Prospects for three-body Higgs decays into extra light scalars

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in collaboration with M. Lindner
based on [arXiv:1609.08127]

LCWS 2016, Morioka

16/12/06

Motivation

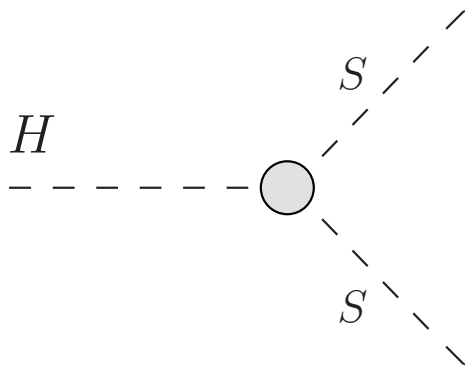
- Enlarged scalar sector
- Exotic/invisible Higgs decays

Scalar portal

new scalar field

$$\mathcal{L} \supseteq -\lambda_p \left(\Phi^\dagger \Phi\right) \left(S^\dagger S\right)$$

SM Higgs doublet



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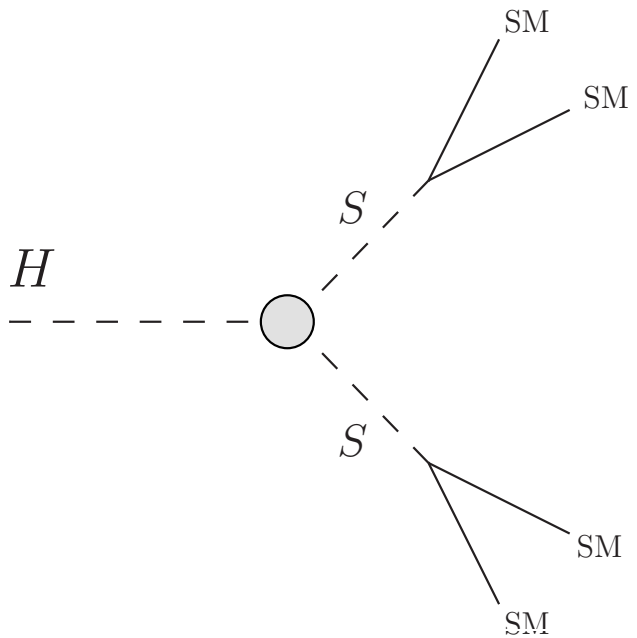

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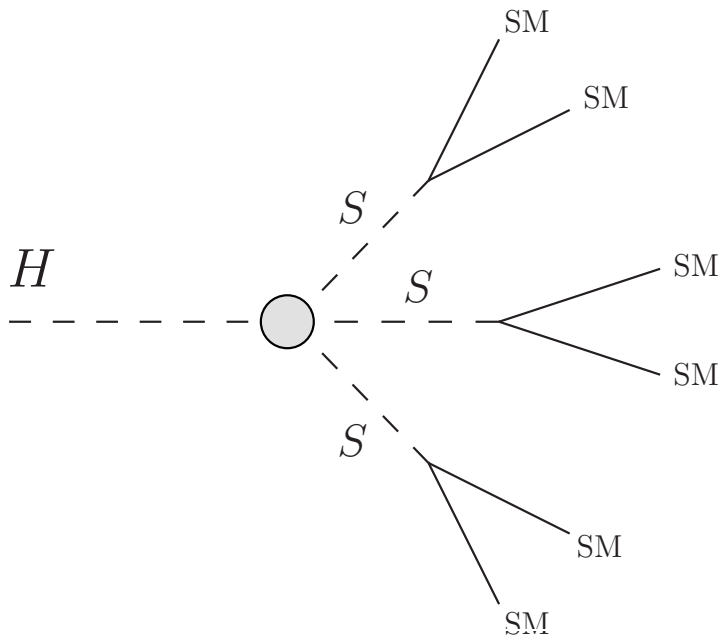

Motivation

- Enlarged scalar sector
- Exotic/invisible Higgs decays
- $H \to 2S \to 4 \times \text{SM}$
- $H \to 3S \to 6 \times \text{SM}$
- $\mathbf{6\mu}$ or $\mathbf{6\tau}$ final states
- very clean signature
- virtually no SM background

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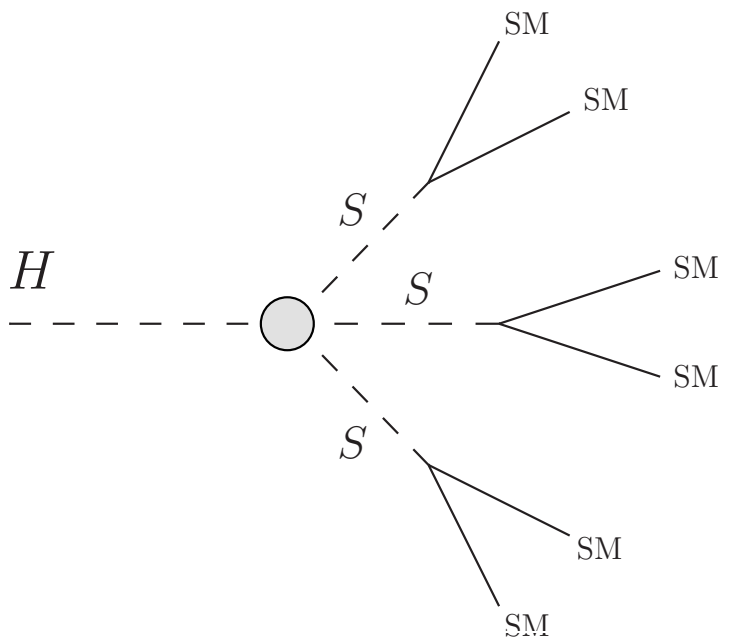


