The Spectrum Of Grand-unified theories

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NAWI Graz
Natural Sciences

FWF
Der Wissenschaftsfonds.

What is this talk about?

Review: 1712.04721

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- Spectra are usually determined from perturbation theory

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- GUTs are an attractive BSM scenario
- Spectra are usually determined from perturbation theory
- Lattice results disagree qualitatively
- Explained by manifest gauge invariance qualitatively and by the Fröhlich-Morchio-Strocchi mechanism quantitatively

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- Anomaly freedom requires careful balance of all three gauge interactions
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- Why?
- Unification of all gauge interactions would explain these features
- Does such a theory exist, which has as a low-energy effective theory the standard model?

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  - Add suitable Higgs particles to use a Brout-Englert-Higgs effect to break it to SU(3)xU(1)
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- Should be testable on the lattice

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- Consider an SU(3) with a single fundamental scalar
- Looks very similar to the standard model Higgs

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

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- Ws W^{a}_{μ} W
- Higgs h_i h
- Couplings g, v, λ and some numbers f^{abc} and t_a^{ij}
- There is a global U(1) symmetry for the Higgs only

Textbook approach

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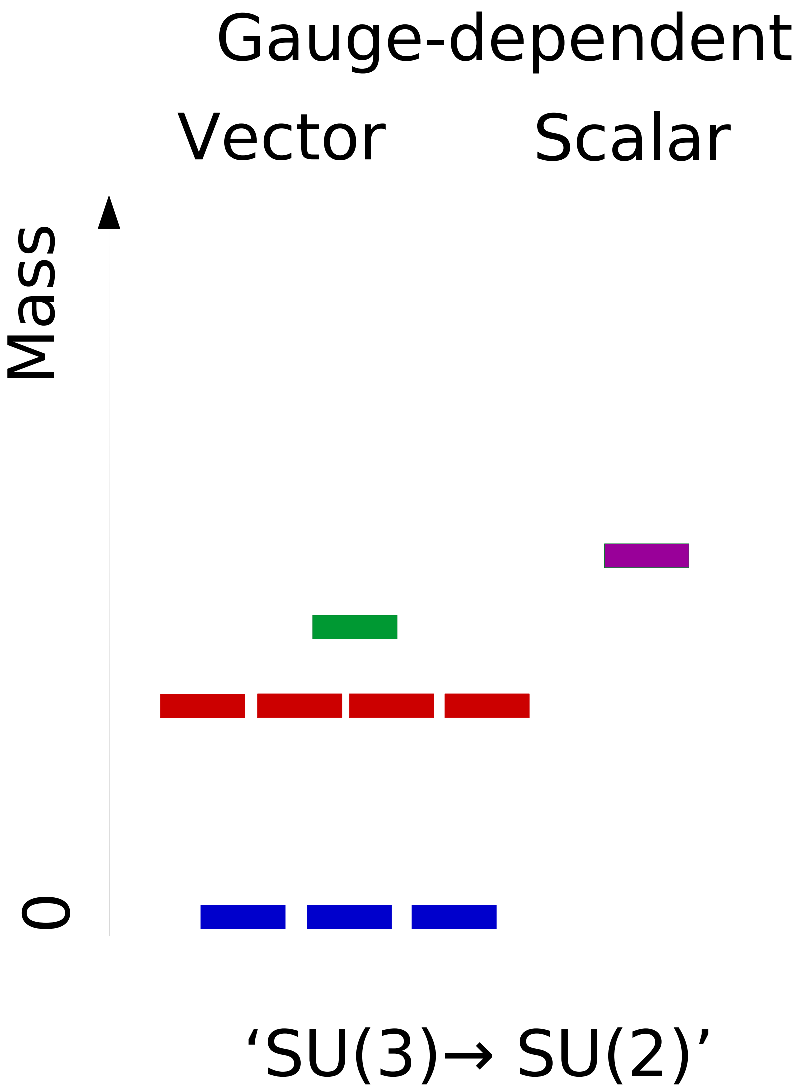
- Get masses and degeneracies at tree-level
- Perform perturbation theory

Spectrum



A problem on the lattice

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  - ...even at weak coupling [Gribov’78,Singer’78,Fujikawa’82]

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- Physics has to be expressed in terms of manifestly gauge-invariant quantities
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  - ...even at weak coupling [Gribov'78,Singer'78,Fujikawa'82]
- Especially on the lattice: No gauge-fixing necessary

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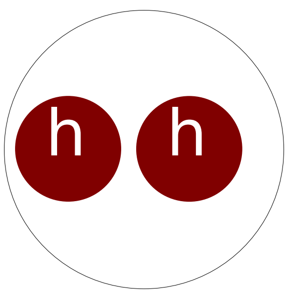

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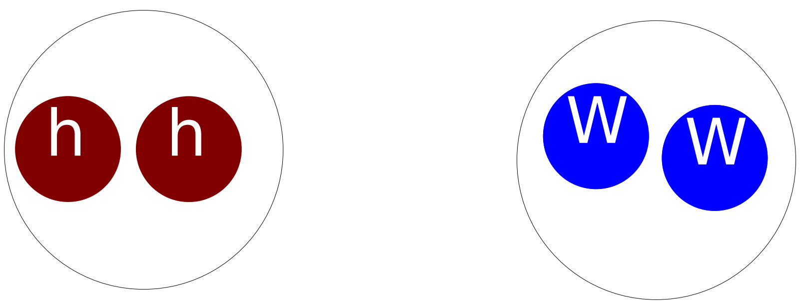

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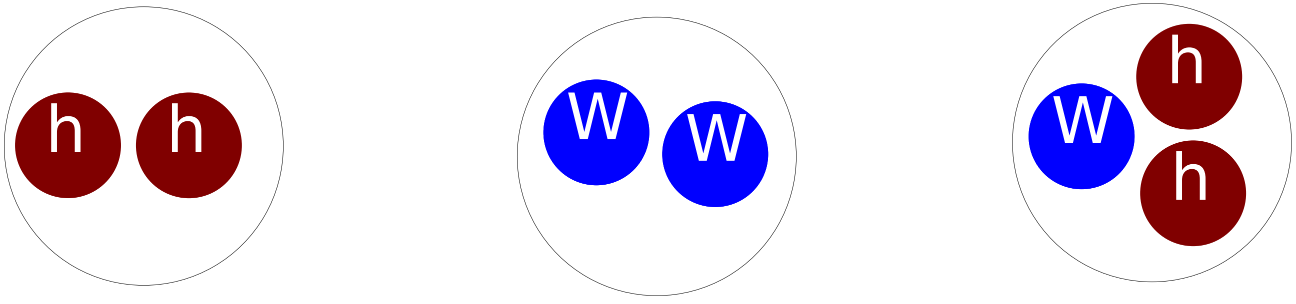
  - Higgs-Higgs, W-W, Higgs-Higgs-W etc.



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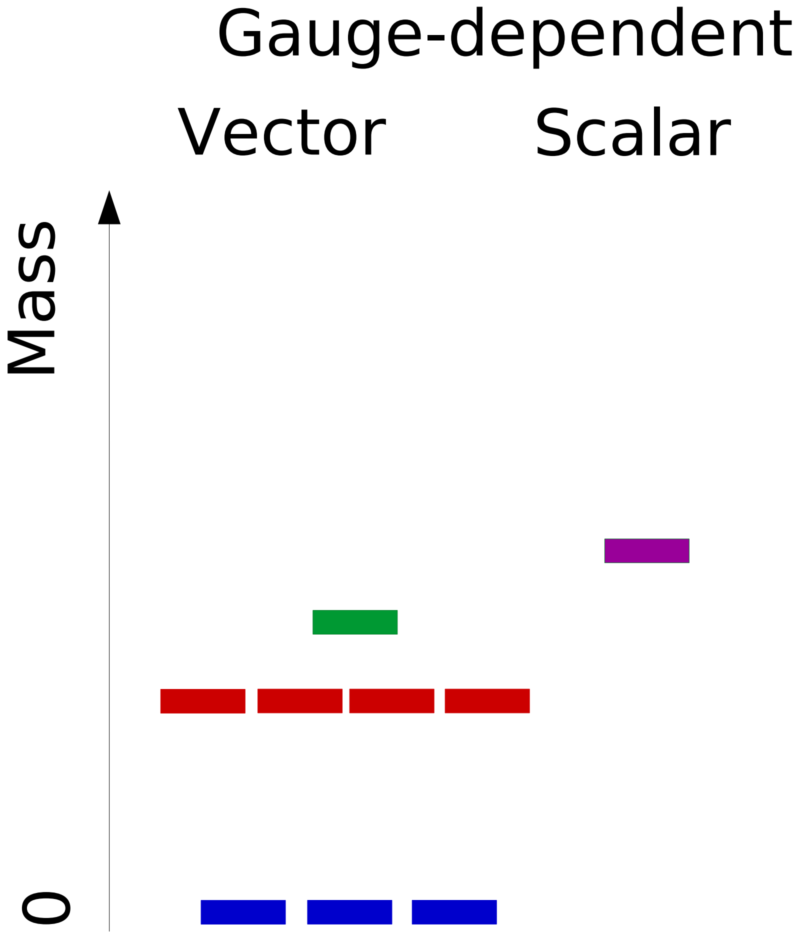
- Formulate gauge-invariant, composite operators
  - Bound state structure
- Depends on theory. Here:
  - Integer J, any P, C
  - Uncharged or charged under (Higgs) U(1)

