

# Probing light-quarks Yukawa couplings & new physics in Higgs + jet(b-jet) studies

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Based on:

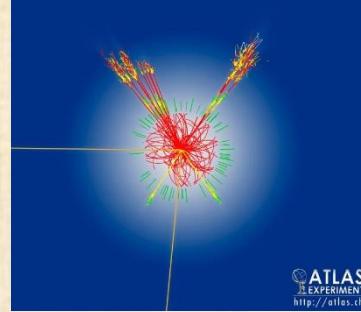
"Light-quark Yukawa & new physics in exclusive high- $p_T$  Higgs + jet(b-jet) events":  
[Jonthan Cohen, SBS, Gad Eilam & Amarjit Soni, arxiv: 1705.09295](#)

# Outline

- Why Higgs + jet (b-jet)?
- Higgs + jet in the SM
- Higgs + jet & New Physics (NP)
  - The kappa-framework
  - The SMEFT-framework
- Concluding remarks

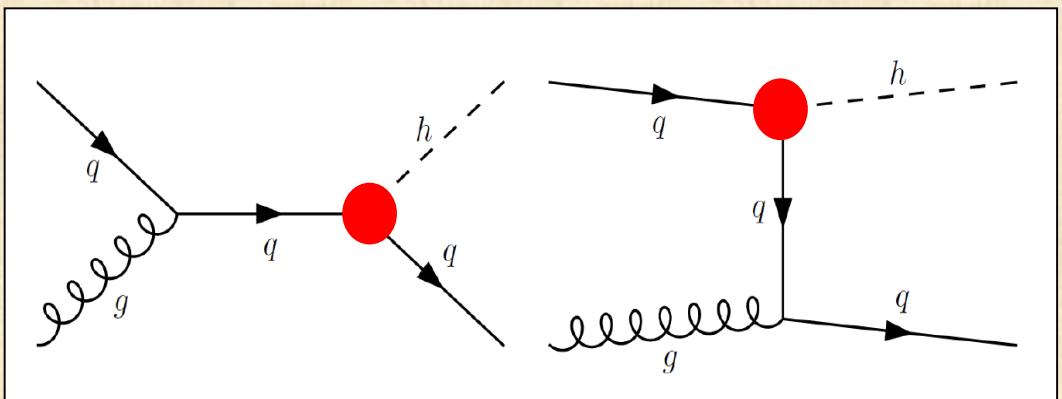


# Why Higgs + jet signal ?



- **Sensitivity to light-quarks Yukawa**

- tree-level mediation of  $pp \rightarrow h+j(j_b)$  may be important due to NP in  $y_q$



- Current exp bounds on Yukawa couplings of light-quarks of the 1<sup>st</sup> & 2<sup>nd</sup> generations are rather weak:

$$y_u, y_d \lesssim 0.5 y_b \quad y_c \lesssim 5 y_b$$

Kagan, Perez, Petriello, Soreq, Stoynev, Zupan, PRL2015 ([arXiv:1406.1722](https://arxiv.org/abs/1406.1722)); Perez, Soreq, Stamou, Tobioka, PRD2015 ([arXiv:1503.00290](https://arxiv.org/abs/1503.00290)); Soreq, Zhu, Zupan, JHEP2016 ([arXiv:1606.09621](https://arxiv.org/abs/1606.09621)); Bishara, Haisch, Monni, Re, PRL2017 ([arXiv:1606.09253](https://arxiv.org/abs/1606.09253))

# Why Higgs + jet signal ?

## • Sensitivity to light-quarks Yukawa

- Any sign of these couplings being significantly enhanced w.r.t SM will undermine the SM prediction

$$y_f \propto m_f/v$$

- Indeed, growing interest in physics of light-quarks Yukawa

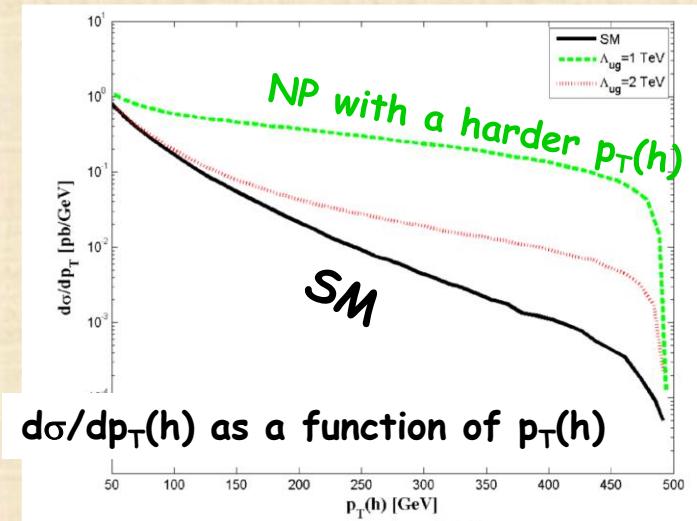
Kagan, Perez, Petriello, Soreq, Stoynev, Zupan, PRL2015 (arXiv:1406.1722); Perez, Soreq, Stamou, Tobioka, PRD2015 (arXiv:1503.00290, arXiv:1505.06689); Soreq, Zhu, Zupan, JHEP2016 (arXiv:1606.09621); Bishara, Haisch, Monni, Re, PRL2017 (arXiv:1606.09253); Bonner, Logan, arXiv:1608.04376; Yu, JHEP2017 (arXiv:1609.06592); Carpenter, Han, Hendricks, Qian, Zhouc PRD2017 (arXiv:1611.05463); Gao, arXiv:1608.01746; Diaz-Cruz, Saldaña-Salazar, NP2016 (arXiv:1405.0990); Han, Wang, arXiv:1704.00790.



# Why Higgs + jet signal ?

EXCLUSIVE!  
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- Exclusive Higgs +  $j(j_b)$  @ the LHC as a probe of NP:
  - High Higgs  $P_T$  distribution may play a key role in distinguishing between NP scenarios:



# Why Higgs + jet signal ?

EXCLUSIVE!  
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- Exclusive Higgs +  $j(j_b)$  @ the LHC as a probe of NP:

- High Higgs  $P_T$  distribution may play a key role in distinguishing between NP scenarios:

- Sensitive to a variety of UV completions: SUSY, heavy top-partners ...

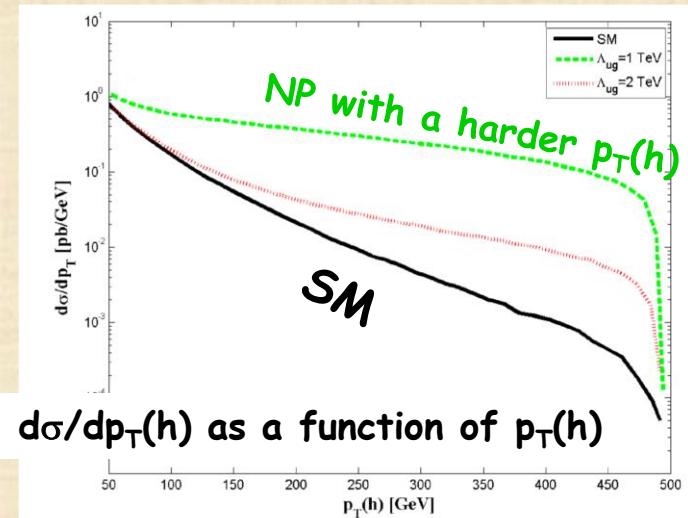
Brein, Hollik, PRD2003 (hep-ph/0305321); Dittmaier, Kramer, Spira, PRD2004 (hep-ph/0309204); Dawson, Jackson, Reina, Wackerlo, PRD2004 (hep-ph/0311067), PRL2005 (hep-ph/0408077), MPL2006 (hep-ph/0508293); Campbell et al, hep-ph/0405302; Banfi, Martin, Sanz, JHEP2014 (arxiv: 1308.4771)

- And to other model-independent approaches: Kappa framework & SMEFT

Grojean, Salvioni, Schlaffer, Weiler, JHEP2014 (arxiv: 1312.3317); Ghosh, Wiebusch, PRD2015 (arxiv: 1411.2029); Dawson, Lewis, Zeng, PRD2014 (arxiv: 1409.6299); Harlander, Neumann, PRD2013 (arxiv: 1308.2225); Bramante, Delgado, Lehman, Martin, PRD2016 (arxiv: 1410.3484); Azatov, Paul, JHEP2014 (arxiv: 1309.5273); Schlaffer, Spannowsky, Takeuchi, Weiler, Wymant, EPJC2014 (arxiv: 1405.4295); Buschmann, Englert, Goncalves, Plehn, Spannowsky, PRD2014 (arxiv: 1405.7651); Grazzini, Ilnicka, Spira, Wiesemann, arxiv: 1612.00283.

