Experimental perspective on HHH

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Mini workshop on HHH

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Ruđer Bošković Institute, Zagreb

Disclaimer

- **Currently no public ATLAS or CMS results on HHH**
  - Consequently, the slides will be a bit boring with a lot of text and few plots
- Being a member of CMS, my views and statements will inevitably be biased toward CMS
- Nevertheless, statements in this presentation are solely mine and not officially endorsed by CMS

Analysis landscape

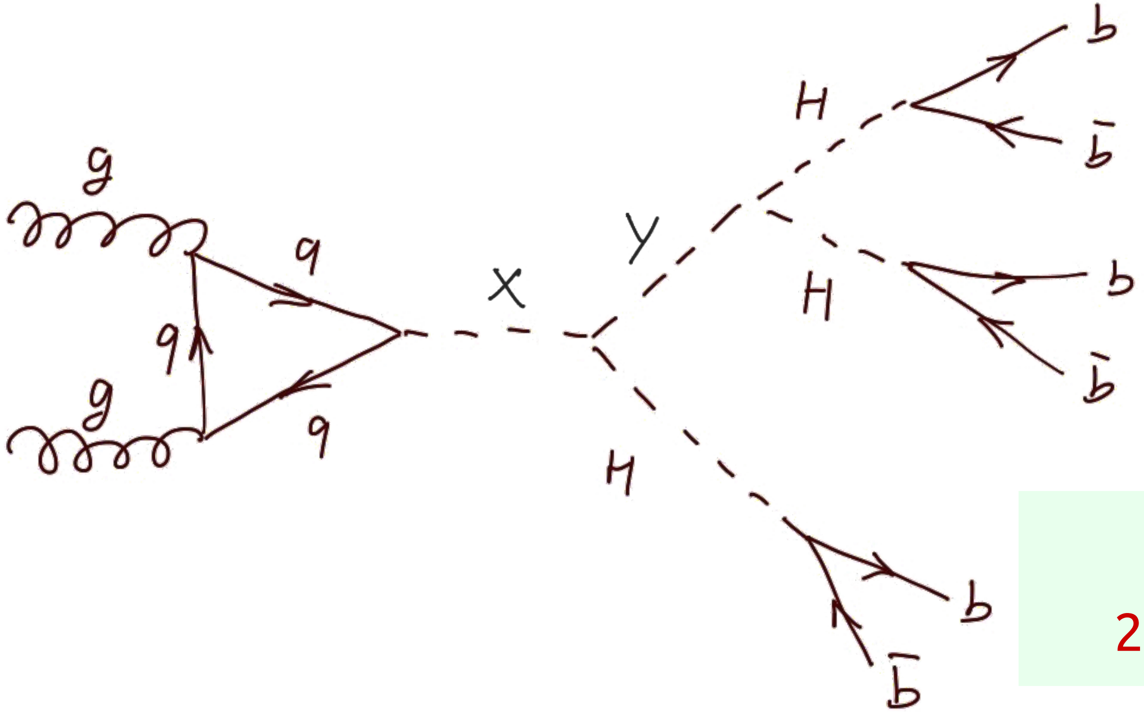
- In CMS, HHH analyses divided into two categories:
  - Non-resonant
  - Resonant

  each done within a different *Physics Analysis Group*
- *Resonant* analysis further divided into:
  - Resolved
  - Boosted (RBI group involved)
- Currently focusing on Run 2 data

- ATLAS might have something similar…

Final state landscape

- The **6b** final state, having the largest branching fraction, currently dominates the final state landscape



Mass hierarchy:

$2m_H < m_Y < m_X - m_H$

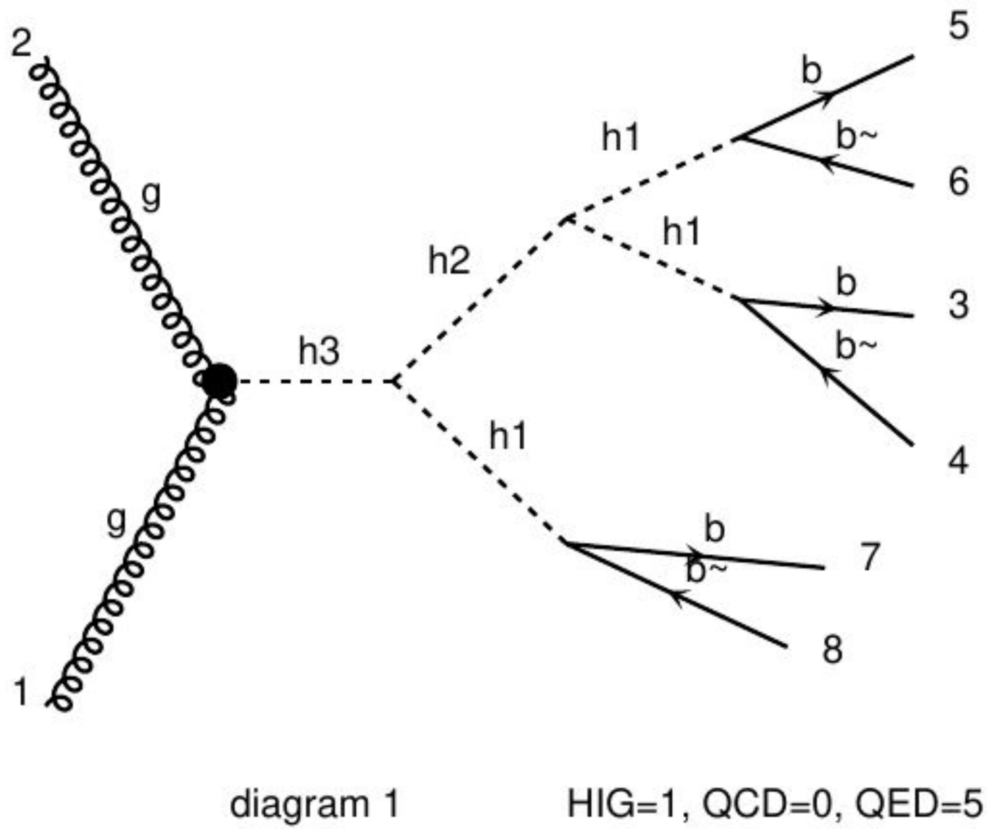
- Non-resonant analyses also include **4b2γ** and **4b2τ** final states

