Matching BSM to SMEFT

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UV-EFT connections

- positivity (and bootstrap) [Adams, Arkani-Hamed, Dubovsky, Nicolis, Rattazzi '06]

  the EFT-space boundaries populated by any QFT

  strict positivity at dim$\geq$8, sum rules at dim-6

- charting

  the conceivable models approaching EFT-space boundaries

- matching [LHC EFT WG note '22]

  the EFT subspace populated by specific UV models

  - diagrammatic (`Matchmakereft`) [Carmona, Lazopoulos, Olgoso, Santiago '21]
  - functional (`CoDEx`, `Matchete`) [Bakshi, Chakrabortty, Patra '18] [Fuentes-Martín, König, Pagès, Thomsen, Wilsch '22]
  - dispersive [GD, De Angelis '23]

Positivity

[Adams, Arkani-Hamed, Dubovsky, Nicolis, Rattazzi '06]

- Unitarity:

$\mathcal{A}^\dagger(+i\epsilon) \overset{\text{CPT}}{=} \mathcal{A}(-i\epsilon)$

sum over intermediate state X

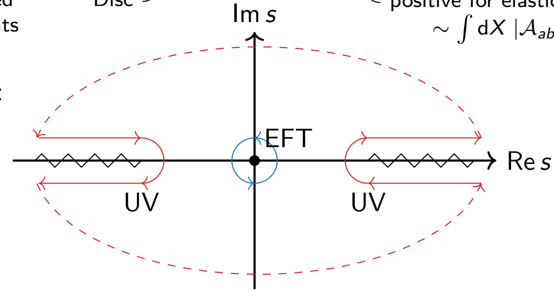
$$(\mathcal{A} - \mathcal{A}^\dagger)/i = \mathcal{A} \cdot \mathcal{A}^\dagger$$

Disc

positive for elastic+forward $\sim \int \mathrm{d}X \, |\mathcal{A}_{ab\to X}|^2$

controlled at 4 points

- Analyticity:



vanishes by Froissart for $n \geq 2$

$$\operatorname*{Res}_{s=0} \frac{\mathcal{A}^{\text{EFT}}_{ab\to ab}(s)}{s^{n+1}} = \frac{1}{2\pi} \int_{\Lambda^2}^{\infty} \frac{\mathrm{d}s}{s^{n+1}} \left[\text{Disc}\, \mathcal{A}^{\text{UV}}_{ab\to ab} + (-1)^n \, \text{Disc}\, \mathcal{A}^{\text{UV}}_{a\bar{b}\to a\bar{b}} \right] + C_\infty$$

≥ 0 $\quad$ ≥ 0

≥ 0 for n even ≥ 2

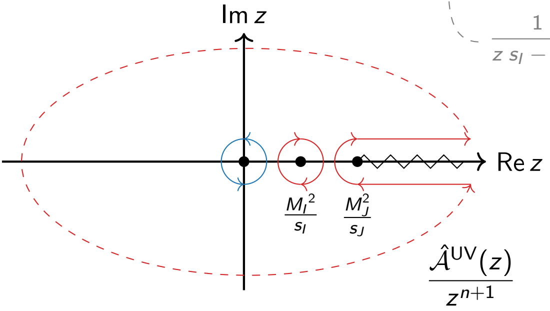
Dispersive matching

- equate $\mathcal{A}^{\text{EFT}}$ and $\mathcal{A}^{\text{UV}}$ order-by-order in the zero-momentum expansion:

$$\text{dilate } s_I \to z\, s_I \quad \text{and} \quad \text{enforce } \operatorname*{Res}_{z=0} \frac{\hat{\mathcal{A}}^{\text{EFT}}(z)}{z^{n+1}} = \operatorname*{Res}_{z=0} \frac{\hat{\mathcal{A}}^{\text{UV}}(z)}{z^{n+1}}$$

