New precision effects from the Brout-Englert-Higgs mechanism

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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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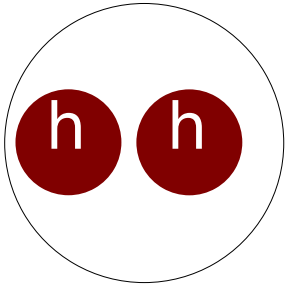

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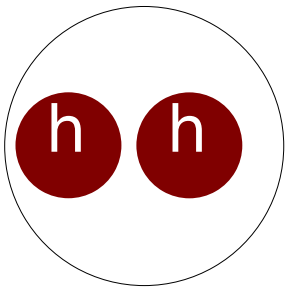

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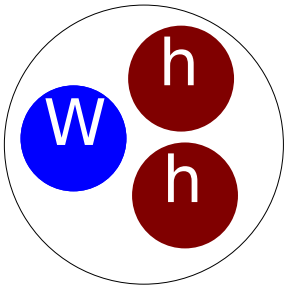

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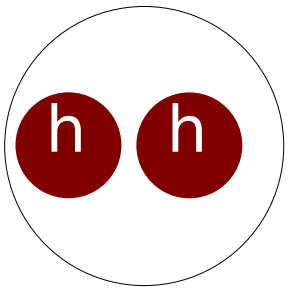

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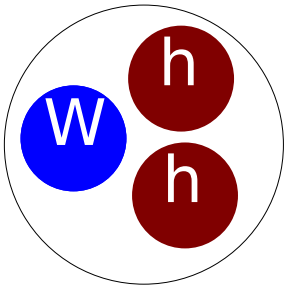

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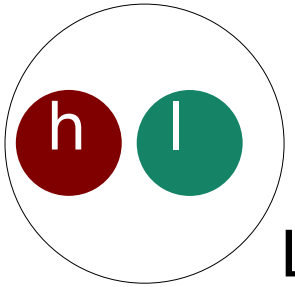

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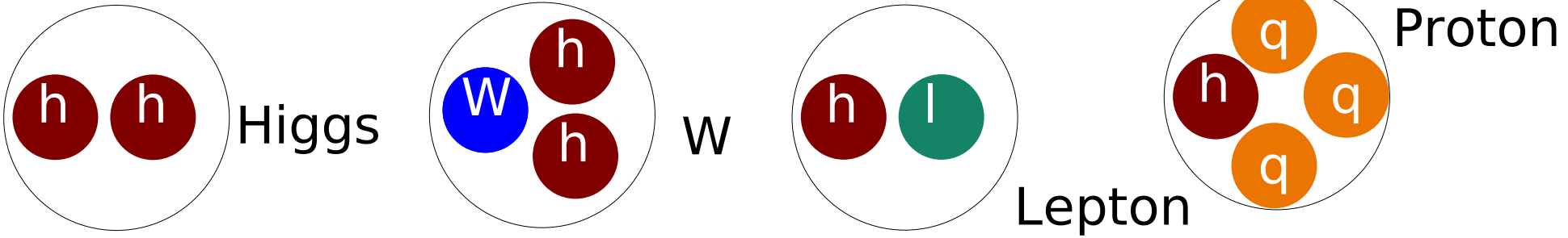

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  - Augments perturbation theory
    - Composite asymptotic states
    - Additional expansion in the Higgs vev

Augmented perturbation theory

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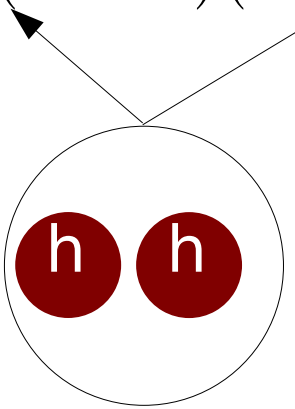

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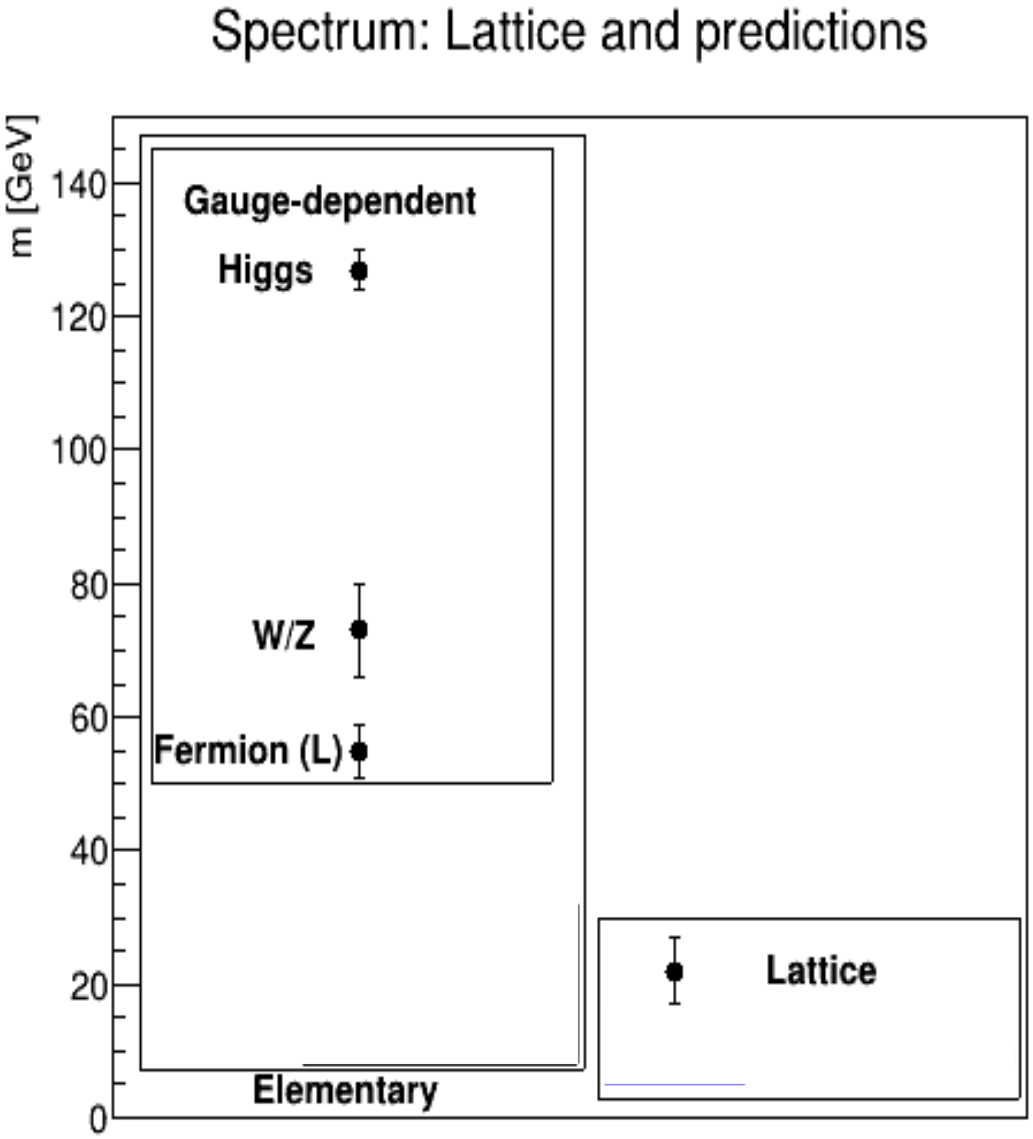

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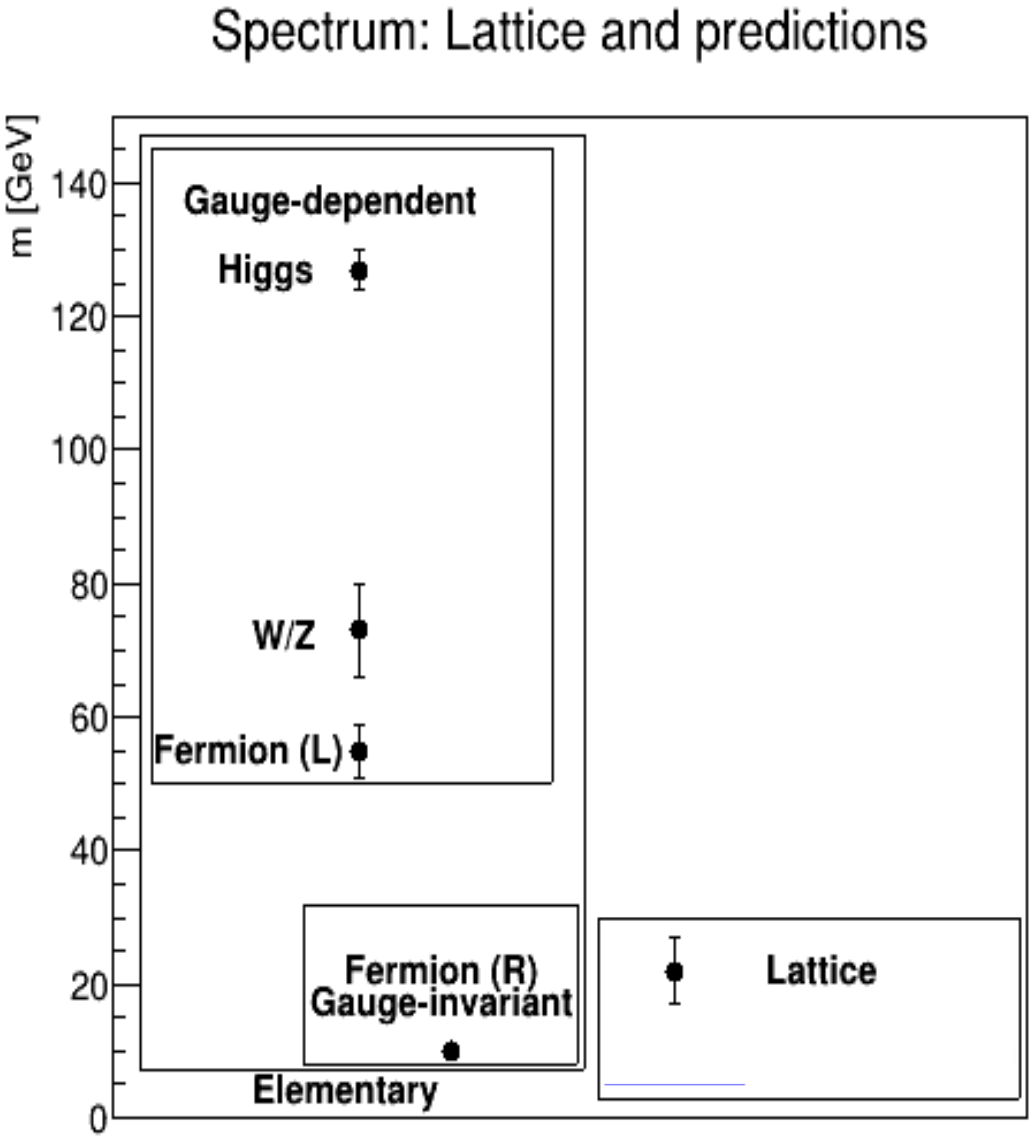

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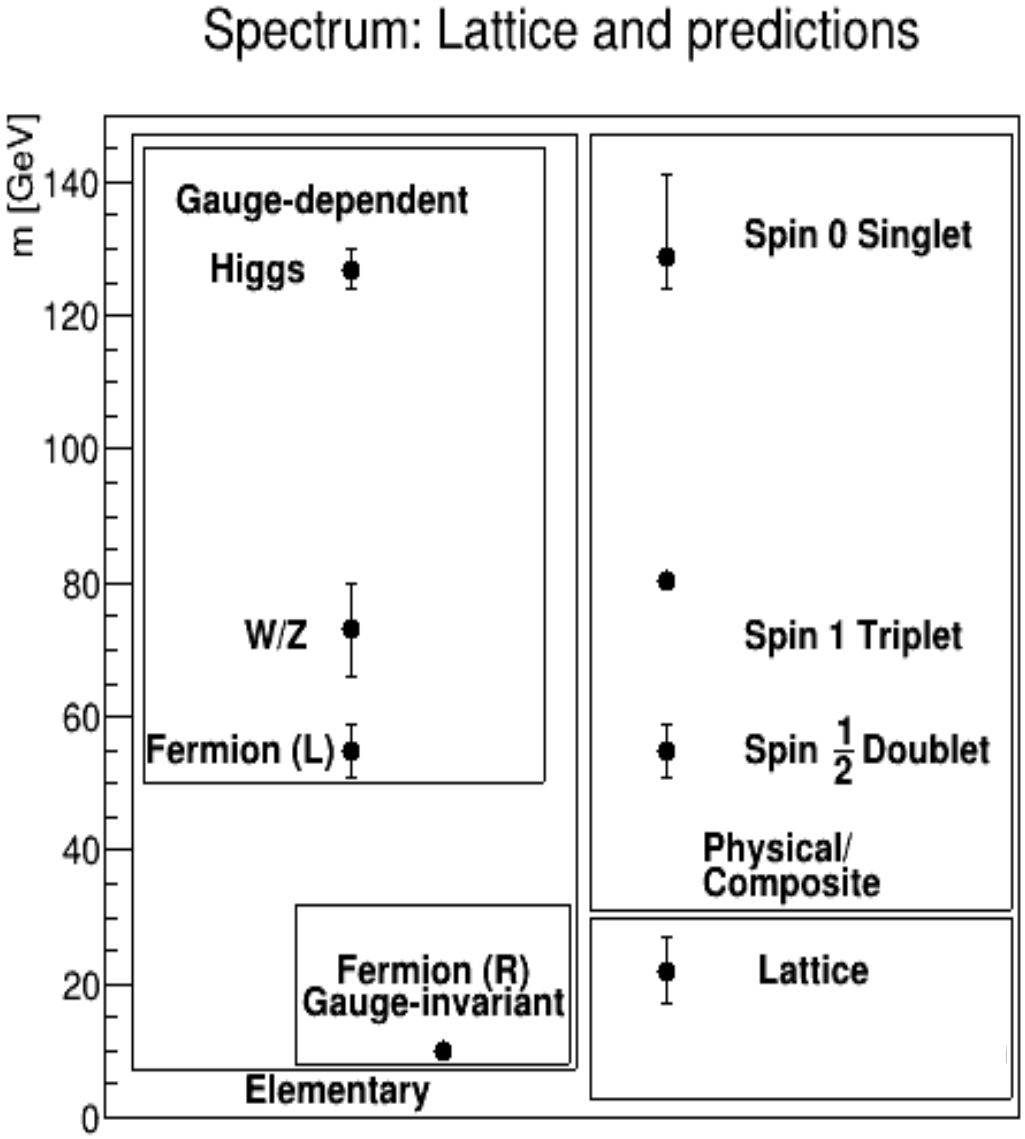

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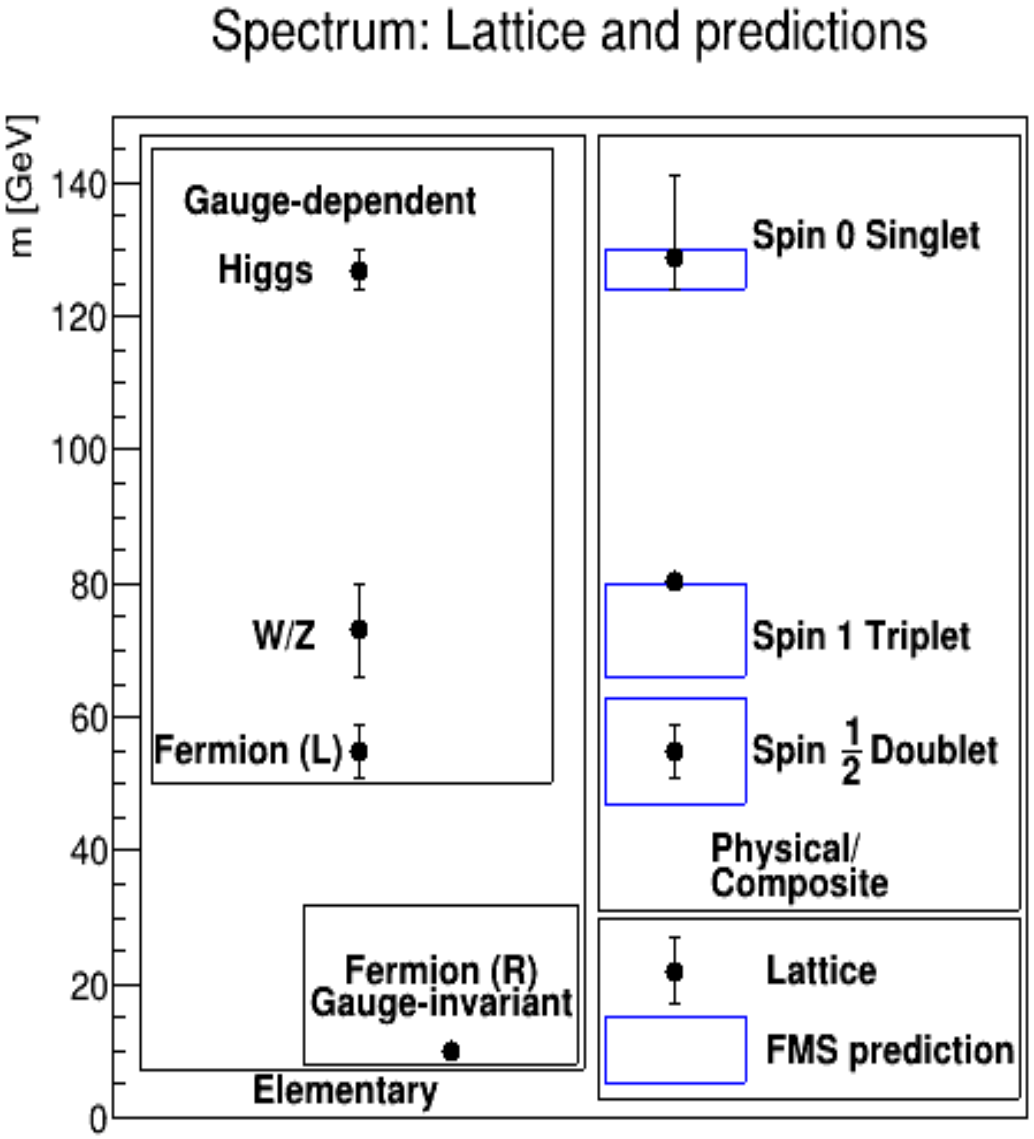
- Supports augmented perturbation theory



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What about this?

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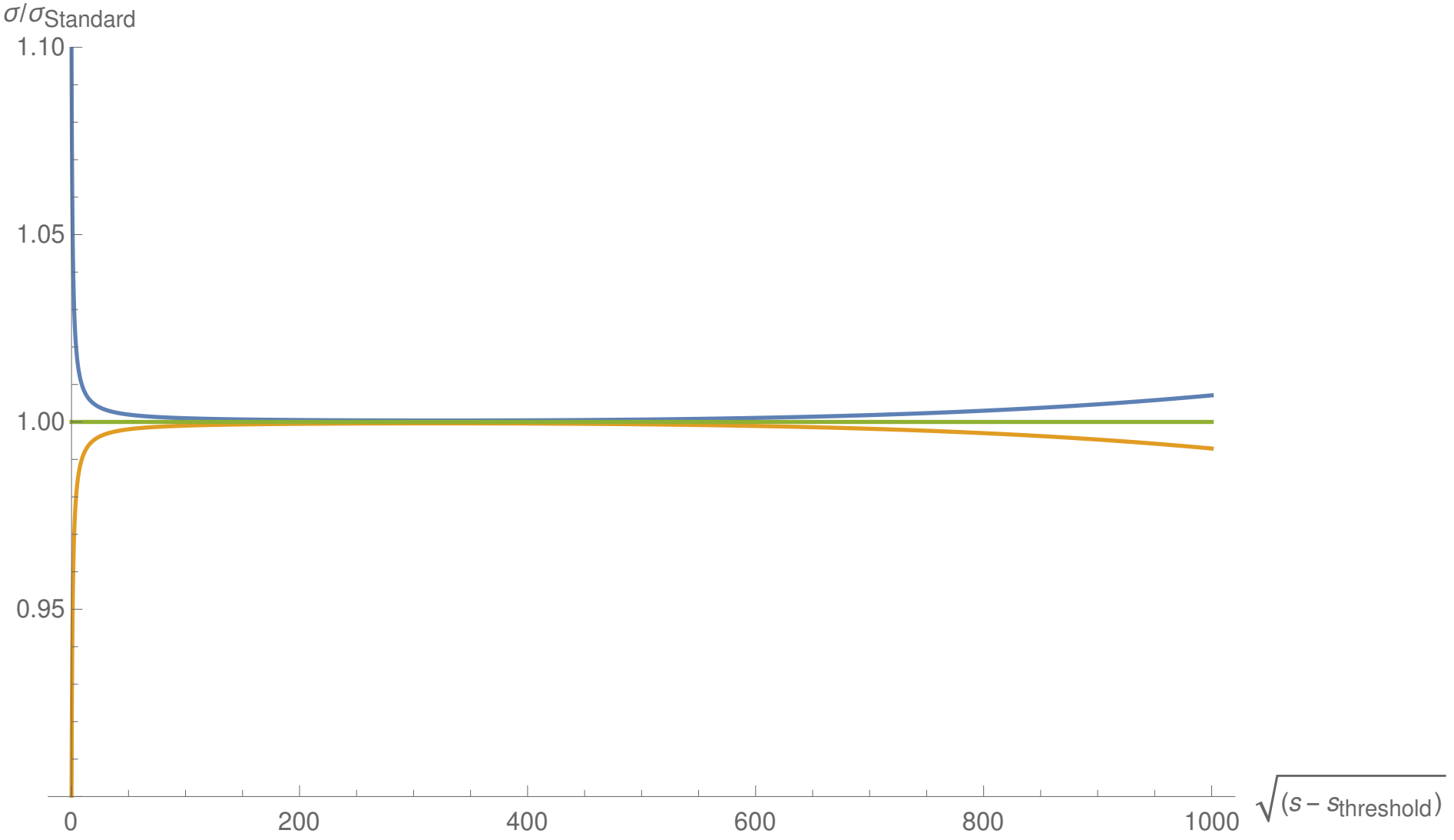

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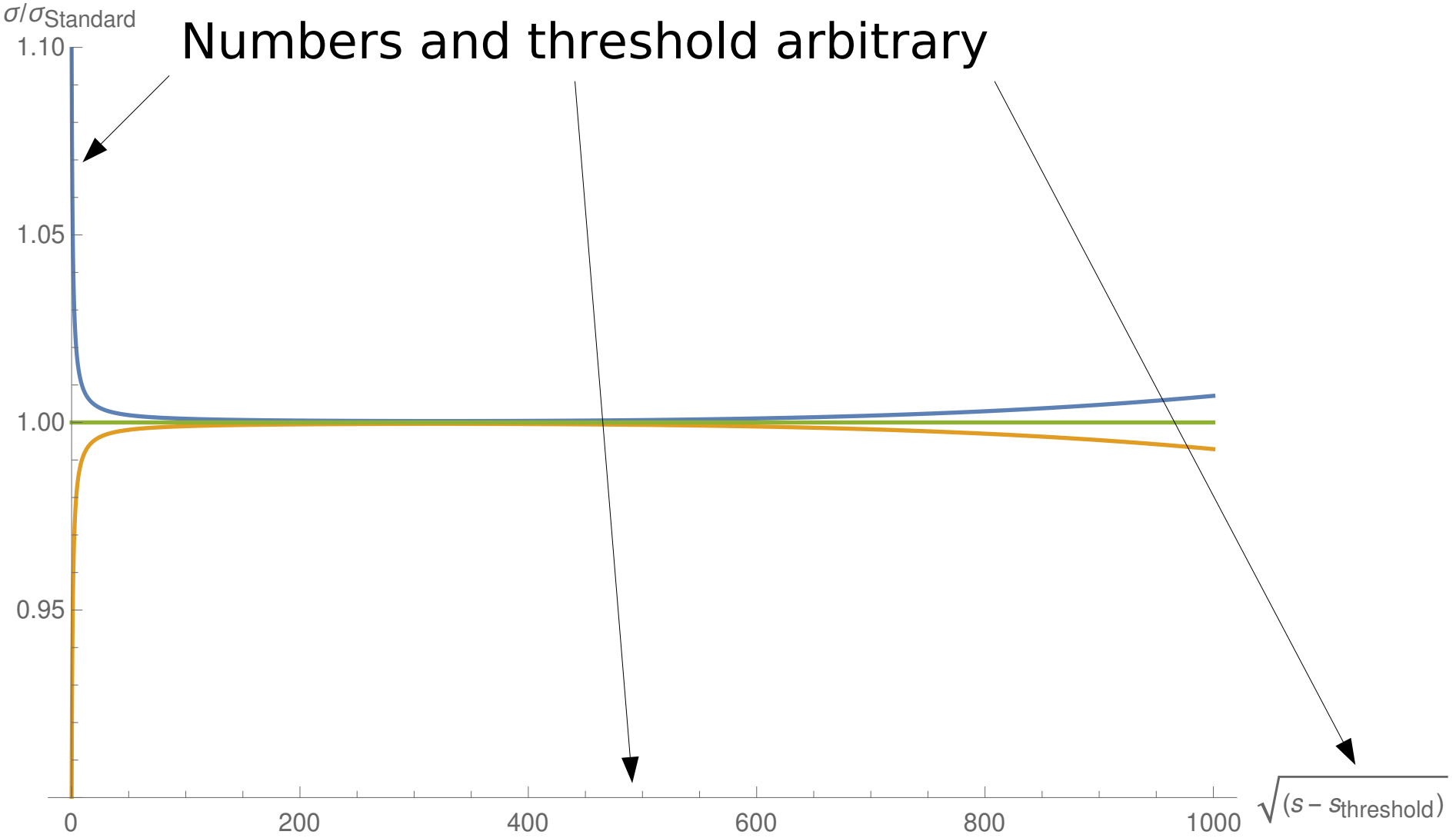

