The lowest-lying spin-1/2 and spin-3/2 Baryon Magnetic Moments in Chiral Perturbation Theory

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Why baryon magnetic moments?

- **Magnetic moment**, a measure of the strength of a system's net magnetic source, is a **fundamental concept in physics**, but it is also widely applied in other fields, such as chemistry, electrical engineering, etc.

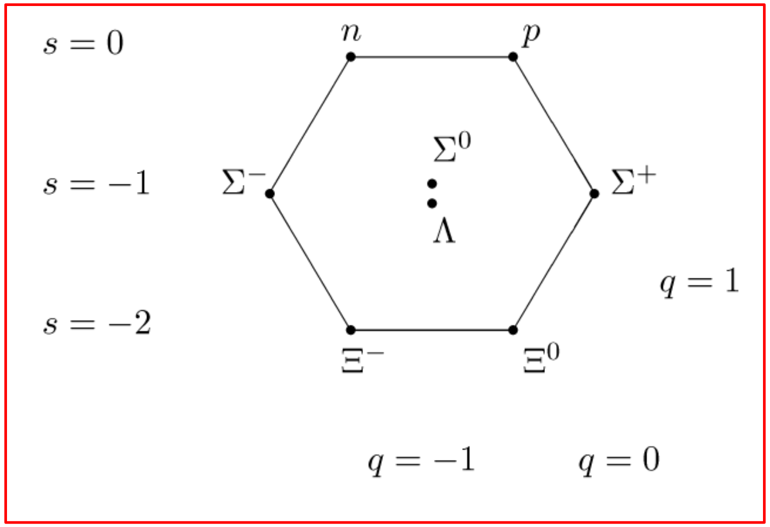
- Elementary particles have **intrinsic magnetic moments**; All point-like charged Dirac particles should have a g-factor ***~2*** *and all neutral ones should have* ***g_S~0****;* ***the contrary indicates that the particles have an internal structure****.*

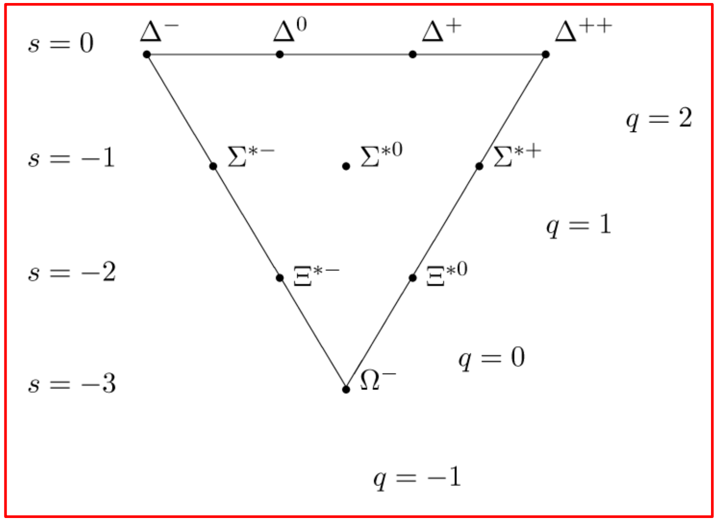
  For instance, the measured proton ***g_S = 5.58*** *and neutron* ***g_S = −3.82*** *show* that they are not point-like particles– a clear indication of their **composite nature.** Nowadays, we know they are composed of 3 (constituent) quarks.

- Measuring and understanding magnetic moments of hadrons have played and will continue to **play an important role** in our understanding of their properties.

The purpose of the present work

Our purpose is to calculate and understand baryon magnetic moments, particularly, those of the **lowest-lying spin-1/2 and spin-3/2 baryons**, i.e.





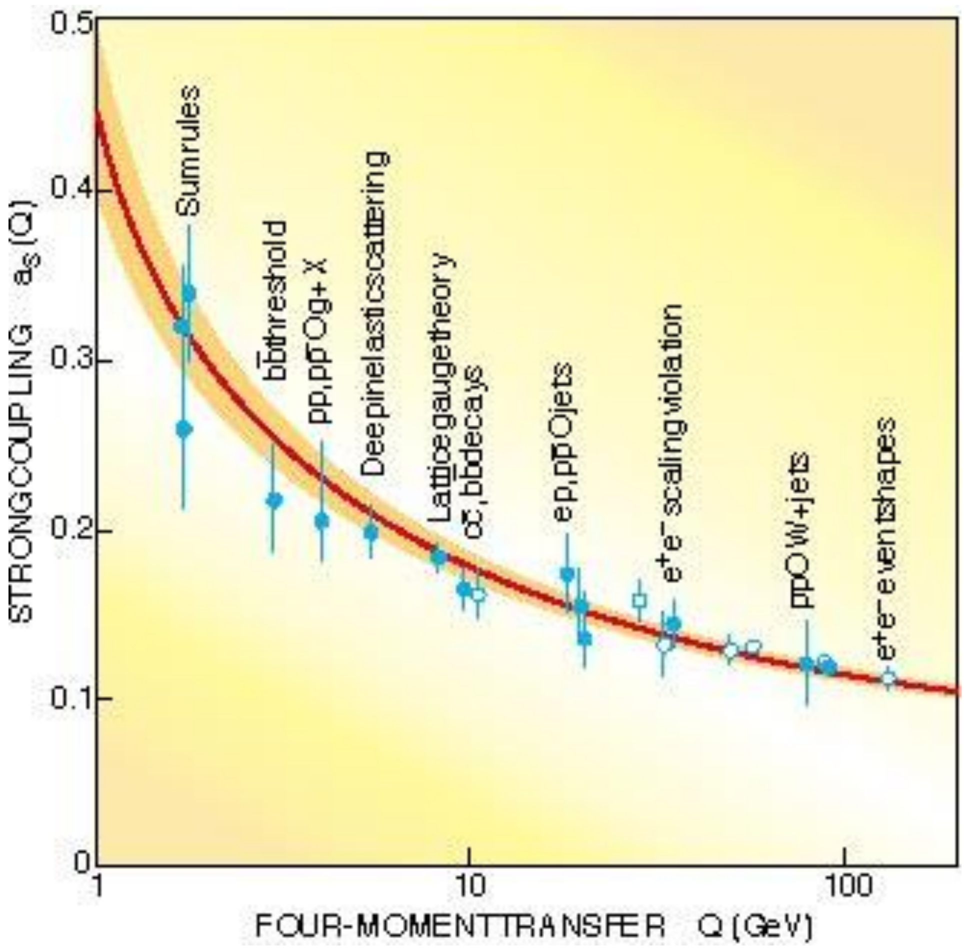
Baryon octet

Baryon decuplet

The question is, of course, how?

