ADVANCED $U\&A$ NUCLEON EM STRUCTURE MODEL AND ITS PREDICTABILITY

C.Adamuscin[1], E.Bartos[1], **S. Dubnička**[1], A.-Z. Dubničková[2]

[1]Institute of Physics SAS, Bratislava, Slovakia
[2]Department of Theoretical Physiscs, Comenius University, Bratislava, Slovakia

20. July 2013

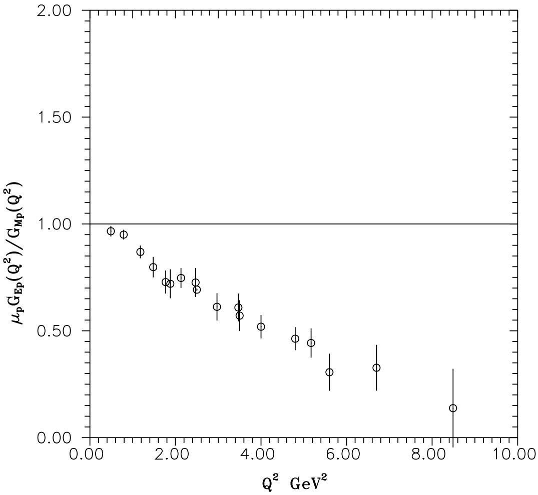
EPS HEP'13

Outline

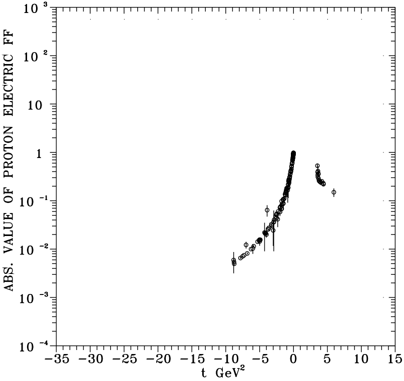
1. **INTRODUCTION**
   - Today's experimental situation
2. **NUCLEON EM FFs $U\&A$ MODEL RESPECTING $SU(3)$ SYMMETRY AND OZI RULE VIOLATION**
3. **VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \rightarrow p\bar{p}$ PROCESS**
4. **$1/2^+$ OCTET HYPERONS EM STRUCTURE**
5. **CONCLUSIONS**

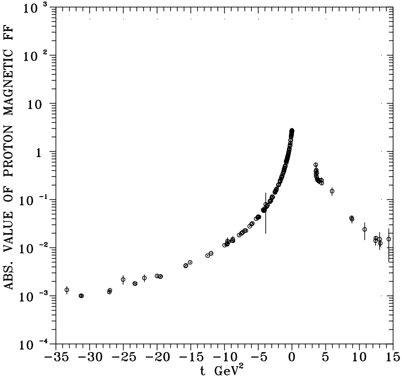
Experimental status

Today's experimental situation on the nucleon EM FFs $G_E^p(t)$ $G_M^p(t)$, $G_E^n(t)$, $G_M^n(t)$ is presented in the following Fgs.

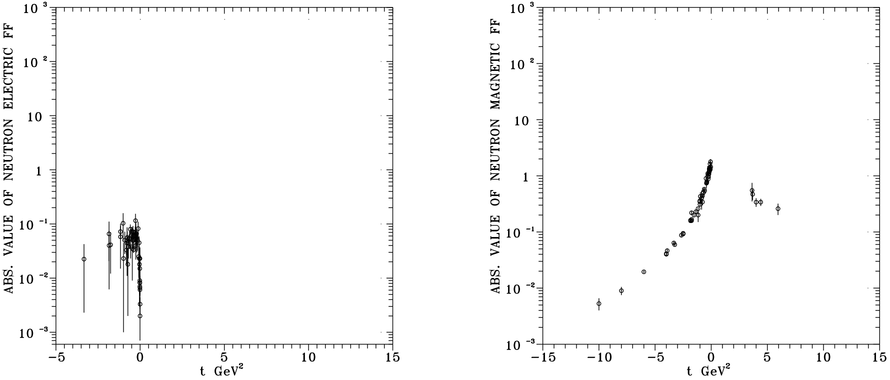


New JLab proton polarization data on the ratio $\mu_p G_{Ep}(t)/G_{Mp}(t)$ from polarization transfer $\vec{e}p \rightarrow e\vec{p}$ process.

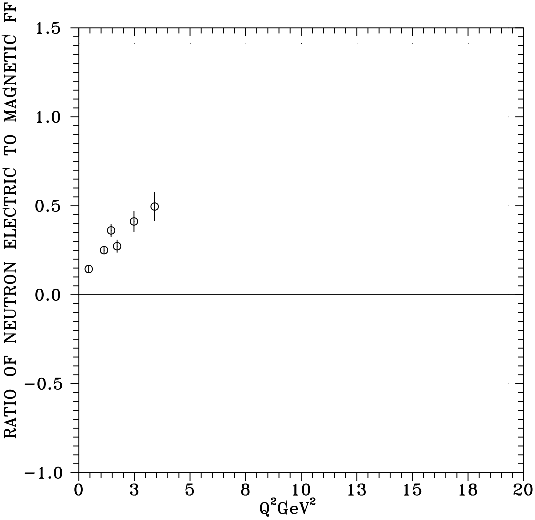




Experimental data on proton electric and magnetic form factors.



Experimental data on neutron electric and magnetic form factors.



Neutron polarization data on the ratio $\mu_n G_{En}(t)/G_{Mn}(t)$.

U&A MODEL OF NUCLEON EM STRUCTURE

For a description of data **we shall apply the** *U&A* **approach**, which already appeared to be **very powerful in a description of the EM structure of the complete nonet**
($\pi^-, \pi^0, \pi^+, K^-, K^0, \bar{K}^0, K^+, \eta, \eta'$)
of psedoscalar mesons.

S.Dubnicka and A.Z.Dubnickova: Eur. Phys. J. Web of Conference 37 (2012) 01003

U&A MODEL OF NUCLEON EM STRUCTURE

Electric and magnetic FFs, $G_E(t)$ and $G_M(t)$, are **very suitable for extraction of experimental data** from the measured cross-sections.

However, for construction of various nucleon EM structure models the flavor-independent **iso-scalar and iso-vector parts of the Dirac and Pauli FFs** are more suitable.

