Model independent studies of new physics in Higgs + jet(b-jet)

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Based on:

"Light-quark Yukawa & new physics in exclusive high-p_T Higgs + jet(b-jet) events":

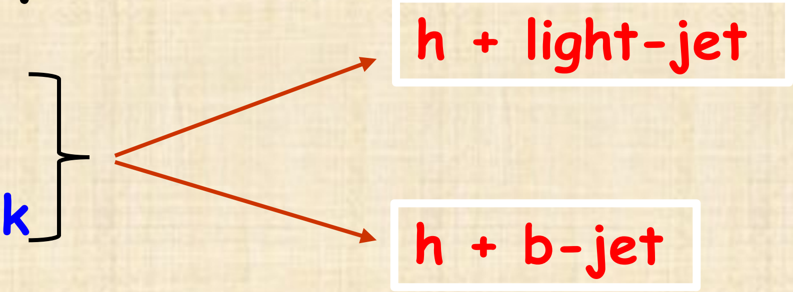
Jonthan Cohen, SBS, Gad Eilam & Amarjit Soni, arxiv: 1705.09295

Outline

- Light quarks Yukawa & Higgs + jet: introductory comments

- Higgs + jet in the SM

- Higgs + jet & New Physics (NP)
    - The kappa-framework
    - The SMEFT-framework

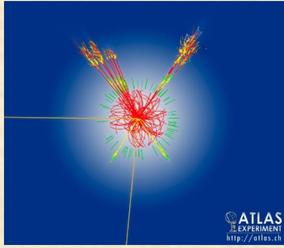


h + light-jet

h + b-jet

- Summary

Why Higgs + jet ?



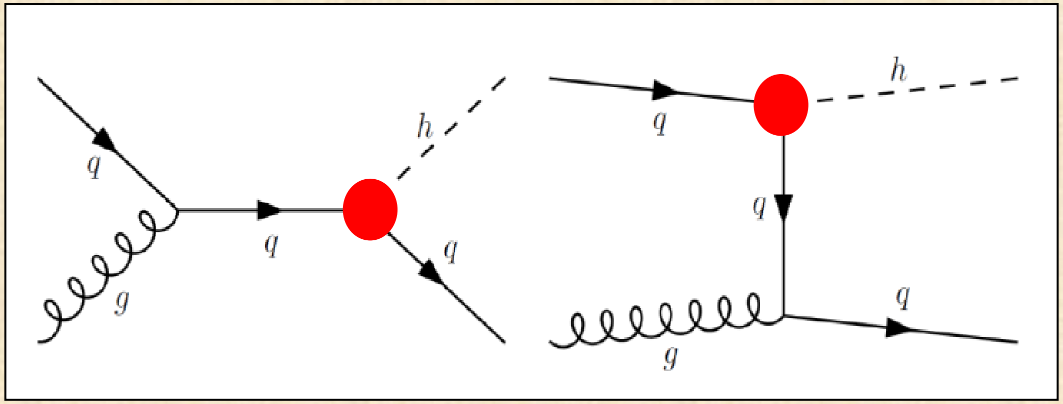
- **Sensitivity to light-quarks Yukawa**

  - Current exp bounds on Yukawa couplings of light-quarks of the 1st & 2nd generations are rather weak: $\boxed{y_u, y_d \lesssim 0.5 y_b \qquad y_c \lesssim 5 y_b}$

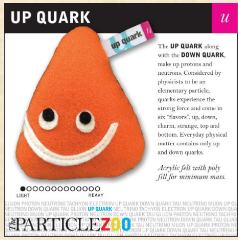
    Kagan, Perez, Petriello, Soreq, Stoynev, Zupan, PRL2015 (arXiv:1406.1722); Perez, Soreq, Stamou, Tobioka, PRD2015 (arXiv:1503.00290); Soreq, Zhu, Zupan, JHEP2016 (arXiv:1606.09621); Bishara, Haisch, Monni, Re, PRL2017 (arXiv:1606.09253)

  - Any sign of these couplings being significantly enhanced w.r.t SM will undermine the SM prediction $\boxed{y_f \propto m_f / v}$

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



Why Higgs + jet ?



- modifications to light-quarks Yukawa:
  - 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.

  - Light quarks Yukawa may play an important role in BSM physics:
    - Partially composite 1st-2nd gen quarks: enhanced Yukawa's from mixing with the strong dynamics (mixing with heavy VLQ …)

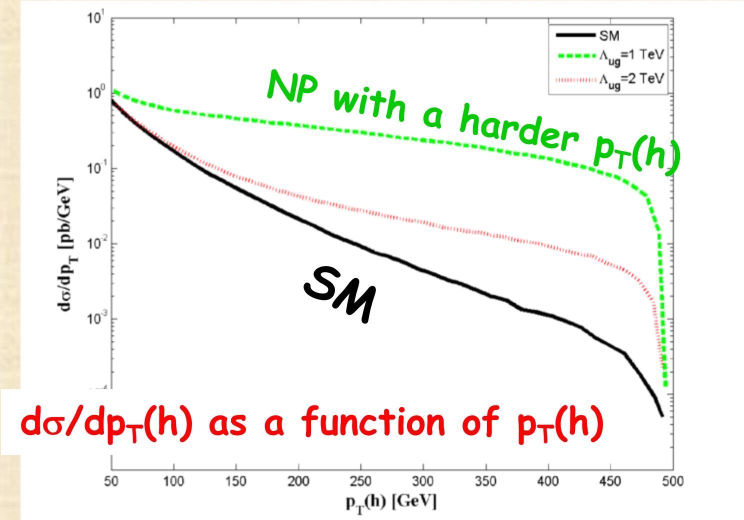
      Delaunay, Grojean, Perez, JHEP2013 (arXiv:1303.5701);
      Delaunay, Flacke, Gonzalez-Fraile, Lee, Panico, Perez, JHEP2014 (arXiv:1311.2072)
    - Modified Y_q may have important implications for Higgs portal DM pheno (DM annihilation altered …)

      Bishara, Brod, Uttayarat, Zupan, JHEP2016 (arXiv:1504.04022)

Why Higgs + jet ?

EXCLUSIVE!
EXCLUSIVE!
EXCLUSIVE!

- **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:*



NP with a harder $p_T(h)$

SM

$d\sigma/dp_T(h)$ as a function of $p_T(h)$

Why Higgs + jet ?

