The SPD project

at the Laboratory of High Energy Physics,
Joint Institute for Nuclear Research, Dubna

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

Roumen Tsenov (LHEP),
for the SPD project team

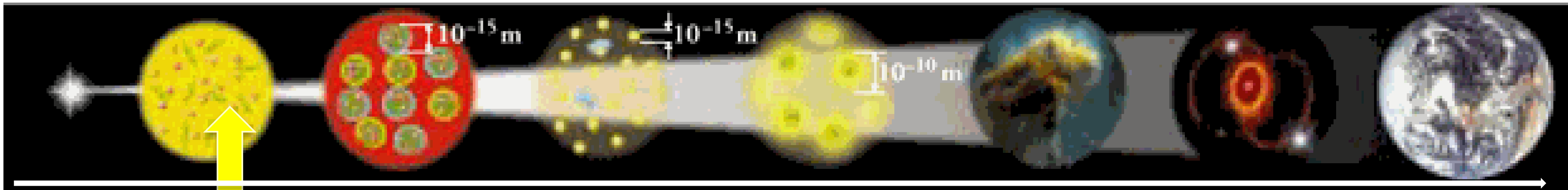
NICA (Nuclotron based Ion Colider fAcility) is the flagship project in high energy physics of the Joint Institute for Nuclear Research

Main targets of the NICA project:

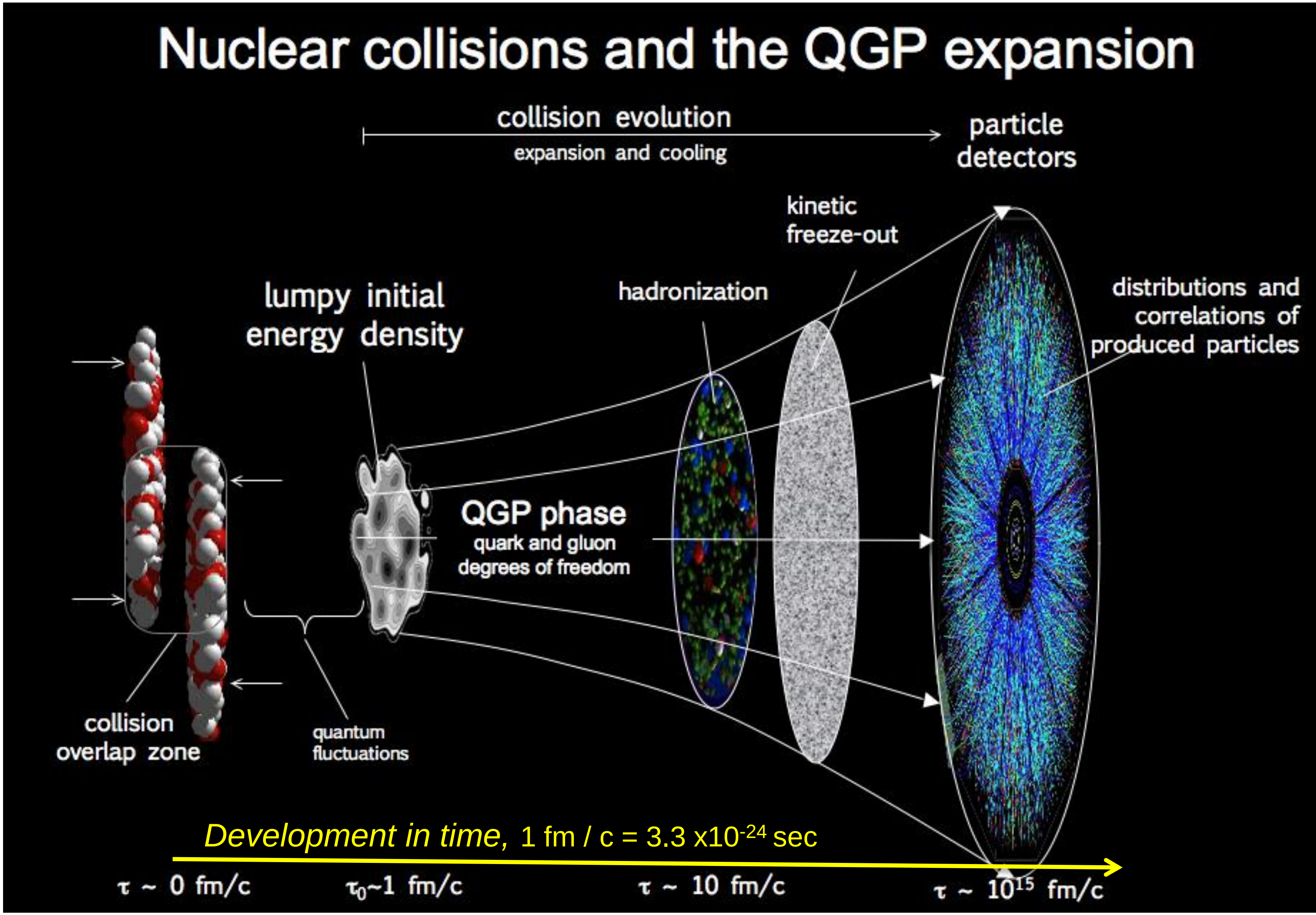
- ***study of hot and dense baryonic matter***
- ***investigation of nucleon spin structure, polarization phenomena***

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+}, $cm^{-2}\ s^{-1}$	**1×10^{27}**
polarized particles	
max. $\sqrt{S}$ for polarized **p**, Gev	**27**
Luminosity for **p**, $cm^{-2}\ s^{-1}$	**1×10^{32}**

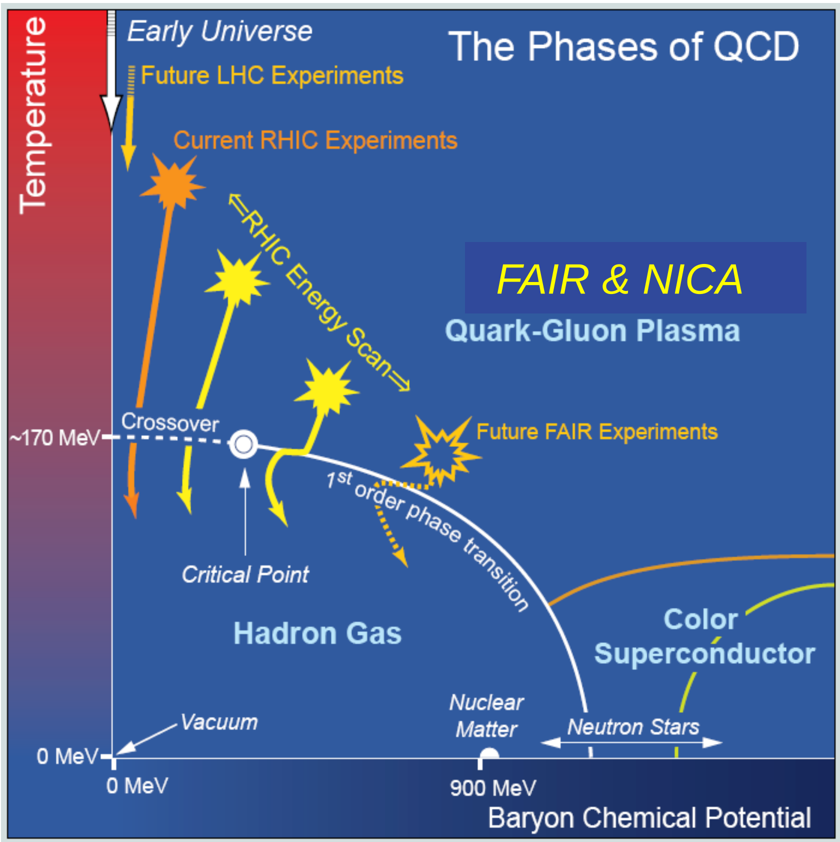
mini "Big Bang" in the laboratory

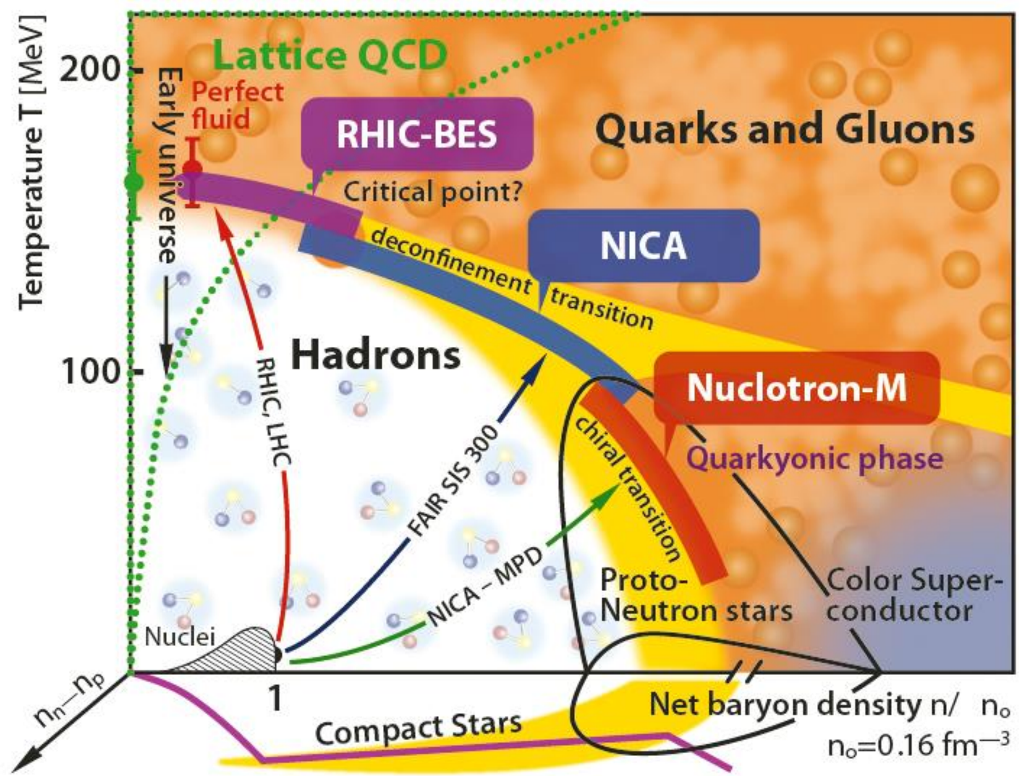


Big Bang	Q-G plasma	p & n formation	low mass nuclei formation	neutral atoms formation	star formation	dispersion of massive elements	Today
T	>10^1[illegible] K	10^{12} K	10^{9} K	4000 K	20 - 3 K	< 20 K	3 K
time	10^-[illegible] s	10^{-4} s	3 min	400 k yr	10^{9} yr	> 10^{9} yr	13.5 10^{9} yr


