

# Local, global, and space-time symmetries

## What is physical?

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8<sup>th</sup> of May 2019  
Jena  
Germany



**NAWI Graz**  
Natural Sciences

**FWF**

Der Wissenschaftsfonds

# What is this talk about?

Review: 1712.04721

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- Global symmetries determine physics
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- How this matters (eg) in BSM theories
- What happens in quantum gravity?

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- Parameters selected for a BEH effect

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- Global U(1) custodial (flavor) symmetry

- Acts as (right-)transformation on the scalar field only

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

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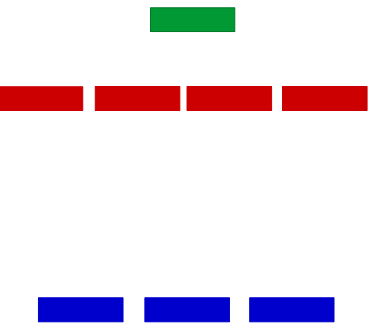
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- Get masses and degeneracies at tree-level
- Perform perturbation theory

# Spectrum

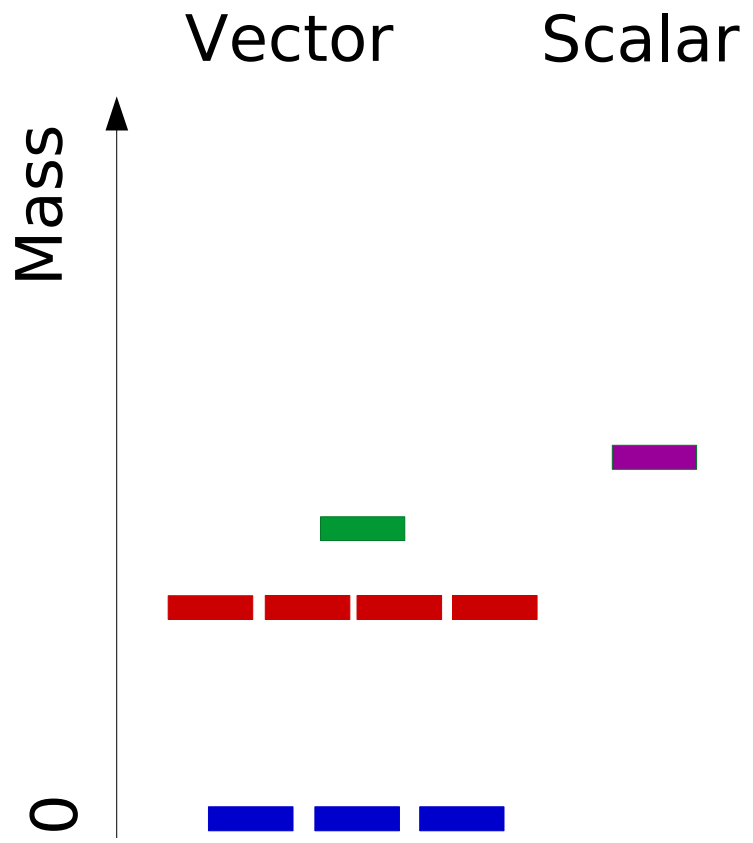
Vector

Mass

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  - ...and gauge-symmetry breaking is not there

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  - And this includes non-perturbative aspects...
  - ...even at weak coupling [Gribov'78, Singer'78, Fujikawa'82]

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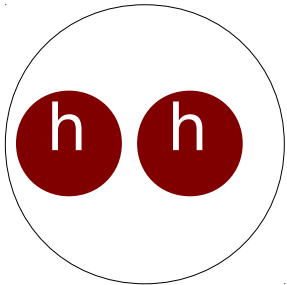
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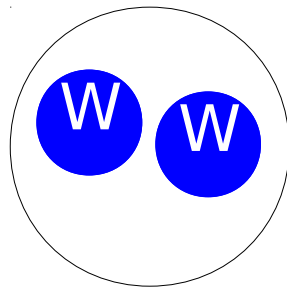
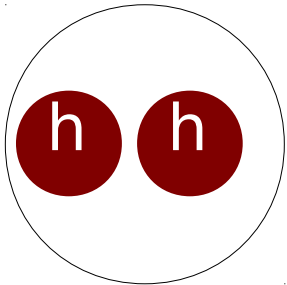
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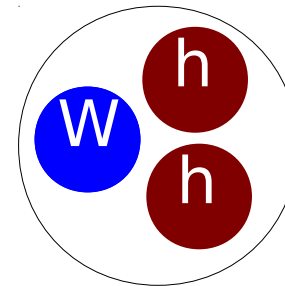
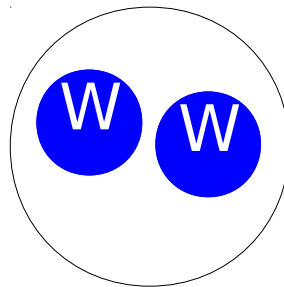
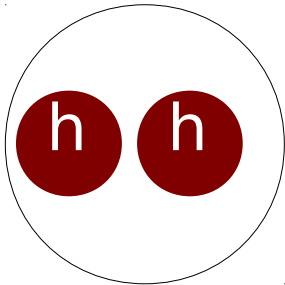
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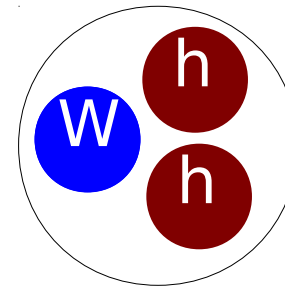
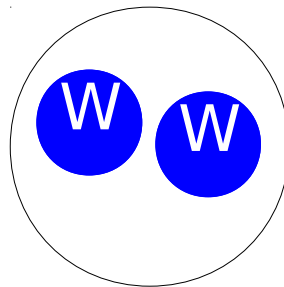
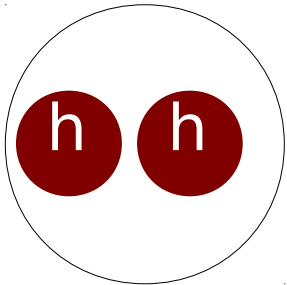
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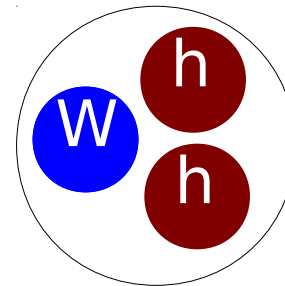
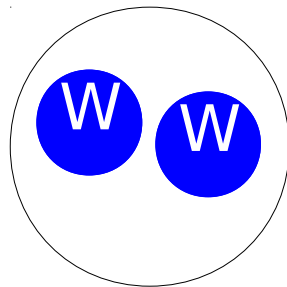
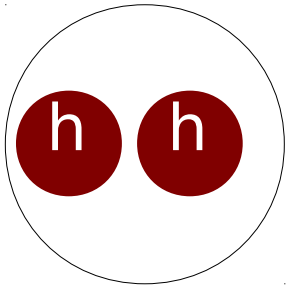


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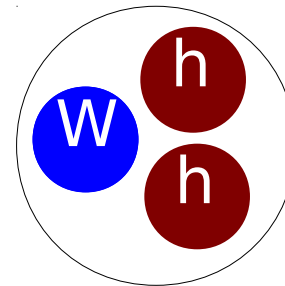
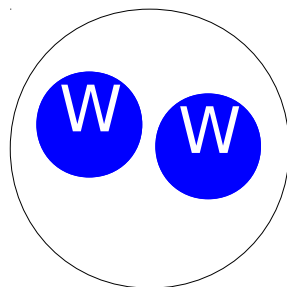
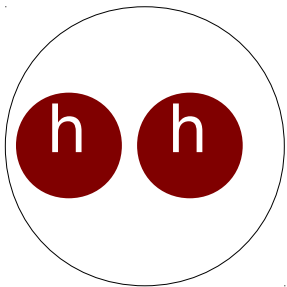


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- Can this matter?

# How to make predictions

[Fröhlich et al.'80,'81,  
Maas & Törek'16,'18,  
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- $J^{PC}$  and custodial charge only quantum numbers

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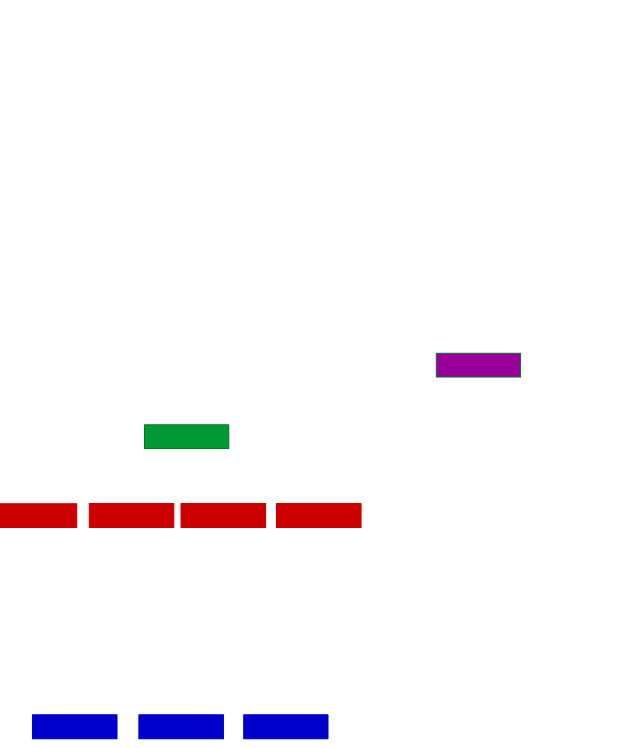
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[Maas & Törek'16,'18  
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Gauge-dependent  
Vector      Scalar

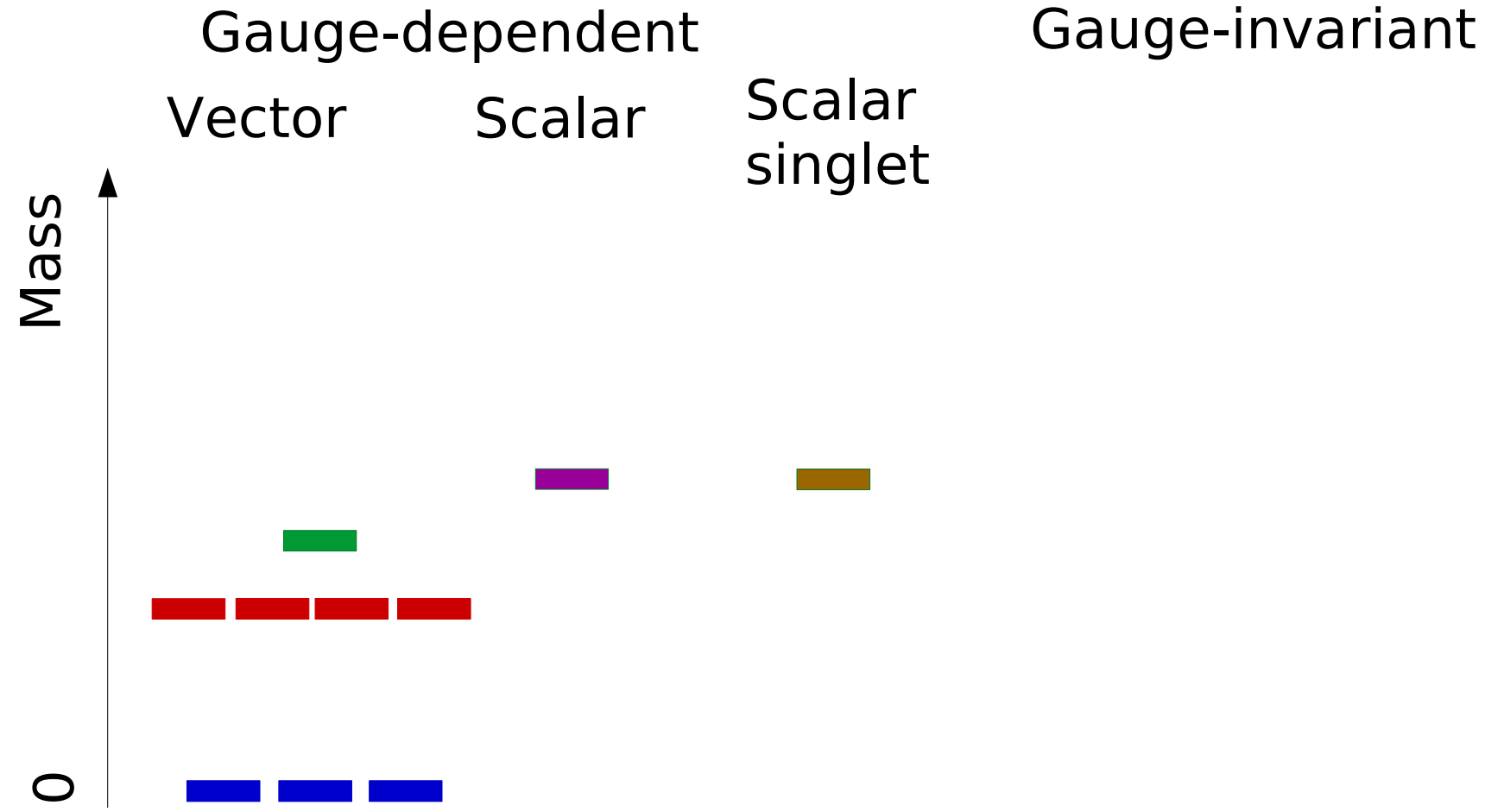
Mass

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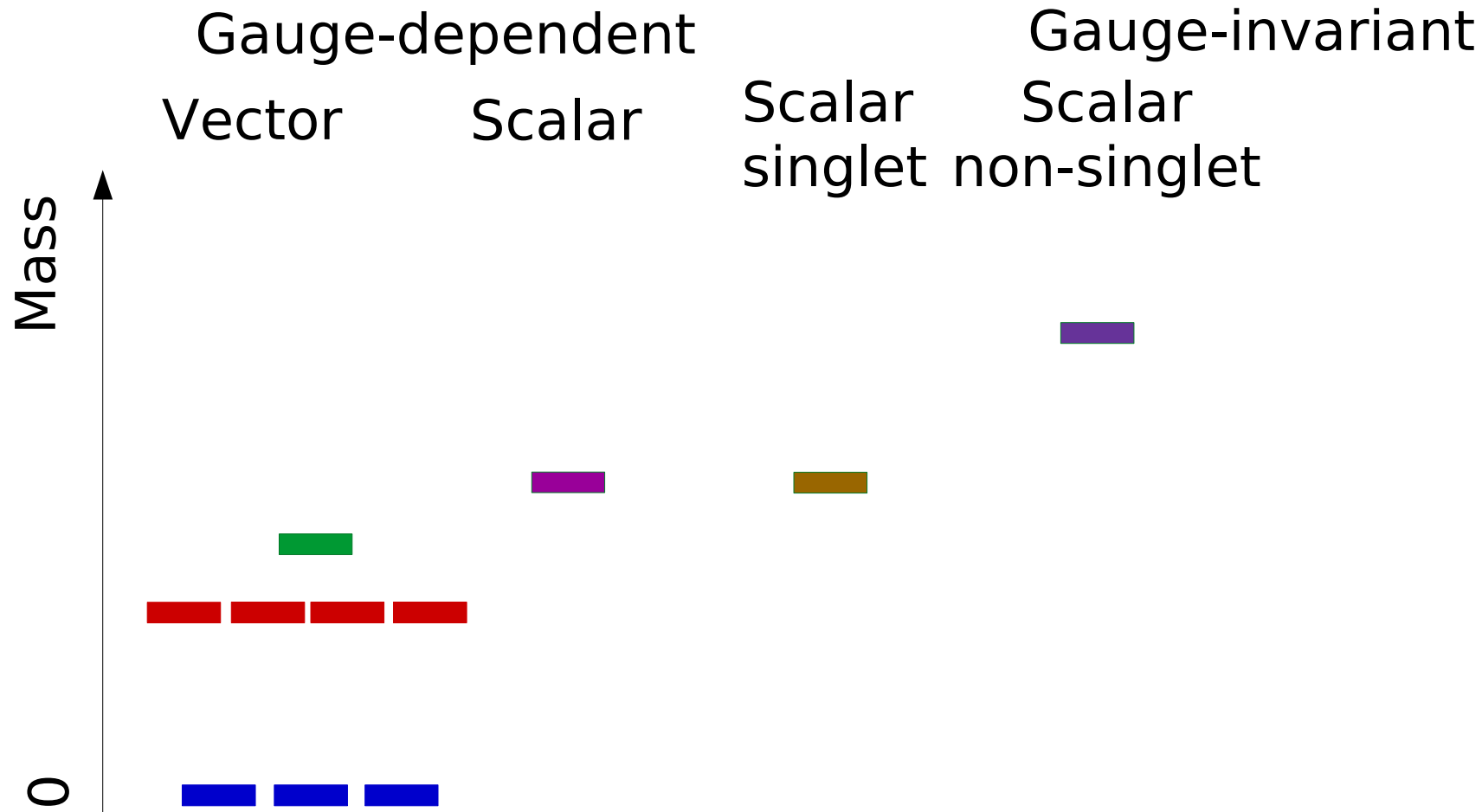
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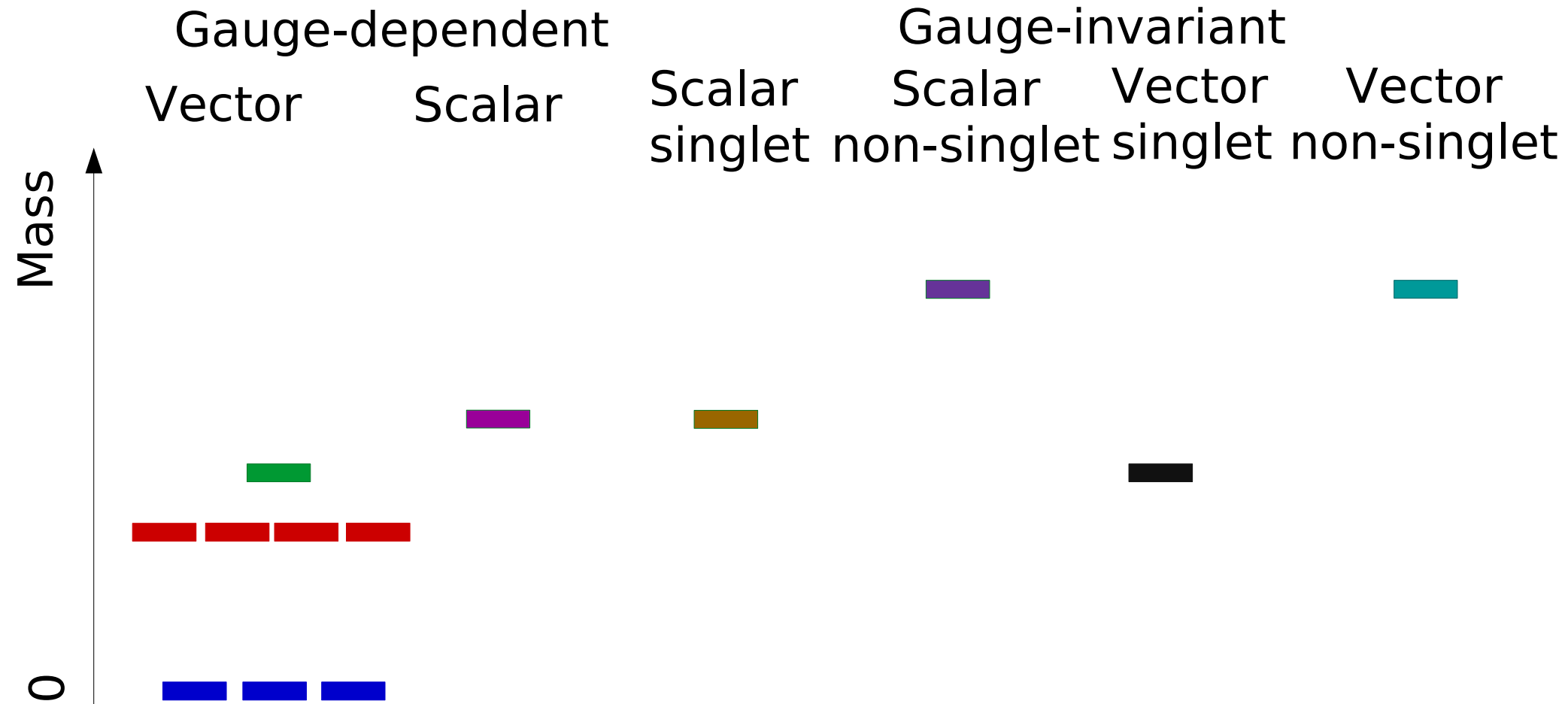
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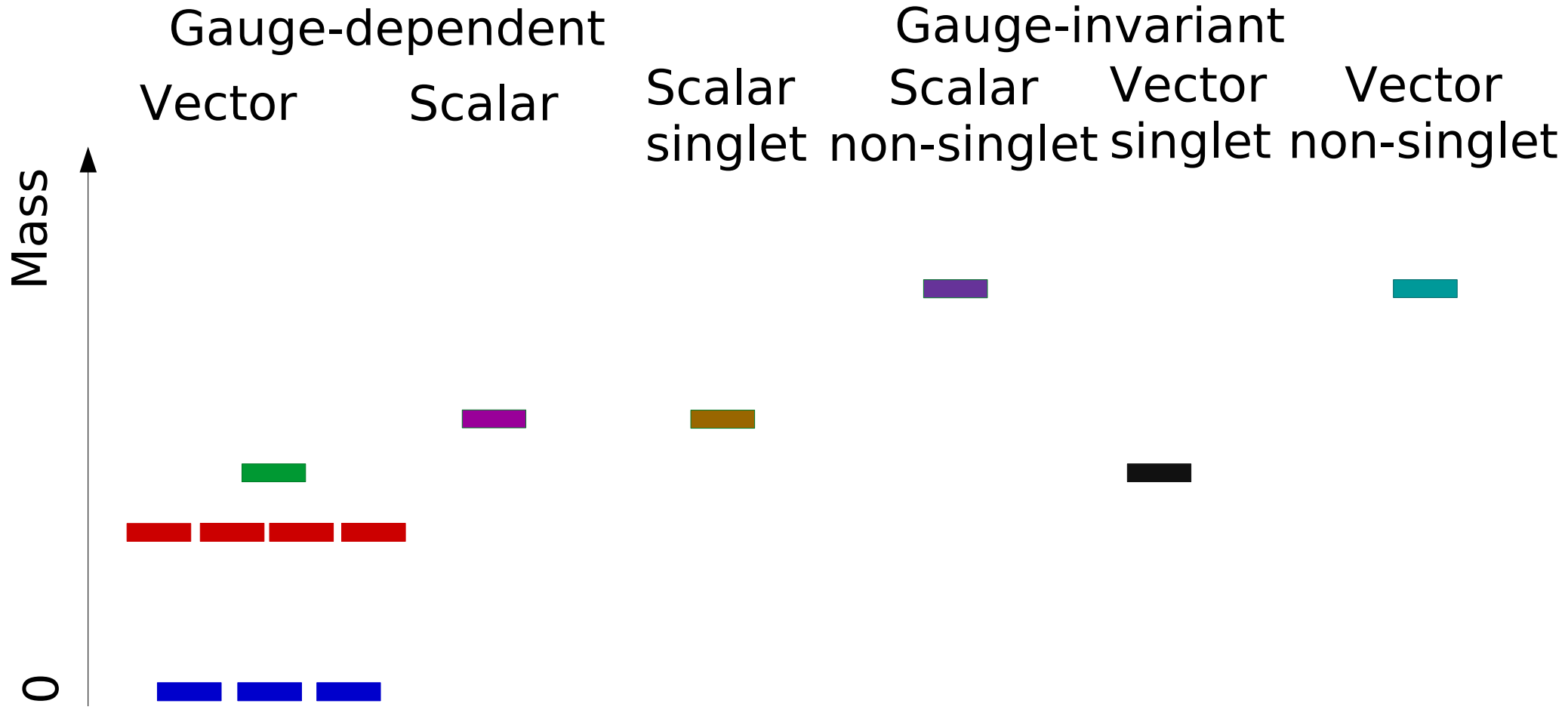
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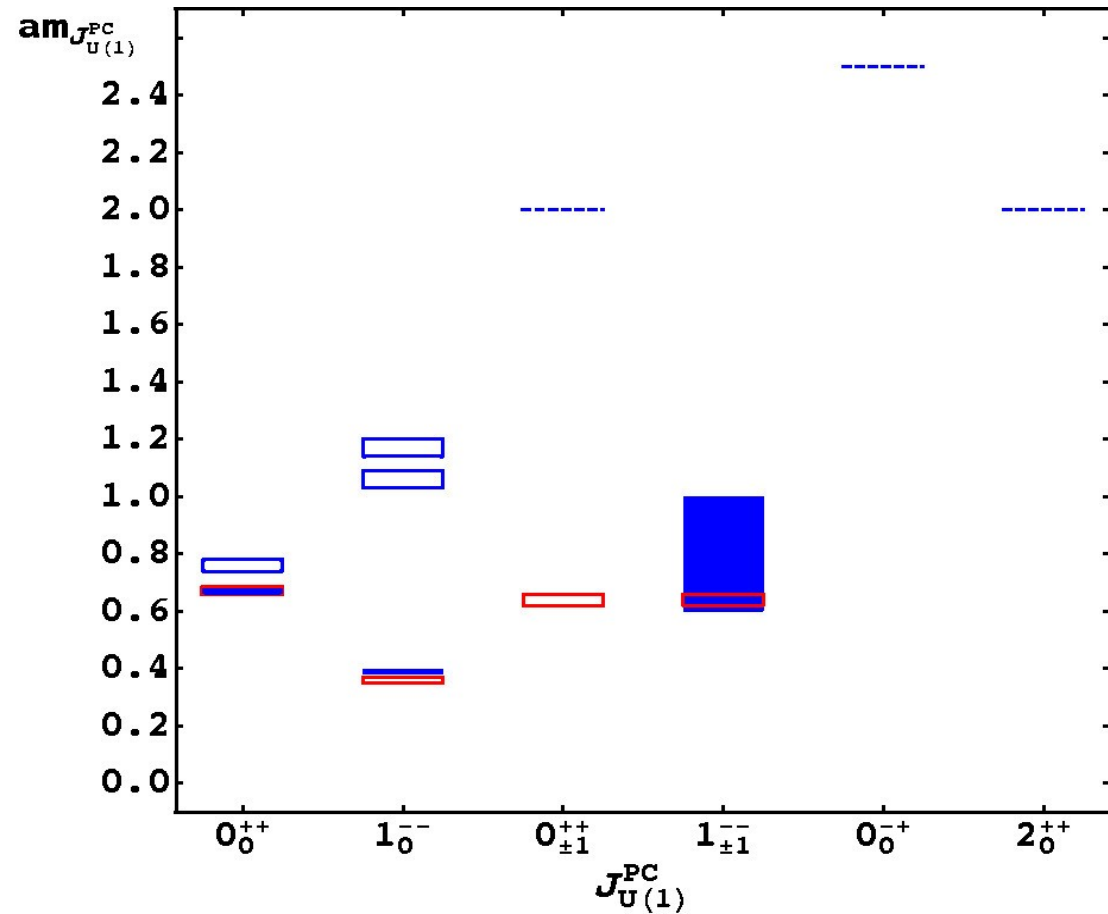


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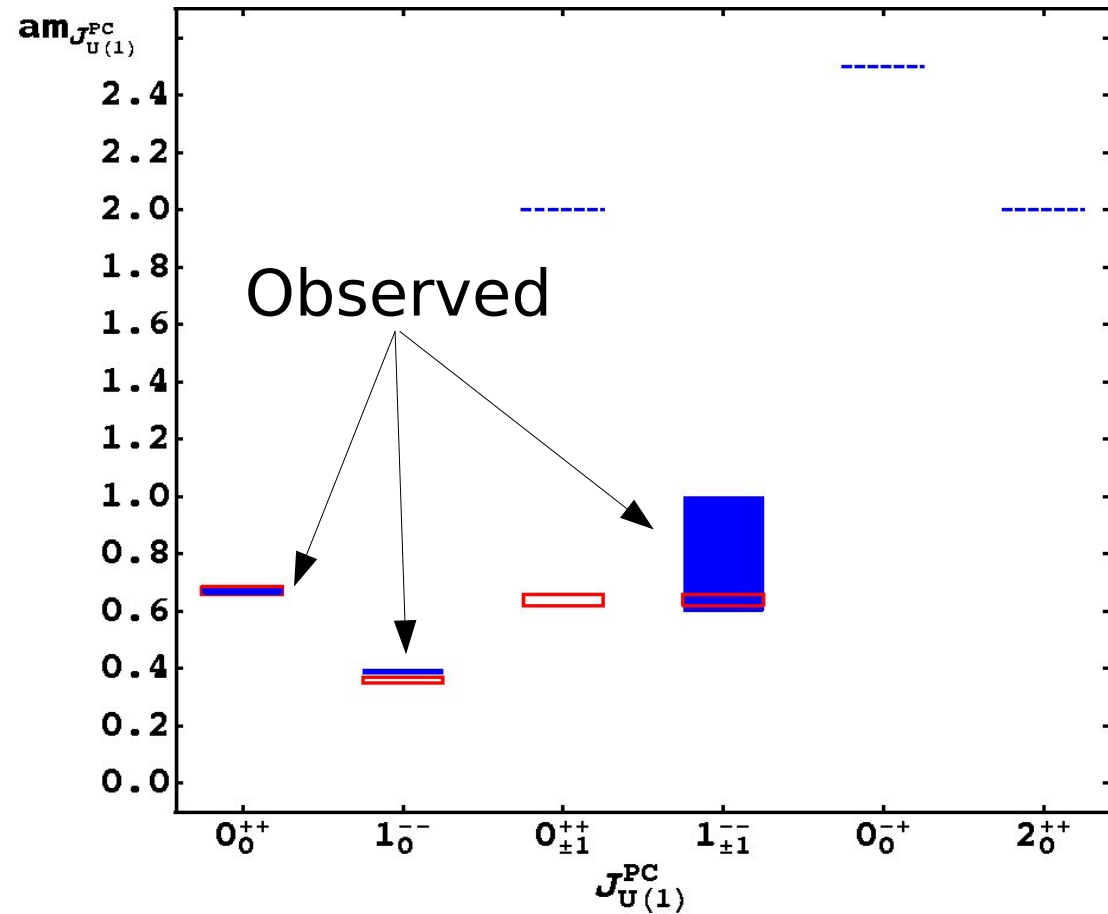


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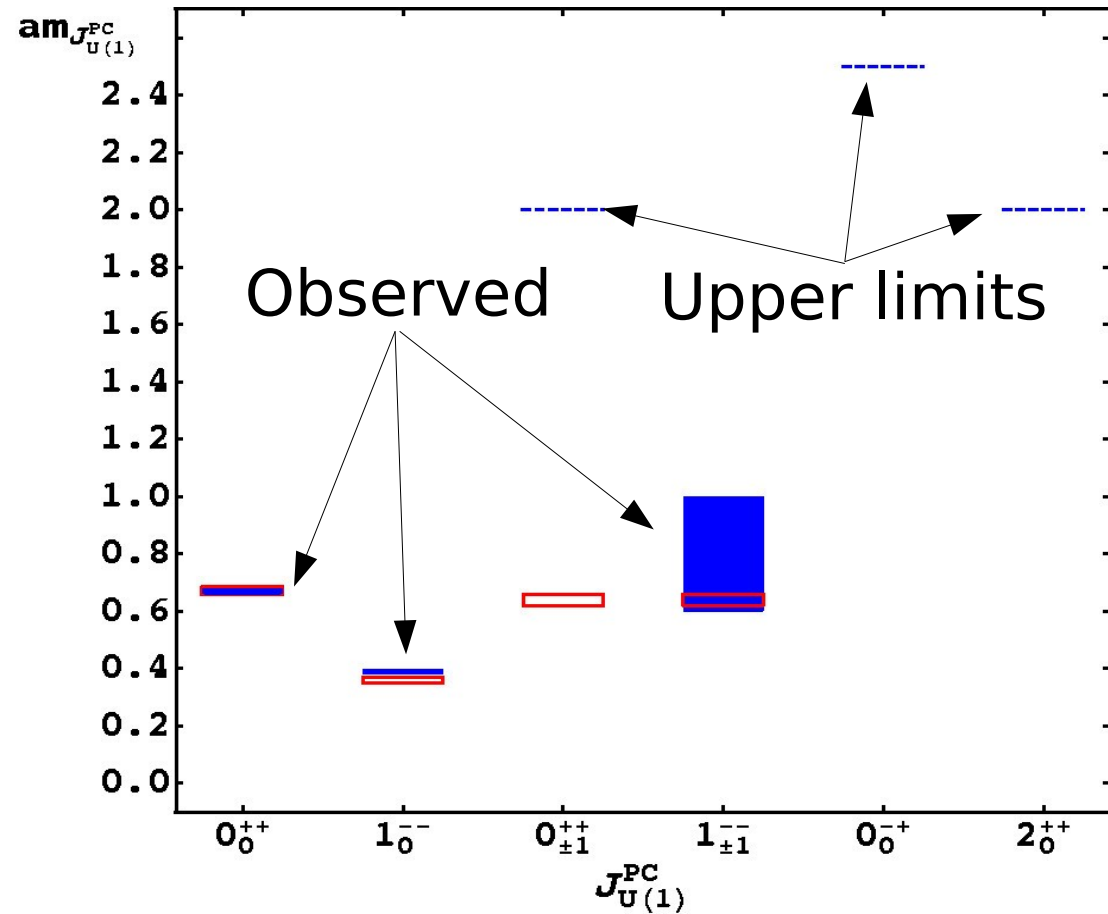


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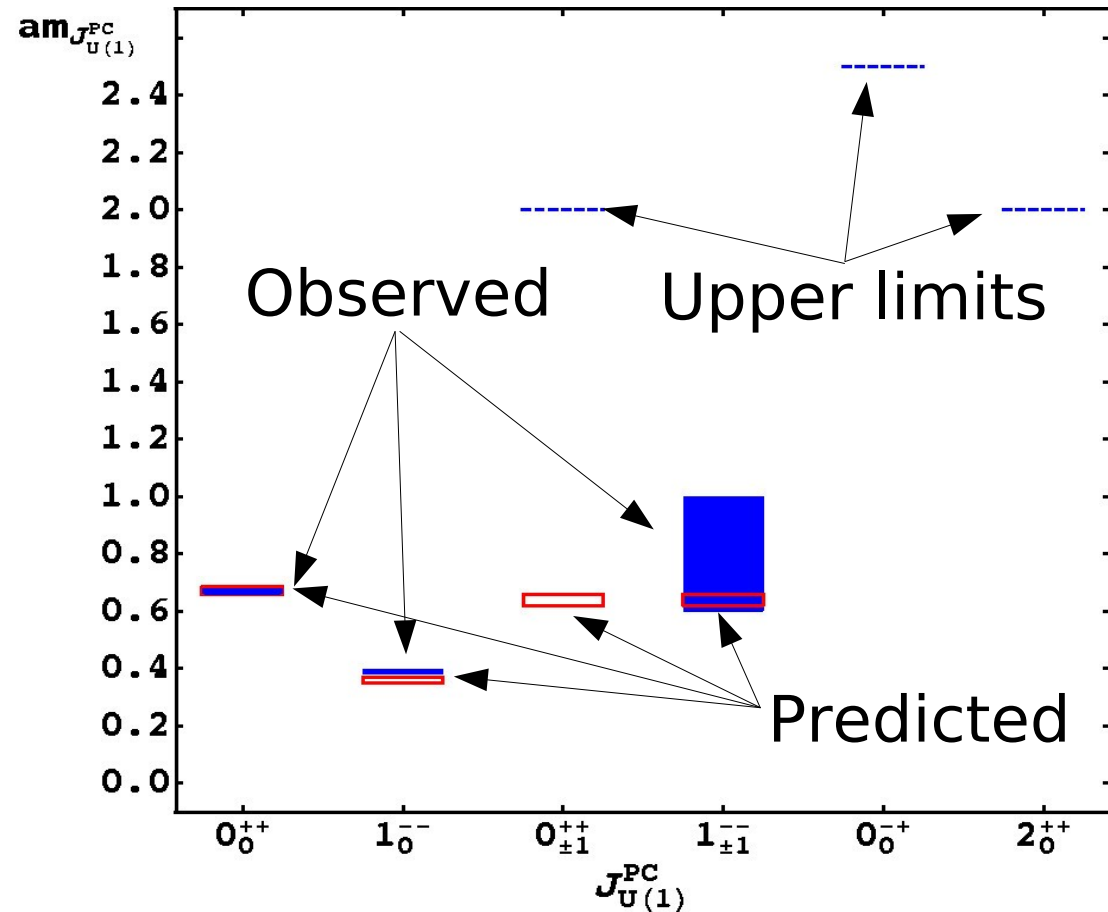


