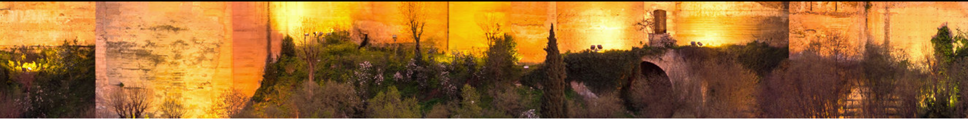
Effective Field Theory after a New-Physics Discovery

Matthias König
Physik-Institut
Universität Zürich

"From the Planck scale to the EW scale"
Granada, Jun 3, 2019



Universität Zürich[UZH]

FNSNF
Schweizerischer Nationalfonds zur Förderung der wissenschaftlichen Forschung

Effective Theories and NP

To describe the impact of NP effects on physical observables, **model-independent parameterizations** are an important tool for the BSM phenomenologist.

Effective Theories and NP

To describe the impact of NP effects on physical observables, **model-independent parameterizations** are an important tool for the BSM phenomenologist.

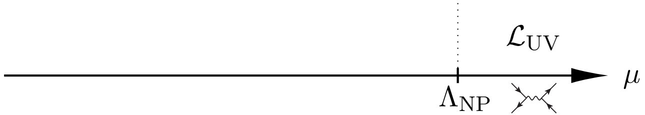
Under the assumption that **NP is heavy**, the **scale separation** between NP and SM **require** the use of **EFTs** to **avoid large logarithms**.

Effective Theories and NP

To describe the impact of NP effects on physical observables, **model-independent parameterizations** are an important tool for the BSM phenomenologist.

Under the assumption that **NP is heavy**, the **scale separation** between NP and SM **require** the use of **EFTs** to **avoid large logarithms**.

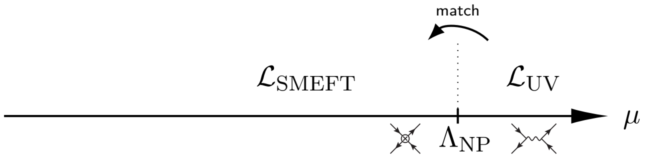
Integrate out high-scale physics → Match onto EFT Lagrangian!
Example: TeV-scale NP in low-energy observables



To describe the impact of NP effects on physical observables, **model-independent parameterizations** are an important tool for the BSM phenomenologist.

Under the assumption that **NP is heavy**, the **scale separation** between NP and SM **require** the use of **EFTs** to **avoid large logarithms**.

Integrate out high-scale physics → Match onto EFT Lagrangian!
Example: TeV-scale NP in low-energy observables

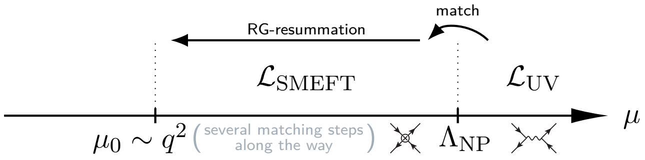


Effective Theories and NP

To describe the impact of NP effects on physical observables, **model-independent parameterizations** are an important tool for the BSM phenomenologist.

Under the assumption that **NP is heavy**, the **scale separation** between NP and SM **require** the use of **EFTs** to **avoid large logarithms**.

Integrate out high-scale physics → Match onto EFT Lagrangian!
Example: TeV-scale NP in low-energy observables

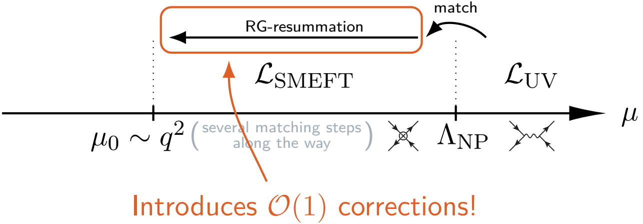


Effective Theories and NP

To describe the impact of NP effects on physical observables, **model-independent parameterizations** are an important tool for the BSM phenomenologist.

Under the assumption that **NP is heavy**, the **scale separation** between NP and SM **require** the use of **EFTs** to **avoid large logarithms**.

Integrate out high-scale physics → Match onto EFT Lagrangian!
Example: TeV-scale NP in low-energy observables

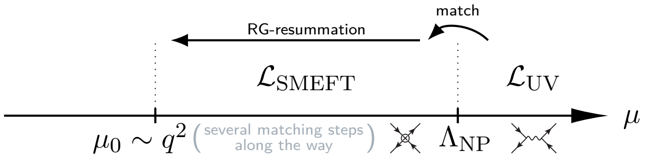


Effective Theories and NP

To describe the impact of NP effects on physical observables, **model-independent parameterizations** are an important tool for the BSM phenomenologist.

