Experimental tests of the *hadron* structure in the *hadron* − *hadron* scattering.

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CONTENT:

1) Concept of the point-like (structureless) and non-point-like (composed, cluster, bound-state or nuclear) particles.

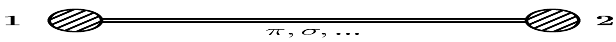
2) Concept breaking experiments:
Oscillation Project with Emulsion-tRacking Apparatus (OPERA): anomaly in flight time of neutrinos from CERN to Gran Sasso (Italy). 23.09.2011

Measurement of the electric dipole moment of the proton and deuteron:
Storage Ring Electric Dipole moment Collaboration (Forschungszentrum Jülich Germany). Measurement 2013-2014.

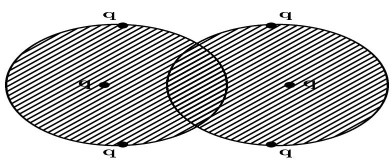
3) Azimuthal angle ϕ dependence of the cross sections and polarizations of the binary $a+b \Longrightarrow a'+b'$ and inclusive $a+b \Longrightarrow a'+X$ $(X = x_1 + x_2 + ... + x_n$ reactions as the experimental test of the particle structure.
Short review of the azimuthal angle ϕ dependence of the existing experimentally observed cross sections and polarizations of the binary $a+b \Longrightarrow a'+b'$ reactions.

1) CRITERION: What object is point-like?

POINT-LIKE PARTICLE: $|V(1,2)| << M_1(M_2)$



PARTICLE EXCHANGE: $|V(1,2)| \sim M_1(M_2)$



OVERLAPPING, CONTACT, QUARK EXCHANGE:
instead of $|V(1,2)| \Longrightarrow$ **interaction of fractals**

1) CRITERION:

Asymptotic particles in QUANTUM FIELD THEORY and in QUANTUM MECHANIC are considered as structureless (point-like) objects which are completely described by three-momenta, mass and quantum numbers only.

Correspondingly, the scattering amplitude and all of the observables are expressed via the mass, three-momenta and quantum numbers of asymptotic particles only.

The same is valid in the general field-theoretical formulations with the quark-gluon degrees of freedom, where hadrons are constructed as quark bound (or cluster) states and the asymptotic composed particle states satisfy the same conditions as the asymptotic states of the structureless (point-like) particles.

Moreover, in the present experiments particles are measured as point-like objects with definite momenta and quantum numbers only.

2) CONCEPT breaking experiments:

OPERA-experiment: anomaly in flight time of neutrinos from CERN to Gran Sasso (Italy). 23.09.2011

The OPERA neutrino experiment at the underground Gran Sasso Laboratory has measured the velocity of neutrinos from the CERN CNGS beam over a baseline of about 730 km with much higher accuracy than previous studies conducted with accelerator neutrinos. The measurement is based on high-statistics data taken by OPERA in the years 2009, 2010 and 2011. Dedicated upgrades of the CNGS timing system and of the OPERA detector, as well as a high precision geodesy campaign for the measurement of the neutrino baseline, allowed reaching comparable systematic and statistical accuracies. An early arrival time of CNGS muon neutrinos with respect to the one computed assuming the speed of light in vacuum of (60.7 $\pm$ 6.9 (stat.) $\pm$ 7.4 (sys.)) ns was measured. This anomaly corresponds to a relative difference of the muon neutrino velocity with respect to the speed of light

$$v(\mu - neutrino) = c + \Delta v$$

$$\frac{\Delta v}{c} = (2.48 \pm 0.28(stat.) \pm 0.30(sys.)) \times 10^{-5}.$$

More than 1500 events

Synchronization of time measures in CERN and Gran Sasso Laboratory ACCURACY $\sim 10^{-9} sec$

Similar results with non-sufficient statistic: 1) in Astrophysics 2) MINOS experiment

2) CONCEPT breaking experiments:

Motivation Storage Ring Electric Dipole moment Collaboration (Forschungszentrum Jülich Germany). Measurement 2013-2014:]

The electric dipole moments (EDM) of fundamental particles are excellent probes of PHYSICS BEYOND THE STANDARD MODEL (SM).

