ICHEP 2026
NATAL | BRAZIL

BSM Phenomenology in the $t\bar{t}hh$ channel

Ricardo D'Elia Matheus

RDM, Oscar J.P. Éboli, Rafiqul Rahaman and Aurore Savoy Navarro
Exploring Higgs EFT in $t\bar{t}hh$ at high luminosity LHC
JHEP 07 (2026) 156 [arXiv: 2602.03842]

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$t\bar{t}hh$ the forgotten channel

"Early" (2014) works[1,2,3]:

$\sigma(pp \to hh) = 34.8\,\mathrm{fb}$ @14TeV[2]

$\sigma(pp \to t\bar{t}hh) = 0.981\,\mathrm{fb}$ @14TeV[2]

λh^3

$\lambda \gtrsim \lambda_{SM}$

$\sigma(pp \to hh) < \sigma_{SM}(pp \to hh)$

$\sigma(pp \to t\bar{t}hh) > \sigma_{SM}(pp \to t\bar{t}hh)$

[1] C. Englert, F. Krauss, M. Spannowsky and J. Thompson, Di-Higgs phenomenology in tthh: The forgotten channel, Phys. Lett. B 743 (2015) 93
[2] R. Frederix et al., Higgs pair production at the LHC with NLO and parton-shower effects, Phys. Lett. B 732 (2014) 142 [arXiv:1401.7340]
[3] T. Liu and H. Zhang, Measuring Di-Higgs Physics via the tthh → ttbbbb Channel, arXiv:1410.1855

$t\bar{t}hh$ the forgotten channel

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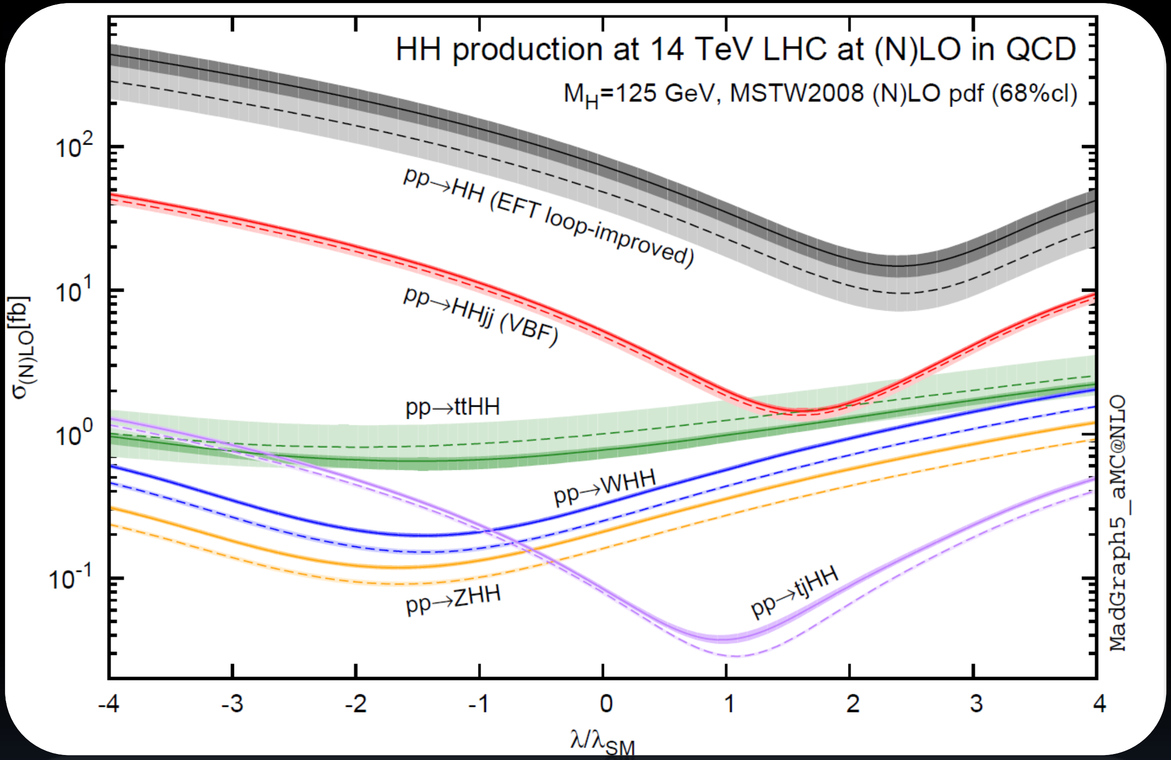

[2]

LO ⟷ Lighter, dashed

NLO ⟷ Darker, continuous

Initial impression: Considering cleaner backgrounds, $t\bar{t}hh$ could be competitive with *hh* in determining λ! (Specially for $\lambda > \lambda_{SM}$)[1,3]

Caveat: reducible backgrounds underestimated! (Specifically: $t\bar{t}$+*jets* and $t\bar{t}2b$+*jets*)

[1] C. Englert, F. Krauss, M. Spannowsky and J. Thompson, Di-Higgs phenomenology in tthh: The forgotten channel, Phys. Lett. B 743 (2015) 93
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$t\bar{t}hh$ the forgotten channel

Recent studies[4,5]: prospects for HL-LHC, @14 TeV @3000 fb^{-1}

CMS[4]: $\mu_{t\bar{t}hh} < 3.14^{+1.27}_{-0.9}$ @95% C.L. (roughly: $S/\sqrt{B} = 0.6\sigma$)

ATLAS[5]: $S/\sqrt{B} = 0.35\sigma$

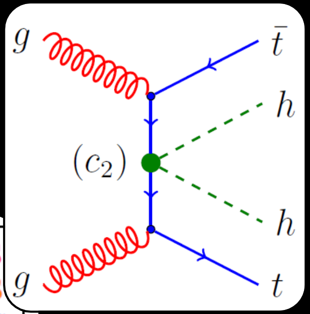
To be contrasted with *hh* production[6]: $S/\sqrt{B} = 4.5\sigma$ (per collaboration, similar conditions as above)

$\rightarrow$ $0.6 \lesssim \kappa_\lambda \lesssim 1.5$ (much stronger than the constraints from $t\bar{t}hh$, as I'll show later)

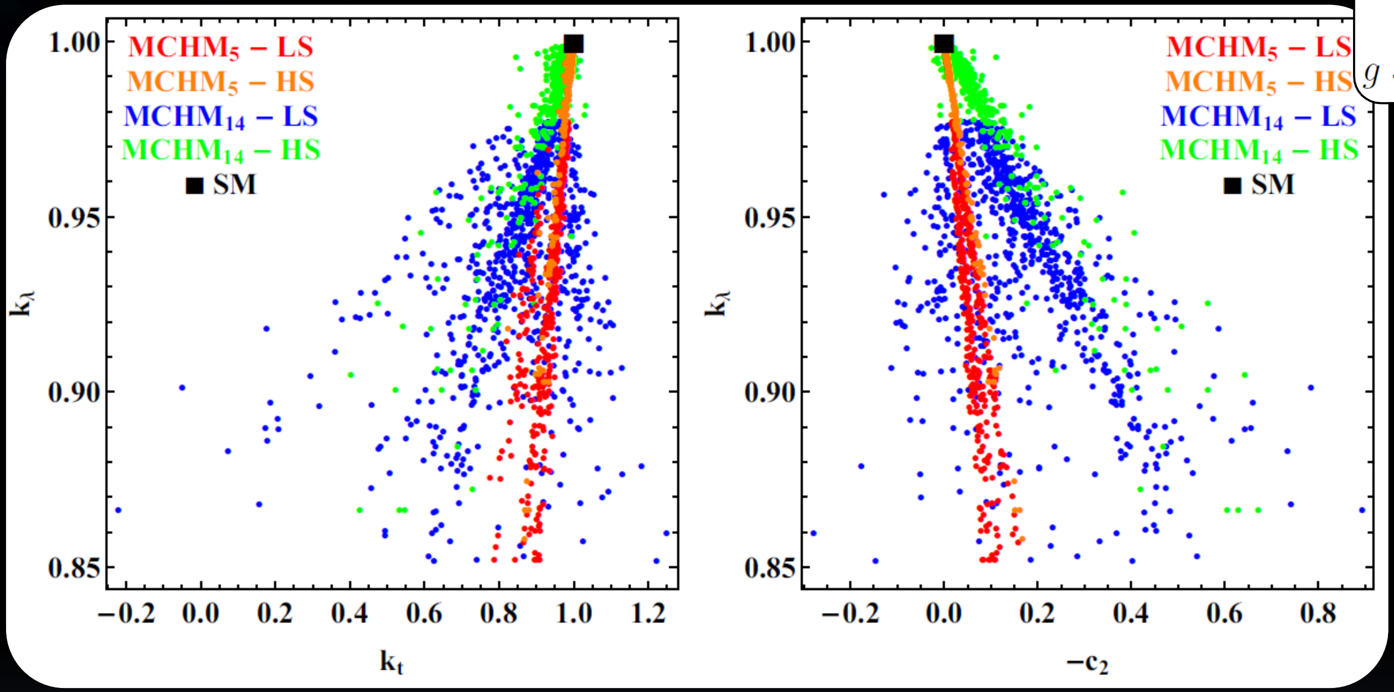
Caveat: much more attention given to *hh*, improvements in $t\bar{t}hh$ possible (reducible backgrounds!)

[4] CMS collaboration, Search for the nonresonant ttHH production in the semileptonic decay of the top pair and the Higgs pair decay into b quarks at the HL-LHC, CMS-PAS-FTR-21-010 (2022)
[5] ATLAS collaboration, Prospects for Observing ttHH Production with the ATLAS Experiment at the HL-LHC, ATL-PHYS-PUB-2016-023 (2016)
[6] ATLAS and CMS Collaborations, Highlights of the HL-LHC physics projections by ATLAS and CMS, ATL-PHYS-PUB-2025-018, CMS-HIG-25-002, arXiv:2504.00672

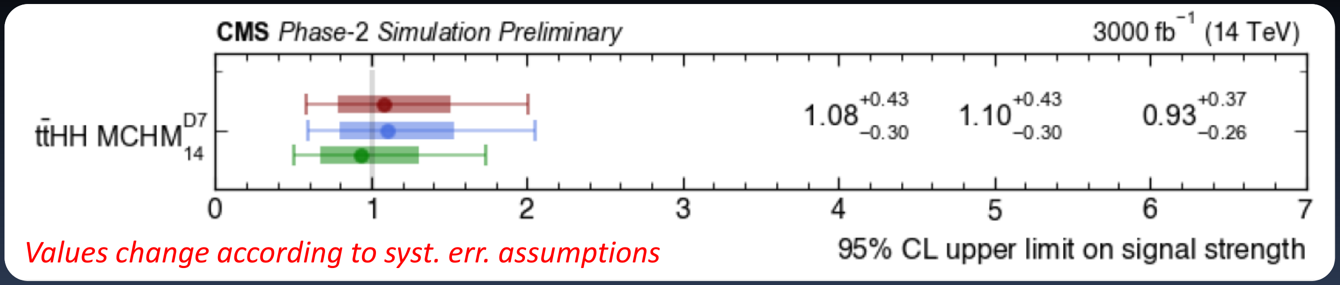
Complementarity of Signals



Non resonant regime of the MCHM (SMEFT) [7]:



Benchmark proposed in [7] (MHCM$_{14}$) was used in [4] and shown to be in reach of the HL-LHC (non-resonantly):



[4] CMS collaboration, Search for the nonresonant ttHH production in the semileptonic decay of the top pair and the Higgs pair decay into b quarks at the HL-LHC, CMS-PAS-FTR-21-010 (2022)
[7] C. Bautista, L. de Lima, **R. D. M.**, E. Pontón, L. A. F. do Prado, A. Savoy-Navarro, Probing the top-Higgs sector with composite Higgs models at present and future hadron colliders, JHEP 03 (2021) 049

SMEFT vs HEFT

$$\mathcal{L}_{\mathrm{HEFT}} = -m_t \left(c_t \frac{h}{v} + c_{tt} \frac{h^2}{v^2} \right) \bar{t}\, t - c_{hhh} \frac{m_h^2}{2v} h^3 + \frac{\alpha_s}{8\pi} \left(c_{ggh} \frac{h}{v} + c_{gghh} \frac{h^2}{v^2} \right) G^a_{\mu\nu} G^{a,\mu\nu} \,.$$

Related in SMEFT:

- *ggh & gghh*
- *tth & tthh*
- *hhh & hhhh*

HEFT	Warsaw
c_{hhh}	$1 - 2\frac{v^2}{\Lambda^2}\frac{v^2}{m_h^2} C_H + 3\frac{v^2}{\Lambda^2} C_{H,\mathrm{kin}}$
c_t	$1 + \frac{v^2}{\Lambda^2} C_{H,\mathrm{kin}} - \frac{v^2}{\Lambda^2}\frac{v}{\sqrt{2}m_t} C_{uH}$
c_{tt}	$-\frac{v^2}{\Lambda^2}\frac{3v}{2\sqrt{2}m_t} C_{uH} + \frac{v^2}{\Lambda^2} C_{H,\mathrm{kin}}$
c_{ggh}	$\frac{v^2}{\Lambda^2}\frac{8\pi}{\alpha_s} C_{HG}$
c_{gghh}	$\frac{v^2}{\Lambda^2}\frac{4\pi}{\alpha_s} C_{HG}$

Multiple channels needed to break blind directions and test the SMEFT hypothesis!

