Polarization studies at Nuclotron & BM@N

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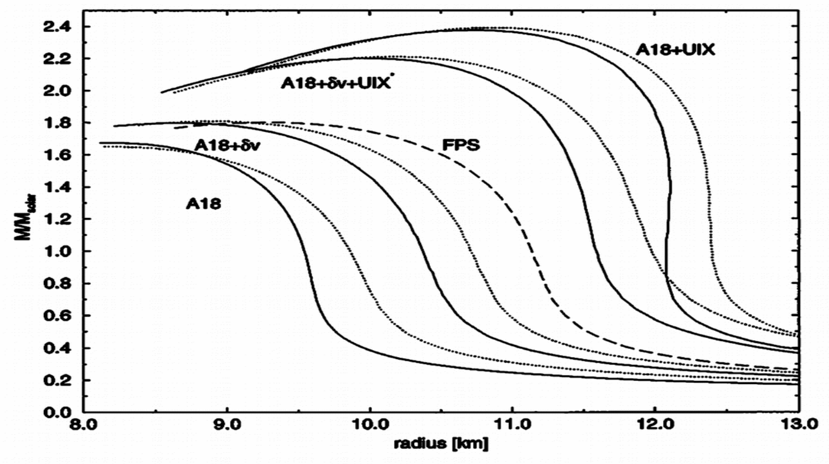
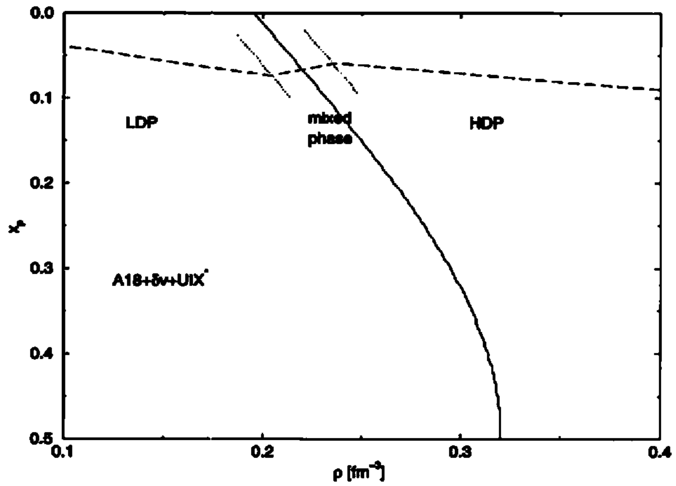
Talk at the 8-th BM@N Collaboration meeting,

2-9 October 2021, Alushta, Russian Federation

Few nucleons systems
as a tool for dense matter studies

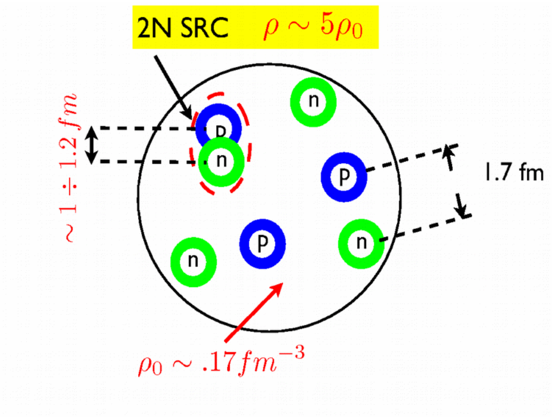
Possible way to obtain the information on the EOS at extreme densities (neutron stars) is the studies of the few nucleon systems.

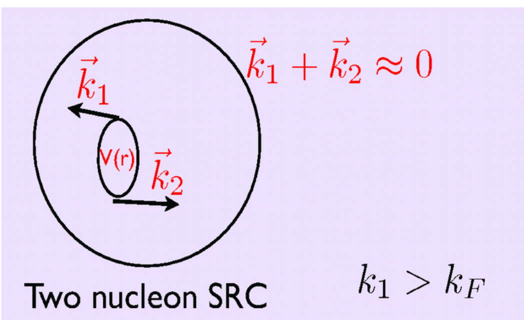




Relativistic effects in 2NF and contribution of 3NF play very important role.(A.Akhmal et al, Phys.Rev. C58 (1998) 1804)

Short range correlations (SRCs)



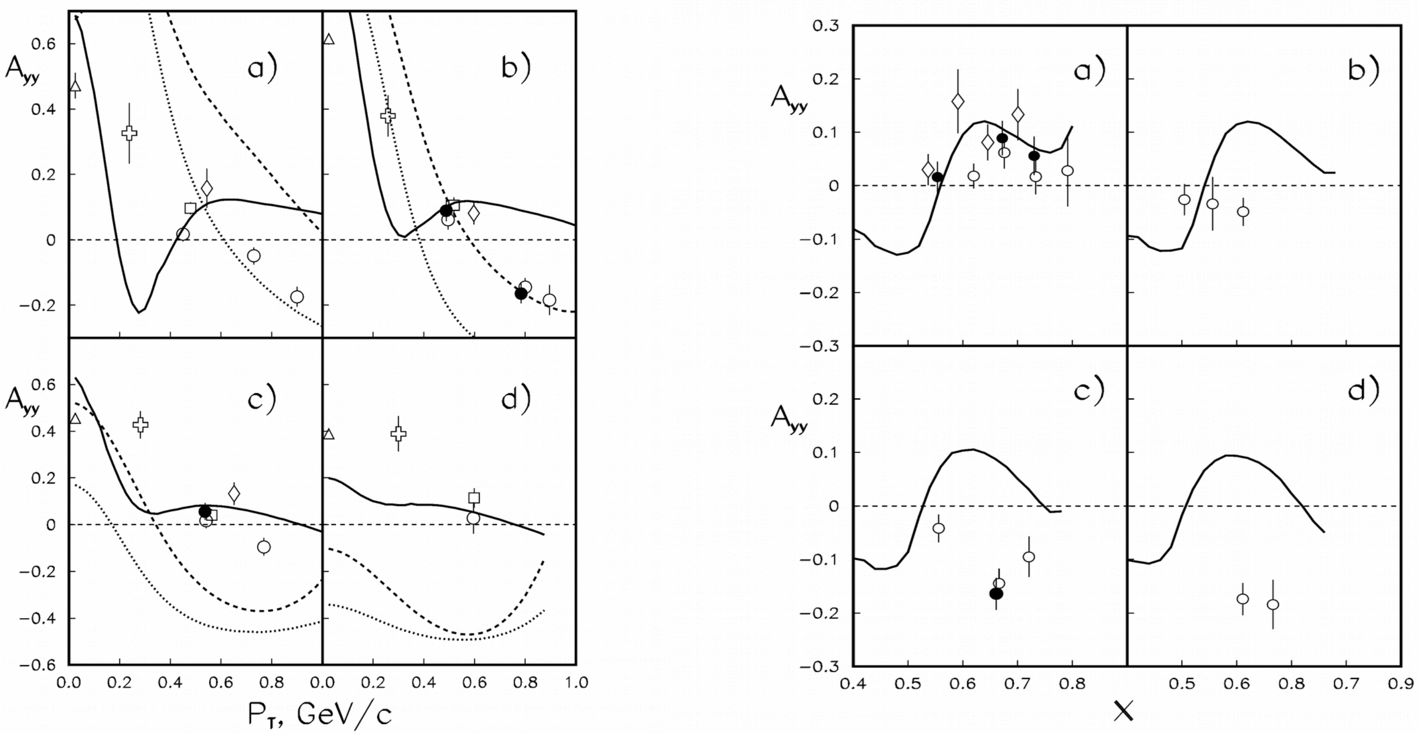


Summary of the theoretical analysis of the experimental findings
practically all of which were predicted well before the data were obtained

- 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 spin structure at short distances.

