# Baryon masses and strangeness suppression in the Unquenched Quark Model

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# From the quark model to the new quark model with higher Fock components: the Unquenched Quark Model

- Aim and motivation
- Extension of the CQM
- The 3P0 Mechanism
- Electro-production of Baryon-Meson resonances
- The strangeness suppression
- Results on proton target
- Self-energy corrections
- Conclusions

# Aim and motivation

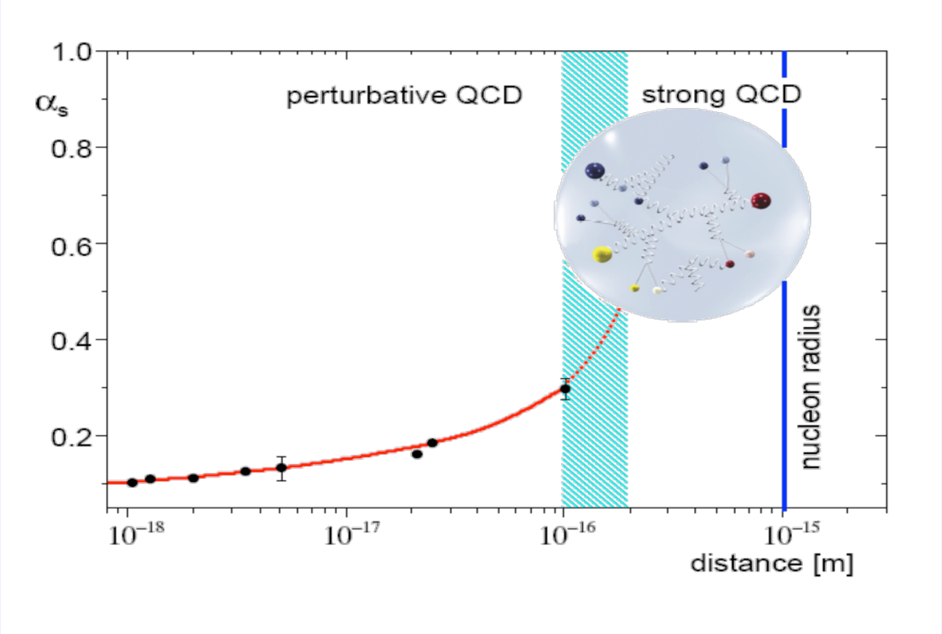
At low energies no solution of QCD is known, since the coupling is strong, it means that the use of perturbative theories is not allowed.