Extended HEFT Space

$t\bar{t}hh$ - Relevant part of the HEFT Lagrangian:

$$
\begin{aligned}
\mathcal{L}_{\text{heft}} \;=\; & \frac{1}{2}\partial_\mu h\, \partial^\mu h - \frac{1}{2} m_h^2 h^2 - (1+\boxed{\delta\kappa_\lambda})\lambda_{SM} v h^3 - \frac{m_t}{v}\left((1+\boxed{\delta\kappa_t})h + \frac{\boxed{c_2}}{v} hh\right)(\bar{t}_L t_R + \text{h.c.}) \\
& + \frac{\alpha_s}{12\pi v}\left(\boxed{c_g} h - \frac{\boxed{c_{2g}}}{2v} hh\right) G^a_{\mu\nu} G^{a\mu\nu} + \left\{ i\frac{g_s}{v^2}\left(\bar{t}\sigma^{\mu\nu} T^a t_R\right) G^a_{\mu\nu} h + \text{h.c.}\right\} \boxed{c_{tg}} \\
+ \; & \left\{ i\frac{g_s}{v^3}\left(\bar{t}\sigma^{\mu\nu} T^a t_R\right) G^a_{\mu\nu} hh + \text{h.c.}\right\} \boxed{c_{tg2}}
\end{aligned}
$$

- In this parametrization $\delta\kappa = c = 0$ is the SM.

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$$+ \left\{i\frac{g_s}{v^3}(\bar{t}\sigma^{\mu\nu}T^a t_R)\,G^a_{\mu\nu}hh + \text{h.c.}\right\}\boxed{c_{tg2}}$$

- In this parametrization $\delta\kappa = c = 0$ is the SM.
- $\delta\kappa_\lambda$, $\delta\kappa_t$, c_2, c_g and c_{2g}, get limits from other channels (notably hh and $t\bar{t}h$). We disregard variations in c_g and $\delta\kappa_t$

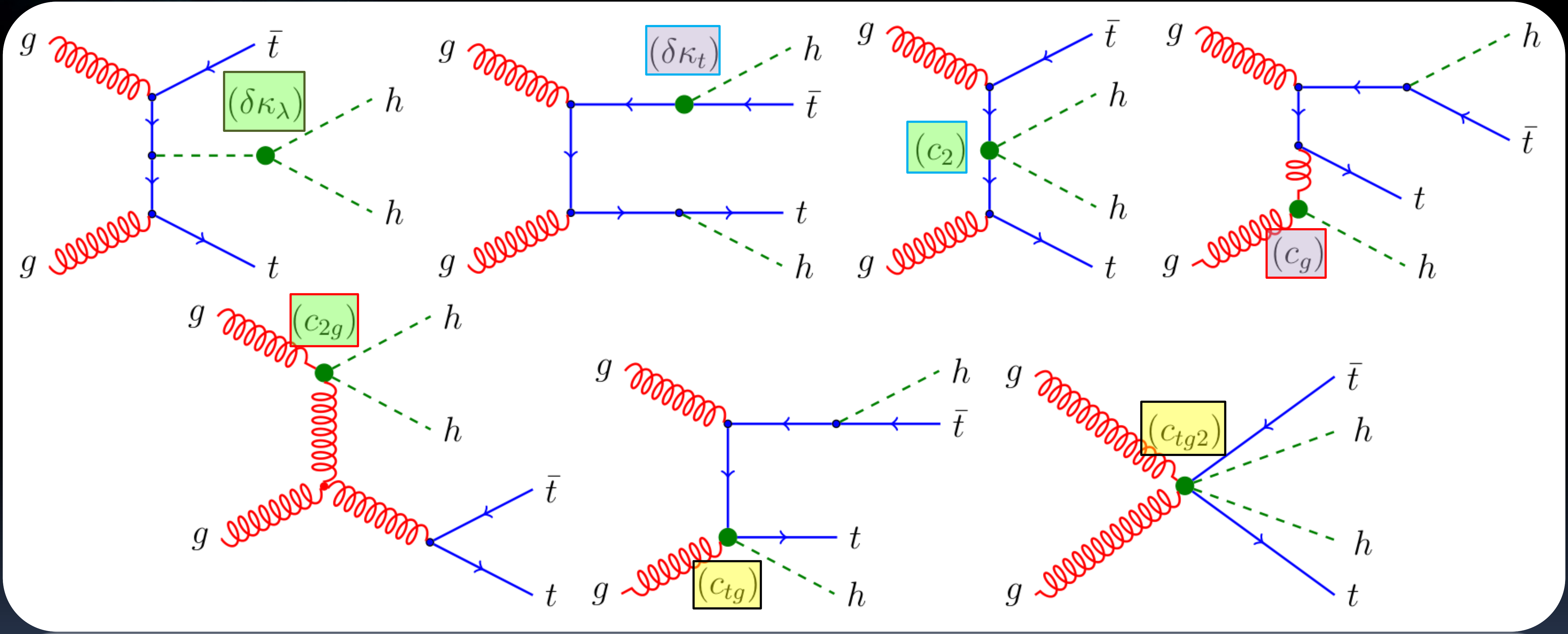
[8] $\delta\kappa_t \in [-0.23,\, 0.03]$

$c_g \in [-0.08,\, 0.15]$

- We explored $\delta\kappa_\lambda$, c_2, c_{2g}, c_{tg} and c_{tg2} in the $t\bar{t}hh$ and $t\bar{t}h$ channel.

[8] CMS collaboration, Combined effective field theory interpretation of Higgs boson, electroweak vector boson, top quark, and multijet measurements, Eur. Phys. J. C 86 (2026) 331

HEFT couplings in the $t\bar{t}hh$ channel



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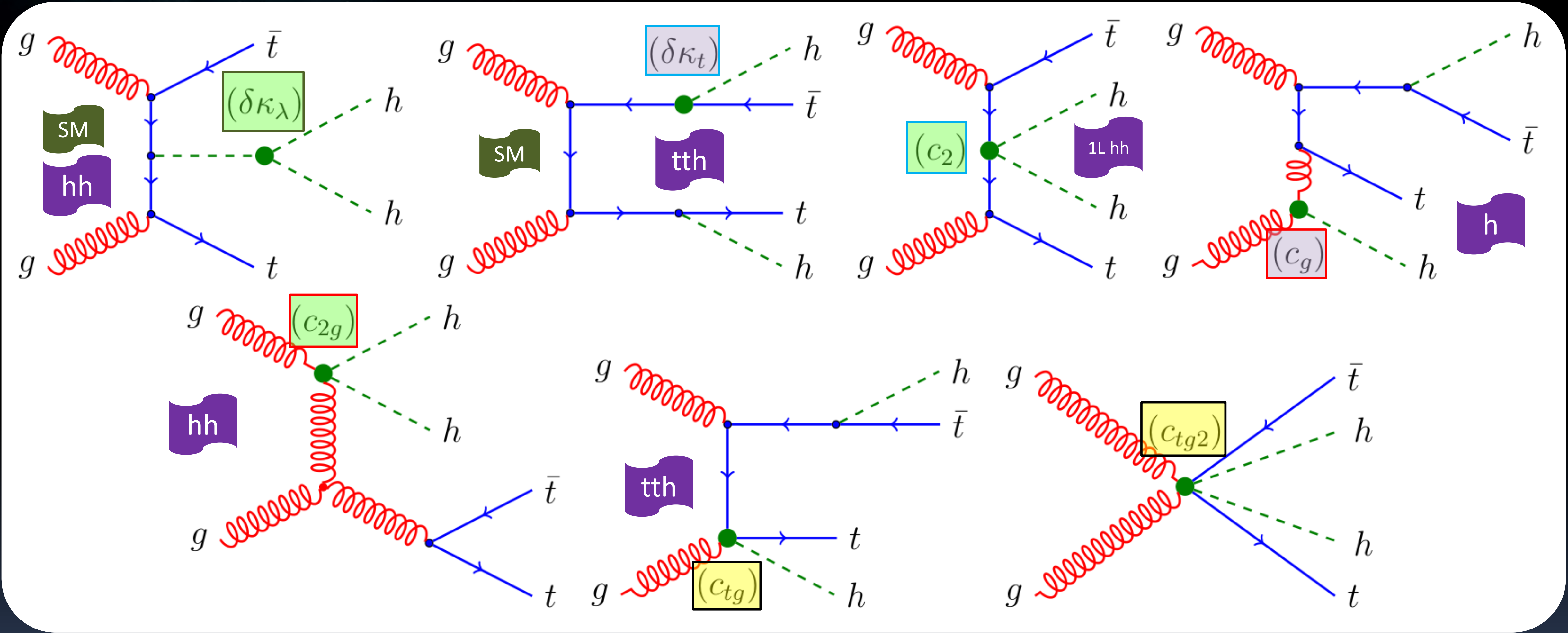
HEFT couplings in the $t\bar{t}hh$ channel



$t\bar{t}hh$ in the Standard Model

Including
Br[h → bb]
Br[Z → bb]

Process	σ [fb]	4J3B (basic-selection)		5J4B		6J5B	
		SL	DL	SL	DL	SL	DL
$t\bar{t}hh$ (S)	0.33	1.54×10^2	1.5×10^1	8.7×10^1	7	3.2×10^1	2
$t\bar{t}h$	287.9	7.33×10^4	5×10^3	1.99×10^4	9.34×10^2	2.63×10^3	8.1×10^1
$t\bar{t}hZ$	0.14	6.4×10^1	6	3.5×10^1	3	1.3×10^1	1
$t\bar{t}Z$	106.6	2.3×10^4	1.85×10^3	5.93×10^3	3.44×10^2	7.35×10^2	2.7×10^1
$t\bar{t}VV$	10.38	1.15×10^3	1.67×10^2	1.98×10^2	2×10^1	2.5×10^1	2
$t\bar{t}t\bar{t}$	11.83	5.7×10^3	1.08×10^3	2.32×10^3	3.89×10^2	5.86×10^2	7.9×10^1
$t\bar{t} + 4b$	373.3	6.83×10^4	5.44×10^3	2.1×10^4	1.45×10^3	4.51×10^3	2.58×10^2
$t\bar{t} + 2b2c$	105.5	1.9×10^4	1.66×10^3	5.49×10^3	4.09×10^2	1.07×10^3	6.6×10^1
$t\bar{t}V + 2b$	8.22	1.94×10^3	1.86×10^2	6.76×10^2	5.3×10^1	1.64×10^2	1.1×10^1
$t\bar{t}h + 2b$	9.38	3.35×10^3	3.1×10^2	1.48×10^3	1.14×10^2	4.35×10^2	2.7×10^1
$t\bar{t} + 4c$	7.81	1.07×10^3	9.3×10^1	2.54×10^2	1.9×10^1	4×10^1	2
$t\bar{t} + 2b$	1.67×10^4	1.68×10^6	1.18×10^5	3.22×10^5	1.77×10^4	3.93×10^4	1.8×10^3
$t\bar{t} +$ jets	6.11×10^5	1.2×10^7	4.66×10^5	8.68×10^5	2.87×10^4	6.02×10^4	1.7×10^3
Tot. BKG (B)	6.29×10^5	1.4×10^7	5.99×10^5	1.25×10^6	5.01×10^4	1.1×10^5	4.06×10^3

