More light on Higgs flavor at the LHC: Higgs couplings to light quarks through h+γ production

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Invisibles Workshop **2021**

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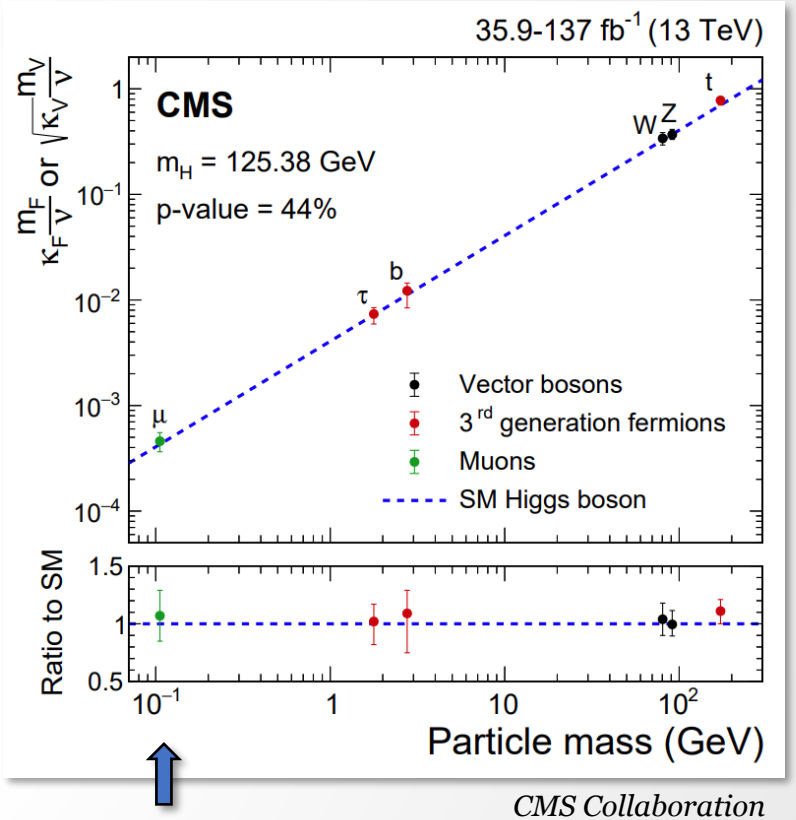
Based on work in collaboration with:
J. A. Aguilar-Saavedra, J. M. No
Phys. Rev. D **103**, 095023
2008.12538

Motivation

While the couplings of the 125 GeV Higgs boson to EW bosons and third-generation fermions have been measured rather precisely at the LHC…



Now including the muon too!

CMS Collaboration
2009.04363

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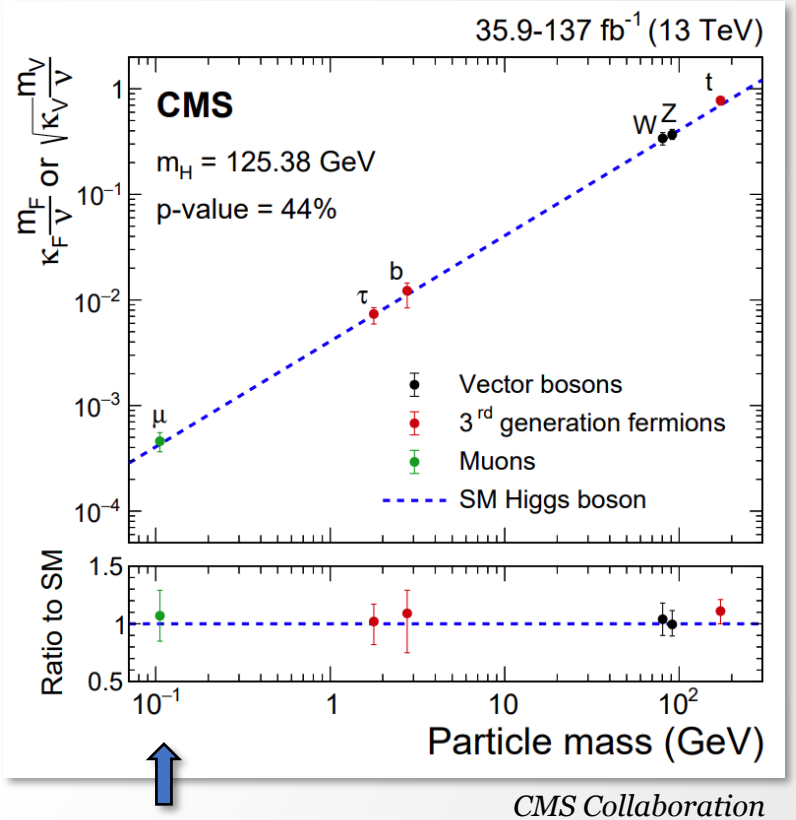
Yukawa couplings to the lighter SM fermions remain weakly constrained (or very weakly, for the first-generation fermions).

