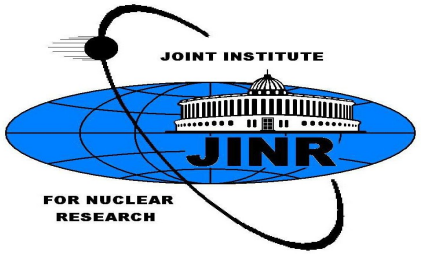
Polarization effects in hadronic reactions in a GeV region



V.P. Ladygin on behalf of DSS collaboration

XXII-th IBSHEPP, September 15-20, 2014 , Dubna, Russia

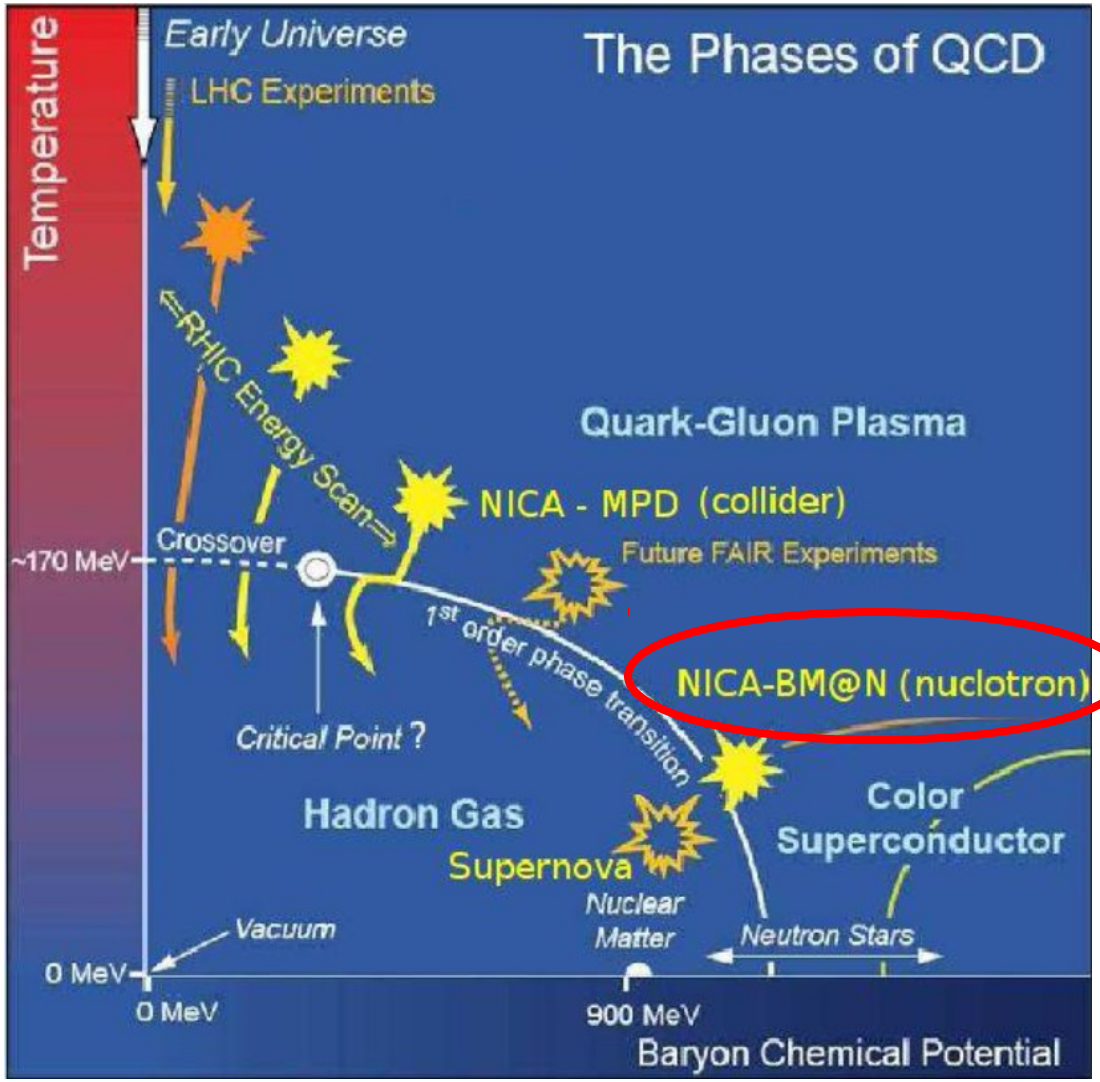
Outline

- **Introduction**
- **Recent results on the cross section energy scan of dp-elastic scattering at intermediate and high energies and preliminary results on dp-nonmesonic breakup**
- **Further studies with extracted beam at Nuclotron**
- **Conclusion**

Collaboration: Bulgaria-JINR-Japan-Romania-Russia-Slovakia

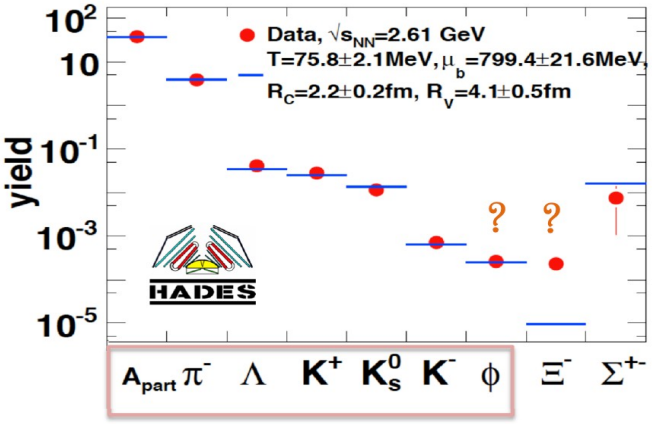
Talk is partly based on the results presented in the reports of P.Kurilkin, S.Piyadin, A.Terekhin

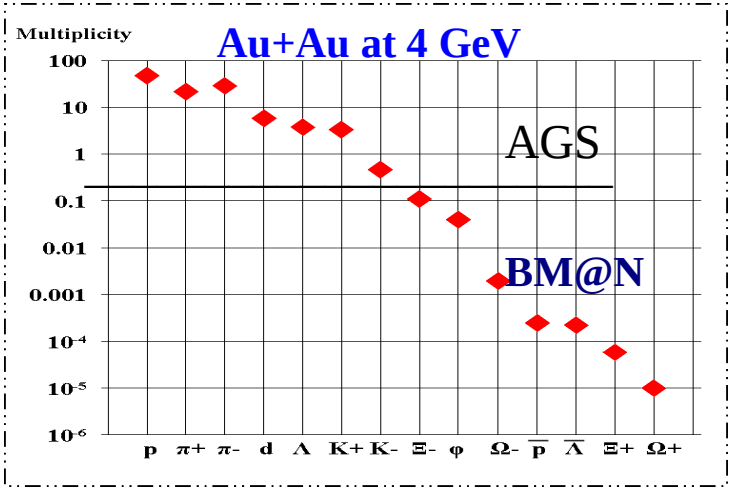
The holy grail of HIC (E.L.Bratkovskaya)



- Study of the phase transition from hadronic to partonic matter – Quark-Gluon-Plasma
- Search for the critical point
- Study of the in-medium properties of hadrons at high baryon density and temperature

Main goal of the BM@N project





~150 Ξ⁻ at HADES (GSI) in Ar+KCl at 1.76 GeV

~250 Ξ⁻ at AGS in Au+Au at 6 GeV

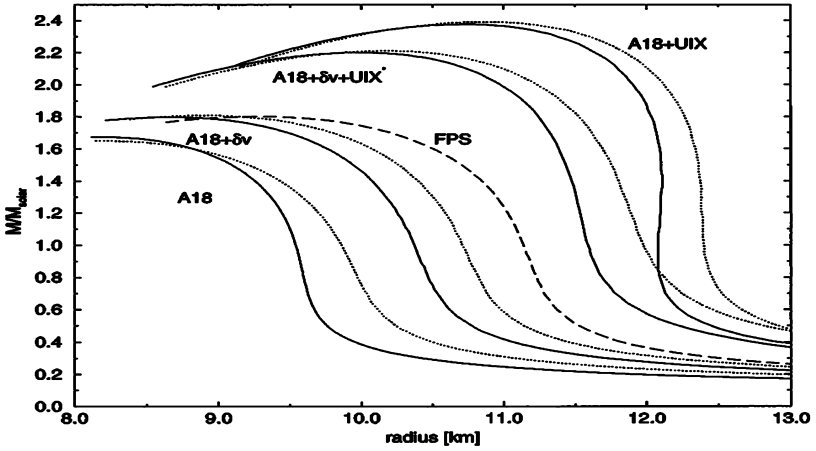
Ω⁻ -hyperons at the Nuclotron energies were not detected!

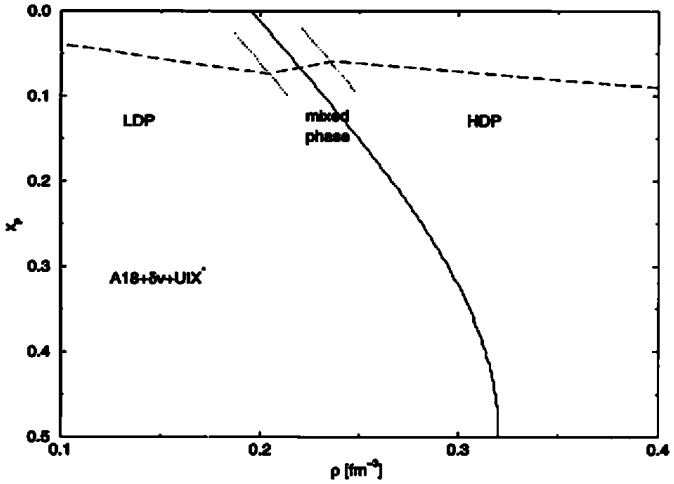
Goal: Study of the earlier phase of nuclear interaction at high densities (3-4ρ_0) by measuring of multi-strange particles (Ξ and Ω hyperons, double hypernuclei etc.) with enormous statistical precision to improve the knowledge on EOS.

Expected statistics $5*10^7$ for Ξ- and 10^6 for Ω^- hyperons at 4 GeV.

Few nucleons systems as a tool for dense matter studies

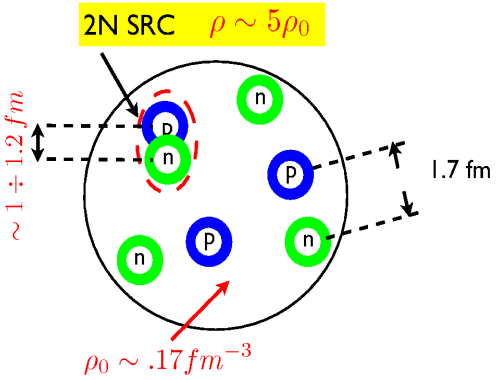
Another way to obtain the information on the EOS at extreme densities (neutron stars) is the studies of the few nucleon systems.

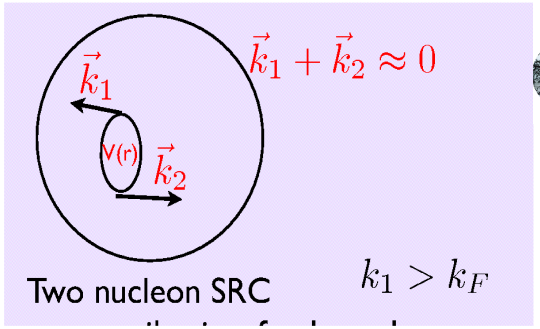




Relativistic effects in 2NF and contribution of 3NF play very important role.

Short range correlations (SRCs)





Summary of the theoretical analysis of the experimental findings
practically all of which were predicted well before the data were obtained

More than ~90% all nucleons with momenta k≥300 MeV/c belong to two nucleon SRC correlations BNL + Jlab +SLAC

Probability for a given proton with momenta 600> k > 300 MeV/c to belong to **pn** correlation is ~ 18 times larger than for **pp** correlation BNL + Jlab

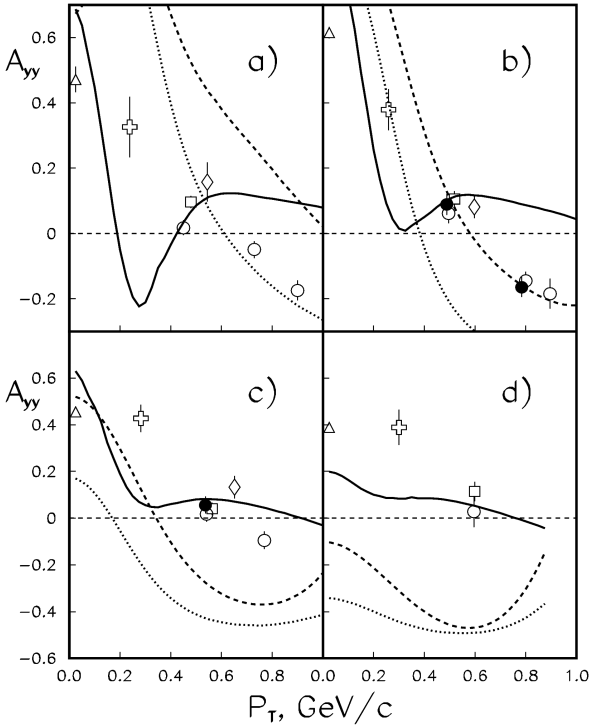
Probability for a nucleon to have momentum > 300 MeV/c in medium nuclei is ~25% BNL + Jlab 04 +SLAC 93

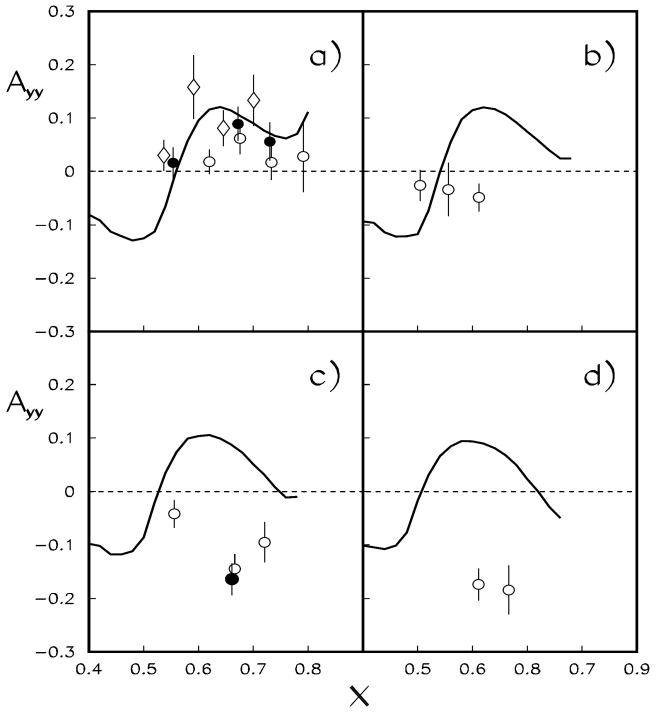
Probability of non-nucleonic components within SRC is small - < 20% - 2N SRC mostly build of two nucleons not 6q, ΔΔ,... BNL + Jlab +SLAC

Three nucleon SRC are present in nuclei with a significant probability Jlab 05

Poor data base on the spin parts of the 2N and 3N short-range correlations. This motivates the necessity to study light nuclei structure at short distances.

Relativistic effects in 2N SRCs (deuteron)





A_{yy} in deuteron inclusive breakup demonstrates the dependence on 2 internal variables: p_T and x_F.

A_{yy} changes the sign at p_T of about 600 MeV/c independently on x_F.

