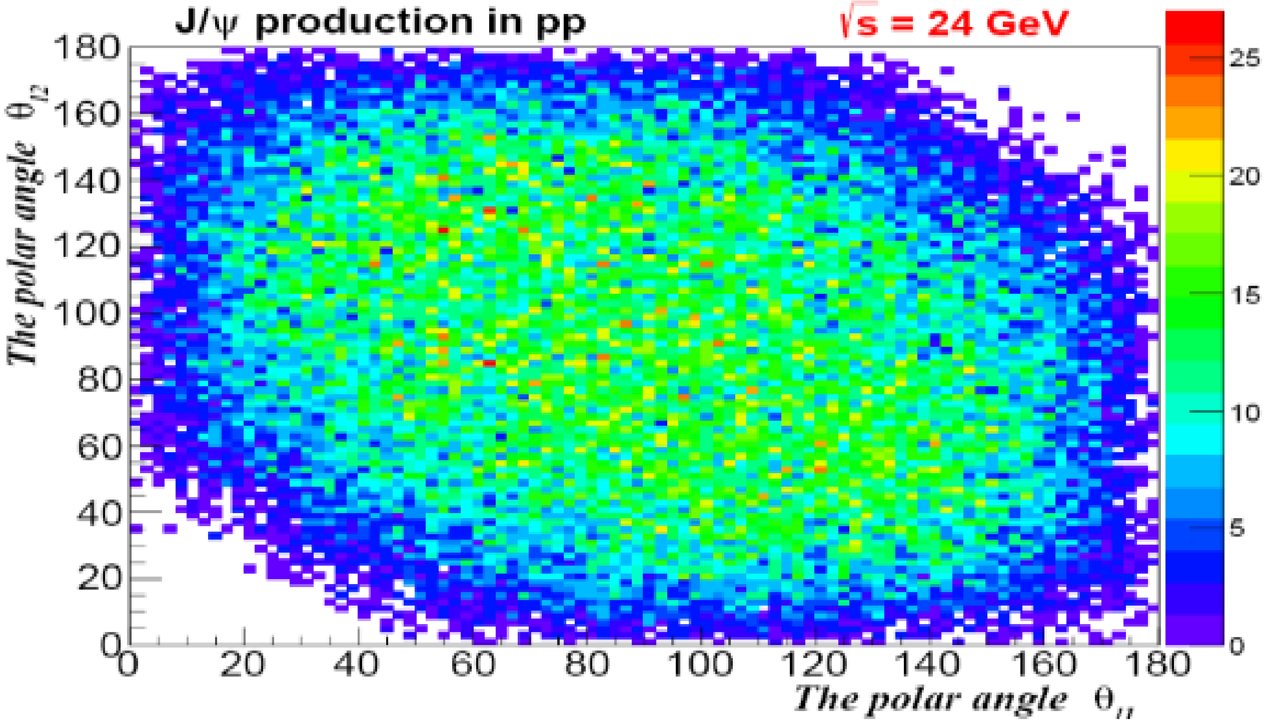
$$h_1^{\perp}(x, \mathbf{k}_T)\Big|_{SIDIS} = -h_1^{\perp}(x, \mathbf{k}_T)\Big|_{DY}$$

$$f_{1T}^{\perp}(x, \mathbf{k}_T)\Big|_{SIDIS} = -f_{1T}^{\perp}(x, \mathbf{k}_T)\Big|_{DY}$$

Crucial test of our understanding of T-odd effects within QCD and the factorization approach to the processes sensitive to transverse parton momenta.

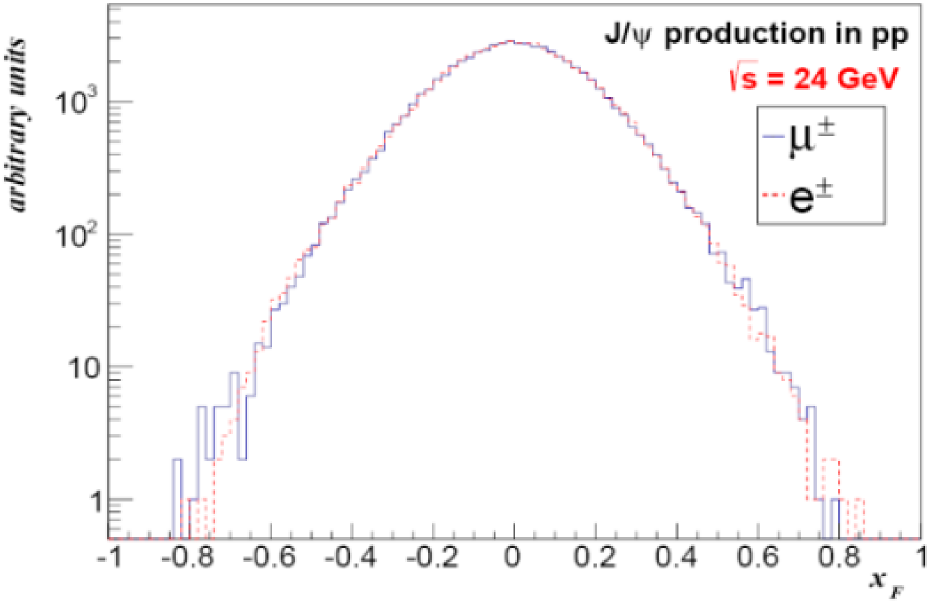
Main tasks and measurements. J/ψ studies.

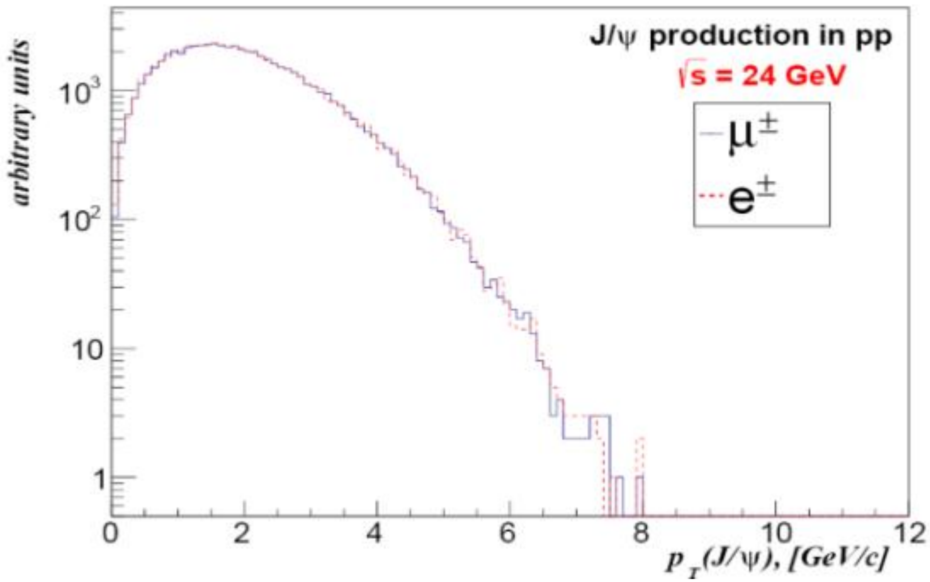
The correlation between lepton polar angles is also studied.
Most of the lepton pairs (61%) are within the 35-145 deg. angular interval;
in 35% of pairs one lepton could be found in the 35-145 deg. angular interval whereas the other – in the 3- 35 deg. interval.
About 3% of leptons could be registered in the forward and backward 3-35 deg. Angular intervals.
These types of angular distributions require almost 4π geometry for SPD.



Main tasks and measurements.
J/ψ studies.

