

The case for an excited "Higgs" within the standard model

Axel Maas

7th of July 2012
ICHEP 2012
Melbourne
Australia



arXiv:1205.6625

DFG

The case for an excited "Higgs" within the standard model and particle/bound-state duality in the weak interactions

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The Higgs sector as a gauge theory

- The Higgs sector is a gauge theory

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$$L = -\frac{1}{4} W_{\mu\nu}^a W_a^{\mu\nu}$$

$$W_{\mu\nu}^a = \partial_\mu W_\nu^a - \partial_\nu W_\mu^a$$



- **Ws** W_μ^a

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- Ws W_μ^a

- Coupling g and some numbers f^{abc}

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- Ws W_μ^a
- No QED: Ws and Zs are degenerate
- Coupling g and some numbers f^{abc}

The Higgs sector as a gauge theory

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$$L = -\frac{1}{4} W_{\mu\nu}^a W_a^{\mu\nu} + (D_{\mu}^{ij} h^j)^{\dagger} D_{ik}^{\mu} h_k$$

$$W_{\mu\nu}^a = \partial_{\mu} W_{\nu}^a - \partial_{\nu} W_{\mu}^a + gf_{bc}^a W_{\mu}^b W_{\nu}^c$$

$$D_{\mu}^{ij} = \delta^{ij} \partial_{\mu}$$

- Ws** W_{μ}^a
- Higgs** h_i
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- Ws**

$$W_\mu^a$$

- Higgs**

$$h_i$$

- No QED: Ws and Zs are degenerate

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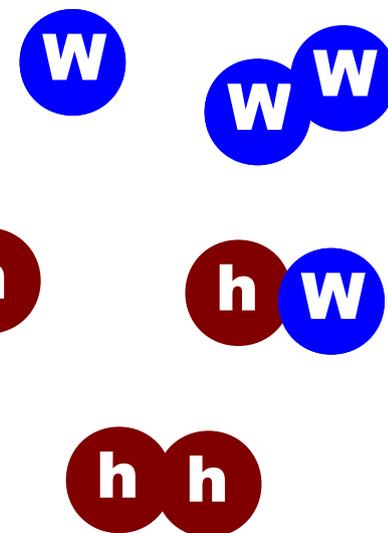
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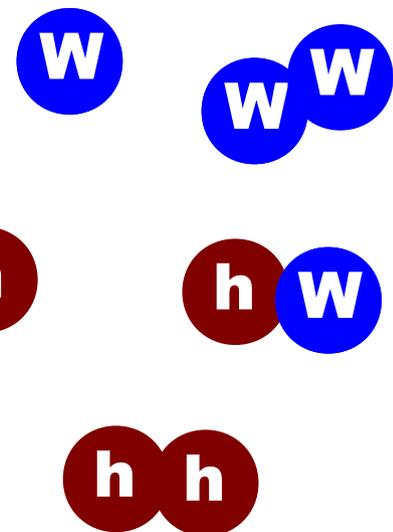
- No QED: Ws and Zs are degenerate

- Couplings g, v, λ and some numbers f^{abc} and t_a^{ij}

- Invariant under arbitrary gauge transformations $\phi^a(x)$

$$W_\mu^a \rightarrow W_\mu^a + (\delta_b^a \partial_\mu - gf_{bc}^a W_\mu^c) \phi^b$$

$$h_i \rightarrow h_i + g t_a^{ij} \phi^a h_j$$



Composite states

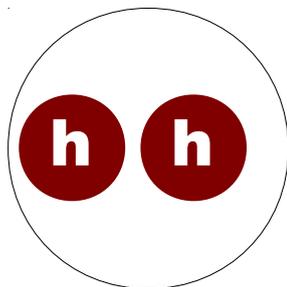
[Fröhlich et al. PLB 80,
't Hooft ASIB 80,
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- Only bound states and cross sections gauge-invariant

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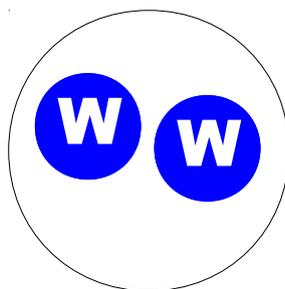
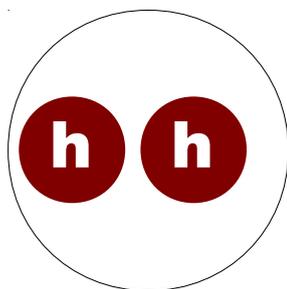
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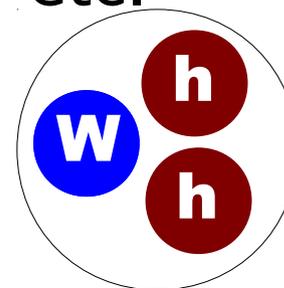
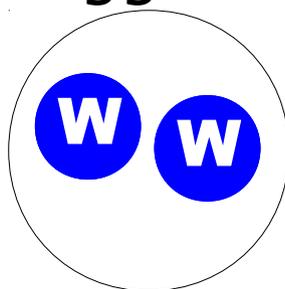
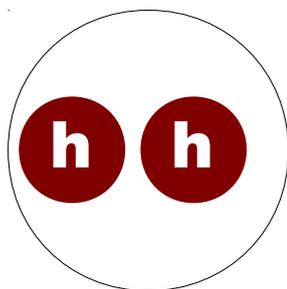
- Only bound states and cross sections gauge-invariant
 - Higgs-Higgs, W-W



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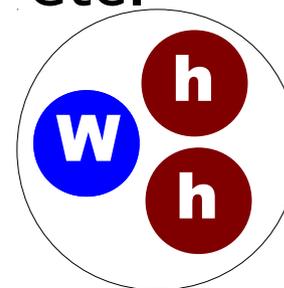
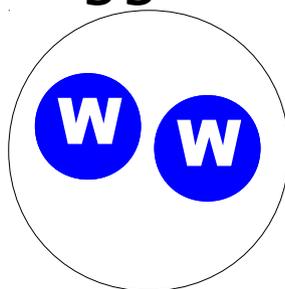
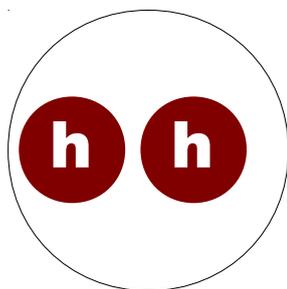
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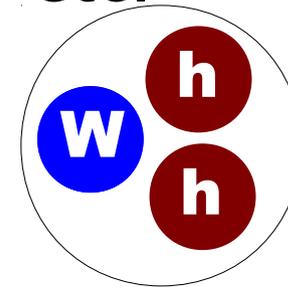
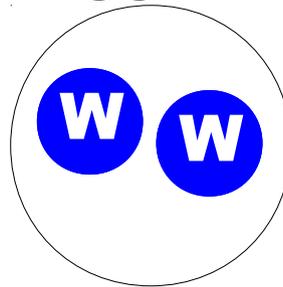
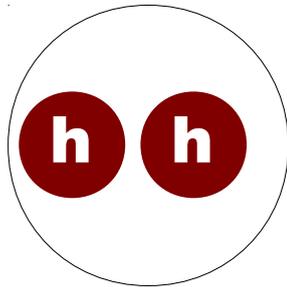


- Are the masses related to the elementary particles' ones?