Yet, given our current lack of understanding of the Higgs flavor structure, their measurement is key to further test the SM mass generation paradigm!

New strategies at the LHC?



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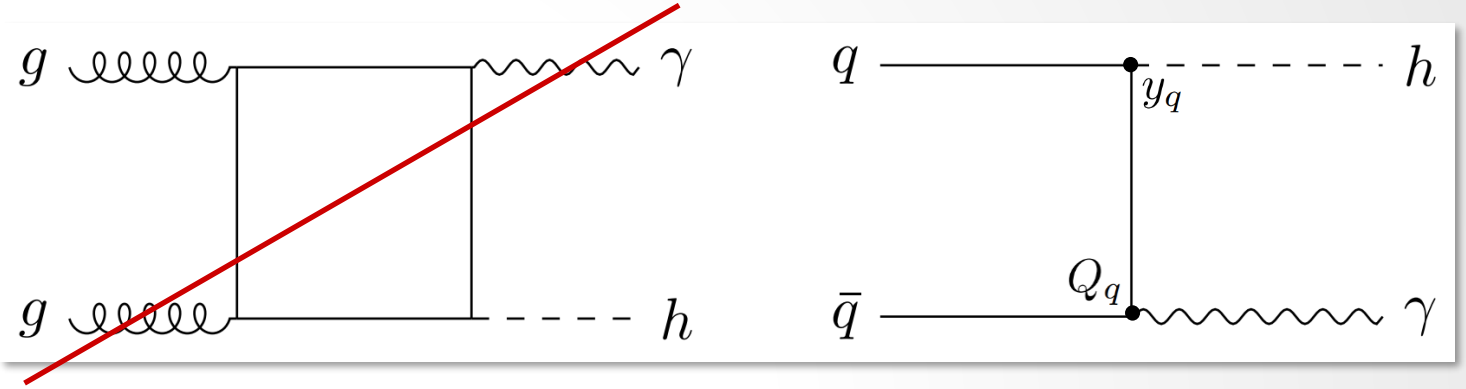
h+γ production

The gluon-initiated contribution naively expected to lead vanishes due to Furry's theorem.



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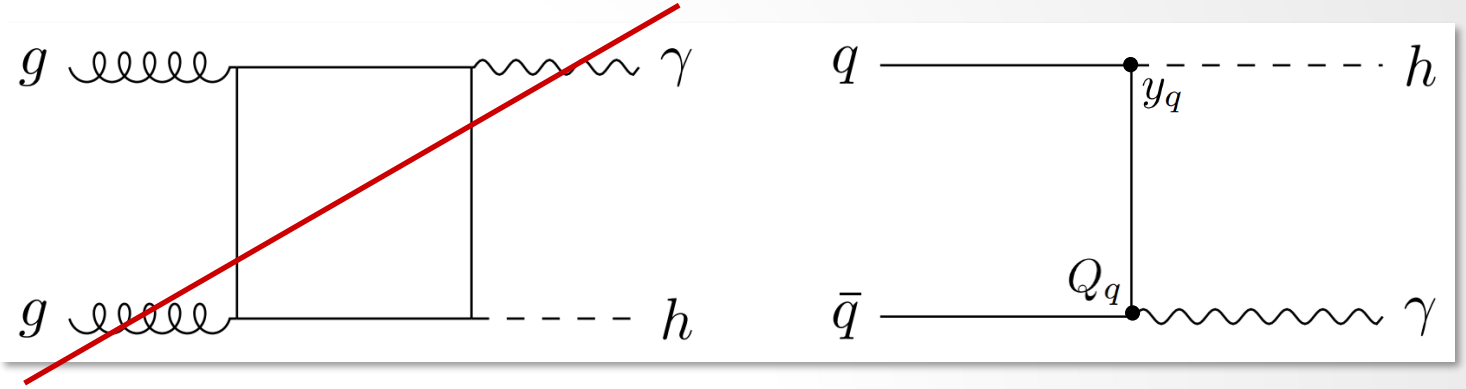

- In the absence of extra partons in the final state, the bottom and charm-initiated contributions lead the production.
- A $(Q_u/Q_d)^2 = 4$ factor enhances up-type quarks contributions w.r.t. that of down-type quarks, so focus on the first.

