Experimental signatures of subtelties in the Brout-Englert-Higgs mechanism

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Moriond 23
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UNI GRAZ

NAWI Graz Natural Sciences

FWF Der Wissenschaftsfonds.

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The puzzle

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- 1970[ies]/1980[ies]: Field theory of BEH effect
  - Electroweak symmetry breaking is not a physical effect
    - Special form of gauge-fixing
  - Confinement and BEH effect are qualitatively the same

Review: 1712.04721

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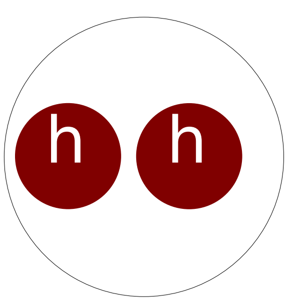

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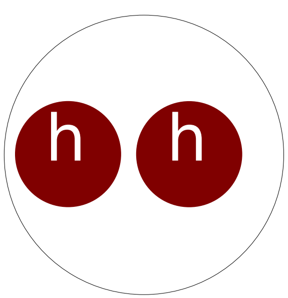

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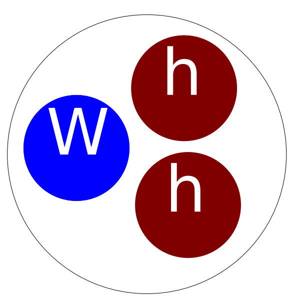

W

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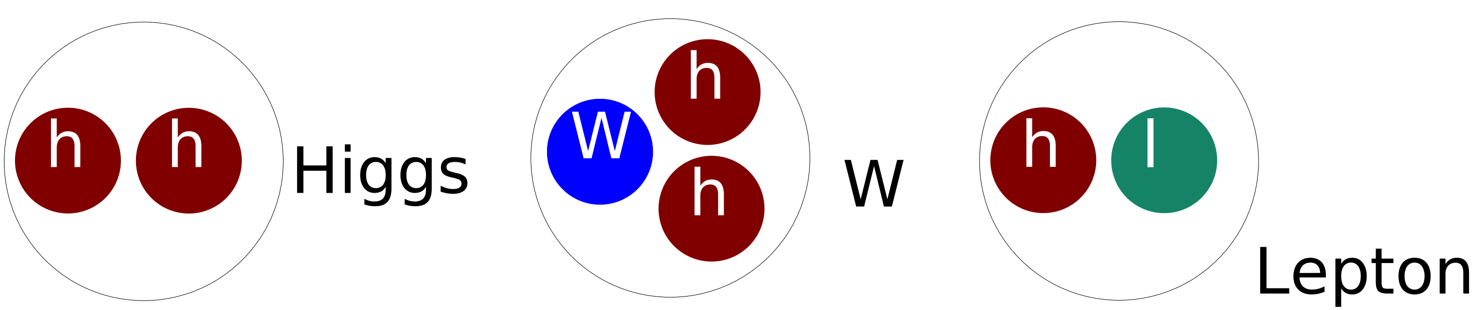

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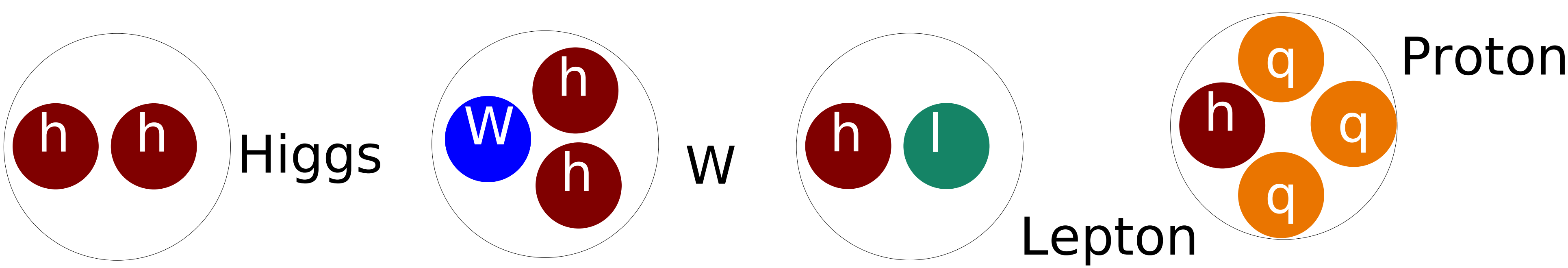

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    - Augments perturbation theory
        - Composite asymptotic states
        - Additional expansion in the Higgs vev

Augmented perturbation theory

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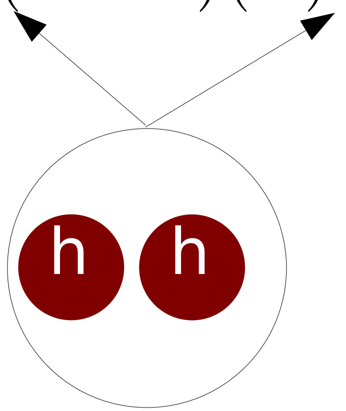

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Trivial two-particle state

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  - Compressed mass scales
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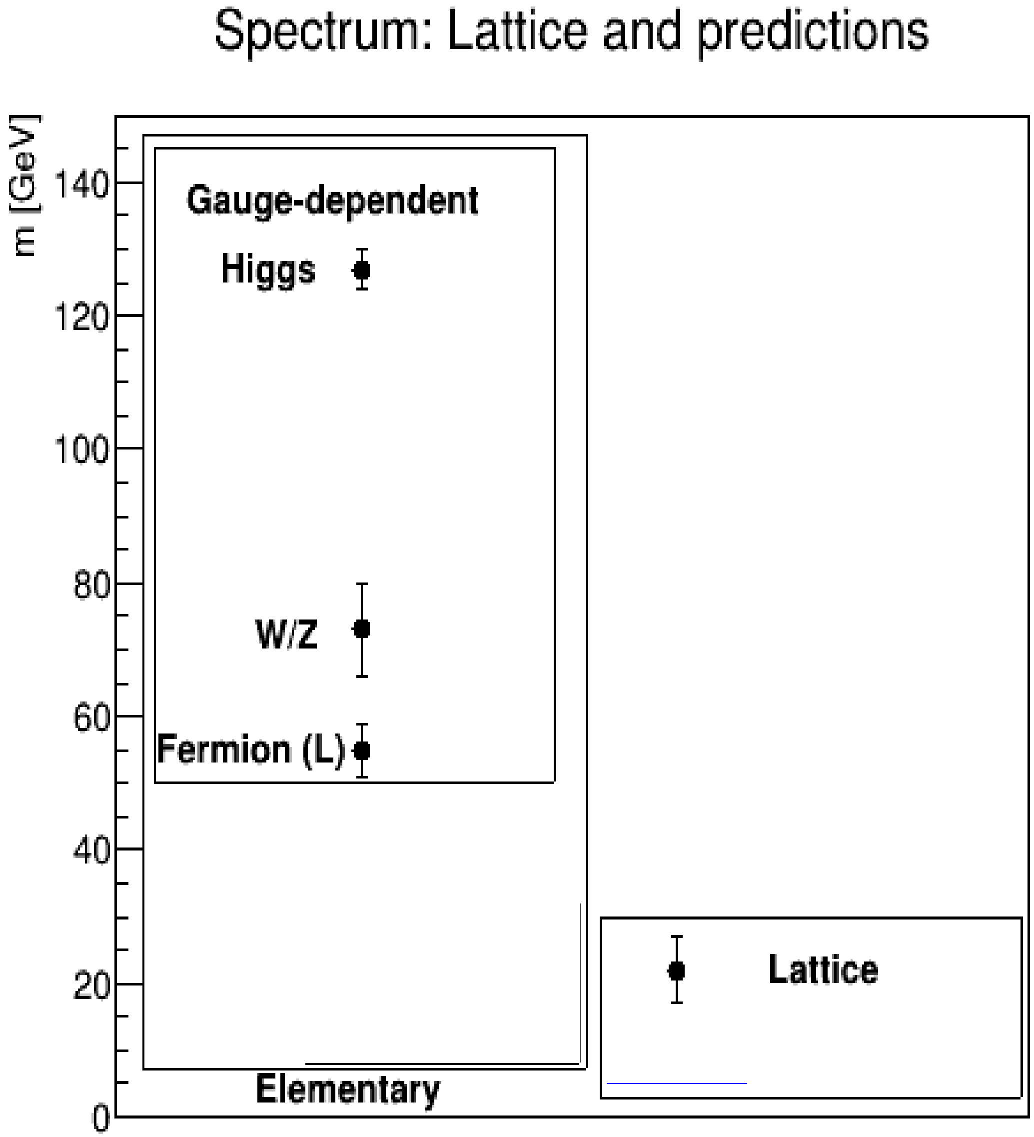

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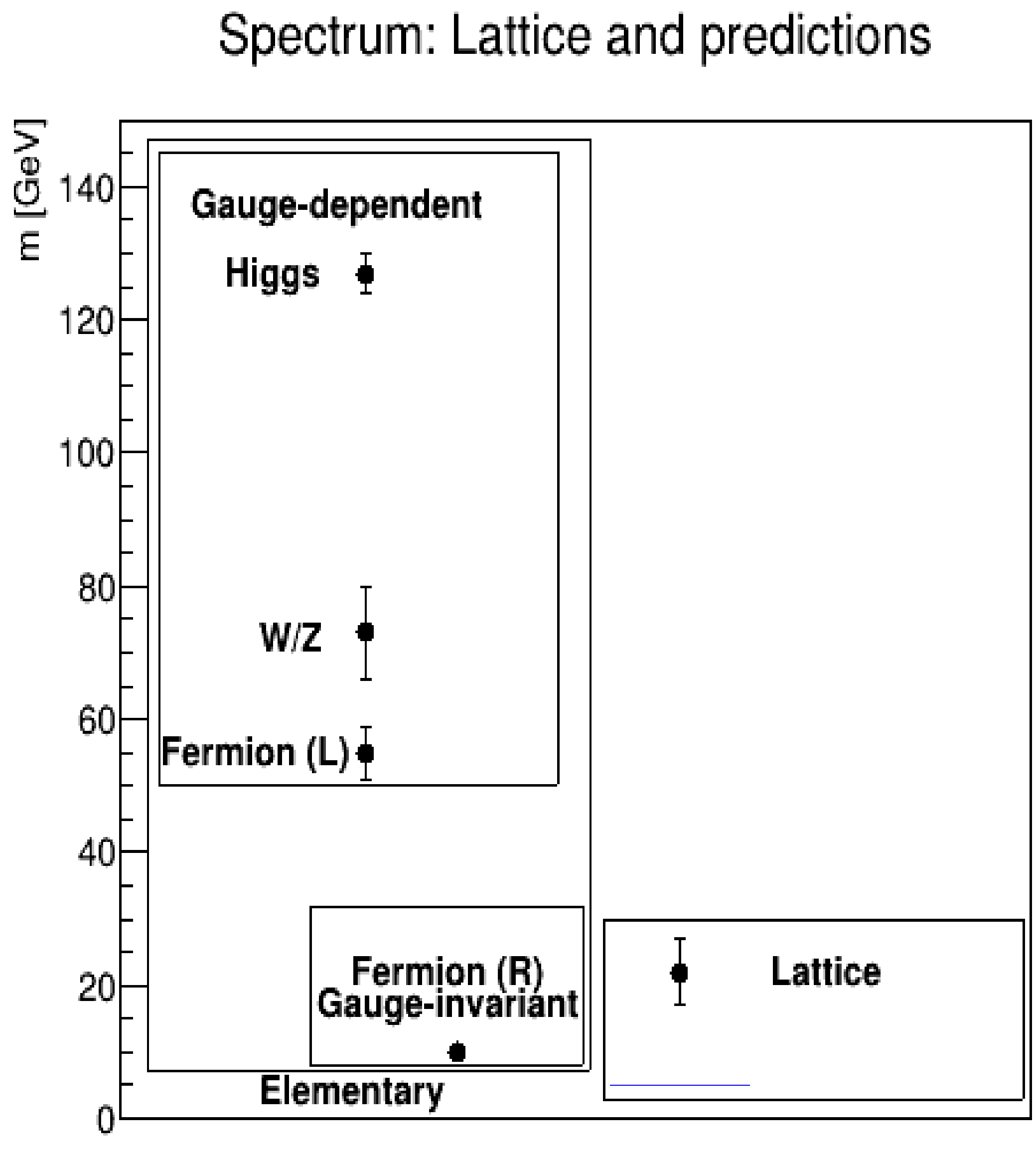

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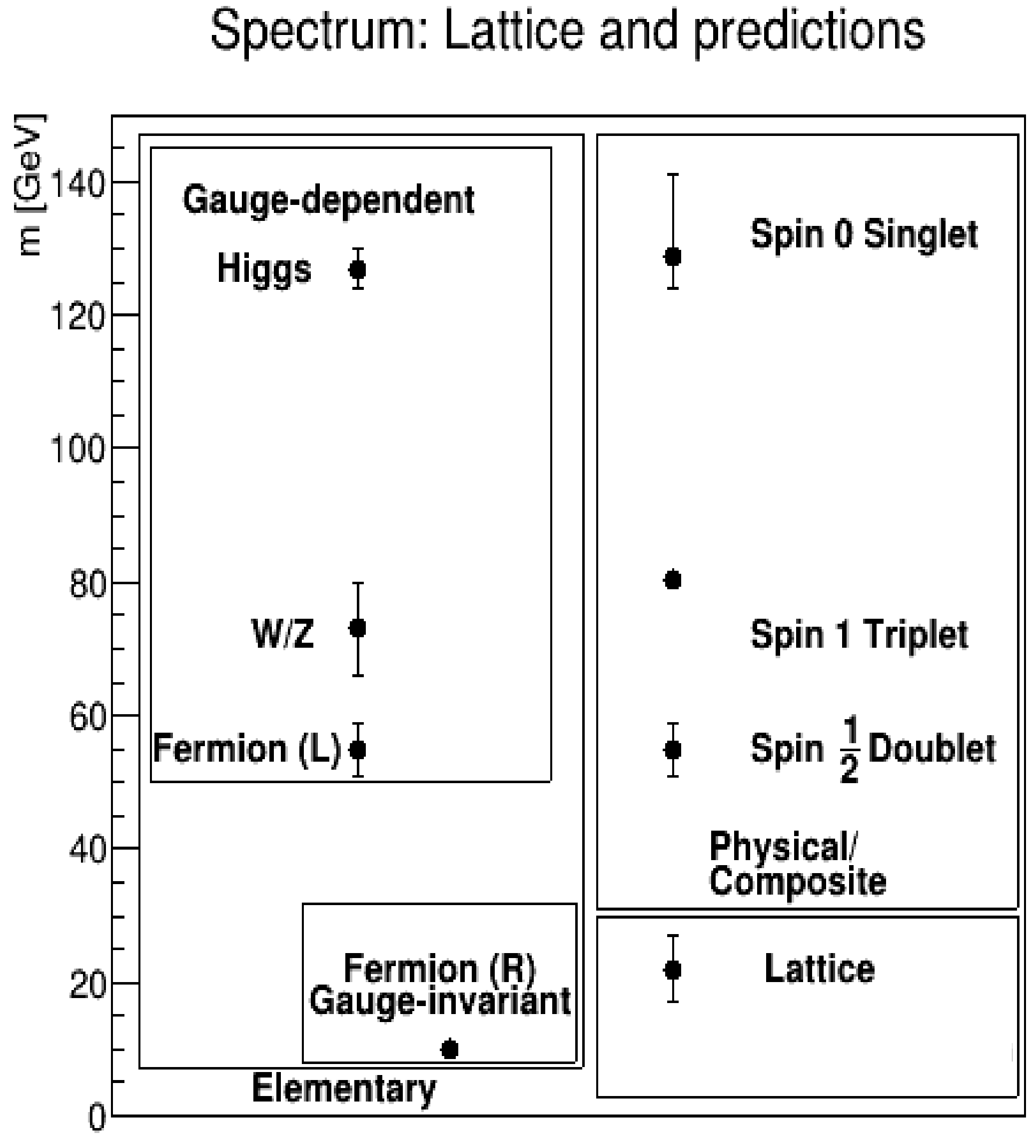