**The Feynman variable, x F , and the transverse momentum, p T ,
of directly produced J/Ψ mesons .**



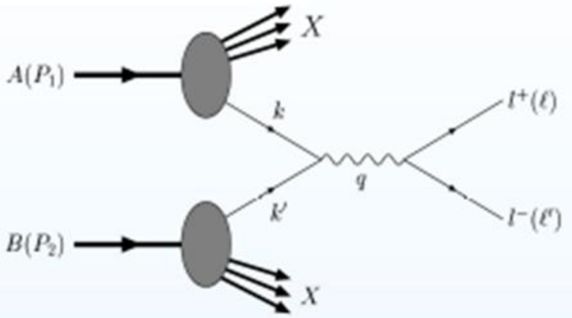


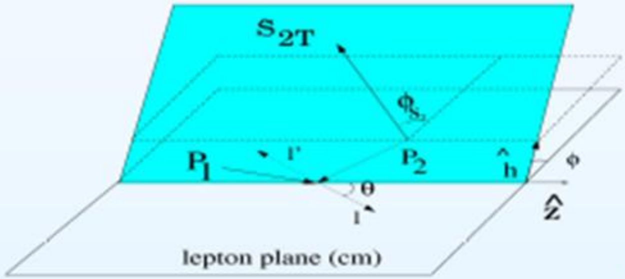
Spin Physics at NICA:MMT-DY

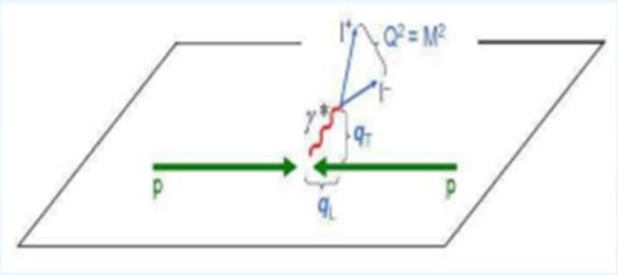
V.A.Matveev, R.M.Muradian, A.N.Tavkhelidze,

JINR P2-4543, JINR Dubna 1969;SLAC-TRANS-0098 JINR R2-4543,Jun 1969

S.D.Drell. T.M.Yan SLAC-PUB-0755. Jun 1970. Phys.Rev.Lett. 25 (1970)





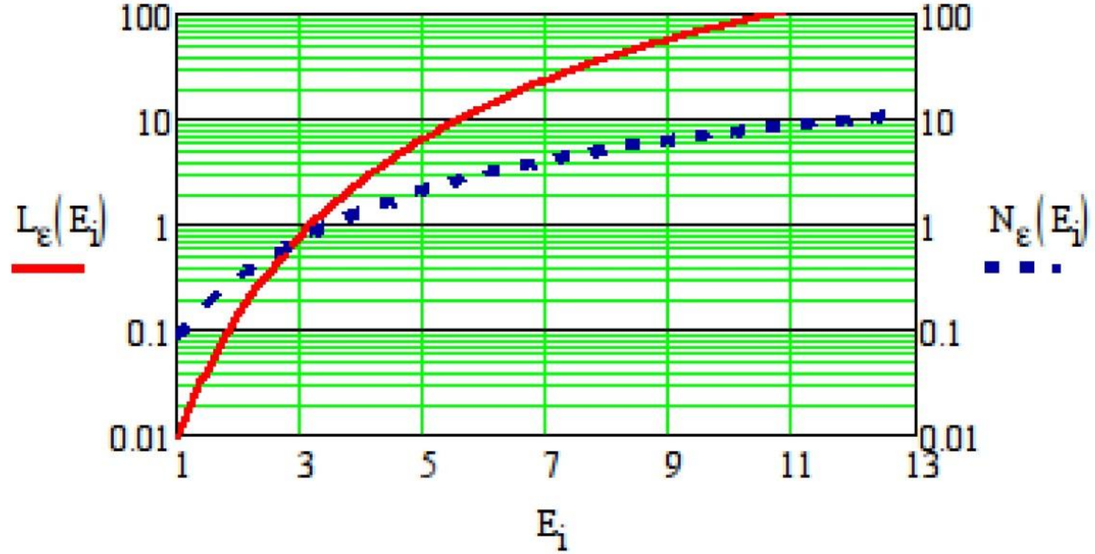


- $x_1 = \frac{Q^2}{2p_1 q}, \quad x_2 = \frac{Q^2}{2p_2 q}$ – fractions of the longitudinal momentum of the hadrons A and B carried by the quark and antiquark which annihilate into virtual photon
- $s = (p_1 + p_2)^2 \simeq 2p_1 p_2$ – the center of mass energy squared

$$Q^2 = M^2 \simeq x_1 x_2 s \equiv \tau s$$
$$y - \frac{1}{2} \ln \frac{x_1}{x_2}$$
$$x_F = x_1 - x_2$$
$$x_1 = \frac{\sqrt{x_F^2 + 4\tau} + x_F}{2} = \sqrt{\tau} e^{y}$$
$$x_2 = \frac{\sqrt{x_F^2 + 4\tau} - x_F}{2} = \sqrt{\tau} e^{-y}$$

- θ – production angle in the dilepton rest frame – polar angle of the lepton pair in the dilepton rest frame
- ϕ – azimuthal angle of lepton pair
- ϕ_S – azimuthal angle of the hadron polarization measured with respect to lepton plane

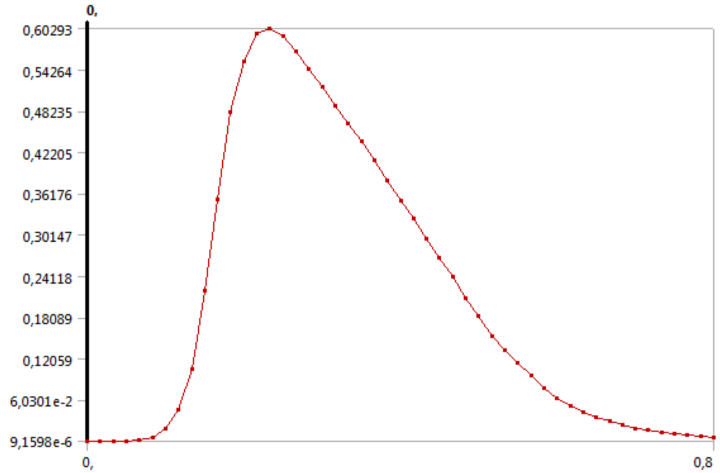
NICA Collider Luminosity in pp Collisions

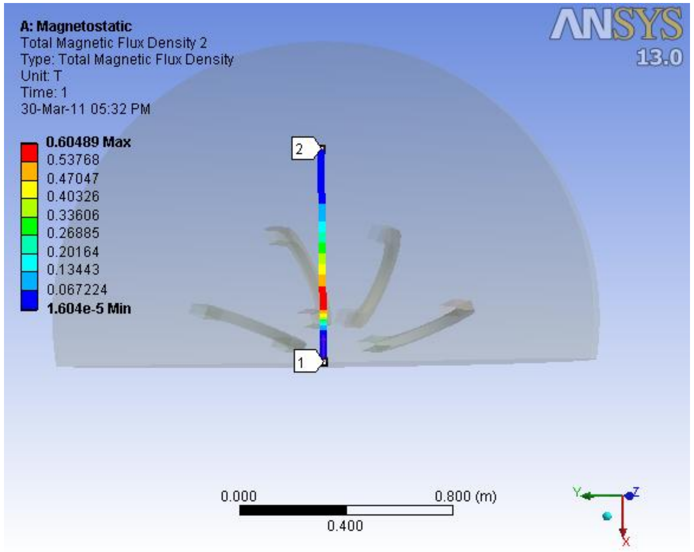


Energy in GeV. Luminosity in 10^{30} cm^{-2}s^{-1}.

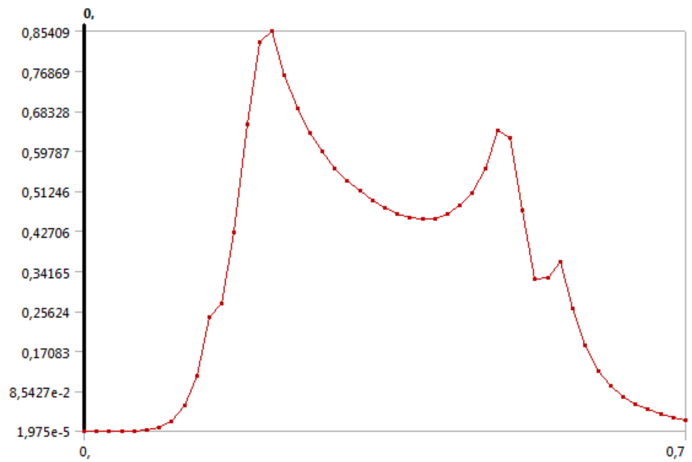
(from A.D.Kovalenko's talk)

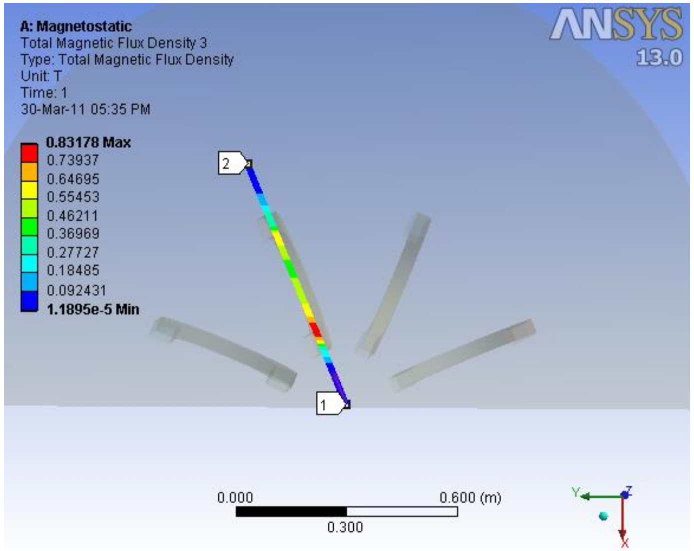
Possible layout of SPD. Magnet.