MG/ME > Pythia
> Delphes

@14 TeV
@3000 fb^{-1}

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$t\bar{t}hh$ in the Standard Model

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$t\bar{t}h+2b$	9.38	3.35×10^{3}	3.1×10^{2}	1.48×10^{3}	1.14×10^{2}	4.35×10^{2}	2.7×10^{1}
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$t\bar{t}+$jets	6.11×10^{5}	1.2×10^{7}	4.66×10^{5}	8.68×10^{5}	2.87×10^{4}	6.02×10^{4}	1.7×10^{3}
Tot. BKG (B)	6.29×10^{5}	1.4×10^{7}	5.99×10^{5}	1.25×10^{6}	5.01×10^{4}	1.1×10^{5}	4.06×10^{3}

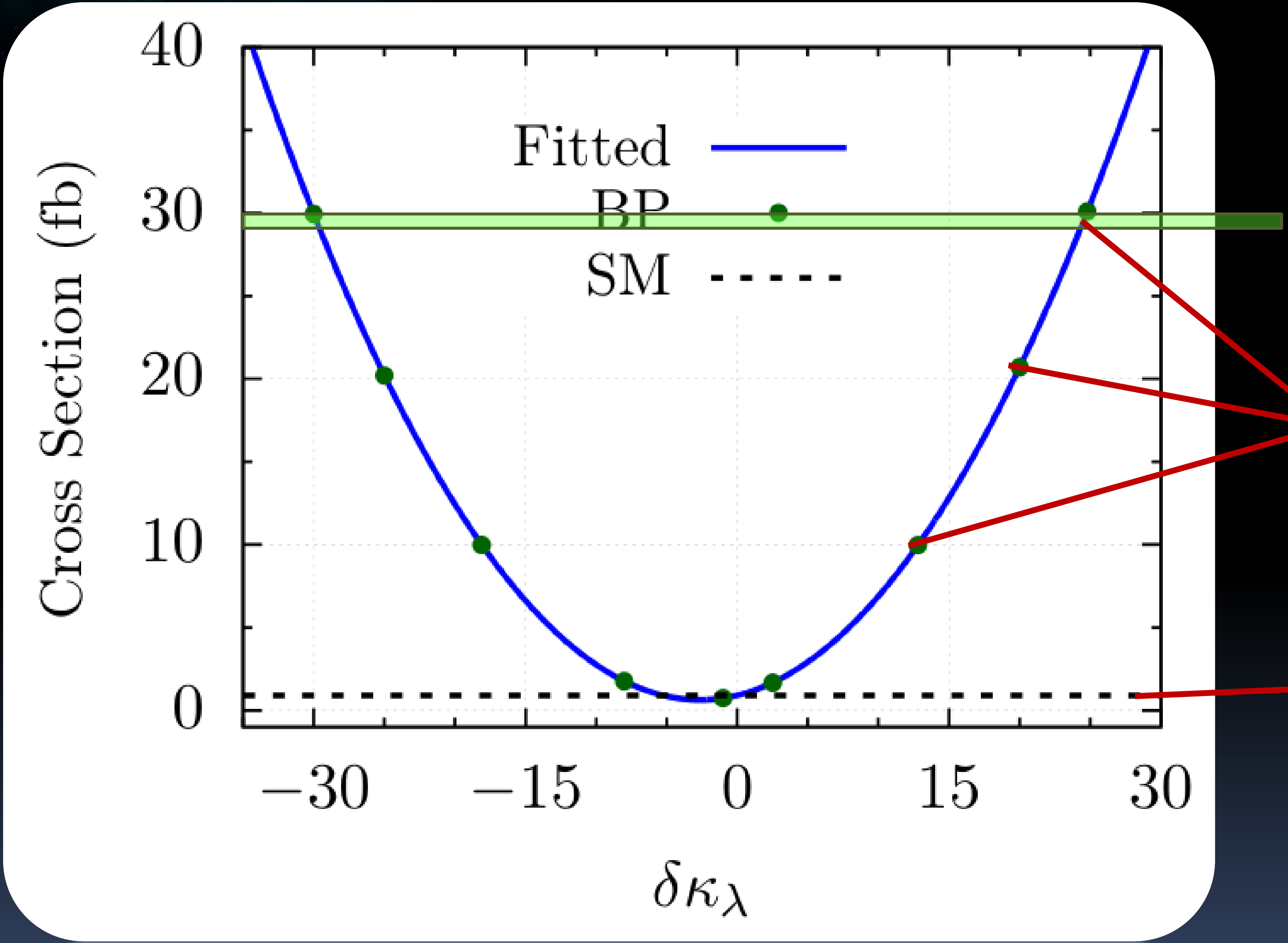
MG/ME > Pythia > Delphes

@14 TeV
@3000 fb^{-1}

$$S/\sqrt{B} \simeq 0.01\sigma \sim 0.1\sigma$$

Resistant even to many b requirement

$t\bar{t}hh$ signal boosted by HEFT

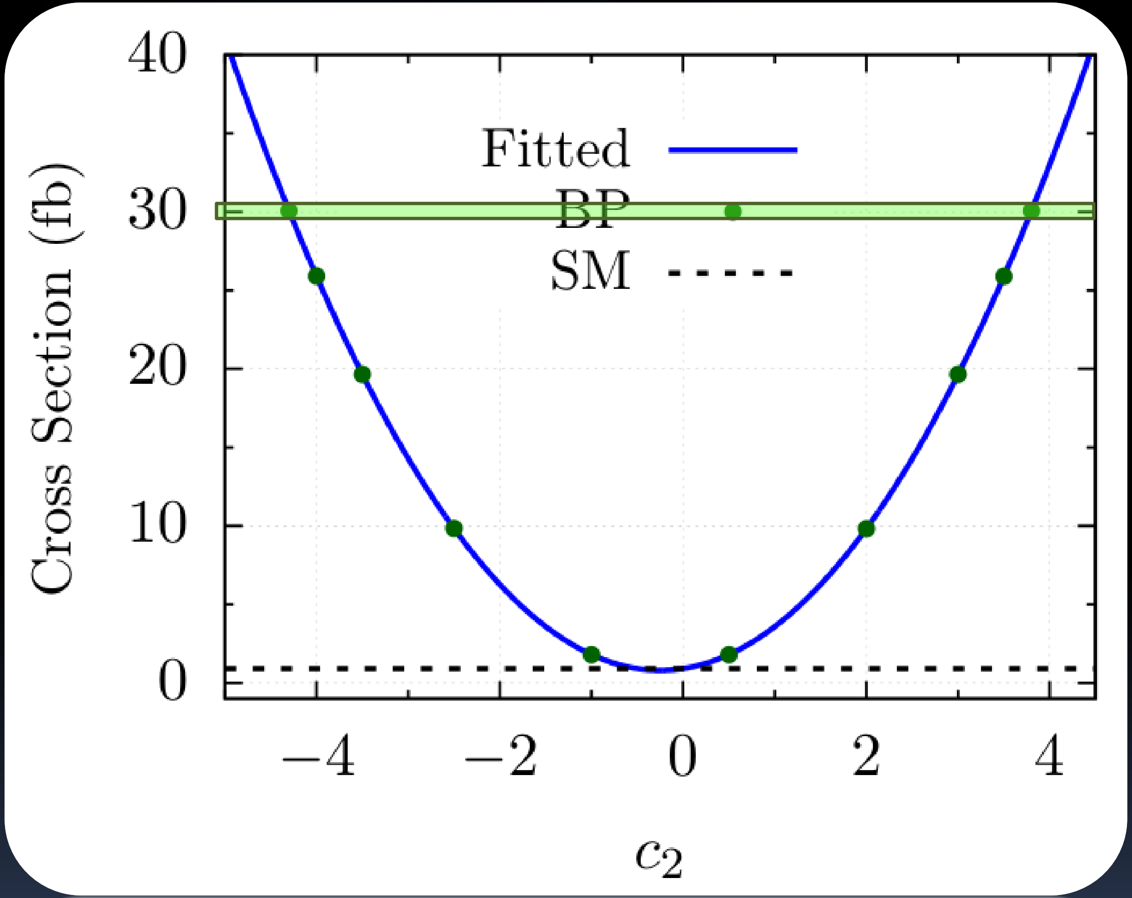


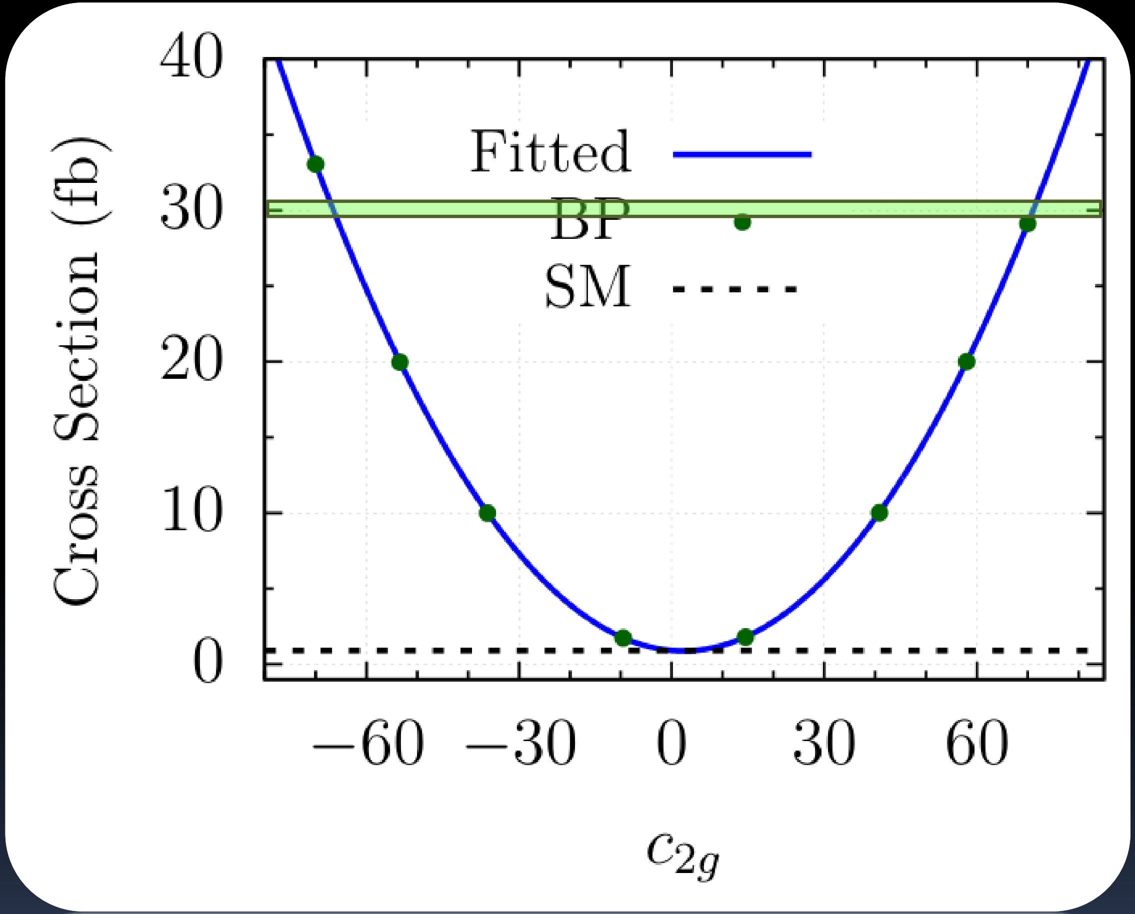
~ 3σ @HL-LHC

Benchmark Points

SM

$t\bar{t}hh$ signal boosted by HEFT





