STrEAMlining EFT Matching

Area 5 LPCC EFT WG, Feb 08, 2021

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arXiv: 2011.02484, 2012.07851
with Timothy Cohen and Zhengkang Zhang

Outline

- EFT matching with functional methods up to one loop

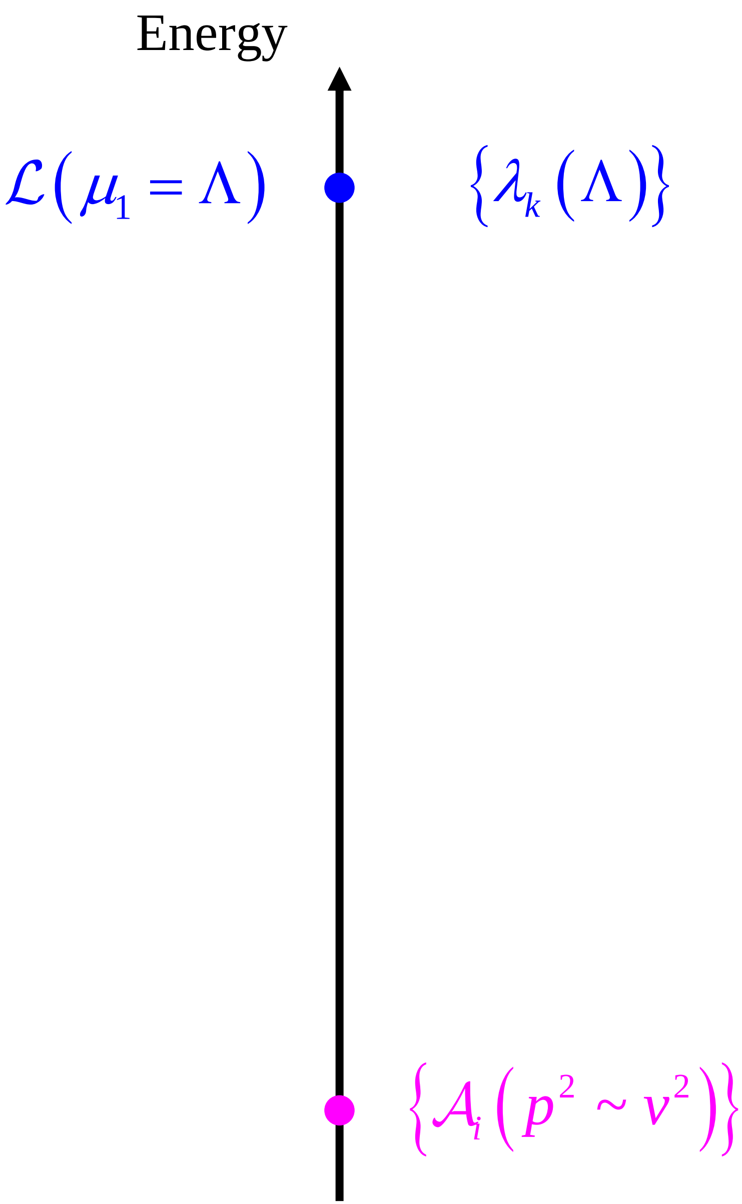
  --- Advantages compared to “amplitude matching”

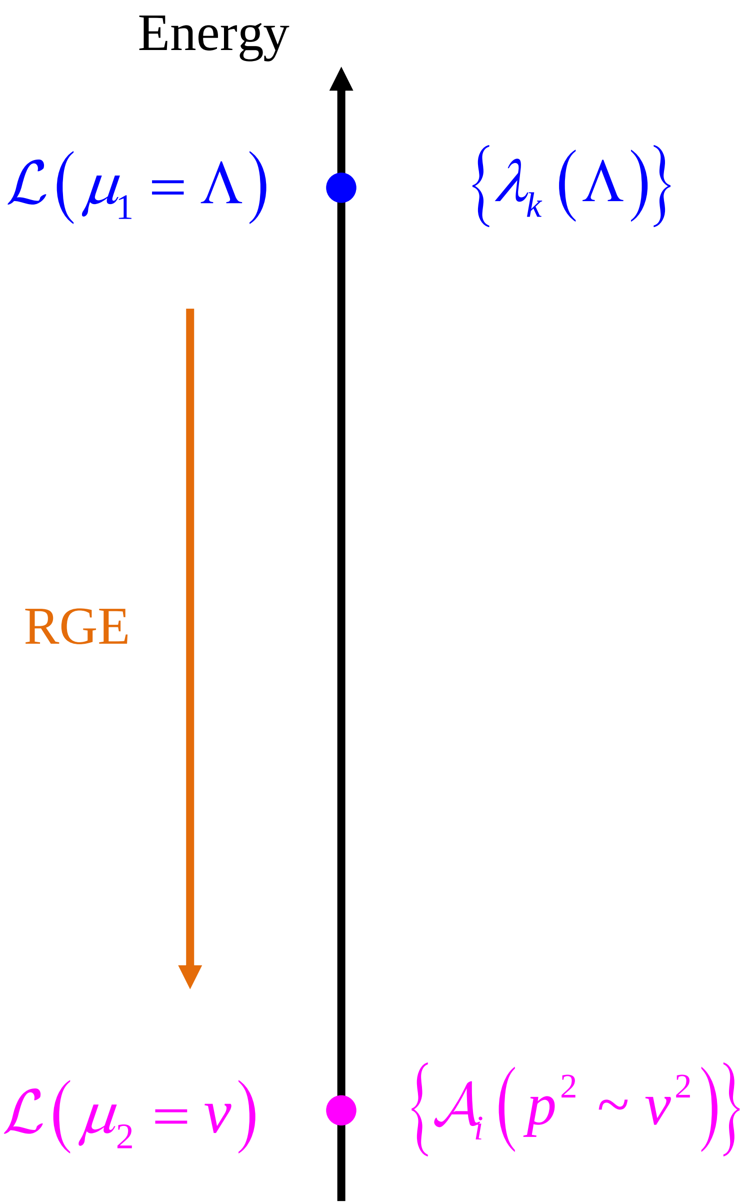
- A new way of organizing functional supertrace evaluation

