OPE Methods for the Holomorphic Higgs Portal

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Based on *P.K., Li, Poland, Stergiou (1401.7690)*

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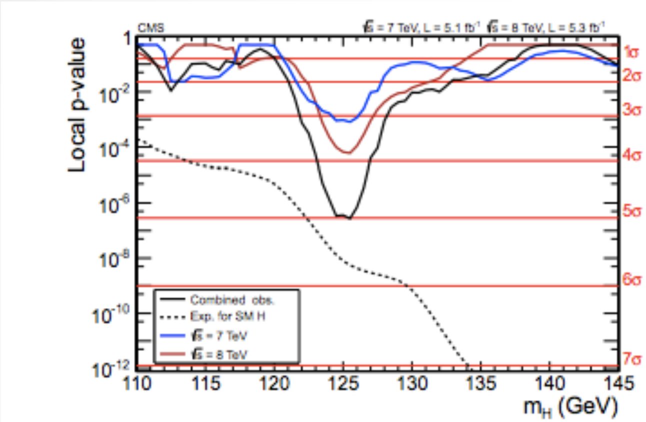
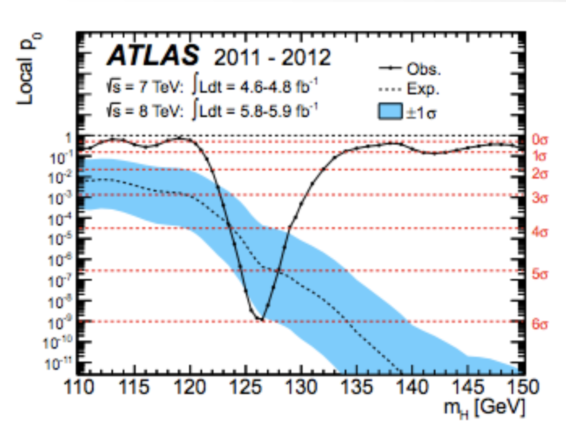
Outline

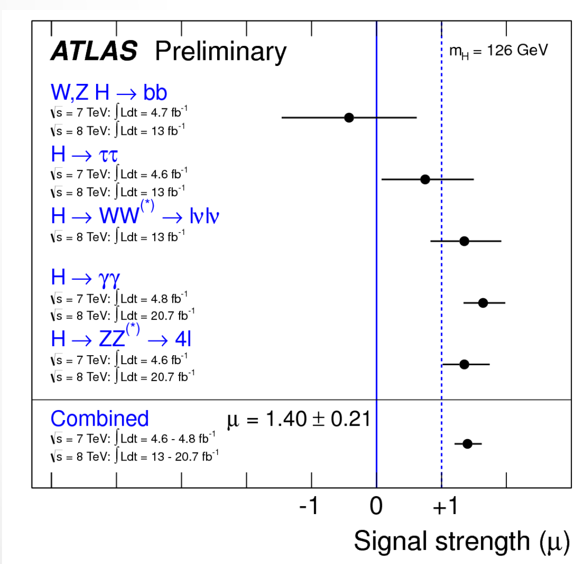
- **Motivation & Introduction**
- **Basic Framework – Generalities**
- **Computations of Higgs Parameters**
- **Reproducing known Results – (Old Problems from a New Perspective)**
- **(New) Possibilities for Solutions**
- **Summary & Future Directions**

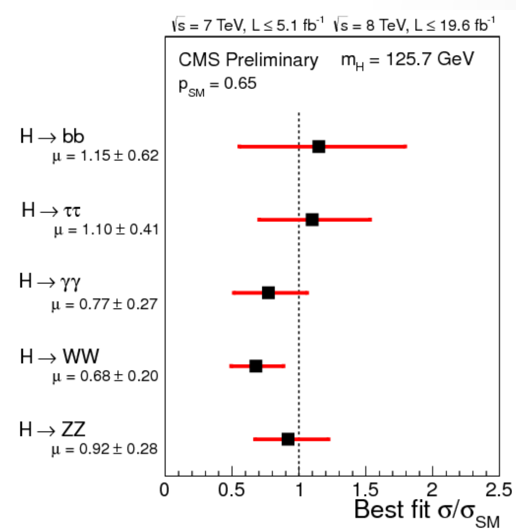
- **Discovery of a Higgs Particle @ 125 GeV**



