

# Particle spectra in Models of New Physics

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with**

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Germany



**NAWI Graz**  
Natural Sciences

**FWF**

Der Wissenschaftsfonds

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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  $t_a^{ij}$

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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 states

[Fröhlich et al. PLB 80,  
't Hooft ASIB 80,  
Bank et al. NPB 79]

- Physical spectrum: Observable particles
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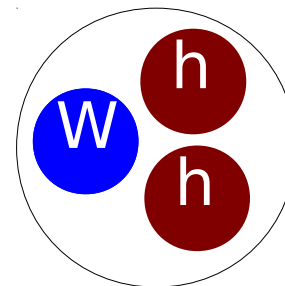
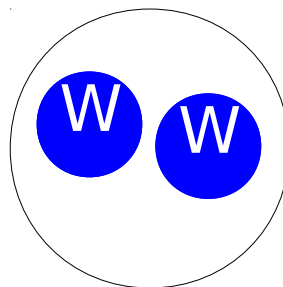
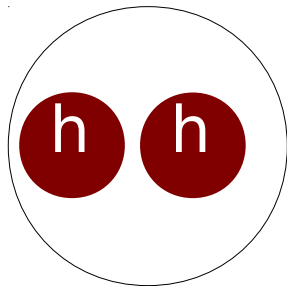
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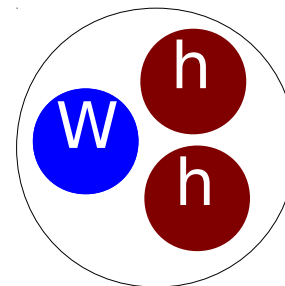
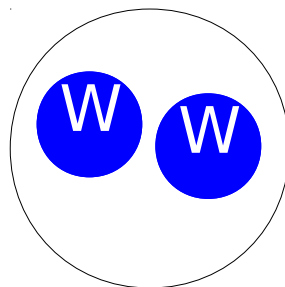
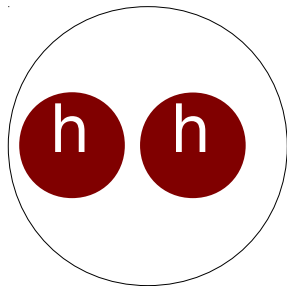
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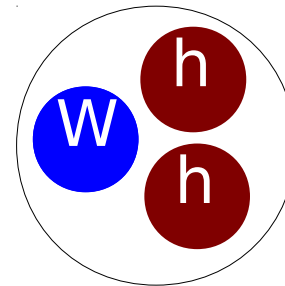
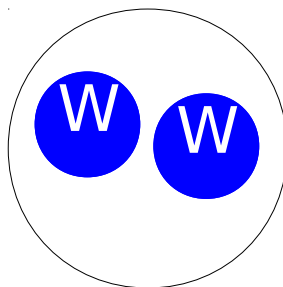
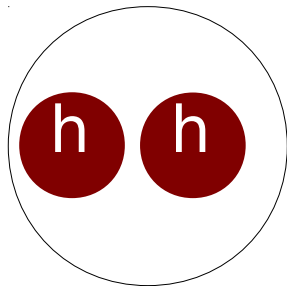


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- Why does perturbation theory work?

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- Fröhlich-Morchio-Strocchi (FMS) mechanism
- Perturbative tool to calculate bound state masses
- Deeply-bound relativistic state
  - Mass defect  $\sim$  constituent mass
  - Cannot be described with quantum mechanics

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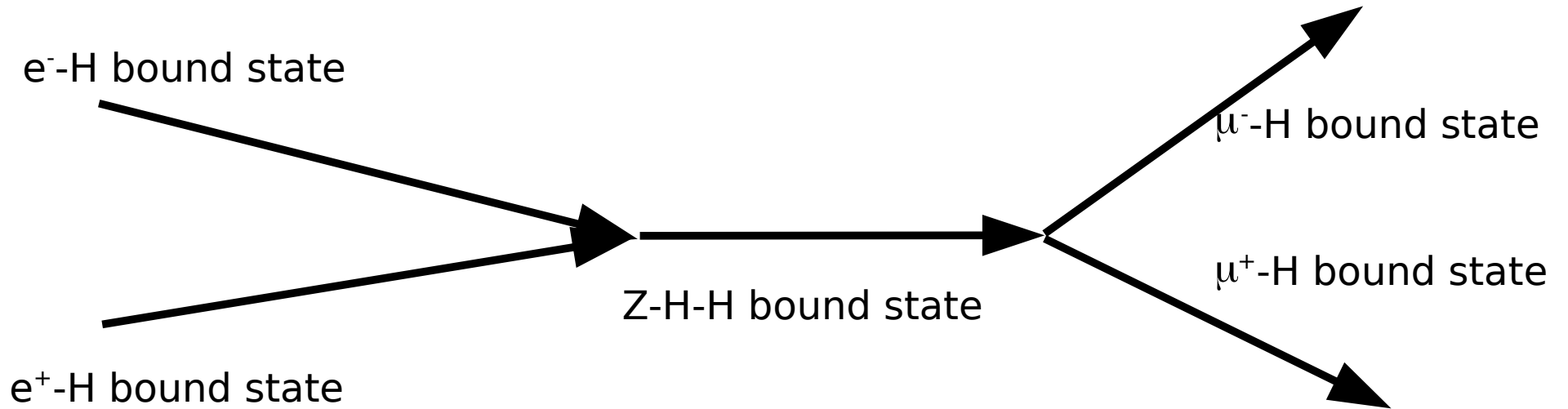
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  - QED similar but simpler