QCD—non-perturbative at low energies

- **Quantum ChromoDynamics—the theory of the strong interaction**



Aymptotic freedom—
Nobel prize in physics 2004

High energy: perturbative QCD successful

Low energy: non-perturbative problematic

Chiral symmetry and its breaking (I)

- Fortunately, **Chiral symmetry and its breaking pattern** allow for a perturbative treatment of QCD at low energy regions

Chiral Perturbation Theory (ChPT)! *(Weinberg, 1979)*

- Quark mass hierarchy:

Up, down, and strange quarks are **light**
Charm, bottom, and top quarks are **heavy**

vs. typical hadronic scale $\boxed{\Lambda \sim 1\mathrm{GeV}}$

- **Idealized world:**

(chirally symmetric)

$\boxed{m_u = m_d = m_s = 0}$

$m_c = m_b = m_t = \infty$, *decouple*

$$\Downarrow \qquad q = q_L + q_R$$

$$\boxed{\mathcal{L}^0_{\mathrm{QCD}}[q_L, q_R; G] = \mathcal{L}^0_{\mathrm{QCD}}[V_L q_L, V_R q_R; G]}$$

$$\Downarrow \qquad V_{L,R} \in \mathrm{SU}(3)_{R,L}$$

$\boxed{\textbf{16 conserved currents and charges: } Q^a_V, Q^a_A, a = 1, \ldots, 8}$

Chiral symmetry and its breaking (II)

- The vacuum is invariant under the vector charge： $Q_V^a|0\rangle = 0$
- The vacuum is not invariant under the axial charge: $Q_A^a|0\rangle \neq 0$
  - **Spontaneous symmetry breaking** ***(Nobel prize in physics, 2008)***
  - 8 **massless** Nambu-Goldstone bosons, i.e., $\pi^\pm, \pi^0, K^\pm, K^0, \bar{K}^0, \eta$
- Real world: π, K, η are not massless—**explicit symmetry breaking**

$$\mathcal{L}_{\rm QCD} = \mathcal{L}^0_{\rm QCD} \underbrace{-\bar{q}_R \mathcal{M} q_L - \bar{q}_L \mathcal{M}^\dagger q_R}$$

$$\mathcal{M} = \mathrm{diag}(m_u, m_d, m_s)$$

small: **perturbative** treatment

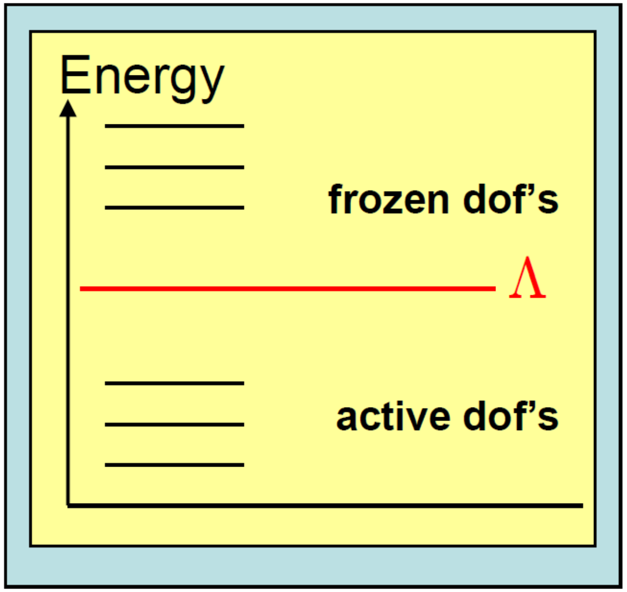
All these features combined with the idea of **effective field theory** leads to Chiral Perturbation Theory!

Effective field theory: Weinberg (1979)

- There exists a **natural cutoff,** which allows for a **separation of scales** such that:

  ✓All high-energy dynamics can be integrated out
  → contact interactions

  ✓One only needs to care about low-energy dof's



- **Expansion in powers of external energy/momenta** Q **over the large scale** Λ

  (instead of expansion in terms of the running coupling constant)

$$\boxed{\mathcal{M} = \sum_i \left(\frac{Q}{\Lambda}\right)^i C(Q/\mu, g_j)}$$

μ-regularization scale
g_j-low energy constants

C, encoding short distance physics, should be of $\mathcal{O}(1)$ **— naturalness**

Chiral Perturbation Theory (ChPT) in essence

- **Maps** quark (u, d, s) dof's to those of the asymptotic states, hadrons

$$\boxed{\mathcal{L}_{\mathrm{QCD}}[q,\bar{q};G] \to \mathcal{L}_{\mathrm{ChPT}}[U,\partial U,\ldots,\mathcal{M},N]}$$

★ U parameterizes the Goldstone bosons
★ ∂U vanishes at $E=\vec{p}=0$ (**Goldstone theorem**)
★ M parameterizes the **explicit symmetry breaking**
★ N denotes interactions with matter fields
★ Exact mapping via chiral Ward identities

- ChPT exploits the symmetry of the QCD Lagrangian and its ground state;

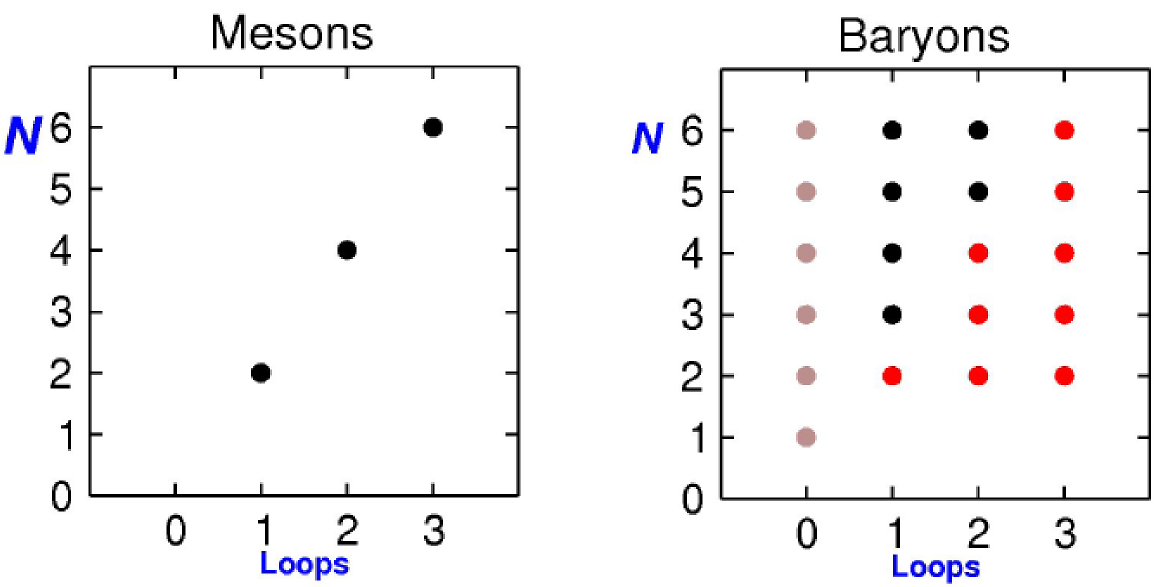
in practice, one solves in a perturbative manner the constraints imposed by chiral symmetry and unitarity by expanding the Green functions in powers of the external momenta and of the quark masses. (J. Gasser, 2003)

Of course, I did not invent any of the above. For further details and reviews, look for the following names: S. Weinberg, H. Leutwyler, J. Gasser, Ulf-G Meissner, V. Vernard, A. Pich, S. Scherer, and many others.…

Baryon ChPT and power counting

- ChPT has been very successful in the mesonic sector–calculations up to p^6 have become standard.