- Indeed, the Higgs  $P_T$  distribution in exclusive Higgs + jets production,  $pp \rightarrow h+nj$ , was one of the prime targets of recent measurements performed by ATLAS & CMS

the ATLAS collab., Ade et al., JHEP2014 (arxiv: 1407.4222) + PLB (arxiv: 1408.3226) + PRL2015 (arxiv: 1504.05833) + JHEP2014 (arxiv: 1604.02997); the CMS collab., Khachatryan et al., EPJC2016 (arxiv: 1508.07819) + JHEP2017 (arxiv: 1606.01522)

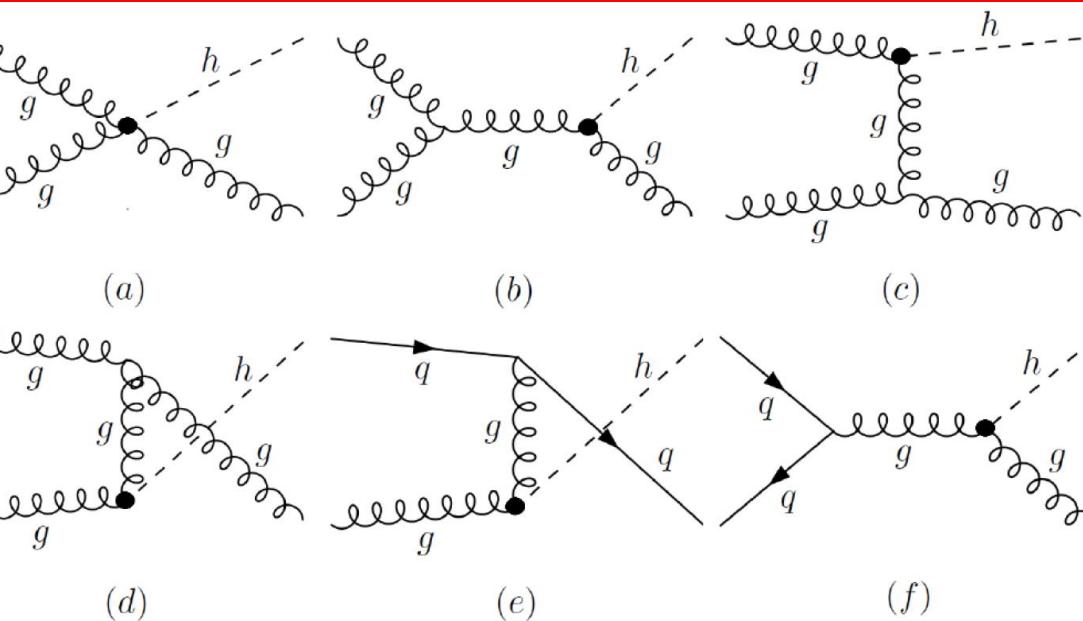


# Higgs + light-jet in the SM:

$$pp \rightarrow h + j, \quad j = g, u, d, s, c$$

- Parameterization of the 1-loop SM ggh vertex  
(mostly the top-loop, tree-level negligible ...):

$$\mathcal{L}_{eff}^{ggh} = C_g^{SM} h G_{\mu\nu}^a G^{\mu\nu,a}, \quad C_g^{SM} \simeq \alpha_s / (12\pi v)$$

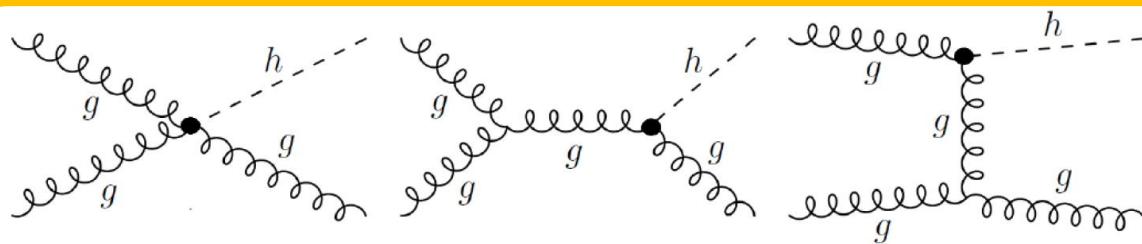


# Higgs + light-jet in the SM: $pp \rightarrow h+j$ ( $j=g,u,d,s,c$ )

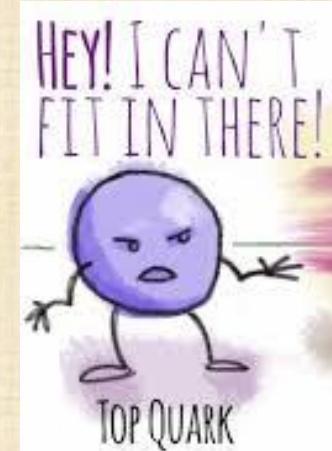
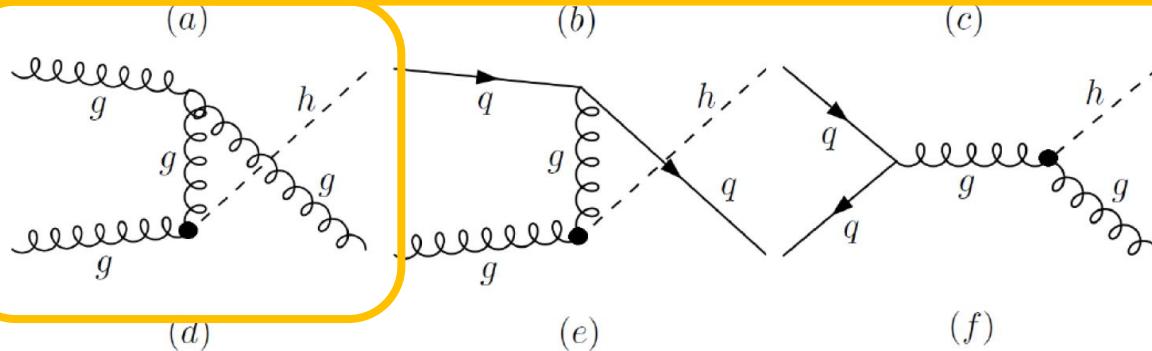
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(leading term)



$gg \rightarrow gh$   
dominant in SM





- Focus on exclusive  $pp \rightarrow h+j(j_b)$  followed by  $h \rightarrow \gamma\gamma$  with the following two NP scenarios:
  - NP comes only in the form of scaled couplings  
**(kappa-framework)**
  - NP can give rise to new interactions that are absent in the SM and that modify the SM Lorentz structure & kinematic  
**(SMEFT)**

# NP studies in Higgs + jet:



- Define a **signal strength** (for  $h+j(j_b)$  followed by  $h \rightarrow \gamma\gamma$ ):

$$\mu_{hj}^{\gamma} = \frac{\mathcal{N}(pp \rightarrow h + j \rightarrow \gamma\gamma + j)}{\mathcal{N}_{SM}(pp \rightarrow h + j \rightarrow \gamma\gamma + j)}$$

$\mathcal{N}$  is the event yield  $\mathcal{N} = \mathcal{L}\sigma\mathcal{A}\epsilon$

luminosity  
CSX  
efficiency  
acceptance



# NP studies in Higgs + jet:



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- Assuming  $\mathcal{A} \simeq \mathcal{A}_{SM}$  :

$$\mu_{hj}^\gamma \simeq \frac{\sigma(pp \rightarrow h + j)}{\sigma_{SM}(pp \rightarrow h + j)} \cdot \frac{BR(h \rightarrow \gamma\gamma)}{BR_{SM}(h \rightarrow \gamma\gamma)}$$

- Using the “cumulative CSX”:

$$\sigma(p_T^{cut}) \equiv \sigma(p_T(h) > p_T^{cut}) = \int_{p_T(h) \geq p_T^{cut}} dp_T \frac{d\sigma}{dp_T}$$

Extra handle on NP effect, also useful minimizing the K-factor at the high  $P_T(h)$   
 e.g., Boughezal et al., JHEP2013, PRL2015, PLB2015



# NP studies in Higgs + jet:

"They have been stuck in that model, like birds in a gilded cage, ever since."



