

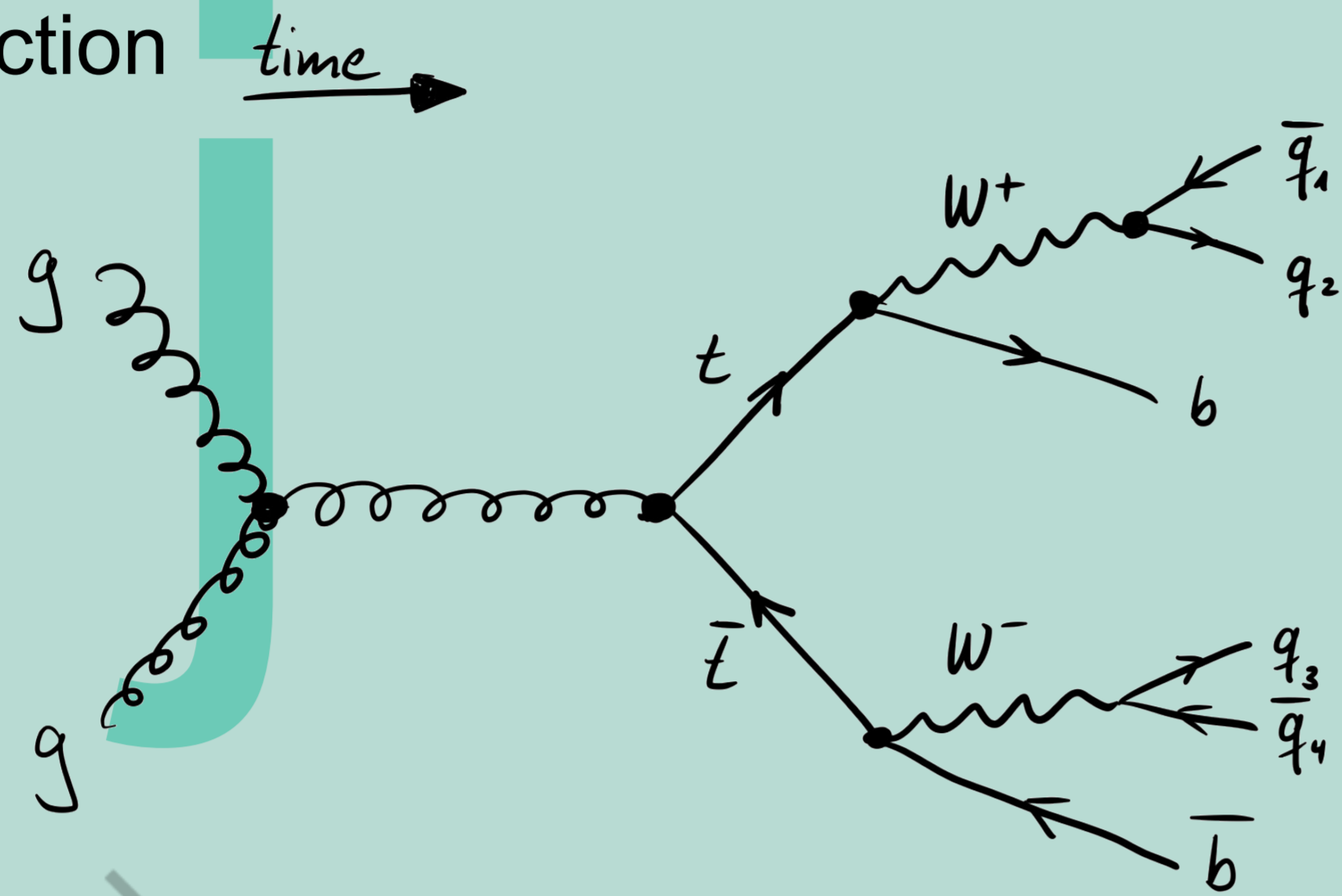


# Solving high multiplicity final states using Graph Neural Networks

- Physics Application of AI Day -

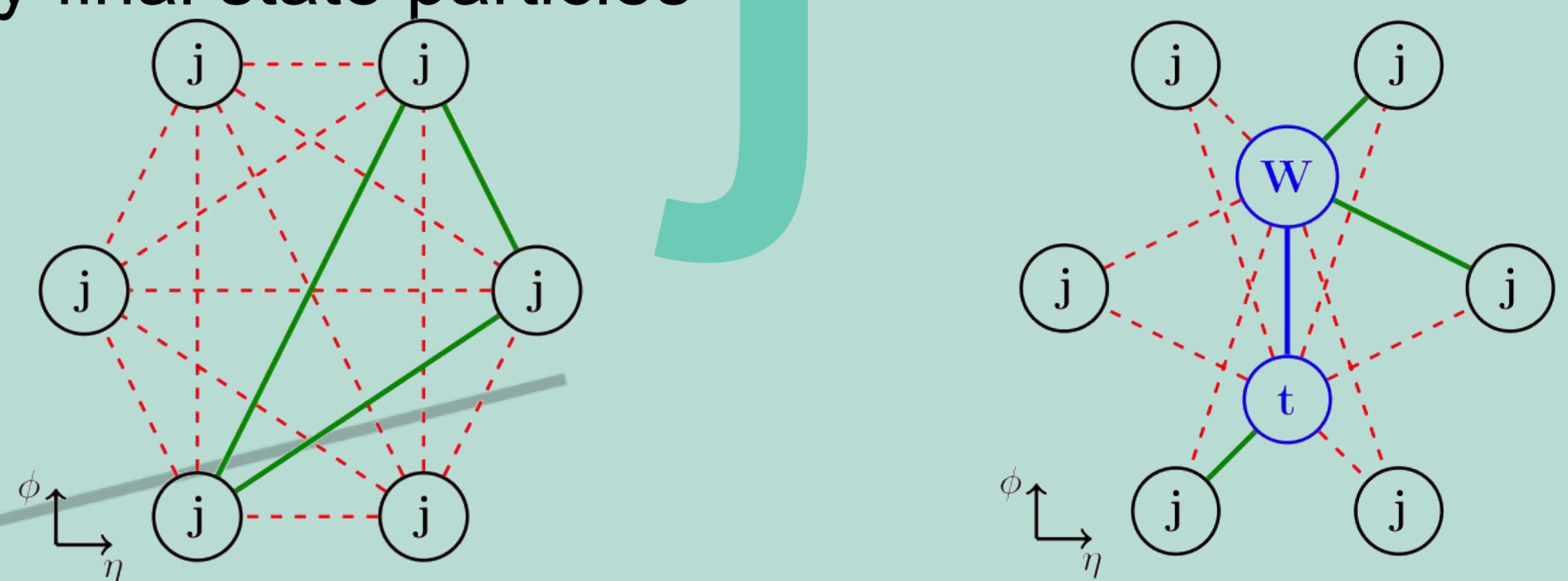
## Problem

- Many final states in the ATLAS experiment have multiple of the same objects in the final state
- Assigning the final state particles to their respective mother particle has many advantages
  - Kinematics of the mother particles
  - Background reduction
- Ttbar pairs can lead to **up to six jets** with four intermediate particles
- Different methods already exist
  - KL Fitter [1]
  - SPA Net [2]



## Idea

- Represent final state particles as **point cloud**
- Insert **helper nodes** as intermediate particles
  - Can use these nodes to regress towards true values of these particles
  - More information should lead to **better** performance
- Compared to fully connected graph, **O(N) edges instead of N(N-1)** with N final state particles
- Building Feynman diagram backwards
- Can **generalize** this approach to **any decay chain** with any final state particles



