Karlsruhe Institute of Technology

Collaborative Research Center TRR 257

P³H

Particle Physics Phenomenology after the Higgs Discovery

# Updates of the `ggHH_SMEFT` (and `ggHH EWChL`) Powheg code

LHC Higgs Working Group

WG4 meeting, 20.10.2023

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in collaboration with Stephen Jones, Matthias Kerner, Jannis Lang, Ludovic Scyboz

# The ggHH and ggHH_SMEFT NLO codes

available at https://powhegbox.mib.infn.it/

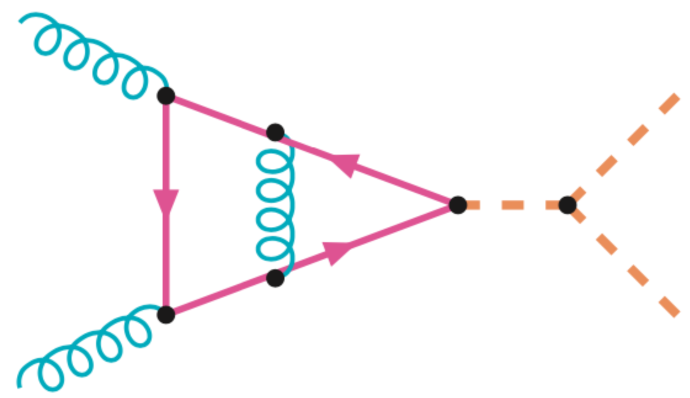
→ User-Process-V2/ggHH

1703.09252 SM: **no changes**

1903.08137 $c_{hhh}, c_t$

2006.16877 $c_{hhh}, c_t, c_{tt}, c_{ggh}, c_{gghh}$
(EWChL, i.e. HEFT)

→ User-Process-V2/ggHH_SMEFT
2204.13045



problem with 2-loop triangle-type diagrams now fixed

# Source of the problem

variation of trilinear coupling in 2-loop virtual contribution implemented as:

$$\mathcal{V}^{\rm 2loop} = \mathcal{V}_{\rm box+tri} + (c_{hhh} - 1)\mathcal{V}_{\rm tri} \qquad \text{SM: } c_{hhh} = 1$$

$$\sigma^{\rm virt+IRsub} \sim 2{\rm Re}\left[(\mathcal{V} + \mathbf{I}) \cdot \mathcal{B}^*\right] \supset 2{\rm Re}\Big[\mathcal{V}_{\rm box+tri} \cdot \mathcal{B}^* + ({\rm c_{hhh}} - 1)\mathcal{V}_{\rm tri} \cdot \mathcal{B}^*\Big]$$

contains $i/\epsilon$

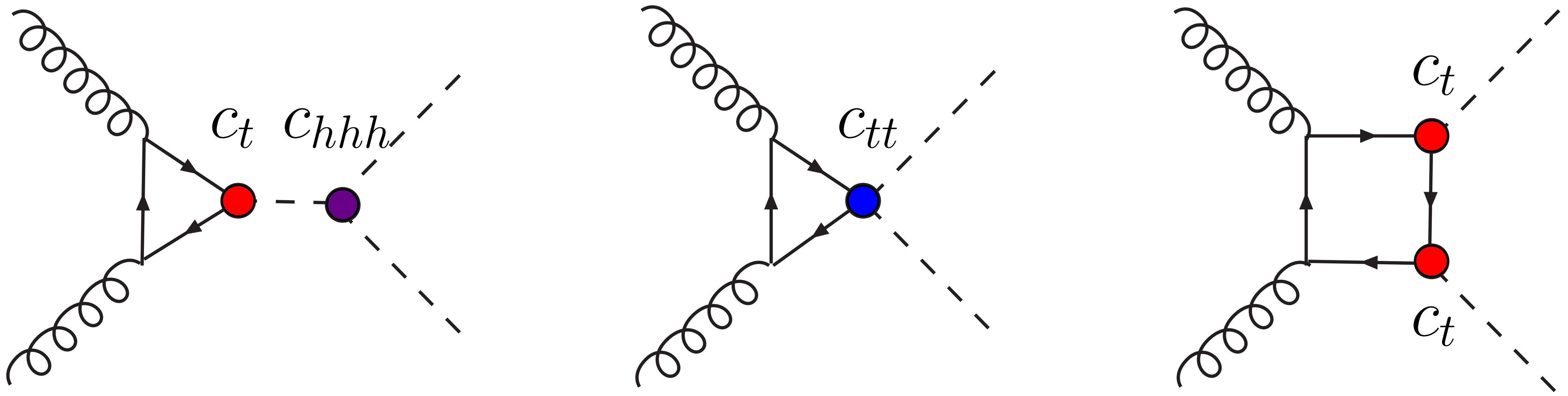
need $\mathcal{O}(\epsilon)$ terms (complex)

**Big Thanks to**

Emmanuele Bagnaschi, Guiseppe Degrassi, Ramona Gröber (arXiv:2309.10525)

