Charm-quark Yukawa Coupling in $h \to c\bar{c}\gamma$ at LHC

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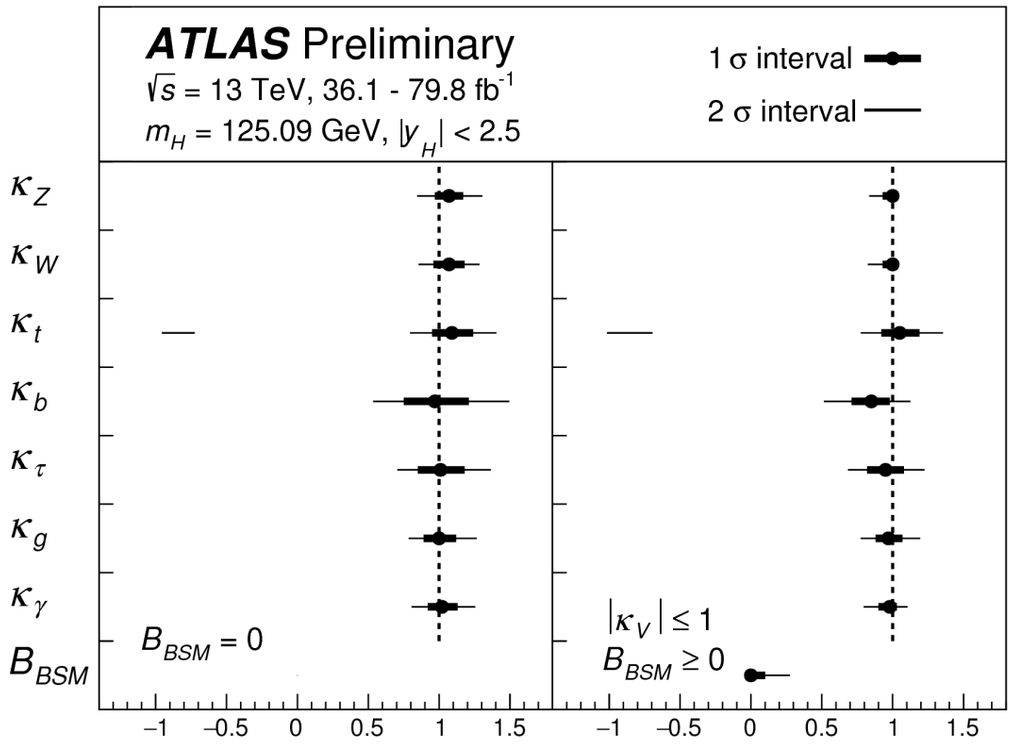
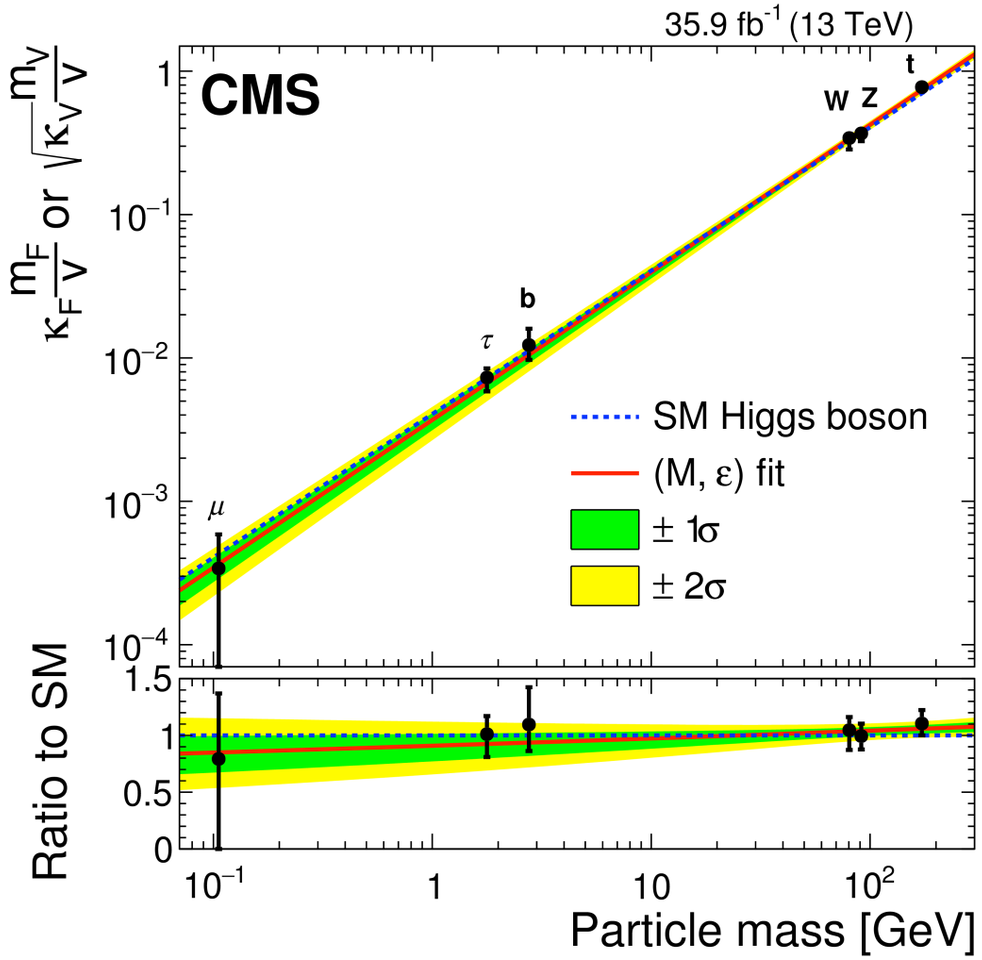
Tao Han, Benjamin Nachman, XW, PLB 793 (2019) 90-96, [arXiv:1812.06992]