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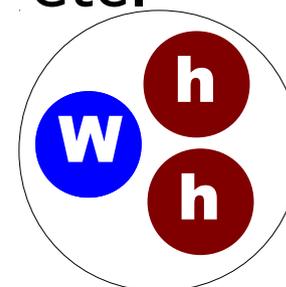
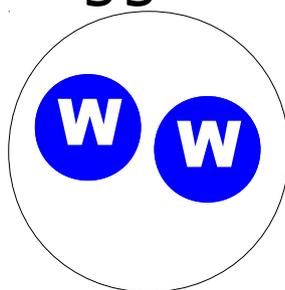
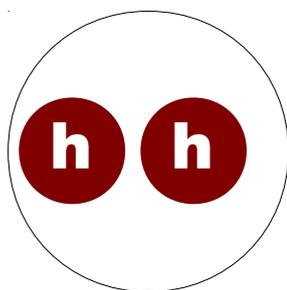
- Are the masses related to the elementary particles' ones?
- Leading order: Duality between elementary states and bound states [Fröhlich et al. PLB 80]

$$\langle (h^+ h)(x)(h^+ h)(y) \rangle$$

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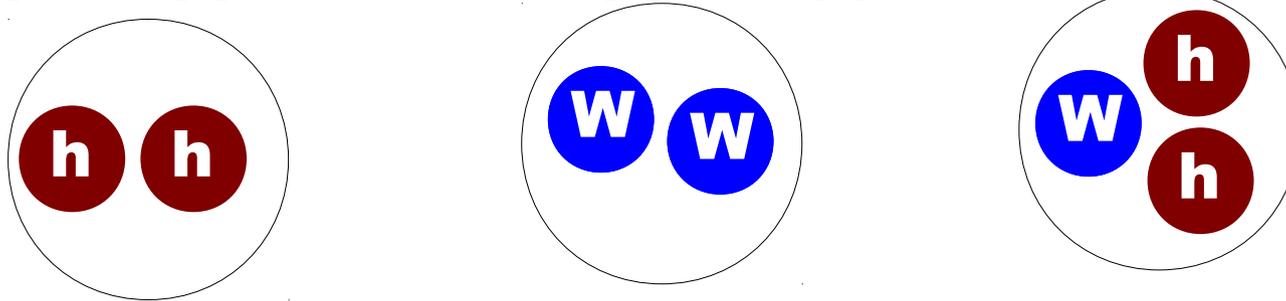
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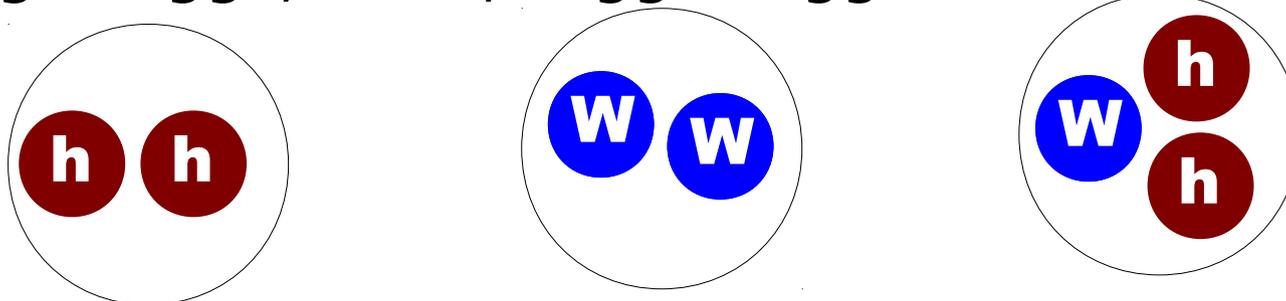
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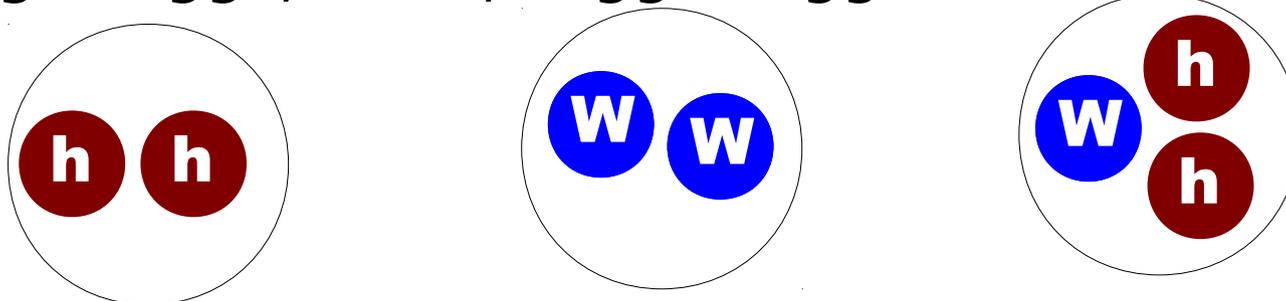
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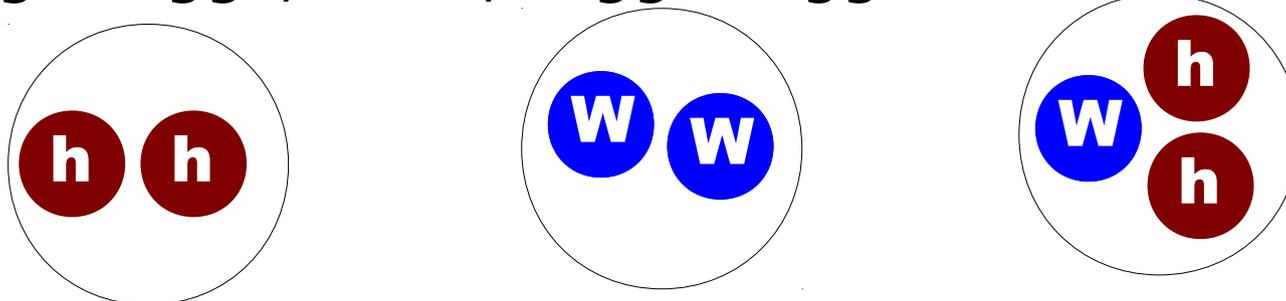
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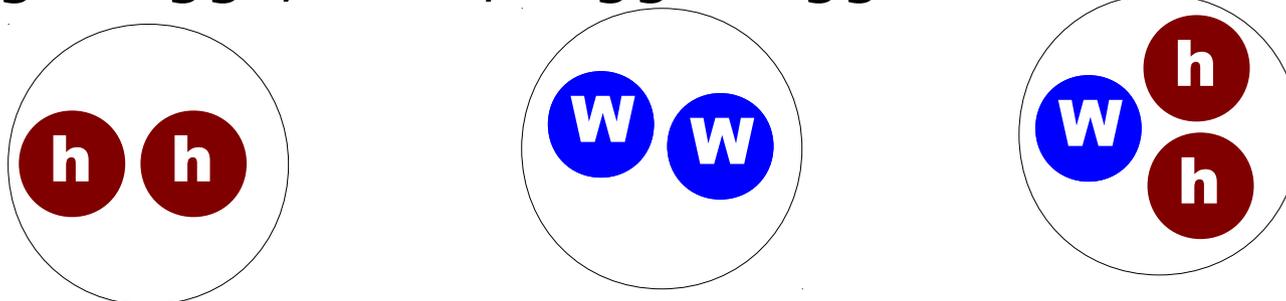
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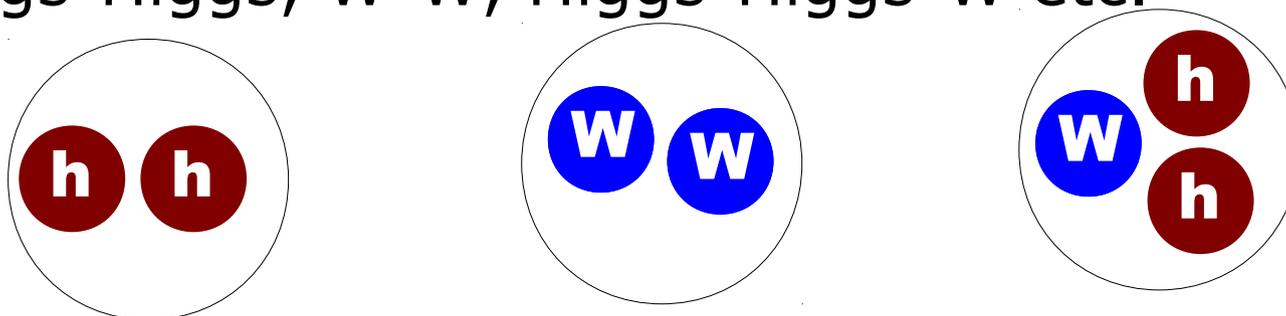
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- Same poles to leading order – unlike QCD quark model
- Similar relation for W and a vector state
- Beyond leading order? Non-perturbatively?