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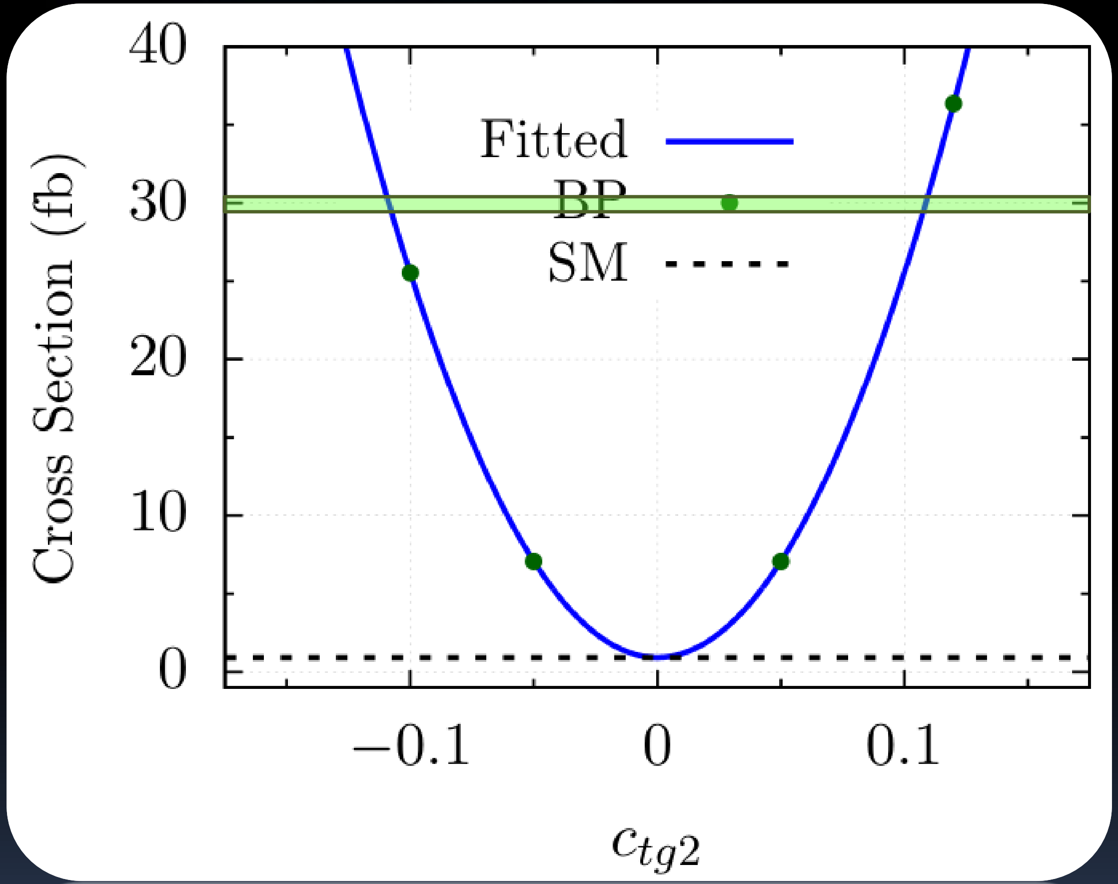
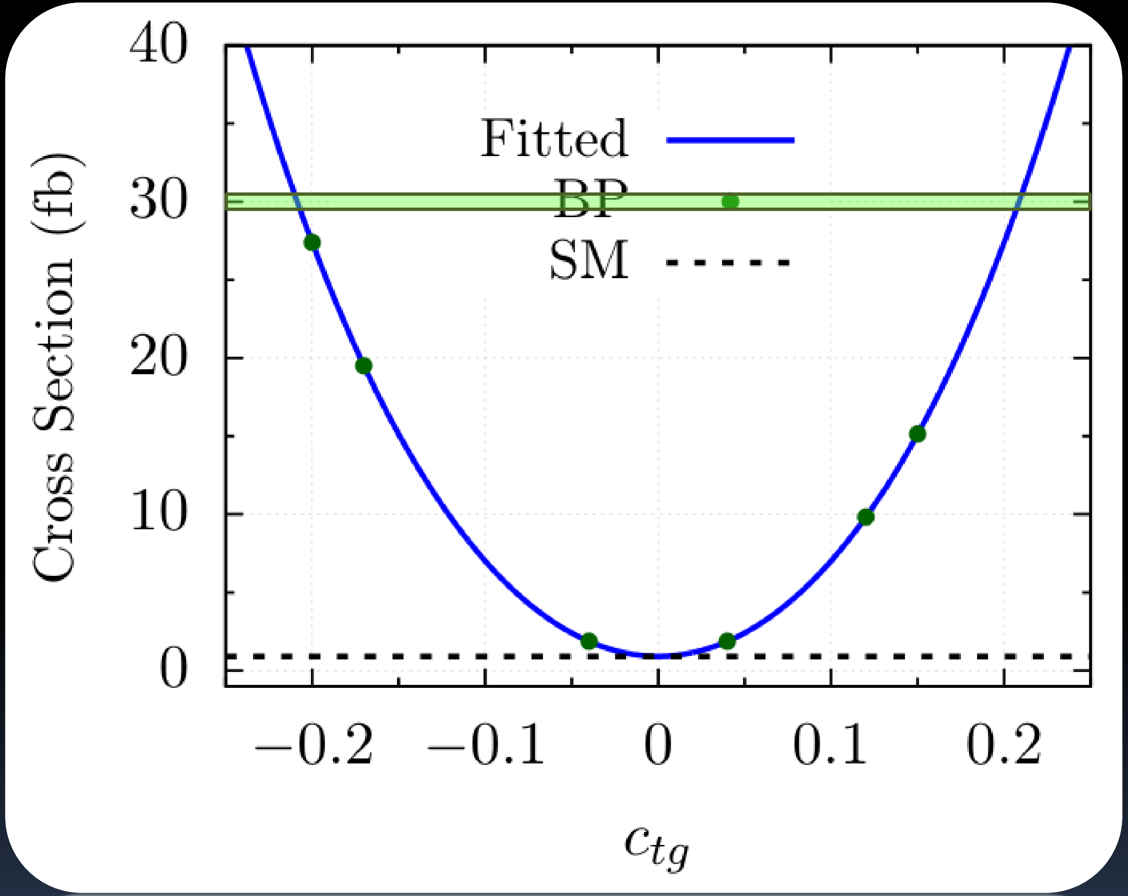
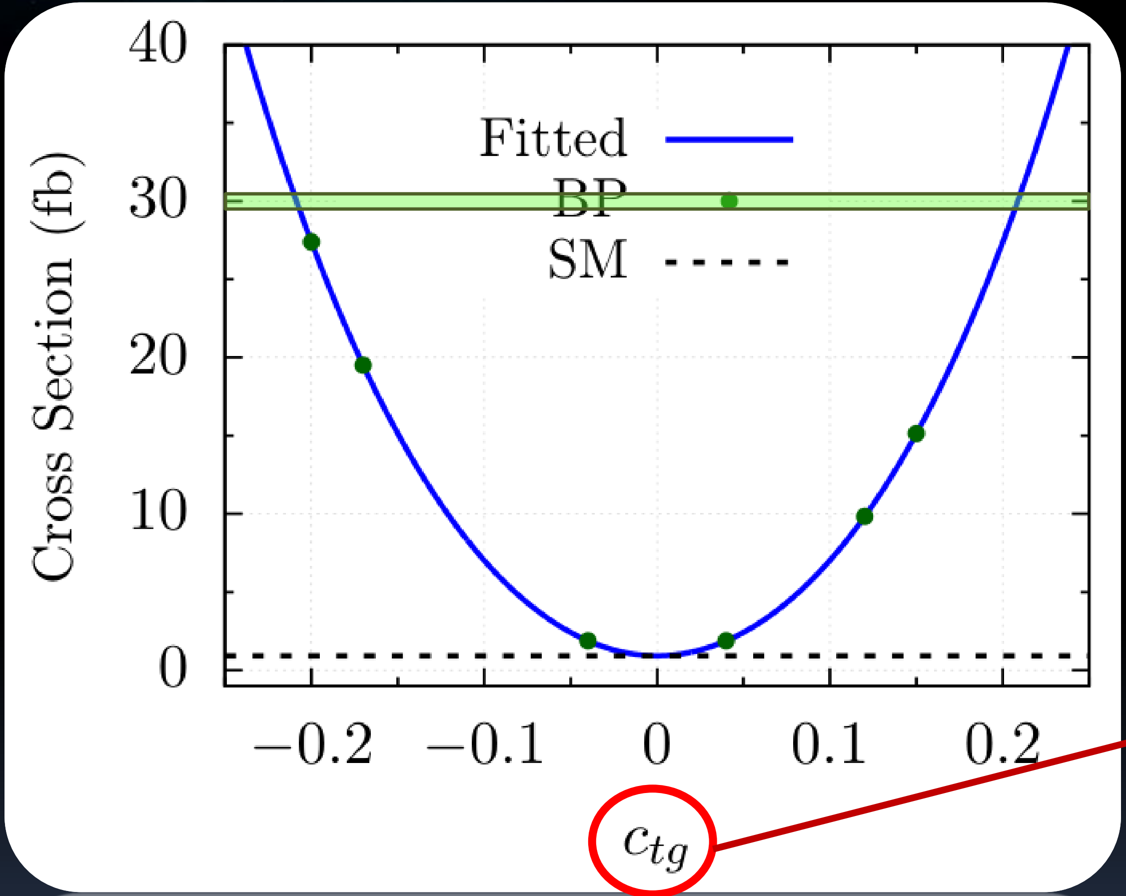




$t\bar{t}hh$ signal boosted by HEFT



$$\sigma_{t\bar{t}h}(c_{tg}) = \underbrace{480}_{\text{SM}} - 0.962 \times c_{tg} + 3.96 \times 10^4 \times c_{tg}^2 \quad \text{fb}$$

Will also contribute to the same search through increased $t\bar{t}h$

INCLUDED in the limits I'll show

Cut-based analysis

Common Criteria	
Number of jets	≥ 4
Number of b-jets	≥ 3
p_T of all jets	≥ 30 GeV
$\lvert\eta\rvert$ of all jets	≤ 3.0
$\lvert\eta\rvert$ of leptons	≤ 3.0

SL	
Number of leptons (N_ℓ)	1
Lepton p_T	≥ 25 GeV
Second lepton p_T	< 15 GeV
MET	≥ 20 GeV

DL	
Number of leptons (N_ℓ)	2 ($\ell^+\ell^-$)
Leading lepton p_T	≥ 25 GeV
Second lepton p_T	≥ 15 GeV
MET	≥ 40 GeV
$\Delta R(\ell^+, \ell^-)$	≥ 0.2