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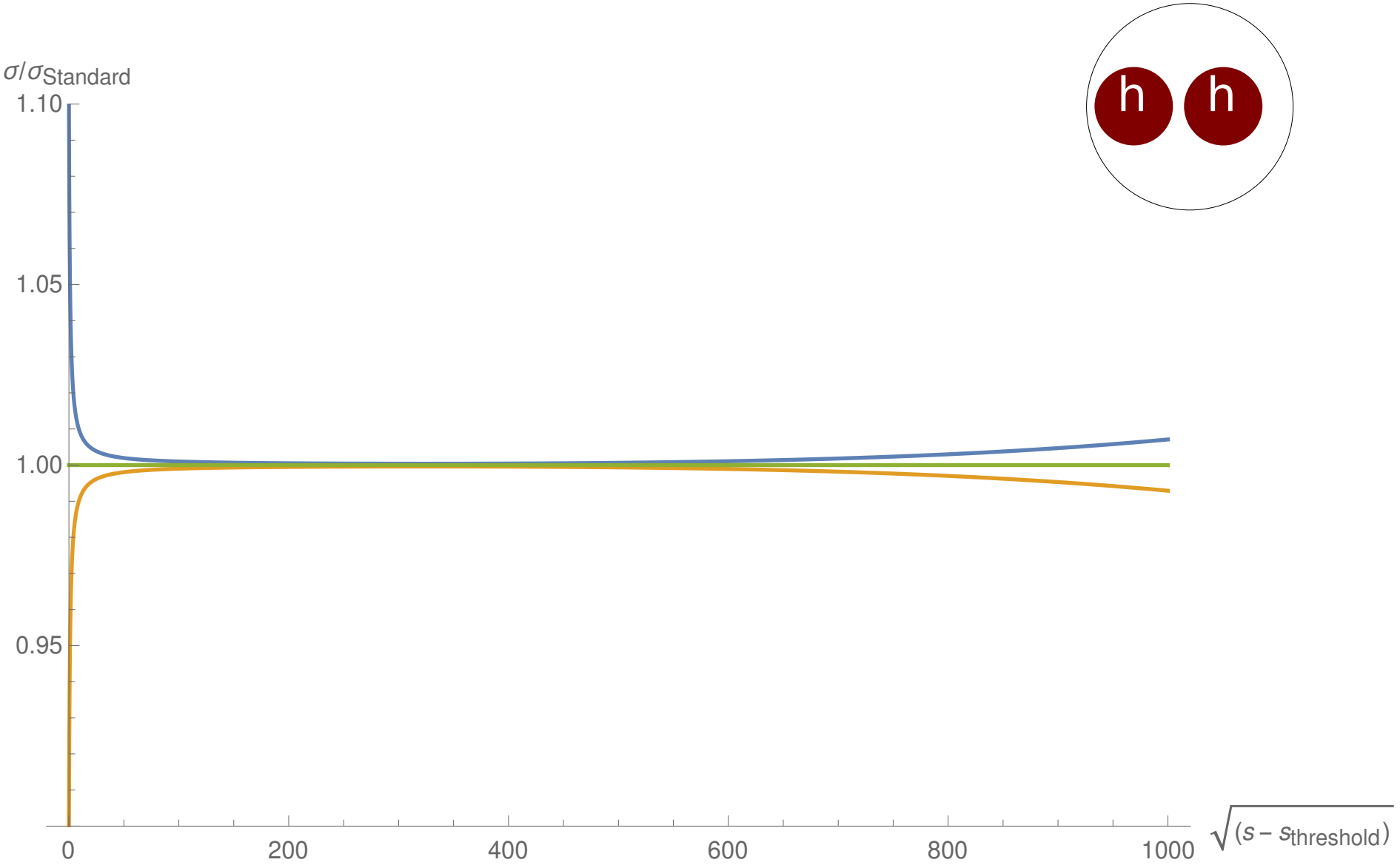

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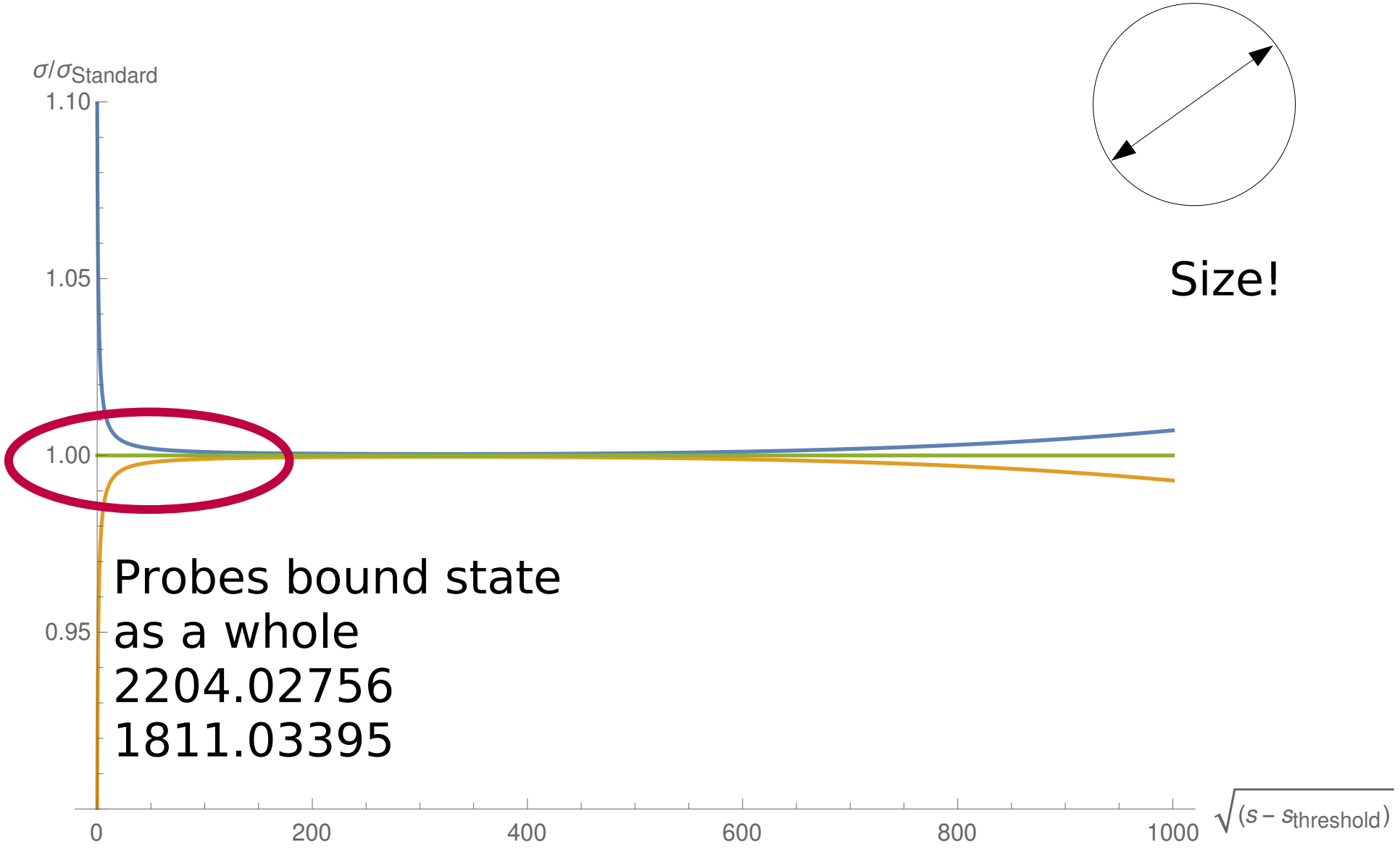

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Scattering length~"size"

Phase shift

Impact of the radius of the Higgs

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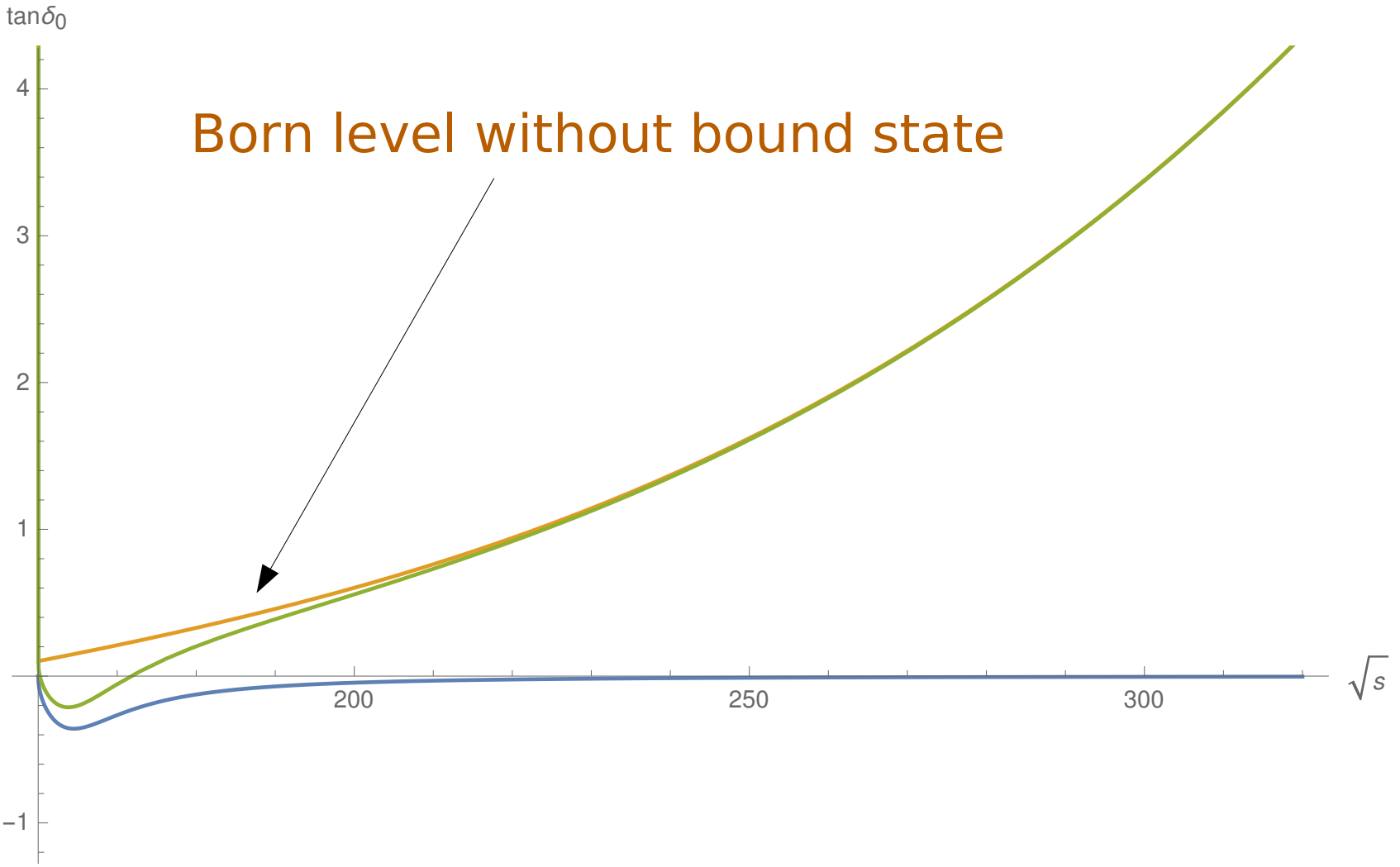
Impact of the radius of the Higgs



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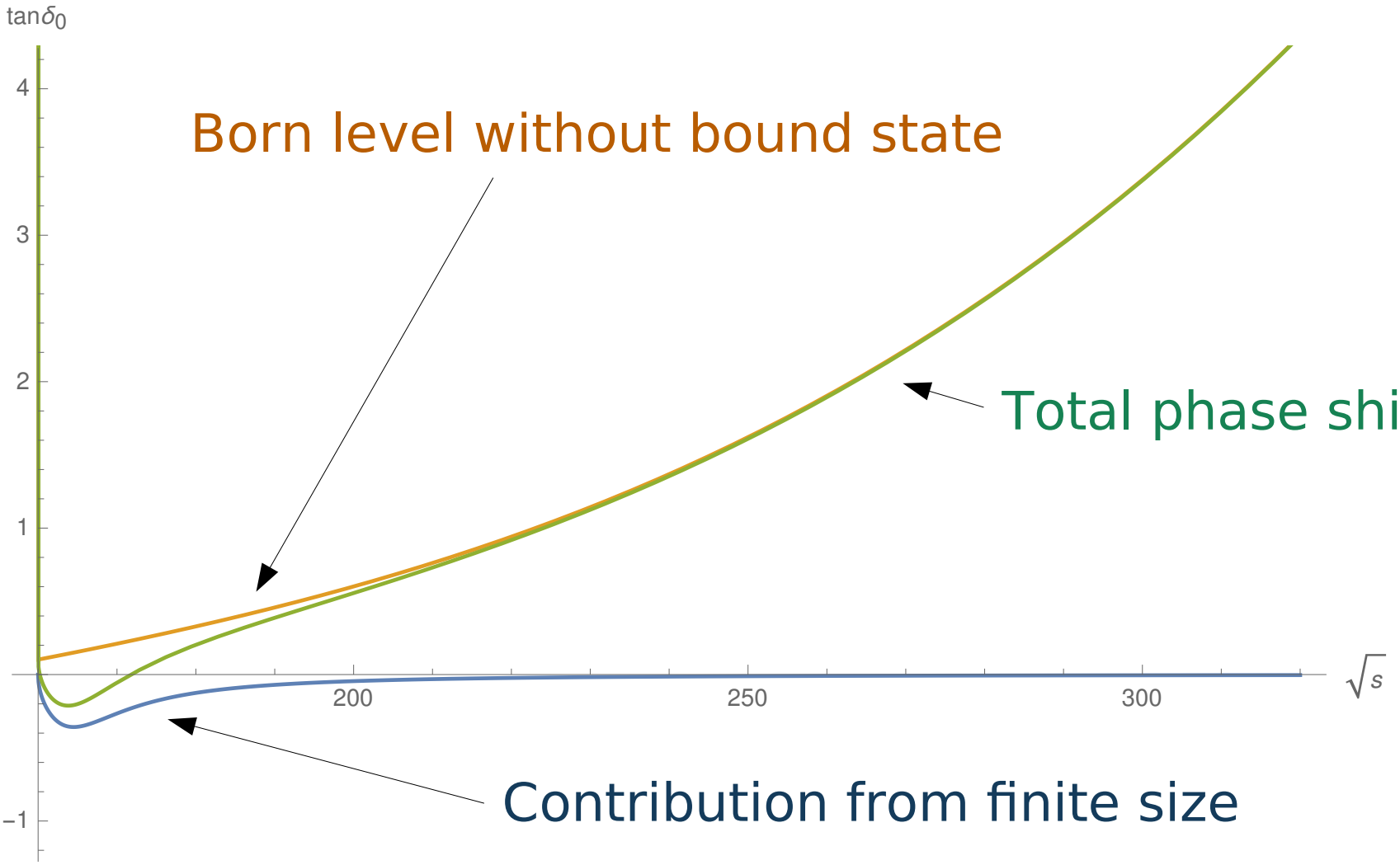

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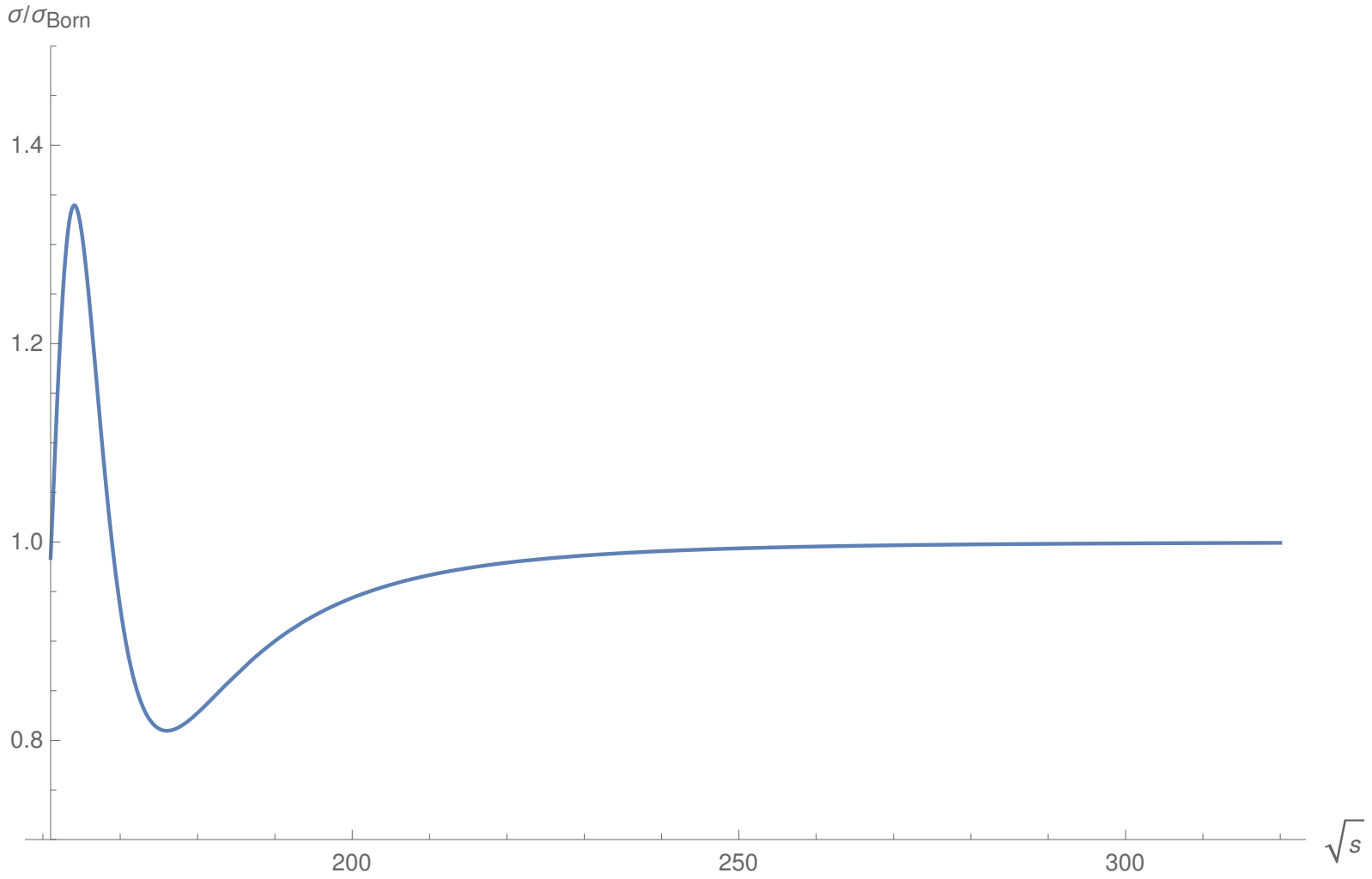

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Impact of the radius of the Higgs

[Jenny, Maas, Riederer'22]

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

Impact of the radius of the Higgs

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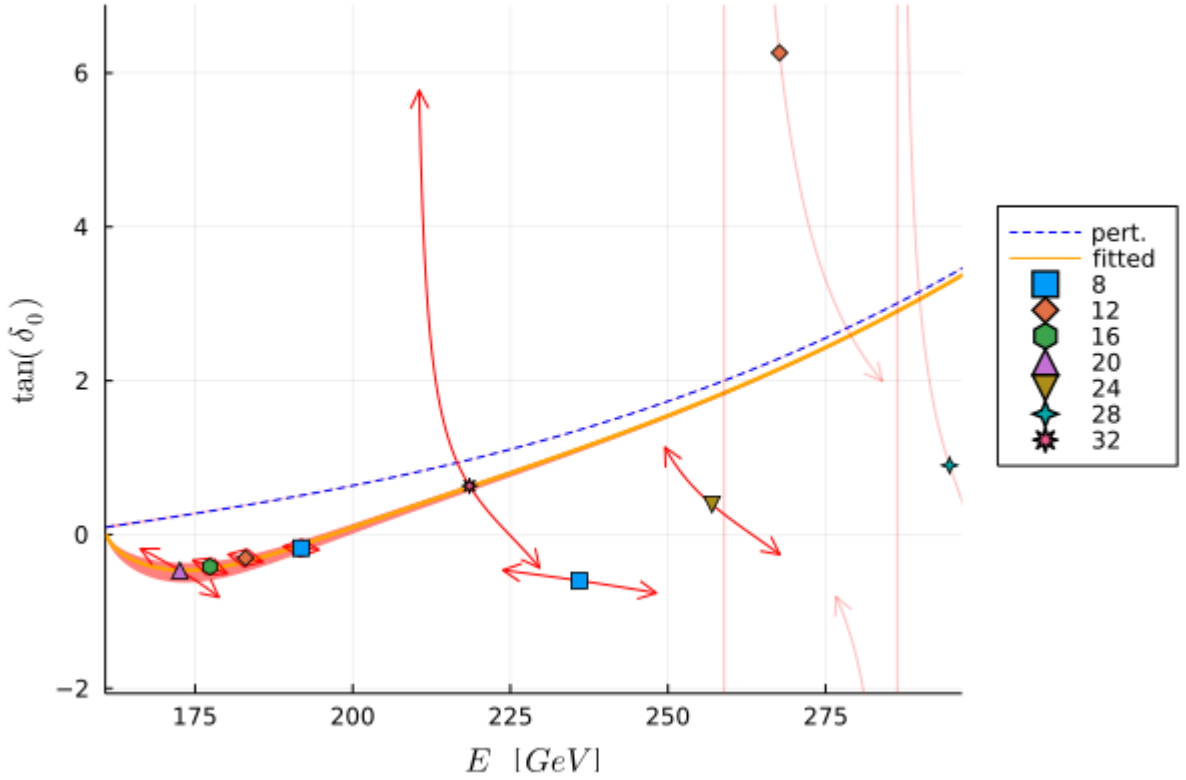

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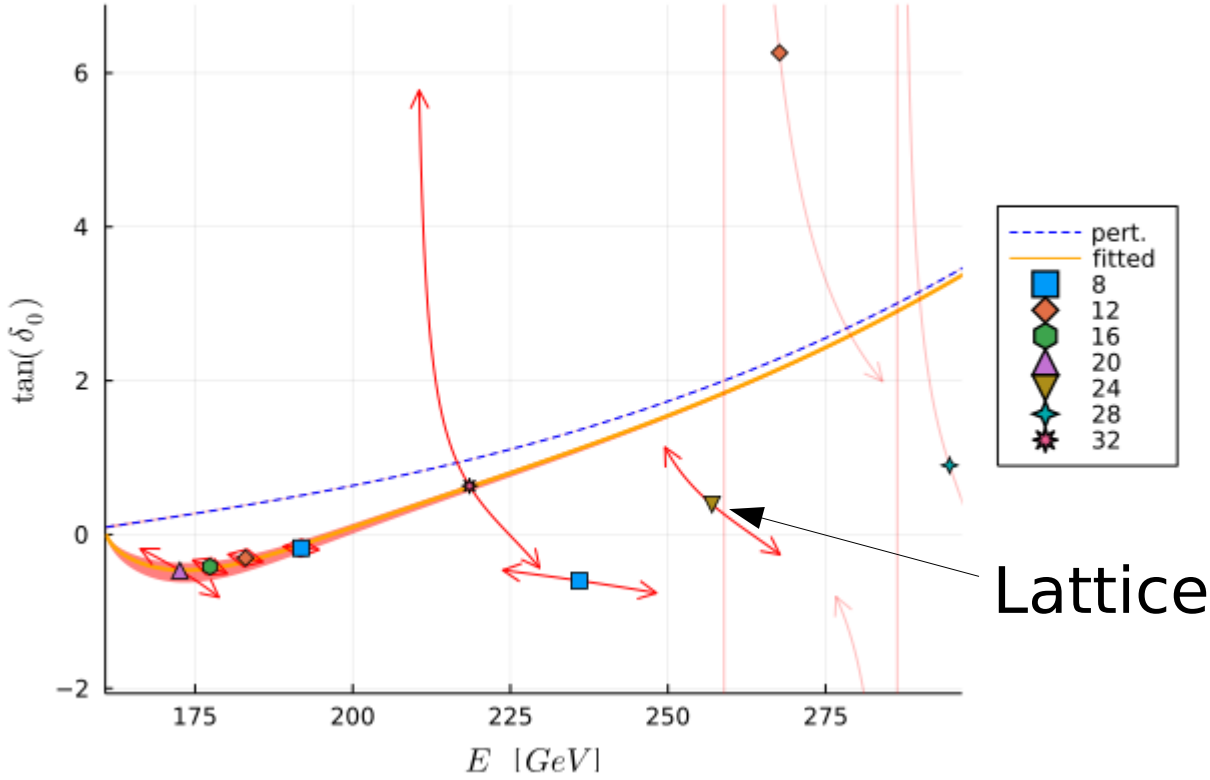

