# Chiral symmetry and form factors of neutrino-nucleon interactions.

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QFTHEP '11, Sochi 24th Sept.– 1st Oct.

# Outline

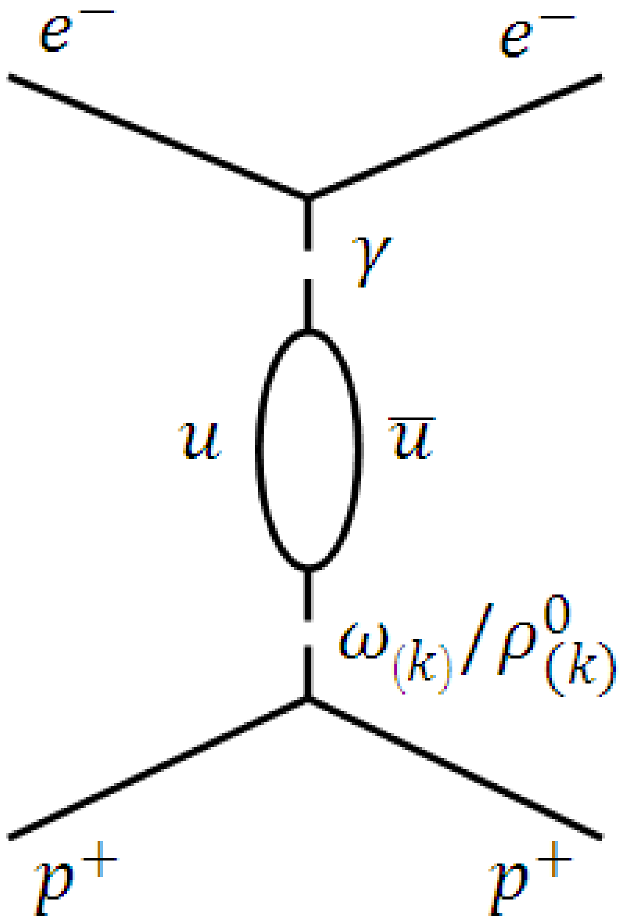
1. Previous studies of elastic eN scattering

2. The united theory of lepton-nucleon interactions

   - Neutrino Charged Currents
   - Neutrino Neutral Currents

# Part I
# Elastic eN scattering
# (Previous studies)

# Vector meson dominance for eN scattering




The idea was originally suggested by **Sakurai**(1969).

Photon **hadronize** to the set of $\boldsymbol{\omega_{(k)}}$ or $\boldsymbol{\rho^0_{(k)}}$ meson via quark loop.

Amplitudes for the hadronization should be introduced in the proper way:

1) either purely **phenomenologically**
2) or using some **regular method**

# The further development of the model of V.D. was conducted by

**E.L. Lomon** *"Extended Gari-Krumpelmann model fits to nucleon electromagnetic form factors"* Phys. Rev. C 64, 035204 (2001)

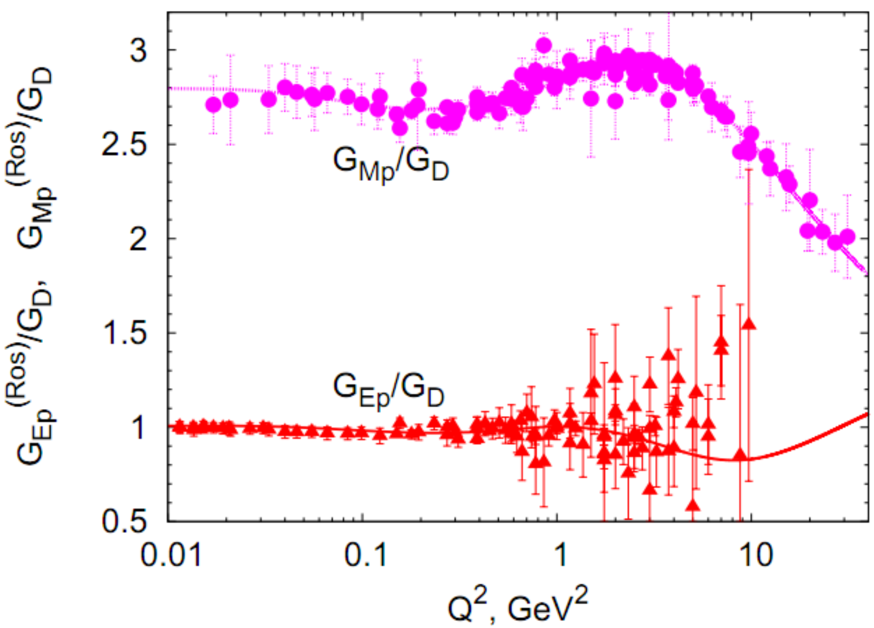
**F. Iachello** *"Structure of the nucleon from electromagnetic form factors."* Eur.Phys.J.A19(2004)

