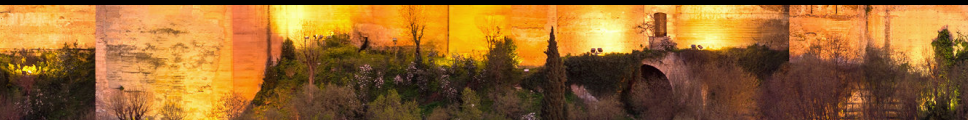




# Effective Field Theory after a New-Physics Discovery

Matthias König  
Physik-Institut  
Universität Zürich

*“From the Planck scale  
to the EW scale”*  
Granada, Jun 3, 2019



Universität  
Zürich<sup>UZH</sup>



SCHWEIZERISCHER NATIONALFONDS  
ZUR FÖRDERUNG DER WISSENSCHAFTLICHEN FORSCHUNG

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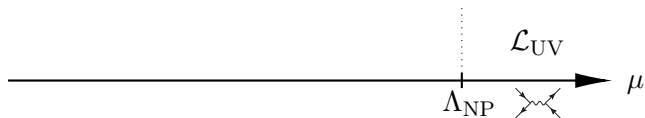
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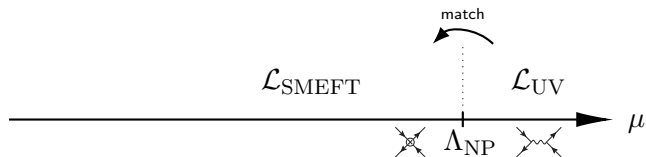
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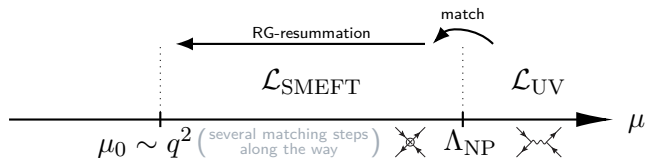
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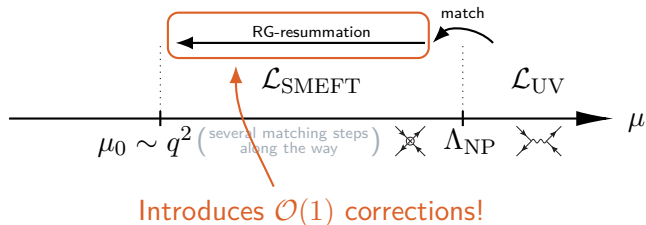
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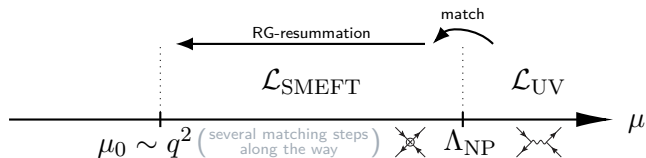
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So what about the case of  $q^2 \sim \Lambda^2$ ?

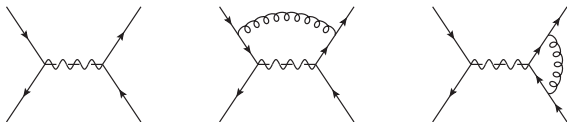


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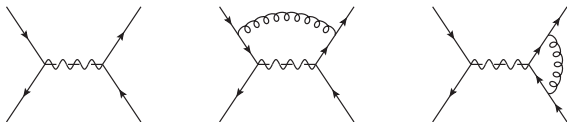
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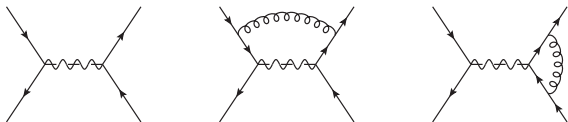


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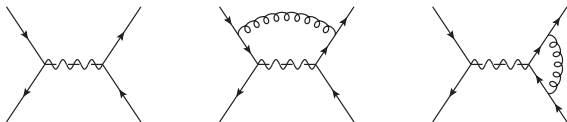


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HAVE YOU TRIED LOGARITHMS?



$\Rightarrow$  Whether  $q^2 \sim m_f^2$  or  $q^2 \sim M^2$ : there are logs to be summed.

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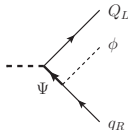
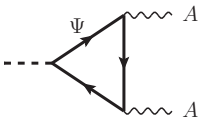
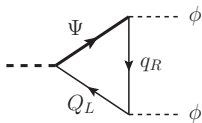
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- 3 The **power-counting** implied by this EFT does **not** reproduce the actual scaling of the amplitudes:

$$\mathcal{A}(S \rightarrow hh) = \mathcal{O}(\lambda^0), \quad \mathcal{A}(S \rightarrow VV) = \mathcal{O}(\lambda), \quad \mathcal{A}(S \rightarrow \bar{f}f) = \mathcal{O}(\lambda)$$

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Lots of (interesting) field-theory implications:

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Somewhat more technical but also **more powerful** than local EFTs!

