BChPT x 1/Nc: masses and currents

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OUTLINE

- General motivation
- The need for combining BChPT and 1/Nc
- BChPT x 1/Nc: brief basics
- Masses, sigma terms
- Vector currents in SU(3)
- Axial currents in SU(3)
- Summary, comments

MOTIVATION

- QCD has small scales:
  i) SChSB gives nearly massless GBs (small quark masses)
  ii) emergent small scale at large Nc: $m_\Delta - m_N = \mathcal{O}(1/N_c)$
- All the small scales MUST be treated consistently in any EFT: in QCD we need to combine ChPT with the 1/Nc expansion!
- There is broad evidence that most aspects of the large Nc limit survive for Nc as small as 3: phenomenological observations and LQCD at Nc>3.
- Enhanced symmetries in large Nc: SU(3) to U(3) in mesons; spin-flavor SU(6) in baryons.
- meson-meson interactions suppressed; meson-baryon interactions can be enhanced by a factor $\sqrt{N_c}$
- Very interesting case BChPT and the 1/Nc expansion: BChPT x 1/Nc

The need for combining BChPT and 1/Nc

Ordinary BChPT (only S=1/2 baryons) has poor convergence

$g_{\pi N}$ is large: need for large CTs

Inclusion of S=3/2 baryons gives significant improvement in convergence: [Jenkins & Manohar; many others]

QCD at large N_c:

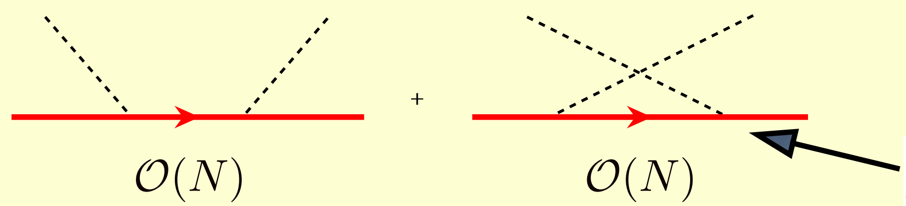
$$F_\pi = \mathcal{O}(\sqrt{N_c})$$
$$m_B = \mathcal{O}(N_c)$$
$$g_A = \mathcal{O}(N_c) \Rightarrow g_{\pi N} = \mathcal{O}(N_c{}^{\frac{3}{2}})$$

well defined large N_c limit imposes constraints!

Ordinary BChPT violates $1/N_c$ power counting

- Emergent dynamical spin-flavor symmetry

[Gervais & Sakita; Dashen & Manohar] last millenium



$g_A \frac{N_c}{F_\pi}\partial_i \pi^a X^{ia} = \mathcal{O}(\sqrt{N_c})$

$$\sim \frac{k^i k'^j}{k_0}\frac{\mathring{g}_A^2 N_c^2}{F_\pi^2}\langle B' \mid [X^{ia}, X^{jb}] \mid B \rangle$$

must be order N_c^0

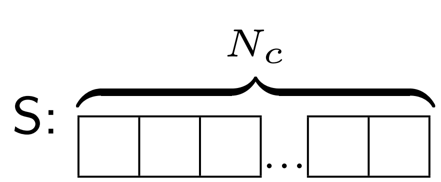
X^{ia} axial current

$$[X^{ia}, X^{jb}] = \mathcal{O}(1/N_c)$$ key requirement at large Nc

$\{T^a, S^i, X^{ia}\}$ generate contracted $SU(2N_f)$ dynamical symmetry

classify baryons in multiplets of $SU(2N_f)$ with generators $\{T^a, S^i, G^{ia}\}$

$$G^{ia} = N_c X^{ia}$$



ground state baryons: tower with $S = \frac{1}{2} \cdots \frac{N_c}{2}$

$\frac{1}{N_c}$ expansion as spin-flavor operator product expansion

$$\langle B' \mid \hat{O}_{QCD} \mid B\rangle = \sum_n C_n \frac{1}{N_c^{\nu_n - 1}} \langle B' \mid \hat{O}_n \mid B\rangle$$

O_n : tensor operator product of spin-flavor generators and momenta
ν_n : spin-flavor n-bodyness of O_n

Example: mass operator in chiral limit:

$$H_{QCD} \Rightarrow N_c m_0 + C_{HF} \frac{1}{N_c} \hat{S}^2 + \mathcal{O}(\frac{1}{N_c^3}) \hat{S}^4 + \cdots$$

expansion is in $1/N_c^2$, $m_\Delta - m_N = \mathcal{O}(\frac{1}{N_c})$

A test: $g_A s$

$\frac{g_A^{N\Delta}}{g_A^N} = 1 + \mathcal{O}(\frac{1}{N_c^2})$ [Dashen & Manohar]

$g_A^N = -1.2724 \pm 0.0023 \qquad g_A^{N\Delta} = -1.235 \pm 0.011$

• BChPT x 1/Nc: brief basics

- $m_B = \mathcal{O}(N_c) \Rightarrow$ HB expansion is a $1/N_c$ expansion
- Lagrangians built with chiral and spin-flavor tensor operators:

$$\mathbf{B}^\dagger \;\; T_\chi \otimes T_{SF} \;\; \mathbf{B}$$

$$\mathbf{B} = \begin{pmatrix} B_{S=1/2} \\ B_{S=3/2} \\ \vdots \\ B_{S=N_c/2} \end{pmatrix} \qquad \text{GS tower of baryon fields}$$

T_χ chiral tensor $\quad T_{SF}$ spin-flavor tensor product of SU(6) generators

chiral and $1/N_c$ power counting determined by operators

LECs: chosen to be $\mathcal{O}(N_c^0)$, have a $1/N_c$ expansion themselves

each Lagrangian term has a well defined *leading* chiral and $1/N_c$ power

need to link chiral and $1/N_c$ expansions: small mass scale $\Delta_{HF} = m_{3/2} - m_{1/2}$

ξ expansion: $\xi = \mathcal{O}(1/N_c) = \mathcal{O}(p)$

Lagrangians in ξ expansion

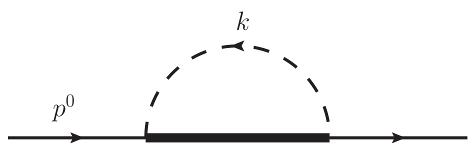
$$\mathcal{L}_B^{(1)} = \mathbf{B}^\dagger(iD_0 - \frac{C_{HF}}{N_c}\hat{S}^2 - \mathring{g}_A u^{ia} G^{ia} + \frac{c_1}{2\Lambda}\hat{\chi}_+)\mathbf{B}$$

$$\begin{aligned}
\mathcal{L}_B^{(2)} &= \mathbf{B}^\dagger\Big\{(-\frac{1}{2N_c m_0} + \frac{w_1}{\Lambda})\vec{D}^2 + (\frac{1}{2N_c m_0} - \frac{w_2}{\Lambda})\tilde{D}_0^2 + \frac{c_2}{\Lambda}\chi_+^0 \\
&+ \frac{C_1^A}{N_c} u^{ia} S^i T^a + \frac{C_2^A}{N_c}\epsilon^{ijk} u^{ia}\{S^j, G^{ka}\} \\
&+ \kappa\,\epsilon^{ijk} F^a_{+ij} G^{ka} + \rho_0 F^0_{-0i} S^i + \rho_1 F^a_{-0i} G^{ia} \\
&+ \frac{\tau_1}{N_c} u_0^a G^{ia} D_i + \frac{\tau_2}{N_c^2} u_0^a S^i T^a D_i + \frac{\tau_3}{N_c}\nabla_i u_0^a S^i T^a + \tau_4 \nabla_i u_0^a G^{ia} + \cdots\Big\}\mathbf{B}
\end{aligned}$$

$$\begin{aligned}
\mathcal{L}_B^{(3)} &= \mathbf{B}^\dagger\Big\{\frac{c_3}{N_c\,\Lambda^3}\hat{\chi}_+^2 + \frac{h_1\Lambda}{N_c^3}\hat{S}^4 + \frac{h_2}{N_c^2\Lambda}\hat{\chi}_+\hat{S}^2 + \frac{h_3}{N_c\Lambda}\chi_+^0\hat{S}^2 + \frac{h_4}{N_c\,\Lambda}\chi_+^a\{S^i, G^{ia}\} \\
&+ \frac{C_3^A}{N_c^2} u^{ia}\{\hat{S}^2, G^{ia}\} + \frac{C_4^A}{N_c^2} u^{ia} S^i S^j G^{ja} \\
&+ \frac{D_1^A}{\Lambda^2}\chi_+^0 u^{ia} G^{ia} + \frac{D_2^A}{\Lambda^2}\chi_+^a u^{ia} S^i + \frac{D_3^A(d)}{\Lambda^2} d^{abc}\chi_+^a u^{ib} G^{ic} + \frac{D_3^A(f)}{\Lambda^2} f^{abc}\chi_+^a u^{ib} G^{ic} \\
&+ g_1^E\,[D_i, E_{+ia} T^a] + \frac{1}{N_c} g_2^E [D_i, E_{+ia} S^j G^{ja}] + \kappa_1 \frac{1}{N_c} B_+^{ia} S^i T^a + \cdots\Big\}\mathbf{B}
\end{aligned}$$

$$\begin{aligned}
\mathcal{L}_B^{(4)} &= \mathbf{B}^\dagger \frac{1}{2\Lambda}\Big\{\frac{1}{\Lambda^2}(\kappa_2 \chi_+^0 B_+^{ia} G^{ia} + \kappa_3 d^{abc}\chi_+^a B_+^{ib} G^{ic} + \kappa_4 \chi_+^a B_+^{ia} S^i) \\
&+ \kappa_5 \frac{1}{N_c^2} B_+^{ia}\{\hat{S}^2, G^{ia}\} + \kappa_6 \frac{1}{N_c} B_+^{ia} S^i T^a + \kappa_7 \frac{1}{N_c^2} B_+^{ia} S^i S^j G^{ja} + \cdots\Big\}\mathbf{B}
\end{aligned}$$

