Measurement of the Spin-Dependent Observables in Elastic NN Collisions at NICA

Which spin-dependent values can be measured by using colliding NN beams at NICA?

Whether experimental conditions at NICA complex are sufficiently acceptable for such measurements?

Why the problem of the data obtaining for elastic NN scattering spin observables in the GeV region and above remains under consideration today?

To specially stress some aspects of our modern understanding of the NN interactions we quote the points of view on this question of the two well known physicists of today: theorist and experimentalist

"The theory of the nucleon-nucleon (NN) interaction in the range of about 1-10 GeV is one of the most pressing open questions of modern nuclear / particle physics.

Below that energy range, chiral effective field theory applies as well as meson theory. At very high energies (~ 100 GeV) perturbative QCD can be used.

But it is the "intermediate" region of a few GeV where theory has big problems. Meaningful theoretical work cannot be done unless we have also data in that critical region. The data for np are very scarce, too few to even pin down a reasonable phenomenology.

For our understanding of the fundamental NN interaction on a broad scale, it is vital to have data for np spin observables in the GeV region. These data will be useful for the entire international nuclear/particle physics Community".

Ruprecht Machleidt.

Prof. of Physics, one of the authors of the Bonn NN potential.

Indeed the elastic NN spin observables data base (in particular np data) is poor for energy region above a few GeV.

Full phenomenological description (energy dependent phase shift analysis) of NN interactions are possible now only up to 3 GeV for pp and 1.3 GeV for np collisions.

There is no dynamical theory (meson exchange, nonperturbative QCD) which can describe measured NN spin dependent observables over energy region above a few GeV.

"For the past 30 years QCD-based calculations have continued to disagree with the ZGS 2-spin & AGS 1-spin elastic data and the ZGS, AGS, Fermilab & RHIC inclusive data.

* These large spin effects do not go to zero at high-energy or high-$P_\perp$ as was predicted.
* No QCD-based model can explain all the large spin effects.

BASIC PRINCIPLE OF SCIENCE: If a theory does not agree with reproducible experimental data, then the theory must be modified.

These precise spin experiments provide experimental guidance for the required modification of the theory of Strong Interactions.

Elastic $d\sigma/dt$, Ann and An experiments at higher energy and $P_\perp$ could provide more guidance, just as the RHIC inclusive An experiments confirmed the similar Fermilab experiments. (E-704 Yokosawa et al.).

Elastic scattering is especially important, because it is the:

Only exclusive process that is large enough to be measured at TeV energy.

This is because proton-proton elastic scattering is dominated by the diffraction due to the millions of inelastic channels competing for the $\sigma_{TOT} \leq 100$ milibarns at TeV energies…"

Prof. A.D. KRISCH. Invited talk at DSPIN-09, 1-5 September 2009, JINR-Dubna

Benefits of the elastic NN scattering investigation

Why the elastic NN scattering spin-dependent observables are most suitable for experimental investigation and attempts of dynamical description of the strong interactions?

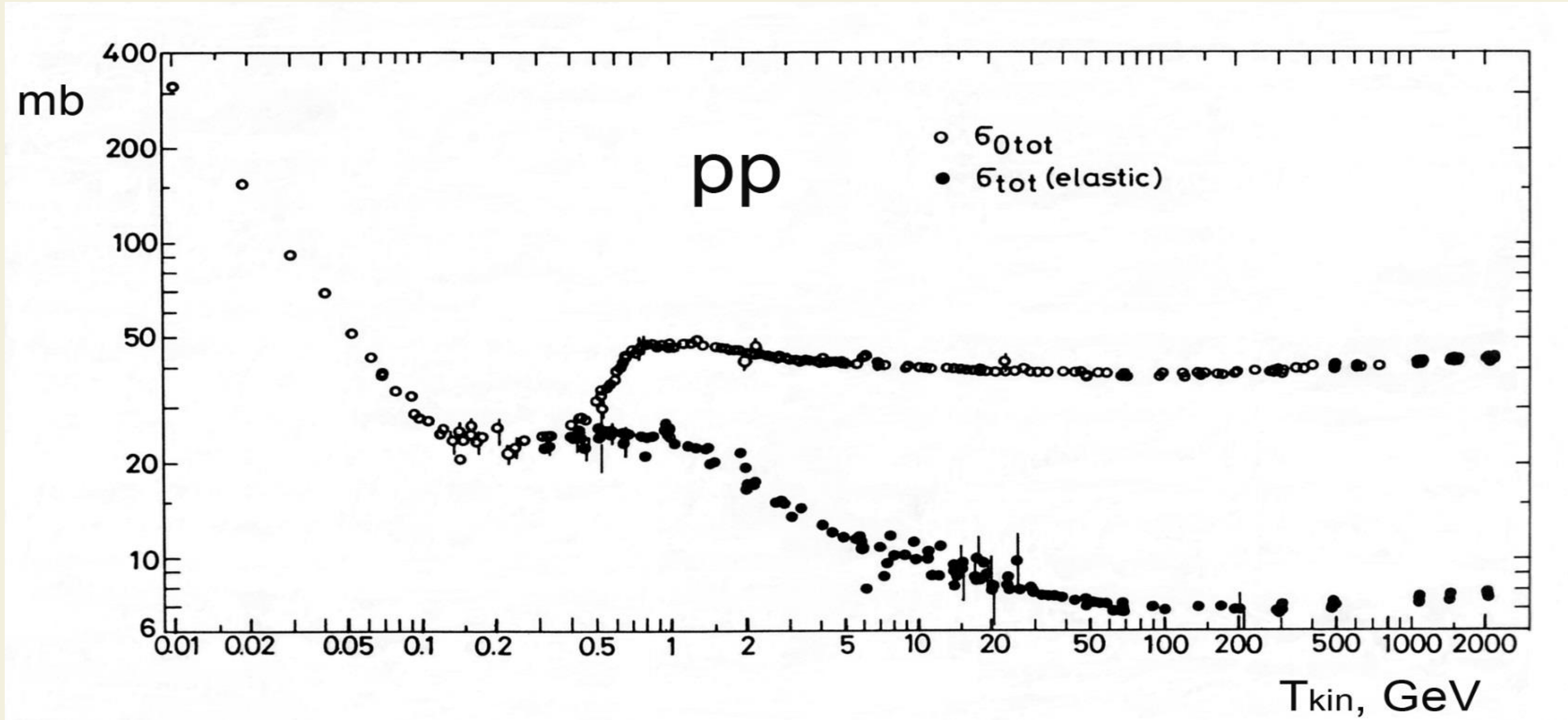
- The corresponding formal description of the NN interaction (S matrix theory) exists.

- Total elastic NN cross sections are large enough over the energy region up to ~ TeV.

