Subleading Higgs effects in $e^+e^- \rightarrow$ fermion+antifermion

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18th of July 2024
ICHEP 2024
Prague
Czech Republic

UNI GRAZ
NAWI Graz
Natural Sciences
FWF Österreichischer Wissenschaftsfonds

What’s up?

Review: 1712.04721
Update: 2305.01960

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Subtle field theory creates new effects in the standard model

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See review for background!

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- Physical spectrum: Observable particles
  - Peaks in (experimental) cross-sections

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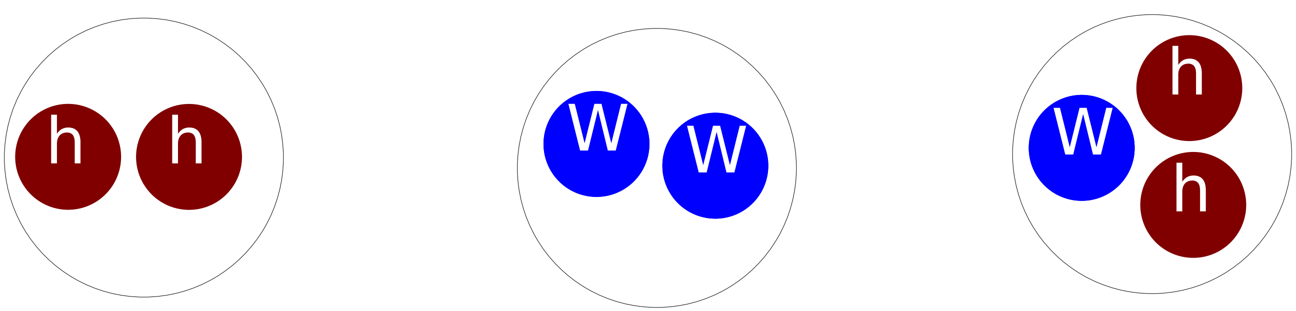
- Gauge-invariant states are composite
  - Higgs-Higgs, W-W, Higgs-Higgs-W etc.



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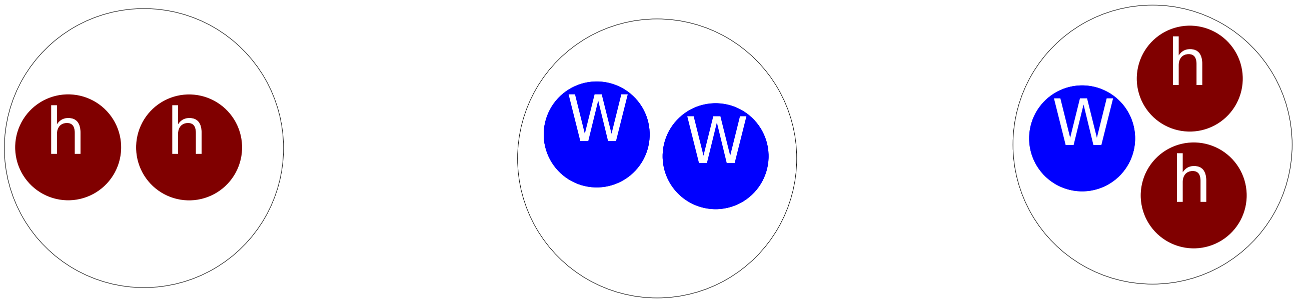

- Why does perturbation theory work?
  - Fröhlich-Morchio-Strocchi mechanism

Fröhlich-Morchio-Strocchi Mechanism

[Fröhlich et al.’80,’81
Maas'12,’17]

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Higgs field

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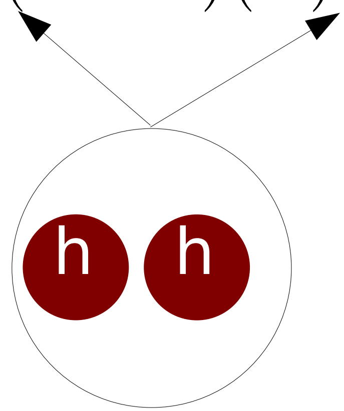

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Augmented perturbation theory

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Trivial two-particle state

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Bound state mass → $\langle (h^+ h)(x)(h^+ h)(y)\rangle$ $= v^2$ $\langle \eta^+(x)\eta(y)\rangle$ ← Higgs mass

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What about this?

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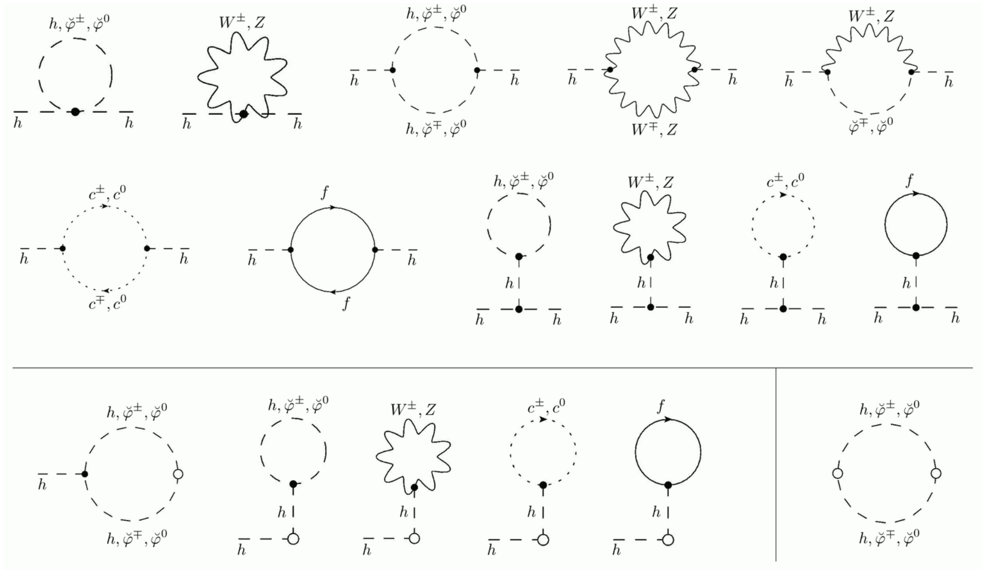

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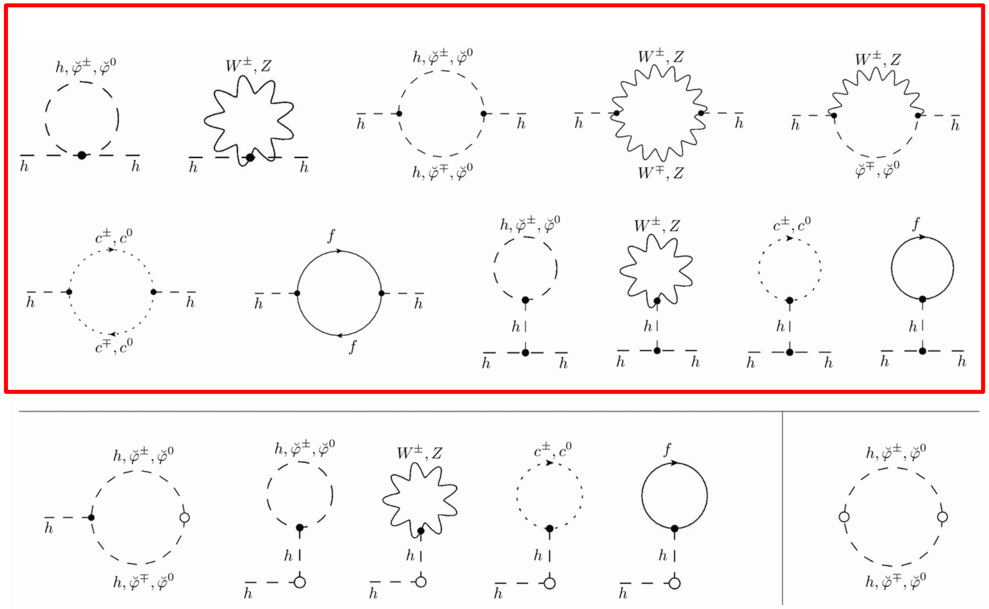

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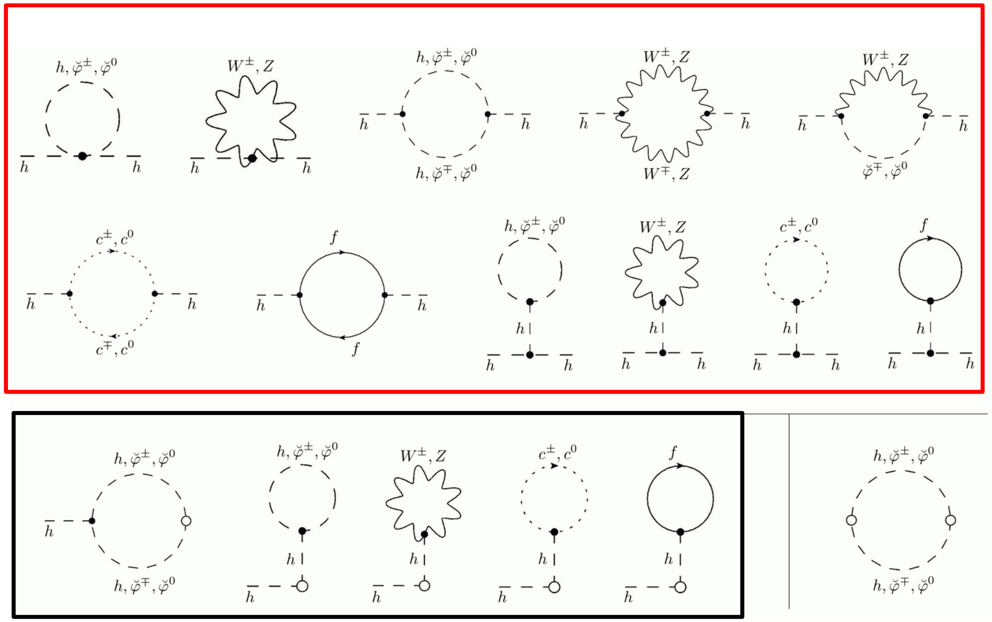

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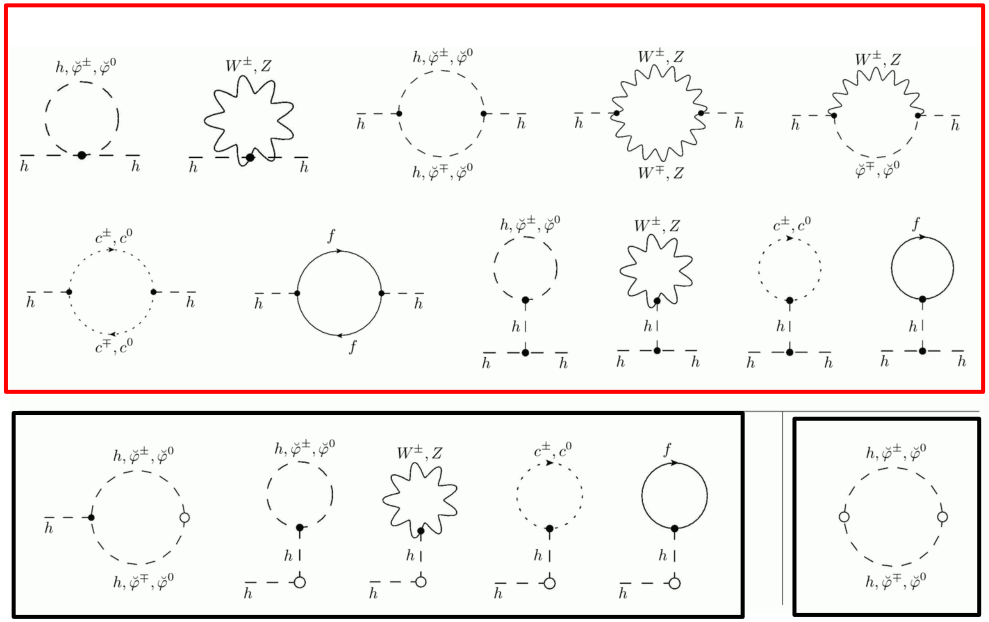