Higgs Coupling Status

ATLAS-CONF-2018-031



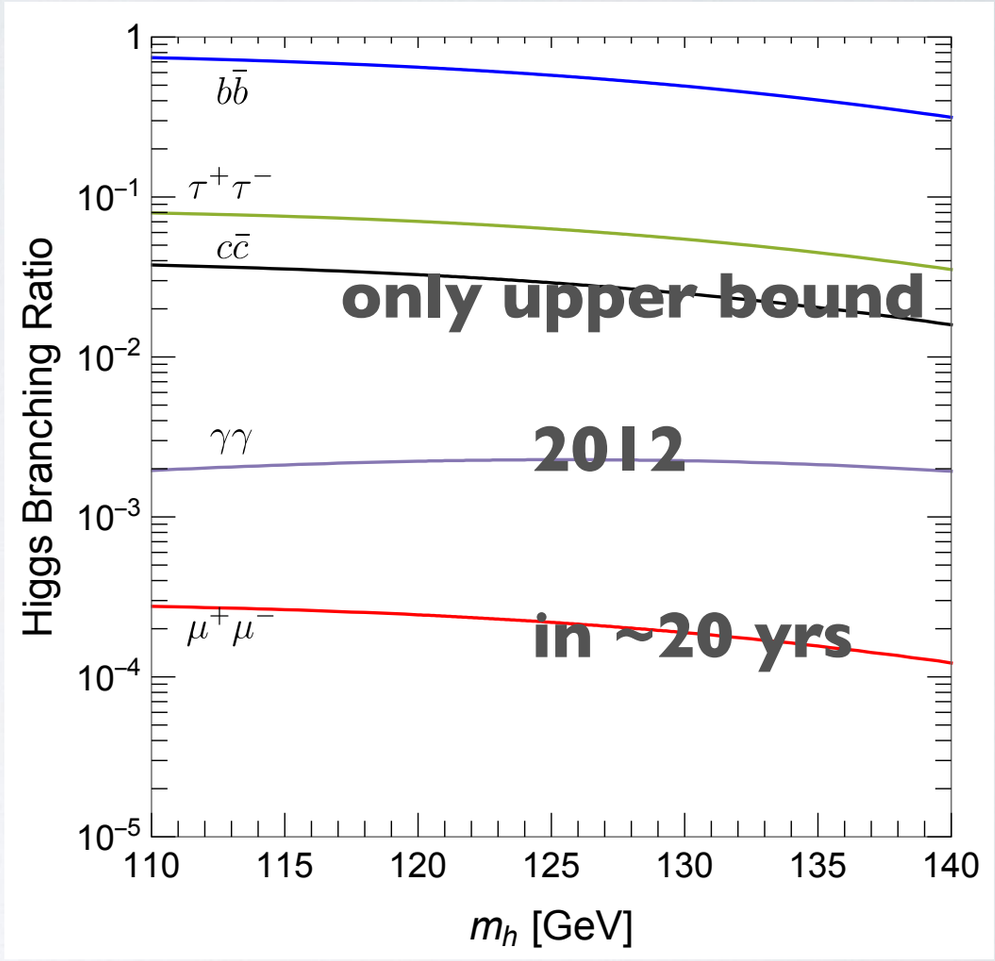
CMS-HIG-17-031



- All 3rd-gen Yukawa couplings observed with 5σ.
- Consistency check of the SM.

2nd-Gen Yukawa

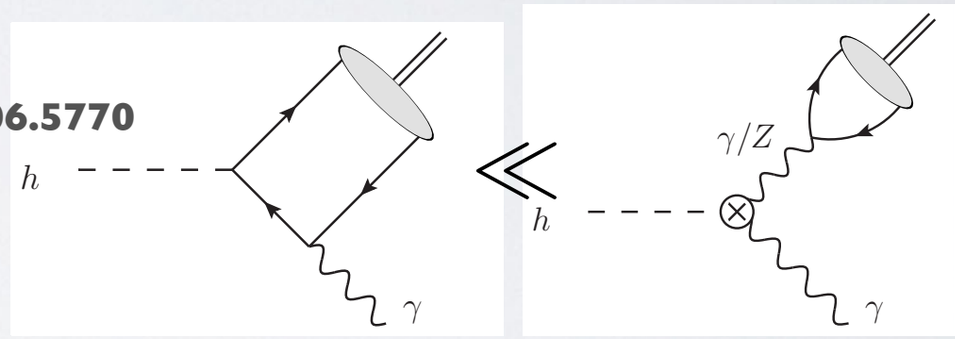
- Confirm the Higgs mechanism.
- $h \to \mu^+\mu^-$ at 9σ at HL-LHC.
- $h \to c\bar{c}$ has large BR but difficult at hadron colliders.



- Lepton colliders like ILC/CEPC are the best place.

Charm Yukawa at LHC

- $pp \to Zh \to (\ell\ell)\,(c\bar{c})$ (see Calvetti's talk)
  - c-tagging required.
  - Best chance so far, ~3 times of the SM Yukawa. **ATL-PHYS-PUB-2018-016**
  - Degenerate with $h \to b\bar{b}$
- $h \to J/\psi\,\gamma \to \ell\ell\gamma$ **Bodwin et al. arXiv:1306.5770**
  - Clean final state
  - Tiny BR~10^{-7}.
  - Less sensitive due to vector meson dominance, ~ 50 times. **ATL-PHYS-PUB-2015-043**

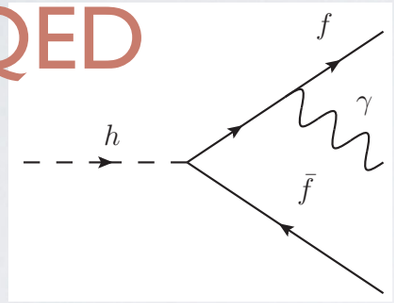


- $h \to c\bar{c}\gamma$ (this talk) **Han, XW, arXiv:1704.00790**
  Han, Nachman, XW, arXiv:1812.06992
- .....

