

Assigning Jets to the Fully-Hadronic $HH \rightarrow bbWW$ Final State Using a Symmetry-Preserving Attention Network

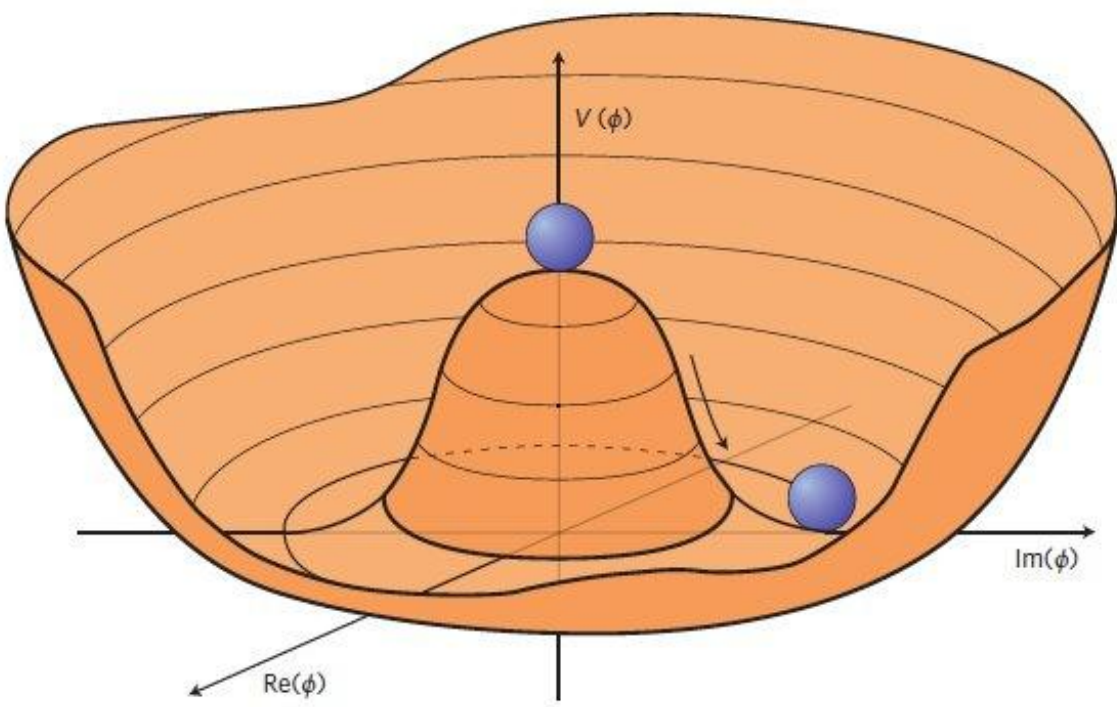
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INTRODUCTION

Studying Di-Higgs production is useful since it...

- Helps understand the shape of the Higgs potential.
- Helps explore *how* particles in the standard model gain their mass.



A prototypical effective 'Mexican hat' potential that leads to 'spontaneous' symmetry breaking. The vacuum, i.e., the lowest-energy state, is described by a randomly-chosen point around the bottom of the brim of the hat. [1].

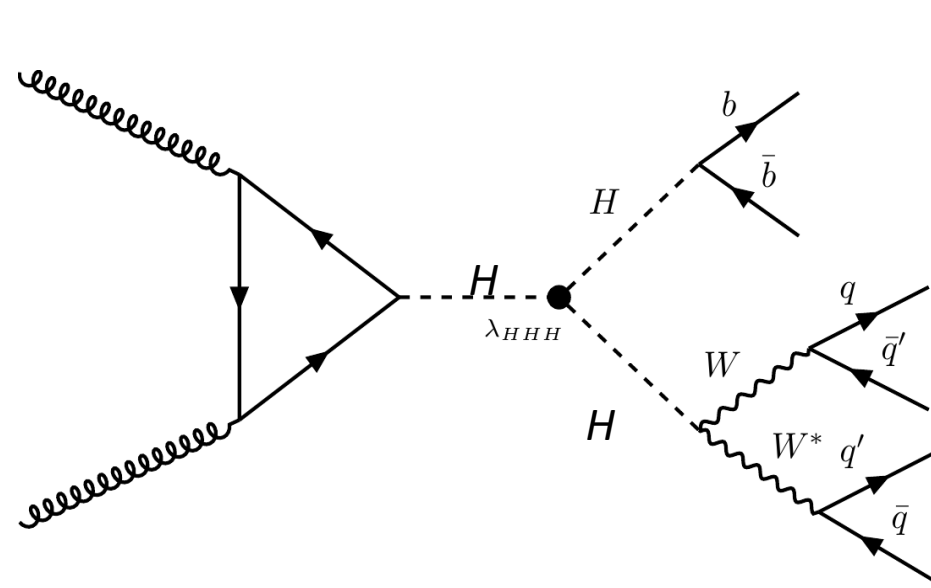
HOW TO MEASURE DI-HIGGS PRODUCTION

A Higgs decays instantly, so we detect what it decays into.