**G. Vereshkov**
**O. Lalakulich** *"Logarithmic corrections and soft photon phenomenology in the multipole model of the nucleon form factors"* Eur. Phys. J. A34 (2007)

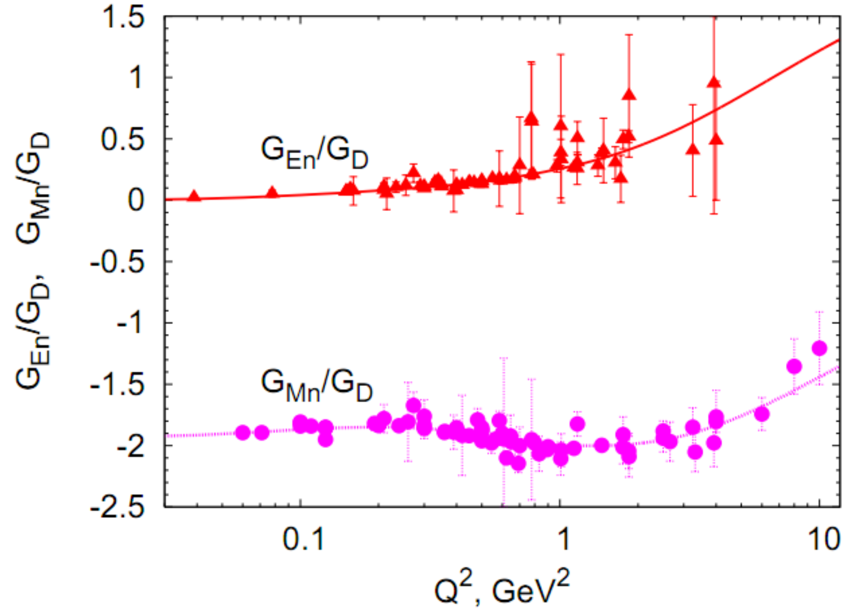
and others

The cross section of the **elastic eN scattering** is parameterized by two functions $\mathbf{G_E(Q^2)}$ and $\mathbf{G_M(Q^2)}$ – electric and magnetic form factors correspondingly.

Results obtained by Vereshkov and Lalaculich using V.D. model:




**proton FFs**




**neutron FFs**

$$G_D = \left(1 + \frac{Q^2}{0.71}\right)^{-2}$$

# Part II
# The united theory of lepton-nucleon interactions

# Physical principles

$$eN \to eN$$

$$\nu n \to \mu^- p^+$$

$$n \to p^+ e^- \bar{\nu}$$

$$\bar{\nu} p^+ \to \mu^+ n$$

$$\nu N \to \nu N$$

- Vector and **pseudovector** dominance model
- Hadronization of intermediate bosons to the set of mesons.
- **Multi-gauge theory**
- **Chiral symmetry** of strong interactions
- **Parameters are the same** for electron and neutrino processes

**Additional form factors** are taken into account because of axial couplings.

# Parameters.

We inroduce **Dirac** terms as $g\sum_k w_k\,\bar{n}\,\gamma^\mu\,n\,\omega_\mu^{(k)}$, where

$$\begin{cases} g & \text{is coupling constant} \\ w_k & \text{weight of each particular generation} \\ \omega_\mu^{(k)} & \text{corresponding meson field} \end{cases}$$

For the gauge invariance: $\boxed{\sum_k w_k = 1}$

Not only **Dirac** ($\gamma^\mu$) but **Pauli** ($\sigma^{\mu\nu}$) terms should be introduced to the model with their own parameters $\boldsymbol{\mu_k}$ as well.