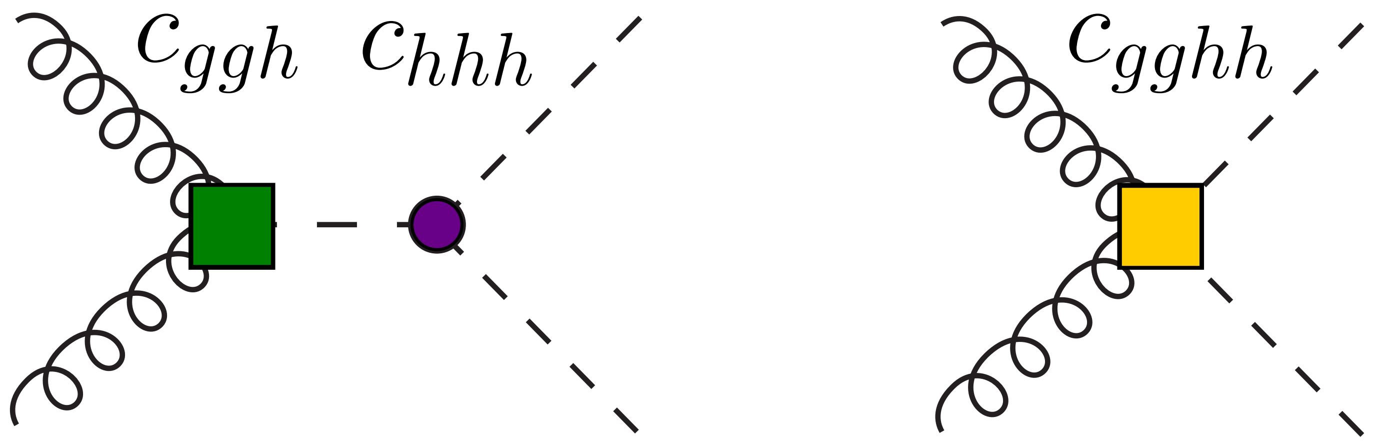
for performing a detailed comparison and for pointing out a discrepancy!

# ggHH HEFT



problem with triangles →

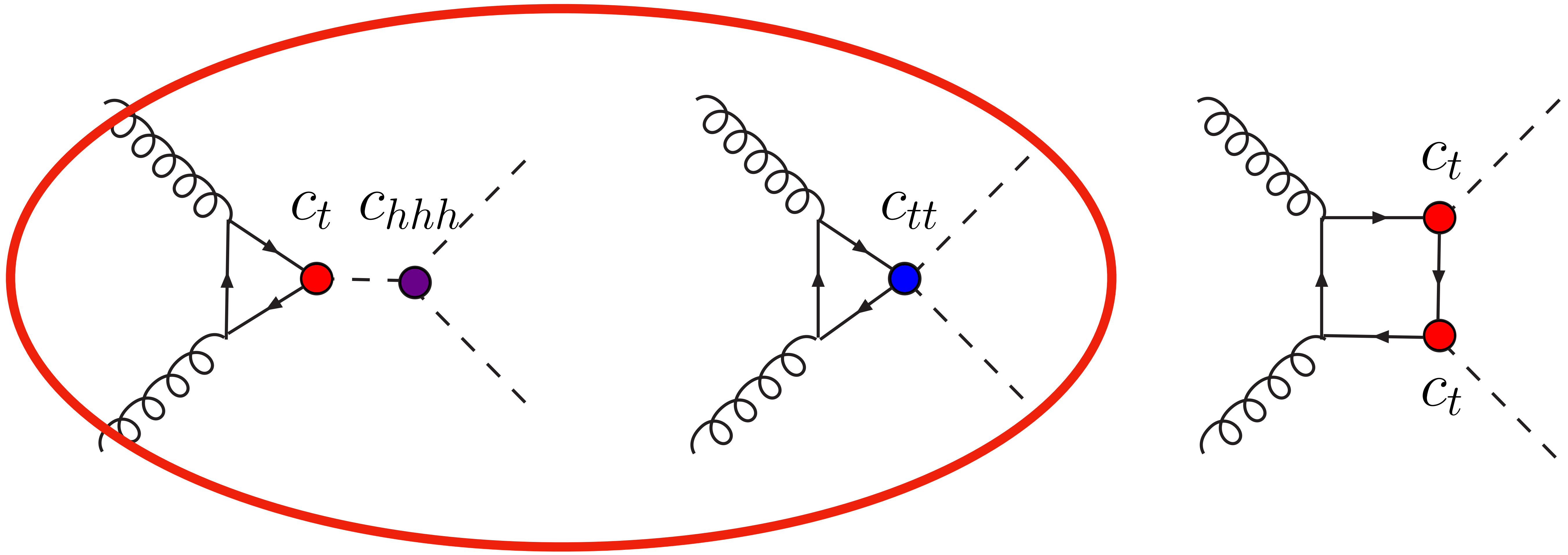
(2-loop only, LO not affected)



