High-energy physics today: do theory and accelerator-based experiments continue to inspire each other?

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The absence of any new fundamental physics signals at energies $\approx$ TeV
$\Rightarrow$ Confusion among both high-energy theorists and experimentalists

Theorists: Why should they explore new physics scenarios endlessly, while there is **no concrete evidence***?*
Experimentalists: What is the physics motivation for ever-active refinement of technicalities, in terms of simulation/analysis/hardware, unless these is **a glimpse of something***?*

Remember Luigi Pirandello's play
'Six Characters in Search of an Author'*:*

"We think we understand each other, but we never really do"

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- *As examples, we take up two cases related to the 125-GeV scalar discovered in 2012*
  (The Higgs or a Higgs-like boson).

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- *The question of whether it is 'the Higgs' or 'a Higgs' is therefore worth pursuing.*

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- *Con: Challenges from pile-up, systematics etc.*

Di-Higgs production....

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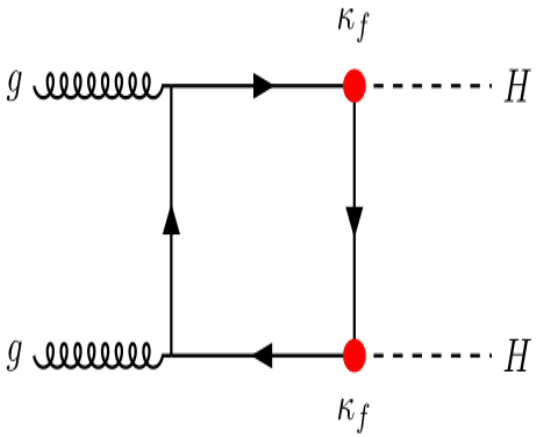
- *Experimentally, with $\kappa = \lambda/\lambda_{SM}$,*
  at 95% CL with $140 fb^{-1}$, $-1.2 < \kappa < 7.2$ (ATLS, 2025),
  $-1.4 < \kappa < 7.8$ (CMS, 2025)


κ_f
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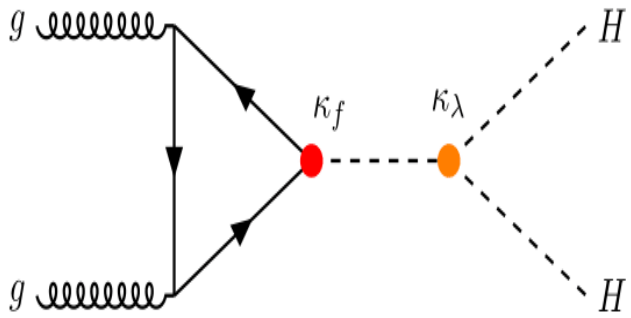
g
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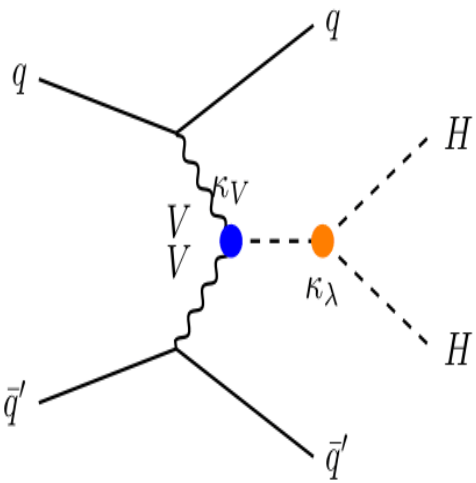
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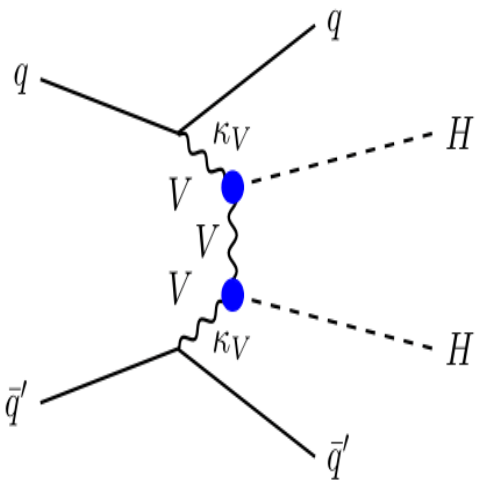
$\bar{q}'$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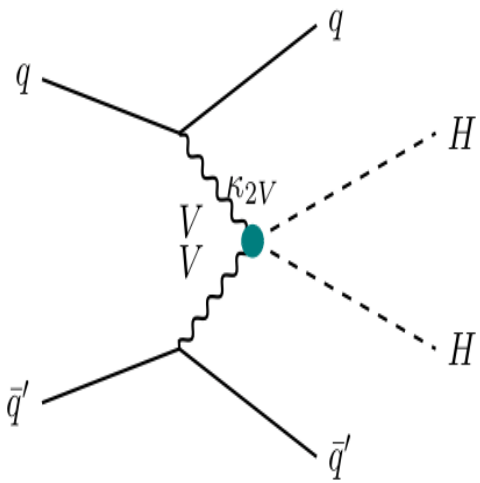
q
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κ_{2V}
V
V
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$\bar{q}'$

