Electroweak Phenomenology from Fundamental Field Theory

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Gießen
Germany

UNI GRAZ

NAWI Graz
Natural Sciences

FWF
Der Wissenschaftsfonds.

What is this talk about?

Review: 1712.04721

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- Phenomenology
  - Particle spectrum and properties
  - Form factors
  - Tests at LHC

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- Why the field theory of the standard model is more tricky than expected
  - But why you did not yet needed to care
- Phenomenology
  - Particle spectrum and properties
  - Form factors
  - Tests at LHC
- Beyond qualitative: BSM
  - Experimental consequences

Review: 1712.04721

Setting the scene
-
The standard model Higgs

A toy model

- Consider an SU(2) with a single fundamental scalar

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- Essentially the standard model Higgs

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- Ws W^a_μ 

- Coupling g and some numbers f^{abc}

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- Couplings g, v, λ and some numbers f^{abc} and t^{ij}_a
- Parameters selected for a BEH effect

A toy model: Symmetries

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- Local SU(2) gauge symmetry

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

$$W_{\mu}^{a}\rightarrow W_{\mu}^{a} \qquad h\rightarrow h\Omega$$

Textbook approach

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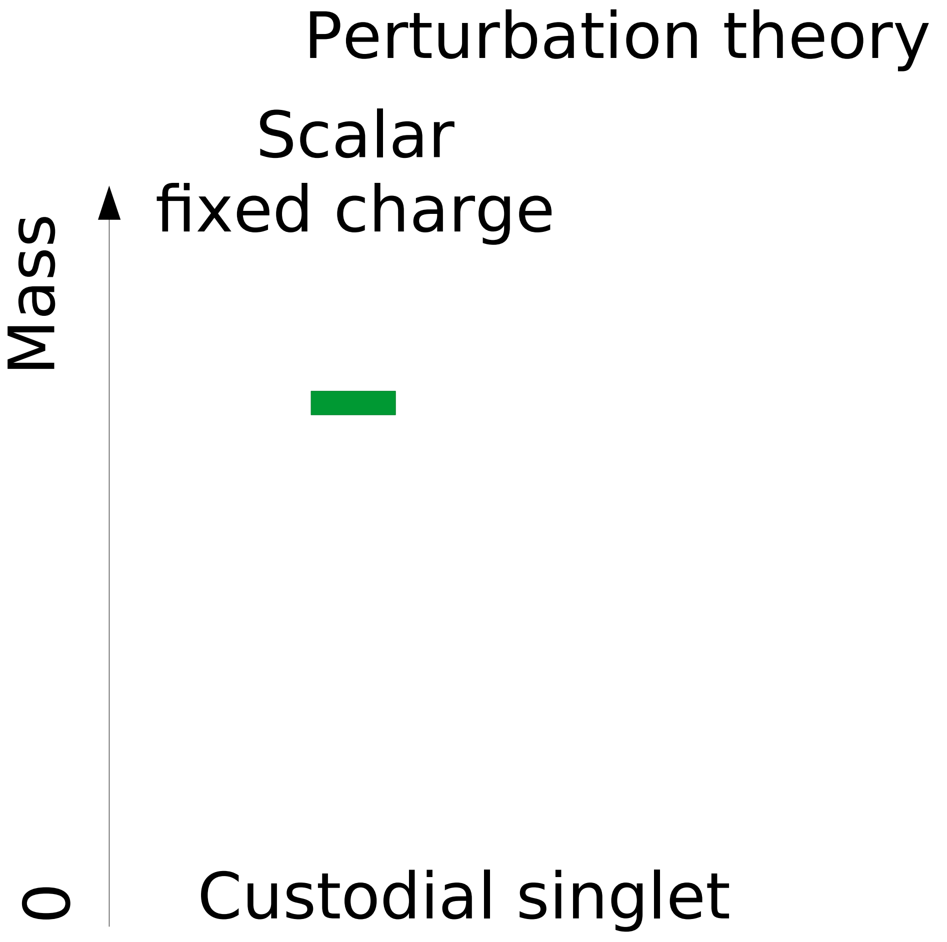
- Get masses and degeneracies at tree-level
- Perform perturbation theory

Physical spectrum

Perturbation theory

Physical spectrum



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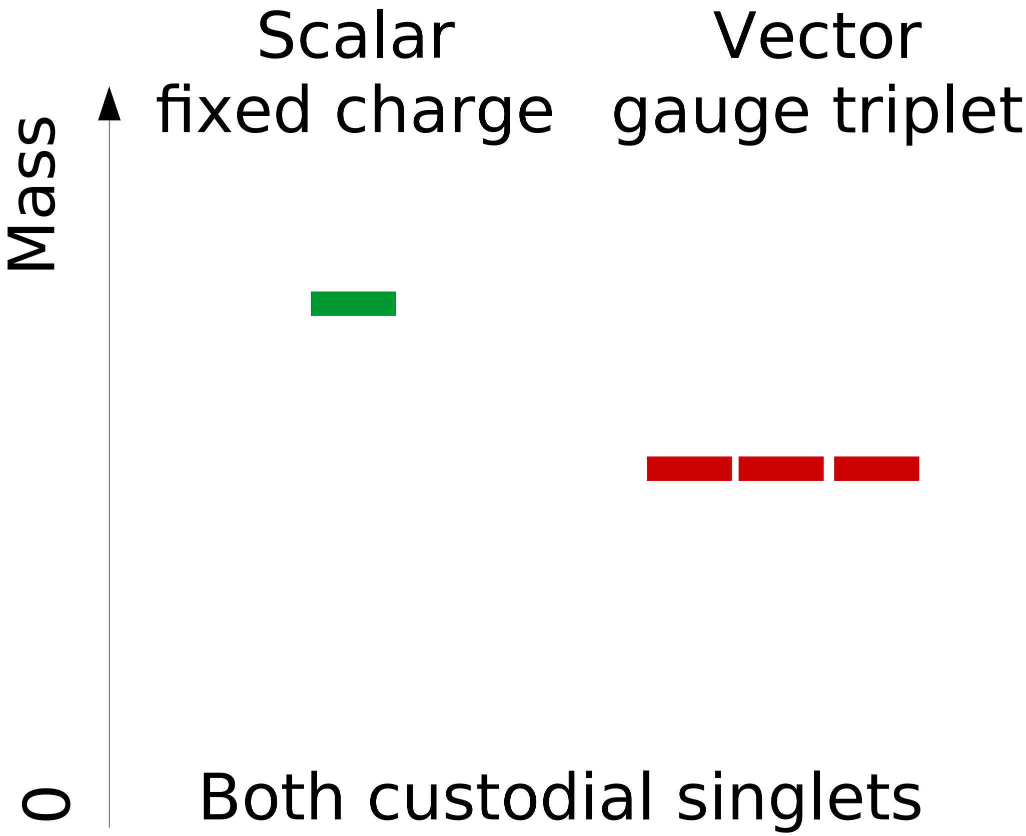

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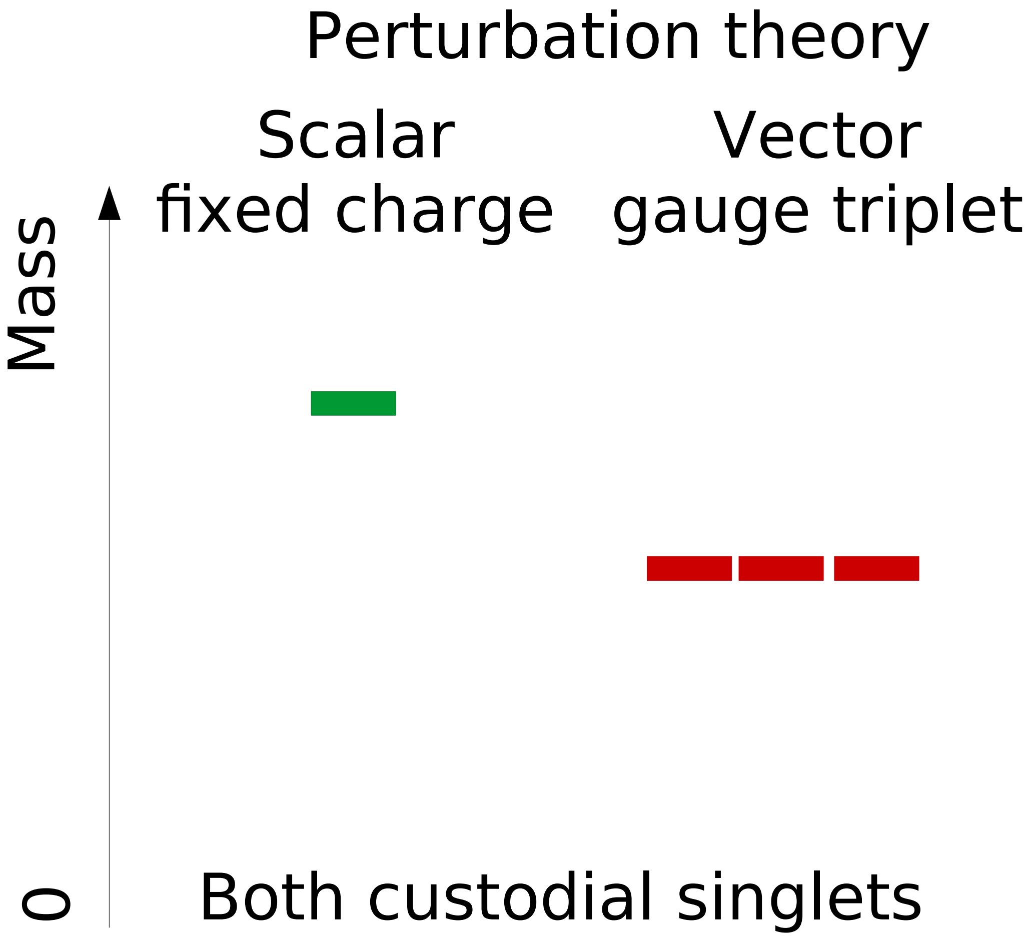

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The origin of the problem

[Fröhlich et al.'80,
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- Physics has to be expressed in terms of manifestly gauge-invariant quantities
  - And this includes non-perturbative aspects...
  - ...even at weak coupling [Gribov’78,Singer’78,Fujikawa’82]

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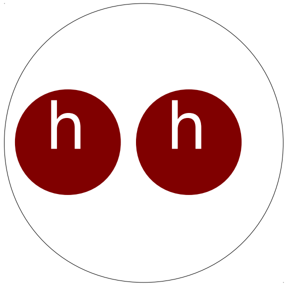

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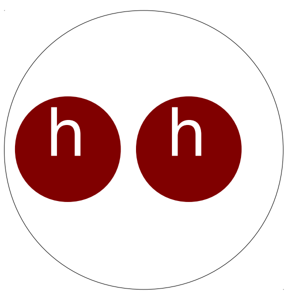

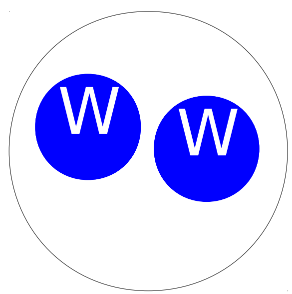

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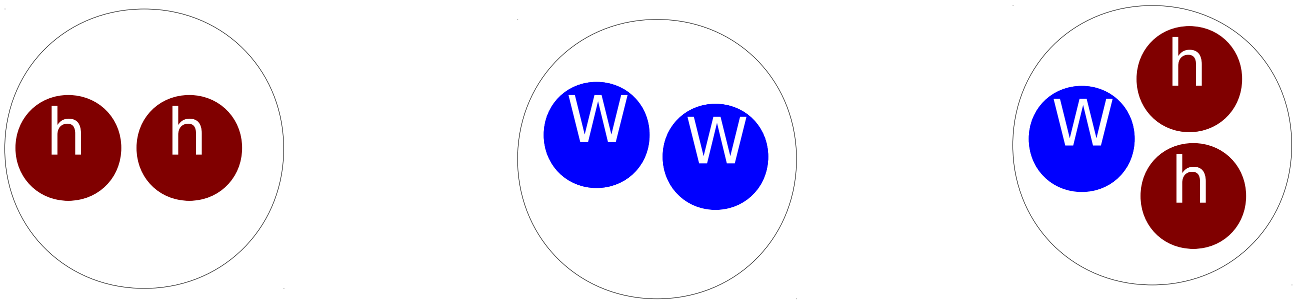

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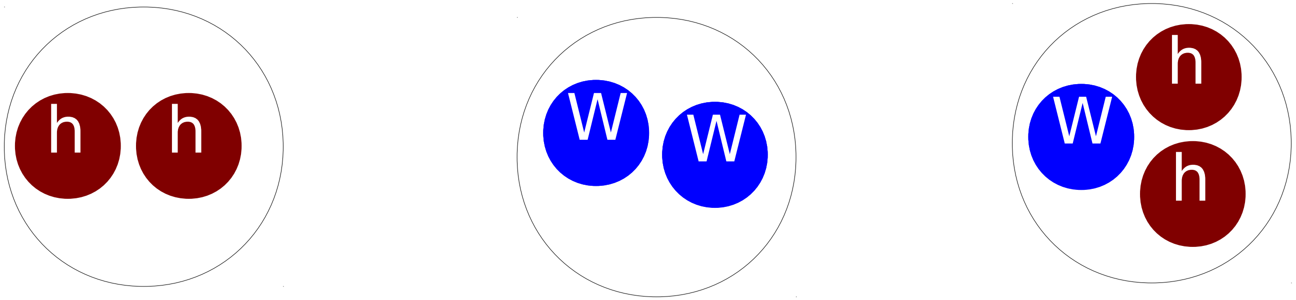

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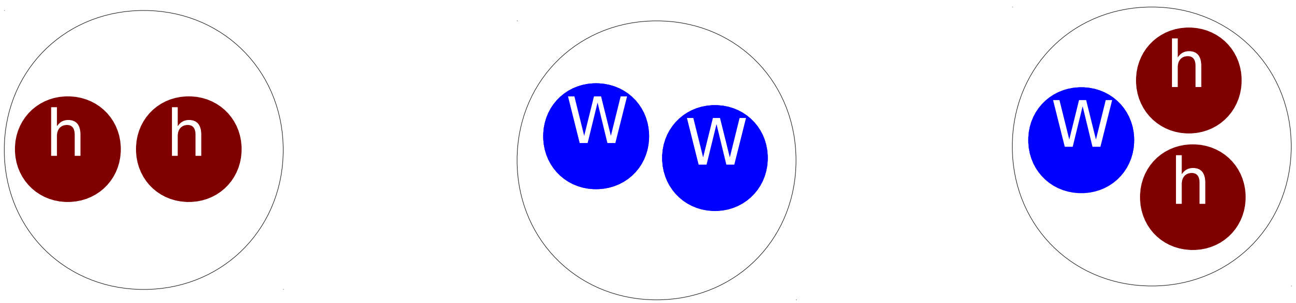

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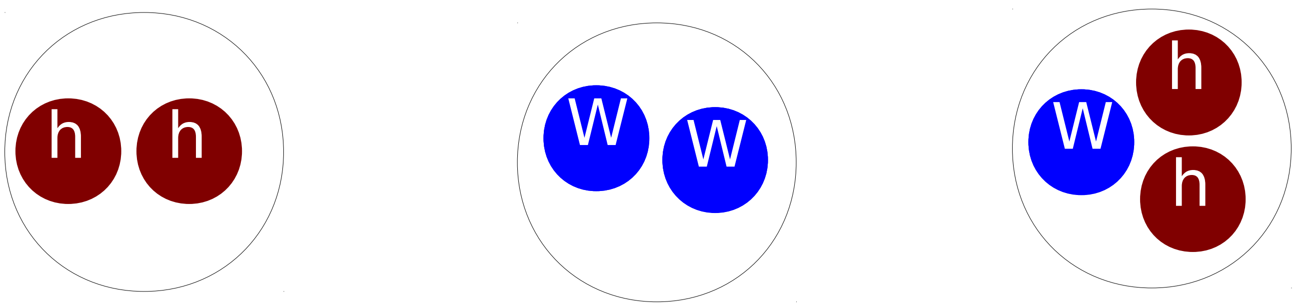

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- Can this matter?

How to make predictions

[Fröhlich et al.’80,’81,
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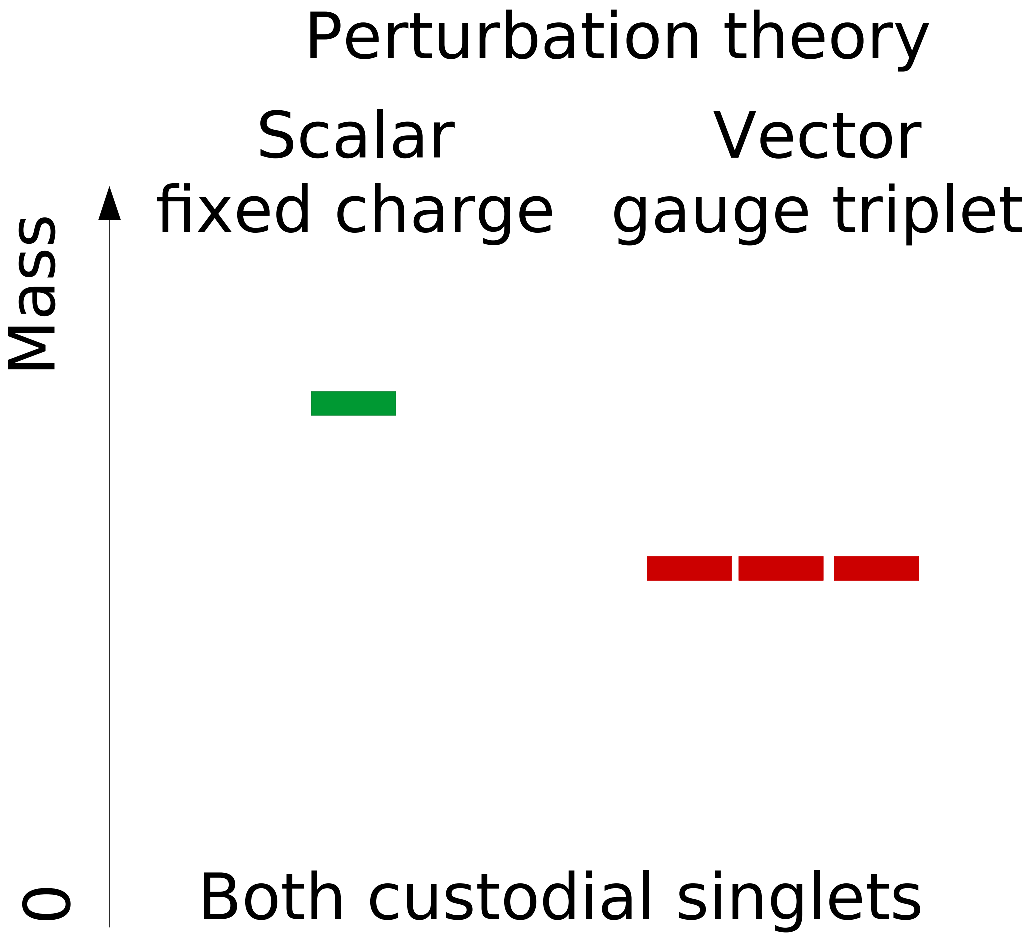
Physical spectrum



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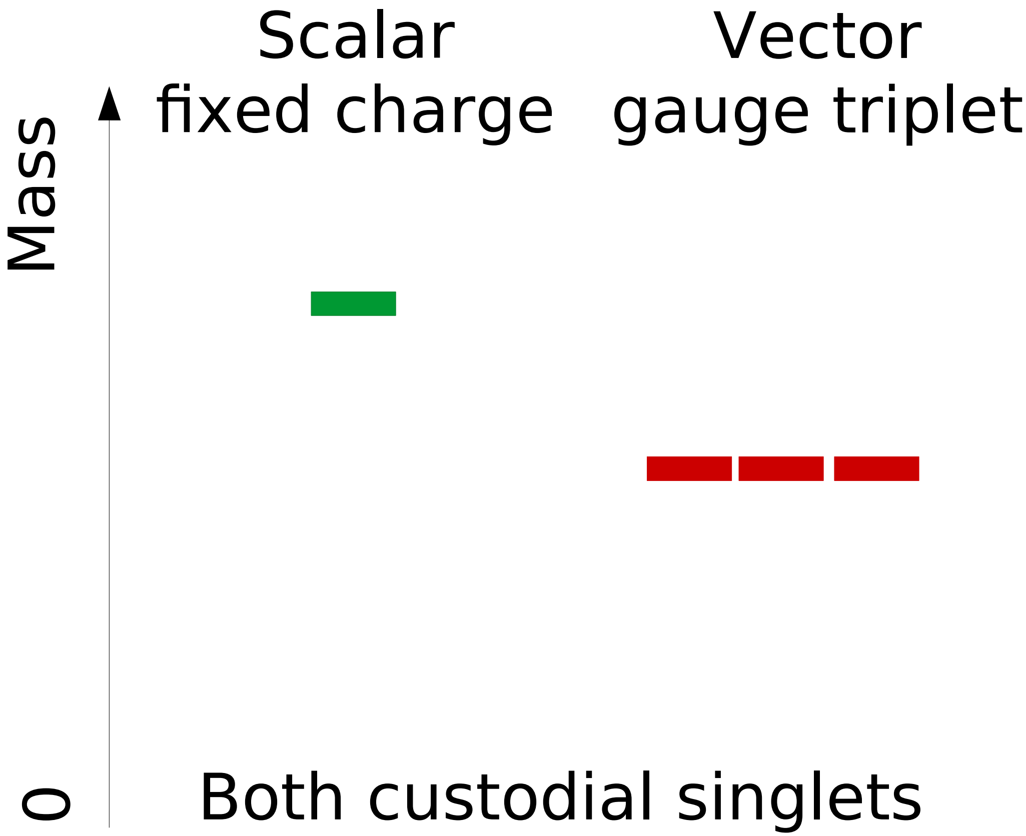
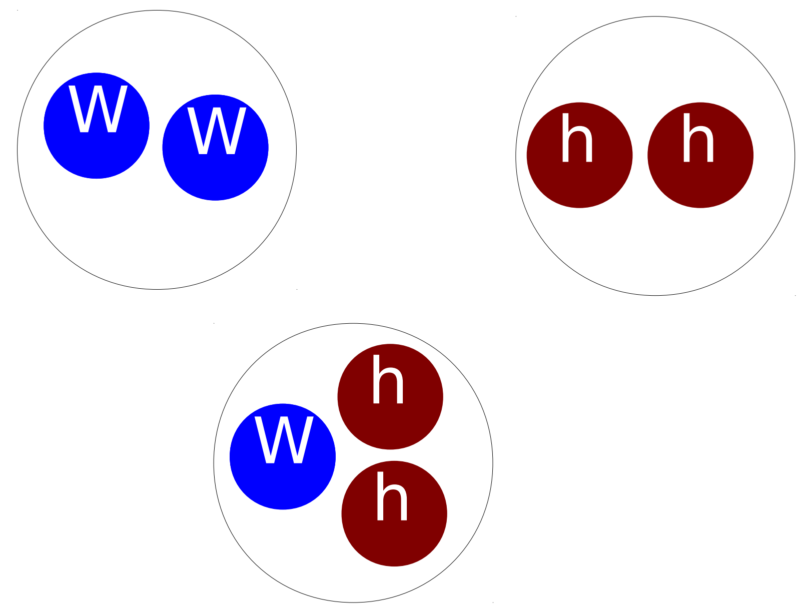
Physical spectrum

Perturbation theory



Composite (bound) states



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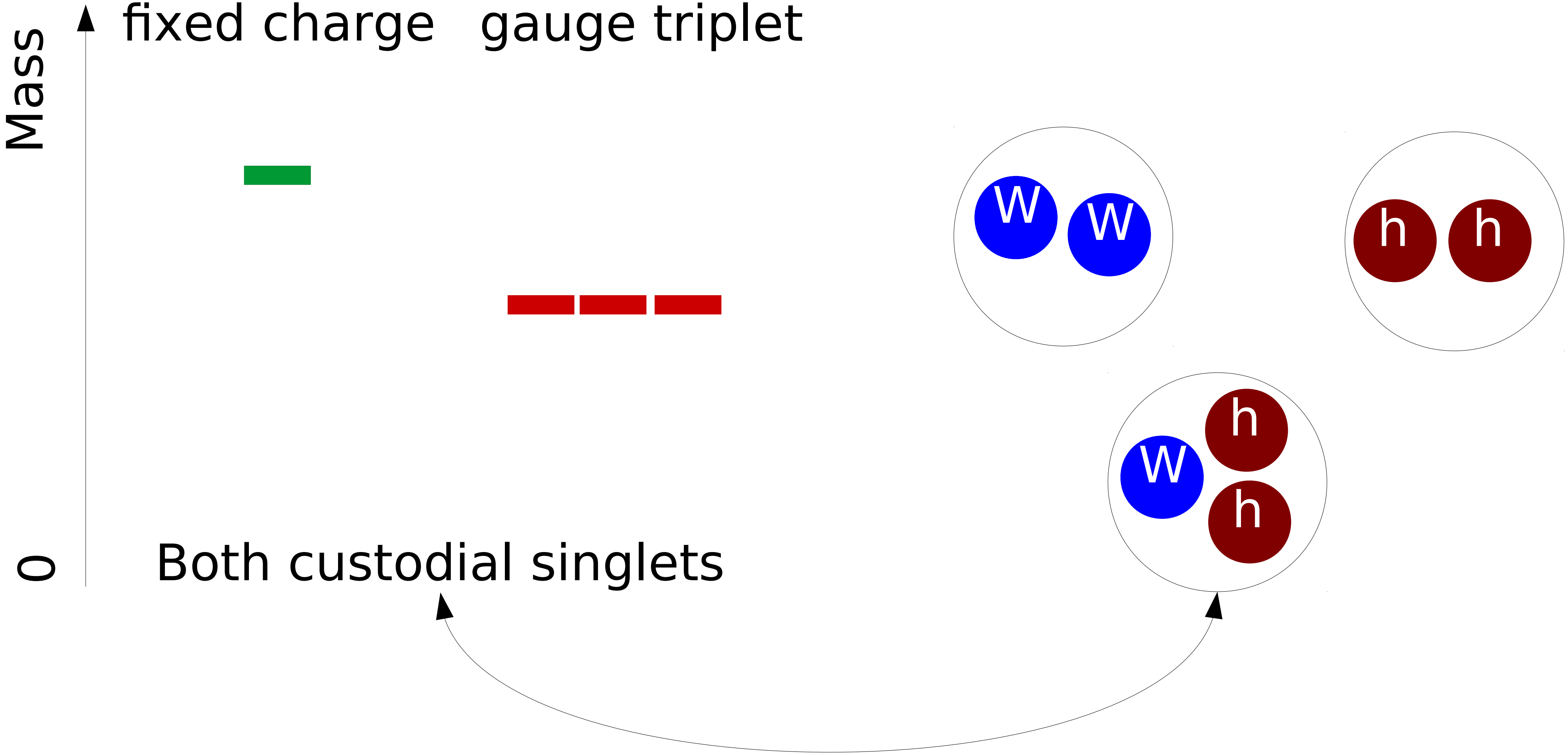
Physical spectrum

Composite (bound) states

Perturbation theory

Scalar
fixed charge

Vector
gauge triplet



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Composite (bound) states
Require
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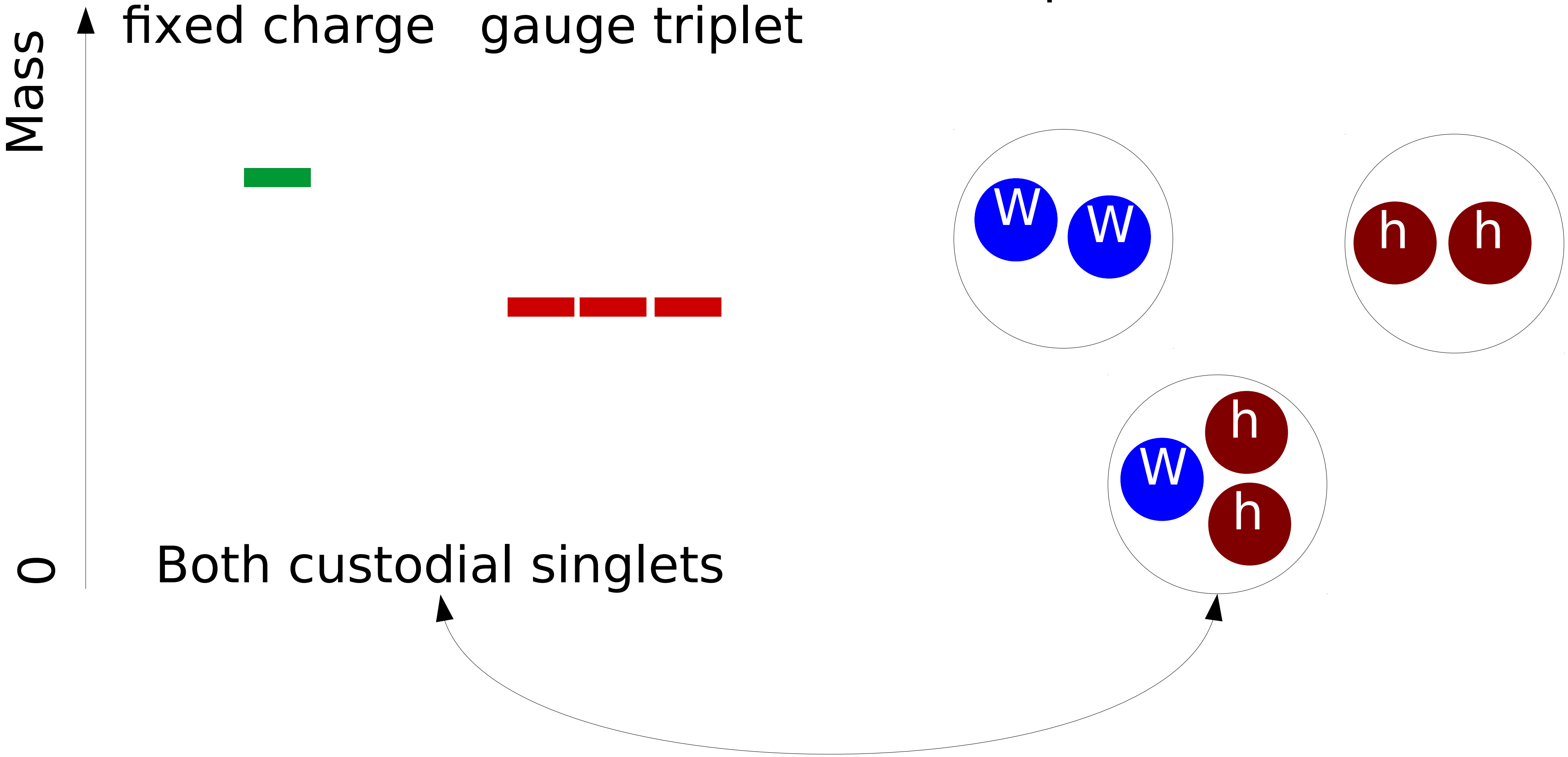

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Physical spectrum

[Maas'12, Maas & Mufti'14]

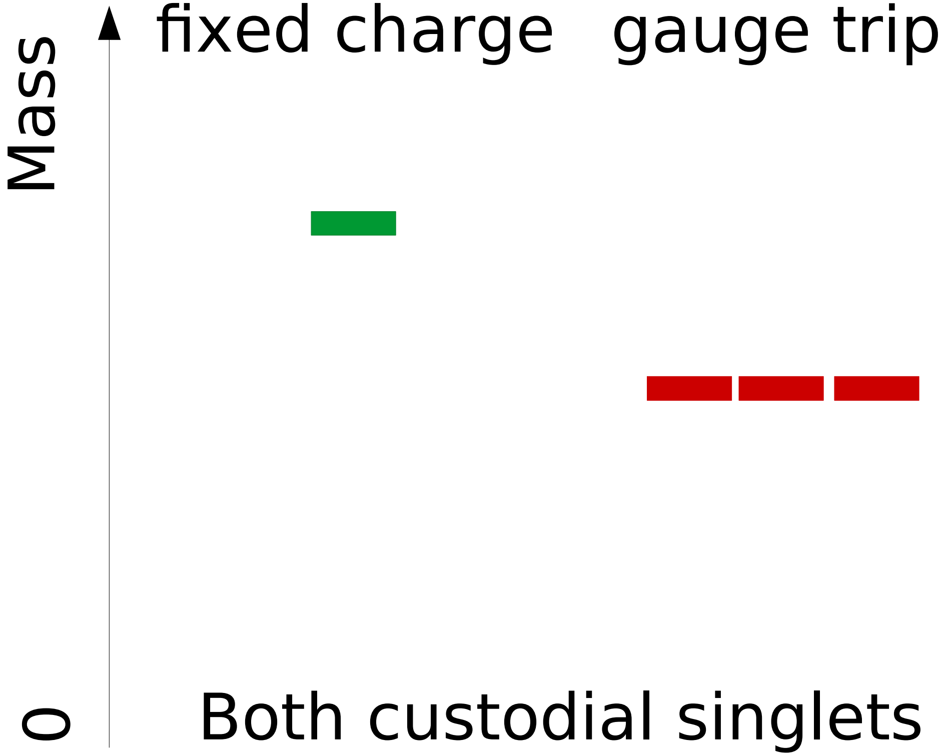
Perturbation theory

Scalar fixed charge

Vector gauge triplet

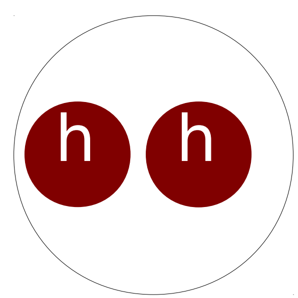
Gauge-invariant

Scalar singlet



Both custodial singlets

$$h(x)^{+} h(x)$$



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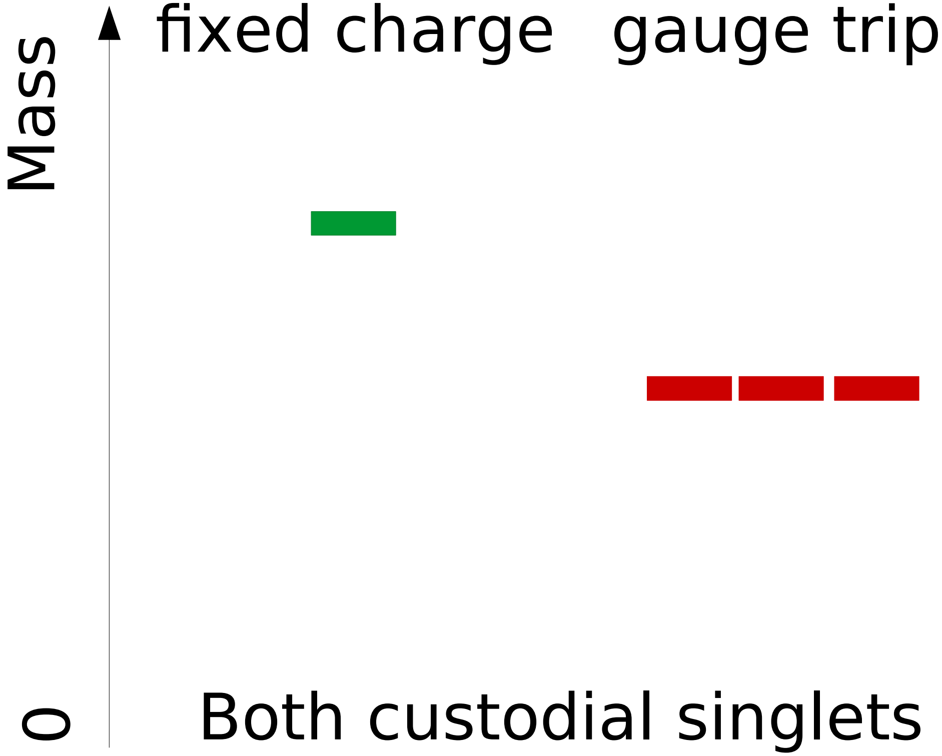

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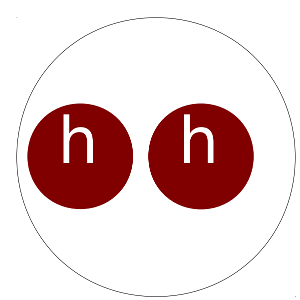