Background estimation strategy

- HHH→6b final state is a good place to employ machine learning techniques to pair jets and classify events
    - See Marko's talk from last year's HHH workshop
- Dominant backgrounds for the 6b final state:
    - QCD multijets → estimated using data-driven techniques
    - ttbar production → typically taken from MC simulation
- In general, prefer one background estimate for all signal hypotheses being tested even at the cost of losing some signal sensitivity (background systematics needs to be done once and for all)
    - More details in the backup about the background estimation strategy used in the *boosted resonant* analysis

Signal samples

- In CMS we are using samples with X and Y scalars as narrow resonances produced in the context of an NMSSM model implemented in MadGraph5_aMC@NLO (data cards for Run 3)



CMS convention:

h3 → X

h2 → Y

h1 → H (SM Higgs)

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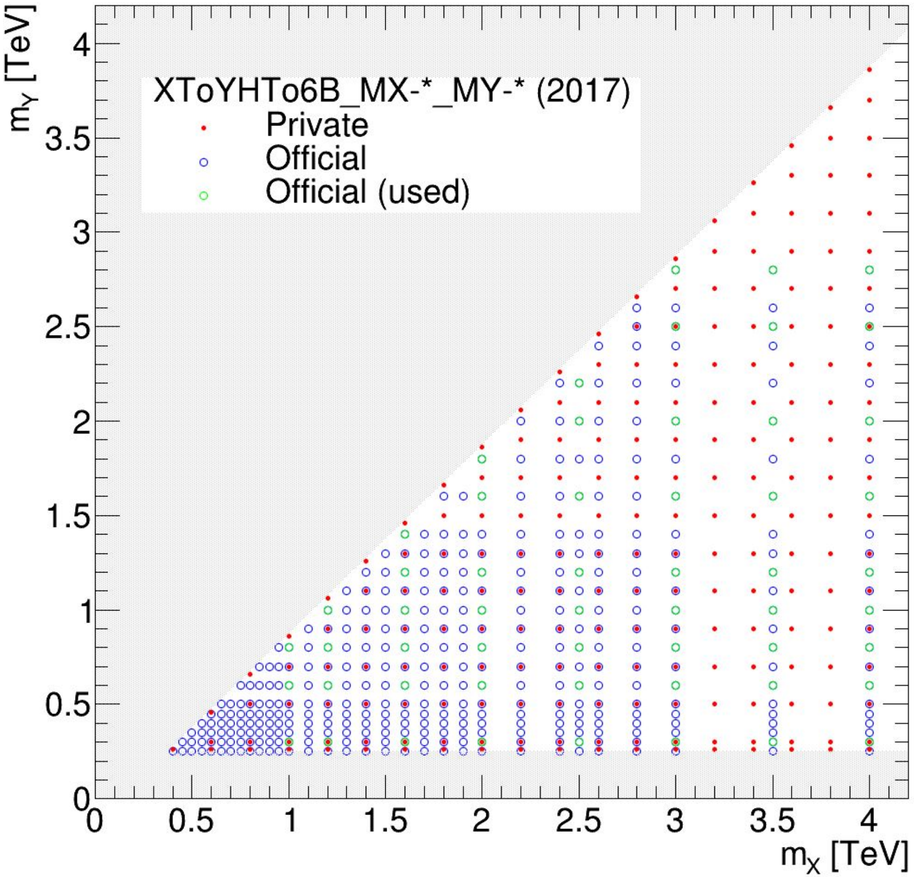

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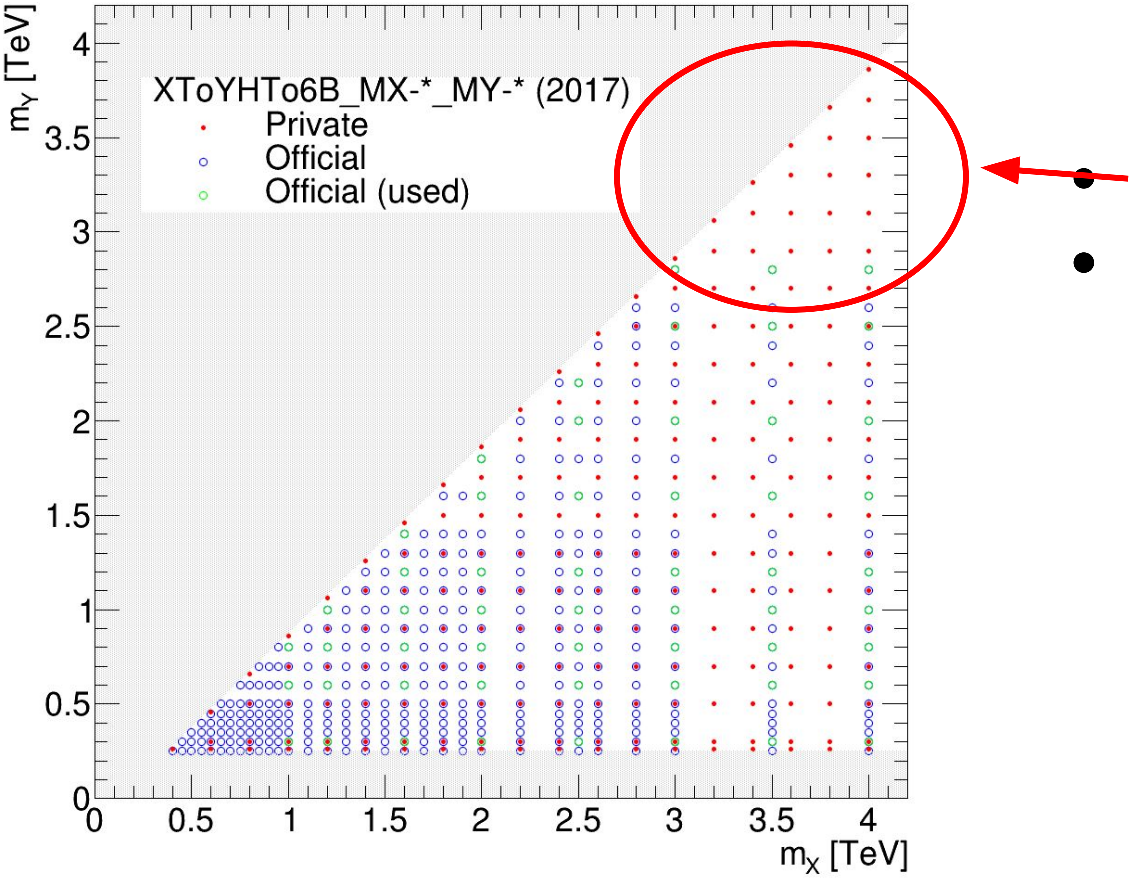

