NICA accelerator complex at LHEP and proposal to study polarization phenomena with its beams (the SPD project)

Roumen Tsenov,
for the SPD project team

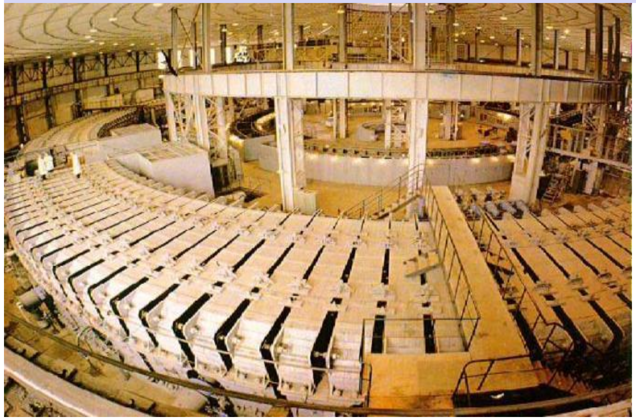
From the Synchrophasotron to the NICA collider

1957 Synchrophasotron

10 GeV proton synchrotron – then the world leader in energy

Start up of the high energy era

V.I.Veksler – discovery of *the Phase Stability Principle* *(1944)*



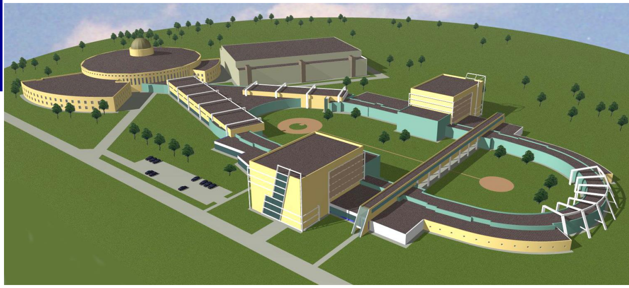
1993 Nuclotron

the first superconducting accelerator of heavy ions based on Dubna type SC magnets

A.M. Baldin – pioneer of relativistic nuclear physics

2019 NICA

Superconducting collider of heavy ions



Study of nuclear matter under extreme conditions and spin physics

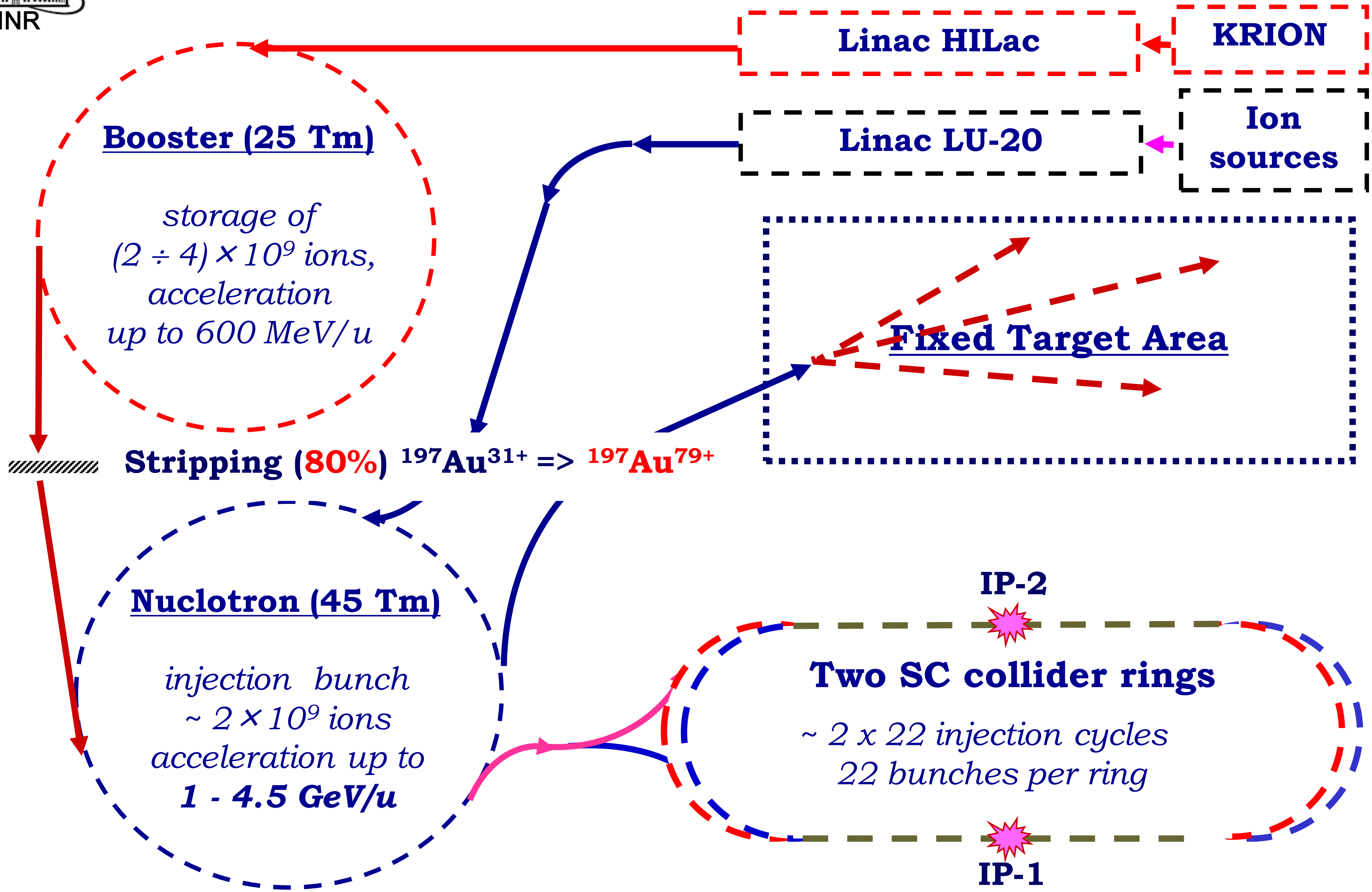
NICA (Nuclotron based Ion Colider fAcility) is the flagship project in high energy physics of the Joint Institute for Nuclear Research

Main targets of the NICA project:

- ***study of hot and dense baryonic matter***
- ***investigation of nucleon spin structure, polarization phenomena***

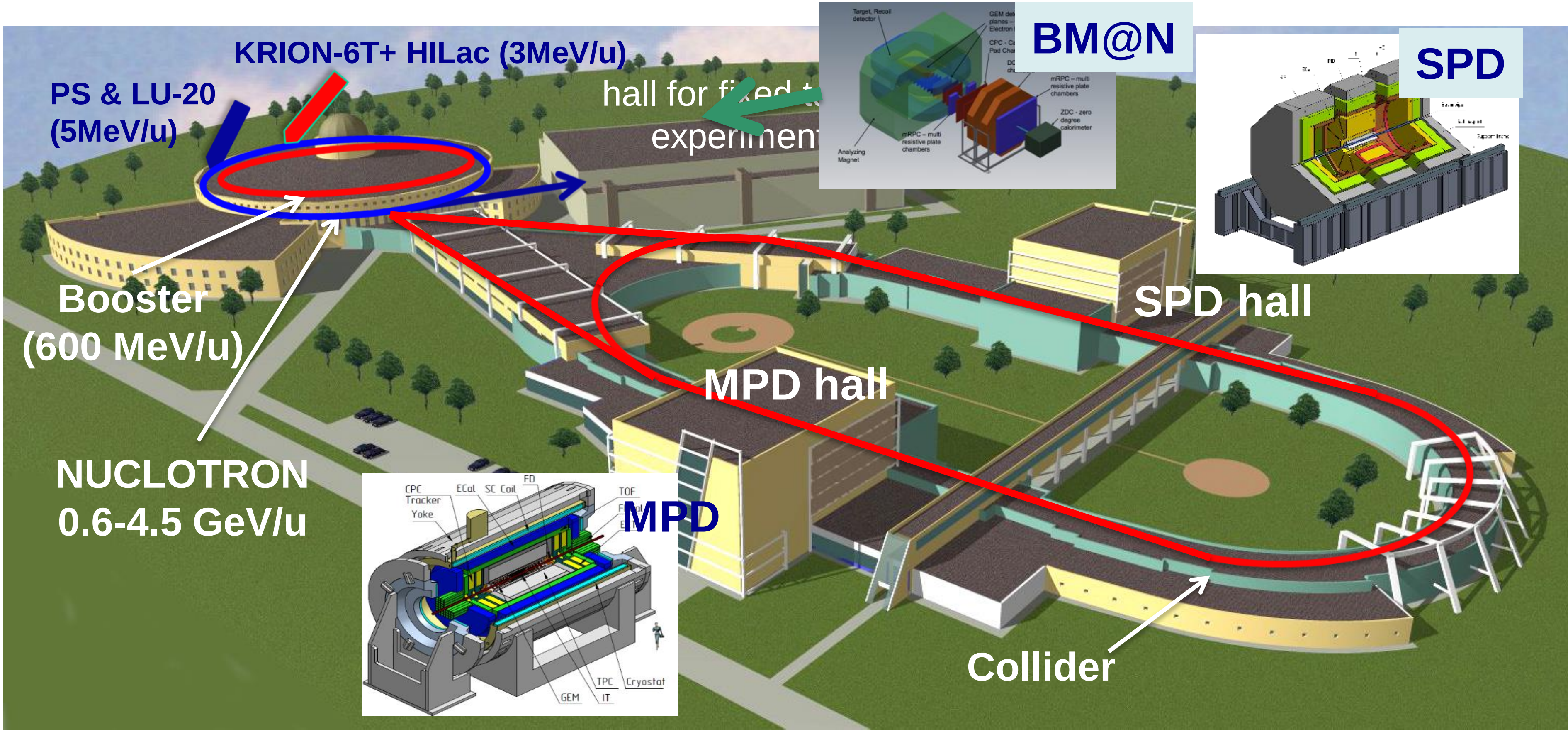
Ring circumference, m	**503.04**
heavy ions	
energy range for ***Au***$^{79+}$*:* $\sqrt{S_{NN}}$*, GeV*	**4 - 11**
r.m.s. $\Delta p/p$*,* 10^{-3}	**1.6**
Luminosity for ***Au***$^{79+}$*,* $cm^{-2}\ s^{-1}$	**1x10**^{27}
polarized particles	
max. $\sqrt{S}$ *for polarized* ***p****, GeV*	**27**
Luminosity for ***p****,* $cm^{-2}\ s^{-1}$	**1x10**^{32}

Structure and Operation Regimes



The NICA complex

existing facilities *to be constructed*



Civil construction, bld.17

http://nucloweb.jinr.ru/nucloserv/205corp.htm

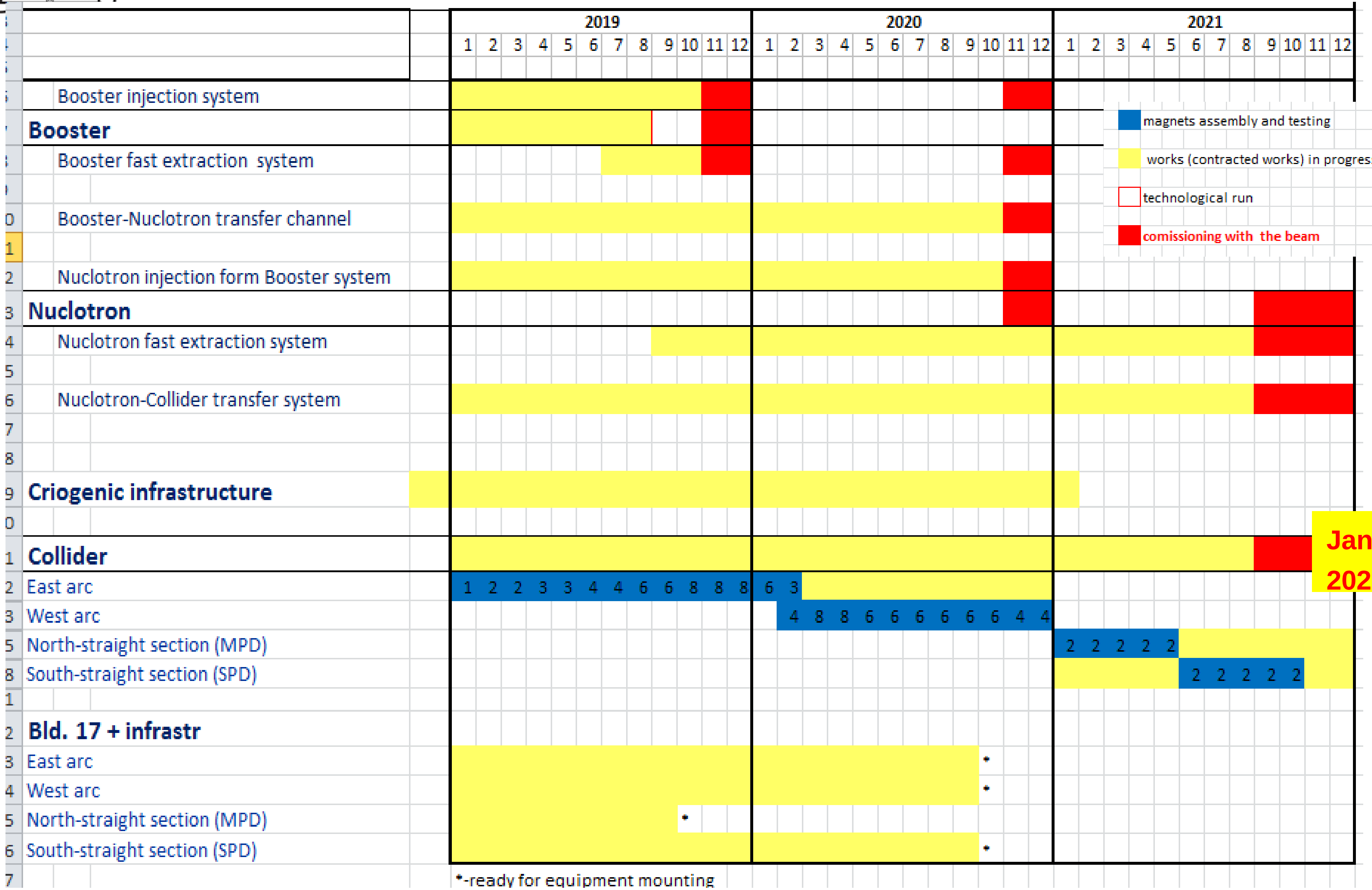
Major milestones

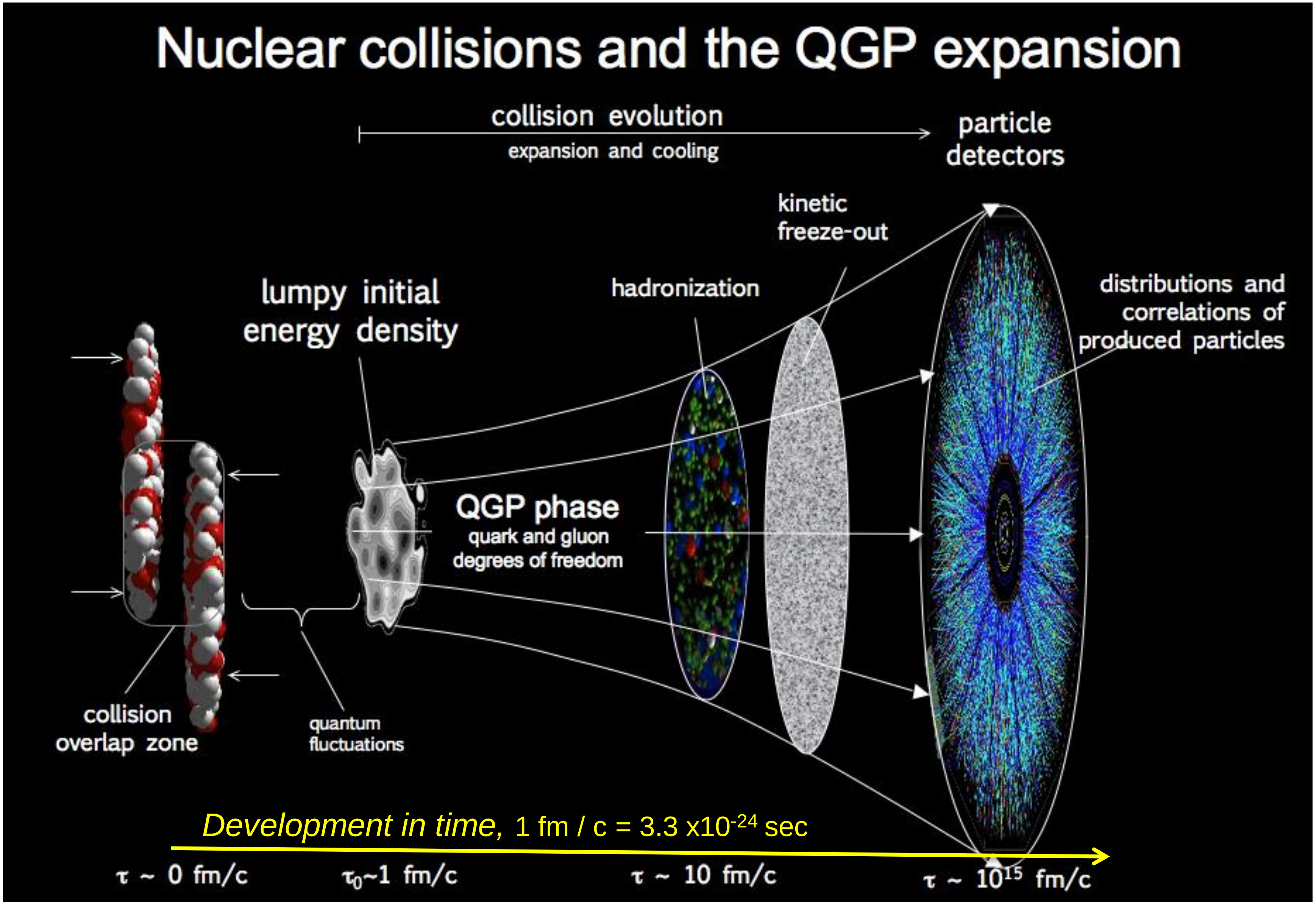
- ***2018*** *– start of* ***BM@N*** *experiment (min. configuration)*
- ***2018 –2019*** *–* ***Booster*** *commissioning*
- ***2019*** *– readiness of* ***MPD Hall***
- ***2019*** *–* ***MPD magnet*** *commissioning*
- ***2020*** *– completion of* ***civil construction*** *(build.* ***17)***
- ***2020*** *–* ***MPD*** *commissioning (****Stage I****)*
- ***2020 –2021*** *–* ***Collider*** *commissioning*
- ***2020*** *– completion of* ***"NICA Center"*** *construction*
- ***2021*** ***–*** *commissioning of* ***Computer center***
- ***2023*** *–* ***MPD*** *commissioning (****Stage II****)*
- ***2025*** ***– SPD*** *commissioning (****Stage I****)*

V. Kekelidze, SC-124
September 20, 2018

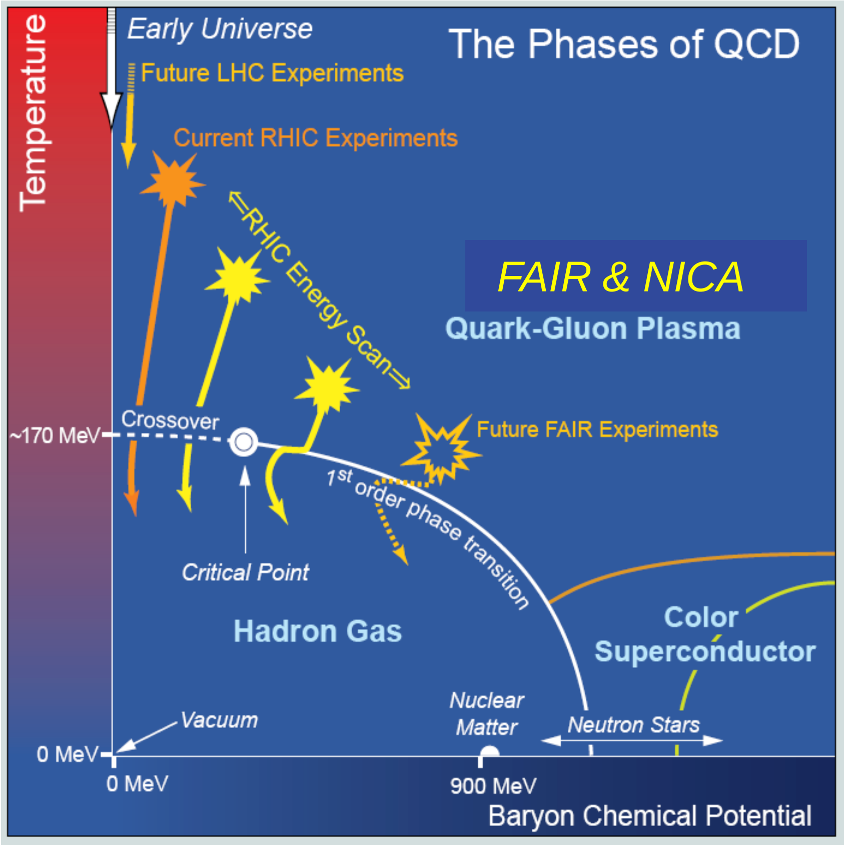
Time-schedule

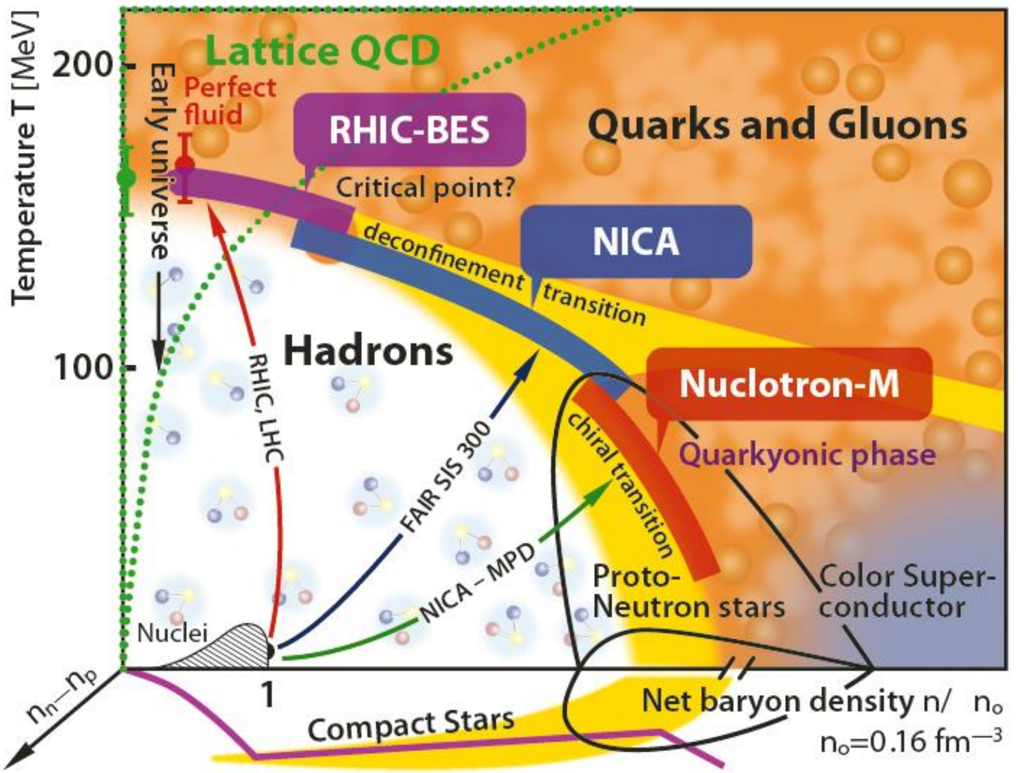
S. Kostromin, PAC June 2019




Nuclear collisions and the QGP expansion
collision evolution
expansion and cooling
particle detectors
kinetic freeze-out
lumpy initial energy density
hadronization
distributions and correlations of produced particles
QGP phase
quark and gluon degrees of freedom
collision overlap zone
quantum fluctuations
Development in time, 1 fm / c = 3.3 x10^-24 sec
τ ~ 0 fm/c
τ0~1 fm/c
τ ~ 10 fm/c
τ ~ 10^15 fm/c

