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Transition Form Factors For $\gamma N \rightarrow \Delta(1700)$

QuantFunc

VALENCIA, 2-6 SEPTEMBER, 2024

Fundamentals of QCD

$$\mathcal{L}_{QCD} = \sum_f \bar{q}_f \left(i\gamma^\mu D_\mu - m_f\right) q_f - \frac{1}{4} G_a^{\mu\nu} G_{\mu\nu}^a$$

$$+\ g.f. + ghosts$$

Gauge covariance

$$D_\mu = \partial_\mu + i g_s \frac{\lambda_a}{2} A_\mu^a$$

$$G_{\mu\nu}^a = \partial_\mu A_\nu^a - \partial_\nu A_\mu^a + g f^{abc} A_\mu^b A_\nu^c$$

Emergent phenomena

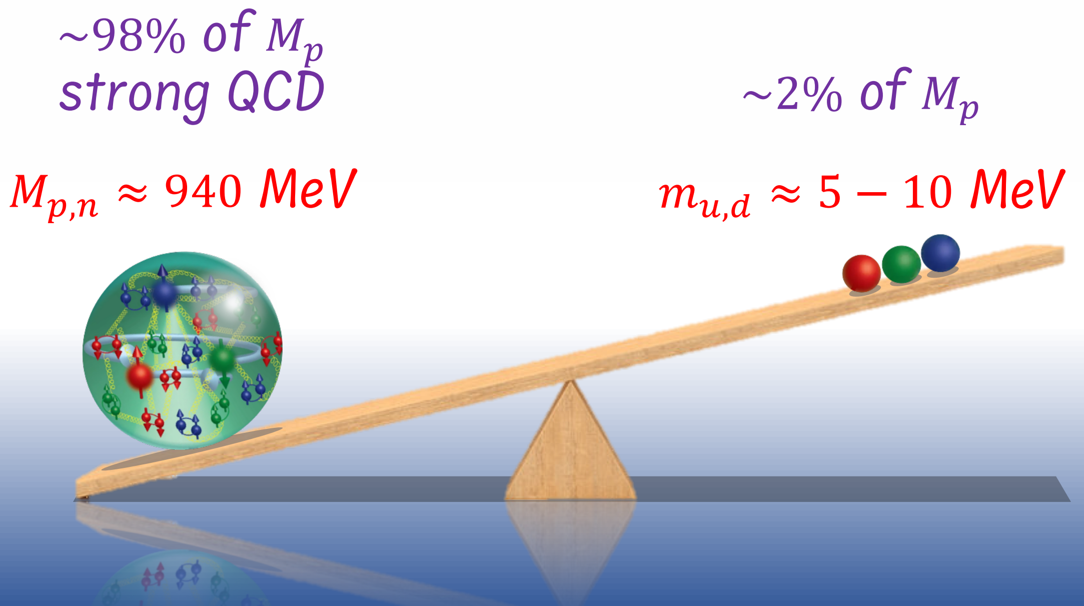
Dynamical Chiral Symmetry Breaking (DCSB)
Confinement
Gluon mass generation (in pure Yang-Mills)
Strongly interacting bound states

Building blocks

q_f – *Quark field: 6 flavours*
A_μ^a – *Gluon field: 8 gauge bosons*

Nucleons

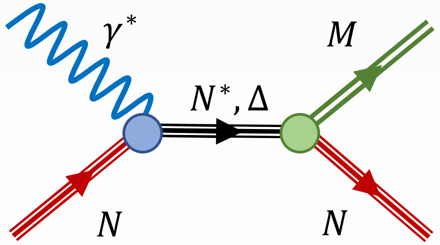
Dominant mass of visible universe
m_f – *Spontaneous Symmetry Breaking*
Higgs mechanism is not enough!

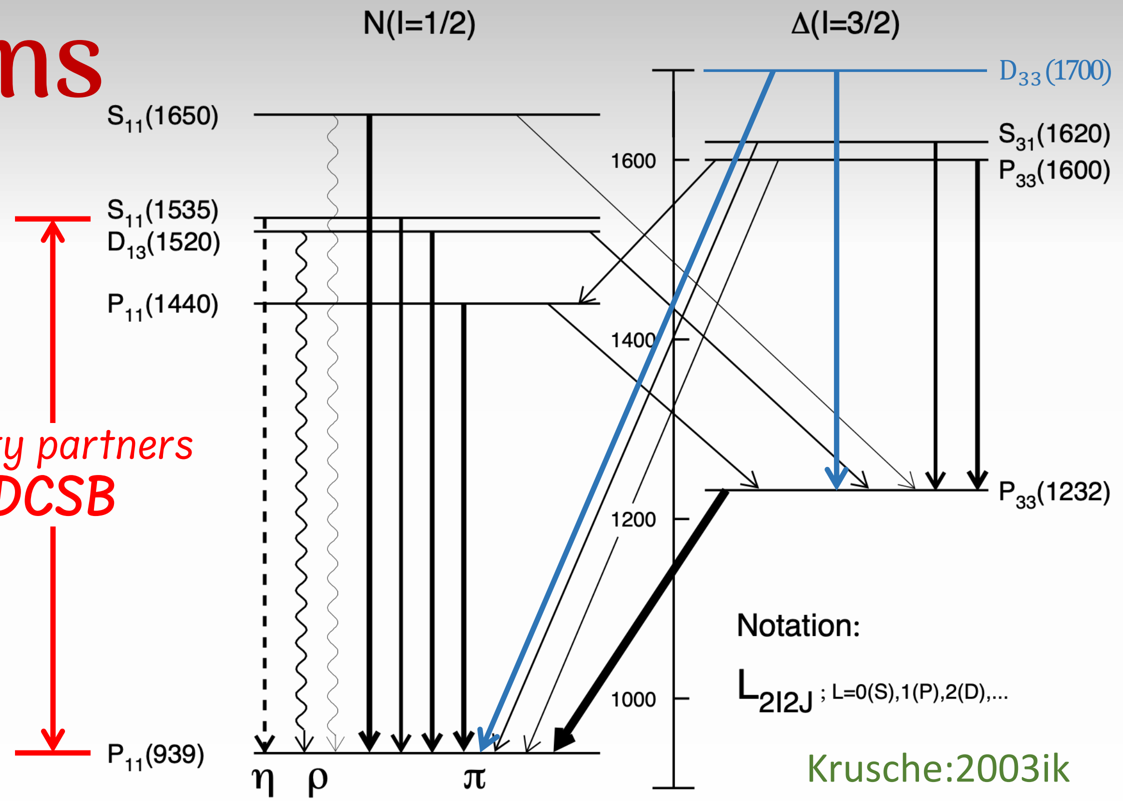


Excited states and transitions

Photo- and electro-production

CEBAF at Jlab
ELSA at Bonn U.
MAMI in Mainz
LEGS at BNL





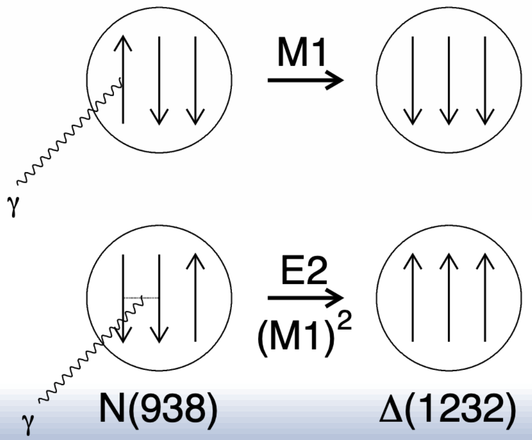
Standard picture: spin-flip

1) *Magnetic dipole M1*
2) *Electric quadrupole E2*
3) *Coulomb quadrupole C2*

Equivalence: Sack FFs

$G_M^*,\ G_E^*,\ G_C^*$

Synergy between experiment and theory



Nucleon resonances are the key to additional and novel features of QCD!!

Theoretical challenges

Mass spectrum
Wave functions
Distribution functions

Krusche:2003ik

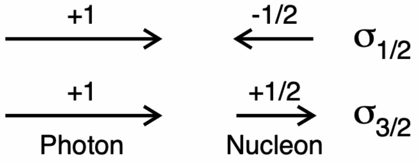
Helicity amplitudes: A glimpse into nucleon resonances

Data from JLab/CLAS and Jlab/Hall C

The Helicity Amplitudes are transition matrix elements of the EM current projection on photon polarization states $\epsilon_\mu^{(\lambda=0,\pm1)}$.

The total cross-section depends on these helicities. Namely, for real photons (only transverse polarizations)

$$\sigma_{tot} = (\sigma_{3/2} + \sigma_{1/2})/2$$



Breit frame interpretation

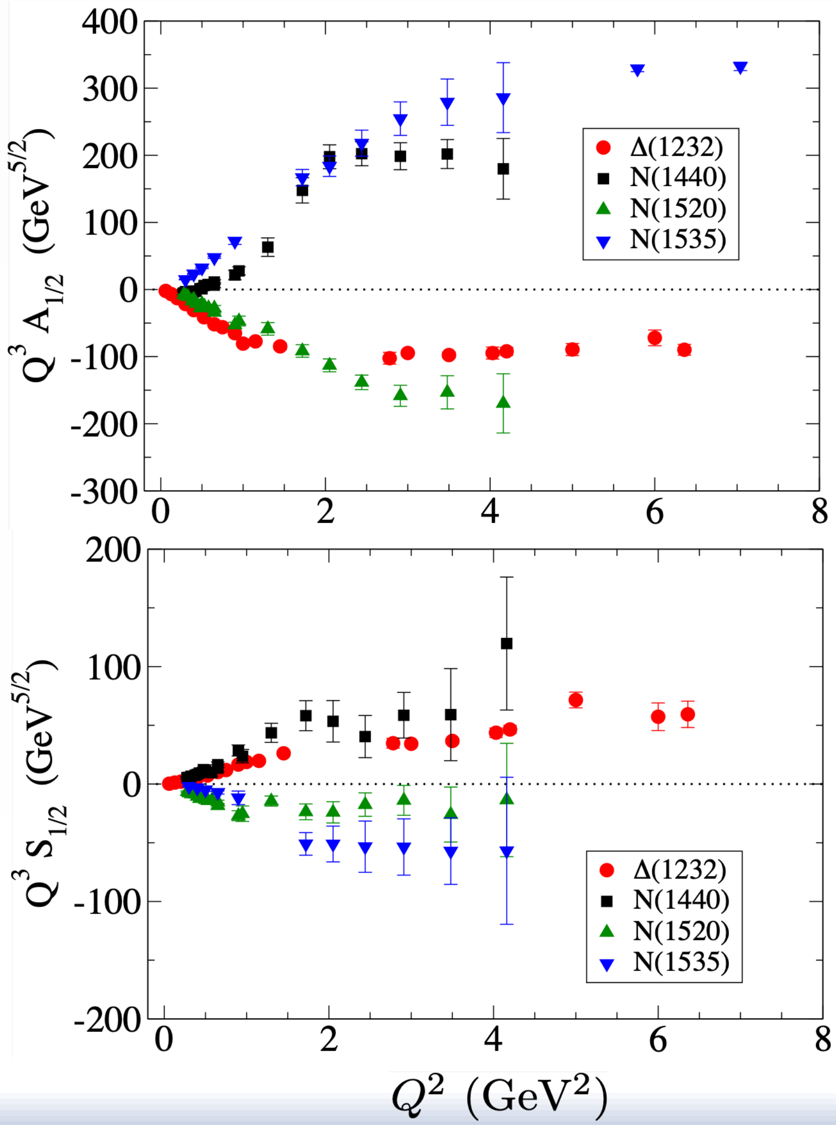
Transverse photons

$$A_{1/2} \sim \left\langle N^*, \lambda_R = +\frac{1}{2} \middle| \epsilon_\mu^{(+)} J^\mu \middle| N, \lambda_N = +\frac{1}{2} \right\rangle_{\mathrm{BF}}$$

$$A_{3/2} \sim \left\langle N^*, \lambda_R = -\frac{3}{2} \middle| \epsilon_\mu^{(-)} J^\mu \middle| N, \lambda_N = +\frac{1}{2} \right\rangle_{\mathrm{BF}}$$