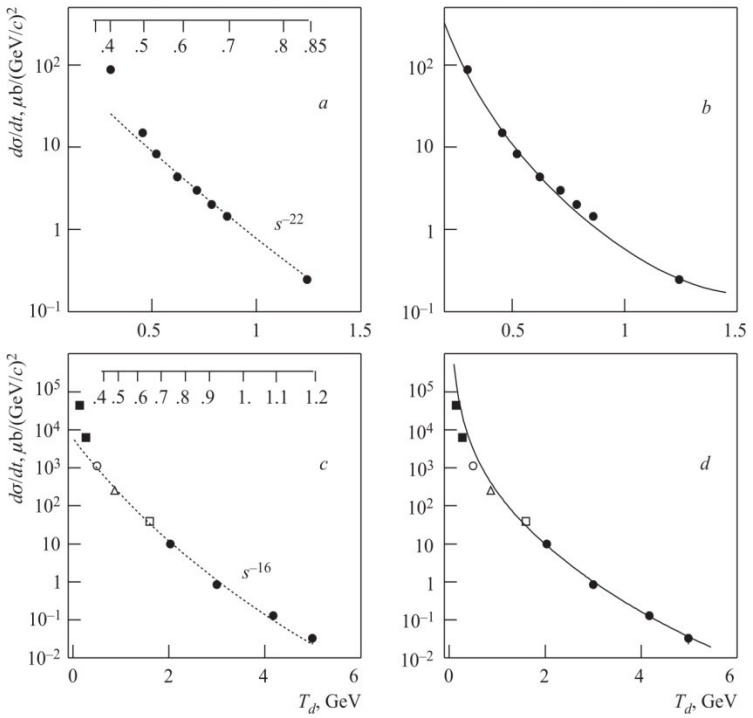
A_{yy} demonstrates negative asymptotic at large p_T .

Quark degrees of freedom

- At high energy s and large transverse momenta p_t the constituent counting roles (CCR) predict the following behavior of the differential cross section for the binary reactions:

$$\frac{d\sigma}{dt}(ab \to cd) = \frac{f(t/s)}{s^{n-2}} \quad ; \quad n = N_a + N_b + N_c + N_d$$

(*Matveev, Muradyan, Tavkhelidze, Brodsky, Farrar et al.*)



Yu. N. Uzikov

(JETP Lett, 81, pp. 303-306, 2005)

For the reaction dd → ^{3}Hen

$$N_A + N_B + N_C + N_D - 2 = 22$$

For the reaction dp → dp

$$N_A + N_B + N_C + N_D - 2 = 16$$

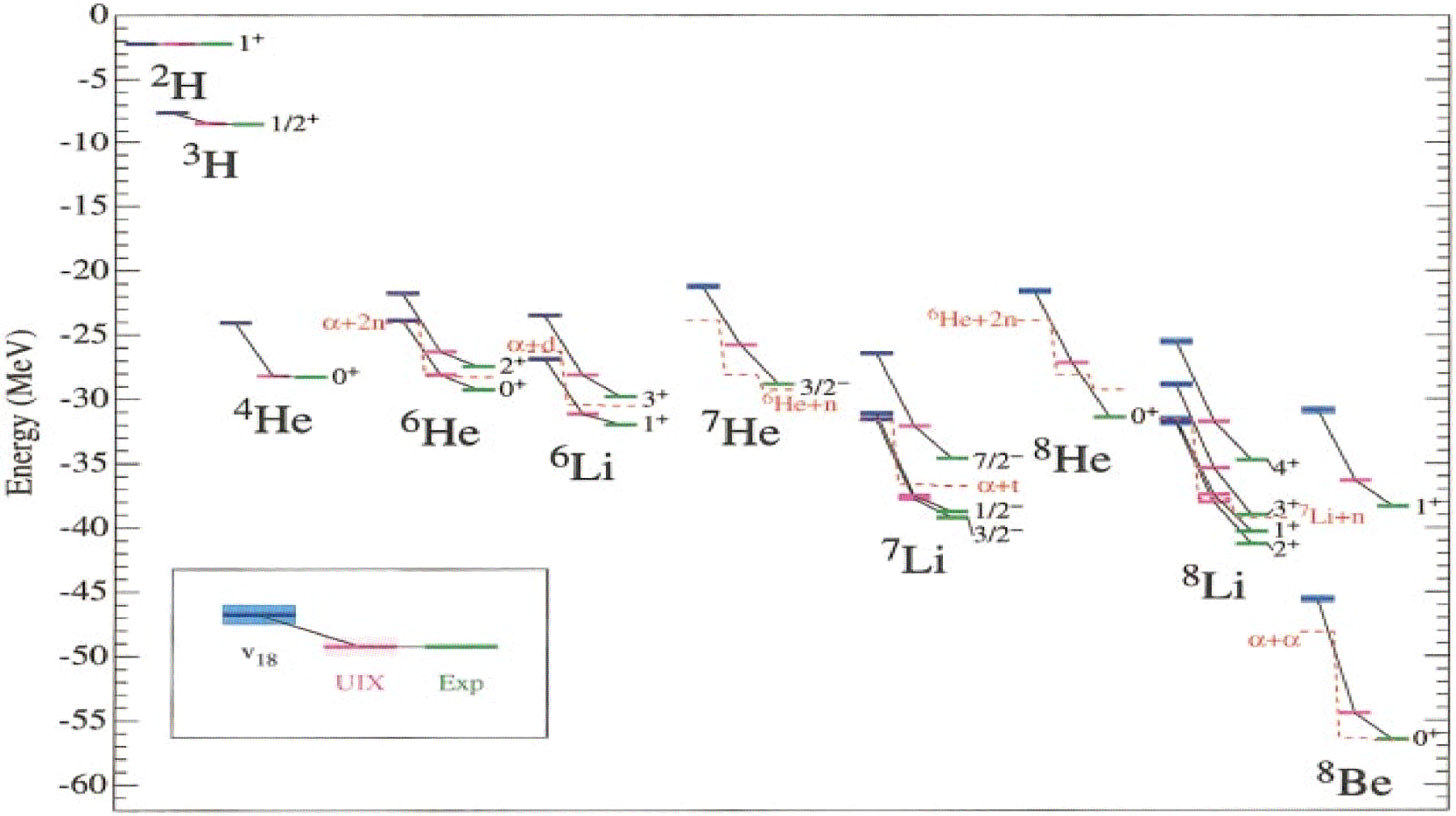
The regime corresponds to CCR can occur already at $T_d \sim 500$ MeV

The purpose of the **DSS** experimental program is to obtain the information about 2NF and 3NF (*including their spin – dependent parts*) from two processes:

1.dp-elastic scattering at the energies between 300 - 2000 MeV;

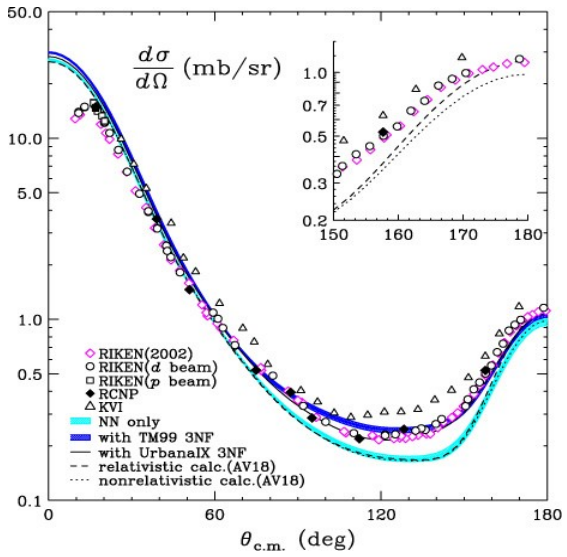
2.dp-breakup with registration of two protons at deuteron energies of 300 - 500 MeV.

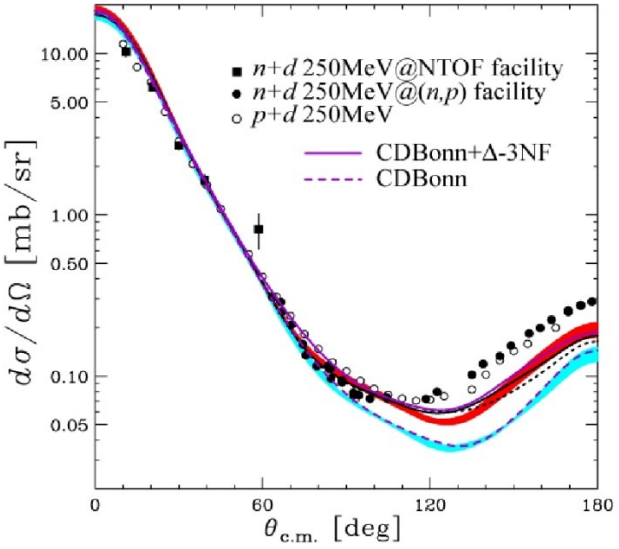
Importance of the spin part of 3NF for binding energies



Spin parts of the 2N and 3N correlations are important to describe the light nuclei structure.

Cross section in dp- elastic scattering at intermediate energies





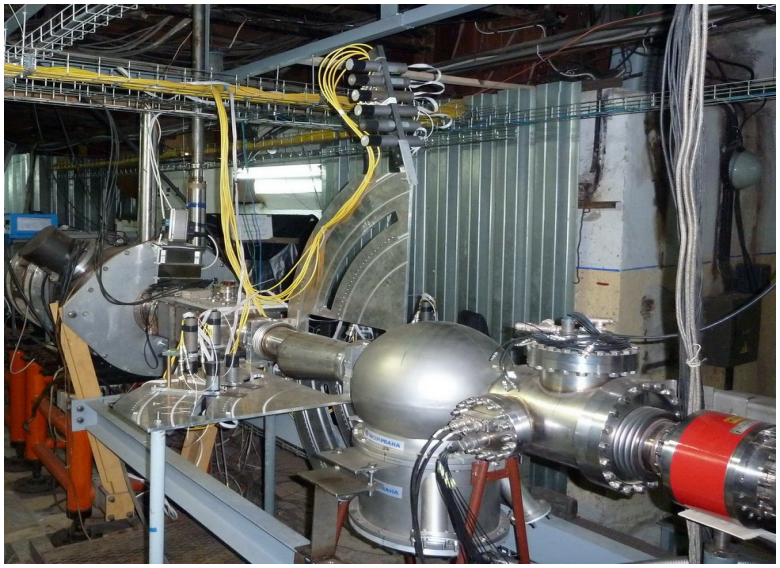
The differential cross section in elastic Nd scattering at the energy of 135 (left figure) and 250 (right figure) MeV/u.

K. Sekiguchi et al., Phys. Rev. Lett. 95, 162301 (2005)

K. Hatanaka et al., Phys. Rev. C 66, 044002 (2002)

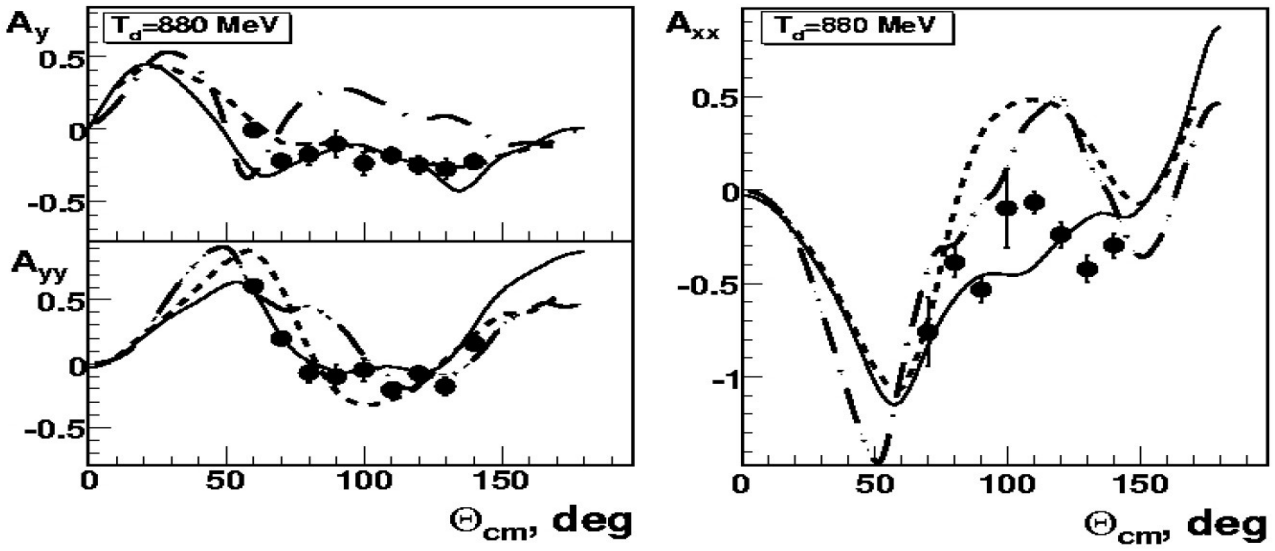
The study of hadronic reactions induced by deuterons at Nuclotron will allow to study the structure of 2N and 3N forces.

Experiments at Internal Target Station at Nuclotron (DSS-project)



Internal Target Station is very well suited for the measurements of the deuteron- induced reactions observables at large scattering angles.

Analyzing powers in dp- elastic scattering at 880 MeV



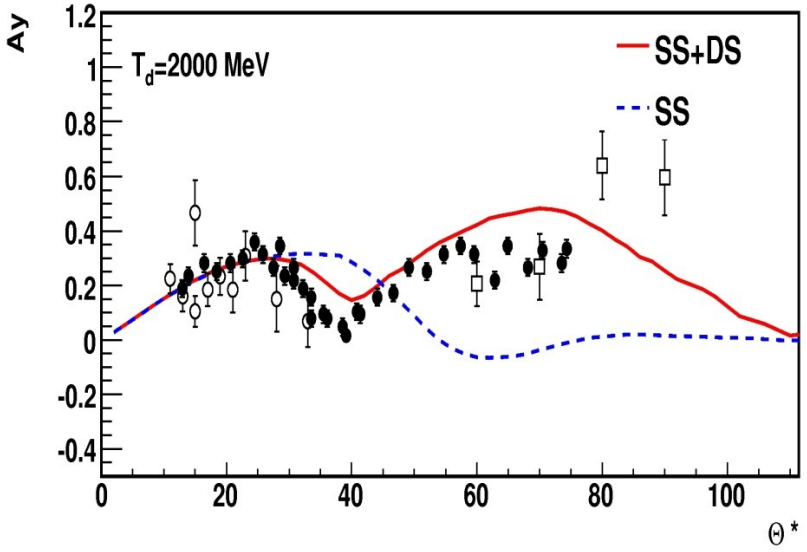
Dashed lines are the multiple scattering model calculations using CD -Bonn DWF (N.B.Ladygina, Phys.Atom.Nucl.71 (2008), 2039)

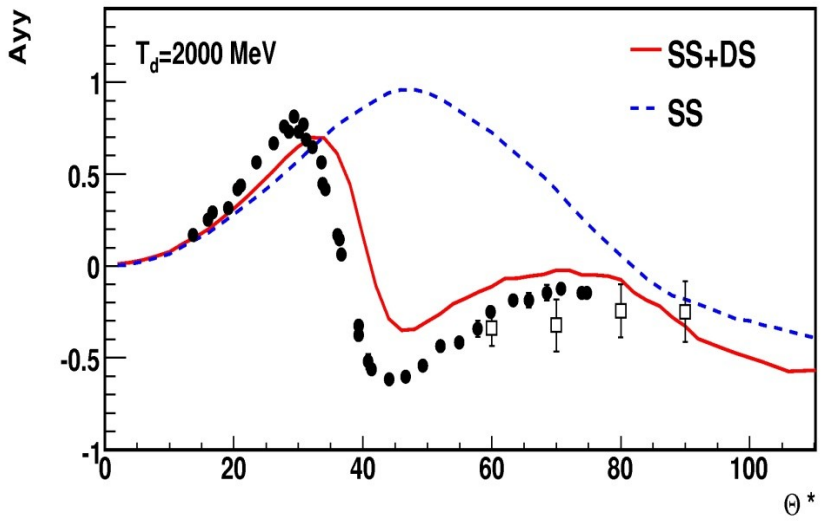
Solid lines are the Faddeev calculations using CD-Bonn potential (H.Witala, private communication)