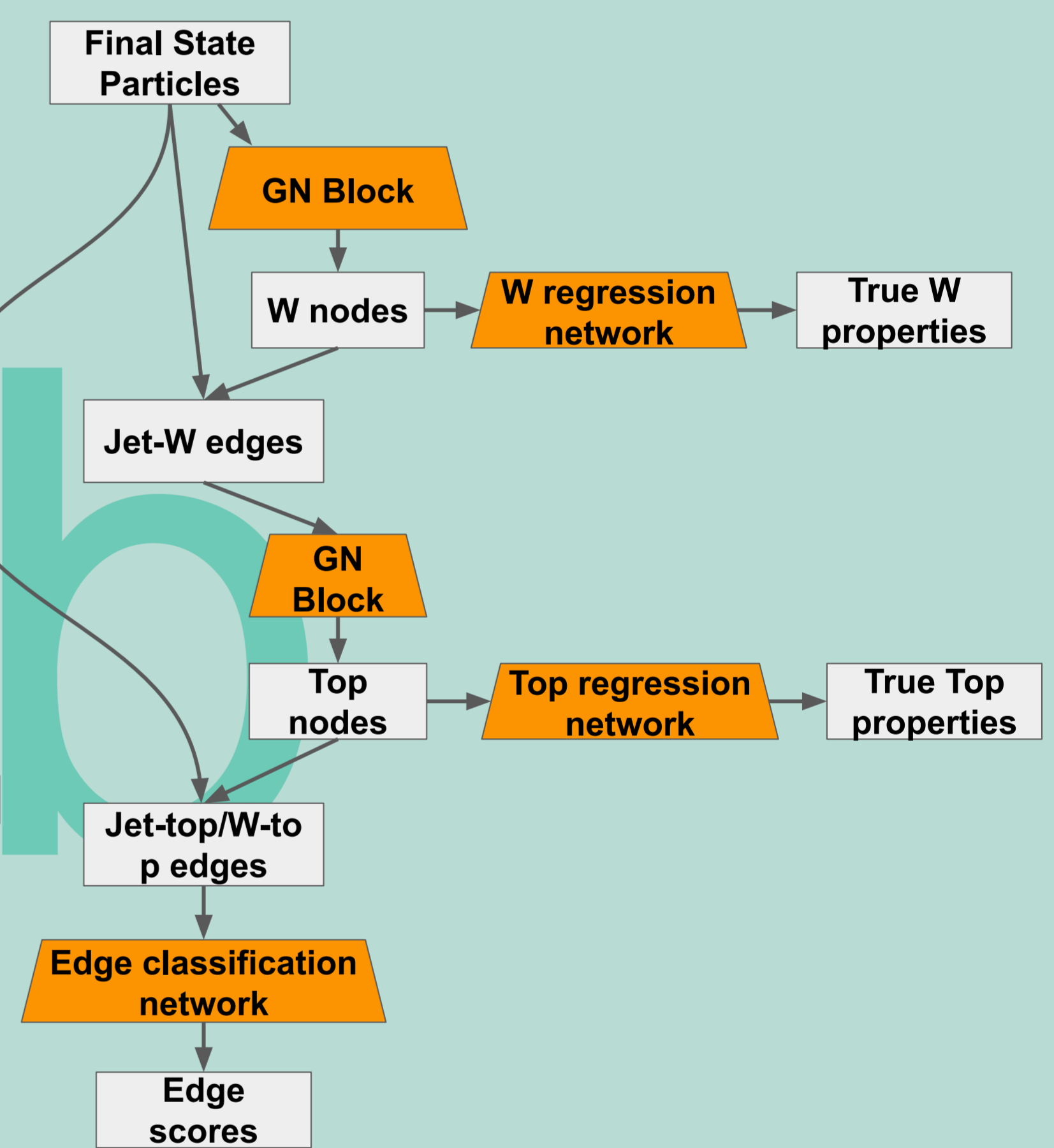
## Symmetric losses

- Only considering Ws for simplicity
- Can't distinguish between the two Ws with only the jets
- We need an order in the network and the predictions for technical reasons but the network could swap the order
- Make sure that we get the **best permutation** of the order of the Ws by using a **symmetric loss function**

$$\mathcal{L} = \min(\mathcal{L}(W_{true}^+, W_{pred}^1) + \mathcal{L}(W_{true}^-, W_{pred}^2), \mathcal{L}(W_{true}^+, W_{pred}^2) + \mathcal{L}(W_{true}^-, W_{pred}^1))$$