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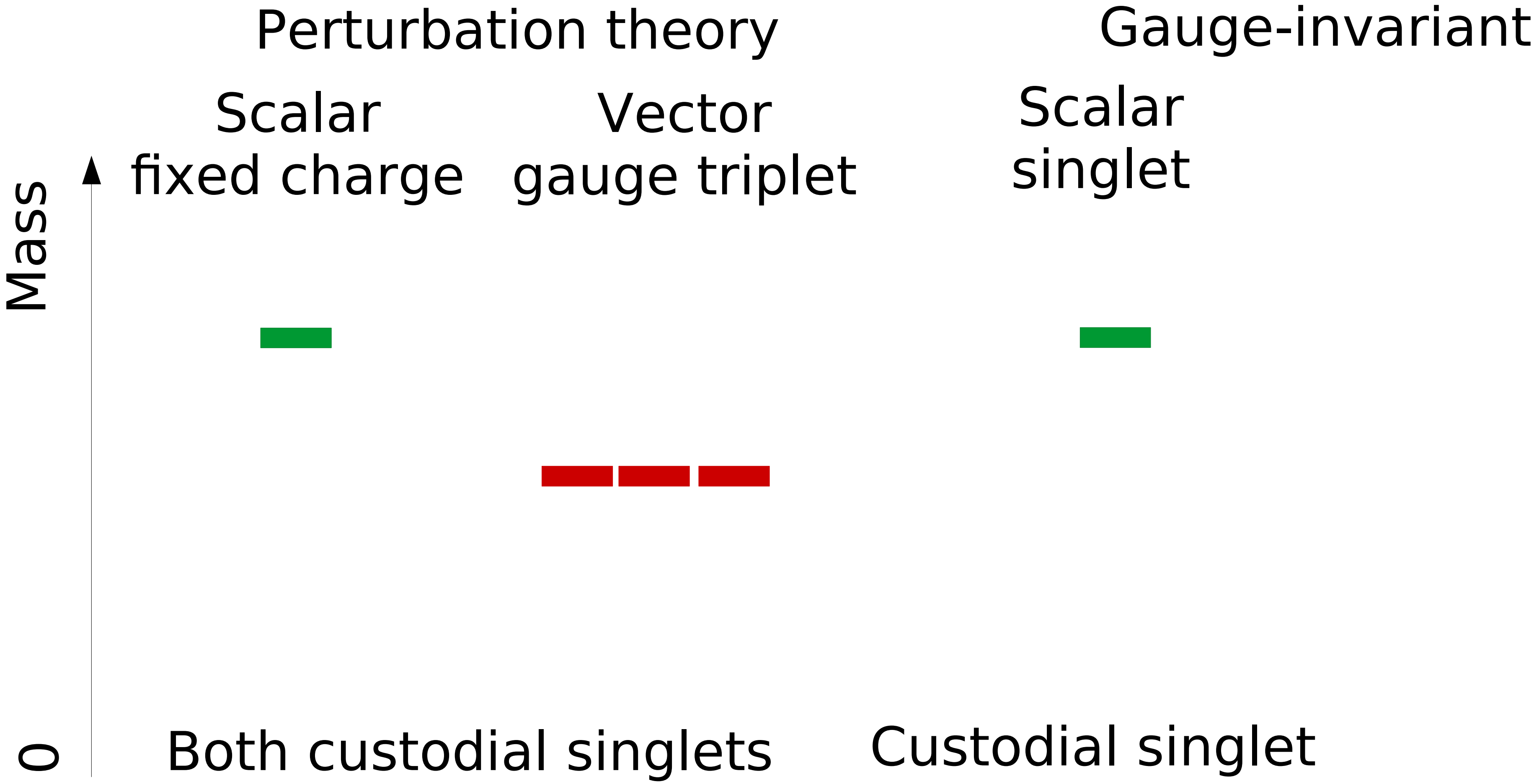

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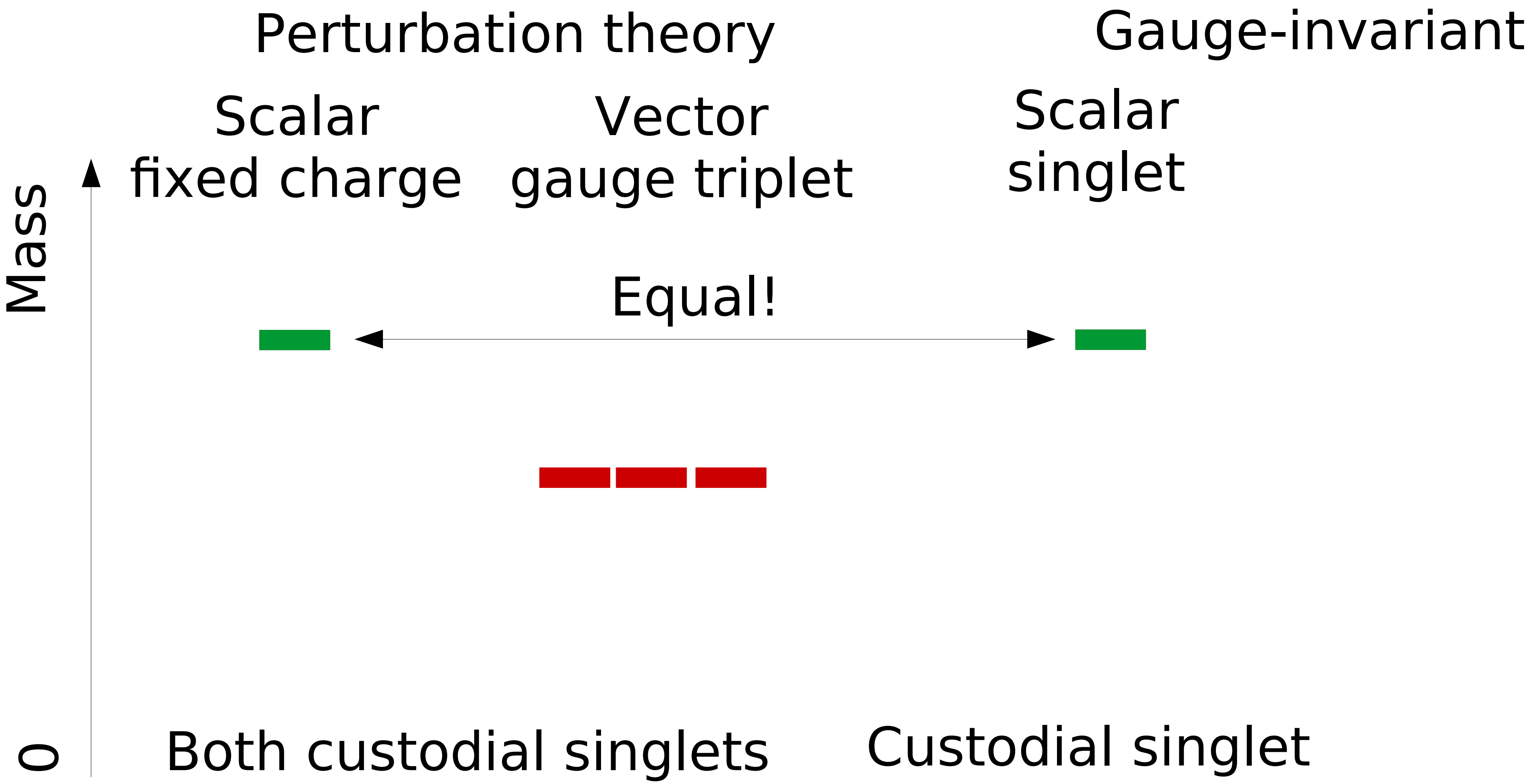

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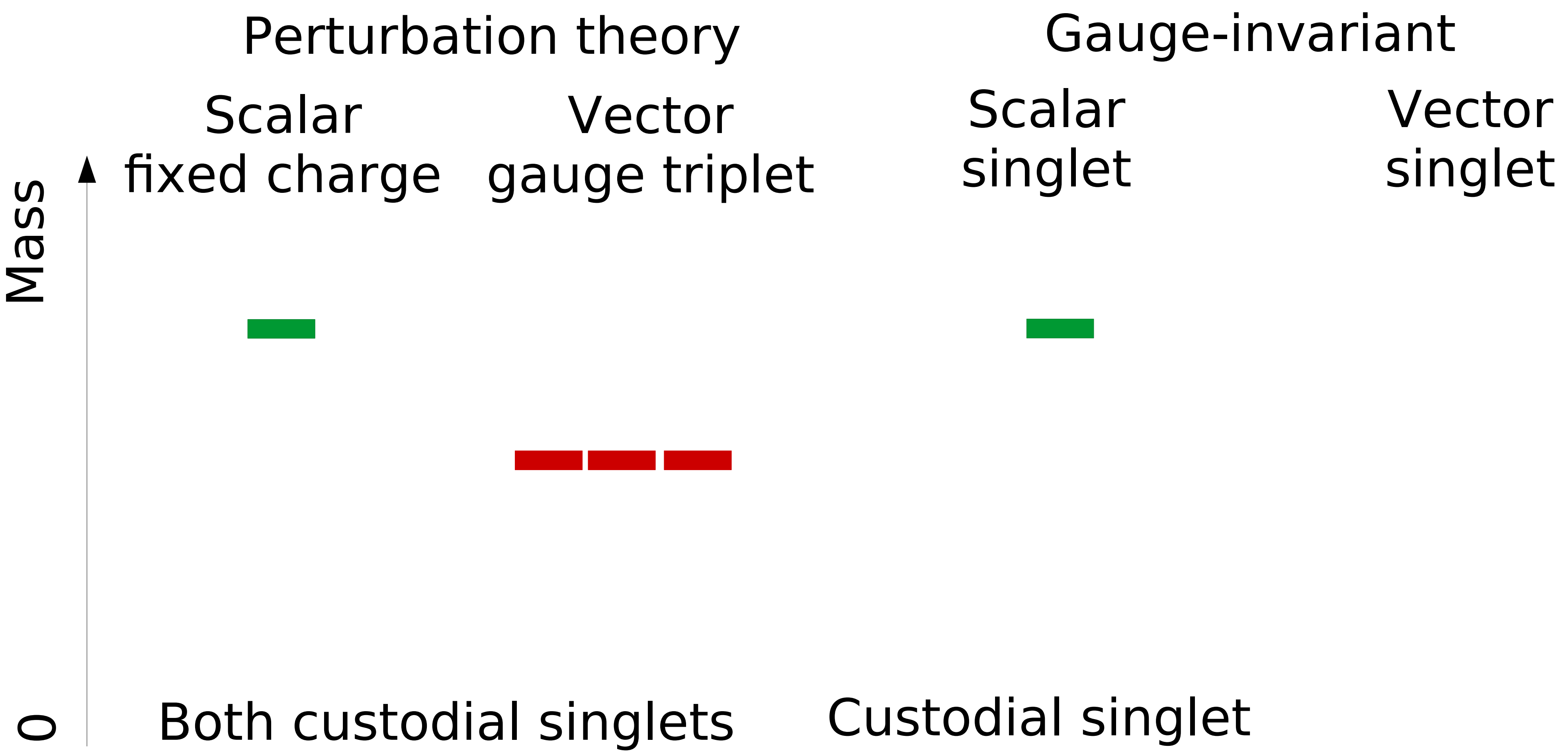
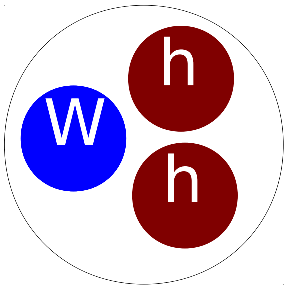


$$tr\, t^a \frac{h^+}{\sqrt{h^+ h}} D_\mu \frac{h}{\sqrt{h^+ h}}$$



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Perturbation theory

Gauge-invariant

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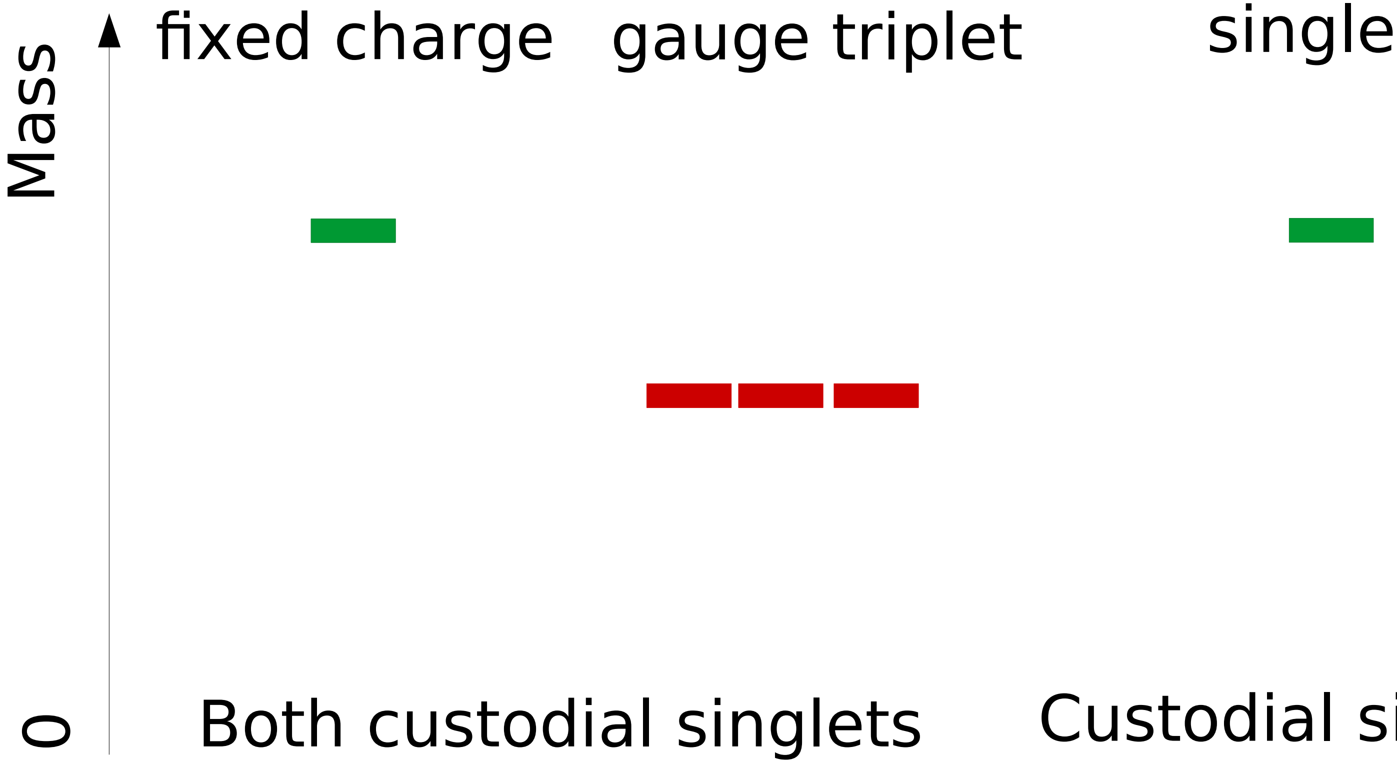

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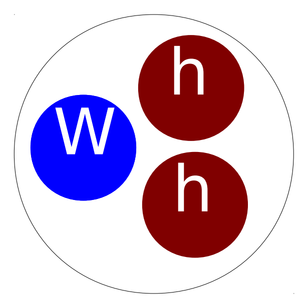

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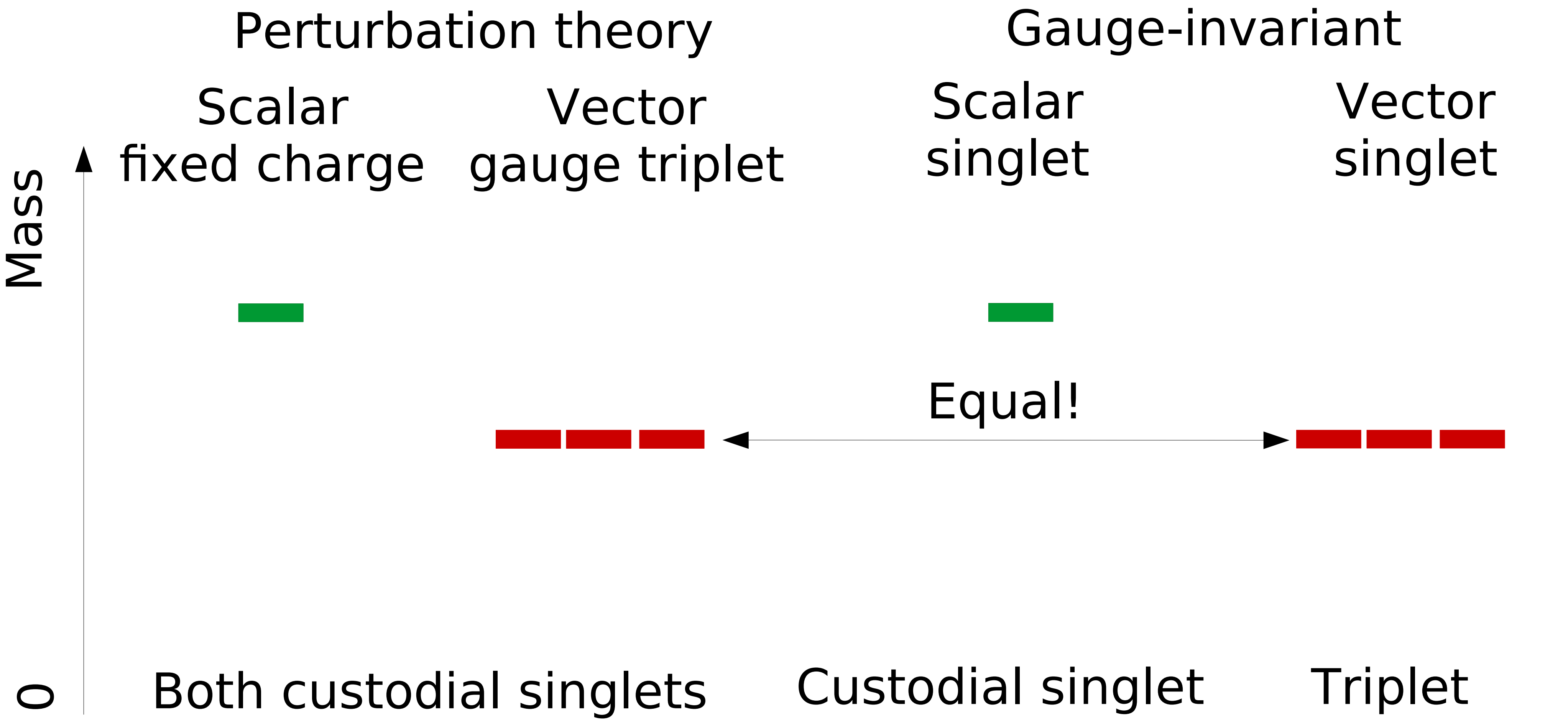

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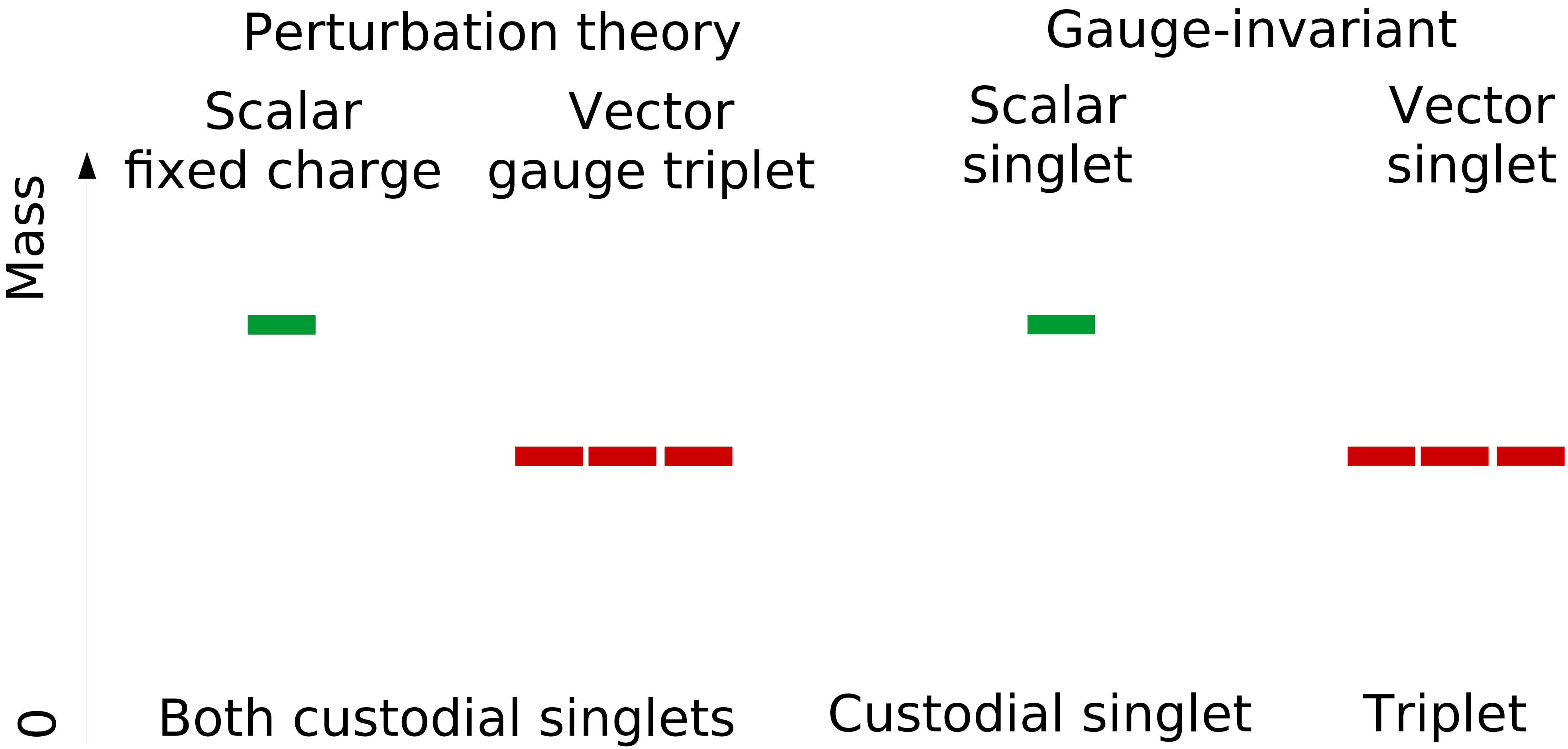

- Confirmed on the lattice
  - Some lattice support for SU(2)xU(1) [Shrock et al. 85-88]

A microscopic mechanism
-
Why on-shell is important

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  - Perform double expansion [Fröhlich et al.'80, Maas’12]
    - Vacuum expectation value (FMS mechanism)
    - Standard expansion in couplings
    - Together: Gauge-invariant perturbation theory

Gauge-invariant perturbation theory

[Fröhlich et al.'80,'81
Maas'12,'17]

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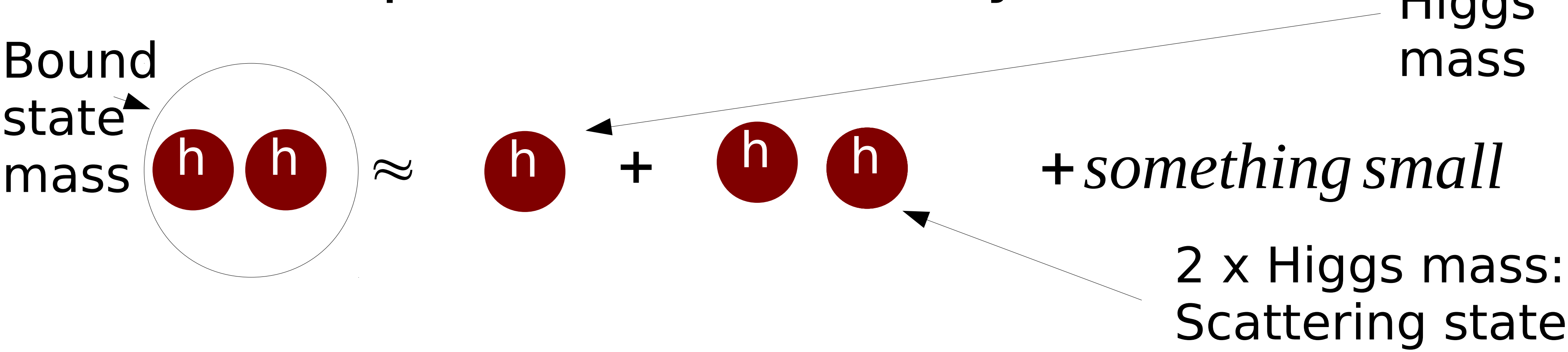

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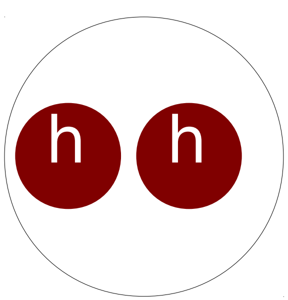
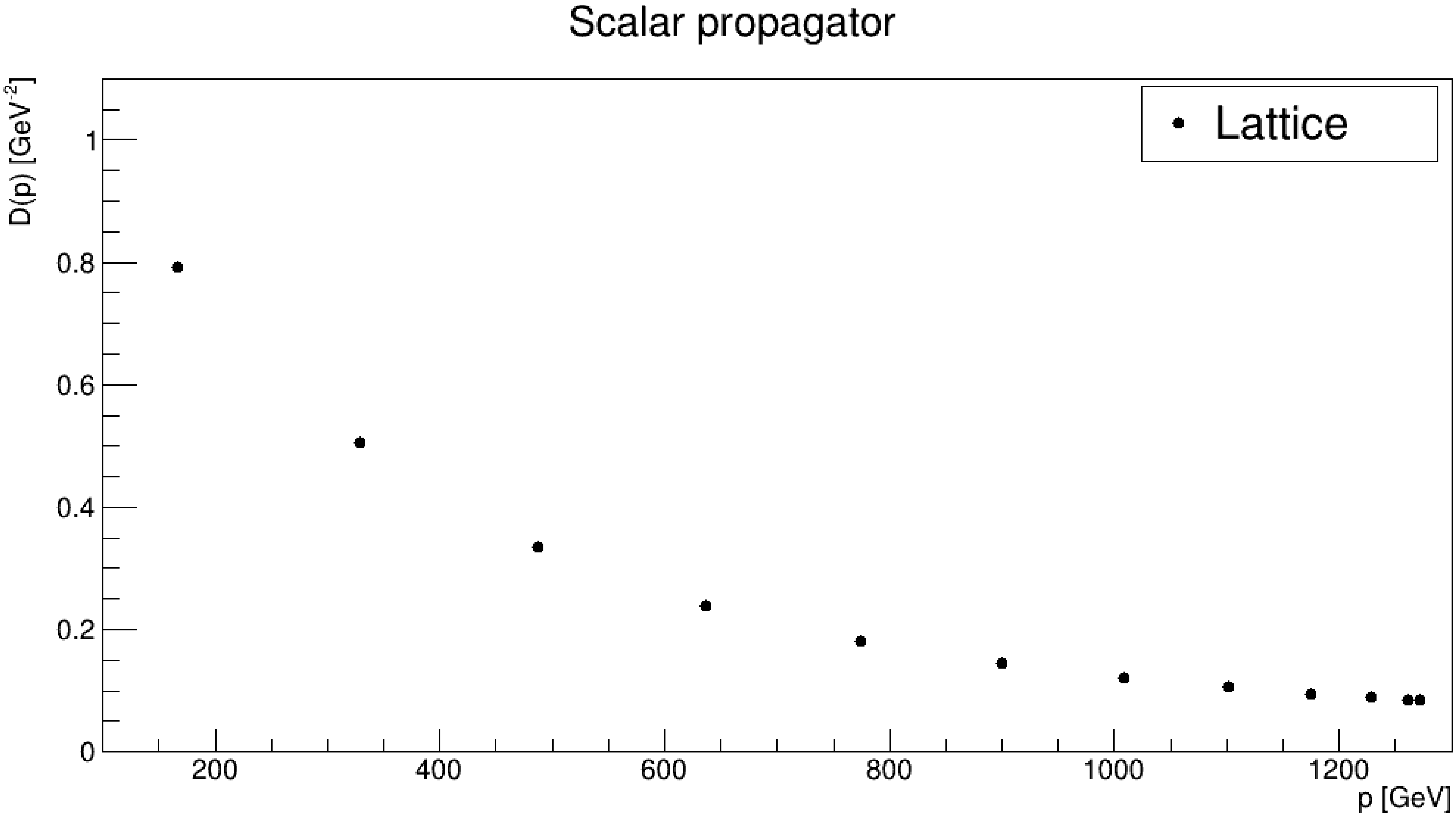
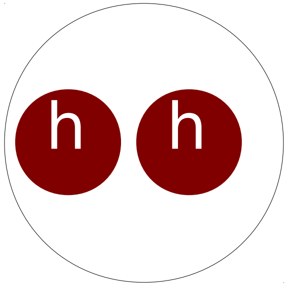


$$= D\left(P^2\right)$$

Gauge-invariant perturbation theory





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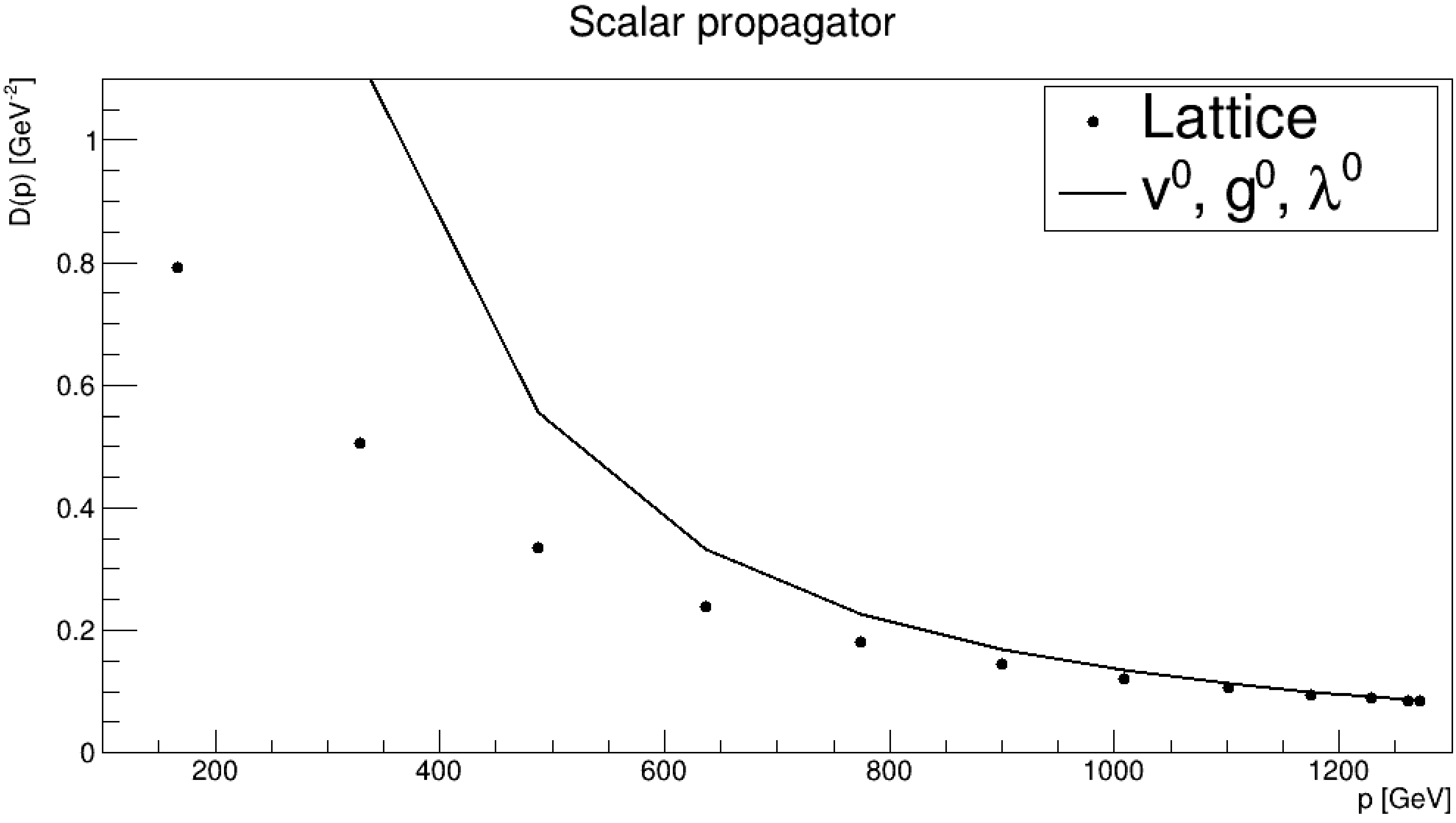

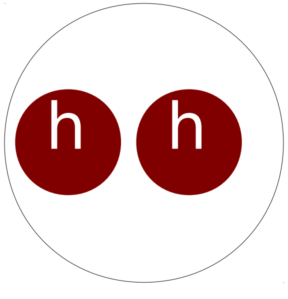

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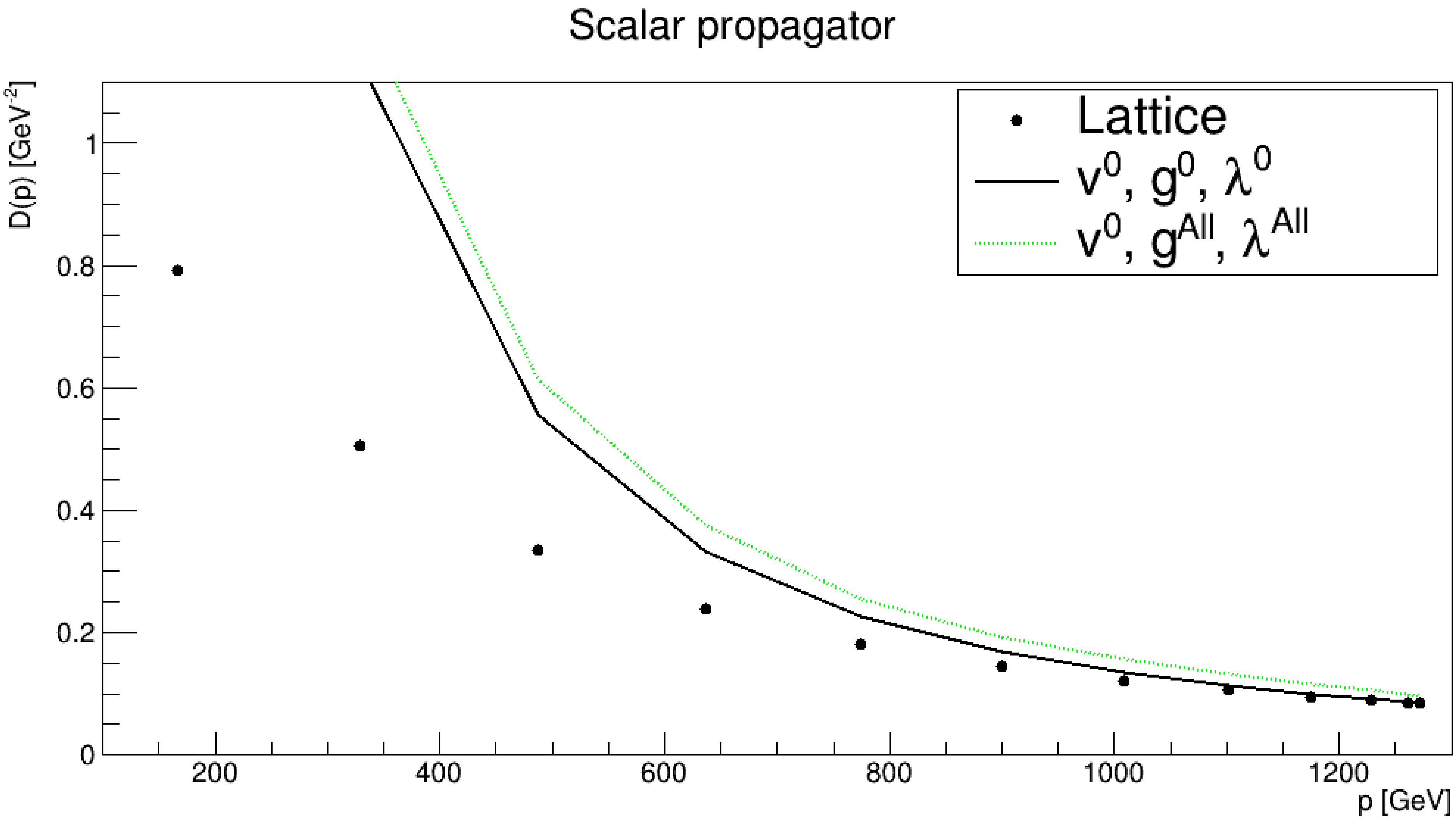