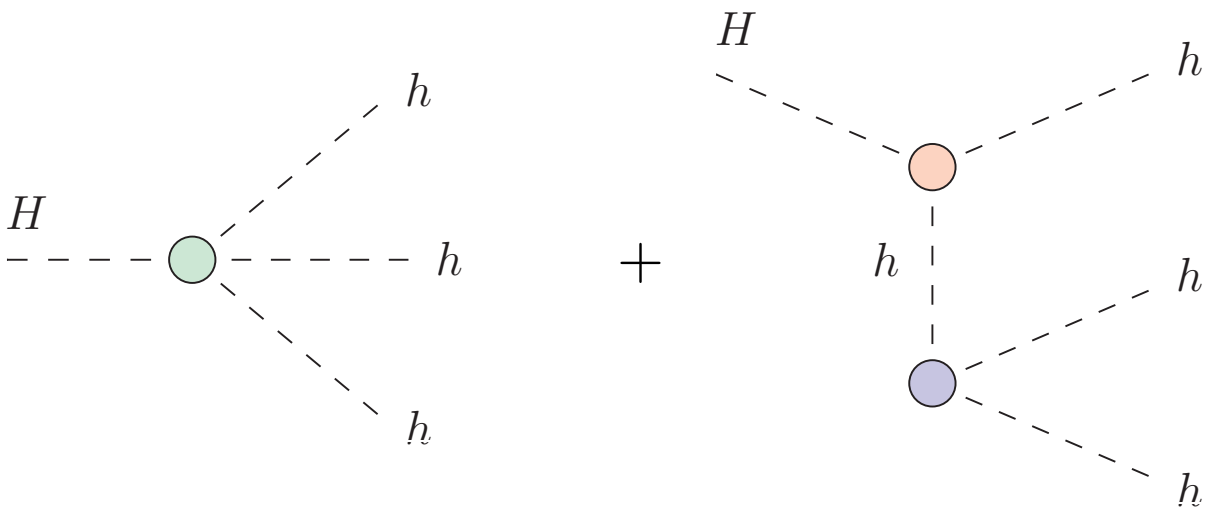
Scalar three-body Higgs decays

Generic scalar sector after EWSB

$m_h \ll m_H = 125.09\,\text{GeV}$

$$V(H,h) = \frac{m_H^2}{2}H^2 + \frac{m_h^2}{2}h^2 + \lambda_{4H}H^4 + \lambda_{4h}h^4 + \kappa_{3H}H^3 + \kappa_{3h}h^3 + \kappa_{2Hh}H^2h + \kappa_{H2h}Hh^2 + \lambda_{2H2h}H^2h^2 + \lambda_{3Hh}H^3h + \lambda_{H3h}Hh^3$$

$\mathcal{M}(H \to 3h) =$



Real scalar singlet extension of the SM

Add a real scalar gauge singlet S to the SM

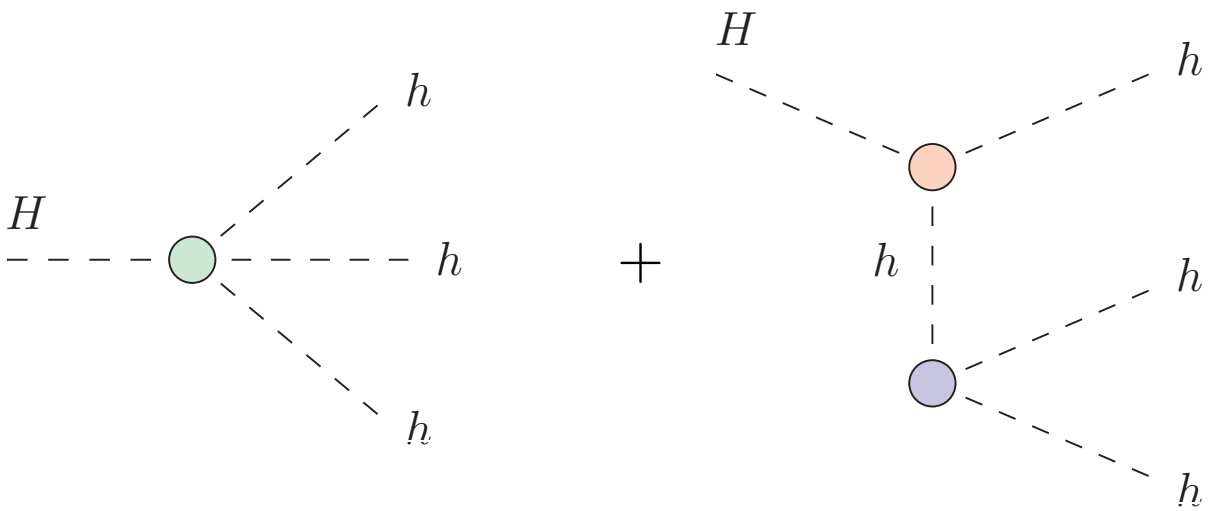
$$V(\Phi, S) = \tfrac{1}{2}\mu^2\Phi^\dagger\Phi + \lambda(\Phi^\dagger\Phi)^2 + \frac{\delta_1}{2}(\Phi^\dagger\Phi)S + \frac{\delta_2}{2}(\Phi^\dagger\Phi)S^2 + \kappa_1 S + \frac{\kappa_2}{2}S^2 + \frac{\kappa_3}{3}S^3 + \frac{\kappa_4}{4}S^4$$