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

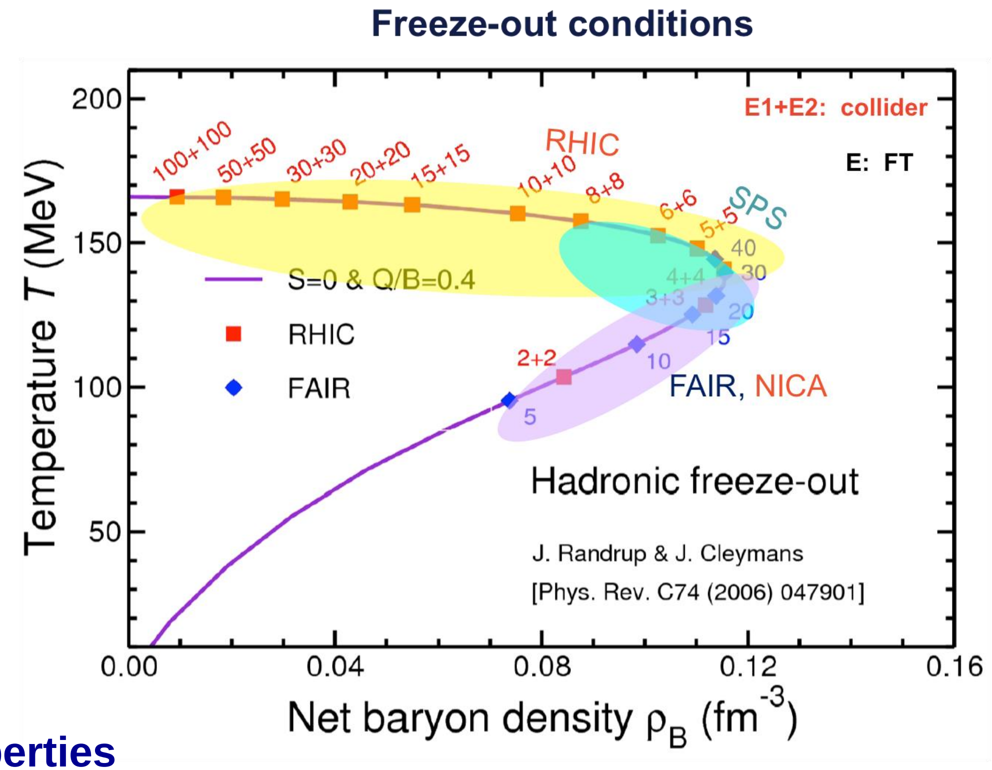




Physics at NICA

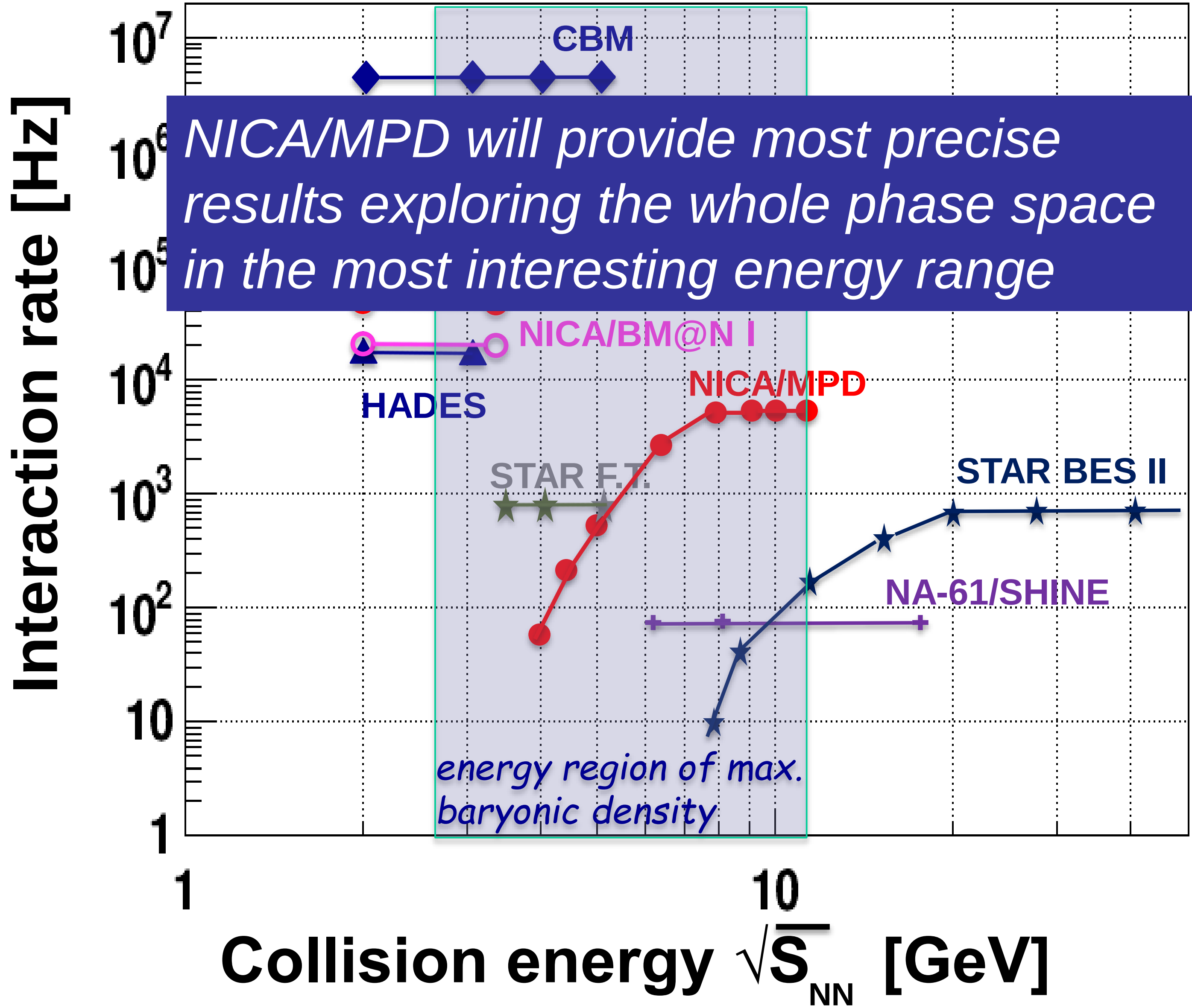
Quark-gluon matter at NICA :

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



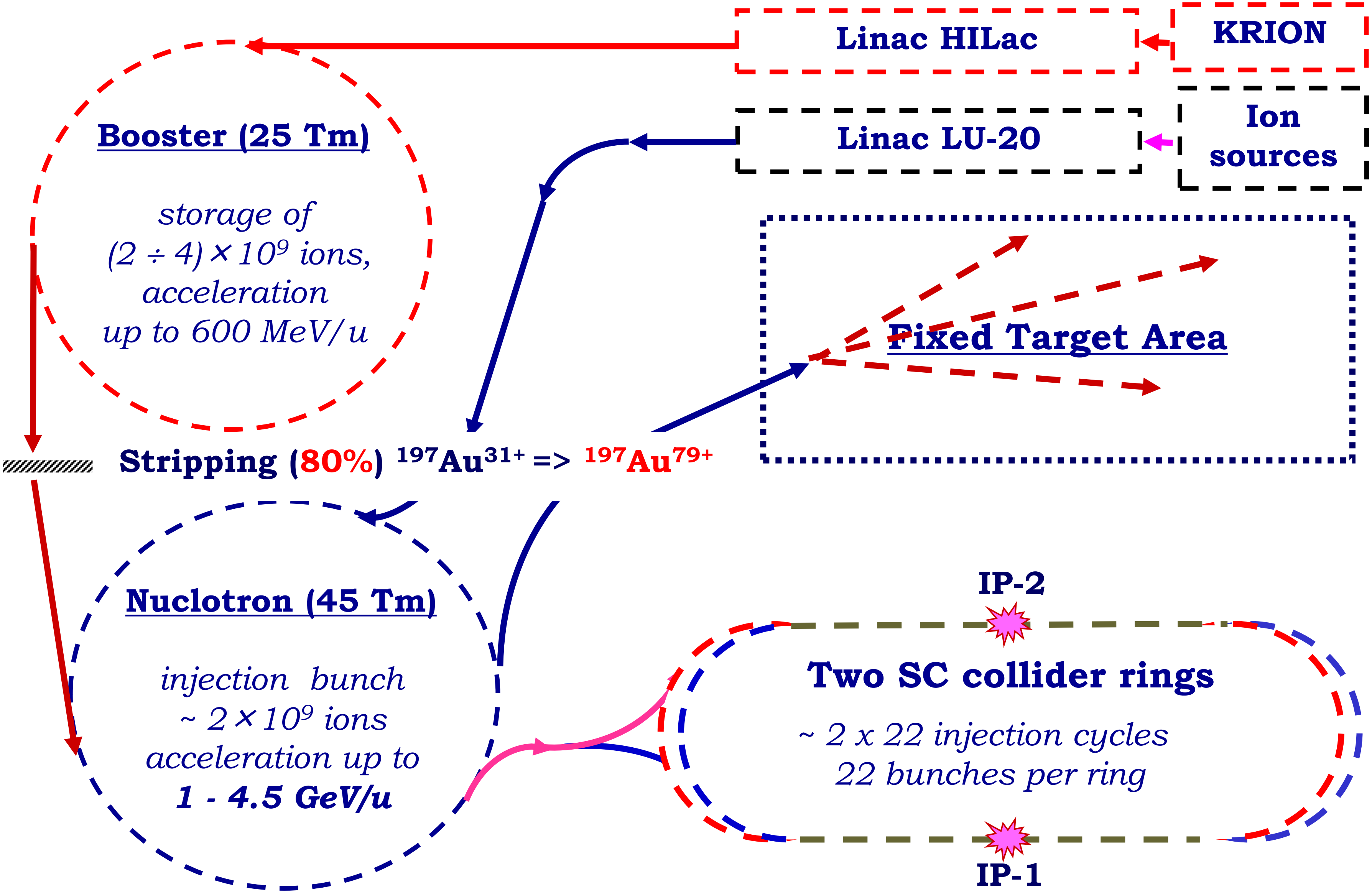
- **Bulk properties, EOS** - *particle yields & spectra, ratios, femtoscopy, flow*
- **In-Medium modification of hadron properties**
- **Deconfinement (chiral), phase transition at high ρ_B** *- enhanced strangeness production*
- **QCD Critical Point -** *event-by-event fluctuations & correlations*
-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

Present and future heavy ion experiments



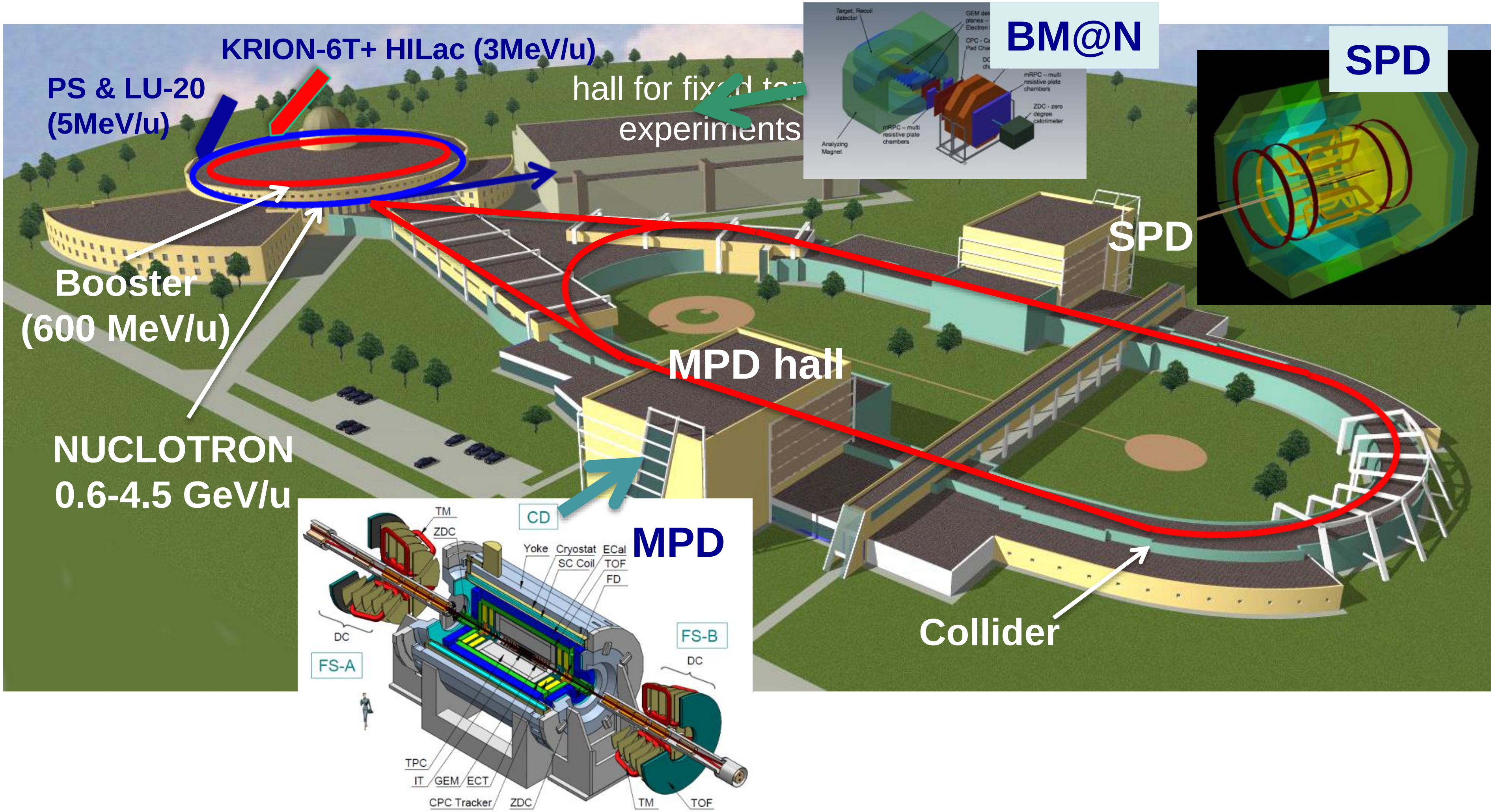
NICA/MPD will provide most precise results exploring the whole phase space in the most interesting energy range

Structure and Operation Regimes



The NICA complex

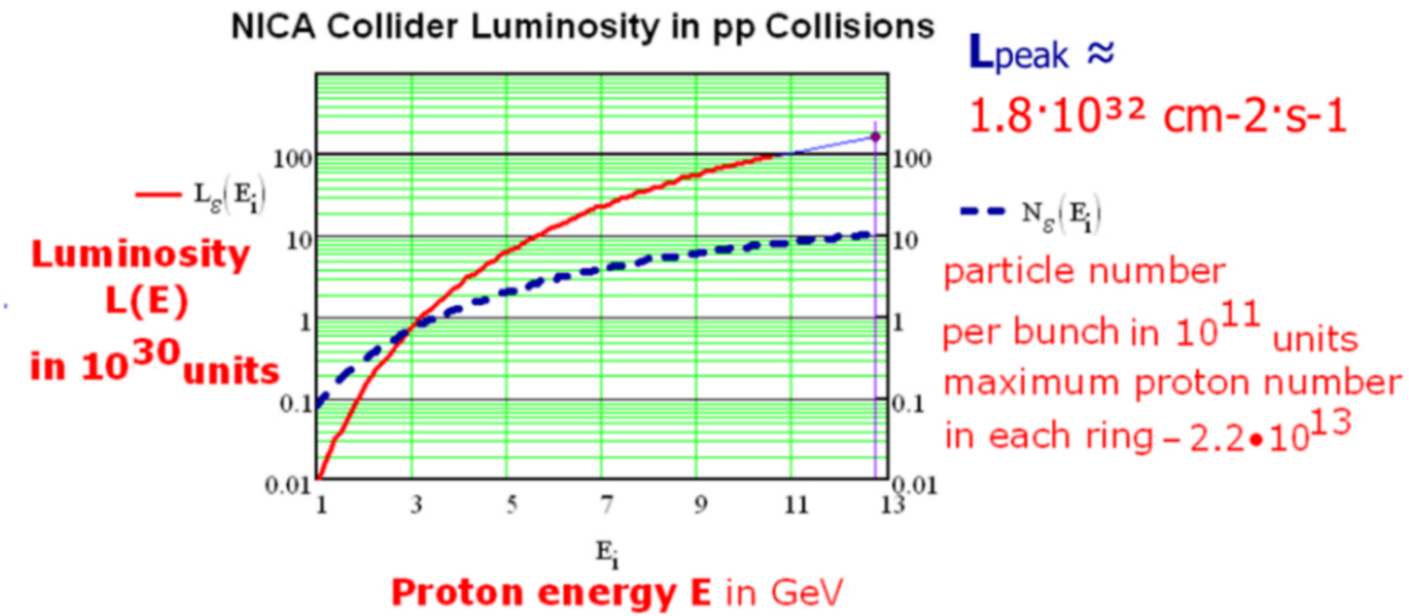
existing facilities ***to be constructed***



Civil Construction, bld.17

June 2018

Polarized beams

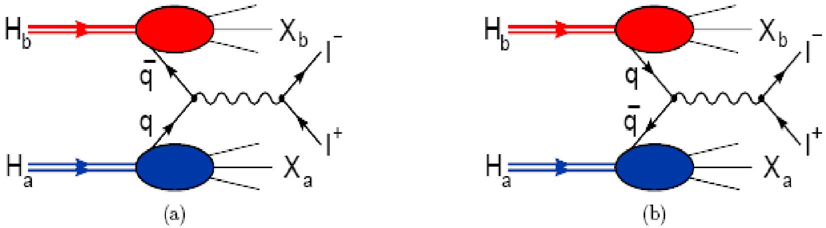


circumference	- 503 m,
number of intersection points (IP)	- 2,
beta function β_{min} in the IP	- 0.35 m,
number of protons per bunch	- $\sim 1 \cdot 10^{12}$,
number of bunches	- 22,
RMS bunch length	- 0.5 m,
incoherent tune shift, $\Delta_{Lasslett}$	- 0.027,
beam-beam parameter, ξ	- 0.067,
beam emittance ε_{nrm} , π mm mrad	- 0.15 (normalized at 12.5 GeV).