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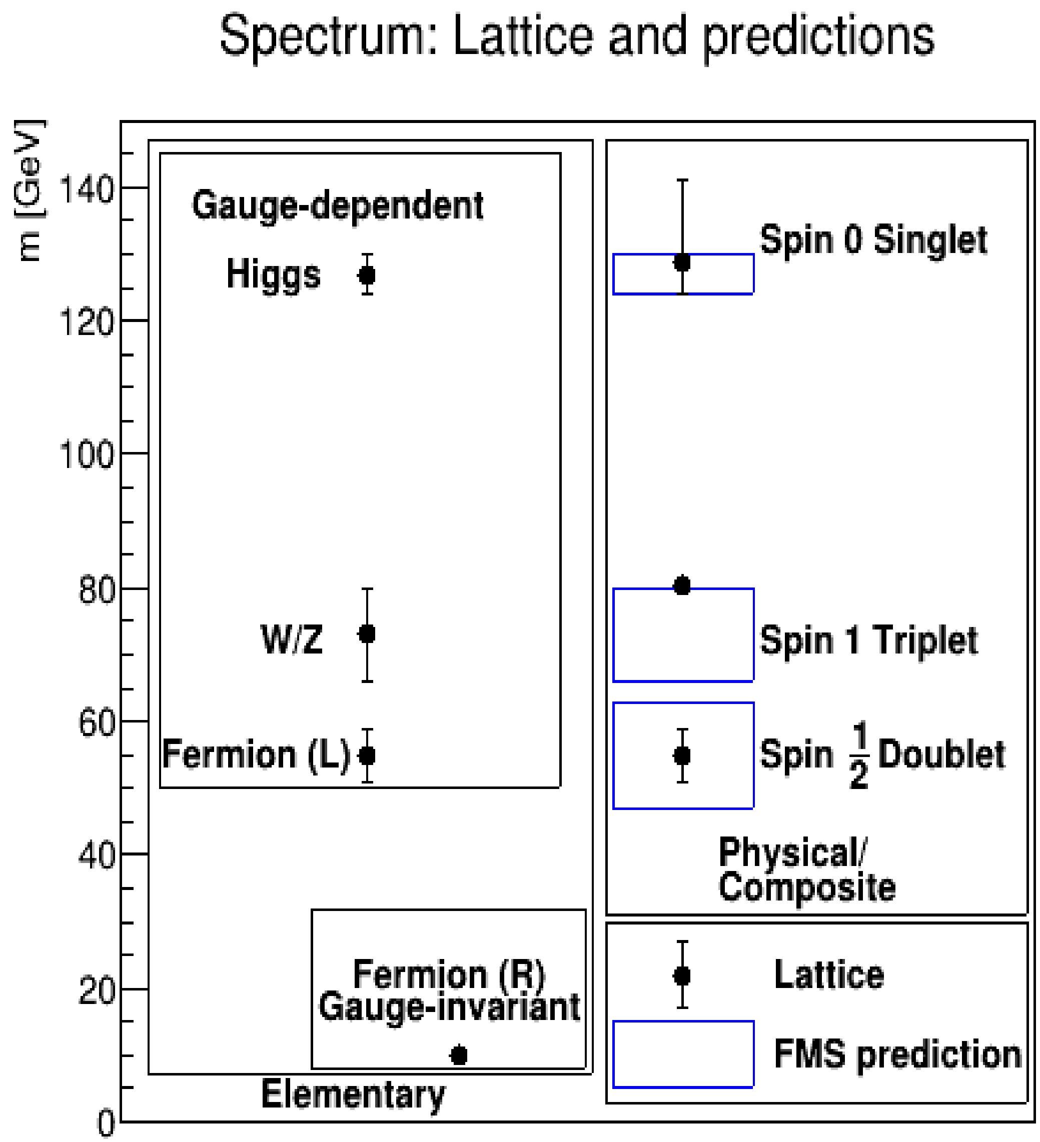
- Supports augmented perturbation theory



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What about this?

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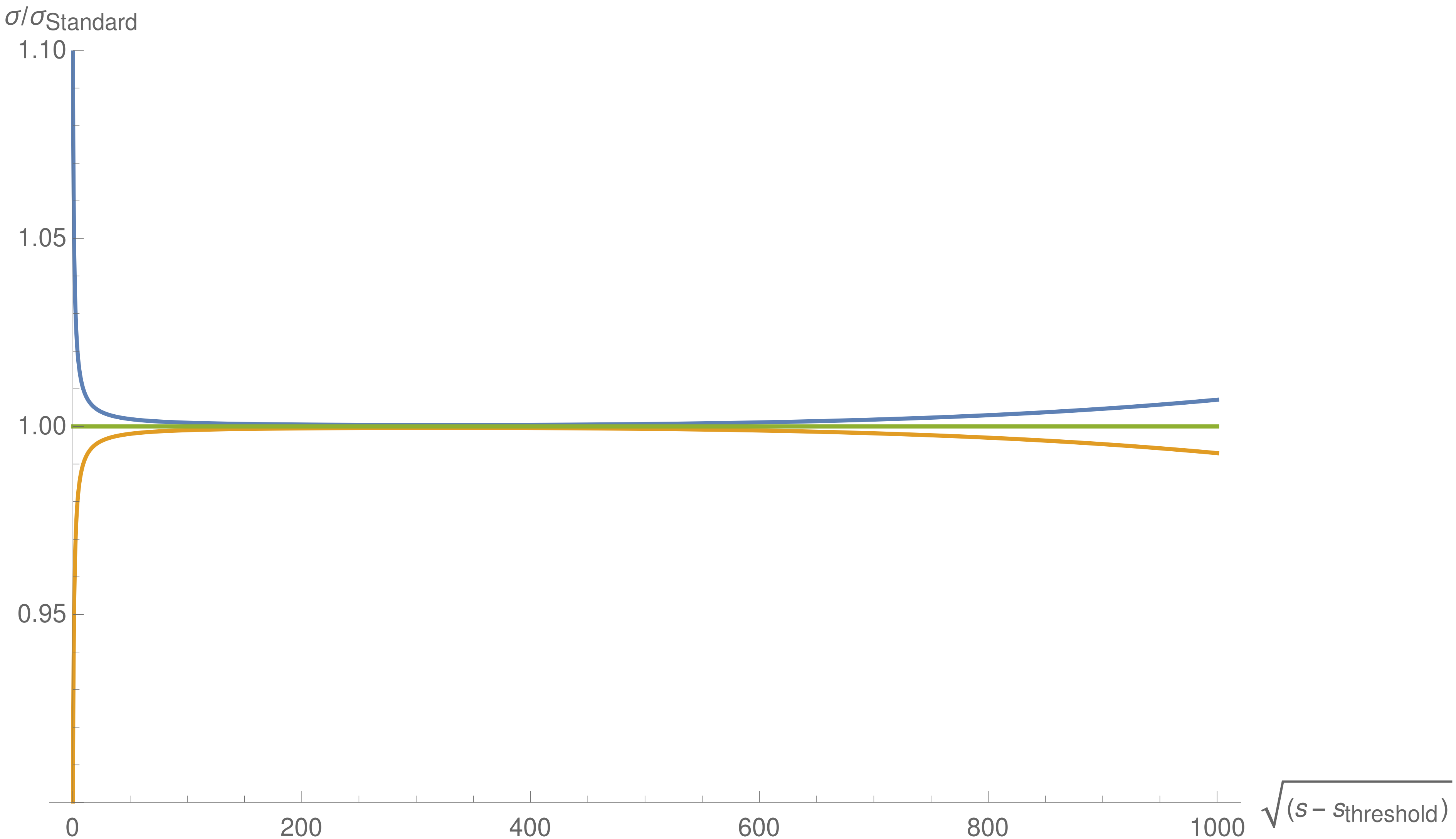

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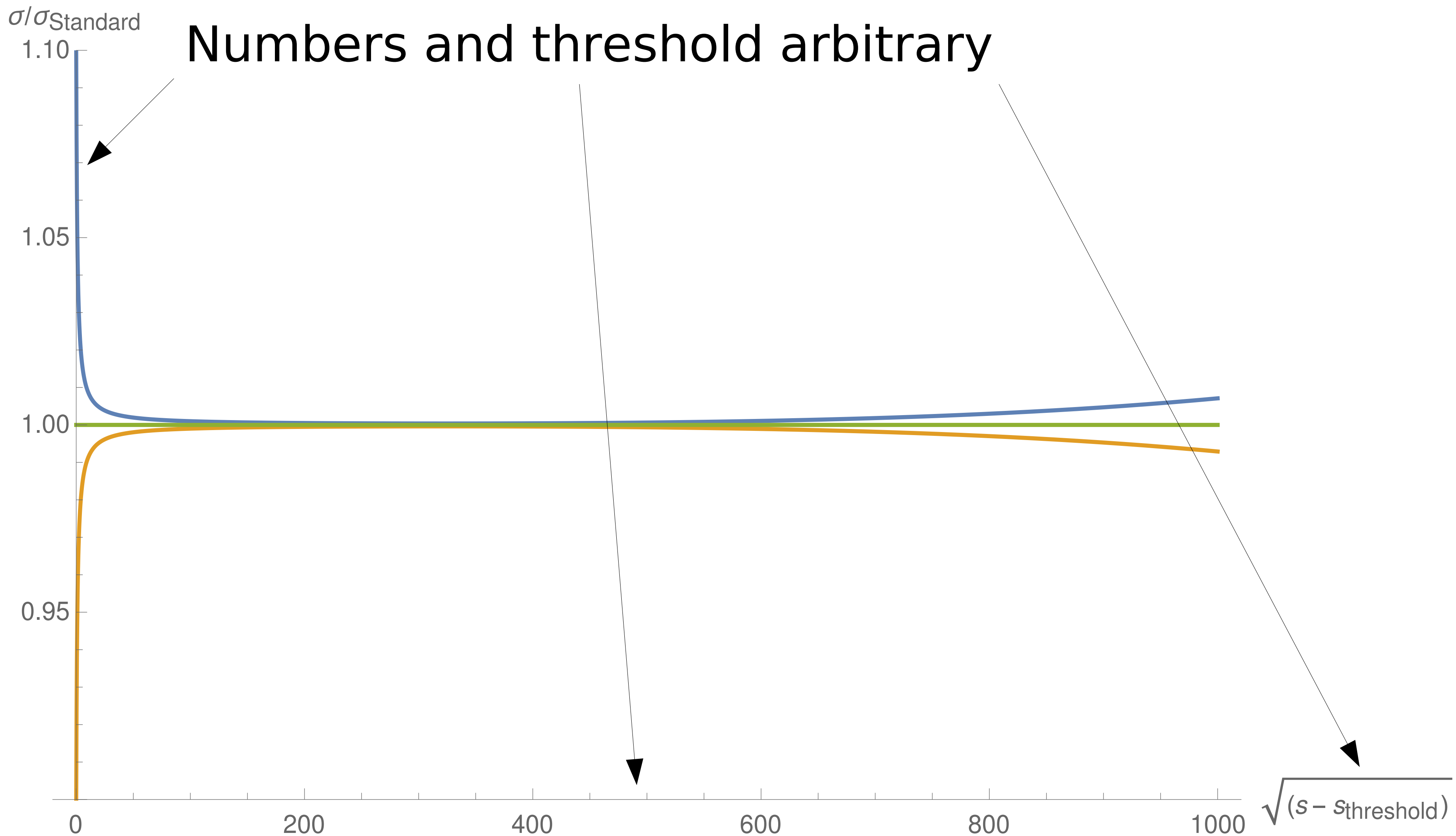

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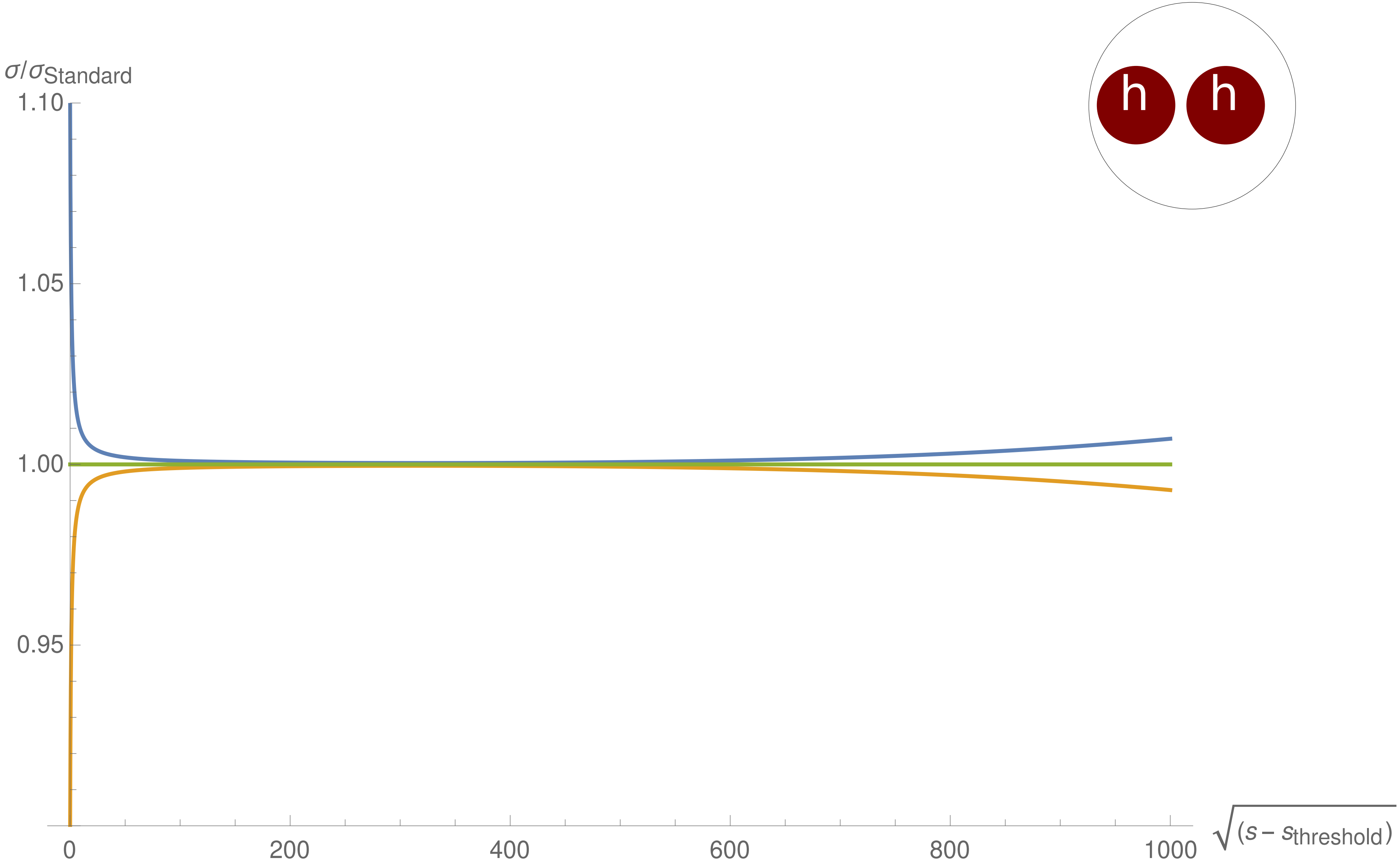