Spectrum



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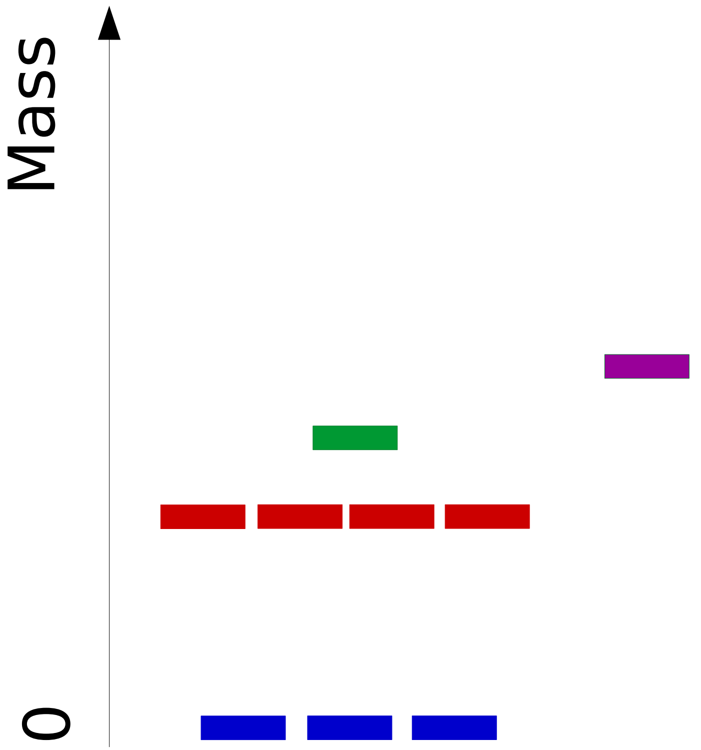
Gauge-dependent

Vector Scalar



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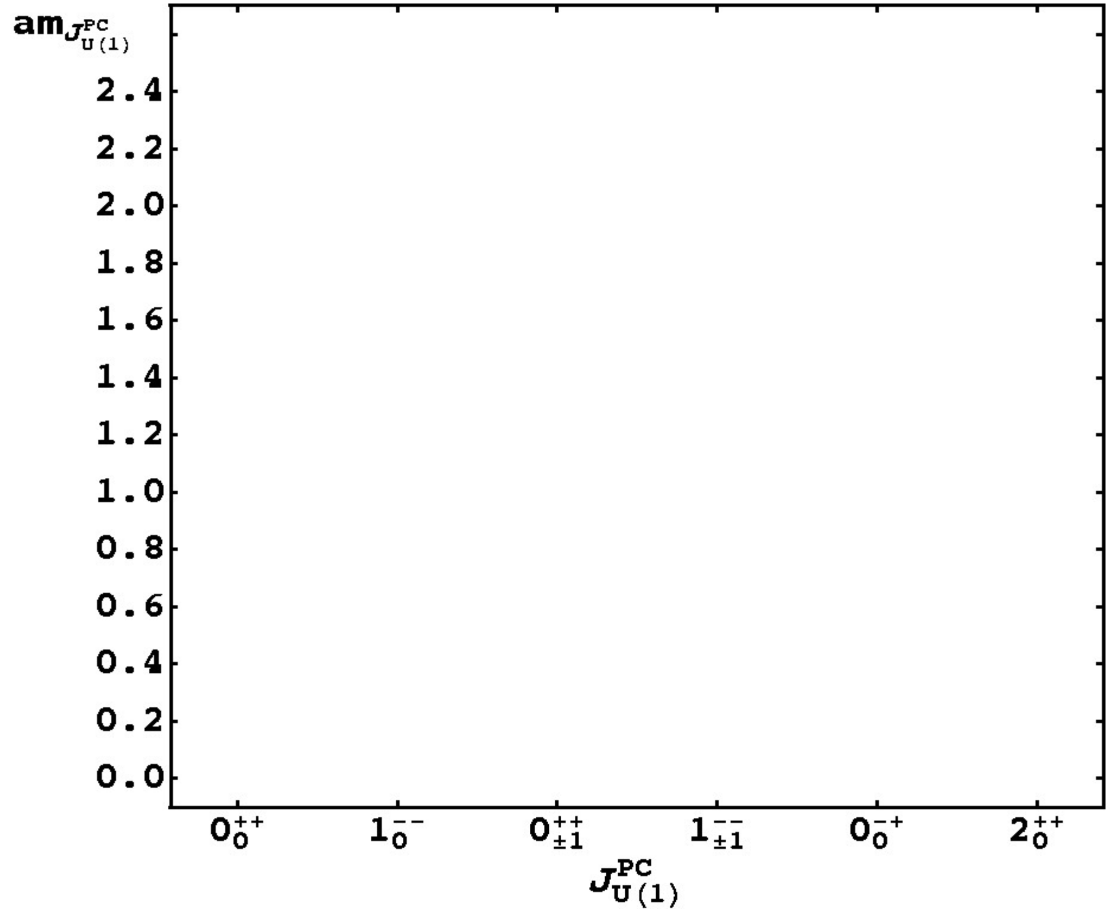

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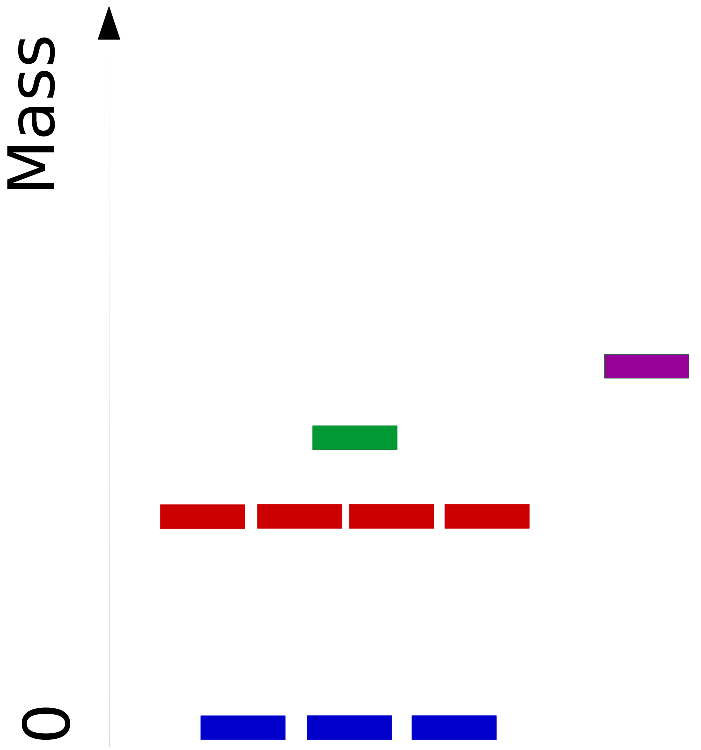

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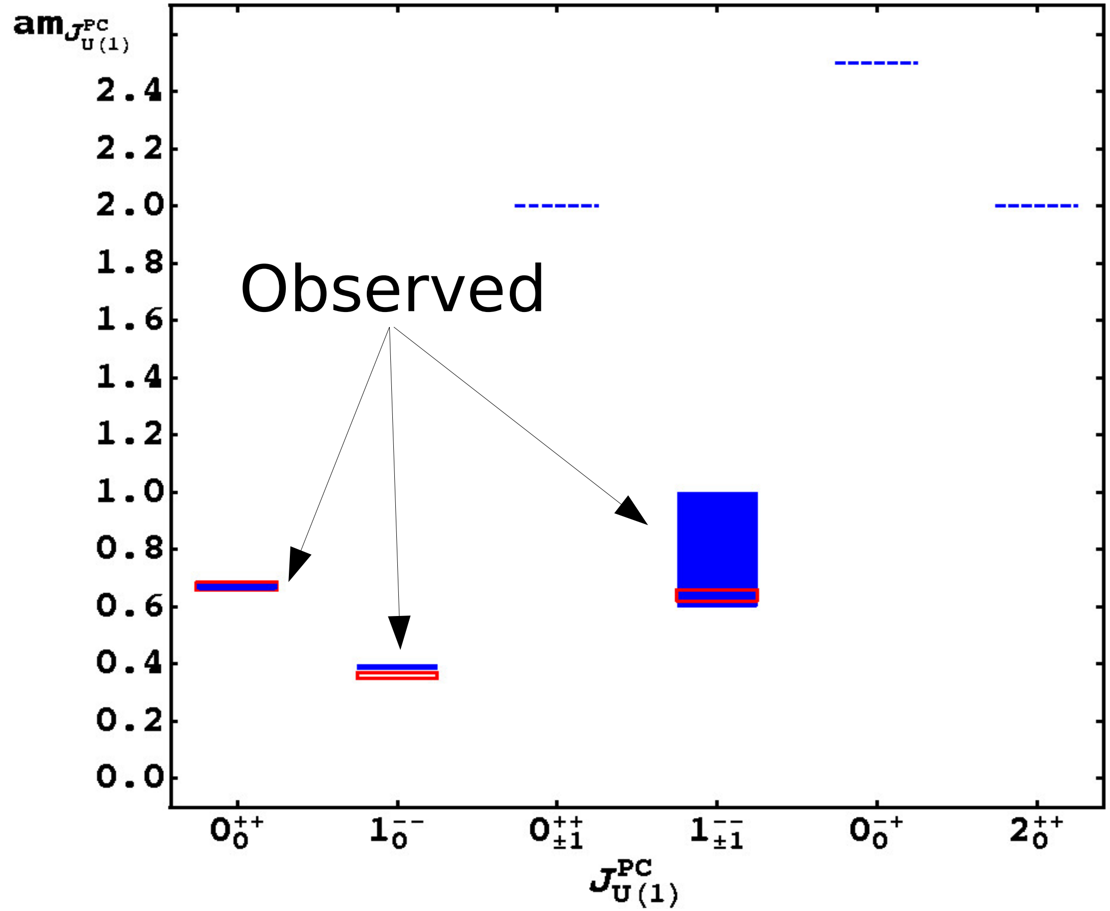

