Baryon-octet transverse densities in ChPT

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Hadron inner structure

- Electromagnetic interactions: clean probes of structure.

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- Compton scattering: polarizabilities.

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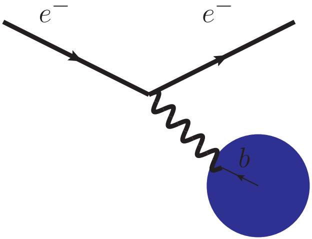
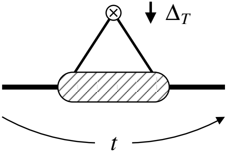
- Compton scattering: polarizabilities.

- Elastic electron scattering: charge/magnetic densities.



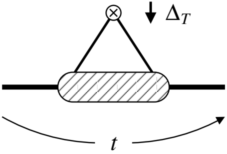
Transverse densities



Current $\longleftrightarrow$ invariant form factors

$$\langle N'|J_\mu|N\rangle \longrightarrow F_1(t), F_2(t)$$

Transverse densities



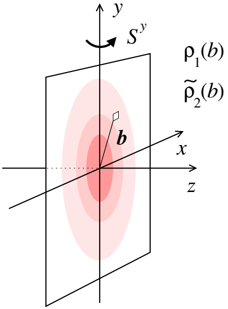
Current $\longleftrightarrow$ invariant form factors

$$\langle N'|J_\mu|N\rangle \longrightarrow F_1(t), F_2(t)$$

Spatial representation: $x^+ = x^0 + x^3 = 0$

Soper, PRD15 1141 (1977); Burkardt, PRD62 071503 (2000);

Miller, PRC76 065209 (2007)



$$F_{1,2}(t) = \int d^2b\, e^{i\boldsymbol{\Delta}_T \boldsymbol{b}}\, \rho_{1,2}(b), \quad t = -\boldsymbol{\Delta}_T^2$$

$$\langle J^+(\boldsymbol{b})\rangle_{y-\mathrm{pol}} = \rho_1(b) \text{ spin-indep.}$$

$$+(2S^y)\cos\phi\, \overbrace{\frac{d}{db}\left[\frac{\rho_2(b)}{2M_N}\right]}^{\widetilde{\rho}_2(b)} \text{ spin-dep.}$$

Why transverse densities?

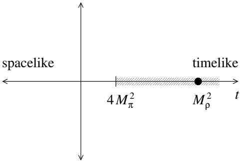
- $\Delta^+ = 0$: **current not affected by vacuum fluctuations!**
  $\Longrightarrow$ We can describe the densities by wave functions.

- Densities give information on general parton distributions.

- The process is high-energy scattering **BUT**
  the densities are generated by low-energy dynamics:
  at $b = O(M_\pi^{-1}) \Rightarrow$ chiral perturbation theory!

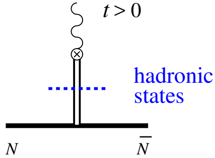
  Strikman and Weiss PRC82 042201 (2010); Granados and Weiss JHEP1401 092 (2014)

Dispersive representation



$$F_{1,2}(t) = \int_{4\mathrm{m}_\pi^2}^{\infty} \frac{dt'}{t' - t - i0} \frac{\mathrm{Im}\, F_{1,2}(t')}{\pi}$$

$\mathrm{Im}\, F_1(t) =$



Unphysical region from theory

Hohler et al., NPB114 505 (1976);

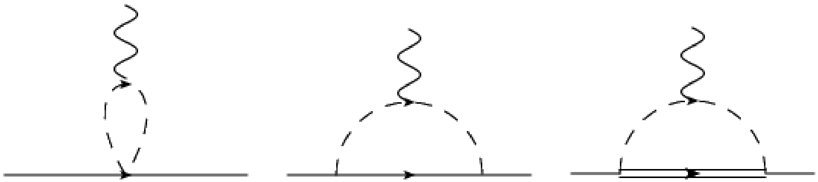
Belushkin et al., PRC75 035202 (2007)

$$\rho_{1,2}(b) = \int_{4m_\pi^2}^{\infty} \frac{dt}{2\pi} K_0(\sqrt{t}b) \frac{\mathrm{Im}\, F_{1,2}(t)}{\pi}$$

Form factors

$K_0 \sim e^{-b\sqrt{t}}$ suppression at large t
$\Longrightarrow$ Distance b is a filter of masses $\sqrt{t} \sim 1/b$

Two-pion cut: peripheral densities from low-mass states!



Chiral perturbation theory

- $E_\gamma \approx \mathcal{O}(m_\pi) \Rightarrow \alpha_s = \mathcal{O}(1)$.
- Perturbative QCD breaks down $\Rightarrow$ EFT: expansion around **other small parameters**.

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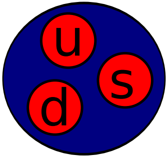
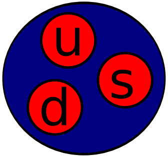
- Perturbative QCD breaks down $\Rightarrow$ EFT: expansion around **other small parameters**.
- Chiral perturbation theory:
  - Small masses, momenta ($m_\pi / m_p \ll 1$): combined expansion!
  - New degrees of freedom: ~~quarks and gluons~~ $\Longrightarrow$ mesons and baryons.

Hyperons



- Hyperons: baryons with **strangeness** $\mathcal{S} \neq 0$.
- Short lifetimes $\Longrightarrow$ densities computed on the lattice.
- Gives space to theoretical predictions!