There are two sets of parameters $\mathbf{w_k}$ and $\boldsymbol{\mu_k}$ for

1) scalar (ω,f) mesons
2) vector(ρ,a) mesons.

To describe *four meson fields* **four gauge groups** are necessary.

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# Objects of the theory and gauge groups.

| | | |
|---|---|---|
| $N=\binom{p}{n}$ | | $U_L^s(1)^{(k)}\times SU_L^s(2)^{(k)}\times U_R^s(1)^{(k)}\times SU_R^s(2)^{(k)}\times U^{EW}(1)$ |
| $\Psi=\binom{\nu_e}{e}$ | | $U^{EW}(1)\times SU_L^{EW}(2)$ |
| **Higgs sector** | **1.** | $SU_L^{EW}(2)\times U_L^s(1)^{(k)}\times SU_L^s(2)^{(k)}$ |
| | **2.** | $U^{EW}(1)\times U_R^s(1)^{(k)}\times SU_R^s(2)^{(k)}$ |
| | **3.** | $U_L^s(1)^{(k)}\times SU_L^s(2)^{(k)}\times U_R^s(1)^{(k)}\times SU_R^s(2)^{(k)}$ |
| | **4.** | $U_L^s(1)^{(k)}\times U_R^s(1)^{(k)}$ |
| | **5.** | $U^{EW}(1)\times SU_L^{EW}(2)$ |

# Charged currents

# Mixing.

Higgs field $SU_L^{EW}(2) \times U_L^s(1)^{(k)} \times SU_L^s(2)^{(k)}$ and one from **SM** generate quadratic form via spontaneous symmetry breaking with non-zero vacuum expectation value.

It's **diagonalization leads to** small mixing between fields:

$$W^{\pm} \Longleftrightarrow L^{\pm}_{(k)} = \frac{1}{\sqrt{2}}(\rho^{\pm}_{(k)} + a^{\pm}_{(k)})$$

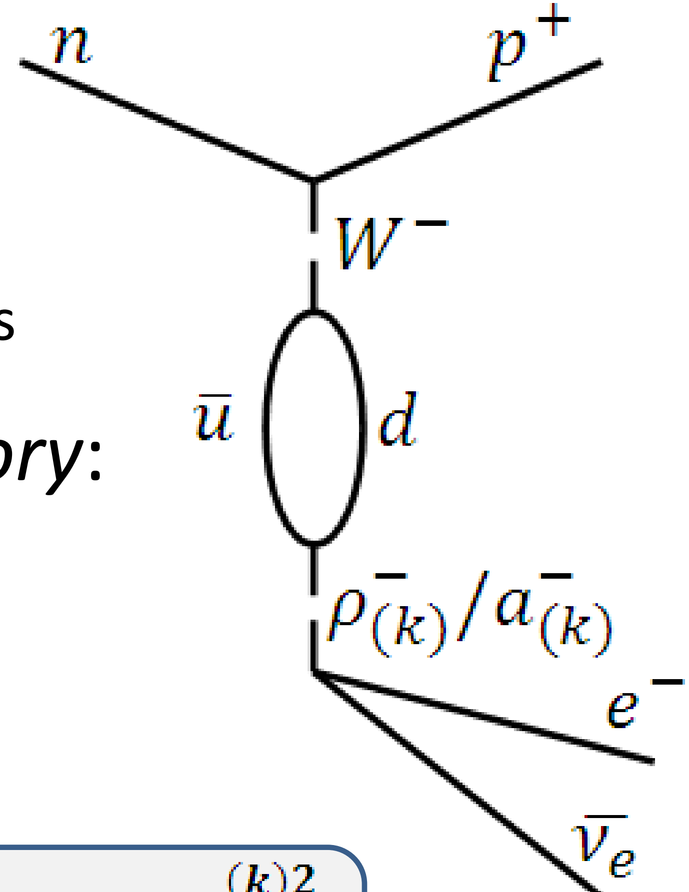
In this way we receive **effective lepton – meson vertex**.