Both sets are related

$$G_E^p(t) = [F_{1N}^s(t) + F_{1N}^v(t)] + \frac{t}{4m_p^2}[F_{2N}^s(t) + F_{2N}^v(t)]$$
$$G_M^p(t) = [F_{1N}^s(t) + F_{1N}^v(t)] + [F_{2N}^s(t) + F_{2N}^v(t)]$$
$$G_E^n(t) = [F_{1N}^s(t) - F_{1N}^v(t)] + \frac{t}{4m_n^{2N}}[F_{2N}^s(t) - F_{2N}^v(t)]$$
$$G_M^n(t) = [F_{1N}^s(t) - F_{1N}^v(t)] + [F_{2N}^s(t) - F_{2N}^v(t)]$$

U&A MODEL OF NUCLEON EM STRUCTURE

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

The **newest Review of Particle Physics**

J.Beringer et al (Particle Data Group), Phys. Rev. D86 (2012) 010001.

provides **just 3 complete trinities of such vector-meson resonances**

$\rho(770), \omega(782), \phi(1020)$
$\omega'(1420), \rho'(1450)), \phi'(1680)$
$\omega''(1650), \rho''(1700), \phi''(2170)$.
then also **OZI rule violation is fulfilled**.
As a result the 9-**resonance (3 iso-vectors and 6 iso-scalars) zero-width** *VMD* **parametrization** of $F^s_{1N}(t), F^v_{1N}(t), F^s_{2N}(t), F^v_{2N}(t)$ can be written down.

$$F^s_{1N}(t) = \frac{1}{2}\frac{m^2_\omega m^2_\phi}{(m^2_\omega - t)(m^2_\phi - t)} +$$

$$+\left\{\frac{m^2_\phi m^2_{\omega'}}{(m^2_\phi - t)(m^2_{\omega'} - t)}\frac{(m^2_\phi - m^2_{\omega'})}{(m^2_\phi - m^2_\omega)} + \frac{m^2_\omega m^2_{\omega'}}{(m^2_\omega - t)(m^2_{\omega'} - t)}\frac{(m^2_\omega - m^2_{\omega'})}{(m^2_\omega - m^2_\phi)} - \right.$$

$$\left. - \frac{m^2_\omega m^2_\phi}{(m^2_\omega - t)(m^2_\phi - t)}\right\}(f^{(1)}_{\omega' NN}/f_{\omega'}) +$$

$$+\left\{\frac{m^2_\phi m^2_{\phi'}}{(m^2_\phi - t)(m^2_{\phi'} - t)}\frac{(m^2_\phi - m^2_{\phi'})}{(m^2_\phi - m^2_\omega)} + \frac{m^2_\omega m^2_{\phi'}}{(m^2_\omega - t)(m^2_{\phi'} - t)}\frac{(m^2_\omega - m^2_{\phi'})}{(m^2_\omega - m^2_\phi)} - \right.$$

$$\left. - \frac{m^2_\omega m^2_\phi}{(m^2_\omega - t)(m^2_\phi - t)}\right\}(f^{(1)}_{\phi' NN}/f_{\phi'}) +$$

$U\&A$ MODEL OF NUCLEON EM STRUCTURE

$$+\left\{\frac{m^2_\phi m^2_{\omega''}}{(m^2_\phi - t)(m^2_{\omega''} - t)}\frac{(m^2_\phi - m^2_{\omega''})}{(m^2_\phi - m^2_\omega)} + \frac{m^2_\omega m^2_{\omega''}}{(m^2_\omega - t)(m^2_{\omega''} - t)}\frac{(m^2_\omega - m^2_{\omega''})}{(m^2_\omega - m^2_\phi)} - \right.$$

$$\left. - \frac{m^2_\omega m^2_\phi}{(m^2_\omega - t)(m^2_\phi - t)}\right\}(f^{(1)}_{\omega'' NN}/f_{\omega''}) +$$

$$+\left\{\frac{m^2_\phi m^2_{\phi''}}{(m^2_\phi - t)(m^2_{\phi''} - t)}\frac{(m^2_\phi - m^2_{\phi''})}{(m^2_\phi - m^2_\omega)} + \frac{m^2_\omega m^2_{\phi''}}{(m^2_\omega - t)(m^2_{\phi''} - t)}\frac{(m^2_\omega - m^2_{\phi''})}{(m^2_\omega - m^2_\phi)} - \right.$$

$$\left. - \frac{m^2_\omega m^2_\phi}{(m^2_\omega - t)(m^2_\phi - t)}\right\}(f^{(1)}_{\phi'' NN}/f_{\phi''}).$$

U&A MODEL OF NUCLEON EM STRUCTURE

$$F_{1N}^{v}(t) = \frac{1}{2}\frac{m_\rho^2 m_{\rho'}^2}{(m_\rho^2 - t)(m_{\rho'}^2 - t)} +$$

$$+\left\{ \frac{m_{\rho'}^2 m_{\rho''}^2}{(m_{\rho'}^2 - t)(m_{\rho''}^2 - t)} \frac{(m_{\rho'}^2 - m_{\rho''}^2)}{(m_{\rho'}^2 - m_\rho^2)} + \frac{m_\rho^2 m_{\rho''}^2}{(m_\rho^2 - t)(m_{\rho''}^2 - t)} \frac{(m_\rho^2 - m_{\rho''}^2)}{(m_\rho^2 - m_{\rho'}^2)} - \right.$$

$$\left. - \frac{m_\rho^2 m_{\rho'}^2}{(m_\rho^2 - t)(m_{\rho'}^2 - t)} \right\} (f_{\rho'' NN}^{(1)} / f_{\rho''}).$$

U&A MODEL OF NUCLEON EM STRUCTURE

$$F^s_{2N}(t) = \frac{1}{2}(\mu_p + \mu_n)\frac{m^2_\omega m^2_\phi m^2_{\omega'}}{(m^2_\omega - t)(m^2_\phi - t)(m^2_{\omega'} - t)} +$$

$$+\left\{\frac{m^2_\phi m^2_{\omega'} m^2_{\phi'}}{(m^2_\phi - t)(m^2_{\omega'} - t)(m^2_{\phi'} - t)}\frac{(m^2_\phi - m^2_{\phi'})(m^2_{\omega'} - m^2_{\phi'})}{(m^2_\phi - m^2_\omega)(m^2_{\omega'} - m^2_\omega)} +\right.$$

$$+\frac{m^2_\omega m^2_{\omega'} m^2_{\phi'}}{(m^2_\omega - t)(m^2_{\omega'} - t)(m^2_{\phi'} - t)}\frac{(m^2_\omega - m^2_{\phi'})(m^2_{\omega'} - m^2_{\phi'})}{(m^2_\omega - m^2_\phi)(m^2_{\omega'} - m^2_\phi)} +$$

$$+\frac{m^2_\omega m^2_\phi m^2_{\phi'}}{(m^2_\omega - t)(m^2_\phi - t)(m^2_{\phi'} - t)}\frac{(m^2_\omega - m^2_{\phi'})(m^2_\phi - m^2_{\phi'})}{(m^2_\omega - m^2_{\omega'})(m^2_\phi - m^2_{\omega'})} -$$

$$\left.-\frac{m^2_\omega m^2_\phi m^2_{\omega'}}{(m^2_\omega - t)(m^2_\phi - t)(m^2_{\omega'} - t)}\right\}(f^{(2)}_{\phi' NN}/f_{\phi'}) +$$