**Many non-perturbative techniques have been developed:**

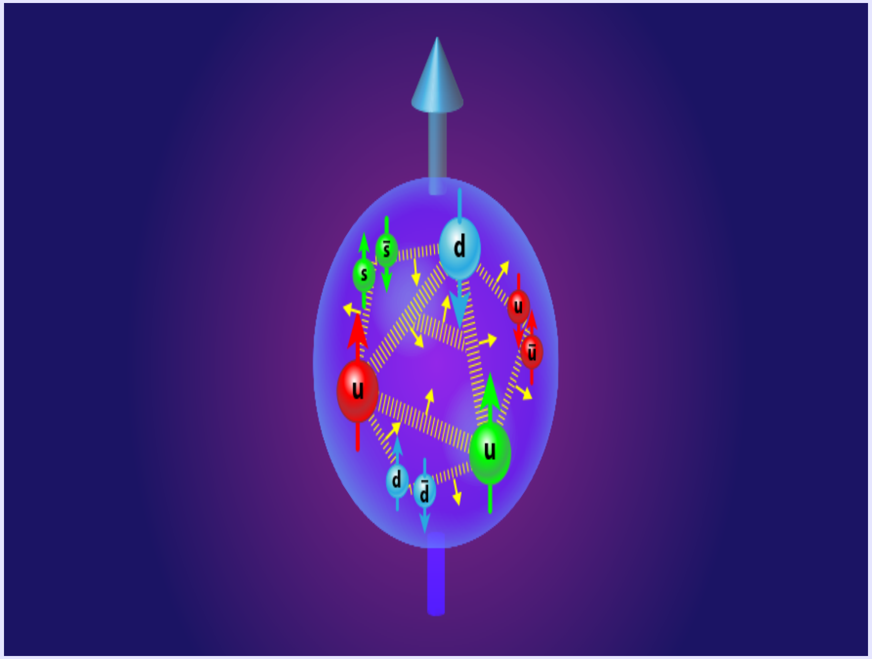
- The quark model
- Lattice calculation

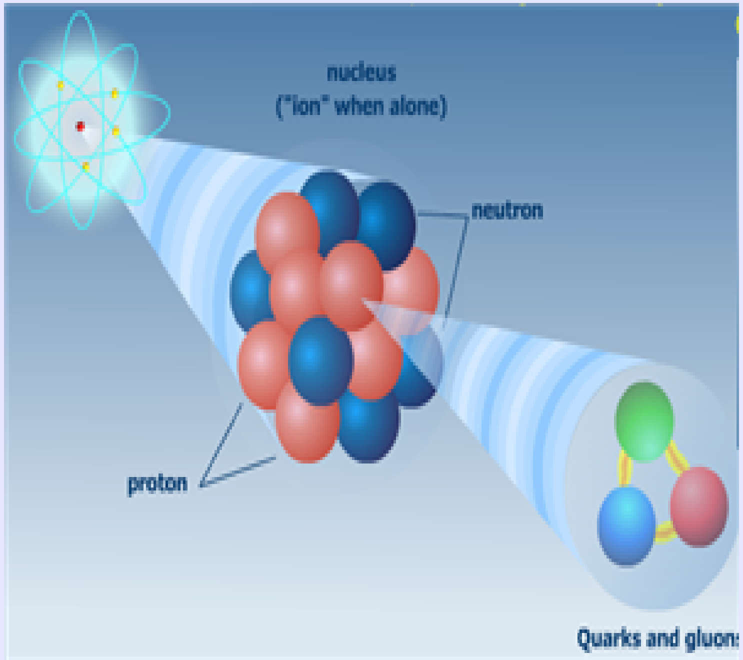
**New degrees of freedom:**

- Strangeness in the nucleon
- The role of the sea quarks
- Gottfried sum rule violation
- Electromagnetic transitions



# The effective degrees of freedom





# The Unquenched Quark Model

The UQM was introduced by E. Santopinto and R. Bijker (2007).

The UQM extends the QM by including the higher Fock components in the wave function.

Some evidence of the extra components were found experimentally by studying the flavor asymmetry in proton. This data is well explained by the UQM, Santopinto, Bijker Phys. Rev. C 82 (2010) 062202.

The wave function is

$$|\psi_A\rangle = \mathcal{N}\left[|A\rangle + \sum_{BClJ}\int d\vec{K}\,dk\;k^2|BC\vec{K},k,lJ\rangle\,\frac{\langle BC\vec{K},k,lJ|T^\dagger|A\rangle}{M_A - E_B - E_C}\right]$$

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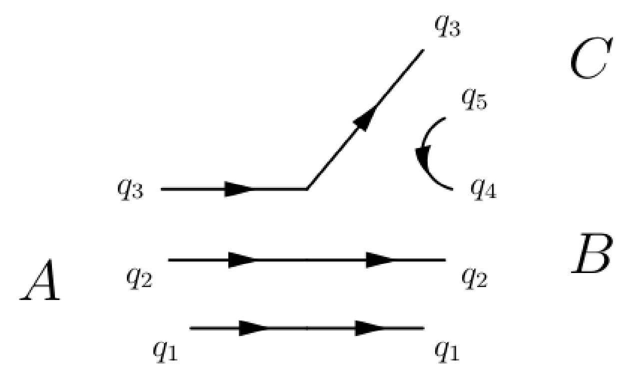
# The 3P0 model

- The 3P0 pair-creation is effective model introduced describe the open-flavor



- The baryon decay proceeds via the creation of additional quark-antiquark pair from the QCD vacuum