Relativistic effects in 2N SRCs (deuteron)

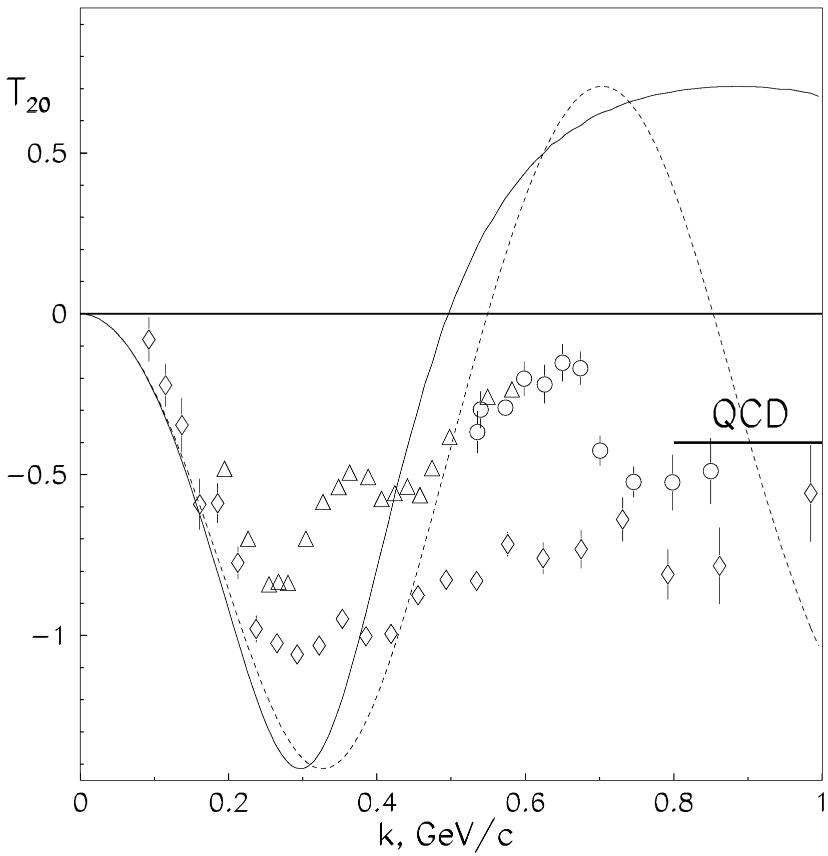


A_{yy} in deuteron inclusive breakup demonstrates the dependence on 2 internal variables: p_T and x_F.

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 .

Non-nucleonic degrees of freedom



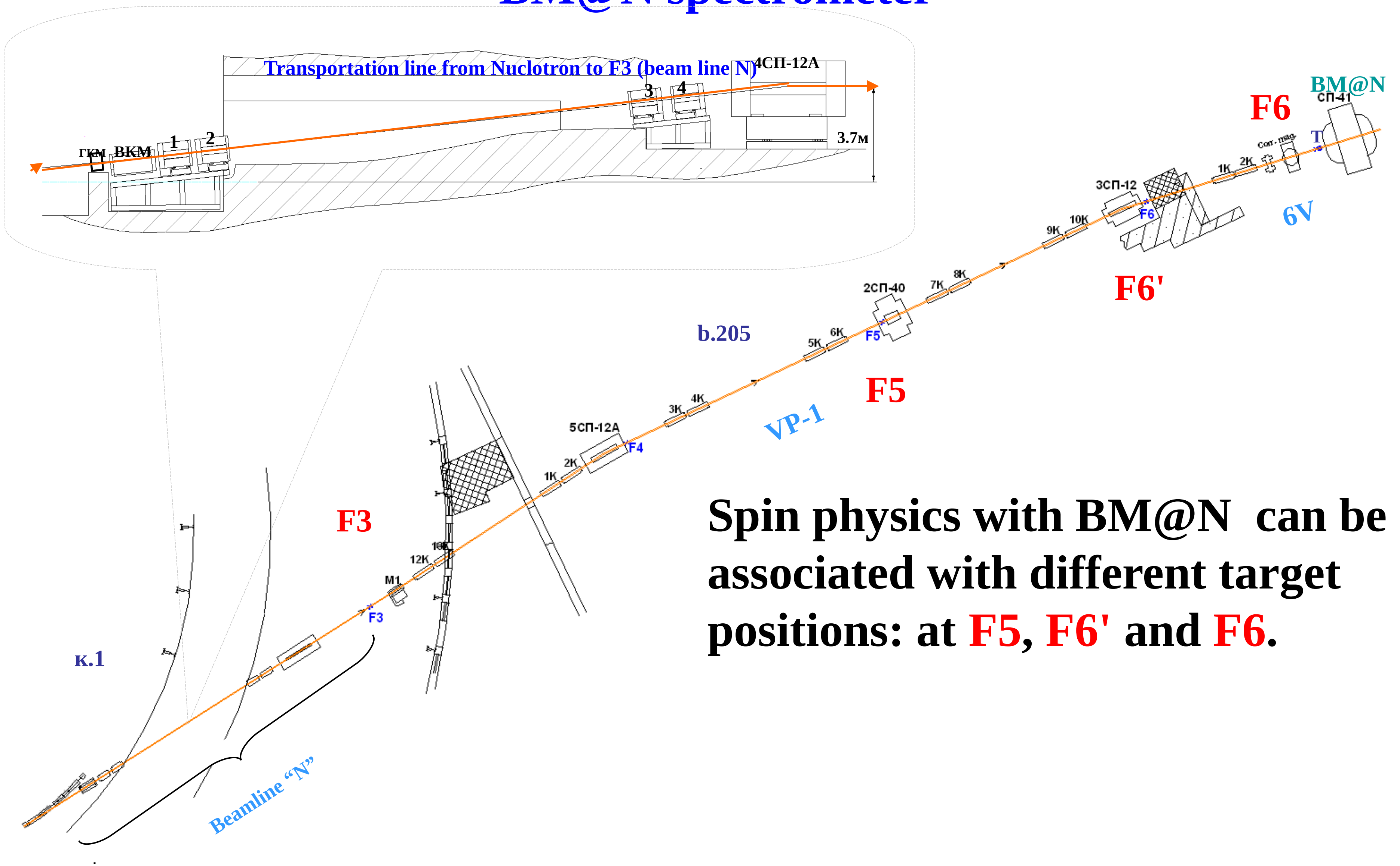
When the distances between the nucleons are comparable with the size of the nucleon, the nucleon-nucleon interaction is a non-local.

The fundamental degrees of freedom, quark and gluons in the frame of QCD, begin also to play a role at the internucleonic distances comparable with the size of the nucleon.

They can manifest as ΔΔ, NN*, N*N*, 6q etc.components.

Data:
V.Punjabi et al., Phys.Lett.B350 (1995) 178
L.S.Azhgirey et al., Phys.Lett.B391 (1997) 22
L.S.Azhgirey et al., Phys.Lett.B387 (1996) 37

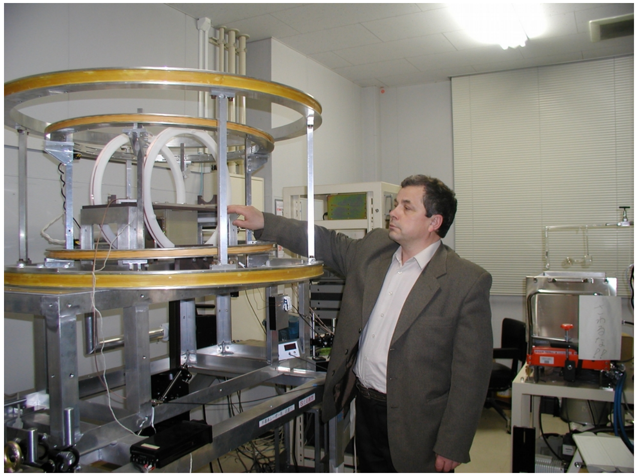
Transportation line of the Nuclotron extracted beam to the BM@N spectrometer



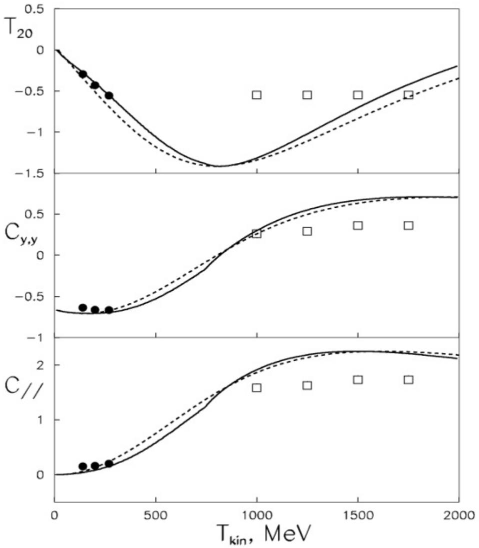
Spin physics with BM@N can be associated with different target positions: at F5, F6' and F6.

