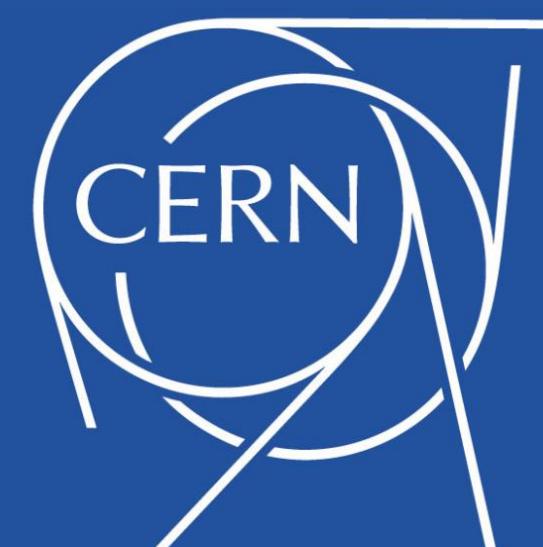


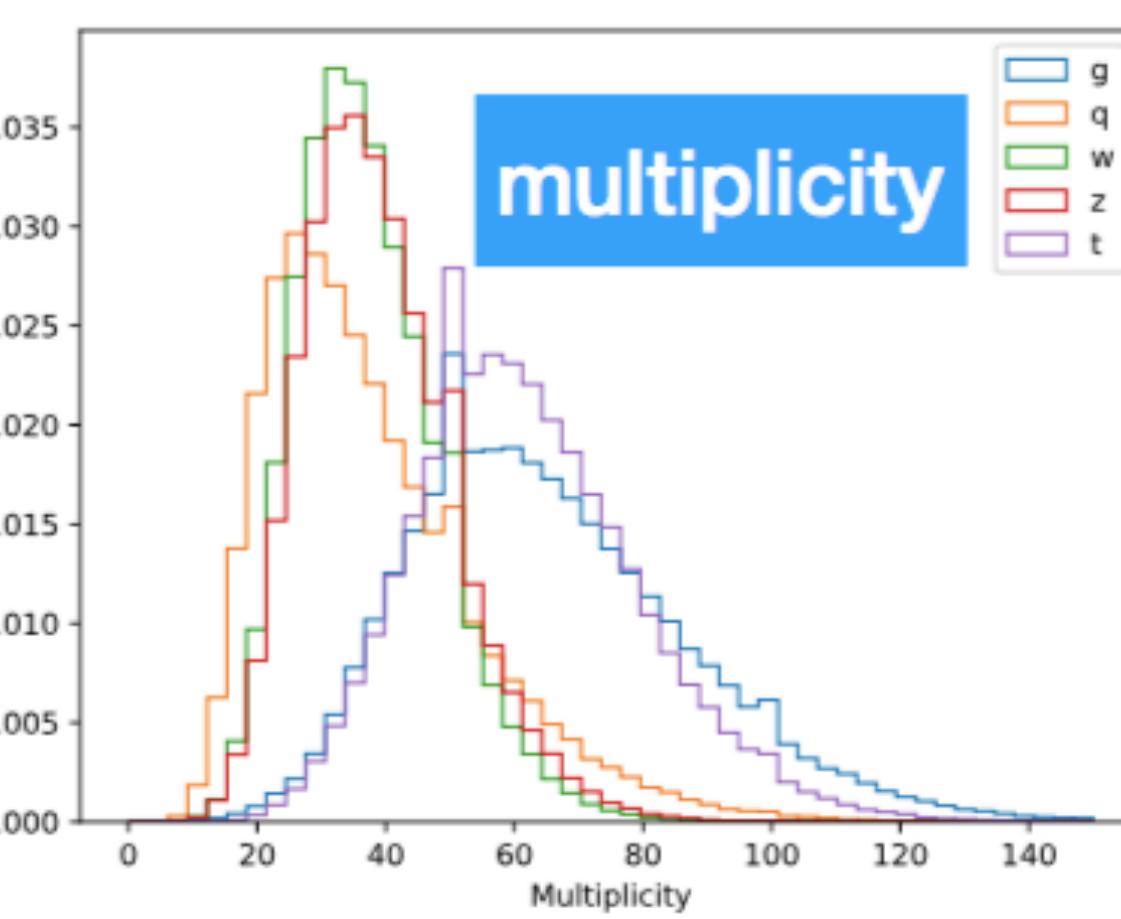
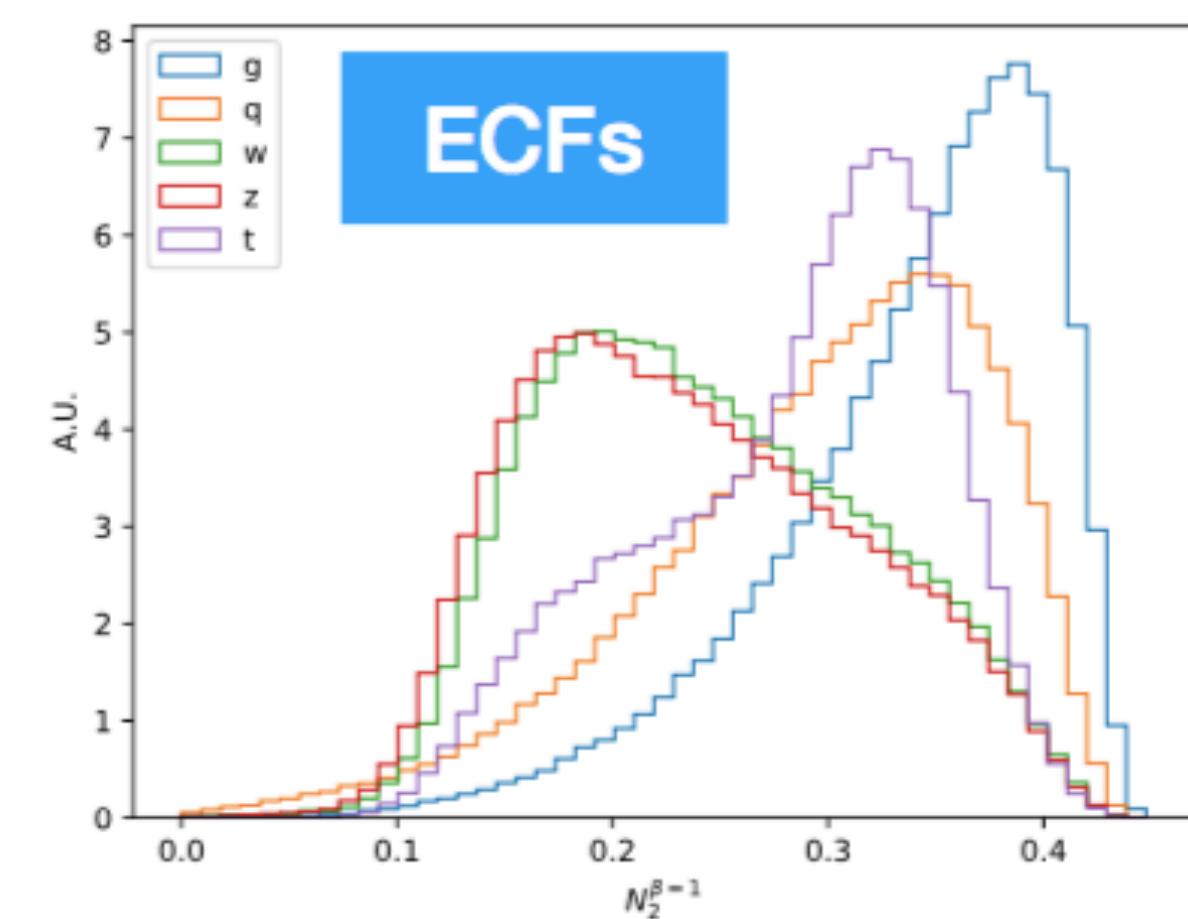
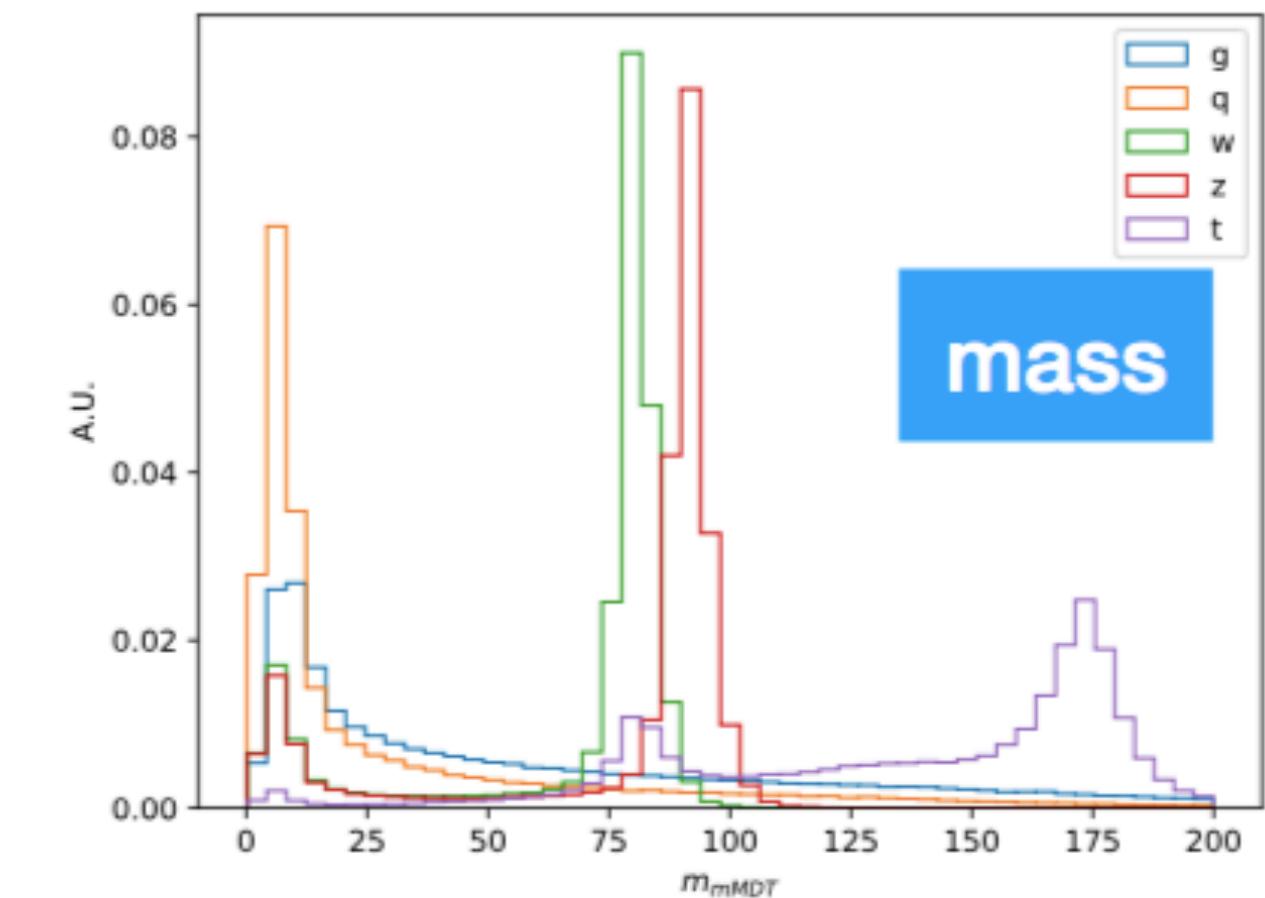
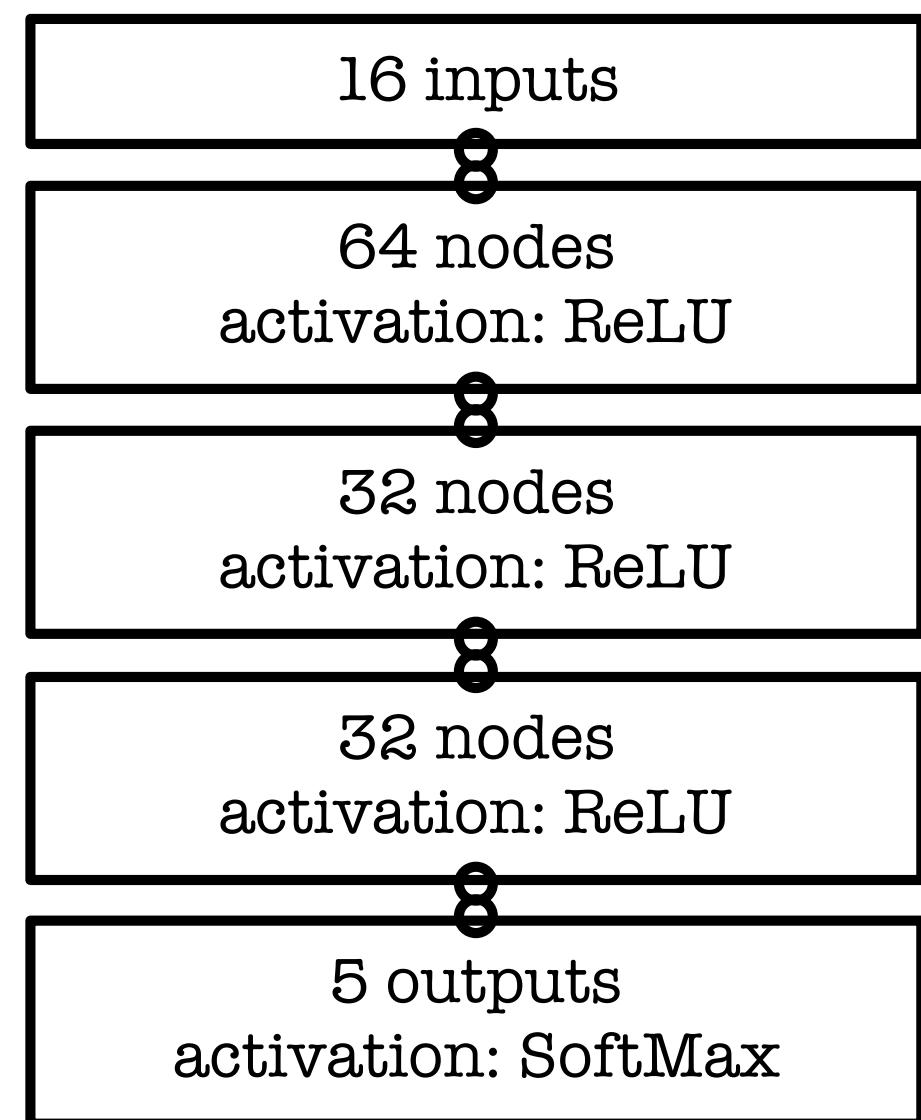
Graph Neural Networks: hands-on session