распределение поля по радиальной оси.





распределение параллельно обмотке.

NICA collider

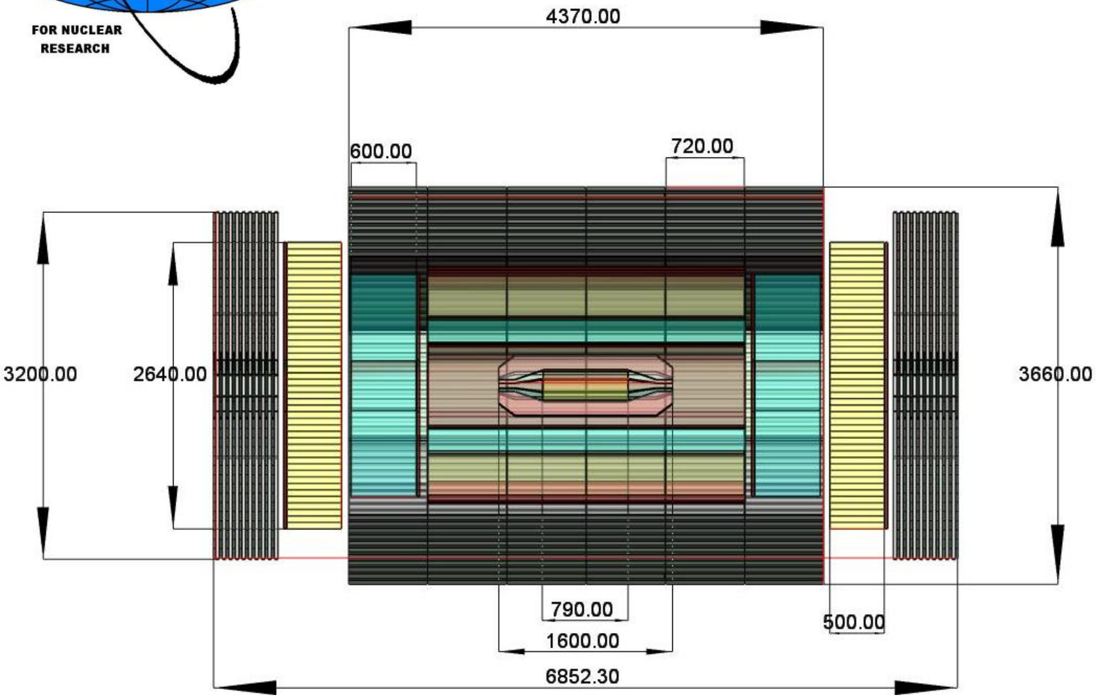
NICA

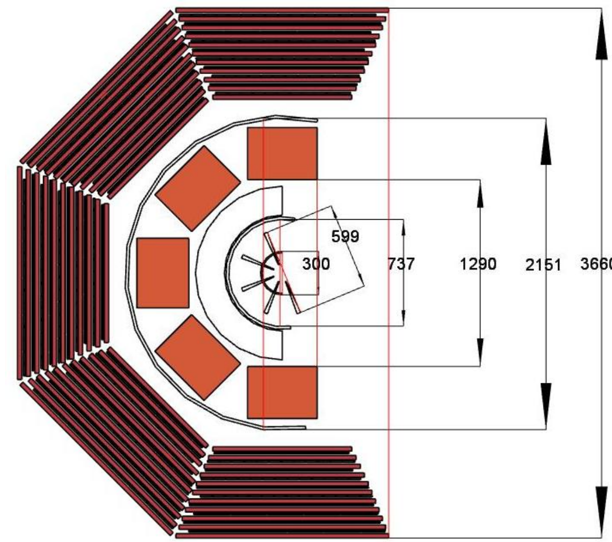
The main requirements to the NICA polarized beam can be summarized as follows:

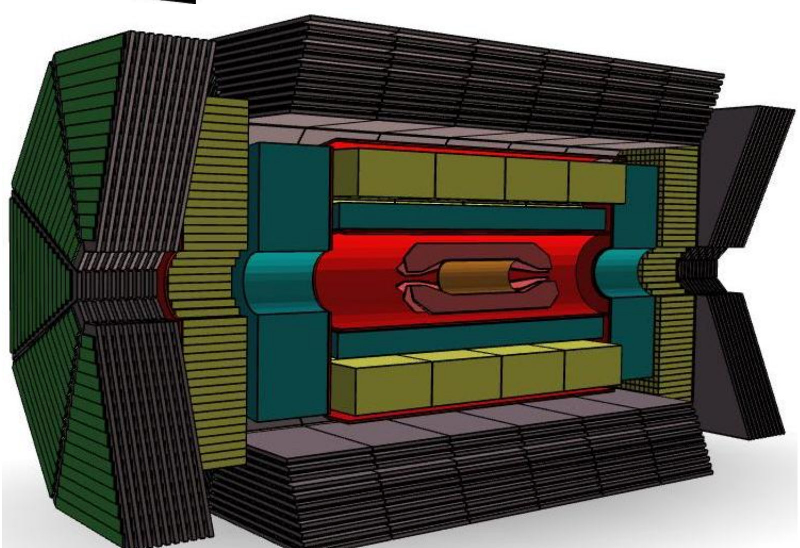
1. The luminosity at level of 10^{30}- 10^{32} $см^{-1}s^{-1}$, for wide energy beams range 5 -12 GeV for proton.
2. At injection it is necessary to provide, that the direction a spin coincided with a vector direction a spin precession in rings.
3. To control on the beams polarization the special locations of polarimeters are necessary, it can be set-ups with gas polarized target (or jet target).
4. To safe beams polarization at long time it is necessary to install the "the Siberian snakes».
5. To minimize the systematical uncertainties for asymmetry measurements it is necessary to provide the spin rotation-that will demand inserts similar to item 4 and number of the superperiods in accelerator up to grater than 4.
6. To provide various spin orientations it is necessary, to equip IP with duplicators (including combinations longitudinal-transersel polarization).
7. To provide of polarized nn and np-collisions, it is necessary to install the stations of stripping protons (probably and neutrons) at the rings. Fixed target experiment.
8. It is necessary to create the system of luminosity measurements with relative accuracy ~ 1% . Using SPD ?
9. The injection system should provide possibility to form the sequence of injection cycles with different spin states (longitudinal, transverse, non polarized).
10. To provide the tenzor polarized deuteron beams and corresponding possibility to operate spin orientation .
11. It is necessary to provide the collisions of polarized beams with different kind of particles: protons-deuteron, protons-helium, deuteron-helium at different energies.

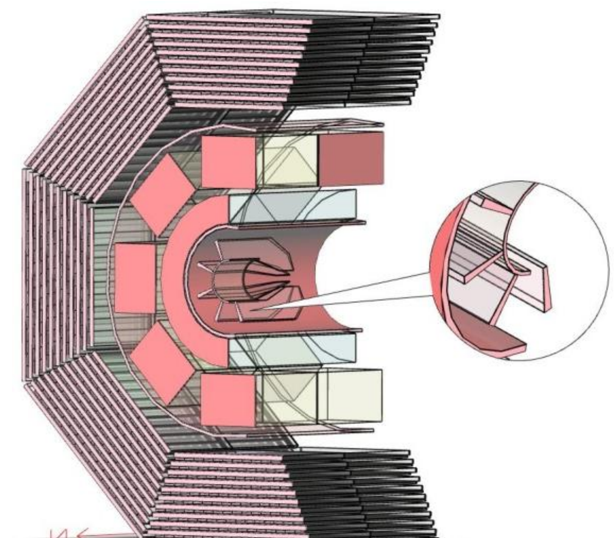
SPD EXPERIMENT AT NICA.

SPD.





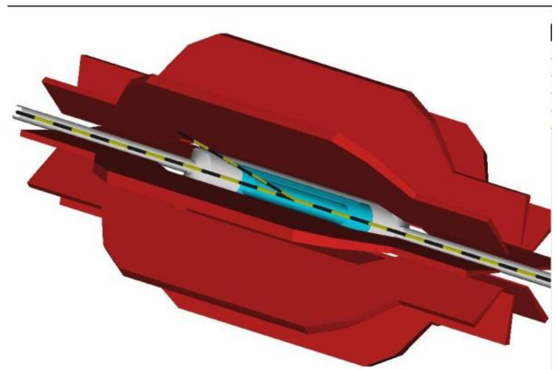


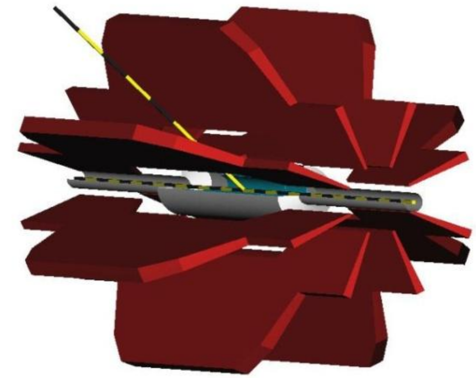


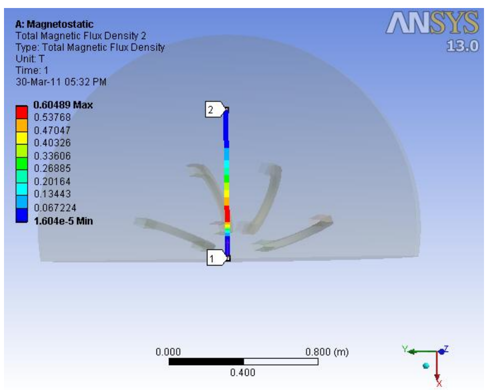
SPD EXPERIMENT AT NICA.