Loops and the non-commutativity of the expansions



$$= \int \frac{d^d k}{(2\pi)^d} \, \frac{i}{k^2 - M_\pi^2} \, \frac{i}{p^0 + k^0 - \underbrace{(m_{B'} - m_B)}_{\mathcal{O}(1/N_c)}} \times \text{vertex factors}$$

contains non-analytic terms:

$$(M_\pi^2 - (m_\Delta - m_N)^2)^{\frac{3}{2}}, \quad tanh^{-1}\left(\frac{(m_\Delta - m_N)}{\sqrt{1/(-M_\pi^2 + (m_\Delta - m_N)^2}}\right)$$

link $1/N_c$ and chiral expansions:

ξ expansion: $\xi = \mathcal{O}(1/N_c) = \mathcal{O}(p)$

equivalent to not expanding non-analytic terms

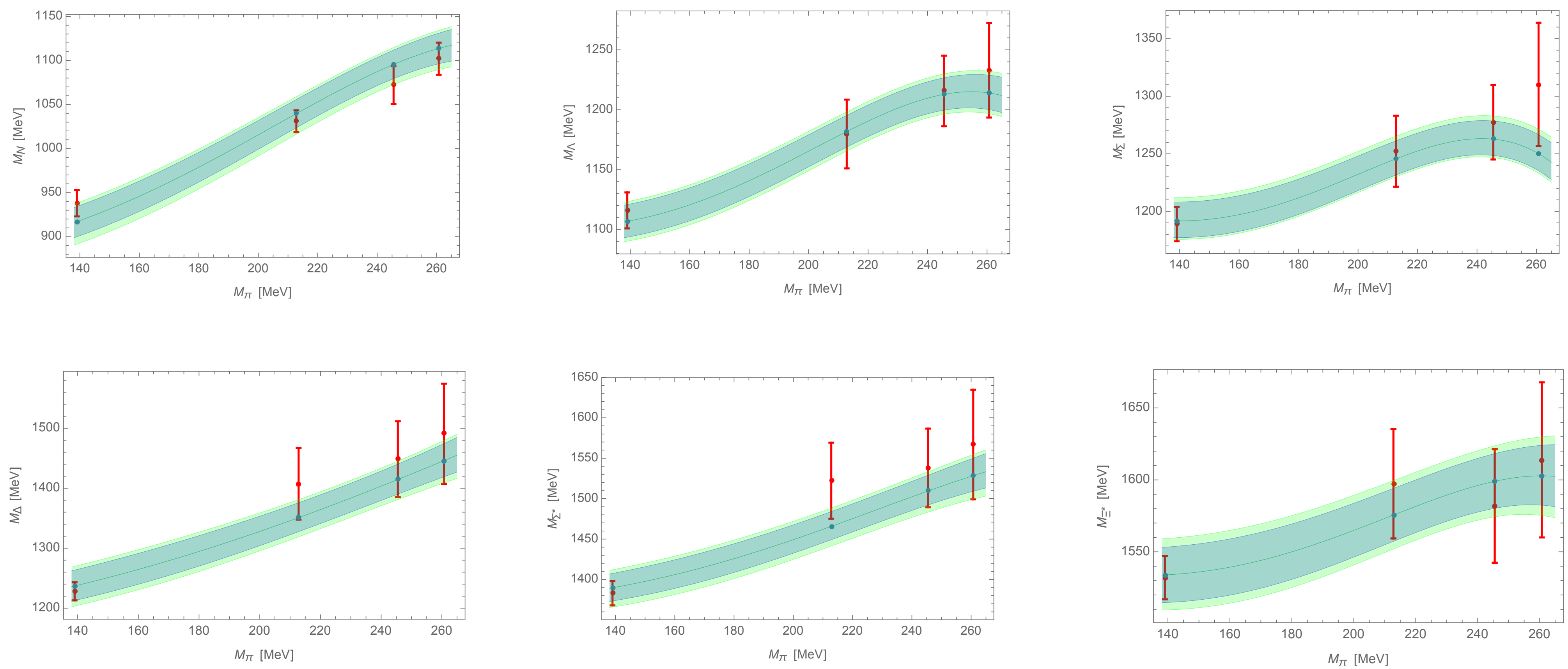
$$\nu_\xi = 1 + 3L + \frac{n_\pi}{2} + \sum_i n_i \left(\nu_{O_i} + \nu_{p_i} - 1\right)$$

• Masses, sigma terms: SU(3)

WF renormalization factor is $\mathcal{O}(N_c)$!
plays key role in N_c power counting consistency in loops

- mass corrections are $\mathcal{O}(N_c)$ (terms proportional to M_{GB}^3)
- SU(3) mass splitting of course $\mathcal{O}(N_c^0)$

M_π dependency from LQCD ($M_K \sim 500$ MeV):
poor convergence above $M_\pi \sim 250$ MeV



[Alexandrou et al (2014), ETMC LQCD Coll.
octet and decuplet baryon masses

Mass relations

GMO

$$\Delta_{GMO} = \text{ Th: } \left(\frac{g_A^N(LO)}{g_A^N}\right)^2 44 \pm 5 \text{ MeV vs Exp: } 25.6 \pm 1.5 \text{ MeV}$$

$$\Delta_{GMO} = -\left(\frac{\mathring{g}_A}{4\pi F_\pi}\right)^2 \left(\frac{2\pi}{3}(M_K^3 - \frac{1}{4}M_\pi^3 - \frac{2}{\sqrt{3}}(M_K^2 - \frac{1}{4}M_\pi^2)^{\frac{3}{2}})\right.$$
$$\left. + \frac{2C_{HF}}{N_c}\left(-M_K^2 \log M_K^2 + \frac{1}{4}M_\pi^2 \log M_\pi^2 + (M_K^2 - \frac{1}{4}M_\pi^2)\log(\frac{4}{3}M_K^2 - \frac{1}{3}M_\pi^2)\right)\right) + \mathcal{O}(1/N_c^3)$$
$$= 37 \text{ MeV} + \mathcal{O}(1/N_c^3)$$

in large N_c, Δ_{GMO} is $\mathcal{O}(1/N_c)$

ES

$$\Delta_{ES} = m_{\Xi^*} - 2m_{\Sigma^*} + m_\Delta =$$
$$\text{Th: } -\left(\frac{g_A^N(LO)}{g_A^N}\right)^2 6.5\text{MeV vs Exp: } -4 \pm 7\text{MeV} = \mathcal{O}(1/N_c)$$

GR

$$\Delta_{GR} = m_{\Xi^*} - m_{\Sigma^*} - (m_\Xi - m_\Sigma) = 0, \qquad \text{Exp: } 21 \pm 7 \text{ MeV},$$

$$\Delta_{GR} = \frac{h_2}{\Lambda}\frac{12}{N_c}(M_K^2 - M_\pi^2) + \underbrace{\text{O}(1/N_c) \text{ UV finite no-analytic terms})}_{\sim 68 \text{ MeV} \times \left(\frac{g_A^N(LO)}{g_A^N}\right)^2}$$