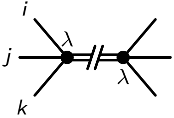
- EFT: $\operatorname*{Res}_{z=0} \frac{\hat{\mathcal{A}}^{\text{EFT}}(z)}{z^{n+1}} = c_n \, \text{poly}_n(s_I)$ with $\mathcal{A}^{\text{EFT}}_{\text{tree}} = \sum_k c_k \, \text{poly}_k(s_I)$
- UV: $\operatorname*{Res}_{z=0} \frac{\hat{\mathcal{A}}^{\text{UV}}(z)}{z^{n+1}} = \oint_{z=0} dz \, \frac{\hat{\mathcal{A}}^{\text{UV}}(z)}{z^{n+1}} = \left[\sum \text{Res} + \int \text{Disc} + \int_\infty \right] \frac{\hat{\mathcal{A}}^{\text{UV}}(z)}{z^{n+1}}$

$\frac{1}{z\, s_I - M_I^2}$ $\qquad$ $\log(M_I^2 - z\, s_I)$



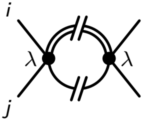
Matching only requires cuts!

Simplest $\Phi\phi^3$ example



$$: \sum_{ijk \text{ channels}} \underset{z=M^2/s_{ijk}}{\text{Res}} \frac{|\mathcal{A}(\phi\phi\phi \to \Phi)|^2}{z s_{ijk} - M^2} \frac{1}{z^{n+1}}$$

$$= \frac{\lambda^2}{M^2} \sum_{\text{channels}} \left(\frac{s_{ijk}}{M^2}\right)^n$$



$$: \frac{1}{2\pi} \sum_{\text{channels}} \int_{M^2/s_{ij}}^{\infty} \frac{dz}{z^{n+1}} \int \text{dLIPS}\, |\mathcal{A}(\phi\phi \to \phi\Phi)|^2$$

$$= \frac{1}{2\pi} \sum_{\text{channels}} \int_{M^2/s_{ij}}^{\infty} \frac{dz}{z^{n+1}} \frac{1}{8\pi} \left(1 - \frac{M^2}{z s_{ij}}\right) \lambda^2$$

$$= \frac{\lambda^2}{16\pi^2 n(n+1)} \sum_{\text{channels}} \left(\frac{s_{ij}}{M^2}\right)^n \qquad \text{for } n > 0$$

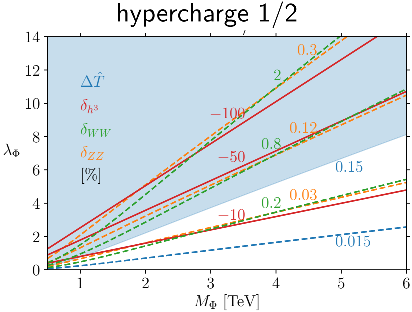
- all EFT orders obtained at once
- nothing to know about, or compute in, the EFT
- fewer legs and loops

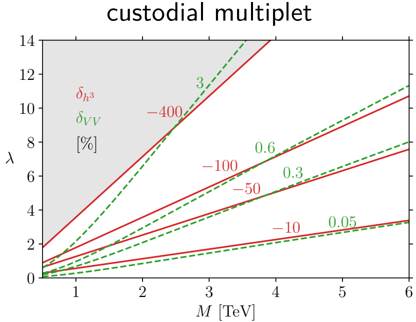
Charting $|H|^6$ with a fourplet scalar

[GD, McCullough, Salvioni '22]
[Chala, Krause, Nardini '18]
[Logan, Rentala '15]

$$\lambda\, H^*H^*(\epsilon H)\Phi + \lambda' \frac{1}{\sqrt{3}} H^*H^*H^*\widetilde{\Phi}'$$

- Distinctive matching pattern: $|H|^6$ only, at tree-level and dim-6
- Loop (and dim-8) custodial symmetry breaking matters





