Intermediate Vector Bosons and Gauge Symmetry

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Poland

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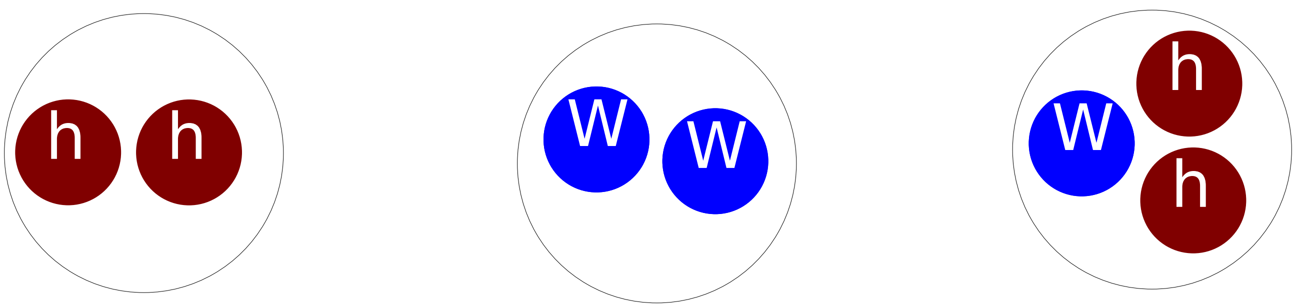
- Gauge-invariant states are composite
  - Higgs-Higgs, W-W, Higgs-Higgs-W etc.



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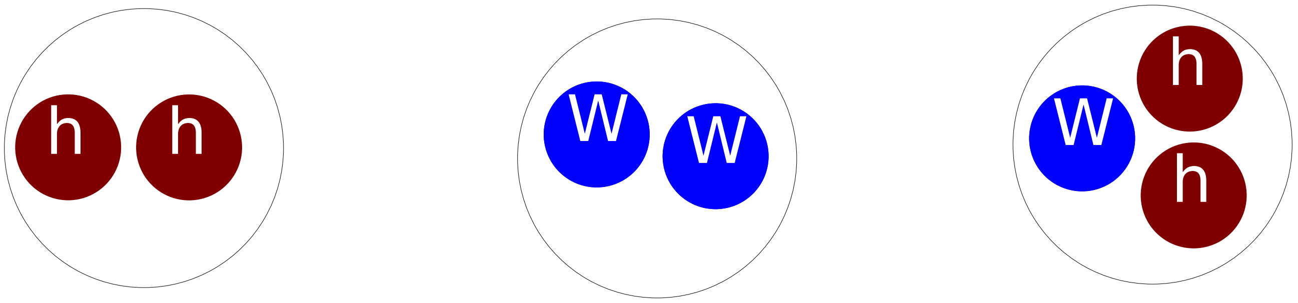

- Why does perturbation theory work?
  - Fröhlich-Morchio-Strocchi mechanism

Fröhlich-Morchio-Strocchi Mechanism

[Fröhlich et al.'80,'81
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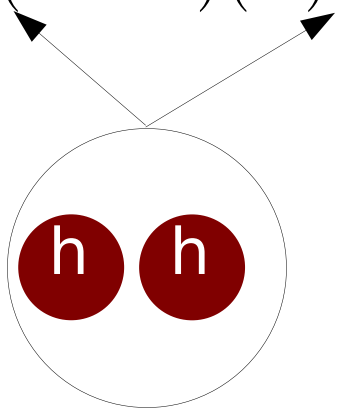

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Trivial two-particle state

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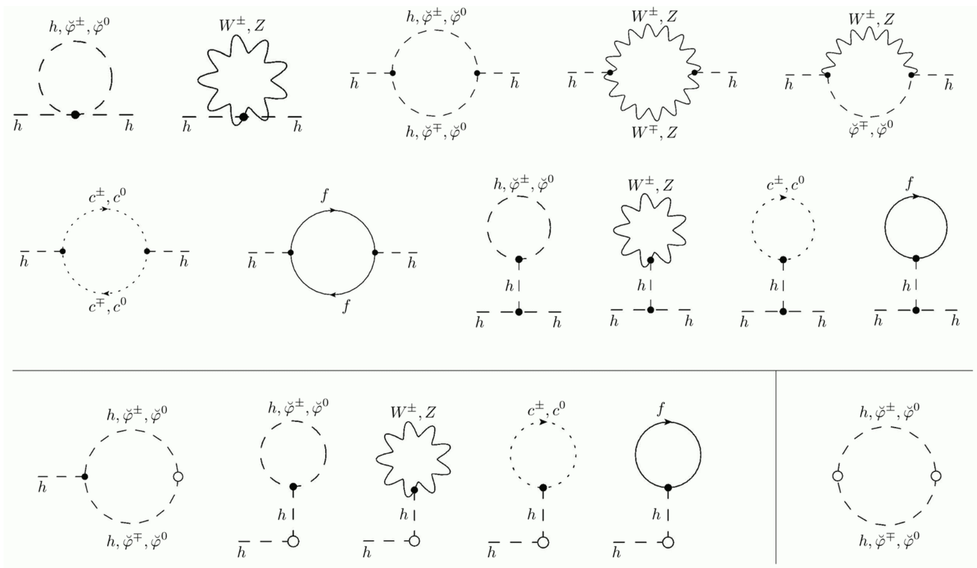

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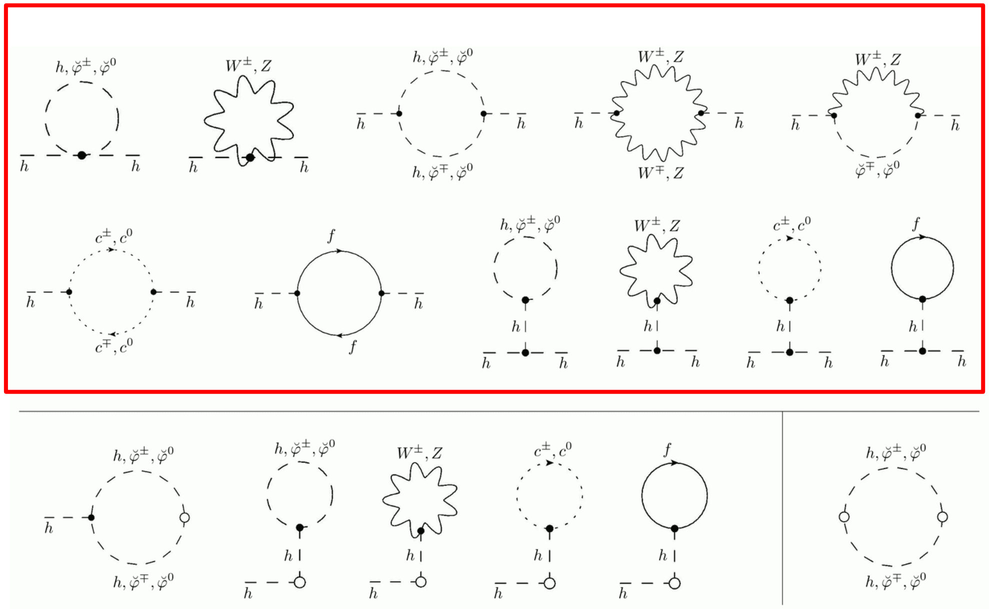

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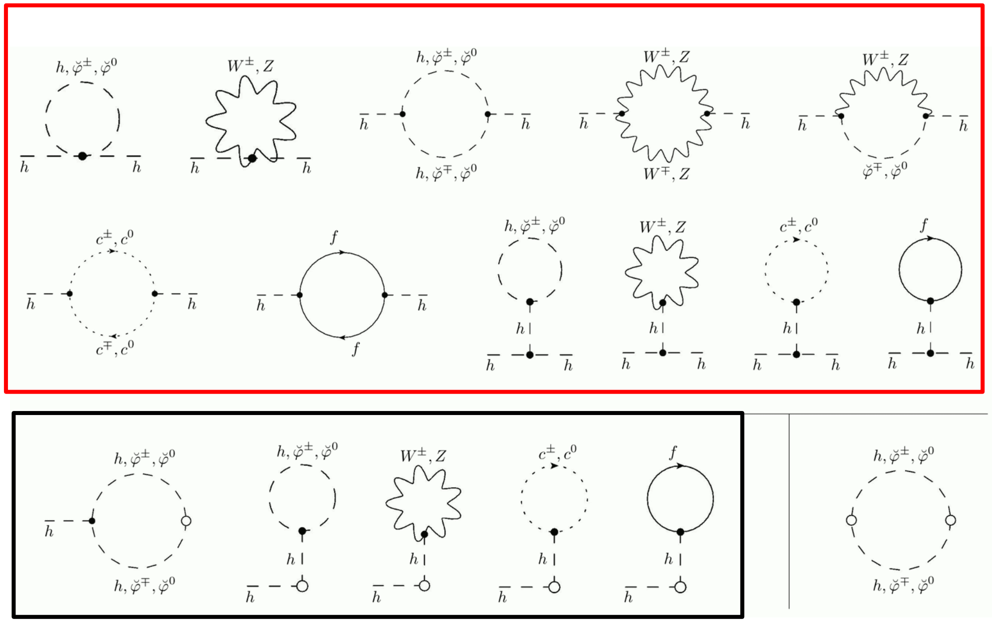

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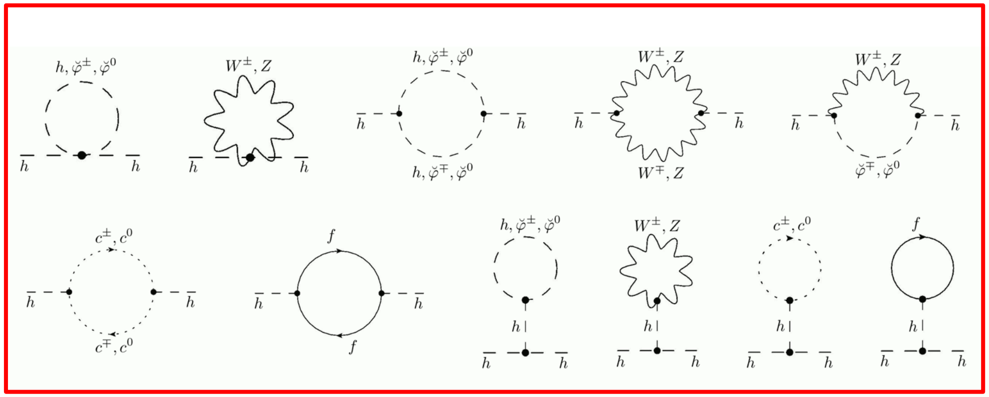

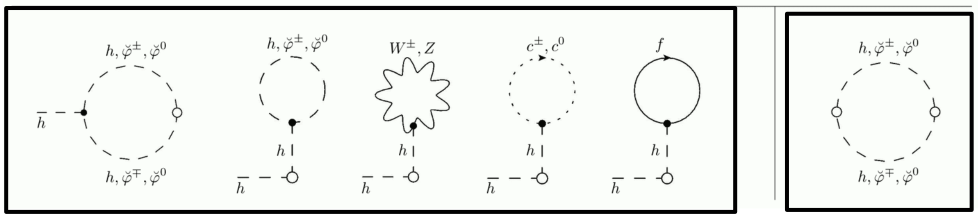

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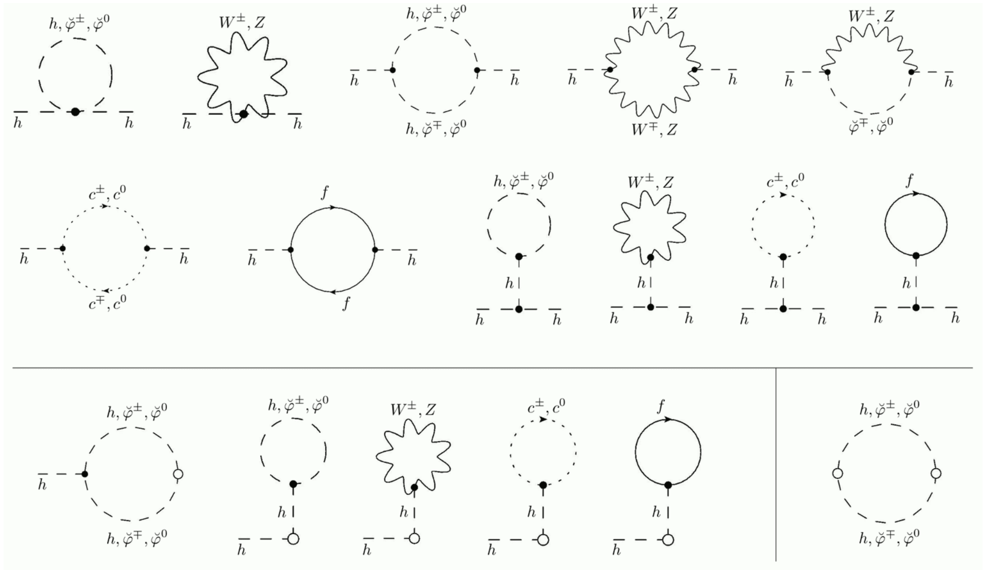