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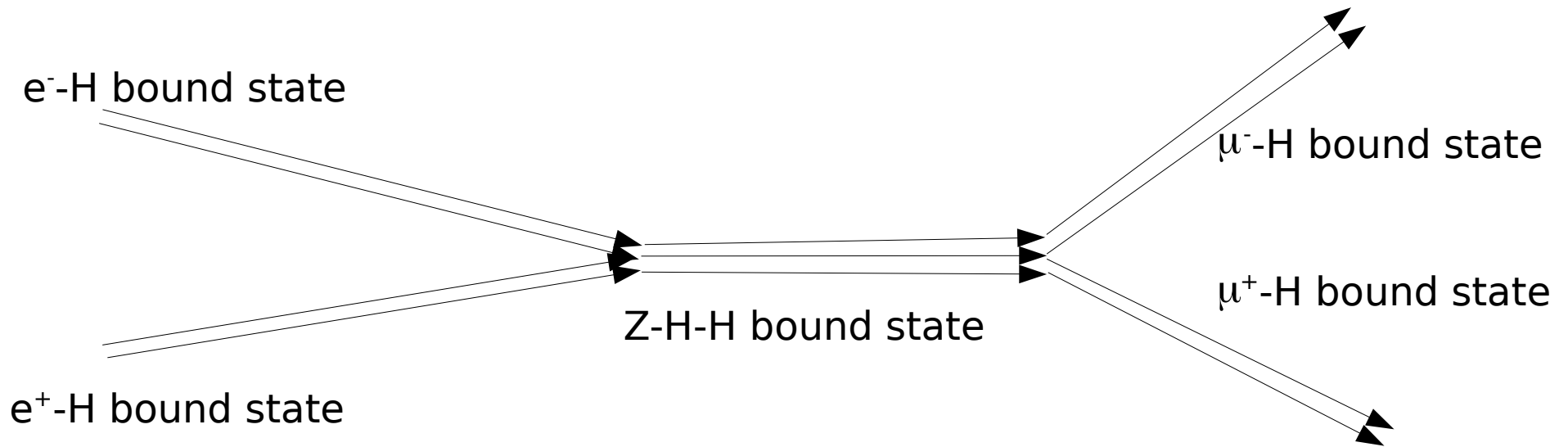
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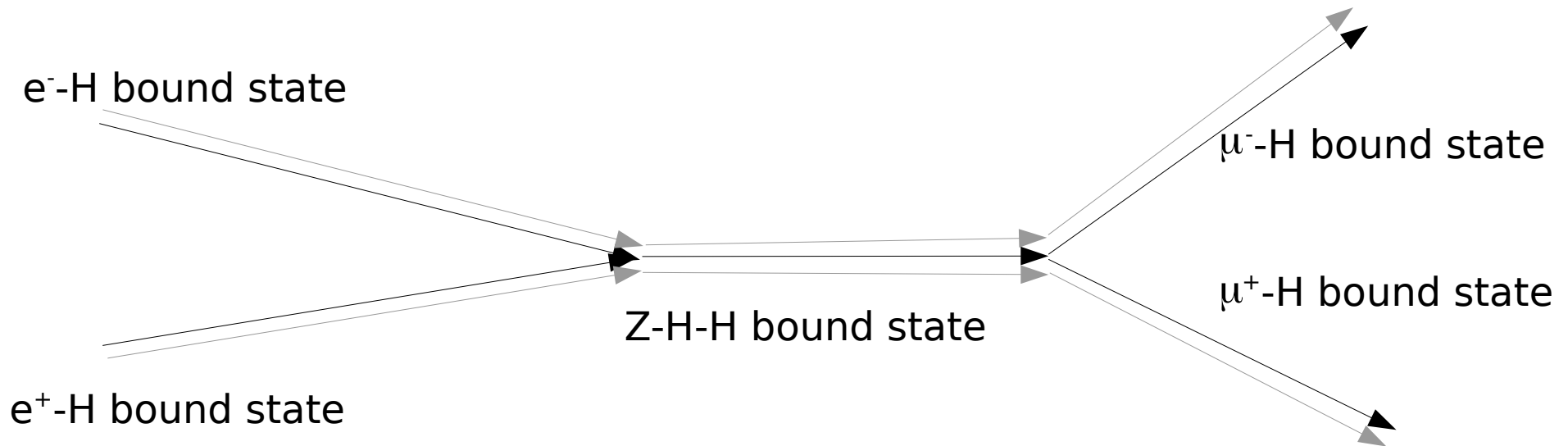
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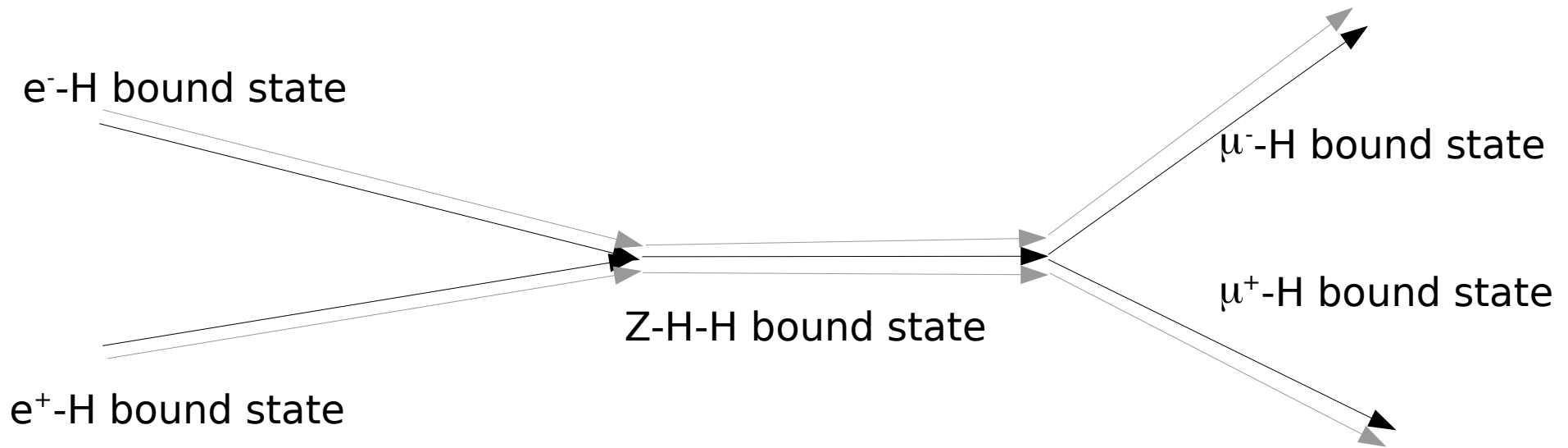
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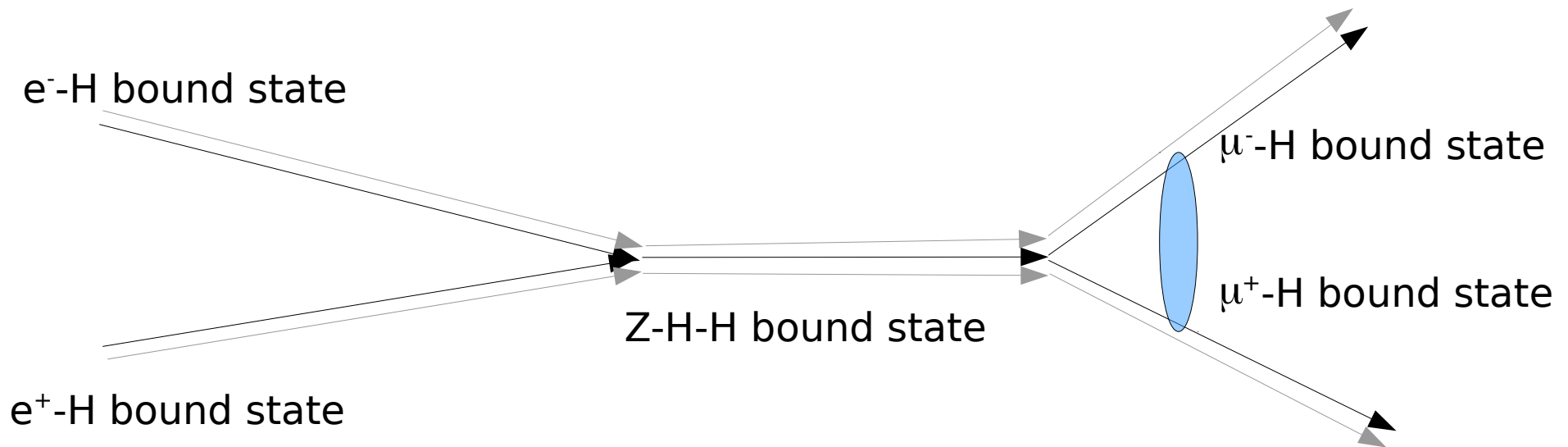
