(A Few) Experimental ThougHHHts

HHH Workshop - Dubrovnik, Croatia, 15.07.23

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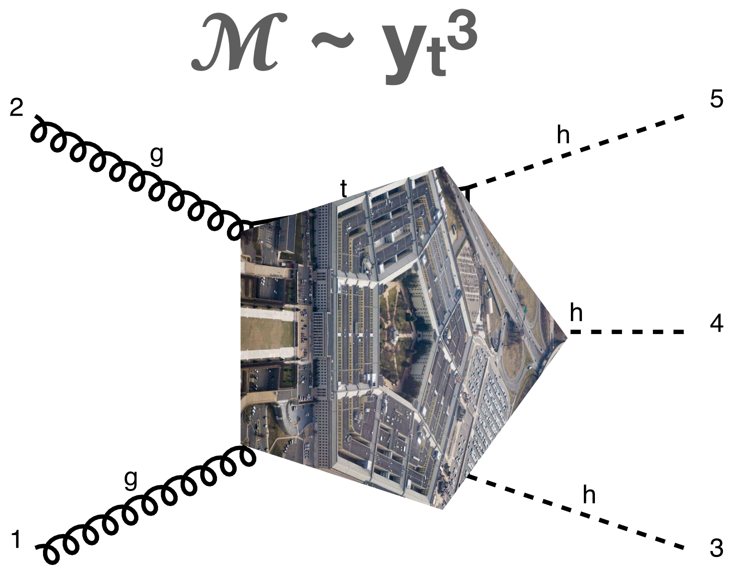
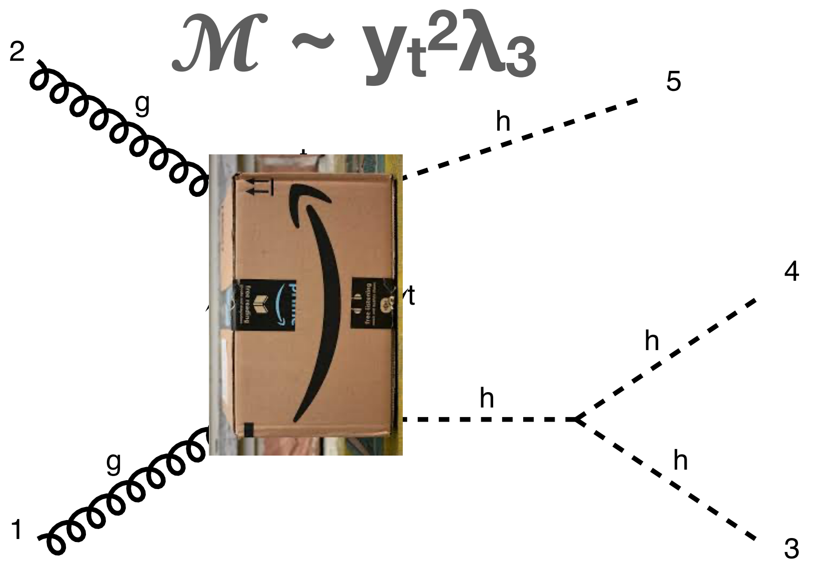
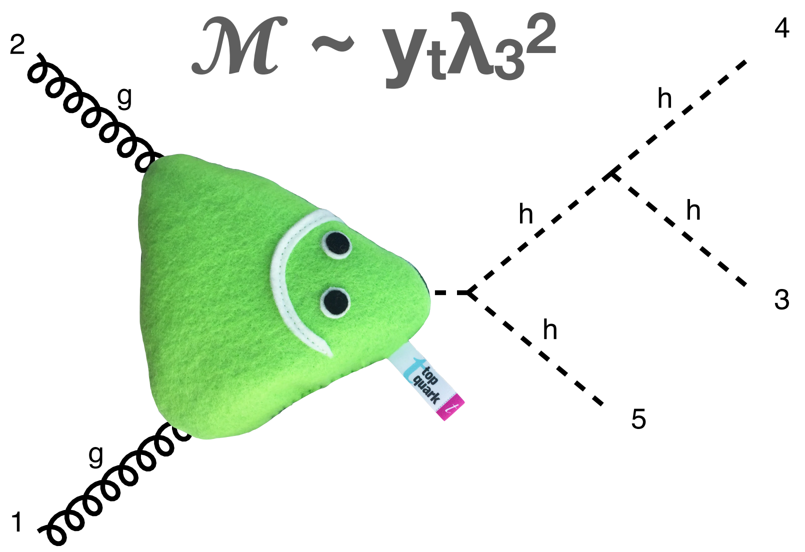
IN HHH SPERAMUS