πN σ-term

Feynman-Hellmann Theorem

$$\sigma_q(B) = \frac{\partial}{\partial m_q} M_B = m_q \langle B \mid \bar{q}q \mid B \rangle$$

$$\hat{\sigma}(B) = m_q \langle B \mid \bar{u}u + \bar{d}d - 2\bar{s}s \mid B \rangle \qquad \sigma_{\pi N} = \hat{\sigma} + \frac{2\hat{m}}{m_s}\sigma_s.$$

$$\sigma_{\pi N} \sim 60 \text{ MeV from } \pi - N \text{ analysis}$$

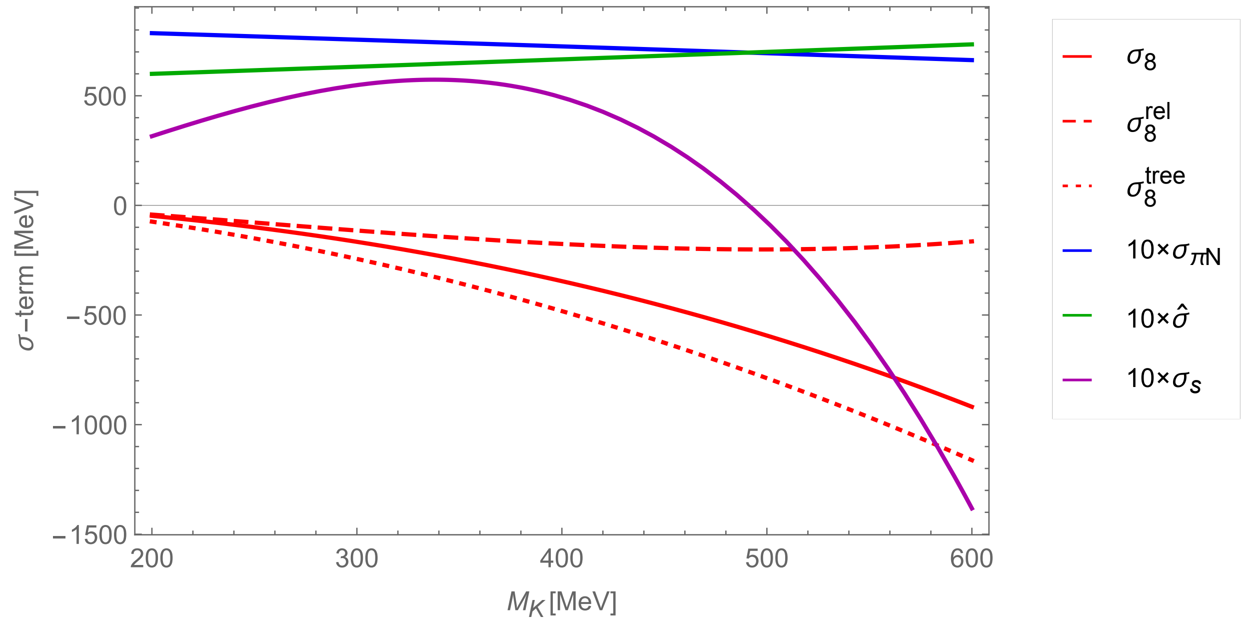
$$\hat{\sigma} = \underbrace{\frac{\hat{m}}{m_s - \hat{m}}\left(\frac{N_c+3}{6}m_\Xi + \frac{2N_c-3}{3}m_\Sigma - \frac{5N_c-3}{6}m_N\right)}_{@N_c=3:\ \sim 23\text{MeV}} + \Delta\hat{\sigma} \leftarrow \mathcal{O}(N_c)$$

$\uparrow$ $\mathcal{O}(N_c)$

$\Delta\hat{\sigma}$: $2.3 \times 10^5 \text{MeV}^3 \times \frac{g_A^2}{F_\pi^2} \sim 40 \text{ MeV}$

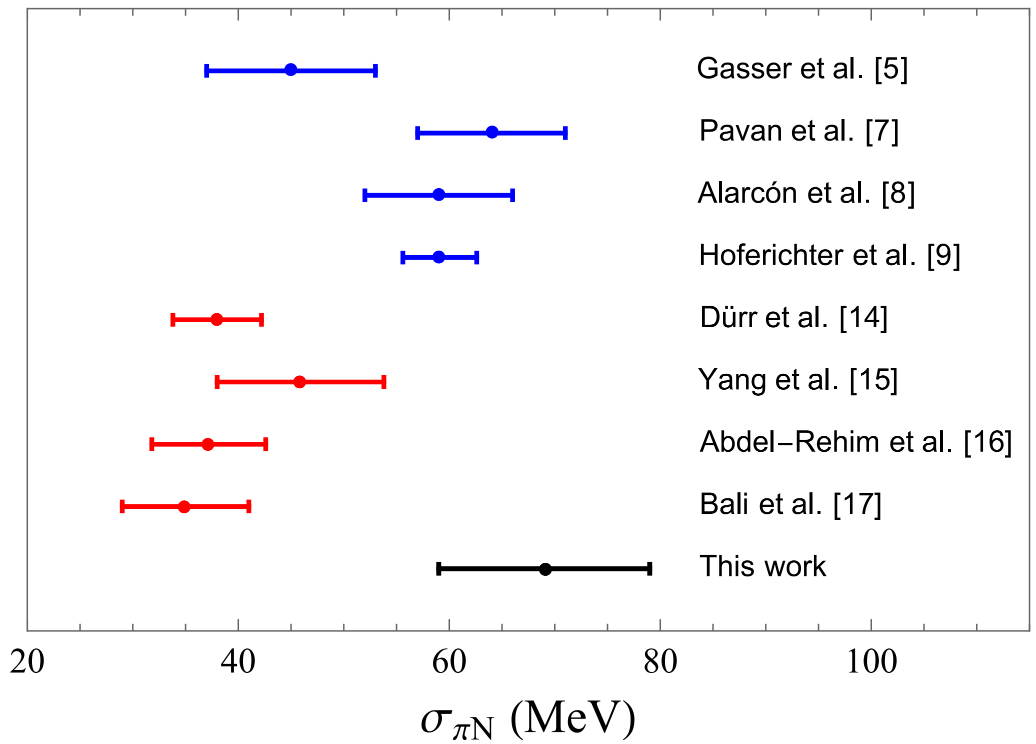
40 % from 8 in loop and 60 % from 10

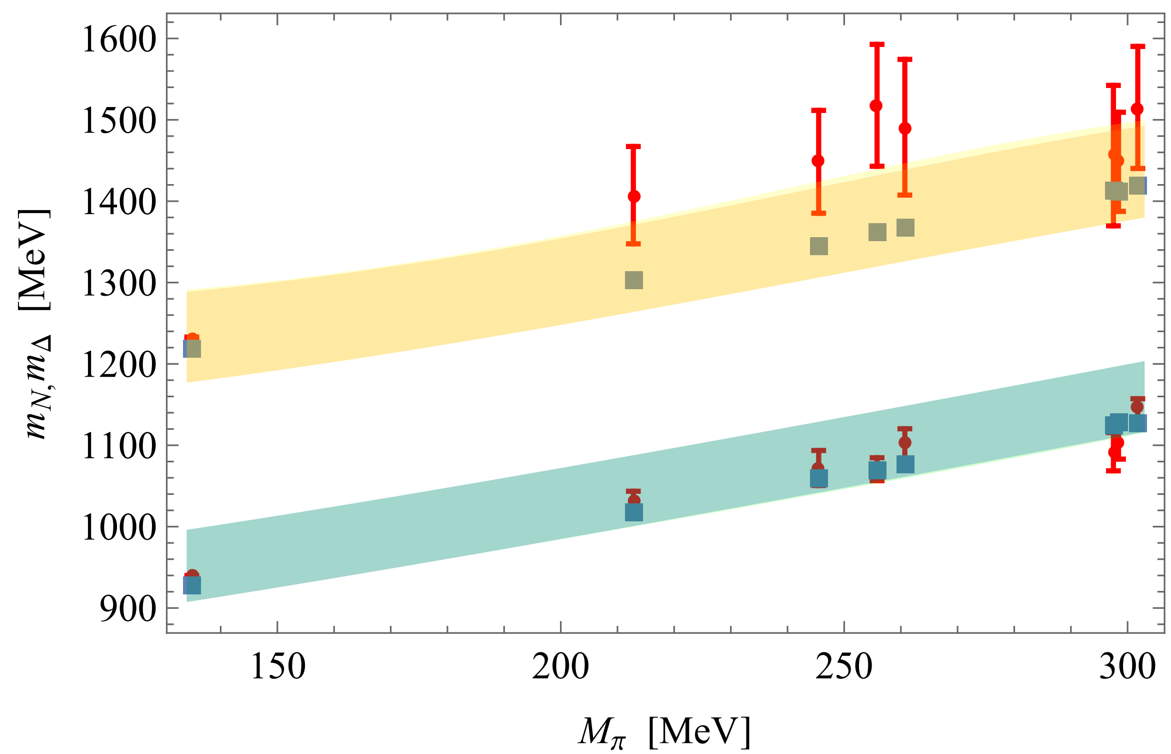
- $\frac{\Delta\sigma_8}{\Delta_{GMO}} \sim -13$: independent of g_A/F_π,
  virtually independent of C_{HF},
  mild dependence on M_K, M_π !
- $\frac{\Delta\sigma_8}{\Delta_{GMO}}$ changes little if one turns off decuplet!
  but g_A from Δ_{GMO} too large, clashes with axial couplings



$$\hat{\sigma} = 70 \pm 9 \text{ MeV} \quad \oplus \quad LQCD \quad \sigma_{\pi N} = 69 \pm 10 \text{ MeV}$$