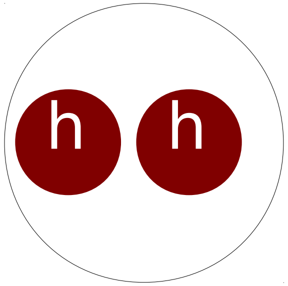

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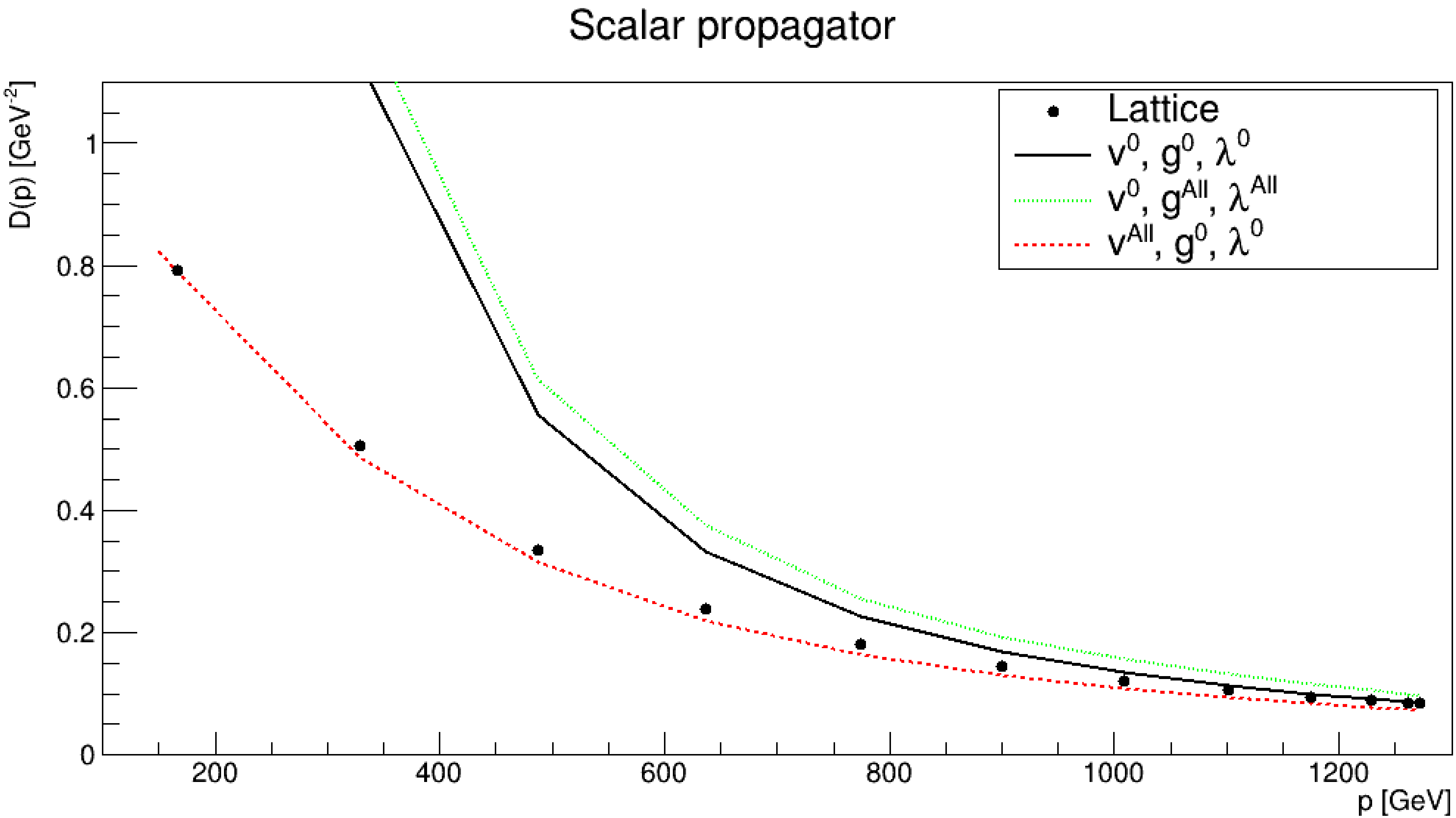

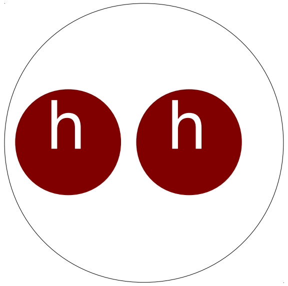

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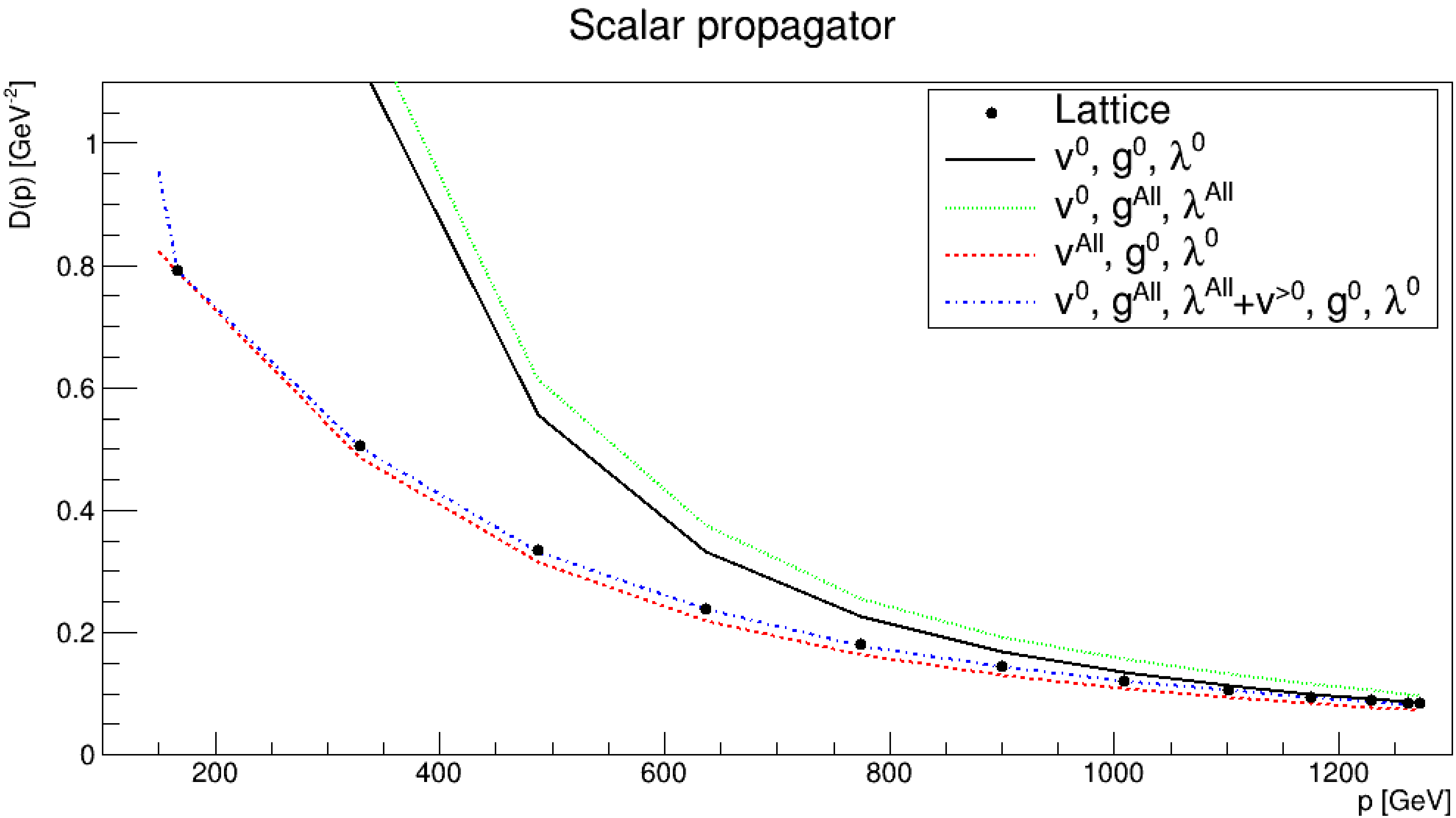

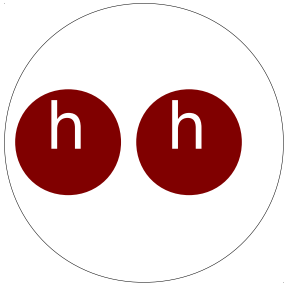

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Exactly one gauge boson for every physical state

Exploring implications
-
Experimental tests

Bound states as extended objects

- Bound states have an extension
  - Can it be measured?

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[Maas,Raubitzke,Török'18]

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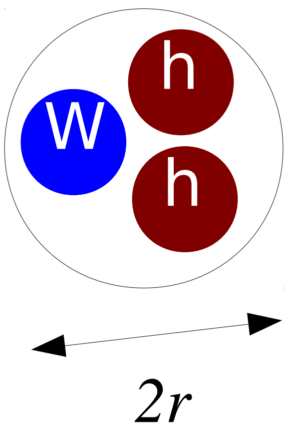

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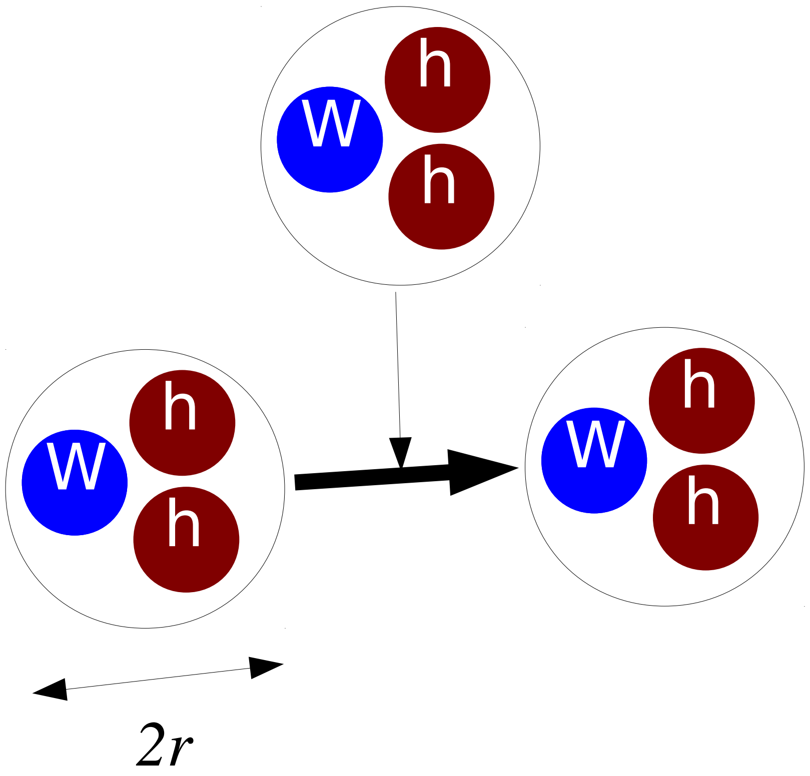
  - Example: Vector
  - Measure the form factor



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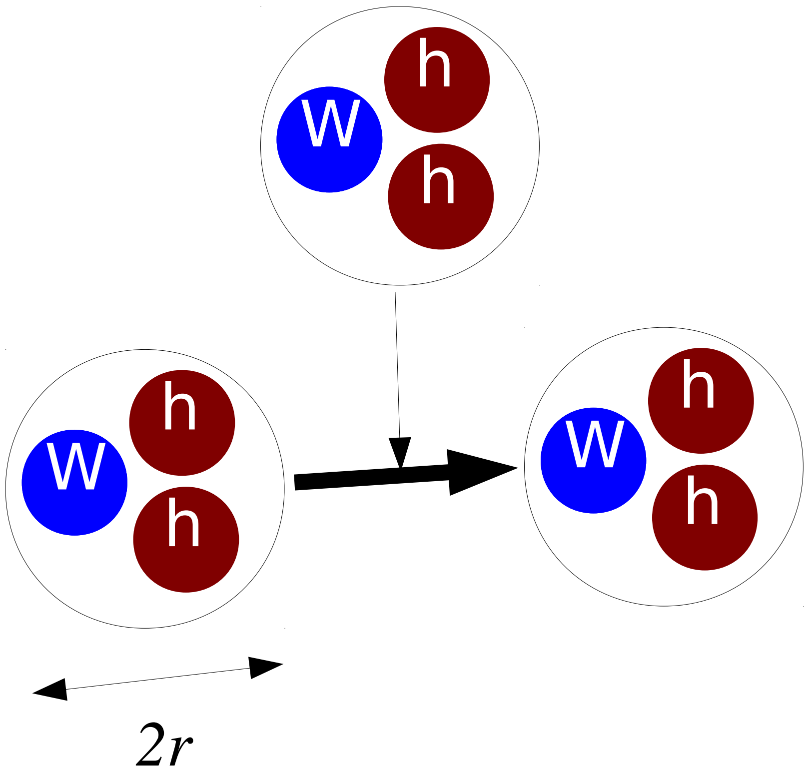

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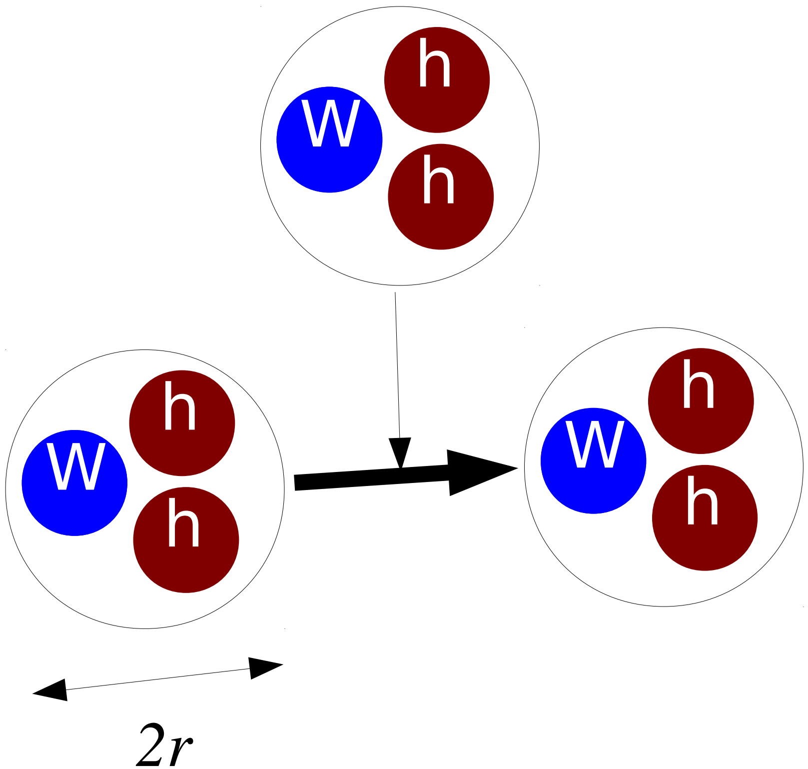

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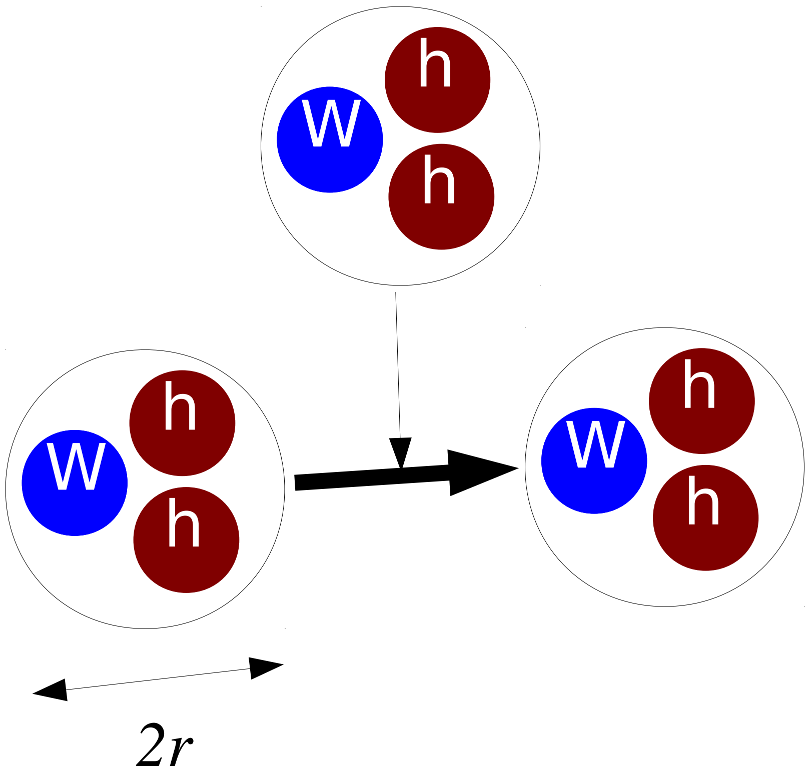

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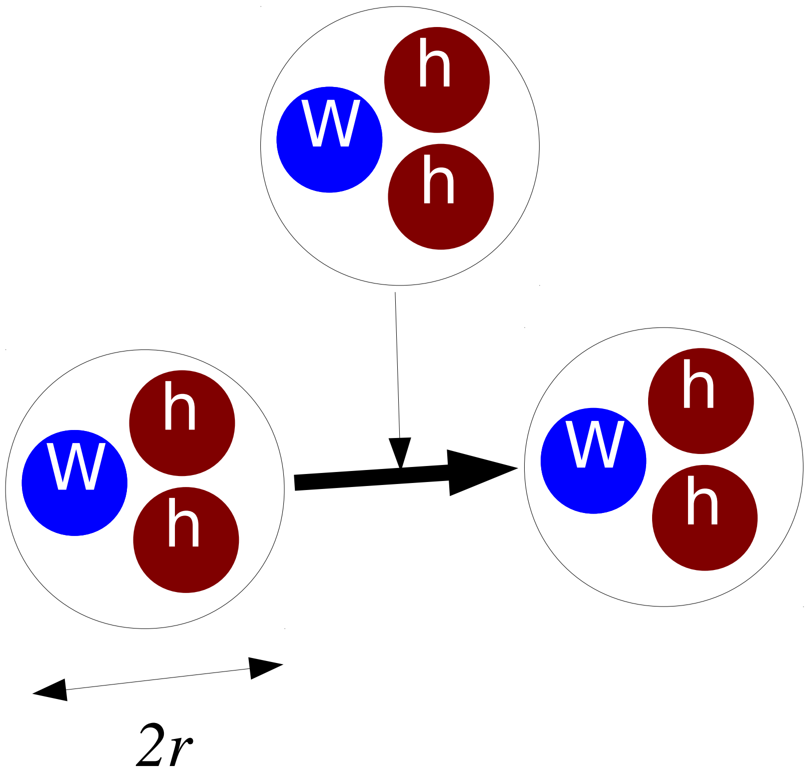

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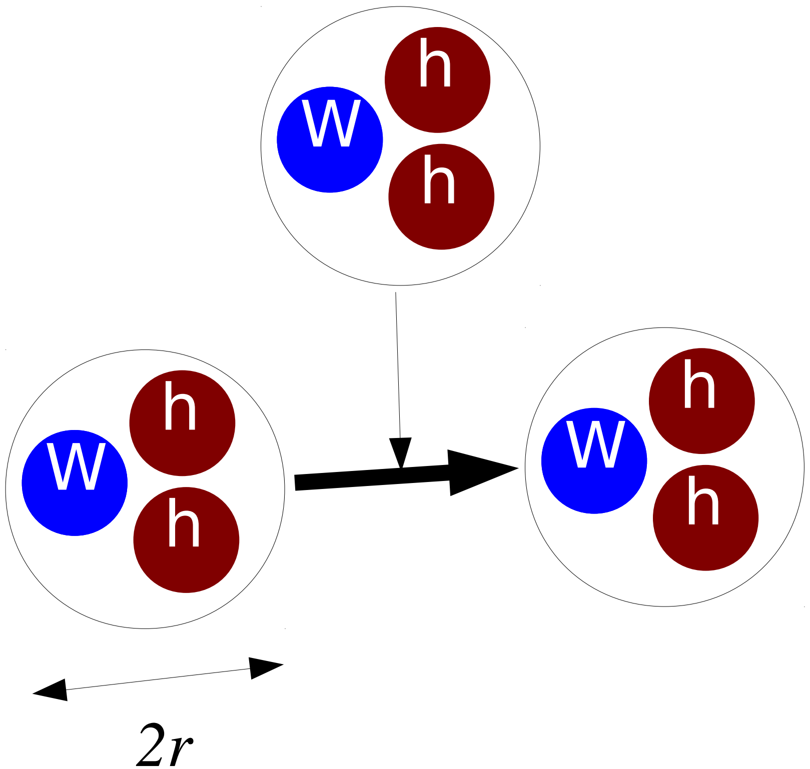

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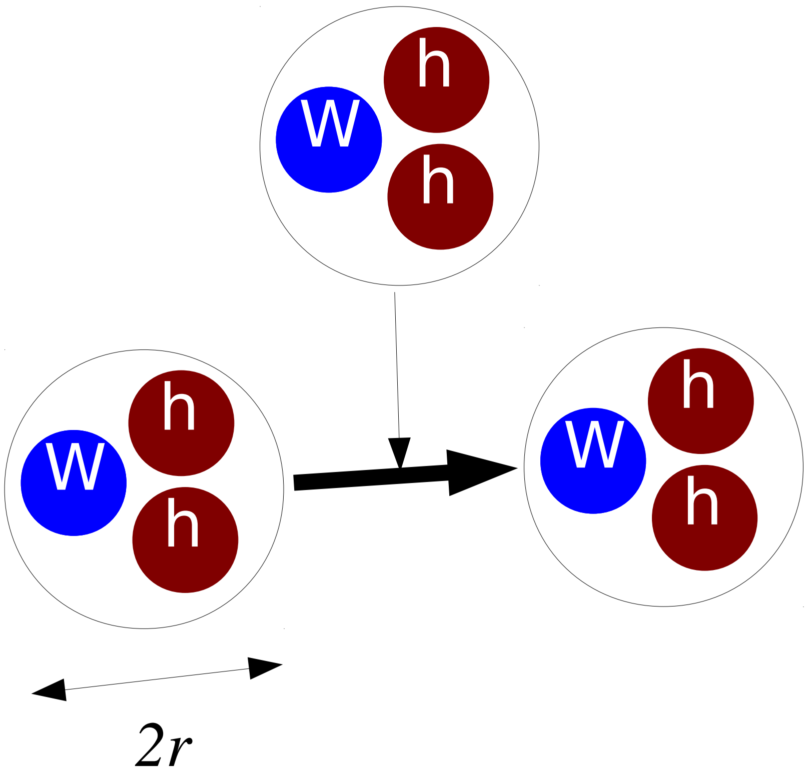

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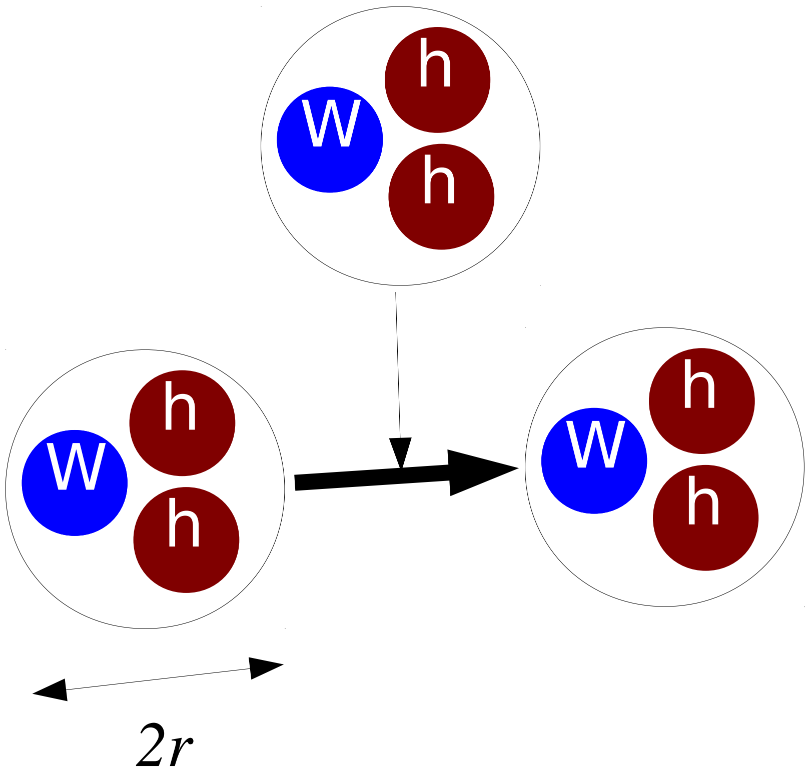

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Bound states as extended objects

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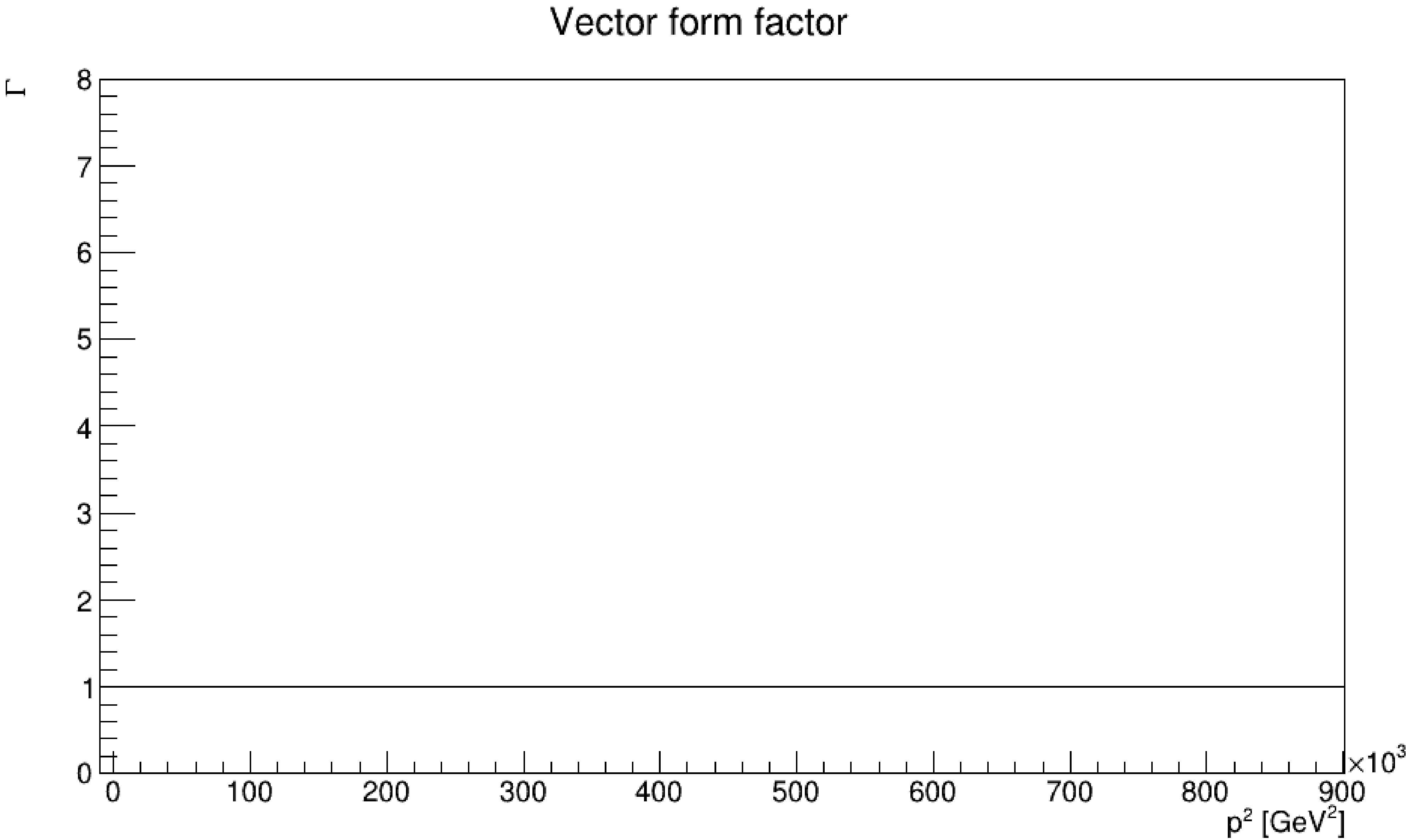

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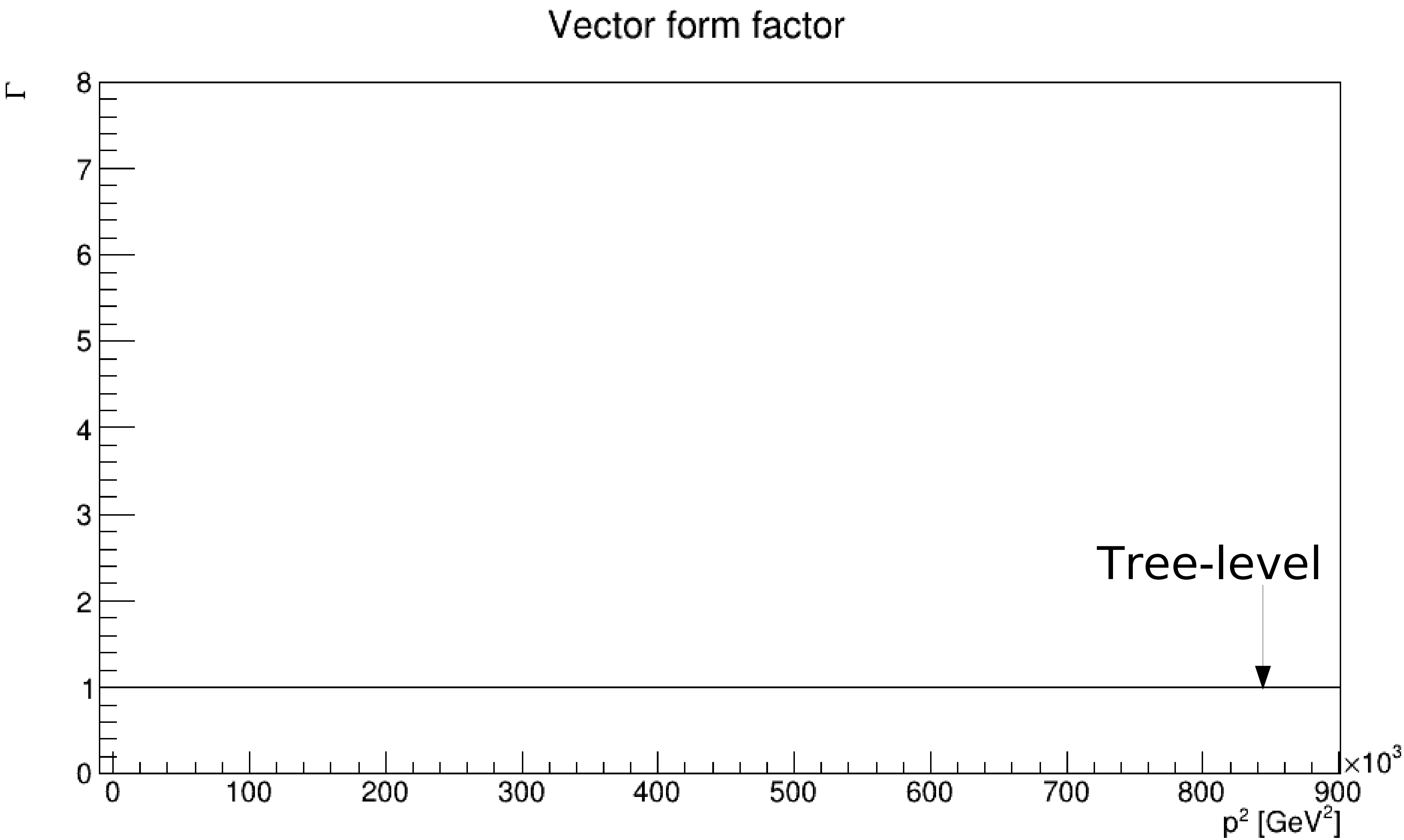

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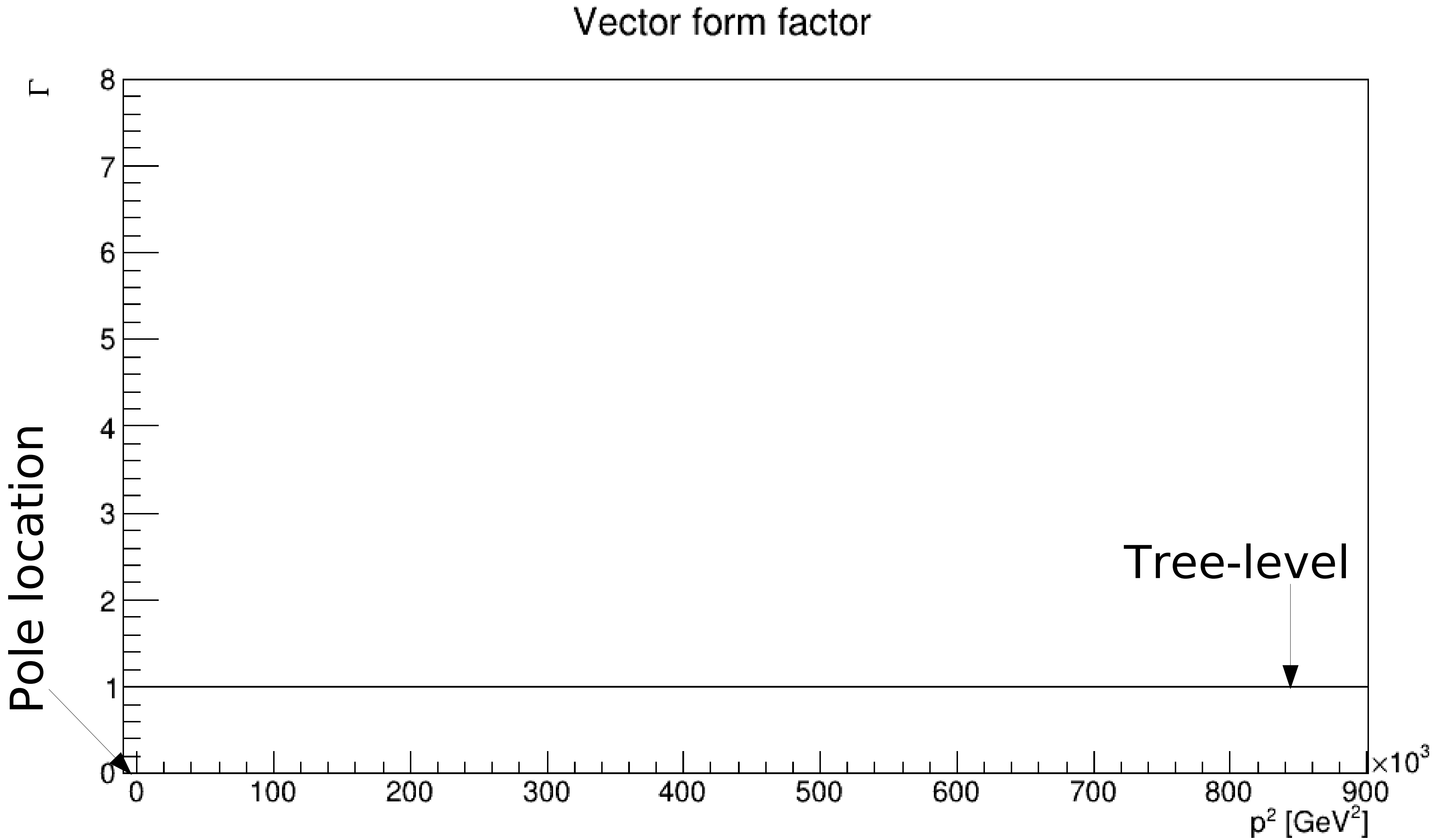