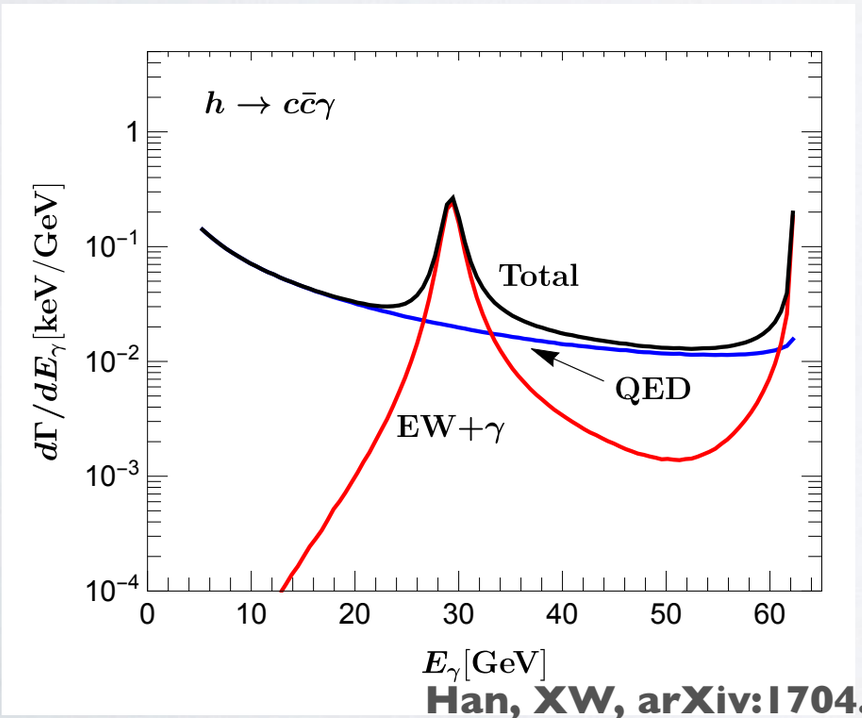
arXiv: 1503.00290, 1507.02916, 1606.09621, 1606.09253, 1609.06592, 1611.05463, 1705.09295

$h \to c\bar{c}\gamma$

- QED radiation at $\mathcal{O}(y_f^2\alpha)$

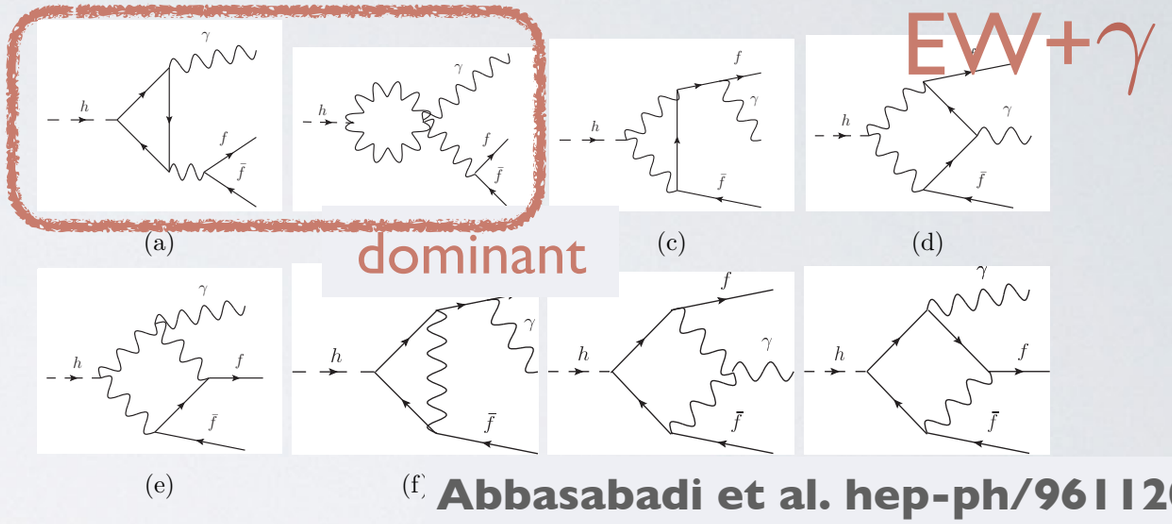


- Yukawa coupling
- Chirality flipping.



Han, XW, arXiv:1704.00790

- EW-loop-induced diagrams at $\mathcal{O}(y_t^2\alpha^3, \alpha^4)$



Abbasabadi et al. hep-ph/9611209

- No Yukawa couplings.
- Chirality-conserving.

- Photon helpful for trigger --- ggF.
- Down-type quark suppressed.

