New approach in separate experimental determination of baryon EM form factors $|G_E^B(t)|$ and $|G_M^B(t)|$ in time-like region

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Outline

INTRODUCTION

According to $SU(3)$ classification of hadrons the ground state baryons

$p, n, \Lambda, \Sigma^+, \Sigma^0, \Sigma^-, \Xi^0, \Xi^-$.

are found in one $1/2^+$ baryon octet.

The electromagnetic (EM) structure of all these particles is completely described by two independent functions,

electric $G_E^B(t)$

and **magnetic** $G_M^B(t)$

form factors (FFs) as functions of **one variable**.

INTRODUCTION

a) **in the space-like region** this variable is squared momentum $t = -Q^2$, **transferred by the virtual photon,** γ^* and the FFs $G_E^B(t)$ and $G_M^B(t)$ are directly connected with **experimentally measurable differential cross section** of the elastic scattering of unpolarized electrons on unpolarized baryons
$e^- B \to e^- B$
by the relation

$$\frac{d\sigma^{lab}(e^- B \to e^- B)}{d\Omega} = \frac{\alpha^2}{4E^2} \frac{cos^2(\theta/2)}{sin^4(\theta/2)} \frac{1}{1 + (\frac{2E}{m_B}) sin^2(\theta/2)}$$

$$\times [\frac{[G_E^B(t)]^2 - \frac{t}{4m_B^2}[G_M^B(t)]^2}{1 - \frac{t}{4m_B^2}} - 2\frac{t}{4m_B^2}[G_M^B(t)]^2 tan^2(\theta/2)] \qquad (1)$$

INTRODUCTION

with $\alpha = 1/137$ the fine structure constant, E the incident electron energy and θ scattering angle.

INTRODUCTION

b) **in the time-like region** this variable is **total energy squared** $t = W^2$ **in the c.m. system** and the FFs $G_E^B(t)$ and $G_M^B(t)$ are connected with **experimentally measurable total cross section** of the electron-positron annihilation into baryon-antibaryon pair

$$\sigma_{tot}^{c.m.}(e^+e^- \to B\bar{B}) = \frac{4\pi\alpha^2\beta_B}{3t}[| G_M^B(t) |^2 + \frac{2m_B^2}{t} | G_E^B(t) |^2] \quad (2)$$

with

$$\beta_B = \sqrt{1 - \frac{4m_B^2}{t}} \quad (3)$$

the **velocity of the baryon in the** e^+e^- **c.m. system**,

INTRODUCTION

and also with corresponding **experimentally measurable differential cross section**

$$\frac{d\sigma^{c.m.}(e^+e^- \to B\bar{B})}{d\Omega} = \frac{\alpha^2\beta_B C}{4t}[\mid G_M^B(t) \mid^2 (1+\cos^2\theta_B) + + \frac{4m_B^2}{t} \mid G_E^B(t) \mid^2 \sin^2\theta_B] \quad (4)$$

where

$$C = \frac{\pi\alpha}{\beta_B} \frac{1}{1-\exp(-\pi\alpha/\beta_B)} \quad (5)$$

is the **Coulomb correction factor** for a point-like baryon, assuming that the baryon is point-like above the $B\bar{B}$ production threshold, and θ_B is the polar angle of the baryon in the e^+e^- c.m. system.

INTRODUCTION

NOTE:
There are **no measurements on the differential cross section (1) of elastic scattering of electrons on hyperons**, since one can not practically prepare any target from hyperons.

A **measurement of the elastic scattering of charged Σ^--hyperon on atomic electrons** for small values of t is done and the mean squared charged radius $< r^2_{\Sigma^- E} >= 0.915 fm^2$ has been determined.

INTRODUCTION

On the other hand, just from the measured differential cross section (1) on the elastic scattering of the unpolarized electrons on unpolarized protons $e^-p \to e^-p$ at different energies **a lot of data** on the proton EM FFs $G_E^p(t)$ and $G_M^p(t)$, **by the so-called Rosenbluth method**, has been obtained.

For the magnetic FF $G_M^p(t)$ they are presented in Fig.1.

INTRODUCTION

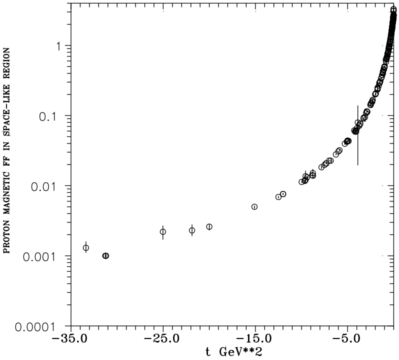


Figure: Proton magnetic FF data in the space-like ($t < 0$) region

INTRODUCTION

Similar **data with dipole behavior** are available also for the electric proton FF $G_E^p(t)$, though dependence of the differential cross section (1) on $G_E^p(t)$ in comparison with $G_M^p(t)$ for large values of t is suppressed.

Even the **scaling law between** $G_E^p(t)$ **and** $G_M^p(t)$ FFs in the form

$G_M^p(t)/\mu_p = G_E^p(t)$

has been established and believed up to 2000.