QCD phase diagram



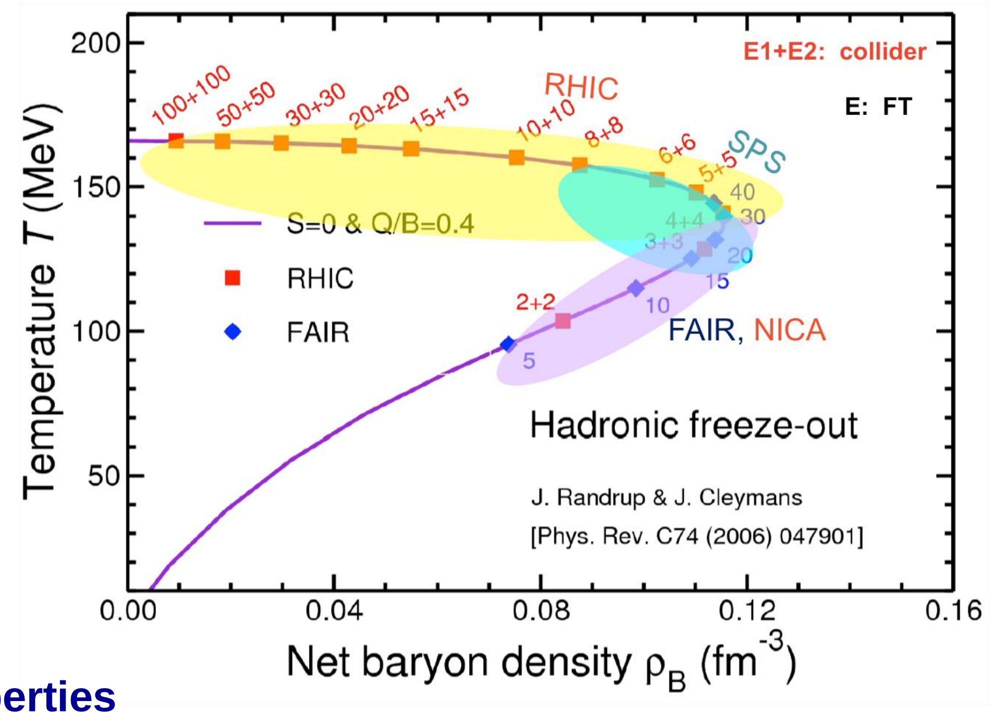


Physics at NICA

Quark-gluon matter at NICA :

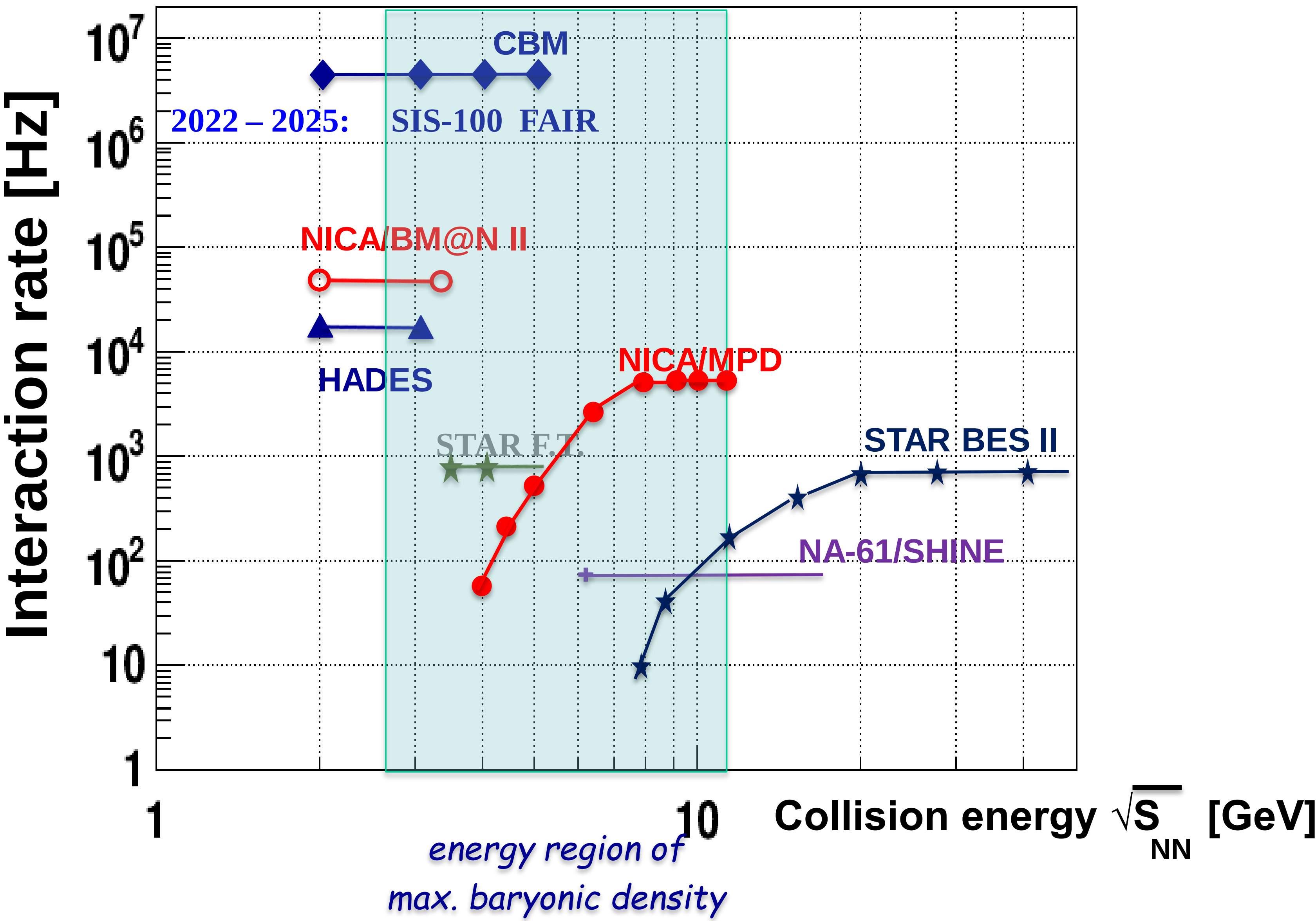
- *Highest net baryon density*
- *Energy range covers onset of deconfinement*
- *Complementary to the RHIC/BES, FAIR and CERN experimental programs*

Freeze-out conditions



- **Bulk properties, EOS** - *particle yields & spectra, ratios, femtoscopy, flow*
- **In-Medium modification of hadron properties**
- **Deconfinement (chiral), phase transition at high ρ_B** - *enhanced strangeness production*
- **QCD Critical Point -** *event-by-event fluctuations & correlations*
- **Strangeness in nuclear matter** - *hypernuclei*

Present and future HI experiments

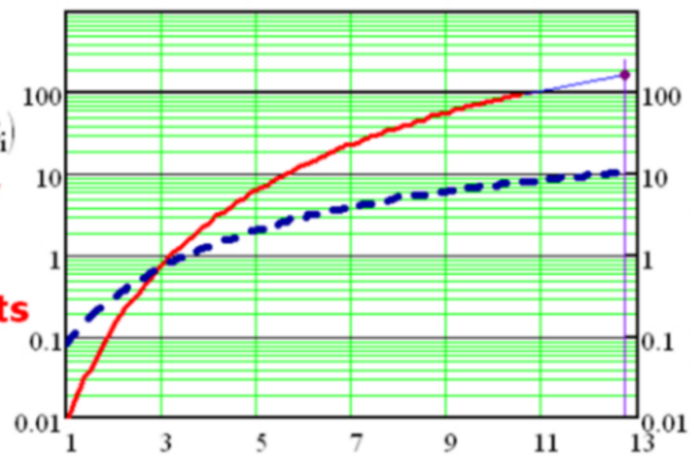


Collisions of polarized particles

Long tradition at the Synchrophasotron and Nuclotron

> 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*

Polarized beams



$L_{peak} \approx$ $1.8 \cdot 10^{32}$ cm-2·s-1

particle number per bunch in 10^{11} units

maximum proton number in each ring – $2.2 \bullet 10^{13}$

A bunch crossing each 80 ns; crossing rate 12.5 MHz .

circumference	- 503 m,
number of intersection points (IP)	- 2,
beta function β_{min} in the IP	- 0.35 m,
number of protons per bunch	- $\sim 1 \cdot 10^{12}$,
number of bunches	- 22,
RMS bunch length	- 0.5 m,
incoherent tune shift, $\Delta_{Lasslett}$	- 0.027,
beam-beam parameter, ξ	- 0.067,
beam emittance ε_{nrm} , π mm mrad	- 0.15 (nc

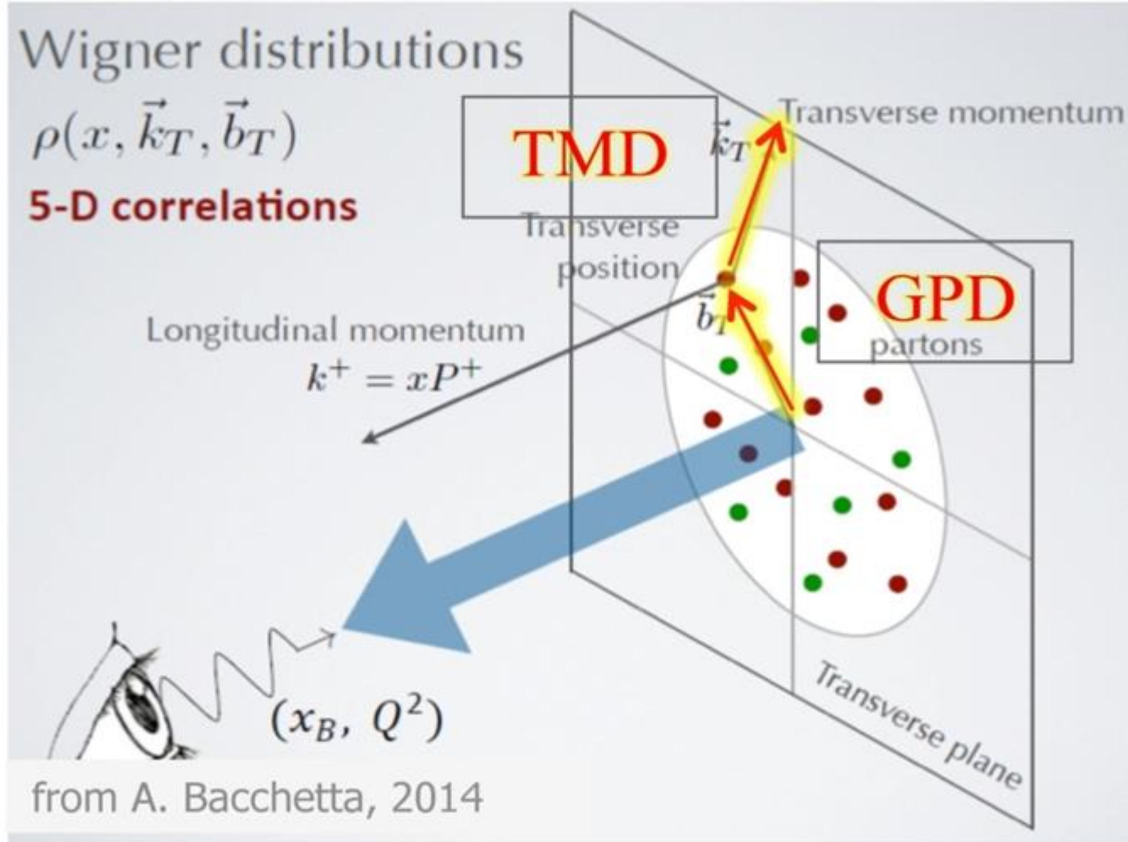
Polarized beams

- **p↑p↑** at $\sqrt{s_{pp}}$ **= 12 - 27 GeV,** $L_{av} \approx 10^{32}$ $cm^{-2}s^{-1}$
- **d↑d↑** at $\sqrt{s_{NN}}$ **= 4 - 13 GeV**
- *longitudinal and transverse polarization at SPD and MPD*

Physics tasks

- Nucleon spin structure studies
- Spin-dependent effects in elastic pp, pd and dd scattering;
- Spin effects in exclusive hadron production;
- Spin effects in production of hadrons with high p_T in interaction of vector and tensor (d) polarized beams;
- Multiquark states and correlations

Spin dependent PDFs



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{(q+g)}$$

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

Nucleon structure and PDFs

Quark / Nucleon	U	L	T
U	number density		Boer-Mulders
L		helicity	worm-gear L
T	Sivers	Kotzinian-Mulders worm-gear T	transversity pretzelosity

spin of the nucleon   spin of the quark k_T

PDFs describe different properties:

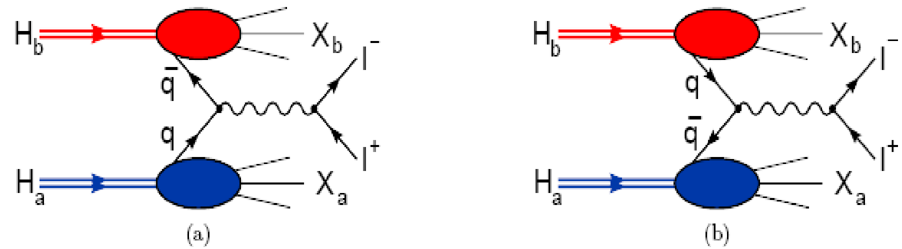
3 PDFs are needed to describe nucleon structure in collinear approximation

8 PDFs are needed if we want to take into account intrinsic transverse momentum k_T of quarks

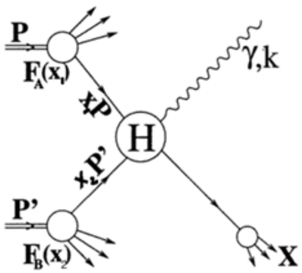
f_1 -- density of partons in non-polarized nucleon;
g_1 -- helicity, longitudinal polarization of quarks in longitudinally polarized nucleon;
$h_\perp$ -- Boer-Mulders, transversely polarized quarks in non-polarized nucleon;
$f^{\perp}_{1T}$ - Sivers, correlation between the transverse polarization of the nucleon (transverse spin) and the transverse momentum of non-polarized quarks; etc…

Physical probes

- **Inclusive and exclusive Drell-Yan pair production;**

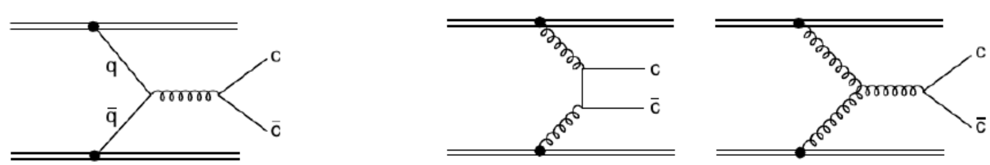


- **Direct photons;**

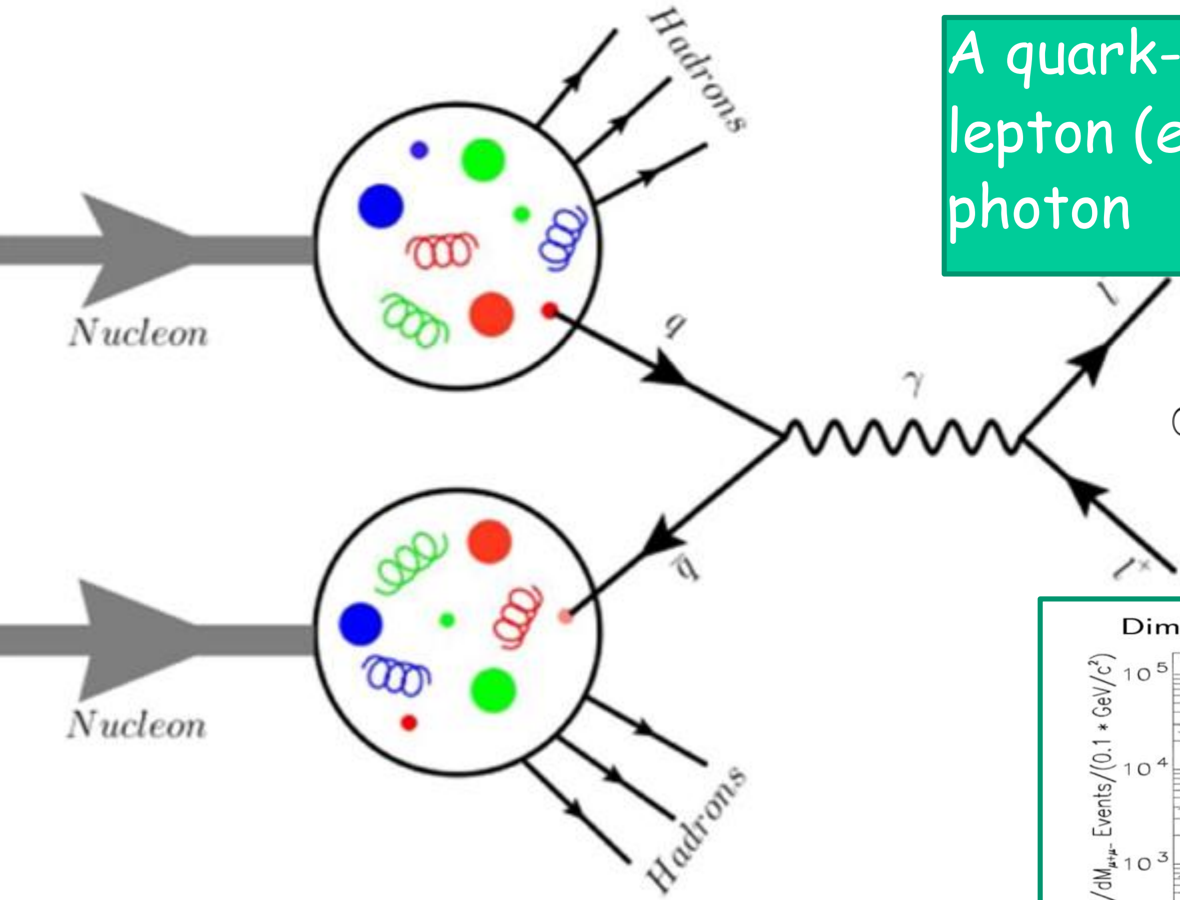


- **Nucleon PDFs by J/ψ production;**

LO $c\bar{c}$ production diagram:

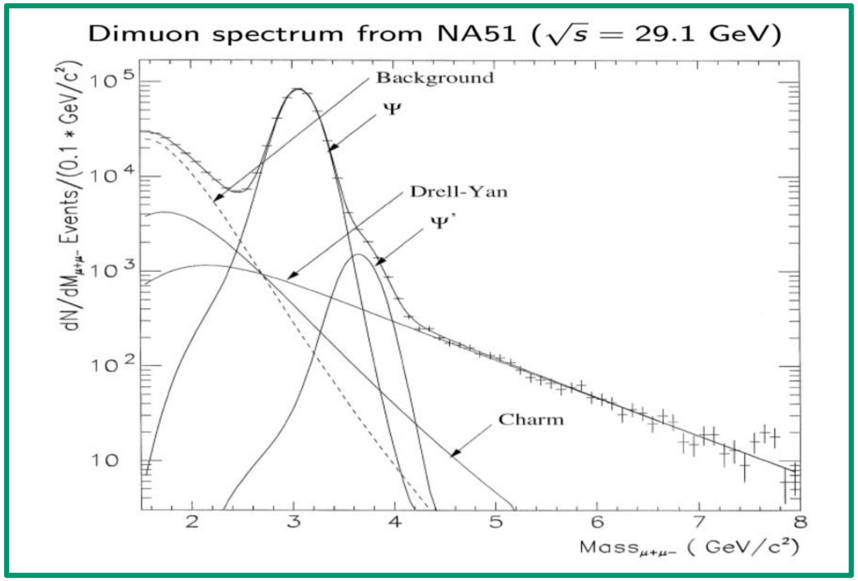


Drell-Yan process



A quark-antiquark pair creates a lepton (e/μ) pair trough a virtual photon

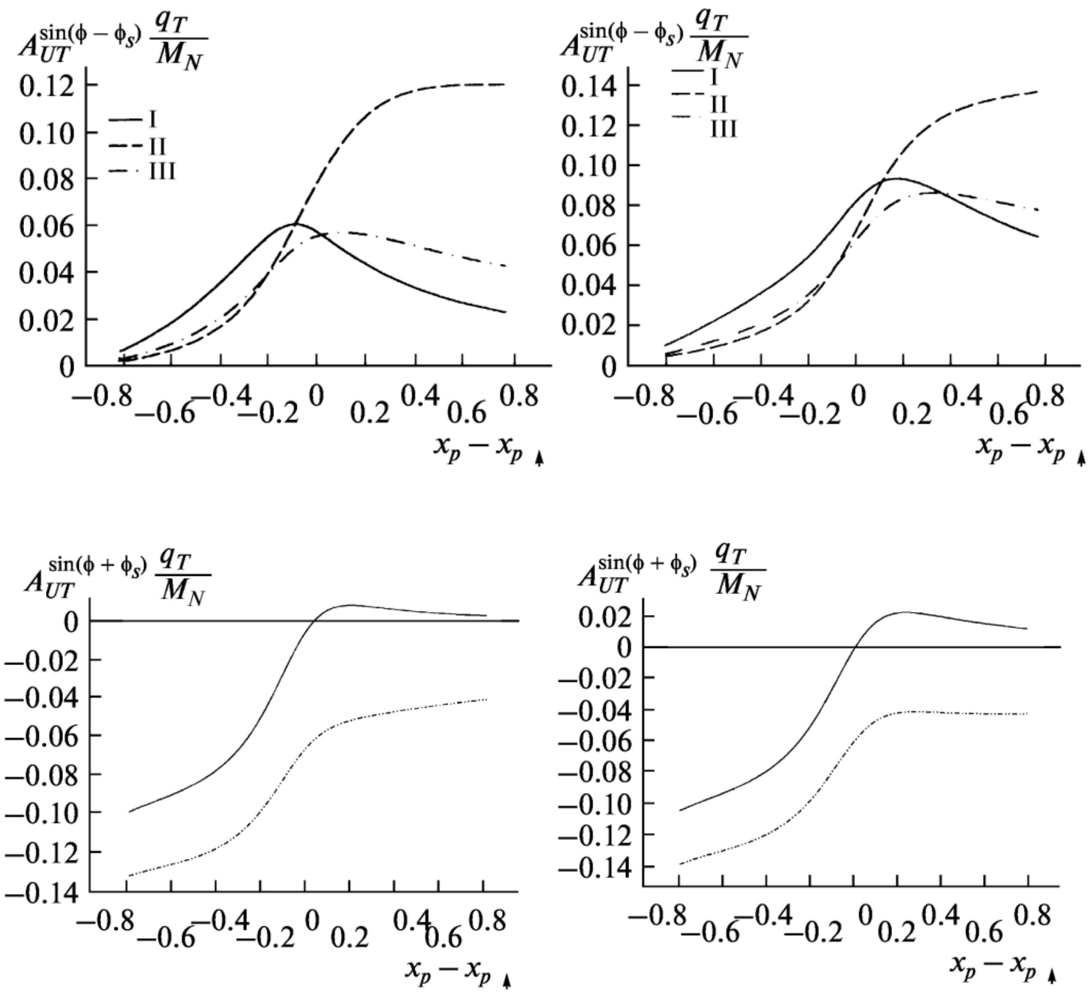
$$\propto PDF_{nucl1} \otimes PDF_{nucl2}$$



We can use this "virtual photon microscope" to look into nucleons and obtain access to PDFs.

Asymmetries in DY pair production

Q^2 = 4 GeV^2 $\qquad$ Q^2 = 15 GeV^2



Sivers

J.C.Collins et al., PRD73 (2006)014021

Boer-Mulders

s= 400 GeV^2

Kinematical ranges and statistics

PRL 119 (2017) 112002

COMPASS-2015 data

- $4.3\ \mathrm{GeV/c^2} < M_{\mu\mu} < 8.5\ \mathrm{GeV/c^2}$
- $q_T > 0.4\ \mathrm{GeV/c}$
- $\langle f \rangle \approx 0.18$
- $\langle P_{Target} \rangle \approx 0.73$

- $\mathrm{t} \approx 1.08864 \times 10^7\mathrm{s}$ (18 weeks, 126 days)

- $\langle x_F \rangle = 0.33$
- $\langle q_T \rangle = 1.2\ \mathrm{GeV/c}$
- $\langle M_{\mu\mu} \rangle = 5.3\ \mathrm{GeV/c^2}$

$\boldsymbol{N_{DY}} = \mathbf{35} \times \mathbf{10^3}$

SPD

- $4.0\ \mathrm{GeV/c^2} < M_{\mu\mu} < 9.0\ \mathrm{GeV/c^2}$
- $\langle P_{beam\ 1,2} \rangle \approx 0.6$

- $\mathrm{L} = 10^{32}\ \mathrm{cm^{-2}s^{-1}}$
- $\mathrm{t} = 10^7\mathrm{s}$ (16.5 weeks)
- $\sigma_{DY[4-9]} = 0.074\ \mathrm{nb}$

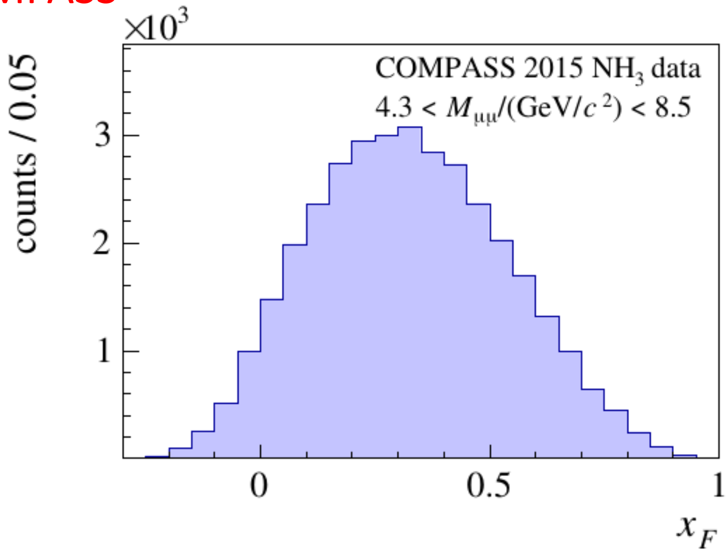
- $\langle x_F \rangle = 0.0$
- $\langle q_T \rangle = 2.4\ \mathrm{GeV/c}$
- $\langle M_{\mu\mu} \rangle = 4.8\ \mathrm{GeV/c^2}$

$N_{DY} = \sigma_{DY} \times L \times t$

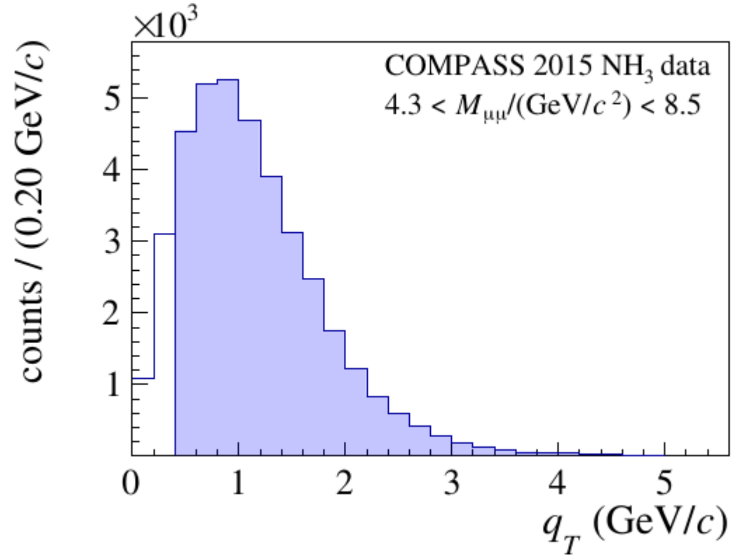
$\boldsymbol{N_{DY}} = \mathbf{88.8} \times \mathbf{10^3}$

$$dA = \frac{1}{P_{b1}P_{b2}} \times \frac{1}{\sqrt{N}}$$

COMPASS

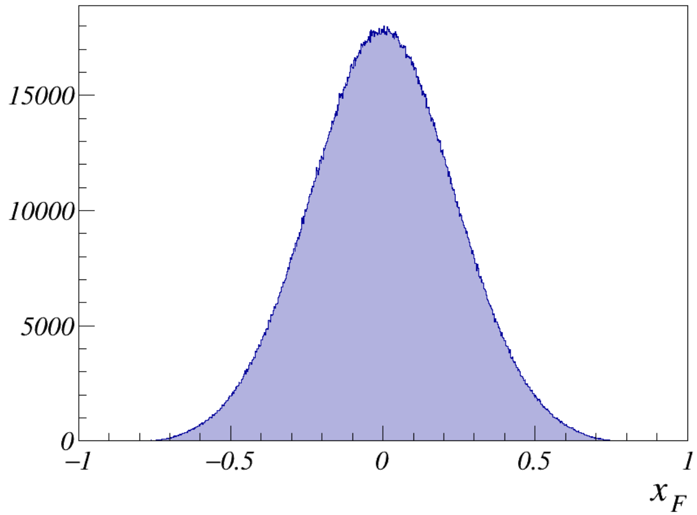


×10^3
counts / 0.05
COMPASS 2015 NH3 data
4.3 < Mμμ/(GeV/c²) < 8.5
1
2
3
0
0.5
1
xF

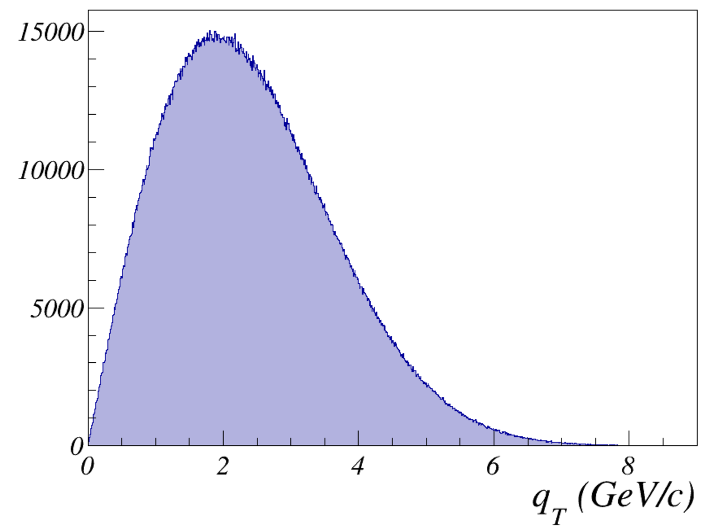


×10^3
counts / (0.20 GeV/c)
COMPASS 2015 NH3 data
4.3 < Mμμ/(GeV/c²) < 8.5
1
2
3
4
5
0
1
2
3
4
5
qT (GeV/c)

SPD



15000
10000
5000
0
–1
–0.5
0
0.5
1
xF



15000
10000
5000
0
0
2
4
6
8
qT (GeV/c)

Unpolarised Drell-Yan

$$\frac{d\sigma}{d\Omega} \propto (F_U^1 + F_U^2) \times \{1 + A_U^1 \cos^2\theta_{CS} + \sin 2\theta_{CS} A_U^{\cos\varphi_{CS}} \cos\varphi_{CS} + \sin^2\theta_{CS} A_U^{\cos 2\varphi_{CS}} \cos 2\varphi_{CS}\}$$

$$\lambda = A_U^1, \ \mu = A_U^{\cos\varphi_{CS}}, \ \nu = 2A_U^{\cos 2\varphi_{CS}}$$

Boer-Mulder Boer-Mulder

$$A_U^{\cos 2\varphi_{CS}} \propto h_{1,\pi}^{\perp q} \otimes h_{1,P}^{\perp q}$$

- **“Naïve” Drell-Yan model**

Collinear (k_T= 0) LO pQCD no rad. processes

$$\lambda = 1, \ \mu = \nu = 0$$

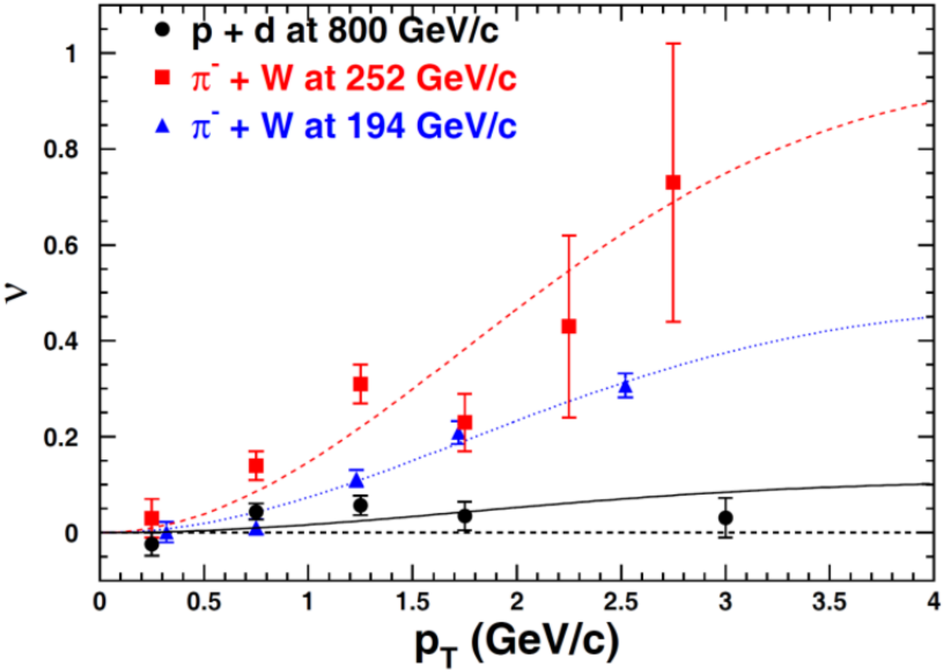
- **Intrinsic transverse motion + QCD effects**

$\lambda \neq 1, \ \mu \neq 0, \ \nu \neq 0,$ but $1 - \lambda = 2\nu$ (Lam-Tung)

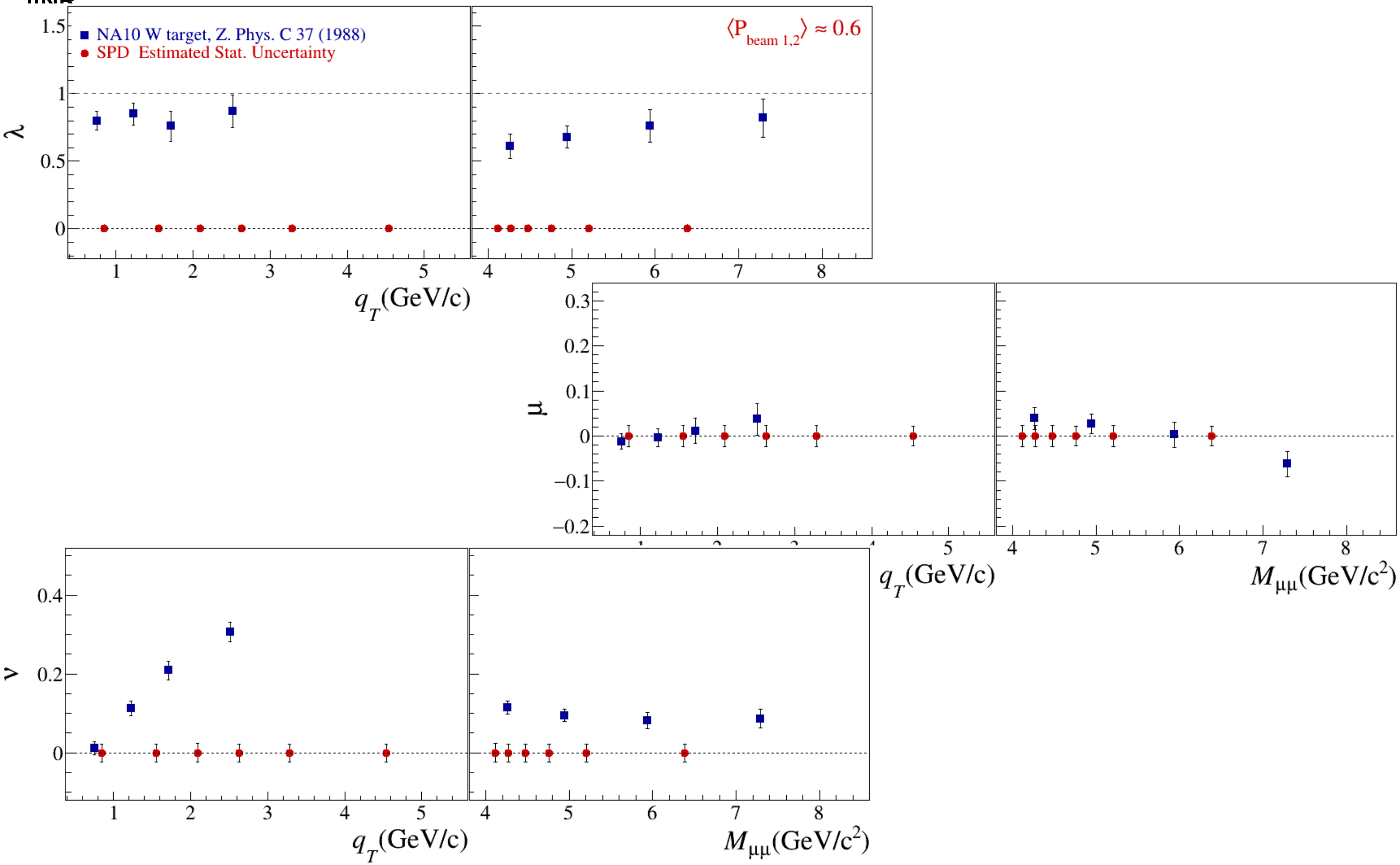
- **Experimentally observed large ν**

and violation of the LT-relation

$$\lambda \neq 1, \ \mu \neq 0, \ \nu \neq 0$$



NA10 vs SPD

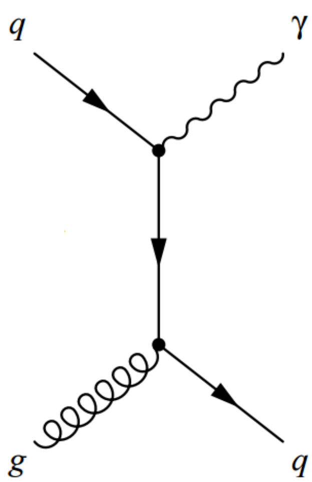


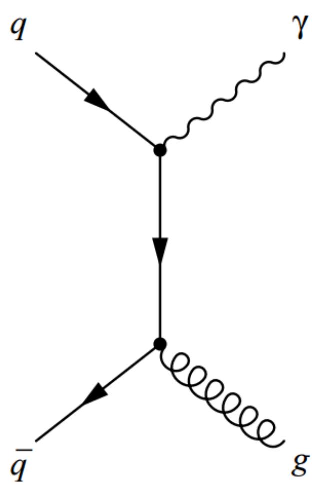
In 6 bins
SPD dA ≈ 0.02

with $\langle P_{beam\ 1,2} \rangle = 1.0$ SPD dA ≈ 0.008

Prompt (direct) photon production

Gluon Compton scattering | **Quark-antiquark annihilation**

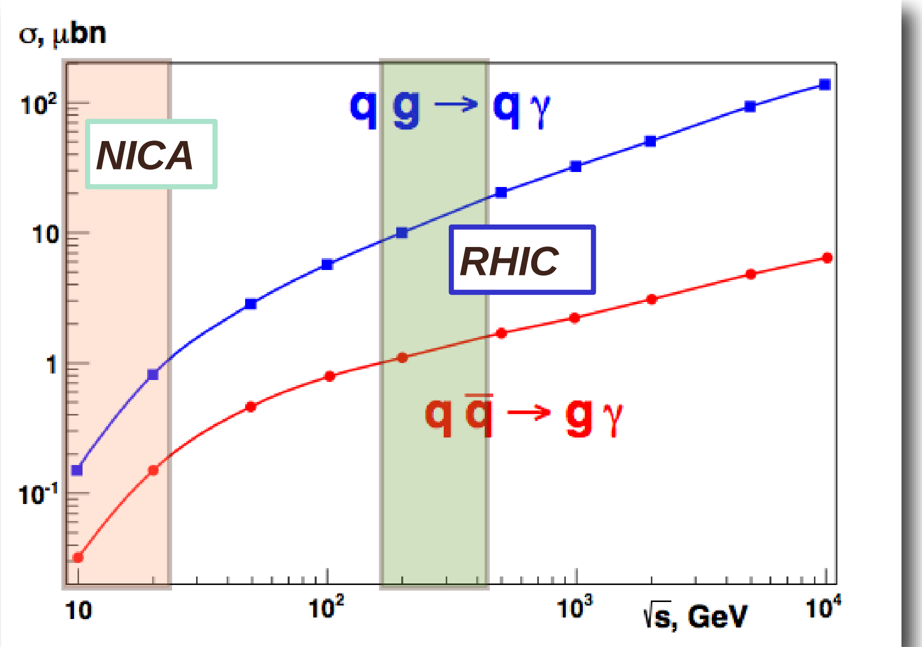




The gluon Compton scattering mechanism dominates…

q g→q γ **85%**

q qbar→g γ **15%**



…so we can obtain access to the contribution of gluon to spin of the nucleon.