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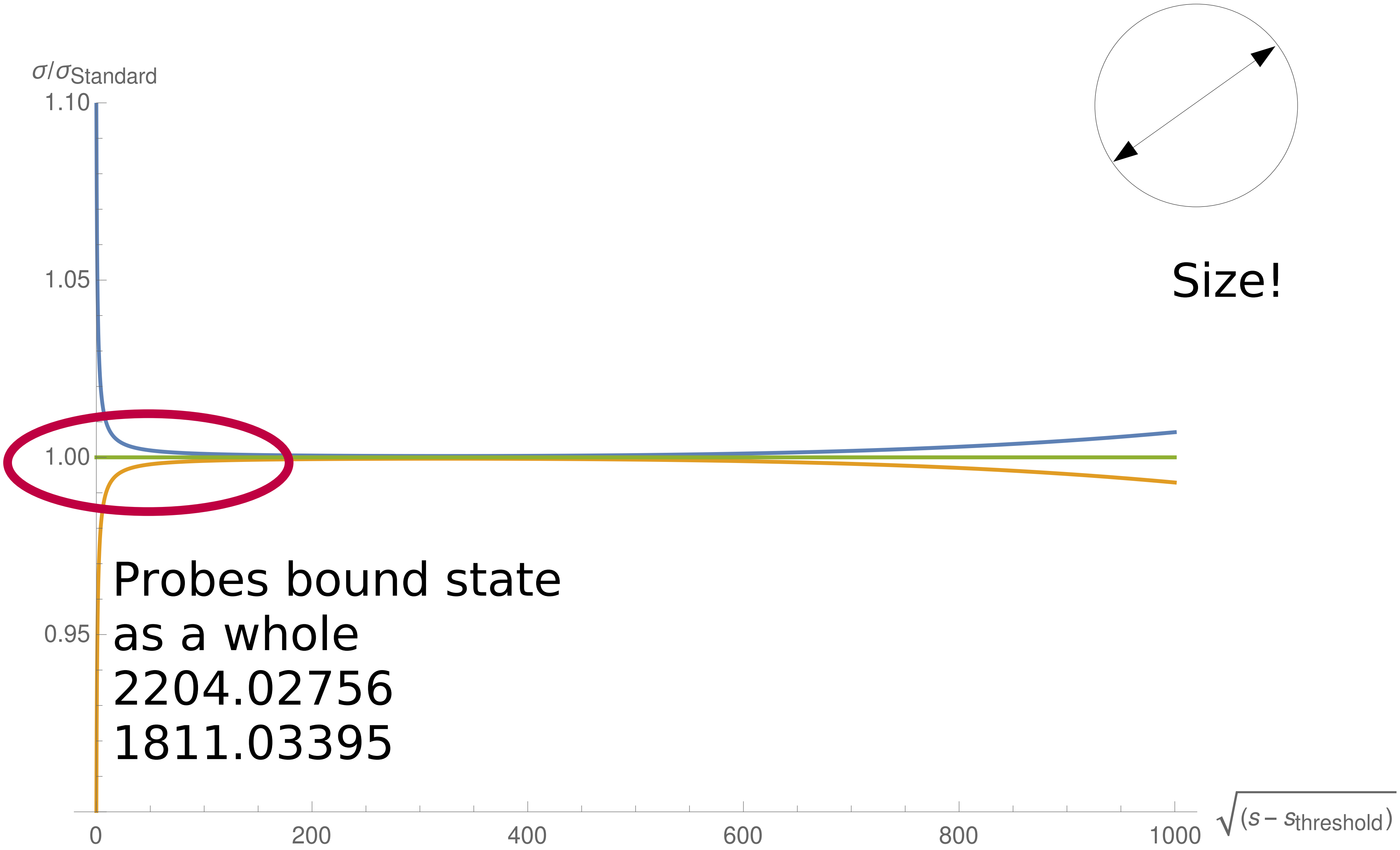

Probes bound state
as a whole
2204.02756
1811.03395

Size!

Radius from elastic scattering in VBS

- Elastic region: $160/180\,GeV \leqslant \sqrt{s} \leqslant 250\,GeV$
  - *s* is the CMS energy in the initial/final ZZ/WW system

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Matrix element

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Partial wave amplitude

Legendre polynom

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Partial wave amplitude

Phase shift

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Scattering length~"size"

Phase shift

Impact of the radius of the Higgs

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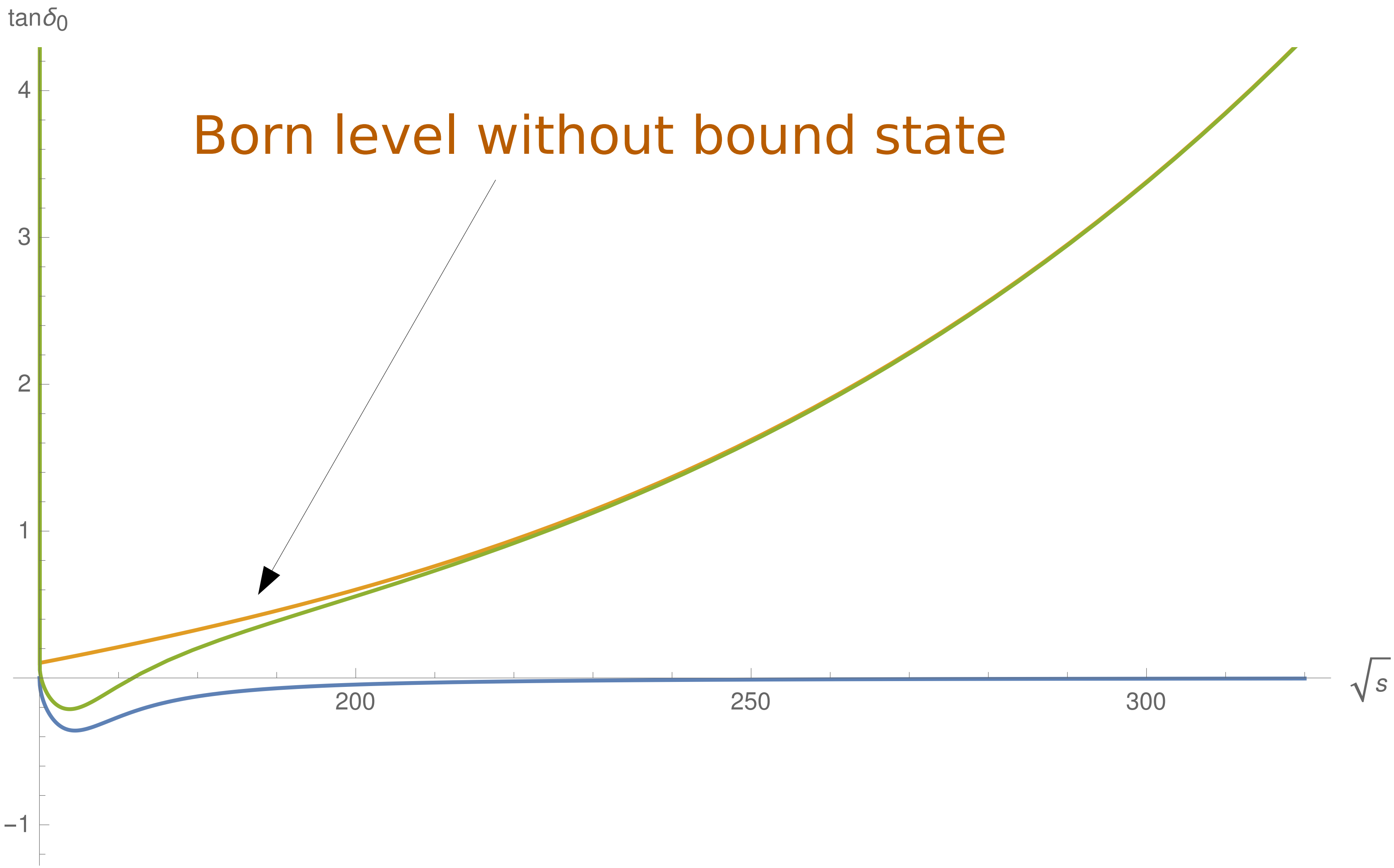
Impact of the radius of the Higgs



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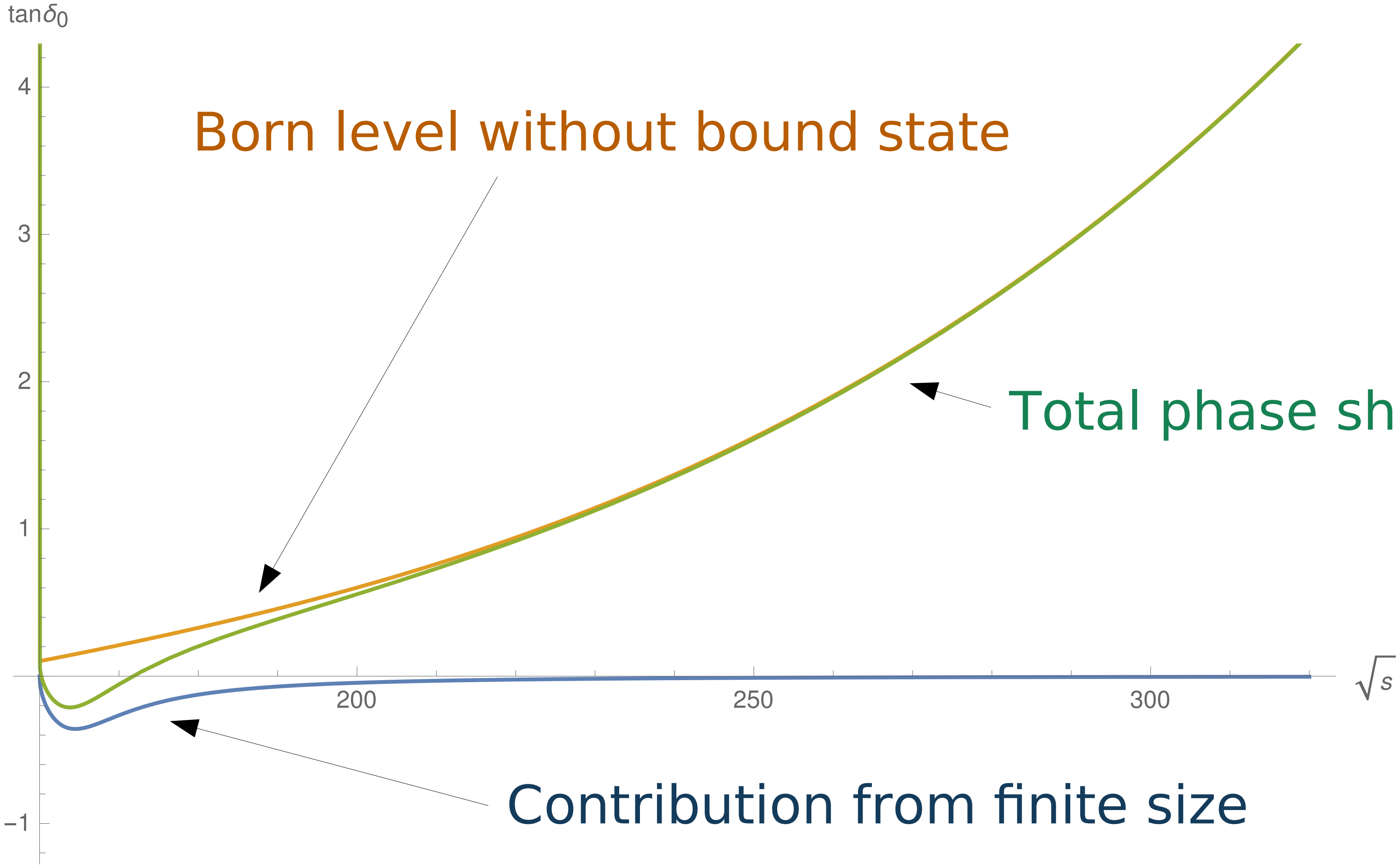

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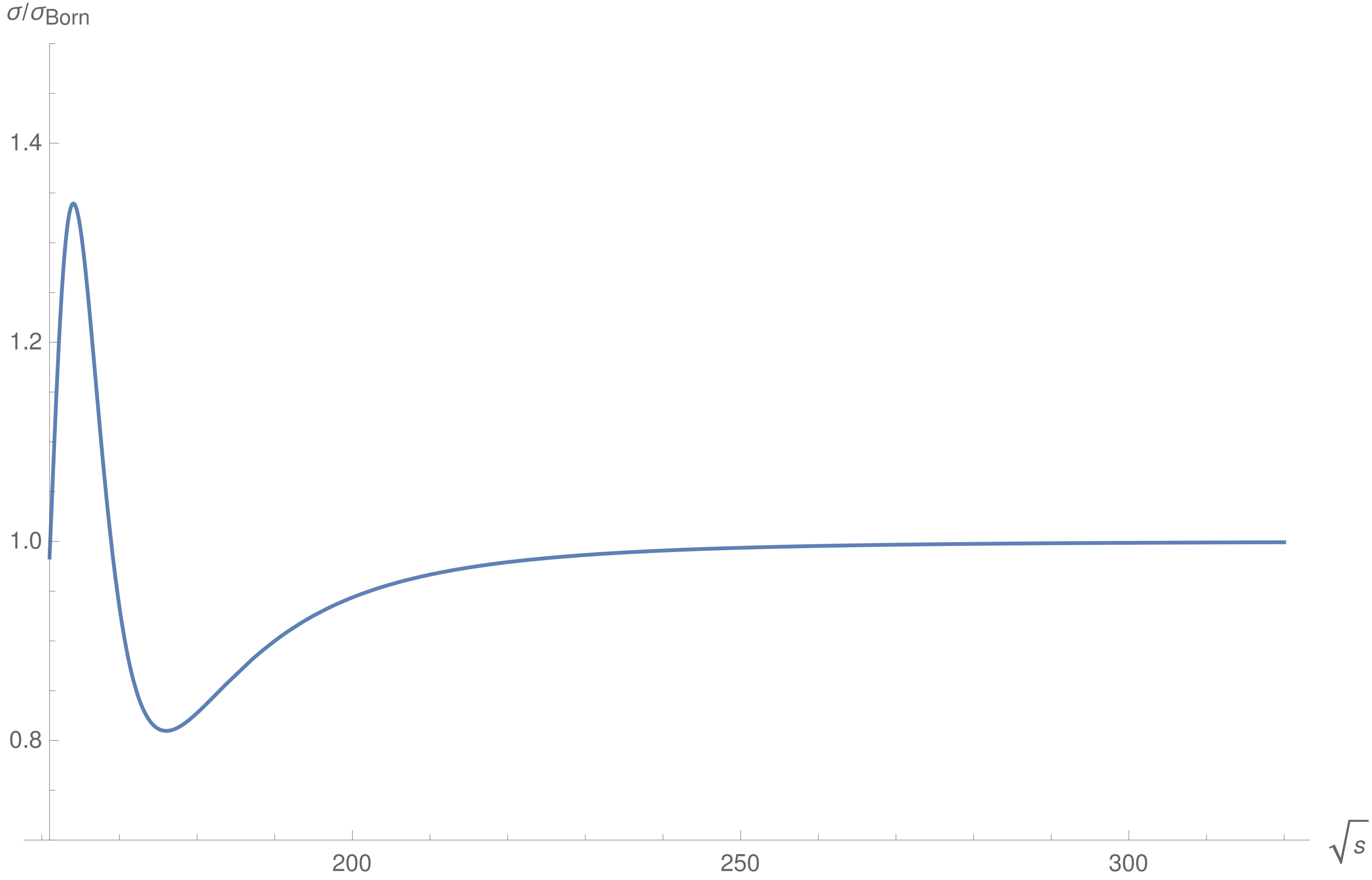