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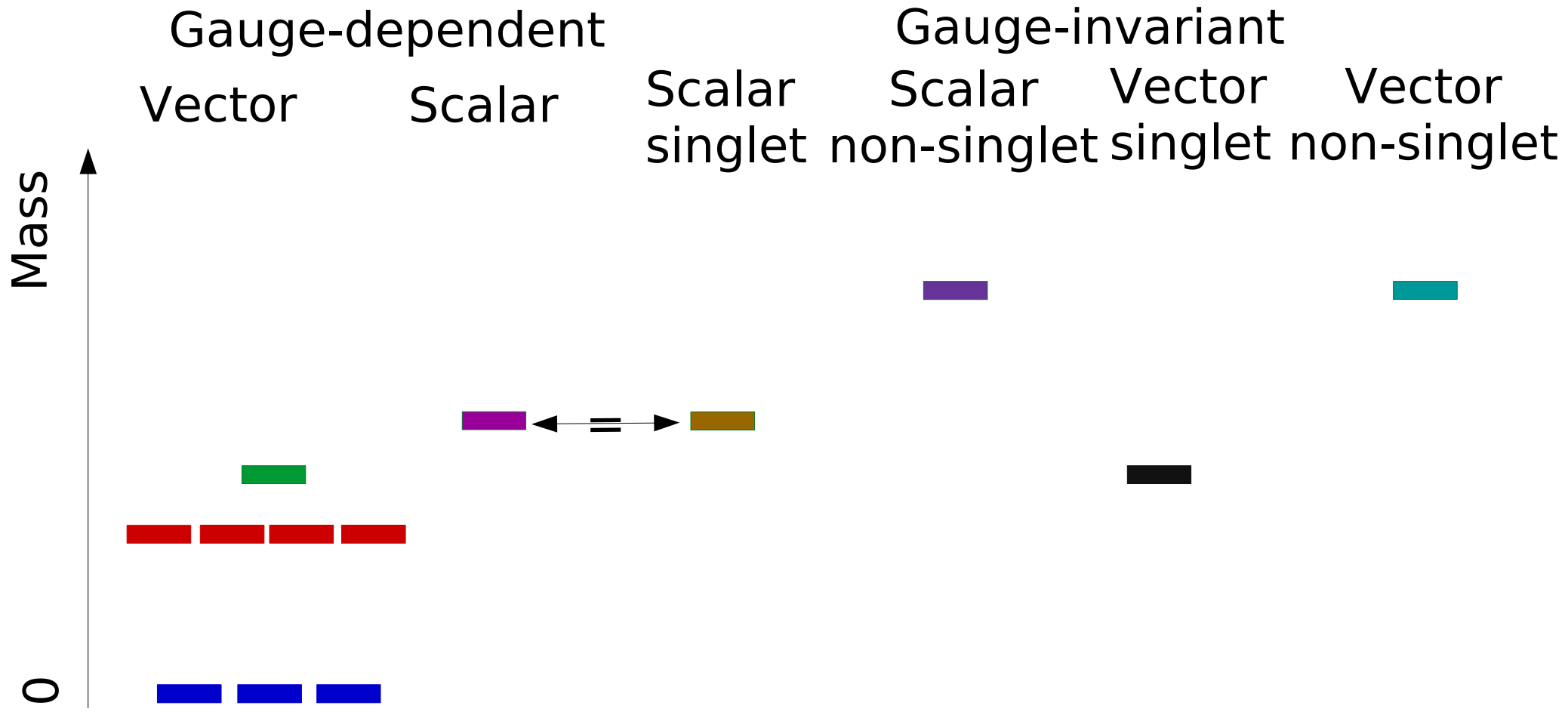
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- Qualitatively different spectrum
- Results in agreement with analytic predictions

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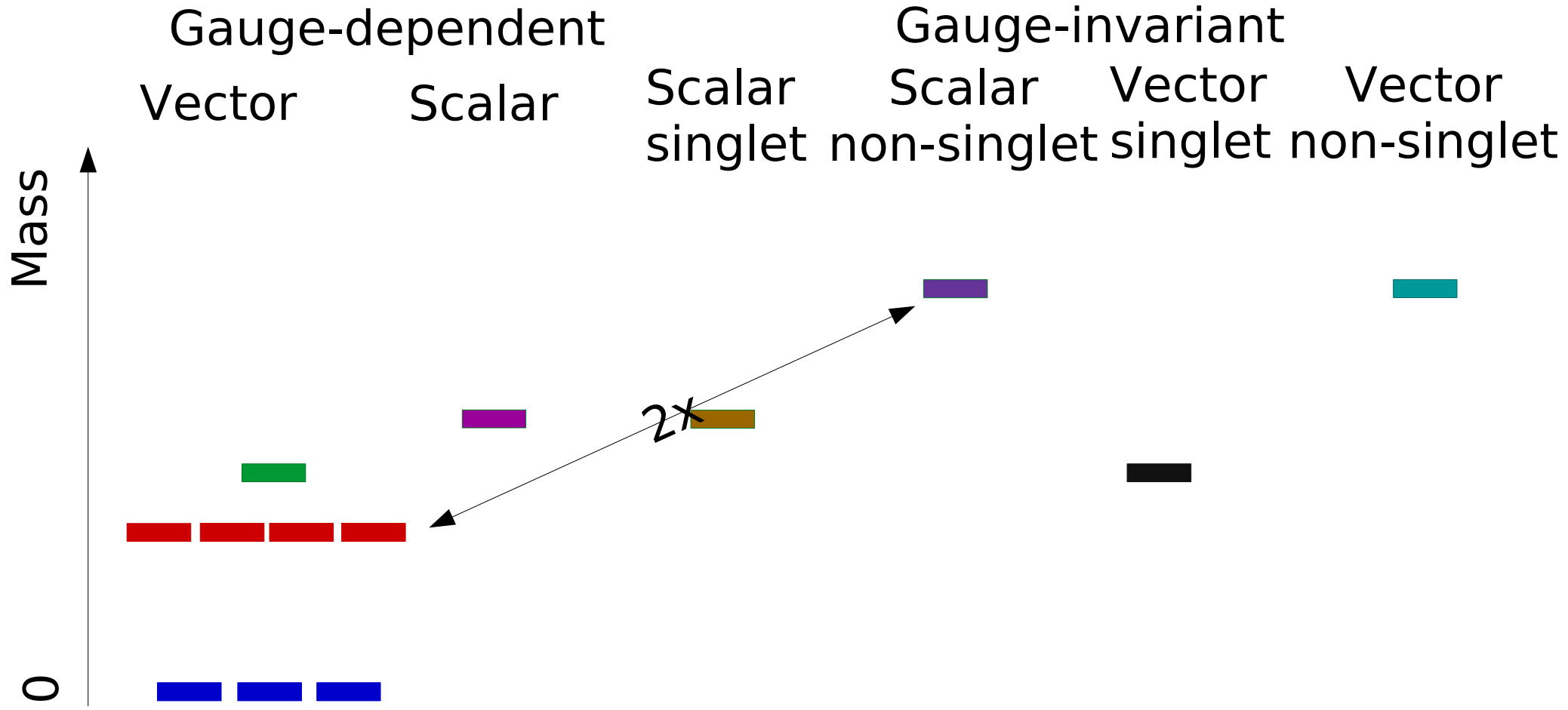
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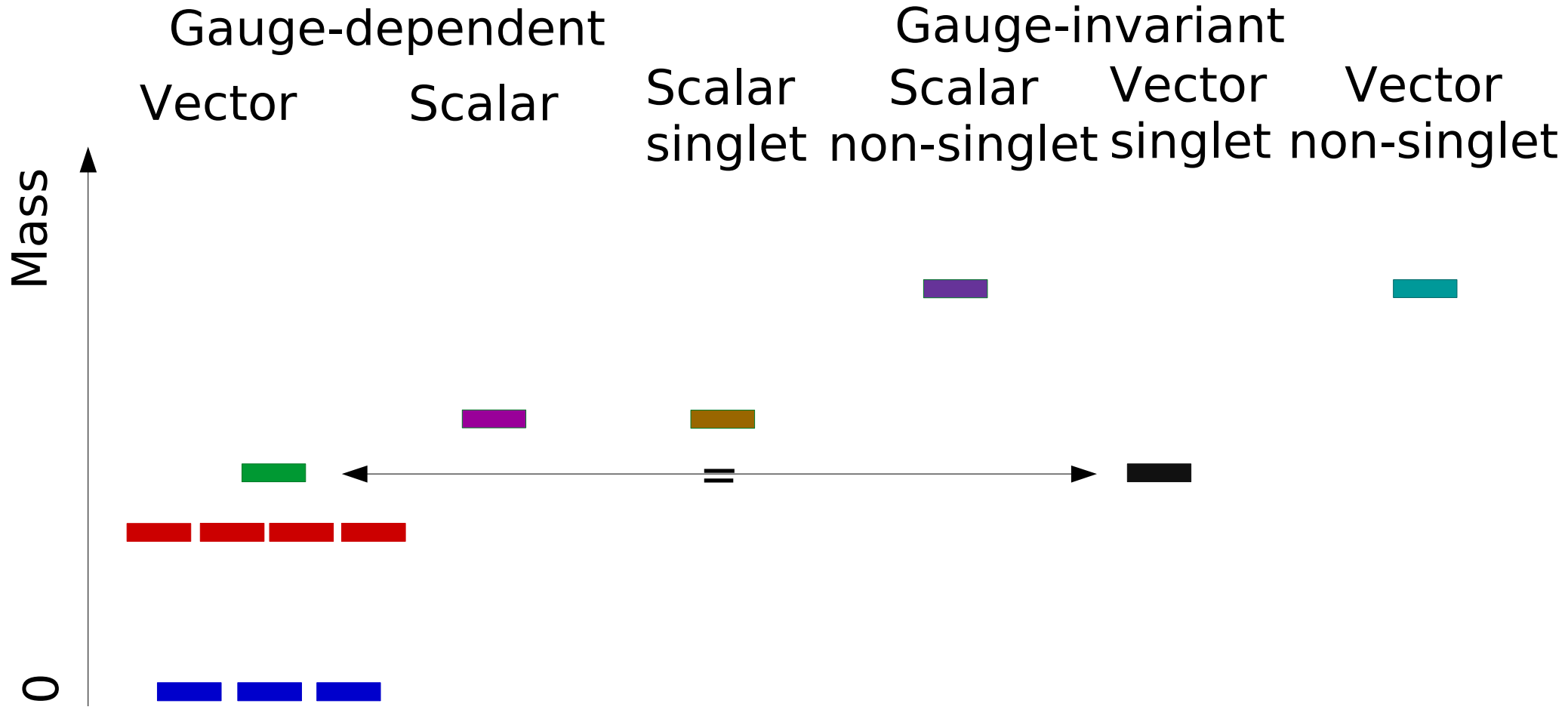
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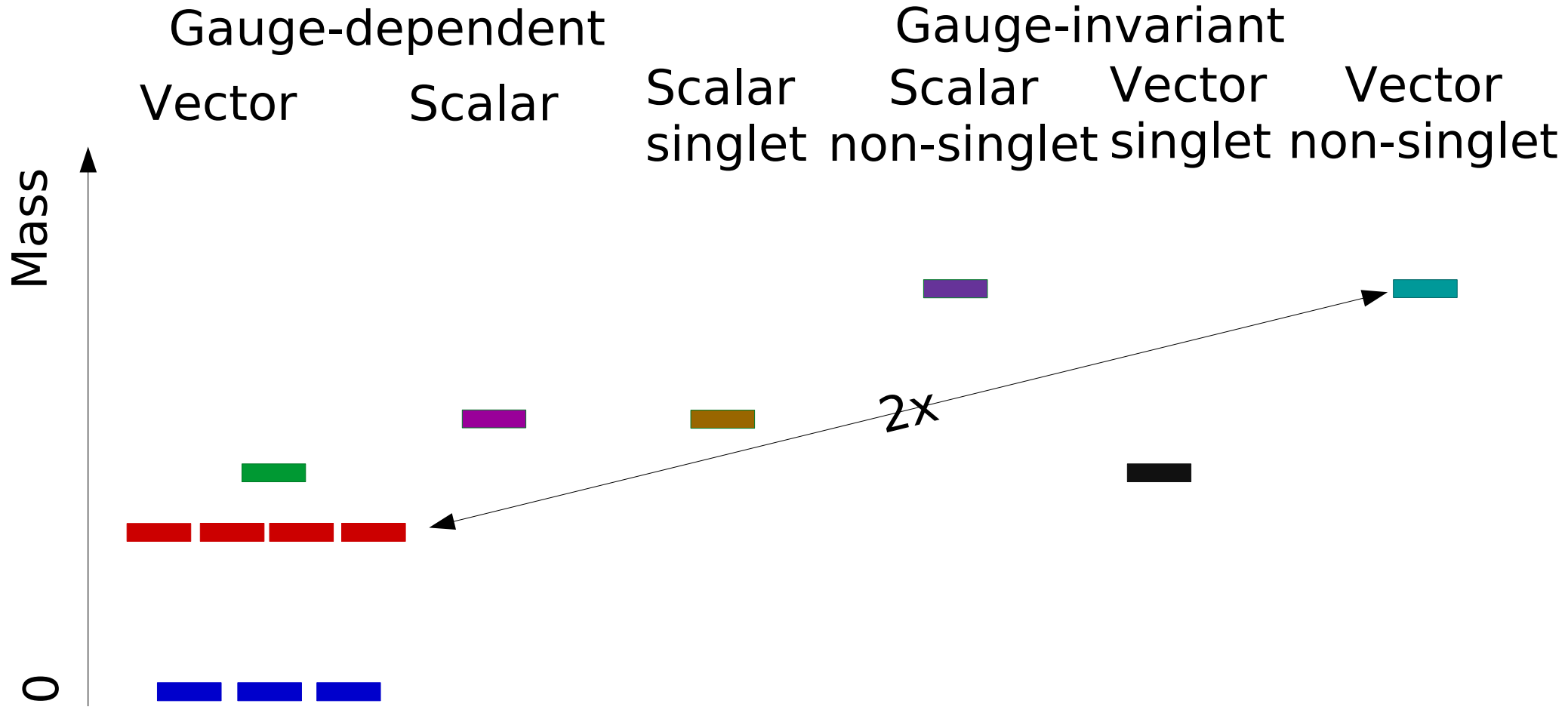


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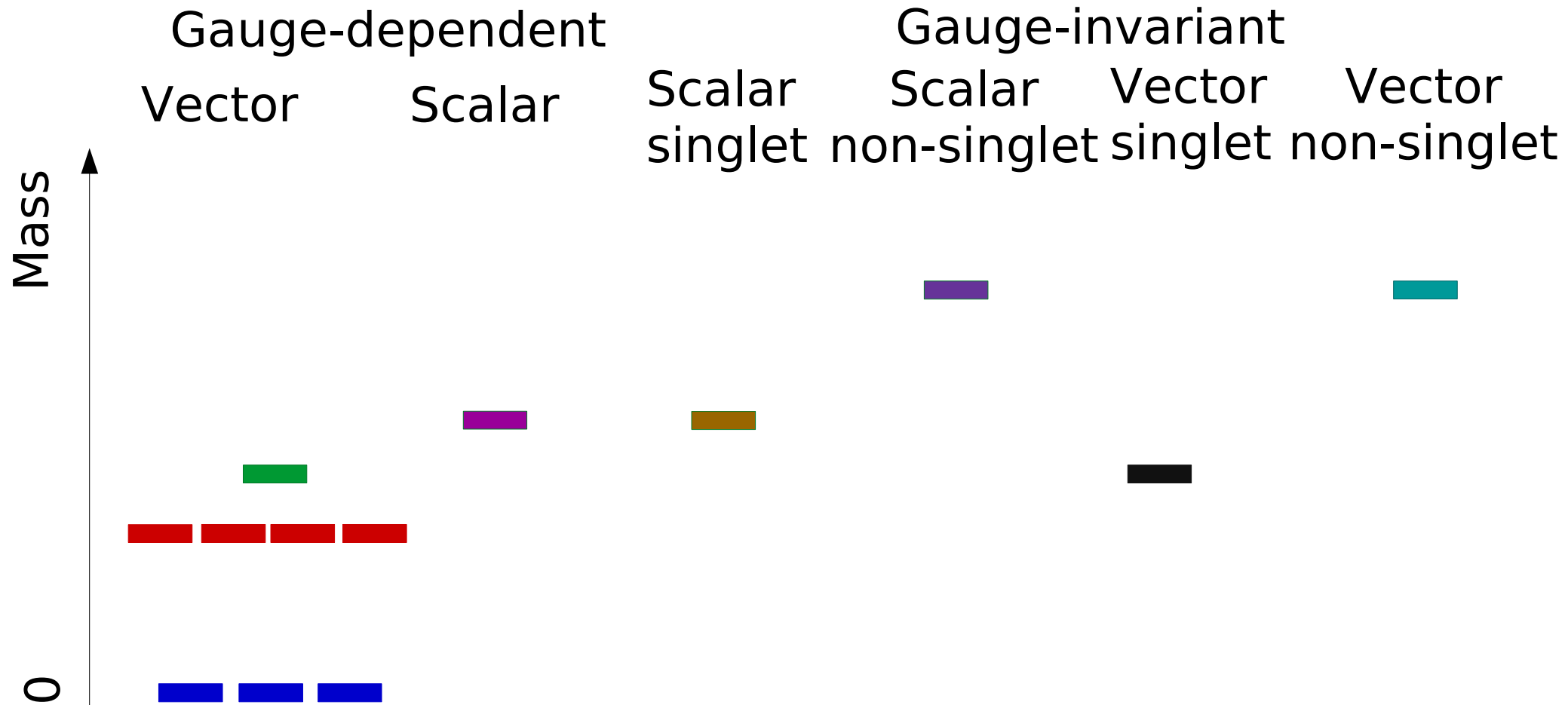
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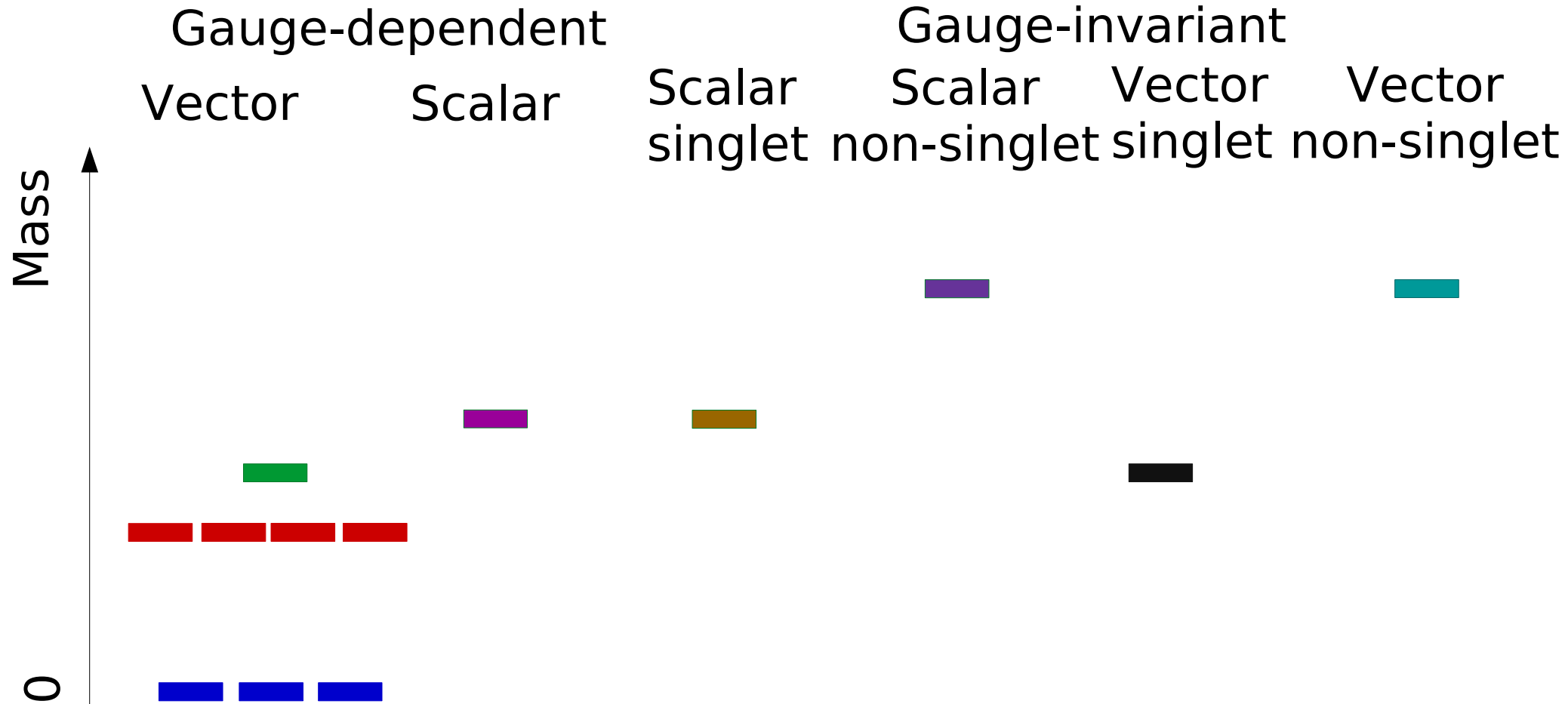
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- No mass gap! - But can be there: Adjoint Higgs

[Maas, Sondenheimer & Törek'17, Shigemitsu & Lee'85, Afferrante, Maas, Törek, unpublished]

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  - Different from perturbation theory
    - Operators limited to asymptotic, elementary, gauge-dependent states
- Formulate gauge-invariant, composite operators
  - Bound state structure – non-perturbative methods?
  - But coupling is still weak and there is a BEH

# How to make predictions

[Fröhlich et al.'80,'81,  
Maas & Törek'16,'18,  
Maas, Sondenheimer & Törek'17]

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  - But coupling is still weak and there is a BEH
  - Perform double expansion [Fröhlich et al.'80, Maas'12]
    - Vacuum expectation value (FMS mechanism)
    - Standard expansion in couplings
    - Together: Gauge-invariant perturbation theory

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[Fröhlich et al.'80,'81  
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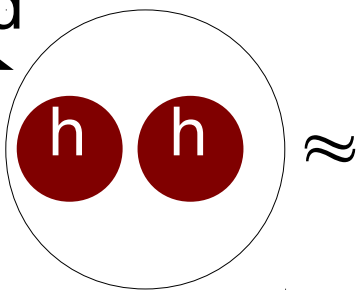
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Bound  
state  
mass



$\approx$



+



+ something small

Higgs  
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[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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- $W_\mu^a$  

- Coupling  $g$  and some numbers  $f^{abc}$



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- **Ws**  $W_\mu^a$  
- **Higgs**  $h_i$  

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- **Ws**  $W_\mu^a$  
- **Higgs**  $h_i$  
- No QED: Ws and Zs are degenerate
- Couplings  $g, v, \lambda$  and some numbers  $f^{abc}$  and  $t_a^{ij}$

# Symmetries of the system

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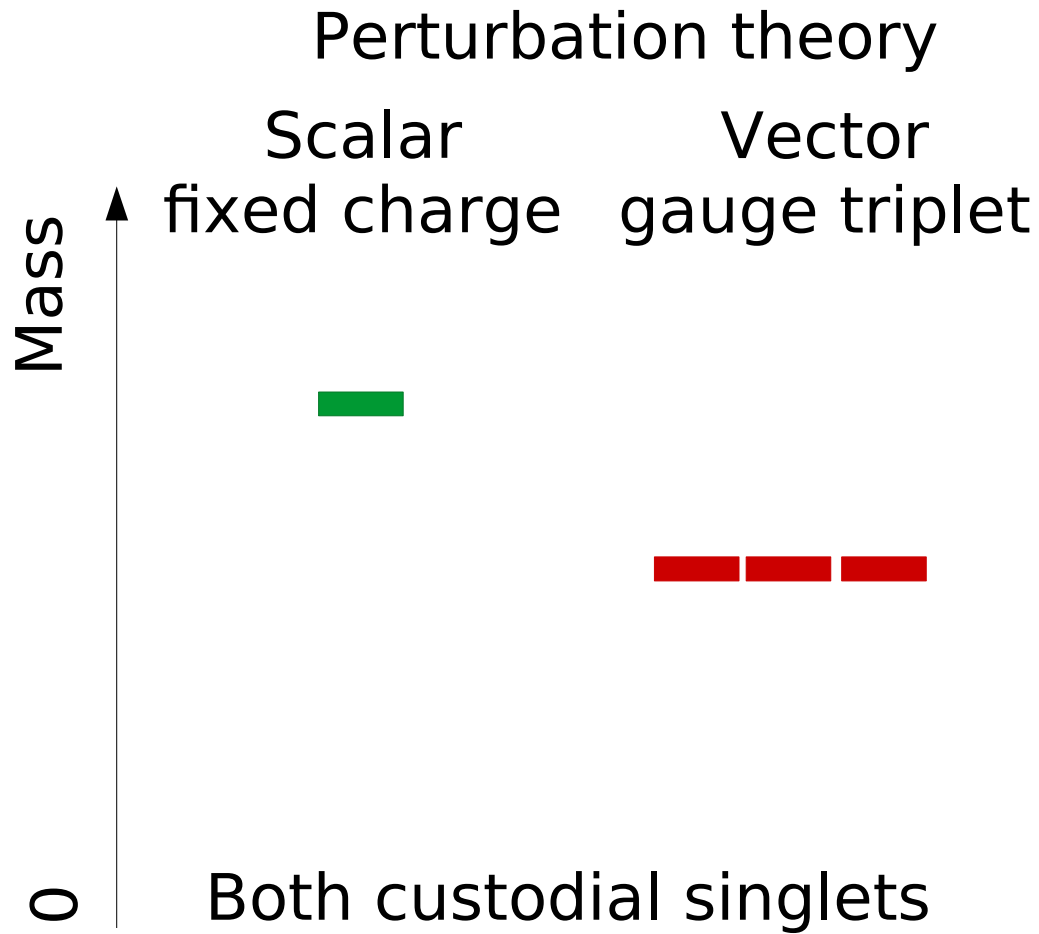
- Global SU(2) Higgs custodial (flavor) symmetry

- Acts as (right-)transformation on the Higgs field only

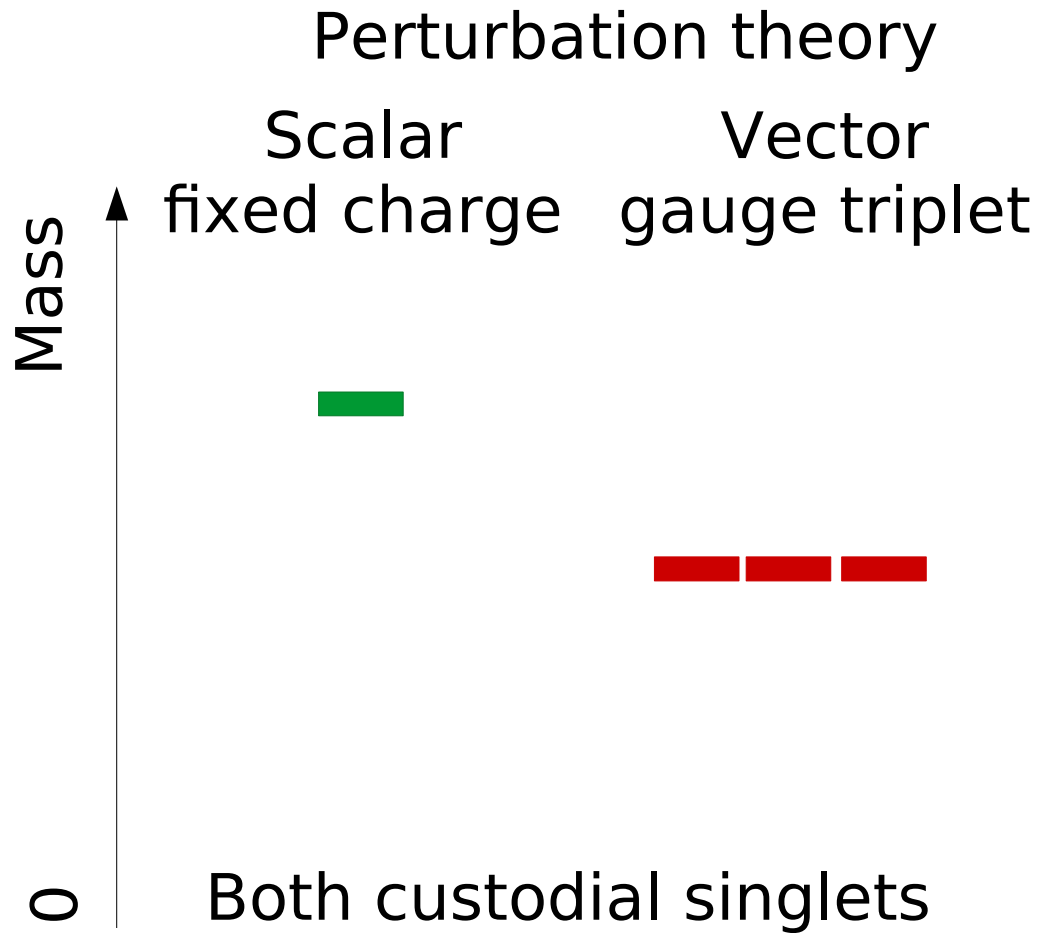
$$W_\mu^a \rightarrow W_\mu^a \qquad h_i \rightarrow h_i + a^{ij} h_j + b^{ij} h_j^*$$



# Physical spectrum

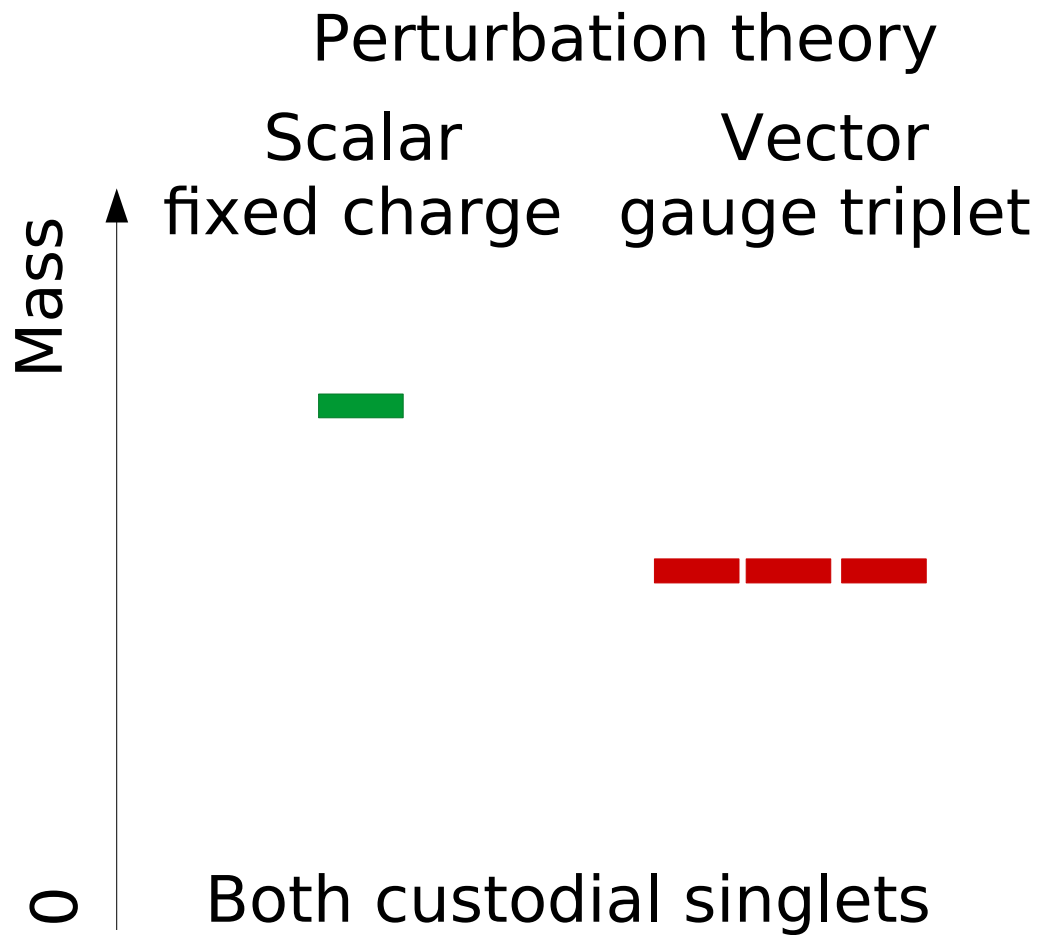


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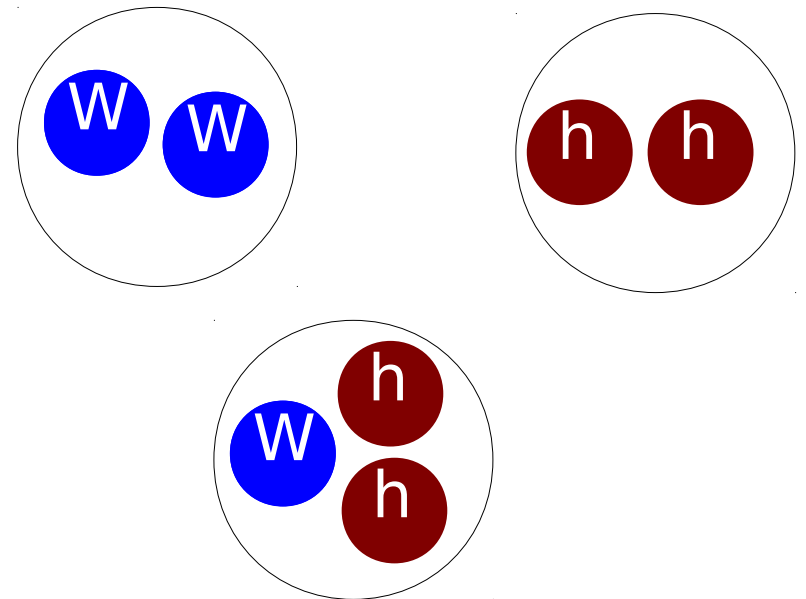


