Lattice 2016
Southampton, UK

Radiative contribution to the effective potential in a composite Higgs model

B. Svetitsky
Tel Aviv University

TACO Collaboration: T. DeGrand, M. Golterman, W. Jay, E. Neil, Y. Shamir, BS (1606.02695)

---

1. The Promised Land:
   SU(5)/SO(5) sigma model *via* SU(4) gauge theory (Ferretti 1404.7137)
2. Latticeland:
   SU(4) gauge theory, $N_f = 2$ sextets $\Longrightarrow$ global SU(4) $\rightarrow$ SO(4)
3. First ingredient of the Higgs potential via $\Pi_{LR}(q^2)$
   — much in common with $\pi^{\pm}$–π^0 EM mass splitting in QCD (JLQCD 2008))

COMPOSITE HIGGS – BASICS

The aim: a light Higgs boson, protected *naturally* from high-energy scales

- Hypercolor: new strong sector with scale $f \gg v$
- Hypercolor theory has spontaneous symmetry breaking: Goldstone bosons will include the Higgs multiplet so $m_h = 0$ and in fact $V(h) = 0$
- Couple to gauge bosons/fermions of SM, generate

$$V_{\text{eff}}(h) = (\alpha - 4\beta)(h/f)^2 + O(h^4)$$

gauge bosons:	$\alpha = (3g^2 + g'^2)C_{LR}$	> 0 (`Witten 1983`)	today's talk
top quark:	$\beta = -(y_t^2/2)C_{\text{top}}$	probably > 0	[*S.E.P.*]

- If $4\beta > \alpha$ then we have EWSB (and maybe $v = \sqrt{2}\langle h \rangle \ll f$)

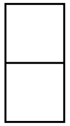
THE MODEL

(Ferretti 2014)

Wanted: $\mathrm{SU}(5)/\mathrm{SO}(5)$ sigma model for Goldstone bosons — $\mathrm{SO}(5) \supset [\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R]_{EW}$

$\Longrightarrow$ demands real representation of hypercolor for fermions

$\Longrightarrow$ restricts color group severely if asymptotically free

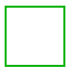
Solution: $\mathrm{SU}(4)$ gauge theory with sextet fermions  — a real representation

With N_f Dirac flavors we would have $\mathrm{SU}(2N_f) \to \mathrm{SO}(2N_f)$;

— but with 5 Majorana fermions we can have $\mathrm{SU}(5) \to \mathrm{SO}(5)$ as desired.

THE LATTICE MODEL (for today)

$N_f = 2$ Dirac fermions: $\mathrm{SU}(4) \to \mathrm{SO}(4)$

(*BONUS:* add  for partially composite top quark — *see next talk by W. Jay*)

CALCULATING THE HIGGS POTENTIAL — gauge contribution

$$C_{LR} = \int_0^\infty dq^2 q^2 \, \Pi_{LR}(q^2)$$

where

$$(q^2\delta_{\mu\nu} - q_\mu q_\nu)\,\Pi_{LR}(q^2) = -\int d^4x \, e^{iqx} \, \langle J_\mu^L(x) J_\nu^R(0) \rangle$$

Analytical guess — saturate with lowest resonances (*"Minimal Hadron Approx"*):

$$\Pi_{LR}(q^2) \approx \frac{f_\pi^2}{q^2} - \frac{f_\rho^2}{q^2 + m_\rho^2} + \frac{f_{a_1}^2}{q^2 + m_{a_1}^2}$$

LATTICE CALCULATION of C_{LR}

- Dynamical fermions: Wilson–clover fermions, nHYP smearing with suppression of dislocations
- Currents calculated from propagators of overlap fermion kernel with valence mass $m_v \neq 0$
- Take chiral limit $m_v \to 0$ — currents satisfy exact chiral Ward identities, give C_{LR}.

LATTICE CALCULATION

- Π_{LR} is the transverse part of

$$\frac{1}{2}\delta_{ab}\Pi^{\text{lat}}_{\mu\nu}(q) = -\sum_x e^{iqx}\,\langle J^L_{\mu a}(x) J^R_{\nu b}(0)\rangle$$

- Direct summation:

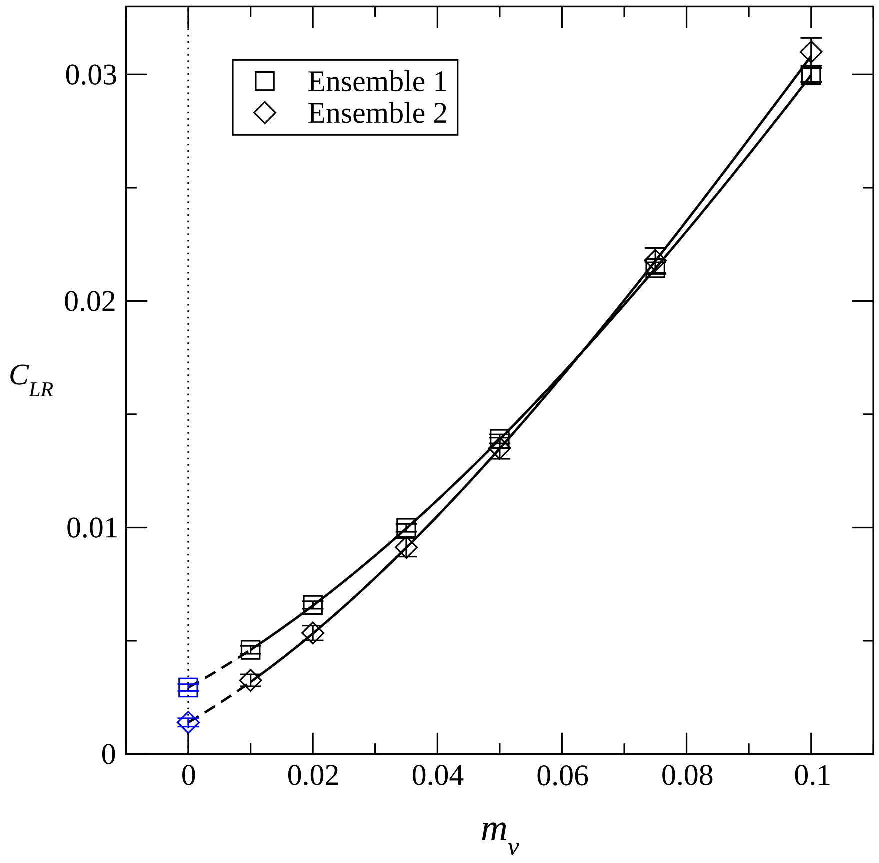
$$C_{LR}(m_v) = \frac{16\pi^2}{V}\sum_{q_\mu}\Pi_{LR}(q_\mu)$$

while modeling pole at $q = 0$ via

$$\Pi_{LR}(q_\mu) \simeq p + \frac{f_\pi^2}{q^2}$$

- The constant we want is $\lim_{m_v \to 0} C_{LR}(m_v)$.
- Discrepancy between the two ensembles . . .

(two ensembles — two *sea* actions):