Prompt photons

The gluon Compton scattering gives access to the gluon content of proton:

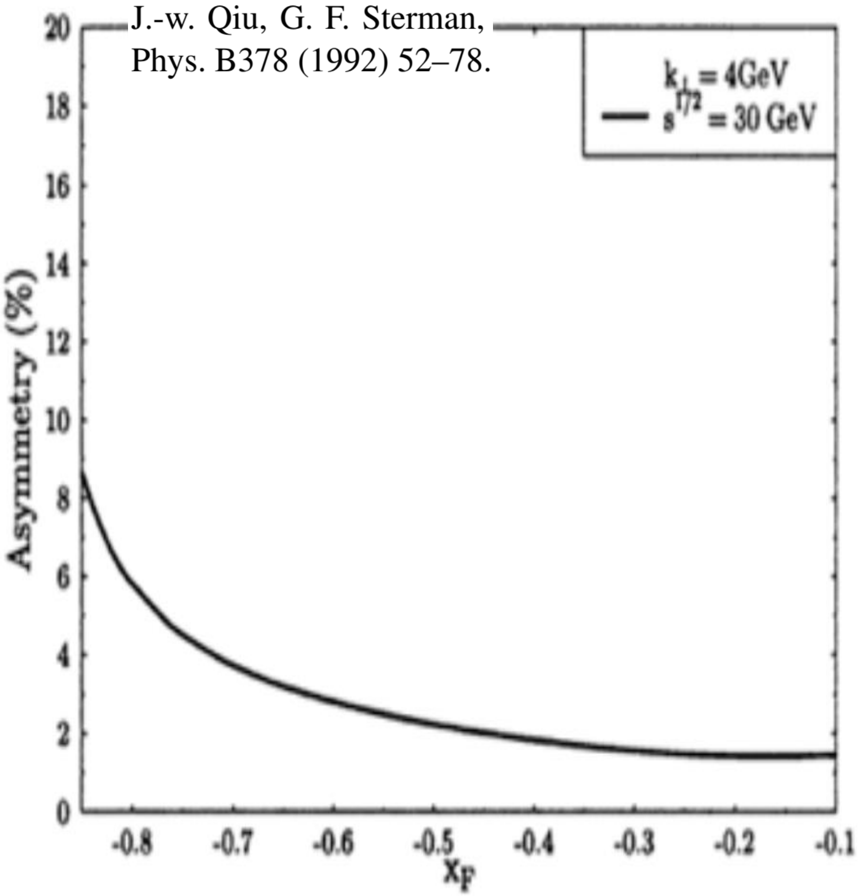
Transverse beam polarization: access to the Sivers function for gluons

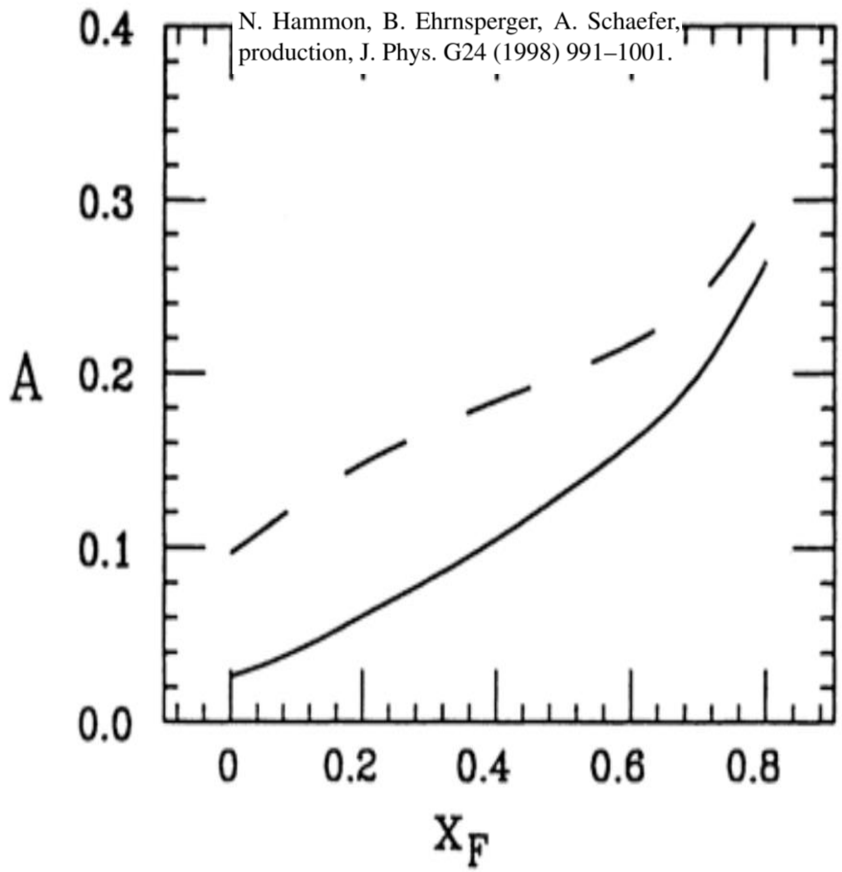
$$\sigma^{\uparrow} - \sigma^{\downarrow} = \sum_i \int_{x_{min}}^{1} dx_a \int d^2\mathbf{k}_{Ta} d^2\mathbf{k}_{Tb} \frac{x_a x_b}{x_a - (p_T/\sqrt{s})\, e^y} [q_i(x_a, \mathbf{k}_{Ta}) \Delta_N G(x_b, \mathbf{k}_{Tb}) \times \frac{d\hat{\sigma}}{d\hat{t}}(q_i G \to q_i \gamma) + G(x_a, \mathbf{k}_{Ta}) \Delta_N q_i(x_b, \mathbf{k}_{Tb}) \frac{d\hat{\sigma}}{d\hat{t}}(G q_i \to q_i \gamma)]$$

Longitudinal beam polarization: access to gluon polarization $\Delta g/g$

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

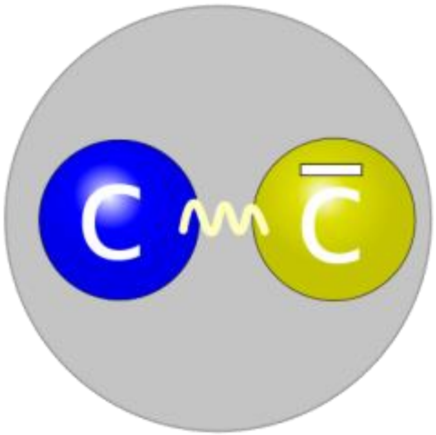
Expected asymmetries in prompt photon production





Charmonium (J/ψ) production

J/Ψ

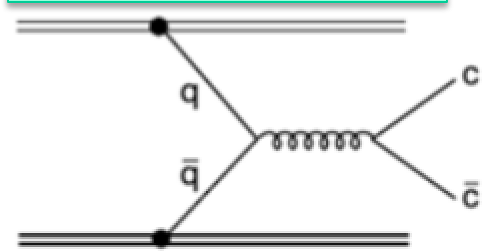


Applicability of the method is limited due the lack of understanding J/ψ production mechanism.

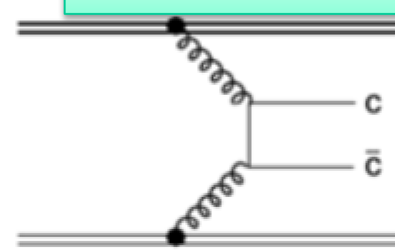
Proton-proton collisions at SPD provide ideal opportunity for verification of theoretical approaches to J/ψ production.

NRQCD

Quark annihilation



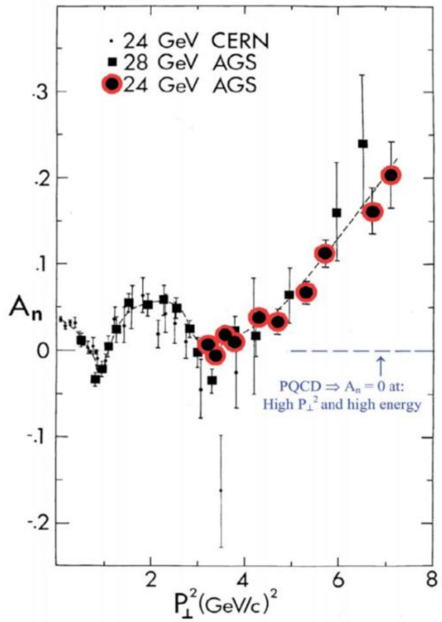
Gluon fusion

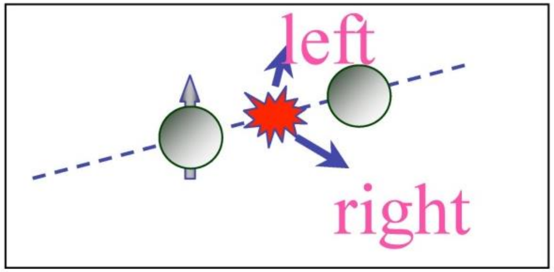


Studying of J/Ψ production gives us access to the gluon PDFs.

Asymmetries in high p_T hadron production

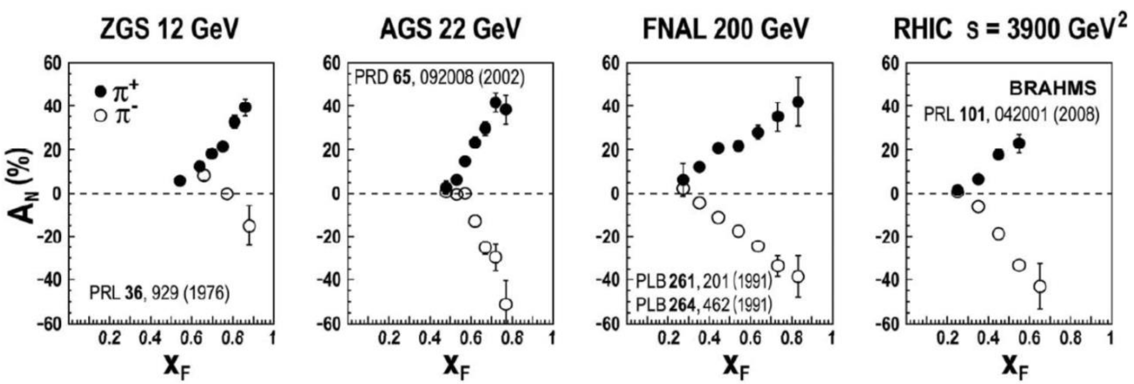
- Diquark properties;
- Confinement laws;
- Nature of the huge spin effects;
- Deuteron spin structure;
- Properties of the bare NΛ- and NK-interactions;
- Nature and properties of the cold super dense baryonic matter (CsDBM) (pA and AA);
- Dilepton production puzzle in np-interaction.





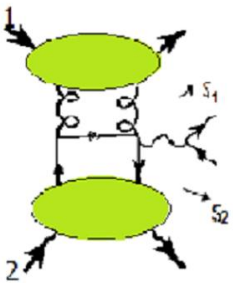
INCLUSIVE PION ASYMMETRY IN PROTON-PROTON COLLISIONS

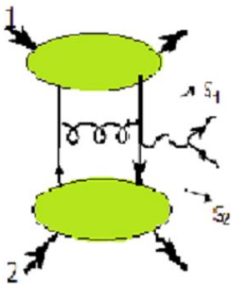
C. Aidala SPIN 2008 Proceeding and CERN Courier June 2009



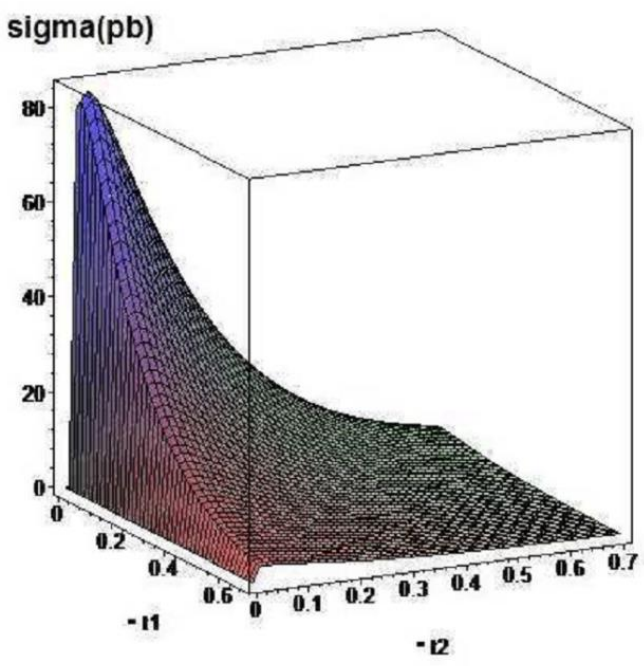
Exclusive DY

S.Goloskokov, P.Kroll and O.Teryaev in progress.





Cross section is integrated over s_1 and s_2 was calculated at NICA energies
Preliminary result for cross section of $p\,p \to p\,p\,l^+\,l^-$ process at NICA energies

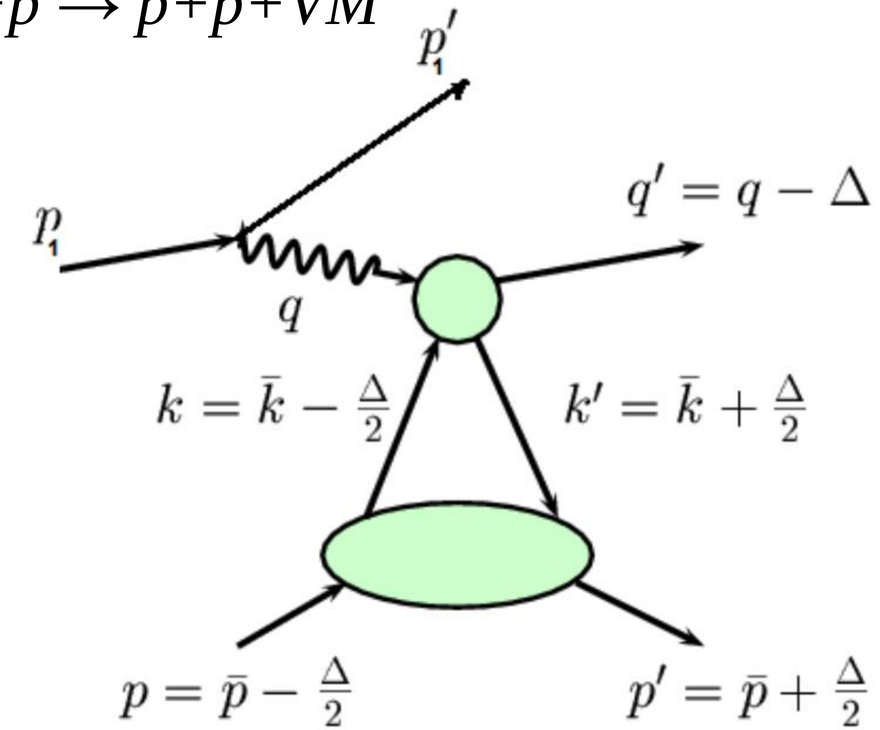


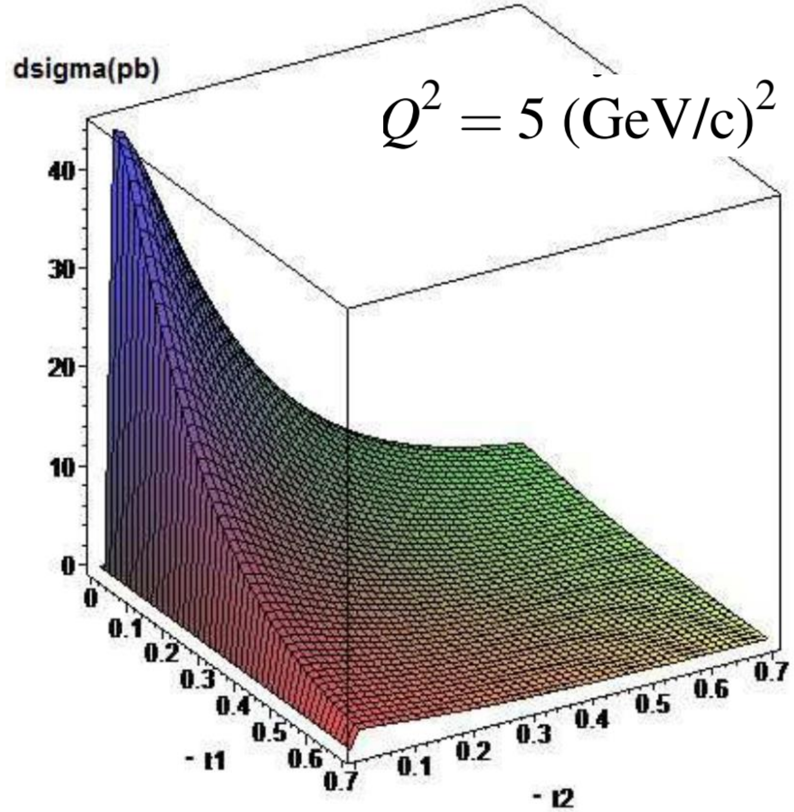
Preliminary results for cross section of exclusive Drell-Yan process over t_1 and t_2 at NICA energies. $\frac{d\sigma}{dQ^2 dt_1 dt_2}$ -in pb/GeV^6. Estimations show that such contribution might be visible. Both final protons should be detected

Integrated over t_1 and t_2 cross section $d\sigma/dQ^2 \sim 5.5$ pb/GeV^2 at $Q^2 = 5$GeV^2 (NICA energies)

GPD through vector meson exclusive production

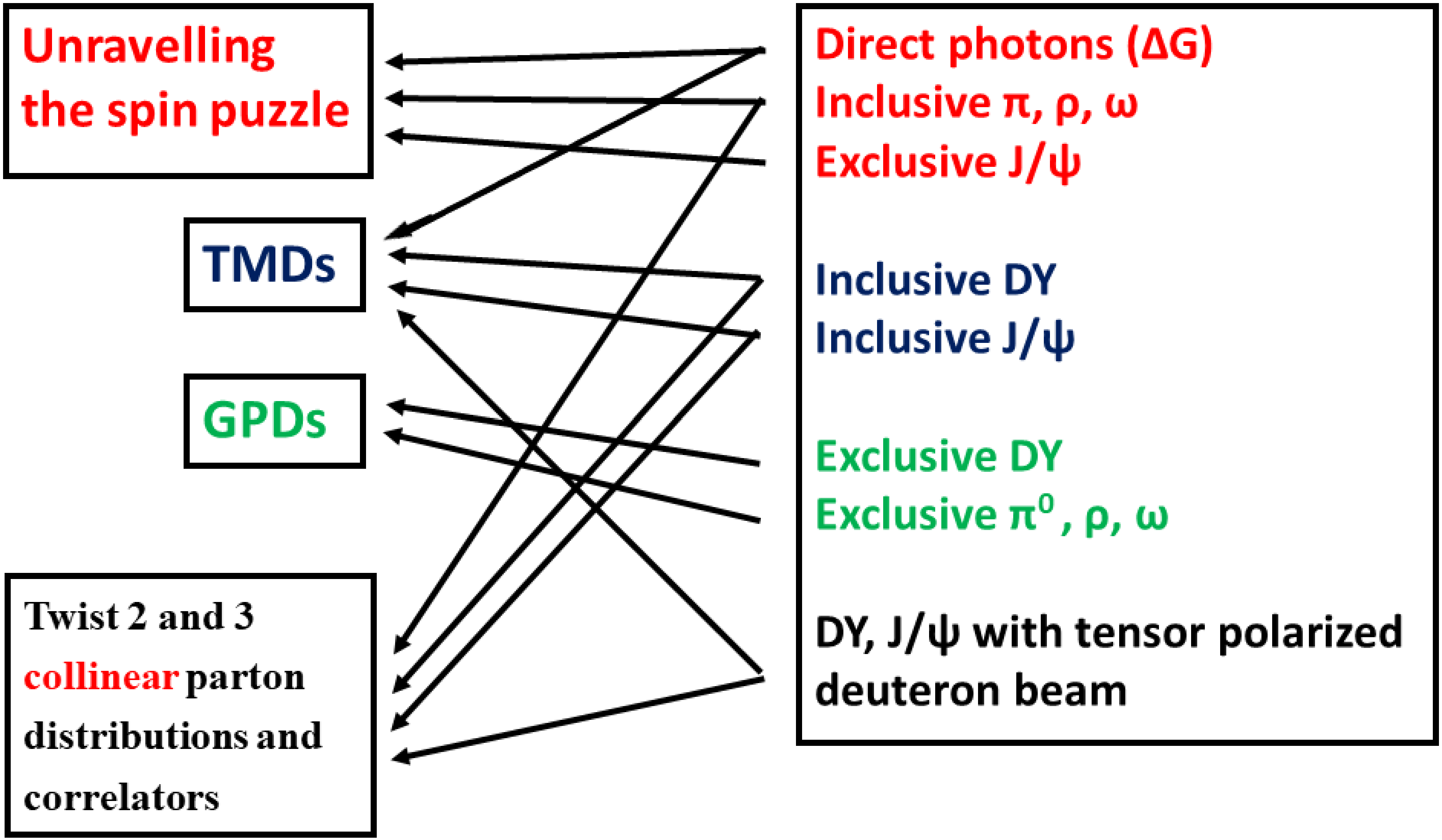
$$p + p \rightarrow p + p + VM$$





Vector meson production

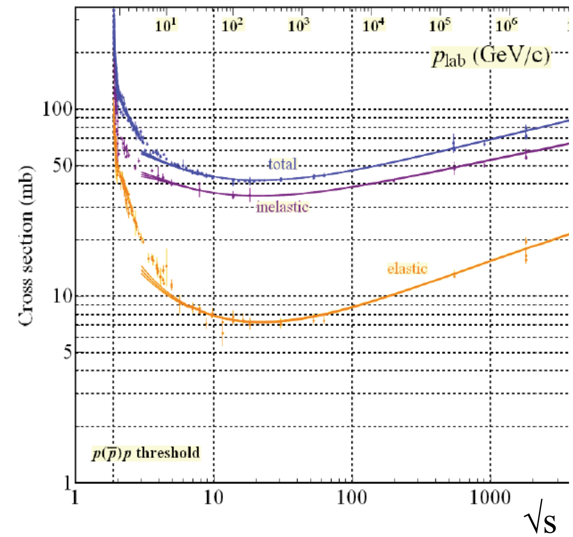
via photoproduction mechanism or odderon exchange.