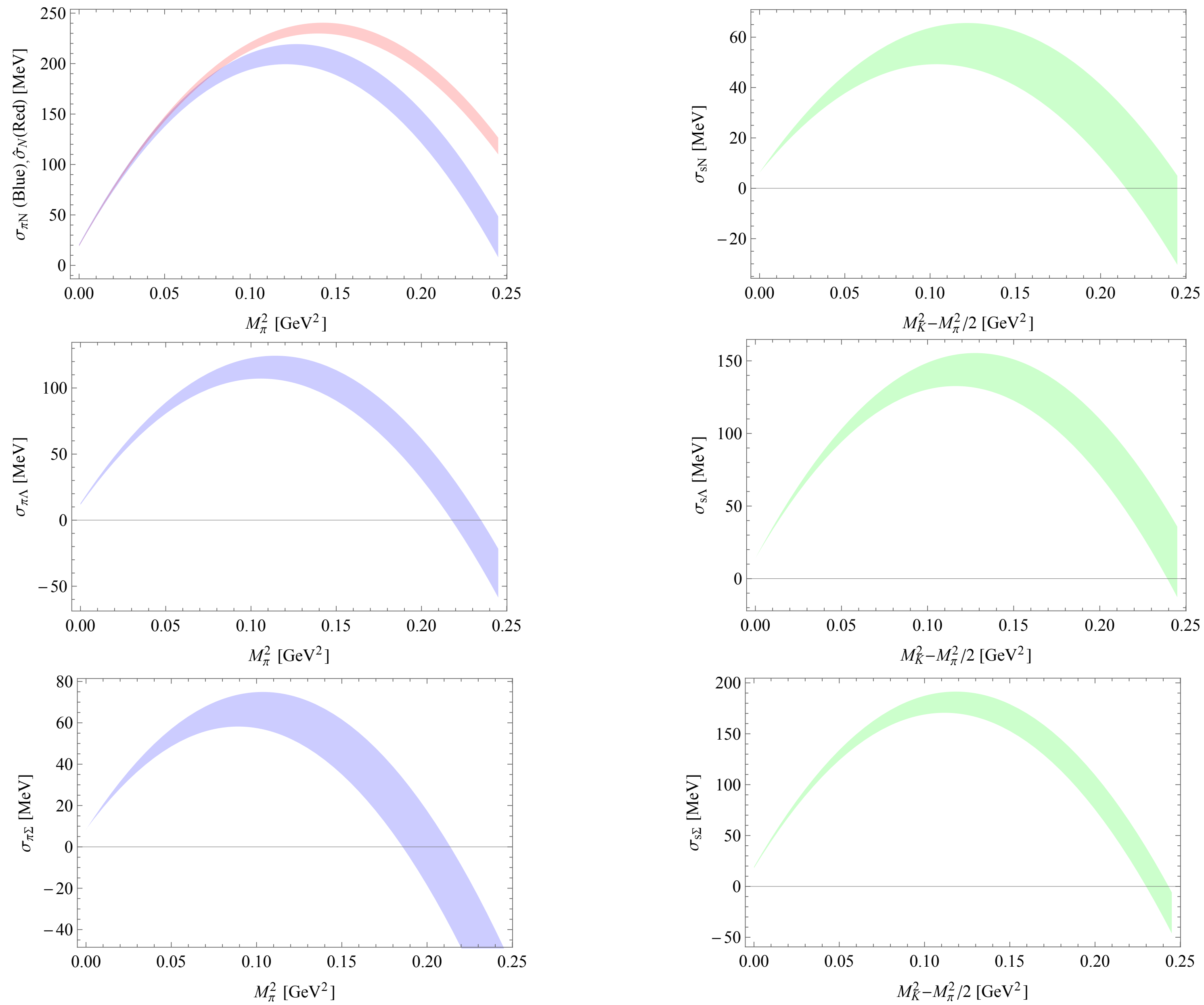
[LQCD: Alexandrou et al (2016)]





[J.M.Alarcon, I.Fernando & JLG (2018)]

Quark mass dependencies of σ terms



Historically misleading statement:
"σ terms gives the quark mass contribution to the baryon mass"
only true in the linear regime $\sigma \propto m_q$

Fit	$\frac{\mathring{g}_A}{F_\pi}$ MeV^{-1}	$\frac{M_0}{N_c}$ MeV	C_{HF} MeV	c_1	c_2	h_2	h_3	h_4	α MeV	β MeV
1	0.0126(2)	364(1)	166(23)	−1.48(4)	0	0	0.67(9)	0.56(2)	−1.63(24)	2.16(22)
2	0.0126(3)	213(1)	179(20)	−1.49(4)	−1.02(5)	−0.018(20)	0.69(7)	0.56(2)	−1.62(24)	2.14(22)
3	0.0126*	262(30)	147(52)	−1.55(3)	−0.67(8)	0	0.64(3)	0.63(3)	−1.63*	2.14*

Fit	$\Delta^{\rm phys}_{GMO}$ MeV	σ_8 MeV	$\Delta\sigma_8$ MeV	$\hat{\sigma}$ MeV	$\sigma_{\pi N}$ MeV	σ_s MeV	σ_3 MeV	$\sigma_{u+d}(p-n)$ MeV
1	25.6(1.1)	−583(24)	−382(13)	70(3)(6)	–	–	−1.0(3)	−1.6(6)
2	25.5(1.5)	−582(55)	−381(20)	70(7)(6)	69(8)(6)	−3(32)	−1.0(4)	−1.6(8)
3	25.8*	−615(80)	−384(2)	74(1)(6)	65(15)(6)	−121(15)	–	–

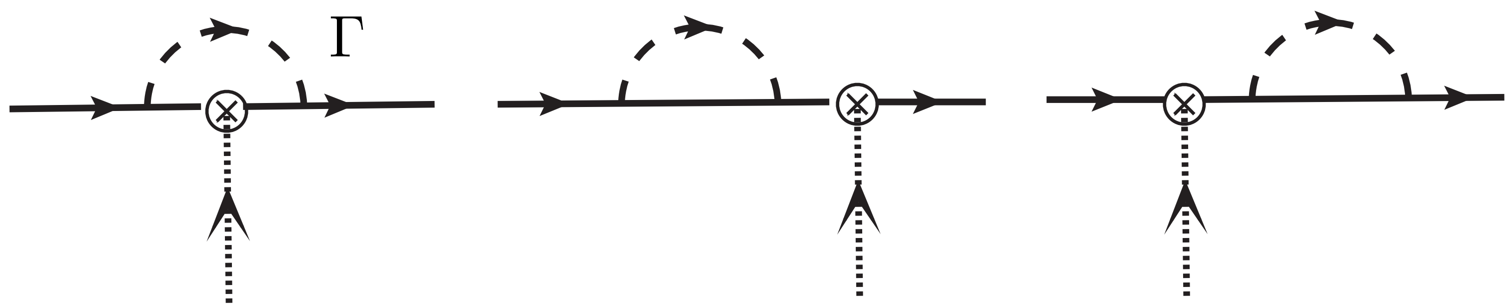
NNLO tree level relation between σ terms

GMO, ES and Gursey-Radicati should be very good

additional ones not suppressed in $1/N_c$: need test-- LQCD some day...

$$\sigma_{Nm_s} = \frac{m_s}{8\hat{m}}\left(-4(N_c-1)\sigma_{N\hat{m}} + (N_c+3)\sigma_{\Lambda\hat{m}} + 3(N_c-1)\sigma_{\Sigma\hat{m}}\right)$$
$$\sigma_{\Lambda m_s} = \frac{m_s}{8\hat{m}}\left(-4(N_c-3)\sigma_{N\hat{m}} + (N_c-5)\sigma_{\Lambda\hat{m}} + 3(N_c-1)\sigma_{\Sigma\hat{m}}\right)$$
$$\sigma_{\Sigma m_s} = \frac{m_s}{8\hat{m}}\left(-4(N_c-3)\sigma_{N\hat{m}} + (N_c+3)\sigma_{\Lambda\hat{m}} + (3N_c-11)\sigma_{\Sigma\hat{m}}\right)$$
$$\sigma_{\Delta m_s} = \frac{m_s}{8\hat{m}}\left(-4(N_c-1)\sigma_{\Delta\hat{m}} - 5(N_c-3)(\sigma_{\Lambda\hat{m}} - \sigma_{\Sigma\hat{m}}) + 4N_c\sigma_{\Sigma^*\hat{m}}\right)$$
$$\sigma_{\Sigma^* m_s} = \frac{m_s}{8\hat{m}}\left(-(N_c-3)(4\sigma_{\Delta\hat{m}} + 5\sigma_{\Lambda\hat{m}} - 5\sigma_{\Sigma\hat{m}}) + 4(N_c-2)\sigma_{\Sigma^*\hat{m}}\right).$$