- **NP signal:**

$$\Delta\mu_{hj}^{\gamma} \equiv | \mu_{hj}^{\gamma} - 1 |$$

$$\mu_{hj}^{\gamma}(SM) = 1$$

- **Statistical significance of signal:**

$$N_{SD} = \frac{\Delta\mu_{hj}^{\gamma}}{\delta\mu_{hj}^{\gamma}}$$

& assume a 5%(1 $\sigma$ ) error:

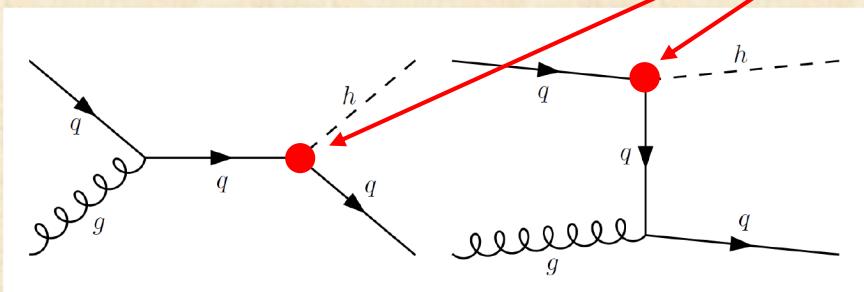
$$\Delta\mu_{hj}^{\gamma}(\text{theory} + \text{exp}) = 0.05(1\sigma)$$

# The kappa-framework

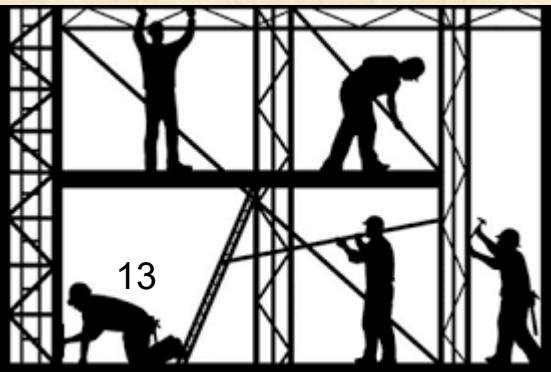
SM:  $\kappa_g=1$ ,  $\kappa_b=1$ ,  $\kappa_c\sim 0.3$ ,  $\kappa_s\sim O(10^{-2})$ ,  $\kappa_{u,d}\sim O(10^{-3})$

$$\kappa_q \equiv \frac{y_q}{y_b^{SM}}$$

$$\mathcal{L}_{eff}^{h+j} = - \sum_{q=u,d,s,c,b} \kappa_q \frac{m_b}{v} h \bar{q} q + \kappa_g C_g h G_{\mu\nu}^a G^{\mu\nu,a}$$



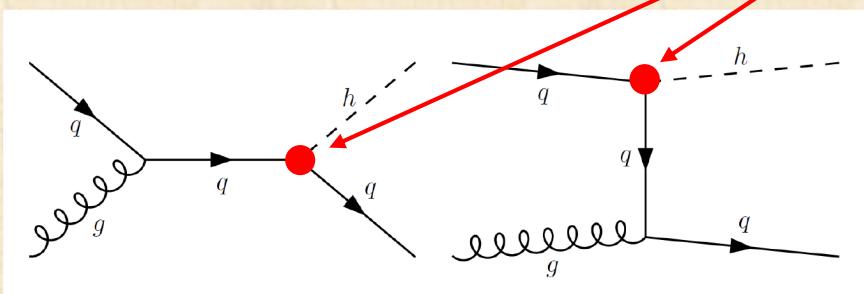
**modifies the SM  
diagrams**



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**modifies the SM  
diagrams**

- For Higgs + light-jet,  $pp \rightarrow h+j$ :

NP from  $\kappa_q \neq 0$  &  $\kappa_g \neq 1$

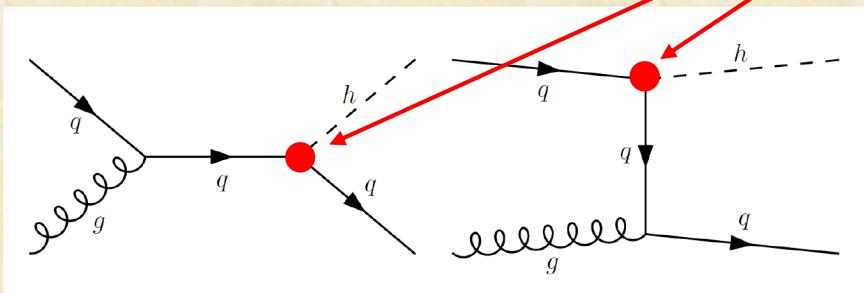
$$\sigma^{hj} = \kappa_g^2 \sigma_{SM}^{hj} + \kappa_q^2 \sigma_{qqh}^{hj}$$

$$\Rightarrow \sigma_{SM}^{hj} \simeq \sigma^{hj}(\kappa_g = 1, \kappa_q = 0)$$

# The kappa-framework

$$\kappa_q \equiv \frac{y_q}{y_b^{SM}}$$

$$\mathcal{L}_{eff}^{h+j} = - \sum_{q=u,d,s,c,b} \kappa_q \frac{m_b}{v} h \bar{q} q + \kappa_g C_g h G_{\mu\nu}^a G^{\mu\nu,a}$$



**modifies the SM  
diagrams**

- For Higgs + b-jet,  $pp \rightarrow h+j_b$ :

$$\sigma^{hj_b} = \kappa_g^2 \sigma_{ggh}^{hj_b} + \kappa_b^2 \sigma_{bbh}^{hj_b}$$

NP from  $\kappa_b \neq 1$  &  $\kappa_g \neq 1$

$$\sigma_{SM}^{hj_b} = \sigma_{ggh}^{hj_b} + \sigma_{bbh}^{hj_b}$$

# *kappa-framework,*

signal strength for  $pp \rightarrow h+j(j_b) \rightarrow \gamma\gamma+j(j_b)$ :

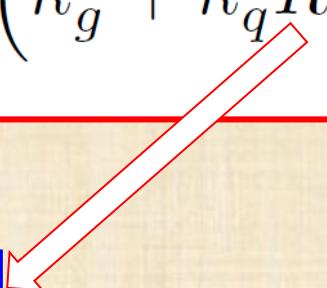
$$\mu_{hj(j_b)}^\gamma \simeq \left( \kappa_g^2 + \kappa_q^2 R_{NP}^{hj(j_b)} \right) \cdot \mu_{h \rightarrow \gamma\gamma}^{j(j_b)}$$

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$$R_{NP}^{hj(j_b)} \equiv \frac{\sigma_{qqh}^{hj(j_b)}}{\sigma_{ggh}^{hj(j_b)}}$$



- the NP contribution scaled with the SM, calculated using the cumulative CSX (for a given  $p_T^{\text{cut}}$ ):
  - contains all the dependence on the Higgs PT
  - where all uncertainties reside: higher-order corrections (K-factor), normalization and factorization scale uncertainties of the PDF, acceptance factors, etc ...

# kappa-framework,

signal strength for  $pp \rightarrow h+j(j_b) \rightarrow \gamma\gamma+j(j_b)$ :

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$$R_{NP}^{hj(j_b)} \equiv \frac{\sigma_{qqh}^{hj(j_b)}}{\sigma_{ggh}^{hj(j_b)}}$$

$$\mu_{h \rightarrow \gamma\gamma}^j = \frac{1}{1 + (\kappa_g^2 - 1) BR_{SM}^{gg} + \kappa_q^2 BR_{SM}^{bb}}$$

$$\mu_{h \rightarrow \gamma\gamma}^{j_b} = \frac{1}{1 + (\kappa_g^2 - 1) BR_{SM}^{gg} + (\kappa_b^2 - 1) BR_{SM}^{bb}}$$

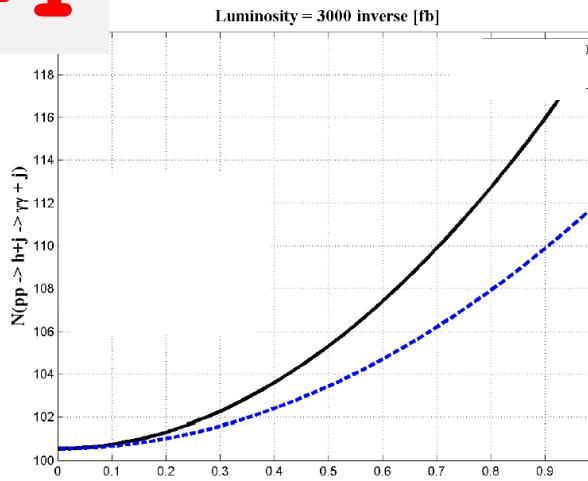
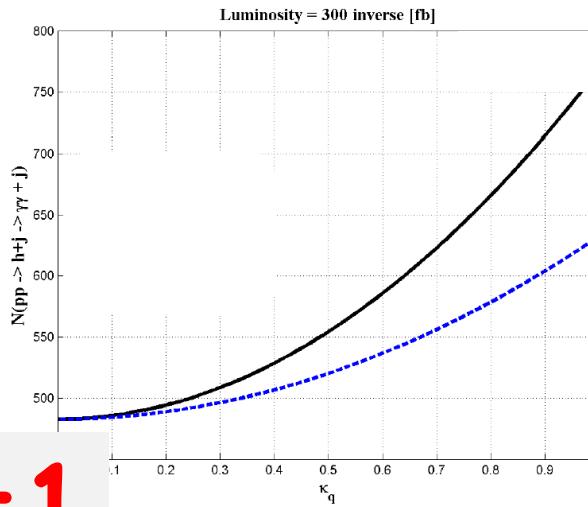
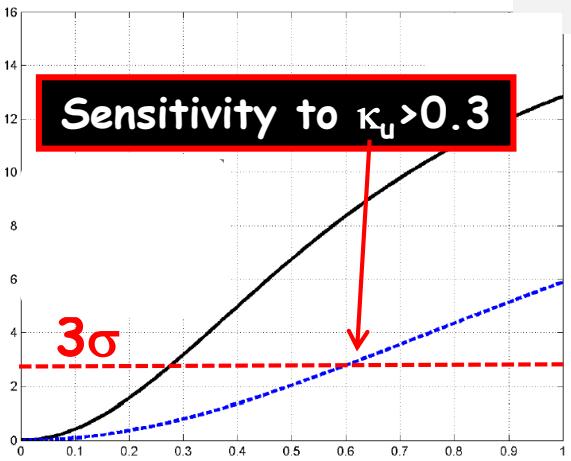
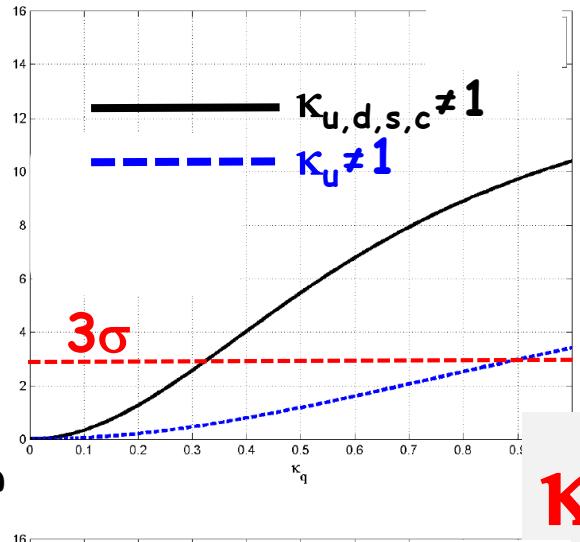
assume no NP in  $h \rightarrow \gamma\gamma$