Maurizio Pierini



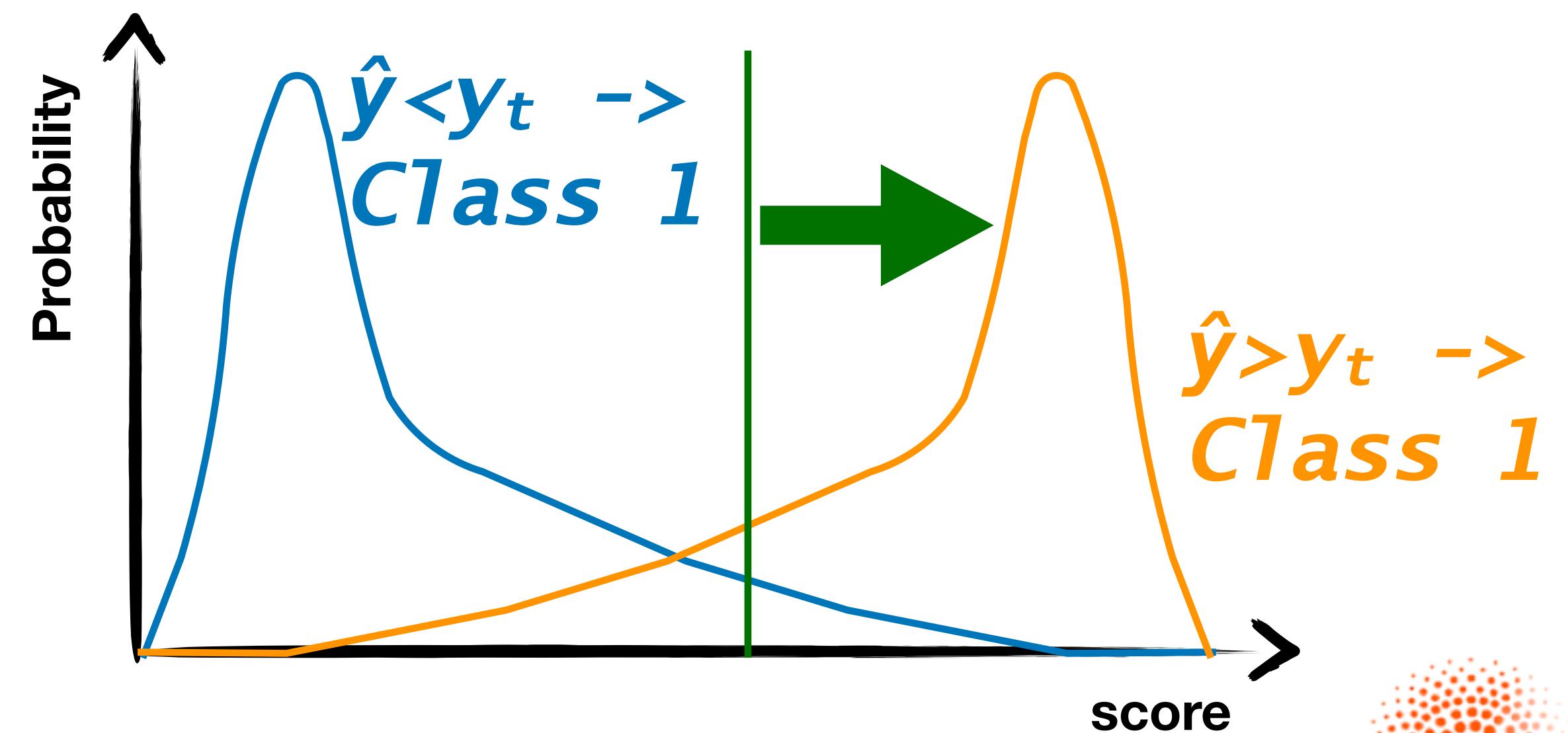
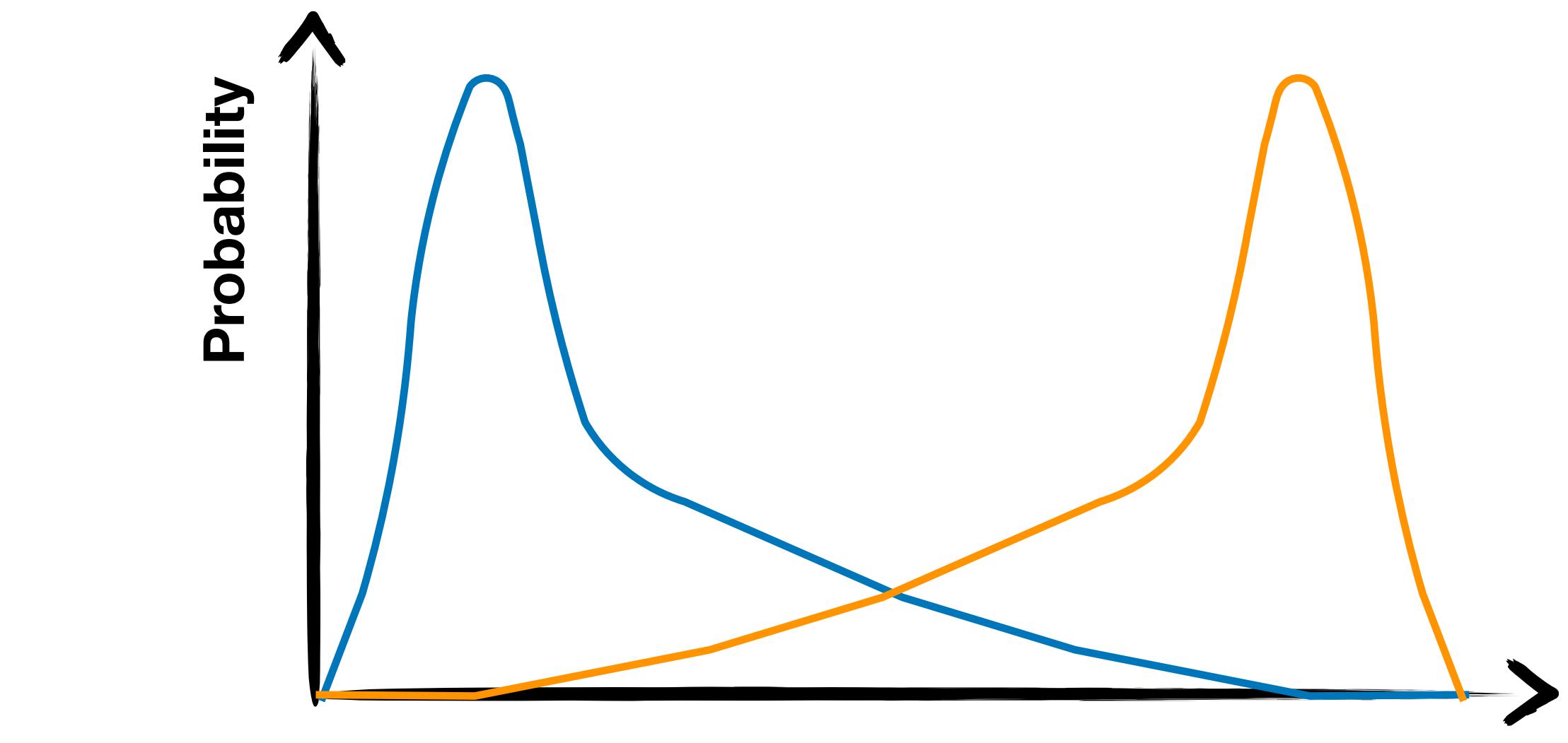
Example: jet tagging