INTRODUCTION

With the papers

M. K. Jones et al, *Phys. Rev. Lett.* **84**, 1398 (2000).
O. Gayou et al, *Phys. Rev. Lett.* **88**, 092301 (2002).
V. Punjabi et al, *Phys. Rev.* C **71**, 055202 (2005).

a **new era of a determination of data on proton EM FFs starts**, which clearly brings the light into the data obtained by the **Rosenbluth method**.

INTRODUCTION

The new method consists in a simultaneous measurement of **the transverse component**

$$P_t = \frac{h}{I_0}(-2)\sqrt{\tau(1+\tau)}G_{Ep}G_{Mp}\tan\theta/2 \qquad (6)$$

and **the longitudinal component**

$$P_l = \frac{h(E_e + E_{e'})}{I_0 m_p}\sqrt{\tau(1+\tau)}G_{Mp}^2\tan^2\theta/2 \qquad (7)$$

of **the recoil proton's polarization** $\overrightarrow{P}$ in the polarized electron scattering plane of the polarization transfer process $\overrightarrow{e}\,p \to e\,\overrightarrow{p}$.

INTRODUCTION

Then **experimental points on the ratio $\mu_p G_E^p(t)/G_M^p(t)$ in the space-like region** from P_t and P_l are extracted by means of the relation

$$\mu_p \frac{G_{Ep}}{G_{Mp}} = -\frac{P_t}{P_l}\frac{(E_e + E_{e'})}{2m_p} \tan\theta/2. \quad (8)$$

The results are seen in Fig.2.

INTRODUCTION

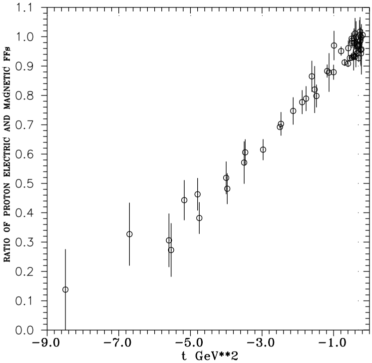


Figure: Data on the ratio $\mu_p G_E^p(t)/G_M^p(t)$ in the space-like ($t < 0$) region from polarization experiments

INTRODUCTION

These data clearly demonstrate that **a general belief in the dipole behavior of the proton electric FF** $G_E^p(t)$ **in the space-like region is no more valid !**

Moreover, **by the analysis of all existing data** on nucleon EM FFs **in space-like and time-like regions simultaneously** with the sophistical *Unitary&Analytic* (U&A) model already more than 10 years ago **an existence of the zero** of the proton electric FF $G_E^p(t)$ approximately at $t_z = -13$ GeV^2 **has been predicted.**

C. Adamuscin, S. Dubnička, A. Z. Dubničková, P. Weisenpacher, *Prog. Part. Nucl. Phys.* **55**, 228 (2005).

INTRODUCTION

A similar situation exists in **the data on baryon EM FFs in the time-like region**.

There are only few experimental points on $\sigma_{tot}(e^+e^- \to Y\bar{Y})$, $Y = \Lambda^0, \Sigma$ and Ξ, and **a lot of data has been obtained** on $\sigma_{tot}(e^+e^- \to p\bar{p})$.

However, it is not a simple task to **draw out a separate information on both** $| G_E^p(t) |$ **and** $| G_M^p(t) |$ **FFs** from $\sigma_{tot}(e^+e^- \to p\bar{p})$.

INTRODUCTION

Practically it has been realized by means of the following two assumptions:

- either it was assumed the equality $\mid G_E^p(t) \mid = \mid G_M^p(t) \mid$, which, however, is **exactly valid only at the threshold of a production of $p\bar{p}$ pairs**, as one can immediately see from definitions of $G_E^p(t)$ and $G_M^p(t)$ through Dirac and Pauli FFs
- or it was assumed the identity $\mid G_E^p(t) \mid = 0$ for the whole interval of measurements and this assumption is **by no means justified**.

Despite of these problesms the data on the absolute value of the proton magnetic FF in time-like region have been obtained as they are presented in Fig.3.

INTRODUCTION

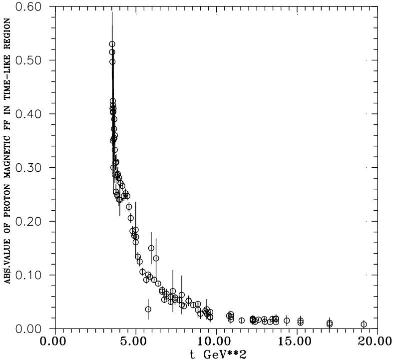


Figure: Proton magnetic FF data in the time-like $(t > 0)$ region

SEPARATE DETERMINATION OF BARYON EM FFs IN TIME-LIKE REGION

To what extent one can believe in these data on proton magnetic FF in time-like region?

Recently **new approach in a determination of the proton magnetic FF** for $t > 4m_p^2$ appeared

J. Lees et al. (BaBar Collab.), *Phys. Rev.* D **87**, 092005 (2013).
M. Ablikim et al. (BESIII Collab.), *Phys. Rev.* D **91**, 112004 (2015).

by a measurement of the proton polar angle θ_p distribution at the SLAC PEP-II asymmetric-energy e^+e^- collider and also at the BEPCII double-ring e^+e^- collider in Beijing.