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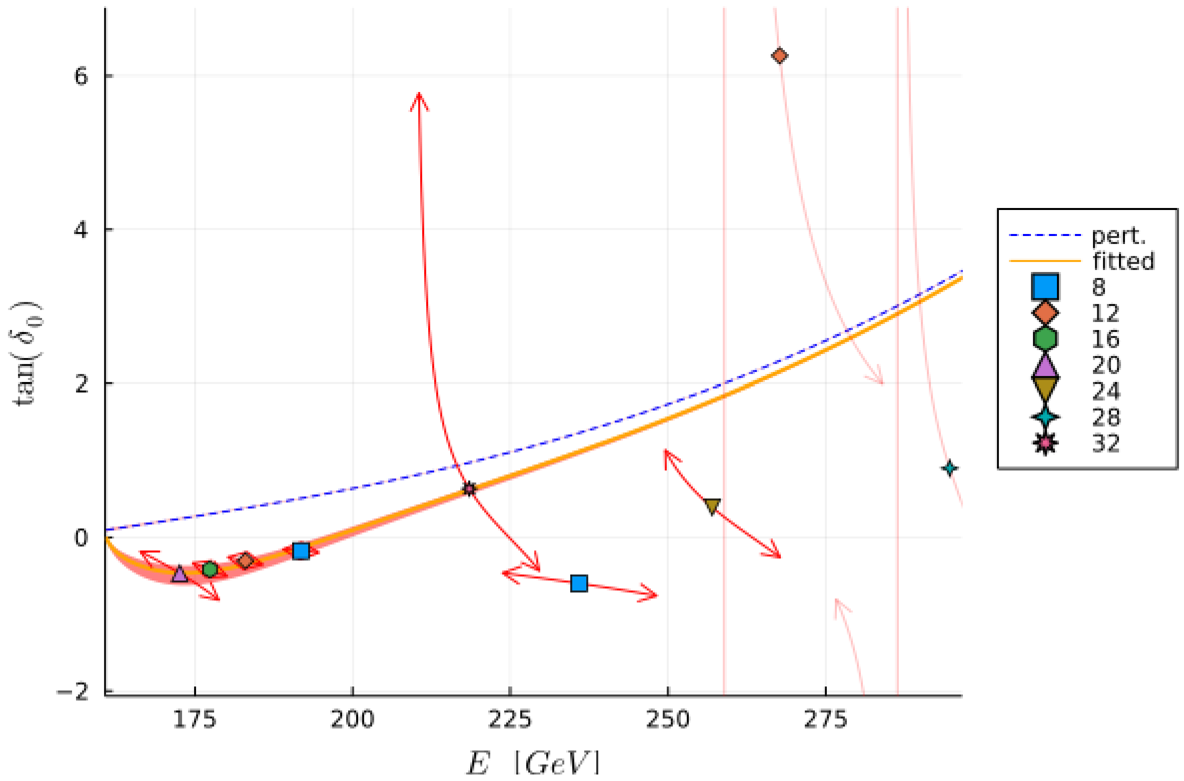

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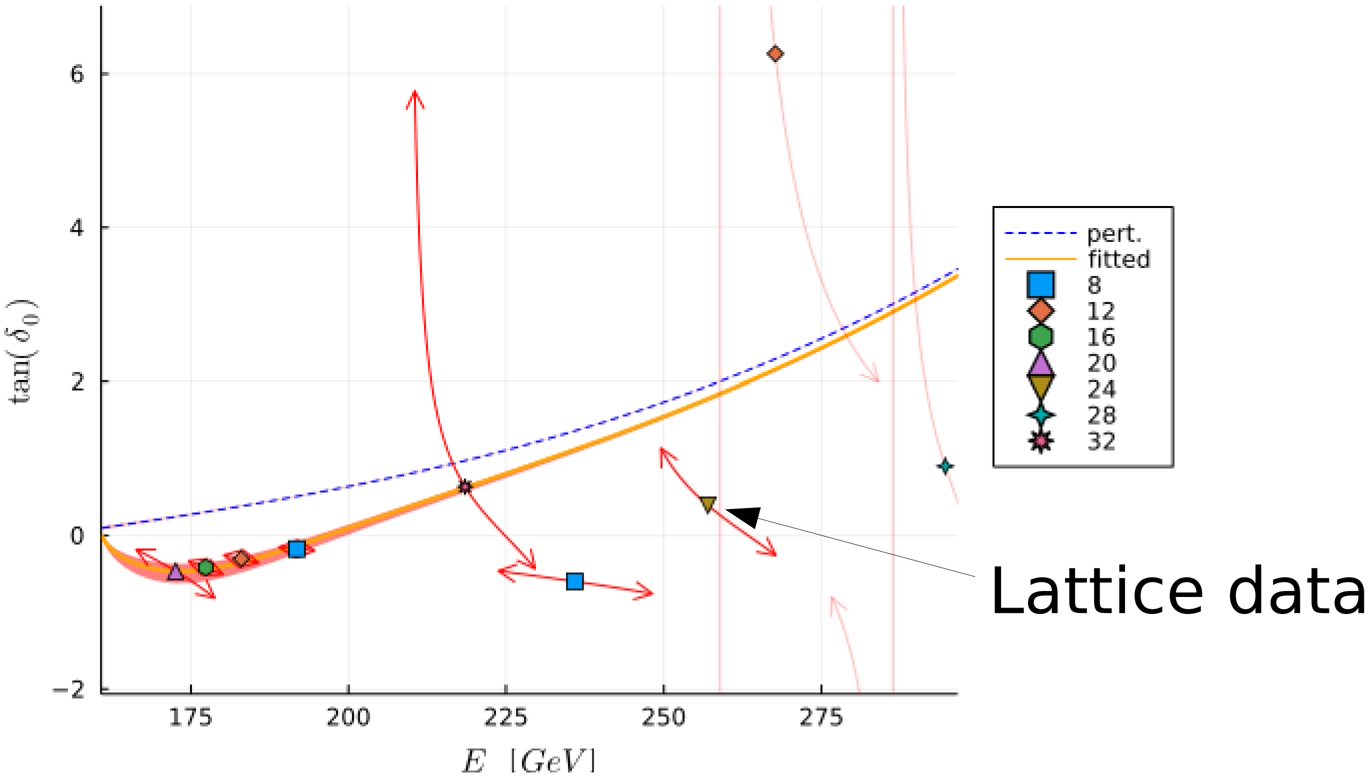

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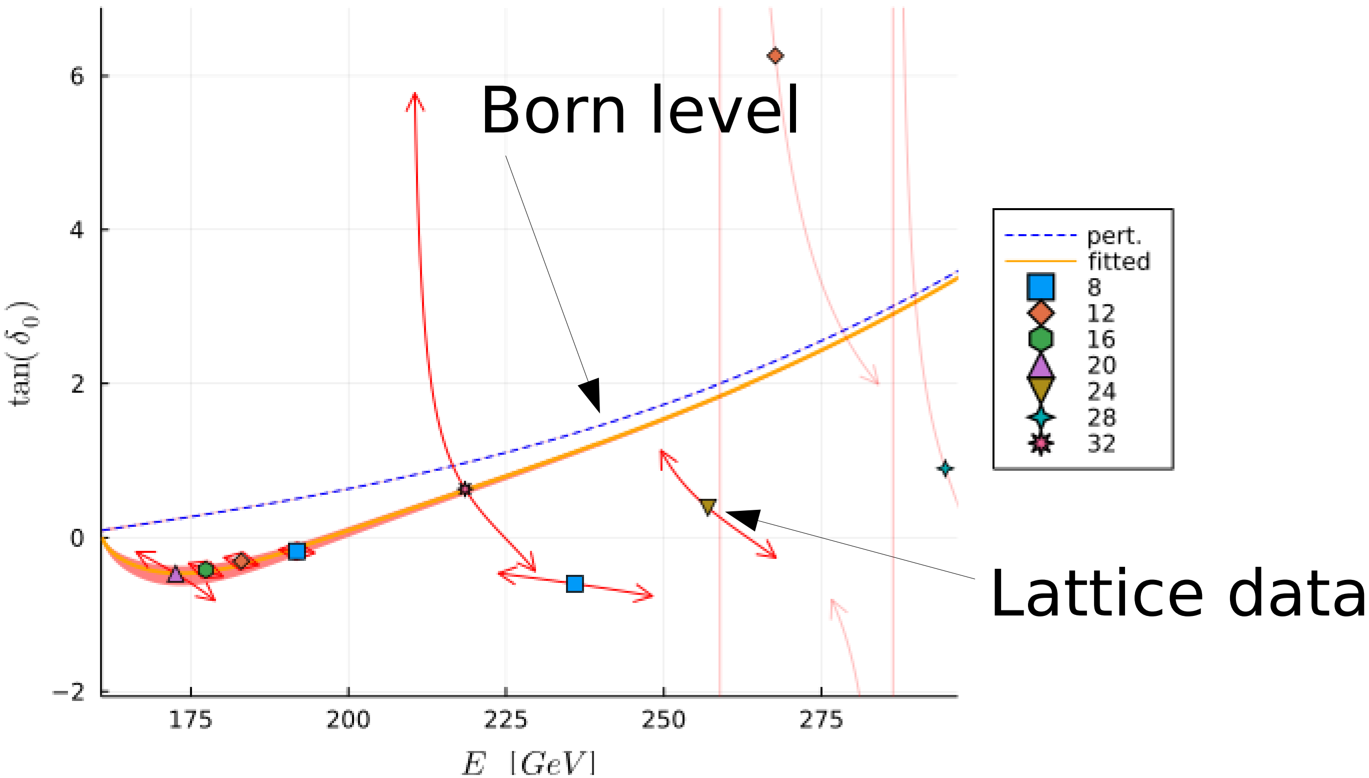

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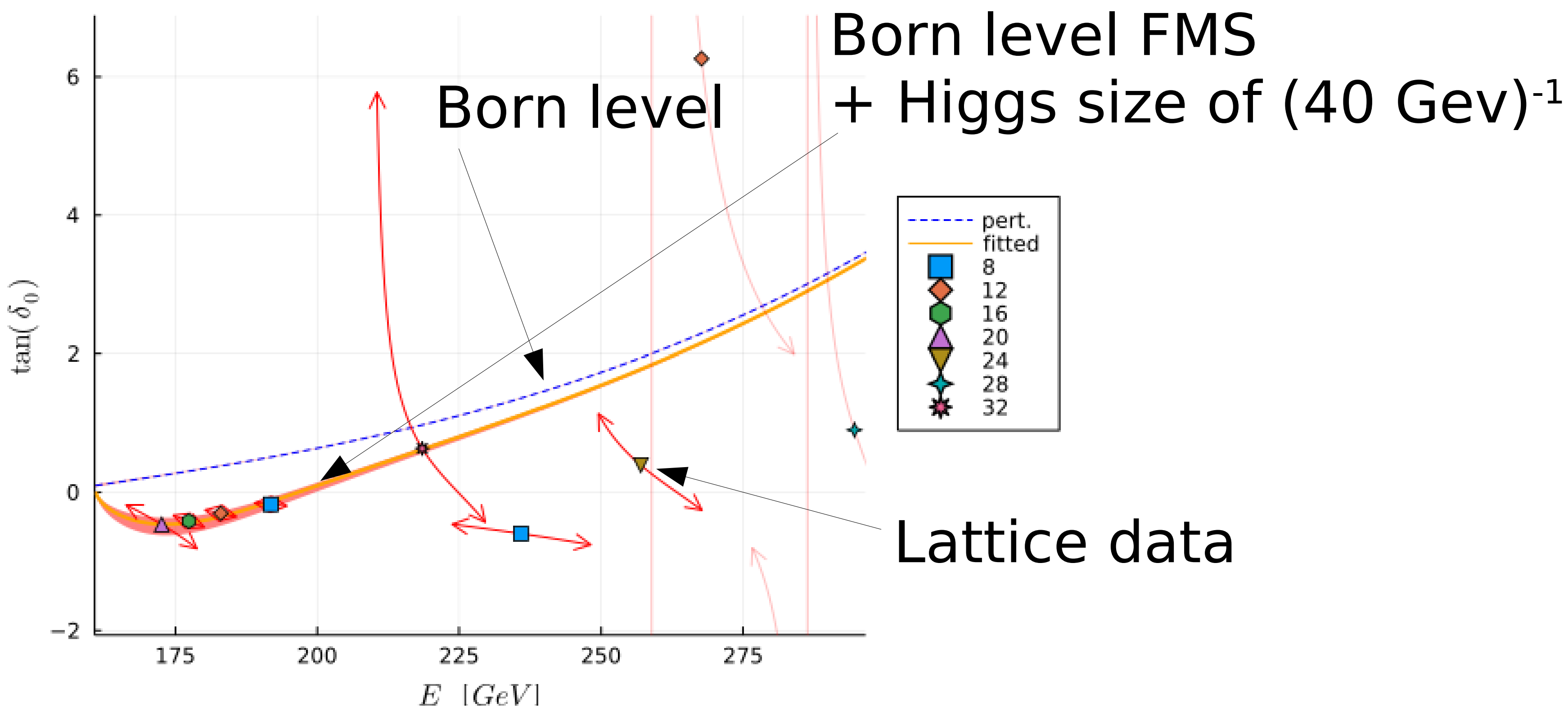

- Reduced SM: Only W/Z and the Higgs
    - Higgs too heavy and too strong weak coupling
    - Qualitatively but not quantitatively

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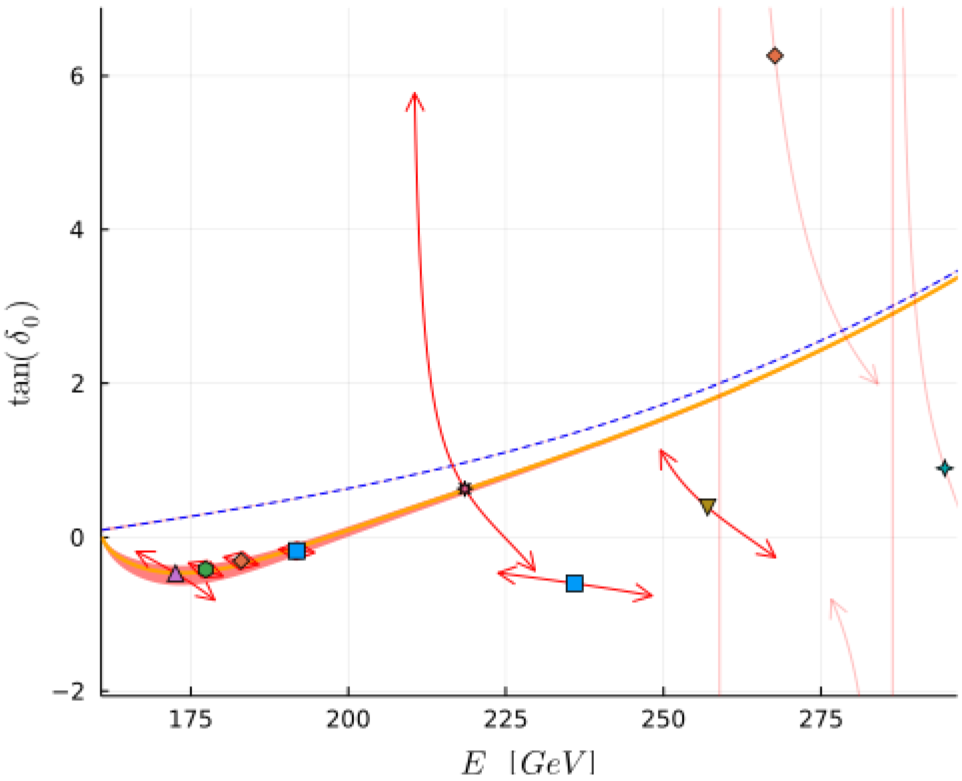