$1/N_c$ power counting for currents at one-loop

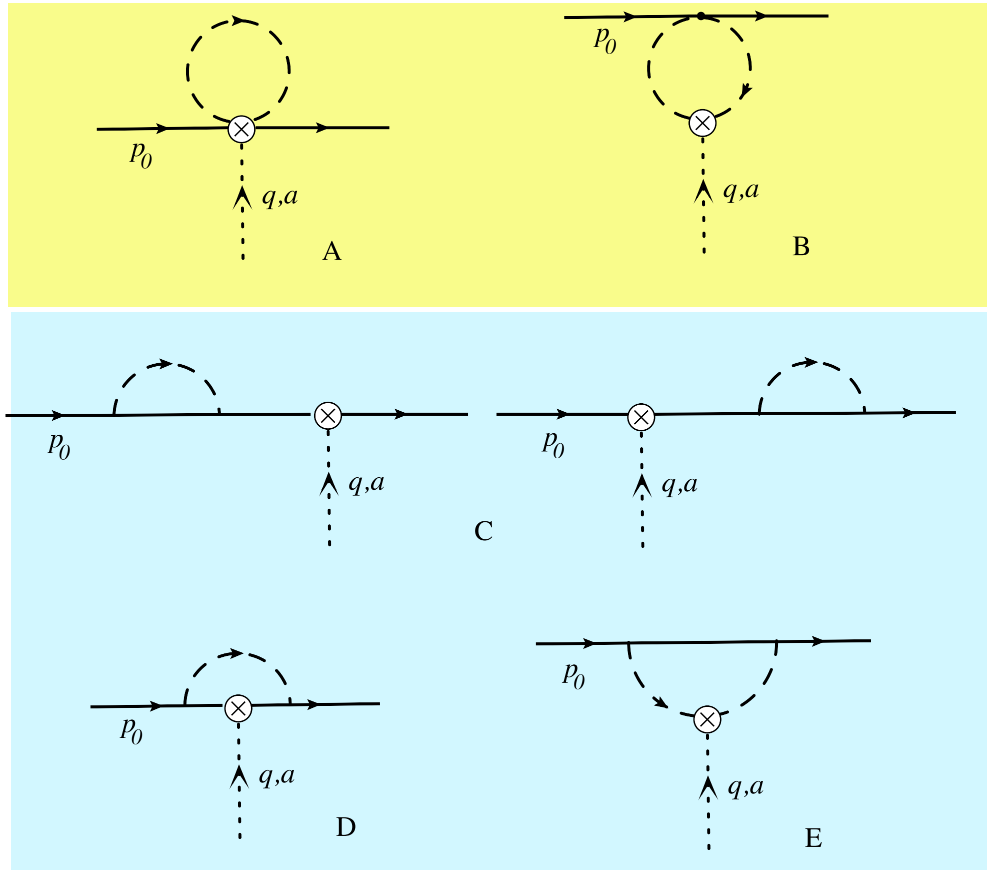


$$\text{UV div} = \frac{1}{(4\pi)^2}\left(\frac{\mathring{g}_A}{F_\pi}\right)^2\Big\{\frac{1}{2}(\lambda_\epsilon+1)M^2_{ab}[G^{ia},[G^{ib},\Gamma]]$$
$$+ \frac{1}{3}(\lambda_\epsilon+2)(2[[G^{ia},\Gamma],[\delta\hat{m},[\delta\hat{m},G^{ia}]]]+[[\Gamma,[\delta\hat{m},G^{ia}]],[\delta\hat{m},G^{ia}]])\Big\}$$

- Individual diagrams violate N_c power counting
- WF renormalization key for consistency
- Diagrams where current couples to GBs or vertices baryon-GB do not violate N_c power counting

Vector Currents

[R.Flores-Mendieta & JLG; I.P.Fernando & JLG]



SU(3) breaking corrections to the vector currents:

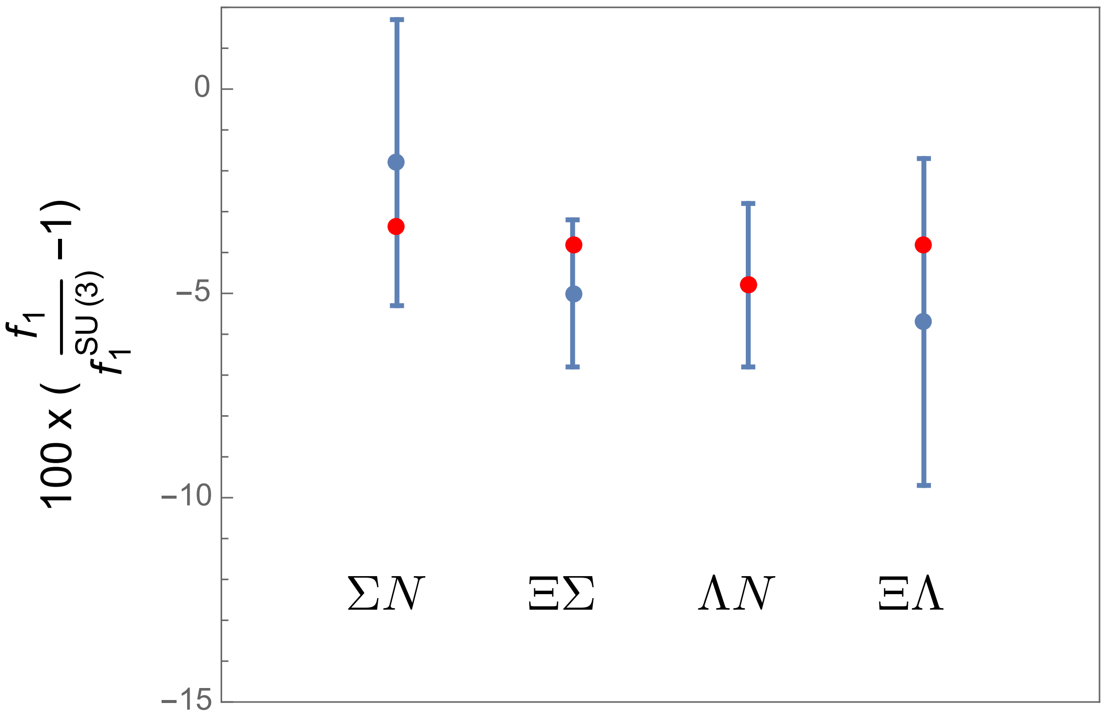
Ademollo-Gatto theorem at $\mathcal{O}(\xi^2)$
non-analytic calculable corrections to AGTh $\mathcal{O}(N_c^0)$,

different spin baryons in loop give $\mathcal{O}(N_c)$ terms!
key cancellations give N_c consistency

SU(3) breaking to vector charges

Charge	$\frac{f_1}{f_1^{SU(3)}}$	$\frac{f_1}{f_1^{SU(3)}} - 1$			
		[Flores-Mendieta & JLG:2014]	[Villadoro:2006]	[Lacour et al:2007]	[Geng et al:2009]
		HBChPT$\times 1/N_c$	HBChPT with 8 and 10	HBChPT only 8	RBChPT with 8 and 10
Λp	0.952	−0.048	−0.080	−0.097	−0.031
$\Sigma^- n$	0.966	−0.034	−0.024	0.008	−0.022
$\Xi^- \Lambda$	0.953	−0.047	−0.063	−0.063	−0.029
$\Xi^- \Sigma^0$	0.962	−0.038	−0.076	−0.094	−0.030

LQCD



[Shanahan et al, (2015)]

$$f_1^{\Sigma\to N}(0) = -0.9662(43), \quad f_1^{\Xi\to\Sigma}(0) = +0.9742(28)$$

[S. Sasaki, (2017)]

Charge radii

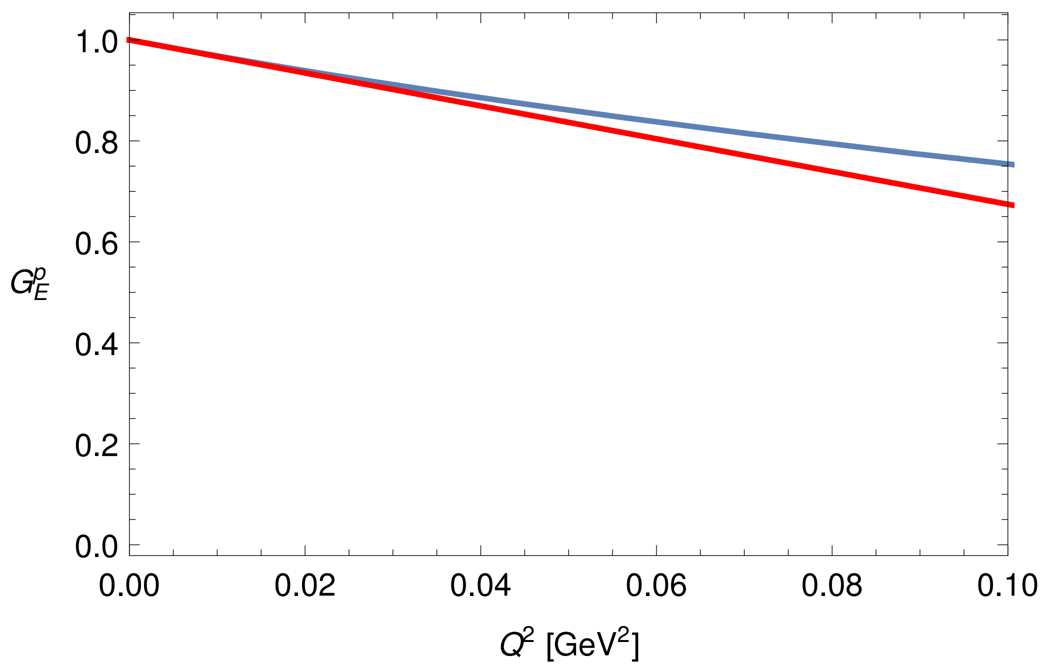
Two possible counter terms
$\propto T^a$ needed to subtract UV div
$\propto S^i G^{ia}$ finite renormalization