EXCLUSIVE!
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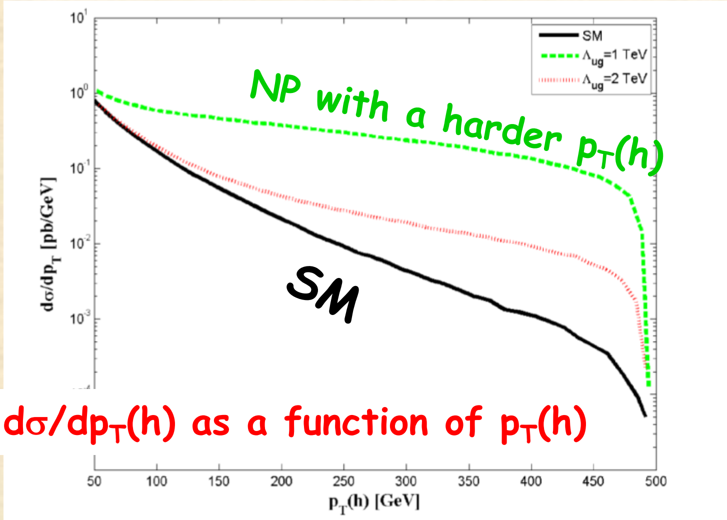
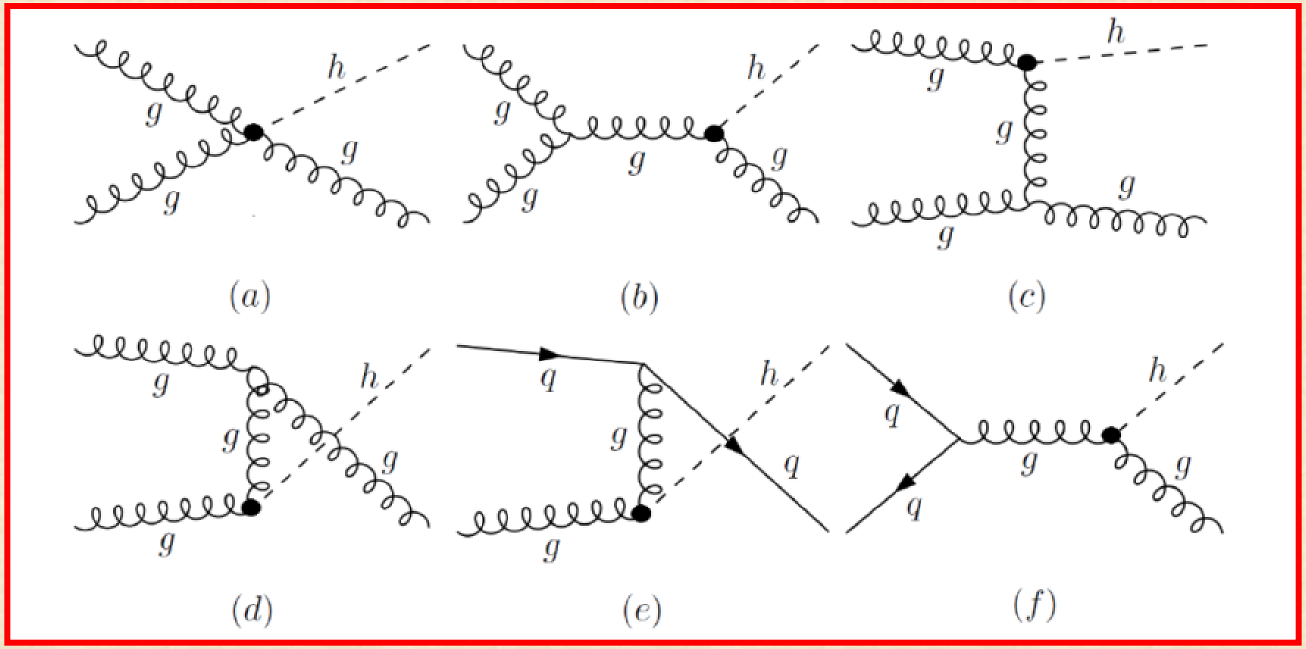
- **Exclusive Higgs + j(j_b) @ the LHC as a probe of NP:**
  - *High Higgs P_T distribution may play a key role in distinguishing between NP scenarios:*
    - **Sensitive to a variety of UV completions: SUSY, heavy top-partners …**
      Brein, Hollik, PRD2003 (hep-ph/0305321); Dittmaier, Kramer, Spira, PRD2004 (hep-ph/0309204); Dawson, Jackson, Reina, Wackeroth, 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 → 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)



$d\sigma/dp_T(h)$ as a function of $p_T(h)$

Higgs + light-jet in the SM:

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



(a) (b) (c)

(d) (e) (f)

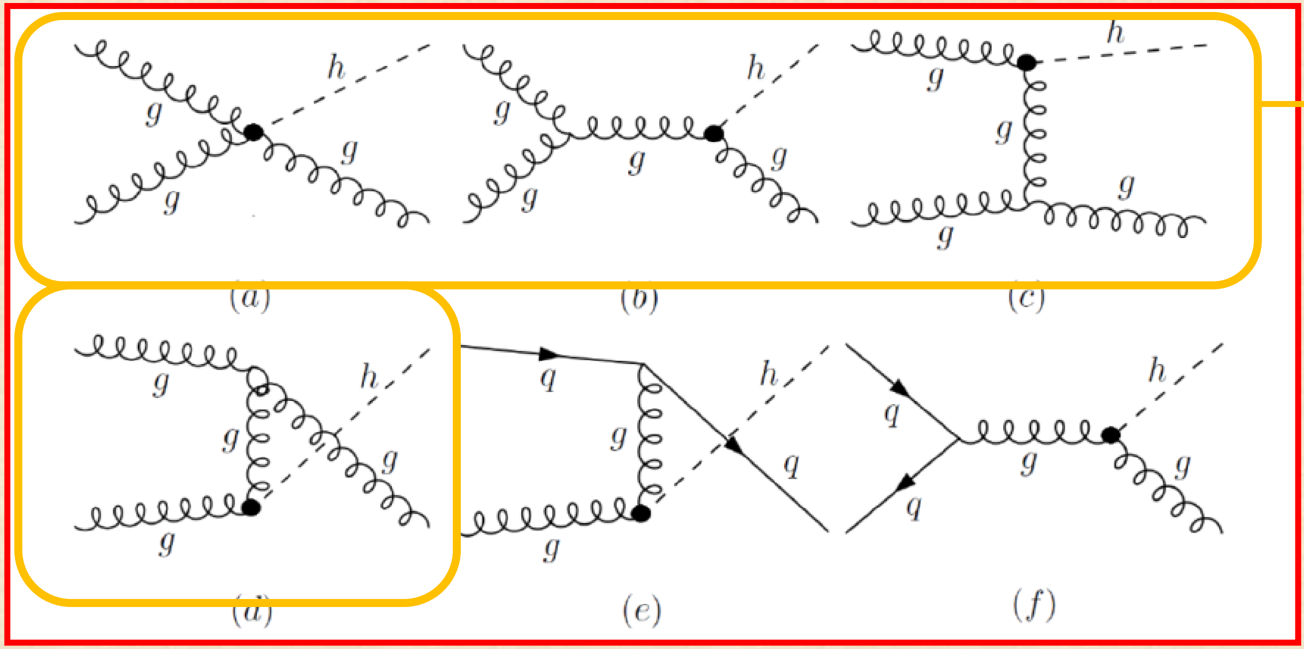
- **Parameterization of the 1-loop SM ggh vertex (mostly the top-loop, tree-level negligible …):**

(leading term)

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

Higgs + light-jet in the SM:

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



$gg \;\to\; gh$

dominant in SM

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NP studies in Higgs + jet:

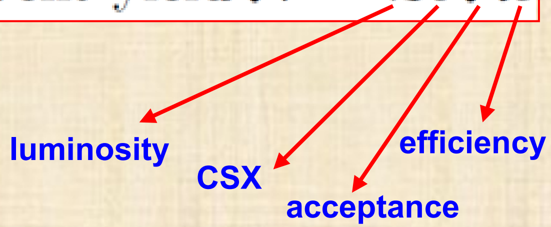
- **We focus on exclusive pp → h+j(j_b) followed by h → $\gamma\gamma$ with the following two NP scenarios:**
  - **NP comes only in the form of scaled couplings**
    (kappa-framework = coupling modifiers)
  - **NP give can rise to new interactions that are absent in the SM and that modify the SM Lorentz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

NP studies in Higgs + jet:

- **Define a signal strength (for h+j(j_b) followed by h → γγ):**

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

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



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

luminosity

CSX

acceptance

efficiency

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

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

- **Using the "cumulative CSX":**

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

Extra handle on NP effect, also useful minimizing the K-factor at the high P_T(h)