- In the one-baryon sector, things become problematic due to the nonzero (large) baryon mass in the chiral limit, which leads to the fact that high-order loops contribute to lower-order results, i.e., **a systematic power counting is lost!**



***red dots* denote possible PCB terms**

J. Gasser et al., NPB 307, 779(1988)

Chiral order = $4L - 2N_M - N_B + \sum_k kV_k.$

Baryon ChPT and power counting: solutions

A proper power-counting is of utmost importance for an EFT: it determines which diagrams to include (**bookkeeping**) and is also **relevant** for convergence studies.

- **Heavy Baryon ChPT**: baryons are treated "semi-relativistically" by a simultaneous expansion in terms of external momenta and $1/M_N$ (*Jenkins et al., 1993*). It converges slowly for certain observables!

- **Relativistic baryon ChPT**: removing power counting breaking terms but retaining higher-order relativistic corrections, thus, keeping relativity.
  - Infrared baryon ChPT (*T. Becher and H. Leutwyler, 1999*)
  - Fully relativistic baryon ChPT–Extended On-Mass-Shell (EOMS) scheme (*J. Gegelia et al., 1999; T. Fuchs et al.,2003*)

- IR scheme separates the full integral into the Infrared and Regular parts:

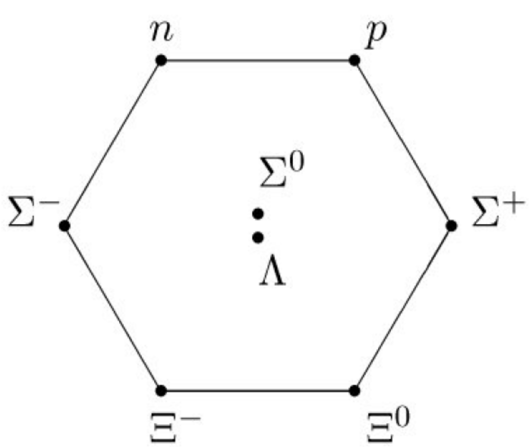
$$H = \frac{1}{ab} = \int_0^1 dz \frac{1}{[(1-z)a + zb]^2} \equiv I + R = \int_0^\infty \dots dz - \int_1^\infty \dots dz$$

Our choice—the EOMS approach

Octet baryon magnetic moments in EOMS BChPT

Phys.Rev.Lett.101:222002,2008.

Magnetic moments of the baryon octet and SU(3) flavor symmetry



- Coleman-Glashow (C-G) relations (1961):
  - Related to the measured proton and neutron MMs;

$$\mu_{\Sigma^+} = \mu_p \quad 2\mu_\Lambda = \mu_n \quad \mu_{\Sigma^-} + \mu_n = -\mu_p$$

$$\mu_{\Sigma^-} = \mu_{\Xi^-} \quad \mu_{\Xi^0} = \mu_n \quad 2\mu_{\Lambda\Sigma^0} = -\sqrt{3}\mu_n$$

  - Nothing but the SU(3) flavor symmetry.

	p	n	Λ	Σ^-	Σ^0	Σ^+	Ξ^-	Ξ^0	$\Lambda\Sigma^0$
Exp.	2.79	-1.91	-0.61	-1.16	—	2.46	-0.65	-1.25	1.61
C-G	2.56	-1.60	-0.80	-0.97	0.80	2.56	-0.97	-1.60	1.38

- The SU(3) f-symmetry is **broken**, as indicated in the above comparison!

A natural question:

How to implement SU(3) breaking in a systematic and well-controlled way– Chiral Perturbation Theory.

ChPT and the baryon octet MMs—a puzzle of 30 years!

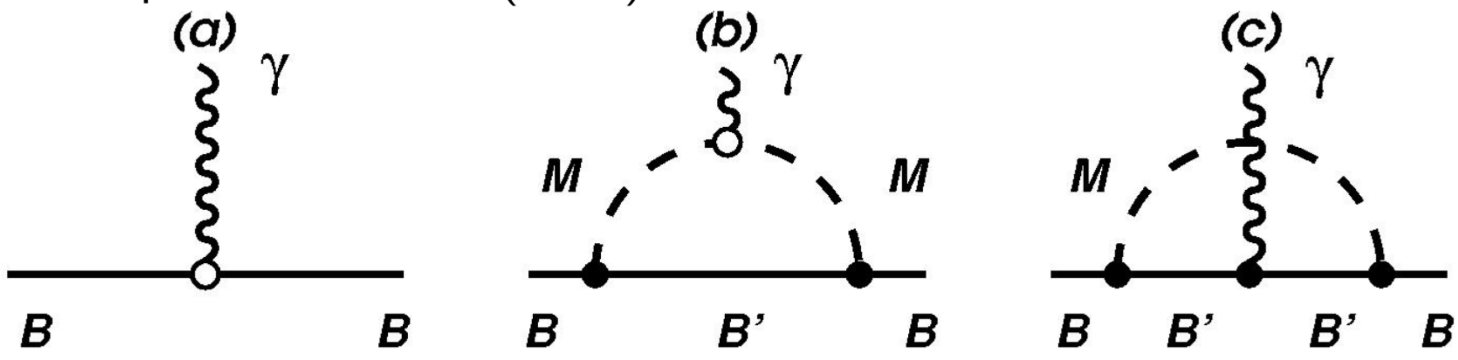
- The ChPT study of the leading SU(3) breaking effects on the MMs of the baryon octet has a long history, which **spans** over **30** years:
  - Pioneering works of Caldi and Pagels on leading chiral corrections (1974).
  - Systematic HBChPT calculations of **Jenkins** et al. (1993), **Meissner** et al. (1997), and others, up to NNLO.
  - Infrared relativistic BChPT by **Kubis** and **Meissner** (2001), up to NNLO.
- All the early attempts found: The **leading SU(3)** breaking effects induced by loops are **too large** and **worsen** the SU(3) symmetric description.
- Many possibilities have been explored to understand this “apparent’’ failure of ChPT

But as we will show in this work, analyticity and relativity play a very important role!

MMs of the baryon octet in ChPT: formalism

- Definition:
  - The matrix element of the electromagnetic current can be parameterized by two form factors:
    $\langle\psi(p')|J^\mu|\psi(p)\rangle = |e|\bar{u}(p')\left\{\gamma^\mu F_1(t) + \frac{i\sigma^{\mu\nu}q_\nu}{2M}F_2(t)\right\}u(p).$
  - At $q^2 = 0$: $F_1(0) = Q$ (charge), $F_2(0) = \kappa$ (anomalous magnetic moment).
  - The fermion (baryon) MM: $\mu \equiv (Q+\kappa)\frac{|e|}{2M} \Longrightarrow \kappa$ is calculated!

- All diagrams up to third order (NLO):



- SU(3)-symmetric contribution ***(a)*** contains 2 low-energy constants (LECs).
- SU(3)-breaking induced by meson masses through loop diagrams ***(b)*** and ***(c)***.