Cut-based analysis

$N_j \geq 6$ $N_b \geq 5$ SL

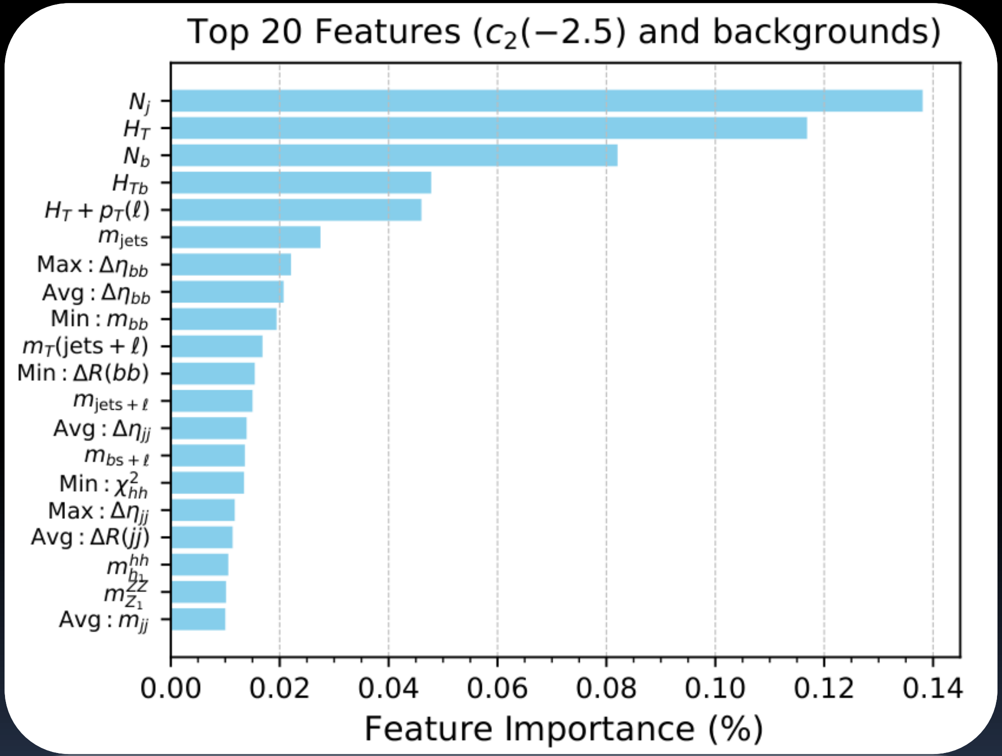
Variable	Cuts
Leading jet p_T	$p_T(j_1) \geq 100\,\text{GeV}$
Second leading jet p_T	$p_T(j_2) \geq 50\,\text{GeV}$
Scalar p_T sum of jets	$H_T \geq 400\,\text{GeV}$
Scalar p_T sum of b-tagged jets	$H_{Tb} \geq 300\,\text{GeV}$
Invariant mass of jets	$m_{\text{jets}} \geq 400\,\text{GeV}$
Minimized-χ^2 for $t\bar{t}hh$ topology	$\text{Min} : \chi^2_{hh} < 2$
p_T of leading reconstructed Higgs for $t\bar{t}hh$ topology	$p_T(h_1)^{hh} > 250\,\text{GeV}$
Sphericity, Aplanarity, C, D	≥ 0.1, ≥ 0.02, ≥ 0.5, ≥ 0.1
H_T-bin edges	400 - 600 - 800 - 900 - 1000 - 1200 - 1600 - 2000 - ∞

χ^2

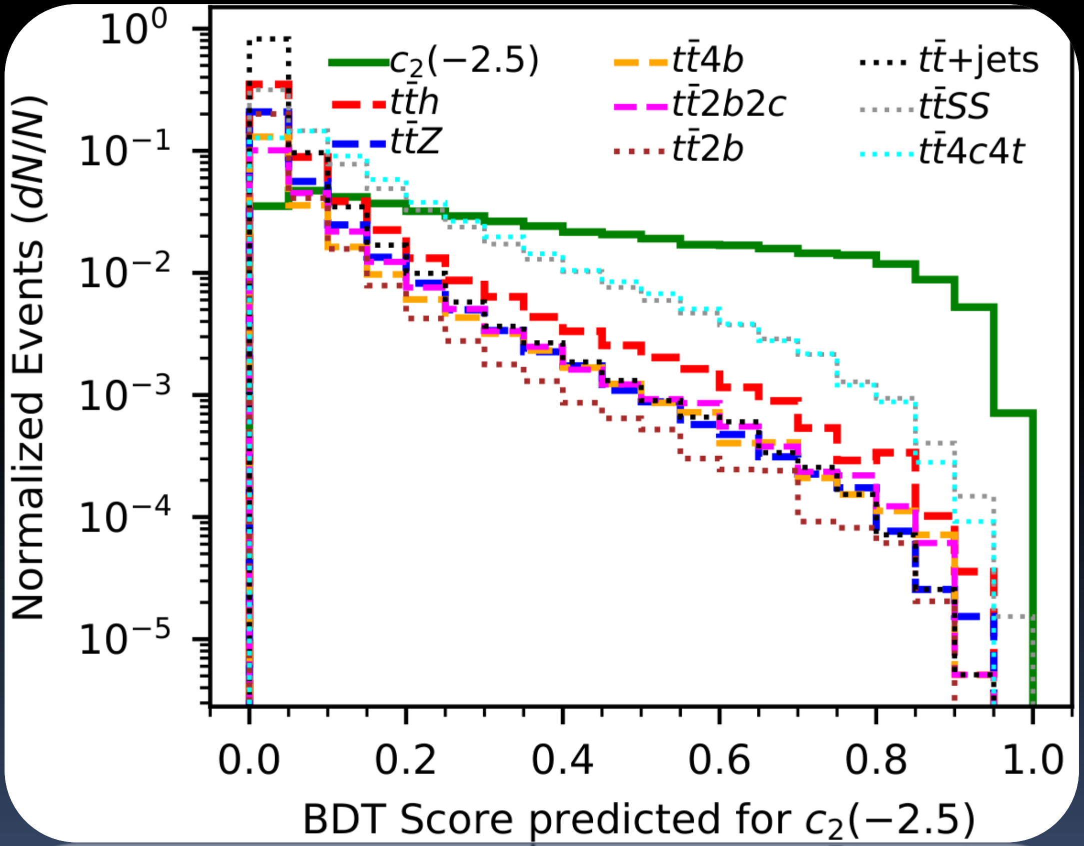
Parametric BDT

Boosted Decision Tree (XGBoost) with the HEFT couplings $\delta\kappa_\lambda$, c_2, c_{2g}, c_{tg} and c_{tg2} as input nodes, even for backgrounds (values taken from the BP)

e.g.:



BDT score used for hypothesis test (χ^2)



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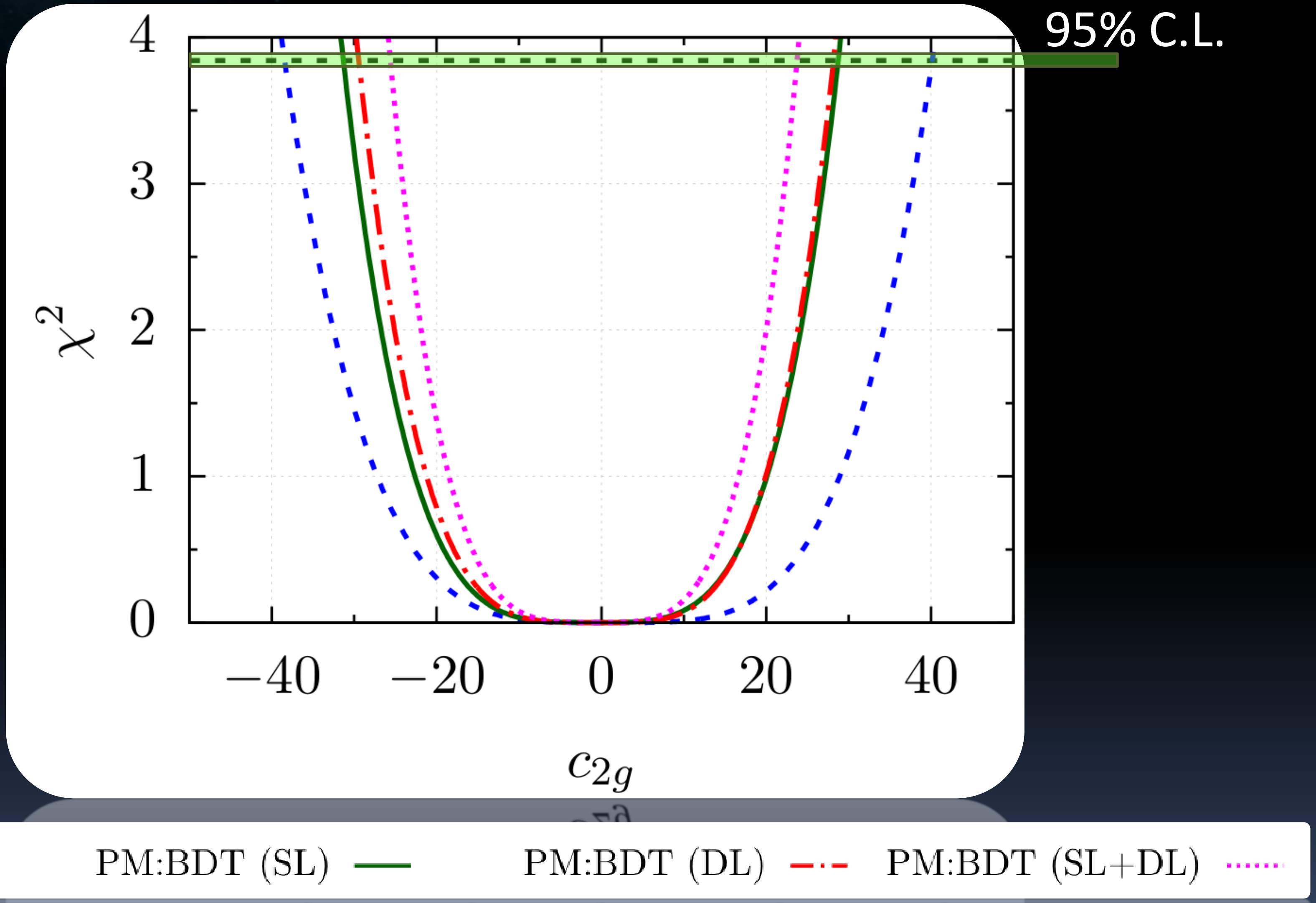
Results



95% C.L.
χ^2
4
3
2
1
0
−40
−20
0
20
40
c_{2g}
Cut:H_T-bin (SL)
PM:BDT (SL)
PM:BDT (DL)
PM:BDT (SL+DL)

Results

Couplings	Cut:H_T-bin (SL)	PM:BDT (SL)	PM:BDT (DL)	PM:BDT (SL+DL)
$\delta\kappa_\lambda$	[-32.4, + 26.8]	[-19.6, + 14.4]	[-19.0, + 17.4]	[-16.5, + 12.9]
c_2	[-2.95, + 2.65]	[-1.68, + 1.95]	[-1.9, + 2.02]	[-1.47, + 1.68]
c_{2g}	[-38.4, + 40.1]	[-31.3, + 28.7]	[-29.4, + 28.2]	[-25.6, + 23.7]
c_{tg}	[-0.042, + 0.039]	[-0.02, + 0.019]	[-0.035, + 0.028]	[-0.019, + 0.018]
c_{tg2}	[-0.053, + 0.053]	[-0.041, + 0.042]	[-0.078, + 0.072]	[-0.040, + 0.041]

Results

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c_{tg2}	[-0.053, + 0.053]	[-0.041, + 0.042]	[-0.078, + 0.072]	[-0.040, + 0.041]

NEW!