A permanent EDM has not been observed so far for any of them.

It would violate both parity (P) and time reversal (T) invariance. If CPT is assumed to be a valid unbroken symmetry, a permanent EDM would hence be a signature of CP violation. The standard model of particle physics predicts a CP violating EDM in fundamental particles at the multi loop level of amplitude more than five orders of magnitude below the sensitivity of present experiments. Therefore searches for a permanent particle EDM render excellent opportunities to test models beyond standard theory where in some cases they predict effects as large as the presently known experimental bounds.

PROTON electro-magnetic vertex with non-invariant PARITY and TIME-reversion

$$< out;\mathbf{p}'|J_\mu(0)|\mathbf{p};in >= \overline{u}(\mathbf{p}')\{\frac{(p'+p)_\mu}{2m_N}G_E((p'-p)^2)+$$

$$i\sigma_{\mu\nu}\frac{(p'-p)^\nu}{2m_N}G_M((p'-p)^2)+\gamma_5\frac{(p'+p)_\mu}{2m_N}G_{E2}((p'-p)^2)\}u(\mathbf{p})$$

$$G_E(0)=e; \qquad G_H(0)=\mu_p$$

$$G_{E2}(0)=d_{E2} \quad P,\ T \quad non-invariant$$

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Depends on TWO four-vectors p and p' ONLY

$$p \equiv p' \equiv (p_o,\mathbf{p}) = (\sqrt{M^2+\mathbf{p}^2}, p); \quad p' \equiv (p'_o,\mathbf{p}') = (\sqrt{M^2+\mathbf{p}'^2},\mathbf{p}')$$

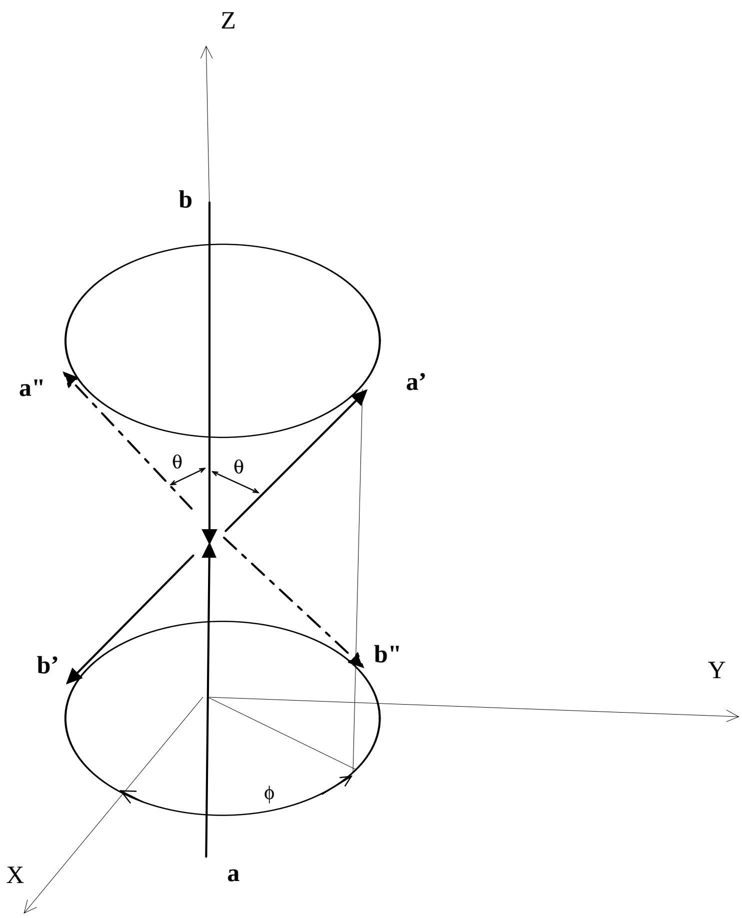
INDEPENDENT are two three vectors ONLY $\mathbf{p}$ and $\mathbf{p}'$

The amplitude of the binary reactions $a+b \Longrightarrow a'+b'$ or of the corresponding inclusive reactions $a+b \Longrightarrow a'+X$ ($X = x_1+x_2+...+x_N$) is embedded on the SCATTERING PLANE because particle a, b, a' and b' are point like and they can be located on the same SCATTERING PLANE.

