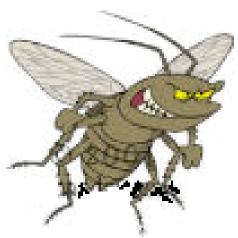
Covariant effective field theory (EFT!)

(or, can the dinosaur learn anything from the cockroach?)

Franz Gross

Outline

Part I: The Covariant Spectator© approach for two and three nucleon interactions at JLab momentum transfers (*aside*)



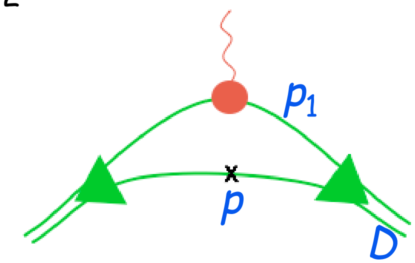
Part II: Ideas for improvements -- toward a Covariant Effective field theory (EFT!) for GeV reactions

Acknowledgements

- CS© collaborators (partial list):
  - J. W. Van Orden and Karl Holinde (NN - 1990)
  - D. O. Riska (2N currents -- 1987)
  - Alfred Stadler (3N -- 1997)
  - John Tjon and Cetin Savkli (Feynman-Schwinger studies -- 1999)
  - Alfred Stadler and Teresa Pena (3N currents -- 2004)
- CS© ***teachers***: Dick Arndt, Ruprecht Machleidt, Nijmegen group
- JLab EFT discussion group (E. Epelbaum, R. Higa, Jose Goity) and Vladimir Pascalutsa
- All the participants at this series of Workshops -- many thanks for very enjoyable and stimulating discussions.
- Its fun to argue, BUT let's not degenerate into a "Fox News syndrome" let's argue about real issues and not fabricated ones

Aside

- Typical JLab process: deuteron form factor at $Q^2 \geq 1$ GeV^2



- In relativistic physics momenta and energies are NOT correlated! We go off the mass-shell, but remain on the energy-shell. In this case (in the Breit system)

$$p^2 = m^2$$

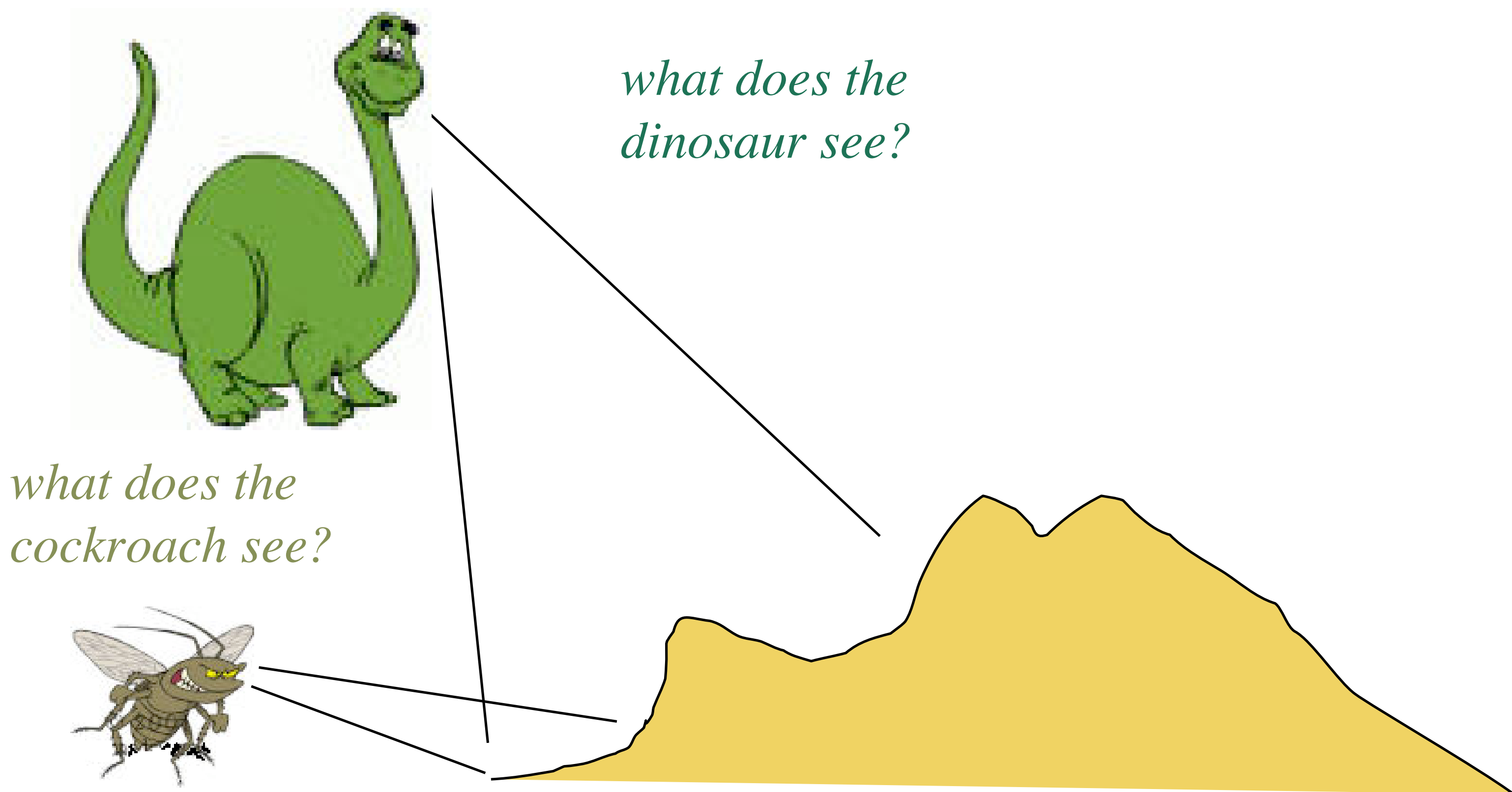
$$p_1^2 = (D-p)^2 = M_d^2 + m^2 - 2\sqrt{M_d^2 + \tfrac{1}{4}Q^2}\sqrt{m^2 + \mathbf{p}^2} + \mathbf{Q}\cdot\mathbf{p} \leq (M_d - m)^2$$