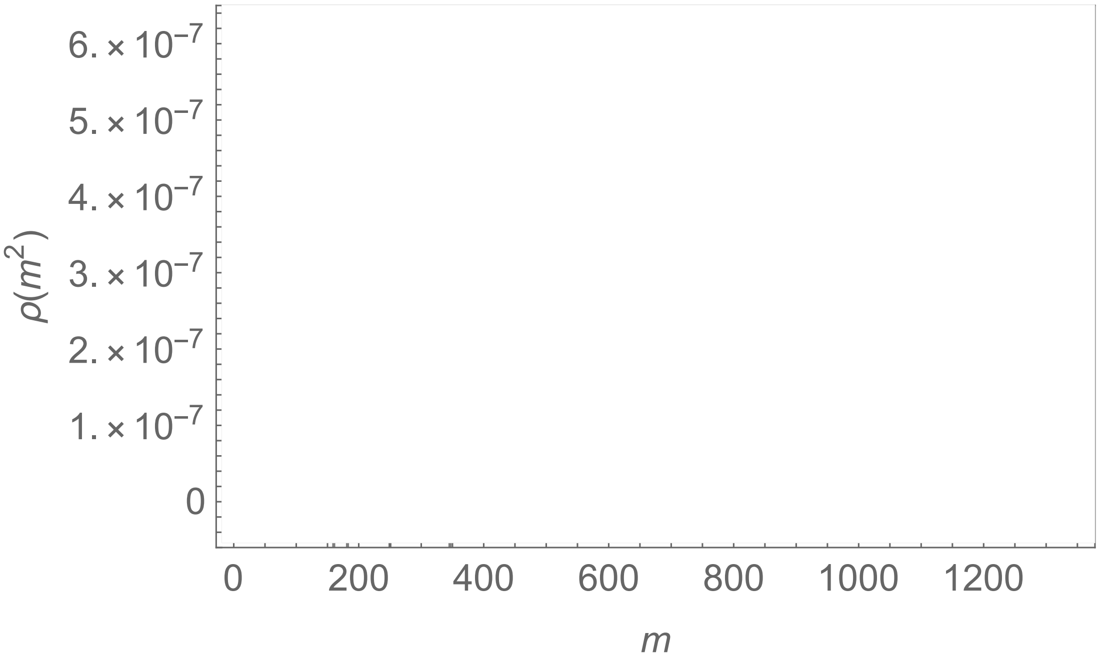

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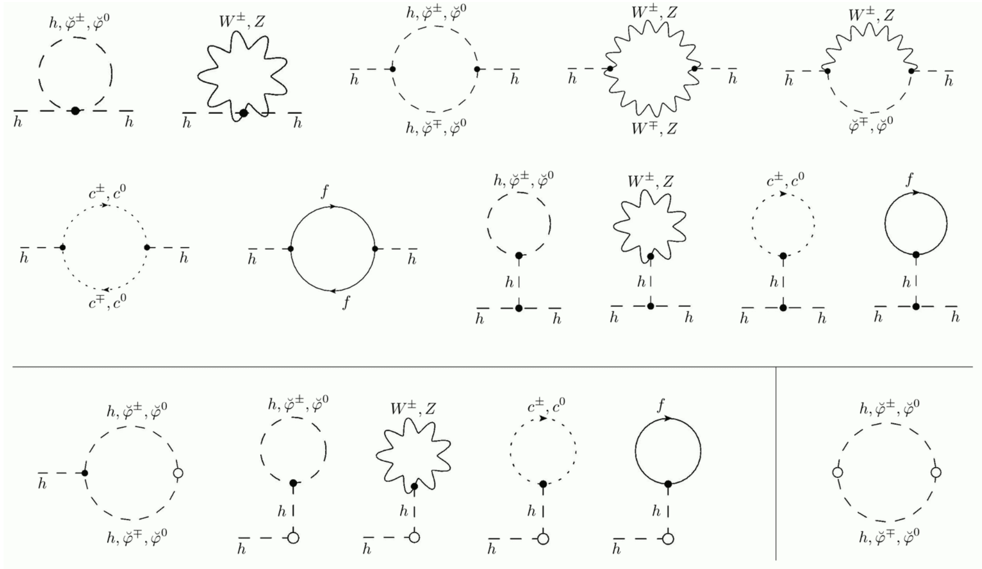

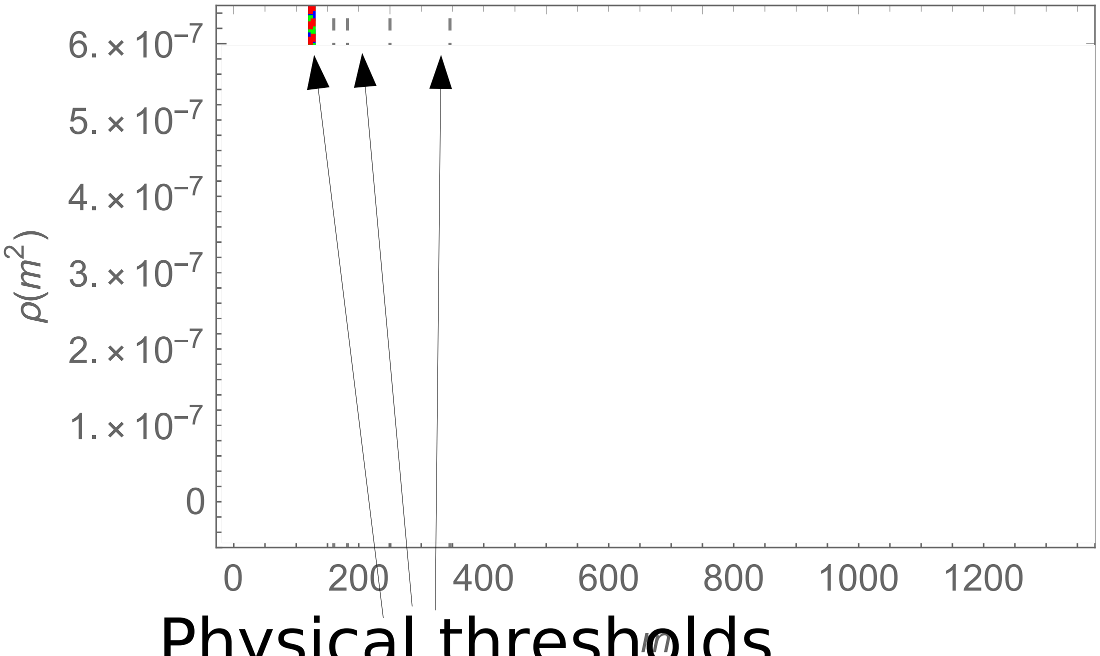

Physical thresholds

[Maas'12,'17
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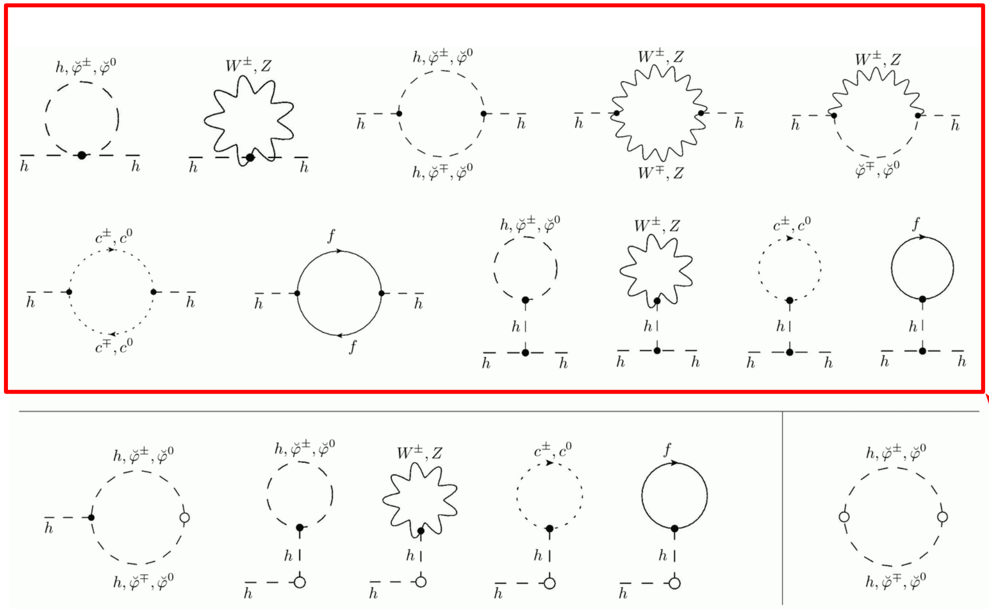

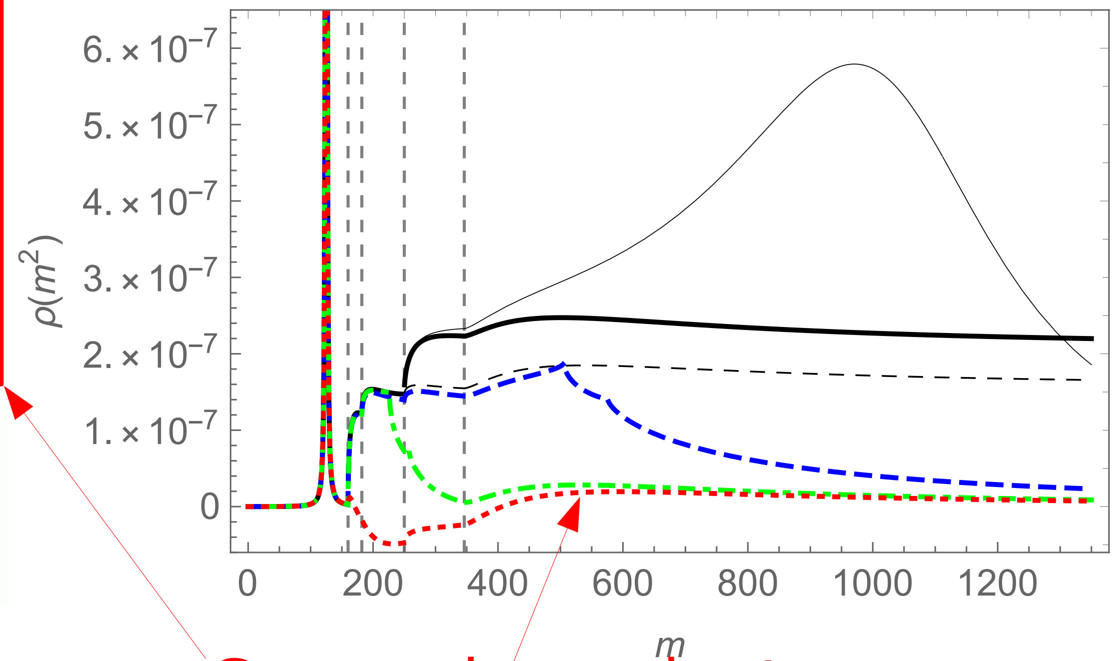

Gauge-dependent

[Maas'12,'17
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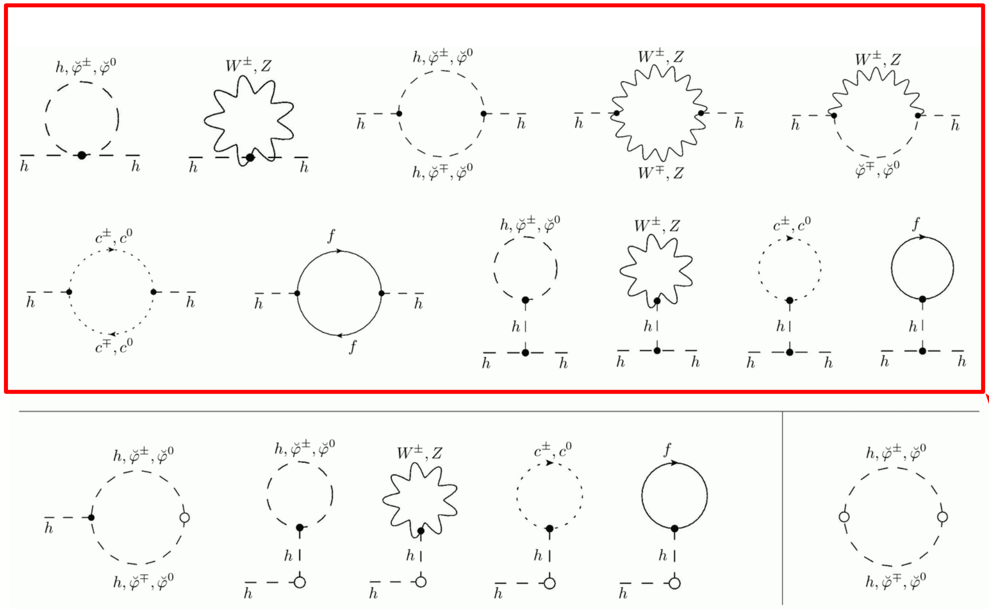