- the NP contribution scaled with the SM, calculated using the cumulative CSX (for a given  $p_T^{\text{cut}}$ ):
  - contains all the dependence on the Higgs PT
  - where all uncertainties reside: higher-order corrections (K-factor), normalization and factorization scale uncertainties of the PDF, acceptance factors, etc ...



**kappa-framework**

# light jet case: $\text{pp} \rightarrow h+j \rightarrow \gamma\gamma+j$ , kappa-framework no NP in hhg ( $\kappa_g=1$ )



$P_T(h) > 100 \text{ GeV}$

Luminosity =  $300 \text{ fb}^{-1}$

$N(\gamma\gamma + j) \sim 500$

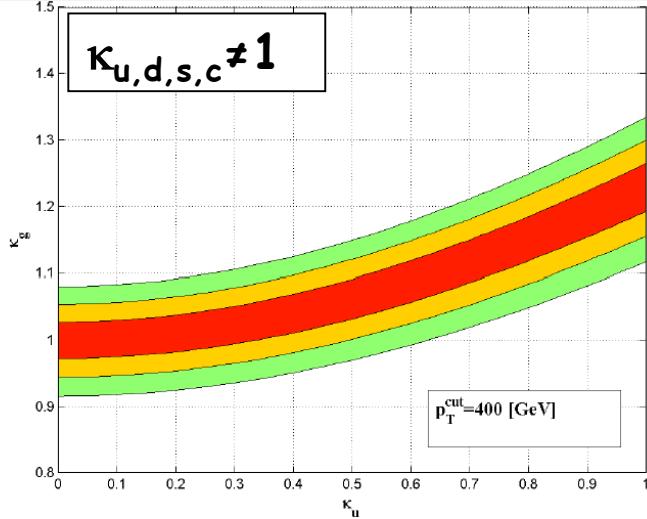
$P_T(h) > 400 \text{ GeV}$

Luminosity =  $3000 \text{ fb}^{-1}$

$N(\gamma\gamma + j) \sim 100$

**light jet case:**  $p\bar{p} \rightarrow h+j \rightarrow \gamma\gamma+j$ , kappa-framework  
 NP in  $qqh$  &  $ggh$  ( $\kappa_g - \kappa_q$  plane)

68%, 95% & 99% allowed ranges in  $\kappa_g - \kappa_q$  plane

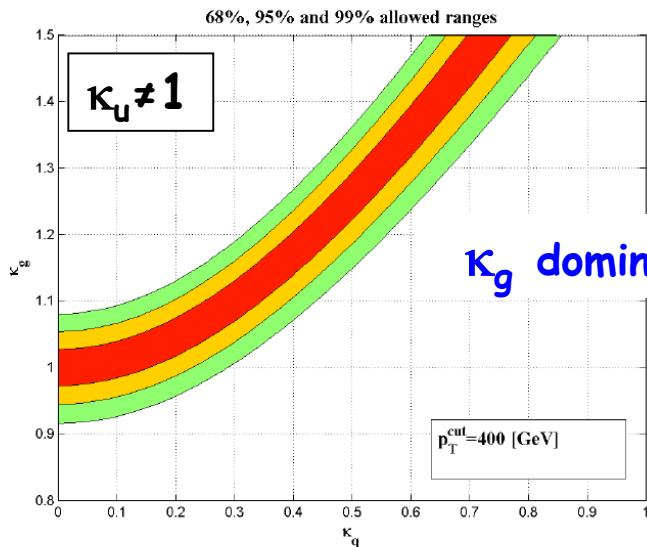


$\kappa_g - \kappa_q$  plane

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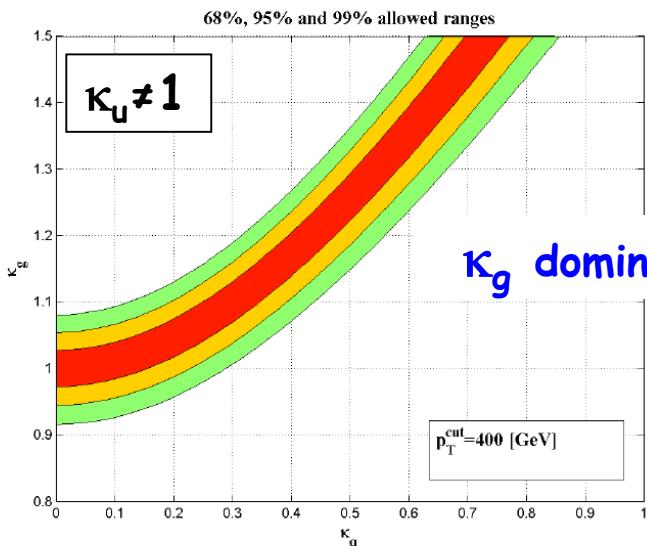
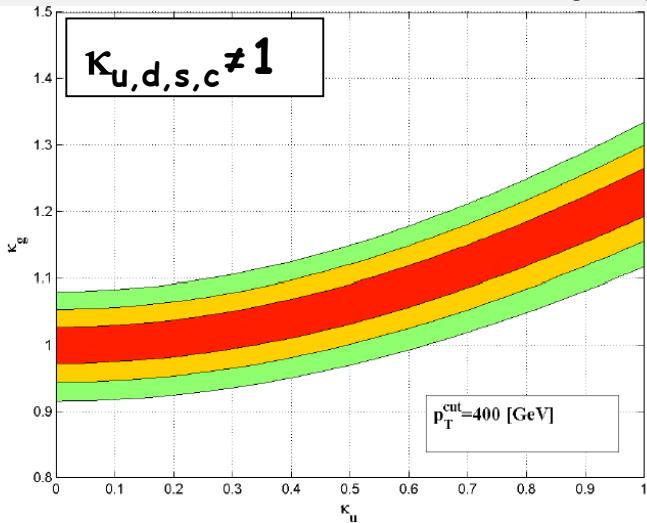


$\kappa_g$  dominant at high  $p_T(h)$

# light jet case: $p\bar{p} \rightarrow h+j \rightarrow \gamma\gamma+j$ , kappa-framework

NP in  $qqh$  &  $ggh$  ( $\kappa_g - \kappa_q$  plane)

