Electric and magnetic timelike form factors of hyperons at large transfer momentum

Gilberto Ramalho

gilberto.ramalho2013@gmail.com
OMEG Institute and Soongsil University, Republic of Korea

In collaboration with:
M.T. Peña (Un. of Lisbon, Portugal), K. Tsushima (Un. Cidade de São Paulo, Brazil) and M.K. Cheoun (OMEG/SSU)

November 13, 2025
Baryons 2025,
International Conference Center, Jeju, South Korea

Plan of the talk

Timelike electromagnetic form factors of hyperons at large q^2

Octet baryons ($J^P = \frac{1}{2}^+$): $J^\mu = F_1 \gamma^\mu + F_2 \frac{i\sigma^{\mu\nu} q_\nu}{2M}$ [Dirac/Pauli FF]

Electric and Magnetic FF: $G_E = F_1 - \frac{Q^2}{4M^2} F_2$, $G_M = F_1 + F_2$

Electromagnetic form factors: $q =$ transfer momentum $Q^2 = -q^2$

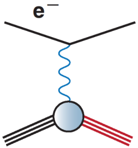
- **Motivation:** Spacelike and Timelike reactions
- **Covariant spectator quark model** for the spacelike region ($q^2 < 0$)
- Extension to the timelike region – Effective FF and ratio $|G_E/G_M|$

G. Ramalho, M.P. Peña and K. Tsushima, PRD 101, 014014 (2020)
G. Ramalho, PRD 103, 074018 (2021)

G. Ramalho, M.P. Peña, K. Tsushima and M. K. Cheoun, PLB 858, 139060 (2024)

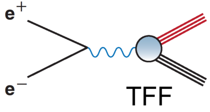
Spacelike and timelike reactions

Spacelike $(q^2 \leq 0)$



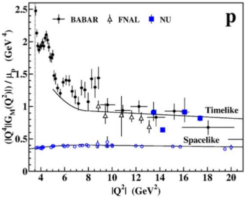
- Electron-Nucleon scattering $\gamma^* N \to N$, $\gamma^* N \to N^*$
- Real Amplitudes & Form Factors
- JLab/CLAS, ...
- Probe structure of Nucleon (elastic) & nucleon excitation (N^*) in terms of q^2
- **Explore** N^*

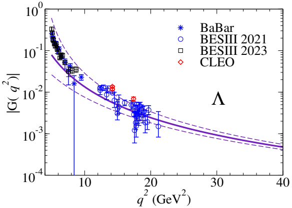
Timelike $(q^2 \geq 4M^2)$

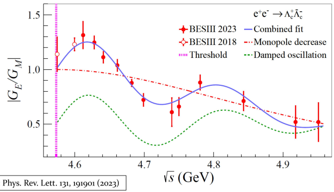


- Annihilation reactions $e^- e^+ \to \gamma^* \to B\bar{B}$
- Complex Form Factors
- CLEO, Belle, BES III, ...
- Probe structure of hyperons B and baryons with heavy quarks in terms of q^2
- **Explore hyperons**

Motivation – Measurements in the timelike region







*BESIII: Phys. Rev. Lett. 131, 191901 (2023)

Early measurements $|G_M|$ nucleon

Effective FF – Hyperons $|G_E|$, $|G_M|$, ($|G_E/G_M|$)

Integrated cross section: BaBar, CLEO, BES III, $\tau = \frac{q^2}{4M^2}$
Effective FF: $|G|^2 =\propto \left[|G_M|^2 + \frac{1}{2\tau}|G_E|^2\right]$

Differential cross section: $|G_E|$, $|G_M|$, $|G_E/G_M|$, BES III

Spin polarization (complete measurements): $\Delta\Phi$ (relative angle), BES III

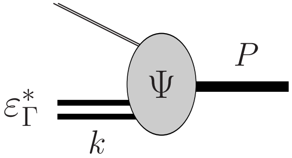
Covariant Spectator Quark Model (CSQM)

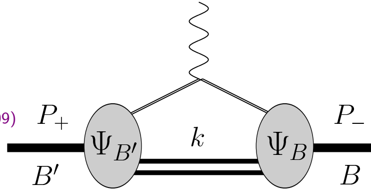
- **Covariant Spectator Theory:** **Baryons** $\equiv (qqq)$
  (1 off-shell $\oplus$ 2 spectator on-shell) Stadler, Gross and Frank, PRC 56, 2396 (1998); Gross and Agbakpe, PRC 73, 015203 (2006)
- Reduction of system to quark-diquark configuration
  diquark on-shell
  Wave functions: $SU_{SF}(6) \otimes O(3)$ symmetries
  Radial w.f. ψ_B **determined phenomenologically**
  (momemtum range parameters: β_1, β_2, β_3, ...)
  Gross, GR and Peña PRC 77, 015202 (2008); PRD 85, 093005 (2012)
- Electromagnetic interaction; relativistic impulse approximation **diquark on-shell**

$$J^\mu = 3 \sum_\Gamma \int_k \overline{\Psi}_{B'}(P_+, k) j_q^\mu \Psi_B(P_-, k)$$

- Constituent quark current $j_q^\mu(q)$ $(q = u, d, s)$
  Simulate quark dressing (gluons and $q\bar{q}$ effects)
  Use **Vector Meson Dominance** parametrization
  GR and MT Peña, PRD 80, 013008 (2009); J. Phys. G **36**, 115011 (2009)
- Phenomenological $SU(6)$ meson cloud – octet baryon
  GR, K Tsushima and AW Thomas, JPG 40, 015102 (2013); GR and K Tsushima, PRD 84, 054014 (2011)