Scalar mixing

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} c_\theta & s_\theta \\ -s_\theta & c_\theta \end{pmatrix} \begin{pmatrix} \phi \\ S \end{pmatrix}$$

Experiments $\Rightarrow$ $\theta \ll 1$

$\mathcal{M}(H \to 3h) =$



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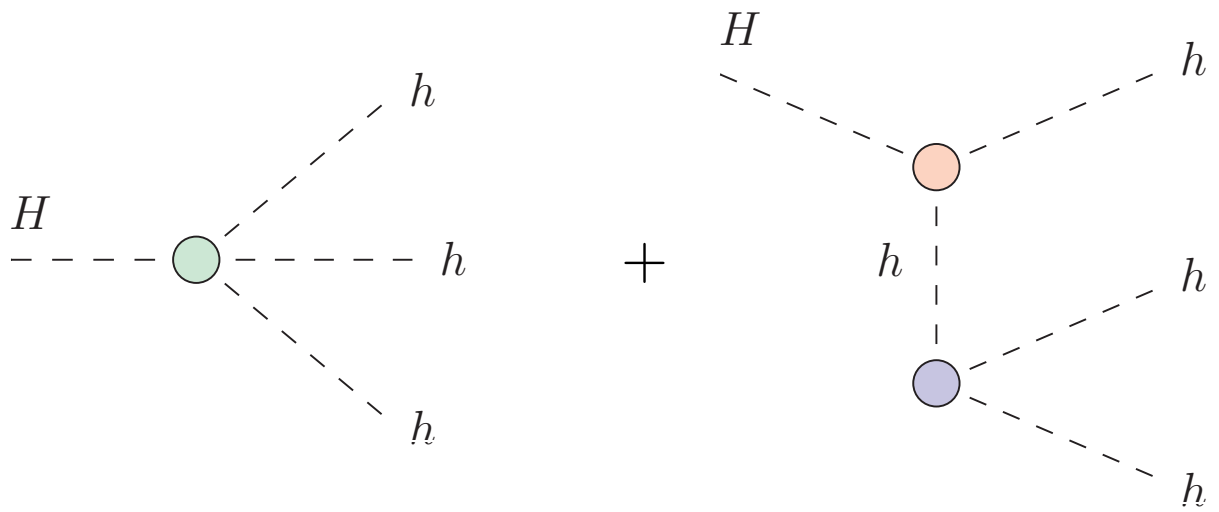
$$\kappa_{H2h} \simeq \tfrac{1}{2}\delta_2 v + \kappa_3\theta$$

$$\kappa_{3h} \simeq \tfrac{1}{3}\kappa_3 - \tfrac{1}{2}\delta_2 v\theta$$

$$\lambda_{H3h} \simeq (\kappa_4 - \tfrac{1}{2}\delta_2)\theta$$

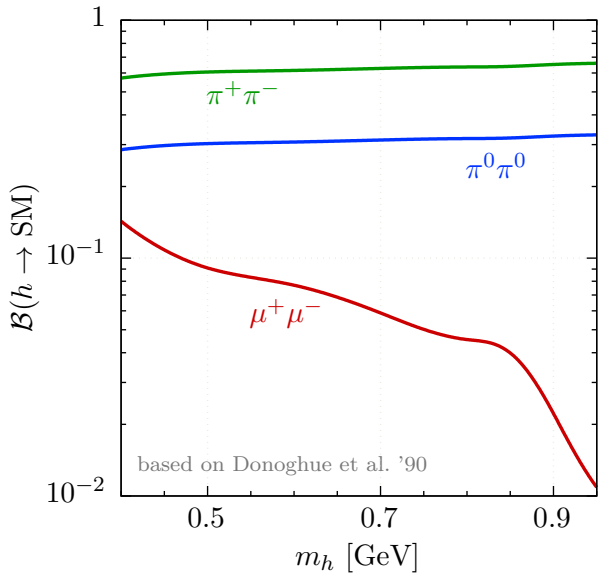
$\mathcal{M}(H \to 3h) =$



Interesting mass ranges for h

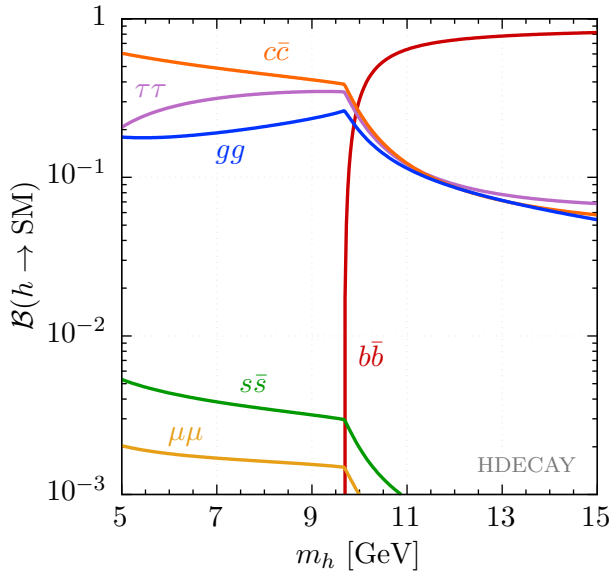
Low-mass scenario

- $m_h \lesssim 1\,\text{GeV} \quad \Rightarrow \quad \theta \lesssim 10^{-3}$
  (Constraints from B-meson decays)
- h decays to π and μ pairs
- Pion channel enhanced by final-state interactions (Raby, West '88)

