Composite Dark Matter from Weak Interactions

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Trento
Italy

UNI GRAZ
NAWI Graz Natural Sciences
FWF Der Wissenschaftsfonds.

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  - Using a concrete example
  - Quite flexible – not yet quantitatively tuned

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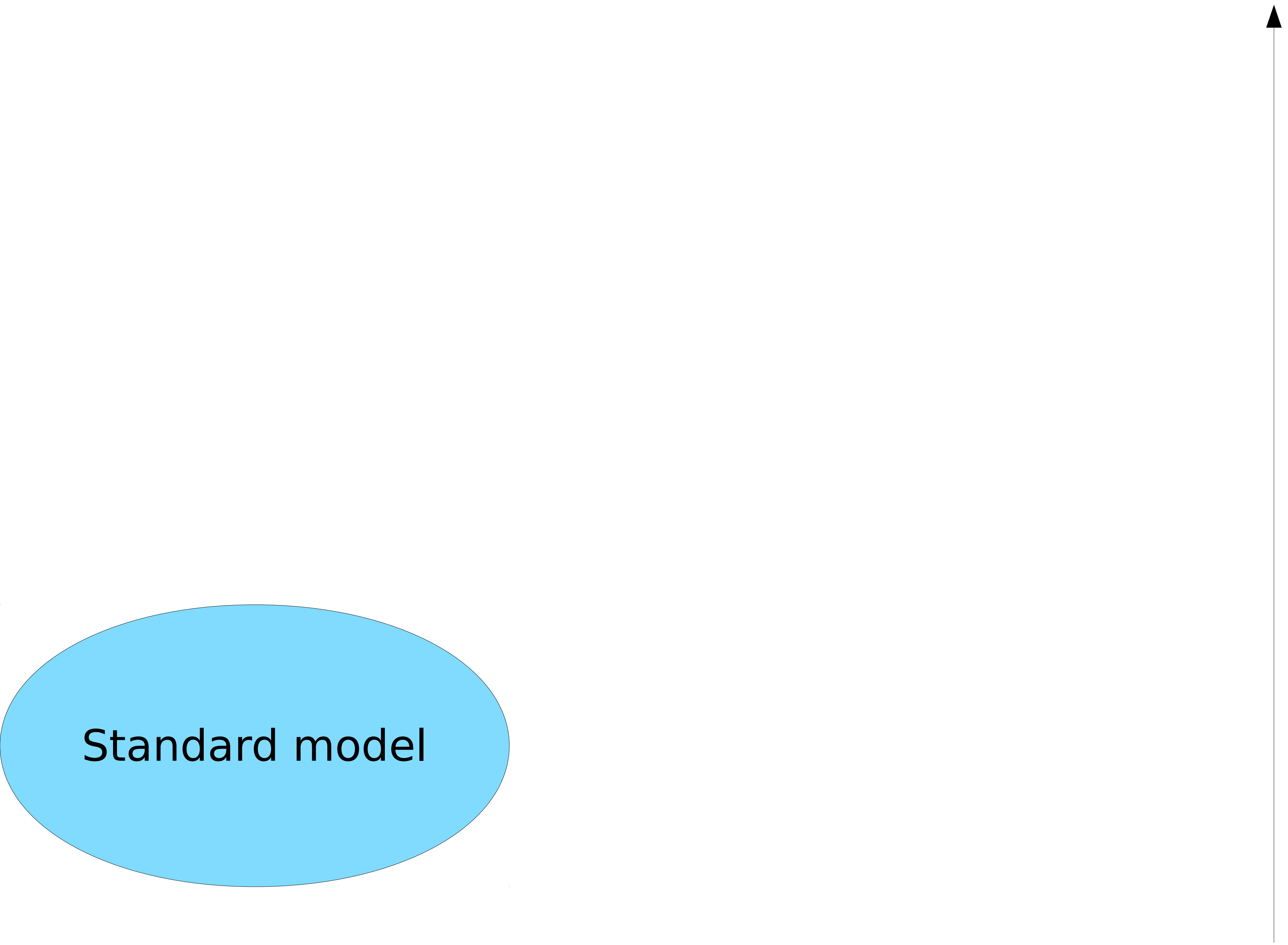
- Develop an analytical toolset for calculations
- Use lattice simulations for confirmation

A concrete example



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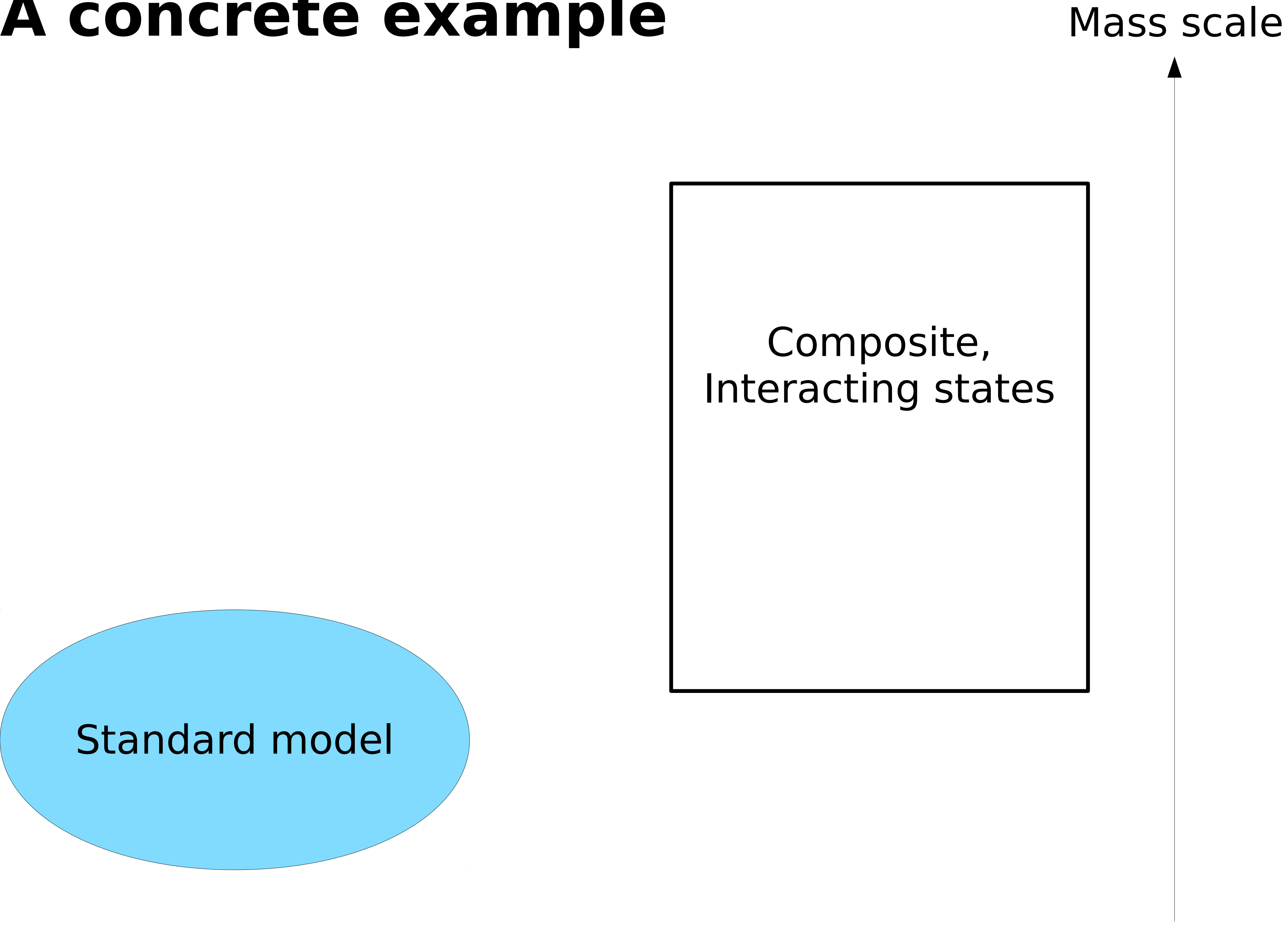

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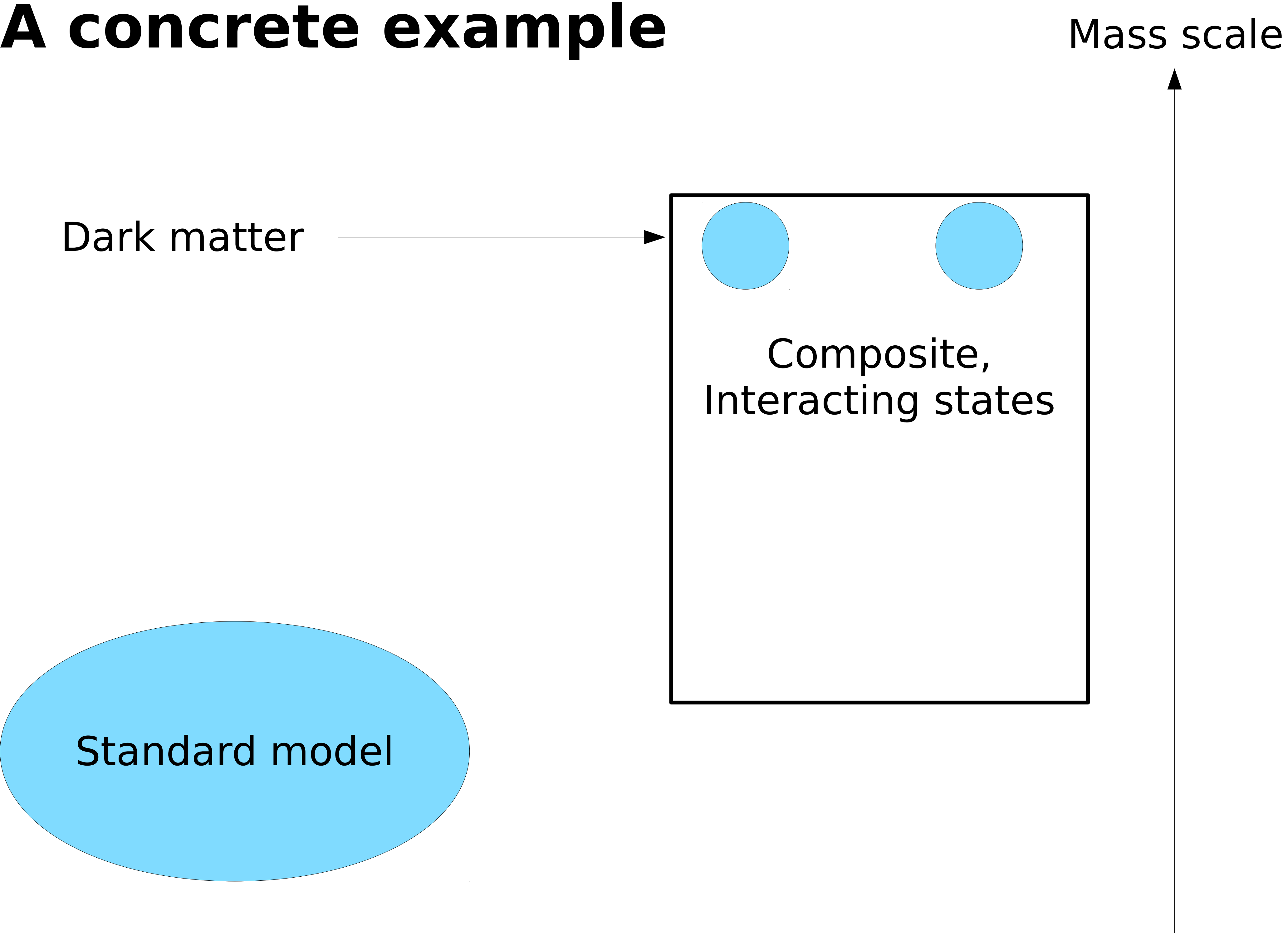

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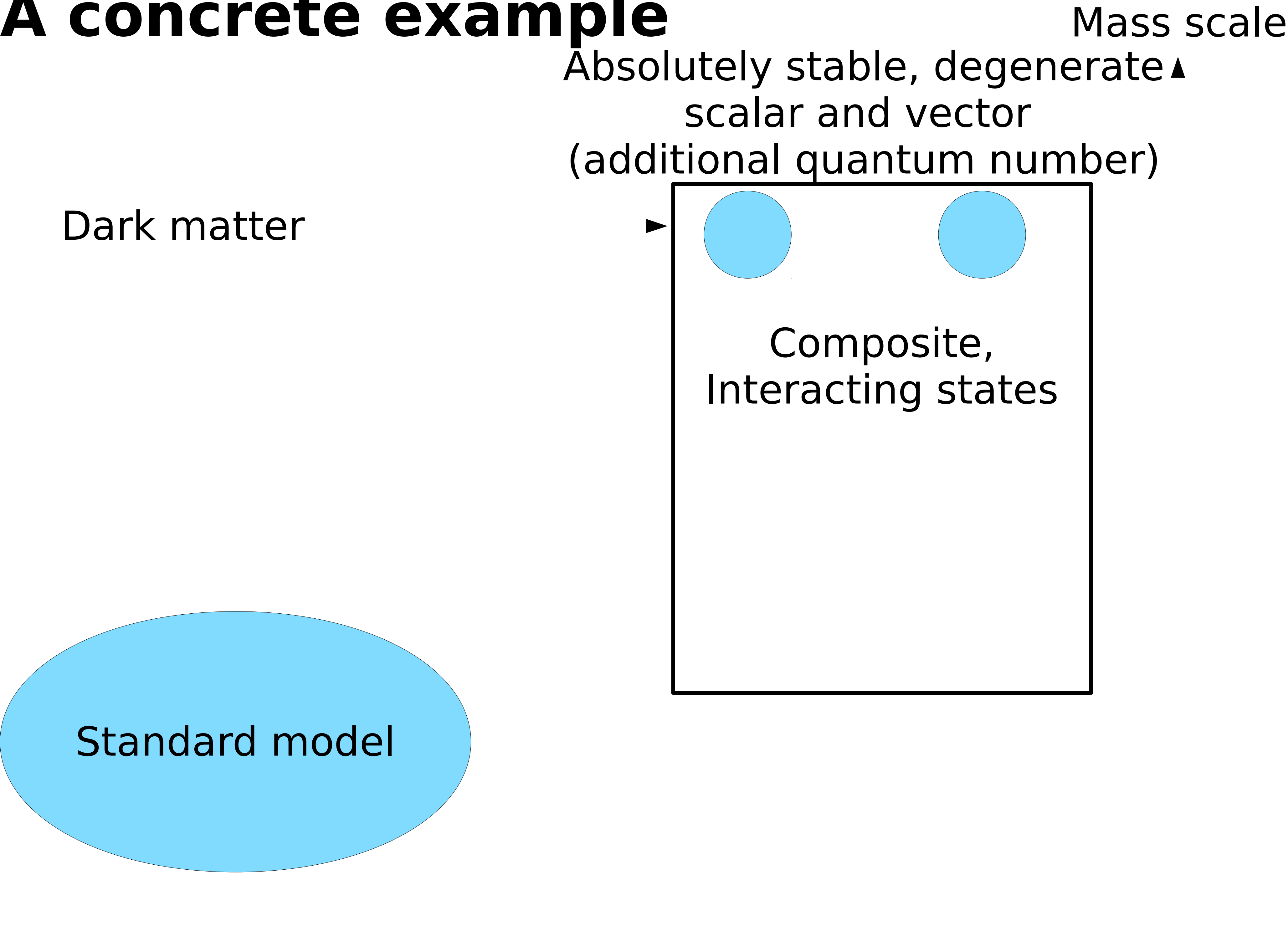

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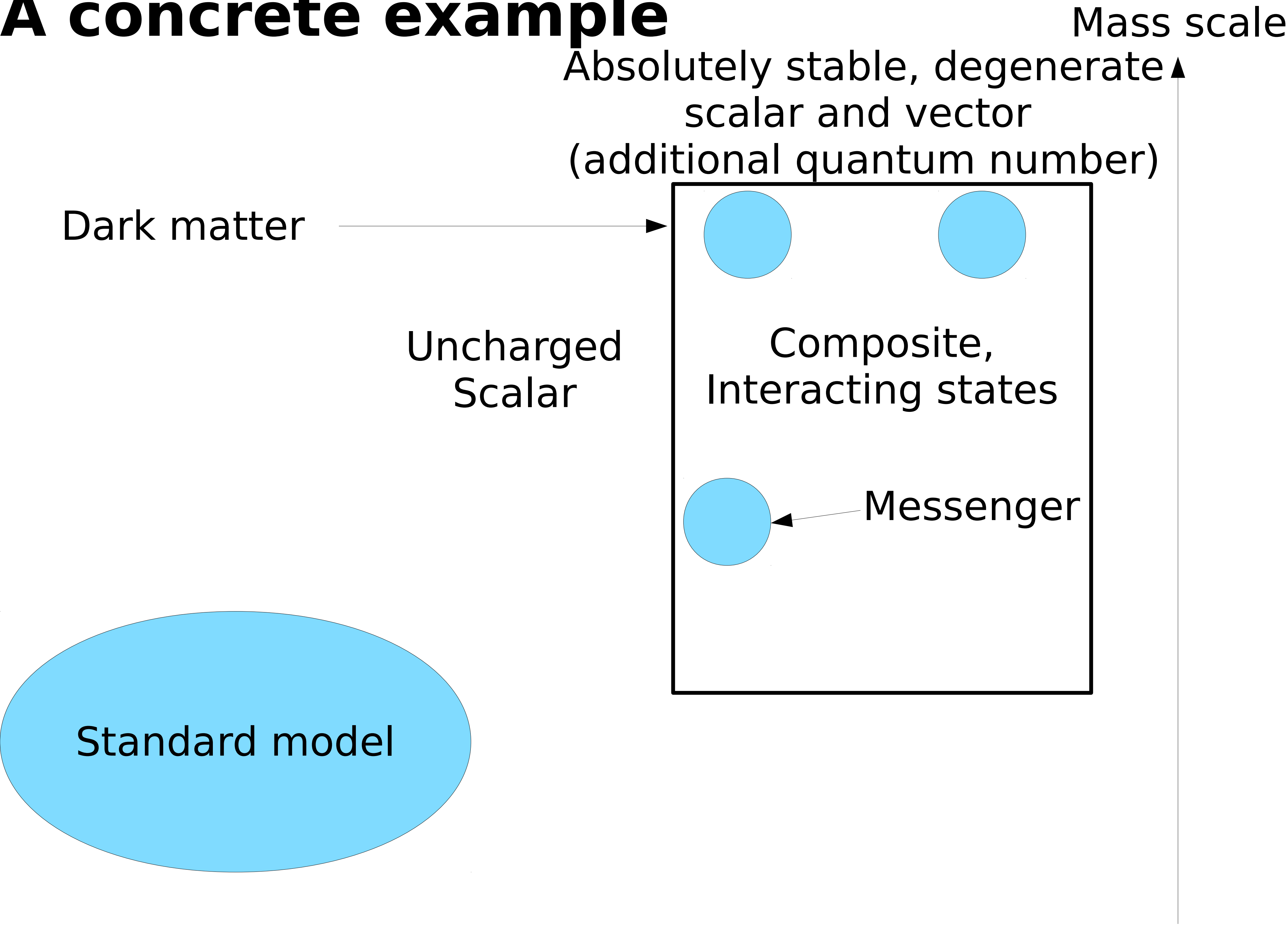

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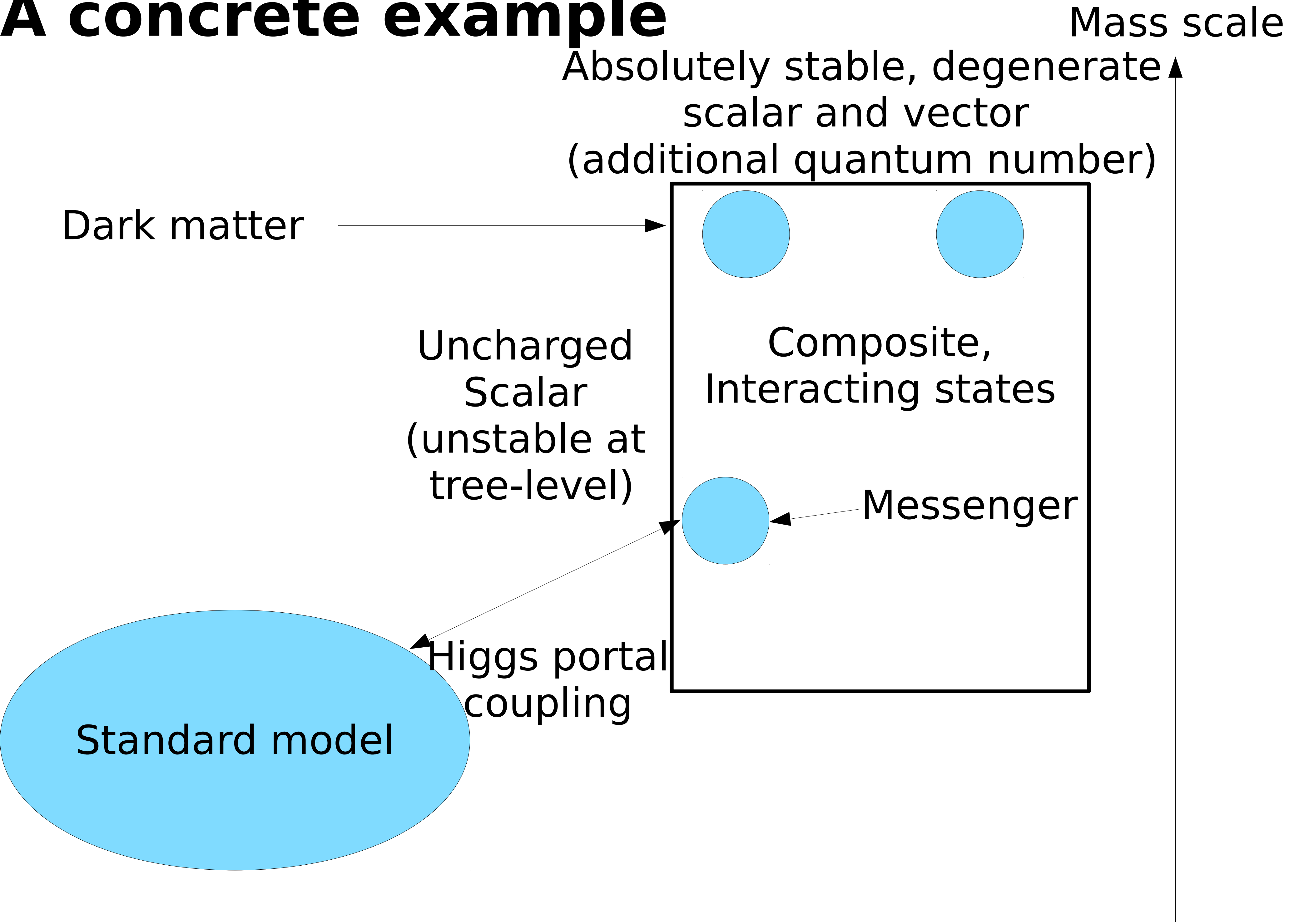

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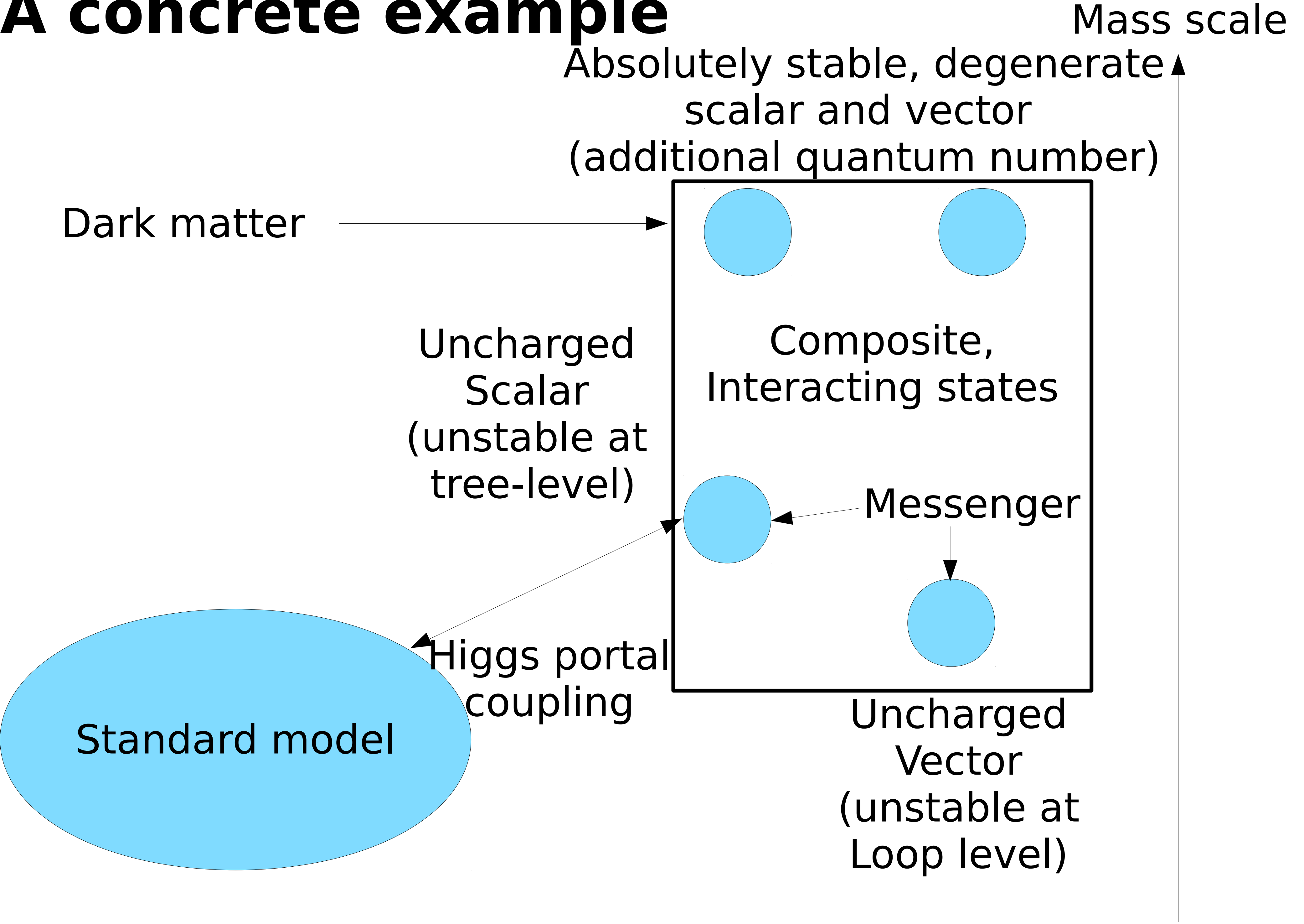