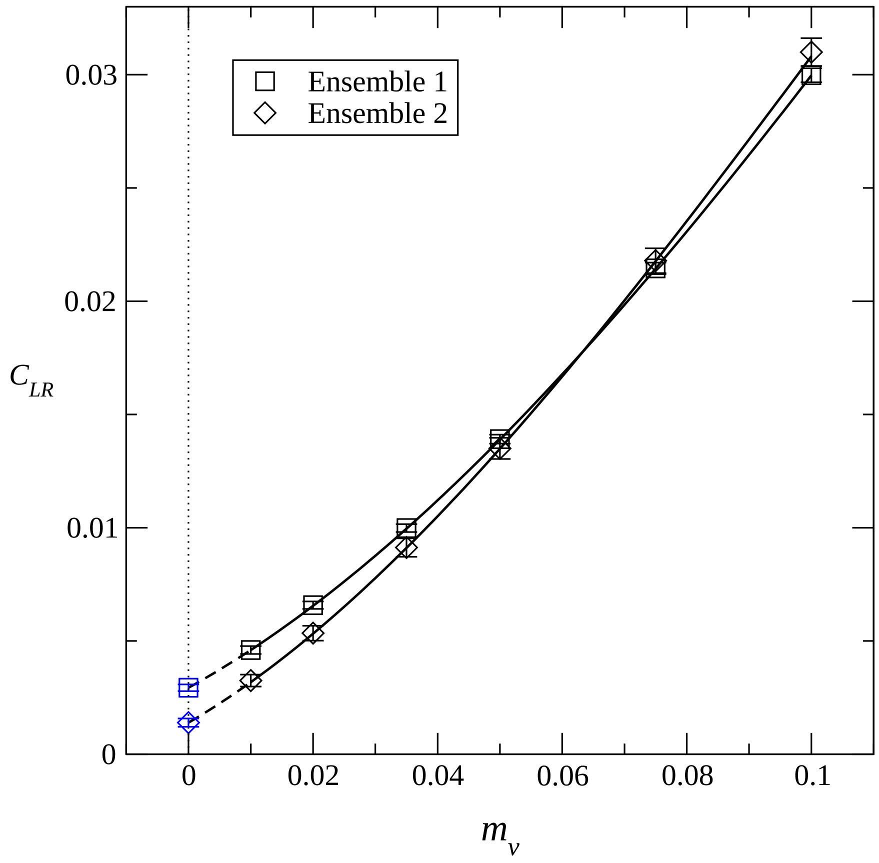
LATTICE CALCULATION

- A hint: Integrating the *Minimal Hadron Approx* (in the chiral limit*) gives

$$C_{LR} \approx f_\pi^2 \frac{m_{a_1}^2 m_\rho^2}{m_{a_1}^2 - m_\rho^2} \log\left(\frac{m_{a_1}^2}{m_\rho^2}\right),$$

i.e., $C_{LR} \propto f_\pi^2$.

(two ensembles — two *sea* actions):



$*$ via the Weinberg sum rules

LATTICE CALCULATION

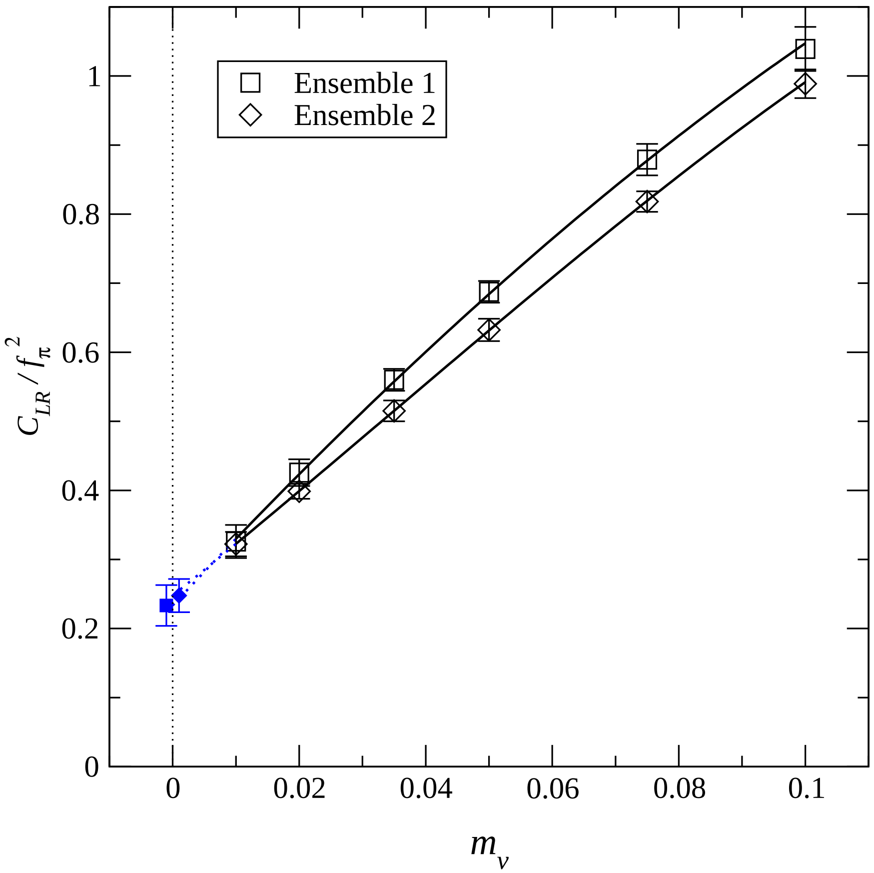
- A hint: Integrating the *Minimal Hadron Approx* (in the chiral limit*) gives

$$C_{LR} \approx f_\pi^2 \frac{m_{a_1}^2 m_\rho^2}{m_{a_1}^2 - m_\rho^2} \log\left(\frac{m_{a_1}^2}{m_\rho^2}\right),$$

  i.e., $C_{LR} \propto f_\pi^2$.