Under the assumption that **NP is heavy**, the **scale separation** between NP and SM **require** the use of **EFTs** to **avoid large logarithms**.

Integrate out high-scale physics $\rightarrow$ Match onto EFT Lagrangian!
Example: TeV-scale NP in low-energy observables



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

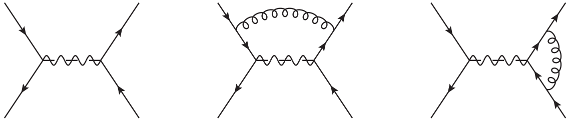
Divergence structure of one-loop amplitudes

Universität Zürich[UZH]

The large logarithms $\left(\frac{\alpha}{\pi} \ln \frac{q^2}{\Lambda^2}\right)$ are **not present** when q^2 is of the **hard scale**.

$\overset{?}{\Rightarrow}$ High-energy processes computable at **fixed order**.

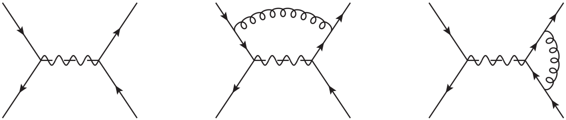
The large logarithms $\left(\frac{\alpha}{\pi}\ln\frac{q^2}{\Lambda^2}\right)$ are **not present** when q^2 is of the **hard scale**.
$\overset{?}{\Rightarrow}$ High-energy processes computable at **fixed order**.



$$i\mathcal{A}_{\rm NLO} \sim i\mathcal{A}_0 \left\{ 1 + \frac{\alpha_s}{\pi}\left(a\log\frac{q^2}{M^2} \;+\; b\log^2\frac{q^2}{m_f^2} \;+\; \text{const.}\right)\right\}$$

The large logarithms $\left(\frac{\alpha}{\pi}\ln\frac{q^2}{\Lambda^2}\right)$ are **not present** when q^2 is of the **hard scale**.

$\overset{?}{\Rightarrow}$ High-energy processes computable at **fixed order**.



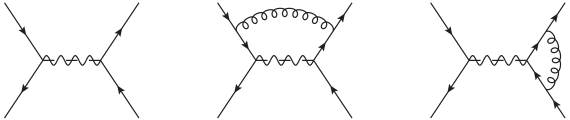
$$i\mathcal{A}_{\rm NLO} \sim i\mathcal{A}_0 \left\{1 + \frac{\alpha_s}{\pi}\left(a\log\frac{q^2}{M^2} + b\log^2\frac{q^2}{m_f^2} + \text{const.}\right)\right\}$$

large log from
heavy mass M^2

Divergence structure of one-loop amplitudes

The large logarithms $\left(\frac{\alpha}{\pi} \ln \frac{q^2}{\Lambda^2}\right)$ are **not present** when q^2 is of the **hard scale**.

$\overset{?}{\Rightarrow}$ High-energy processes computable at **fixed order**.



$$i\mathcal{A}_{\text{NLO}} \sim i\mathcal{A}_0 \left\{ 1 + \frac{\alpha_s}{\pi} \left(a \log \frac{q^2}{M^2} + b \log^2 \frac{q^2}{m_f^2} + \text{const.} \right) \right\}$$

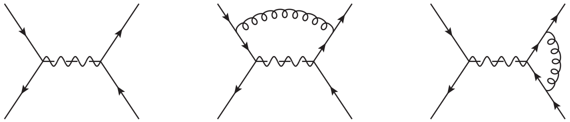
large log from heavy mass M^2

large **double** log from soft/collinear IR singularities

Divergence structure of one-loop amplitudes

The large logarithms $\left(\frac{\alpha}{\pi}\ln\frac{q^2}{\Lambda^2}\right)$ are **not present** when q^2 is of the **hard scale**.

$\overset{?}{\Rightarrow}$ High-energy processes computable at **fixed order**.



$$i\mathcal{A}_{\text{NLO}} \sim i\mathcal{A}_0 \left\{1 + \frac{\alpha_s}{\pi}\left(a\log\frac{q^2}{M^2} + b\log^2\frac{q^2}{m_f^2} + \text{const.}\right)\right\}$$

large log from heavy mass M^2

large **double** log from soft/collinear IR singularities

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

Assuming discovery of a resonance S, how to describe decays to SM particles with $m_{\mathrm{SM}}/m_S = \lambda \ll 1$?