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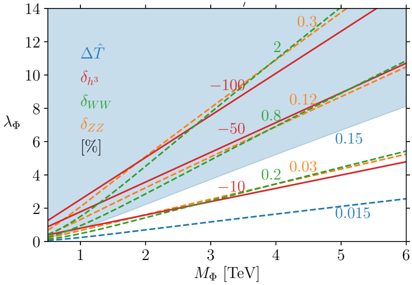
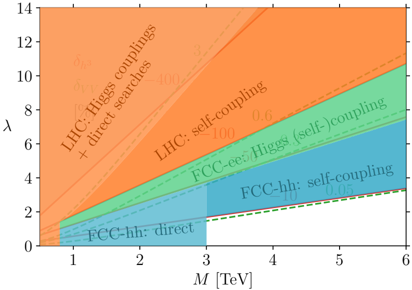
hypercharge 1/2



custodial multiplet

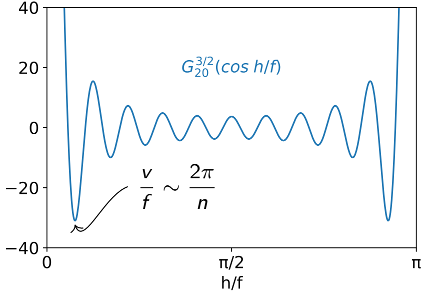


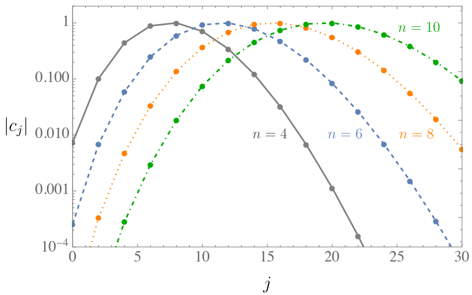
Charting $|H|^6$ with Gegenbauer potentials

[GD, McCullough, Salvioni '22]

$$G_{n=6}^{\frac{N-1}{2}=\frac{3}{2}}(\cos\frac{h}{f}) \;\propto\; 1 - 27\cos^2\frac{h}{f} + 99\cos^4\frac{h}{f} - \frac{429}{5}\cos^6\frac{h}{f}$$

- small vev, radiatively stable, for $SO(N+1)/SO(N)$ pion Higgs
- also generates $\delta\kappa_\lambda/\delta\kappa_V \sim \mathcal{O}(100)$
- delayed convergence of EFT coefficients





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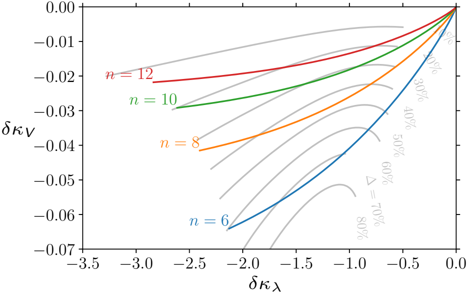
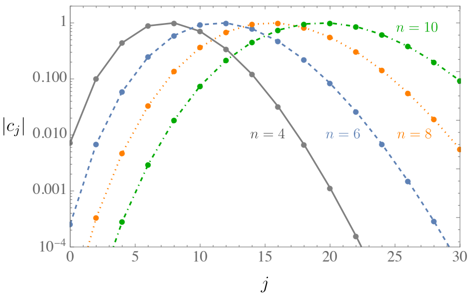
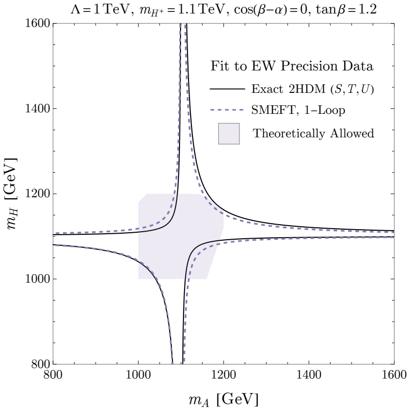
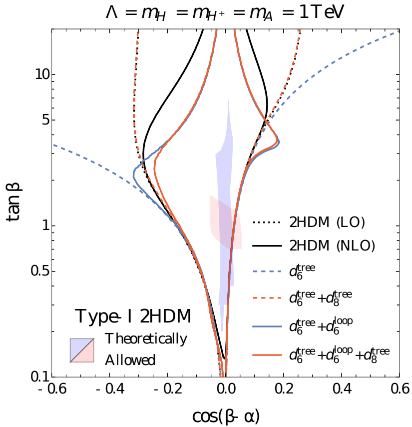