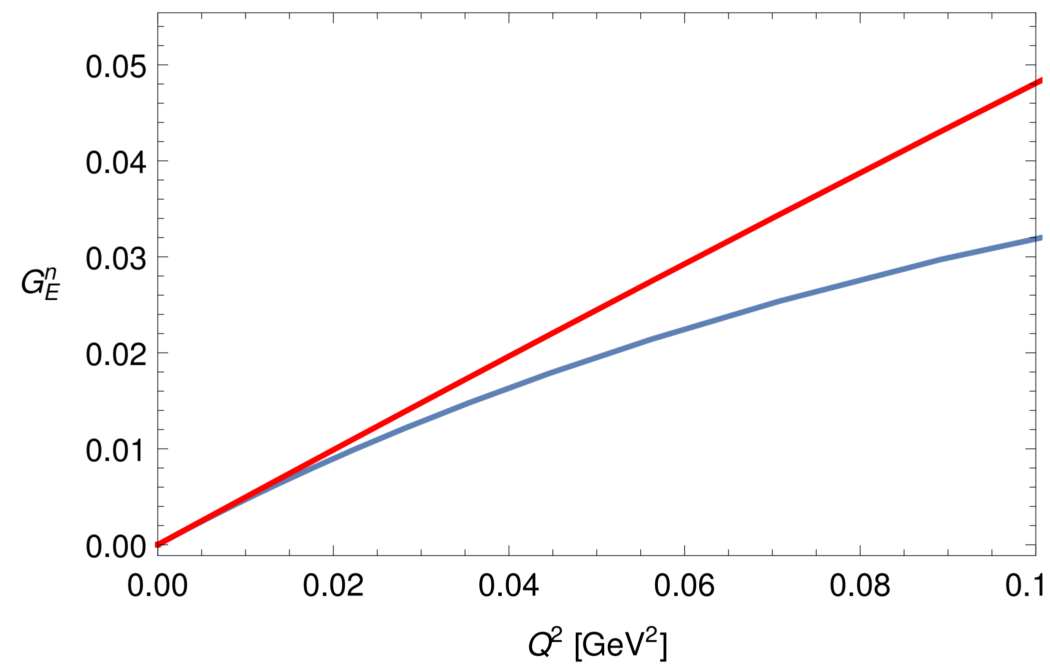
fix LECs with p and n charge radii

	$g_1^E = 1.48$	$g_2^E = 0.74$	
Baryon	$\langle r^2 \rangle_{\rm Th}[fm^2]$	Exp	CT
p	0.7658	0.7658 ± 0.01068	0.66
n	-0.1161	-0.1161 ± 0.0022	-0.049
Σ^-	0.74	0.61 ± 0.16	0.61

Baryon	$\langle r^2 \rangle_{\rm Th}[fm^2]$	$\langle r^2 \rangle_{\rm CT}(\mu = m_\rho)[fm^2]$
p	0.7658	0.655
n	-0.1161	-0.049
Σ^+	0.801	0.655
Σ^0	0.029	0.024
Σ^-	-0.741	-0.606
Λ	-0.029	-0.024
Ξ^0	-0.016	-0.049
Ξ^-	-0.692	-0.606

Charge form factors at low Q^2





BChPT x 1/Nc
Exp [Arrington et al.]

Interesting lesson:

Curvature of FFs ($\frac{d^2}{dQ^{2^2}} G^E(Q^2)$) from loop non-analytic terms

Correct signs, but too small!; cancellation between diags B and E

Detailed long distance (peripheral) charge distribution consistent with N_c power counting
[Alarcon, Granados, Weiss]

Magnetic moments

LO: only one operator : $\kappa\,\mu_N G^{ia}$

Ratio	Exp	LO
p/n	-1.46	-1.5
Σ^+/Σ^-	-2.12	$-3.$
Λ/Σ^+	-0.25	$-1/3$
p/Σ^+	1.14	$1.$
Ξ^0/Ξ^-	1.92	$2.$
p/Ξ^0	-2.23	-1.5
Δ^{++}/Δ^+	1.37	$2.$
Ω^-/Δ^+	-0.75	$-1.$
p/Δ^+	1.03	$1.$

SU(3) breaking is important

NNLO Counterterms

$$\frac{1}{\Lambda}\kappa_1\frac{1}{N_c}B_+^{ia}S^iT^a+\frac{1}{2\Lambda}\left\{\frac{1}{\Lambda^2}(\kappa_2\chi_+^0B_+^{ia}G^{ia}+\kappa_3 d^{abc}\chi_+^aB_+^{ib}G^{ic}+\kappa_4\chi_+^aB_+^{ia}S^i)\right.$$
$$+\quad\left.\kappa_5\frac{1}{N_c^2}B_+^{ia}\{\hat{S}^2,G^{ia}\}+\kappa_6\frac{1}{N_c^2}B_+^{ia}S^iS^jG^{ja}\right\}$$

NNLO Magnetic moments: 1-loop

LECs	
κ	2.00
κ_1	3.36
κ_2	0
κ_3	1.69
κ_4	0.61
κ_5	-5.67
κ_6	0

Octet	$\mu_{\mathrm{Th}}[\mu_N]$	$\mu_{\mathrm{Exp}}[\mu_N]$
p	2.724	2.79285
n	-1.92	-1.91304
Σ+	2.457	2.458
Σ0	0.717	–
Σ-	-1.02	-1.16
Λ	-0.60	-0.61
Ξ0	-1.29	-1.25
Ξ-	-0.65	-0.65

Decuplet	$\mu_{\mathrm{Th}}[\mu_N]$	$\mu_{\mathrm{Exp}}[\mu_N]$
Δ^{++}	5.1	3.7
Δ^{+}	2.5	2.7
Δ^{0}	-0.13	–
Δ^{-}	-2.8	–
Σ^{*+}	2.7	–
Σ^{*0}	0.1	–
Σ^{*-}	-2.5	–
Ξ^{*0}	0.3	–
Ξ^{*-}	-2.2	–
Ω	-2.0	-2.0

Magnetic radii

$\kappa_0 = 10.5$

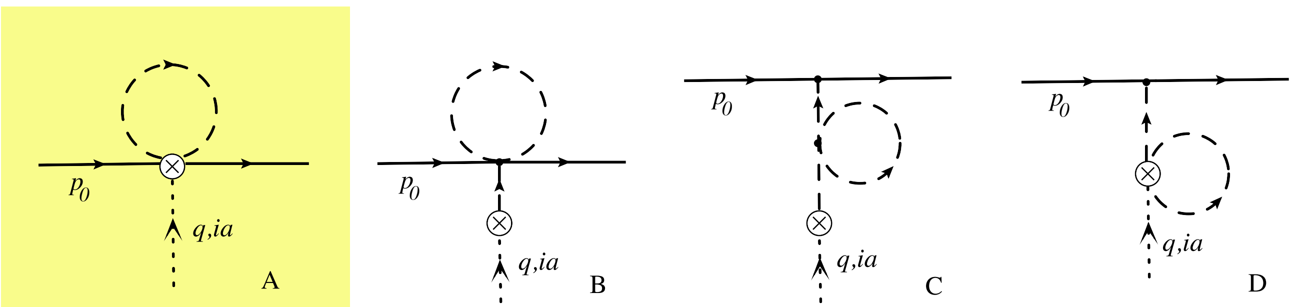
Baryon	$< r^2 >_{\mathrm{Exp}}$ [fm^2]	$< r^2 >_{\mathrm{Th}}$ [fm^2]	$< r^2 >_{\mathrm{Loop}}$ $(\mu = m_\rho)$[fm^2]
p	0.78	0.86	0.28
n	0.87	0.86	0.32

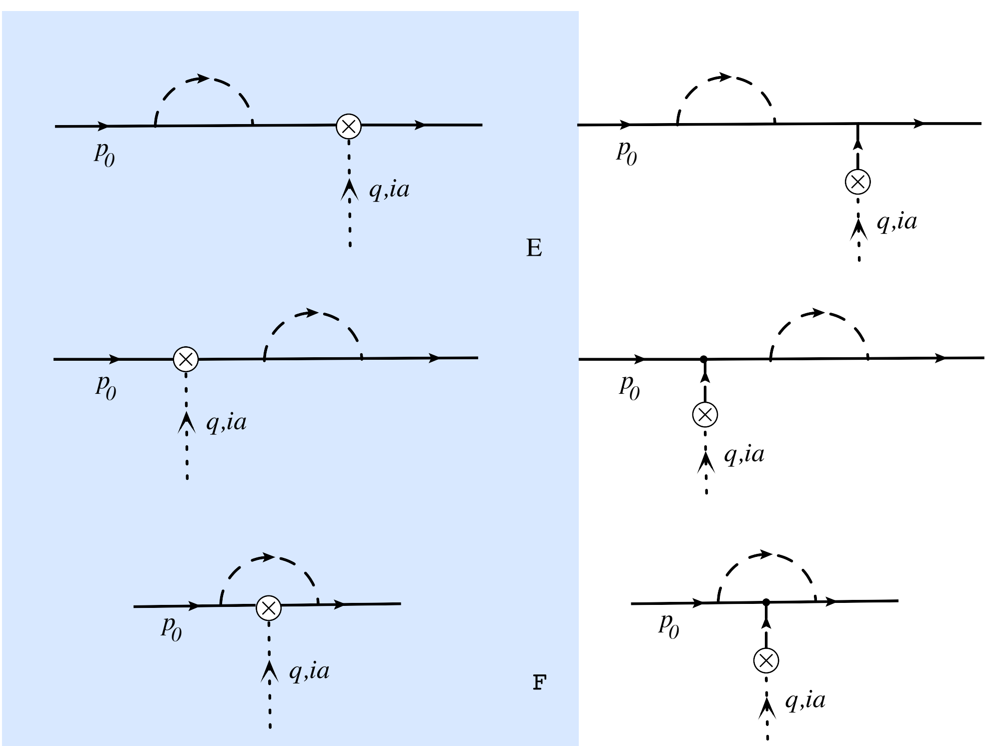
Axial-vector currents

[Flores-Mendieta, Hernandez & Hofmann; Fernando & JLG] [SU(2): A. Calle-Cordon & JLG]