**The 3P0 operator is given by**

$$T^\dagger = -3\gamma_0 \int d\vec{p}_4\, d\vec{p}_5\, \delta(\vec{p}_4+\vec{p}_5)\, C_{45}\, F_{45}\, V(\vec{p}_4-\vec{p}_5)\, [\chi_{45} \times \mathcal{Y}_1(\vec{p}_4-\vec{p}_5)]^{(0)}_0\, b^\dagger_4(\vec{p}_4)\, d^\dagger_5(\vec{p}_5)\,.$$

# Improvements to the 3P0 model
Phys. Rev. D94 074040 (2016)

## The effective size of the pair

We used a Gaussian function to describe the pair-creation vertex:

$$V(\vec{p}_4 - \vec{p}_5) = e^{-\alpha_d^2(\vec{p}_4-\vec{p}_5)^2/8}.$$

## The strangeness suppression

The production of s-quarks is suppressed in comparison with the light u-and d-quarks, Phys.Lett.B 366 447 and Phys.Rev.Lett. 113 152004(2014).

We replaced the SU(3) -flavor-singlet wave function of the pair:

$$\phi_0 = \frac{1}{\sqrt{3}}\left[|u\bar{u}\rangle + |d\bar{d}\rangle + |s\bar{s}\rangle\right] \quad \Longrightarrow \phi_0' = \frac{1}{\sqrt{2+\left(\frac{m_n}{m_s}\right)^2}}\left[|u\bar{u}\rangle + |d\bar{d}\rangle + \frac{m_n}{m_s}|s\bar{s}\rangle\right]$$

# Results

## Phys. Rev. D94 074040 (2016)

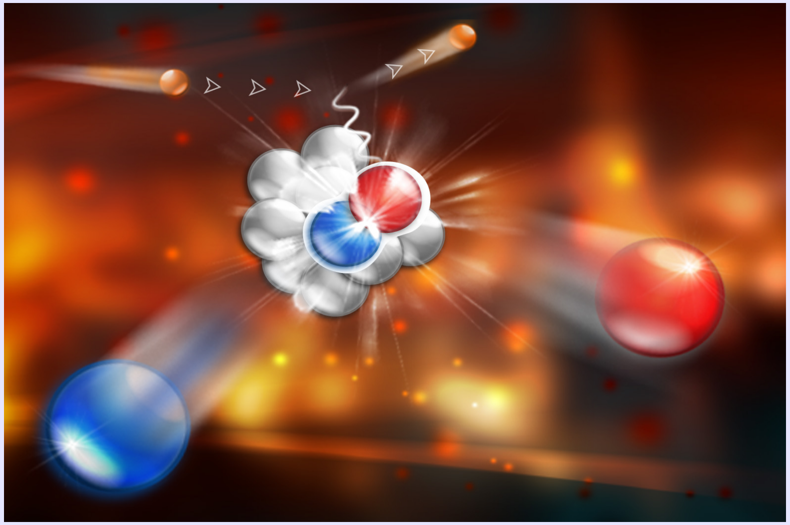
We predicted the strong decay widths of 190 resonances for all the open-flavor channels (about 10 channels). Thus, we computed around 1500 partial widths.

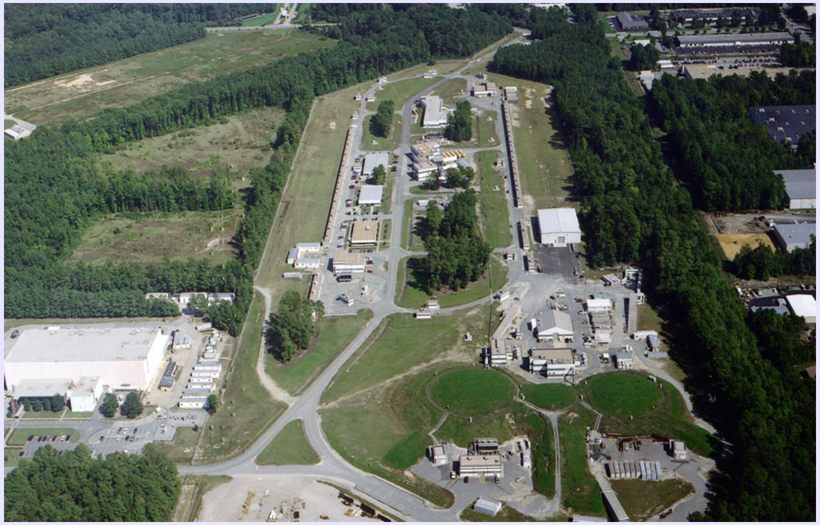
For the first time, we computed the decays of hyperons and we presented the flavor couplings, that can be used for any quark model.