benchmark points with large values of

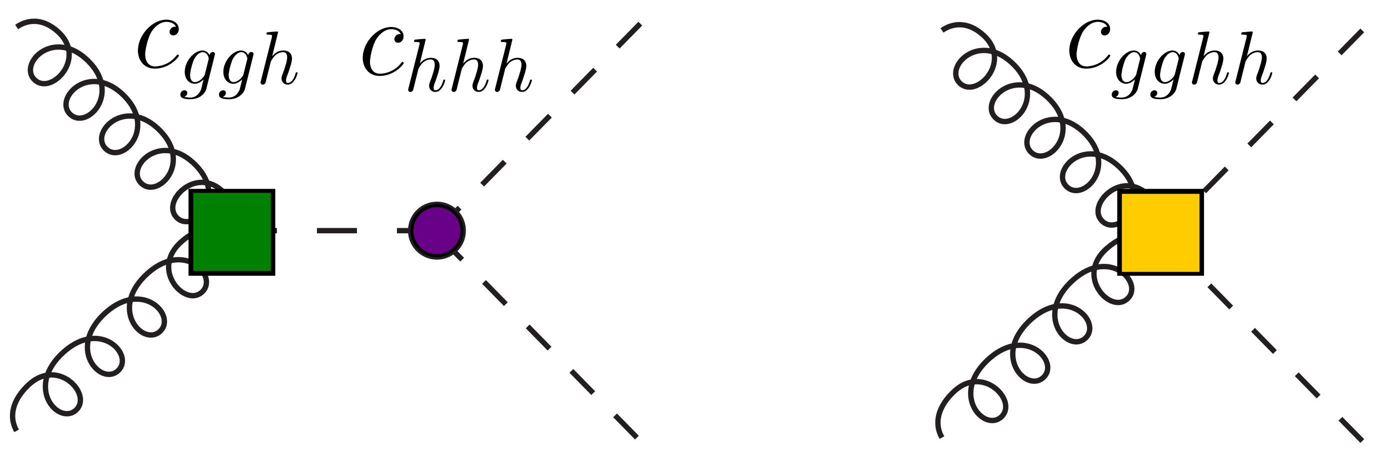
$c_{hhh}, c_{tt}$ are affected most

# ggHH HEFT



problem with triangles →

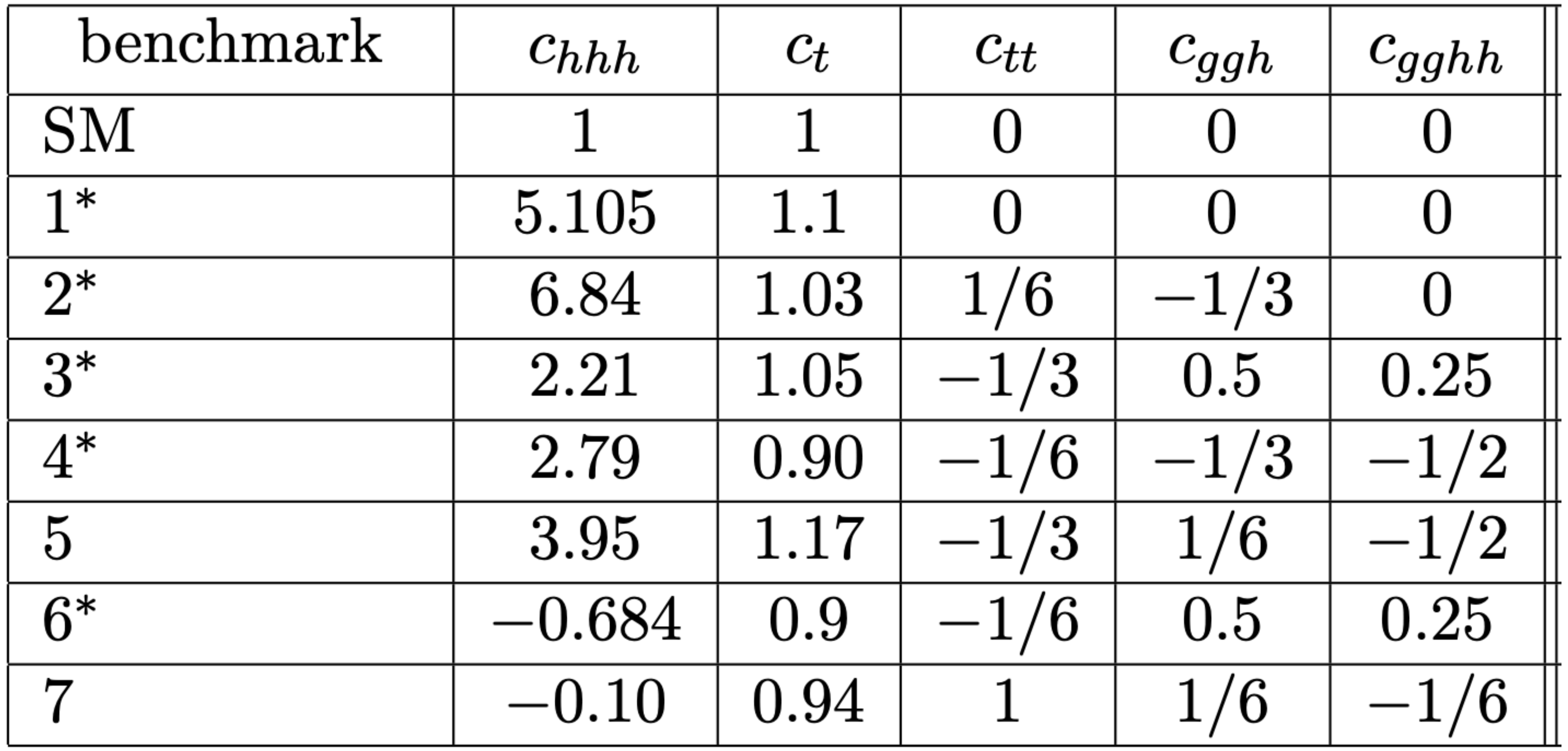
(2-loop only, LO not affected)