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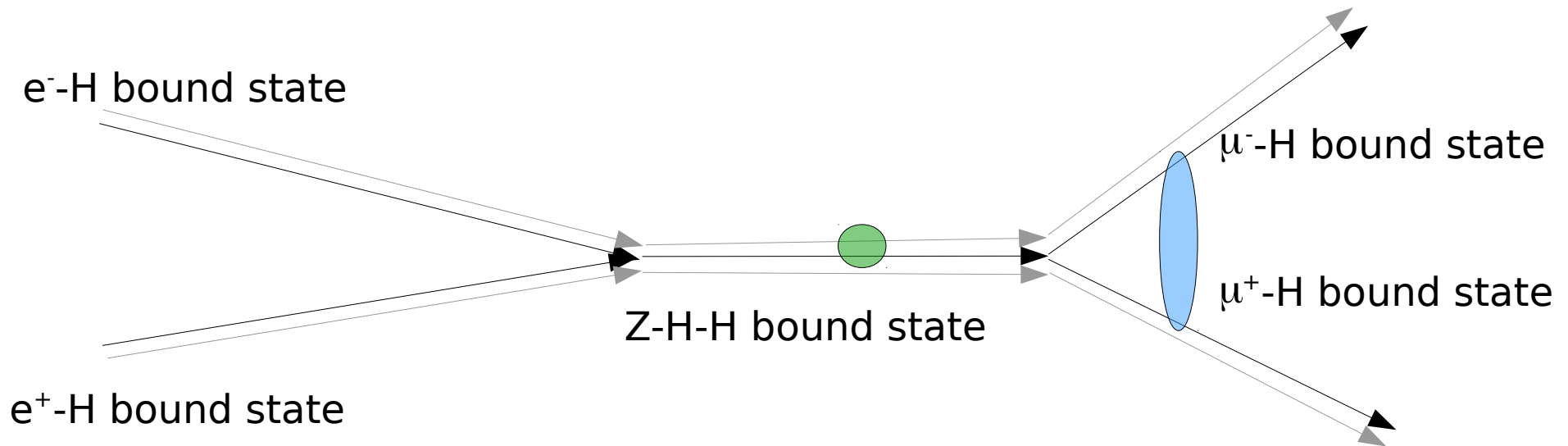
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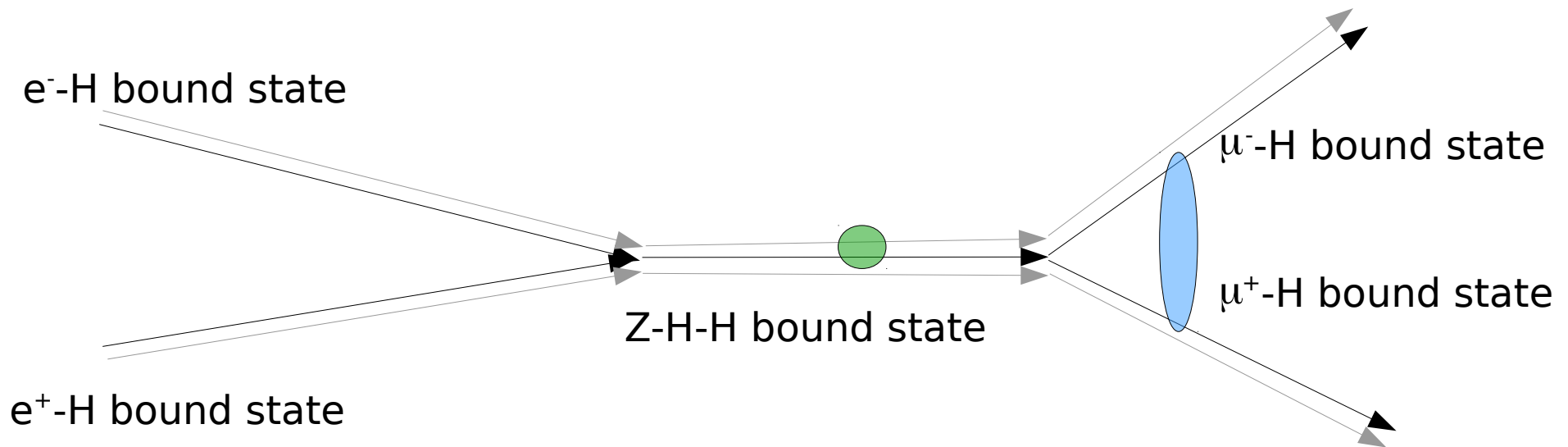
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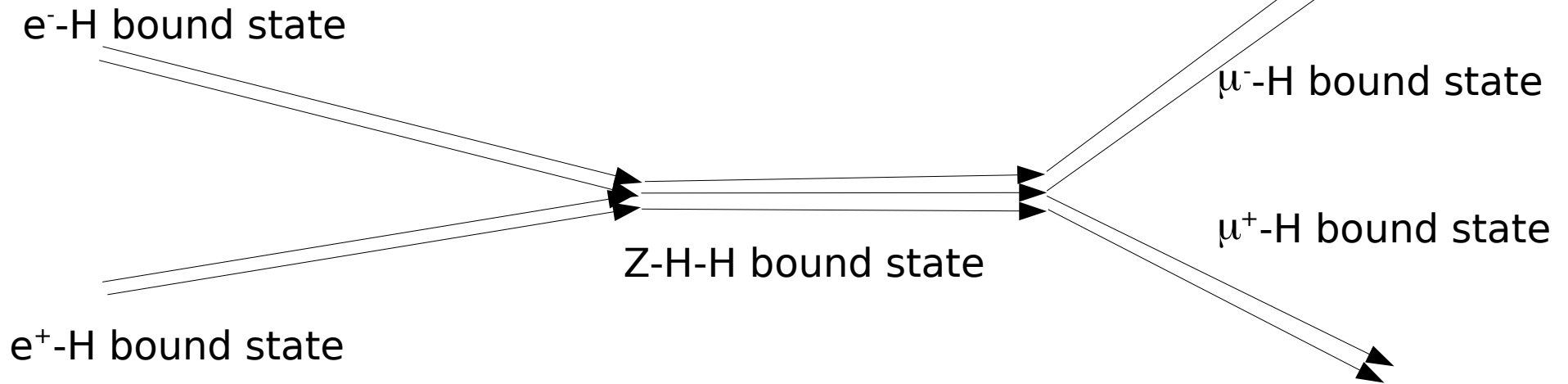
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- 750 GeV: excitation of the  $0^+$  state? – perhaps pure SM!