SEPARATE DETERMINATION OF BARYON EM FFs IN TIME-LIKE REGION

Both centers **dispose an enough large integrated luminosity** L for such experiments, in order **to provide model independent values of** $|G_M^p(t)|$, which can in principle prove or disprove correctness of the values from the measured total cross sections.

The method consists **in a fitting of the data on the proton polar angle** θ_p **distribution** by

$$F(\cos\theta_p) = N_{norm}[1 + \cos^2\theta_p + \frac{4m_p^2}{t}(R^p)^2(1 - \cos^2\theta_p) \qquad (9)$$

where $R^p = | G_E^p/G_M^p |$, $N_{norm} = \frac{2\pi\alpha^2\beta L}{4t}[1.94 + 5.04\frac{m_p^2}{t}R^2] | G_M^p |^2$ is the overall normalization factor.

SEPARATE DETERMINATION OF BARYON EM FFs IN TIME-LIKE REGION

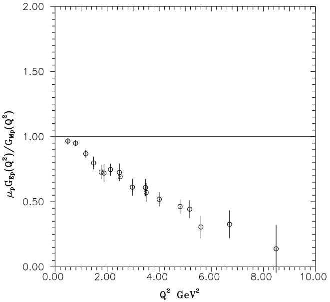
The results of the fitting are the **absolute values of the magnetic proton FF** $\mid G_M^p(t) \mid$ **and the ratio** $R^p = \mid G_E^p(t)/G_M^p(t) \mid$, from BaBar Collab. at $t = 3.66, 3.95, 4.25, 4.62, 5.29, 7.29 GeV^2$ and from BESIII Collab. at $t = 4.98, 5.76, 9.39 GeV^2$.

Nine points not far away from the proton-antiproton threshold is **not enough to verify correctness of existing data on** $\mid G_M^p(t) \mid$ obtained by other methods. So, finally we have decided **to investigate a consistency of obtain results on** $R^p = \mid G_E^p(t)/G_M^p(t) \mid$ with all other existing nucleon FF data in space-like and time-like region by means of the sophistical 9 resonance $U\&A$ nucleon EM structure model, respecting SU(3) symmetry and OZI rule violation.

EXPERIMENTAL STATUS ON NUCLEON EM STRUCTURE

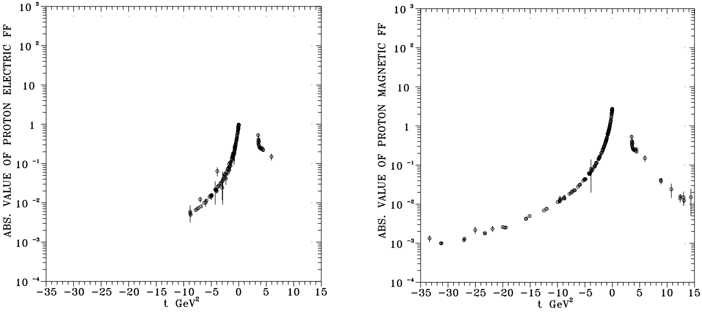
Present-day experimental information on the nucleon EM FFs $G_E^p(t)$ $G_M^p(t)$, $G_E^n(t)$, $G_M^n(t)$ consists of **10 different sets of data in various regions** and they are graphically presented in the following Figs.

EXPERIMENTAL STATUS ON NUCLEON EM STRUCTURE



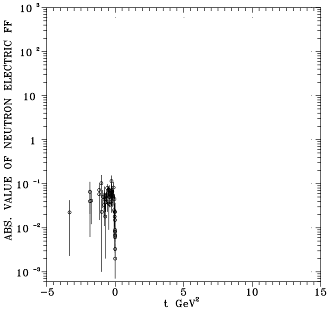
New JLab proton polarization data on the **ratio** $\mu_p G_E^p(t)/G_M^p(t)$, which **clearly demonstrate violation of the dipole behavior of** $G_E^p(t)$ **in space-like region**.

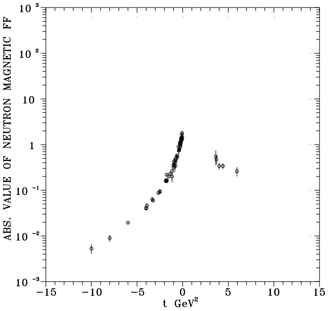
EXPERIMENTAL STATUS ON NUCLEON EM STRUCTURE



Experimental data on **proton electric and magnetic FFs** in space-like and time-like regions.

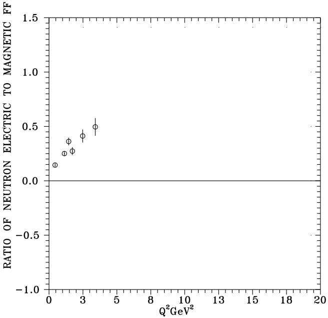
EXPERIMENTAL STATUS ON NUCLEON EM STRUCTURE





Experimental data on **neutron electric and magnetic FFs** in space-like and time-like regions.