Dott-dashed lines are the optical-potential calculations using Dibaryon DWF (M.Shikhalev, Phys.Atom.Nucl.72 (2009), 588)

Published in **P.K.Kurilkin et al., Phys.Lett.B715 (2012) 61-65**

A_y and A_{yy} in dp- elastic scattering at 2000 MeV



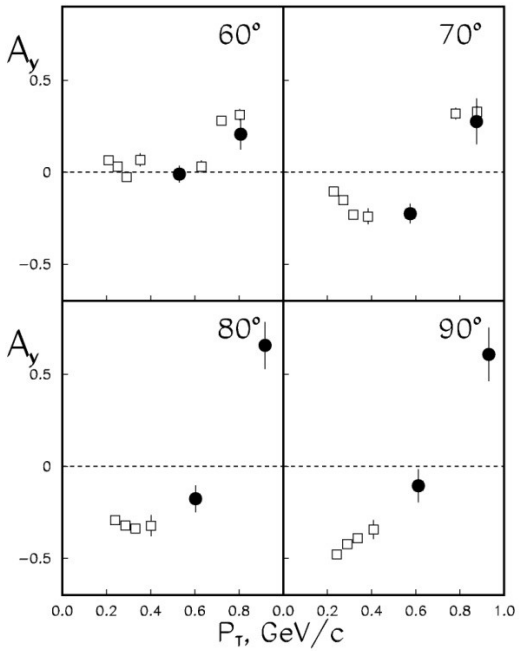


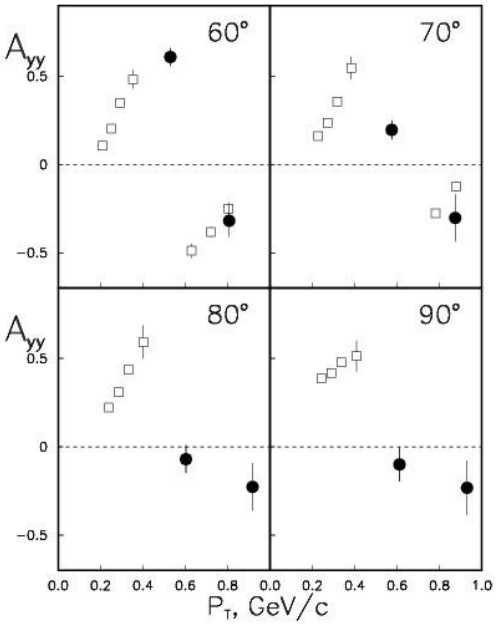
Open squares are the data obtained at Nuclotron JINR.
Open circles are the Synchrophasotron data (V.V.Glagolev, Eur. Phys. J. A48 (2012) 182)

Solid symbols are the data obtained by ANL group (Haji-Saied et al., Phys.Rev.C.36 (1987) 2010).

Dashed and solid lines are the relativistic multiple scattering model calculations using CD-Bonn DWF taking into account single scattering and single+double scattering, respectively.

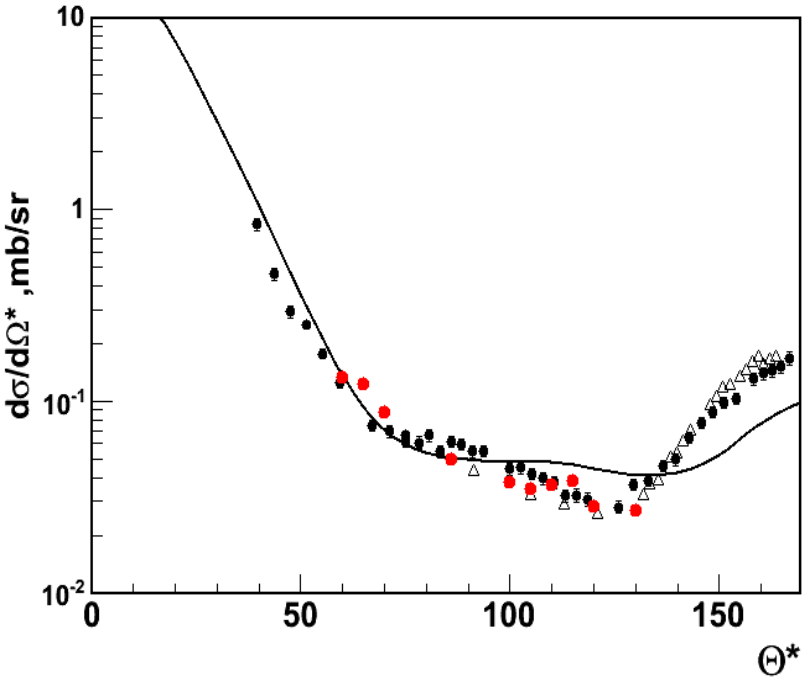
Energy dependence of the dp-elastic scattering analyzing powers at fixed scattering angles in the c.m.s.





- Full symbols are the data obtained at JINR
- Open symbols are the data obtained at RIKEN, Saclay and ANL.
- The study of the energy dependence of the analyzing powers in dp- elastic scattering at large p_T is one of the tools to study spin effects in **cold dense matter**

Cross section in *dp*- elastic scattering at 880 MeV



- **The results of the multiple scattering model are in agreement with the cross section data in the range 30 - 130º.**
- **Double scattering dominates over single scattering at the angles larger than 70º.**
- **Deviation of the data on the calculations at backward angles are related with the s-type of the FM 3NF.**
- **Is the deviation on the data from the calculations around 90º manifestation of 3N short range forces?**

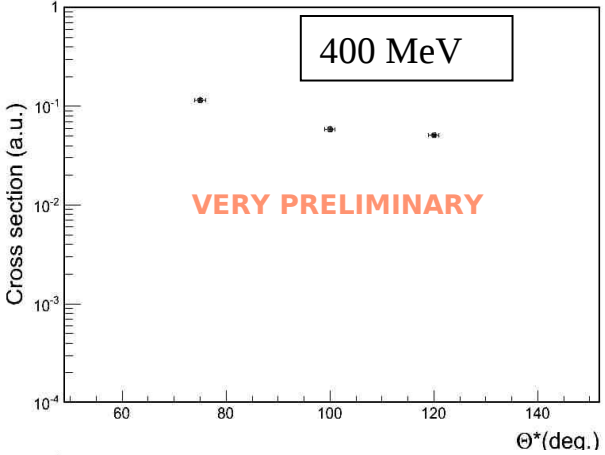
World data:

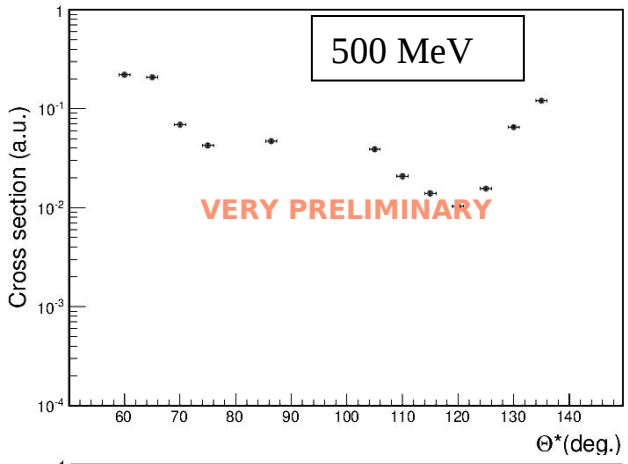
N.E.Booth et al., Phys.Rev.D4 (1971) 1261

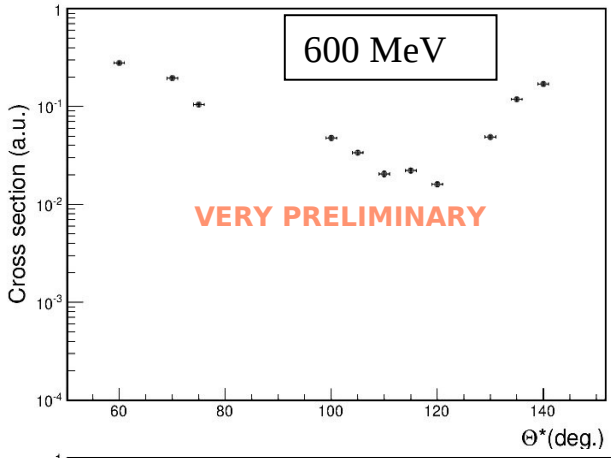
J.C.Alder et al., Phys.Rev.C6 (1972) 2010

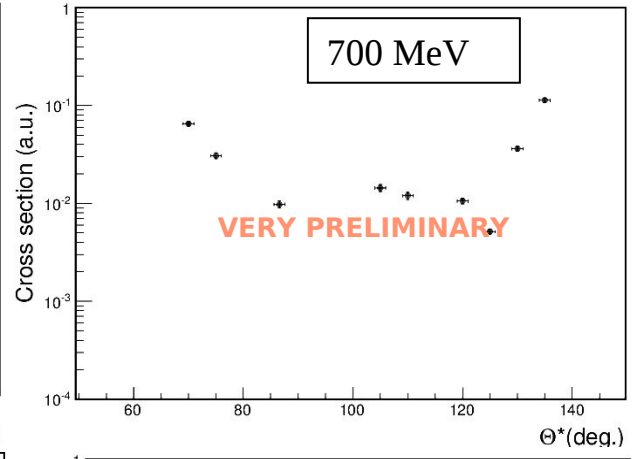
Relativistic multiple scattering model calculation:
N.B.Ladygina, Eur.Phys.J, A42 (2009) 91

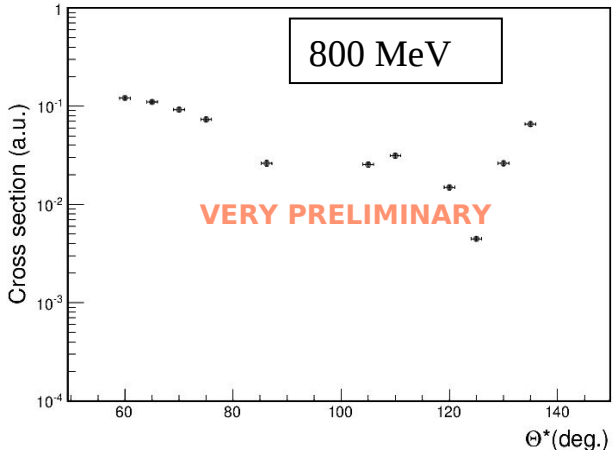
Red circles are the preliminary LHEP-JINR results: DSS-project at Nuclotron.