Polarization observables for polarized deuteron induced reactions

Target position is in F5

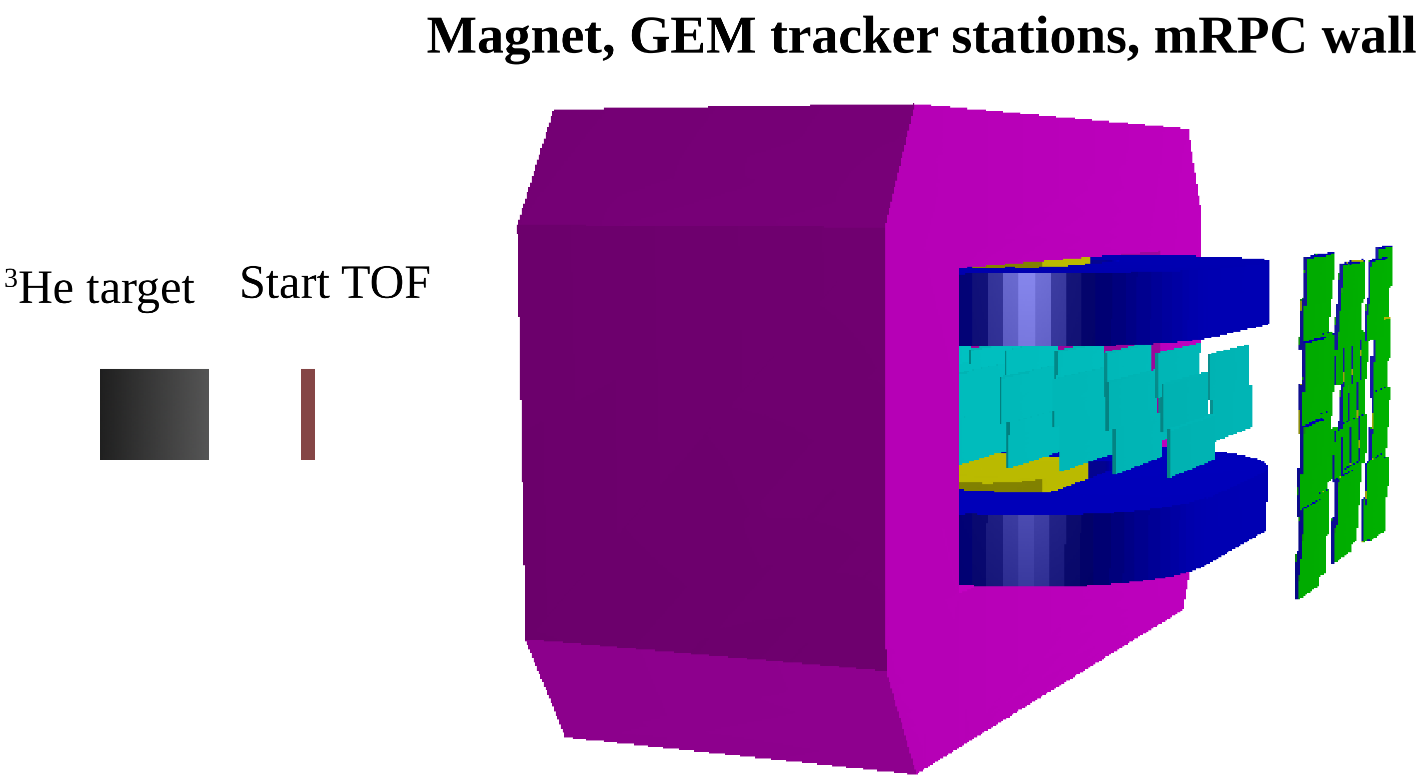


$^{3}He(d,p)^{4}He$



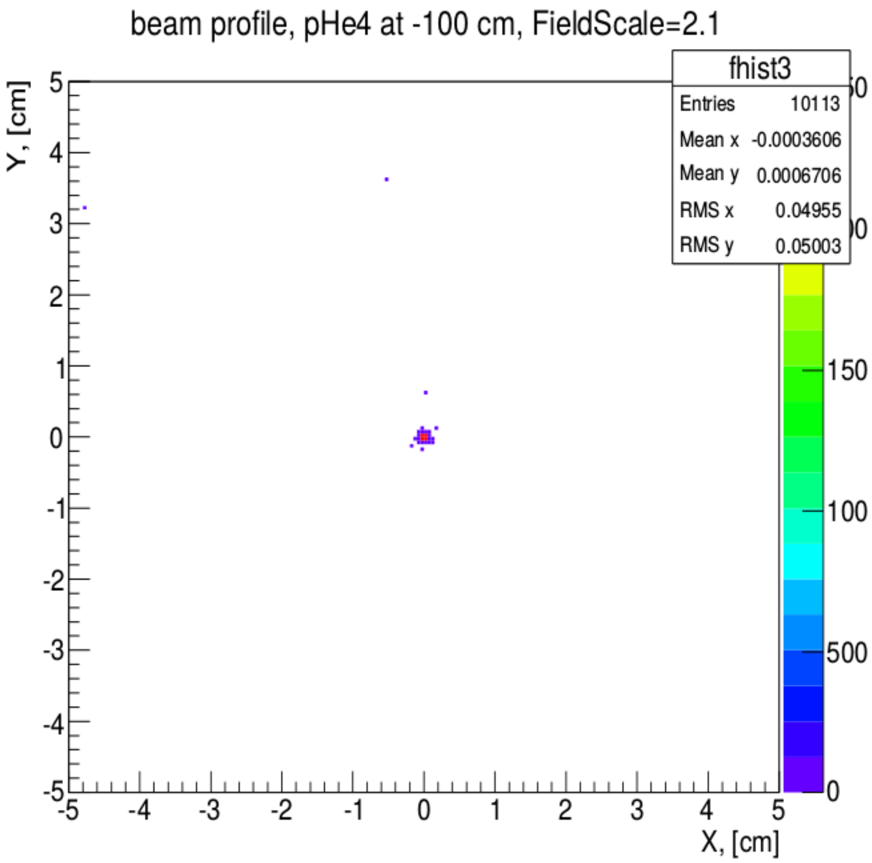
- **The measurements of the tensor analyzing power T_{20} and spin correlation $C_{y,y}$ in the $^{3}He(d,p)^{4}He$ reaction in the kinetic energy range between 1.0 and 1.75 GeV can be performed at the BM@N area.**
- **The polarization observables for the p(d,p)d, d(d,p)t and d(A,p(0°))X at intermediate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

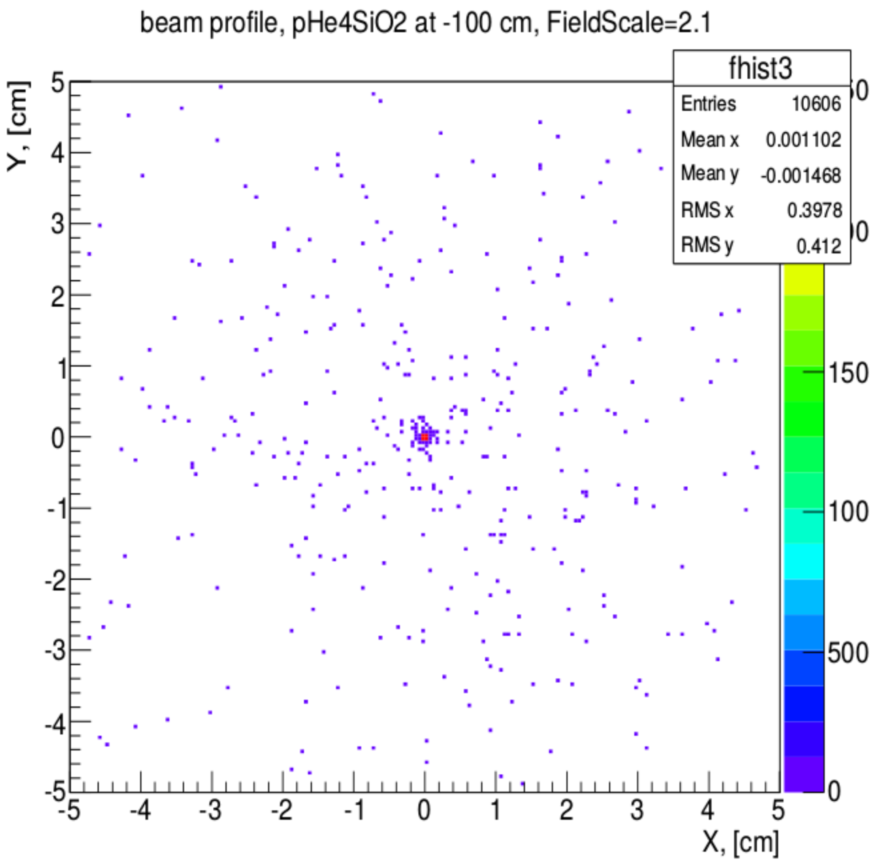
Simulation for the ^{3}He(d,p)^{4}He reaction at 1.5 GeV



The BM@N setup configuration for “inclusive” ^{3}He spin experiment (no BM@N target).

