Baryon structure in chiral effective field theory on the light front

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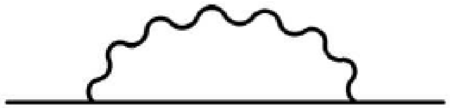
Outline

- Introduction
- Formalism: covariant light-front dynamics
- Formalism: renormalization scheme
- Vertex function: equation
- Vertex function: solution
- Perspectives

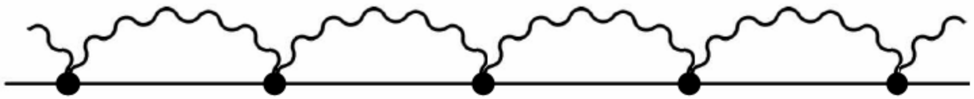
Introduction

Need of a non-perturbative framework to calculate bound state properties

easy with πNN coupling



to be generalized for $\pi\pi NN$ case

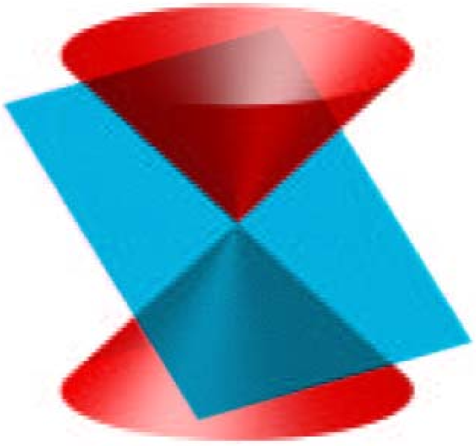


Formalism: light-front dynamics

- Standard LFD: $t + z = 0$

  (blue plane)

  Not invariant under spatial rotations!



- Covariant LFD: $\omega \cdot x = 0$

  $\omega^2 = 0$

  (any plane tangential to the red cone)

$\omega = (1, 0, 0, -1)$ corresponds to standard LFD

Check of rotational invariance: any observable should be independent of ω

Formalism: Fock representation

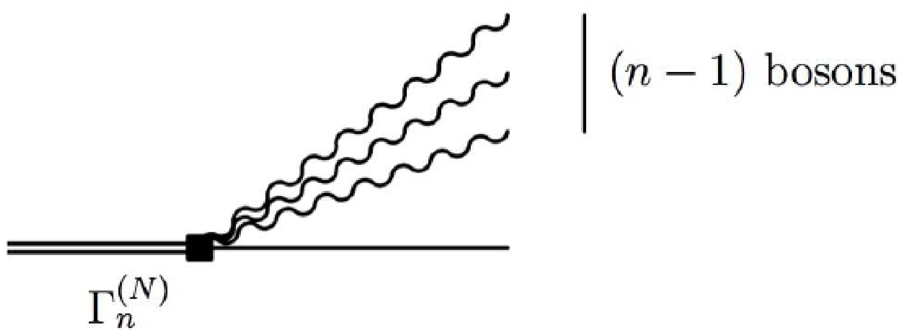
The state vector

$$\varphi(p) = |1\rangle + |2\rangle + \ldots + |N\rangle + \ldots$$

N – the maximal number of Fock sectors under consideration

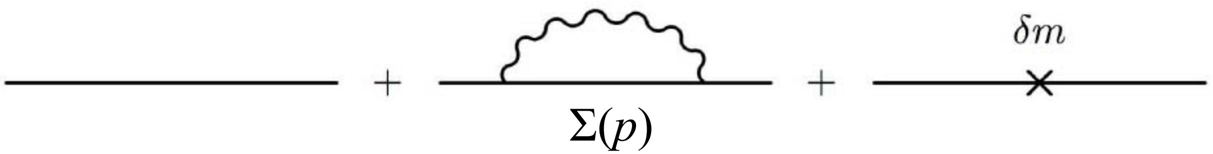
n – number of constituents in a given Fock sector, $n \leq N$