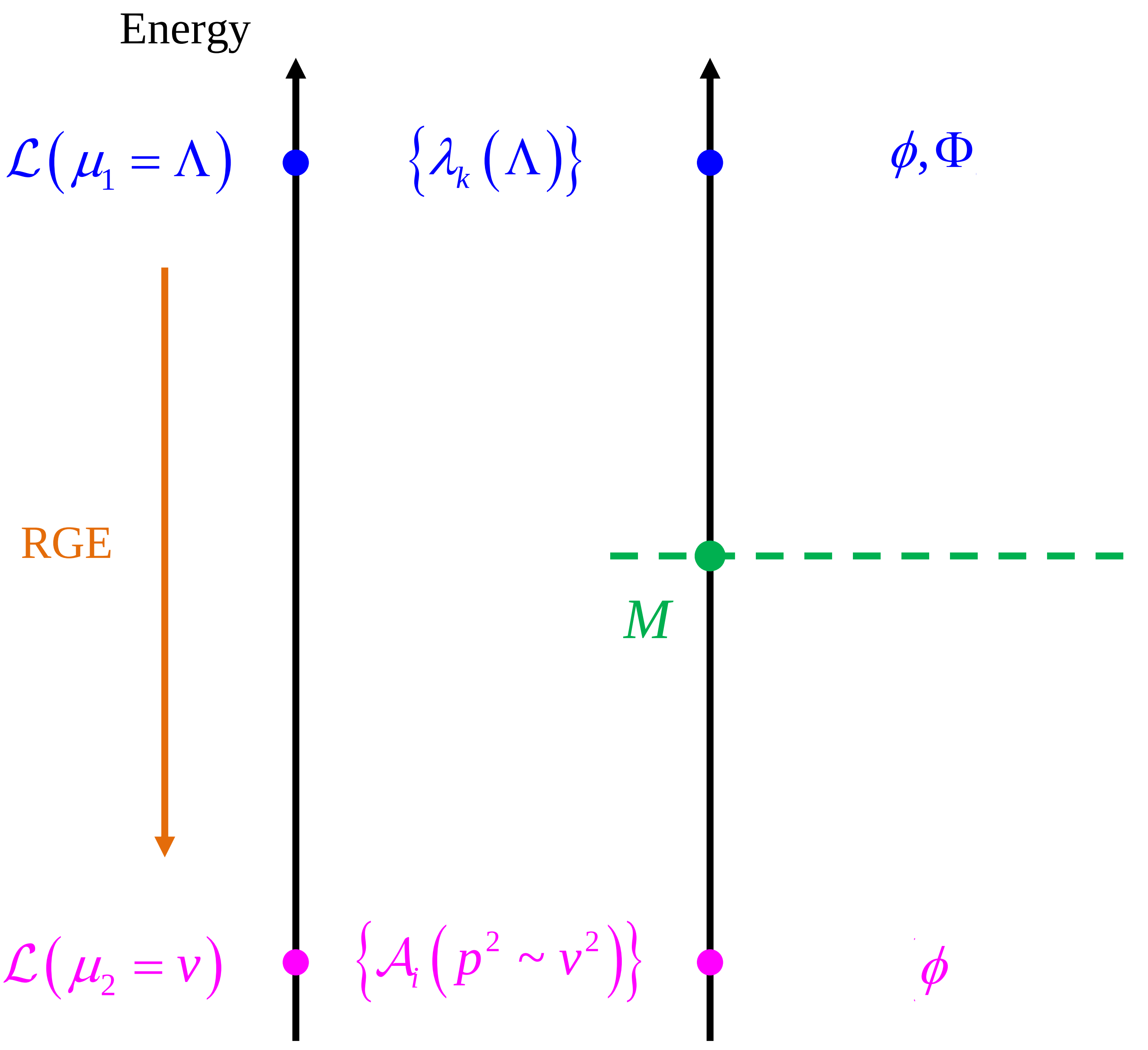
  --- Log-type and power-type

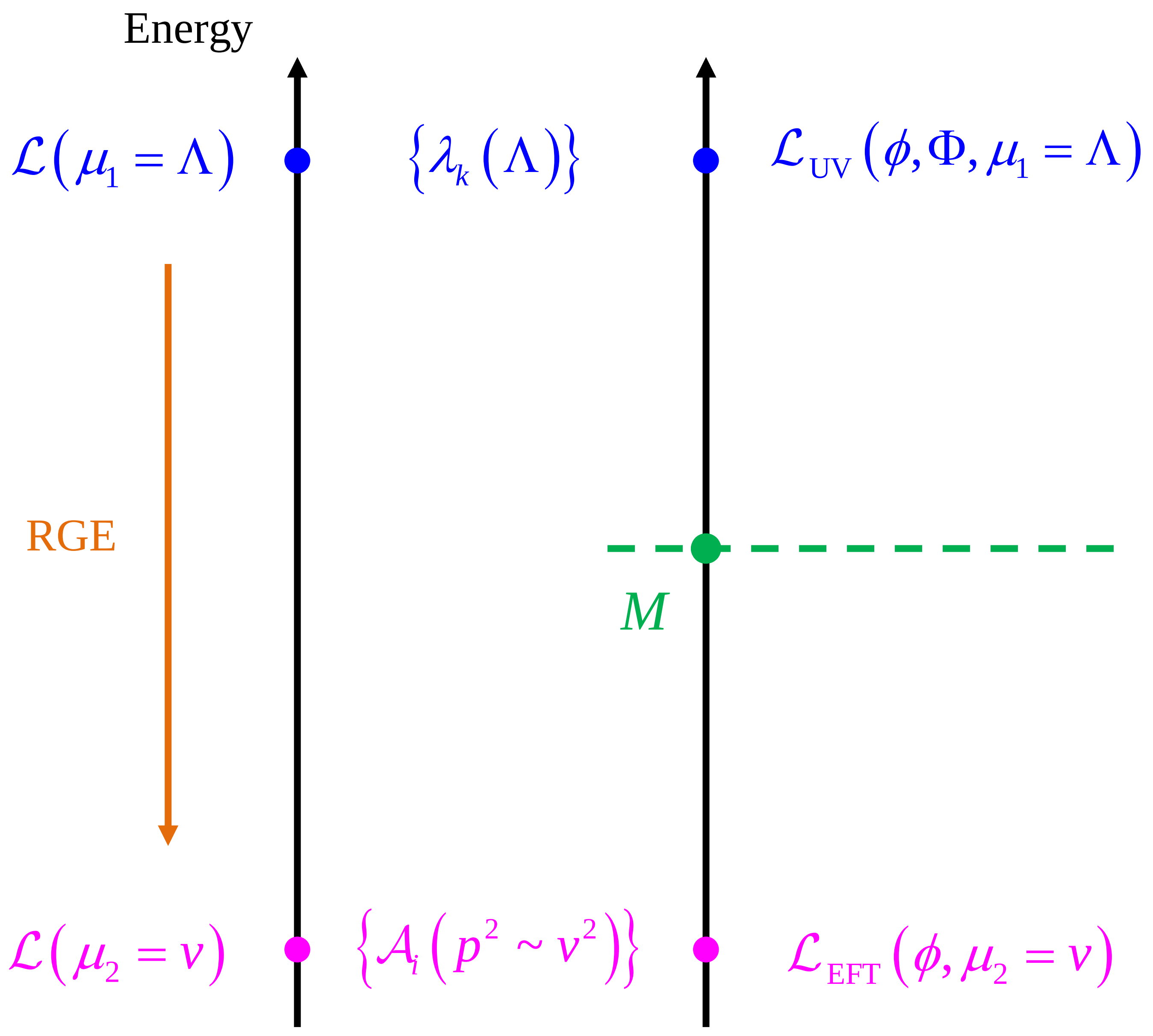
- STrEAM (SuperTrace Evaluation Automated for Matching)

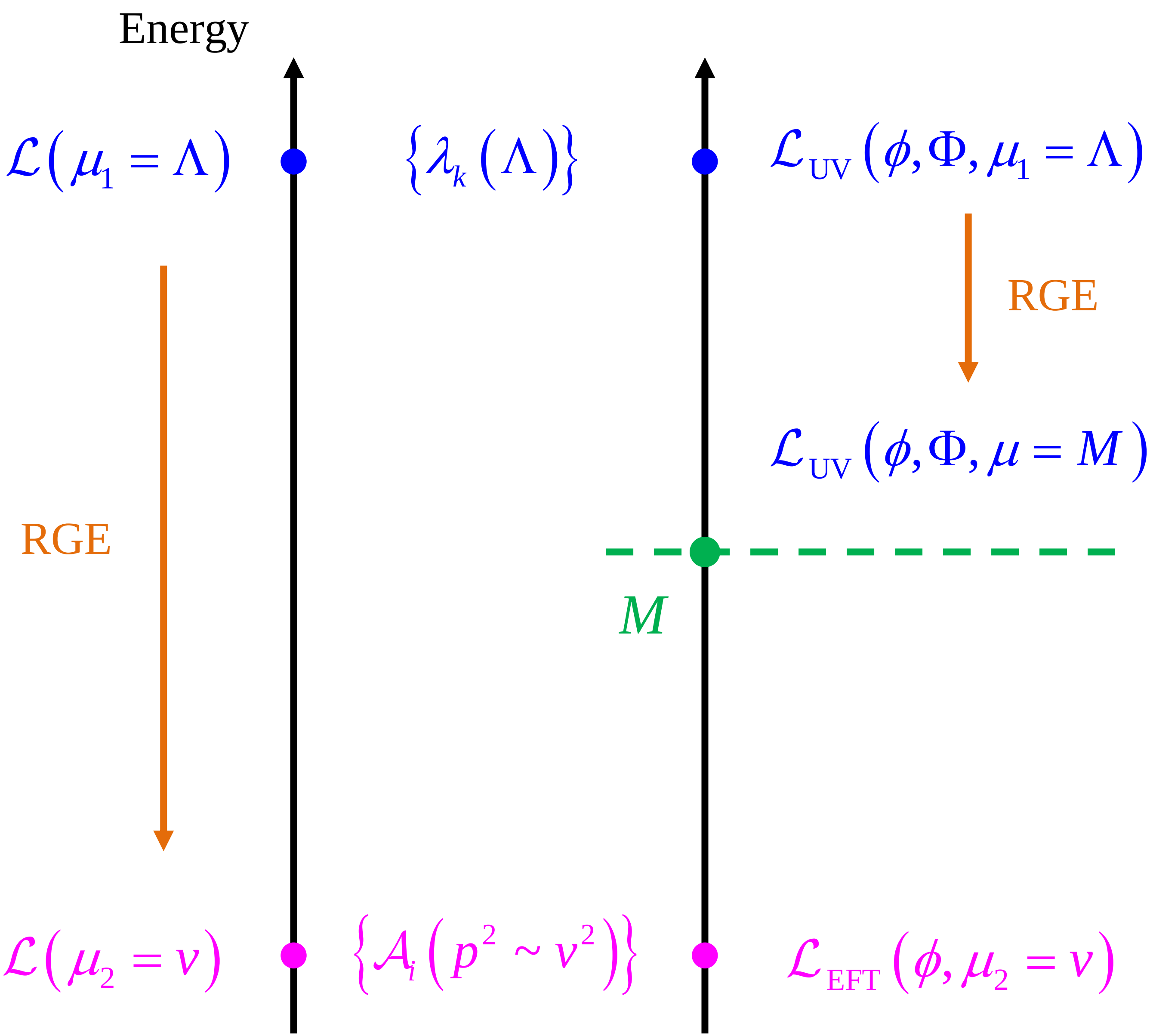
  --- Automates supertrace evaluations with CDE


Energy
$\mathcal{L}(\mu_1 = \Lambda)$
$\{\lambda_k(\Lambda)\}$
$\{\mathcal{A}_i(p^2 \sim v^2)\}$


Energy
$\mathcal{L}(\mu_1 = \Lambda)$
$\{\lambda_k(\Lambda)\}$
RGE
$\mathcal{L}(\mu_2 = v)$
$\{\mathcal{A}_i(p^2 \sim v^2)\}$


Energy
$\mathcal{L}(\mu_1 = \Lambda)$
$\{\lambda_k(\Lambda)\}$
ϕ, Φ
RGE
M
$\mathcal{L}(\mu_2 = v)$
$\{\mathcal{A}_i(p^2 \sim v^2)\}$
ϕ


Energy
$\mathcal{L}(\mu_1 = \Lambda)$
$\{\lambda_k(\Lambda)\}$
$\mathcal{L}_{\mathrm{UV}}(\phi, \Phi, \mu_1 = \Lambda)$
RGE
M
$\mathcal{L}(\mu_2 = v)$
$\{\mathcal{A}_i(p^2 \sim v^2)\}$
$\mathcal{L}_{\mathrm{EFT}}(\phi, \mu_2 = v)$