Setup

$$L = -W_{\mu\nu}^a W_a^{\mu\nu} / 4 + (D_\mu^{ij} h^j)^\dagger D_{ik}^\mu h_k + \lambda (h^a h_a^\dagger - v^2)^2$$

- Tree-level setup Higgs+W

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- Tree-level setup Higgs+W
 - 't Hooft gauge
 - W mass: 80.375 GeV (sets the scale)
 - Higgs mass: 155 GeV, Higgs vev: 246 GeV

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 - W mass, Higgs vev both zero
 - Higgs mass: 77.5i GeV

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- Translate both to tree-level parameters
 - $v=246$ GeV
 - $\lambda=0.0496$ ($4!\lambda=1.19$)
 - $g=0.653$ ($\alpha=0.0340$)
- Quite perturbative

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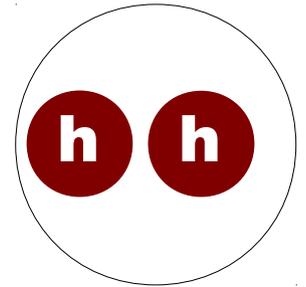
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- Non-perturbative: Simulate Higgs+W

Higgsonium vs. Higgs

- 0^{++} bound state channel

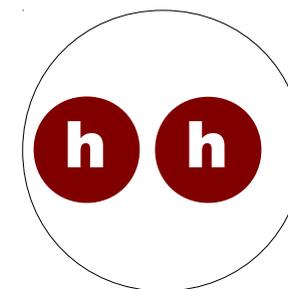
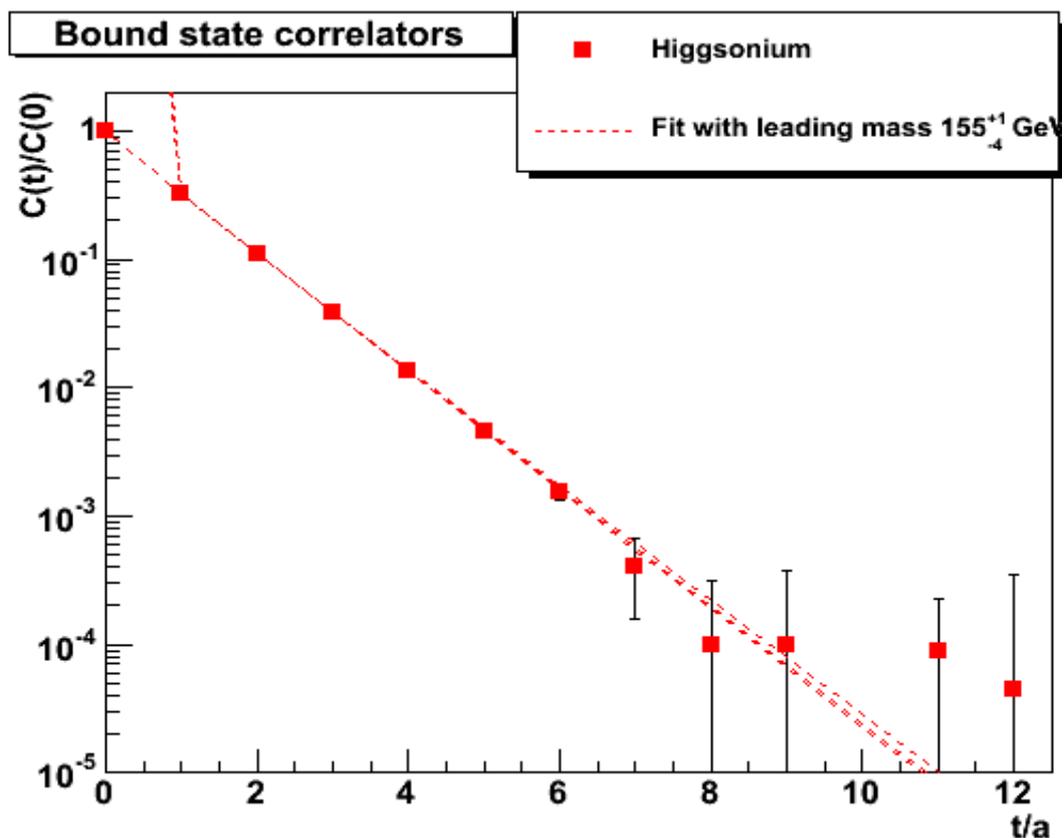
Higgsonium vs. Higgs



- 0^{++} bound state channel
 - Lowest state is almost pure Higgsonium $h^+(x)h(x)$

Higgsonium vs. Higgs

[Maas, EPJC 2011, '12
24⁴, $\beta=2.3$, $\kappa=0.32$ $\lambda=1$]