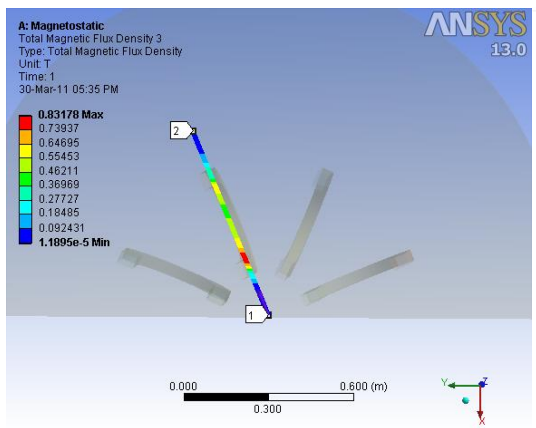
SPD.Torrid magnet.

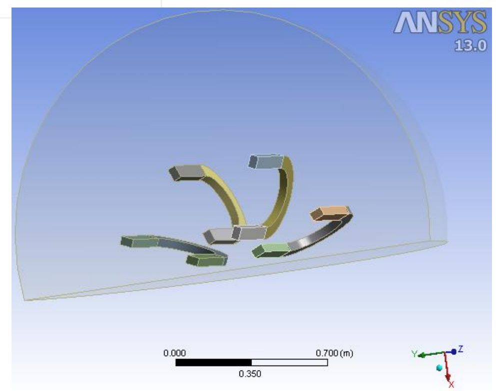
- 8 coils
- ~100 x 40 cm coils
- average integrated field: ~ 0.8 - 1.0 Tm
- acceptance ~ 80 %

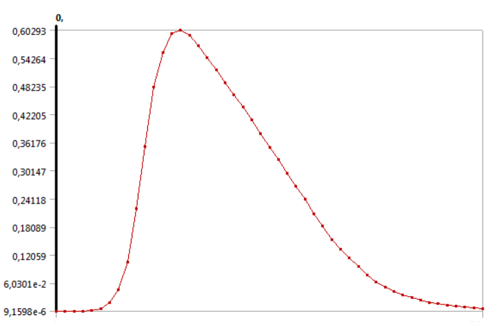


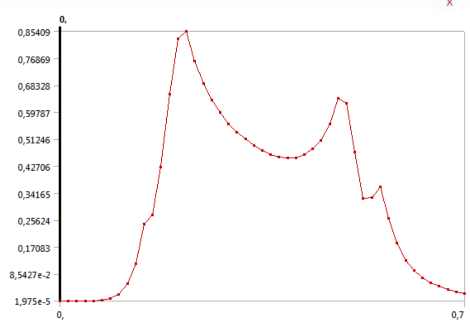


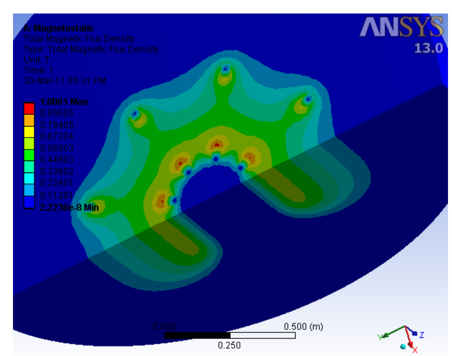








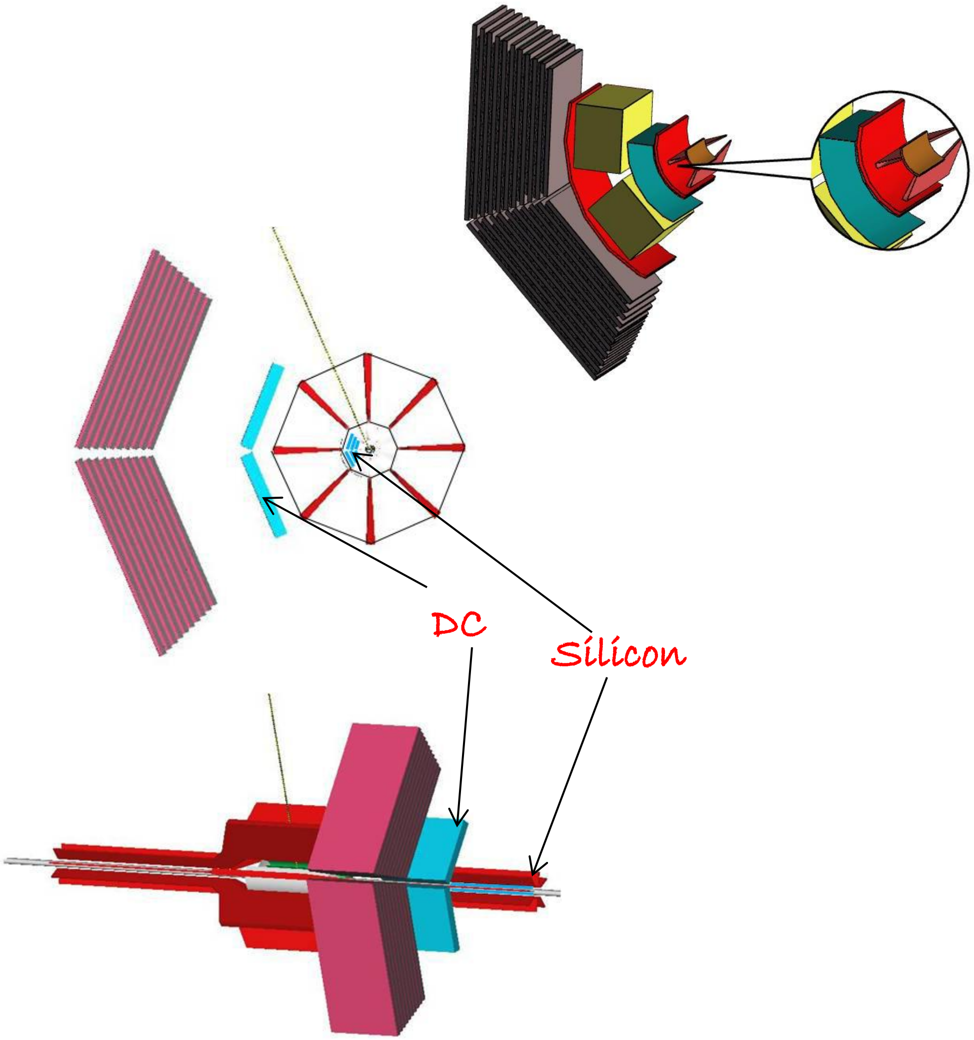




Done by Pivin R.

SPD EXPERIMENT AT NICA.

SPD. Vertex detector and DC.



Several layers of double sided Silicon strips can provide a precise vertex reconstruction and tracking of the particles before they reach the magnet.

The design should use a small number of silicon layers to minimize the radiation length of the tracking material.

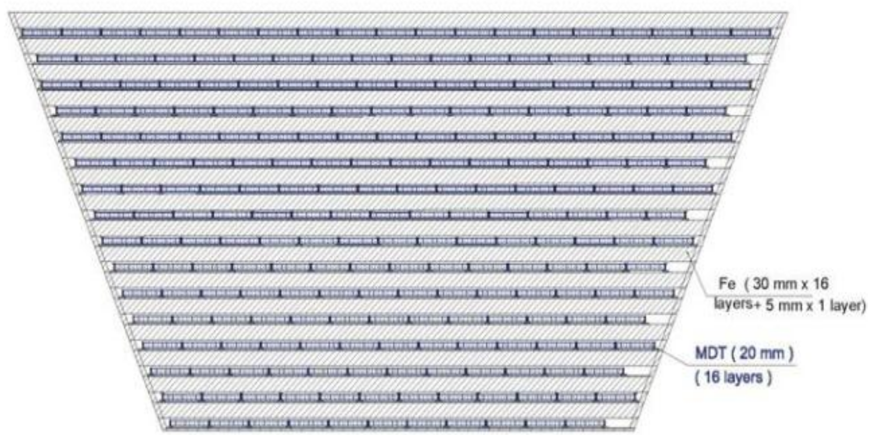
With a pitch of 50-100 µm it is possible to reach an spatial resolution of 20-30 µm.