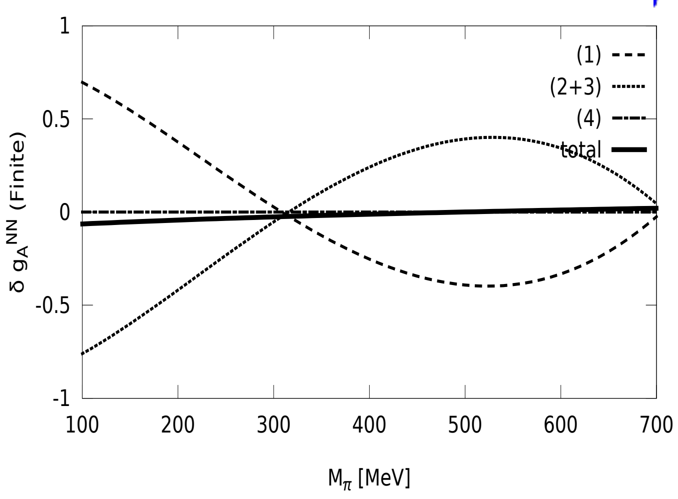
Definition of axial couplings

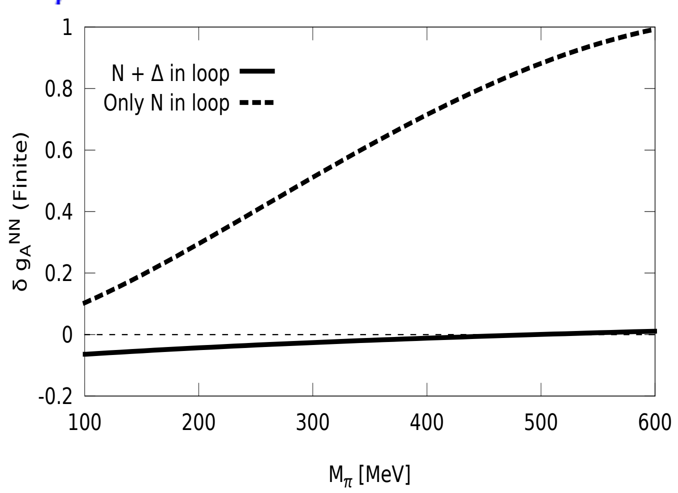
$$\langle B' \mid A^{ia} \mid B \rangle = \frac{6}{5} g_A^{aBB'} \langle B' \mid G^{ia} \mid B \rangle$$





$\mu = m_\rho$





cancellations to accuracy $1/N_c^2$

in large N_c persist at $N_c = 3$

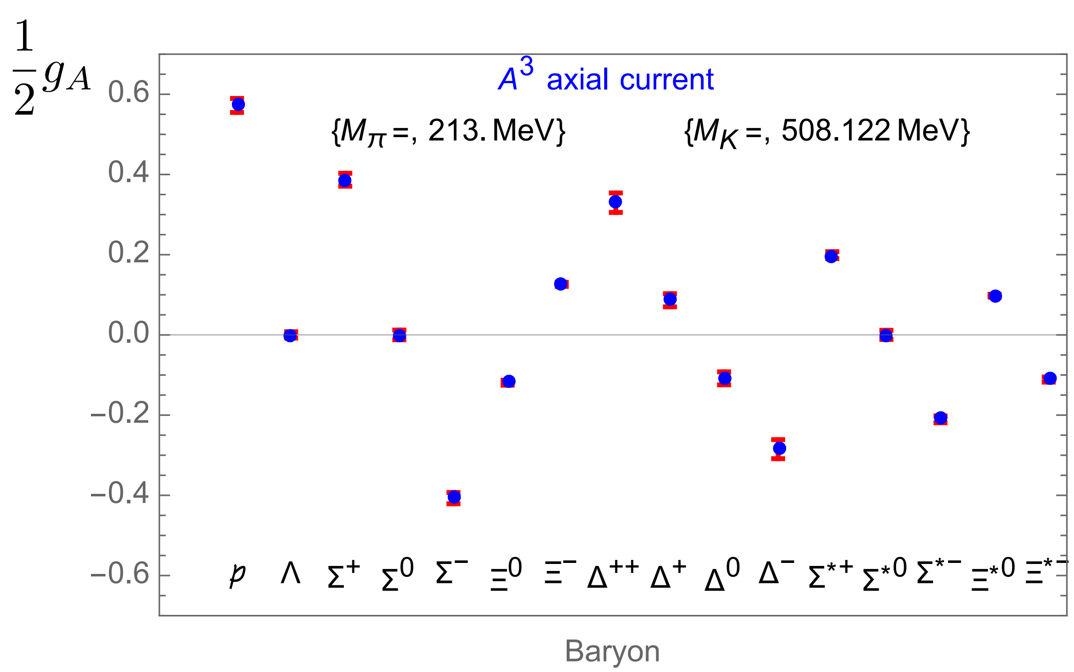
Fit to SU(3) LQCD g_A's

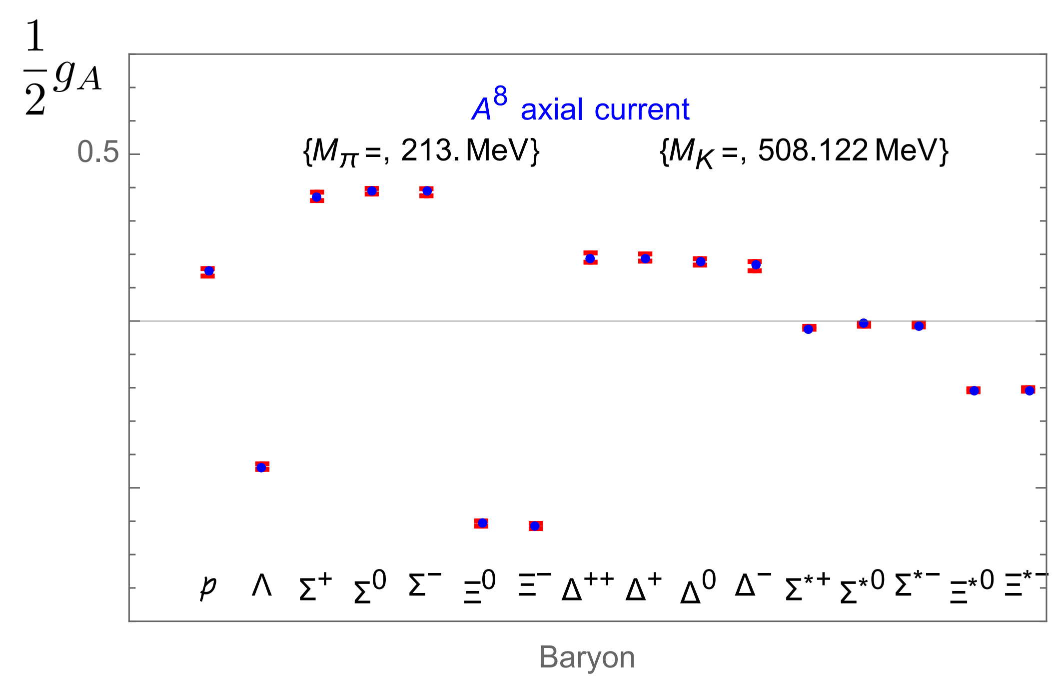
Key observed feature:@ fixed M_K, g_A's have little dependence on M_π

SU(3) calculation by Cyprus Group [Alexandrou et al, (2016)]
g_A^{3BB} and g_A^{8BB}