EXPERIMENTAL STATUS ON NUCLEON EM STRUCTURE



Neutron polarization data on the **ratio** $\mu_n G_E^n(t)/G_M^n(t)$.

CONSISTENCY CHECK OF R^p WITH OTHER NUCLEON EM STRUCTURE DATA

The nucleon *U&A* EM structure model **respects all known theoretical properties** of nucleon EM FFs, like

- assumed analyticity
- unitarity conditions
- normalizations
- experimental fact of a creation of vector-meson resonances in e^+e^--annihilation processes into hadrons
- asymptotic behaviors as predicted by the quark model
- SU(3) symmetry and OZI rule violation

CONSISTENCY CHECK OF R^p WITH OTHER NUCLEON EM STRUCTURE DATA

Consideration of the $SU(3)$ symmetry in nucleon EM structure model means - **always complete trinity of vector-mesons ($\rho, \omega, \phi; \rho', \omega', \phi'$; etc.) has to be taken into account** as they are presented in Review of Particle Physics

$\rho(770), \omega(782), \phi(1020)$
$\omega'(1420), \rho'(1450)), \phi'(1680)$
$\omega''(1650), \rho''(1700), \phi''(2170)$.
and by a consideration of contributions of ϕ mesons also **OZI rule violation is fulfilled**.

The results are presented in Fig.8, from which one see that they are not very consistent with all other existing nucleon EM FF data.

CONSISTENCY CHECK OF R^p WITH OTHER NUCLEON EM STRUCTURE DATA

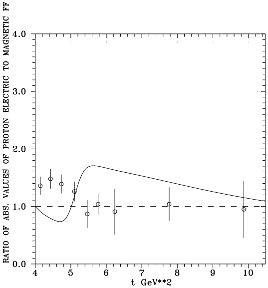


Figure: Prediction of the absolute value of proton electric to magnetic FFs ratio behavior in time-like region by *U&A* model respecting $SU(3)$ symmetry and OZI rule violation.

CONSISTENCY CHECK OF R^p WITH OTHER NUCLEON EM STRUCTURE DATA

The previous Fig. shows, that the **new method of the separate experimental determination of proton EM FFs in time-like region** is in the phase of a development and several values on the ratios R^p and $|G^p_M(t)|$ obtained by *BaBarColl*. and by *BESIIIColl*. have to be considered only as **demonstration of a perspective of the approach based on the measurement of the proton polar angle θ_p distribution.**

We are convinced that such experiments will be improved in a precision and in future they will produce correct values of R and $|G_M(t)|$ separately not only for protons but also for other members of the $1/2^+$ octet baryons, including hyperons.

U&A MODEL OF Λ HYPERON EM STRUCTURE

Therefore, further **we shall try to predict**, by means of the corresponding *U&A* model, **a behavior of** $|G_M^\Lambda(t)|$ **and** R^Λ **for the** Λ**-hyperon,** which are very useful to be known at the preparation of their experimental determination from the measured Λ-hyperon polar angle θ_Λ distribution at the $e^+e^- \to \Lambda\bar{\Lambda}$ process.

The EM structure of the Λ-hyperon is **completely described by two independent functions, the electric** $G_E^\Lambda(t)$ **and magnetic** $G_M^\Lambda(t)$ **FFs**, dependent on one variable, momentum transfer squared $t = -Q^2$.

U&A MODEL OF Λ HYPERON EM STRUCTURE

These both FFs can be **decomposed only into iso-scalar parts of the Dirac and Pauli FFs**

$$G_E^\Lambda(t) = F_{1s}^\Lambda(t) + \frac{t}{4m_\Lambda^2} F_{2s}^\Lambda(t) \qquad (10)$$

$$G_M^\Lambda(t) = F_{1s}^\Lambda(t) + F_{2s}^\Lambda(t)$$

since the Λ-hyperon has no charged partner.

U&A MODEL OF Λ HYPERON EM STRUCTURE

Then the *U&A* model of Λ-hyperon EM structure is obtained by a substitution for iso-scalar parts of the Dirac and Pauli FFs **one analytic and smooth from** $-\infty$ **to** $+\infty$ **function** in the forms

U&A MODEL OF Λ HYPERON EM STRUCTURE

$$F^{\Lambda}_{1s}[V(t)] = \left(\frac{1-V^2}{1-V_N^2}\right)^4 \cdot \quad (11)$$

$$\cdot \Bigg[H_{\phi''}(V)H_{\omega'}(V)\frac{(C^{1s}_{\phi''}-C^{1s}_{\omega'})}{(C^{1s}_{\phi''}-C^{1s}_{\omega''})} + H_{\omega''}(V)H_{\omega'}(V)\frac{(C^{1s}_{\omega''}-C^{1s}_{\omega'})}{(C^{1s}_{\omega''}-C^{1s}_{\phi''})} -$$

$$-H_{\omega''}(V)H_{\phi''}(V)\Bigg](f^{(1s)}_{\omega'\Lambda\Lambda}/f_{\omega'}) +$$

$$+\left(\frac{1-V^2}{1-V_N^2}\right)^4 \Bigg[H_{\phi''}(V)H_{\phi'}(V)\frac{(C^{1s}_{\phi''}-C^{1s}_{\phi'})}{(C^{1s}_{\phi''}-C^{1s}_{\omega''})} + H_{\omega''}(V)H_{\phi'}(V)\frac{(C^{1s}_{\omega''}-C^{1s}_{\phi'})}{(C^{1s}_{\omega''}-C^{1s}_{\phi''})} -$$

$$-H_{\omega''}(V)H_{\phi''}(V)\Bigg](f^{(1s)}_{\phi'\Lambda\Lambda}/f_{\phi'}) +$$