# β-decay

Standard expression originates from effective Fermi theory:

$$|M|^2 = 16\, G_F^2 \cos^2\theta_c\, (1 + 3\alpha)$$

where $\alpha = 1.25$ is defined from experiments




## *Connection with the gauge theory*:

$G_F$ is formed by $\left\{ \begin{array}{l} \text{mixing parameter} \\ \text{group constants} \\ \text{meson propagators} \end{array} \right.$

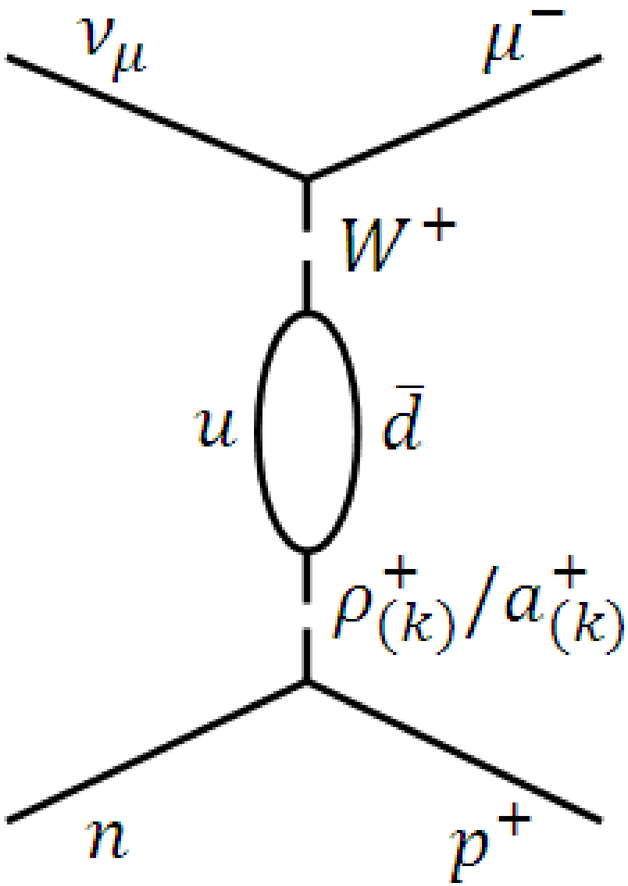
$\cos\theta_c$ occurs due to u-d quark twist

Expression for $\alpha$ via theoretical parameters:
(witch is used for refit of eN data)

$$\boxed{\alpha = \sum_k w_k \frac{m_\rho^{(k)2}}{m_a^{(k)2}}}$$

- sum rule

# Quasi elastic νN scattering




In this case the cross section is parameterized by ***four*** form factors**:**

1. Vector Dirac $\mathbf{F_1(Q^2)}$
2. Vector Pauli $\mathbf{F_2(Q^2)}$
3. Axial Dirac $\mathbf{G_A(Q^2)}$
4. Pseudoscalar $\mathbf{G_{PS}(Q^2)}$

First and second are not independent , they strongly related with $\mathbf{G_E(Q^2)}$ and $\mathbf{G_M(Q^2)}$ from **eN scattering** .

Contribution of $\mathbf{G_{PS}(Q^2)}$ is proportional to lepton masses and **negligible.**

Thus, only $\mathbf{G_A(Q^2)}$ should be determined from experimental data.