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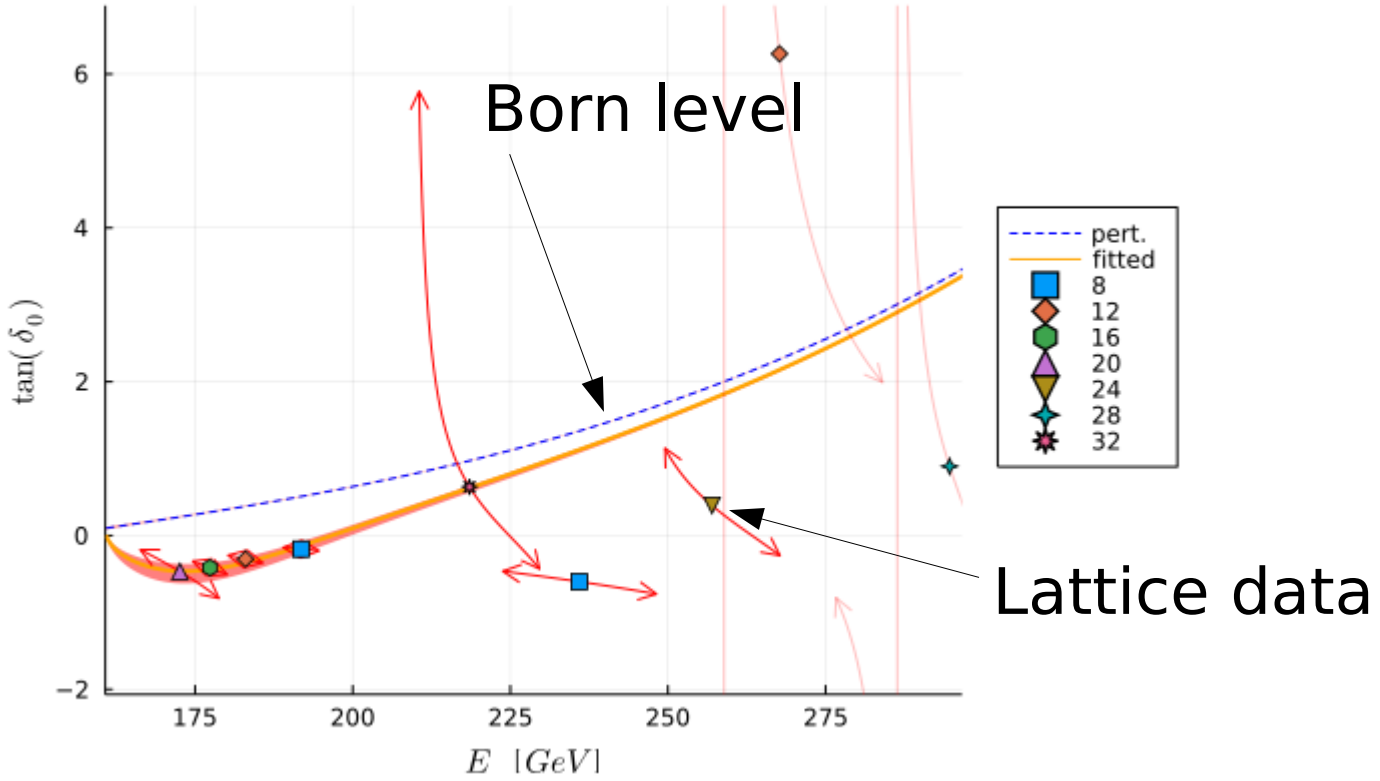

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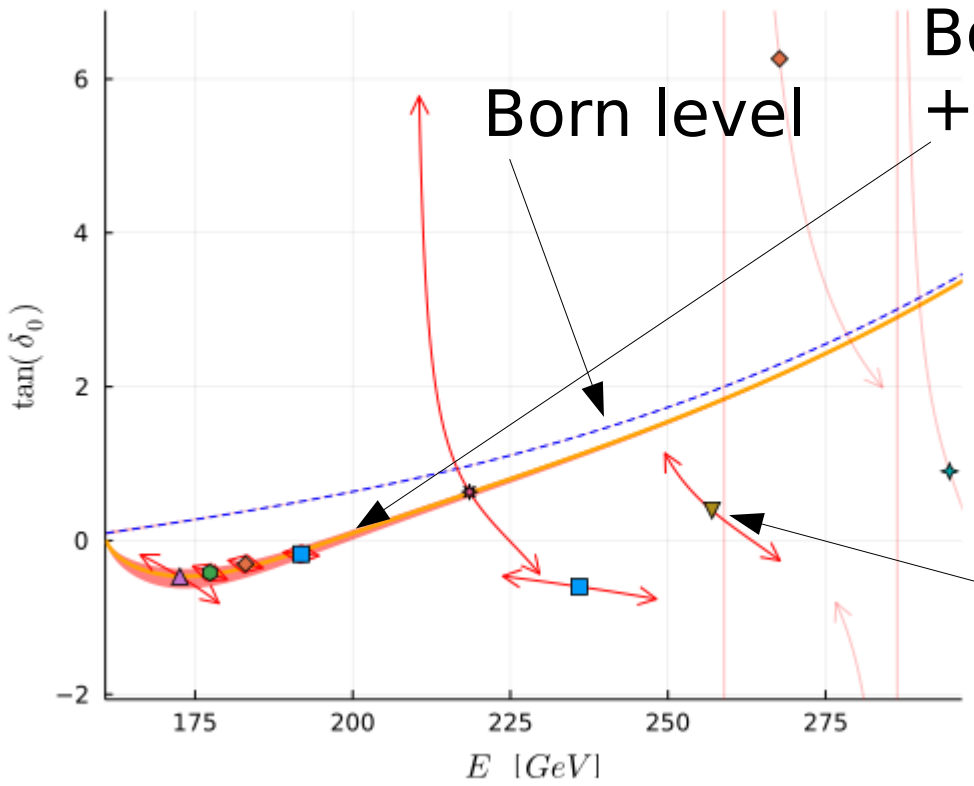

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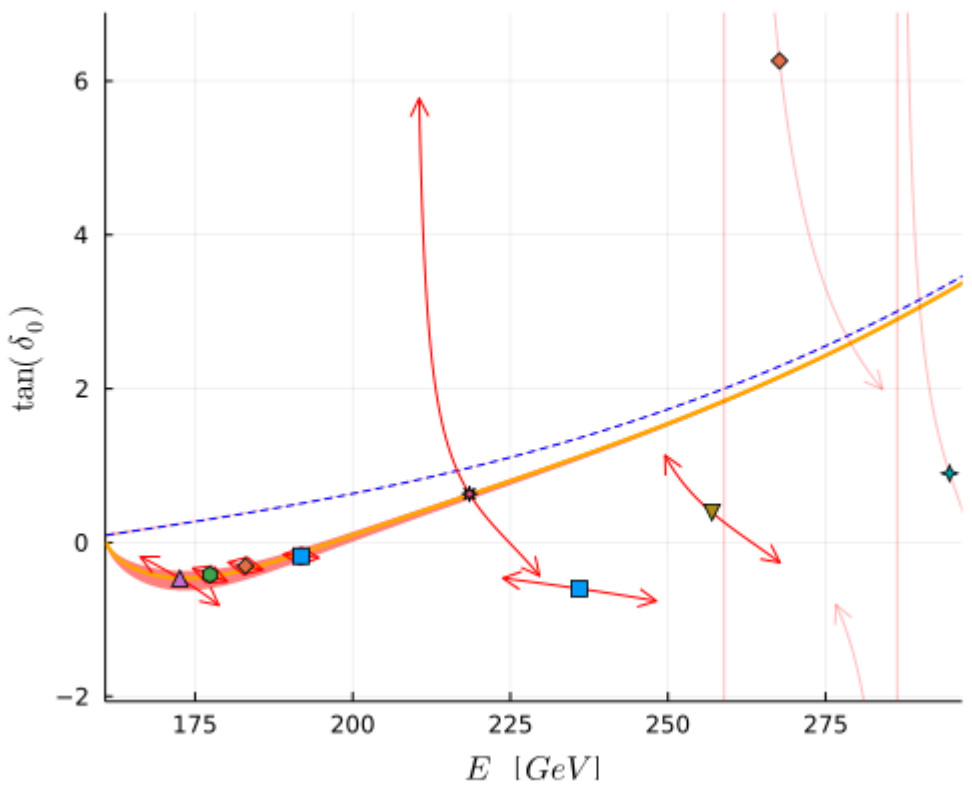

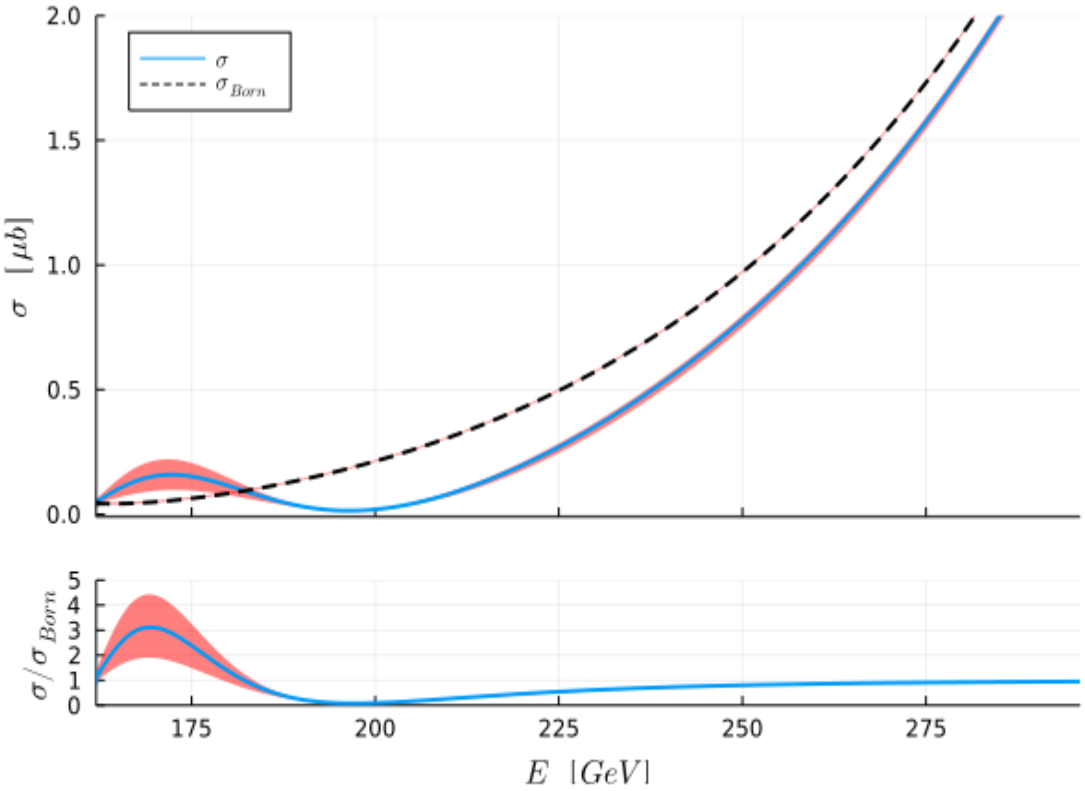

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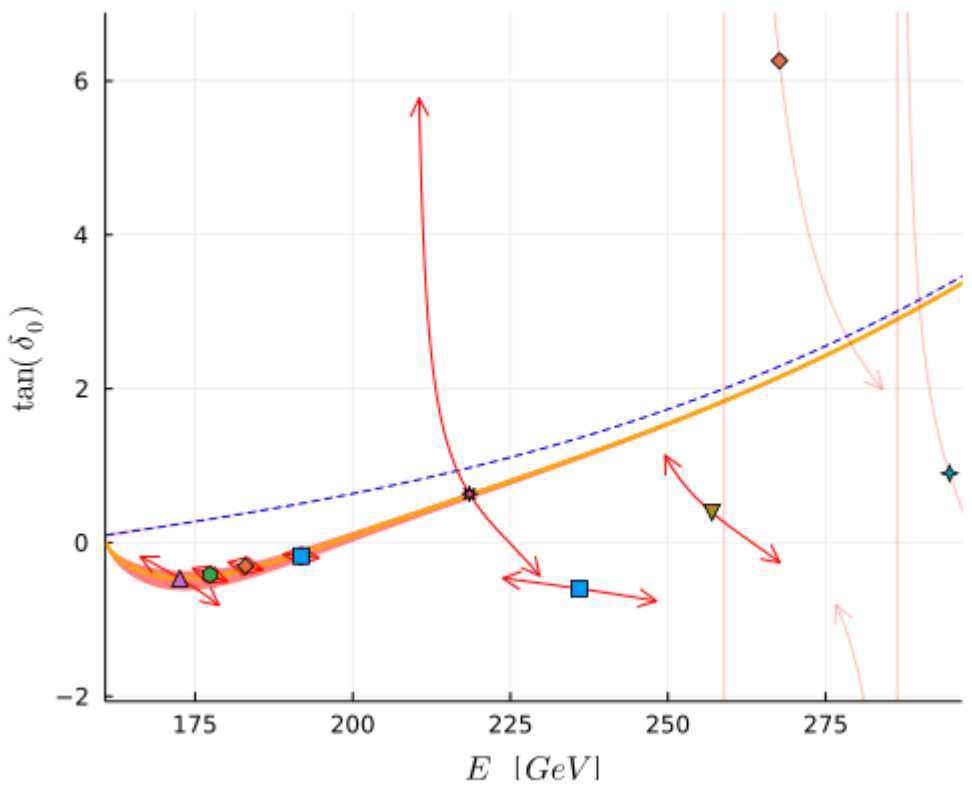

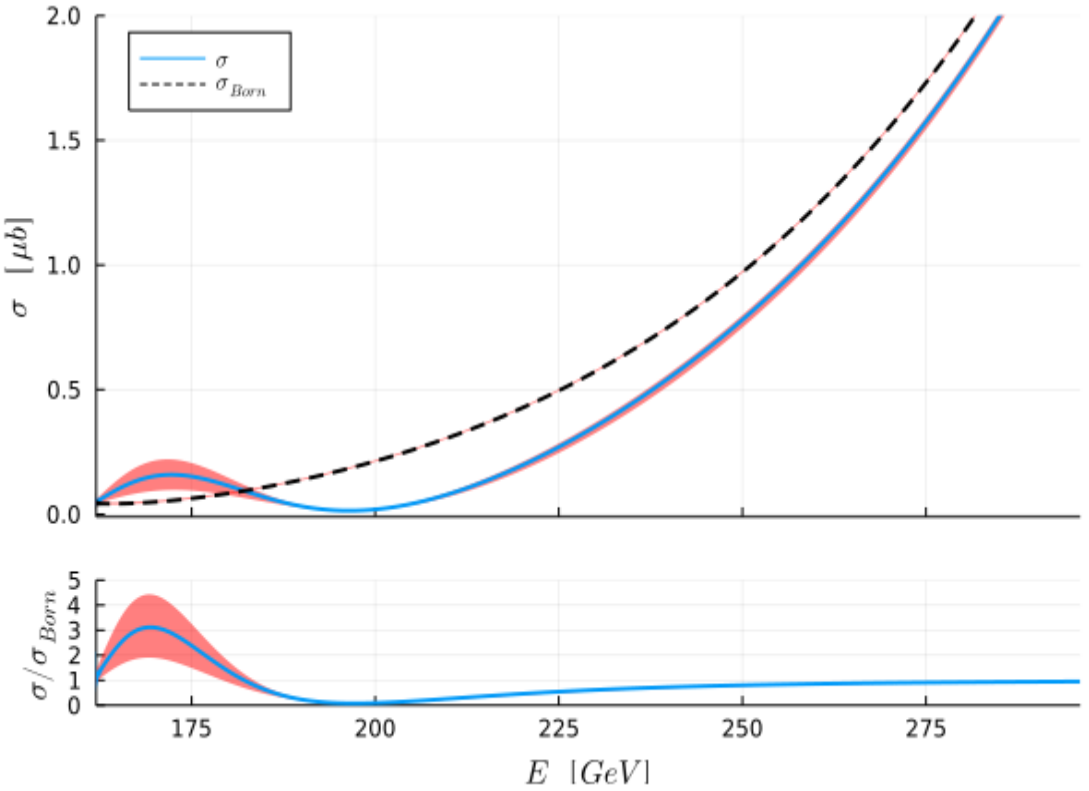

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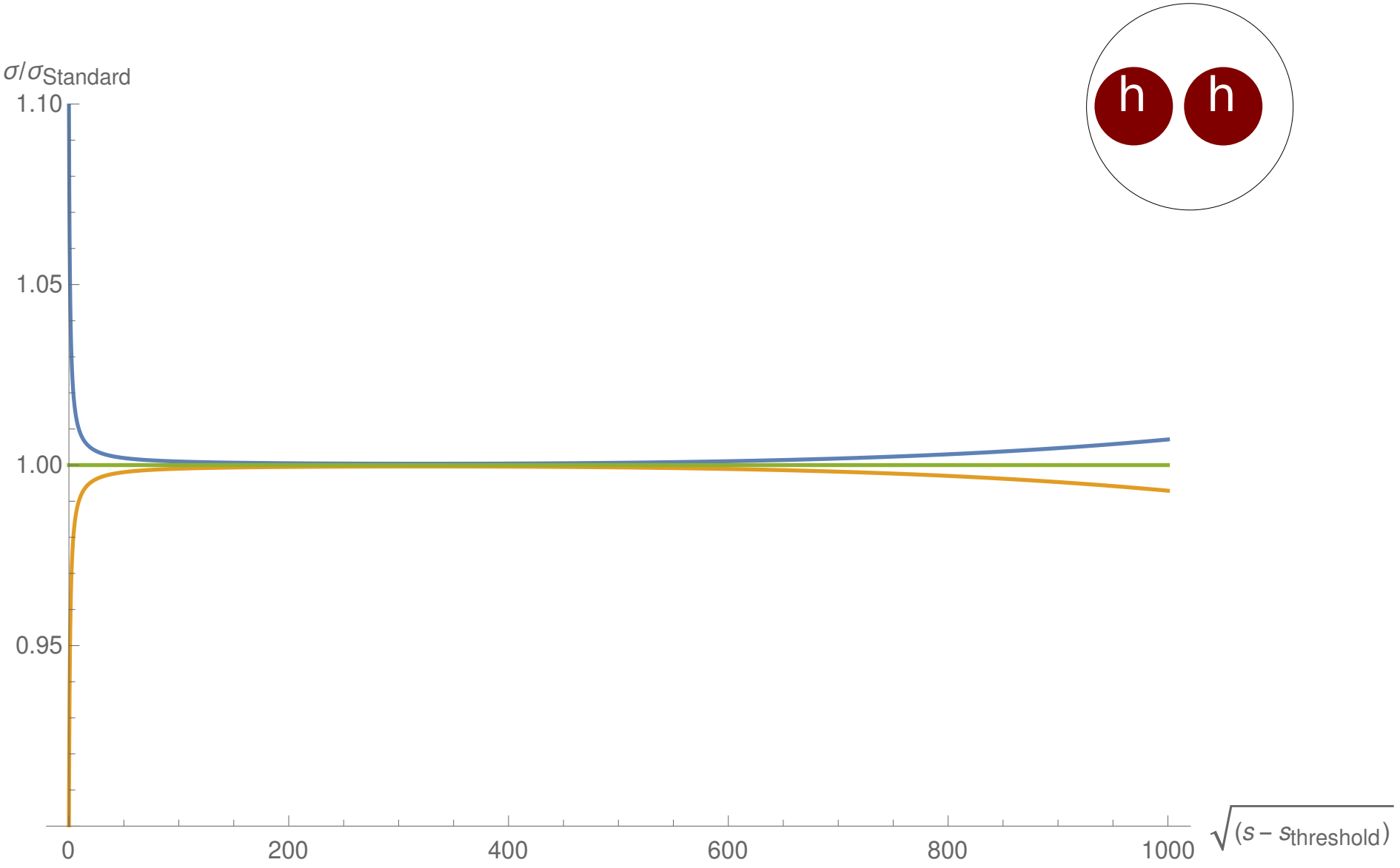
  - Qualitatively but not quantitatively
- Trend seen in ATLAS/CMS off-shell ZZ→ 4l [Talks @Higgs 2022]
  - 1.11(7) 180-220 GeV (ATLAS)/~0.8(2) 220-275 GeV (CMS)

Generic behavior: DIS-like



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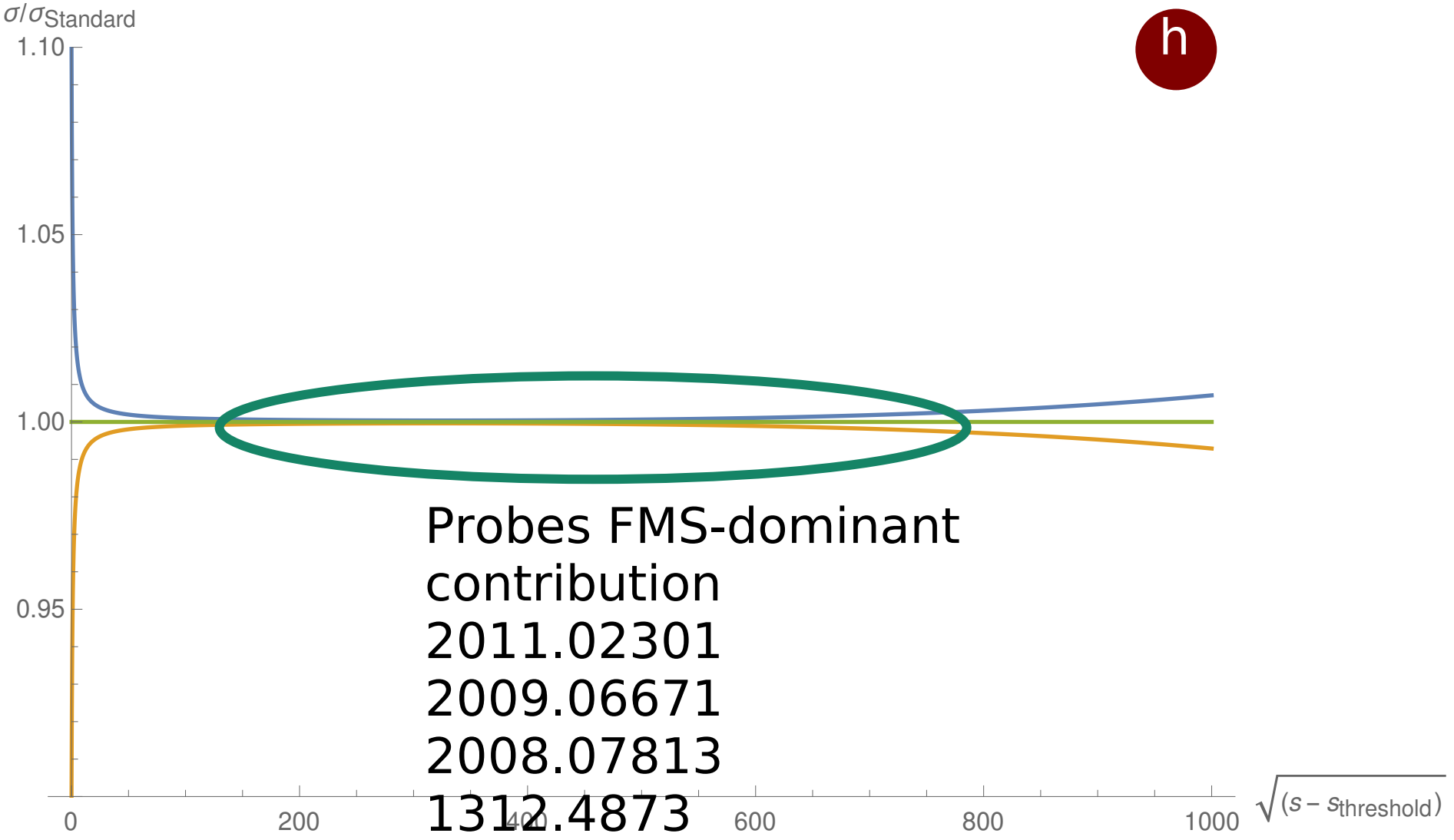