68%, 95% & 99% allowed ranges in  $\kappa_g - \kappa_q$  plane



$\kappa_g - \kappa_q$  plane

$p_T(h) > 400 \text{ GeV}$

Luminosity =  $3000 \text{ fb}^{-1}$

$N(\gamma\gamma + j) \sim 100$

Statistical significance  $N_{SD} = \frac{\Delta\mu_{hj}^f}{\delta\mu_{hj}^f}$

$\kappa_u \neq 0, \kappa_d = \kappa_s = \kappa_c = 0$

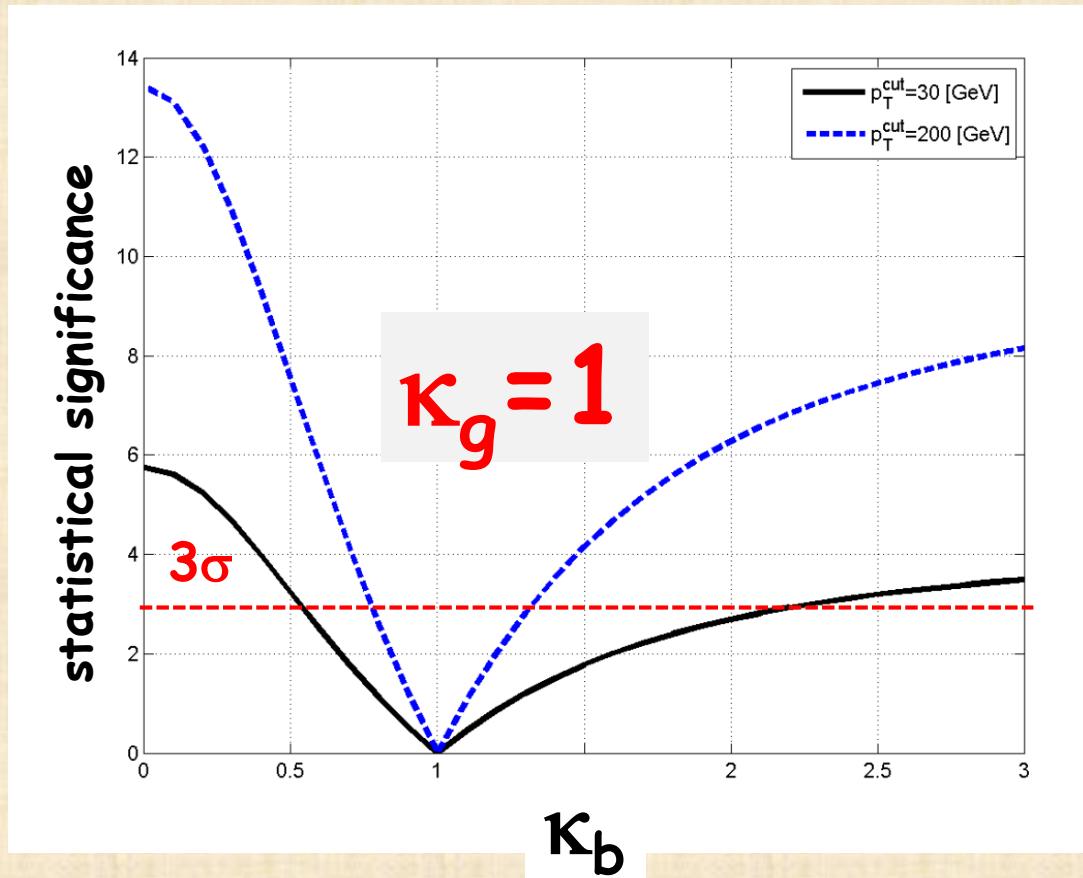
	$\kappa_u = 0$	$\kappa_u = 0.25$	$\kappa_u = 0.5$
$\kappa_g = 0.8$	6.79	$7.12^{-0.03}_{+0.03}$	$8.0^{-0.11}_{+0.10}$
$\kappa_g = 0.9$	3.53	$3.97^{-0.03}_{+0.03}$	$5.14^{-0.11}_{+0.10}$
$\kappa_g = 1.0$	0	$0.56^{-0.03}_{+0.03}$	$2.03^{-0.11}_{+0.10}$
$\kappa_g = 1.1$	3.78	$3.09^{+0.03}_{-0.03}$	$1.30^{+0.11}_{-0.10}$
$\kappa_g = 1.2$	7.75	$6.95^{+0.03}_{-0.03}$	$4.84^{+0.11}_{-0.10}$

$\kappa_q \neq 0$  for all  $q = u, d, s, c$

	$\kappa_q = 0$	$\kappa_q = 0.25$	$\kappa_q = 0.5$
$\kappa_g = 0.8$	6.79	$8.30^{-0.05}_{+0.04}$	$11.13^{-0.13}_{+0.12}$
$\kappa_g = 0.9$	3.53	$5.43^{-0.05}_{+0.04}$	$9.03^{-0.13}_{+0.12}$
$\kappa_g = 1.0$	0	$2.32^{-0.05}_{+0.04}$	$6.74^{-0.13}_{+0.12}$
$\kappa_g = 1.1$	3.78	$1.01^{+0.05}_{-0.04}$	$4.26^{-0.13}_{+0.12}$
$\kappa_g = 1.2$	7.75	$4.55^{+0.04}_{-0.04}$	$1.61^{-0.13}_{+0.11}$

e.g.,  $\kappa_g < 0.8$  with  $\kappa_u > 0.25$   
can be excluded @  $7\sigma$

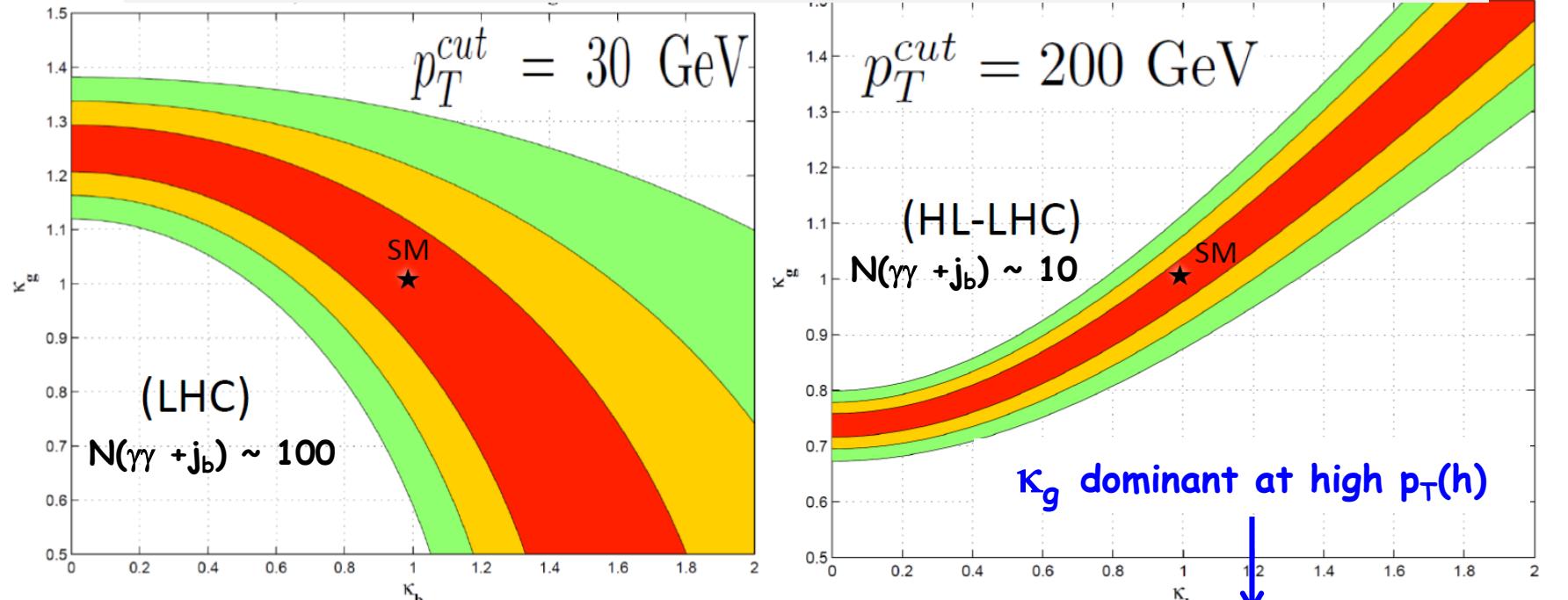
***b-jet case:***  $\text{pp} \rightarrow h + j_b \rightarrow \gamma\gamma + j_b$ , kappa-framework  
no NP in  $hgg$  ( $\kappa_g = 1$ )



$p_T(h) > 200 \text{ GeV}$ : sensitivity to  $\kappa_b < 0.8$  &  $\kappa_b > 1.3$

**b-jet case:**  $\text{pp} \rightarrow h + j_b \rightarrow \gamma\gamma + j_b$ , kappa-framework  
 NP in  $qqh$  &  $ggh$  ( $\kappa_g - \kappa_b$  plane)