$$\begin{pmatrix} \Delta \\ \Sigma^* \\ \Xi^* \\ \Omega \end{pmatrix} \rightarrow \begin{pmatrix} \Delta\eta_1 \\ \Sigma^*\eta_1 \\ \Xi^*\eta_1 \\ \Omega\eta_1 \end{pmatrix} = \mathcal{N} \begin{pmatrix} \frac{1}{3} \\ \frac{2+\frac{m_n}{m_s}}{9} \\ \frac{1+2\frac{m_n}{m_s}}{9} \\ \frac{1}{3}\frac{m_n}{m_s} \end{pmatrix}$$

# Electro-production of Baryon-Meson resonances

We applied the UQM formalism to investigate the role of the sea quarks in the Baryon-Meson electro-production from proton at Jlab, Phys.Rev.Lett. 113 152004(2014).



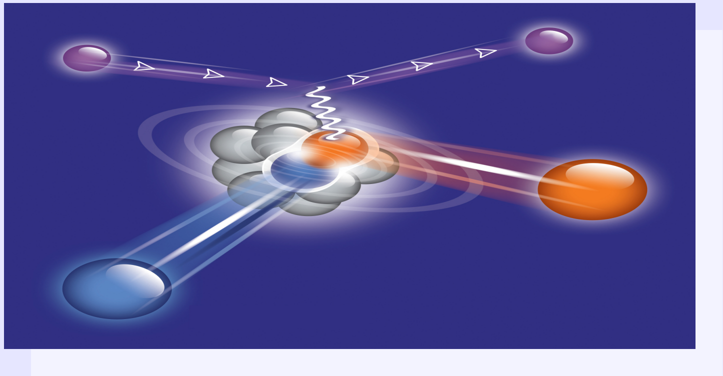


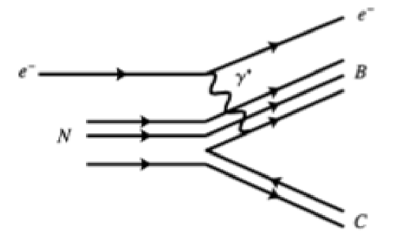
Jefferson Lab
Thomas Jefferson National Accelerator Facility

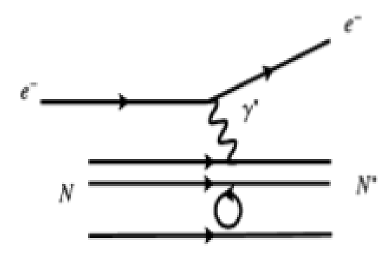
# The branching ratios in the UQM of exclusive reactions

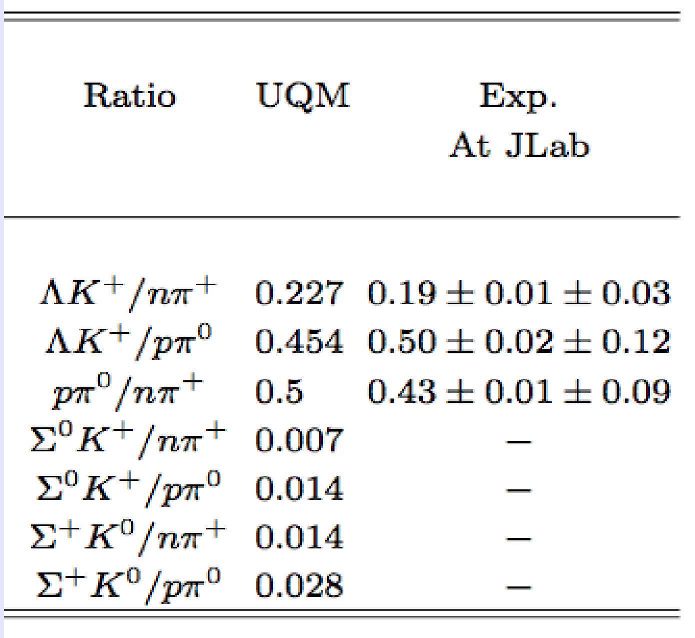
We computed the production ratios of Baryon-Meson states in exclusive reactions. Our results are in good agreement with the data, **reported in Phys.Rev.Lett. 113 152004(2014).**