Experiment tells that somehow the left is correct

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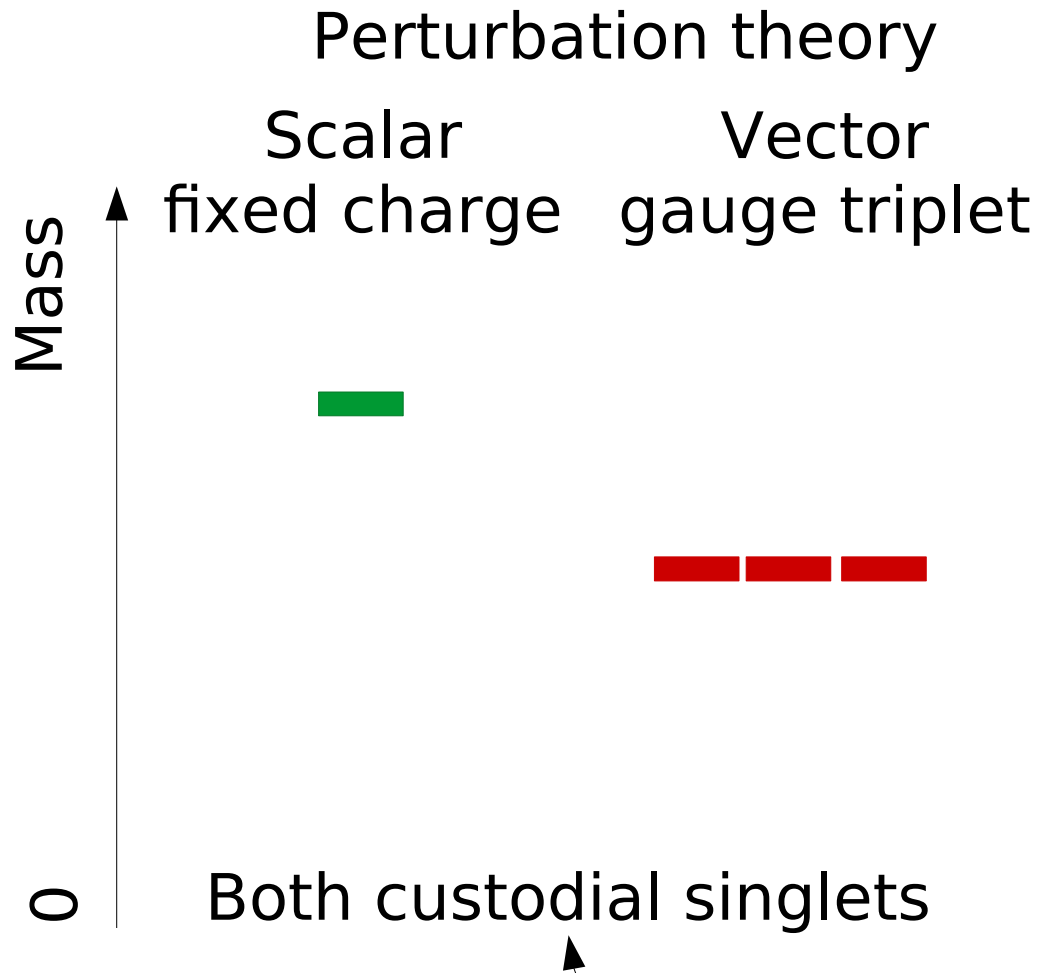


Composite (bound) states

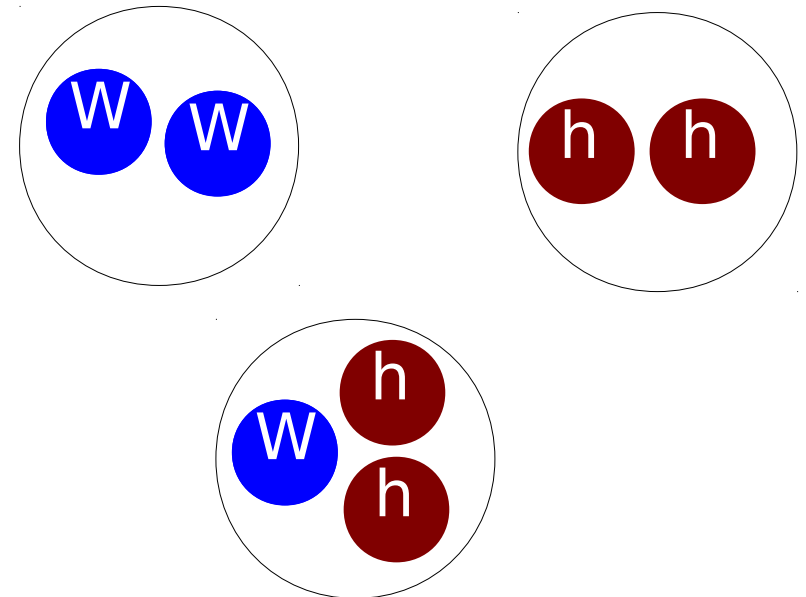


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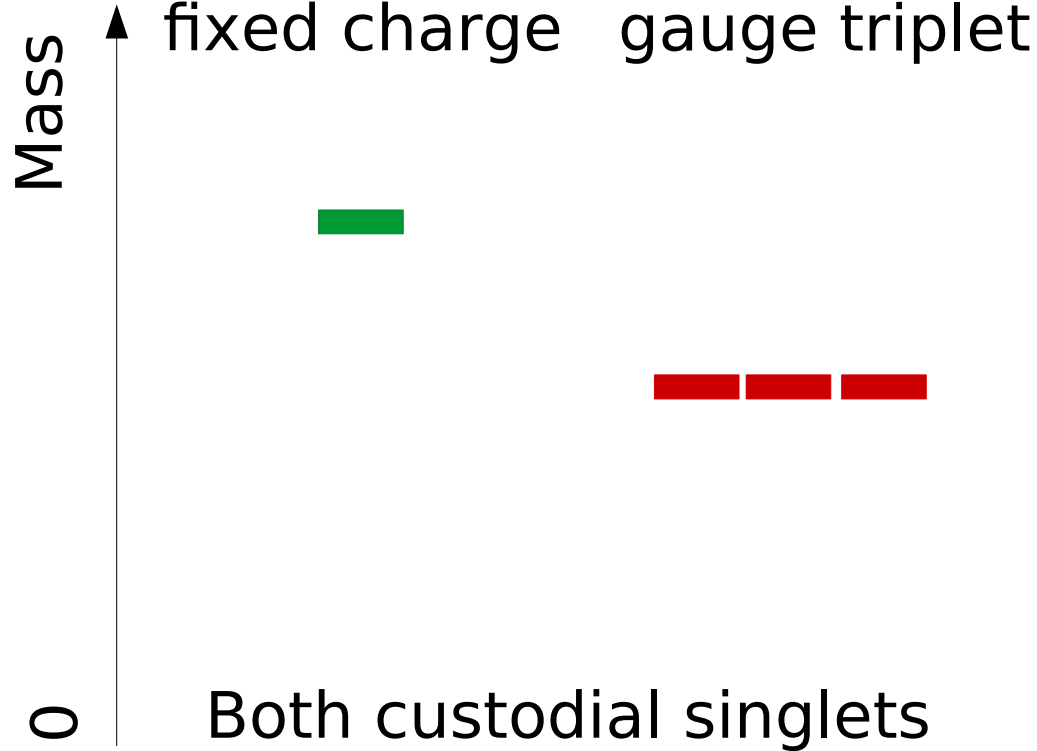
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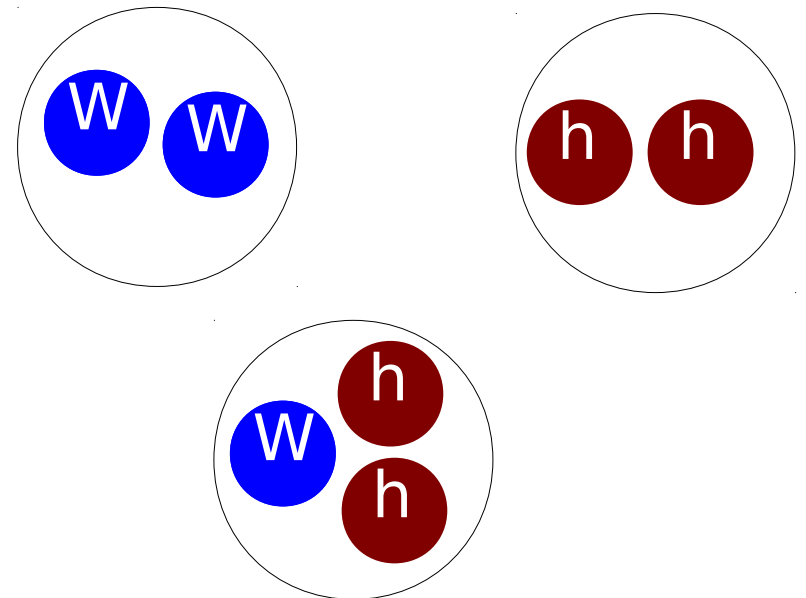
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# Physical spectrum

Perturbation theory  
Scalar fixed charge      Vector gauge triplet



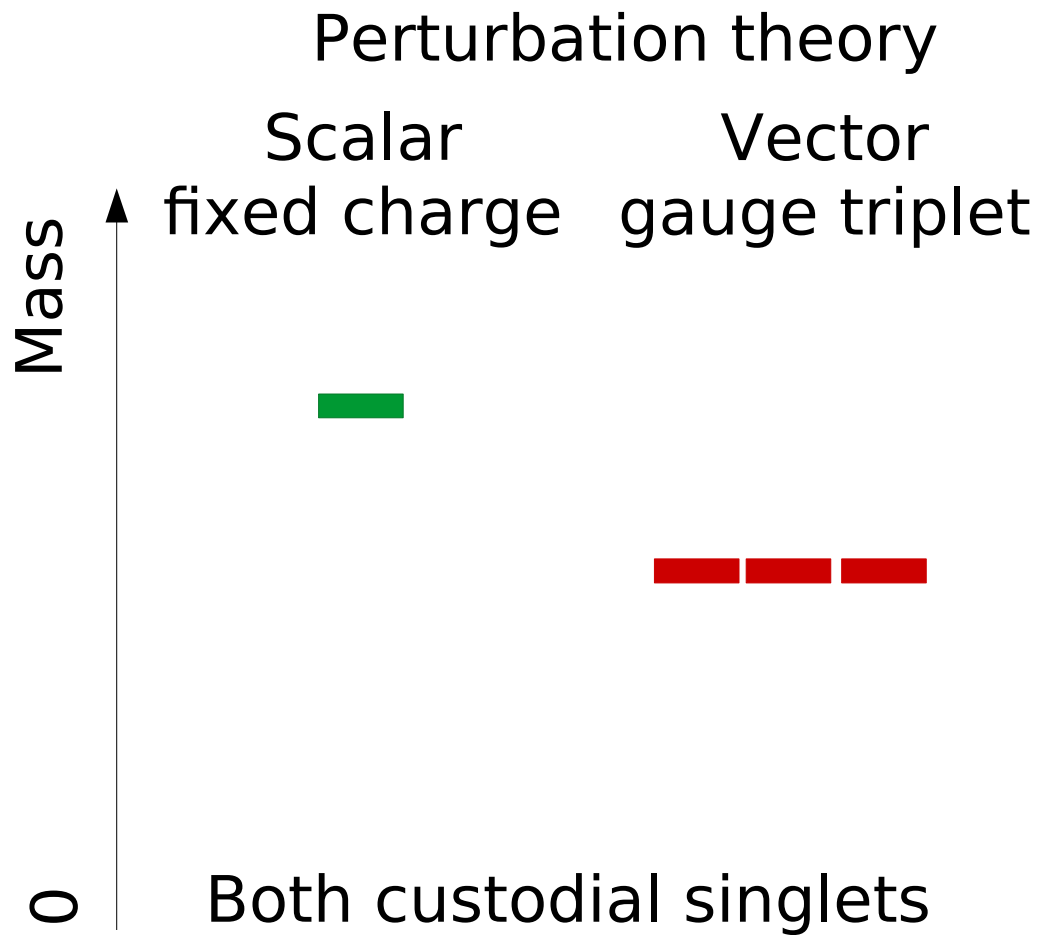
Composite (bound) states  
Require non-perturbative methods



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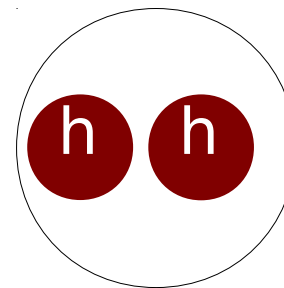
[Maas'12, Maas & Mufti'14]



Gauge-invariant

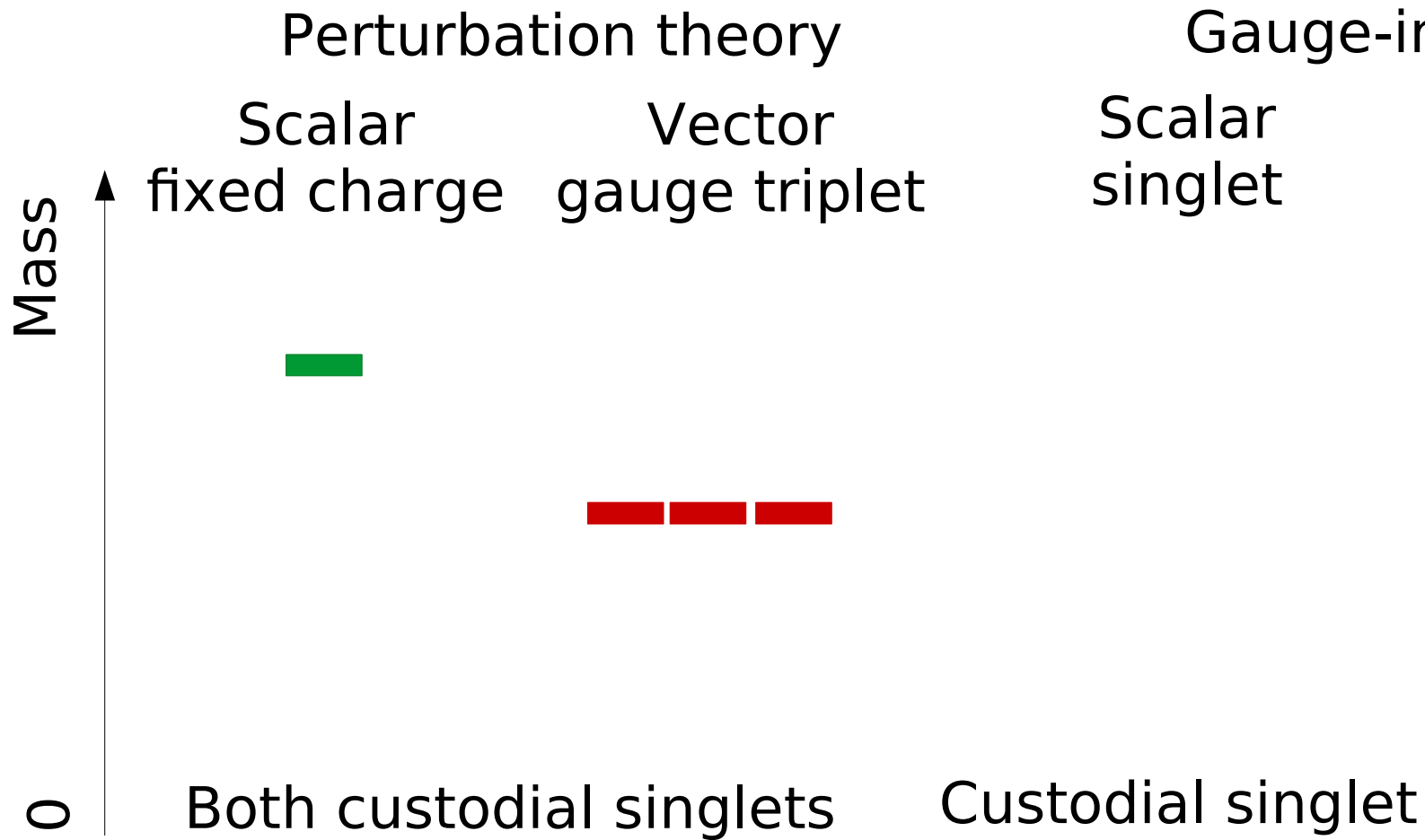
Scalar singlet

$$h(x)^+ h(x)$$

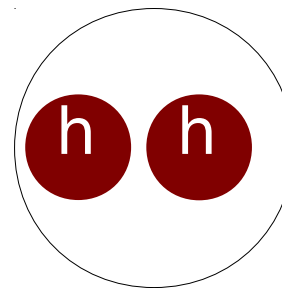


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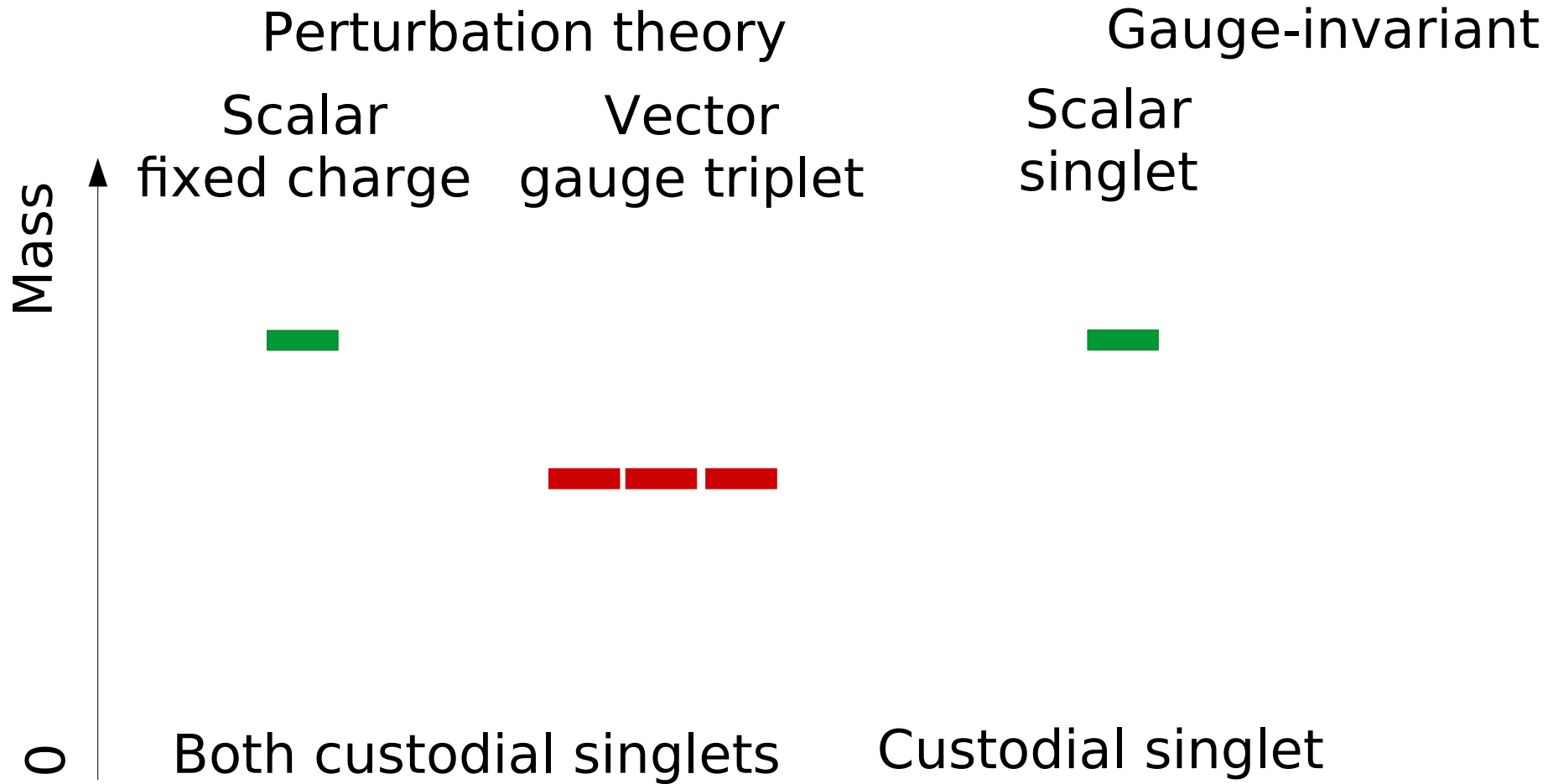


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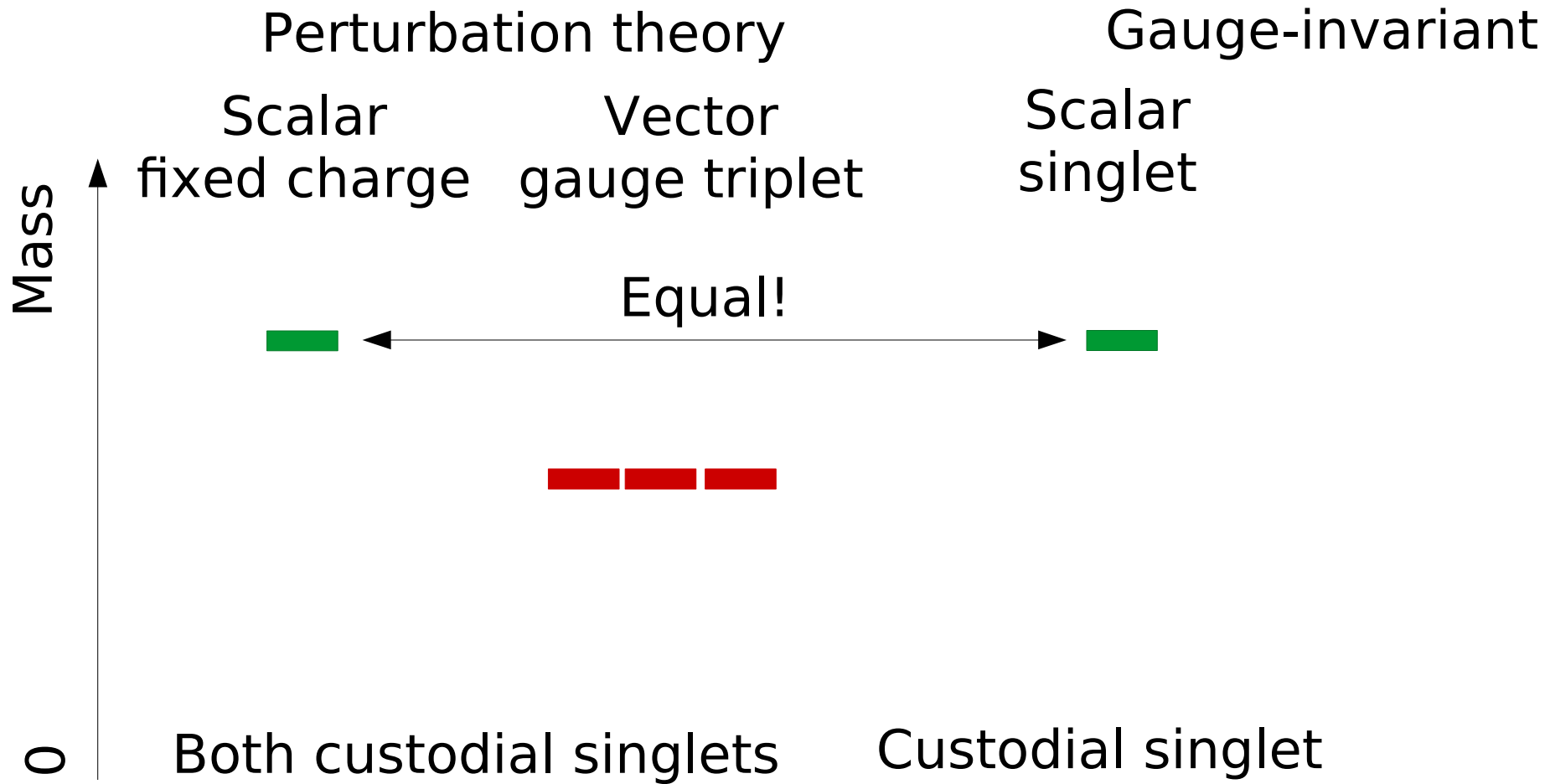
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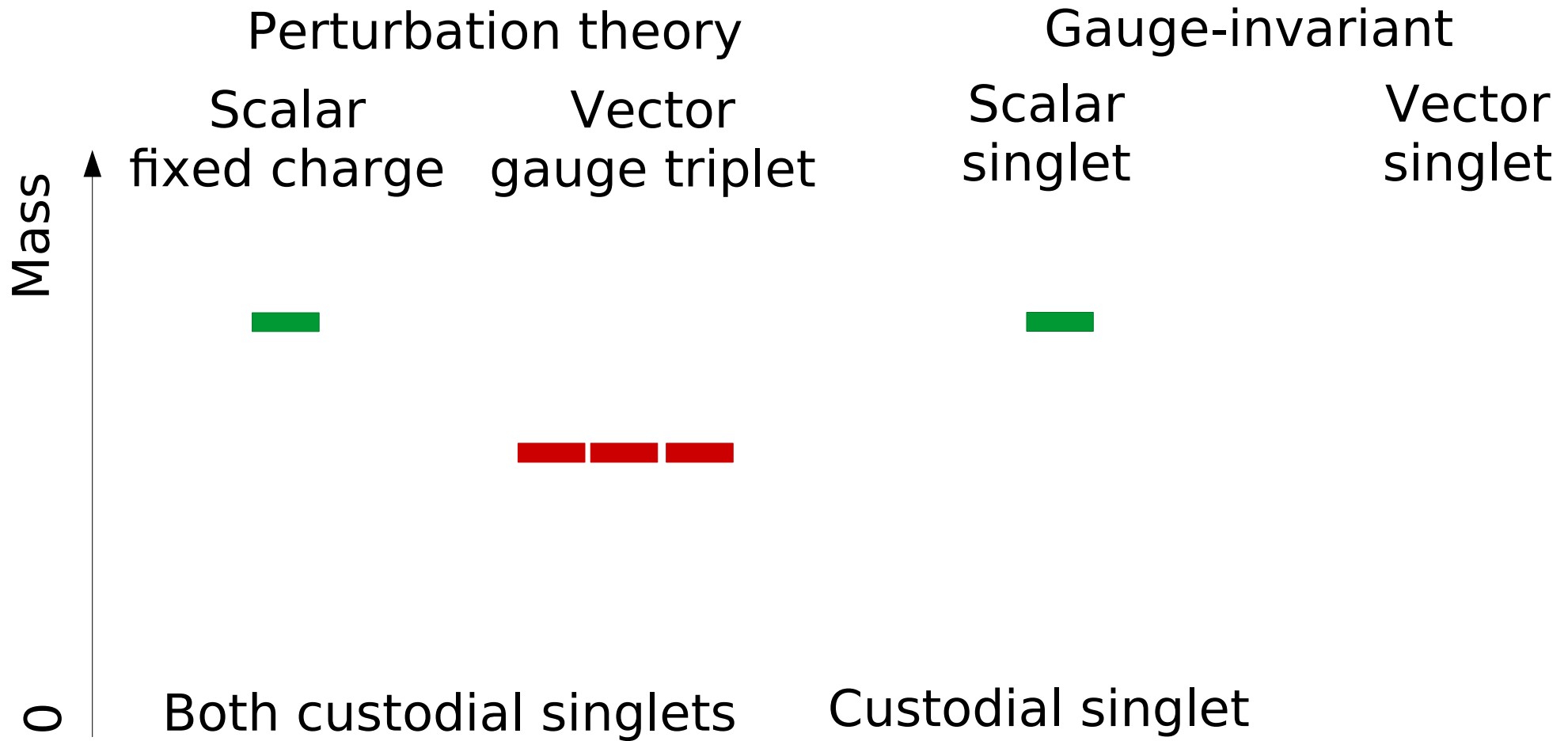
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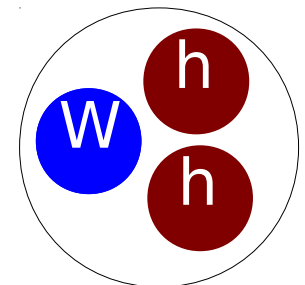
- Predicted in GIPT and confirmed on the lattice

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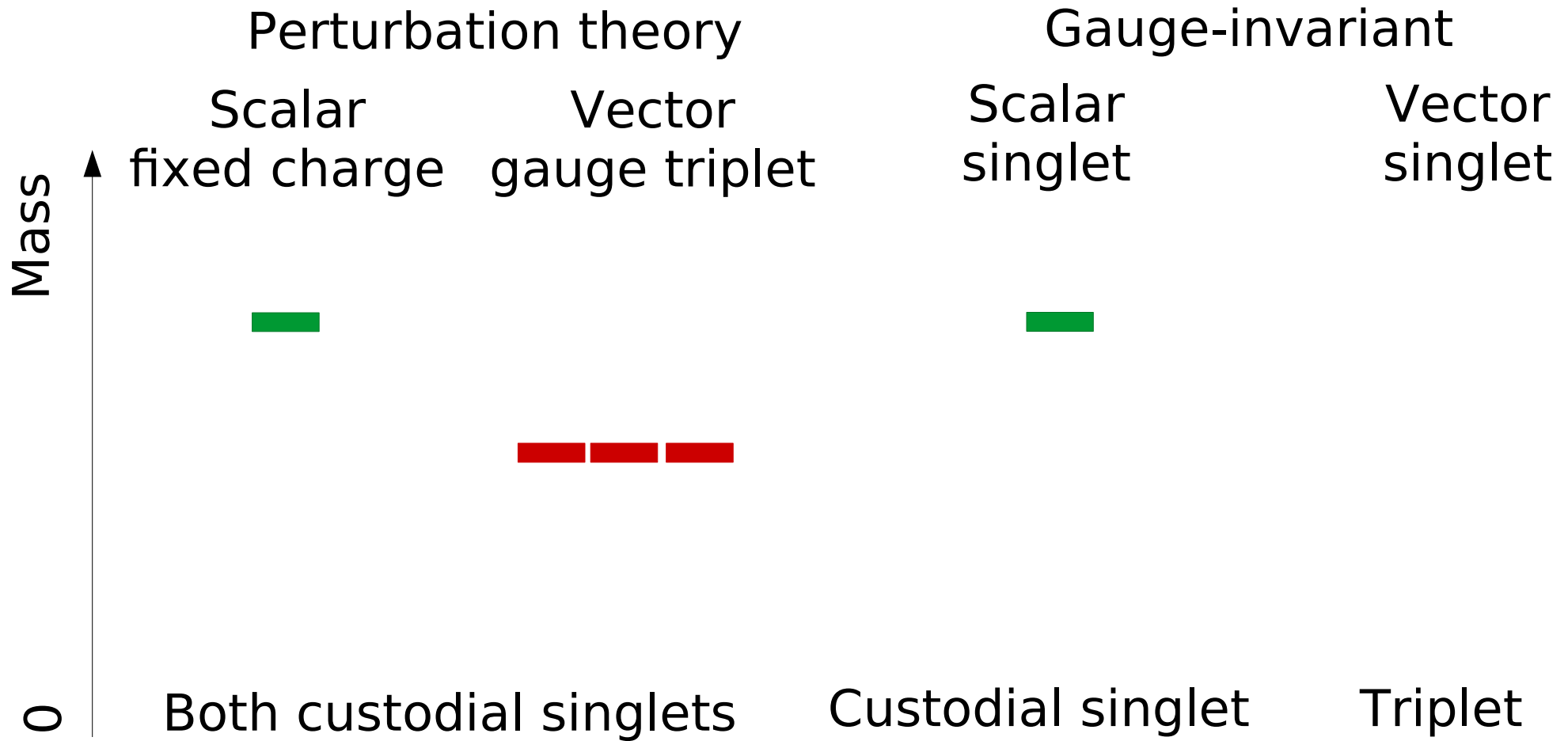


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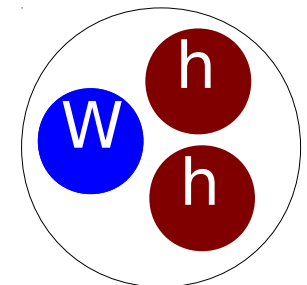


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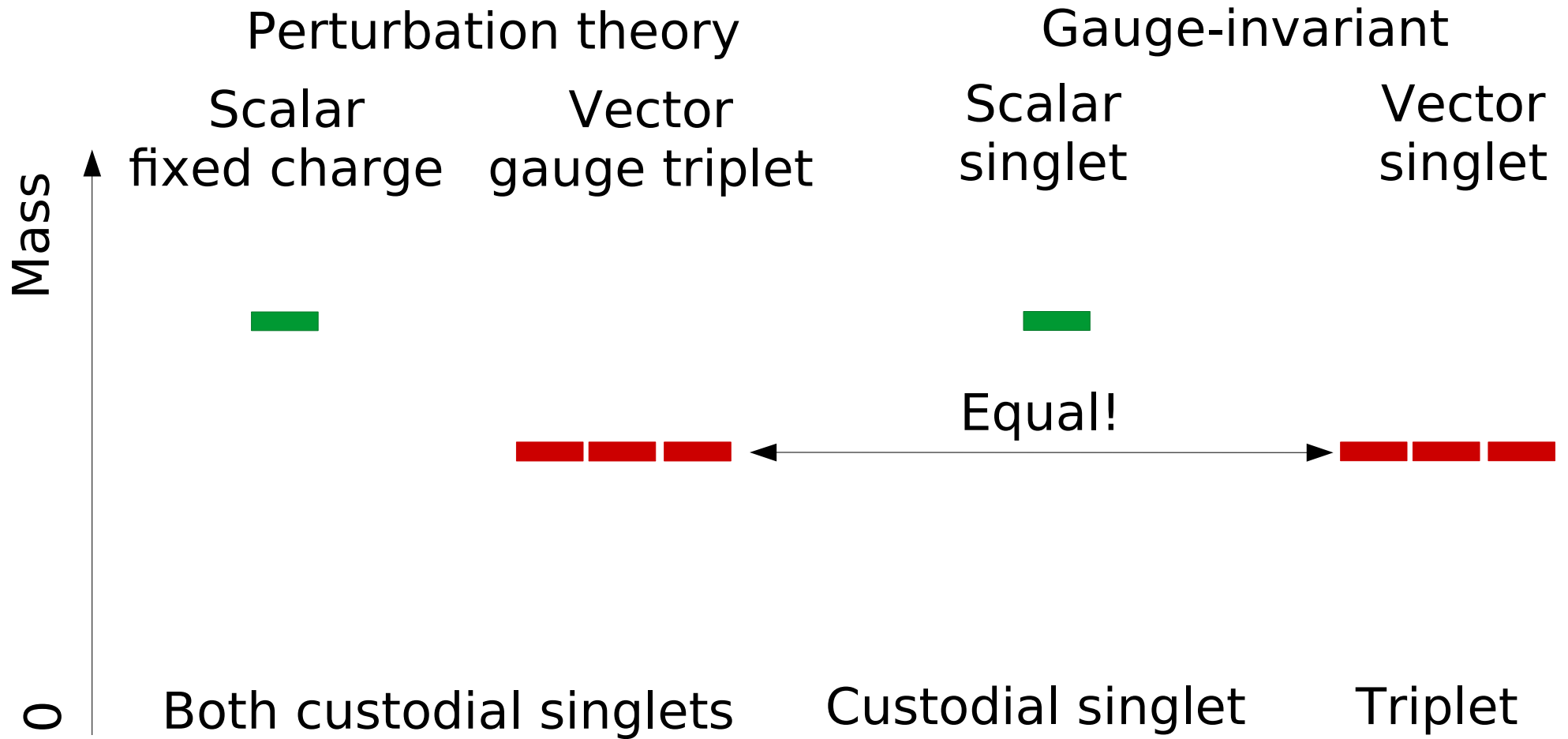