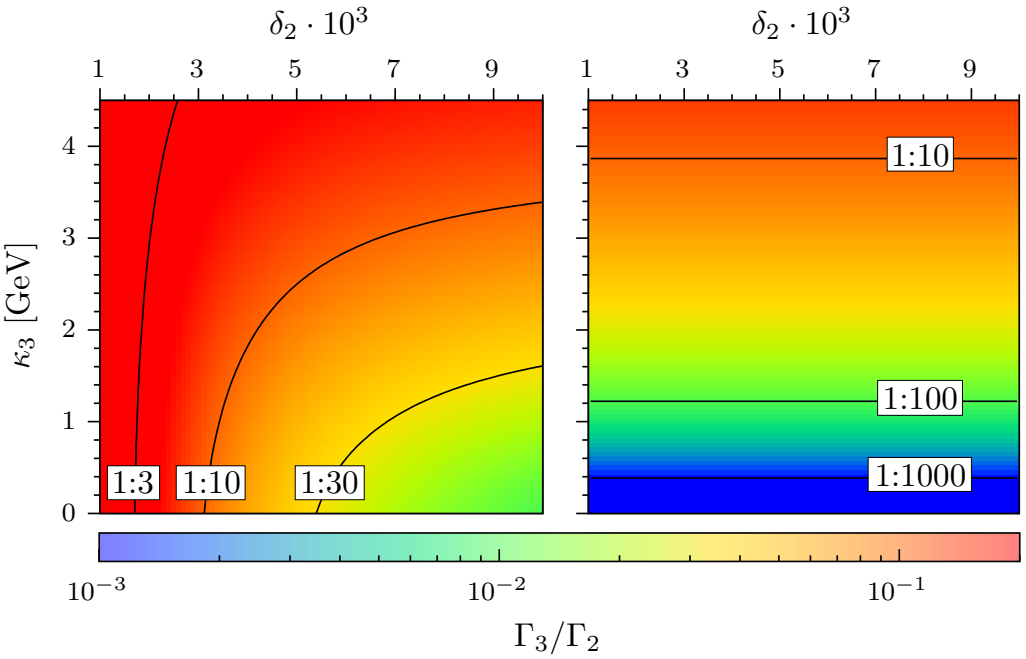


High-mass scenario

- $5\,\text{GeV} \lesssim m_h \ll m_H \quad \Rightarrow \quad \theta \lesssim 0.1$
  (Constraints from LEP searches)
- h decays to heaviest open final state



Low-mass scenario – results for $m_h = 500\,\mathrm{MeV}$



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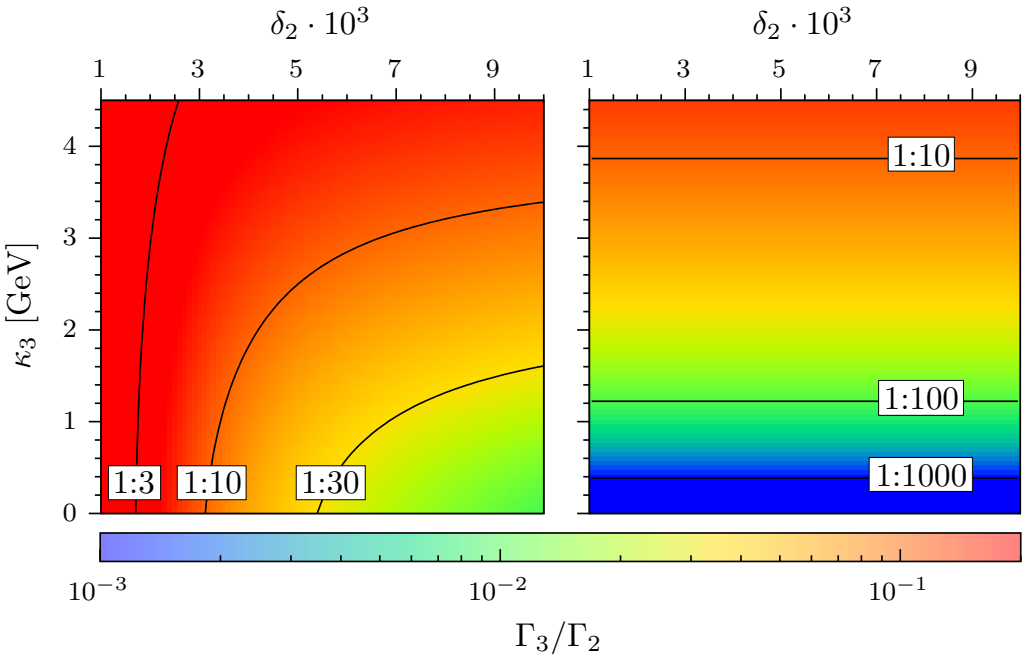

Consistency requirements

- ✓ perturbative unitarity
- ✓ perturbativity
- ✓ non-standard Higgs decays
- ✓ vacuum stability

