Superconformal Operator Product Expansion and General Gauge Mediation

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based on

arXiv:1107.1721, 1109.4940 [hep-th] and work in progress

with Kenneth Intriligator and Andreas Stergiou

Outline

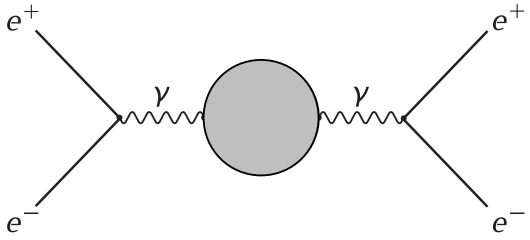
(S)OPE UV/IR applications

- Non-CFTs $\Rightarrow$ Conformally covariant OPEs
- Softly broken symmetries as spontaneously broken symmetries
  - Symmetry breaking seen as IR effect (via field or spurion vev)
  - Symmetry restored in UV theory
  - $\Rightarrow$ (S)OPE selection rules

$\Rightarrow$ Strongly-coupled IR physics described by weakly-coupled UV physics through (S)OPE

- Example: QCD
  - Not conformal (non-trivial RG flow)
  - IR physics $\Rightarrow$ Theory with chiral symmetry breaking $(\langle\bar{Q}Q\rangle \neq 0)$ and confinement $(\langle G_{\mu\nu}^{A} G^{A\mu\nu}\rangle \neq 0)$
  - UV physics $\Rightarrow$ Asymptotically free CFT
  - $\Rightarrow$ QCD sum rules Shifman, Vainshtein, Zakharov (1979)

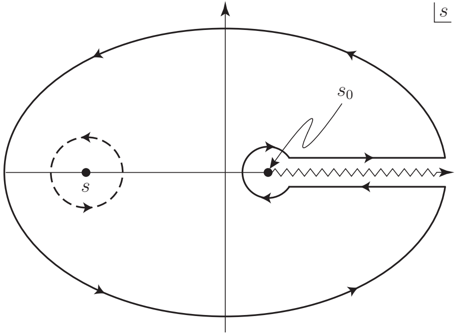
Probe hadron sector from lepton sector through gauge interactions (UV/IR physics separated using OPE)



$$\Pi_{\mathrm{hadron},\mu\nu}(p) = ie^2 \int d^4x\, e^{-ip\cdot x} \langle j_\mu(x) j_\nu(0)\rangle$$

$$\mathcal{O}_i(x)\mathcal{O}_j(0) = \sum_k c_{ij}^k(x)\mathcal{O}_k(0)$$

OPE, analyticity and optical theorem ⇒ Relations between total cross section and OPE coefficients



$$\Pi_{\text{hadron}}(s) = \frac{1}{2\pi i}\int_{s_0}^{\infty} ds' \, \frac{\text{Disc}\,\Pi_{\text{hadron}}(s')}{s'-s}$$

$$\sigma_{e^+e^-\to\text{hadrons}}(s) = \frac{2\pi i\alpha}{s}\text{Disc}\,\Pi_{\text{hadron}}(s)$$

Operator product expansion: Review

Operator product expansion

$$\begin{aligned}
\mathcal{O}_i(x)\mathcal{O}_j(0) &= \sum_k \frac{c_{ij}^k}{x^{\Delta_i+\Delta_j-\Delta_k}}\mathcal{O}_k(0) \\
&= \sum_{\text{primary } k} \frac{c_{ij}^k}{x^{\Delta_i+\Delta_j-\Delta_k}} F^{\Delta_k}_{\Delta_i\Delta_j}(x,P)\mathcal{O}_k(0)
\end{aligned}$$

- Short distance physics expressed in terms of local operators
- Wilson coefficients $\Rightarrow$ UV physics
- Vacuum expectation values $\Rightarrow$ IR physics
- OPE constrained by conformal symmetry $\Rightarrow$ Wilson coefficients of descendants determined by Wilson coefficients of primaries Ferrara, Gatto, Grillo (1971)

Superconformal operator product expansion

$$\mathcal{O}_i(x)\mathcal{O}_j(0) \stackrel{?}{=} \sum_{\text{superprimary } k} \frac{c_{ij}^k}{x^{\Delta_i+\Delta_j-\Delta_k}} F_{ij}^k(x, P, Q, \bar{Q})\mathcal{O}_k(0)$$

$$\begin{aligned} \mathcal{T}_\mu(z) &= j_\mu^R(x) + \theta^\alpha \mathcal{S}_{\alpha\mu}(x) + \bar{\theta}^{\dot{\alpha}} \bar{\mathcal{S}}_{\dot{\alpha}\mu}(x) + 2\theta\sigma^\nu\bar{\theta} T_{\nu\mu}(x) + \cdots \\ \mathcal{J}(z) &= J(x) + i\theta j(x) - i\bar{\theta}\bar{j}(x) - \theta\sigma^\mu\bar{\theta} j_\mu(x) + \cdots \end{aligned}$$