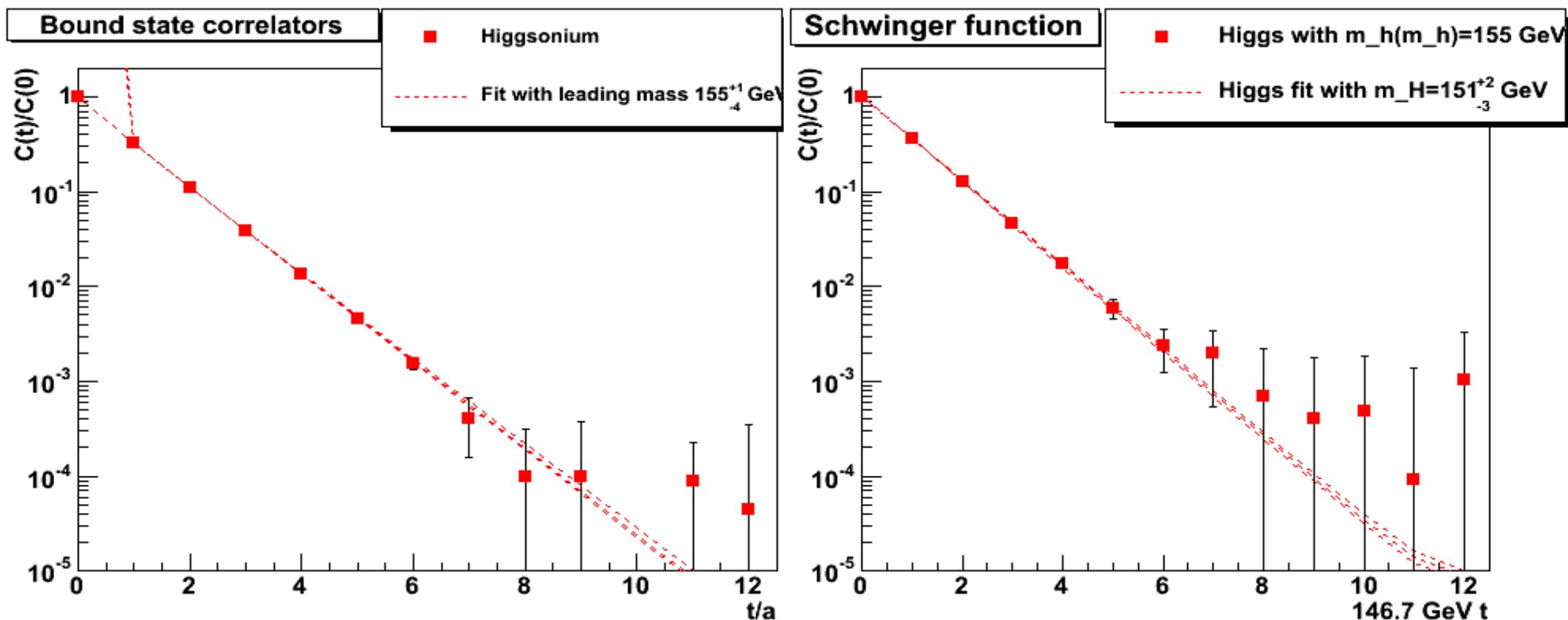


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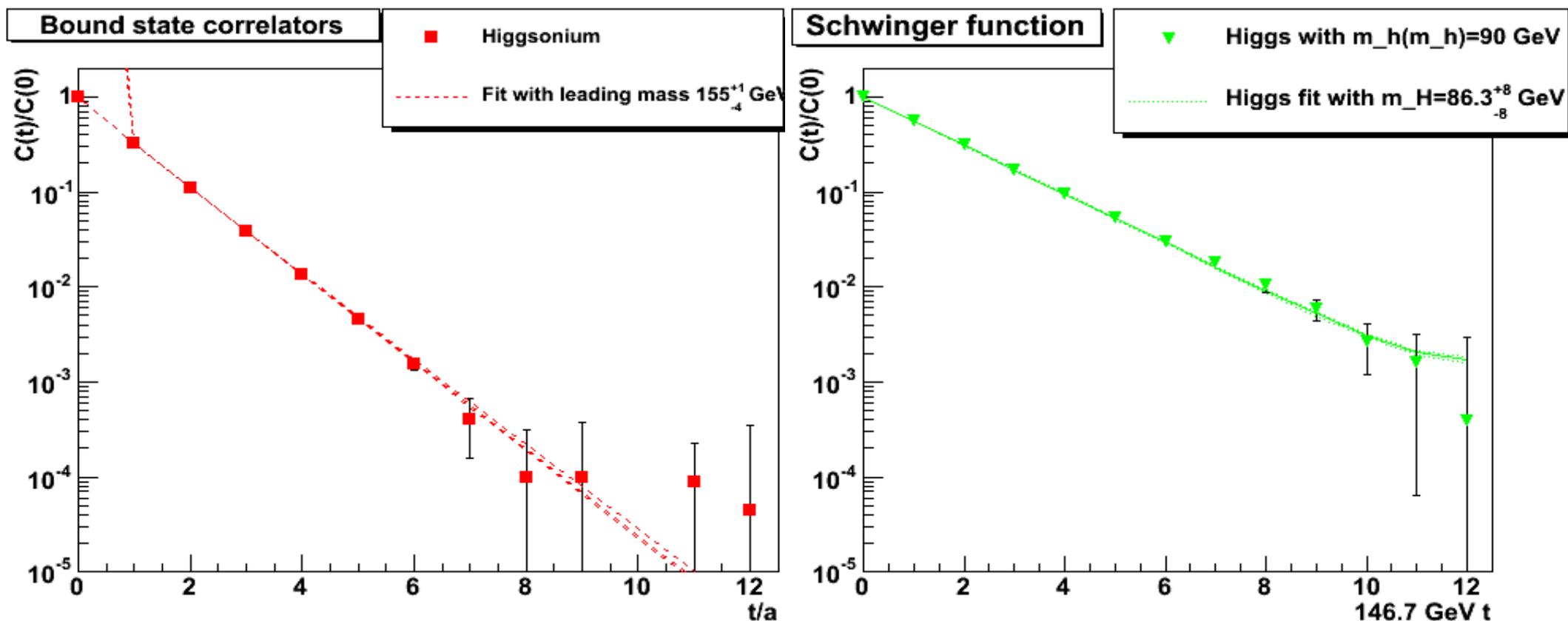
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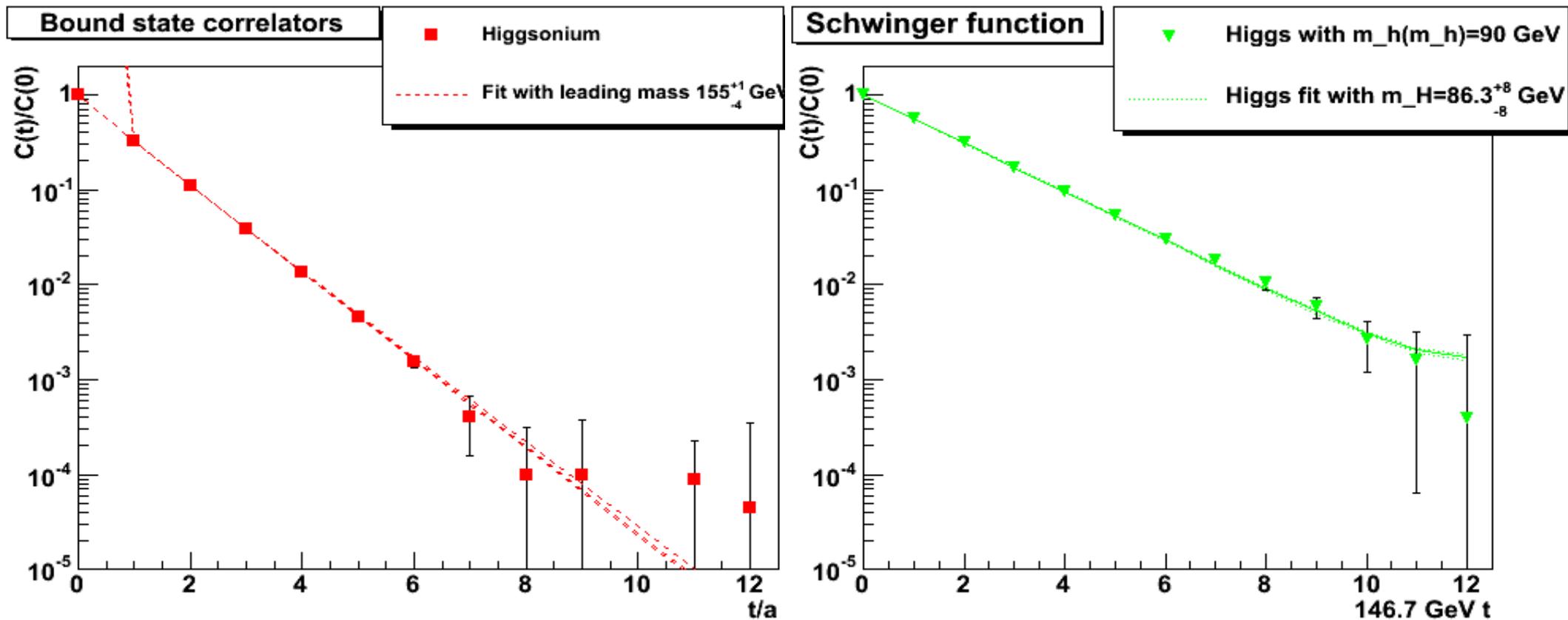