U&A MODEL OF Λ HYPERON EM STRUCTURE

$$+\left(\frac{1-V^2}{1-V_N^2}\right)^4\left[H_{\phi''}(V)L_\omega(V)\frac{(C^{1s}_{\phi''}-C^{1s}_{\omega})}{(C^{1s}_{\phi''}-C^{1s}_{\omega''})}+H_{\omega''}(V)L_\omega(V)\frac{(C^{1s}_{\omega''}-C^{1s}_{\omega})}{(C^{1s}_{\omega''}-C^{1s}_{\phi''})}-\right.$$

$$\left.-H_{\omega''}(V)H_{\phi''}(V)\right](f^{(1s)}_{\omega\Lambda\Lambda}/f_\omega)+$$

$$+\left(\frac{1-V^2}{1-V_N^2}\right)^4\left[H_{\phi''}(V)L_\phi(V)\frac{(C^{1s}_{\phi''}-C^{1s}_{\phi})}{(C^{1s}_{\phi''}-C^{1s}_{\omega''})}+H_{\omega''}(V)L_\phi(V)\frac{(C^{1s}_{\omega''}-C^{1s}_{\phi})}{(C^{1s}_{\omega''}-C^{1s}_{\phi''})}-\right.$$

$$\left.-H_{\omega''}(V)H_{\phi''}(V)\right](f^{(1s)}_{\phi\Lambda\Lambda}/f_\phi)$$

dependent on 5 physically interpretable parameters,
$(f^{(1s)}_{\omega'\Lambda\Lambda}/f_{\omega'}), (f^{(1s)}_{\phi'\Lambda\Lambda}/f_{\phi'}), (f^{(1s)}_{\omega\Lambda\Lambda}/f_\omega), (f^{(1s)}_{\phi\Lambda\Lambda}/f_\phi), t^{1s}_{in}$

$U\&A$ MODEL OF Λ HYPERON EM STRUCTURE

and

$$F^{\Lambda}_{2s}[U(t)] = \left(\frac{1-U^2}{1-U_N^2}\right)^6 \left[\mu_\Lambda H_{\omega''}(U) H_{\phi''}(U) H_{\omega'}(U)\right] + \tag{12}$$

$$+\left(\frac{1-U^2}{1-U_N^2}\right)^6 \Bigg[H_{\phi''}(U)H_{\omega'}(U)H_{\phi'}(U)\frac{(C^{2s}_{\phi''}-C^{2s}_{\phi'})(C^{2s}_{\omega'}-C^{2s}_{\phi'})}{(C^{2s}_{\phi''}-C^{2s}_{\omega''})(C^{2s}_{\omega'}-C^{2s}_{\omega''})} +$$

$$+H_{\omega''}(U)H_{\omega'}(U)H_{\phi'}(U)\frac{(C^{2s}_{\omega''}-C^{2s}_{\phi'})(C^{2s}_{\omega'}-C^{2s}_{\phi'})}{(C^{2s}_{\omega''}-C^{2s}_{\phi''})(C^{2s}_{\omega'}-C^{2s}_{\phi''})} +$$

$$+H_{\omega''}(U)H_{\phi''}(U)H_{\phi'}(U)\frac{(C^{2s}_{\omega''}-C^{2s}_{\phi'})(C^{2s}_{\phi''}-C^{2s}_{\phi'})}{(C^{2s}_{\omega''}-C^{2s}_{\omega'})(C^{2s}_{\phi''}-C^{2s}_{\omega'})} -$$

$$-H_{\omega''}(U)H_{\phi''}(U)H_{\omega'}(U)\Bigg](f^{(2s)}_{\phi'\Lambda\Lambda}/f_{\phi'}) +$$