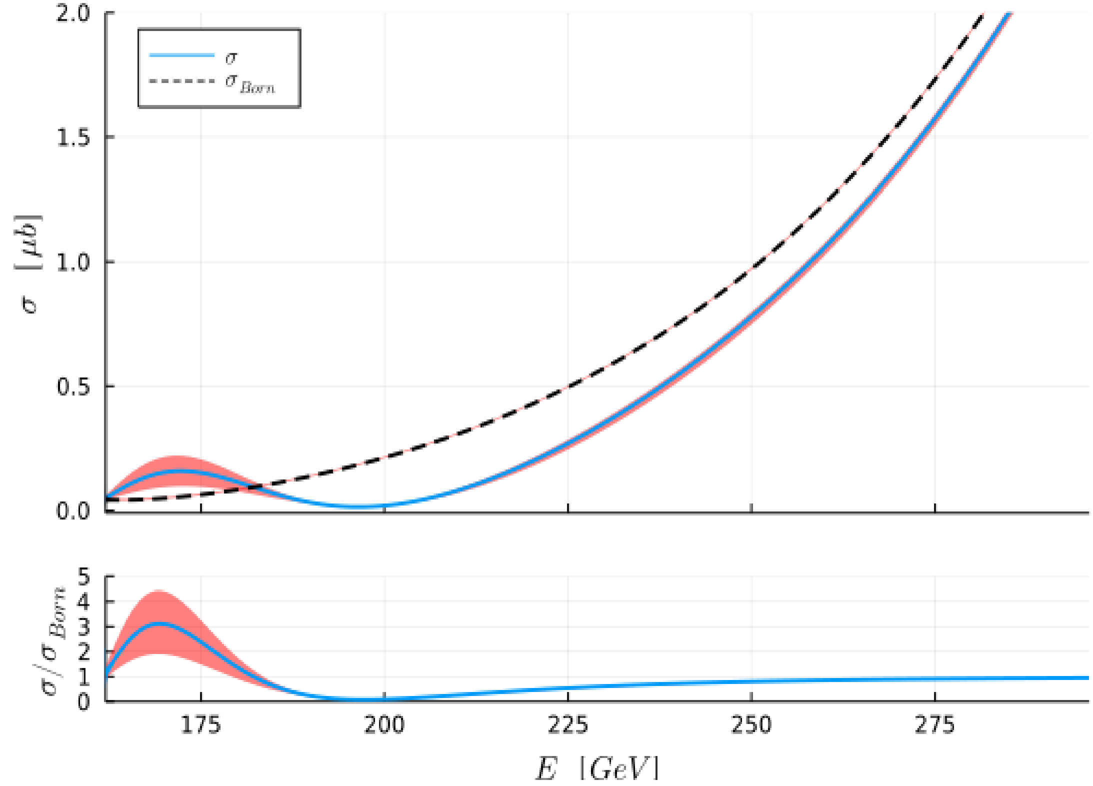

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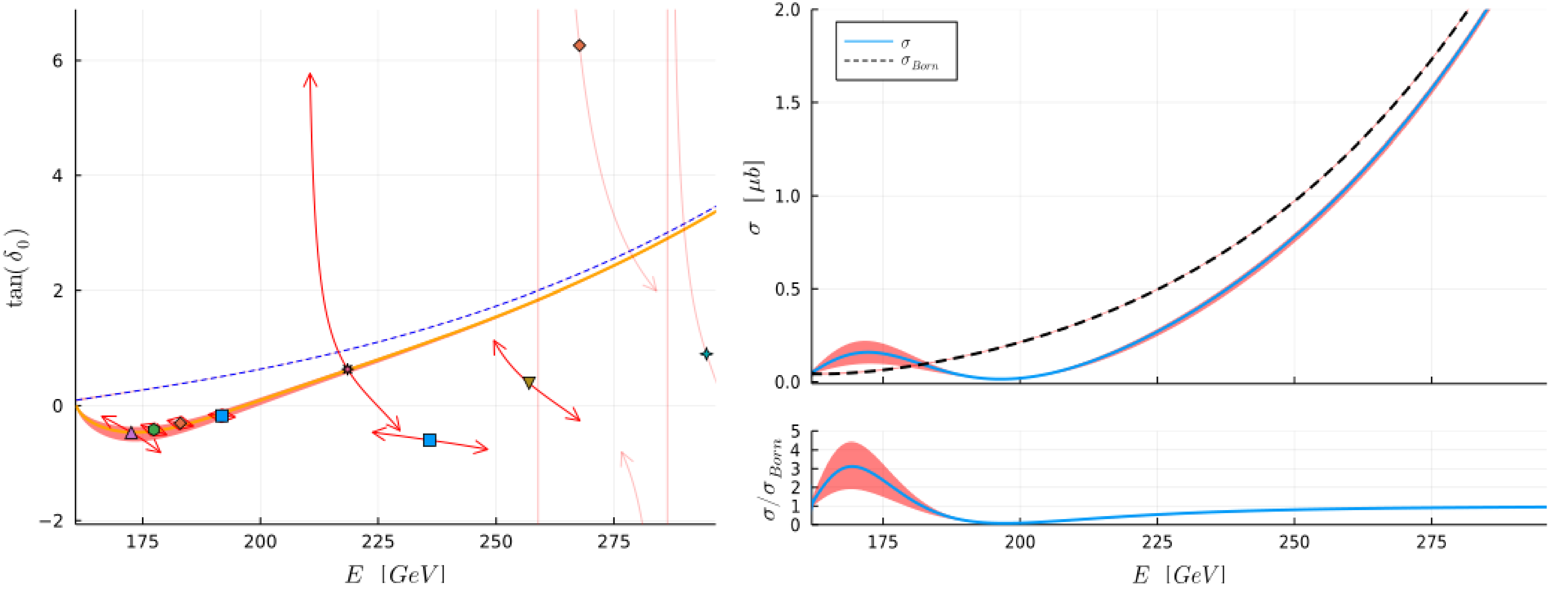
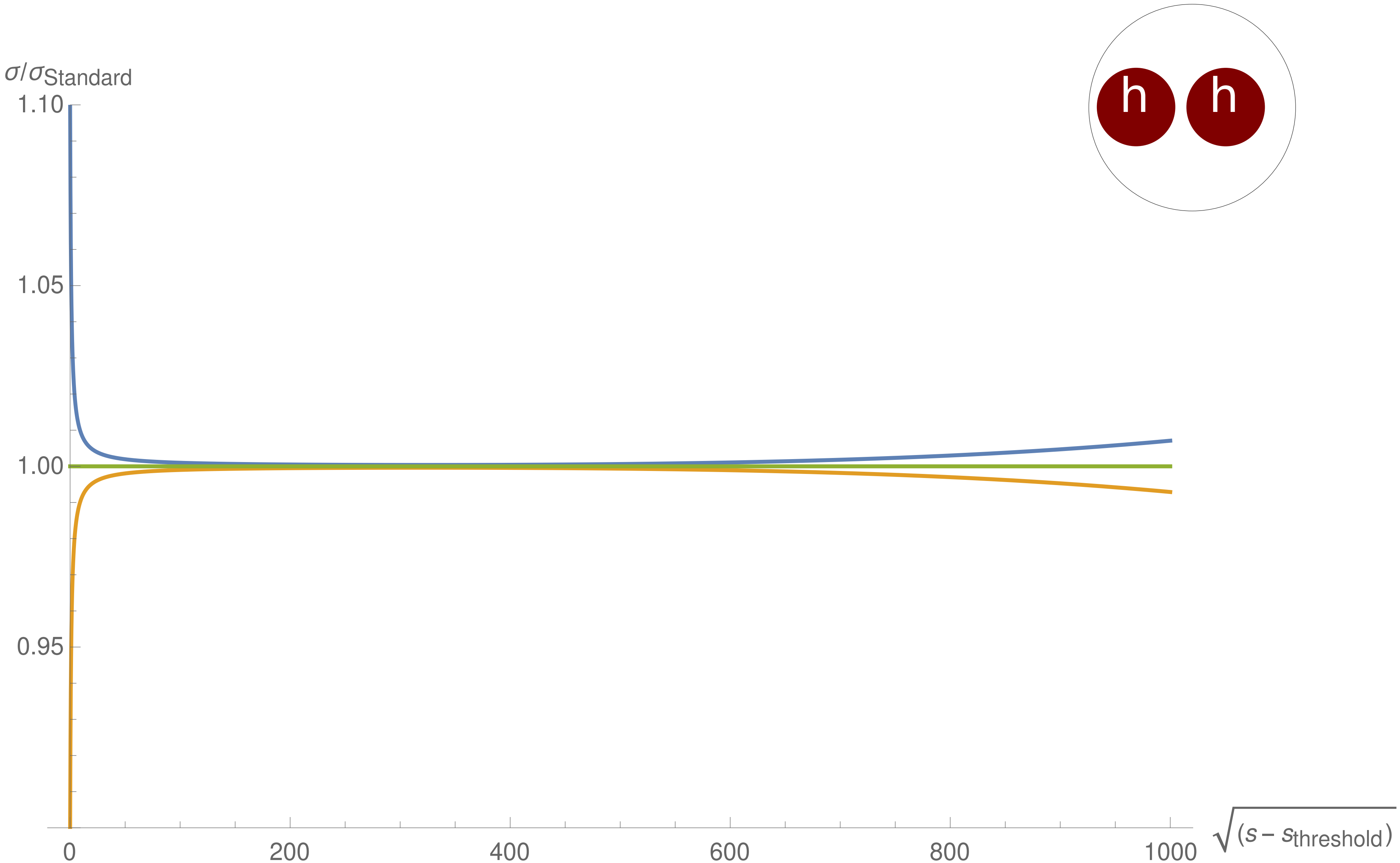


- Reduced SM: Only W/Z and the Higgs
    - Higgs too heavy and too strong weak coupling
    - Qualitatively but not quantitatively
- Trend seen in ATLAS/CMS off-shell ZZ→ 4l [Talks @Higgs 2022]
    - 1.11(7) 180-220 GeV (ATLAS)/~0.8(2) 220-275 GeV (CMS)

Generic behavior: DIS-like



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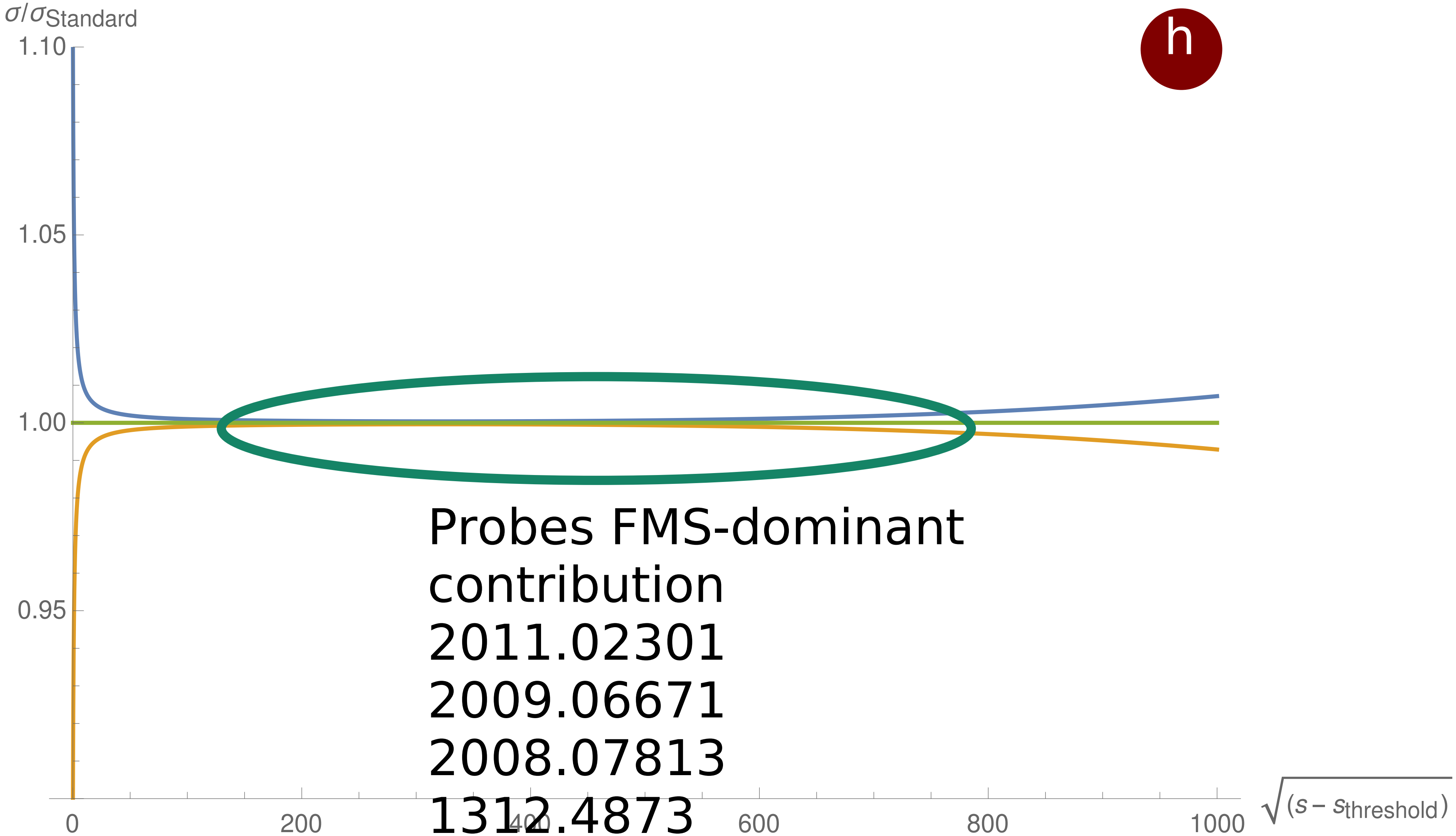

Probes FMS-dominant contribution
2011.02301
2009.06671
2008.07813
1312.4873

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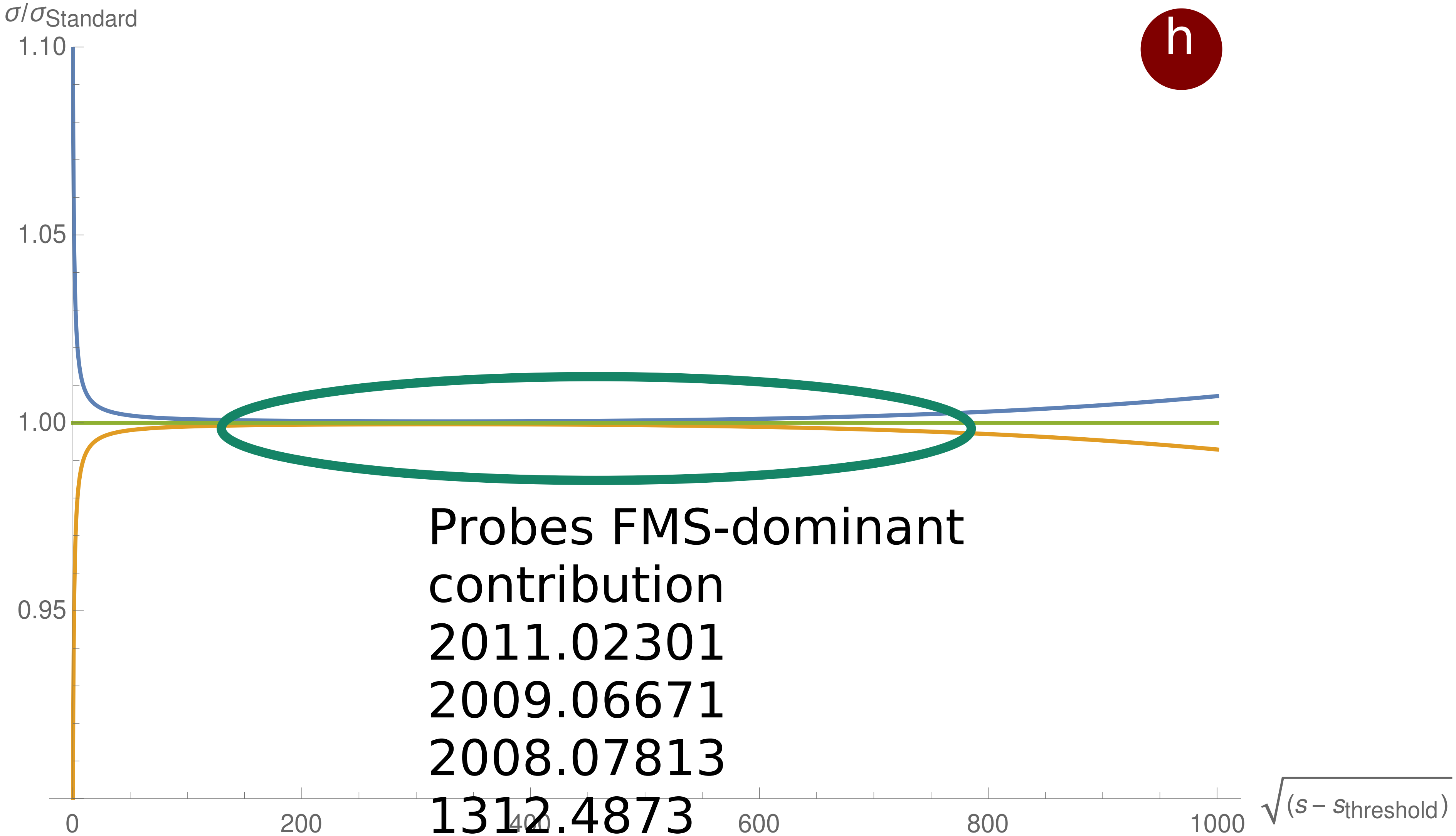