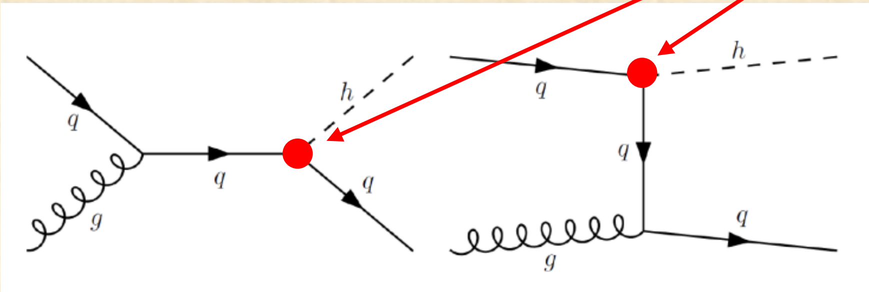
e.g., Boughezal et al., JHEP2013,PRL2015, PLB2015

The kappa-framework

SM: κ_g=1, κ_b=1, κ_c~ 0.3, κ_s~ O(10^{-2}), $\kappa_{u,d}$~ O(10^{-3})

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

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



modifies the SM diagrams

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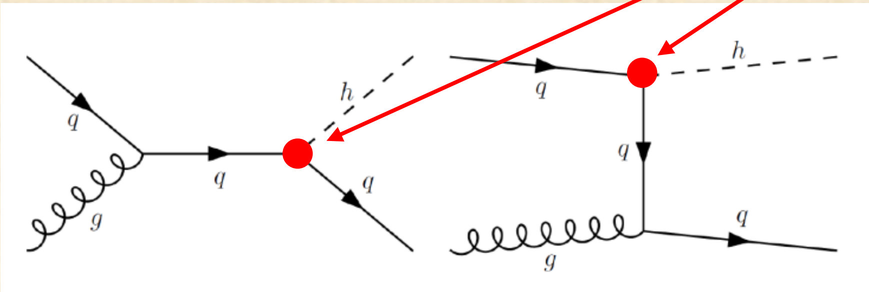


modifies the SM diagrams

- **For Higgs + light-jet, pp → h+j:**

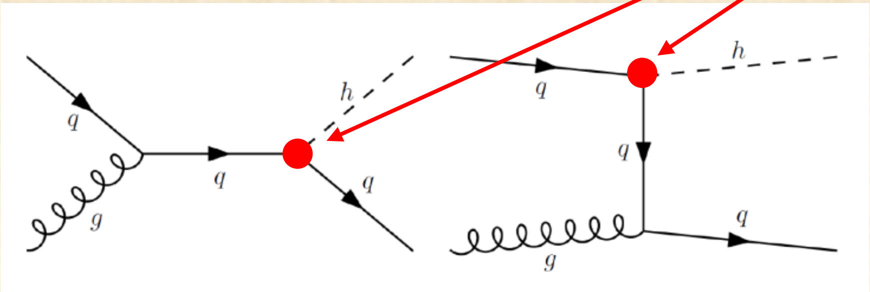
NP from $\kappa_q \neq 0$ & $\kappa_g \neq 1$

$$\sigma^{hj} = \kappa_g^2 \sigma_{SM}^{hj} + \kappa_q^2 \sigma_{qqh}^{hj} \Rightarrow \sigma_{SM}^{hj} \simeq \sigma^{hj}(\kappa_g = 1, \kappa_q = 0)$$

The kappa-framework

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

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



modifies the SM diagrams

- **For Higgs + b-jet, pp → h+j_b:**

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

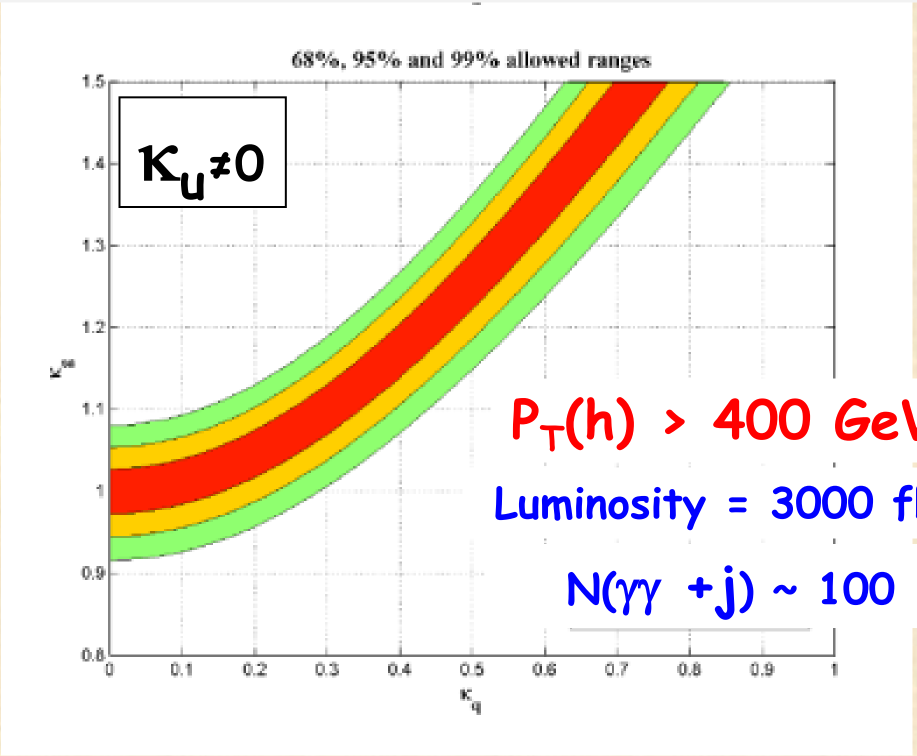
$$\boxed{\sigma^{hj_b} = \kappa_g^2 \sigma_{ggh}^{hj_b} + \kappa_b^2 \sigma_{bbh}^{hj_b}} \Rightarrow \boxed{\sigma_{SM}^{hj_b} = \sigma_{ggh}^{hj_b} + \sigma_{bbh}^{hj_b}}$$

kappa-framework

light jet case: pp → h+j → $\gamma\gamma$+j, kappa-framework

NP in qqh & ggh (κ_g - κ_q plane)

68%, 95% & 99% allowed ranges in κ_g - κ_q plane



$P_T(h)$ > 400 GeV

Luminosity = 3000 fb^{-1}

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

assume a 5%(1σ) error:

$$\delta\mu^{\gamma}_{hj}(theory+exp)=0.05(1\sigma)$$

light jet case: pp $\rightarrow$ h+j $\rightarrow$ $\gamma\gamma$+j, kappa-framework

NP in qqh & ggh (κ_g - κ_q plane)

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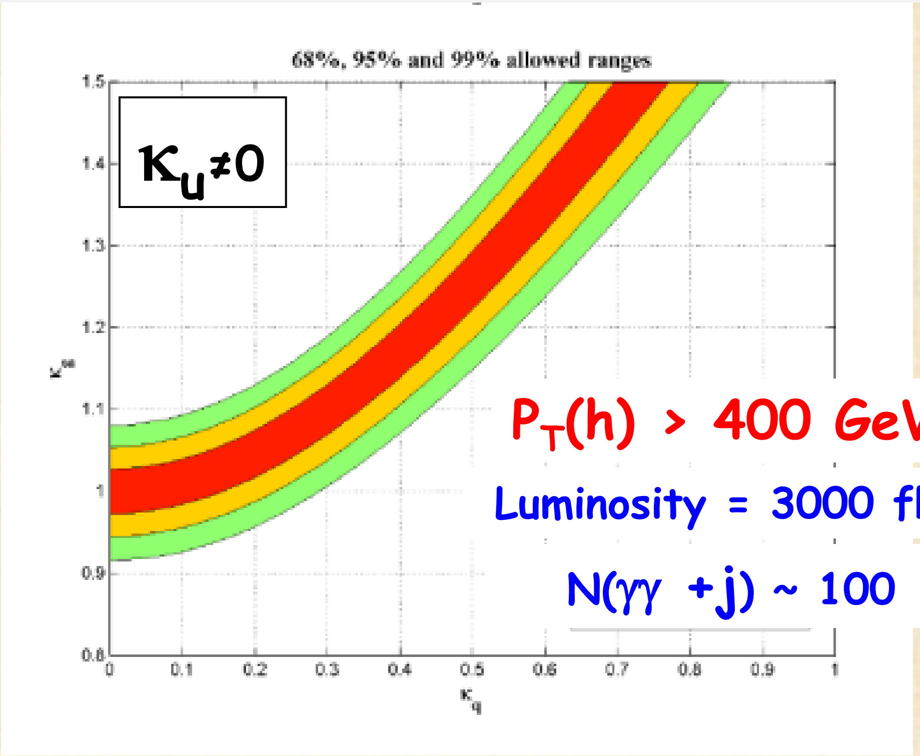

