SPIN PHYSICS AT NICA

A.P. Nagaytsev, JINR , Dubna

NICA Project

JOINT INSTITUTE FOR NUCLEAR RESEARCH

The goal of the NICA project is construction at JINR of the new accelerator facility that consists of

- cryogenic heavy ion source,
- source of polarized protons and deuterons,
- "old" linac LU-20,
- a new heavy ion linear accelerator,
- a new Booster-synchrotron,
- the existing proton synchrotron Nuclotron,upgraded to Nuclotron-M,
- two new superconducting storage rings of the collider,
- new set of transfer channels.

http://nica.jinr.ru

NICA Project

<u>The facility will have to provide:</u>

- ion-ion (Au) and ion-proton collisions

  $1 \div 4.5$ GeV/u, $L \sim 10^{27}$ $cm^{-2}s^{-1}$,

- collisions of polarized proton-proton (deuteron-deuteron) beams

  5-12.6 GeV (2-5.8 GeV/u), $L > 10^{30}$ $cm^{-2}s^{-1}$,

  polarization ?

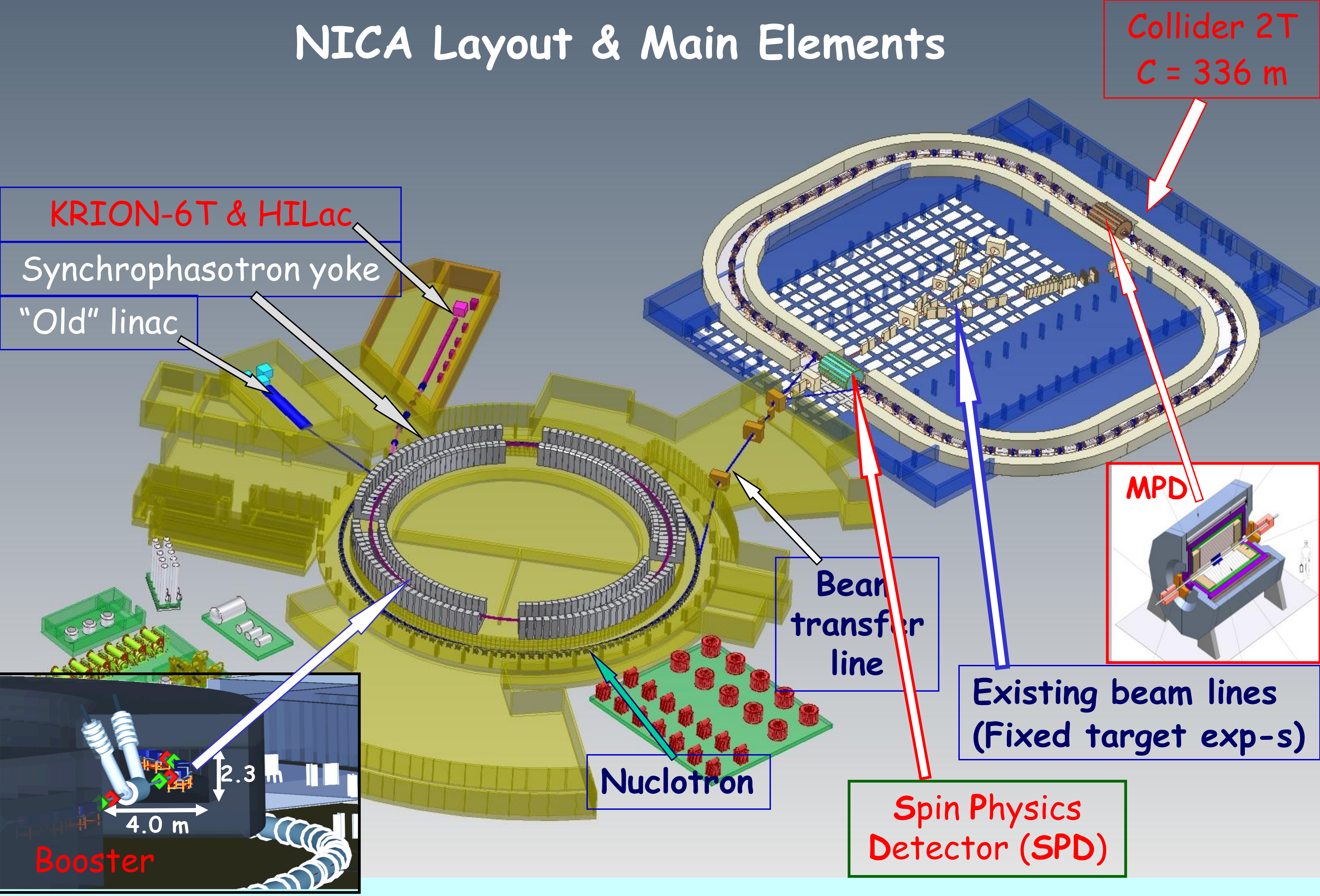
- Fixed target experiments,
- Experiments with internal target,
- Two interaction points (IP). Two detectors.

The Multi Purpose Detector (MPD), aimed for experimental studies of hot and dense strongly interacting QCD matter and search for possible manifestation of signs of the mixed phase and critical endpoint in heavy ion collisions.

<u>The second one is used for the Spin Physics Detector (SPD).</u>

http://nica.jinr.ru

NICA Layout & Main Elements



http://nucloweb.jinr.ru/nica/index1.htm

Spin Physics at NICA. Polarised Beam Source

The Source of Polarized Ions project assumes the design and construction of a universal high-intensity Source of Polarized Deuterons (Protons) using a charge-exchange plasma ionizer.

The output ↑D^+ (↑H^+) current of the source is expected to be at a level of 10 mA

The polarization will be up to 90% of the maximal vector (1) for ↑D^+ (↑H^+) and tenzor (+1,-2) for ↑D^+ polarization

The new source will make it possible to have the polarized deuteron (proton) beam intensity up to the level of 10^{10} d(p)/pulse

Realization of the project is carried out in close cooperation with INR of RAS (Moscow).

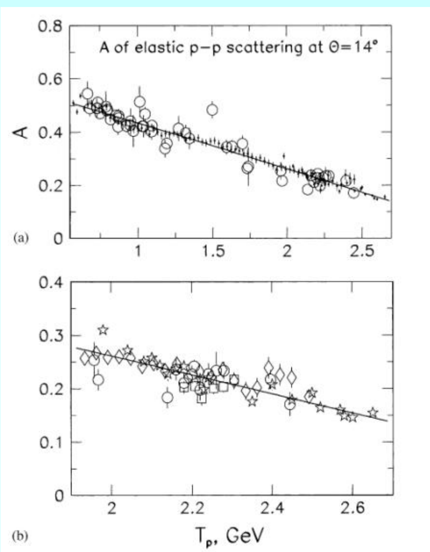
The equipment based on the CIPIOS ion source (IUCF, Bloomington, USA)

Spin Physics at NICA. Polarimetry

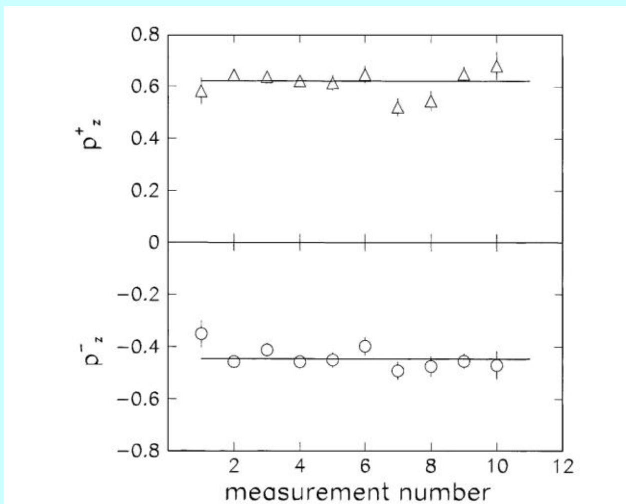
Conceptial project on Beam Polarisation measurements is under preparation.

The aim of the project is to provide the absolute measurements of Proton and Deuteron Beam Polarisation with relative accuracy better 3-5% and relative monitoring the polarization.

The measurements of analysing power in various elastic and quasielastic processes (dp, pp, pC, dC).



The analyzing power A_{oono}(pp) at $\theta_{lab} = 14°$
The solid line is the result of the quadratic fit



The polarization of the proton beam during the experiment

Experience on polarimetry at LHEP:NIM A497 203, 340-349

The measurement of vector polarization of deuteron beam at P_d=2.5-9.0 GeV based on elastic and quasielastic processes.