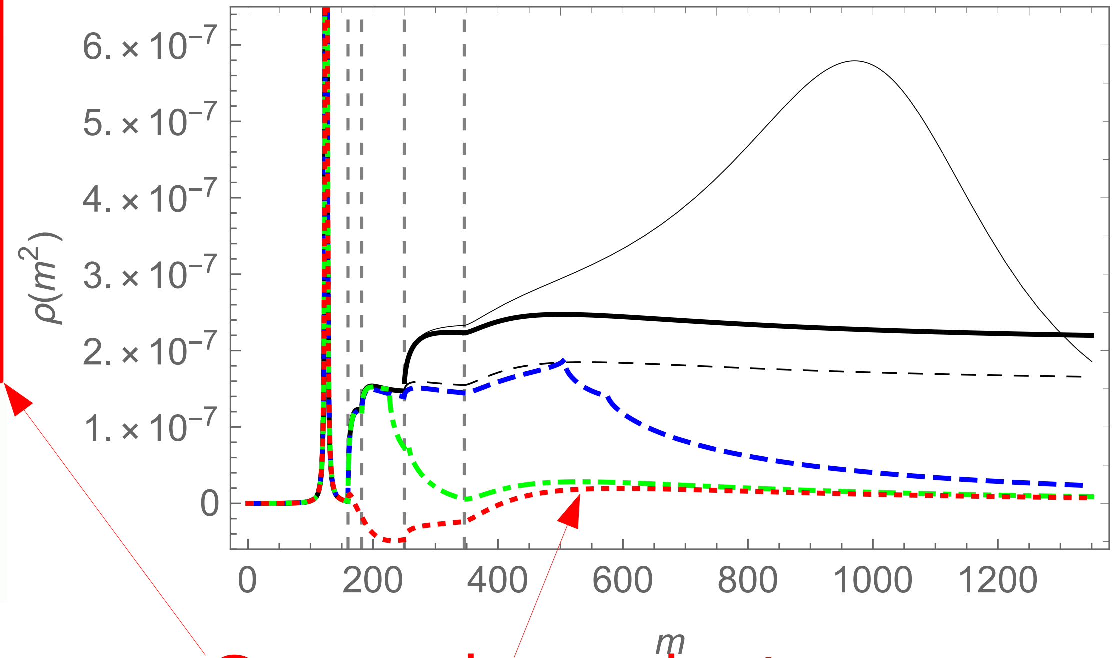

Gauge-dependent

Unphysical features:

Positivity violation

Additional thresholds

[Maas'12,'17
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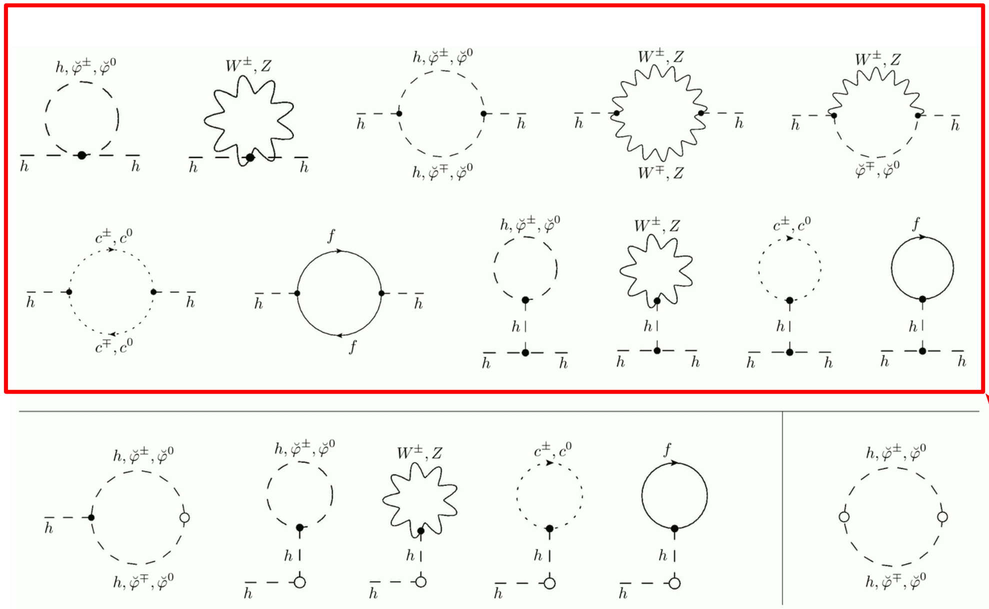

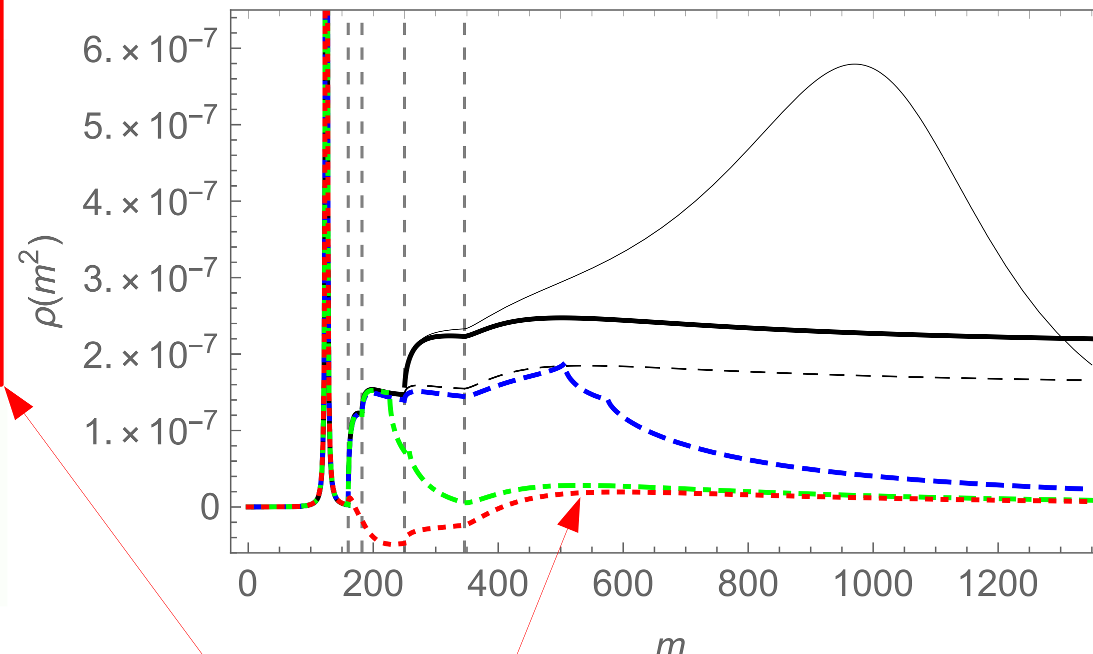

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Not a consequence of instability: Occurs even for an asymptotically stable Higgs in a toy theory

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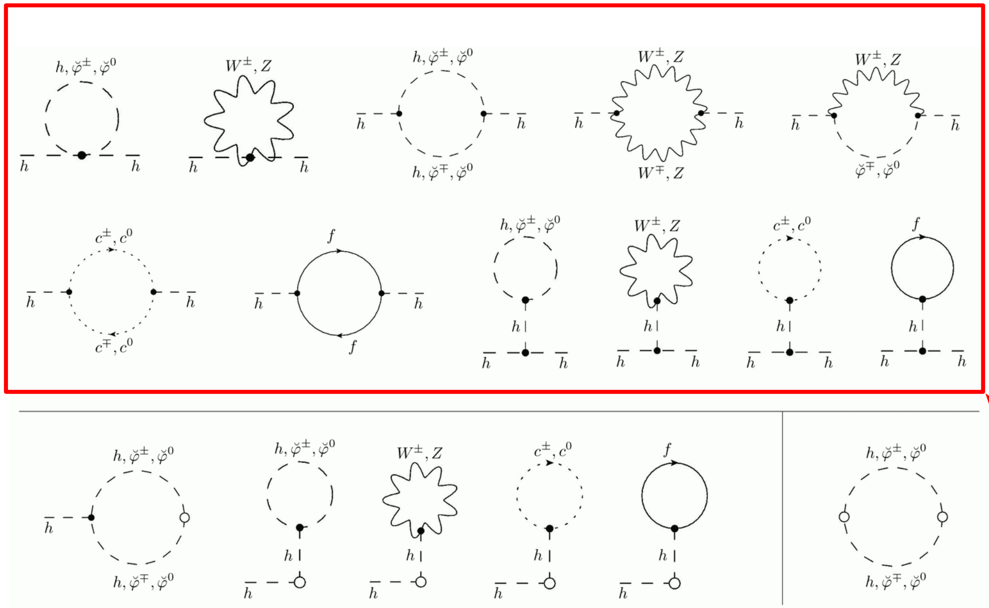

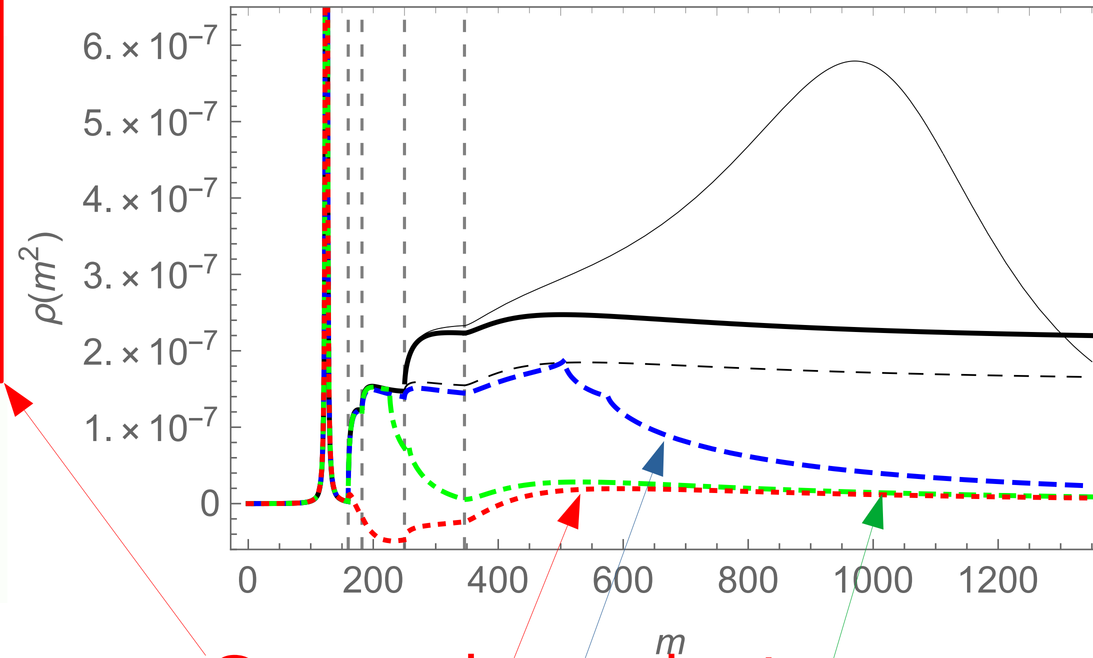

Gauge-dependent

Other gauge choices

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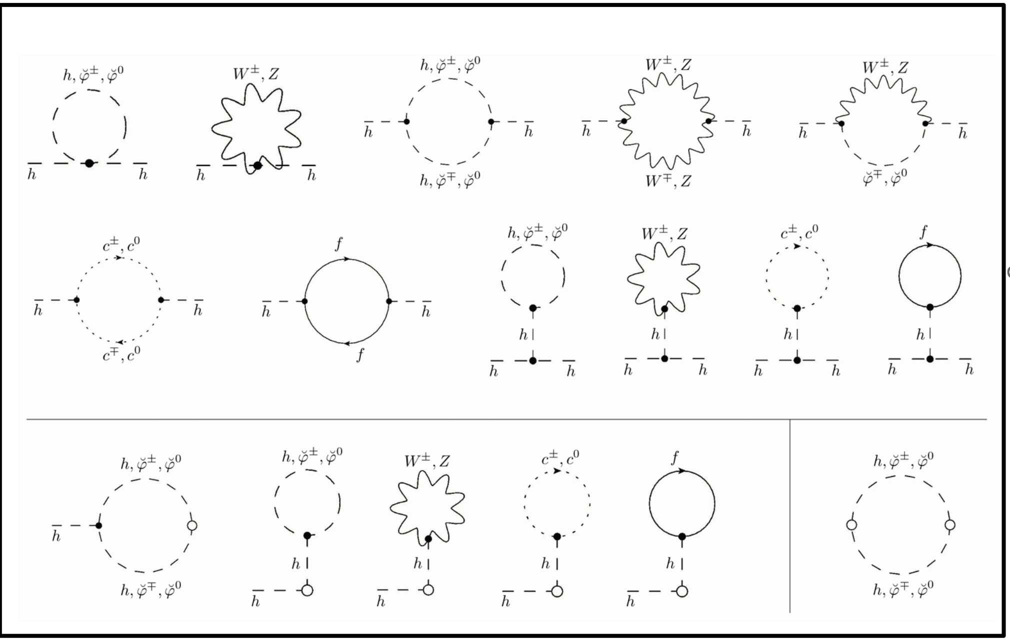