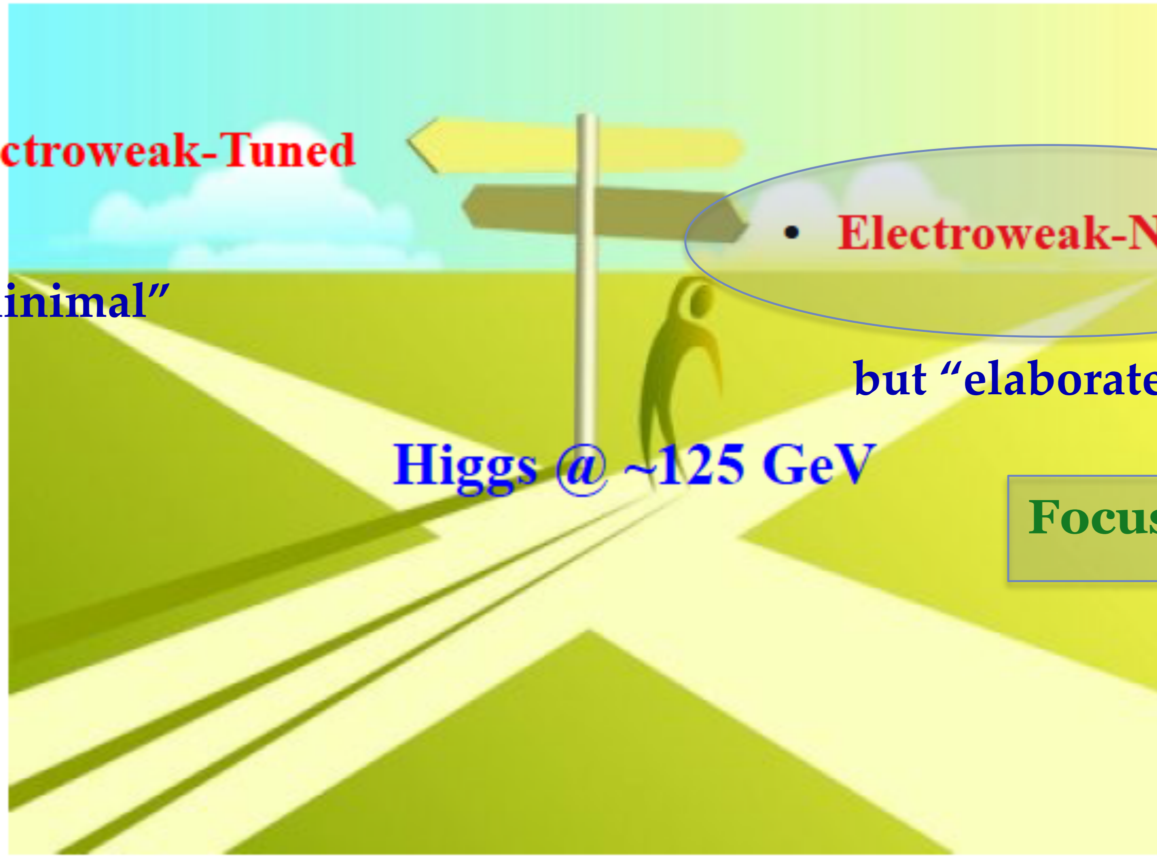


- **Signal consistent with that of a SM-like Higgs**





At Crossroads.....



