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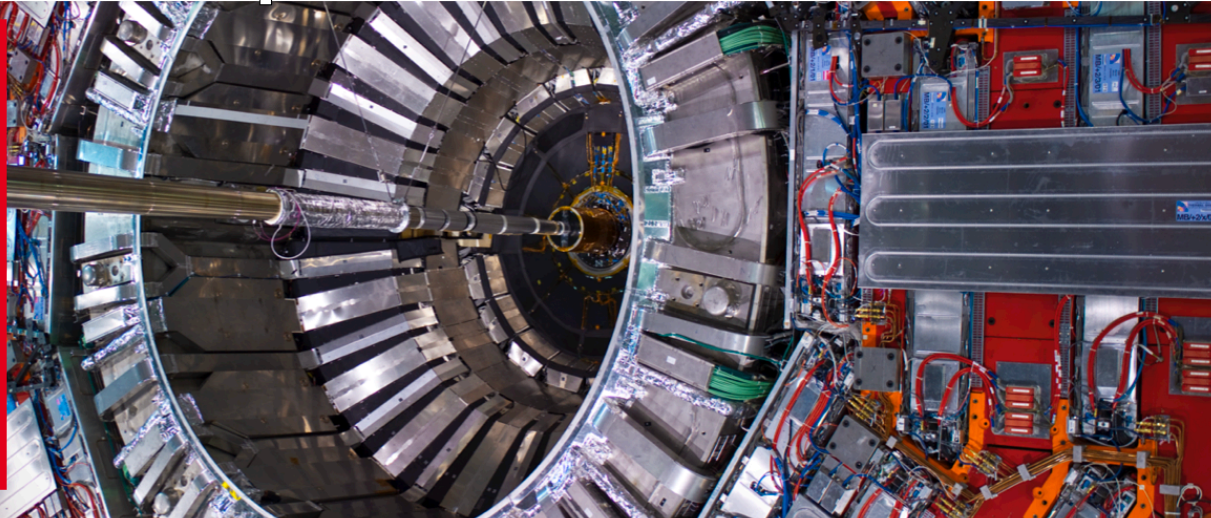
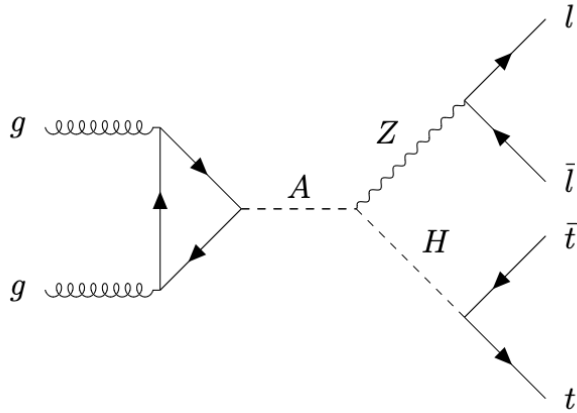
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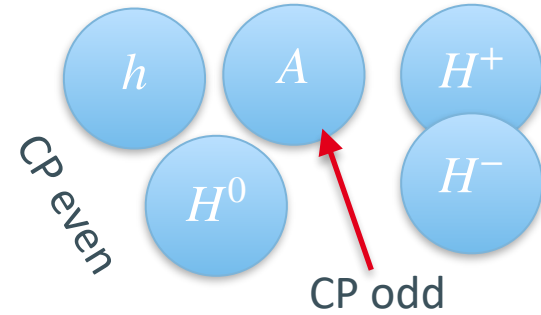
Matteo Bonanomi, Lukas Ebeling, **Yannick Fischer**, Johannes Haller, Daniel Hundhausen, Matthias Schröder, Bianca Weidner

Search for 2HDM Heavy Higgs Bosons in the $t\bar{t}Z$ Final State at CMS

DPG spring conference 2025, Göttingen

Two Higgs Doublet Model (2HDM)

- Additional Higgs doublet $\rightarrow$ **5 Higgs bosons**
- Important free parameters:
 - $\tan(\beta) = \frac{v_1}{v_2}$
 - $\cos(\beta - \alpha) \rightarrow 0$ (alignment-limit, ensures SM-like behavior of h)