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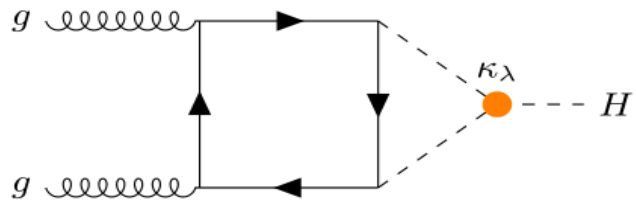
- *Similarly, the vector boson fusion (VBF) and top-Higgstrahlung contributions involve κ_V, κ_{2V}, κ_t*
- *Thus, considering lowest-order contributions alone, the best fit for κ_λ remains highly entangled, and also model-dependent*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g
κ_λ
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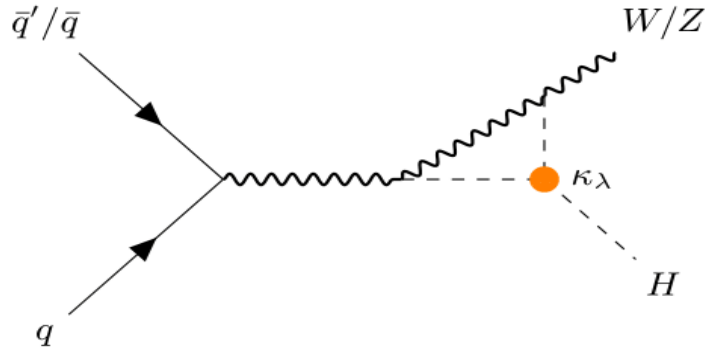
$\bar{q}'/\bar{q}$
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κ_λ
H
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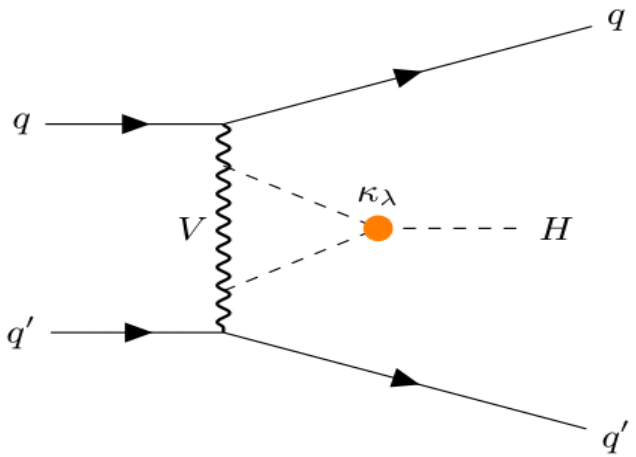
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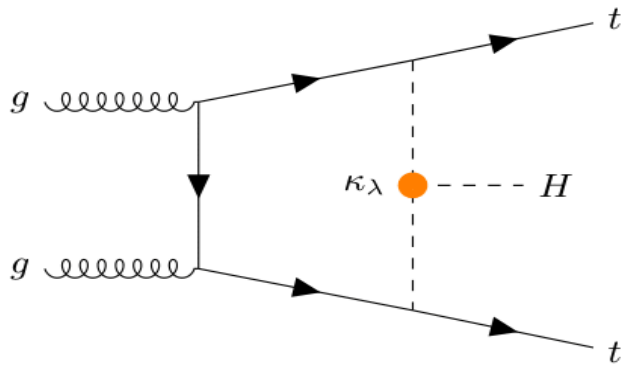
q'
q'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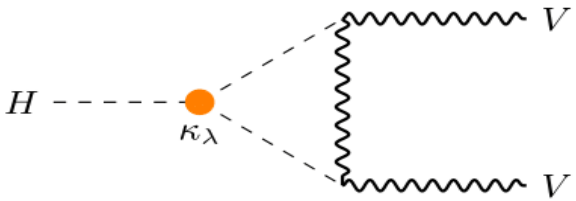
t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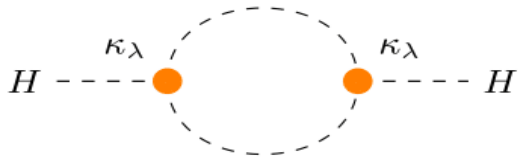
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- $b\bar{b}WW, b\bar{b}WW$ *final states: Crucial are the MET measurements: connected with*
  (a) Variables like MT2 which help in filtering out the signals
  (b) Jet reconstruction