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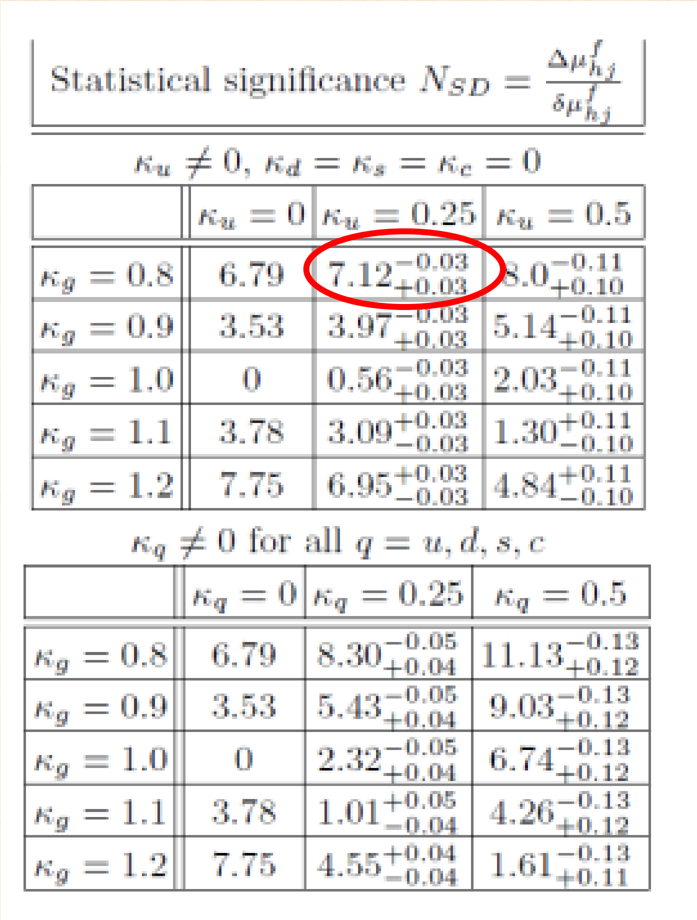


Statistical significance $N_{SD} = \frac{\Delta\mu^f_{hj}}{\delta\mu^f_{hj}}$

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

	$\kappa_u = 0$	$\kappa_u = 0.25$	$\kappa_u = 0.5$
$\kappa_g = 0.8$	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 $q = u, d, s, c$

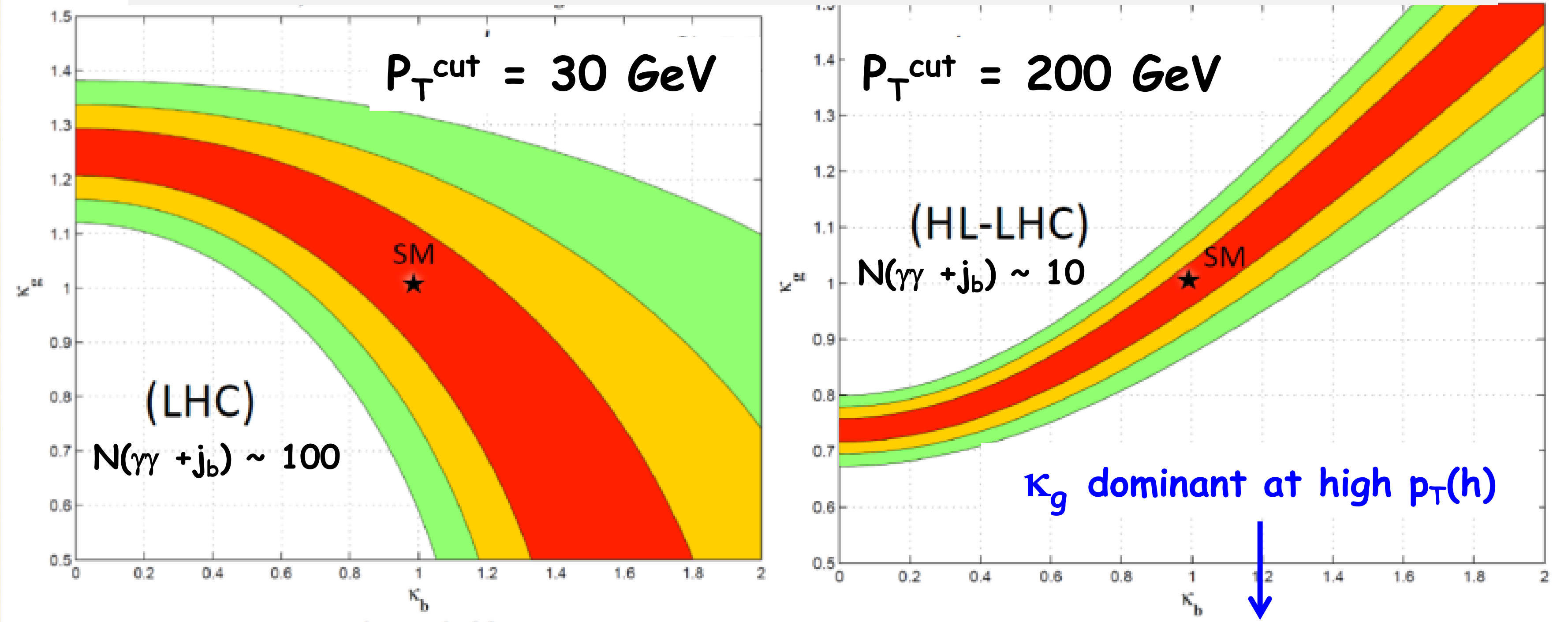
	$\kappa_q = 0$	$\kappa_q = 0.25$	$\kappa_q = 0.5$
$\kappa_g = 0.8$	6.79	$8.30^{-0.05}_{+0.04}$	$11.13^{-0.13}_{+0.12}$
$\kappa_g = 0.9$	3.53	$5.43^{-0.05}_{+0.04}$	$9.03^{-0.13}_{+0.12}$
$\kappa_g = 1.0$	0	$2.32^{-0.05}_{+0.04}$	$6.74^{-0.13}_{+0.12}$
$\kappa_g = 1.1$	3.78	$1.01^{+0.05}_{-0.04}$	$4.26^{-0.13}_{+0.12}$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

e.g., κ_g < 0.8 with κ_u > 0.25 can be excluded @ 7σ

b-jet case: pp → h+j_b → γγ+j_b, kappa-framework

NP in qqh & ggh (κ_g - κ_q plane)