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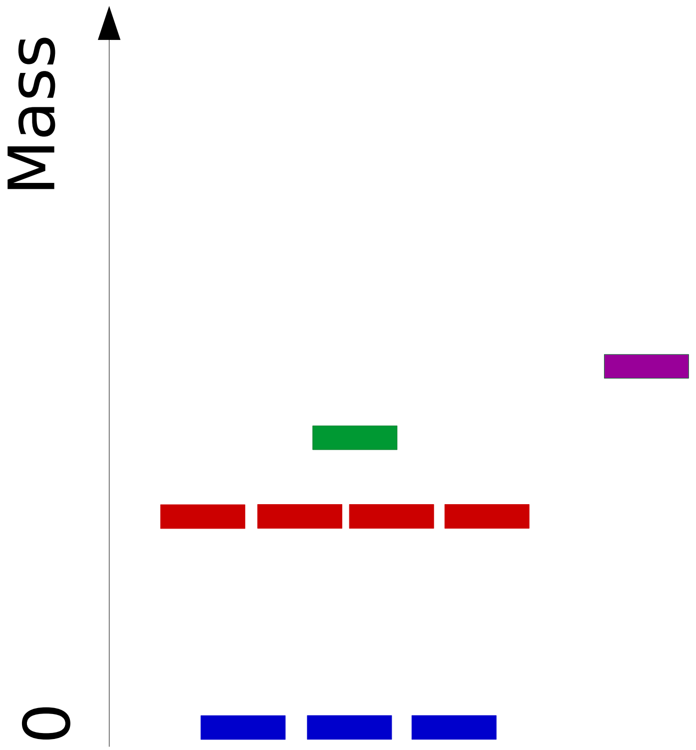

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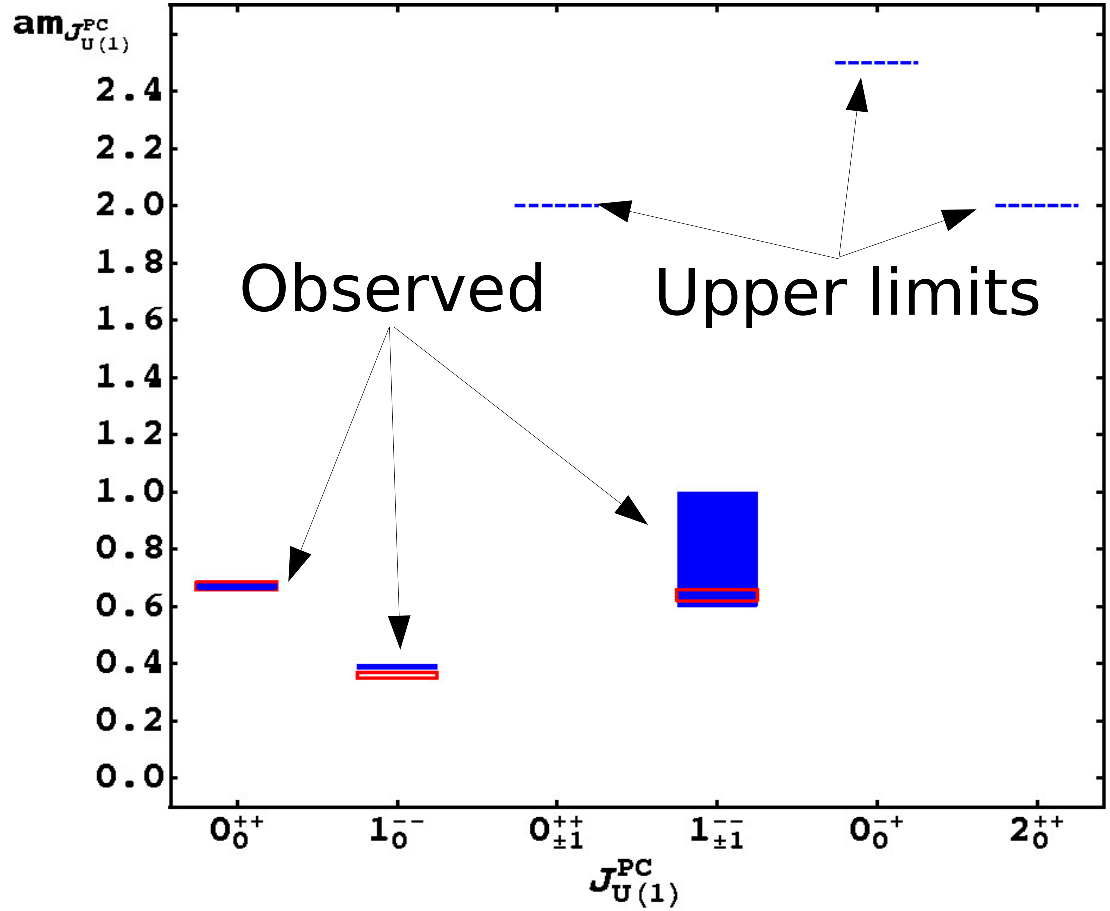

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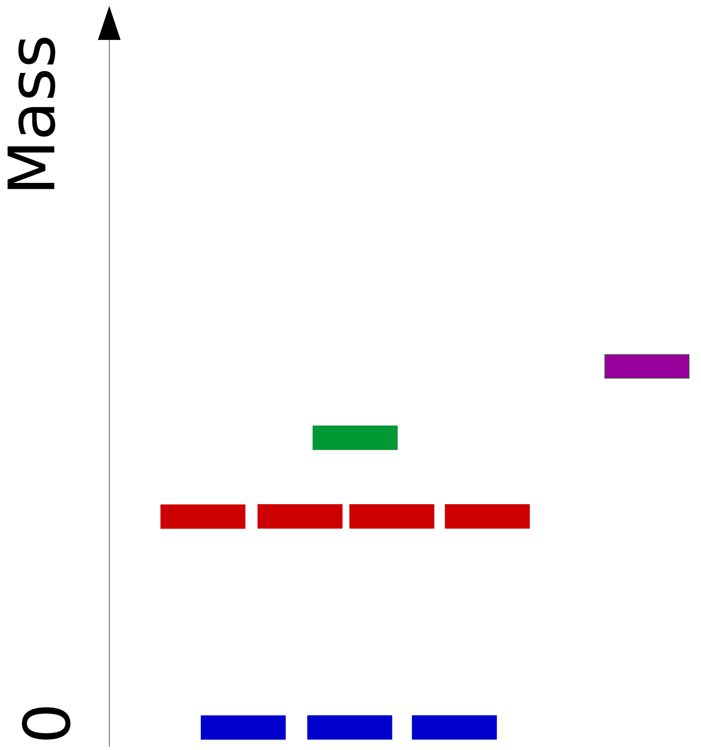

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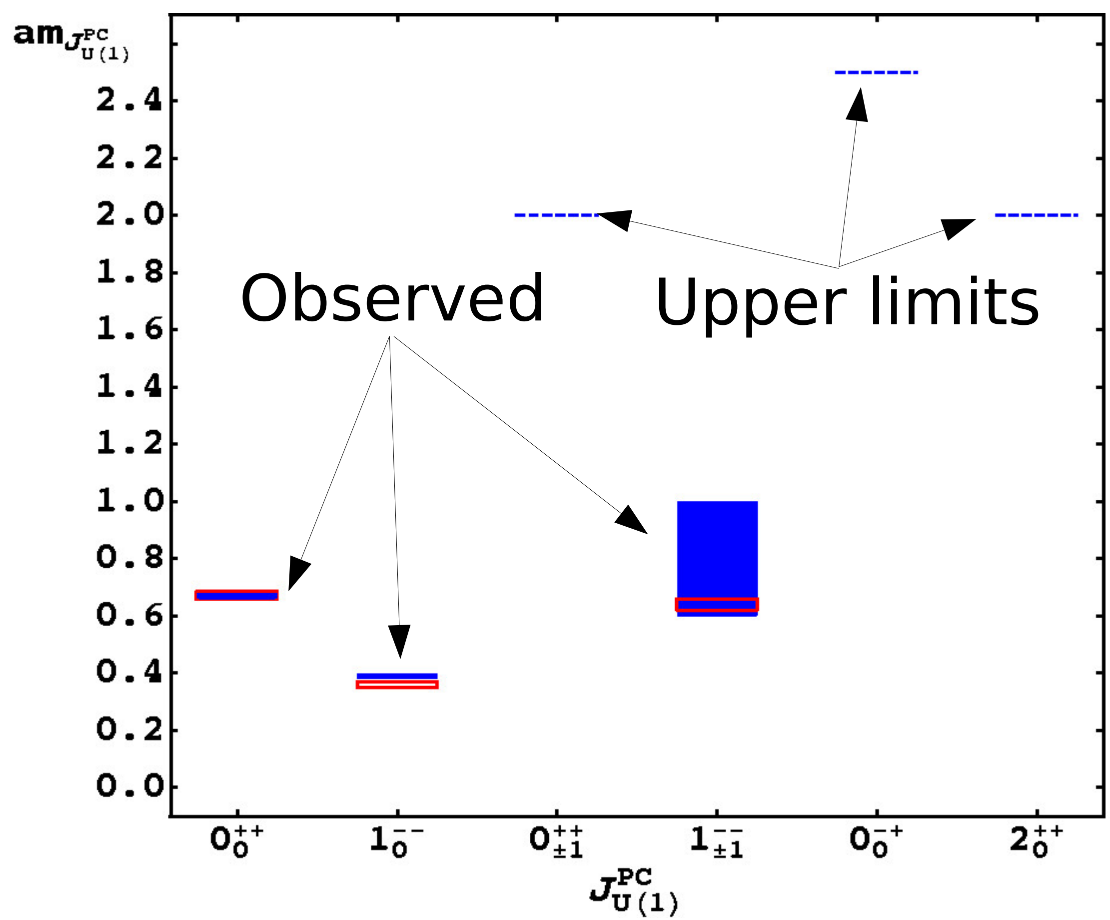