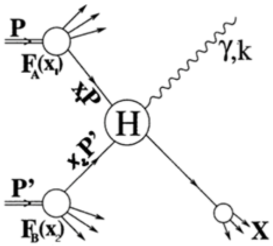
Bunch crossing each 80 ns; crossing rate 12.5 MHz .

Physics tasks

- **Nucleon spin structure studies**
  - **Drell-Yan pair production;**

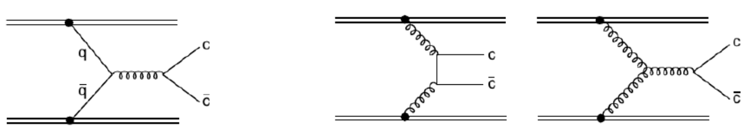


  - **Direct photons;**



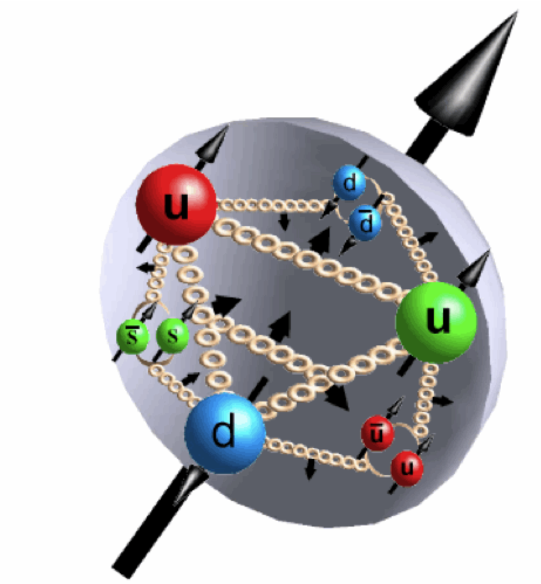
  - **Nucleon PDFs by J/ψ production;**

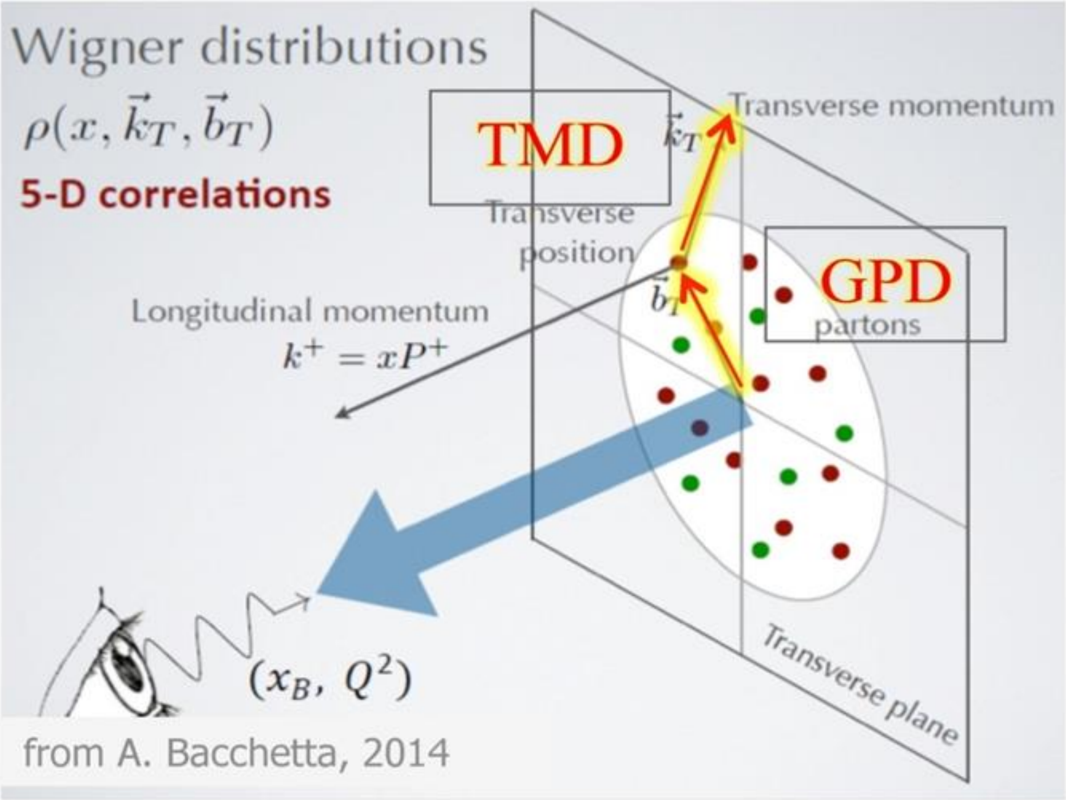
LO $c\bar{c}$ production diagram:



- **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 ;**
- *etc….*

Spin dependent PDFs

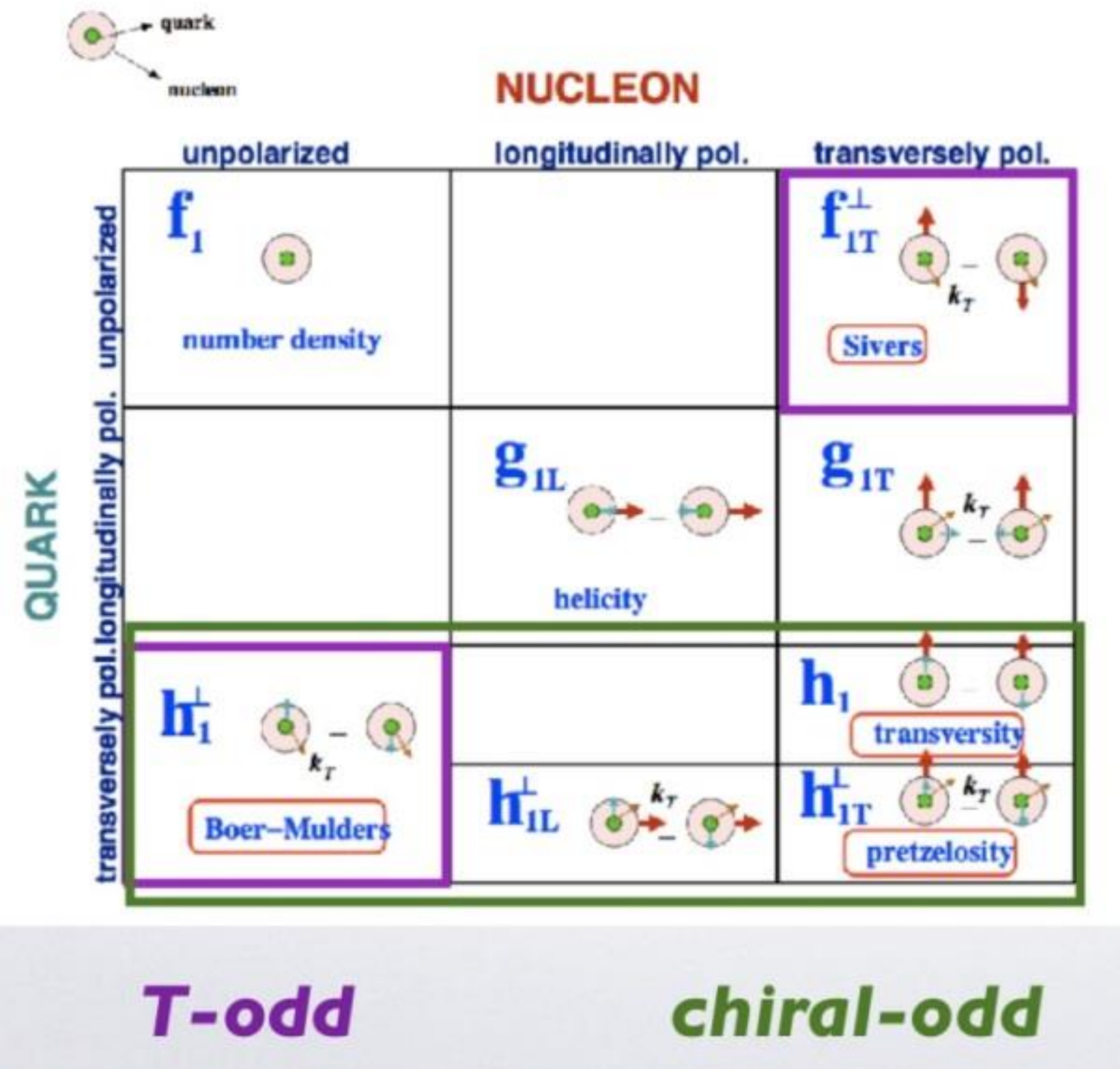




Transversity Momentum Distributions: TMD (x,k_T)
probe the transverse parton momentum dependence

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

TMD and GPD



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

Structure functions

1. Transversity: $A_{UT}^{\sin(\phi+\phi_S)}$, represents the number distribution of transversely polarized quarks in a transversely polarized nucleon;

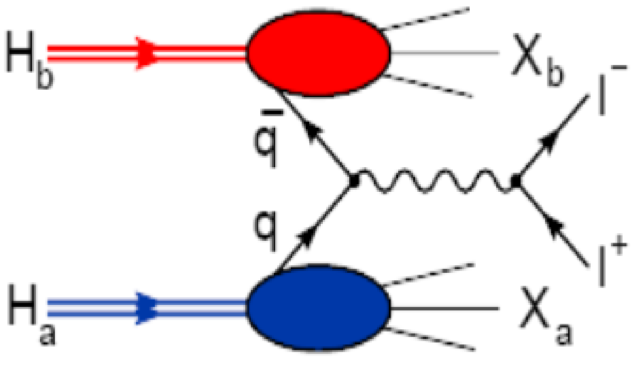
2. Sivers: $A_{UT}^{\sin(\phi-\phi_S)}$, represents the distribution over the transverse momentum of non-polarized quarks in a transversely polarized nucleon;

3. Pretzelosity: $A_{UT}^{\sin(3\phi-\phi_S)}$, represents the distribution over the transverse momentum of transversely polarized quarks in a transversely polarized nucleon;

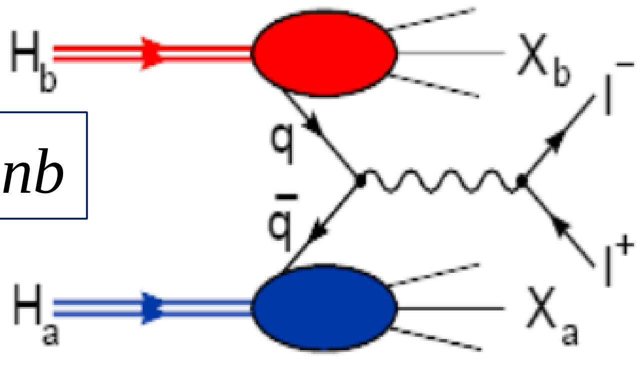
4. Boer-Mulders: $A_{UU}^{\cos(2\phi_h)}$, represents the distribution over the transverse momentum of transversely polarized quarks in a non-polarized nucleon;

5. Worm-Gears: $A_{UL}^{\cos(2\phi_h)}$, represents the distribution over the transverse momentum of longitudinally polarized quarks in a longitudinally polarized nucleon.