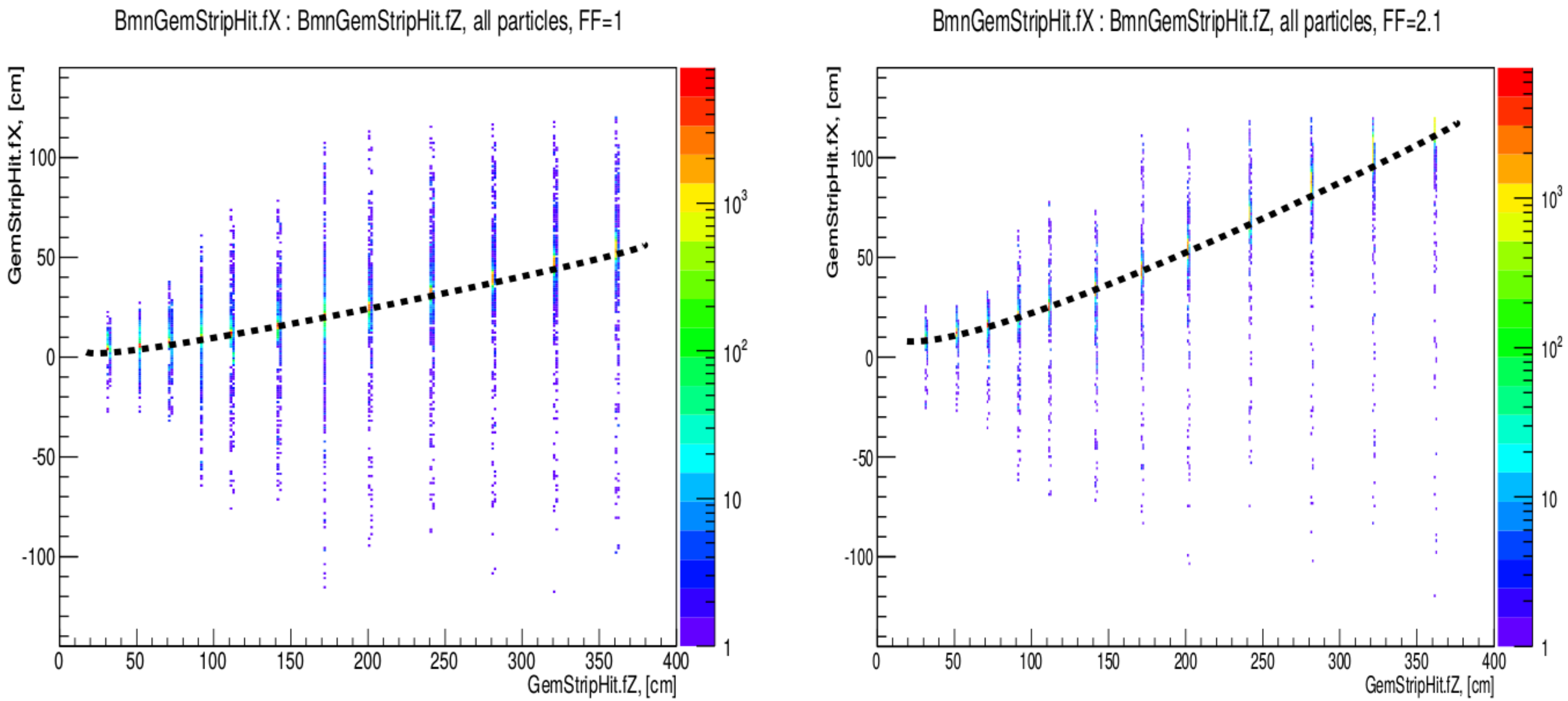
Simulation for the $^{3}He(d,p)^{4}He$ reaction at 1.5 GeV





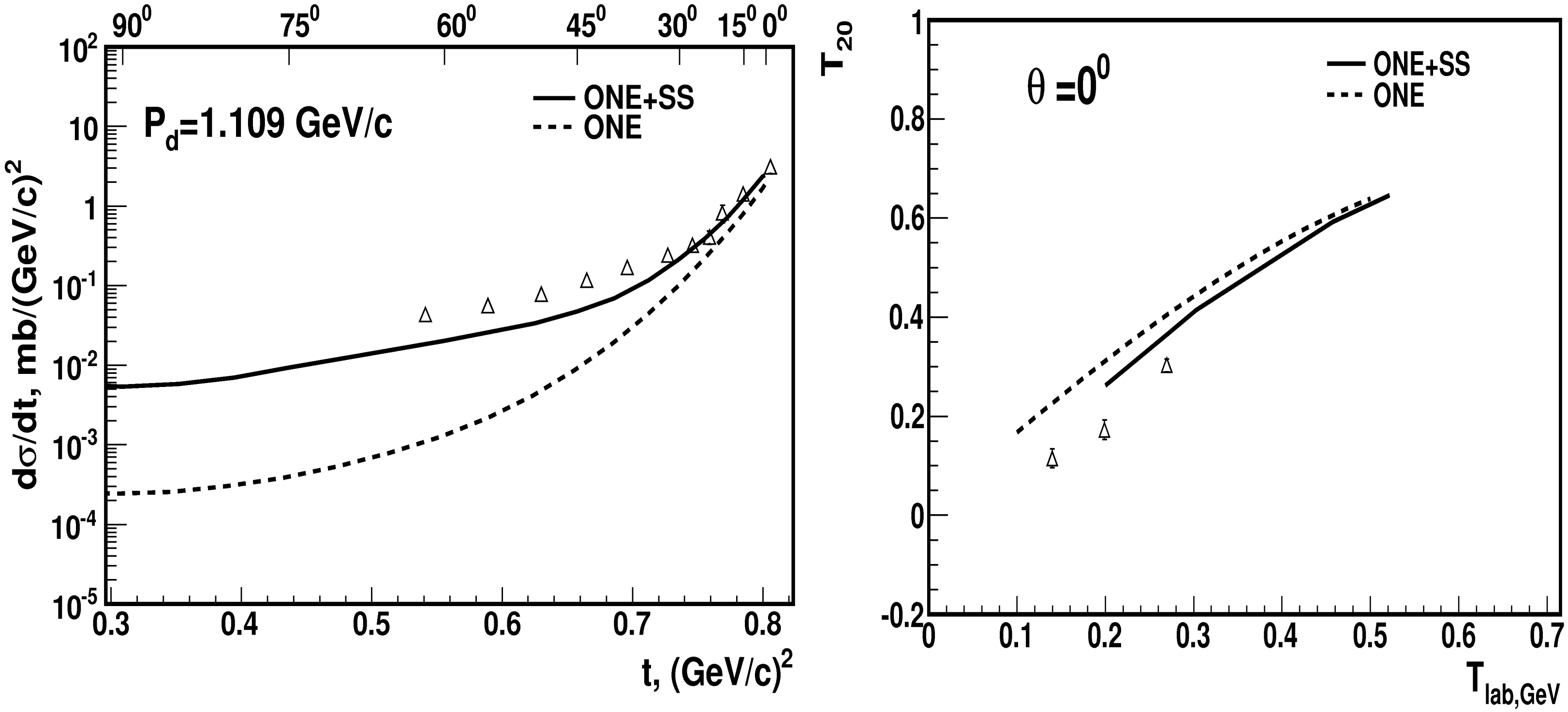
The XY profiles of the secondary proton beam (in front of the BM@N tracker) for the ^{3}He target only (left panel) and ^{3}He target + 2 mm of quartz radiator of TOF start counter (right panel).

Simulation for the $^{3}He(d,p)^{4}He$ reaction at 1.5 GeV



The XZ profile of the secondary beam hits in the GEM tracker stations for the magnetic field By of 0.4 T (left panel) and 0.9 T (right panel).

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.
Detection of proton or ^{3}He with BM@N spectrometer.

Similar scheme is applicable for the d(A,p(0°))X , d(A,d(0°))X and d(A,π$^-$(0°))X reactions for proton, deuterium and nuclear targets.

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.

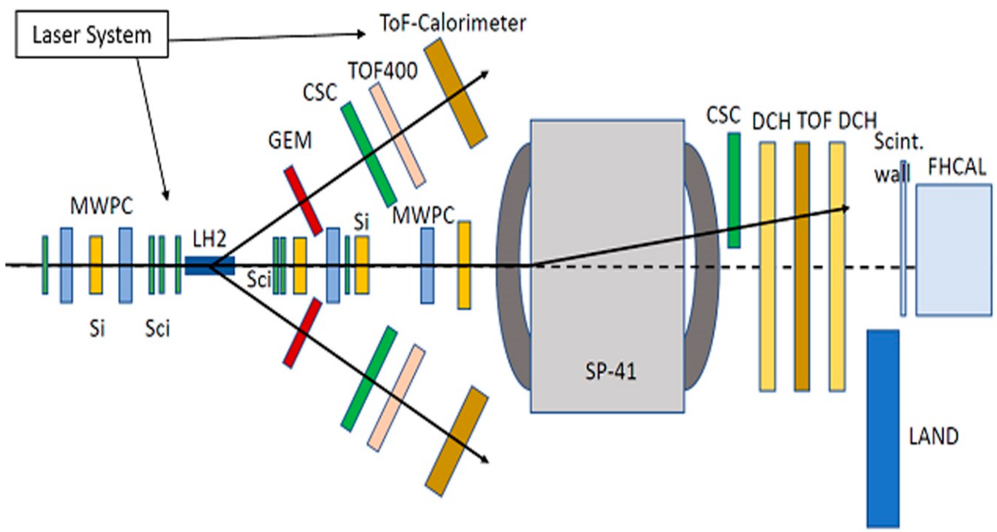
-The polarization properties of the baryonic resonances can be studied in the d(A,d)X reaction.

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

To be hardly realized at BM@N due to modification of the VP1 beam transportation line.

Polarization observables for polarized deuteron induced reactions

Target position is near F6
Additional non-magnetic arm(s)



- The vector analyzing powers A_y in quasi-elastic $np \to pn$ (with the proton spectator detection) and $pp \to pp$ reactions.