Trigger

- Not all data recorded at LHC.

$$\text{pp collision @40 MHz} \Rightarrow \text{L1 trigger @100 kHz} \Rightarrow \text{HLT @1 kHz}$$

$$(\text{HL-LHC projection}) \Rightarrow \text{L1 trigger @ 1 MHz} \Rightarrow \text{HLT @ 10 kHz}$$

- Large background from $pp \to jj\gamma, jjj$
- We propose a new trigger for $h \to c\bar{c}\gamma$

$$p_{Tj} > 27 \text{ GeV}, \quad p_{T\gamma} > 20 \text{ GeV},$$
$$|\eta| < 2.5, \quad \text{and} \quad \Delta R > 0.4$$

$$90 \text{ GeV} < M_{jj\gamma} < 160 \text{ GeV}.$$

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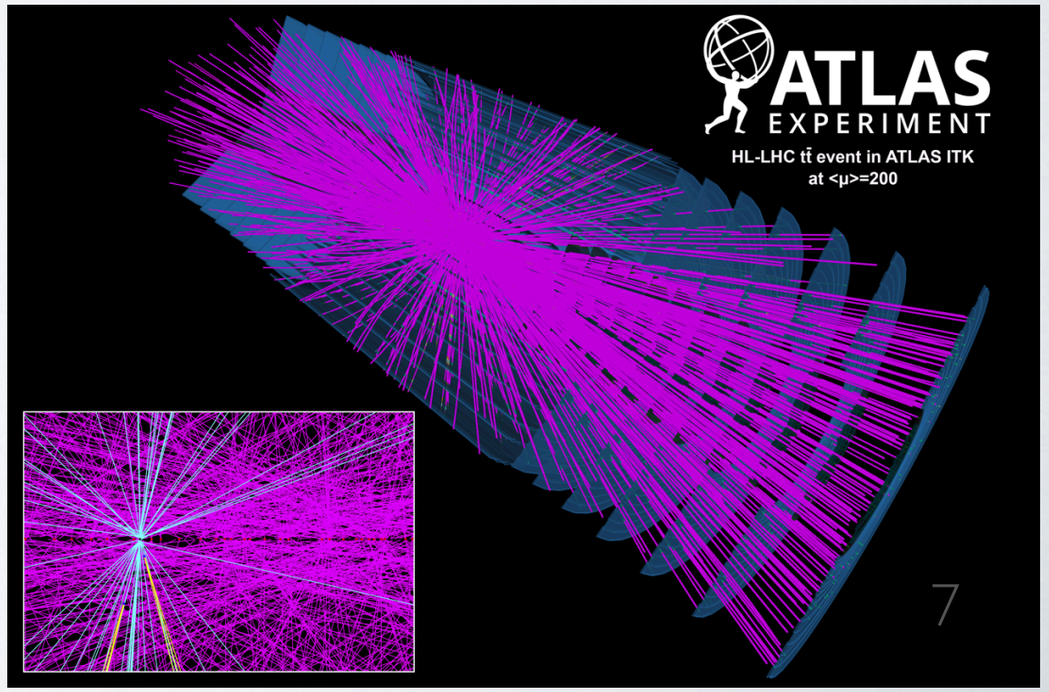
$$r_c = \frac{\sum p_T^{\text{track}}}{p_T^{\text{jet}}} > 0.2$$