Longitudinal photons

$$S_{1/2} \sim \left\langle N^*, \lambda_R = -\frac{1}{2} \middle| \epsilon_\mu^{(0)} J^\mu \middle| N, \lambda_N = +\frac{1}{2} \right\rangle_{\mathrm{BF}}$$



Connection with EM multipoles depends on J^P

Krusche:2003ik, Ramalho:2023hqd

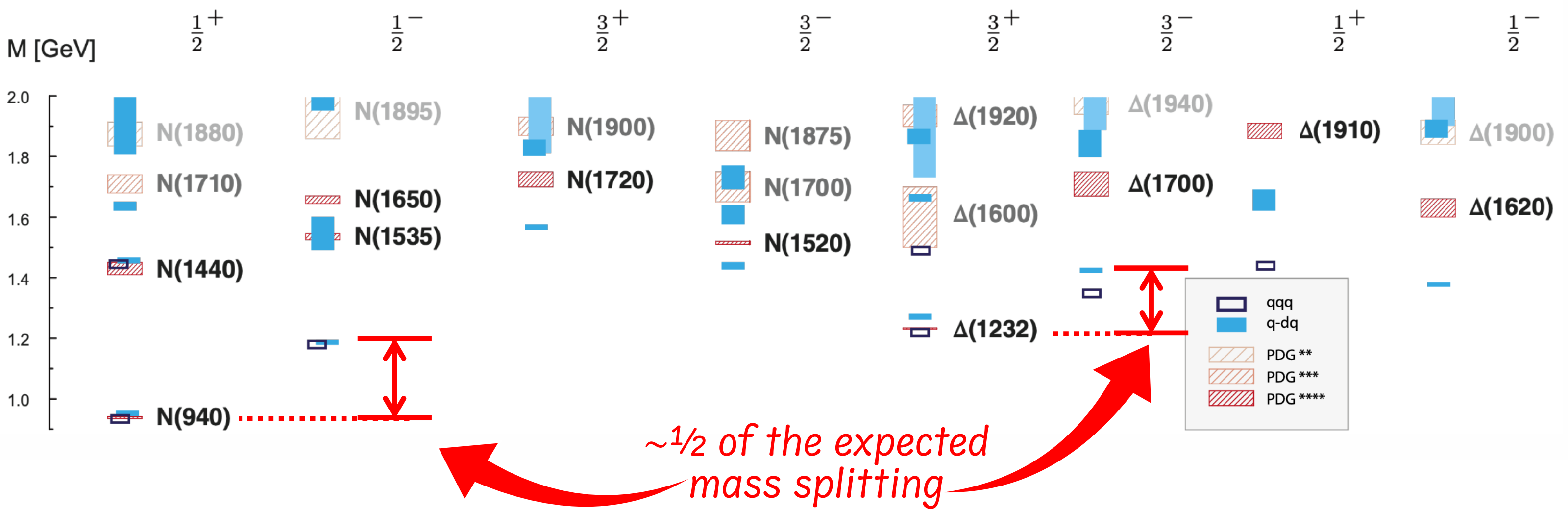
Quark-Diquark picture

Rainbow-Ladder (RL)

In this approximation, the masses of $N(1/2^+)$ and $\Delta(3/2^+)$ agree with experiment.

The remaining spin-parity channels are too ligth, e.g. the ground state partity partners $N(1535)$ and $\Delta(1700)$.

Nucleon and Delta spectrum RL



Barabanov:2020jvn, Eichmann:2016hgl

Quark-Diquark picture

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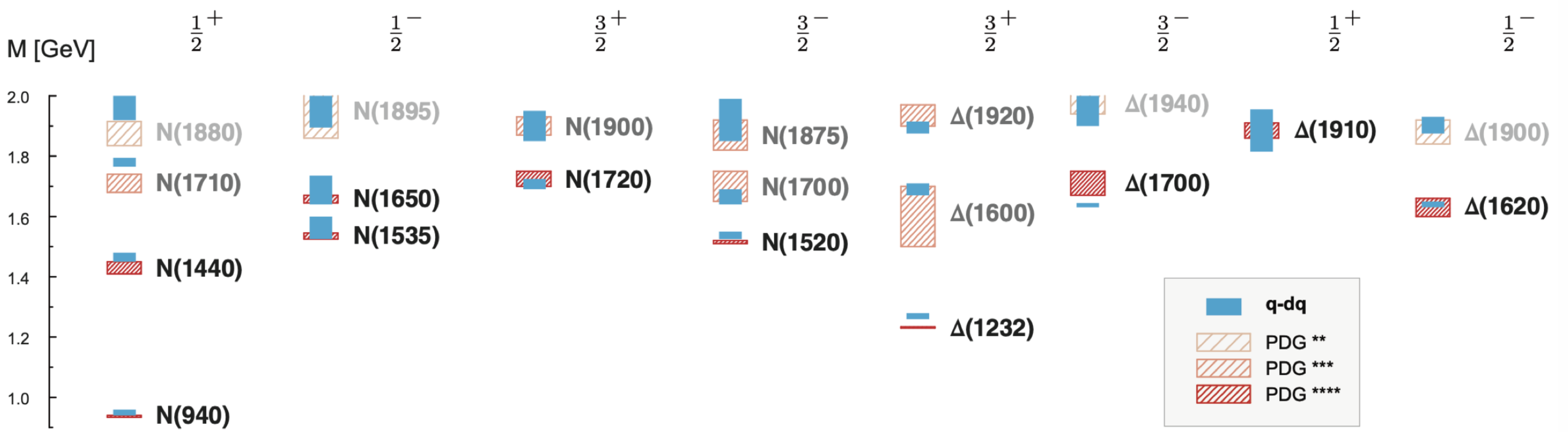
"Beyond" RL

Nucleon and Delta spectrum with reduced strength in the pseudoscalar and vector diquark channels.

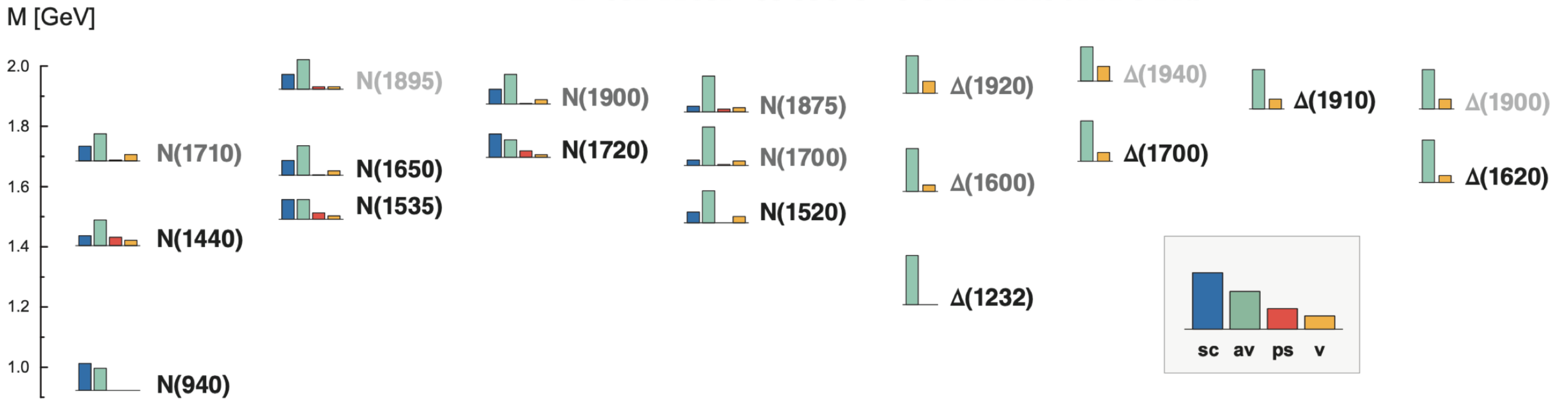
In $N(1/2^+)$and $\Delta(3/2^+)$ only scalar (sc) and axial-vector (av) diquarks play a role.

Pseudoscalar (ps) and vector (v) diquarks provide small contributions.

Nucleon and Delta spectrum RL+



Partial wave contributions

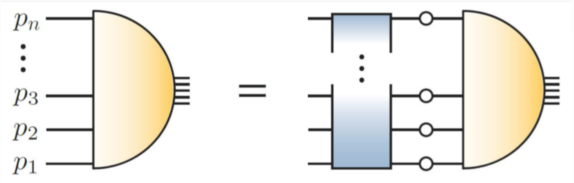


Axial-vector diquark: Significant in many channels!

Barabanov:2020jvn, Eichmann:2016hgl

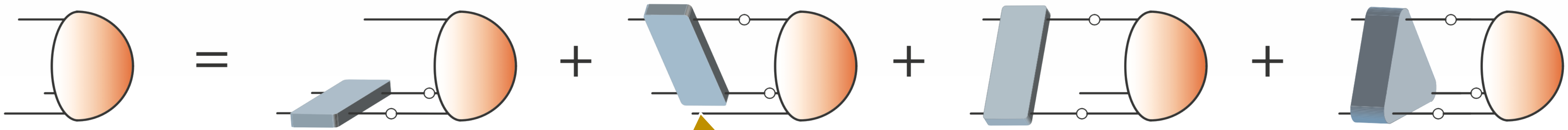
Bound states: continuum approach

n-valence-quark equation



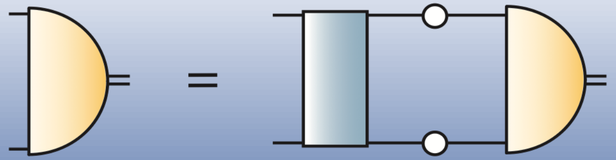
Masses (pole position) and amplitudes for n-valence-quark (antiquark) hadrons obtained as solutions of Poincaré-covariant equations for the corresponding bound state.