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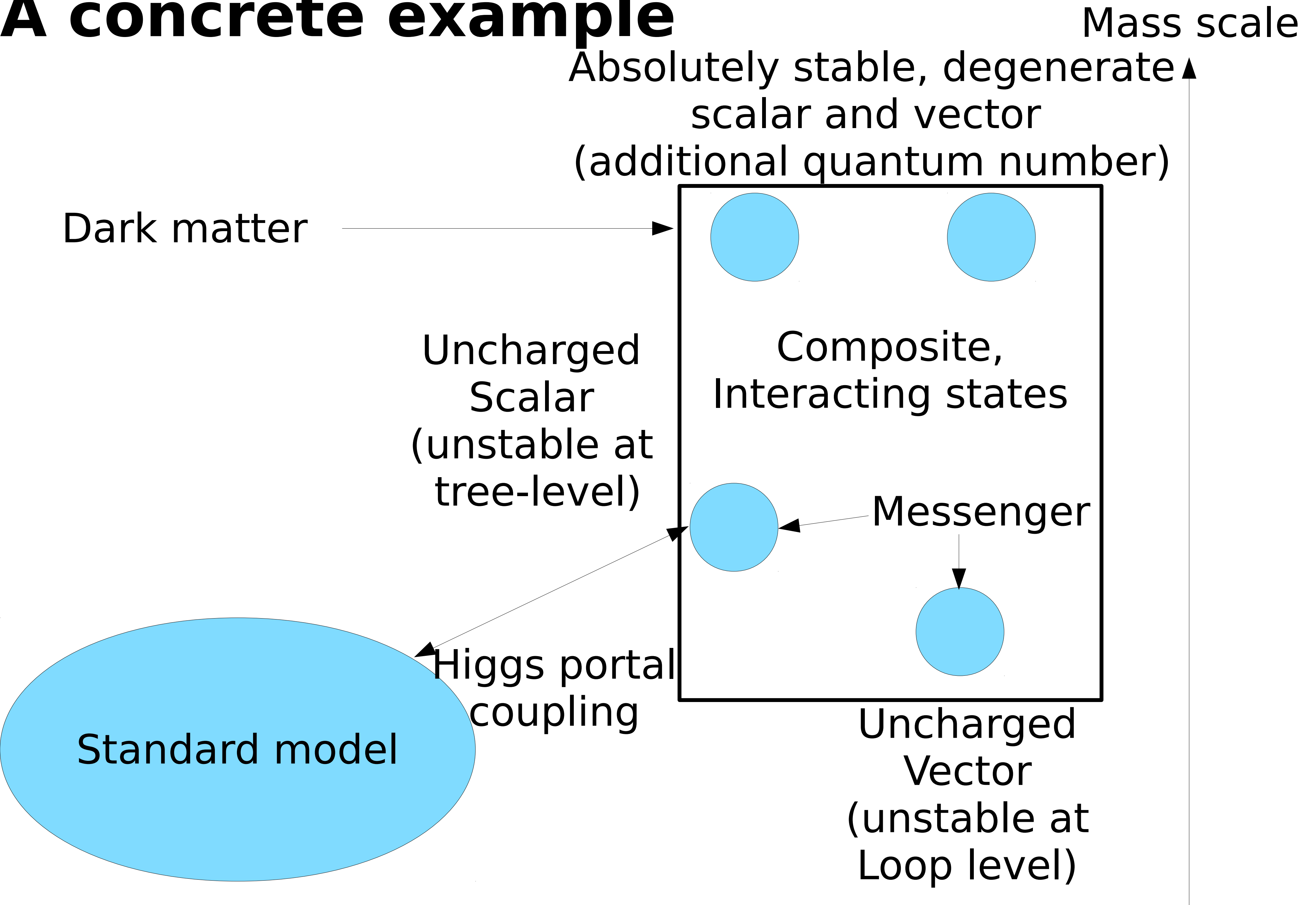
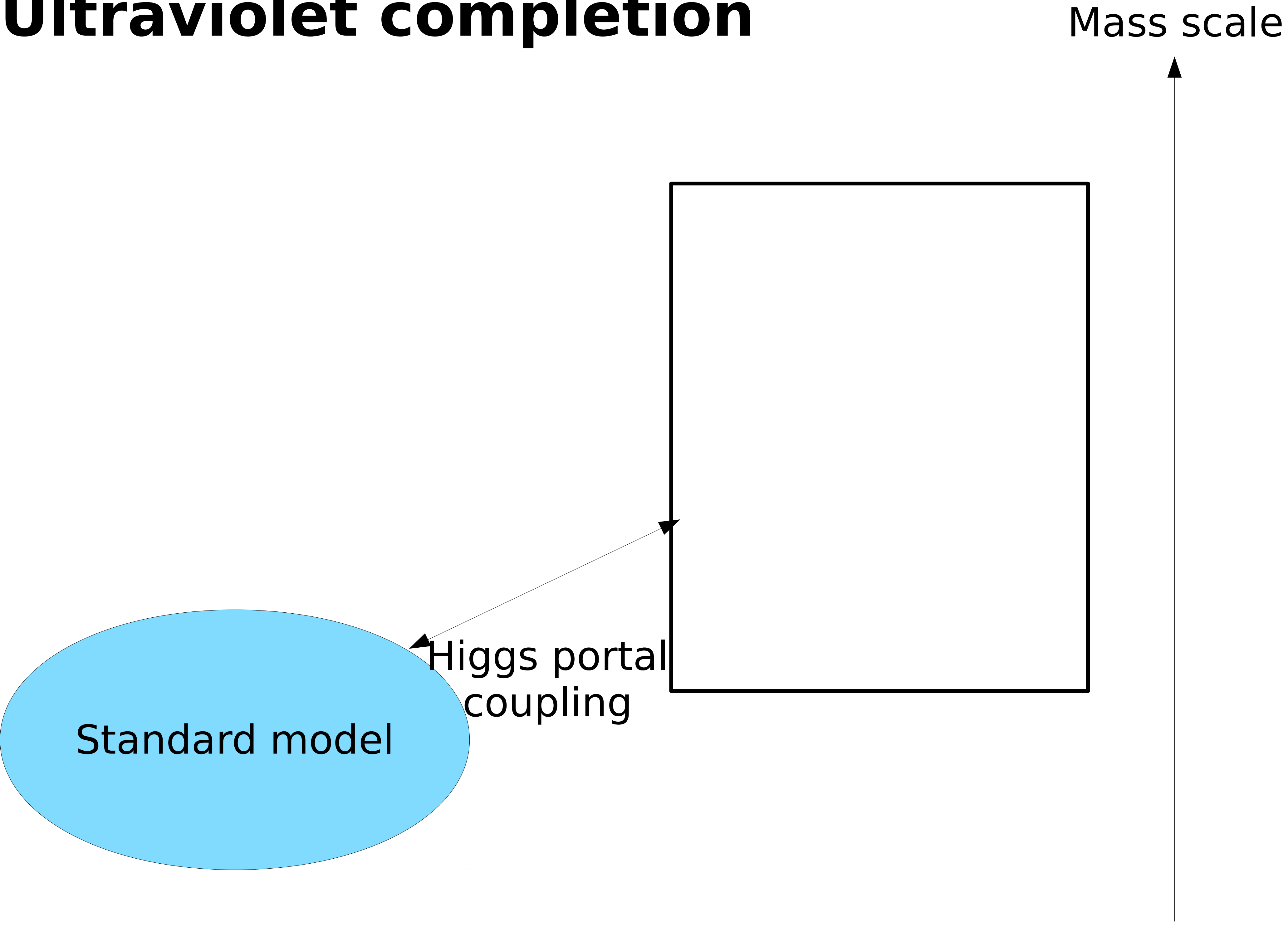


Calculable

Ultraviolet completion



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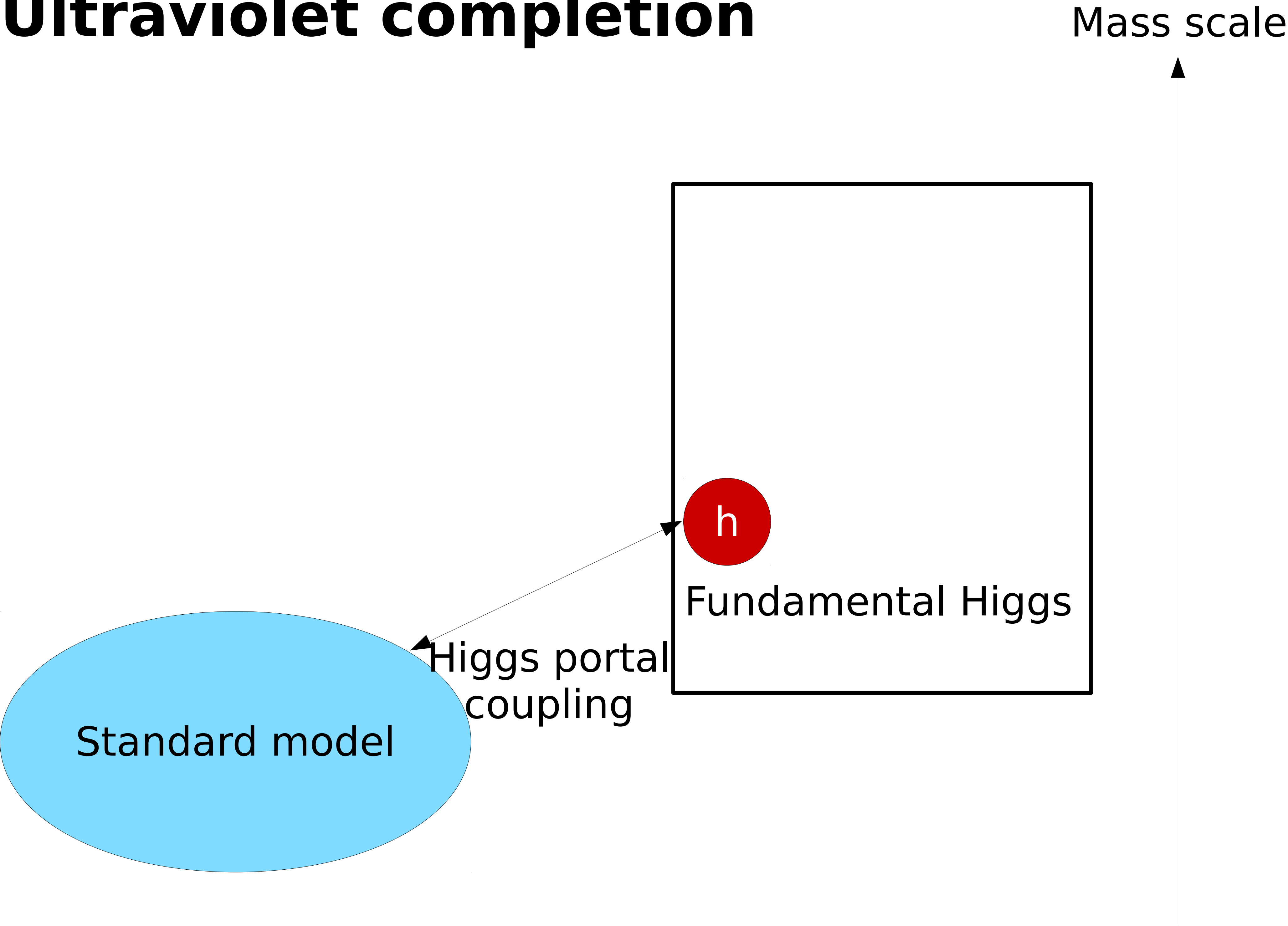

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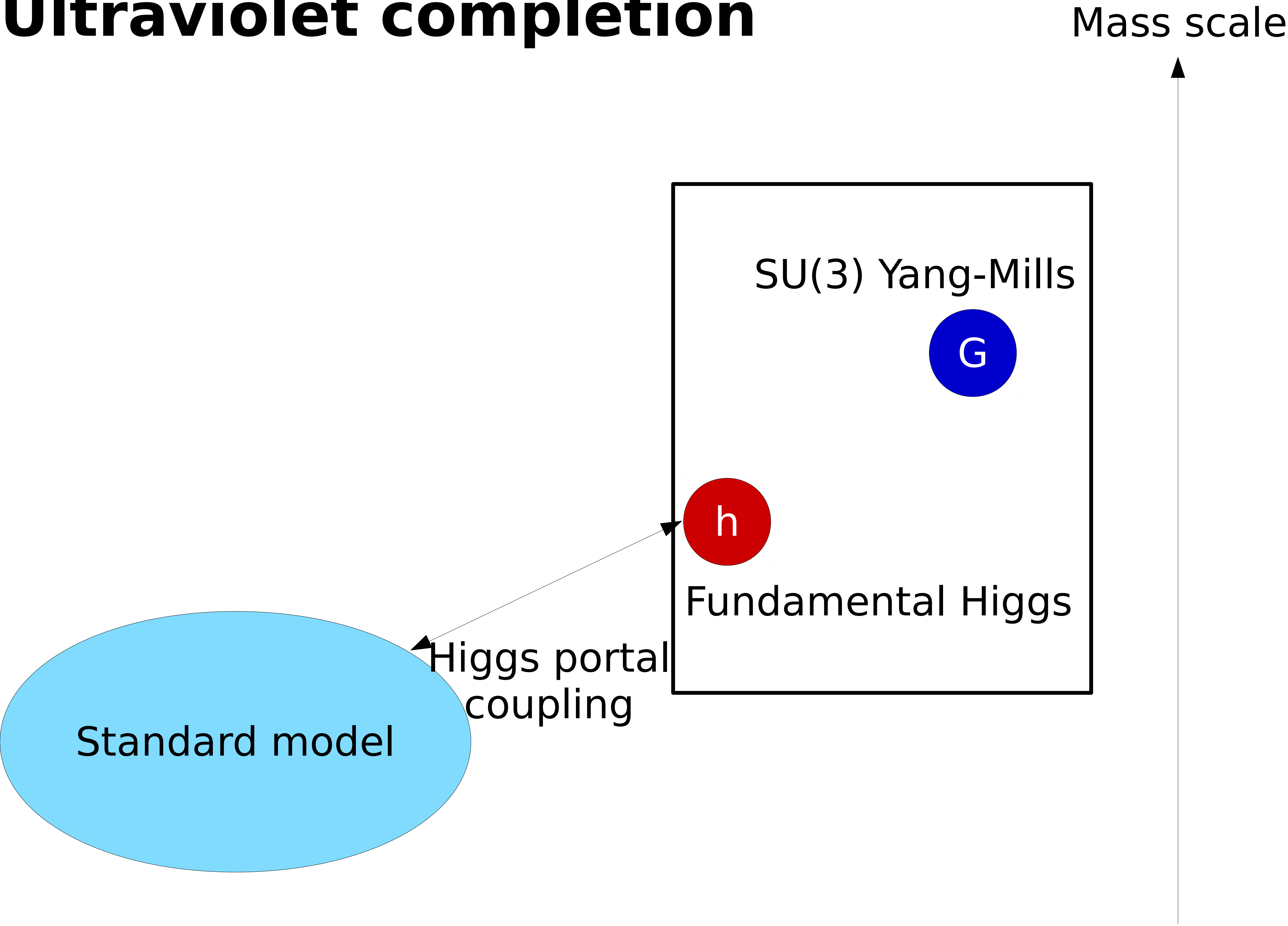

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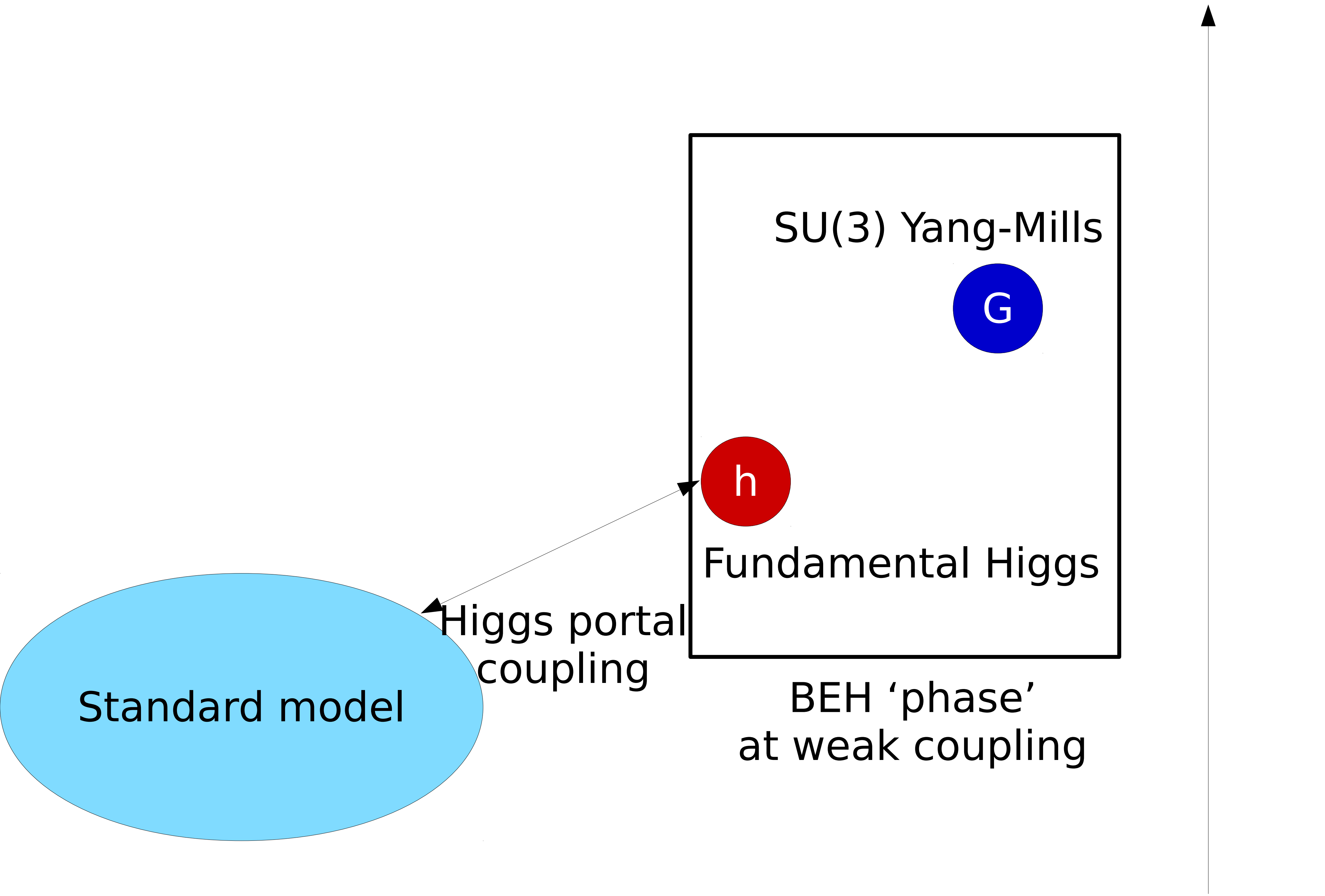

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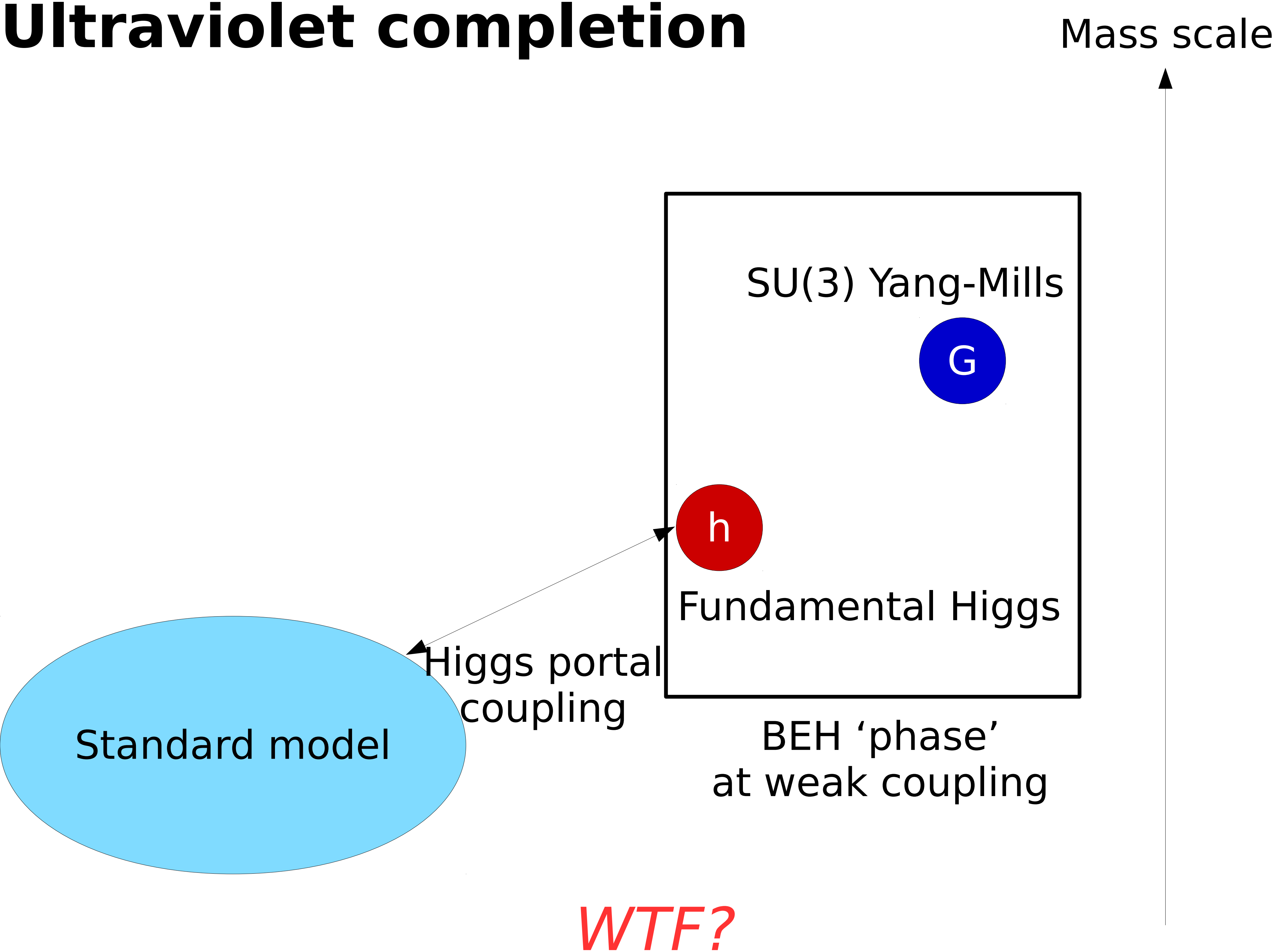

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- All of this will be answered
  - More background: 1712.04721 (Review)

A simpler starting point

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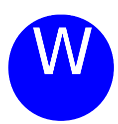
- The Higgs sector is a gauge theory

$$L = -\frac{1}{4} W^{a}_{\mu\nu} W_{a}^{\mu\nu}$$

$$W^{a}_{\mu\nu} = \partial_{\mu} W^{a}_{\nu} - \partial_{\nu} W^{a}_{\mu} + g f^{a}_{bc} W^{b}_{\mu} W^{c}_{\nu}$$

- Ws W^{a}_{μ} 

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- Ws W_{μ}^{a} W
- Higgs h_i h
- No QED: Ws and Zs are degenerate
- Couplings g, v, λ and some numbers f^{abc} and t_{a}^{ij}

Symmetries of the system

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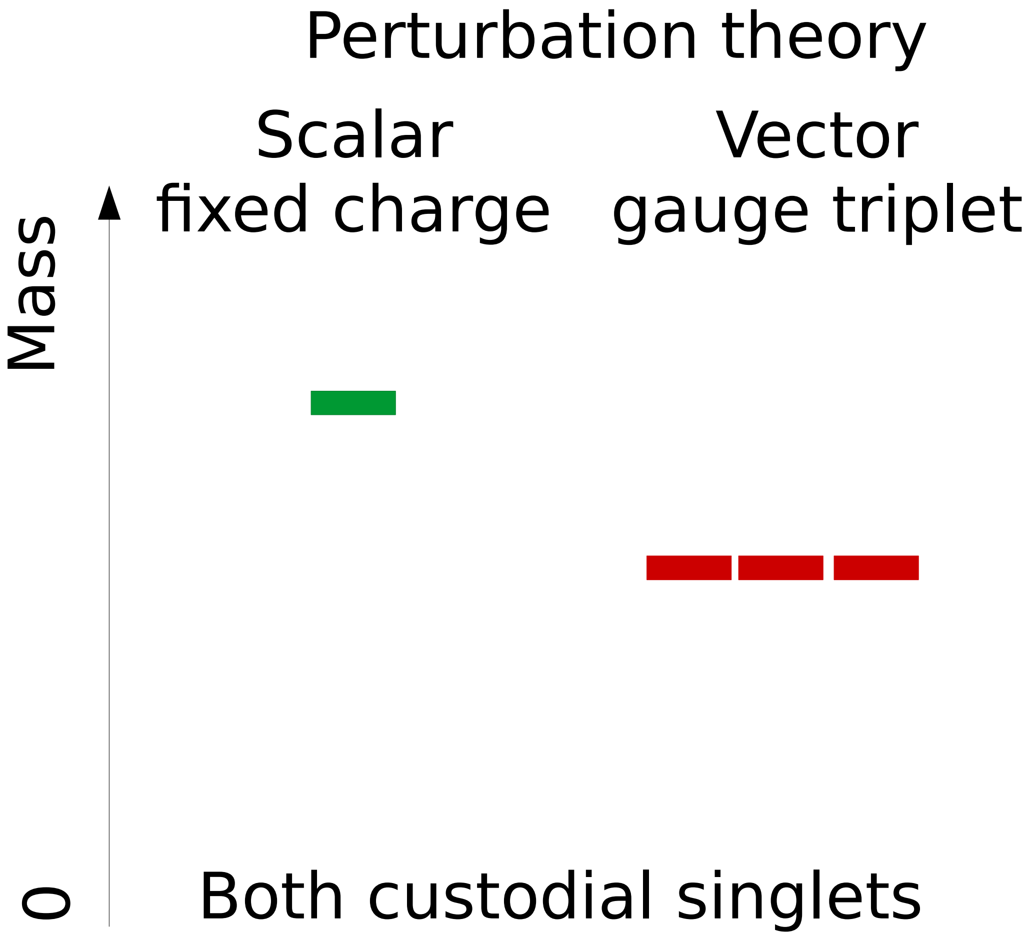
- Global SU(2) Higgs custodial (flavor) symmetry
  - Acts as (right-)transformation on the Higgs field only

$$W_{\mu}^{a}\rightarrow W_{\mu}^{a} \qquad h_{i}\rightarrow h_{i}+a^{ij}h_{j}+b^{ij}h_{j}^{*}$$

Physical spectrum



The origin of the problem

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  - And this includes non-perturbative aspects…
  - ...even at weak coupling

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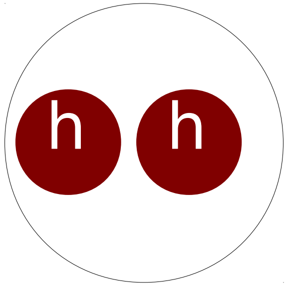

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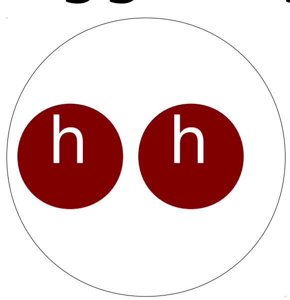

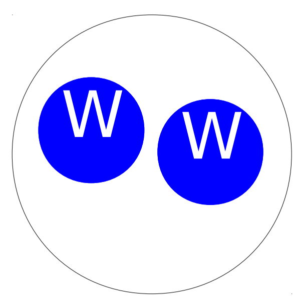

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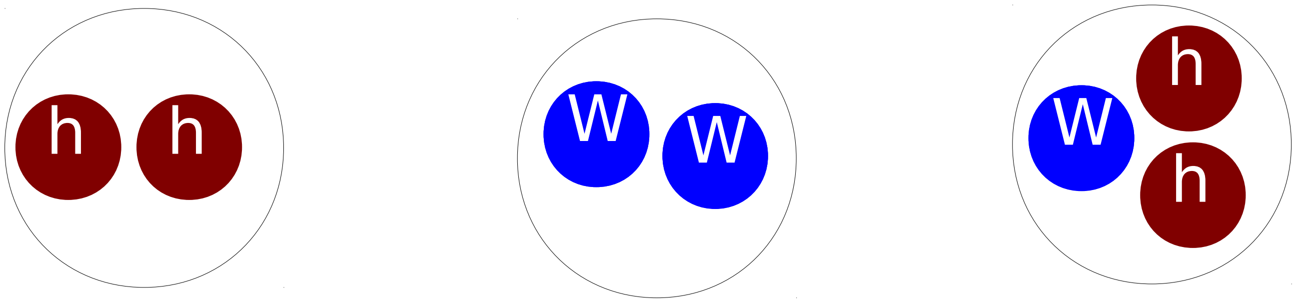

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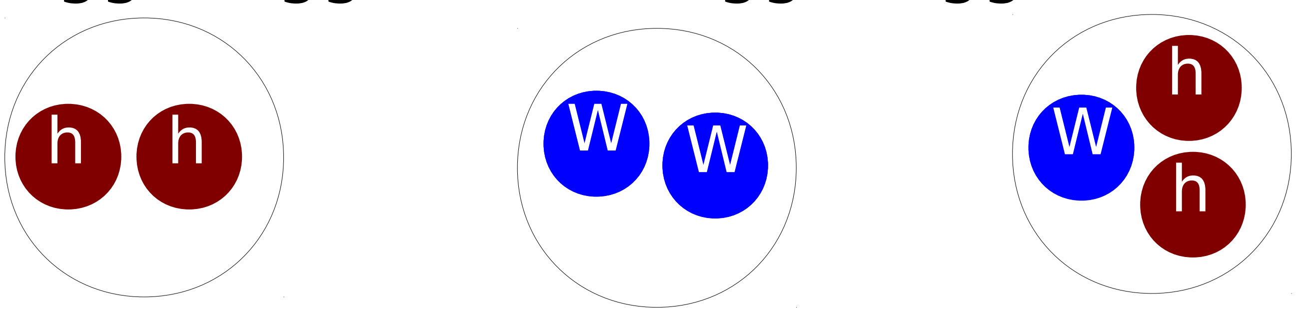