68%, 95% & 99% allowed ranges in κ_g - κ_b plane



κ_g dominant at high $p_T(h)$

high and low $p_T(h)$: probing complimentary regims in κ_g - κ_b plane

b-jet case: pp → h+j_b → $\gamma\gamma$+j_b, kappa-framework

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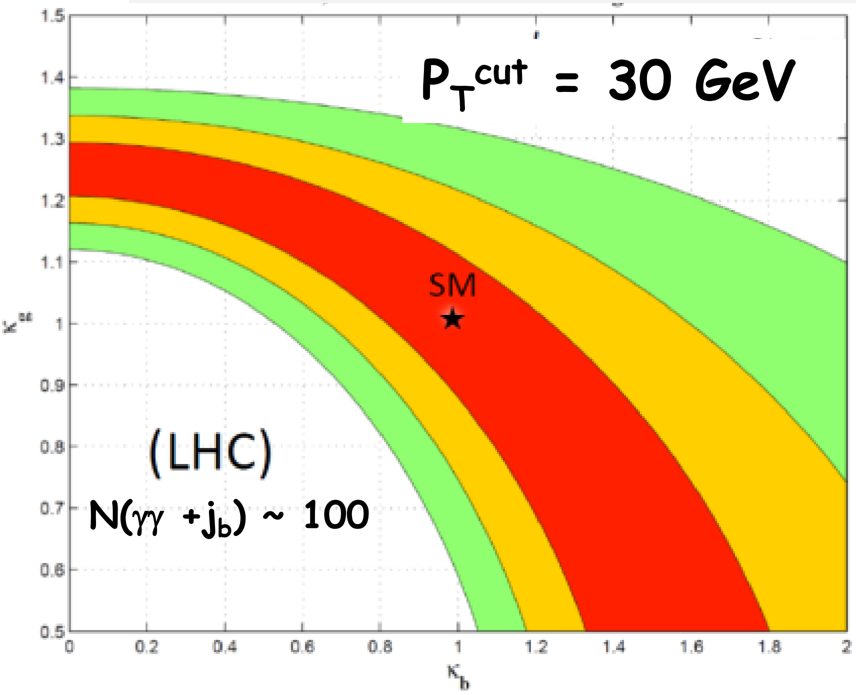

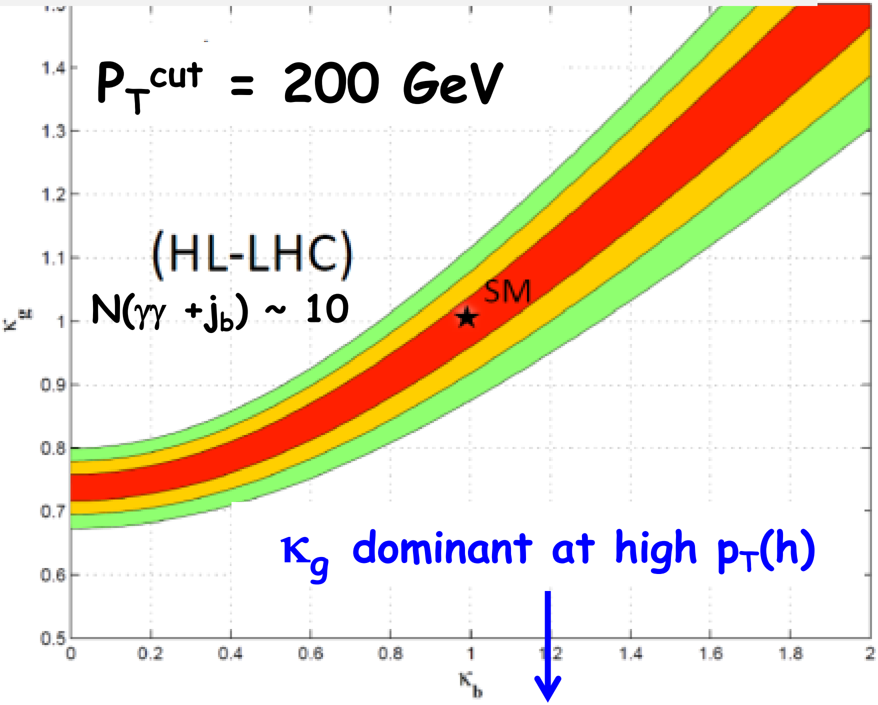

κ_g dominant at high p_T(h)

high and low p_T(h): probing complimentary regims in κ_g - κ_b plane

Statistical significance $N_{SD} = \frac{\Delta\mu^f_{hj_b}}{\delta\mu^f_{hj_b}}$

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

e.g., κ_g < 0.8 with κ_b > 1.5 can be excluded @ 7σ

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

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

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

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\mathcal{O}_{dg} &= \left(\bar{Q}_L \sigma^{\mu\nu} T^a d_R \right) \phi G^a_{\mu\nu} + h.c. \, ,
\end{aligned}\right\}$$

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

light-quarks version of these operators often neglected, assuming $\propto y_{u,d}$ e.g., for MFV …

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**

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

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\end{aligned}\right\}$$

Chromo-magnetic dipole moment like operators

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

The SMEFT

operators that can be "mapped" into the kappa-framework

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

$$\mathcal{O}_{d\phi} = \left(\phi^\dagger \phi\right)\left(\bar{Q}_L \phi d_R\right)$$

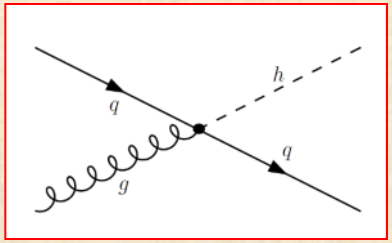
$$\mathcal{O}_{\phi g} = \left(\phi^\dagger \phi\right) G^a_{\mu\nu} G^{a,\mu\nu}$$