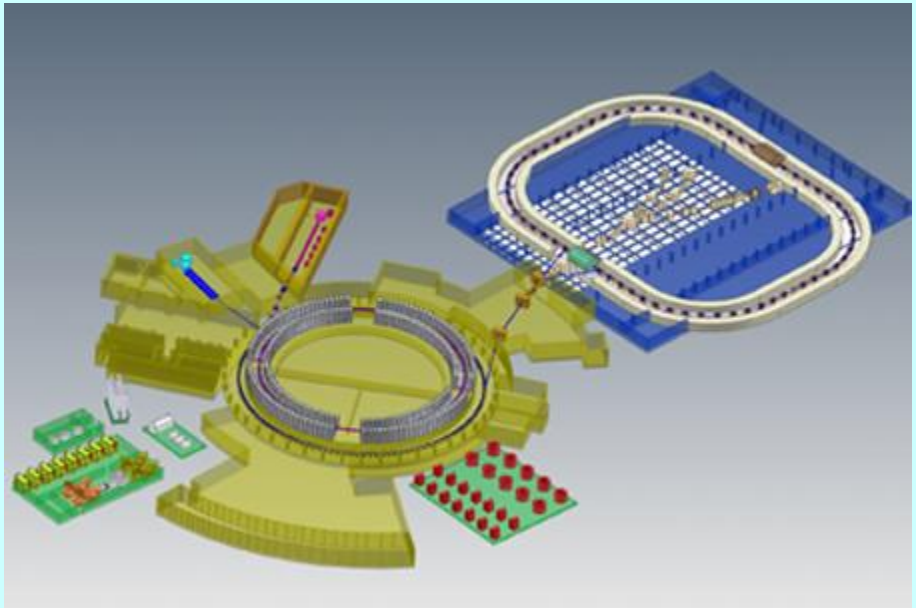
Spin Physics at NICA.Physics Program

Spin physics at NICA with with polarized beams, subjects under consideration

- ►Studies of DY processes
- ►Studies of J/Ψ production processes
- ►Studies of elastic reactions

Spin effects in one and two hadron production processes
Spin effects in photoproduction
Spin effects in various exclusive reactions
Spectroscopy of quarkonia with any available decay modes

Diffractive processes
Hidden color in light nuclei
Color transparency



Leading twist PDFs with trivial p_T dependence

$$f_{1q} \equiv q,\ g_{1q} = \Delta q,\ h_{1q} \equiv \Delta_T q$$

with non-trivial p_T dependence

$f_{1T}^{\perp}(x, p_T),\ \ h_1^{\perp}(x, p_T)$ - T-odd PDFs

$g_{1T}^{\perp}(x, p_T)$ - pretzelosity

$h_{1T}^{\perp}(x, p_T),\ \ h_{1L}^{\perp}(x, p_T)$ - of some interest

Quark correlator on light cone $(z^+ = 0, p^+ = xP^+)$

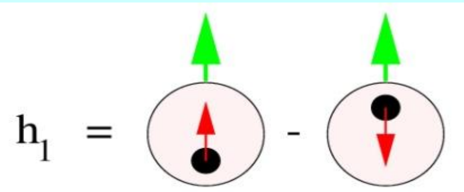
$$\phi(x, \vec{p}_T) = \int \frac{dz^- d^2\vec{z}_T}{(2\pi)^3} e^{ipz} \left\langle N(P,S) \right| \bar{\psi}_j(0) \left\{ gauge\ link \right\} \bar{\psi}_i(z) \left| N(P,S) \right\rangle$$

$$\frac{1}{2} tr\left[\gamma^+ \phi(x, \vec{p}_T)\right] = f_1 - \frac{\varepsilon^{jk} p_T^j S_T^k}{M_N} f_{1T}^{\perp} \qquad \frac{1}{2} tr\left[\gamma^+ \gamma_5 \phi(x, \vec{p}_T)\right] = S_L g_1 + \frac{\vec{p}_T \vec{S}_T}{M_N} g_{1T}^{\perp}$$

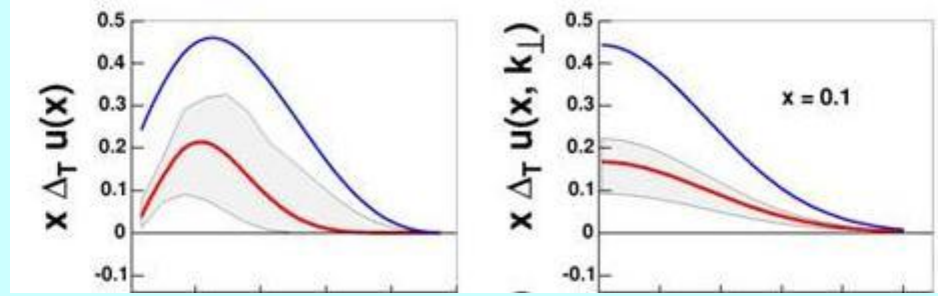
$$\frac{1}{2} tr\left[i\sigma^{j+} \gamma_5 \phi(x, \vec{p}_T)\right] = S_T^j h_1 + \frac{\varepsilon^{jk} p_T^k}{M_N} h_1^{\perp} + S_L \frac{p_T^j}{M_N} h_{1L}^{\perp} + \frac{(p_T^j p_T^k - \frac{1}{2} \vec{p}_T^{\,2} \sigma^{jk}) S_T^k}{M_N^2} h_{1T}^{\perp}$$

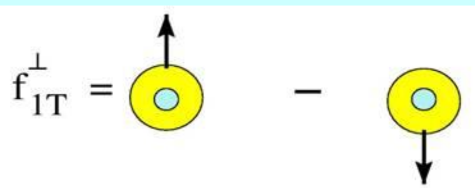
Spin Physics at NICA

$$l^{\uparrow} + p(D)^{\uparrow} \to l' + h + X :$$



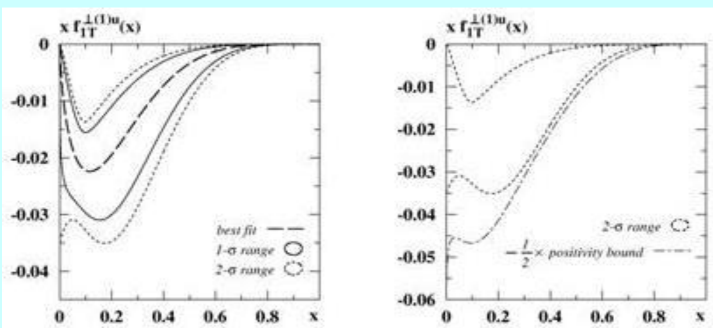
Transversity (HERMES, COMPASS)

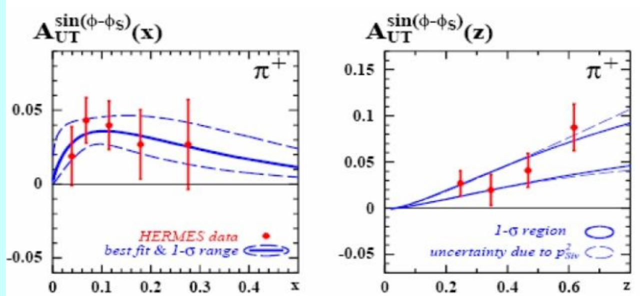




Sivers PDF

$$A_{UT}^{\sin(\phi-\phi_S)} \propto \frac{f_{1T}^{\perp a}(x, \mathbf{p}_T^2) \otimes D_1^a(z, \mathbf{K}_T^2)}{f_1^a(x) D_1^a(z)}$$

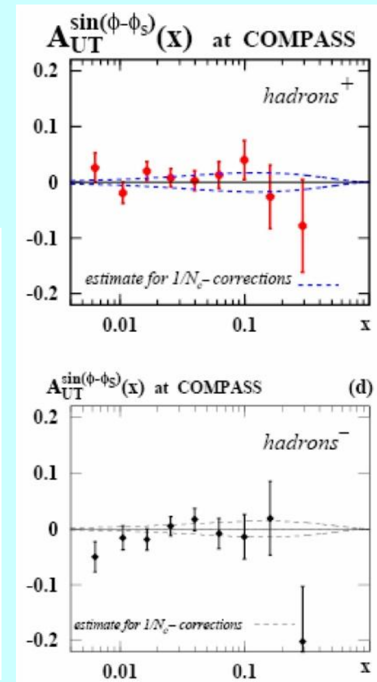




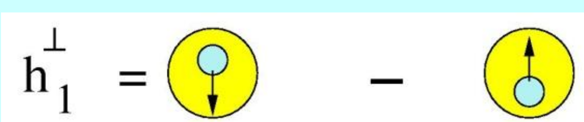
x-dependence (input) Good description!

z-dependence (not used) Cross-check: Ok!

Collins, AE, et al. PRD73(2006) 014021



$$l + p(D) \to l' + h + X$$



Boer-Mulders PDF **Poorly known, only E906 data**

Spin Physics at NICA. Change of Sign

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

J.C. Collins, Phys. Lett. B536 (2002) 43

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

J. Collins, talk at LIGHT CONE 2008

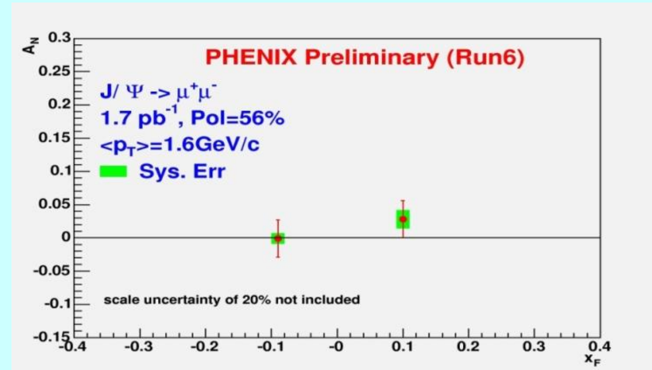
Crucial test of our understanding of T-odd effects within QCD and the factorization approach to the processes sensitive to transverse parton momenta.