Spatial resolution would be provide 50-80 µm for precision of the vertex reconstruction, and permits to reject the secondary decays of mesons into leptons.

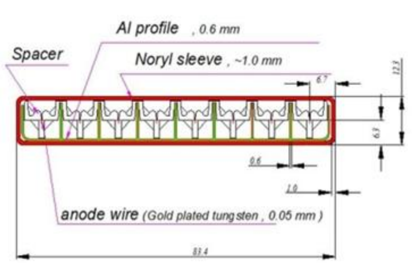
The coordinate resolution of 150-200 µm can be achieved with conventional Drift Chambers. The chambers can be assembled as modules consisting of several pairs of tracking planes with wires at 30 ; 0 ; 0 ; +30 deg. with respect to the direction parallel to the magnetic field lines. This can provide the momentum resolution of the order of 13 % over the kinematic range of the detector.

SPD EXPERIMENT AT NICA.

SPD.Range System.



MDT cross-section



The system of MDT layers with Fe layers called by Range System (RS) is used in SPD as moun detector and main element of Particle Identification System.

It can provide the clean (>95%) muon identification for muon momenta grater than 1 GeV.

The combination of responses from EM calorimeter and RS can be used for the identification of pions and protons in the wide energy range.

RS provides good coordinate accuracy.

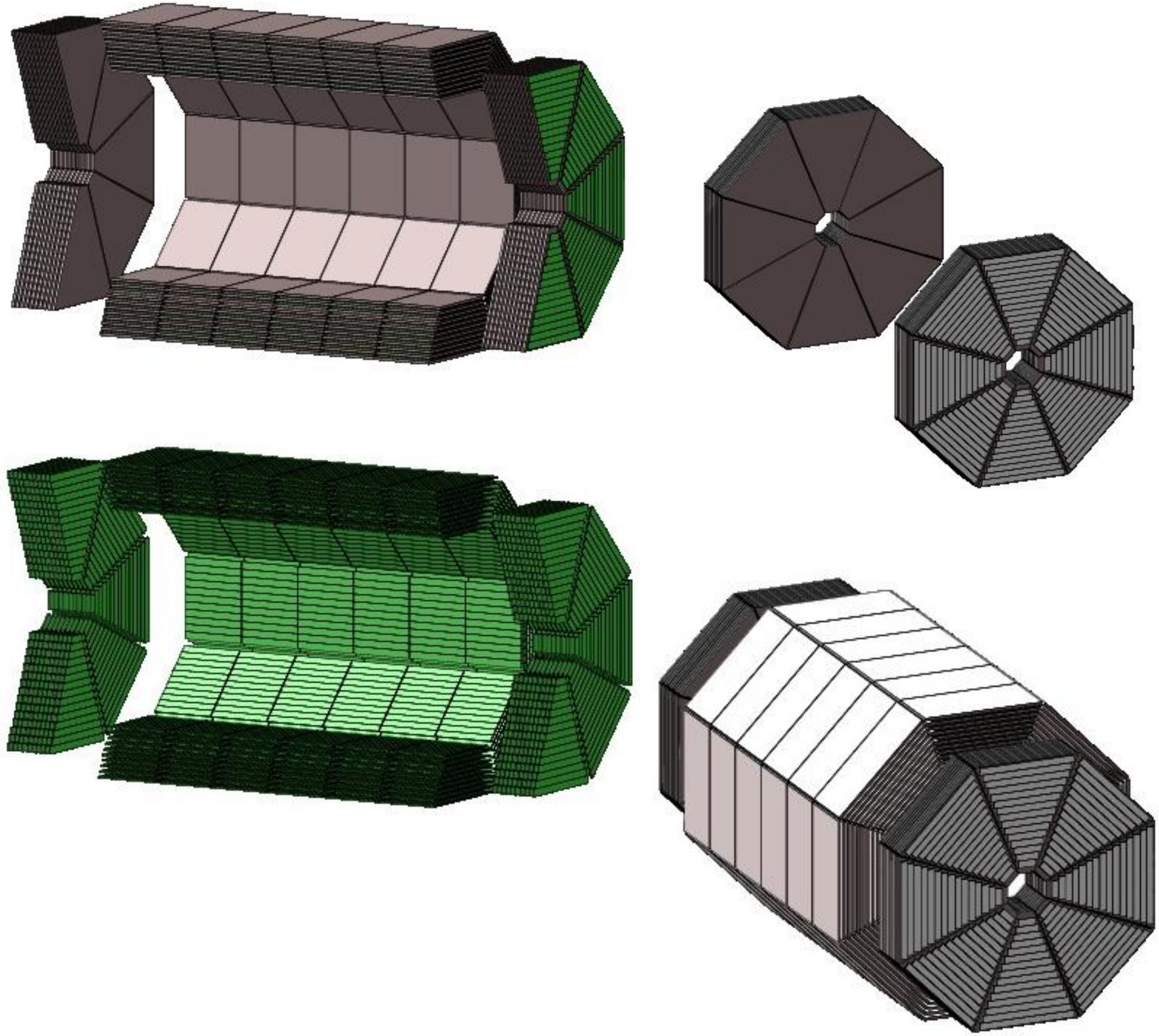
Plots are from “ Muon TDR for PANDA ”, PANDA Collab., November 2011

V.Abazov et al., Instrum.Exp.Tech.53:648-652,2010, Prib.Tekh.Eksp.5:32-36,2010.

DLNP group, leader G.Alexeev

SPD EXPERIMENT AT NICA.

SPD.Range System.



The Range System consists of two parts:
Barrel and two End cups.

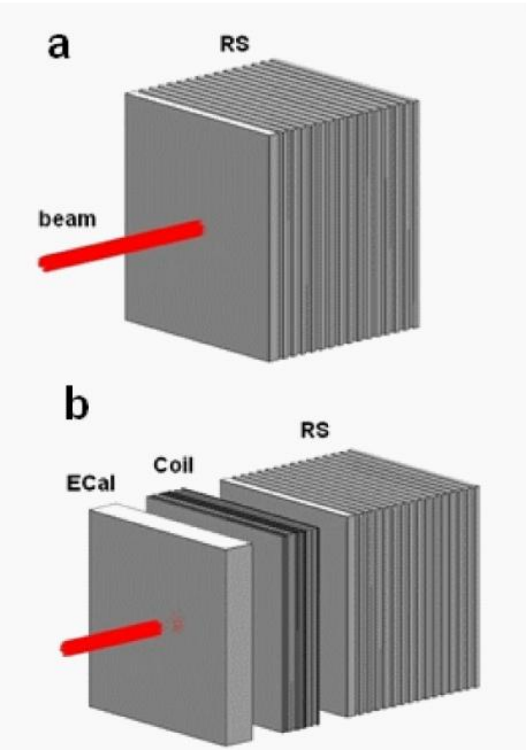
The preliminary sizes of RS are as follows:
about 6.8 m along beam line and 3.7 m in diameter.

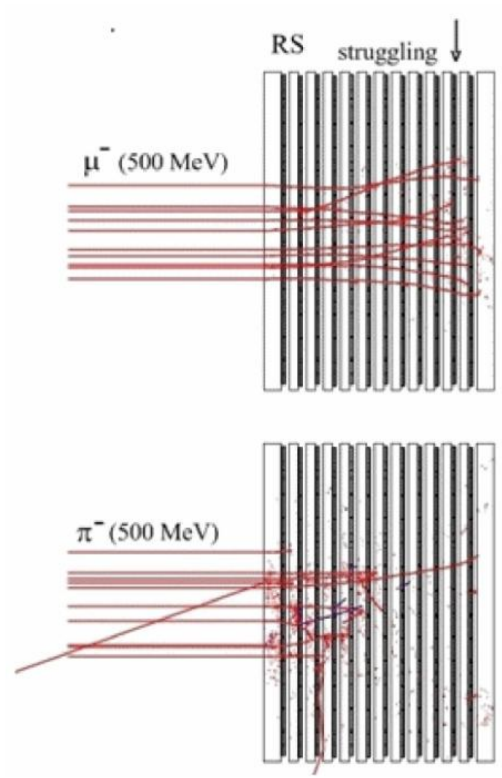
The RS designed with consists of 4140 MDT units for barell, 2x1200 units for End-cups.