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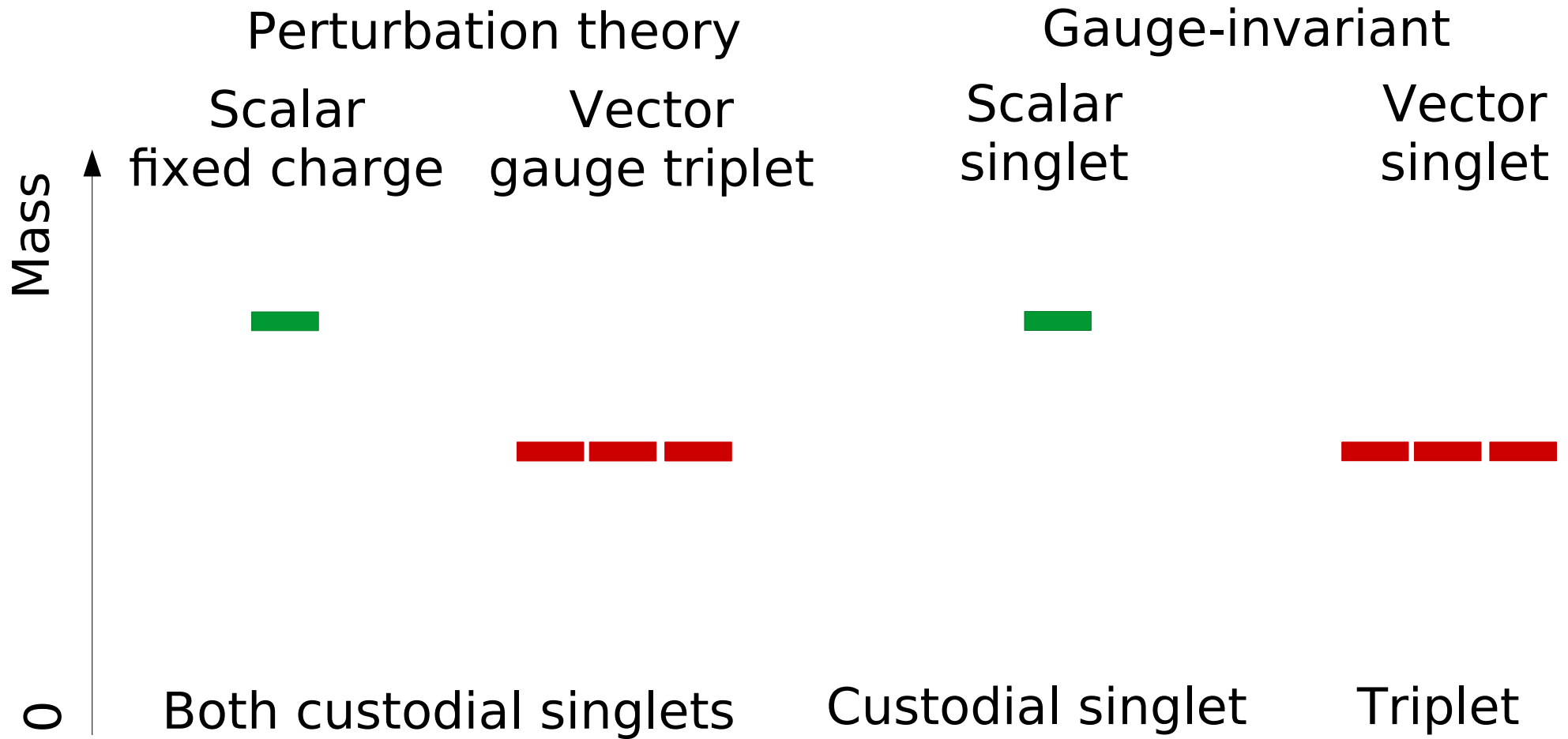
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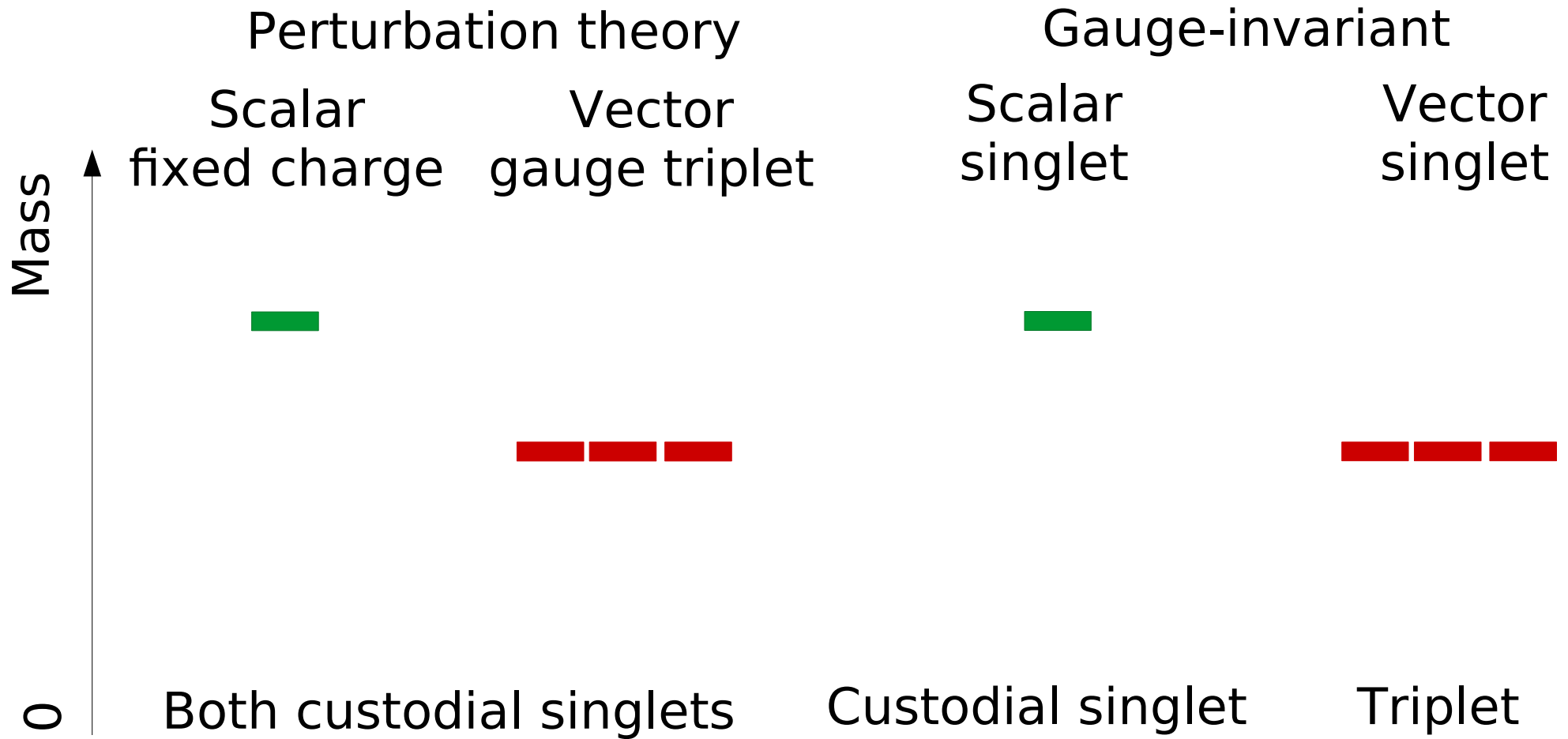
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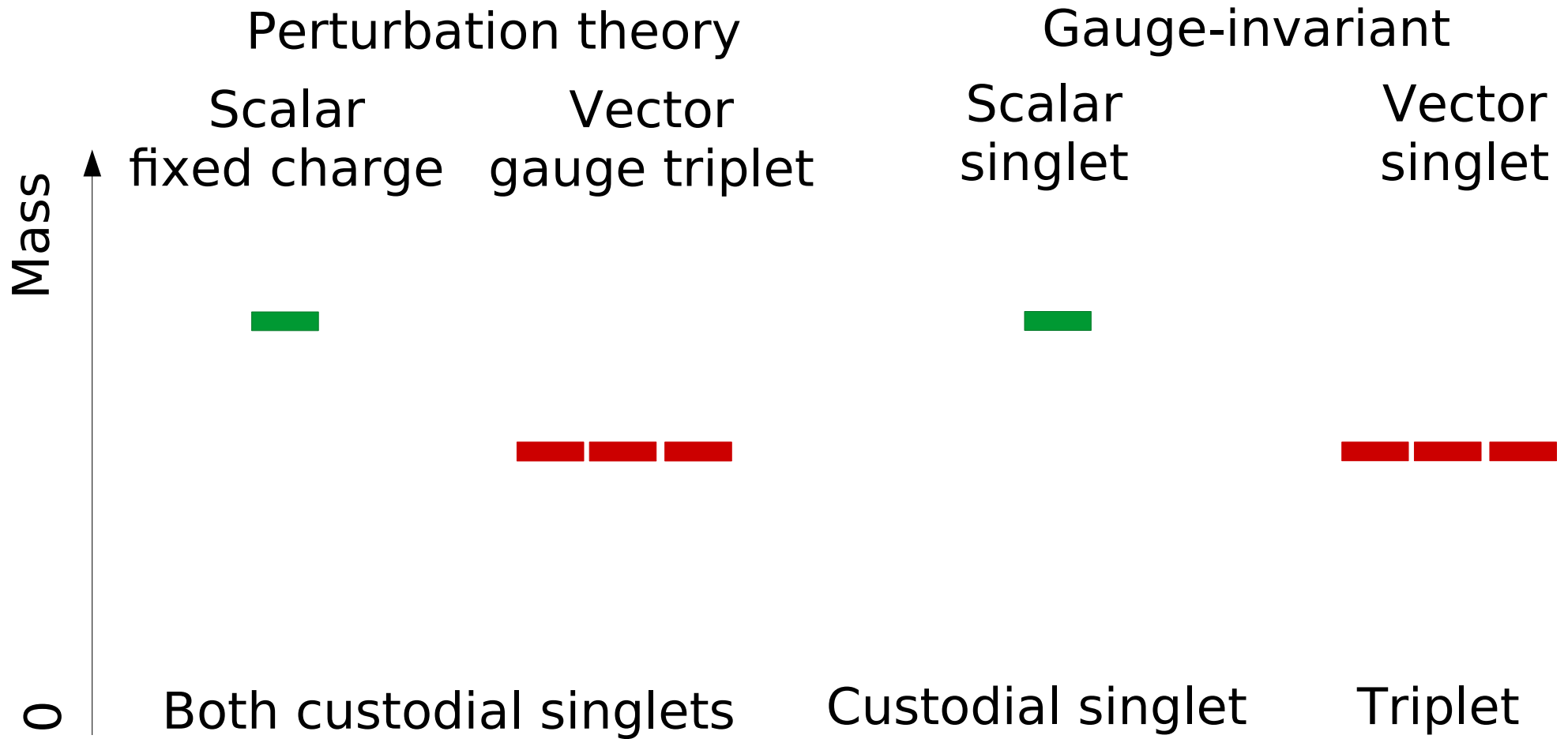
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  - Rest of the standard model?

# 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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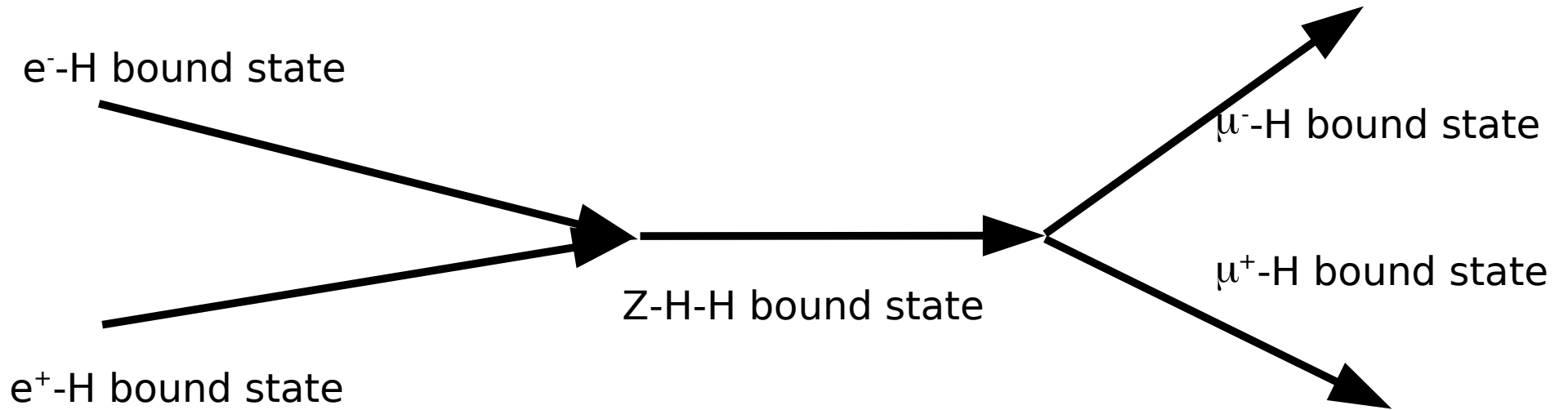
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- Implications for experiment?

# How events looks like (LEP/ILC)

[Maas'12]

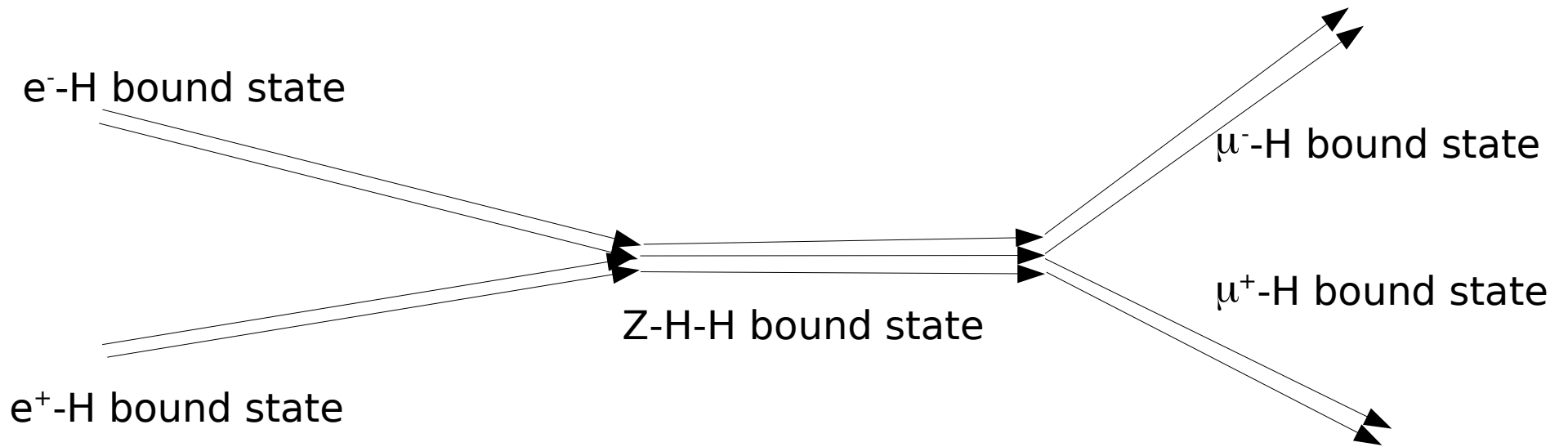


- Collision of bound states



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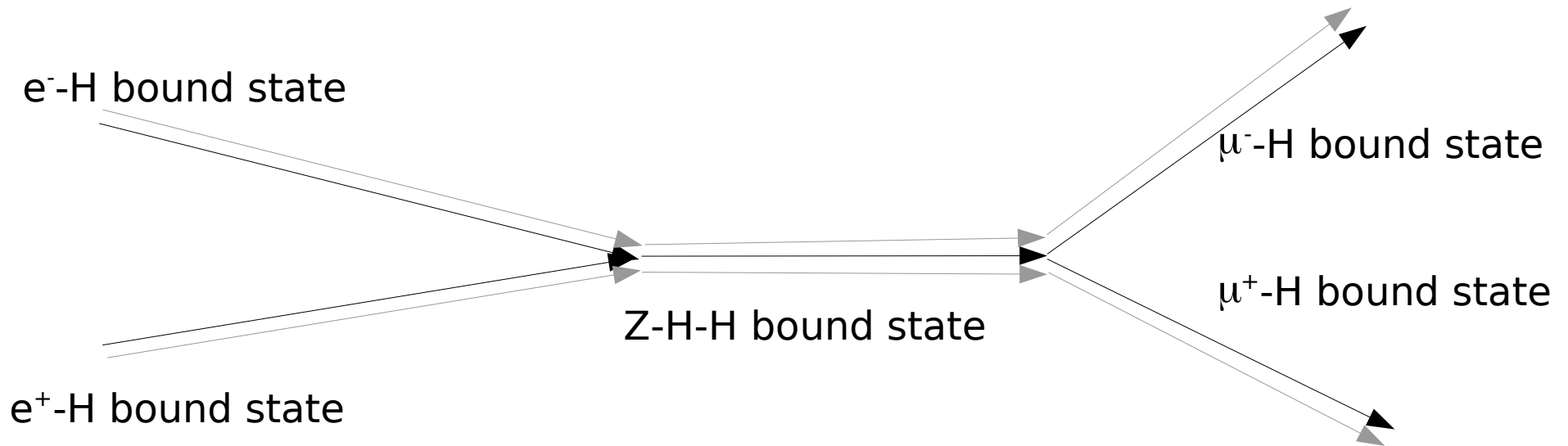
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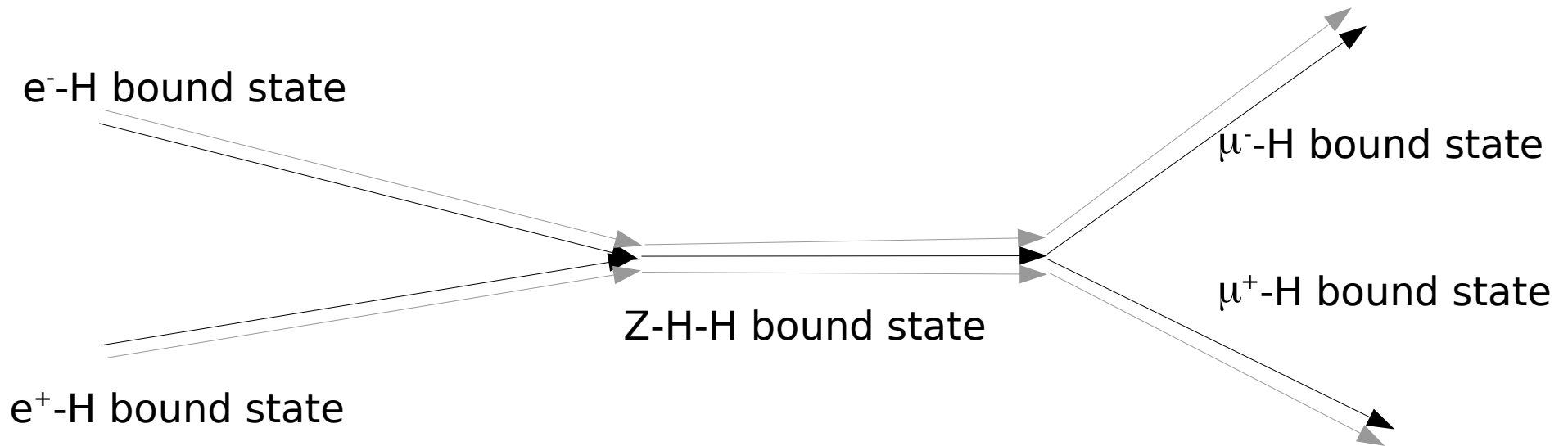
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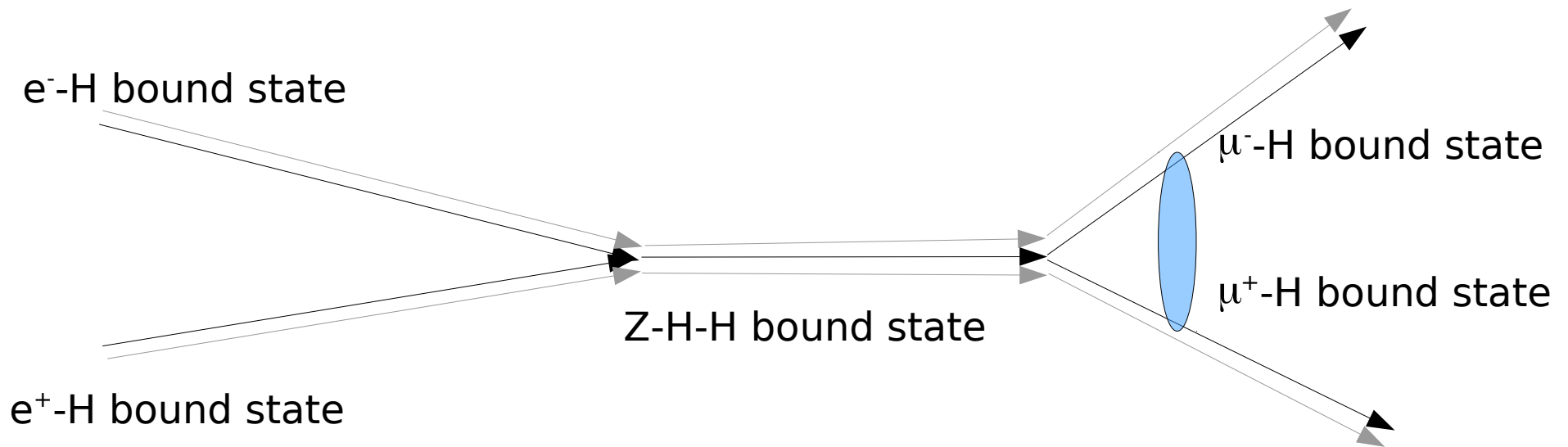
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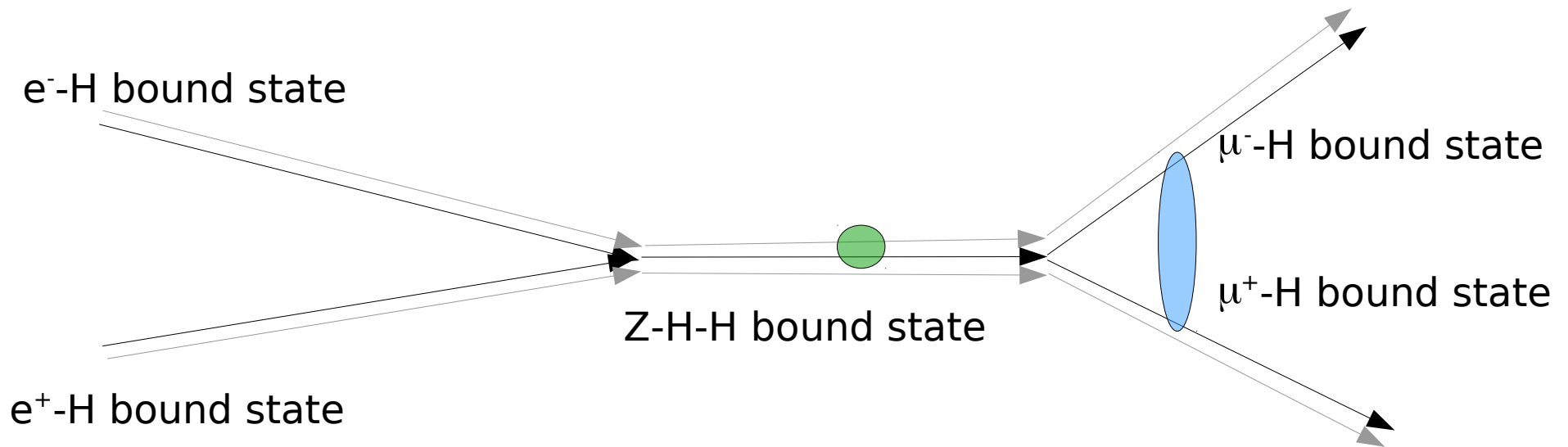
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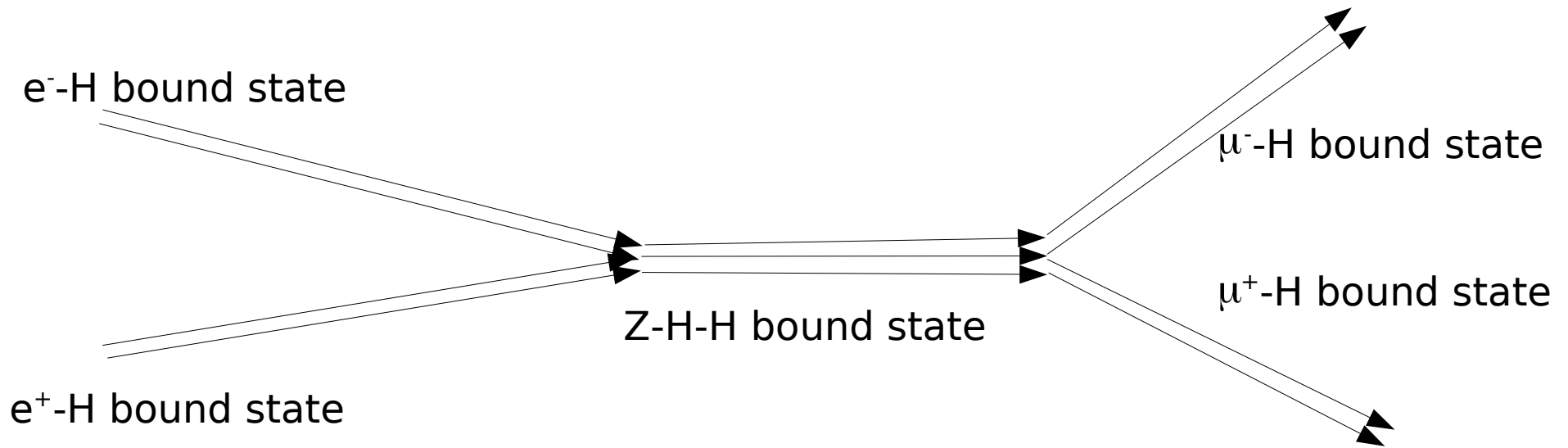
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- Collision of bound states - 'constituent' particles
- Higgs partners just spectators
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  - **Ordinary ones**: Large and detected
  - **New ones**: **Small**, require more sensitivity

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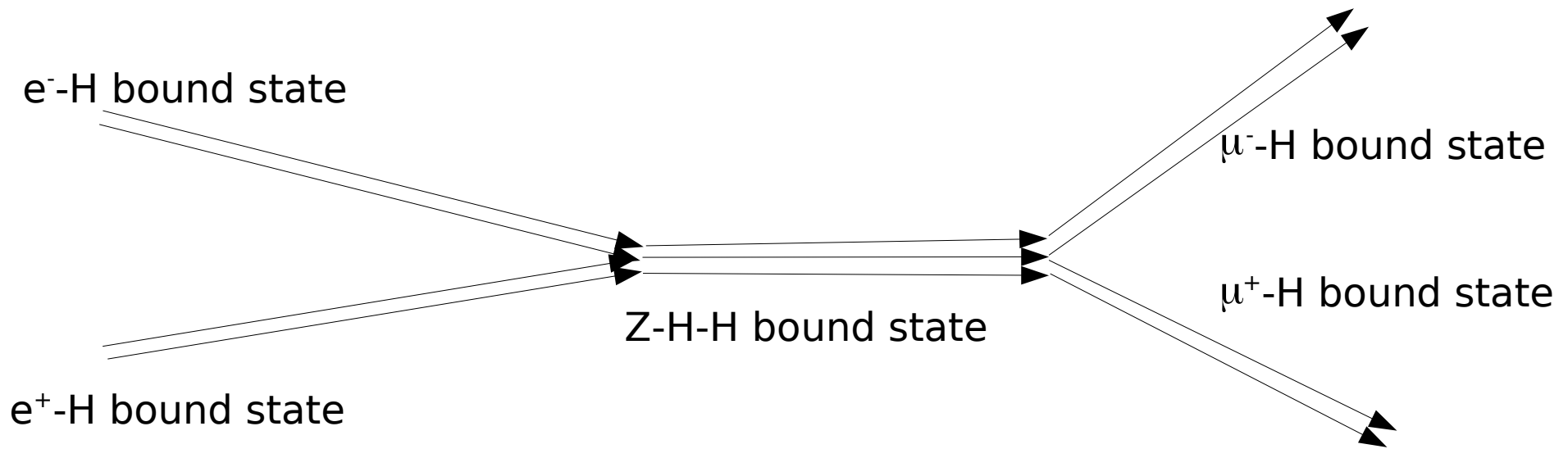
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Egger et al.'17]



- Description of impact?

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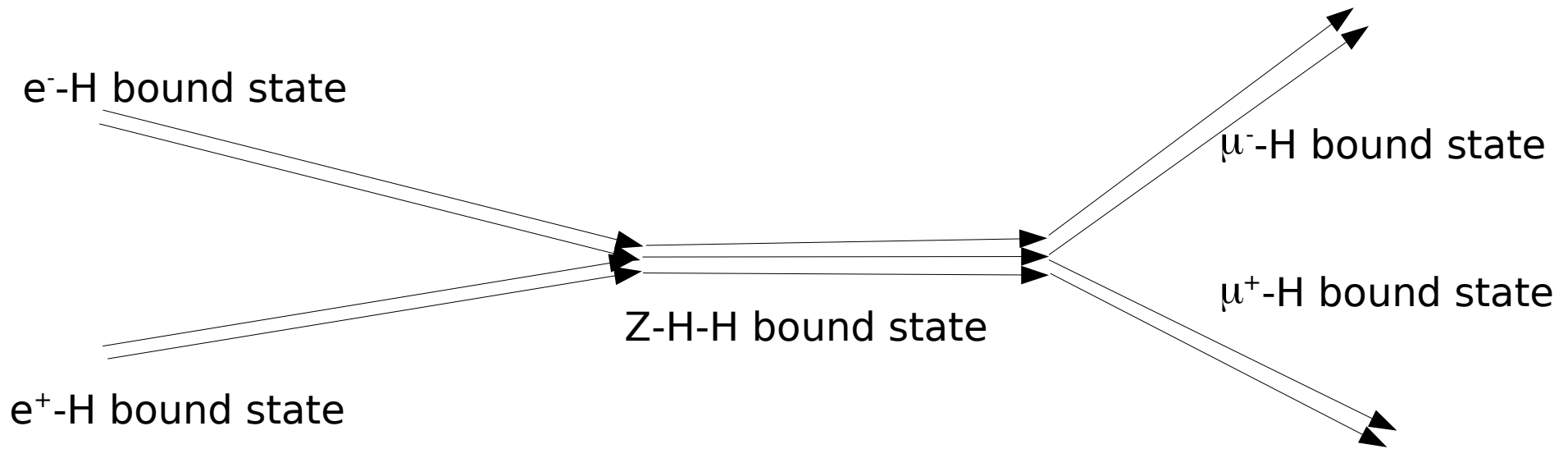
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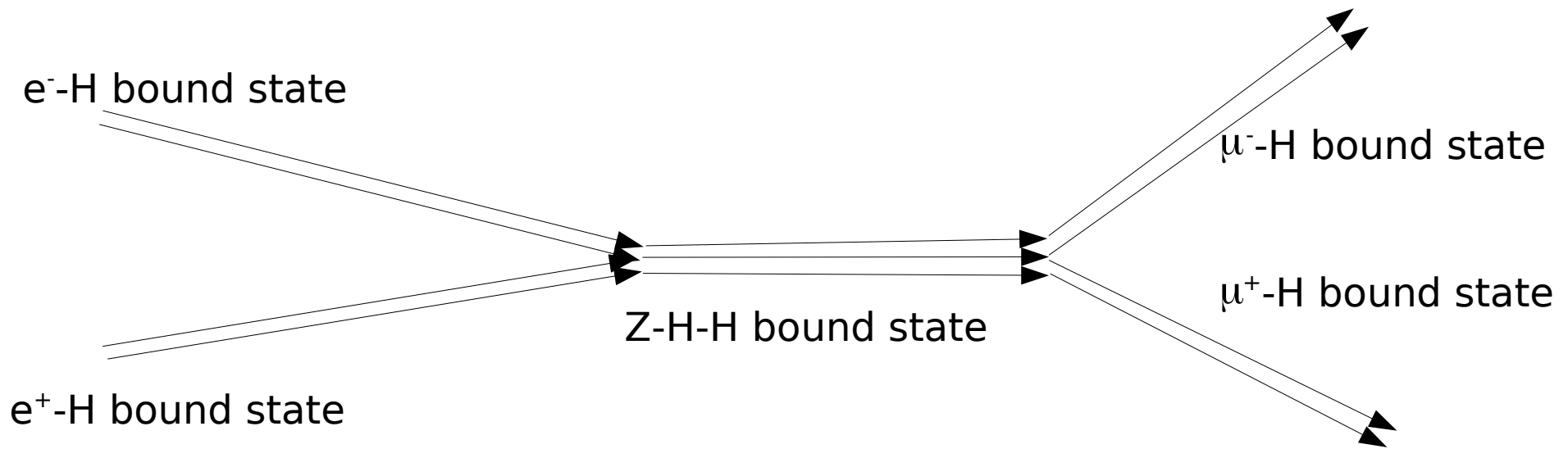
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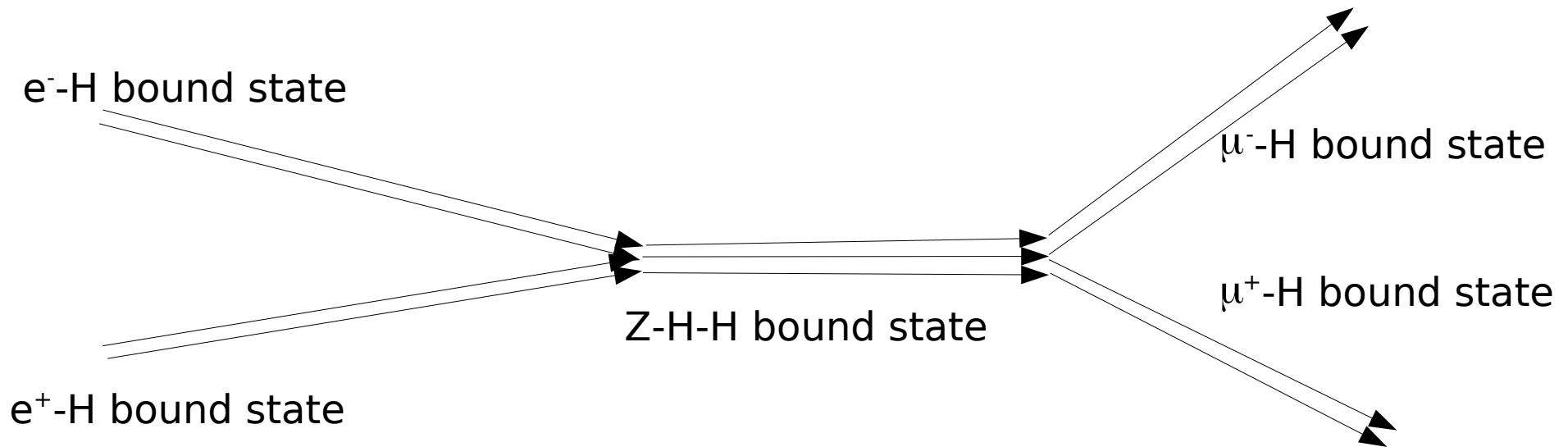
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- Ordinary contribution