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

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

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

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



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

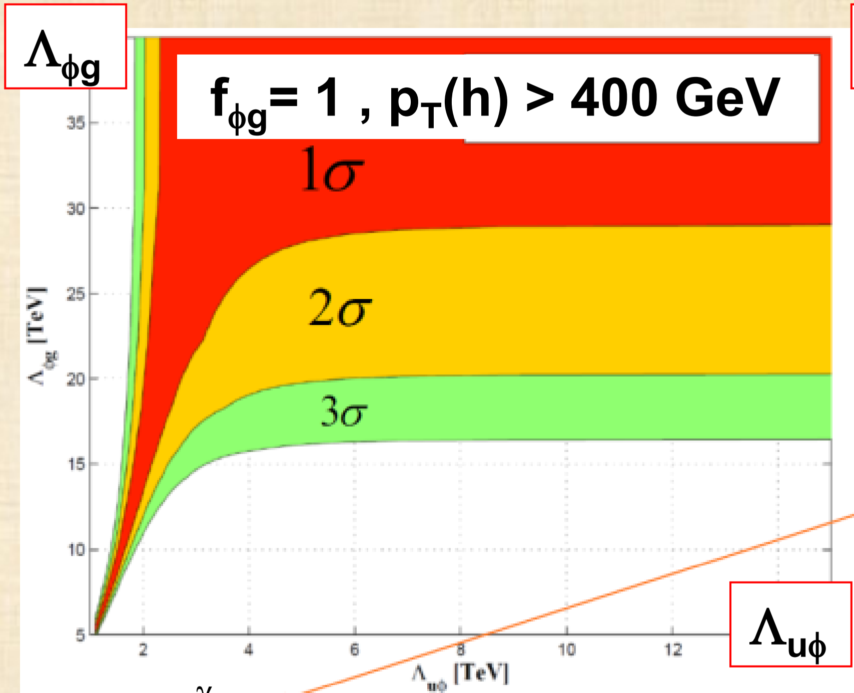
SMEFT

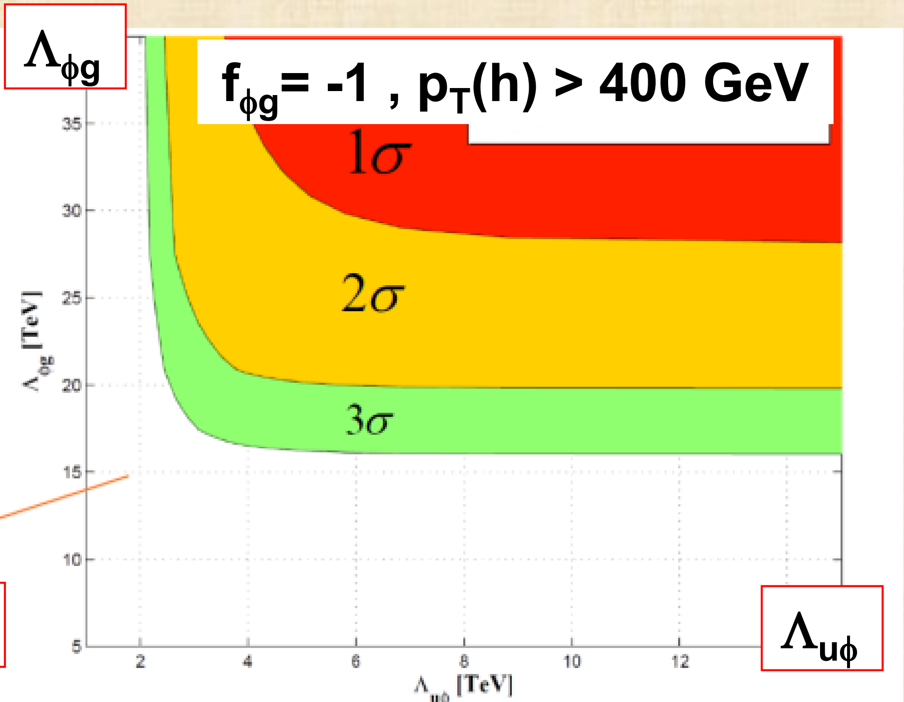
light jet case: pp → h+j → γγ+j

operators that can be "mapped" into the kappa-framework

$$\mathcal{O}_{u\phi} = (\phi^\dagger\phi)\left(\bar{Q}_L\tilde{\phi}u_R\right)$$
$$\mathcal{O}_{\phi g} = (\phi^\dagger\phi)\,G^a_{\mu\nu}G^{a,\mu\nu}$$

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





- μ^{γ}_{hj} consistent with SM at 3σ will exclude NP with typical scales of

$$\boxed{\Lambda_{\phi g} \lesssim 15 \text{ TeV and } \Lambda_{u\phi} \lesssim 2 \text{ TeV for } f_{\phi g} = -1}$$

b-jet case: pp → h+j$_b$ → γγ+j$_b$

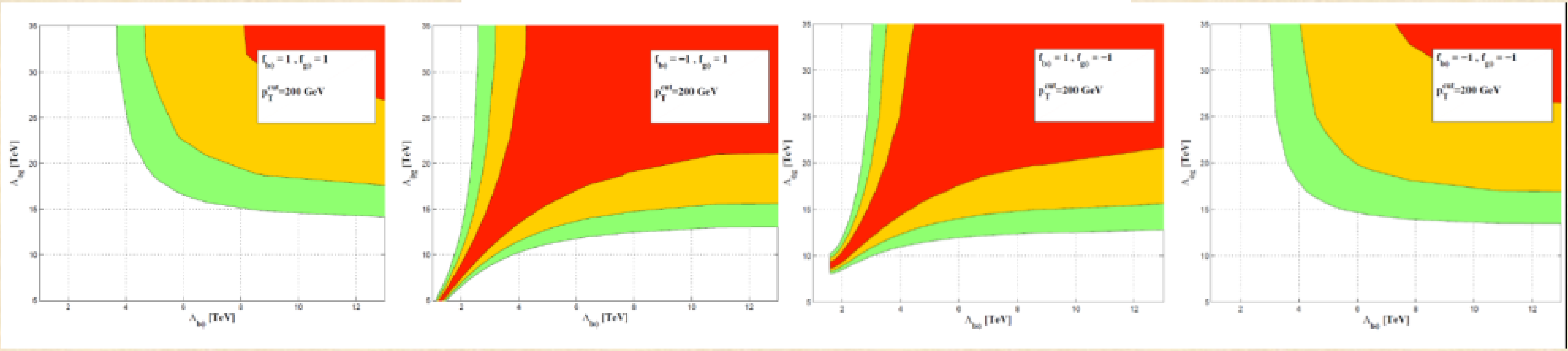
operators that can be "mapped" into the kappa-framework

$$\mathcal{O}_{d\phi} = (\phi^\dagger \phi)(\bar{Q}_L \phi d_R)$$

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

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

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



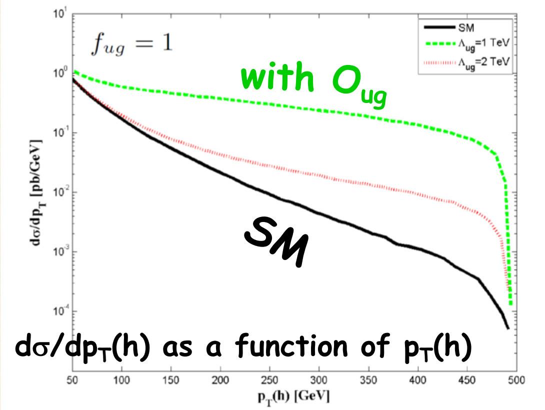
- A slightly better sensitivity than h+j (light-jet case)
- Better sensitivity at high $p_T(h)$

light jet case: pp → h+j → γγ+j

CMDM-like operators for the u-quark

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

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



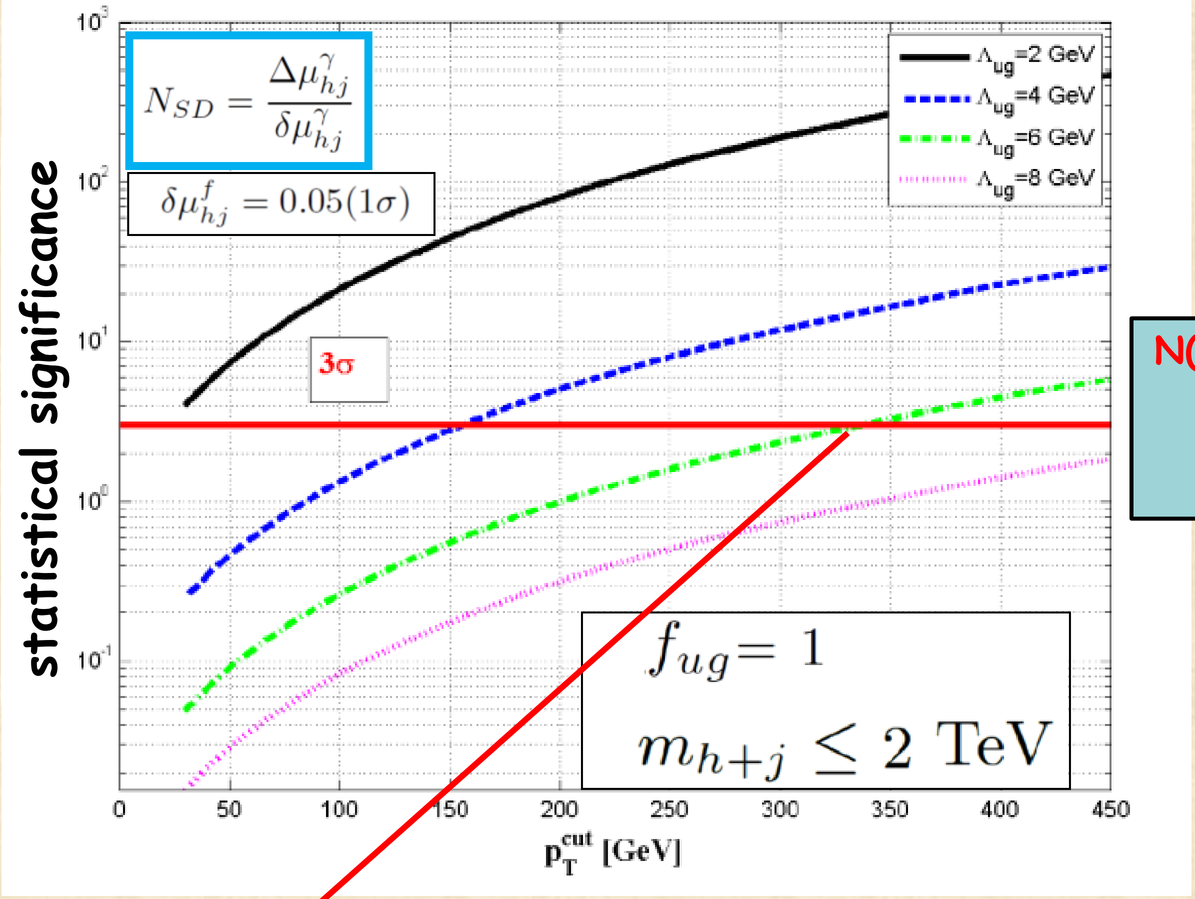
$d\sigma/dp_T(h)$ as a function of $p_T(h)$