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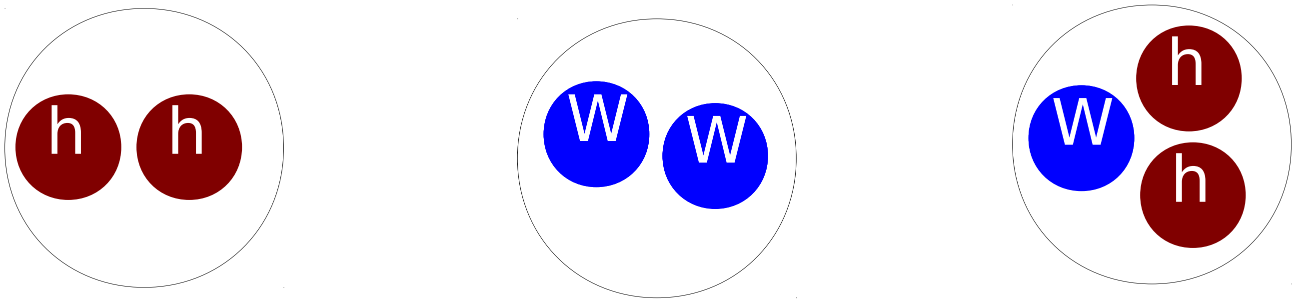

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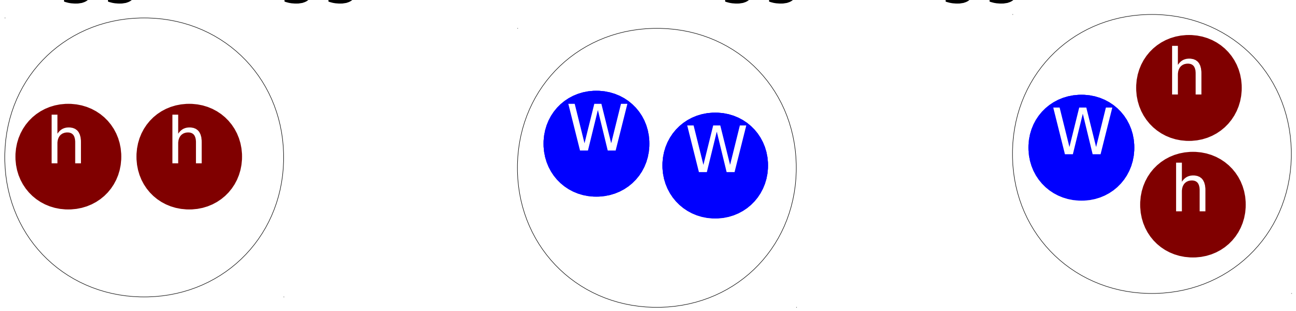

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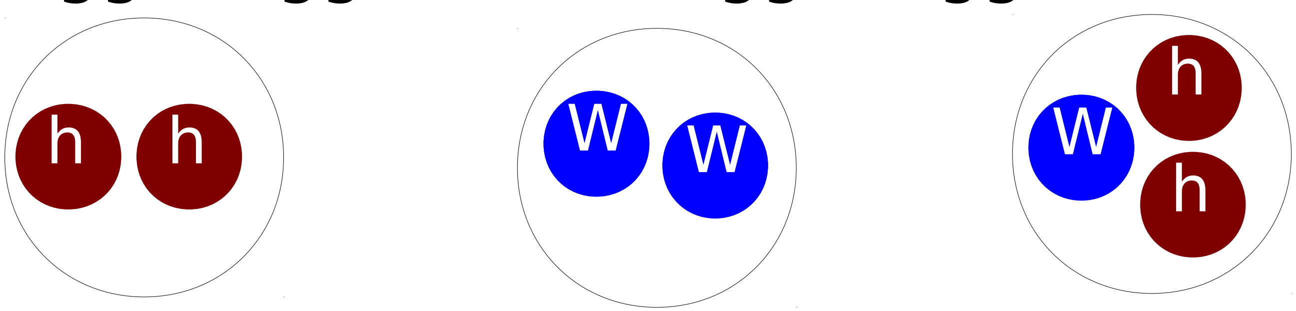

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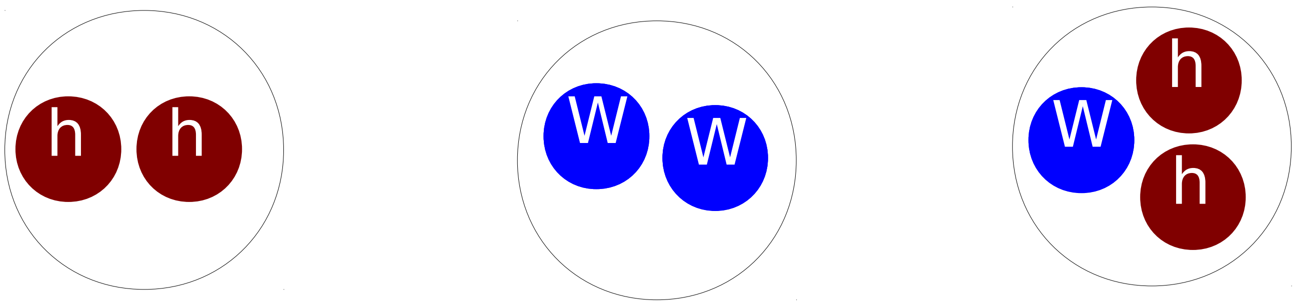

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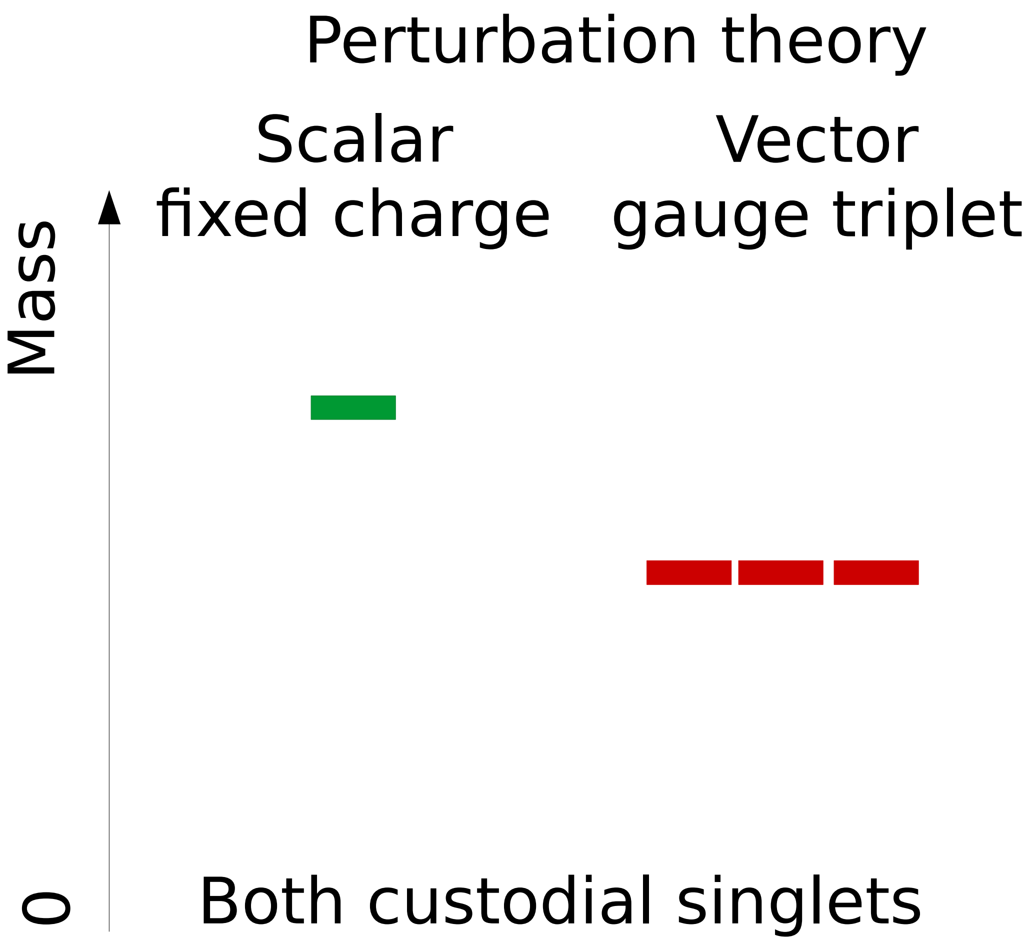
- Can this matter?

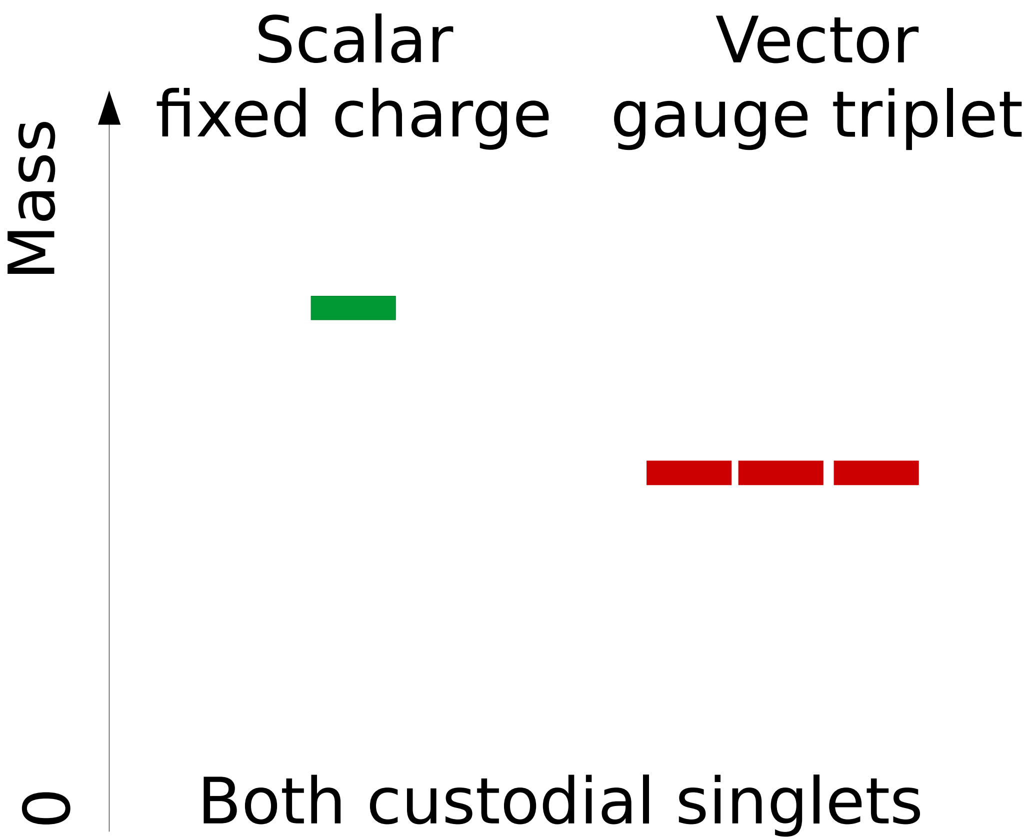
Physical spectrum



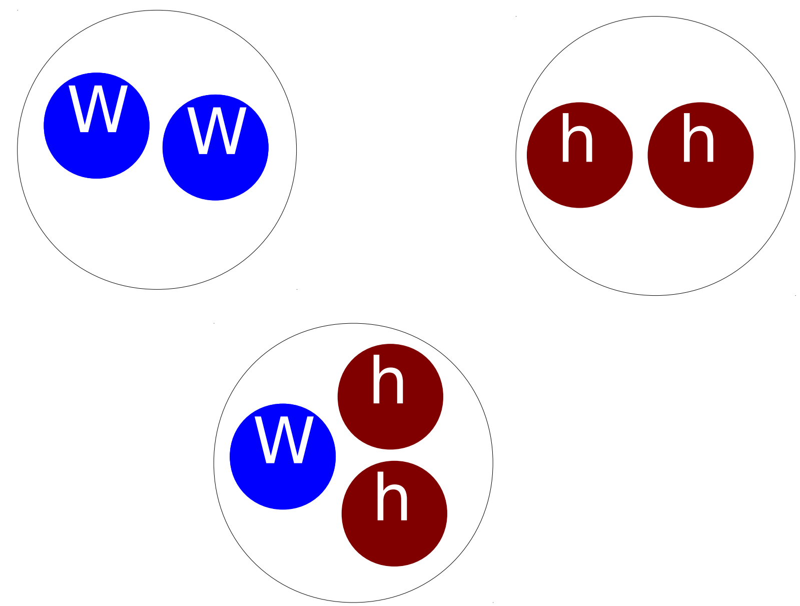
Experiment tells that somehow the left is correct

Physical spectrum

Perturbation theory



Composite (bound) states



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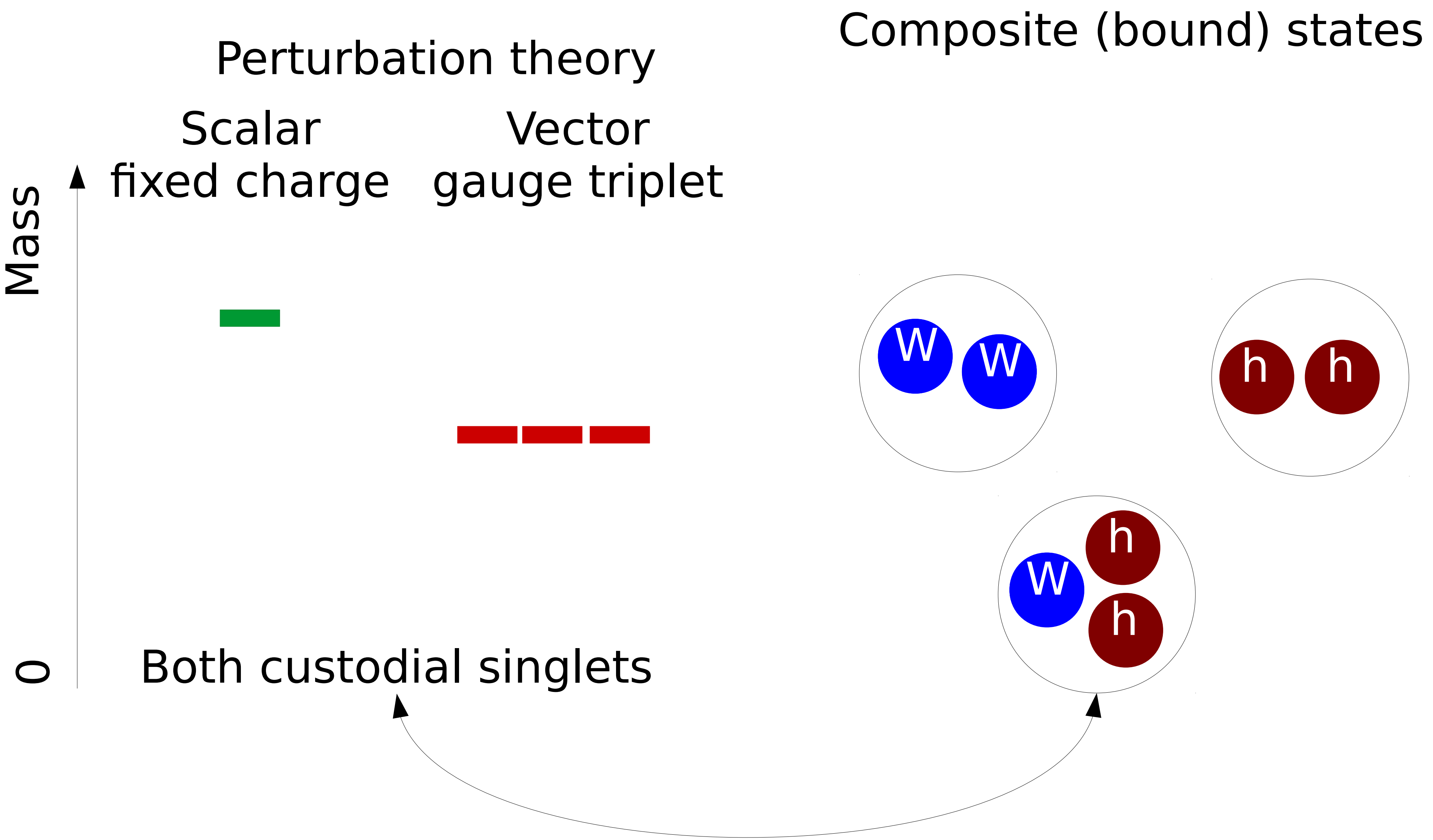
Physical spectrum



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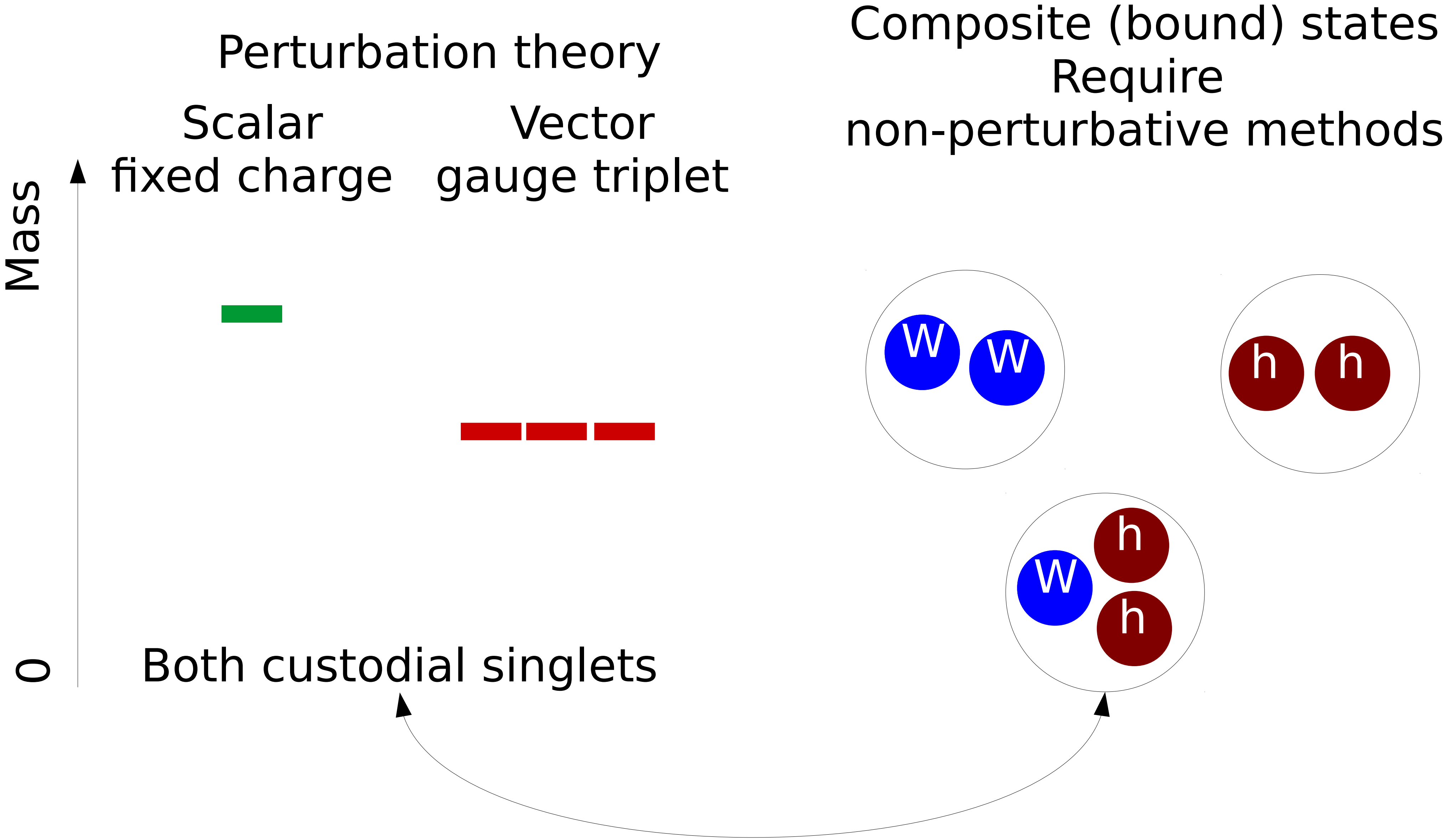

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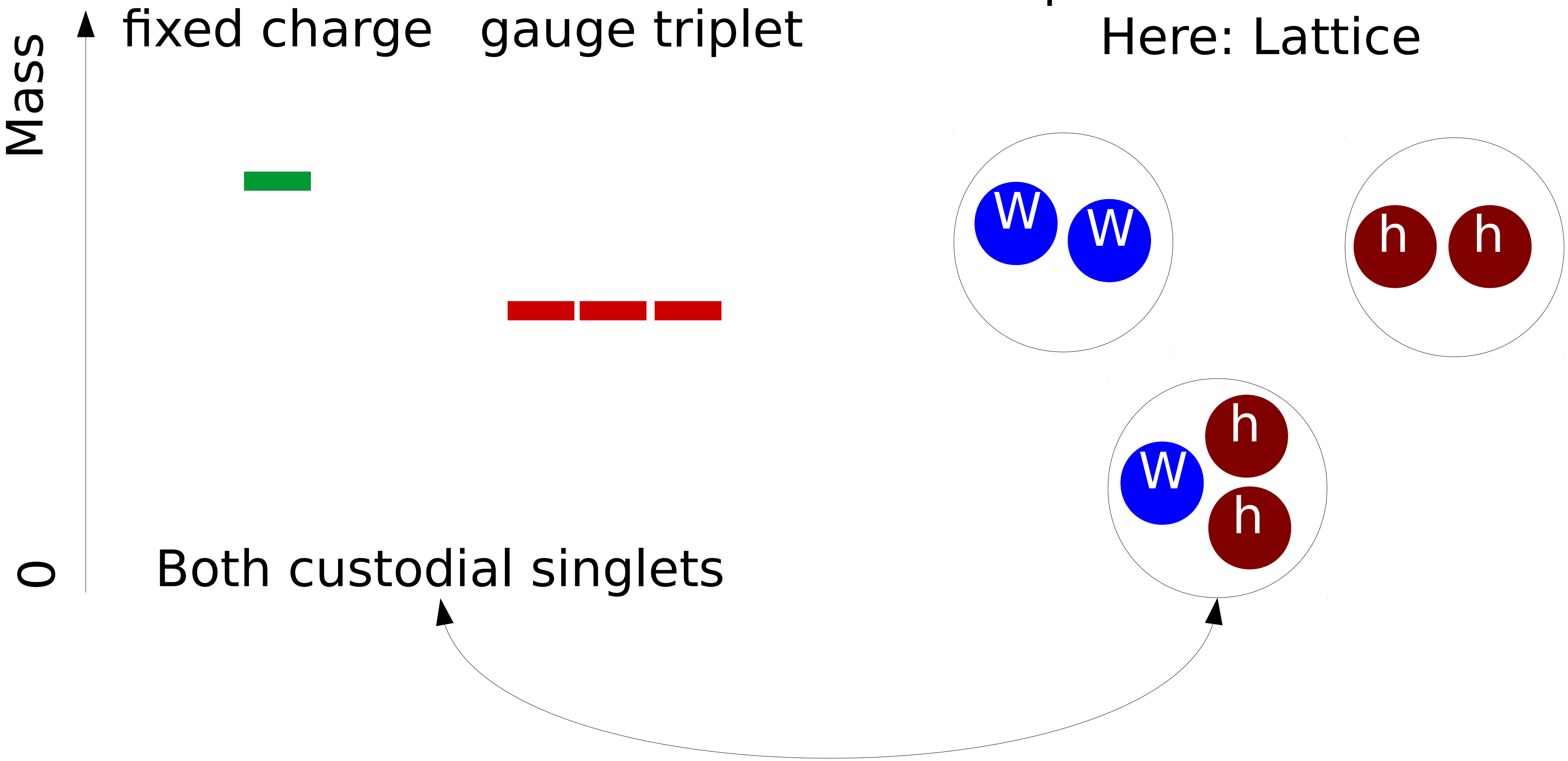
Physical spectrum

Perturbation theory

Scalar fixed charge — Vector gauge triplet

Composite (bound) states
Require
non-perturbative methods
Here: Lattice



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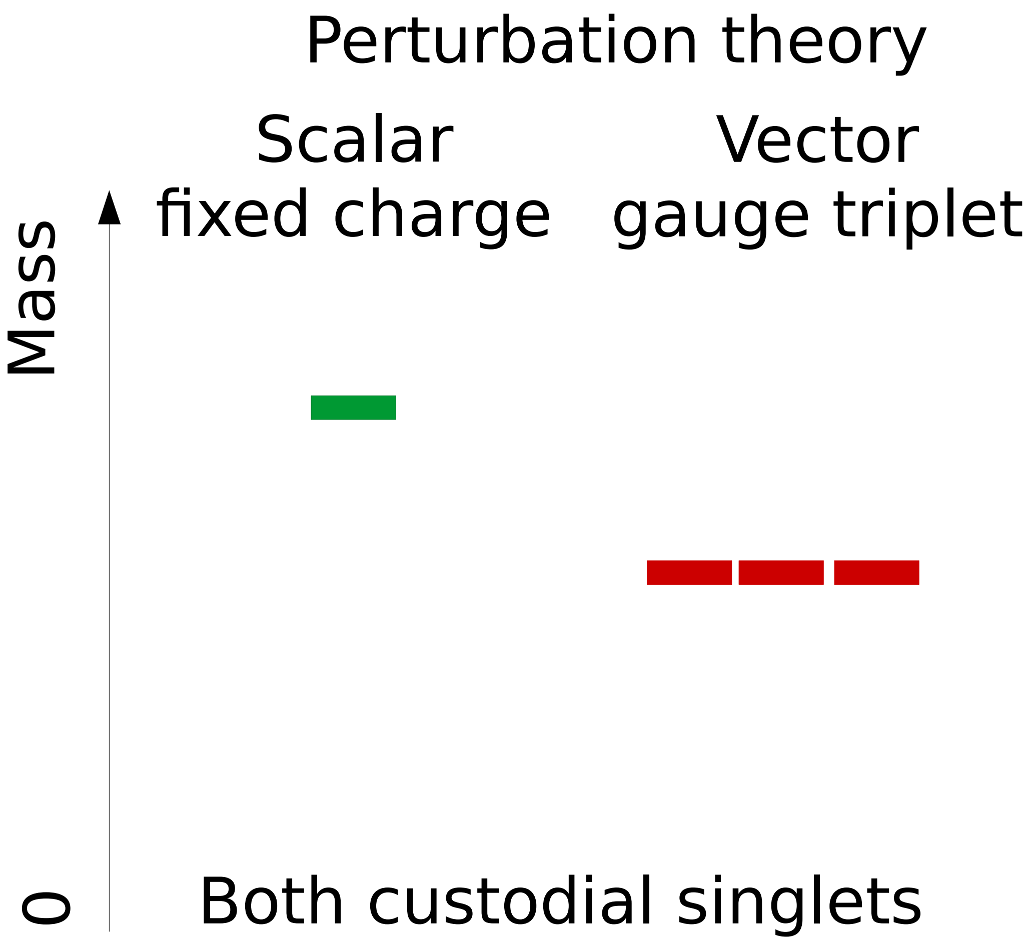

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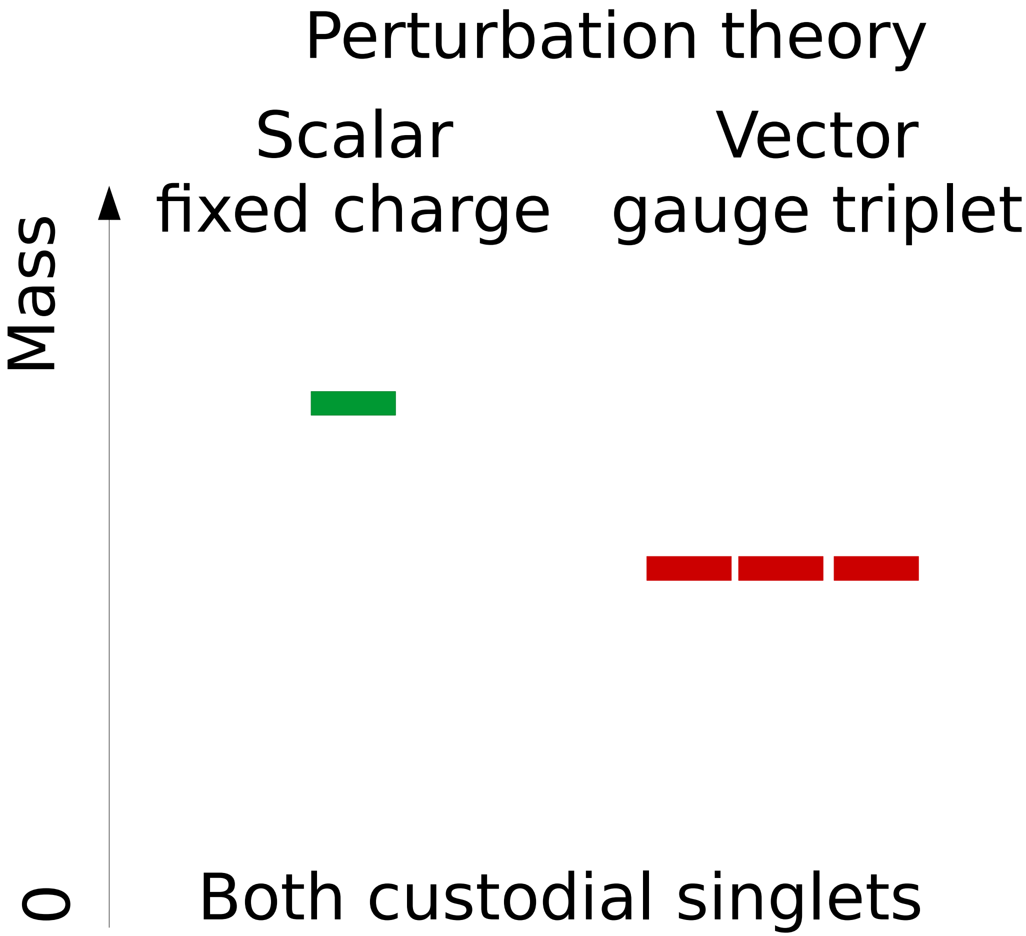