- Higgs 1:** two b-quarks (58%, the most common decay) [2]
- Higgs 2:** two W bosons (22%, the second most common) [2]
- Ws:** each decays to quarks ("4q") $\rightarrow$ gives highest yield of events.
 - Each W has a ~67% chance of decaying hadronically.

	bb	WW	$\tau\tau$	ZZ	$\gamma\gamma$
bb	34%				
WW	25%	4.6%			
$\tau\tau$	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
$\gamma\gamma$	0.26%	0.10%	0.028%	0.012%	0.0005%

Share of di-Higgs events for each pair of decays. $bbWW$ (red box) is 25% [3]



HHbbWW feynman diagram

CHALLENGES TO MEASURING DI-HIGGS

- One W from $H \rightarrow WW$ has mass < 80 GeV (harder to reconstruct)
- QCD multijet events: consequence of hadronic decays.
- Ttbar: $t\bar{t}bbWW(4q) \rightarrow$ same final state as signal.
- Comparison of cross sections show how rare signal process is.

Process	Cross section (how often process happens)
HHbbWW	3.5
QCD	Varies by pt (largest: 8.857×10^{11})
ttbar	4.084×10^5

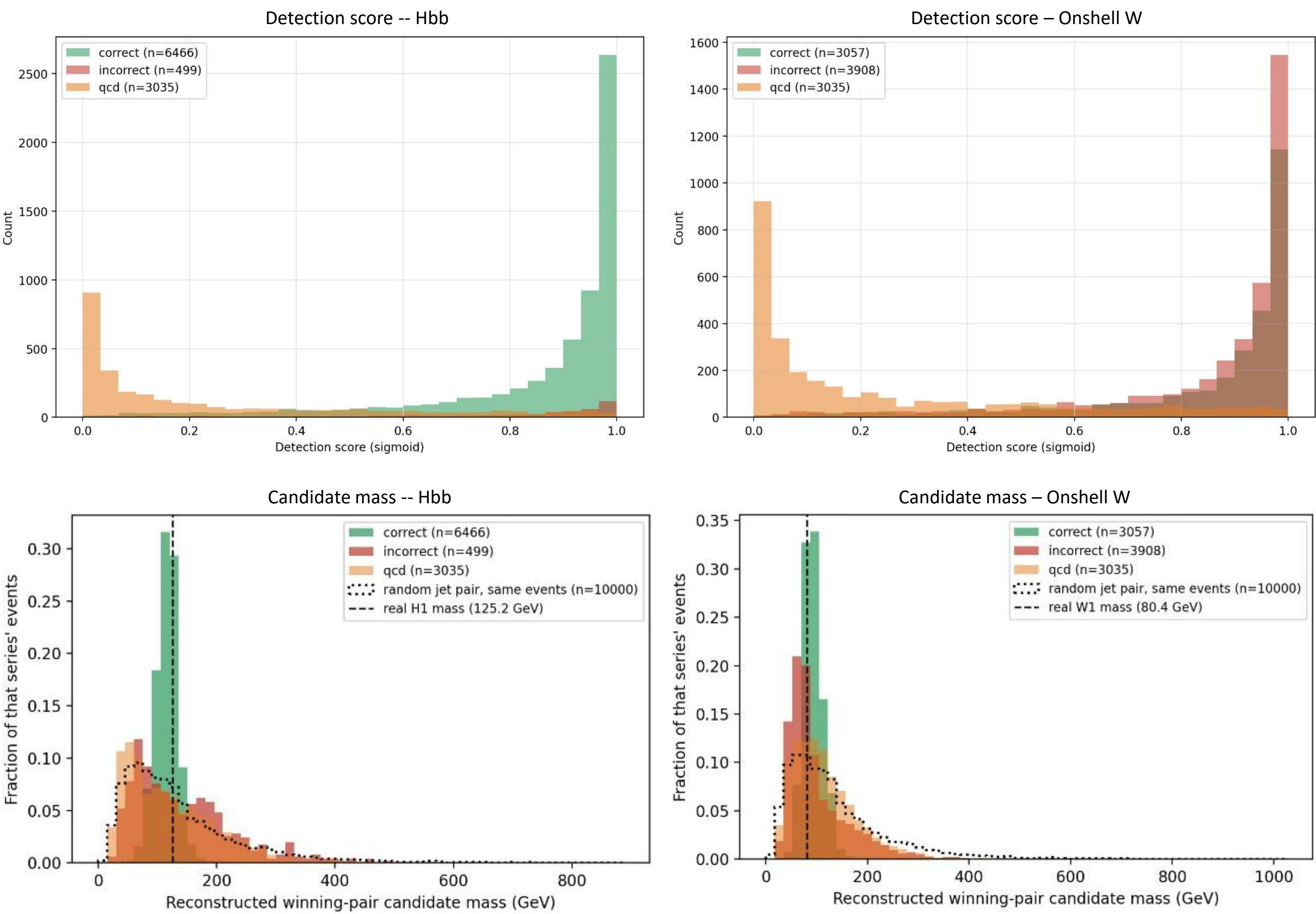
Current Results

The network separates signal from background.