- You have a jet at LHC: spray of hadrons coming from a “shower” initiated by a fundamental particle of some kind (quark, gluon, W/Z/H bosons, top quark)
- You have a set of jet features whose distribution depends on the nature of the initial particle
- You can train a network to start from the values of these quantities and guess the nature of your jet
- To do this you need a sample for which you know the answer



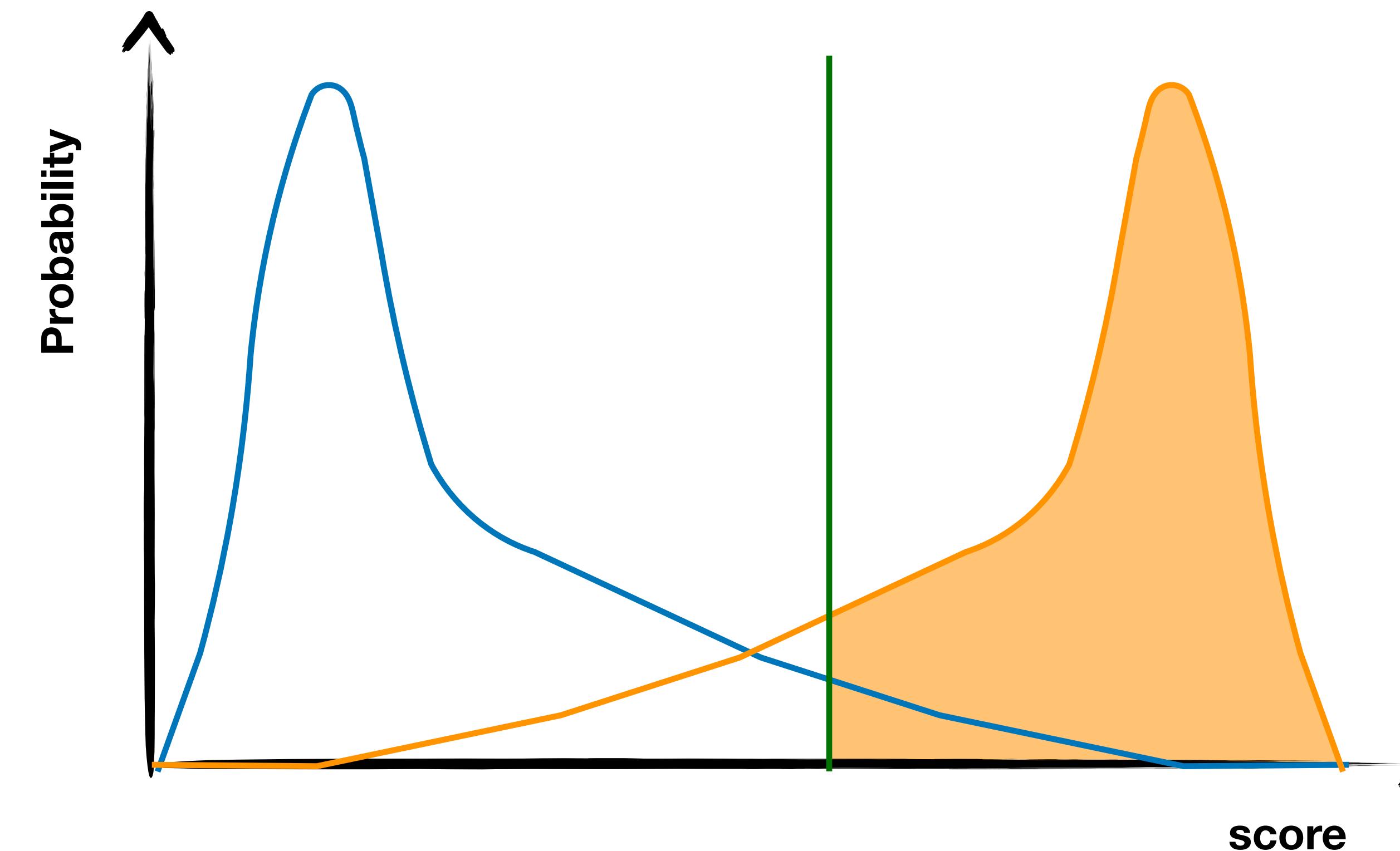
What is a ROC curve?

- Consider a binary classifier
- Its output \hat{y} is a number in $[0, 1]$
- If well trained, value should be close to 0 (1) for class-0 (class-1) examples
- One usually defines a threshold y_t such that:
 - $\hat{y} > y_t \rightarrow \text{Class 1}$
 - $\hat{y} < y_t \rightarrow \text{Class 0}$