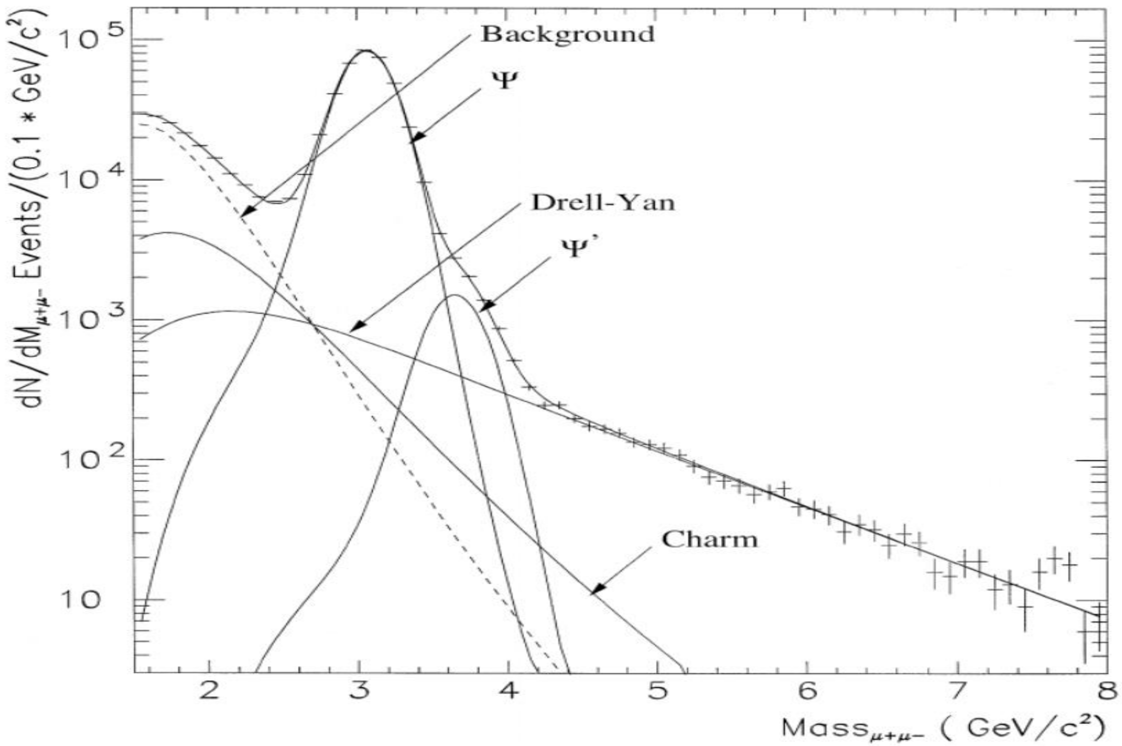
Drell-Yan pairs



$\sigma_{tot} \sim 9\ nb$

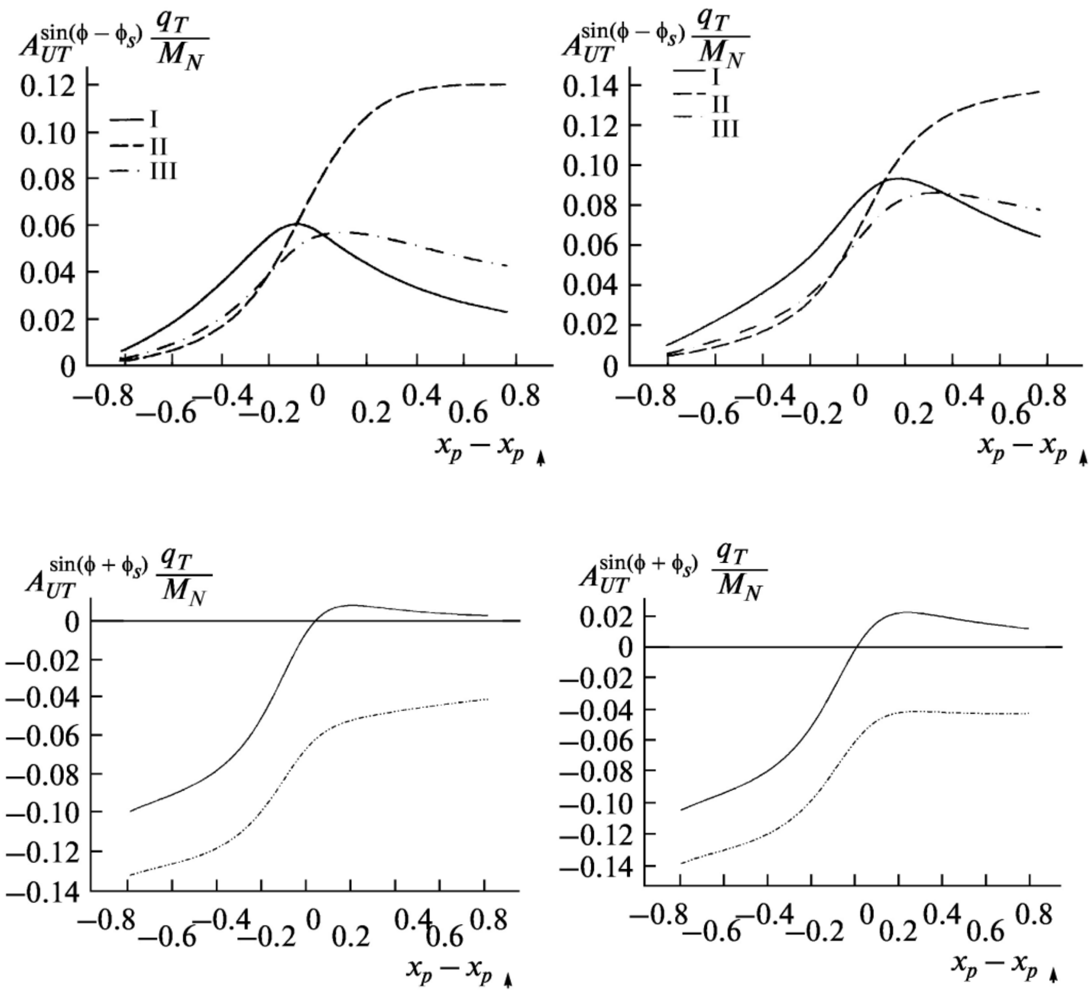


Dimuon spectrum from NA51 ($\sqrt{s} = 29.1$ GeV)



Asymmetries in DY pair production

Q^2 = 4 GeV^2 Q^2 = 15 GeV^2



Sivers

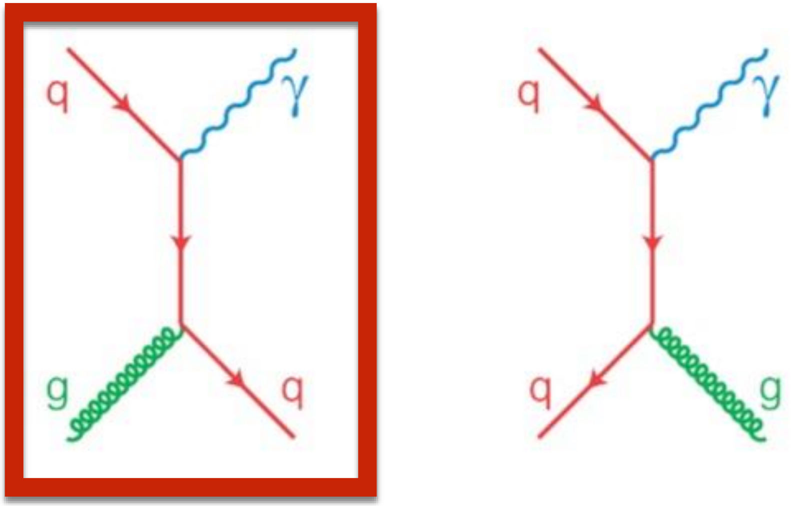
J.C.Collins et al., PRD73 (2006)014021

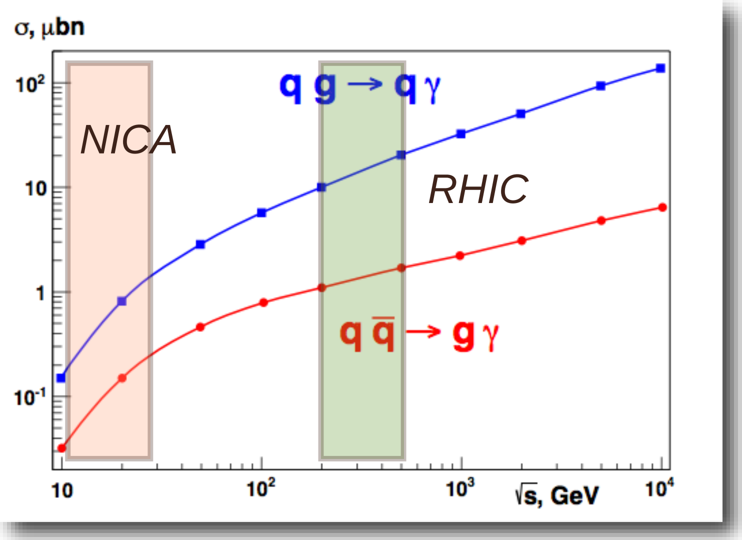
Boer-Mulders

s= 400 GeV^2

Prompt photons

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





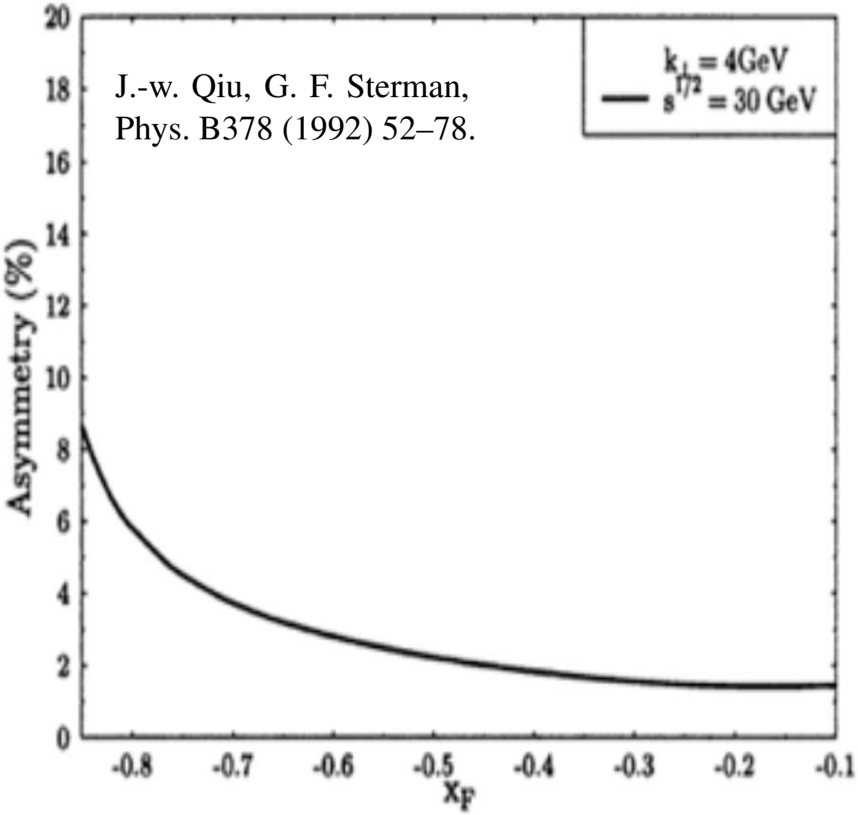
Transverse beam polarization: access to the Sivers function for gluons

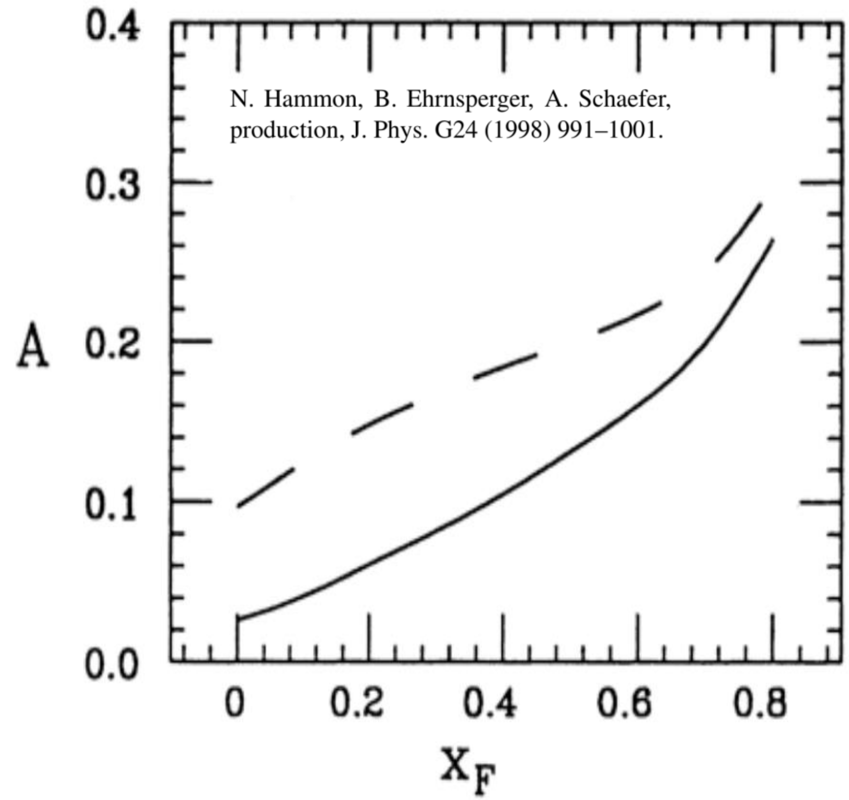
$$\sigma^{\uparrow} - \sigma^{\downarrow} = \sum_i \int_{x_{min}}^{1} dx_a \int d^2\mathbf{k}_{Ta} d^2\mathbf{k}_{Tb} \frac{x_a x_b}{x_a - (p_T/\sqrt{s})\, e^y} \left[q_i(x_a, \mathbf{k}_{Ta}) \Delta_N G(x_b, \mathbf{k}_{Tb}) \right.$$
$$\left. \times \frac{d\hat{\sigma}}{d\hat{t}}(q_i G \to q_i \gamma)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

Longitudinal beam polarization: access to gluon polarization Δg/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

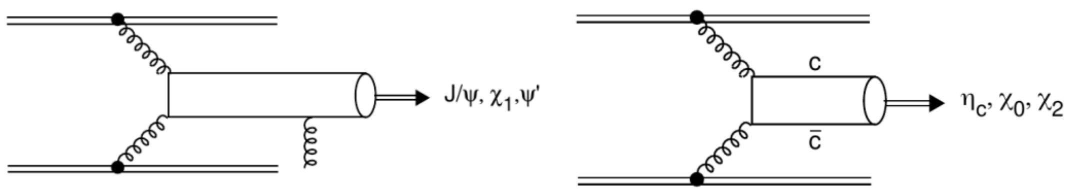




Charmonia production

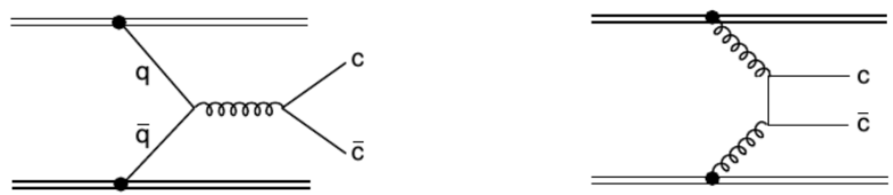
Gluon fusion

Charmonia production is sensitive to gluon distributions of colliding hadrons.