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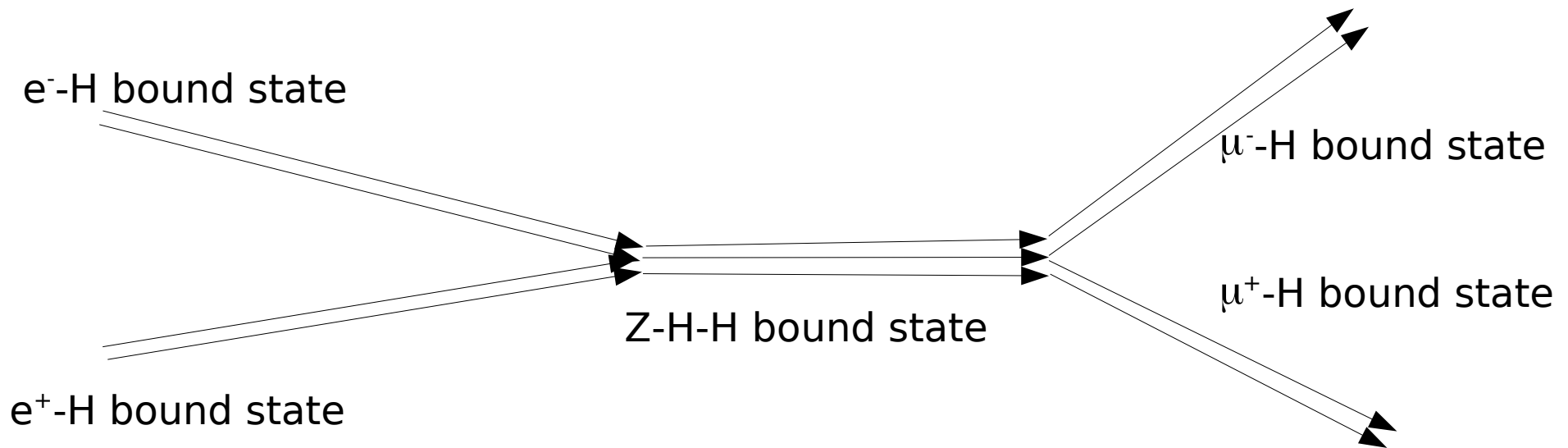
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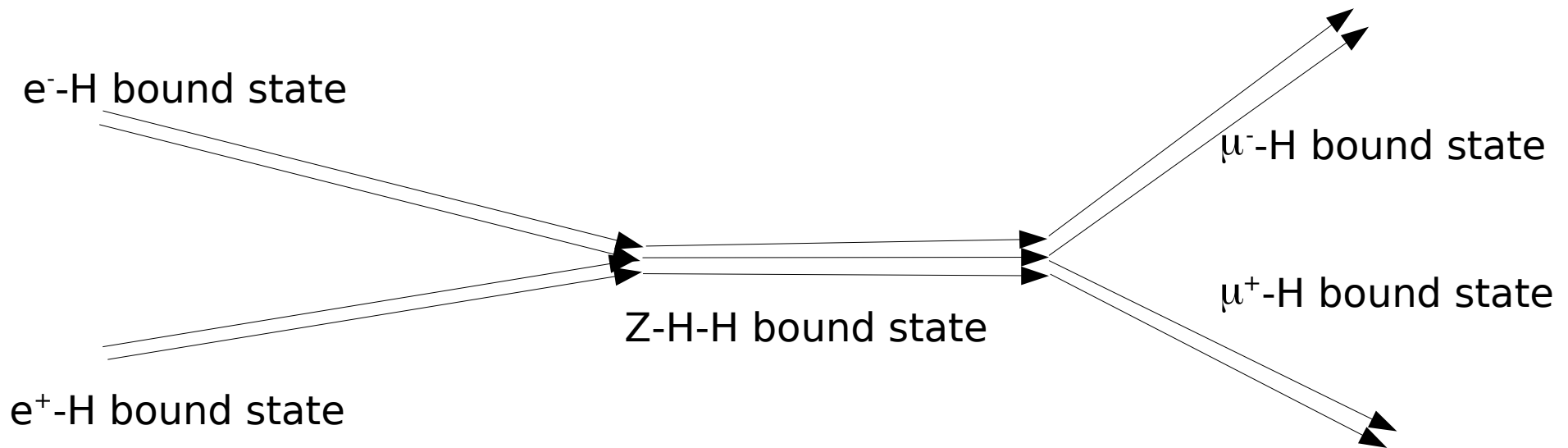
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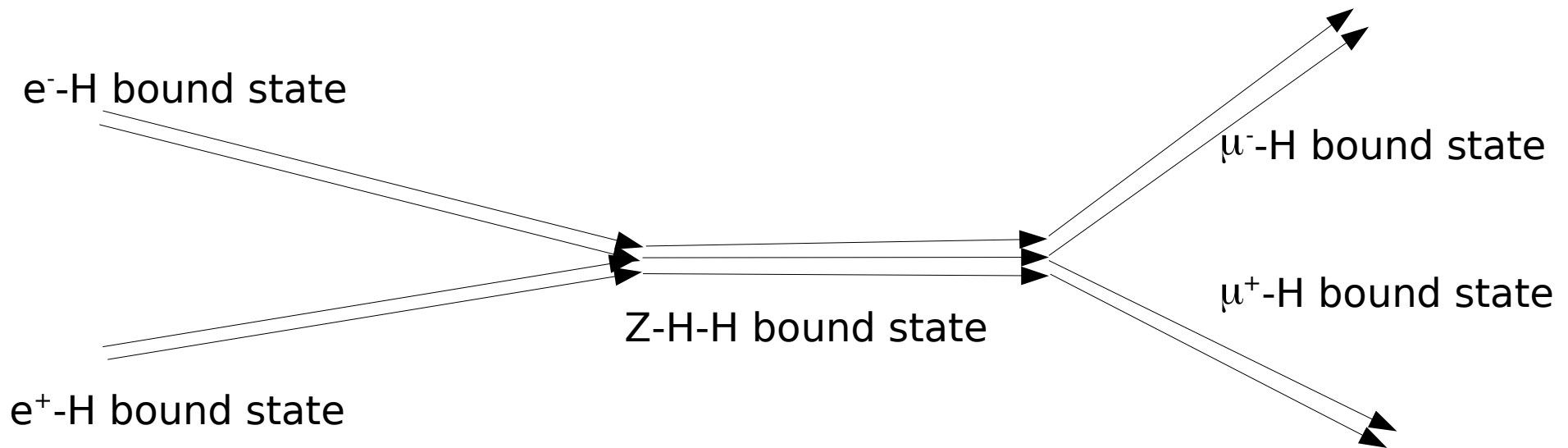
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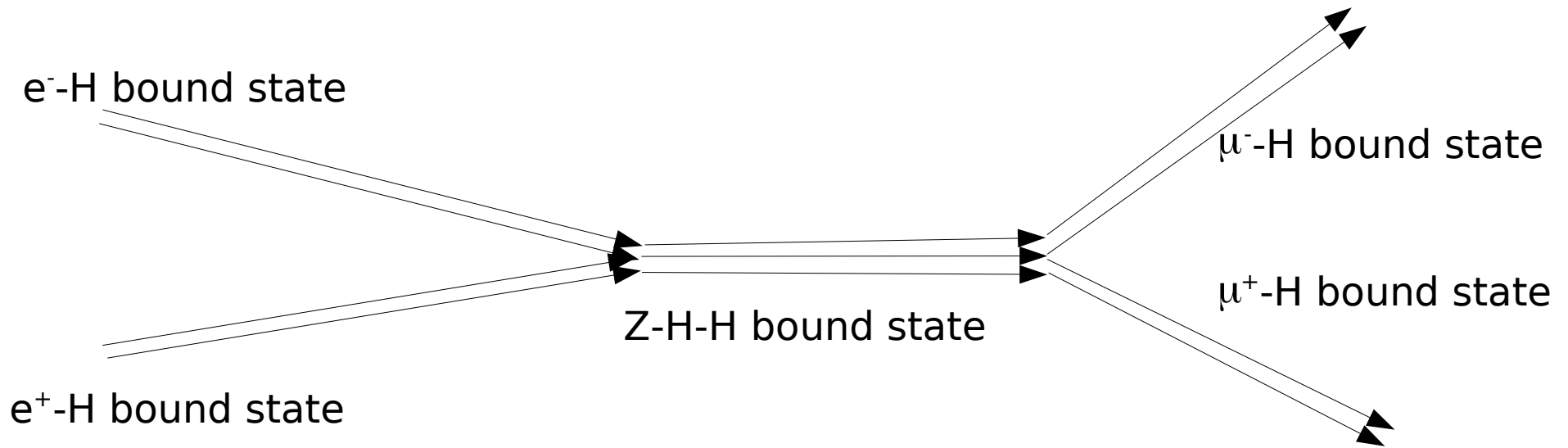
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- Ordinary contribution
- Modification of ordinary contribution
- Higgs as initial state
- More contributions...complicated

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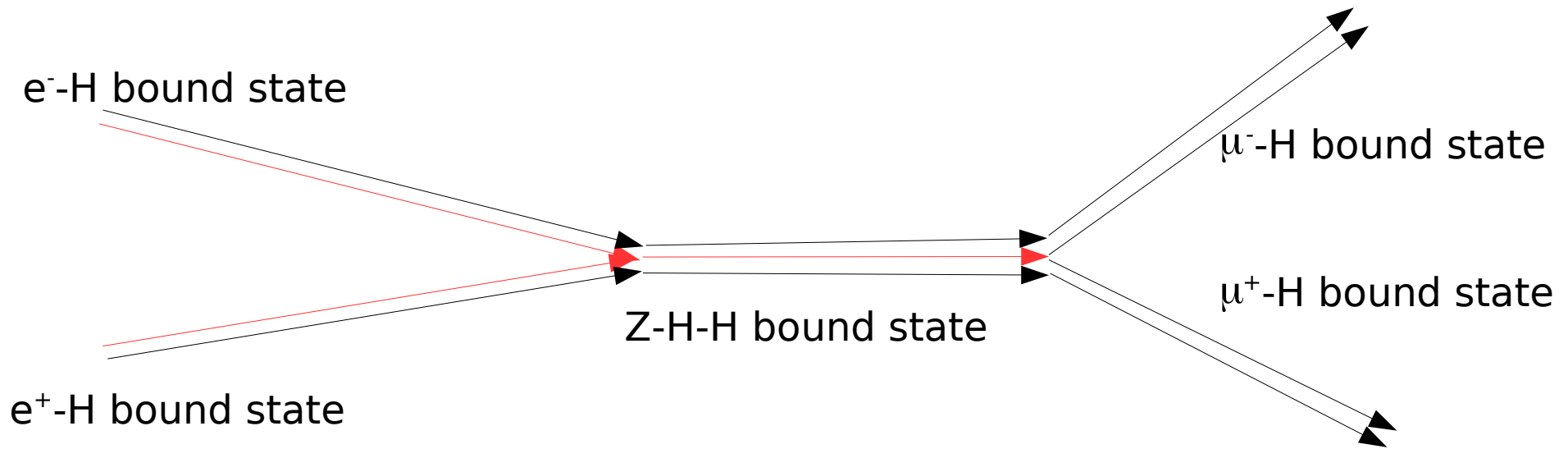
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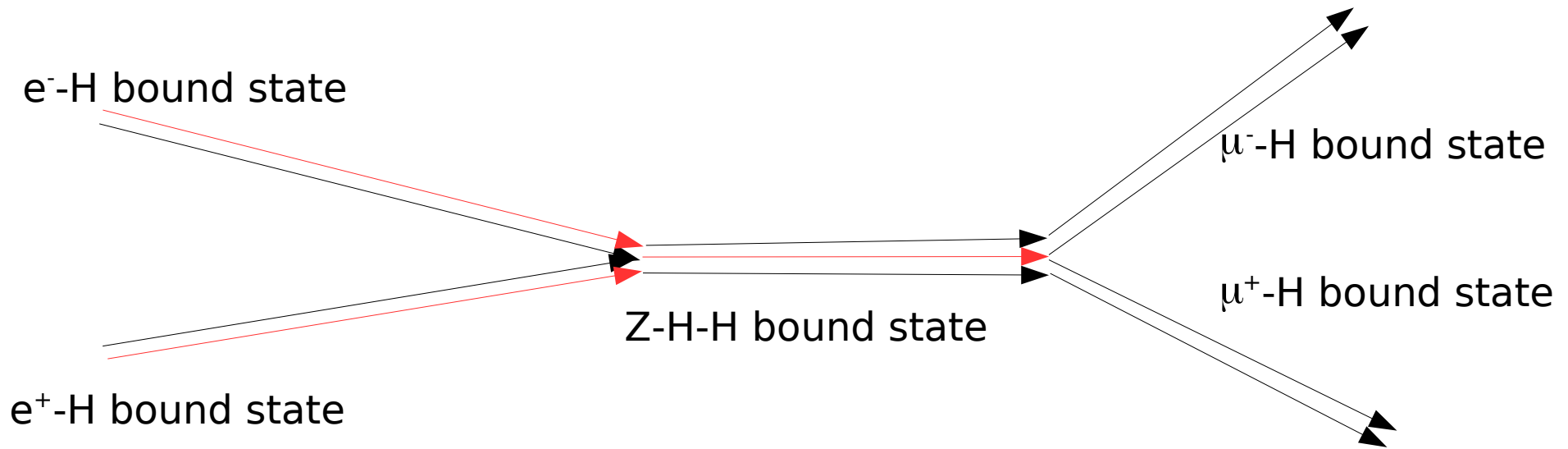
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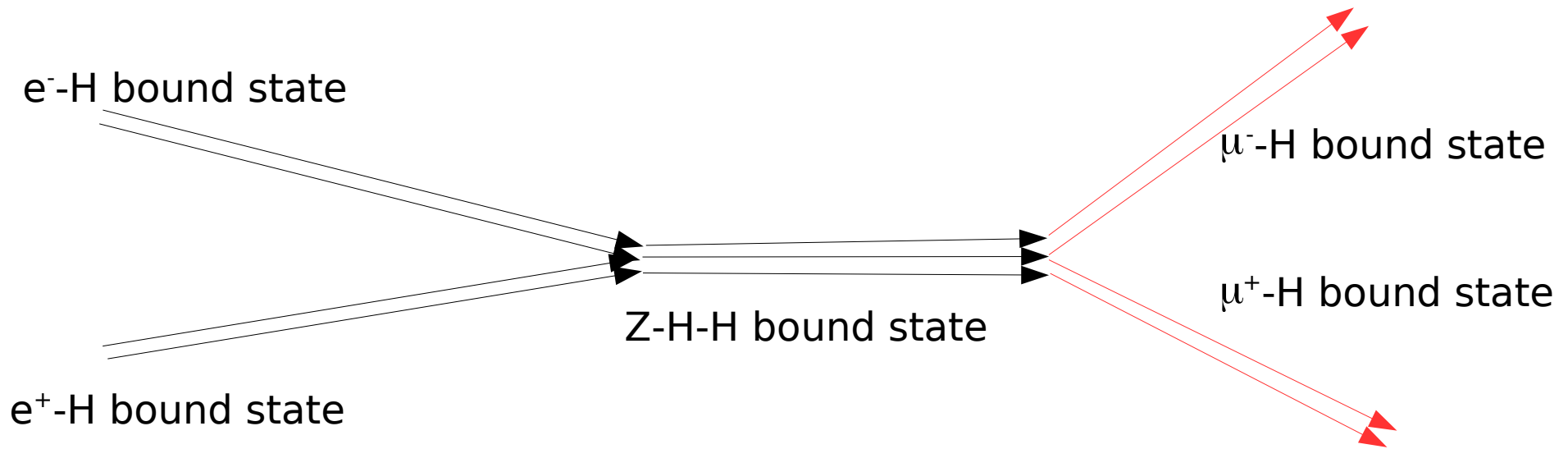


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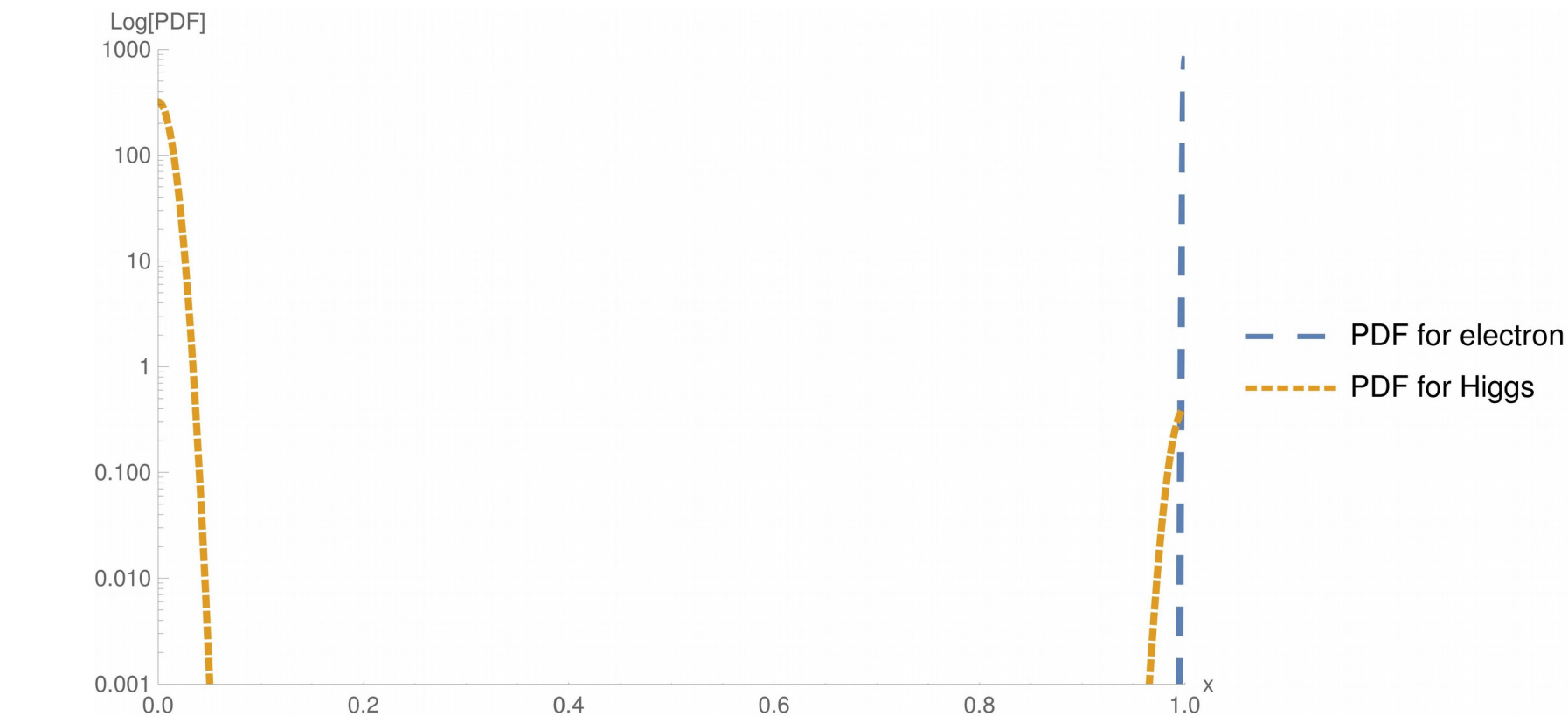
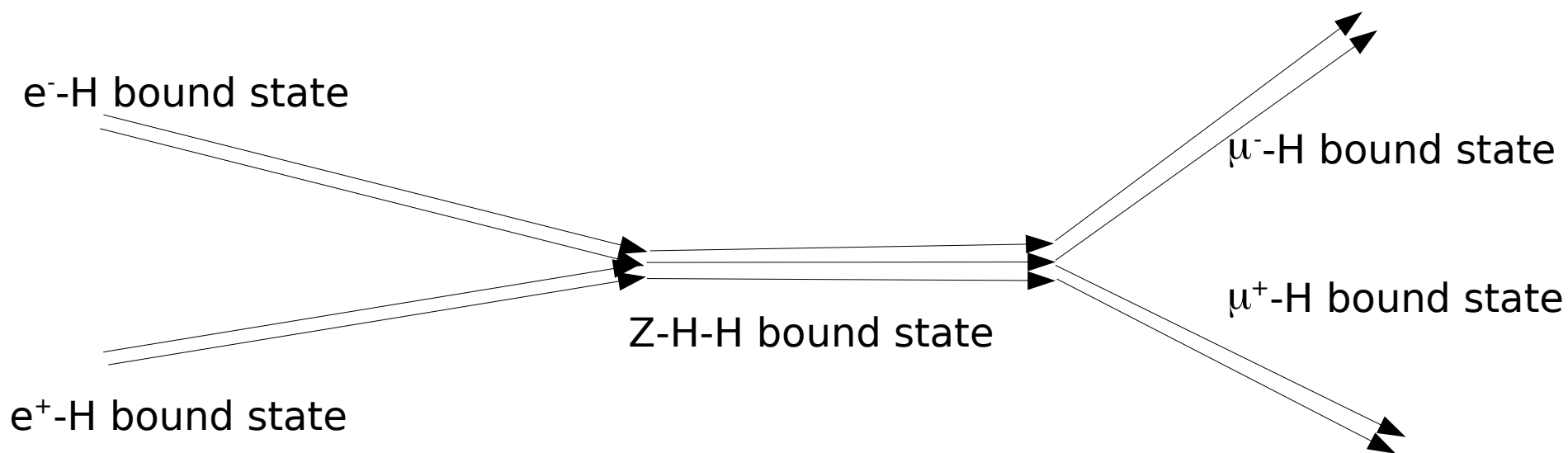
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- Description of impact? PDF-type language!
- Interacting particles either electrons or Higgs
- Fragmentation 100% efficient – like for quarks

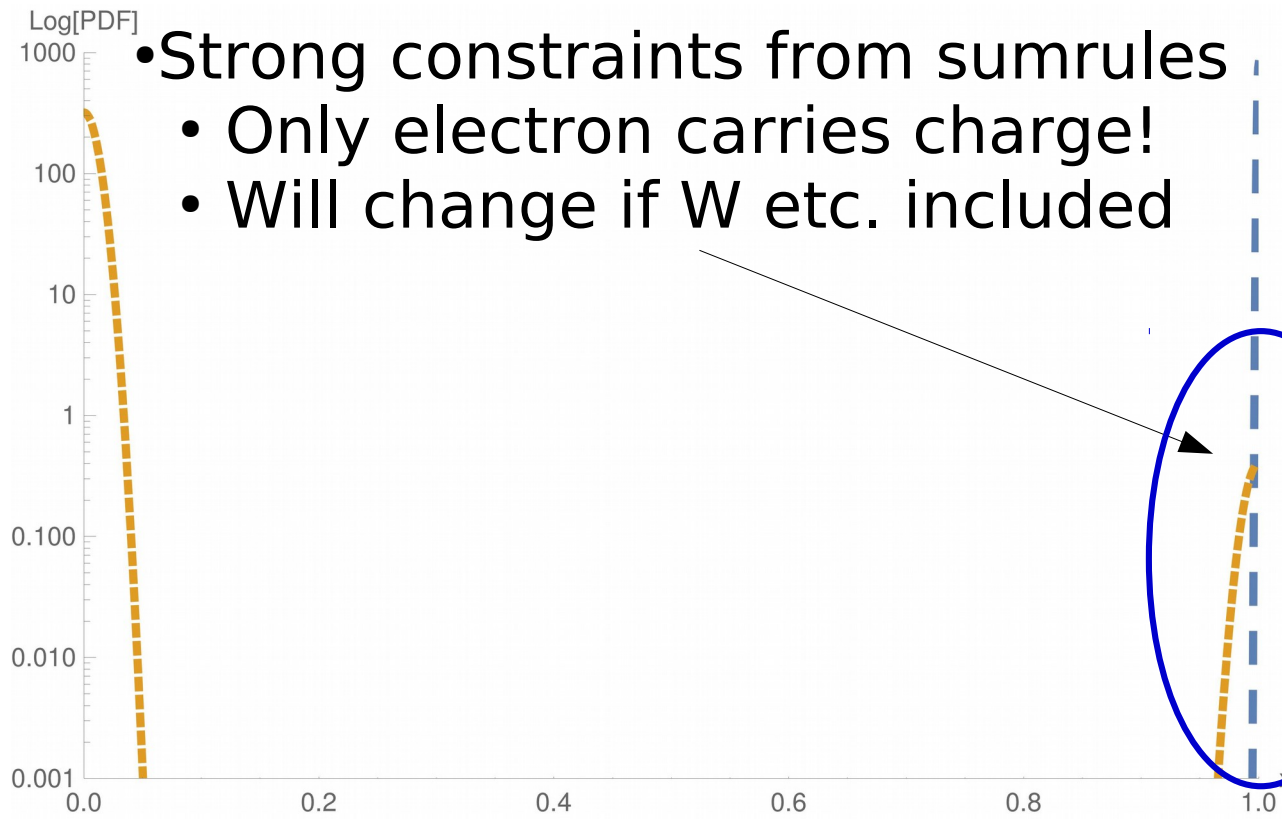
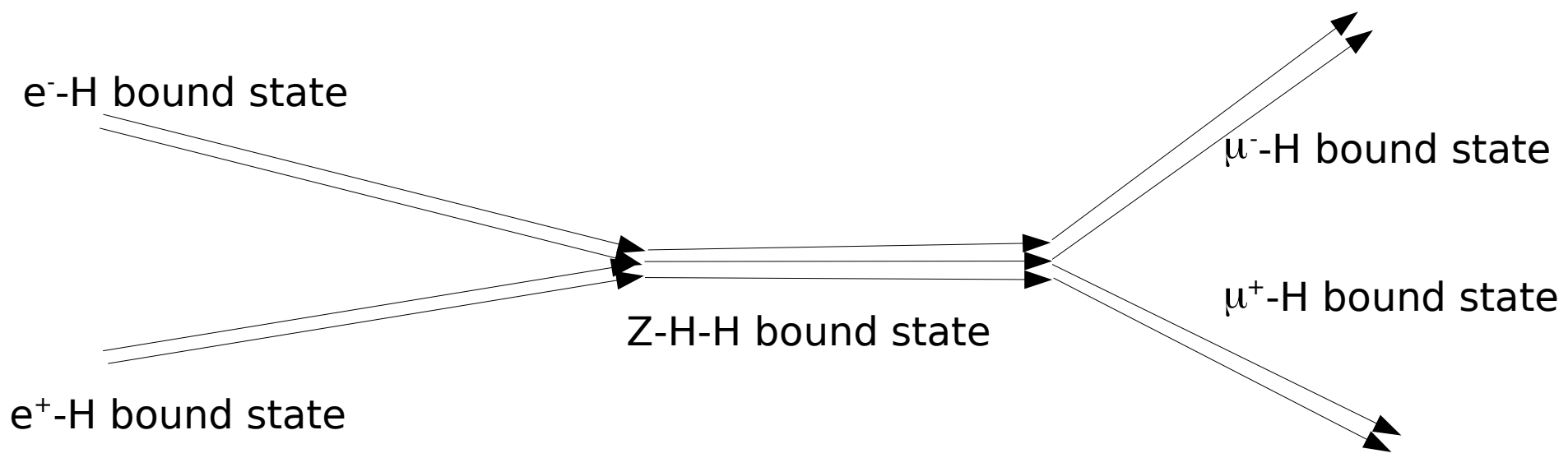
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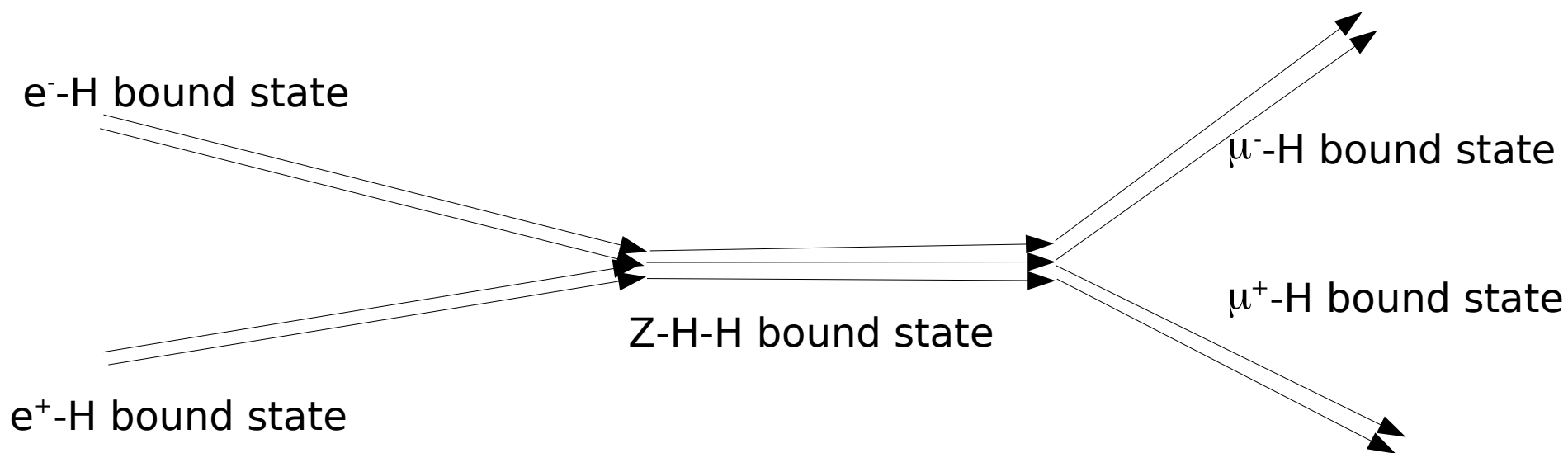
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— PDF for electron  
- - - PDF for Higgs

Electron carries everything

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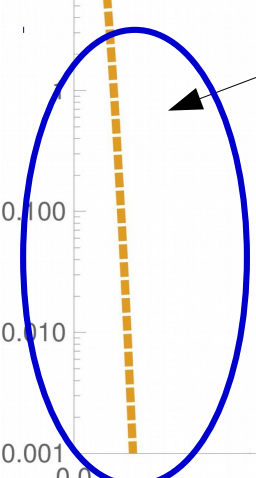
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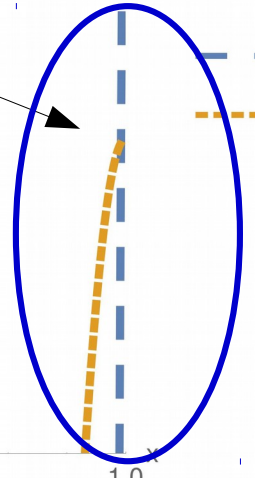
Log[PDF]

1000  
100  
10  
0.100  
0.010  
0.001

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Higgs at 0 energy  
Just like a condensate

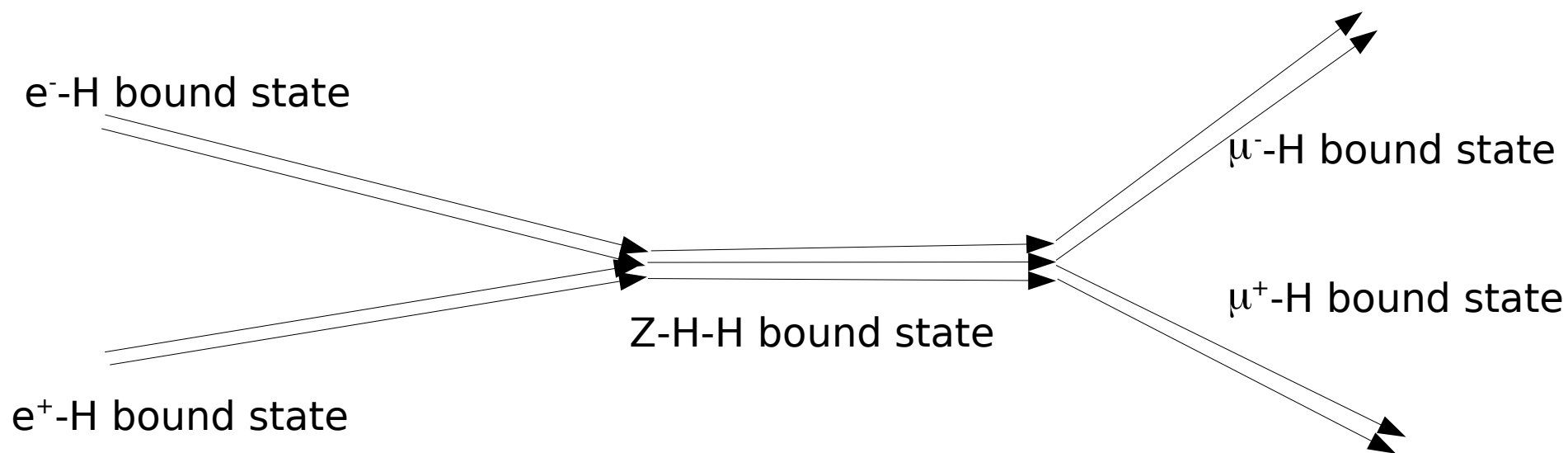


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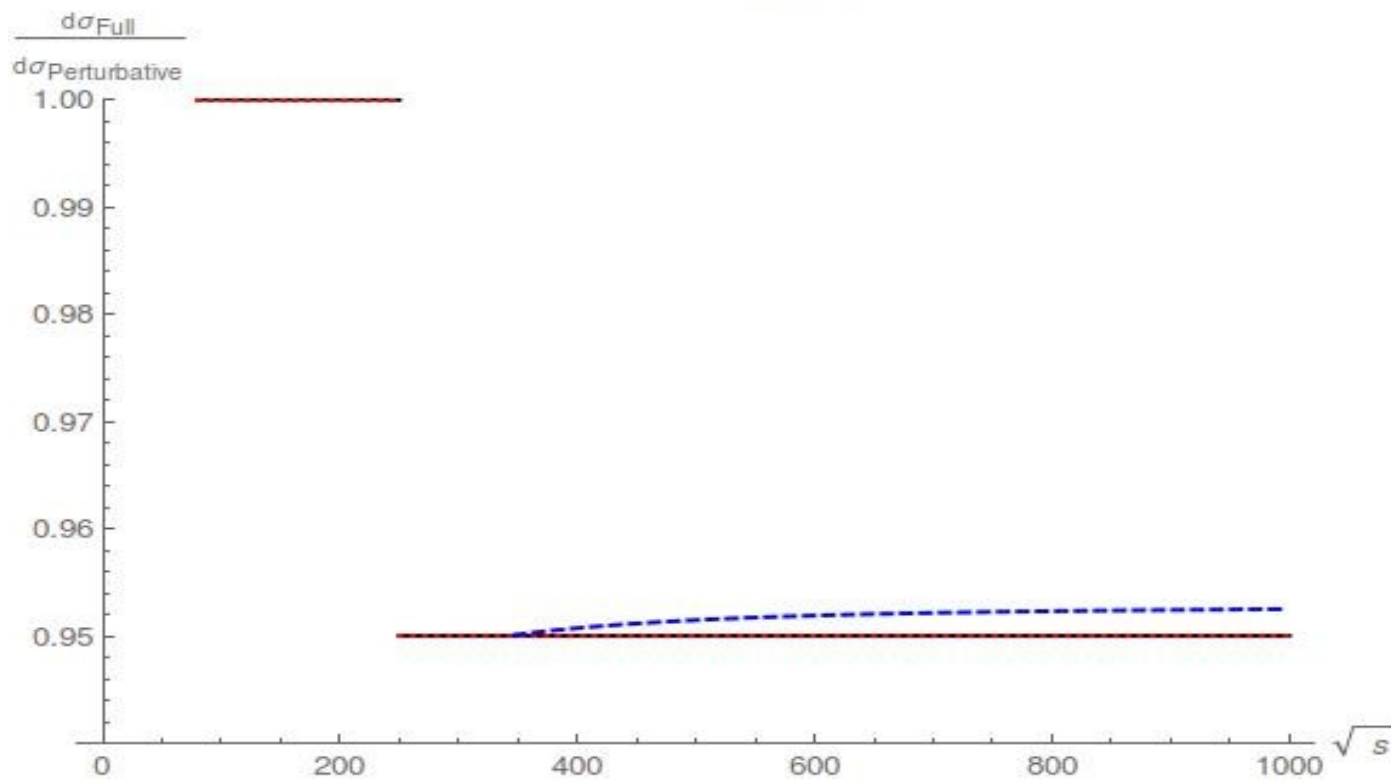
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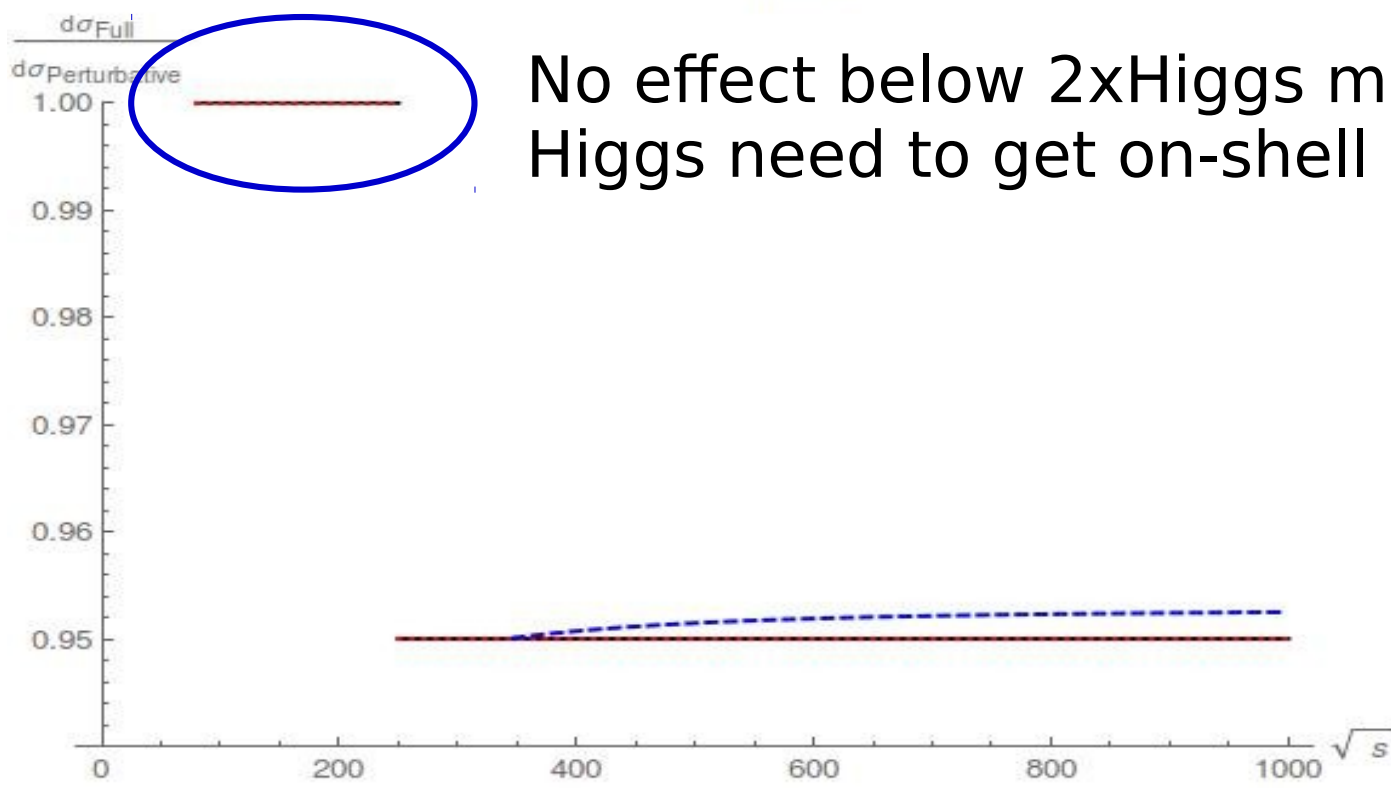
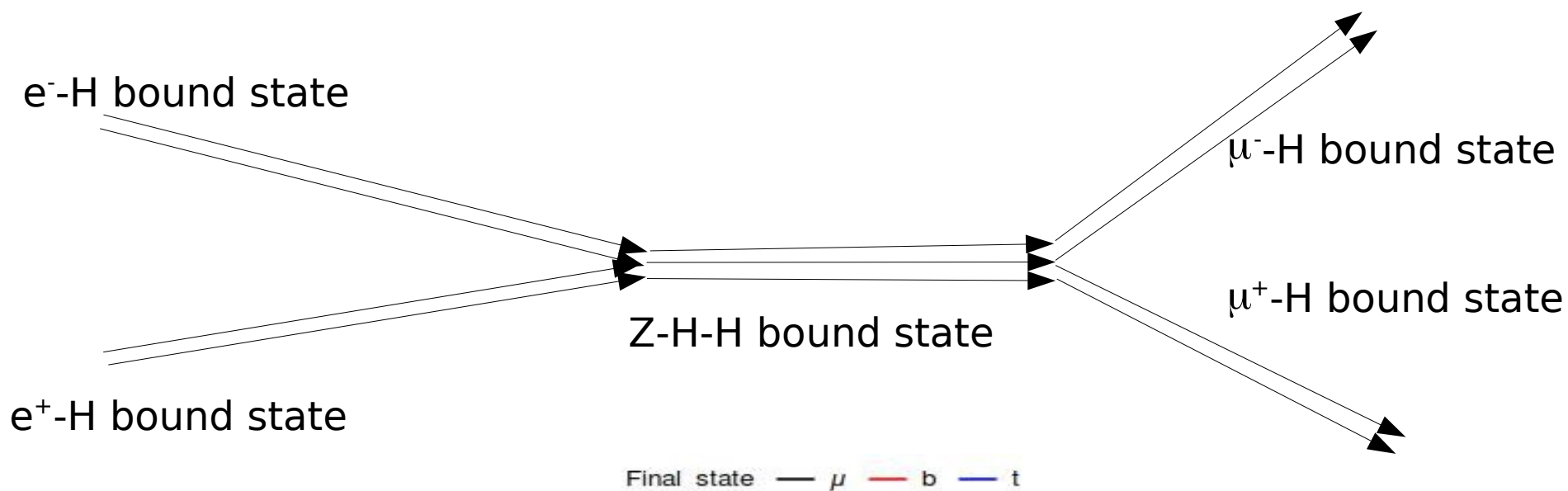