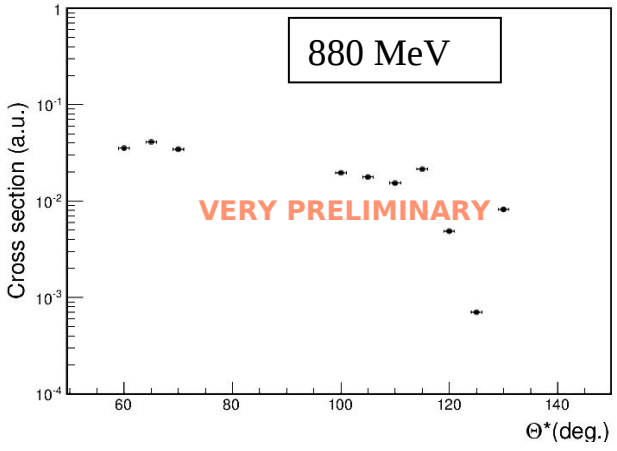


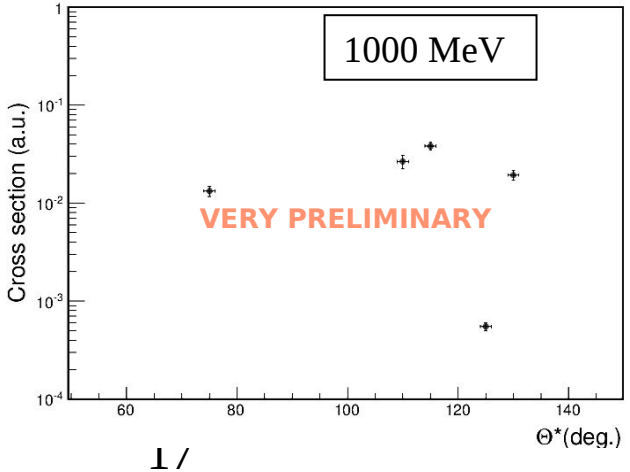








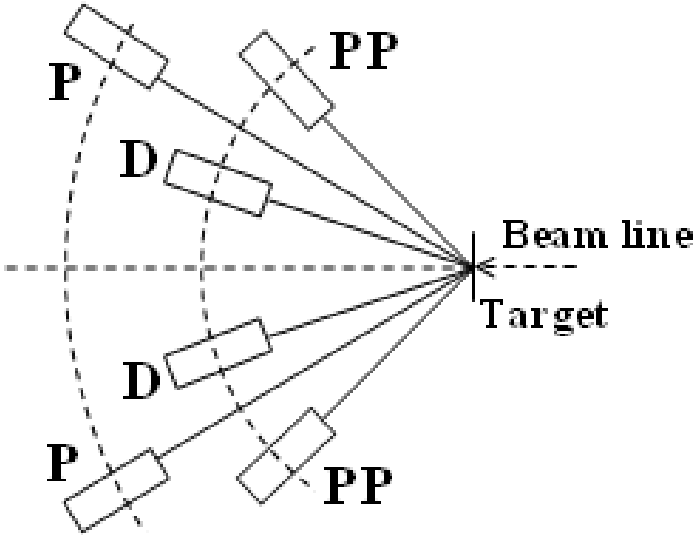


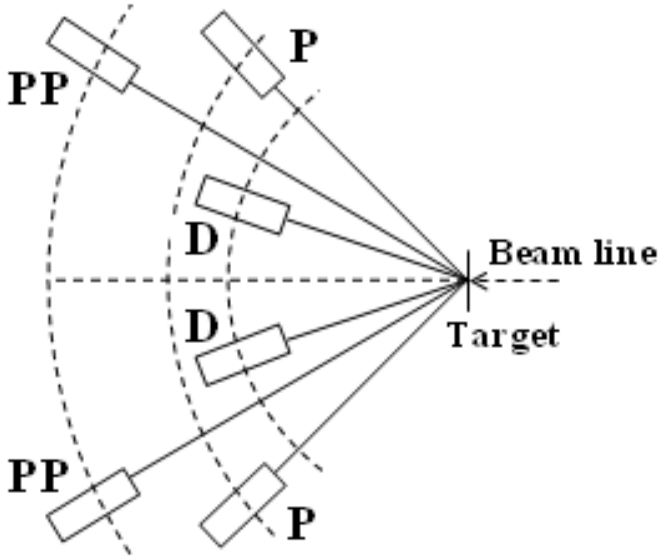


Cross section in *dp*-elastic scattering 400-1000 MeV

Scheme of the HE-dp experiment

A.Terekhin





P = 20x60x20 mm^3

D = 10x40x24 mm^3

PP = 50x50x20 mm^3

March 2013,2014

P = 20x60x20 mm^3

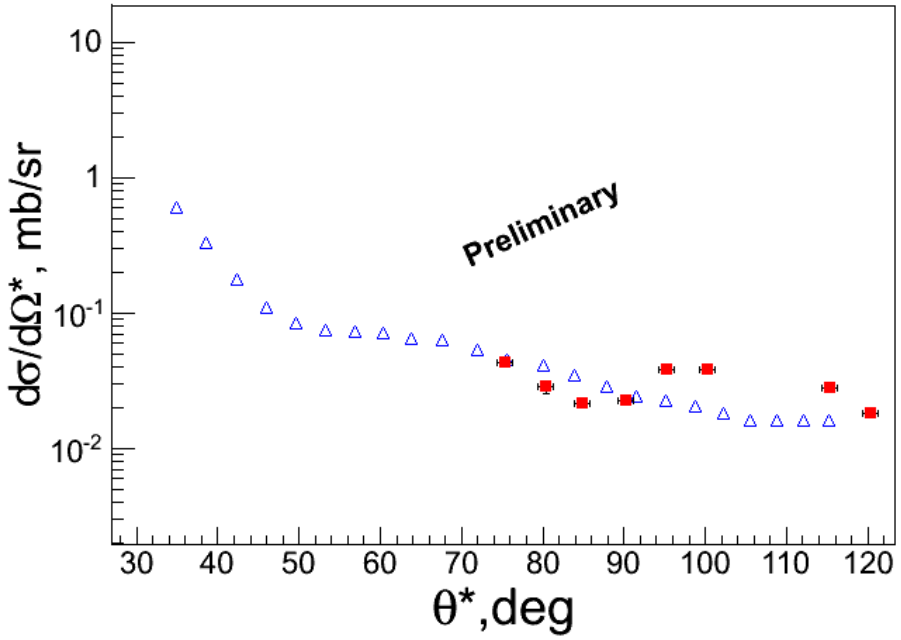
D = 50x50x20 mm^3

PP = ϕ100x200 mm^3

December 2012

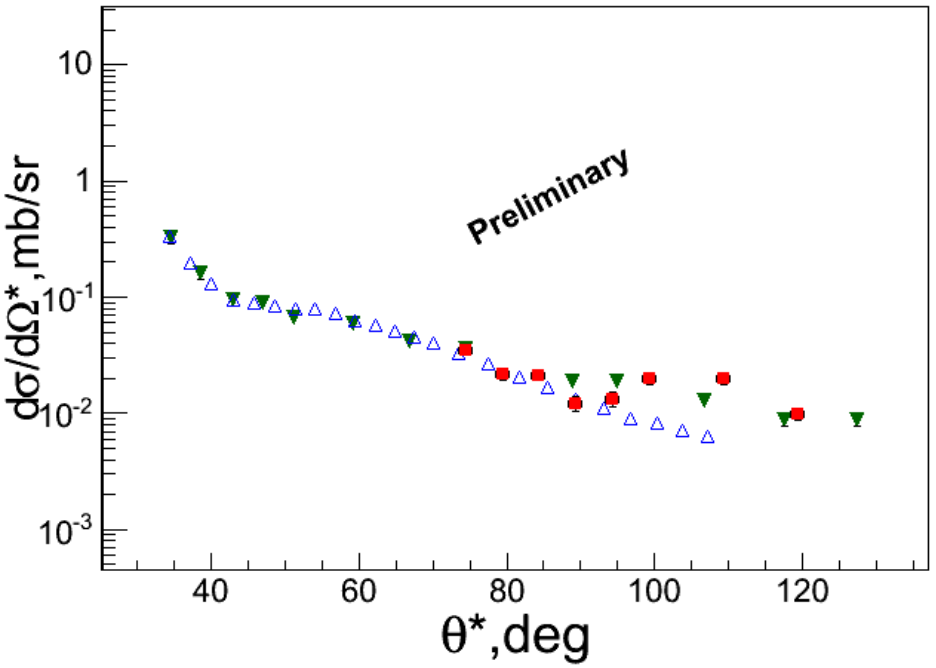
dp-elastic differential cross section

1300 MeV



Triangles – data at 641.3 MeV/n (Culmez E. Phys.Rev.C, V43, №5, 1991)

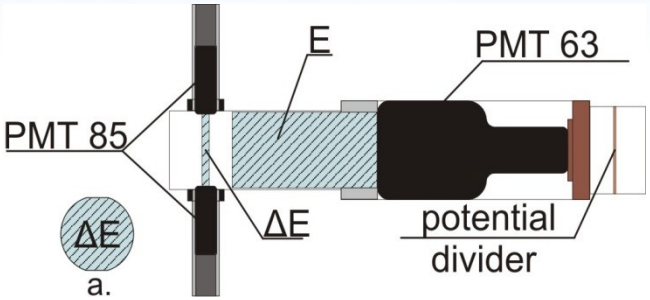
1500 MeV

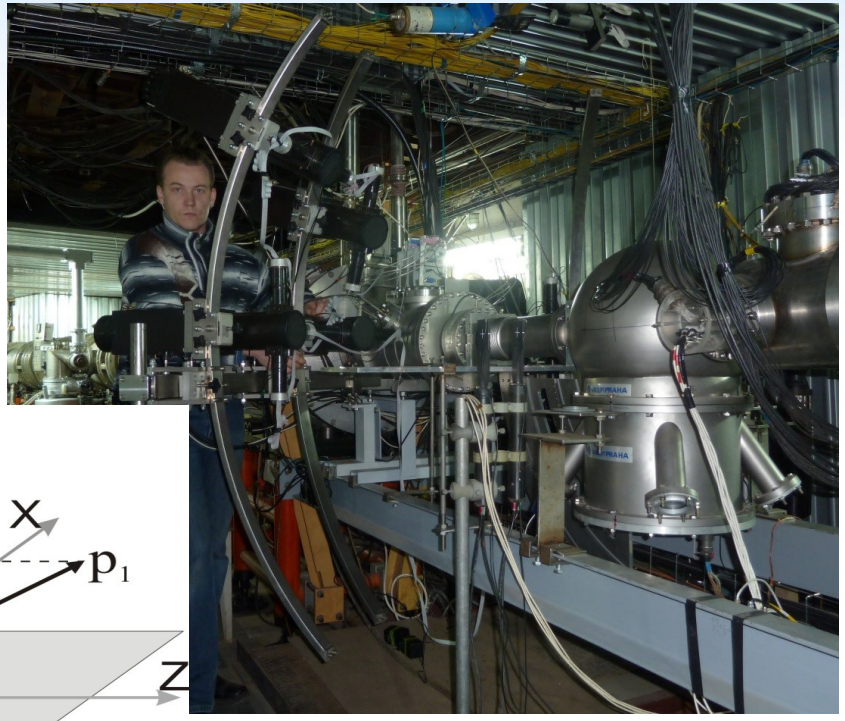


Blue triangles – data at 792.7 MeV/n (Culmez E. Phys.Rev.C, V43, №5, 1991)

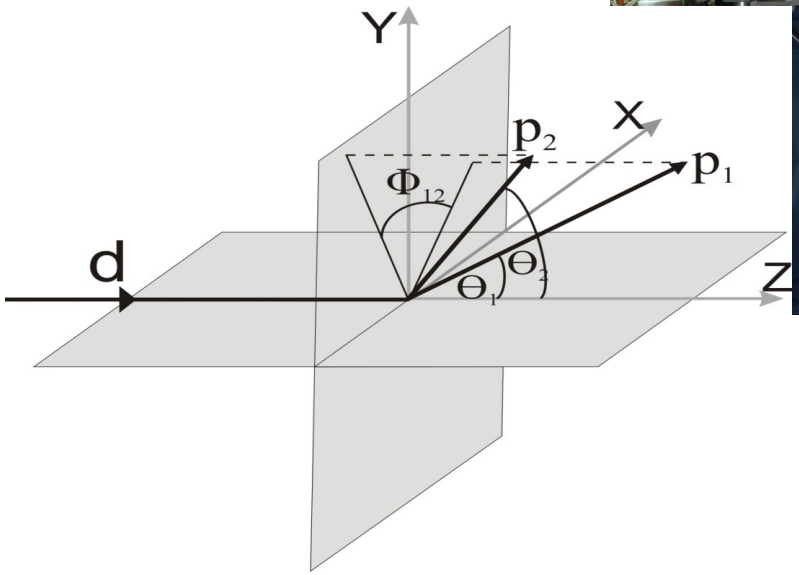
Green triangles – data from 800 MeV/n (Winkelmann E. Phys.Rev.C, V21, №6, 1980)

Experimental system for dp-breakup.





Θ (12°, 45°)
Φ (0°, 360°)
Space angle of
the detector 4.6°.

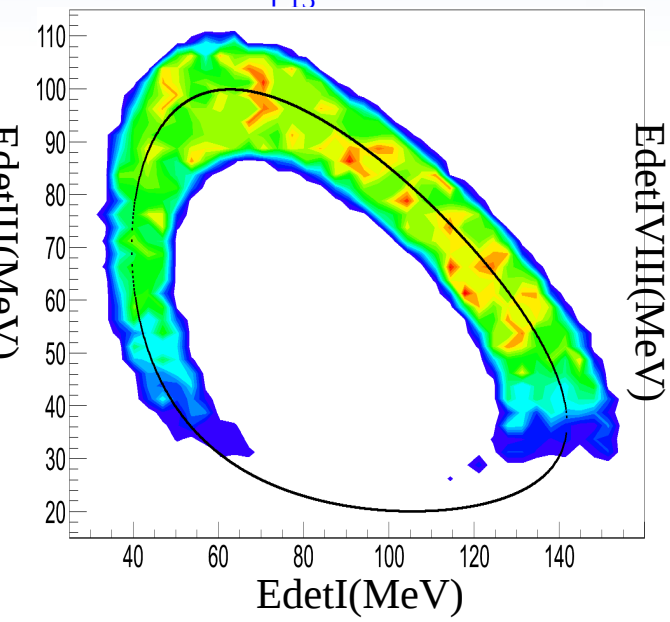


S.Piyadin

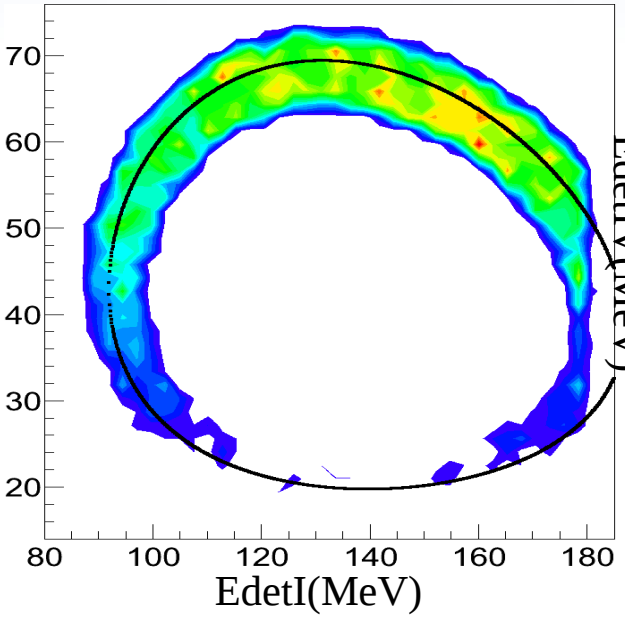
The deuteron energy of 400 MeV.

DSS Deuteron Spin Structure

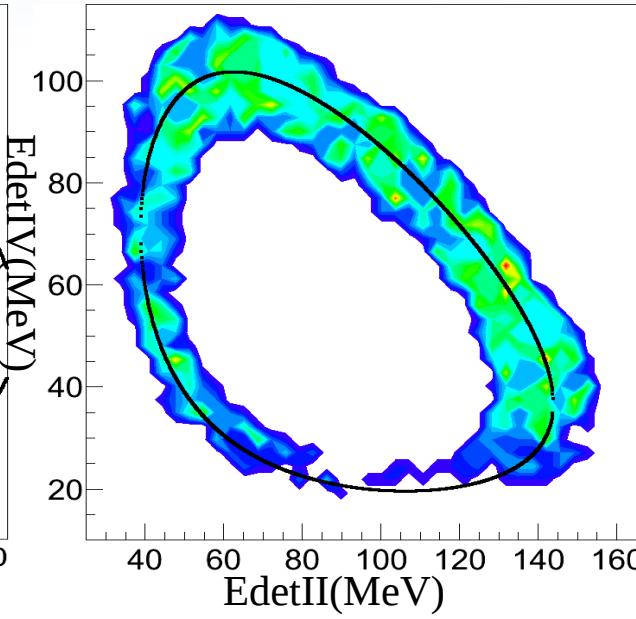
$\Theta_1 = 25^0$, $\Theta_3 = 33.7^0$, $\varphi_{13} = 44.6^0$



$\Theta_1 = 25.2^0$, $\Theta_8 = 53.6^0$, $\varphi_{18} = 135.5^0$

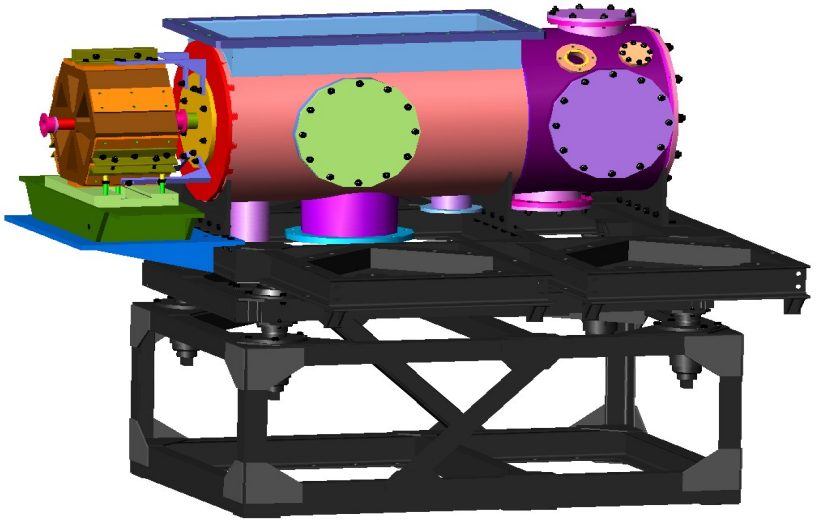


$\Theta_2 = 25^0$, $\Theta_4 = 33.7^0$, $\varphi_{24} = 46.5^0$



Correlations of the proton energies with the cut on missing mass (940MeV±10MeV) of deuteron energy 400 MeV.

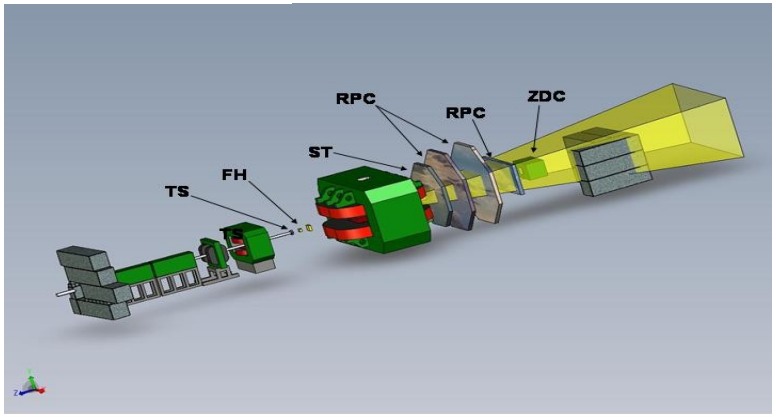
New Polarized Deuteron Source for LHEP

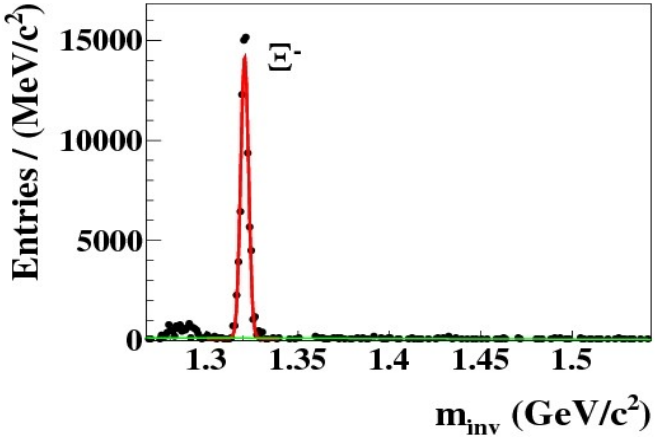


- New source will provide up to $2*10^{10}$ ppp and higher values of polarization than POLARIS.
- Part of the IUCF source is used for the construction. The putting into operation of new PIS is planned in 2015-2016.
- Large variety of the spin modes. For instance, DSS project will use the spin modes with the following ideal values of (p_z,p_{zz}): (0,0), (0,-2), (2/3,0) and (-1/3,+1)

Figure of merit will increase by a factor ~ 10^3

Physics at BM@N





Physics for the BM@N spectrometer with inner tracker:

-The measurements of the (sub)threshold cascade hyperons production in order to obtain the information on the nuclear matter EOS.