- Missing official Run 2 samples
- Requested the following (m_X, m_Y) points:
  - (2500, 2300), (3500, 3000), (3500, 3300), (4000, 3000), (4000, 3500), (4000, 3800)

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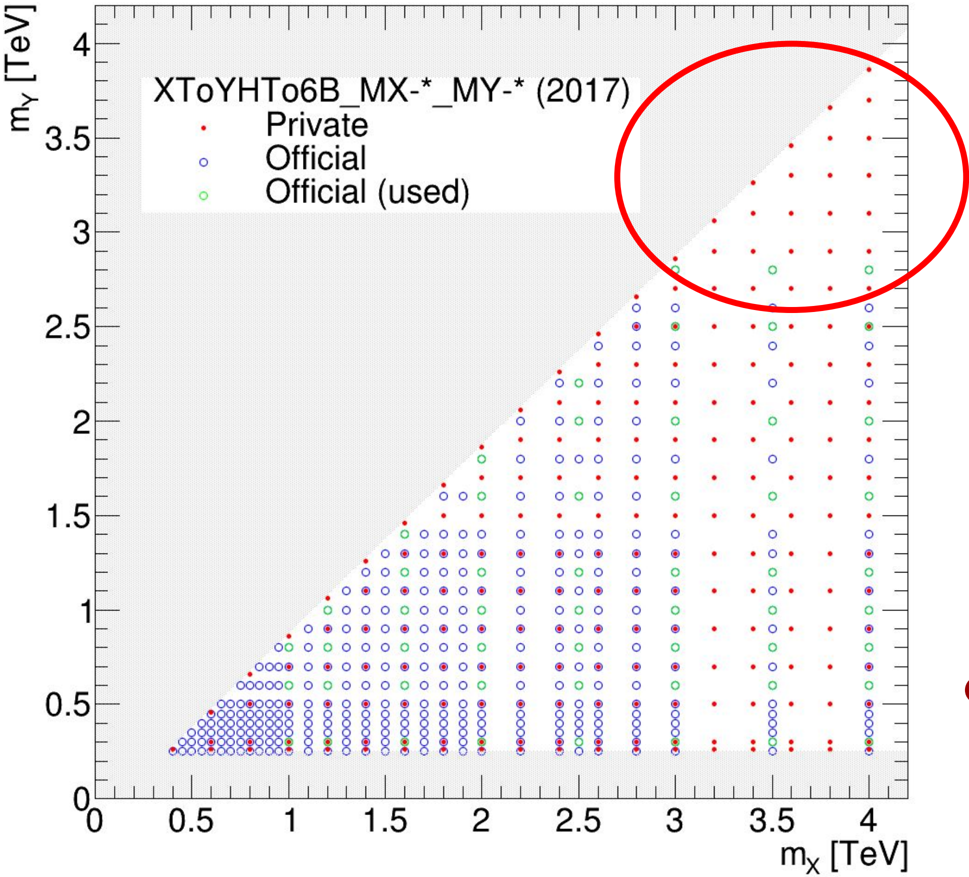

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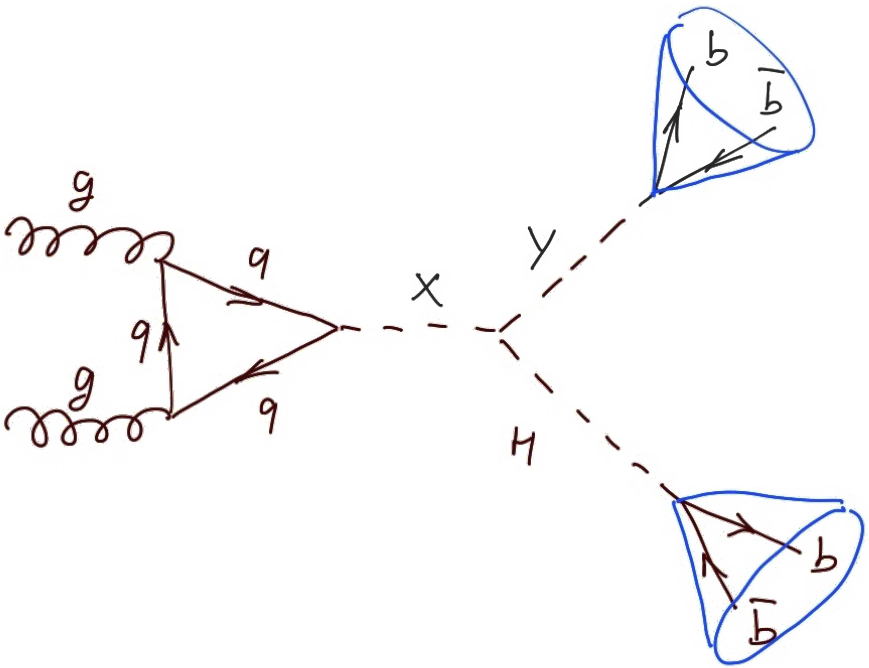
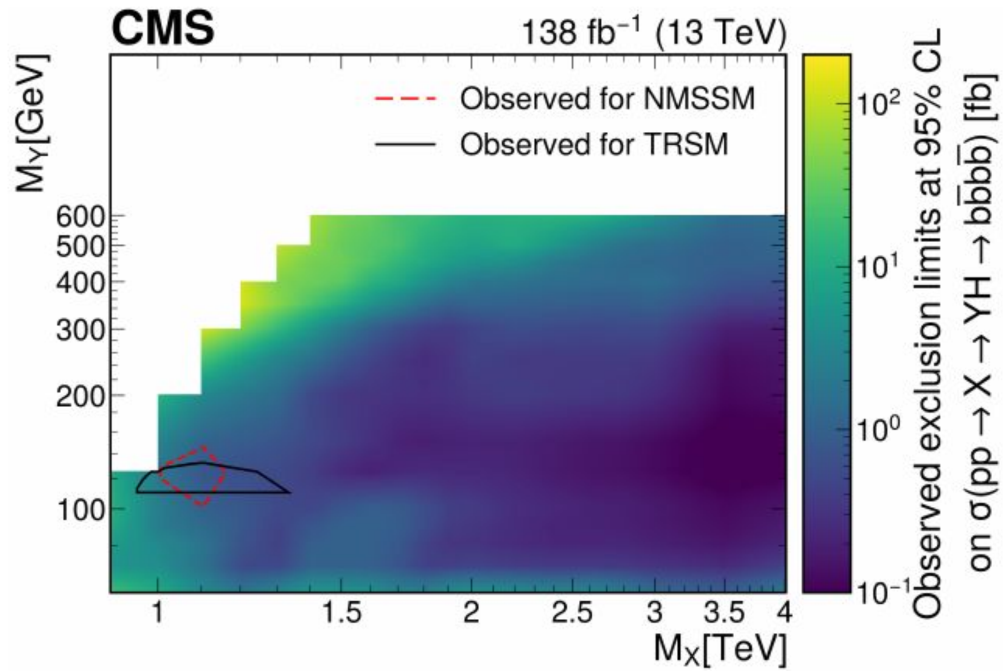
- How (un)realistic are these?