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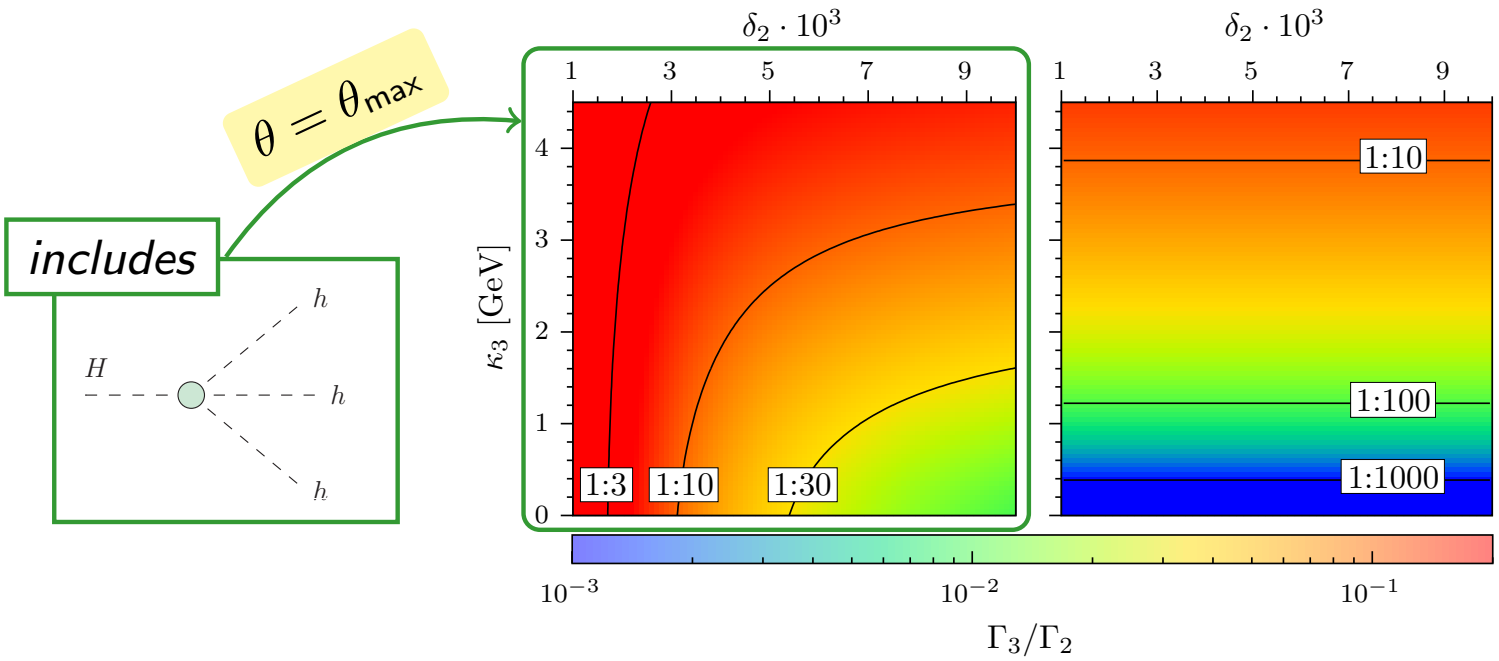

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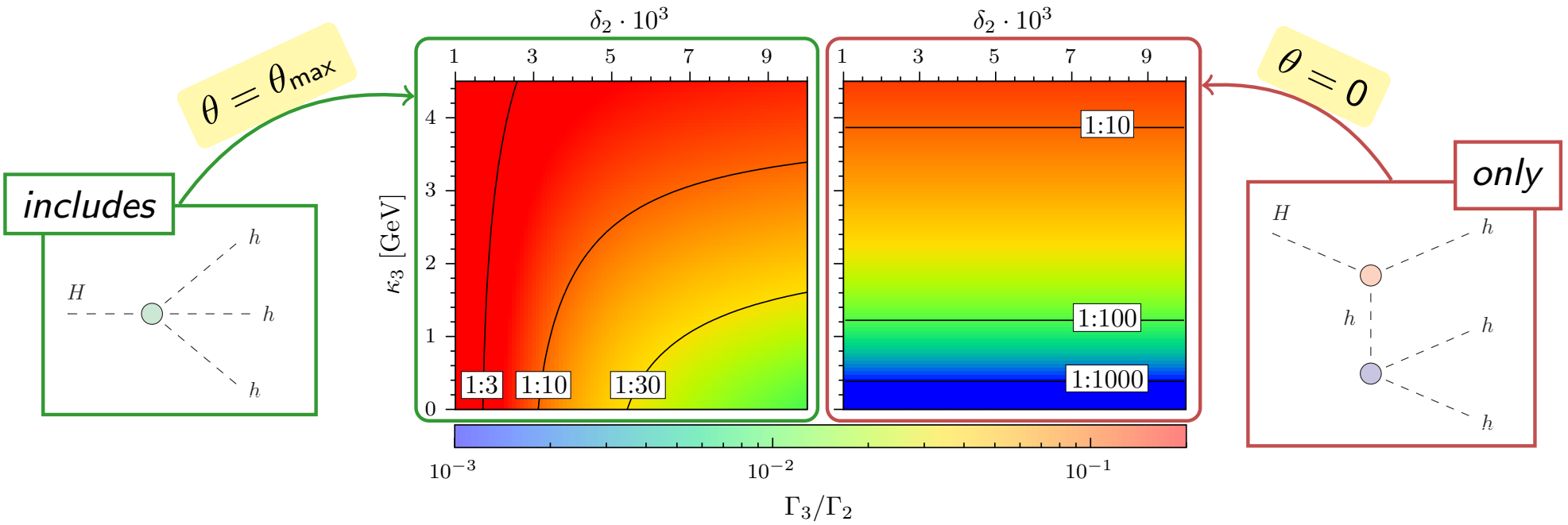