(Partial Wave Analysis).

- The tensor A_{yy} and vector A_y analyzing powers in elastic $dp \to pd$ reaction.

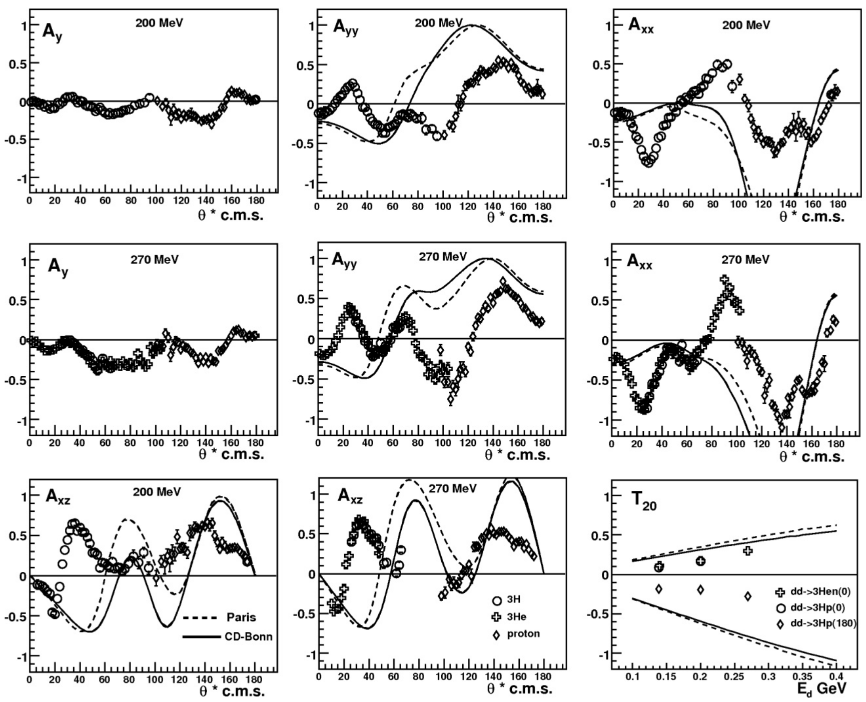
(Glauber approach).

- The tensor A_{yy} and vector A_y analyzing powers in the $dp \to ppn$ reaction.

(SRC spin structure).

Polarization observables for polarized deuteron induced reactions

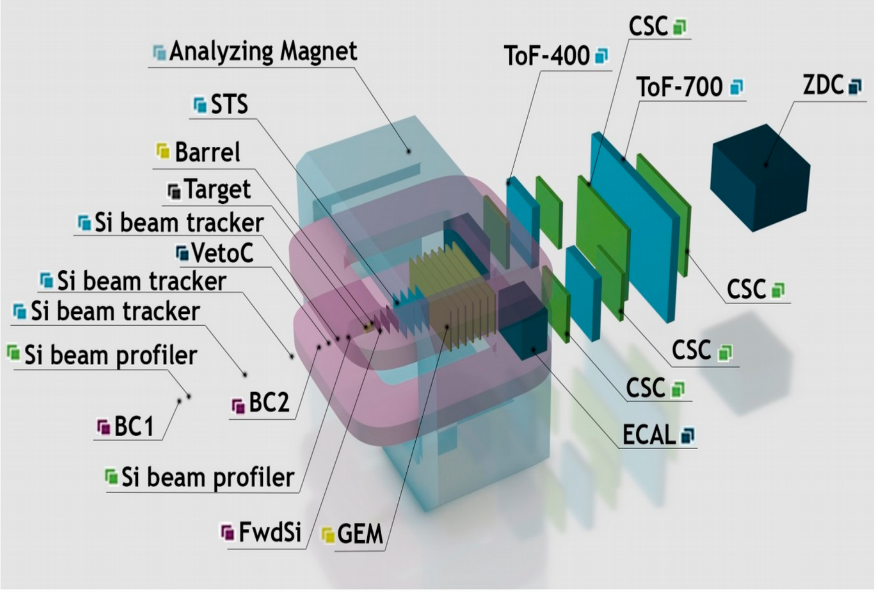
Target position is near F6



-The tensor A_{yy} and vector A_y analyzing powers in dd→ ^{3}Hp (^{3}Hen) reaction at forward angles to study unexplained structure in tensor observables sensitive to the 3-body spin structure.

Polarization observables for polarized deuteron induced reactions

Target position is in F6 (near SP41 pole)



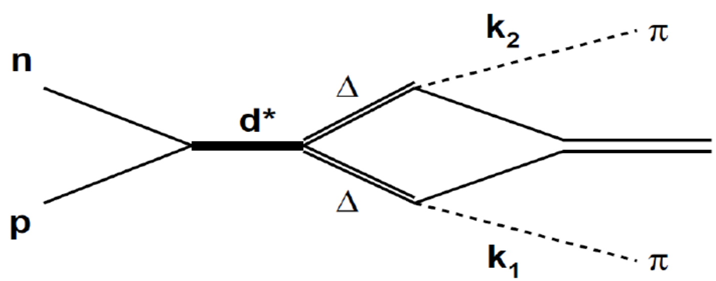
Physics of Baryonic resonances.

The measurements of the tensor A_{yy} and vector A_y analyzing powers in exclusive $d(p, pp(^1S_0))X$ and $d(p, d)X$ reactions between 2 and 6 GeV of the deuteron kinetic energies. Detection of the pions in the final state are very important.

Hot topic: d*(2380) - 0(3+) resonance

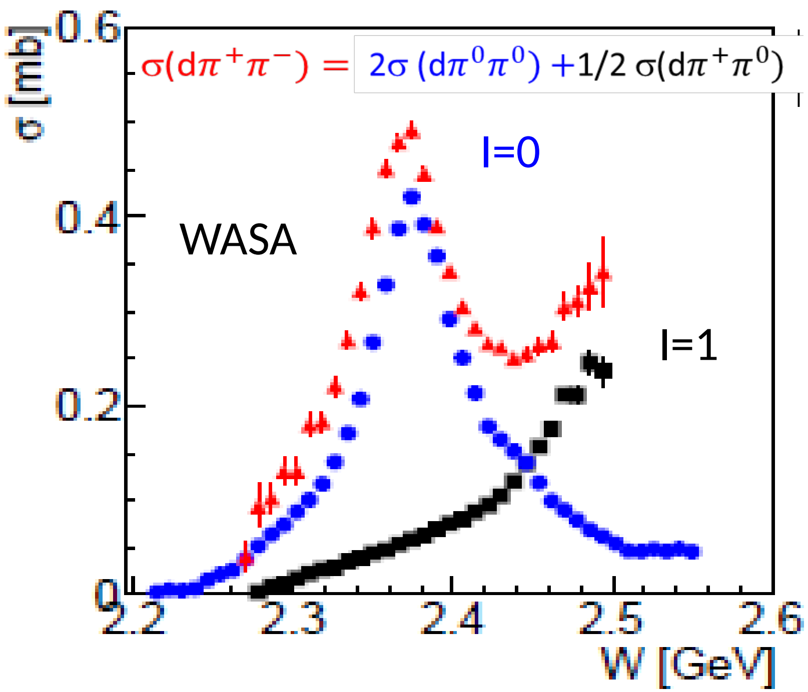
d*(2380): I=0 J=3+ Γ=70 MeV

- Compact hexaquark or
- $\Delta\Delta/D_{12}\pi$ „molecular" state ?

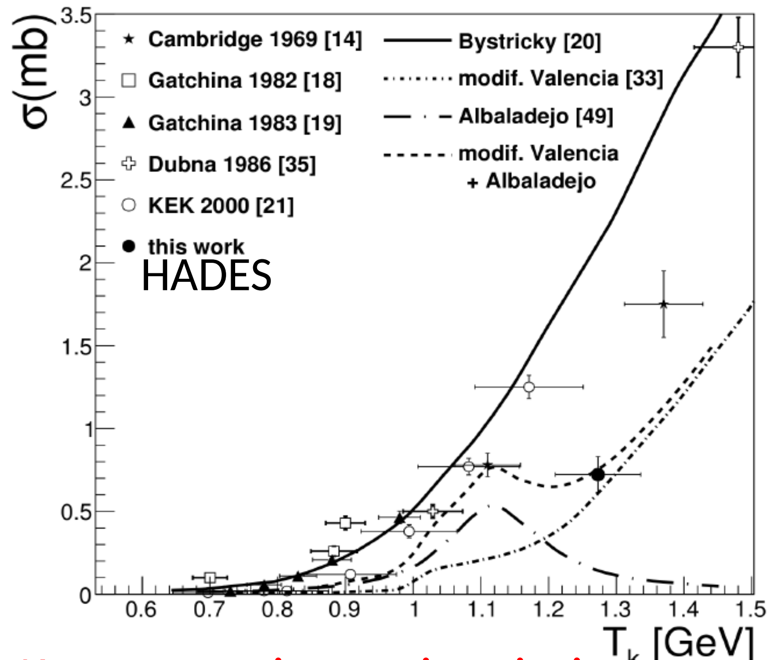


(pn) ?