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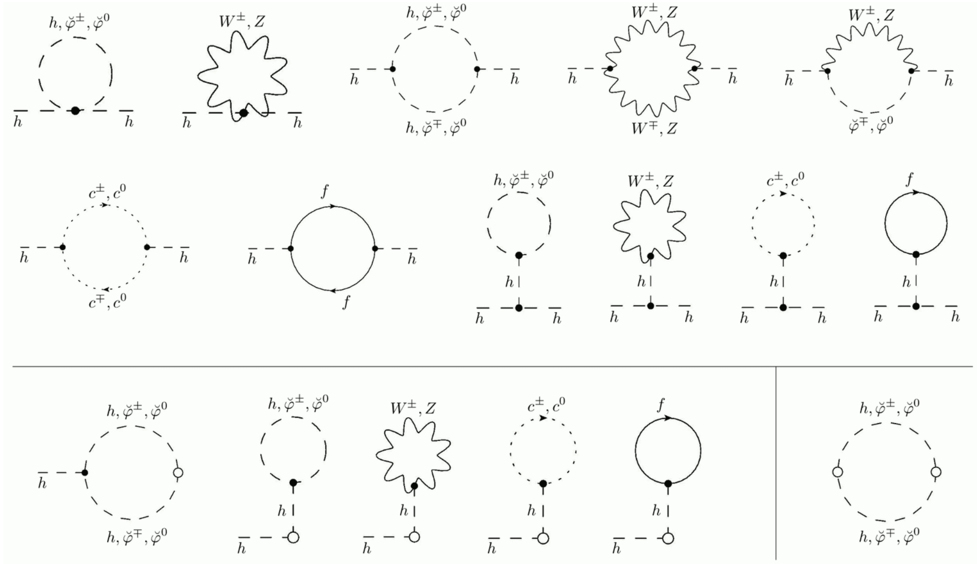

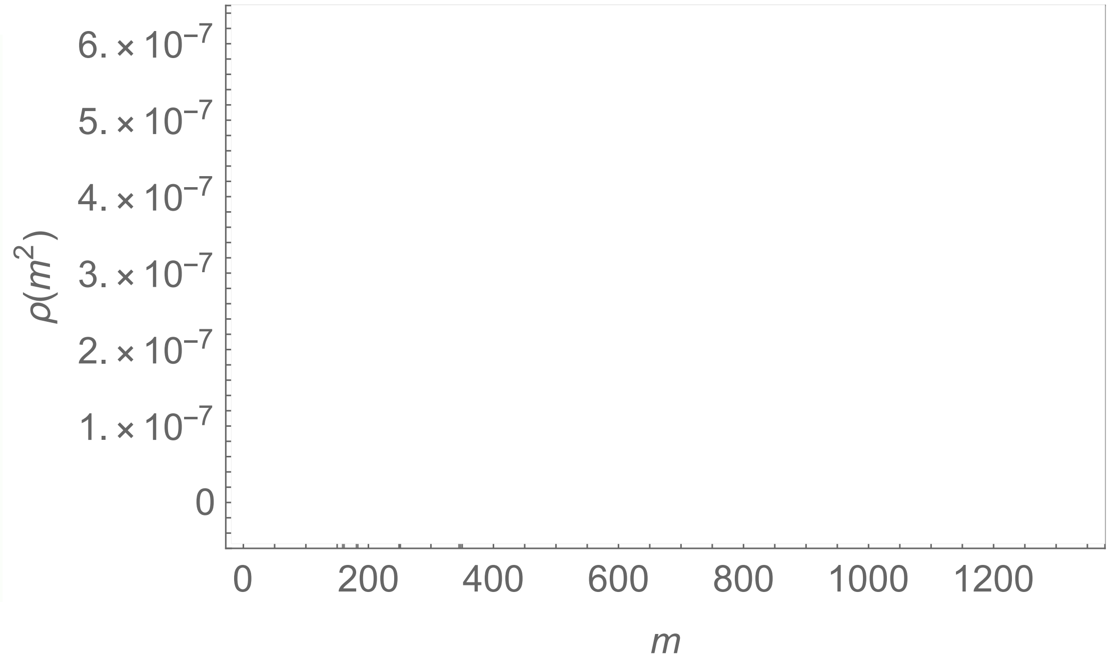

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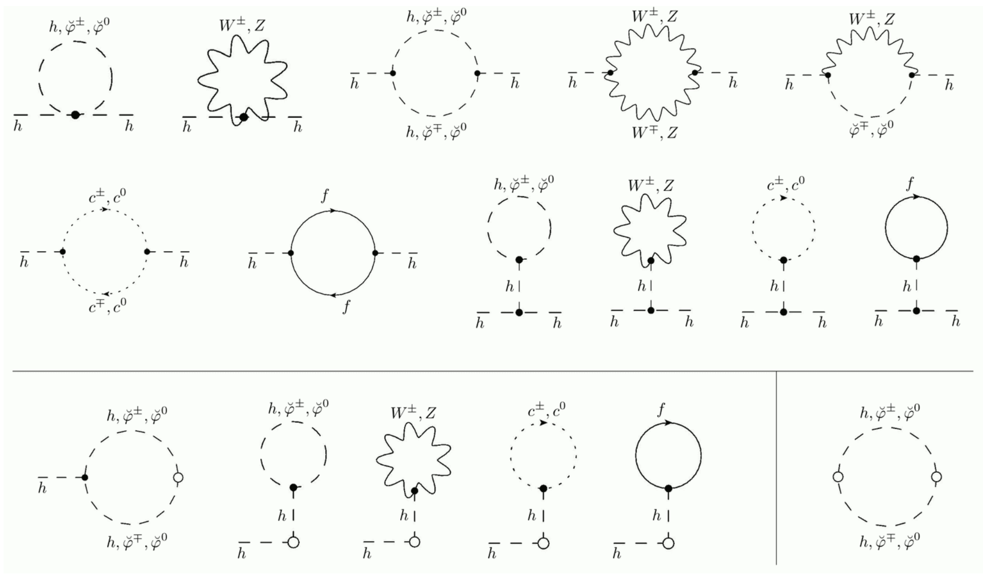

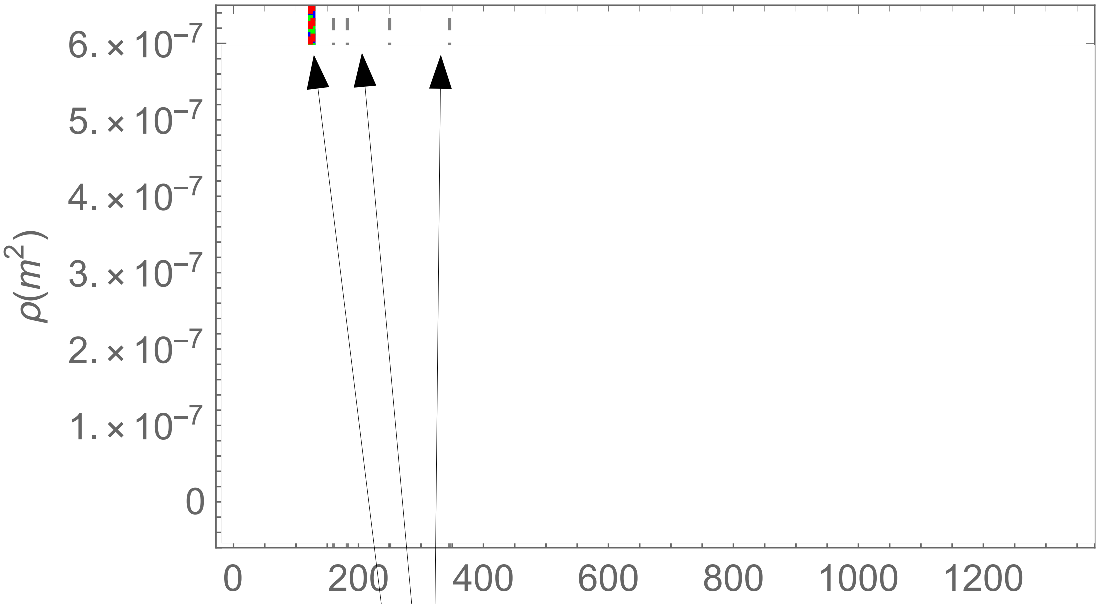

Physical thresholds

[Maas'12,'17
Maas & Sondenheimer'20
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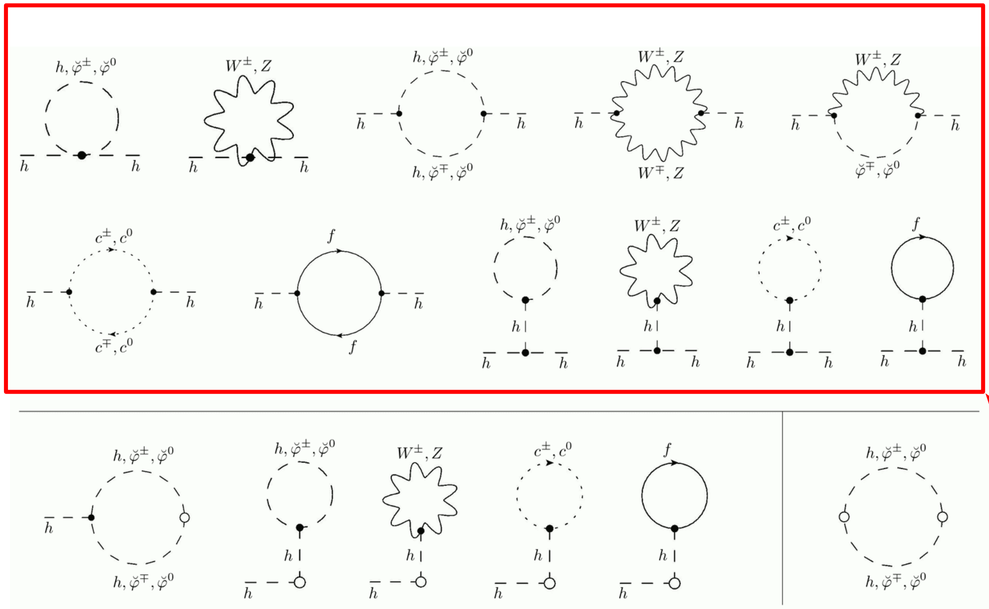