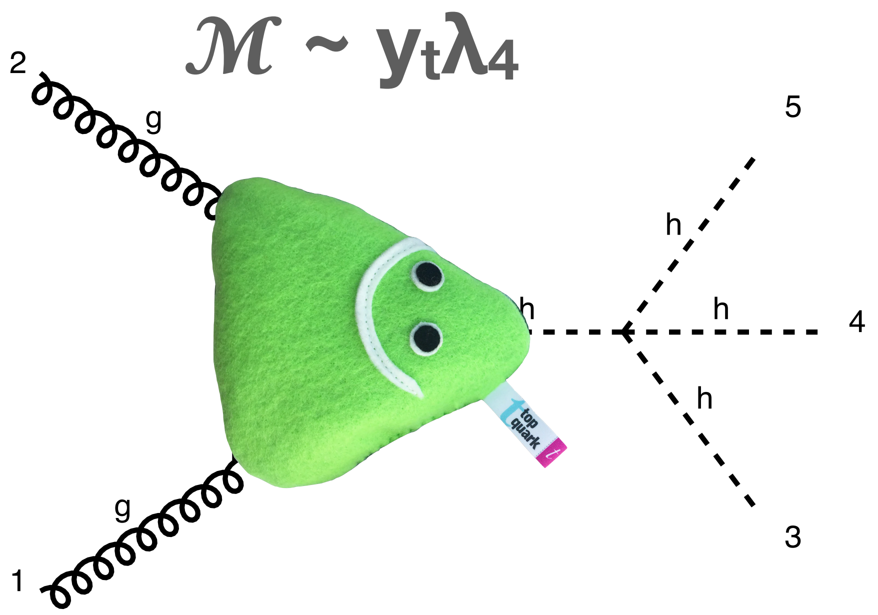
Diagrammatics

- LO: 50 top quark loop diagrams + 50 bottom loop ones; ignore the latter
- Four classes:
  - Pentagon: $\sim y_t^3$ - 24 diagrams; destructively interfere with "signal"
  - Box: $\sim y_t^2 \lambda_3$ - 18 diagrams, proportional to λ_3 - destructive int.
  - Triangle: $\sim y_t \lambda_3^2$ - 6 diagrams, proportional to λ_3^2 - destructive int.
  - Quartic: $\sim y_t \lambda_4$ - 2 diagrams, sensitive to quartic coupling - don't interfere with other diagrams to the fist order
- N.B. Given the $\lambda_3 = \lambda_4 = 0.13$ in the SM, box diagrams dominate in the SM, but not necessarily at large λ_3
  - Challenge - identify the phase space where triangular diagrams dominate - might enhance the sensitivity to large λ_3









Branching Fractions

- H(bb) = 58.1%, H(ττ) = 6.26%, H(WW) = 21.5%, H(gg) = 8.18%, H(ZZ) = 2.6%, H(γγ) = 0.23%
- σ_{HHH}(14 TeV, NNLO) = 0.1fb
- Aim at $\sigma^{95} = 100 \times \sigma_{HHH} = 10$ fb; Run 2 x σ^{95} ~ 1000 events; Run 2 x σ^{95} x ε ~100 events
- To set a limit, need expected yield of 3 signal events: do not consider Br < 3% for now
- **HHH → 6b: 19.5%**
- **HHH → bbbbττ: 6.3%; bbbb$\tau_h\tau_h$: 2.7%**
- **HHH → bbbbWW → 4b4j: 9.9%**
- **HHH → bbbbgg → 4b2j: 8.3%**
- HHH → bbbbWW → 4b2jℓv: 5.9%
- ~~HHH → bbττWW → 2b2τ4j: 2.1%~~
- ~~HHH → bbbbWW → 4b2ℓ2v: 0.9%~~
- ~~HHH → bbττττ: 0.68%~~
- ~~HHH → bbbbγγ: 0.23%~~