Therefore, the nontrivial dependence on the azimuthal angle ϕ of the observables of the binary reactions $a+b \Longrightarrow a'+b'$ or of the corresponding inclusive reactions $a+b \Longrightarrow a'+X$ can be considered as the experimental test of the particles a, b, a' and b'.

3) AZIMUTHAL ANGLE ϕ-dependence as indication of the structure of particles

Structureless (point-like) particles in the initial and the final states of the binary reactions $a + b \Longrightarrow a' + b'$ or $a + b \Longrightarrow a' + X$ $(X = x_1 + x_2 + ... + x_n)$ are always embedded on the Three points (structureless particles) are always placed on the plane.



Azimuthal angle ϕ dependence in c.m. system. The cross sections of the binary reactions of the structureless particles are ϕ-independent. The dependence of the polarisations of the binary reactions is a priory analytically given.

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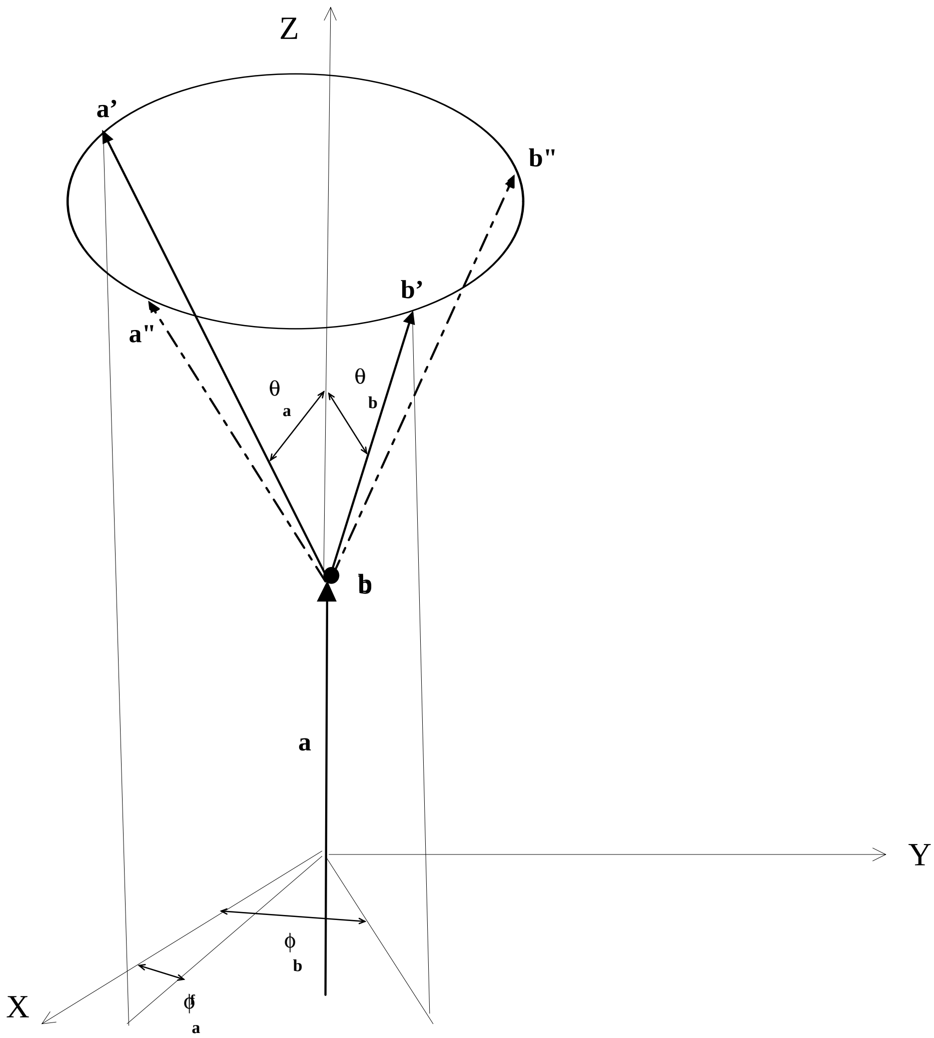