Faddeev equation



Interaction kernels: sum of all possible n-body contributions

Bethe-Salpeter equation

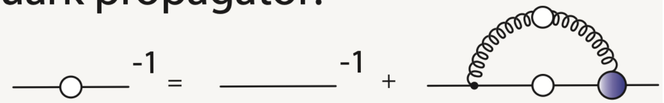


Knowledge of QCDs n-piont Green functions required

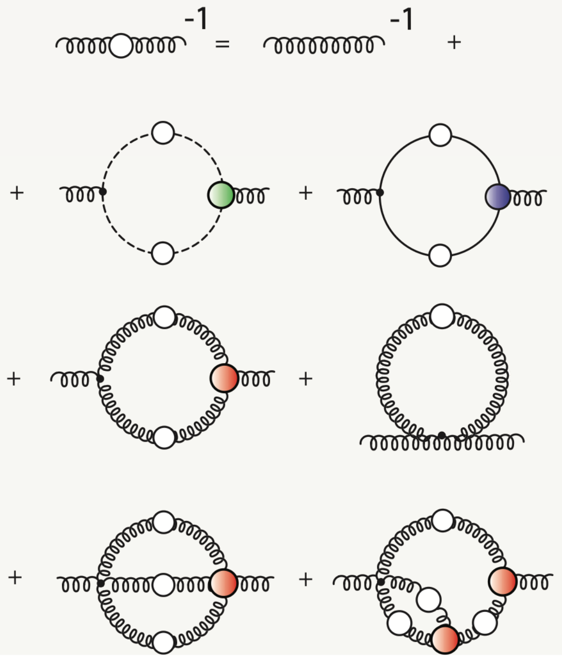
Barabanov:2020jvn, Eichmann:2016hgl

Schwinger-Dyson Equations

Quark propagator:

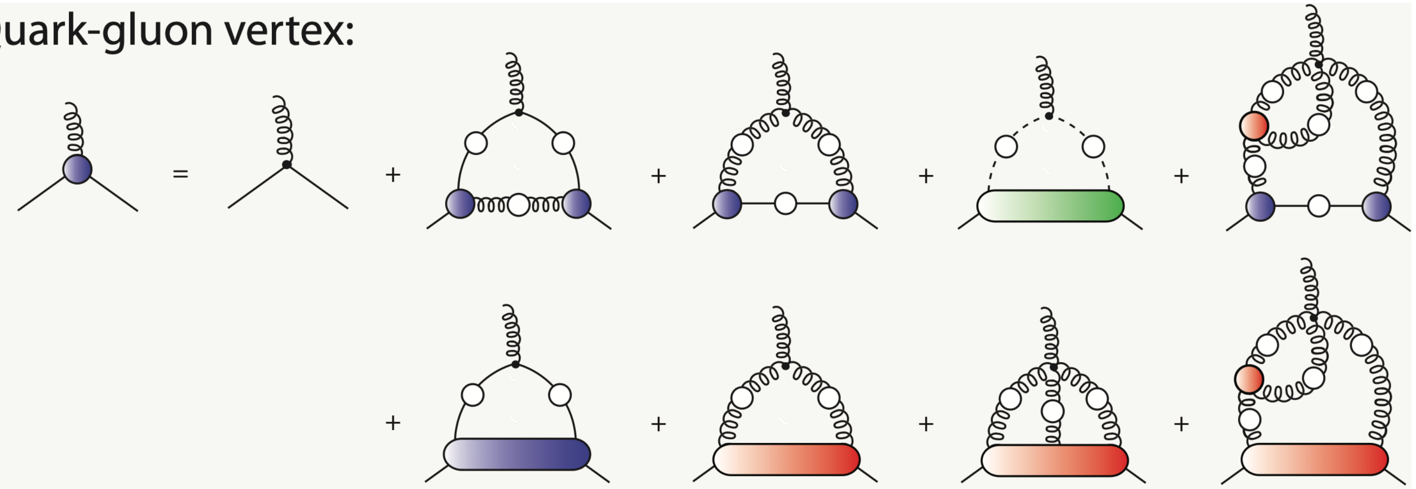


Gluon propagator:



- *Fundamental field equations of any QFT*
- *Self-consostent, coupled system*
- *Poincaré covariance*
- *Gauge invariance*
- *Derivation independent of couplings*
- *Bridge between low and hight energy regimes*

Quark-gluon vertex:

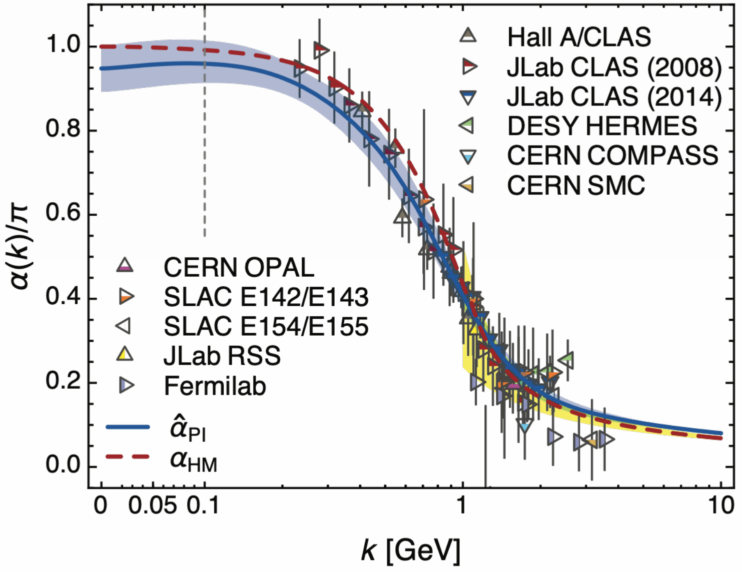


Eichmann:2009zx

Non-perturbative insights

SDEs and LQCD suggest infrared finite running coupling, gluon dressing and quark mass function

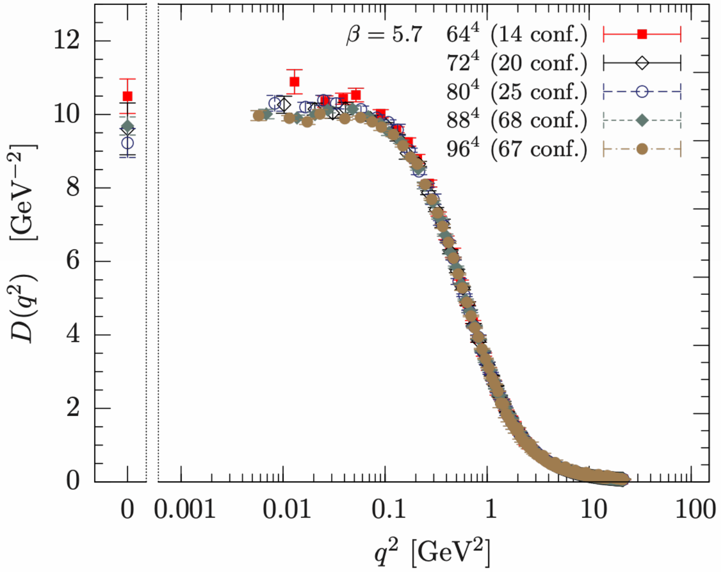
Running coupling



$$\alpha(\zeta^2) \;=\; g^2(\zeta^2)/[4\pi]$$

$\alpha \approx \pi$

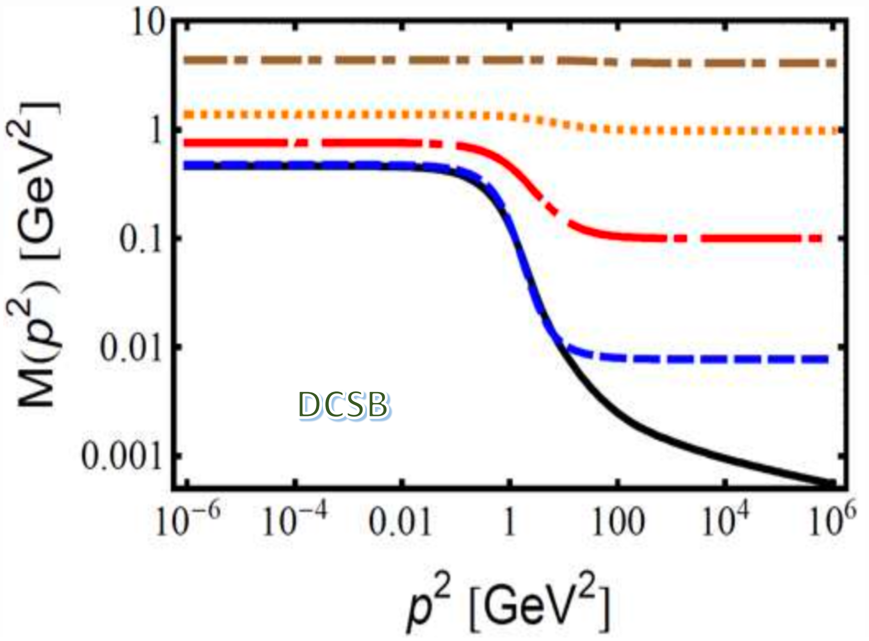
Gluon propagator



$$\mathcal{D}_{\mu\nu}(q) = \Delta(q^2)\left[\delta_{\mu\nu} - \frac{q_\mu q_\nu}{q^2}\right] + \xi\frac{q_\mu q_\nu}{q^4}$$

$m_g \approx 500$ *MeV*

Quark mass



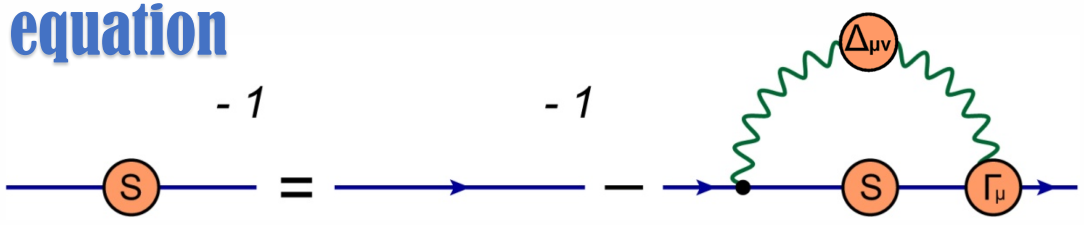
$$\mathcal{S}_f(p) = \frac{\mathcal{Z}_{2f}(p^2)}{i\gamma\cdot p + \mathcal{M}_f(p^2)}$$