- Electroweak-Tuned

but "minimal"

- Electroweak-Natural

but "elaborate"

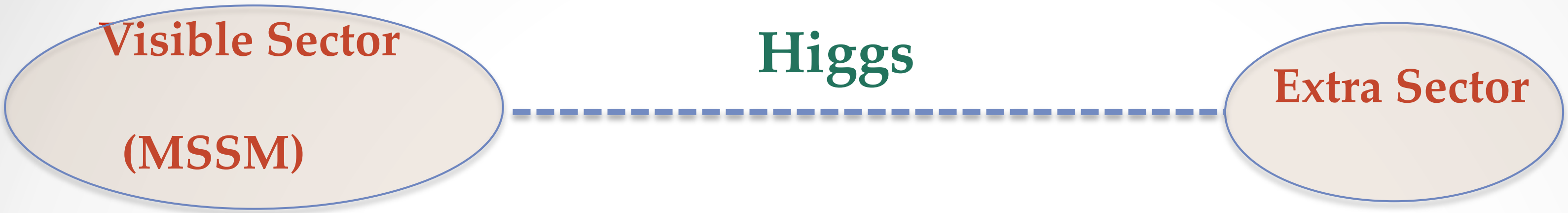
Higgs @ ~125 GeV

Focus on today

More Data will Decide !

For concreteness, stay within the SUSY paradigm

"Holomorphic" Higgs Portal



$$W = \lambda_u \mathcal{H}_u \mathcal{O}_u + \lambda_d \mathcal{H}_d \mathcal{O}_d.$$

- H_u and H_d assumed to have dimension close to unity.
- λ_u, λ_d taken to be perturbative (taking into account dimensional dependence)
- But Extra sector (to which O_u and O_d belong) could be strongly coupled in general.

  -- superconformal in the UV, but develops a mass gap in the IR

Examples – "Single Sector Models" in Gauge mediation.
Messengers coupled to strong Dynamical ~~SUSY~~ (DSB) sector.

"Integrate-out" dynamics of the Extra sector

carry out the path integral over O_u and O_d

Azatov et al 1106.3646,1106.4815; Kitano et al 1206.4053; Stancato et al 0807.3961 Gherghetta, Pomarol 1107.4697; Komargodski, Seiberg 0812.3900; Craig et al 1302.2642, Knapen et al 1311.7107, …

Goal : Study Effective Higgs Lagrangian from general perspective

This Work : To quadratic order (p =0) , Future : To quartic order

$$\mathscr{L} = \mathcal{Z}_u F^\dagger_{H_u} F_{H_u} + \mathcal{Z}_d F^\dagger_{H_d} F_{H_d} + \left(\mu \int d^2\theta\, \mathcal{H}_u \mathcal{H}_d + \text{c.c.}\right) - V^{(\text{soft})}_{\text{Higgs}} - V^{(\text{other})}_{\text{Higgs}},$$

$$V^{(\text{soft})}_{\text{Higgs}} = m^2_{H_u} H^\dagger_u H_u + m^2_{H_d} H^\dagger_d H_d + (B_\mu H_u H_d + \text{c.c.}) + (A_u H_u F^\dagger_{\mathcal{H}_u} + A_d H_d F^\dagger_{\mathcal{H}_d} + \text{c.c.}),$$

$$V^{(\text{other})}_{\text{Higgs}} = (a'_u\, H_u F_{\mathcal{H}_d} + \text{c.c.}) + (a'_d\, F_{\mathcal{H}_u} H_d + \text{c.c.}) + (\gamma\, F_{\mathcal{H}_u} F_{\mathcal{H}_d} + \text{c.c.}).$$

- Usual soft terms and μ term.
- Terms in $V_{higgs}^{(other)}$ present in general as well.
  Example : Wrong Higgs Trilinears a_u', a_d'.

If |F|/M² < 1,

Can show that parameters in $V_{higgs}^{(other)}$ suppressed by powers of |F|/M² .

Distler, Robbins 0807.2006; Komargodski, Seiberg 0812.3900

"Integrating out" procedure yields for $V_{higgs}^{(soft)}$:

$$\mu = \frac{i}{8}\lambda_u\lambda_d \left\langle \int d^4x\, e^{-ip\cdot x} Q^\alpha(O_u(x)) Q_\alpha(O_d(0)) \right\rangle\Big|_{p\to 0},$$

$$B_\mu = \frac{i}{2^5}\lambda_u\lambda_d \left\langle \int d^4x\, e^{-ip\cdot x} Q^2(O_u(x)) Q^2(O_d(0)) \right\rangle\Big|_{p\to 0},$$