The many-body vertex fuction

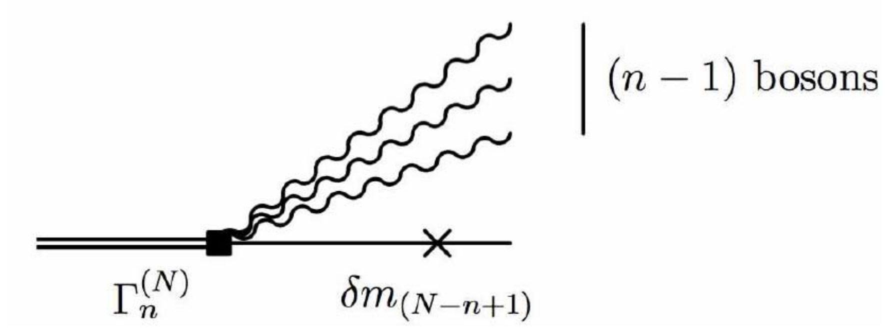


Formalism: renormalization

Contribution to the physical fermion propagator



The general case: dependence on the Fock sector

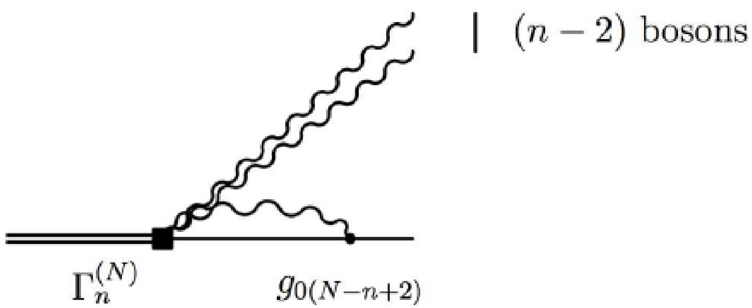


(maximal number of particles in which
the fermion line can fluctuate)

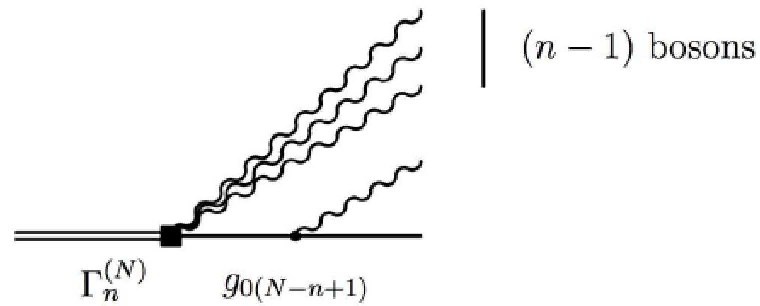
Formalism: renormalization

Bare coupling constant: the same strategy

- Interaction with internal bosons

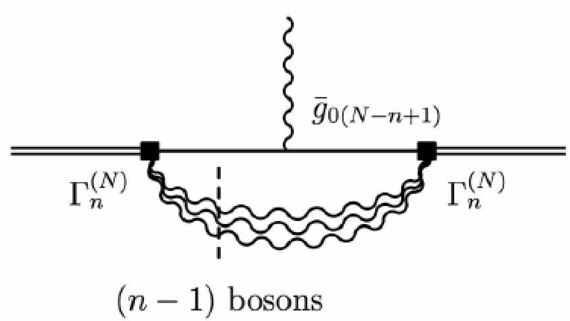


the number of particles in which the fermion line can fluctuate after absorbtion



… before emission

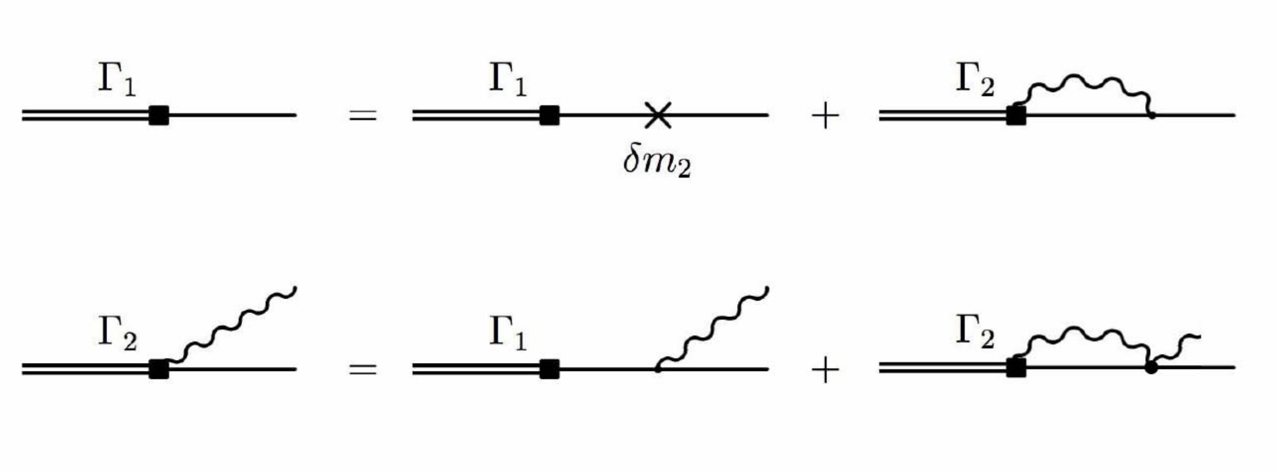
- Interaction with external bosons



Lagrangian and the vertex functions

$$L_{int} = -\frac{1}{2}\frac{g_A}{F_0}\bar{\Psi}\,\gamma^{\mu}\,\gamma_5\,\tau^b\,\partial_{\mu}\phi^b\,\Psi - \frac{1}{4F_0^2}\bar{\Psi}\,\gamma^{\mu}\,\vec{\tau}\,\cdot\,\vec{\phi}\,\times\,\partial_{\mu}\vec{\phi}\,\Psi + \ldots$$