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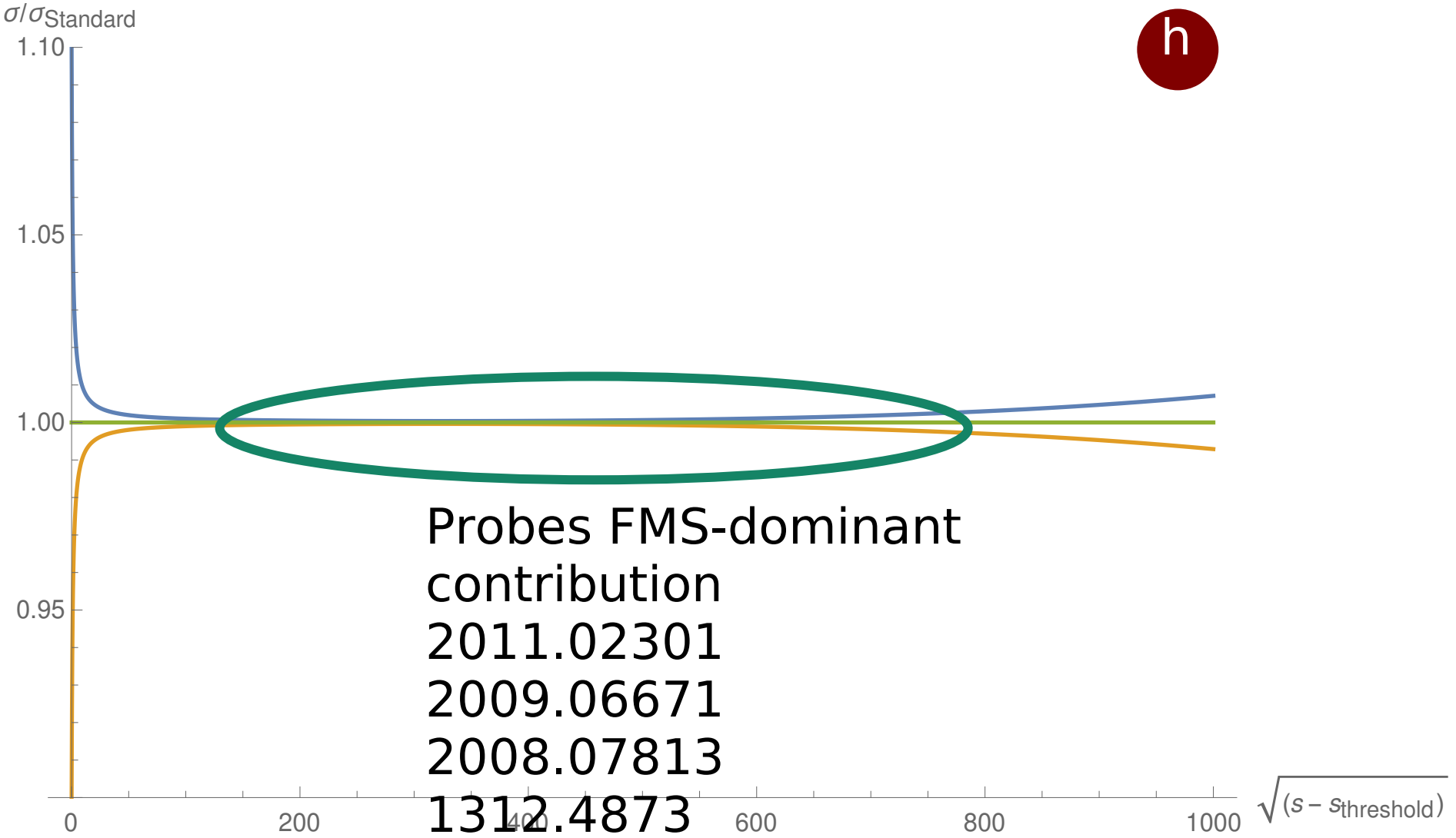


Probes FMS-dominant contribution

2011.02301

2009.06671

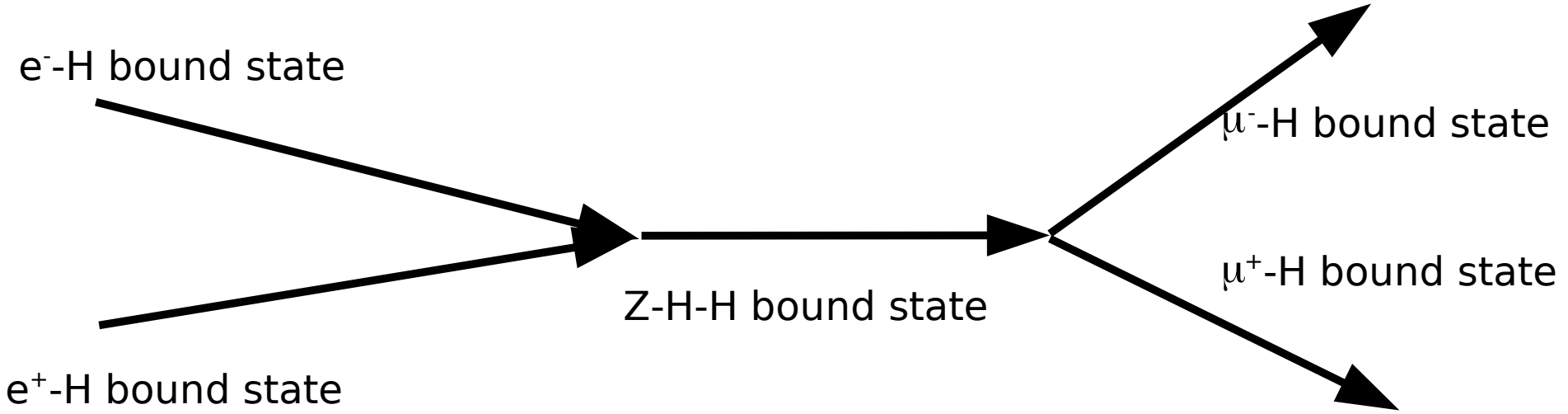
2008.07813

1312.4873

Standard pheno!

How events looks like (LEP/ILC)

[Maas'12]



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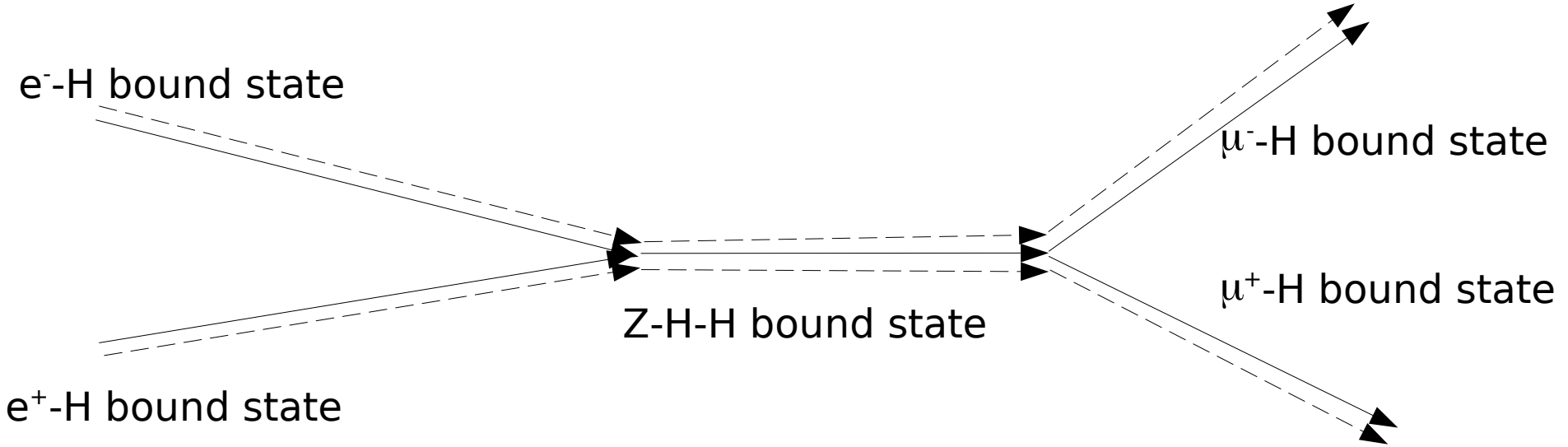

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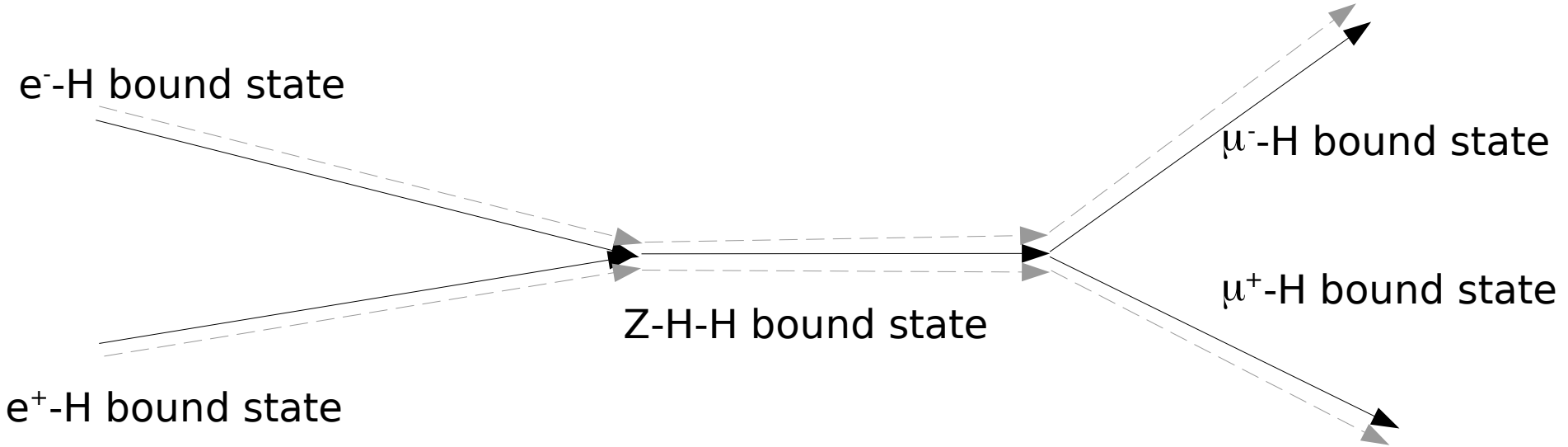
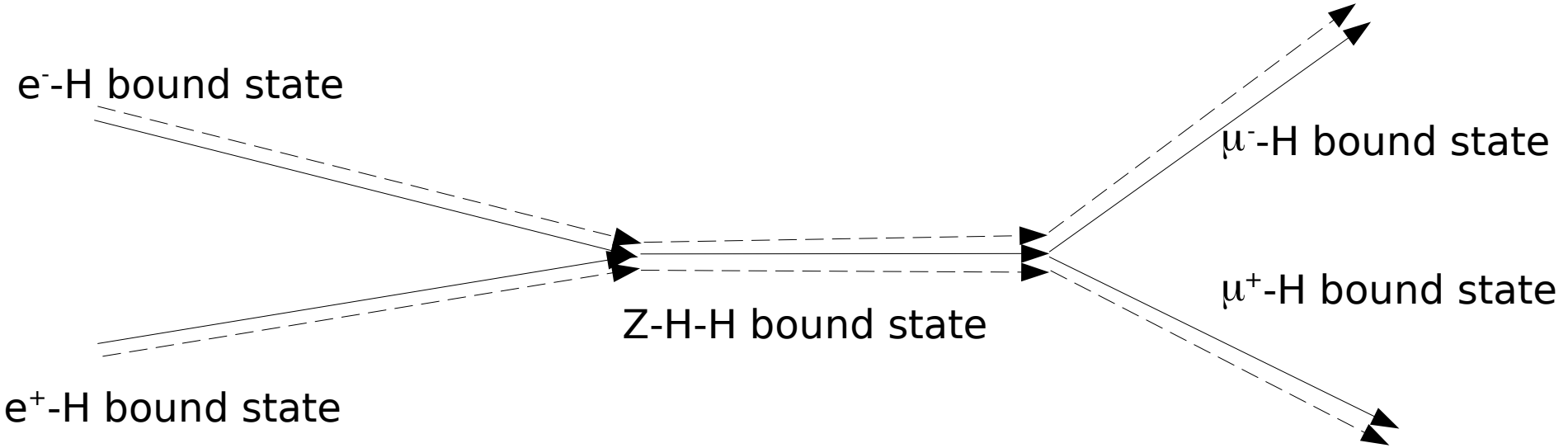


- Collision of bound states - 'constituent' particles
- Standard perturbation theory
  - Higgs partners just spectators
  - Similar to pp collisions

How events looks like (LEP/ILC)

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



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

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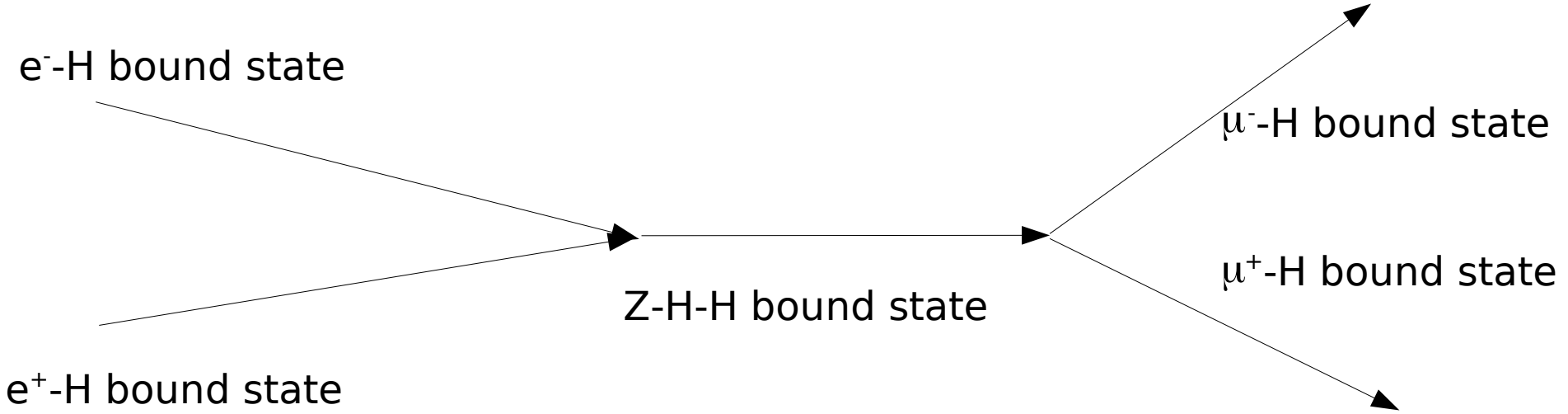

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NLO: 1525 diagrams

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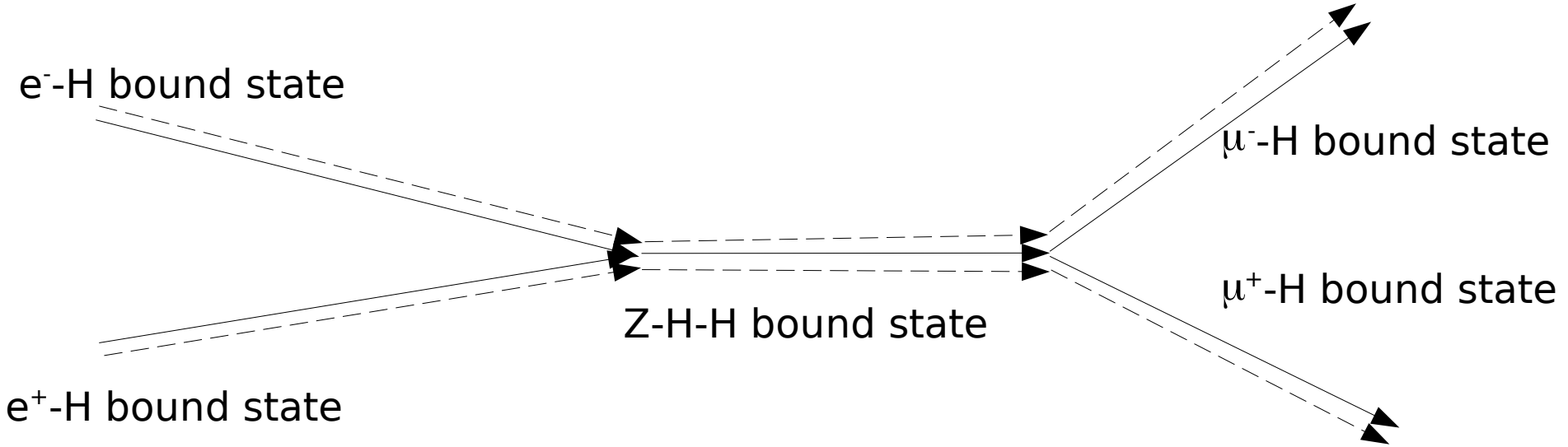

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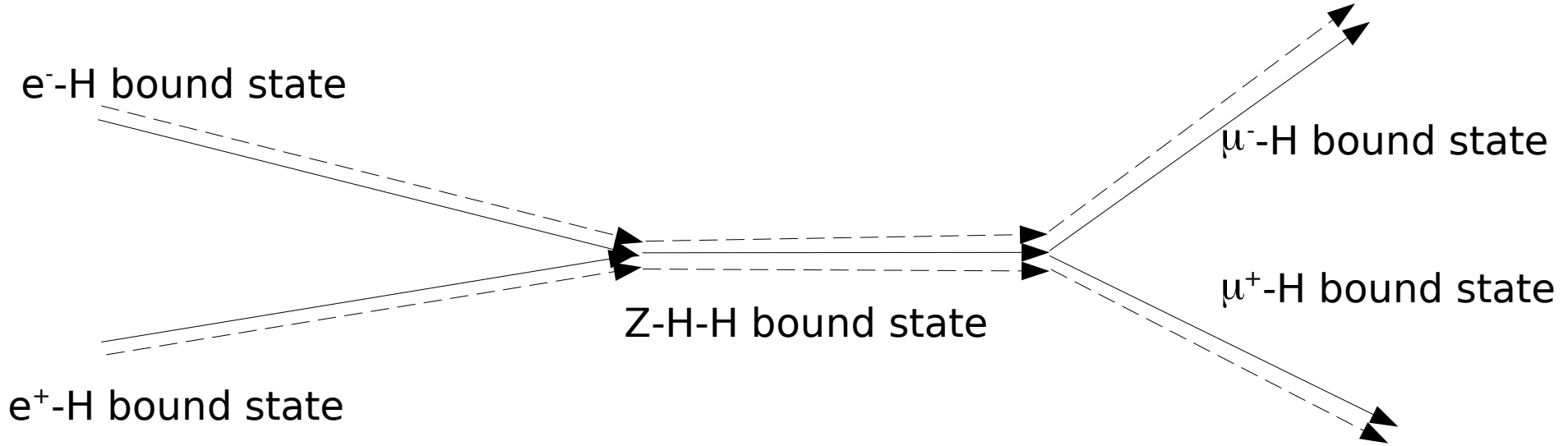

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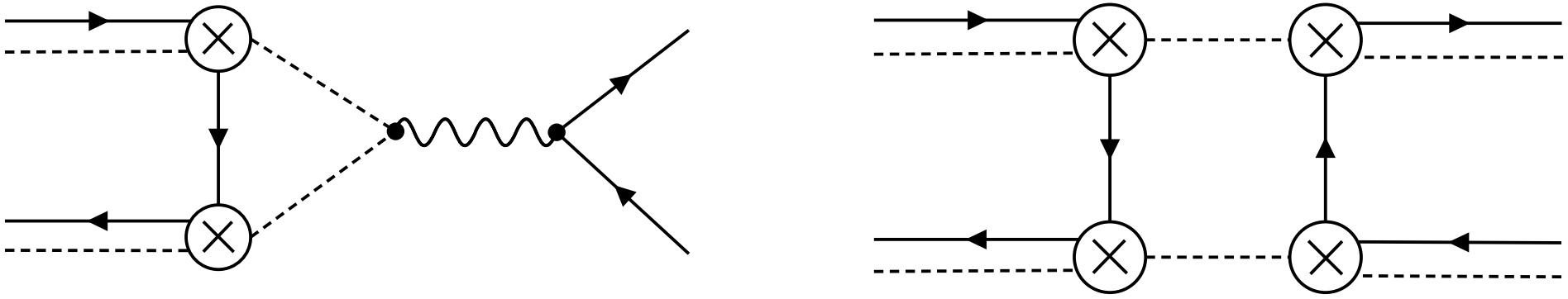

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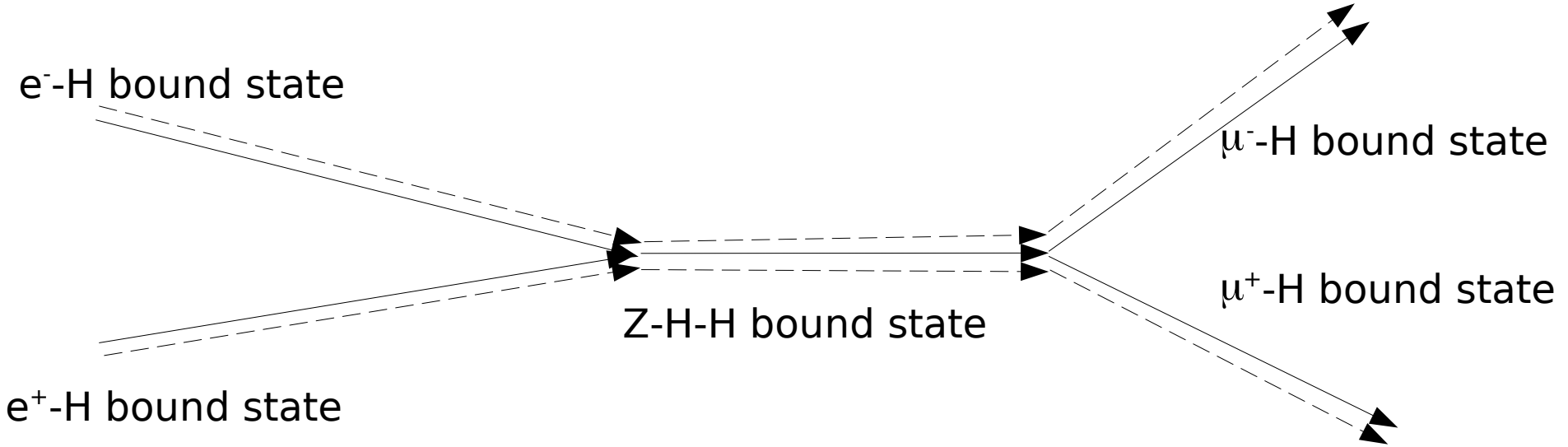

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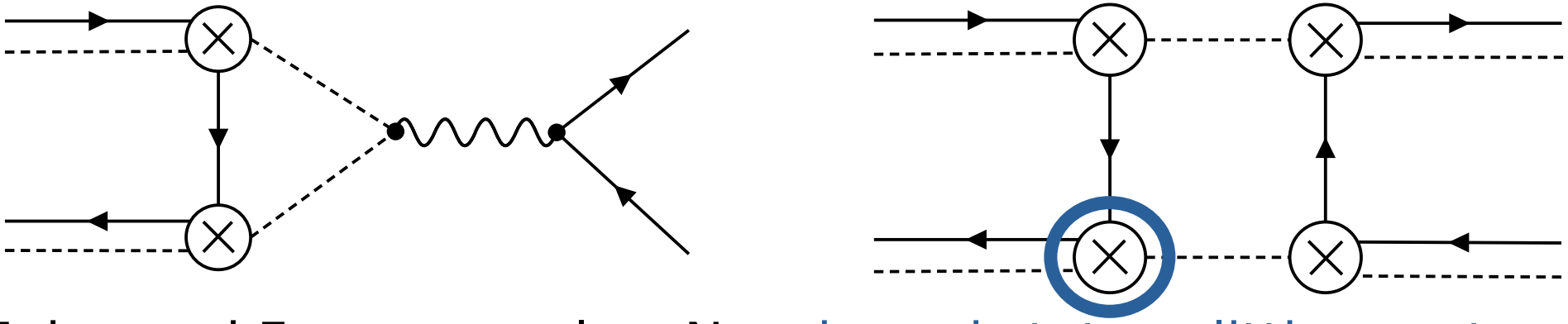