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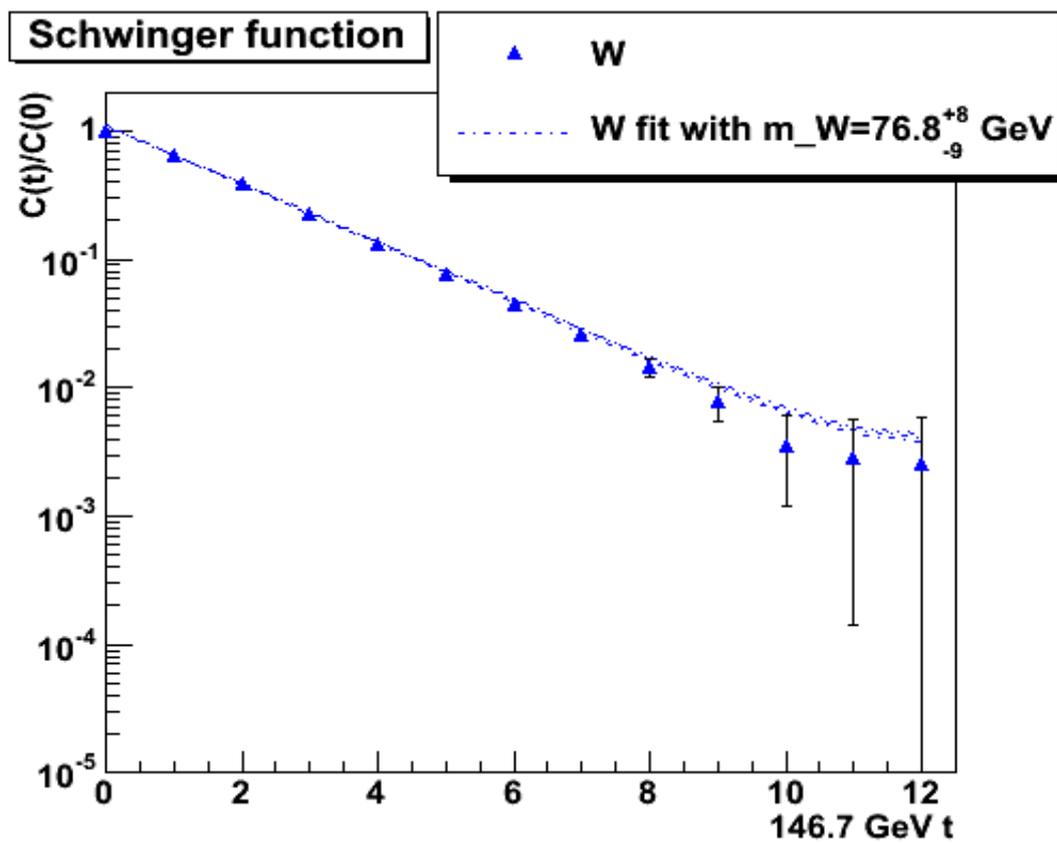
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 - Mass is scheme-dependent
- Duality holds **only** in an appropriate scheme