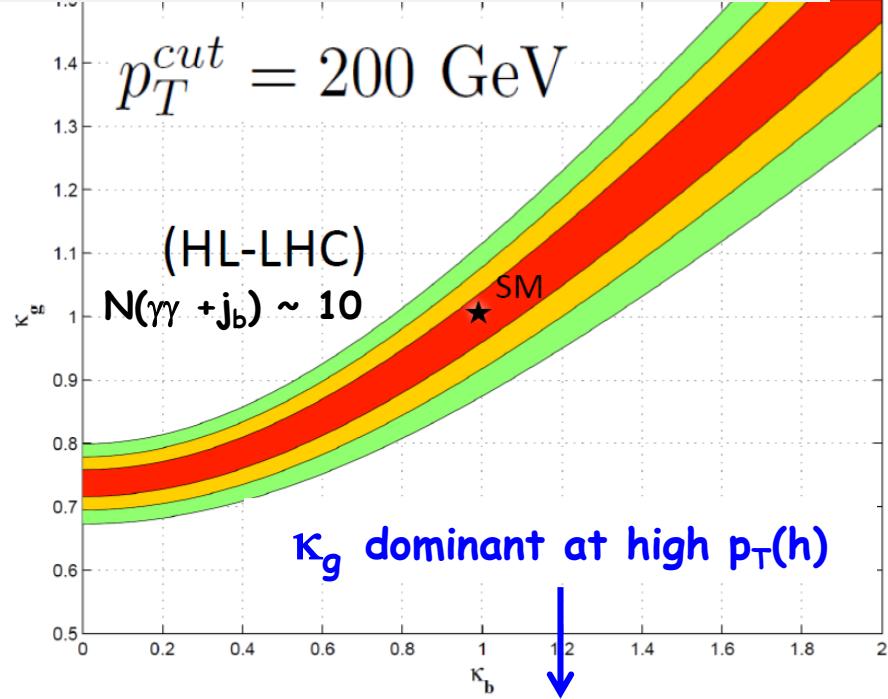
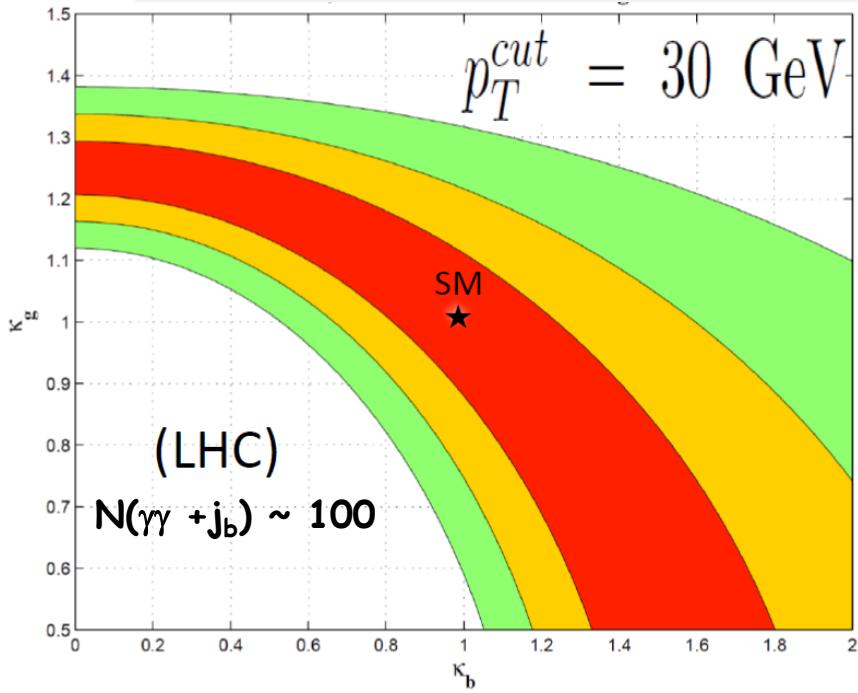
68%, 95% & 99% allowed ranges in  $\kappa_g - \kappa_b$  plane



high and low  $p_T(h)$ : probing  
 complimentary regimes in  
 $\kappa_g - \kappa_b$  plane

**b-jet case:**  $\text{pp} \rightarrow h + j_b \rightarrow \gamma\gamma + j_b$ , kappa-framework  
 NP in  $qqh$  &  $ggh$  ( $\kappa_g - \kappa_b$  plane)

68%, 95% & 99% allowed ranges in  $\kappa_g - \kappa_b$  plane



$$\text{Statistical significance } N_{SD} = \frac{\Delta \mu_{h,j_b}^f}{\delta \mu_{h,j_b}^f}$$

	$\kappa_b = 0.5$	$\kappa_b = 0.75$	$\kappa_b = 1$	$\kappa_b = 1.25$	$\kappa_b = 1.5$
$\kappa_g = 0.8$	$0.4^{+0.6}_{-0.3}$	$2.8^{+0.08}_{-0.08}$	$4.6^{+0.3}_{-0.3}$	$6.0^{+0.6}_{-0.6}$	$6.9^{+0.7}_{-0.7}$
$\kappa_g = 0.9$	$3.5^{+0.8}_{-0.8}$	$0.2^{+0.3}_{-0.3}$	$2.4^{+0.2}_{-0.2}$	$4.3^{+0.4}_{-0.4}$	$5.6^{+0.7}_{-0.7}$
$\kappa_g = 1.0$	$7.5^{+1.0}_{-1.0}$	$3.3^{+0.4}_{-0.5}$	0	$2.4^{+0.3}_{-0.3}$	$4.2^{+0.6}_{-0.6}$
$\kappa_g = 1.1$	$11.8^{+1.3}_{-1.3}$	$6.7^{+0.7}_{-0.7}$	$2.6^{+0.2}_{-0.2}$	$0.4^{+0.2}_{-0.2}$	$2.6^{+0.5}_{-0.5}$
$\kappa_g = 1.2$	$16.1^{+1.5}_{-1.5}$	$10.2^{+0.9}_{-0.9}$	$5.3^{+0.3}_{-0.3}$	$1.7^{+0.07}_{-0.07}$	$0.9^{+0.4}_{-0.4}$

high and low  $p_T(h)$ : probing complementary regimes in  $\kappa_g - \kappa_b$  plane

e.g.,  $\kappa_g < 0.8$  with  $\kappa_b > 1.5$  can be excluded @  $7\sigma$

# The SMEFT

(see e.g., Warsaw basis arxiv:1008.4884)

- Expanding the SM with a subset of dim. 6 operators relevant for the Higgs+jet signal

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_{i=u\phi,d\phi,ug,dg,\phi g} \frac{f_i}{\Lambda_i^2} \mathcal{O}_i$$

$$\begin{aligned}
 \mathcal{O}_{u\phi} &= (\phi^\dagger \phi) (\bar{Q}_L \tilde{\phi} u_R) + h.c. , \\
 \mathcal{O}_{d\phi} &= (\phi^\dagger \phi) (\bar{Q}_L \phi d_R) + h.c. , \\
 \mathcal{O}_{ug} &= (\bar{Q}_L \sigma^{\mu\nu} T^a u_R) \tilde{\phi} G_{\mu\nu}^a + h.c. , \\
 \mathcal{O}_{dg} &= (\bar{Q}_L \sigma^{\mu\nu} T^a d_R) \phi G_{\mu\nu}^a + h.c. , \\
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 \end{aligned}$$

# The SMEFT

(see e.g., Warsaw basis arxiv:1008.4884)

- Expanding the SM with a subset of dim. 6 operators relevant for the Higgs+jet signal

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_{i=u\phi,d\phi,ug,dg,\phi g} \frac{f_i}{\Lambda_i^2} \mathcal{O}_i$$

$$\begin{aligned}\mathcal{O}_{u\phi} &= (\phi^\dagger \phi) (\bar{Q}_L \tilde{\phi} u_R) + h.c. , \\ \mathcal{O}_{d\phi} &= (\phi^\dagger \phi) (\bar{Q}_L \phi d_R) + h.c. , \\ \mathcal{O}_{ug} &= (\bar{Q}_L \sigma^{\mu\nu} T^a u_R) \tilde{\phi} G_{\mu\nu}^a + h.c. , \\ \mathcal{O}_{dg} &= (\bar{Q}_L \sigma^{\mu\nu} T^a d_R) \phi G_{\mu\nu}^a + h.c. , \\ \mathcal{O}_{\phi g} &= (\phi^\dagger \phi) G_{\mu\nu}^a G^{a,\mu\nu}\end{aligned}$$

light-quark operators  
often neglected, assuming  
 $\propto y_{u,d}$  e.g., for MFV ...

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 \end{aligned}$$

Chromo-magnetic dipole moment like operators

# The SMEFT

operators that can be  
“mapped” into the kappa-  
framework

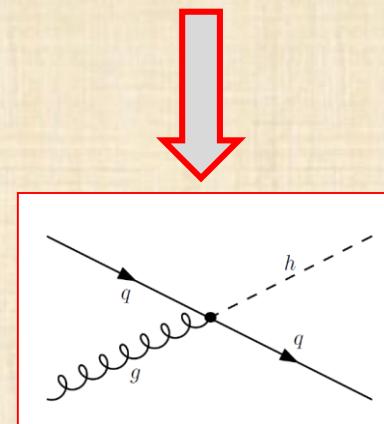
$$\begin{aligned}\mathcal{O}_{u\phi} &= (\phi^\dagger \phi) (\bar{Q}_L \tilde{\phi} u_R) \\ \mathcal{O}_{d\phi} &= (\phi^\dagger \phi) (\bar{Q}_L \phi d_R) \\ \mathcal{O}_{\phi g} &= (\phi^\dagger \phi) G_{\mu\nu}^a G^{a,\mu\nu}\end{aligned}$$



$$\kappa_q \simeq \frac{y_q^{SM}}{y_b^{SM}} - \frac{f_{q\phi}}{y_b^{SM}} \frac{v^2}{\Lambda_{q\phi}^2} , \quad \kappa_g = 1 + \frac{12\pi f_{\phi g}}{\alpha_s} \frac{v^2}{\Lambda_{\phi g}^2}$$