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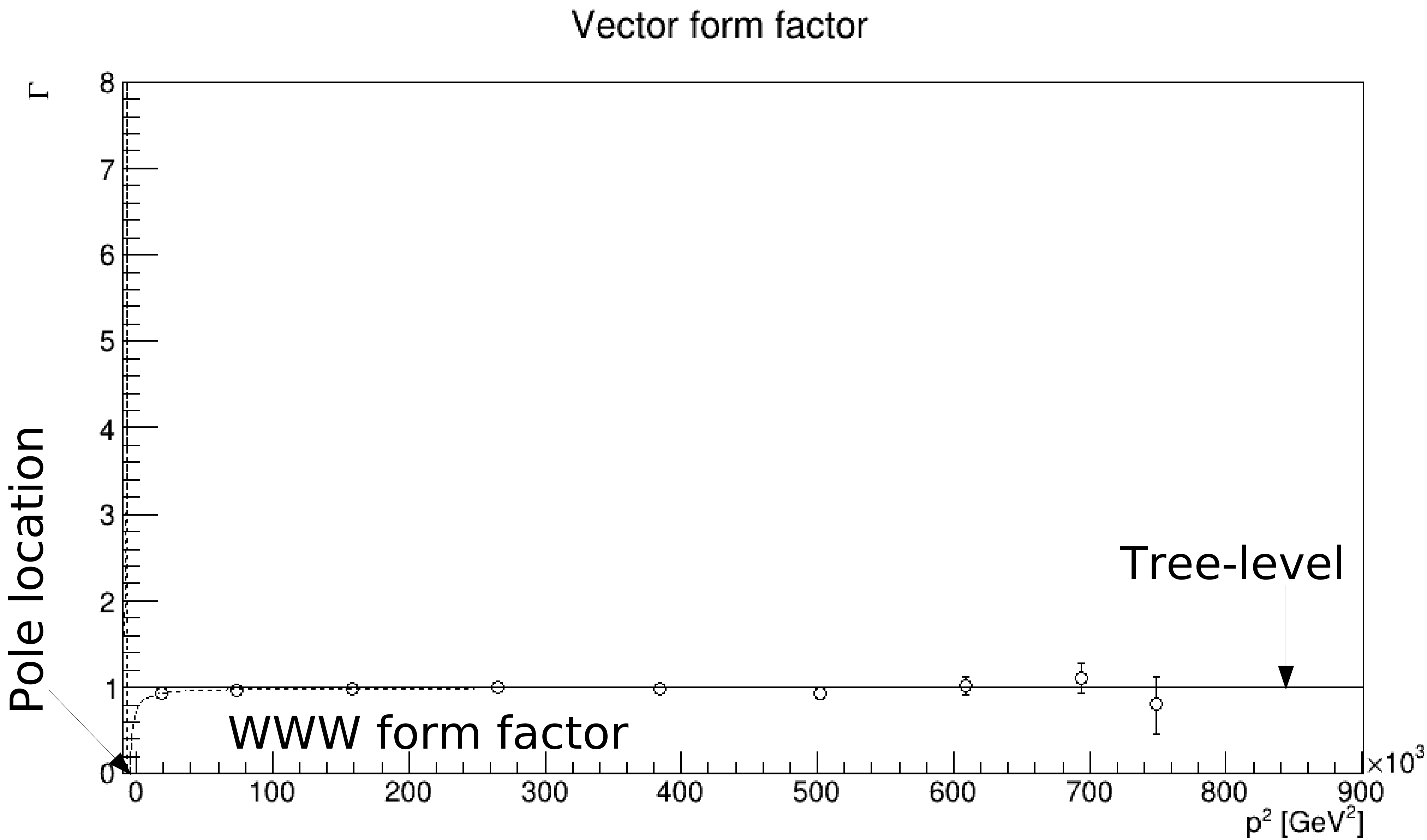

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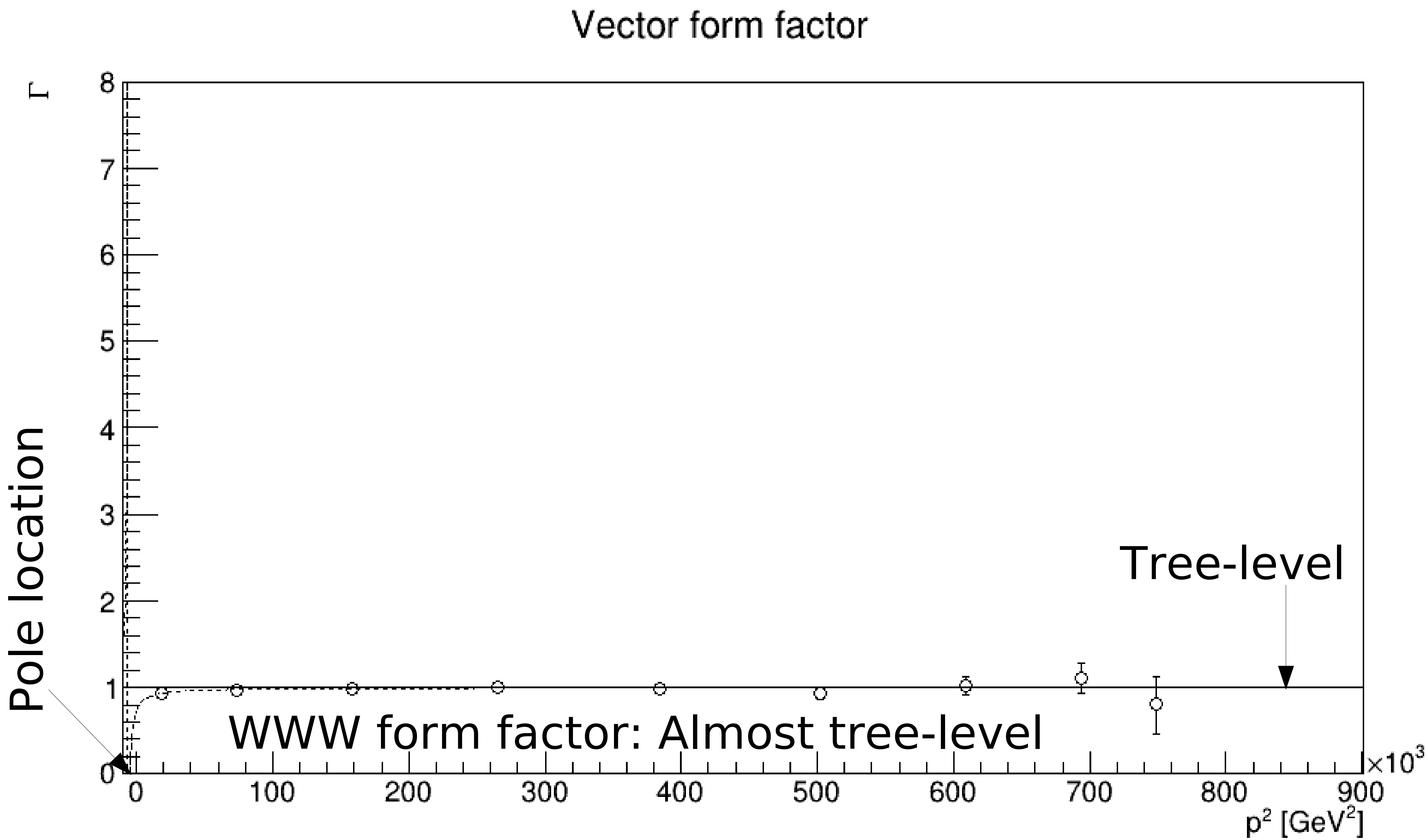

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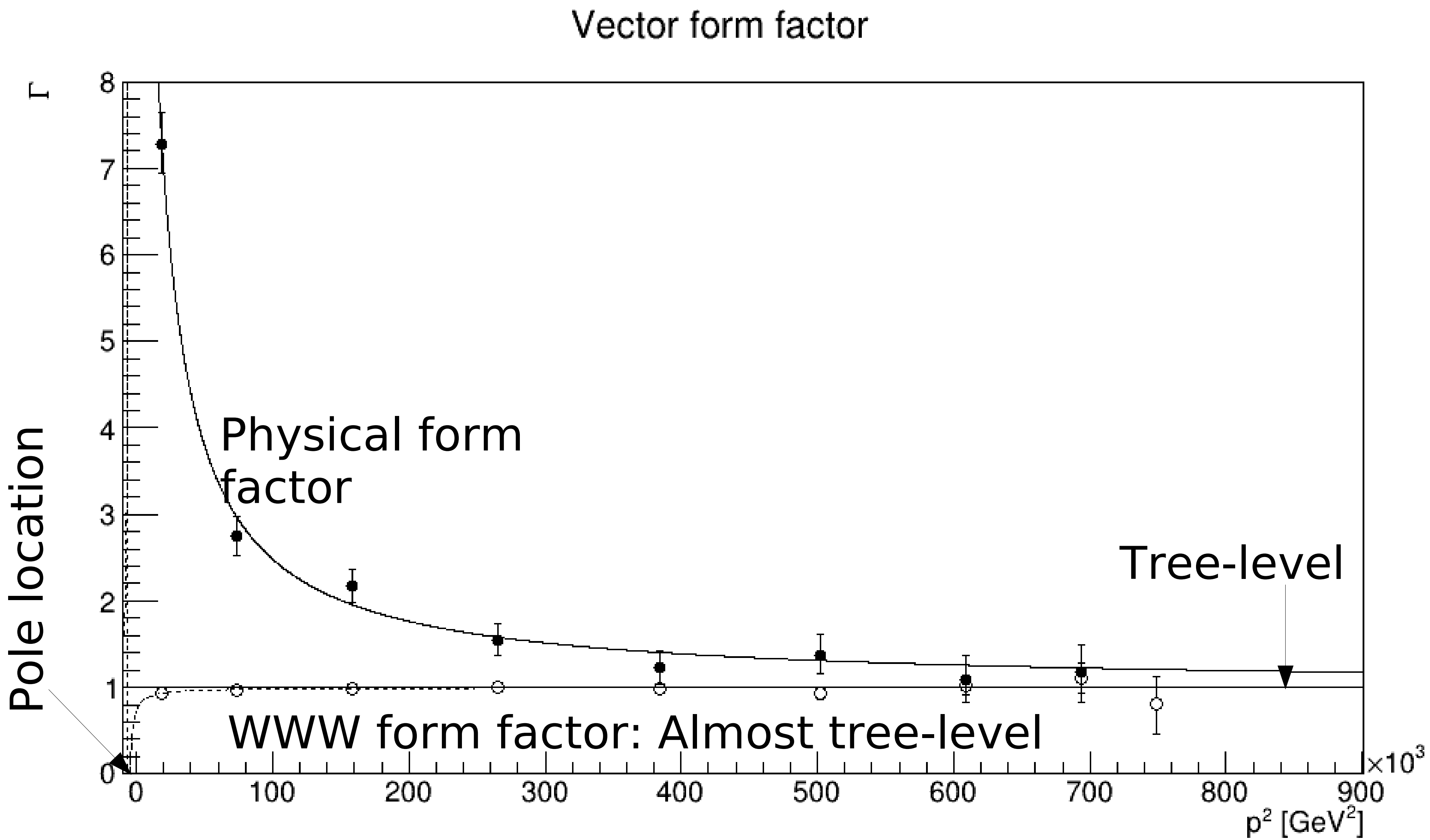

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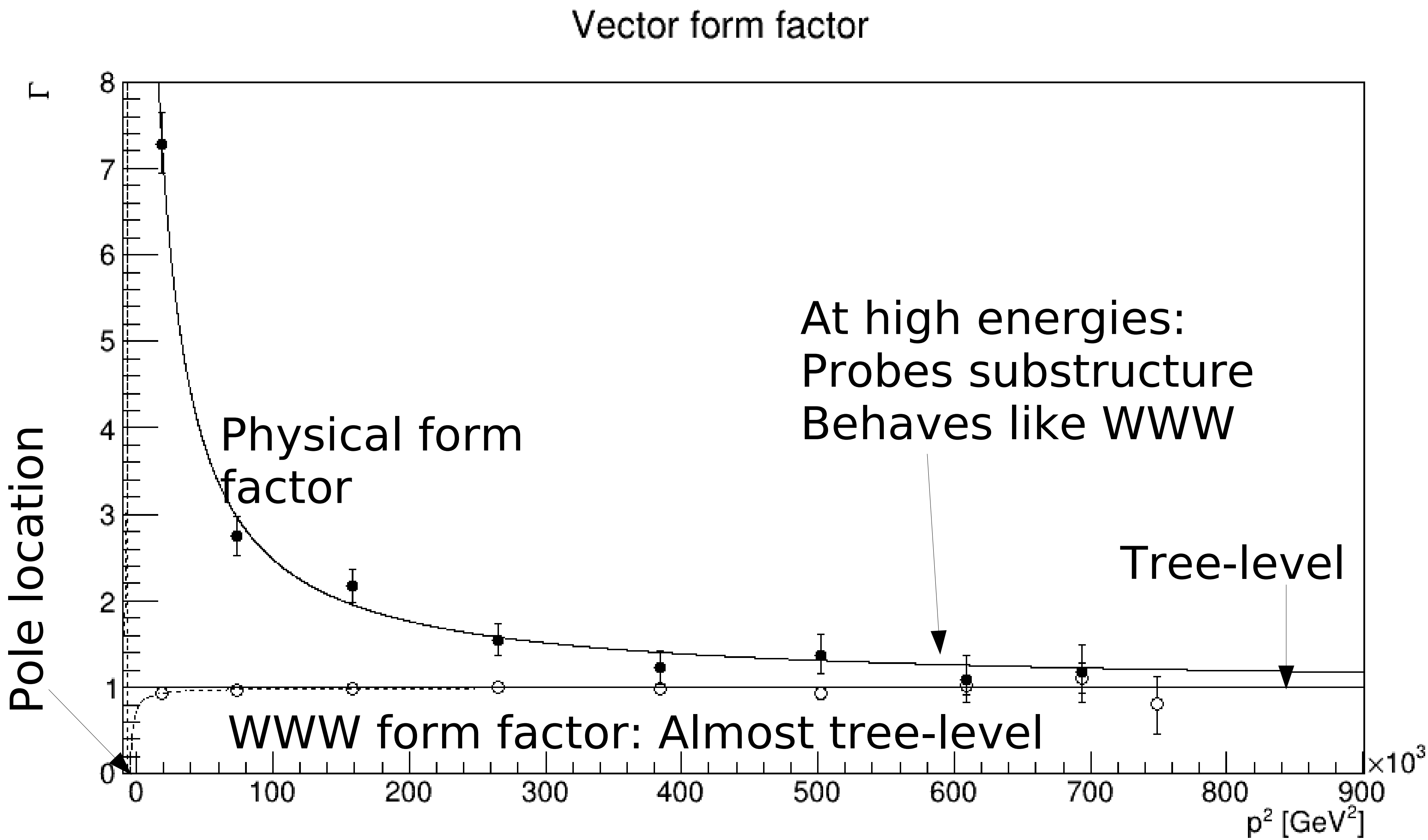

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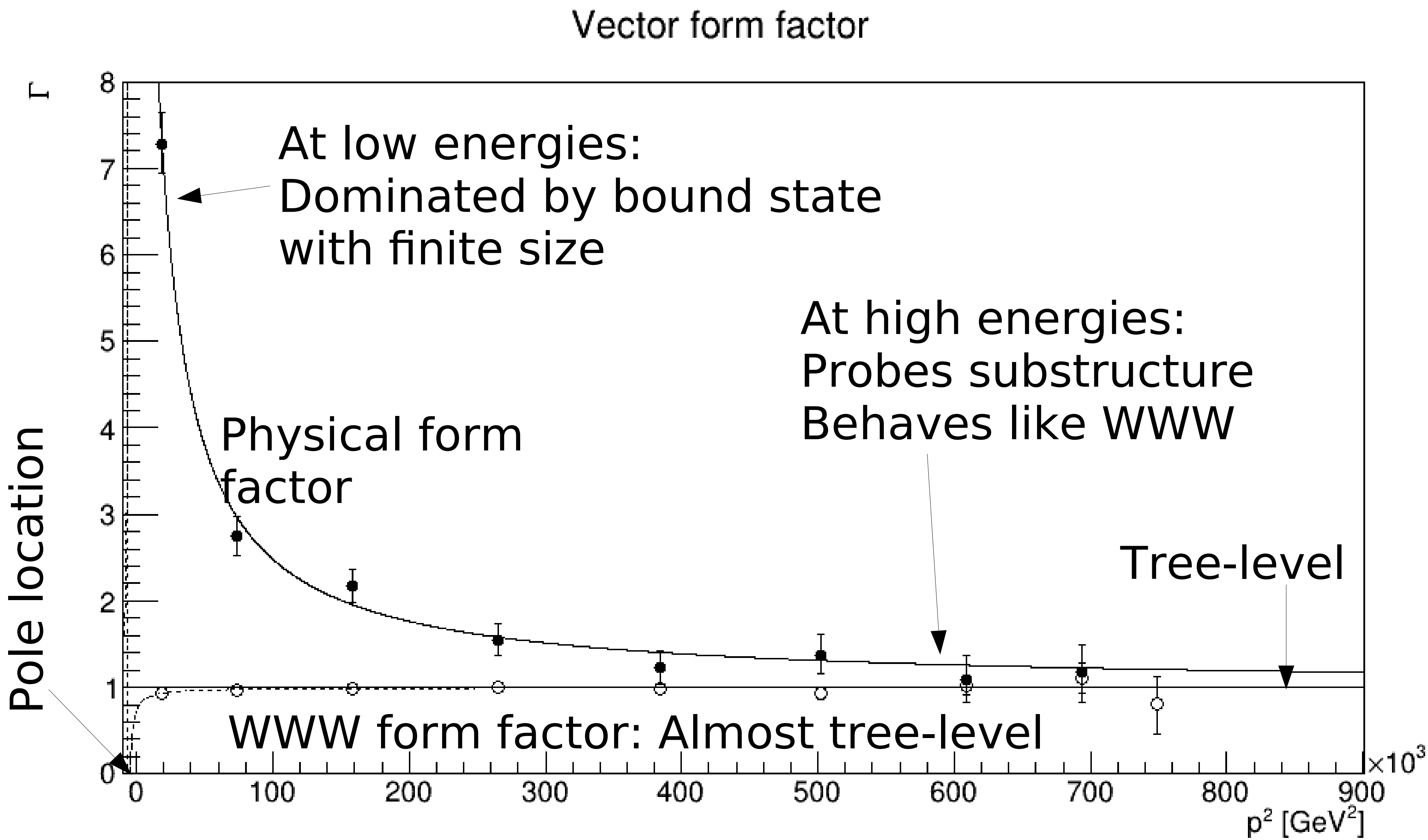

- Physical $mr\sim 2$ while gauge-dependent W has $mr\sim 0.5i$

Exploring implications
-
Full standard model

Flavor

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

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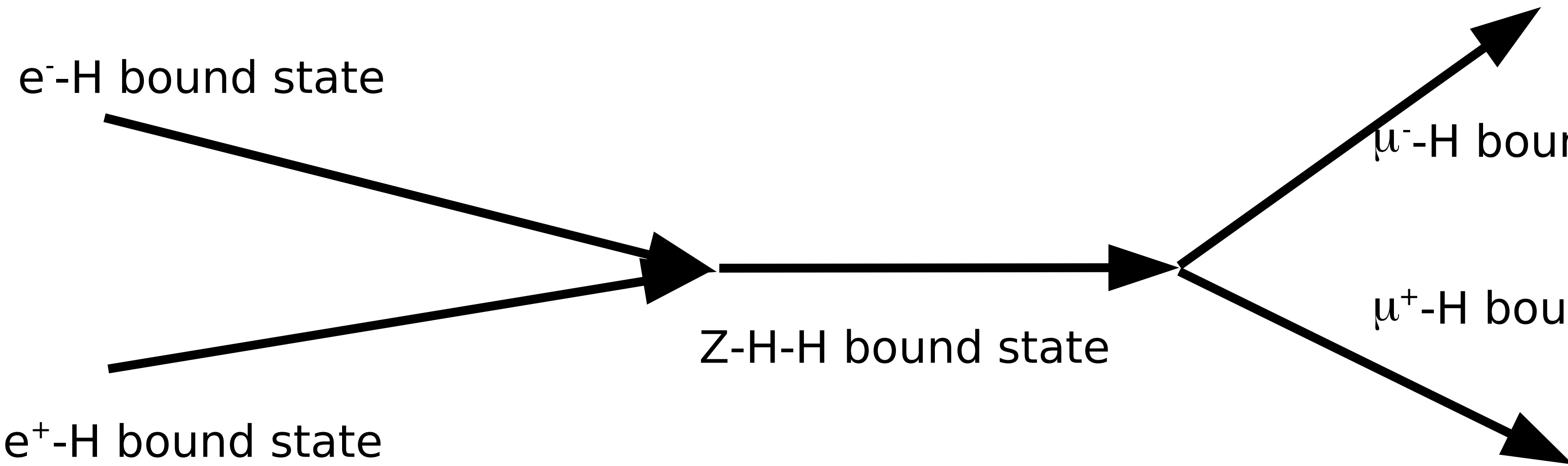
How events looks like (LEP/ILC)

[Maas'12]



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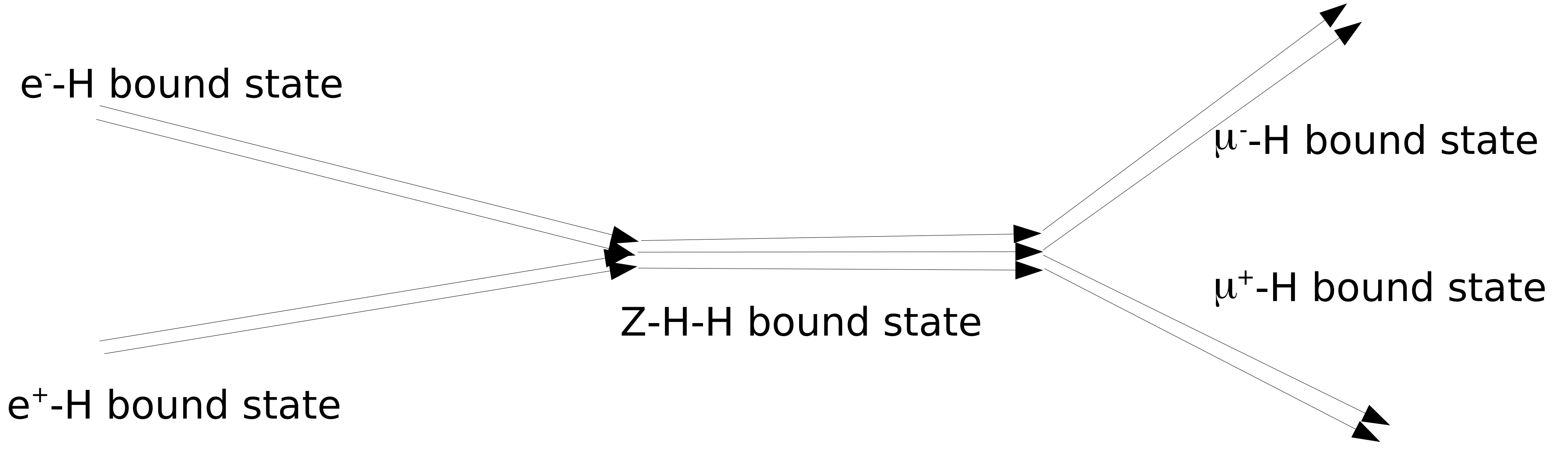

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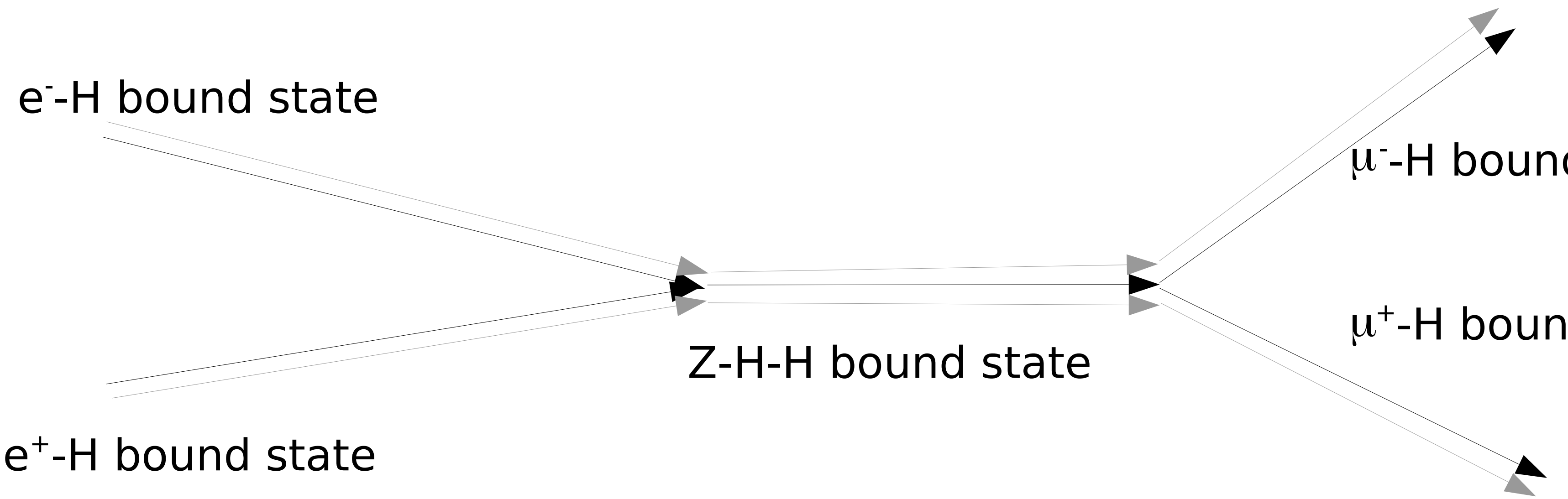

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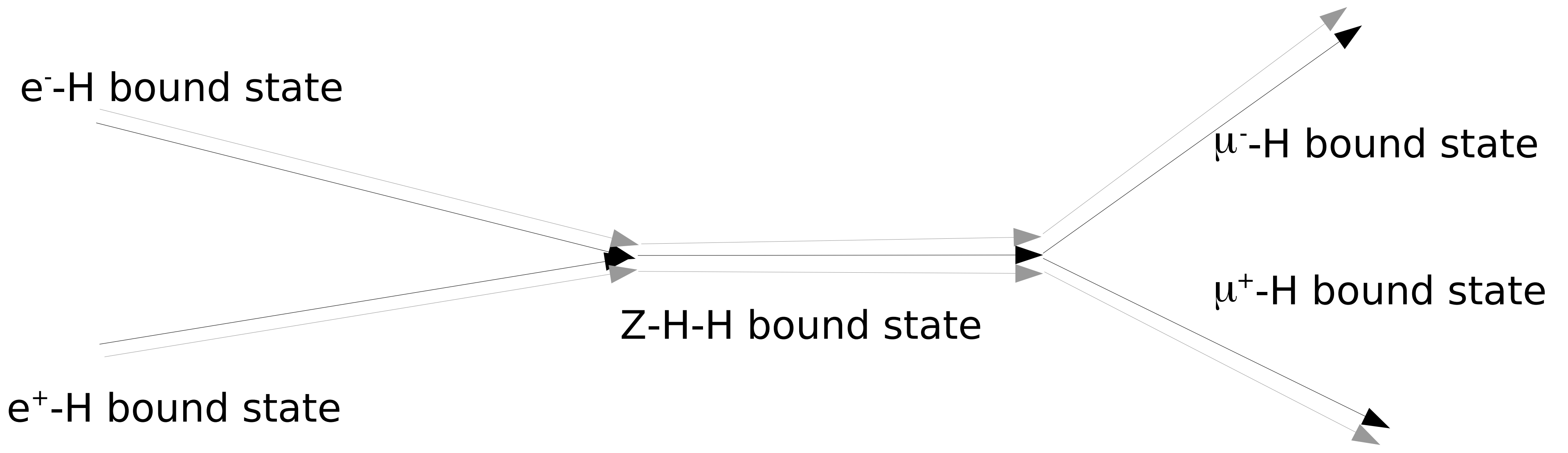

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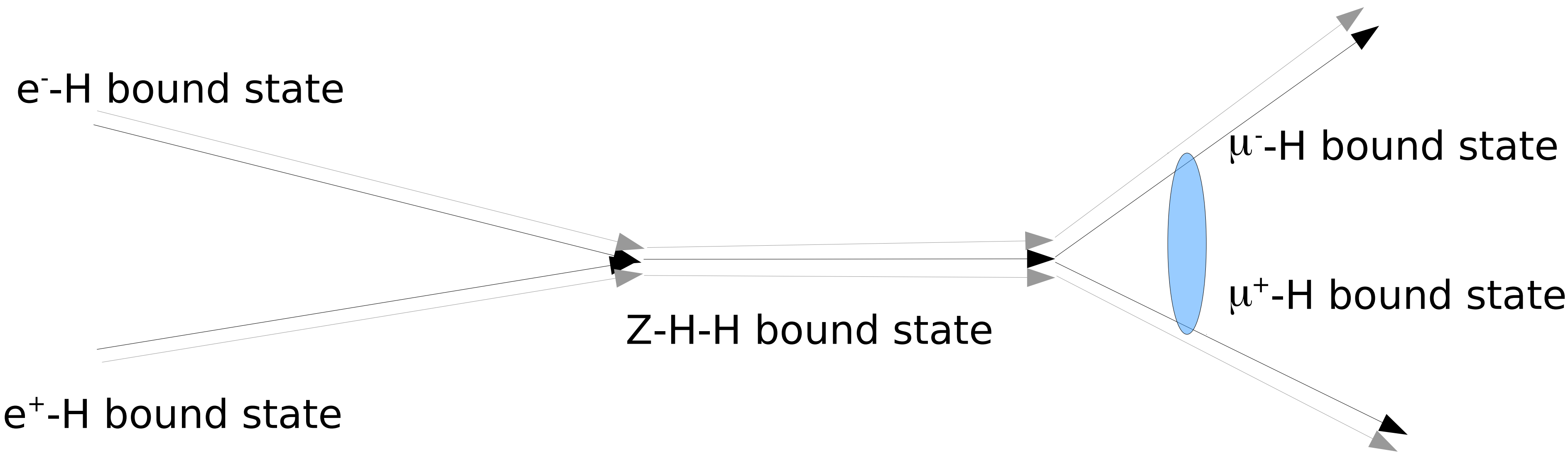

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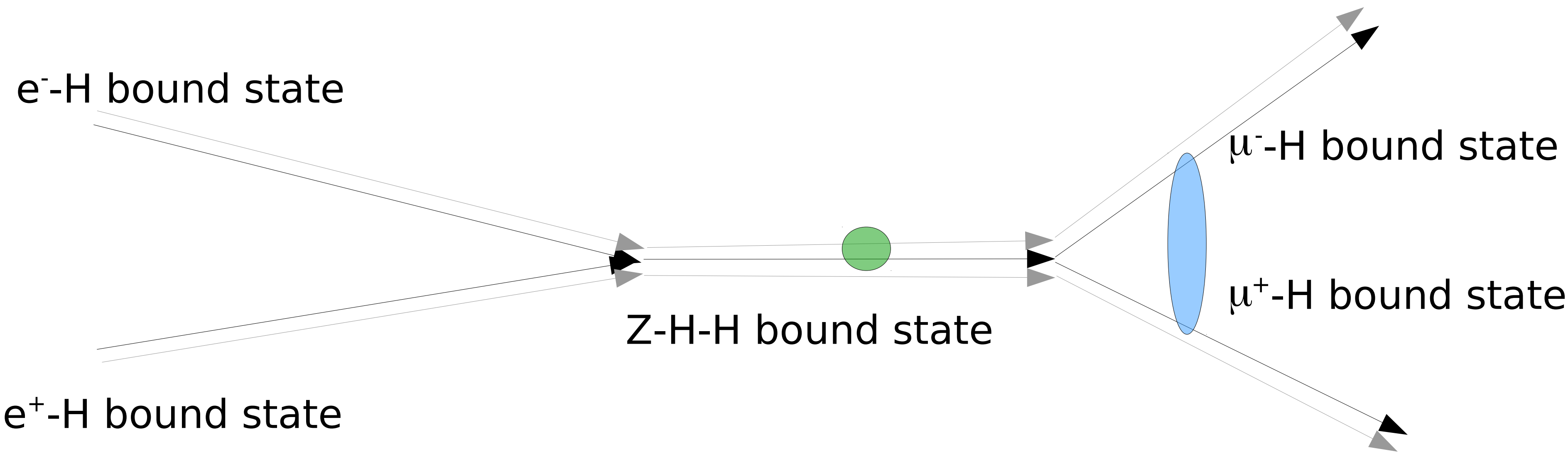

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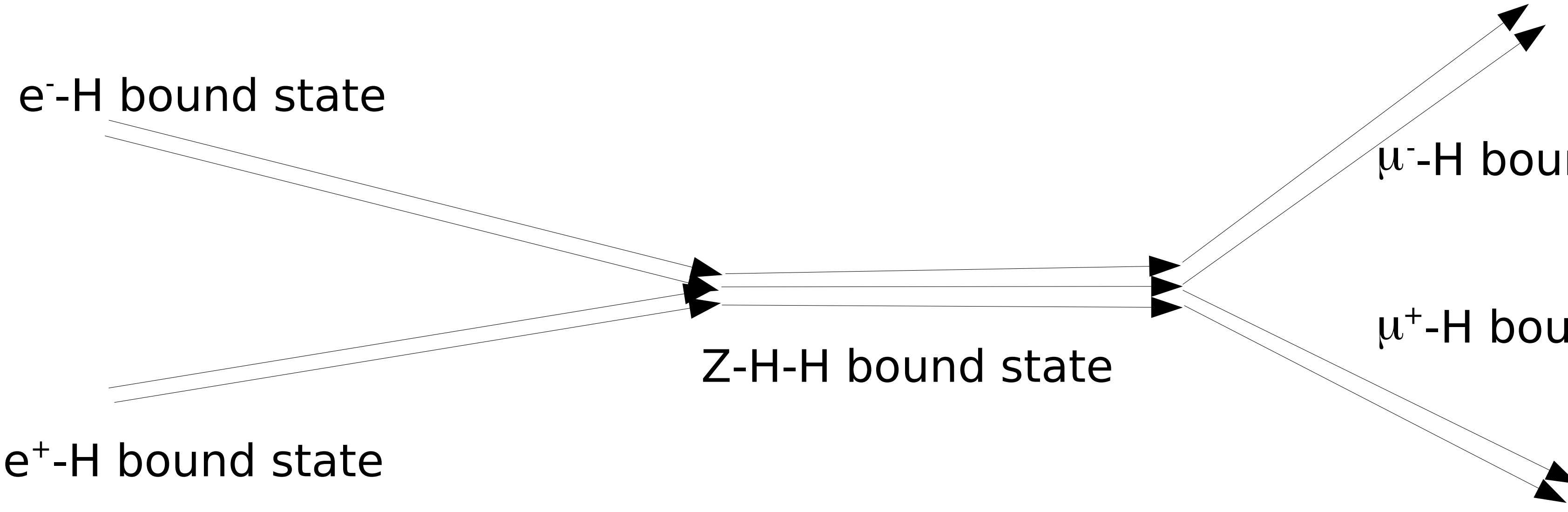