Energy
$\mathcal{L}(\mu_1 = \Lambda)$
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$\mathcal{L}_{\mathrm{UV}}(\phi, \Phi, \mu_1 = \Lambda)$
RGE
RGE
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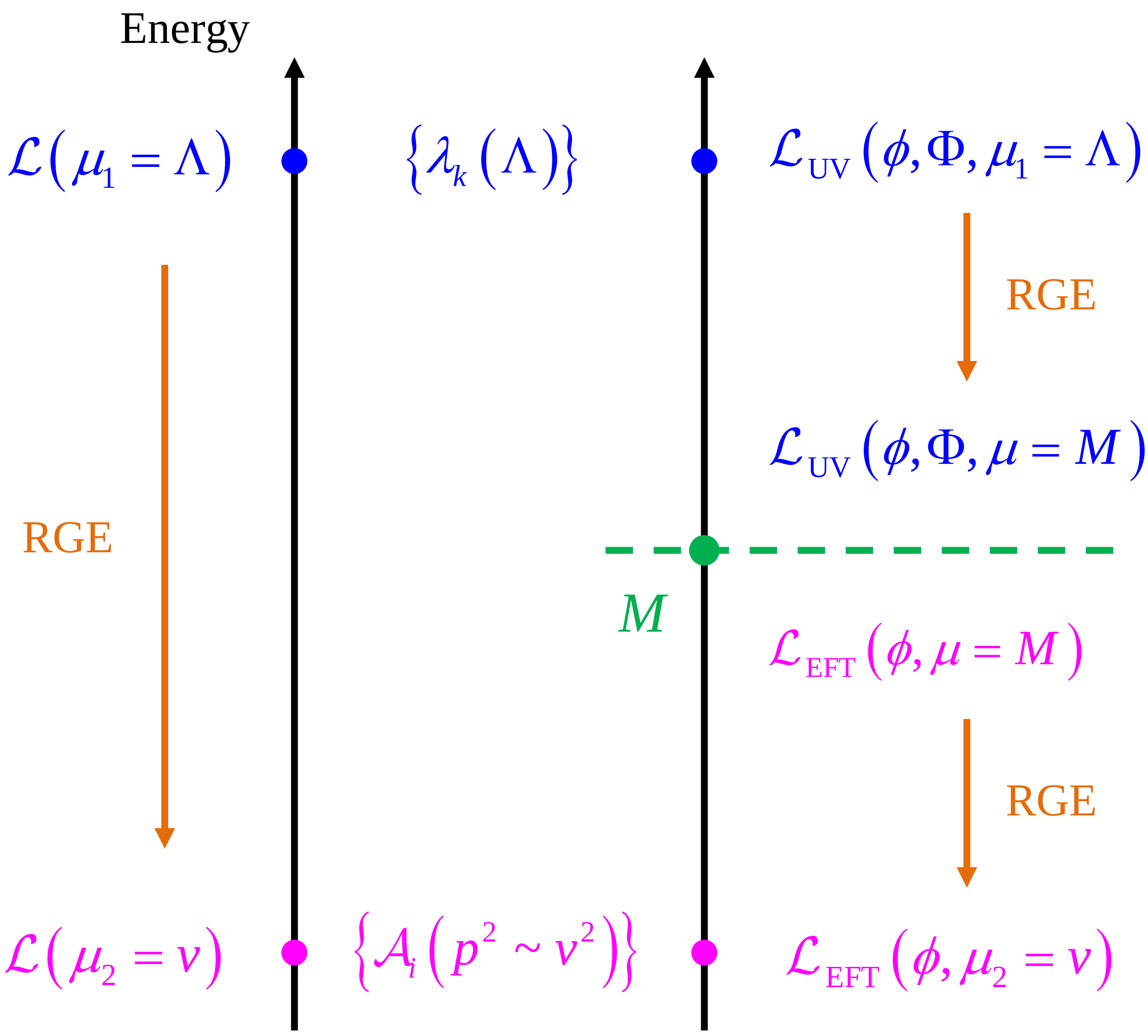
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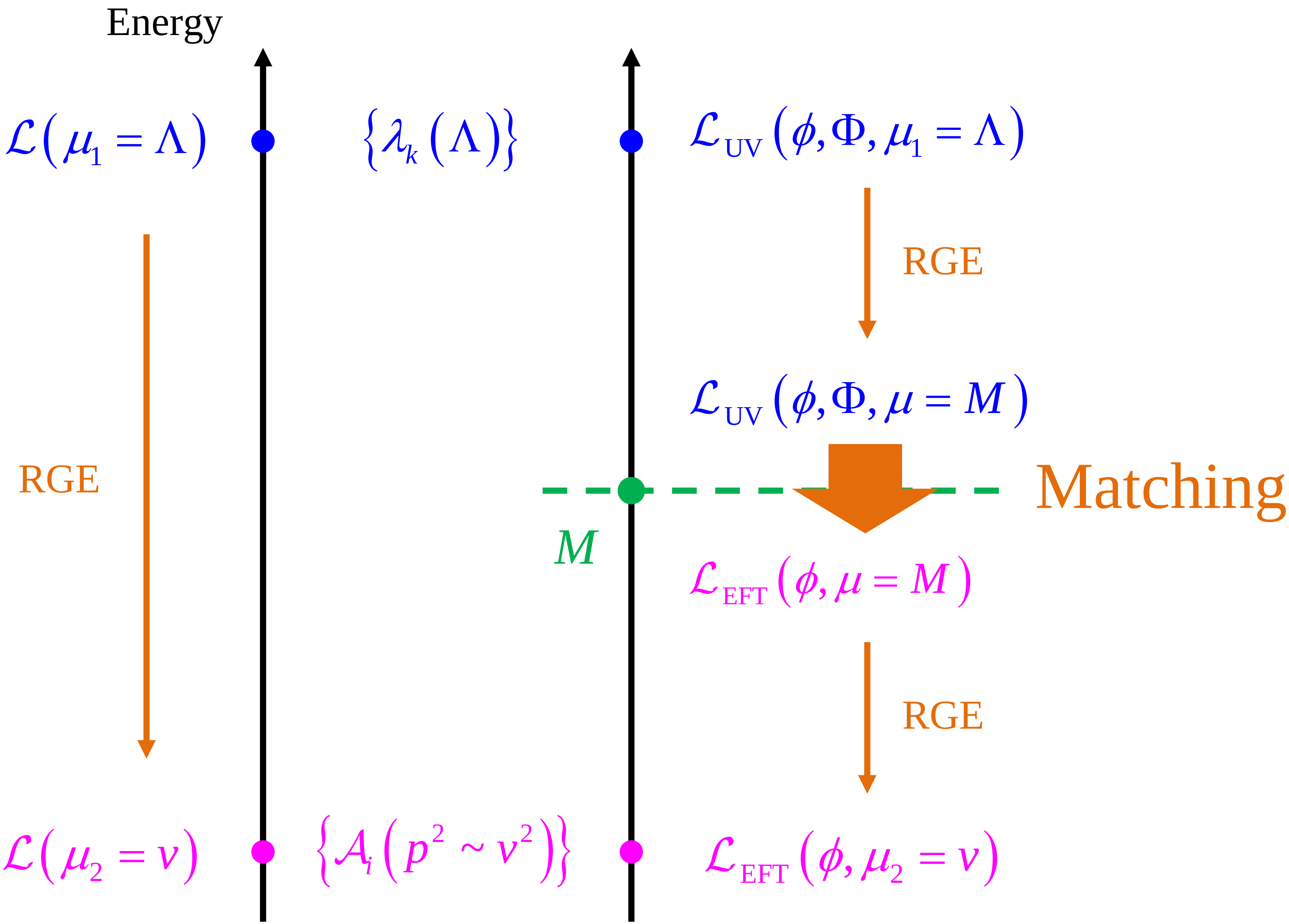
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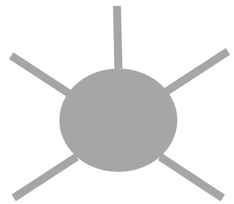
RGE
RGE
$\mathcal{L}_{\text{UV}}(\phi, \Phi, \mu = M)$
Matching
M
$\mathcal{L}_{\text{EFT}}(\phi, \mu = M)$
RGE
$\mathcal{L}(\mu_2 = v)$
$\{\mathcal{A}_i(p^2 \sim v^2)\}$
$\mathcal{L}_{\text{EFT}}(\phi, \mu_2 = v)$

Matching via Amplitudes

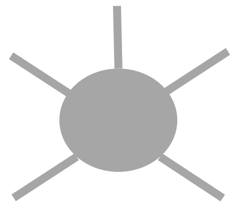
$$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{BSM}}\left(\phi_{\text{SM}}, \Phi_{\text{BSM}}\right)$$



$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i C_i\, \mathcal{O}_i\left(\phi_{\text{SM}}\right)$$

Matching via Amplitudes

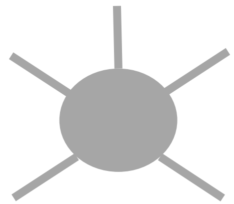
$$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{BSM}}\left(\phi_{\text{SM}}, \Phi_{\text{BSM}}\right) \Rightarrow \left\{\mathcal{A}_{\text{UV}}\left(\lambda_{\text{UV}}\right)\right\}$$



$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i C_i \mathcal{O}_i\left(\phi_{\text{SM}}\right)$$

Matching via Amplitudes

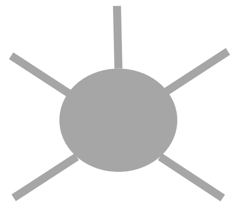
$$\mathcal{L}_{\rm UV} = \mathcal{L}_{\rm SM} + \mathcal{L}_{\rm BSM}\left(\phi_{\rm SM}, \Phi_{\rm BSM}\right) \Rightarrow \left\{\mathcal{A}_{\rm UV}\left(\lambda_{\rm UV}\right)\right\}$$



$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i C_i\,\mathcal{O}_i\left(\phi_{\rm SM}\right) \Rightarrow \left\{\mathcal{A}_{\rm SMEFT}\left(C_i\right)\right\}$$

Matching via Amplitudes

$$\mathcal{L}_{\mathrm{UV}} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\mathrm{BSM}}\left(\phi_{\mathrm{SM}}, \Phi_{\mathrm{BSM}}\right) \Rightarrow \left\{\mathcal{A}_{\mathrm{UV}}\left(\lambda_{\mathrm{UV}}\right)\right\}$$

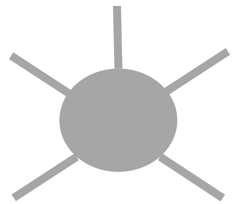


$$\Updownarrow \;\Rightarrow\; C_i\left(\lambda_{\mathrm{UV}}\right)$$

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_i C_i \mathcal{O}_i\left(\phi_{\mathrm{SM}}\right) \Rightarrow \left\{\mathcal{A}_{\mathrm{SMEFT}}\left(C_i\right)\right\}$$

Matching via Amplitudes

$$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{BSM}}\left(\phi_{\text{SM}}, \Phi_{\text{BSM}}\right) \rightarrow \left\{\mathcal{A}_{\text{UV}}\left(\lambda_{\text{UV}}\right)\right\}$$



$$\updownarrow \; \rightarrow C_i\left(\lambda_{\text{UV}}\right)$$

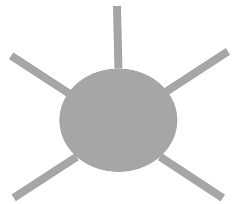
$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i C_i \mathcal{O}_i\left(\phi_{\text{SM}}\right) \rightarrow \left\{\mathcal{A}_{\text{SMEFT}}\left(C_i\right)\right\}$$

SM + Singlet —matched onto→ SMEFT

- M. Jiang, N. Craig, Y.-Y. Li, and D. Sutherland, arXiv: 1811.08878
- U. Haisch, M. Ruhdorfer, E. Salvioni, E. Venturini, and A. Weiler, arXiv: 2003.05936

Matching via Amplitudes

$$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{BSM}}\left(\phi_{\text{SM}}, \Phi_{\text{BSM}}\right) \Rightarrow \left\{\mathcal{A}_{\text{UV}}\left(\lambda_{\text{UV}}\right)\right\}$$



$$C_i\left(\lambda_{\text{UV}}\right)$$

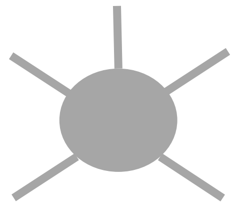
$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i C_i \mathcal{O}_i\left(\phi_{\text{SM}}\right) \Rightarrow \left\{\mathcal{A}_{\text{SMEFT}}\left(C_i\right)\right\}$$

Disadvantages:

1. Need to know the effective operators $\left\{\mathcal{O}_i\left(\phi\right)\right\}$ in advance

Matching via Amplitudes

$$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{BSM}}\left(\phi_{\text{SM}}, \Phi_{\text{BSM}}\right) \;\Rightarrow\; \left\{\mathcal{A}_{\text{UV}}\left(\lambda_{\text{UV}}\right)\right\}$$



$$\Updownarrow \;\Rightarrow\; C_i\left(\lambda_{\text{UV}}\right)$$

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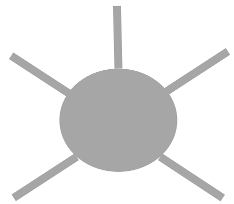
1. Need to know the effective operators $\left\{\mathcal{O}_i\left(\phi\right)\right\}$ in advance
2. Need to figure out the set of amplitudes $\left\{\mathcal{A}_i\right\}$ that can determine C_i