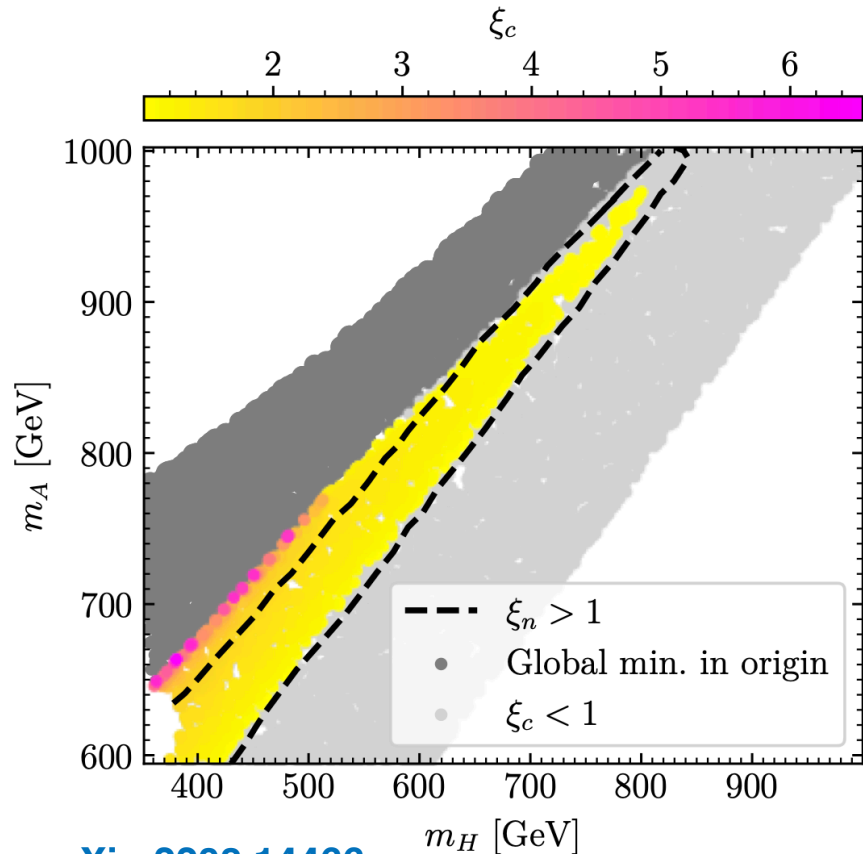
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- JHEP06(2020)163



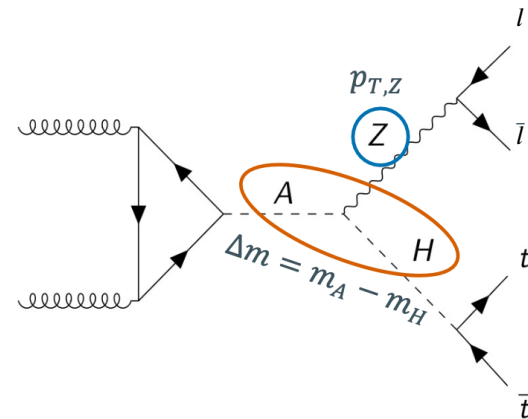
First order electroweak phase transition

- For this analysis: assume $m_A \neq m_H$
- Dubbed smoking gun channel for first order electroweak phase transition
- Possible explanations for matter/antimatter asymmetry may include extend Higgs sectors