41% - Focus on these topologies: 4b + jets

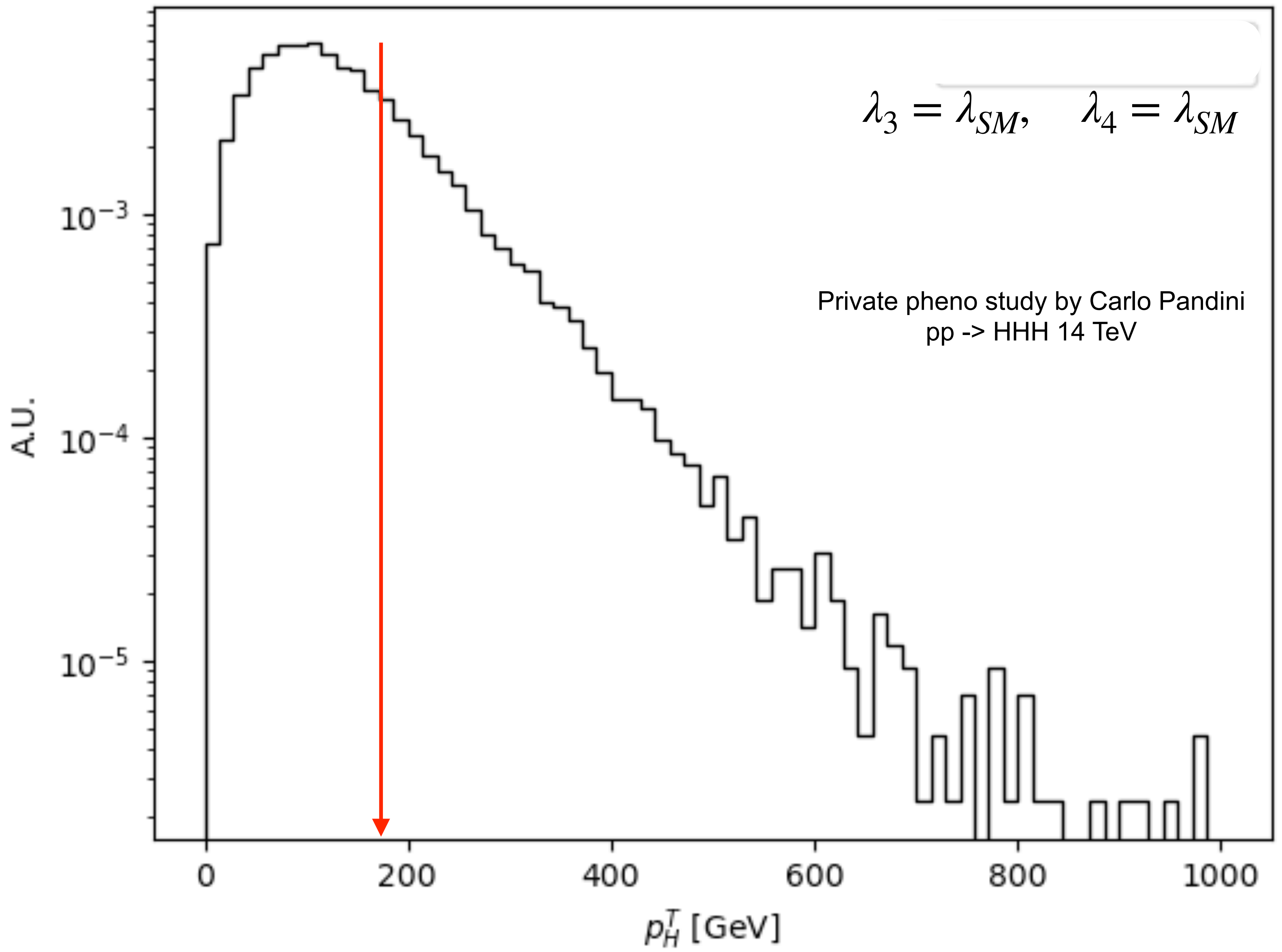
N.B.1: this is SIMPLER than HH → 4b
All the techniques developed for that analysis can be reused if desired
Backgrounds by construction are order of magnitude or more lower