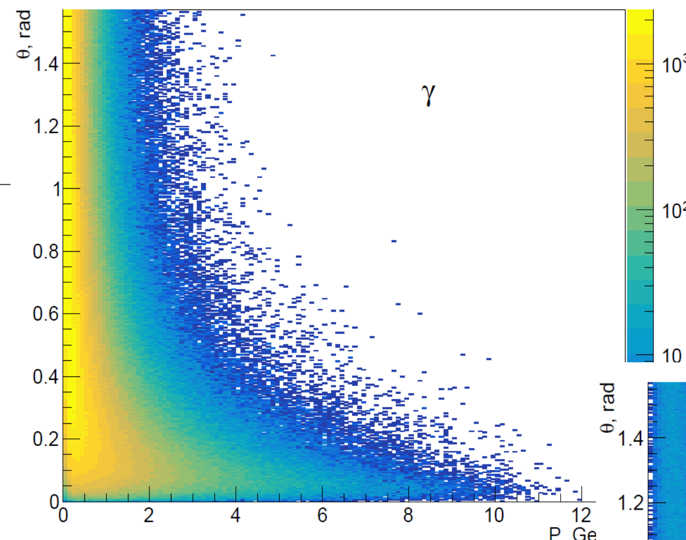

Unravelling the spin puzzle
TMDs
GPDs
Twist 2 and 3 collinear parton distributions and correlators
Direct photons (ΔG)
Inclusive π, ρ, ω
Exclusive J/ψ
Inclusive DY
Inclusive J/ψ
Exclusive DY
Exclusive π⁰, ρ, ω
DY, J/ψ with tensor polarized deuteron beam

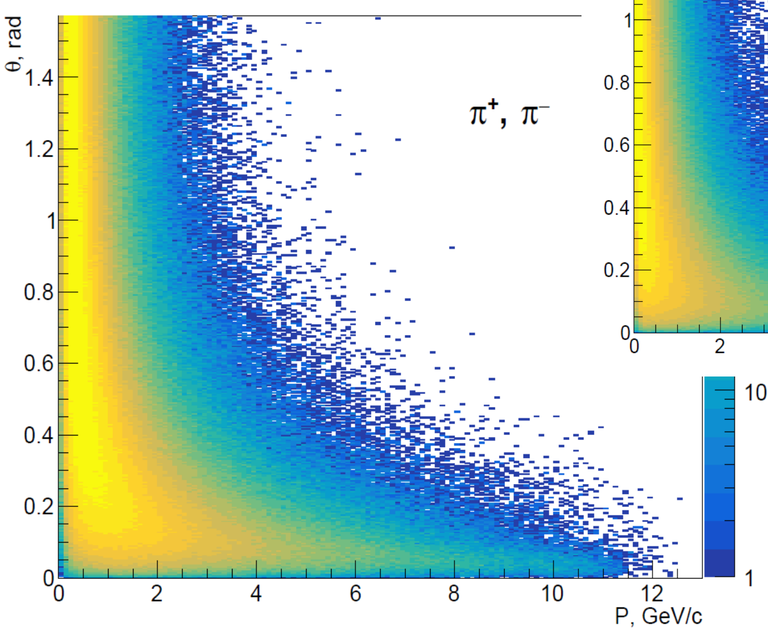
Minimum biased events

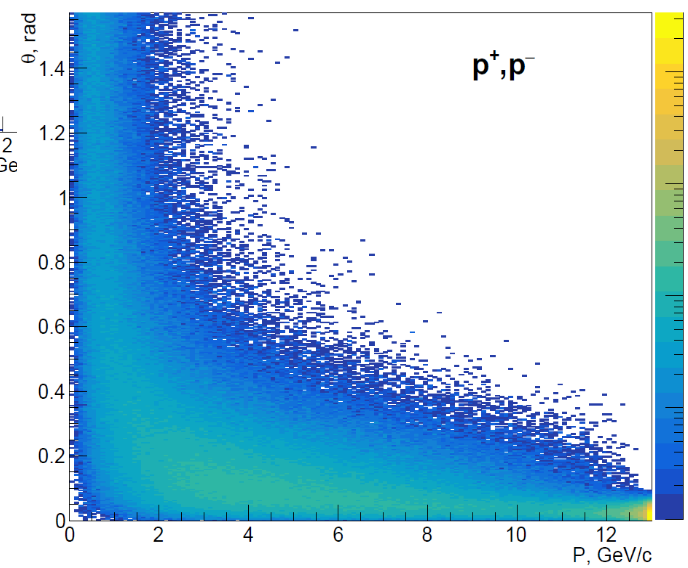
PYTHIA 6, $\sqrt{s_{pp}}$ = 26 GeV; 4 MHz event rate

- Average charged particle multiplicity ≈ 7.8
- Average neutral particle multiplicity ≈ 6.5



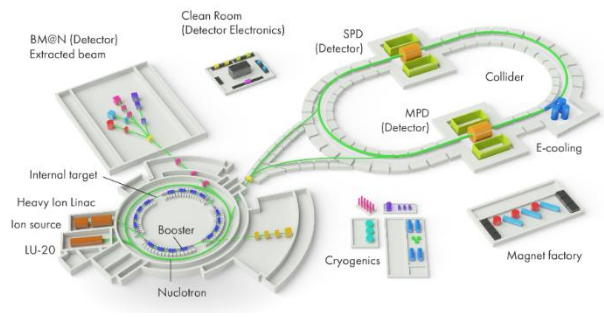


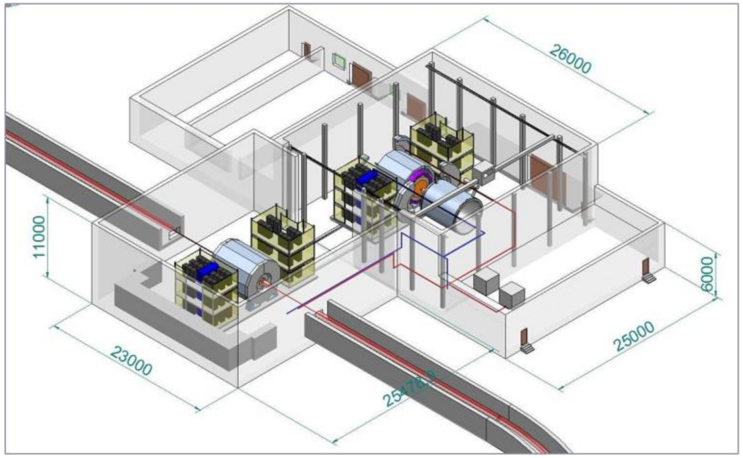




from A. Guskov

Requirements for the SPD

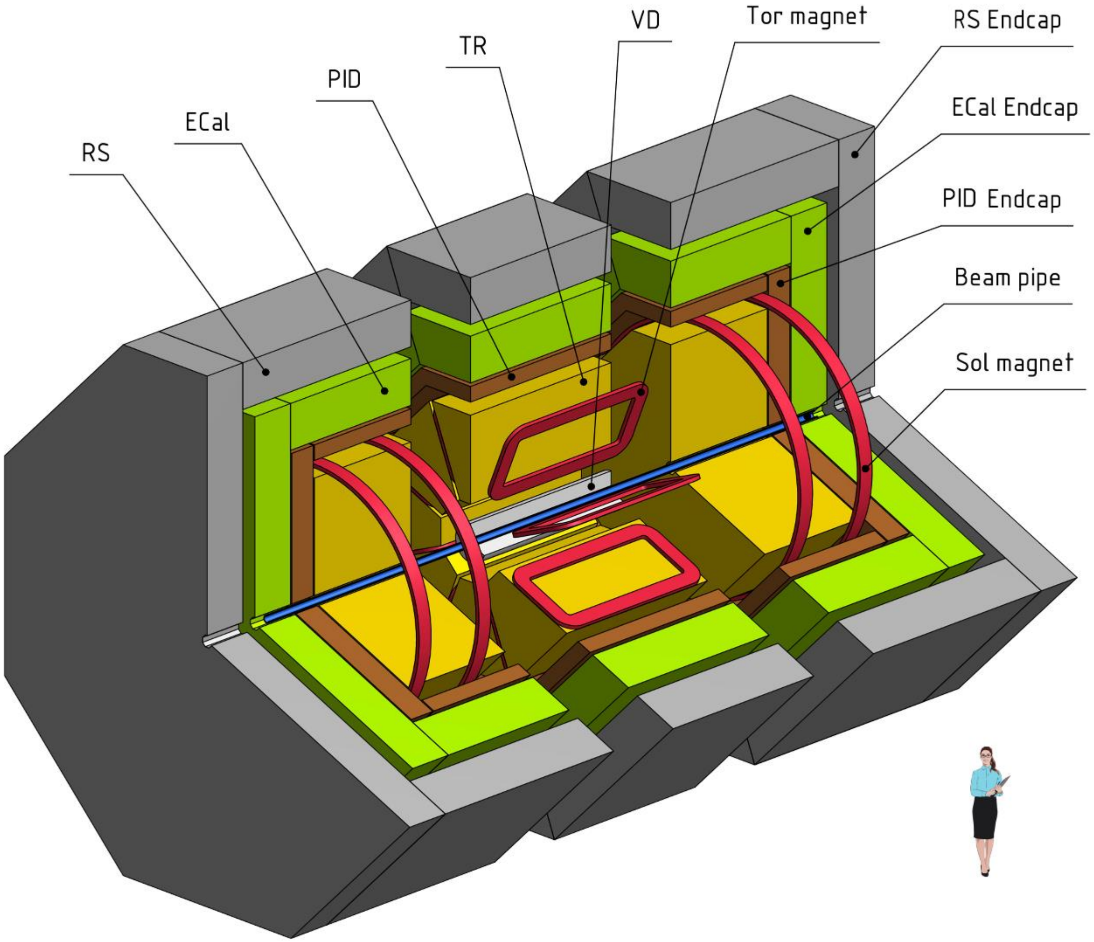




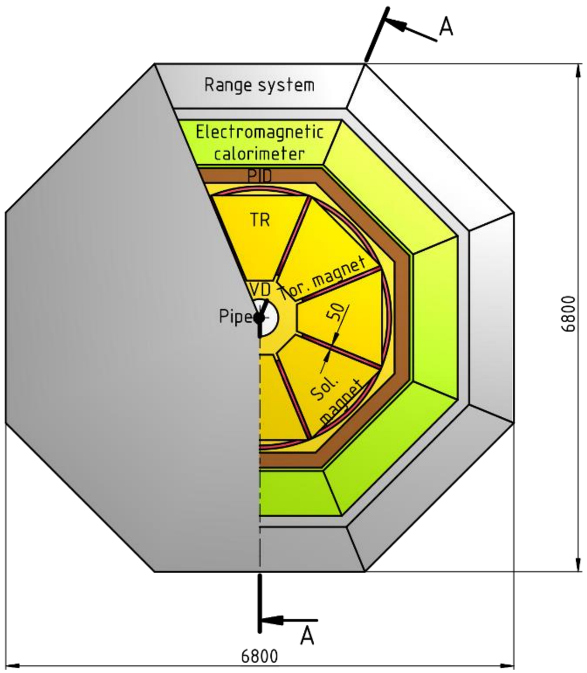
- close to 4π geometrical acceptance;
- high-precision (~50 µm) and fast vertex detector;
- high-precision (~100 µm) and fast tracker,
- good particle ID capabilities;
- efficient muon range system,
- good electromagnetic calorimeter,
- low material budget over the track paths,
- trigger and DAQ system able to cope with event rates at luminosity of 10^{32} (cm.s)$^{-1}$,
- modularity and easy access to the detector elements, that makes possible further reconfiguration and upgrade of the facility.

General view

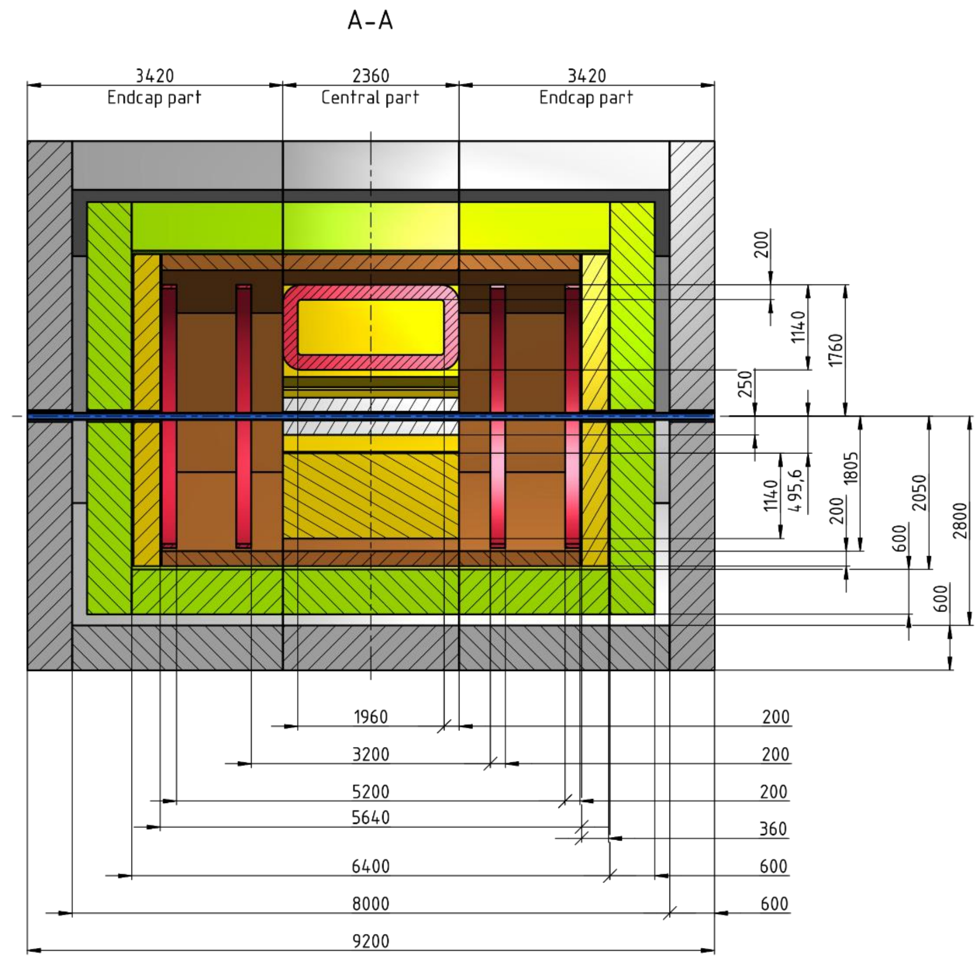
- Length: 9.2 m;
- Diameter: 6.8 m;
- Mass: 1800 t;
- Consists of three modules;
- Easy way to rearrange.



Dimensions



A
Range system
Electromagnetic calorimeter
PID
TR
VD
Tor. magnet
Pipe
50
Sol. magnet
6800
A
6800



A-A
3420
Endcap part
2360
Central part
3420
Endcap part
200
1140
1760
250
1140
495,6
200
1805
2050
600
2800
600
1960
200
3200
200
5200
200
5640
360
6400
600
8000
600
9200

Hybrid magnetic system

½ model symmetry

$$B^{(z)}(x,y,0)=0.$$

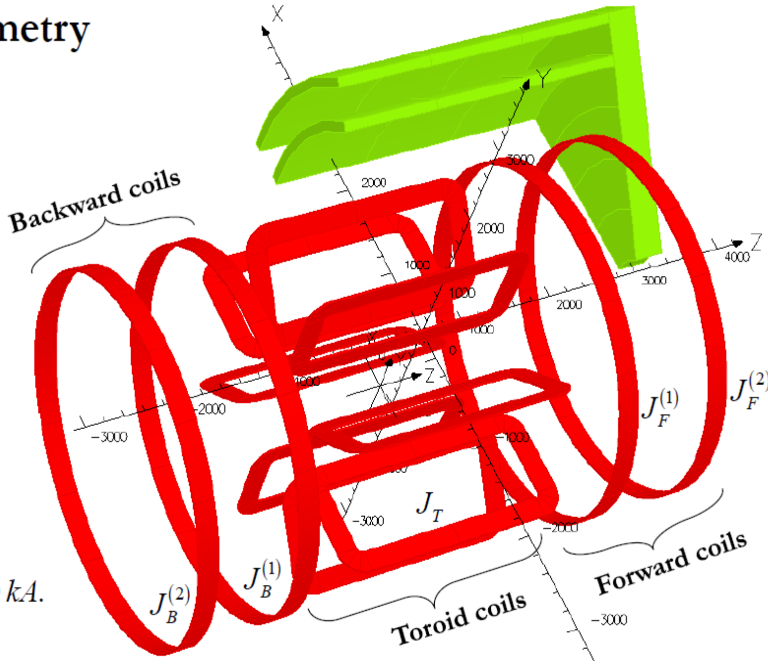
$$J_T = 40\frac{A}{mm^2},$$

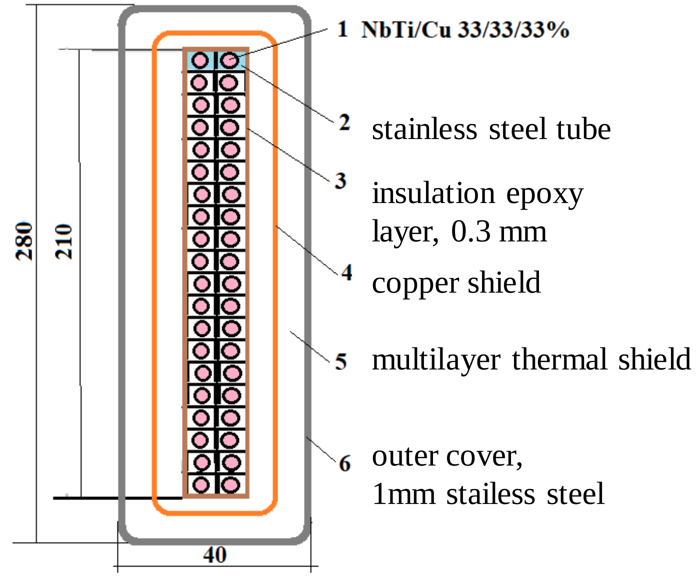
$$J_{B\backslash F}^{(1,2)} = \mp 80\frac{A}{mm^2},$$

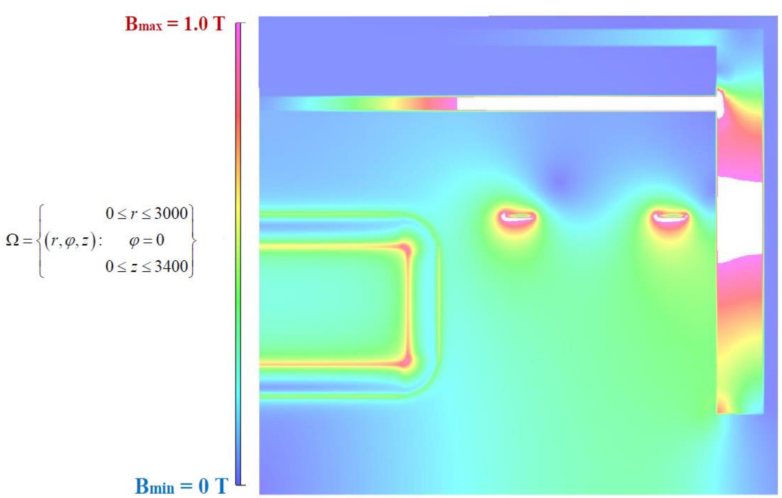
$$S = 200\times 20\,mm^2,$$

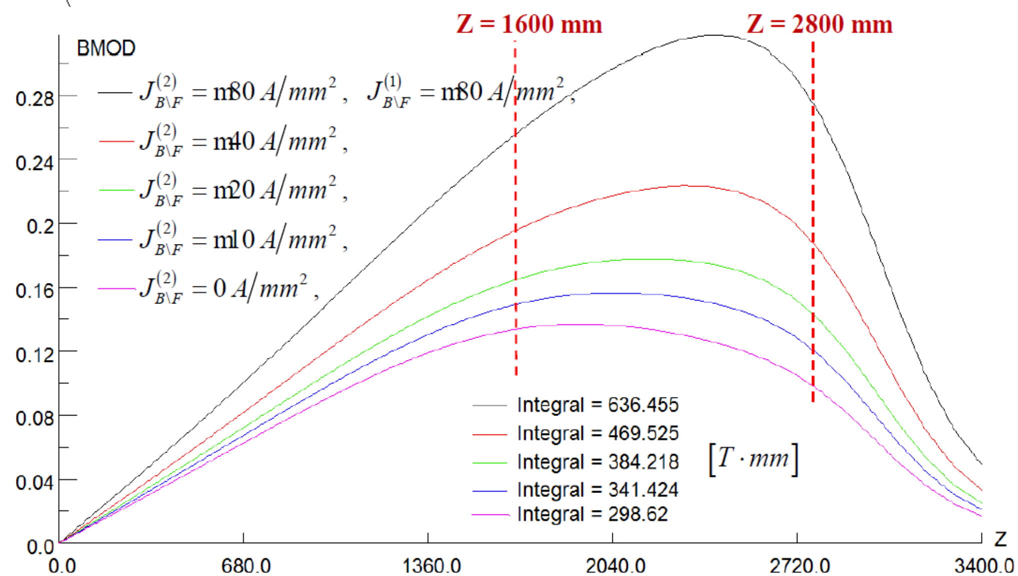
$$I_T = J_T\cdot S = 160\,kA,$$

$$I_{B\backslash F} = J_{B\backslash F}\cdot S = \mp 320\,kA.$$

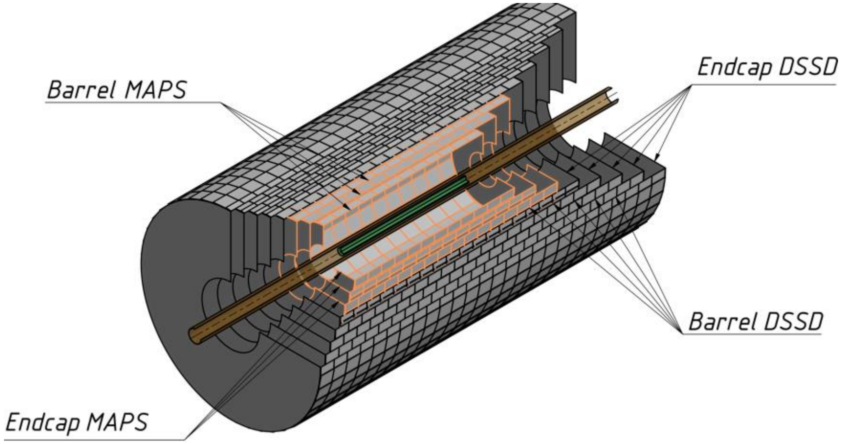






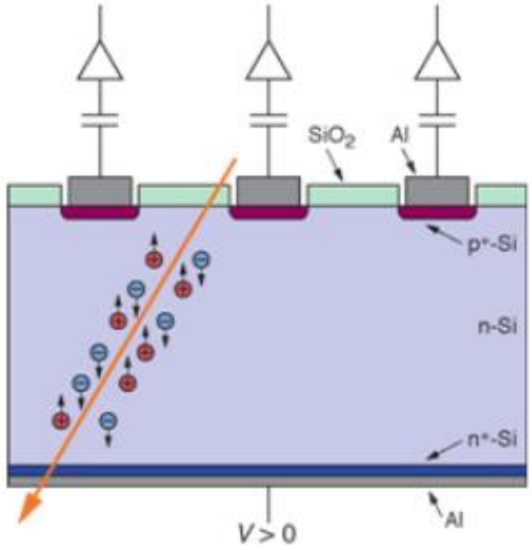


Vertex detector (Inner tracker)