W mass for
different lattice parameters

Physical spectrum

[Maas'12, Maas & Mufti'13]

Perturbation theory

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Vector
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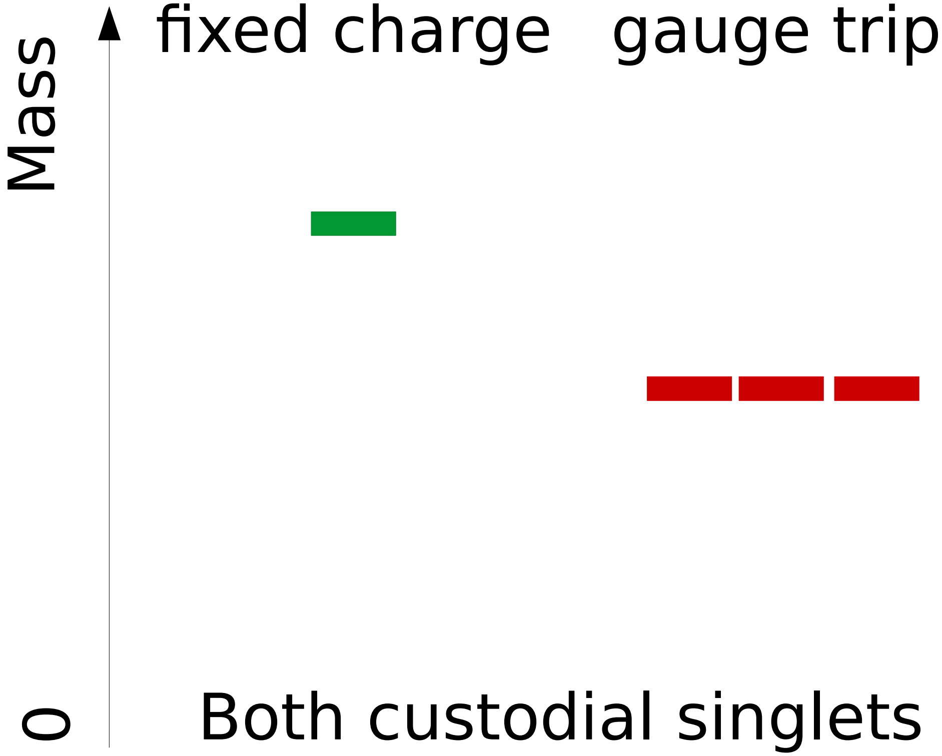
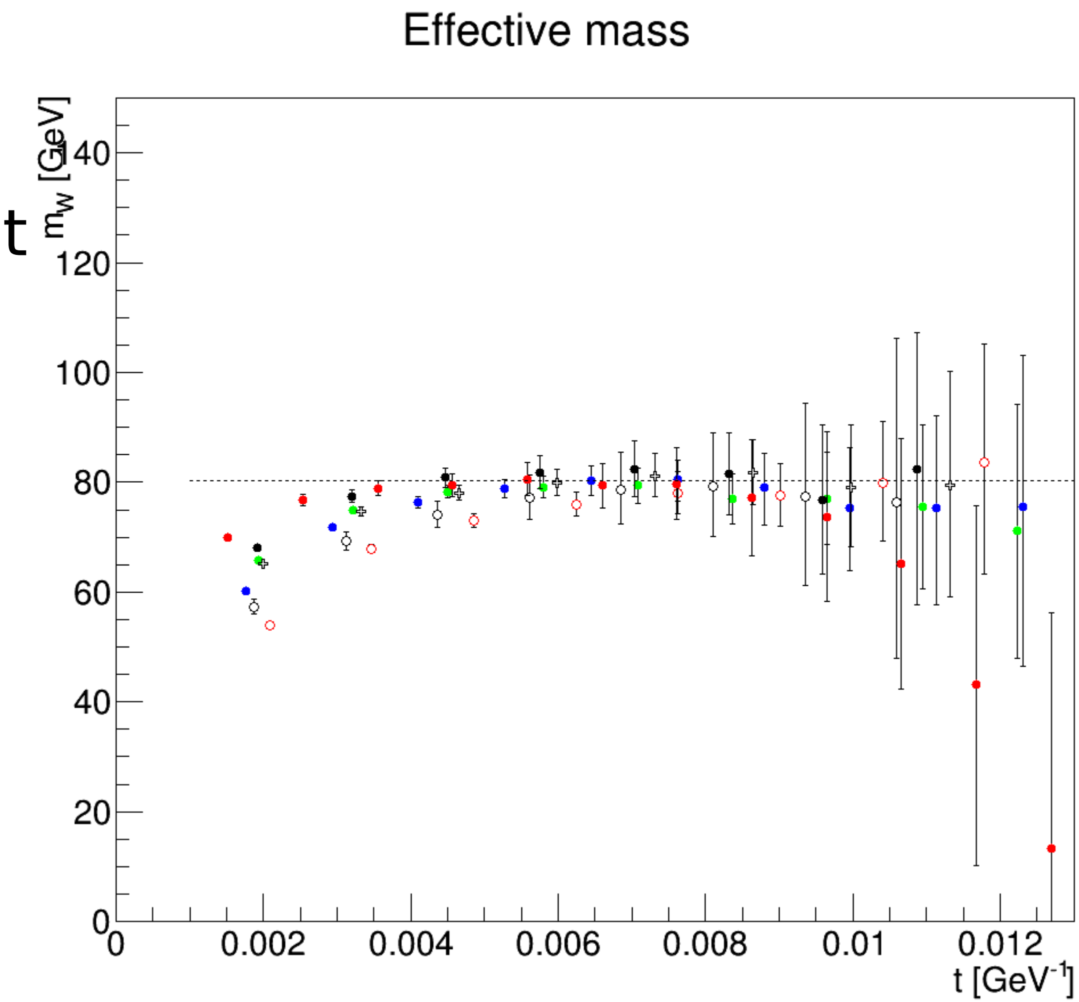


Both custodial singlets



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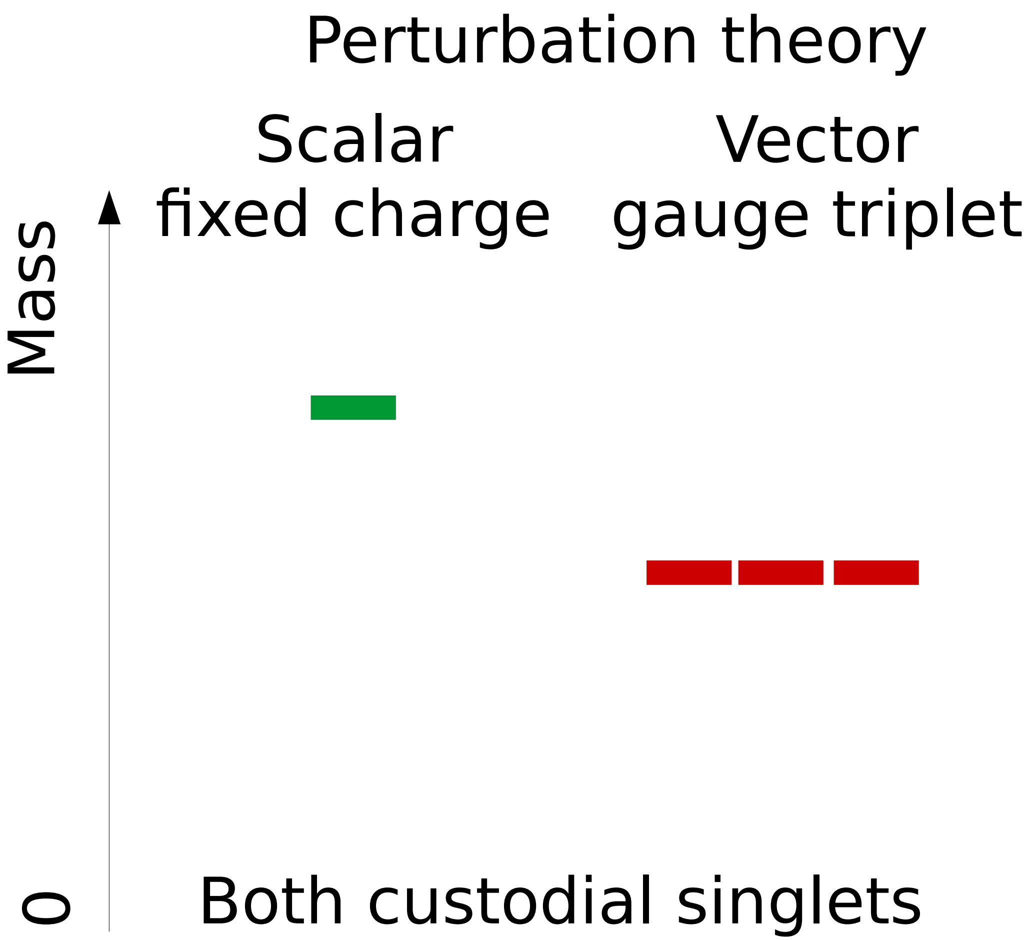

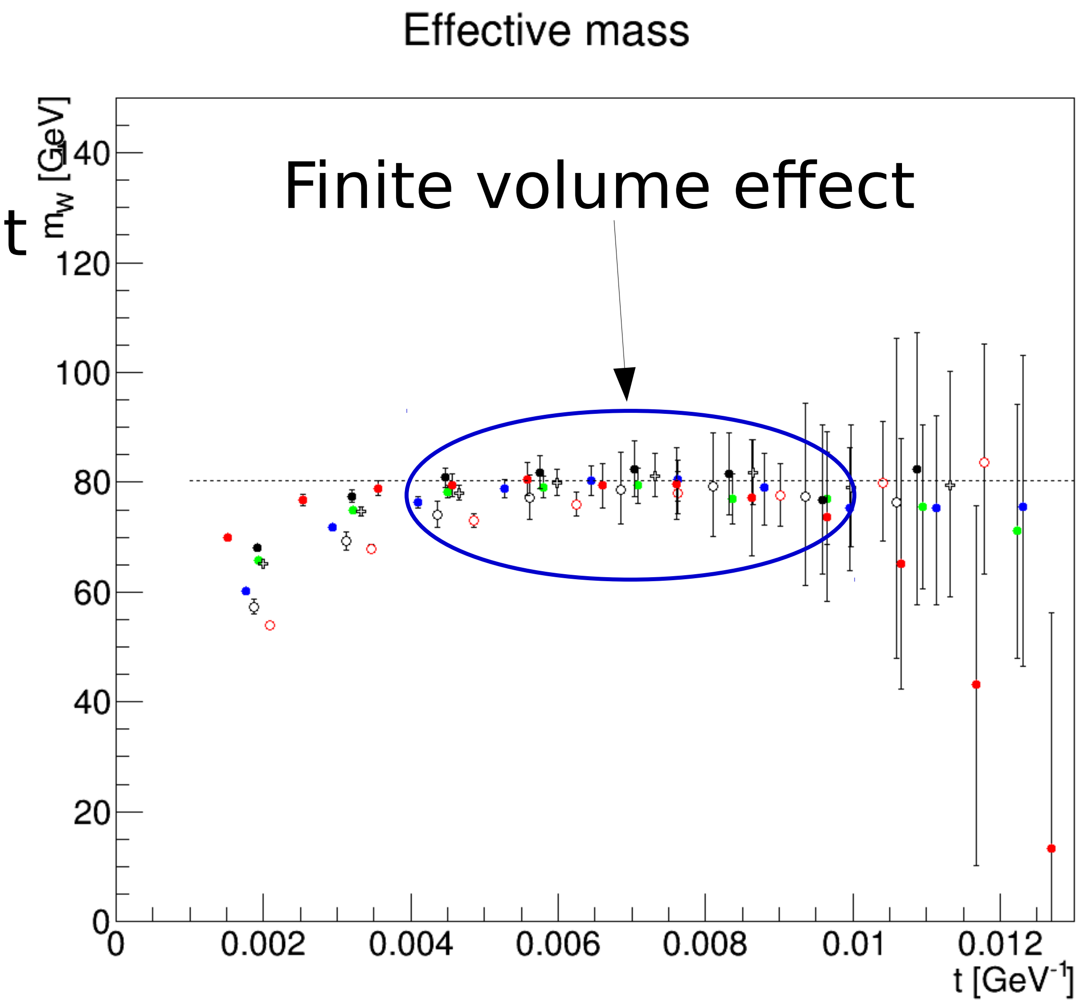

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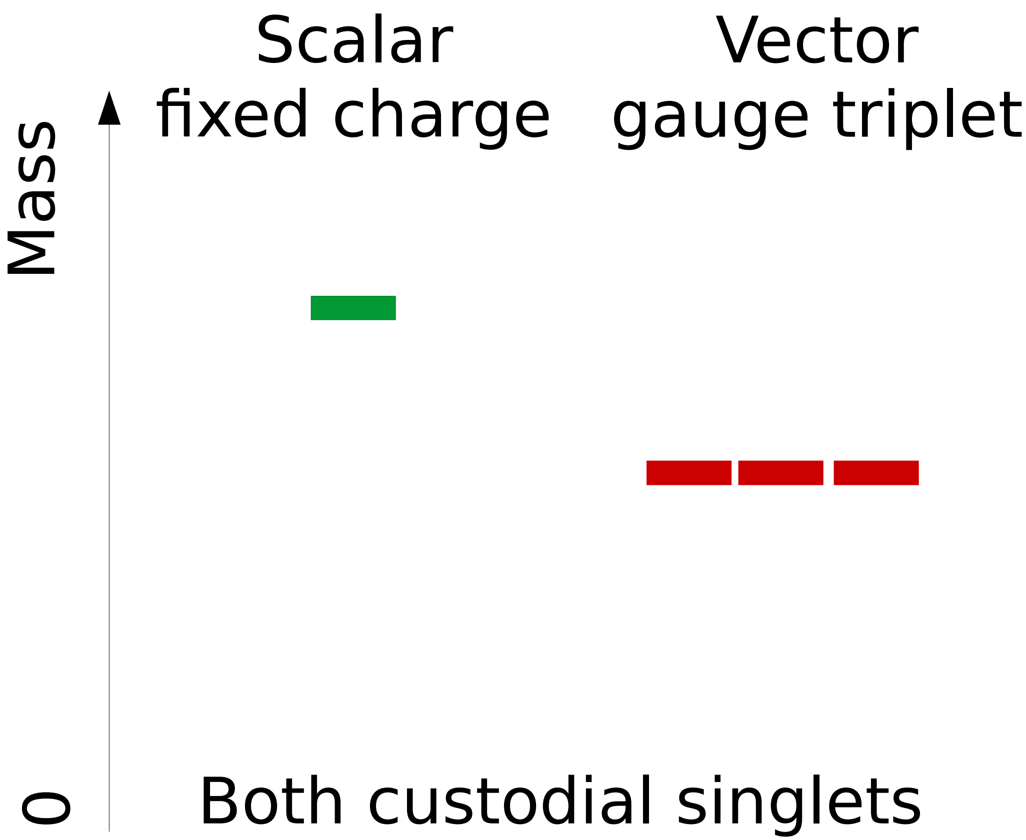

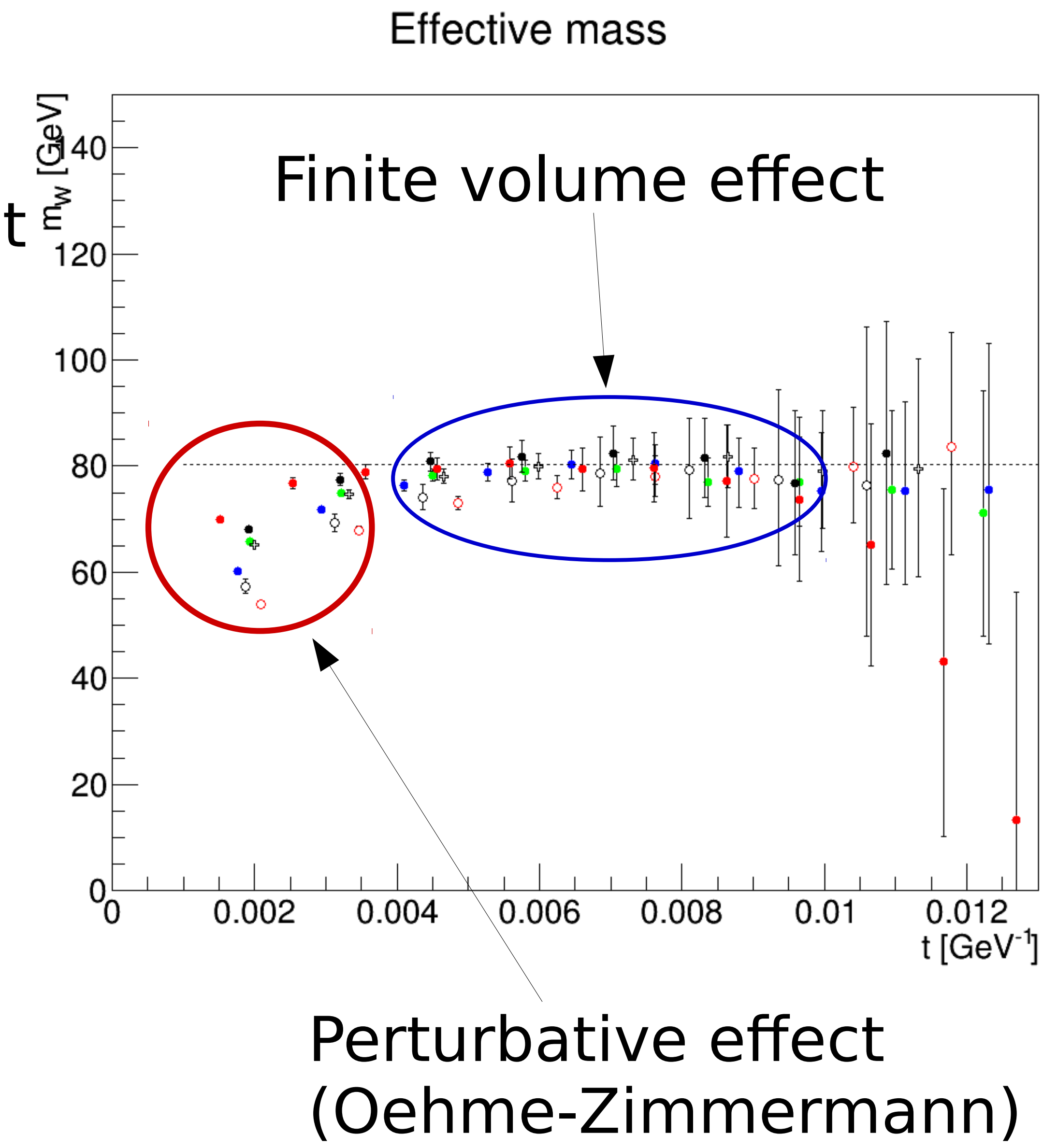

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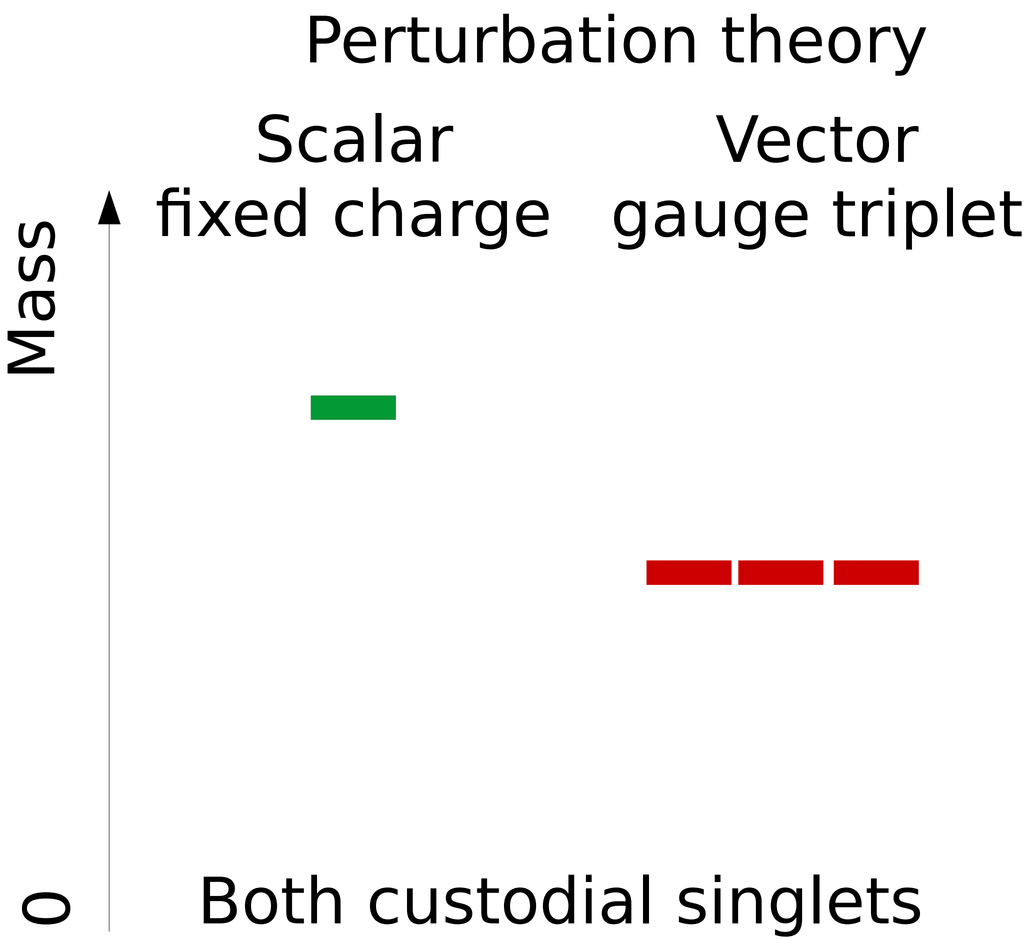

Higgs for
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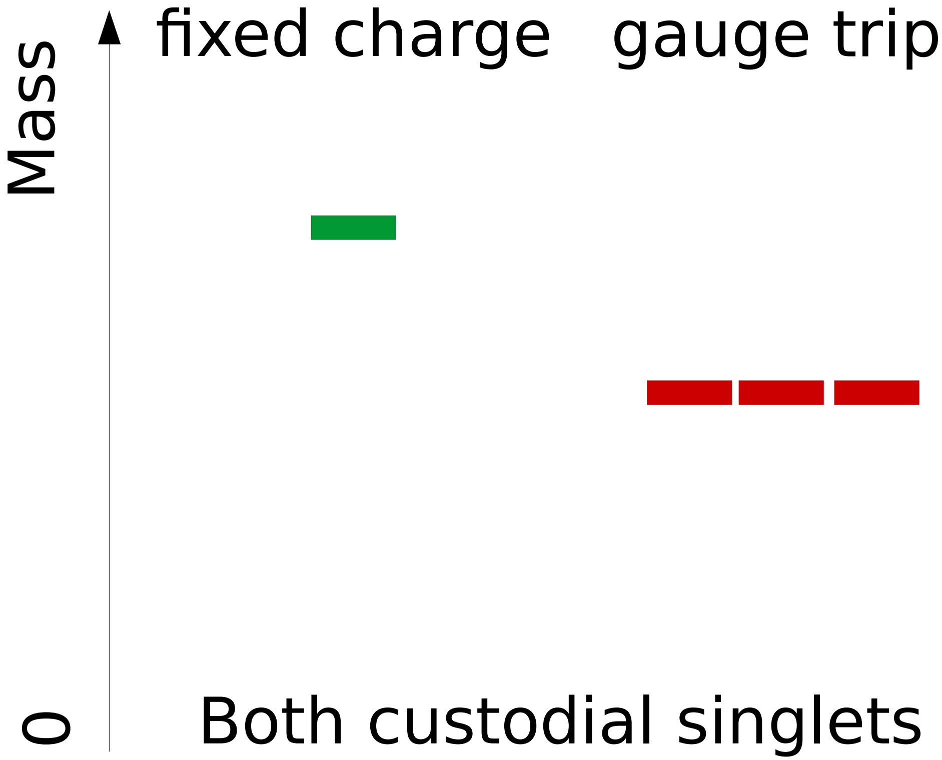
[Maas'12, Maas & Mufti'13]

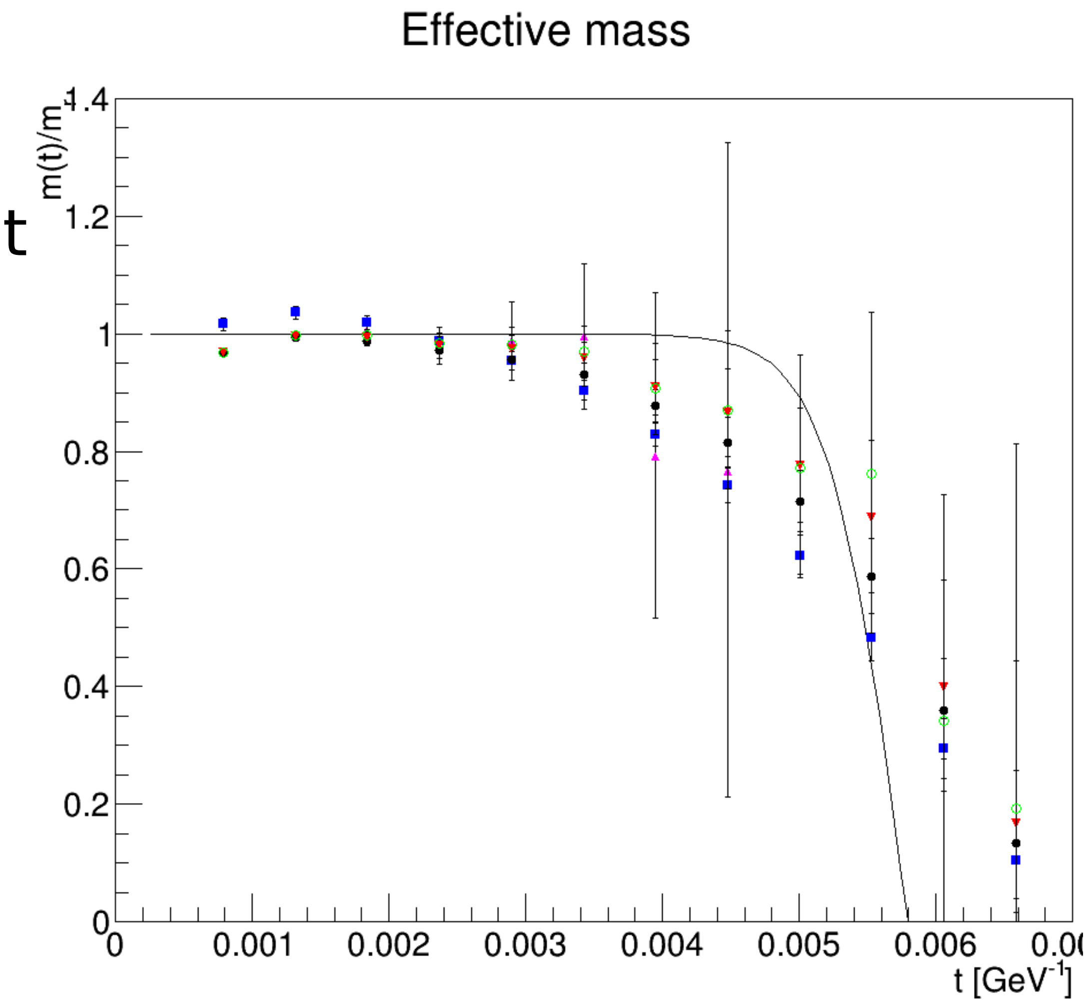
Perturbation theory

Scalar
fixed charge

Vector
gauge triplet



Both custodial singlets



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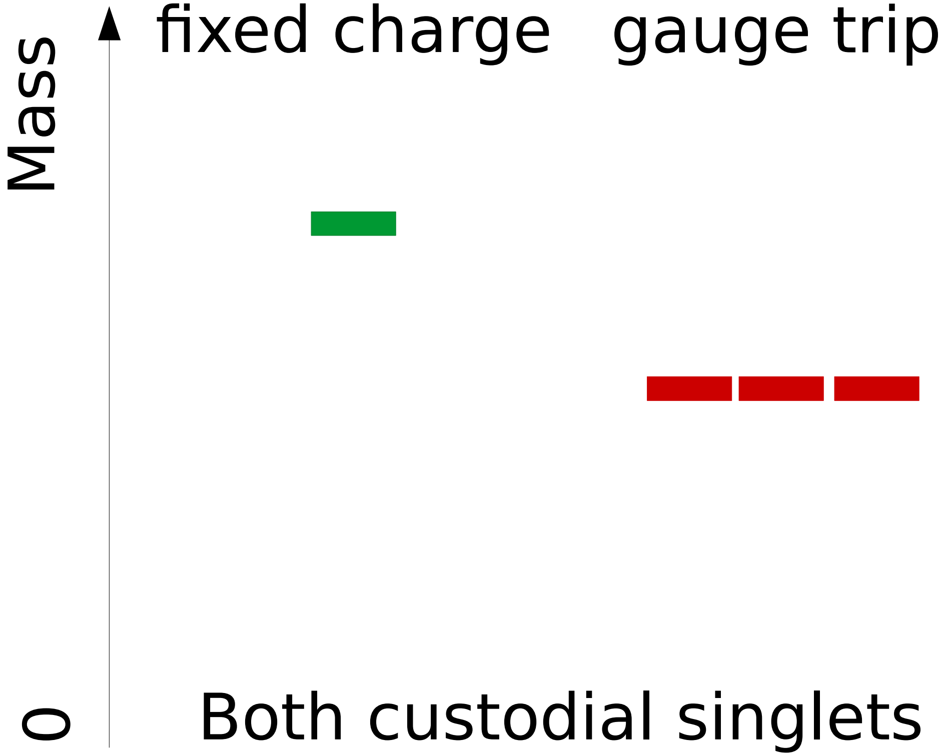