$\leftarrow$ time



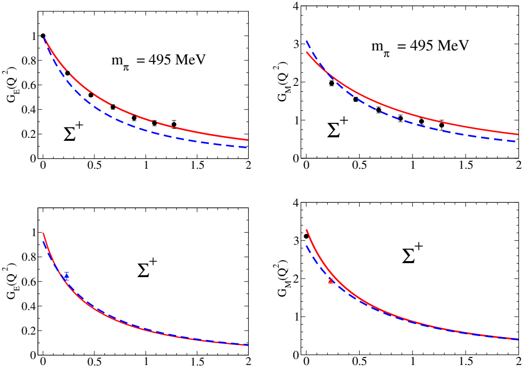


Hyperon electromagnetic form factors in the spacelike region ($q^2 \leq 0$)

GR and K Tsushima, PRD 84, 054014 (2011)

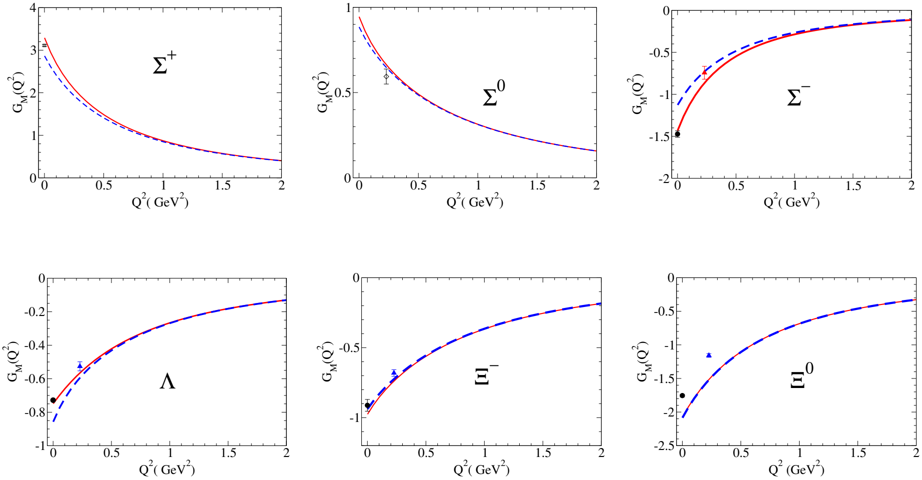
Octet baryon EM form factors in lattice QCD & physical

- **Step 1:**
  Calibrate model/lattice QCD
  Quark current fixed (VMD):
  $f_{i\ell}(Q^2; m_v, M_N) \to f_{i\ell}(Q^2; m_v^{\rm latt}, M_N^{\rm latt})$
  Fit radial wave functions:
  $\psi_B(M_B) \to \psi_B(M_B^{\rm latt})$
  Bare parameters: no meson cloud contamination (large m_π)
- **Step 2:** Bare contribution extrapolated to $m_\pi = m_\pi^{\rm phy}$
- **Step 3:** Include **meson cloud** contributions: **Physical FF:**
  $G_\ell = Z_B \left[G_\ell^{\rm B} + G_\ell^{\rm MC} \right]$



Model can be used to calculate **octet baryon FF** in **different ranges of** Q^2

Hyperons – Magnetic form factors



Hyperon electromagnetic form factors in the timelike region $q^2 > 4M_B^2$

large q^2 regime

Measurements of $|G|$ and $|G_E/G_M|$

PRD 101, 014014 (2020)

PLB 858, 139060 (2024)

Elastic form factors – Timelike vs Spacelike $Q^2 = -q^2$

Asymptotic relations between spacelike ($G_\ell^{\rm SL}$) and the timelike regions ($G_\ell^{\rm TL}$) $\ell = E, M$

$$G_\ell(q^2) \overset{q^2 \to \infty}{=} G_\ell(-q^2)$$

Phragmén—Lindelöf theorem, Pacetti, Ferroli, Tomasi-Gustafsson, Phys. Rep. 550—551, 1 (2015), App. D

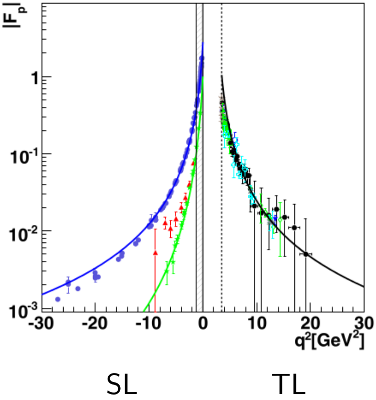
There is a gap between $]-\infty, 0]$ and $[4M^2, +\infty[$

Finite corrections (central value):

$$G_\ell^{\rm TL}(q^2) \simeq G_\ell^{\rm SL}(q^2 - 2M^2)$$

Kuraev, Dbeyssi, Tomasi-Gustafsson, PLB 712, 240 (2012)

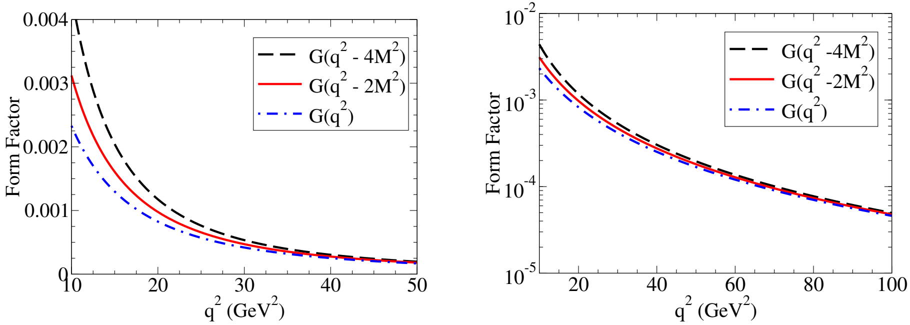
Proton form factors G_M, $|G_M|$



Elastic form factors – Timelike vs Spacelike Example

Finite corrections to asymptotic result: $G^{\mathrm{TL}}(q^2) \simeq G(q^2 - 2M^2)$

Theoretical bands: Lower limit $q^2 \to q^2$ Upper limit: $q^2 \to q^2 - 4M^2$



$$G(Q^2) = \left(\frac{\Lambda_D^2}{\Lambda_D^2 + Q^2} \right)^2, \qquad \Lambda_D^2 = 0.71 \text{ GeV}^2$$