pp

σtot,

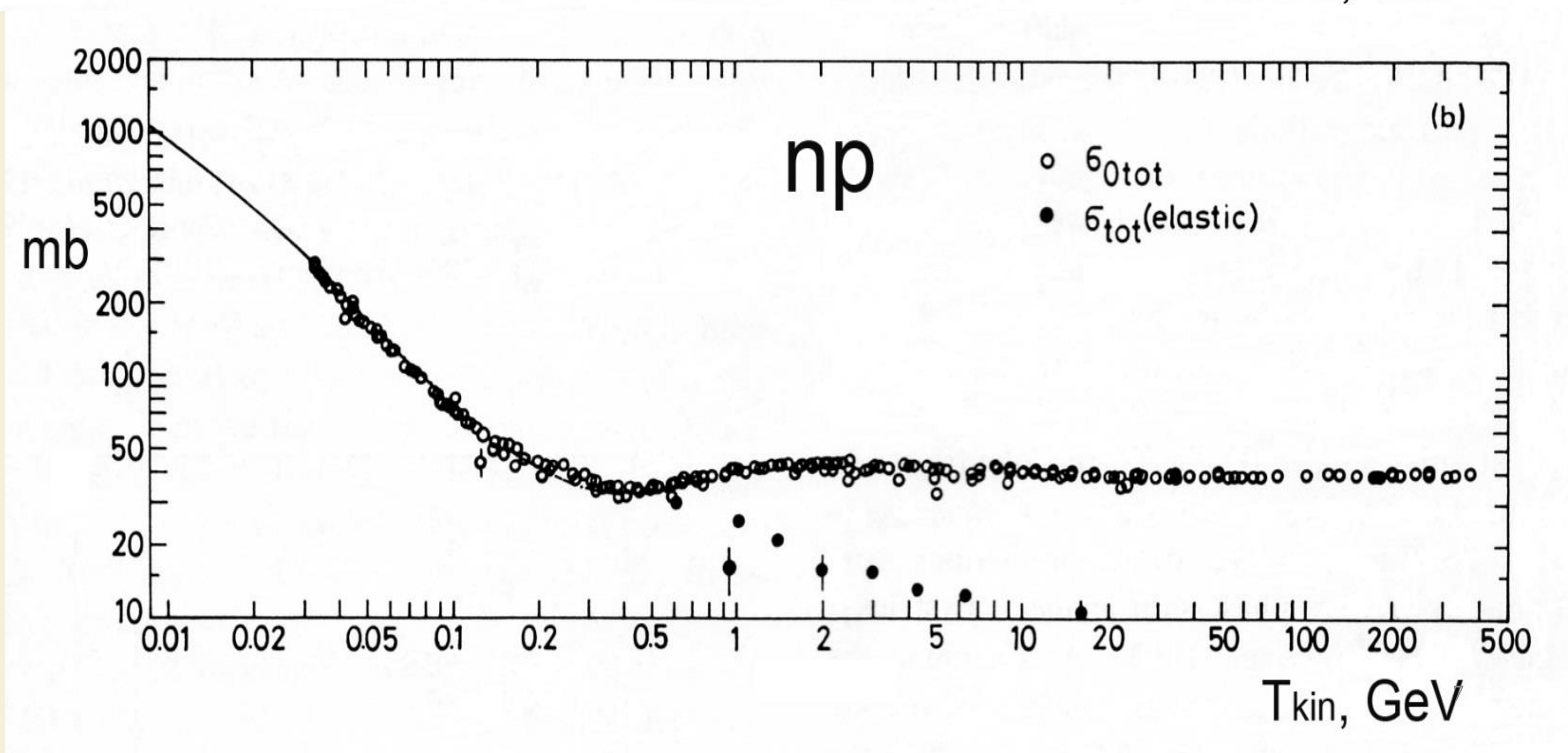
σtot elastic



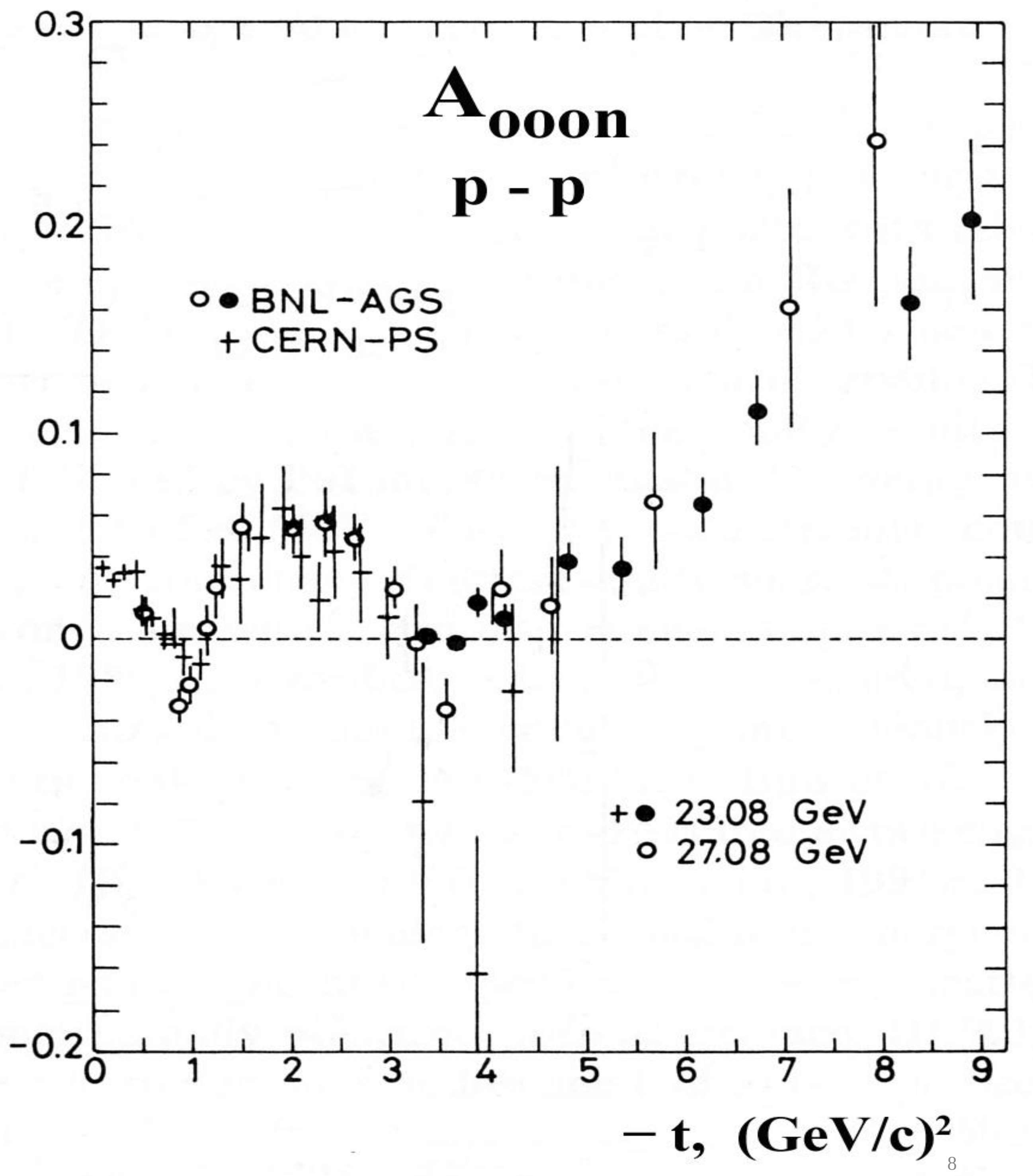
np

σtot,

σtot elastic



- Spin effects are large enough over a wide energy region and four momentum transfer.



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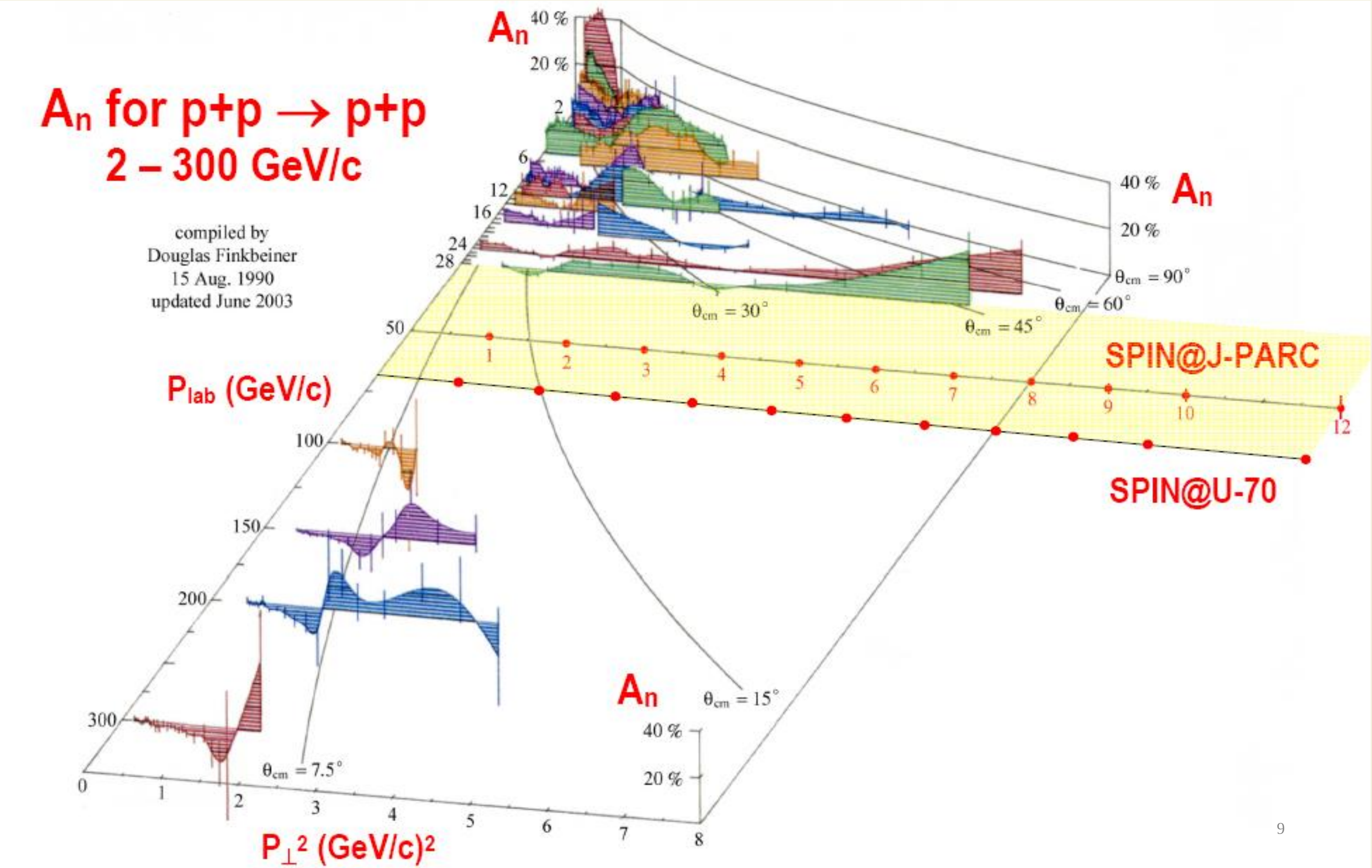


Benefits of elastic NN values measuring at NICA

- Colliding polarized nucleon beams usage for the considered measurements has a number of significant preferences with comparison to the "fixed" target experiments:

- detectors angular acceptance stretches over full solid angle 4 π rad;
- wide ranges of energy and 4-momentum transfer;
- "target" without background impurities.