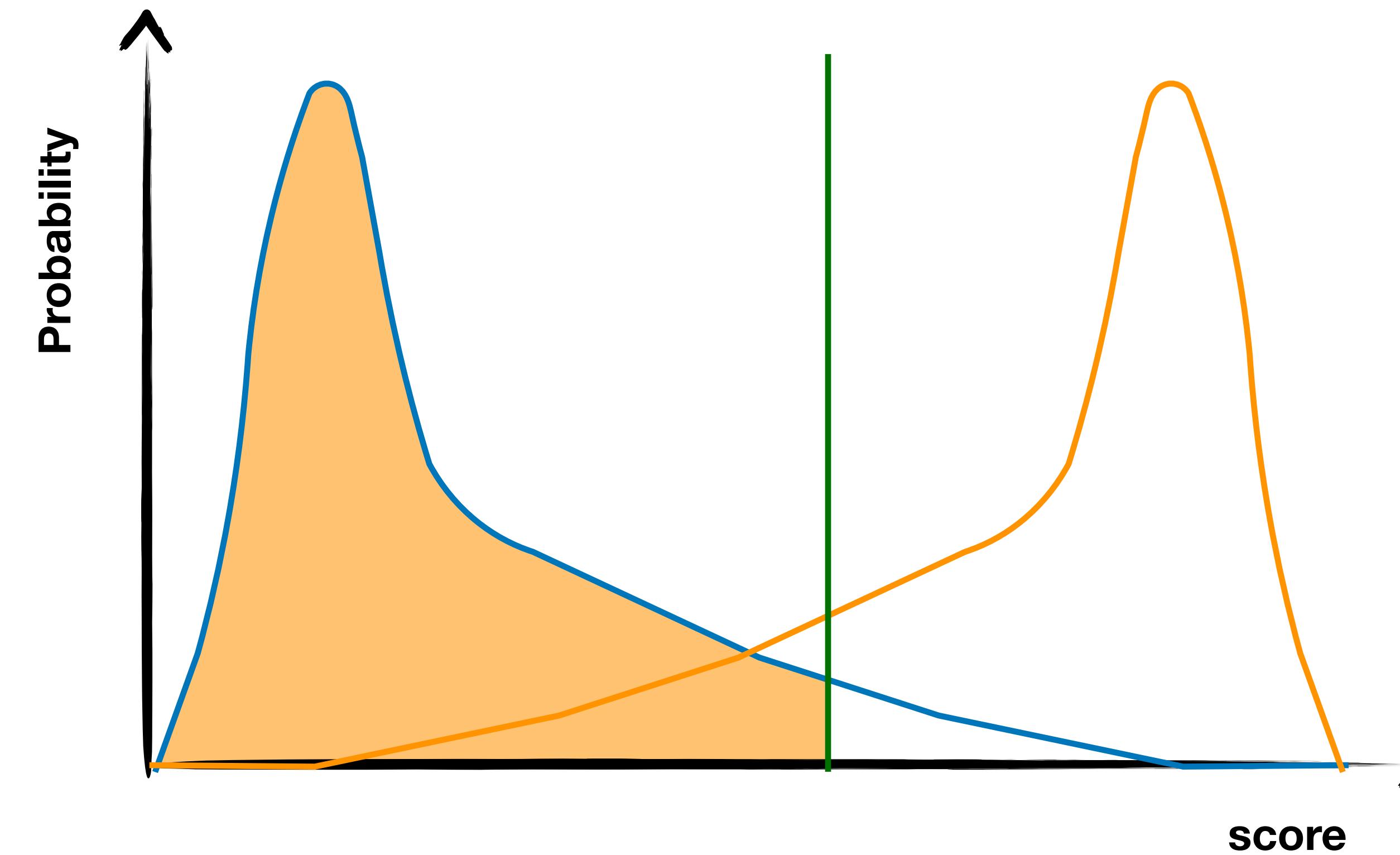
What is a ROC curve?

- A given threshold defines the following qualities
 - True-positives: Class-1 events above the threshold
 - True-negatives: Class-0 events below the threshold
 - False-positives: Class-0 events above the threshold
 - False-negatives: Class-1 events below the threshold



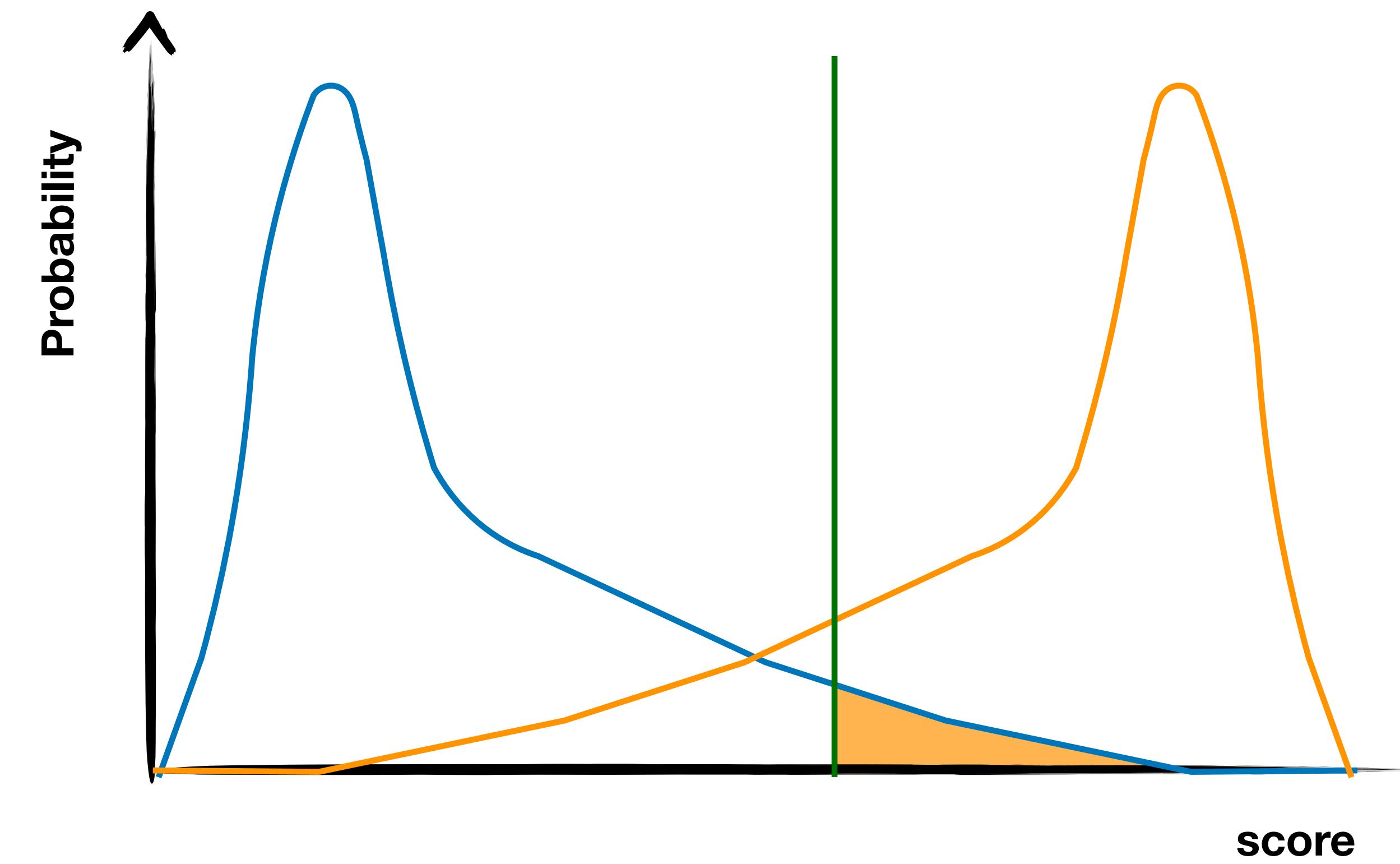
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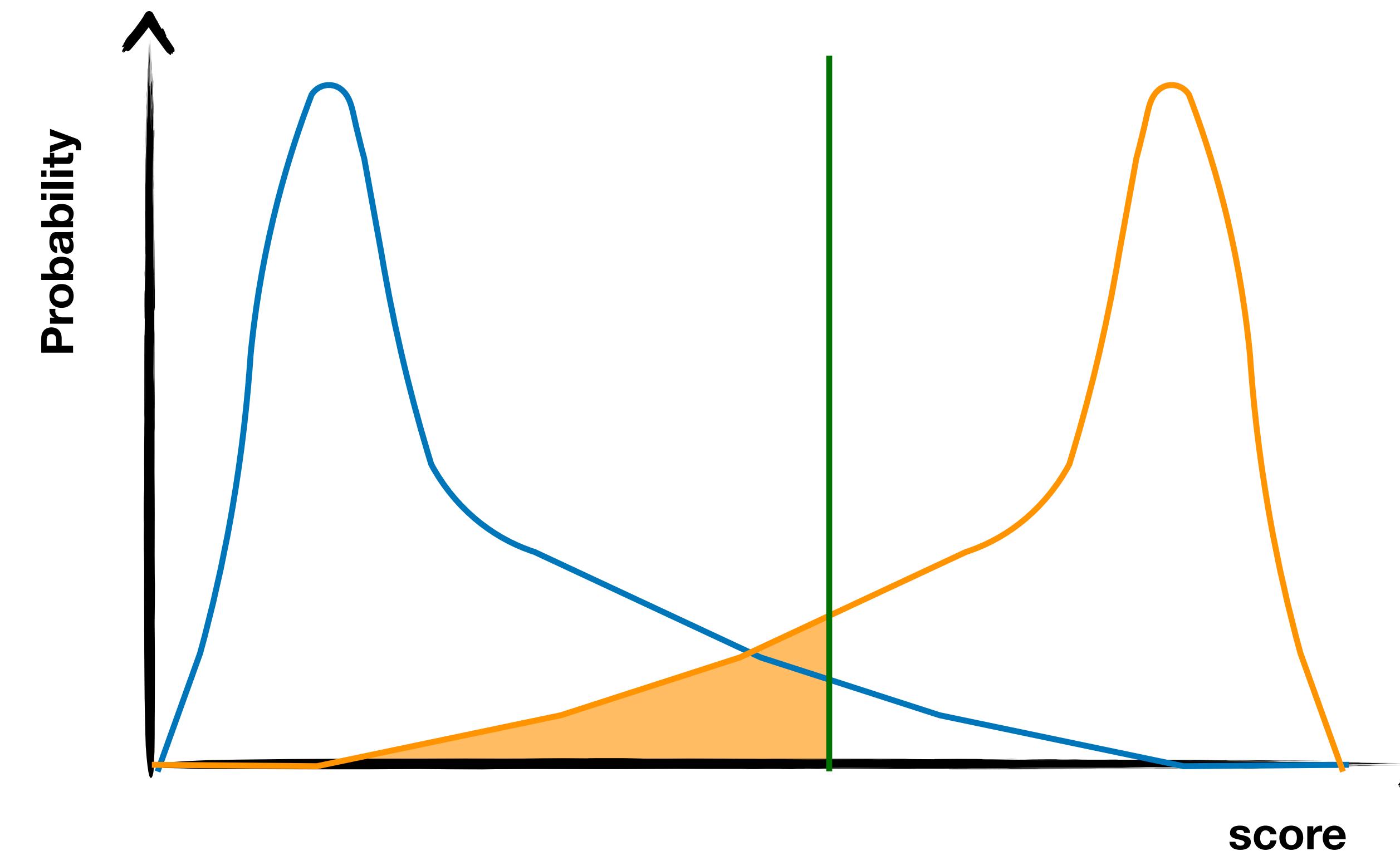
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What is a ROC curve?