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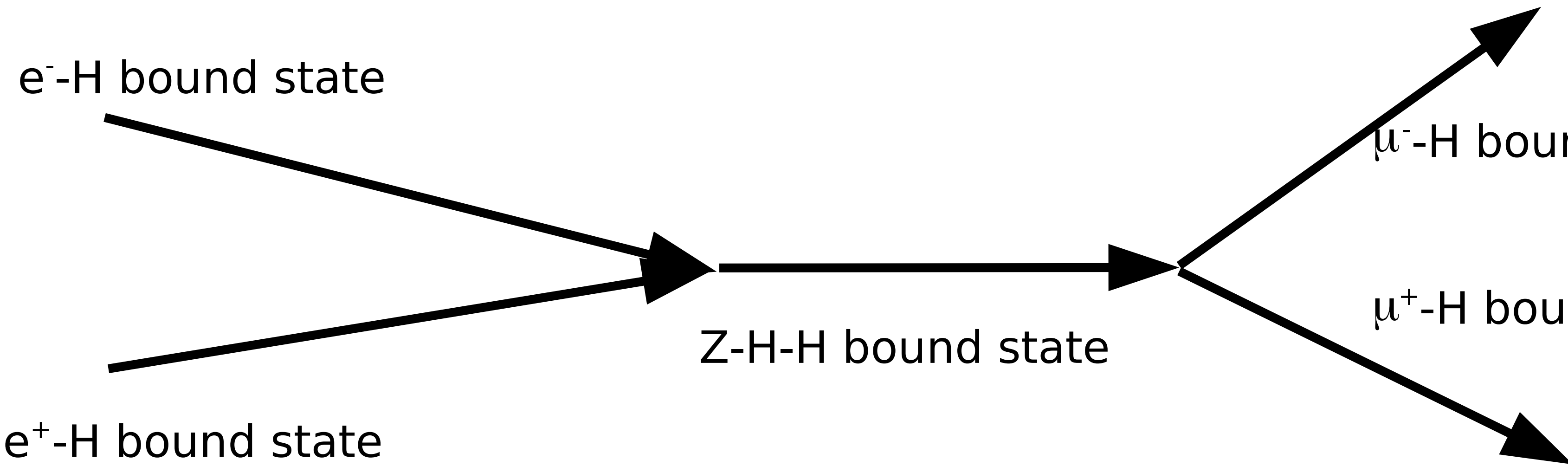
Standard pheno!

How events looks like (LEP/ILC)

[Maas'12]



- Collision of bound states

How events looks like (LEP/ILC)

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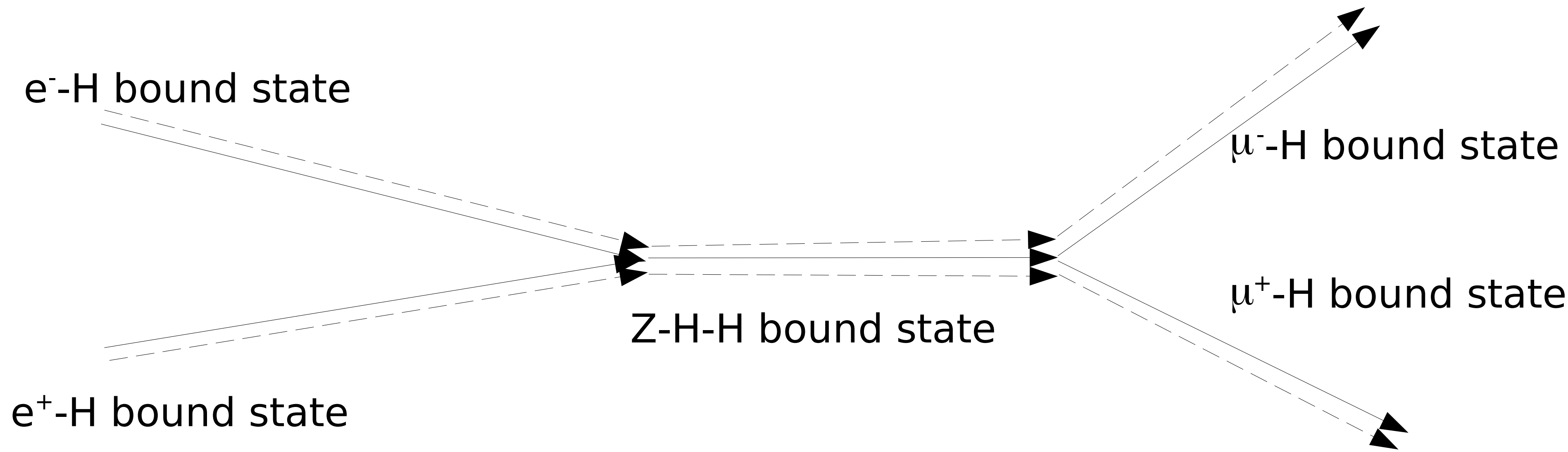

- Collision of bound states - 'constituent' particles

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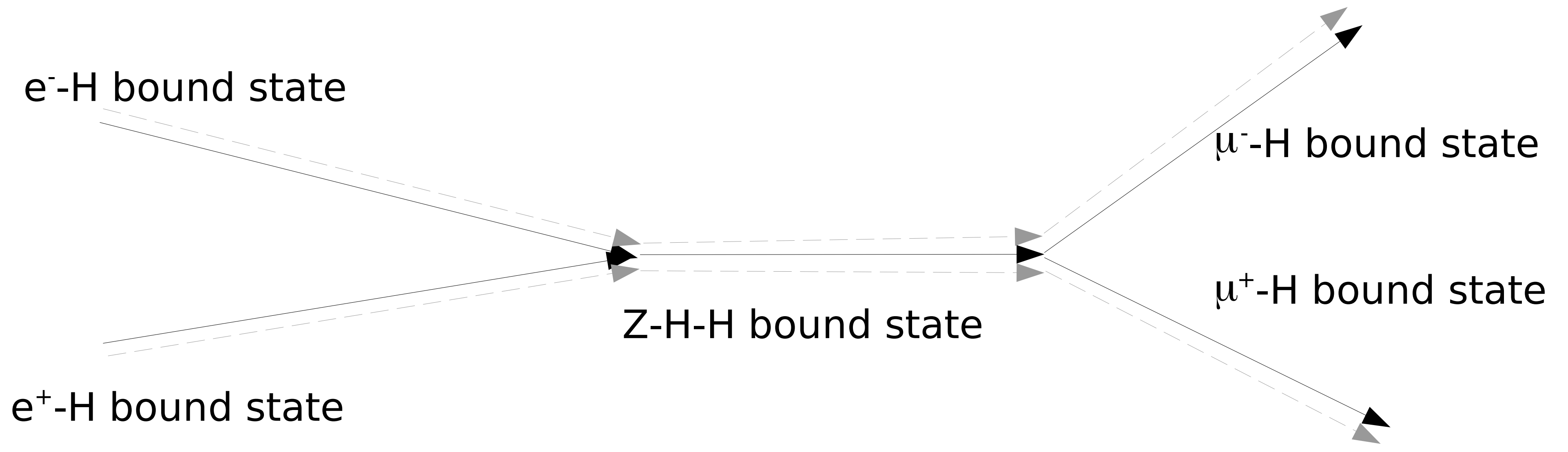
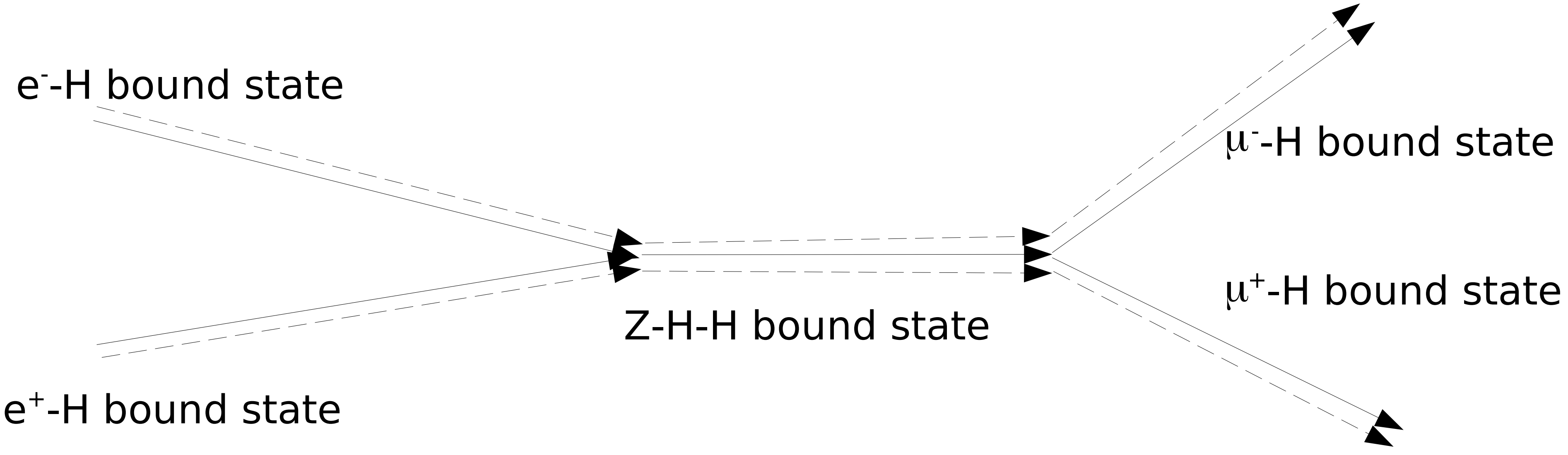


- Collision of bound states - 'constituent' particles
- Standard perturbation theory
  - Higgs partners just spectators
  - Similar to pp collisions

How events looks like (LEP/ILC)

[Maas'12, Egger et al.'17]



$$\langle hehe | h\mu\, h\mu \rangle$$

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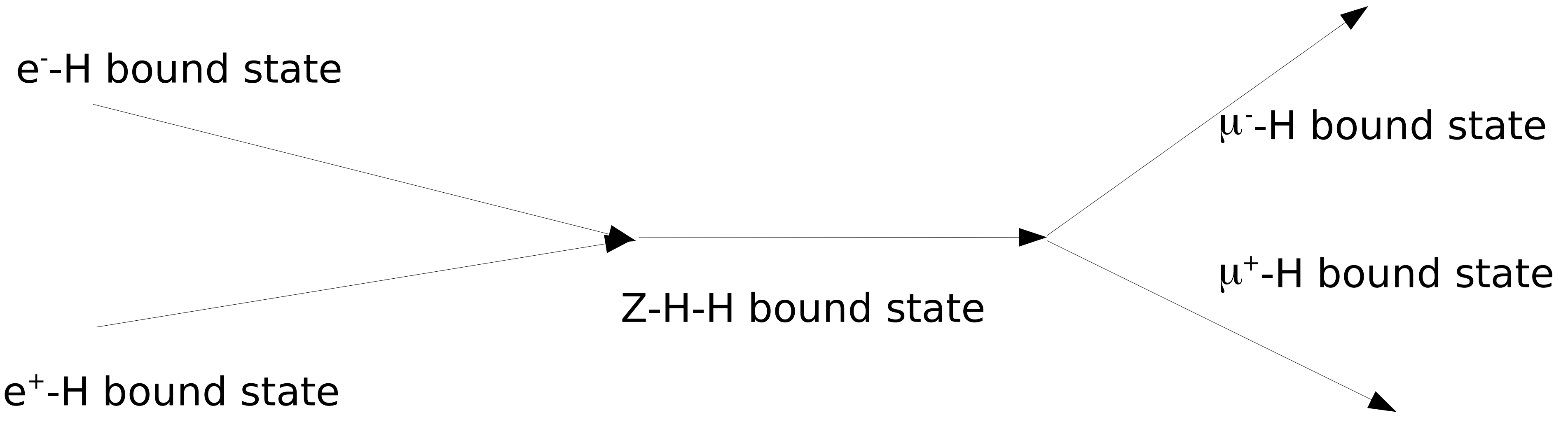

$$\langle hehe | h\mu\, h\mu \rangle = \langle ee | \mu\, \mu \rangle$$

NLO: 1525 diagrams

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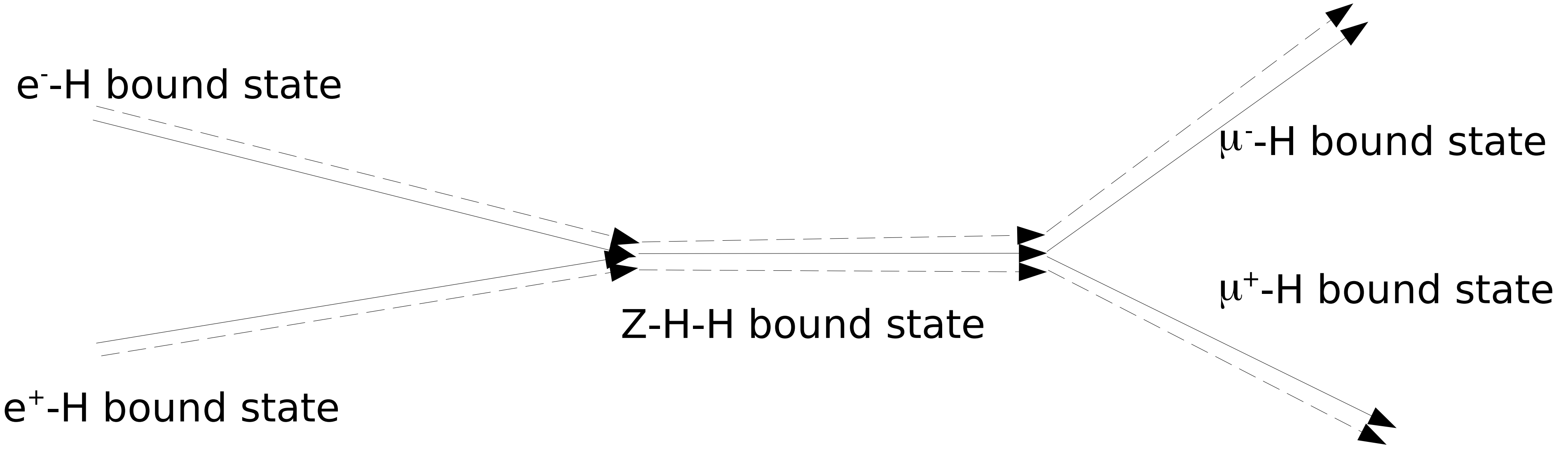

$$\langle hehe|h\mu\, h\mu\rangle = \langle ee|\mu\,\mu\rangle + \langle\eta\,\eta\rangle\langle ee|\mu\,\mu\rangle + \langle ee\rangle\langle\eta\,\eta|\mu\,\mu\rangle + \ldots$$