EOMS BChPT results: Analytical

- SU(3)-symmetric description (order 2) depends on Clebsch-Gordan coeff., known MB couplings, and two LECs. b_D and b_F:

$$\kappa_B^{(2)} = \alpha_B b^D + \beta_B b^F$$

- SU(3)-breaking is induced by loop-functions $H^{(b)}(m)$ and $H^{(c)}(m)$, which are convergent, do not contain unknown LEC's, and are genuine predictions of ChPT at this order!:

$$\kappa_B^{(3)} = \frac{1}{8\pi^2 F_\phi^2}\left(\sum_{r=\pi,K} \xi_{BM}^{(b)} H^{(b)}(m_r) + \sum_{r=\pi,K,\eta} \xi_{BM}^{(c)} H^{(c)}(m_r)\right)$$

$$H^{(b)}(m) = -M^2 + 2m^2 + \frac{2m\left(m^4 - 4m^2M^2 + 2M^4\right)}{M^2\sqrt{4M^2 - m^2}} \arccos\left(\frac{m}{2\,M}\right) + \frac{m^2}{M^2}(2M^2 - m^2)\log\left(\frac{m^2}{M^2}\right)$$

$$H^{(c)}(m) = M^2 + 2m^2 + \frac{2m^3\left(m^2 - 3M^2\right)}{M^2\sqrt{4M^2 - m^2}} \arccos\left(\frac{m}{2\,M}\right) + \frac{m^2}{M^2}(M^2 - m^2)\log\left(\frac{m^2}{M^2}\right).$$

The ***M^2*** terms break power counting, and have to be removed *.*

EOMS vs. HBChPT and IR BChPT

- EOMS: $H^{(b,c)} \equiv H^{(b,c)}_{\rm full}$, **fulfills both relativity and analyticity!**

$$b_6^D \longrightarrow \tilde{b}_6^D = b_6^D + \frac{3DFM_B^2}{2\pi^2 F_\phi^2}, \quad b_6^F \longrightarrow \tilde{b}_6^F = b_6^F$$

- Heavy Baryon ChPT, breaks both!

$$H^{(b)}(m) \simeq \pi m M_B + \cdots, \quad H^{(c)}(m) \simeq 0 + \cdots.$$

- Infrared ChPT: $H^{(b,c)} = H^{(b,c)}_{\rm full} - R^{(b,c)}$, breaks analyticity!

$$\begin{aligned} R^{(b)}(m) &= -M_B^2 + \frac{19m^4}{6M_B^2} - \frac{2m^6}{5M_B^4} + \cdots, \\ R^{(c)}(m) &= M_B^2 + 2m^2 + \frac{5m^4}{2M_B^2} - \frac{m^6}{2M_B^4} + \cdots. \end{aligned}$$

EOMS BChPT results: Numerical

$$\chi^2 = \sum(\mu_{th} - \mu_{exp})^2$$

	p	n	Λ	Σ^-	Σ^0	Σ^+	Ξ^-	Ξ^0	$\Lambda\Sigma^0$	χ^2
C-G	2.56	-1.60	-0.80	-0.97	0.80	2.56	-0.97	-1.60	1.38	**0.46**
HB	3.01	-2.62	-0.42	-1.35	0.42	2.18	-0.52	-0.70	1.68	**1.01**
IR	2.08	-2.74	-0.64	-1.13	0.64	2.41	-1.17	-1.45	1.89	**1.83**
EOMS	2.58	-2.10	-0.66	-1.10	0.66	2.43	-0.95	-1.27	1.58	**0.18** ★
Exp.	2.79	-1.91	-0.61	-1.16	—	2.46	-0.65	-1.25	1.61	—

- Contribution of the chiral series [LO(1+NLO/LO)]:

$$\mu_p = 3.47(1-0.257), \quad \mu_n = -2.55(1-0.175), \quad \mu_\Lambda = -1.27(1-0.482),$$

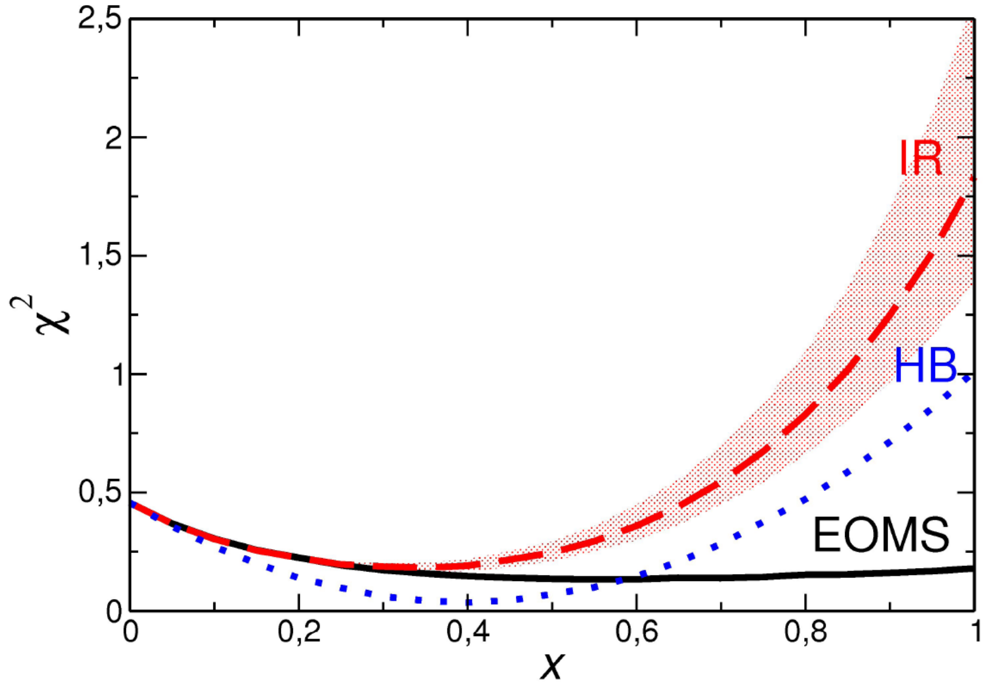
$$\mu_{\Sigma^-} = -0.93(1+0.187), \quad \mu_{\Sigma^+} = 3.47(1-0.300), \quad \mu_{\Sigma^0} = 1.27(1-0.482),$$

$$\mu_{\Xi^-} = -0.93(1+0.025), \quad \mu_{\Xi^0} = -2.55(1-0.501), \quad \mu_{\Lambda\Sigma^0} = 2.21(1-0.284).$$

✓**The EOMS NLO-calculation improves the C-G relations!**

✓**Better convergence: NLO/LO *≤50%; vs. .≤70% and ≤300% in HB and IR!***

EOMS BChPT results: Chiral and SU(3) evolution



- $x \equiv m/m_{phys}$ with m the meson masses
- **An indication of the importance of analyticity and relativity**.