Enhanced Feynman rules: New bound state splitting vertex

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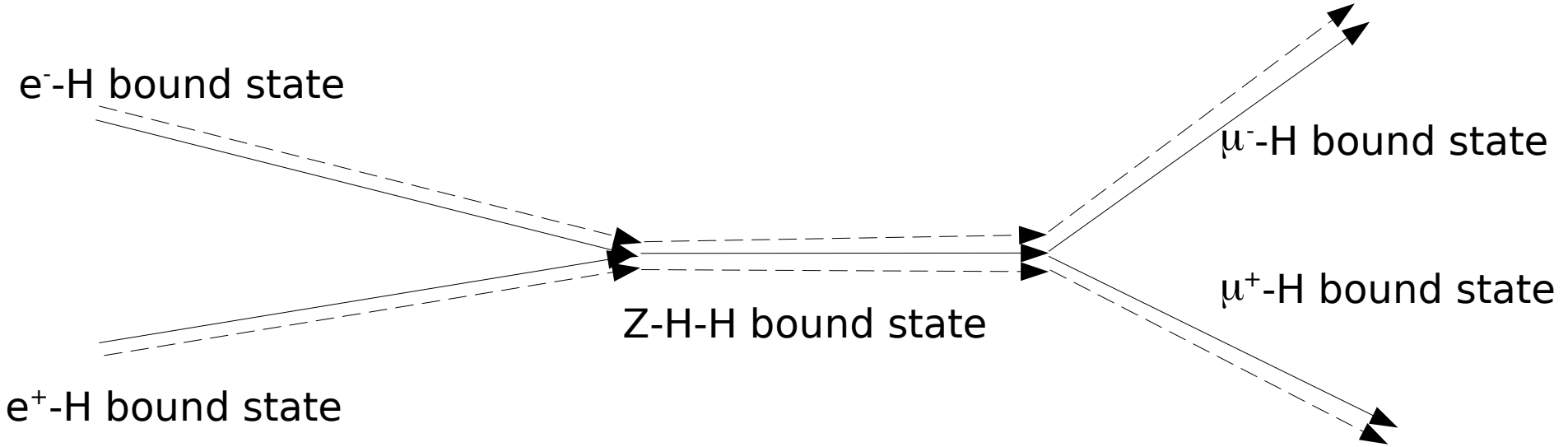

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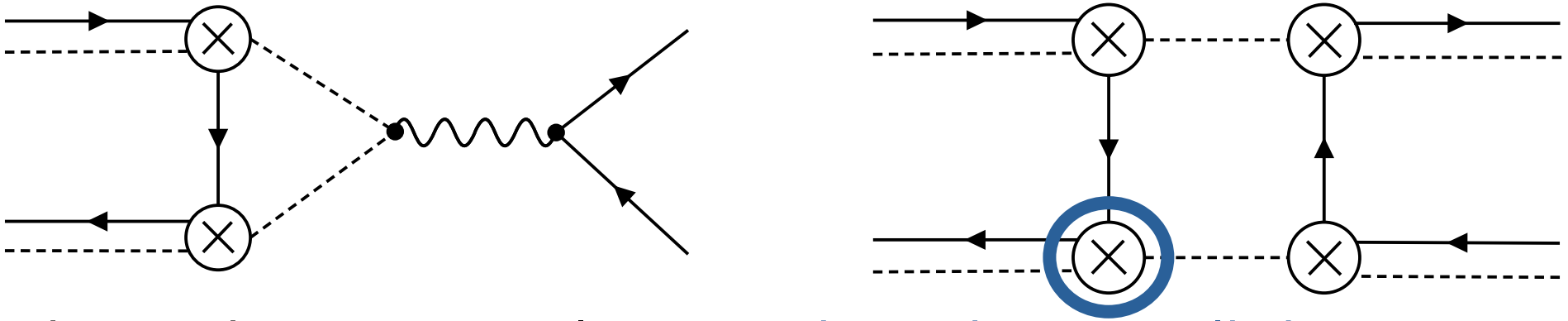

Enhanced Feynman rules: New bound state splitting vertex

Can be calculated with standard tools: Managable

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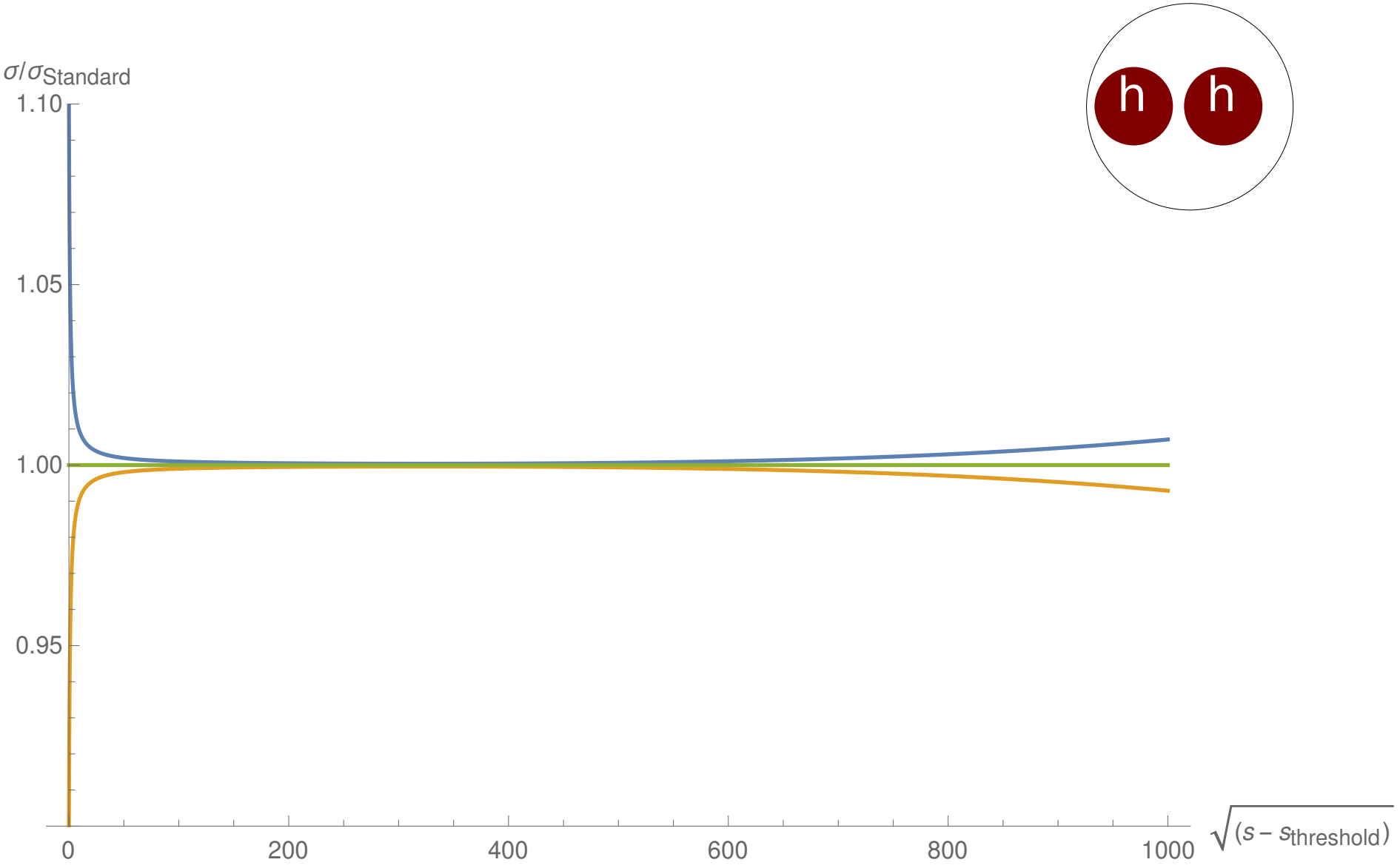

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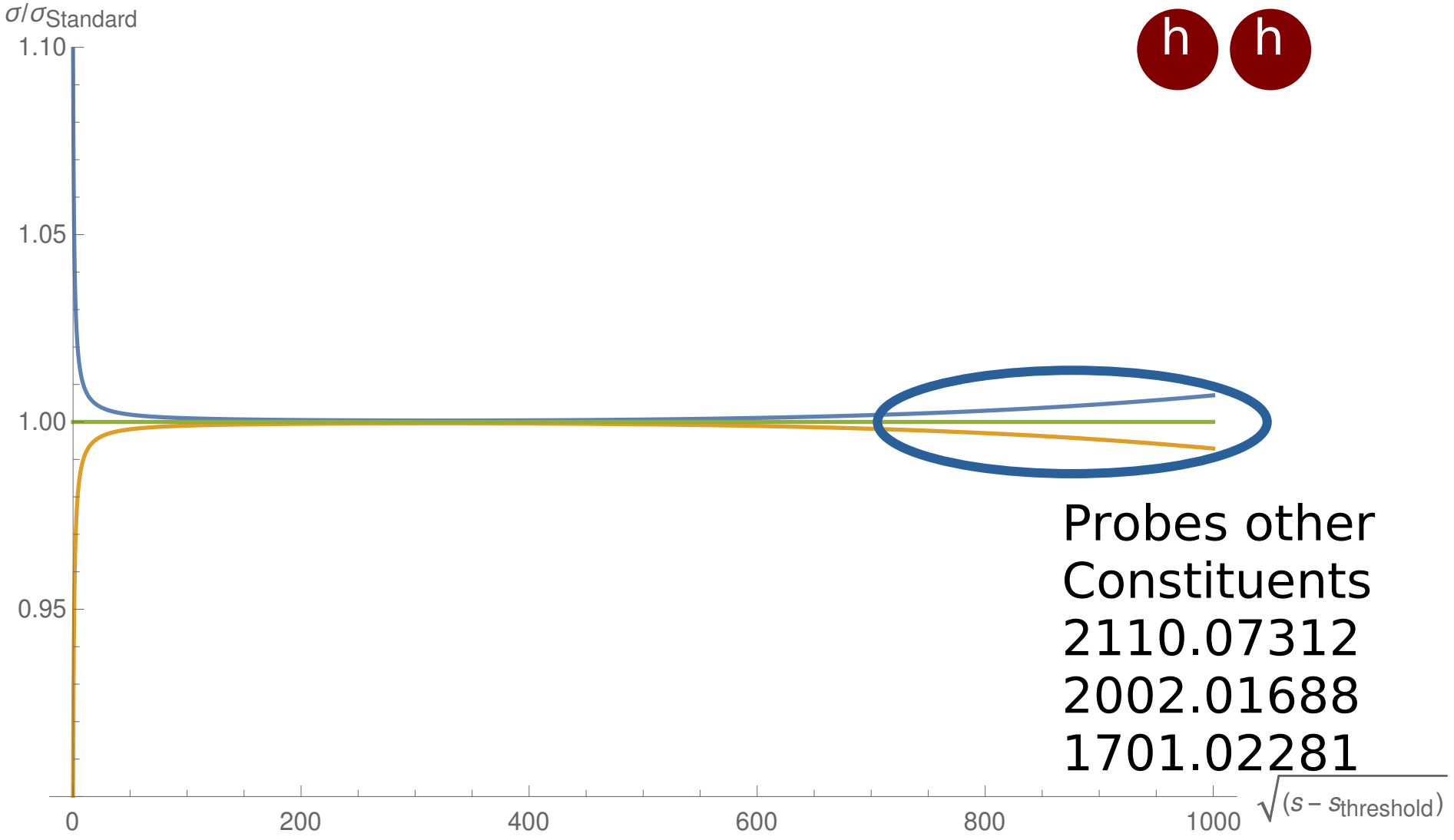

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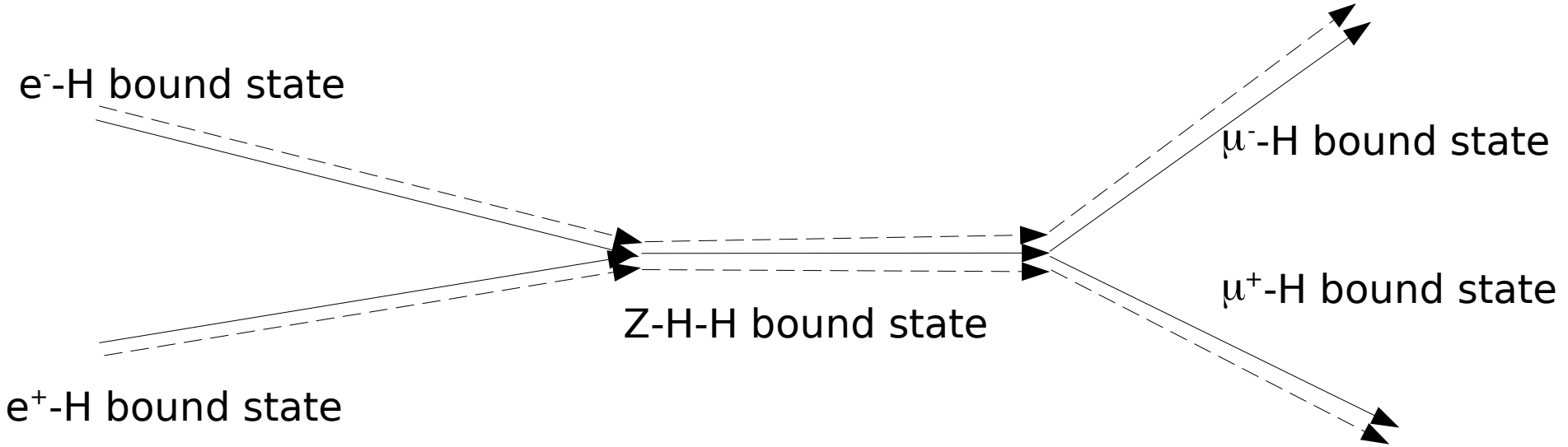

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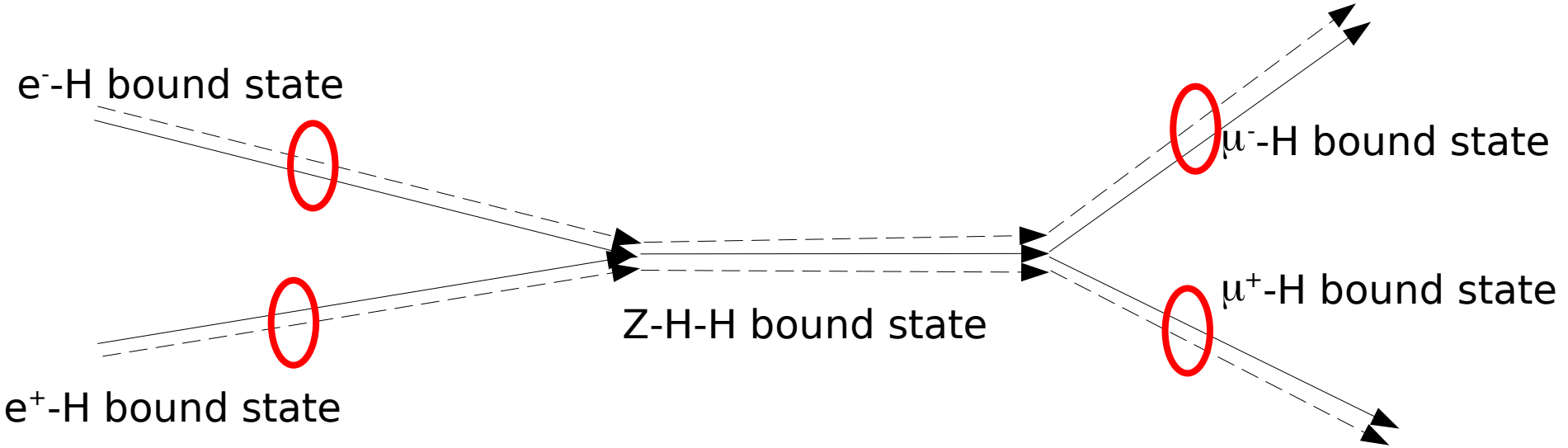

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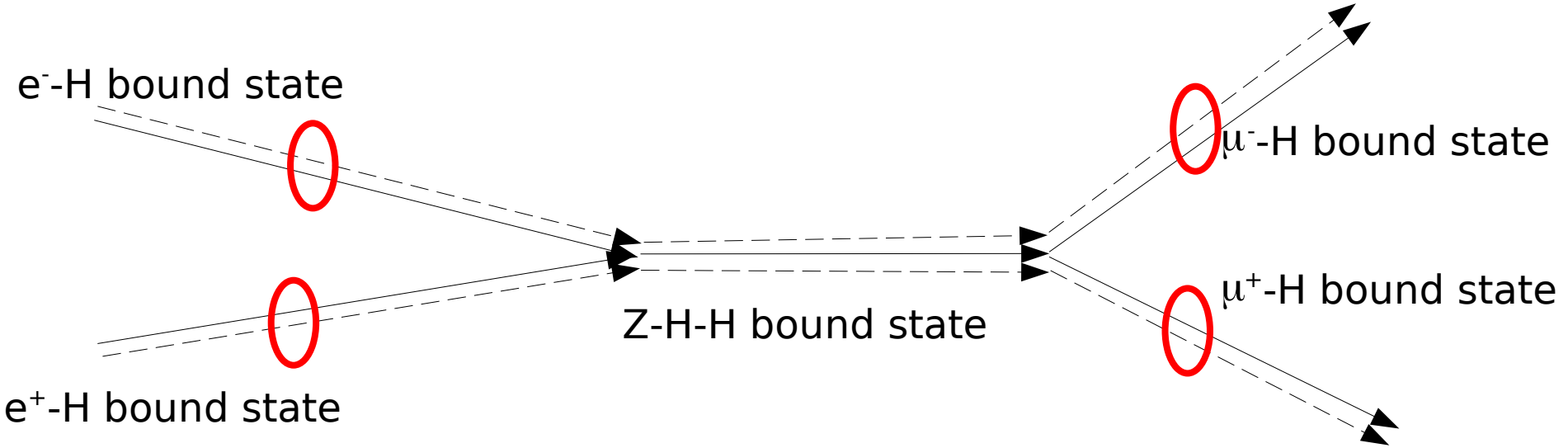

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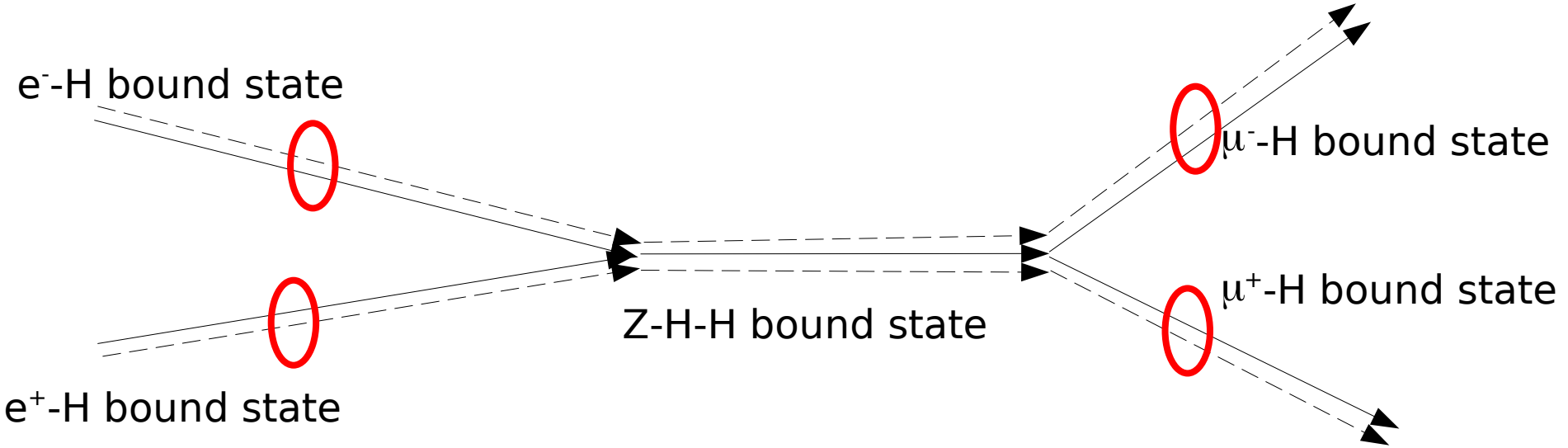
[Maas'12, Maas, Reiner'22 Fernbach et al.'20]



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Beyond the standard model

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

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Toy model: SU(3)+Higgs

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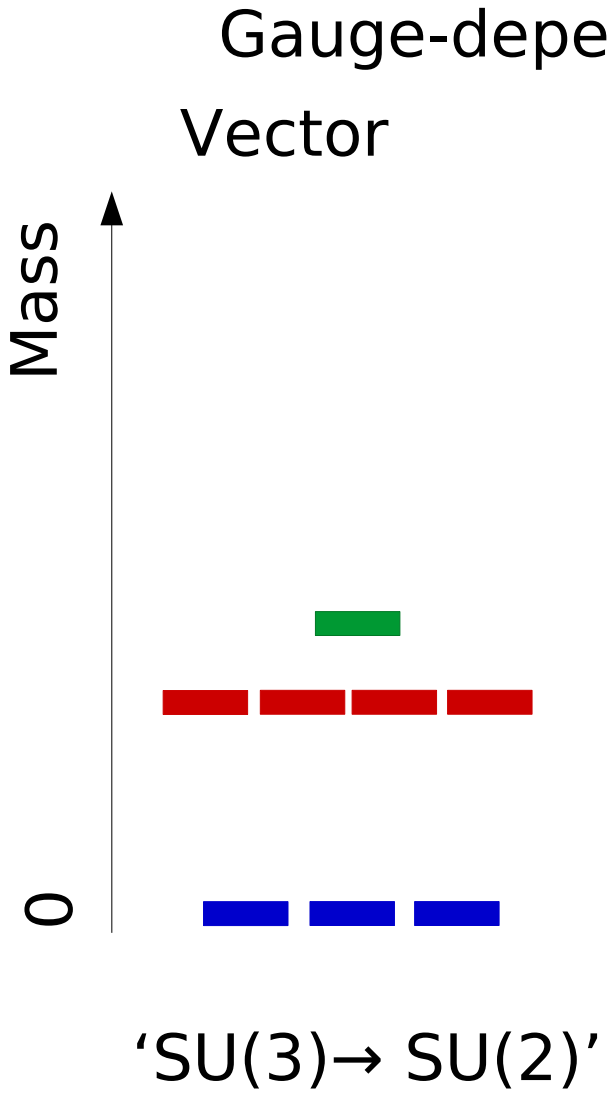

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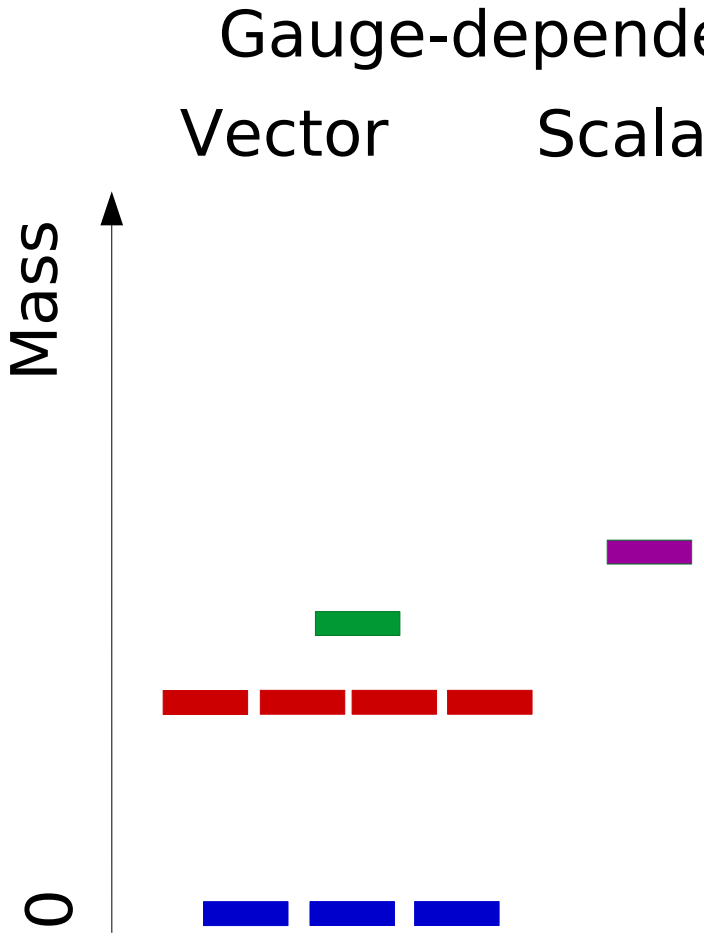