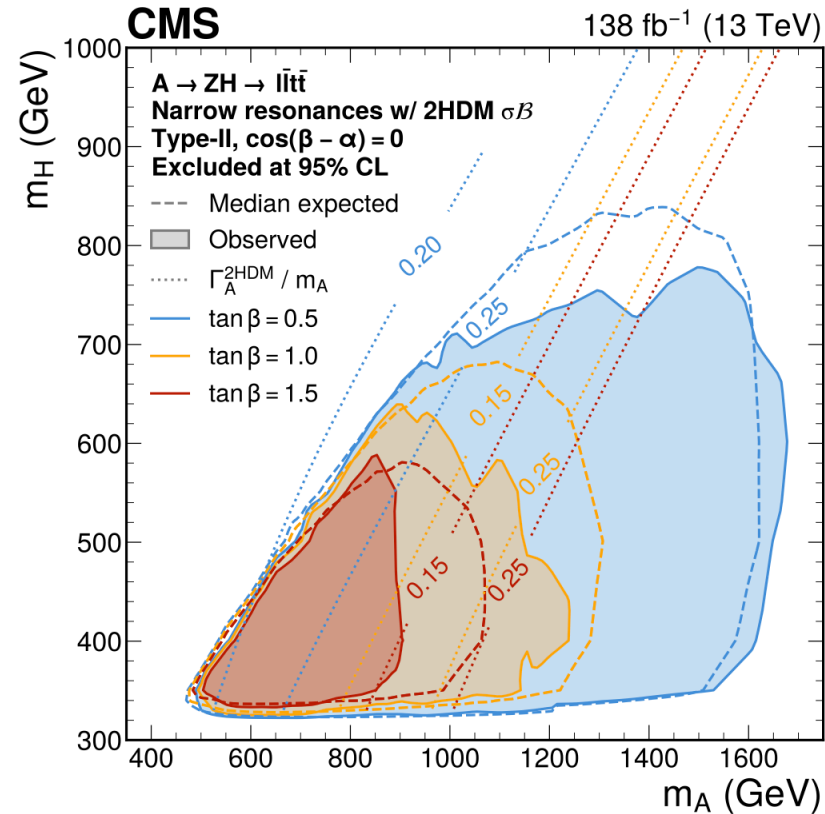


Search for 2HDM Higgs bosons in $t\bar{t}Z$ final state

- Run 2 analyses targeting resonant $A \rightarrow ZH(\rightarrow t\bar{t})$ production
 - ATLAS ($t\bar{t} \rightarrow \text{leptons+jets}$): 2.85 σ local excess observed at $m_{A/H} = 650$ GeV [JHEP 02 \(2024\) 197](#)
 - CMS ($t\bar{t} \rightarrow \text{all jets}$): [arXiv:2412.00570 \(subm. to PLB\)](#)
 - excess not confirmed
 - Final sensitive observable: 2D distribution of $p_T(Z)$ and $\Delta m = m_A - m_H$ [JHEP 151 \(2018\)](#)



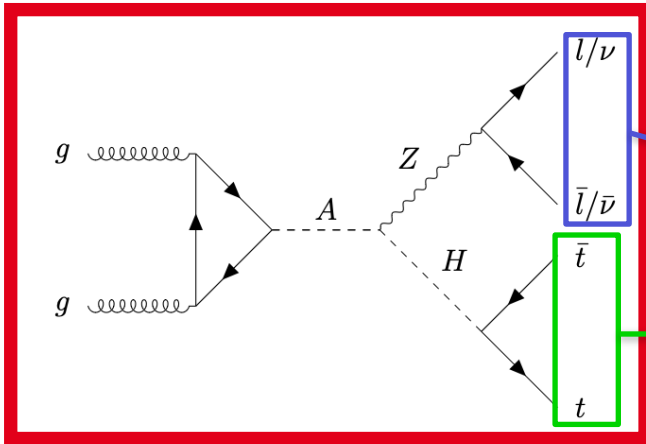
Excluded 2HDM parameter space



[arXiv:2412.00570](https://arxiv.org/abs/2412.00570) (subm. to PLB)

Run 3 Analysis

- Luminosity used so far: 7.96 fb^{-1} (first half of 2022 data taking period)