Experimental data for the elastic NN spin dependent observables contain full information about NN interaction properties: pp data for the isovector part, np data for the isoscalar part and spin-dependent results for the spin characteristics.

A four-subscript notation $\mathbf{X}_{\mathbf{srbt}}$ for experimental quantities, introduced by Puzikov L.D., Ryndin R.M. and Smorodinskii (Zh.ETFiz. 32, 1957, 592), is used. Subscripts s, r, b, and t refer to the polarization components of the scattered, recoil, beam, and target particles, respectively.

If an initial particle is unpolarized or a final particle polarization not analyzed, the corresponding subscript is set equal to zero.

Which spin-dependent elastic NN observables can be measured by the detectors for NICA?

A compact design of complex detector for the colliders does not allows measurements of the scattered and recoil particles polarizations. For such purposes the secondary scattering of analyzed particle and the devices large enough – polarimeters are needed.

Therefore the NICA detectors use allows to measure the elastic NN spin observables with nonzero two last indices only.

These are differential NN cross section $\mathbf{I_{oooo}}$, analyzing powers for primary reactions with polarized beam $\mathbf{A_{ooio}}$ or target $\mathbf{A_{oook}}$, and spin correlation parameters $\mathbf{A_{ooik}}$ in primary reactions with polarized both the beam and target.

Which experimental quantities have to be measured to obtain the spin-dependent NN observables?

Expression for the differential cross sections for scattering of polarized nucleon beam with energy E on the polarized target nucleons with the scattered particle detection at an angle of θ is

$$[\mathbf{d\sigma/d\Omega}]^{\mathbf{pol}}(E,\theta) = \mathbf{d\sigma/d\Omega^o}(E,\theta)\,[\,1 + \mathbf{A_{oono}}(E,\theta)\,\mathbf{P}_{Bn} + \mathbf{A_{ooon}}(E,\theta)\,\mathbf{P}_{Tn}$$
$$+ \mathbf{A_{oonn}}(E,\theta)\,\mathbf{P}_{Bn}\,\mathbf{P}_{Tn} + \mathbf{A_{ooss}}(E,\theta)\,\mathbf{P}_{Bs}\,\mathbf{P}_{Ts}$$
$$+ \mathbf{A_{ookk}}(E,\theta)\,\mathbf{P}_{Bk}\,\mathbf{P}_{Tk}$$
$$+ \mathbf{A_{oosk}}(E,\theta)\,(\mathbf{P}_{Bs}\,\mathbf{P}_{Tk} + \mathbf{P}_{Bk}\,\mathbf{P}_{Ts}\,)\,] \qquad (1)$$

where $\mathbf{d\sigma/d\Omega^o}\,(E,\theta)$ is the cross section for unpolarized nucleons.

Using this formula one can obtain the expression for an asymmetry $\mathbf{a}$

In the NN scattering with opposite signs of nucleon beam polarizations.

For example, for $\mathbf{P}_{Bn} = \mathbf{P}_{Tn} = \mathbf{P}_{Bs} = \mathbf{P}_{Ts} = 0$ and $\mathbf{P}_{Bk} \neq 0$, $\mathbf{P}_{Tk} \neq 0$ and sign $\mathbf{P}_{Bk} = \pm 1$ we have

$$[d\sigma/d\Omega]^{+} - [d\sigma/d\Omega]^{-} =$$

$$= [d\sigma/d\Omega]^{o} (1 + A_{ookk} |P_{Bk}^{+}| P_{Tk}) - [d\sigma/d\Omega]^{o} (1 - A_{ookk} |P_{Bk}^{-}| P_{Tk}) =$$

$$= 2 [d\sigma/d\Omega]^{o} A_{ookk} |P_{Bk}| P_{Tk} . \quad (2)$$

$$[d\sigma/d\Omega]^{+} + [d\sigma/d\Omega]^{-} =$$

$$= [d\sigma/d\Omega]^{o} (1 + A_{ookk} |P_{Bk}^{+}| P_{Tk}) + [d\sigma/d\Omega]^{o} (1 - A_{ookk} |P_{Bk}^{-}| P_{Tk}) =$$

$$= 2 [d\sigma/d\Omega]^{o}. \quad (3)$$

Then the asymmetry will be

$$a = ([d\sigma/d\Omega]^{+} - [d\sigma/d\Omega]^{-}) / ([d\sigma/d\Omega]^{+} + [d\sigma/d\Omega]^{-}) =$$

$$= (2 [d\sigma/d\Omega]^{o} A_{ookk} |P_{Bk}| P_{Tk}) / (2 [d\sigma/d\Omega]^{o}) = A_{ookk} |P_{Bk}| P_{Tk} . \quad (4)$$

Thus in order to obtain the spin-dependent NN observables we have to measure the asymmetry, that is the elastic differential cross sections for opposite signs of the polarizations of colliding polarized particles.

To measure the elastic NN differential cross section we have to select the elastic NN events among all inelastic ones.

For the elastic NN interaction in the centre-of-mass system the outgoing nucleons have the following kinematical characteristics:

1. This nucleons have equal momentum values.
2. The nucleon momenta have opposite directions.
3. The nucleon momenta do not depend from the scattering angle θ_{CM}.

These conditions define the requirements for the NICA detectors to select the elastic NN scattering events.

Polarized and non-polarized p-; d - beams:

longitudinal and transverse polarization in MPD and SPD

p↑p↑ at $\sqrt{s_{pp}} = 12 \div 27$ GeV (5 ÷ 12.6 GeV kinetic energy)

d↑d↑ at $\sqrt{s_{NN}} = 4 \div 13$ GeV (2 ÷ 5.5 GeV/u kinetic energy)

$L_{average} \approx 1 \cdot 10^{32}$ $cm^{-2}s^{-1}$ (at $\square s_{pp} \geq 27$ GeV)

Using the pp polarized colliding beams the isospin I = 1 spin-dependent observables can be measured in elastic pp collisions.

In polarized dd collisions both the pp and np quasielastic A_{ooio} and A_{ooik} observables can be measured over wide CM angular range. Nucleons in deuteron have the same polarization value $P\uparrow_N = P\uparrow_d$ and half deuteron kinetic energy $T_N = ½ T_d$.

Colliding beams (bunches) intensity monitoring

Relative monitoring of the obtained angular distributions of elastic NN scattering events can be made by using information (signals) from the pickup electrodes placed at both sides of the intersection beams point.

Since the measured value of the asymmetry is the ratio of difference and sum of elastic events yields, measured in the same data taking run, the absolute beams intensity monitoring is not required.

Sequence of particles polarization sign in bunches

When performing relative measurements of spin NN observables extremely important to avoid result systematic errors due to long-term drifts in the measuring conditions. For this purpose it is preferably to keep each bunch polarization sign (+ or - or 0) starting from the particles injection in the Nuclotron from a polarized ions source up to the moment of the colliding beams interaction at the intersection points.

For the A_{oonn} and A_{ookk} measurements the following sequences of particles polarization signs in bunches are need
"+", "+", "-", "-", "+", "+", "-","-" and "+", "-", "-", "+", "+", "-", "-","+" .

The design of the source of polarized deuteron ions has a possibility for organizing the needed sequence of polarization signs in bunches for both colliding beams.

NICA polarized beams polarimetry

For the measurement and continuously monitoring of the values and signs of colliding beam polarizations a complete and reliable polarimetry system is needed.

From this reason it is desired to have a number of polarimeters at several places along the polarized beam preparation line and at each of accumulated polarized beams inside the collider.

The beam line polarimeters have be placed:

1. Low energy polarimeter – before polarized beam injection into Nuclotron
2. Polarimeter inside the Nuclotron ring (using internal target station)
3. Special devices (polarimeters) placed at each of accumulated polarized collider beams for beam polarization measurement.
4. Detection by NICA detectors the elastic NN scattering events will be able to determine the left-right asymmetries of the reaction yield. This will enable us to estimate the polarization values of the colliding beams directly at the interaction point. This could be done both for proton and deuteron colliding beams.