$$D^2 = M_d^2$$

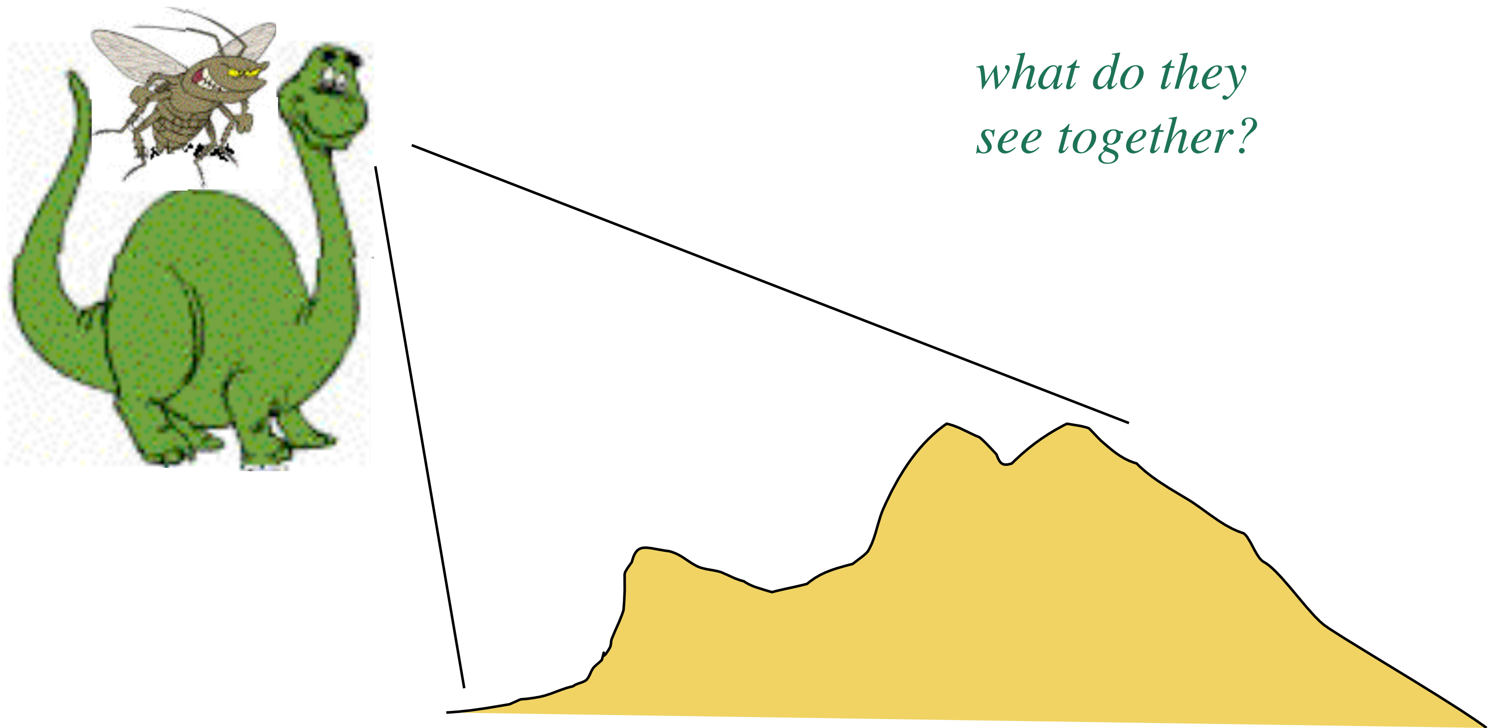
  If p is large, we are far off-shell and probe the short range structure (the important relative momenta are of order **Q**/4), but still the rest energy of the deuteron is FIXED at its mass; the only energy change is due to the Lorentz boost

- In nonrelativistic physics we go off the energy shell but remain on the mass shell. In this case $E + E_1 = \sqrt{m^2 + \mathbf{p}^2} + \sqrt{m^2 + \left(\tfrac{1}{2}\mathbf{Q} - \mathbf{p}\right)^2} \geq 2m$ and energy and momentum are correlated

The true landscape #1



The true landscape #2



what do they see together?

Part I

Covariant Spectator© theory - philosophy

Few body nuclear physics at JLab (GeV) energies (conventional EFT NOT an option - *aside*).

What do we do?

- Preserve all symmetries
  - *Poincare invariance essential -- manifest covariance useful*
  - unitarity (conservation of flux)
  - electromagnetic gauge invariance
  - chiral invariance
- Microscopic dynamics
  - OBE dynamics with point couplings, but form factors for the self energies of each hadron
  - Organizational principle -- include exchanges of all mesons and quantum numbers up to about 1 GeV. Cutoff at the nucleon mass scale.
  - Mesons needed: π, 2π (σ_0, σ_1), η, ρ, ω plus short distance counter terms.
- Maintain consistency
  - electromagnetic currents constrained by WT identities (but still not unique)
  - three-body forces constrained by two-body forces

Covariant Spectator© theory -- Definition

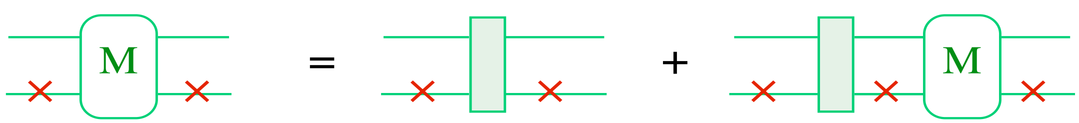
- The spectator theory starts from the *n*-body Bethe-Salpeter equation and restricts *n*-1 particles to their positive energy mass shells. The propagator for these particles is replaced by

$$S_{\alpha\beta}(p) = \frac{(m+\not{p})_{\alpha\beta}}{m^2 - p^2 - i\varepsilon} \Rightarrow 2\pi i \delta_+(m^2 - p^2) \sum_s u_\alpha(\mathbf{p},s)\bar{u}_\beta(\mathbf{p},s)$$

- Integration over the *n*-1 internal energies (p_0) places these particles on their *positive energy* mass-shell. All 4-d integrations reduce to 3-d integrations.