# Quasi elastic νN scattering

$$F_1(Q^2) = \sum_k \frac{w_k\, m_\rho^{(k)2}}{m_\rho^{(k)2} + Q^2}; \quad F_2(Q^2) = \sum_k \frac{\mu_k\, m_\rho^{(k)2}}{m_\rho^{(k)2} + Q^2}; \quad G_A(Q^2) = \sum_k \frac{w_k\, m_\rho^{(k)2}}{m_a^{(k)2} + Q^2};$$

$$\sum_k w_k\, m_\rho^{(k)2} = 0 \qquad \sum_k \mu_k\, m_\rho^{(k)2} = 0 \qquad \sum_k \mu_k\, m_\rho^{(k)4} = 0$$

In high $Q^2$ region QCD gains its power, that's why we should take into account QCD asymptotes, which were calculated in following papers:


S.J. Brodsky, G.R. Farrar, Phys.Rev. **D11**,1309 (1975)

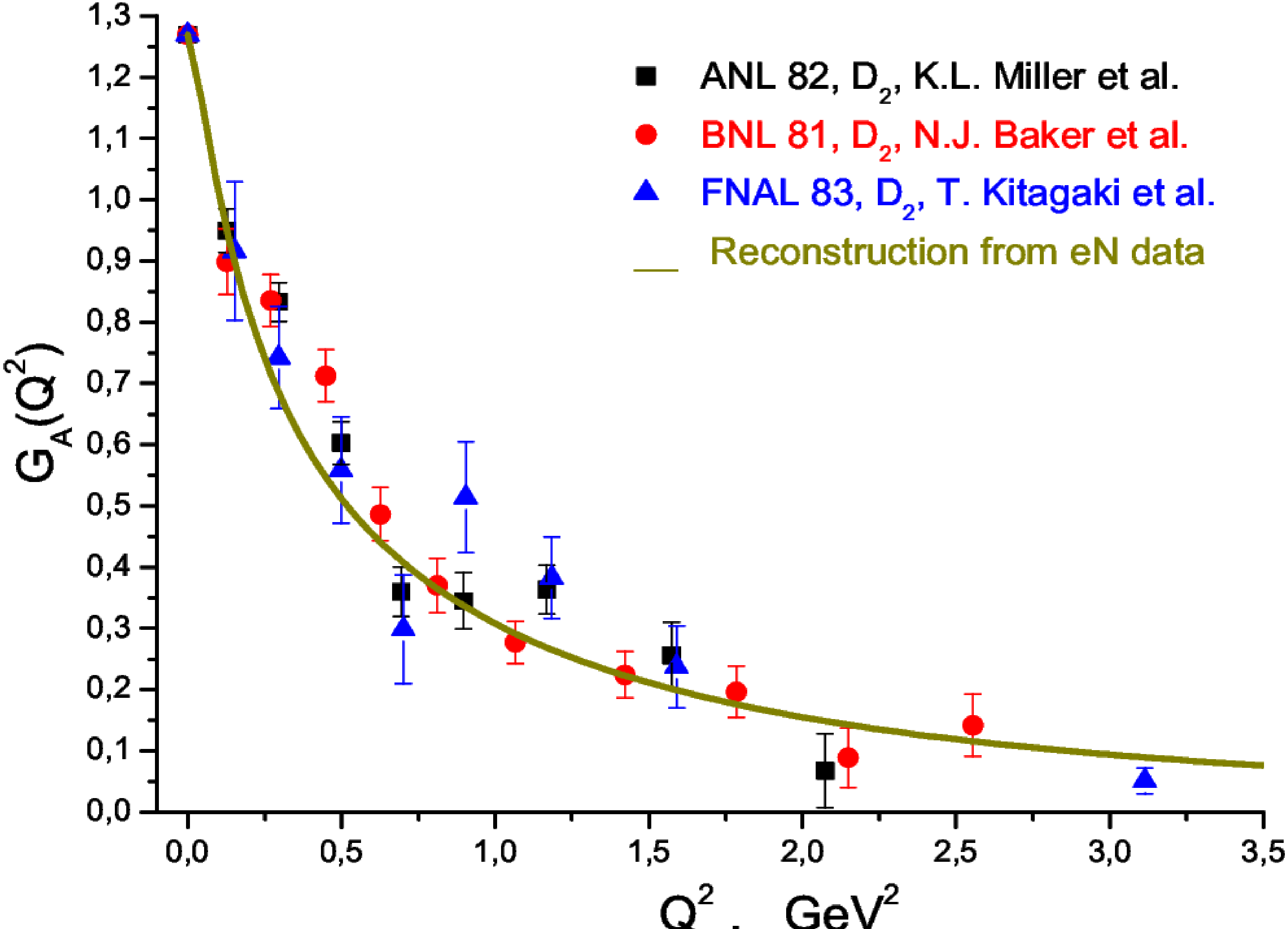
G.P. Lepage, S.J. Brodsky, Phys. Rev. **D22**,2157 (1980)