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- *Q: How to see such light pseudoscalars at the HL-LHC? The answer depends on several issues that are best addressed by experimentalists*

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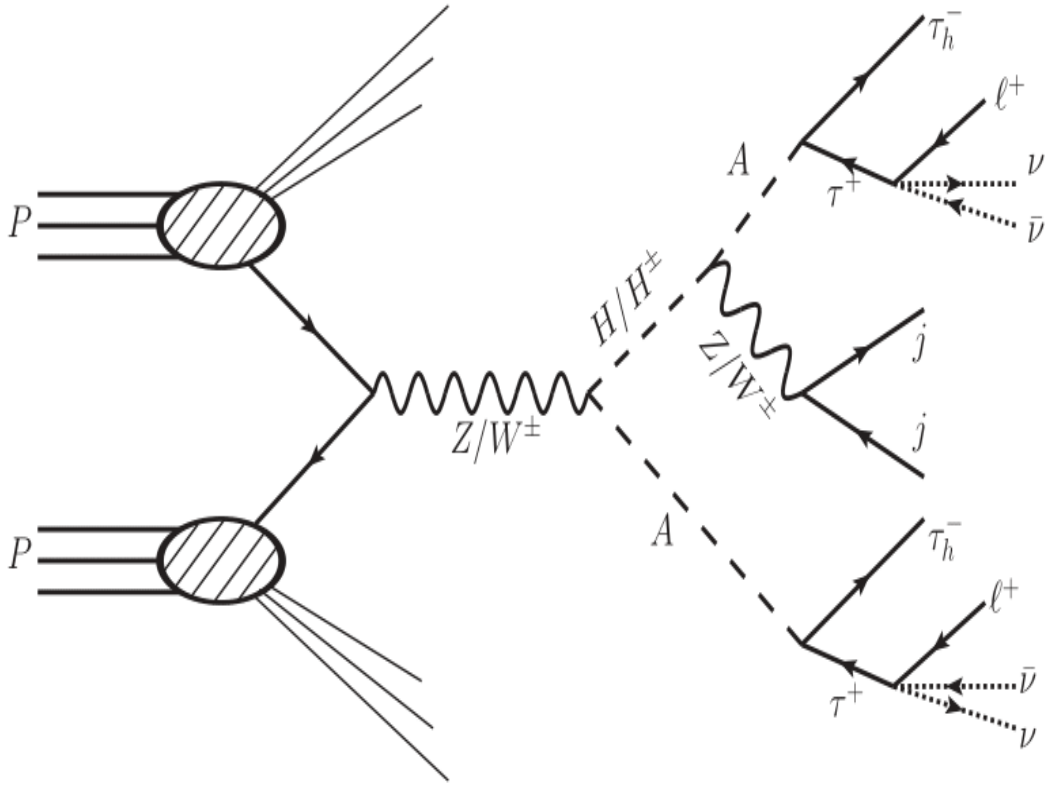
- *Thus, direct signals has been looked for via electroweak cascade*