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

CMDM-like operators for the u-quark

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

Sensitivity to NP as a function of the lower $p_T(h)$ cut



N(pp $\rightarrow$ h+j $\rightarrow$ $\gamma\gamma$+j) ~ O(10) & O(100)

with L=300 fb^{-1} & L=3000 fb^{-1}
Acceptance ~ 0.5 …

e.g.,

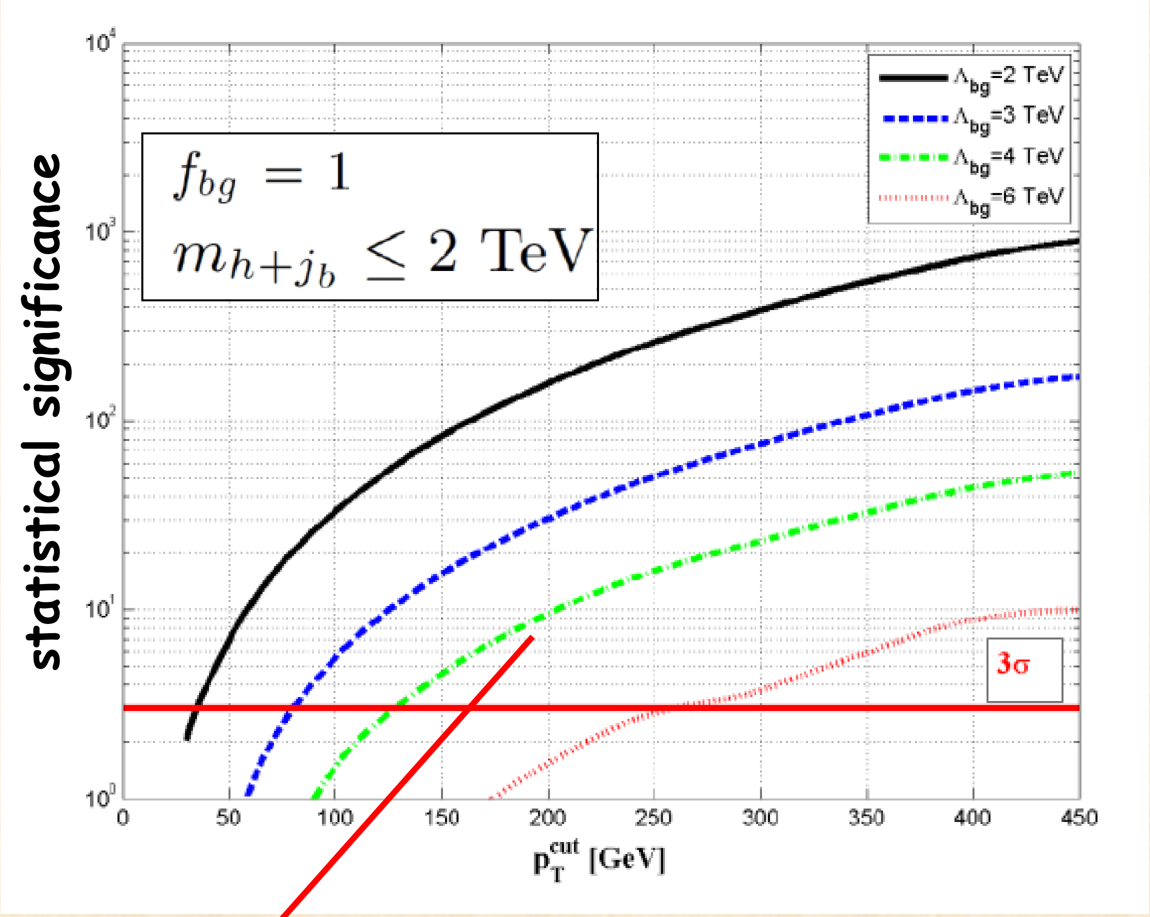
If $\Lambda_{ug} = 6$ TeV then $p_T^{cut} \sim 350$ GeV required to obtain 3σ effect

b-jet case: pp $\rightarrow$ h+j_b $\rightarrow$ $\gamma\gamma$+j_b

CMDM-like operators for the b-quark

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

Sensitivity to NP as a function of the lower $p_T(h)$ cut



N(pp $\rightarrow$ h+j_b $\rightarrow$ $\gamma\gamma$+j_b) ~ 50

with L=3000 fb^{-1}

Acceptance ~ 0.5 & ε_b~ 0.7

e.g.,

O(10σ) sensitivity to b-CMDM of a typical scale Λ_{bg} ~ 4 TeV, with $p_T(h)$ > 200 GeV

SUMMARY

CONCLUSION

- The exclusive pp → $h+j(j_b)$ Higgs production channel @ the LHC is a rather sensitive probe of several forms of NP associated with the light (& b)-quarks Yukawa's & with 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 → $h+j(j_b)$:
    the kappa-framework and/or SMEFT

SUMMARY

CONCLUSION

- The exclusive $pp \to h+j(j_b)$ @ 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 $pp \to h+j(j_b)$: the kappa-framework and/or SMEFT
- We find: exclusive Higgs+jet(b-jet) channel followed by $h \to \gamma\gamma$ [$pp \to h+j(j_b) \to \gamma\gamma+j(j_b)$] 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 …

backups

NP studies in Higgs + jet:

- **NP signal:** $\boxed{\Delta\mu^{\gamma}_{hj} \equiv | \mu^{\gamma}_{hj} - 1 |}$ $\left[\boxed{\mu^{\gamma}_{hj}(SM) = 1} \right]$

- **Statistical significance of signal:** $\boxed{N_{SD} = \frac{\Delta\mu^{\gamma}_{hj}}{\delta\mu^{\gamma}_{hj}}}$

& assume a 5%(1σ) error: $\boxed{\delta\mu^{\gamma}_{hj}(theory + exp) = 0.05(1\sigma)}$

kappa-framework,

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

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

kappa-framework,

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

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

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

- the NP contribution scaled with the SM, calculated using the comulative CSX (for a given p_T^{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 → h+j(j$_b$) → γγ+j(j$_b$):