Matching via Amplitudes

$$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{BSM}}\left(\phi_{\text{SM}}, \Phi_{\text{BSM}}\right) \quad \Rightarrow \quad \left\{\mathcal{A}_{\text{UV}}\left(\lambda_{\text{UV}}\right)\right\}$$



$$C_i\left(\lambda_{\text{UV}}\right)$$

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i C_i \mathcal{O}_i\left(\phi_{\text{SM}}\right) \quad \Rightarrow \quad \left\{\mathcal{A}_{\text{SMEFT}}\left(C_i\right)\right\}$$

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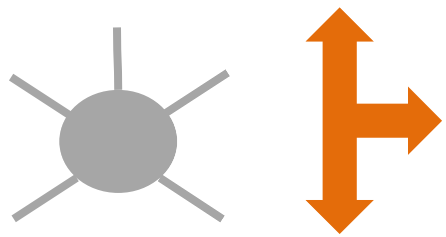
2. Need to figure out the set of amplitudes $\left\{\mathcal{A}_i\right\}$ that can determine C_i

--- often complicated by linear redundancies among $\mathcal{O}_i\left(\phi\right)$

Matching via Amplitudes

$$\mathcal{L}_{\mathrm{UV}} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\mathrm{BSM}}\left(\phi_{\mathrm{SM}}, \Phi_{\mathrm{BSM}}\right) \rightarrow \left\{\mathcal{A}_{\mathrm{UV}}\left(\lambda_{\mathrm{UV}}\right)\right\}$$



$$C_i\left(\lambda_{\mathrm{UV}}\right)$$

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1. Need to know the effective operators $\left\{\mathcal{O}_i\left(\phi\right)\right\}$ in advance
2. Need to figure out the set of amplitudes $\left\{\mathcal{A}_i\right\}$ that can determine C_i

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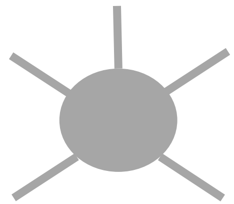
3. Computationally expensive

Matching via Amplitudes

$$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{BSM}}\left(\phi_{\text{SM}}, \Phi_{\text{BSM}}\right) \Rightarrow \left\{\mathcal{A}_{\text{UV}}\left(\lambda_{\text{UV}}\right)\right\}$$

Ideally



$$C_i\left(\lambda_{\text{UV}}\right)$$

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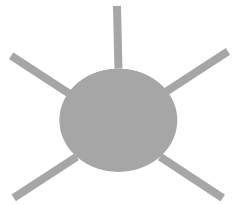
Matching via Amplitudes

$\mathcal{L}_{\text{UV}} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{BSM}}(\phi_{\text{SM}}, \Phi_{\text{BSM}}) \rightarrow \{\mathcal{A}_{\text{UV}}(\lambda_{\text{UV}})\}$ $\quad \Gamma_{\text{UV, 1LPI}}[\phi]$

Ideally $\downarrow$



$C_i(\lambda_{\text{UV}})$

Functional Matching $\updownarrow$

$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i C_i \mathcal{O}_i(\phi_{\text{SM}}) \rightarrow \{\mathcal{A}_{\text{SMEFT}}(C_i)\}$ $\quad \Gamma_{\text{EFT, 1PI}}[\phi]$

Disadvantages:

1. Need to know the effective operators $\{\mathcal{O}_i(\phi)\}$ in advance
2. Need to figure out the set of amplitudes $\{\mathcal{A}_i\}$ that can determine C_i

   --- often complicated by linear redundancies among $\mathcal{O}_i(\phi)$

3. Computationally expensive

$$\mathcal{L}_{\rm EFT}^{(\rm tree)} = \mathcal{L}_{\rm UV}\left(\phi, \Phi = \Phi_{\rm c}[\phi]\right) \qquad \left.\frac{\delta S_{\rm UV}}{\delta \Phi}\right|_{\Phi=\Phi_{\rm c}[\phi]} = 0$$

$$\int \mathrm{d}^4 x\, \mathcal{L}_{\rm EFT}^{(\text{1-loop})} = \frac{i}{2}\,\mathrm{STr}\log\left[\left.-\frac{\delta^2 S_{\rm UV}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\rm c}}\right]\Bigg|_{\rm hard}$$

$$\mathcal{L}_{\mathrm{EFT}}^{(\mathrm{tree})} = \mathcal{L}_{\mathrm{UV}}\left(\phi, \Phi = \Phi_{\mathrm{c}}[\phi]\right) \qquad \left.\frac{\delta S_{\mathrm{UV}}}{\delta \Phi}\right|_{\Phi=\Phi_{\mathrm{c}}[\phi]} = 0$$

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Scope of validity:

- Any spin: scalars, fermions, vector bosons

$$\mathcal{L}_{\mathrm{EFT}}^{(\mathrm{tree})} = \mathcal{L}_{\mathrm{UV}}\left(\phi, \Phi = \Phi_{\mathrm{c}}[\phi]\right) \qquad \left.\frac{\delta S_{\mathrm{UV}}}{\delta \Phi}\right|_{\Phi=\Phi_{\mathrm{c}}[\phi]} = 0$$

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Scope of validity:

- Any spin: scalars, fermions, vector bosons
- Contributions from heavy-light loops

$$\mathcal{L}_{\text{EFT}}^{(\text{tree})} = \mathcal{L}_{\text{UV}}\left(\phi, \Phi = \Phi_{\text{c}}[\phi]\right) \qquad \left.\frac{\delta S_{\text{UV}}}{\delta \Phi}\right|_{\Phi=\Phi_{\text{c}}[\phi]} = 0$$

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Scope of validity:

- Any spin: scalars, fermions, vector bosons
- Contributions from heavy-light loops
- Derivative interactions in UV

$$\mathcal{L}_{\mathrm{EFT}}^{(\mathrm{tree})} = \mathcal{L}_{\mathrm{UV}}\left(\phi, \Phi = \Phi_{\mathrm{c}}[\phi]\right) \qquad \left.\frac{\delta S_{\mathrm{UV}}}{\delta \Phi}\right|_{\Phi=\Phi_{\mathrm{c}}[\phi]} = 0$$

$$\int \mathrm{d}^4 x\, \mathcal{L}_{\mathrm{EFT}}^{(\text{1-loop})} = \frac{i}{2}\,\mathrm{STr}\log\left[-\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\mathrm{c}}} \right]\Bigg|_{\mathrm{hard}}$$

Scope of validity:

- Any spin: scalars, fermions, vector bosons
- Contributions from heavy-light loops
- Derivative interactions in UV
- Non-renormalizable interactions in UV

$$\mathcal{L}_{\mathrm{EFT}}^{(\mathrm{tree})} = \mathcal{L}_{\mathrm{UV}}\left(\phi, \Phi = \Phi_{\mathrm{c}}[\phi]\right) \qquad \left.\frac{\delta S_{\mathrm{UV}}}{\delta \Phi}\right|_{\Phi=\Phi_{\mathrm{c}}[\phi]} = 0$$

$$\int \mathrm{d}^4 x\, \mathcal{L}_{\mathrm{EFT}}^{(1\text{-loop})} = \frac{i}{2}\,\mathrm{STr}\log\left[\left. -\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\mathrm{c}}}\right]\Bigg|_{\mathrm{hard}}$$

Scope of validity:

- Any spin: scalars, fermions, vector bosons
- Contributions from heavy-light loops
- Derivative interactions in UV
- Non-renormalizable interactions in UV
- Non-relativistic EFT matching, e.g. HQET

$$\mathcal{L}_{\text{EFT}}^{(\text{tree})} = \mathcal{L}_{\text{UV}}\left(\phi, \Phi = \Phi_{\text{c}}[\phi]\right)$$

$$\left.\frac{\delta S_{\text{UV}}}{\delta \Phi}\right|_{\Phi=\Phi_{\text{c}}[\phi]} = 0$$

$$\int \mathrm{d}^4x\, \mathcal{L}_{\text{EFT}}^{(\text{1-loop})} = \frac{i}{2}\,\text{STr}\log\left[-\left.\frac{\delta^2 S_{\text{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\text{c}}}\right]\Bigg|_{\text{hard}}$$

How to evaluate this functional SuperTrace?

Scope of validity:

- Any spin: scalars, fermions, vector bosons
- Contributions from heavy-light loops
- Derivative interactions in UV
- Non-renormalizable interactions in UV
- Non-relativistic EFT matching, e.g. HQET

$$\mathcal{L}_{\text{UV}}\left(\phi,\Phi\right)=\frac{1}{2}\phi\left(-\partial^2-m^2\right)\phi-\frac{\lambda}{24}\phi^4+\frac{1}{2}\Phi\left(-\partial^2-M^2\right)\Phi-\frac{\kappa}{4}\phi^2\Phi^2-\frac{\lambda_\Phi}{24}\Phi^4$$

$$\left(-\partial^2-M^2\right)\Phi_{\text{c}}-\frac{\kappa}{2}\phi^2\Phi_{\text{c}}-\frac{\lambda_\Phi}{6}\Phi_{\text{c}}^3=0 \qquad \Rightarrow \qquad \Phi_{\text{c}}\left[\phi\right]=0$$

$$\mathcal{L}_{\mathrm{UV}}(\phi,\Phi)=\frac{1}{2}\phi\left(-\partial^2-m^2\right)\phi-\frac{\lambda}{24}\phi^4+\frac{1}{2}\Phi\left(-\partial^2-M^2\right)\Phi-\frac{\kappa}{4}\phi^2\Phi^2-\frac{\lambda_\Phi}{24}\Phi^4$$

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$$-\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\mathrm{c}}}=\begin{pmatrix}\partial^2+m^2+\frac{\lambda}{2}\phi^2+\frac{\kappa}{2}\Phi_{\mathrm{c}}^2 & \kappa\phi\Phi_{\mathrm{c}} \\ \kappa\phi\Phi_{\mathrm{c}} & \partial^2+M^2+\frac{\kappa}{2}\phi^2+\frac{\lambda_\Phi}{2}\Phi_{\mathrm{c}}^2\end{pmatrix} \qquad \begin{pmatrix}\phi \\ \Phi\end{pmatrix}$$

$$\mathcal{L}_{\mathrm{UV}}(\phi,\Phi)=\frac{1}{2}\phi\left(-\partial^2-m^2\right)\phi-\frac{\lambda}{24}\phi^4+\frac{1}{2}\Phi\left(-\partial^2-M^2\right)\Phi-\frac{\kappa}{4}\phi^2\Phi^2-\frac{\lambda_\Phi}{24}\Phi^4$$

$$\left(-\partial^2-M^2\right)\Phi_{\mathrm{c}}-\frac{\kappa}{2}\phi^2\Phi_{\mathrm{c}}-\frac{\lambda_\Phi}{6}\Phi_{\mathrm{c}}^3=0 \qquad \Rightarrow \qquad \Phi_{\mathrm{c}}[\phi]=0$$