Where is this relevant?

- It is relevant when comparing experimental limits with theory predictions
- Example of X→HY→4b

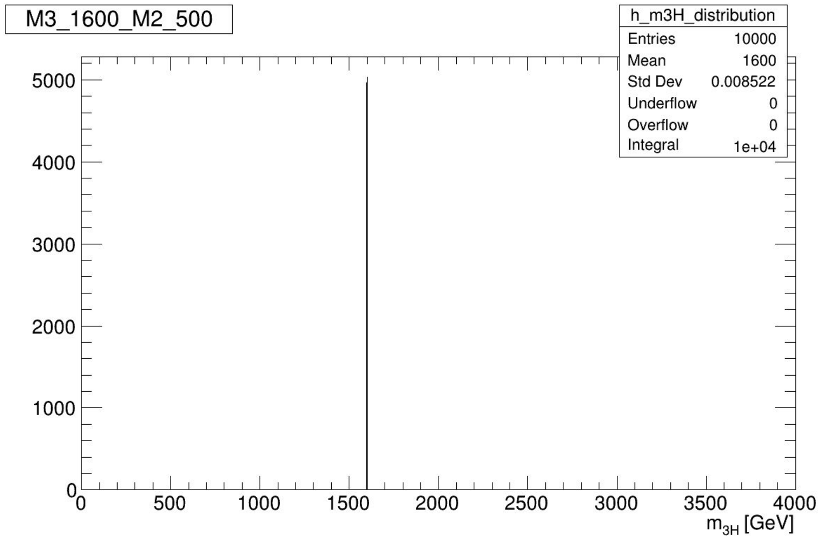
[Phys. Lett. B 842 (2023) 137392]



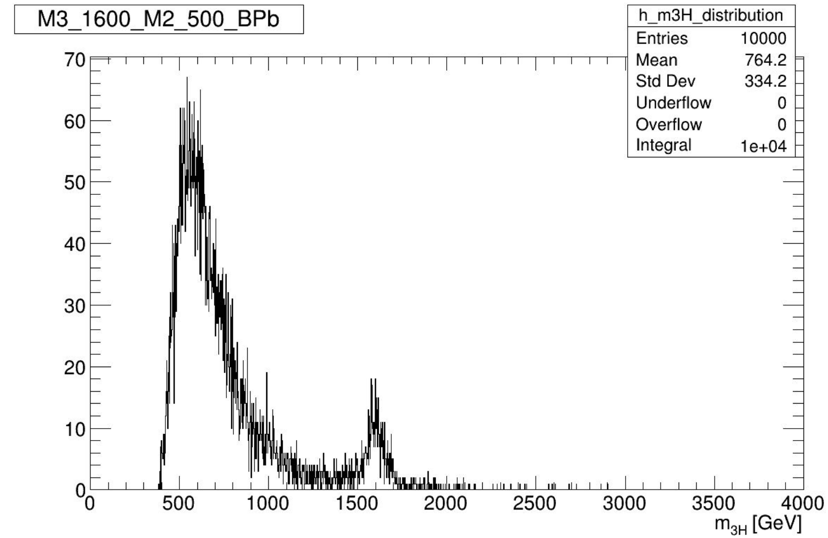


Model comparison

NMSSM (narrow width)