Physics for the first stage of the BM@N spectrometer:

-In-medium effects for strangeness and vector mesons decaying in hadron modes

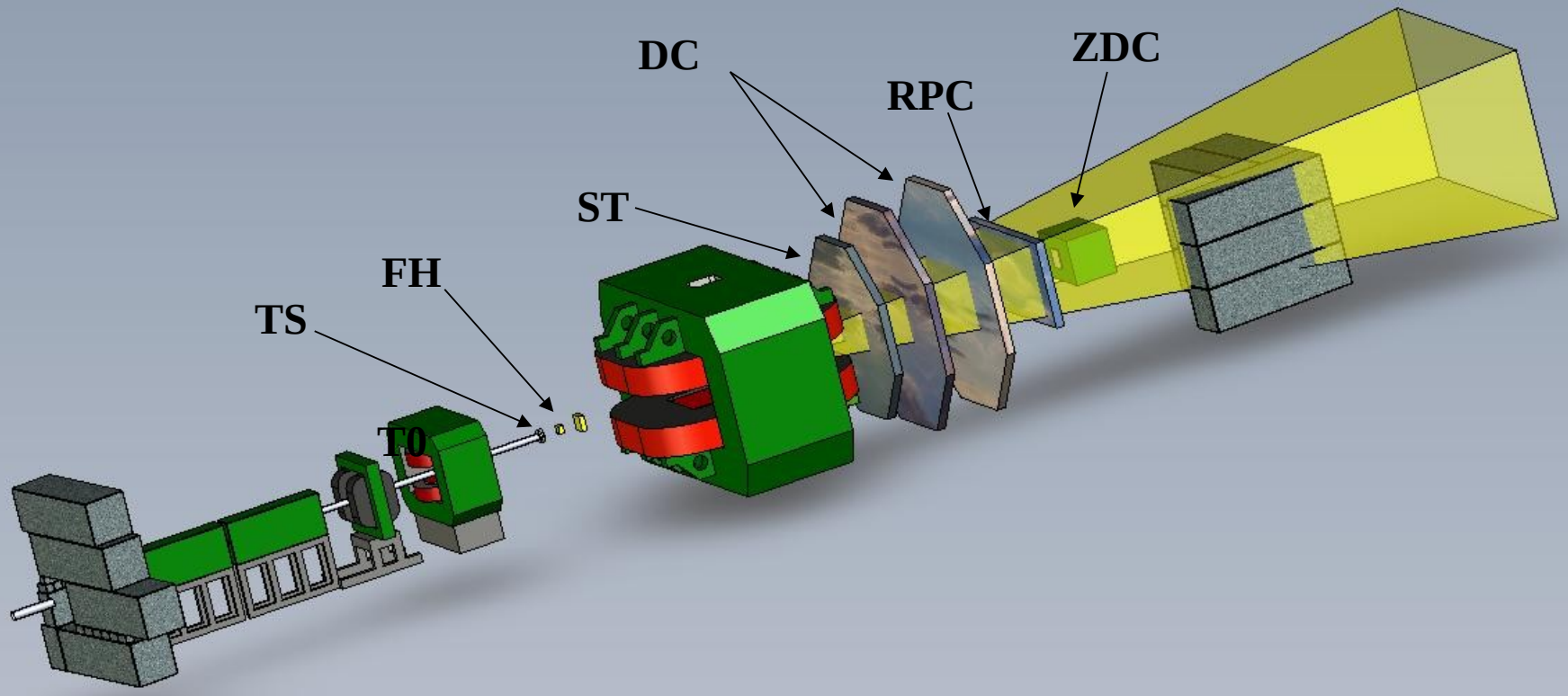
-Flows, polarizations, vorticity and azhimuthal correlations of hadrons

-Femtoscopy for different hadrons (and photons)

-NN, NA, dA and interactions as the reference for AA collisions

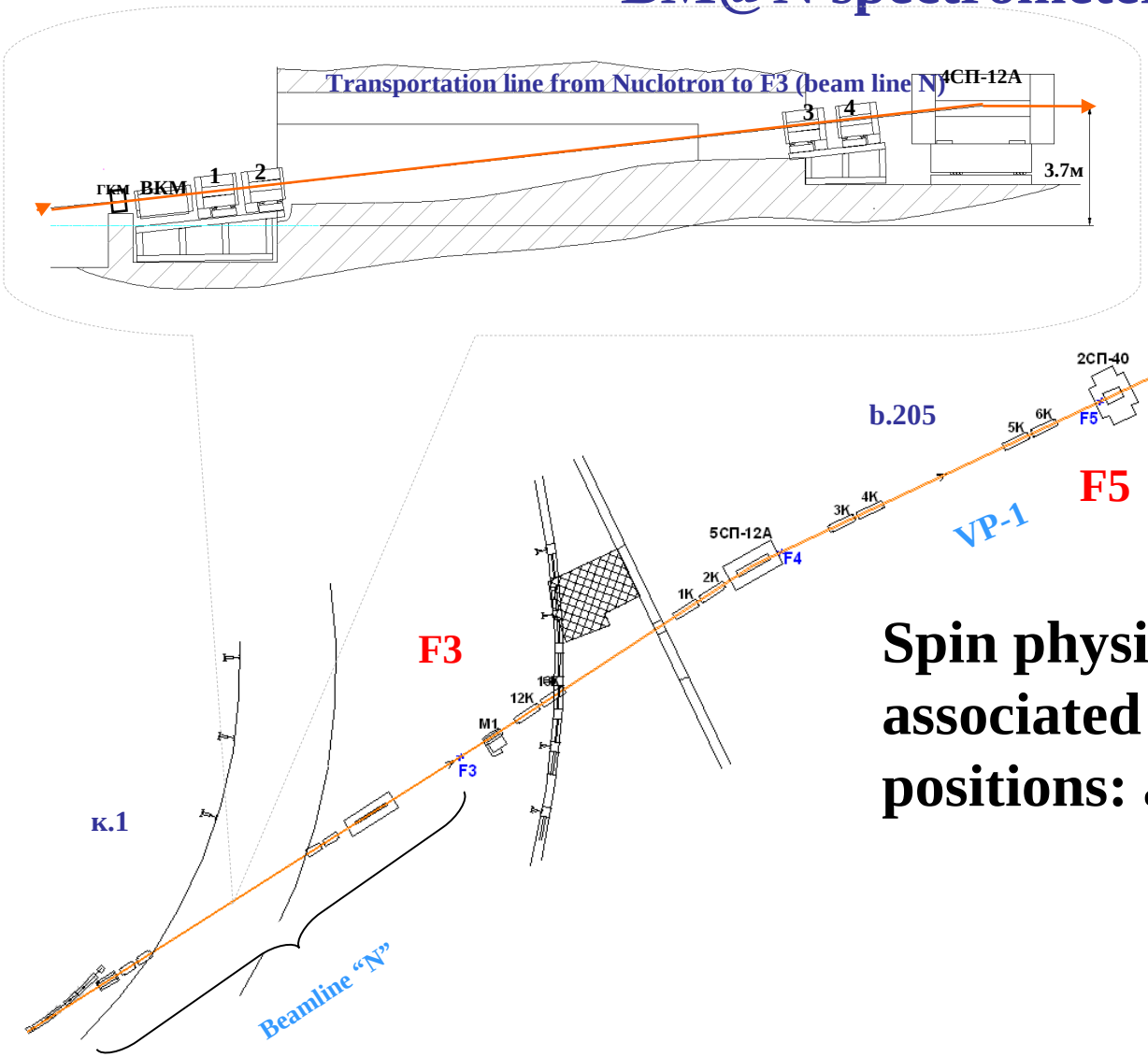
(including spin observables!) -can be done even without inner tracker

Stage 1 of BM@N setup for spin studies



Target Station is 2-3 m upstream of the analyzing magnet
RPC at the distance of 8-10 m from the target
Forward (FH) and Outer (DC) trackers are necessary

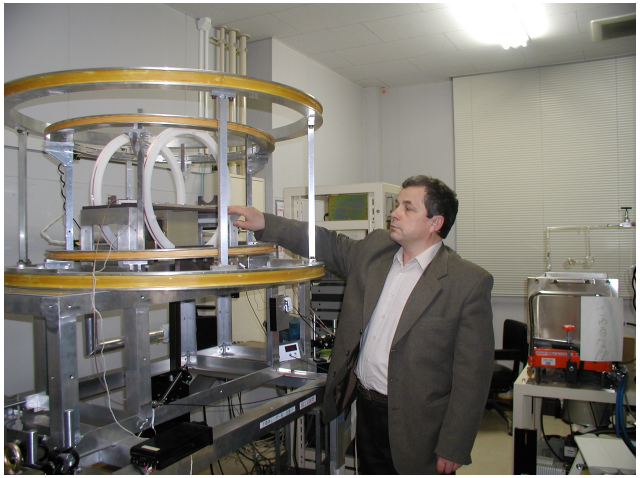
Transportation line of the Nuclotron extracted beam to the BM@N spectrometer



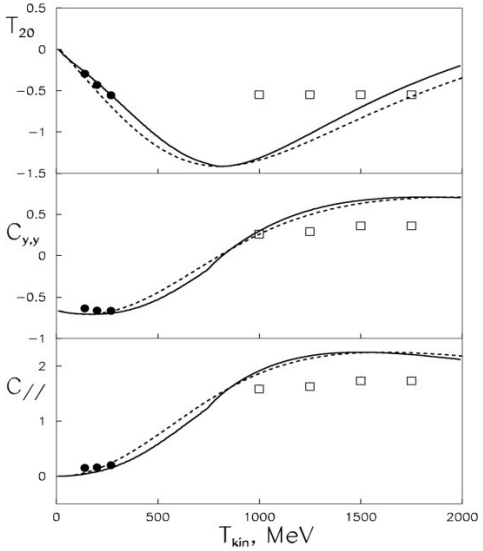
Spin physics with BM@N can be associated with different target positions: at F5, F6' and F6.

Polarization observables for polarized deuteron induced reactions

Target position is in F5



^{3}He(d,p)^{4}He



- **The measurements of the tensor analyzing power T_{20} and spin correlation $C_{y,y}$ in the ^{3}He(d,p)^{4}He reaction in the kinetic energy range between 1.0 and 1.75 GeV can be performed at the BM@N area.**
- **The polarization observables for the p(d,p)d, d(d,p)t and d(A,p(0^o))X at intermediate and high energies also can be studied.**
- **Non-nucleonic degrees of freedom and baryonic resonances properties can be studied in the d(A,d(0^o))X and d(A,π^-(0^o))X reactions at different energies.**
- **The tensor analyzing power T_{20} can be studied for the meson production in the d(A,3He(0^o))X reactions.**

Polarization observables for polarized deuteron induced reactions

Target position is in F6'

-The measurements of the tensor A_{yy} and vector A_y analyzing powers in inclusive deuteron breakup, d(A,p)X , at large transverse momenta and the highest Nuclotron energy can be performed in order to study relativistic effects.

- Non-nucleonic degrees of freedom can be studied vis the measurements of the tensor A_{yy} and vector A_y analyzing powers in $d(A,\pi^-)X$ reaction.

-The polarization properties of the baryonic resonances can be studied in the d(A,d)X reaction.

Experiments require additional TOF detector between F6' and F6 points.

Polarization observables for polarized deuteron induced reactions

Target position is in F6

-The measurements of the tensor A_{yy} and vector A_y analyzing powers in quasi-elastic and inelastic $d(A, pp(^1S_0))X$ reaction between 2 and 6 GeV of the deuteron kinetic energies. Detection of the pions in the final state are important.

-Investigation of the vector analyzing power A_y in neutron induced reactions (with the proton spectator detection) like $np \rightarrow pn$, $np \rightarrow pp\pi^-$, $np \rightarrow pn\pi^+\pi^-$, $np \rightarrow d\pi^+\pi^-$ etc. reactions at the energies 1-5 GeV.

Last experiment requires large size of RPC wall.

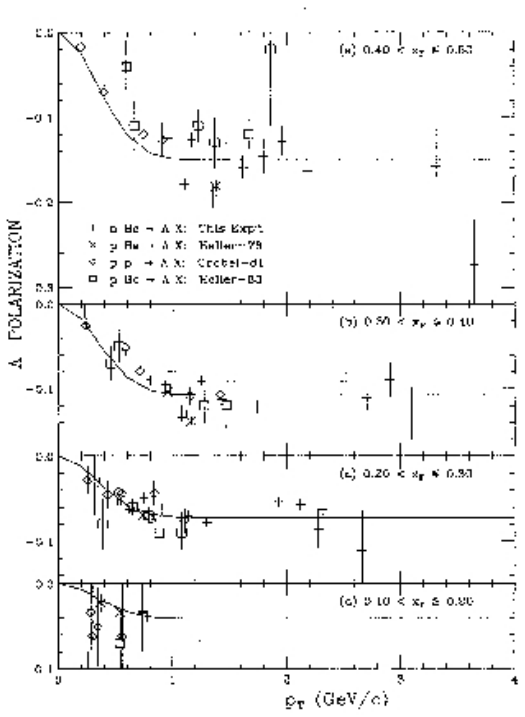
Polarization of strange baryons as a tool to study the phase transition

New probes to investigate the properties of hot matter produced in heavy-ion collisions at high energies can be the polarization of the strange (multistrange) baryons. One of the proposed signatures is the study the change in the polarization properties of Λ^0 hyperons as compared to that in proton-proton collisions proposed by

A.D. Panagiotou (1986); *A. Ayala et al. (2002)*

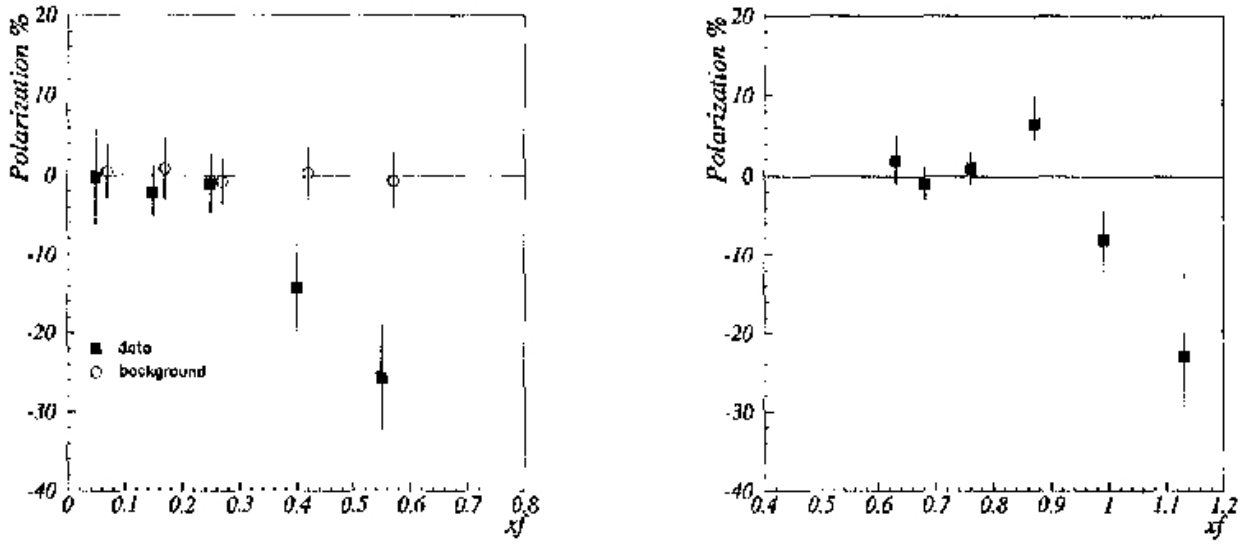
- A large polarization effect was observed in proton-induced reactions for the Λ^0 production which was satisfactorily explained by the semiclassical recombination model.
- In the case of relativistic nucleus-nucleus collisions, the expectation is that, Λ^0's coming from the zone where the critical density for QGP formation has been achieved, are produced through the coalescence of independent slow sea **u**, **d** and **s** quarks. Consequently, the plasma creates Λ^0 with zero polarization.
- Therefore, in the case of QGP formation the depolarization effect compare to proton-induced reaction should be observed.