- The three approaches agree in the vicinity of the chiral limit.
- IR and EOMS coincide up to $x \sim 0.4$. IR description then gets worse.
- Shaded area(s) represent the variation 0.8GeV$\leq M_0 \leq$ 1.1GeV.
- Only EOMS exhibits a proper behavior (at this order)!

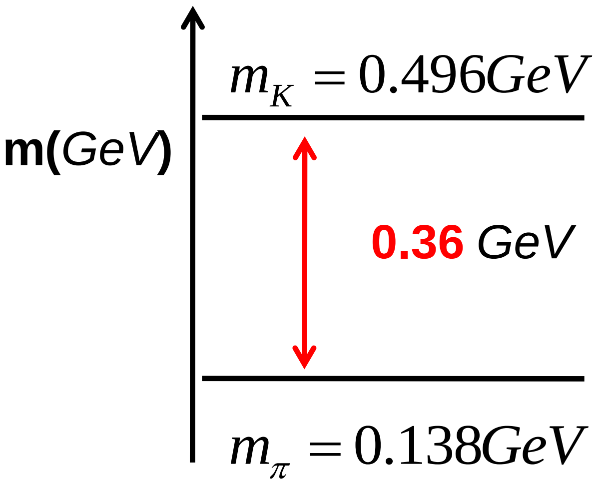
Octet baryon magnetic moments in EOMS BChPT

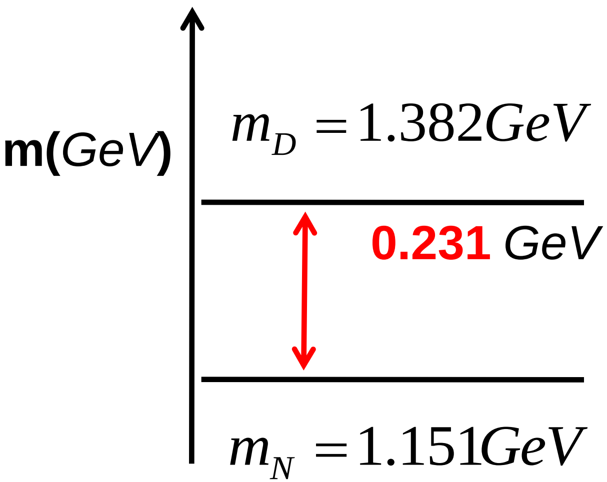
—the contributions of virtual decuplet baryons

"Virtual" particles—particles inside loops

Phys.Lett.B676:63-68,2009.

Why virtual (dynamical) decuplet baryons?





- ChPT relies on the validity of the assumption that all the higher energy dynamics can be integrated out or, in other words,. encoded into the LEC's.

- This may not be (totally) true in the present case because $m_D - m_B \sim 0.231$ *GeV* is similar to the pion mass and even smaller than the kaon (eta) mass. Therefore, in SU(3) baryon ChPT, one has to be cautious about the exclusion of decuplet baryons.

Description of spin-3/2 particles can be subtle!

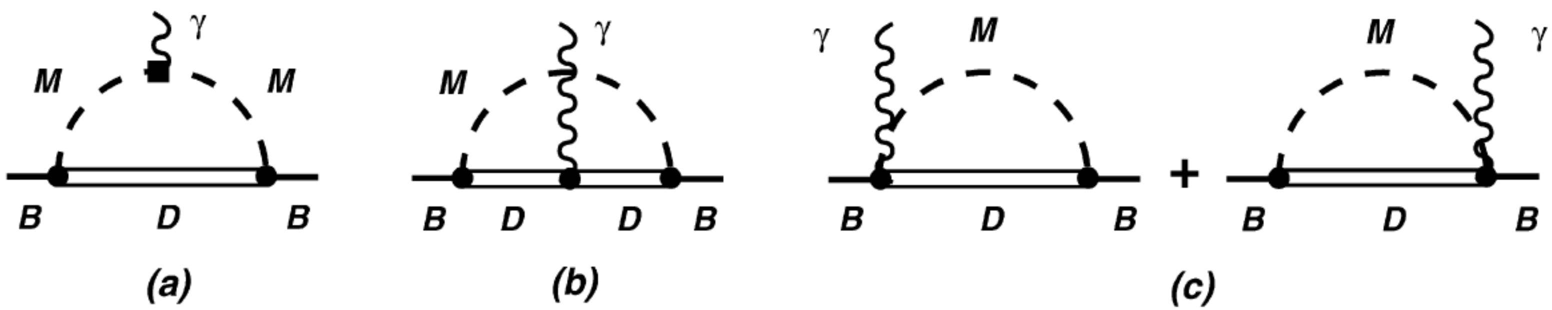
- Description of decuplet baryons (higher spin particles in general) is very **subtle:** Particularly, the conventional **Rarita-Schwinger (RS)** representation is a field with **16** components, while only **8** of them are physical. One has to be careful about the contributions of the unphysical spin-1/2 modes. See e.g.

V. Pascalutsa, Phys. Lett. B 503, 85 (2001)
V. Pascalutsa, et al., Phys. Rep. 437, 125 (2007)
C. Hacker et al., PRC 72 (2005) 055203.

- In the work, we have adopted the **"consistent coupling scheme"** , which, through field-redefinition, has a better control of the contribution of the unphysical spin-1/2 fields. Details can be found in *Phys.Lett.B676:63-68,2009.*

Diagrams and Lagrangians

Feynman diagrams



Lagrangians:

$$\mathcal{L}_D = \bar{T}^{abc}_{\mu}(i\gamma^{\mu\nu\alpha}D_\alpha - M_D\gamma^{\mu\nu})T^{abc}_{\nu},$$

$$\mathcal{L}'^{(1)}_{\phi BD} = \frac{i\mathcal{C}}{M_D F_\phi}\varepsilon^{abc}(\partial_\alpha \bar{T}^{ade}_{\mu})\gamma^{\alpha\mu\nu}B^e_c\partial_\nu\phi^d_b + \text{h.c.},$$

$\mathcal{C}$ is determined from the Δ width

Propagator:

$$S^{\mu\nu}(p) = -\frac{\not{p}+M_D}{p^2-M_D^2+i\epsilon}\left[g^{\mu\nu} - \frac{1}{d-1}\gamma^\mu\gamma^\nu - \frac{1}{(d-1)M_D}(\gamma^\mu p^\nu - \gamma^\nu p^\mu) - \frac{d-2}{(d-1)M_D^2}p^\mu p^\nu\right],$$