pn->dππ

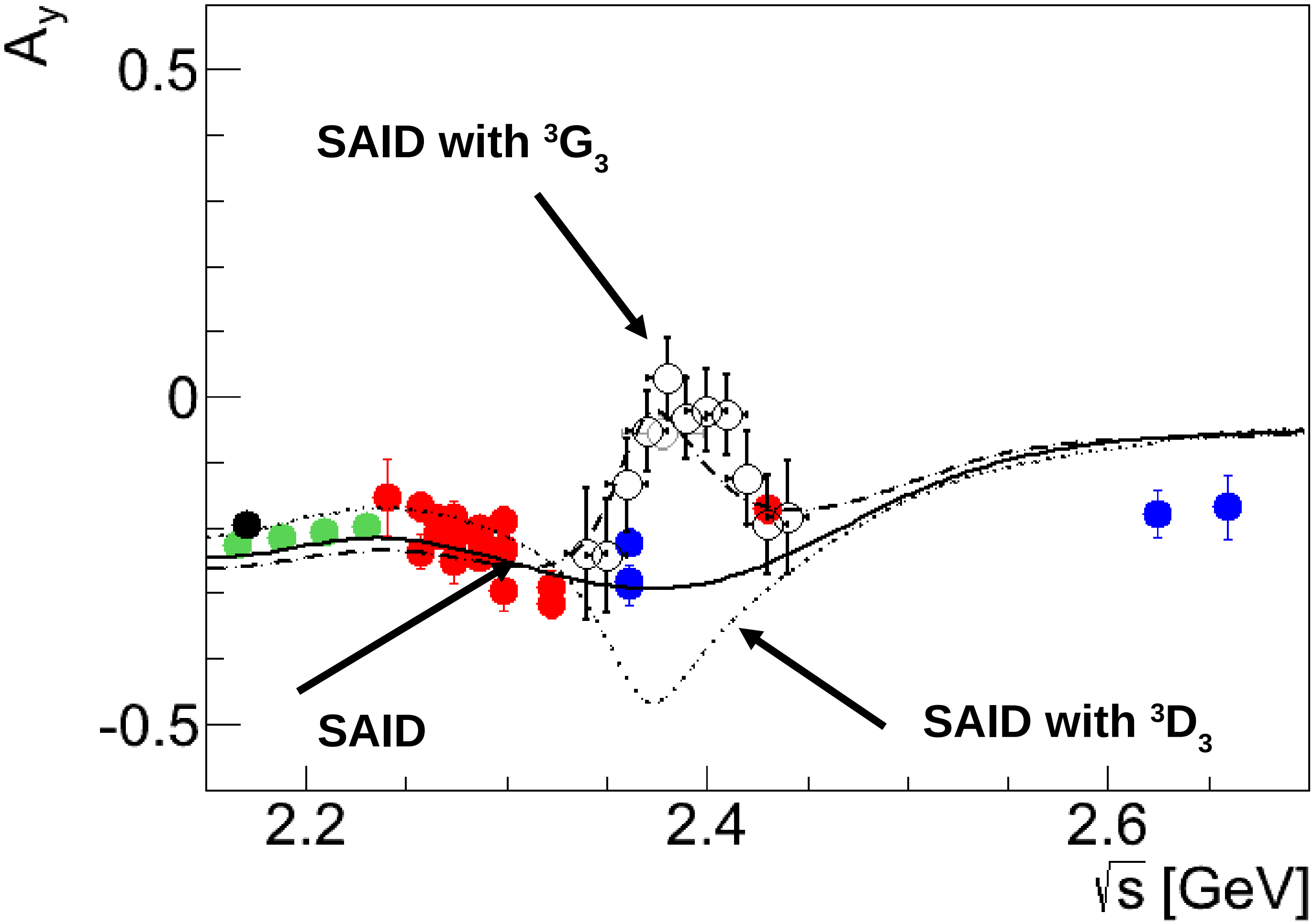


pn->pn$\pi^+\pi^-$



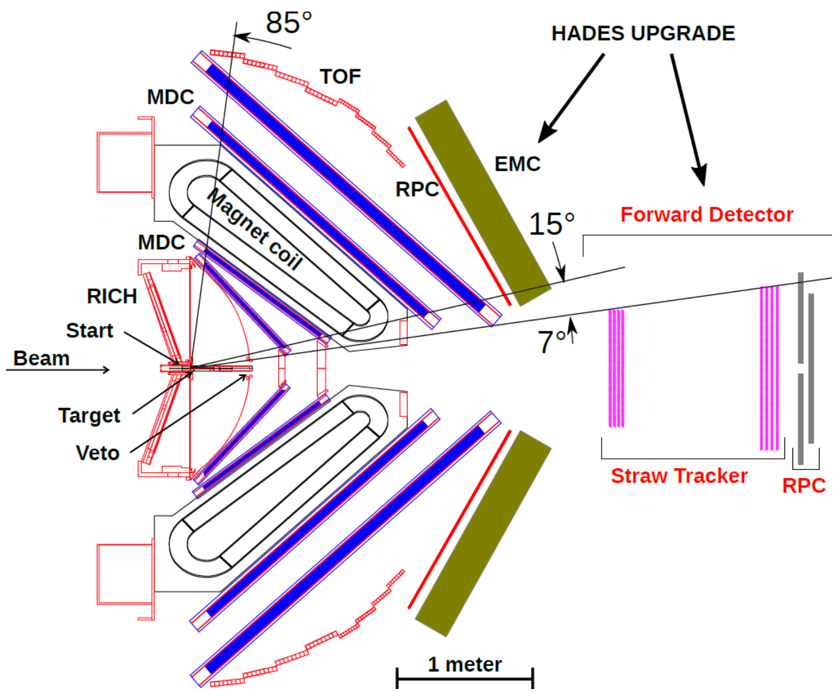
No resonance signature in excitation function of pn -> new HADES measurement!

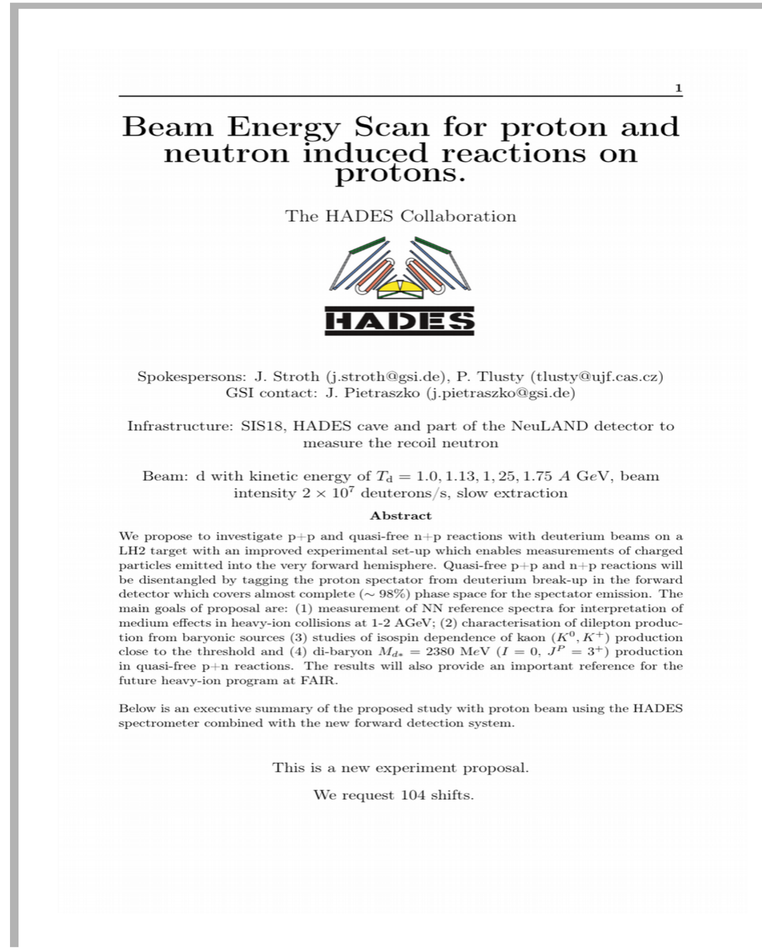
Structure in analyzing power of np→pn



Polarization effects are very large!

HADES plans





1

Beam Energy Scan for proton and neutron induced reactions on protons.