Theoretical uncertanities became **very small** at **large** q^2

Timelike form factors – Effective FF $|G(q^2)|$

$e^+e^- \to \gamma^* \to B\bar{B}$ – **Integrated** cross-section

$G_E(q^2)$ and $G_M(q^2)$ not measured directly

Cross section: $\tau = \frac{q^2}{4M^2}$, $\beta = \sqrt{1 - \frac{1}{\tau}}$, $C \simeq 1$

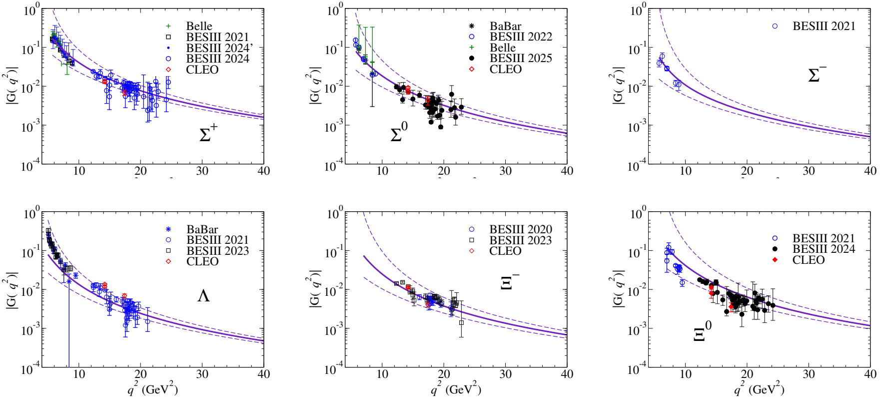
$$\boldsymbol{\sigma}_{\mathbf{Born}} = \frac{4\pi\alpha^2\beta C}{3q^2}\left(1 + \frac{1}{2\tau}\right)|G(q^2)|^2$$

$$|G(q^2)|^2 = \frac{2\tau|G_M(q^2)|^2 + |G_E(q^2)|^2}{2\tau + 1}$$

Calculations (2020): GR, MT Peña and K Tsushima PRD 101, 014014 (2020)
Ignore imaginary components and relative phases (very large q^2)

Data: CLEO ($q^2 = 14$, 17 GeV^2); New BES III 2020, 2021, ..., 2025

Hyperon elastic form factors **at large** q^2 $(e^+e^- \to B\bar{B})$

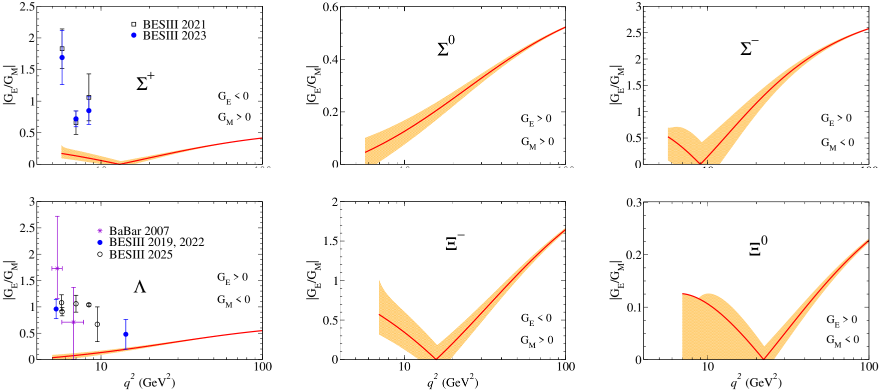


New BES III data: Λ (2021); Ξ^- (2020, 2023); Σ^+ (2024); Ξ^0 (2024); Σ^0 **(2025)**;

Waiting for Σ^- data; PRL 124, 032002 (2020); PLB 814, 136110 (2021); JHEP 11, 228 (2023); PRD 109, 034029 (2024); PRD 111, L051502 (2025); CLEO, PRD 96, 092004 (2017)

GR, MT Peña, K Tsushima and MK Cheoun, PLB 858, 139060 (2024) — **Good agreement $q^2 > 15$ GeV^2**

Hyperon ratios $|G_E/G_M|$



Model calculations for $|G_E|/|G_M|$ (real functions) much smaller than data

Σ^+, Λ: Data from BESIII 2021, 2022, 2023, 2025 & BaBar

PLB 814, 136110 (2021) PRD 105, L011101 (2022); PRL 132, 081904 (2024); PRL 135, 191902 (2025)

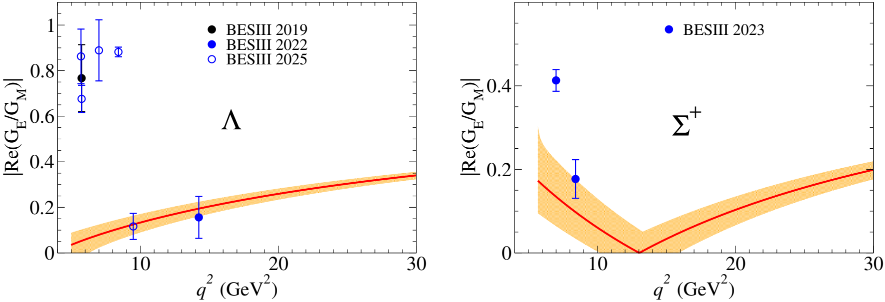
Model not comparable with data **OR** **Data not at the range of the calculations (large q^2)**

Hyperon ratios $|G_E/G_M|$ – Model vs Data BES III

Model calculation valid for the limit $\mathrm{Im}(G_E) = 0$, $\mathrm{Im}(G_M) = 0$

Data (real and imaginary components): $\frac{G_E}{G_M} = \frac{|G_E|}{|G_M|} e^{i\Delta\Phi}$