$U\&A$ MODEL OF Λ HYPERON EM STRUCTURE

$$
\begin{aligned}
&+\left(\frac{1-U^2}{1-U_N^2}\right)^6 \Bigg[H_{\phi''}(U)H_{\omega'}(U)L_\omega(U)\frac{(C^{2s}_{\phi''}-C^{2s}_{\omega})(C^{2s}_{\omega'}-C^{2s}_{\omega})}{(C^{2s}_{\phi''}-C^{2s}_{\omega''})(C^{2s}_{\omega'}-C^{2s}_{\omega''})}+\\
&+H_{\omega''}(U)H_{\omega'}(U)L_\omega(U)\frac{(C^{2s}_{\omega''}-C^{2s}_{\omega})(C^{2s}_{\omega'}-C^{2s}_{\omega})}{(C^{2s}_{\omega''}-C^{2s}_{\phi''})(C^{2s}_{\omega'}-C^{2s}_{\phi''})}+\\
&+H_{\omega''}(U)H_{\phi''}(U)L_\omega(U)\frac{(C^{2s}_{\omega''}-C^{2s}_{\omega})(C^{2s}_{\phi'}-C^{2s}_{\omega})}{(C^{2s}_{\omega''}-C^{2s}_{\omega'})(C^{2s}_{\phi''}-C^{2s}_{\omega'})}-\\
&-H_{\omega''}(U)H_{\phi''}(U)H_{\omega'}(U)\Bigg](f^{(2s)}_{\omega\Lambda\Lambda}/f_\omega)+
\end{aligned}
$$

U&A MODEL OF Λ HYPERON EM STRUCTURE

$$+\left(\frac{1-U^2}{1-U_N^2}\right)^6\Bigg[H_{\phi''}(U)H_{\omega'}(U)L_\phi(U)\frac{(C^{2s}_{\phi''}-C^{2s}_{\phi})(C^{2s}_{\omega'}-C^{2s}_{\phi})}{(C^{2s}_{\phi''}-C^{2s}_{\omega''})(C^{2s}_{\omega'}-C^{2s}_{\omega''})}+$$

$$+H_{\omega''}(U)H_{\omega'}(U)L_\phi(U)\frac{(C^{2s}_{\omega''}-C^{2s}_{\phi})(C^{2s}_{\omega'}-C^{2s}_{\phi})}{(C^{2s}_{\omega''}-C^{2s}_{\phi''})(C^{2s}_{\omega'}-C^{2s}_{\phi''})}+$$

$$+H_{\omega''}(U)H_{\phi''}(U)L_\phi(U)\frac{(C^{2s}_{\omega''}-C^{2s}_{\phi})(C^{2s}_{\phi''}-C^{2s}_{\phi})}{(C^{2s}_{\omega''}-C^{2s}_{\omega'})(C^{2s}_{\phi''}-C^{2s}_{\omega'})}-$$

$$-H_{\omega''}(U)H_{\phi''}(U)H_{\omega'}(U)\Bigg](f^{(2s)}_{\phi\Lambda\Lambda}/f_\phi)$$

dependent on 4 physically interpretable parameters
$(f^{(2s)}_{\phi'\Lambda\Lambda}/f_{\phi'}), (f^{(2s)}_{\omega\Lambda\Lambda}/f_\omega), (f^{(2s)}_{\phi\Lambda\Lambda}/f_\phi), t^{2s}_{in}$.

$U\&A$ MODEL OF Λ HYPERON EM STRUCTURE

where

$$L_r(V) = \frac{(V_N - V_r)(V_N - V_r^*)(V_N - 1/V_r)(V_N - 1/V_r^*)}{(V - V_r)(V - V_r^*)(V - 1/V_r)(V - 1/V_r^*)},$$

$$C_r^{1s} = \frac{(V_N - V_r)(V_N - V_r^*)(V_N - 1/V_r)(V_N - 1/V_r^*)}{-(V_r - 1/V_r)(V_r - 1/V_r^*)}, r = \omega, \phi$$

$$H_l(V) = \frac{(V_N - V_l)(V_N - V_l^*)(V_N + V_l)(V_N + V_l^*)}{(V - V_l)(V - V_l^*)(V + V_l)(V + V_l^*)},$$

$$C_l^{1s} = \frac{(V_N - V_l)(V_N - V_l^*)(V_N + V_l)(V_N + V_l^*)}{-(V_l - 1/V_l)(V_l - 1/V_l^*)}, l = \omega', \phi', \omega'', \phi''$$

$U\&A$ MODEL OF Λ HYPERON EM STRUCTURE

$$L_r(U) = \frac{(U_N - U_r)(U_N - U_r^*)(U_N - 1/U_r)(U_N - 1/U_r^*)}{(U - U_r)(U - U_r^*)(U - 1/U_r)(U - 1/U_r^*)},$$

$$C_r^{2s} = \frac{(U_N - U_r)(U_N - U_r^*)(U_N - 1/U_r)(U_N - 1/U_r^*)}{-(U_r - 1/U_r)(U_r - 1/U_r^*)}, r = \omega, \phi$$

$$H_l(U) = \frac{(U_N - U_l)(U_N - U_l^*)(U_N + U_l)(U_N + U_l^*)}{(U - U_l)(U - U_l^*)(U + U_l)(U + U_l^*)},$$

$$C_l^{2s} = \frac{(U_N - U_l)(U_N - U_l^*)(U_N + U_l)(U_N + U_l^*)}{-(U_l - 1/U_l)(U_l - 1/U_l^*)}, l = \omega', \phi', \omega'', \phi''$$

This model is **defined on four-sheeted Riemann surface** and one can simply verify that it includes all required properties.