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$$\int d^4x\,\mathcal{L}_{\mathrm{EFT}}^{(\text{1-loop})}=\frac{i}{2}\,\mathrm{STr}\log\left[-\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\mathrm{c}}}\right]\Bigg|_{\mathrm{hard}}=\frac{i}{2}\,\mathrm{STr}\log\left(\partial^2+M^2+\frac{\kappa}{2}\phi^2\right)$$

$$\mathcal{L}_{\text{UV}}(\phi,\Phi)=\frac{1}{2}\phi\left(-\partial^2-m^2\right)\phi-\frac{\lambda}{24}\phi^4+\frac{1}{2}\Phi\left(-\partial^2-M^2\right)\Phi-\frac{\kappa}{4}\phi^2\Phi^2-\frac{\lambda_\Phi}{24}\Phi^4$$

$$\left(-\partial^2-M^2\right)\Phi_{\text{c}}-\frac{\kappa}{2}\phi^2\Phi_{\text{c}}-\frac{\lambda_\Phi}{6}\Phi_{\text{c}}^3=0 \qquad \Rightarrow \qquad \Phi_{\text{c}}[\phi]=0$$

$$-\left.\frac{\delta^2 S_{\text{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\text{c}}}=\begin{pmatrix}\partial^2+m^2+\frac{\lambda}{2}\phi^2+\frac{\kappa}{2}\Phi_{\text{c}}^2 & \kappa\phi\Phi_{\text{c}}\\ \kappa\phi\Phi_{\text{c}} & \partial^2+M^2+\frac{\kappa}{2}\phi^2+\frac{\lambda_\Phi}{2}\Phi_{\text{c}}^2\end{pmatrix} \qquad \begin{pmatrix}\phi\\ \Phi\end{pmatrix}$$

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$$i\,\text{STr}\log\left[P^2-M^2-U(\phi)\right] \qquad , \qquad P_\mu\equiv iD_\mu$$

$$i\,\mathrm{STr}\log\left[P^2 - M^2 - U(\phi)\right] = i\int \mathrm{d}^d x \int \frac{\mathrm{d}^d q}{(2\pi)^d} \log\left[\left(P_\mu - q_\mu\right)^2 - M^2 - U(\phi)\right] \quad , \quad P_\mu \equiv iD_\mu$$

$$i\,\mathrm{STr}\log\left[P^2 - M^2 - U(\phi)\right] = i\int \mathrm{d}^d x \int \frac{\mathrm{d}^d q}{(2\pi)^d}\log\left[\left(P_\mu - q_\mu\right)^2 - M^2 - U(\phi)\right] \quad , \quad P_\mu \equiv iD_\mu \quad , \quad F_{\mu\nu} \equiv -i\left[P_\mu, P_\nu\right]$$

$$i\,\mathrm{STr}\log\left[P^2-M^2-U(\phi)\right]=i\int \mathrm{d}^d x\int\frac{\mathrm{d}^d q}{(2\pi)^d}\log\left[\left(P_\mu-q_\mu\right)^2-M^2-U(\phi)\right]\quad,\quad P_\mu\equiv iD_\mu\quad,\quad F_{\mu\nu}\equiv -i\left[P_\mu,P_\nu\right]$$

Coleman-Weinberg potential:

$$=\int \mathrm{d}^4x\frac{1}{16\pi^2}\mathrm{tr}\left\{\frac{1}{2}\left(M^2+U\right)^2\left(\log\frac{\mu^2}{M^2+U}+\frac{3}{2}\right)\right\}+\mathcal{O}\left(P_\mu\right)$$

$$i\,\mathrm{STr}\log\left[P^2 - M^2 - U(\phi)\right] = i\int \mathrm{d}^d x \int \frac{\mathrm{d}^d q}{(2\pi)^d} \log\left[\left(P_\mu - q_\mu\right)^2 - M^2 - U(\phi)\right] \quad , \quad P_\mu \equiv iD_\mu \quad , \quad F_{\mu\nu} \equiv -i\left[P_\mu, P_\nu\right]$$

Coleman-Weinberg potential:

$$= \int \mathrm{d}^4 x \frac{1}{16\pi^2} \mathrm{tr}\left\{\frac{1}{2}\left(M^2 + U\right)^2 \left(\log\frac{\mu^2}{M^2 + U} + \frac{3}{2}\right)\right\} + \mathcal{O}\left(P_\mu\right)$$

Two-derivative generalization: (Cohen, Craig, XL, Sutherland, arXiv: 2008.08597)

$$= \int \mathrm{d}^4 x \frac{1}{16\pi^2} \mathrm{tr}\left\{\frac{1}{2}\left(M^2 + U\right)^2 \left(\log\frac{\mu^2}{M^2 + U} + \frac{3}{2}\right) - \frac{1}{12}\frac{1}{M^2 + U}\left(P_\mu U\right)^2\right\} + \mathcal{O}\left(P_\mu^3\right)$$

$$i\,\mathrm{STr}\log\left[P^2 - M^2 - U(\phi)\right] = i\int \mathrm{d}^d x \int \frac{\mathrm{d}^d q}{(2\pi)^d} \log\left[\left(P_\mu - q_\mu\right)^2 - M^2 - U(\phi)\right] \quad , \quad P_\mu \equiv iD_\mu \quad , \quad F_{\mu\nu} \equiv -i\left[P_\mu, P_\nu\right]$$

Coleman-Weinberg potential:

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Up to mass dim-6 (UOLEA): (Henning, XL, Murayama, arXiv: 1412.1837)

$$i\,\mathrm{STr}\log\left[P^2-M^2-U(\phi)\right]=i\int \mathrm{d}^d x\int\frac{\mathrm{d}^d q}{(2\pi)^d}\log\left[\left(P_\mu-q_\mu\right)^2-M^2-U(\phi)\right]\quad,\quad P_\mu\equiv iD_\mu\quad,\quad F_{\mu\nu}\equiv -i\left[P_\mu,P_\nu\right]$$

Coleman-Weinberg potential:

$$=\int \mathrm{d}^4 x\frac{1}{16\pi^2}\mathrm{tr}\left\{\frac{1}{2}\left(M^2+U\right)^2\left(\log\frac{\mu^2}{M^2+U}+\frac{3}{2}\right)\right\}+\mathcal{O}\left(P_\mu\right)$$

Two-derivative generalization: (Cohen, Craig, XL, Sutherland, arXiv: 2008.08597)

$$=\int \mathrm{d}^4 x\frac{1}{16\pi^2}\mathrm{tr}\left\{\frac{1}{2}\left(M^2+U\right)^2\left(\log\frac{\mu^2}{M^2+U}+\frac{3}{2}\right)-\frac{1}{12}\frac{1}{M^2+U}\left(P_\mu U\right)^2\right\}+\mathcal{O}\left(P_\mu^3\right)$$

Up to mass dim-6 (UOLEA): (Henning, XL, Murayama, arXiv: 1412.1837)

$$=\int \mathrm{d}^4 x\frac{1}{16\pi^2}\mathrm{tr}\left\{\begin{aligned}&\frac{1}{2}M^4\left(\log\frac{\mu^2}{M^2}+\frac{3}{2}\right)+M^2\left(\log\frac{\mu^2}{M^2}+1\right)U+\left(\log\frac{\mu^2}{M^2}\right)\left(\frac{1}{2}U^2-\frac{1}{12}F_{\mu\nu}F^{\mu\nu}\right)\\&+\frac{1}{M^2}\left[\frac{-i}{90}F_\mu{}^\nu F_\nu{}^\rho F_\rho{}^\mu+\frac{1}{60}\left(P^\mu F_{\mu\nu}\right)\left(P_\rho F^{\rho\nu}\right)-\frac{1}{6}U^3-\frac{1}{12}\left(P_\mu U\right)^2+\frac{1}{12}UF_{\mu\nu}F^{\mu\nu}\right]\\&+\frac{1}{M^4}\left[\begin{aligned}&\frac{1}{24}U^4+\frac{1}{12}U\left(P_\mu U\right)^2+\frac{1}{120}\left(P^2U\right)\left(P^2U\right)\\&+\frac{i}{60}\left(P^\mu U\right)\left(P^\nu U\right)F_{\mu\nu}-\frac{1}{60}UF_{\mu\nu}UF^{\mu\nu}-\frac{1}{40}U^2F_{\mu\nu}F^{\mu\nu}\end{aligned}\right]\\&+\frac{1}{M^6}\left[-\frac{1}{60}U^5-\frac{1}{20}U^2\left(P_\mu U\right)^2-\frac{1}{30}U\left(P^\mu U\right)U\left(P_\mu U\right)\right]+\frac{1}{M^8}\frac{1}{120}U^6\end{aligned}\right\}+\mathcal{O}(\text{dim-8})$$

$$i\,\mathrm{STr}\log\left(P^2 - M^2 - U\right) = i\,\mathrm{STr}\log\left(P^2 - M^2\right) - \sum_{n=1}^{\infty}\frac{1}{n}\,i\,\mathrm{STr}\left[\left(\frac{1}{P^2 - M^2}U\right)^n\right]$$

$$i\,\mathrm{STr}\log\left(P^2 - M^2 - U\right) = i\,\mathrm{STr}\log\left(P^2 - M^2\right) - \sum_{n=1}^{\infty}\frac{1}{n}\,i\,\mathrm{STr}\left[\left(\frac{1}{P^2 - M^2}U\right)^n\right]$$

$$\int d^4x\,\mathcal{L}_{\mathrm{EFT}}^{(\text{1-loop})} = \frac{i}{2}\mathrm{STr}\log\left[\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta\left(\phi,\Phi\right)^2}\right|_{\Phi=\Phi_c}\right]\Bigg|_{\text{hard}}$$

Cohen, XL, Zhang, arXiv: 2011.02484

$$= \frac{i}{2}\,\mathrm{STr}\log\left(K - X\right)\Big|_{\text{hard}}$$

$$i\,\mathrm{STr}\log\left(P^2 - M^2 - U\right) = i\,\mathrm{STr}\log\left(P^2 - M^2\right) - \sum_{n=1}^{\infty}\frac{1}{n}\,i\,\mathrm{STr}\left[\left(\frac{1}{P^2 - M^2}U\right)^n\right]$$

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Cohen, XL, Zhang, arXiv: 2011.02484

$$= \frac{i}{2}\mathrm{STr}\log\left(K - X\right)\Big|_{\mathrm{hard}} = \frac{i}{2}\mathrm{STr}\log K\Big|_{\mathrm{hard}} - \frac{i}{2}\sum_{n=1}^{\infty}\frac{1}{n}\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}}$$

$$i\,\mathrm{STr}\log\left(P^2-M^2-U\right)=i\,\mathrm{STr}\log\left(P^2-M^2\right)-\sum_{n=1}^{\infty}\frac{1}{n}i\,\mathrm{STr}\left[\left(\frac{1}{P^2-M^2}U\right)^n\right]$$