P
P
$Z/W^{\pm}$
$H/H^{\pm}$
A
A
$Z/W^{\pm}$
τ_h^-
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j
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ν
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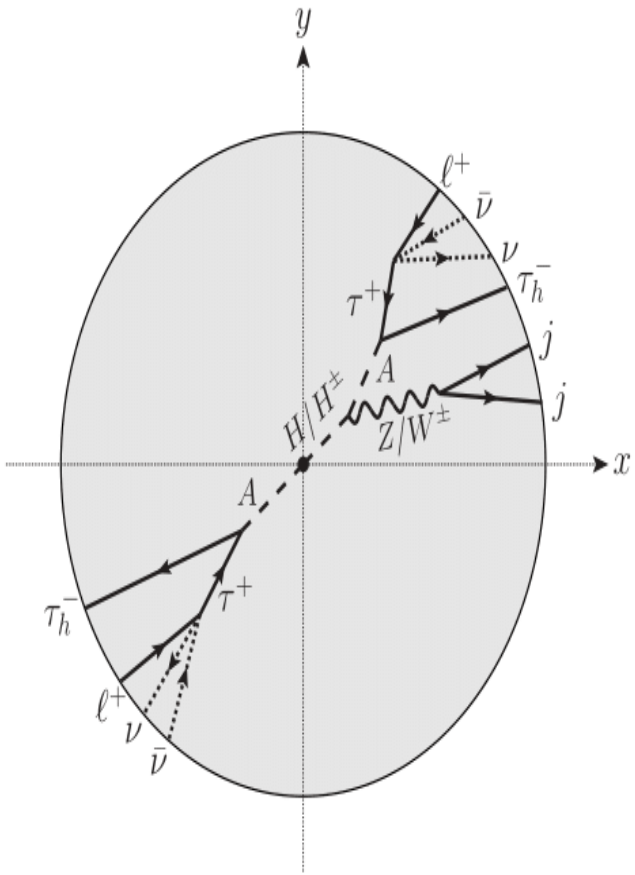
(a)


y
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A
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(b)

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- *Challenges:*
  (a) Improved jet reconstruction algorithm and τ-tagging
  (b) reduction of overall systematics at HL-LHC