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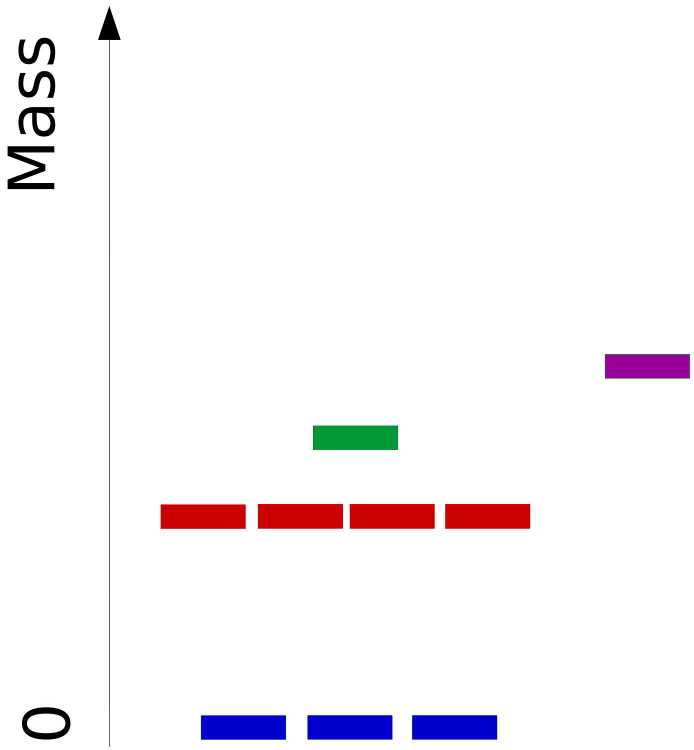

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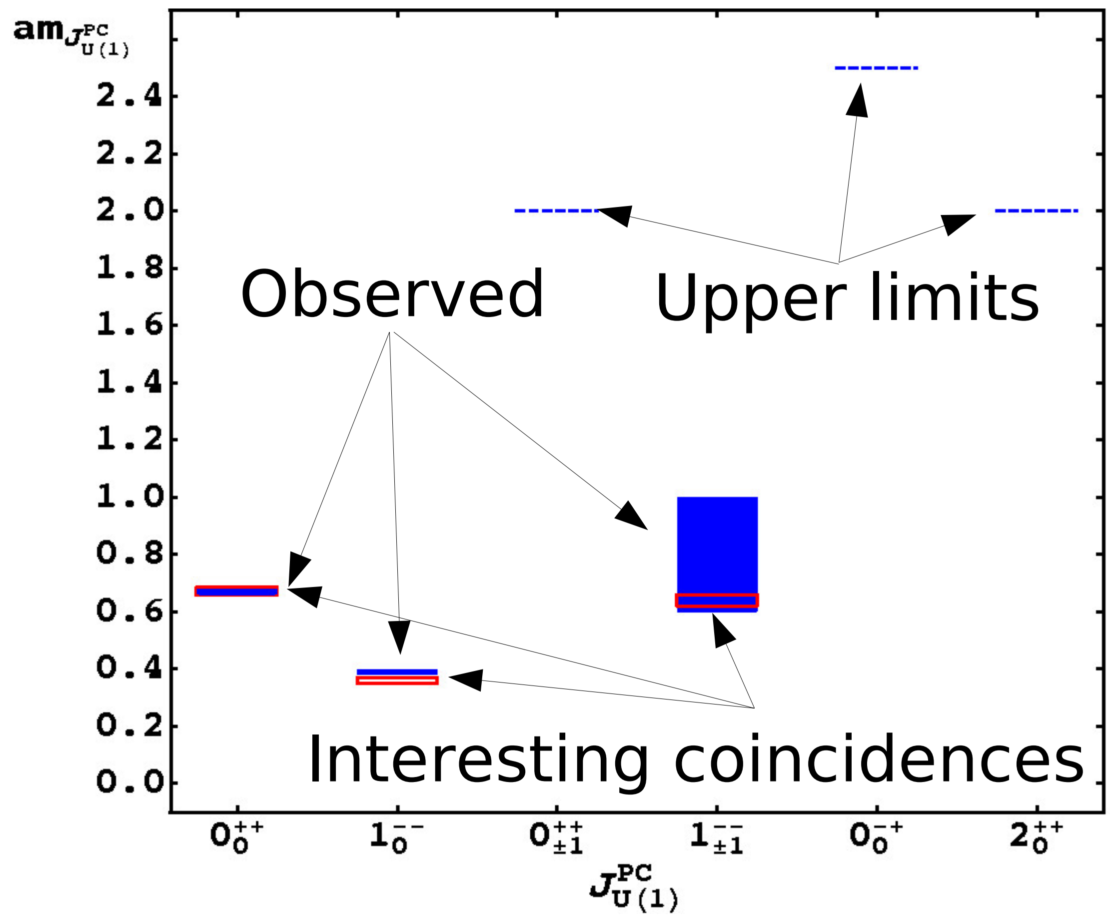

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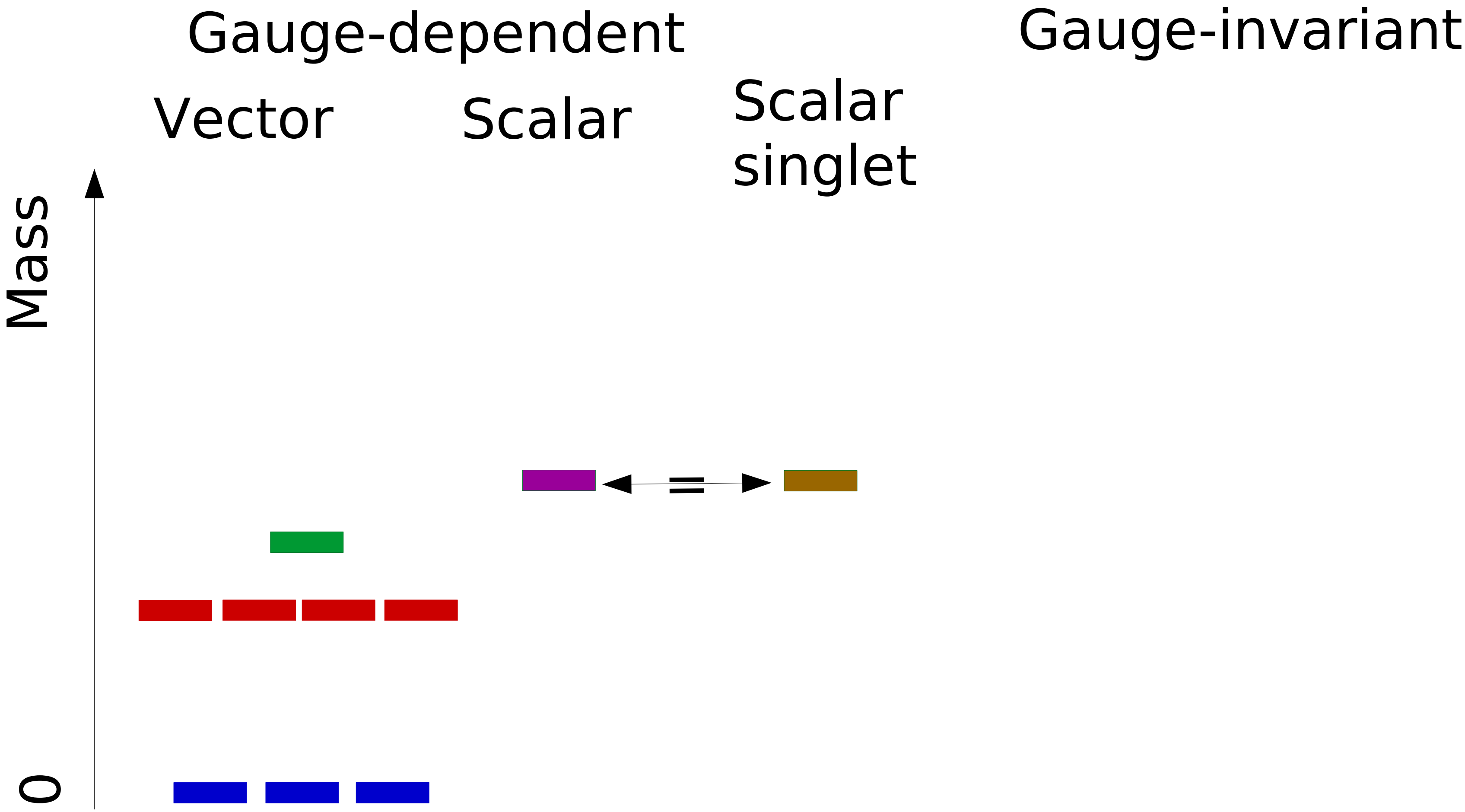