$M_{u,d} \approx 300 - 500$ *MeV*

Bowman:2004jm, Bogolubsky:2009dc, Aguilar:2008xm, Binosi:2016nme, deTeramond:2024ikl

Contact Interaction

Gap equation



$$\mathcal{S}_f^{-1}(p) = \mathcal{Z}_{2f}\left(i\gamma\cdot p + m_f^0\right) + \Sigma_f(p)$$

$$\Sigma_f(p) = C_F \mathcal{Z}_{1f}\int_{dq}^{\Lambda} g_s^2 \mathcal{D}_{\mu\nu}(p-q)\gamma^\mu \mathcal{S}_f(q)\Gamma_f^\nu(p,q)$$

CI

$$\mathcal{S}_f^{-1}(p) = i\gamma\cdot p + m_f + 4\pi\, C_F \frac{\alpha_{IR}}{m_g^2}\int \frac{d^4q}{(2\pi)^4}\gamma_\mu \mathcal{S}_f(q)\gamma_\mu$$

Primary goal: Elucidate the sensitivity of (pion) form factors to the pointwise behaviour of quark interactions

RL truncation

$$\mathcal{Z}_{1f} g_s^2 \mathcal{D}_{\mu\nu}(p-q)\Gamma_f^\nu(p,q) \to k^2\mathcal{G}(k^2)\mathcal{D}^0_{\mu\nu}(k)\gamma^\nu$$

Momentum-indep vector-exchange interaction

$$k^2\mathcal{G}(k^2)\mathcal{D}^0_{\mu\nu}(k) \to 4\pi\alpha_{IR}\frac{\delta_{\mu\nu}}{m_g^2}$$

$\alpha_{IR} = 0.93\pi$ $m_g = 500$ MeV

Solution

$M_{u,d} = 370$ MeV

$$\mathcal{S}_f^{-1}(p) = i\gamma\cdot p + M_f$$

Symmetry-preserving regularization

$$\frac{1}{s+M_f^2} \to \int_{\tau_{uv}^2}^{\tau_{ir}^2} d\tau\, e^{-\tau\left(s+M_f^2\right)}$$

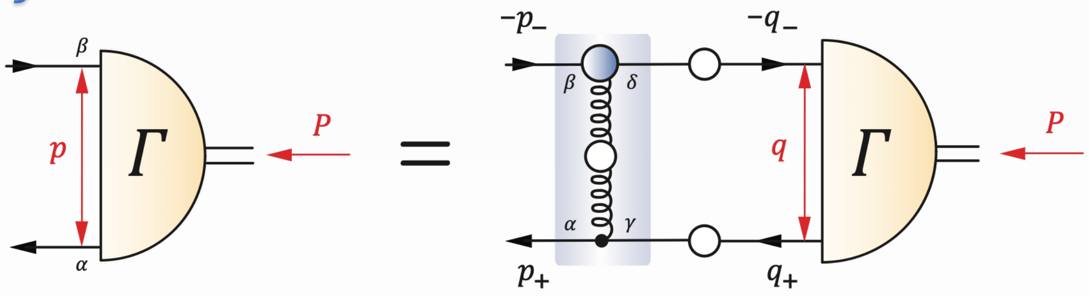
$$1/\tau_{uv} = 0.905\,\mathrm{GeV}$$

$$1/\tau_{ir} = 0.24\,\mathrm{GeV}$$

Gutierrez-Guerrero:2010waf, Roberts:2010rn

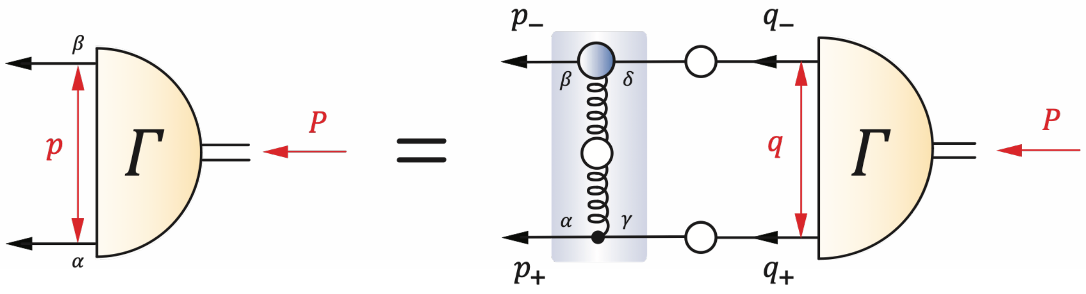
Bethe-Salpeter equation

Mesons J^{PC}



$$\Gamma_{f\bar{g}}(p,P) = -4\pi\, C_F \frac{\alpha_{IR}}{m_g^2} \int \frac{d^4q}{(2\pi)^4} \gamma_\mu \mathcal{S}_f(q+P)\Gamma_{f\bar{g}}(q,P)\mathcal{S}_{\bar{g}}(q)\gamma_\mu$$

Diquarks $I(J^P)$



$$\Gamma_{fg}(p,P) = -\frac{4\pi}{2}\, C_F \frac{\alpha_{IR}}{m_g^2} \int \frac{d^4q}{(2\pi)^4} \gamma_\mu \mathcal{S}_f(q+P)\Gamma_{fg}(q,P)C^\dagger \mathcal{S}_g(q)\gamma_\mu$$

Non-exotic channels: J^P meson partners with J^{-P} diqurk

$$J^{PC} = 0^{-+},\ 1^{--},\ 0^{++},\ 1^{++},\ 1^{+-}$$

$$I(J^P) = 0(0^+),\ 1(1^+),\ 0(0^-),\ 0(1^-),\ 1(1^-)$$

CI forbids

BS Amplitudes

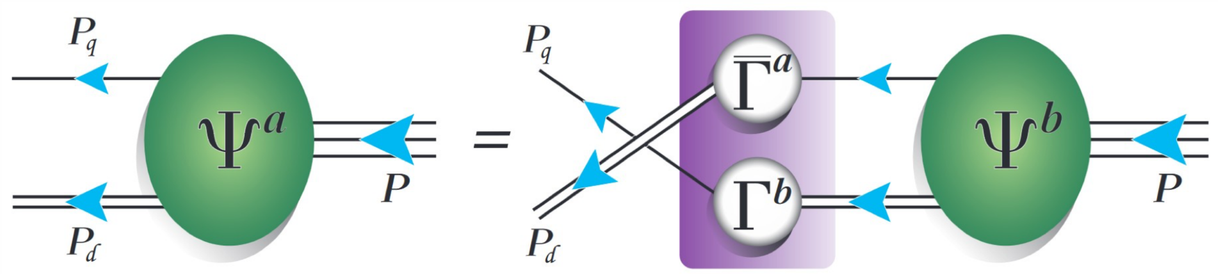
$$\begin{aligned}
\Gamma^{0^{-+}}(P) &= \gamma_5 \left[iE^{0^{-+}}(P) + \frac{\gamma\cdot P}{2M} F^{0^{-+}}(P) \right] \\
\Gamma^{0^{++}}(P) &= \mathbb{1} E^{0^{++}}(P) \\
\Gamma_\mu^{1^{--}}(P) &= \gamma_\mu^T E^{1^{--}}(P) + \frac{1}{2M}\sigma_{\mu\nu}P_\nu F^{1^{--}}(P) \\
\Gamma_\mu^{1^{++}}(P) &= \gamma_5 \left[\gamma_\mu^T E^{1^{++}}(P) + \frac{1}{2M}\sigma_{\mu\nu}P_\nu F^{1^{++}}(P) \right]
\end{aligned}$$

Ground-state masses

Meson	Exp.	CI	Diquarks Mass
π	0.139	0.14	$(qq)_{0^+} = 0.78$
ρ	0.78	0.93	$(qq)_{1^+} = 1.06$
σ	1.2	1.22	$(qq)_{0^-} = 1.15$
a_1	1.260	1.37	$(qq)_{1^-} = 1.33$

Roberts:2011cf, Roberts:2011wy, Yin:2019bxe, Chen:2012qr, Gutierrez-Guerrero:2019uwa, Gutierrez-Guerrero:2021rsx, Yin:2021uom, Barabanov:2020jvn

Faddeev Equation



Faddeev amplitude (FA)

In the dynamical quark-diquark picture

$$\Psi = \Psi_1 + \Psi_2 + \Psi_3$$

Subscript identifies spectator quark

Static appoximation $S^T(k) \to \dfrac{g_B^2}{M_u}$ *Controls diquark contributions with oposite P*

For $I(J^P) = \frac{1}{2}(\frac{1}{2}^{\pm})$

$$\Psi_3^N(p_i, \alpha_i, \tau_i) = \mathcal{N}_3^{(qq,0^+)} + \mathcal{N}_3^{(qq,1^+)} + \mathcal{N}_3^{(qq,0^-)} + \mathcal{N}_3^{(qq,1^-)}$$

Dominant correlations

$$\mathcal{N}_3^{(qq,0^+)}(p_i, \alpha_i, \tau_i) = \left[\Gamma^{(qq,0^+)}\left(\frac{1}{2}p_{[12]}; K\right)\right]_{\alpha_1\alpha_2}^{\tau_1\tau_2} \Delta^{(qq,0^+)}(K)[\mathcal{S}(l;P)u(P)]_{\alpha_3}^{\tau_3}$$

$$\mathcal{N}^{(qq,1^+)}(p_i, \alpha_i, \tau_i) = \left[t^i\Gamma_\mu^{(qq,1^+)}\left(\frac{1}{2}p_{[12]}; K\right)\right]_{\alpha_1\alpha_2}^{\tau_1\tau_2} \Delta_{\mu\nu}^{(qq,1^+)}(K)[\mathcal{A}_\nu^i(l;P)u(P)]_{\alpha_3}^{\tau_3}$$

CI relevant structures

$$\mathcal{S}^\pm = s^\pm \mathbf{I}_{\rm D}\, \mathcal{G}^\pm \qquad \mathcal{G}^{+(-)} = \mathbf{I}_{\rm D}(\gamma_5)$$

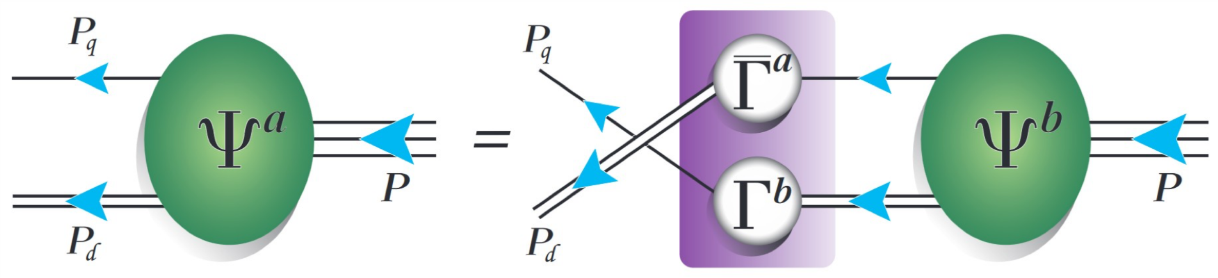
$$i\mathcal{P}^\pm = p^\pm \gamma_5\, \mathcal{G}^\pm$$

$$i\mathcal{A}_\mu^{\pm j} = (a_1^{\pm j}\gamma_5\gamma_\mu - i a_2^{\pm j}\gamma_5 \hat{P}_\mu)\, \mathcal{G}^\pm$$

$$i\mathcal{V}_\mu^\pm = (v_1^\pm \gamma_\mu - i v_2^\pm \mathbf{I}_{\rm D} \hat{P}_\mu)\gamma_5\, \mathcal{G}^\pm$$