This shows another manifestation of the sea-quarks, Phys.Lett. B759, 214-217 (2016)





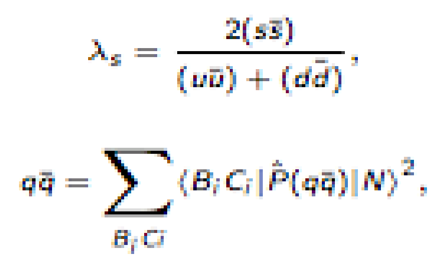




| Ratio | UQM | Exp.<br>At JLab |
|---|---|---|
| $\Lambda K^+/n\pi^+$ | 0.227 | $0.19 \pm 0.01 \pm 0.03$ |
| $\Lambda K^+/p\pi^0$ | 0.454 | $0.50 \pm 0.02 \pm 0.12$ |
| $p\pi^0/n\pi^+$ | 0.5 | $0.43 \pm 0.01 \pm 0.09$ |
| $\Sigma^0 K^+/n\pi^+$ | 0.007 | – |
| $\Sigma^0 K^+/p\pi^0$ | 0.014 | – |
| $\Sigma^+ K^0/n\pi^+$ | 0.014 | – |
| $\Sigma^+ K^0/p\pi^0$ | 0.028 | – |

# The strangeness-suppression factor in the UQM

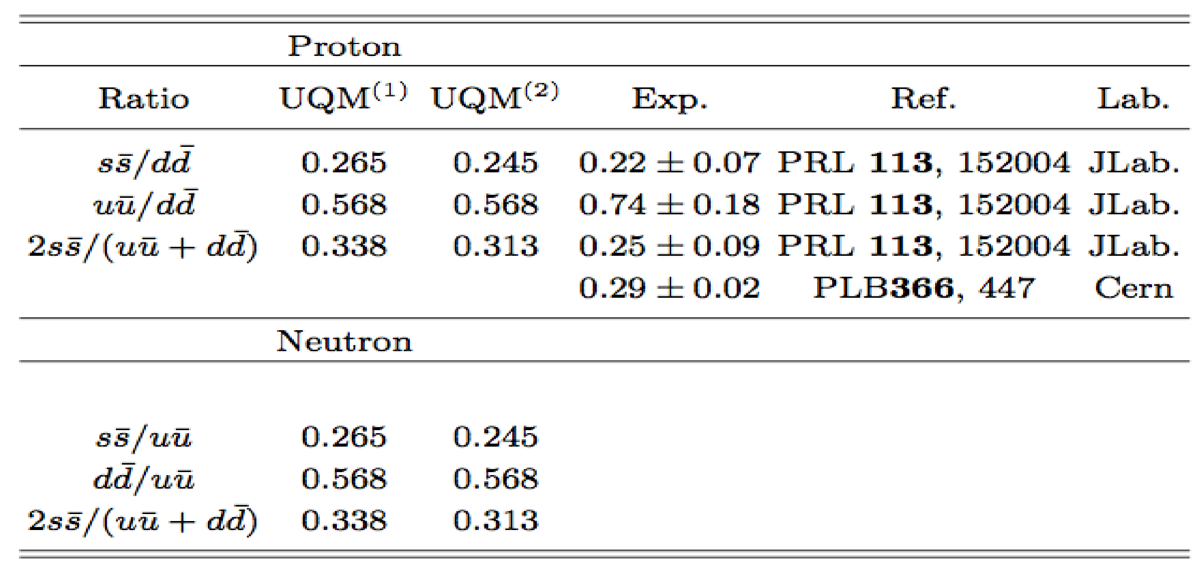
The extraction of the so-called strangeness-suppression factor