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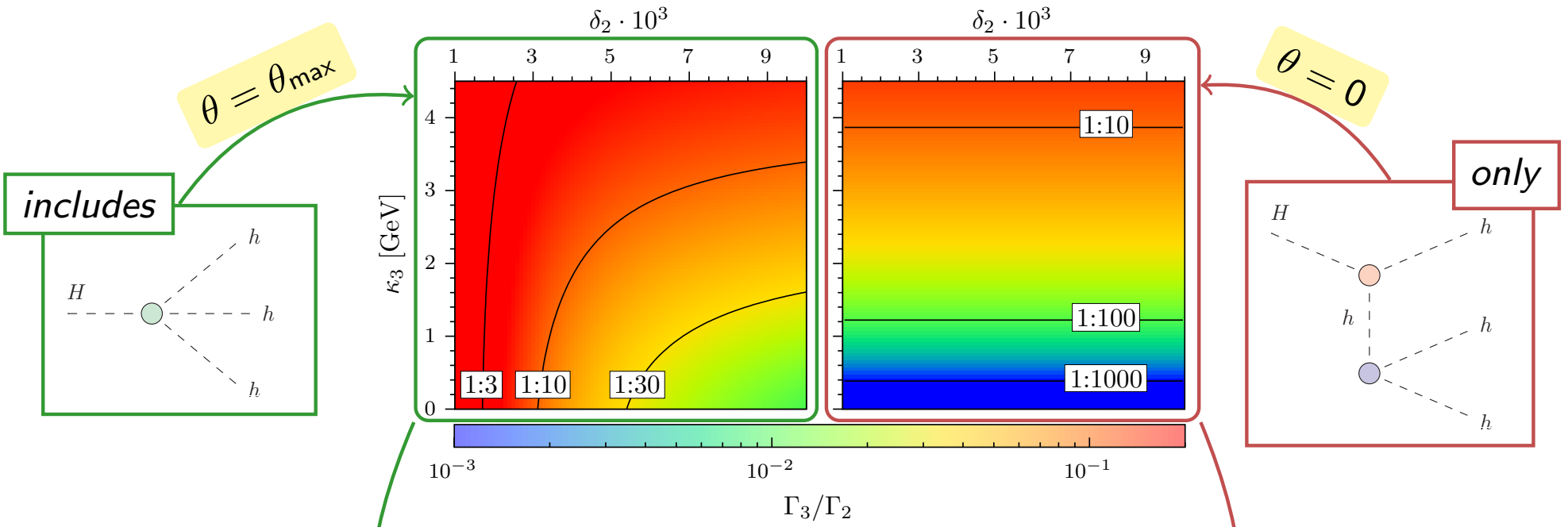

LHC @ 14 TeV, 300 fb^{-1}

Signal	4μ	6μ	$4\mu 2\pi$
Events	14000	170	5100

Signal	4μ	6μ	$4\mu 2\pi$
Events	14000	7	210

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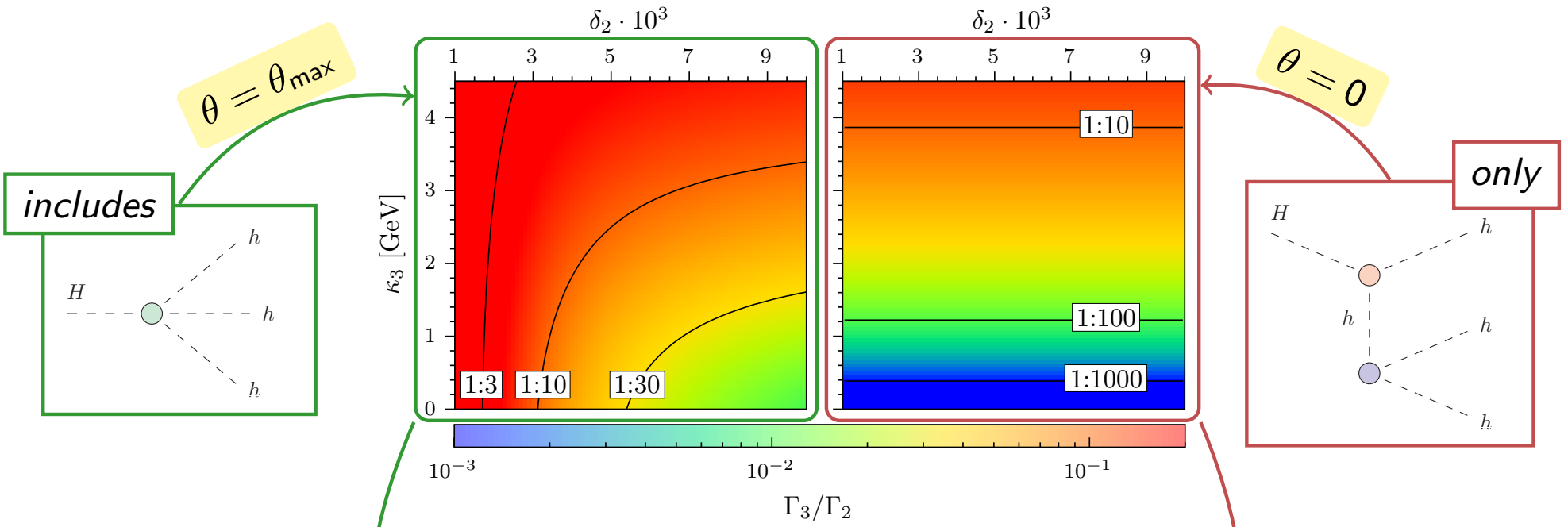