CMDM-like operators  
that generate a new  
Lorentz structure and  
different  $h+j$  kinematics

$$\begin{aligned}\mathcal{O}_{ug} &= (\bar{Q}_L \sigma^{\mu\nu} T^a u_R) \tilde{\phi} G_{\mu\nu}^a \\ \mathcal{O}_{dg} &= (\bar{Q}_L \sigma^{\mu\nu} T^a d_R) \phi G_{\mu\nu}^a\end{aligned}$$



$$\delta\sigma_{hj} \propto \left(\frac{s}{\Lambda^2}\right)^2$$



SMEFT

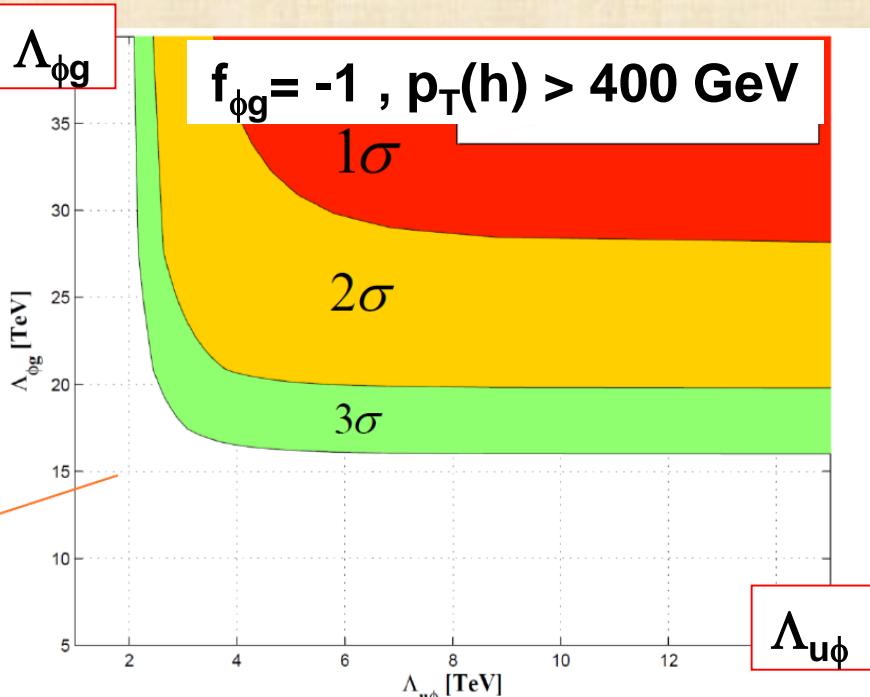
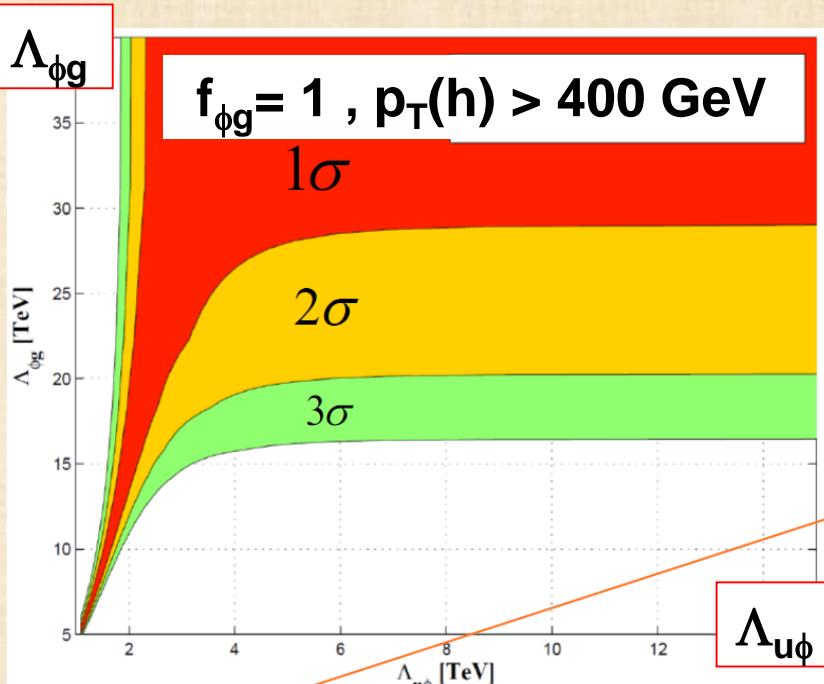
light jet case:  $\text{pp} \rightarrow h+j \rightarrow \gamma\gamma+j$

operators that can be  
“mapped” into the kappa-  
framework

$$\mathcal{O}_{u\phi} = (\phi^\dagger \phi) (\bar{Q}_L \tilde{\phi} u_R)$$

$$\mathcal{O}_{\phi g} = (\phi^\dagger \phi) G_{\mu\nu}^a G^{a,\mu\nu}$$

$$|f_{u\phi}| = 1, \quad \left| \mu_{hj}^{\gamma} - 1 \right| \leq 0.05, \ 0.1 \text{ and } 0.15$$



- $\mu_{hj}^{\gamma}$  consistent with SM at  $3\sigma$  will exclude NP with typical scales of  $\Lambda_{\phi g} \lesssim 15 \text{ TeV}$  and  $\Lambda_{u\phi} \lesssim 2 \text{ TeV}$  for  $f_{\phi g} = -1$

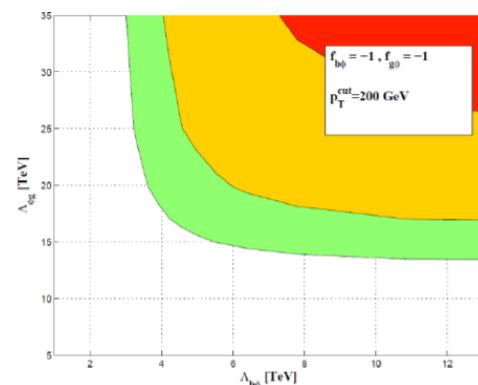
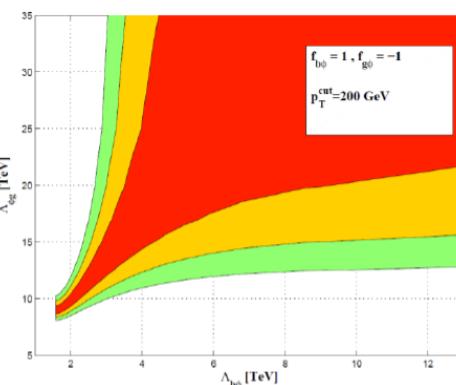
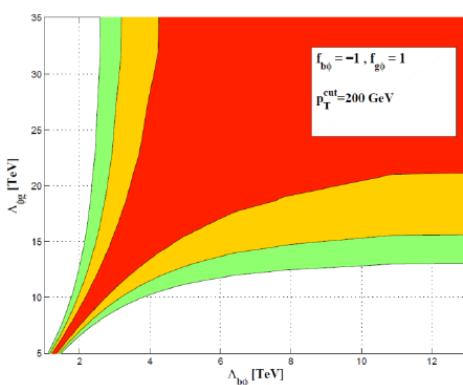
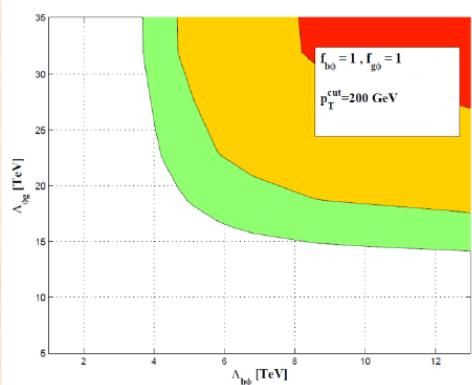
**b-jet case:**  $\text{pp} \rightarrow h + j_b \rightarrow \gamma\gamma + j_b$

operators that can be  
“mapped” into the kappa-  
framework

$$\begin{aligned}\mathcal{O}_{d\phi} &= (\phi^\dagger \phi) (\bar{Q}_L \phi d_R) \\ \mathcal{O}_{\phi g} &= (\phi^\dagger \phi) G_{\mu\nu}^a G^{a,\mu\nu}\end{aligned}$$