N.B.2: WW → lvjj, while promising, doesn't have a mass peak

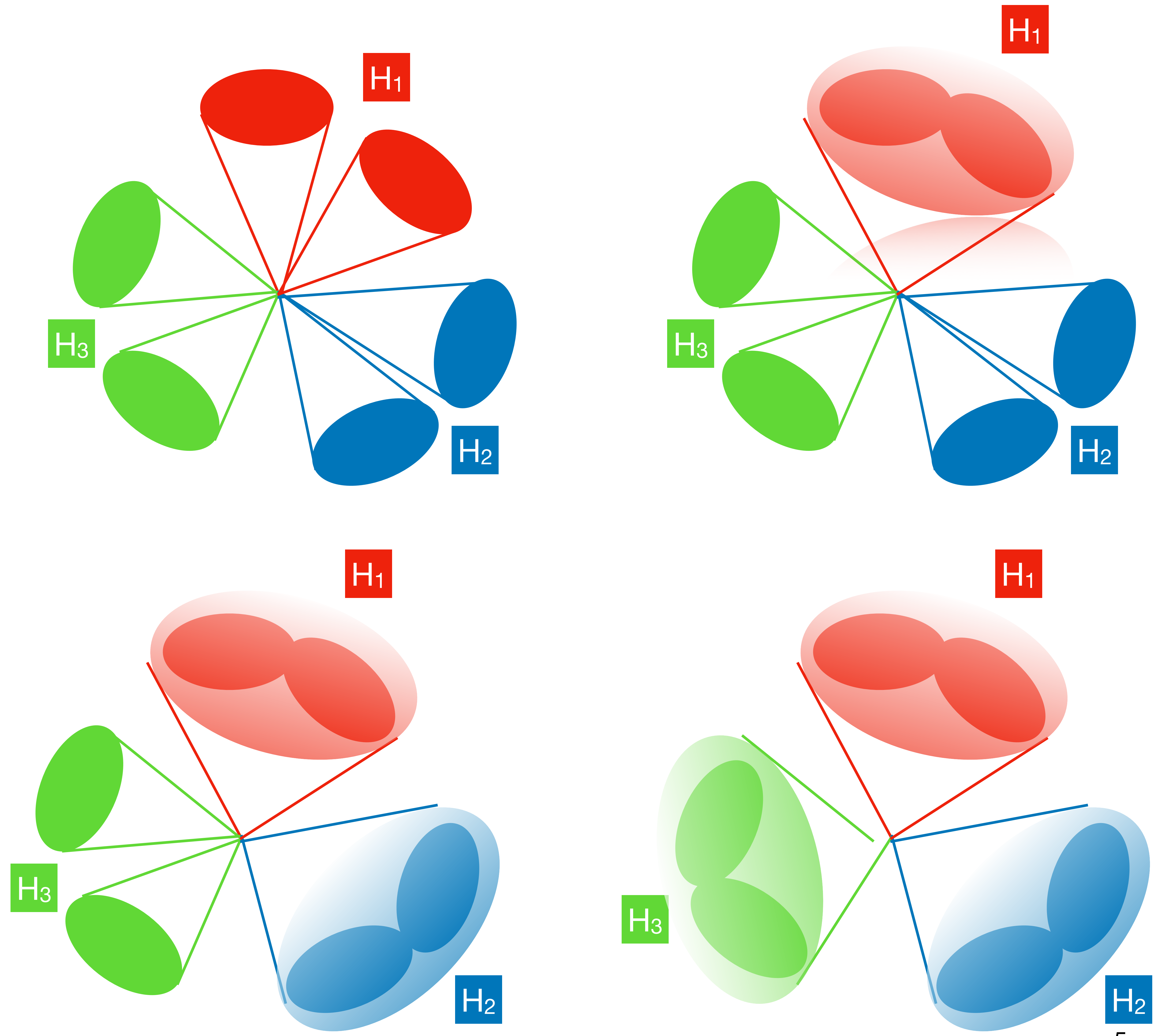
Jet Merging

- Merged jets help tremendously against combinatorics:
  - HHH → 6b: $C^2{}_6 \times C^2{}_4 \times C^2{}_2 / 3! = 15 \times 6 \times 1 / 6 = 15$ combinations
  - HHH → 4b+J: $C^2{}_4 \times C^2{}_2 / 2! = 6 \times 1 / 2 = 3$ combinations!
  - HHH → 2b+2J and HHH → 3J = 1 combination each!!
- N.B.1. Average Higgs boson p_T in HHH production ~200 GeV - boosted topologies are not rare
- N.B.2.: for a 200 GeV p_T, $\theta \approx 2/\gamma \approx 1.25$, so R ~ 1.0 jets are effective in catching Higgs boson decays

Osama Karkout's talk



Toward Merged Topologies



- Our experience: merged jet topologies offer better performance than resolved ones
  - Smaller combinatorics
  - Substructure variables are apparently more powerful than what we use in the resolved case
- Idea: why bother with resolved, fully merged, and partially merged topologies?
  - Work with CA1.5-2.0 jets and have at least two out of three Higgs boson decays merged!
  - No combinatorics, and the advantage of using jet substructure techniques!