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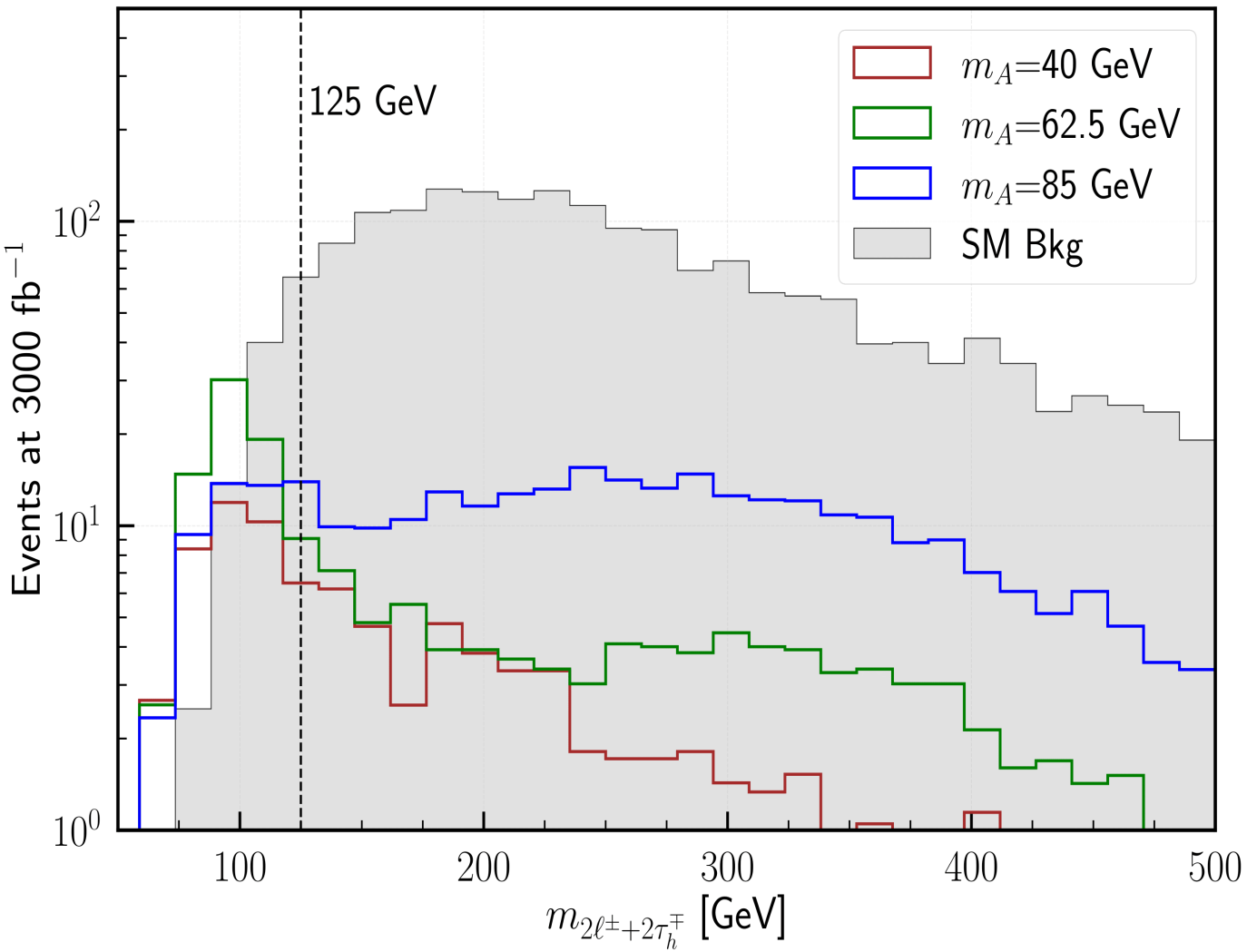
125 GeV
m_A=40 GeV
m_A=62.5 GeV
m_A=85 GeV
SM Bkg
Events at 3000 fb^{-1}
10^0
10^1
10^2
100
200
300
400
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$m_{2\ell^\pm+2\tau_h^\mp}$ [GeV]