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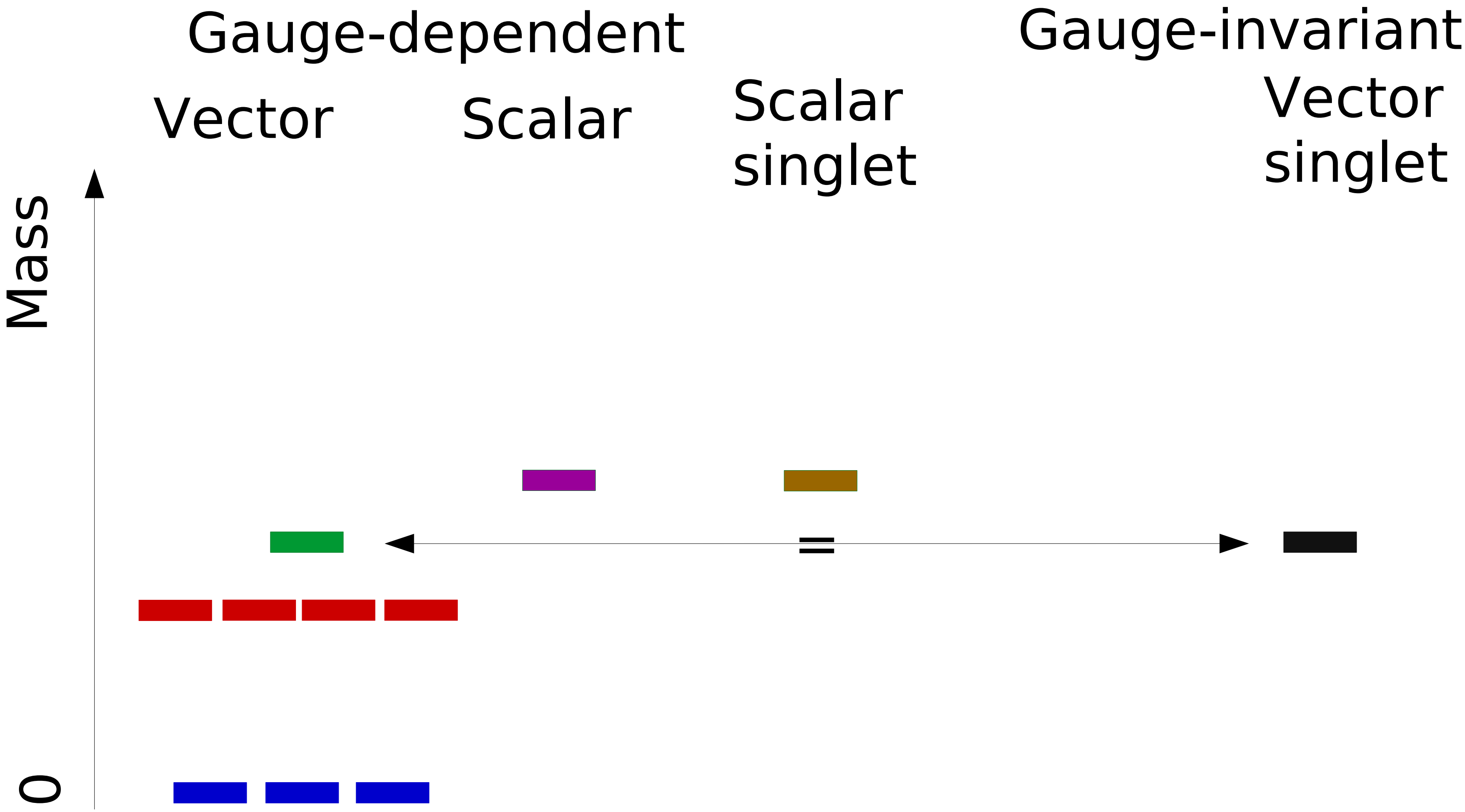

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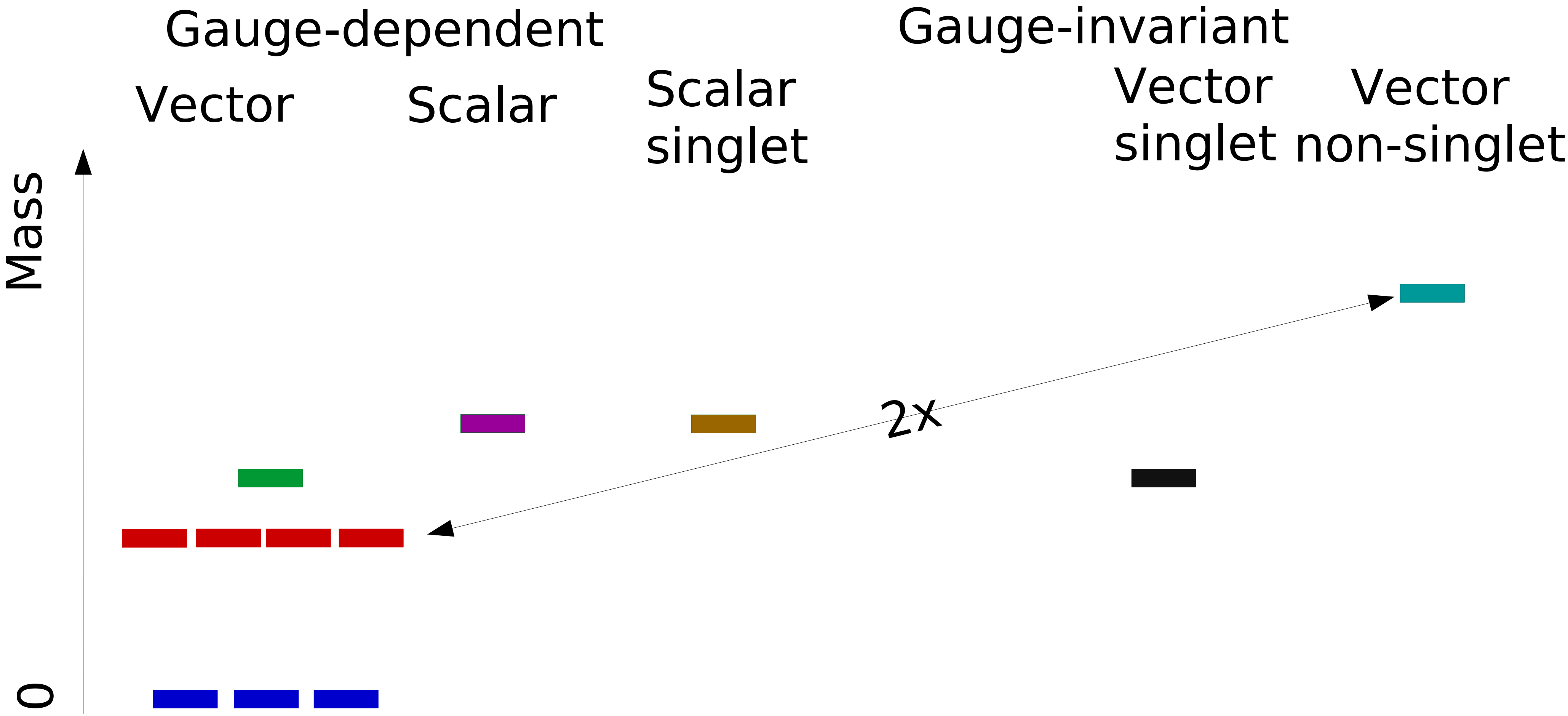

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Higgs field

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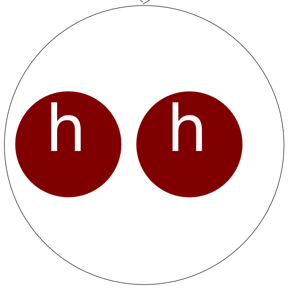

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2 x Higgs mass: Scattering state

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4) Compare poles on both sides

Fröhlich-Morchio-Strocchi Mechanism

[Fröhlich et al.’80,’81
Maas'12,’17
Maas & Sondenheimer’20]

1) Formulate gauge-invariant operator

0$^+$ singlet: $\langle (h^+ h)(x)(h^+ h)(y)\rangle$

2) Expand Higgs field around fluctuations $h = v + \eta$

$$\langle (h^+ h)(x)(h^+ h)(y)\rangle = v^2\langle \eta^+(x)\eta(y)\rangle$$

Calculable: 2009.06671

$$+ v\langle \eta^+ \eta^2 + \eta^{+2} \eta\rangle + \langle \eta^{+2} \eta^2\rangle$$

3) Standard perturbation theory

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What about the vector?