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Maas & Egger, unpublished]

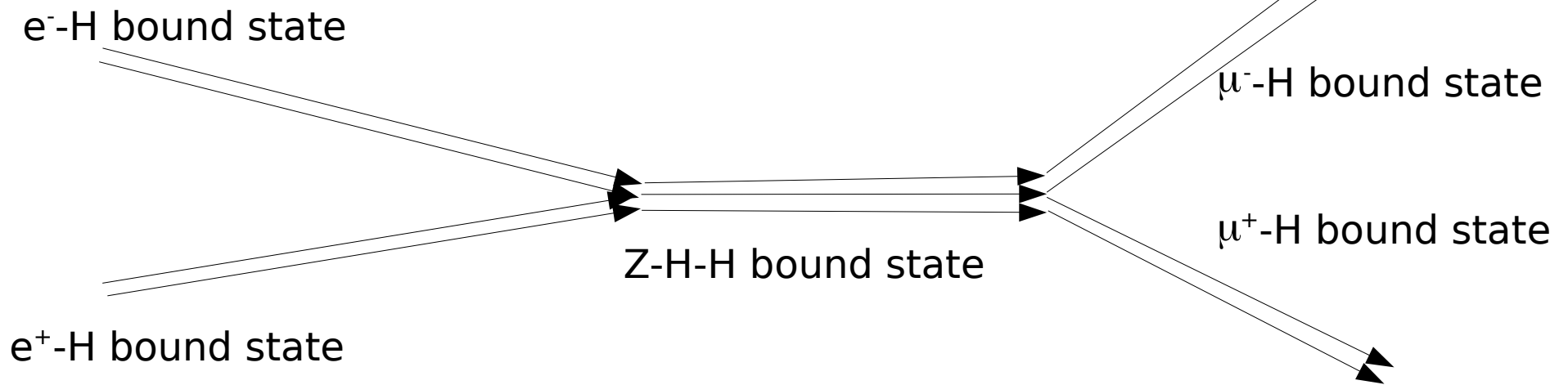


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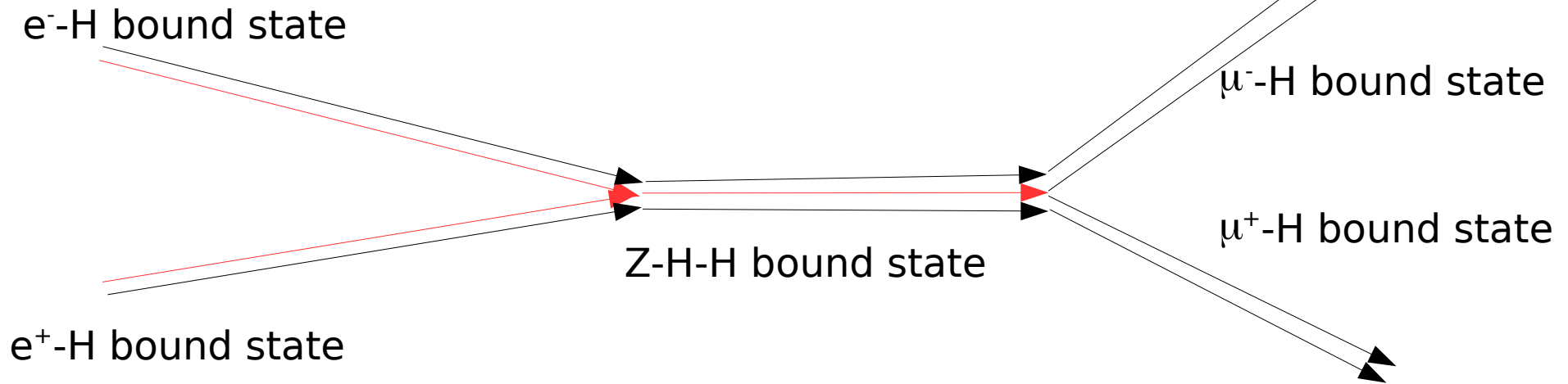
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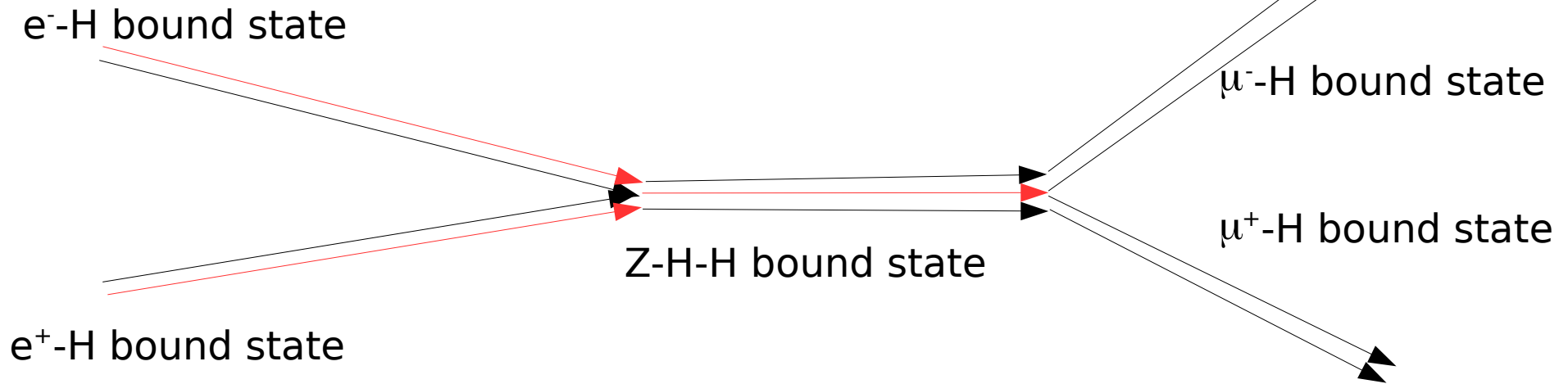
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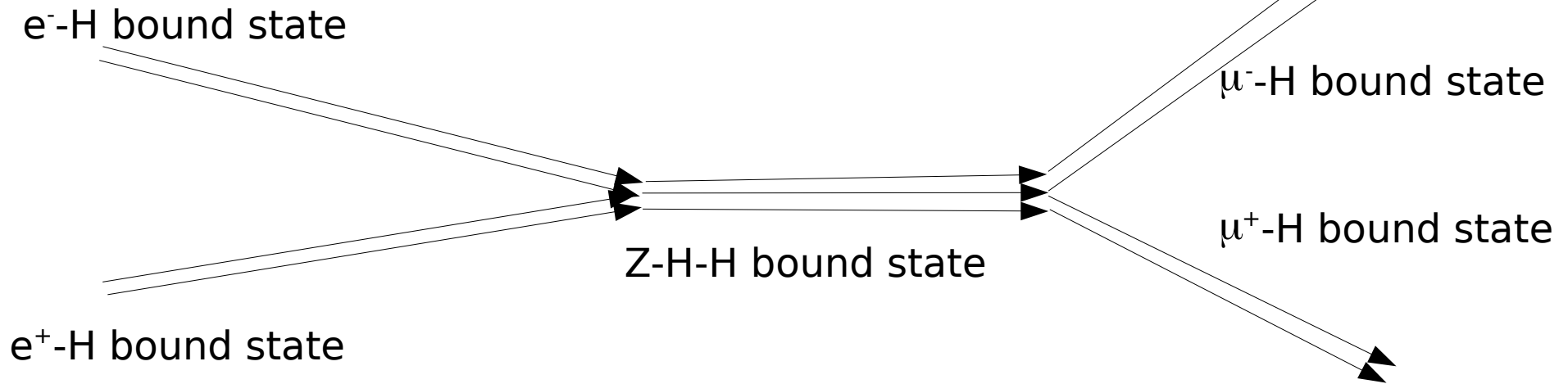
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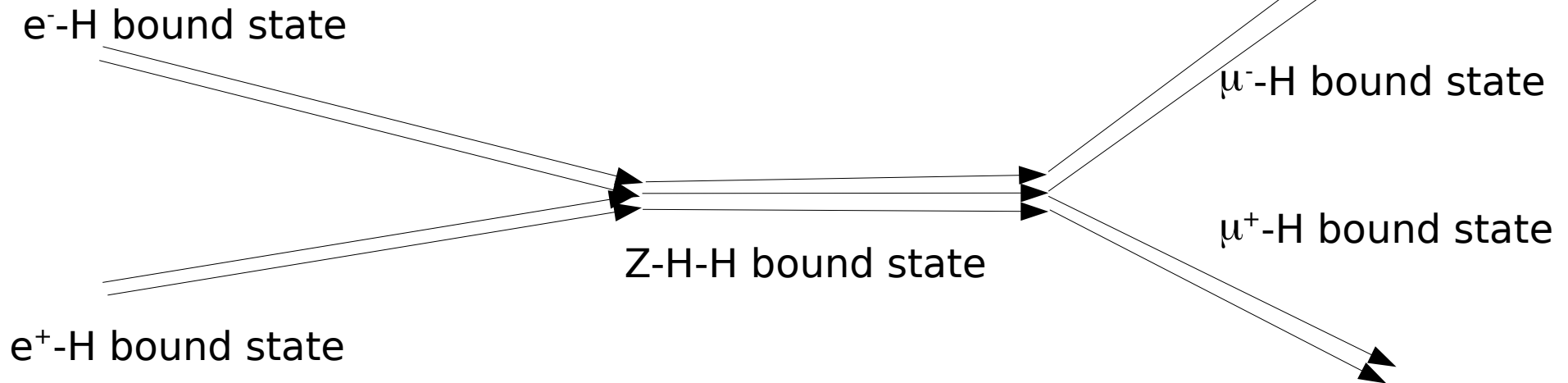
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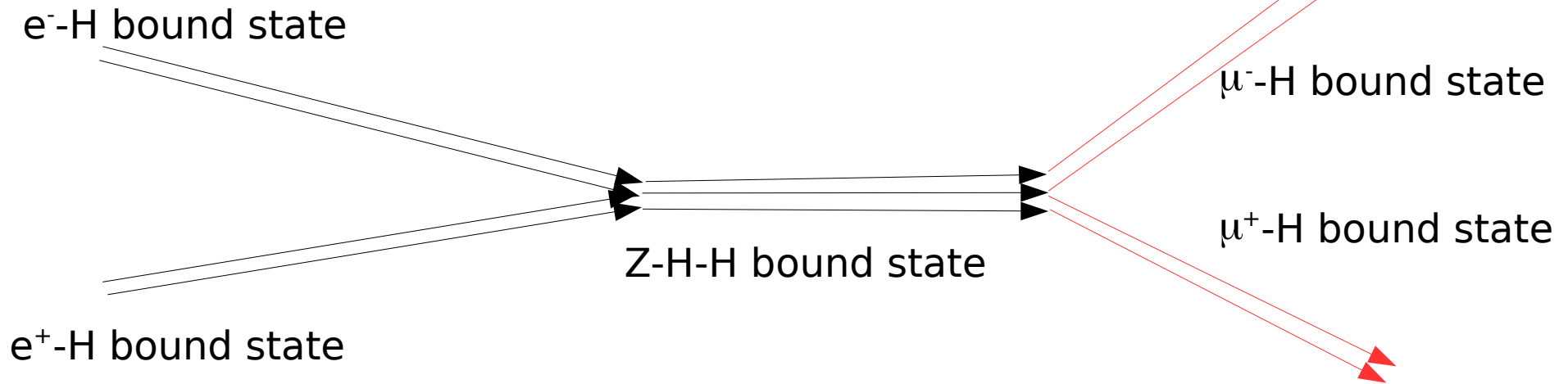
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- Fragmentation 100% efficient – like for quarks