$$\delta A_{u,d} = -\frac{i}{8}|\lambda_{u,d}|^2 \left\langle \int d^4x\, e^{-ip\cdot x} Q^2[O_{u,d}(x) O^\dagger_{u,d}(0)] \right\rangle\Big|_{p\to 0},$$

$$\delta m^2_{H_{u,d}} = -\frac{i}{2^5}|\lambda_{u,d}|^2 \left\langle \int d^4x\, e^{-ip\cdot x} Q^2\bar{Q}^2[O_{u,d}(x) O^\dagger_{u,d}(0)] \right\rangle\Big|_{p\to 0}.$$

$$Q(O) \equiv [Q, O\}.$$

Komargodski, Seiberg 0812.3900

Assumption : μ forbidden in the SUSY limit

Comments:

- Parameters defined in the zero-momentum limit

* μ, Bμ, -- **"CHIRAL – CHIRAL"** Two-point function

* A_u, A_d, m_{Hu}^2, m_{Hd}^2 -- **"CHIRAL – ANTICHIRAL"** Two-point function

OPE Methods & Dispersion Relations

- Apply the Operator Product Expansion (OPE) to the two-point functions.

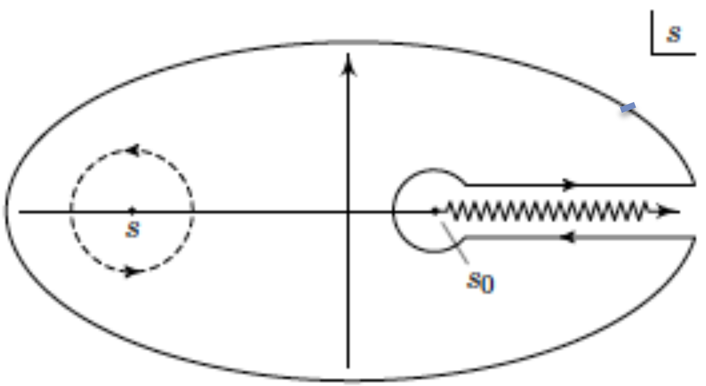
$$\mathcal{O}_i(x)\,\mathcal{O}_j(0) = \sum_k \underbrace{c_{ij}{}^k(x)}_{\text{UV}}\,\underbrace{\mathcal{O}_k(0)}_{\text{IR}},$$

- Identify operators that can obtain *vevs* consistent with Poincare & Gauge invariance.
- Compute Wilson coefficients $c^k{}_{ij}(x)$ or $\sim C^k{}_{ij}(p^2)$ using superconformal symmetry.

Analytically continue to large time-like momenta (physical region s' > 0) .

- Use

$$A(s) = \frac{1}{2\pi i}\int_{s_0}^{\infty} ds'\,\frac{\mathrm{Disc}\,A(s')}{s'-s} = \frac{1}{\pi}\int_{s_0}^{\infty} ds'\,\frac{\mathrm{Im}\,A(s')}{s'-s}.$$



to compute Wilson coefficients at any other *s* **(even at s = 0)**

Assumption:
Branch-cut starting at some threshold $s_o = (2M)^2$, no other singularities

- **Compute Chiral-Chiral OPE $\mathcal{O}_u * \mathcal{O}_d$ and Chiral-Antichiral OPE $\mathcal{O}_{u,d} * \mathcal{O}_{u,d}^\dagger$**
- **For $\mathcal{O}_u * \mathcal{O}_d$ OPE to contain $\mathcal{O}^I$ and $\mathcal{O}_{u,d} * \mathcal{O}_{u,d}^\dagger$ OPE to contain $\mathcal{O}^I$, need to compute**

$$\langle \mathcal{O}_u \mathcal{O}_d \mathcal{O}^{I\,\dagger} \rangle \text{ and } \langle \mathcal{O}_{u,d} \mathcal{O}^\dagger_{u,d} \mathcal{O}^{I\,\dagger} \rangle$$

- **3-point functions for primary superfields computed for a general $\mathcal{N}$=1, 4D Superconformal Field Theory (SCFT) in**
  Osborn hep-th/9808041; Poland, Simmons-Duffin 1009.2087