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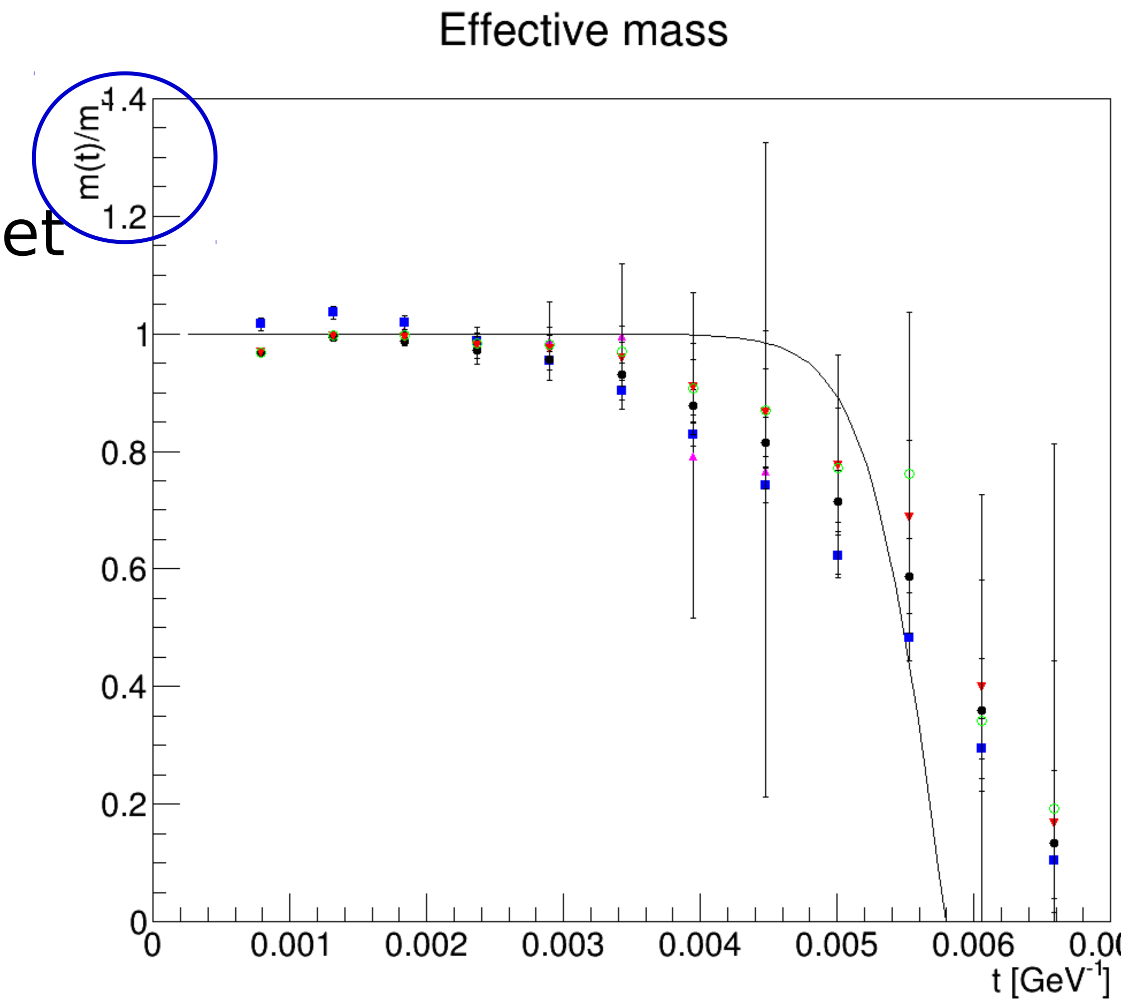

Higgs for
different lattice parameters
-
Higgs mass
requires renormalization

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Perturbation theory

Gauge-invariant

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Vector
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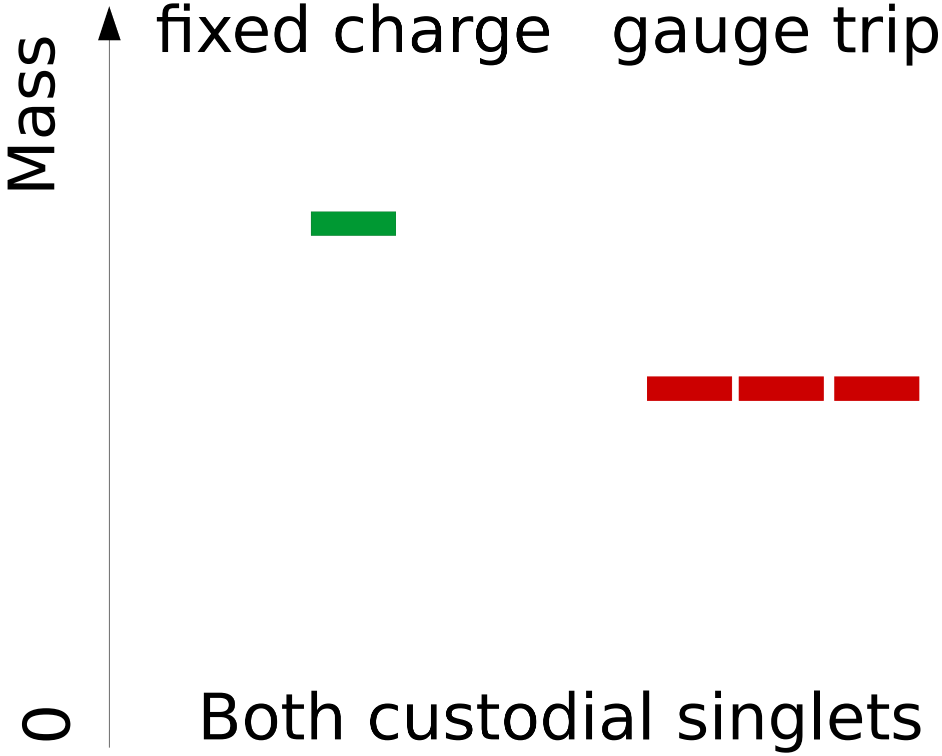

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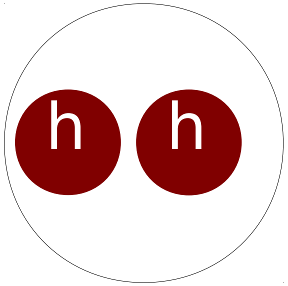

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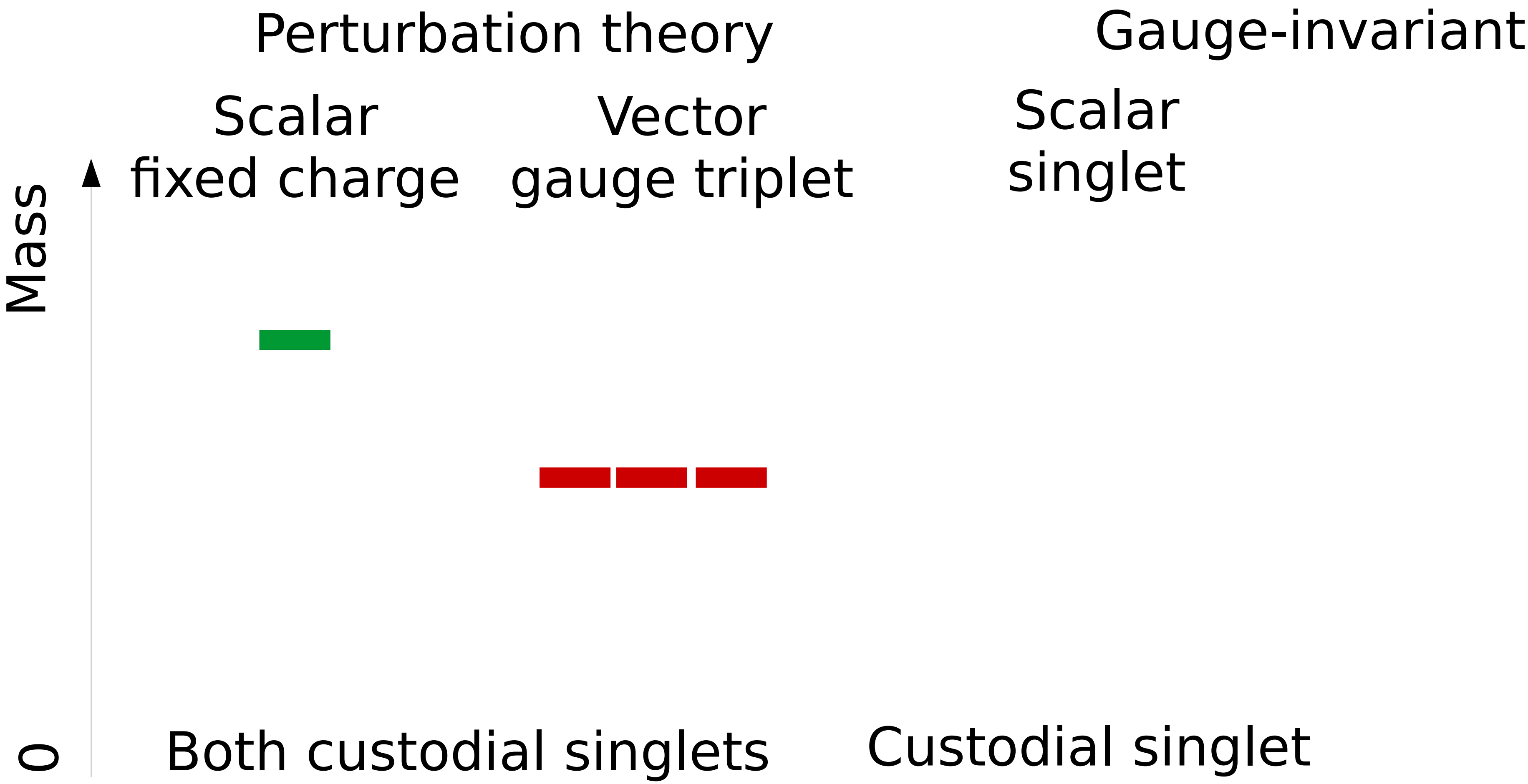

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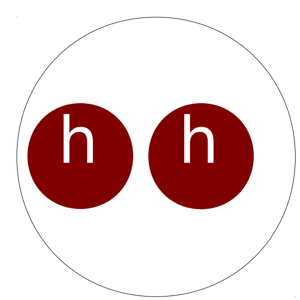

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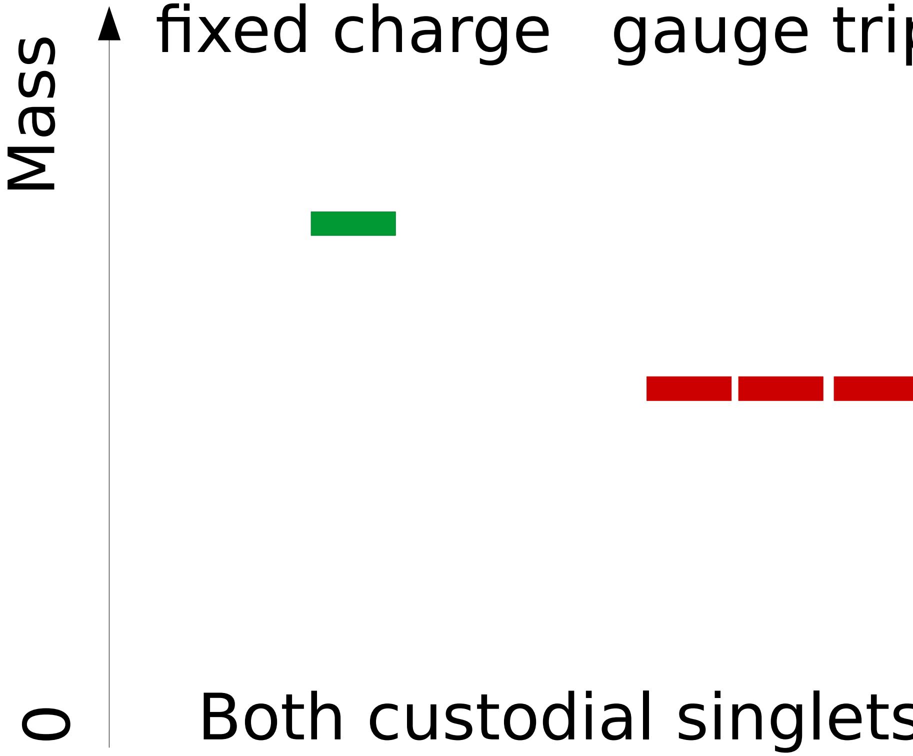

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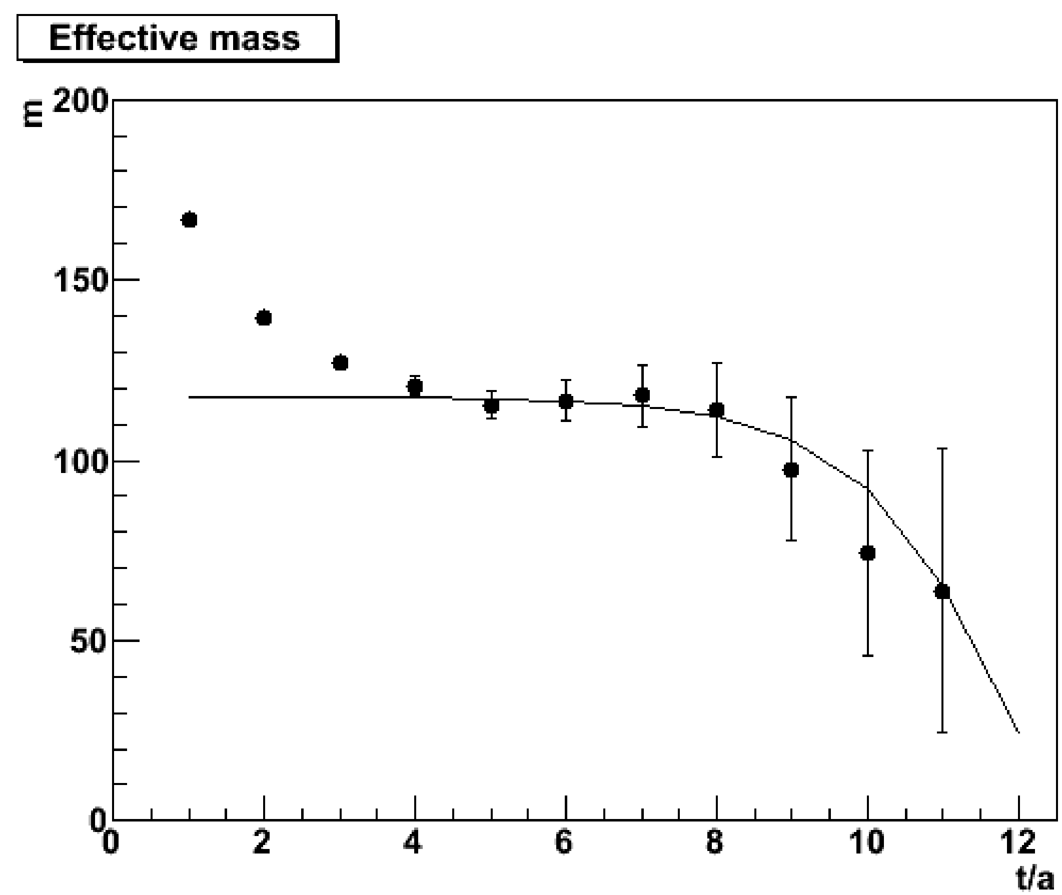

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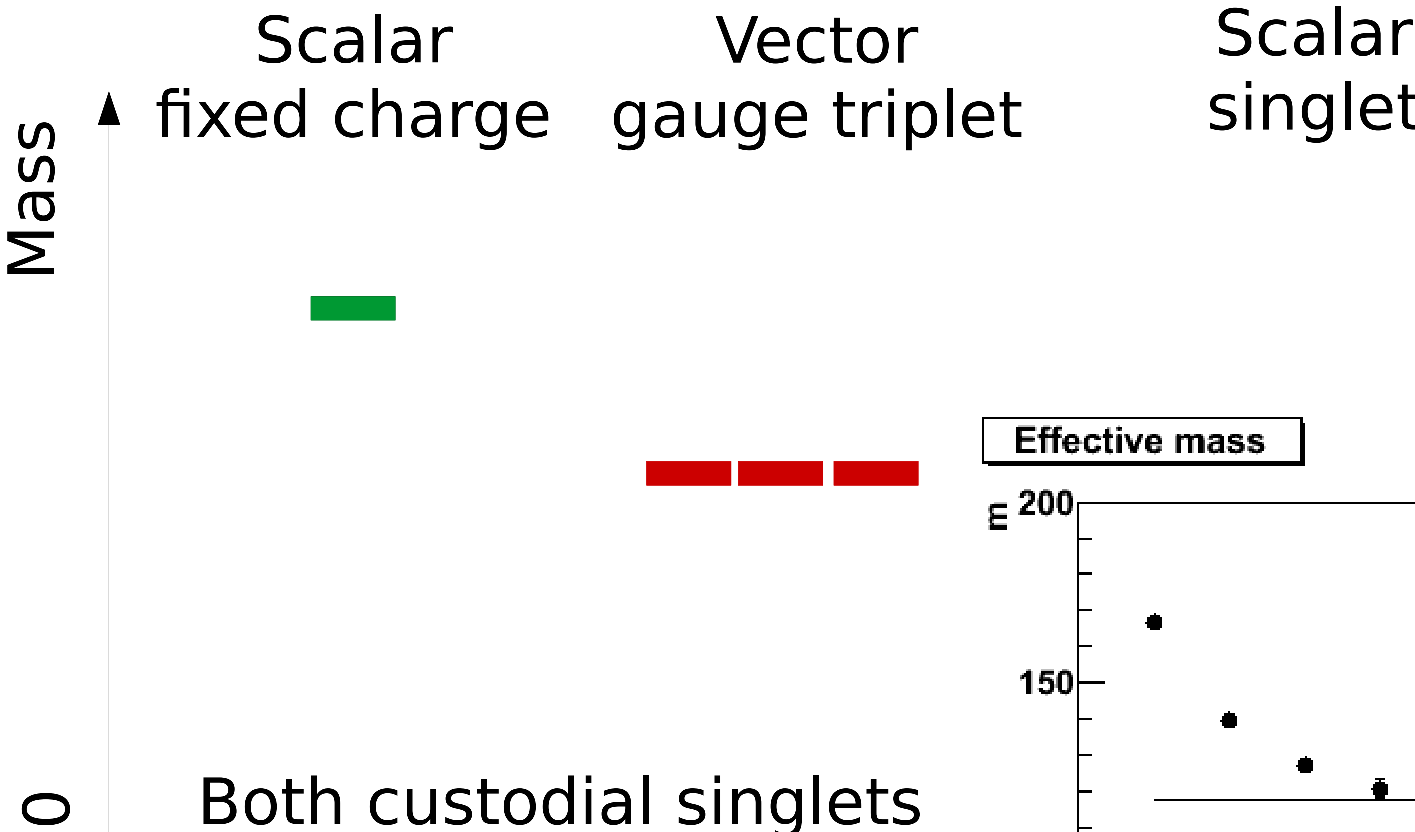

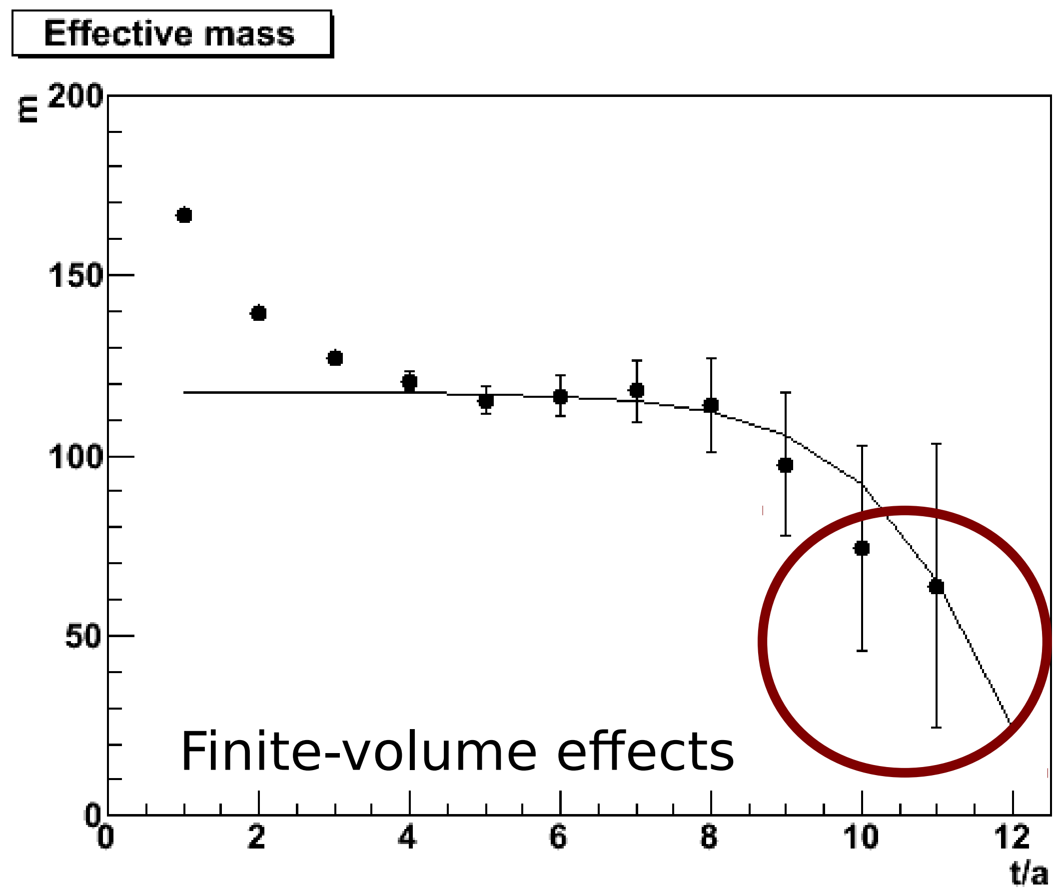

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Perturbation theory | Gauge-invariant

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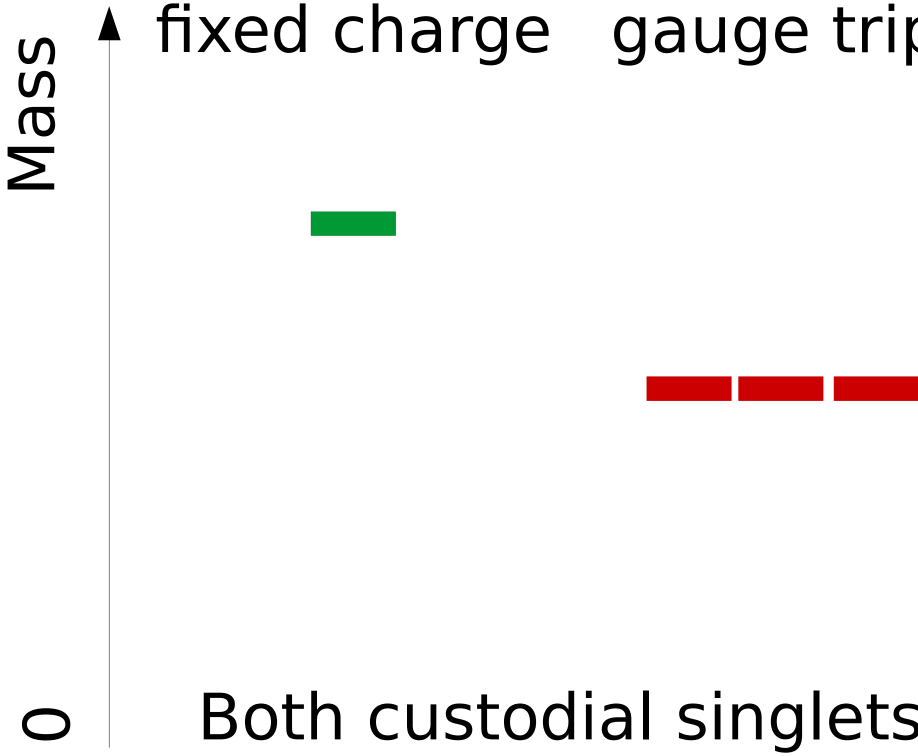