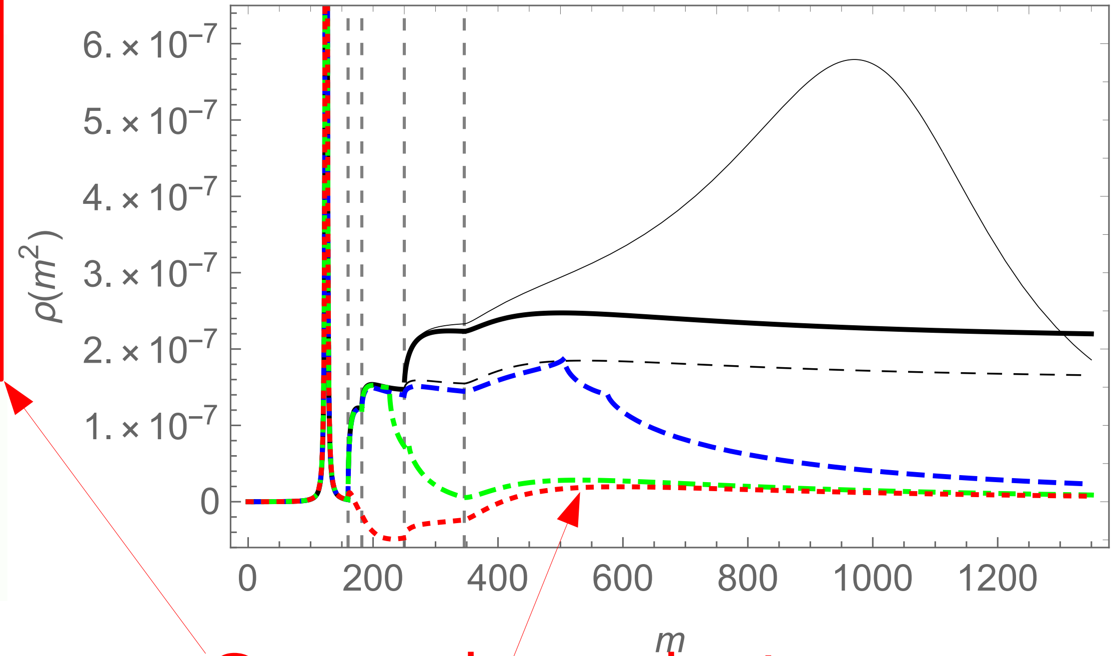

Gauge-dependent

[Maas'12,'17
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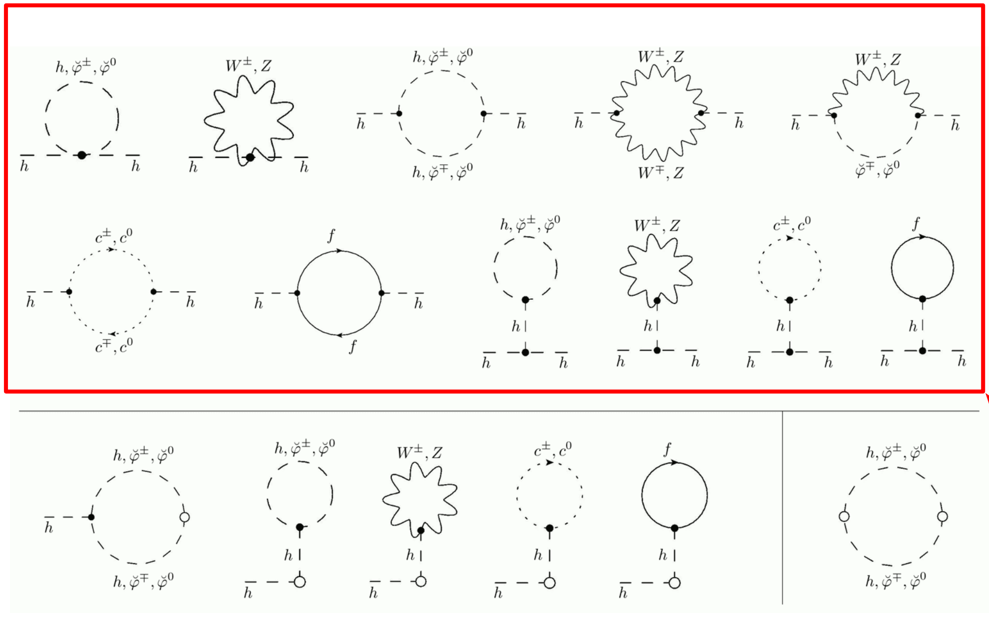

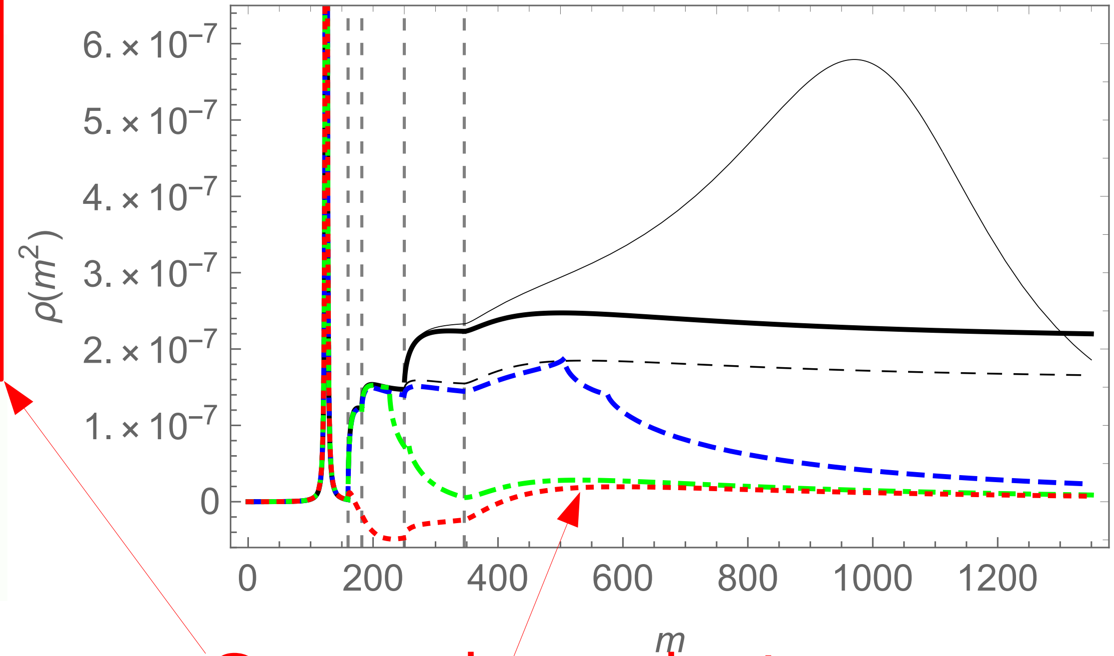

Gauge-dependent
Unphysical features:
Positivity violation
Additional thresholds

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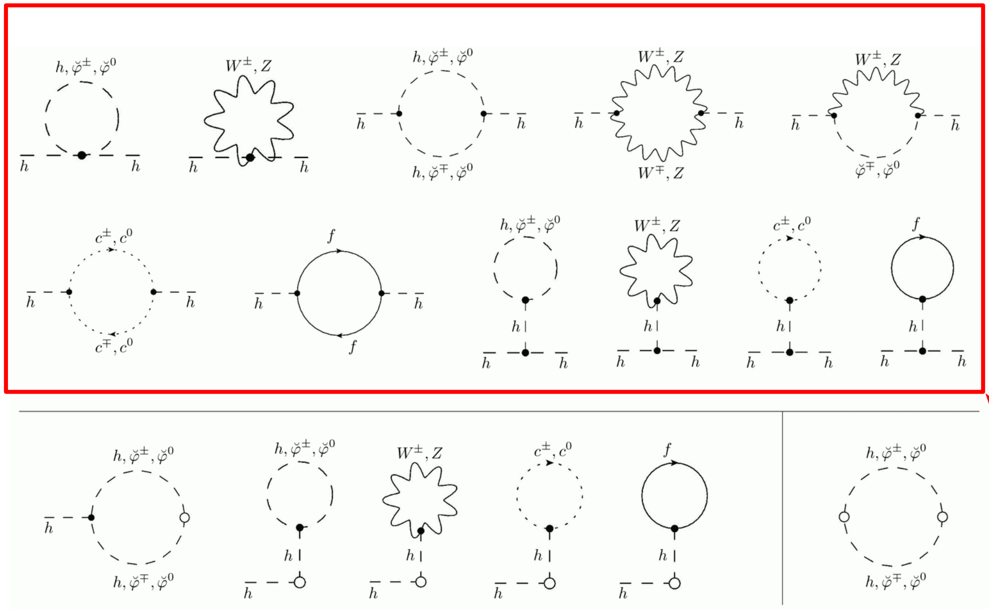

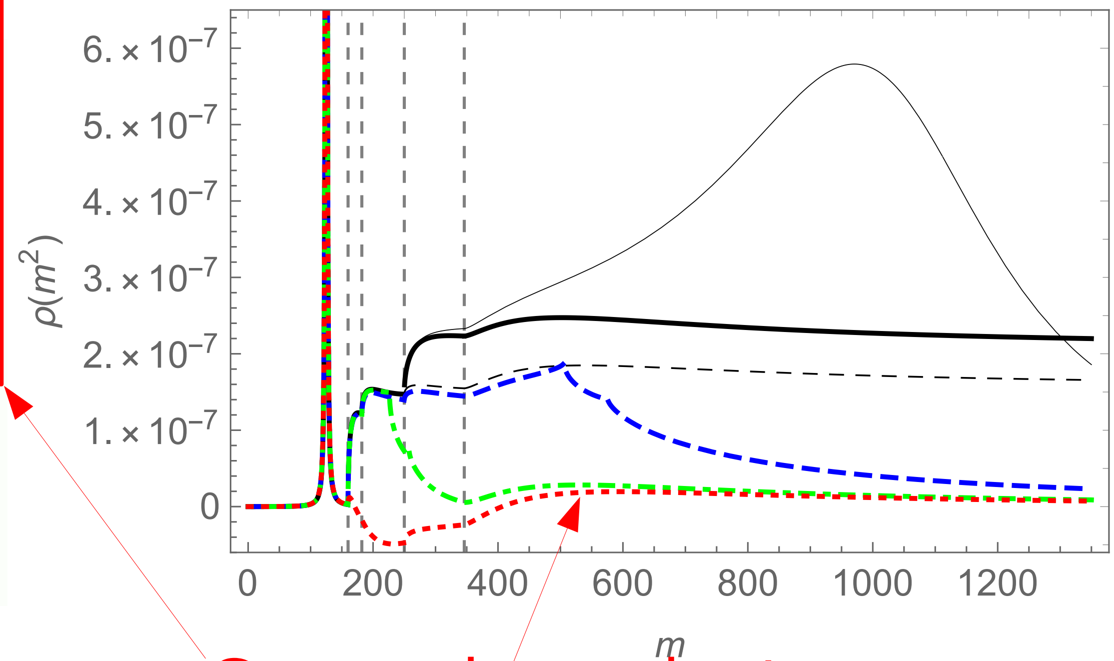

Gauge-dependent

Unphysical features:

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Additional thresholds

Not a consequence of instability: Occurs even for an asymptotically stable Higgs in a toy theory

[Maas'12,'17
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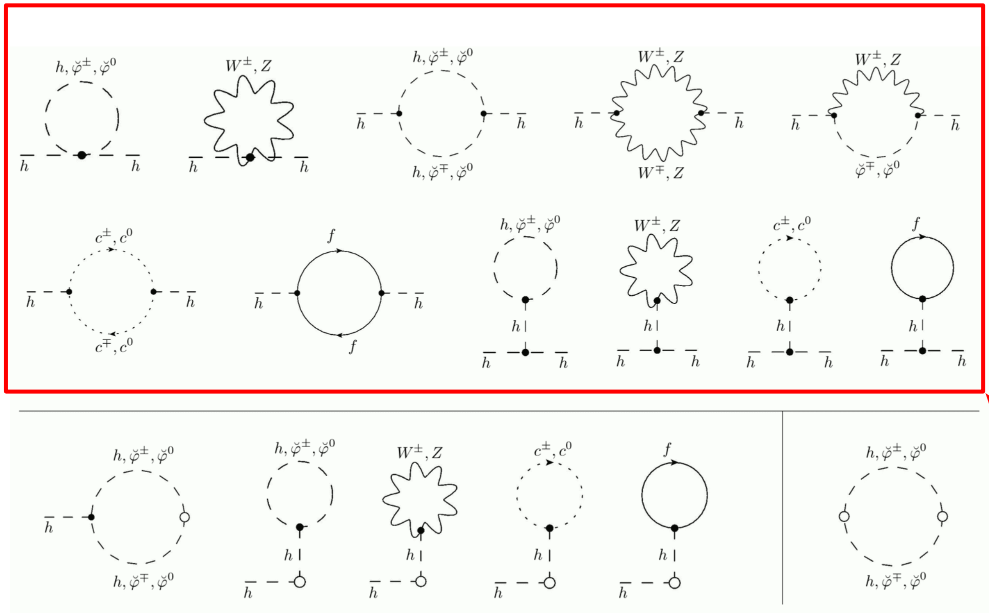