PRD 105, L011101 (2022), PRL 135, 191902 (2025) PRL 132, 081904 (2024)



Compare model with **real part:** $\left|\mathrm{Re}\left(\frac{G_E}{G_M}\right)\right| = \frac{|G_E|}{|G_M|} |\cos(\Delta\Phi)|$

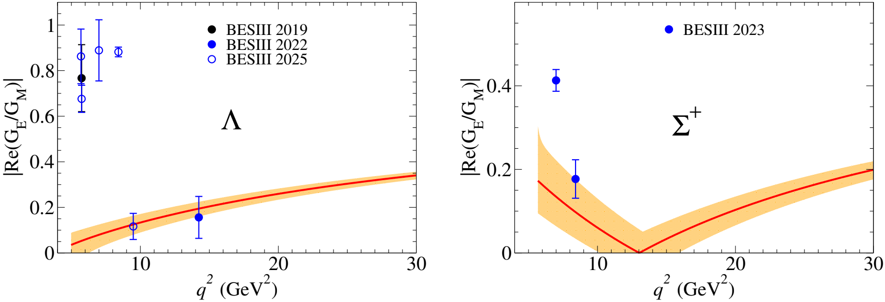
Model predictions for $\left|\mathrm{Re}\left(\frac{G_E}{G_M}\right)\right|$ – **Uncertanities on $\Delta\Phi$ not included**

Hyperon ratios $|G_E/G_M|$ – Model vs Data BES III

Model calculation valid for the limit $\mathrm{Im}(G_E) = 0$, $\mathrm{Im}(G_M) = 0$

Data (real and imaginary components): $\frac{G_E}{G_M} = \frac{|G_E|}{|G_M|} e^{i\Delta\Phi}$

PRD 105, L011101 (2022), PRL 135, 191902 (2025) PRL 132, 081904 (2024)



Compare model with **real part:** $\left|\mathrm{Re}\left(\frac{G_E}{G_M}\right)\right| = \frac{|G_E|}{|G_M|} |\cos(\Delta\Phi)|$

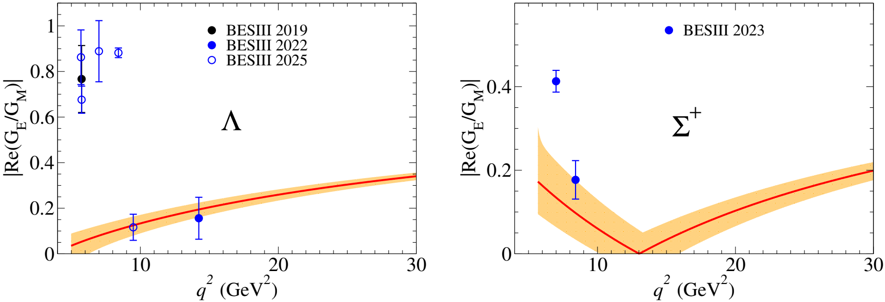
Model predictions for $\left|\mathrm{Re}\left(\frac{G_E}{G_M}\right)\right|$ – large q^2 data needed to test model

Hyperon ratios $|G_E/G_M|$ – Model vs Data BES III

Model calculation valid for the limit $\mathrm{Im}(G_E) = 0$, $\mathrm{Im}(G_M) = 0$

Data (real and imaginary components): $\frac{G_E}{G_M} = \frac{|G_E|}{|G_M|} e^{i\Delta\Phi}$

PRD 105, L011101 (2022), PRL 135, 191902 (2025) PRL 132, 081904 (2024)



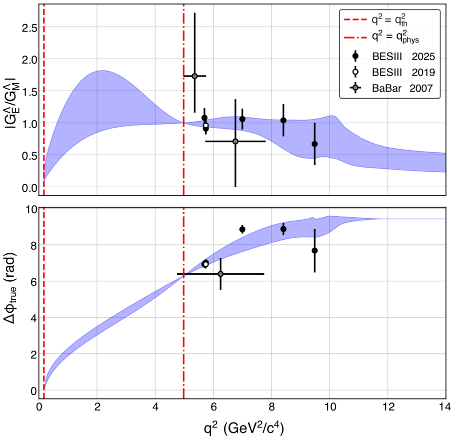
Compare model with **real part:** $\left|\mathrm{Re}\left(\frac{G_E}{G_M}\right)\right| = \frac{|G_E|}{|G_M|} |\cos(\Delta\Phi)|$

q^2 too low for conclusions; Test calculations w/ $q^2 \gtrsim 20$ GeV^2

Hyperon ratios $|G_E/G_M|$ – Model vs Data – Remarks

Recent result: Λ

- Λ form factors BES III: PRL 135, 191902 (2025)
- Model: A. Mangoni, et al, PRD 104, 116016 (2021)
  $q^2 > 10$ GeV^2:
  $\Delta\Phi = 3\pi$ $(e^{i\Delta\Phi} = -1)$



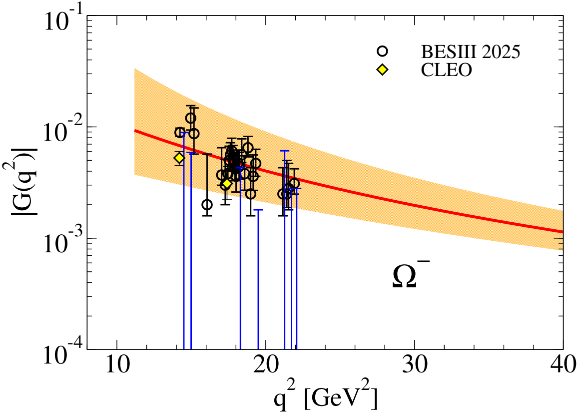
Remarks:

- Model calculations Λ
  $q^2 \gtrsim 10$ GeV^2:
  $\left|\mathrm{Re}\left(\frac{G_E}{G_M}\right)\right| \approx \frac{|G_E|}{|G_M|}$
- We have a global model for the octet baryon hyperons (Λ, Σ, Ξ)