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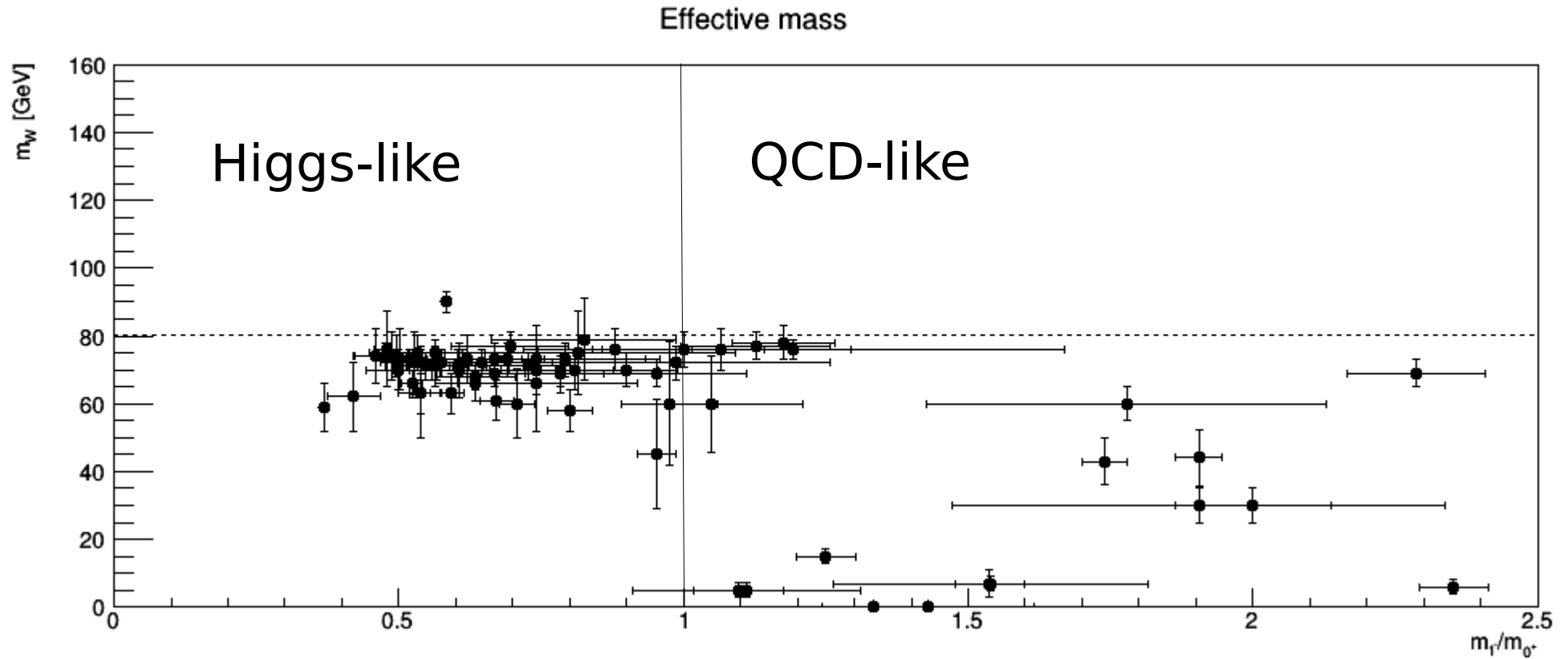
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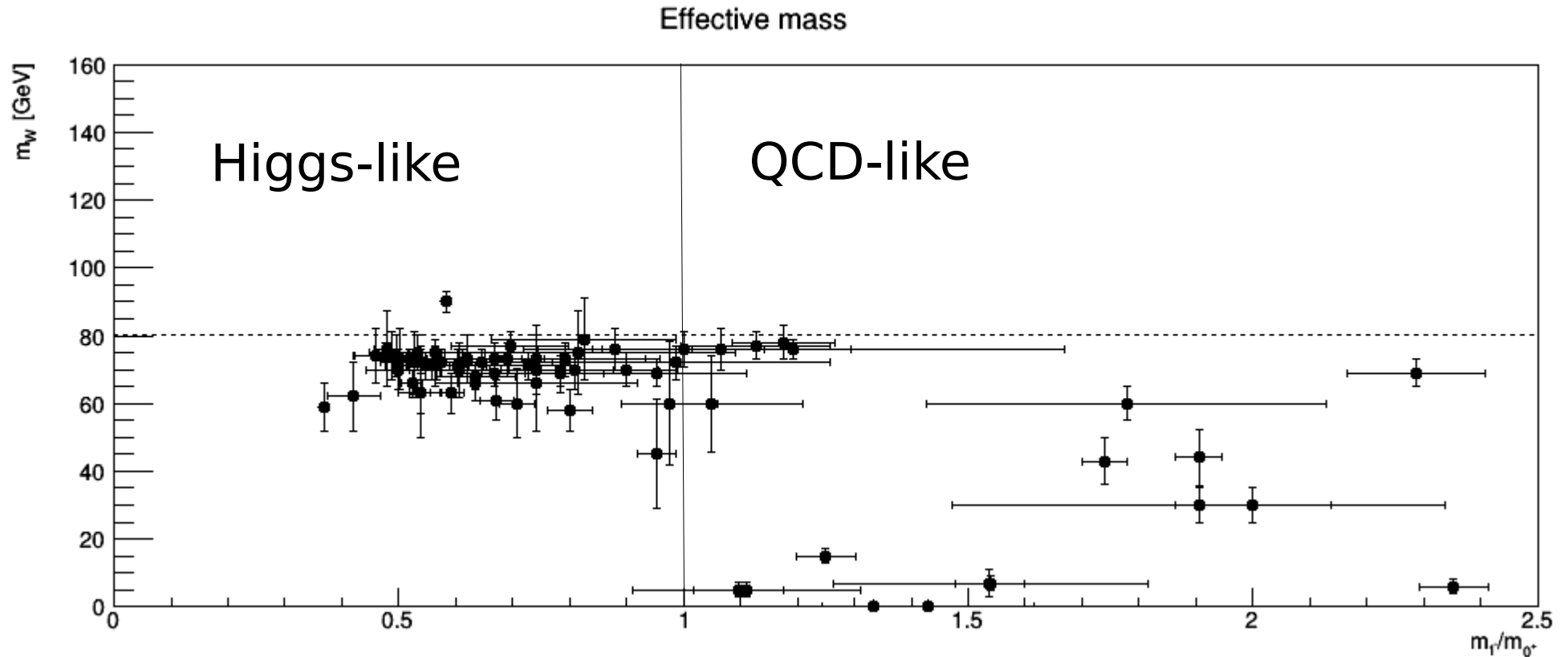
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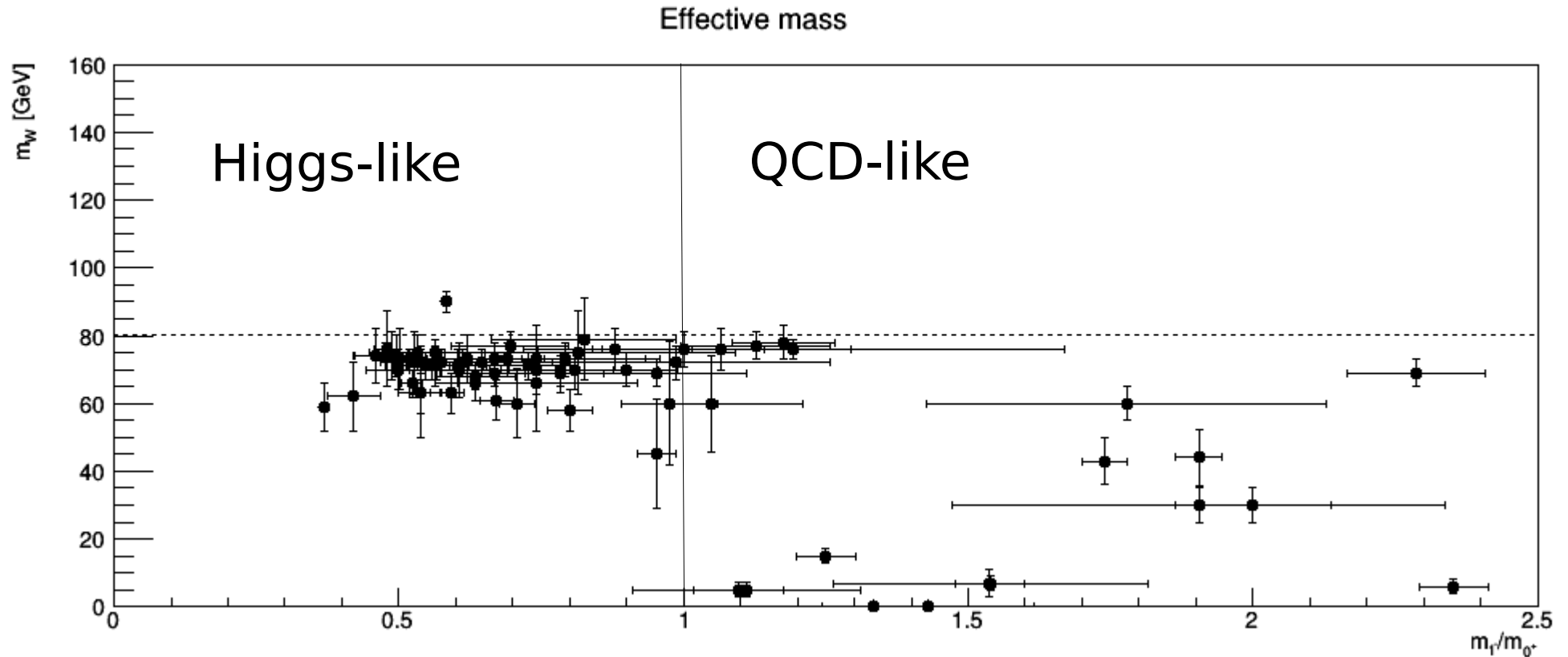
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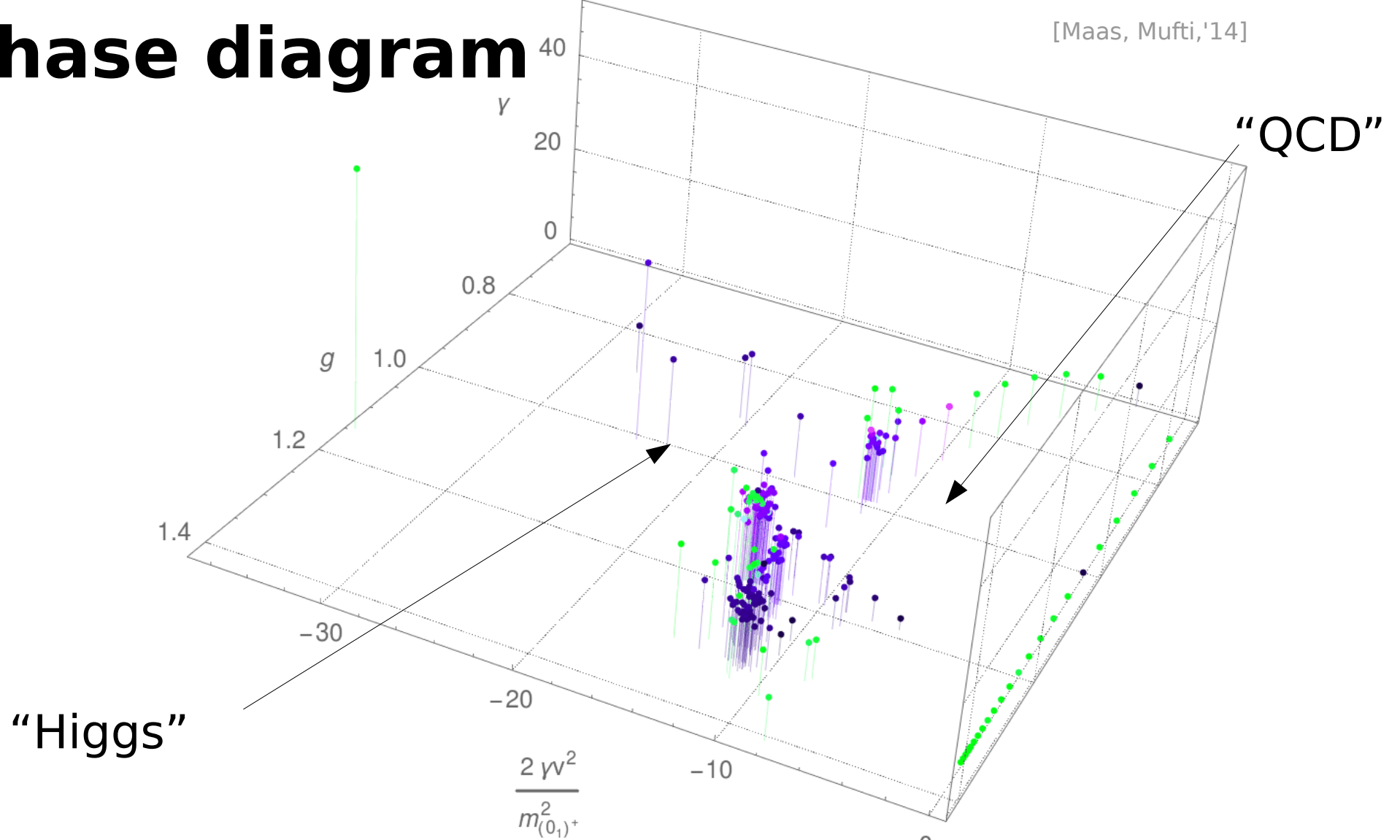
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- FMS mechanism works well throughout Higgs region
  - For scalar difficult if unstable