Final state —  $\mu$  — b — t



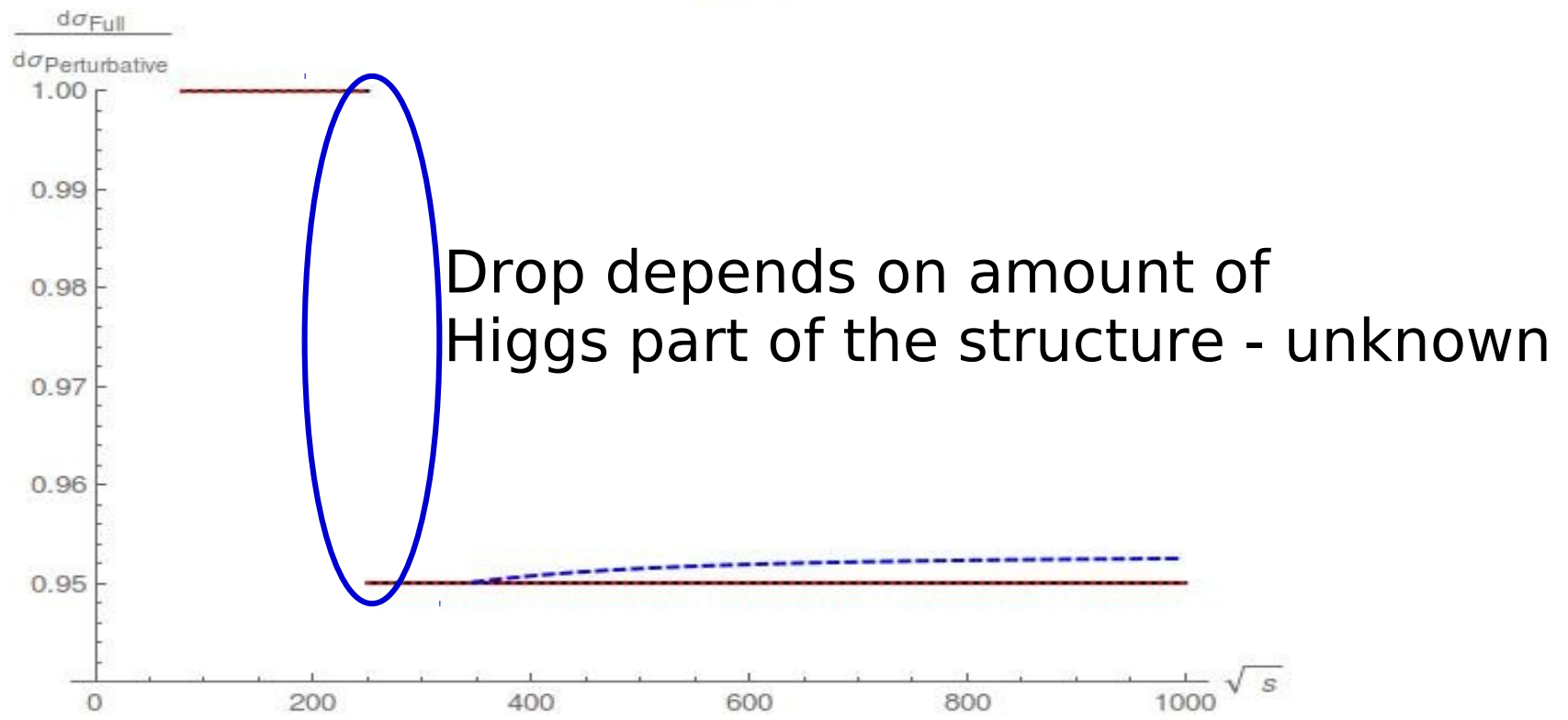
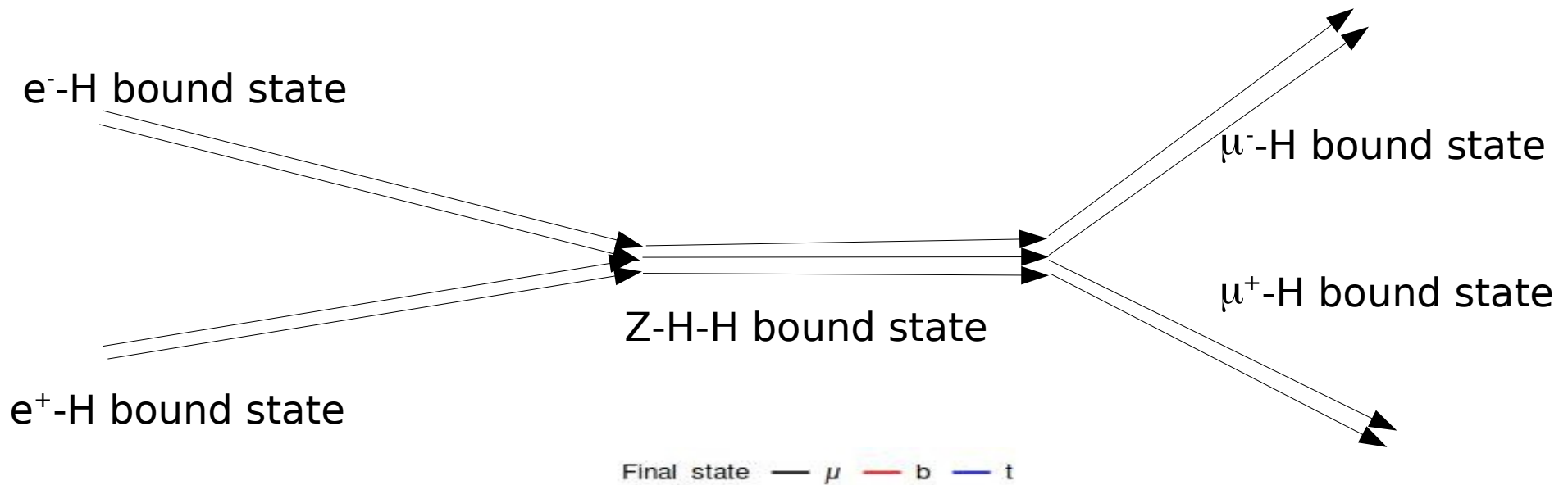
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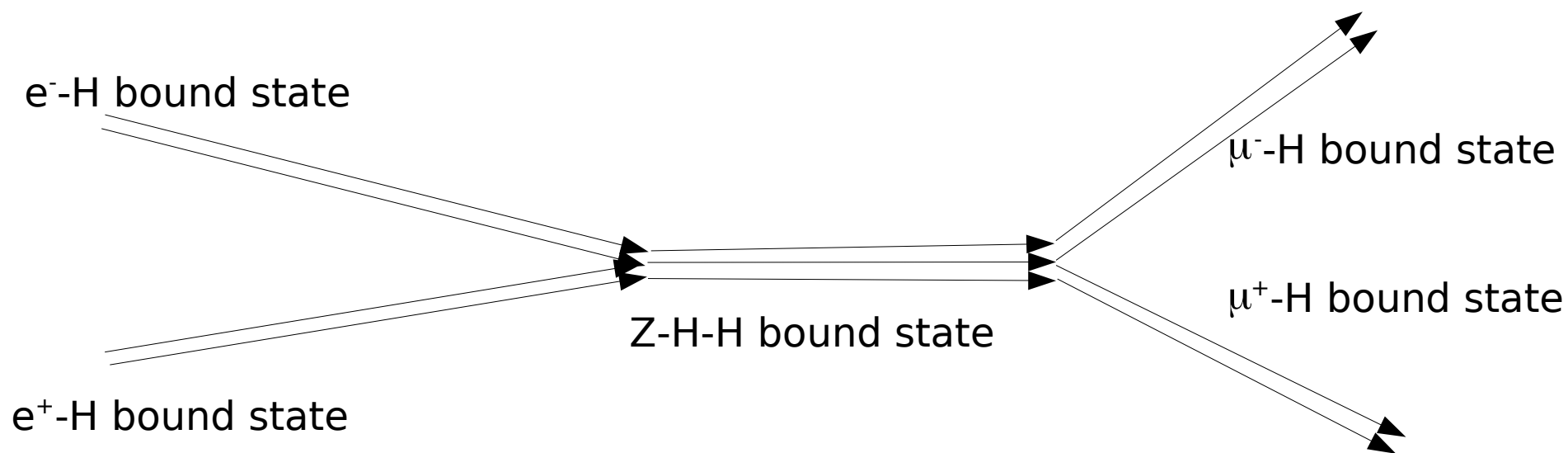
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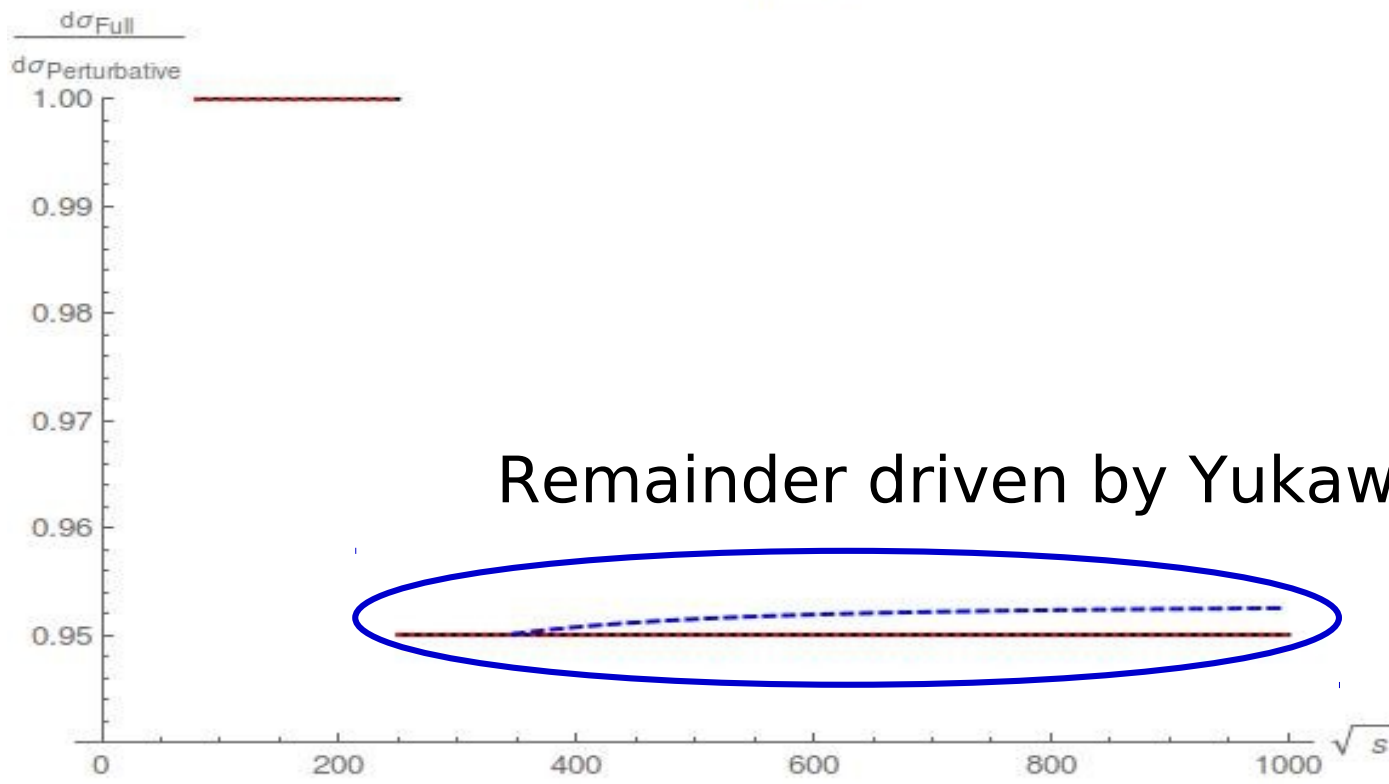


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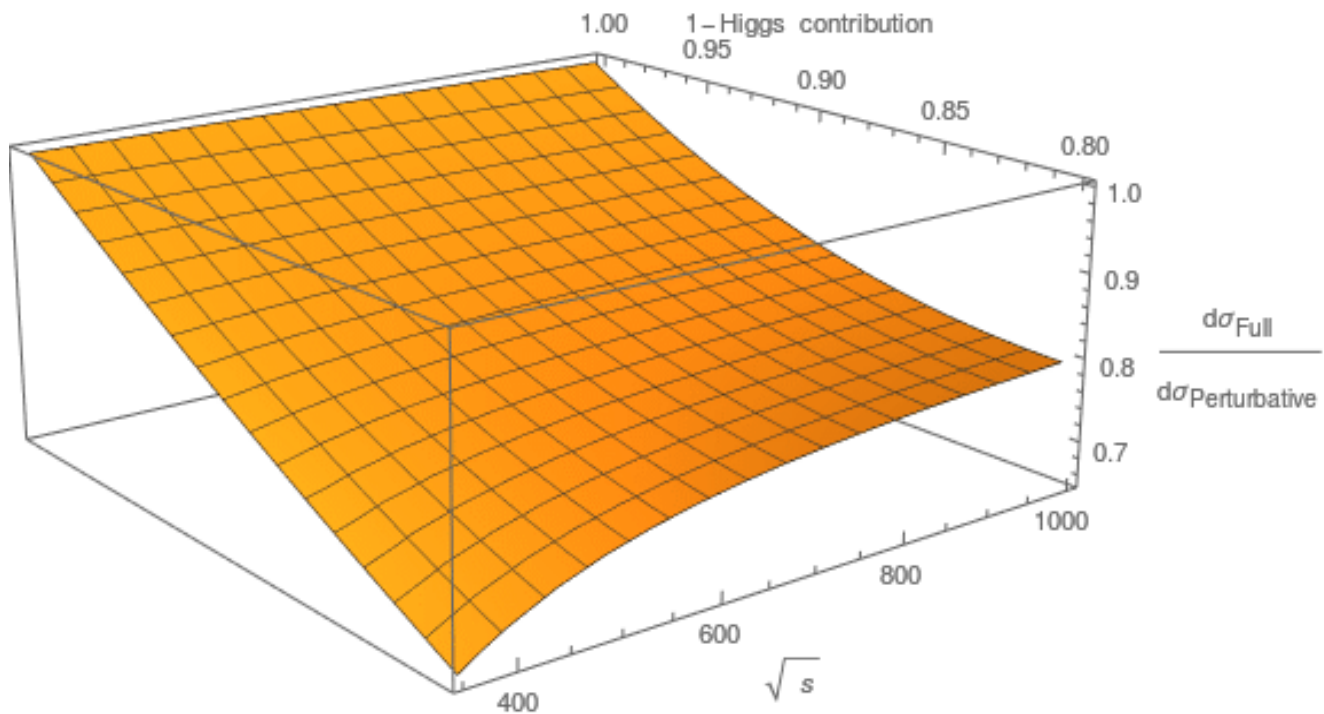
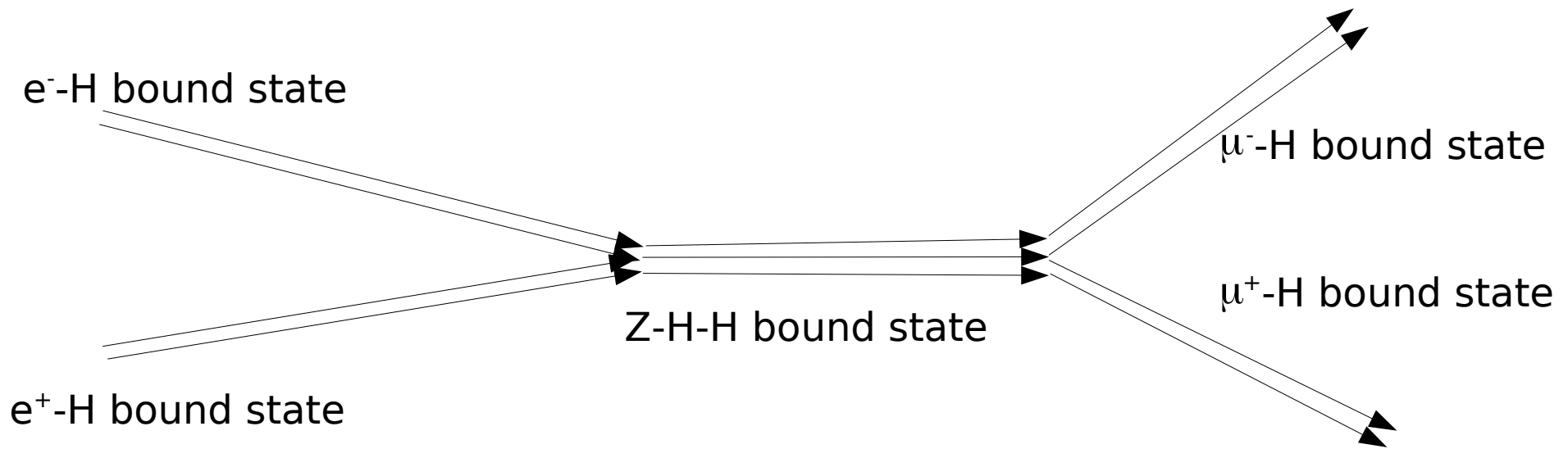
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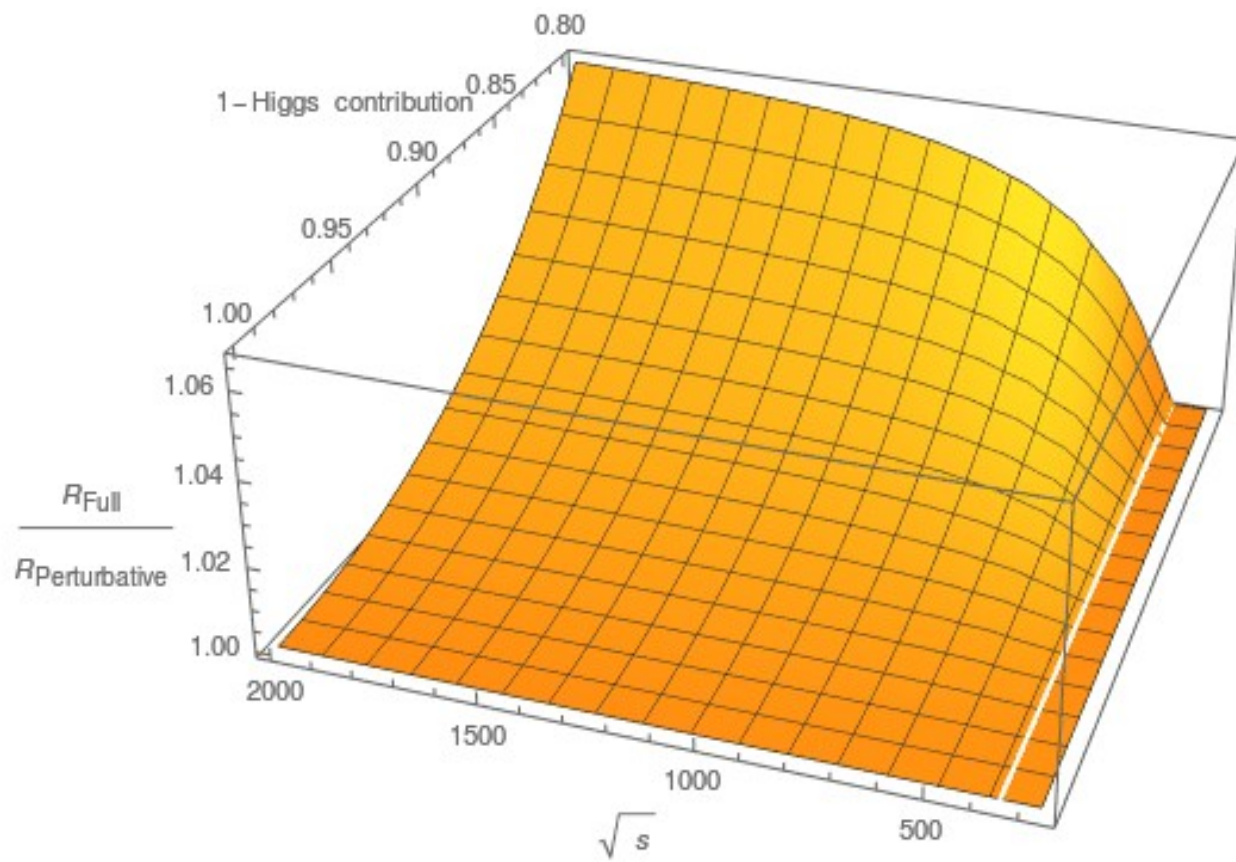
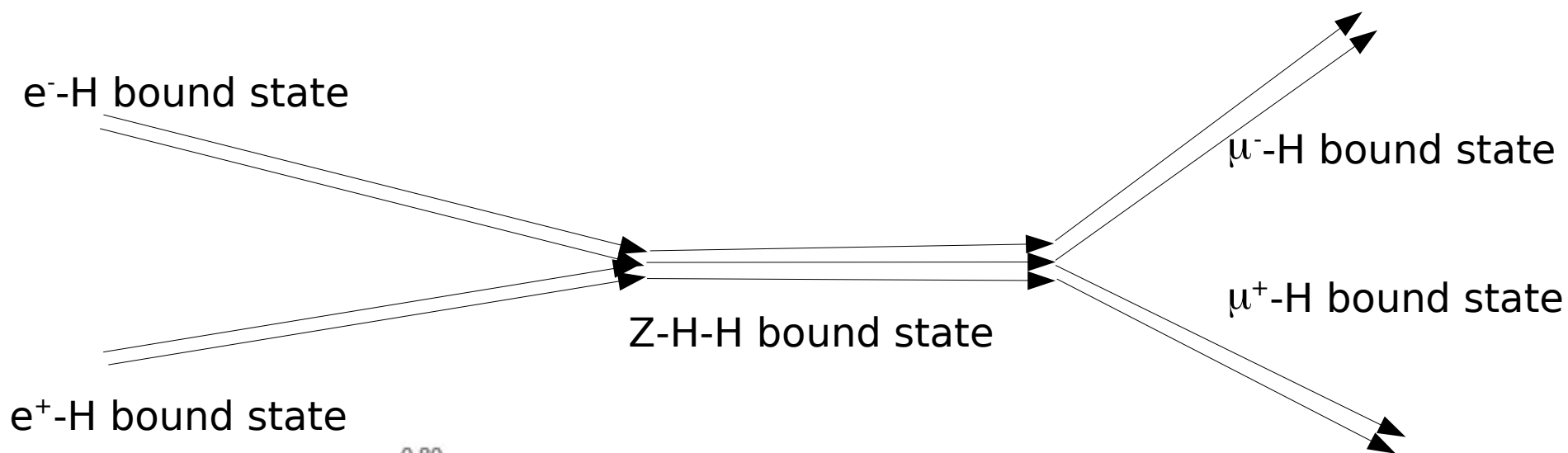
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Top case:  
Strong dependence  
on the amount of  
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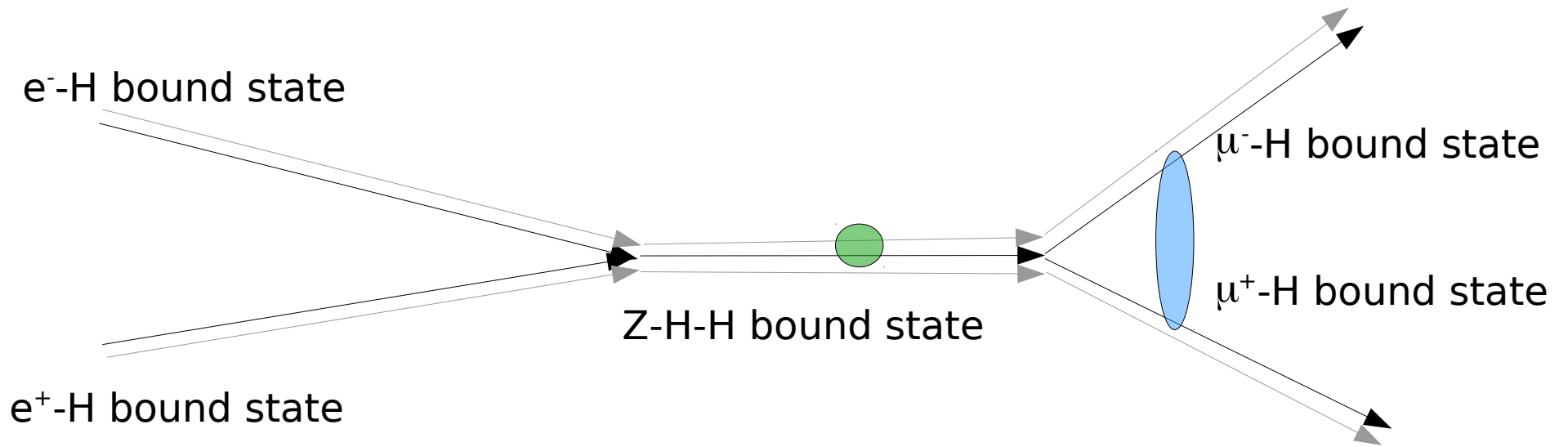
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Not all quantities are  
equally influenced

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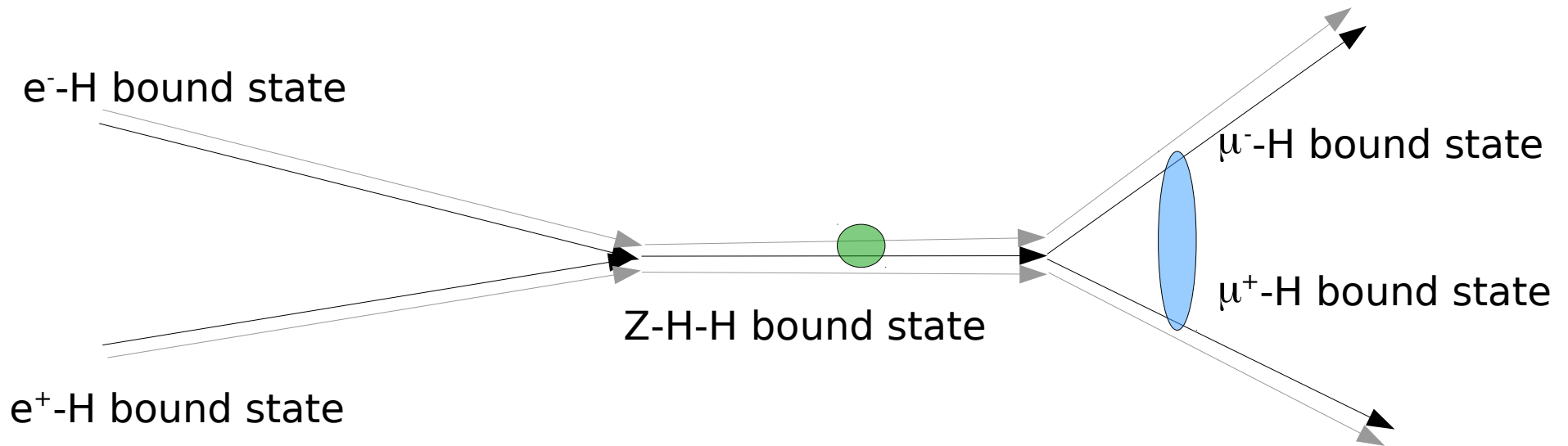
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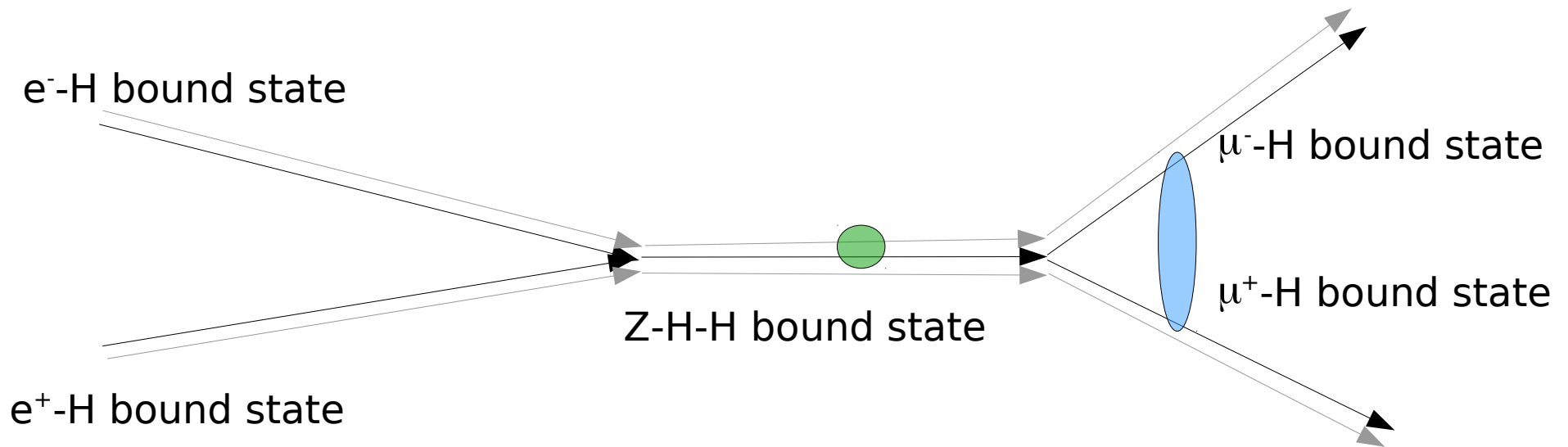
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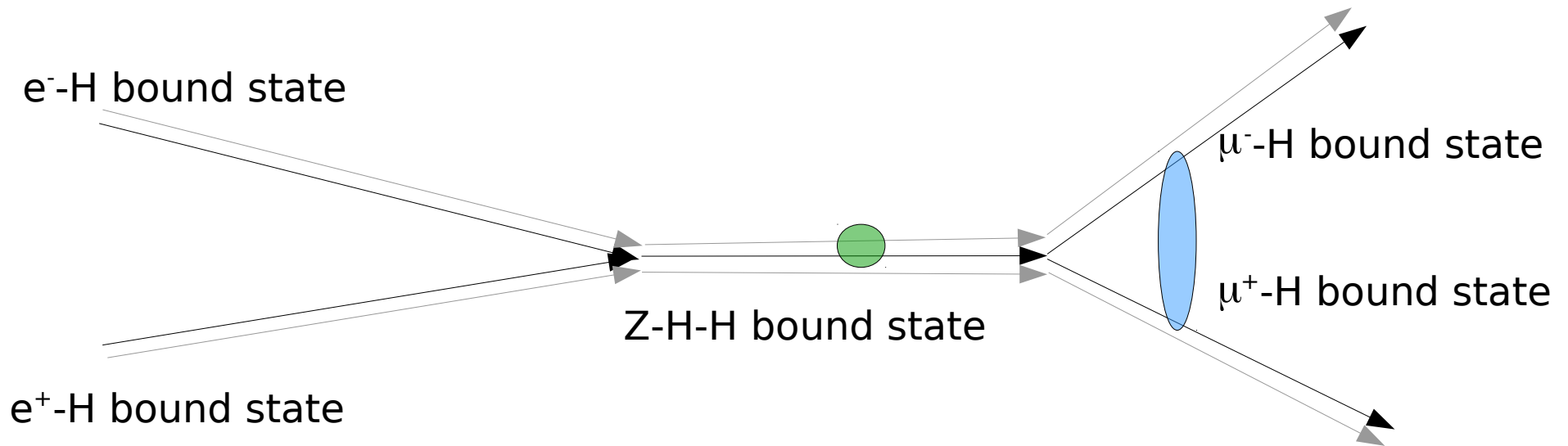
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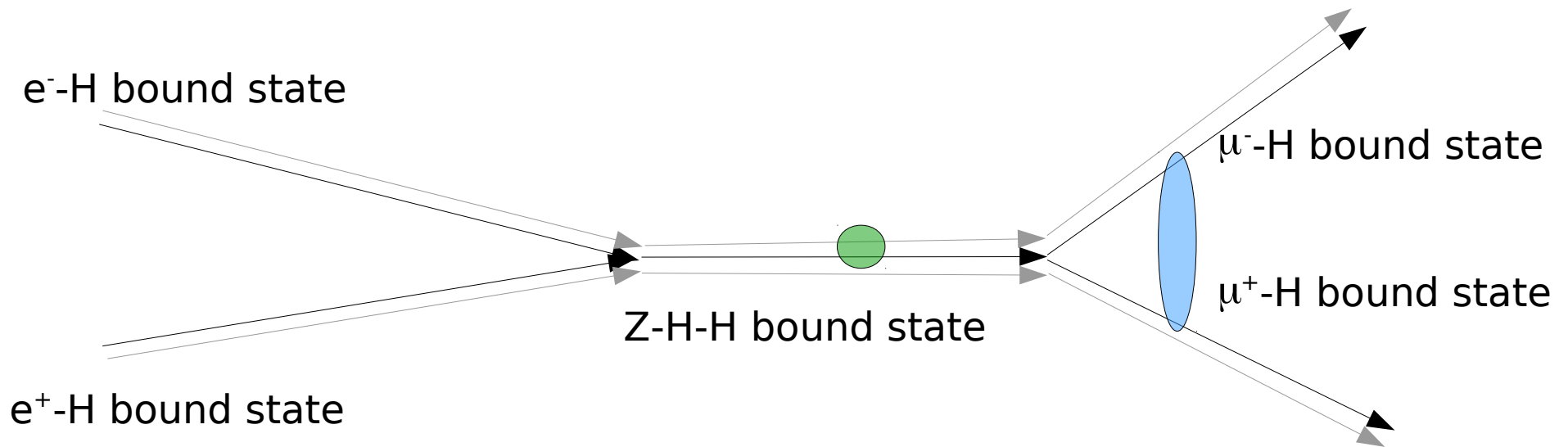
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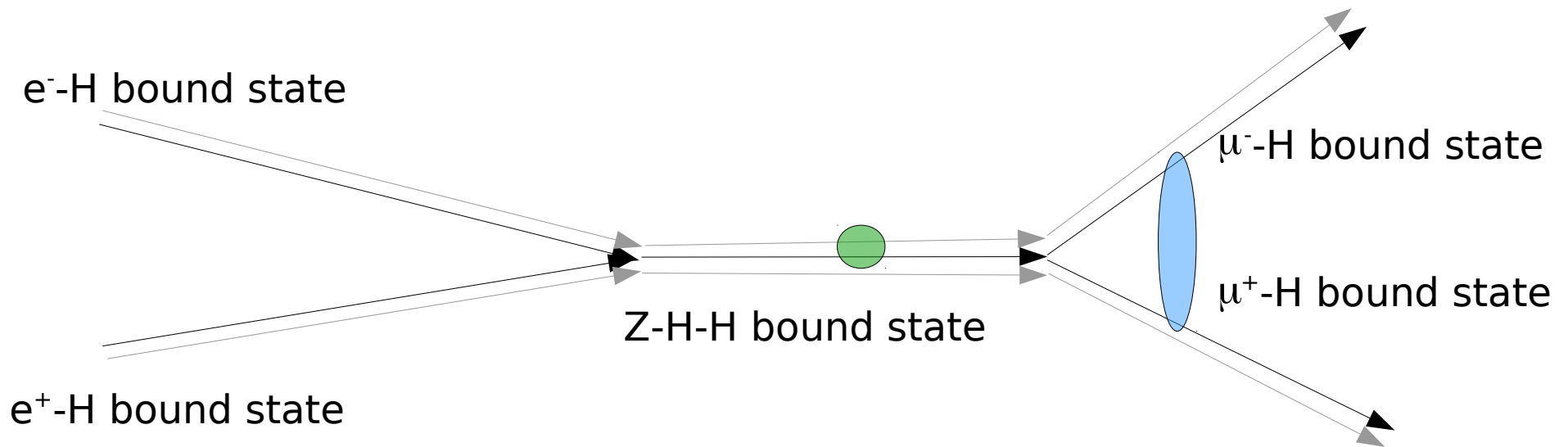
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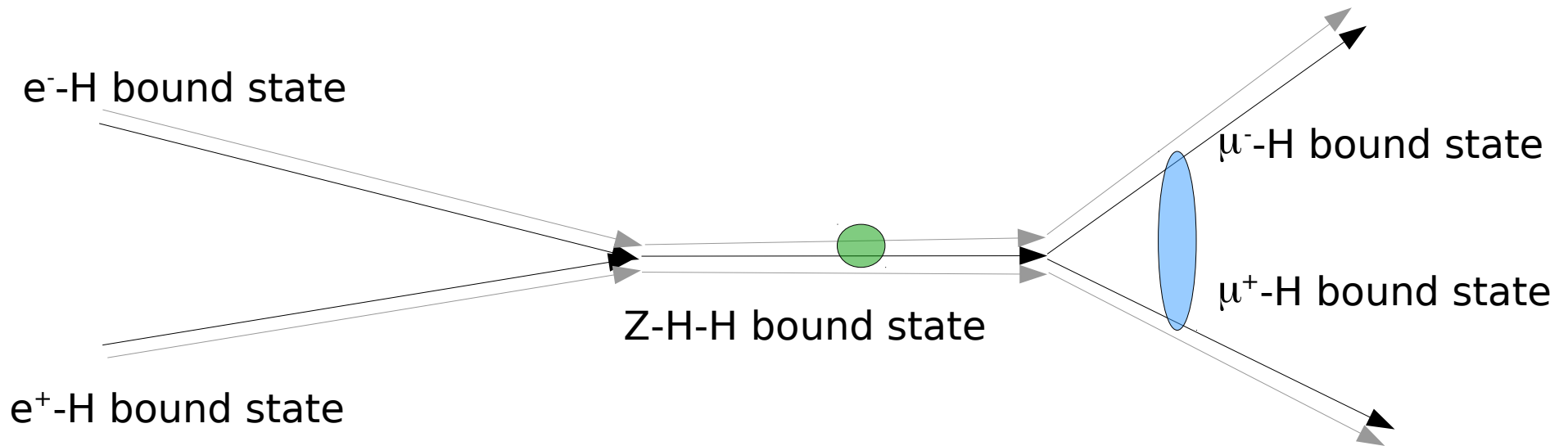