U&A MODEL OF NUCLEON EM STRUCTURE

$$+\left\{\frac{m^2_\phi m^2_{\omega'} m^2_{\omega''}}{(m^2_\phi - t)(m^2_{\omega'} - t)(m^2_{\omega''} - t)} \frac{(m^2_\phi - m^2_{\omega''})(m^2_{\omega'} - m^2_{\omega''})}{(m^2_\phi - m^2_\omega)(m^2_{\omega'} - m^2_\omega)} + \right.$$

$$+\frac{m^2_\omega m^2_{\omega'} m^2_{\omega''}}{(m^2_\omega - t)(m^2_{\omega'} - t)(m^2_{\omega''} - t)} \frac{(m^2_\omega - m^2_{\omega''})(m^2_{\omega'} - m^2_{\omega''})}{(m^2_\omega - m^2_\phi)(m^2_{\omega'} - m^2_\phi)} +$$

$$+\frac{m^2_\omega m^2_\phi m^2_{\omega''}}{(m^2_\omega - t)(m^2_\phi - t)(m^2_{\omega''} - t)} \frac{(m^2_\omega - m^2_{\omega''})(m^2_\phi - m^2_{\omega''})}{(m^2_\omega - m^2_{\omega'})(m^2_\phi - m^2_{\omega'})} -$$

$$\left. - \frac{m^2_\omega m^2_\phi m^2_{\omega'}}{(m^2_\omega - t)(m^2_\phi - t)(m^2_{\omega'} - t)} \right\}(f^{(2)}_{\omega'' NN}/f_{\omega''}) +$$

U&A MODEL OF NUCLEON EM STRUCTURE

$$
\begin{aligned}
&+\left\{\frac{m_\phi^2 m_{\omega'}^2 m_{\phi''}^2}{(m_\phi^2-t)(m_{\omega'}^2-t)(m_{\phi''}^2-t)}\frac{(m_\phi^2-m_{\phi''}^2)(m_{\omega'}^2-m_{\phi''}^2)}{(m_\phi^2-m_\omega^2)(m_{\omega'}^2-m_\omega^2)}+\right.\\
&+\frac{m_\omega^2 m_{\omega'}^2 m_{\phi''}^2}{(m_\omega^2-t)(m_{\omega'}^2-t)(m_{\phi''}^2-t)}\frac{(m_\omega^2-m_{\phi''}^2)(m_{\omega'}^2-m_{\phi''}^2)}{(m_\omega^2-m_\phi^2)(m_{\omega'}^2-m_\phi^2)}+\\
&+\frac{m_\omega^2 m_\phi^2 m_{\phi''}^2}{(m_\omega^2-t)(m_\phi^2-t)(m_{\phi''}^2-t)}\frac{(m_\omega^2-m_{\phi''}^2)(m_\phi^2-m_{\phi''}^2)}{(m_\omega^2-m_{\omega'}^2)(m_\phi^2-m_{\omega'}^2)}-\\
&\left.-\frac{m_\omega^2 m_\phi^2 m_{\omega'}^2}{(m_\omega^2-t)(m_\phi^2-t)(m_{\omega'}^2-t)}\right\}(f^{(2)}_{\phi''NN}/f_{\phi''})
\end{aligned}
$$

U&A MODEL OF NUCLEON EM STRUCTURE

$$F_{2N}^{v}(t) = \frac{1}{2}\frac{m_\rho^2 m_{\rho'}^2 m_{\rho''}^2}{(m_\rho^2 - t)(m_{\rho'}^2 - t)(m_{\rho''}^2 - t)}$$

to be **automatically normalized** and governing the **asymptotic behaviors** as predicted by the quark model of hadrons.

By the non-linear transformations

$$t = t_0^s + \frac{4(t_{in}^{1s} - t_0^s)}{[1/V(t) - V(t)]^2}; \quad t = t_0^v + \frac{4(t_{in}^{1v} - t_0^v)}{[1/W(t) - W(t)]^2};$$
$$t = t_0^s + \frac{4(t_{in}^{2s} - t_0^s)}{[1/U(t) - U(t)]^2}; \quad t = t_0^v + \frac{4(t_{in}^{2v} - t_0^v)}{[1/X(t) - X(t)]^2}.$$

and a subsequent **inclusion of the nonzero values of vector-meson widths**, for every iso-scalar and iso-vector Dirac and Pauli FF, one obtains just **one analytic and smooth from** $-\infty$ **to** $+\infty$ **function** in the forms

U&A MODEL OF NUCLEON EM STRUCTURE

$$
\begin{aligned}
F^s_{1N}[V(t)] = \left(\frac{1-V^2}{1-V_N^2}\right)^4 \Bigg\{ \frac{1}{2} L_\omega(V) L_\phi(V) + \\
+ \Bigg[L_\phi(V) L_{\omega'}(V) \frac{(C^{1s}_\phi - C^{1s}_{\omega'})}{(C^{1s}_\phi - C^{1s}_\omega)} + L_\omega(V) L_{\omega'}(V) \frac{(C^{1s}_\omega - C^{1s}_{\omega'})}{(C^{1s}_\omega - C^{1s}_\phi)} - \\
- L_\omega(V) L_\phi(V) \Bigg] (f^{(1)}_{\omega' NN}/f_{\omega'}) + \\
+ \Bigg[L_\phi(V) H_{\phi'}(V) \frac{(C^{1s}_\phi - C^{1s}_{\phi'})}{(C^{1s}_\phi - C^{1s}_\omega)} + L_\omega(V) H_{\phi'}(V) \frac{(C^{1s}_\omega - C^{1s}_{\phi'})}{(C^{1s}_\omega - C^{1s}_\phi)} - \\
- L_\omega(V) L_\phi(V) \Bigg] (f^{(1)}_{\phi' NN}/f_{\phi'}) + \\
+ \Bigg[L_\phi(V) H_{\omega''}(V) \frac{(C^{1s}_\phi - C^{1s}_{\omega''})}{(C^{1s}_\phi - C^{1s}_\omega)} + L_\omega(V) H_{\omega''}(V) \frac{(C^{1s}_\omega - C^{1s}_{\omega''})}{(C^{1s}_\omega - C^{1s}_\phi)} - \\
- L_\omega(V) L_\phi(V) \Bigg] (f^{(1)}_{\omega'' NN}/f_{\omega''}) + \\
+ \Bigg[L_\phi(V) H_{\phi''}(V) \frac{(C^{1s}_\phi - C^{1s}_{\phi''})}{(C^{1s}_\phi - C^{1s}_\omega)} + L_\omega(V) H_{\phi''}(V) \frac{(C^{1s}_\omega - C^{1s}_{\phi''})}{(C^{1s}_\omega - C^{1s}_\phi)} - \\
- L_\omega(V) L_\phi(V) \Bigg] (f^{(1)}_{\phi'' NN}/f_{\phi''}) \Bigg\}
\end{aligned}
$$