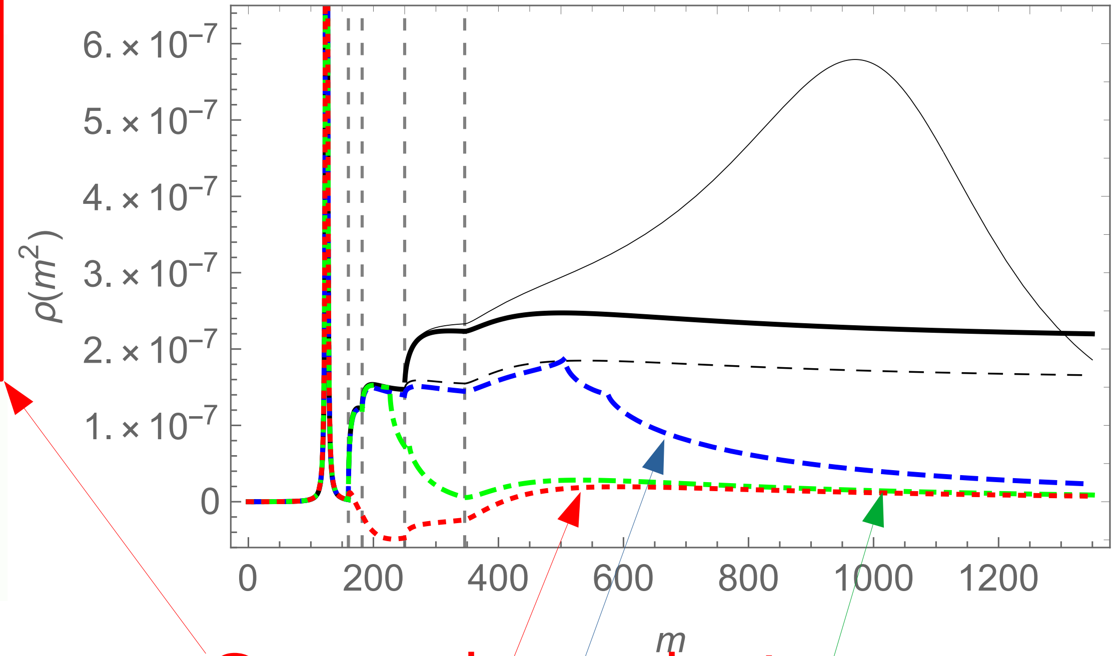

Gauge-dependent

Other gauge choices

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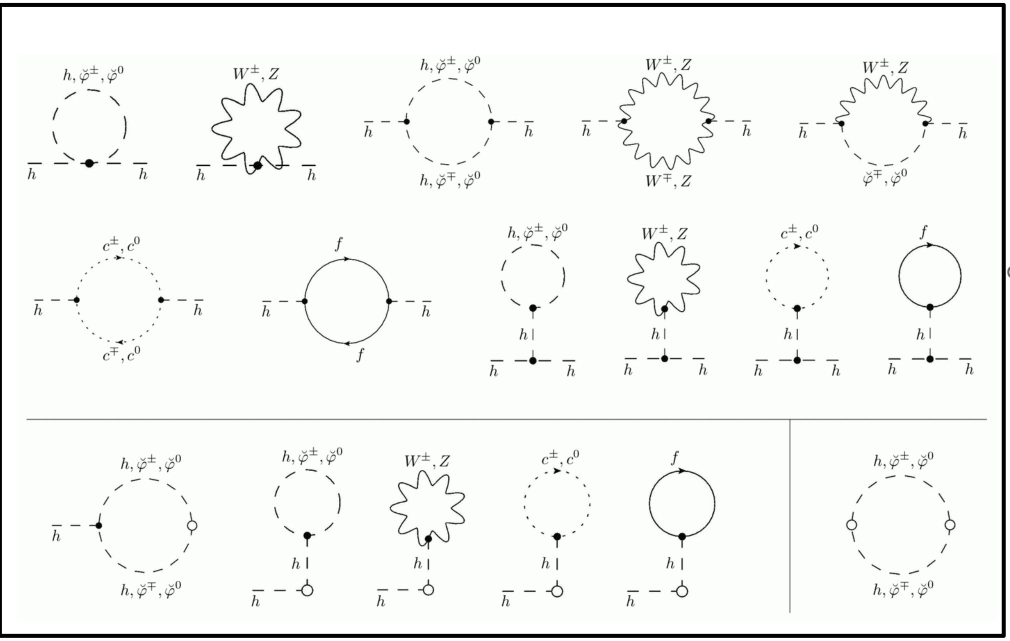

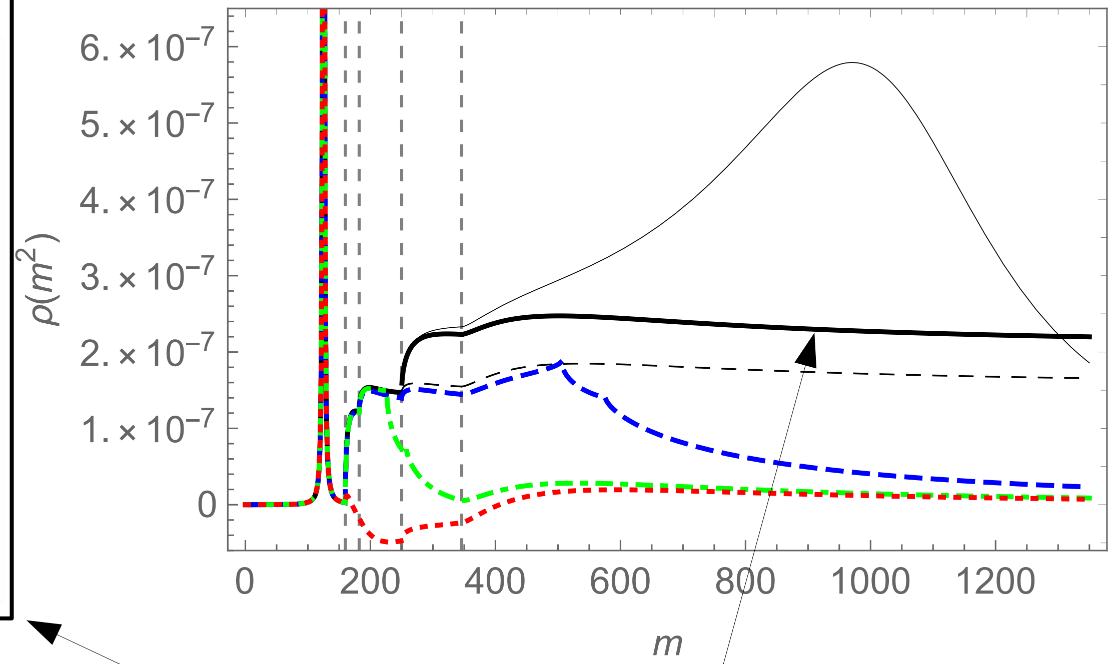

Physical – same for all gauge choices

[Maas'12,'17
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Flavor

[Fröhlich et al.'80,
Egger, Maas, Sondenheimer'17]

- Flavor has two components
  - Global SU(3) generation
  - Local SU(2) weak gauge (up/down distinction)

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- Can this be true? Lattice test

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[Afferrante,Maas,Sondenheimer,Törek'20]

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  - Compressed mass scales
  - One generation
  - Degenerate leptons and neutrinos
  - Dirac fermions: left/right-handed non-degenerate
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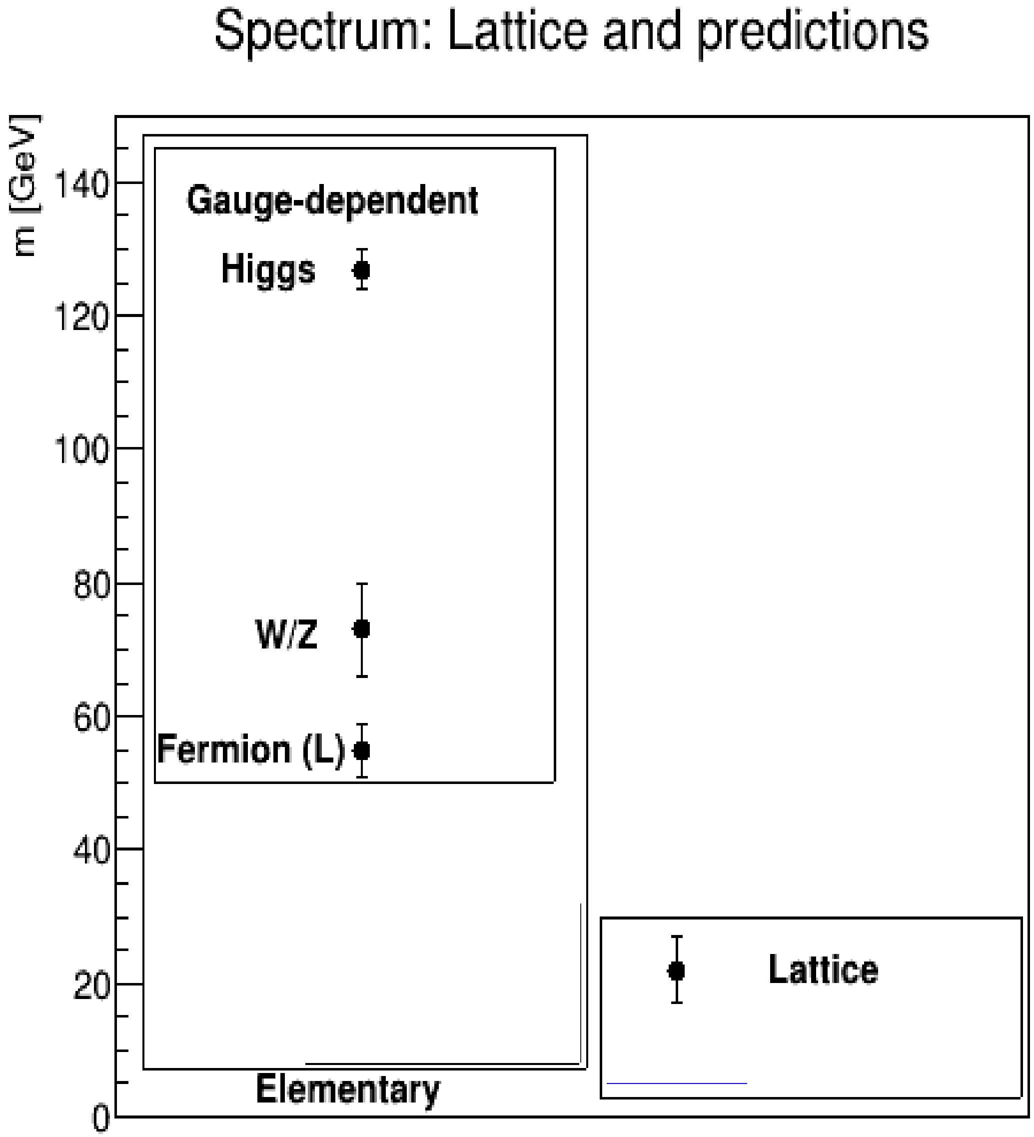