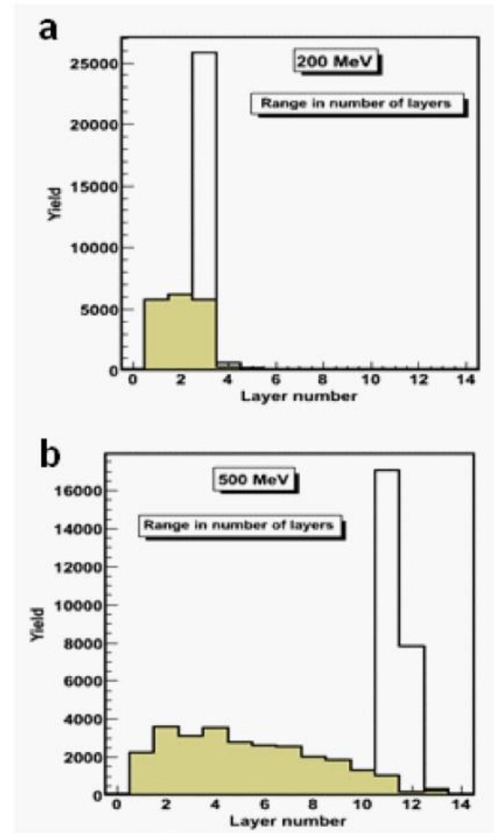
Total: 6540 ch.

SPD EXPERIMENT AT NICA.

SPD.Range System.



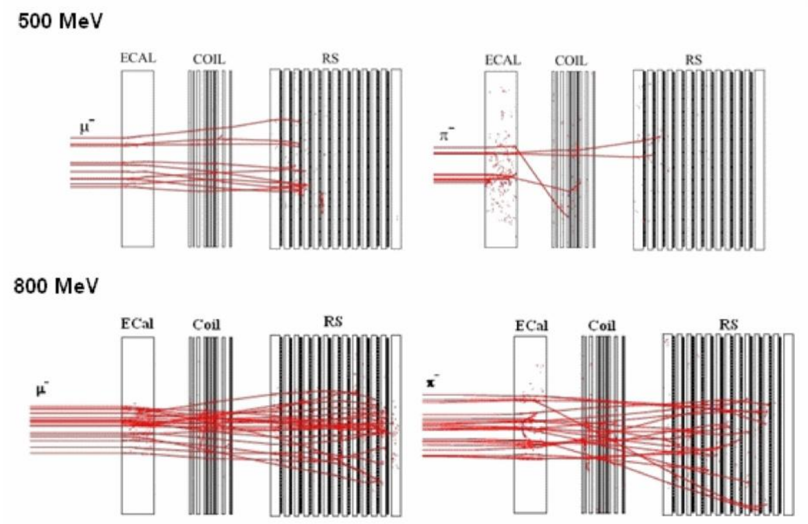


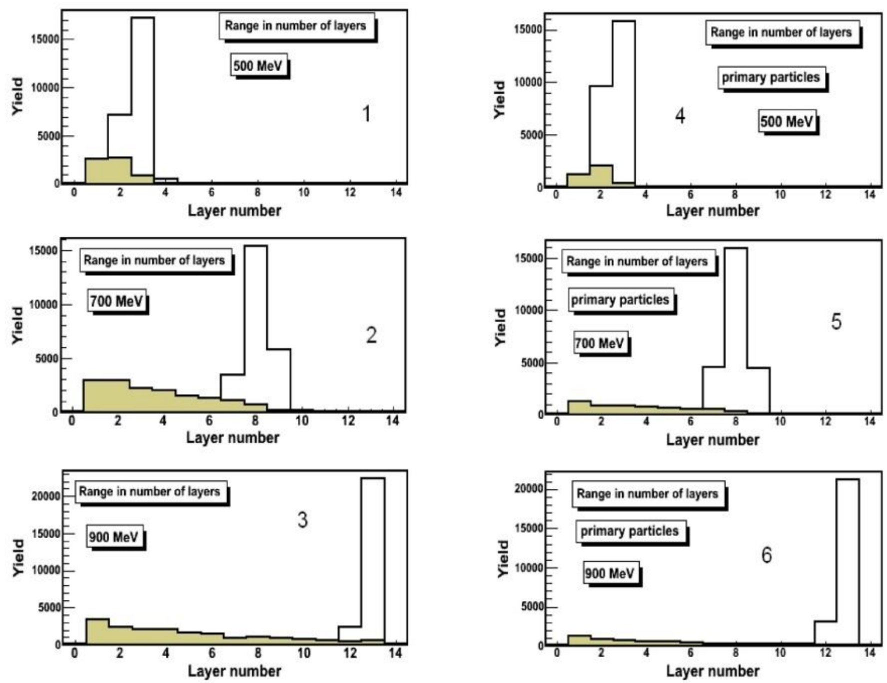


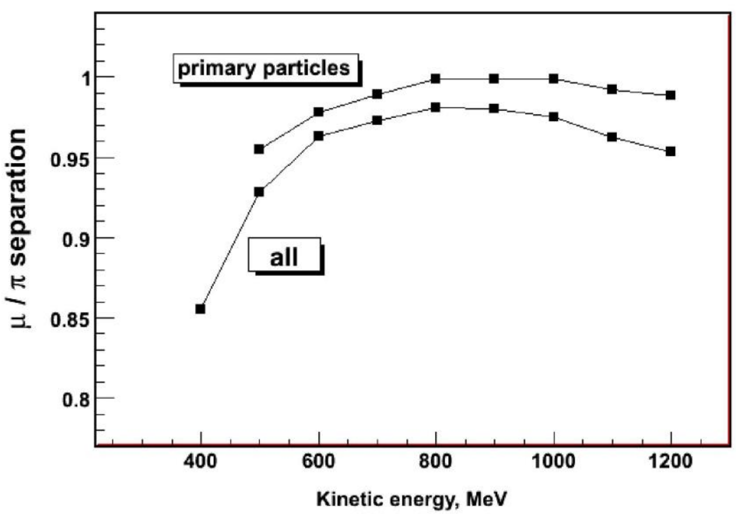
Plots are from " Muon TDR for PANDA ", PANDA Collab., November 2011

SPD EXPERIMENT AT NICA.

SPD.Range System.





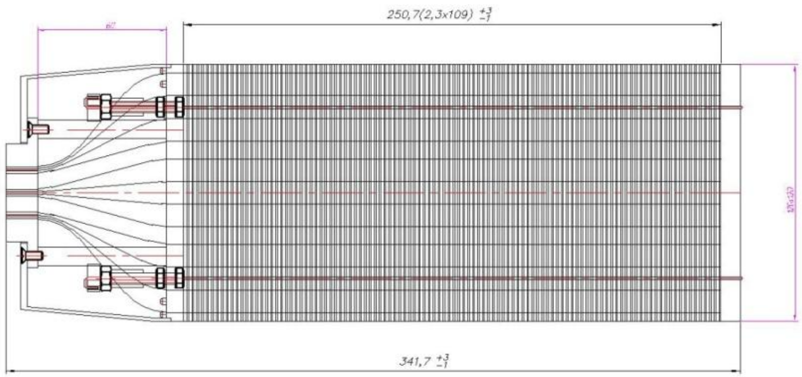


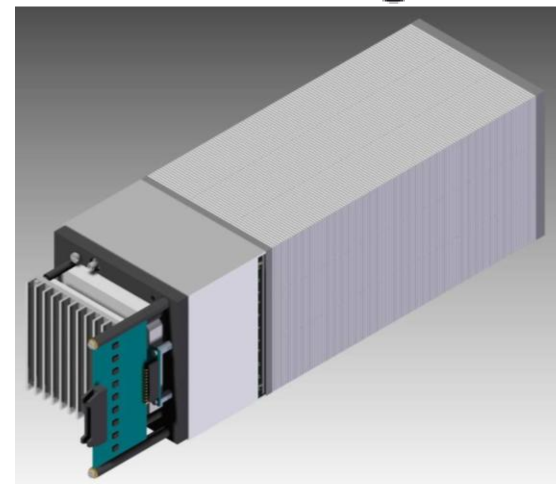
Estimated μ/π for E>1 GeV is more than 96%

Plots are from " Muon TDR for PANDA ", PANDA Collab., November 2011

SPD EXPERIMENT AT NICA.

SPD.EMC.