Ω^- form factors: Model and data

Predictions of Ω^- effective FF: GR, PRD 103, 074018 (2021)

Global fit to Ω^- data (SL data: weight 96.3%)



New BES III data: arXiv:2508.01359 [hep-ex] upper limit of $|G| = 0$ — blue line

Outlook and conclusions

- Covariant Quark Model developed for **spacelike region** $(q^2 = -Q^2 < 0)$
  Describe Lattice QCD (bare) & Physical data (MC dressing)
- Model extended to **timelike region** $(q^2 > 4M_B^2)$
  Opportunity to study dynamical structure of hyperons $(q^2 \neq 0)$
  Large q^2 (asymptotic relations),
  - **Unified model for Λ, Σ and Ξ** ..., expecting results for Σ^-
  - Predictions for effective FF $G(q^2)$: Data: $q^2 \gtrsim 15$ GeV^2
    Compatible with **new large q^2 data** within **theoretical bands**
  - Predictions for $\left|\mathrm{Re}\left(\frac{G_E}{G_M}\right)\right|$:
    We may expect a slower convergence of model w/ data [negl. $\mathrm{Im}(G_\ell)$]
    Data: $q^2 \sim 10$ GeV^2: Too early for conclusions; Need more precise $\Delta\Phi$
    Promising results for the **highest values of q^2:** Λ, Σ^+
    Model calculations may be tested by $q^2 \gtrsim 20$ GeV^2 data
- Possible extension for baryons with c-quarks $(\Lambda_c^+$, ...)

Thank you

More questions: gilberto.ramalho2013@gmail.com

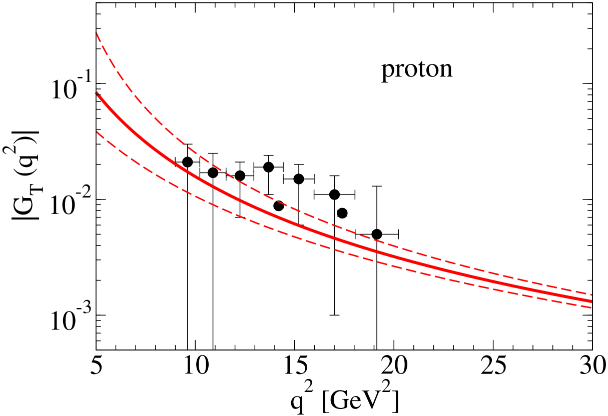
Scacelike and timelike calculations

- Model for the octet baryon/decuplet baryon – spacelike
  - **Octet baryon electromagnetic form factors in nuclear medium,**
    G. Ramalho, K. Tsushima and A. W. Thomas, **J. Phys. G 40, 015102 (2013).**
  - **Octet baryon electromagnetic form factors in a relativistic quark model**,
    G. Ramalho and K. Tsushima, **Phys. Rev. D 84, 054014 (2011).**
  - **A Relativistic quark model for the Ω^- electromagnetic form factors,**
    G. Ramalho, K. Tsushima and F. Gross, **Phys. Rev. D 80, 033004 (2009).**
- Extension of model to the timelike region
  - **Hyperon electromagnetic timelike elastic form factors at large q^2,**
    G. Ramalho, M. T. Peña and K. Tsushima, **Phys. Rev. D 101, 014014 (2020).**
  - **Electromagnetic form factors of the Ω^- baryon**
    in the spacelike and timelike regions,
    G. Ramalho, **Phys. Rev. D 103, 074018 (2021).**
  - **Electromagnetic $|G_E/G_M|$ ratios of hyperons at large q^2,**
    G. Ramalho, M. T. Peña, K. Tsushima and M.K. Cheoun,
    Phys. Lett. B 858 139060 (2024).

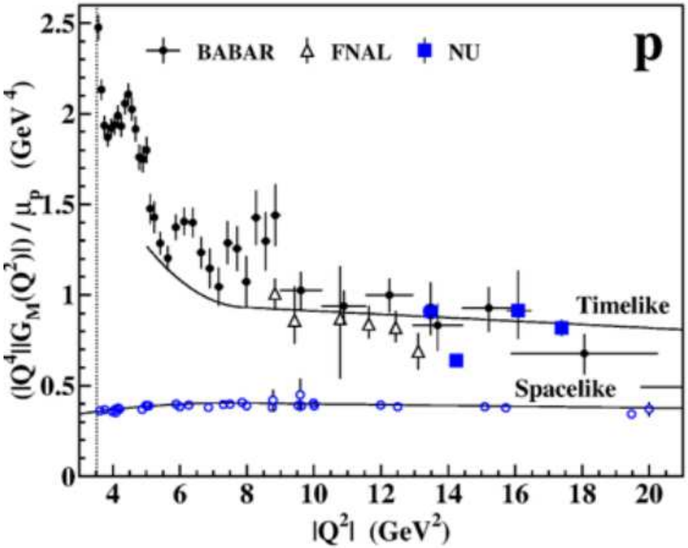
More ...

Backup slides

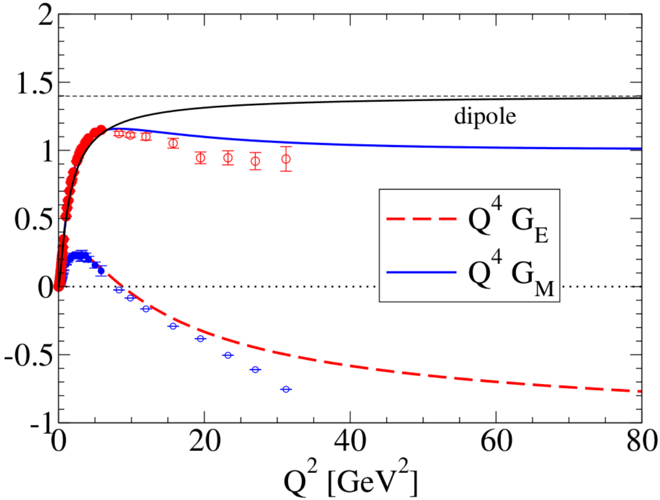
Proton data (spacelike and timelike)