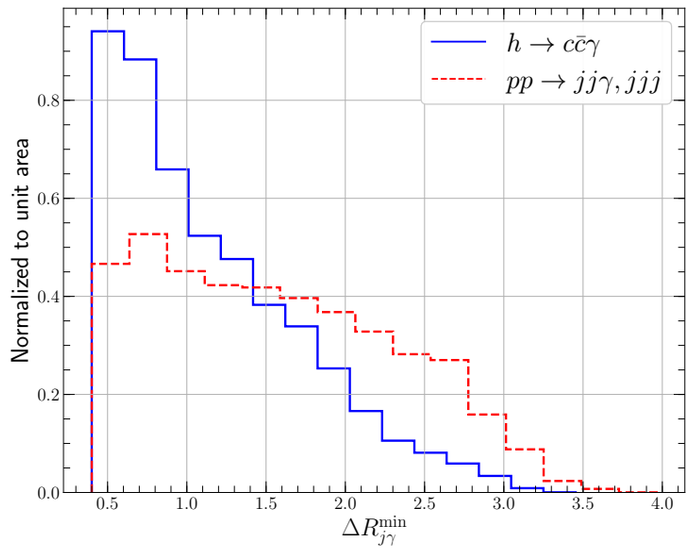


Result

- Event selection

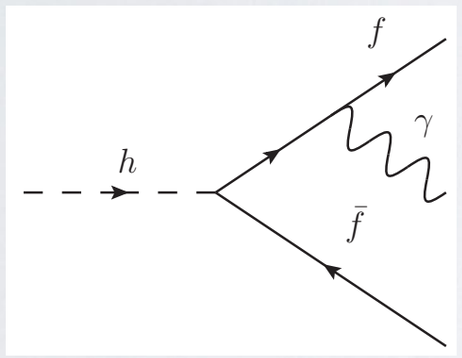
$$p_{Tj}^{\max} > 40 \text{ GeV}$$

$$\Delta R_{j\gamma}^{\min} < 1.8$$



ATLAS, arXiv:1802.04329

Operating Point	ϵ_c	ϵ_b	ϵ_j
I	20%	33%	0.13%
II	30%	33%	1%
III	41%	50%	3.3%



	Working Point	Signal (QED)	Background events	Background event rate [Hz]	$S/\sqrt{S+B}$ $[10^{-2}]$
Level-1 (L1)	No Tag	-	-	9.55×10^3	-
1 c-tag	I	269	3.37×10^8	5.62	1.47