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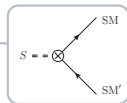
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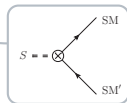
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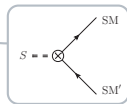


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**Based on:**

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*Stefan Alte, MK, Matthias Neubert*

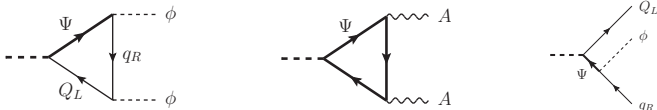
JHEP **1808** (2018) 095, [arXiv:1806.01278]

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**Effective Theory for a Heavy Scalar Coupled to the SM via Vector-Like Quarks**

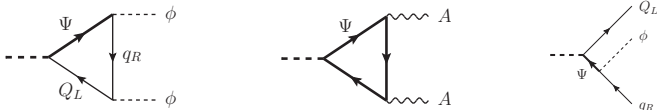
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[arXiv:1902.04593]



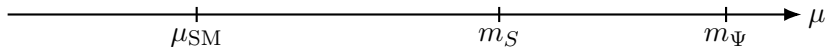
Even if the heavy quarks in these diagrams have  $m_\Psi \gg m_S$ , the “SMEFT+S” separates only  $m_\Psi$  from  $m_S$ , but not  $m_S$  from  $m_{\text{SM}}$ !

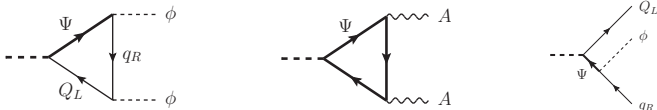




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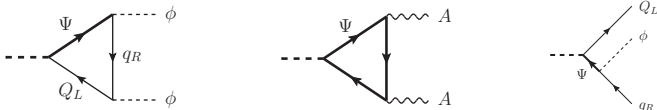


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- If  $m_\Psi \sim m_S$ , then we integrate can out  $\Psi$  **without** taking the **local limit, directly matching** the UV theory onto the SCET.



Operators responsible for the most relevant decays of the  $S$ :

At  $\mathcal{O}(\lambda^2)$ :



$$O_{AA} = S g_{\mu\nu}^{\perp} \mathcal{A}_c^{\mu,a} \mathcal{A}_{\bar{c}}^{\nu,a}$$

$$S \rightarrow \text{jets}$$

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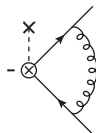
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Details and full list of operators:



[Alte, MK, Neubert (2018), JHEP 1808 (2018) 095]

Radiative corrections introduce **large (Sudakov) logarithms**, arising from soft-collinear divergences.

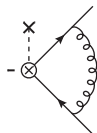


The diagram shows a quark line (solid line with an arrow) entering from the left and exiting to the right. A gluon loop (curly line) is attached to the quark line. A dashed line with an 'x' at its end represents a soft-collinear divergence. The diagram is followed by an approximation symbol (~) and the LO matrix element  $\mathcal{M}_{\text{LO}}$  multiplied by a bracketed term:  $\left\{ 1 + \frac{\alpha_s(\mu) C_F}{\pi} \ln^2 \frac{\mu^2}{m_q^2} \right\}$ .

$$\sim \mathcal{M}_{\text{LO}} \left\{ 1 + \frac{\alpha_s(\mu) C_F}{\pi} \ln^2 \frac{\mu^2}{m_q^2} \right\}$$



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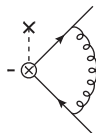


The diagram shows a quark loop (represented by a wavy line) attached to a vertex (represented by a circle with a cross). A dashed line with an 'x' at its end indicates a soft-collinear divergence. The diagram is followed by an approximation symbol (~) and the LO matrix element  $\mathcal{M}_{\text{LO}}$  multiplied by a bracketed term:  $\left\{ 1 + \frac{\alpha_s(\mu) C_F}{\pi} \ln^2 \frac{\mu^2}{m_q^2} \right\}$ .

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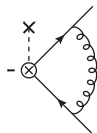
The diagram shows a quark loop (curly line) with two external lines (straight lines). The loop is attached to a vertex marked with a cross (x) and a minus sign (-). The loop is oriented clockwise. The external lines are also oriented clockwise. The diagram is followed by an approximation symbol (~) and a mathematical expression.

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Because the logs are **quadratic**, their impact is **significant!**

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The diagram shows a quark loop with a soft-collinear divergence. A dashed line with an 'x' marks the divergence point. The loop is connected to external lines. The diagram is followed by an approximation symbol and the LO matrix element with a logarithmic correction.

$$\sim \mathcal{M}_{\text{LO}} \left\{ 1 + \frac{\alpha_s(\mu) C_F}{\pi} \ln^2 \frac{\mu^2}{m_q^2} \right\}$$


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

Important effects when predicting **decay rates** or putting **constraints** on models!

As an illustration, assume  $M = 2.5$  TeV.