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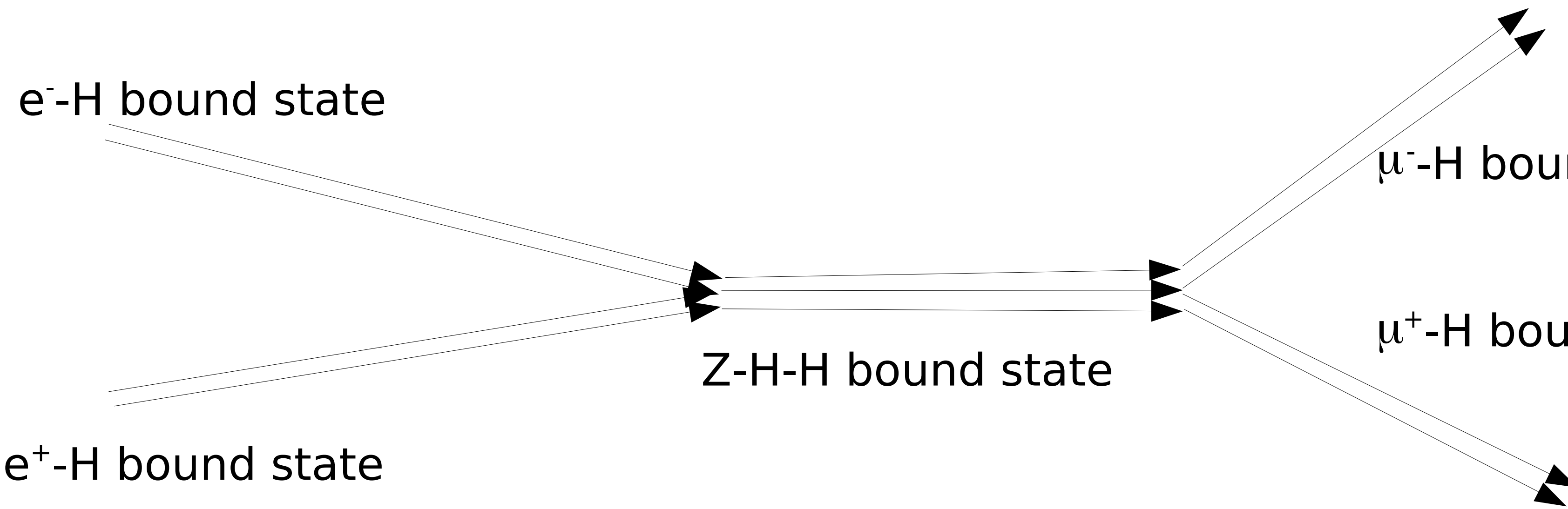

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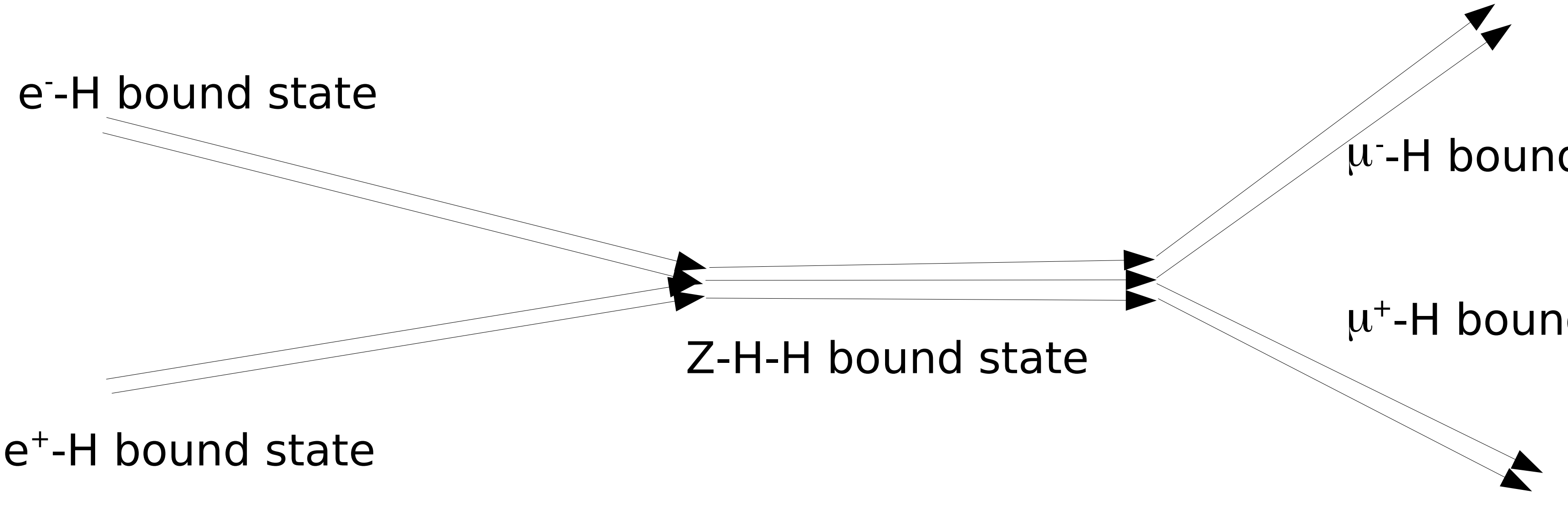

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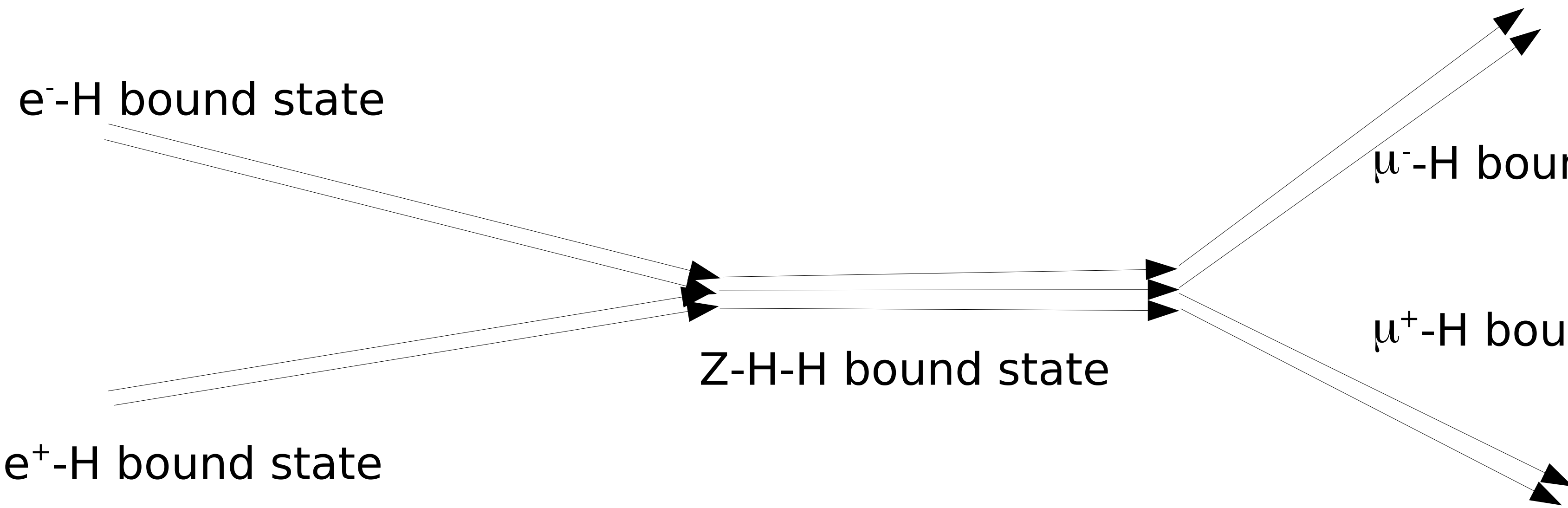

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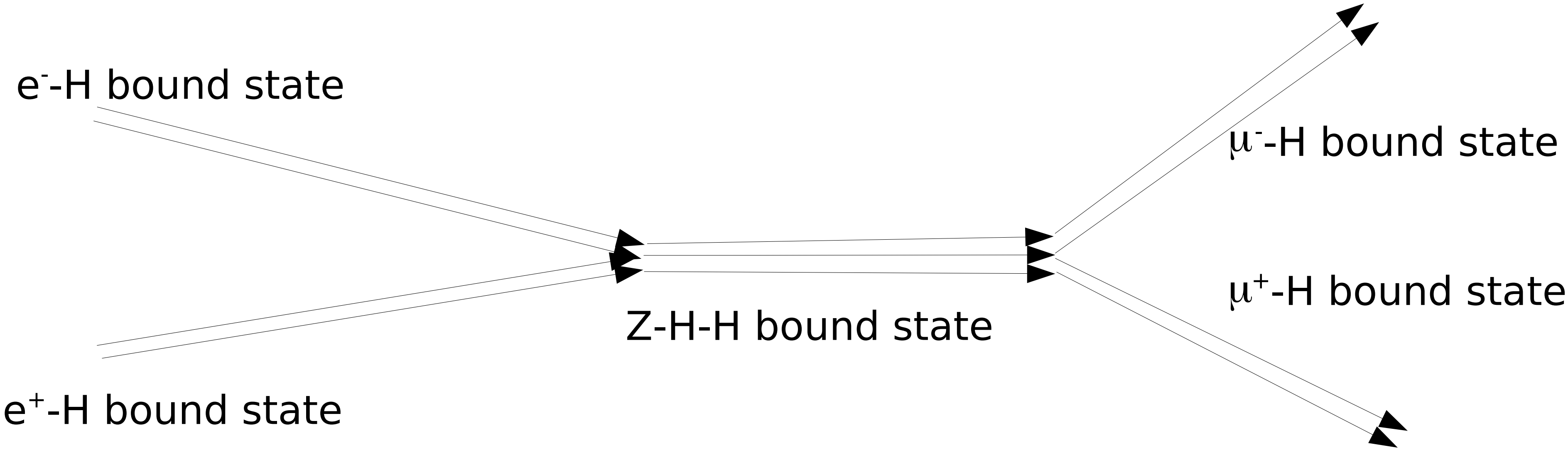

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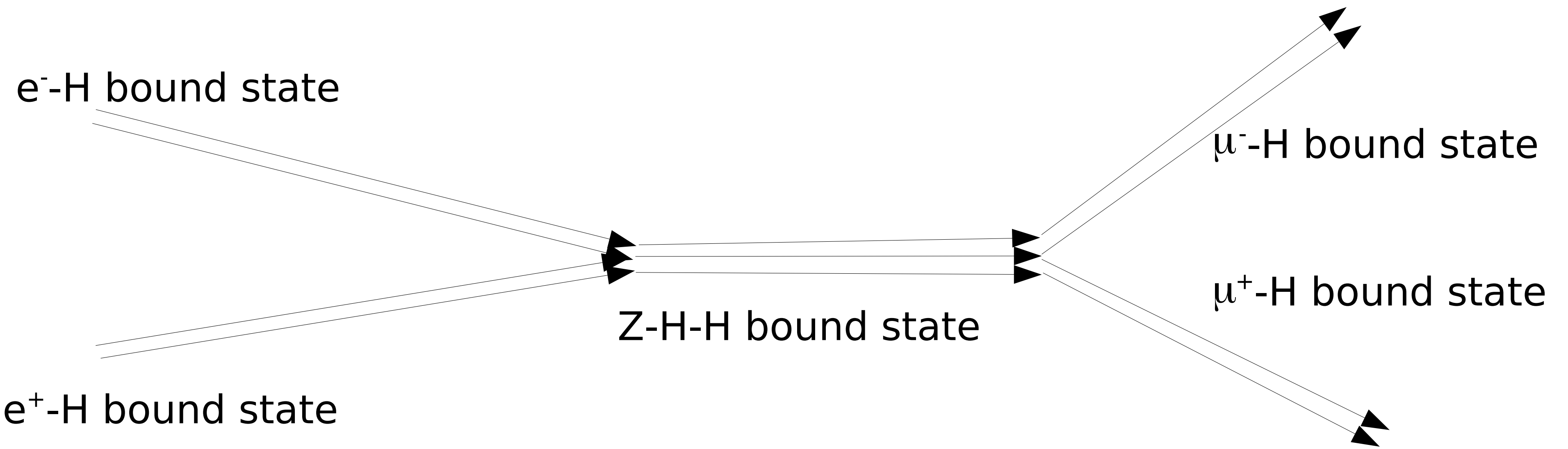

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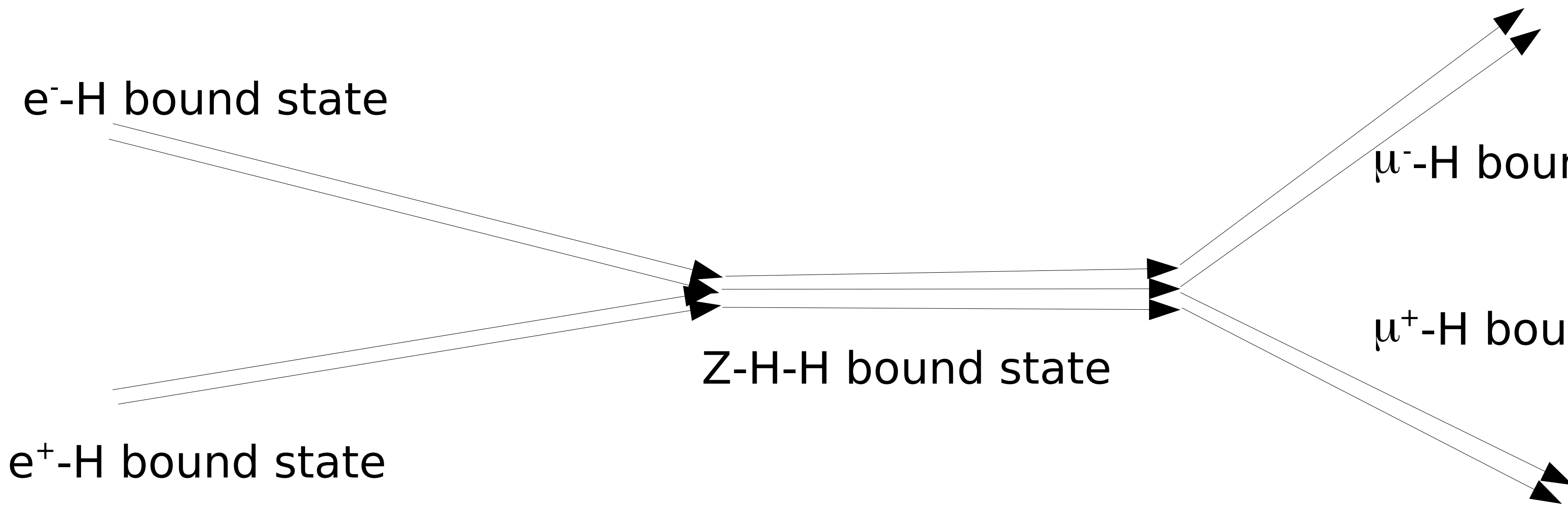

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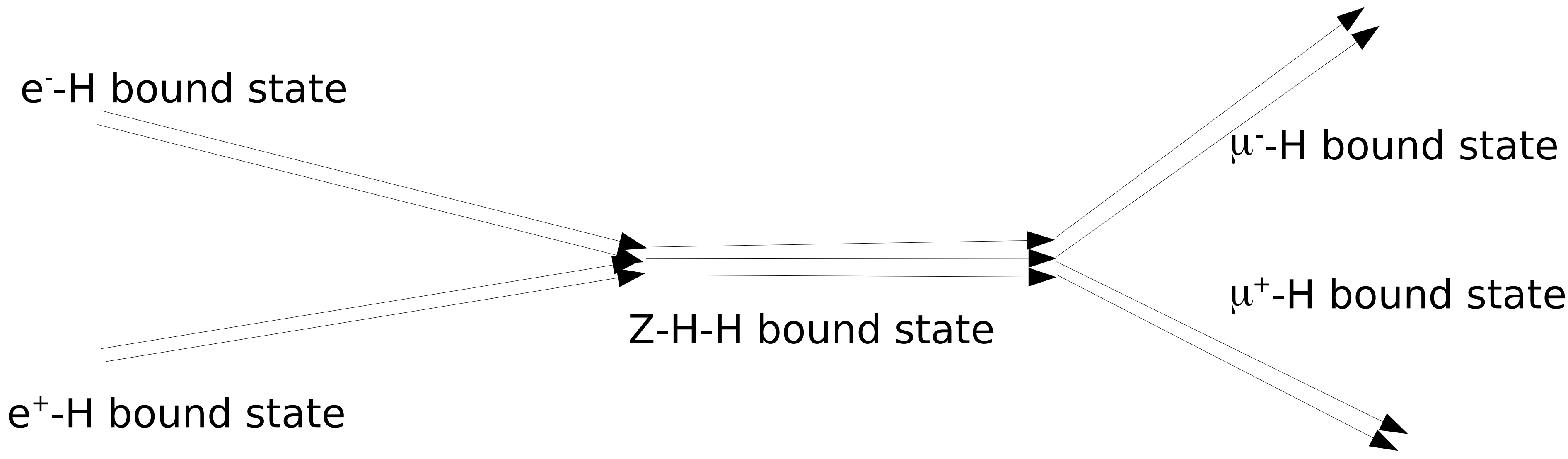

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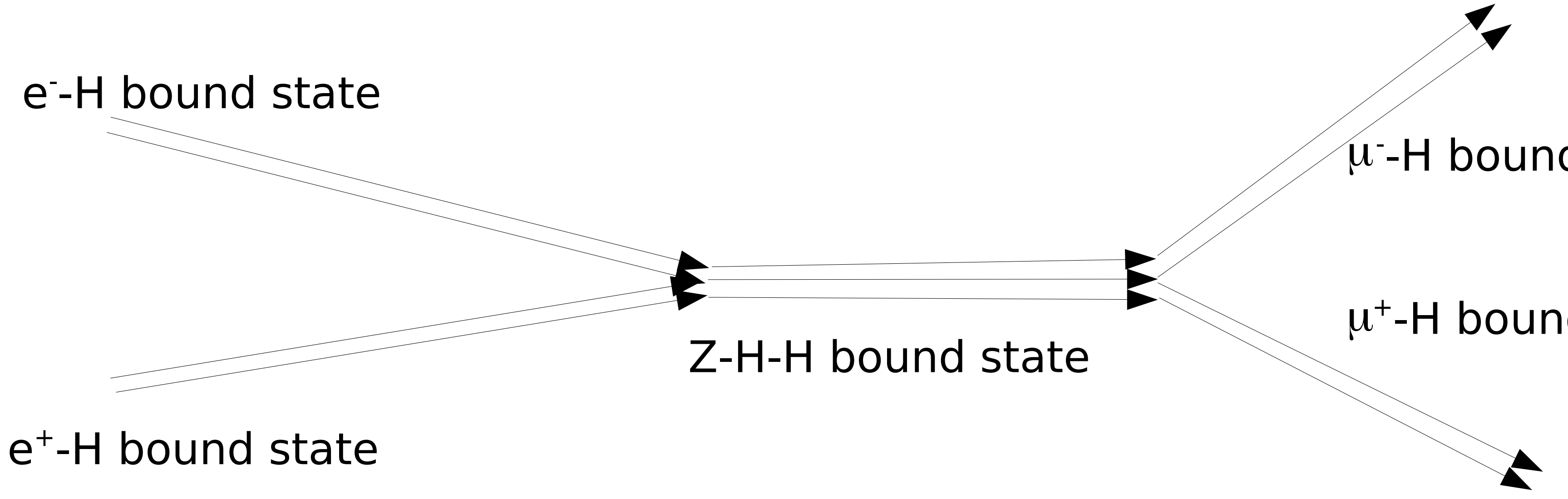

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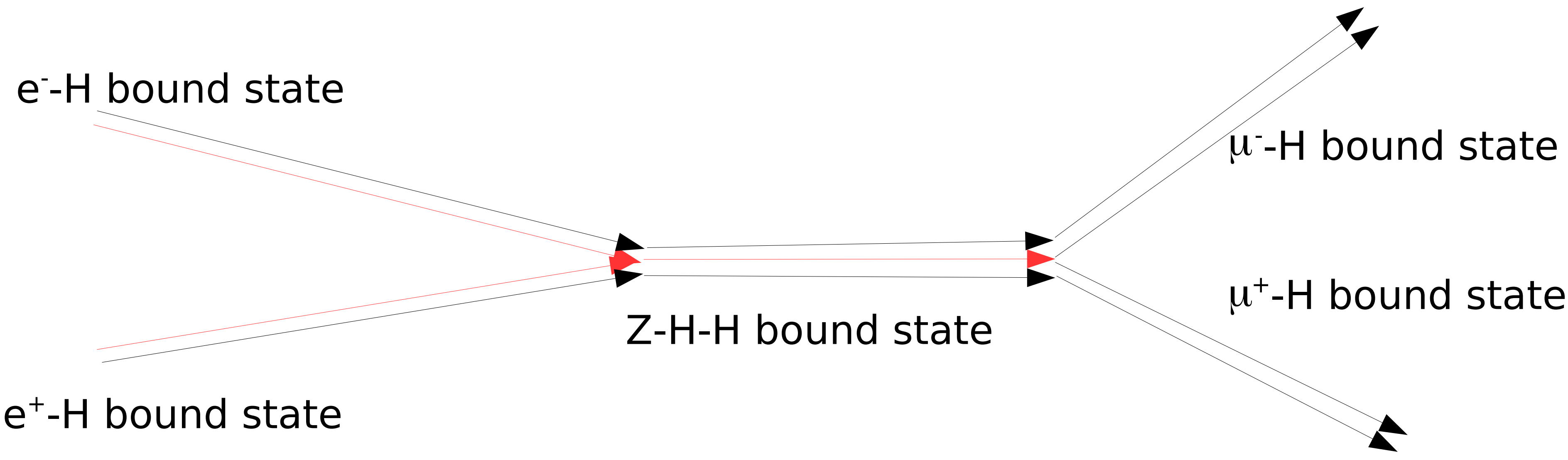

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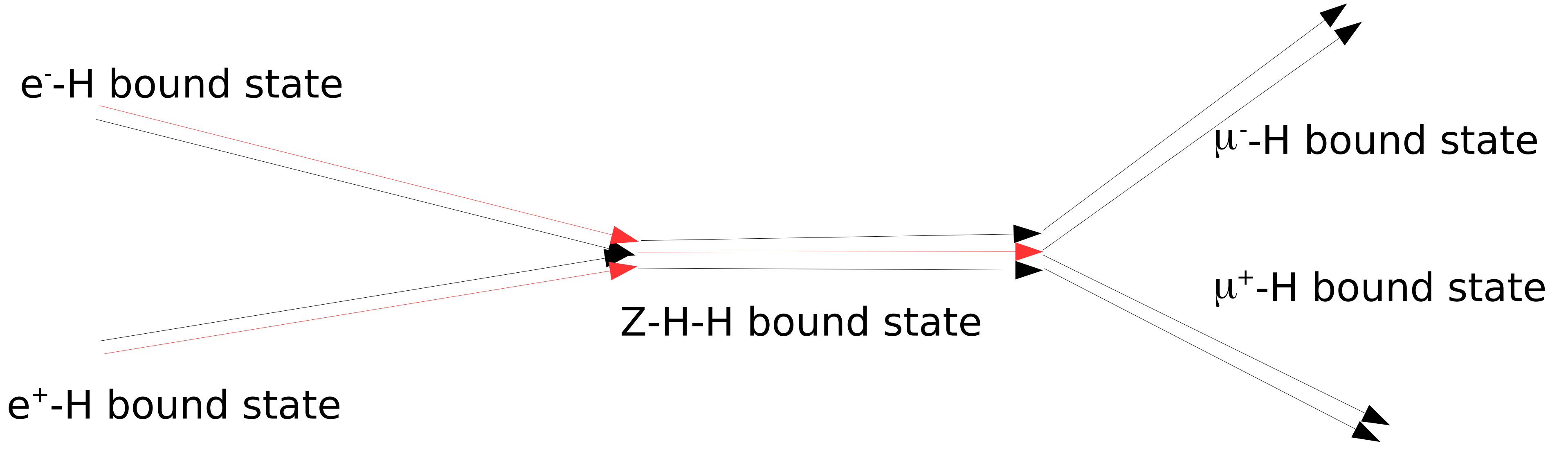

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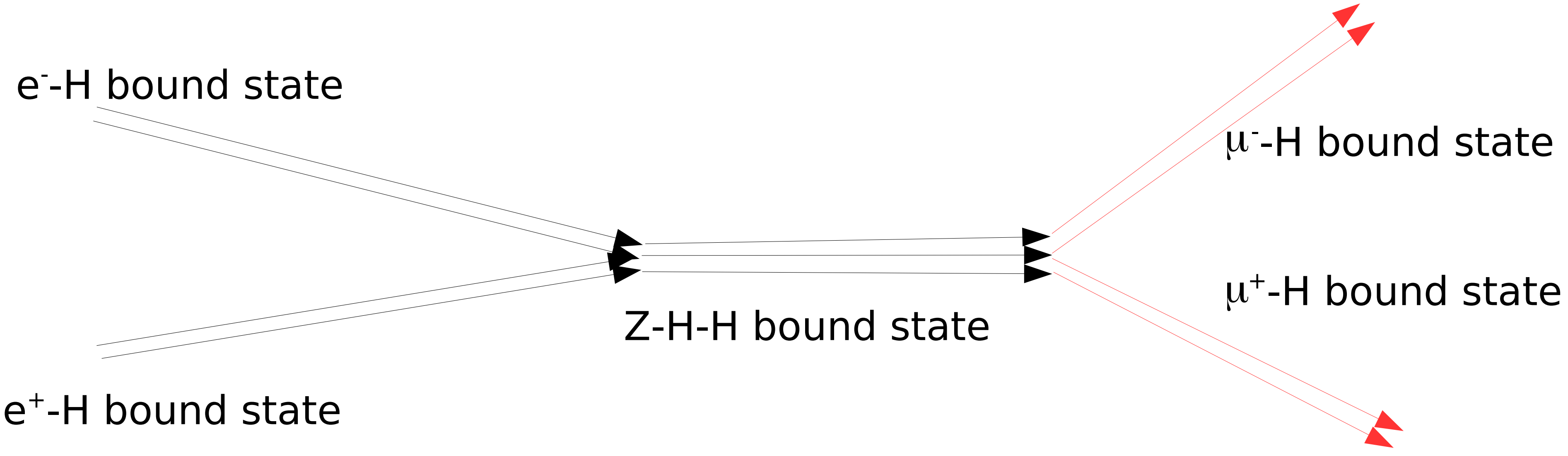

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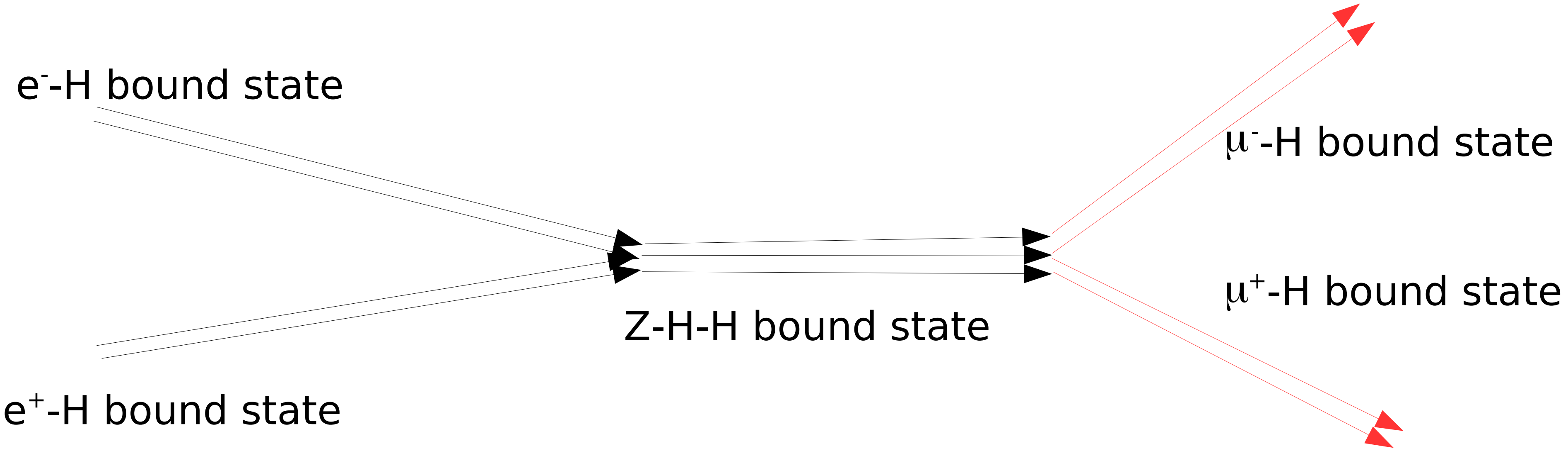

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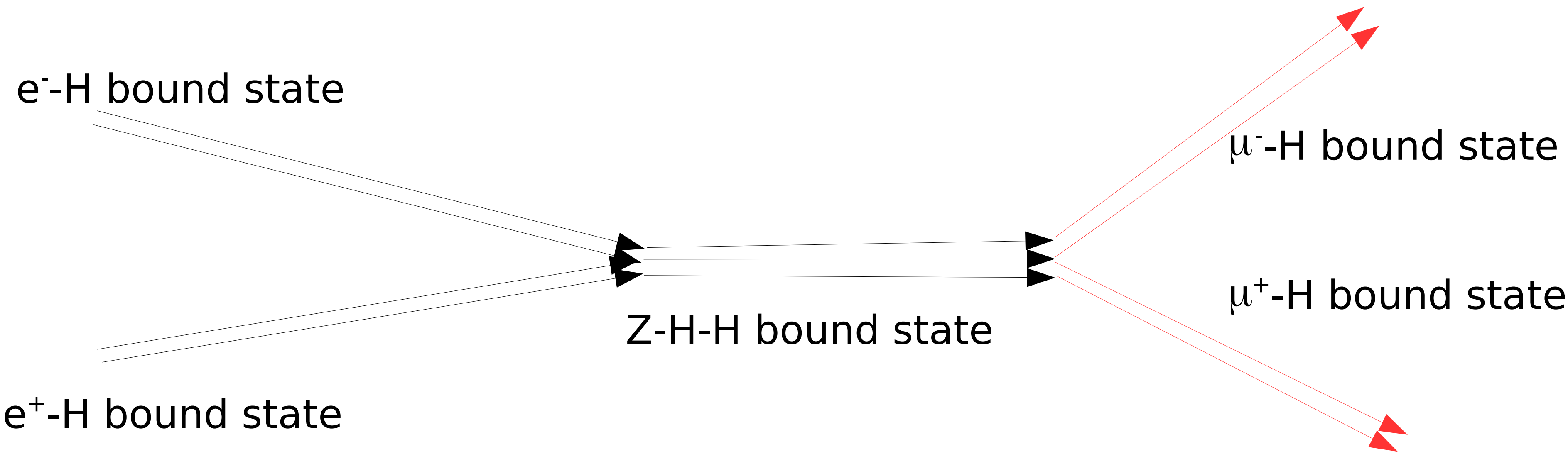

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  - Strong couplings to Higgs: tops, weak gauge bosons

Constraining the valence Higgs

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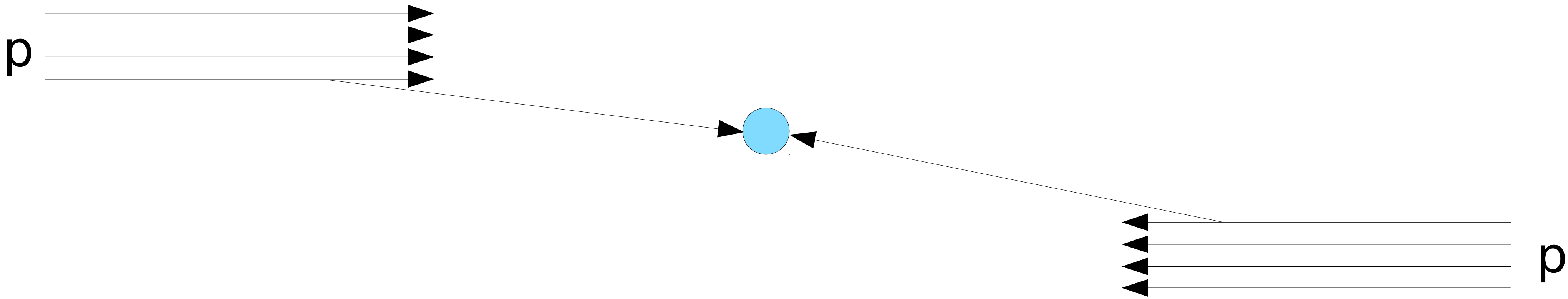

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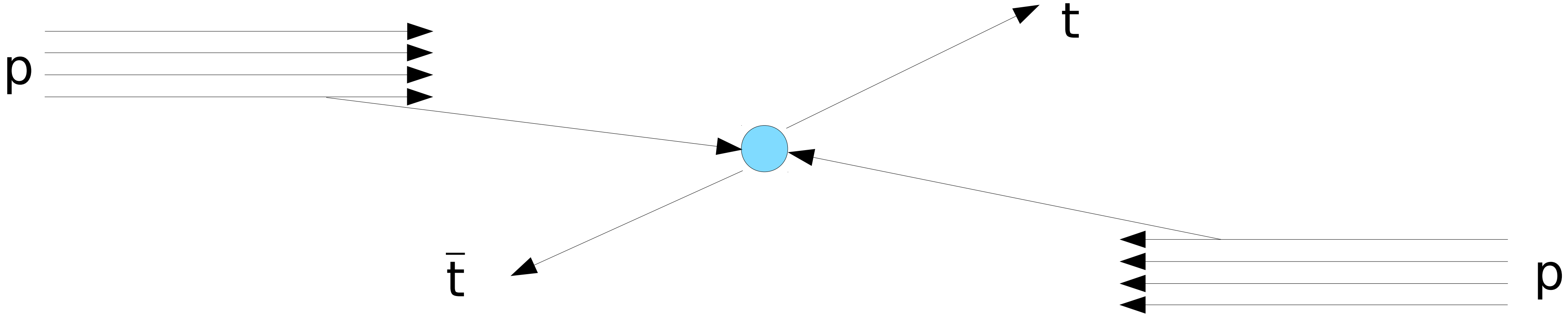

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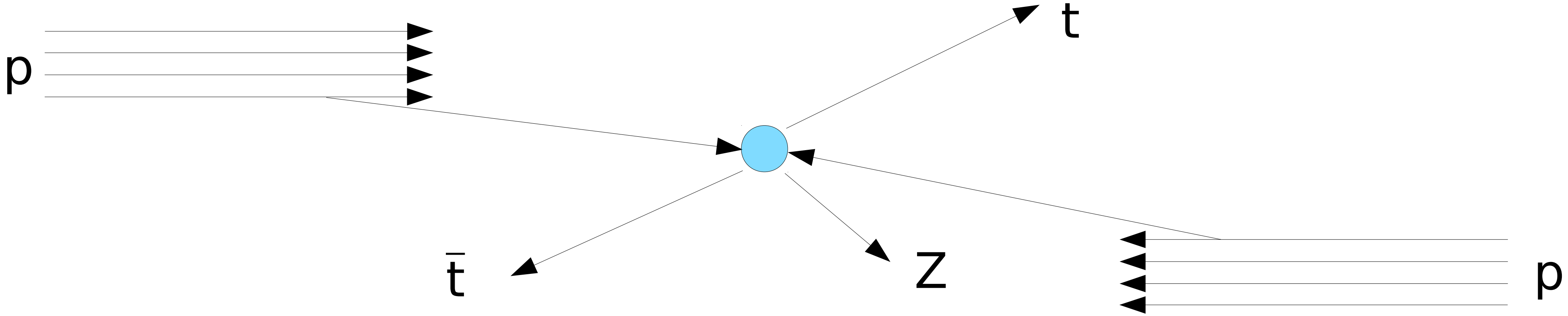

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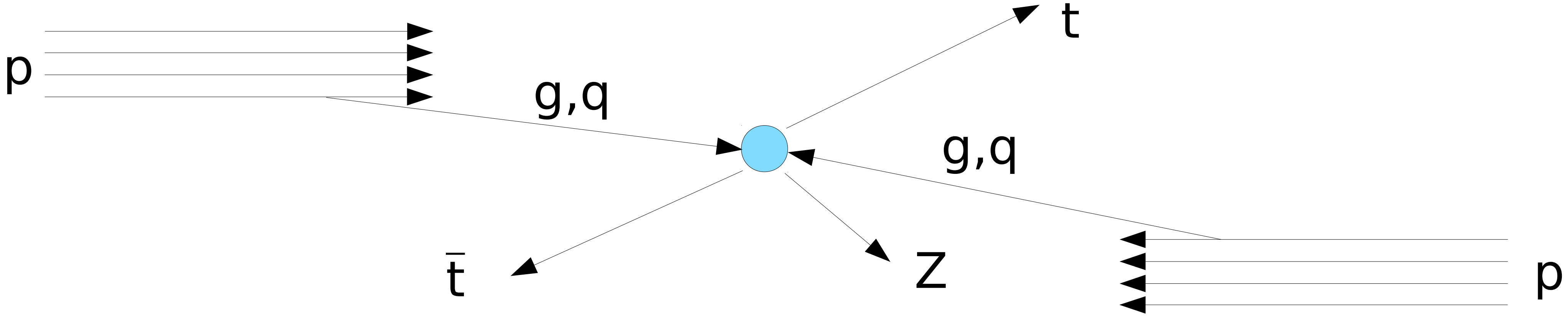