# Phase diagram

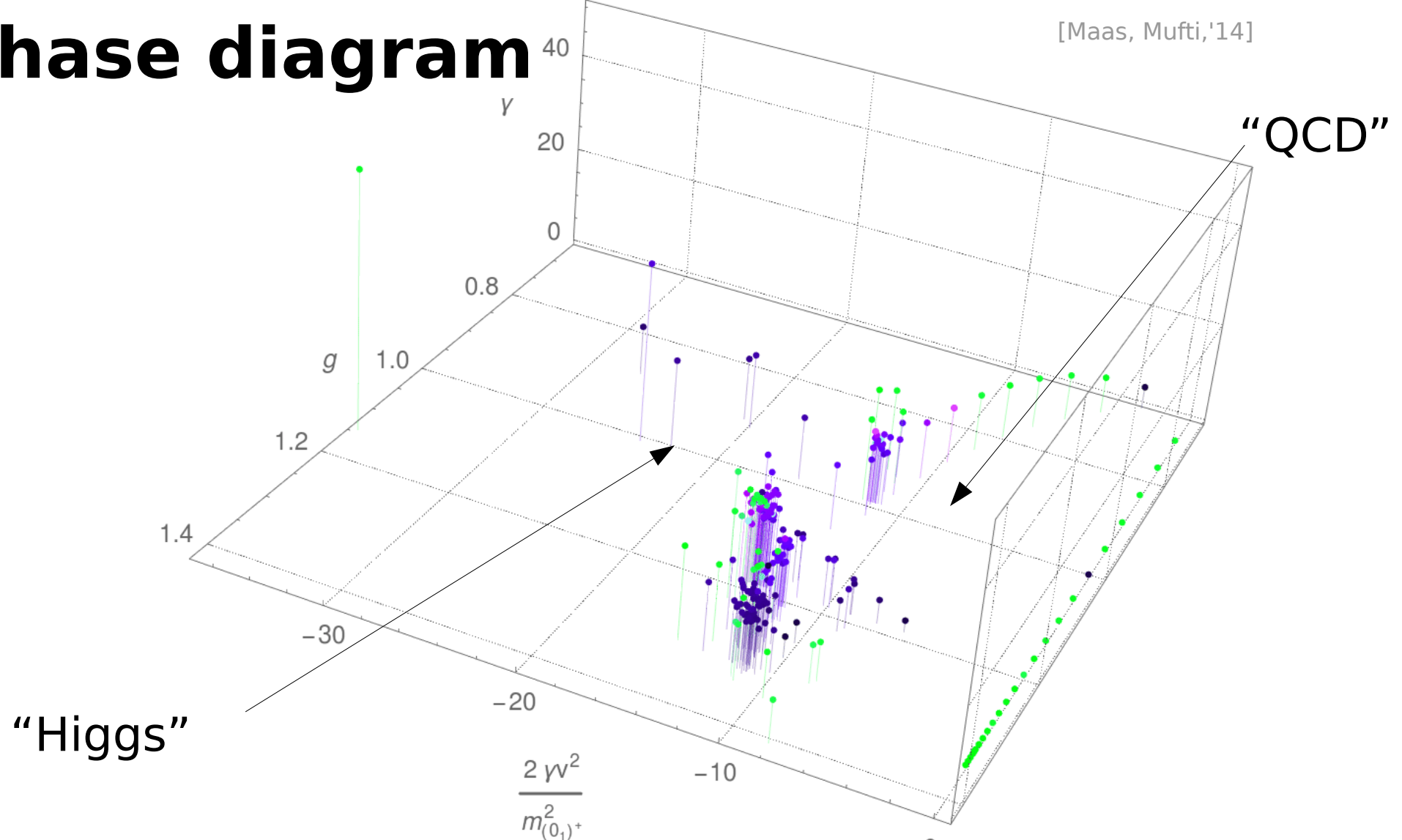
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- Contradiction to perturbation theory for some range?
  - No light Higgs, BEH effect suppressed at weak coupling

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- Has to be checked for BSM theories

# Implications for 2HDM

[Maas,'15,  
Maas & Pedro'16]

- Additional Higgs doublet
- Enlarged custodial group

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- Validity: Requires non-perturbative check