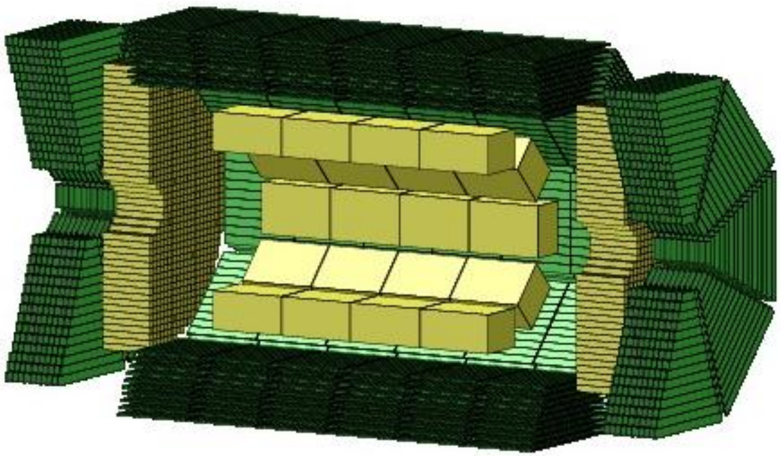
Technology	Shashlyk
Scintillator	Polystyrene Kharkov
Absorber	Lead
Number of layers	109
Sc / Pb plates thickness, mm	1.5/0.8
Pb/Sc plates dimension, cm	12.0x12.0
Moliere radius, cm	3.5
Radiation length, cm	1,64
Number of tower	9
Fiber	BICRON BCF91AMC d=1.2 mm
Number of fibers per tower	16
Diam. of bundle, mm	6.5
Light guide	Winston cone glued to photodetector
Photodetector	MAPD -Zecotek
Total thickness, cm	25.2(~ 15 X0)
ADC	MSADC
Thermostabilization	Peltier cooler

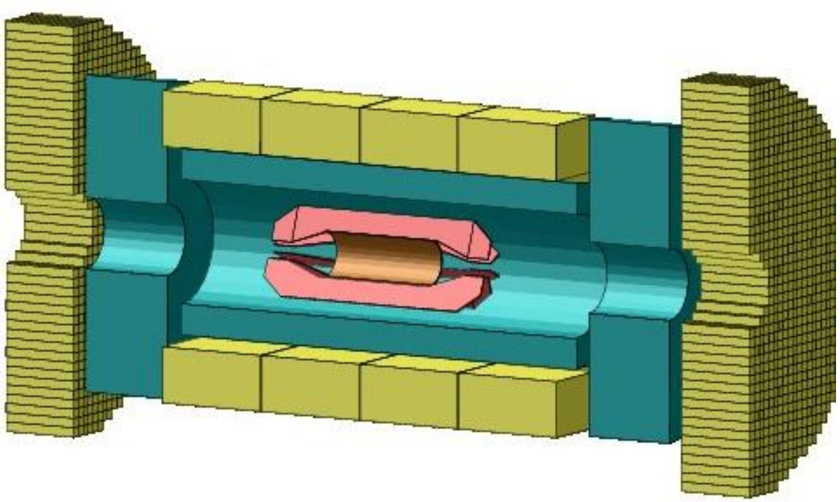
Module:

- size is 12x12 cm^2
- 9 cells, size is 4x4 cm^2
- 9 MSADC channels
- Temperature stabilization system (Peltier element, electronics)
- 9 Amplifiers
- 9 light collection system
- Control system (LED, Laser)
- Power supply

SPIN PHYSICS AT NICA.

SPD.EMC.





- The calorimeter consists of ``shashlyk'' modules with the application of new readout based on AMPD technology.

- The module design is defined with R&D performed in COMPASS.

- The calorimeter will be used for the
- triggering of DY electrons.

- There are three parts of EM: barrel and two end-caps with 4384 of 9th towers modules (39465 ch.)

Module production in ISMA, Kharkov
MAPDs from Zicotek
Assembling and testing in JINR

SPIN PHYSICS AT NICA.

SPD. Trigger system.

Trigger logic could have two-level structure.

Dedicated hardware processors may be used at Level 1 which receives signals from the scintillation hodoscopes, EM calorimeter and the Range System. Using FPGA technology and look-up memories it is possible to organize flexible and efficient triggering.

Local and total energy deposit in the calorimeter, multiplicity in the hodoscopes and information from the range system provide primary event selection.

At Level 2 more time consuming operations could be done. These include search for tracks in the Drift Chambers and the Range System, check of track matching with EM calorimeter hits etc.

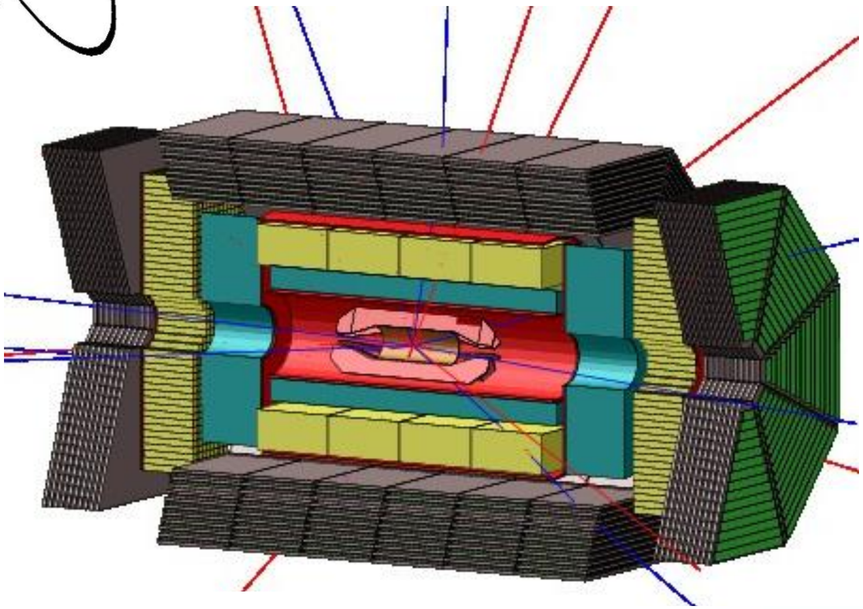
Information from the silicon detectors could also be employed (if needed) at this stage.

Simulations of physics processes with use of real geometry, detector granularity and resolutions are planned in order to develop trigger scheme and selection algorithms.

(prepared by A.Kulikov)

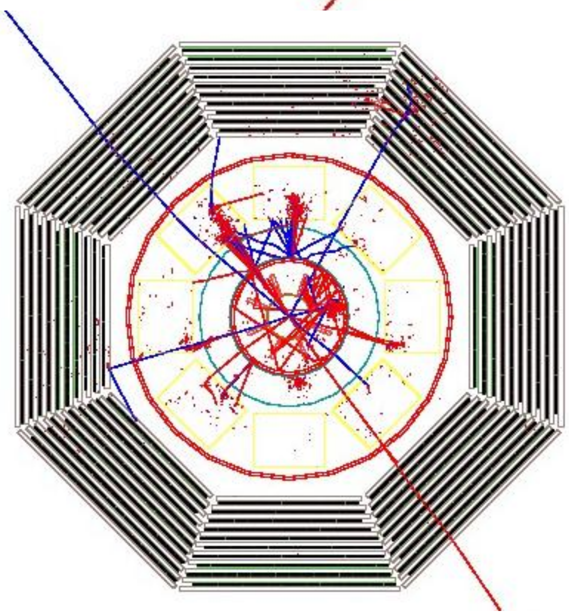
SPIN PHYSICS AT NICA.

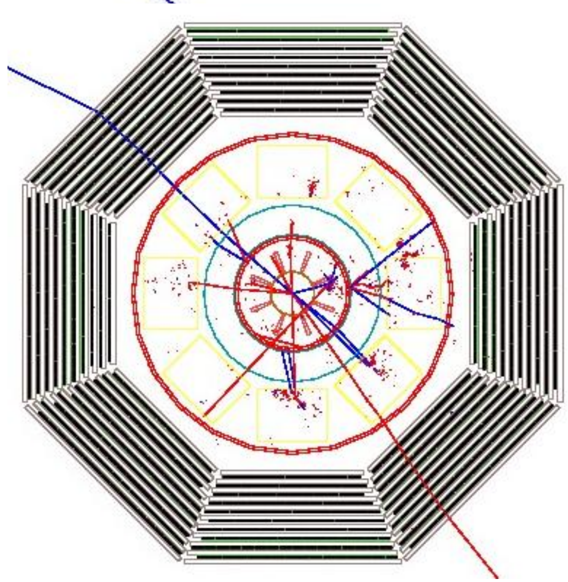
SPD.MC studies.

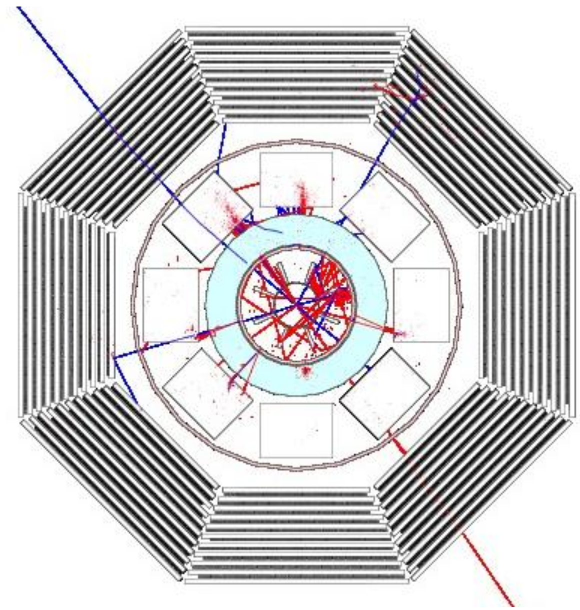


Simulation of MMT-DY in SPD

- for pp beams with E=12.6 GeV;
- pure MMT-DY events;
- PYTHIA generator was used;
- VC, DC, EMC,RS have to be fired.