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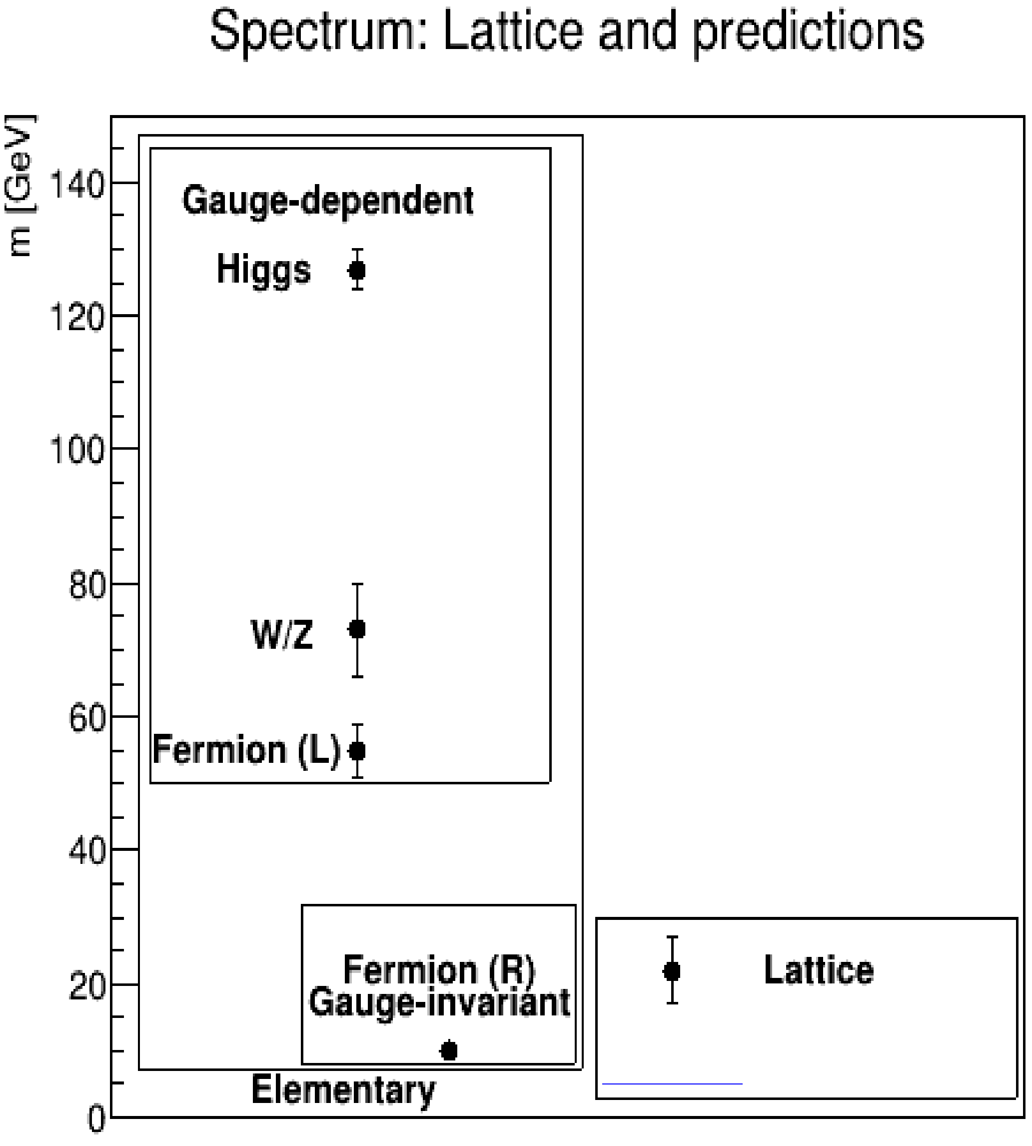
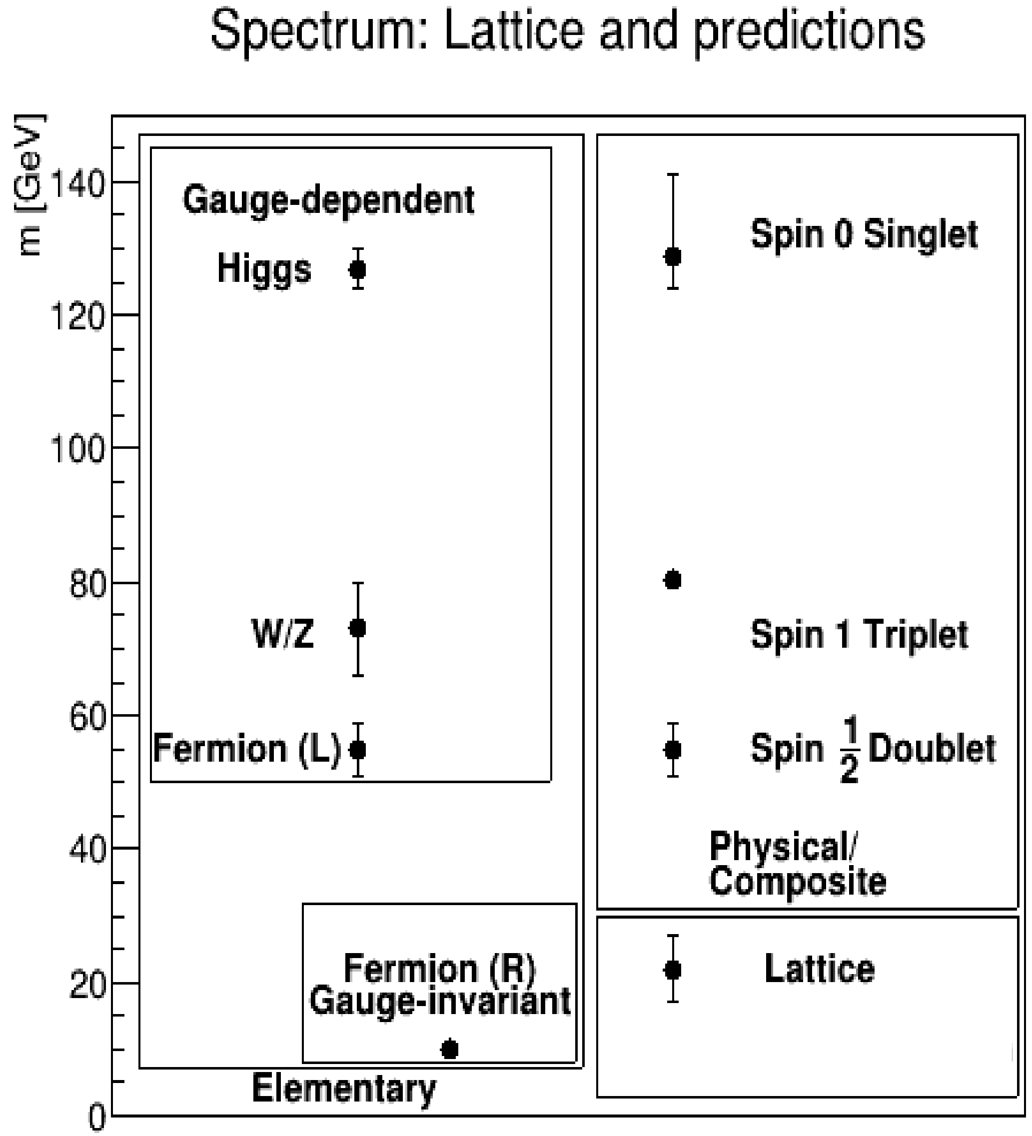


Flavor on the lattice

[Afferrante,Maas,Sondenheimer,Törek'20]

- Only mock-up standard model
  - Compressed mass scales
  - One generation
  - Degenerate leptons and neutrinos
  - Dirac fermions: left/right-handed non-degenerate
  - Quenched
- Same qualitative outcome
  - FMS construction
  - Mass defect
  - Flavor and custodial symmetry patterns



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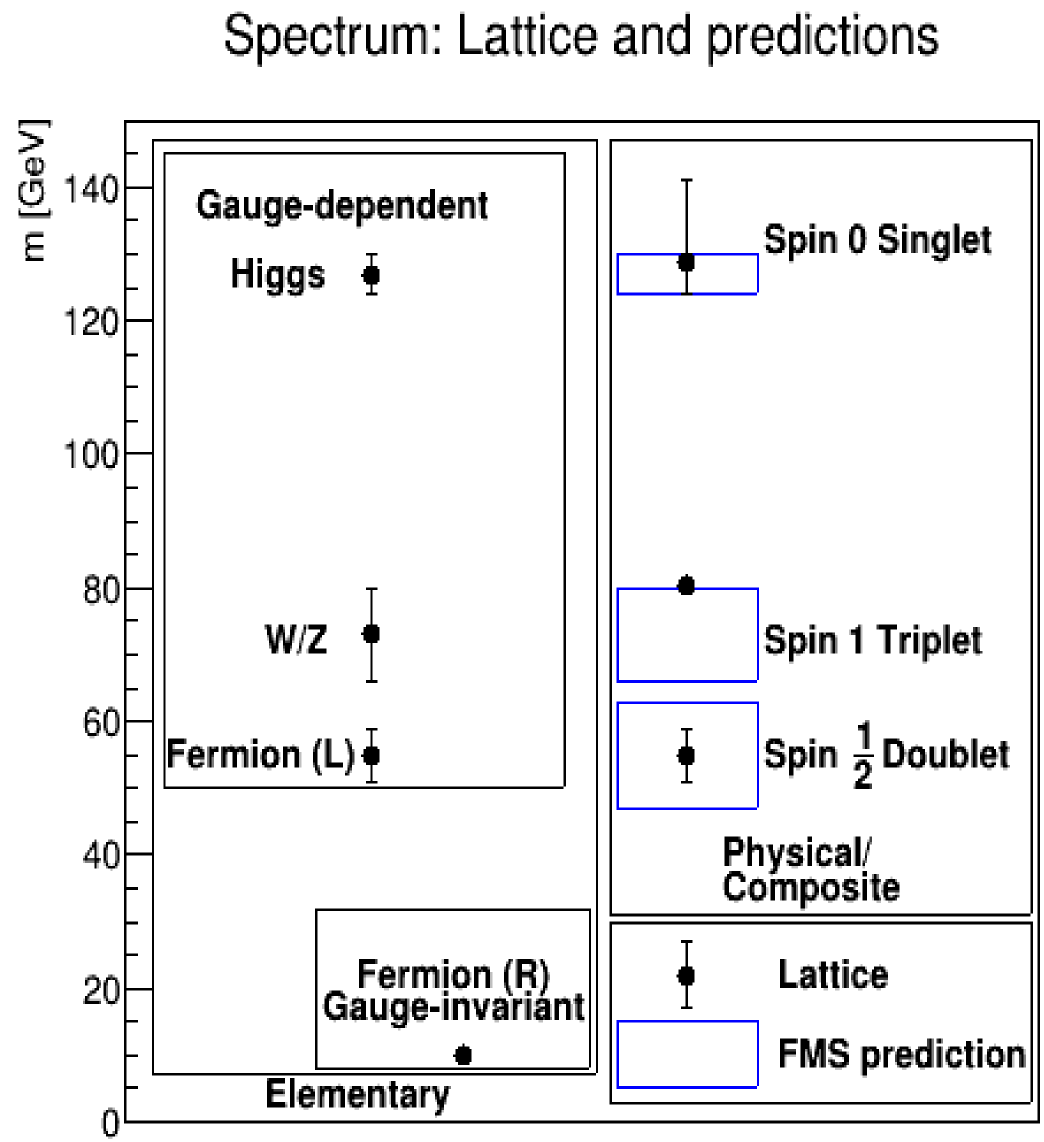

Scattering

[Maas et al.'17
Maas & Reiner '22
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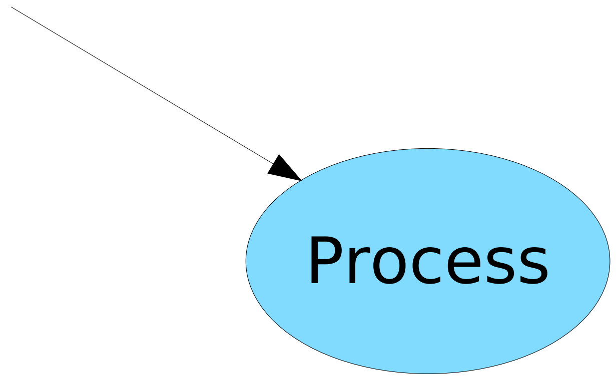
Incoming (asymptotic) particle
Standard LSZ: Elementary particle



$$\langle f(p) \ldots \rangle$$

Scattering

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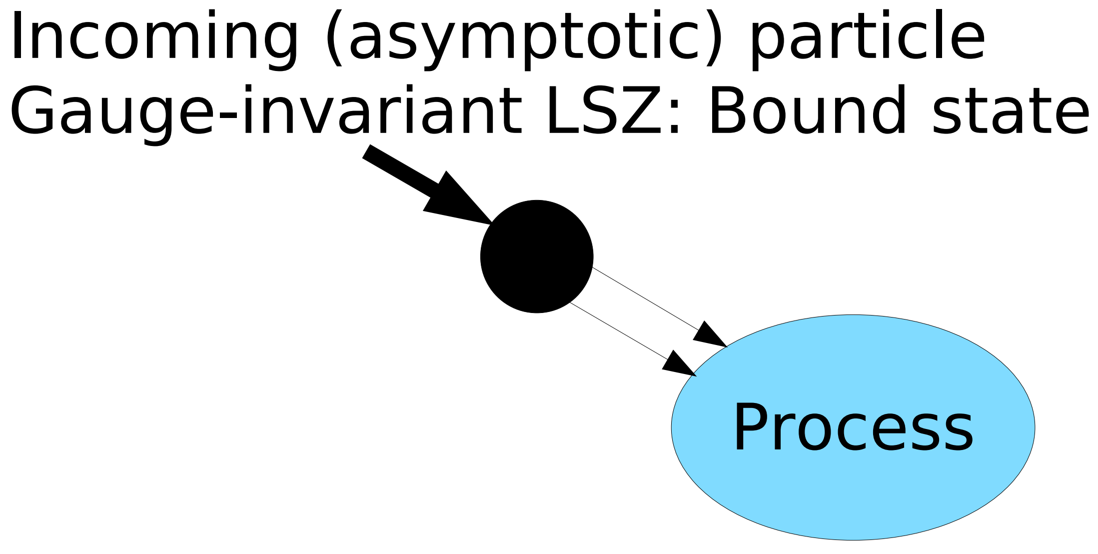

$$\langle (Hf)(p)\ldots\rangle$$

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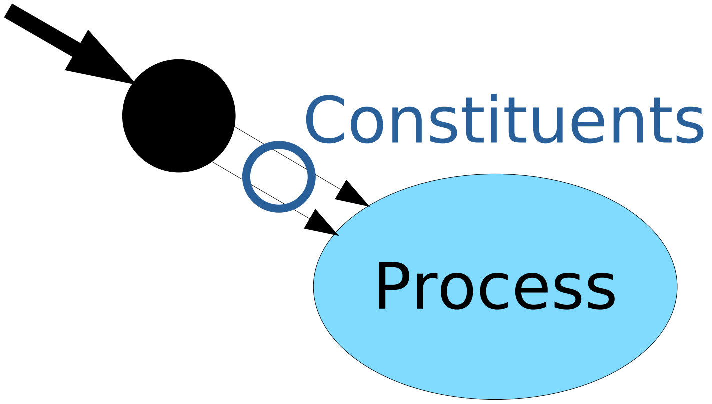
Gauge-invariant LSZ: Bound state