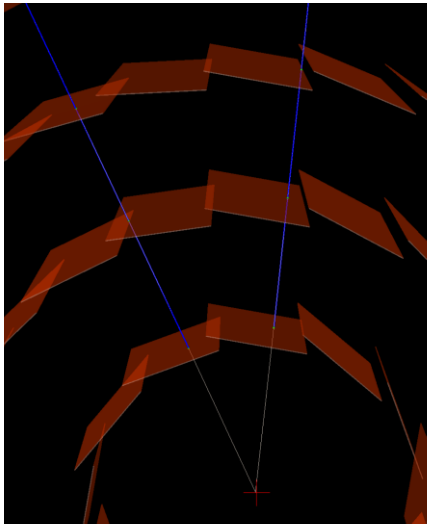


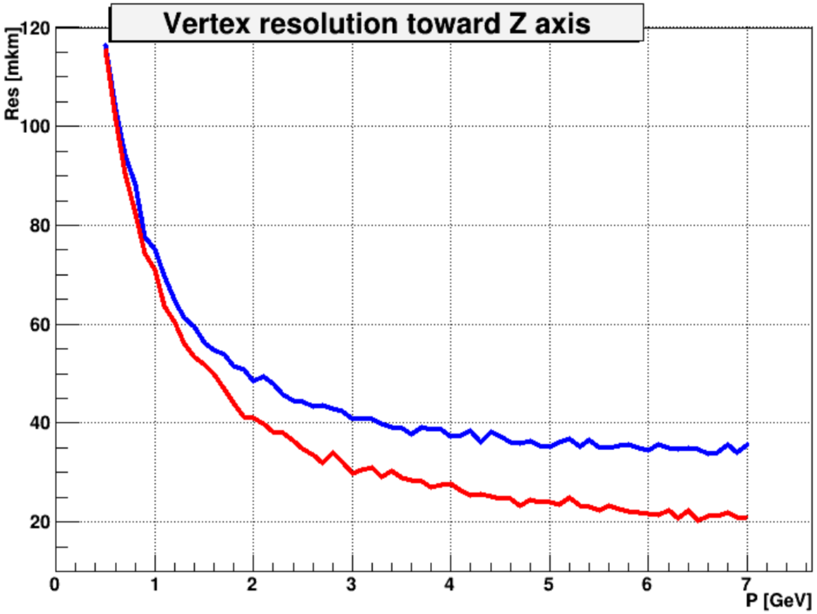
Charged particle creates electron/hole pairs, which migrates to electrodes creating signal in the nearest strips

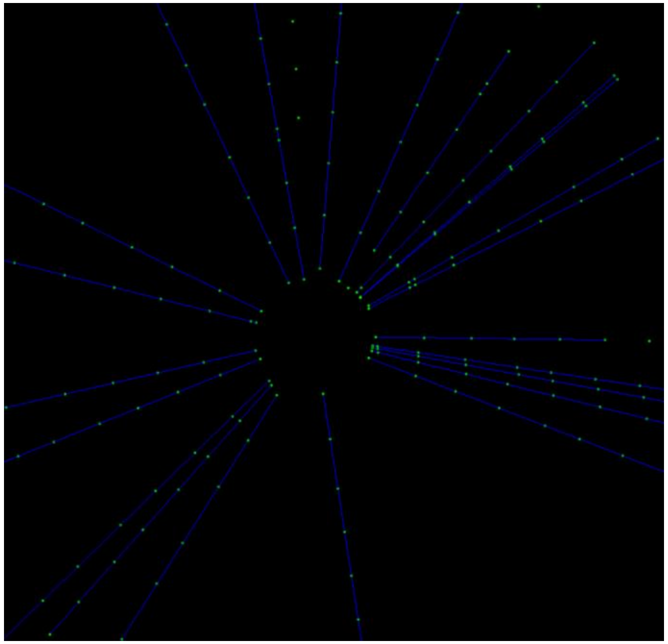
- Silicon vertex detector around the beam pipe;
- Several layers of double sided silicon strips and MAPS;
- Optimized number of layers w.r.t. material budget;
- Goal: few tens of μm resolution for the vertex reconstruction.



- Six particles from the vertex
- Vertex detector with 5 layers
- Silicon resolution: 50 mkm (blue) and 25 mkm (red)

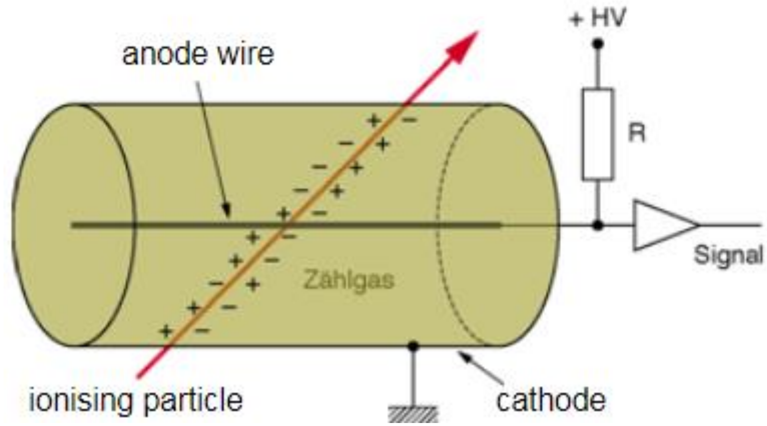


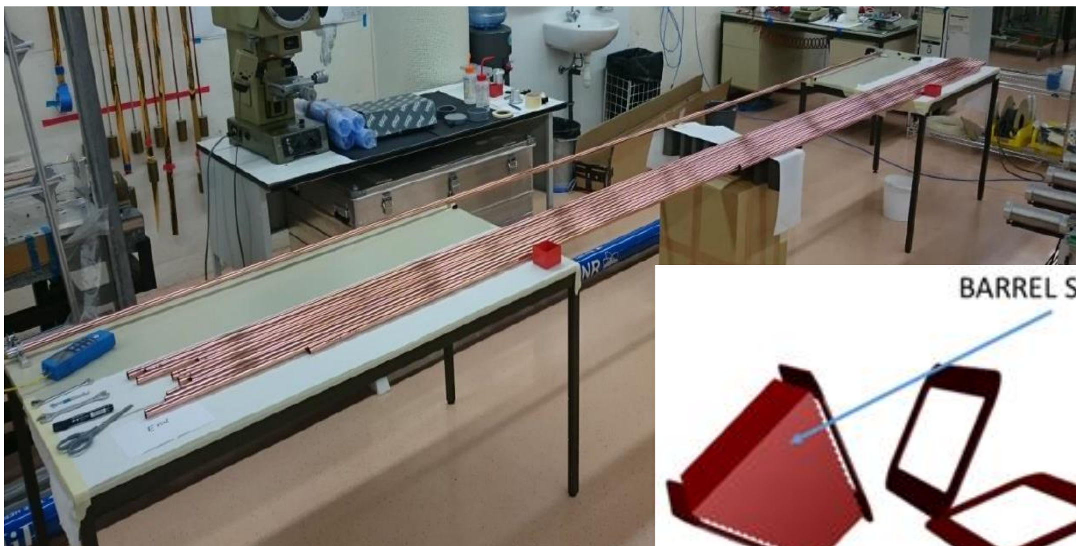


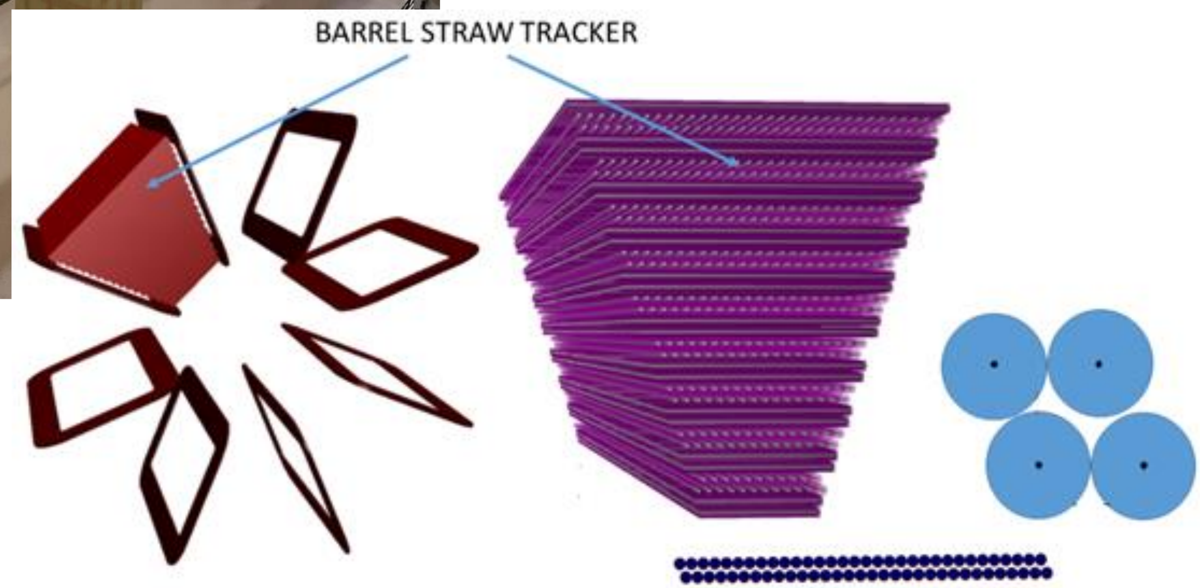


Central tracker

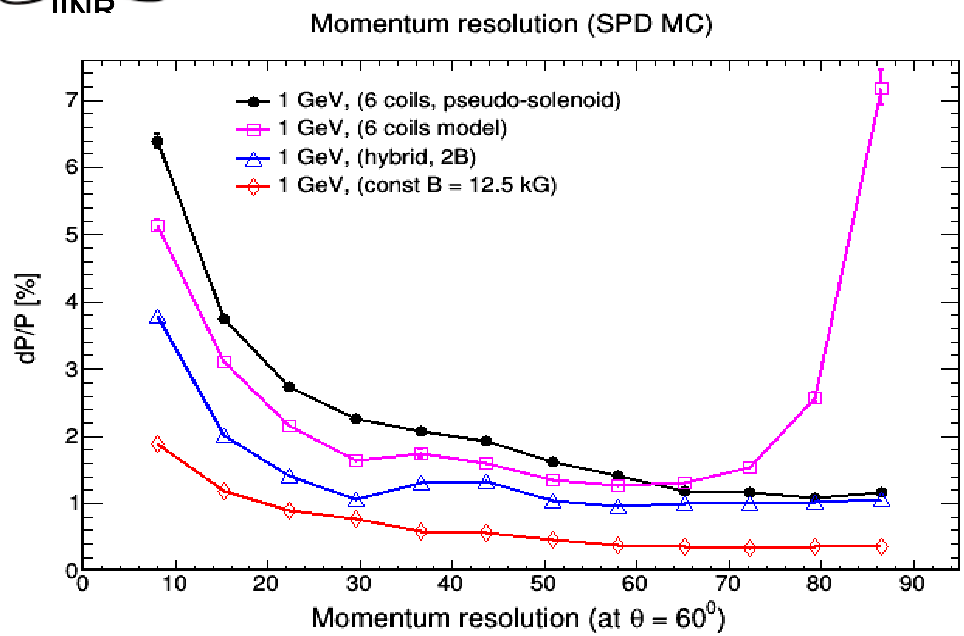
- Minimum material on the particle tracks (X_0 ~ 0.1);
- Time (~ 100 ns) and spatial resolution (~100 μm);
- Expected particle rates (DAQ rates) ~ MHz;
- Technology developed also in JINR, production workshops available

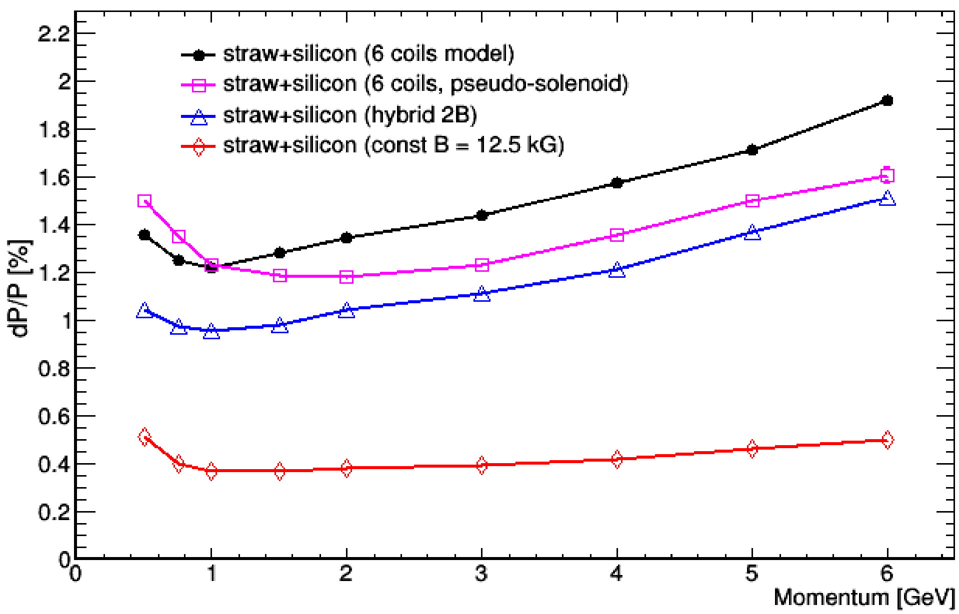




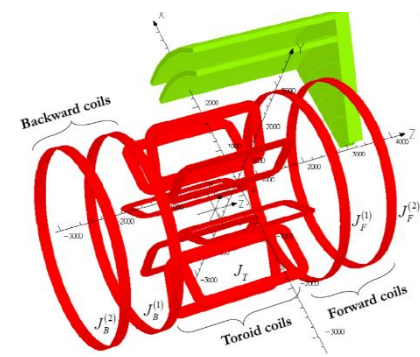


Momentum resolution

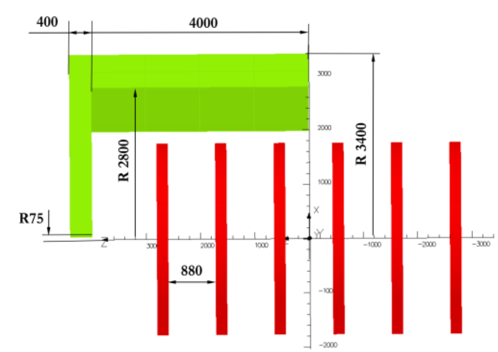




Hybrid magnetic system



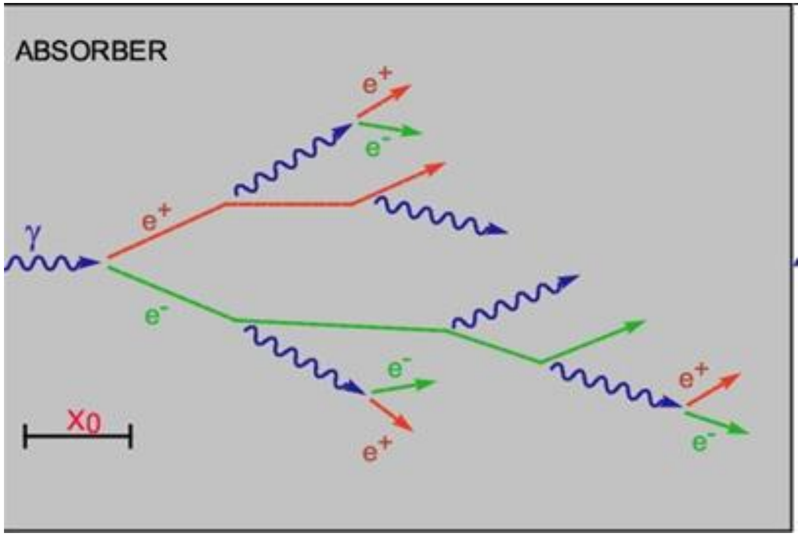
Vertex Det.: 5 silicon layers of 300 μm thickness each; **Barrel TS**: 8 straw-tube layers, two planes of 1 cm thickness in each

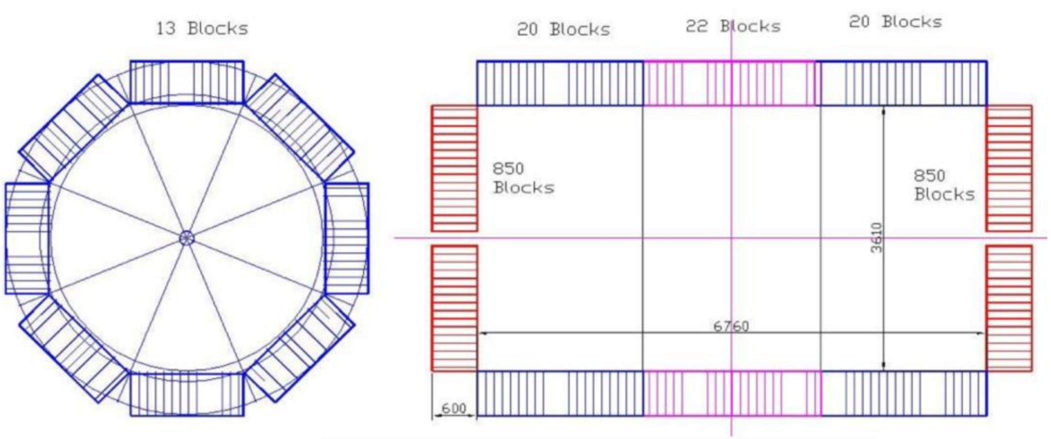


Pseudo-solenoidal or 3↔3

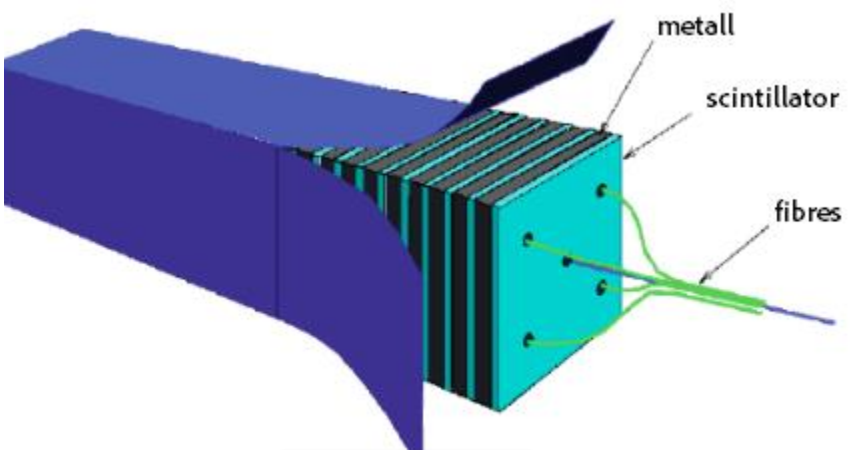
Electromagnetic calorimeter

- Photon energy range 0.1 - 10 GeV;
- Due to space limitations the total length of the ECAL module should be less than 50 cm;
- Required energy resolution <10.0%/√E (GeV) and energy threshold below 100 MeV;
- Design ("shashlik") similar of that for KOPIO ECal