Yin:2019bxe , Yin:2021uom, Barabanov:2020jvn, Segovia:2013uga, Raya:2021pyr

Faddeev Equation



Static appoximation $S^T(k) \to \dfrac{g_B^2}{M_u}$

For $I(J^P) = \frac{1}{2}(\frac{1}{2}^{\pm})$ sc av ps v

$$\Psi_3^N(p_i,\alpha_i,\tau_i) = \mathcal{N}_3^{(qq,0^+)} + \mathcal{N}_3^{(qq,1^+)} + \mathcal{N}_3^{(qq,0^-)} + \mathcal{N}_3^{(qq,1^-)}$$

Suppresed for N(940)

Dominant correlations

$$\mathcal{N}_3^{(qq,0^+)}(p_i,\alpha_i,\tau_i) = \left[\Gamma^{(qq,0^+)}\left(\frac{1}{2}p_{[12]};K\right)\right]_{\alpha_1\alpha_2}^{\tau_1\tau_2} \Delta^{(qq,0^+)}(K)[\mathcal{S}(l;P)u(P)]_{\alpha_3}^{\tau_3}$$

$$\mathcal{N}^{(qq,1^+)}(p_i,\alpha_i,\tau_i) = \left[t^i\Gamma_\mu^{(qq,1^+)}\left(\frac{1}{2}p_{[12]};K\right)\right]_{\alpha_1\alpha_2}^{\tau_1\tau_2} \Delta_{\mu\nu}^{(qq,1^+)}(K)[\mathcal{A}_\nu^i(l;P)u(P)]_{\alpha_3}^{\tau_3}$$

Faddeev amplitude (FA)

In the dynamical quark-diquark picture

$$\Psi = \Psi_1 + \Psi_2 + \Psi_3$$

Subscript identifies spectator quark

$$m_{N(940)} = 1.14\,, \quad m_{N(1535)} = 1.73\,,$$

baryon	s	a_1^1	a_2^1	p	v_1	v_2
$N(940)\frac{1}{2}^+$	0.88	0.38	−0.06	0.02	0.02	0.00
$N(1535)\frac{1}{2}^-$	0.66	0.20	0.14	0.68	0.11	0.09

CI relevant structures

$$\mathcal{S}^\pm = s^\pm \mathbf{I}_\mathrm{D}\mathcal{G}^\pm \qquad \mathcal{G}^{+(-)} = \mathbf{I}_\mathrm{D}(\gamma_5)$$

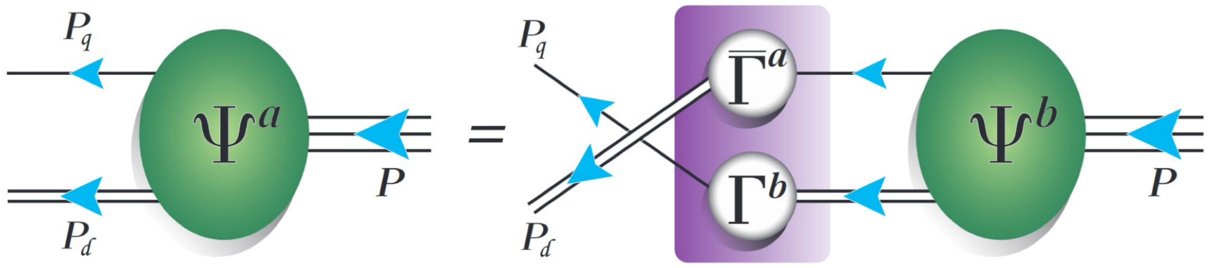
$$i\mathcal{P}^\pm = p^\pm \gamma_5 \mathcal{G}^\pm$$

$$i\mathcal{A}_\mu^{\pm j} = (a_1^{\pm j}\gamma_5\gamma_\mu - i a_2^{\pm j}\gamma_5 \hat{P}_\mu)\mathcal{G}^\pm$$

$$i\mathcal{V}_\mu^\pm = (v_1^\pm \gamma_\mu - i v_2^\pm \mathbf{I}_\mathrm{D}\hat{P}_\mu)\gamma_5\mathcal{G}^\pm$$

Yin:2019bxe , Yin:2021uom, Barabanov:2020jvn, Segovia:2013uga, Raya:2021pyr

Faddeev Equation



Faddeev amplitude (FA)

In the dynamical quark-diquark picture

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Static appoximation $S^T(k) \to \frac{g_B^2}{M_u}$

For $I(J^P) = \frac{3}{2}(\frac{3}{2}^{\pm})$

$$\Psi_3^{\Delta}(p_i, \alpha_i, \tau_i) = \mathcal{D}_3^{(qq,1^+)}$$

Reminder

- *Not possible to combine $I = 0 \oplus I = 1/2$ to obtain $I = 3/2$.*
- *CI only supports $1(1^+)$ axial-vector diquark*

Dominant correlations

$$\mathcal{D}_3^{(qq,1^+)} = \left[t^+\Gamma_\mu^{(qq,1^+)}\left(\frac{1}{2}p_{[12]}; K\right)\right]_{\alpha_1\alpha_2}^{\tau_1\tau_2} \Delta_{\mu\nu}^{(qq,1^+)}(K)[\mathcal{D}_{\nu\rho}(l;P)u_\rho(P)\varphi_+]_{\alpha_3}^{\tau_3}$$

CI relevant structures

$$\mathcal{D}_{\nu\rho}(l;P) = s(P)\mathbf{I}_D\delta_{\nu\rho}$$

Solutions

$$\Delta(1232)\tfrac{3}{2}^+ = 1.39\ GeV \qquad \Delta(1700)\tfrac{3}{2}^- = 2.07\ GeV$$

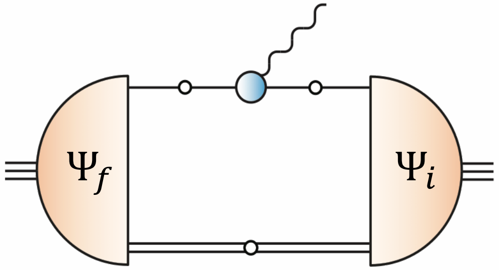
**Solutions entail $s(P) = 1$.*
**Elastic FFs yield normalization.*
**Transition FFs require normalized FA.*

Yin:2019bxe , Yin:2021uom, Barabanov:2020jvn, Segovia:2014aza, Segovia:2013uga, Raya:2021pyr

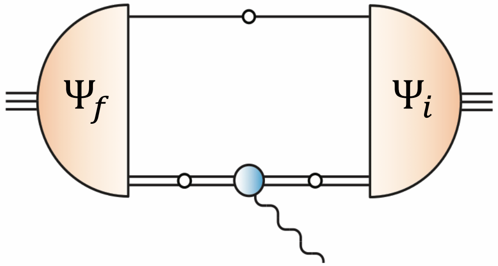
Electromagnetic currents

In the quark-diquark approach, either Elastic and Transition currents can be separated into 3 fundamental contributions

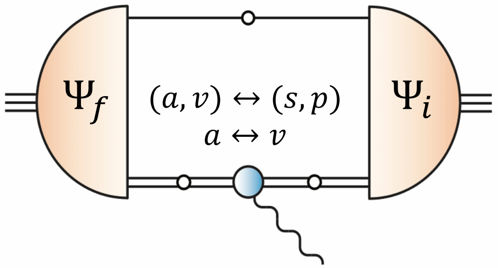
Photon hits quark



Photon hits diquark (elastic)



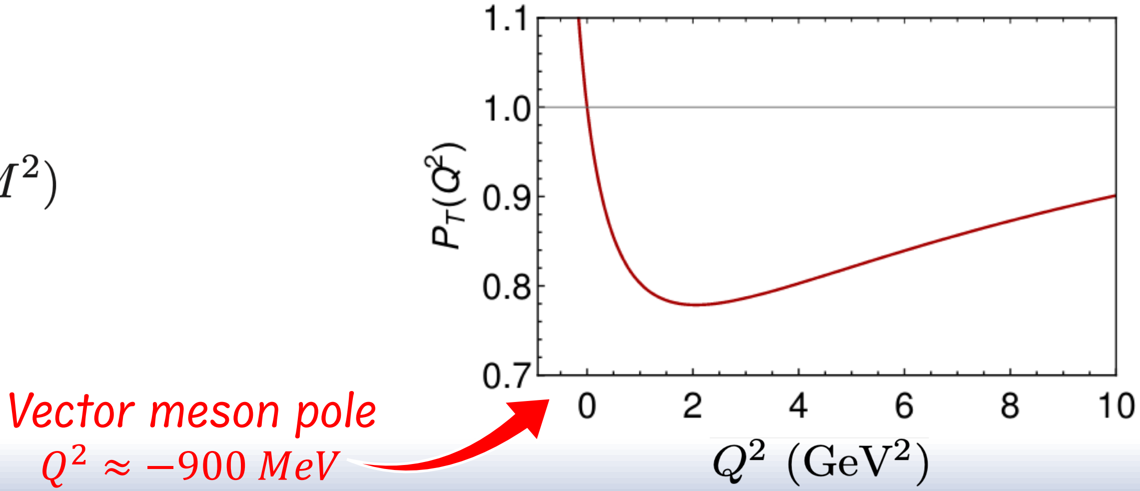
Photon hits diquark (diquark transition induced)



Quark-Photon vertex

$$\Gamma_\mu(Q) = \gamma_\mu^L + \gamma_\mu^T P_T(Q^2) + \frac{\eta}{2M}\sigma_{\mu\nu}Q_\nu \exp(-Q^2/4M^2)$$

- *Vector Ward-Green Takahashi identity ensured*
- *Dressing consistent with truncation*
- *Anomalous Magnetic Moment η incorporated*



Eichmann:2016jqx, Wilson:2011aa

Nucleon (940) EFFs

The EM current can be expressed in terms of Dirac and Pauli FFs

$$J_\mu(K,Q) = ie\,\bar{u}(P_f)\left(\gamma_\mu F_1(Q^2) + \frac{1}{2m_N}\sigma_{\mu\nu}\,Q_\nu\,F_2(Q^2)\right)u(P_i),$$