The HADES Collaboration

HADES

Spokespersons: J. Stroth (j.stroth@gsi.de), P. Tlusty (tlusty@ujf.cas.cz)
GSI contact: J. Pietraszko (j.pietraszko@gsi.de)

Infrastructure: SIS18, HADES cave and part of the NeuLAND detector to measure the recoil neutron

Beam: d with kinetic energy of $T_\mathrm{d} = 1.0, 1.13, 1, 25, 1.75$ A GeV, beam intensity 2×10^7 deuterons/s, slow extraction

Abstract

We propose to investigate p+p and quasi-free n+p reactions with deuterium beams on a LH2 target with an improved experimental set-up which enables measurements of charged particles emitted into the very forward hemisphere. Quasi-free p+p and n+p reactions will be disentangled by tagging the proton spectator from deuterium break-up in the forward detector which covers almost complete ($\sim$ 98%) phase space for the spectator emission. The main goals of proposal are: (1) measurement of NN reference spectra for interpretation of medium effects in heavy-ion collisions at 1-2 AGeV; (2) characterisation of dilepton production from baryonic sources (3) studies of isospin dependence of kaon (K^0, K^+) production close to the threshold and (4) di-baryon $M_{d*} = 2380$ MeV ($I = 0$, $J^P = 3^+$) production in quasi-free p+n reactions. The results will also provide an important reference for the future heavy-ion program at FAIR.

Below is an executive summary of the proposed study with proton beam using the HADES spectrometer combined with the new forward detection system.

This is a new experiment proposal.

We request 104 shifts.

BM@N advantages:

-magnetic analysis in forward direction

-polarized beam!

Investigation of the vector analyzing power A_y in neutron induced reactions (with the proton spectator detection) like $np \to pn$, $np \to pp\pi^-$, $np \to pn\pi^+\pi^-$, $np \to d\pi^+\pi^-$ etc. reactions at the energies 1.0-2.0 GeV.

Conclusion

BM@N setup is well suited for the physics with polarized deuterons using new SPI.

Such measurements can provide new insight to spin structure of SRC, mechanisms of baryonic resonances and d* production.

However, such program requires the advanced extracted deuteron beam polarimetry.

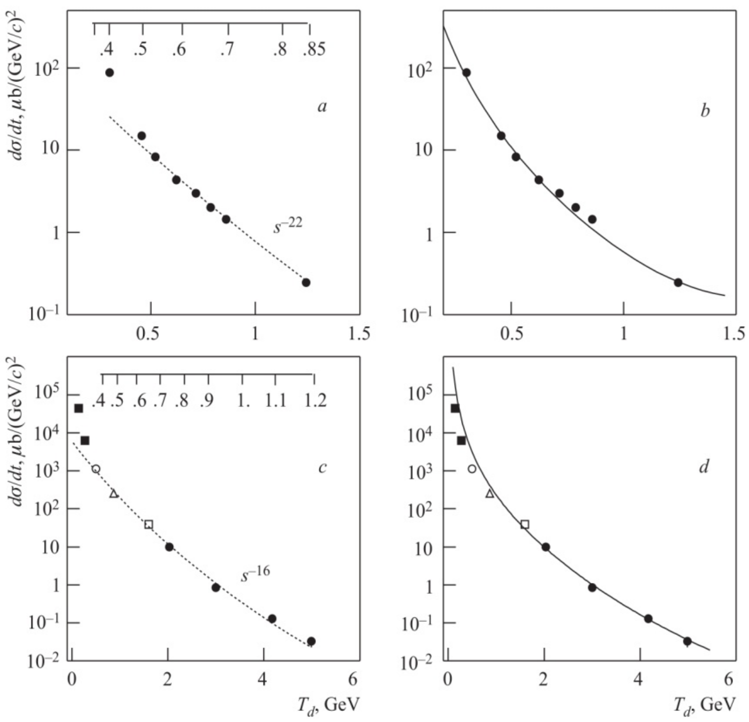
Thank you for the attention!

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 → ³Hen

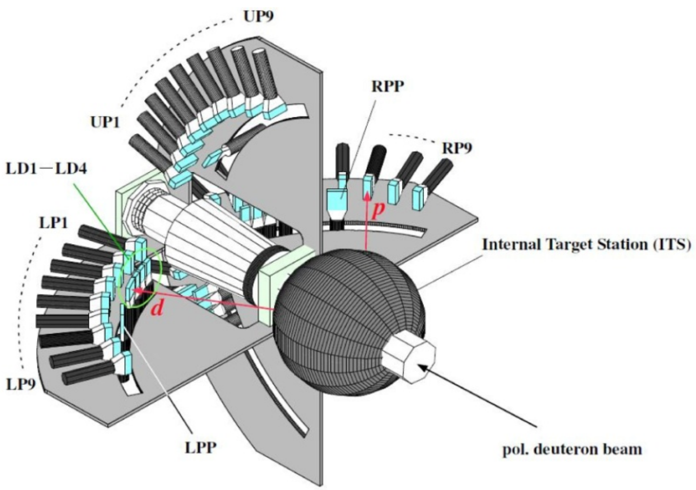
$$N_A + N_B + N_C + N_D - 2 = 22$$

For the reaction dp → dp

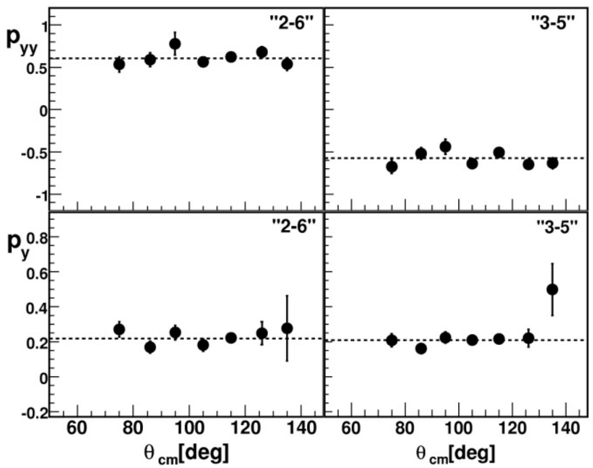
$$N_A + N_B + N_C + N_D - 2 = 16$$

The regime corresponds to CCR can occur already at T_d ~ 500 MeV

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.

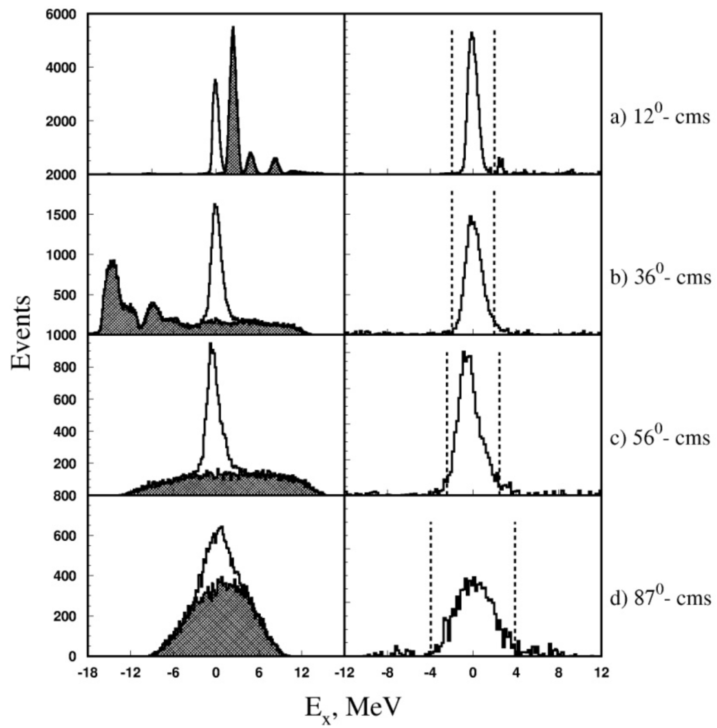


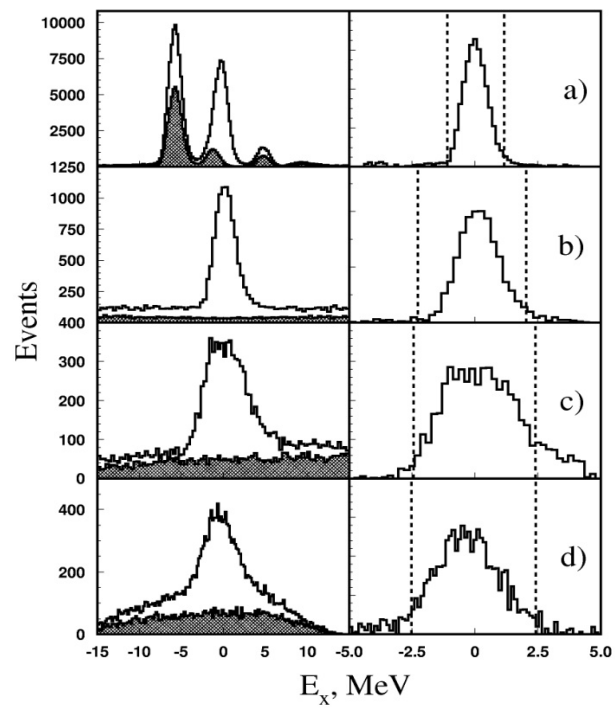
Tensor p_{yy} and vector p_y polarization of the beam for “2-6” and “3-5” spin modes of PIS POLARIS as a function of the deuteron scattering angle in the c.m.s.