Polarization of Λ^0 in nucleon-nucleus collisions.



- Λ^0's produced in **pp** and **pA** scattering are transverse polarized (along the $(\vec{\mathbf{p}}_\Lambda \times \vec{\mathbf{p}}_\mathbf{p})$ axis).
- The polarization is independent of the beam energy and nearly independent of $\mathbf{x_F}$.
- The polarization increases in magnitude linearly with the transverse momentum of the Λ^0.
- Ξ^0, Ξ^- and Σ^- baryons have the same polarization as Λ^0. Σ^0 and Σ^+ baryons have the same value, but opposite sign of polarization as Λ^0.
- $\bar{\Lambda}^0$'s are non-polarized.

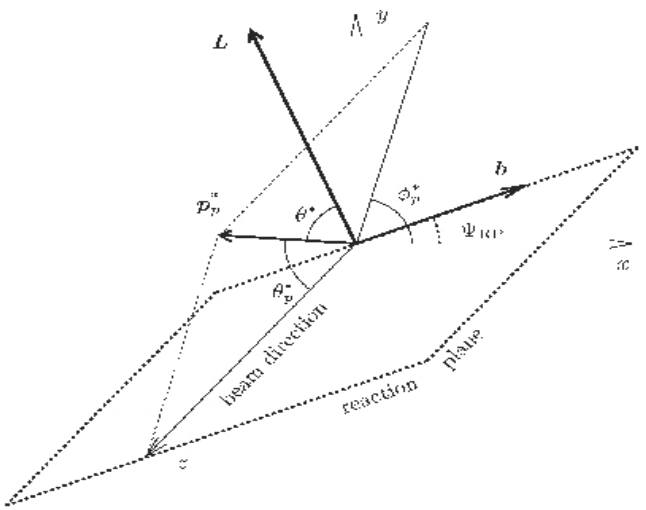
Λ^0 polarization in Au-Au collisions at 11.5 GeV/A.



The produced Λ^0's are still polarized at freeze-out which means the spin direction is only little affected by the rescattering phase after hadronization.

However, there was no scan versus centrality in this experiment.

Global polarization in noncentral collisions.

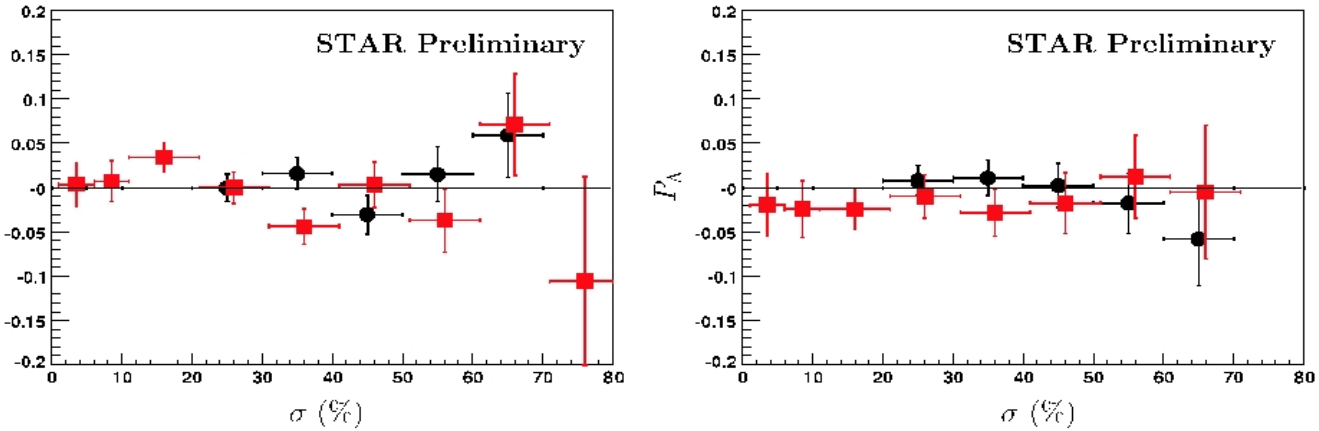


- System in the noncentral collisions have large orbital angular momentum, which manifests in the polarization of secondary particles along the direction of the system angular momentum.
- Parton interaction in noncentral relativistic nucleus-nucleus collisions leads to the global polarization of the produced quarks. This value for RHIC energies can be about 30% and would lead to the global polarization of hyperons.
- Global polarization of hyperons:

$$\mathcal{P}_{\mathbf{H}} = \frac{\mathbf{8}}{\pi\alpha} < \mathbf{sin}(\psi^*_{\mathbf{p}} - \mathbf{\Psi_{RP}}) >$$

Requires ZDC and Forward Wall for the RP determination

Global Λ^0 and $\bar{\Lambda}^0$ polarization in Au-Au non-central collisions at RHIC.



- *Z.-T.Liang et al. (2005,2007)*

  In the recombination mechanism $\mathcal{P}_\Lambda = \mathcal{P}_s \approx \mathbf{0.3}$ and the same for hyperons and anti-hyperons. In the model based hard termal loop (HTL) gluon propagator hyperon polarization is $\mathbf{0.03} \leq \mathcal{P}_\Lambda \leq \mathbf{0.15}$ depending on the temperature of QGP formed.

- The global polarization for Λ^0 and $\bar{\Lambda}^0$ obtained at STAR is consistent with zero (except large p_T).

Vorticity and Λ hyperons polarization (O.Teryaev)

Polarization – searched

at RHIC and not found

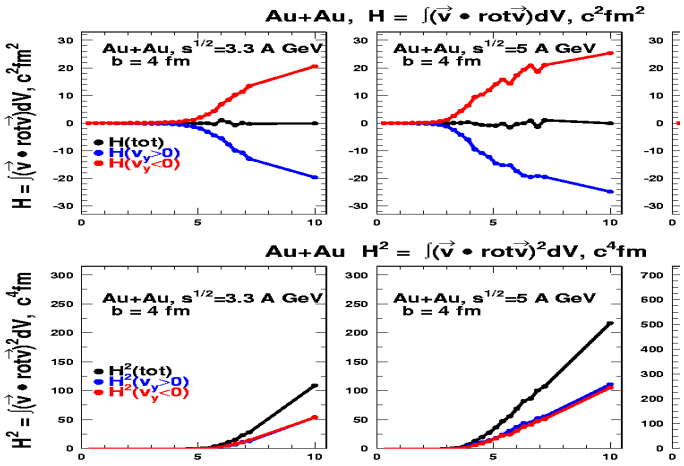
May appear due to large

(strange) chemical potential

at MPD&BMN at NICA

Simulation of vorticity and

(hydrodynamic) helicity



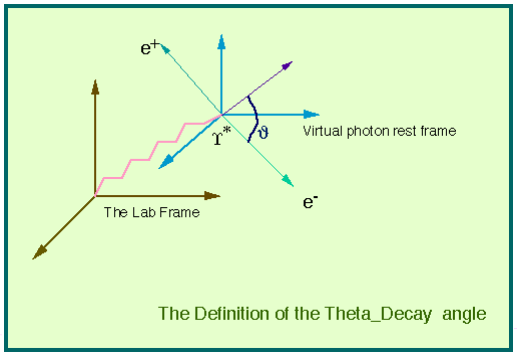
and estimates of polarization - effect of % order

Dilepton angular distributions (E.Bratkovskaya)

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta d\varphi} = \left(1 + B\cos^2\theta + \mu \sin 2\theta \cos\varphi + \frac{\nu}{2}\sin^2\theta\cos 2\varphi\right)$$

B, μ, ν : **anisotropy coefficients - related to helicity structure functions and the spin density matrix elements of the virtual photon**

$d\sigma/d(\cos\theta) \sim 1 + B\cos^2\theta$, B=[-1,+1]



In the helicity frame, i.e. θ in rest frame of γ* w.r.t. p(γ*) in source frame:

Different elementary alignment mechanisms:

- **pseudoscalar mesons (e.g. π^0 and η): photon transversality B = +1**
- **vector mesons (ρ, ω and ϕ): no preferred spin orientation of VM B = 0**
- **$\pi\pi$ annihilation: p wave (L=1 ⊥ to $\pi\pi$ scattering plane) B = -1**
- **baryonic resonances N* decays: B ≠ 0**
- **NN and πN bremsstrahlung: B ≠ 0**

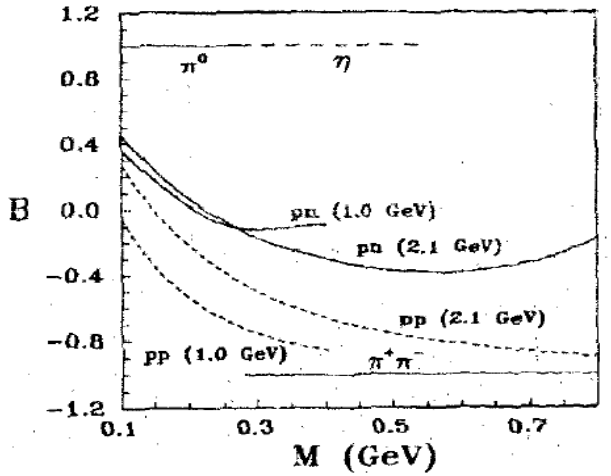


Fig. 1. *M* dependence of the decay anisotropy coefficient for different elementary dilepton sources: the Dalitz decay of η and π^0 mesons, $\pi^+\pi^-$ -annihilation, *pn* and *pp* bremsstrahlung (at two energies).

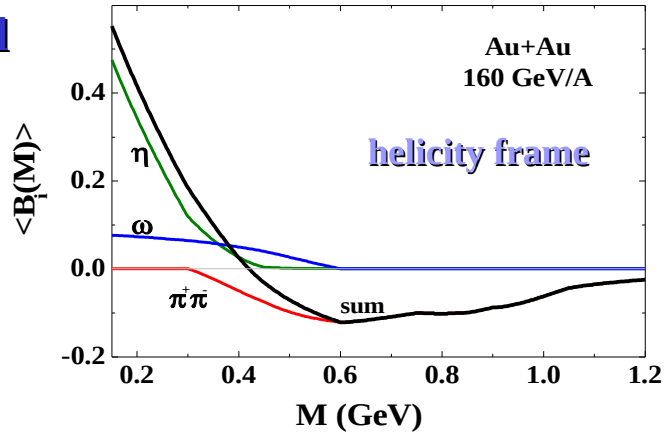
Bratkovskaya, Toneev, Teryaev et al., Phys. Lett. B 348 (1995) 283 , 325; B 362 (1995) 17, B376 (1996) 12

Results on anisotropy coefficients

Anisotropy coefficients for heavy-ion collisions – avaraging over all possible directions of virtual photons → $< B_{\pi\pi} >_{AA} \sim -0.1$ – smearing of signal compared to elementary reactions ($B_{\pi\pi} = -1$)

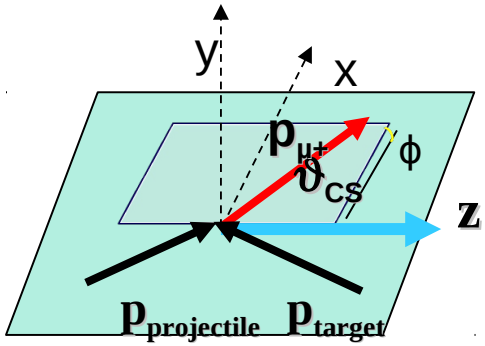
Note: B in helicity frame!

BUU model: Bratkovskaya, Cassing, Mosel , Z.Phys.C75 (1997) 119



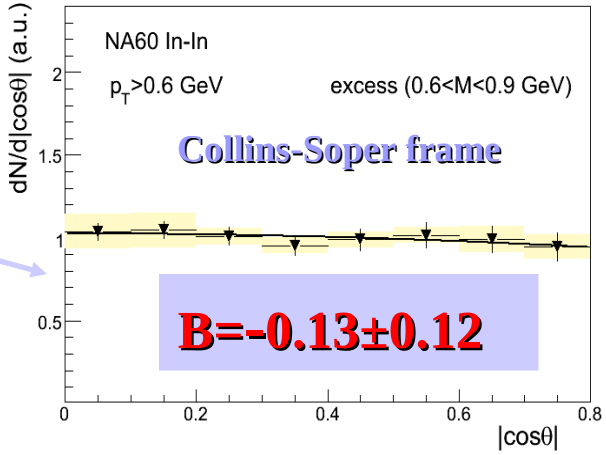
NA60 measured anisotropy coefficients!

Choice of reference frame: **Collins-Soper**



In rest frame of virtual photon: θ - angle between the positive muon $p_{\mu+}$ and z-axis; z axis is a bisector between p_{proj} & - p_{target}

NA60: Phys. Rev. Lett. 102 (2009) 222301



NA60: Zero polarization within errors !