ILC @ 250 GeV, 500 fb^{-1}

Signal	6μ	4π	6π
Events	2	13000	1550

Signal	6μ	4π	6π
Events	0	13000	60

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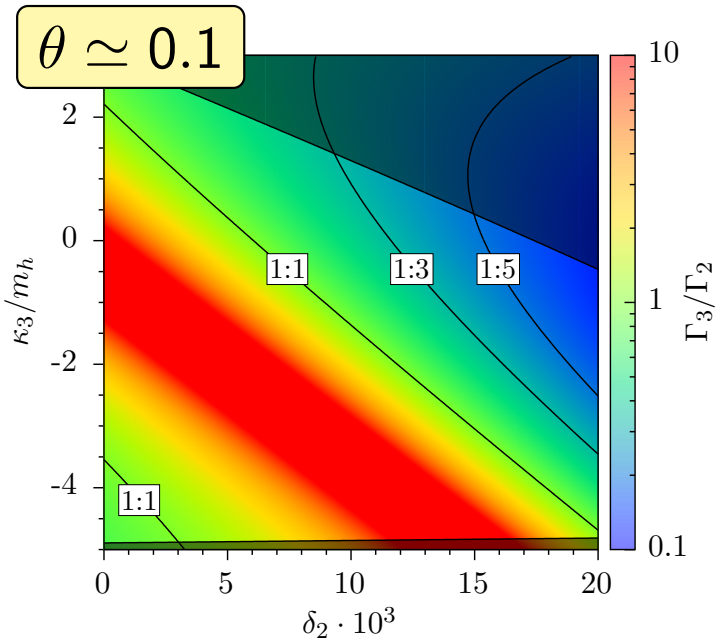

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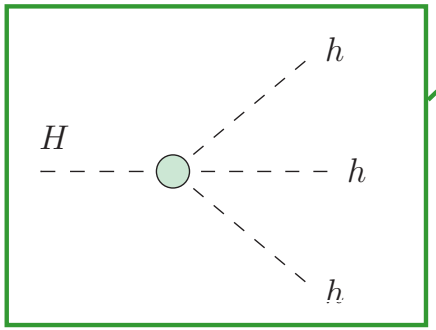
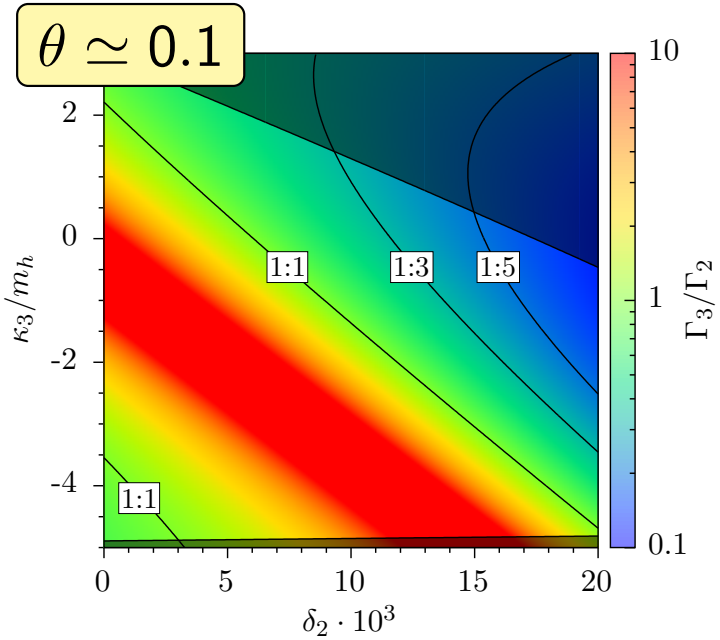
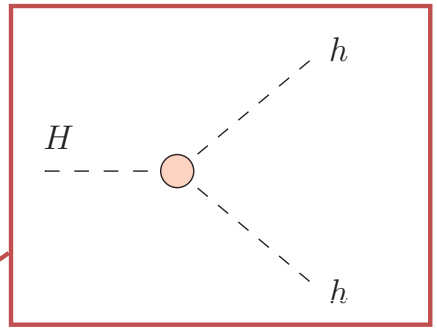


can contribute significantly





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$$\kappa_{H2h} \simeq \frac{\delta_2}{2} v + \kappa_3 \theta$$

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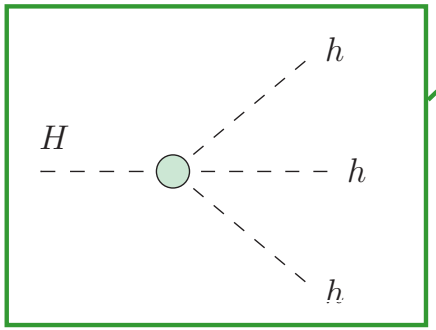

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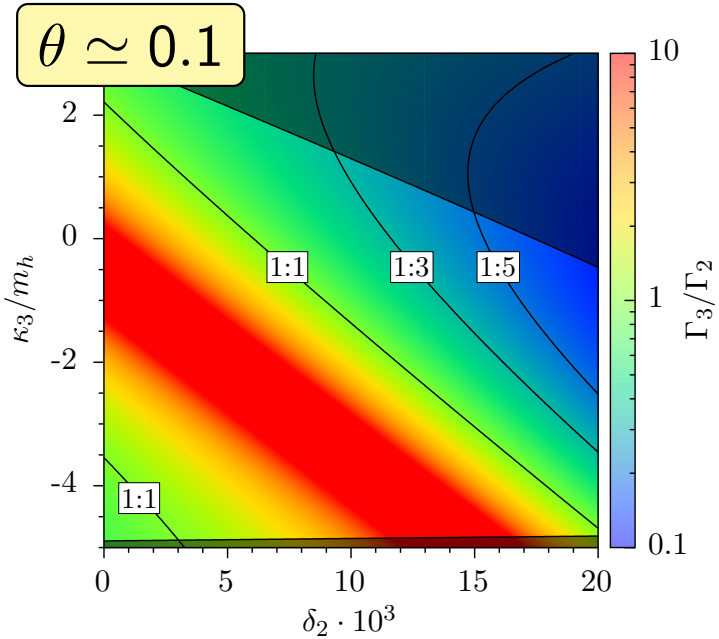