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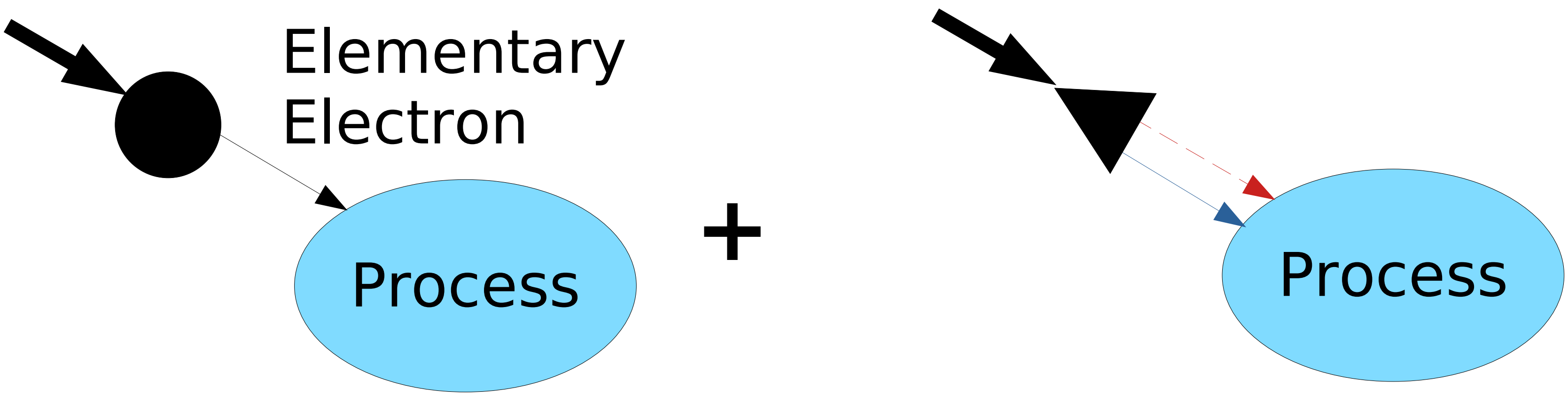
FMS LSZ: Elementary and fluctuations



$$v\langle f(p)\ldots\rangle + \int dq\, \Gamma(P,q)\, D_f(p-q)\, D_h(q)\, \langle h(q)\, f(P-q)\ldots\rangle$$

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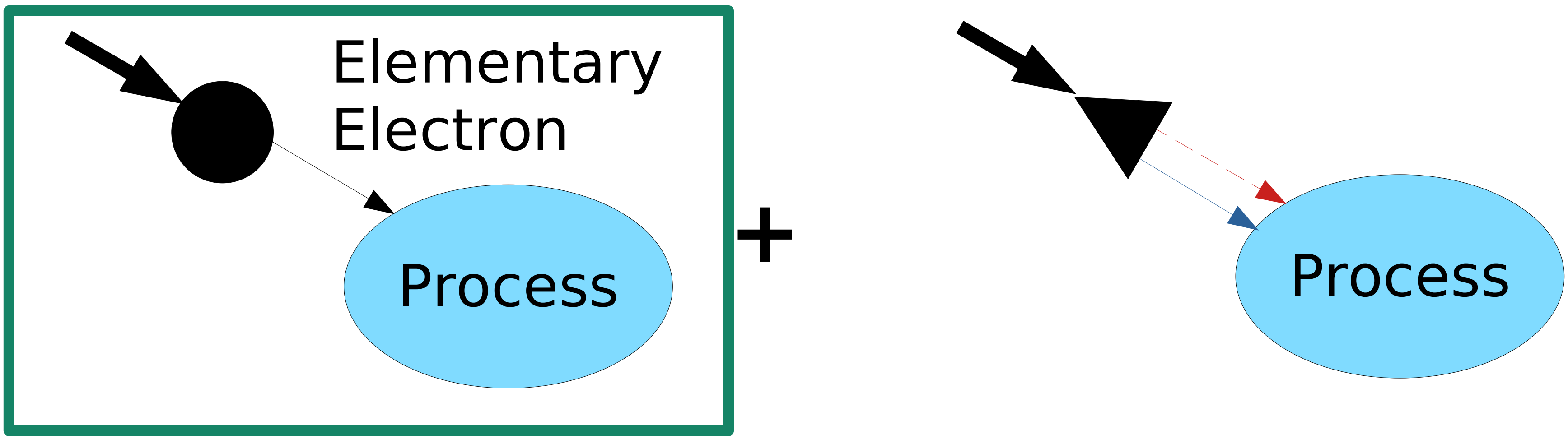

Standard perturbation theory

$$\boxed{v\langle f(p)\ldots\rangle}+\int dq\,\Gamma(P,q)\,D_f(p-q)\,D_h(q)\langle h(q)f(P-q)\ldots\rangle$$

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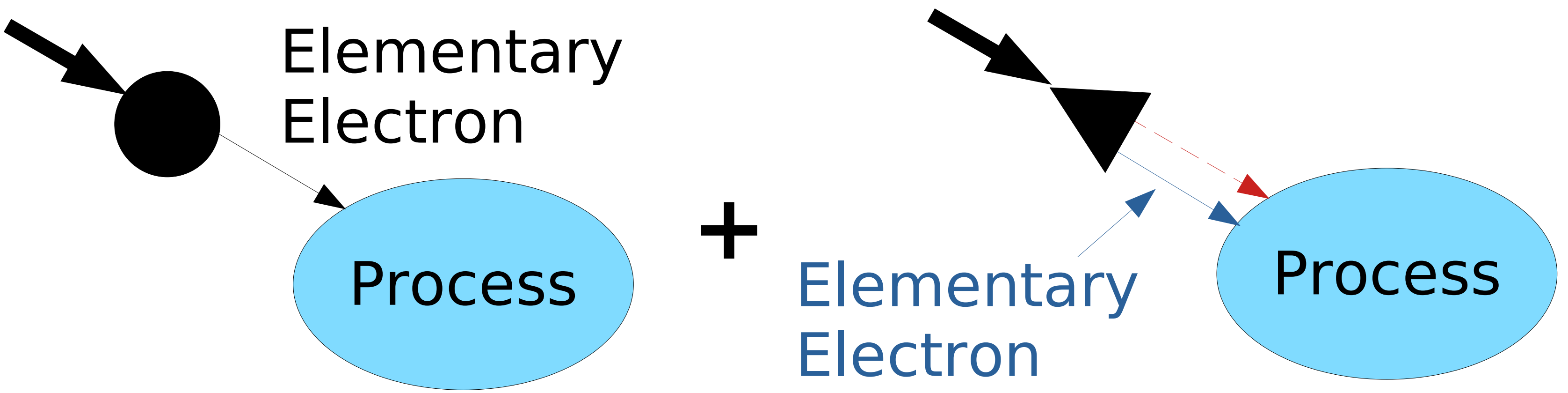

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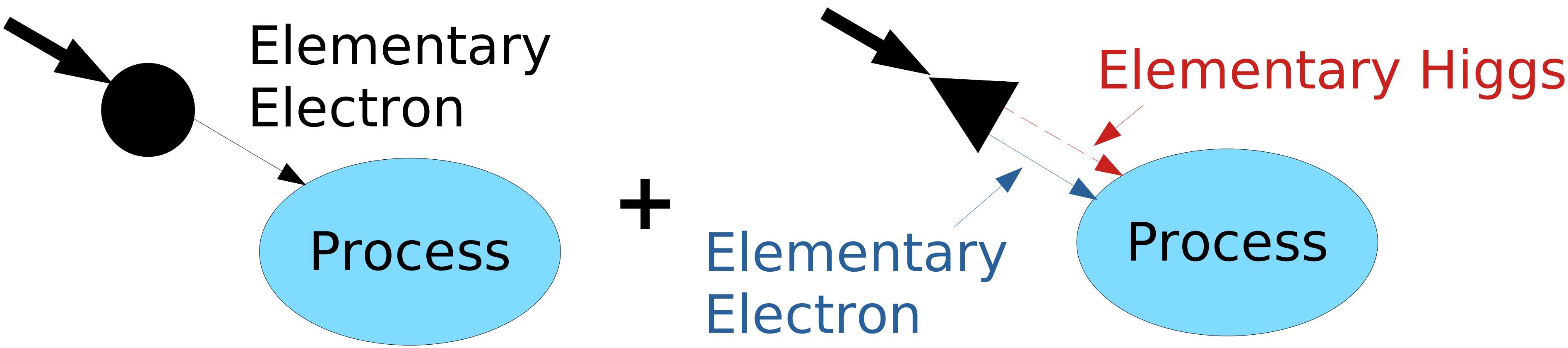

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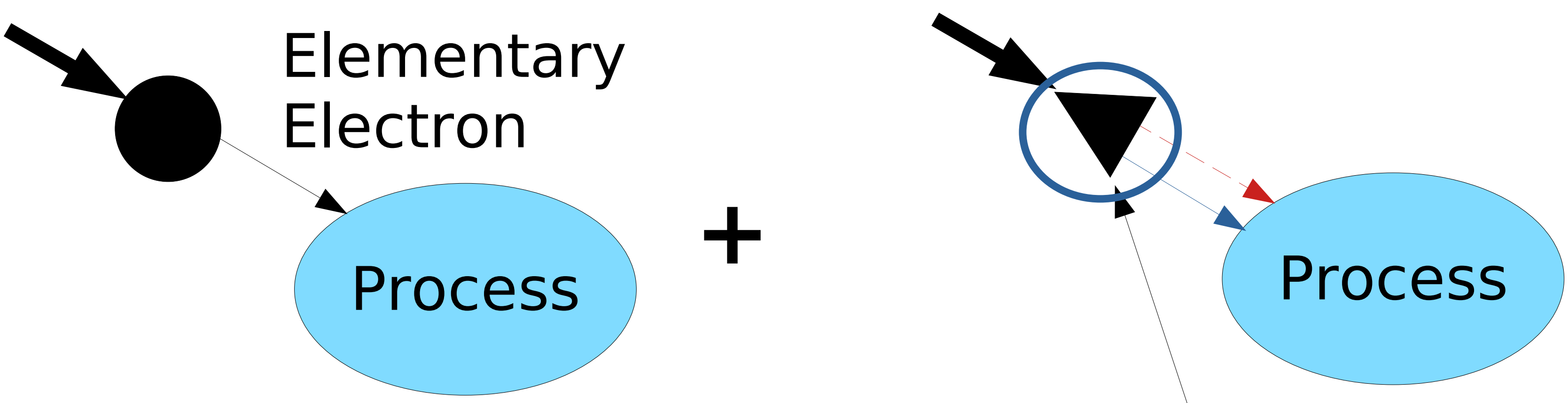