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Decay channel	$U_{RG}(\mu_0, M) = C(\mu_0)/C(M)$	$\Gamma_{\text{resum}}/\Gamma_{\text{fixed}} =  U_{RG} ^2$
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



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



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Resummation is **important**, rates always **decreased!**

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**Thank you for your attention!**

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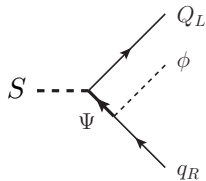
## Bonus slides

Matching example in a concrete UV theory:

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Supplement the SM with  $S$  and a set of vector-like fermions:

[Alte, MK, Neubert (2019), [arXiv:1902.04593]]



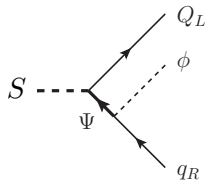
$$= i\delta_{\alpha\beta}(\bar{u}P_R v) \frac{(V_Q^\dagger G_d)}{u\xi - 1}, \quad \xi = \frac{m_S^2}{m_\Psi^2}.$$

momentum fraction between  $\phi$  and  $Q_L$

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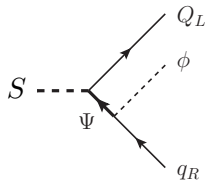
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Compare with EFT amplitude  $\rightarrow C_{Q_L \bar{d}_R \phi}(u, \mu) = \frac{V_Q^\dagger G}{u\xi - 1}$ .  
(all given in the paper)

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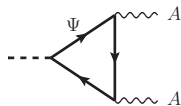
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Compare with EFT amplitude  $\rightarrow C_{Q_L \bar{d}_R \phi}(u, \mu) = \frac{V_Q^\dagger G}{u\xi - 1}.$

Also, in the limit of  $m_\Psi \gg m_S$ :  $C_{Q_L \bar{d}_R \phi}(u, \mu) = -V_Q^\dagger G$ ,  
which depends neither on  $m_S$  nor on  $u \rightarrow$  local!

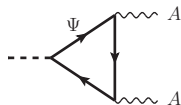
Many coefficients generated at the loop-level, for example:

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$$\rightarrow C_{GG}(m_S) = \frac{T_F}{\pi^2} \left[ \left( \frac{4m_\Psi^2}{m_S^2} - 1 \right) \arcsin^2 \left( \frac{m_S}{2m_\Psi} \right) - 1 \right]$$

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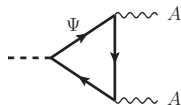
The diagram shows a triangle loop. The top-left vertex is connected to a dashed line representing an incoming fermion. The top edge of the triangle is a fermion line labeled  $\Psi$  with an arrow pointing right. The right edge is a vertical fermion line with an arrow pointing down. The bottom edge is a fermion line with an arrow pointing left. Two wavy lines representing scalar particles, both labeled  $A$ , are attached to the right vertex of the triangle.

$$\rightarrow C_{GG}(m_S) = \frac{T_F}{\pi^2} \left[ \left( \frac{4m_\Psi^2}{m_S^2} - 1 \right) \arcsin^2 \left( \frac{m_S}{2m_\Psi} \right) - 1 \right]$$

Wilson coefficient depends again on the momentum transfer ( $Q^2 = m_S^2$ ).



Many coefficients generated at the loop-level, for example:



The diagram shows a triangle loop. The left vertex is connected to a dashed line. The top and bottom edges of the triangle are fermion lines with arrows pointing clockwise, labeled with the Greek letter  $\Psi$ . The right vertex is connected to two wavy lines, both labeled with the letter  $A$ .

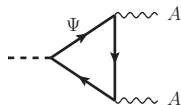
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**Take-away message:**

Many coefficients generated at the loop-level, for example:



The diagram shows a triangle loop with fermion lines (arrows) and wavy boson lines. The top vertex is labeled  $\Psi$ . The right side has two wavy lines labeled  $A$ . A dashed line enters from the left.

$$\rightarrow C_{GG}(m_S) = \frac{T_F}{\pi^2} \left[ \left( \frac{4m_\Psi^2}{m_S^2} - 1 \right) \arcsin^2 \left( \frac{m_S}{2m_\Psi} \right) - 1 \right]$$

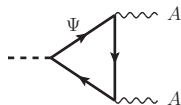
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**Take-away message:**

Matching no work of magic!

Many coefficients generated at the loop-level, for example:



The diagram shows a triangle loop with a fermion line (labeled  $\Psi$ ) and two scalar external lines (labeled  $A$ ). The fermion line enters from the left, goes up, then right, then down, and exits to the left. The scalar lines enter from the top and bottom right, and exit to the right. The loop is formed by the fermion line and two scalar lines.

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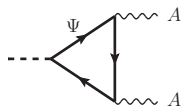
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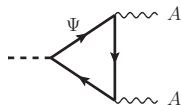
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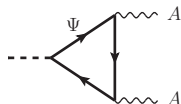
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Just compute amplitudes,

expand around  $\lambda = m_{SM}/m_S$  small,

equate with the EFT amplitudes,

use the RG to resum the large logs!



No. 28—"Three Log" Load of Sugar Pine at the Mill Pond.