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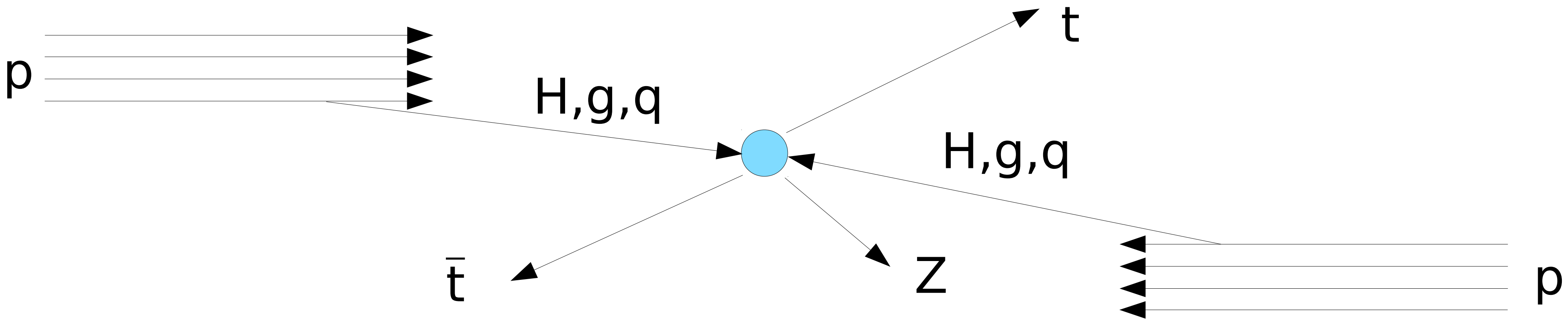

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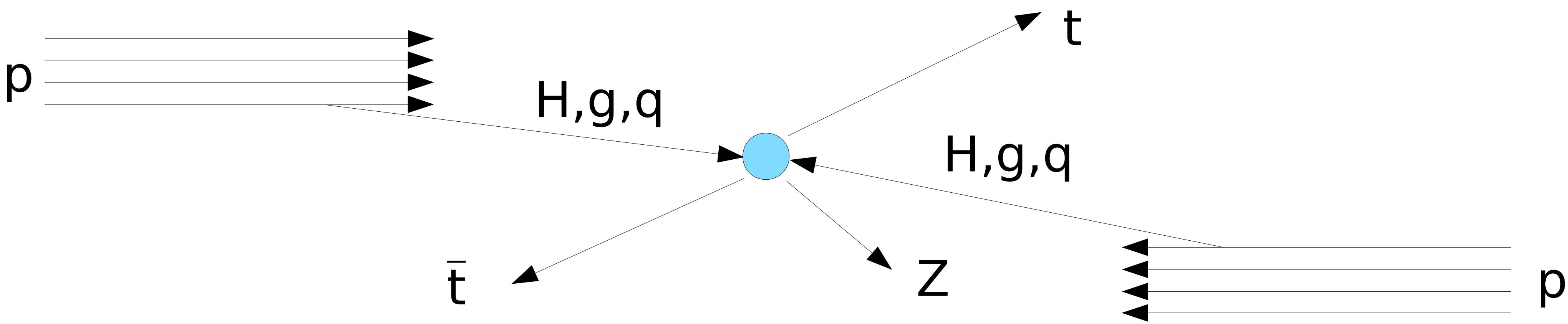

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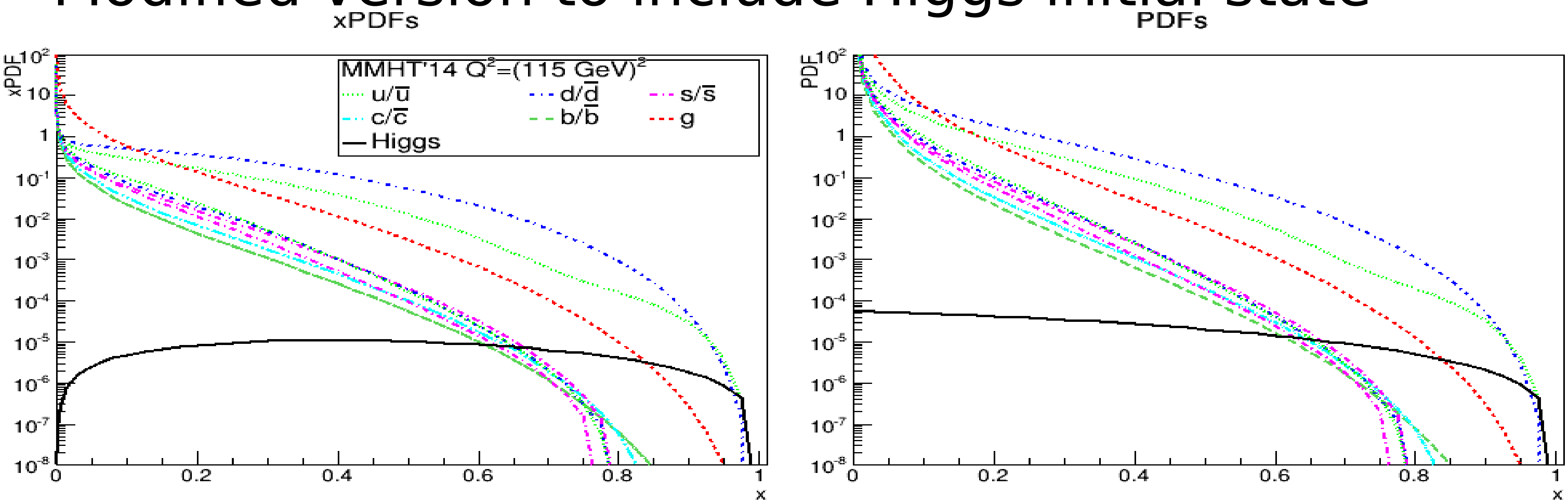

Starting guess: Higgs PDF still ‘condensate’-like

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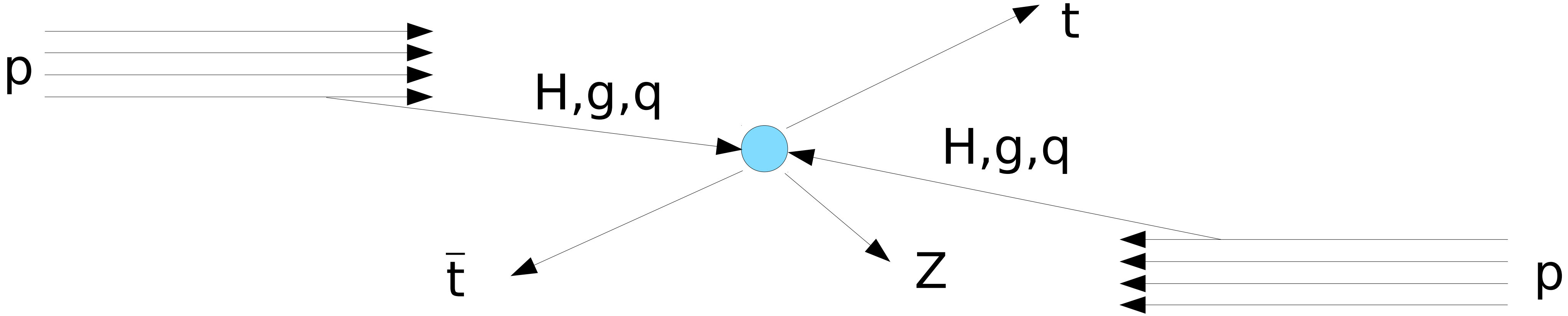

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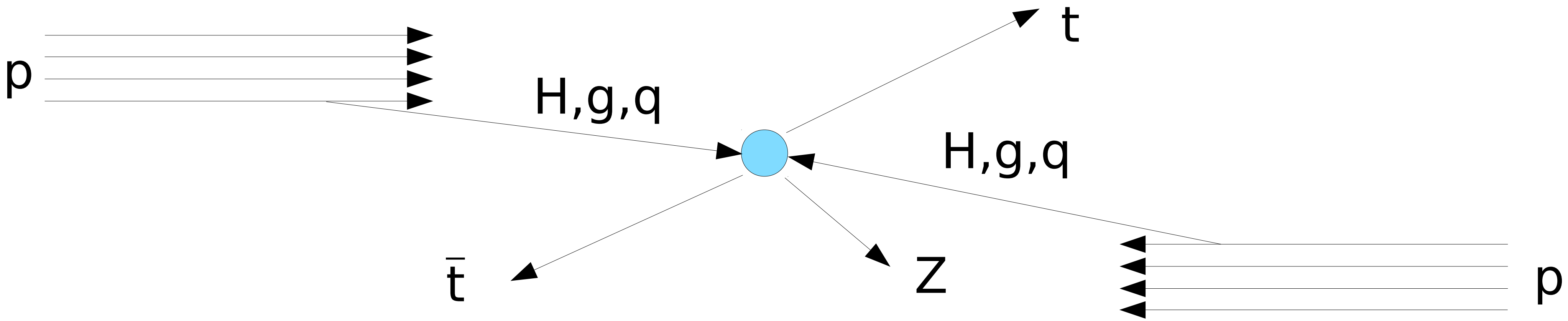

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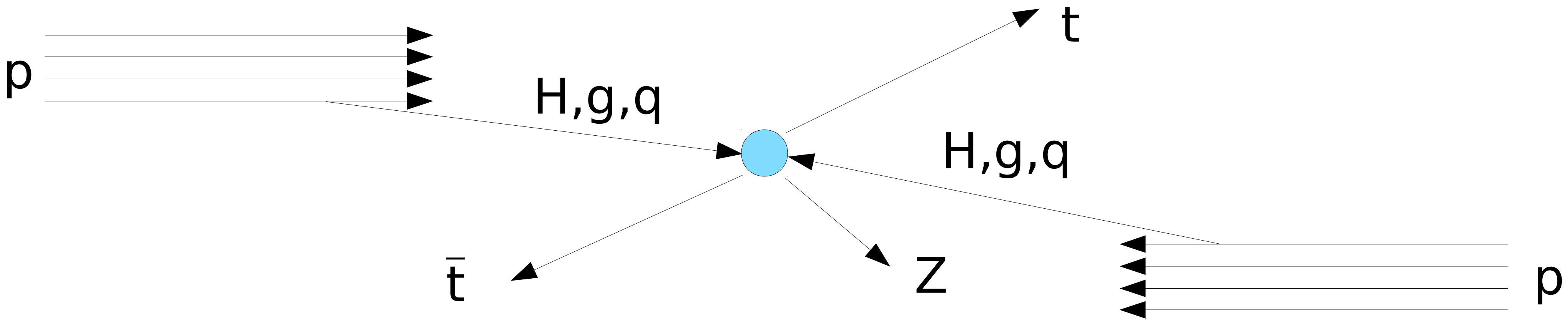

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- Creates full events
  - Every particle with all properties
  - Calculations of cross sections

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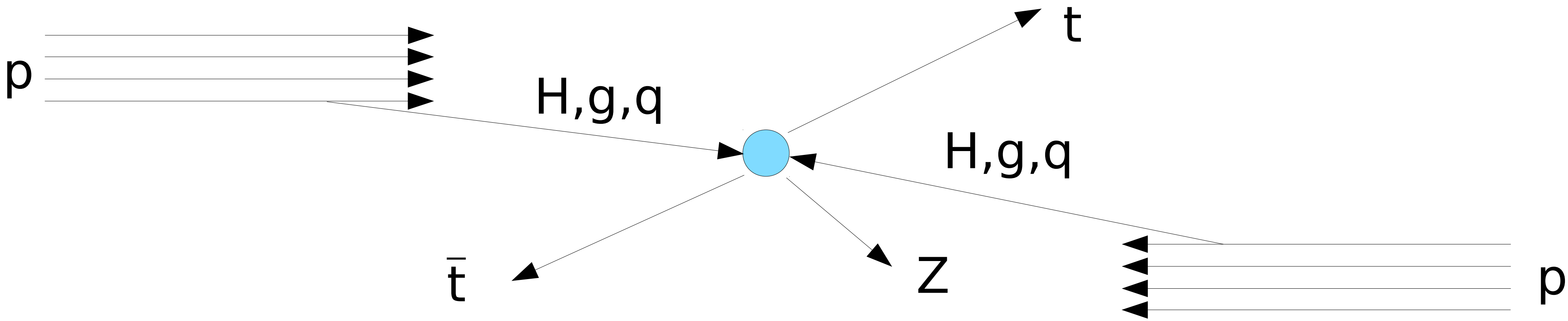

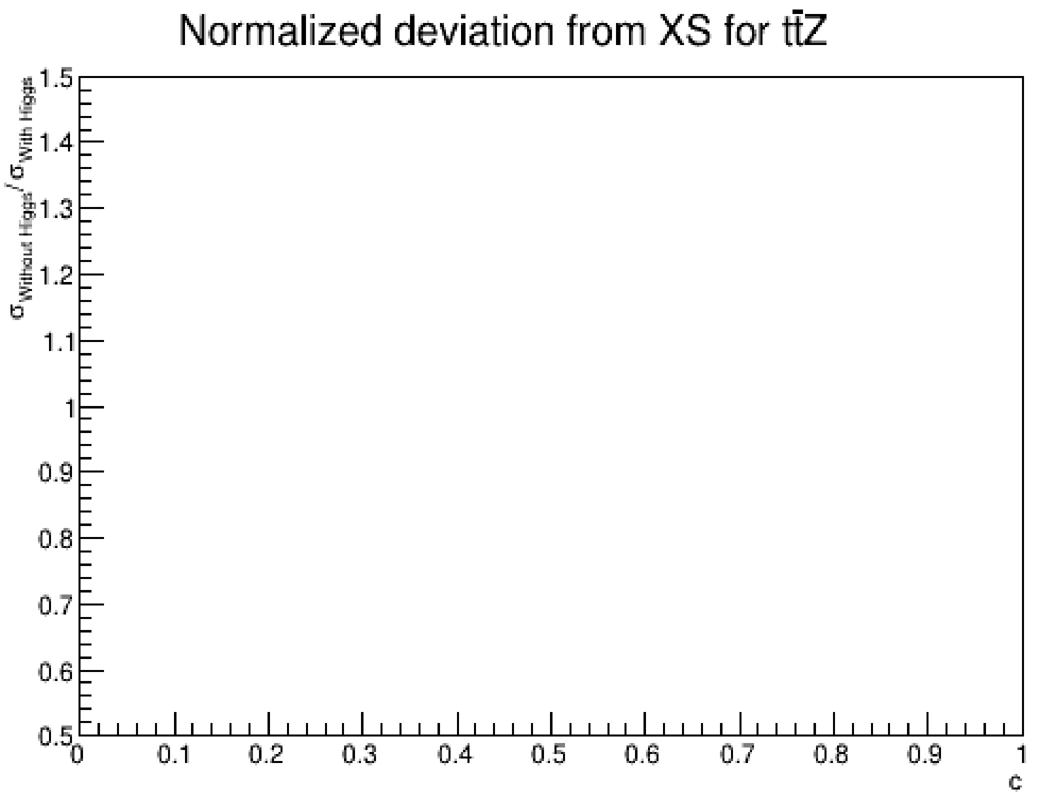

‘Higgs content of the proton’

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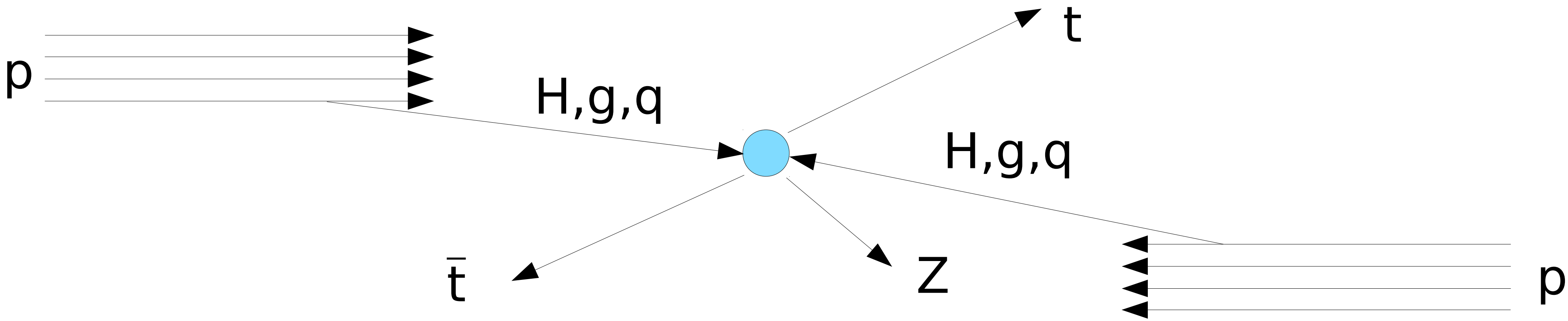

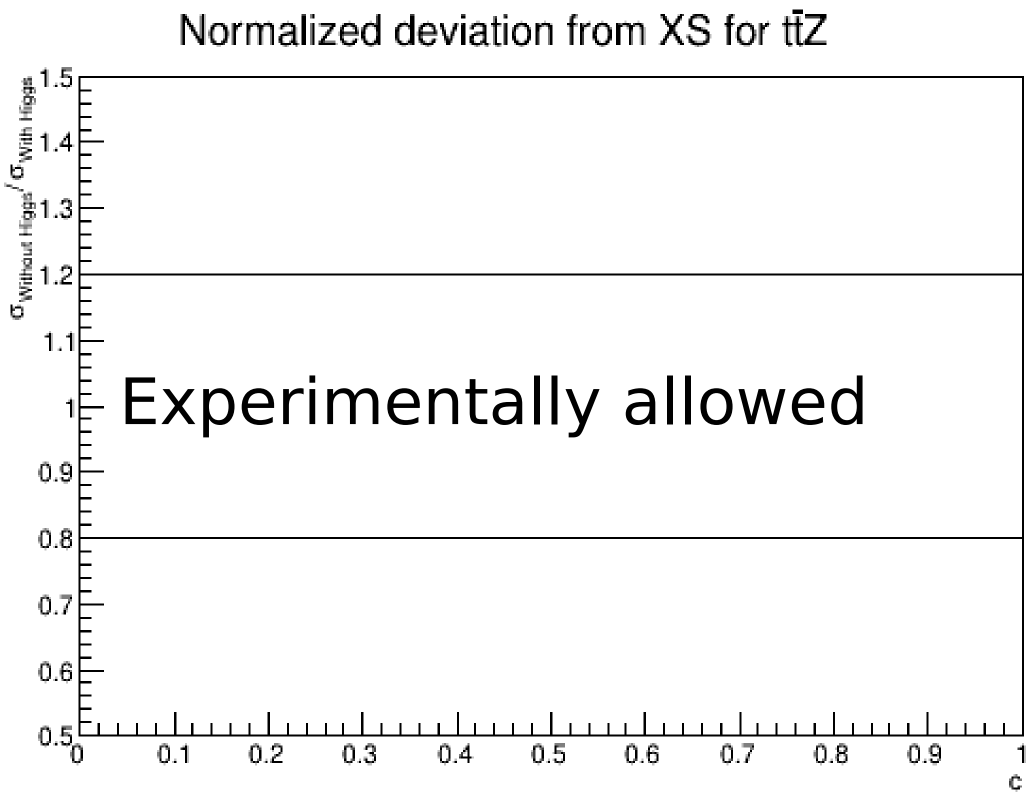

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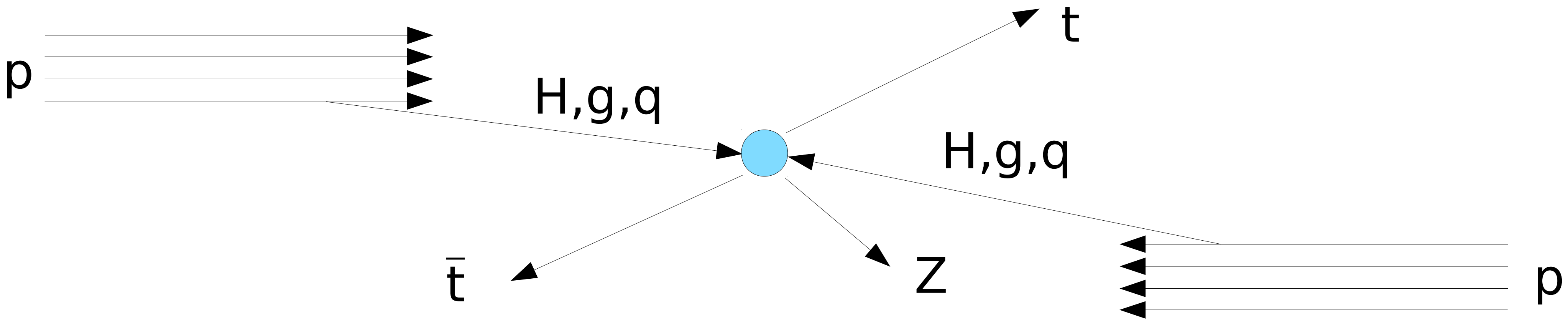

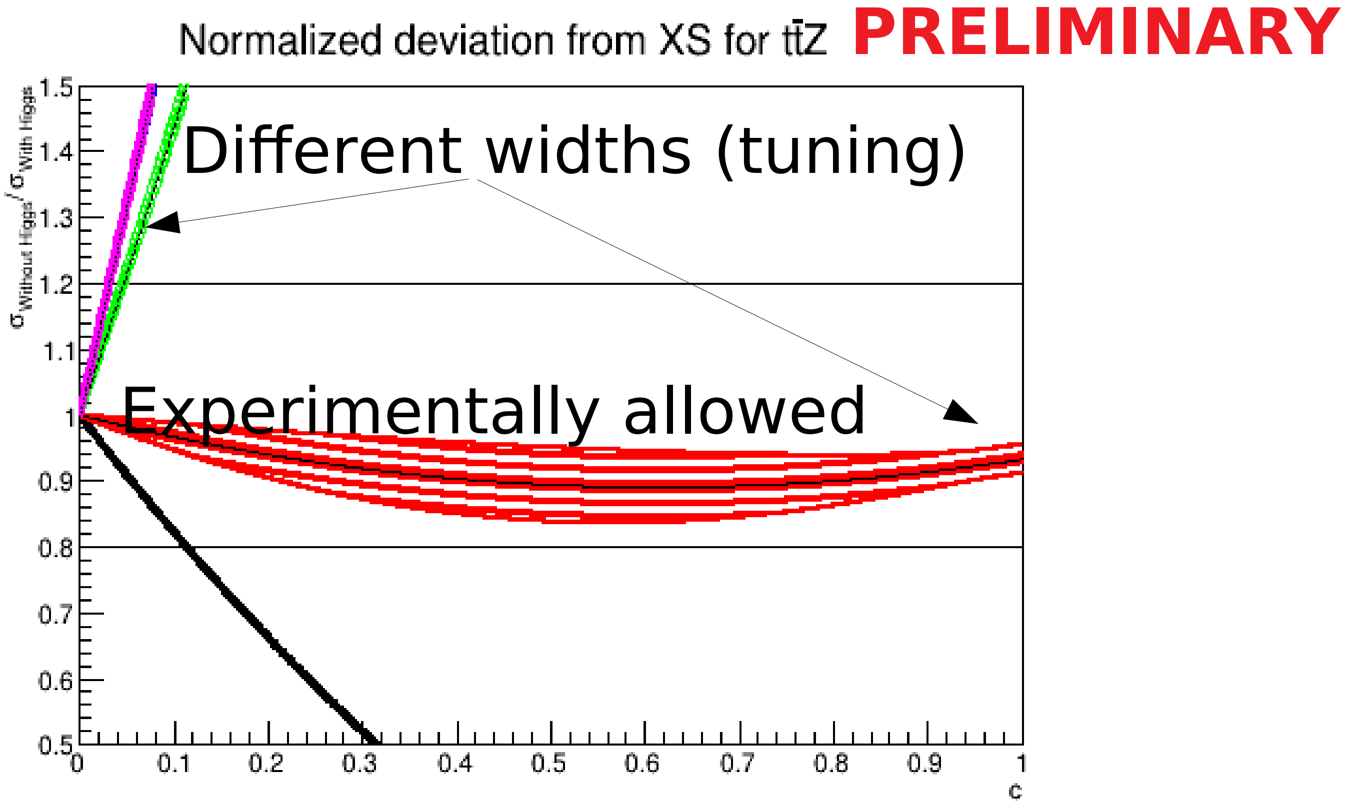

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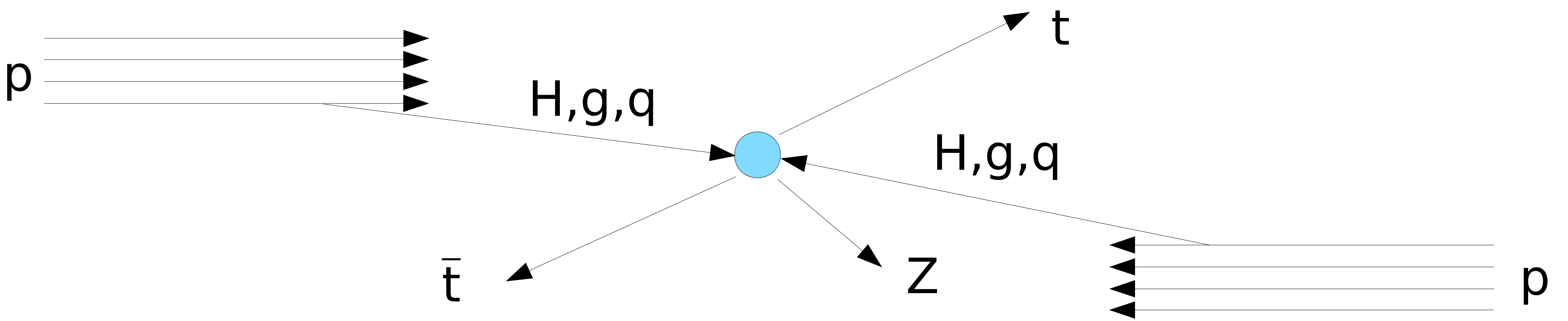
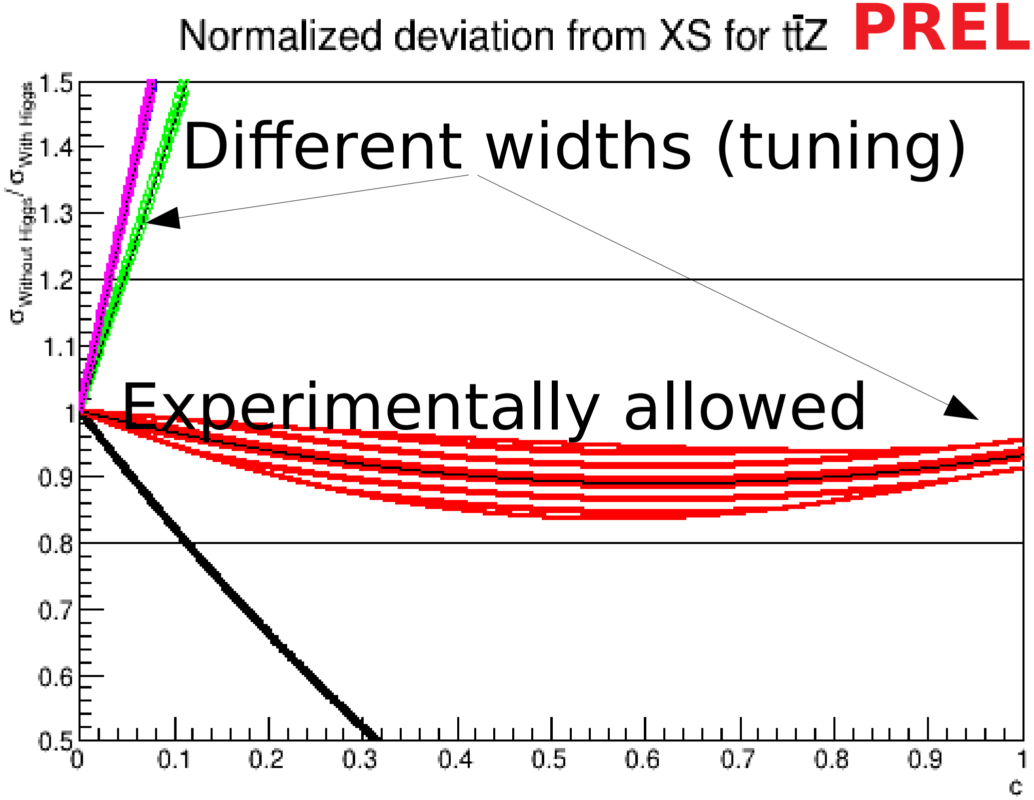
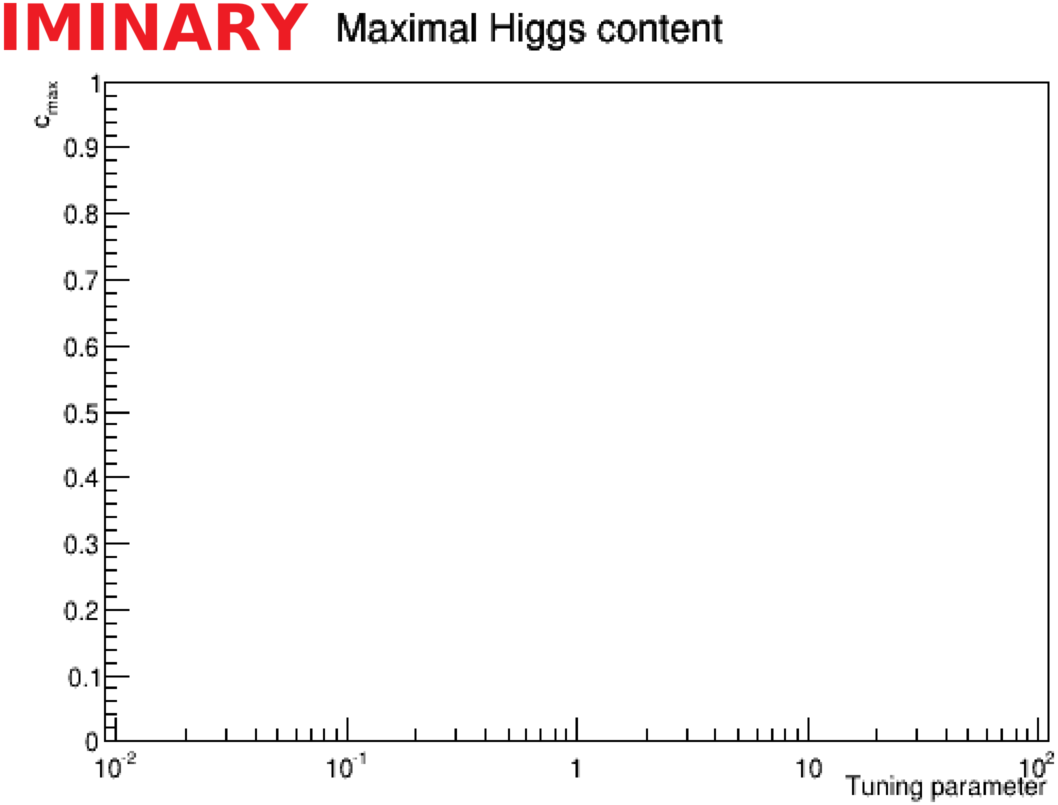


PRELIMINARY





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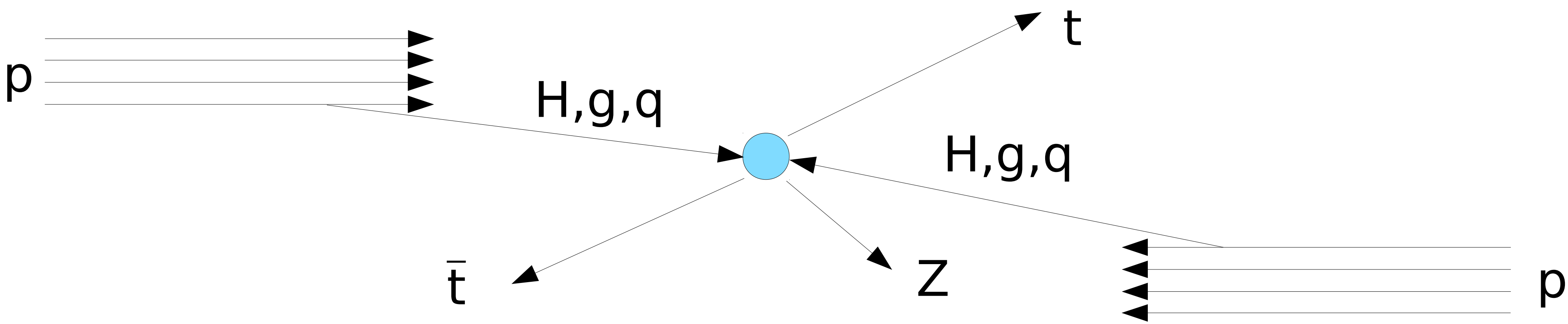

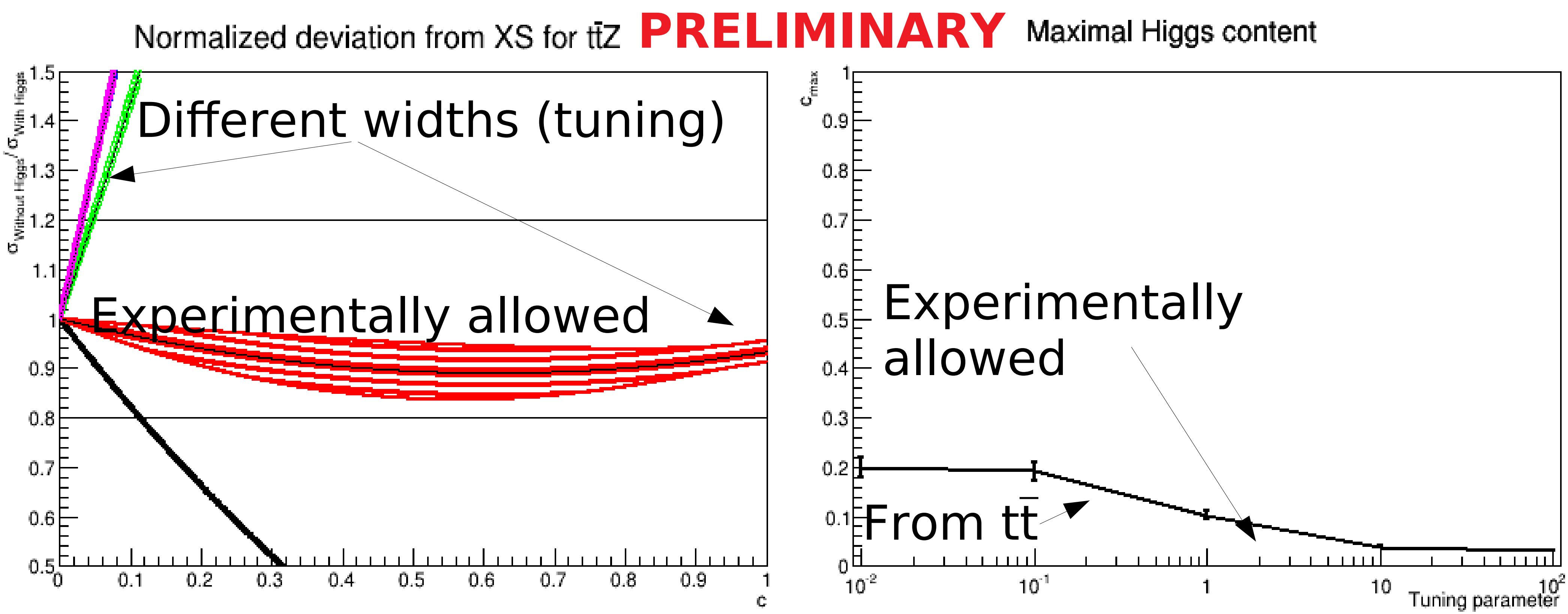

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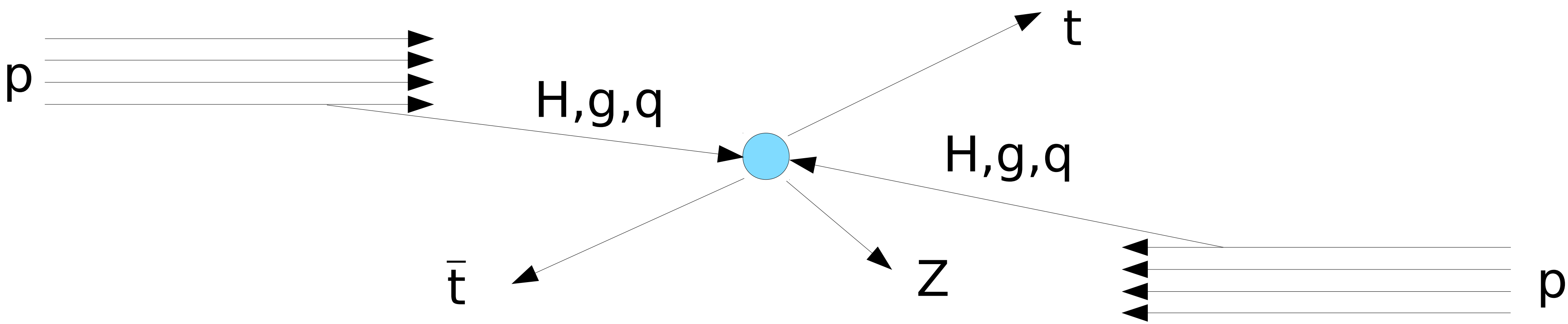