Assuming discovery of a resonance S, how to describe decays to SM particles with $m_{\rm SM}/m_S = \lambda \ll 1$?
During the diphoton-delirium: "SMEFT$+$ S"

$$\mathcal{L}_{\rm eff} = \frac{C_\phi}{\Lambda} S|D_\mu\phi|^2 + \frac{C_g}{\Lambda} S F^a_{\mu\nu} F^{a,\mu\nu} + \frac{C_u}{\Lambda} S\, \bar{Q}_L \tilde{\phi} u_R + \frac{C_d}{\Lambda} S\, \bar{Q}_L \phi d_R$$

Resonances

Assuming discovery of a resonance S, how to describe decays to SM particles with $m_{\rm SM}/m_S = \lambda \ll 1$?
During the diphoton-delirium: "SMEFT+ S"

$$\mathcal{L}_{\rm eff} = \frac{C_\phi}{\Lambda} S|D_\mu \phi|^2 + \frac{C_g}{\Lambda} S F^a_{\mu\nu} F^{a,\mu\nu} + \frac{C_u}{\Lambda} S\,\bar{Q}_L \tilde{\phi} u_R + \frac{C_d}{\Lambda} S\,\bar{Q}_L \phi d_R$$

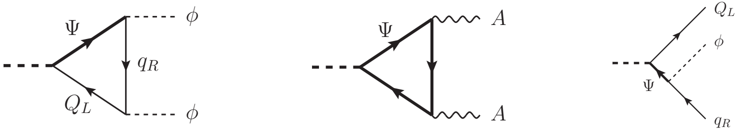
Not in **general** valid, because now $q^2 \sim \Lambda_{\rm NP}$!

Assuming discovery of a resonance S, how to describe decays to SM particles with $m_{\mathrm{SM}}/m_S = \lambda \ll 1$?
During the diphoton-delirium: "SMEFT+ S"

$$\mathcal{L}_{\text{eff}} = \frac{C_\phi}{\Lambda} S|D_\mu\phi|^2 + \frac{C_g}{\Lambda} S F^a_{\mu\nu} F^{a,\mu\nu} + \frac{C_u}{\Lambda} S\, \bar{Q}_L \tilde{\phi} u_R + \frac{C_d}{\Lambda} S\, \bar{Q}_L \phi d_R$$

Not in **general** valid, because now $q^2 \sim \Lambda_{\mathrm{NP}}$!

1. The **UV completion** might generate these operators **close** to m_S
   $\rightarrow$ Operators non-local for $m_{\mathrm{NP}} \sim m_S$!



Resonances

Assuming discovery of a resonance S, how to describe decays to SM particles with $m_{\rm SM}/m_S = \lambda \ll 1$?
During the diphoton-delirium: "SMEFT+ S"

$$\mathcal{L}_{\rm eff} = \frac{C_\phi}{\Lambda} S|D_\mu\phi|^2 + \frac{C_g}{\Lambda} S F^a_{\mu\nu} F^{a,\mu\nu} + \frac{C_u}{\Lambda} S\,\bar{Q}_L \tilde{\phi} u_R + \frac{C_d}{\Lambda} S\,\bar{Q}_L \phi d_R$$

Not in **general** valid, because now $q^2 \sim \Lambda_{\rm NP}$!

1. The **UV completion** might generate these operators **close** to m_S $\rightarrow$ Operators non-local for $m_{\rm NP} \sim m_S$!
2. Wilsonian EFT **misses** hard radiation of **SM particles** with **large virtualities**!

Assuming discovery of a resonance S, how to describe decays to SM particles with $m_{\rm SM}/m_S = \lambda \ll 1$?
During the diphoton-delirium: "SMEFT+ S"

$$\mathcal{L}_{\rm eff} = \frac{C_\phi}{\Lambda} S|D_\mu\phi|^2 + \frac{C_g}{\Lambda} S F^a_{\mu\nu} F^{a,\mu\nu} + \frac{C_u}{\Lambda} S\,\bar{Q}_L\tilde{\phi}u_R + \frac{C_d}{\Lambda} S\,\bar{Q}_L\phi d_R$$

Not in **general** valid, because now $q^2 \sim \Lambda_{\rm NP}$!