About 6500 modules

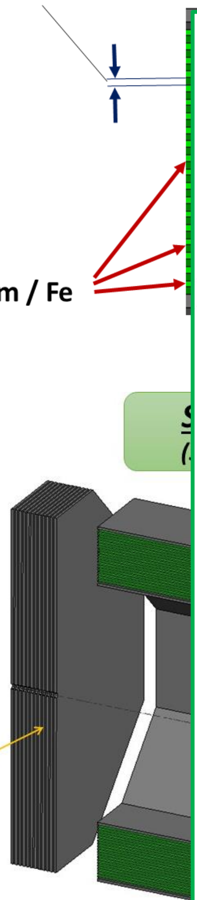


Shashlik

Range system

35 mm – gaps for MDT detectors

19 x30 mm / Fe

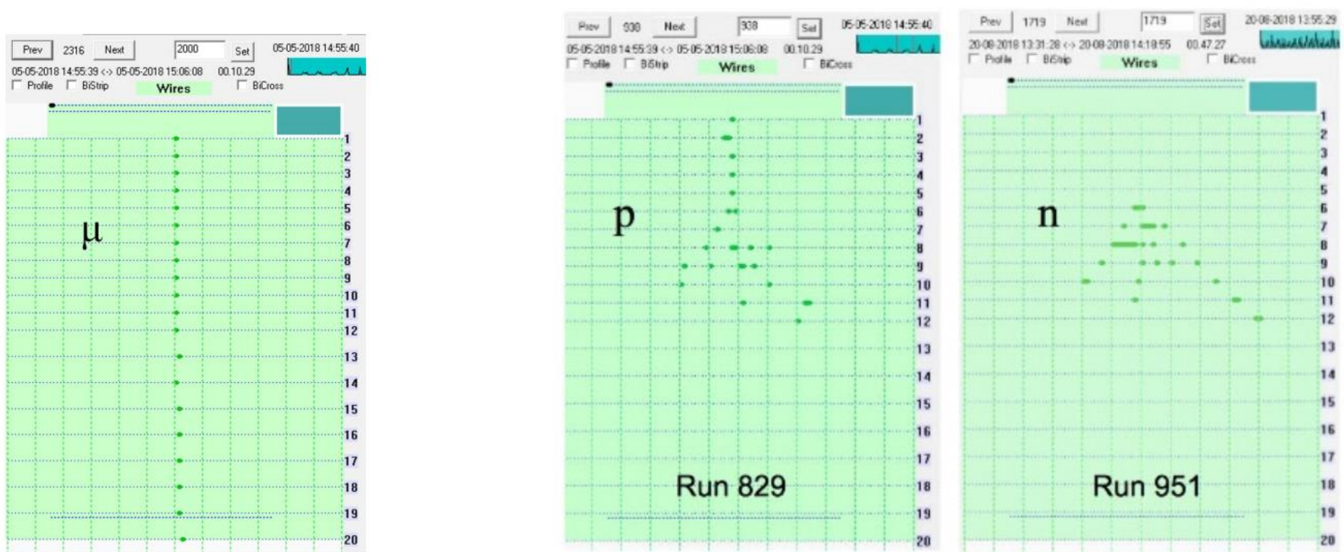


PID pictures of Muon System

(single point equals one hit wire – 1x1 cm2; beam momentum – 5 GeV/c)

muonic sample -> 'straight' line

hadronic sample -> shower

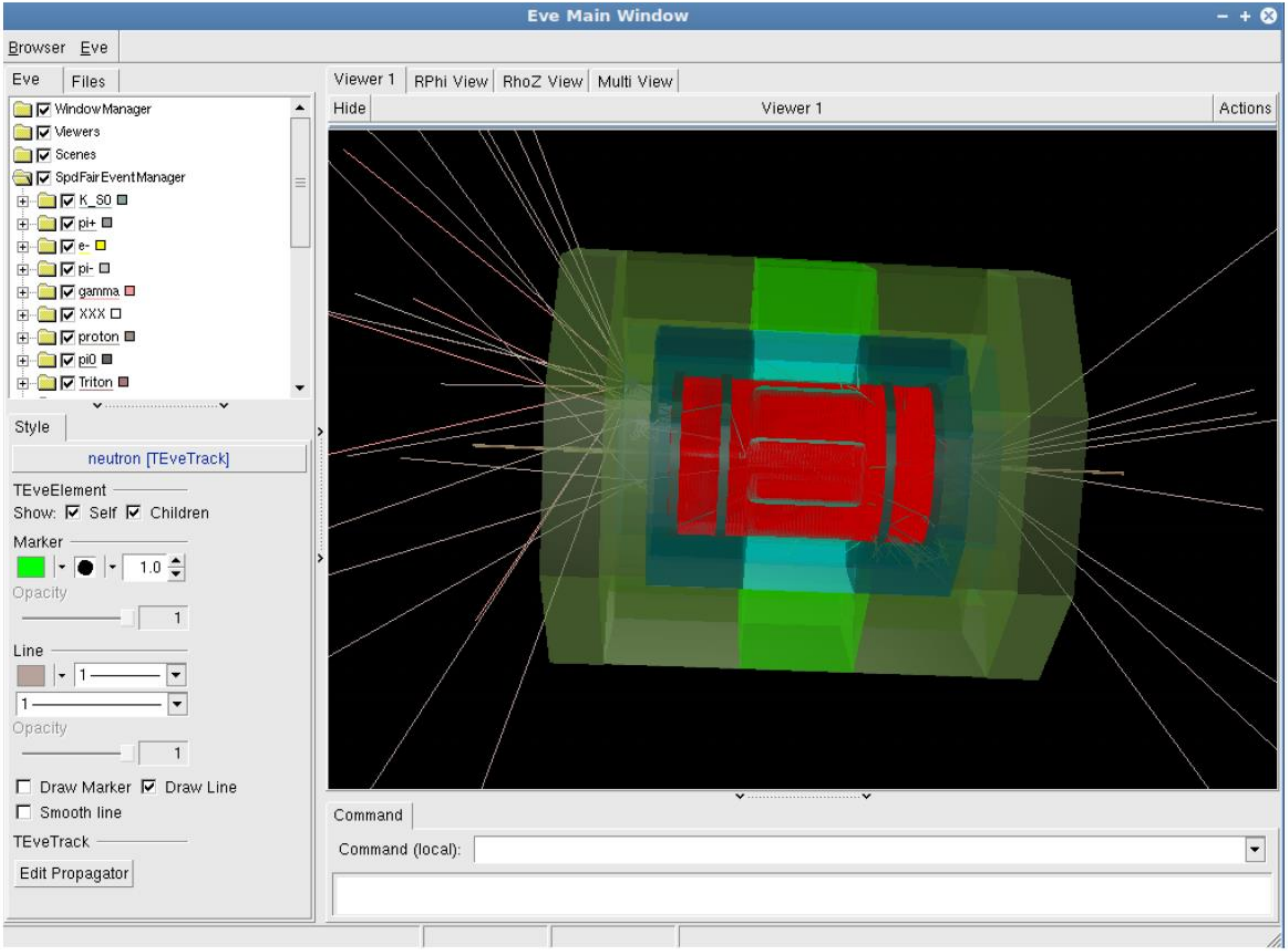


now at the DLNP of JINR

DAQ

- The SPD DAQ may be developed *a la* upgraded DAQ of the COMPASS experiment;
- Event rate 3.0 MHz (at $L=10^{32}$ $cm^{-2}s^{-1}$, $\sqrt{s}$=27 GeV);
- Rough preliminary estimation of the total data flux from the detectors (Si tracker + straw tracker + PID + ECal + Range system): 10-20 GBytes/s (no detailed simulation results available yet);
- Triggered or trigger-less DAQ: to be decided.

Software and computing



SPD advantages:

- measurements with pp, pd and dd beams,
- possibility to perform energy scan with small steps,
- measurements via muon and electron-positron pairs,
- operations with non-polarized, transverse and longitudinally polarized beams and their combinations,
- possibility to extract all first order PDFs in one experiment.

HOME INSTITUTE, EXPERIMENT	RHIC, STAR	RHIC, fsPHENIX	NICA, SPD
Beams	pp, pA, pHe^3	pp pA, pHe^3	pp,pd, dd, pHe^3, dHe^3
Polarization	0.6	0.6	0.6-0.8
Luminosity, cm^{-1} s^{-1}	$5\cdot10^{32}$	$(0.8\text{-}6)\cdot10^{32}$	10^{32}
$\sqrt{s}$, GeV	160,200, 500	160,200, 500	10-26
X_1, range	0.3-1.0	0.3-1.0	0.1-0.8
Q_T, GeV	1-10	1-10	0.5-6
Lepton pairs	μ+μ-	μ+μ-	μ+μ-, e+e-
Start of data taking	>2020	>2021	2025
Measurements			
Transversity	yes	yes	yes
Boer-Mulders	yes	yes	yes
Sivers	yes	yes	yes
Predzelosity	no	yes	yes
Worm-Gear	yes	no	yes
Flavour separation	yes	yes	yes
Exclusive DY	yes	no	yes
Deuteron quadrupole structure	no	no	yes

Collaborating institutions – 25 so far

- ✓ National Science Laboratory, Armenia
- ✓ Institute of Applied Physics of the Belarus Academy of Sciences;
- Gomel State Technical University, Belarus;
- Institute for Nuclear Problems of BSU – Minsk;
- Chilean cluster of universities, Chile
- Tsinghua University, Tsinghua, China
- Instituto Superior de Tecnologías y Ciencias Aplicadas (INsTEC), Havana University;
- ✓ Charles University, Prague;
- ✓ Technical University, Prague
- INFN section of Turin and University of Turin;
- CEA, Saclay, France;
- ✓ Warsaw University of Technology;
- ✓ Tomsk State University;
- Tomsk Polytechnic University;
- ✓ Lebedev Physics Institute of the RAS, Moscow;
- ✓ Institute for High Energy Physics, Protvino;
- ✓ Institute of Nuclear Physics of the Moscow State University;
- Institute for Nuclear Research of the RAS, Troitsk;
- ✓ Institute for Theoretical and Experimental Physics, Moscow;
- St. Petersburg Nuclear Physics Institute, Gatchina;
- St. Petersburg State University;
- St. Petersburg Polytechnic University;
- ✓ Samara National Research University;
- ✓ Belgorod National Research University;
- Kharkov National University, Kiev, Ukraine

Protocols for joint research within the SPD project signed.

✓ EoI letters received

Bilateral agreements on NICA exist.

Start of the SPD project

- **Letter of Intent** presented at the JINR PAC in summer 2014, where:
  - the physics program of the experiment was developed;
  - requirements to NICA polarized beams were formulated;
  - desired detector characteristics and sketch of the facility were given;
- A few presentation at international conferences about the physics potential and program of the SPD were given;
- Several workshops on spin physics at NICA were organized:
  - NICA-SPIN-2013, Дубна, 17-19.03.2013
  - SPIN-Praha-2013, 7-13.07.2013
  - NICA-SPIN-2014, Praha, 11-16.02.2014
  - SPIN-Praha-2015, 26-31.07.2015
  - **DSPIN2013, DSPIN2015, DSPIN2017**

arXiv: 1408.3959

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

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

Compiled by the Drafting Committee:
I.A. Savin, A.V. Efremov, D.V. Peshekhonov, A.D. Kovalenko, O.V.Teryaev, O.Yu. Shevchenko, A.P. Nagajcev, A.V. Guskov, V.V. Kukhtin, N.D. Topilin.

(Letter of Intent presented at the meeting of the JINR Program Advisory Committee (PAC) for Particle Physics on 25–26 June 2014.)

In 2017 a new stage of the project started:
From LoI to CDR (Conceptual Design Report)

Roadmap

- JINR project for the SPD design (Jan. 2019);

Conceptual and technical design of the Spin Physics Detector (SPD) at the NICA collider

- Setting up of the collaboration, MoU (2020);
- Preparation of the Conceptual Design Report (2019);
- Preparation of the Technical Design Report, including prototyping (2020-2022).

Construction of the detector would take at least three years (2022-2025) and first measurements could be expected as early as close to the end of 2025…

SPD/NICA will provide a unique opportunity

*not available at other facilit*ies

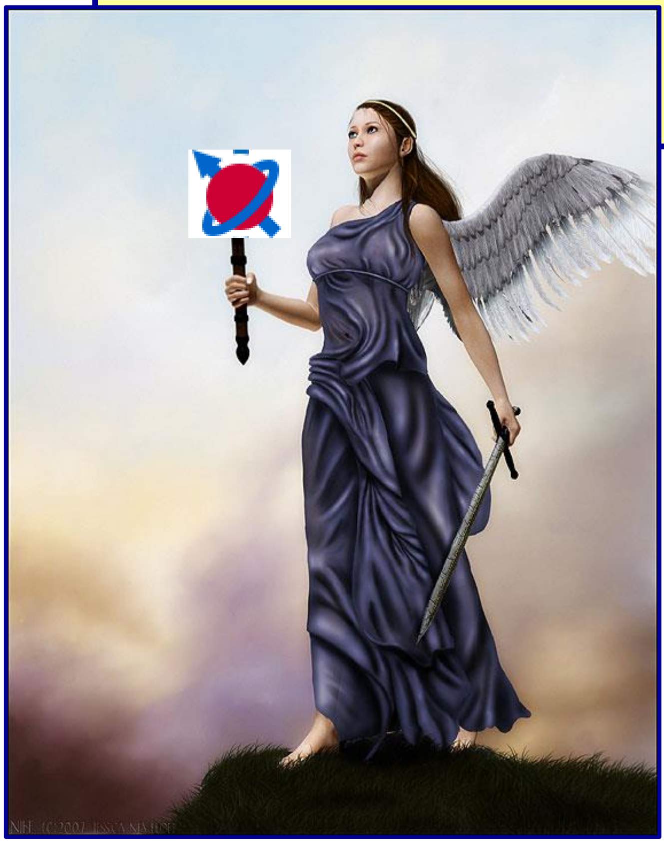
to study all of the PDFs in one experiment

and obtain comprehensive information

on the nucleon spin structure

at high statistical level

with minimal systematic uncertainties



You are welcome

to join the SPD/NICA

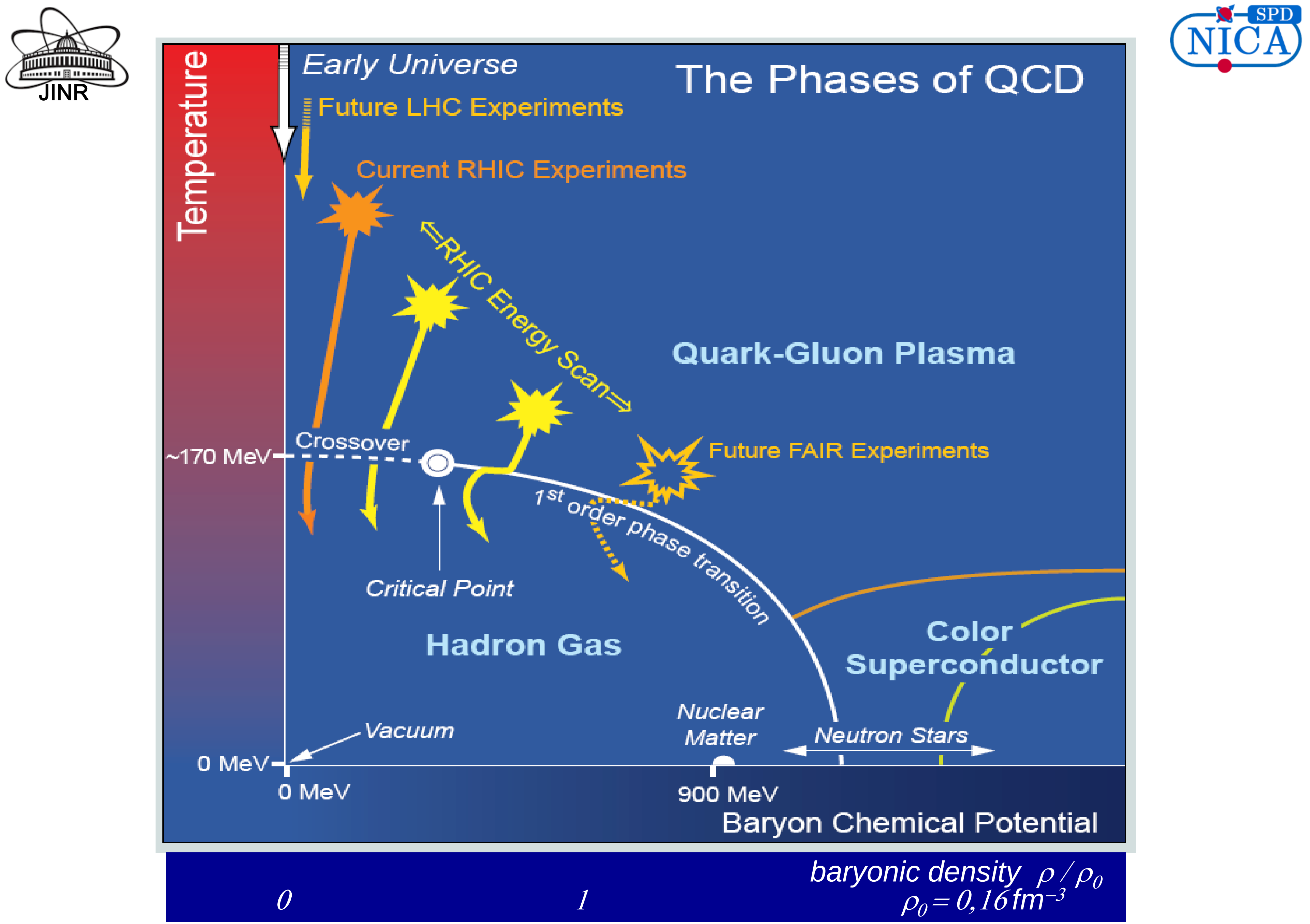
project!

Web site: *spd.jinr.ru*.

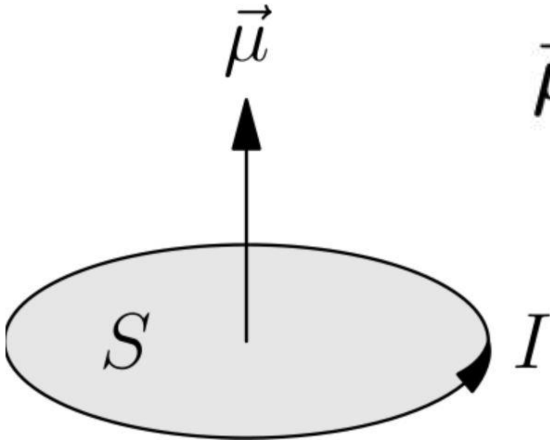
Contact person: Roumen Tsenov

(*tsenov@jinr.ru*)

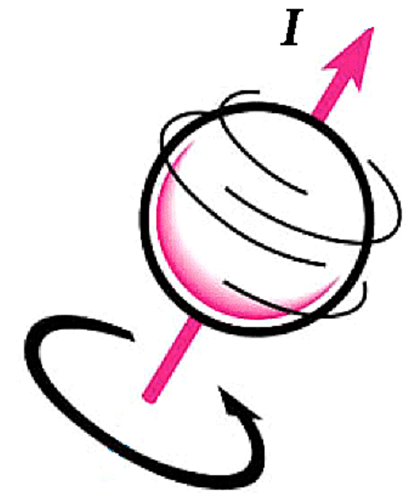
Back-up


JINR
SPD
NICA
The Phases of QCD
Early Universe
Temperature
Future LHC Experiments
Current RHIC Experiments
⇐RHIC Energy Scan⇒
Quark-Gluon Plasma
Future FAIR Experiments
~170 MeV
Crossover
Critical Point
1 st order phase transition
Hadron Gas
Color Superconductor
Nuclear Matter
Vacuum
Neutron Stars
0 MeV
0 MeV
900 MeV
Baryon Chemical Potential
baryonic density ρ / ρ0
0
1
ρ0 = 0,16 fm–3

Spin and magnetic moment



$$\vec{\mu}_{\mathrm{S}} = g\,\frac{q}{2m}\,\vec{S} = \gamma\vec{S}$$



$$\mu_{\mathrm{B}} = \frac{e\hbar}{2m_{\mathrm{e}}}$$

nuclear magneton:

$$\mu_{\mathrm{N}} = \frac{e\hbar}{2m_{\mathrm{p}}}$$

$$\mu_{\mathrm{p}} = 2.79\mu_{\mathrm{N}}$$

$$\mu_{\mathrm{n}} = -1.91\mu_{\mathrm{N}}$$

$$\mu_{\mathrm{d}} = 0.86\mu_{\mathrm{N}}$$

for the electron:

$$\vec{\mu}_{\mathrm{S}} = -\frac{g\mu_{\mathrm{B}}\vec{\sigma}}{2}$$

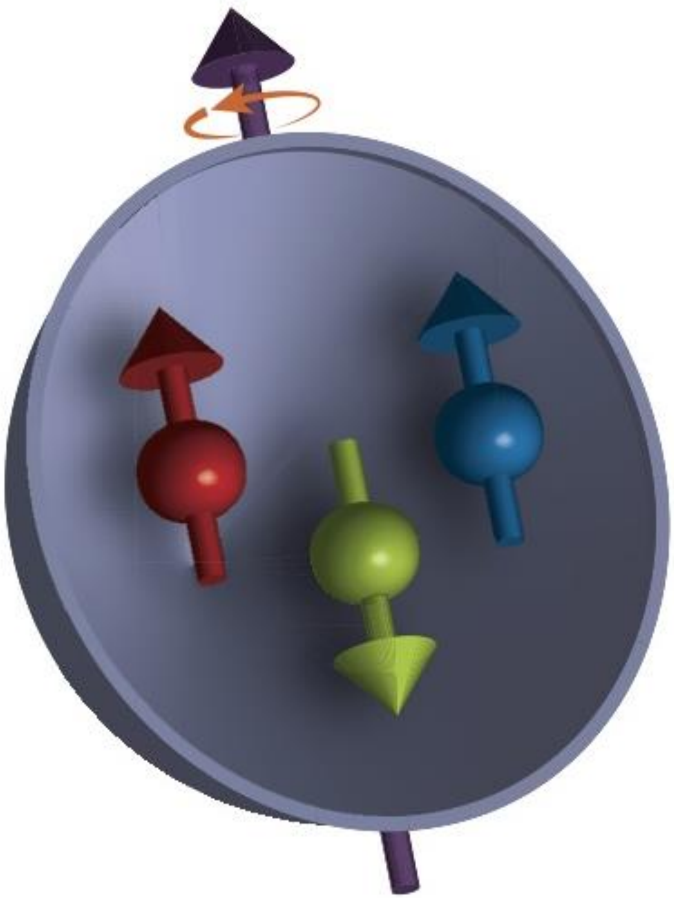
Nucleon spin structure

Before 1988

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma_{\text{quarks}}$$

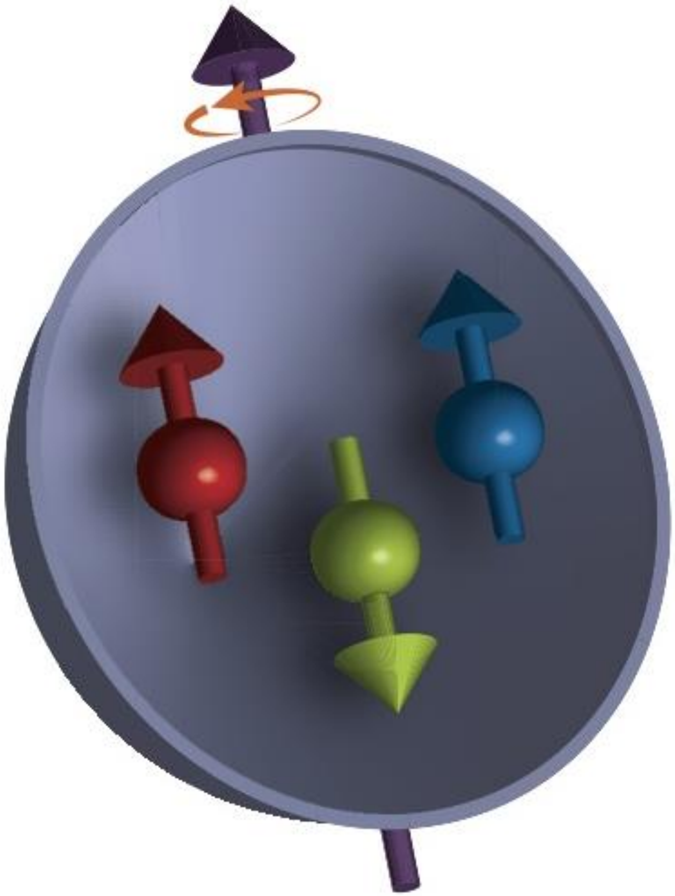
The quark model says:
the nucleon spin is carried only by quarks.