TRSM



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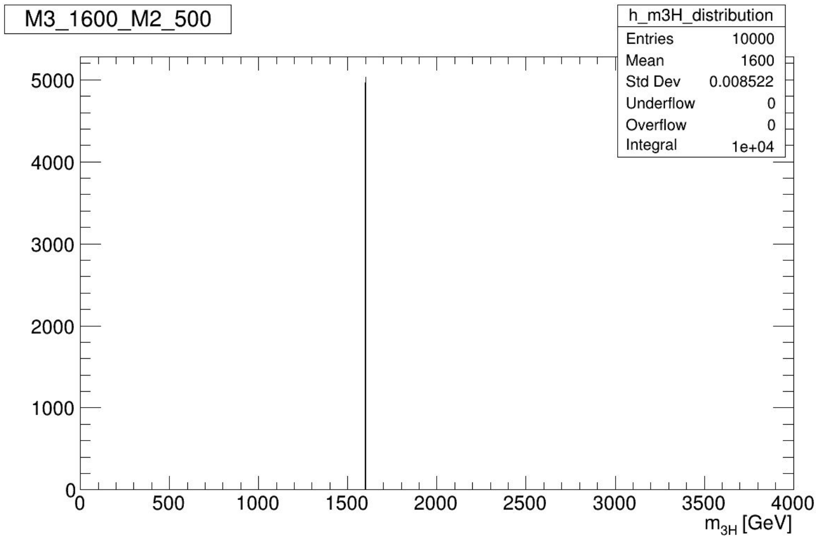
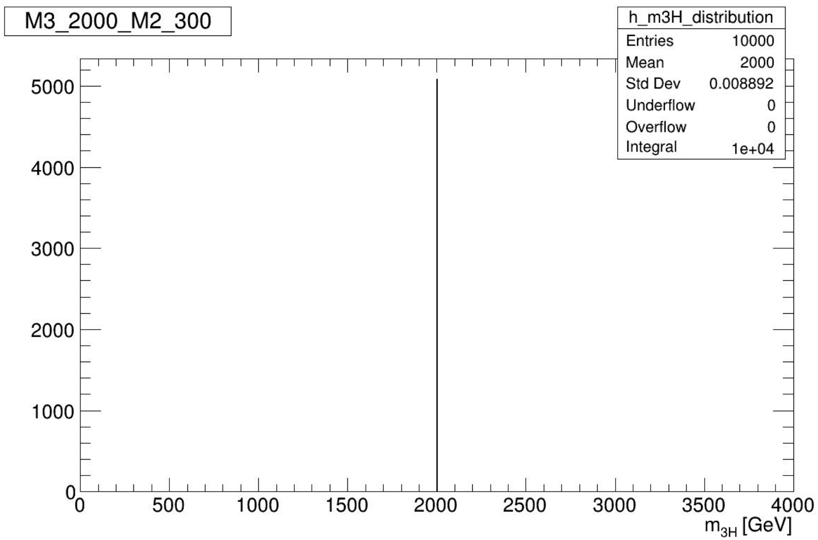
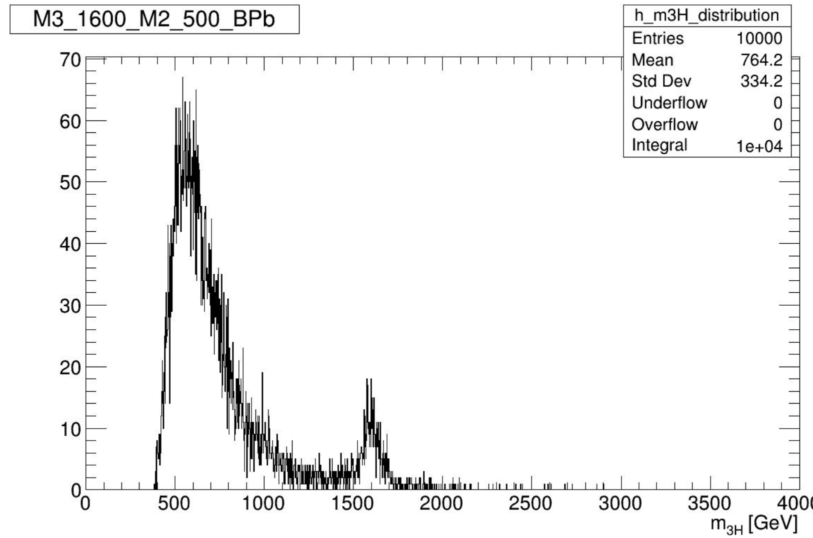
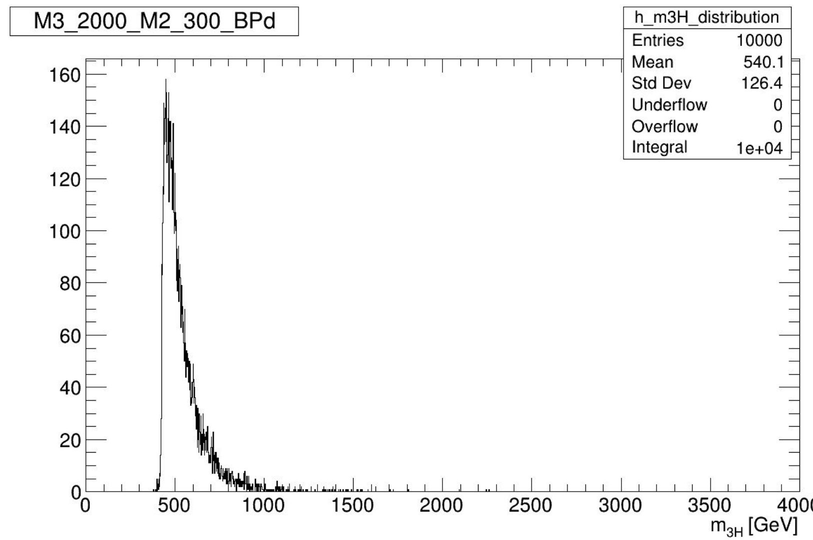




TRSM





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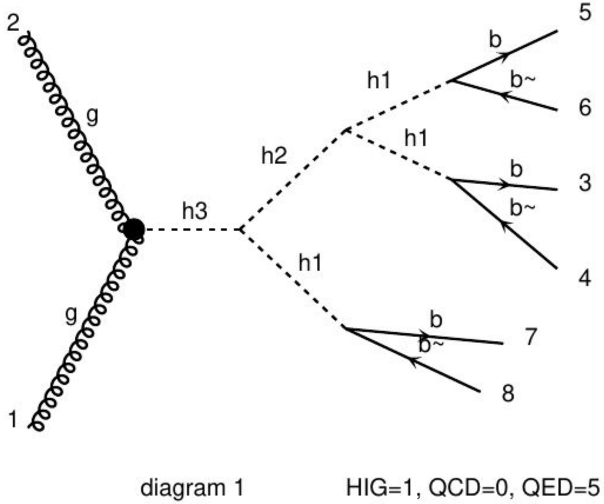
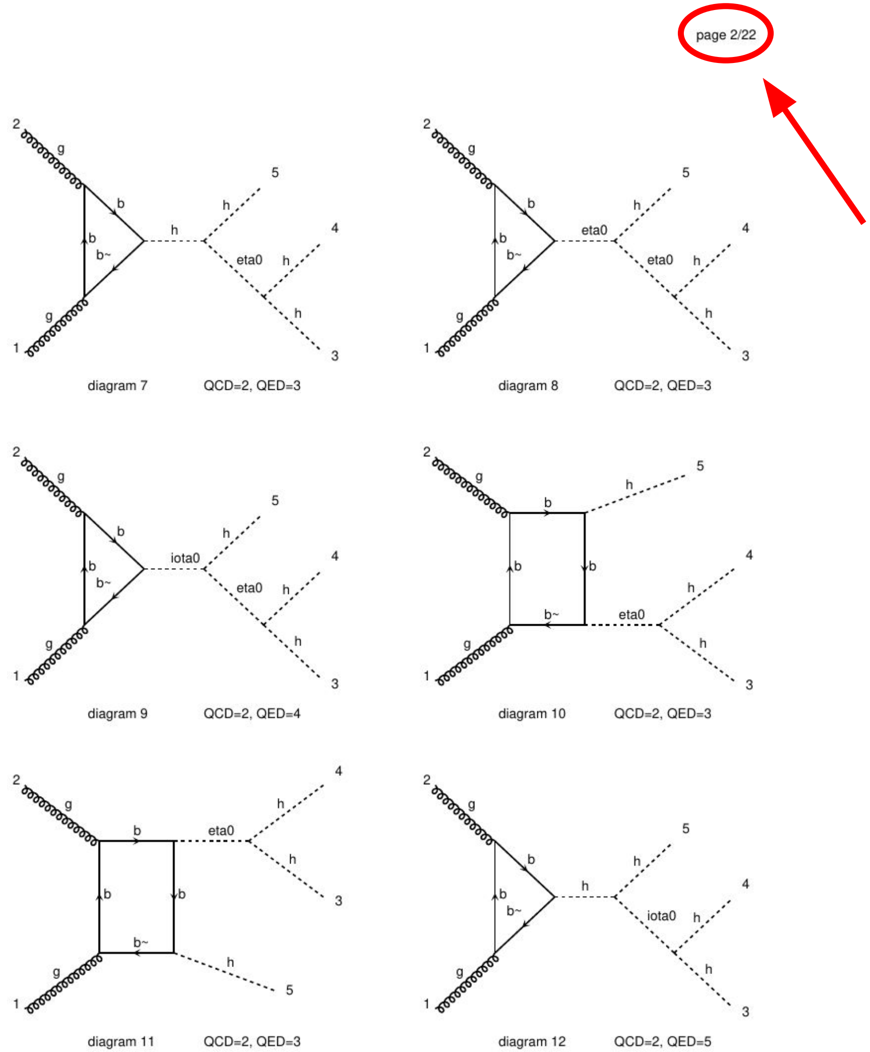