- Remark: These on-shell particles do not *propagate* in intermediate states. The spinors are absorbed into matrix elements, and the on-shell particles becomes part of the "source" for the single propagating off-shell particle.

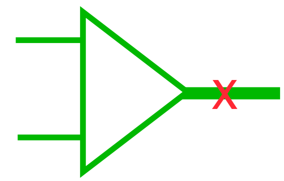
- The two body scattering equation is, diagrammatically,



Both the BS and the CS© theories have a close connection to field theory

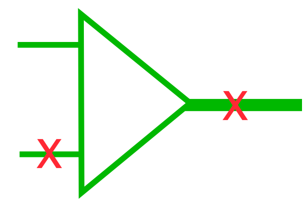
★ The Bethe-Salpeter amplitude is a well defined field theoretic matrix element:

$$\Psi(x_1, x_2) = \left\langle 0 \,|\, T\big(\psi(x_1)\psi(x_1)\big) \,|\, d \right\rangle$$



★ The Covariant Spectator© amplitude is *also* a well defined field theoretic amplitude:

$$\Psi(x_1) = \left\langle N \,|\, \psi(x_1) \,|\, d \right\rangle$$



★ Equations for the Bethe-Salpeter and the Spectator* amplitudes can be derived from field theory

- Both are manifestly covariant under *all* Poincaré transformations (advantage)
- Both incorporate negative energy (antiparticle) states (disadvantage?)

*O. W. Greenberg's "n-quantum approximation"

Properties of the two-body Spectator© amplitude

★ from translational invariance:

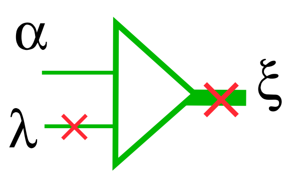
$$\int d^4x e^{-ip\cdot x}\langle n|\psi(x)|d\rangle = (2\pi)^4\delta^4(p+n-d)\langle n|\psi(0)|d\rangle$$

exact
conservation of momentum
and energy at the vertex

★ from rotational invariance

$$\langle n,\lambda|\psi_\alpha(0)|d,\xi\rangle = \frac{1}{\sqrt{2M_d(2\pi)^3}}\left[S(p)\Gamma^\mu(p)\,C\,\right]_{\alpha\beta}\bar{u}^{\mathrm{T}}_\beta(-\mathbf{p},\lambda)\xi_\mu$$

$$= \left\{\psi^{+\mu}_{\lambda'\lambda}(\mathbf{p})\;u_\alpha(\mathbf{p},\lambda') + \psi^{-\mu}_{\lambda'\lambda}(\mathbf{p})\;v_\alpha(-\mathbf{p},\lambda')\right\}\xi_\mu$$



positive energy spinor

negative energy spinor

exact
the most general form possible for the coupling of a spin 1 particle to two spin 1/2 particles, one off-shell

★ from transformations under boosts

$$B(\Lambda)\langle n,\lambda|\psi_\alpha(0)|d,\xi\rangle = B_{\alpha\alpha'}\langle\Lambda n,\lambda'|\psi_{\alpha'}(0)|\Lambda d,\Lambda\xi\rangle\,D^{(1/2)}_{\lambda'\lambda}(\omega)$$

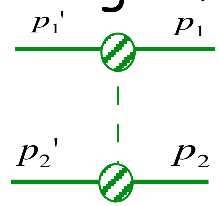
boost matrix for off-shell particle in Dirac space

Wigner rotation of the spin of the on-shell particle

exact
obtained from Wigner rotations and Dirac boost matrix

Dynamics: phenomenological OBE

★ One boson exchange diagram:



$$\Rightarrow \quad \frac{\Lambda(p_1',p_1)\,\Lambda(p_2',p_2)}{m_m^2-(p_1'-p_1)^2}$$

★ Scalar: σ_0NN (and σ_1NN) coupling

$$\Lambda(p',p)=g+\boxed{\frac{\nu}{2m}\left[2m-\not p'-\not p\right]}$$

zero on-shell

★ Pseudoscalar: πNN (and ηNN) coupling

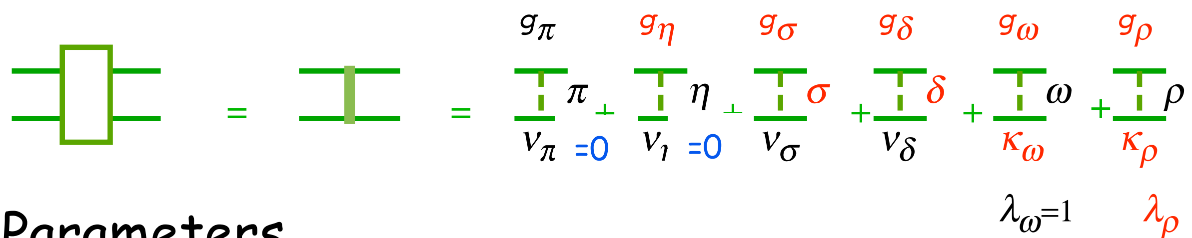
$$\Lambda(p',p)=g\left\{\gamma^5-\boxed{\frac{1-\nu}{2m}\left[\left(m-\not p'\right)\gamma^5+\gamma^5\left(m-\not p\right)\right]}\right\}$$

★ Vector: ρNN (and ωNN) coupling

$$\Lambda(p',p)=g\left\{\gamma^\mu+\frac{\kappa}{2m}i\sigma^{\mu\nu}(p'-p)_\nu+\boxed{\frac{\nu}{2m}\left[\left(m-\not p'\right)\gamma^\mu+\gamma^\mu\left(m-\not p\right)\right]}\right\}$$