$f_{1T}^{\perp}(x, \mathbf{k}_T)\Big|_{SIDIS}$ $h_1^{\perp}(x, \mathbf{k}_T)\Big|_{SIDIS}$ Poorly known

Spin Physics at NICA.J/Ψ

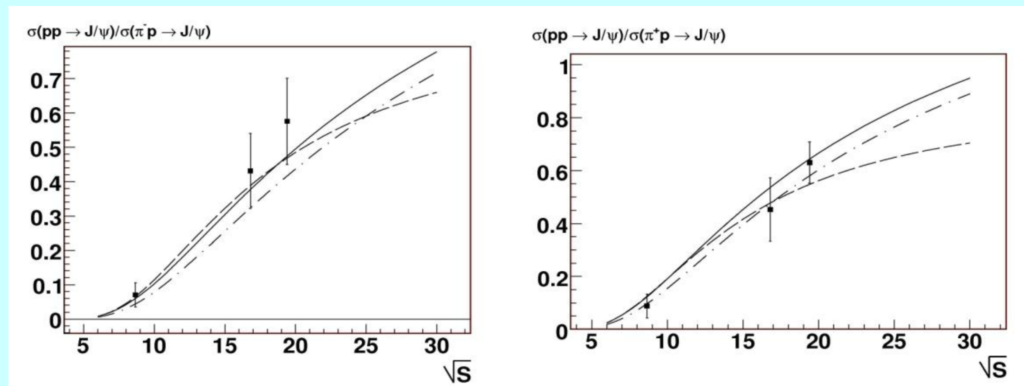
Polarized J/Ψ production:
Poor data from BNL(Phenix) only,

therefore test DY and J/Ψ duality is of importance



Transversity and Boer-Mulders PDFs from J/Ψ production with low s (duality model)

N. Anselmino, V. Barone, A. Drago, N. Nikolaev, PL B594 (2004) 1997
V. Barone, Z. Lu, B. Ma, Eur. Phys. J. C49 (2007) 967
A.Sissakian, O. Shevchenko, O. Ivanov, JETP Lett 86 (2007) 751



Ratios of cross-sections calculated with two models in comparison with the experimental data. Solid line corresponds to the ``duality'' model. Dashed line corresponds to the ``gluon evaporation'' model Dot-dashed line corresponds to ``gluon evaporation'' model without gluon contribution.

Tests of models for unpolarized/polarized J/Ψ production (gluon evaporation, NRQCD,...)

$\pi^{\pm} p(p\uparrow)$ - COMPASS $pp(p\uparrow)$ - NICA SPD

Spin Physics at NICA. Drell-Yan and J/Ψ

Studies of DY and J/Ψ processes with polarized/unpolarized p and D beams

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

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

Boer-Mulders PDF

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

Sivers PDFs
(Efremov,… PLB 612 (2005), PRD 73(2006));

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

Transversity PDF (Anselmino, Efremov, …)

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

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

Transversity and first moment of Boer-Mulders PFDs
(Sissakian, Shevchenko, Nagaytsev , Ivanov, PRD 72(2005), EPJ C46 ,2006 C59, 2009)

$$p^{\rightarrow}(D^{\rightarrow})\,p^{\leftarrow}(D^{\leftarrow}) \rightarrow \gamma^* X \rightarrow l^+ l^- X$$

Longitudinally polarized sea and strange PDFs and tenzor deuteron structure (Teryaev, …)

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

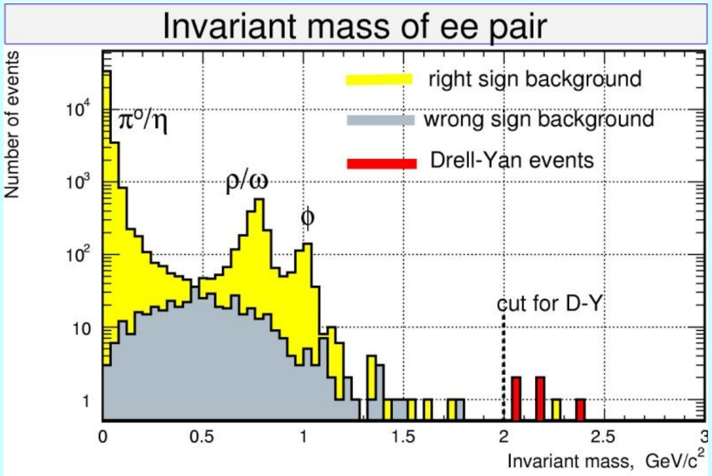
Estimations were done for 1 month of data taking.
For 3 years of data taking:
we expect to take ~100K DY events

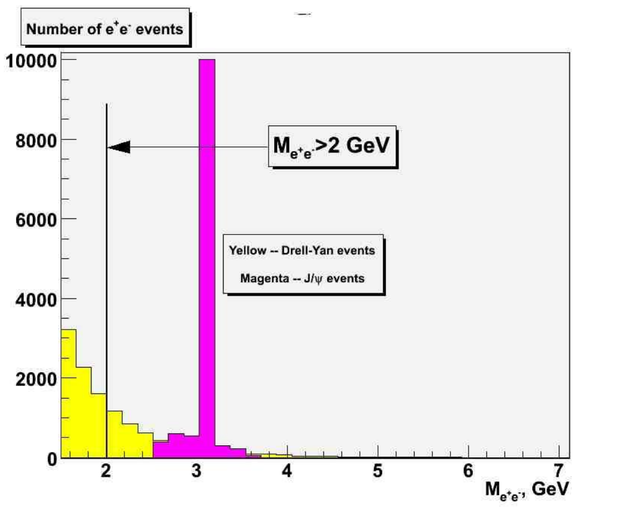
	σ_{DY} total, nb	$L, cm^{-2}s^{-1}$	K events
PAX, $\sqrt{s} = 14.6 GeV$	~ 2	$\sim 10^{30}$	~ 10
NICA, $\sqrt{s} = 20 GeV$	~ 1	$\sim 10^{30}$	~ 5
NICA, $\sqrt{s} = 26 GeV$	~ 1.3	$\sim 10^{30}$	~ 7

cut on Q, GeV	1.5	1.6	1.7	1.8	1.9	2.0
NICA, $\sqrt{s} = 20\,GeV$						
σ_{DY} total,nb	2.54	1.94	1.59	1.32	1.1	0.9
N events for a month, K	14.1	10.5	8.8	7.3	6.1	5
NICA, $\sqrt{s} = 26\,GeV$						
σ_{DY} total,nb	3.3	2.7	2.3	1.9	1.6	1.3
N events for a month, K	18	15	13	10	9	7
PAX, $\sqrt{s} = 14.6\,GeV$						
σ_{DY} total,nb	5.1	4.33	3.5	2.9	2.46	2.09
N events for a month, K	24.4	20.7	16.7	13.9	11.8	10

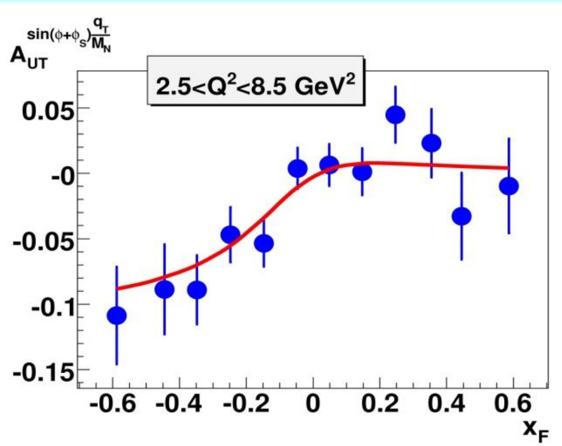
$\sqrt{s}$, GeV	20	26
$\sigma_{J/\psi} \cdot B_{e^+e^-}$, nb	10	16
N events for a month, K	55	88

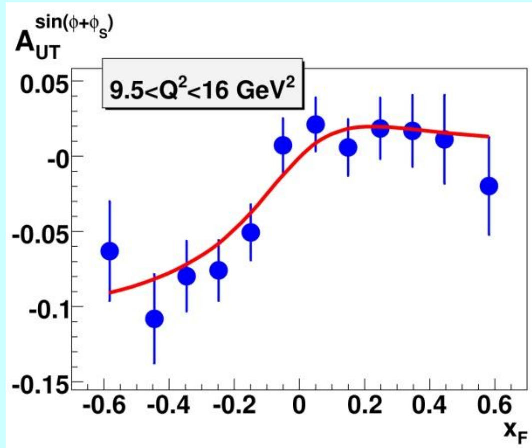
$\sqrt{s}$, GeV	20	26
σ_{DY}, nb	0.9	1.3
N events for a month, K	5	7

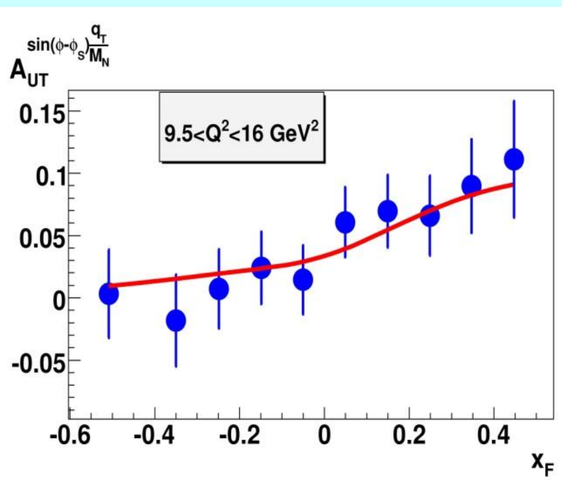


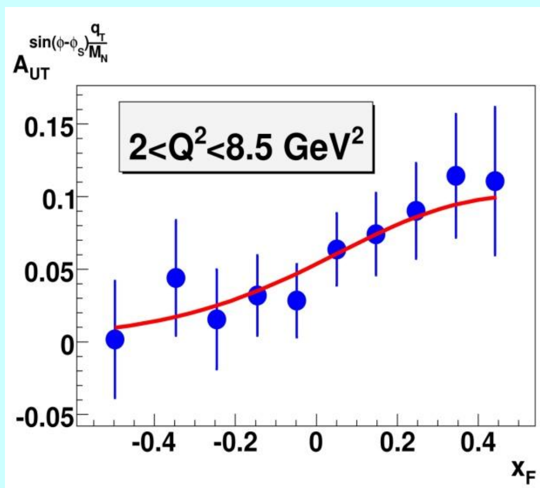


Spin Physics at NICA.Polarized DY









The set of original software packages (MC simulation, generator etc.) were developed for the feasibility studies of DY polarized processes