- so look at the ratio $C_{LR}/f_\pi^2 \Longrightarrow$

(two ensembles — two *sea* actions):



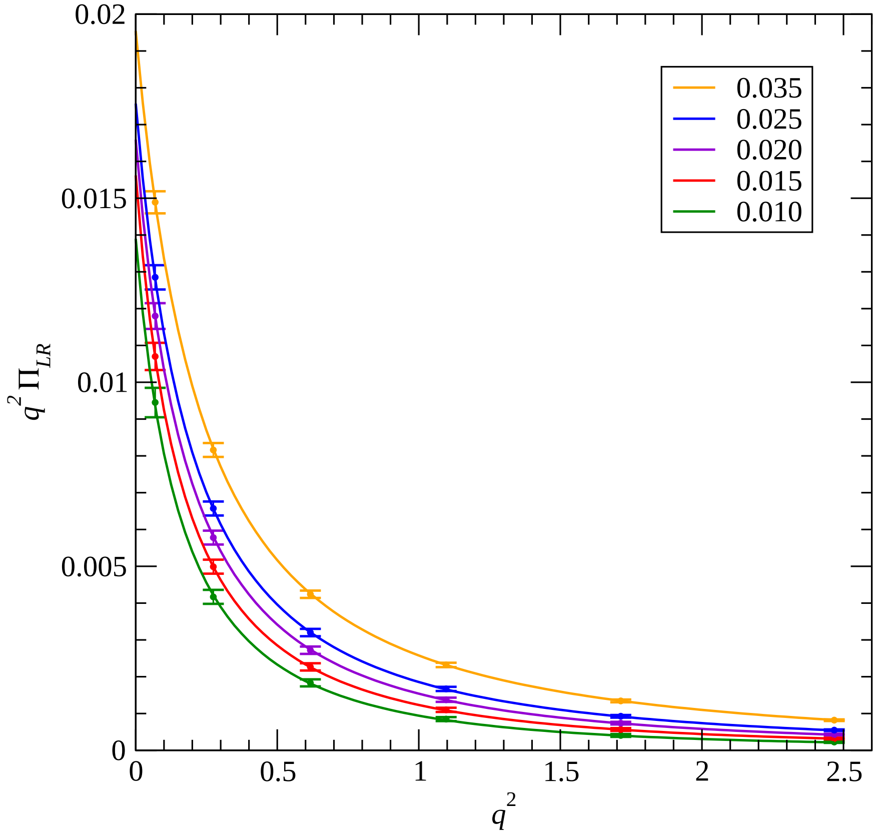
---

* via the Weinberg sum rules

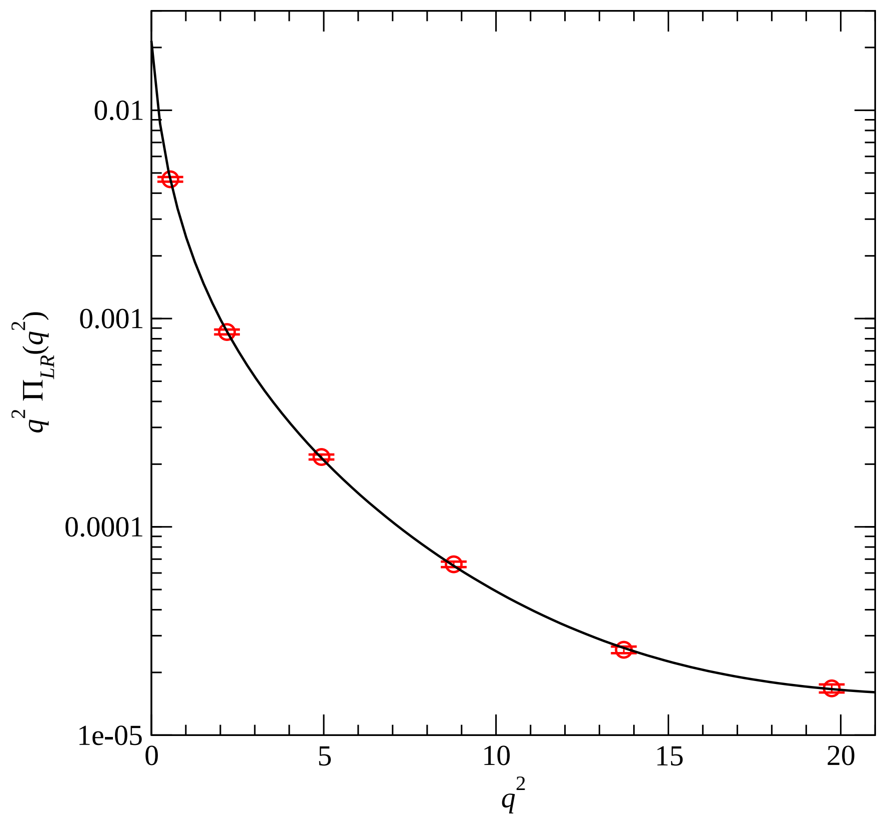
ALTERNATIVE PATH to C_{LR} — Fit to the MINIMAL HADRON formula, integrate $\int dq^2\, q^2\, \Pi_{LR}$

$$\Pi_{LR}(q^2) \approx \frac{f_\pi^2}{q^2} - \frac{f_\rho^2}{q^2 + m_\rho^2} + \frac{f_{a_1}^2}{q^2 + m_{a_1}^2} \qquad \text{(5 free parameters)}$$