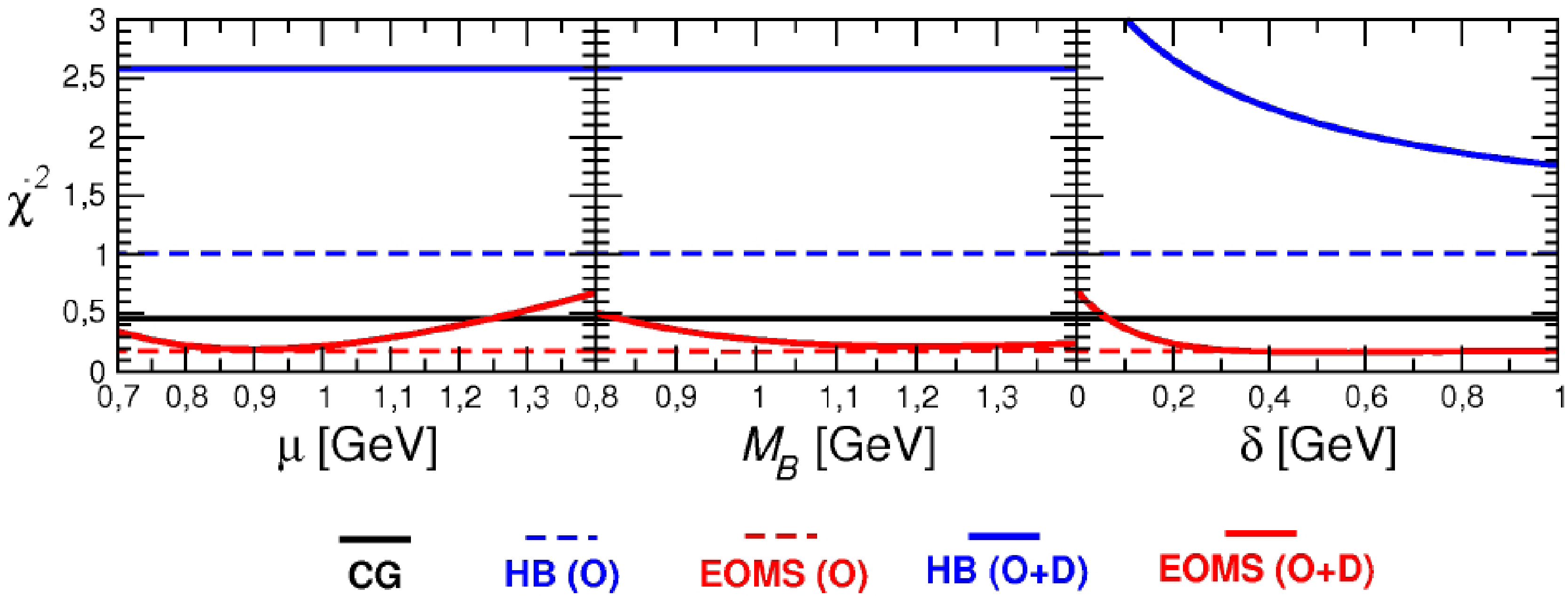
Numerical results

	Tree level $\mathcal{O}(p^2)$	Heavy Baryon $\mathcal{O}(p^3)$		Covariant EOMS $\mathcal{O}(p^3)$		Expt.
		O	O+D	O	O+D (consist.)	
p	2.56	3.01	3.47	2.60	2.61	2.793(0)
n	-1.60	-2.62	-2.84	-2.16	-2.23	-1.913(0)
Λ	-0.80	-0.42	-0.17	-0.64	-0.60	-0.613(4)
Σ^-	-0.97	-1.35	-1.42	-1.12	-1.17	-1.160(25)
Σ^+	2.56	2.18	1.77	2.41	2.37	2.458(10)
Σ^0	0.80	0.42	0.17	0.64	0.60	...
Ξ^-	-1.60	-0.70	-0.41	-0.93	-0.92	-0.651(3)
Ξ^0	-0.97	-0.52	-0.56	-1.23	-1.22	-1.250(14)
$\Lambda\Sigma^0$	1.38	1.68	1.86	1.58	1.65	$\pm$1.61(8)
b_6^D	2.40	4.71	5.88	3.92	4.30	
b_6^F	0.77	2.48	2.49	1.28	1.03	...
$\tilde{\chi}^2$	0.46	1.01	2.58	0.18	0.22	

✓**Inclusion of the virtual decuplet contributions only has a small effect.**

✓**The full NLO (O+D) predictions are again better than the C-G relations**

χ^2 dependence on inputs



- Improvement over CG for $0.7 \leq \mu \leq 1.3$ GeV.
- Mild dependence on the average baryon mass M_B ($\delta = 0.231$ GeV).
- The Decuplet contributions vanish as $\delta \to \infty$–decoupling.

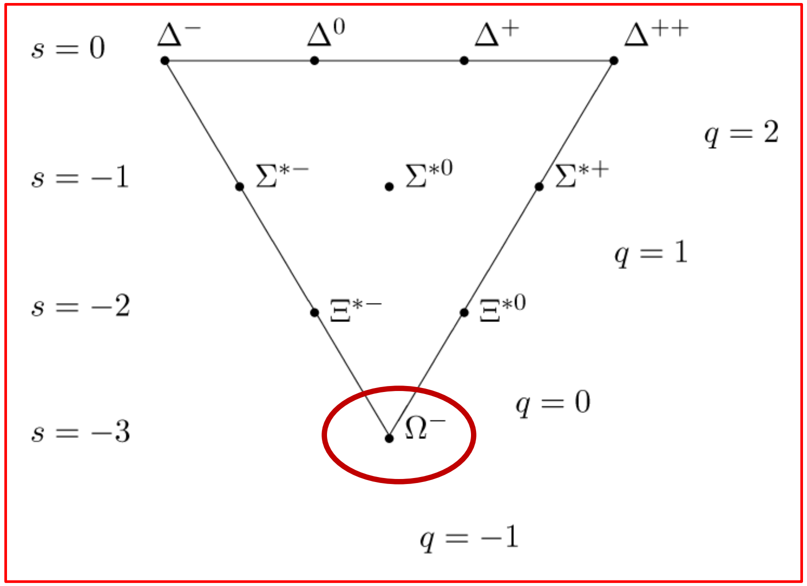
Overall, O+D provide a better description of data than C-G

Decuplet baryon magnetic moments in EOMS ChPT

Phys.Rev.D80:034027,2009.

Renewed interests in the MM's of the decuplet baryons

- Renewed interests in the MDMs of Δ++ and Δ+,
  - **Experiments:** e.g., Kotulla (2008)
  - **Lattice QCD:** Leinweber et al. (1992), Lee et al. (2005), Aubin et al. (2008), Alexandrou et al. (2009), Boinepalli et al. (2009), ...