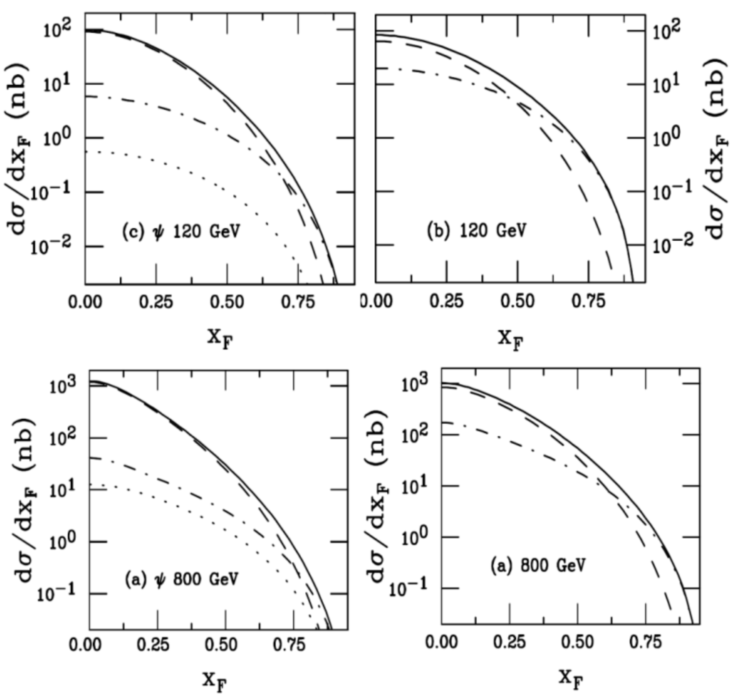


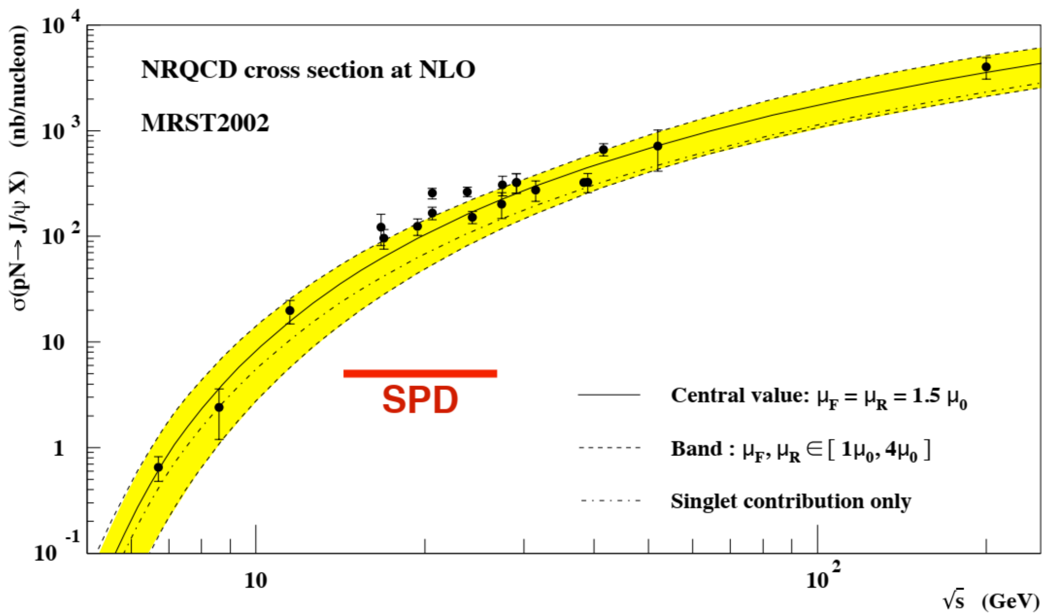
CS diagrams from Int. J Mod Phys A10:3043-3070 1995

Quark annihilation



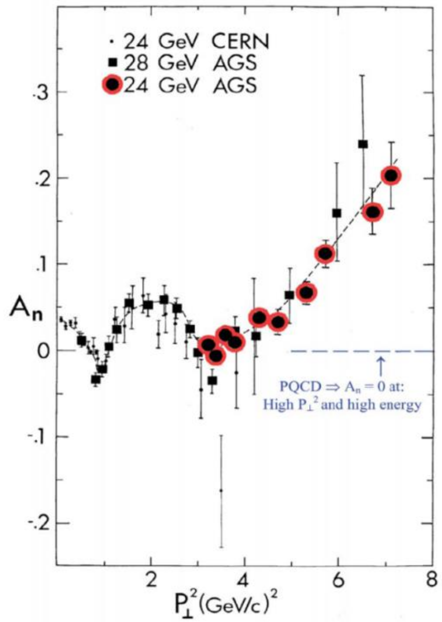
NRQCD CEM

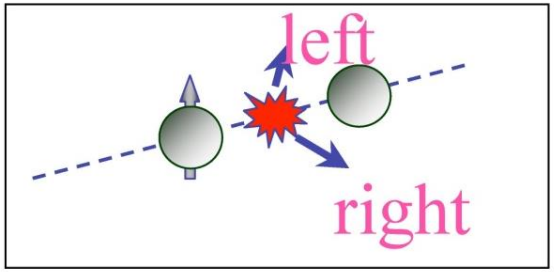




Asymmetries in high p_T hadron production

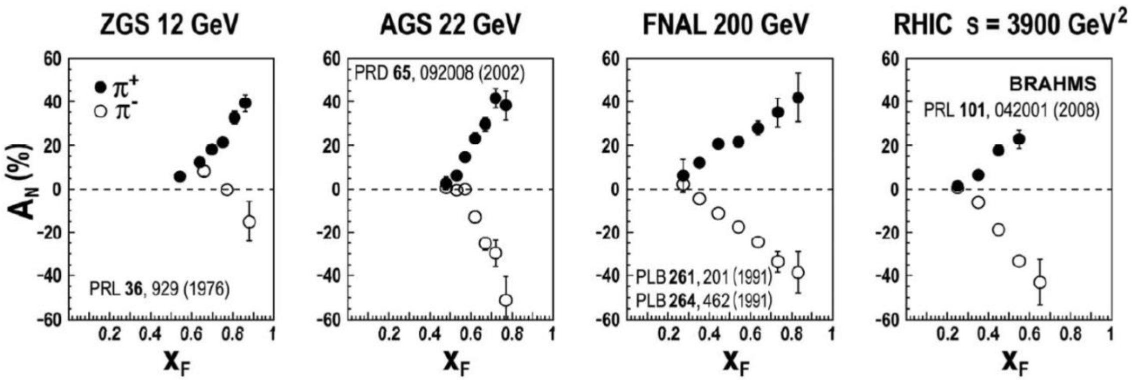
- Diquark properties;
- Confinement laws;
- Nature of the huge spin effects;
- Deuteron spin structure;
- Properties of the bare NΛ- and NK-interactions;
- Nature and properties of the cold super dense baryonic matter (CsDBM) (pA and AA);
- Dilepton production puzzle in np-interaction.

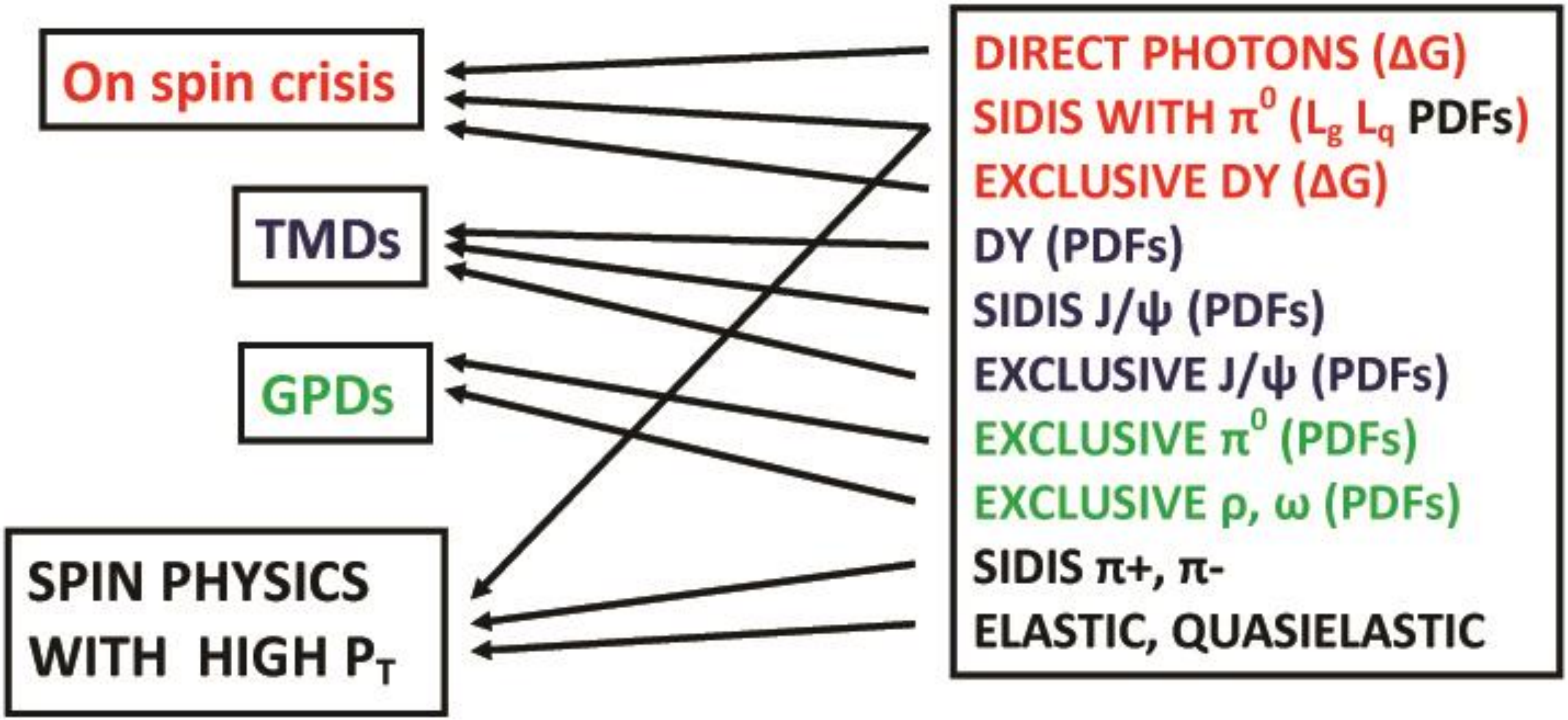




INCLUSIVE PION ASYMMETRY IN PROTON-PROTON COLLISIONS

C. Aidala SPIN 2008 Proceeding and CERN Courier June 2009

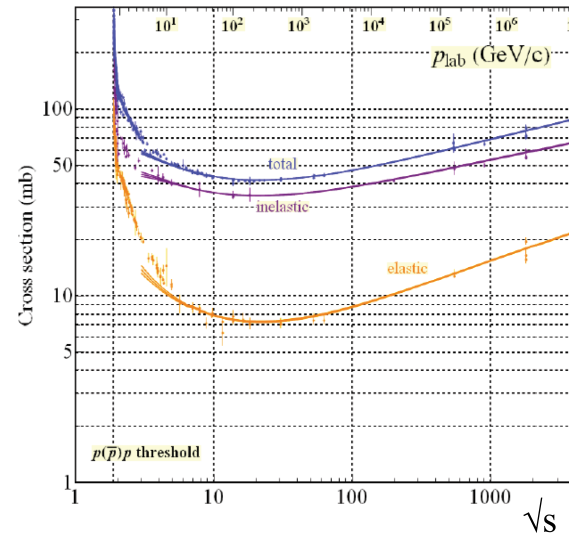


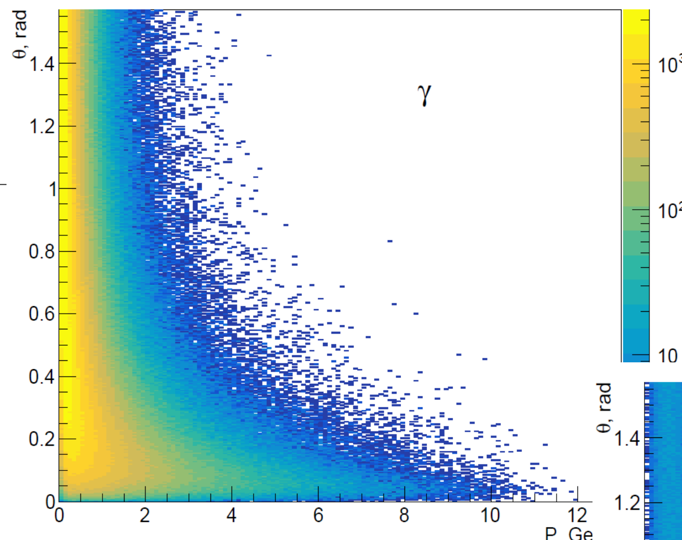

On spin crisis
TMDs
GPDs
SPIN PHYSICS WITH HIGH P_T
DIRECT PHOTONS (ΔG)
SIDIS WITH π^0 (L_g L_q PDFs)
EXCLUSIVE DY (ΔG)
DY (PDFs)
SIDIS J/ψ (PDFs)
EXCLUSIVE J/ψ (PDFs)
EXCLUSIVE π^0 (PDFs)
EXCLUSIVE ρ, ω (PDFs)
SIDIS π+, π-
ELASTIC, QUASIELASTIC