2HDM matched at one-loop

[Das Bakshi, Dawson, Fontes, Homiller '24]





- EWPO constraints arising first at one-loop
  - mild impact so far; more important with new Z pole?
- more accurate large-tan β description
  - from Yukawa operators; probed with new Higgs measurements

[Dawson, Fontes, Quezada-Calonge, Sanz-Cillero '23]

Scalar UVs matched to HEFT

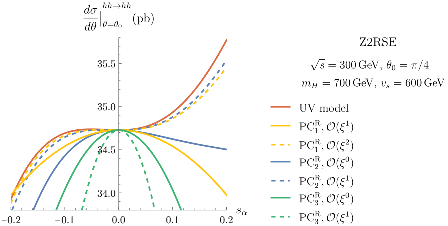
- different UV-parameter power countings consistently lead to polynomial $\mathcal{L}_{\text{EFT}}$

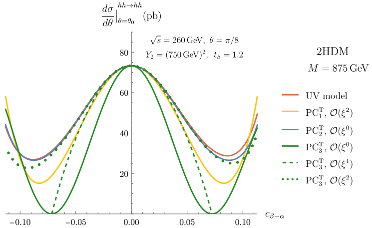
  choices of parameterisation and small params ($\sim\xi$): inverse physical heavy mass
  +? extra scalar vev
  +? mixing angles

- one power counting PC$_1$ corresponds to the decoupling limit and SMEFT

  others need $\mathcal{O}(1)$ params $\to 0$ to reproduce the SM

- best convergence depends on the observable, theory, and parameter point:



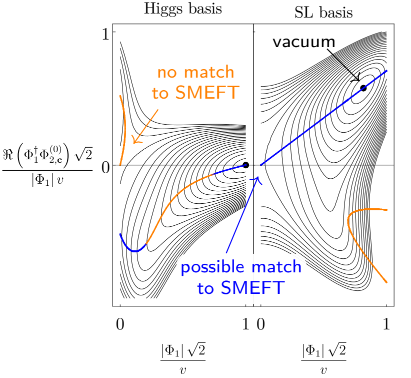


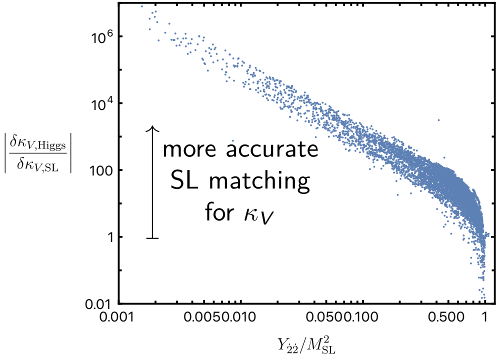
¿? extract on-shell amplitude coefficients in the small momenta expansion

  unambiguous and no expansion of UV parameter ratios?

Geometry-improved 2HDM matching

- EFT as field sub-manifold; $U(2)_{\Phi_{1,2}}$ family of field bases
- *Straight-Line bases:* zero-deriv. classical solution for Φ_2 is linear in Φ_1
- matches to SMEFT whenever possible
- allows matching to all orders in Φ_1
  has a Φ_2 mass close to physical } $\times$10–100 accuracy





Matching BSM to SMEFT

Effective field theories efficiently interpolate
between UV models and IR data.

Precision measurements,
probing indirectly scales higher than the experimental ones,
are ideal EFT territory.

Working our the EFT-UV connexions is essential
to understand EFT parameter space and result implications.

Progress is ongoing!