TRSM



Concluding remarks

- Experimentalists like to produce model-independent limits
- Experimentalists like to compare their limits with theory
- However, need to be careful that such comparisons actually make sense

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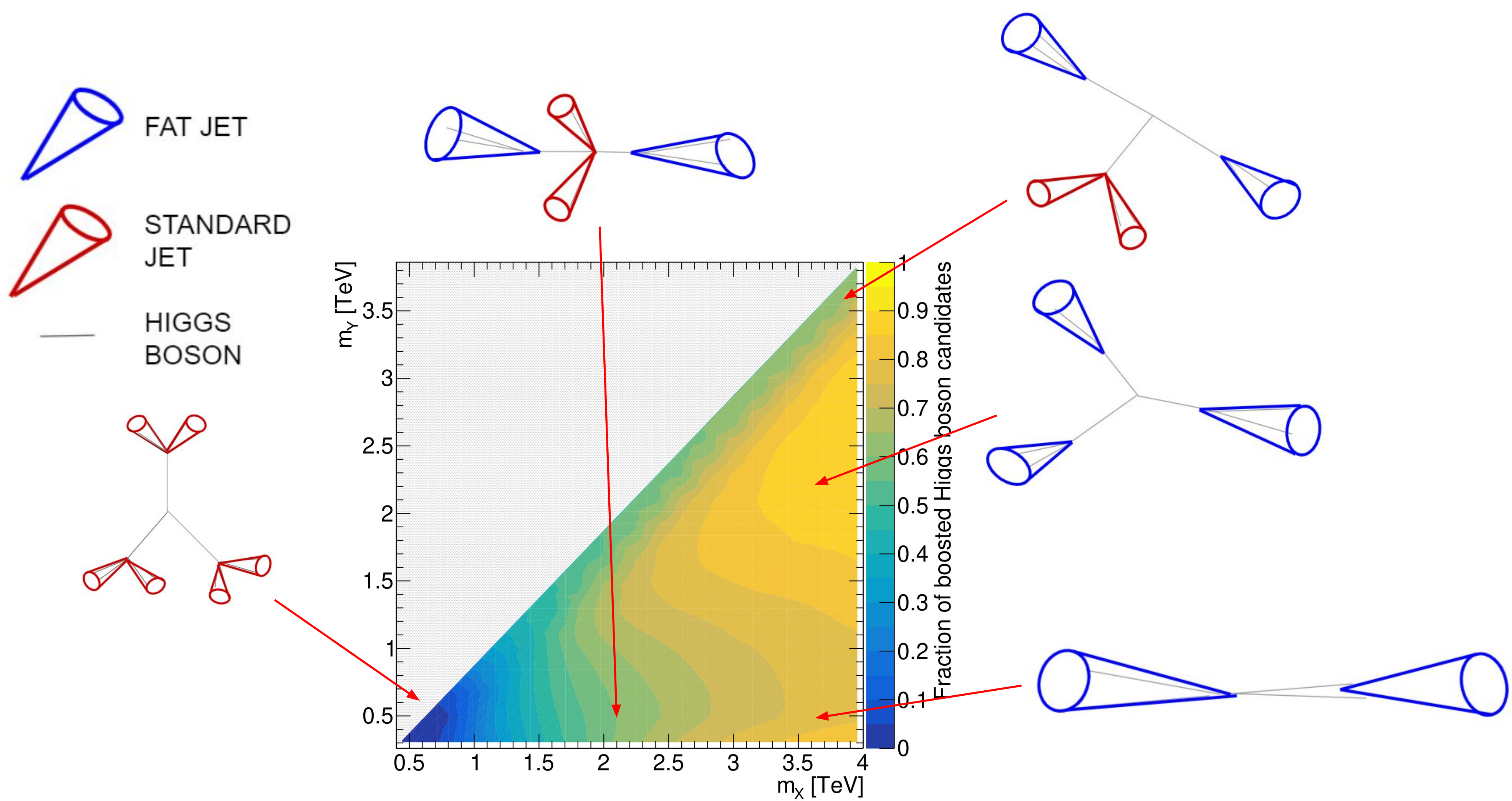
- Hope to have public results available for the next HHH workshop