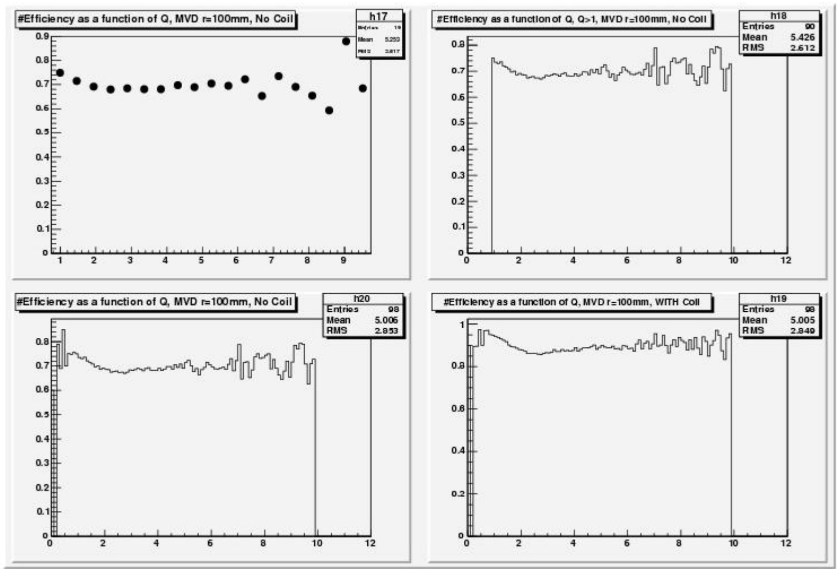


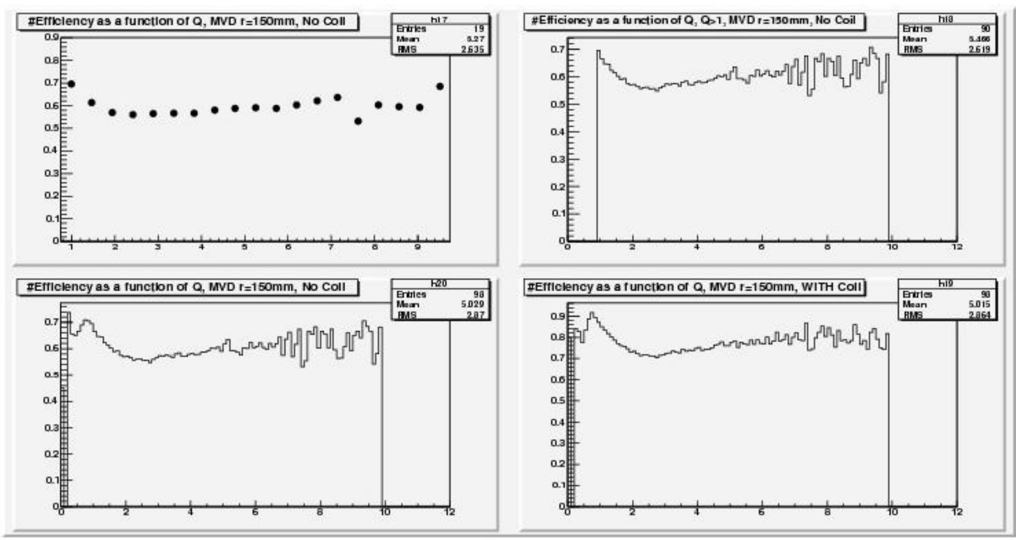




SPIN PHYSICS AT NICA.

SPD.MC studies.





Geometrical effciencies for MMT-DY events with two various position of Vertex detector:
- left plots are at 10 cm from beam line;
- right plots are at 15 cm from beam line.

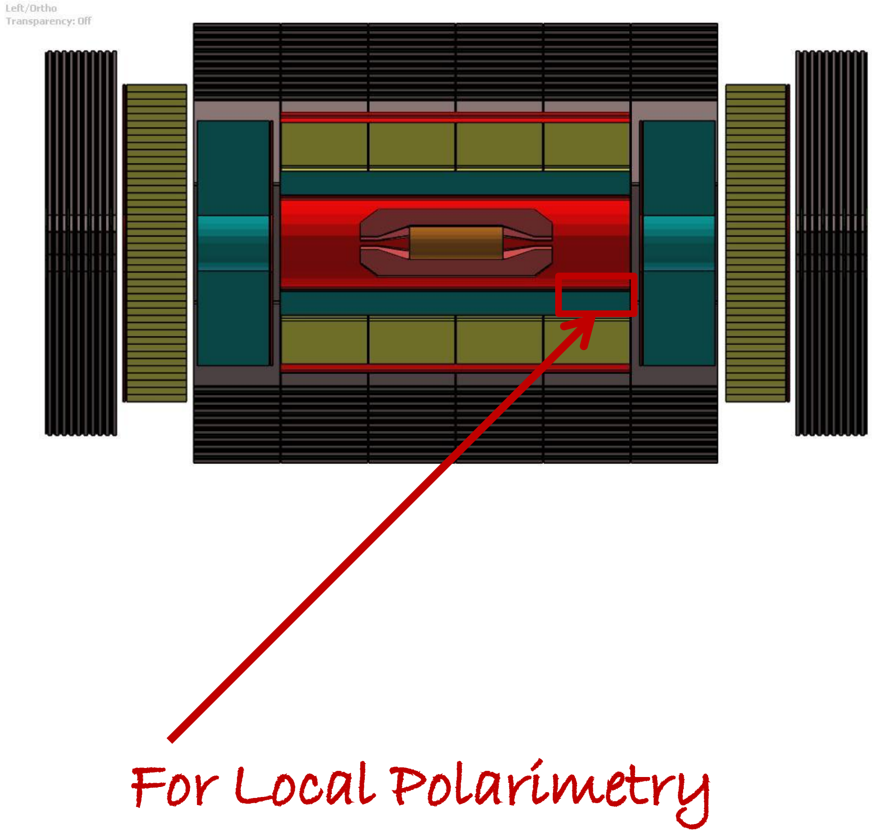
Total efficiencies are ~ 0.6 - 0.7

MC studies by Rodionov V., Macharashvili G. and Meshcheryakov G.

SPD EXPERIMENT AT NICA

SPD.Local Polarimetry.

Main require the tracking system placed in the forward direction.



Proton-proton elastic scattering at forward angles.

- The fast scattered proton at small angles can be detected by the wall of the scintillation counters placed in front of the electromagnetic calorimeter.
- The recoil proton can be detected by the inner silicon tracker and barrel TOF system placed out of the magnetic field.
- Due to 8 sectors structure of the SPD one can easily organize the trigger for «pp- elastic scattering» events because of comlanarity condition.

Inclusive charged pion production also can be used for the local polarimetry purpose.

Three stations of silicon detectors can be installed in front of the drift chambers in each endcup parts of the SPD.

Local polarimetry also can be provided by the measurements of the inclusive neutral pion production.

Proposals were prepared by Ladygin V.

DY experiments in the world.

Table 1: List of the present and future DY experiments in the world.

Experiment	CERN, COMP.-II	FAIR, PANDA	FNAL, E-906	SPAS-CHARM	RHIC, STAR	RHIC, PHENIX	NICA, SPD
mode	***FixTar***	***FixTar***	***FixTar***	***FixTar***	***collider***	***collider***	***collider***
Beam/target	π^-, *p*	*anti-p, p*	π^-, *p*	$\pi^\pm$, *pol.p*	*pp*	*pp*	*pp, pd,dd*
Polarization:b/t	*0; 0.8*	*0; 0*	*0; 0*	*0; 0.5*	*0.5*	*0.5*	*0.9*
Luminosity	$2\cdot 10^{33}$	$2\cdot 10^{32}$	$3.5\cdot 10^{35}$		$5\cdot 10^{32}$	$5\cdot 10^{32}$	10^{32}
$\sqrt{s}$***, GeV***	*19*	*6*	*16*	*8*	*200, 500*	*200, 500*	*10-26*
$x_{1(beam)}$ ***range***	*0.1-0.9*	*0.1-0.6*	*0.1-0.9*	*0.1-0.3*	*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,	$\mu^-\mu^+$	$\mu^-\mu^+$	$\mu^-\mu^+$		$\mu^-\mu^+$	$\mu^-\mu^+$	$\mu^-\mu^+$, e^+e^-
Data taking	*2014*	*>2018*	*2013*		*>2016*	*>2016*	*>2018*
Transversity	NO	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