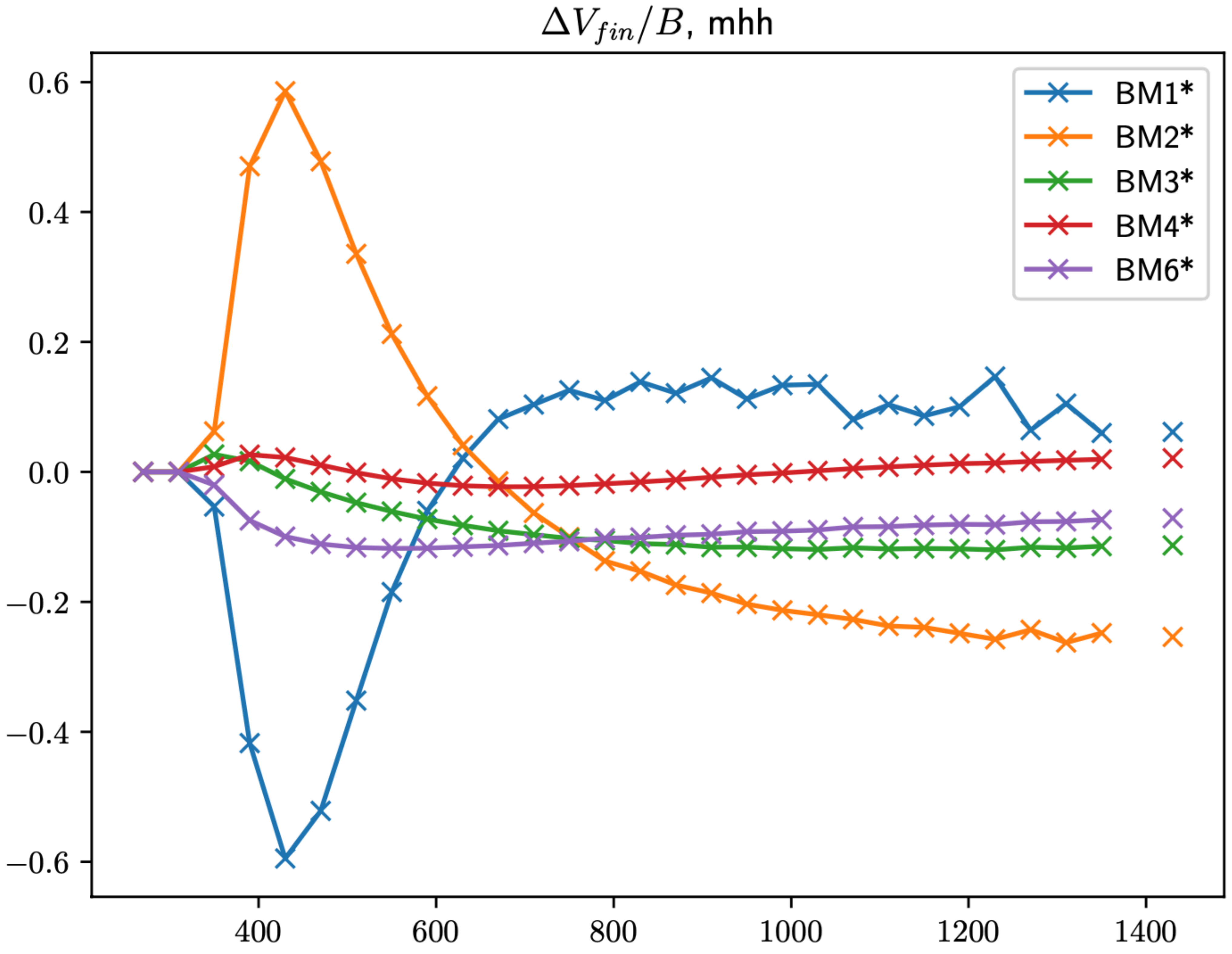
benchmark points with large values of

$c_{hhh}, c_{tt}$ are affected most

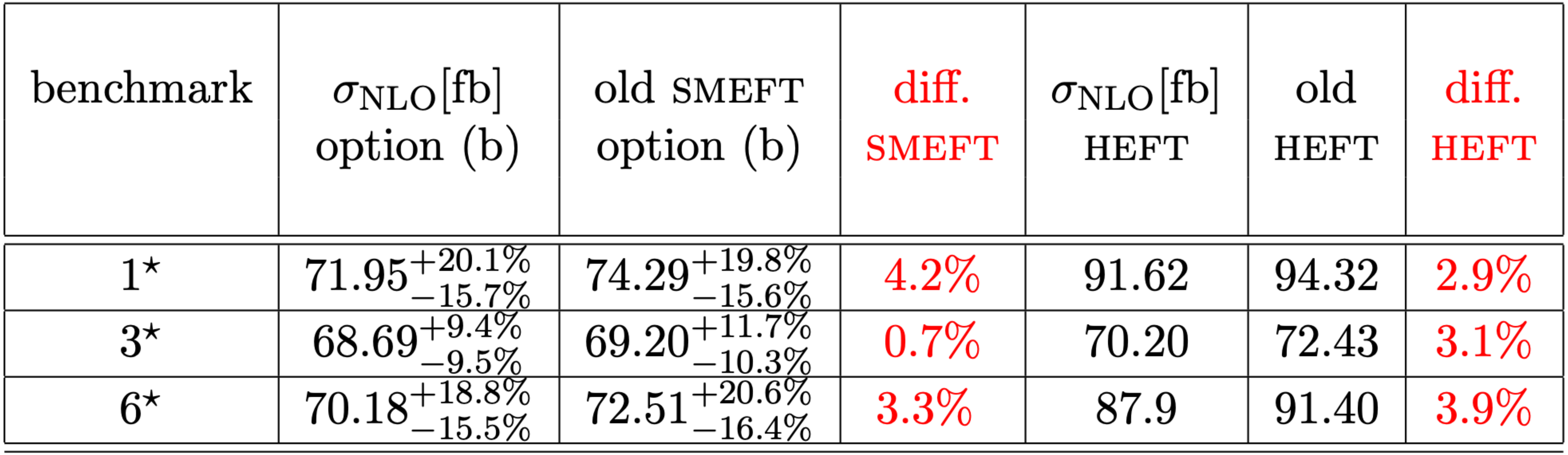
# benchmark points



| benchmark | $c_{hhh}$ | $c_t$ | $c_{tt}$ | $c_{ggh}$ | $c_{gghh}$ |
|---|---|---|---|---|---|
| SM | 1 | 1 | 0 | 0 | 0 |
| 1* | 5.105 | 1.1 | 0 | 0 | 0 |
| 2* | 6.84 | 1.03 | $1/6$ | $-1/3$ | 0 |
| 3* | 2.21 | 1.05 | $-1/3$ | 0.5 | 0.25 |
| 4* | 2.79 | 0.90 | $-1/6$ | $-1/3$ | $-1/2$ |
| 5 | 3.95 | 1.17 | $-1/3$ | $1/6$ | $-1/2$ |
| 6* | $-0.684$ | 0.9 | $-1/6$ | 0.5 | 0.25 |
| 7 | $-0.10$ | 0.94 | 1 | $1/6$ | $-1/6$ |