$$F^v_{1N}[W(t)] = \left(\frac{1-W^2}{1-W_N^2}\right)^4 \left\{ \frac{1}{2} L_\rho(W) L_{\rho'}(W) + \right.$$

$$+ \left[L_{\rho'}(W) H_{\rho''}(W) \frac{(C^{1v}_{\rho'} - C^{1v}_{\rho''})}{(C^{1v}_{\rho'} - C^{1v}_{\rho})} + L_\rho(W) H_{\rho''}(W) \frac{(C^{1v}_{\rho} - C^{1v}_{\rho''})}{(C^{1v}_{\rho} - C^{1v}_{\rho'})} - \right.$$

$$\left. \left. - L_\rho(W) L_{\rho'}(W) \right] (f^{(1)}_{\rho'' NN} / f_{\rho''}) \right\}$$

U&A MODEL OF NUCLEON EM STRUCTURE

$$
\begin{aligned}
F^s_{2N}[U(t)] = \left(\frac{1-U^2}{1-U_N^2}\right)^6 \Big\{ & \frac{1}{2}(\mu_p+\mu_n) L_\omega(U) L_\phi(U) L_{\omega'}(U) + \\
+ \Big[& L_\phi(U) L_{\omega'}(U) H_{\phi'}(U) \frac{(C^{2s}_\phi - C^{2s}_{\phi'})(C^{2s}_{\omega'} - C^{2s}_{\phi'})}{(C^{2s}_\phi - C^{2s}_\omega)(C^{2s}_{\omega'} - C^{2s}_\omega)} + \\
& + L_\omega(U) L_{\omega'}(U) H_{\phi'}(U) \frac{(C^{2s}_\omega - C^{2s}_{\phi'})(C^{2s}_{\omega'} - C^{2s}_{\phi'})}{(C^{2s}_\omega - C^{2s}_\phi)(C^{2s}_{\omega'} - C^{2s}_\phi)} + \\
& + L_\omega(U) L_\phi(U) H_{\phi'}(U) \frac{(C^{2s}_\omega - C^{2s}_{\phi'})(C^{2s}_\phi - C^{2s}_{\phi'})}{(C^{2s}_\omega - C^{2s}_{\omega'})(C^{2s}_\phi - C^{2s}_{\omega'})} - \\
& - L_\omega(U) L_\phi(U) L_{\omega'}(U) \Big] (f^{(2)}_{\phi' NN}/f_{\phi'}) + \\
+ \Big[& L_\phi(U) L_{\omega'}(U) H_{\omega''}(U) \frac{(C^{2s}_\phi - C^{2s}_{\omega''})(C^{2s}_{\omega'} - C^{2s}_{\omega''})}{(C^{2s}_\phi - C^{2s}_\omega)(C^{2s}_{\omega'} - C^{2s}_\omega)} + \\
& + L_\omega(U) L_{\omega'}(U) H_{\omega''}(U) \frac{(C^{2s}_\omega - C^{2s}_{\omega''})(C^{2s}_{\omega'} - C^{2s}_{\omega''})}{(C^{2s}_\omega - C^{2s}_\phi)(C^{2s}_{\omega'} - C^{2s}_\phi)} + \\
& + L_\omega(U) L_\phi(U) H_{\omega''}(U) \frac{(C^{2s}_\omega - C^{2s}_{\omega''})(C^{2s}_\phi - C^{2s}_{\omega''})}{(C^{2s}_\omega - C^{2s}_{\omega'})(C^{2s}_\phi - C^{2s}_{\omega'})} - \\
& - L_\omega(U) L_\phi(U) L_{\omega'}(U) \Big] (f^{(2)}_{\omega'' NN}/f_{\omega''}) +
\end{aligned}
$$

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

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

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

$$-L_\omega(U)L_\phi(U)L_{\omega'}(U)\Bigg](f^{(2)}_{\phi'' NN}/f_{\phi''})\Bigg\}$$

U&A MODEL OF NUCLEON EM STRUCTURE

$$F_{2N}^{v}[X(t)] = \left(\frac{1-X^2}{1-X_N^2}\right)^6 \left\{\frac{1}{2}(\mu_p - \mu_n) L_\rho(U) L_{\rho'}(U) H_{\rho''}(U)\right\}$$

where

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

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

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

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

$$L_k(W) = \frac{(W_N - W_k)(W_N - W_k^*)(W_N - 1/W_k)(W_N - 1/W_k^*)}{(W - W_k)(W - W_k^*)(W - 1/W_k)(W - 1/W_k^*)},$$

$$C_k^{1v} = \frac{(W_N - W_k)(W_N - W_k^*)(W_N - 1/W_k)(W_N - 1/W_k^*)}{-(W_k - 1/W_k)(W_k - 1/W_k^*)}, k = \rho, \rho'$$

$$H_{\rho''}(W) = \frac{(W_N - W_{\rho''})(W_N - W^*_{\rho''})(W_N + W_{\rho''})(W_N + W^*_{\rho''})}{(W - W_{\rho''})(W - W^*_{\rho''})(W + W_{\rho''})(W + W^*_{\rho''})},$$

$$C^{1v}_{\rho''} = \frac{(W_N - W_{\rho''})(W_N - W^*_{\rho''})(W_N + W_{\rho''})(W_N + W^*_{\rho''})}{-(W_{\rho''} - 1/W_{\rho''})(W_{\rho''} - 1/W^*_{\rho''})},$$