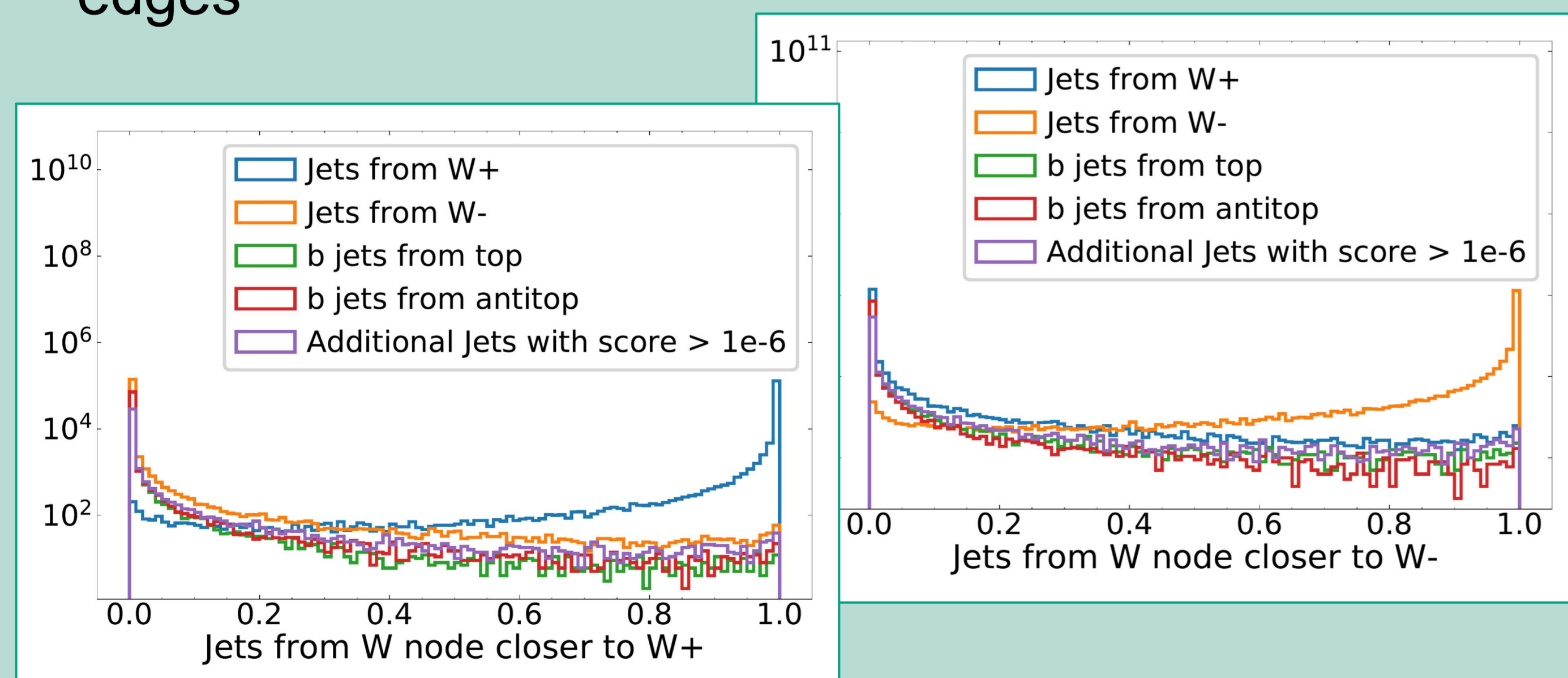
## Network structure

1. Original final state particles exchange information via a **Graph Network**
2. W nodes are formed
3. Information exchange between jets and Ws
4. Top nodes are formed
5. Information exchange between tops, Ws, and jets
6. Classification of edges
  - W and top nodes used for regression