Family of OBE models for *NN* scattering based on 1993 calculations

★ Kernel of the integral equation was represented by OBE



$$\lambda_\rho = 1 - \frac{\nu_\rho}{\kappa_\rho}$$

★ 13 Parameters

		spin parity	I-spin	mass	$g^2/4\pi$	κ	# of Para
	π	0^-	1	134.98	13.34	--	0
	η	0^-	0	548.8	3.0 ± 0.25	--	1
σ_0	σ	0^+	0	≈ 500	5.0 ± 0.5	--	2
σ_1	δ	0^+	1	≈ 500	0.6 ± 0.4*	--	2
	ω	1^-	0	782.8	15.0 ± 1.0	≈ 0.2	2
	ρ	1^-	1	760.0	0.8 ± 0.2	7.0 ± 0.5	3

cutoffs

$\Lambda_\pi \approx 2000$

$\Lambda_m \approx 1300$

$\Lambda_N \approx 1800$

ρ mixing

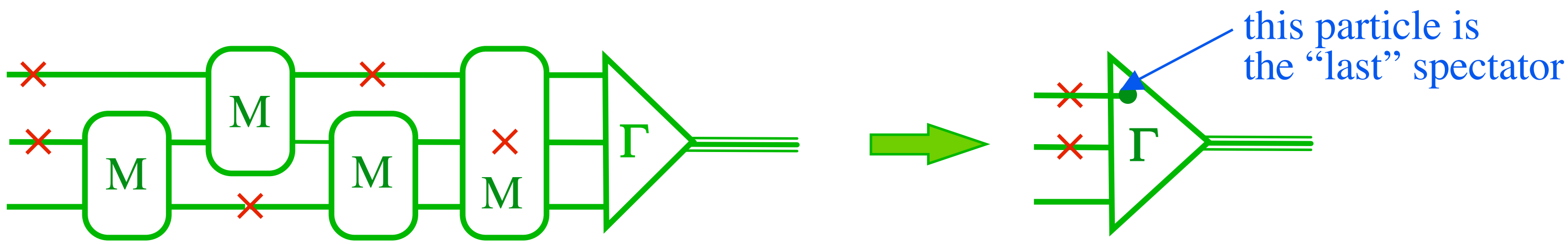
$\lambda_\rho = 1.55 \pm 0.4$

We fixed the ratio of the ν's
$$\begin{cases} \nu_\sigma = -0.75\, \nu_{g^2/4\pi} \\ \nu_\delta = 2.60\, \nu_{g^2/4\pi} \end{cases}$$

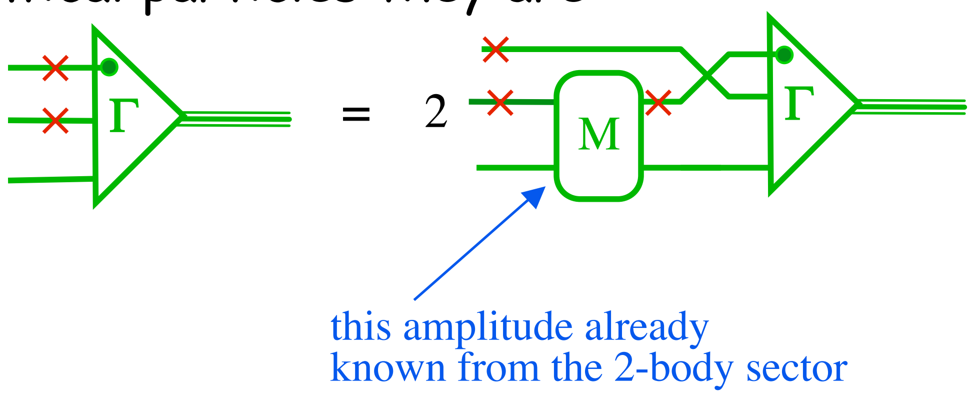
χ^2/datum ~ 2.2

Spectator equations for three-body systems*

★ Define three-body vertex functions for each possibility



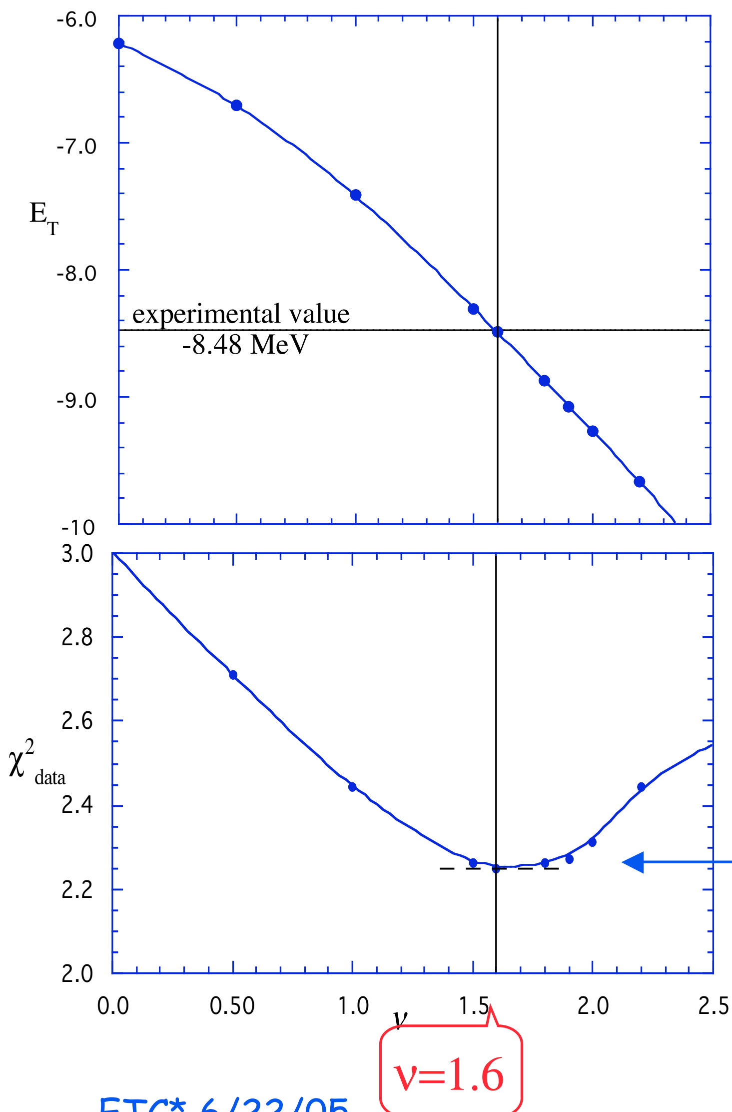
★ then three body Faddeev-like equations emerge automatically.
For identical particles they are:



*Alfred Stadler, FG, and Michael Frank, Phys. Rev. C **56**, 2396 (1997)

3N binding energy is very sensitive to ν

(off shell coupling of the scalar mesons)*



ν=1.6 $(\nu_\sigma = -1.2,\ \nu_\delta = 4.16)$ is strongly favored, both by the 3N binding energy and the 2N data!

experimental binding energy at ν=1.6!

best fit to the 2N data (minimum χ^2) at ν=1.6!

*three body calculations done with Alfred Stadler, Phys. Rev. Letters **78**, 26 (1997)

Recent results (in progress): *OBE model for NN scattering*

★ Kernel of the integral equation is still represented by OBE

★ Recent fit (*still under development*) with 21 Parameters

	spin parity	I-spin	mass	$g^2/4\pi$	κ	ν	# of Para
γ	1^-	--	0.001				0
$\pi^\pm$	0^-	1	139.57	13.93	--	-0.098	2
π^0	0^-	1	134.98	13.93	--	-0.098	--
η	0^-	0	548.8	4.899	--	1.540	2
σ_0	0^+	0	447	2.597	--	-7.872	3
σ_1	0^+	1	534	1.165	--	3.400	3
ω	1^-	0	717	9.409	0.222	0.313	4
ρ	1^-	1	912	2.270	5.383	-2.107	4

Thanks to J. de Swart for helpful advice. ($\pi^\pm$, π^0)

Cutoffs (3)

Λ_π=1786

Λ_m = 1192

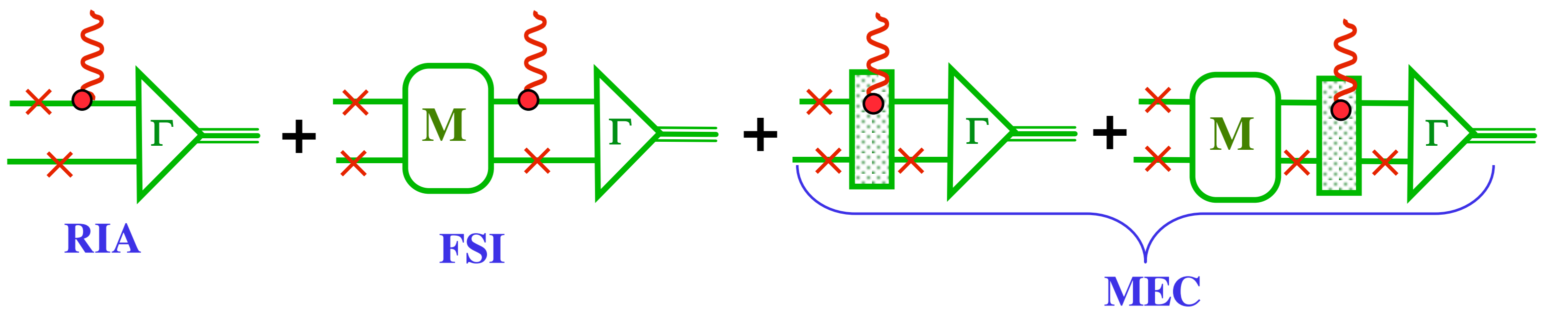
Λ_N = 1861

★ χ^2 /datum = 1.26 (for the 2001 data set) !

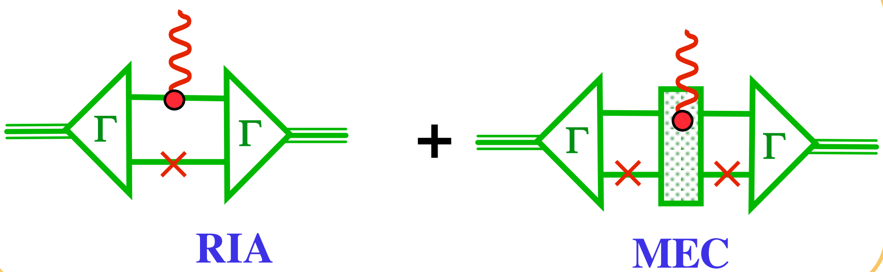
Thanks to Mart Rentmeester and Rob Timmermans for helpful discussions about data