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

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

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

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

$$L_k(X) = \frac{(X_N - X_k)(X_N - X_k^*)(X_N - 1/X_k)(X_N - 1/X_k^*)}{(X - X_k)(X - X_k^*)(X - 1/X_k)(X - 1/X_k^*)},$$
$$C_k^{2v} = \frac{(X_N - X_k)(X_N - X_k^*)(X_N - 1/X_k)(X_N - 1/X_k^*)}{-(X_k - 1/X_k)(X_k - 1/X_k^*)}, k = \rho, \rho'$$

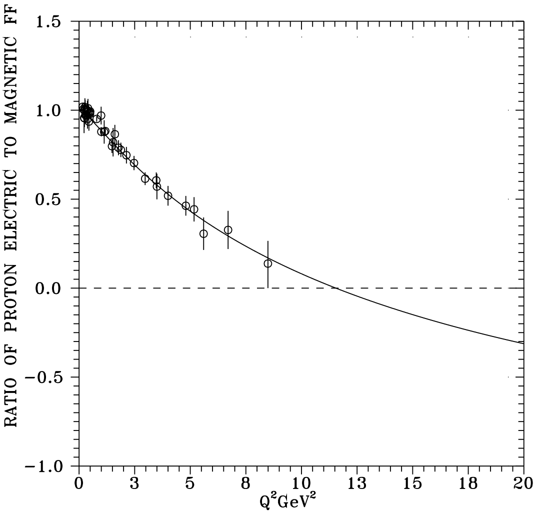
$$H_{\rho''}(X) = \frac{(X_N - X_{\rho''})(X_N - X_{\rho''}^*)(X_N + X_{\rho''})(X_N + X_{\rho''}^*)}{(X - X_{\rho''})(X - X_{\rho''}^*)(X + X_{\rho''})(X + X_{\rho''}^*)},$$
$$C_{\rho''}^{2v} = \frac{(X_N - X_{\rho''})(X_N - X_{\rho''}^*)(X_N + X_{\rho''})(W_X + X_{\rho''}^*)}{-(X_{\rho''} - 1/X_{\rho''})(X_{\rho''} - 1/X_{\rho''}^*)}.$$

U&A MODEL OF NUCLEON EM STRUCTURE

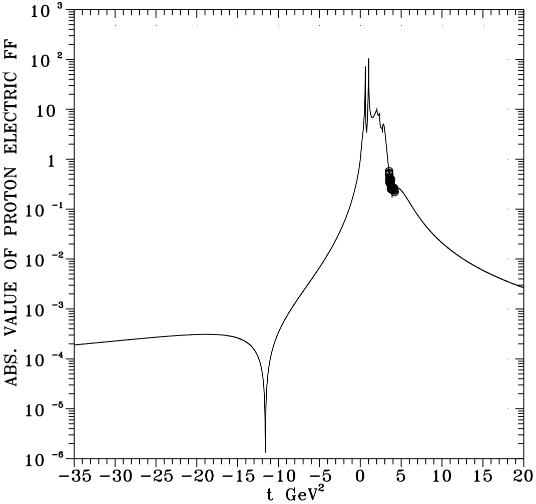
This advanced model is **defined on four-sheeted Riemann surface** and includes all required properties like

- **experimental fact of a creation of unstable vector-meson resonances** in e^+e^- annihilation processes into hadrons
- the **analytic properties** of FFs
- the **reality conditions**
- **unitarity conditions** of FFs
- **normalizations** of FFs
- **asymptotic behaviors** of FFs

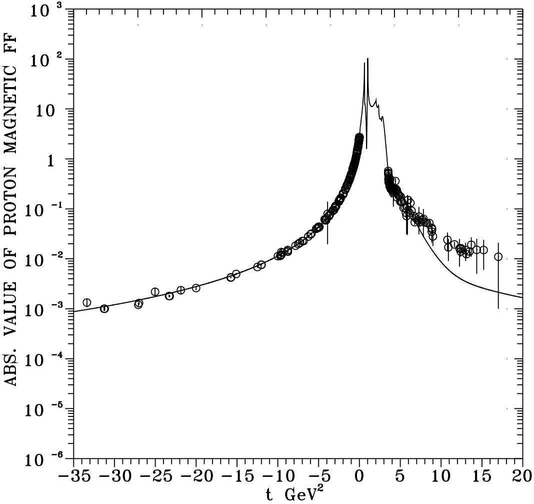
and moreover, **describes all today's nucleon EM FFs data in space-like and time-like regions simultaneously.**



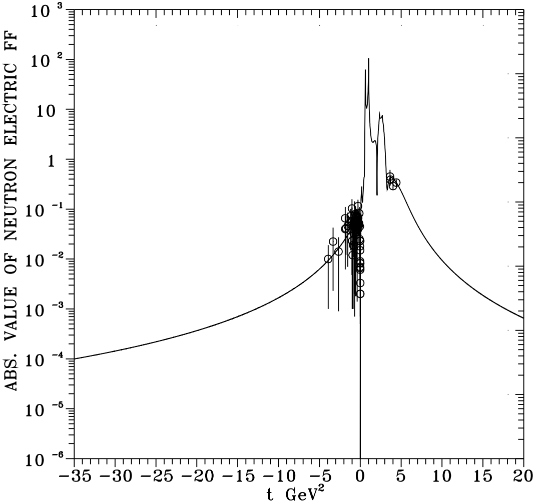
Prediction of proton electric to magnetic FFs ratio behavior by *U&A* model respecting *SU*(3) symmetry and OZI rule violation



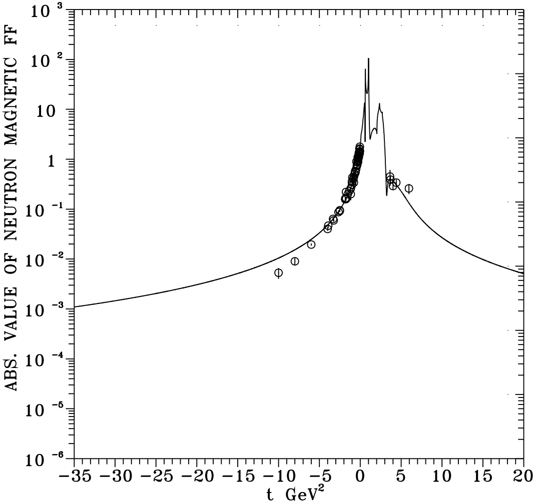
Prediction of proton electric FF behavior by *U&A* model respecting $SU(3)$ symmetry and OZI rule violation