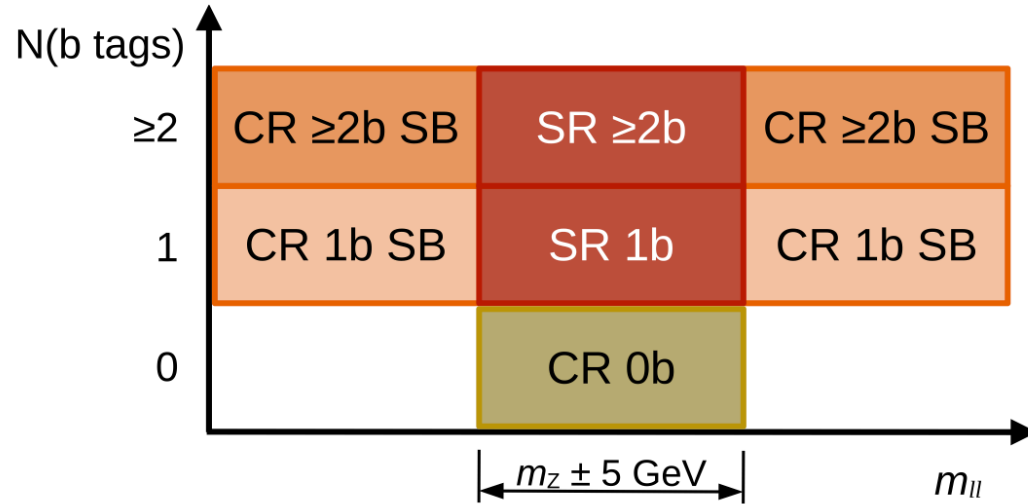


- Event selection:

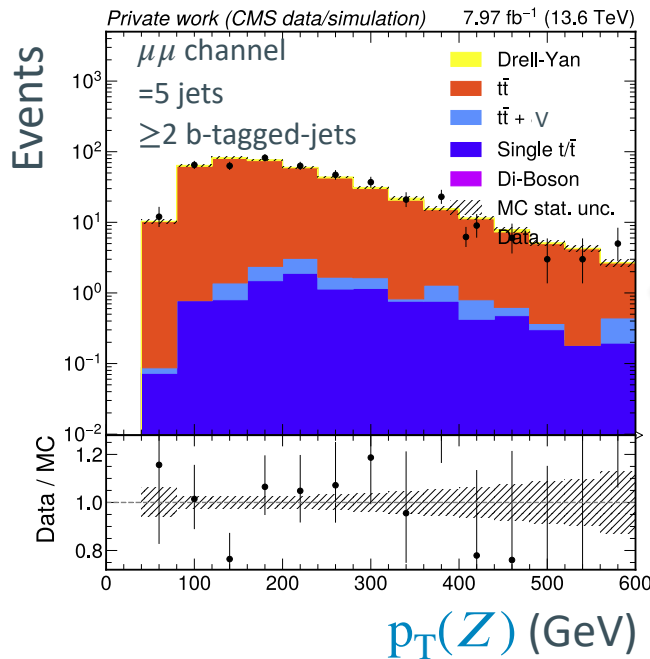
- Exactly 2 opposite-sign, same-flavour leptons (e/μ)

- ≥ 5 jets, ≥ 1 of which b-tagged

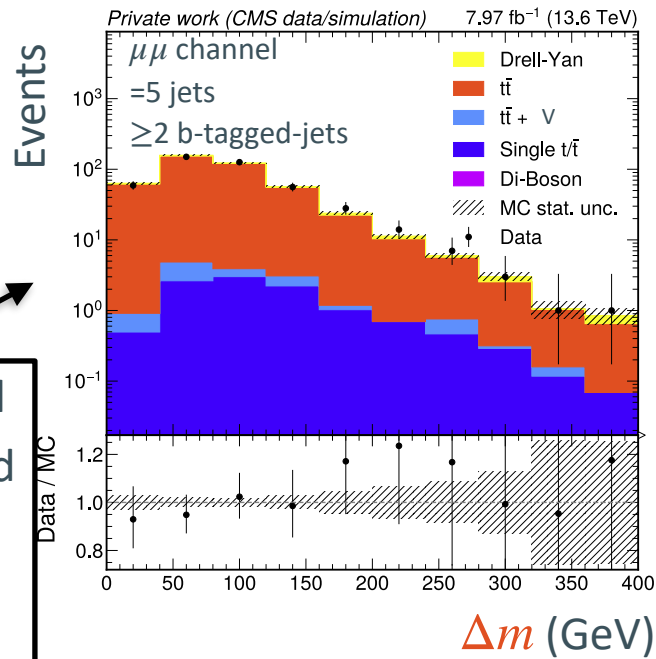
- **Signal categories** defined with respect to number of jets and number of b-tagged jets
- Background control regions:
 - m_{ll} outside Z mass window (SB) for $t\bar{t}$
 - 0 b-tagged jets and 4 jets for DY