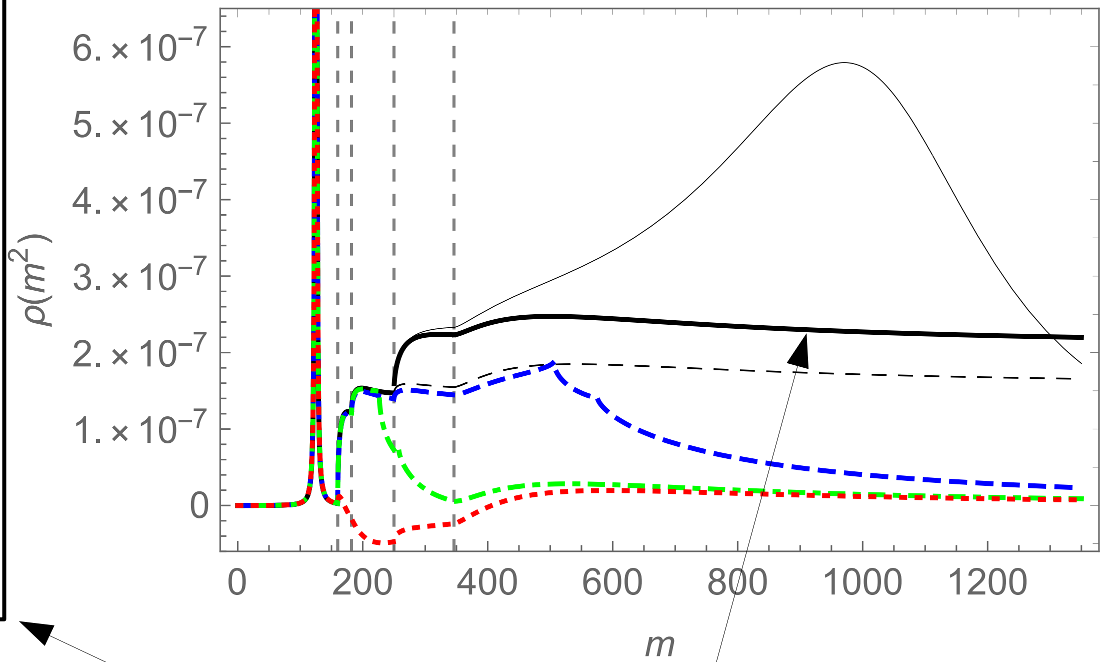

Physical – same for all gauge choices

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[Fröhlich et al.’80,’81
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Gauge-invariant operator has on-shell physical, observable polarization states

Flavor

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

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  - Global SU(3) generation
  - Local SU(2) weak gauge (up/down distinction)

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- Gauge-invariant state, but custodial doublet
- Yukawa terms break custodial symmetry
  - Different masses for doublet members

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)
- Same argument: Weak gauge not observable
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- Gauge-invariant state, but custodial doublet
- Yukawa terms break custodial symmetry
  - Different masses for doublet members
- Can this be true? Lattice test

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
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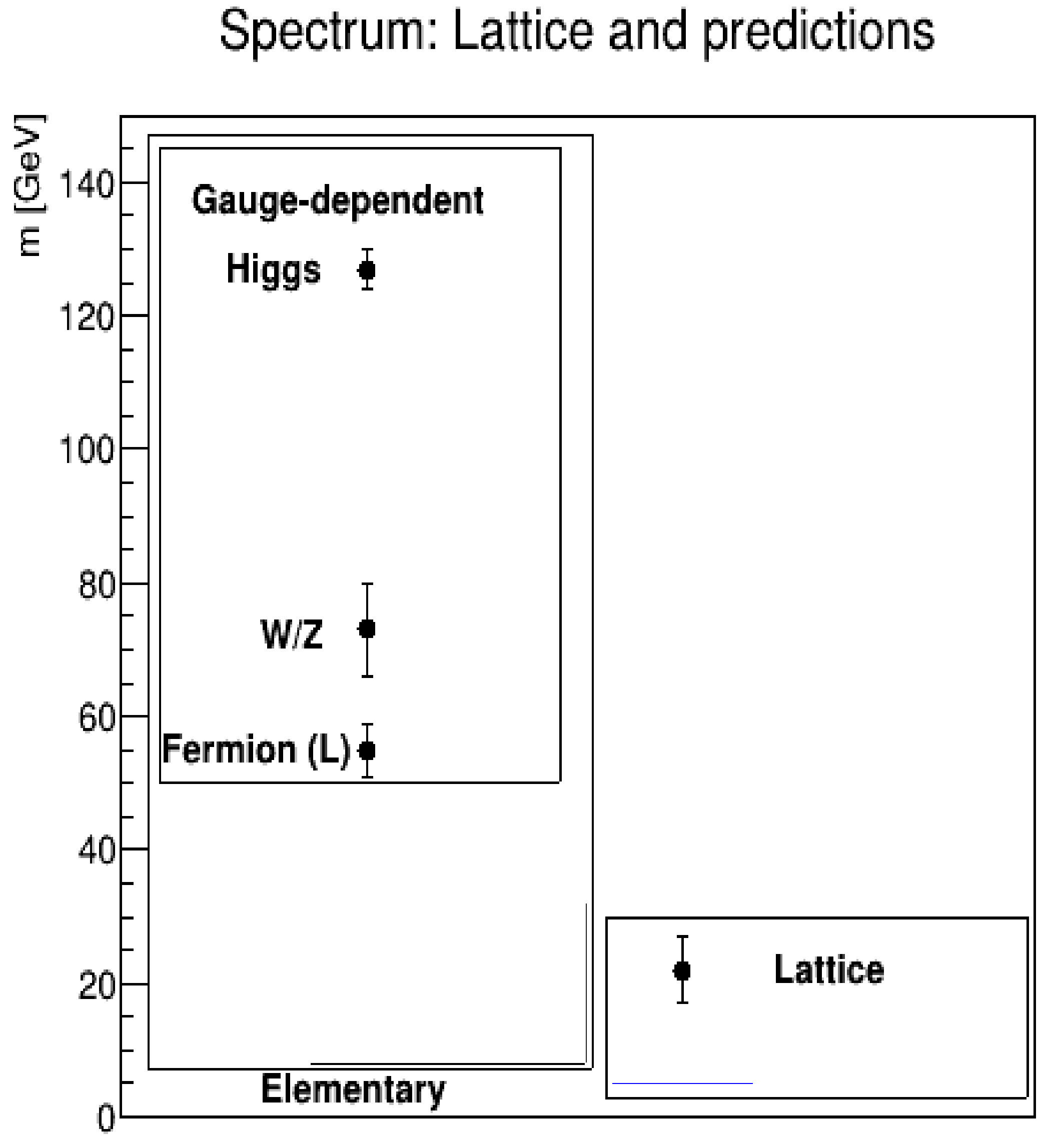

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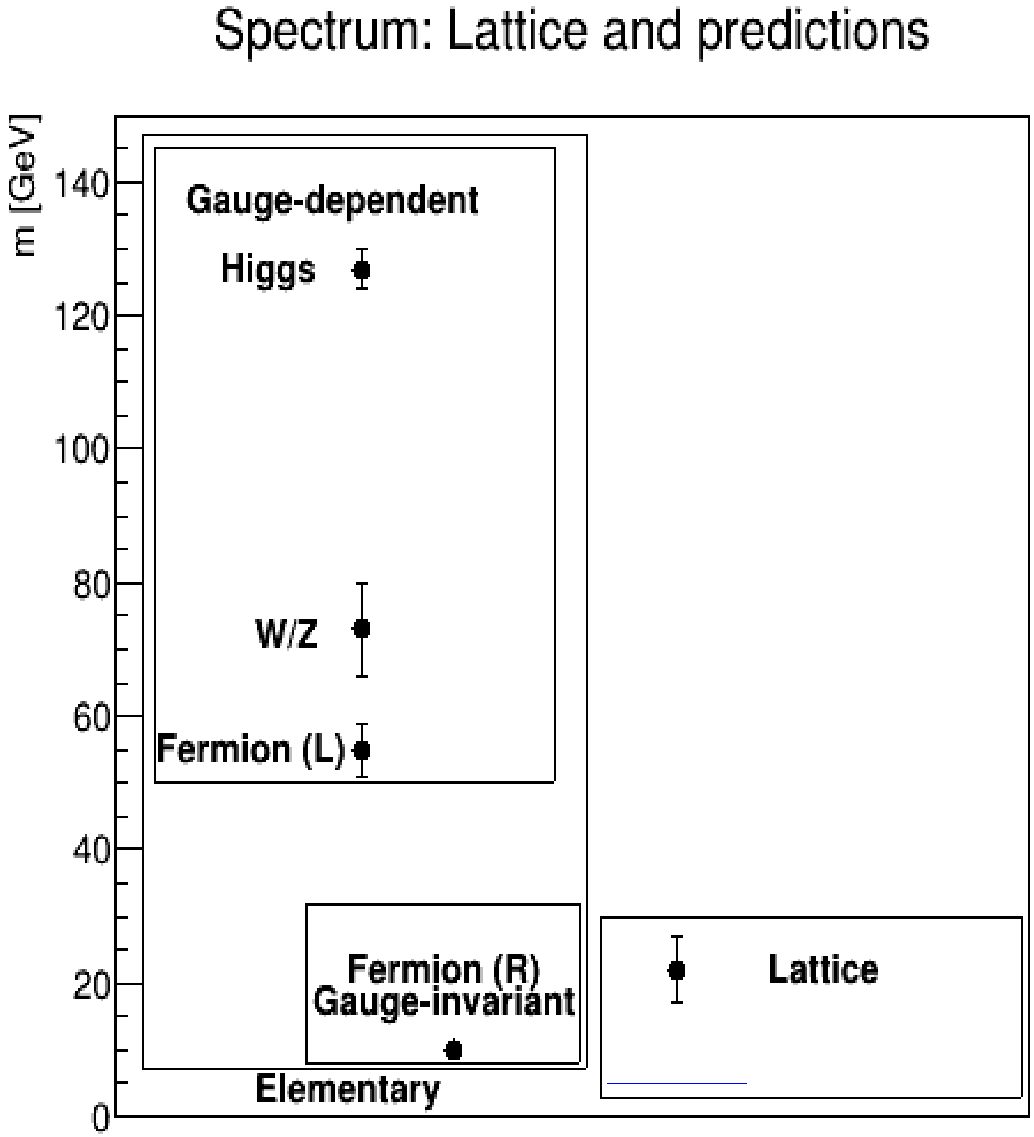

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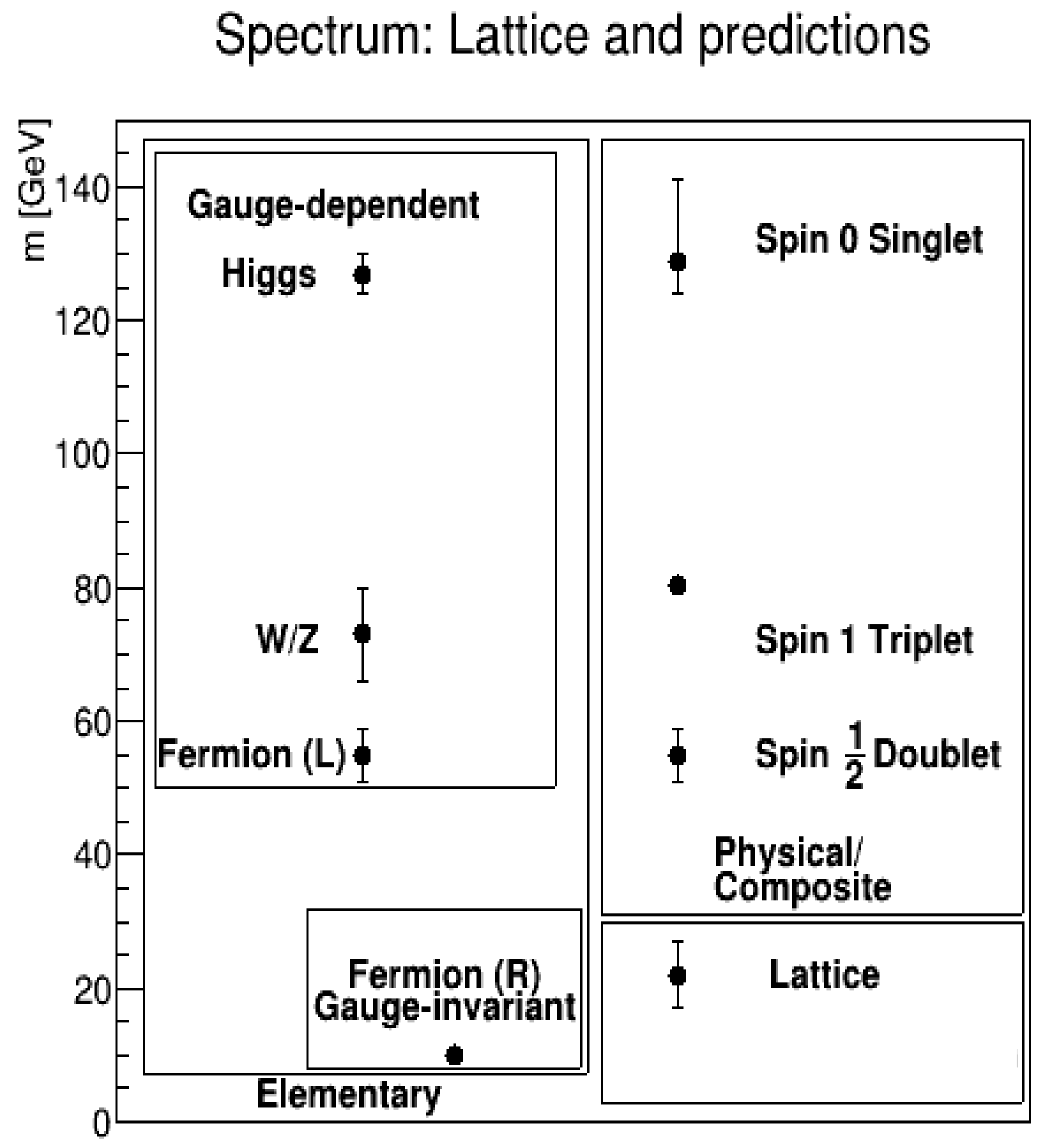