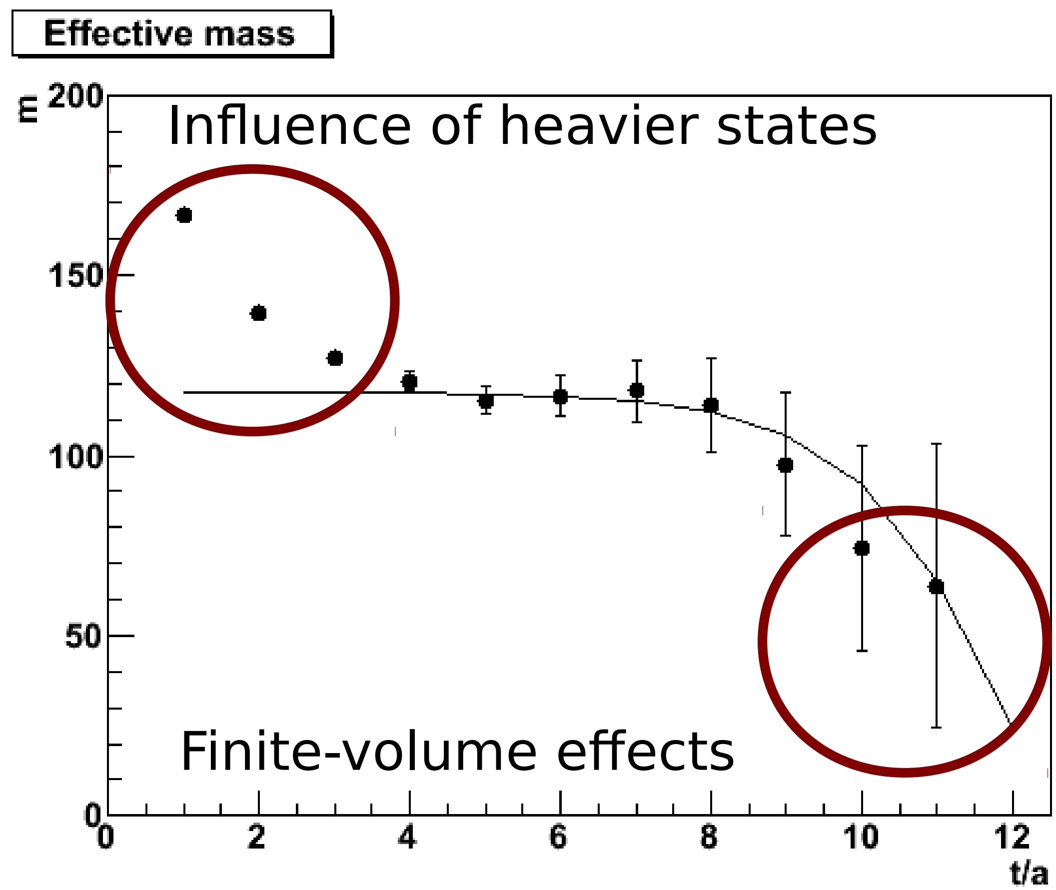

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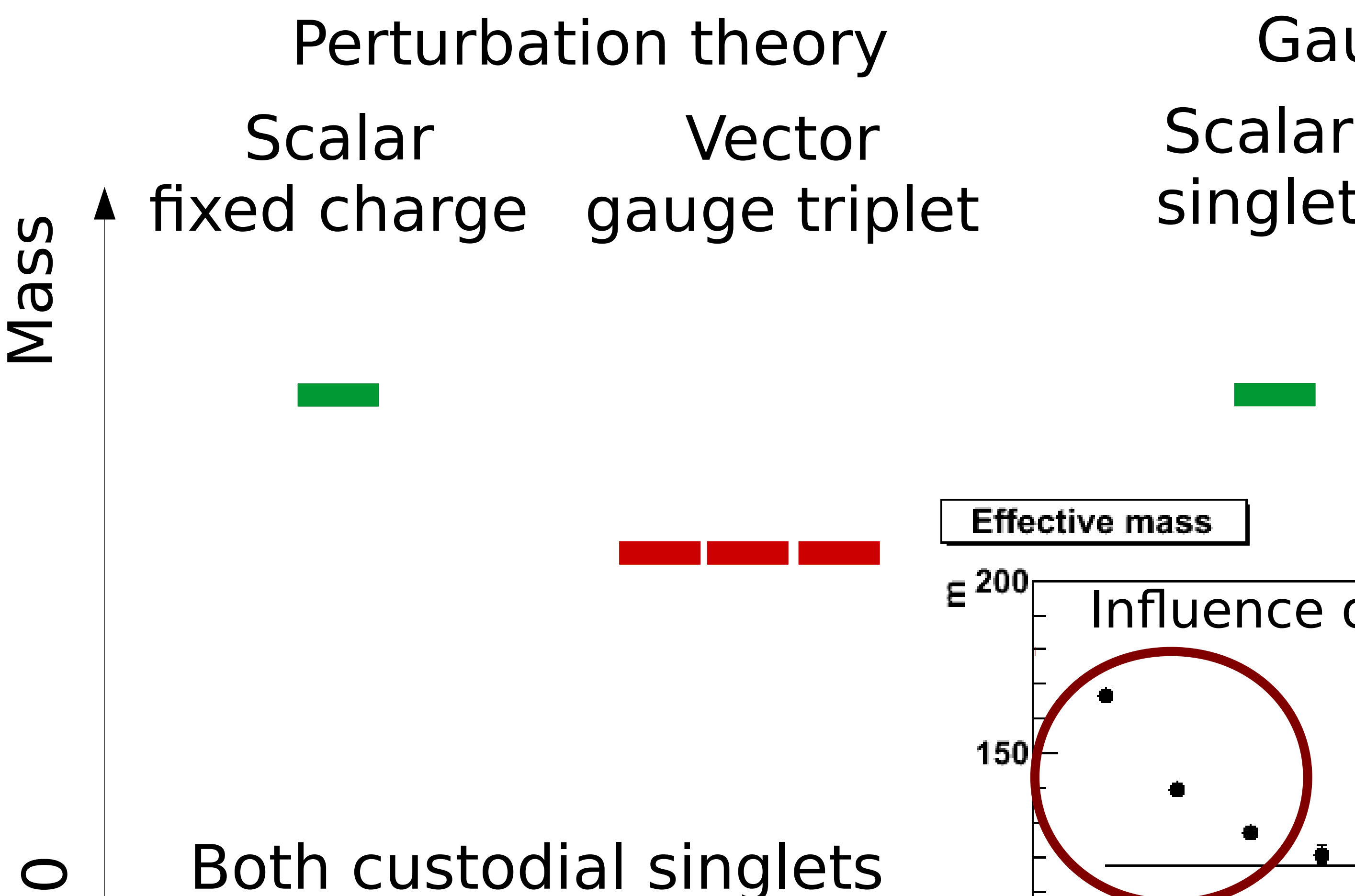

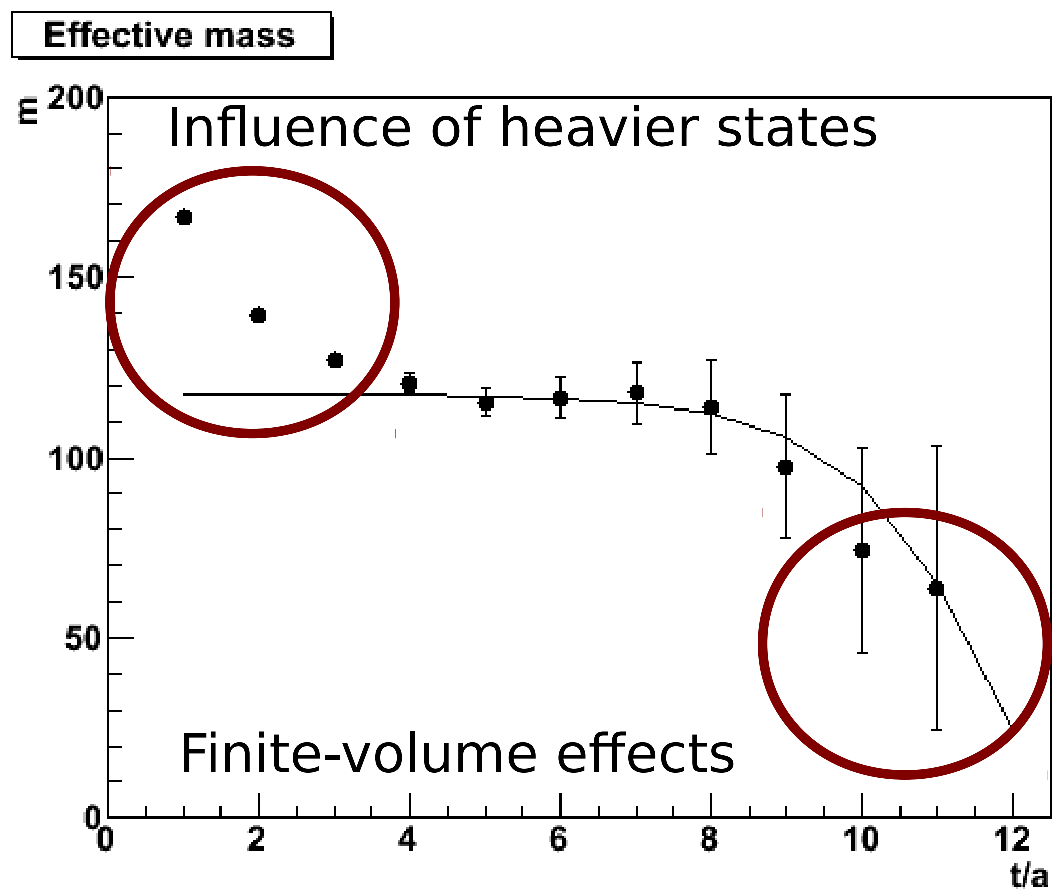

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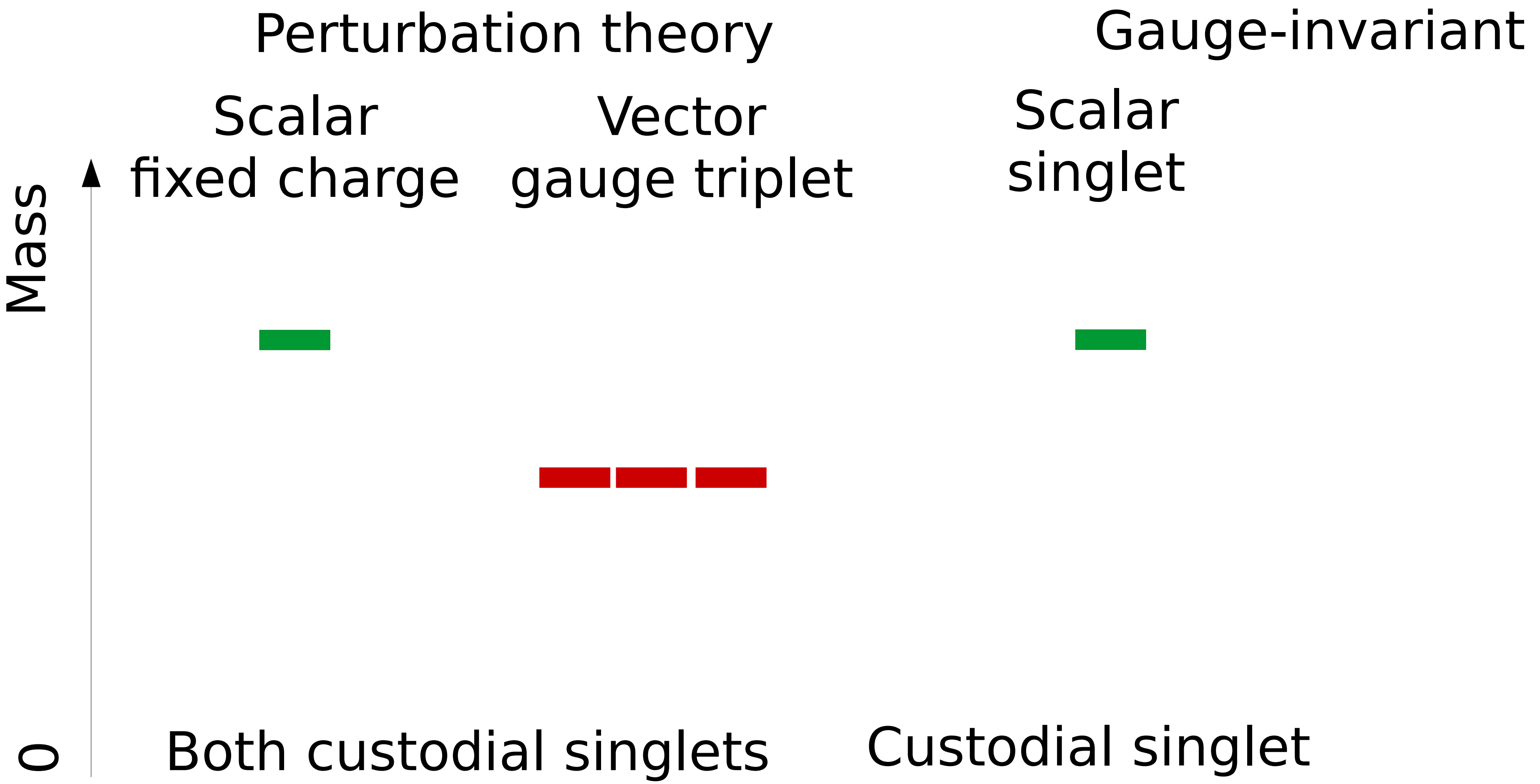

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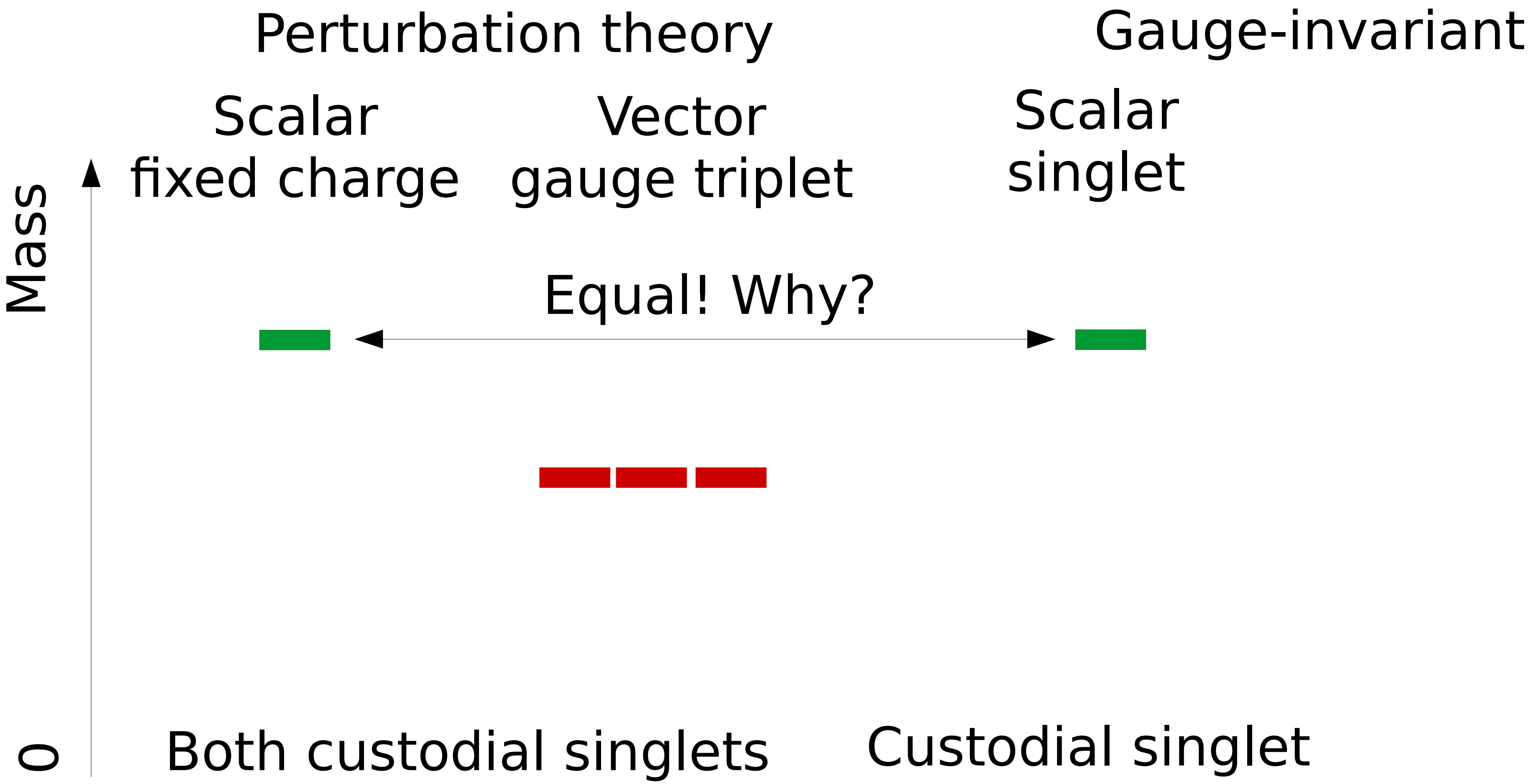

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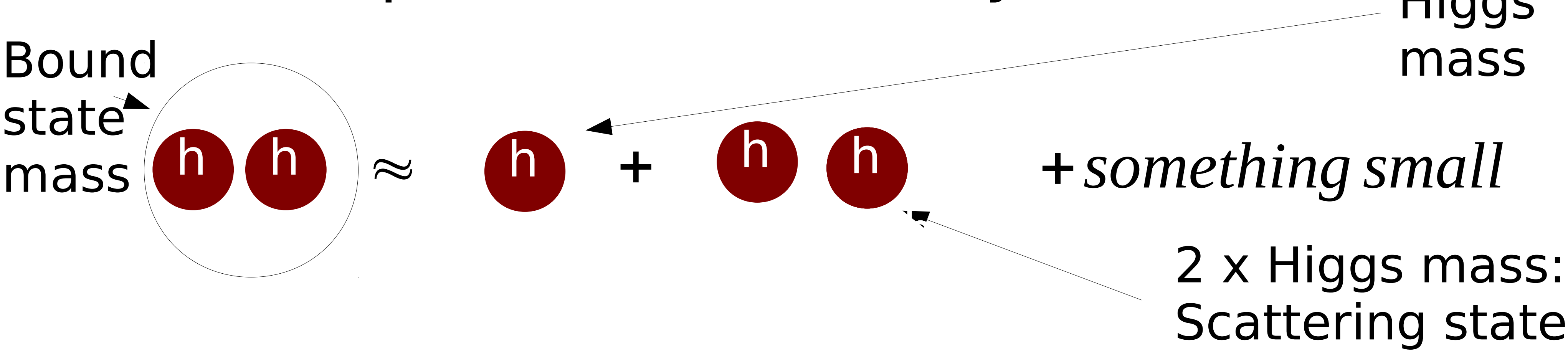

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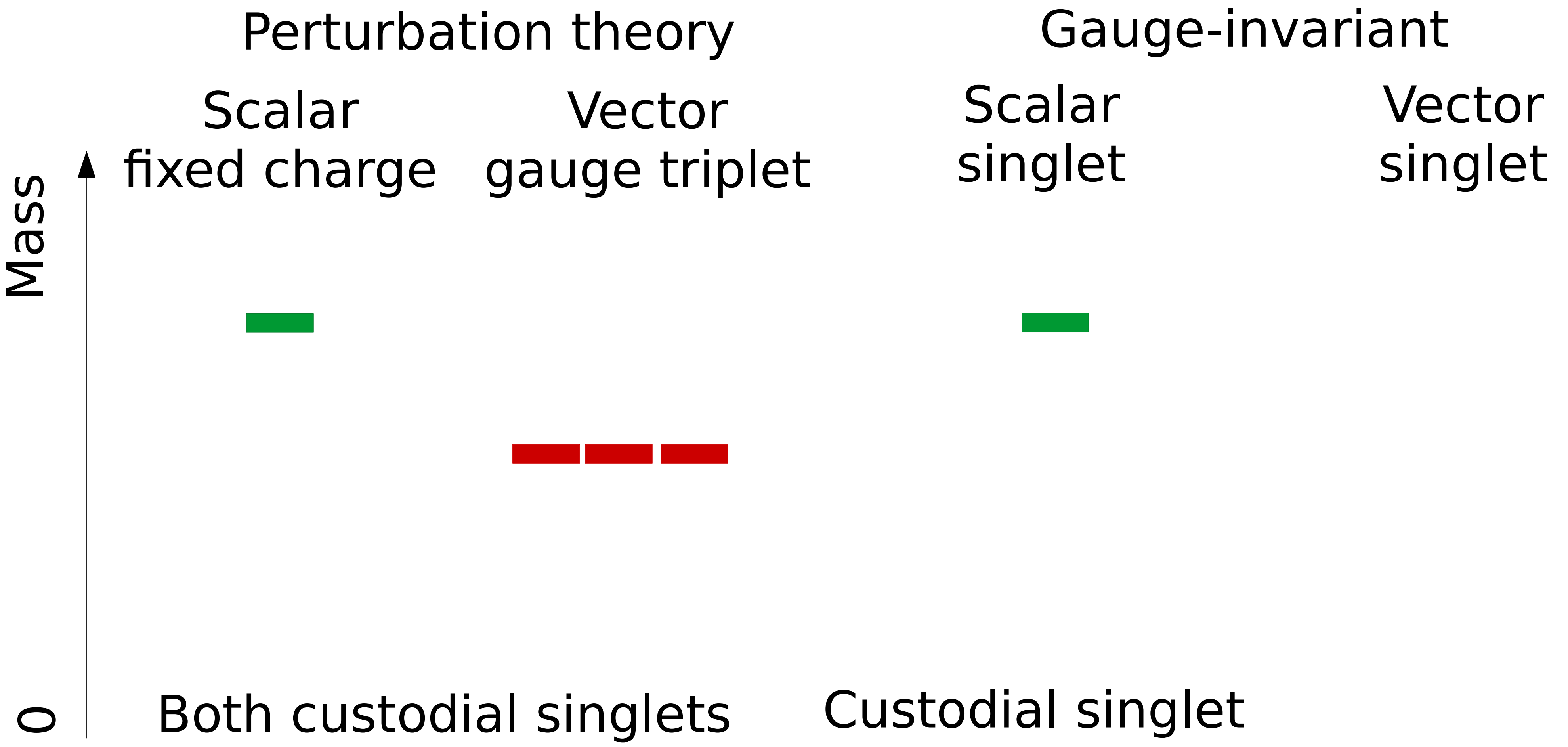
- Fröhlich-Morchio-Strocchi (FMS) mechanism
- Deeply-bound relativistic state
  - Mass defect~constituent mass
  - Cannot describe with quantum mechanics
  - Very different from QCD bound states

Physical spectrum



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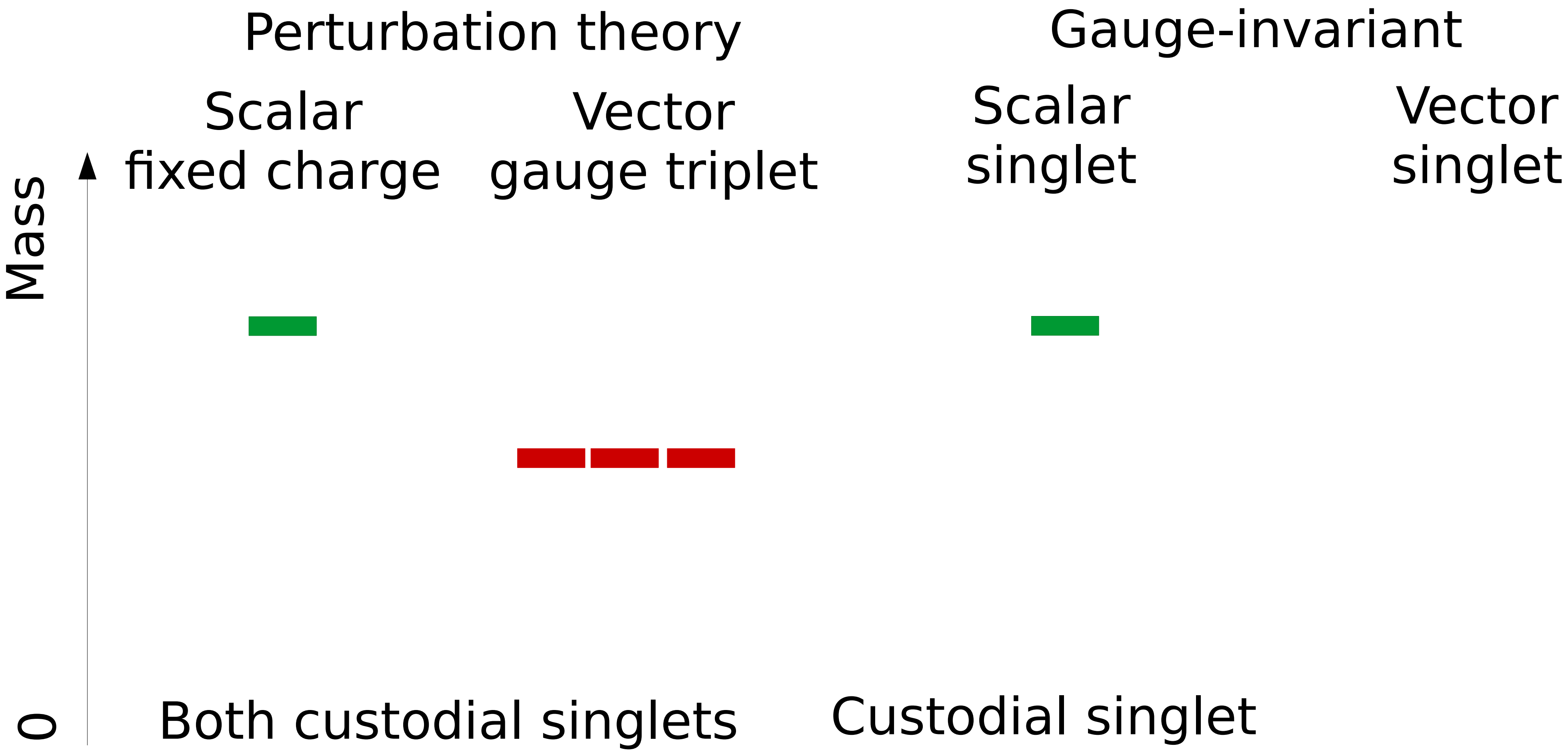

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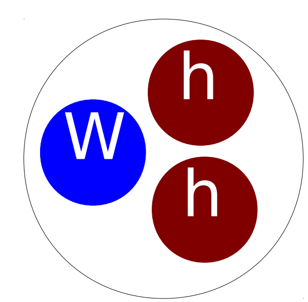

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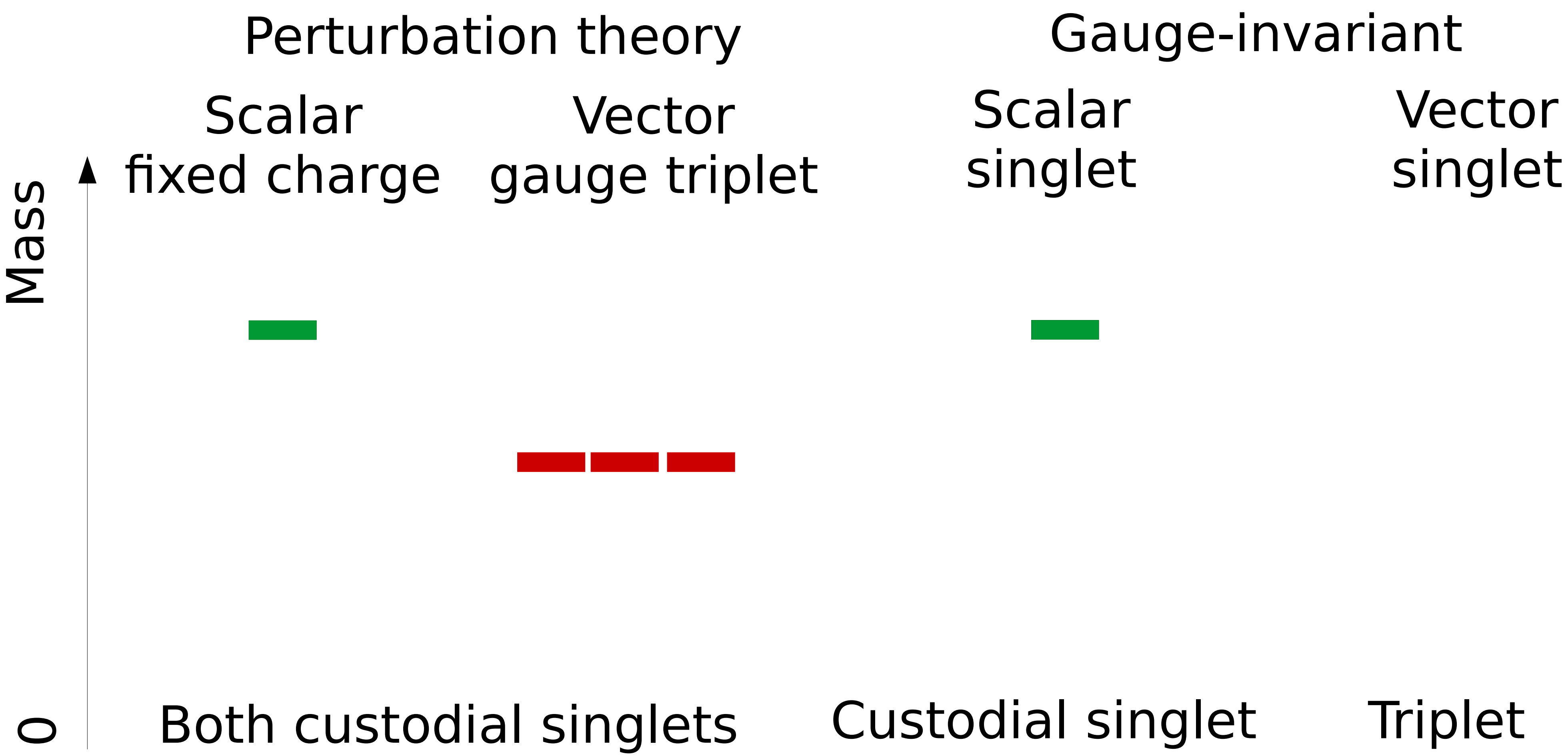

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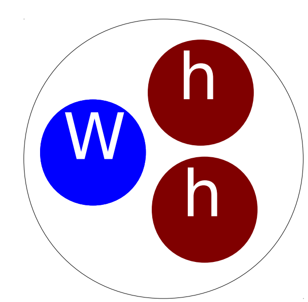