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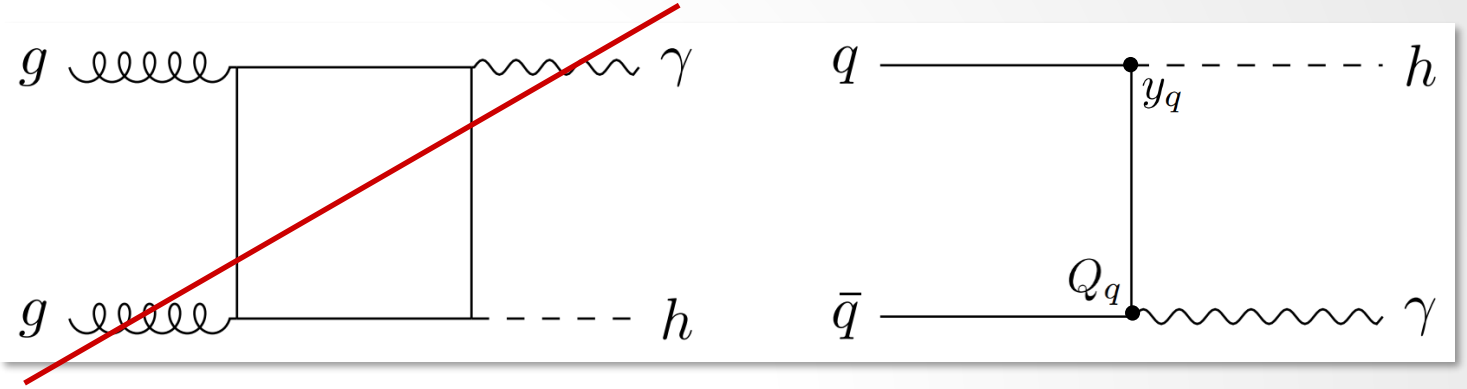

- In the absence of extra partons in the final state, the bottom and charm-initiated contributions lead the production.
- The SM cross-section is unsurprisingly small, but quadratically sensitive to any BSM enhancement of the light quark Yukawa couplings: $y_u(m_h) \sim y_c^{\rm SM}(m_h) \rightarrow \sigma_{u\bar{u}} \sim 1.3$ fb
- A $(Q_u/Q_d)^2 = 4$ factor enhances up-type quarks contributions w.r.t. that of down-type quarks, so focus on the first.
- For its relatively large branching ratio and clean experimental profile, we focus on the decay:

$$h \rightarrow WW^* \rightarrow \ell^+\nu\ell^-\bar{\nu}$$

Dominant Backgrounds

$h \to WW^* \to \ell^+\nu\ell^-\bar{\nu}$ + γ

$(\ell = e/\mu)$

$pp \to$ $\ell^+\nu\ell^-\bar{\nu}\gamma$

$Z\gamma \quad Z \to \tau^+\tau^-$

$t\bar{t}\gamma \quad t \to bW$

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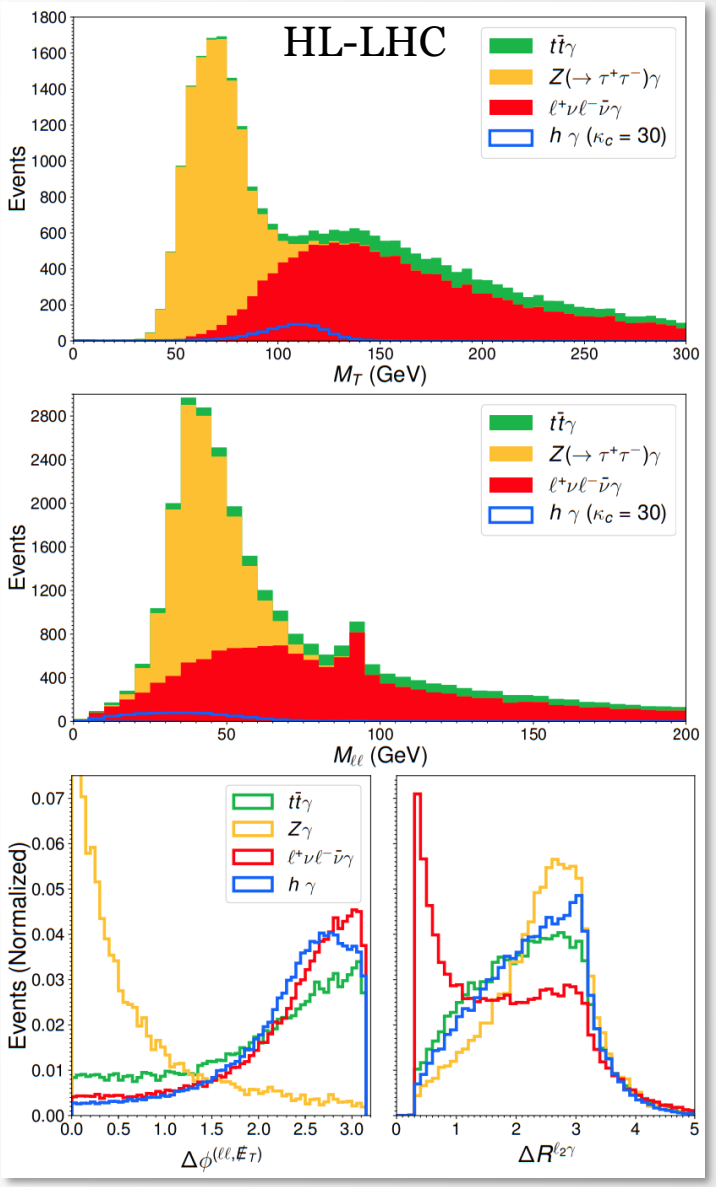
Very rich event kinematics!

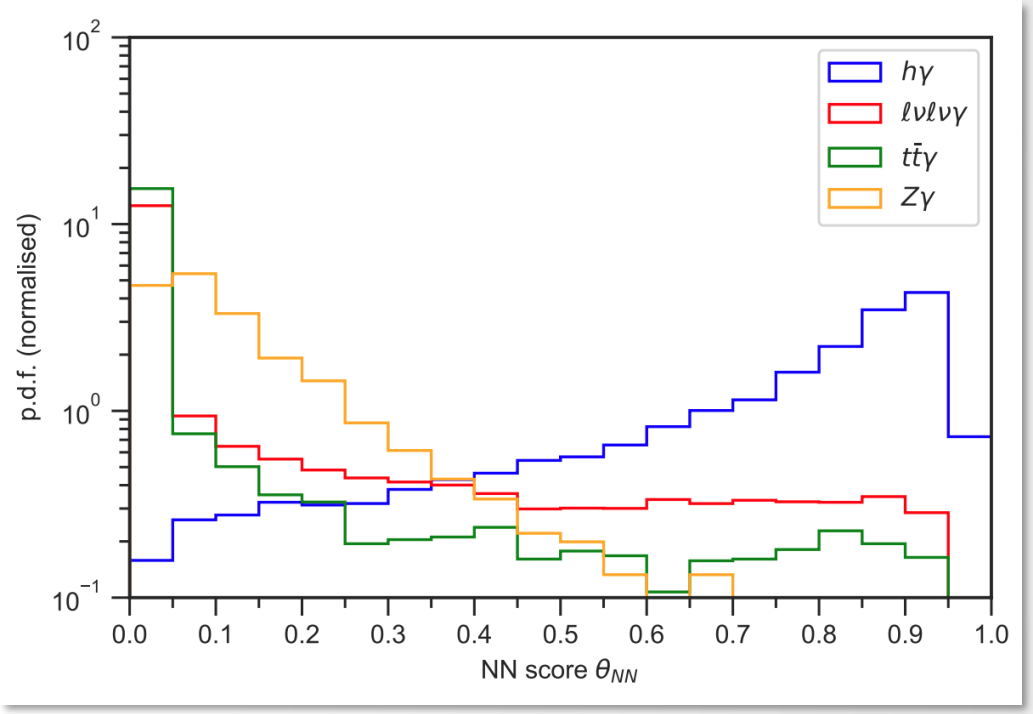
$$M_T\,,\, M_{\ell\ell}\,,\, M_{\ell\ell\gamma}\,,\, p_T^{\ell_1}\,,\, p_T^{\ell_2}\,,\, p_T^{\gamma}\,,\, \not{E}_T\,,$$
$$\Delta\phi^{\ell\ell}\,,\, \Delta\phi^{\ell_1\gamma}\,,\, \Delta\phi^{\ell_2\gamma}\,,\, \Delta\phi^{(\ell\ell,\not{E}_T)}\,,\, \eta^{\ell_1}\,,\, \eta^{\ell_2}\,,\, \eta^{\gamma}$$



Multivariate Analysis & Results

How to better exploit them?