Before proceeding the yield evaluations for elastic NN collision's at the NICA beams we briefly recall some features of the elastic scattering kinematics:

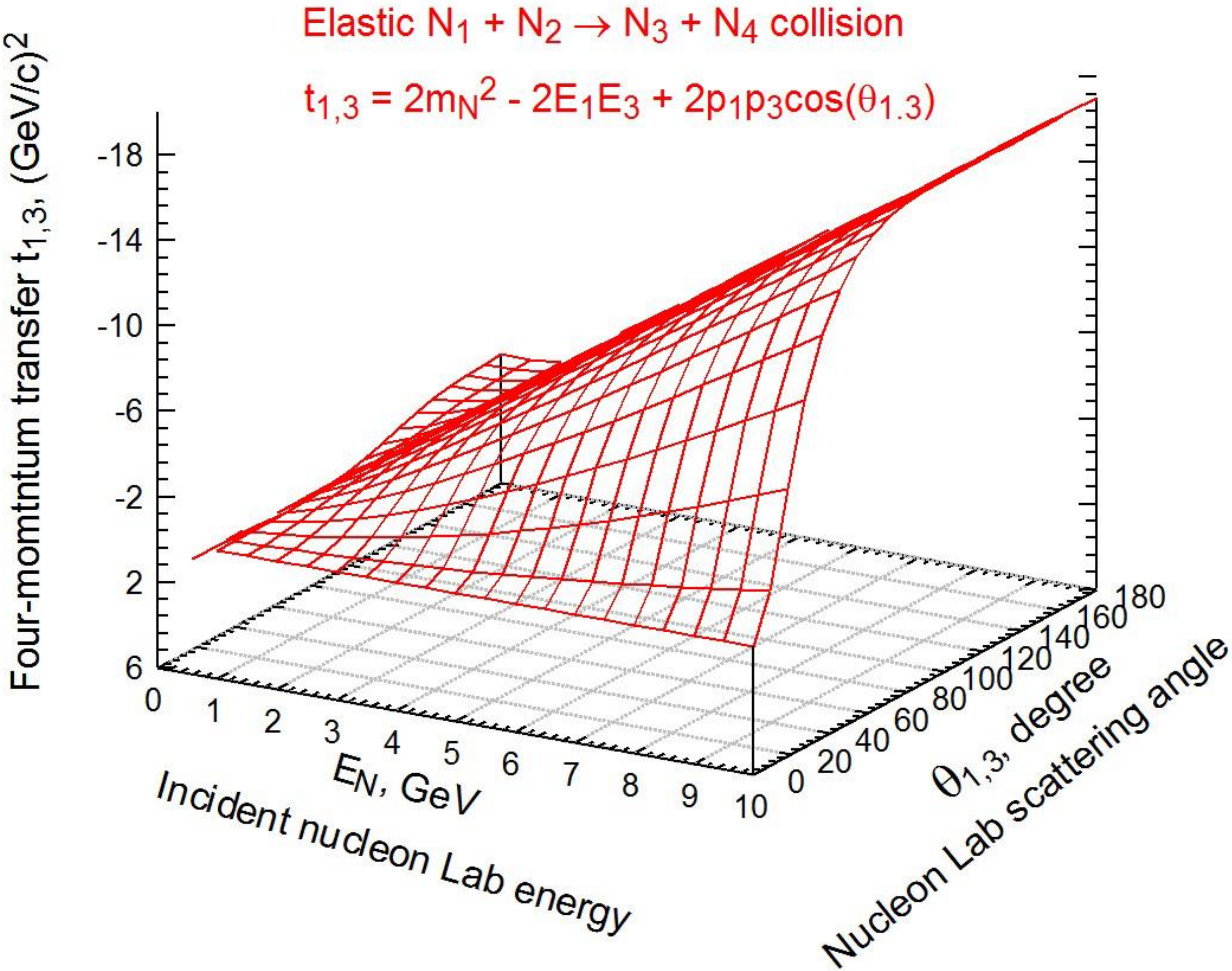
− for conventional experiments with the "fixed” target, in laboratory coordinate system,

and

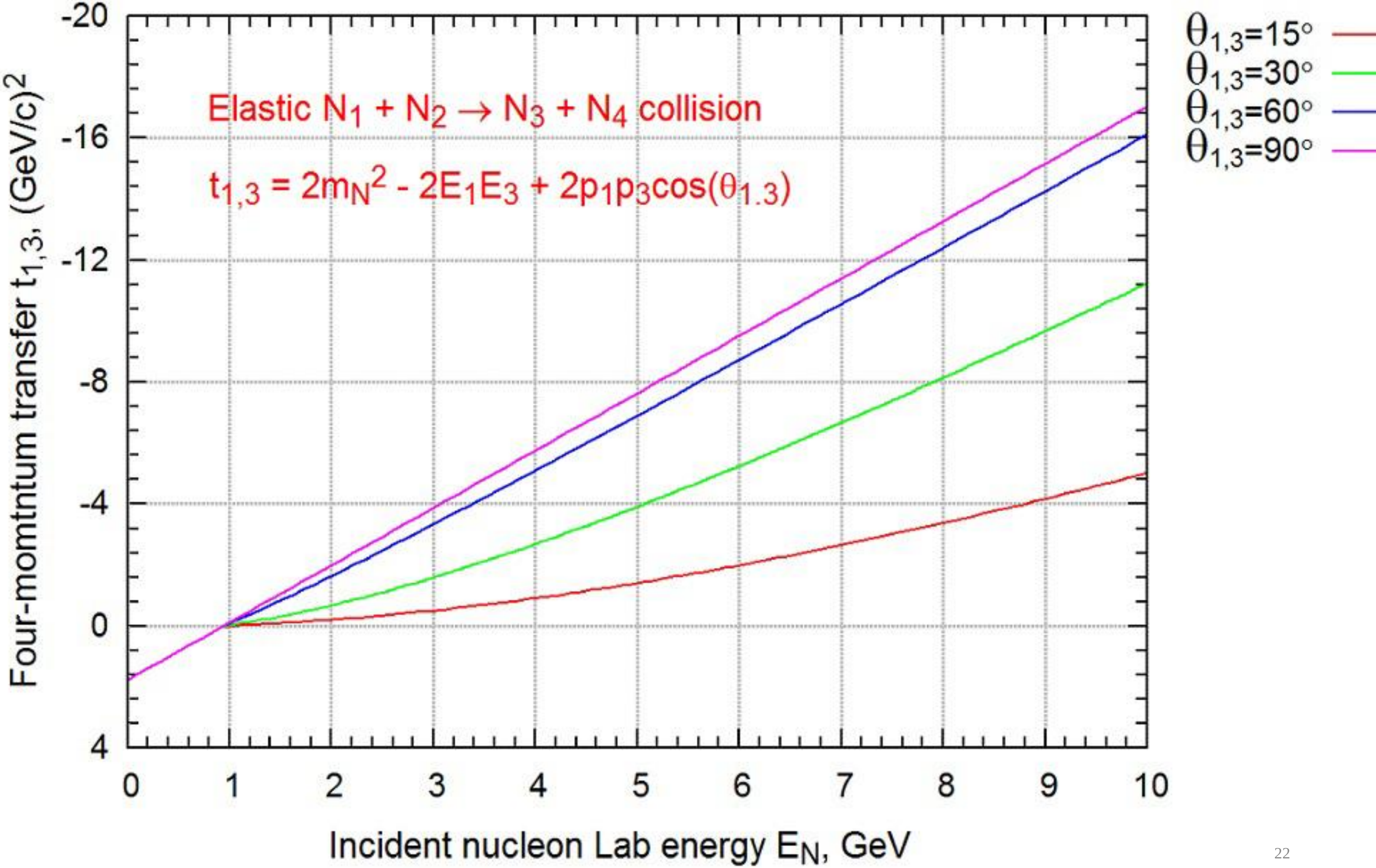
− for the system of colliding beams, that is the colliding hadrons centre-of-mass.

Note significant benefit of collisions research in centre-of-mass in comparison with experiments with "fixed" targets.