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Cohen, XL, Zhang,
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$$=\frac{i}{2}\mathrm{STr}\log\left(K-X\right)\Big|_{\mathrm{hard}}=\frac{i}{2}\mathrm{STr}\log K\Big|_{\mathrm{hard}}-\frac{i}{2}\sum_{n=1}^{\infty}\frac{1}{n}\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}}$$

$$-\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_c}=\begin{pmatrix}\partial^2+m^2+\frac{\lambda}{2}\phi^2+\frac{\kappa}{2}\Phi_c^2 & \kappa\phi\Phi_c\\ \kappa\phi\Phi_c & \partial^2+M^2+\frac{\kappa}{2}\phi^2+\frac{\lambda_\Phi}{2}\Phi_c^2\end{pmatrix}$$

$$i\,\mathrm{STr}\log\left(P^2 - M^2 - U\right) = i\,\mathrm{STr}\log\left(P^2 - M^2\right) - \sum_{n=1}^{\infty}\frac{1}{n}\,i\,\mathrm{STr}\left[\left(\frac{1}{P^2 - M^2}U\right)^n\right]$$

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Cohen, XL, Zhang, arXiv: 2011.02484

$$= \frac{i}{2}\mathrm{STr}\log\left(K - X\right)\Big|_{\mathrm{hard}} = \frac{i}{2}\mathrm{STr}\log K\Big|_{\mathrm{hard}} - \frac{i}{2}\sum_{n=1}^{\infty}\frac{1}{n}\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}}$$

Focusing on relativistic EFTs:

$$K_i = \begin{cases} P^2 - m_i^2 & (\text{spin - }0) \\ \not{P} - m_i & (\text{spin - }1/2) \\ -\eta^{\mu\nu}\left(P^2 - m_i^2\right) & (\text{spin - }1) \end{cases}$$

$$-\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_c} = \begin{pmatrix} \partial^2 + m^2 + \frac{\lambda}{2}\phi^2 + \frac{\kappa}{2}\Phi_c^2 & \kappa\phi\Phi_c \\ \kappa\phi\Phi_c & \partial^2 + M^2 + \frac{\kappa}{2}\phi^2 + \frac{\lambda_\Phi}{2}\Phi_c^2 \end{pmatrix}$$

$$i\,\mathrm{STr}\log\left(P^2-M^2-U\right)=i\,\mathrm{STr}\log\left(P^2-M^2\right)-\sum_{n=1}^{\infty}\frac{1}{n}i\,\mathrm{STr}\left[\left(\frac{1}{P^2-M^2}U\right)^n\right]$$

$$\int d^4x\,\mathcal{L}_{\mathrm{EFT}}^{(1\text{-loop})}=\frac{i}{2}\mathrm{STr}\log\left[\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_c}\right]\Bigg|_{\mathrm{hard}}$$

Cohen, XL, Zhang, arXiv: 2011.02484

$$=\frac{i}{2}\mathrm{STr}\log\left(K-X\right)\Big|_{\mathrm{hard}}=\frac{i}{2}\mathrm{STr}\log K\Big|_{\mathrm{hard}}-\frac{i}{2}\sum_{n=1}^{\infty}\frac{1}{n}\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}}$$

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$$\int \mathrm{d}^4x\,\mathcal{L}_{\mathrm{EFT}}^{(1\text{-loop})}=\frac{i}{2}\mathrm{STr}\log\left[\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\mathrm{c}}}\right]\Bigg|_{\mathrm{hard}}$$

Log-type

Cohen, XL, Zhang, arXiv: 2011.02484

$$=\frac{i}{2}\mathrm{STr}\log\left(K-X\right)\Big|_{\mathrm{hard}}=\frac{i}{2}\mathrm{STr}\log K\Big|_{\mathrm{hard}}-\frac{i}{2}\sum_{n=1}^{\infty}\frac{1}{n}\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}}$$

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$$-\left.\frac{\delta^2 S_{\mathrm{UV}}}{\delta(\phi,\Phi)^2}\right|_{\Phi=\Phi_{\mathrm{c}}}=\begin{pmatrix}\partial^2+m^2+\frac{\lambda}{2}\phi^2+\frac{\kappa}{2}\Phi_{\mathrm{c}}^2 & \kappa\phi\Phi_{\mathrm{c}}\\ \kappa\phi\Phi_{\mathrm{c}} & \partial^2+M^2+\frac{\kappa}{2}\phi^2+\frac{\lambda_\Phi}{2}\Phi_{\mathrm{c}}^2\end{pmatrix}$$

$$i\,\mathrm{STr}\log\left(P^2-M^2-U\right)=i\,\mathrm{STr}\log\left(P^2-M^2\right)-\sum_{n=1}^{\infty}\frac{1}{n}i\,\mathrm{STr}\left[\left(\frac{1}{P^2-M^2}U\right)^n\right]$$

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Log-type

Power-type

Cohen, XL, Zhang, arXiv: 2011.02484

$$=\frac{i}{2}\mathrm{STr}\log\left(K-X\right)\Big|_{\mathrm{hard}}=\frac{i}{2}\mathrm{STr}\log K\Big|_{\mathrm{hard}}-\frac{i}{2}\sum_{n=1}^{\infty}\frac{1}{n}\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}}$$

Focusing on relativistic EFTs:

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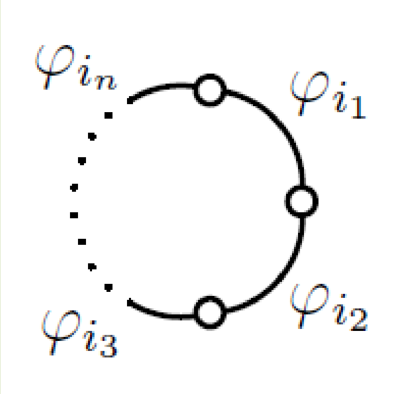
Power-type:

$$-i\,\mathrm{STr}\left[\left(\frac{1}{K}X\right)^{n}\right]\Bigg|_{\mathrm{hard}} = -i\,\mathrm{STr}\left(\frac{1}{K_{i_1}}X_{i_1 i_2}\frac{1}{K_{i_2}}X_{i_2 i_3}\cdots\frac{1}{K_{i_n}}X_{i_n i_1}\right)\Bigg|_{\mathrm{hard}}$$

Power-type:

$$-i\,\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}} = -i\,\mathrm{STr}\left(\frac{1}{K_{i_1}}X_{i_1 i_2}\frac{1}{K_{i_2}}X_{i_2 i_3}\cdots\frac{1}{K_{i_n}}X_{i_n i_1}\right)\Bigg|_{\mathrm{hard}}$$

Covariant graphs:

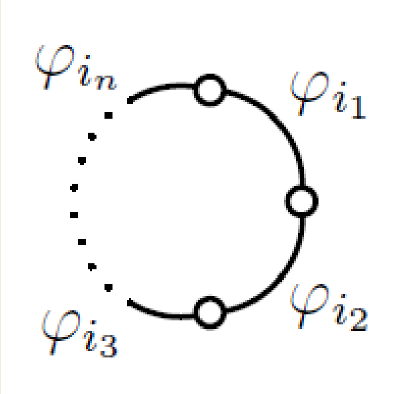


Power-type:

$$-i\,\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\text{hard}} = -i\,\mathrm{STr}\left(\frac{1}{K_{i_1}}X_{i_1 i_2}\frac{1}{K_{i_2}}X_{i_2 i_3}\cdots\frac{1}{K_{i_n}}X_{i_n i_1}\right)\Bigg|_{\text{hard}}$$

$$\frac{1}{K_i} \sim \begin{cases} \dfrac{1}{P^2 - m_i^2} \equiv \Delta_i \\ \dfrac{1}{\not{P} - m_i} \equiv \Lambda_i \end{cases}$$

Covariant graphs:



Power-type:

$$-i\,\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}} = -i\,\mathrm{STr}\left(\frac{1}{K_{i_1}}X_{i_1 i_2}\frac{1}{K_{i_2}}X_{i_2 i_3}\cdots\frac{1}{K_{i_n}}X_{i_n i_1}\right)\Bigg|_{\mathrm{hard}}$$

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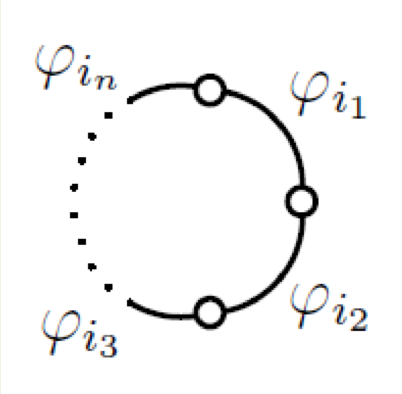
$$X_{ij} = U_{ij} + P_\mu Z_{ij}^\mu + \bar{Z}_{ij}^\mu P_\mu + \mathcal{O}\left(P_\mu^2\right)$$

$$X_{ij} \sim \left(P_{\mu_1}\cdots P_{\mu_n}\right)U_k\left(P_{\nu_1}\cdots P_{\nu_m}\right)$$

Covariant graphs:



$$-i\,\mathrm{STr}\left[f\right]\Big|_{\mathrm{hard}} \quad , \quad f = \left[\,\cdots\left(P_{\mu_1}\cdots P_{\mu_n}\right)\left(\Delta_i \text{ or } \Lambda_i\right)\left(P_{\nu_1}\cdots P_{\nu_m}\right)U_k\cdots\,\right]$$

Power-type:

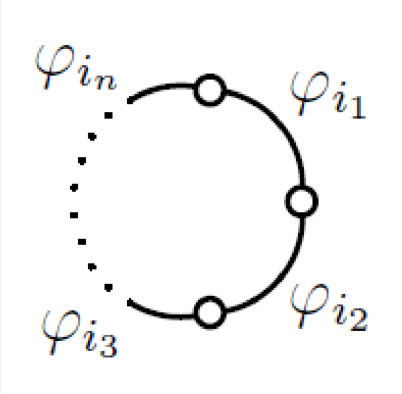
$$-i\,\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}} = -i\,\mathrm{STr}\left(\frac{1}{K_{i_1}}X_{i_1 i_2}\frac{1}{K_{i_2}}X_{i_2 i_3}\cdots\frac{1}{K_{i_n}}X_{i_n i_1}\right)\Bigg|_{\mathrm{hard}}$$

$$\frac{1}{K_i}\sim\begin{cases}\dfrac{1}{P^2-m_i^2}\equiv\Delta_i \\[2ex] \dfrac{1}{\not{P}-m_i}\equiv\Lambda_i\end{cases} \quad ,$$

$$X_{ij} = U_{ij} + P_\mu Z_{ij}^\mu + \bar{Z}_{ij}^\mu P_\mu + \mathcal{O}\left(P_\mu^2\right)$$

$$X_{ij} \sim \left(P_{\mu_1}\cdots P_{\mu_n}\right)U_k\left(P_{\nu_1}\cdots P_{\nu_m}\right)$$