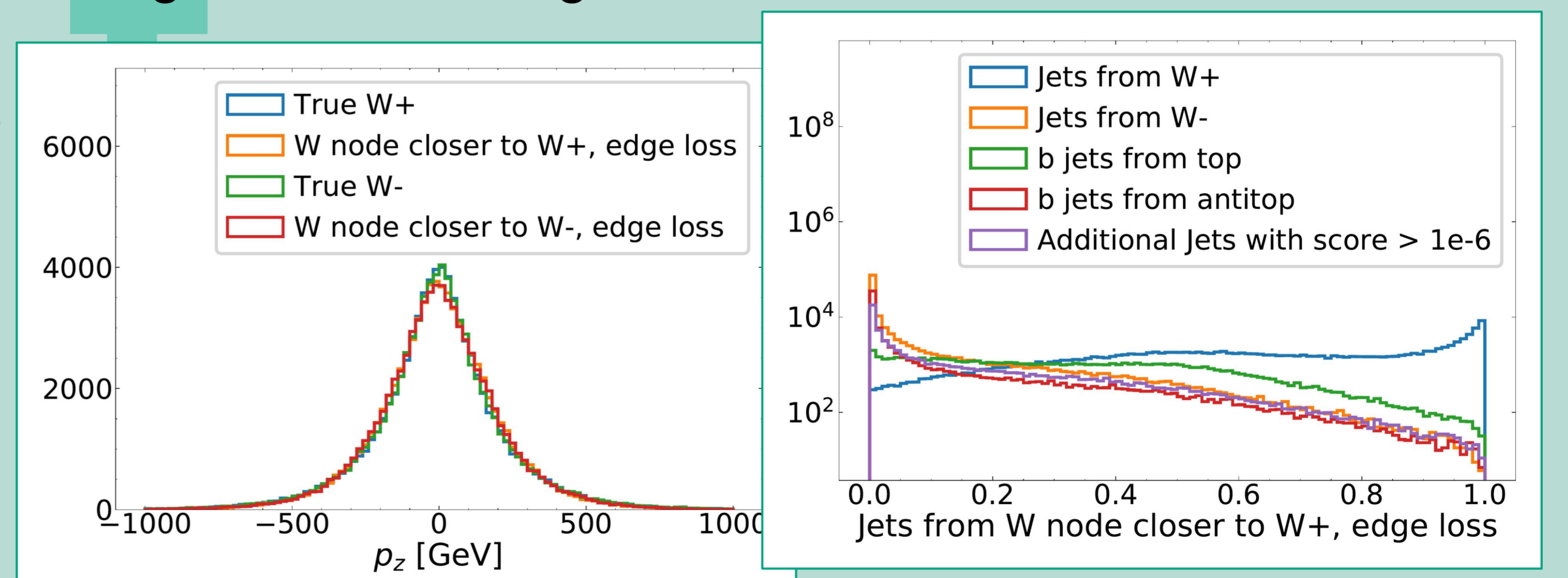


## Proof of concept and first results

- First tests using only Ws
- As proof of concept use true W values as W nodes
- **Very good separation** of true jet-W edges and false edges



- Whole network up to Ws
- Instead of standard ATLAS coordinates (pT, eta, phi) uses **cartesian coordinates** (px, py, pz) to avoid issues with periodic phi
- Fairly small network already achieves good regression and edge classification results



[1] arxiv 1312.5595 [2] arxiv 2010.09206