Data in the CR modelled well

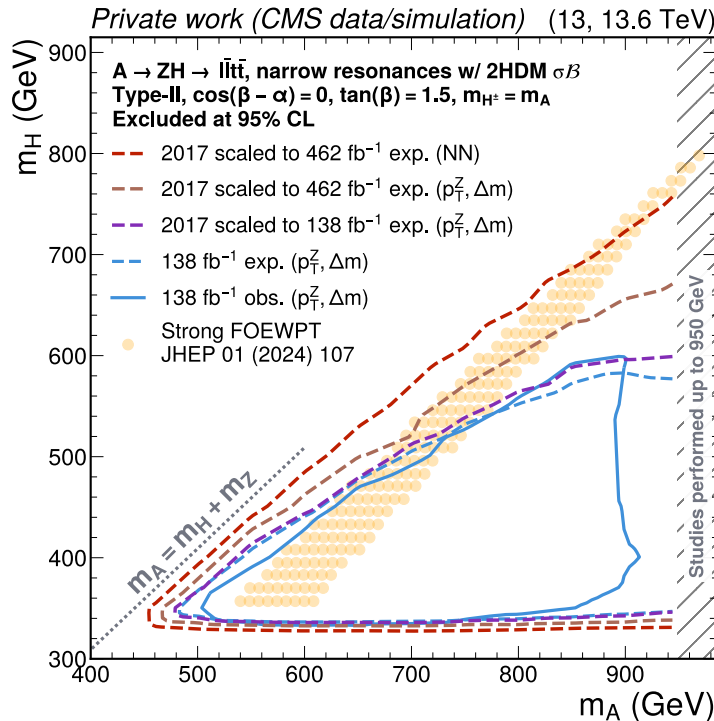


m_{ll} sideband
 ≥ 2 b-tagged
 jets
 = 5 jets
 μ channel



New analysis strategy

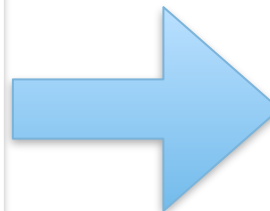
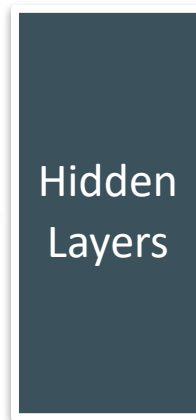
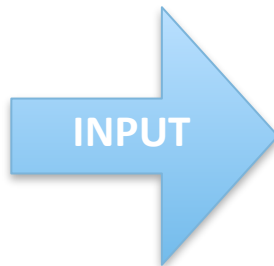
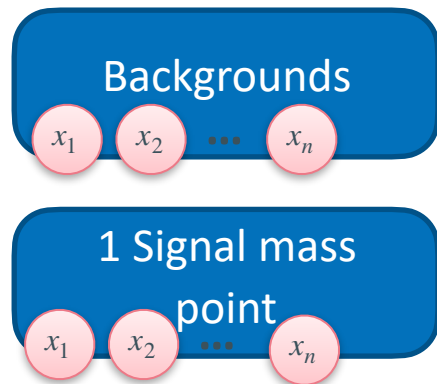
- Replace 2D distribution ($p_T, \Delta m = m_A - m_H$) with neural network (NN) output score
- projection of Run 2 data with NN approach promise significantly better limits