Covariant graphs:



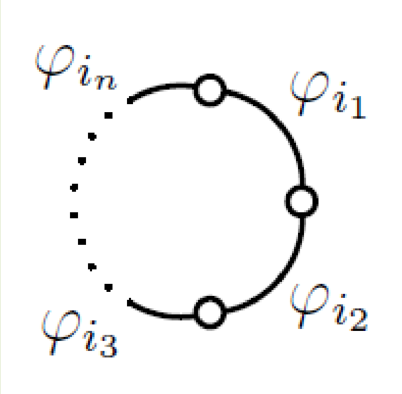
$$-i\,\mathrm{STr}[f]\big|_{\mathrm{hard}} \quad , \quad f=\Big[\cdots\left(P_{\mu_1}\cdots P_{\mu_n}\right)\left(\Delta_i \text{ or } \Lambda_i\right)\left(P_{\nu_1}\cdots P_{\nu_m}\right)U_k\cdots\Big]$$

Power-type:

$$-i\,\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Bigg|_{\mathrm{hard}} = -i\,\mathrm{STr}\left(\frac{1}{K_{i_1}}X_{i_1 i_2}\frac{1}{K_{i_2}}X_{i_2 i_3}\cdots\frac{1}{K_{i_n}}X_{i_n i_1}\right)\Bigg|_{\mathrm{hard}}$$

$$\frac{1}{K_i}\sim\begin{cases}\dfrac{1}{P^2-m_i^2}\equiv\Delta_i\\[2ex]\dfrac{1}{\not{P}-m_i}\equiv\Lambda_i\end{cases} \quad , \quad \begin{aligned}&X_{ij}=U_{ij}+P_\mu Z_{ij}^\mu+\bar{Z}_{ij}^\mu P_\mu+\mathcal{O}\left(P_\mu^2\right)\\ &X_{ij}\sim\left(P_{\mu_1}\cdots P_{\mu_n}\right)U_k\left(P_{\nu_1}\cdots P_{\nu_m}\right)\end{aligned}$$

Covariant graphs:



Log-type: can be converted into power-type

$$\frac{\partial}{\partial M^2}\left[i\,\mathrm{STr}\log\left(P^2-M^2\right)\right]=-i\,\mathrm{STr}\left(\frac{1}{P^2-M^2}\right) \quad , \quad \frac{\partial}{\partial M}\left[i\,\mathrm{STr}\log\left(\not{P}-M\right)\right]=-i\,\mathrm{STr}\left(\frac{1}{\not{P}-M}\right)$$

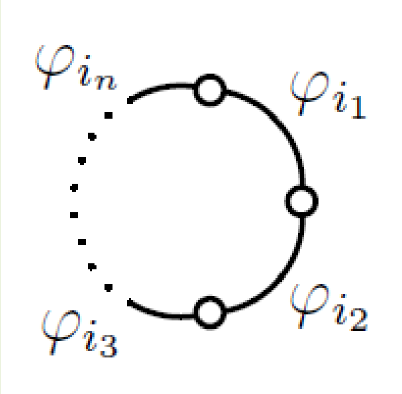
$$-i\,\mathrm{STr}\left[f\right]\Big|_{\text{hard}} \quad , \quad f = \left[\cdots\left(P_{\mu_1}\cdots P_{\mu_n}\right)\left(\Delta_i \text{ or } \Lambda_i\right)\left(P_{\nu_1}\cdots P_{\nu_m}\right)U_k\cdots\right]$$

Power-type: Any functional supertrace can be evaluated with CDE

$$-i\,\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Big|_{\text{hard}} = -i\,\mathrm{STr}\left(\frac{1}{K_{i_1}}X_{i_1 i_2}\frac{1}{K_{i_2}}X_{i_2 i_3}\cdots\frac{1}{K_{i_n}}X_{i_n i_1}\right)\Big|_{\text{hard}}$$

$$\frac{1}{K_i} \sim \begin{cases} \dfrac{1}{P^2 - m_i^2} \equiv \Delta_i \\ \dfrac{1}{\not{P} - m_i} \equiv \Lambda_i \end{cases} \quad , \quad \begin{aligned} & X_{ij} = U_{ij} + P_\mu Z_{ij}^\mu + \bar{Z}_{ij}^\mu P_\mu + \mathcal{O}\left(P_\mu^2\right) \\ & X_{ij} \sim \left(P_{\mu_1}\cdots P_{\mu_n}\right)U_k\left(P_{\nu_1}\cdots P_{\nu_m}\right) \end{aligned}$$

Covariant graphs:



Log-type: can be converted into power-type

$$\frac{\partial}{\partial M^2}\left[i\,\mathrm{STr}\log\left(P^2 - M^2\right)\right] = -i\,\mathrm{STr}\left(\frac{1}{P^2 - M^2}\right) \quad , \quad \frac{\partial}{\partial M}\left[i\,\mathrm{STr}\log\left(\not{P} - M\right)\right] = -i\,\mathrm{STr}\left(\frac{1}{\not{P} - M}\right)$$

The scope of STrEAM:

Cohen, XL, Zhang, arXiv: 2012.07851

$$-i\,\mathrm{STr}\left[f\right]\Big|_{\mathrm{hard}} \quad , \quad f = \left[\cdots\left(P_{\mu_1}\cdots P_{\mu_n}\right)\left(\Delta_i \text{ or } \Lambda_i\right)\left(P_{\nu_1}\cdots P_{\nu_m}\right)U_k\cdots\right]$$

Power-type: Any functional supertrace can be evaluated with CDE

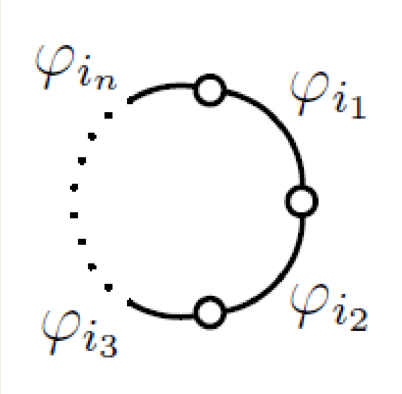
$$-i\,\mathrm{STr}\left[\left(\frac{1}{K}X\right)^n\right]\Big|_{\mathrm{hard}} = -i\,\mathrm{STr}\left(\frac{1}{K_{i_1}}X_{i_1 i_2}\frac{1}{K_{i_2}}X_{i_2 i_3}\cdots\frac{1}{K_{i_n}}X_{i_n i_1}\right)\Big|_{\mathrm{hard}}$$

$$\frac{1}{K_i} \sim \begin{cases} \dfrac{1}{P^2 - m_i^2} \equiv \Delta_i \\ \dfrac{1}{\not{P} - m_i} \equiv \Lambda_i \end{cases} \quad ,$$

$$X_{ij} = U_{ij} + P_\mu Z_{ij}^\mu + \bar{Z}_{ij}^\mu P_\mu + \mathcal{O}\left(P_\mu^2\right)$$

$$X_{ij} \sim \left(P_{\mu_1}\cdots P_{\mu_n}\right)U_k\left(P_{\nu_1}\cdots P_{\nu_m}\right)$$

Covariant graphs:



Log-type: can be converted into power-type

$$\frac{\partial}{\partial M^2}\left[i\,\mathrm{STr}\log\left(P^2 - M^2\right)\right] = -i\,\mathrm{STr}\left(\frac{1}{P^2 - M^2}\right) \quad , \quad \frac{\partial}{\partial M}\left[i\,\mathrm{STr}\log\left(\not{P} - M\right)\right] = -i\,\mathrm{STr}\left(\frac{1}{\not{P} - M}\right)$$

STrEAM.m and STrEAM_examples.nb
https://github.com/EFTMatching/STrEAM

$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[2]}\right]\Bigg|_{\mathrm{hard}} = \int \mathrm{d}^4x\,\frac{1}{16\pi^2}\,\mathrm{tr}\left[m_1^2\left(1-\log\frac{m_1^2}{\mu^2}\right)U_1+\frac{1}{12m_1^2}F_{\mu\nu}F^{\mu\nu}U_1+\mathcal{O}(\text{dim-8})\right]$$

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$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[2]}\right]\Bigg|_{\mathrm{hard}} = \int \mathrm{d}^4x\,\frac{1}{16\pi^2}\,\mathrm{tr}\left[m_1^2\left(1-\log\frac{m_1^2}{\mu^2}\right)U_1+\frac{1}{12m_1^2}F_{\mu\nu}F^{\mu\nu}U_1+\mathcal{O}(\text{dim-8})\right]$$

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$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[2]}\right]\Big|_{\text{hard}} = \int d^4x\,\frac{1}{16\pi^2}\,\mathrm{tr}\left[m_1^2\left(1-\log\frac{m_1^2}{\mu^2}\right)U_1 + \frac{1}{12m_1^2}F_{\mu\nu}F^{\mu\nu}U_1 + \mathcal{O}(\text{dim-8})\right]$$

```
In[2]:= SuperTrace[6, {Δ1, U1}, Udimlist → {2}, display → True]
```

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1\right]\Big|_{\text{hard}} = \int d^4x\;\frac{1}{16\,\pi^2}\;\mathrm{tr}\{$$

$-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2$ $\quad(U_1)\quad$ (dim−2)

$\frac{1}{12\,m_1^2}$ $\quad(F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_2})\,(U_1)\quad$ (dim−6)

}

Out[2]= $\left\{\left\{\left\{\left\{-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2\right\}\right\},\{\{U_1\}\},2\right\},\left\{\left\{\left\{\frac{1}{12\,m_1^2}\right\}\right\},\{\{F_{\mu_1,\mu_2}\},\{F_{\mu_1,\mu_2}\},\{U_1\}\},6\right\}\right\}$

STrEAM.m and STrEAM_examples.nb

https://github.com/EFTMatching/STrEAM

$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[2]}\right]\Big|_{\mathrm{hard}} = \int d^4x\,\frac{1}{16\pi^2}\,\mathrm{tr}\left[m_1^2\left(1-\log\frac{m_1^2}{\mu^2}\right)U_1+\frac{1}{12m_1^2}F_{\mu\nu}F^{\mu\nu}U_1+\mathcal{O}(\text{dim-8})\right]$$

In[2]:= `SuperTrace[6, {Δ1, U1}, Udimlist → {2}, display → True]`

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1\right]\Big|\mathrm{hard} = \int d^4x\,\frac{1}{16\,\pi^2}\,\mathrm{tr}\{$$

$-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2 \quad (U_1) \quad$ (dim−2)

$\frac{1}{12\,m_1^2} \quad (F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_2})\,(U_1) \quad$ (dim−6)