We train a NN to discriminate the hγ signal from SM backgrounds.



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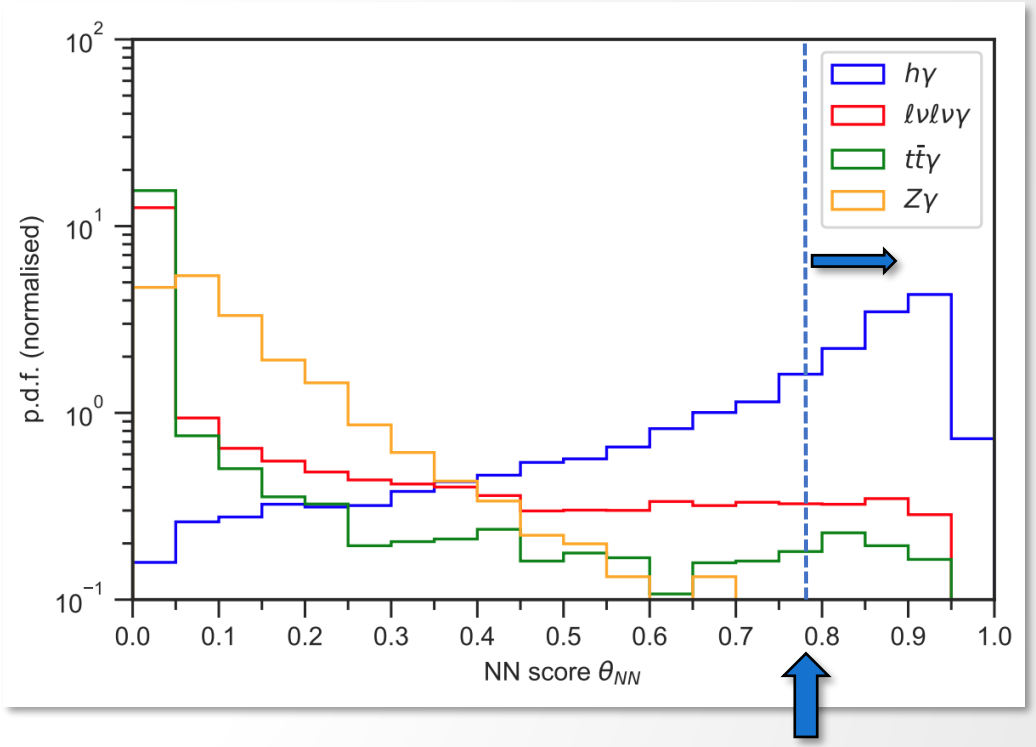

Optimal region:

$$\theta_{\mathrm{NN}} > 0.78$$

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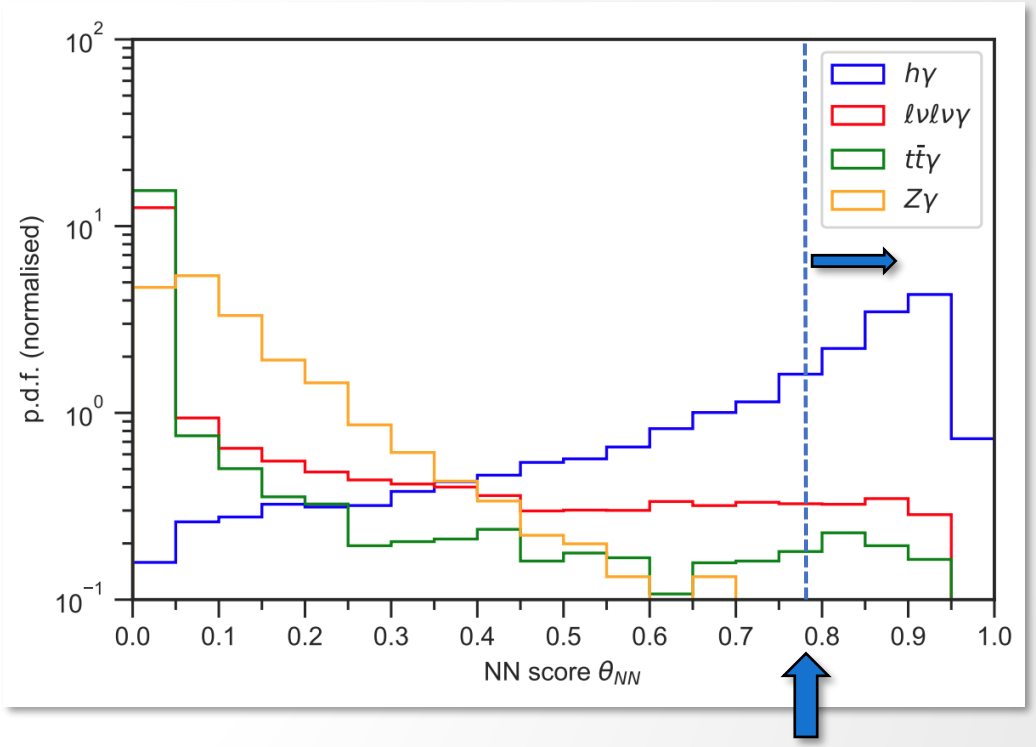
HL-LHC ($3\ ab^{-1}$) reach:

$$|\kappa_c| < 11.8$$
$$|\kappa_u| < 1930$$
95% C.L.



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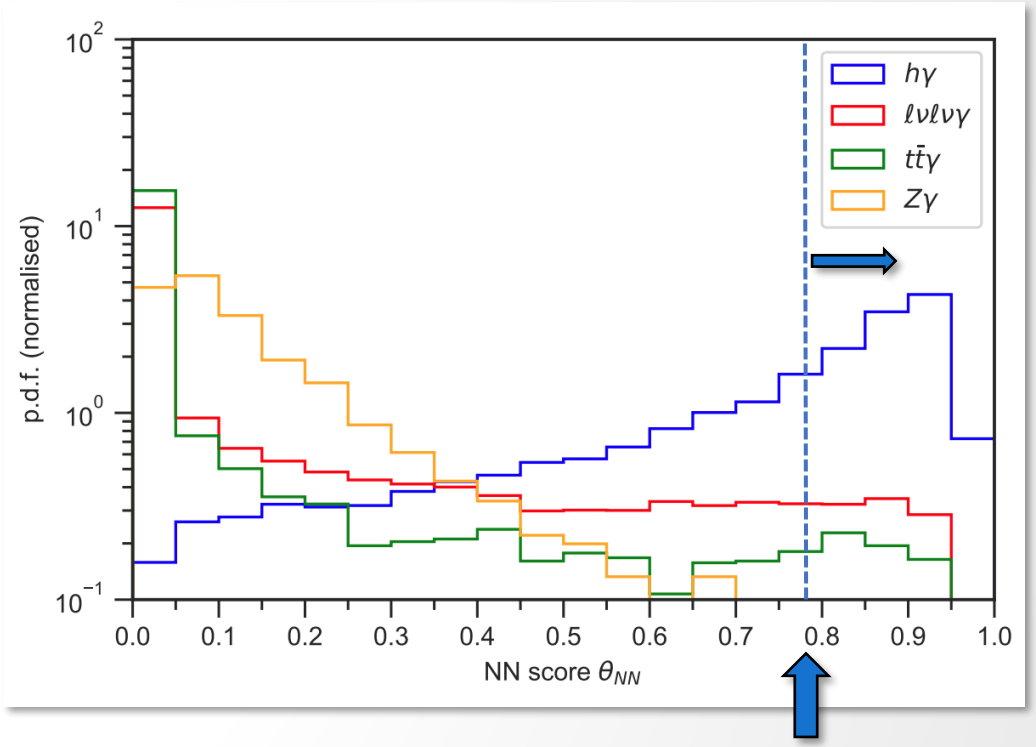

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Not far from testing up-charm universality!

Key points

- h+γ is a very rare process, yet unobserved at the LHC…
- While it may not be competitive with the most sensitive probes for the charm… powerful tool to constrain the up quark Yukawa!
- But also a very sensitive probe of the Higgs boson couplings to light quarks!
- High complementarity! associated production with a photon differentiates between up and down-type quarks.
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Thank you

come chat over the poster for more details!