[Maas & Törek'16]

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Only one state remains in the spectrum at mass of gauge boson 8 (heavy singlet)

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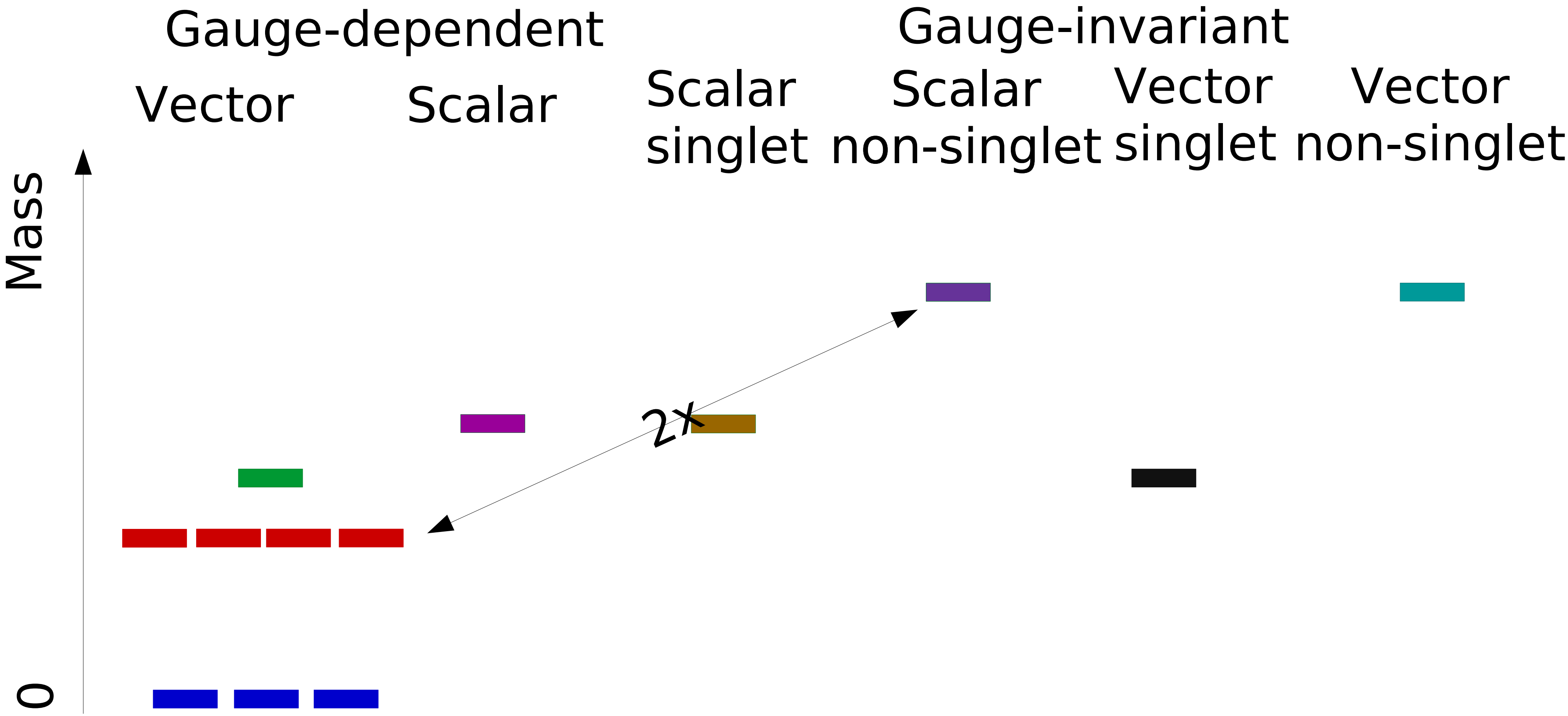
Charged states need additional assumptions

[Maas, Sondenheimer, Török'17]

Spectrum

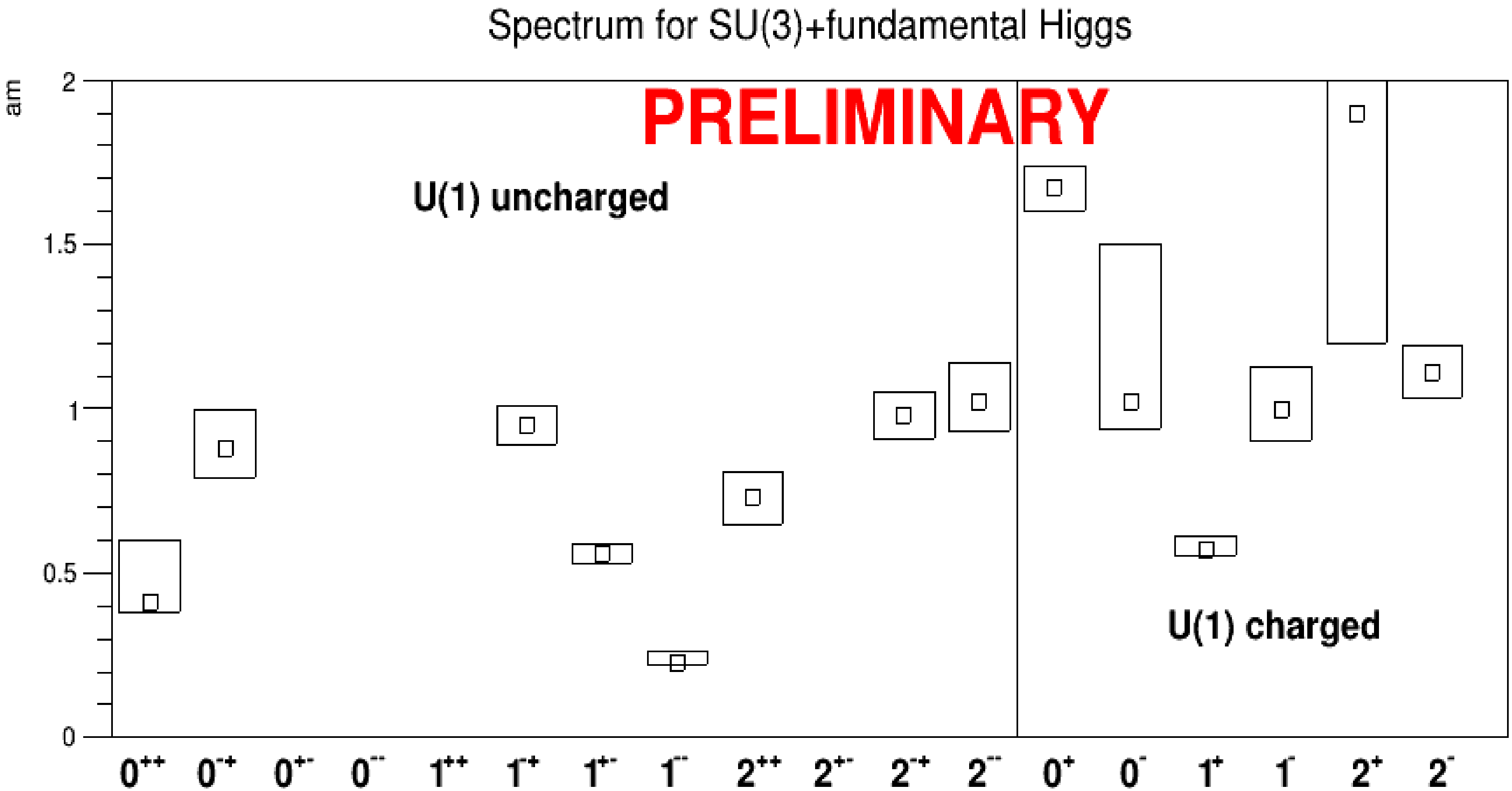
[Maas & Törek'16,'18
Maas, Sondenheimer & Törek'17]



- Qualitatively different spectrum
- Gauge-dependent particles can also be calculated

Spectrum

[Maas & Törek’16,'18
Maas, Sondenheimer & Törek'17
Dobson, Maas, Riedere, unpublished]



- Full spectroscopy will check further FMS predictions
- Results so far show no additional light levels
- U(1) charged: Do not exist in perturbation theory

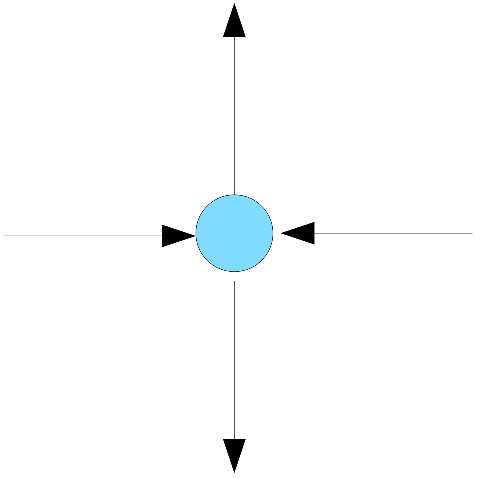
Experimental consequences

Experimental consequences

[Maas & Törek'18
Maas'17]

- Add fundamental fermions

Experimental consequences [Maas & Törek'18 Maas'17]