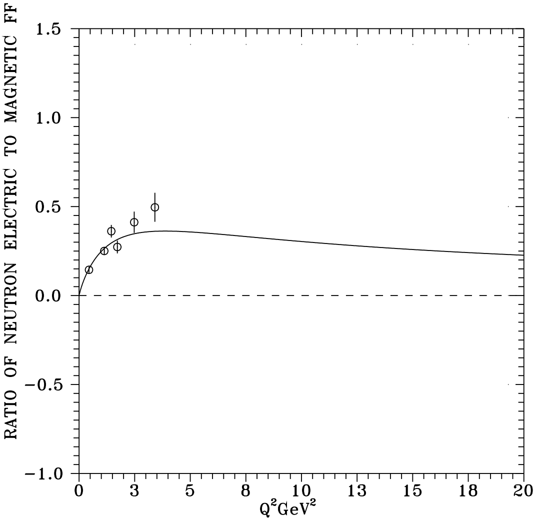
Prediction of proton magnetic FF behavior by *U&A* model respecting $SU(3)$ symmetry and OZI rule violation



Prediction of neutron electric FF behavior by *U&A* model respecting $SU(3)$ symmetry and OZI rule violation



Prediction of neutron magnetic FF behavior by *U&A* model respecting $SU(3)$ symmetry and OZI rule violation



Prediction of neutron electric to magnetic FFs ratio behavior by *U&A* model respecting *SU*(3) symmetry and OZI rule violation

VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \to p\bar{p}$ PROCESS

The advanced *U&A* nucleon EM structure **model is analytic** - it **creates the nonzero imaginary parts of the FFs** in a natural way **starting from the lowest branch points** on the positive real axis - therefore, it **can be applied for the predictions of the vector and tensor polarizations** of the final protons and antiprotons in the $e^+e^- \to p\bar{p}$ process.

VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \to p\bar{p}$ PROCESS

In order to find an explicit forms of **single spin polarization observables** (either for p or for $\bar{p}$) one has to calculate the traces in the numerator and denominator of

$$\vec{P} = \frac{j_{ij}\, Tr[F_i F_j^{\dagger} \vec{\sigma}]}{j_{ij}\, Tr[F_i F_j^{\dagger}]}.$$

where,

$$\vec{F} = \sqrt{s}\left[G_{Mp}(s)(\vec{\sigma} - \vec{n}\vec{\sigma}.\vec{n}) + \frac{2m_p}{\sqrt{s}} G_{Ep}(s)\vec{n}\vec{\sigma}.\vec{n}\right]$$

VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \to p\bar{p}$ PROCESS

$$j_{ij} = 2s(\ \delta_{ij} - m_i m_j + \lambda i \varepsilon_{ijl} m_l\ )$$

is the **lepton tensor with longitudinally polarized** e^- **or** e^+

$\vec{\sigma}$ are **Pauli matrices**, $\vec{n}$ is the **unit vector** along the three momentum $\vec{q}$ of p and $\vec{m}$ is the **unit vector** of incoming longitudinally polarized e^- or e^+.

As a result one gets

VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \to p\bar{p}$ PROCESS

the components of the vector polarization $\vec{P}$ of p or $\bar{p}$ in the reaction $e^+e^- \to p\bar{p}$

$$P_x = -\frac{2\sin\theta \cdot Re[G_{Ep}(s)G^*_{Mp}(s)]\tau}{|G_{Ep}(s)|^2\sin^2\theta/\tau + |G_{Mp}(s)|^2(1+\cos^2\theta)} \quad (1)$$

$$P_y = -\frac{\frac{1}{\sqrt{\tau}} Im(G_{Ep}(s)G^*_{Mp}(s))\sin 2\vartheta}{|G_{Ep}(s)|^2\sin^2\vartheta/\tau + |G_{Mp}(s)|^2(1+\cos^2\vartheta)}; \quad (2)$$

$$P_z = \frac{2\cos\theta|G_{Mp}(s)|^2}{|G_{Ep}(s)|^2\sin^2\theta/\tau + |G_{Mp}(s)|^2(1+\cos^2\theta)}, \quad (3)$$

assuming 100% i.e. $\lambda = 1$ longitudinal polarization of e^- or e^+.

VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \to p\bar{p}$ PROCESS

Similarly, one can calculate **explicite forms of double polarization observables** from

$$P_{kl} = \frac{j_{ij} Tr[F_i \sigma_k F_j^\dagger \sigma_l]}{j_{ij} Tr[F_i F_j^\dagger]}$$

with

$k, l = x, y, z$

Considering longitudinally polarized either e^- **or** e^+ and calculating the traces in numerator and denominator, respectively, one finds

VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \to p\bar{p}$ PROCESS

$$
\begin{aligned}
P_{xx} &= \frac{|G_{Mp}(s)|^2\cos^2\vartheta - \frac{1}{\tau}|G_{Ep}(s)|^2\sin^2\vartheta}{\frac{1}{\tau}|G_{Ep}(s)|^2\sin^2\vartheta + |G_{Mp}(s)|^2(1+\cos^2\vartheta)};\\
P_{yy} &= \frac{|G_{Mp}(s)|^2(1+\sin^2\vartheta) - \frac{1}{\tau}|G_{Ep}(s)|^2\sin^2\vartheta}{\frac{1}{\tau}|G_{Ep}(s)|^2\sin^2\vartheta + |G_{Mp}(s)|^2(1+\cos^2\vartheta)};\\
P_{zz} &= \frac{|G_{Mp}(s)|^2\sin^2\vartheta - \frac{1}{\tau}|G_{Ep}(s)|^2\cos^2\vartheta}{\frac{1}{\tau}|G_{Ep}(s)|^2\sin^2\vartheta + |G_{Mp}(s)|^2(1+\cos^2\vartheta)};\\
P_{xy} &= P_{yx} = 0;\\
P_{xz} &= P_{zx} = \frac{\frac{1}{\sqrt{\tau}}Re[G^*_{Mp}(s)G_{Ep}(s)]\sin 2\vartheta}{\frac{1}{\tau}|G_{Ep}(s)|^2\sin^2\vartheta + |G_{Mp}(s)|^2(1+\cos^2\vartheta)};\\
P_{yz} &= P_{zy} = -2\frac{\frac{1}{\sqrt{\tau}}Im[G^*_{Mp}(s)G_{Ep}(s)]\sin\vartheta}{\frac{1}{\tau}|G_{Ep}(s)|^2\sin^2\vartheta + |G_{Mp}(s)|^2(1+\cos^2\vartheta)};
\end{aligned}
$$