To be compared with (caveat: multi channel analyses!):

hh

[9] $\delta\kappa_\lambda \in [-2.6,\ 5.6]$

[10] $c_2 \in [-0.19,\ 0.7]$

[11] $c_2 \in [-0.28,\ 0.59]$

[10] $c_{2g} \in [-1.47,\ 1.14]$

$t\bar{t}hh$

[12] $c_2 \in [-3.9,\ 3.3]$

[13] $c_2 \in [-6.6,\ 6.4]$

[9] ATLAS collaboration, Study of Higgs boson pair production in the HH → bbγγ final state with 308 fb⁻¹ of data collected at √s = 13 TeV and 13.6 TeV by the ATLAS experiment, Phys. Lett. B 876 (2026) 140280

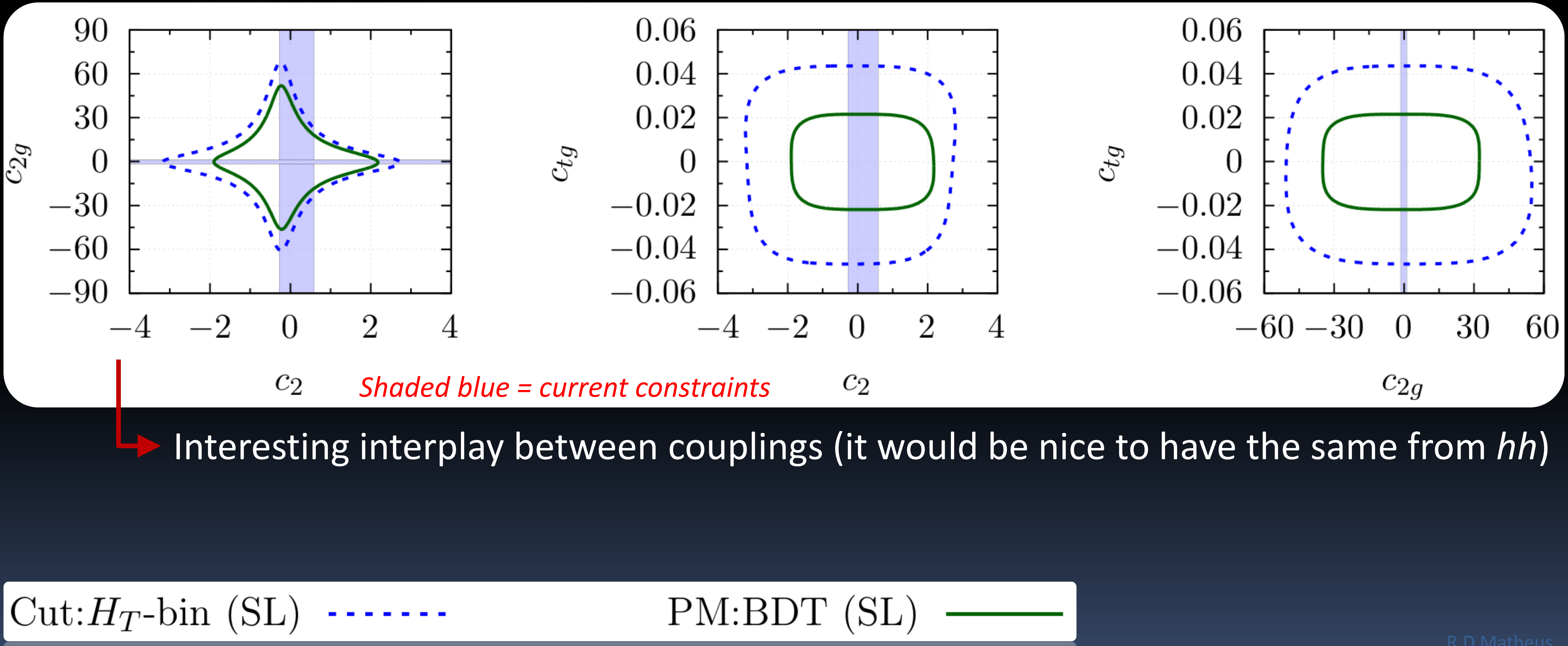
[10] ATLAS collaboration, Combination of Searches for Higgs Boson Pair Production in pp Collisions at s=13 TeV with the ATLAS Detector, Phys. Rev. Lett. 133 (2024) 101801

[11] CMS collaboration, Combination of searches for nonresonant Higgs boson pair production in proton-proton collisions at √s = 13 TeV, arXiv:2510.07527

[12] ATLAS collab., Search for Higgs boson pair production in association with top-quark pairs using 196 fb−1 of proton-proton collision data at √s = 13 and 13.6 TeV with the ATLAS detector, arXiv:2603.13113

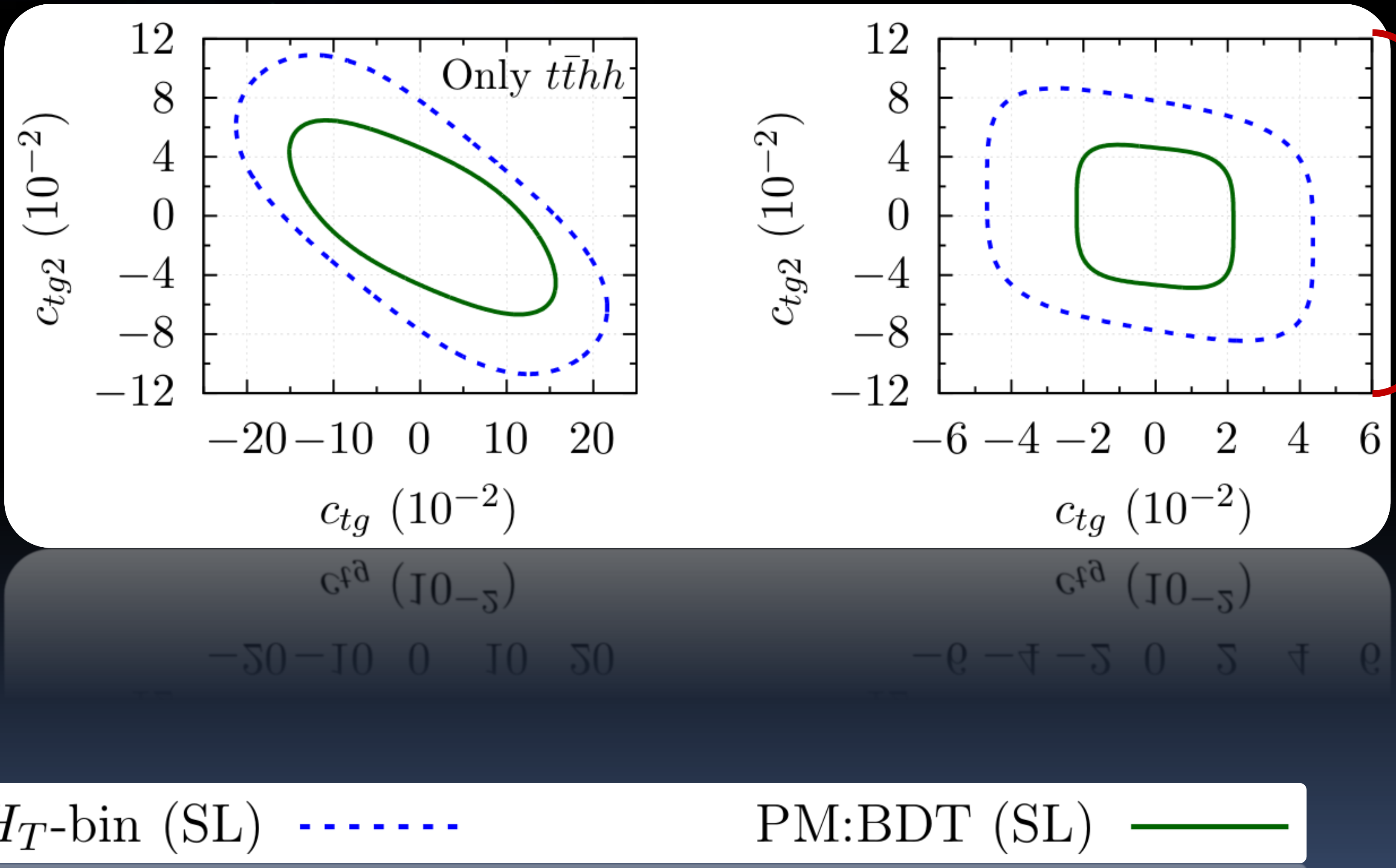
[13] Filip Bilandzija talk yesterday, Di-Higgs searches at CMS, https://indico.cern.ch/event/1522800/contributions/6987287/,

Results



Interesting interplay between couplings (it would be nice to have the same from *hh*)

Results



Correlation between couplings weakened by $t\bar{t}h$ contribution

R.D.Matheus

Take-home messages

- Rare channels can provide cross-check and complementary information, breaking blind directions and allowing to differentiate UV completions.

- $t\bar{t}hh_{\mathrm{BSM}}$ is within reach and this channel can provide constraints, but hard work is still needed

- Chromo-magnetic-like operators still largely unexplored:
  - c_{tg} can be constrained by $t\bar{t}h$
  - c_{tg2} only accessible through $t\bar{t}hh$

Thank you for the attention!

R.D.Matheus

Extras

HEFT Cross Section

Each coupling is expanded up to the power that it appears at tree level in the cross section of the $t\bar{t}hh$ channel, couplings fitted **one** at a time.

$$\begin{aligned}\sigma_{t\bar{t}hh}(c_{\text{HEFT}}) = \underbrace{0.914}_{\text{SM}} &- 0.207 \times \delta\kappa_\lambda + 0.0391 \times \delta\kappa_\lambda^2 \\ &- 0.891 \times c_2 + 1.79 \times c_2^2 \\ &+ 0.0281 \times c_{2g} + 0.0062 \times c_{2g}^2 \\ &- 0.0052 \times c_{tg} + 590 \times c_{tg}^2 + 0.0833 \times c_{tg}^3 + 1781 \times c_{tg}^4 \\ &+ 0.0212 \times c_{tg2} + 2462 \times c_{tg2}^2 \quad \text{fb},\end{aligned}$$

HEFT Cross Section

Each coupling is expanded up to the power that it appears at tree level in the cross section of the $t\bar{t}hh$ channel, couplings fitted **two** at a time.

$$
\begin{aligned}
\sigma_{t\bar{t}hh}(c_i,c_j) = {} & 0.384\times\delta\kappa_\lambda\times c_2 \\
& +0.0321\times\delta\kappa_\lambda\times c_{2g} - 3.19\times10^{-3}\times\delta\kappa_\lambda\times c_{2g}^2 + 4.93\times10^{-4}\times\delta\kappa_\lambda^2\times c_{2g}^2 \\
& +8.16\times10^{-3}\times\delta\kappa_\lambda\times c_{tg} - 6.49\times10^{-4}\times\delta\kappa_\lambda^2\times c_{tg} + 1.83\times10^{2}\times\delta\kappa_\lambda\times c_{tg}^2 + 25.6\times\delta\kappa_\lambda^2\times c_{tg}^2 \\
& +0.0396\times c_2\times c_{2g} + 0.0135\times c_2^2\times c_{2g} + 9.97\times10^{-3}\times c_2\times c_{2g}^2 + 0.0163\times c_2^2\times c_{2g}^2 \\
& -6.57\times10^{-3}\times c_2\times c_{tg} + 11.9\times c_2\times c_{tg}^2 \\
& +1.83\times10^{-3}\times c_{2g}\times c_{tg} - 0.0249\times c_{2g}\times c_{tg}^2 \\
& +1848\times c_{tg}\times c_{tg2} - 0.973\times c_{tg}^2\times c_{tg2}\,. \qquad \text{(A.1)}
\end{aligned}
$$

BDT Details

Classes:

- HEFT – tthh,
- tth,
- ttZ,
- tt + 4b,
- tt + 2b2c,
- tt + 2b,
- tt + jets,
- ttSS,
- tt4c4t