RESULTS

$B\mu$:

$$B_\mu = \frac{i}{2^5}\lambda_u\lambda_d \left\langle \int d^4x\, e^{-ip\cdot x} Q^2(\mathcal{O}_u(x)) Q^2(\mathcal{O}_d(0)) \right\rangle \Big|_{p\to 0},$$

$$Q^2\mathcal{O}_u(x) Q^2\mathcal{O}_d(0) = \sum_i c^i_{B_\mu} Q^2 \mathcal{O}_{3,0;i}(0), \qquad c^i_{B_\mu} = -2^6 \frac{\lambda_{\mathcal{O}_u\mathcal{O}_d\mathcal{O}_{3,0;i}}}{C_{\mathcal{O}_{3,0;i}}} x^{\Delta_{\mathcal{O}_{3,0;i}} - \Delta_{\mathcal{O}_u} - \Delta_{\mathcal{O}_d} - 1},$$

Only one type of operator : $Q^2(\mathcal{O}_{3,0})$ contributes.

- **μ :**

$$\mu = \frac{i}{8}\lambda_u\lambda_d \left\langle \int d^4x\, e^{-ip\cdot x} Q^\alpha(O_u(x)) Q_\alpha(O_d(0)) \right\rangle\Big|_{p\to 0},$$

$$Q^\alpha O_u(x) Q_\alpha O_d(0) = c_{\mu;1} Q^2 O_{1,0}(0) + c_{\mu;2} Q^\alpha O_{2,1\,\alpha}(0) + \sum_i \left(c^i_{\mu;3} O_{3,0;i}(0) + c^i_{\mu;4}[Q^2\bar{Q}^2 O_{3,0;i}]_p(0) + c^i_{\mu;5}[Q\sigma_\mu \bar{Q} O^\mu_{3,1;i}]_p(0)\right) + \cdots ,$$

$$c_{\mu;1} = 2^4 \frac{\lambda_{O_u O_d O_{1,0}}}{C_{O_{1,0}}} \frac{\Delta_{O_u}\Delta_{O_d}}{(\Delta_{O_u}+\Delta_{O_d})(\Delta_{O_u}+\Delta_{O_d}-1)}, \qquad c_{\mu;2} = \frac{\lambda_{O_u O_d O_{2,1}}}{C_{O_{2,1}}} \frac{\Delta_{O_u}-\Delta_{O_d}}{\Delta_{O_u}+\Delta_{O_d}-2},$$

$$c^i_{\mu;3} = \tilde{c}^i_{\mu;3} x^{\Delta_{O_{3,0;i}}-\Delta_{O_u}-\Delta_{O_d}-1}, \qquad c^i_{\mu;4} = \tilde{c}^i_{\mu;4} x^{\Delta_{O_{3,0;i}}-\Delta_{O_u}-\Delta_{O_d}+1}, \qquad c^i_{\mu;5} = \tilde{c}^i_{\mu;5} x^{\Delta_{O^\mu_{3,1;i}}-\Delta_{O_u}-\Delta_{O_d}},$$

- **Operators appearing :** $Q^2(\mathcal{O}_{1,0})$, $Q^\alpha(\mathcal{O}_{2,1\alpha})$, $\mathcal{O}_{3,0}$, $Q^2\bar{Q}^2 O_{3,0}$, $Q\sigma^\mu\bar{Q}(\mathcal{O}_{3,1\,\mu})|_{pr}$

Dominant contribution : $\mathcal{O}_{3,,0}$

Similarly, **$A_{u,d}$: $Q^2(\mathcal{O}^{u,d}{}_{o})$; & $\delta m^2{}_{Hu,d}$: $Q^2\bar{Q}^2(\mathcal{O}^{u,d}{}_{o})$**

Important: Different Operators contribute to different parameters.