1. The **UV completion** might generate these operators **close** to m_S $\rightarrow$ Operators non-local for $m_{\rm NP} \sim m_S$!
2. Wilsonian EFT **misses** hard radiation of **SM particles** with **large virtualities**!
3. The **power-counting** implied by this EFT does **not** reproduce the actual scaling of the amplitudes:

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

Soft-Collinear Effective Theory

For heavy $\rightarrow$ light transitions, the appropriate framework is **Soft-Collinear Effecitve Theory** (SCET)

For heavy $\rightarrow$ light transitions, the appropriate framework is **Soft-Collinear Effecitve Theory** (SCET)

Idea: Integrate out fields with **large invariant mass** - either **heavy fields** or light fields with **large virtualities**!

For heavy $\to$ light transitions, the appropriate framework is **Soft-Collinear Effecitve Theory** (SCET)

Idea: Integrate out fields with **large invariant mass** - either **heavy fields** or light fields with **large virtualities**!

The low-energy theory has **effective fields** with $k^2 \sim 0$, but **individual components** can be **large**:

$$k^\mu = (\Lambda, 0, 0, -\Lambda)$$ - “collinear mode”

For heavy $\rightarrow$ light transitions, the appropriate framework is **Soft-Collinear Effecitve Theory** (SCET)

Idea: Integrate out fields with **large invariant mass** - either **heavy fields** or light fields with **large virtualities**!

The low-energy theory has **effective fields** with $k^2 \sim 0$, but **individual components** can be **large**:

$k^\mu = (\Lambda, 0, 0, -\Lambda)$ - "collinear mode"

$\rightarrow$no suppression $\frac{\partial_\mu}{\Lambda}\phi_c$ for some components, unlike SMEFT!

For heavy $\rightarrow$ light transitions, the appropriate framework is **Soft-Collinear Effecitve Theory** (SCET)

Idea: Integrate out fields with **large invariant mass** - either **heavy fields** or light fields with **large virtualities**!

The low-energy theory has **effective fields** with $k^2 \sim 0$, but **individual components** can be **large**:

$k^\mu = (\Lambda, 0, 0, -\Lambda)$ - “collinear mode”
$k^\mu = O(\epsilon)$ - “soft mode”

For heavy $\rightarrow$ light transitions, the appropriate framework is **Soft-Collinear Effecitve Theory** (SCET)

Idea: Integrate out fields with **large invariant mass** - either **heavy fields** or light fields with **large virtualities**!

The low-energy theory has **effective fields** with $k^2 \sim 0$, but **individual components** can be **large**:

$k^\mu = (\Lambda, 0, 0, -\Lambda)$ - "collinear mode"
$k^\mu = O(\epsilon)$ - "soft mode"

Lots of (interesting) field-theory implications:

non-local operators, $\mathcal{C} \cdot \langle \mathcal{O} \rangle \rightarrow \int d\omega\, \mathcal{C}(\omega) \cdot \langle \mathcal{O} \rangle (\omega)$, Wilson lines, power-counting $\neq$ field mass-dimension, multiple effective fields per particle, ...

For heavy $\to$ light transitions, the appropriate framework is **Soft-Collinear Effecitve Theory** (SCET)

Idea: Integrate out fields with **large invariant mass** - either **heavy fields** or light fields with **large virtualities**!

The low-energy theory has **effective fields** with $k^2 \sim 0$, but **individual components** can be **large**:

$k^\mu = (\Lambda, 0, 0, -\Lambda)$ - "collinear mode"
$k^\mu = O(\epsilon)$ - "soft mode"

Lots of (interesting) field-theory implications:

non-local operators, $\mathcal{C} \cdot \langle \mathcal{O} \rangle \to \int d\omega \, \mathcal{C}(\omega) \cdot \langle \mathcal{O} \rangle (\omega)$, Wilson lines, power-counting $\neq$ field mass-dimension, multiple effective fields per particle, . . .

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

A bottom-up approach

Assume a new spin-0, gauge-singlet particle S and build a general framework based on **Soft-Collinear Effective Theory** (SCET) in the SMEFT-spirit:

A bottom-up approach

Assume a new spin-0, gauge-singlet particle S and build a general framework based on **Soft-Collinear Effective Theory** (SCET) in the SMEFT-spirit:

Write out all possible operators:

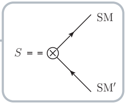
$$\mathcal{L}_{\text{eff}} = \sum_i \mathcal{C}_i \otimes \left(S \cdot \mathcal{J}_i^{\text{SM}} \right)$$

A bottom-up approach

Assume a new spin-0, gauge-singlet particle S and build a general framework based on **Soft-Collinear Effective Theory** (SCET) in the SMEFT-spirit:

Write out all possible operators:

$$\mathcal{L}_{\text{eff}} = \sum_i \mathcal{C}_i \otimes \left(S \cdot \mathcal{J}_i^{\text{SM}} \right)$$

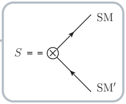


A bottom-up approach

Assume a new spin-0, gauge-singlet particle S and build a general framework based on **Soft-Collinear Effective Theory** (SCET) in the SMEFT-spirit:

Write out all possible operators:

$$\mathcal{L}_{\text{eff}} = \sum_i \mathcal{C}_i \otimes \left(S \cdot \mathcal{J}_i^{\text{SM}}\right)$$



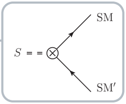
This EFT separates the scales m_S and m_{SM} and the RG running of $\mathcal{C}_i$ resums the corresponding (double-) logs!