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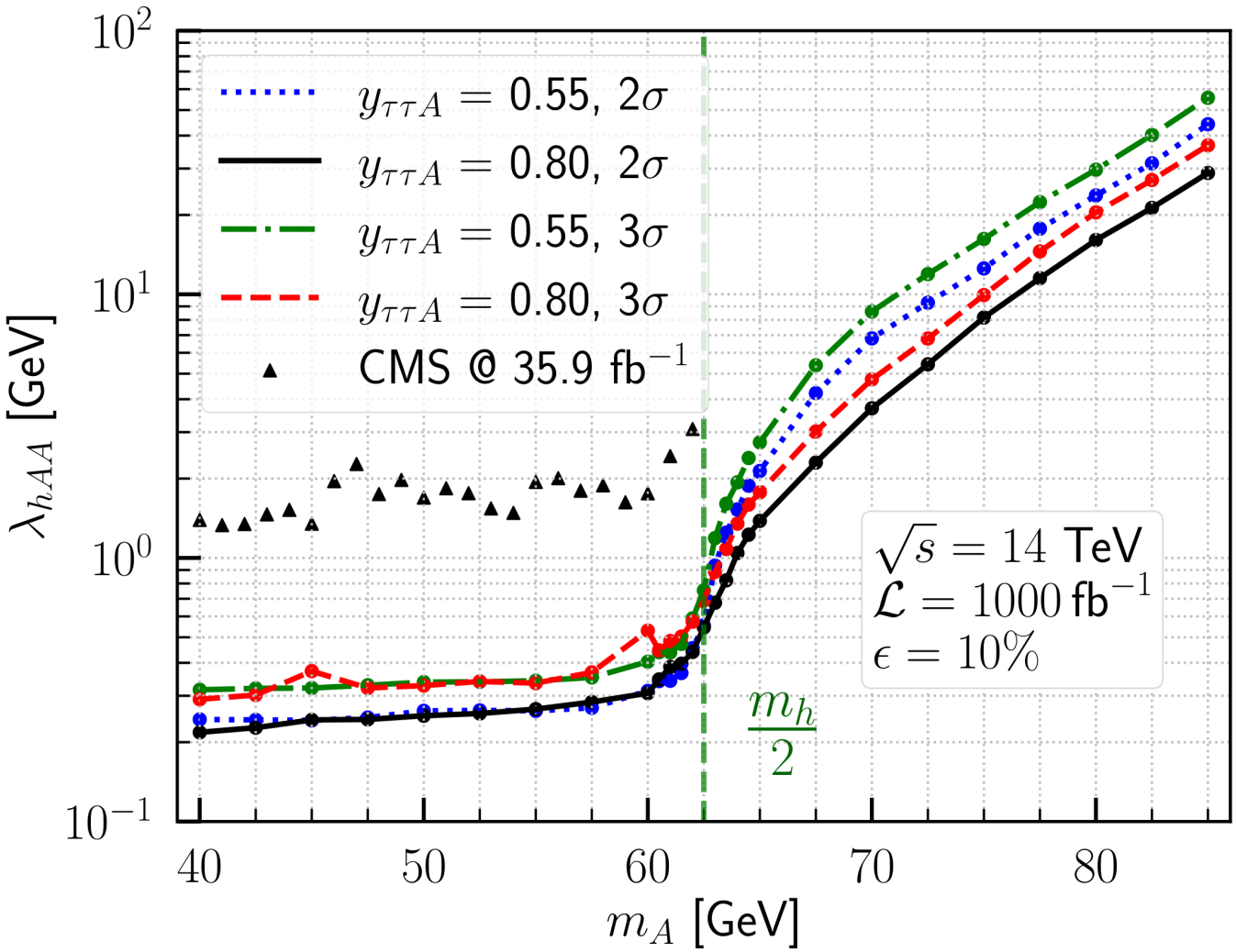
$y_{\tau\tau A} = 0.55,\ 2\sigma$
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CMS @ 35.9 fb^{-1}
$\sqrt{s} = 14$ TeV
$\mathcal{L} = 1000\,\text{fb}^{-1}$
$\epsilon = 10\%$
$\frac{m_h}{2}$
λ_{hAA} [GeV]
m_A [GeV]
10^2
10^1
10^0
10^{-1}
40
50
60
70
80

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- *Criteria that comes to one's rescue:*
  (a) MET $\leq$ 40 GeV
  (b) $m_{inv}[(b\bar{b})_{m_A}\ell^+\ell^-] \approx m_h$
  (c) In addition, an $m_{(b\bar{b})}$ peak at m_A rises above the continuum background by about one order

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- *Additinal challenge:*
  (a) Improving b-tagging efficiency at low-energy
  (b) Overall systematics which enables detection even with $1000 fb^{-1}$

"Life is full of strange absurdities, which do not need to appear plausible, since they are true."

— Luigi Pirandello, Six Characters in Search of an Author