Two body current operator in the spectator theory©

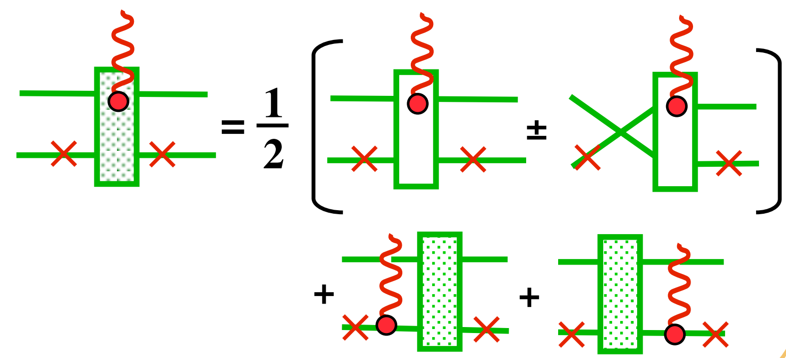
★ Inelastic Scattering



★ Elastic Scattering

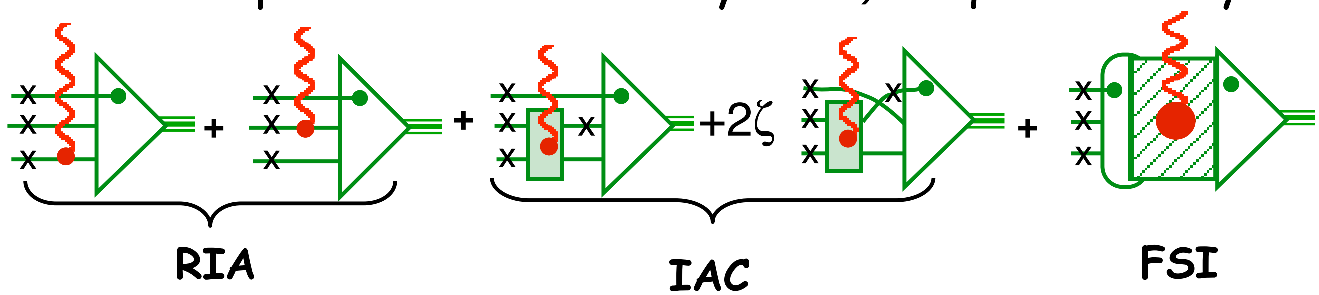


★ Interaction current

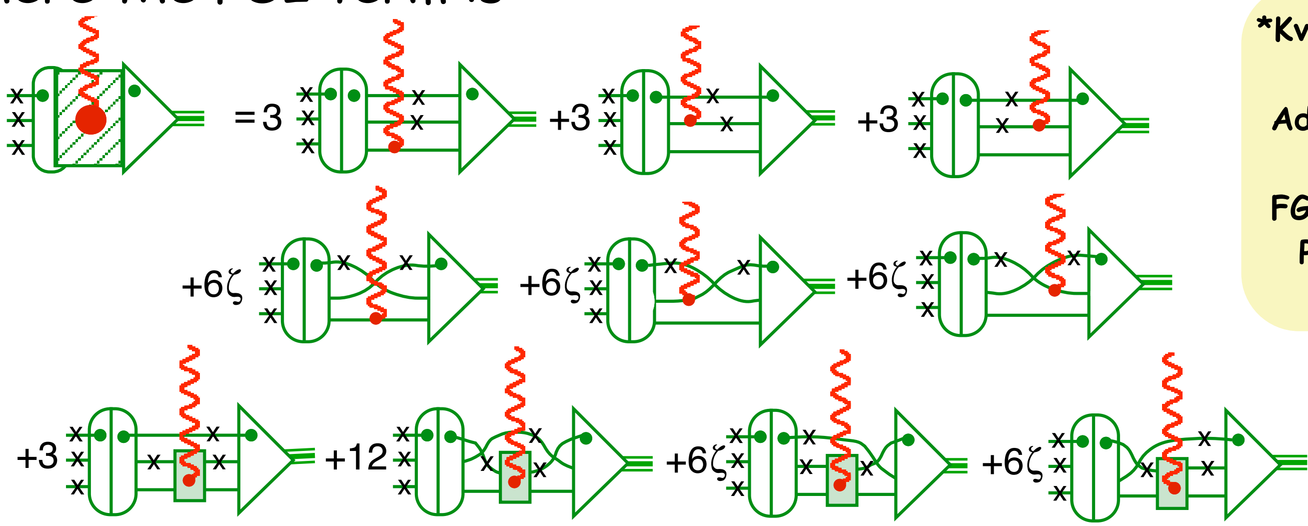


Three body current operator in the spectator theory©*

★ The gauge invariant three-body breakup current in the spectator theory (with on-shell particles labeled by an x) requires many diagrams



where the FSI term is



*Kvinikhidze & Blankleider,
PRC 56, 2973 (1997)
Adam & Van Orden
PRC 71: 034003 (2005)
FG, A. Stadler, & T. Pena
PRC 69: 034007 (2004)

Conclusions to part I

★ We have a covariant theory (CS© theory) suitable for the calculation of 2 and 3 body electromagnetic observables when the excitations are small but the momentum transfers are large.

★ It has been (and is being) applied to NN (and 3N?) scattering, deuteron form factors, electrodisintegration of the deuteron, ^{3}He form factors, and 2 and 3 body electrodisintegration of ^{3}He.

★ The goals are to

- explain these interactions in terms of a consistent dynamics based on the CS© theory using a covariant OBE model.
- determine the parameters of the OBE model and the OBE interaction currents that emerge.
- compare these effective interactions with QCD predictions!

Part II

Can the ideas of EFT improve the *CS©* theory?

- ★ At present, regularization and short range physics are both contained in the form factors
- ★ The most important of these is the nucleon form factor

$$S(p)=\frac{f(p)}{m-\not{p}};\quad f(p)=\frac{2(\Lambda^2-m^2)^2}{(\Lambda^2-p^2)^2+(\Lambda^2-m^2)^2}$$

The fits are very sensitive to Λ

- ★ Use the ideas of EFT to separate these two roles:
  - Regularize using the PDS of Kaplan, Savage, and Wise
  - Parameterize short range physics using constants
- ★ Assume that the physics is "known" up to exchange masses of about 1 GeV. Short range physics is above 1 GeV

Overview -- Report on work in progress

★ Assumptions:

- Ignore the "known" physics corresponding to exchanges of bosons with masses less than 1 GeV (add this later).
- Parameterize the short range physics with contact interactions of the $|\bar{\psi}\psi|^2$ type.
- Chose the mass scale M for the $|\bar{\psi}\psi|^2$ interaction to be $\geq m$ (the nucleon mass)
- Regularize using power divergence subtraction (PDS)

★ Example: the $^1S_0$ partial wave

Lagrangian for a $^1S_0$ state

★ Introduce the $NN \Rightarrow {}^1S_0$ vertex function

$$\Gamma^{0+}(x) = (C\gamma^5)_{ab}\psi_a(x)\psi_b(x) = \psi^{\mathrm{T}}(x)C\gamma^5\psi(x)$$

★ Then, the Lagrangian density for a $^1S_0$ state is

$$L(x) = \overline{\psi}(x)\left(i\overset{\leftrightarrow}{\partial\!\!\!/} - m\right)\psi(x) - \lambda\left[\Gamma^{0+}(x)\right]^{\dagger}\Gamma^{0+}(x)$$

★ In d dimensions, λ has dimensions of ℓ^{2-d}, so the coupling is

$$\lambda = \frac{\lambda_0}{M^{2-d}}$$

where λ_0 is dimensionless.