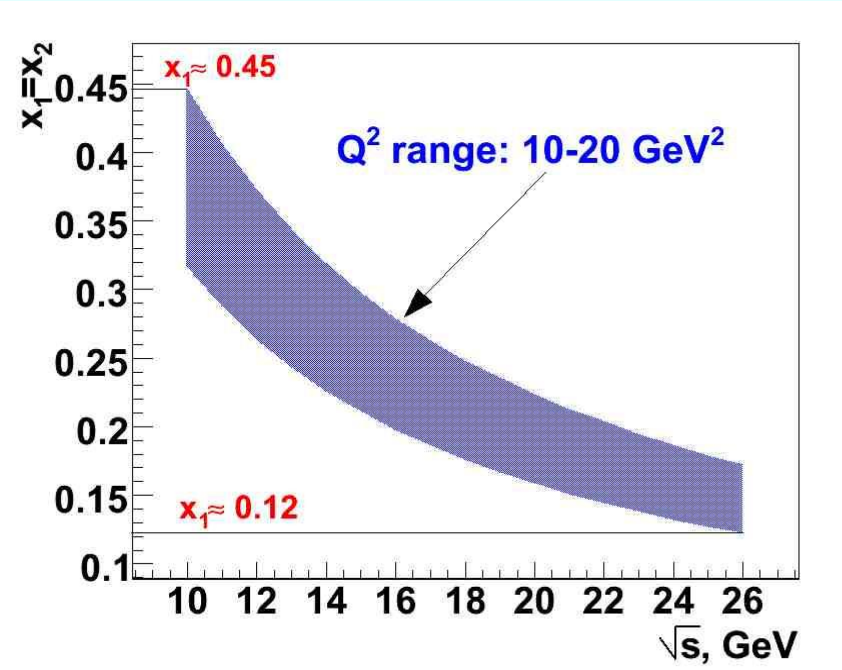
The SSA asymmetries.
Top:access to transversity and Boer-Mulders PDFs.
(Sissakian, Shevchenko, Nagaytsev,PRD 72 (2005), EPJ C46 (2006))

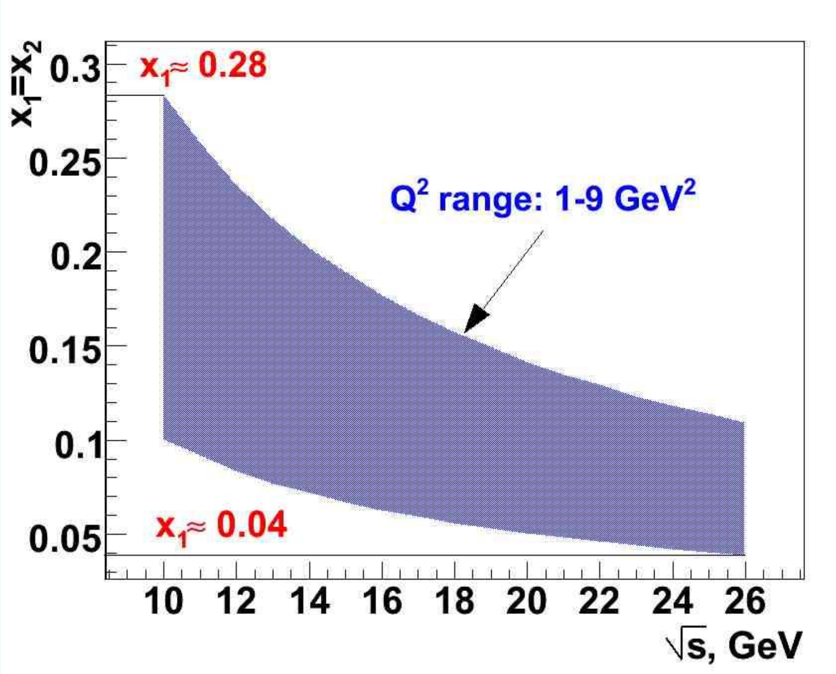
Bottom: access to Sivers PDFs (Efremov,… PLB 612(2005), PRD 73(2006));

Alsymmetries are estimated for 100 K DY events

Spin Physics at NICA.J/Ψ and DY

The dependence of the accesible range on Bjorken variable versus √s for DY and J/Ψ measurements





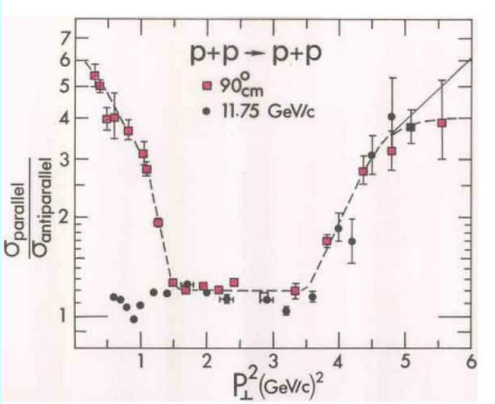
Especially important for duality test!

Spin Physics at NICA.Elastic Reactions

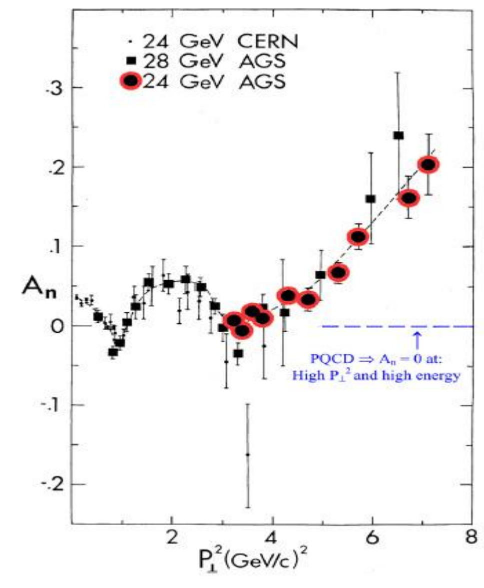
Differential cross section in pp, A_n A_{nn} up to maximal values of -t . Krisch effect. Especially important for pd and dd elastic reactions.

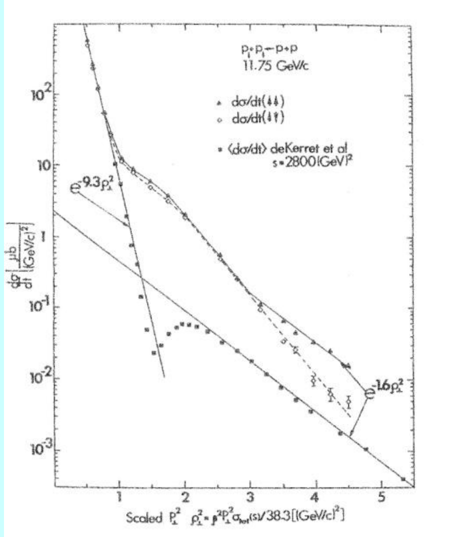
Measurements of amplitudes of elastic pp cross section. Total cross sections for elastic pp and pd reactions in pure initial spin states. Comparison of the differential cross sections and analyzing powers of elastic and quasielastic pp reactions.

Polarimetry concept with elastic reactions is under preparation

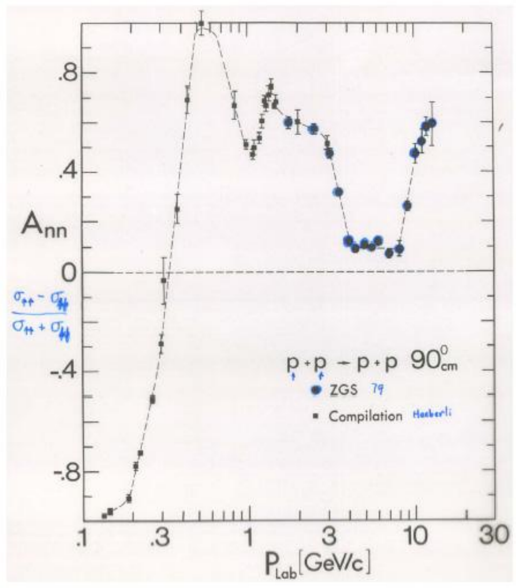


The measured spins-parallel/spins-antiparallel ratio is plotted against P_t^2.