A.V. Belitsky, X.d. Ji, F. Yuan, Phys Rev Lett. **91**, 092003 (2003)

S.J. Brodsky, J.R. Hiller, D.S. Hwang, V.A. Karmanov, Phys. Rev., **D69,** 0760001 (2004)


In case of **three meson generations**,
if all **sum rules** and **eN results** are mentioned
there are ***no free parameters*** for $G_A(Q^2)$.

The theory describes scattering on **free nucleons**. That is why only **deuterium** chamber experiments could be used. Results are following:



# Neutral currents

# Mixing

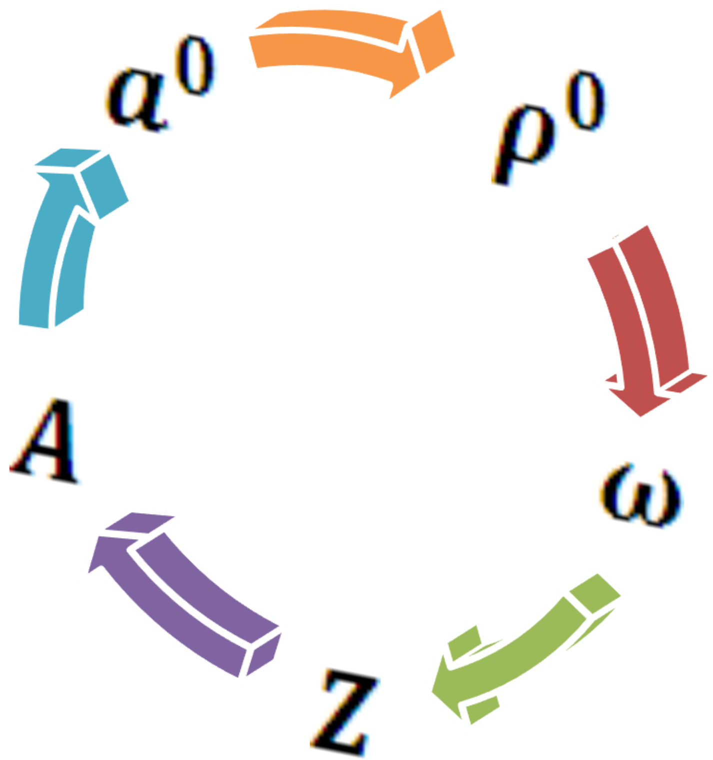
An additional mechanism is required to introduce effective **e-ω vertex**. It is **U(1) mixing**.

$$U^{EW}(1) \rightarrow B_{\mu} \qquad U_L^s(1)^{(k)} + U_R^s(1)^{(k)} \rightarrow \omega_{\mu}$$