	II	349	5.18×10^8	8.63	1.54
	III	401	8.83×10^8	14.7	1.35
2 c-tags	I	29	1.14×10^7	0.191	0.878
	II	66	2.23×10^7	0.371	1.42
	III	126	5.79×10^7	0.966	1.66

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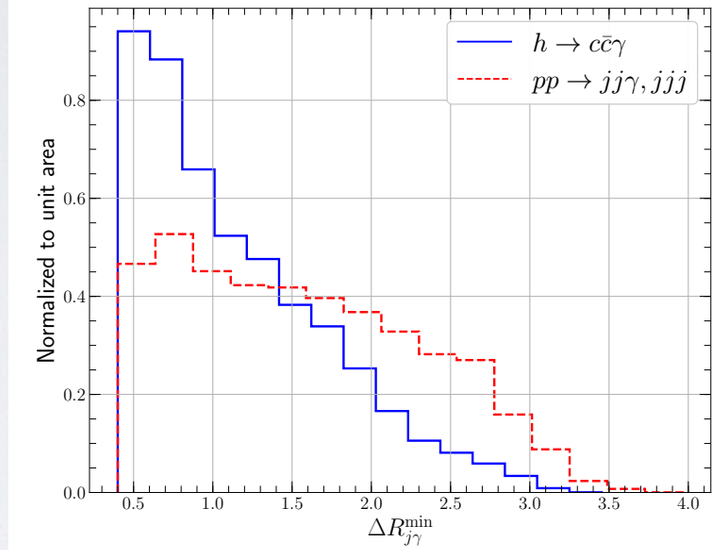

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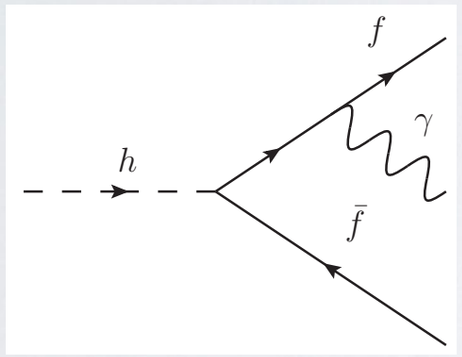

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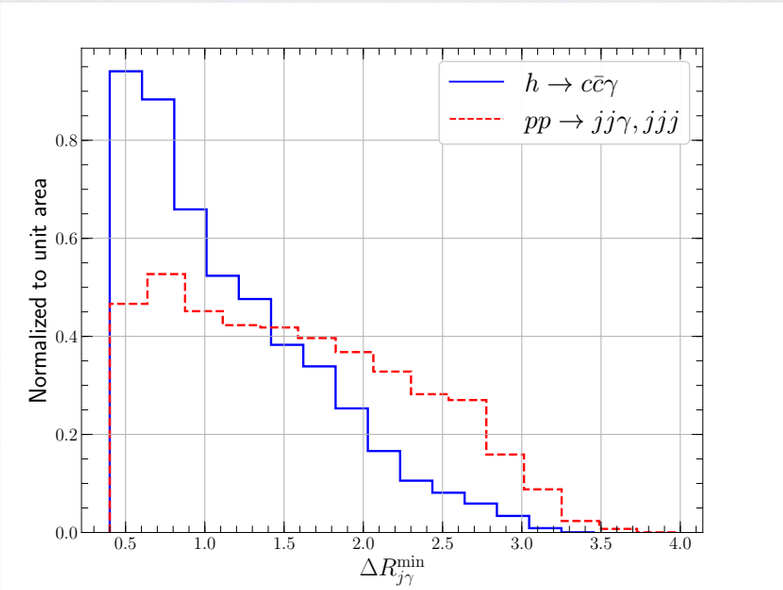