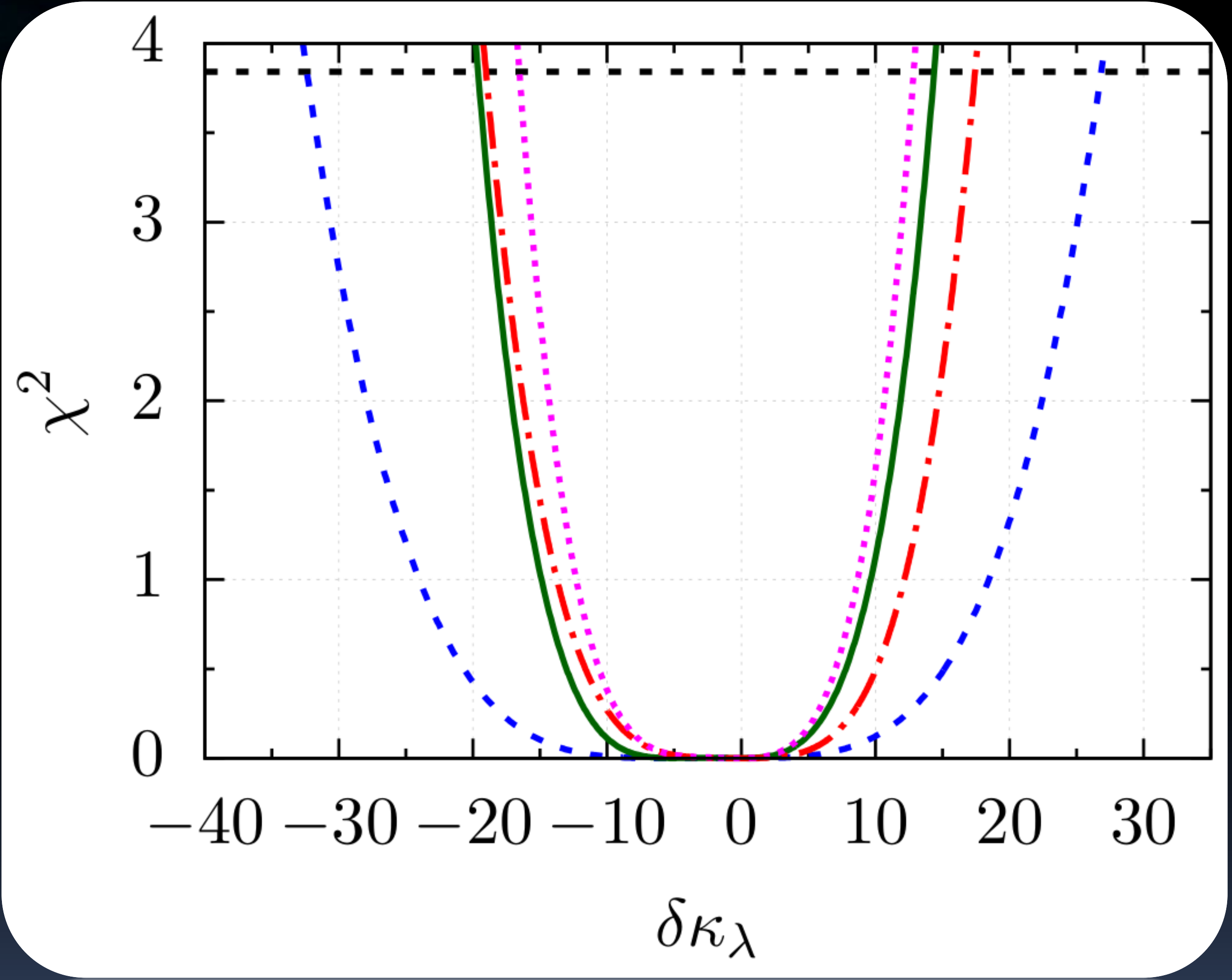
ttSS: {ttZh, ttVV, ttV + 2b, tth + 2b}

tt4c4t: {tttt, tt + 4c}

BDT Details

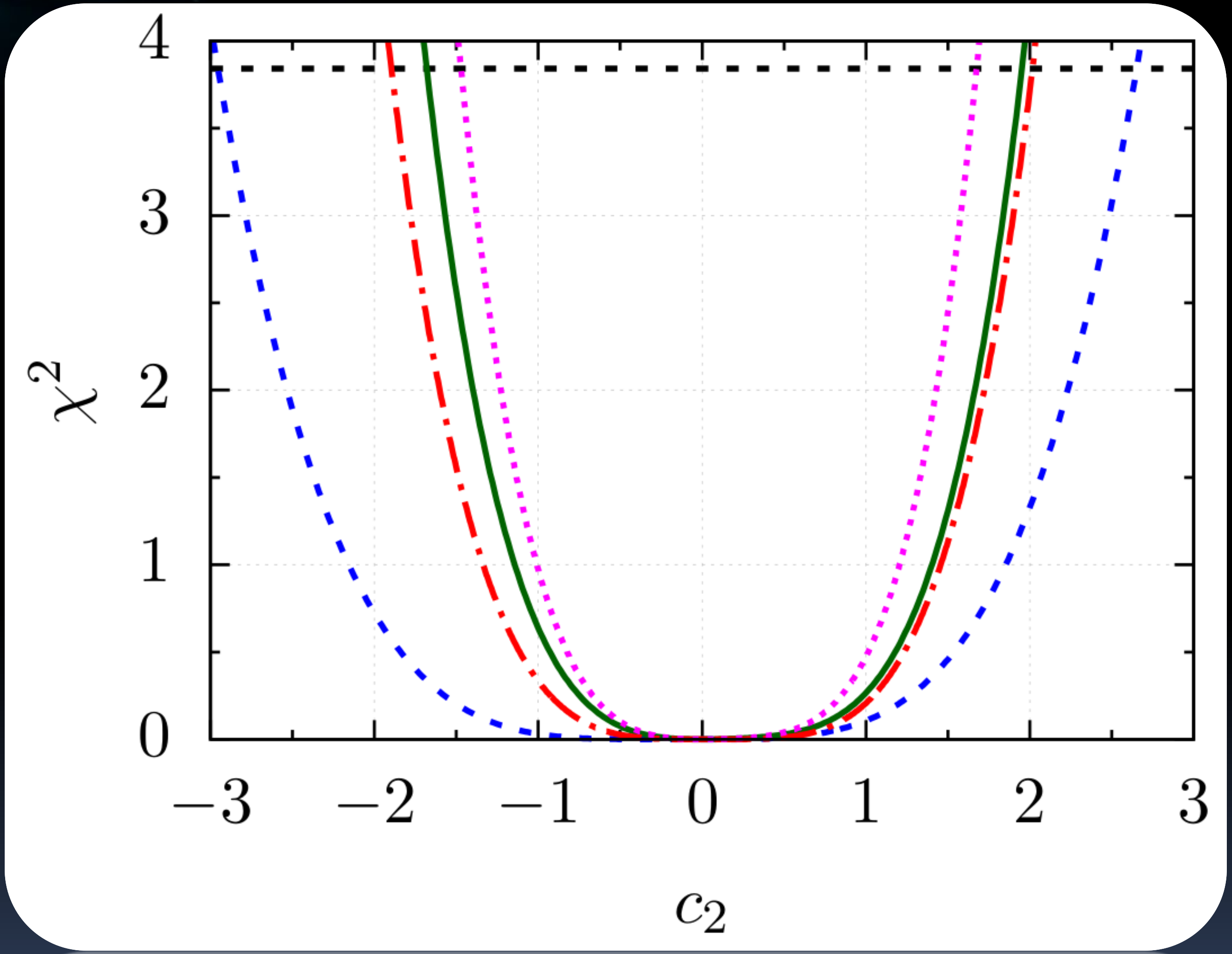
Group	Variables
Object multiplicity	N_j, N_b,
Transverse momenta	$p_T(\ell)$, $p_T(j_1)$, $p_T(j_2)$, $p_T(j_3)$, $p_T(j_4)$,
Pseudo-rapidity	$\eta(\ell)$, $\eta(j_1)$, $\eta(j_2)$, $\eta(j_3)$, $\eta(j_4)$,
Missing energy and Hadronic p_T,	MET, H_T, H_{Tb}, $H_T + p_T(\ell)$,
Invariant masses	m_{jets}, $m_{\text{jets}+\ell}$, $m_T(\text{jets} + \ell)$, $m_T(MET + \text{jets} + \ell)$, m_{bs}, $m_{bs+\ell}$,
Conic separation	$\Delta R(\ell, j_1)$, $\Delta R(\ell, j_2)$, $\Delta R(\ell, j_3)$, $\Delta R(\ell, j_4)$,
Azimuthal separation	$\Delta\phi(\ell, j_1)$, $\Delta\phi(\ell, j_2)$, $\Delta\phi(\ell, j_3)$, $\Delta\phi(\ell, j_4)$, $\Delta\phi(\ell^+, \ell^-)$ - DL, $\Delta\phi(MET, \ell)$, $\Delta\phi(MET, j_1)$, $\Delta\phi(MET, j_2)$, $\Delta\phi(MET, j_3)$, $\Delta\phi(MET, j_4)$,
Min, Max, average mass	Min : m_{bb}, Max : m_{bb}, Avg : m_{bb}, Min : m_{jj}, Max : m_{jj}, Avg : m_{jj},
Min, Max, average rapidity gap	Min : $\Delta\eta_{bb}$, Max : $\Delta\eta_{bb}$, Avg : $\Delta\eta_{bb}$, Min : $\Delta\eta_{jj}$, Max : $\Delta\eta_{jj}$, Avg : $\Delta\eta_{jj}$,
Min, Max, average conic separation	Min : $\Delta R(bb)$, Max : $\Delta R(bb)$, Avg : $\Delta R(bb)$, Min : $\Delta R(jj)$, Max : $\Delta R(jj)$, Avg : $\Delta R(jj)$,
Minimized χ^2 for hh, hZ, ZZ topology	Min : χ^2_{hh}, Min : χ^2_{hZ}, Min : χ^2_{ZZ},
Reconstructed variables	$m_{h_1}^{hh}$, $p_T(h_1)^{hh}$, $m_{h_2}^{hh}$, $p_T(h_2)^{hh}$, m_h^{hZ}, $p_T(h)^{hZ}$, m_Z^{hZ}, $p_T(Z)^{hZ}$, $m_{Z_1}^{ZZ}$, $p_T(Z_1)^{ZZ}$, $m_{Z_2}^{ZZ}$, $p_T(Z_2)^{ZZ}$, $\Delta\phi(\ell, h_1)$, $\Delta\phi(\ell, h_2)$, $\Delta\phi(h_1, h_2)$,
Event shape variables	Sphericity, Aplanarity, C, D.

Single Parameter χ^2



Cut:H_T-bin (SL) PM:BDT (SL) PM:BDT (DL) PM:BDT (SL+DL)

Single Parameter χ^2



Cut:H_T-bin (SL) PM:BDT (SL) PM:BDT (DL) PM:BDT (SL+DL)