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

$$\mu^{j}_{h\to\gamma\gamma} = \frac{1}{1+\left(\kappa_g^2-1\right)BR^{gg}_{SM}+\kappa_q^2 BR^{bb}_{SM}}$$

$$\mu^{j_b}_{h\to\gamma\gamma} = \frac{1}{1+\left(\kappa_g^2-1\right)BR^{gg}_{SM}+\left(\kappa_b^2-1\right)BR^{bb}_{SM}}$$

assume no NP in h → γγ

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

- the NP contribution scaled with the SM, calculated using the comulative CSX (for a given p_T^{cut}):
  - contains all the dependence on the Higgs PT
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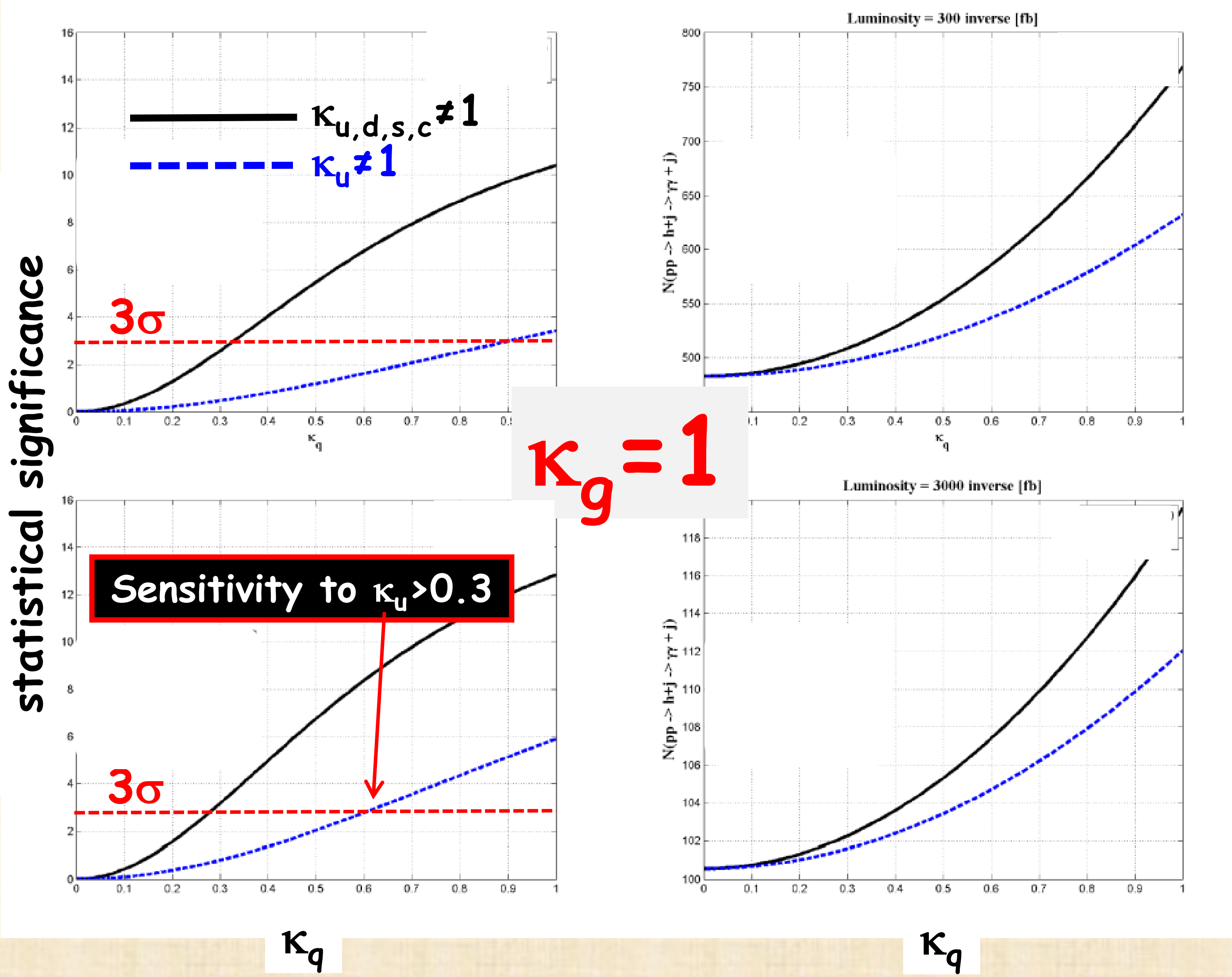
light jet case: pp $\rightarrow$ h+j $\rightarrow$ $\gamma\gamma$+j, kappa-framework

no NP in hhg (κ_g=1)



P_T(h) > 100 GeV

Luminosity = 300 fb^{-1}

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

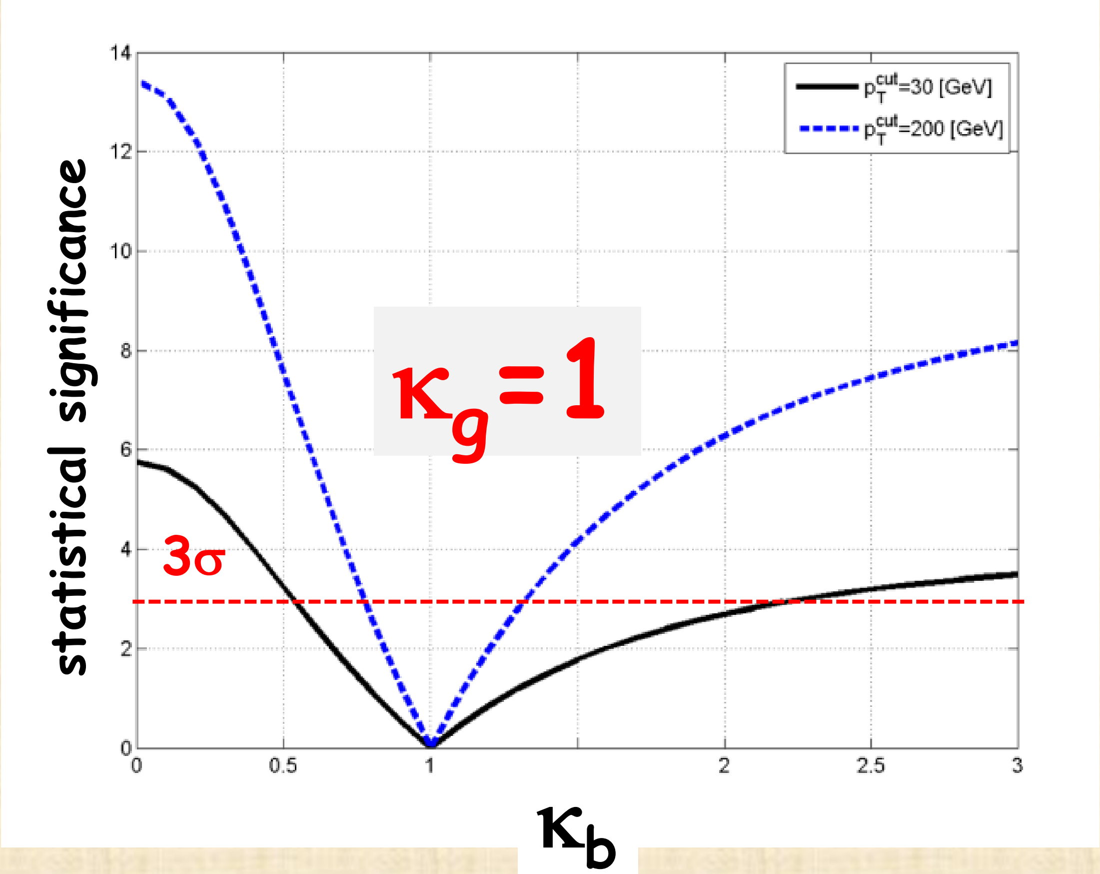
P_T(h) > 400 GeV

Luminosity = 3000 fb^{-1}

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

b-jet case: pp $\longrightarrow$ h+j_b $\longrightarrow$ $\gamma\gamma$+j_b, kappa-framework

no NP in hgg (κ_g=1)



$p_T(h)$ > 200 GeV: sensitivity to κ_b<0.8 & κ_b>1.3