A bottom-up approach

Assume a new spin-0, gauge-singlet particle S and build a general framework based on **Soft-Collinear Effective Theory** (SCET) in the SMEFT-spirit:

Write out all possible operators:

$$\mathcal{L}_{\text{eff}} = \sum_i \mathcal{C}_i \otimes \left(S \cdot \mathcal{J}_i^{\text{SM}} \right)$$



This EFT separates the scales m_S and m_{SM} and the RG running of $\mathcal{C}_i$ resums the corresponding (double-) logs!

Based on:

Effective Field Theory after a New-Physics Discovery

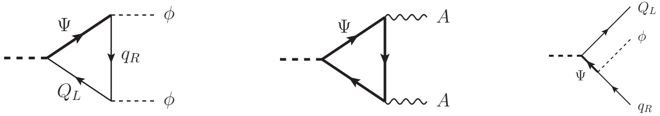
Stefan Alte, MK, Matthias Neubert

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

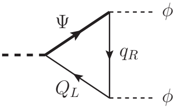
Effective Theory for a Heavy Scalar Coupled to the SM via Vector-Like Quarks

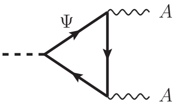
Stefan Alte, MK, Matthias Neubert

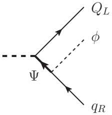
[arXiv:1902.04593]



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

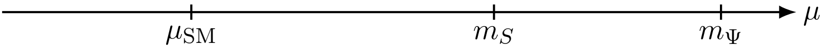




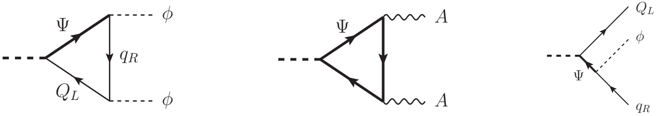


Even if the heavy quarks in these diagrams have $m_\Psi \gg m_S$, the "SMEFT+S" separates only m_Ψ from m_S, but not m_S from $m_{\rm SM}$!

Whether Ψ is heavy or not, does not really matter* for the SCET:



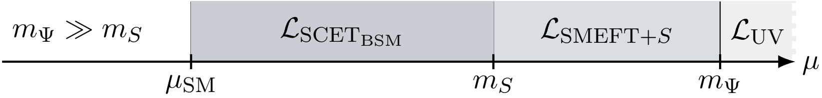
SCET beyond the SM



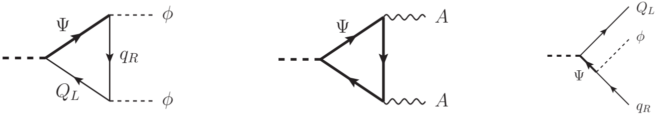
Even if the heavy quarks in these diagrams have $m_\Psi \gg m_S$, the "SMEFT+S" separates only m_Ψ from m_S, but not m_S from $m_{\rm SM}$!

Whether Ψ is heavy or not, does not really matter* for the SCET:

- If $m_\Psi \gg m_S$, then we integrate can out Ψ Wilson-style and obtain the "SMEFT+S". To properly separate the scales m_S and $\mu_{\rm SM}$, we **match** this EFT **onto the SCET**.



SCET beyond the SM



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

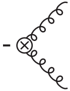
Whether Ψ is heavy or not, does not really matter* for the SCET:

- If $m_\Psi \gg m_S$, then we integrate can out Ψ Wilson-style and obtain the "SMEFT+S". To properly separate the scales m_S and μ_{SM}, we **match** this EFT **onto the SCET**.
- If $m_\Psi \sim m_S$, then we integrate can out Ψ **without** taking the **local limit**, **directly matching** the UV theory onto the SCET.