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

In order to predict $|G_M^\Lambda(t)|$ and $R^\Lambda(t)$ in time-like region, first **one has to determine numerical values** of the following **parameters**,

$$F_{1s}^\Lambda \quad : \quad (f^{(1s)}_{\omega'\Lambda\Lambda}/f_{\omega'}), (f^{(1s)}_{\phi'\Lambda\Lambda}/f_{\phi'}), (f^{(1s)}_{\omega\Lambda\Lambda}/f_{\omega}), (f^{(1s)}_{\phi\Lambda\Lambda}/f_{\phi}) \qquad (13)$$

$$F_{2s}^\Lambda \quad : \quad (f^{(2s)}_{\phi'\Lambda\Lambda}/f_{\phi'}), (f^{(2s)}_{\omega\Lambda\Lambda}/f_{\omega}), (f^{(2s)}_{\phi\Lambda\Lambda}/f_{\phi})$$

if the values $t_{in}^{1s} = 1.0442 GeV^2$ and $t_{in}^{2s} = 1.0460 GeV^2$ are **taken from the nucleon FF data analysis**, where the results appeared not to be very sensitive on the position of these effective inelastic thresholds and therefore one can expect that they will not be changed too much also in the case of the Λ-hyperon.

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

The **numerical values of these coupling constant ratios** in the Λ-hyperon EM structure model can be predicted theoretically:

1) by using $SU(3)$ invariant Lagrangian

$$L_{VB\bar{B}} = \frac{i}{\sqrt{2}} f^F [\bar{B}^{\alpha}_{\beta}\gamma_\mu B^{\beta}_{\gamma} - \bar{B}^{\beta}_{\gamma}\gamma_\mu B^{\alpha}_{\beta}](V_\mu)^{\gamma}_{\alpha} + \\ + \frac{i}{\sqrt{2}} f^D [\bar{B}^{\beta}_{\gamma}\gamma_\mu B^{\alpha}_{\beta} + \bar{B}^{\alpha}_{\gamma}\gamma_\mu B^{\beta}_{\gamma}](V_\mu)^{\gamma}_{\alpha} + \\ + \frac{i}{\sqrt{2}} f^S \bar{B}^{\alpha}_{\beta}\gamma_\mu B^{\beta}_{\alpha}\omega^0_\mu \tag{14}$$

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

describing **strong interactions of the nonet of vector-mesons** (and their excitations) **with** $1/2^+$ **octet baryons**, where $B, \bar{B}$ and V are baryon, anti-baryon and vector-meson **octuplet matrices** and ω^0_μ is omega-meson singlet.

2) further, the **results from the analysis of all existing data on nucleon EM structure**.

3) also, provided that the **universal vector-meson coupling constants** f_V **in all considered coupling constants ratios are known numerically**.

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

The **SU(3) invariant Lagrangian of vector meson-baryon interactions** provides the relations

$$f^{(1s)}_{\omega'\Lambda\Lambda} = \frac{1}{\sqrt{2}}\cos\theta' f_1^{S'} + \frac{1}{\sqrt{3}}\sin\theta' f_1^{D'} \quad (15)$$

$$f^{(1s)}_{\phi'\Lambda\Lambda} = \frac{1}{\sqrt{2}}\sin\theta' f_1^{S'} - \frac{1}{\sqrt{3}}\cos\theta' f_1^{D'} \quad (16)$$

$$f^{(1s)}_{\omega\Lambda\Lambda} = \frac{1}{\sqrt{2}}\cos\theta f_1^{S} + \frac{1}{\sqrt{3}}\sin\theta f_1^{D} \quad (17)$$

$$f^{(1s)}_{\phi\Lambda\Lambda} = \frac{1}{\sqrt{2}}\sin\theta f_1^{S} - \frac{1}{\sqrt{3}}\cos\theta f_1^{D} \quad (18)$$

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

$$f^{(2s)}_{\phi'\Lambda\Lambda} = \frac{1}{\sqrt{2}} \sin\theta' f_2^{S'} - \frac{1}{\sqrt{3}} \cos\theta' f_2^{D'} \tag{19}$$

$$f^{(2s)}_{\omega\Lambda\Lambda} = \frac{1}{\sqrt{2}} \cos\theta f_2^{S} + \frac{1}{\sqrt{3}} \sin\theta f_2^{D} \tag{20}$$

$$f^{(2s)}_{\phi\Lambda\Lambda} = \frac{1}{\sqrt{2}} \sin\theta f_2^{S} - \frac{1}{\sqrt{3}} \cos\theta f_2^{D} \tag{21}$$

with $\theta = 43.8^0$ and $\theta' = 50.3^0$, following from the **Gell-Mann-Okubo quadratic mass formulae.**

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

Taking the values of $f_1^S, f_1^D, f_1^{S'}$ and $f_1^{D'}$, also $f_2^S, f_2^D, f_2^{S'}$ and $f_2^{D'}$, from our recent paper

C.Adamuscin, E.Bartos, S.Dubnicka, A.Z.Dubnickova:
Numerical values of the f^F, f^D and f^S coupling constants in the SU(3) invariant interaction Lagrangian of the vector-meson nonet with $1/2^+$ octet baryons
Phys. Rev. C **93** (2016) 055208.

one finds $f^{(1s)}_{\omega'\Lambda\Lambda} = 6.7905$; $f^{(1s)}_{\phi'\Lambda\Lambda} = -10.3105$;
$f^{(1s)}_{\omega\Lambda\Lambda} = 25.2836$; $f^{(1s)}_{\phi\Lambda\Lambda} = -16.7162$ and
$f^{(2s)}_{\phi'\Lambda\Lambda} = -1.6409$; $f^{(2s)}_{\omega\Lambda\Lambda} = 4.9933$; $f^{(2s)}_{\phi\Lambda\Lambda} = -12.5090$.