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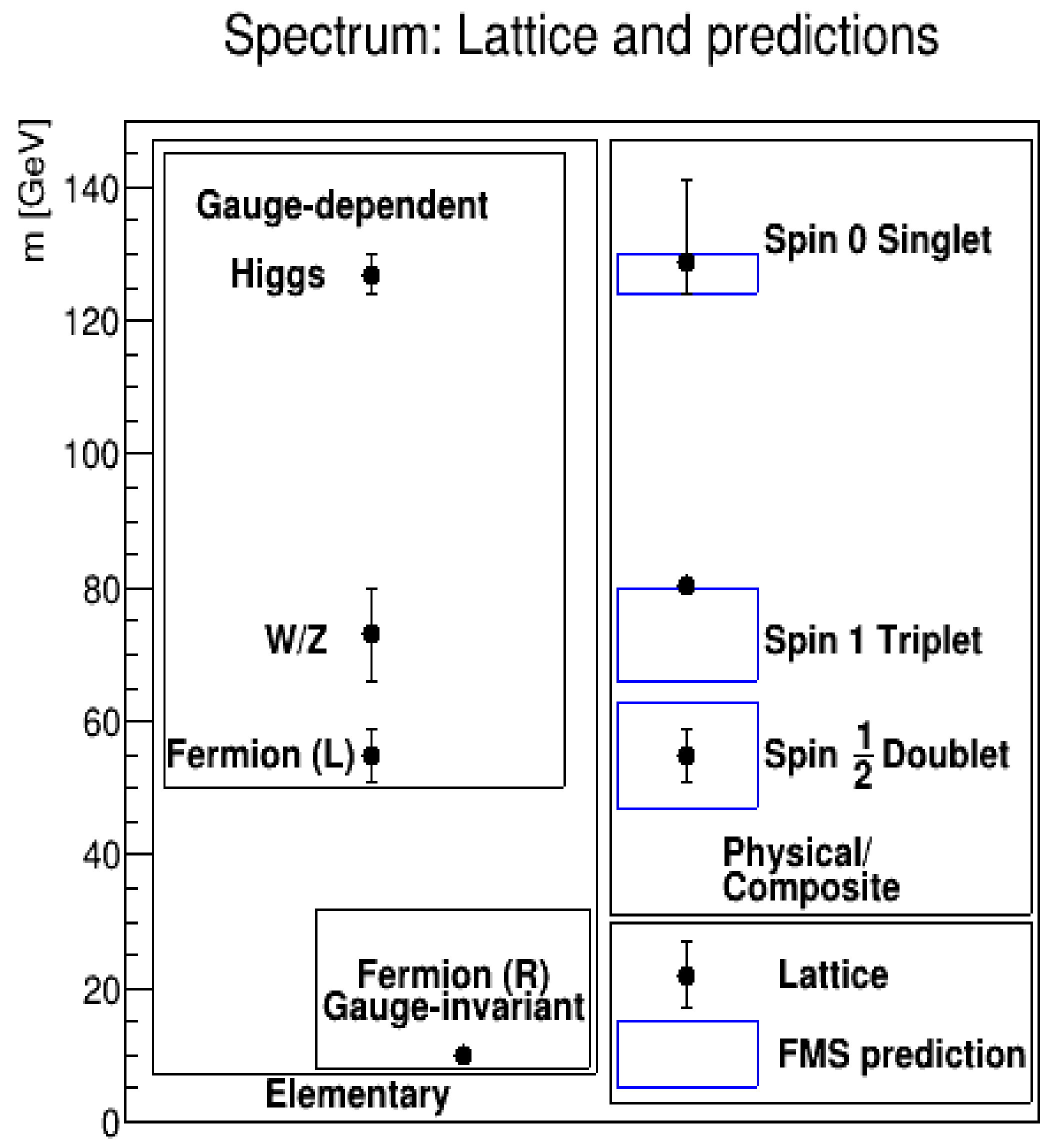
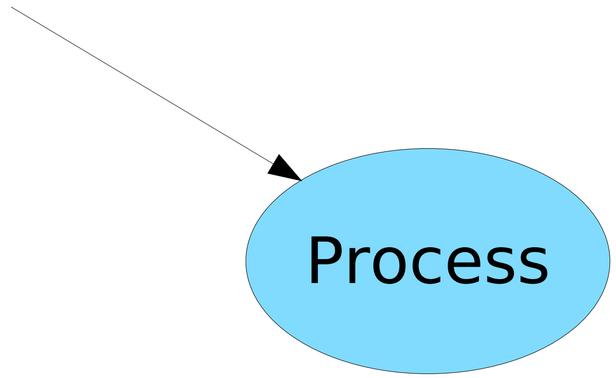
- Supports FMS prediction



Scattering

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

Incoming (asymptotic) particle
Standard LSZ: Elementary particle



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

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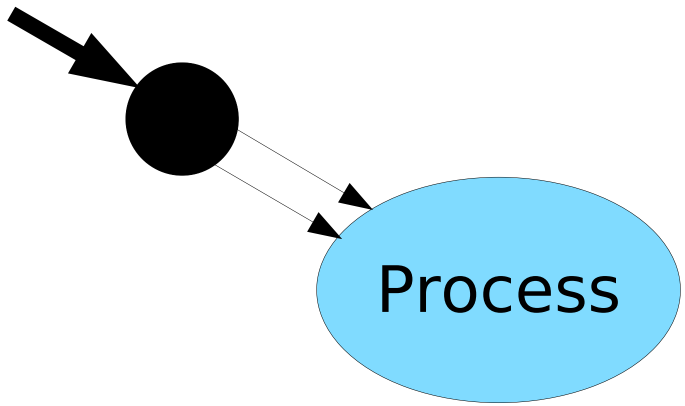
Gauge-invariant LSZ: Bound state



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

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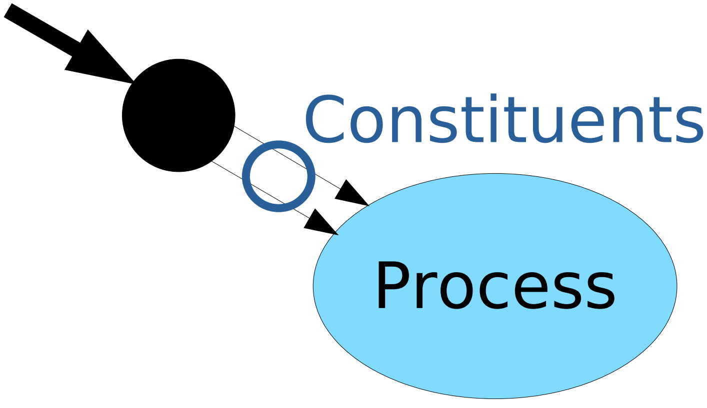

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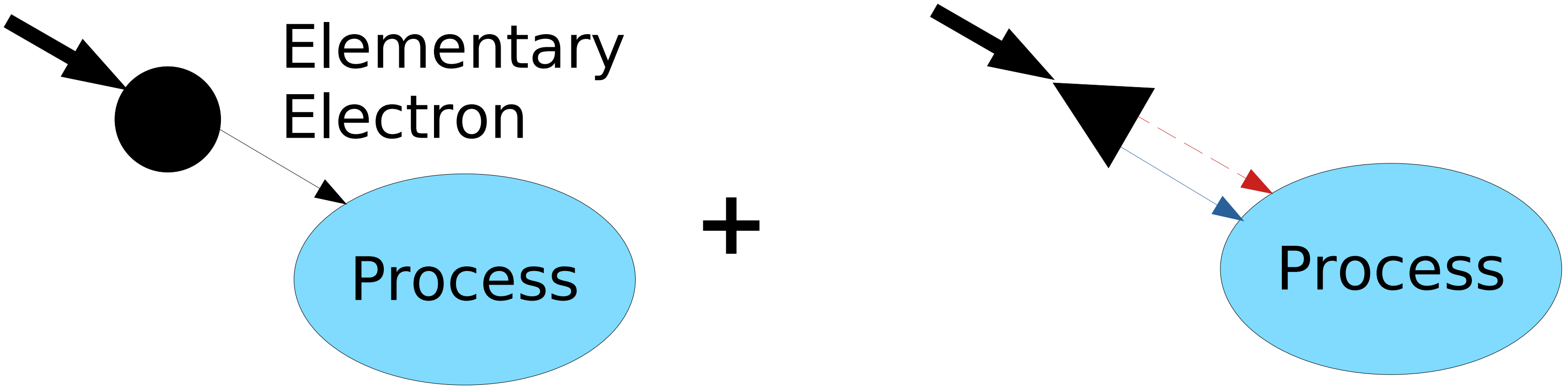

$$v\langle f(p)...\rangle + \int dq\,\Gamma(P,q)\,D_f(p-q)\,D_h(q)\langle h(q) f(P-q)...\rangle$$

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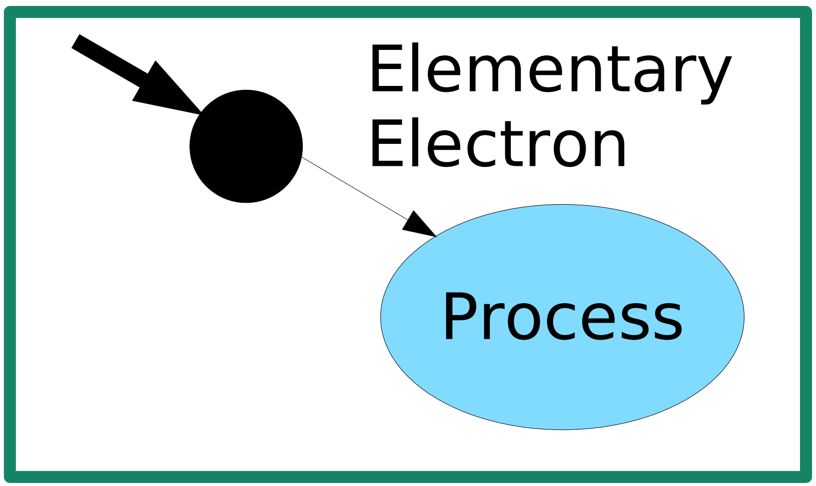

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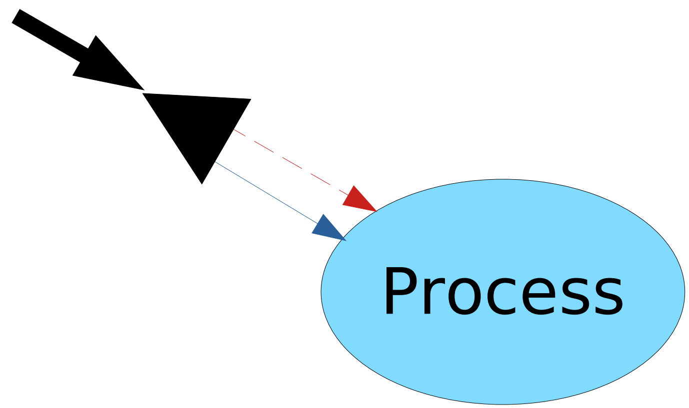

Standard perturbation theory

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

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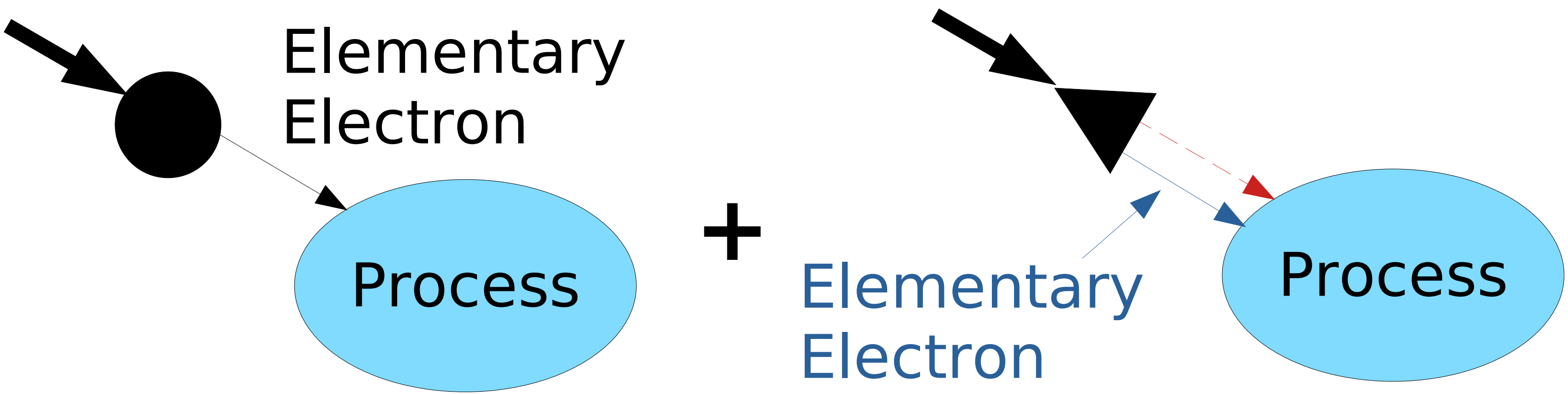