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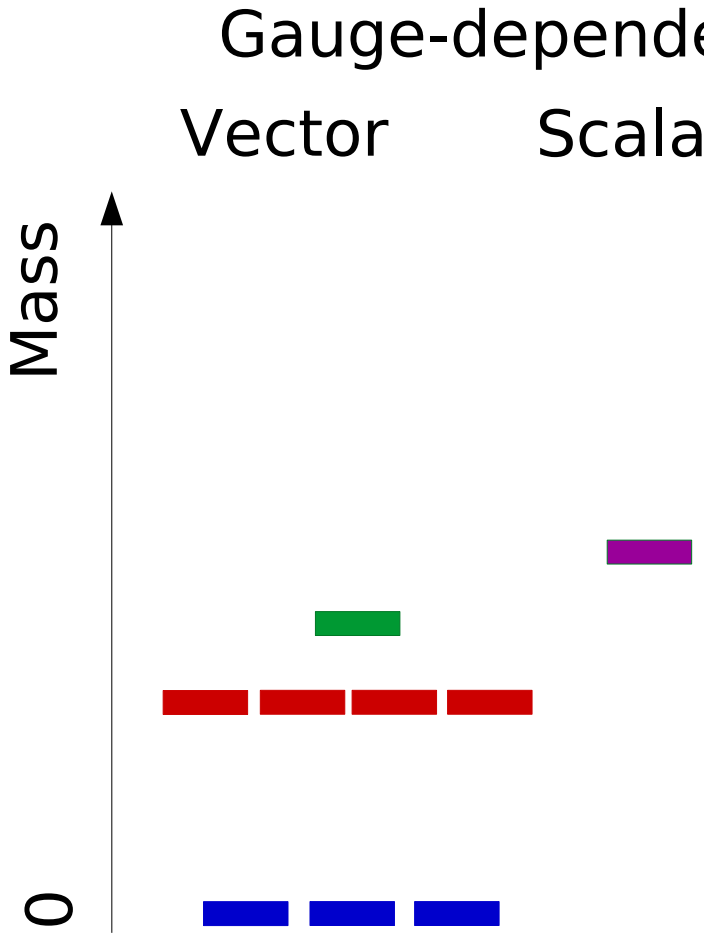

Confirmed in gauge-fixed lattice calculations [Maas et al.'16]

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[Maas & Törek'16,'18
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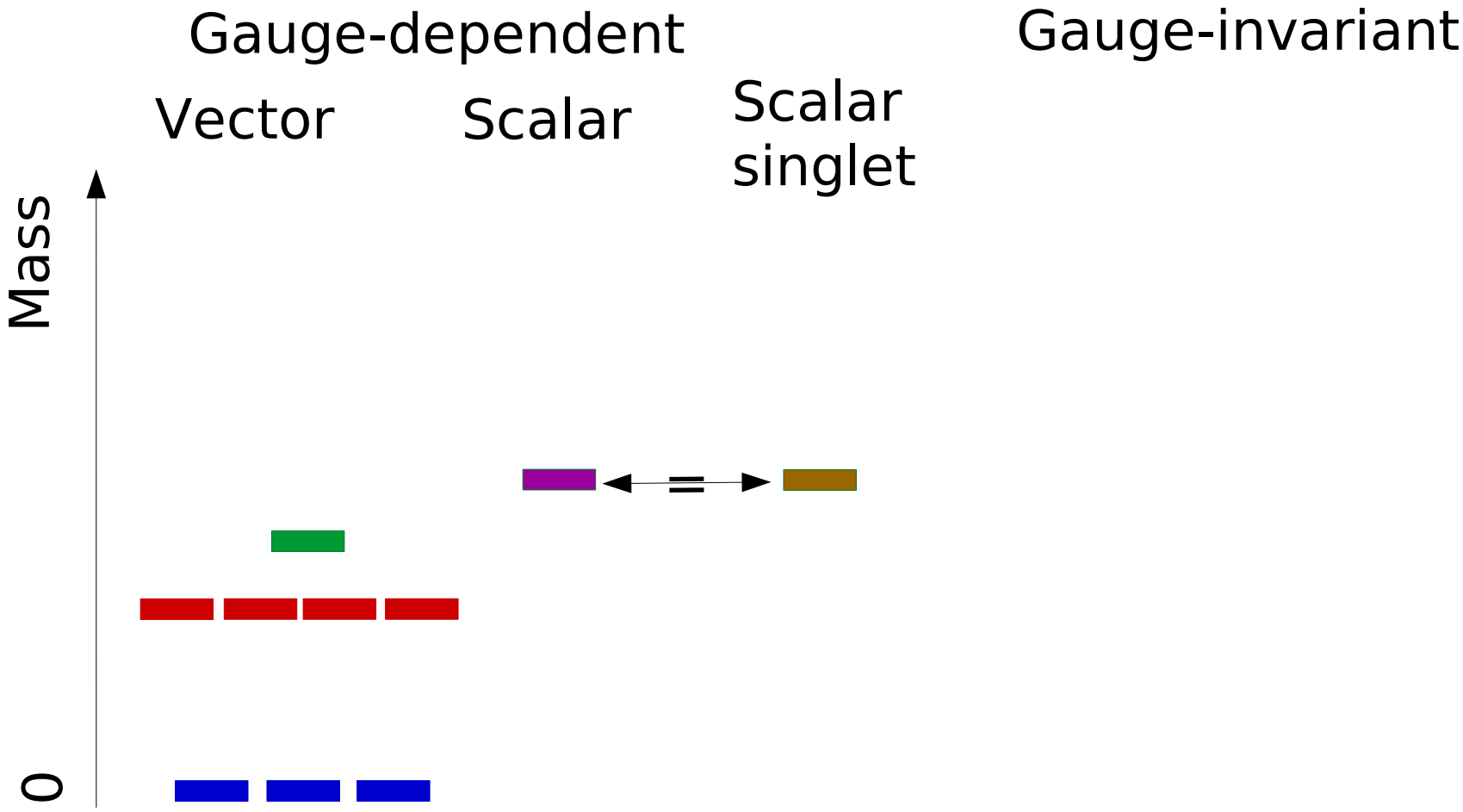

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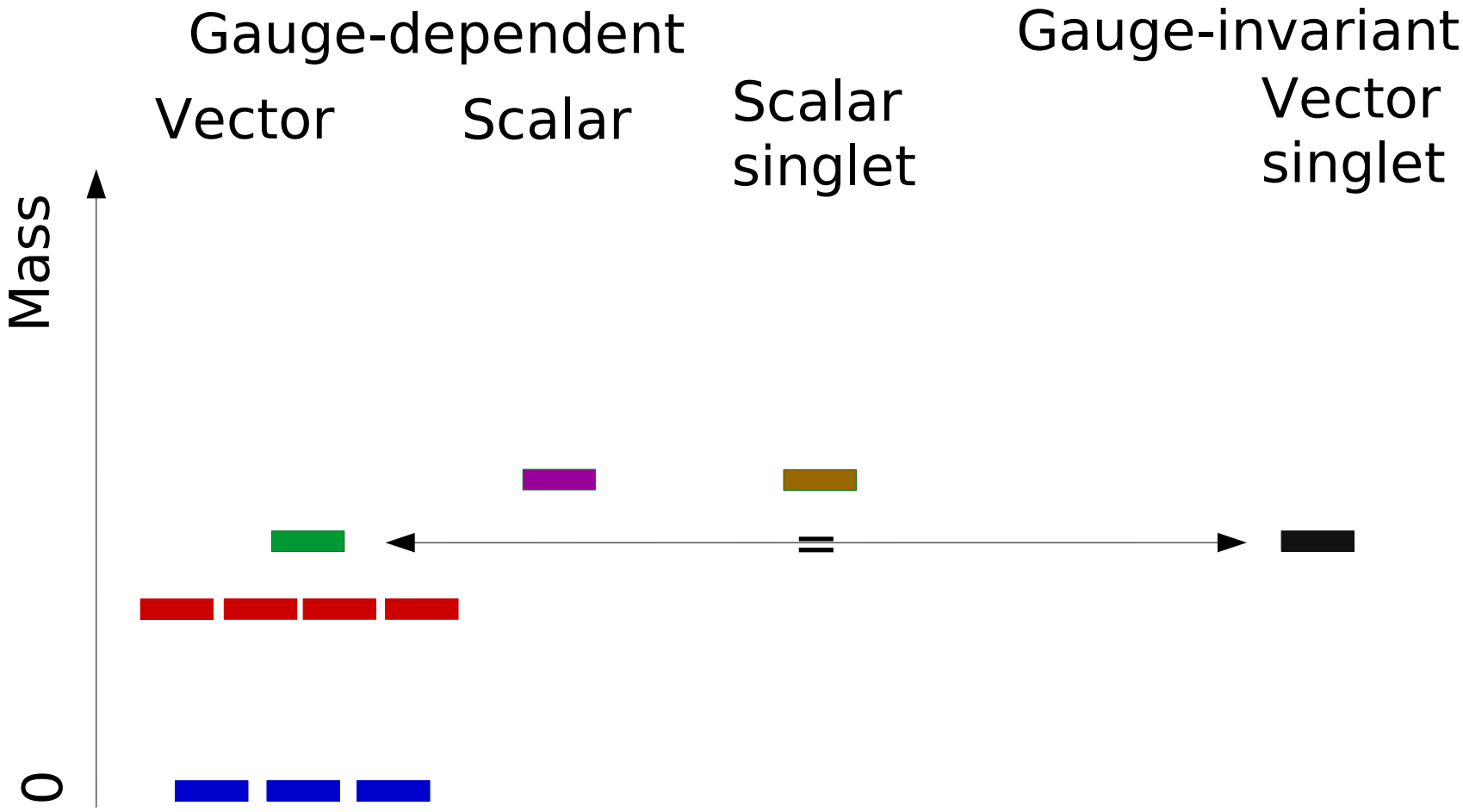

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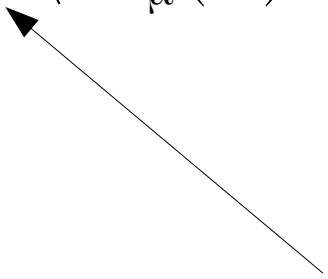

Matrix from group structure

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Matrix from group structure

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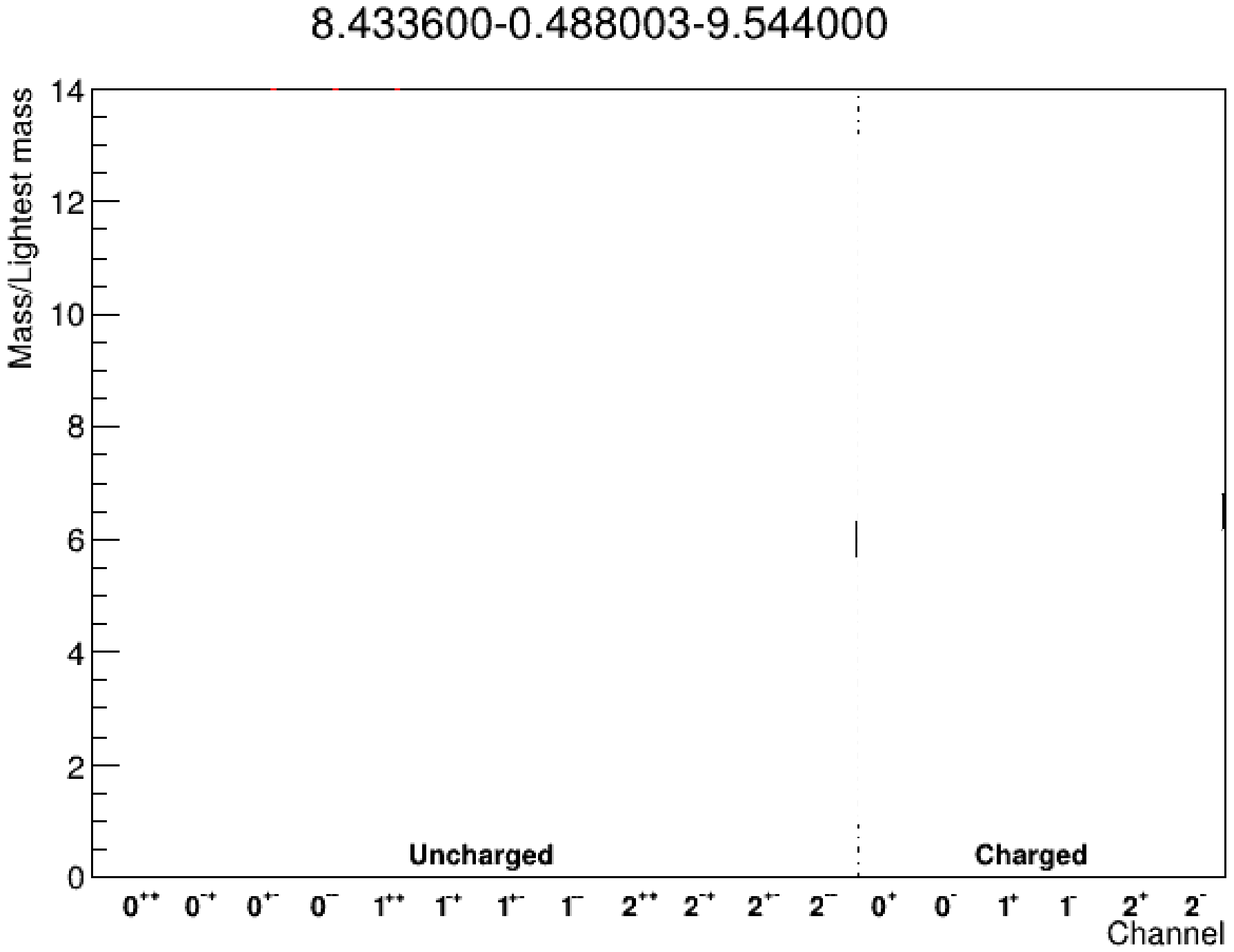
Only one state remains in the spectrum at mass of gauge boson 8 (heavy singlet)

Spectrum

PRELIMINARY

[Dobson et al.'21]



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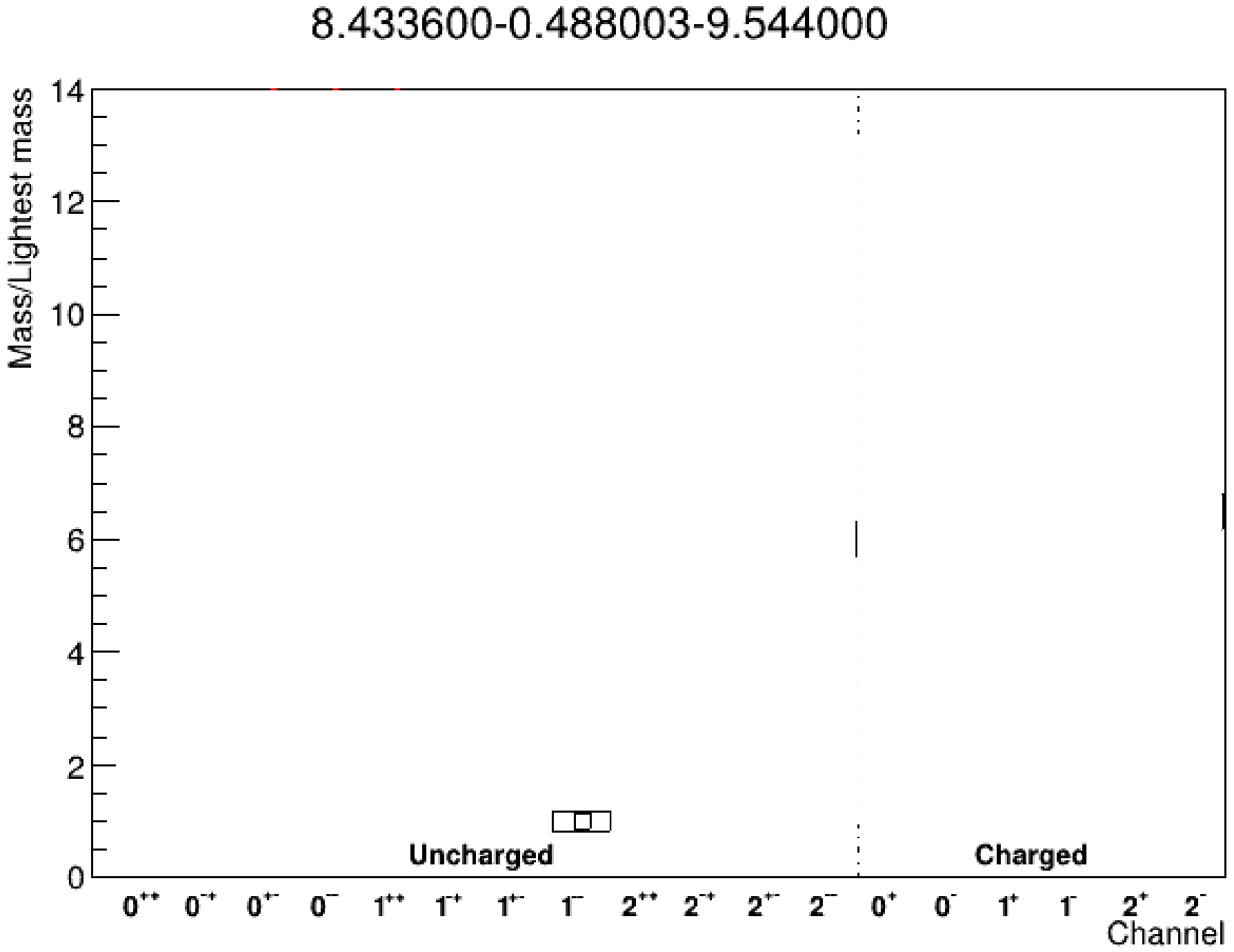

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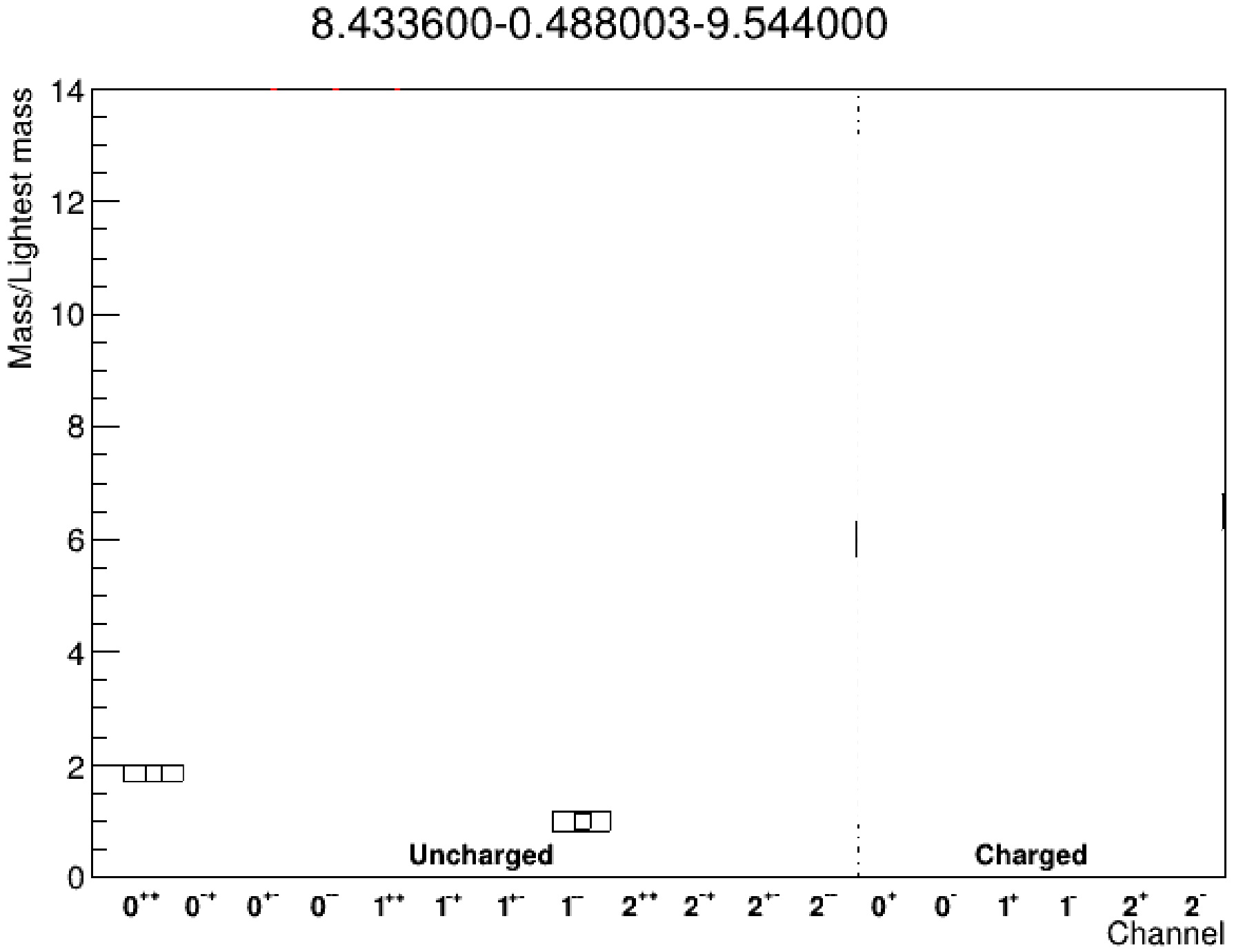

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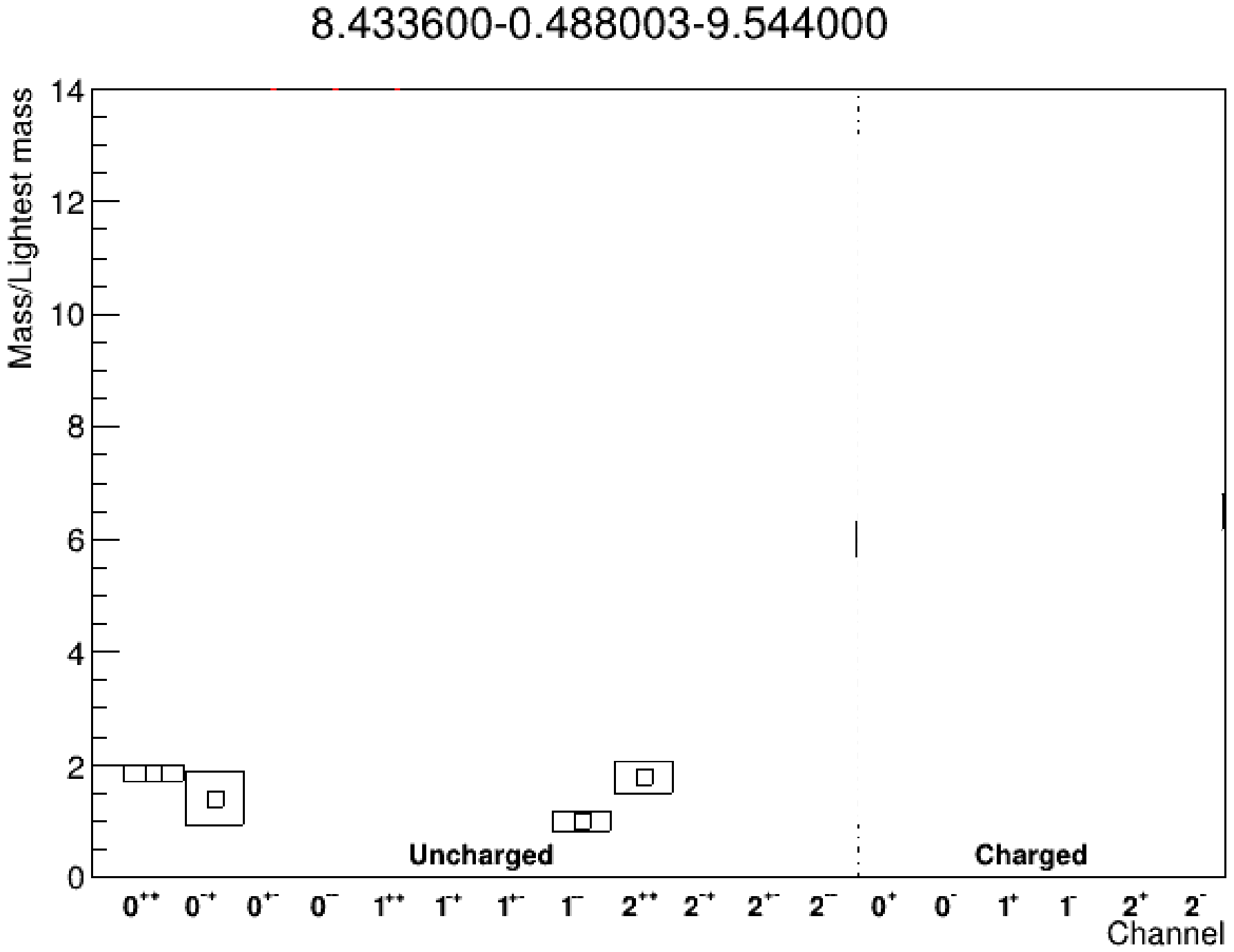