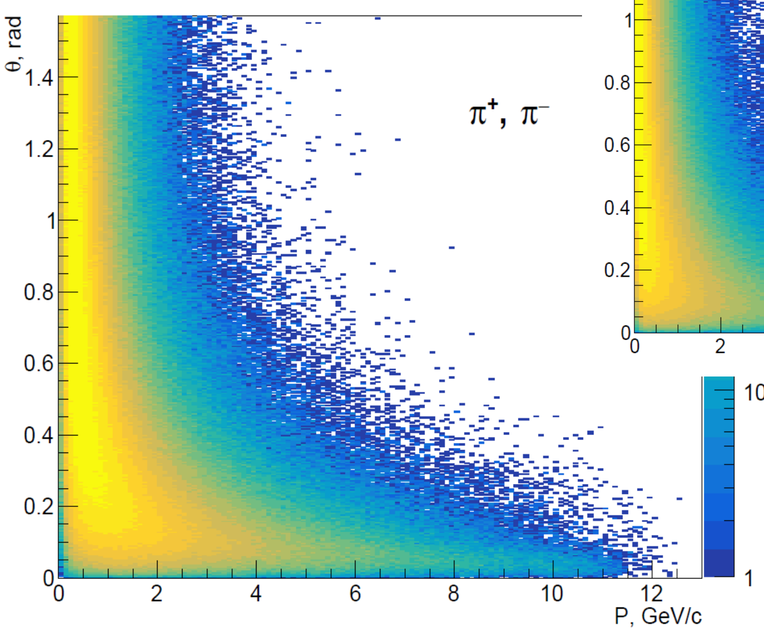
Minimum biased events

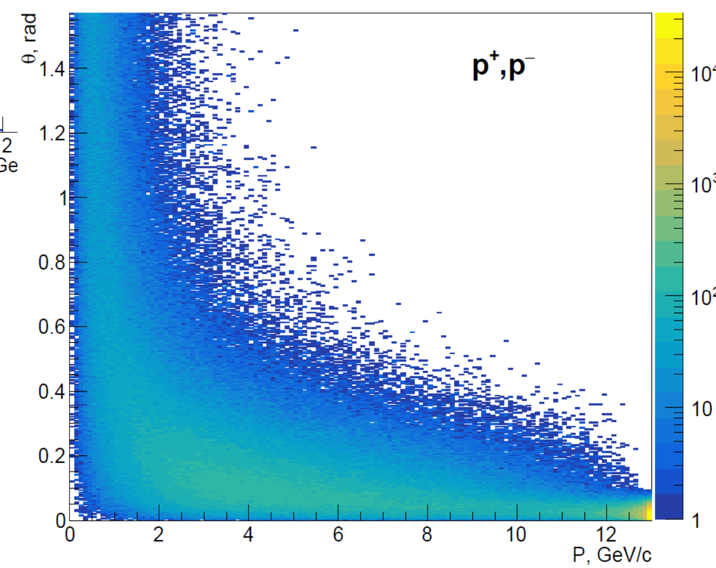
PYTHIA 6, $\sqrt{s_{pp}}$ = 26 GeV; 4 MHz event rate

- Average charged particles' multiplicity ~ 14
- Average neutral particles' multiplicity ~ 23



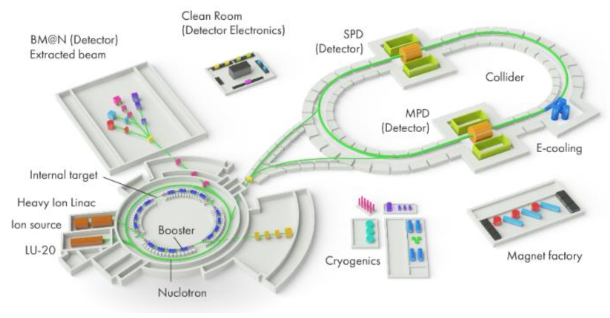


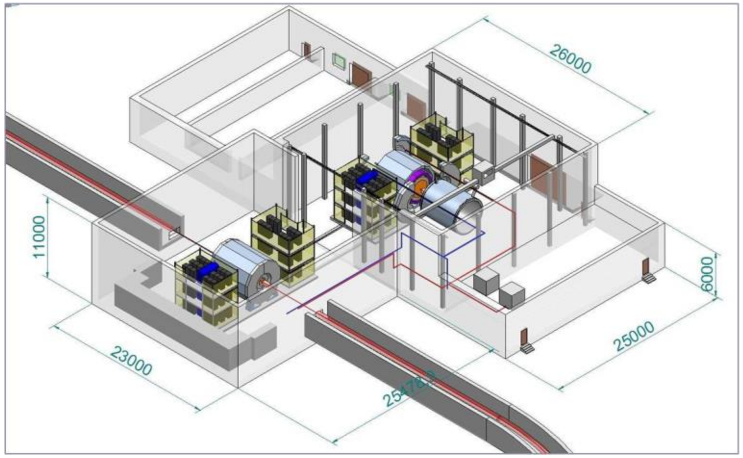




from A. Guskov

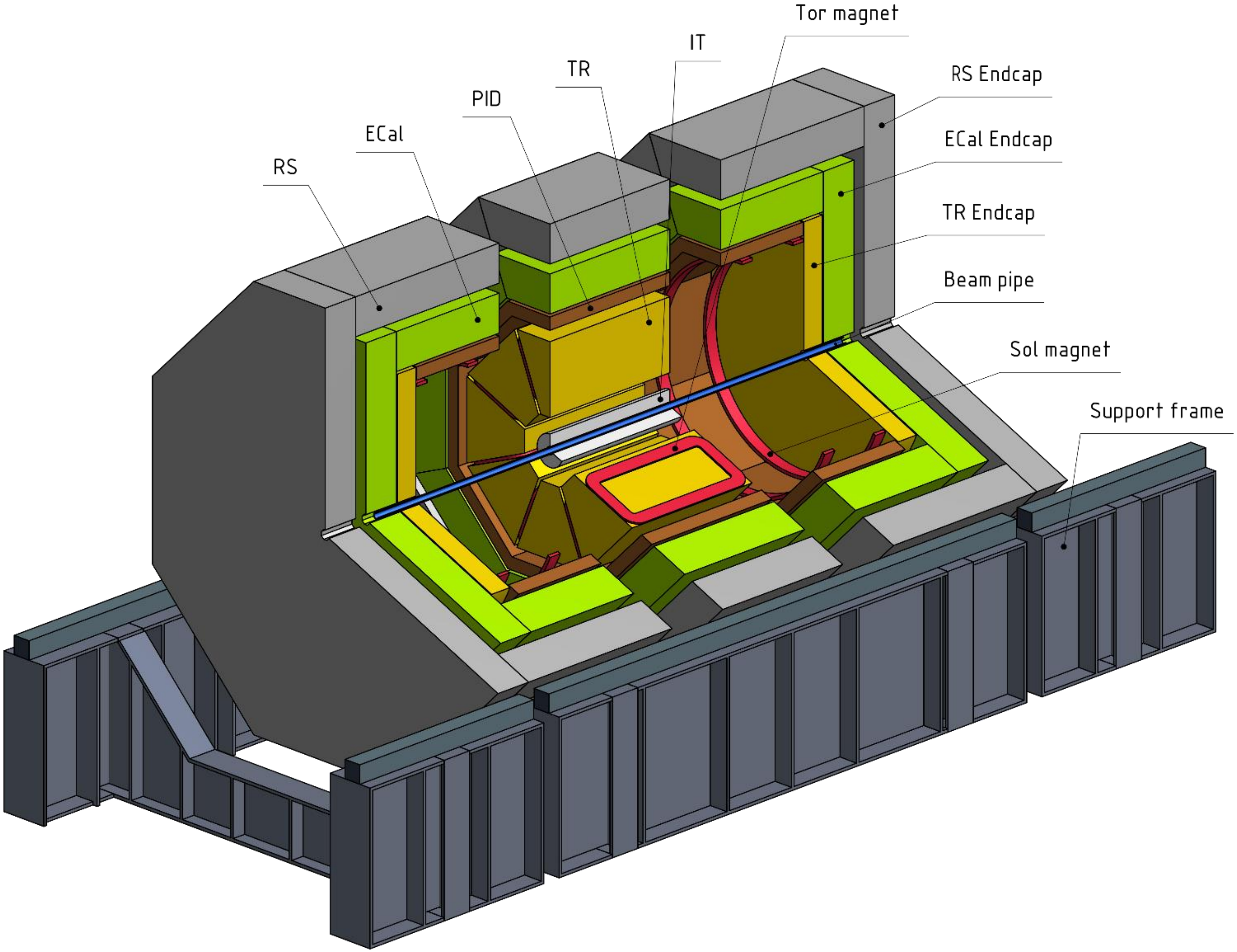
Requirements for the SPD



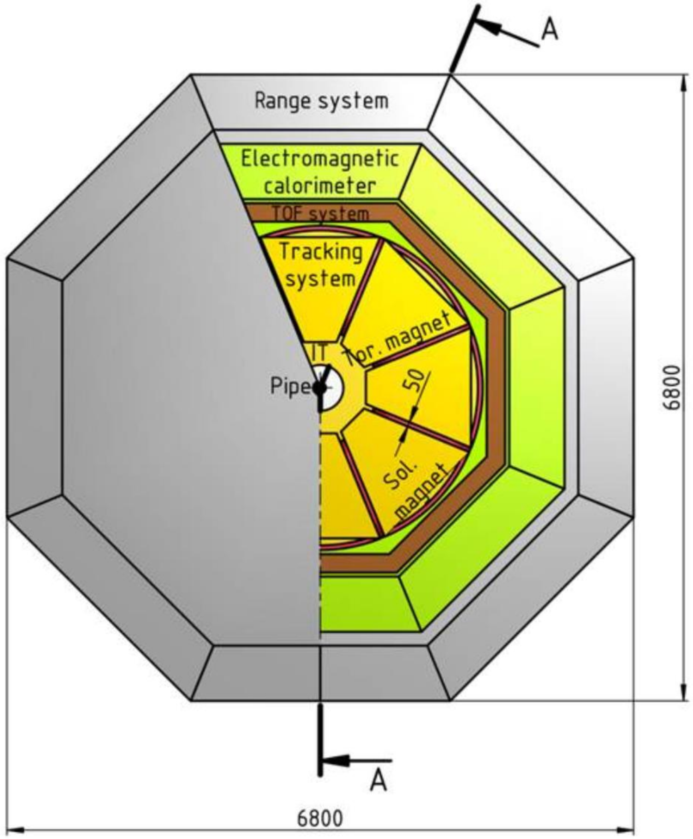


- close to 4π geometrical acceptance;
- high-precision (~50 μm) and fast vertex detector;
- high-precision (~100 μm) and fast tracker,
- good particle ID capabilities;
- efficient muon range system,
- good electromagnetic calorimeter,
- low material budget over the track paths,
- trigger and DAQ system 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.

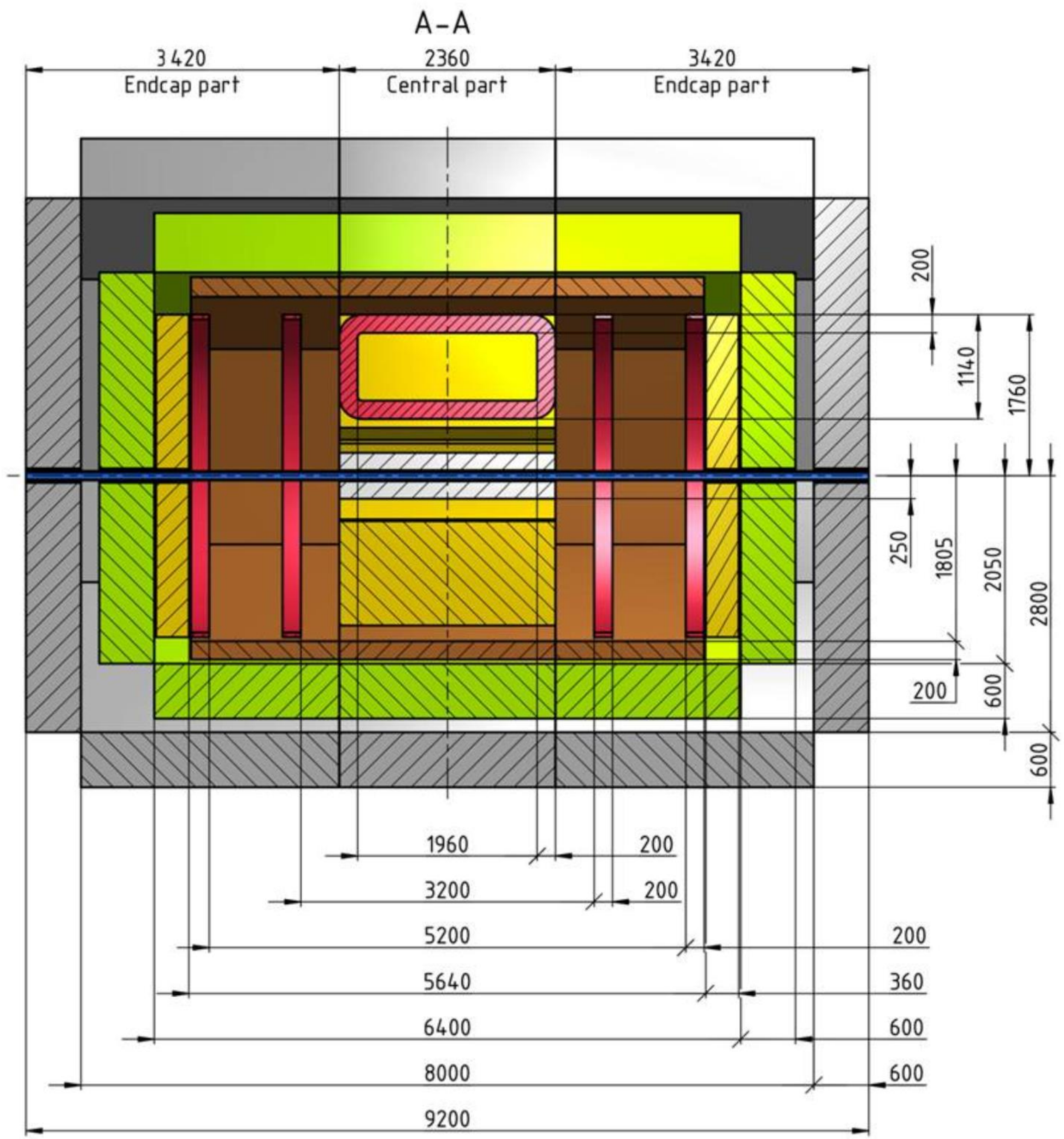
General view



Dimensions



A
Range system
Electromagnetic calorimeter
TOF system
Tracking system
IT
Tor. magnet
Pipe
50
Sol. magnet
6800
A
6800