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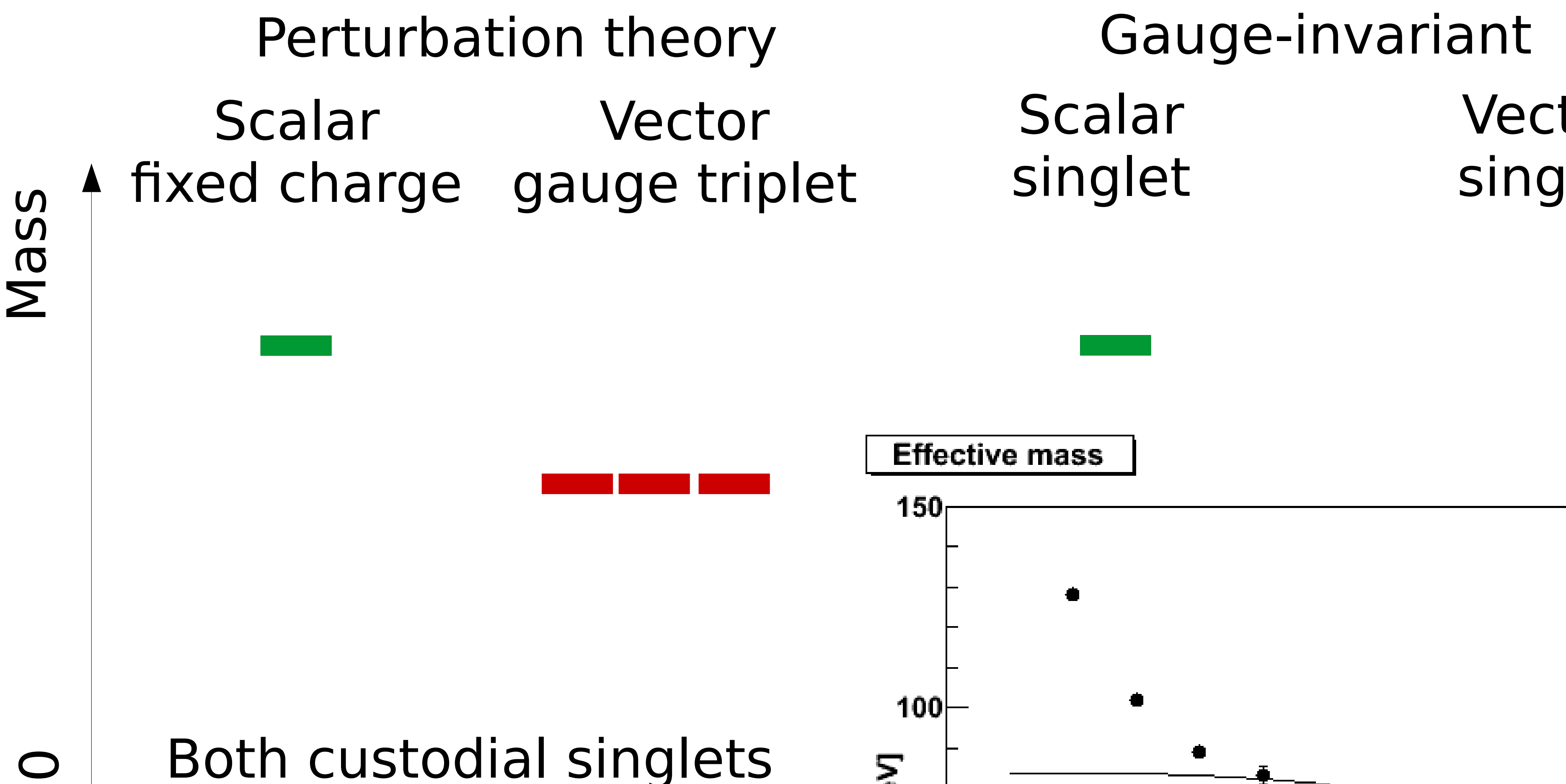

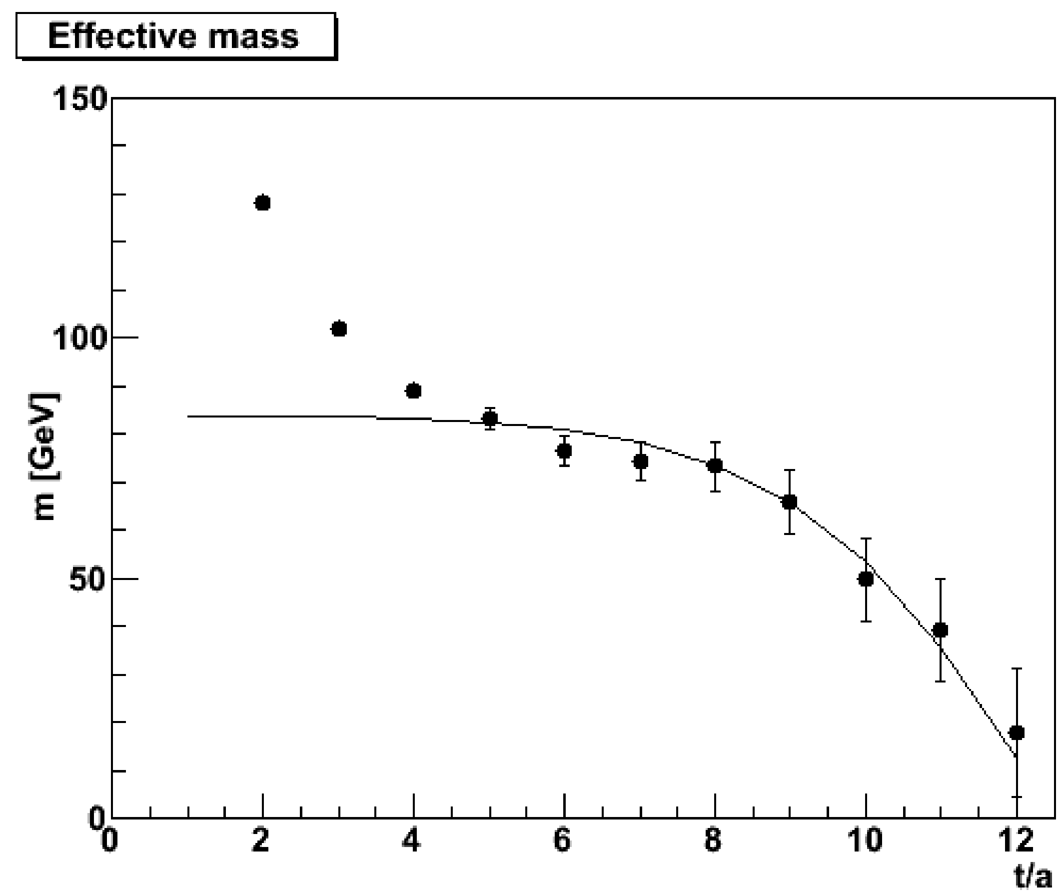

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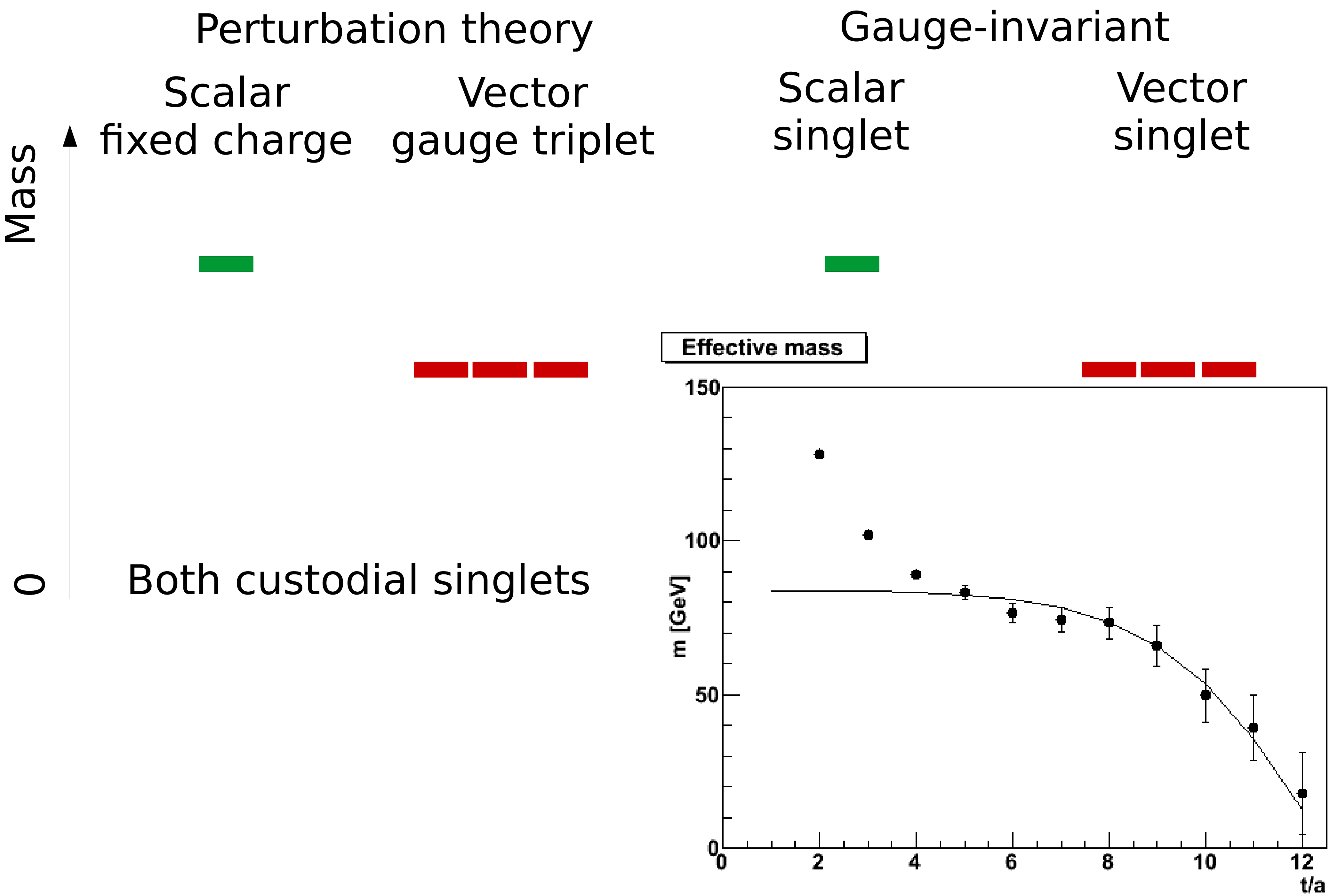

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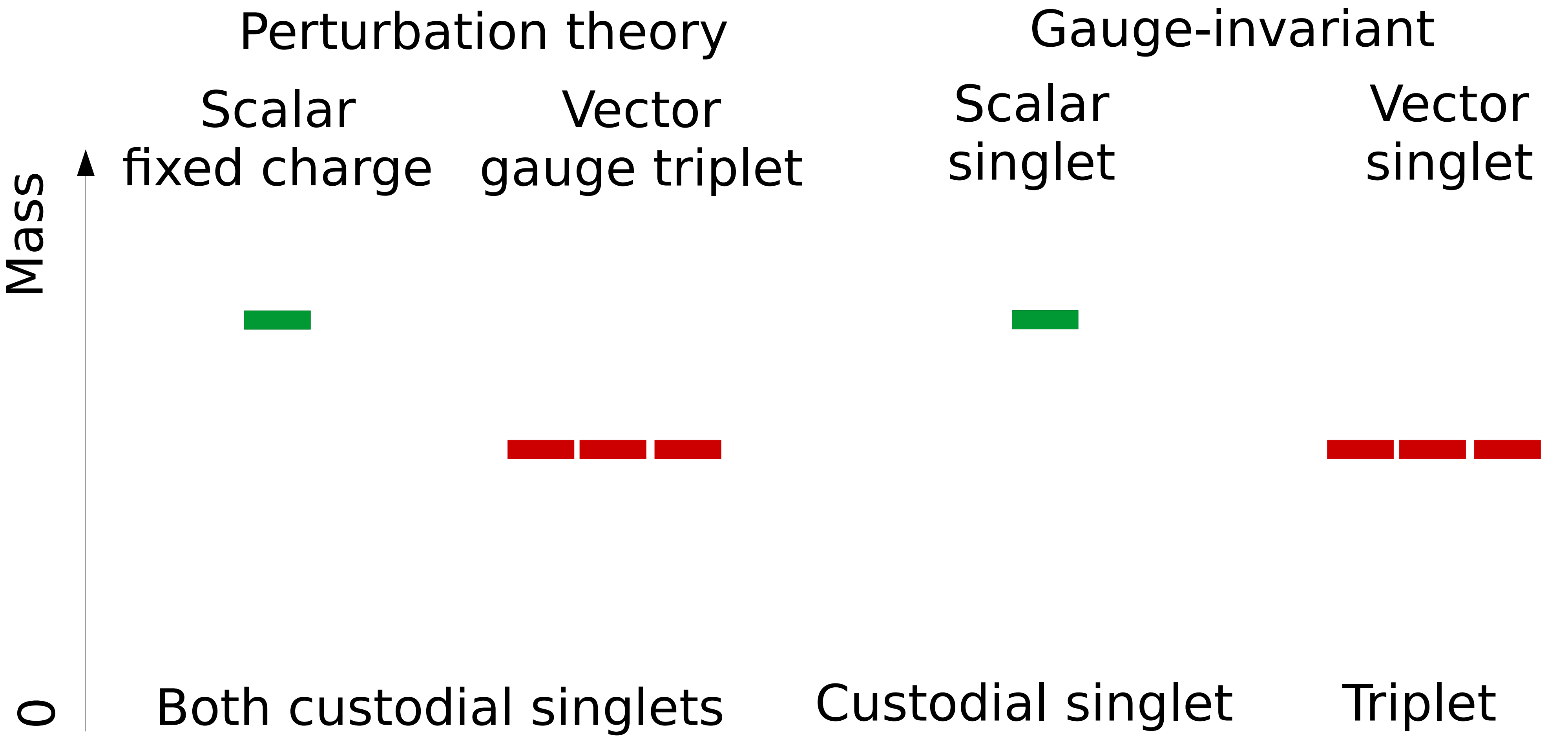

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  - Exchanges a gauge for a custodial triplet

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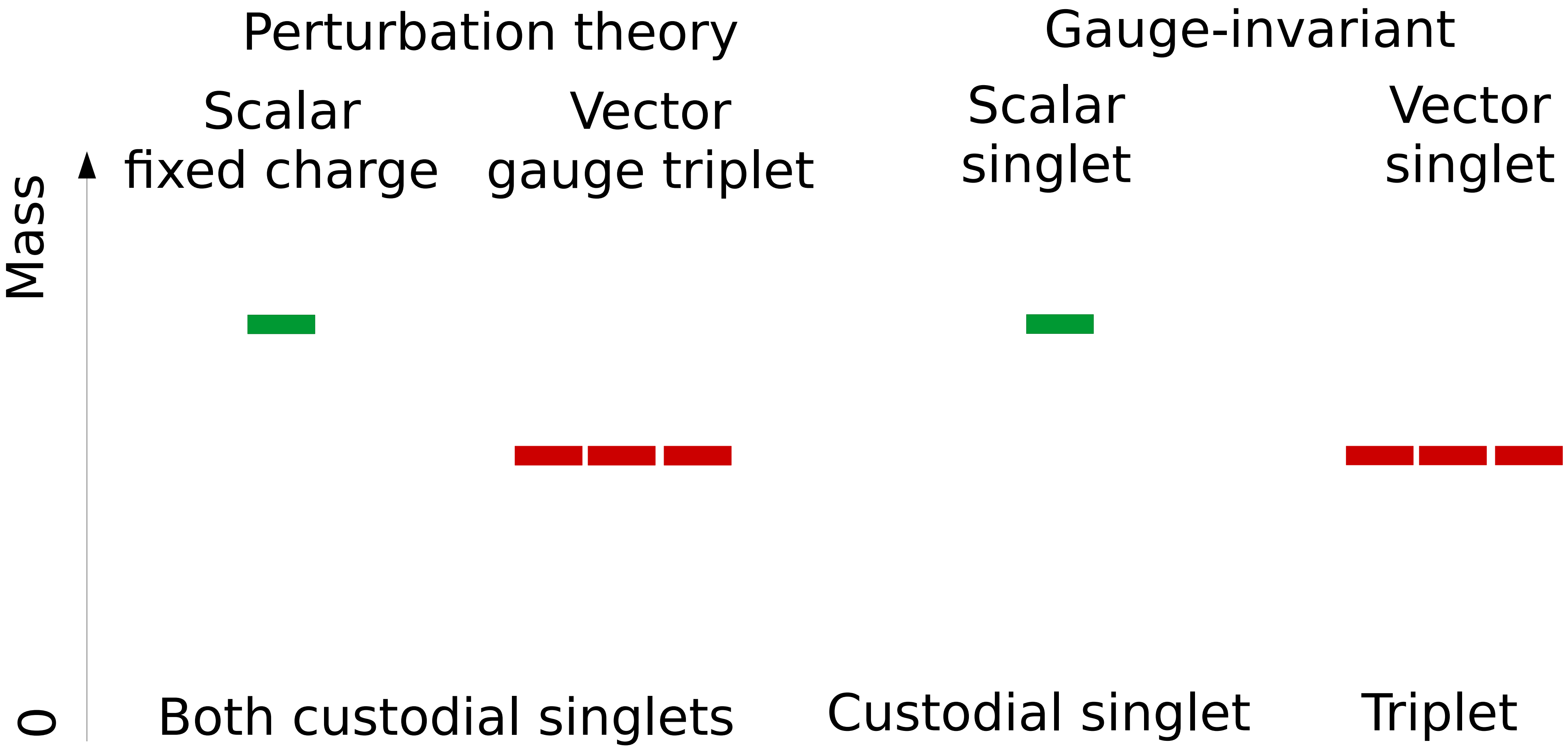

- Quantitatively equivalent spectrum

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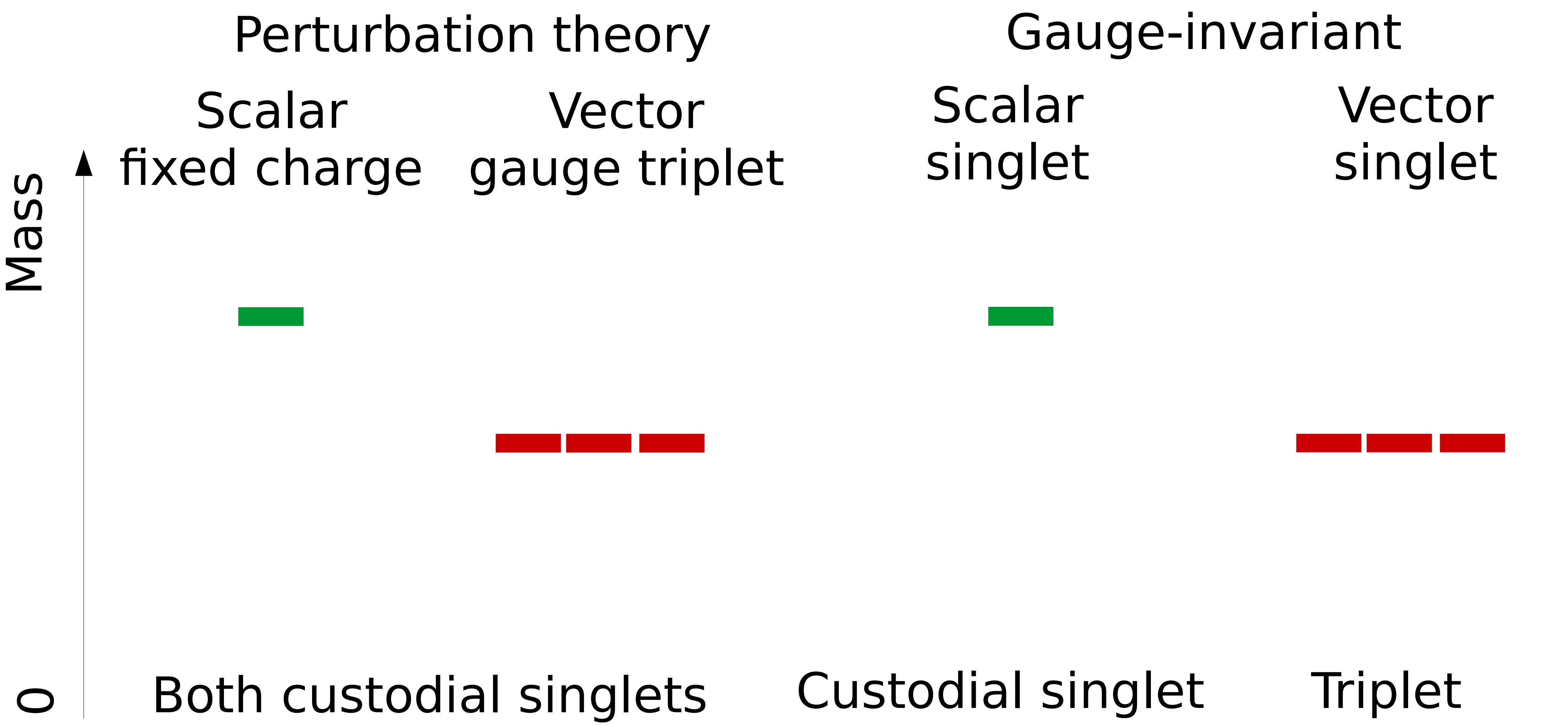

- Quantitatively equivalent spectrum
- Special to this case? Standard model?
  - Lattice also for SU(2)xU(1) [Shrock et al. 85-88]

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  - Standard model structure is special
  - Fluctuations can invalidate

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- Global U(1) Higgs custodial (flavor) symmetry
  - Acts as (right-)transformation on the Higgs field only

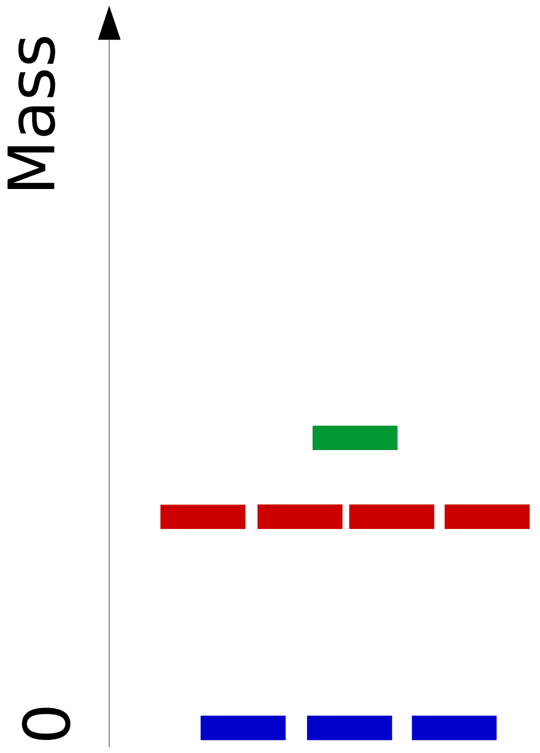
$$W_{\mu}^{a}\rightarrow W_{\mu}^{a} \qquad h\rightarrow \exp(ia)h$$

Toy-GUT: Vectors

[Maas & Törek'16,'18
Maas, Sondenheimer & Törek'17]

Perturbation theory

Gauge-dependent



Predictions using GIPT

[Maas & Törek'16,'18
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Dark Sector

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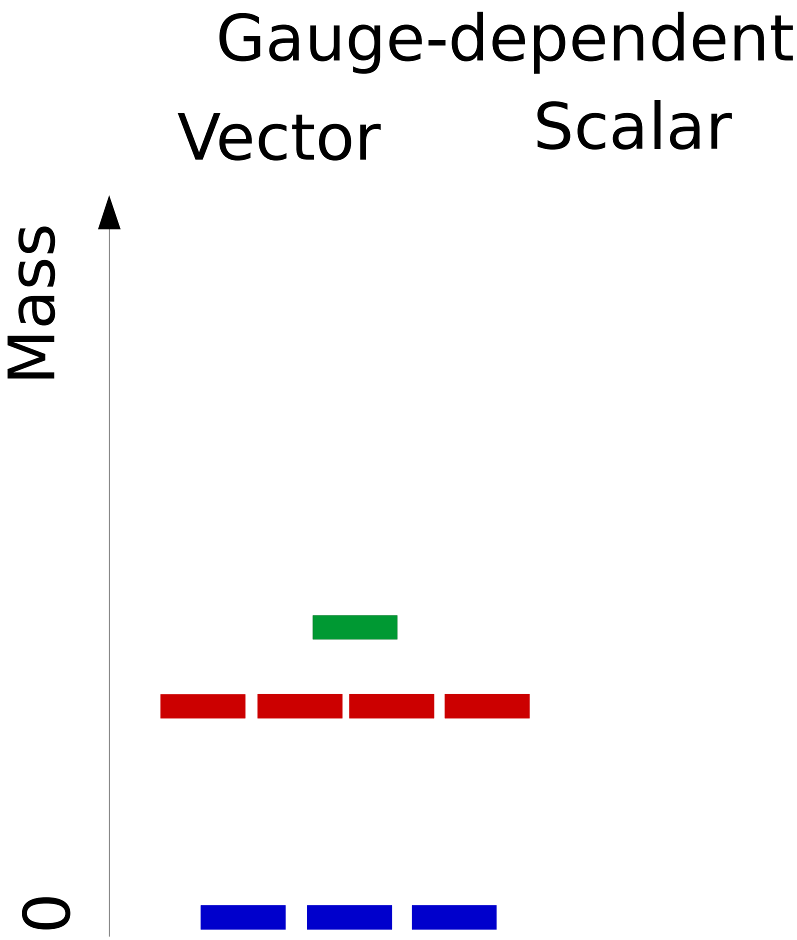

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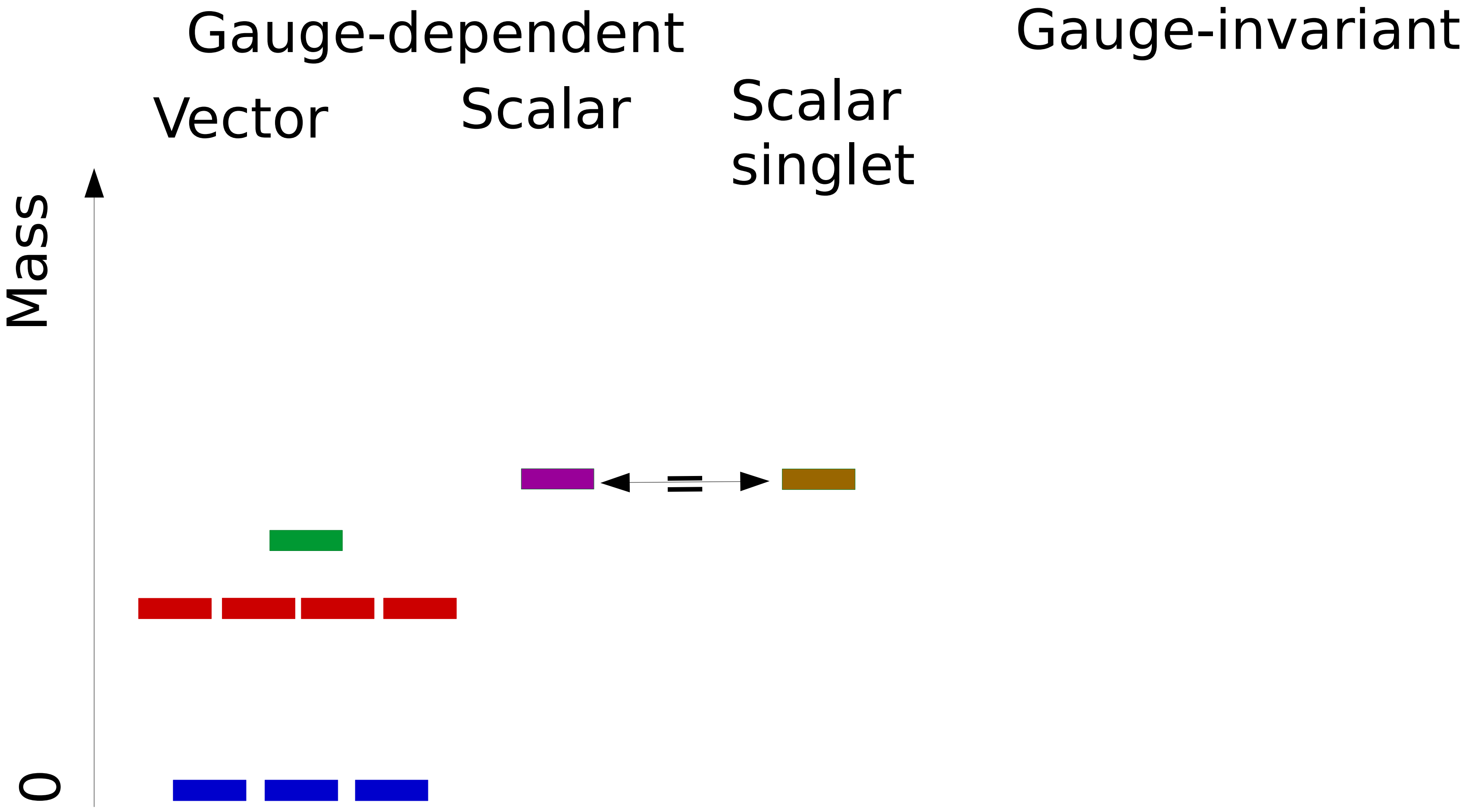