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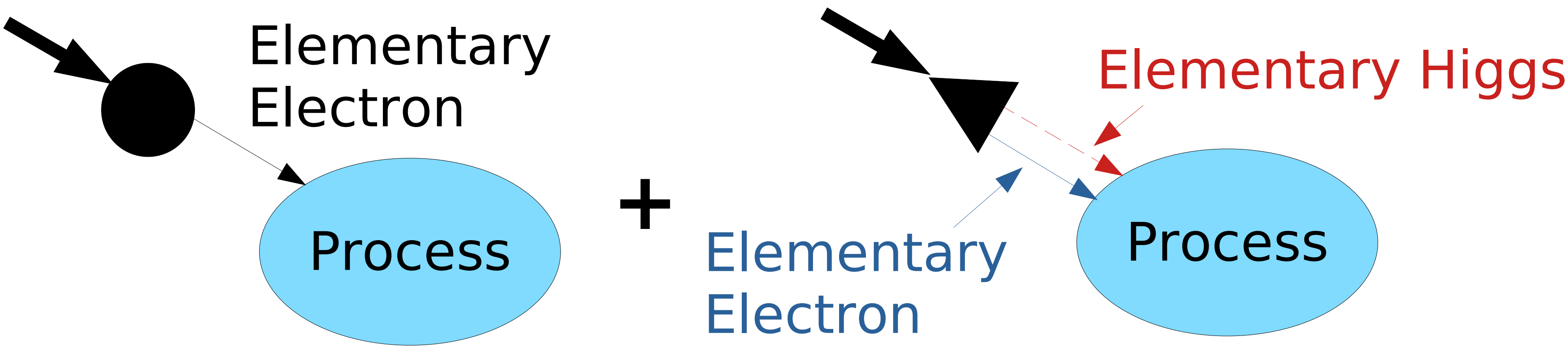

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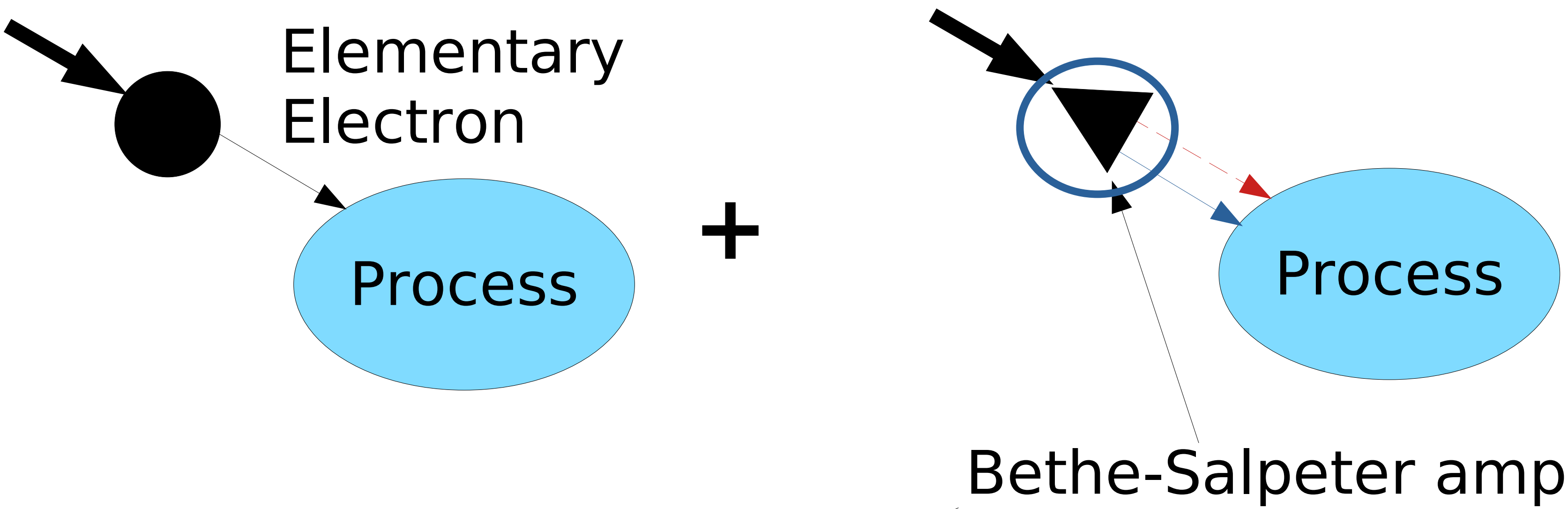

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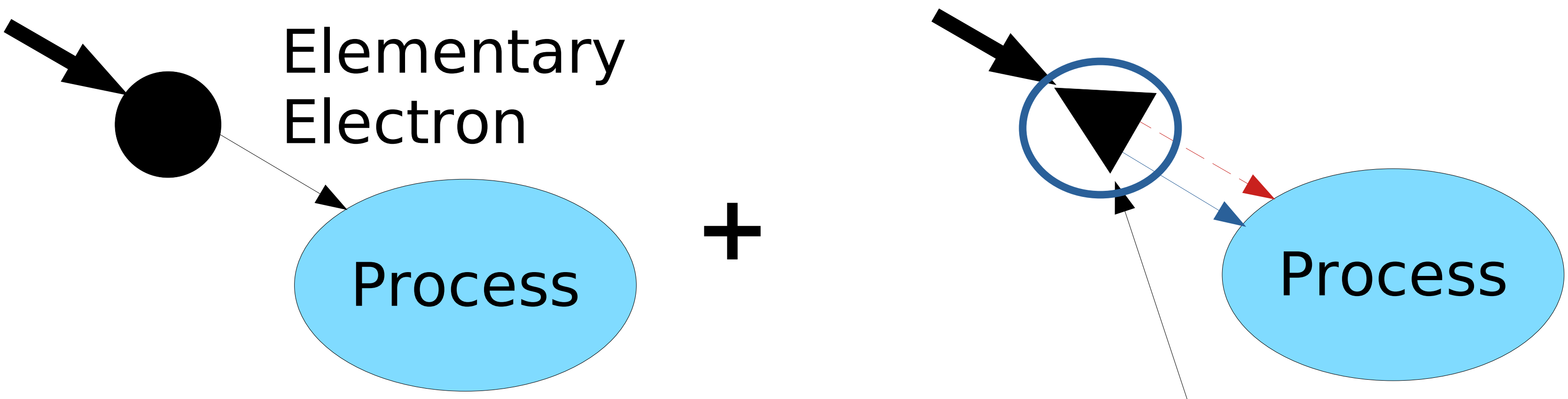


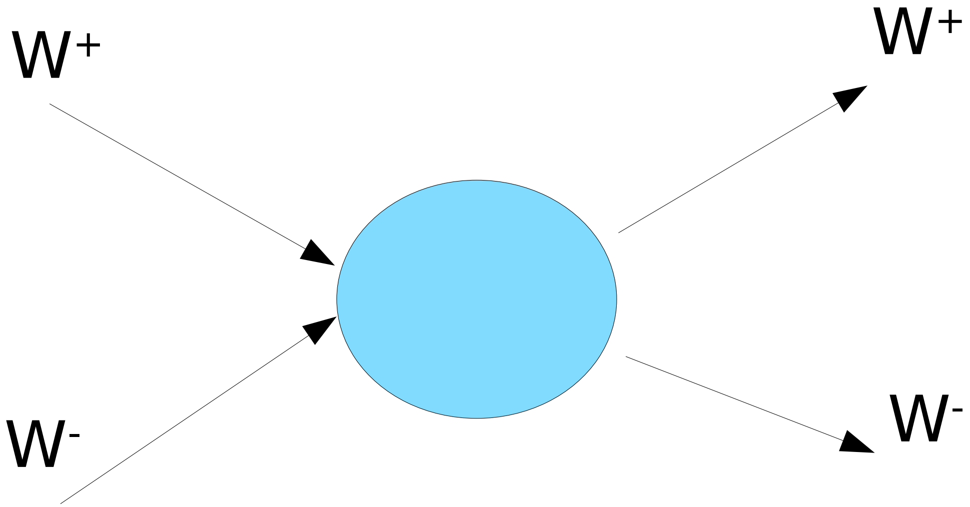
Bethe-Salpeter amplitude:
Calculabe in augmented PT

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

Phase shifts in on-shell VBS/VBF

[Jenny, Maas, Riederer'22]

Phase shifts in on-shell VBS/VBF



Elastic scattering, s-wave, $160^2<s<250^2$

[Jenny, Maas, Riederer'22]

Phase shifts in on-shell VBS/VBF

- Reduced SM: Only W/Z and the Higgs
  - Parameters slightly different
    - Higgs 145 GeV and weak coupling larger
    - Standard lattice Lüscher analysis
  - Qualitatively but not quantitatively

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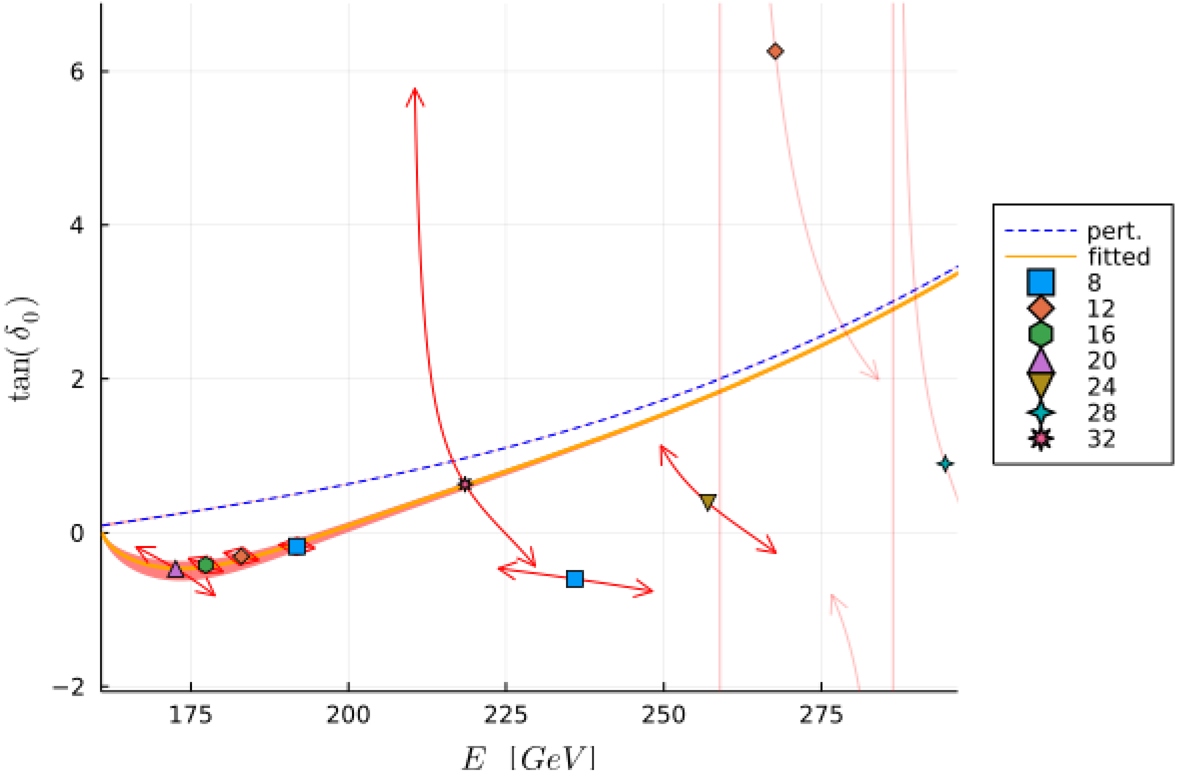