Bethe-Salpeter amplitude

$$v\langle f(p)\ldots\rangle+\int dq\,\Gamma(P,q)\,D_f(p-q)\,D_h(q)\langle h(q)f(P-q)\ldots\rangle$$

Bethe-Salpeter Amplitude

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Calculable itself in augmented perturbation theory

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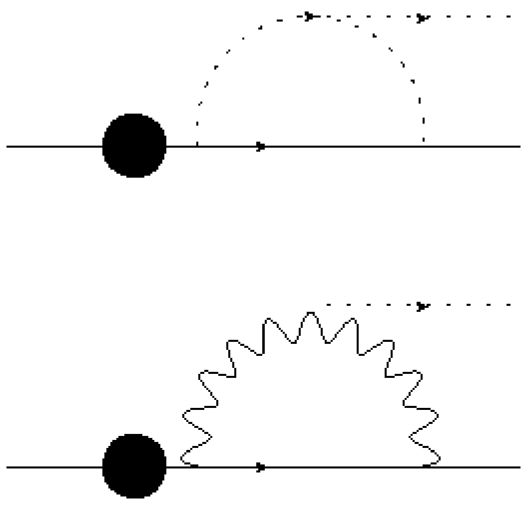

$$v_i \Gamma_{ijk}^{ffh}(P, P-q, q)$$

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[Maas, Plätzer et al. unpublished]

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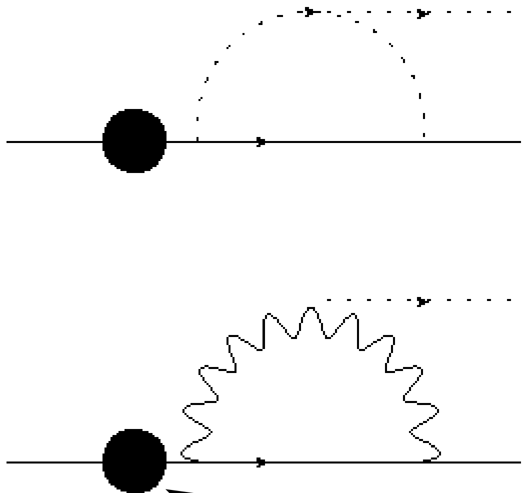

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Binding-to-constituent transition

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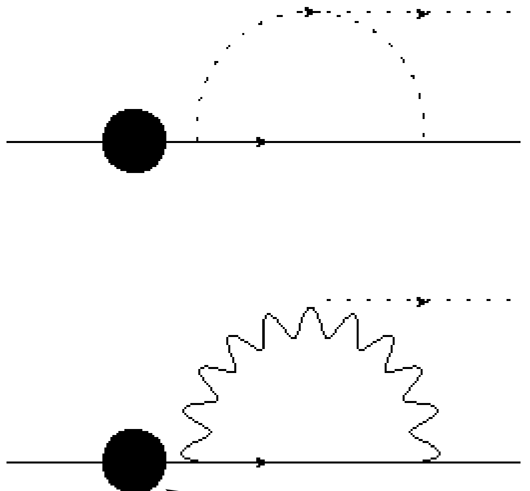

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Reweights standard diagrams

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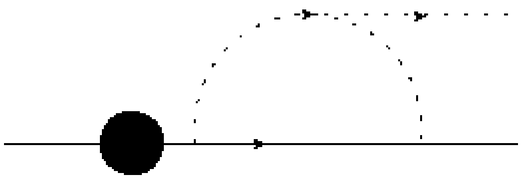

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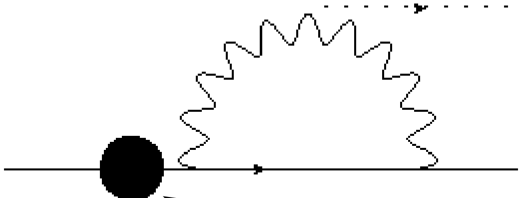

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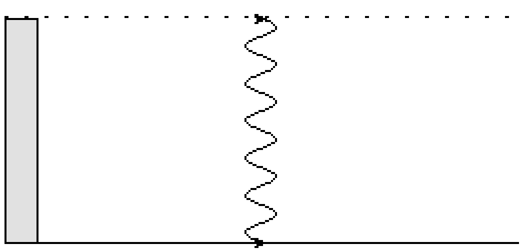

$$\int dk\, \Gamma_{iijk}(P-k, k, P-q, q)$$

Bethe-Salpeter Amplitude

[Maas, Plätzer et al. unpublished]

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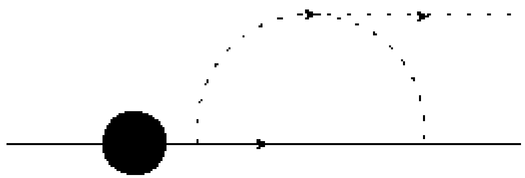

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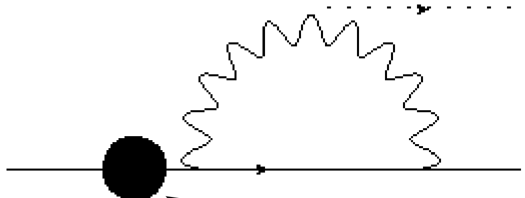

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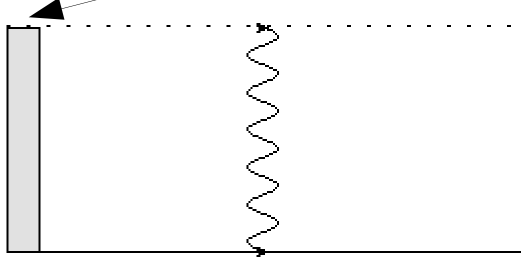

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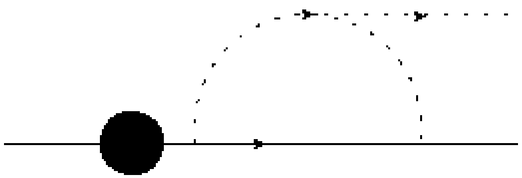

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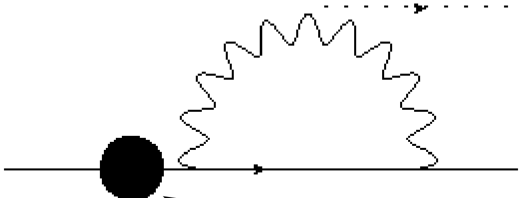

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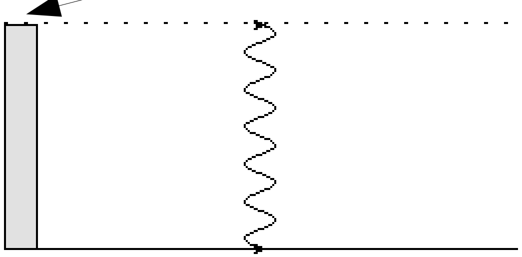

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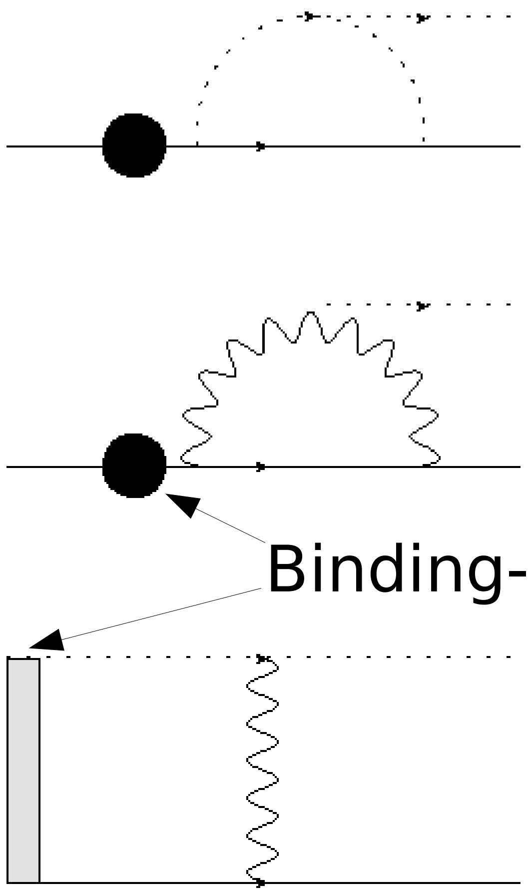

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Both raise (in the standard model) the number of loops by 1

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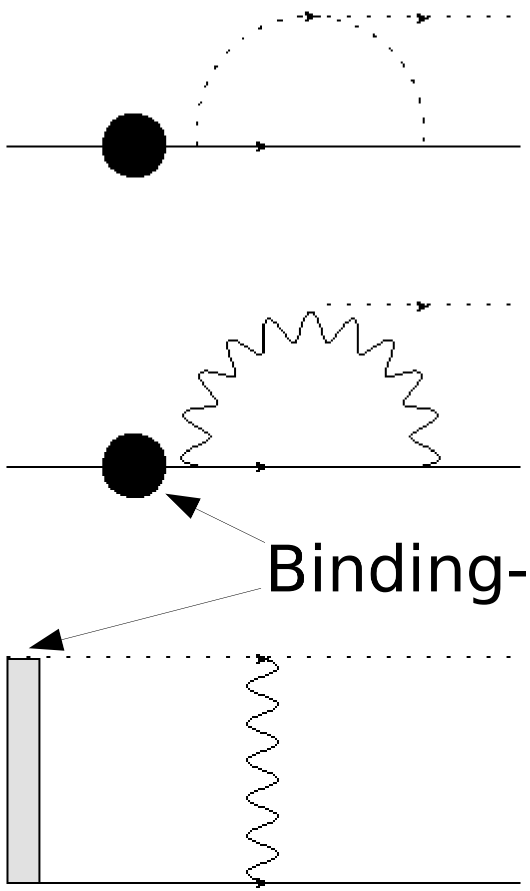

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Both raise (in the standard model) the number of loops by 1
But neither are Yukawa suppressed

Impact on processes

[Maas, Plätzer et al. unpublished
Egger et al.'17, Maas et al. '22]

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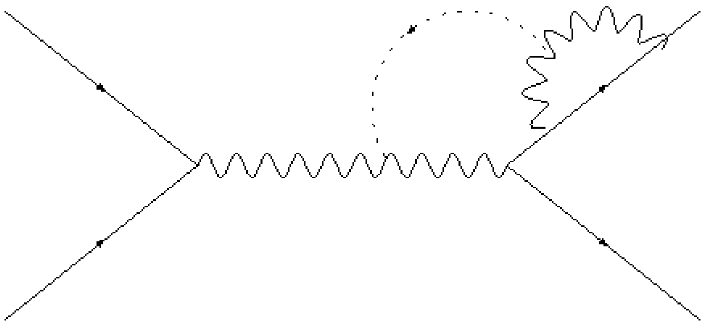
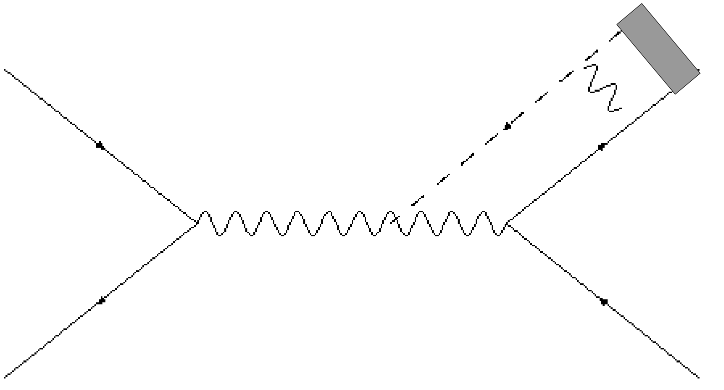
Process f̄f → f̄f: 2-loop (in g_{weak}) suppressed contribution