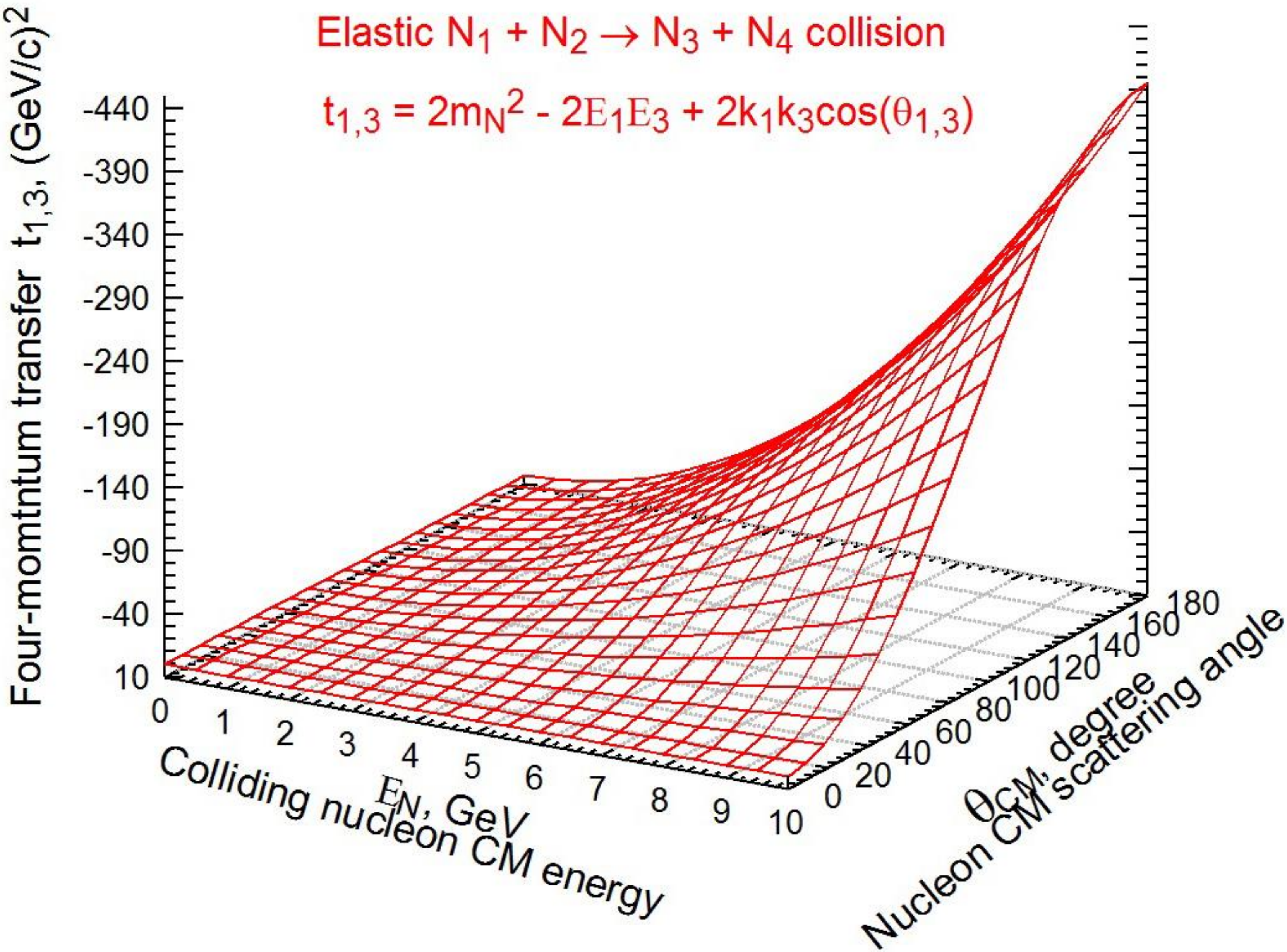
Kinematics of Nucleon-Nucleon collisions with FIX target



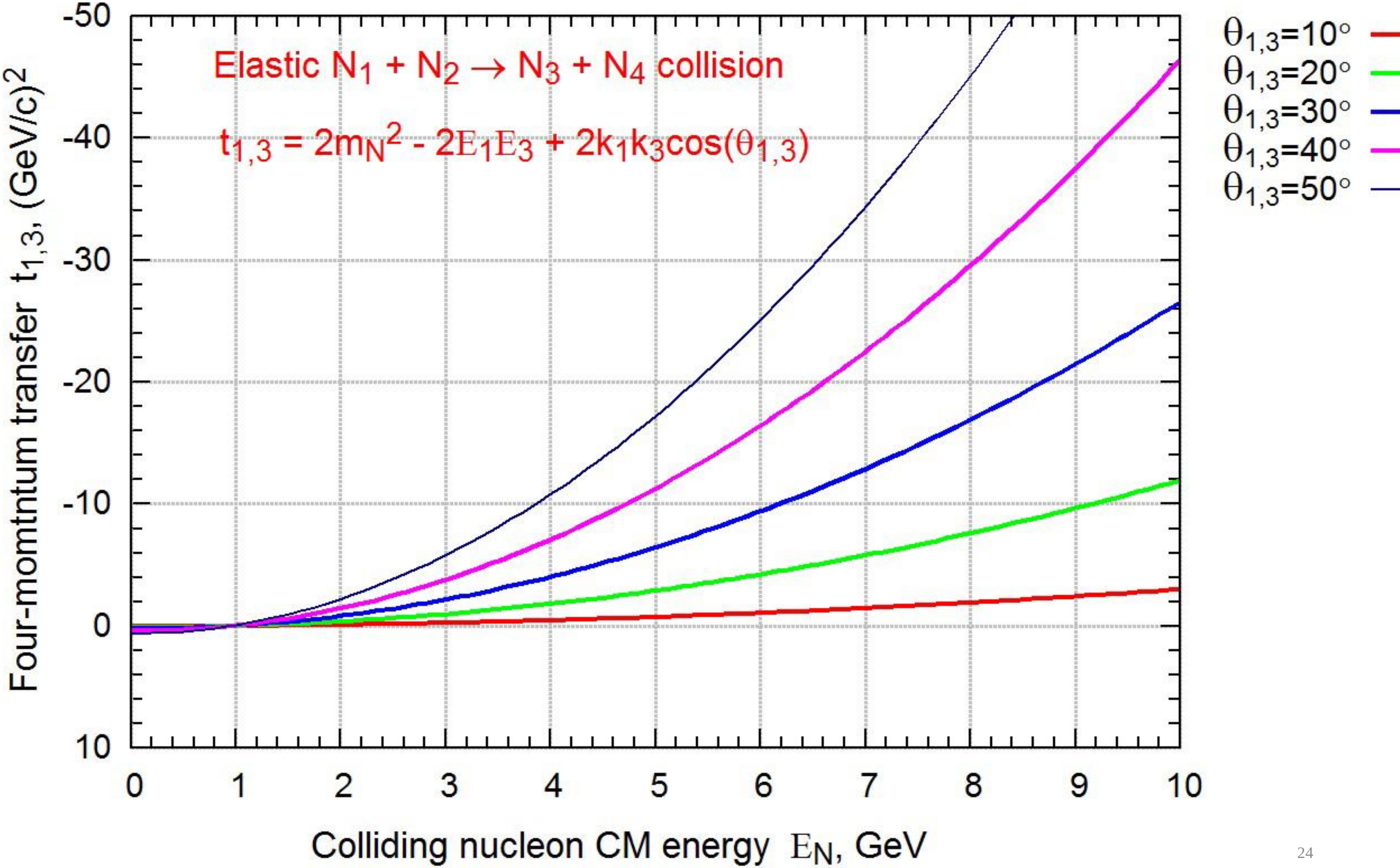
Kinematics of Nucleon-Nucleon collisions with FIX target



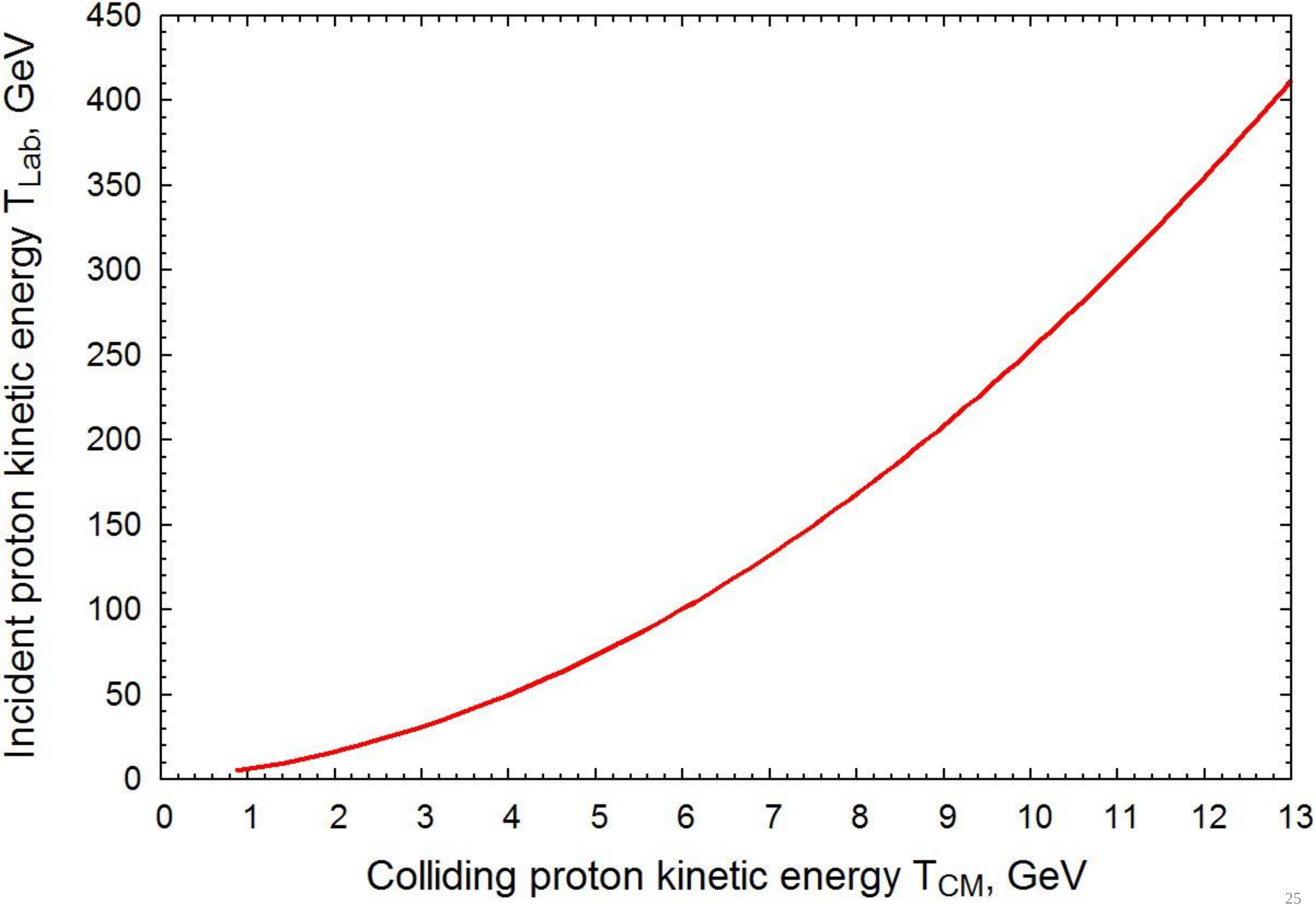
Kinematics of Nucleon-Nucleon collisions at CM system