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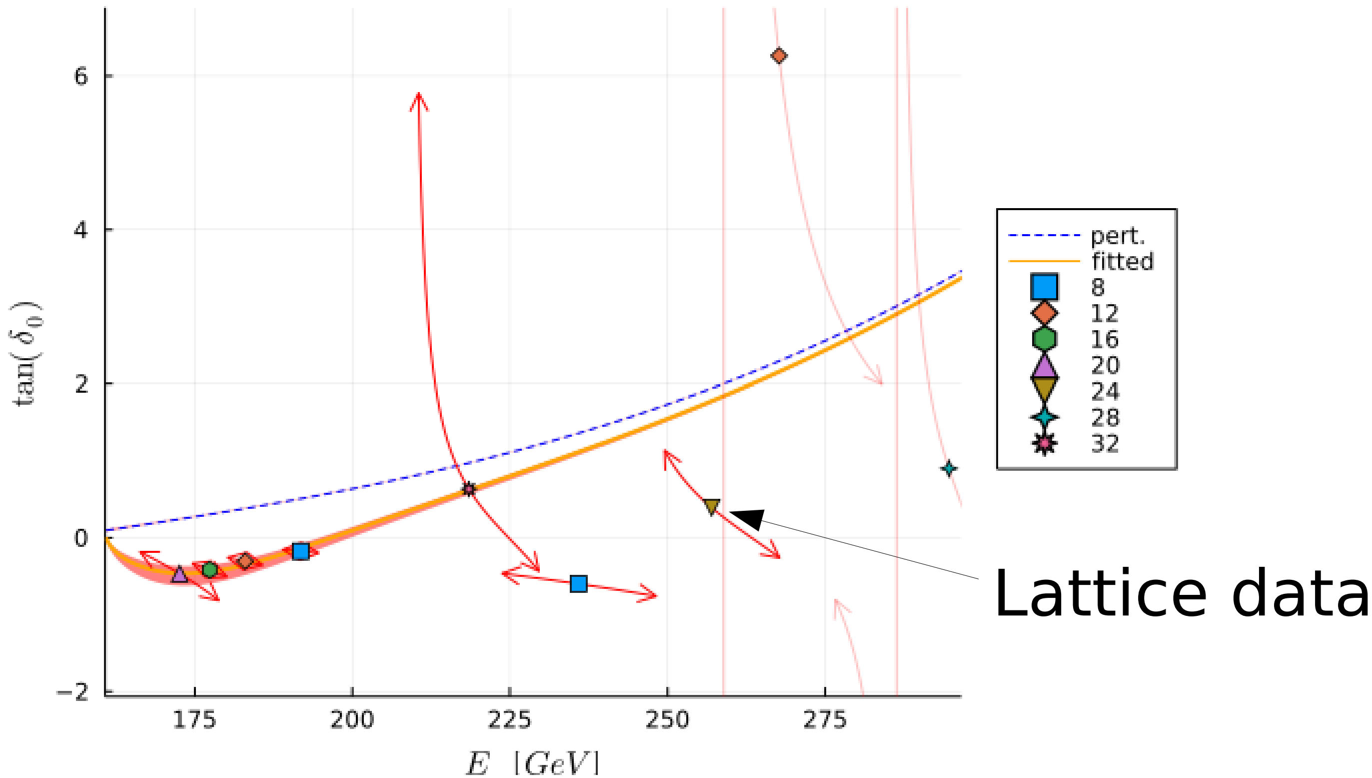

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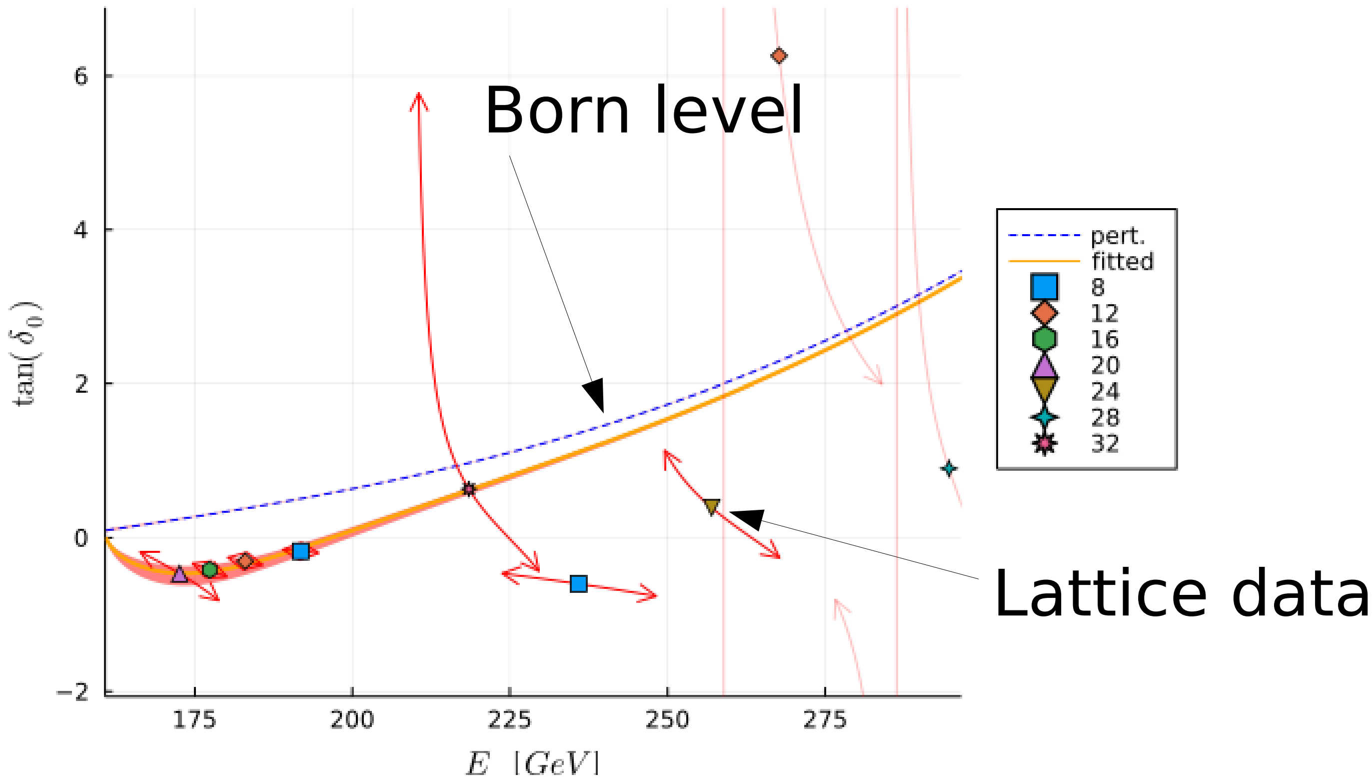

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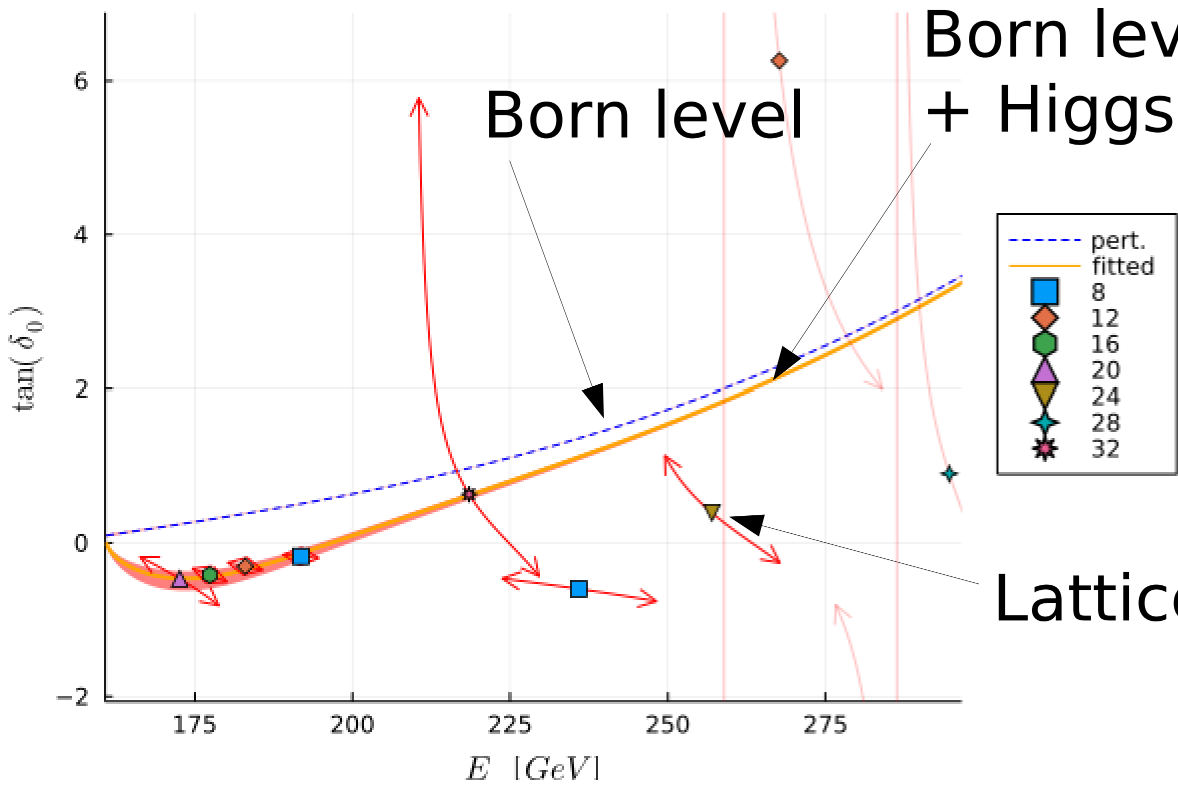

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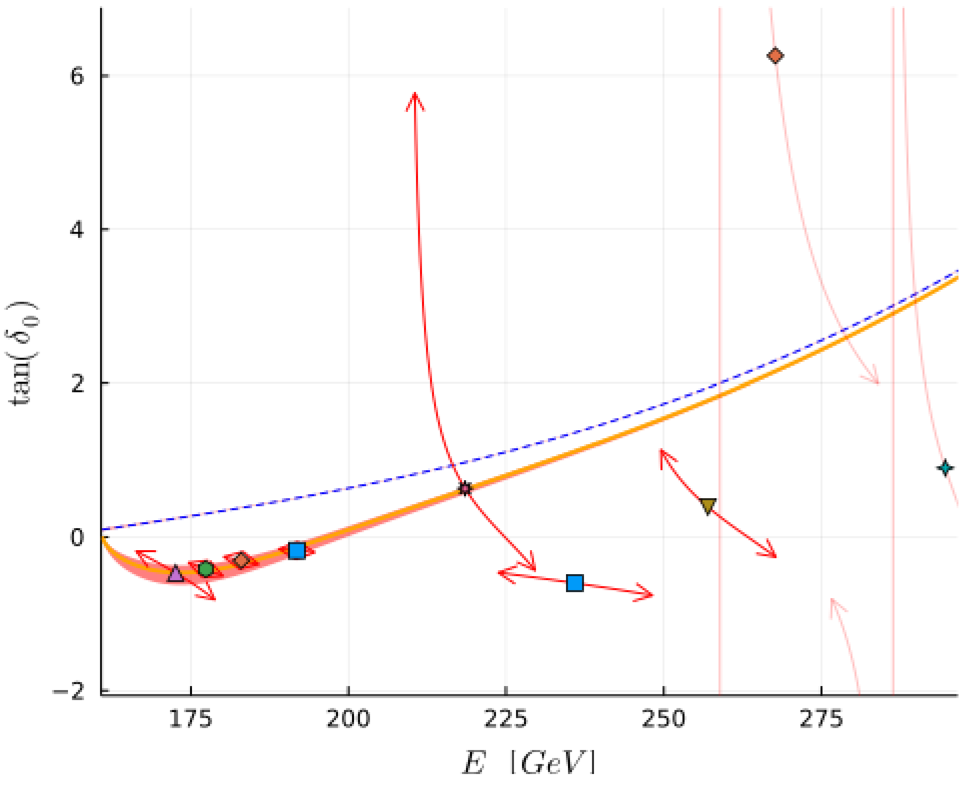

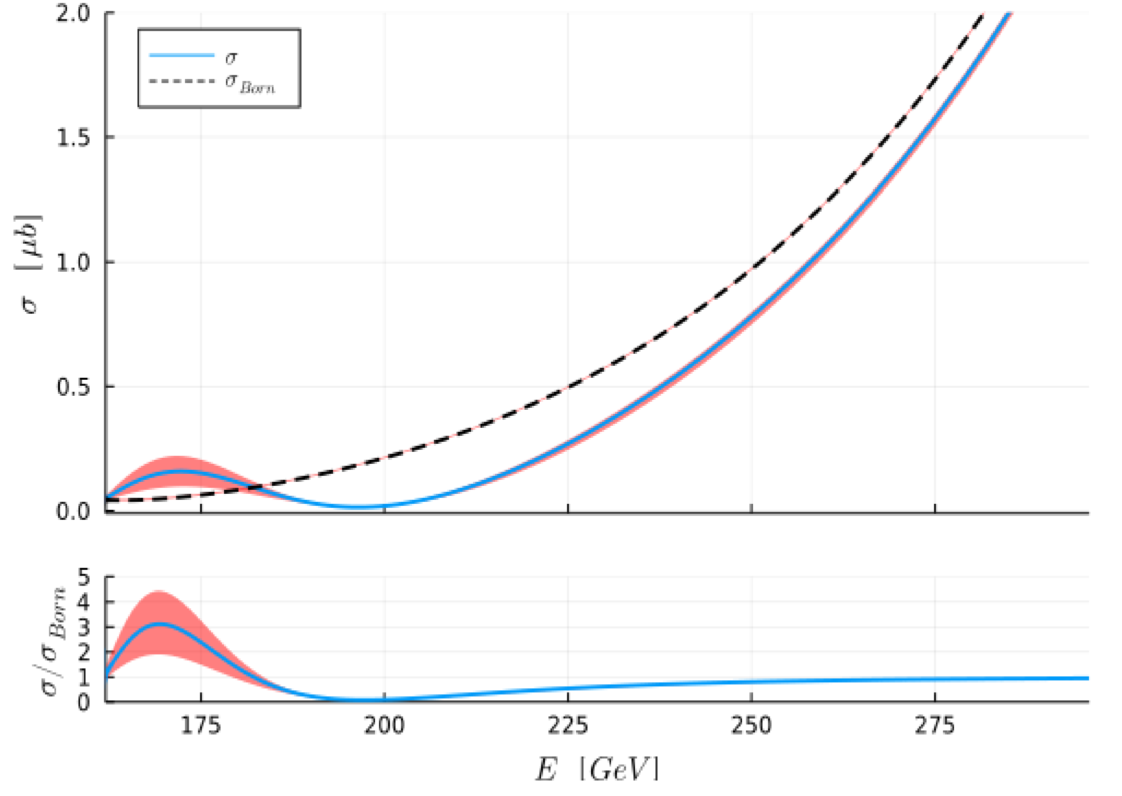

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[Ciafaloni et al. '00]