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

The **numerical values** of the **universal vector meson coupling constants** $f_\omega = 17.0620$, $f_\phi = -13.4428$ **are found from an experimental PDG values on** $\Gamma(V \to e^+e^-)$ by means of the relation $\Gamma(V \to e^+e^-) = \frac{\alpha^2 m_V}{3}(\frac{f_V^2}{4\pi})^{-1}$, the $f_{\omega'} = 47.6022$ is calculated from the lepton width estimated by Donnachie and Clegg in

A.Donnachie and A.B.Clegg, Z. Phys. C **42** (1989) 663

and $f_{\phi'} = -33.6598$ is found from the relations $f_{\rho'}^2 : f_{\omega'}^2 : f_{\phi'}^2 = \frac{1}{9} : 1 : \frac{1}{2}$ following from the quark structure of the corresponding vector mesons and the electric charges of the constituent quarks from which these vector mesons are compounded.

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

Then the **numerical values** of all **unknown parameters** in the *U&A* Λ-hyperon EM structure model are

$$F^{\Lambda}_{1s} : (f^{(1s)}_{\omega'\Lambda\Lambda}/f_{\omega'}) = 0.14265, (f^{(1s)}_{\phi'\Lambda\Lambda}/f_{\phi'}) = 0.30631, \quad (22)$$

$$(f^{(1s)}_{\omega\Lambda\Lambda}/f_{\omega}) = 1.48187, (f^{(1s)}_{\phi\Lambda\Lambda}/f_{\phi}) = 1.24351$$

$$F^{\Lambda}_{2s} : (f^{(2s)}_{\phi'\Lambda\Lambda}/f_{\phi'}) = 0.04875, (f^{(2s)}_{\omega\Lambda\Lambda}/f_{\omega}) = 0.29266, \quad (23)$$

$$(f^{(2s)}_{\phi\Lambda\Lambda}/f_{\phi}) = 0.93054$$

which **provide theoretical predictions of** $|G^{\Lambda}_M(t)|$ **and** $R^{\Lambda}(t)$ **in time-like region** as they are presented in Figs.9 and 10.

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

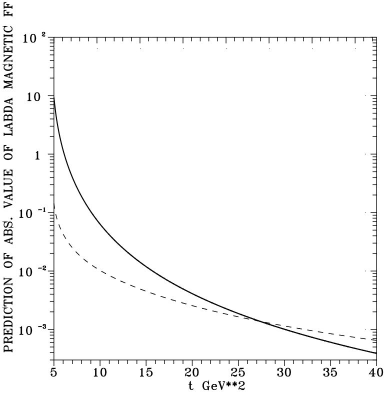


Figure: Predicted Λ-hyperon magnetic FF in time-like ($t > 0$) region

PREDICTIONS OF $|G_M(t)|$ AND R FOR LAMBDA

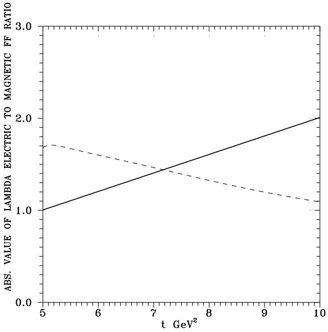


Figure: Predicted ratio of Λ-hyperon electric to magnetic FF in time-like ($t > 0$) region

Conclusions

- **It was reminded** how appearance of data on the ratio G_E^p/G_M^p in space-like region from proton polarization experiments **disproved the belief in the dipole behavior of the proton electric FF** $G_E^p(t)$.
- The **new approach in separate experimental determination of proton EM form factors** $|G_E^p(t)|$ **and** $|G_M^p(t)|$ **by BaBar Collab. and BESIII Collab. in time-like region** has been shortly reviewed.

Conclusions

- In the framework of the $U\&A$ **nucleon EM structure model** a consistency of the obtained **data on the ratio** $|G_E^p|/|G_M^p|$ **by BaBar Collab. and BESIII Collab.** have been tested with all other existing nucleon EM FF data in space-like and timelike regions.
- The **advanced** Λ**-hyperon** $U\&A$ **EM structure model has been constructed** and behaviors of the $|G_M^\Lambda(t)|$ and the ratio $|G_E^\Lambda|/|G_M^\Lambda|$ are predicted in time-like region, which are **planned to be determined in a measurements of the** Λ**-hyperon polar angle** θ_Λ **distribution** $F(\cos\theta_\Lambda)$ in the $e^+e^- \to \Lambda\bar{\Lambda}$ process.

Thank you