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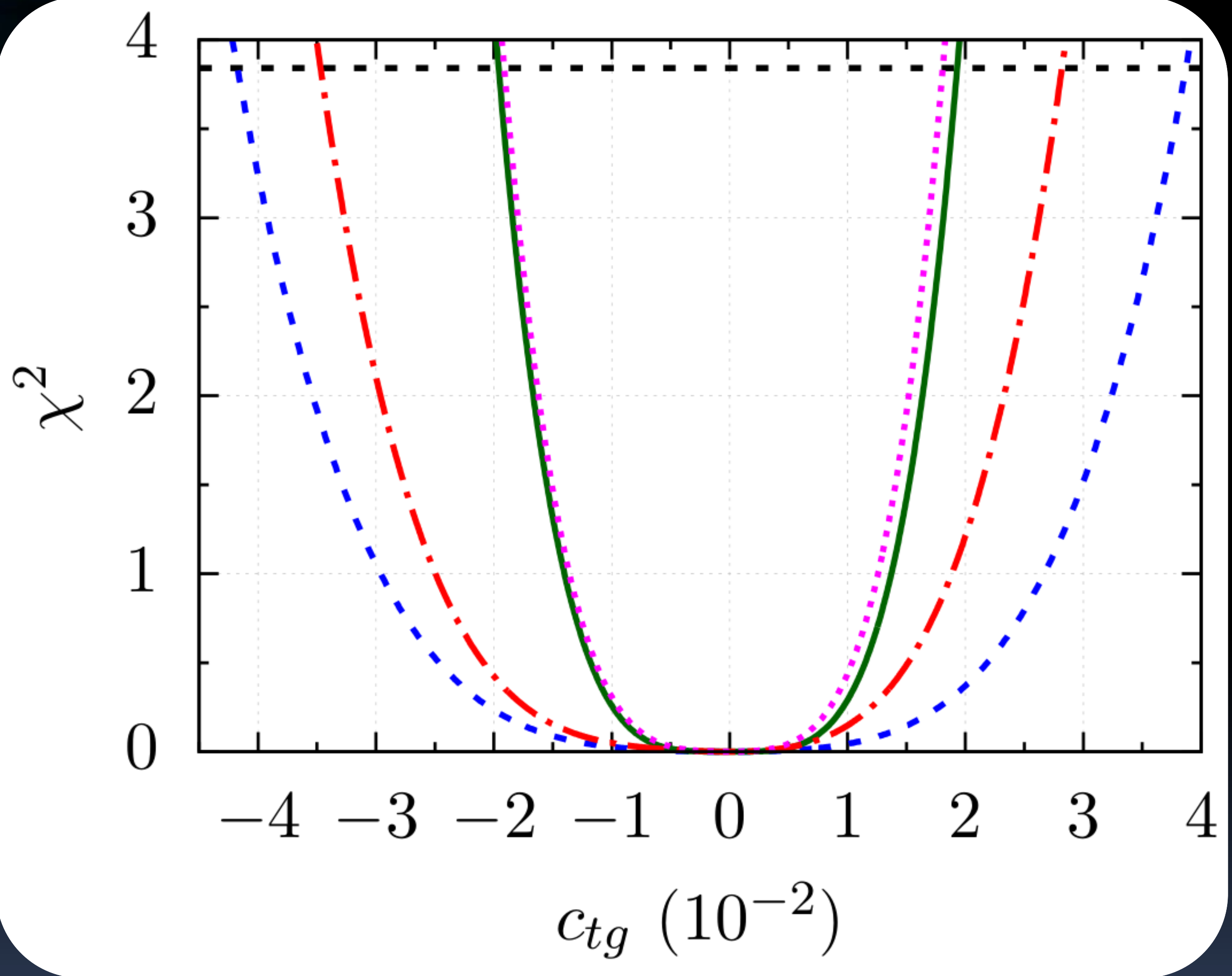
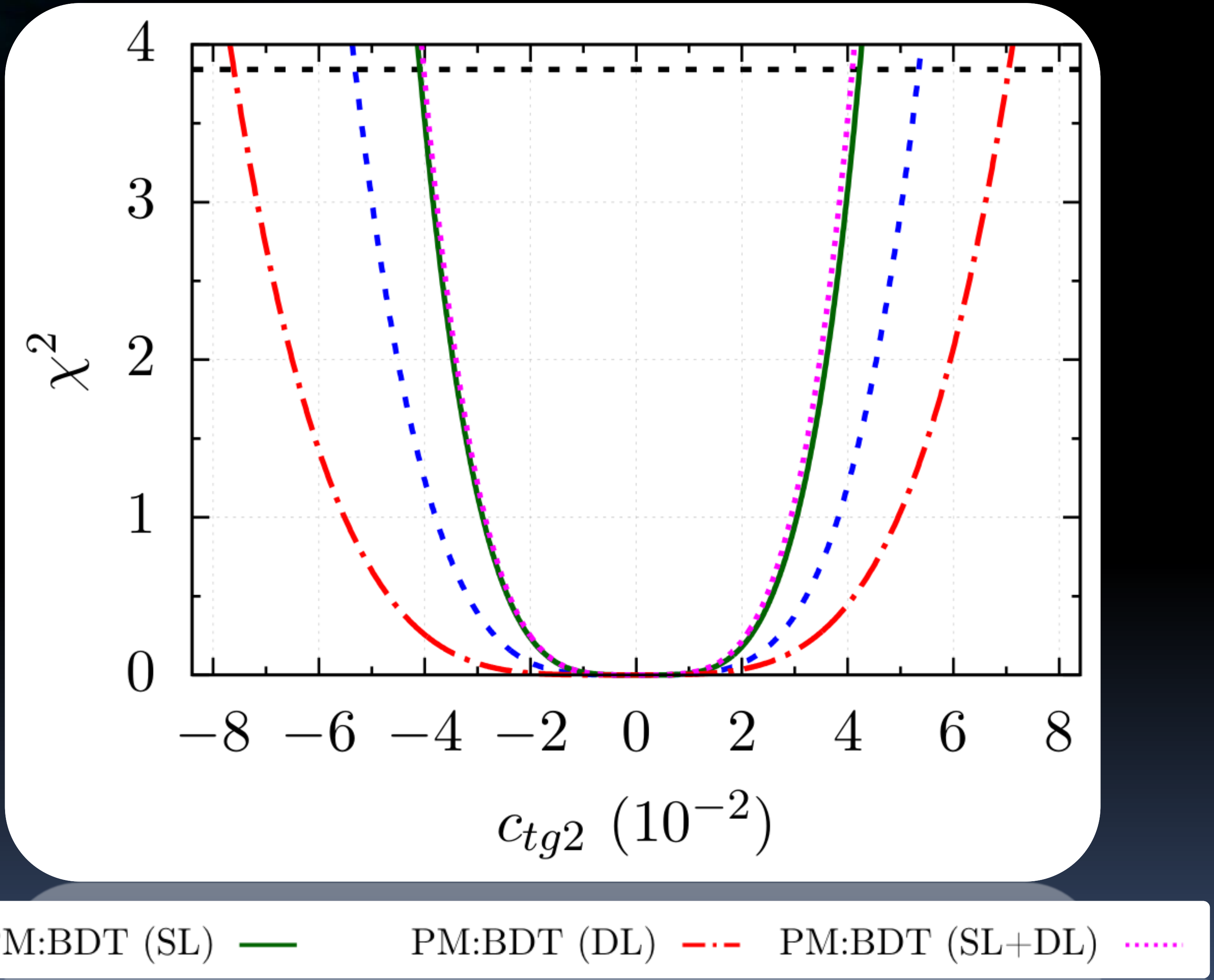
Single Parameter χ^2

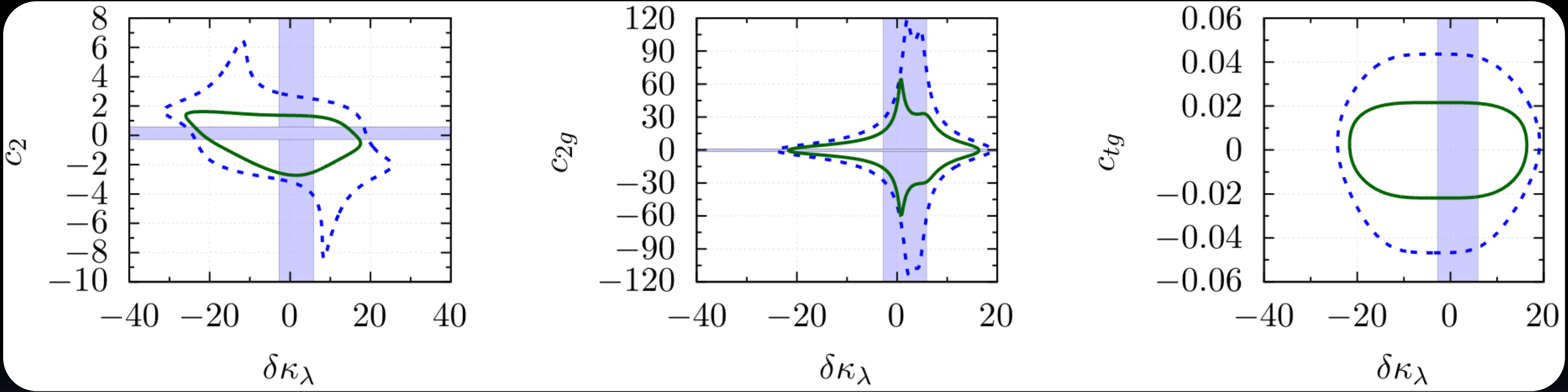


Cut:H_T-bin (SL) PM:BDT (SL) PM:BDT (DL) PM:BDT (SL+DL)

Single Parameter χ^2



Two Parameter χ^2 contours



Cut:H_T-bin (SL) PM:BDT (SL)

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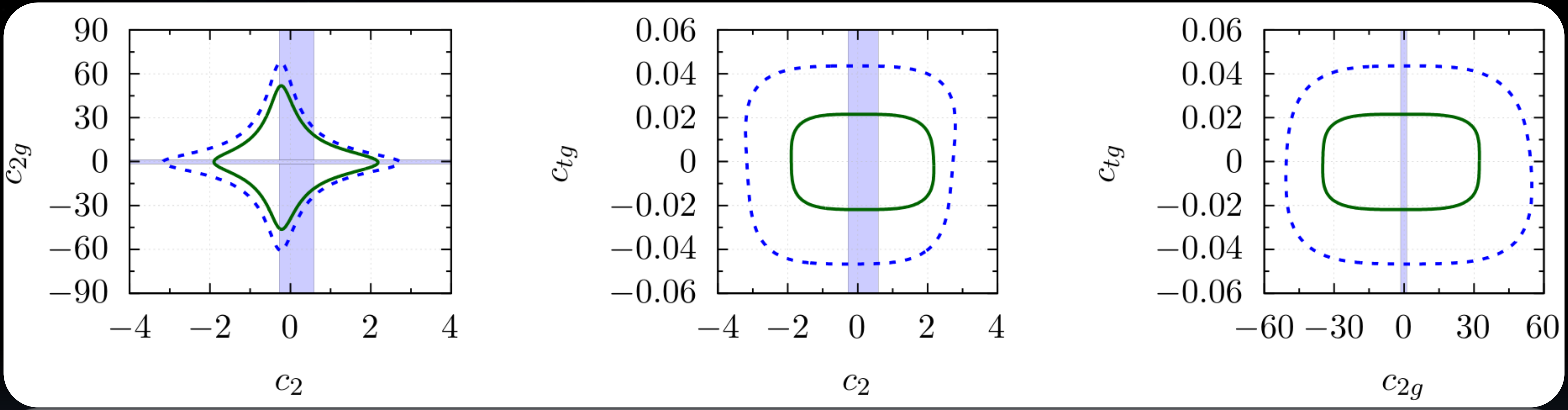
Two Parameter χ^2 contours



Cut:H_T-bin (SL) PM:BDT (SL)

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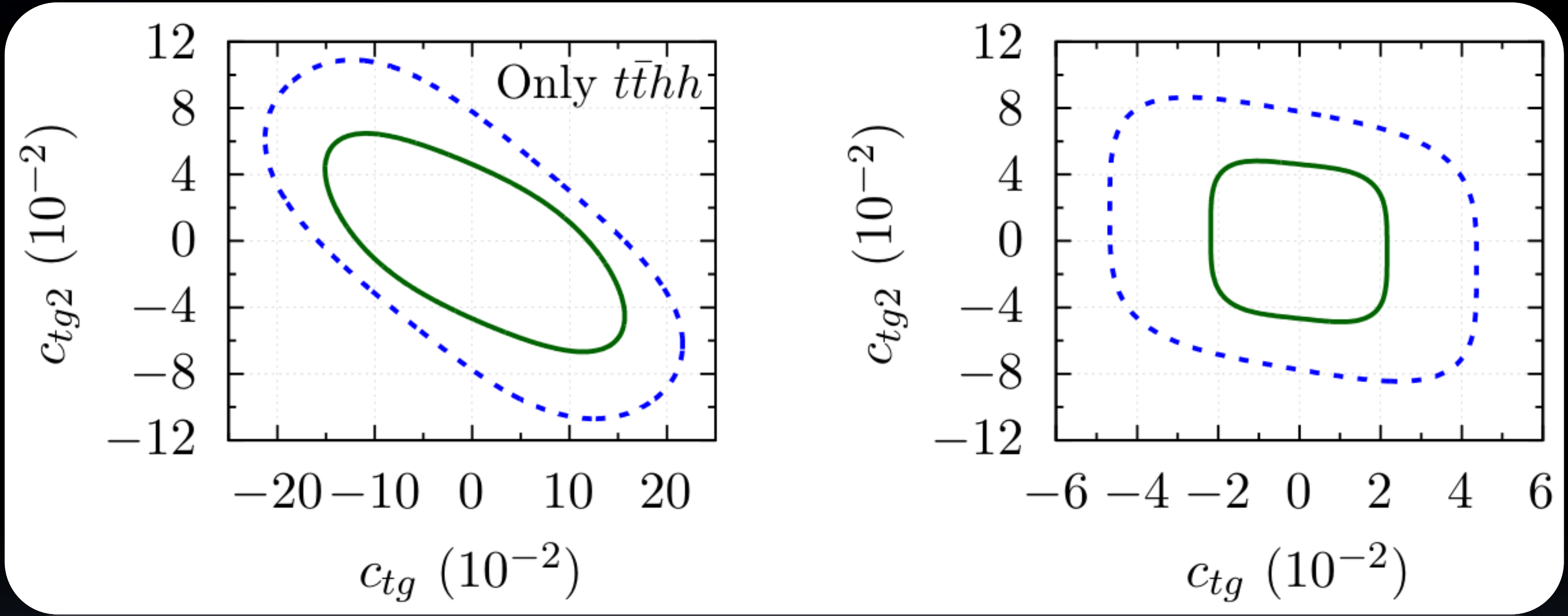
Two Parameter χ^2 contours



Cut:H_T-bin (SL) PM:BDT (SL)