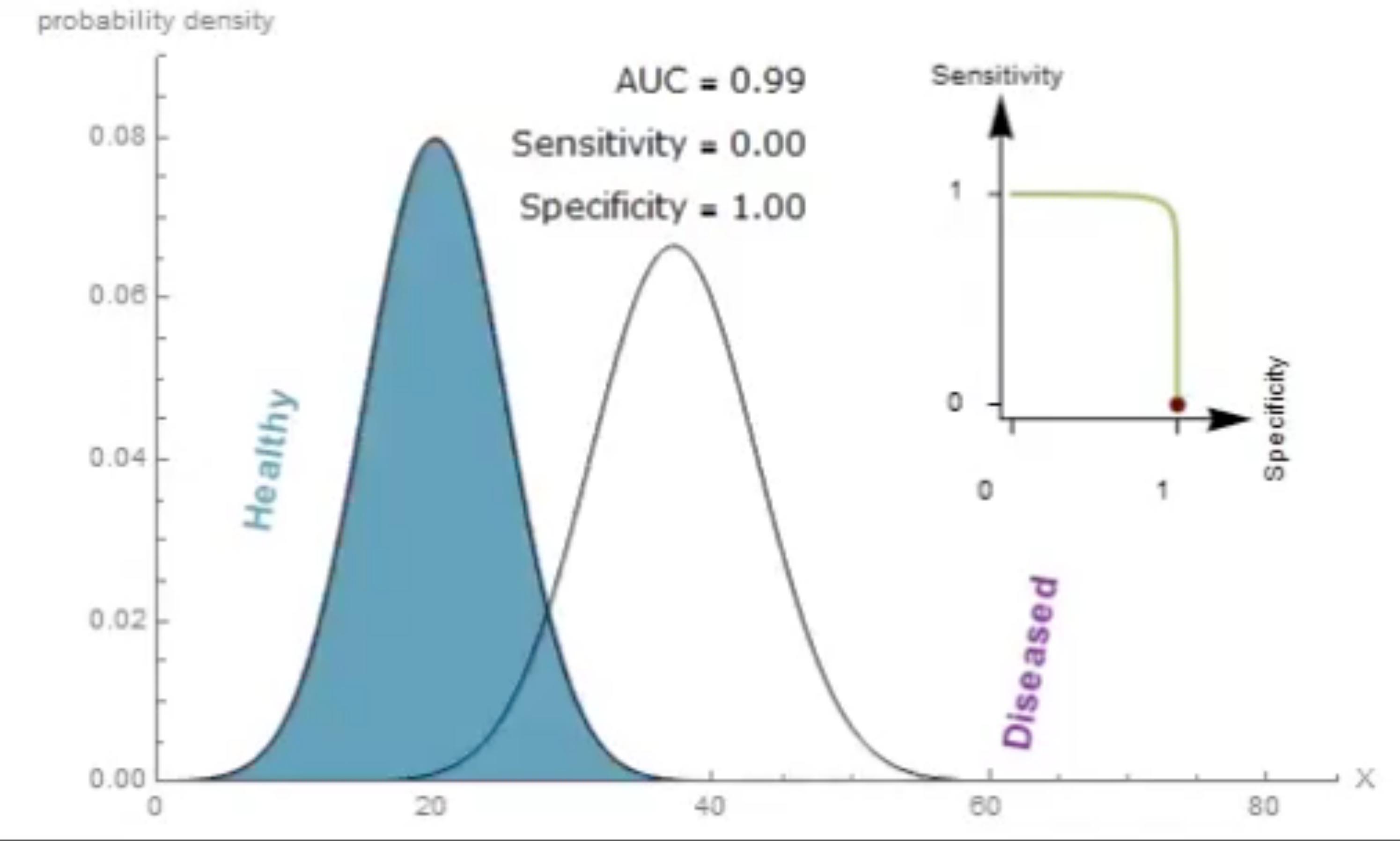
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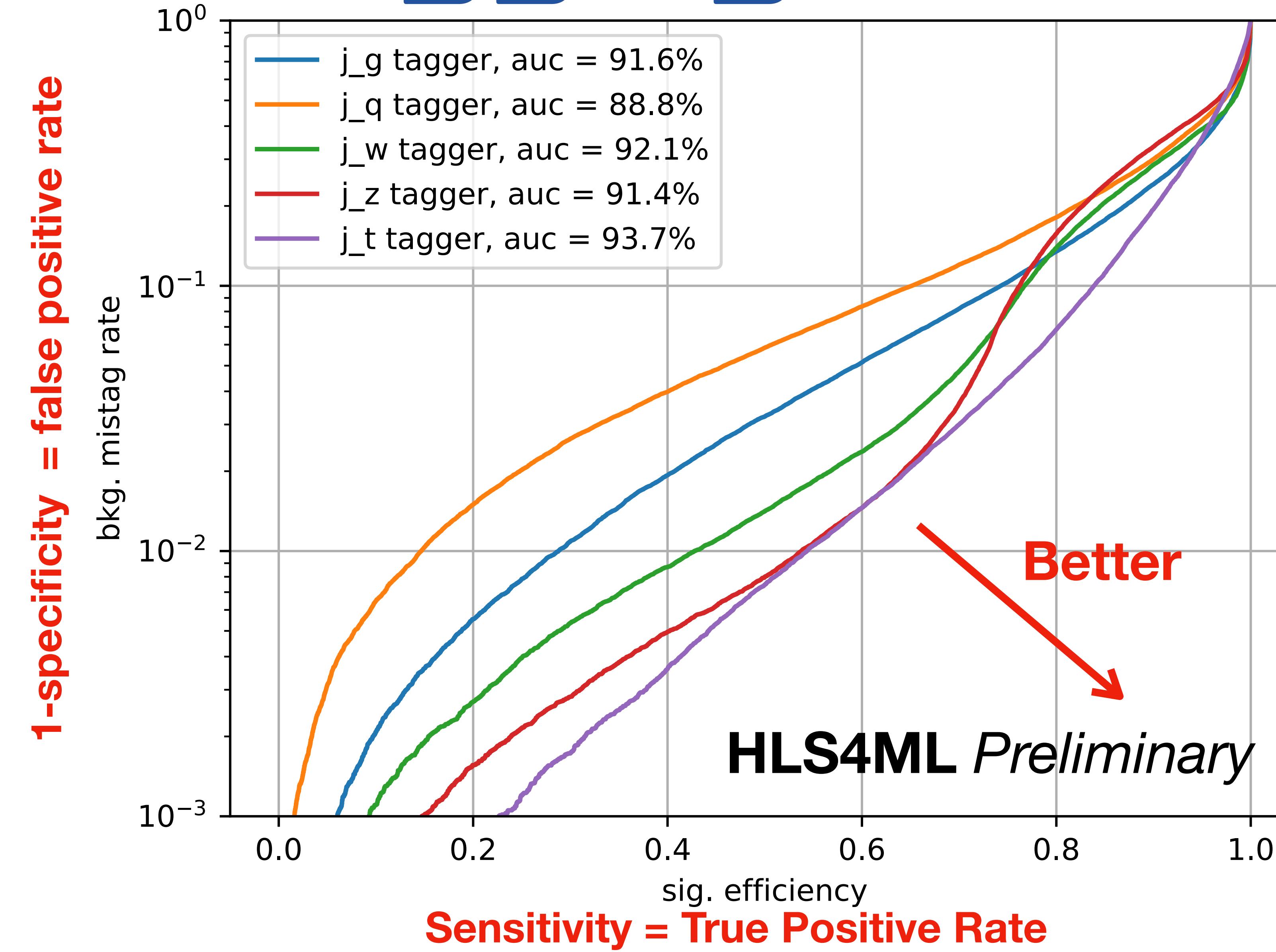
Classifier metrics

- Accuracy: $(TP+TN)/Total$
- *The fraction of events correctly classified*
- Sensitivity: $TP/(Total \ positive)$
- We call it signal efficiency
- Specificity: $TN/(Total \ negative)$
- We call it 1-mistag
- These metrics depend on the chosen threshold
- To build a threshold-independent metric, we need a ROC curve

What is a ROC curve?