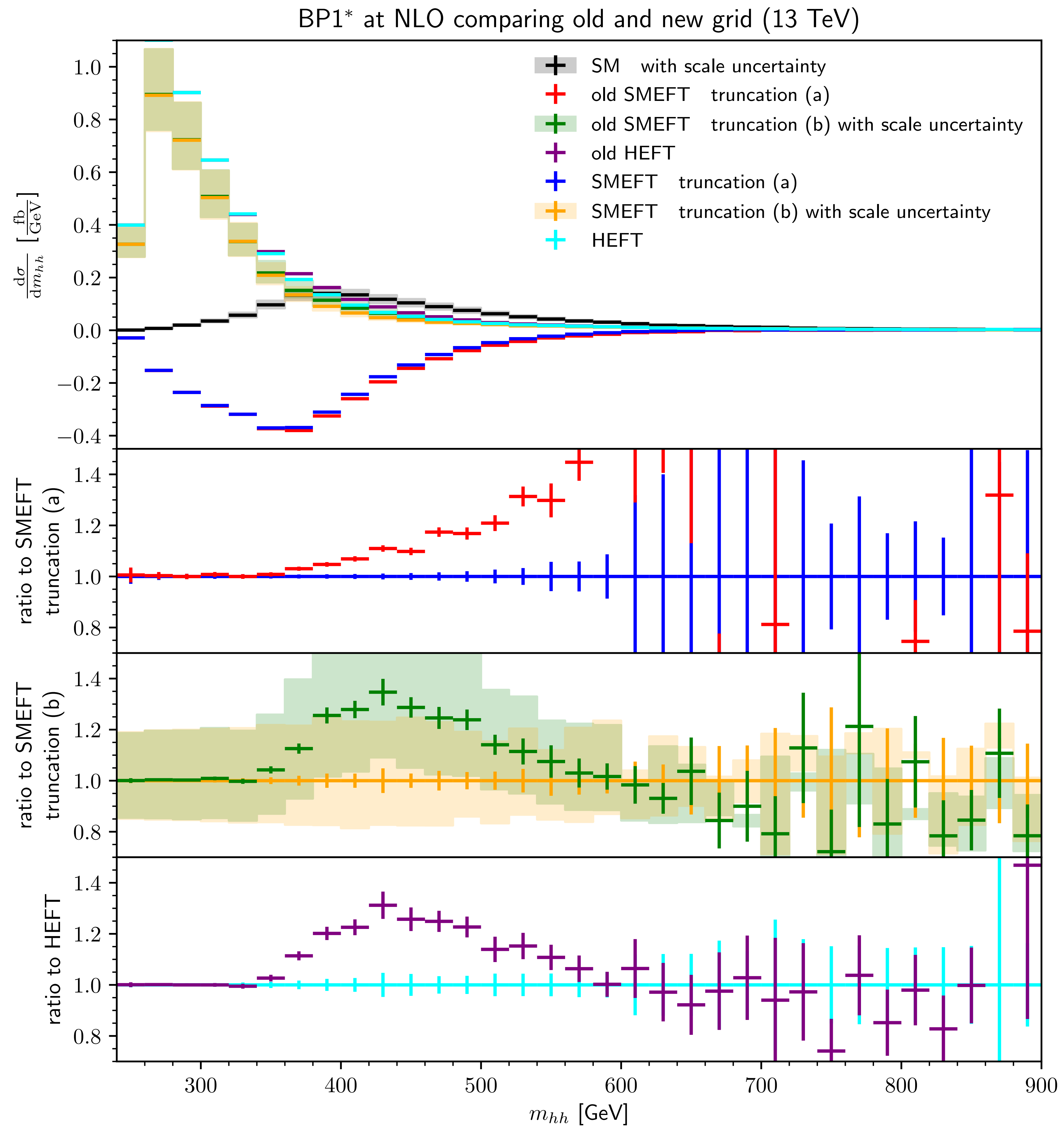
# total cross sections



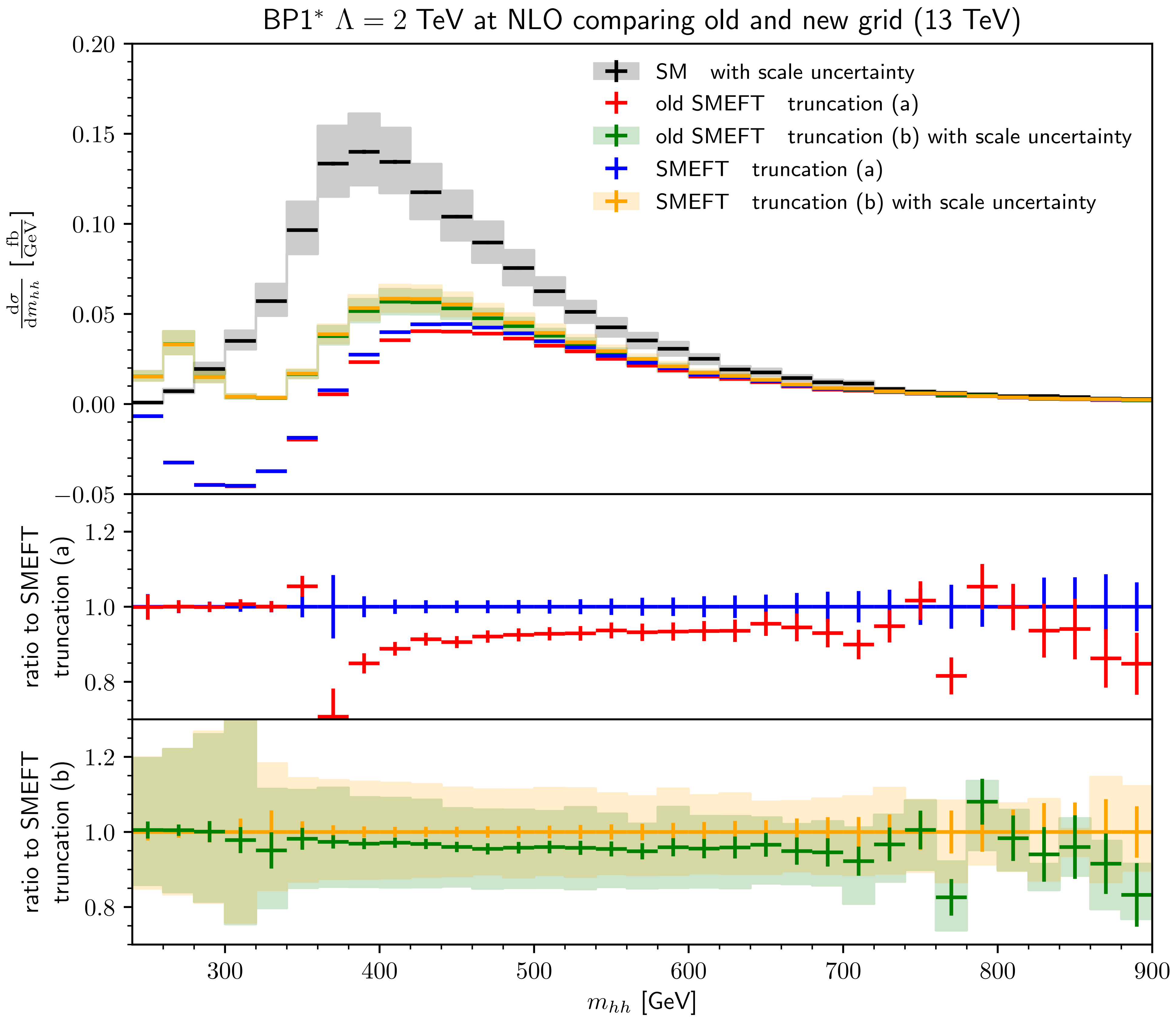
| benchmark | $\sigma_{\rm NLO}$[fb]<br>option (b) | old SMEFT<br>option (b) | diff.<br>SMEFT | $\sigma_{\rm NLO}$[fb]<br>HEFT | old<br>HEFT | diff.<br>HEFT |
|---|---|---|---|---|---|---|
| $1^\star$ | $71.95^{+20.1\%}_{-15.7\%}$ | $74.29^{+19.8\%}_{-15.6\%}$ | 4.2% | 91.62 | 94.32 | 2.9% |
| $3^\star$ | $68.69^{+9.4\%}_{-9.5\%}$ | $69.20^{+11.7\%}_{-10.3\%}$ | 0.7% | 70.20 | 72.43 | 3.1% |
| $6^\star$ | $70.18^{+18.8\%}_{-15.5\%}$ | $72.51^{+20.6\%}_{-16.4\%}$ | 3.3% | 87.9 | 91.40 | 3.9% |