- Discrete factor groups could yield doubling



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# Implications for GUTs

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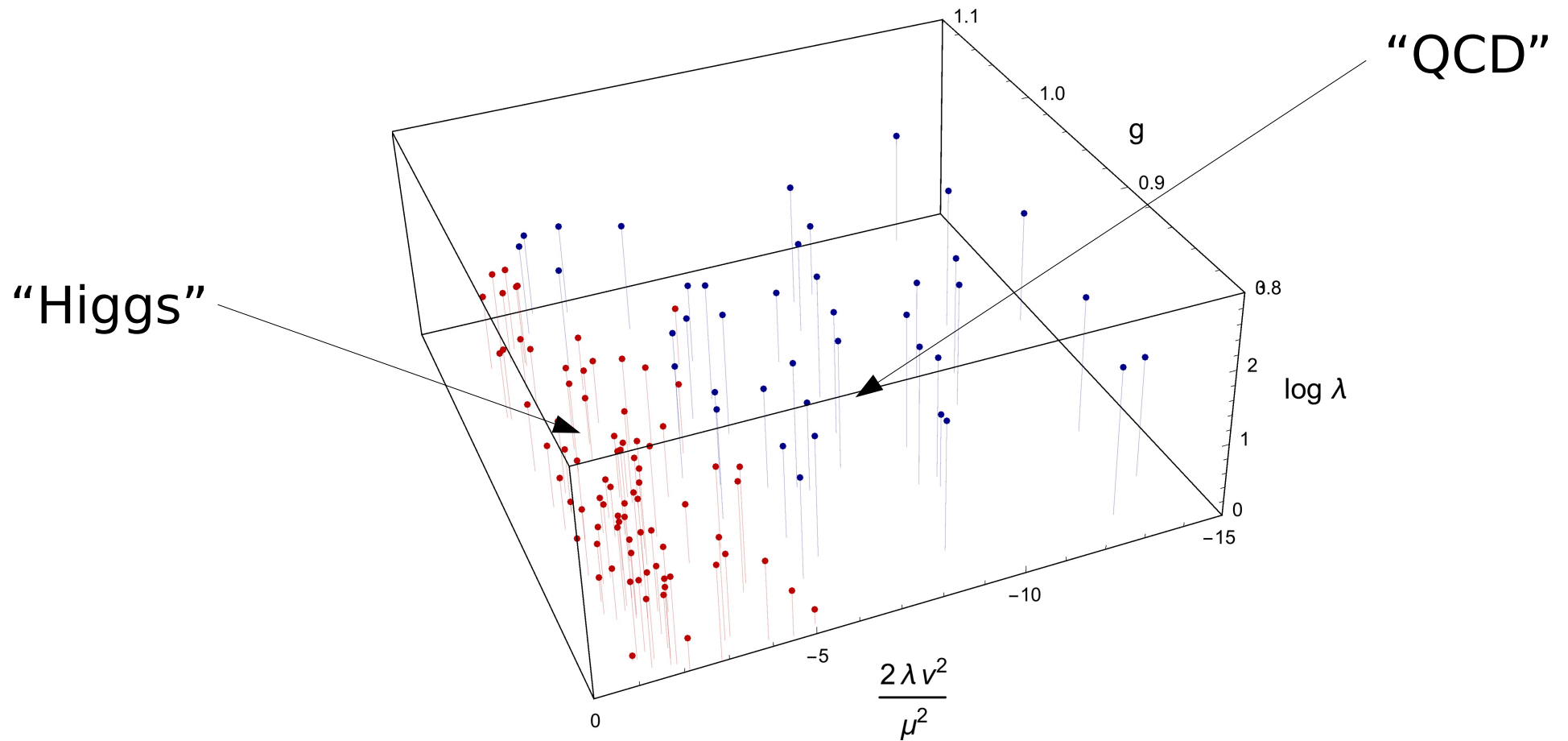
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  - ...or something else?

# Test for GUTs

[Maas, '15, Toerek & Maas '15  
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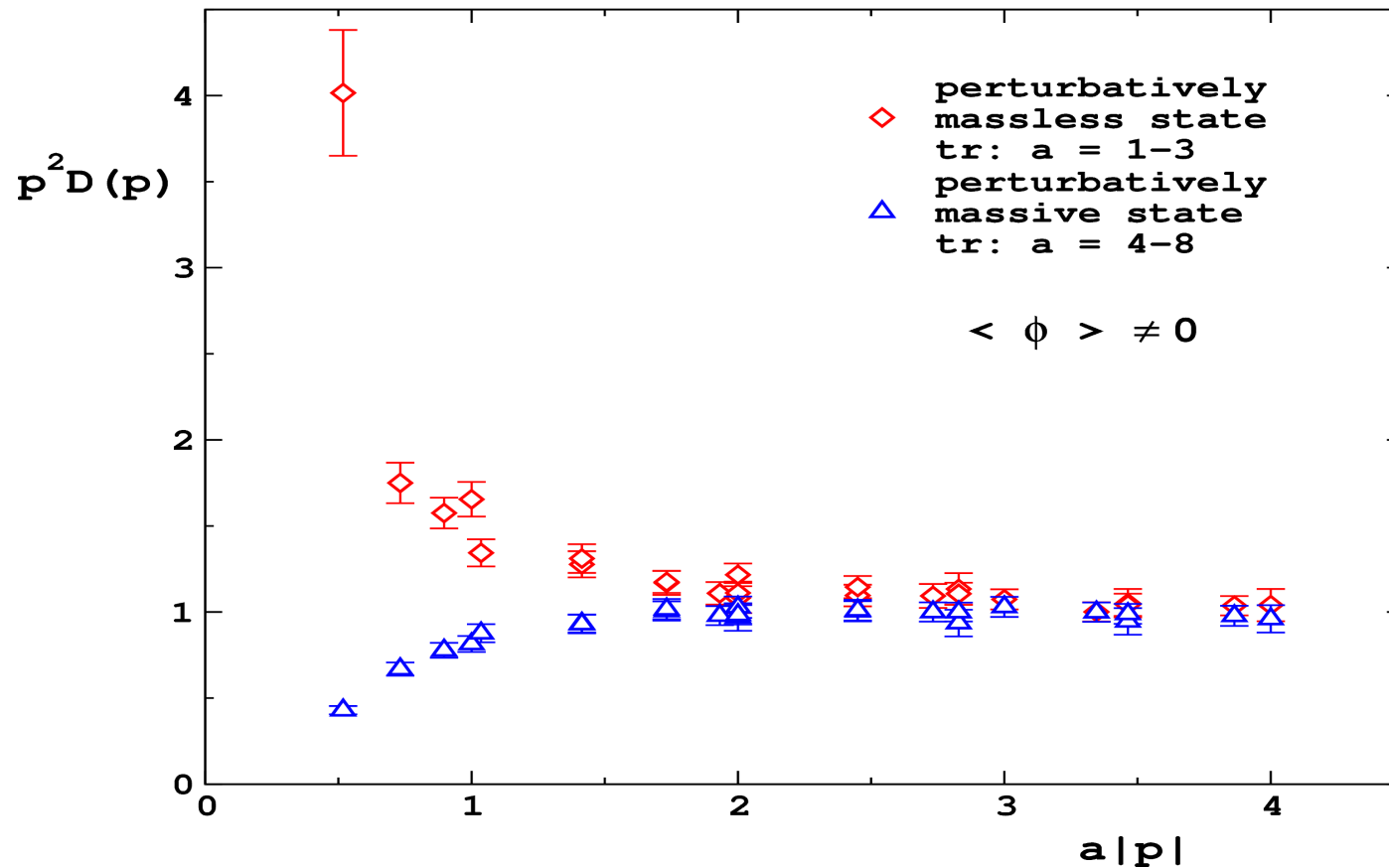
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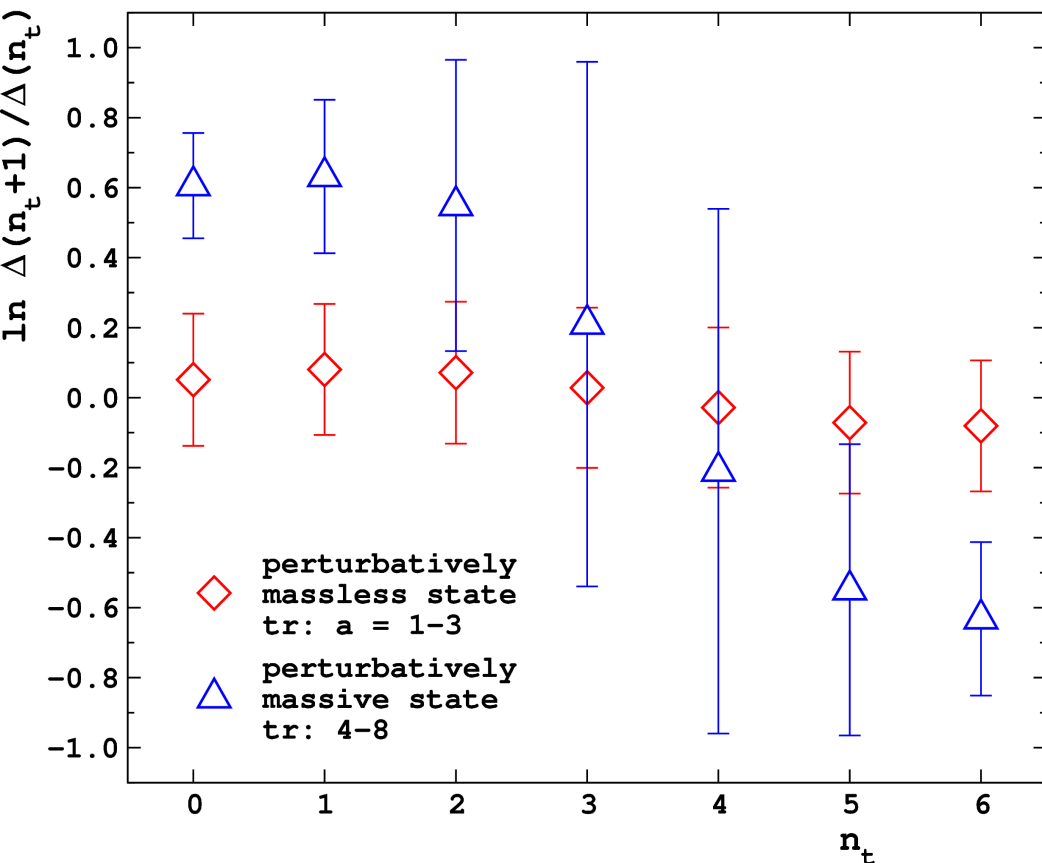