Resonances

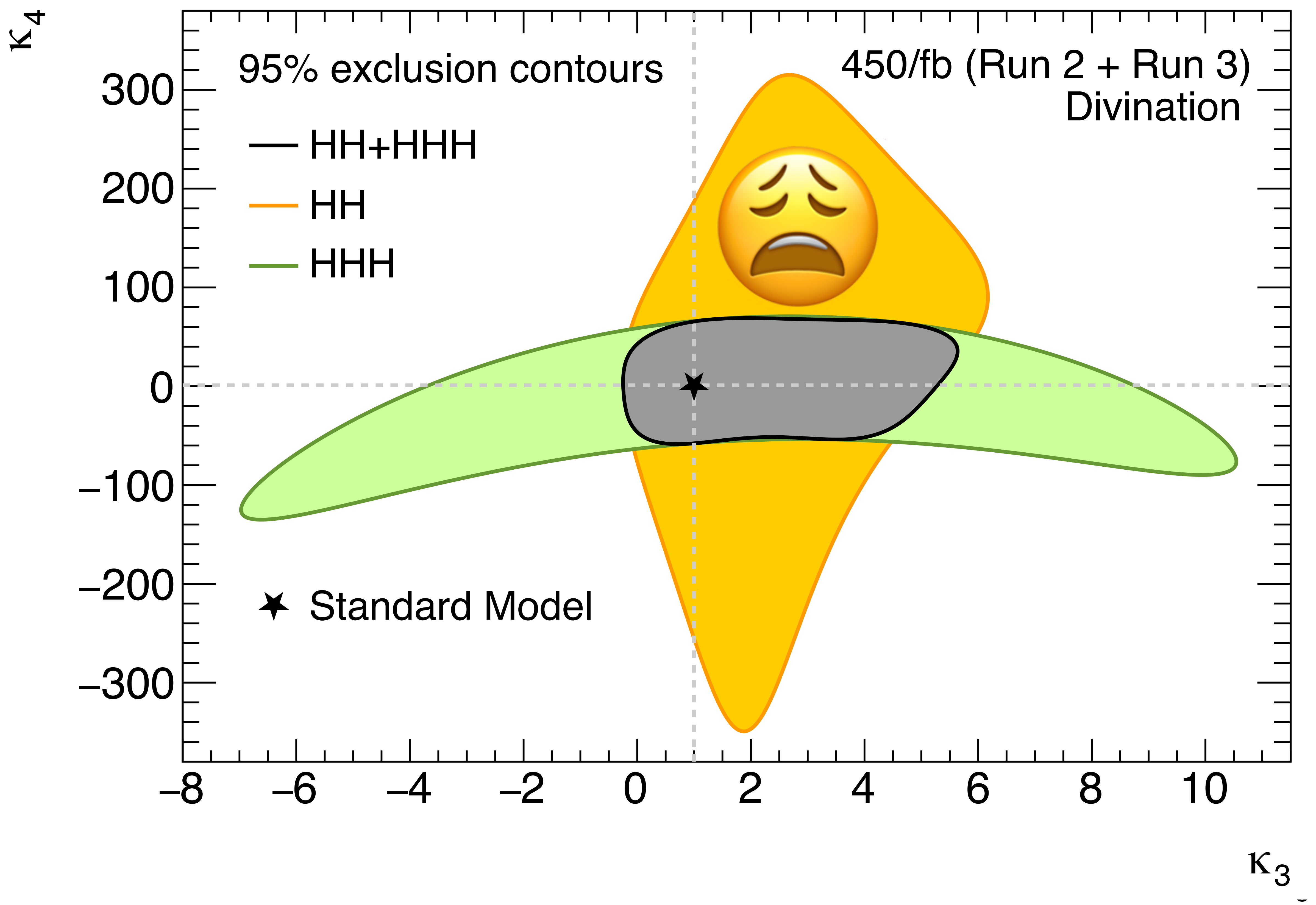
- We know that resonances could easily boost the HHH cross section by 2 orders of magnitude (HHH → HH)
- E.g., 2101.0031 (2RSM)
    - pp → h_3 → h_2h_1 → $h_1h_1h_1$ (h_1 = H(125))
    - M_3 = 500 GeV, M_2 = 300 GeV, σ ~ 40 fb
- At the LHC, we are good at looking at pp → X → AB (jj, ll, ɣɣ, VV, VH, HH, Vɣ, Hɣ, Va, aa) as well as more complex decays fr pair production: e.g., pp → gg → 6j
- We rarely do single resonance searches decaying in three objects
    - The Z → XY search program is still in its infancy
    - Recent example: CMS search PAS EXO-22-008 for pp → X → jjj (either directly Z' → ggg, or via an intermediate resonance g_{KK} → Rg → ggg or q* → qV → qqq) - first of a kind at colliders (cf. ~50 pp → X → jj searches from ATLAS+CMS)
- As a side remark, we should also do VVH and VHH searches!
    - The latter gives direct access to κ_{2V}

Triggers

- In the approach I suggest, we need the same triggers (and largely the analysis!) as (boosted) HH → 4b search
- As you saw, CMS had rather efficient triggers in Run 2, and have installed even more efficient (partially parked) triggers in Run 3
- General trigger strategy: H_T ~ 300 GeV + 2-3 b tagged jets (PNet)
- If one wishes to also pursue the 4b+2j+$l\nu$ channel, isolated single-lepton triggers would suffice

My Conclusions

- Think before you get engaged into analysis!
- The difference is obvious:



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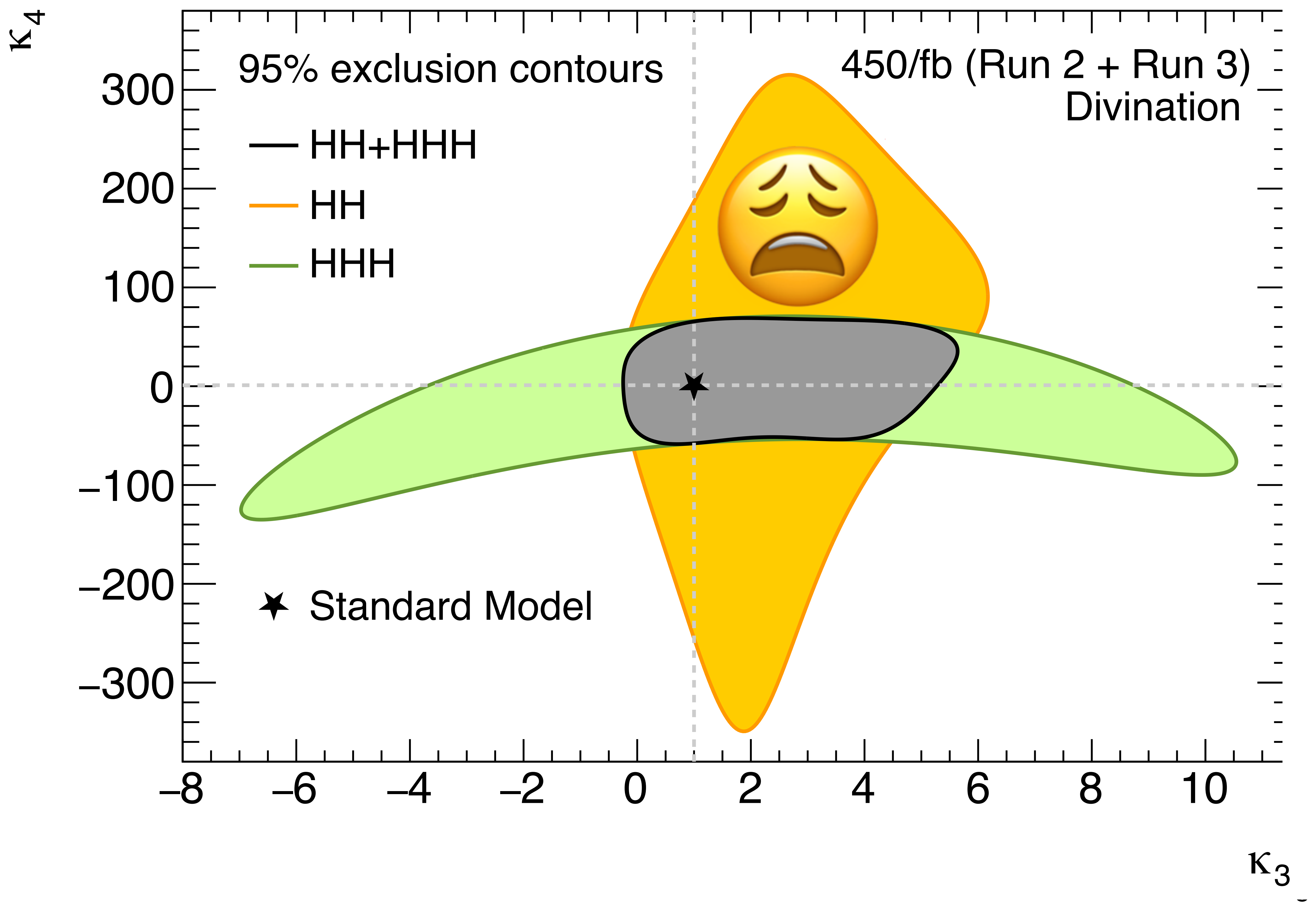