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

Hybrid magnetic system

½ model symmetry

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

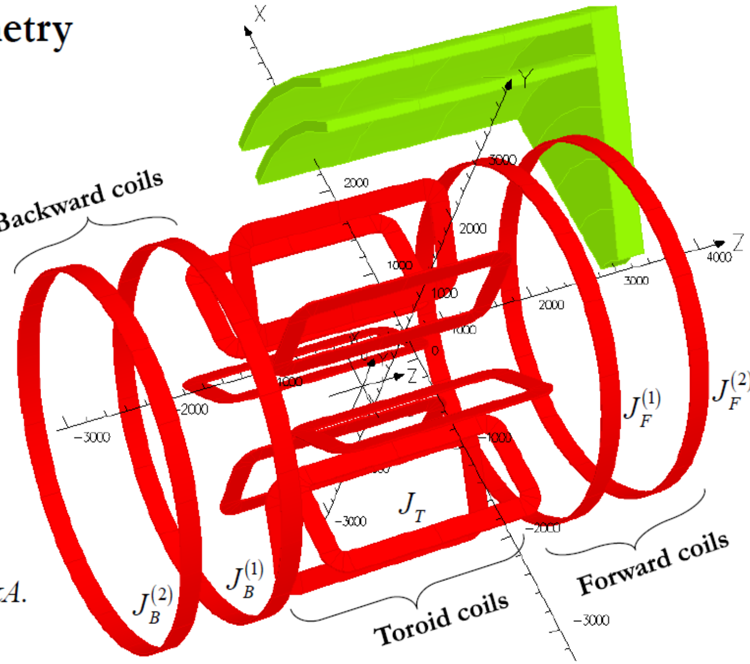
$$J_T = 40\frac{A}{mm^2},$$

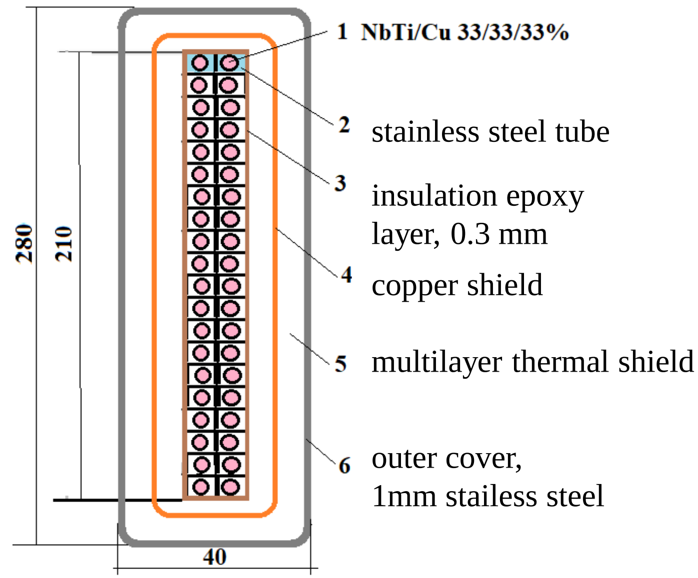
$$J_{B\backslash F}^{(1,2)} = \mp 80\frac{A}{mm^2},$$

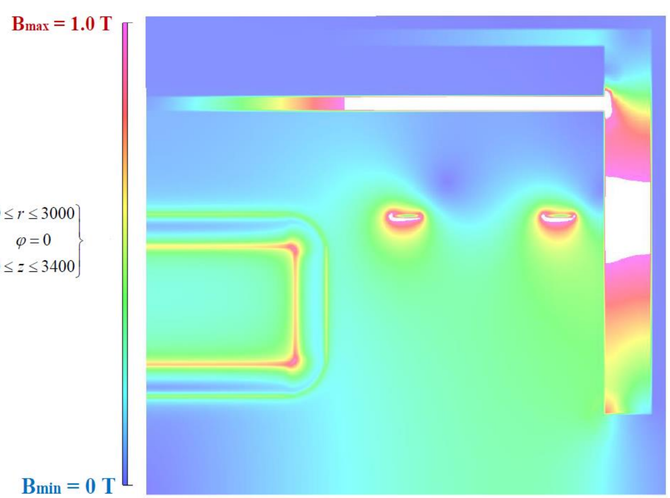
$$S = 200\times 20\,mm^2,$$

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

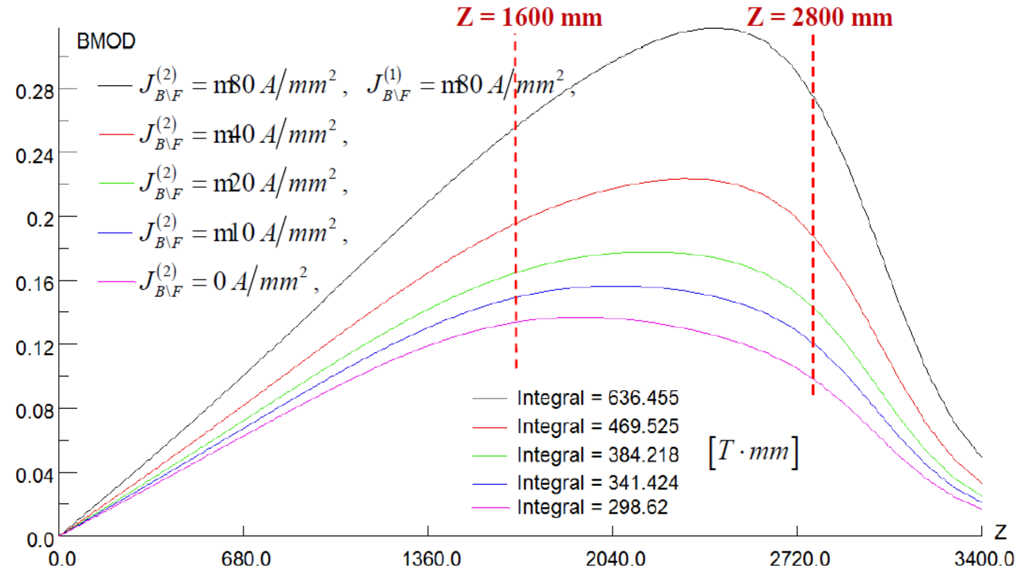
$$I_{B\backslash F} = J_{B\backslash F}\cdot S = \mp 320\,kA.$$



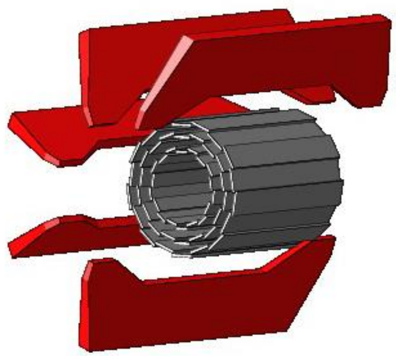




$$\Omega=\left\{(r,\varphi,z):\ \begin{matrix}0\le r\le 3000\\ \varphi=0\\ 0\le z\le 3400\end{matrix}\right\}$$

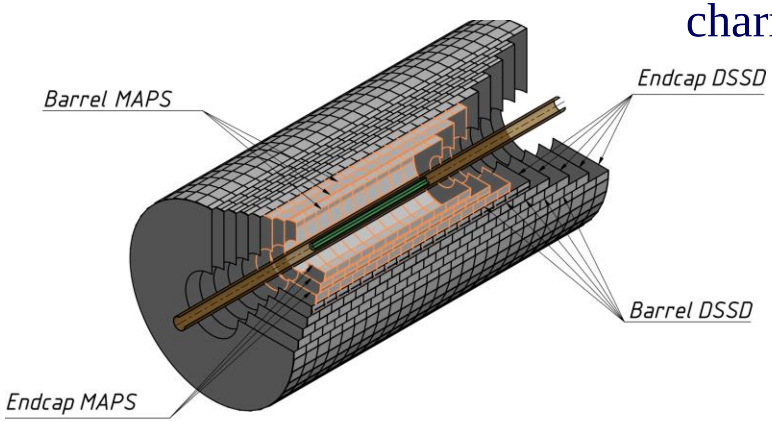


Vertex detector / Inner tracker

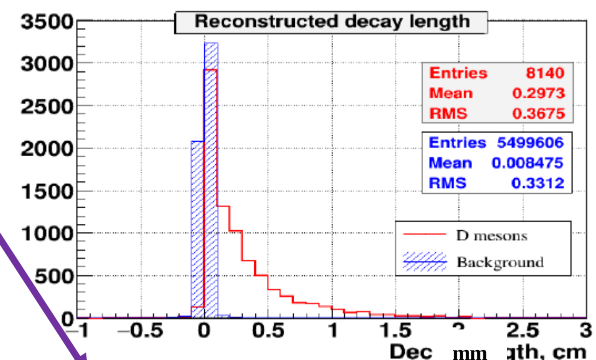


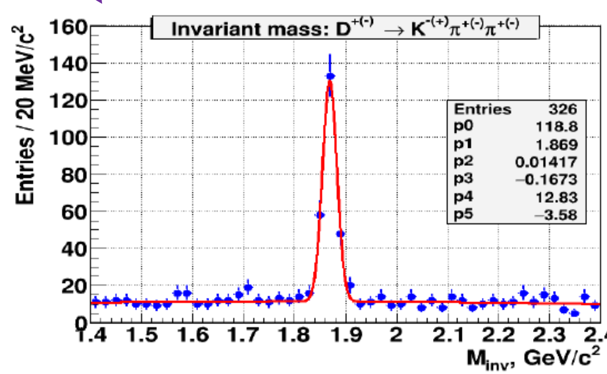
<u>Silicon Vertex Detector</u>

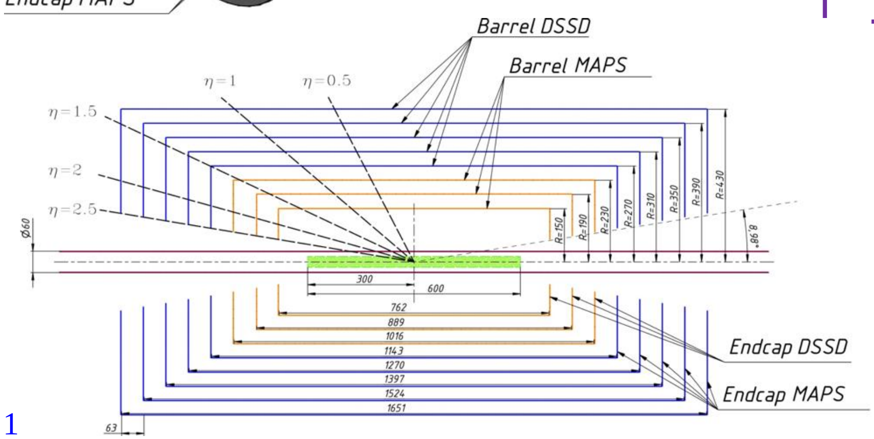
- Silicon vertex detector around the beam pipe;
- Several layers of double sided silicon strips or MAPS;
- Optimized number of layers w.r.t. material budget;
- Goal: few tens of μm resolution for the vertex reconstruction → detection of particles with open charm and rejection of (π) decay muons.



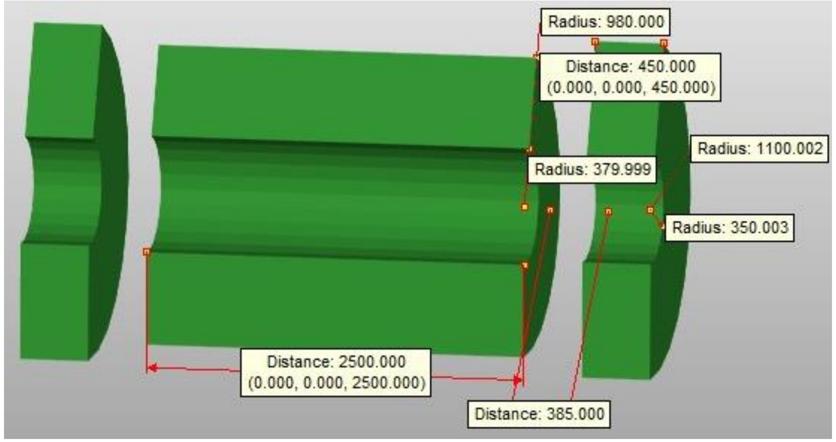
From A. Zinchenko, MPD ITS with MAPS → open charm registration