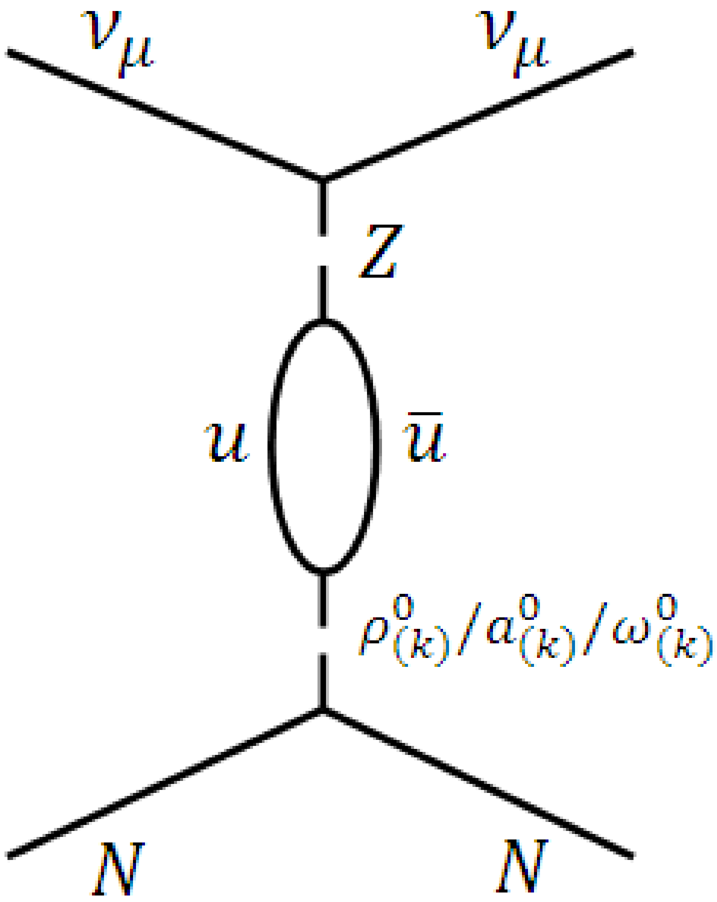
Cross term in kinematic sector is not forbidden by symmetry principles:

$$-\frac{1}{4} B_{\mu\nu} B^{\mu\nu} + \varepsilon\, B_{\mu\nu}\omega^{\mu\nu} - \frac{1}{4}\omega_{\mu\nu}\omega^{\mu\nu}$$

Diagonalization of both kinematic and Higgs quadratic forms leads to mixing of **five fields**



# Elastic νN scattering




The main goal is to reproduce data on elastic νN scattering.
Only one deuterium chamber experiment is available – **BNL E-734**.

**Current status:**

– Mixing has been **done** successfully

–The full lagrangian of neutral current sector has been written. It **does not contain** undetermined parameters.

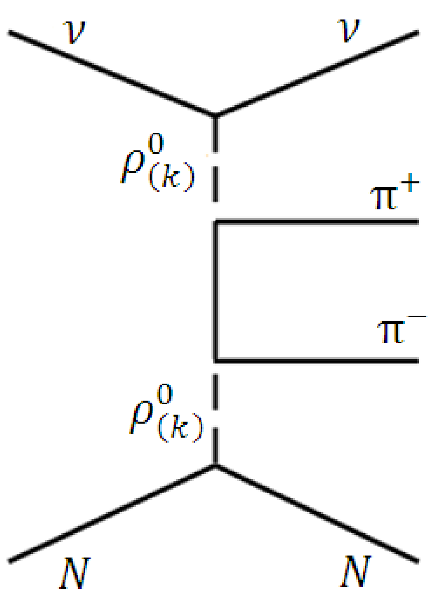
– Comparison with experimental data is **not finished** yet.

# Conclusions.

• Gauge theory of **lepton – nucleon interactions** has been investigated.

• It is based on **meson dominance** and **chiral symmetry** of strong interactions.

• **Asymptotic** conditions, fit of **eN data** and **β-decay data** allow to **fix** all the parameters.




The theory also gives an opportunity of studying some other processes caused by strong interactions.