Isovector-vector state

[Maas, EPJC 2011, '12
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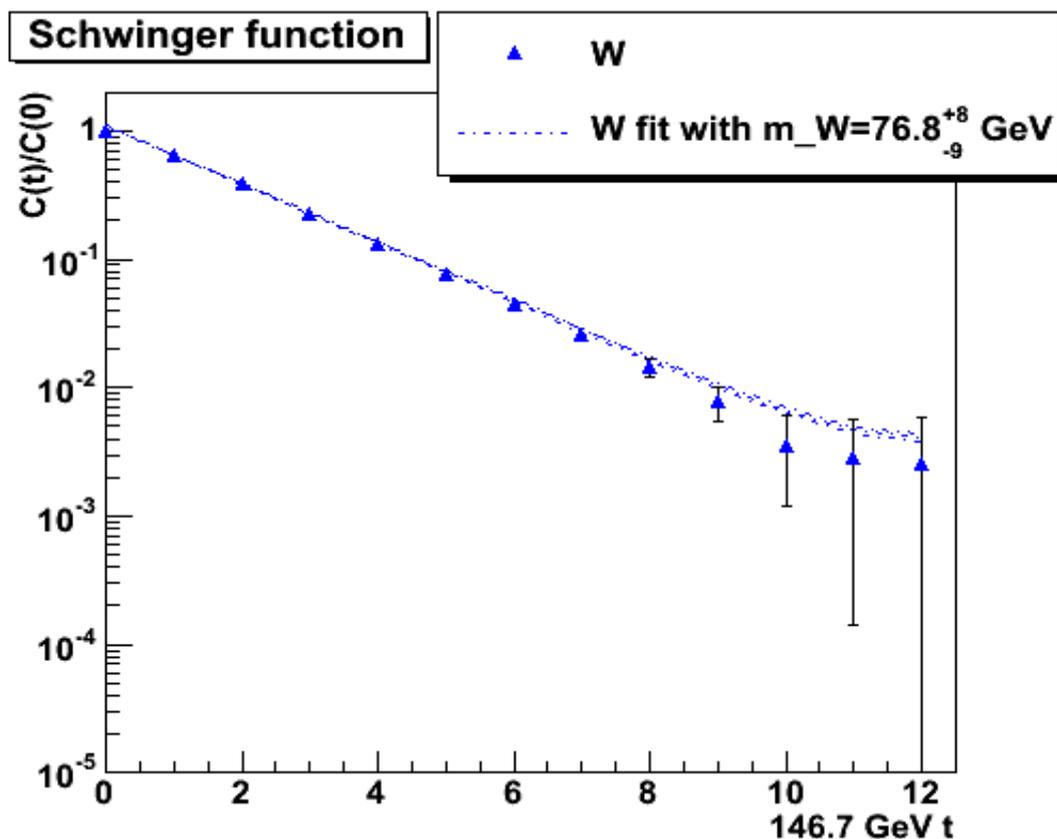
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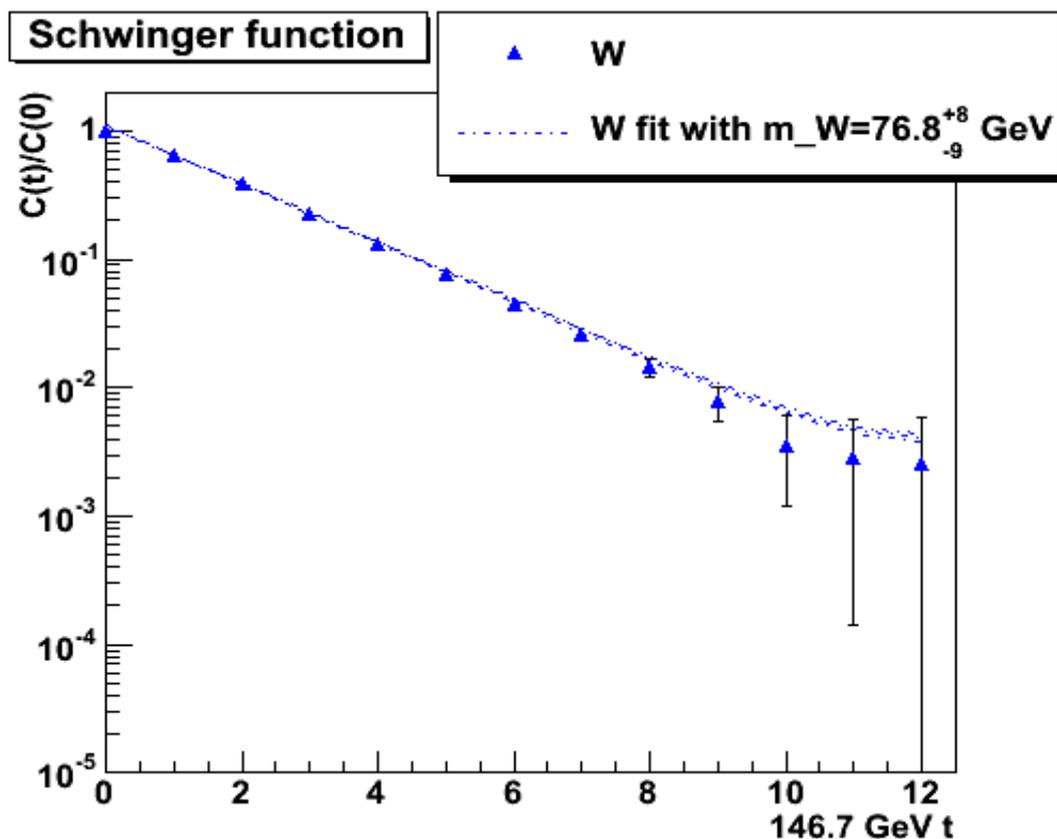
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- Vector state with operator $tr t^a \frac{h^+}{\sqrt{h^+ h}} D_\mu \frac{h}{\sqrt{h^+ h}}$