Power counting (naive)

- Scales: there are only three scales in the problem: *p, m,* and *M.*

  First, assume $p \sim m \ll M$, so that $\delta \approx \frac{p}{M} \sim \frac{m}{M} \ll 1$

- Naive dimensional counting gives a superficial divergence *D* for any *NN scattering* Feynman diagram equal to

$$D = (d-2)\,(n-1)$$

  where n is the number of vertices (or the order) of the diagram. Hence we expect the size of any diagram $V^{(n)}$ to go like

$$V^{(n)} \approx \frac{\lambda_0}{M^{d-2}}\left(\lambda_0 \delta^{d-2}\right)^{n-1}$$

- *Conclusion:* if $\lambda_0 \sim 1$, *and* $d > 2$, perturbation theory applies.

Power counting (nonrelativistic domain)

★ Assume, $p \ll m$. Introduce a new scale $\alpha = \dfrac{p}{m} \sim \delta^2 \ll \delta$

★ Then the n^{th} order diagram has the form:

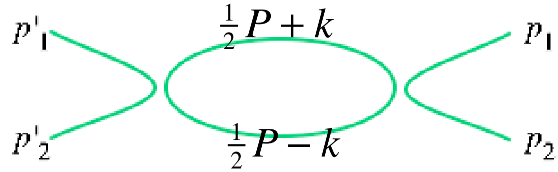
$$V^{(n)} \approx \frac{\lambda_0}{M^{d-2}}\left(\lambda_0\left(\frac{m}{M}\right)^{d-2}\left[1 + c_1\alpha + \sum_1^\infty c_n\alpha^n\right]\right)^{n-1}$$

large "constant" term (1) ~ 1 ($c_1\alpha$) small remainder term ($\sum_1^\infty c_n\alpha^n$)

★ Assume that the term of order α is of order 1. Then only the terms of order α^2 or smaller can be ignored. All other terms must be summed to all orders. Hence:

- All diagrams contribute to the constant term. This depends on the scale, and will be fixed phenomenologically.
- The task is to calculate the terms of order α, which are independent of the scale.

Example: the *s*-channel bubble



The *s*-channel bubble *B(s)* is $V^{(2)}(s) = \lambda^2 B(s)(C\gamma^5)_{a'b'}(C\gamma^5)_{ba}$

where ε_d=2-d/2, $\mathbf{p}^2=m^2-s/4$, and

$$\lambda B(s) = -i\frac{\lambda_0}{2M^{d-2}}\int\frac{d^dk}{(2\pi)^d}\frac{\mathrm{tr}\left[C\gamma^5\left(m+\frac{1}{2}\not{P}+\not{k}\right)C\gamma^5\left(m+\frac{1}{2}\not{P}-\not{k}\right)^T\right]}{\left[m^2-\left(\frac{1}{2}P+k\right)^2-i\varepsilon\right]\left[m^2-\left(\frac{1}{2}P-k\right)^2-i\varepsilon\right]}$$

$$= \frac{\lambda_0\Gamma(\varepsilon_d)M^{2\varepsilon_d-2}}{(4\pi)^{2-\varepsilon_d}}\int_{-\frac{1}{2}}^{\frac{1}{2}}dz\left\{\frac{4m^2}{\left(\mathbf{p}^2+sz^2\right)^{\varepsilon_d}}-\frac{6-4\varepsilon_d}{(1-\varepsilon_d)\left(\mathbf{p}^2+sz^2\right)^{\varepsilon_d-1}}\right\}$$

$$\lim_{d\to 4}\lambda B(s) = \lambda_0\left\{\mu-\frac{\mathbf{p}\sqrt{s}}{8\pi M^2}+R\left(\mathbf{p}^2\right)\right\}$$

with the large constant $\mu = \frac{1}{2\pi}+\frac{m^2}{8\pi^2M^2}\left(\Gamma'(1)-\log\left(\frac{4\pi m^2}{M^2}\right)+3-\frac{10}{9}\log 2\right)$

and the small remainder $R(\mathbf{p}^2) = \frac{\mathbf{p}\sqrt{s}}{4\pi^2M^2}\arctan\frac{2\mathbf{p}}{\sqrt{s}}-\frac{\mathbf{p}^2}{4\pi^2M^2}\left(\Gamma'(1)-\log\left(\frac{4\pi m^2}{M^2}\right)+2-\frac{5}{9}\log 2\right)$

Summation of the leading bubble terms gives

$$M^{0+}(s) = \frac{\lambda_0}{M^2}\left[1 + \lambda B(s) + \left(\lambda B(s)\right)^2 + \bullet\bullet\bullet\bullet\right]$$

$$= \frac{\lambda_0}{M^2 - \lambda_0\left(\mu M^2 - \dfrac{\mathbf{p}\sqrt{s}}{8\pi}\right)} = \frac{1}{M^2\left(\dfrac{1}{\lambda_0} - \mu\right) + \dfrac{\mathbf{p}\sqrt{s}}{8\pi}}$$

$$= \frac{8\pi}{m_0^2 + \mathbf{p}\sqrt{s}}$$

where m_0 is a parameter fixed by the effective range expansion.