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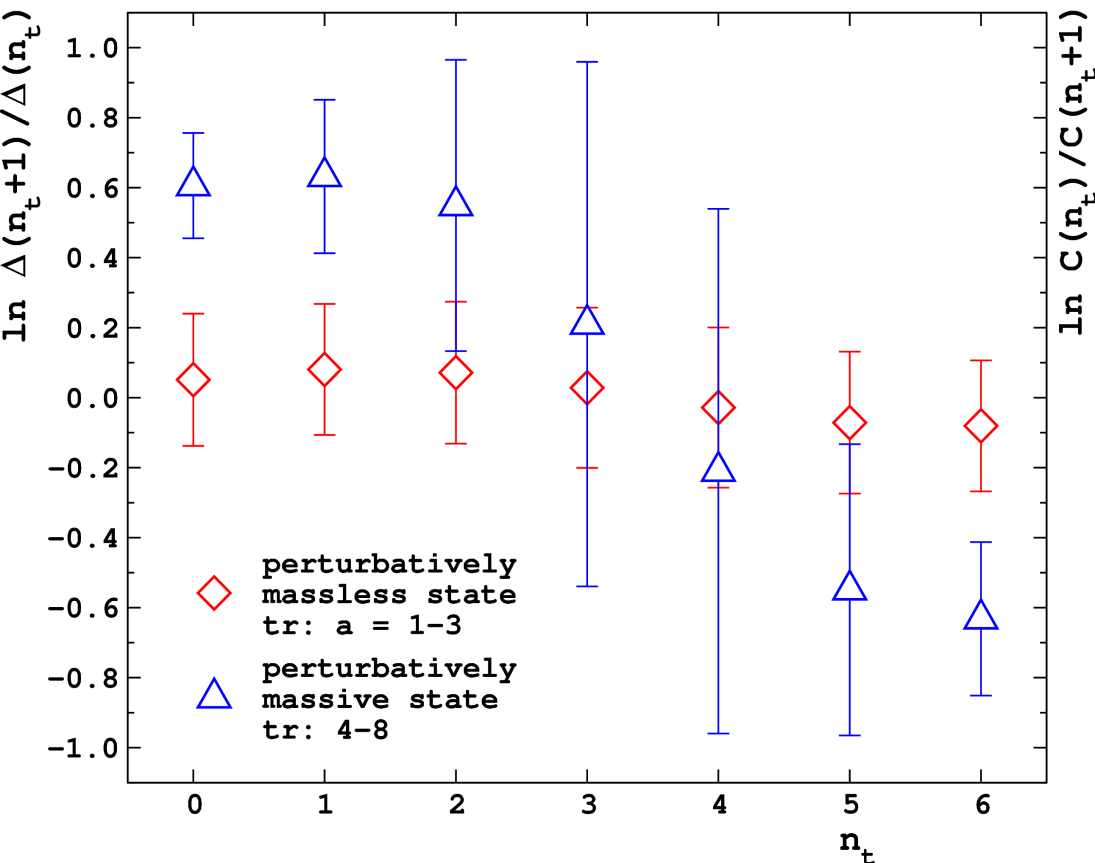


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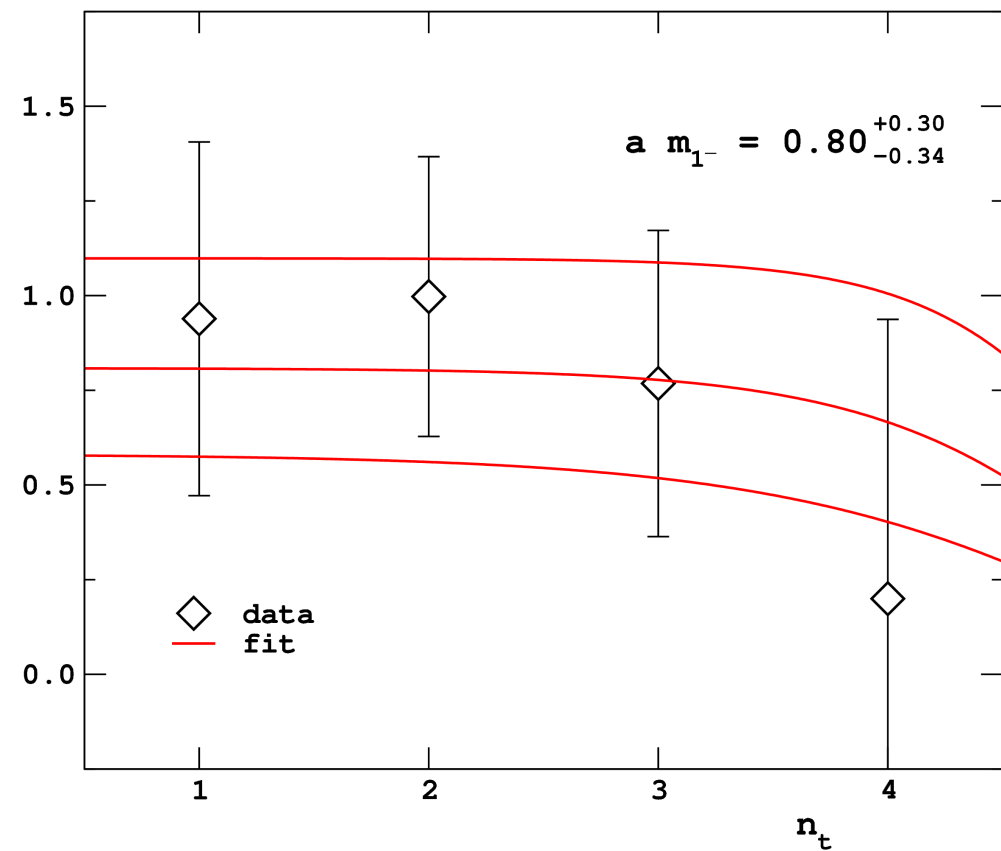
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- No hint of massless physical state (yet?)
  - Check of FMS prediction requires more statistics

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- Observable states must still be gauge-invariant
  - Needs to create Higgs and W/Z(!) signals by (new) bound states
  - Vectors must be lighter
    - Behavior not yet seen for strong interactions
    - Usually: Scalars and pseudoscalars

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- Applicable to beyond-the standard model
  - Structural requirement: Multiplets must match
  - Dynamical requirement: Small fluctuations
  - Verification requires non-perturbative methods
- Can be used to test theories
  - Check for low-mass states
- Theories without BEH effect challenging

55<sup>th</sup> International Winter School on Theoretical Physics

## Bound States and Resonances

13<sup>th</sup>-17<sup>th</sup> of February 2017

Lecturers include C. Fischer, "LHCb", C. Pica, S. Prelovsek, A. Szczepaniak

Admont, Styria, Austria

St. Goar 2017

## Bound States in QCD and Beyond II

20<sup>th</sup>-23<sup>rd</sup> of February 2017

St. Goar, Germany

Official Announcements coming soon!