effects on total cross sections below 5% level

# ggHH_SMEFT benchmark point 1* old vs new



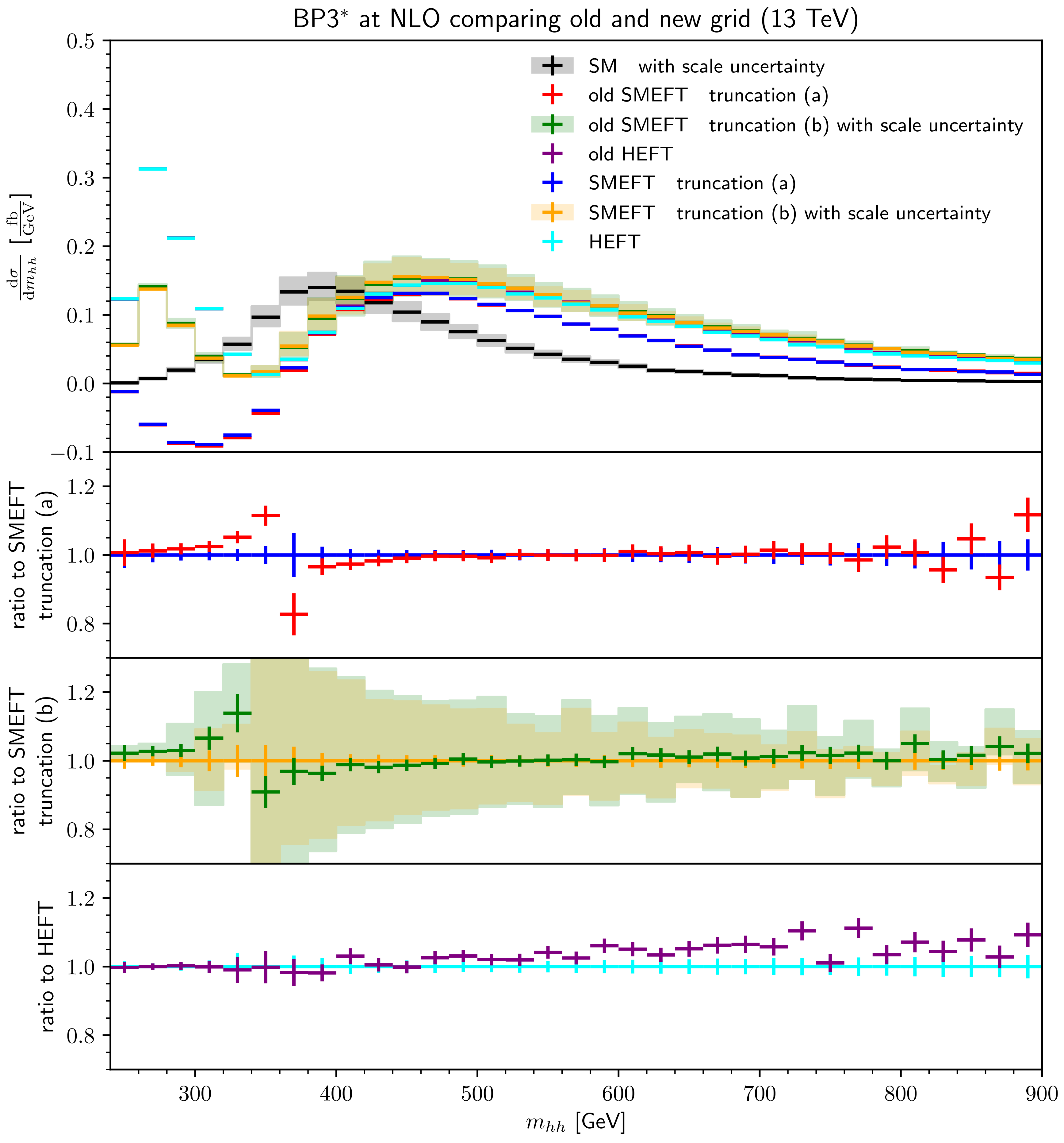
$\Lambda = 1\,\text{TeV}$

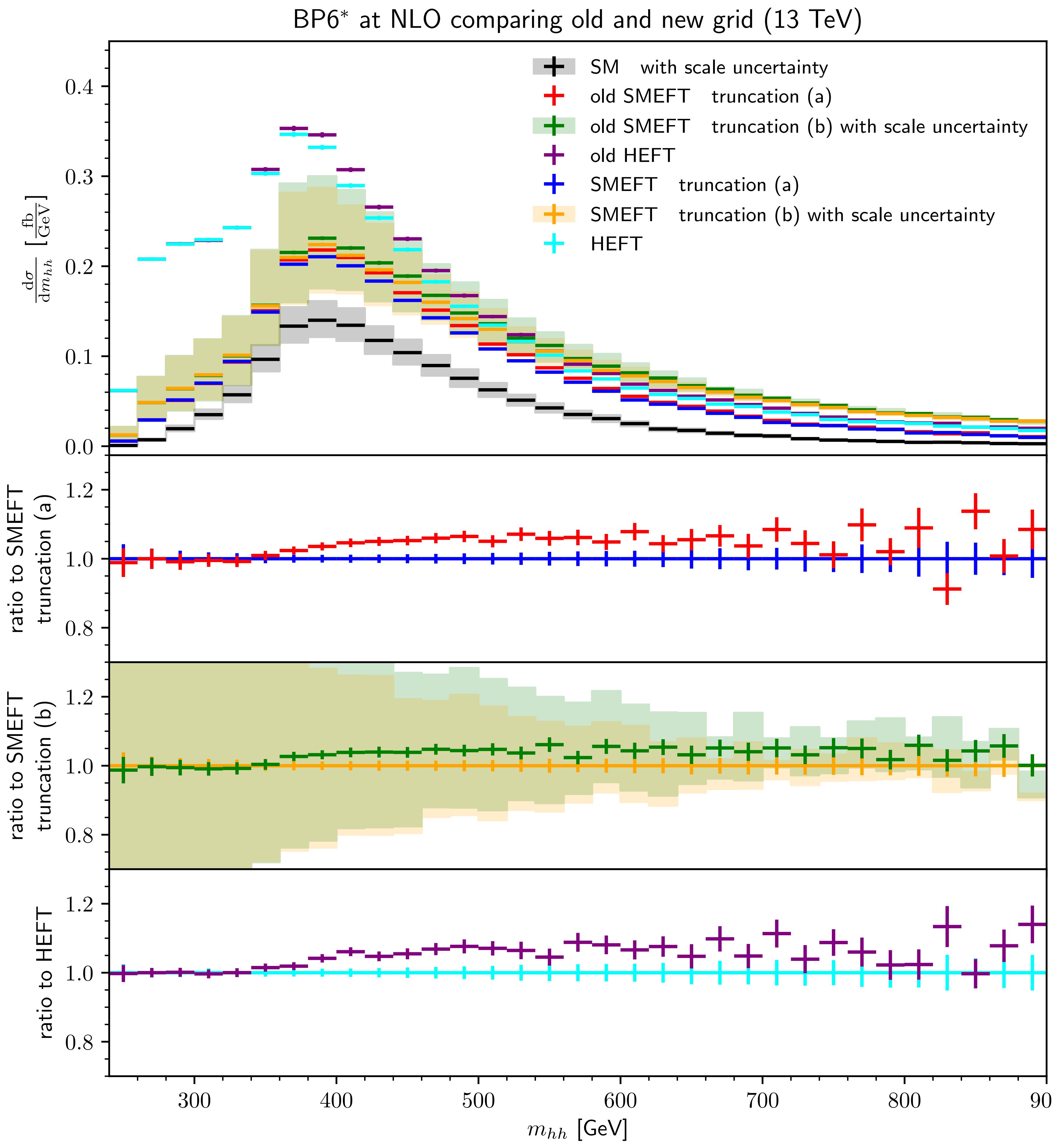


$\Lambda = 2\,\text{TeV}$

# ggHH_SMEFT benchmark points 3* and 6*

$$\Lambda = 1\,\mathrm{TeV}$$





# Other improvements in new version

- problem with file locking in parallel runs fixed: first do `./run.sh warmup`
  (when using own runscripts, otherwise warmup will be done automatically by run.sh)
- updates of run script:
  - exit statement after parallel stage 2 removed
  - parallel stages 3, 4: initialisation of `xgriditeration` fixed
- documentation updated

# Summary

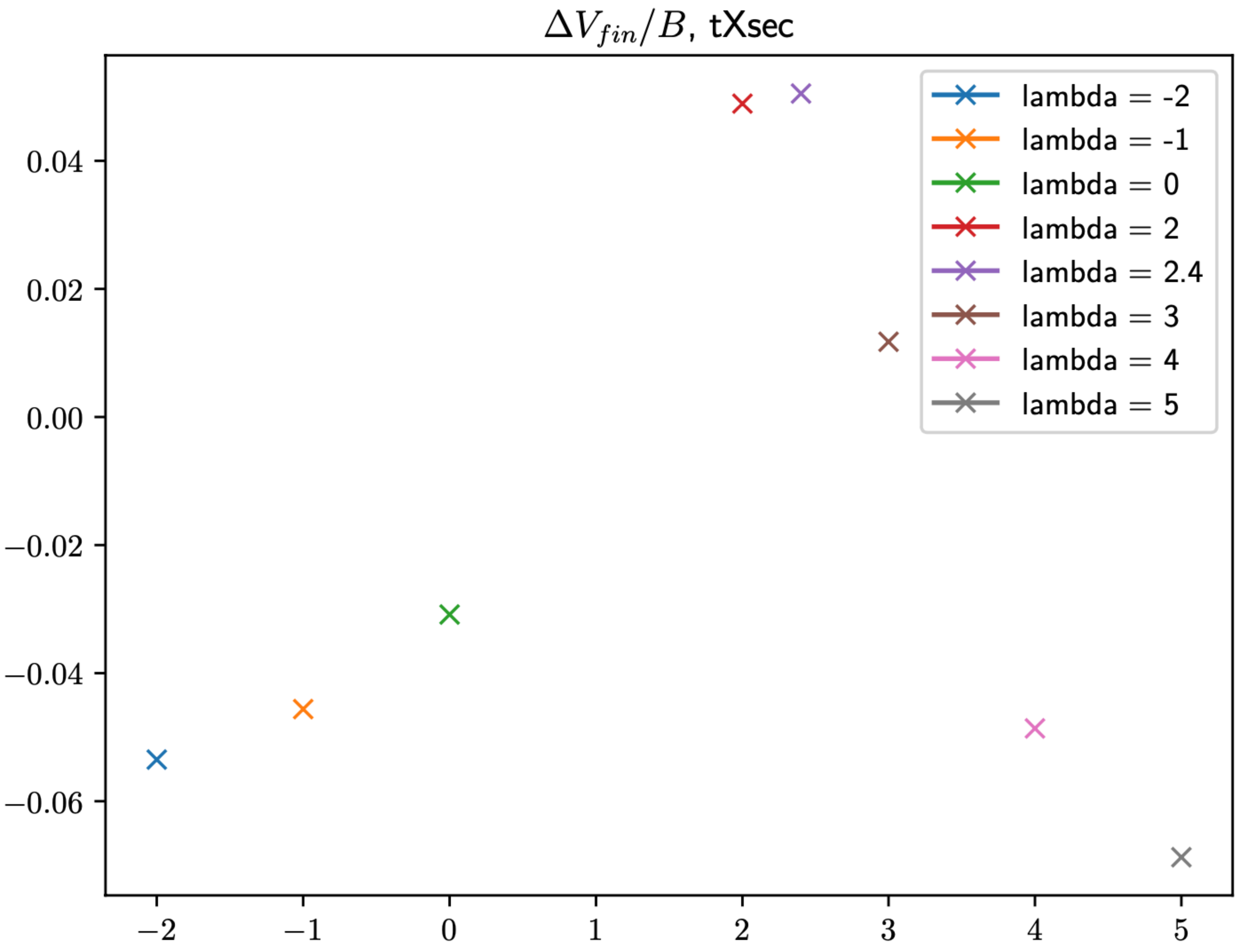
- Powheg code ggHH_SMEFT fixed, new version available in svn repo POWHEG-BOX-V2
- public grid also fixed (https://github.com/mppmu/hhgrid)
- ggHH HEFT fix will be public very soon (only updates in python handling of the grid are missing)
- errata on arXiv coming out soon
- discrepancy up to 35% in mHH distribution close to virtual top pair production threshold for benchmark point 1*
- discrepancies below 5% level for total cross sections and benchmark points 3* and 6*

Apologies to all users of the code

and

Thank you for your patience!

# Differences due to Vfin in total cross section


$\Delta V_{fin}/B$, tXsec
lambda = -2
lambda = -1
lambda = 0
lambda = 2
lambda = 2.4
lambda = 3
lambda = 4
lambda = 5