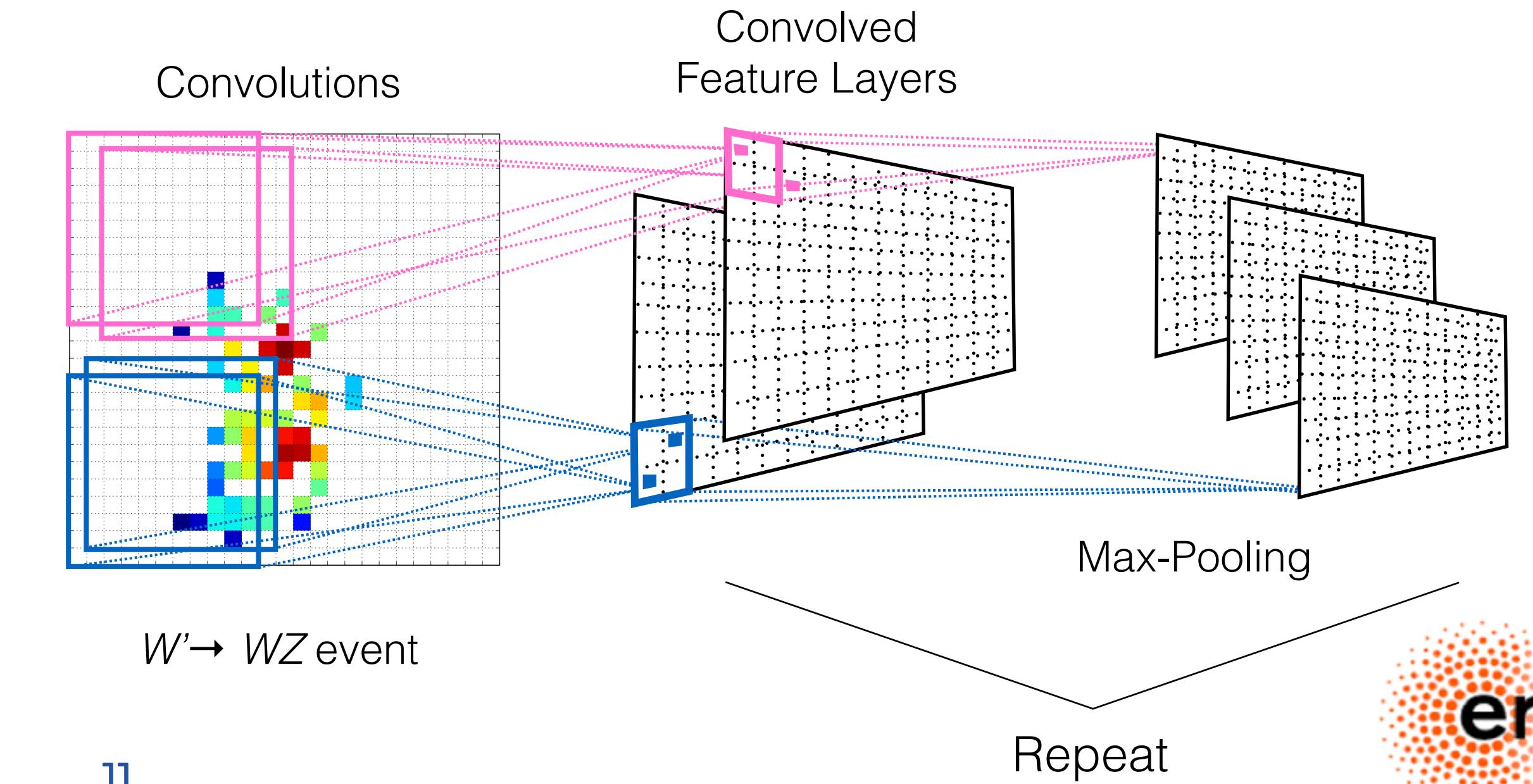
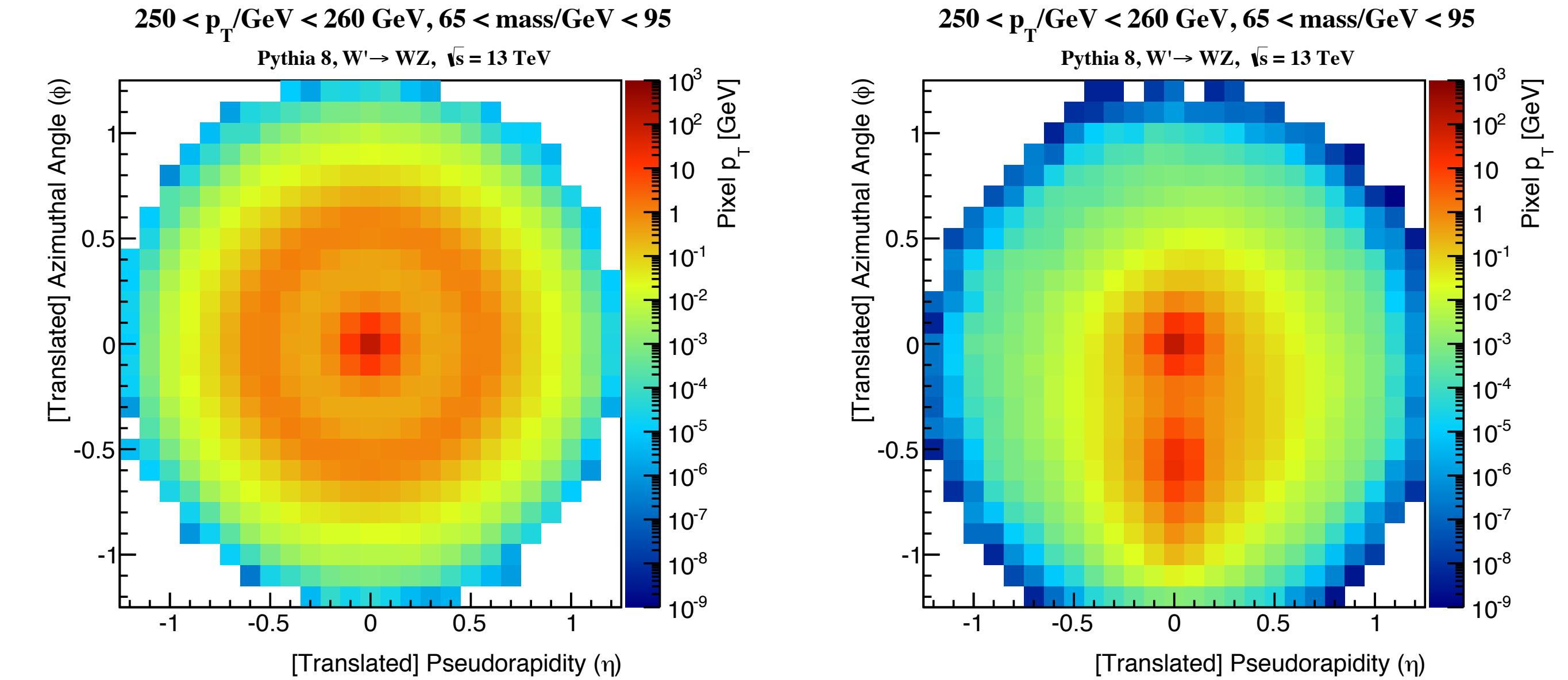


Jet tagging ROC curve



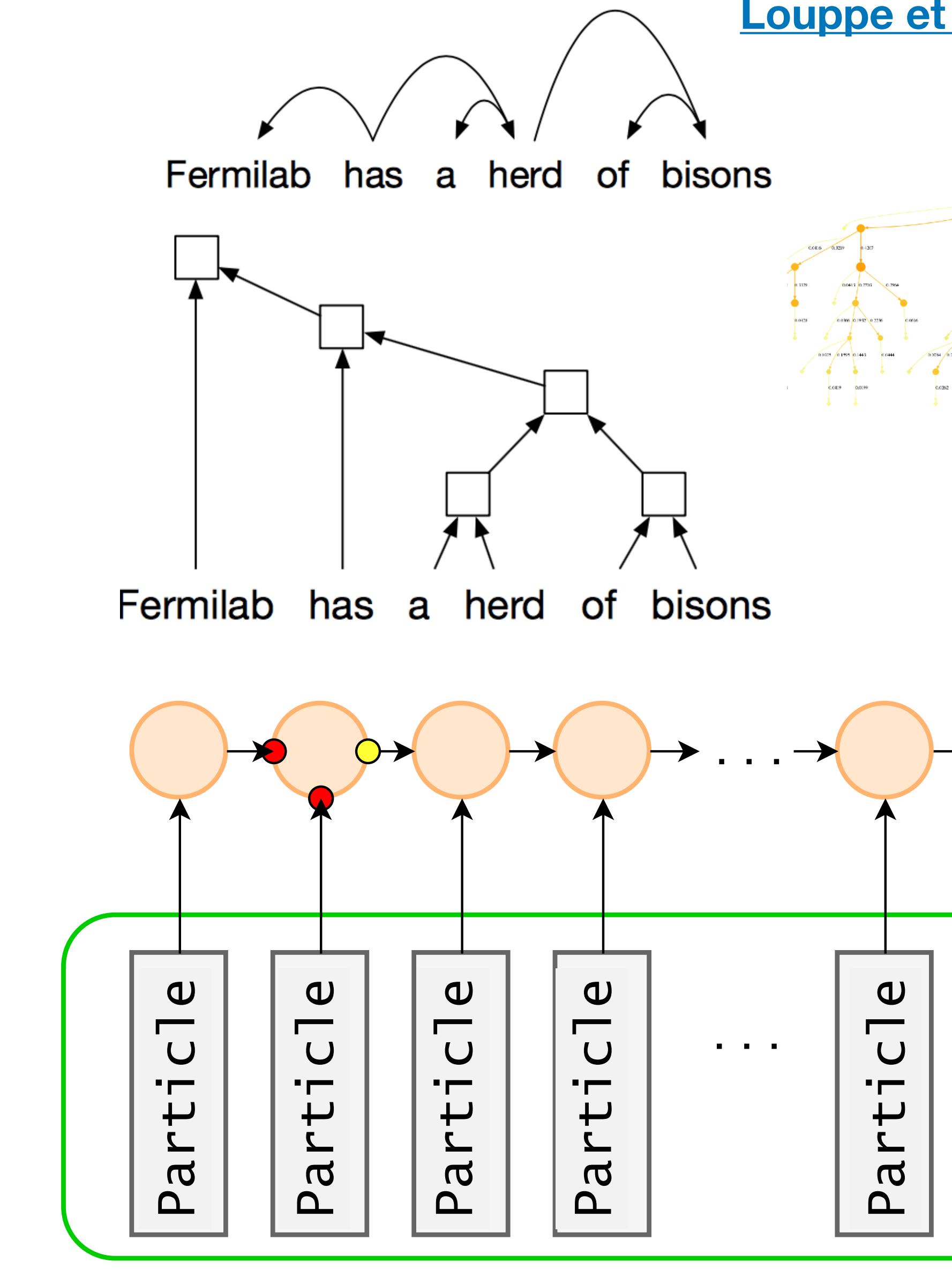
Example: particles as images

- *Bin the jet section in pixels*
- *Record energy deposited in each pixel*
- *Turn the array of pixel into a “temperature” picture*
- *Use the image to run identification through computing vision*