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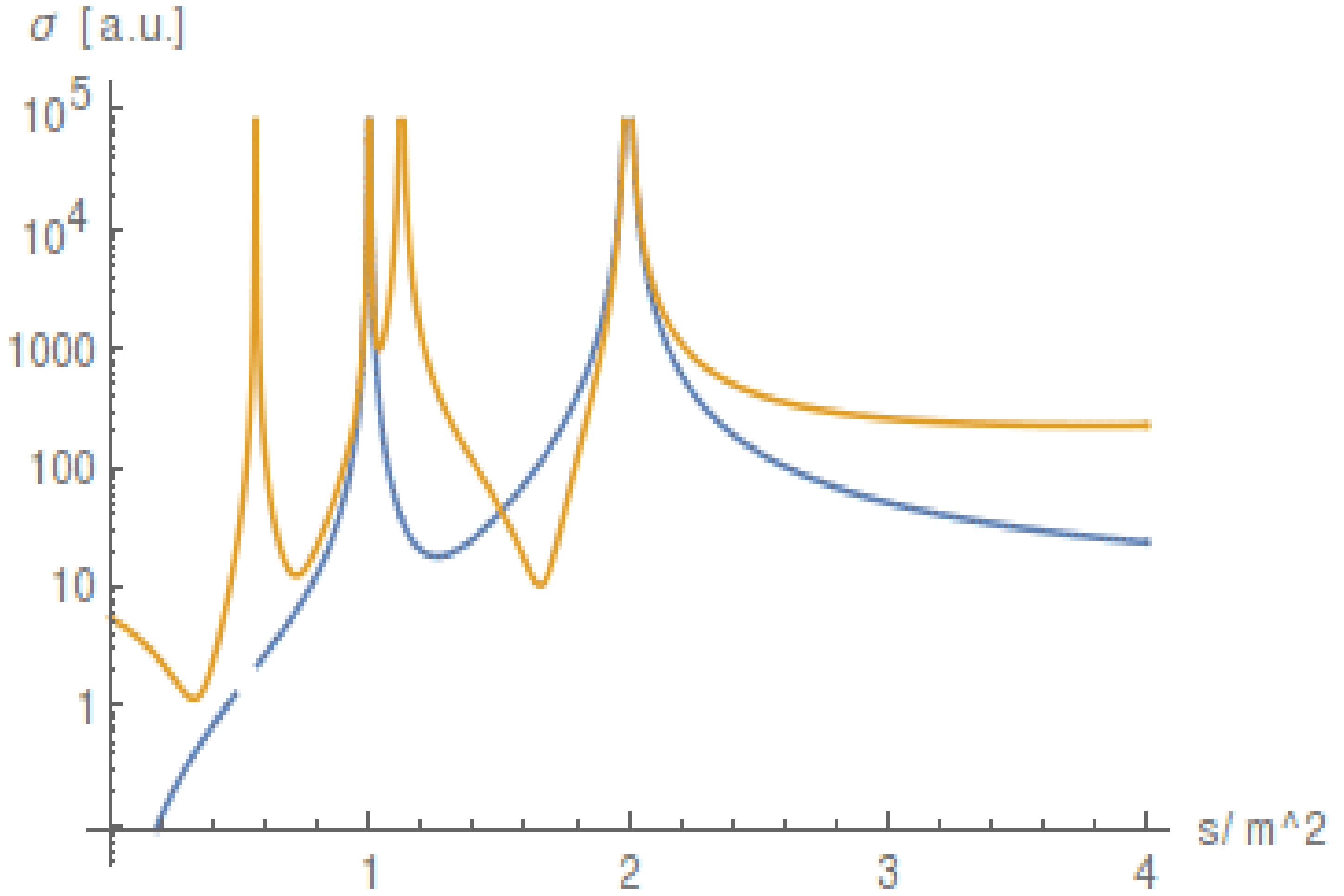

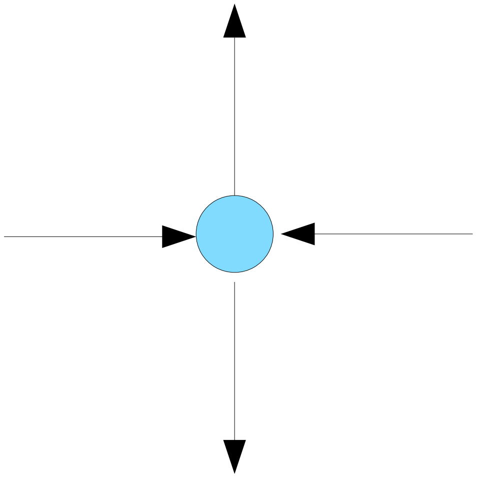

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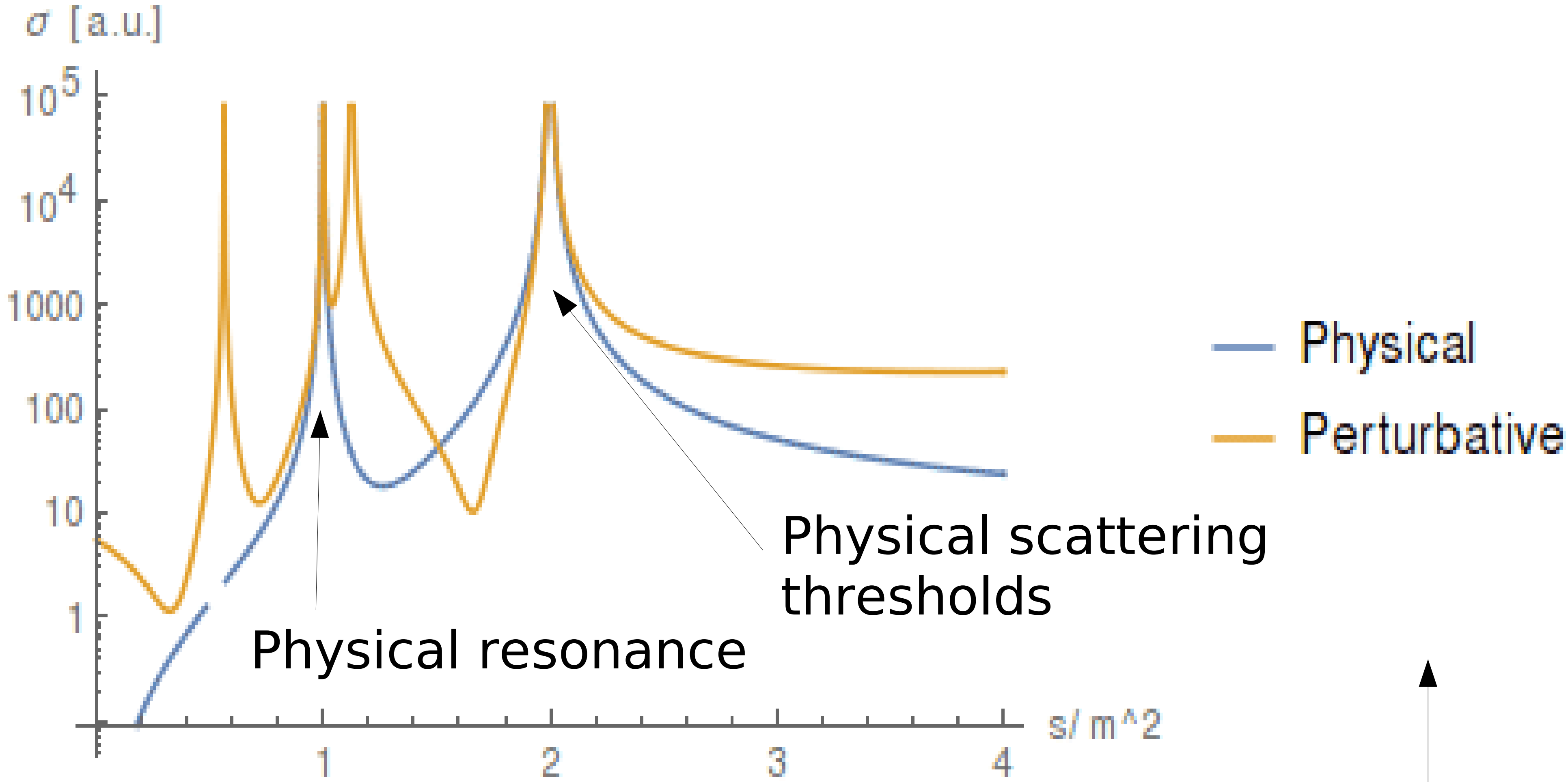