Hyperons



$$SU(2) \longrightarrow SU(3)$$

$$\begin{pmatrix} p \\ n \end{pmatrix} \longrightarrow \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}$$

$$\pi^\pm, \pi^0 \longrightarrow \pi^\pm, \pi^0, K^\pm, K^0, \eta$$

$$\Delta(1232) \longrightarrow \Delta^\pm, \Delta^{++}, \Delta^0, \Sigma^{*\pm}, \Sigma^{*0}, \Xi^{*-}, \Xi^{*0}, \Omega$$

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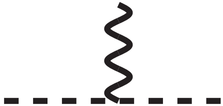
The Lagrangian

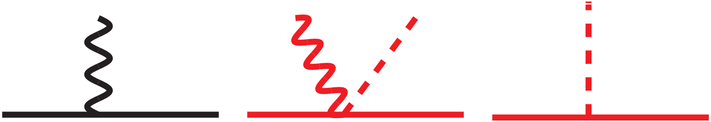
$$\mathcal{L}^{(2)}_{\phi\phi} = \frac{F_0^2}{4}\mathrm{Tr}\left(\nabla_\mu U \nabla^\mu U^\dagger + \chi_+\right)$$



The Lagrangian

$$\mathcal{L}_{\phi\phi}^{(2)} = \frac{F_0^2}{4}\text{Tr}\left(\nabla_\mu U \nabla^\mu U^\dagger + \chi_+\right)$$

$$\mathcal{L}_{\phi B}^{(1)} = \text{Tr}\left(\bar{B}(i\not{D} - m)B\right) + \frac{D}{2}\text{Tr}\left(\bar{B}\gamma^\mu \left\{u_\mu, B\right\}\gamma_5\right) + \frac{F}{2}\text{Tr}\left(\bar{B}\gamma^\mu \left[u_\mu, B\right]\gamma_5\right)$$



Inclusion of the decuplet

Why do we include the **spin-$3/2$ states**?
Experiment: Strong coupling to octet baryons
Theory: Correct large N_c behaviour recovered

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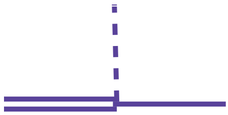
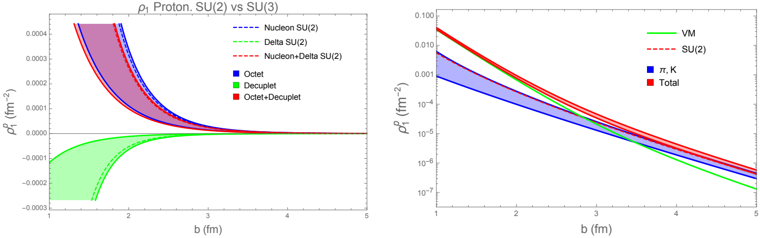
Theory: Correct large N_c behaviour recovered

$$\mathcal{L}^{(1)}_{\Delta\phi B} = \frac{-\mathrm{i}\sqrt{2}\mathcal{C}}{F_0 M_\Delta} \bar{B}^{ab} \varepsilon^{cda} \gamma^{\mu\nu\lambda} (\partial_\mu \Delta_\nu)^{dbe} (\mathrm{D}_\lambda \phi)^{ce} + \text{H.c.}$$



Nucleons revisited

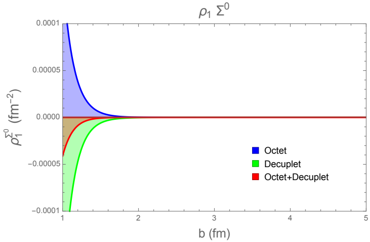


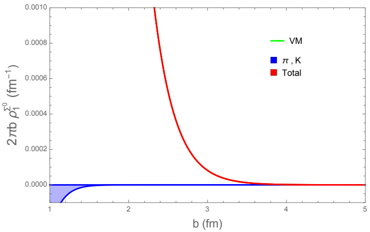
- First: reproduce the $SU(2)$ results in

  Granados and Weiss, JHEP01, 092 (2014); Ledwig et al., PRD85, 034013 (2012)

- Then: extend to $SU(3)$
- Vector-meson contribution (ρ, ω, ϕ) relevant in central regions only

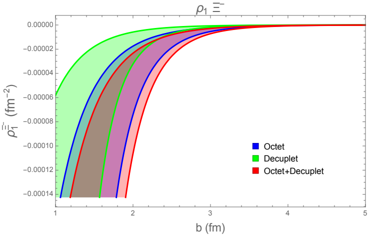
Compact Λ and Σ^0

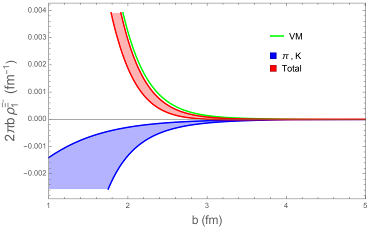




- Isospin limit: pion loops cancel out exactly
- Octet and decuplet contributions almost cancel out
- Central vector-meson contributions: very compact objects!

Relevance of the decuplet for Ξ^- and Ξ^0





- Octet and decuplet give almost the same contribution!
- The decuplet is relevant even in peripheral regions.

Summary and outlook

- Prediction for octet-baryon densities.
- Periphery: $SU(3)$ ChPT with decuplet.
- More central regions: vector-meson contributions.

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- Transition form factors.

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Muito obrigada!