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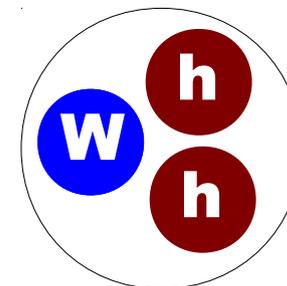
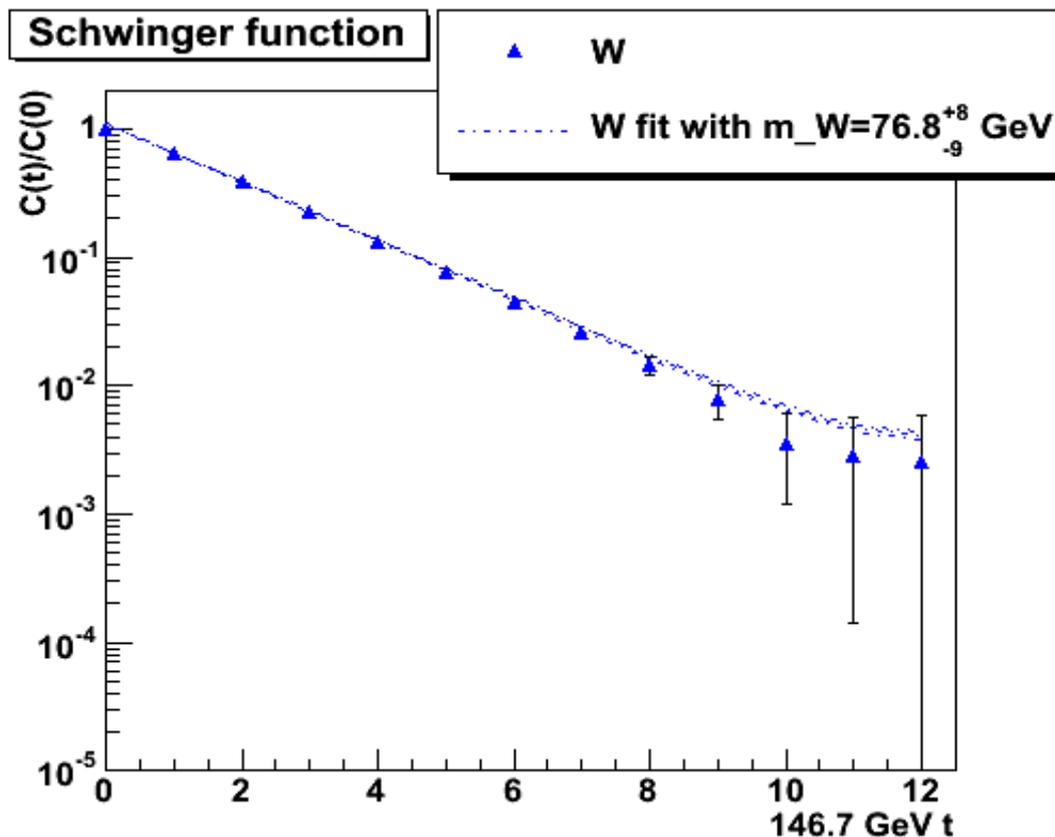
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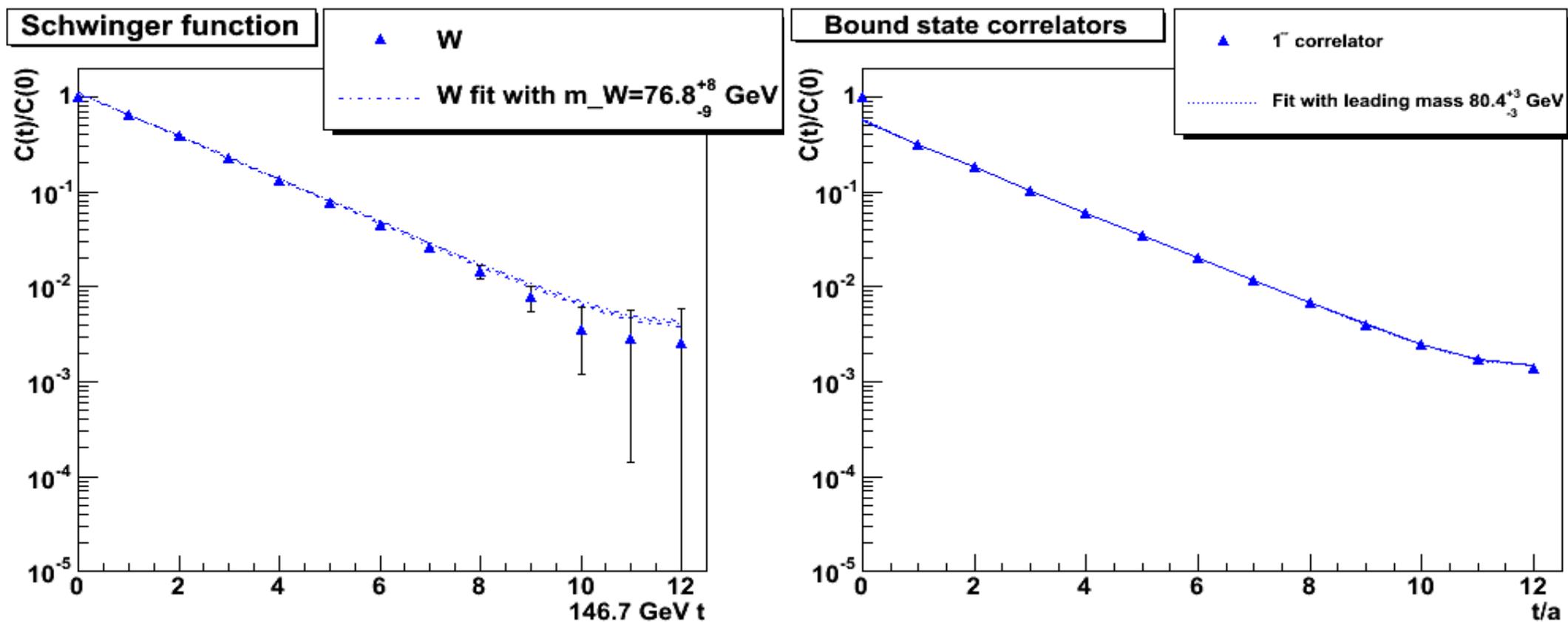
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- Vector state with operator $tr t^a \frac{h^+}{\sqrt{h^+ h}} D_\mu \frac{h}{\sqrt{h^+ h}}$
- Non-polynomial in the fields
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Isovector-vector state

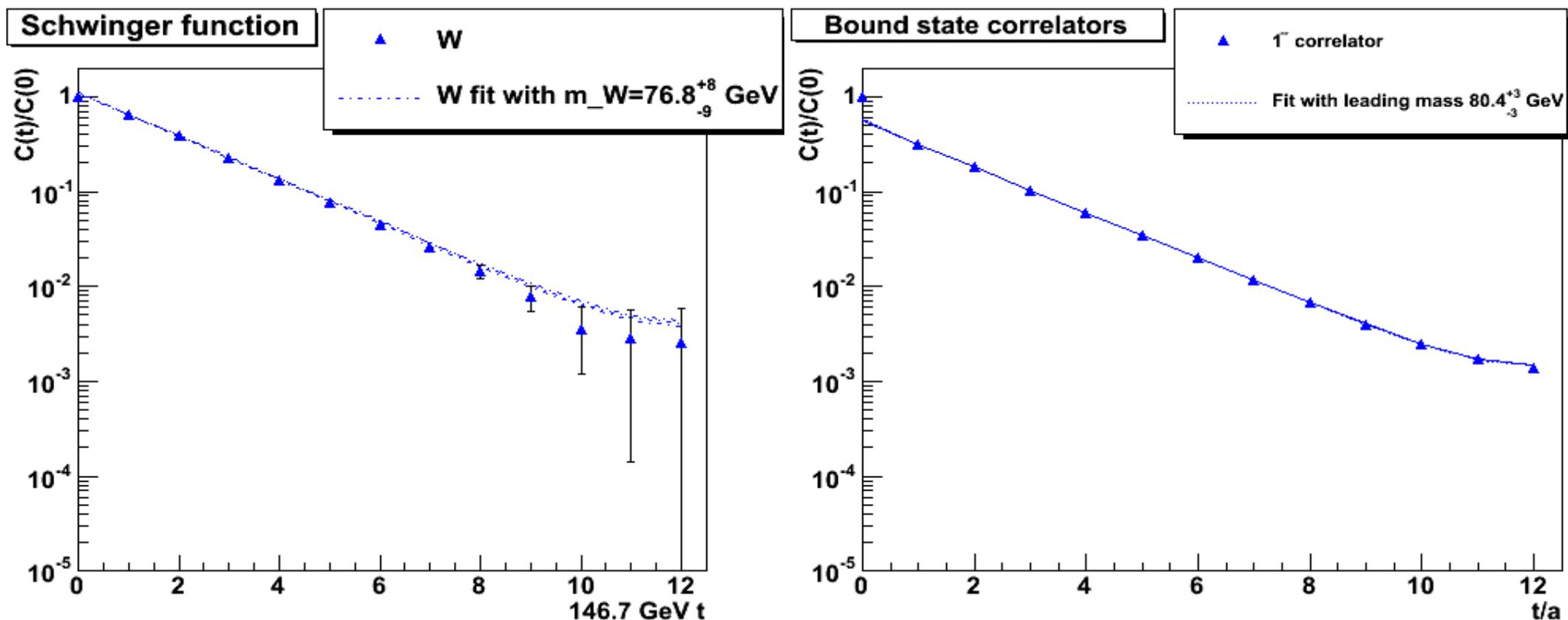
[Maas, EPJC 2011, '12
24⁴, $\beta=2.3$, $\kappa=0.32$ $\lambda=1$]