Operator basis - examples

Operators responsible for he most relevant decays of the S:

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



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

$S \to$ jets

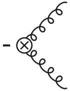
$S \to \gamma\gamma$

$S \to WW$

Operator basis - examples

Operators responsible for he most relevant decays of the S:

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

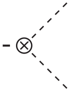


$$O_{AA} = S\, g^{\perp}_{\mu\nu}\, \mathcal{A}^{\mu,a}_{c}\, \mathcal{A}^{\nu,a}_{\bar{c}}$$

$S \to$ jets

$S \to \gamma\gamma$

$S \to WW$



$$O_{\phi\phi}(\mu) = S\, \left(\Phi^{\dagger}_{n_1} \Phi_{n_2} + \Phi^{\dagger}_{n_2} \Phi_{n_1} \right)$$

$S \to$ hh

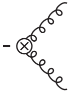
$S \to W_L W_L$

$S \to Z_L Z_L$

Operator basis - examples

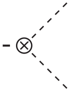
Operators responsible for he most relevant decays of the S:

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



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

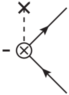
$S \to$ jets
$S \to \gamma\gamma$
$S \to WW$



$$O_{\phi\phi}(\mu) = S\, \left(\Phi_{n_1}^{\dagger}\, \Phi_{n_2} + \Phi_{n_2}^{\dagger}\, \Phi_{n_1}\right)$$

$S \to$ hh
$S \to W_L W_L$
$S \to Z_L Z_L$

At $\mathcal{O}(\lambda^3)$:



$$O_{F_L \bar{f}_R}^{ij}(\mu) = S\, \bar{\chi}_{L,n_1}^{i}\, \Phi_0\, \chi_{R,n_2}^{j}$$

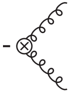
$S \to$ jets (subleading)
$S \to t\bar{t}$

Operator basis - examples

Universität Zürich UZH

Operators responsible for he most relevant decays of the S:

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

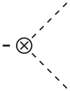


$$O_{AA} = S\, g^{\perp}_{\mu\nu}\, \mathcal{A}^{\mu,a}_{c}\, \mathcal{A}^{\nu,a}_{\bar{c}}$$

$S \to$ jets

$S \to \gamma\gamma$

$S \to WW$



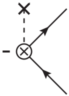
$$O_{\phi\phi}(\mu) = S\, \left(\Phi^{\dagger}_{n_1} \Phi_{n_2} + \Phi^{\dagger}_{n_2} \Phi_{n_1} \right)$$

$S \to$ hh

$S \to W_L W_L$

$S \to Z_L Z_L$

At $\mathcal{O}(\lambda^3)$:



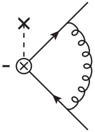
$$O^{ij}_{F_L \bar{f}_R}(\mu) = S\, \bar{\chi}^{i}_{L,n_1}\, \Phi_0\, \chi^{j}_{R,n_2}$$

$S \to$ jets (subleading)

$S \to t\bar{t}$

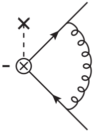
Details and full list of operators: ☞ [Alte, MK, Neubert (*2018*), JHEP 1808 (2018) 095]

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



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

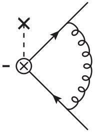
Radiative corrections introduce **large (Sudakov) logarithms**, arising from soft-collinear divergences.



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

Resummation proceeds, as usual, via **renormalization** of the effective Lagrangian.

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



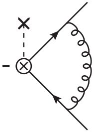
$$\sim \quad \mathcal{M}_{\rm LO} \left\{ 1 + \frac{\alpha_s(\mu)\, C_F}{\pi} \ln^2 \frac{\mu^2}{m_q^2} \right\}$$

Resummation proceeds, as usual, via **renormalization** of the effective Lagrangian.

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

Resummation of large logarithms

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



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

Resummation proceeds, as usual, via **renormalization** of the effective Lagrangian.

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

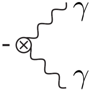
Important effects when predicting **decay rates** or putting **constraints** on models!

Resumation: Numerology

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

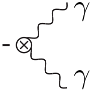
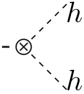
Resummation: Numerology

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

Decay channel	$U_{RG}(\mu_0, M) = C(\mu_0)/C(M)$	$\Gamma_{\rm resum}/\Gamma_{\rm fixed} = \lvert U_{RG}\rvert^2$
	$U_{WW}(m_W, M) = 0.8\, e^{0.23i}$ $U_{BB}(m_W, M) = 1$	0.67

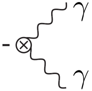
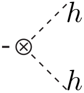
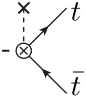
Resummation: Numerology