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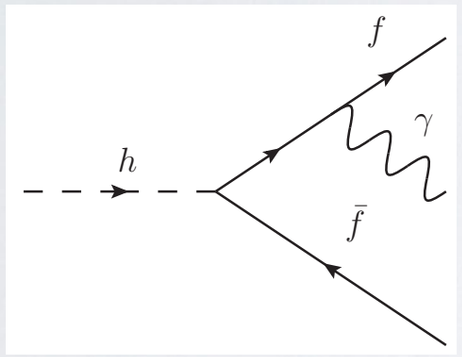

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B/S ~ 10^5-10^6

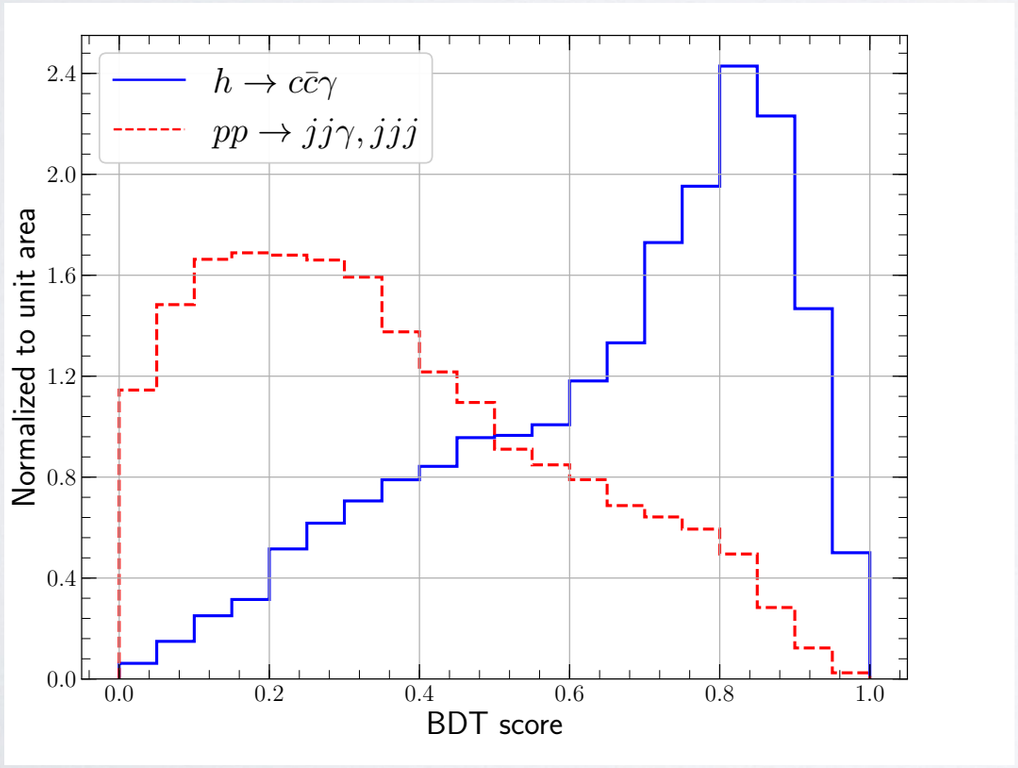
Bound on Yukawa Coupling

- Parametrize the modification of charm Yukawa as

$$y_c^{\rm BSM} = \kappa_c\, y_c^{\rm SM} \implies N_{\rm sig} \simeq \kappa_c^2 N_{\rm sig,QED}^{\rm SM}$$

- At 95% CL_S and in the absence of systematics

$$\kappa_c = \sqrt{\mu} < 10.4,\ \ 9.4,\ \ 9.3$$



- Optimized using Boosted Decision Tree (BDT)

$$\kappa_c < 9.6,\ \ 8.8,\ \ 8.6$$

Summary

- Probing the charm-quark Yukawa coupling in $h \to c\bar{c}\gamma$
- Novel triggering strategy proposed.
- About 8 times of the SM value at 2σ level at the HL-LHC .