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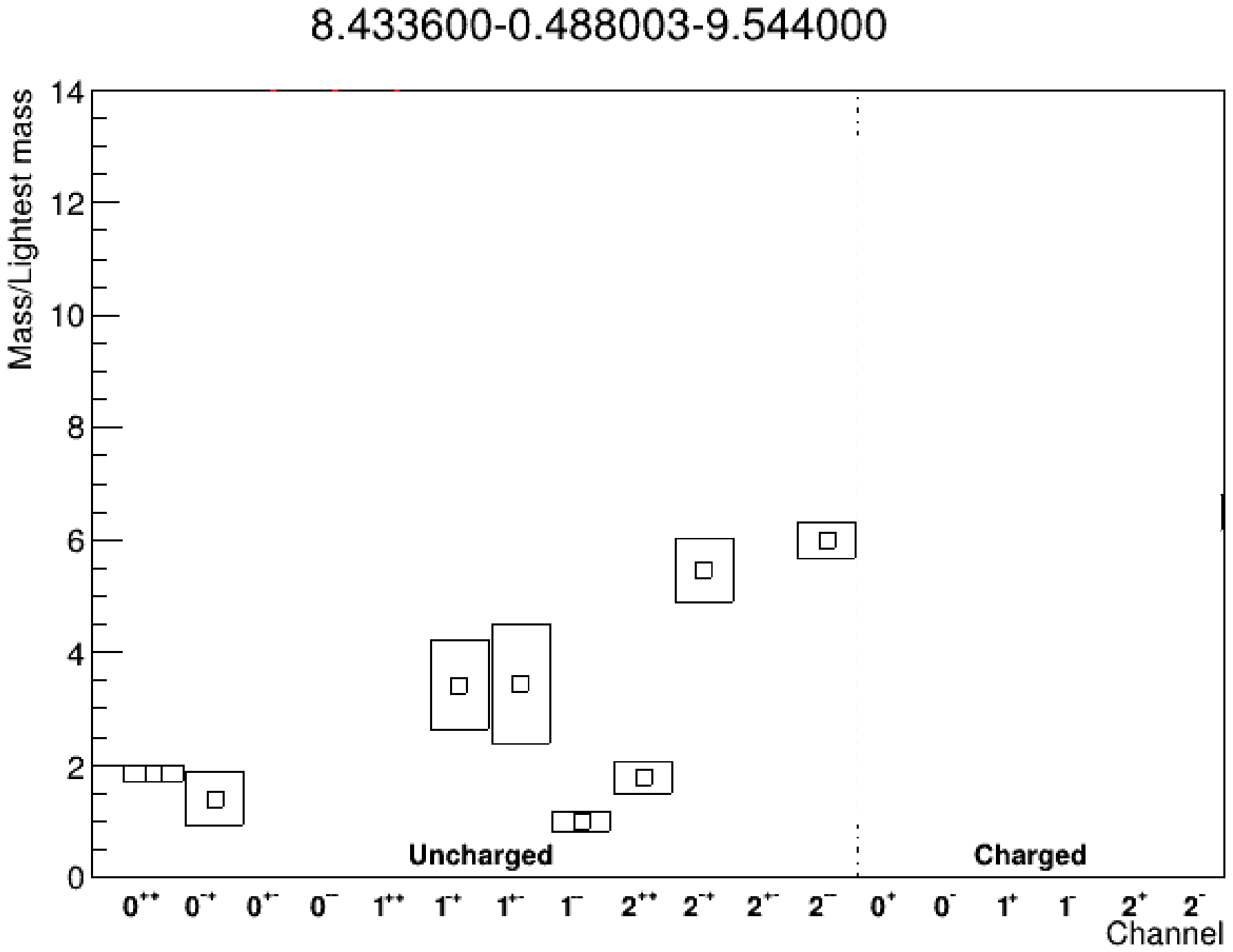

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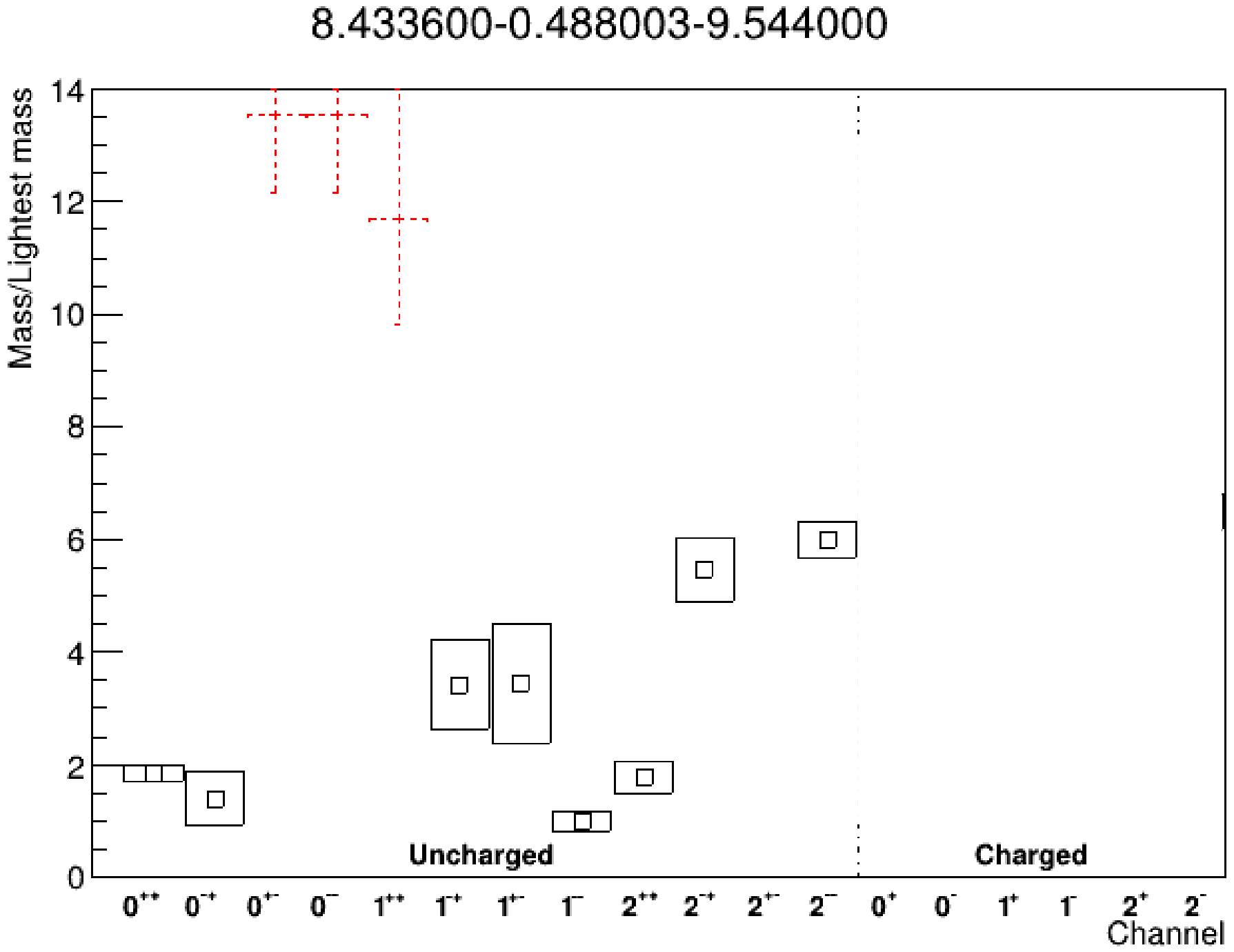

Spectrum

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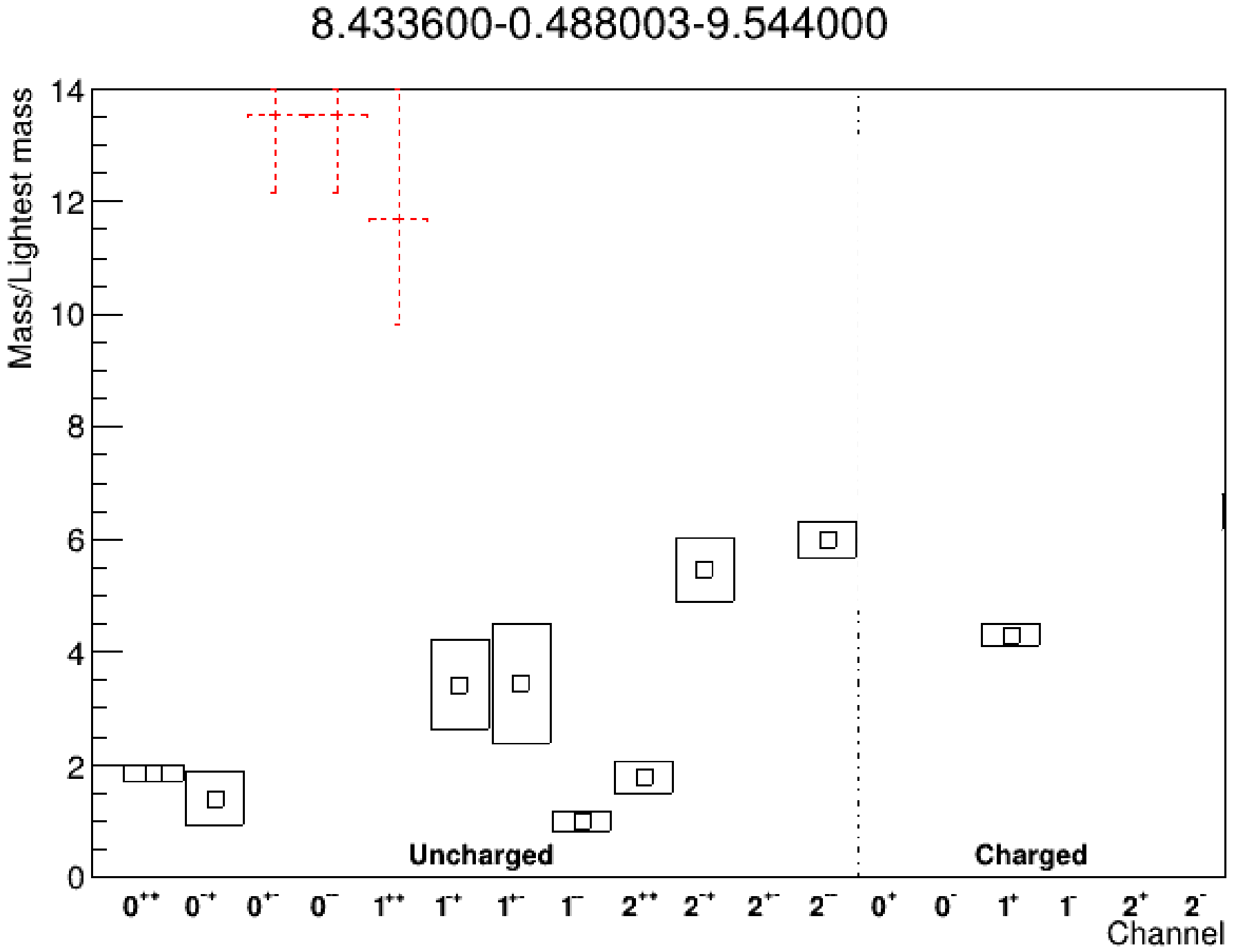

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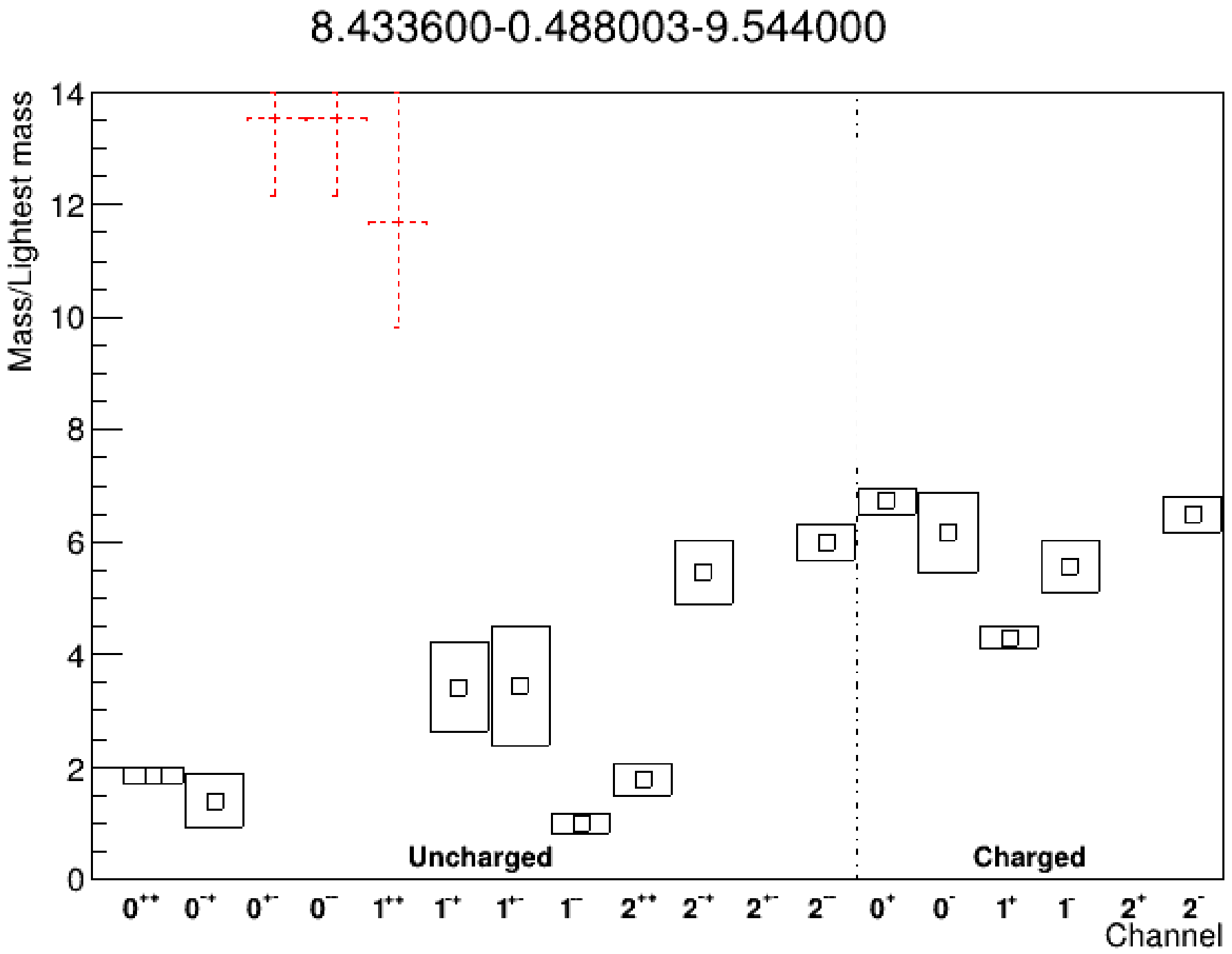

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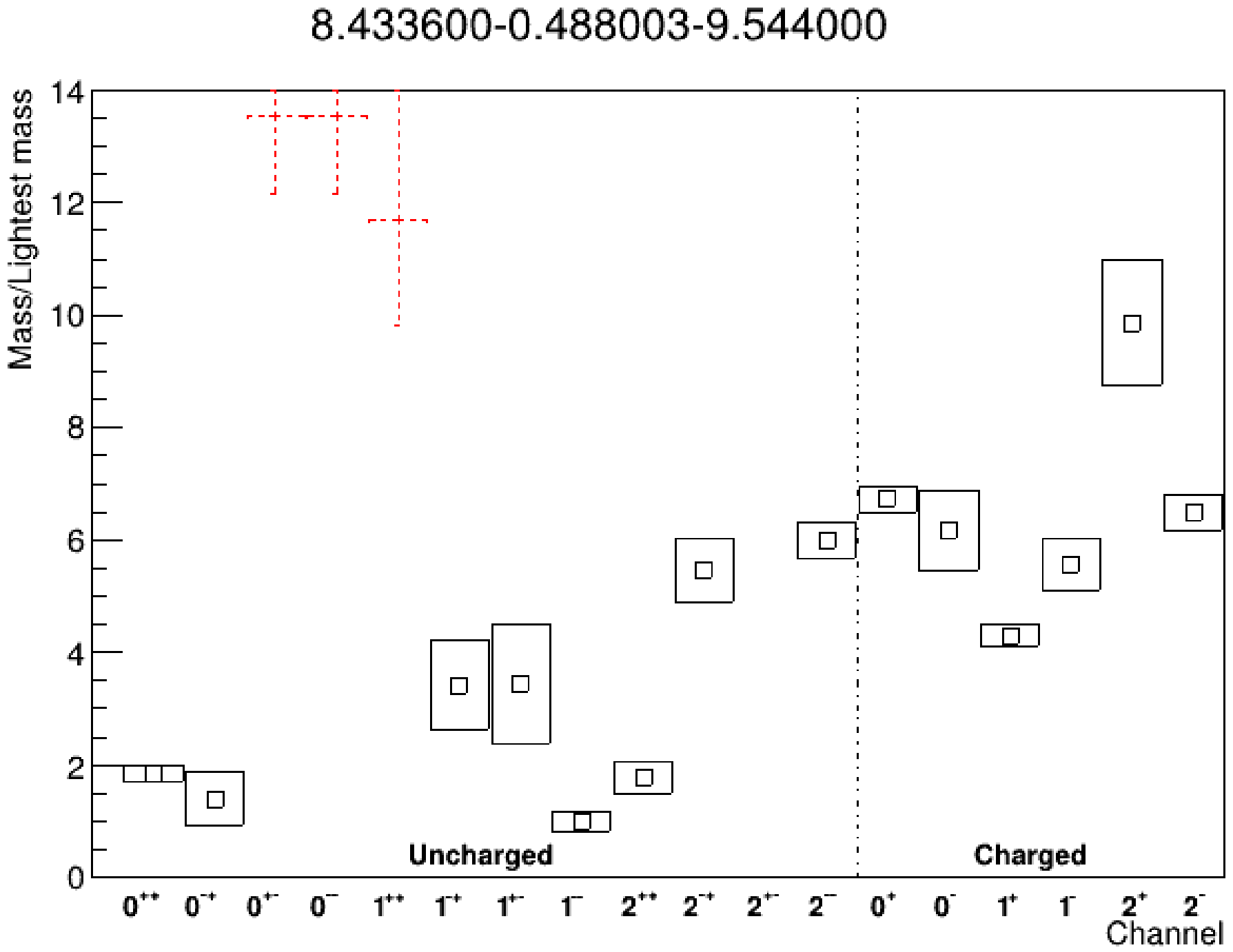

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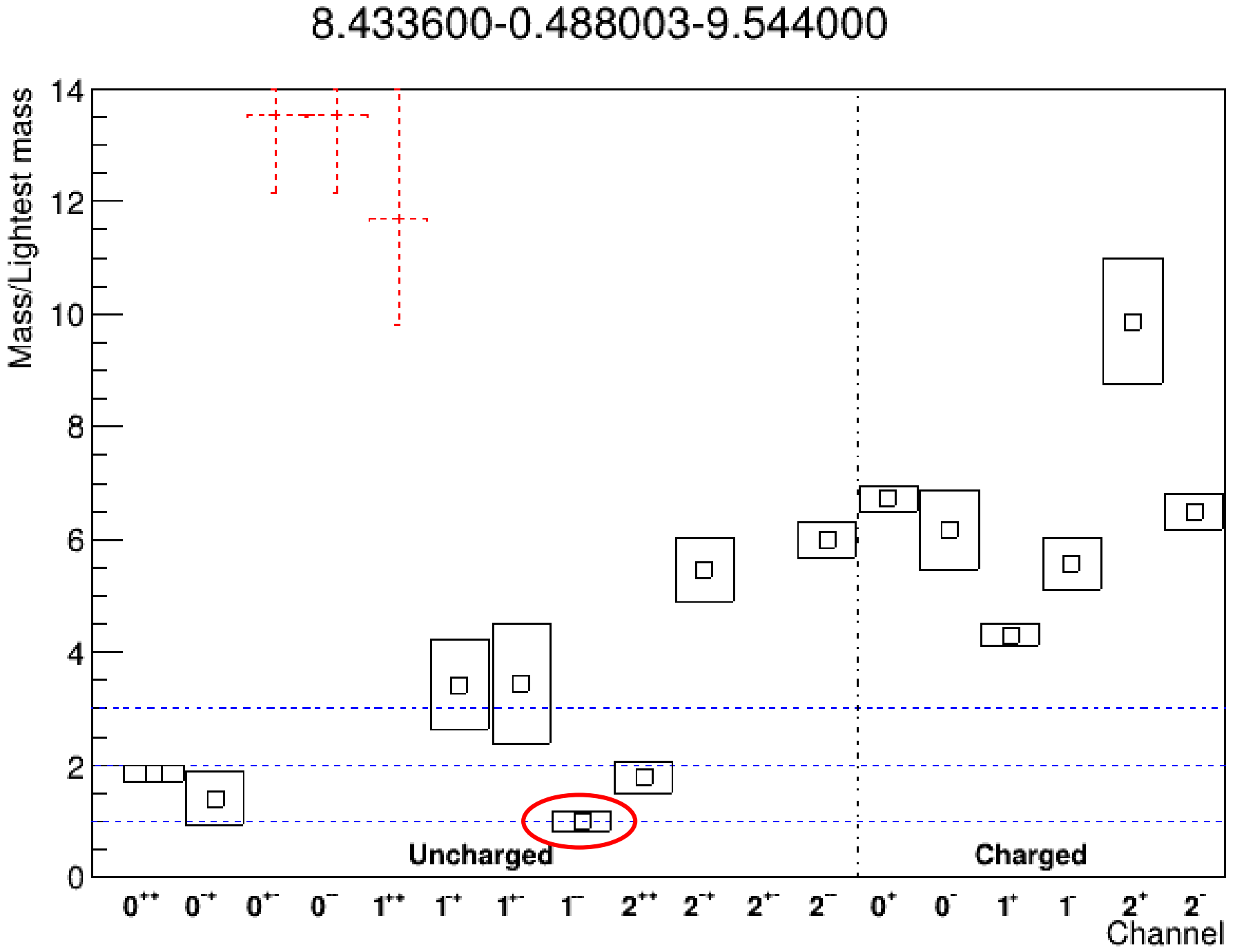