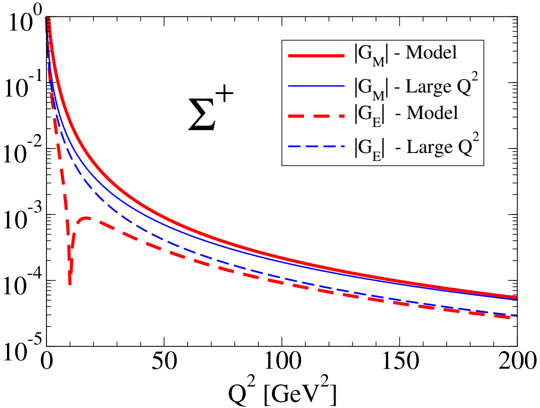
Proton data (spacelike and timelike) [CLEO, PRL 110, 022002 (2013)]



Proton data – large Q^2



Comparison with pointlike quarks



Model: exact (*extended quarks*) —— - - - -

Large Q^2: pointlike quarks [$f_{1l}(Q^2) \to \lambda_q$ & $Q^2 f_{2l}(Q^2) \to$ const.] —— - - - -

Convergence for $Q^2 \approx 150$ GeV^2 (perturbative regime – pQCD)

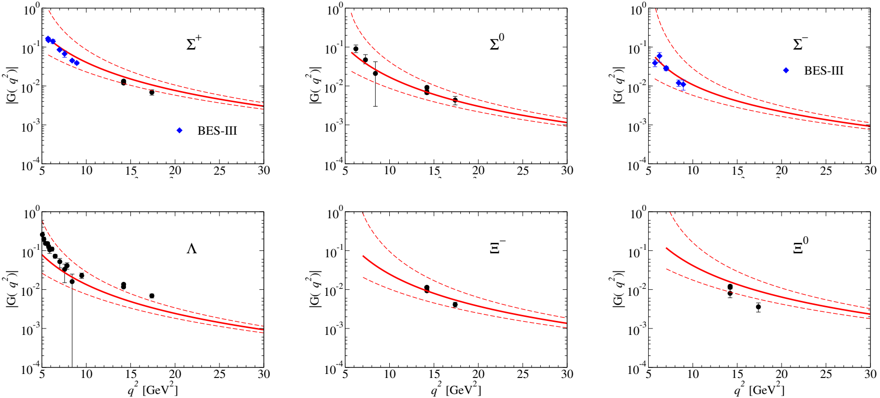
Elastic form factors – Summary of results

- The estimates of $|G|$ have the magnitude of the data
- Approximated agreement with data within the **theoretical bands for large q^2**
- Average $\frac{G^{\rm exp}}{G^{\rm mod}} \simeq 1$
- What about larger values ?
  - Predictions
    Table up to $q^2 = 60$ GeV^2
  - How far are we from pQCD estimates ? (pointlike quarks)

B	$\left\langle \frac{G^{\rm exp}}{G^{\rm mod}} \right\rangle$
Λ	2.19
Σ^+	0.65
Σ^0	1.08
Ξ^0	0.60
Ξ^-	1.08
Average	1.12

Table: Comparison between the ratios between the experimental value ($G^{\rm exp}$) and the model estimate of G ($G^{\rm mod}$) for the different baryons, for $q^2 \simeq 14.2$ and 17.4 GeV^2.

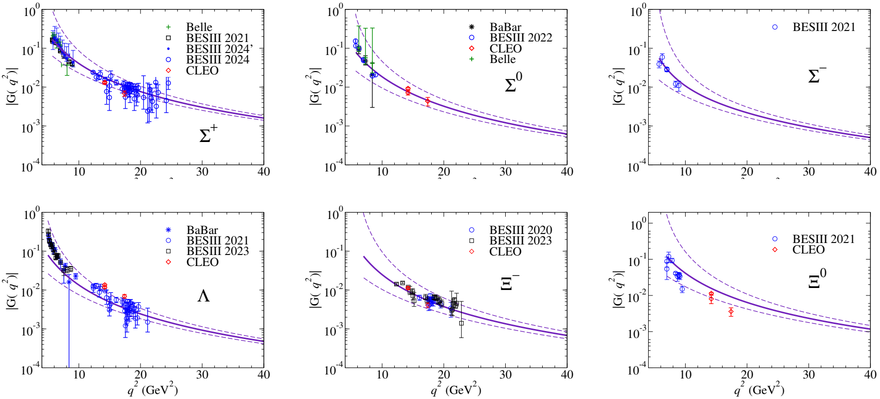
Hyperon elastic form factors **at large** q^2 ($e^+e^- \to B\bar{B}$) [old]



GR, MT Peña and K Tsushima PRD 101, 014014 (2020) — Data from CLEO, BaBar, BES-III (new data Σ^-)

Approximated description of the large q^2 data $\left\langle \frac{G^{\rm exp}}{G^{\rm mod}} \right\rangle \simeq 1.1$; Not much large q^2 data (2020)

Hyperon elastic form factors **at large** q^2 ($e^+e^- \to B\bar{B}$)

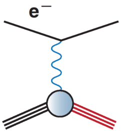


GR, MT Peña and K Tsushima PRD 101, 014014 (2020) **– Old calculation**

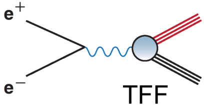
New BES III data Σ^+, Λ, Ξ^- PRL 124, 032002 (2020); PLB 814, 136110 (2021); JHEP 11, 228 (2023)

GR, MT Peña, K Tsushima and MK Cheoun, PLB 858, 139060 (2024) – Good agreement $q^2 > 15$ **GeV**^{2}

Spacelike and timelike reactions – elastic case



TFF
JLab/CLAS:
most world data



BES III, BELLE II

Spacelike reactions:

$e^- N \to e^- N$ $(e^- B \to e^- B)$

G_E, G_M real functions (2 numbers)

- Rosenbluth separation method
  $\frac{d\sigma}{d\Omega} \propto \left(\tau G_M^2 + \epsilon G_E^2\right)$, $(\tau = \frac{Q^2}{4M^2}, \epsilon^{-1} \propto \tan^2\frac{\theta}{2} + ...)$
- Transfer polarization method: $\frac{G_E}{G_M}$

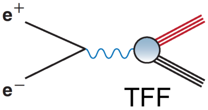
Timelike reactions: $e^- e^+ \to \gamma^* \to B\bar{B}$

G_E, G_M complex functions ($|G_E|$, $|G_M|$, $\Delta\Phi =$ rel. phase)

- Differential cross-section (one-γ-exchange)
  $\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta C}{4q^2}\left[|G_M|^2(1+\cos^2\theta) + \frac{1}{\tau}|G_E|^2 \sin^2\theta\right]$
- Integrated cross-section $(\tau = \frac{q^2}{4M^2})$
  $\sigma(q^2) = \frac{4\pi\alpha^2\beta C}{3q^2}\left[|G_M|^2 + \frac{1}{2\tau}|G_E|^2\right]$
  [...] define effective form factor

Timelike reactions

Timelike reactions: $e^- e^- \to \gamma^* \to B\bar{B}$; $|G_E|$, $|G_M|$, $\Delta\Phi$



- The first measurements in timelike region (proton)
  BaBar, FENICE, DM ... low precision
  $|G_M|$, $|G_E|$ not separated (assumed $|G_M| = |G_E|$)

  Babar PRD 73, 012005 (2006); BESIII PRD 91, 112004 (2015)
- Integrated cross-sections (Λ, $\Sigma^{0\pm}$, $\Xi^{0,-}$)

  Hyperon effective FF: BaBar PRD 76, 092006 (2007); CLEO PRD 96, 092004 (2017); BESIII PRD 105, L011101 (2022)
- Differential cross-section
  Measurements of ratio $|G_E/G_M|$ (Λ, Σ^+)

  BaBar PRD 76, 092006 (2007); BESIII PRD 105, L011101 (2022); BESIII PRL 132, 081904 (2024)
- Complete measurements (phase) Λ, Σ^+

  Measurement of Hyperon spin polarization (asymmetry α_B)

  BESIII PRD 105, L011101 (2022); BESIII PRL 132, 081904 (2024)

This presentation: **effective FF**: $|G|^2 \propto |G_M|^2 + \frac{1}{2\tau}|G_E|^2$ & $\left|\frac{G_E}{G_M}\right|$ ... no result for $\Delta\Phi$

Formalism

Octet baryon EM form factors in lattice QCD (p, Σ^+)

Step 1: Calibrate model using lattice QCD data

Quark current fixed; Fit radial wave functions

Bare parameters determined without contamination of meson cloud effects (large m_π)

Lattice QCD (bare):

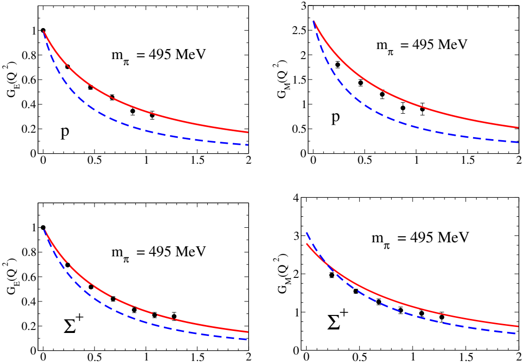
- Quark current – VMD $\ell = 0, \pm$

$$f_{i\ell}(Q^2; m_v, M_N) \to f_{i\ell}(Q^2; m_v^{\rm latt}, M_N^{\rm latt})$$

- Radial wave functions (fit):

$$\psi_B(M_B) \to \psi_B(M_B^{\rm latt})$$

GR, MT Peña, JPG 36, 115011 (2009);
PRD 80, 013008 (2009);
GR, K Tsushima, F Gross, PRD 80, 033004 (2009);
GR, K Tsushima, AW Thomas, JPG 40, 015102 (2013)

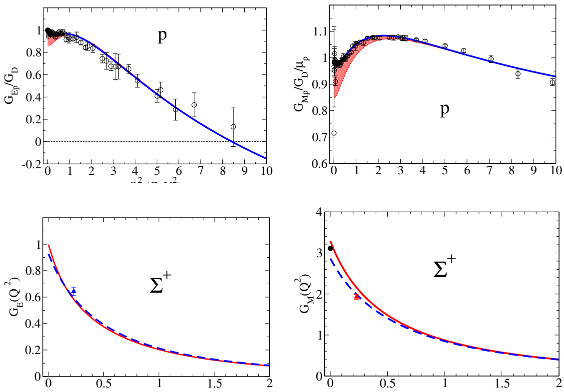


— Lattice - - - Physical

Step 2: Bare contribution extrapolated to $m_\pi = m_\pi^{\rm phy}$

Step 3: Include **meson cloud** contributions: **Physical FF:** $G_\ell = Z_B \left[G_\ell^{\rm B} + G_\ell^{\pi} \right]$

G_ℓ^{π} calibrated by **physical data** Nucleon EMFF & Octet baryon magnetic moments



- - - Bare —– Bare + Meson Cloud

Model can be used to calculate **octet baryon FF** in **different regimes of Q^2**

CSQM: **Octet** wave function (1)

S-state approximation (quark-diquark) P: Baryon; k: diquark

F Gross, GR and K Tsushima, PLB 690, 183 (2010):

$$\Psi_B(P,k) = \frac{1}{\sqrt{2}} \left[|M_S\rangle \Phi_S^0 + |M_A\rangle \Phi_S^1 \right] \psi_B(P,k)$$