NLO: 1525 diagrams+3431 diagrams

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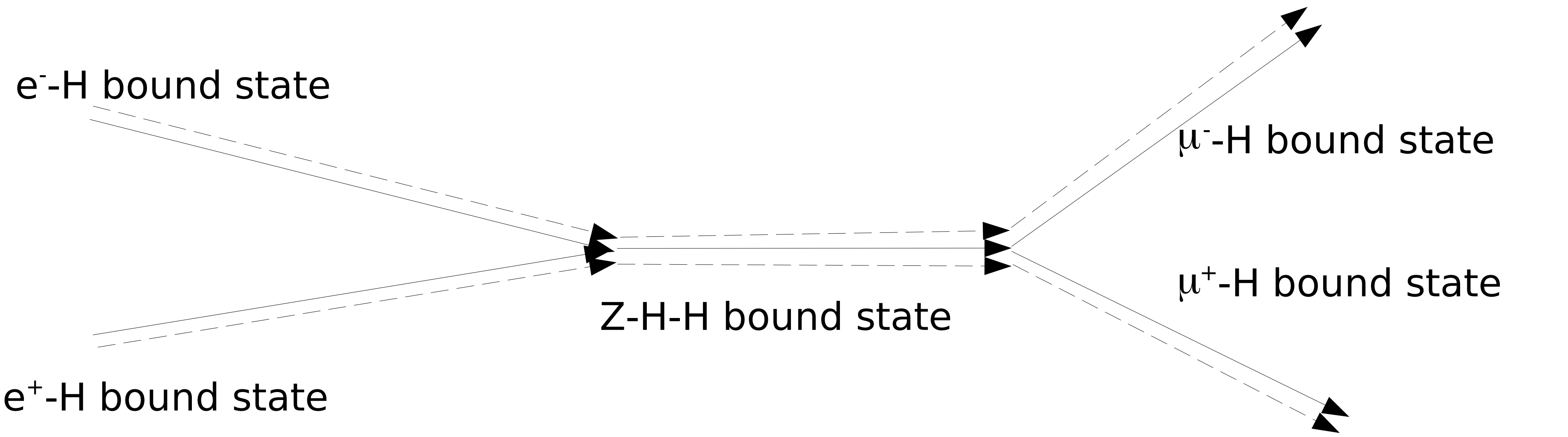

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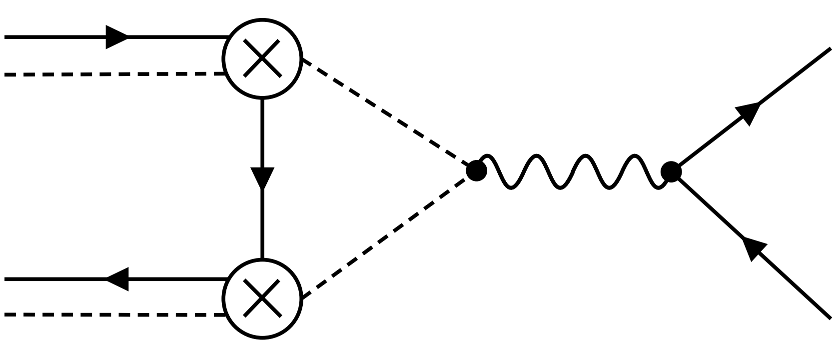

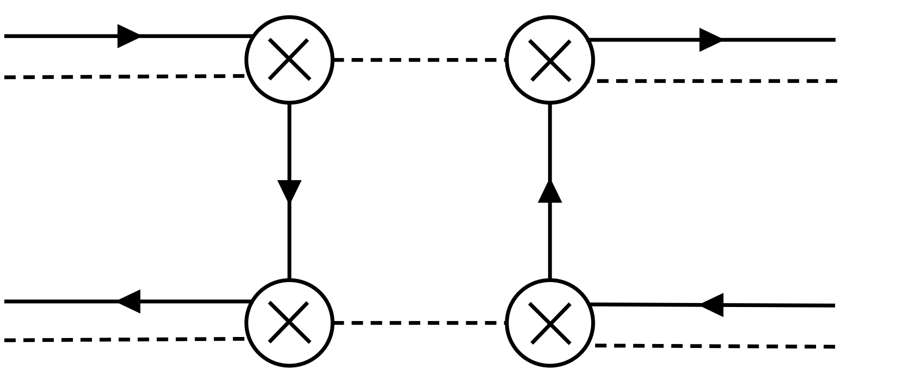

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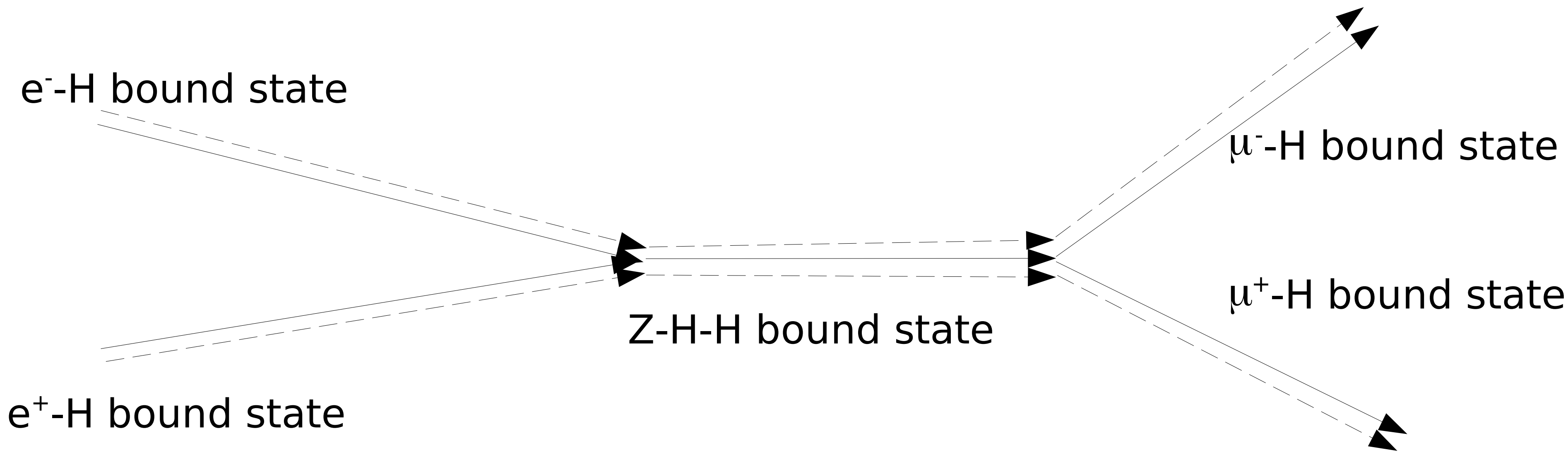

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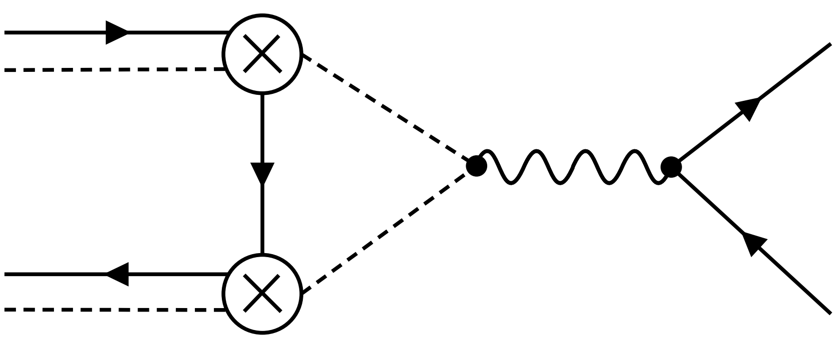

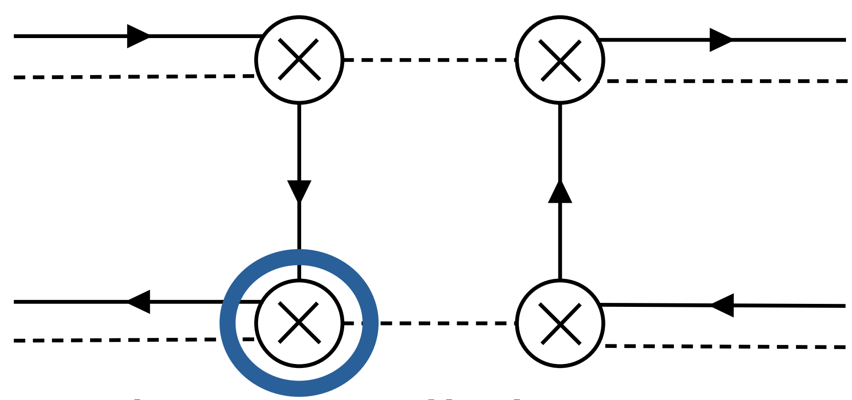

Enhanced Feynman rules: New bound state splitting vertex

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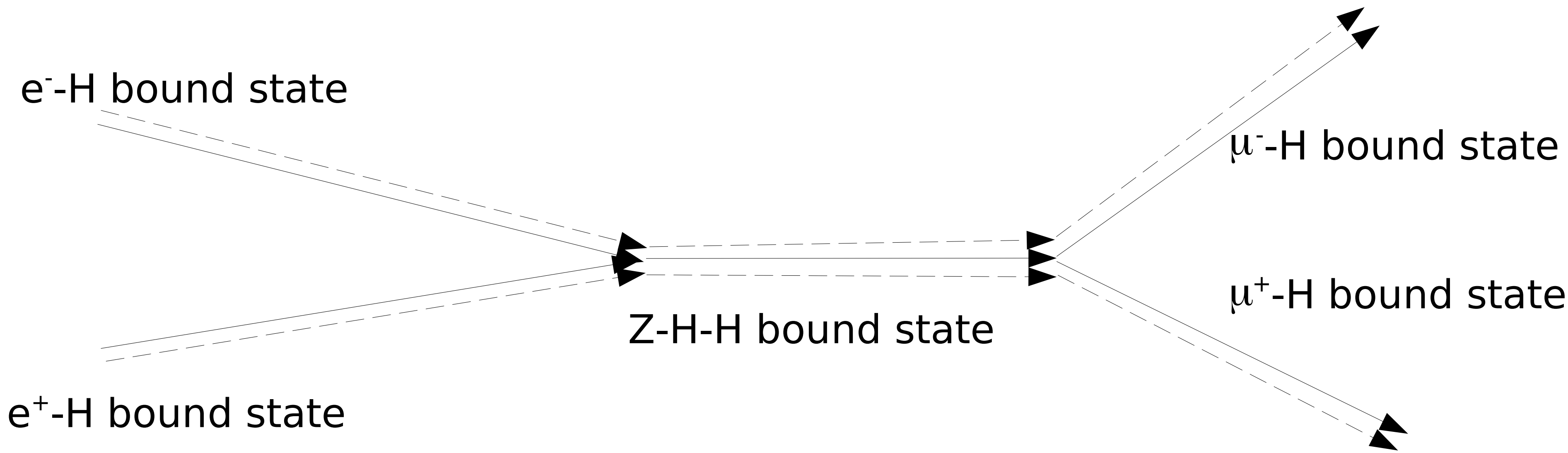

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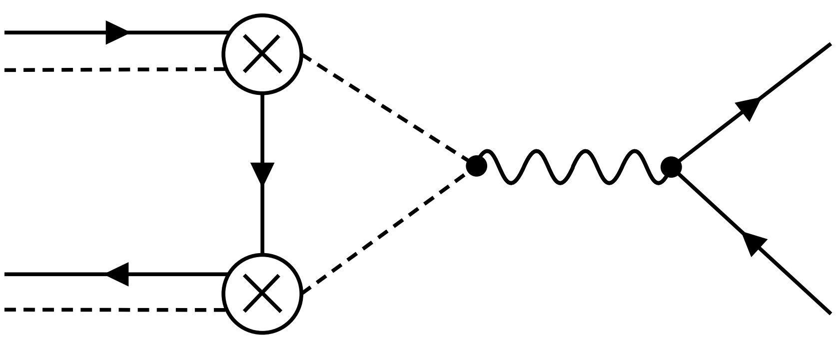
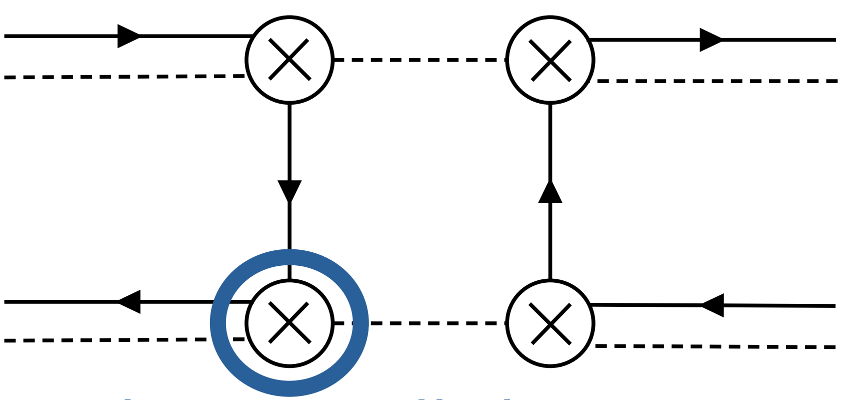
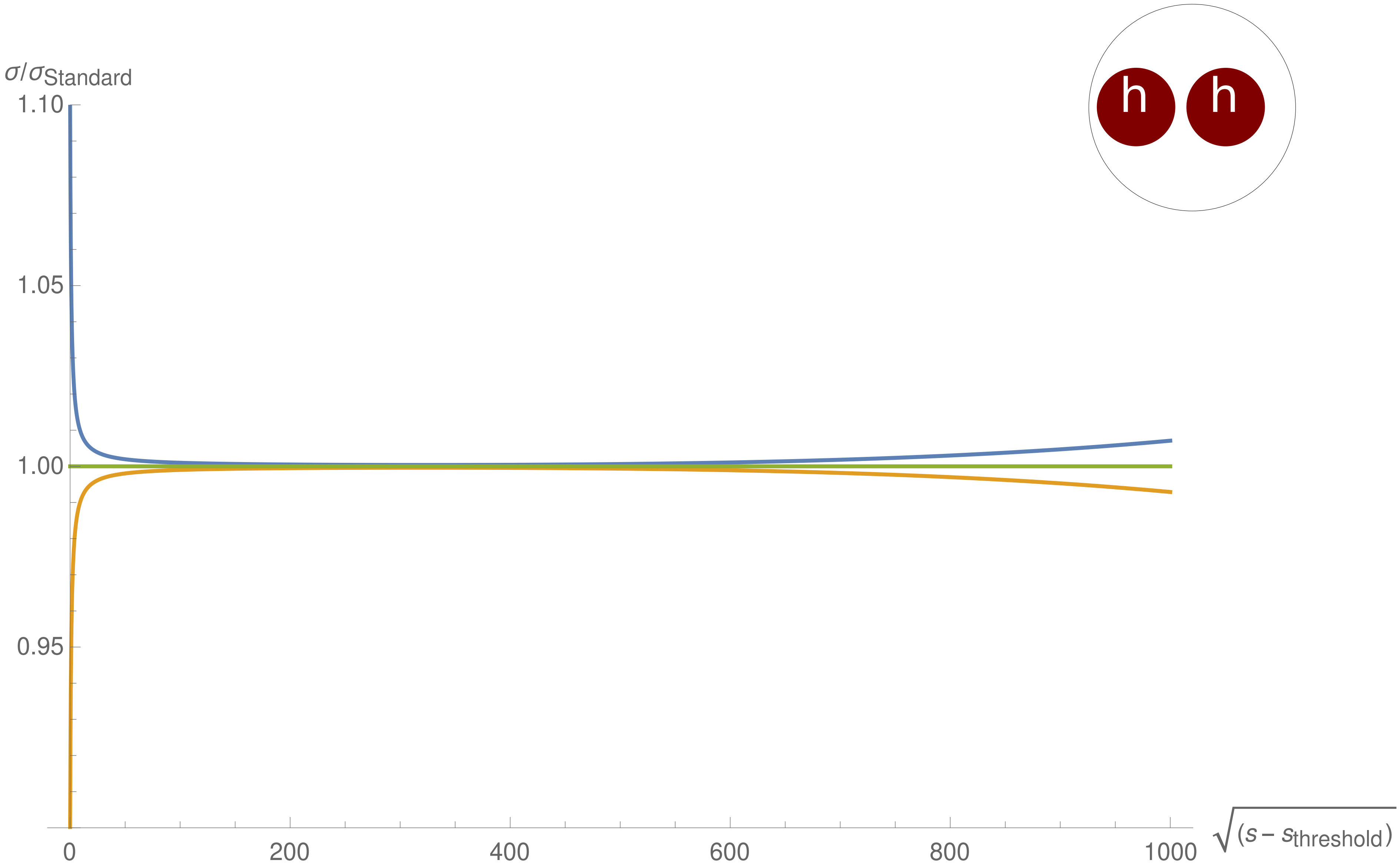