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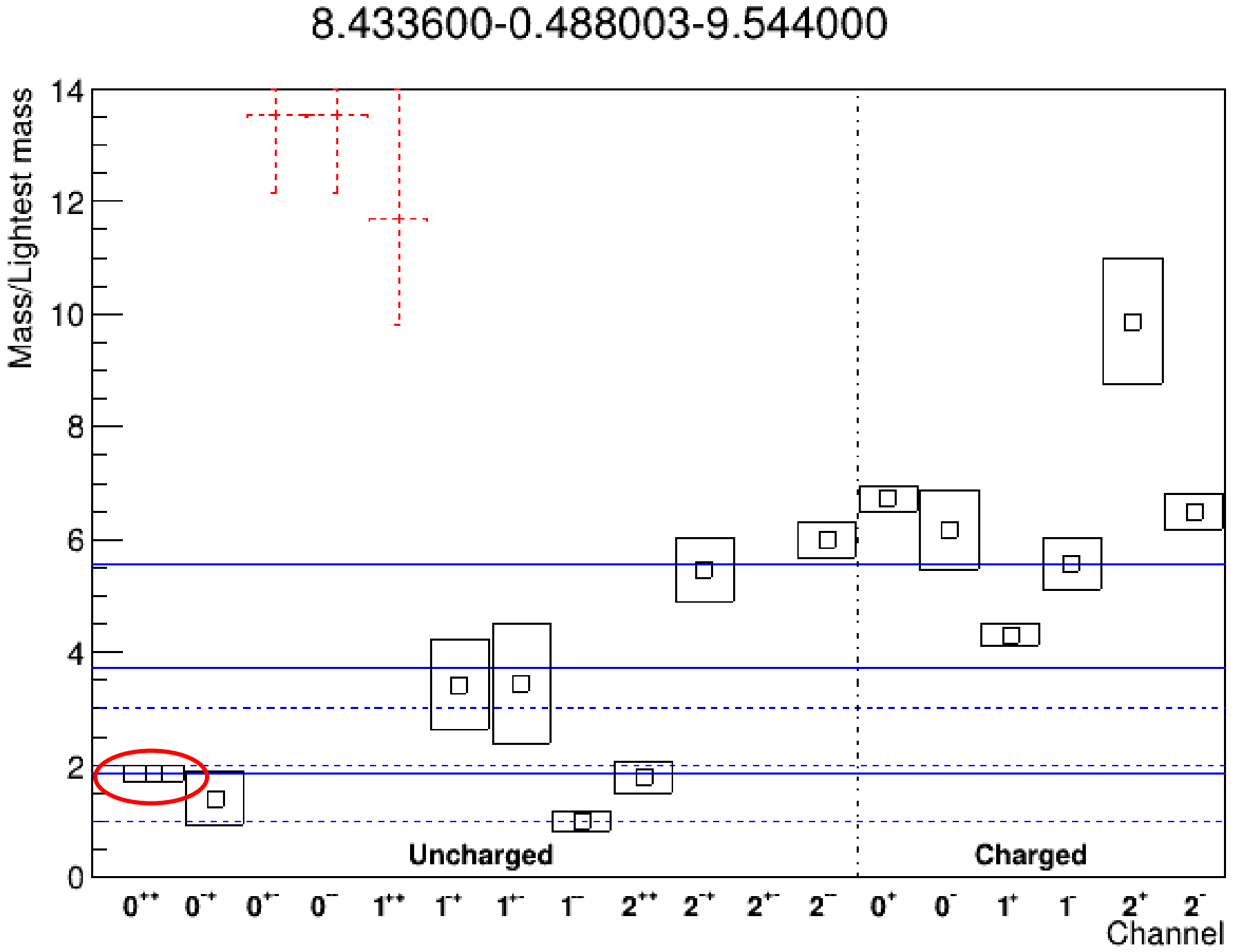

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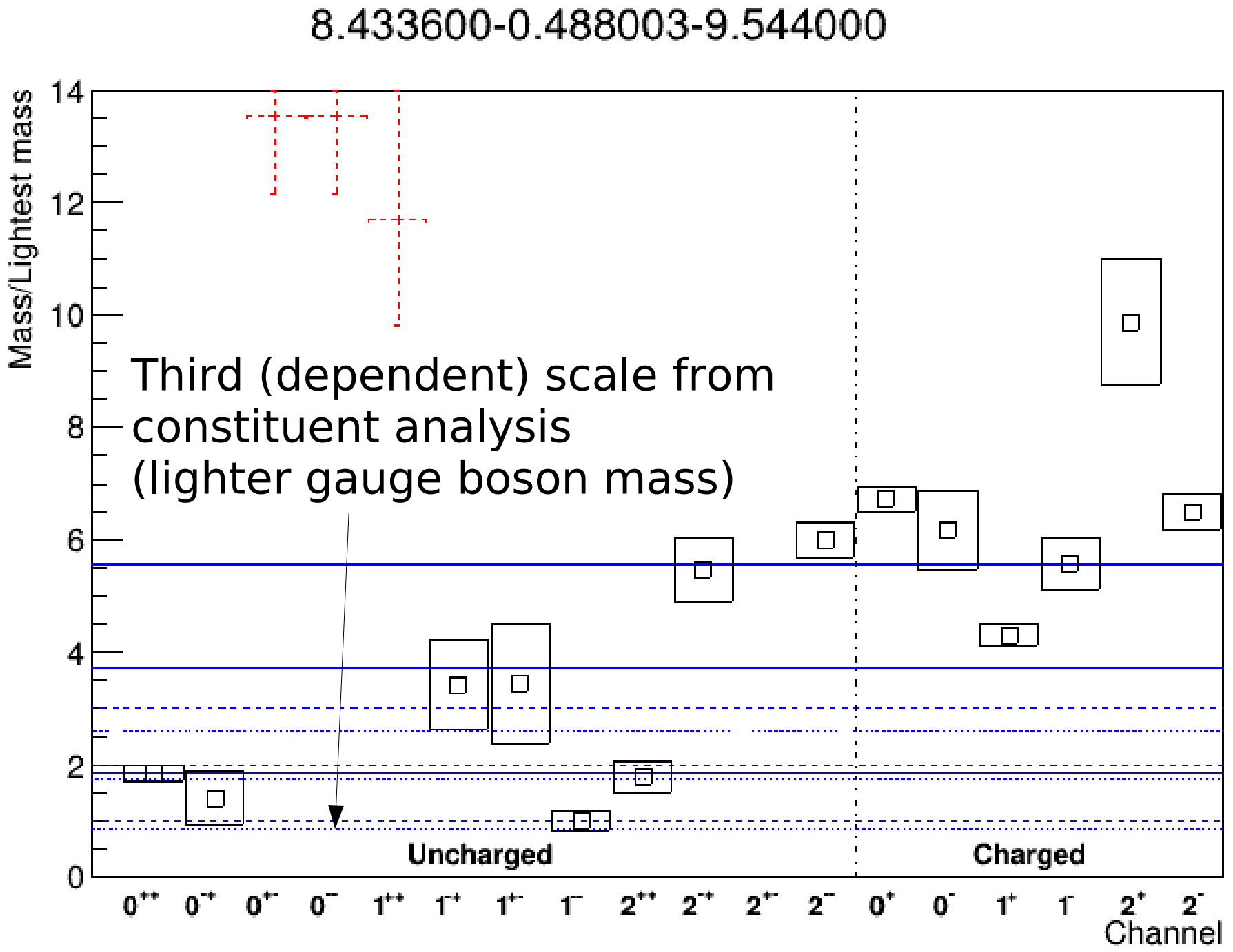

Experimental consequences

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[Maas & Törek'18
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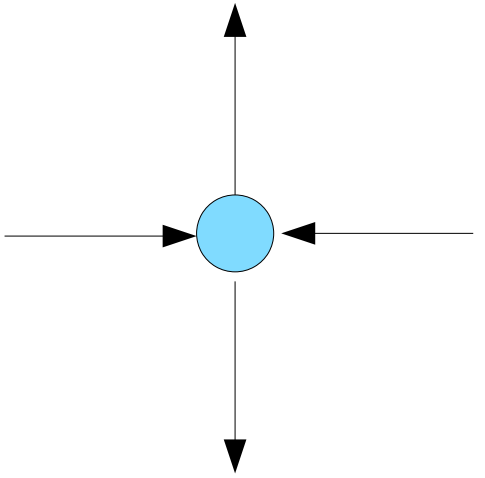

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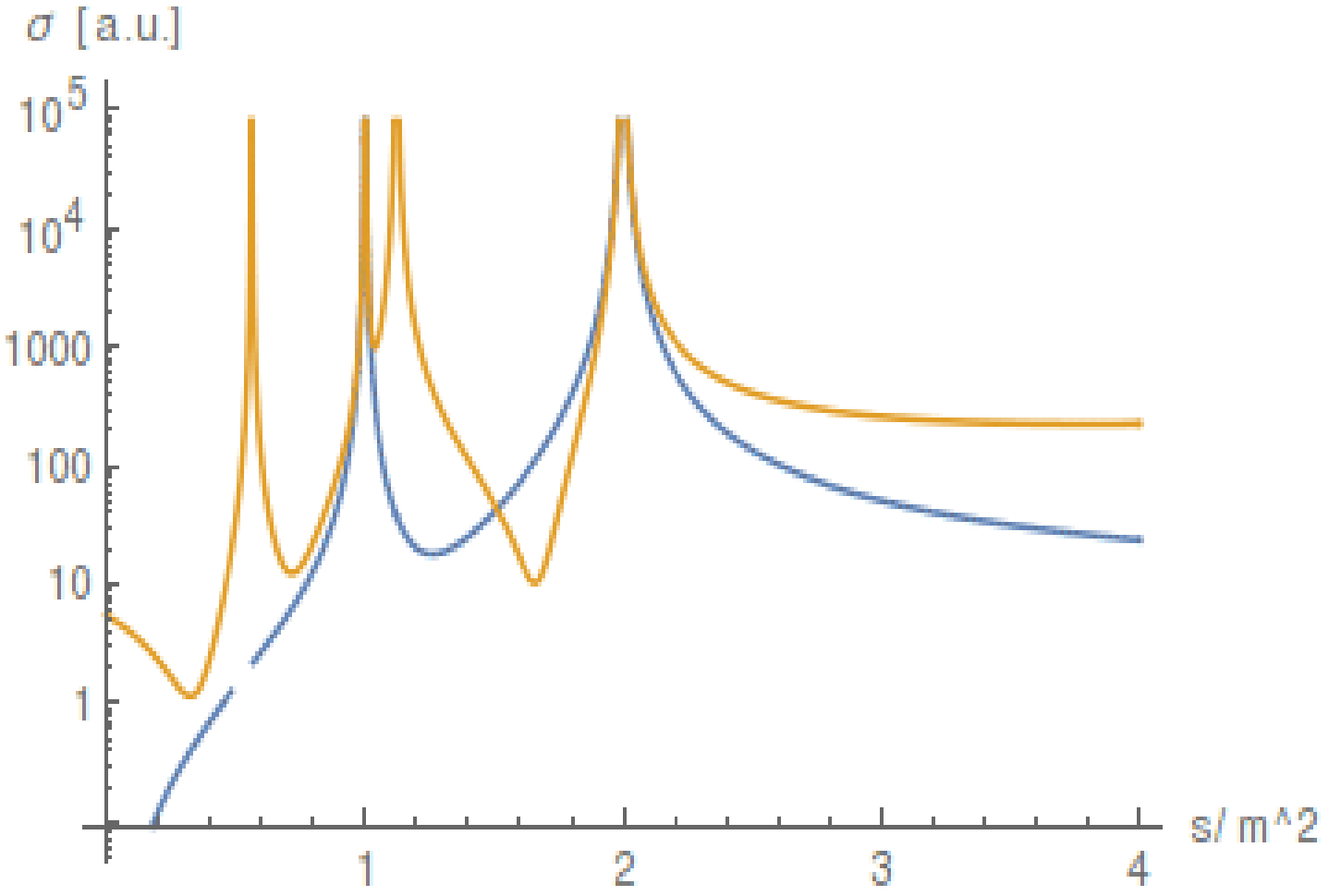

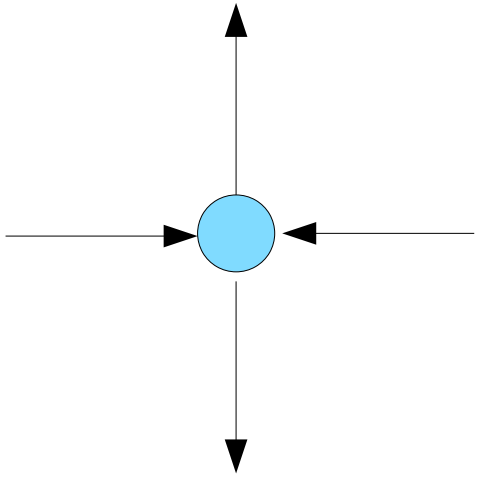

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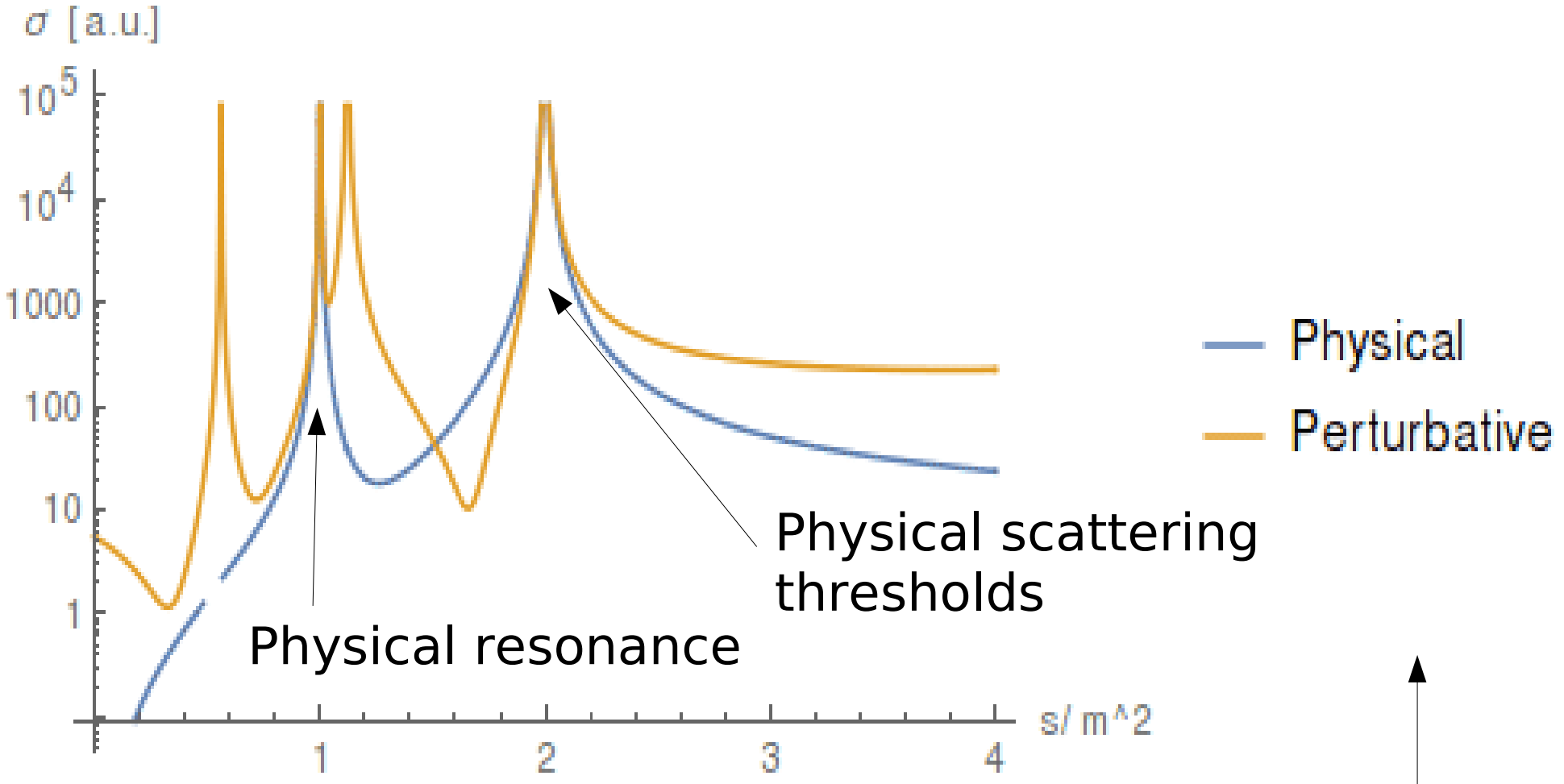

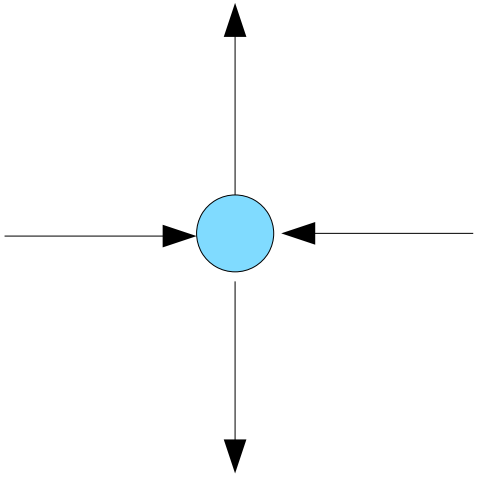

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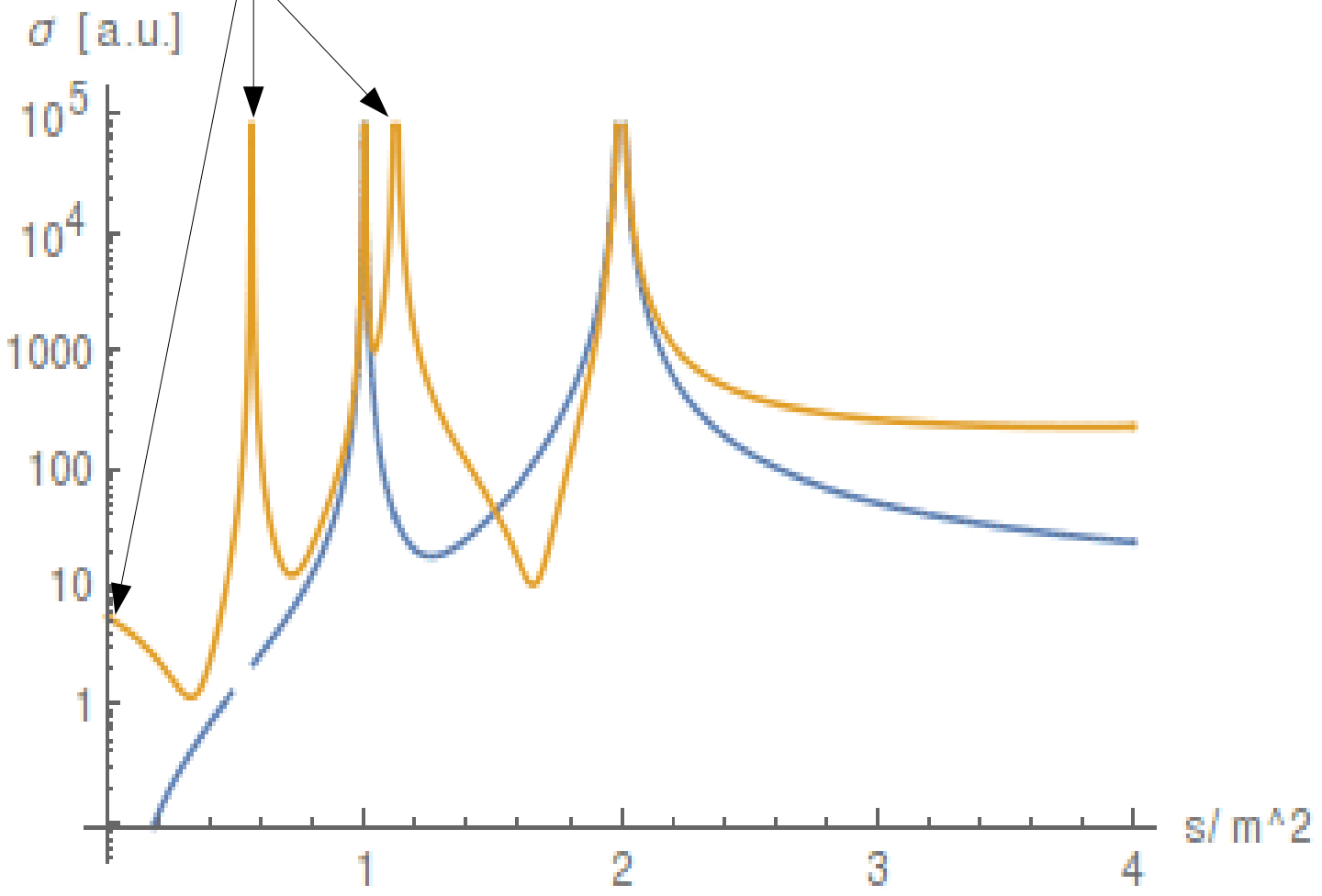
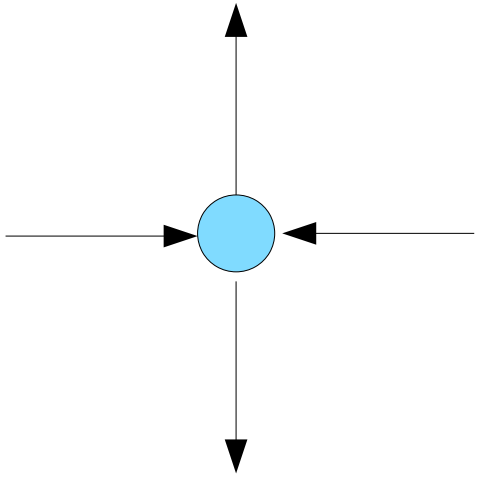
Ghost peaks from unphysical particles in perturbation theory





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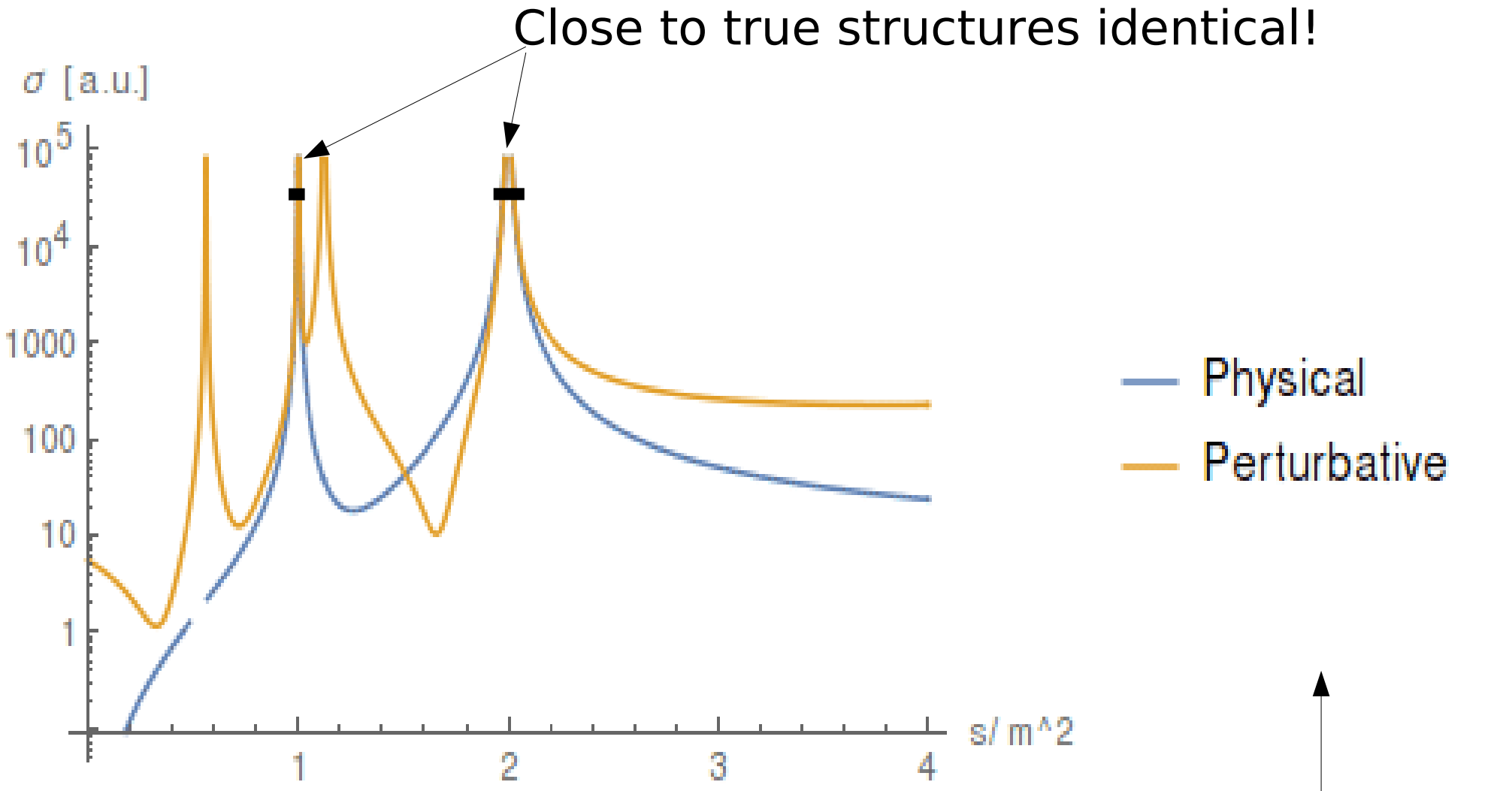

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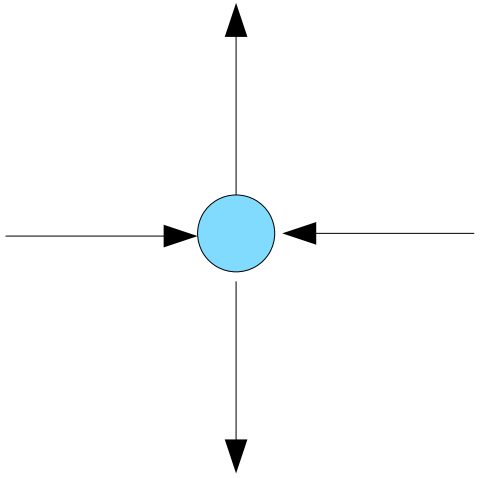

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Review: 1712.04721

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Review: 1712.04721