- OPE constrained by superconformal symmetry
- Sum over superprimaries instead of primaries

$\Rightarrow$ Wilson coefficients of superdescendants NOT fully determined by Wilson coefficients of superprimaries (existence of superconformal 3-point invariants) ! Osborn (1998)

Current-current SOPE

Superconformal 3-point correlation functions for current superfields

$$\langle \mathcal{J}(z_1)\mathcal{J}(z_2)\mathcal{O}^{\mu_1\cdots\mu_\ell}(z_3)\rangle = \frac{1}{x_{\bar{1}3}{}^2 x_{\bar{3}1}{}^2 x_{\bar{2}3}{}^2 x_{\bar{3}2}{}^2}\, t^{\mu_1\cdots\mu_\ell}_{\mathcal{J}\mathcal{J}\mathcal{O}_\ell}(X_3,\Theta_3,\bar{\Theta}_3)$$

- $\mathcal{O}^{\mu_1\cdots\mu_\ell}$ real spin-ℓ superfield with vanishing R-charge
- $t_{\mathcal{J}\mathcal{J}\mathcal{O}}(X,\Theta,\bar{\Theta})$ fully determined by superconformal symmetry and current superconservation JFF, Intriligator, Stergiou (2011)

$\Rightarrow$ (Non-universal) 4-point $\langle J(x_1)J(x_2)J(x_3)J(x_4)\rangle$ superconformal blocks

General gauge mediation: Overview

- SUSY breaking hidden sector connected to visible sector through gauge interactions Buican, Meade, Seiberg, Shih (2008)
  - Decoupled hidden sector in $g_{\text{SM}} \to 0$ limit
  - Universal visible sector SUSY breaking effects introduced via loops

$\Rightarrow$ Current-current correlation functions (even without hidden sector Lagrangian)

$$\mathcal{J}(z) = J(x) + i\theta j(x) - i\bar{\theta}\bar{j}(x) - \theta\sigma^\mu\bar{\theta} j_\mu(x) + \cdots$$

$$\langle J(x)J(0)\rangle, \; \langle j_\alpha(x)\bar{j}_{\dot{\alpha}}(0)\rangle, \; \langle j_\mu(x)j_\nu(0)\rangle, \; \langle j_\alpha(x)j_\beta(0)\rangle$$

Cross sections

OPE constraints, analyticity and optical theorem

$$\sigma_{\text{visible}\to D^*\to\text{hidden}}(s) = -\frac{(4\pi\alpha_{\text{SM}})^2}{s}\sum_k \text{Im}[\tilde{c}^k_{JJ}(s)]\langle\mathcal{O}_k(0)\rangle$$

$$\sigma_{\text{visible}\to\lambda^*_\alpha\to\text{hidden}}(s) = f_{1/2}(\text{Im}[\tilde{c}^k_{JJ}(s)])$$

$$\sigma_{\text{visible}\to A^*_\mu\to\text{hidden}}(s) = f_1(\text{Im}[\tilde{c}^k_{JJ}(s)])$$

- Consistent with direct computation in ordinary minimal gauge mediation Martin (1996)
- Good approximation with first few terms

Visible sector SUSY breaking masses

OPE constraints and analyticity

$$M_{\text{gaugino}} \approx \sum_k \frac{\alpha_{\text{SM}} \operatorname{Im}[s^{d_k/2}\, \tilde{c}^k_{JJ}(s)]}{2^{d_k-1} d_k M^{d_k}} \langle Q^2(\mathcal{O}_k(0))\rangle$$

$$m^2_{\text{sfermion}} \approx 4\pi\alpha_{\text{SM}} Y \langle J(x)\rangle - \sum_k \frac{\alpha^2_{\text{SM}} c_2 \operatorname{Im}[s^{d_k/2}\, \tilde{c}^k_{JJ}(s)]}{2^{d_k+1}\pi d_k^2 M^{d_k}} \langle \bar{Q}^2 Q^2(\mathcal{O}_k(0))\rangle$$

- Exaclty equivalent to the usual $f(x)$ and $g(x)$ functions of ordinary minimal gauge mediation Martin (1996)
- Good approximation with first few terms

Other research interests

Scale and conformal invariance

- Non-conformal scale-invariant theories
  - RG flow recurrent behaviors
  - Consistent with weak and strong version of c-theorem
- Generalized c-theorem
  - Conformal recurrent behaviors

Dark matter

- Model building
- Constraints
  - Direct and indirect detection experiments
  - Collider experiments
  - Astrophysical observations (e.g. white dwarfs)