D. Hundhausen, PhD Thesis, Universität Hamburg

New analysis strategy

DNN

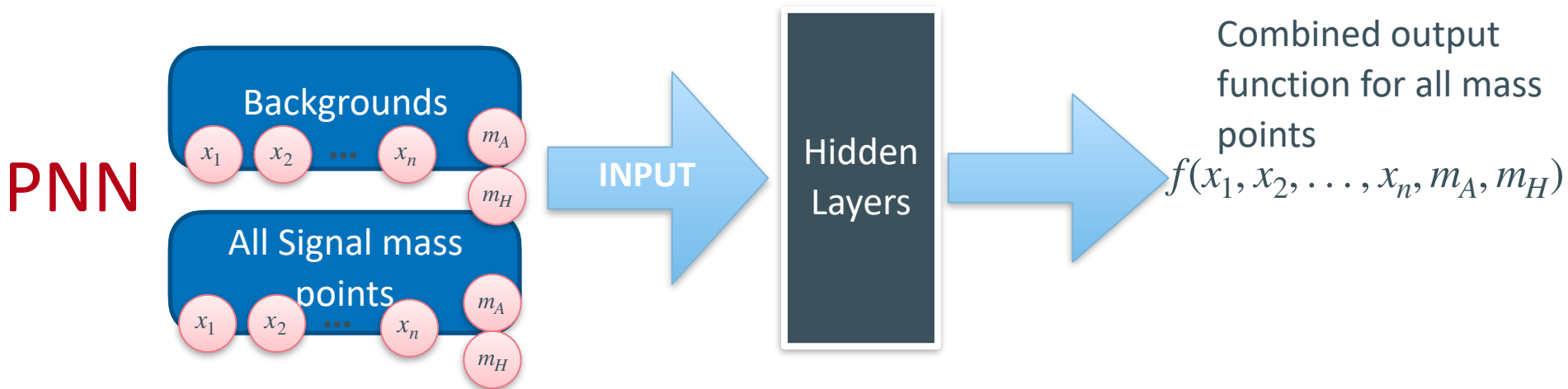


Output function for
each mass point

$$f(x_1, x_2, \dots, x_n)$$

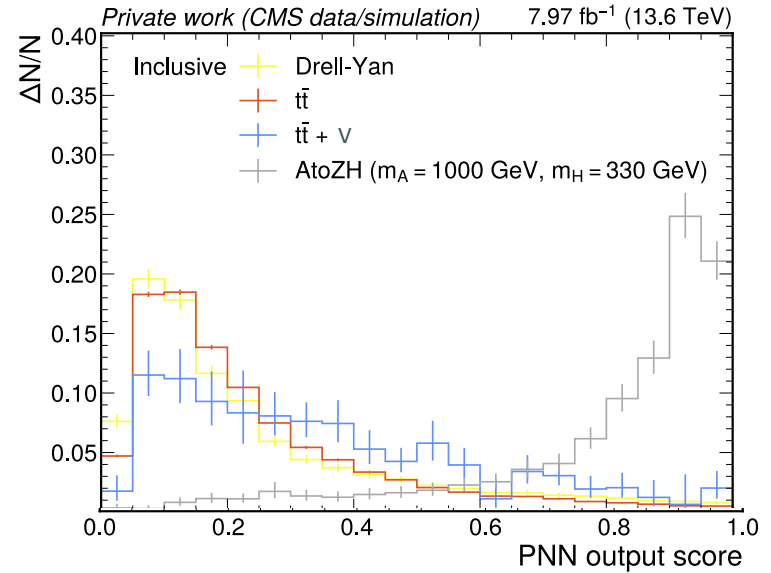
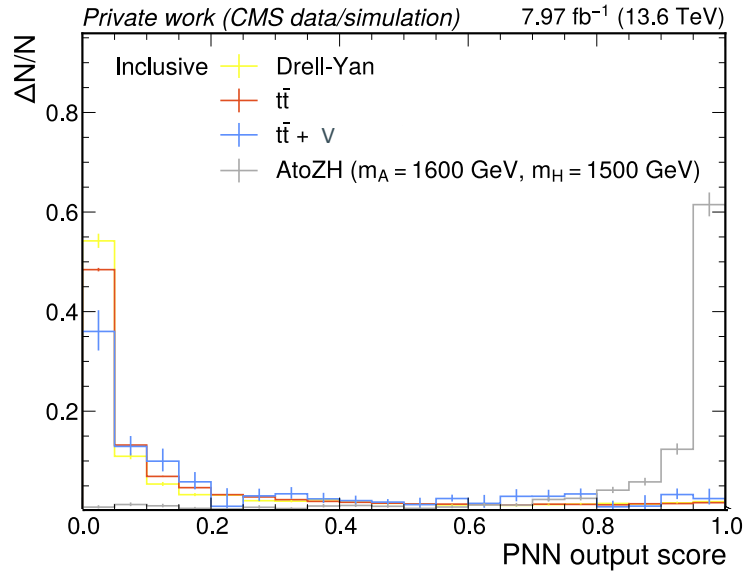
- Classic DNN: One network for each mass point