Top: detection score. Signal events pile up near 1, background near 0.

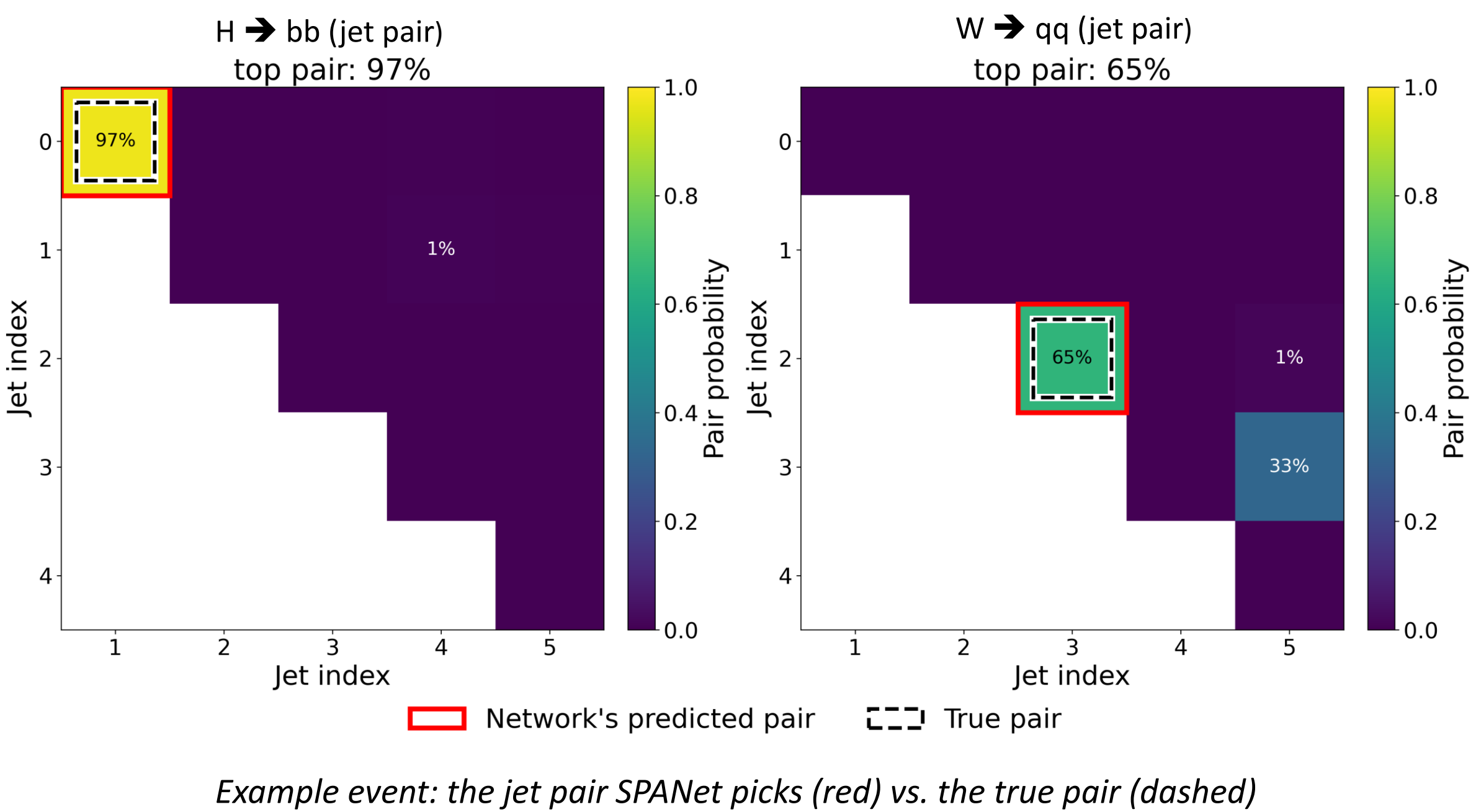
Bottom: reconstructed mass. Correct picks peak at the Higgs (125 GeV) and W (80 GeV) mass. Wrong picks and background look like random jet pairs.

Simulated events only: a first step toward seeing HH in real data.