The proton-proton elastic cross section near 12 GeV in pure initial spin states is plotted against the scaled P_t^2-variable



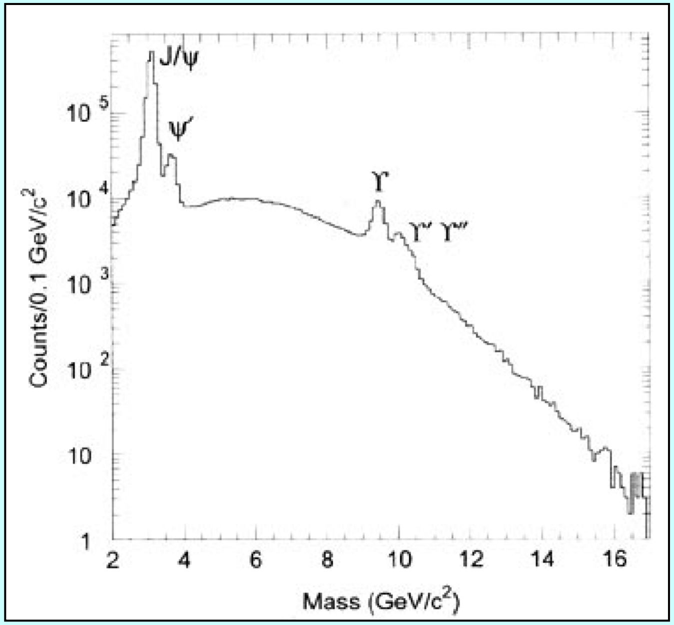
Spin Physics at NICA. Detector

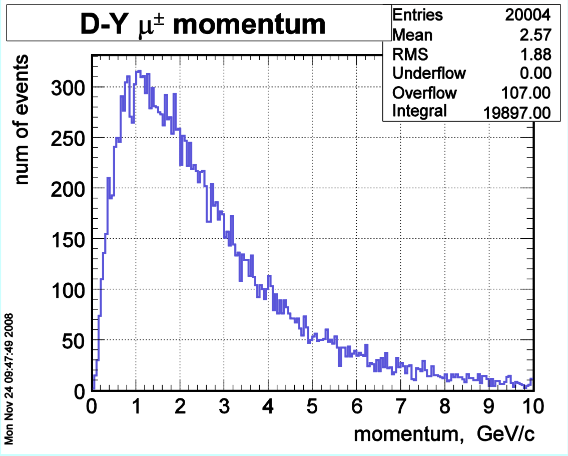
Important requirements for detector (SPD) :

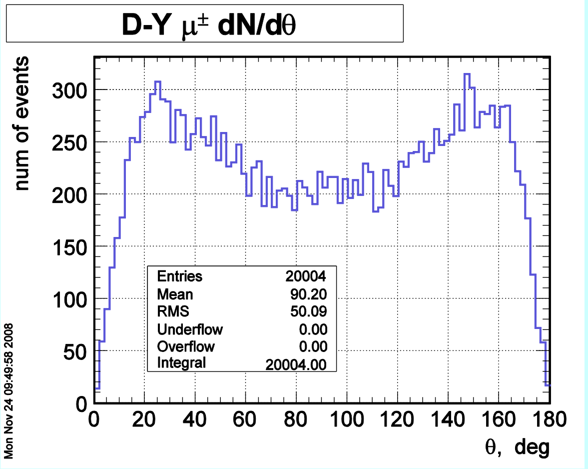
1) 4 π geometry
2) Precision vertex reconstrustion (minimal Xo)
3) Advanced tracking system
4) Good angular resolution – very important for azimuthal spin asymmetries measurements in the wide kinematical region
5) Particle identification

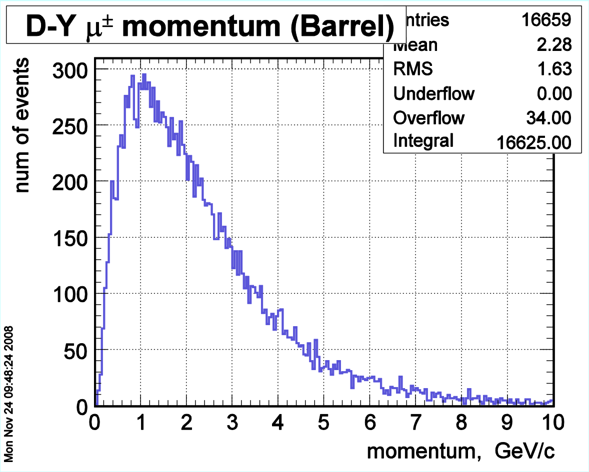
We use experience of the detector design for collider mode (GSI, PAX and RHIC, STAR, PHENIX) and for fixed target mode (CERN, COMPASS).

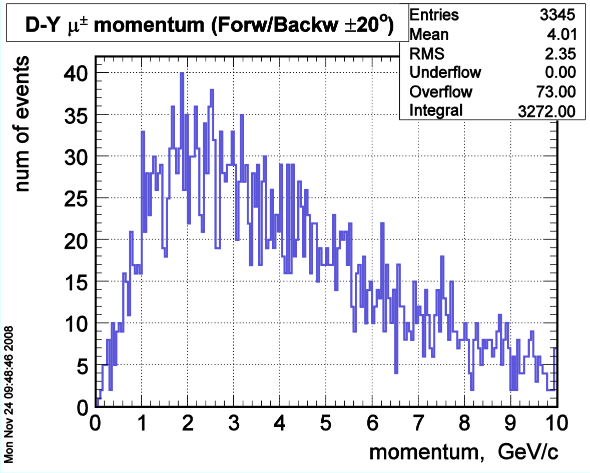
MC simulation of DY processes











Multiplicity for event pp with $\sqrt{s}$-26 GeV

Charged(neutral) 13.5 (22.5)

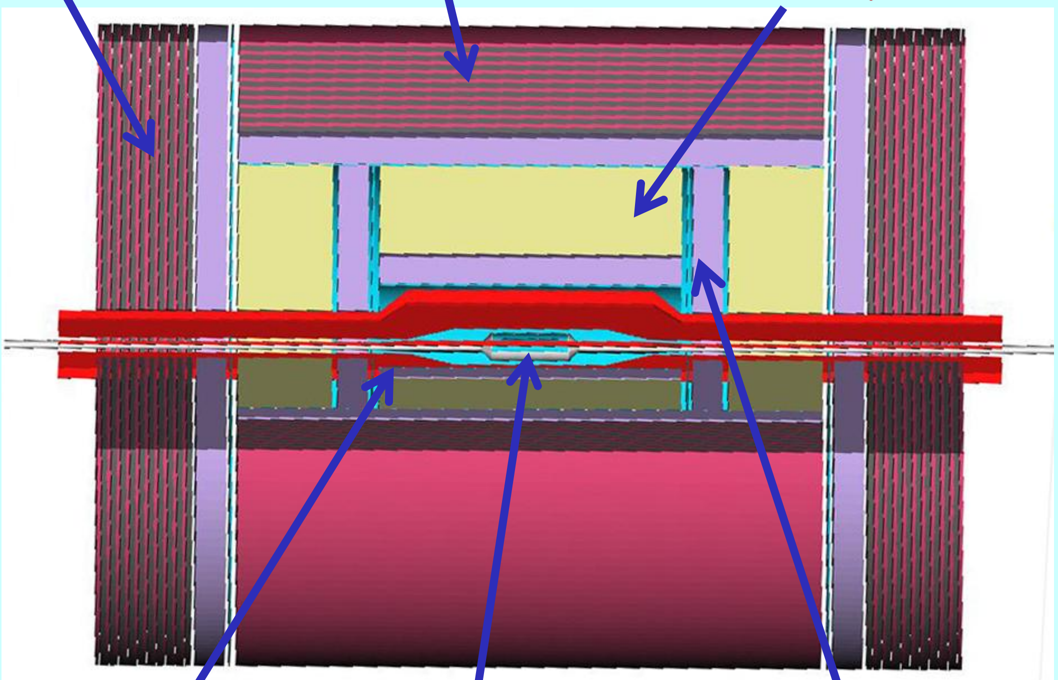
π+(-) 4.6(3.9)

π0 4.8

K+(-) 0.4(0.3)

K0 0.7

Spin Physics at NICA. Detector



Preliminary scheme of the SPD:

- Toroid magnet system
  about 60 cm in radius
- Silicon or MicroMega (Vertex)
- Drift chambers (DC)
- EM Calorimeter (EMC)
  inner radius is about 80 cm
  outer radius is about130 cm
- Range System (RS)
  (JINR contribution to PANDA
  G.Alexeev et al. Private commun.)
  inner radius is about 130 cm
  outer radius is about 180 cm
- Trigger counters
- EndCap detectors with RS, tracking system and EMC

SPD Barell is about 3.6 m in radius

SPD lenght is about 5 m

Spin Physics at NICA.SPD-NICA Project

http://nica.jinr.ru (2nd Interaction Point)

SPD-NICA project is under preparation at 2nd interaction point of NICA collider. The purpose of this experiment is the study of the nucleon spin structure with high intensity polarized light nuclear beams.

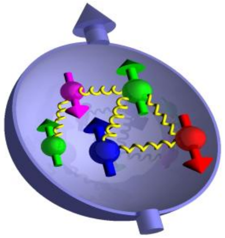
- high collision proton (deuteron) energy up to
  $\sqrt{s} \sim 26(12)$ GeV
- the average luminosity up to 10^{30} cm^2/s
- both proton and deuteron beams can be effectively polarized.

Collaborators are welcomed !

JOINT INSTITUTE

JINR

FOR NUCLEAR RESEARCH



NICA

Thank you for attention!