Equations for the πN vertex functions in the case of the two-body Fock space truncation:



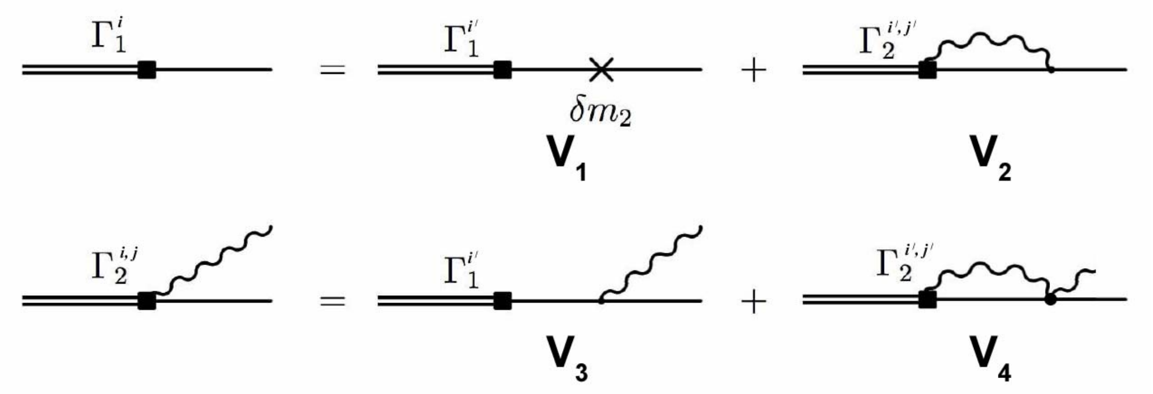
Pauli-Villars regularization

Extending Fock space and introducing indices:

$i = 0$ (physical) and 1 (Pauli-Villars) fermions

$j = 0$ (physical) and $1, 2$ (Pauli-Villars) bosons

System of equations:



$$\begin{aligned} \bar{u}(p_{1i})\Gamma_1^i u(p) &= \bar{u}(p_{1i})\left(V_1 + V_2\right)u(p), \\ \bar{u}(k_{1i})\Gamma_2^{ij} u(p) &= \bar{u}(k_{1i})(V_3 + V_4)u(p). \end{aligned}$$

Vertex functions representation

$$\bar{u}(k_{1i})\Gamma_1^i u(p) = (m_i - m^2) a_1^i \bar{u}(k_{1i}) u(p) \ ,$$

$$\bar{u}(k_{1i})\Gamma_2^{ij} u(p) = i\bar{u}(k_{1i}) \left((\not{k}_{2j} - \not{\omega}\tau)\, b_1^{ij}(R_\perp, x) + \frac{m\ \not{\omega}}{\omega \cdot p}\, b_2^{ij}(R_\perp, x) \right) \gamma_5 u(p) \ .$$

$$\tau = \frac{s - m^2}{2\,\omega \cdot p}$$

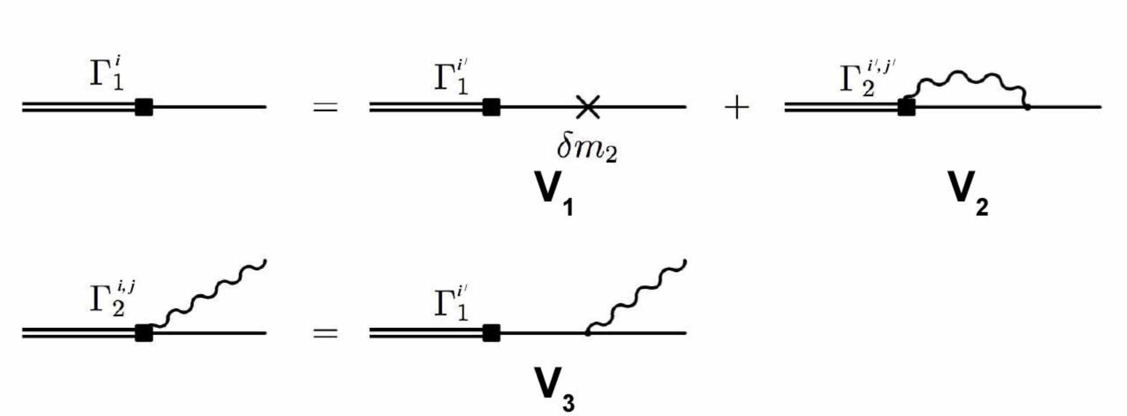
In our case a_1^i, b_1^{ij}, b_2^{ij} are constants depending on i only