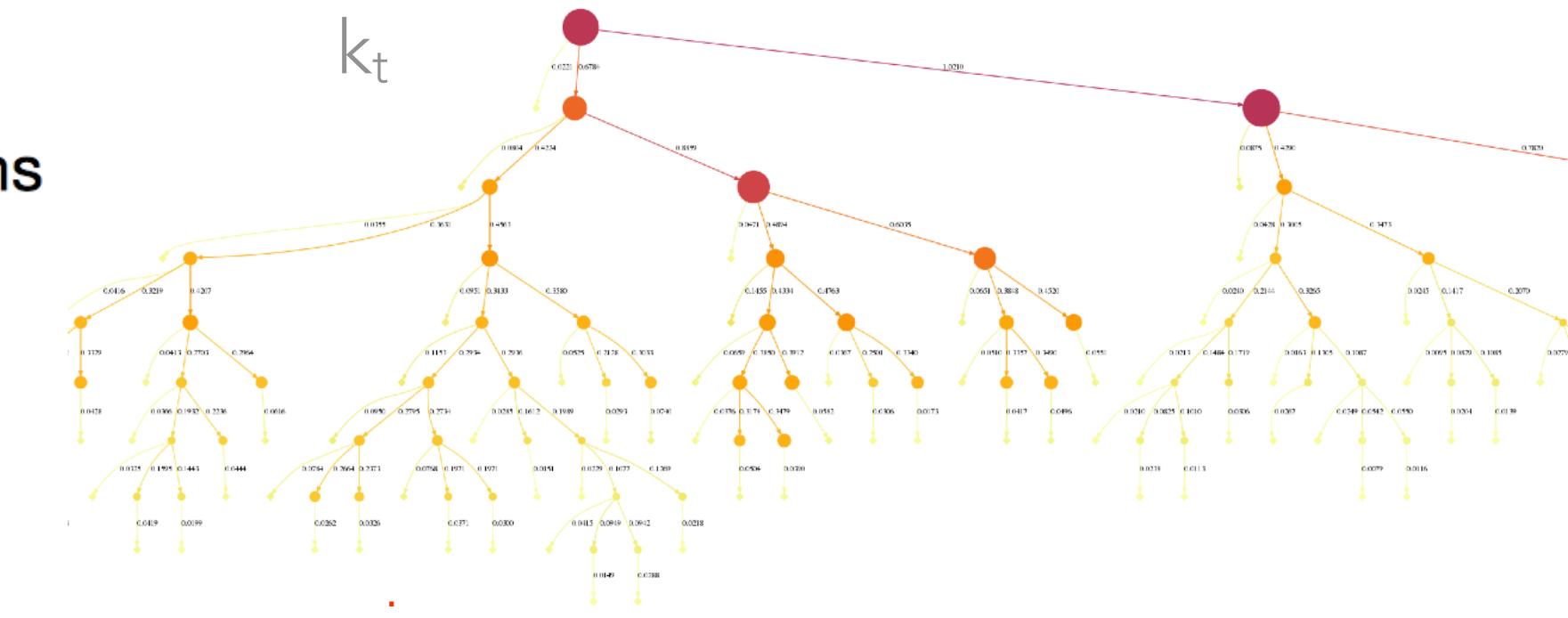


Example: particles as text

- Deep Learning also allows to analyse structured data, e.g. text or speech
- With structured data, the order (grammar in a sentence) is essential to extract information (the meaning of the sentence)
- Similarly, we can process particles in showers as structured data and learn Nature's grammar (physics laws)



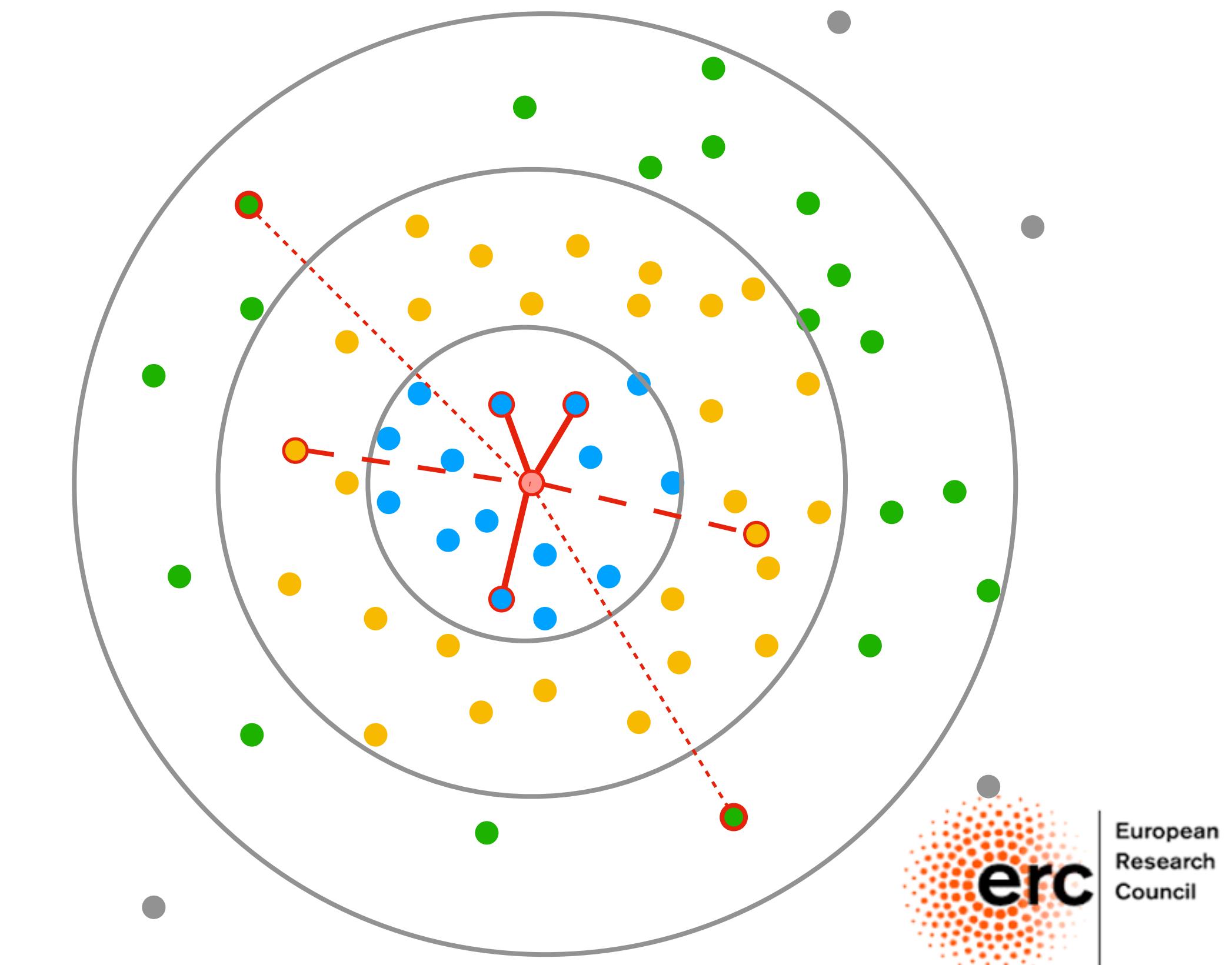
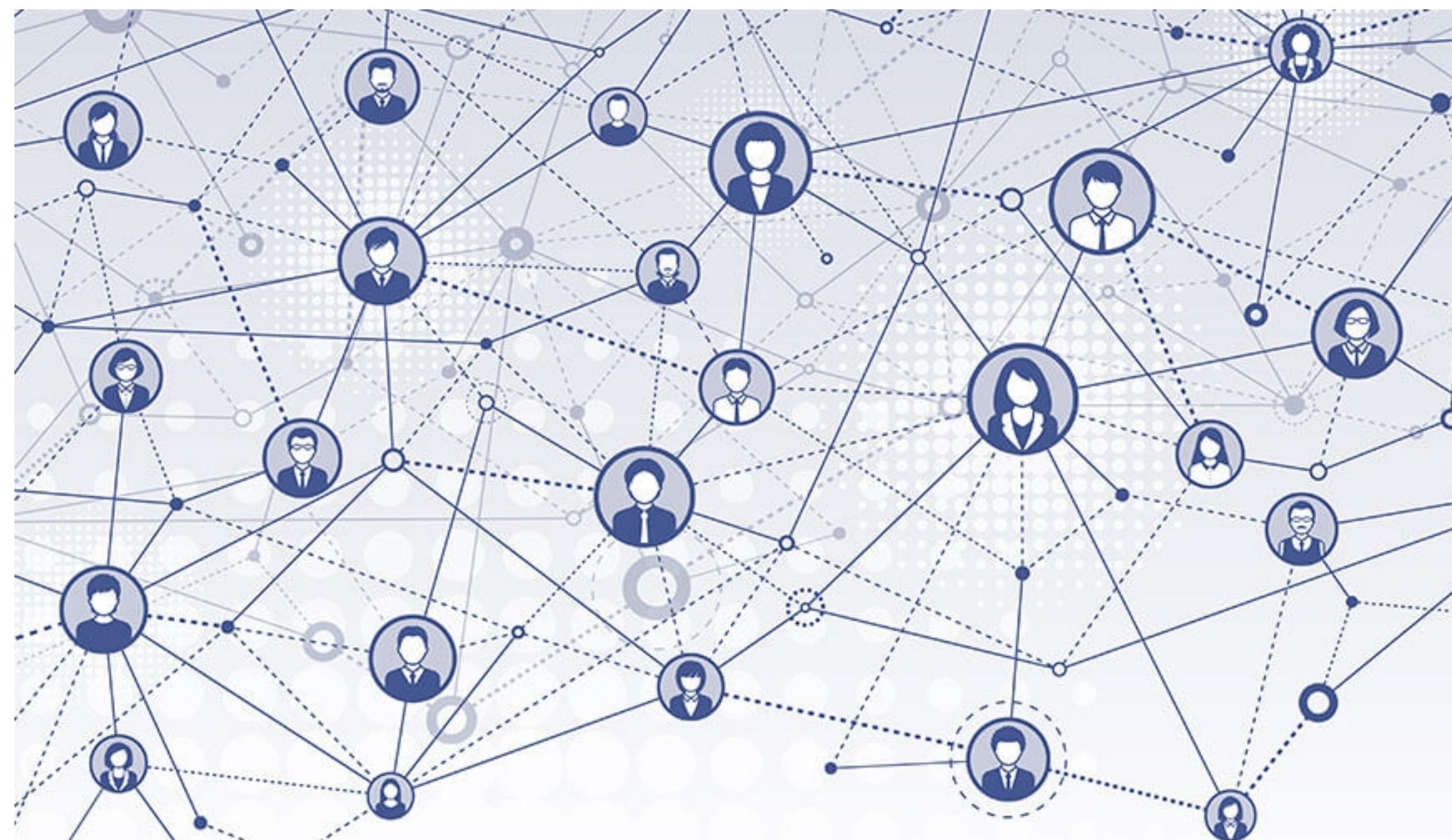
[Louppe et al., https://arxiv.org/abs/1702.00748](https://arxiv.org/abs/1702.00748)