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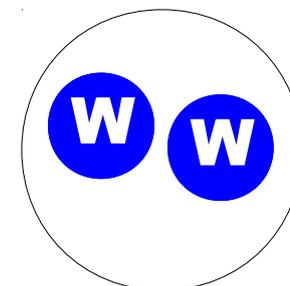
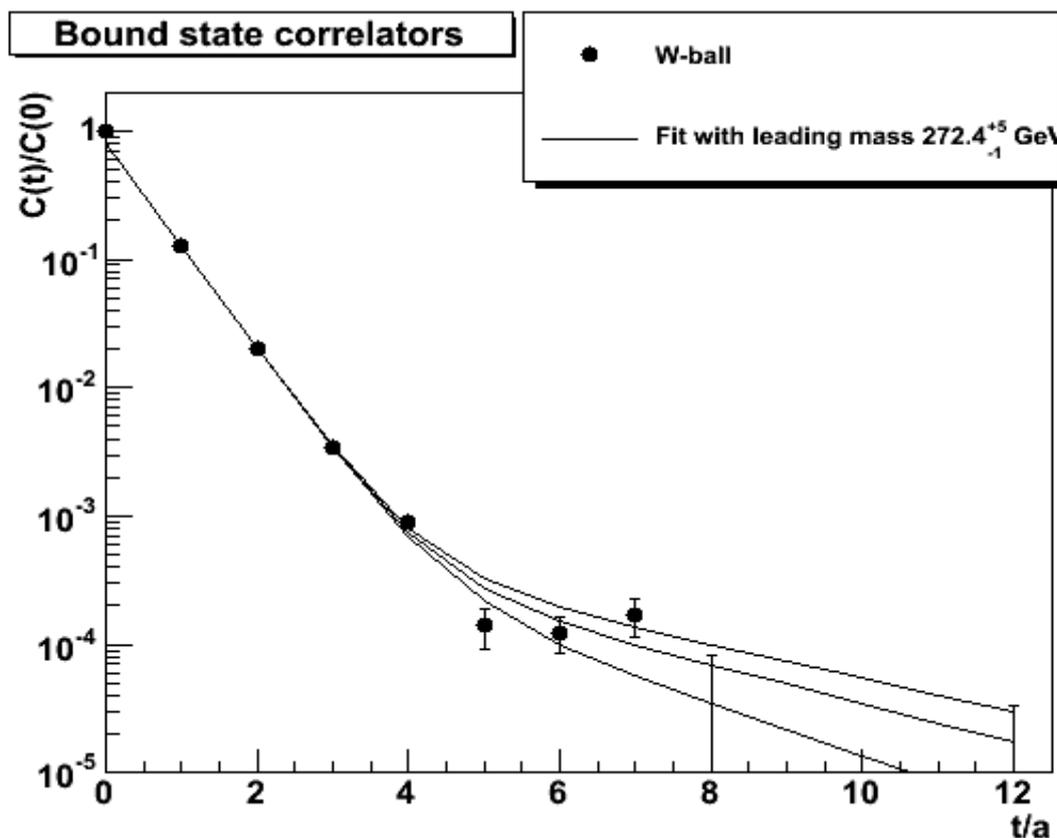
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- Cross section resonances associated with physical particles: Bound states
 - Similar to quarkonium resonances
 - No large differences for light Higgs

Consequences II – Excited states

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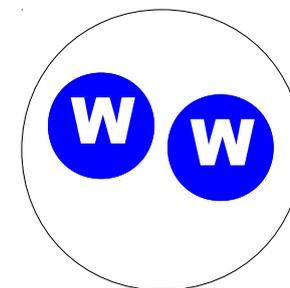
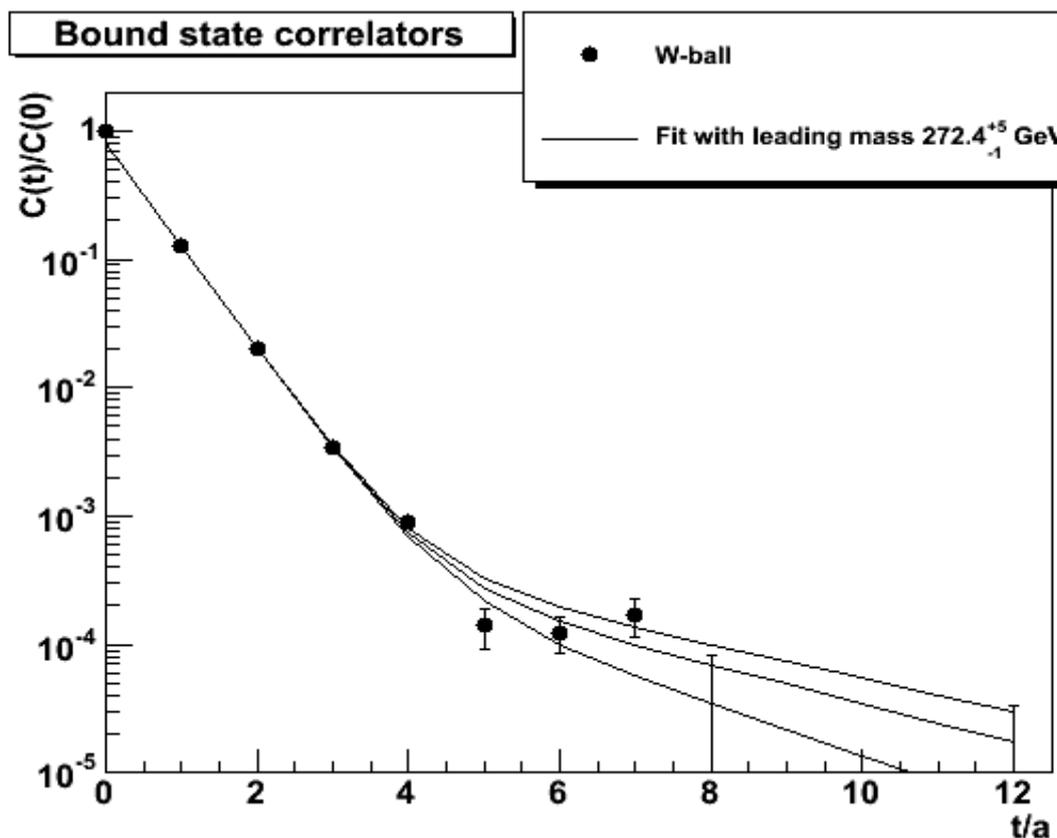
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[Maas '12]

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- Non-perturbatively interesting even for a light Higgs