Azimuthal angle ϕ dependence in lab. system. The cross sections $< \frac{d^2\sigma}{d\theta d\phi} >$ of the structureless particles are ϕ-independent. The dependence of the polarisations of the binary reactions is a priory analytically defined.

I. $< \frac{d^2\sigma}{d\theta d\phi} >$ **means average over spins.** $< \frac{d^2\sigma}{d\theta d\phi}(\mathbf{p}', \mathbf{p}) >$ **is embedded in the plane for the point-like particle interactions.**

II. The ϕ**-dependence of the beam and target particle polarizations are decreased via interaction in the final states and average over the final particle spins.**

III. Preferable observable for the ϕ**-dependence are:**

A) Inclusive reactions with the big transverse momentum.

B) Cross sections with big four momentum transfer $|t| \sim M_a^2$**,** $|t| \sim M_b^2$ **and** $|t| \sim M_{a'}^2$ **in** $a + b \Longrightarrow a' + X$**.**

C) Final particle polarizations with the four momentum transfer $|t| \sim M^2$**.**

Where from arise an additional vector which generates the non-trivial ϕ dependence in the cross sections and polarization observables of binary reactions $a + b \Longrightarrow a' + b'$ and corresponding observables of the inclusive reactions $a + b \Longrightarrow a' + X$?

SIMPLEST EXAMPLE:

"Explicitly covariant light-front dynamics (LFD) and relativistic few-body systems."

J.C. Carbonell, B. Degasperis, V.A. Karmanov and J.F. Mathiot."

Physics Reports 300 (1998)215.

LFD is defined on the plane $\omega_\mu x^\mu = \sigma$.

σ covariant light-front time:

Usually—— Non-covariant-time: $\omega_\mu = (1, 0, 0, 0)$ then $\sigma = x_o \equiv t$.

In LFD $t^+ = t + z$ $\omega^{(o)}_\mu = (1, 0, 0, -1)$ and $\omega^{(o)\mu}\omega^{(o)}_\mu = 0$ is convenient for $P_z = \infty$.

In LFD is achieved a quantitative (and some-times qualitative) description of the experimental observables of the elecro-magnetic interactions of the NN-systems in the few GeV energy region.

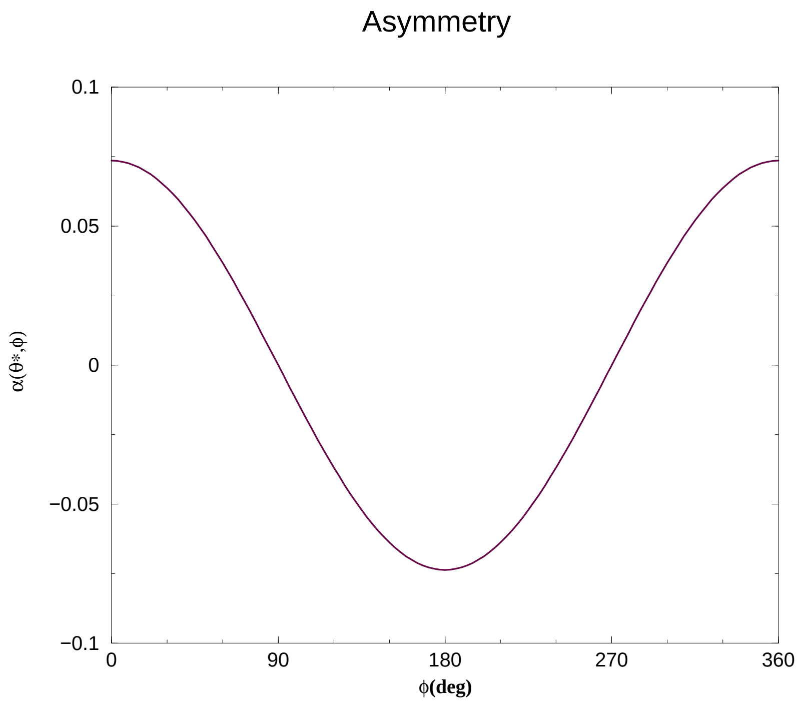
But the corresponding amplitudes depends on the ADDITIONAL vector