Enhanced Feynman rules: New bound state splitting vertex

Can be calculated with standard tools: Managable

Generic behavior: DIS-like



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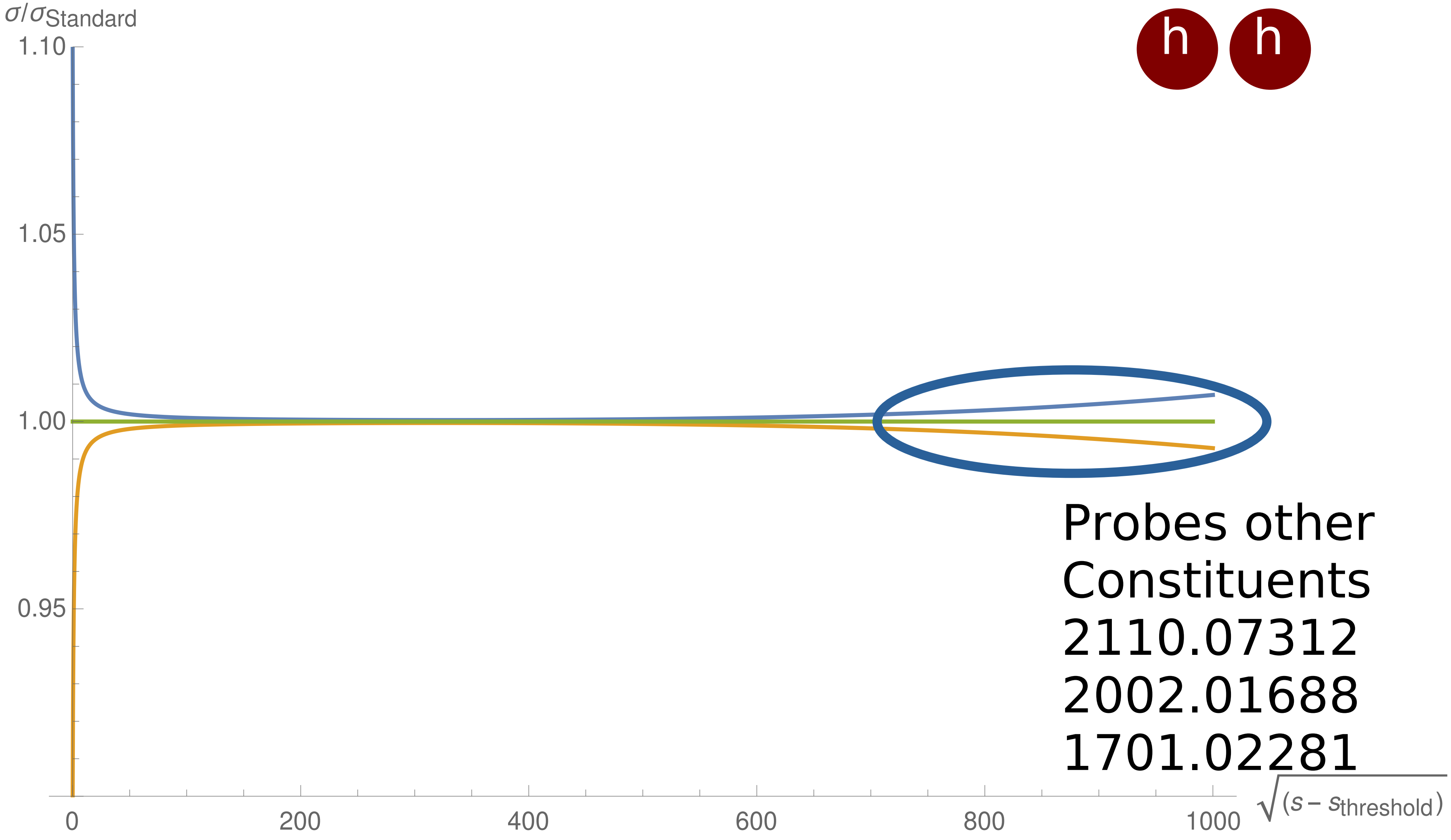

Probes other
Constituents
2110.07312
2002.01688
1701.02281

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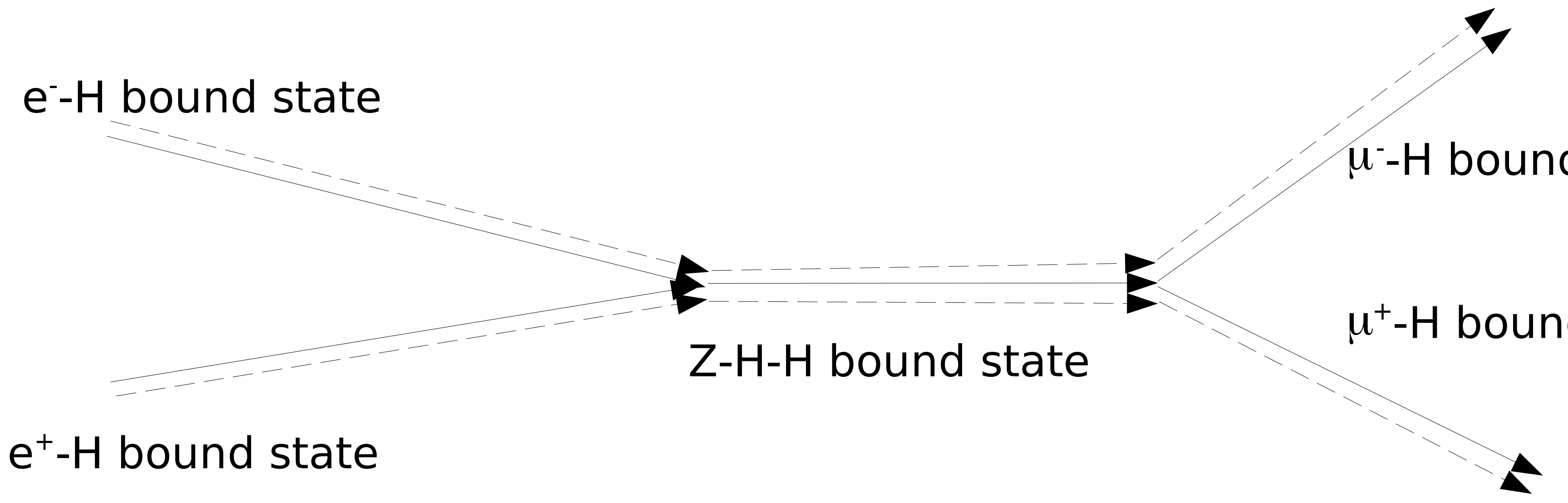

- Collision of bound states - 'constituent' particles
  - Gauge-invariant: Just like hadrons

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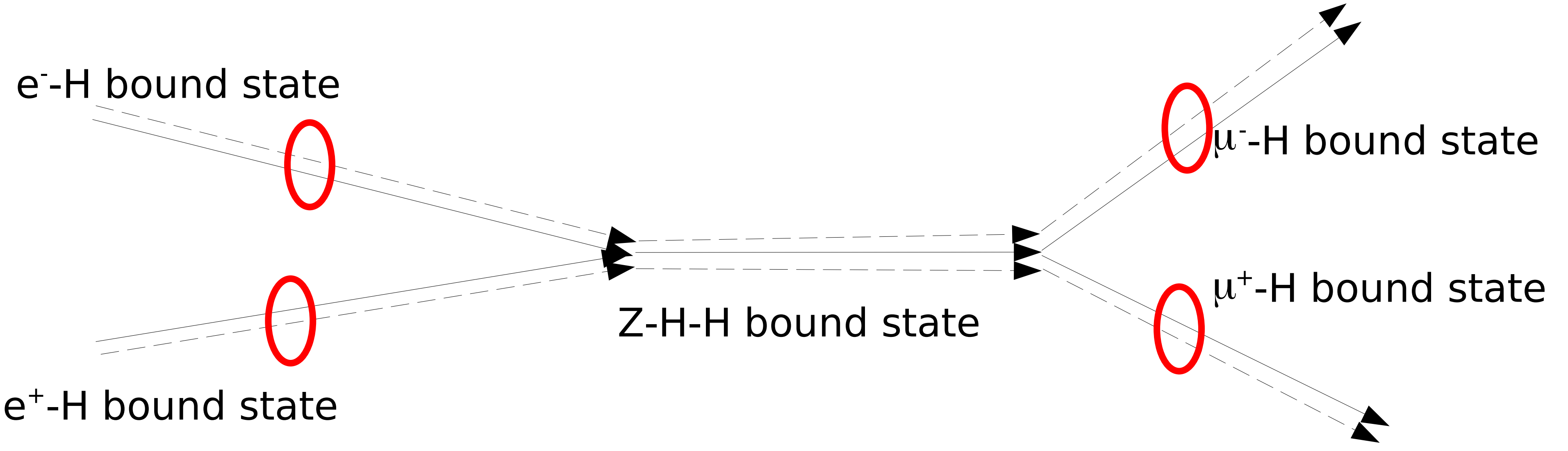
[Maas'12, Maas, Reiner'22]



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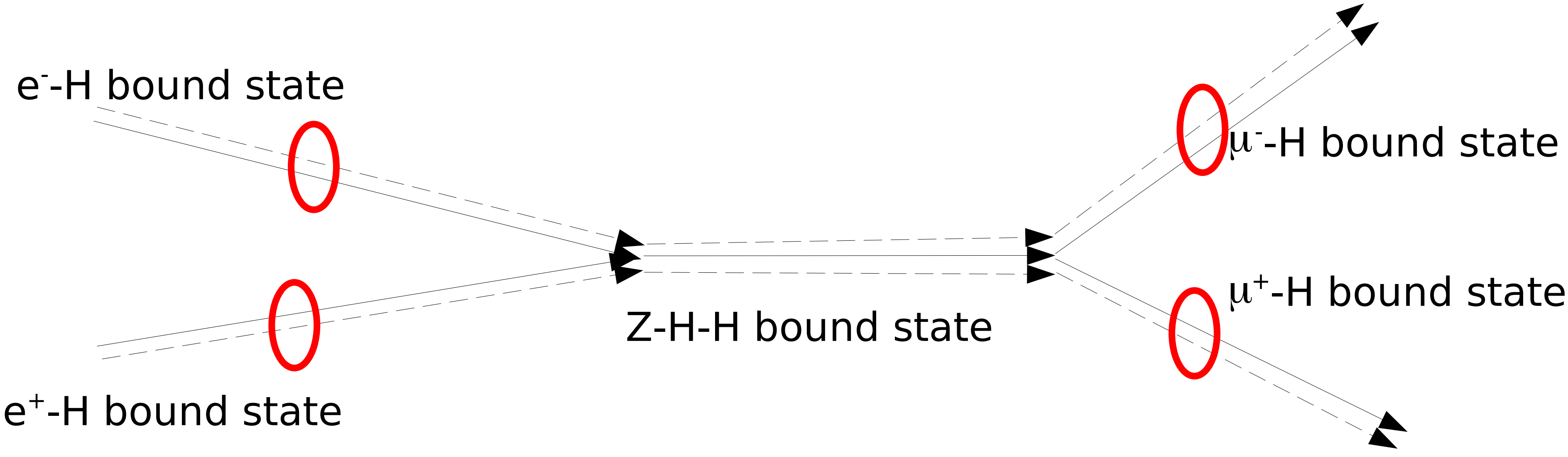

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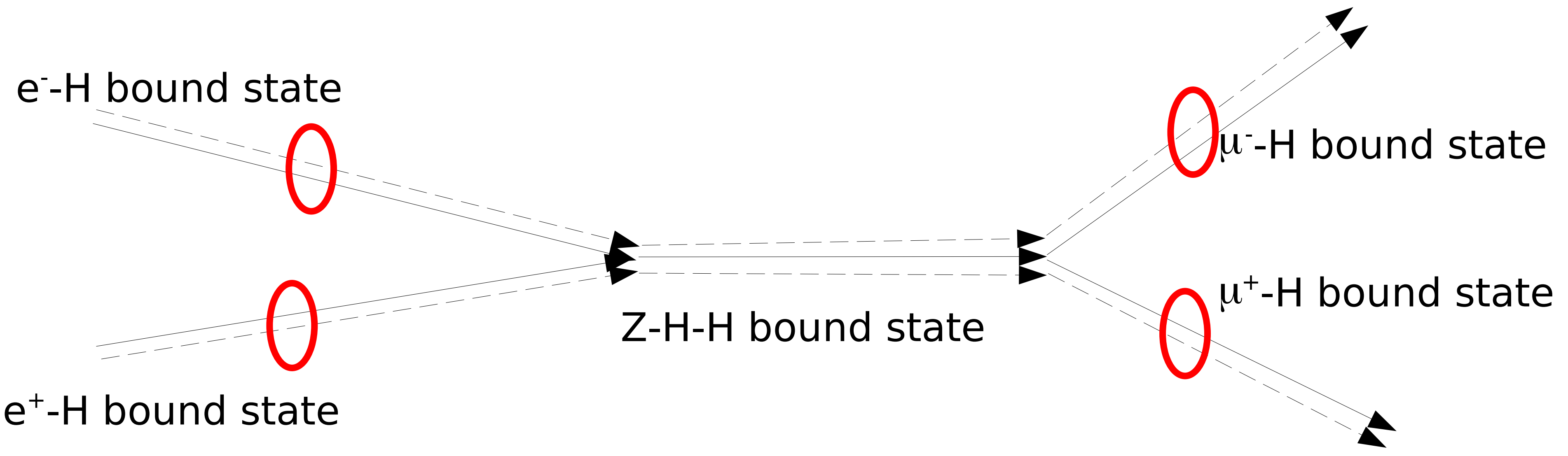
[Maas'12, Maas, Reiner'22 Fernbach et al.'20]



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    - At TeV colliders of order strong corrections
    - Generalizes to the LHC
      - PDFs at high energies affected

Summary

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  - Confirmed by lattice
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Review: 1712.04721

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- Unaccounted-for SM background
  - Or: Guaranteed discovery of the effect in the SM or a serious theoretical problem
- FMS mechanism applicable to many theories
  - 2HDM, GUTs, MSSM, quantum gravity
  - Qualitative impact in many new physics scenarios