Baryon	Magnetic moment of quark model	Computed (μ_N)	Observed (μ_N)
p	$4/3\ \mu_u - 1/3\ \mu_d$	2.79	2.793
n	$4/3\ \mu_d - 1/3\ \mu_u$	−1.86	−1.913



Experiment: *(EMC, Nucl. Phys. B 328 (1989) 1)*

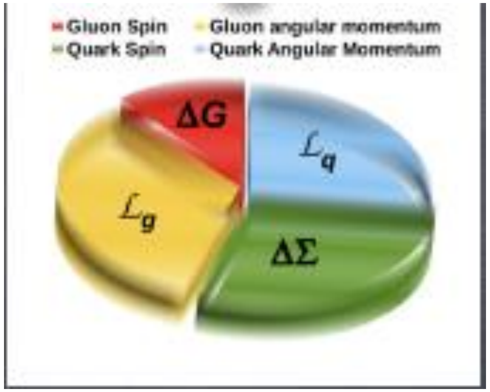
$$\frac{1}{2} = \frac{1}{2}\Delta\sum_{\text{quarks}}$$



PROBLEM: According to the experimental data, only 30% of the nucleon spin is carried by quarks. Where does the rest of the spin come from?

Spin and 3D structure of hadrons

Spin puzzle: small contribution of quarks (may be fractional because of density matrix rather than wave function description) to the proton spin

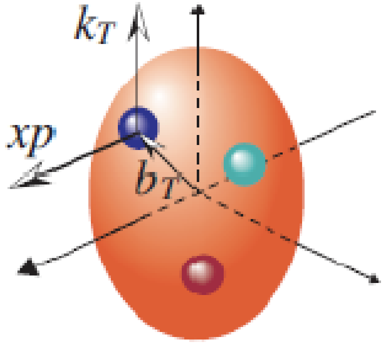


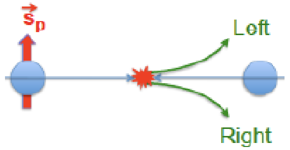
The deficit may be due to:

1.Gluon average spin ΔG, and

2.Orbital motion L related to transverse (completing 3D) structure of proton

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_q + \mathcal{L}_g$$





All ingredients can be explored at SPD!

Main instrument: transverse spin asymmetries

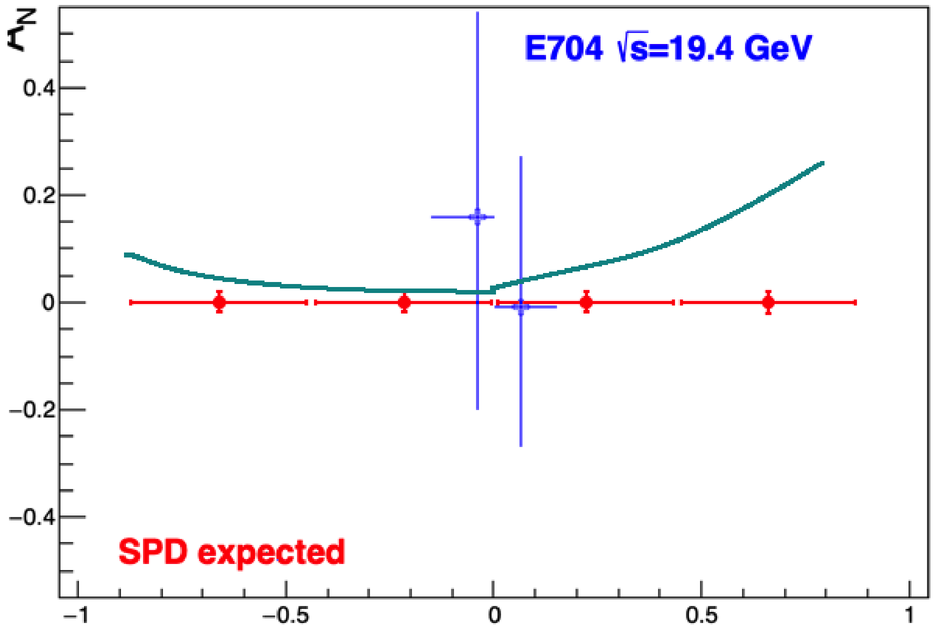
The simplest transverse asymmetry : left-right;

more involved: azimuthal modulations

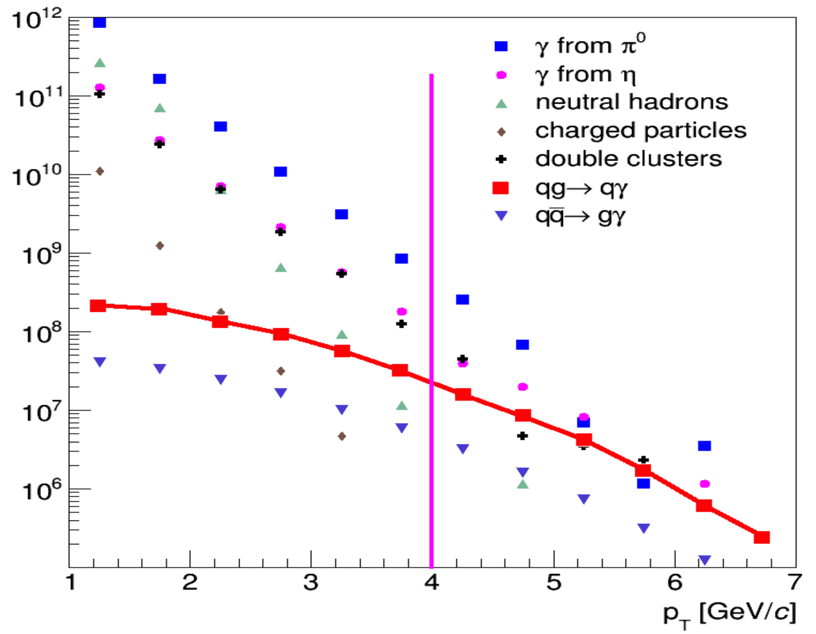
Prompt photon asymmetries: accuracy

Statistics: 3×10^7 prompt photons with p_T>4 GeV/c for one year of data taking (10^7 s). It could keep statistical uncertainty of A_N and A_{LL} asymmetries measurement below 0.001 level.

Main contribution to systematics comes from MC-dependent subtraction of background from decay photons, charged particles etc. The expected total error does not exceed $(1\text{-}2)\times10^{-2}$.



SPD expectations, previous measurement at similar kinematic range and theory predictions for A_N



Signal and different sources of background for prompt photon production

Similar accuracy is expected for A_{LL} while the expected asymmetry is between ±0.05

SPD data for A_N and A_{LL} at $\sqrt{s}\sim20$ GeV will be complementary to the expected results from RHIC ($\sqrt{s}\sim200$ GeV) and corresponds to the region of typically larger values of ΔG/G

O. Teryaev, SPD meeting

29 April 2019

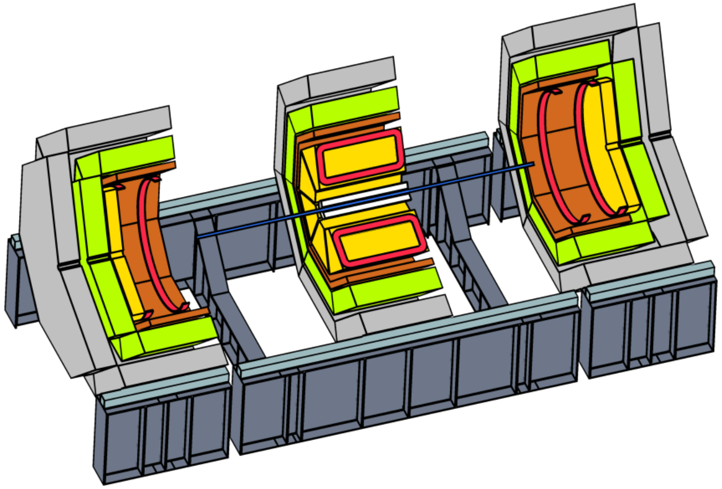
Problems for NICA

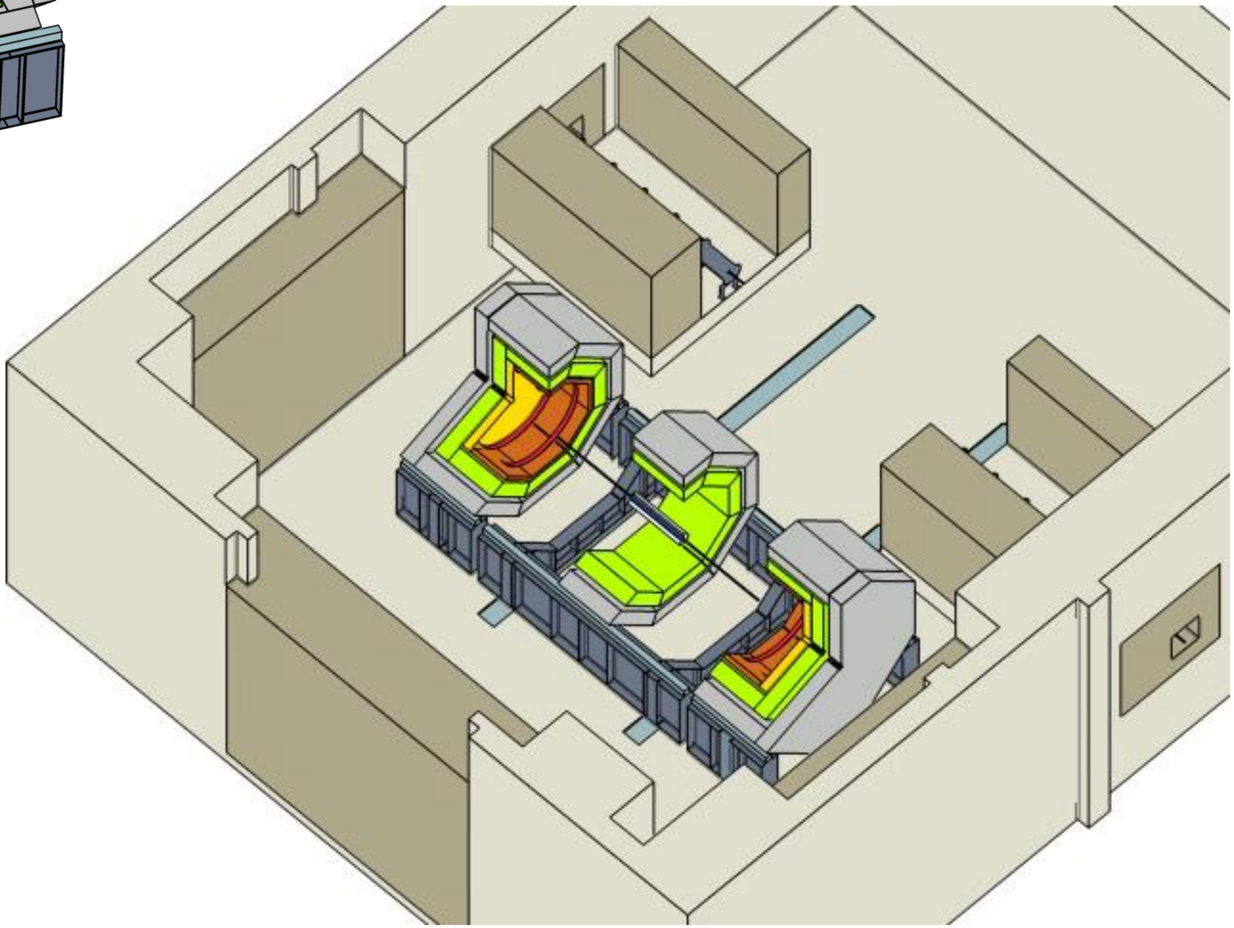
- SPD LoI: TMDs@DY
- TMDs – J/Ψ, γ
- GPDs: Exlusive DY-type (smaller x-section but lower background)
- GPDs from TMDs (pressure?!)
- Fracture – SSAs with extra hadrons
- Relation of HIC/hadronic spin (MPD/SPD) – polarization for hadrons, light and heavy ions

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	$2\cdot10^{33}$	$2\cdot10^{32}$	$3.5\cdot10^{35}$		$5\cdot10^{32}$	$5\cdot10^{32}$	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,	***μ-μ+***	***μ-μ+***	***μ-μ+***		***μ-μ+***	***μ-μ+***	***μ-μ+, 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

Year 2014

Reconfigurable design





JINR participation: 112 authors, 37.7 FTE

- Laboratory of High-Energy Physics
  - authors: 74
  - FTE: 24.4
- Laboratory of Nuclear Problems
  - authors: 30
  - FTE: 11.3
- Laboratory of Theoretical Physics
  - authors: 6
  - FTE: 2
- Directorate (1), Laboratory of Information Technologies (1)

COMPASS data, pion beam

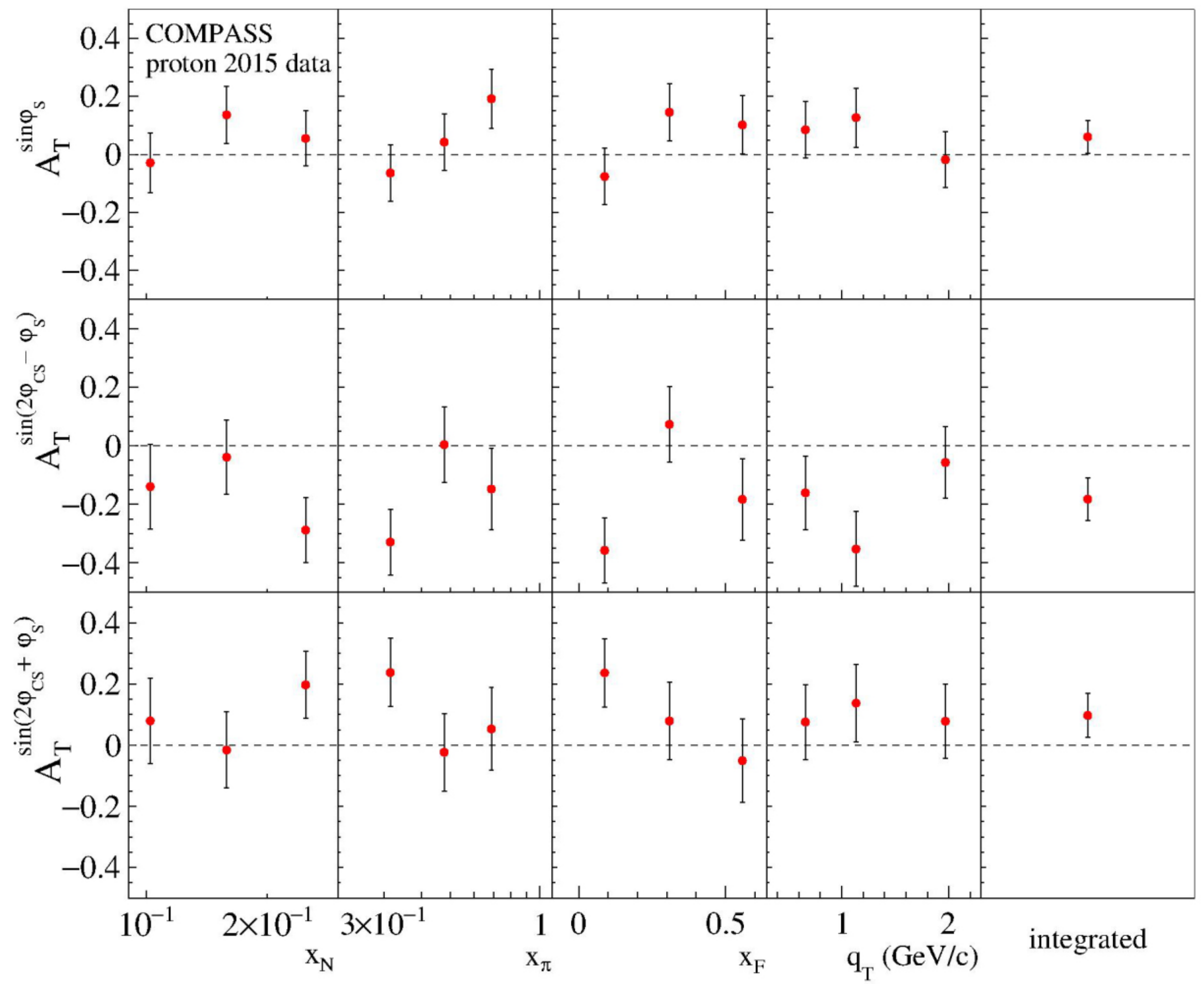
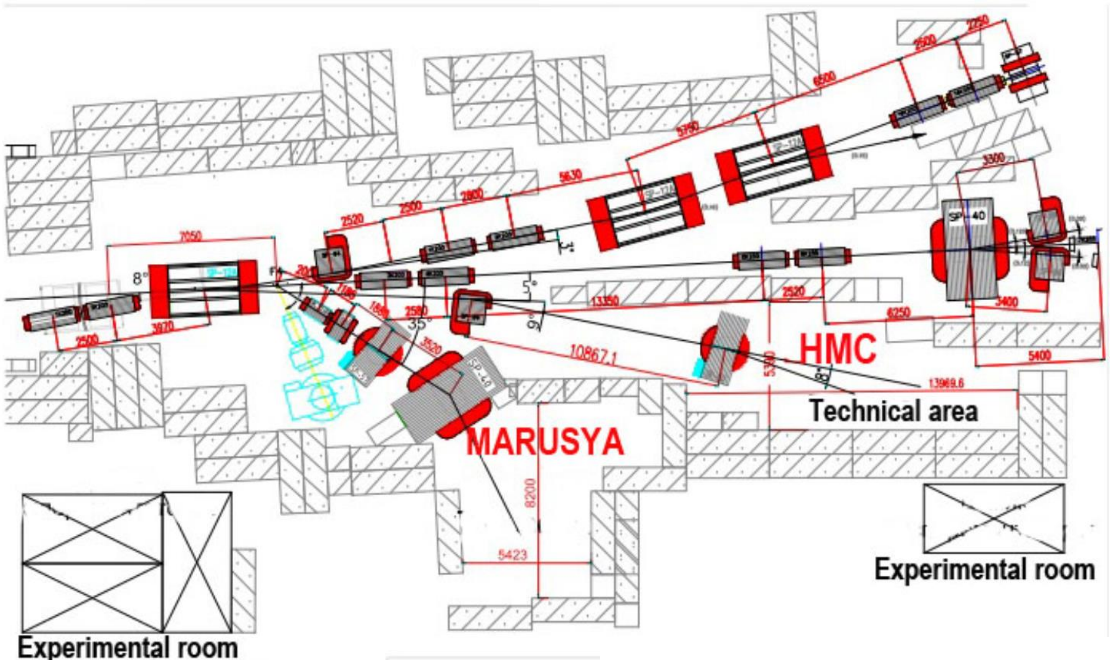


Figure 4: COMPASS data on Drell–Yan pair production spin asymmetries related to Sivers, transversity and pretzelosity TMD PDFs (top to bottom).

Systems that have not been thought out yet…

- System for particle ID (multigap glass RPCs, Micromegas, Aerogel Cherenkov?);
- "Zero degree" system (fine grained hadron calorimeter?)
- Front-end electronics of the different subsystems;

Beam test facility



P, MeV/c	d	p,n	$\pi^{\pm}$	K^{+}	K^{-}	$\mu^{\pm}$	$e^{\pm}$
400	10^3	10^5	10^5	10^3	10^2	10^3	10^3
800	10^3	10^4	10^4	10^3	10^2	10^3	10^3
1500	10^2	10^4	10^4	10^3	10^2	10^2	10^2
2000	10^4	10^5	10^4	10^3	10^2	10^2	10^2
7000	10^4	10^6	10^3	10^3	10^2	10^2	10^2