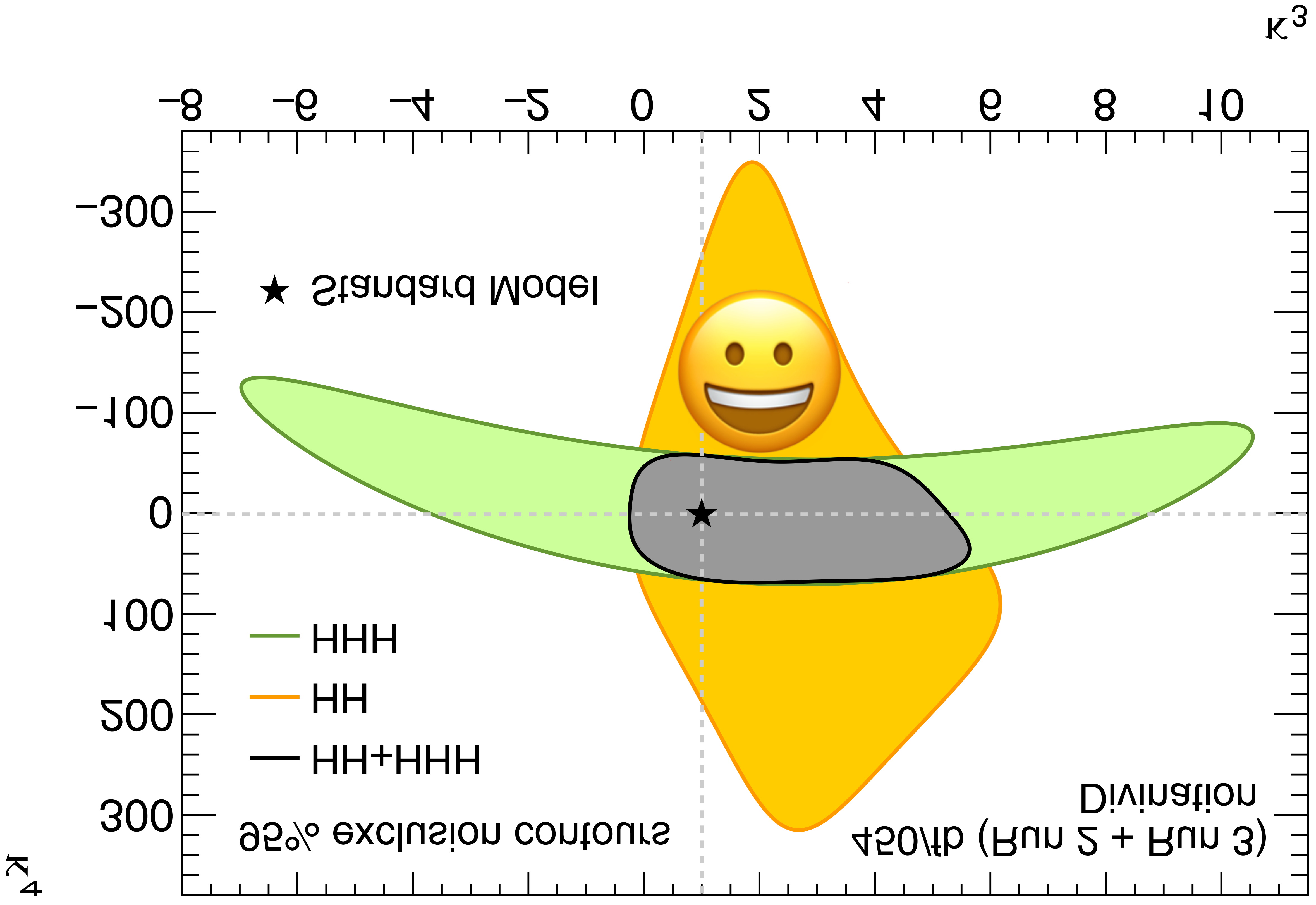

ChatGPT Conclusions

- In the realm of particles so grand,
  Where mysteries lie in each strand,
  The Higgs boson takes its place,
  With secrets held in its embrace.

- Its self-coupling, a subtle dance,
  A tryst of particles in cosmic expanse.
  Yet direct measurements remain unseen,
  As scientists strive to grasp its serene.

- Indirect constraints like whispers told,
  Unveiling truths in the particles' fold.
  With bounds and limits, we seek to find,
  The Higgs self-coupling, an enigma entwined.