Hence, λ_0 runs with M according to:

$$\lambda_0 = \frac{1}{\mu + \dfrac{m_0^2}{8\pi M^2}}$$

and M has a pole (or resonance) at

$$s = 2m^2\left(1 \pm \sqrt{1 - \frac{m_0^4}{m^4}}\right)$$

The *u*- and *t*-channel bubbles

- ★ New feature of relativistic theory is the presence of *u*- and *t*-channel bubbles
- ★ We can show(?) that these are analytic in p^2 near $p^2 \sim 0$. Hence they contribute only to the constant and p^2 terms, and their effect can be absorbed into adjustable parameters
- ★ Conclusion: the presence of *u*- and *t*- channel bubbles does not change the conclusions drawn from study of *s*-channel bubbles

Conclusion:
Power counting for relativistic theory in a nonrelativistic domain

- ★ Each diagram is of the form $M = \text{Constant} + c_1\alpha + R(\alpha^2)$
- ★ All diagrams contribute a constant term, which sometimes violates power counting. This does not matter since the constant term is simply a parameter describing the short range physics that must be fit to the data.
- ★ Only diagrams with an elastic cut contribute non-analytic terms of order α, and these can be calculated and summed.
- ★ The remainder terms $R(\alpha^2)$ are analytic and can be absorbed into derivative terms in the Lagrangian. These are then fit to the data.
- ★ Not much predictive power, but divergences are handled without form factors. (Is this really an advantage?)

Connection with the Covariant Spectator© theory

★ If $A_\pm - i\varepsilon = m^2 - \left(\tfrac{1}{2}P \pm k\right)^2 - i\varepsilon = \left(E_k - \tfrac{1}{2}P_0 \mp k_0 - i\varepsilon\right)\left(E_k + \tfrac{1}{2}P_0 \pm k_0 - i\varepsilon\right)$

$$A_+ - A_- - i\varepsilon = -2P\cdot k - i\varepsilon$$

the CS© theory gives the following bubble contribution

$$B_{CS}(s) = -\frac{i}{4}\int \frac{d^dk}{(2\pi)^d} N \left\{ \frac{1}{(A_- - A_+ - i\varepsilon)(A_+ - i\varepsilon)} + \frac{1}{(A_+ - A_- - i\varepsilon)(A_- - i\varepsilon)} \right\}$$

a — *one pole LHP*

b — *one pole UHP*

$$= -\frac{i}{4}\int \frac{d^dk}{(2\pi)^d} N \int_0^\infty dx \left\{ \frac{1}{\left[(1-x)A_+ + xA_- - i(1+x)\varepsilon\right]^2} + \frac{1}{\left[(1-x)A_- + xA_+ - i(1+x)\varepsilon\right]} \right\}$$

x=1/2+z   x=1/2-z

$$= -\frac{i}{4}\int \frac{d^dk}{(2\pi)^d} N \left\{ \int_{-\frac{1}{2}}^{\infty} dz \frac{1}{\left[(\tfrac{1}{2}-z)A_+ + \left(\tfrac{1}{2}+z\right)A_- - i(\tfrac{3}{2}+z)\varepsilon\right]^2} + \int_{-\infty}^{\frac{1}{2}} dz \frac{1}{\left[\left(\tfrac{1}{2}+z\right)A_- + (\tfrac{1}{2}-z)A_+ - i(\tfrac{3}{2}-z)\varepsilon\right]} \right\}$$

Connection with the Covariant Spectator© theory (2)

★ Hence

$$B_{CS}(s) = \frac{i}{4}\int \frac{d^dk}{(2\pi)^d}\int_{-\infty}^{\infty} dz \frac{N}{\left[(\frac{1}{2}-z)A_+ + \left(\frac{1}{2}+z\right)A_- - i(\frac{3}{2}+z)\varepsilon\right]^2} + \frac{1}{2}B(s)$$

$$\mu' - \frac{\mathbf{p}\sqrt{s}}{8\pi M^2} + \frac{1}{2}R\left(\mathbf{p}^2\right)$$

Different constant and half the remainder term

THEREFORE, in an EFT sense, equivalent to the full bubble term

★ CS© theory is equivalent (from an EFT! point of view) to the full field theory. (Is this useful?)

Extensions and reinterpretation: EFT! in a relativistic domain

★ Suppose we are in the relativistic domain ($p \sim m$). Then either:

- power counting works, because $\lambda_0 \ll (M/m)^2$ and the physics is perturbative, or
- $\lambda_0 \sim (M/m)^2$, power counting does not work, and all diagrams are of equal size, and all must be summed

★ Even if power counting does NOT work, we may

- separate the terms nonanalytic in p^2 from those which are analytic, and sum them using *s*-channel bubbles. These terms are predicted by the theory (up to the arbitrary constant!). Is this important??
- adjust the size of the analytic terms by adding derivative terms to the Lagrangian. These cannot be predicted. There is also no longer an organizational principle for choosing derivatives -- all are of equal size.

★ In either case, this relativistic effective theory has no content (i.e.) is purely phenomenological (in common with its nonrelativistic counterpart). But we have found a way to regularize and handle the short range physics.

Where do we go from here? One scenario:

- ★ Step 1: Start with a kernel of the form

$$V = \mu - \frac{\mathbf{p}\sqrt{s}}{8\pi M^2} + c_2\mathbf{p}^2 + c_4\mathbf{p}^4 + \cdots$$

- ★ Fit data

adjustable parameters

- ★ Add the pion (and other meson exchanges?) in an attempt to reduce the number of unknown short range parameters. For example, get c_2 and c_4 from meson exchange??

- ★ Calculate meson exchange without form factors or cutoffs using a “two potential” formalism and a Pade' series.

Where do we go from here? One scenario (2)

★ the "two potential" series is

$$M = M_m + (1 + M_m)|0\rangle \frac{\lambda}{1 + \lambda B(1 + M_m)} \langle 0|(1 + M_m)$$

★ the Pade series is used to calculate M_m

$$M_m = \sum_{n=1}^{2p} c_n x^n = \frac{\sum_{n=1}^{p} d_n^1 x^n}{\sum_{n'=1}^{p} d_{n'}^2 x^{n'}}$$

Conclusions to Part II

★ What has been learned from this exercise?

- A full power counting scheme, with accompaning organizational principle, seems to exist only in nonrelativistic situations.
- BUT it can be done with either a relativistic, or nonrelativistic formalism.
- From the EFT! point of view, CS© theory is just as good as a full field theory (to be thought about some more)

★ Does this help justify our original approach and calculations?

★ Why do relativistic calculations?

- justified if fewer parameters are needed to fit data and a greater unity between dynamics and interaction currents can be achieved

END