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

Decay channel	$U_{RG}(\mu_0, M) = C(\mu_0)/C(M)$	$\Gamma_{\text{resum}}/\Gamma_{\text{fixed}} = \lvert U_{RG}\rvert^2$
	$U_{WW}(m_W, M) = 0.8\, e^{0.23i}$ $U_{BB}(m_W, M) = 1$	0.67
	$U_{\phi\phi}(m_h, M) = 0.79\, e^{0.08i}$	0.62

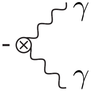
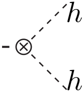
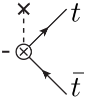
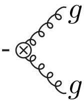
Resummation: Numerology

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

Decay channel	$U_{RG}(\mu_0, M) = C(\mu_0)/C(M)$	$\Gamma_{\text{resum}}/\Gamma_{\text{fixed}} = \|U_{RG}\|^2$
	$U_{WW}(m_W, M) = 0.8\, e^{0.23i}$ $U_{BB}(m_W, M) = 1$	0.67
	$U_{\phi\phi}(m_h, M) = 0.79\, e^{0.08i}$	0.62
	$U_{t\bar{t}}(m_t, M) = 0.9\, e^{0.31i}$	0.81

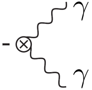
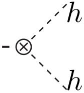
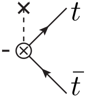
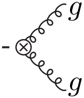
Resummation: Numerology

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

Decay channel	$U_{RG}(\mu_0, M) = C(\mu_0)/C(M)$	$\Gamma_{\text{resum}}/\Gamma_{\text{fixed}} = \lvert U_{RG}\rvert^2$
	$U_{WW}(m_W, M) = 0.8\, e^{0.23i}$ $U_{BB}(m_W, M) = 1$	0.67
	$U_{\phi\phi}(m_h, M) = 0.79\, e^{0.08i}$	0.62
	$U_{t\bar{t}}(m_t, M) = 0.9\, e^{0.31i}$	0.81
	$U_{GG}(\mu_j, M) = 0.38\, e^{0.98i}$ $\mu_j = 100$ GeV	0.15

Resummation: Numerology

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

Decay channel	$U_{RG}(\mu_0, M) = C(\mu_0)/C(M)$	$\Gamma_{\text{resum}}/\Gamma_{\text{fixed}} = \lvert U_{RG}\rvert^2$
	$U_{WW}(m_W, M) = 0.8\, e^{0.23i}$ $U_{BB}(m_W, M) = 1$	0.67
	$U_{\phi\phi}(m_h, M) = 0.79\, e^{0.08i}$	0.62
	$U_{t\bar{t}}(m_t, M) = 0.9\, e^{0.31i}$	0.81
	$U_{GG}(\mu_j, M) = 0.38\, e^{0.98i}$ $\mu_j = 100$ GeV	0.15

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

Conclusions

- The approach "SMEFT for low-energy, fixed order for collider" does not really hold.

Conclusions

- The approach "SMEFT for low-energy, fixed order for collider" does not really hold.
- **Heavy new particles** inject **large energies** into **light final states**!

Conclusions

- The approach “SMEFT for low-energy, fixed order for collider” does not really hold.
- **Heavy new particles** inject **large energies** into **light final states**!
- This leads to large logs $\alpha \log^2(m_{\mathrm{NP}}^2/m_{\mathrm{SM}}^2)$ that need to be **resummed**!

Conclusions

- The approach “SMEFT for low-energy, fixed order for collider” does not really hold.
- **Heavy new particles** inject **large energies** into **light final states**!
- This leads to large logs $\alpha \log^2(m_{\mathrm{NP}}^2/m_{\mathrm{SM}}^2)$ that need to be **resummed**!
- Resummation effects can **impact constraints** derived from collider searches.

Conclusions

- The approach "SMEFT for low-energy, fixed order for collider" does not really hold.
- **Heavy new particles** inject **large energies** into **light final states**!
- This leads to large logs $\alpha \log^2(m_{\mathrm{NP}}^2/m_{\mathrm{SM}}^2)$ that need to be **resummed**!
- Resummation effects can **impact constraints** derived from collider searches.
- SCET Operator basis, EFT amplitudes and anomalous dimensions **are provided** for your matching convenience.

Conclusions

- The approach "SMEFT for low-energy, fixed order for collider" does not really hold.
- **Heavy new particles** inject **large energies** into **light final states**!
- This leads to large logs $\alpha \log^2(m_{\mathrm{NP}}^2/m_{\mathrm{SM}}^2)$ that need to be **resummed**!
- Resummation effects can **impact constraints** derived from collider searches.
- SCET Operator basis, EFT amplitudes and anomalous dimensions **are provided** for your matching convenience.
- Lots of work to do: Operator bases and RGEs for **other NP resonances** (non-singlet, spin-1...) - see Bianka's talk!