The MM of Ω^- is well measured

$2.02 \pm 0.05 \mu_n$

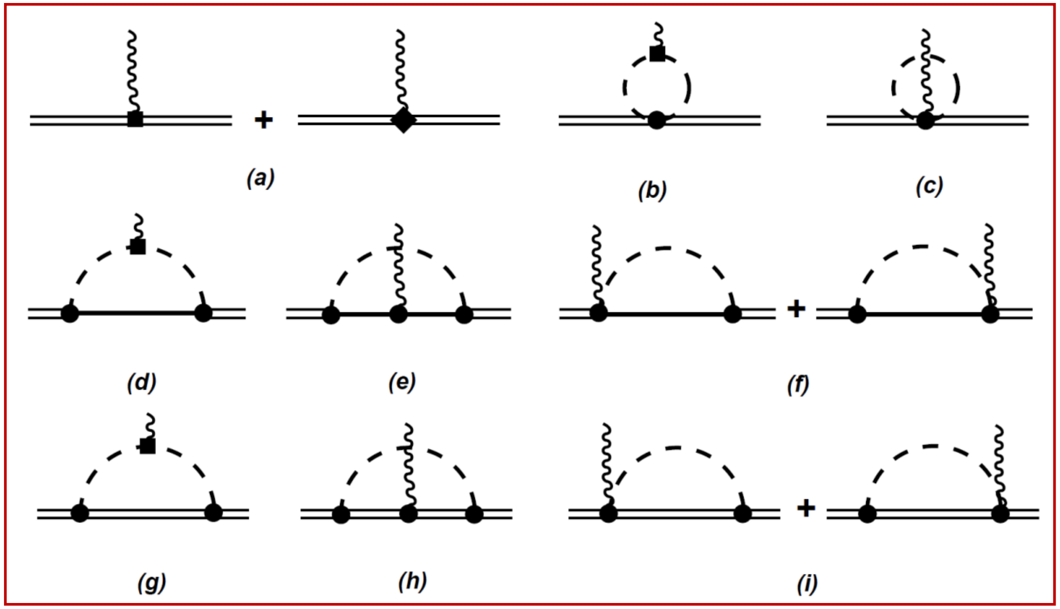
- There exist many theoretical predictions, such as Quark models, QCD sum rules, large Nc , HBChPT,

Definitions and Feynman diagrams

$$\langle T(p')|J^\mu|T(p)\rangle = -\bar{u}_\alpha(p')\left\{\left[F_1^*(\tau)\gamma^\mu + \frac{i\sigma^{\mu\nu}q_\nu}{2M_D}F_2^*(\tau)\right]g^{\alpha\beta} + \left[F_3^*(\tau)\gamma^\mu + \frac{i\sigma^{\mu\nu}q_\nu}{2M_D}F_4^*(\tau)\right]\frac{q^\alpha q^\beta}{4M_D^2}\right\}u_\beta(p),$$

Magnetic dipole FF: $$G_{M1}(\tau) = (F_1^*(\tau) + F_2^*(\tau)) + \frac{4}{5}\tau G_{M3}(\tau),$$

Magnetic moment: $$\mu = \frac{e}{2M_D}G_{M1}(0) = \frac{e}{2M_D}(Q + F_2^*(0)),$$



Diagrams up to NLO

Lagrangians and parameter values

In order to calculate the previously shown diagrams, one needs

$$\mathcal{L}^{(1)}_{\phi BD} = \frac{i\,\mathcal{C}}{M_D F_\phi}\,\varepsilon^{abc}\left(\partial_\alpha \bar{T}^{ade}_\mu\right)\gamma^{\alpha\mu\nu}B^e_c\,\partial_\nu\phi^d_b + \mathrm{h.c.},$$

C **is fixed to reproduce the Δ width**

$$\mathcal{L}^{(1)}_{\phi DD} = \frac{i\mathcal{H}}{M_D F_\phi}\bar{T}^{abc}_\mu\gamma^{\mu\nu\rho\sigma}\gamma_5\left(\partial_\rho T^{abd}_\nu\right)\partial_\sigma\phi^c_d,$$

H **is fixed by its large Nc relation with** g_A

$$\mathcal{L}^{(2)}_{\gamma DD} = -\frac{g_d}{8M_D}\bar{T}^{abc}_\mu\sigma^{\rho\sigma}g^{\mu\nu}\left(F^+_{\rho\sigma}, T_\nu\right)^{abc},$$

g_d **is fixed in such a way that the** Ω^- **MM is reproduced**

2.02±0.05μ_n

Numerical results

	Δ^{++}	Δ^{+}	Δ^{0}	Δ^{-}	Σ^{*+}	Σ^{*0}	Σ^{*-}	Ξ^{*0}	Ξ^{*-}	Ω^{-}
SU(3)-symm.	4.04	2.02	0	-2.02	2.02	0	-2.02	0	-2.02	-2.02
NQM [10]	5.56	2.73	-0.09	-2.92	3.09	0.27	-2.56	0.63	-2.2	-1.84
RQM [12]	4.76	2.38	0	-2.38	1.82	-0.27	-2.36	-0.60	-2.41	-2.35
χQM [14]	6.93	3.47	0	-3.47	4.12	0.53	-3.06	1.10	-2.61	-2.13
χQSM [16]	4.85	2.35	-0.14	-2.63	2.47	-0.02	-2.52	0.09	-2.40	-2.29
QCD-SR [21]	4.1(1.3)	2.07(65)	0	-2.07(65)	2.13(82)	-0.32(15)	-1.66(73)	-0.69(29)	-1.51(52)	-1.49(45)
lQCD [34]	6.09(88)	3.05(44)	0	-3.05(44)	3.16(40)	0.329(67)	-2.50(29)	0.58(10)	-2.08(24)	-1.73(22)
lQCD [36]	5.24(18)	0.97(8)	-0.035(2)	-2.98(19)	1.27(6)	0.33(5)	-1.88(4)	0.16(4)	-0.62(1)	—
large N_c [25]	5.9(4)	2.9(2)	—	-2.9(2)	3.3(2)	0.3(1)	-2.8(3)	0.65(20)	-2.30(15)	-1.94
HBχPT [28]	4.0(4)	2.1(2)	-0.17(4)	-2.25(19)	2.0(2)	-0.07(2)	-2.2(2)	0.10(4)	-2.0(2)	-1.94
This work	6.04(13)	2.84(2)	-0.36(9)	-3.56(20)	3.07(12)	0	-3.07(12)	0.36(9)	-2.56(6)	-2.02
Expt. [4]	5.6±1.9	$2.7^{+1.0}_{-1.3} \pm 1.5 \pm 3$	—	—	—	—	—	—	—	-2.02±0.05

Compared to 2nd order and HB results, our NLO EOMS results seem to be more **consistent** with **current experimental data**

- Uncertainties solely due to varying **μ** from 0.7 to 1.3 GeV
- Higher-order contributions, (**naively**), can be as large as **50%** of the NLO