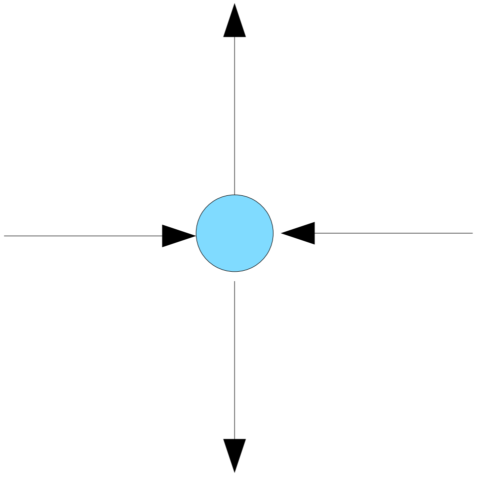

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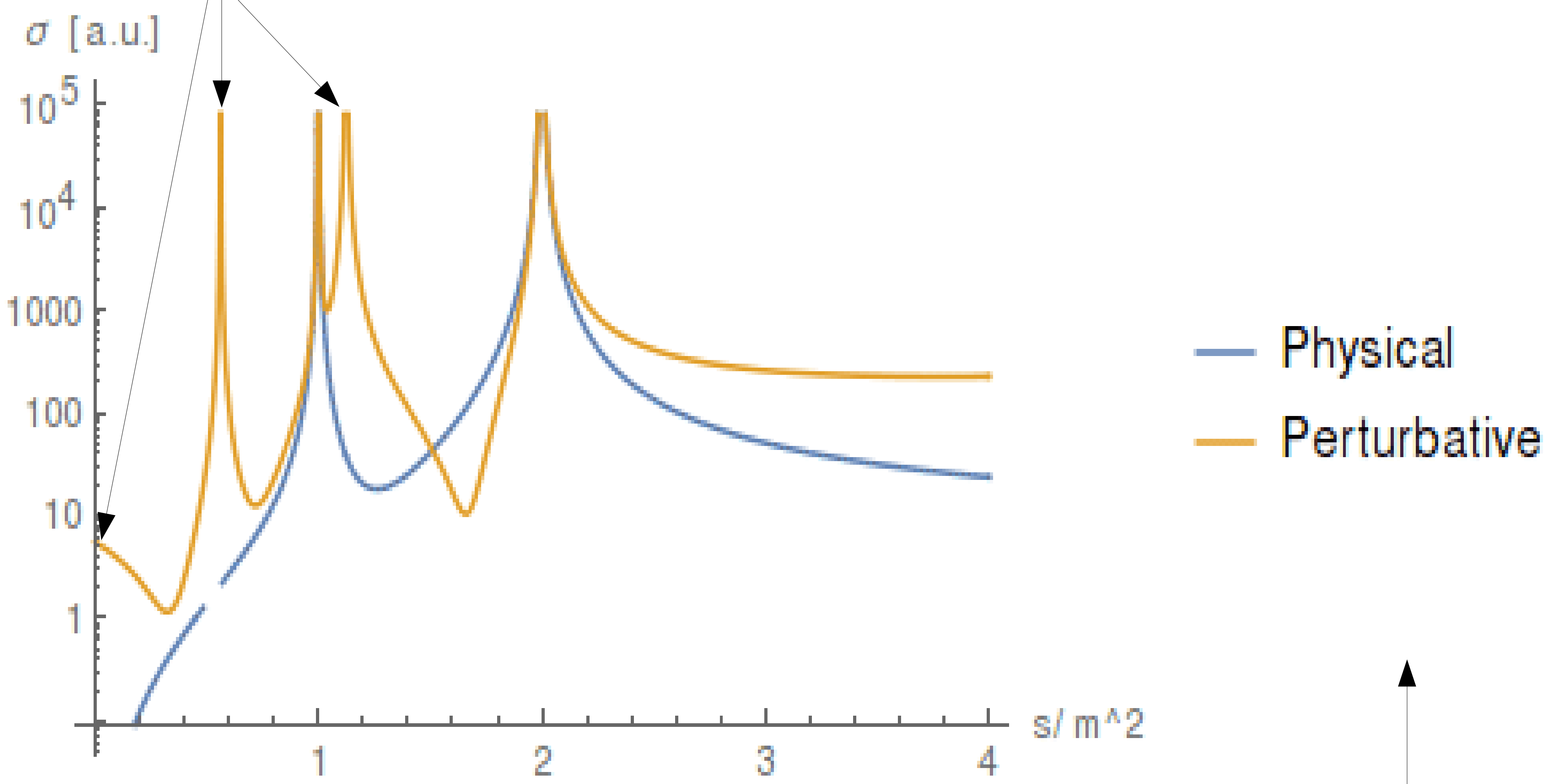
Ghost peaks from unphysical particles in perturbation theory



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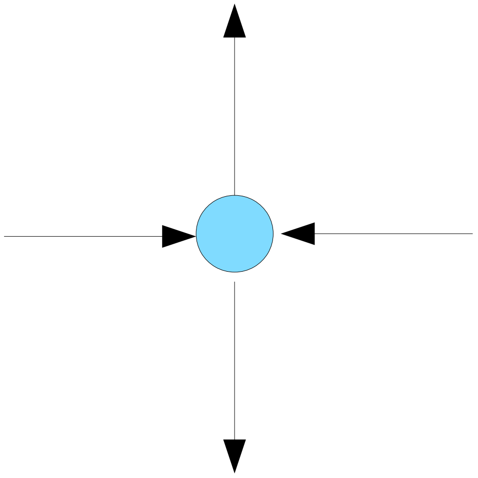

Experimental consequences

[Maas & Török'18
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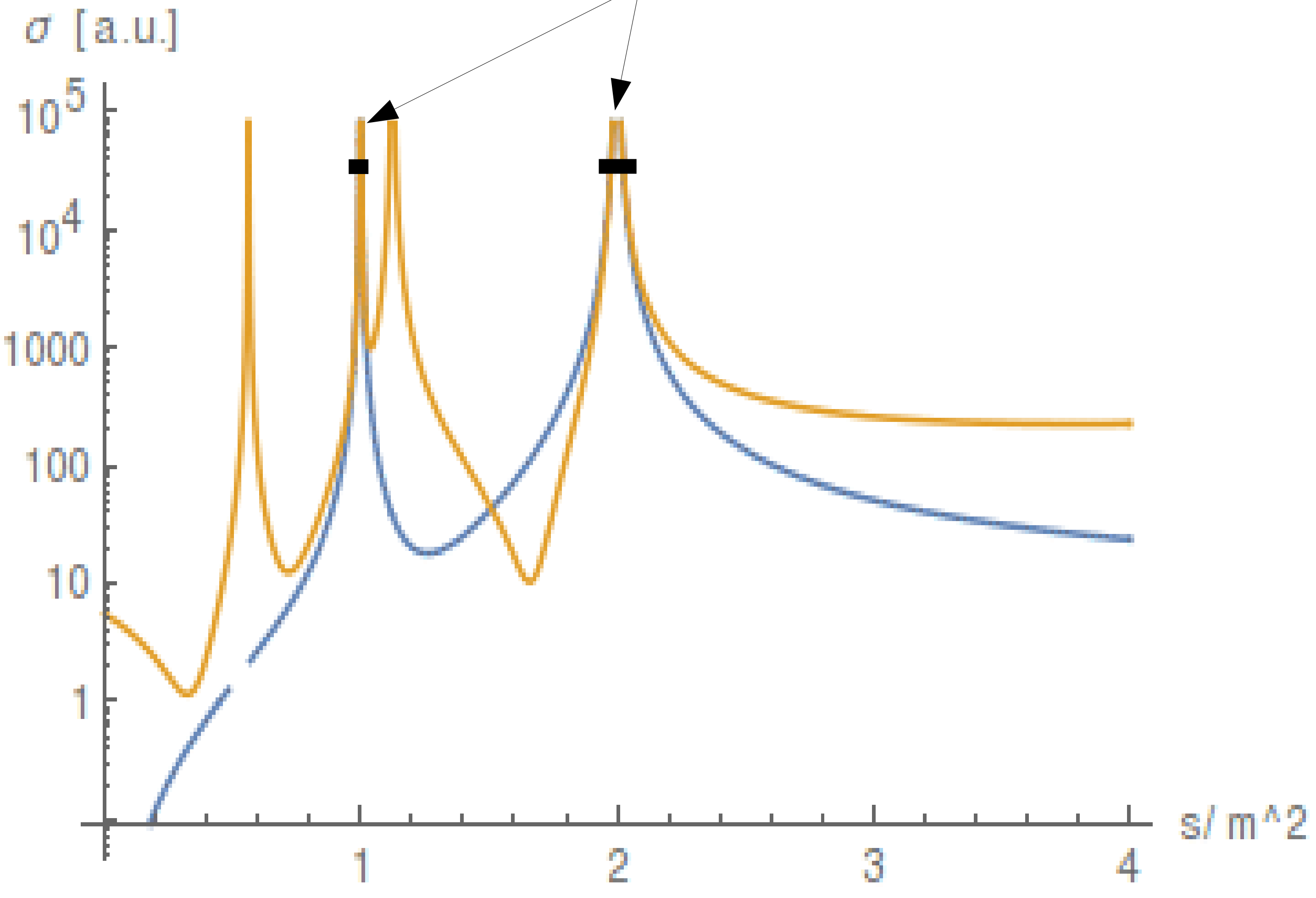
Close to true structures identical!



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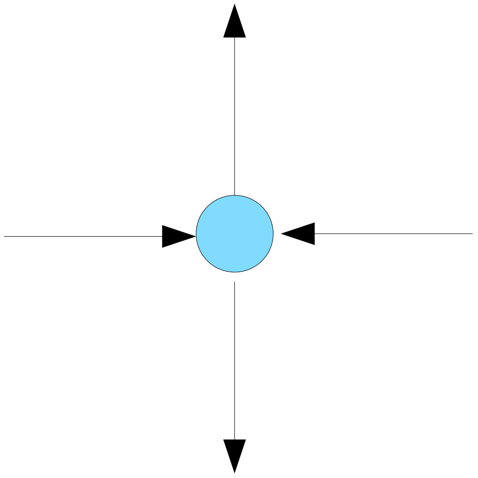

Beyond the toy model

[Maas, Sondenheimer & Törek'17, Sondenheimer'19]

- Generic problem in GUT scenarios [Sondenheimer'19]
  - Many standard scenarios are ruled out
  - Too few or too many particles at low mass
  - Includes popular scenarios like SU(5), SO(10), Pati-Salam

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  - Standard model has a special structure – protects the spectrum [Fröhlich et al.'80,'81]
- Requires to rebuild GUT phenomenology
  - Photon as composites possible [Afferrante et al.'20]

Summary

- Perturbative methods to determine GUT spectra fail qualitatively
- Fröhlich-Morchio-Strocchi mechanism yields a suitable, practical alternative
- Phenomenlogy of GUTs needs to be redone