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- What about LHC? What about protons?

# Flavor of hadrons

[Egger, Maas, Sondenheimer'17]

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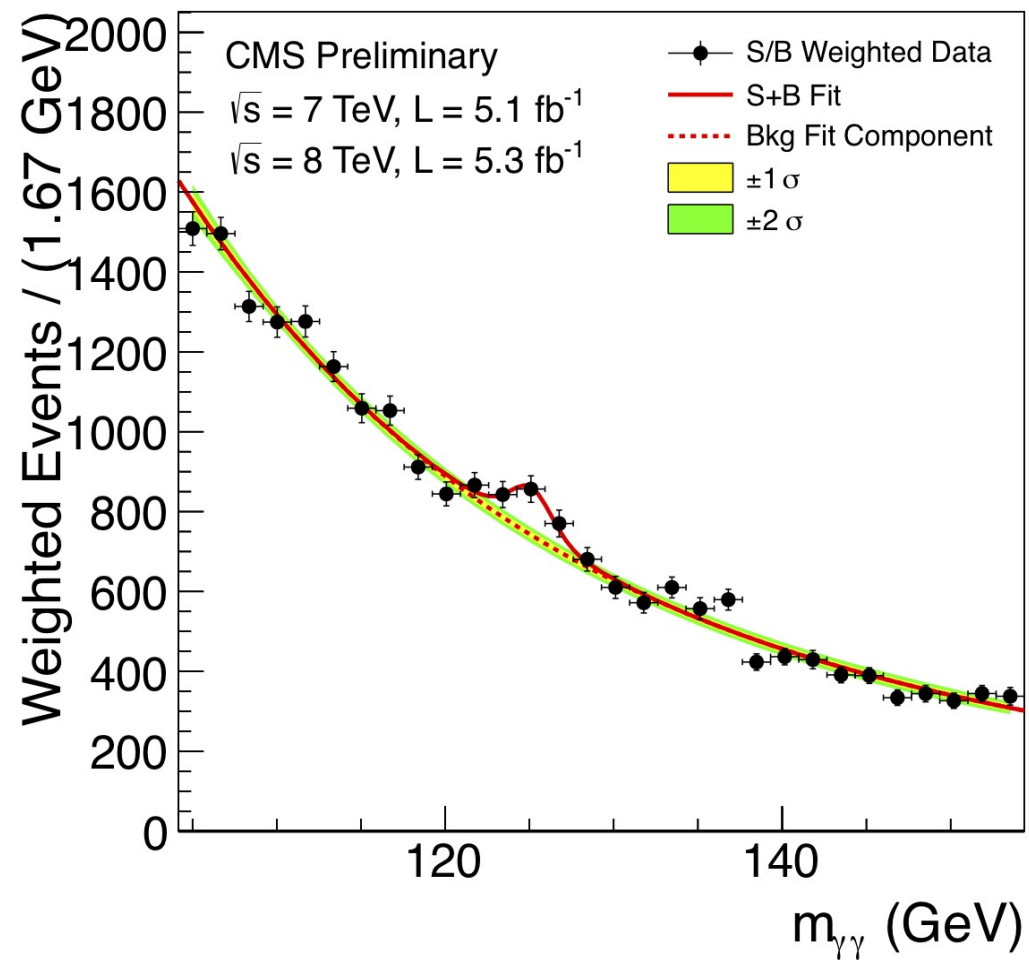
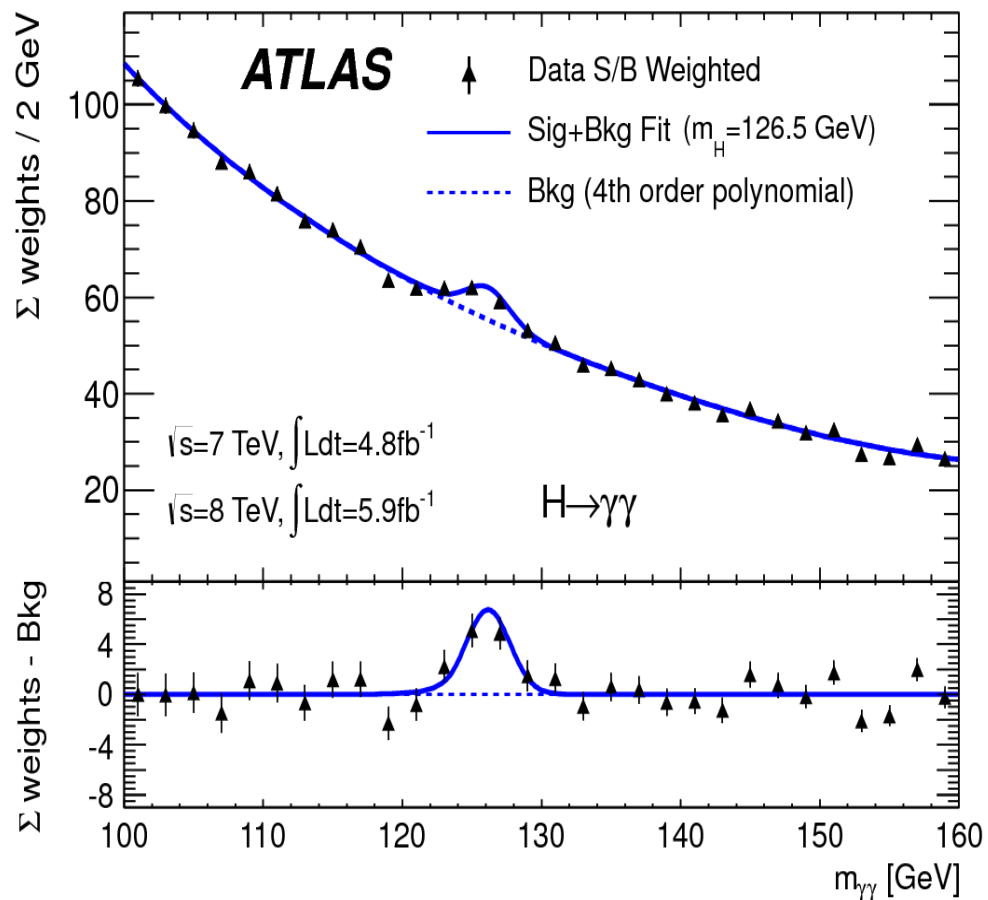
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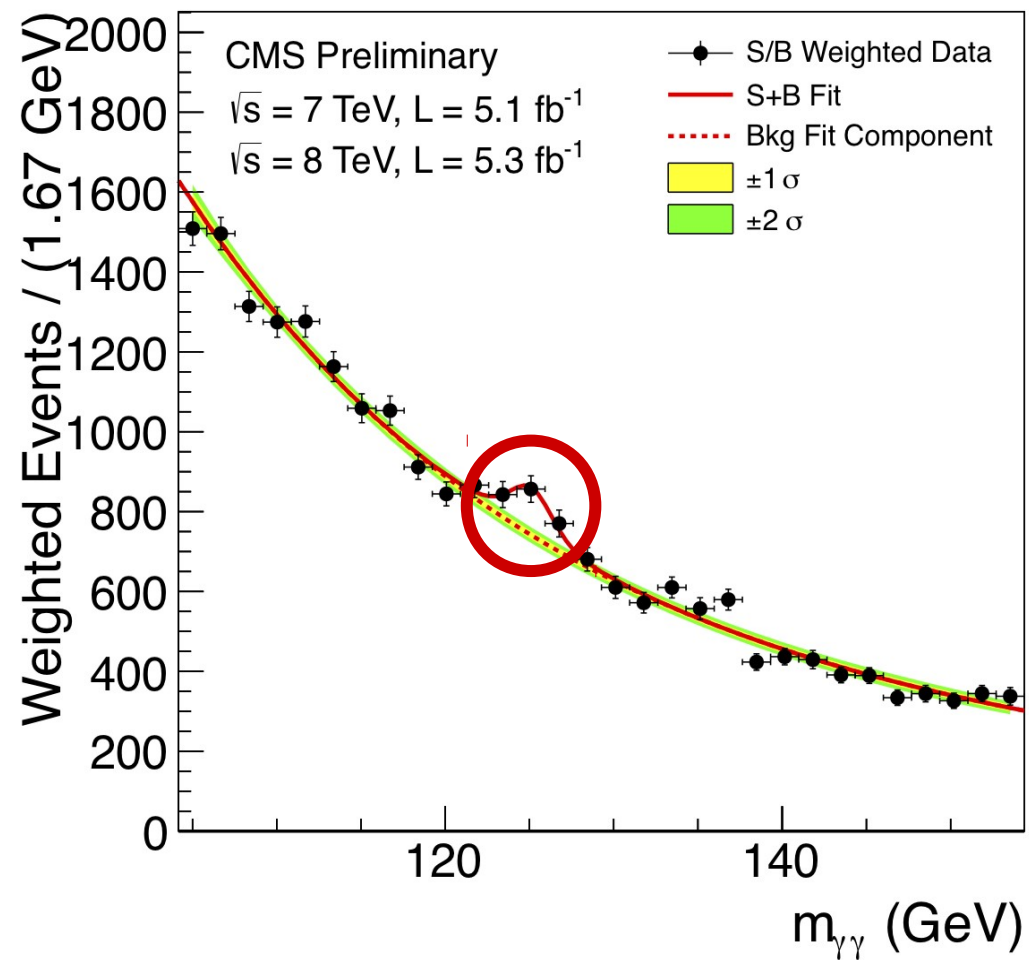
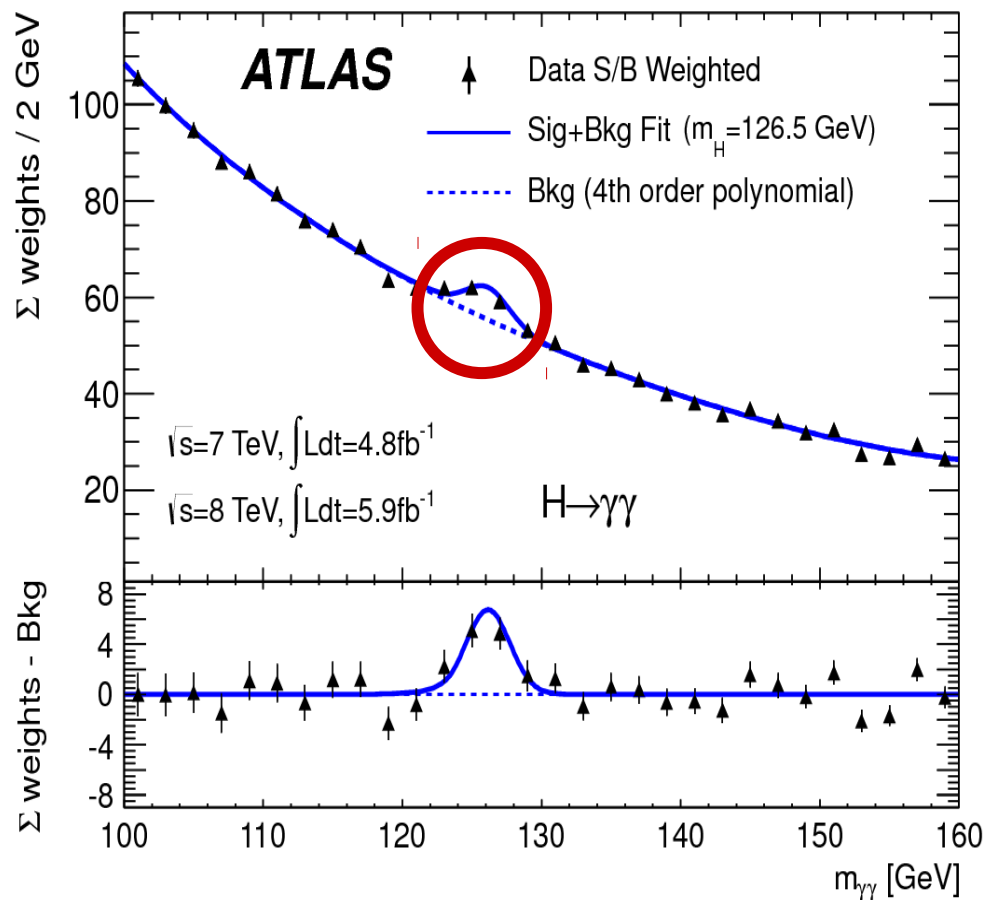
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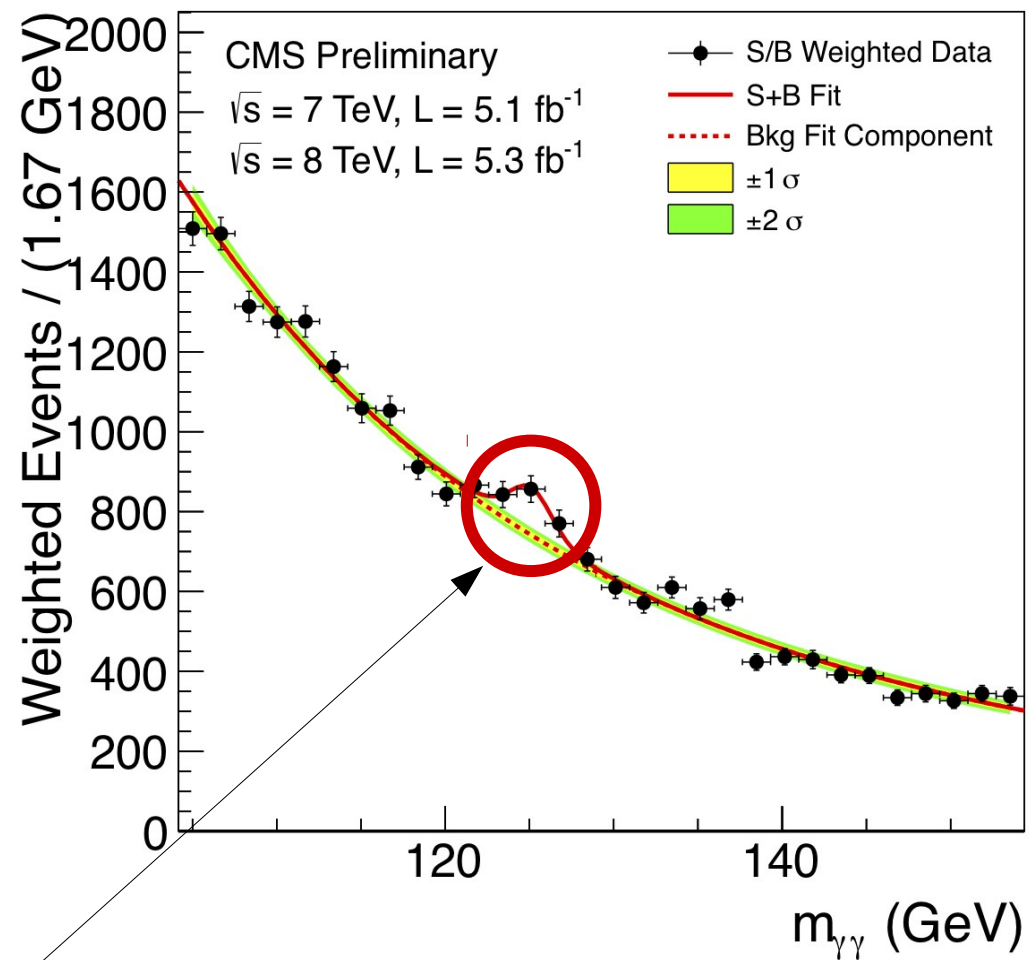
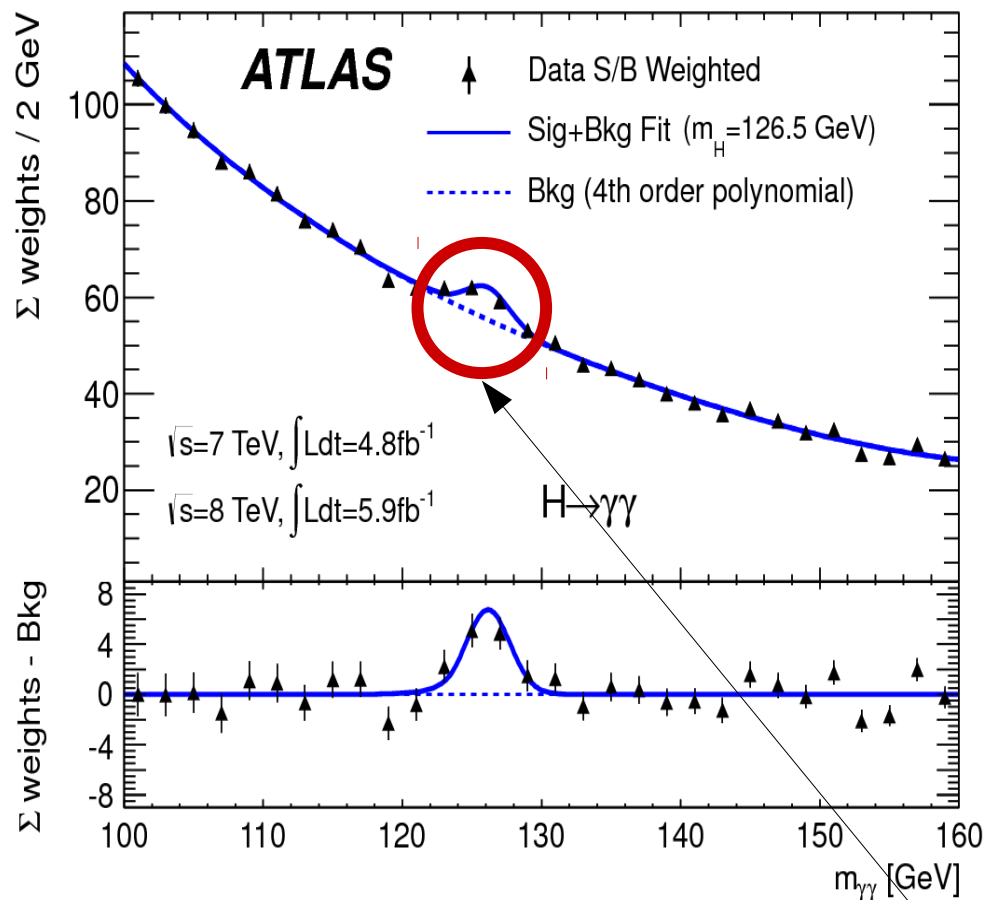
# This is physical



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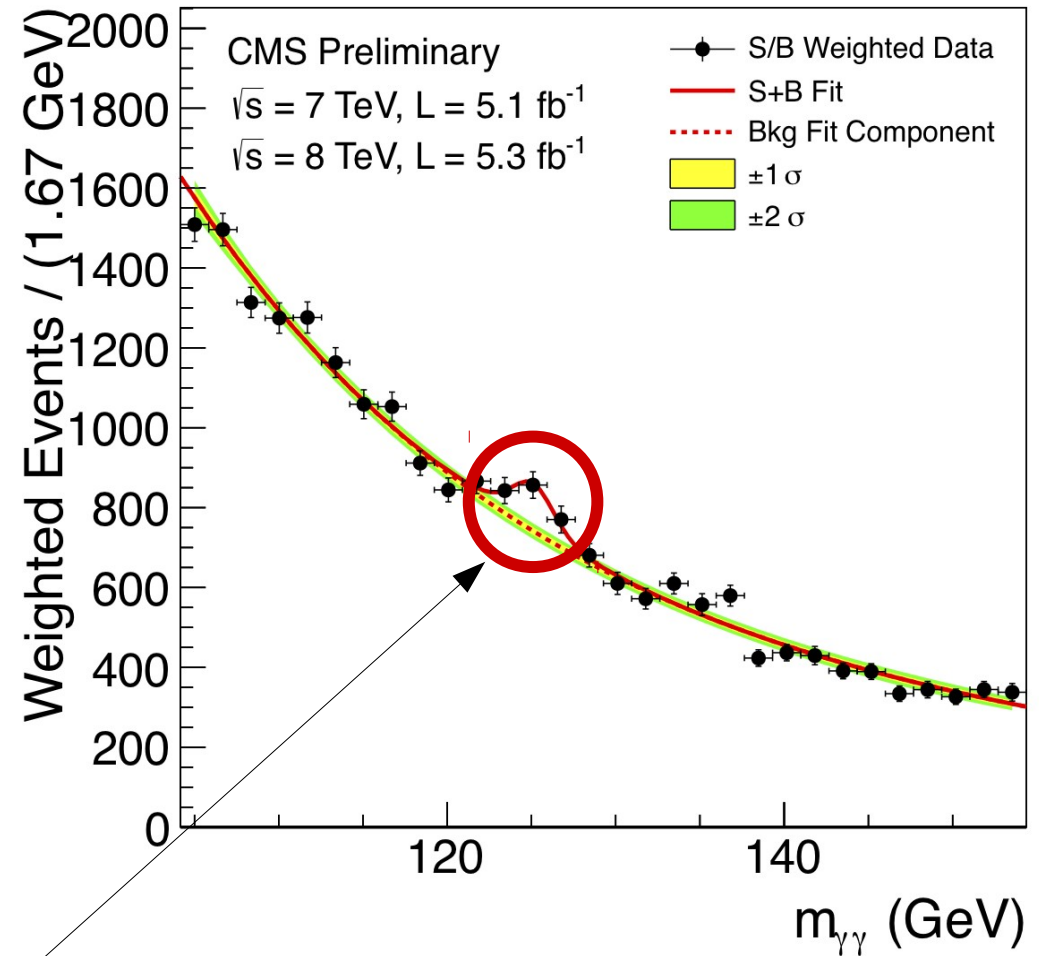
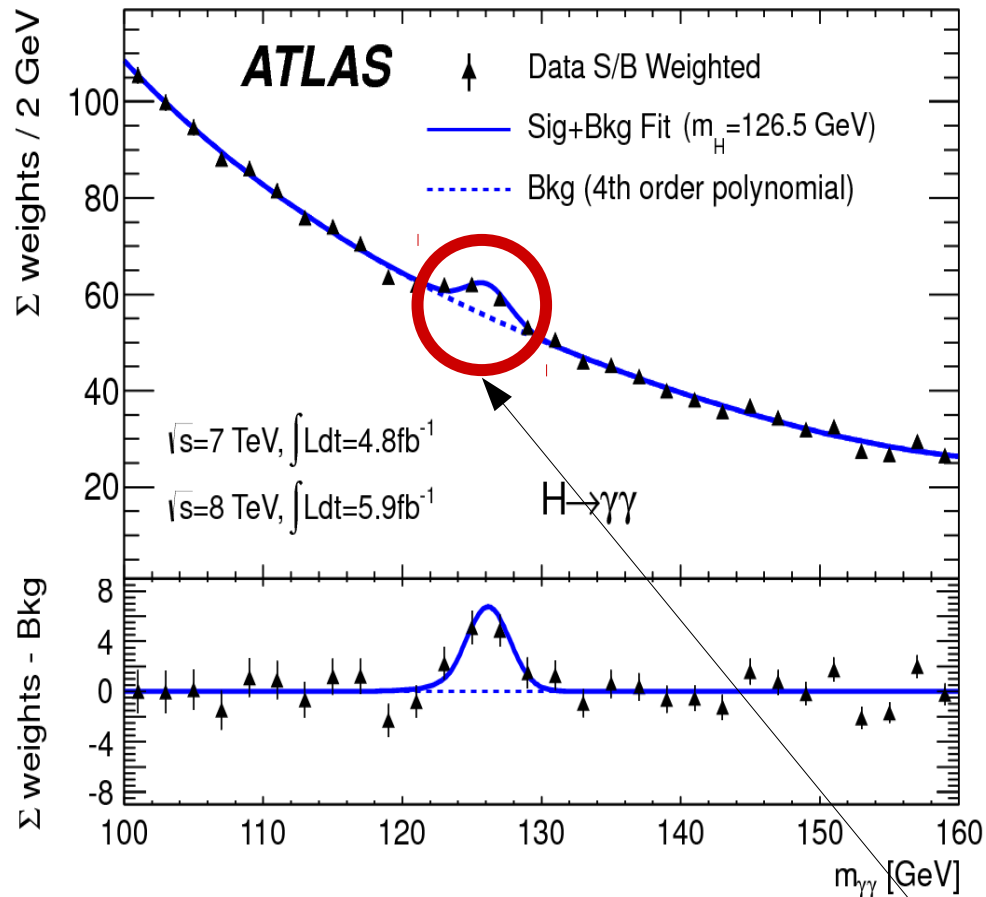


# This is physical



Bound state

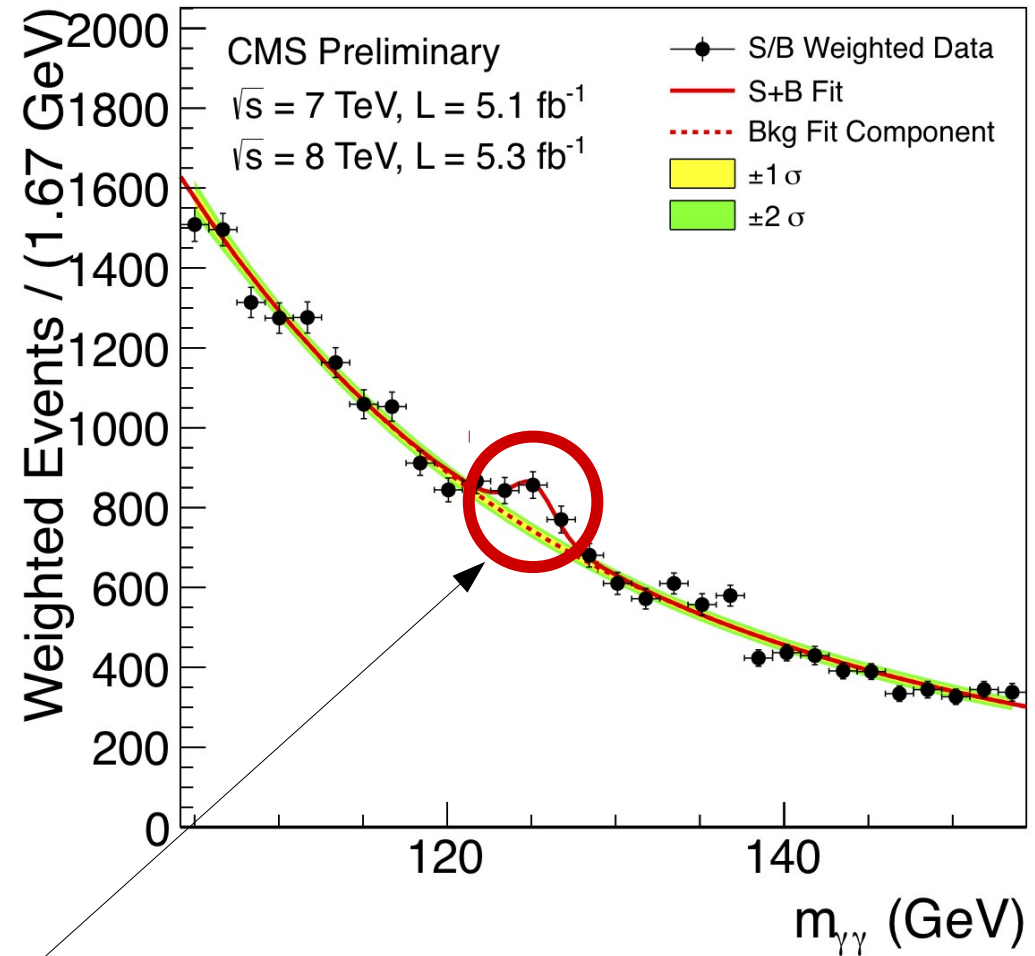
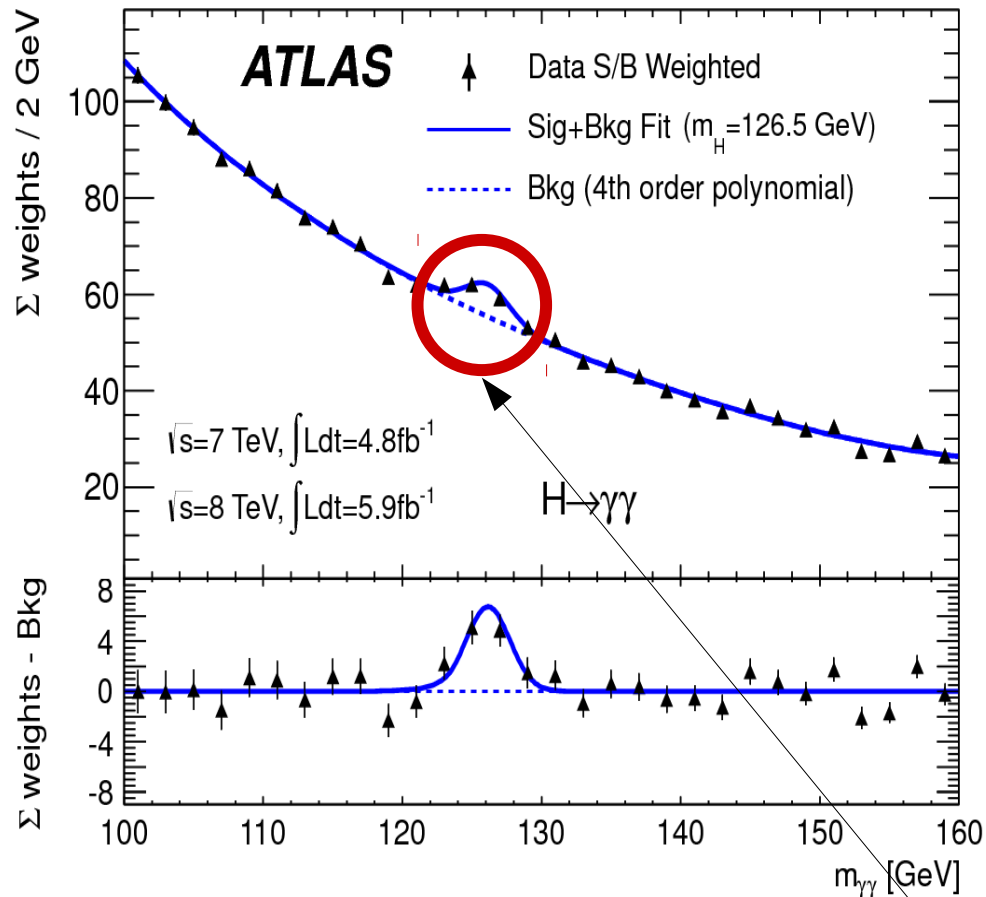
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Bound state

Manifestly invariant under local symmetries  
Classified by global symmetries

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Needs to be taken into account for BSM signals