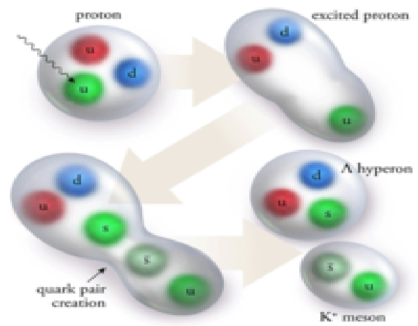
$$\lambda_s = \frac{2\langle s\bar{s}\rangle}{\langle u\bar{u}\rangle + \langle d\bar{d}\rangle},$$

$$q\bar{q} = \sum_{B_i C_i} \langle B_i C_i | \hat{P}(q\bar{q}) | N \rangle^2,$$

Our results were published in **Phys.Lett. B759, 214-217 (2016)**



| Ratio | UQM$^{(1)}$ | UQM$^{(2)}$ | Exp. | Ref. | Lab. |
|---|---|---|---|---|---|
| **Proton** | | | | | |
| $s\bar{s}/d\bar{d}$ | 0.265 | 0.245 | $0.22 \pm 0.07$ | PRL **113**, 152004 | JLab. |
| $u\bar{u}/d\bar{d}$ | 0.568 | 0.568 | $0.74 \pm 0.18$ | PRL **113**, 152004 | JLab. |
| $2s\bar{s}/(u\bar{u} + d\bar{d})$ | 0.338 | 0.313 | $0.25 \pm 0.09$ | PRL **113**, 152004 | JLab. |
| | | | $0.29 \pm 0.02$ | PLB**366**, 447 | Cern |
| **Neutron** | | | | | |
| $s\bar{s}/u\bar{u}$ | 0.265 | 0.245 | | | |
| $d\bar{d}/u\bar{u}$ | 0.568 | 0.568 | | | |
| $2s\bar{s}/(u\bar{u} + d\bar{d})$ | 0.338 | 0.313 | | | |



# Self-energy corrections [EPJA53 115 (2017)]

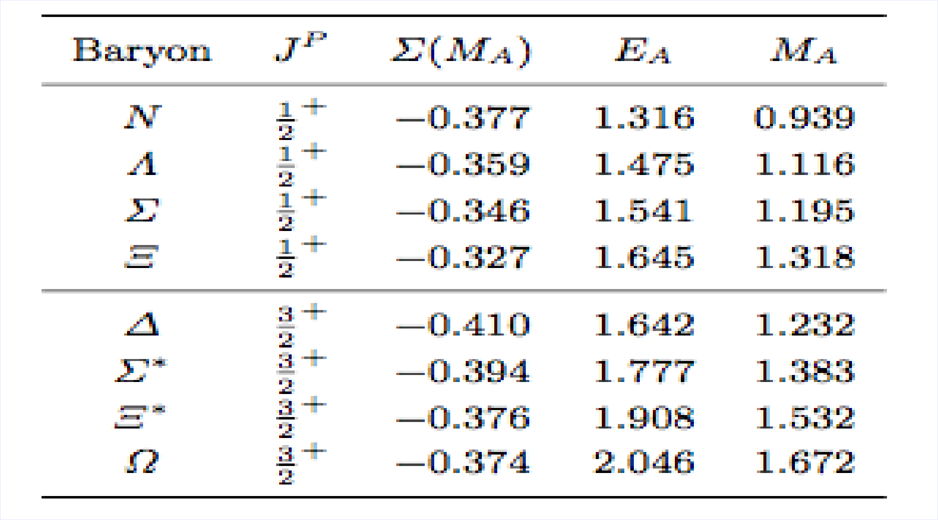
In the UQM, the extra components give a self-energy correction to the mass as follows

$$M_A = E_A + \Sigma(M_A)$$

where

$$\Sigma(M_A) = \sum_{BC} \int_0^\infty k^2 dk \, \frac{|M_{A\to BC}(k)|^2}{M_A - E_{BC}(k)} ,$$