}

Out[2]= $\left\{\left\{\left\{\left\{-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2\right\}\right\},\{\{U_1\}\},2\right\},\left\{\left\{\left\{\frac{1}{12\,m_1^2}\right\}\right\},\{\{F_{\mu_1,\mu_2}\},\{F_{\mu_1,\mu_2}\},\{U_1\}\},6\right\}\right\}$

STrEAM.m and STrEAM_examples.nb
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$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[2]}\right]\Bigg|_{\rm hard} = \int d^4x \frac{1}{16\pi^2}\,\mathrm{tr}\left[m_1^2\left(1-\log\frac{m_1^2}{\mu^2}\right)U_1 + \frac{1}{12m_1^2}F_{\mu\nu}F^{\mu\nu}U_1 + \mathcal{O}(\text{dim-8})\right]$$

In[2]:= **SuperTrace[6, {Δ1, U1}, Udimlist → {2}, display → True]**

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1\right]\Big|_{\rm hard} = \int d^4x\ \frac{1}{16\,\pi^2}\ \mathrm{tr}\{$$

$-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2$ $\quad (U_1) \quad$ (dim−2)

$\frac{1}{12\,m_1^2}$ $\quad (F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_2})\,(U_1) \quad$ (dim−6)

}

Out[2]= $\left\{\left\{\left\{\left\{-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2\right\}\right\},\ \{\{U_1\}\},\ 2\right\},\ \left\{\left\{\left\{\frac{1}{12\,m_1^2}\right\}\right\},\ \{\{F_{\mu_1,\mu_2}\},\ \{F_{\mu_1,\mu_2}\},\ \{U_1\}\},\ 6\right\}\right\}$

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$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[2]}\right]\Bigg|_{\mathrm{hard}} = \int \mathrm{d}^4x \frac{1}{16\pi^2}\mathrm{tr}\left[m_1^2\left(1-\log\frac{m_1^2}{\mu^2}\right)U_1 + \frac{1}{12m_1^2}F_{\mu\nu}F^{\mu\nu}U_1 + \mathcal{O}(\text{dim-8})\right]$$

```
In[2]:= SuperTrace[6, {Δ1, U1}, Udimlist → {2}, display → True]
```

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1\right]\Big|_{\mathrm{hard}} = \int d^4x\ \frac{1}{16\pi^2}\ \mathrm{tr}\{$$

$-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2$	(U_1)	(dim−2)
$\frac{1}{12\,m_1^2}$	$(F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_2})\,(U_1)$	(dim−6)

$\}$

Out[2]= $\left\{\left\{\left\{\left\{-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2\right\}\right\},\{\{U_1\}\},2\right\},\left\{\left\{\left\{\frac{1}{12\,m_1^2}\right\}\right\},\{\{F_{\mu_1,\mu_2}\},\{F_{\mu_1,\mu_2}\},\{U_1\}\},6\right\}\right\}$

STrEAM.m and STrEAM_examples.nb
https://github.com/EFTMatching/STrEAM

$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[2]}\right]\Bigg|_{\mathrm{hard}} = \int d^4x \frac{1}{16\pi^2}\mathrm{tr}\left[m_1^2\left(1-\log\frac{m_1^2}{\mu^2}\right)U_1 + \frac{1}{12m_1^2}F_{\mu\nu}F^{\mu\nu}U_1 + \mathcal{O}(\text{dim-8})\right]$$

dimension truncation

```
In[2]:= SuperTrace[6, {Δ1, U1}, Udimlist → {2}, display → True]
```

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1\right]\Big|_{\mathrm{hard}} = \int d^4x\ \frac{1}{16\pi^2}\ \mathrm{tr}\{$$

$-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2$ $\quad(U_1)\quad$ (dim-2)

$\frac{1}{12\,m_1^2}$ $\quad(F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_2})\,(U_1)\quad$ (dim-6)

}

$$\text{Out[2]=}\ \left\{\left\{\left\{\left\{-\left(-1+\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]\right)m_1^2\right\}\right\},\{\{U_1\}\},2\right\},\left\{\left\{\left\{\frac{1}{12\,m_1^2}\right\}\right\},\{\{F_{\mu_1,\mu_2}\},\{F_{\mu_1,\mu_2}\},\{U_1\}\},6\right\}\right\}$$

massless (covariant) propagator

$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[1]}\frac{1}{P^2-m_2^2}P_\mu Z^{\mu[1]}\frac{1}{P^2}U_3^{[2]}\frac{1}{P^2-m_2^2}U_4^{[1]}\right]\Bigg|_{\text{hard}}$$

```
In[7]:= SuperTrace[6, {Δ1, U1, Δ2, Pν, Zν, Δ0, U3, Δ2, U4}, Udimlist → {1, 1, 2, 1}, display → True];
```

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1\frac{1}{P^2-m_2^2}P_\nu Z_\nu\frac{1}{P^2}U_3\frac{1}{P^2-m_2^2}U_4\right]\Big|_{\text{hard}} = \int d^4x\,\frac{1}{16\pi^2}\,\mathrm{tr}\{$$

$$\frac{3-2\,\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]}{4\,m_1^4}\quad (U_1)\,(Z_{\mu_1})\,(P_{\mu_1}U_3)\,(U_4)\quad (\text{dim}-6)$$

$$\frac{3-2\,\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]}{2\,m_1^4}\quad (U_1)\,(P_{\mu_1}Z_{\mu_1})\,(U_3)\,(U_4)\quad (\text{dim}-6)$$

$$\frac{5-2\,\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]}{4\,m_1^4}\quad (P_{\mu_1}U_1)\,(Z_{\mu_1})\,(U_3)\,(U_4)\quad (\text{dim}-6)$$

$$\}$$

derivative interaction massless (covariant) propagator

$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[1]}\frac{1}{P^2-m_2^2}P_\mu Z^{\mu[1]}\frac{1}{P^2}U_3^{[2]}\frac{1}{P^2-m_2^2}U_4^{[1]}\right]\Bigg|_{\mathrm{hard}}$$

```
In[7]:= SuperTrace[6, {Δ1, U1, Δ2, Pν, Zν, Δ0, U3, Δ2, U4}, Udimlist → {1, 1, 2, 1}, display → True];
```

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1\frac{1}{P^2-m_2^2}P_\nu Z_\nu\frac{1}{P^2}U_3\frac{1}{P^2-m_2^2}U_4\right]\Big|_{\mathrm{hard}} = \int d^4x\ \frac{1}{16\pi^2}\ \mathrm{tr}\{$$

$\frac{3-2\,\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]}{4\,m_1^4}$ $(U_1)(Z_{\mu_1})(P_{\mu_1}U_3)(U_4)$ (dim-6)

$\frac{3-2\,\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]}{2\,m_1^4}$ $(U_1)(P_{\mu_1}Z_{\mu_1})(U_3)(U_4)$ (dim-6)

$\frac{5-2\,\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]}{4\,m_1^4}$ $(P_{\mu_1}U_1)(Z_{\mu_1})(U_3)(U_4)$ (dim-6)

}

fermionic (covariant) propagator

$$-i\,\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1^{[1]}\frac{1}{P^2-m_2^2}U_2^{[3/2]}\frac{1}{\not{P}}U_3^{[3/2]}\frac{1}{P^2-m_2^2}U_4^{[1]}\right]\Bigg|_{\mathrm{hard}}$$

In[8]:= **SuperTrace**[6, {Δ₁, U₁, Δ₂, U₂, Δ₀, U₃, Δ₂, U₄}, **Udimlist** → {1, 3/2, 3/2, 1}, **display** → True];

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}U_1\frac{1}{P^2-m_2^2}U_2\frac{1}{\mathrm{Pslash}}U_3\frac{1}{P^2-m_2^2}U_4\right]\Big|_{\mathrm{hard}} = \int d^4x\,\frac{1}{16\pi^2}\,\mathrm{tr}\{$$

$$\frac{3-2\,\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]}{4\,m_1^4}\quad (U_1)\,(U_2)\,(P_{\mu_1}\gamma_{\mu_1}U_3)\,(U_4)\qquad (\mathrm{dim}{-}6)$$

$$\frac{1}{2\,m_1^4}\quad (U_1)\,(P_{\mu_1}U_2)\,(\gamma_{\mu_1}U_3)\,(U_4)\qquad (\mathrm{dim}{-}6)$$

$$\frac{5-2\,\mathrm{Log}\left[\frac{m_1^2}{\mu^2}\right]}{4\,m_1^4}\quad (P_{\mu_1}U_1)\,(U_2)\,(\gamma_{\mu_1}U_3)\,(U_4)\qquad (\mathrm{dim}{-}6)$$

}

Log-type

$$\frac{\partial}{\partial m_1^2}\left[i\,\mathrm{STr}\log\left(P^2-m_1^2\right)\right]=-i\,\mathrm{STr}\left(\frac{1}{P^2-m_1^2}\right) \qquad \frac{\partial}{\partial m_1}\left[i\,\mathrm{STr}\log\left(\not{P}-m_1\right)\right]=-i\,\mathrm{STr}\left(\frac{1}{\not{P}-m_1}\right)$$

```
In[3]:= SuperTrace[6, {Δ1}, display → True];
```

$$-i\mathrm{STr}\left[\frac{1}{P^2-m_1^2}\right]\Big|_{\mathrm{hard}} = \int d^4x\,\frac{1}{16\pi^2}\,\mathrm{tr}\Big\{$$

$\frac{1}{12\,m_1^2}$	$(F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_2})$	(dim-4)
$\frac{i}{90\,m_1^4}$	$(F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_3})\,(F_{\mu_2,\mu_3})$	(dim-6)
$\frac{1}{60\,m_1^4}$	$(P_{\mu_1}P_{\mu_2}F_{\mu_2,\mu_3})\,(F_{\mu_1,\mu_3})$	(dim-6)

$\Big\}$

```
In[4]:= SuperTrace[6, {Λ1}, NoγinU → True, display → True];
```

$$-i\mathrm{STr}\left[\frac{1}{\mathrm{Pslash}-m_1}\right]\Big|_{\mathrm{hard}} = \int d^4x\,\frac{1}{16\pi^2}\,\mathrm{tr}\Big\{$$

$\frac{1}{6\,m_1}$	$(F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_2})$	(dim-4)
$-\frac{i}{90\,m_1^3}$	$(F_{\mu_1,\mu_2})\,(F_{\mu_1,\mu_3})\,(F_{\mu_2,\mu_3})$	(dim-6)
$\frac{1}{15\,m_1^3}$	$(P_{\mu_1}P_{\mu_2}F_{\mu_2,\mu_3})\,(F_{\mu_1,\mu_3})$	(dim-6)

$\Big\}$

Summary

- EFT matching is systematically solved by functional methods at tree and one-loop level

- A new way of organizing functional supertrace evaluation

  --- step-by-step prescription in Sec. 5 of arXiv: 2011.02484

- A Mathematica package that automates supertrace evaluation

  --- Manual in arXiv: 2012.07851

  --- STrEAM.m https://github.com/EFTMatching/STrEAM