$|M_S\rangle, |M_A\rangle$: flavor states; $\Phi_S^{0,1}$: spin states

B	$\vert M_S\rangle$	$\vert M_A\rangle$
p	$\frac{1}{\sqrt{6}}\left[(ud+du)u - 2uud\right]$	$\frac{1}{\sqrt{2}}(ud-du)u$
n	$-\frac{1}{\sqrt{6}}\left[(ud+du)d - 2ddu\right]$	$\frac{1}{\sqrt{2}}(ud-du)d$
Λ^0	$\frac{1}{2}\left[(dsu-usd)+s(du-ud)\right]$	$\frac{1}{\sqrt{12}}\left[s(du-ud)-(dsu-usd)-2(du-ud)s\right]$
Σ^+	$\frac{1}{\sqrt{6}}\left[(us+su)u-2uus\right]$	$\frac{1}{\sqrt{2}}(us-su)u$
Σ^0	$\frac{1}{\sqrt{12}}\left[s(du+ud)+(dsu+usd)-2(ud+du)s\right]$	$\frac{1}{2}\left[(dsu+usd)-s(ud+du)\right]$
Σ^-	$\frac{1}{\sqrt{6}}\left[(sd+ds)d-2dds\right]$	$\frac{1}{\sqrt{2}}(ds-sd)d$
Ξ^0	$-\frac{1}{\sqrt{6}}\left[(ud+du)s-2ssu\right]$	$\frac{1}{\sqrt{2}}(us-su)s$
Ξ^-	$-\frac{1}{\sqrt{6}}\left[(ds+sd)s-2ssd\right]$	$\frac{1}{\sqrt{2}}(ds-sd)s$

CSQM: **Octet** wave function (2) $SU(3)$ breaking

Radial wave functions: $\psi_B[(P-k)^2]$

Defined in terms of

$$\chi_B = \frac{(M_B - m_D)^2 - (P-k)^2}{M_B m_D}$$

$$\psi_N(P,k) = \frac{N_N}{m_D(\beta_1 + \chi_N)(\beta_2 + \chi_N)}$$

$$\psi_\Lambda(P,k) = \frac{N_\Lambda}{m_D(\beta_1 + \chi_\Lambda)(\beta_3 + \chi_\Lambda)}$$

$$\psi_\Sigma(P,k) = \frac{N_\Sigma}{m_D(\beta_1 + \chi_\Sigma)(\beta_3 + \chi_\Sigma)}$$

$$\psi_\Xi(P,k) = \frac{N_\Xi}{m_D(\beta_1 + \chi_\Xi)(\beta_4 + \chi_\Xi)}$$

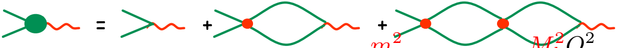
β_i: momentum range parameters (m_D units); $\beta_4 > \beta_3 > \beta_2 > \beta_1$

long range: β_1 (all systems)

short range: β_2 (lll systems); β_3 (sll systems); β_4 (ssl systems)

CSQM: Photon-Quark coupling [Extra]

- $j_q^\mu = j_1 \gamma^\mu + j_2 \frac{i\sigma^{\mu\nu} q_\nu}{2M_N}$, Quark form factors: $j_i = \frac{1}{2} f_{i+} \lambda_0 + \frac{1}{6} f_{i-} \lambda_3 + \frac{1}{2} f_{i0} \lambda_s$
  [parametrize gluon and $q\bar{q}$ dressing of quarks] λ_l: Gell-Mann matrices
  Vector meson dominance parameterization: PRD 80, 033004 (2009)



$$f_{1\pm} = \lambda_q + (1-\lambda_q)\frac{m_v^2}{m_v^2+Q^2} + c_\pm \frac{M_h^2 Q^2}{(M_h^2+Q^2)^2}$$

$$f_{10} = \lambda_q + (1-\lambda_q)\frac{m_\phi^2}{m_\phi^2+Q^2} + c_0 \frac{M_h^2 Q^2}{(M_h^2+Q^2)^2}$$

$$f_{2\pm} = \kappa_\pm \left\{ d_\pm \frac{m_v^2}{m_v^2+Q^2} + (1-d_\pm)\frac{M_h^2}{M_h^2+Q^2} \right\}$$

$$f_{20} = \kappa_0 \left\{ d_0 \frac{m_\phi^2}{m_\phi^2+Q^2} + (1-d_0)\frac{M_h^2}{M_h^2+Q^2} \right\}$$

Light mesons ($m_v = m_\rho$), m_ϕ and **effective** heavy meson: $M_h = 2M_N$
Fix coefficients (c_0, $c_\pm$, d_0, $d_+ = d_-$) and a. m. m. $\kappa_\pm$, κ_0, – universal parameters
Use: Nucleon EM form factors; lattice QCD data (decuplet baryon)

Ω^- form factors

What do we know about the Ω^-?

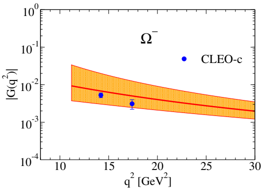
- Mass, charge and μ_{Ω^-}
- Form factors G_{E0}, G_{M1}, G_{E2}
  Lattice QCD; physical m_s

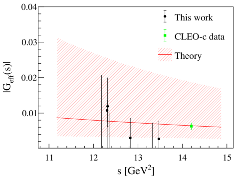
- G_{M3} unknown
- Asymptotic relation
  $G_{M1} \propto \frac{Q^2}{4M^2} G_{M3}$
- TL: Effective FF $q^2 \sim 18$ GeV^2
  $G_E = (G_{E0}, G_{E2})$, $G_M = (G_{M1}, G_{M3})$

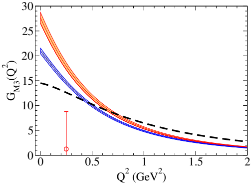
Quark model analysis

BESIII PRD 107 5, 052003 (2023)

G_{M3}







New data - not large q^2; Global analysis (SL + TL/large q^2) **can help** to determine G_{M3}