→ completely random orientation of annihilating particles (pions or quarks) in 3 dimensions

→ thermal origin of dimuons

***Warning:** + some small residual polarization of hadronic origin?!

Conclusion

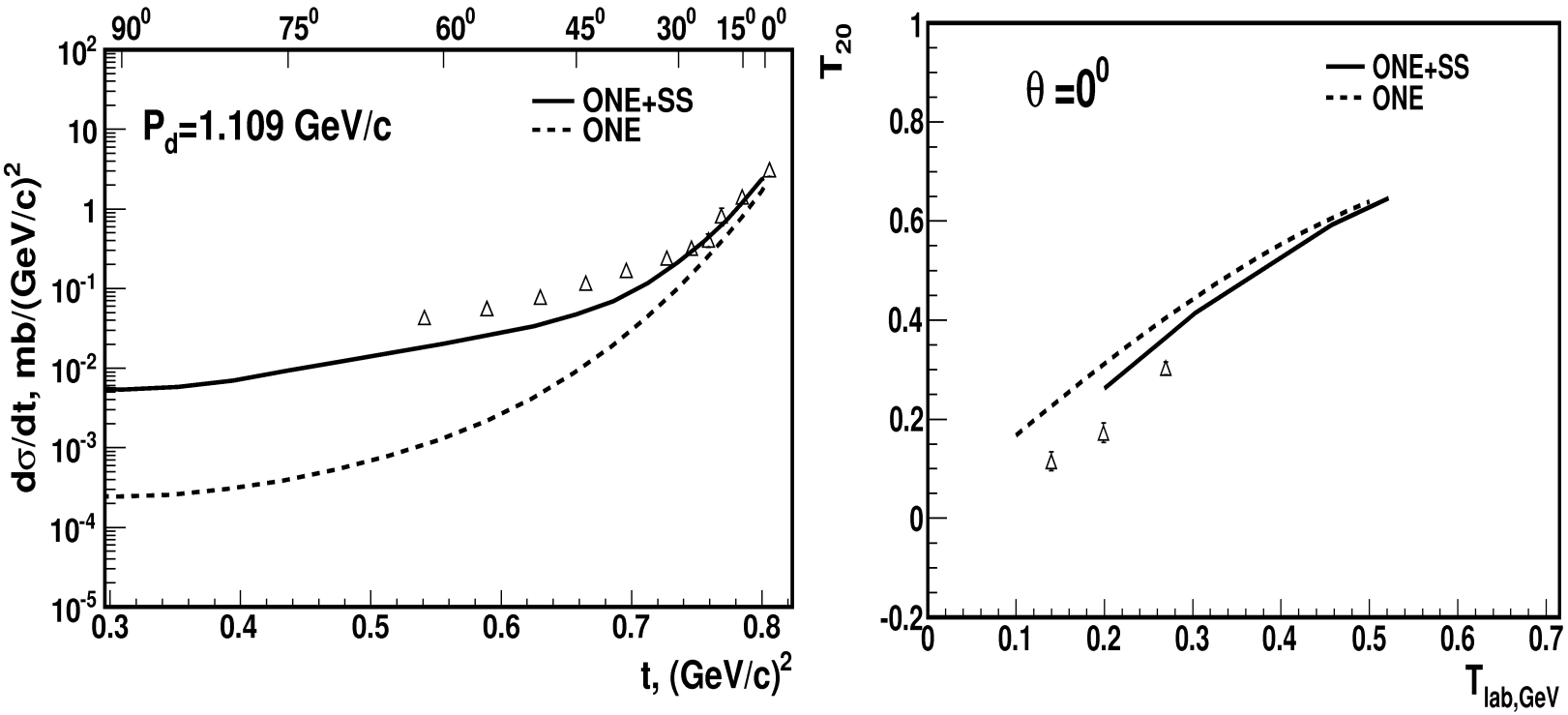
The new data on the analyzing powers A_y, A_{yy} and A_{xx} in dp- elastic scattering at various energies up to 2000 MeV and well as for the dp-nonmesonic breakup at the energies between 300 and 500 MeV for different kinematic configurations can be measured at ITS at the Nuclotron.

Measuremets of the polarization effects in the heavy ion collisions can significantly enrich the physics at BM@N.

First stage of the BM@N setup (without or with reduced version of the inner tracker) is well suited for the physics with polarized deuterons using new PIS. However, such program requires the advanced deuteron polarimetry.

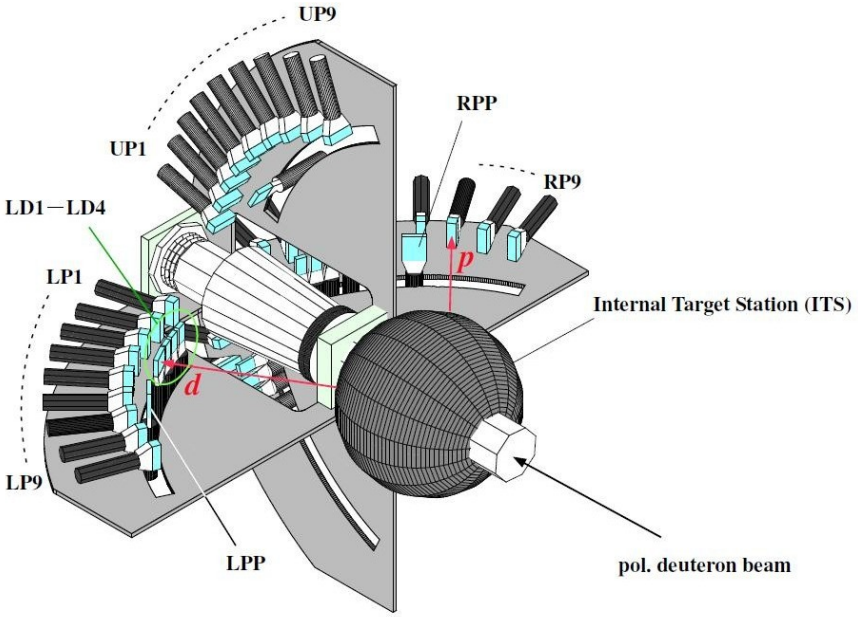
Thank you for the attention!!!

dd → ^{3}Hen(^{3}Hp) reactions at Nuclotron energies



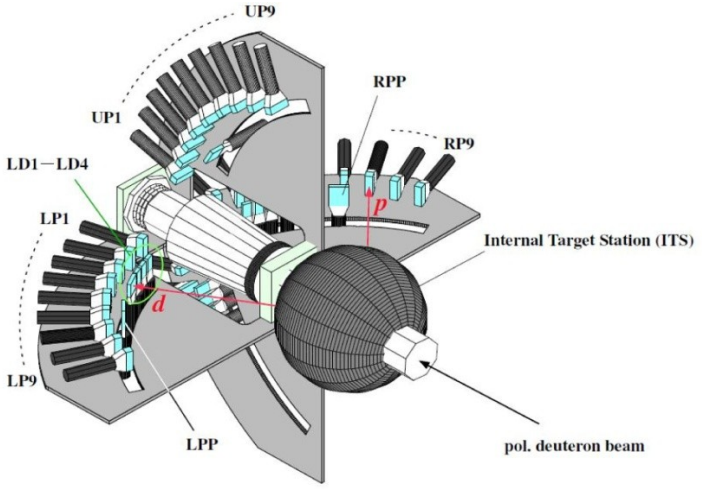
The relativistic multiple scattering model can be successfully used to describe the dd → ^{3}Hen(^{3}Hp) reactions in a GeV region at the Nuclotron.
The calculations require a large amount of CPUs.
The results will be published in Few Body Systems (talk N.B.Ladygina).

CNS-JINR setup to study dp- elastic scattering

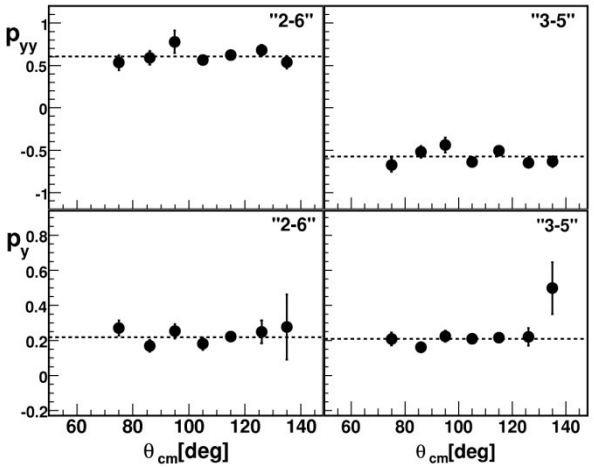


- Deuterons and protons in coincidences using scintillation counters
- Internal beam and thin CH_2 target (C for background estimation)
- Polarization measurement at 270 MeV
- Analyzing powers measurement at 880 and 2000 MeV
- The data were taken for three spin modes of PIS: unpolarized, “2-6” and “3-5” $(p_z,p_{zz}) = (0,0)$, $(1/3,1)$ and $(1/3,-1)$

Measurement of the deuteron beam polarization at ITS using CNS detection system at 270 MeV



A schematic view of the polarimeter setup installed downstream the ITS spherical chamber.



Tensor p_{yy} and vector p_y polarization of the beam for “2-6” and “3-5” spin modes of PIS POLARIS as a function of the deuteron scattering angle in the c.m.s.

- Main deuteron beam polarimeter at Nuclotron-M.
- dp- elastic scattering at large scattering angles in the center of mass system.
- The detectors cover the angular range 60-140° in the c.m.s.

(P.K. Kurilkin et al., Nucl. Instr. and Meth. A 642 (2011) 45)

Deuteron beam polarimetry at the ITS at Nuclotron-M

Measurement of the beam polarization is an important element in different physical experiments.

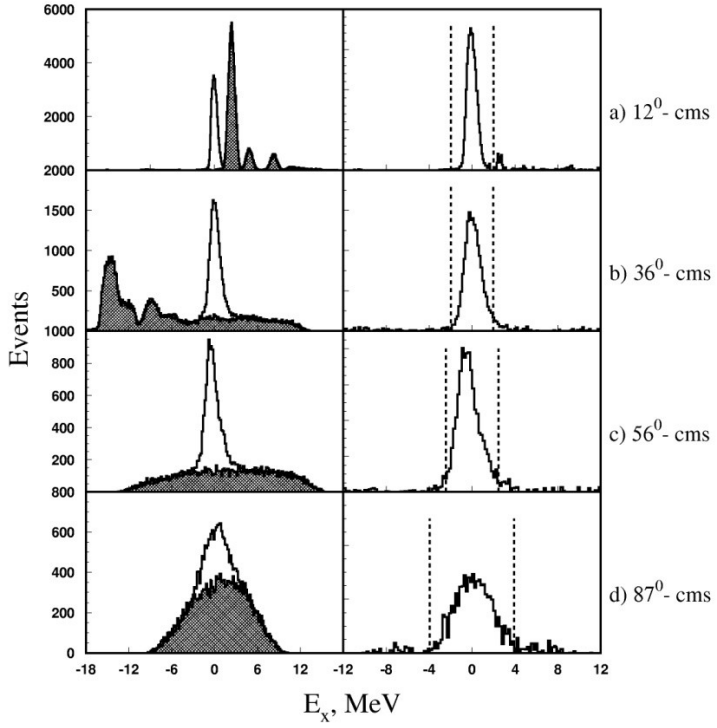
dp elastic scattering at large angles(Θ_{cm}>60º) – the deuteron beam polarimetry at RIKEN (E_d~100MeV).

The advantages of the use of the dp- elastic scattering at large angles(Θ_{cm}>60º) at the 270 – 2000 MeV energy range:

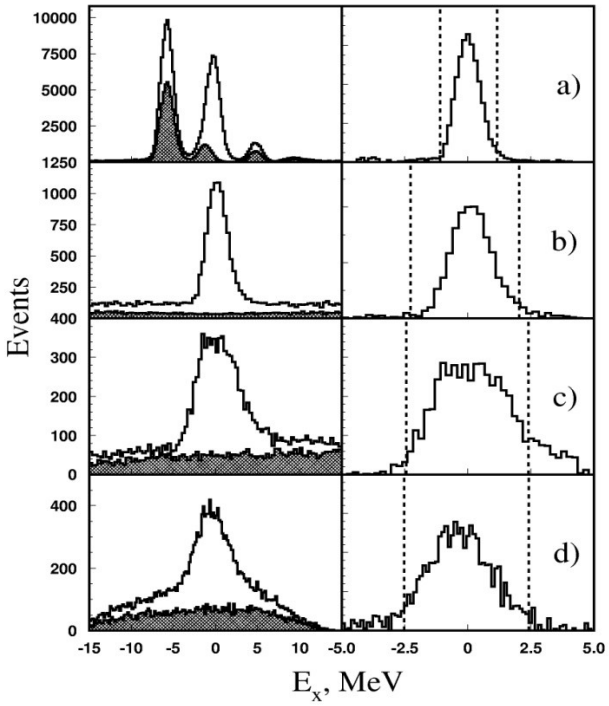
- Analyzing powers of this reaction have large values.
- The kinematical coincidence measurement of the deuteron and proton with plastic scintillation counters sufficient for event identification.

Talk of Pavel Kurilkin at this Conference

Subtraction of carbon contribution



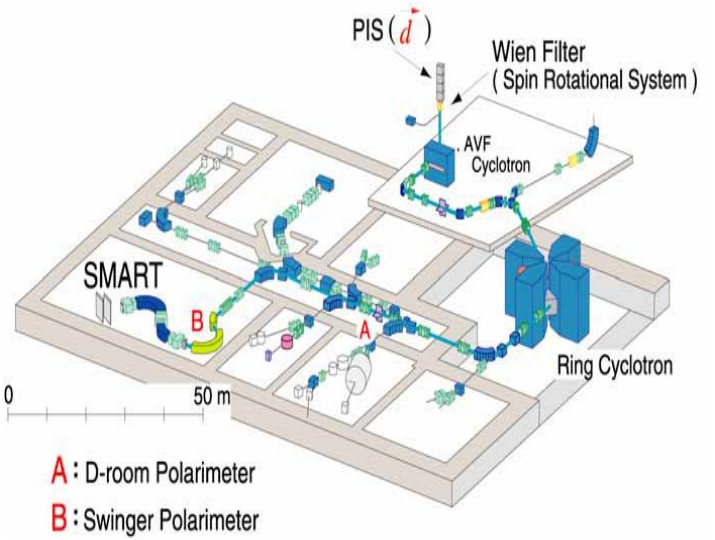
The quality of the carbon contribution subtraction for dd->^{3}Hp at 200 MeV at several scattering angles in c.m.s.



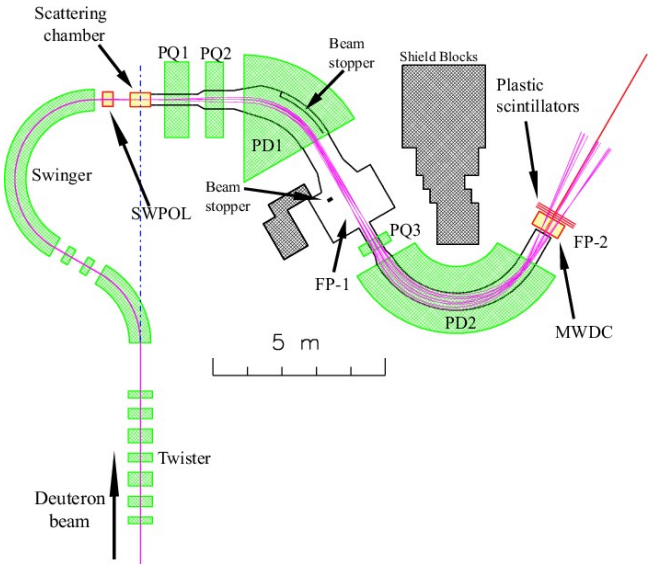
The quality of the carbon contribution subtraction for dd->^{3}Hen at 270 MeV at several scattering angles in c.m.s.

R308 experiment at RIKEN

- Investigation of the ^{3}H, ^{3}He and deuteron spin structure at short distances at the energies 140, 200, 270 MeV.
- Polarization observables comparison from mirror channels: ^{3}Hp and ^{3}Hen.