$\mathbf{n} = L_{Lorentz\ boost}(\mathbf{P})^\mu \omega^{(o)}_\mu$.

Additional dependence of observables over an azimuthal angle ϕ through the interaction with the covariant time!

EXAMPLES:

Analyzing power A_y in pp collisions.
COSY-TOF (Jülich-2007) $p_{lab}^{beam} = 3065 MeV/c$ $42^o < \theta^* < 46^o$
$|t| \simeq 2(GeV/c)^2$ and $> 7\ 10^6$ events for 24 values of ϕ.



The dependence of $A_y(\theta^*, \phi)$ on azimuthal angle is taken in a cosine function. Therefore the asymmetry by polarized beam proton is

$$Asymmetry\ beam{-}particle\ polarization: \quad \alpha(\theta^*, \phi) = \frac{\frac{d\sigma}{dt}^{\uparrow} - \frac{d\sigma}{dt}^{\downarrow}}{\frac{d\sigma}{dt}^{\uparrow} + \frac{d\sigma}{dt}^{\downarrow}} = P_y A_y(\theta^*) cos\phi$$

$P_x A_x(\theta^* sin\phi) = 0$**, spin of proton is** $P||y \quad P_x = 0$

$$\alpha(\theta^*, \phi) = \frac{n^{\uparrow} - n^{\downarrow}}{n^{\uparrow} + n^{\downarrow}} \quad n^{(\uparrow,\downarrow)} = \frac{d\sigma}{dt}^{(\uparrow,\downarrow)} * Luminescence$$

$$P_y = 0.32 \quad A_y(\theta^* \simeq 45^o) \simeq 0.23(SAID)$$

UNCERTAINTIES: only statistical uncertainties are given by ϕ analyse.

Calibration of the Polarimeter POMME by proton energies between 1 and 2.4 GeV.

Cheung at al, NIS A363(1995) 561.

pp **scattering at 1.6GeV. Second scattering on carbon for calibration and** ϕ **distribution for extraction of the analyzing power of proton-carbon** $A_{pC}(\theta^*)$**.**

$$Asymmetry: \quad \mathcal{R}(\theta,\phi) = \frac{n^{\uparrow} - n^{\downarrow}}{n^{\uparrow} + n^{\downarrow}} = P_p A_{pC} cos\phi$$

$$Fourier\ Analysis \quad \mathcal{R}(\theta,\phi) = A_0(\theta) + A_1(\theta)cos\phi + A_2(\theta)sin\phi + ...$$

$$A_{pC}(\theta) = A_{1(\theta)}/p_p$$

A_2 **gives** $\sim 4\%$ **correction for small four-momentum transfer** t**.**
UNCERTAINTIES: Contribution from $A_2 \sin\phi$ **is** $\sim 4\%$**.**

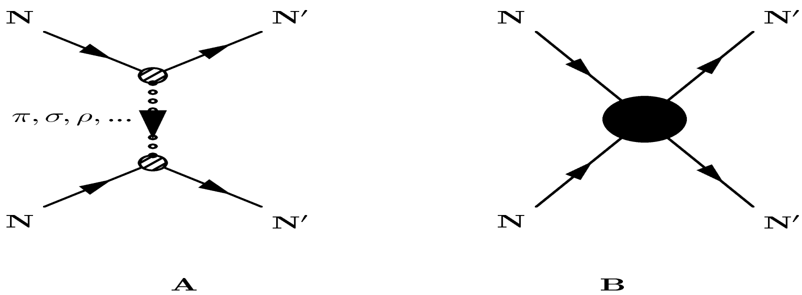
All oscillations are omitted.