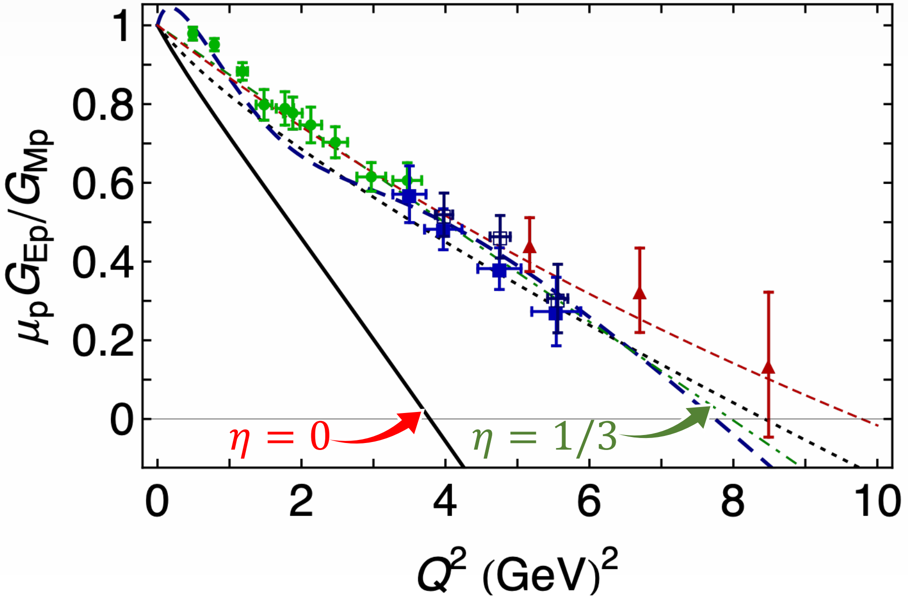
with $K=(P_i+P_f)/2$ *and* $Q=P_f-P_i$.

It is convenient to define the so-called Sack FFs

$$G_M(Q^2) = F_1(Q^2) + F_2(Q^2)$$

$$G_E(Q^2) = F_1(Q^2) - \frac{Q^2}{4m_N^2}F_2(Q^2)$$

Nucleon



Nucleon (940) EFFs

The EM current can be expressed in terms of Dirac and Pauli FFs

$$J_\mu(K,Q) = ie\,\bar{u}(P_f)\left(\gamma_\mu F_1(Q^2) + \frac{1}{2m_N}\sigma_{\mu\nu}\,Q_\nu\,F_2(Q^2)\right)u(P_i).$$

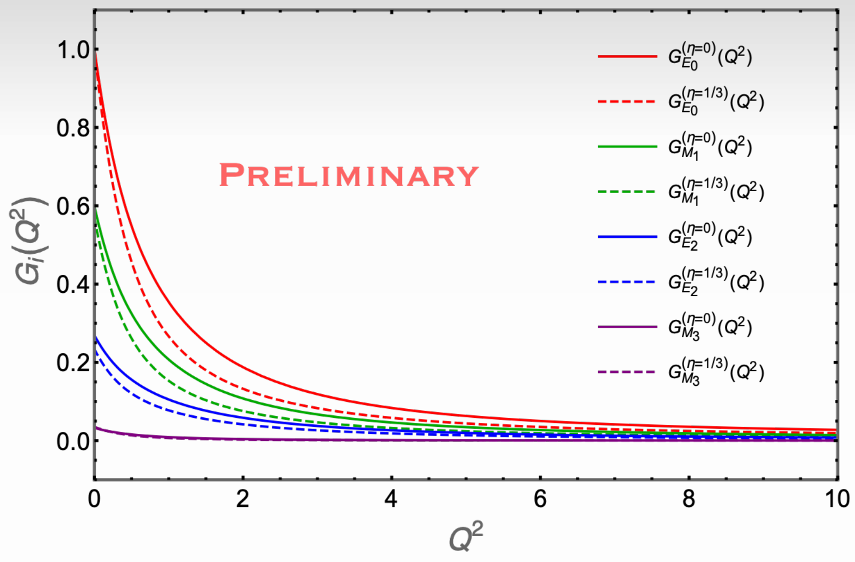
with $K=(P_i+P_f)/2$ *and* $Q=P_f-P_i$.

It is convenient to define the so-called Sack FFs

$$G_M(Q^2) = F_1(Q^2) + F_2(Q^2)$$

$$G_E(Q^2) = F_1(Q^2) - \frac{Q^2}{4m_N^2}F_2(Q^2)$$

Delta(1700)



Delta (1700) EFFs

$$J^{\mu,\lambda\omega}(P,Q) = \Lambda_+(P_f)R_{\lambda\alpha}(P_f)\gamma_5\Gamma^{\mu,\alpha\beta}(P,Q)\gamma_5\Lambda_+(P_i)R_{\beta\omega}(P_i)$$

Where (in terms of Dirac and Pauli FFs)

$$\Gamma_{\mu,\alpha\beta}(K,Q) = \left[(F_1^*+F_2^*)i\gamma_\mu - \frac{F_2^*}{m_\Delta}K_\mu\right]\delta_{\alpha\beta} - \left[(F_3^*+F_4^*)i\gamma_\mu - \frac{F_4^*}{m_\Delta}K_\mu\right]\frac{Q_\alpha Q_\beta}{4m_\Delta^2}$$

Sack FFs

$$G_{E0}(Q^2) = \left(1+\frac{2\tau_\Delta}{3}\right)(F_1^*-\tau_\Delta F_2^*) - \frac{\tau_\Delta}{3}(1+\tau_\Delta)(F_3^*-\tau_\Delta F_4^*),$$

$$G_{M1}(Q^2) = \left(1+\frac{4\tau_\Delta}{5}\right)(F_1^*+F_2^*) - \frac{2\tau_\Delta}{5}(1+\tau_\Delta)(F_3^*+F_4^*),$$

$$G_{E2}(Q^2) = (F_1^*-\tau_\Delta F_2^*) - \frac{1}{2}(1+\tau_\Delta)(F_3^*-\tau_\Delta F_4^*),$$

$$G_{M3}(Q^2) = (F_1^*+F_2^*) - \frac{1}{2}(1+\tau_\Delta)(F_3^*+F_4^*),$$

Segovia:2014aza, Segovia:2013uga, Eichmann:2011aa, Wilson:2011aa

$\gamma N \to \Delta(1700)$ Transition FFs

The EM current for the transition of $\frac{1}{2}\left(\frac{1}{2}^{+}\right) \to \frac{3}{2}\left(\frac{3}{2}^{-}\right)$ *is expressed in terms of Jones-Scadron* (G_i^*) *FFs*

$$J^{\mu,\lambda}(P,Q) = \Lambda_+(P_f) R_{\lambda\alpha}(P_f) i\Gamma^{\alpha\mu}(P,Q) \Lambda_+(P_i)$$

where the $\gamma N\Delta$ *vertex is expressed as*

$$\Gamma^{\alpha\mu} = b\left[\frac{i\omega}{2\lambda_+}(G_M^\star - G_E^\star)\gamma_5 \varepsilon^{\alpha\mu\gamma\delta} K^\gamma \hat{Q}^\delta - G_E^\star \mathcal{P}_Q^{\alpha\gamma} \mathcal{P}_K^{\gamma\mu} - \frac{i\tau}{\omega} G_C^\star \hat{Q}^\alpha K^\mu\right]$$

with

$$\tau = \frac{Q^2}{2(m_\Delta^2 + m_N^2)} \qquad b = \sqrt{\frac{3}{2}}\left(1 + \frac{m_\Delta}{m_N}\right) \qquad \lambda_\pm = \frac{(m_\Delta \pm m_N)^2 + Q^2}{2(m_\Delta^2 + m_N^2)} \qquad \omega = \sqrt{\lambda_+ \lambda_-}$$

Diquark contributions

Isoscalar-scalar $0(0^+)$: $[ud]_{0^+}$
Isovector-pseudovector $1(1^+)$: $\{uu\}_{1^+}$, $\{ud\}_{1^+}$, $\{dd\}_{1^+}$

For $p^+(uud)$: $[ud]_{0^+}$, $\{uu\}_{1^+}$, $\{ud\}_{1^+}$
For $n^0(udd)$: $[ud]_{0^+}$, $\{ud\}_{1^+}$, $\{dd\}_{1^+}$

Isovector-pseudovector $1(1^+)$: $\{uu\}_{1^+}$, $\{ud\}_{1^+}$, $\{dd\}_{1^+}$
Isovector-vector $1(1^-)$: *FORBIDEN in CI*

For $\Delta^{++}(uuu)$: $\{uu\}_{1^+}$
For $\Delta^{+}(uud)$: $\{uu\}_{1^+}$, $\{ud\}_{1^+}$
For $\Delta^{0}(udd)$: $\{ud\}_{1^+}$, $\{dd\}_{1^+}$
For $\Delta^{-}(ddd)$: $\{dd\}_{1^+}$

Segovia:2014aza, Segovia:2013uga, Eichmann:2011aa

$\gamma N \to \Delta(1700)$ Transition FFs

The EM current for the transition of $\frac{1}{2}\left(\frac{1}{2}^{+}\right) \to \frac{3}{2}\left(\frac{3}{2}^{-}\right)$ *is expressed in terms of Jones-Scadron* (G_i^*) *FFs*

$$J^{\mu,\lambda}(P,Q) = \Lambda_+(P_f) R_{\lambda\alpha}(P_f) i\Gamma^{\alpha\mu}(P,Q)\Lambda_+(P_i)$$

where the $\gamma N \Delta$ *vertex is expressed as*

$$\Gamma^{\alpha\mu} = b\left[\frac{i\omega}{2\lambda_+}(G_M^\star - G_E^\star)\gamma_5 \varepsilon^{\alpha\mu\gamma\delta} K^\gamma \hat{Q}^\delta - G_E^\star \mathcal{P}_Q^{\alpha\gamma}\mathcal{P}_K^{\gamma\mu} - \frac{i\tau}{\omega} G_C^\star \hat{Q}^\alpha K^\mu\right]$$

with

$$\tau = \frac{Q^2}{2(m_\Delta^2 + m_N^2)} \qquad b = \sqrt{\frac{3}{2}}\left(1 + \frac{m_\Delta}{m_N}\right) \qquad \lambda_\pm = \frac{(m_\Delta \pm m_N)^2 + Q^2}{2(m_\Delta^2 + m_N^2)} \qquad \omega = \sqrt{\lambda_+ \lambda_-}$$

Diquark contributions

Photon hits quark

$\gamma p \longrightarrow \Delta^+$: $(u, \{ud\}_{1^+})$ & $(d, \{uu\}_{1^+})$
$\gamma n \longrightarrow \Delta^0$: $(u, \{dd\}_{1^+})$ & $(d, \{ud\}_{1^+})$

Photon hits diquark (elastic)