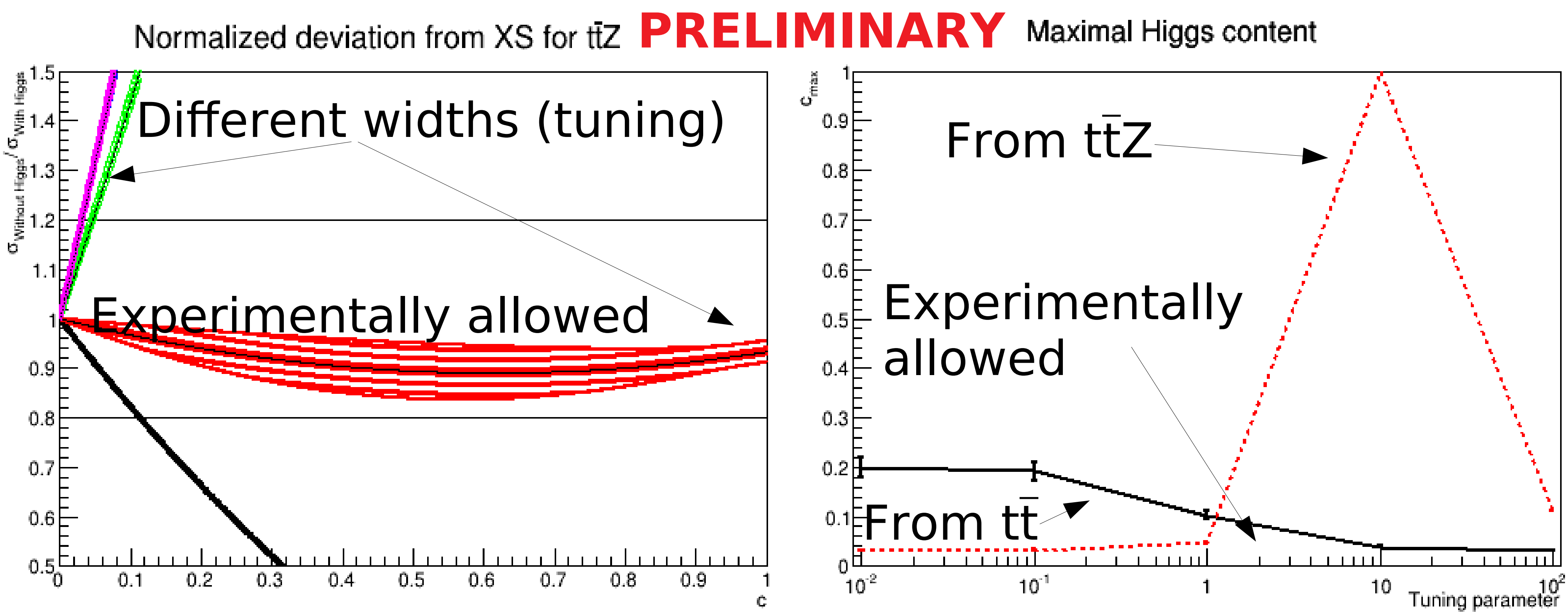

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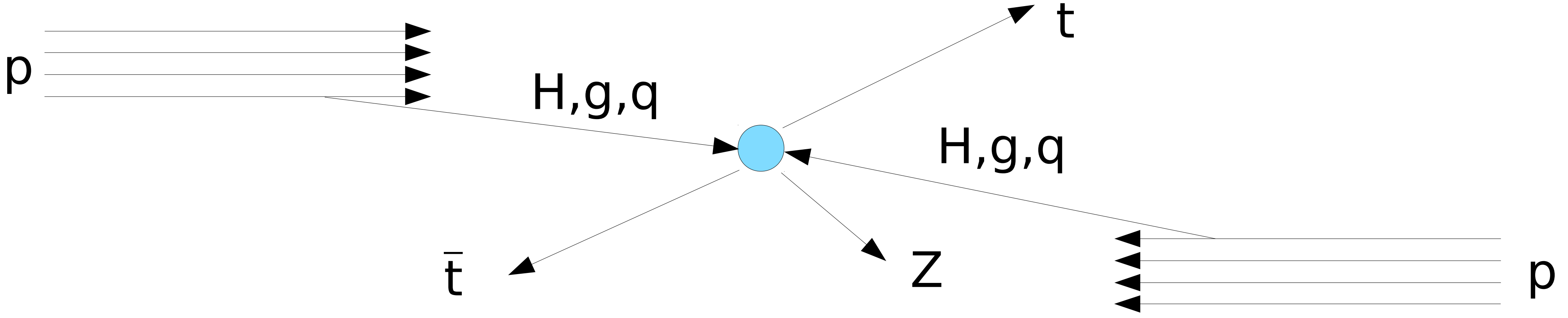

Add: Partial differential crosssections, CMS detector simulation

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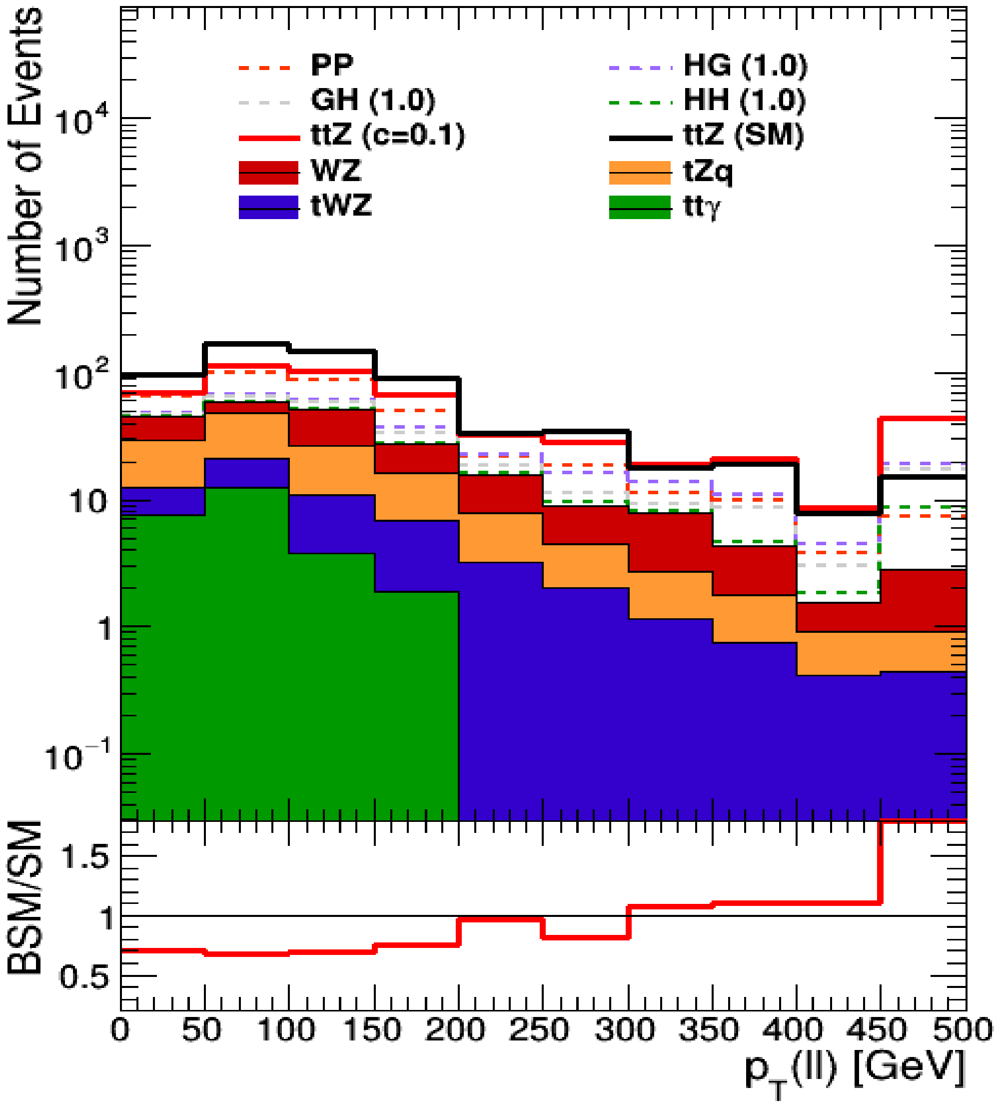
PRELIMINARY



Add: Partial differential crosssections, CMS detector simulation

Constraining the valence Higgs

PRELIMINARY

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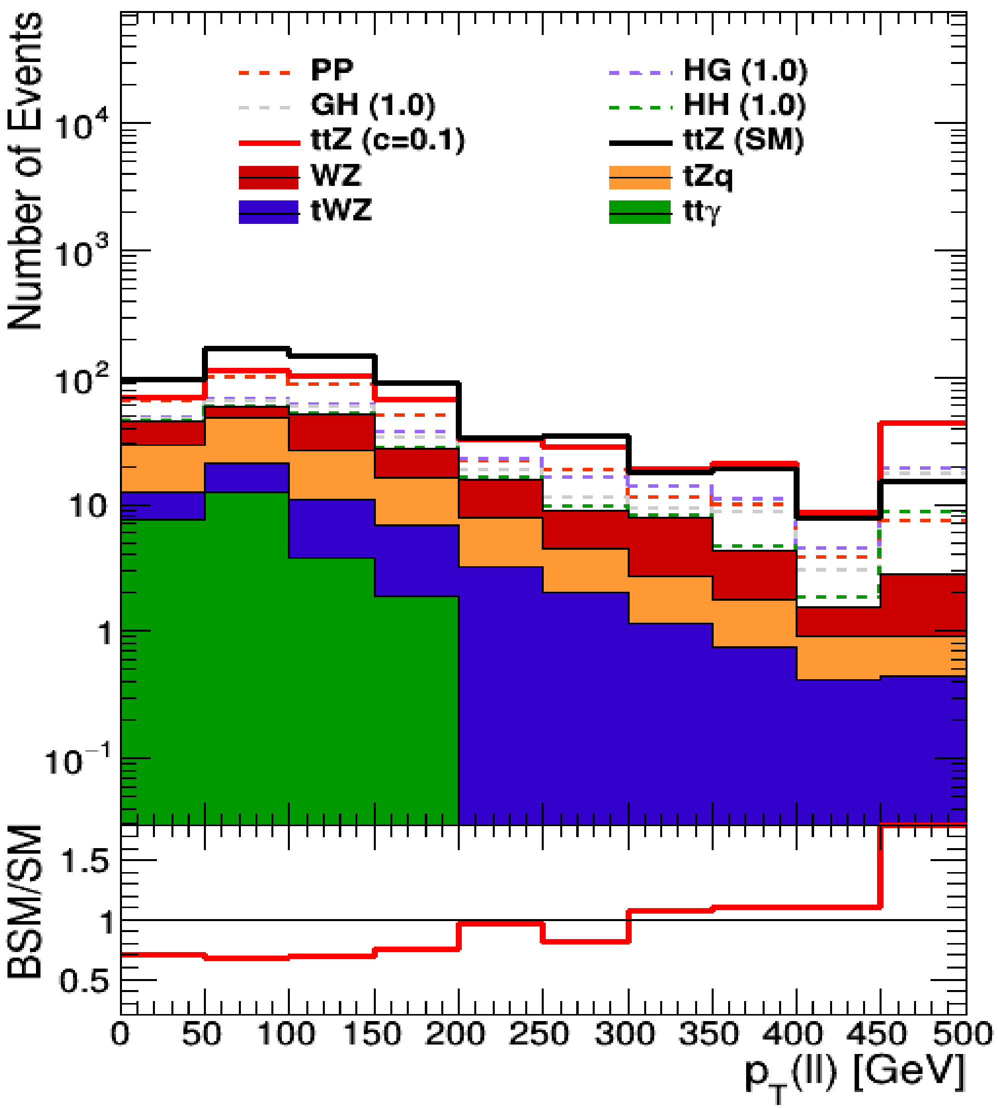

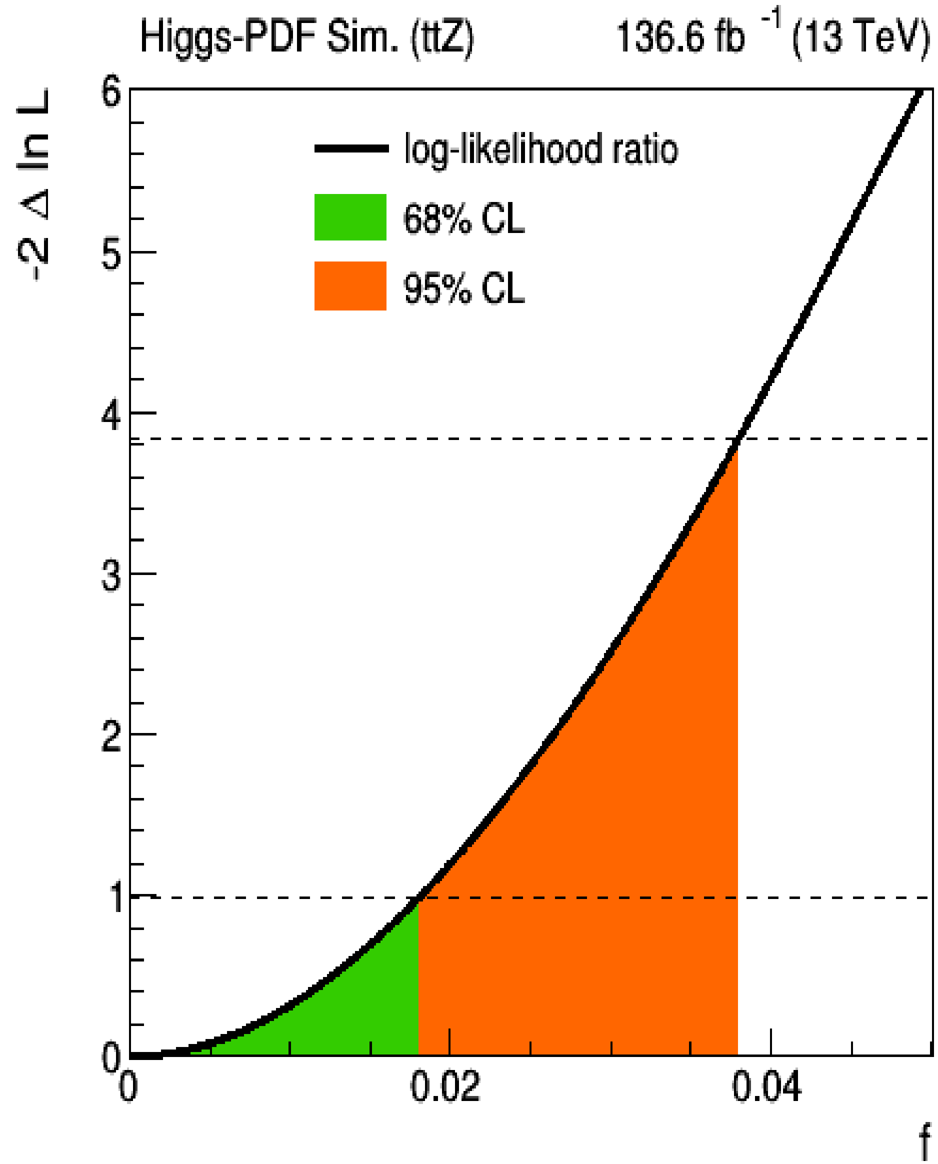

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New physics
-
Qualitative changes

Beyond the standard model

[Maas'15
Maas, Sondenheimer, Törek'17]

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A toy model

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A toy model

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

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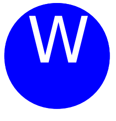
- Ws W^{a}_{μ} 

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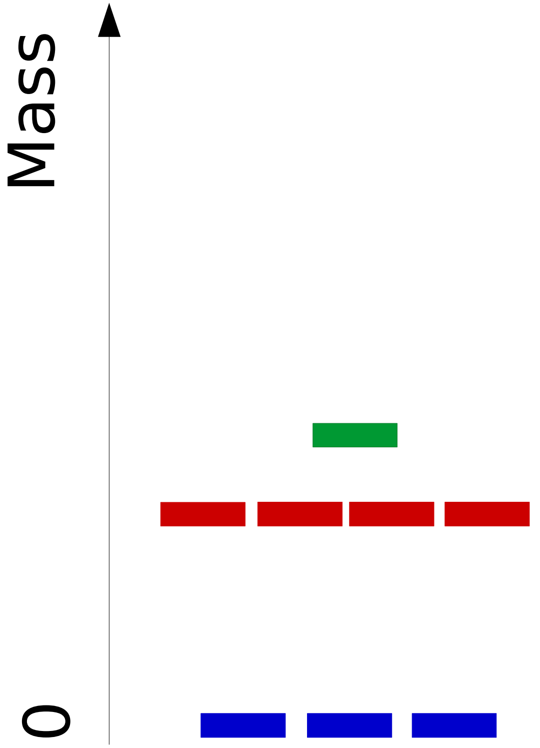
- Global U(1) custodial (flavor) symmetry
  - Acts as (right-)transformation on the scalar field only

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

Spectrum

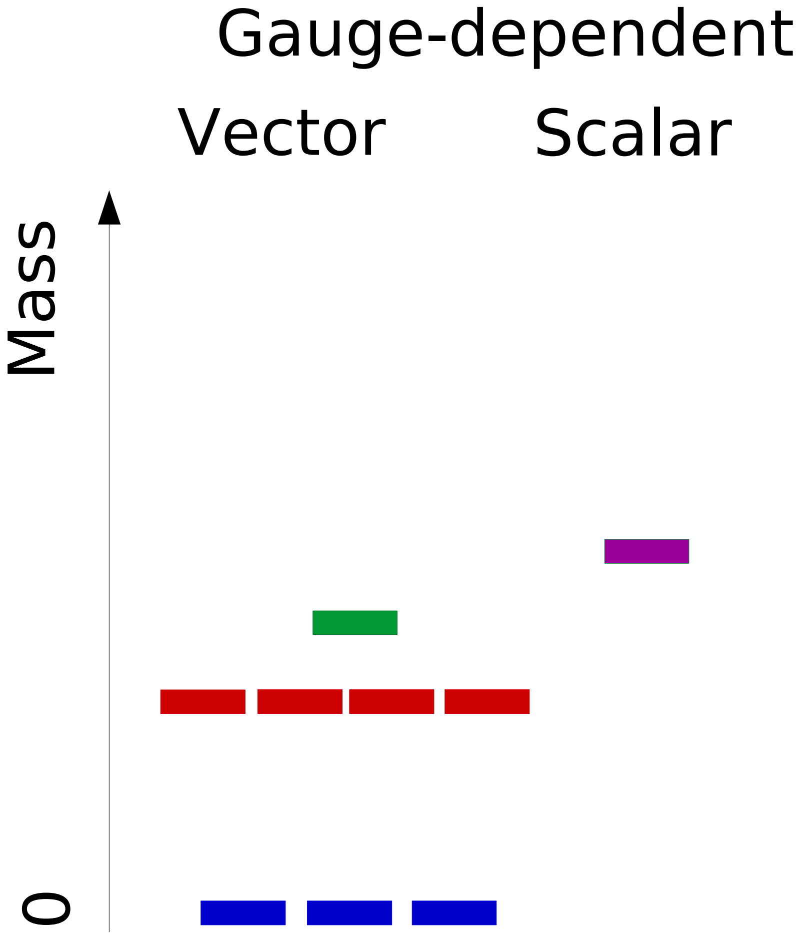
Gauge-dependent

Vector



‘SU(3)→ SU(2)’

Spectrum



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[Maas & Törek'16,'18
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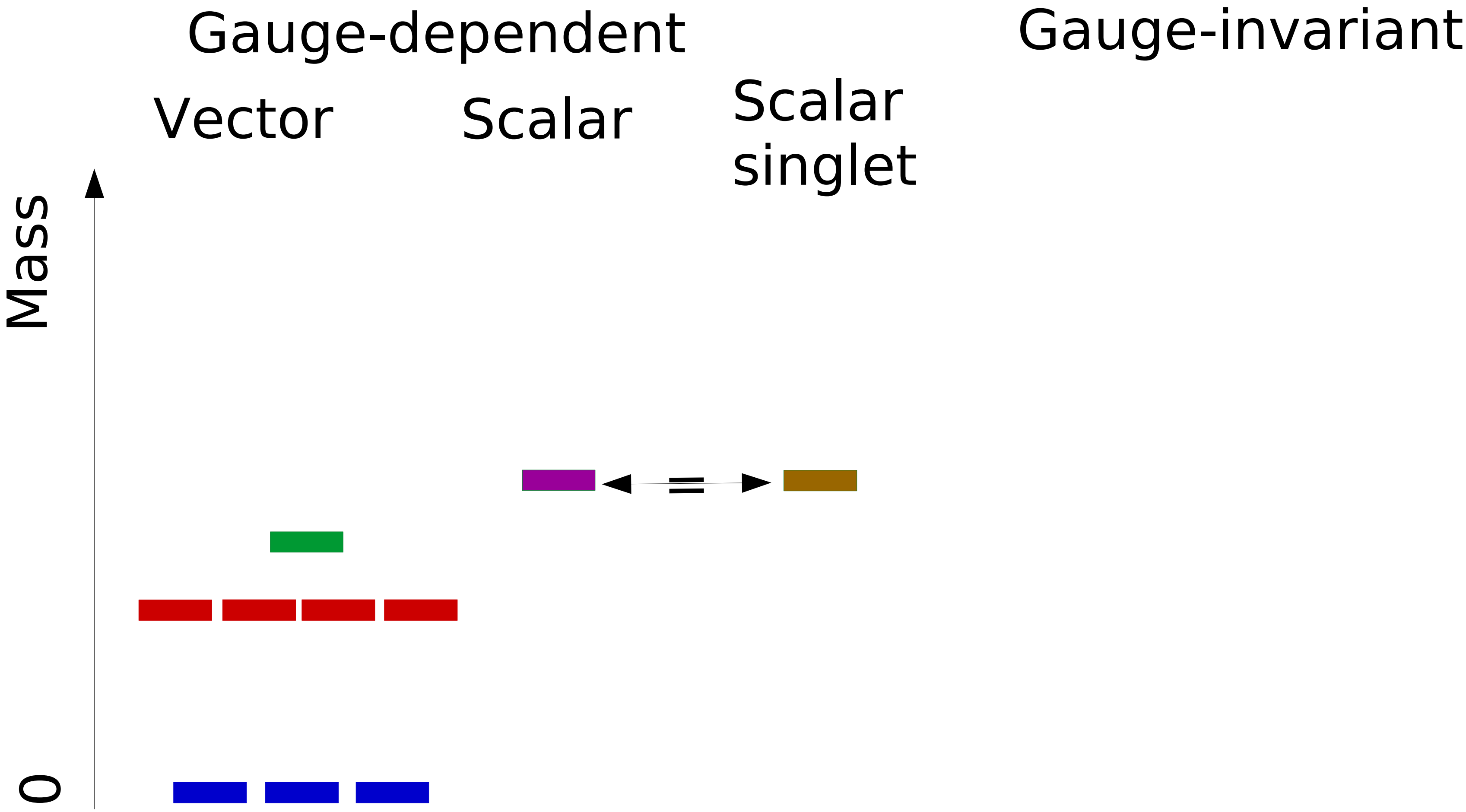

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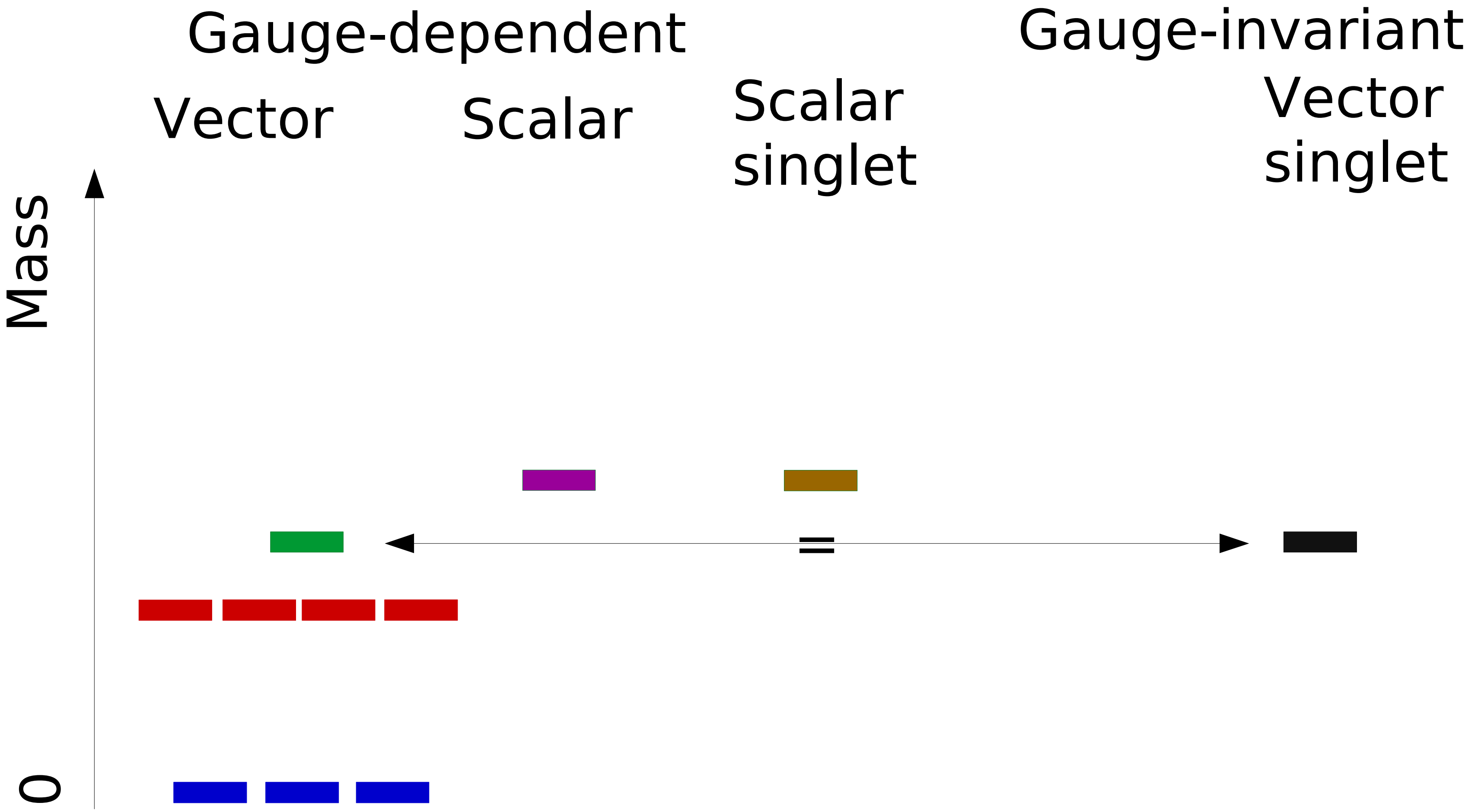

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Matrix from group structure

c^{ab} projects out only one field

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

Spectrum

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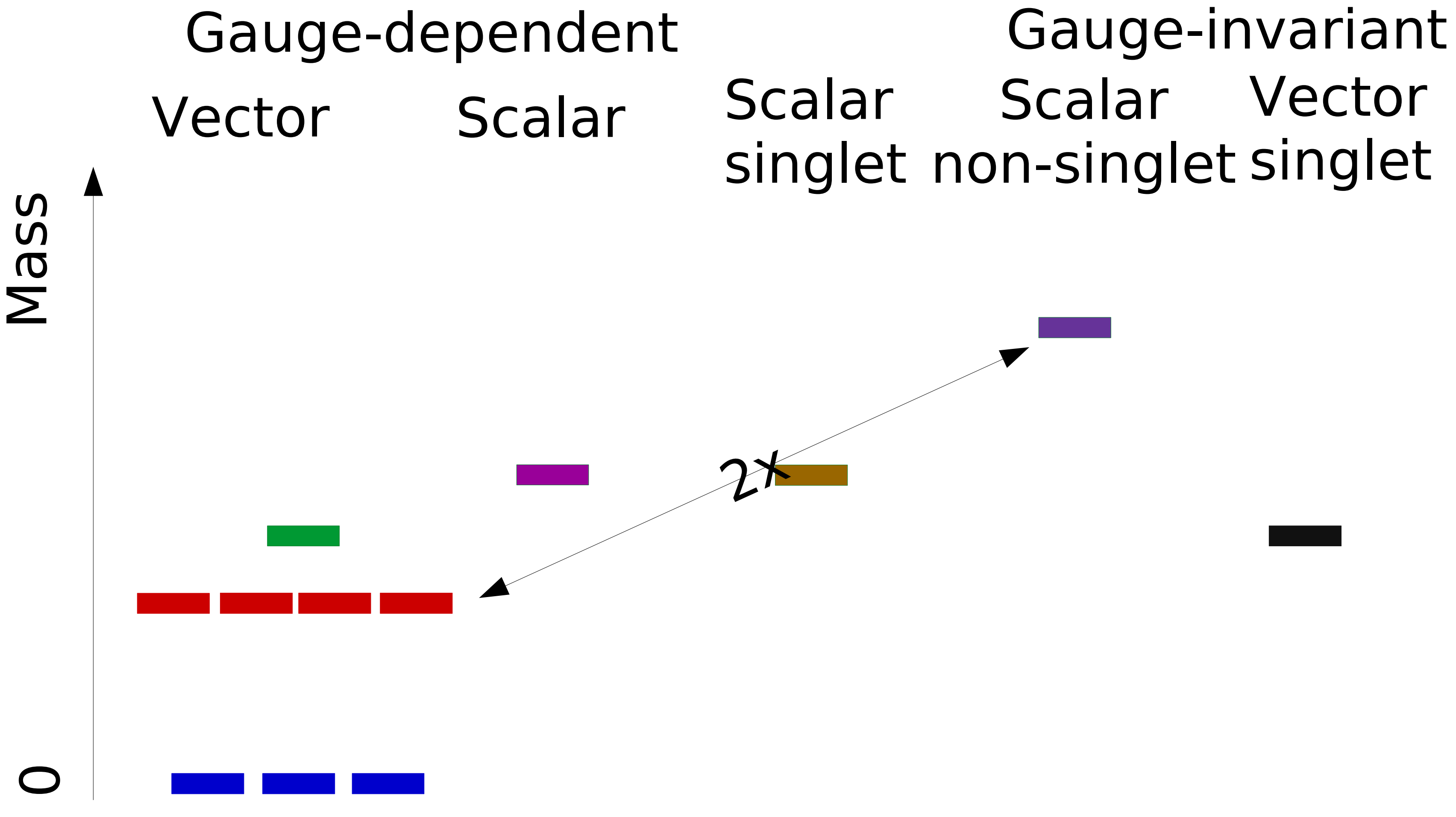

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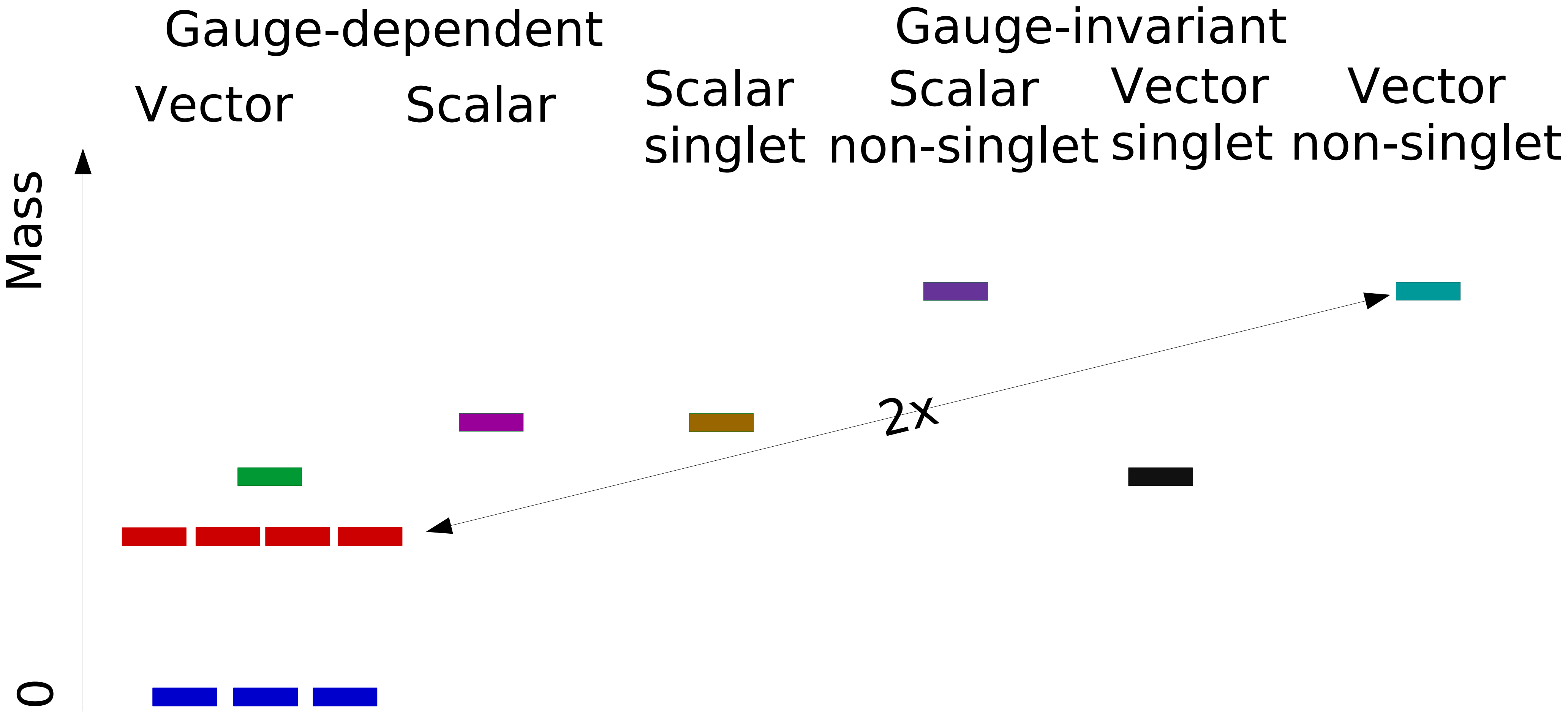

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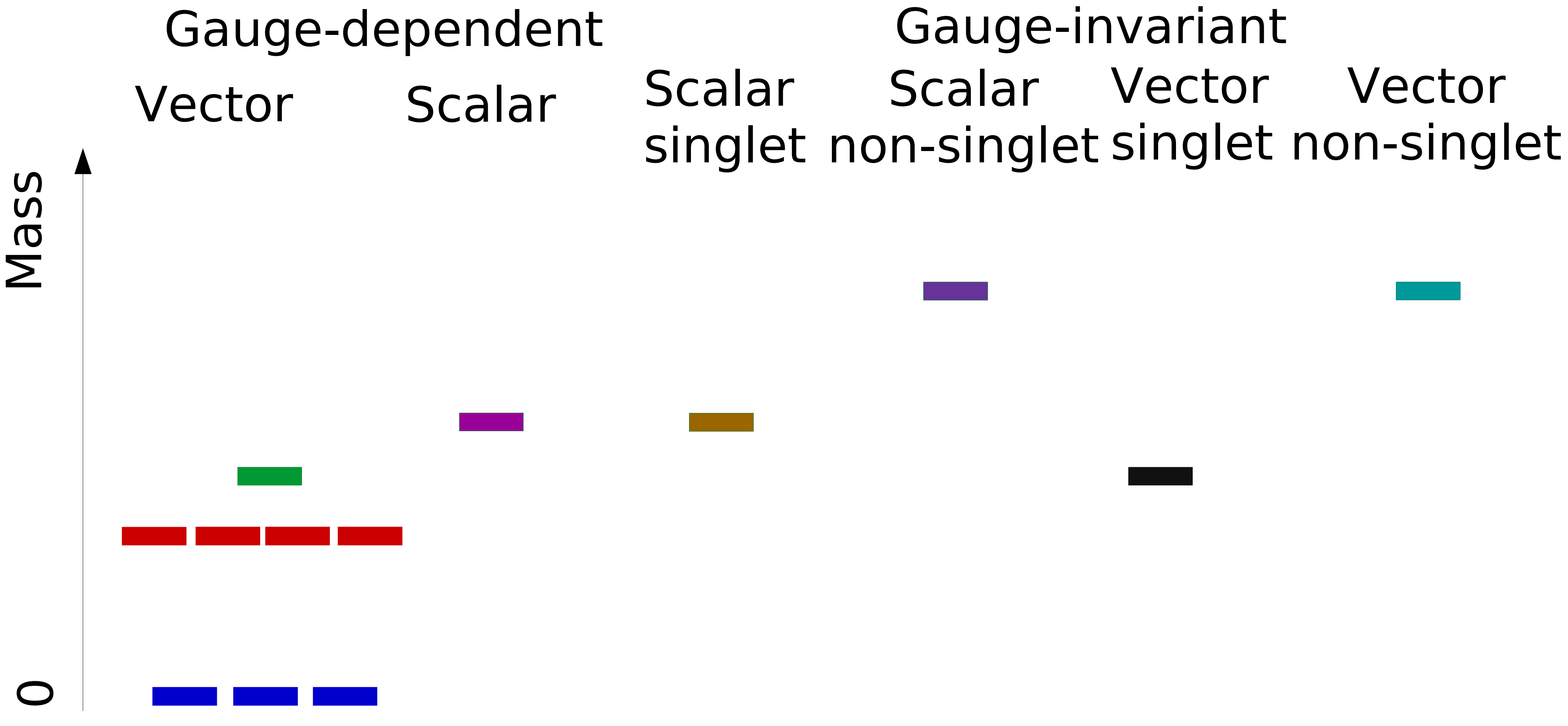

- Qualitatively different spectrum
- No mass gap!