Old problems from a New perspective

- **Reproduce μ/ Bμ problem of weakly coupled models from this formalism.**

-- in particular original Model studied in *Dvali et al hep-ph/9603238*

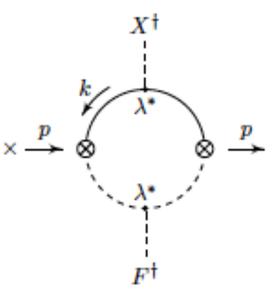
μ : $$i\int d^4x\, e^{-ip\cdot x}\, Q^{\alpha}(\Phi_1\Phi_2(x))\, Q_{\alpha}(\tilde{\Phi}_1\tilde{\Phi}_2(0)) = \bar{c}_{X^{\dagger}F^{\dagger}}(s)\, X^{\dagger}F^{\dagger}(0) + \cdots\,, \qquad s = -p^2.$$

Leading contribution to $O_{3,0}$

Higher-order contributions -- $X^{\dagger} F^{\dagger} (X^{\dagger} X)^n (F^{\dagger} F)^m$

$$\bar{c}_{X^{\dagger}F^{\dagger}}(s) = \frac{(\lambda^{*})^2}{2\pi^2}\frac{1}{s}\ln\frac{-s}{\mu^2} + \cdots\,,$$

$$\mu \approx -\frac{1}{2}\frac{\lambda_u\lambda_d\lambda^{*}}{16\pi^2\lambda}\frac{F^{\dagger}}{X}.$$

$$-i\bar{c}_{X^{\dagger}F^{\dagger}}(s) = -2^3 \times$$ 
$$= \frac{i(\lambda^{*})^2}{\pi^2}\frac{1}{Q^2}\int_0^1 dx\, x\frac{x(1-x)+2\xi}{(x(1-x)+\xi)^2},$$

Compute contributions from higher orders $X^{\dagger} F^{\dagger} (X^{\dagger} X)^n (F^{\dagger} F)^m$ – resum them

Result matches precisely ! Similarly for Bμ, $A_{u,d}$, $M^2_{hu,d}$

(New) Possibilities for Solutions

Basic Idea: 1) Different Operators contribute to different Higgs Parameters.
2) Their *vevs* determined by non-trivial IR dynamics

-- "simple" parametrics may not hold.

Possibilities :

i) EWSB with $B\mu/\mu^2 <\sim 1$ & $m_{Hu,d}^2 / A_{u,d}^2 <\sim 1$

$$\frac{\langle Q^2\, O_{3,0}\rangle}{|\langle O_{3,0}\rangle|^2} \simeq \frac{|c_\mu|^2}{c_{B\mu}}; \qquad \frac{\langle Q^2 \bar{Q}^2\, O_0^{\mathrm{u}}\rangle}{|\langle Q^2\, O_0^{\mathrm{u}}\rangle|^2} \simeq \frac{|c_{A_{u,d}}|^2}{c_{m^2_{H_{u,d}}}}$$

ii) EWSB with "Lopsided Gauge Mediation" *Csaki et al 0809.4492; DeSimone et al 1103.6033, Schafer-Nameki et al 1005.0841*

$$c_{m^2_{H_u}} \langle Q^2 \bar{Q}^2\, O_0^{\mathrm{u}}\rangle \ll c_{B\mu} \langle Q^2\, O_{3,0}\rangle \ll c_{m^2_{H_d}} \langle Q^2 \bar{Q}^2\, O_0^{\mathrm{d}}\rangle$$

iii) Conformal Sequestering : *Luty, Sundrum hep-th/0105137; hep-th/0111231 Schmaltz, Sundrum th/0608051; Roy, Schmaltz. 0708.3593; Murayama, Nomura, Poland 0709.0775*

Summary

- Developed a general and systematic formalism to compute parameters in the Higgs Lagrangian, when Higgs couples to another sector via the superpotential

$$W = \lambda_u \mathcal{H}_u \mathcal{O}_u + \lambda_d \mathcal{H}_d \mathcal{O}_d$$

- Valid even when extra sector strongly coupled in the IR.

  -- superconformal in the UV, mass gap in IR.

OPE methods provide a powerful organizing principle

-- Deeper insight into problems of SUSY breaking & mediation.
-- Possibilities for various solutions of these problems, some *qualitatively new,* in the sense that cannot be seen in the spurion limit.
-- All of them can be described by the OPE formalism

Future

- Apply results to realistic models of dynamical ~~SUSY~~ and mediation and compute Wilson coefficients and Higgs parameters explicitly.

- Study Quartic terms in the Higgs Potential - requires more advanced techniques