Backup slides

Heavy ions in NICA

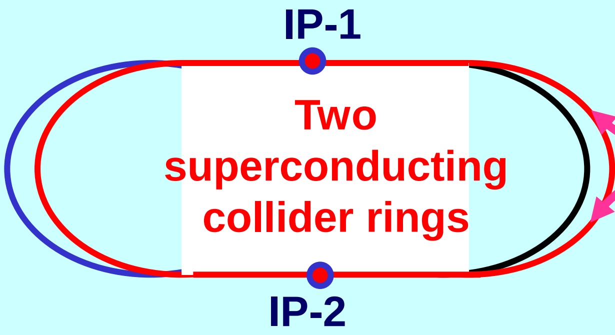
Operation regime and parameters

Injector: 2×10^9 ions/pulse of $^{197}Au^{32+}$
at energy of 6.2 MeV/u

Booster (25 Tm)
1(2-3) single-turn injection,
storage of 2 (4-6)$\times10^9$,
acceleration up to 100 MeV/u,
electron cooling,
acceleration
up to 600 MeV/u

Collider (45 Tm)
Storage of
32 bunches $\times$ $1\cdot10^9$ ions per ring
at 1÷4.5 GeV/u,
electron and/or stochastic cooling

Stripping (80%) $^{197}Au^{32+} \Rightarrow {}^{197}Au^{79+}$



Nuclotron (45 Tm)
injection of one bunch
of 1.1×10^9 ions,
acceleration up to
1÷4.5 GeV/u max.

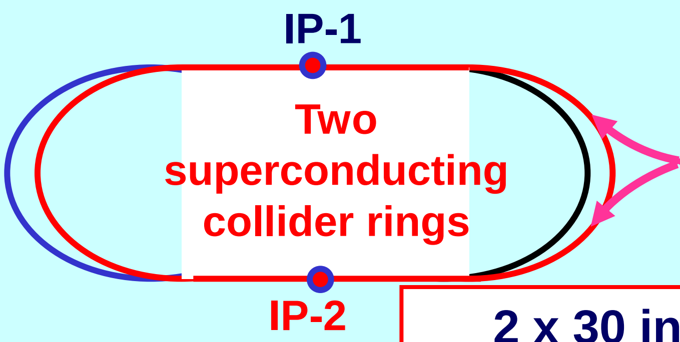
Stacking with BB and S-Cooling
2 x 30 injection cycles (5 min)

Polarized beams in NICA

Operation regime and parameters

LU-20("Old Linac"): 2×10^{10} ions/pulse of p at energy of 20 MeV, d – 5 MeV/u

Collider (45 Tm)
Storage of
20 bunches $\times$ $2\cdot10^{10}$ particles per ring



2 x 30 injection cycles (5 min)

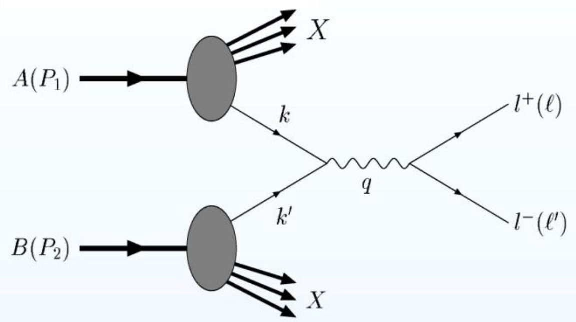
Nuclotron (45 Tm)
Adiabatic bunching
acceleration
d up to 5.8 GeV/u
p up to 12.6 GeV

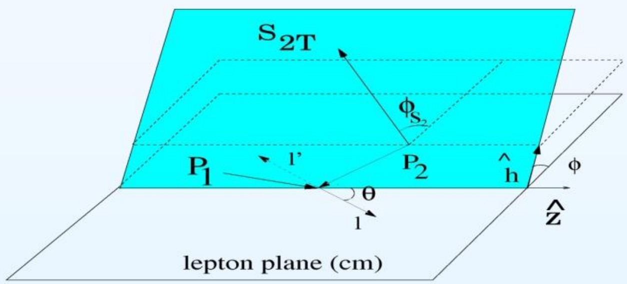
Spin Physics at NICA:MMT-DY

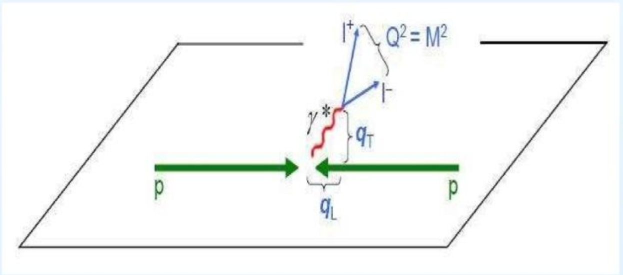
V.A.Matveev, R.M.Muradian, A.N.Tavkhelidze,

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

  $Q^2 = M^2 \simeq x_1 x_2 s \equiv \tau s$

  $y = \frac{1}{2} \ln \frac{x_1}{x_2}$

  $x_F = x_1 - x_2$

  $x_1 = \frac{\sqrt{x_F^2 + 4\tau} + x_F}{2} = \sqrt{\tau} e^{y}$

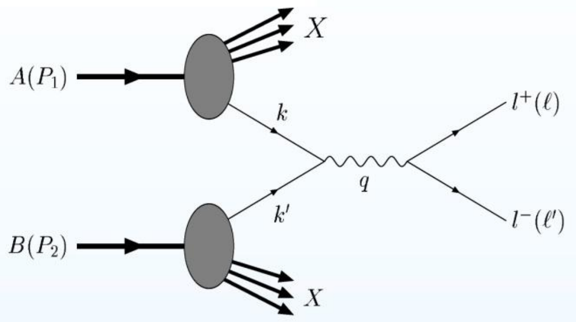
  $x_2 = \frac{\sqrt{x_F^2 + 4\tau} - x_F}{2} = \sqrt{\tau} e^{-y}$
- θ – production angle in the dilepton rest frame – polar angle of the lepton pair in the dilepton rest frame
- ϕ – azimuthal angle of lepton pair
- ϕ_S – azimuthal angle of the hadron polarization measured with respect to lepton plane

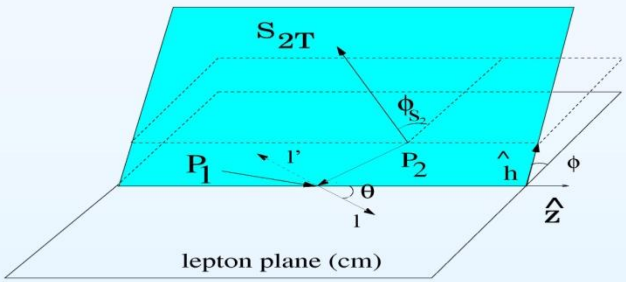
Spin Physics at NICA:DY

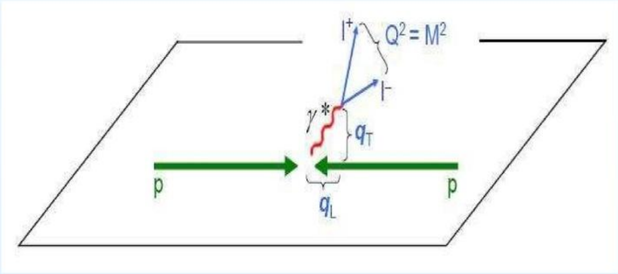
V.A.Matveev, R.M.Muradian, A.N.Tavkhelidze,

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)







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$$x_F = x_1 - x_2$$
$$x_1 = \frac{\sqrt{x_F^2 + 4\tau} + x_F}{2} = \sqrt{\tau}e^{y}$$
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- 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

Spin Physics at NICA. Detector

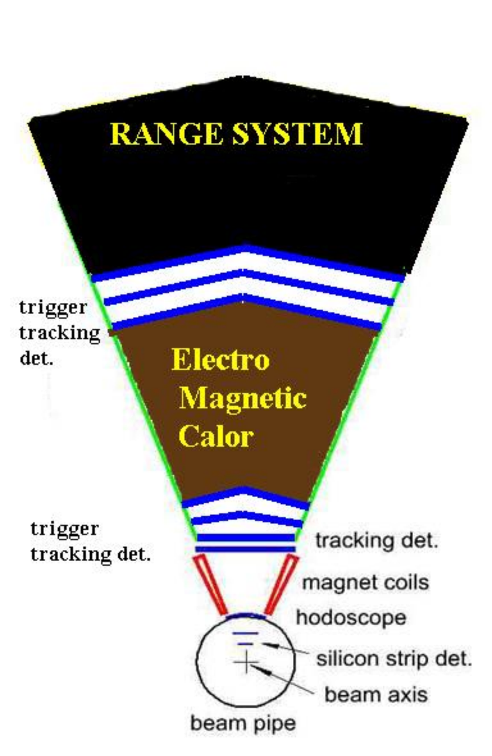
Silicon Detector
Several layers of double-sided Silicon strip detector. The design should be prepared with a smaller number of silicon layers to minimize the radiation length of the tracking material. With a pitch of 50-100 μm it is possible to reach an spatial resolution of 20-30 μm.

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 transverse to the plane of the coil, i.e. parallel to the magnetic field lines.