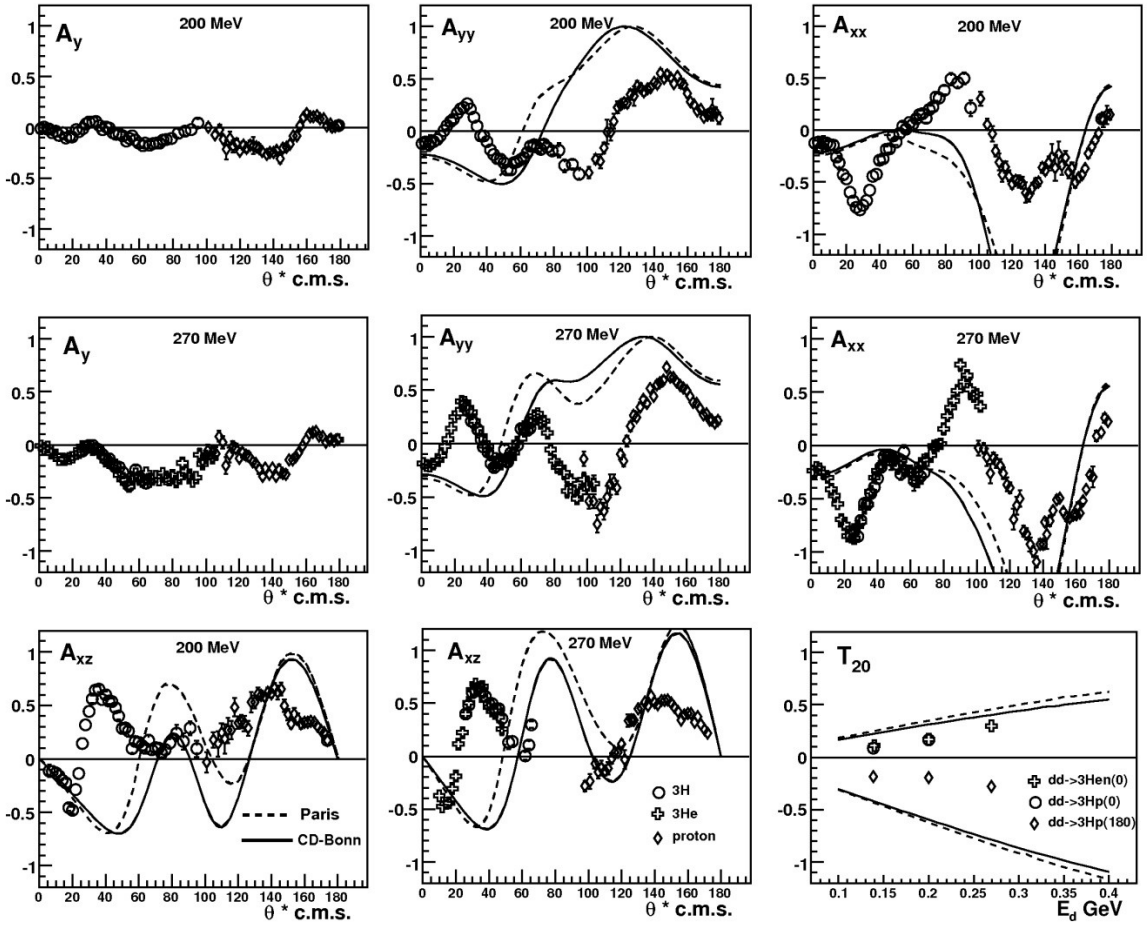


RIKEN Accelerator Research Facility.



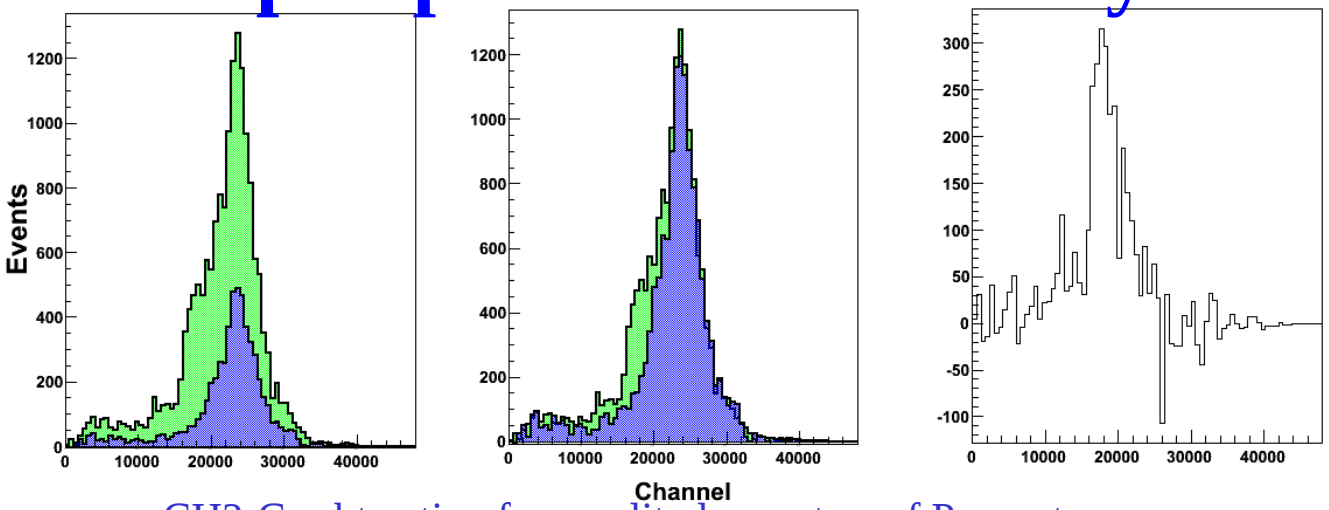
SMART spectrometer.

Polarization observables from the dd → ^{3}Hen(^{3}Hp) reactions (Japan-JINR)



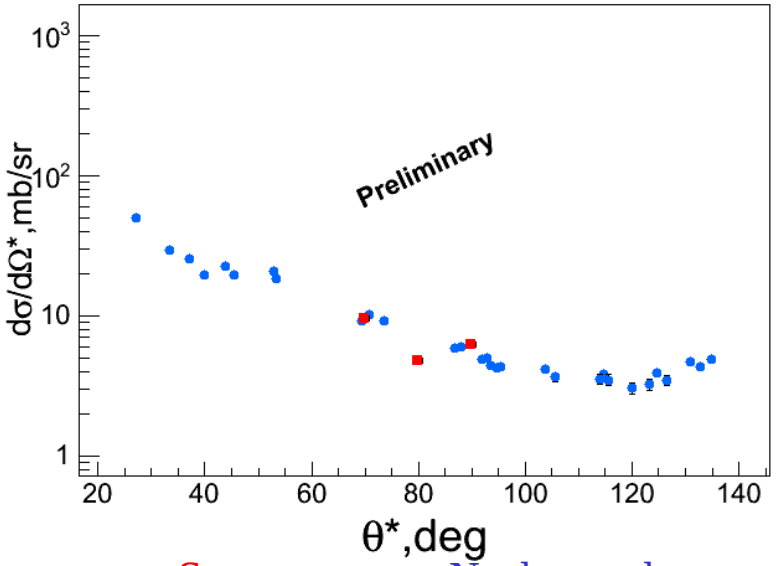
The solid curve is the result of the ONE calculations using CD-Bonn ^{3}He and deuteron wave functions. The dotted curve is the result of the ONE calculations using ^{3}He and deuteron wave functions derived from Paris potential. The ^{3}He wave function were taken from the work (V.Baru Eur.Phys.J.A16:437-446,2003).

HE dp-experiment data analysis



CH2-C subtraction for amplitude specters of P-counter.

Differential cross section at 2000 MeV



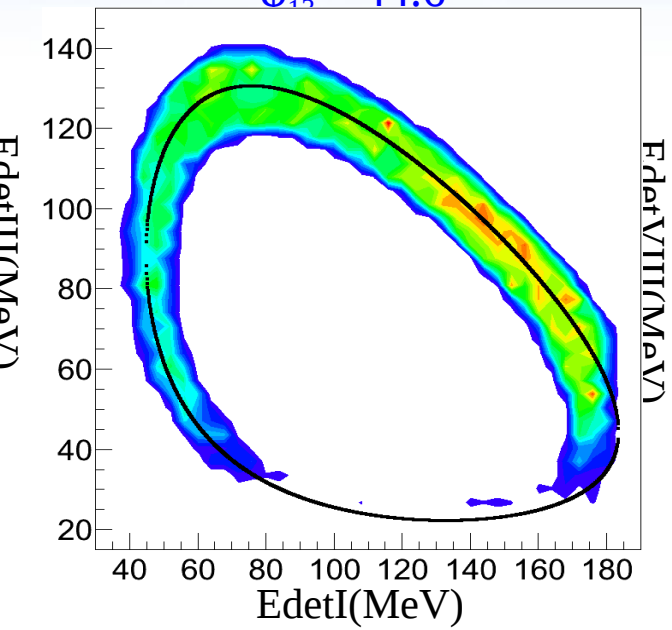
Squares – new Nuclotron data

Circles – Bennett G. W. et al. Phys. Rev. Lett. 1976. V.19 P. 387-390.

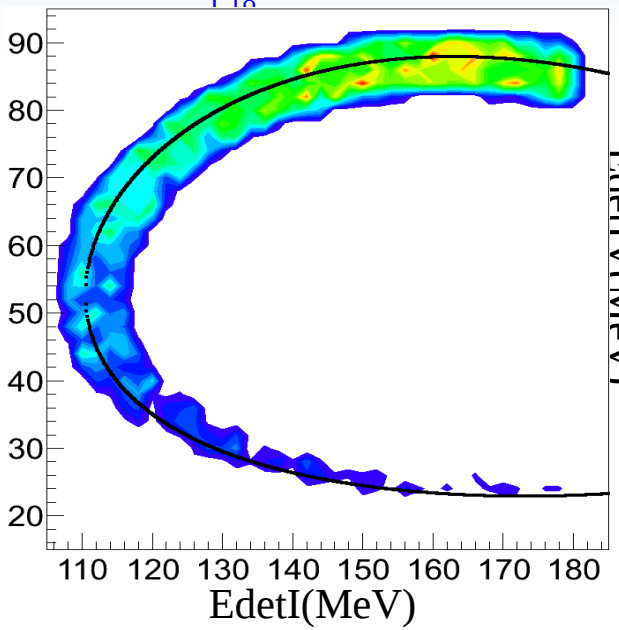
The deuteron energy of 500 MeV.

DSS Deuteron Spin Structure

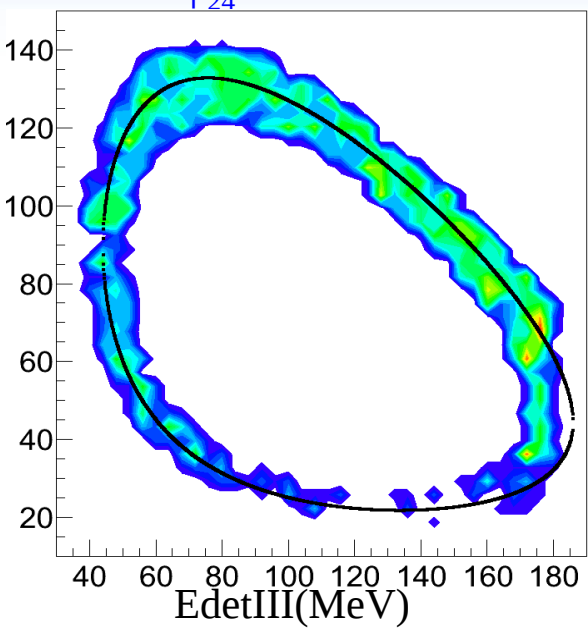
$\Theta_1 = 24.7^0$, $\Theta_3 = 33.3^0$, $\varphi_{13} = 44.6^0$



$\Theta_1 = 24.7^0$, $\Theta_8 = 53.3^0$, $\varphi_{18} = 135.4^0$



$\Theta_2 = 24.7^0$, $\Theta_4 = 33.3^0$, $\varphi_{24} = 46.5^0$

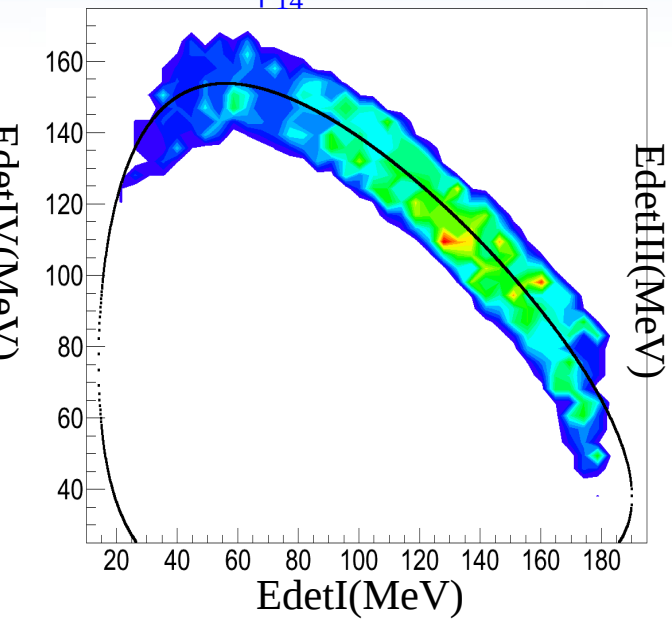


Correlations of the proton energies with the cut on missing mass (940MeV±10MeV) of deutron energy 500 MeV.

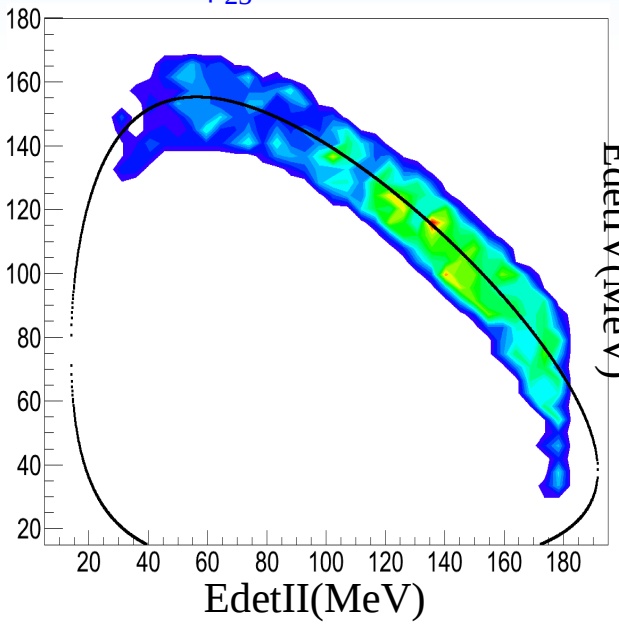
The deuteron energy of 300 MeV.

DSS Deuteron Spin Structure

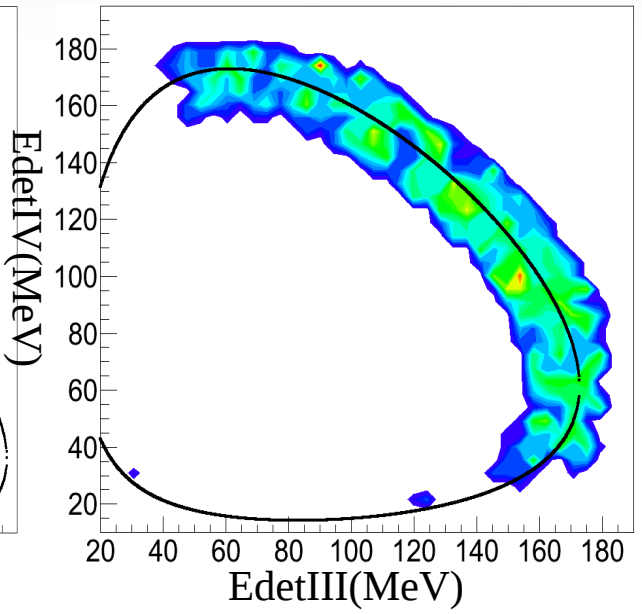
$\Theta_1 = 25.2^0$, $\Theta_4 = 33.9^0$, $\varphi_{14} = 135.3^0$



$\Theta_2 = 25.2^0$, $\Theta_3 = 33.9^0$, $\varphi_{23} = 133.5^0$



$\Theta_3 = 33.9^0$, $\Theta_4 = 33.9^0$, $\varphi_{34} = 180^0$



Correlations of the proton energies with the cut on missing mass (940MeV±10MeV) of deutron energy 300 MeV.