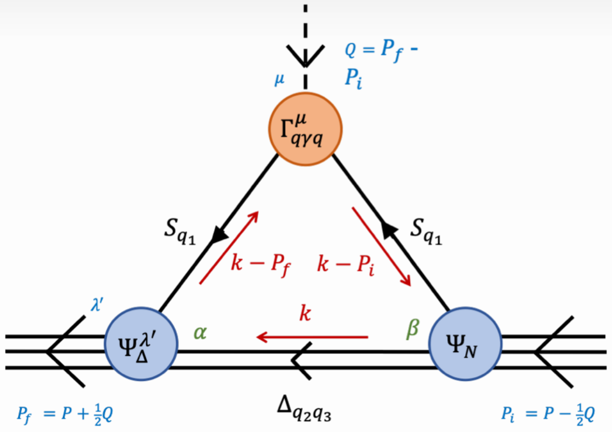
$\gamma p \longrightarrow \Delta^+$: $(u, \{ud\}_{1^+} \longrightarrow \{ud\}_{1^+})$
$(d, \{uu\}_{1^+} \longrightarrow \{uu\}_{1^+})$
$\gamma n \longrightarrow \Delta^0$: $(u, \{dd\}_{1^+} \longrightarrow \{dd\}_{1^+})$
$(d, \{ud\}_{1^+} \longrightarrow \{ud\}_{1^+})$

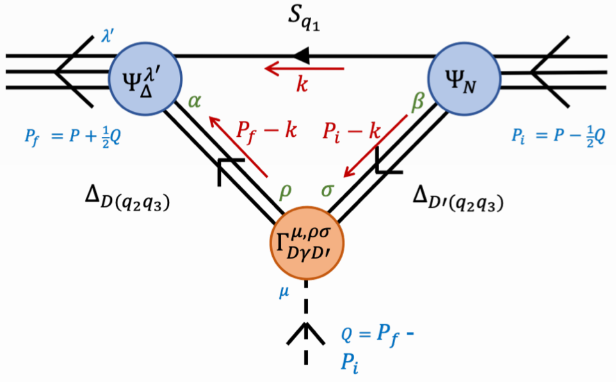
Photon hits diquark (diquark transition induced)

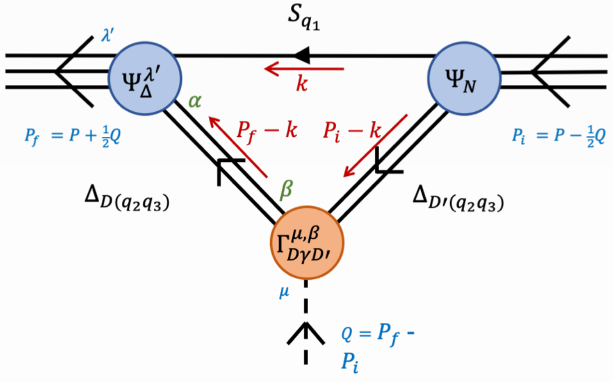
$\gamma p \longrightarrow \Delta^+$: $(u, [ud]_{0^+} \longrightarrow \{ud\}_{1^+})$
$\gamma n \longrightarrow \Delta^0$: $(d, [ud]_{0^+} \longrightarrow \{ud\}_{1^+})$

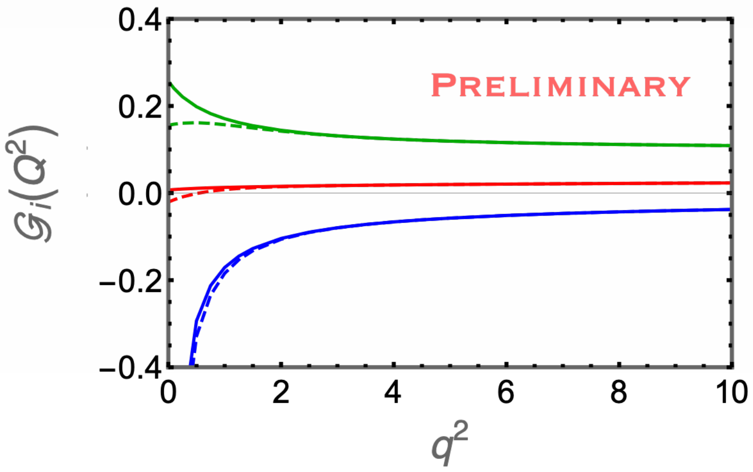
Segovia:2014aza, Segovia:2013uga, Eichmann:2011aa