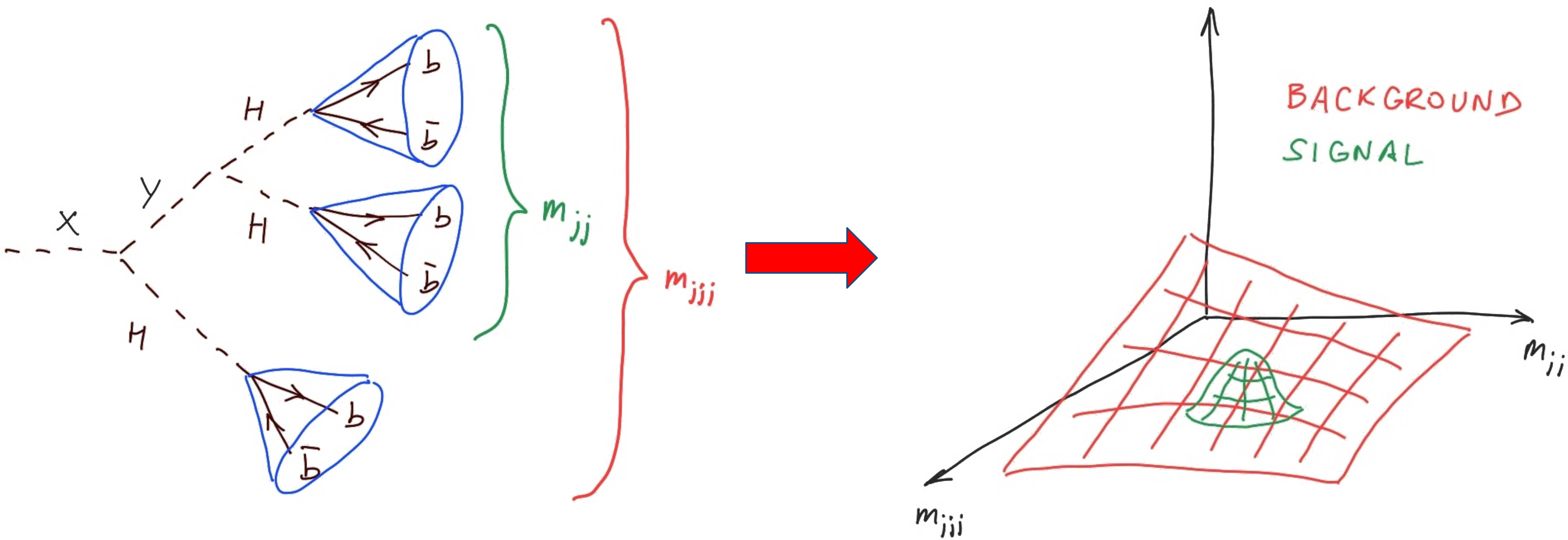
Backup

Final state topologies (generator level)



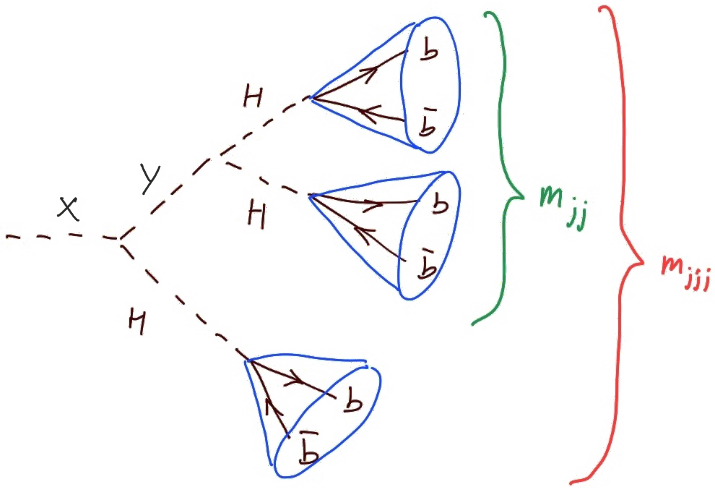
Search strategy

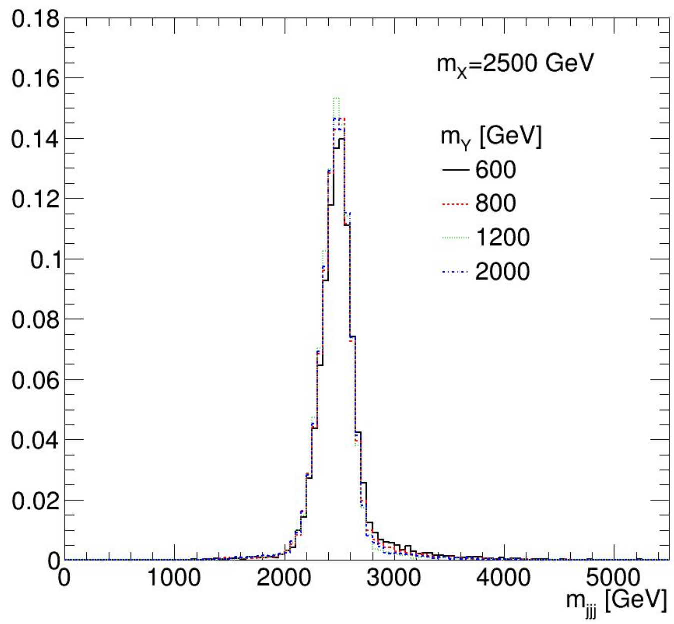
- Presence of two massive resonances X and Y in the final state
  → **2D bump hunt**