Spectrum

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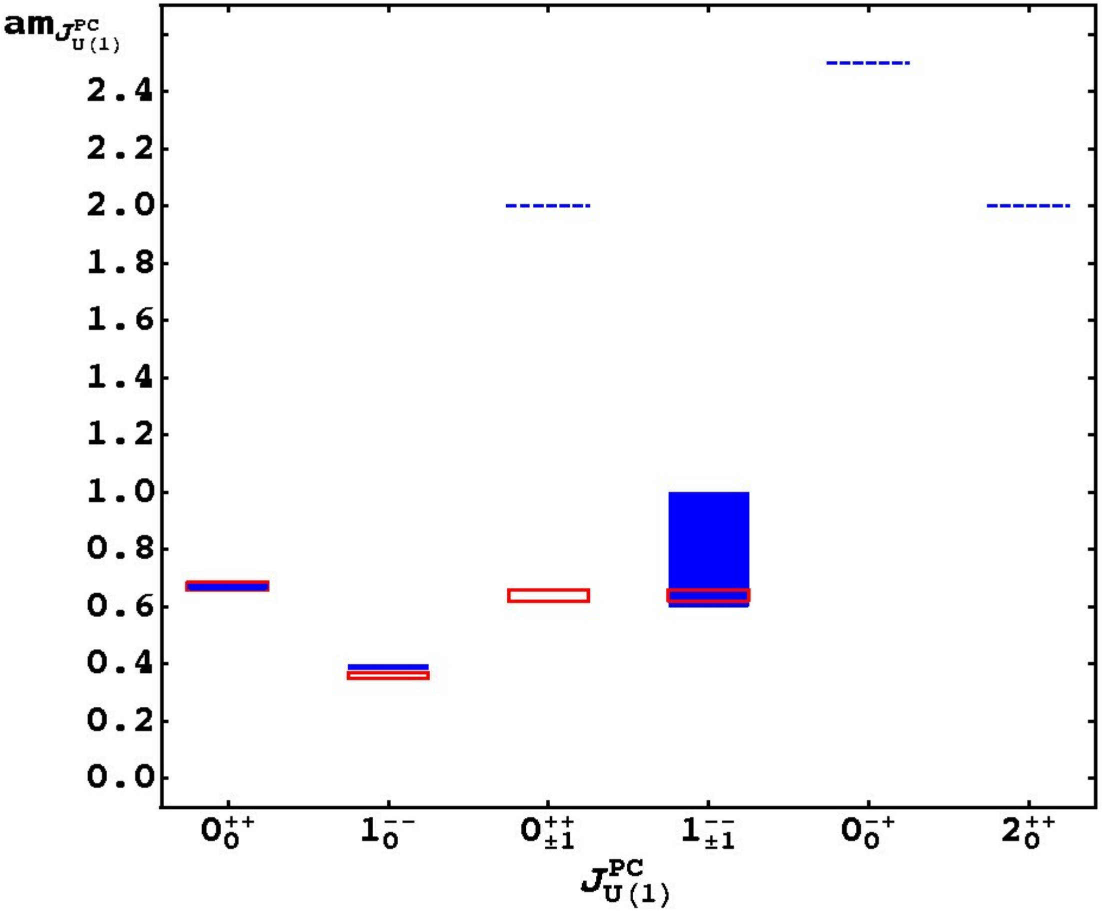
Gauge-invariant

Scalar singlet	Scalar non-singlet	Vector singlet	Vector non-singlet



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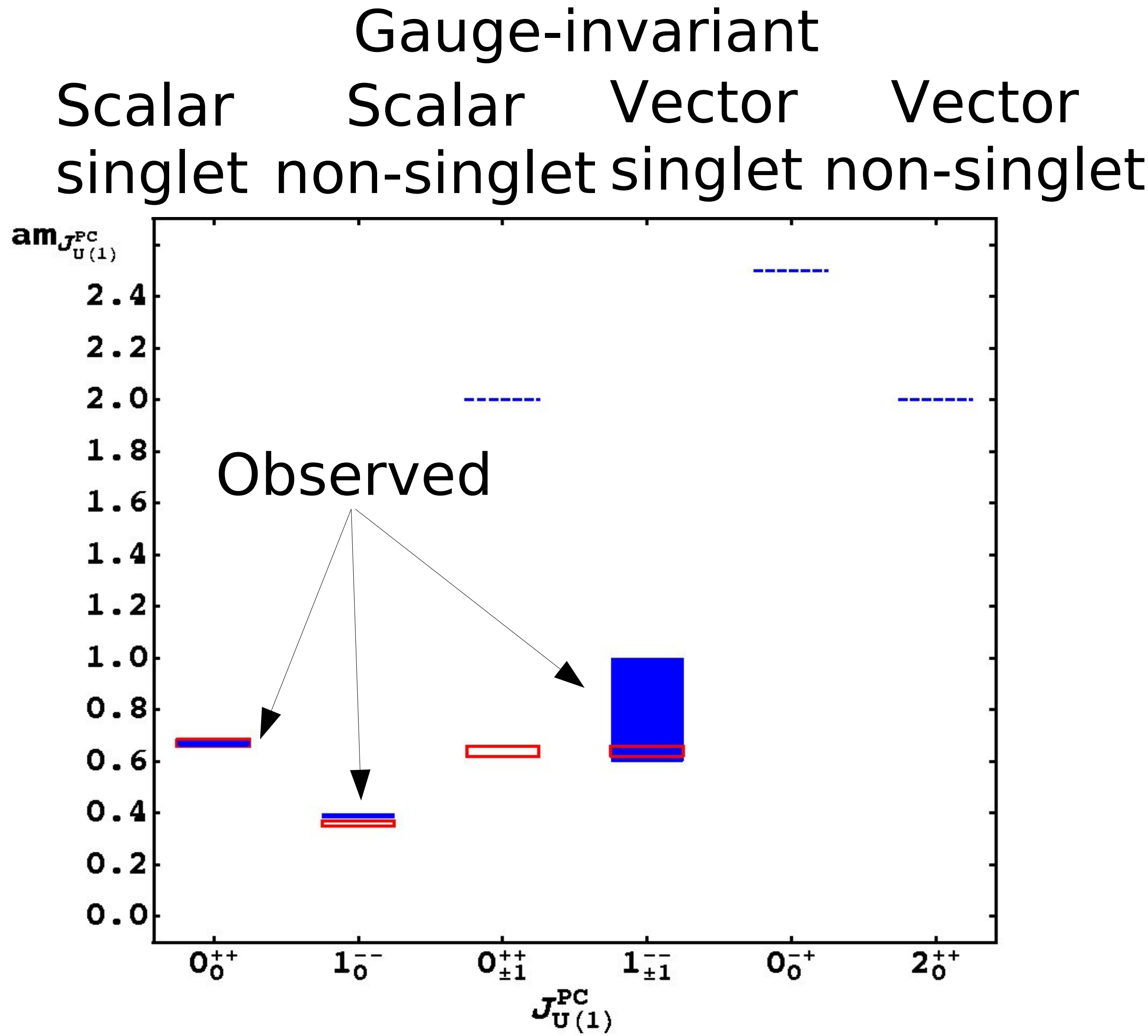

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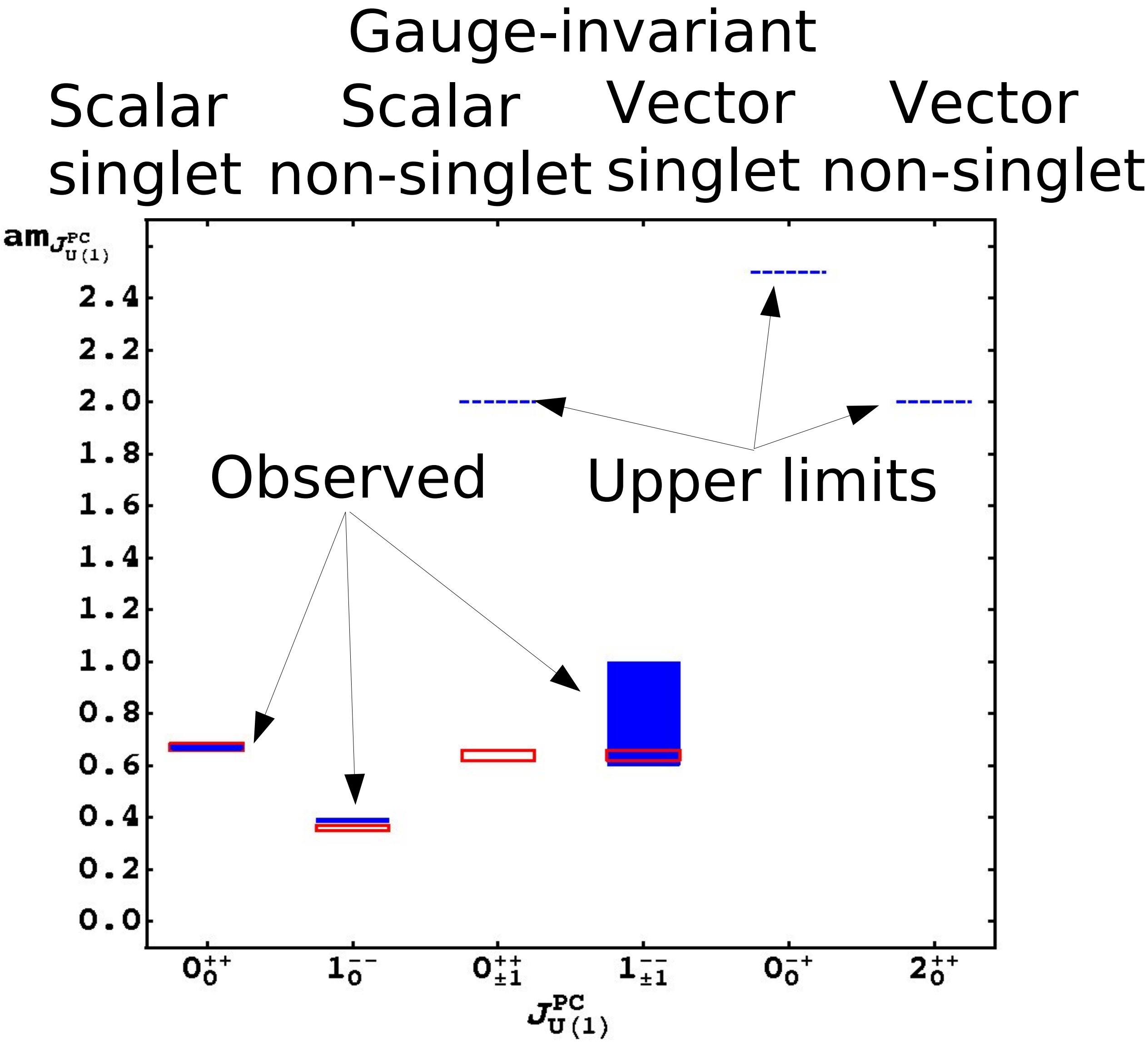

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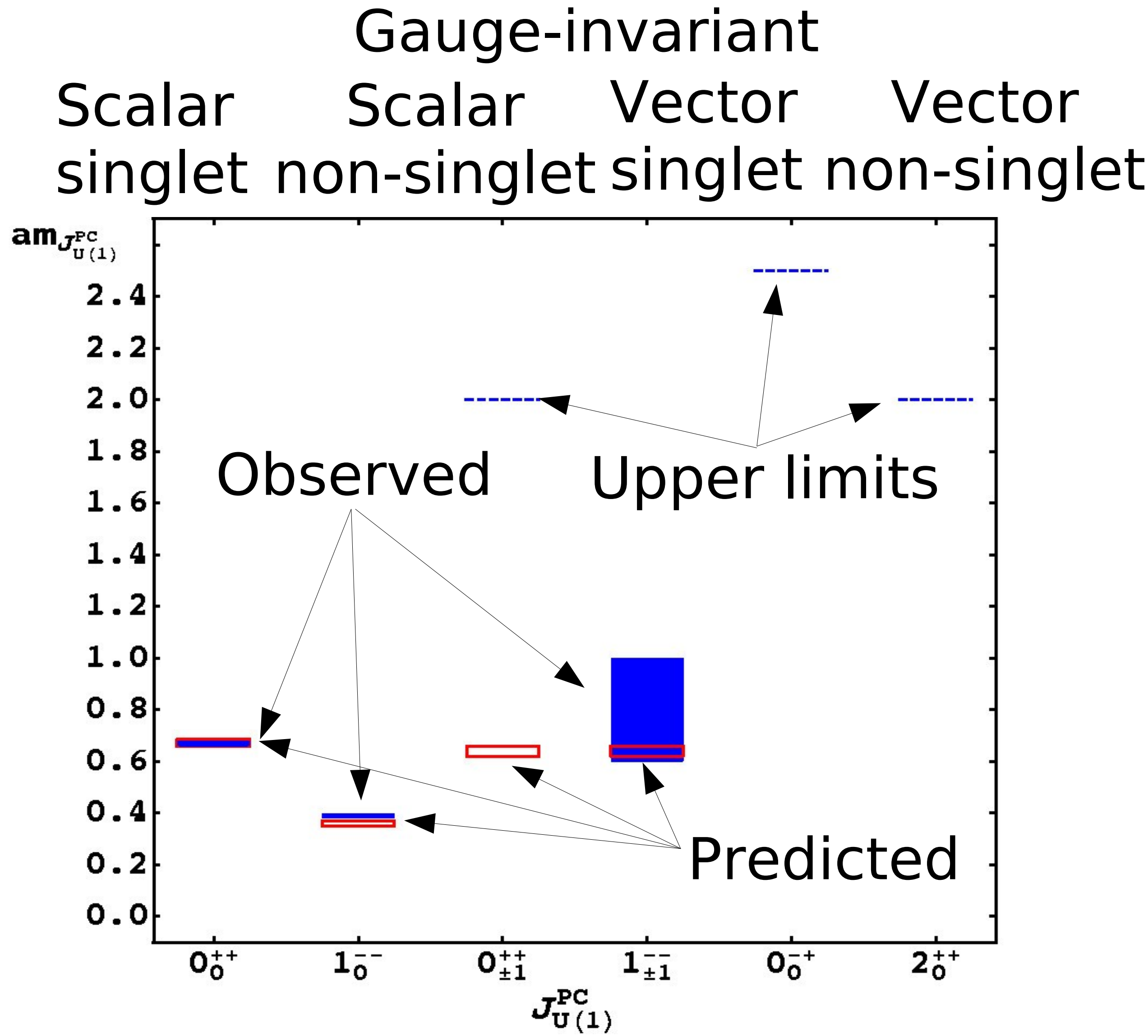

- Qualitatively different spectrum
- Results in agreement with analytic predictions

Experimental consequences

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[Maas & Törek'18
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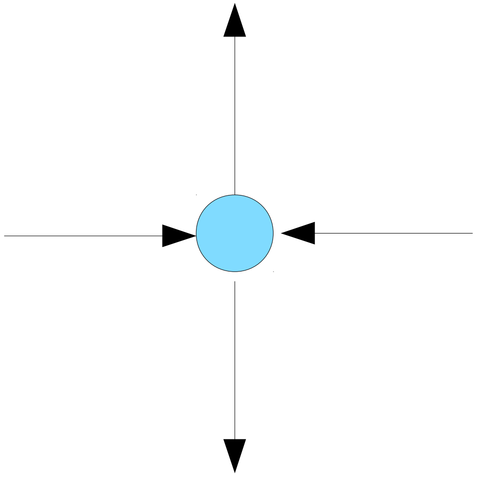
- Add fundamental fermions

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



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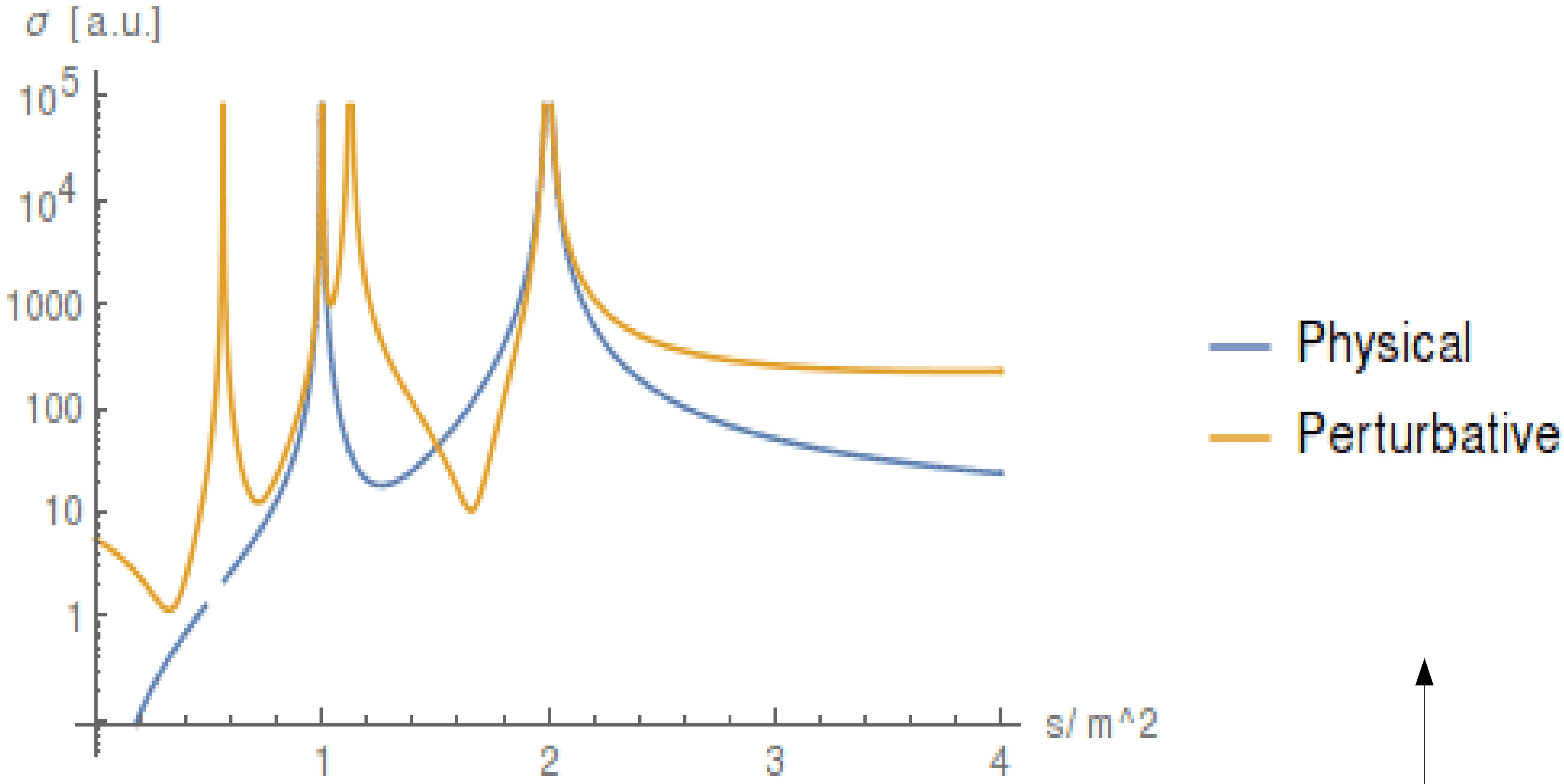

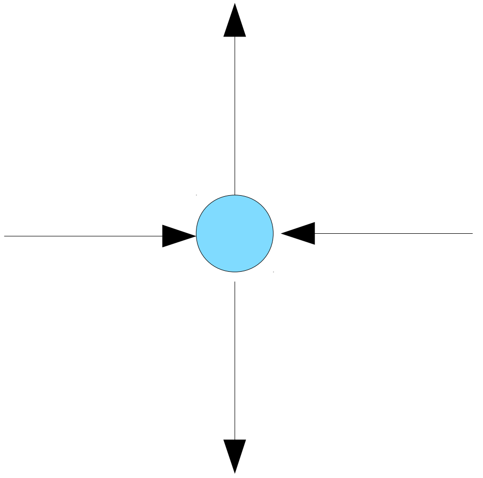

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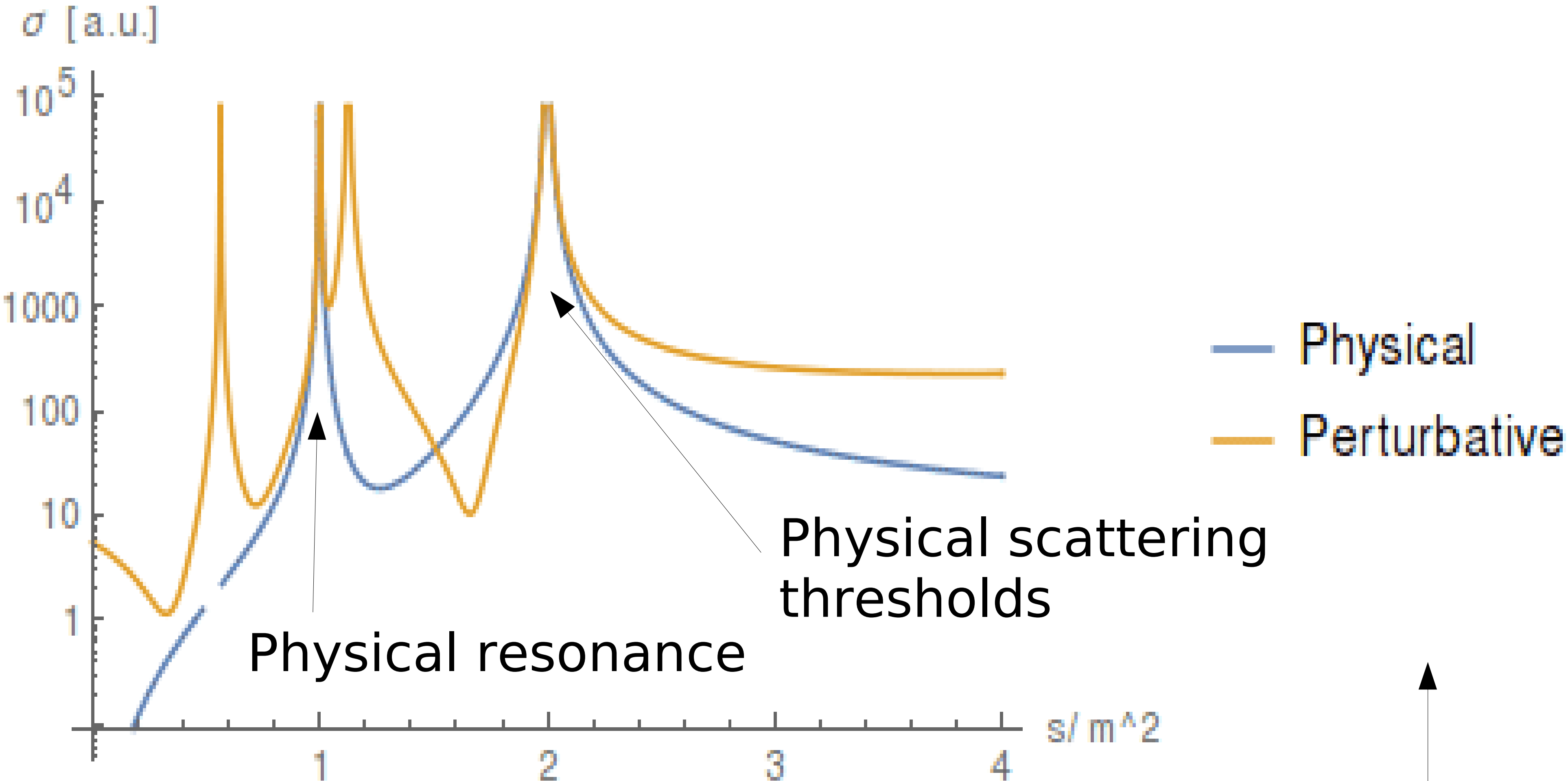

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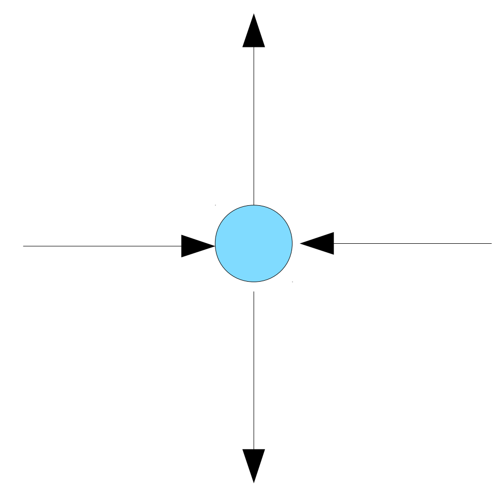

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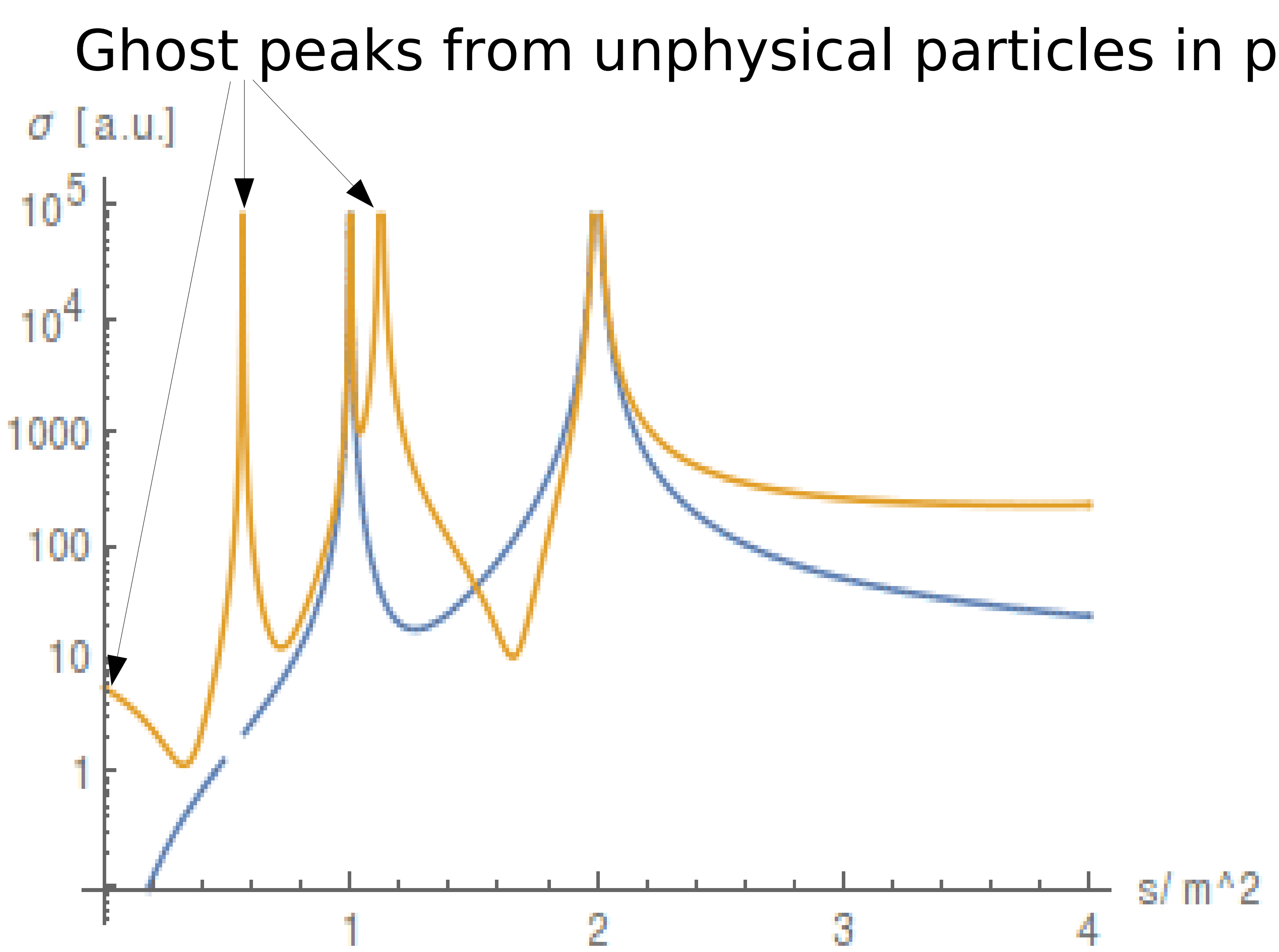
Ghost peaks from unphysical particles in perturbation theory



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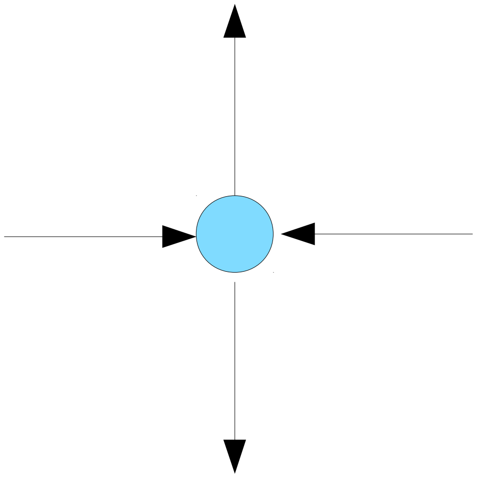

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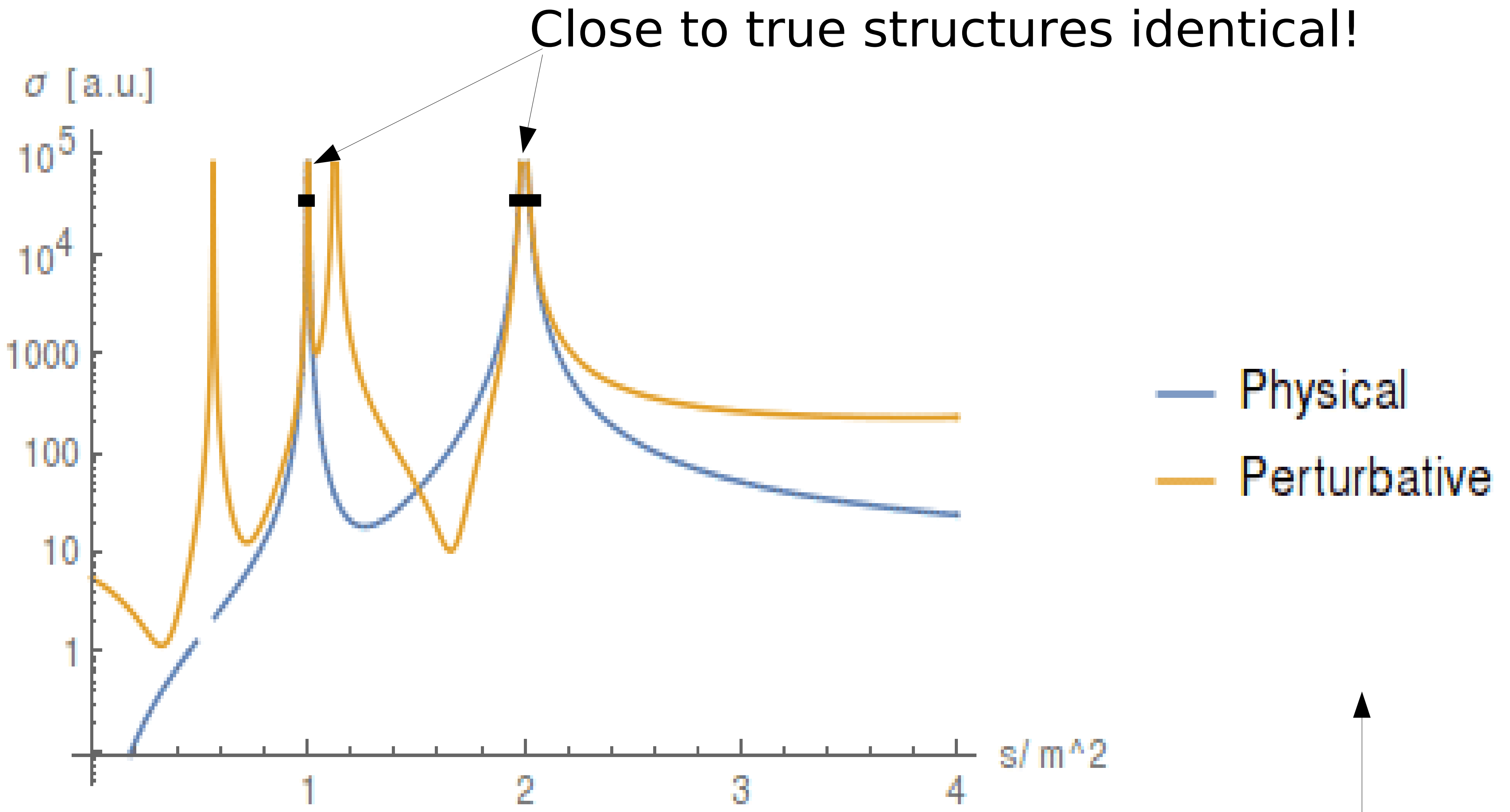

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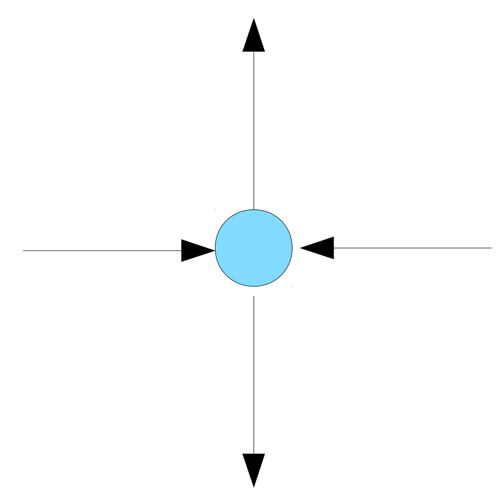

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- What happens in quantum gravity?
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