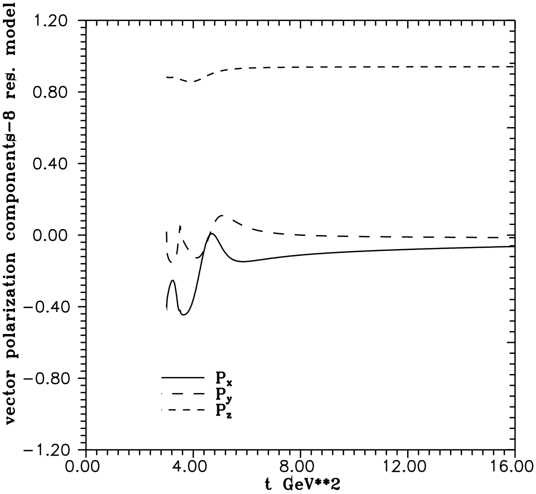
VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \to p\bar{p}$ PROCESS

Every of components P_{kl} characterizes
a **polarization of the proton** p **at the direction of** k**, if antiproton** $\bar{p}$ **is polarized at the direction** l
and
quantities P_{kl} are calculated for
100% **longitudinally polarized of** e^- **or** e^+.

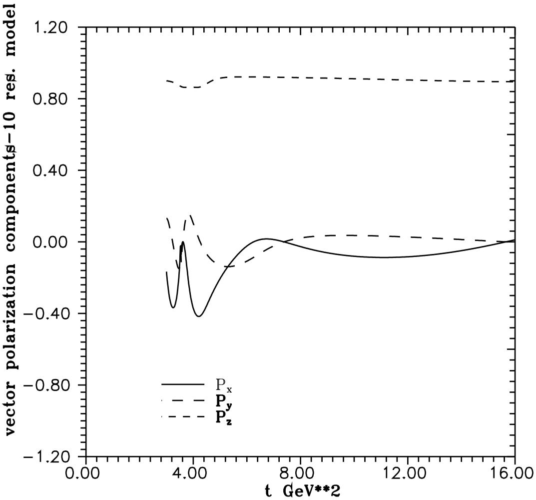
VECTOR AND TENSOR POLARIZATIONS IN $e^+e^- \rightarrow p\bar{p}$ PROCESS

By application of the **advanced** 9 **resonance** $U\&A$ **nucleon EM structure model** we are able to **predict vector and tensor polarizations** as a function of the energy.

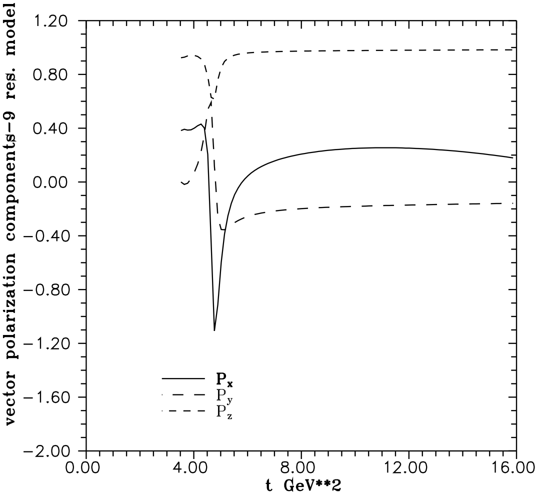
However, **in the past we have elaborated also** 8 **and** 10 **resonance** $U\&A$ **nucleon EM structure models** and we further present predictions by all of them for comparison.



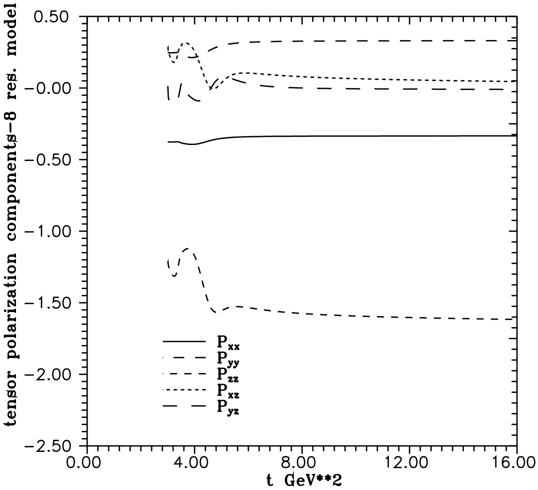
Vector polarization components - 8 resonance model



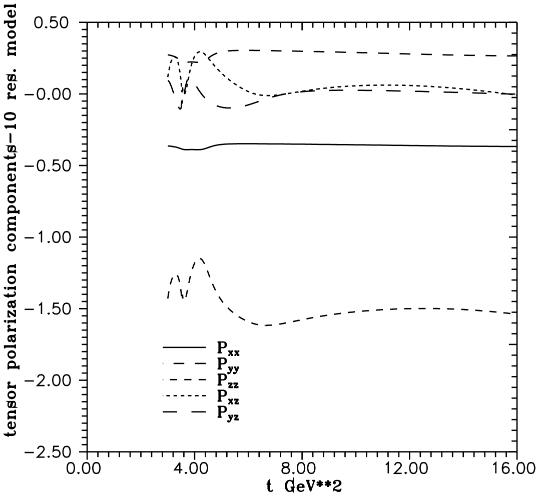
Vector polarization components - 10 resonance model



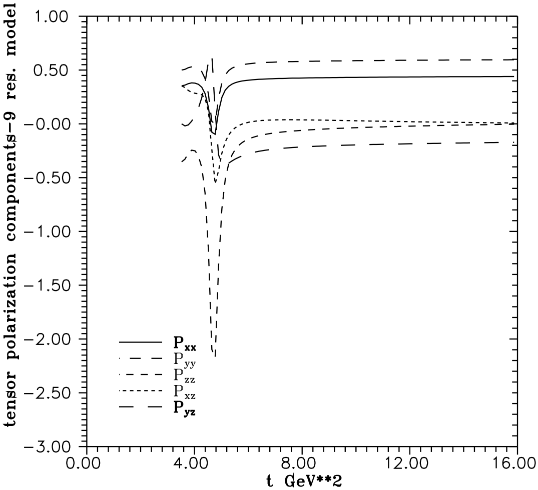
Vector polarization components - 9 resonance model



Tensor polarization components - 8 resonance model



Tensor polarization components - 10 resonance model



Tensor polarization components - 9 resonance model

HYPERONS EM STRUCTURE

One can use the **advanced** $U\&A$ **nucleon EM structure model for a description of the complete** $1/2^+$ **octet hyperons EM structure**, to be represented by the Sachs electric $G_E^h(t)$ and magnetic $G_M^h(t)$ FFs of hyperons.