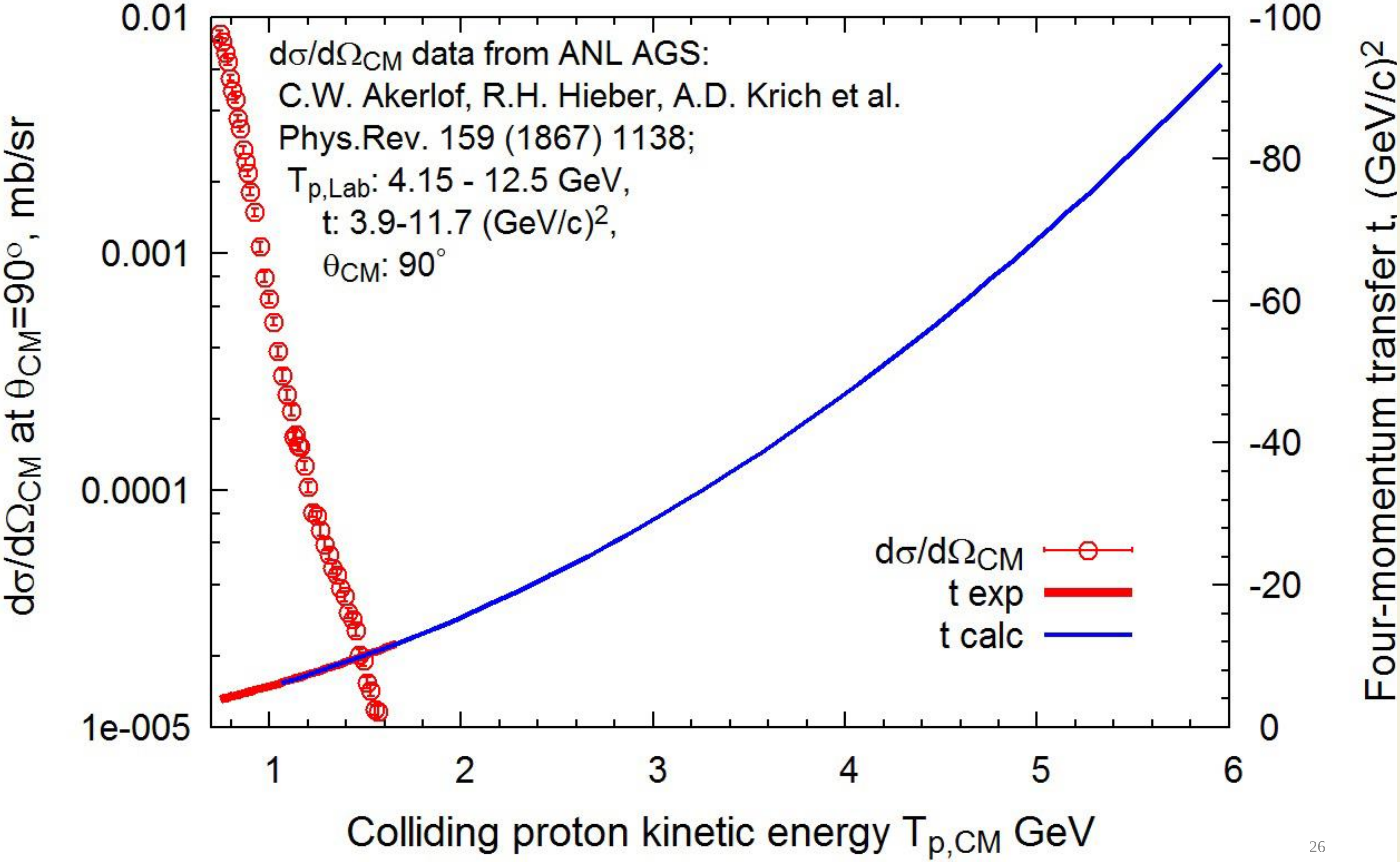
Kinematics of Nucleon-Nucleon collisions at CM system



Incident nucleon energy T_{Lab} versus colliding nucleon energy T_{CM}



CM differential cross sections for pp collisions at $\theta_{CM}=90^\circ$ and 4-momentum transfer t versus colliding proton kinetic energy T_p

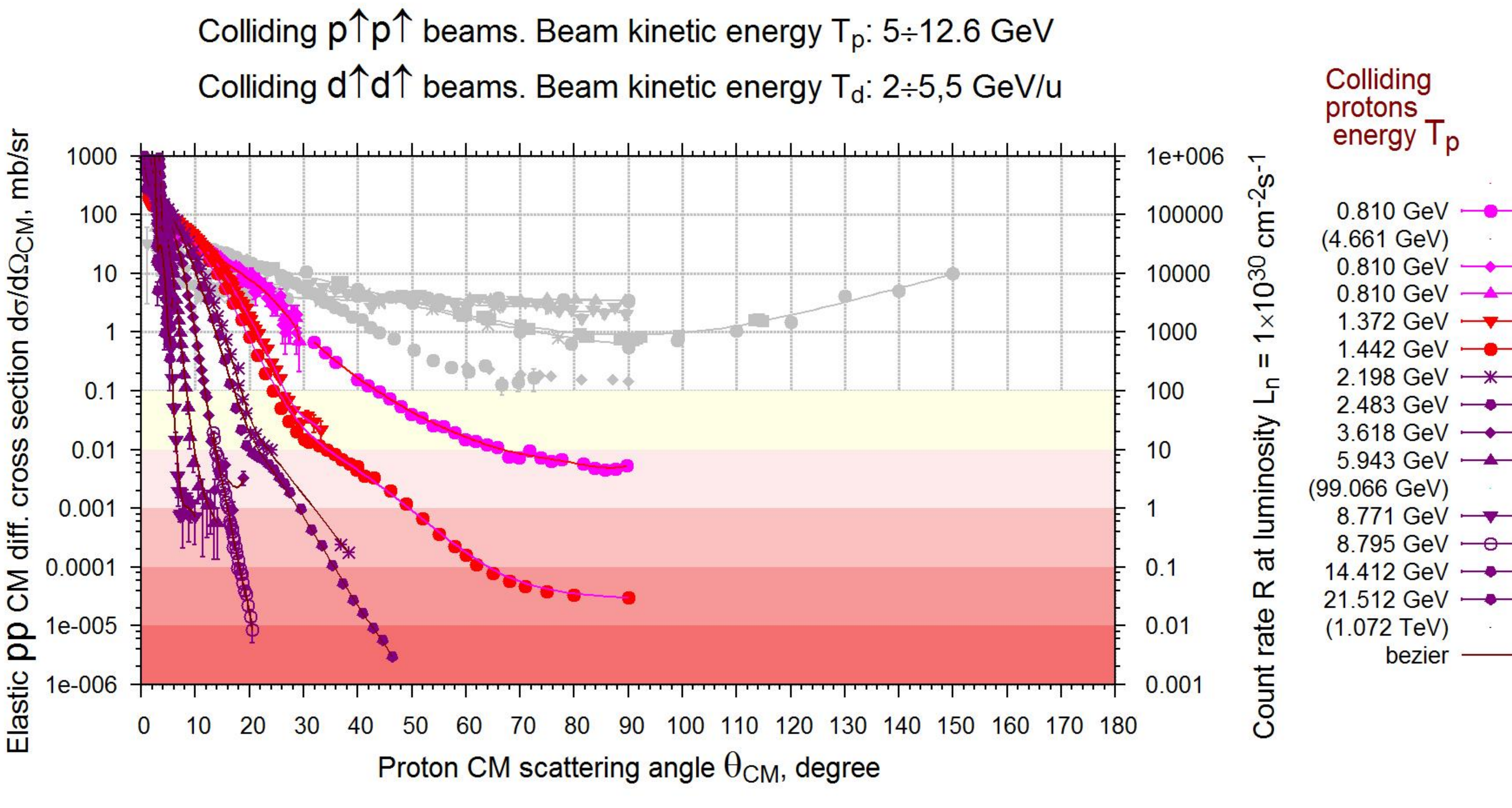


Estimations of the elastic event yields for the spin-dependent NN values measurement at NICA