Symmetry Preserving Attention Network (SPANet)

- In:** kinematic variables (pt, η , ϕ , energy) and tagging information (btag, ctag, quark-gluon discriminator).
- Train:** on simulation, where correct jet assignments are known; correct matches are rewarded & incorrect matches are punished.
- Out:** the most likely jet pair for each particle, plus a detection score for how signal-like the event is.



How the network functions

- Embedding:** each jet's momentum and tags become a long vector of numbers, so the network can describe every jet in rich detail.
- Central transformer:** attention lets every jet "look at" every other jet, so the network learns how jets relate across the whole event.
- Particle transformers:** one for each particle we want to rebuild ($H \rightarrow bb$, $W \rightarrow qq$). Each learns the jet relationships that matter for its own particle, which makes the assignment problem much easier.
- Tensor attention:** scores every possible jet pair (the matrix above). The highest score is the network's pick.

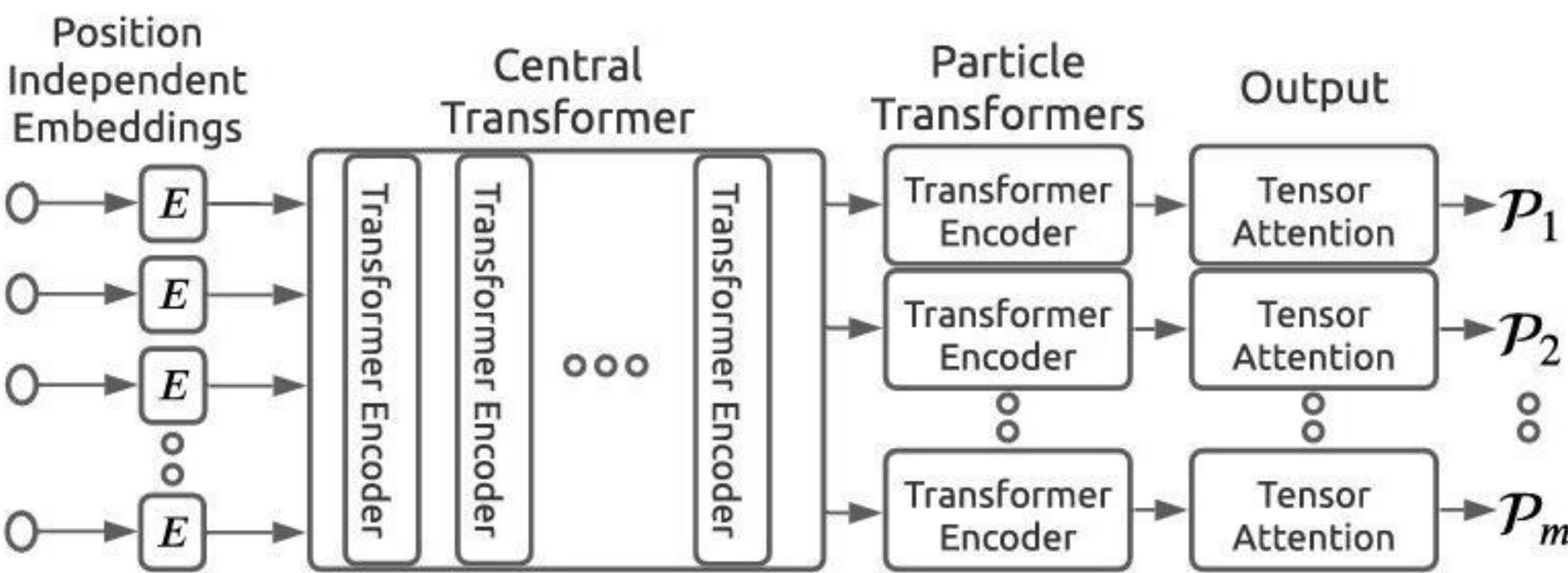


Diagram of SPANet architecture [4]

- Symmetry-preserving:** swapping two identical jets (e.g. the two b-quarks) can never change the answer.

Conclusion

Current work is showing promise, but more work is needed to improve results further.

$\rightarrow$ Even with this detection score, background still dominates

Next step: a combined fit.

$\rightarrow$ Current variables: Higgs masses, W mass, and detection score.

$\rightarrow$ Signal and background look different in each, so a combined fit may help separate signal from background further

REFERENCES

- [1] J. Ellis et al, 2015, "A Historical Profile of the Higgs Boson"
- [2] H. Okawa, 2017, "Measurements & BSM Searches in the Higgs Sector at the LHC"
- [3] J. Veatch, 2022, "Searches for Resonant Scalar Boson Pair Production Using Run 2 LHC Proton-Proton Collision Data"
- [4] A. Shmakov, et. al, 2022, "SPANet: Generalized permutationless set assignment for particle physics using symmetry preserving attention"