Conclusions

- The approach "SMEFT for low-energy, fixed order for collider" does not really hold.
- **Heavy new particles** inject **large energies** into **light final states**!

Thank you for your attention!

- SCET Operator basis, EFT amplitudes and anomalous dimensions **are provided** for your matching convenience.
- Lots of work to do: Operator bases and RGEs for **other NP resonances** (non-singlet, spin-1...) - see Bianka's talk!

Bonus slides

A matching example

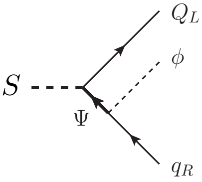
Matching example in a concrete UV theory:

A matching example

Matching example in a concrete UV theory:

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

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



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

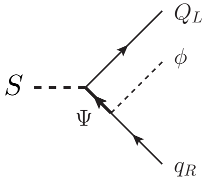
↑ momentum fraction between ϕ and Q_L

A matching example

Matching example in a concrete UV theory:

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

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



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

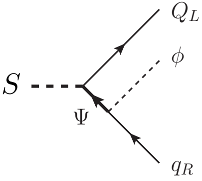
Compare with EFT amplitude $\rightarrow$ $C_{Q_L\bar{d}_R\phi}(u,\mu) = \dfrac{V_Q^\dagger G}{u\,\xi - 1}$.

(all given in the paper)

Matching example in a concrete UV theory:

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

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



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

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

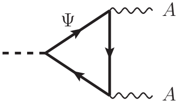
Also, in the limit of $m_\Psi \gg m_S$: $C_{Q_L\bar{d}_R\phi}(u,\mu) = -V_Q^\dagger G$,

which depends neither on m_S nor on u $\rightarrow$ local!

More matching

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

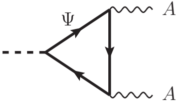
Many coefficients generated at the loop-level, for example:



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

More matching

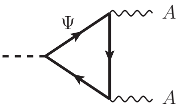
Many coefficients generated at the loop-level, for example:



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

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

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



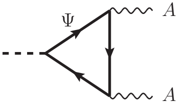
$$\rightarrow C_{GG}(m_S) = \frac{T_F}{\pi^2}\left[\left(\frac{4m_\Psi^2}{m_S^2}-1\right)\arcsin^2\left(\frac{m_S}{2m_\Psi}\right)-1\right]$$

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

Take-away message:

More matching

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

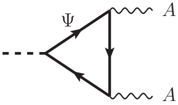


$$\to C_{GG}(m_S) = \frac{T_F}{\pi^2}\left[\left(\frac{4m_\Psi^2}{m_S^2} - 1\right)\arcsin^2\left(\frac{m_S}{2m_\Psi}\right) - 1\right]$$

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

Take-away message:
Matching no work of magic!

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



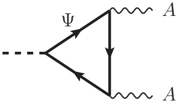
$$\to C_{GG}(m_S) = \frac{T_F}{\pi^2}\left[\left(\frac{4m_\Psi^2}{m_S^2} - 1\right)\arcsin^2\left(\frac{m_S}{2m_\Psi}\right) - 1\right]$$

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

Take-away message:
Matching no work of magic!
Just compute amplitudes,

More matching

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



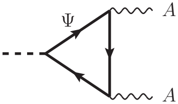
$$\rightarrow C_{GG}(m_S) = \frac{T_F}{\pi^2}\left[\left(\frac{4m_\Psi^2}{m_S^2} - 1\right)\arcsin^2\left(\frac{m_S}{2m_\Psi}\right) - 1\right]$$

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

Take-away message:
Matching no work of magic!
Just compute amplitudes,
expand around $\lambda = m_{\mathrm{SM}}/m_S$ small,

More matching

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



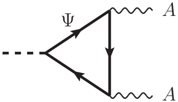
$$\to C_{GG}(m_S) = \frac{T_F}{\pi^2}\left[\left(\frac{4m_\Psi^2}{m_S^2} - 1\right)\arcsin^2\left(\frac{m_S}{2m_\Psi}\right) - 1\right]$$

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

Take-away message:
Matching no work of magic!
Just compute amplitudes,
expand around $\lambda = m_{\rm SM}/m_S$ small,
equate with the EFT amplitudes,

More matching

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



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

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

Take-away message:
Matching no work of magic!
Just compute amplitudes,
expand around $\lambda = m_{\mathrm{SM}}/m_S$ 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.