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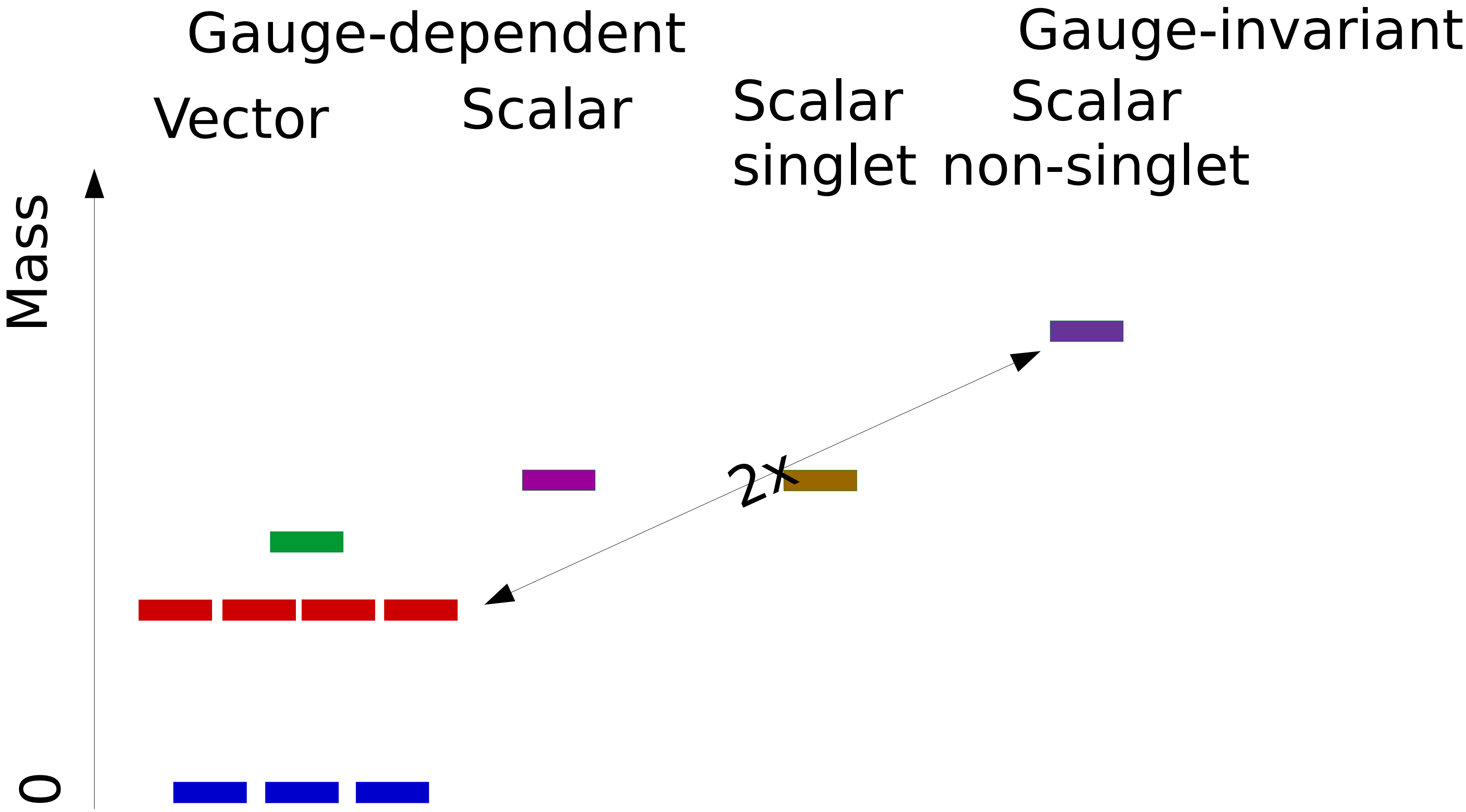

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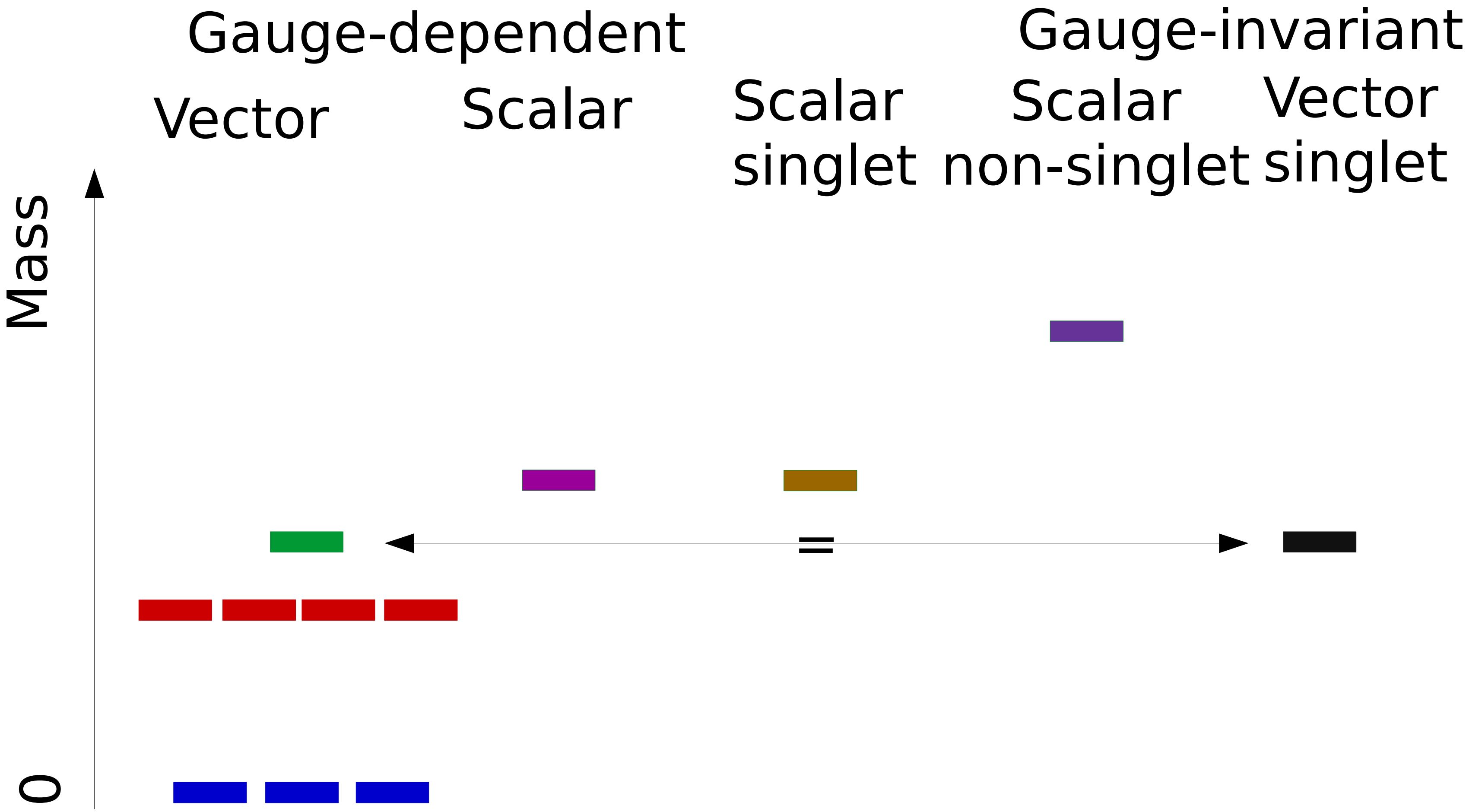

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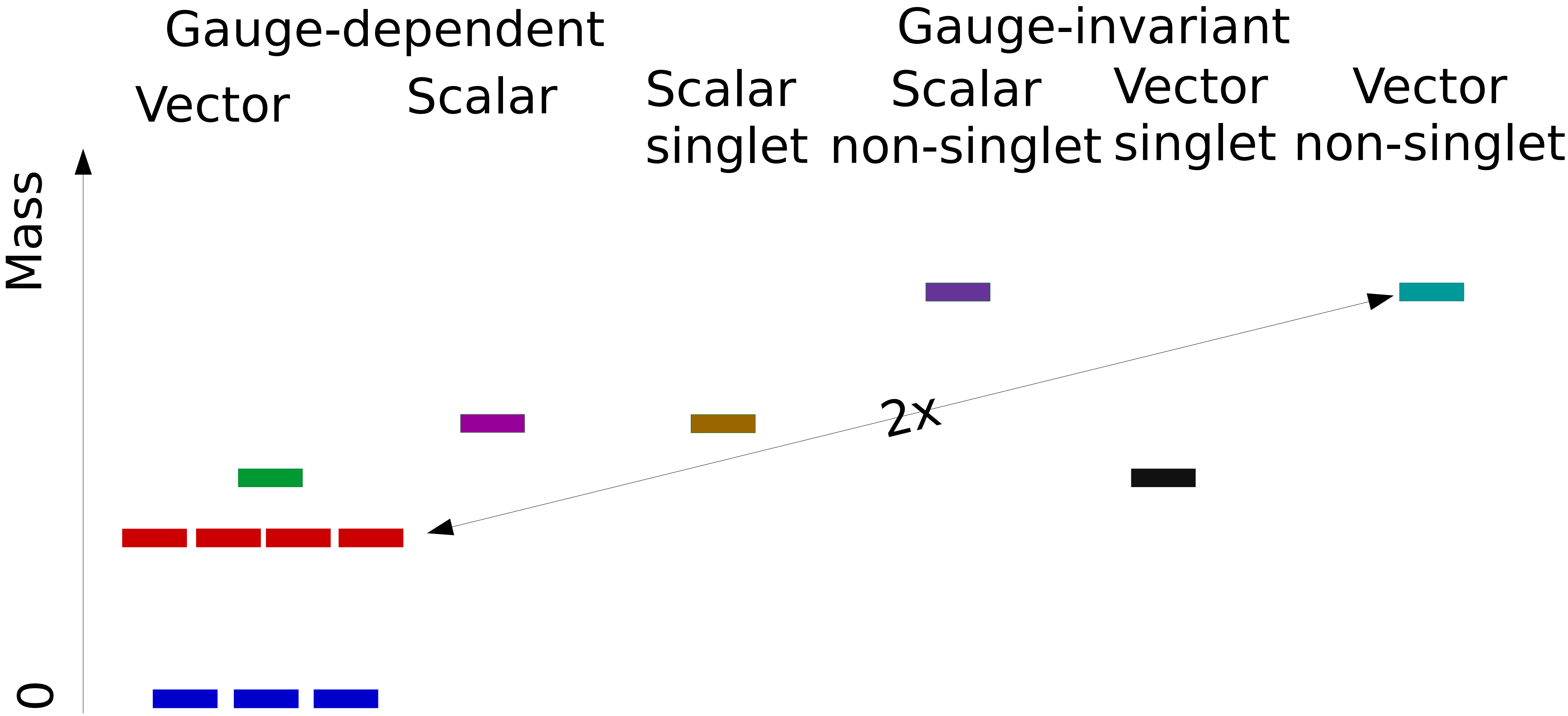

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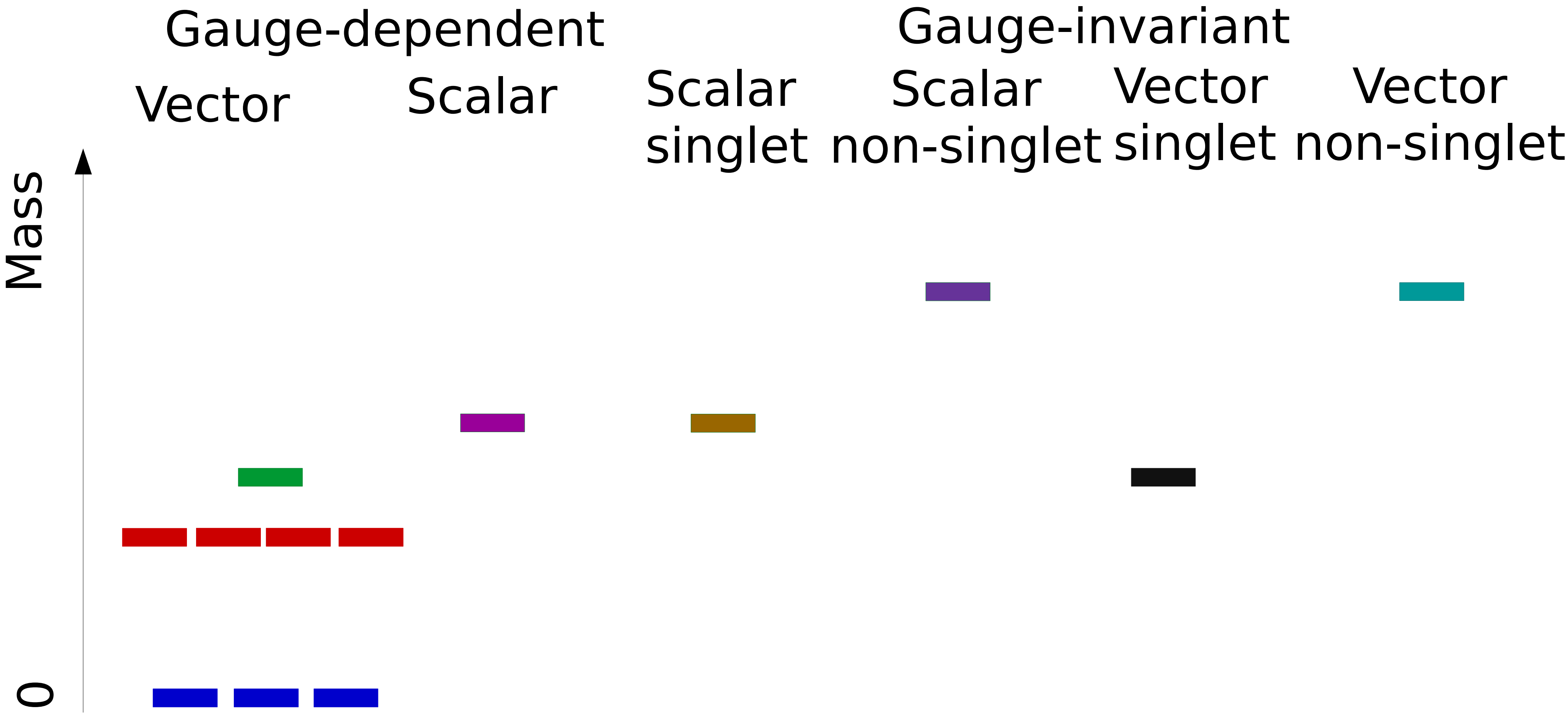

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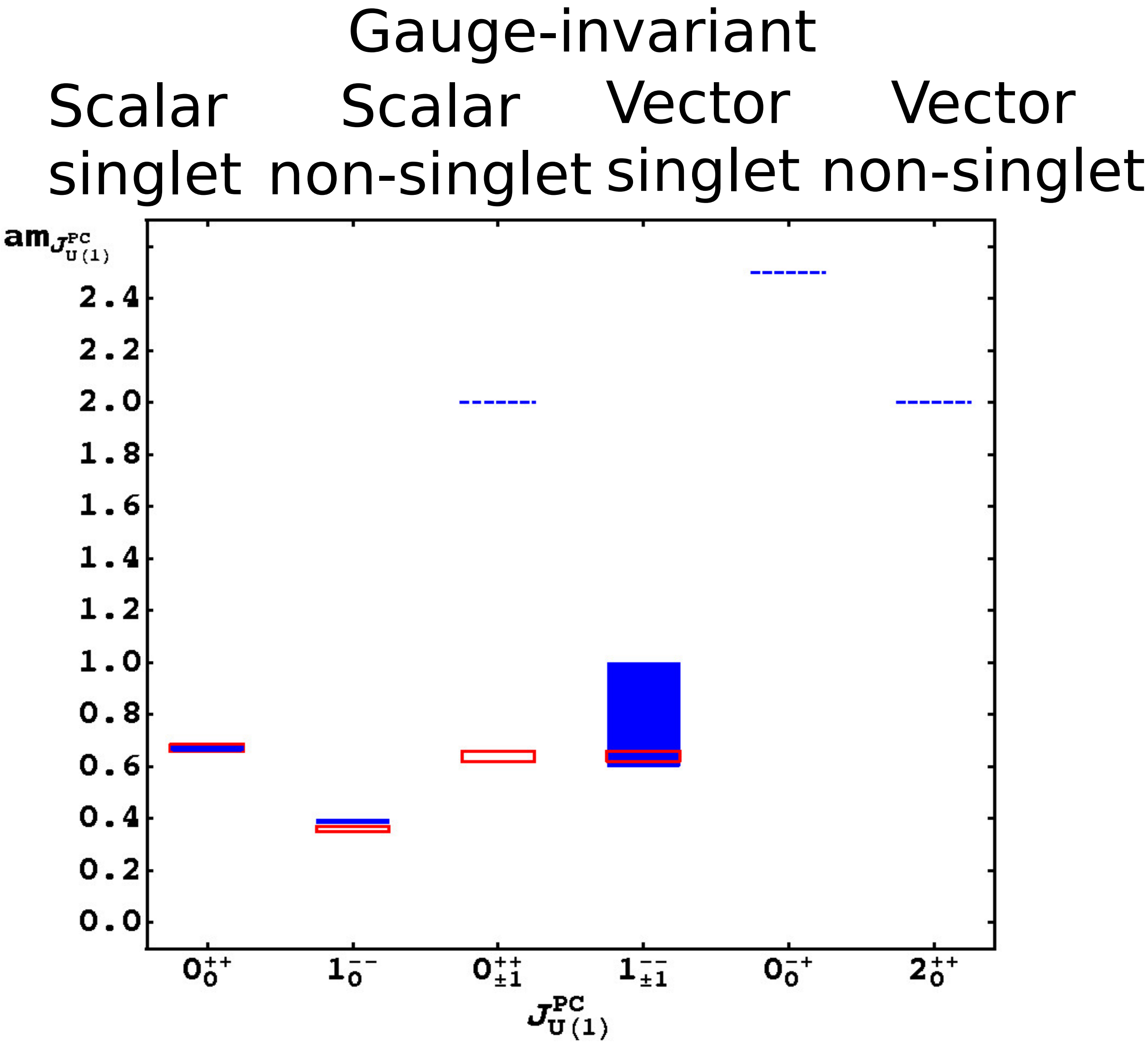

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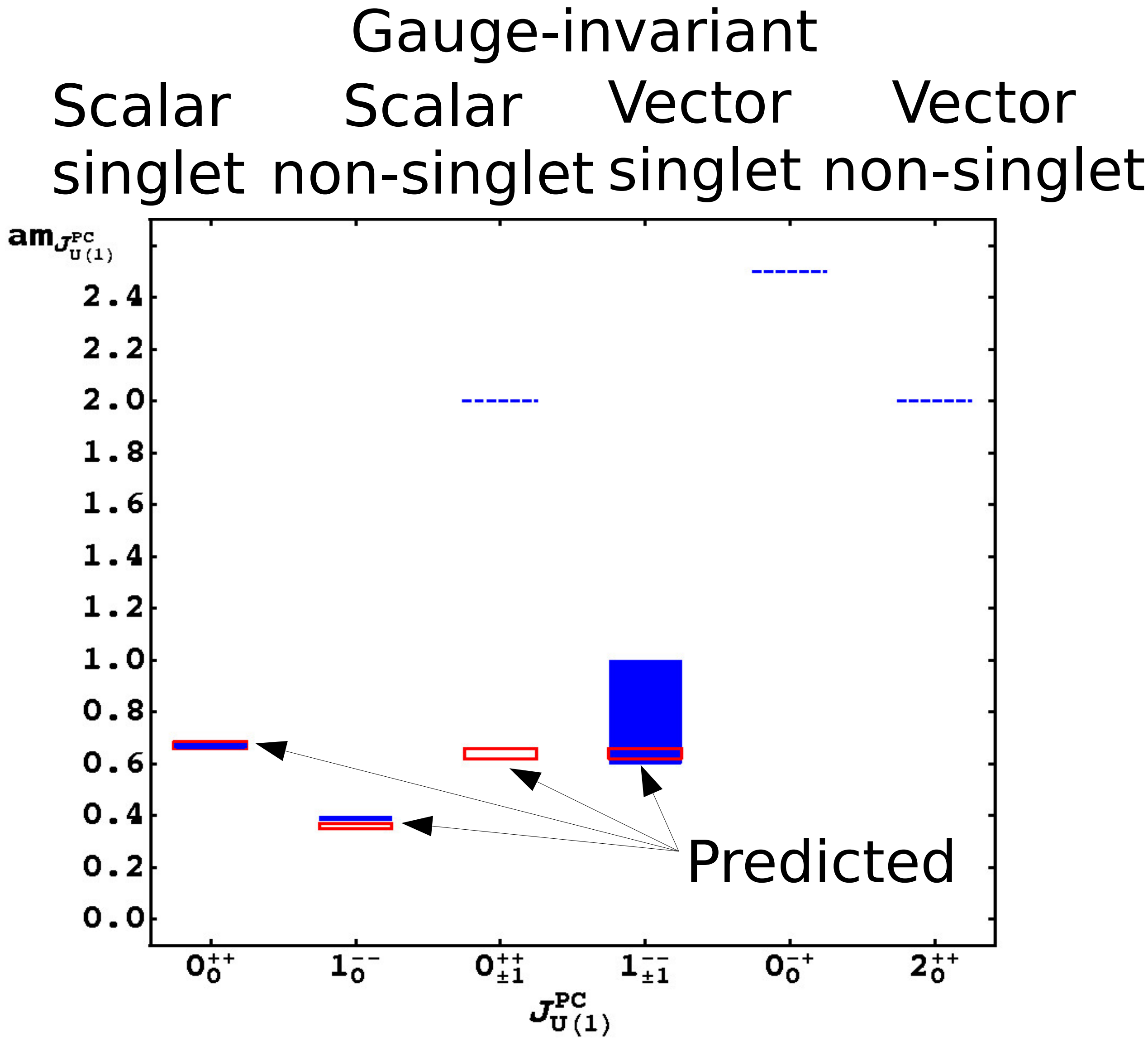

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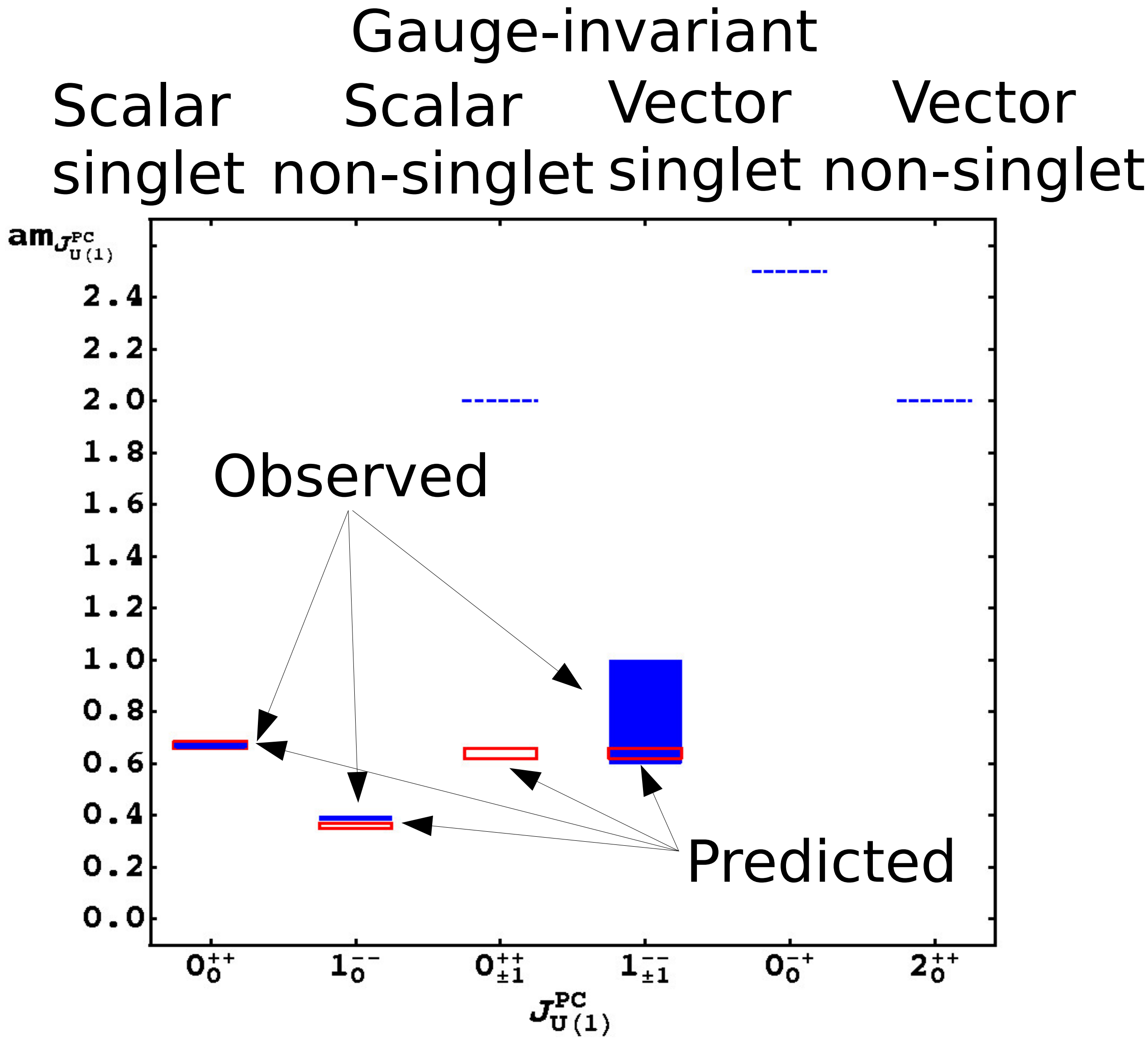

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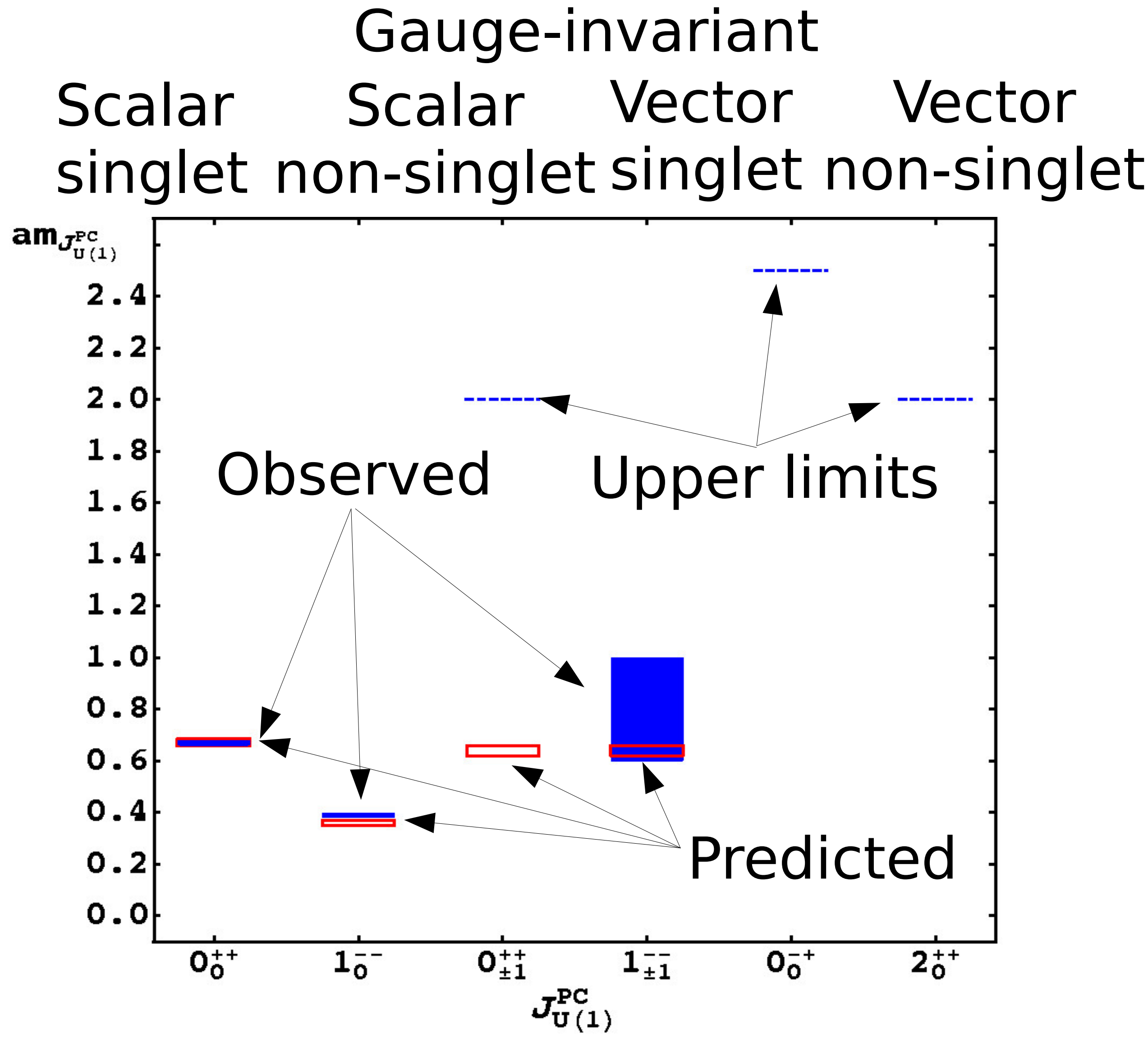

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