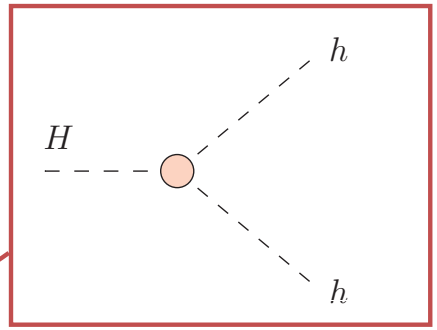

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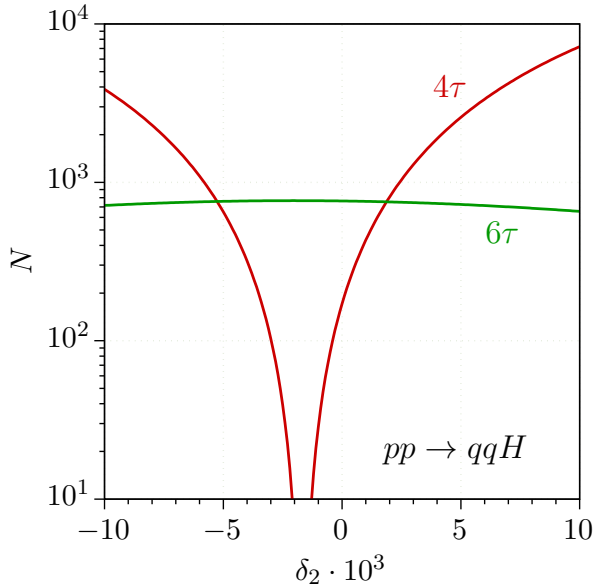
- possibly discovery channel



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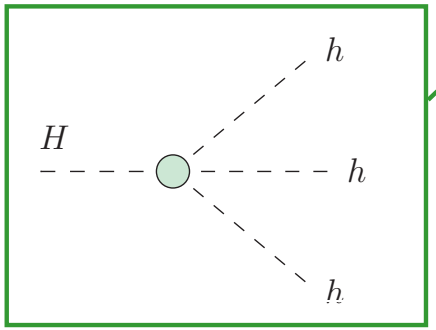

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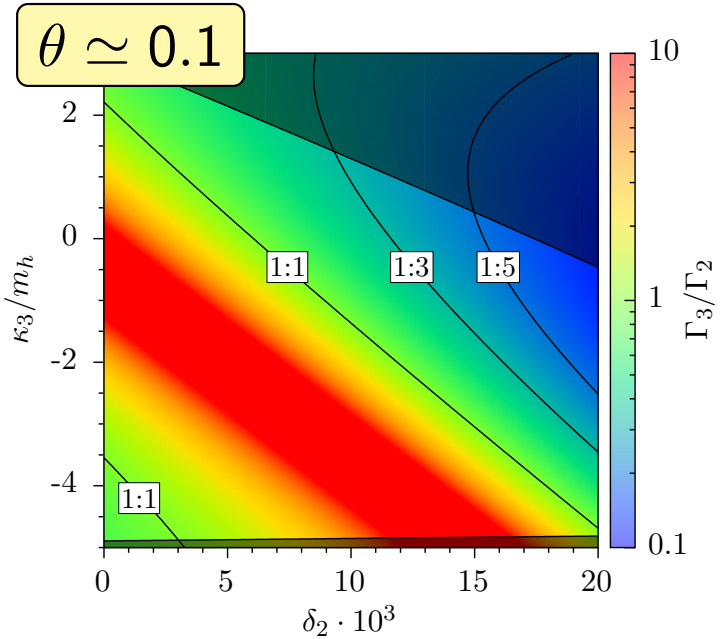

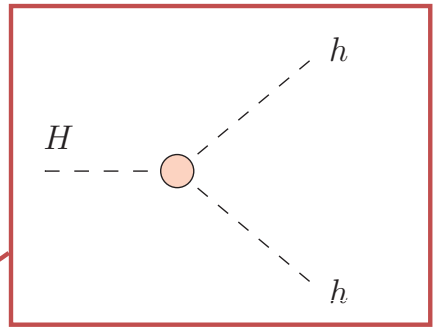

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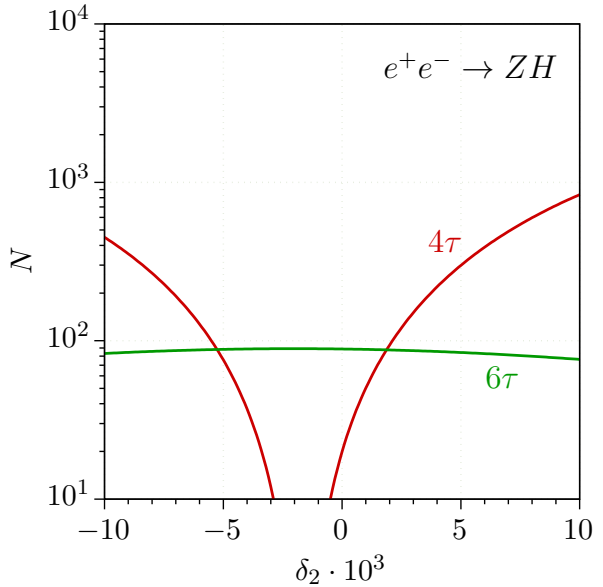

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- May be observable both at the LHC and at future e^+e^- machines.
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