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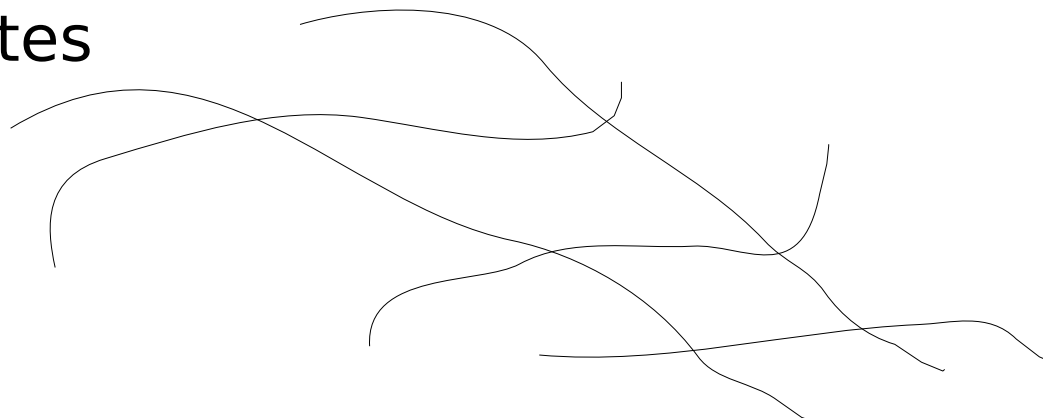
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  - Here: Kibble-Sciama-type [Kibble'61,Sciama'62]
  - Arguments remain unaltered for other options
- Can be viewed in various ways
  - Here: Emphasize analogy to particle physics

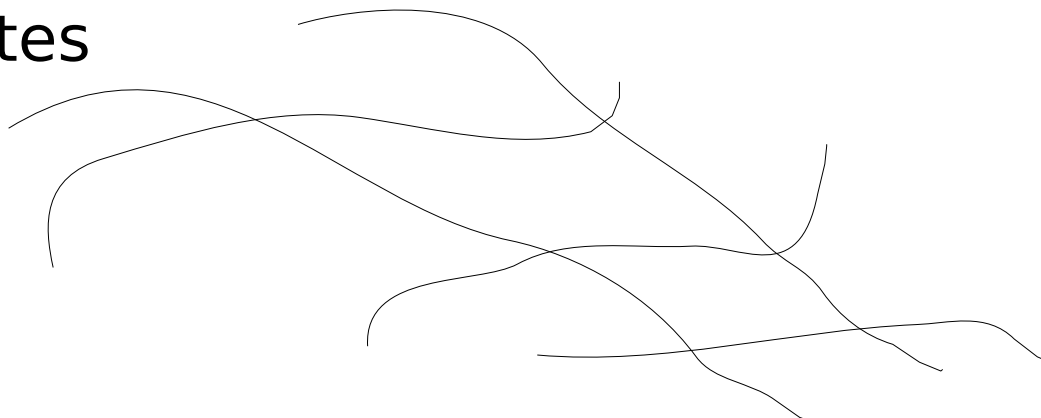
# Gravity as a gauge theory

“Usual” curved coordinates

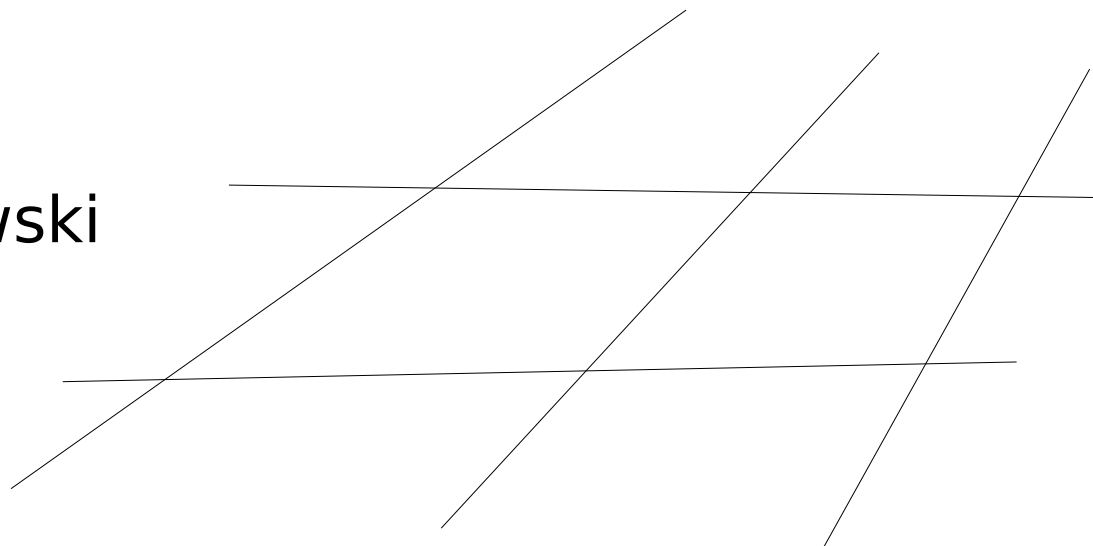


# Gravity as a gauge theory

“Usual” curved coordinates



“Underlying”  
rigid flat Minkowski  
coordinates:  
Standard clocks  
& sticks



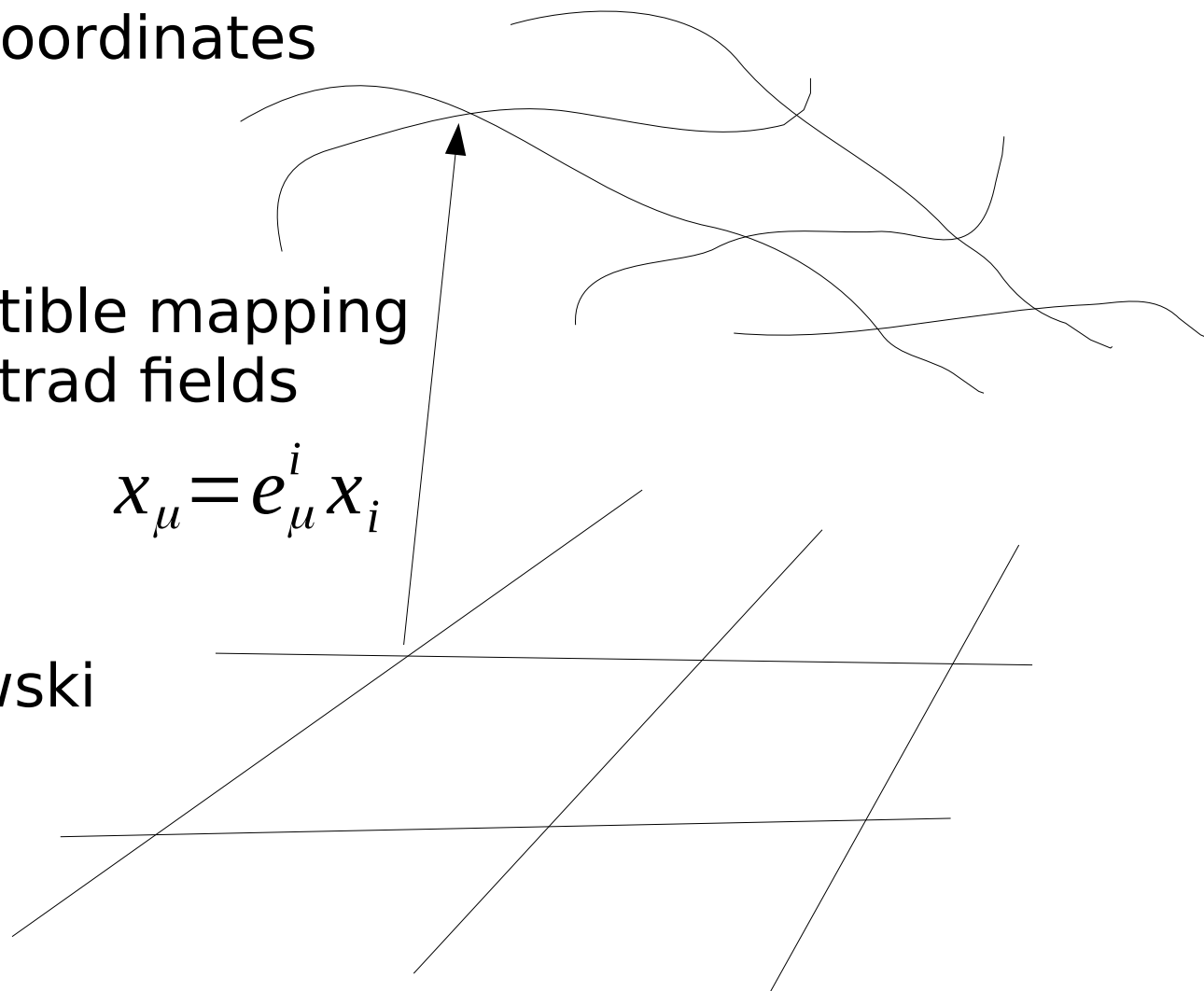
# Gravity as a gauge theory

“Usual” curved coordinates

Invertible mapping  
by tetrad fields

$$x_{\mu} = e_{\mu}^i x_i$$

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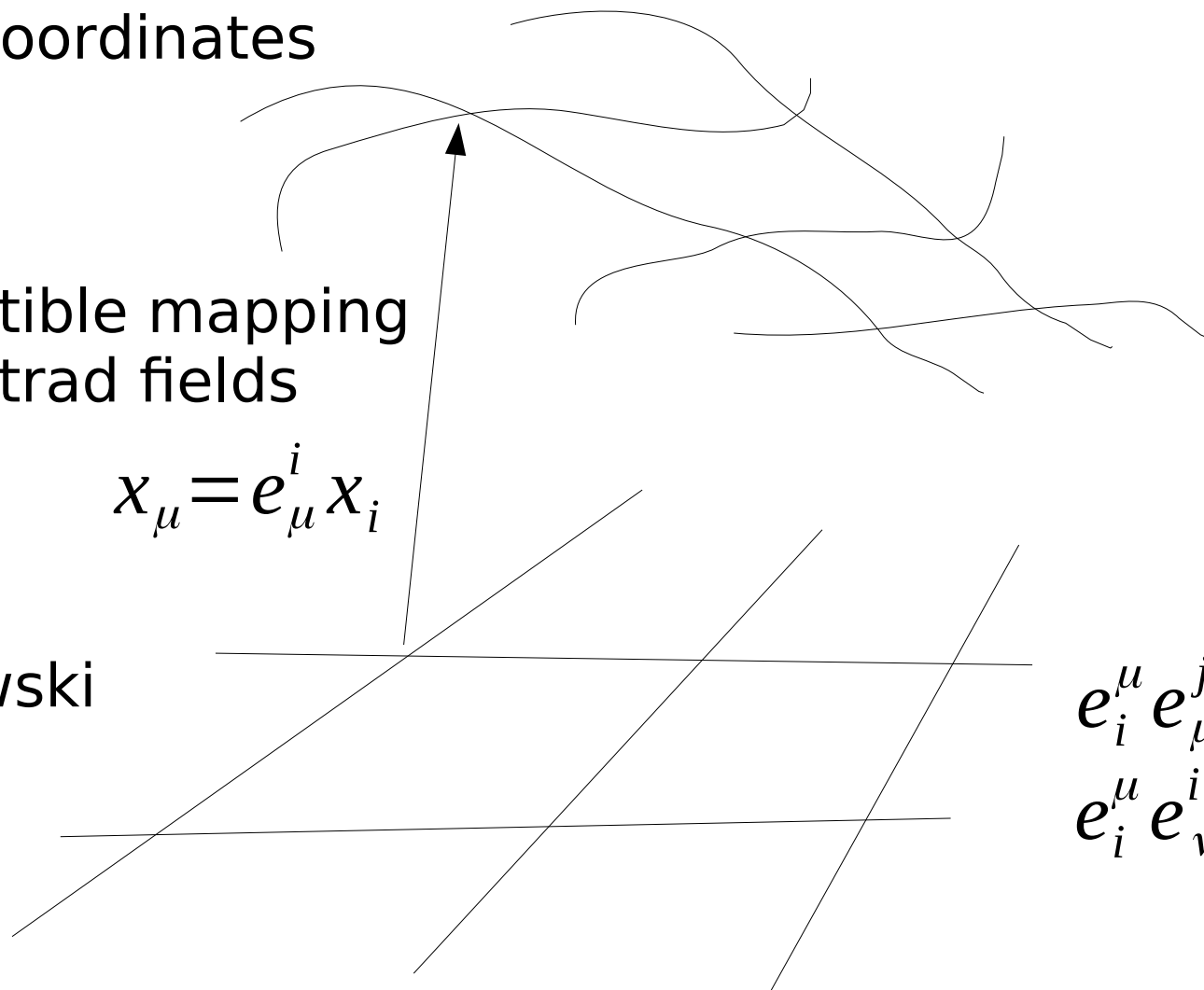
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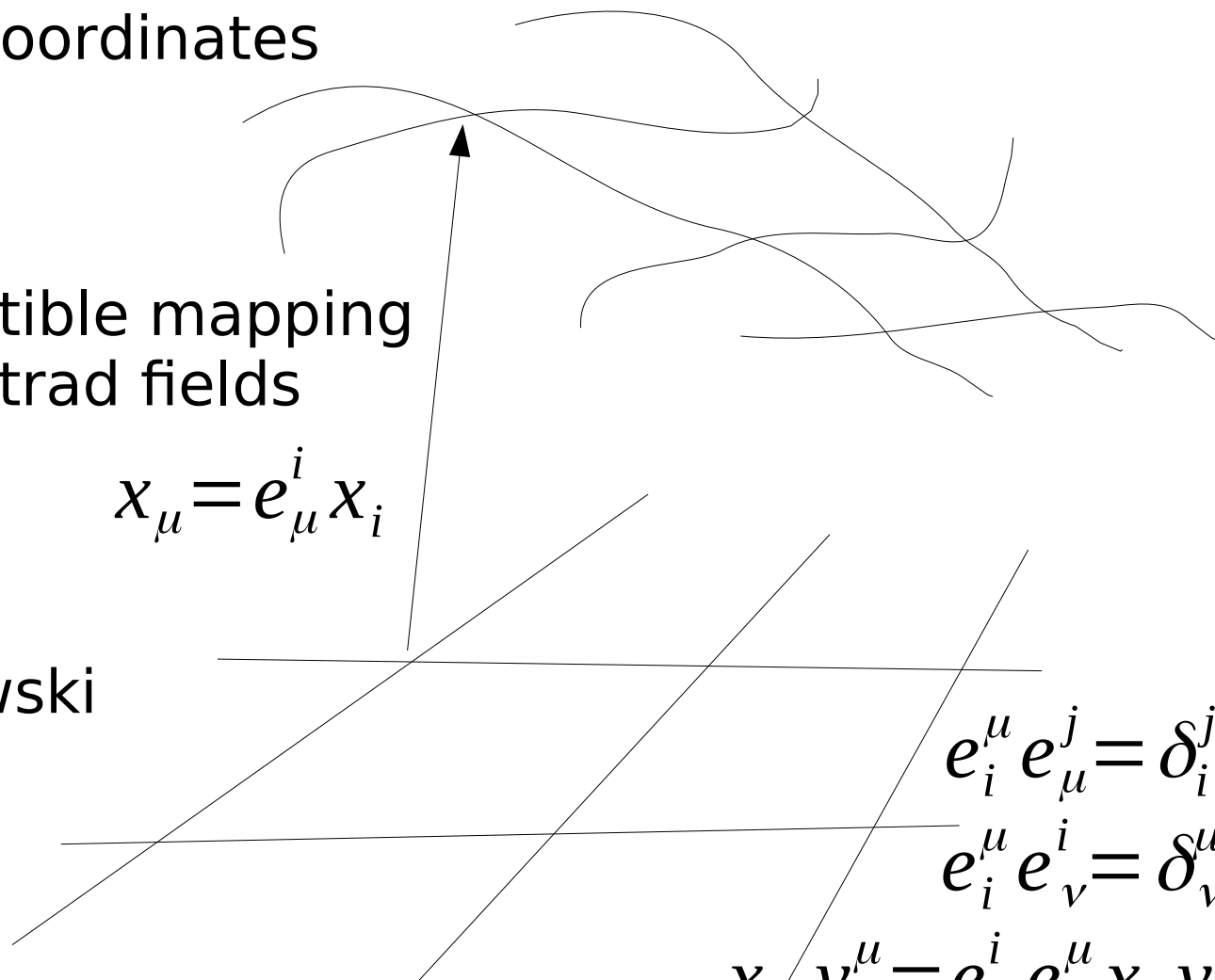
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Metric from the tetrads

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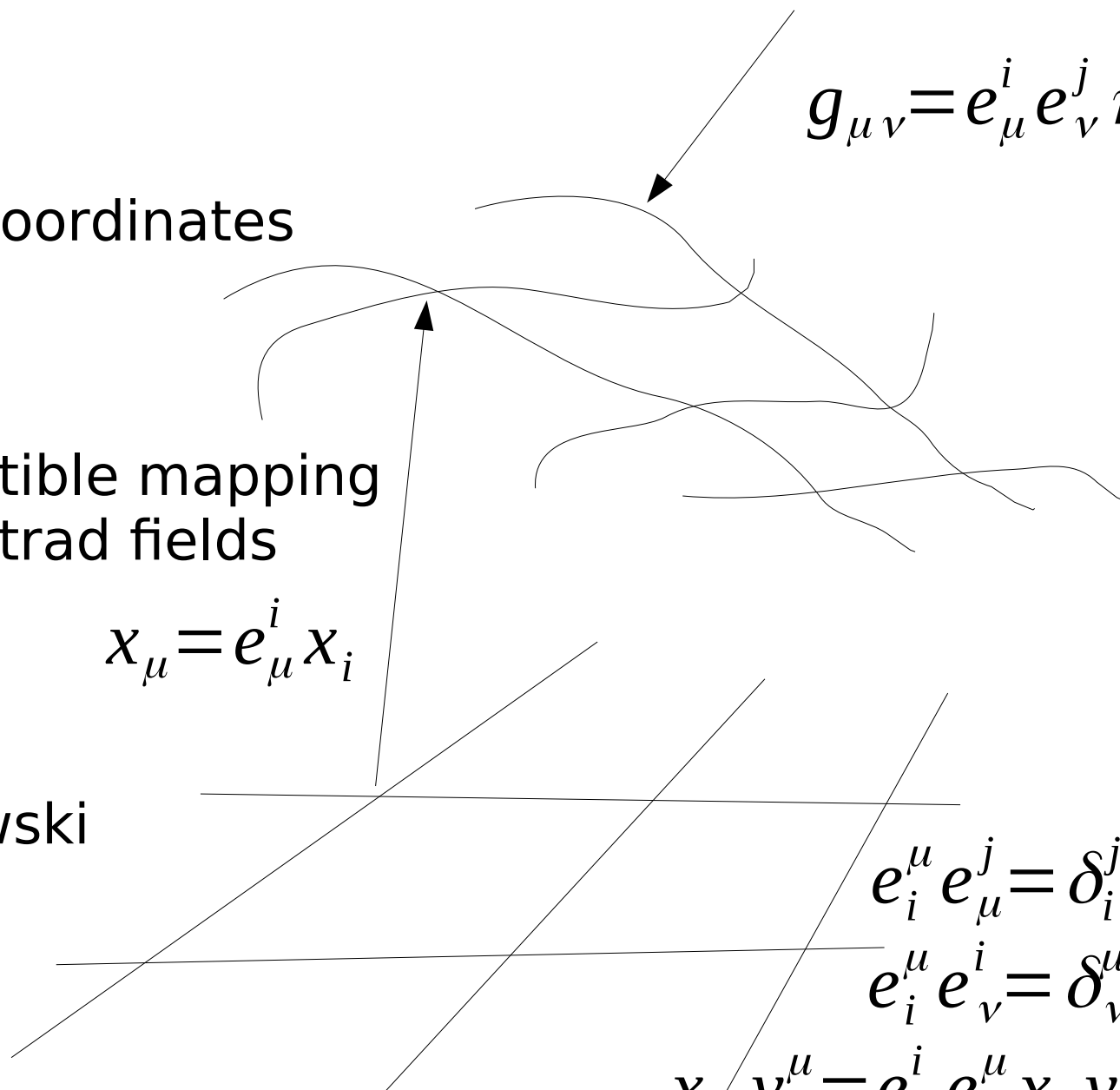
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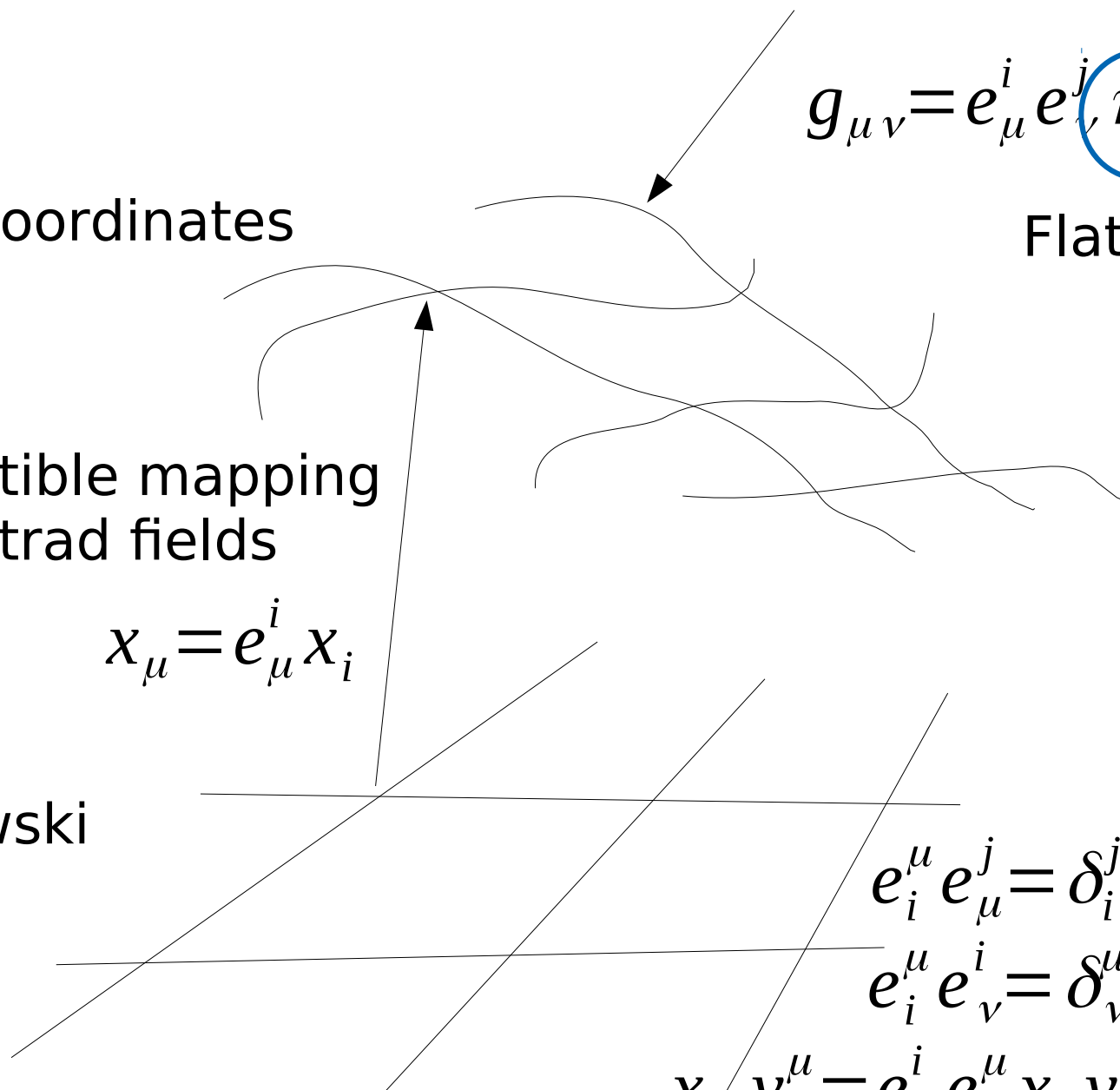
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Tensor fields live at each point

$$\phi_{a\dots r}(x_\mu)$$

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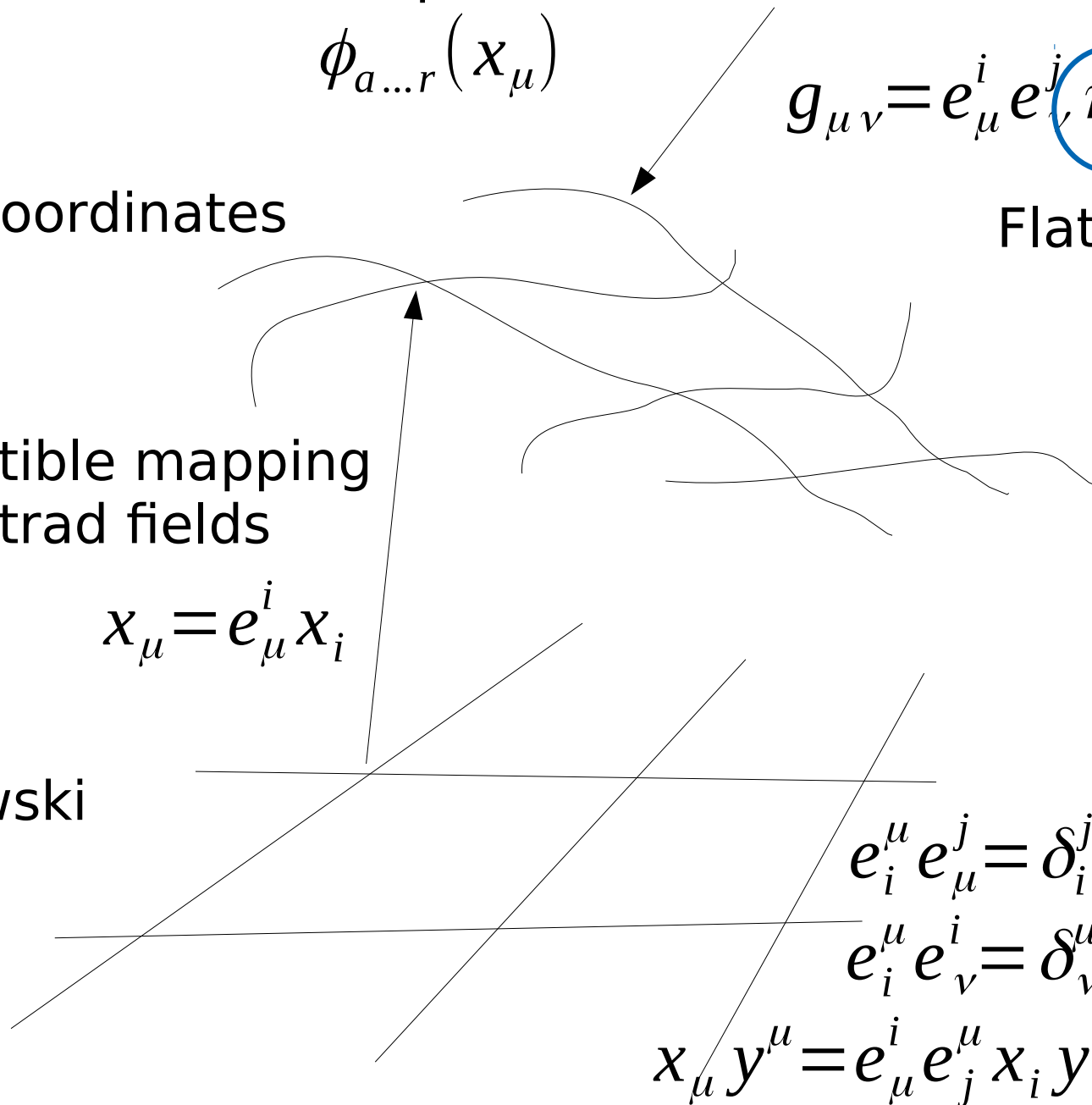
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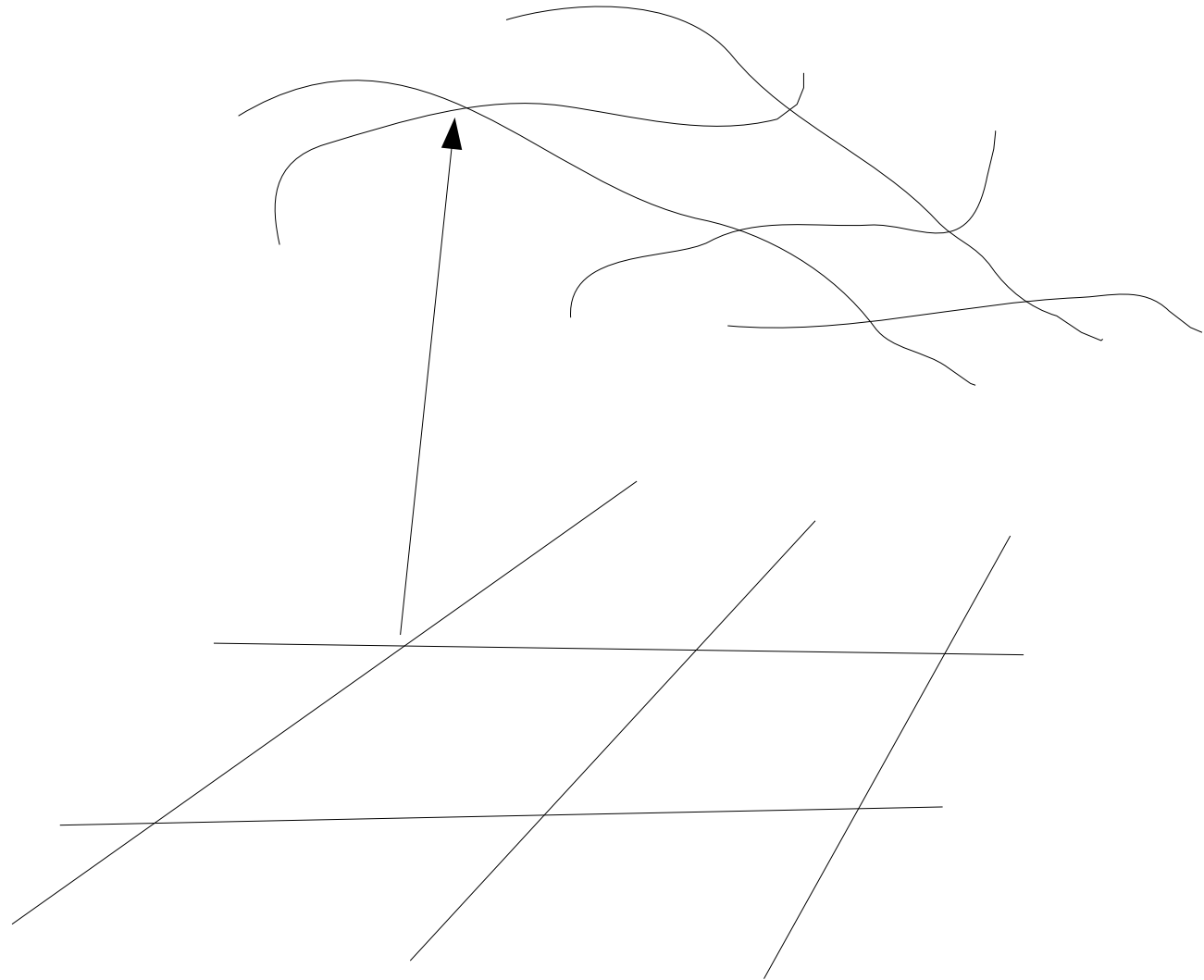
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[Hehl et al.'76]

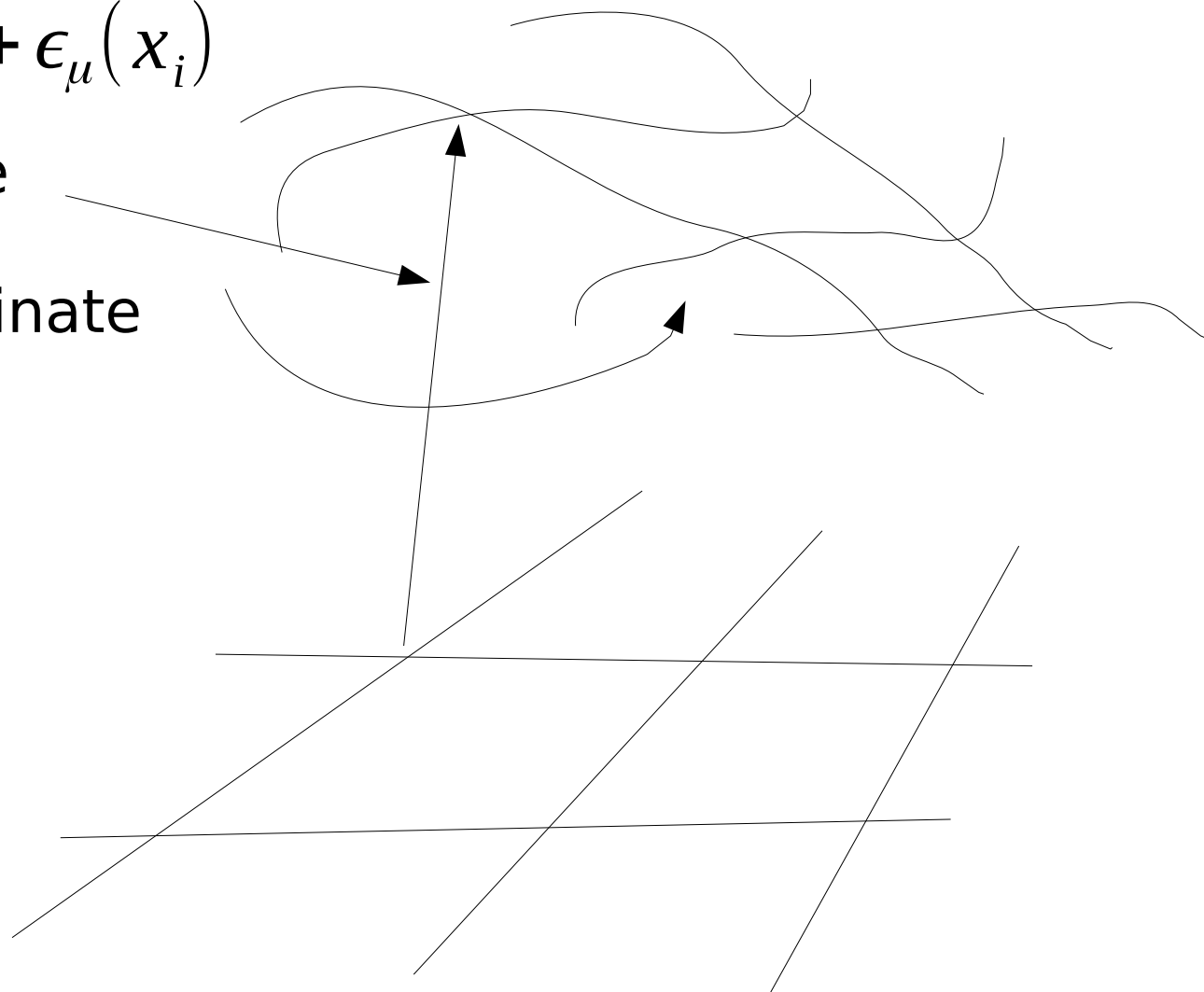


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Local space-time  
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components

$$x_{\mu}(x_i) \rightarrow x_{\mu}(x_i) + \epsilon_{\mu}(x_i)$$

Local coordinate  
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Spin transformation - gauge field is independent connection:  
A gauge field for spin and tetrad for momentum

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Non-Abelian:  
Gribov-Singer  
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- Extended Lagrangian: Dynamical tetrad

$$L_1 = \alpha R^2 + \beta \left( \Delta_\mu e_\nu^i - \Delta_\nu e_\mu^i \right)^2$$

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    - Not impossible
      - Massless vector bound states in Georgi-Glashow  
[Maas, Sondenheimer & Törek'17, Shigemitsu & Lee'85, Afferrante, Maas, Törek, unpublished]
      - Does not violate Weinberg-Witten
        - Includes gravity fields

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  - Likely not: Coordinates gauge-dependent
  - Charge conservation on standard coordinates

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- Interesting consequences for both new physics and standard model physics

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- Simulations in quantum gravity?
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