They **can be decomposed into the flavor independent iso-scalar and iso-vector parts of the Dirac and Pauli FFs**

HYPERONS EM STRUCTURE

$$G_E^{\Lambda}(t) = F_{1s}^{\Lambda}(t) + \frac{t}{4m_{\Lambda}^2} F_{2s}^{\Lambda}(t)$$
$$G_M^{\Lambda}(t) = F_{1s}^{\Lambda}(t) + F_{2s}^{\Lambda}(t)$$
$$G_E^{\Sigma^0}(t) = F_{1s}^{\Sigma}(t) + \frac{t}{4m_{\Sigma}^2} F_{2s}^{\Sigma}(t)$$
$$G_M^{\Sigma^0}(t) = F_{1s}^{\Sigma}(t) + F_{2s}^{\Sigma}(t)$$
$$G_E^{\Sigma+,\Sigma^-}(t) = [F_{1s}^{\Sigma}(t) \pm F_{1v}^{\Sigma}(t)] + \frac{t}{4m_{\Sigma}^2}[F_{2s}^{\Sigma}(t) \pm F_{2v}^{\Sigma}(t)]$$
$$G_M^{\Sigma+,\Sigma^-}(t) = [F_{1s}^{\Sigma}(t) \pm F_{1v}^{\Sigma}(t)] + [F_{2s}^{\Sigma}(t) \pm F_{2v}^{\Sigma}(t)]$$
$$G_E^{\Xi^0,\Xi^-}(t) = [F_{1s}^{\Xi}(t) \pm F_{1v}^{\Xi}(t)] + \frac{t}{4m_{\Xi}^2}[F_{2s}^{\Xi}(t) \pm F_{2v}^{\Xi}(t)]$$
$$G_M^{\Xi^0,\Xi^-}(t) = [F_{1s}^{\Xi}(t) \pm F_{1v}^{\Xi}(t)] + [F_{2s}^{\Xi}(t) \pm F_{2v}^{\Xi}(t)]$$

HYPERONS EM STRUCTURE

Now, it is **sufficient to substitute for the iso-scalar and iso-vector parts of the Dirac and Pauli FFs** the expressions **from nucleons**, however, with the following change in the **corresponding coupling constant ratios**

$N \Rightarrow \Lambda, \Sigma^0, \Sigma^\pm, \Xi^{0,-}$

In a such way one has the *U&A* **hyperons EM structure model**, however dependent on **unknown coupling constat ratios**.
In nucleons we have **determined them in a fitting procedure of existing data**.

However, in the case of hyperons there are no sufficient data.

But also **in this case on finds the solution.**

The $SU(3)$ **invariant Lagrangian**

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

provides the relations

HYPERONS EM STRUCTURE

$$
\begin{aligned}
f^{1,2}_{\rho NN} &= \frac{1}{2}(f^{D}_{1,2} + f^{F}_{1,2}) \\
f^{1,2}_{\omega NN} &= \frac{1}{\sqrt{2}} cos\theta f^{S}_{1,2} - \frac{1}{2\sqrt{3}} sin\theta (3 f^{F}_{1,2} - f^{D}_{1,2}) \\
f^{1,2}_{\phi NN} &= \frac{1}{\sqrt{2}} sin\theta f^{S}_{1,2} + \frac{1}{2\sqrt{3}} cos\theta (3 f^{F}_{1,2} - f^{D}_{1,2})
\end{aligned}
$$

$\Gamma(V \to e^{+}e^{-}) = \frac{\alpha^2 m_V}{3} (\frac{f_V^2}{4\pi})^{-1}$

$$
\begin{aligned}
f^{1,2}_{\omega\Lambda\Lambda} &= \frac{1}{\sqrt{2}} cos\theta f^{S}_{1,2} + \frac{1}{\sqrt{3}} sin\theta f^{D}_{1,2} \\
f^{1,2}_{\phi\Lambda\Lambda} &= \frac{1}{\sqrt{2}} sin\theta f^{S}_{1,2} - \frac{1}{\sqrt{3}} cos\theta f^{D}_{1,2} \\
f^{1,2}_{\rho\Sigma\Sigma} &= -f^{F}_{1,2} \\
f^{1,2}_{\omega\Sigma\Sigma} &= \frac{1}{\sqrt{2}} cos\theta f^{S}_{1,2} - \frac{1}{\sqrt{3}} sin\theta f^{D}_{1,2} \\
f^{1,2}_{\phi\Sigma\Sigma} &= \frac{1}{\sqrt{2}} sin\theta f^{S}_{1,2} + \frac{1}{\sqrt{3}} cos\theta f^{D}_{1,2} \\
f^{1,2}_{\rho\Xi\Xi} &= \frac{1}{2}(f^{D}_{1,2} - f^{F}_{1,2}) \\
f^{1,2}_{\omega\Xi\Xi} &= \frac{1}{\sqrt{2}} cos\theta f^{S}_{1,2} + \frac{1}{2\sqrt{3}} sin\theta(3f^{F}_{1,2} + f^{D}_{1,2}) \\
f^{1,2}_{\phi\Xi\Xi} &= \frac{1}{\sqrt{2}} sin\theta f^{S}_{1,2} - \frac{1}{2\sqrt{3}} cos\theta(3f^{F}_{1,2} + f^{D}_{1,2})
\end{aligned}
$$

similarly for **excited states**

$\omega'(1420), \rho'(1450)), \phi'(1680)$
$\omega''(1650), \rho''(1700), \phi''(2170),$

where $\theta = 39.83^o$ is the **mixing angle** to be determined by the **Gell-Mann-Okubo quadratic mass formula**

$$m_\phi^2 cos^2\theta + m_\omega^2 sin^2\theta = \frac{4m_{K^*}^2 - m_\rho^2}{3}.$$

Conclusions

- The advanced *U&A* **nucleon EM structure model**, describing all today's experimental data in space-like and time-like regions simultaneously, has bee elaborated
- The model **realistic vector and tensor polarizations in the** $e^+e^- \rightarrow p\bar{p}$ **process** predicts
- A **description of EM structure of the complete** $1/2^+ octetbaryons$ by means of the *U&A* nucleon EM structure model and $SU(3)$ symmetry has been sketched.

Thank you