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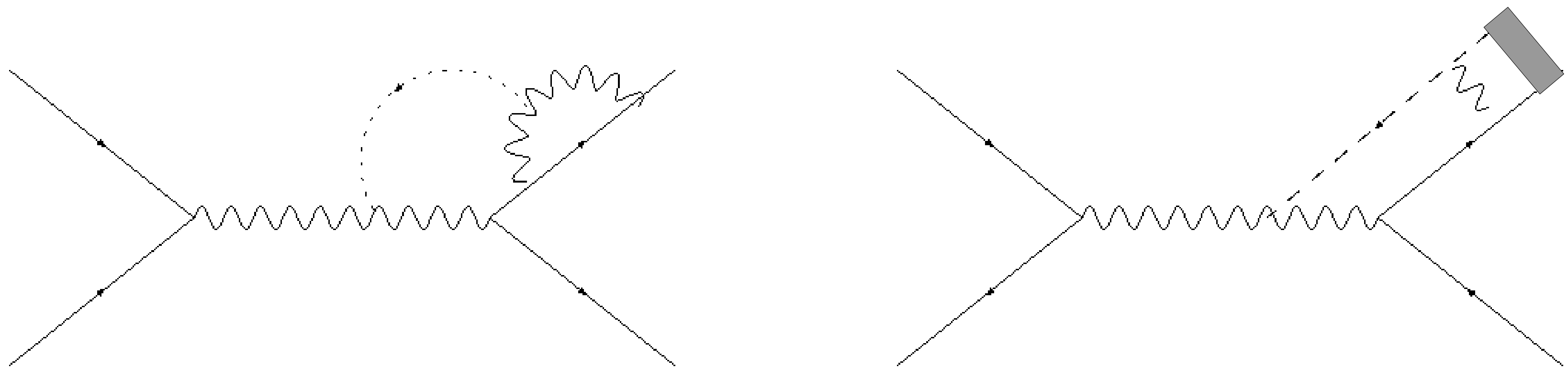
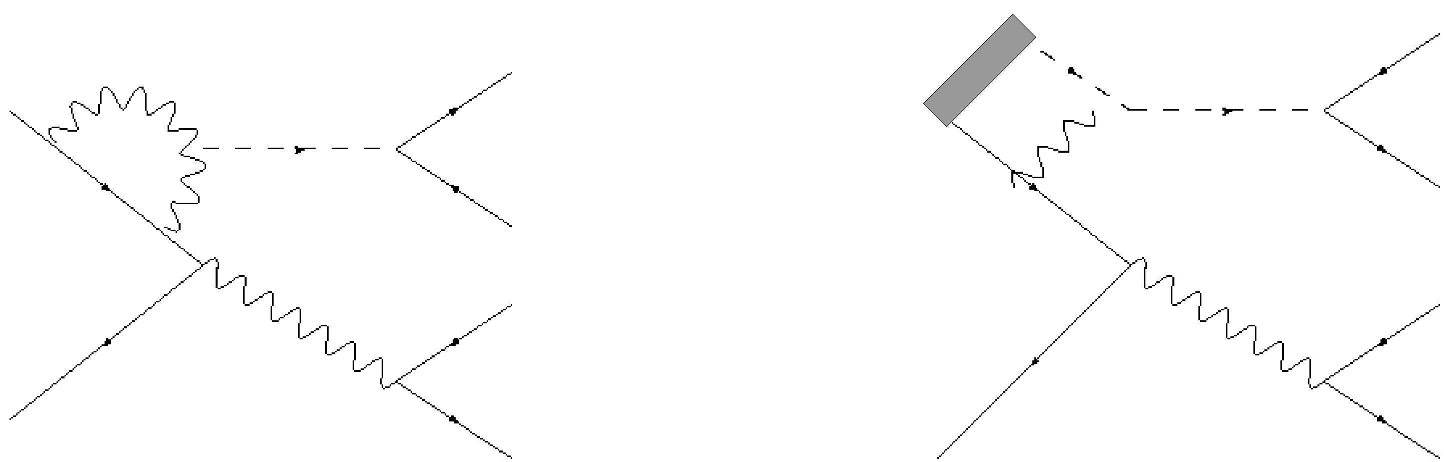


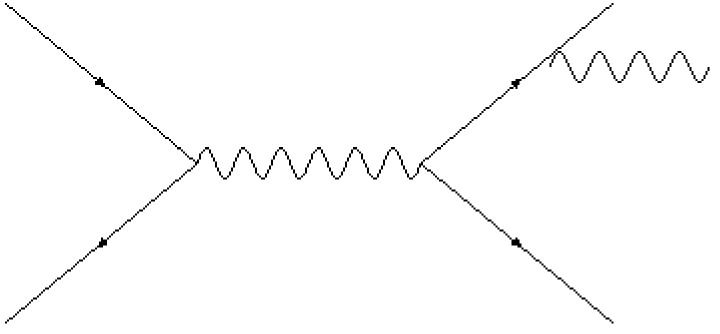


Process ff → ffff 1-loop ($g_{weak}y$) suppressed contribution

Resummation effects

[Ciafaloni et al. '00
Maas et al.'22]

Standard perturbation theory



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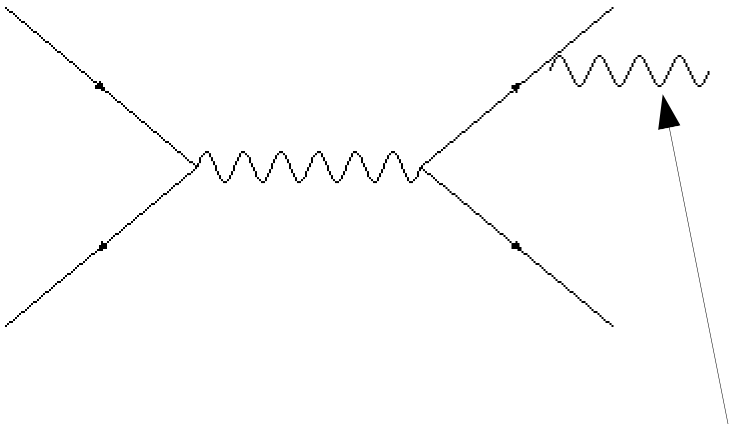

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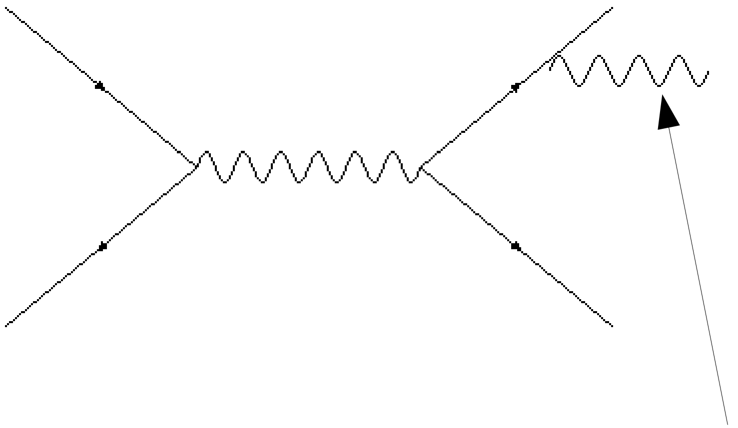

Resumming real emission

$$\sim \ln^2 \frac{s}{m_W^2}$$

at 1 TeV of the same order as strong corrections

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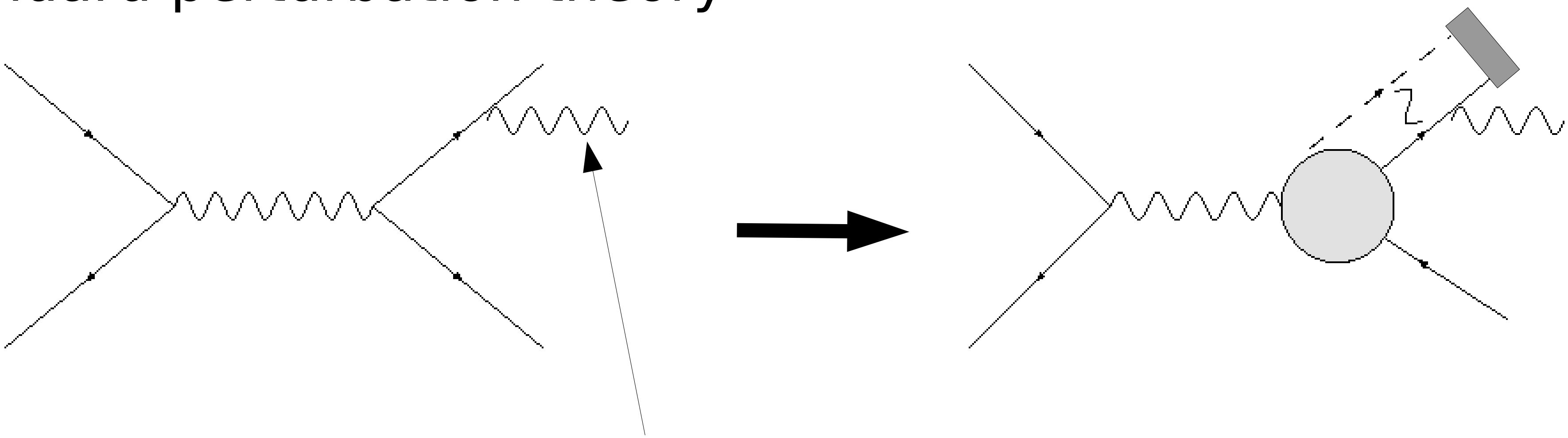
Standard perturbation theory

Augmented by correct asymptotic state



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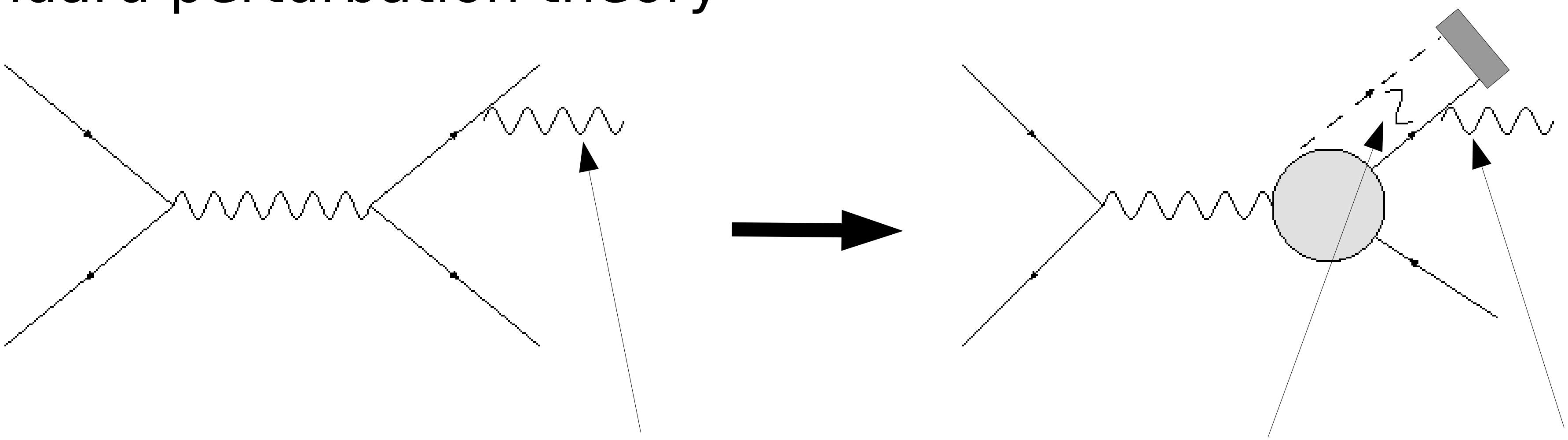

Resumming real emission

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at 1 TeV of the same order as strong corrections

Virtual and real emissions compensate (BN/KLN theorems)
- substantial change

Summary

Review: 1712.04721
Update: 2305.01960

- Field theory requires change of asymptotic states
  - Can be treated using FMS-augmented perturbation theory
  - Changes in the SM at one or two loop orders

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