RHIC: Polarized p-p elastic scattering at $\sqrt{s} = 200GeV$ with small t.

Oderon-Pomeron problem

Oderon is a putative negative charge conjugate to Pomeron. Oderon-Pomeron determines the leading t-channel term (dominance Regge trajectory) in the high energy region.

I. More complicate as single-pole SINGULARITY at $t = 0$.



ODARON-POMERON as simulation of the NN overlapping (contact) term.

II. $C = +1$ charge, $J = 1$, $I = 0$ (Leader-Trueman, PRD -61 (2000) 077504).

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DOUBLE spin asymmetries $\sigma^{ab} \equiv \frac{d\sigma(a,b)}{dt} / < \frac{d\sigma(a,b)}{dt} >$**:**

$$A_{NN} = \frac{\sigma^{\uparrow\uparrow+\downarrow\downarrow} - \sigma^{\uparrow\downarrow+\downarrow\uparrow}}{\sigma^{\uparrow\uparrow+\downarrow\downarrow} + \sigma^{\uparrow\downarrow+\downarrow\uparrow}}$$

$$A_{SS} = \frac{\sigma^{\uparrow\uparrow-\downarrow\downarrow} - \sigma^{\uparrow\downarrow-\downarrow\uparrow}}{\sigma^{\uparrow\uparrow+\downarrow\downarrow} + \sigma^{\uparrow\downarrow+\downarrow\uparrow}}$$

ϕ**-dependence for the total differential cross section of the point-like protons:**

$$2\pi \frac{d^2\sigma}{d\theta^{c.m.} d\phi}(\theta, \phi) =< \frac{d\sigma}{d\theta^{c.m.}} > [1+$$

$$(P_B + P_T) A_N cos\phi + P_B P_T (A_{NN} cos^2\phi + A_{SS} sin^2\phi)]$$

Polarizations P_B, P_T **are determined through the left-right asymmetries.** A_N **asymmetry of scattered particle**

$$A_N = \frac{\sigma^{\longleftarrow} - \sigma^{\longrightarrow}}{\sigma^{\longleftarrow} + \sigma^{\longrightarrow}}$$

I. The existence of the Oderon-Pomeron states is yet not confirmed

II. There was obtained but not analysed the polarizations for large t**.**

III. The possible violation of the polarizations formulas for the point-like $p-p$ **elastic (i.e. dependence over the variables** $sin\phi$**,** $cos^3\phi$**,** $sin^3\phi, ...$ **of** $\frac{d^2\sigma}{d\theta^{c.m.} d\phi}(\theta, \phi)$ **was not considered.**

STRUCTURELESS (POINT-LIKE) PROTON is described via the definite mass, spin, isospin and four-momentum $q_p = (\sqrt{m_N^2 + \mathbf{q_p}^2}, \mathbf{q}_p)$.

The standard form of the point-like pp scattering amplitude (Bystritky-Lehar 1978)

$$f(E,\theta,\phi) \equiv F(s,t,\phi) = a(E,\theta) + b(E,\theta)(\mathbf{s_1}\cdot\mathbf{n})(\mathbf{s_2}\cdot\mathbf{n})$$

$$+c(E,\theta)(\mathbf{s_1}\cdot\mathbf{m})(\mathbf{s_2}\cdot\mathbf{m})$$

$$+d(E,\theta)(\mathbf{s_1}\cdot\mathbf{l})(\mathbf{s_2}\cdot\mathbf{l}) + e(E,\theta)((\mathbf{s_1}+\mathbf{s_2})\cdot\mathbf{n})$$

Generalisation with sixth T-non-invariant amplitude in La-France-Winternitz 1980.