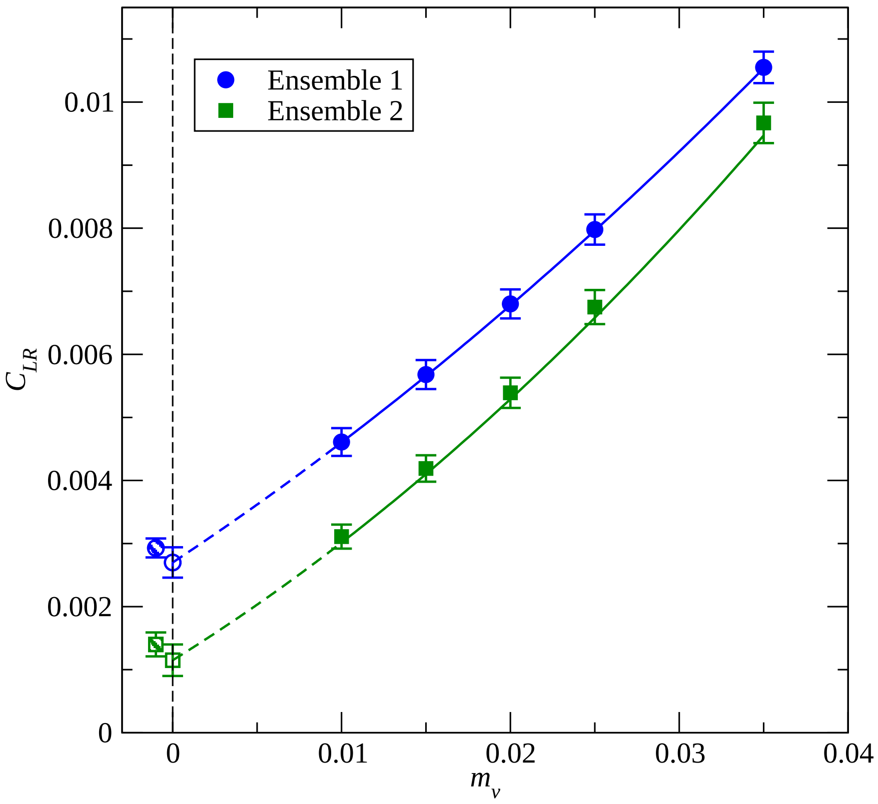
Ray along one axis:



Diagonal ray:



Result of $\int dq^2\, q^2\, \Pi_{LR}$:

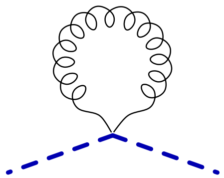


- Consistent with direct summation in the chiral limit (hatched points).
- Individual fits: Excellent χ^2 with *MHA* for m_v not too large.
- f_π consistent with spectroscopic value used above. ρ, a_1 not so much.
- We have studied systematics of the fit/integration procedures.
- Consistent results for C_{LR}/f_π^2 between ensembles, but no continuum limit yet.

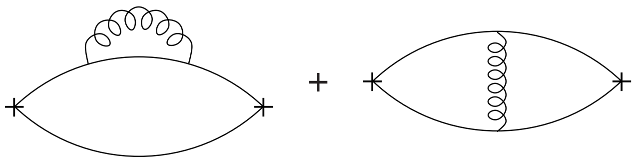
SUPPLEMENTAL

CALCULATING THE HIGGS POTENTIAL — gauge contribution

Gauge tadpole on Higgs propagator

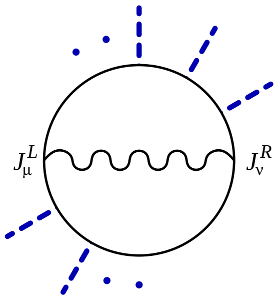


becomes in the gauge theory



where “+” is a vertex to the GB.
(Hyperglue not shown.)

In the chiral Lagrangian for the GB’s,
all n-GB amplitudes are related



— including the zero-GB amplitude!

SO

$$C_{LR} = \int_0^\infty dq^2 q^2 \, \Pi_{LR}(q^2)$$

where

$$(q^2 \delta_{\mu\nu} - q_\mu q_\nu) \, \Pi_{LR}(q^2) = - \int d^4x \, e^{iqx} \, \langle J_\mu^L(x) J_\nu^R(0) \rangle$$