New analysis strategy

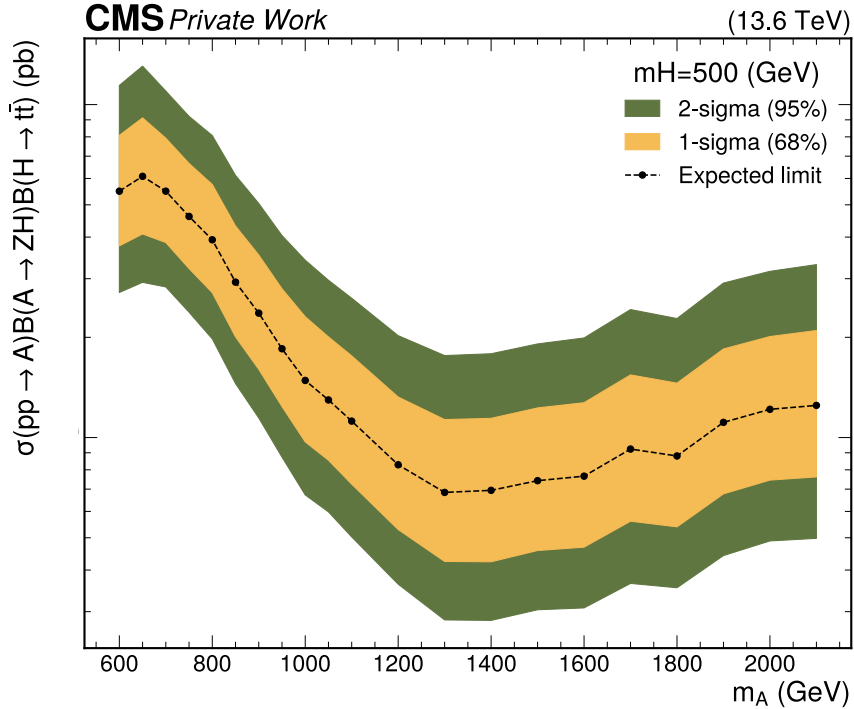


- Parametrized DNN: One network for all mass points
- Idea: Network learns signal topologies depending on m_A and m_H
- PNN only trained in the signal region

PNN output score

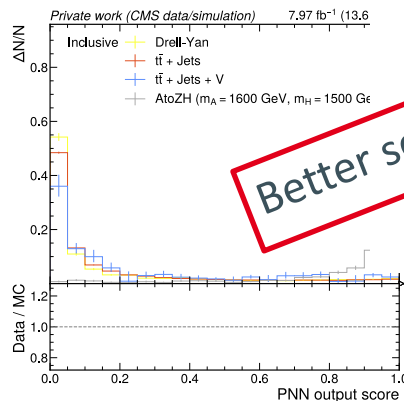


First limits with Run 3 data



- Analysis workflow in place, now ready to head out and start exploring the rest of the parameter space

- $A \rightarrow ZH \rightarrow t\bar{t}Z$ probes interesting 2HDM parameter space
- Search with Run 2 data enters unknown territory
- Improvements for Run 3 analysis under development



Better sensitivity