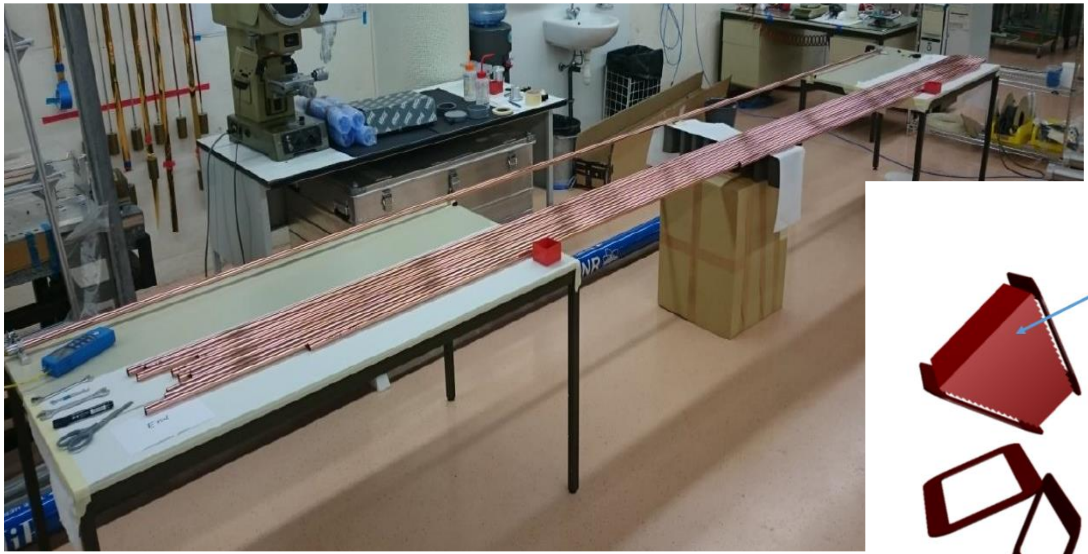


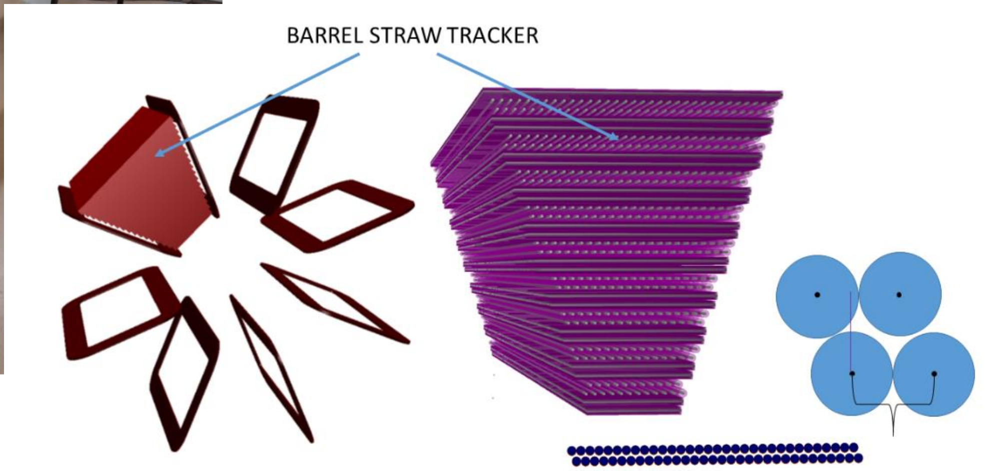


Central tracker: straw tubes

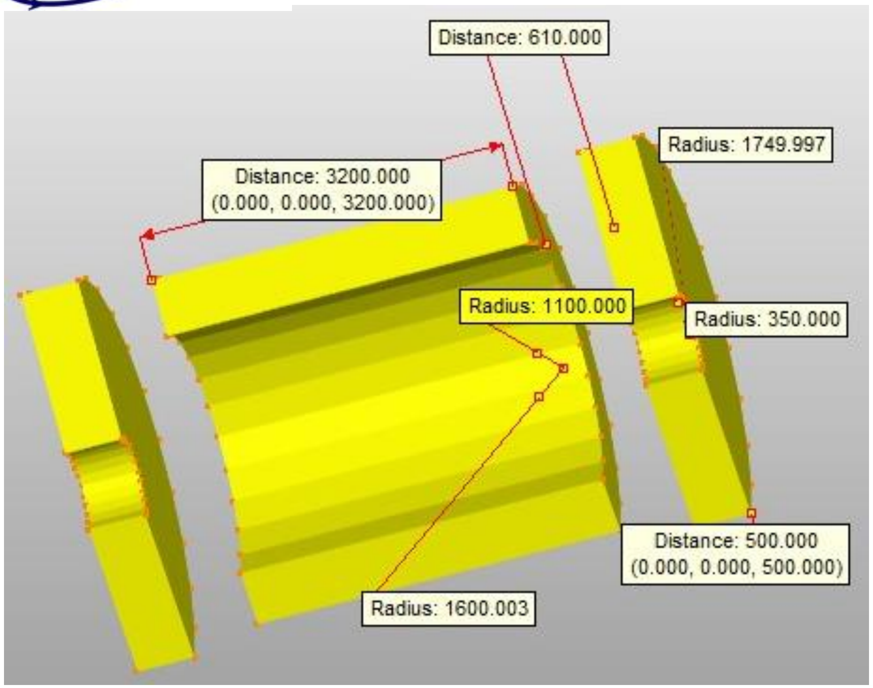


- Minimum material on the particle tracks (X_0 ~ 0.1);
- Time (~ 100 ns) and spatial resolution (~100 μm);
- Expected particle rates (DAQ rates) ~ MHz;
- Technology developed also in JINR, production workshops available

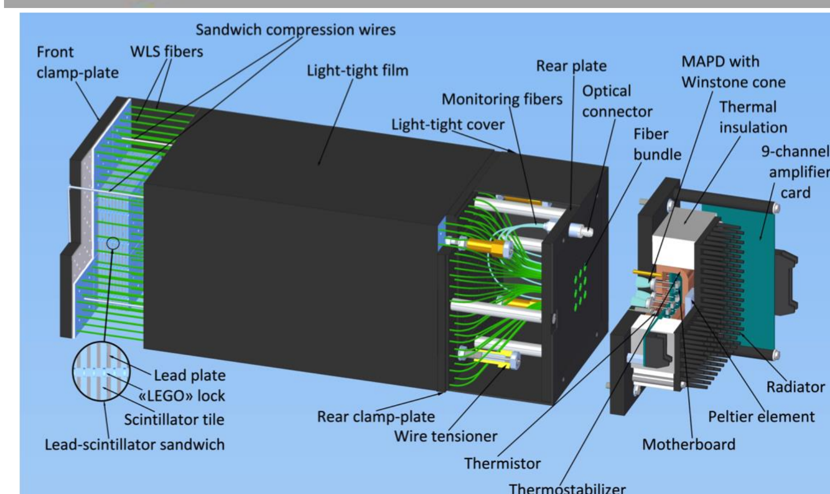




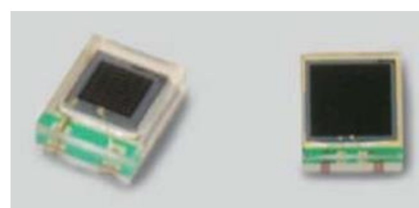
ECal



- 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.
- The version of ECal modules developed at JINR for the COMPASS-II experiment at CERN could be a good candidate ("shashlik" design);
- Crystal variant is being considered, too.

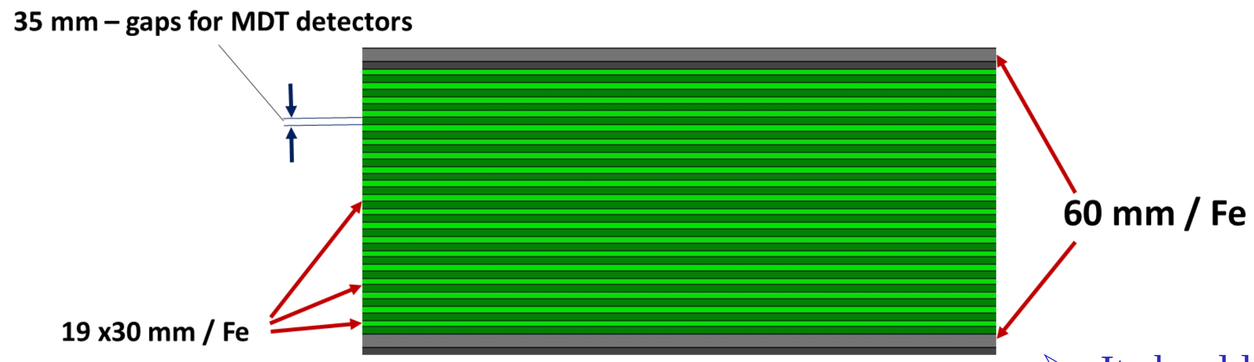


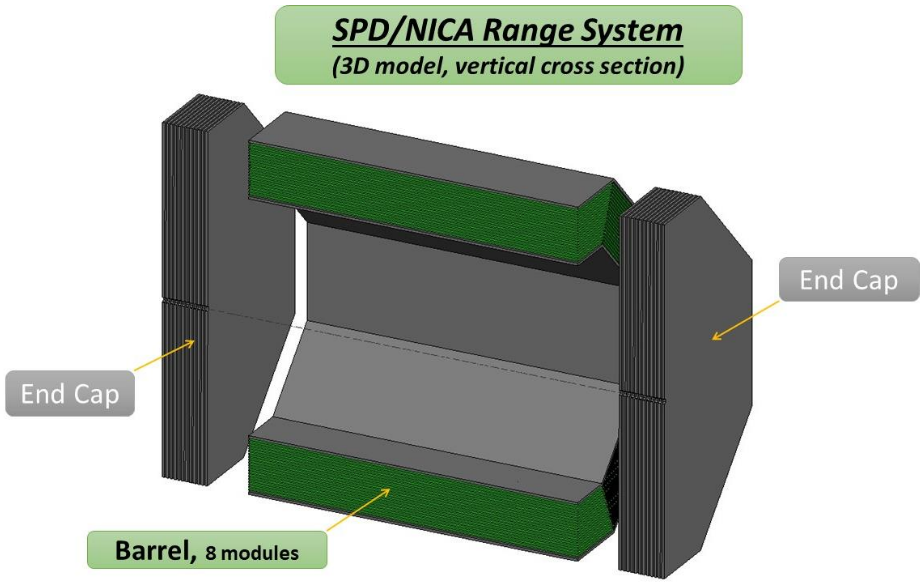
Avalanche multichannel photodetectors



Surface mount type Custom made

Range system





- It should provide good (>95%) muon identification for momenta above 1 GeV.
- Combination of responses from the ECal and RS could give additional lever for regecting of pions and protons in a wide energy range.
- The RS also provides additional coordinate measurement.

Our design will follow closely the design of the PANDA experiment range system (at FAIR, GSI) being developed now at the DLNP of JINR

DAQ

- The SPD DAQ may be developed *a la* FPGA-based 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 + RPC + ECal + range system): 10-20 GBytes/s (no detailed simulation results available yet);
- Triggered or trigger-less DAQ: to be decided.

Project status and roadmap

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)

Status

- Simplified detector sketch and simulations of basic physics processes (Oct. 2017- end of 2018) **ONGOING**;
- Development of a simplified design of the detector and costing **ONGOING**;
- Negotiations for an international collaboration and sharing of responsibilities for the design and construction of the facility **ONGOING** :
  - INFN section of Turin and University of Turin;
  - Charles University, Prague;
  - Technical University, Prague
  - Tomsk State University;
  - Tomsk Polytechnic University;
  - Institute of Applied Physics of the Belarus Academy of Sciences;
  - Gomel State Technical University, Belarus;
  - Institute for High Energy Physics, Protvino;
  - Institute of Nuclear Physics of the Moscow State University;
  - Institute for Nuclear Research, Troitsk;
  - Lebedev Physics Institute, Moscow;
  - Institute for Theoretical and Experimental Physics, Moscow;
  - St. Petersburg Nuclear Physics Institute, Gatchina;
  - St. Peterspurg State University;
  - St. Petersburg Polytechnic University
  - …

Protocols for joint research within the SPD project signed.

Bilateral agreements on NICA exist.

Roadmap

- Writing up of a formal JINR project for the SPD design (*i.e. for preparation of the Conceptual and Technical Design Reports*) and submission of the project to the PAC for Particle Physics:
  - status report presented at the PAC meeting in Jan. 2018;
  - submission of the application to the PAC in Nov. 2018 for their meeting in Jan. 2019;
- Setting up of the collaboration and election of its management bodies (2019);
- Signing of an MoU based on "*Regulations for the organization of experiments conducted by international collaborations using the capabilities of the JINR basic facilities*" *http://www.jinr.ru/wp-content/uploads/JINR_Docs/Regulation_for_the_organization_of_experiments_eng.doc* (2019).

Roadmap (cont'd)

- Preparation of the Conceptual Design Report (2019);
- Preparation of the Technical Design Report, including prototyping – first stage (2020 – 2022), second stage (2023);
- Construction of the detector (2022-2025);
- First measurements – 2025…

Roadmap

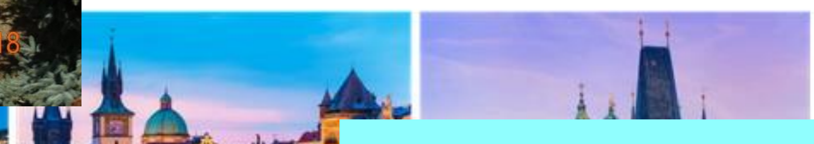
- JINR project for the SPD design (Jan. 2019);
- Setting up of the collaboration, MoU (2019);
- Preparation of the Conceptual Design Report (2019);
- Preparation of the Technical Design Report (including prototyping)

  - first stage (2020 – 2022)

  - second stage (2023);
- Construction of the detector (2022-2025);
- First measurements – 2025…

op on Spin Physics

a-2018)



Organizing Committee

List of registrants

Scientific Programme

Timetable

Accommodation

Transportation

Registration Form

Fee

Visa Application

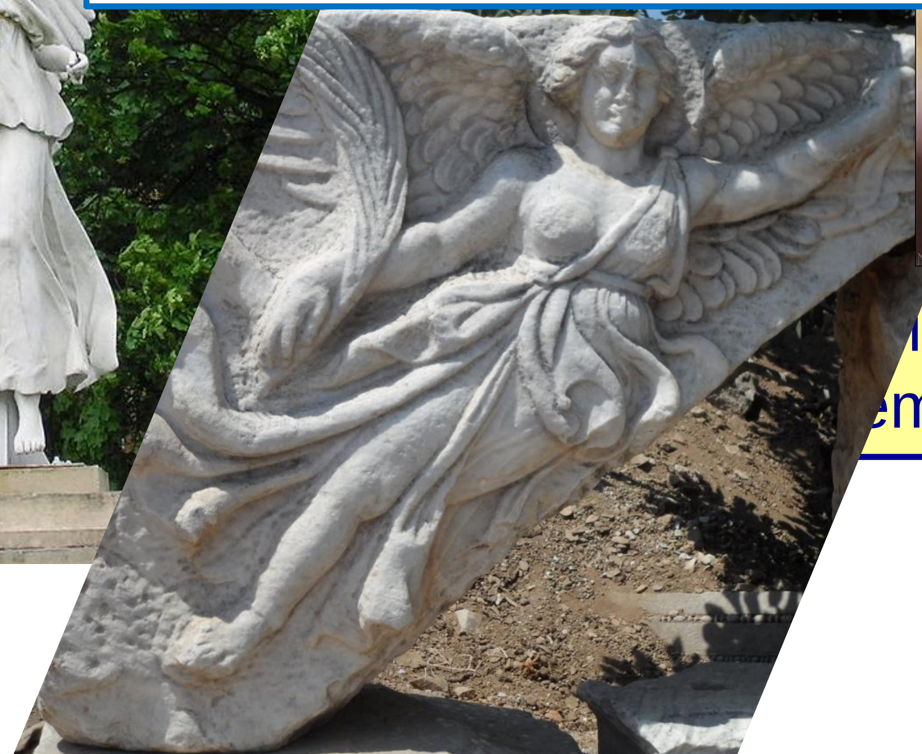
Contacts

This Internationa
series of meeting
and Astrophysics
the Joint Institut
in Czech Republi
/doku.php?id=co

You are welcome to join the SPD/NICA project!

Web site: *spd.jinr.ru*.

Contact person: Roumen Tsenov (*tsenov@jinr.ru*)



...on spin structure
...igh statistical level
...ematic uncertainties