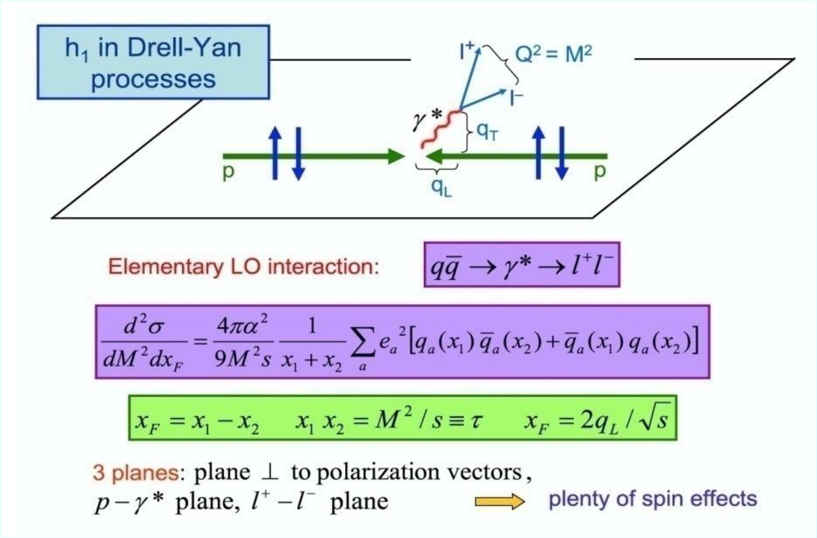
EM Calorimeter
The calorimeter can consists of ``shashlyk'' modules with the application of new readout technics based on AMPD technology. The modules can have an area of 4x4 cm2 and a length of 30-40 cm. The expected energy resolution can be~ (5 %)/sqrt(E) +1-3%.

Hodoscopes
Sets of hodoscope planes are used for triggering. Also, to improve the lepton identification, the passive Pb radiator (about 2 radiation lengths) can be placed in front of the external hodoscope, which allows to initiate the electromagnetic showers.

End-cap Detectors
Notice that both End-cap regions are equally important for the PDFs extraction from DY and J/P si production processes. That is why the end-cap detector should be designed with the RS, EM calorimeter, trigger and coordinate systems.



Spin Physics at NICA: MMT-DY



The angular distribution analysis of unpolarized Drell-Yan events:

$$R \equiv \frac{d\sigma^{(0)}/d\Omega}{\sigma^{(0)}} \qquad \hat{R} = \frac{\int d^2\mathbf{q}_T[|\mathbf{q}_T|^2/M_1M_2][d\sigma^{(0)}/d\Omega]}{\int d^2\mathbf{q}_T\sigma^{(0)}}$$

The form for $\hat{R}$ angular distribution:

$$\hat{R} = \frac{3}{16\pi}(\gamma(1+\cos^2\Theta) + \hat{k}\cos 2\phi \sin^2\Theta)$$

$$\hat{k}(x_1,x_2)|_{\bar{p}p^{\uparrow}\to l^+l^-X} \simeq 8\frac{h_{1u}^{\perp(1)}(x_1)h_{1u}^{\perp(1)}(x_2)}{f_{1u}(x_1)f_{1u}(x_2)}$$

$$h_{1q}^{\perp(n)}(x) \equiv \int d^2\mathbf{k}_T\left(\frac{\mathbf{k}_T^2}{2M^2}\right)^n h_{1q}^{\perp}(x,\mathbf{k}_T^2)$$

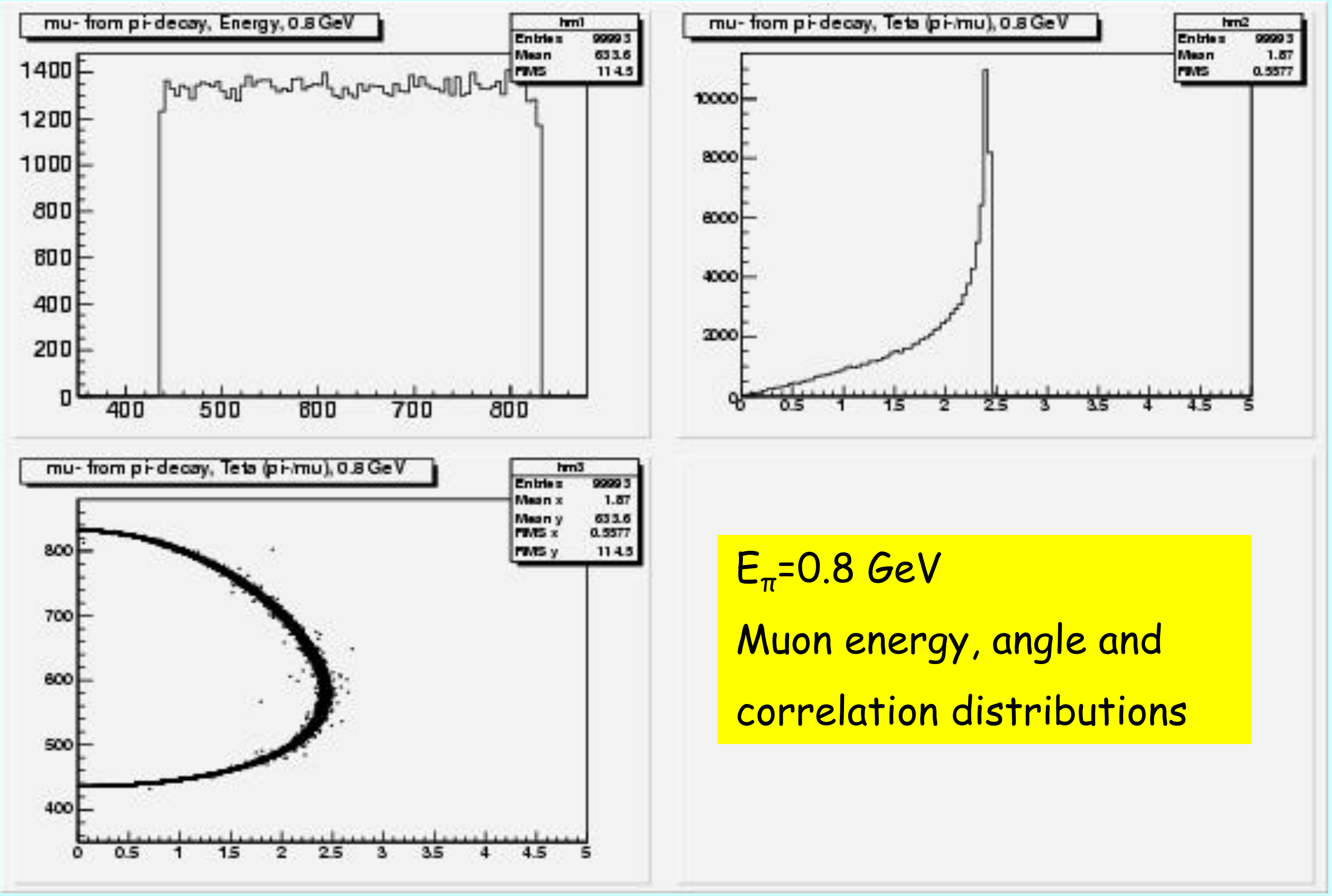
n-th moments of k_T dependent $h_u^{\perp}$ are defined in the standard way

: by virtue of charge conjugation symmetry:

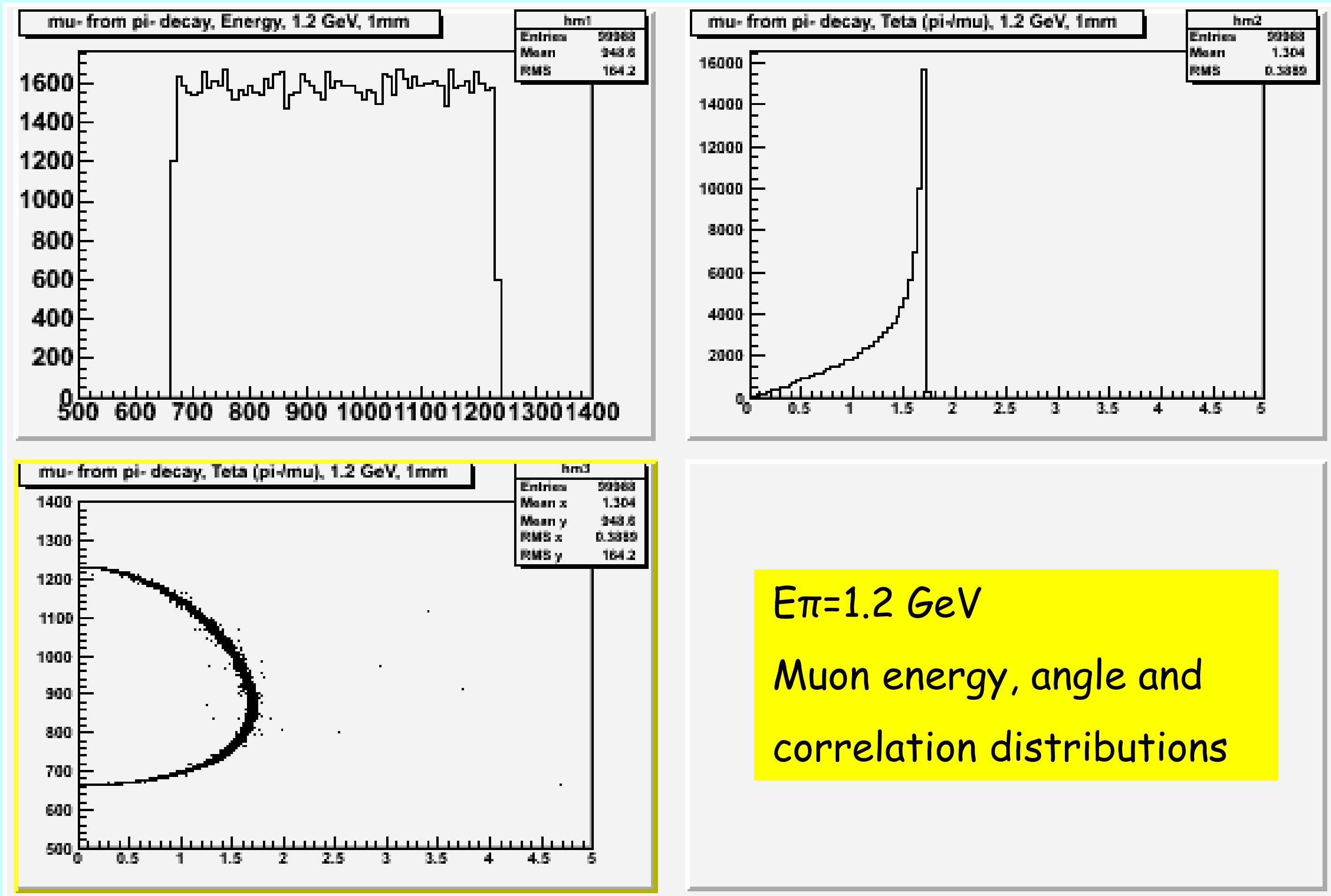
Single-polarized Drell-Yan – SSA:

$$\hat{A}_h \sim \frac{h_{1u}^{\perp(1)}(x_1)h_{1u}(x_2)}{f_{1u}(x_1)f_{1u}(x_2)}$$