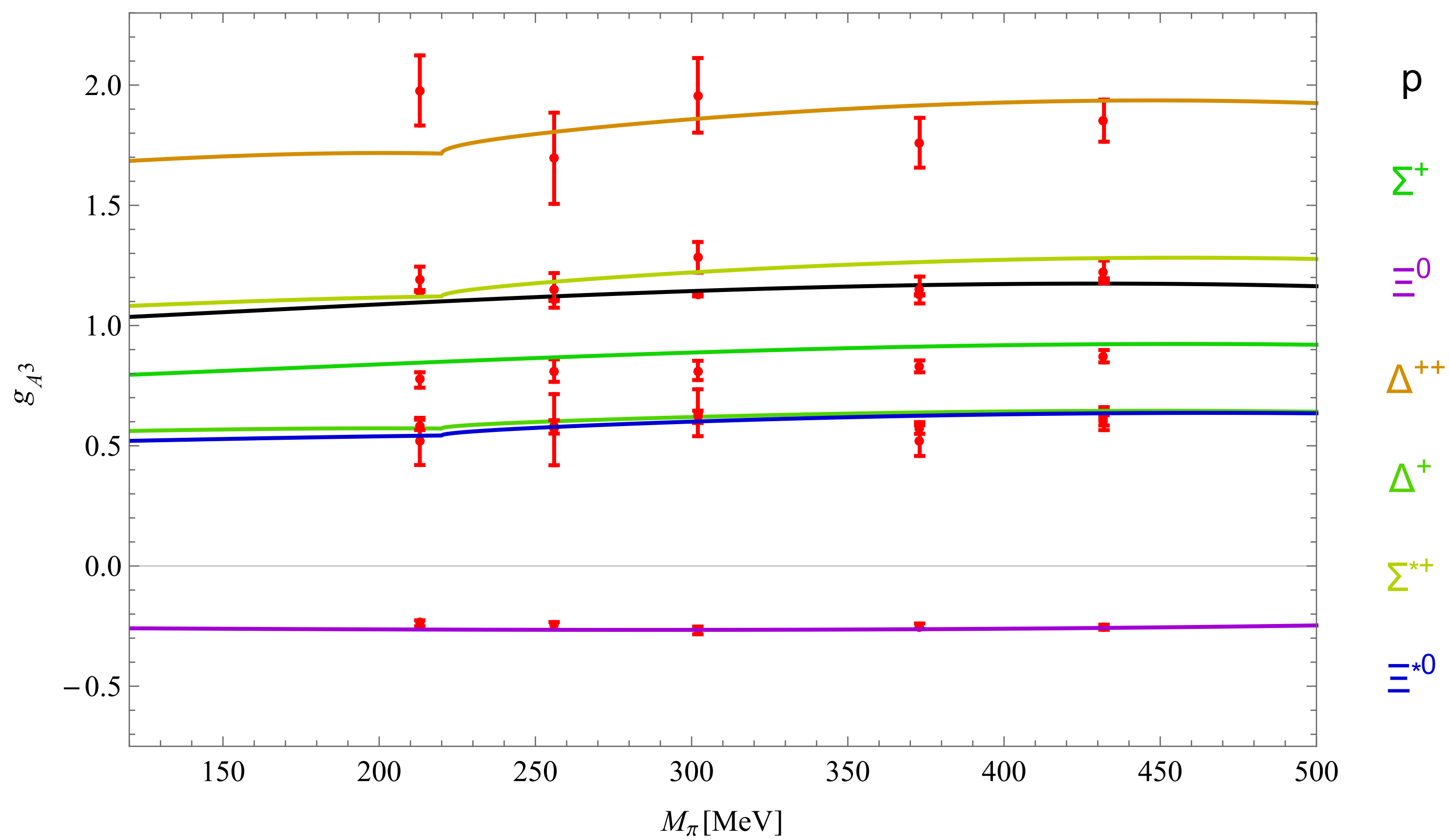
Fit	χ^2_{dof}	$\overset{\circ}{g}_A$	$\delta\overset{\circ}{g}_A$	C_1^A	C_2^A	C_3^A	C_4^A	D_1^A	D_2^A	D_3^A	D_4^A
LO	3.9	1.35	...	...	...	...	...	...	...	...	...
NLO Tree	0.91	1.42	...	−0.18	...	...	...	...	0.009	...	...
NLO Full	1.08	1.02	0.15	−1.11	0.	1.08	0.	−0.56	−0.02	−0.08	0.
	1.13	1.04	0.08	−1.17	0.	1.15	0.	−0.59	−0.02	−0.09	0.
	1.19	1.06	0.	−1.23	0.	1.21	0.	−0.62	−0.03	−0.09	0.

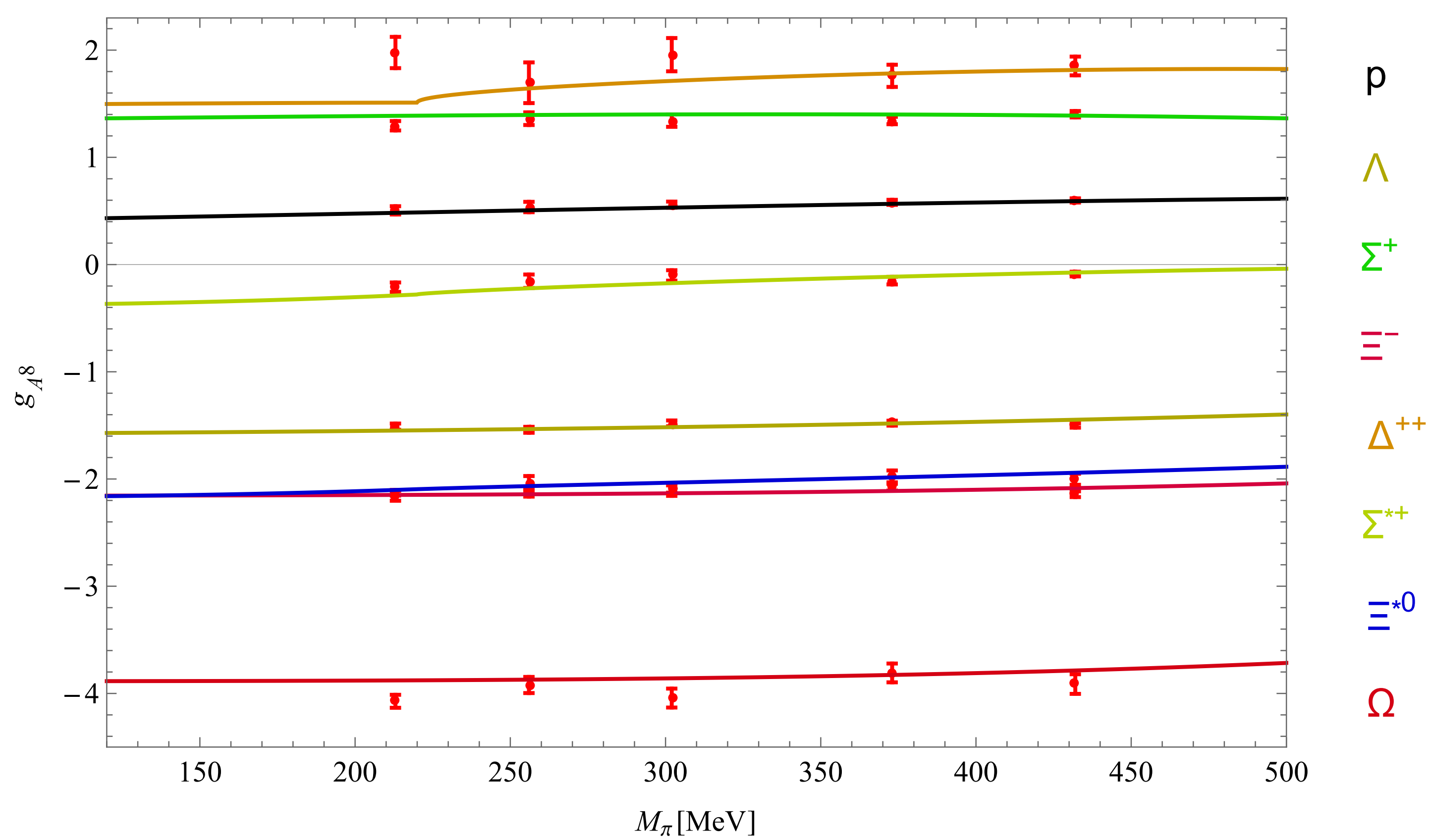
[I. Fernando & JLG (2018)]





Mild M_π dependence of axial couplings cannot be described without the cancellations of N_c violating terms





Observations on axial couplings

- show most prominently the need for theory consistent with $1/N_c$ expansion
- natural fit at one-loop of the axial couplings from SU(3) LQCD
- impossible to fit g_As of octet when turning off decuplet
- in SU(3): $g_A^N(LO)/g_A^N \sim 0.8$ from fit to axial couplings and from Δ_{GMO}
- numerous relations among axial couplings with calculable corrections

Summary and comments

- BChPT x 1/Nc improves convergence by eliminating large Nc power violating terms from loop corrections.

- In baryons it requires implementing a dynamical spin-flavor symmetry, broken at sub-leading orders in 1/Nc: use to implement BChPT x 1/Nc

- It affects every observable

- Convergence improvement is especially important in SU(3).

- New insights on σ terms.

- Axial couplings are particularly important tests of the approach.

- New results for the vector currents.

- Need for more LQCD results at different values of $m_{u,d,s}$.

- Works in progress:
  i) Compton scattering [with Ishara Fernando and Cintia Willemyns].
  ii) $\pi - N$ scattering [with Dulitha Jayakodige].