DEPENDENCE ON THE AZIMUTHAL ANGLE ϕ IS ANALITICALLY SEPARATED:

Mutually orthogonal unit vectors

$\mathbf{n} = \frac{(\mathbf{p}'\times\mathbf{p})}{|(\mathbf{p}'\times\mathbf{p})|}$;

$\mathbf{m} = \frac{(\mathbf{p}'-\mathbf{p})}{|(\mathbf{p}'-\mathbf{p})|}$;

$\mathbf{l} = \frac{(\mathbf{p}'+\mathbf{p})}{|(\mathbf{p}'+\mathbf{p})|}$

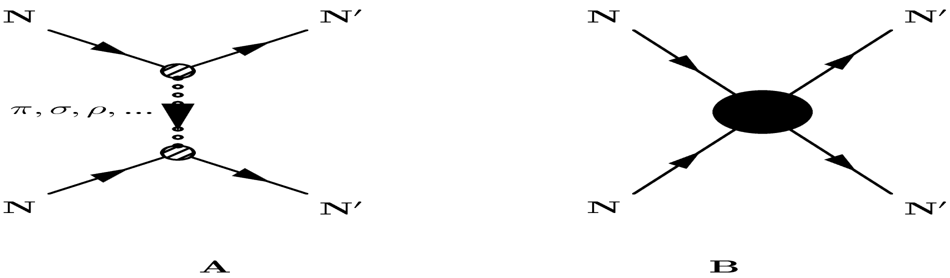
and $\mathbf{p} = \mathbf{q}_1 = -\mathbf{q}_2$.

Simple asymmetries are function of $cos\phi$ only. The double asymmetries are function of $cos\phi$, $cos^2\phi$ and $sin^2\phi$.

Polarization observables of the NN elastic scattering are determined by the a, b, c, d, e ϕ-independent amplitudes.

HADRONS AS A COMPOSITE PARTICLES: OVERLAPPI

CONTACT, QUARK EXCHANGE TERMS

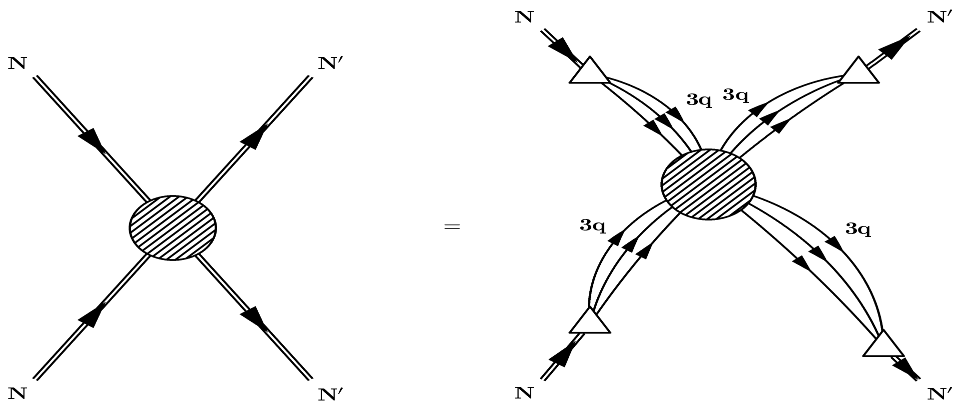


General (nontrivial) dependence on ϕ of the NN scattering amplitude is:

$$f_{composed}(E,\theta,\phi) = a(E,\theta,\phi) + b(E,\theta,\phi)(\mathbf{s_1}\cdot\mathbf{n})(\mathbf{s_2}\cdot\mathbf{n})$$
$$+c(E,\theta,\phi)(\mathbf{s_1}\cdot\mathbf{m})(\mathbf{s_2}\cdot\mathbf{m}) + d(E,\theta,\phi)(\mathbf{s_1}\cdot\mathbf{l})(\mathbf{s_2}\cdot\mathbf{l})$$
$$+e(E,\theta,\phi)((\mathbf{s_1}+\mathbf{s_2})\cdot\mathbf{n})$$

This expression predicts an essential dependence on ϕ of the NN cross sections, polarization observables and asymmetries.