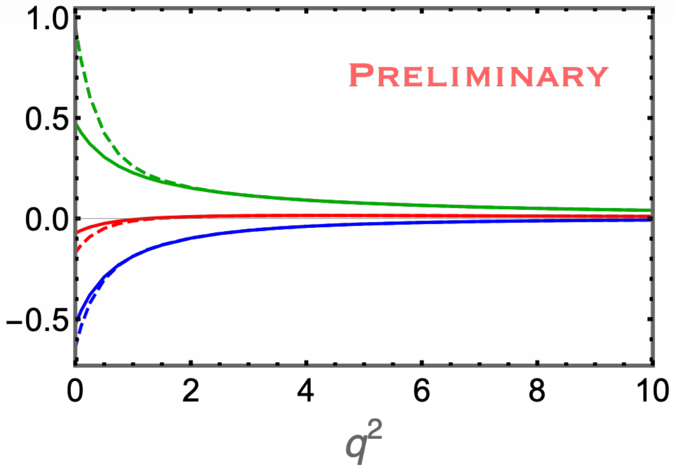
Individual contributions

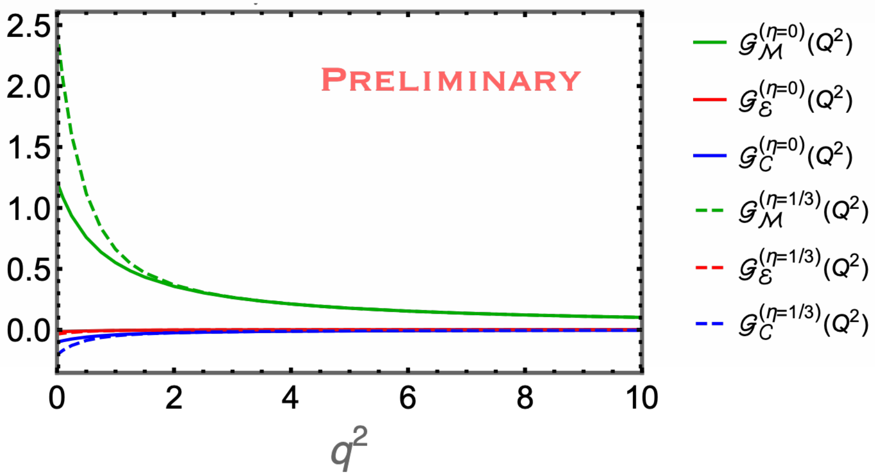






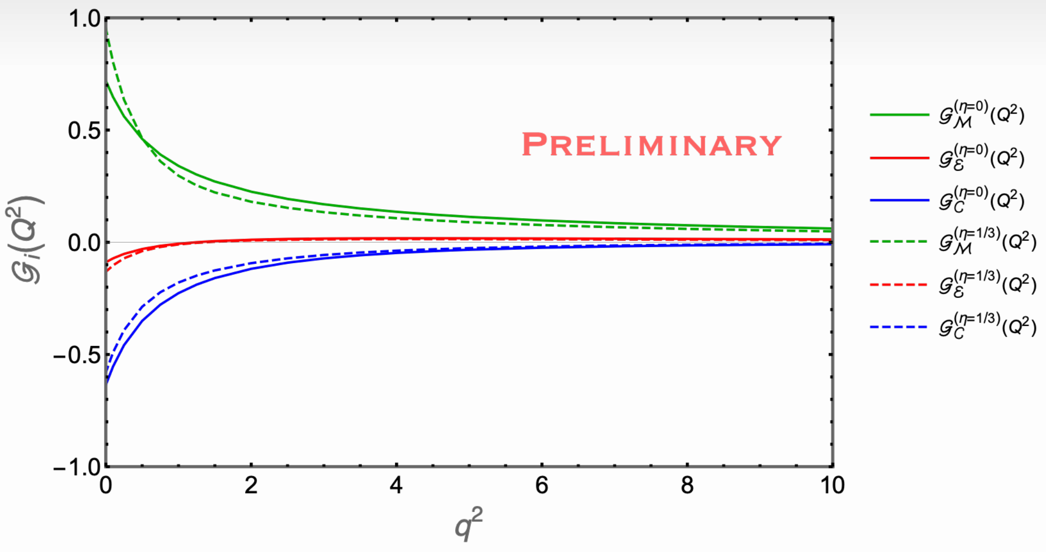


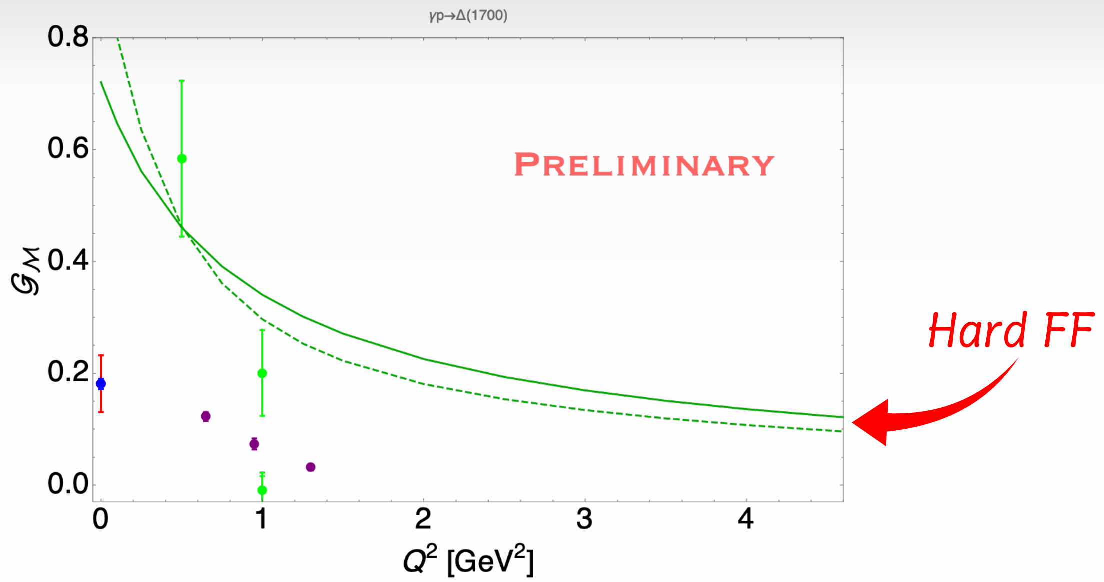


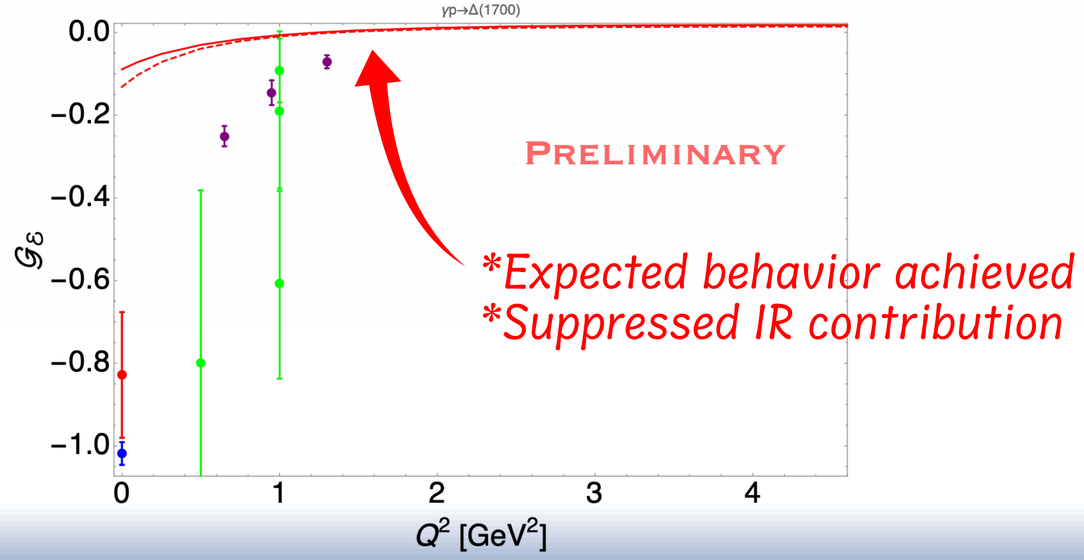


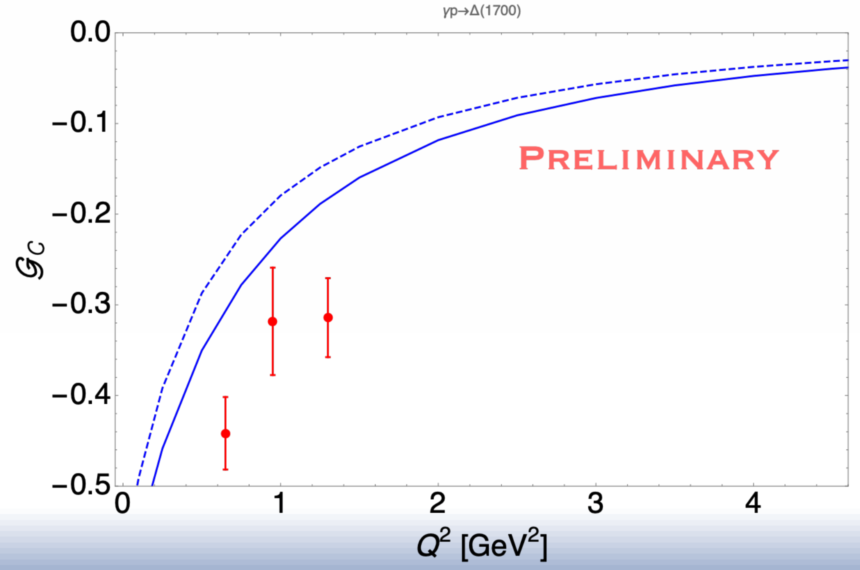
Full contributions

Data – Exclusive meson electroproduction off Protons:
https://userweb.jlab.org/~mokeev/resonance_electrocouplings/









Helicity Amplitudes

Data – Exclusive meson electroproduction off Protons:
https://userweb.jlab.org/~mokeev/resonance_electrocouplings/

For $\frac{1}{2}\left(\frac{1}{2}^+\right) \to \frac{3}{2}\left(\frac{3}{2}^-\right)$, linearly related to Jones-Scadron FFs as follows:

$$A_{1/2}(Q^2) = -\frac{1}{4F_{1-}}\left[G_E(Q^2) - 3G_M(Q^2)\right]$$

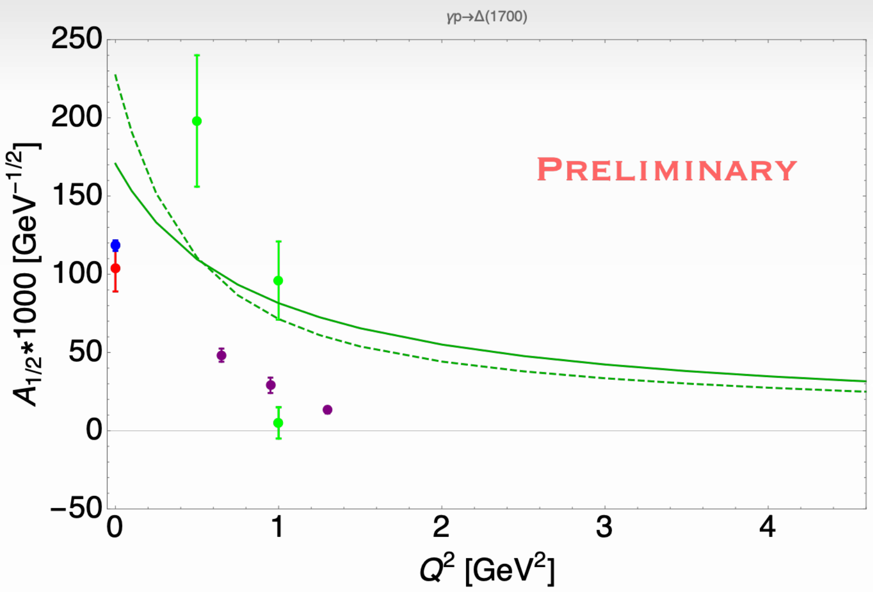
$$A_{3/2}(Q^2) = -\frac{\sqrt{3}}{4F_{1-}}\left[G_E(Q^2) + G_M(Q^2)\right]$$

$$S_{1/2}(Q^2) = -\frac{1}{\sqrt{2}F_{1-}}\frac{|\mathbf{q}|}{2M_R}G_C(Q^2)$$

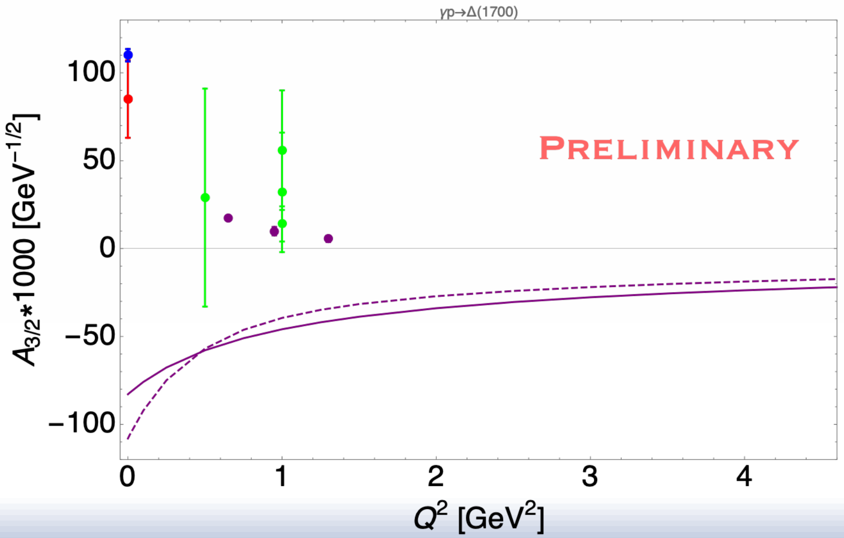
with

$$Q^2_\pm = (M_R \pm M)^2 + Q^2 \qquad K = \frac{M_R^2 - M^2}{2M_R}$$

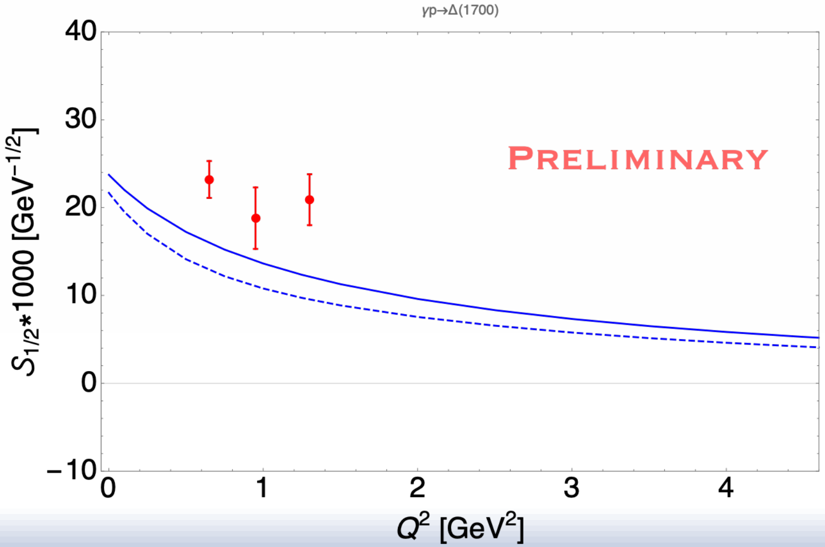
$$F_{1\pm} = \sqrt{\frac{3}{2}}\frac{M}{6(M_R \pm M)}\frac{1}{\mathcal{A}_{1\mp}} \qquad \mathcal{A}_{1\mp} = \frac{1}{2\sqrt{3}}\sqrt{\frac{2\pi\alpha}{K}}\sqrt{\frac{Q^2_\mp}{4MM_R}}$$



Hard FF



Sign flip



Summary

- *Dynamical diquark correlations playi a crucial role in the internal structure of hadrons.*
- *The strong diquark correlations revealed by the BSE provide insights into the nature of quark interactions within baryons.*
- *Available experimental data offers a window to test QCD models, providing crucial validation for theoretical predictions.*
- *TFFs are important for identifying dynamical diquark correlations and serve as a test for the presence of these correlations in baryons.*
- *Electromagnetic transitions are sensitive to the baryon wavefunction and provide an essential path to understanding DCSB.*
- *The CI model offers a simplified yet insightful approach to calculating form factors, reproducing the overall behavior while reducing computational complexity.*
- *We presented preliminary results for the* $\gamma N \rightarrow \Delta(1700)$ *TFFs using a CI where only scalar and axial-vector diquarks are considered. These diquarks are non-point correlations. The existence of non-point diquark is closely connected with the emergence of hadron masses and Dynamical Chiral Symmetry Breaking (DCSB).*
- *The magnetic FF* G_M *and* $A_{1/2}$ *exhibit a hard behavior in the UV domain.*
- *The electric FF* G_E *and* $A_{3/2}$ *achieve the expected behavior, but infrared IR details remain underrepresented.*