is the self-energy correction



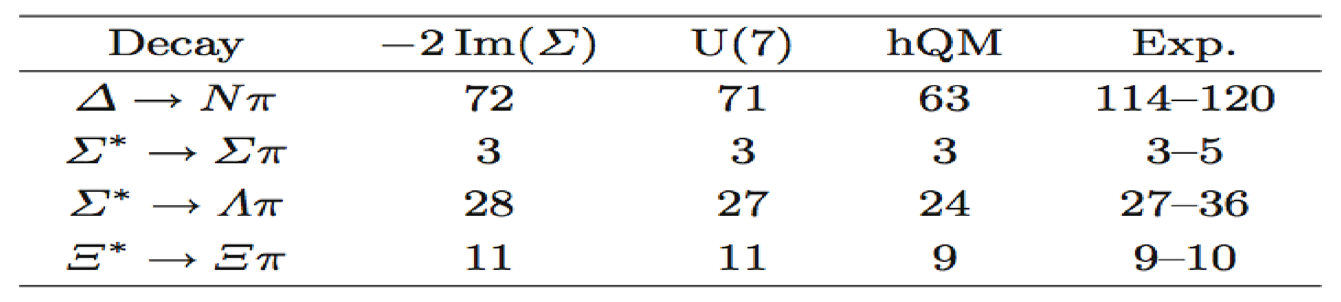
| Baryon | $J^P$ | $\Sigma(M_A)$ | $E_A$ | $M_A$ |
|---|---|---|---|---|
| $N$ | $\frac{1}{2}^+$ | $-0.377$ | 1.316 | 0.939 |
| $\Lambda$ | $\frac{1}{2}^+$ | $-0.359$ | 1.475 | 1.116 |
| $\Sigma$ | $\frac{1}{2}^+$ | $-0.346$ | 1.541 | 1.195 |
| $\Xi$ | $\frac{1}{2}^+$ | $-0.327$ | 1.645 | 1.318 |
| $\Delta$ | $\frac{3}{2}^+$ | $-0.410$ | 1.642 | 1.232 |
| $\Sigma^*$ | $\frac{3}{2}^+$ | $-0.394$ | 1.777 | 1.383 |
| $\Xi^*$ | $\frac{3}{2}^+$ | $-0.376$ | 1.908 | 1.532 |
| $\Omega$ | $\frac{3}{2}^+$ | $-0.374$ | 2.046 | 1.672 |

# Self-energy corrections
# [EPJA 53:115 (2007)]

Test of our results,

$$\Sigma(M_A) = \mathcal{P}\int_{M_B+M_C}^{\infty} \frac{dE_{BC}}{M_A - E_{BC}} \frac{kE_BE_C}{E_{BC}} |\mathcal{M}_{A\to BC}(k)|^2 - i\pi\left\{\frac{kE_BE_C}{M_A}|\mathcal{M}_{A\to BC}(k)|^2\right\}_{E_{BC}=M_A} ,$$

the imaginary part of the self energy corrections is related to the total decay width as follows $\Gamma(A \to BC) = -2\,\mathrm{Im}(\Sigma)$



| Decay | $-2\,\mathrm{Im}(\Sigma)$ | U(7) | hQM | Exp. |
|---|---|---|---|---|
| $\Delta \longrightarrow N\pi$ | 72 | 71 | 63 | 114–120 |
| $\Sigma^* \longrightarrow \Sigma\pi$ | 3 | 3 | 3 | 3–5 |
| $\Sigma^* \longrightarrow \Lambda\pi$ | 28 | 27 | 24 | 27–36 |
| $\Xi^* \longrightarrow \Xi\pi$ | 11 | 11 | 9 | 9–10 |

# Conclusions

We used an extension of the quark model to describe the baryon-meson electro-production from proton target. This is the first theoretical calculation that it is in good agreement with the new data, reported in Phys.Rev.Lett. 113 152004(2014)

We found that the virtual components dominate the Baryon-Meson electro-production. It is another evidence of the sea quarks in baryons, and the experimental data confirm this picture.

We extracted the strangeness-suppression factor which is in good agreement with the new experimental data measured at JLab and Cern.

Finally, we computed the self-energy corrections to the baryon masses. As a check we extracted the strong decay widths from the imaginary part of the self energy and compared them with the experimental data. .