Nucleons are not point-lake particles, but one can measure three-momentum of nucleons only. .
Therefore, the initial and final nucleons and their three-momenta are placed on the same plane. But due to the intermediate multi-quark interactions, the NN amplitude is sufficient different in the different scattering planes.
Degeneracy over ϕ of the NN cross sections is violated.



A. I. MACHAVARIANI and AMAND FAESSLER;//

Annals of Phys.409(2004)p.49-92:

Separation of the quark-gluon and meson degrees of freedom in the NN potential.

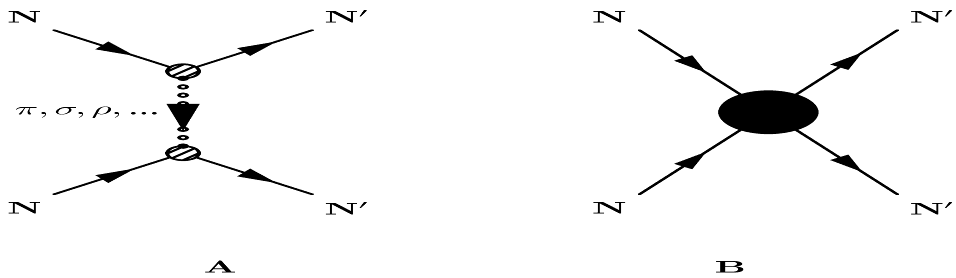


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Diagram A: perturbation (one-particle exchange) part of the NN interaction

Diagram B: non-perturbation part of interaction.

Diagram B contains the effective $N - M\ N'$ vertex with M which is constructed from $q\overline{q}$ and $2q - 2\overline{q}$.

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ϕ-dependence lead to the size parameter of interaction, which indicates the inhomogeneous distribution of the intermediate particles in the different scattering-planes.

This inhomogeneous distribution of the intermediate particles corresponds to the inhomogeneous potential (interaction).

TWO-BODY POINT-LIKE PARTICLE INTERACTION $\Longleftrightarrow$ MANY-BODY INTERMEDIATE PARTICLE INTERACTION

The experimental evidence of the proton structure effects can be done by observation of the anomalous ϕ distributions in the related observables. For the pp collisions this implies the evidence the following anomalies:

Anomalous $sin\phi$, $sin^3\phi$, $cos^3\phi$ etc. dependence of asymmetries and differential cross sections.

The most promising energy region for determination of these anomalous (ϕ) distribution is $E \sim 2 - 5GeV$ with $|t| \sim 1(Gev/c)^2$, where the quark structure effects are nowadays indisputable.

The inhomogeneity in this region is generated by the mass of nucleon and masses of the intermediate particles.

In the high energy region $E \sim 100{-}200GeV$ the anomalous ϕ dependence can generate the intermediate quark cluster or quark over-lapping interaction.

The SCALE of the anomalous ϕ dependence can be estimated:

I. If the total accuracy of the presented experimental data about ϕ distribution of the spin asymmetries is less than 1%.

Unfortunately, the non-perturbation multi-loop calculations are model dependent and their accuracy is non-predictable.

II. If the four-momentum transfer is big $|t| \sim M_N$

III. Inclusive reactions $a + b \Longrightarrow a' + X$ with big transverse momentum.

CONCLUSION

During the last 20 years the accuracy of the different measuring instruments is sufficiently improved. This allows to perform the high precision experiments to justify or refute the first principles of the particle physics. .

The high precision measurement of the azimuthal ϕ-angle in the cross sections and polarization observables of the reactions $a + b \Longrightarrow a' + b'$ or $a + b \Longrightarrow a' + X$ $(X = x_1 + x_2 + ... + x_n)$ provides us with the model independent experimental test of the hadron structure.