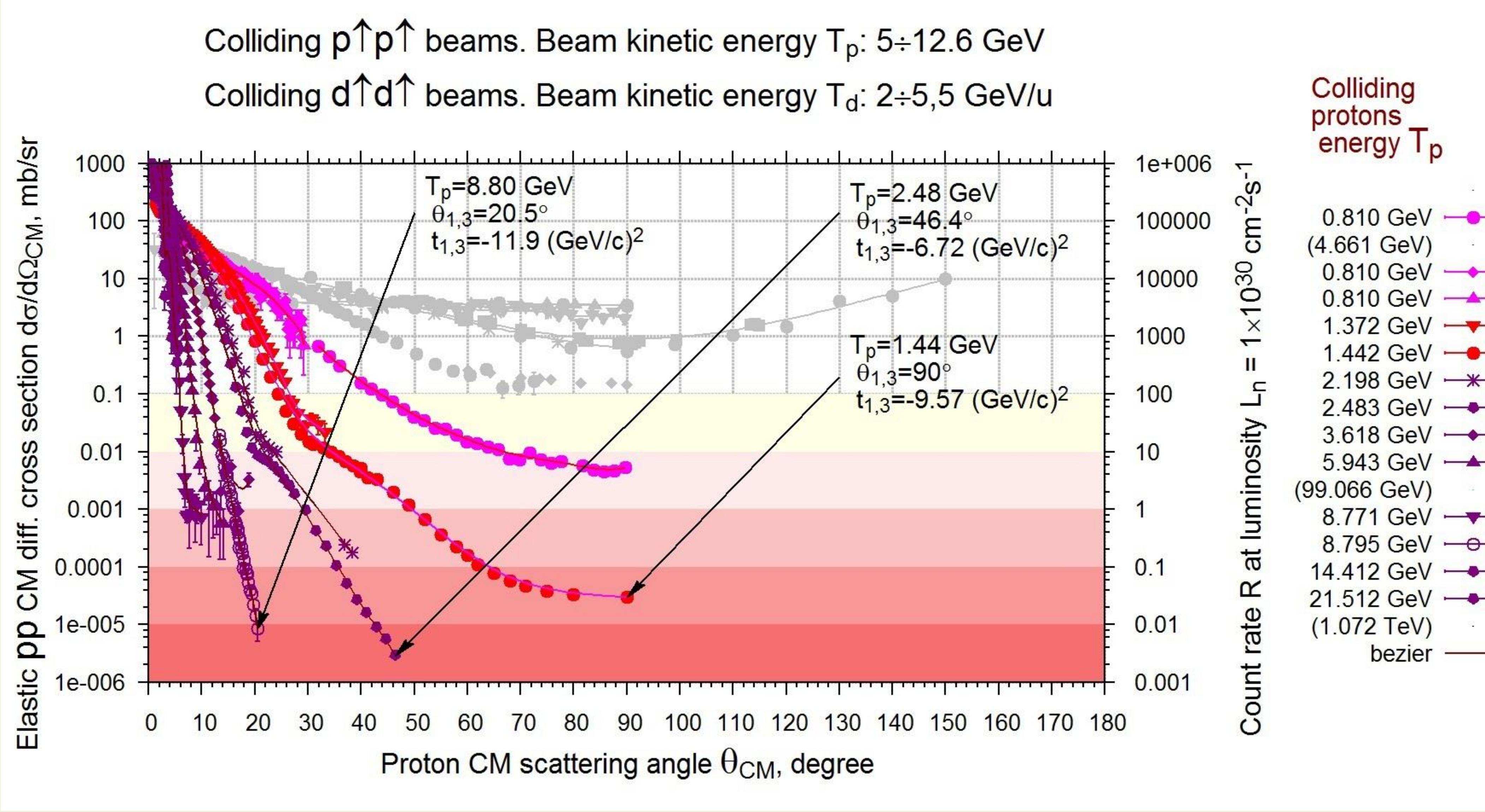
Below we present the existing data on differential pp and np cross-sections at the Center of Mass system.

Using these data will provide a realistic assessment of the outputs of processes we're interested elastic pp and np scattering.

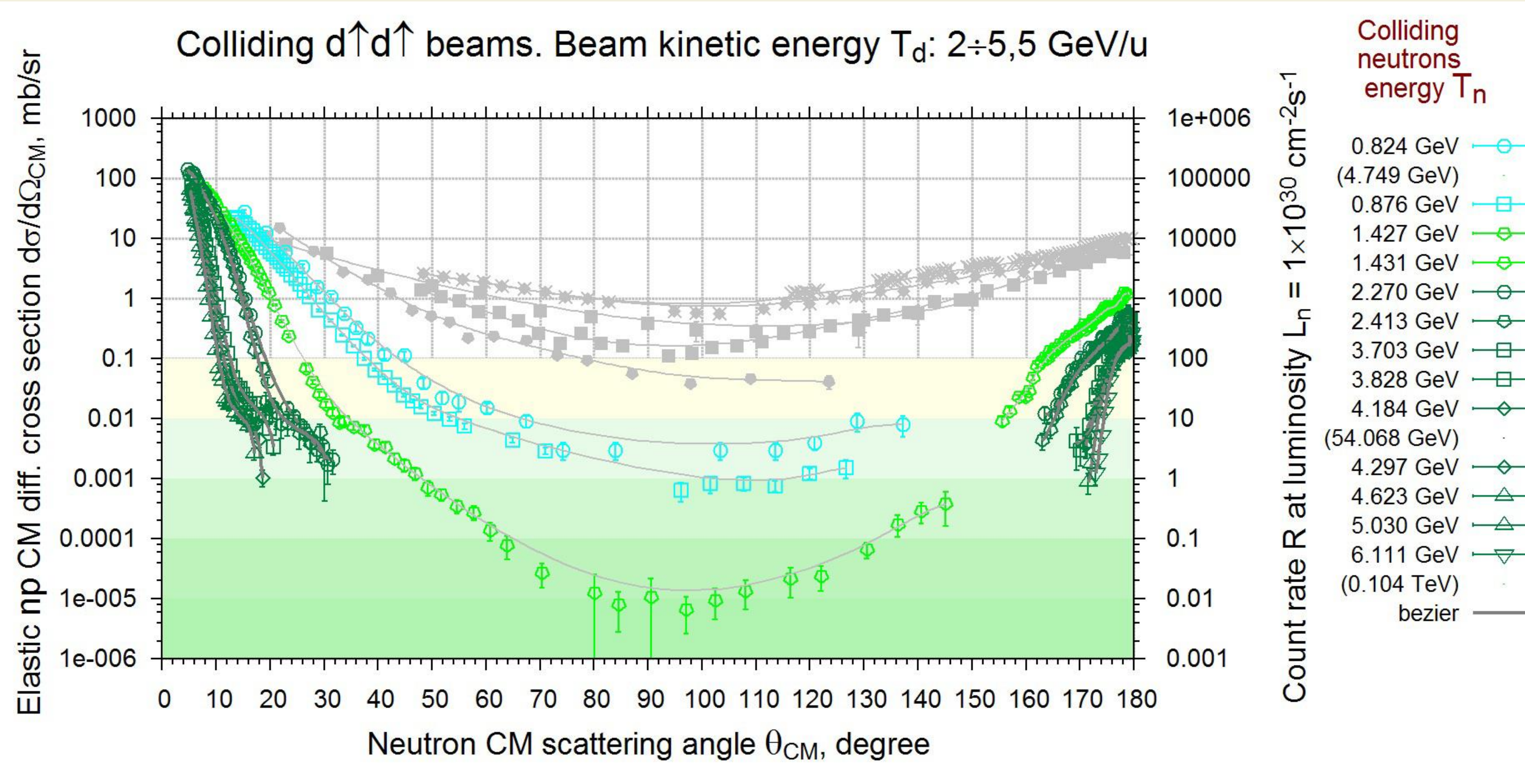
The existing dataset allows us to make assessments at several angles of the scattered nucleons in the whole range of energies of the colliding particles.