- 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)

Subtraction of carbon contribution





5°

32°

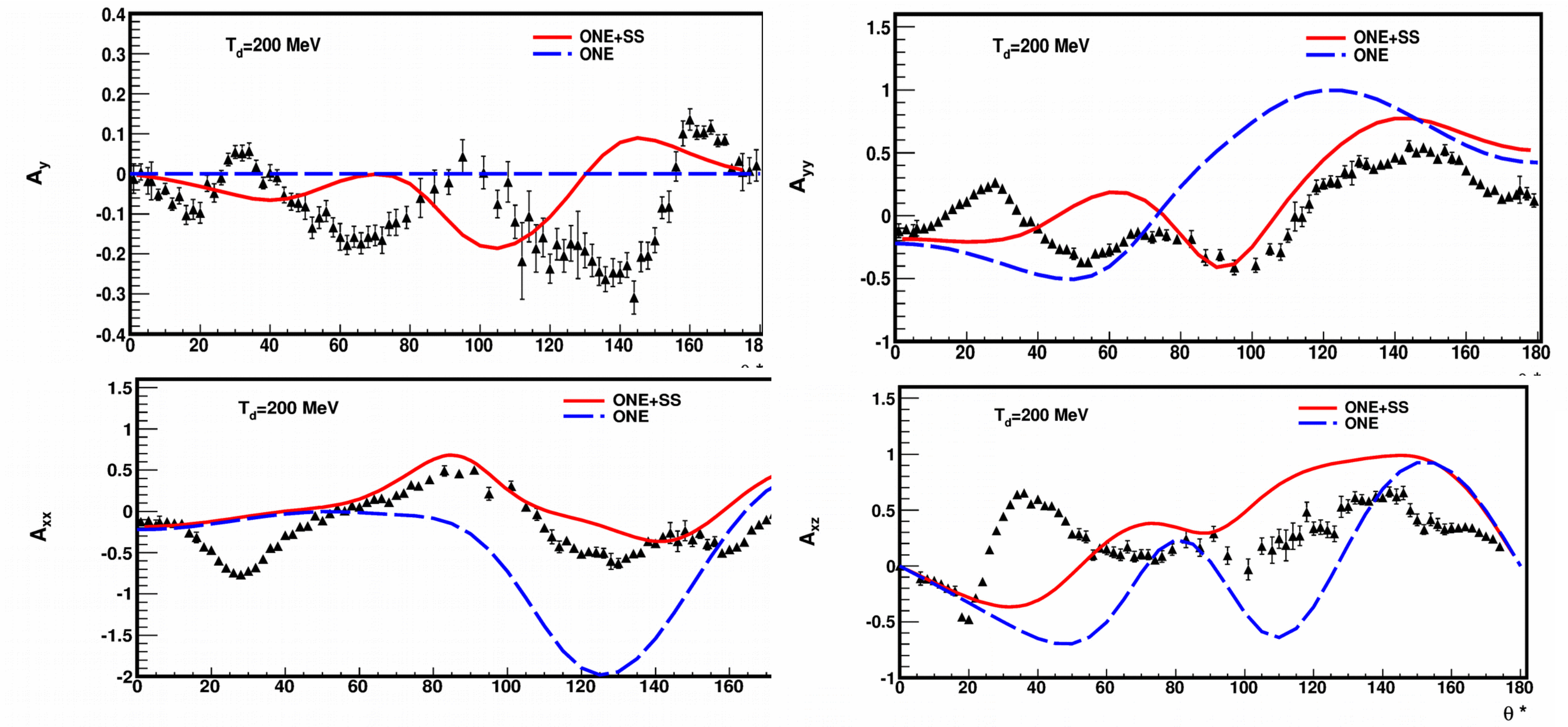
54°

94°

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.

Polarization effects in the dd → ^{3}Hen(^{3}Hp) reactions at Nuclotron energies



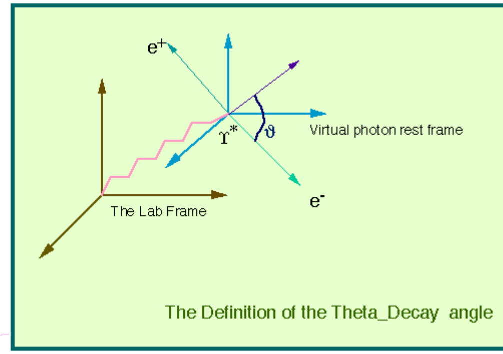
The relativistic multiple scattering model was successfully used to describe the dd → ^{3}Hen(^{3}Hp) reactions in a GeV region at the Nuclotron.
The calculations require a large amount of CPUs.
The results were published in FBS, PRC, PPN.

N.Ladygina - theory
A.Kurilkin – experiment

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**
- **ππ annihilation: p wave (L=1 ⊥ to ππ scattering plane) B = -1**
- **baryonic resonances N* decays: B ≠ 0**
- **NN and πN bremsstrahlung: B ≠ 0**

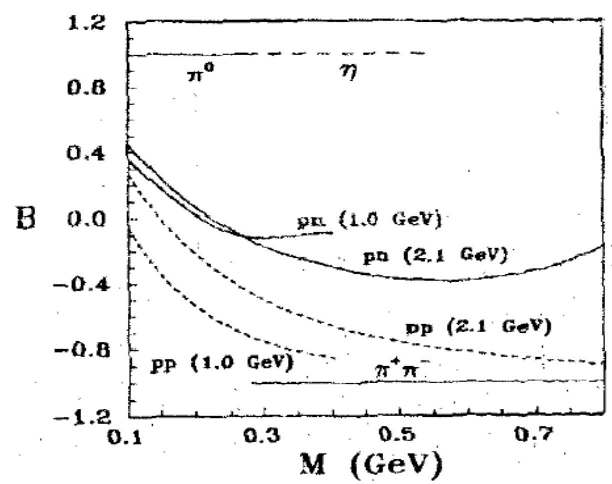


Fig. 1. M dependence of the decay anisotropy coefficient for different elementary dilepton sources: the Dalitz decay of η and π^0 mesons, $\pi^+\pi^-$ -annihilation, pn and pp bremsstrahlung (at two energies).

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

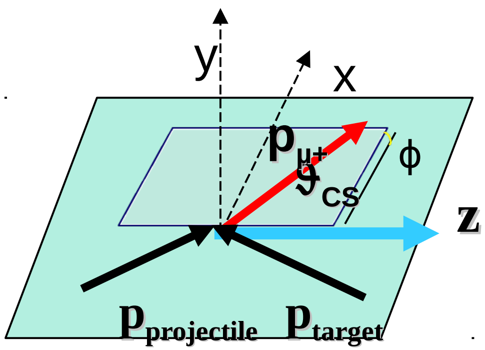
Results on anisotropy coefficients

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

Note: B in helicity frame!

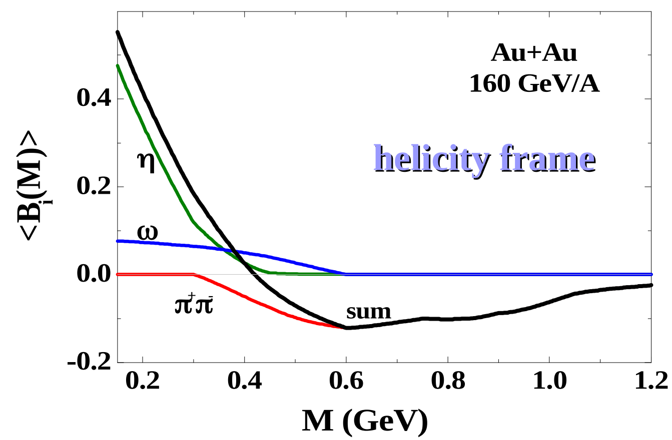
NA60 measured anisotropy coefficients!

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

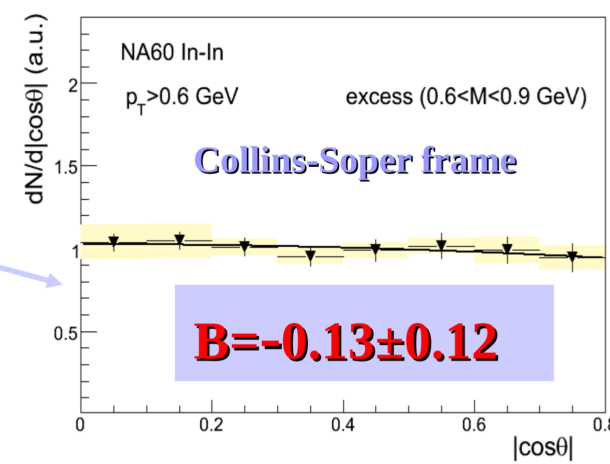


In rest frame of virtual photon: θ - angle between the positive muon $p_{\mu+}$ and z-axis; z axis is a bisector between p_{proj} & - p_{target}

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



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?!