Muons from π→μν decay



Muons from π→μν decay



Eπ=1.2 GeV

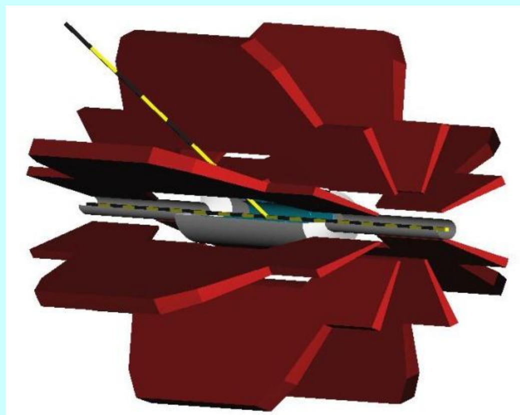
Muon energy, angle and correlation distributions

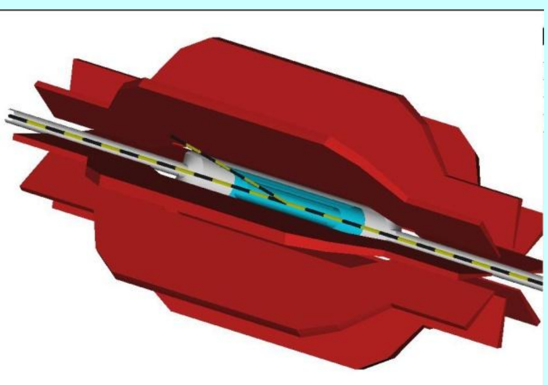
Spin Physics at NICA:Drell-Yan

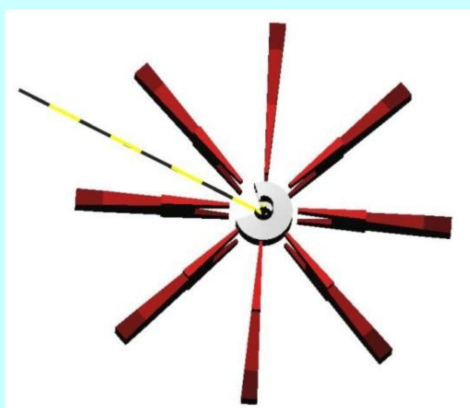
Experiment	Status	Remarks
E615	Finished	Only unpolarized
NA10,38,50	Finished	Only unpolarized
E886, 906	Running	Only unpolarized
RHIC	Running	Detector upgrade for DY measurements (collider)
PANDA	Plan > 2016	Unpolarized fixed target
PAX	Plan > 2016	Preparation in progress
COMPASS	Plan > 2010	Fixed target, only valence PDFs
J-PARC	Plan > 2011	Low s (60-100 GeV^2), only unpolarized proton beam
SPASCHARM	Plan?	s ~ 140 GeV^2 for unpolarized proton beam
NICA	Plan 2014	s ~ 670 GeV^2 for polarized proton beams, high luminosity (collider)

Proposal on SPD Toroid Magnet

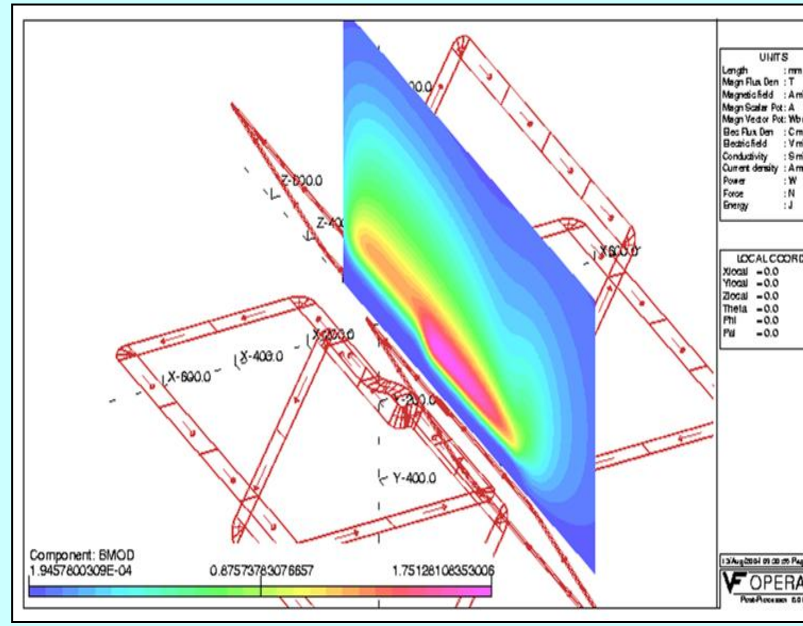
- 8 coils
- Size of coil ~100 cm x 60 cm
- average integrated field: ~ 1.0 Tm
- acceptance ~ 80 %





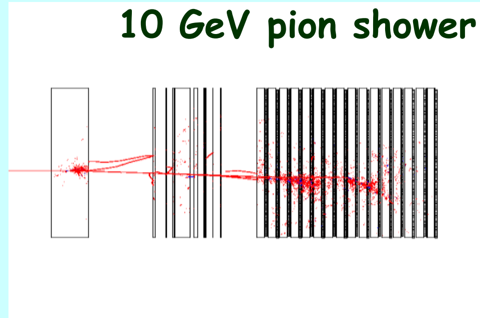


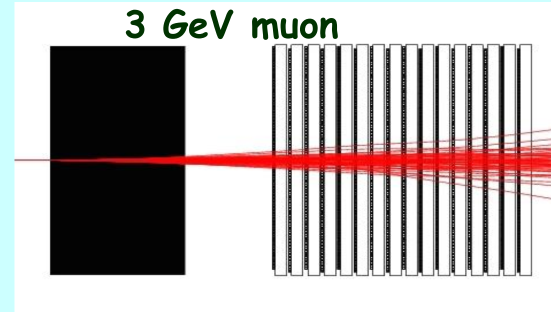
PAX Toroid Magnet



- size of coil 80 cm x 60 cm
- 3 mm x 50 mm cross section (1450 A/mm^2)
- average integrated field: 0.6 Tm
- free acceptance > 80 %

Range System

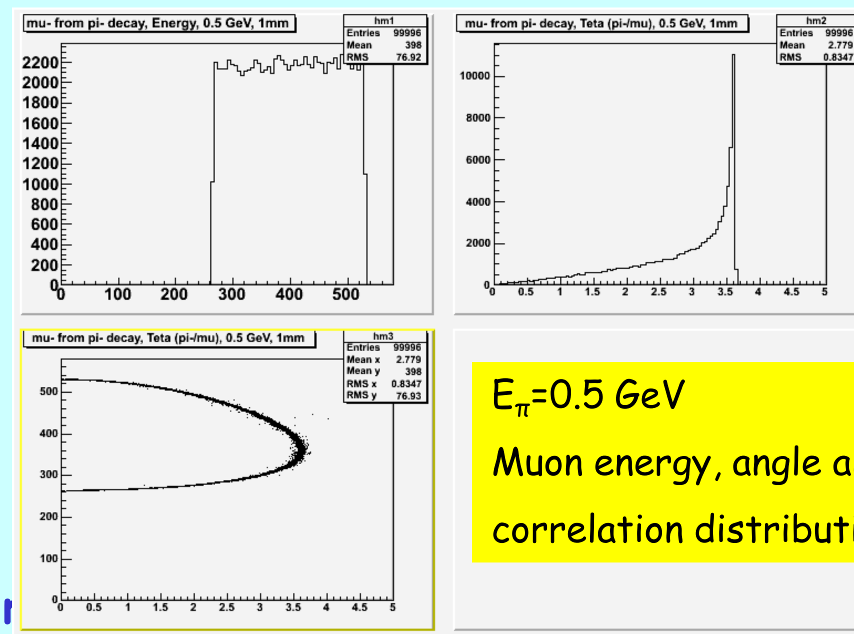




<u>RS can be used as:</u>

1. Muon Filter
2. PID for protons and pions
3. To reduce background from muons produced by pion decays
4. Hadron Calorimeter with energy resolution ~ 100/sqrt(E)

RS consists of 10 layers, 3cm of Fe and 2cm of Mini-Drift Chambers (MDC) each.



E_π=0.5 GeV

Muon energy, angle and correlation distributions

Scheme of RS for SPD

.

RS consists of two parts:

Barrel and two End cups.

Sizes:

~ about 5 m along beam line,

~ 3.6 m in diameter,

~ RS unit consists of 1080 MDC channels for Barell and 2x1280 for End cups.

MC simulation is in progress.