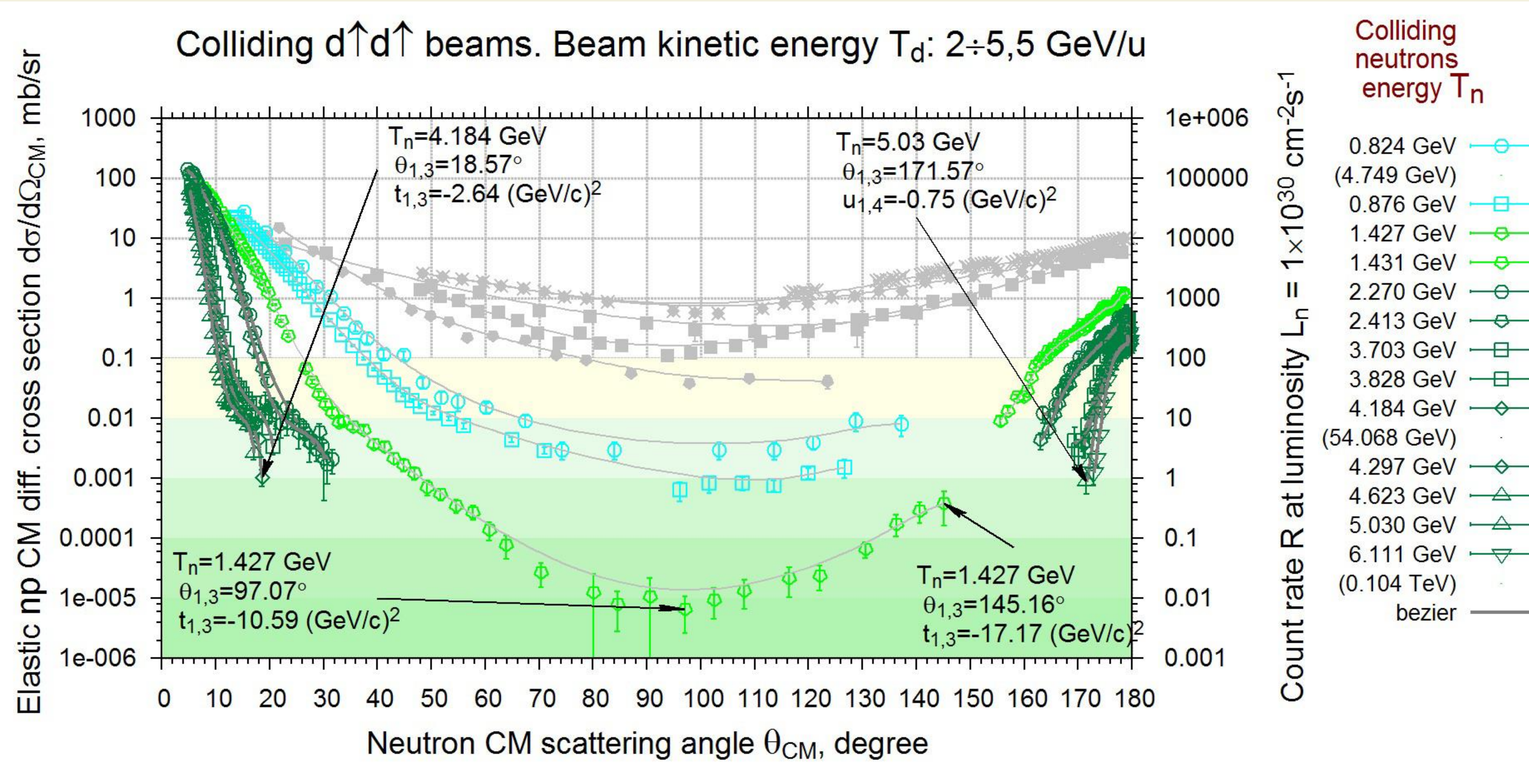


Colliding p↑p↑ beams. Beam kinetic energy T_p: 5÷12.6 GeV
Colliding d↑d↑ beams. Beam kinetic energy T_d: 2÷5,5 GeV/u
Elastic pp CM diff. cross section $d\sigma/d\Omega_{CM}$, mb/sr
Count rate R at luminosity $L_n = 1\times10^{30}$ $cm^{-2}s^{-1}$
Proton CM scattering angle θ_{CM}, degree
1000
100
10
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
1e+006
100000
10000
1000
100
10
1
0.1
0.01
0.001
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Colliding protons energy T_p
0.810 GeV
(4.661 GeV)
0.810 GeV
0.810 GeV
1.372 GeV
1.442 GeV
2.198 GeV
2.483 GeV
3.618 GeV
5.943 GeV
(99.066 GeV)
8.771 GeV
8.795 GeV
14.412 GeV
21.512 GeV
(1.072 TeV)
bezier



Colliding p↑p↑ beams. Beam kinetic energy T_p: 5÷12.6 GeV
Colliding d↑d↑ beams. Beam kinetic energy T_d: 2÷5,5 GeV/u
T_p=8.80 GeV
$\theta_{1,3}$=20.5°
$t_{1,3}$=-11.9 (GeV/c)^2
T_p=2.48 GeV
$\theta_{1,3}$=46.4°
$t_{1,3}$=-6.72 (GeV/c)^2
T_p=1.44 GeV
$\theta_{1,3}$=90°
$t_{1,3}$=-9.57 (GeV/c)^2
Elastic pp CM diff. cross section $d\sigma/d\Omega_{CM}$, mb/sr
Proton CM scattering angle θ_{CM}, degree
Count rate R at luminosity $L_n = 1\times10^{30}$ $cm^{-2}s^{-1}$
Colliding protons energy T_p
0.810 GeV
(4.661 GeV)
0.810 GeV
0.810 GeV
1.372 GeV
1.442 GeV
2.198 GeV
2.483 GeV
3.618 GeV
5.943 GeV
(99.066 GeV)
8.771 GeV
8.795 GeV
14.412 GeV
21.512 GeV
(1.072 TeV)
bezier


Colliding d↑d↑ beams. Beam kinetic energy T_d: 2÷5,5 GeV/u
Elastic np CM diff. cross section $d\sigma/d\Omega_{CM}$, mb/sr
1000
100
10
1
0.1
0.01
0.001
0.0001
1e-005
1e-006
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180
Neutron CM scattering angle θ_{CM}, degree
1e+006
100000
10000
1000
100
10
1
0.1
0.01
0.001
Count rate R at luminosity $L_n = 1\times10^{30}$ $cm^{-2}s^{-1}$
Colliding neutrons energy T_n
0.824 GeV
(4.749 GeV)
0.876 GeV
1.427 GeV
1.431 GeV
2.270 GeV
2.413 GeV
3.703 GeV
3.828 GeV
4.184 GeV
(54.068 GeV)
4.297 GeV
4.623 GeV
5.030 GeV
6.111 GeV
(0.104 TeV)
bezier



Colliding d↑d↑ beams. Beam kinetic energy T_d: 2÷5,5 GeV/u
Elastic np CM diff. cross section dσ/dΩ_CM, mb/sr
Neutron CM scattering angle θ_CM, degree
Count rate R at luminosity L_n = 1×10^30 cm^-2s^-1
T_n=4.184 GeV
θ_1,3=18.57°
t_1,3=-2.64 (GeV/c)^2
T_n=5.03 GeV
θ_1,3=171.57°
u_1,4=-0.75 (GeV/c)^2
T_n=1.427 GeV
θ_1,3=97.07°
t_1,3=-10.59 (GeV/c)^2
T_n=1.427 GeV
θ_1,3=145.16°
t_1,3=-17.17 (GeV/c)^2
Colliding neutrons energy T_n
0.824 GeV
(4.749 GeV)
0.876 GeV
1.427 GeV
1.431 GeV
2.270 GeV
2.413 GeV
3.703 GeV
3.828 GeV
4.184 GeV
(54.068 GeV)
4.297 GeV
4.623 GeV
5.030 GeV
6.111 GeV
(0.104 TeV)
bezier

Event rate comparison for the collider and "fix" target experiments

Planned luminosity in the spin experiments at the collider is estimated by a value of $L=1\times10^{30}$ sm^{-2} s^{-1} for the polarized pp colliding beams. Thus 1 count per second will be for the events with total cross section of $\sigma_{tot} \sim 10^{-30}$ sm^{-2} (1 μb).

In the "fix" target experiments with polarized proton target ($n_H \sim 10^{24}$ sm^{-2}) and at the polarized proton beam intensity of $I \sim 10^{10}$ p/cycle, 1 count per second will be for the events with total cross section of $\sigma_{tot} \sim 10^{-34}$ sm^{-2} (100 pb).

Summary

- The possibilities for investigation of the elastic NN scattering observables at NICA collider are shown.
- The differential NN cross section I_{oooo}, analyzing powers for primary reactions with polarized beam A_{oono} or target A_{ooon}, and spin correlation parameters A_{ookk} and A_{oonn} in primary reactions with polarized both the beam and target can be measured.
- The planned luminosity of polarized colliding beams allows to obtain enough high event rate for such measurements.
- Use of the colliding polarized beams has a number of suitable preferences with comparison to the “fixed” target experiments (detectors angular acceptance stretches over full solid angle 4π rad, wider ranges of energy and four momentum transfer , “target” without background impurities).

Thank you for attention

The data planned to be obtained in
the measurements of the elastic
NN scattering observables
will promote a creation
of an adequate phenomenological
and theoretical description
of the NN interaction
above 3 GeV Lab energy region.

We emphasize the following.

“BASIC PRINCIPLE OF SCIENCE: If a theory does not agree with reproducible experimental data, then the theory must be modified.”

The precise existing and those to be obtained experimental data on spin dependent NN values provide experimental guidance for the required modification of the strong interactions theory.

It is imperative to obtain new precise elastic NN spin data over the energy region of interest is obvious now.

Measurement of the Spin-Dependent Observables in Elastic NN Collisions at NICA

Which spin-dehendent values can be measured

by using colliding NN beams at NICA?

Whether experimental conditions

at NICA complex are sufficiently acceptable