$$p_T^{cut} = 200 \text{ GeV}$$

$$(f_{b\phi}, f_{\phi g}) = (1, 1), (1, -1), (-1, 1), (-1, -1)$$

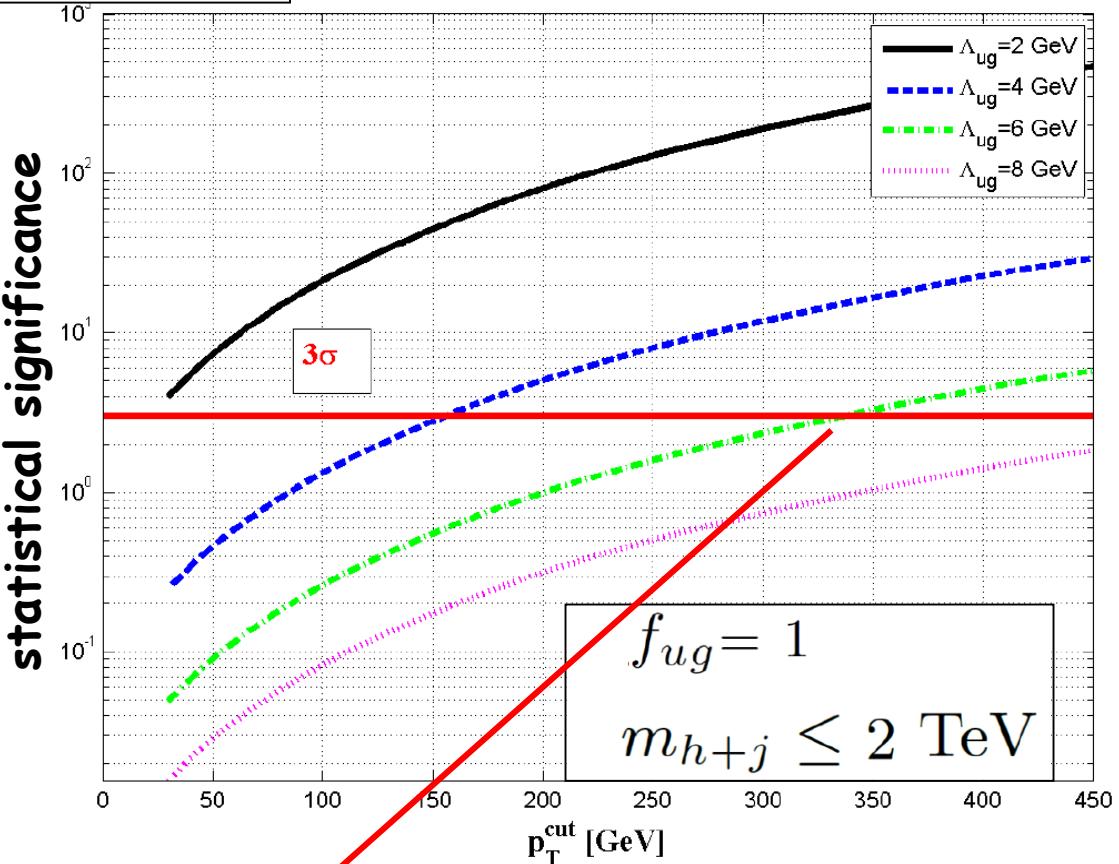


- A slightly better sensitivity than  $h+j$  (light-jet case)
- Better sensitivity at high  $p_T(h)$

light jet case:  $\text{pp} \rightarrow h+j \rightarrow \gamma\gamma+j$

$$N_{SD} = \mu_{hj}^f / \delta\mu_{hj}^f$$

$$\delta\mu_{hj}^f = 0.05(1\sigma)$$



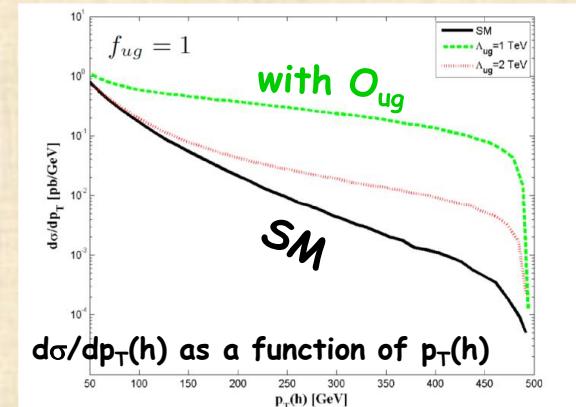
e.g.,

If  $\Lambda_{ug} = 6 \text{ TeV}$  then  $p_T^{\text{cut}} \sim 350 \text{ GeV}$  required to obtain  $3\sigma$  effect

CMDM-like operators for the u-quark

$$\mathcal{O}_{ug} = (\bar{Q}_L \sigma^{\mu\nu} T^a u_R) \tilde{\phi} G_{\mu\nu}^a$$

Recall:  
gives rise to a much harder  $p_T(h)$  spectrum ...



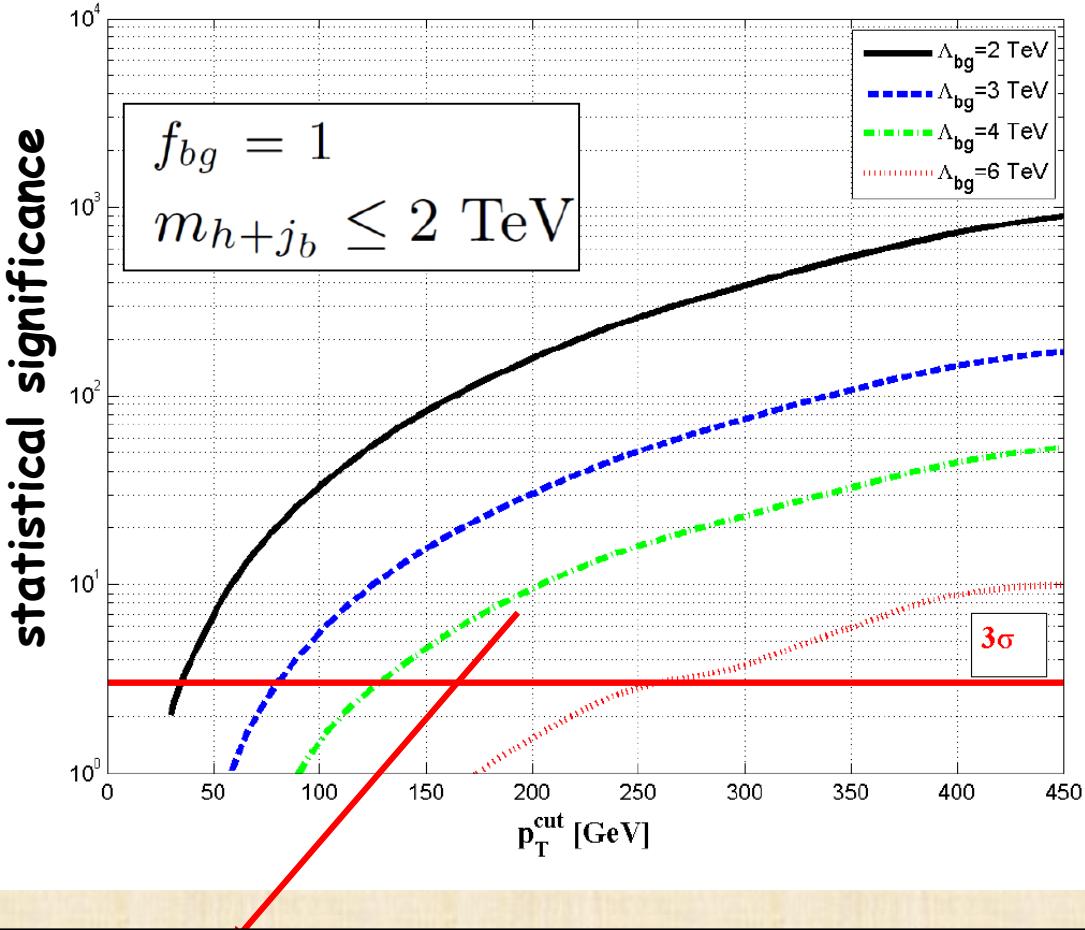
$N(\text{pp} \rightarrow h+j \rightarrow \gamma\gamma+j) \sim O(10) \text{ & } O(100)$

with  $L=300 \text{ fb}^{-1}$  &  $L=3000 \text{ fb}^{-1}$   
Acceptance  $\sim 0.5 \dots$

**b-jet case:**  $\text{pp} \rightarrow h + j_b \rightarrow \gamma\gamma + j_b$

$$N_{SD} = \mu_{hj}^f / \delta\mu_{hj}^f$$

$$\delta\mu_{hj}^f = 0.05(1\sigma)$$



CMDM-like operators for  
the b-quark

$$\mathcal{O}_{dg} = (\bar{Q}_L \sigma^{\mu\nu} T^a d_R) \phi G_{\mu\nu}^a$$

$N(\text{pp} \rightarrow h + j_b \rightarrow \gamma\gamma + j_b) \sim 50$   
with  $L = 3000 \text{ fb}^{-1}$   
Acceptance  $\sim 0.5$  &  $\epsilon_b \sim 0.7$

e.g.,

$O(10\sigma)$  sensitivity to b-CMDM of a typical scale  $\Lambda_{bg} \sim 4 \text{ TeV}$ , with  $p_T(h) > 200 \text{ GeV}$



- The exclusive  $pp \rightarrow h + j(j_b)$  @ the LHC is a rather sensitive probe of several forms of NP associated with the light (& b)-quarks Yukawa's & gluon-Higgs-quarks couplings
- The signal strength formalism &  $p_T(h)$  distributions are useful for extracting the various types of NP
  - Useful parameterizations of NP in  $pp \rightarrow h + j(j_b)$ : the kappa-framework and/or SMEFT



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  - Useful parameterizations of NP in  $pp \rightarrow h + j(j_b)$ :  
the kappa-framework and/or SMEFT
- We find: exclusive Higgs+jet(b-jet) channel followed by  $h \rightarrow \gamma\gamma$  [ $pp \rightarrow h + j(j_b) \rightarrow \gamma\gamma + j(j_b)$ ] can be sensitive to scales of NP ranging from a few TeV to  $O(10)$  TeV, depending on flavor, chirality and Lorentz structure of the underlying NP ...