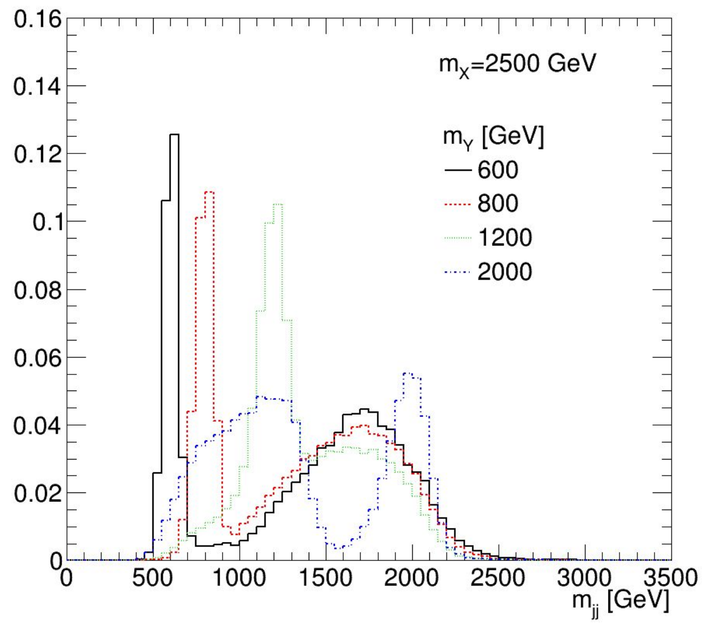


m_{jjj} and m_{jj} distributions

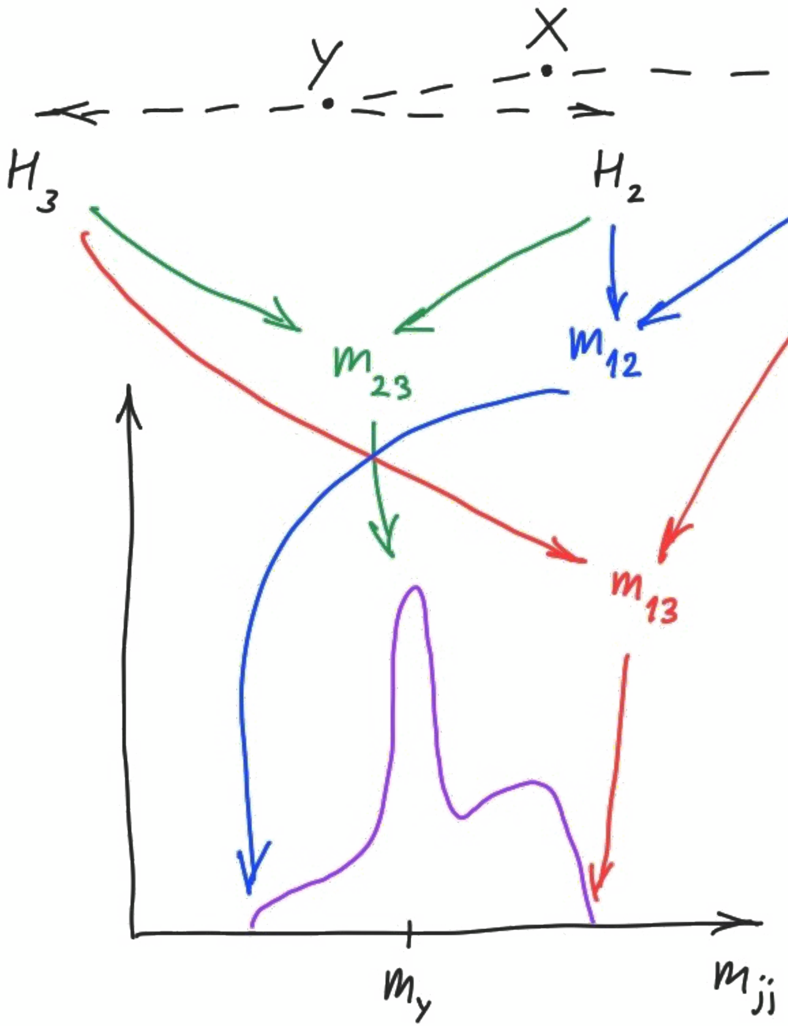
- Trijet mass m_{jjj} straightforward
  - Invariant mass of the 3 Higgs candidates
  - Expect to see a peak at m_X
- Dijet mass m_{jj} less straightforward
  - 3 possible pairs. No general way to find the right combination
    → Solution: take all 3 pairs (3 entries per event!)
  - Still expect to see a peak at m_Y





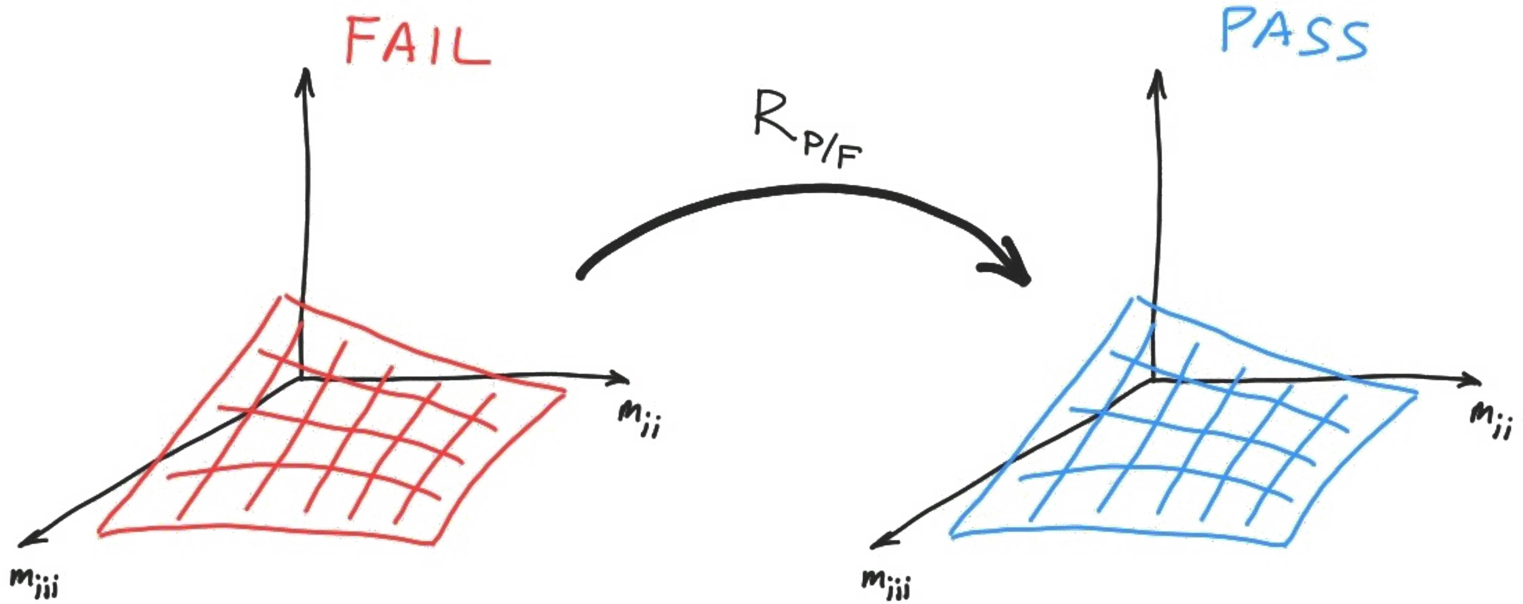


m_{jj} distribution features



Background estimation method

- Fully hadronic final state → Dominant background from SM multijet production ("QCD") → Data-driven background estimation
- **2DAlphabet** method
  - Generalized ABCD method (see [Matej's talk] from 2022 Higgs Pairs Workshop)



- 2 event **categories**: signal-depleted fail and signal-rich pass category
- $\mathbf{R_{P/F}}$ **transfer function** relates backgrounds in the two categories

A bit of 2DAlphabet algebra

- More specifically, a smooth $R_{P/F}$ transfer function relates event yields of the data-driven background components in the pass (P) and fail (F) categories
- Event yields in the *i*-th bin are related as follows:

$$n_F^{\mathrm{QCD}}(i) = n_F^{\mathrm{data}}(i) - n_F^{\mathrm{bkg,\ MC}}(i)$$

Background component in the fail category taken from MC

$$n_P^{\mathrm{QCD}}(i) = n_F^{\mathrm{QCD}}(i) \cdot R_{P/F}(i)$$

Fully data-driven background estimation with this component set to 0

- $R_{P/F}$ modelled as a simple low-order 2D polynomial, e.g.

$$R_{P/F}(x, y) = a + b \cdot x + c \cdot y$$