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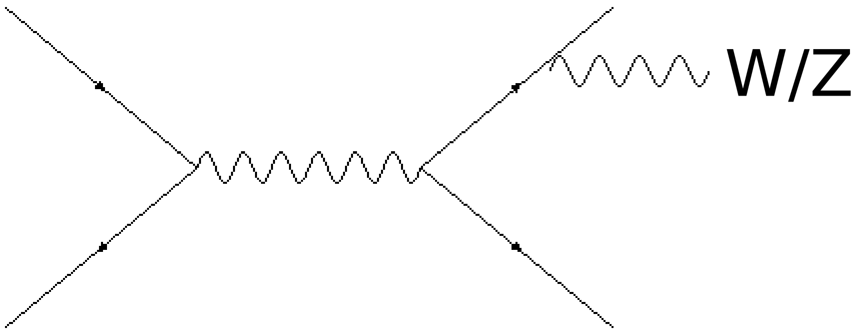

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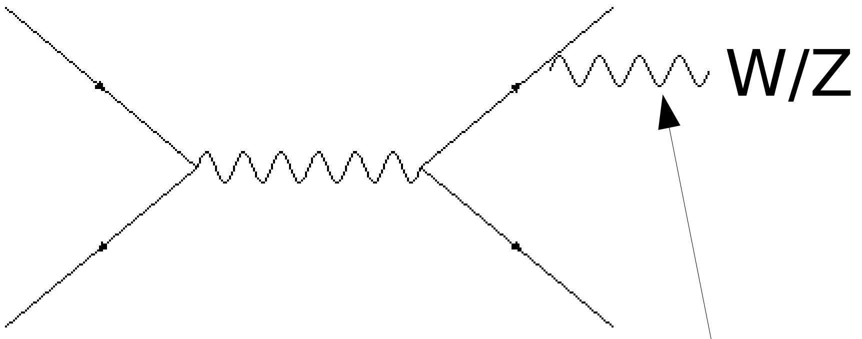

Resumming real emission

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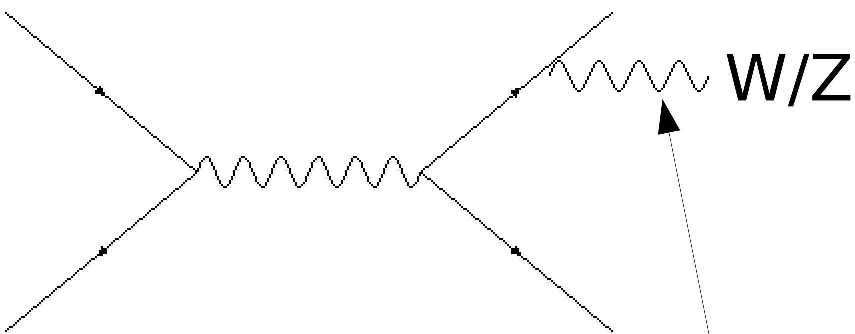

Resumming real (almost collinear) emission: Weak jet

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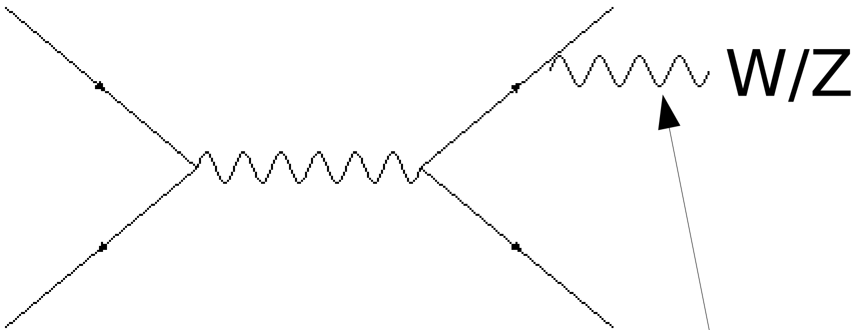

Resumming real (almost collinear) emission: Weak jet

$$\frac{\Delta\sigma}{\sigma_{no\,resummation}} \sim \ln^2 \frac{s}{m_W^2}$$

at 1 TeV of the same order as strong corrections

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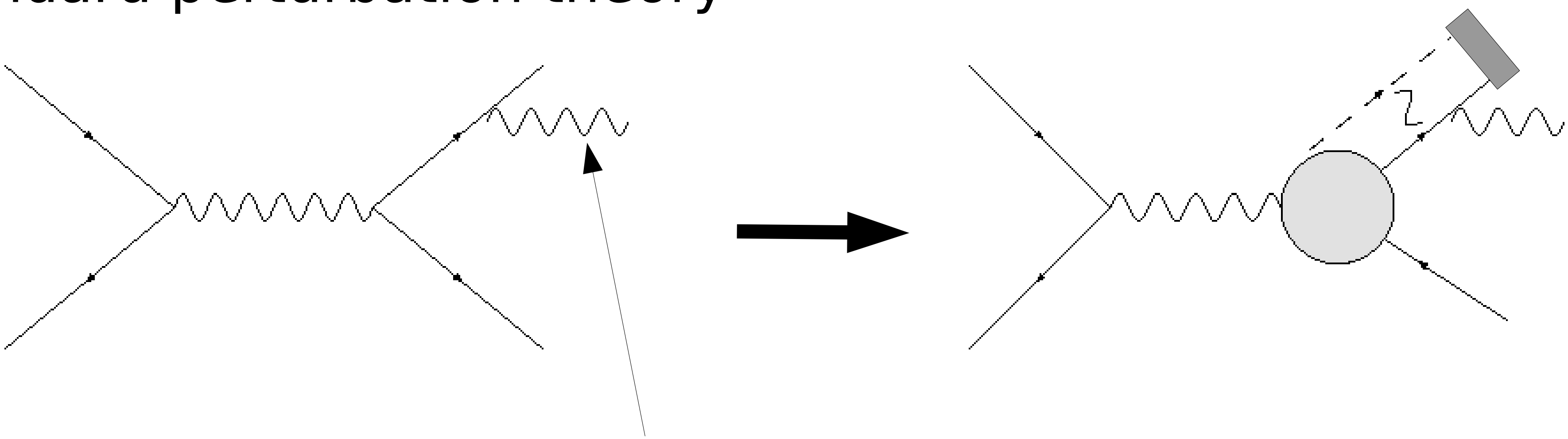
Standard perturbation theory

Augmented by correct asymptotic state



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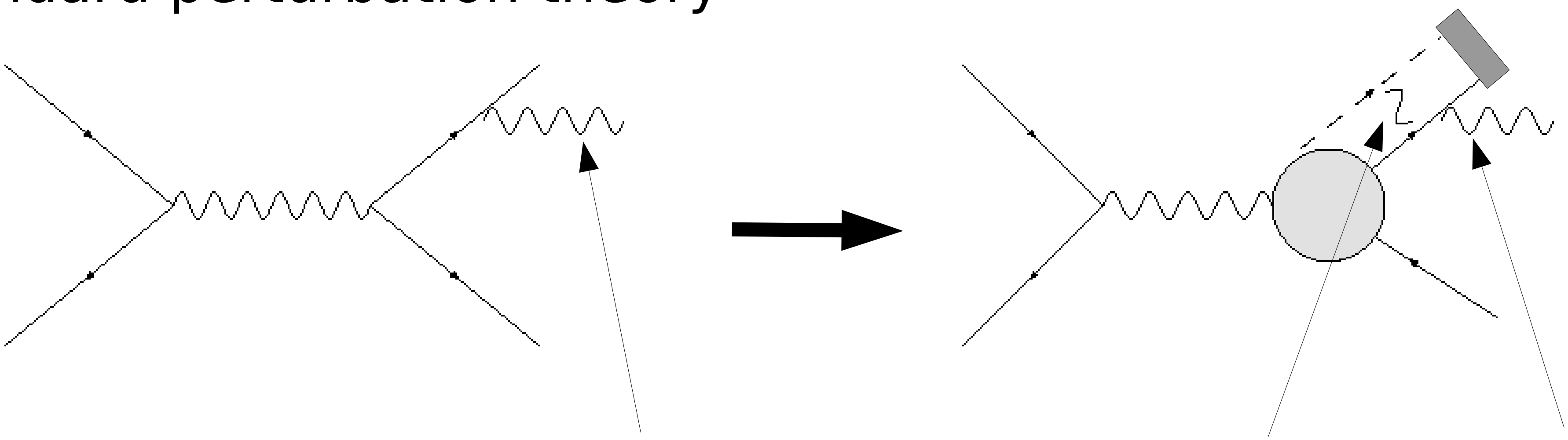

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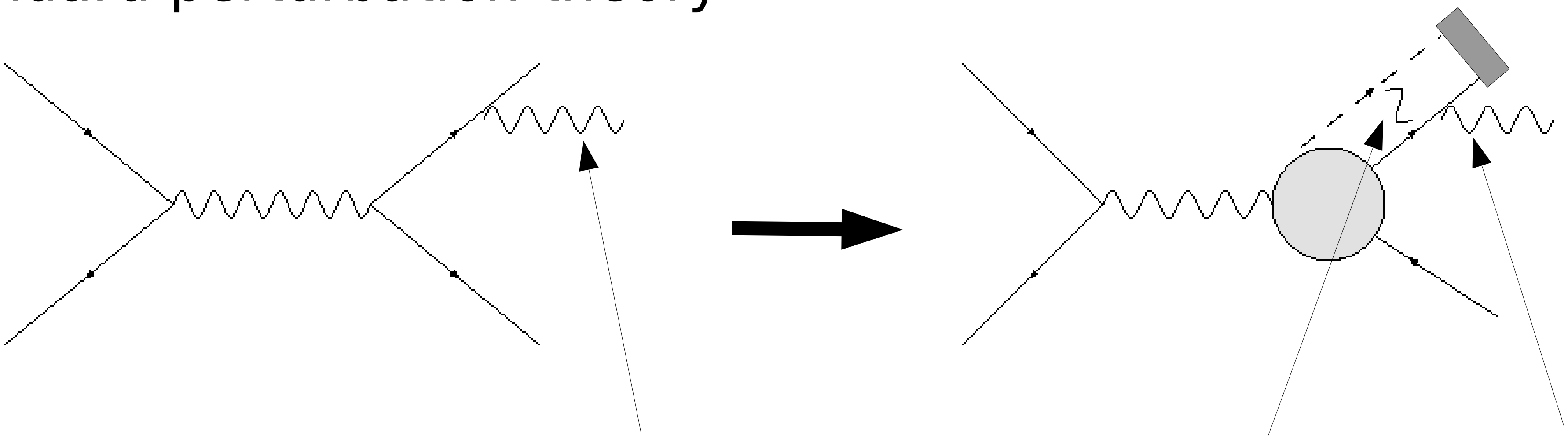

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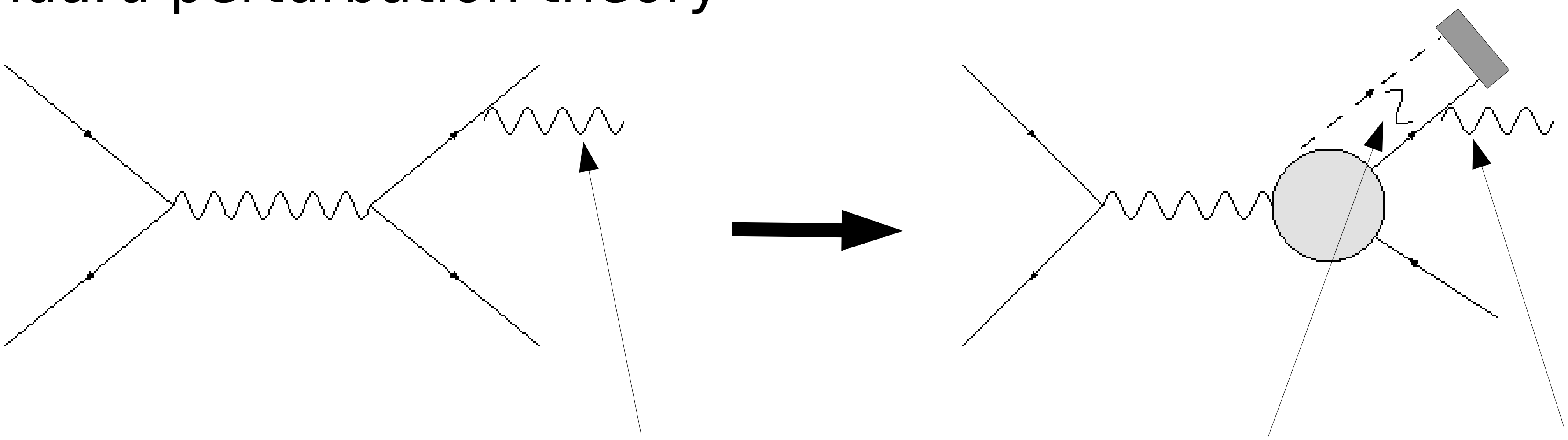

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Less weak jets

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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