Summary and Conclusions

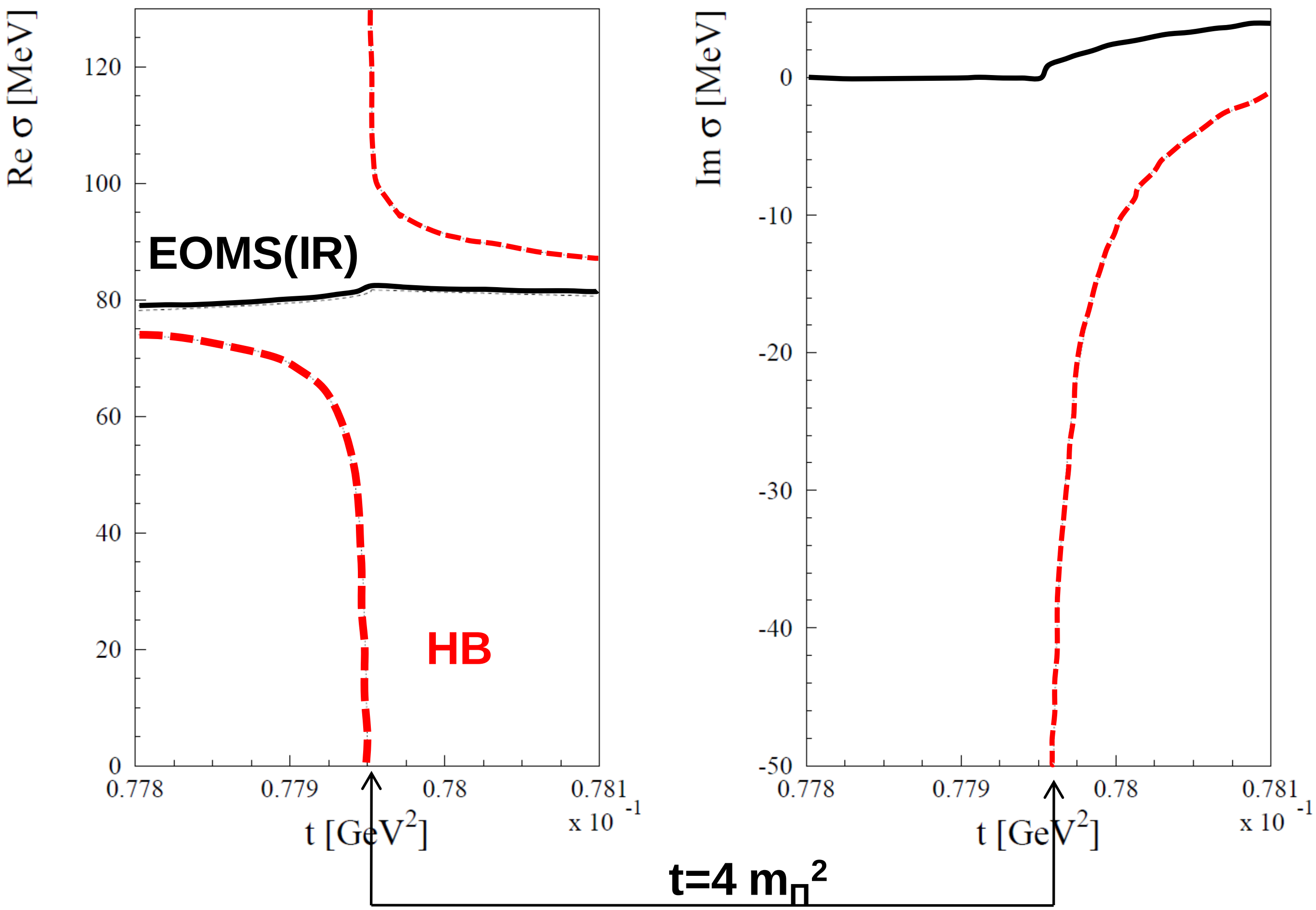
- Our studies show that by paying **due attention** to the **analyticity** and **relativity** of **the loop functions**, and to **the description of spin-3/2 particles**. ChPT can describe the magnetic moments of both **octet** and **decuplet** baryons **quite well** up to **NLO**.

- At NNLO, however, the number of the low-energy-constants is **large enough to fit all the data**. Therefore, to go into higher orders, we need more inputs (maybe from Lattice QCD).

- One advantage of ChPT is to describe different physical processes with a limited set of low-energy-constants. We are now applying the **EOMS baryon ChPT** to more observables.

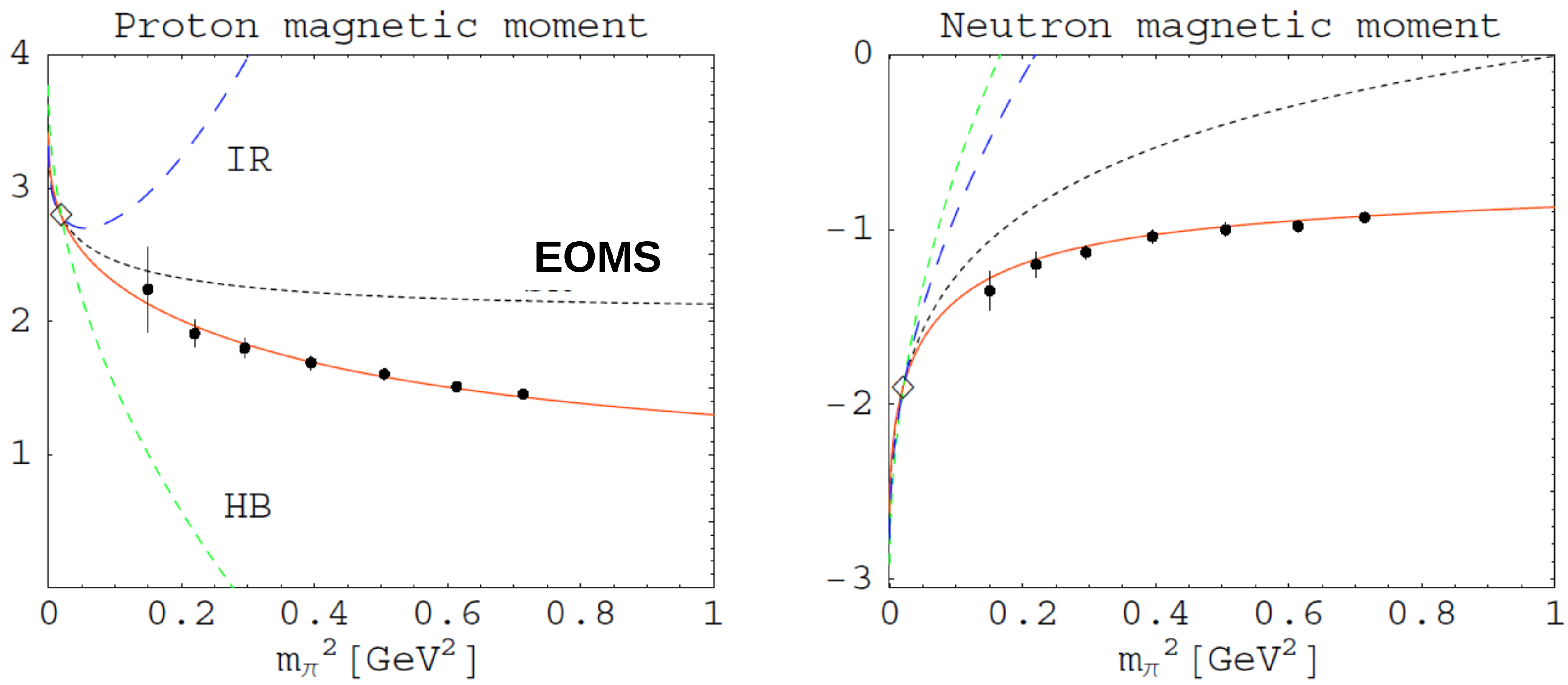
Your suggestions on what might be interesting are extremely welcome!

Real and Imaginary parts of the nucleon scalar form factor at q^3



S. Scherer, arXiv:0908.3425

Proton and neutron magnetic moments: chiral extrapolation



V. Pascalutsa et al., Phys.Lett.B600:239-247,2004.