Necessary condition: the physical on-mass shell vertex function should not depend on ω

$$b_2^{\,i=0,\,j=0}\,(s = m^2) = 0$$

Solution without contact term

Equations:



Solution:

$$b_1^{ij} = \frac{g_A}{F_0} m a_1^0 - \frac{g_A}{2F_0}\frac{(m_1+m)(m_1+m_i)}{(m+m_i)} a_1^1\,,$$

$$b_2^{ij} = \frac{g_A}{2F_0}\frac{(m_1^2-m^2)(m-m_i)}{2m} a_1^1\,.$$

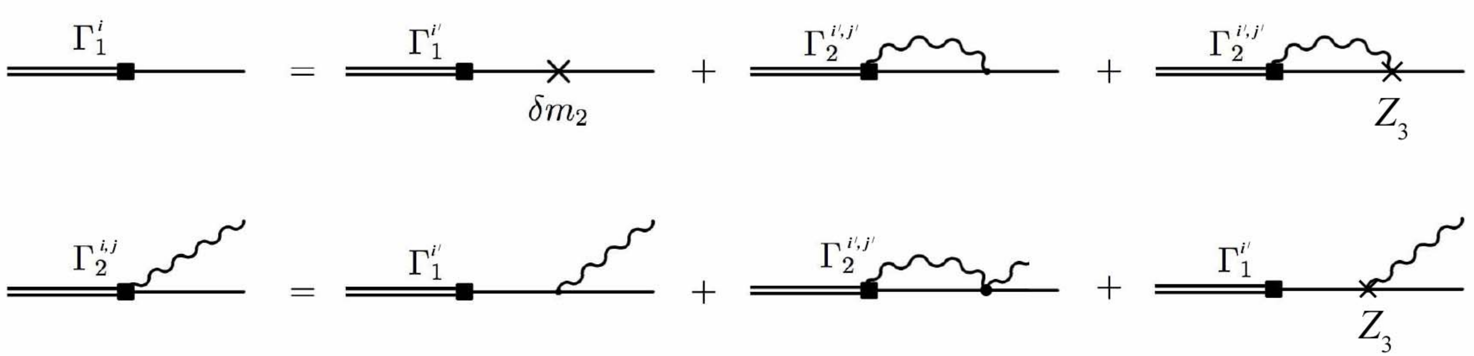
The condition $b_2^{\,i=0,\,j=0}(s=m^2)=0$ is satisfied automatically

Solution with contact term

$$b_2{}^{i=0,\, j=0}\,(s = m^2) = const \neq 0$$

We need a new ω-dependent counterterm to kill it

$$L_{int} = -\frac{1}{2}\frac{g_A}{F_0}\bar{\Psi}\,\gamma^\mu\,\gamma_5\,\tau^b\,\partial_\mu\phi^b\,\Psi - \frac{1}{4F_0^2}\bar{\Psi}\,\gamma^\mu\,\vec{\tau}\cdot\vec{\phi}\times\partial_\mu\vec{\phi}\,\Psi + i\,Z_3\,\bar{\Psi}\,\not{\omega}\,\gamma_5\,\tau^b\,\phi^b\,\Psi + \ldots$$



With this counterterm $b_2{}^{i=0,\, j=0}\,(s = m^2) = 0$

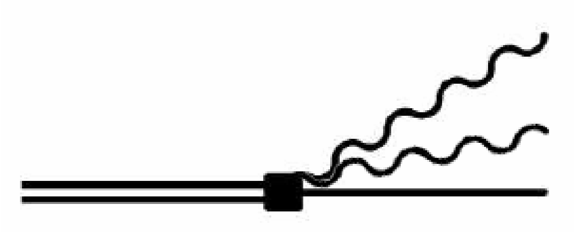
Perspectives

- Test the presented strategy for 1 nucleon and 1 pion

Calculate: $m_N(m_\pi)$ dependence

scalar and electromagnetic form factors

- Calculations for 1 nucleon and 2 pions



} Δ and Roper resonance contributions

Calculations are already done for the Yukawa model (scalar meson)