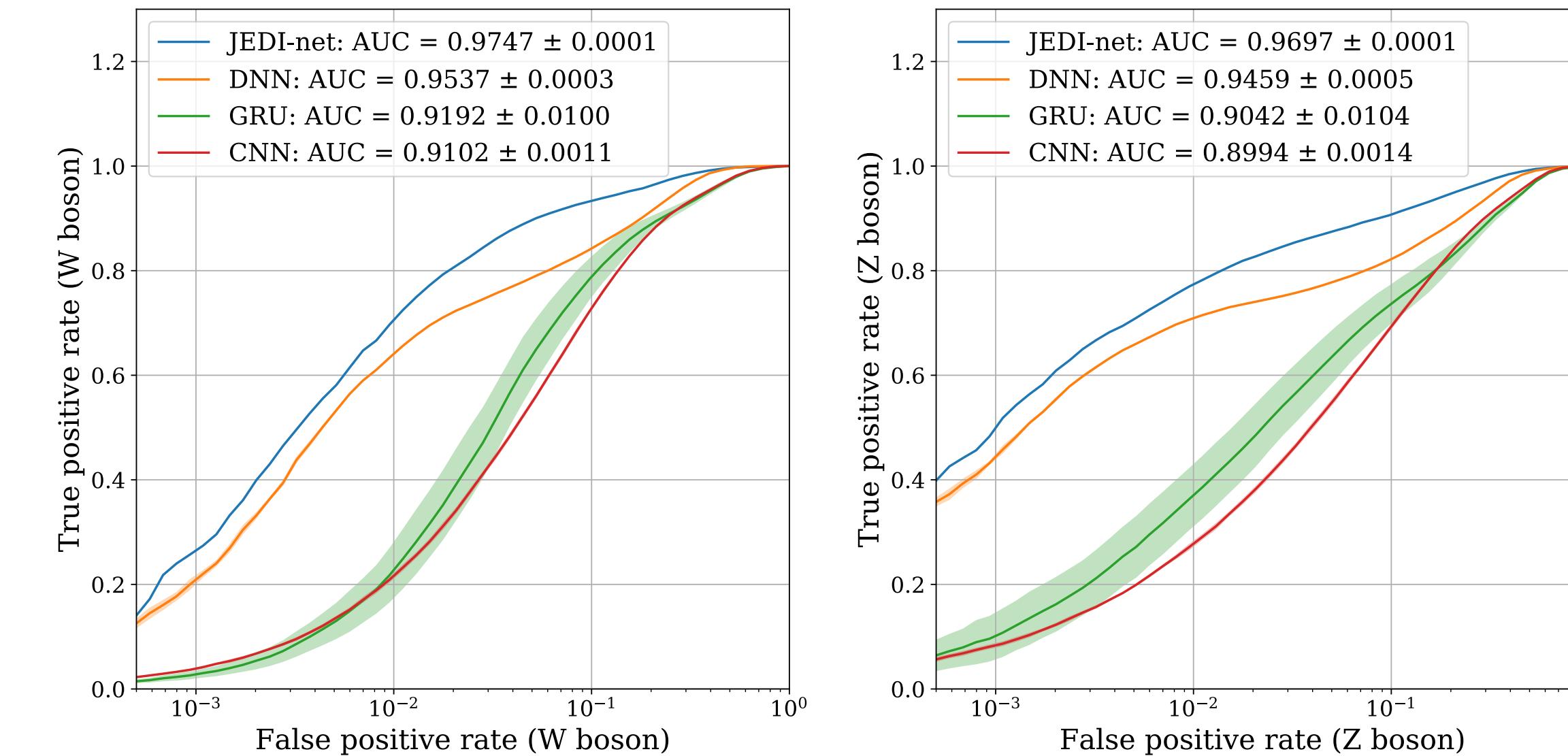
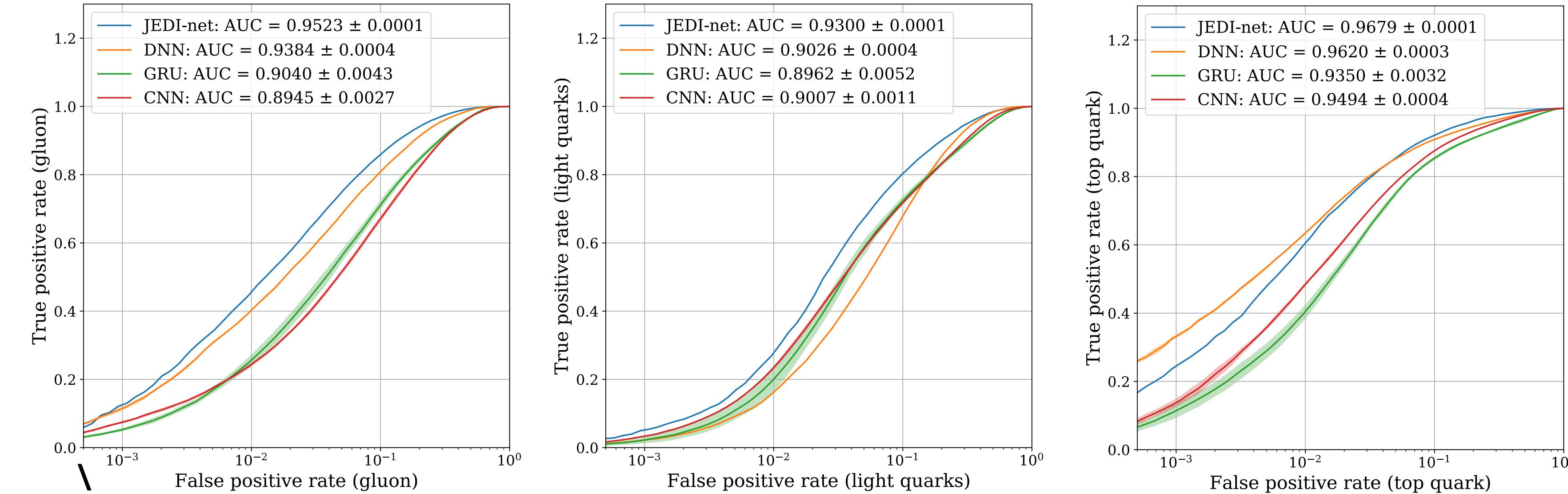
Which Particle?
Which Energy?
Which Direction?

Example: particles as graphs

- Or, one can represent the ensemble of particles as a graph
- Each vertex of the graph is a particle, with its features (energy, direction, charge, etc.)
- In this case (sparse input collection of objects), one can use graph networks like in social-media analyses



A comparison





A look at Interaction Network

- *Graph Building: sending and receiving matrix*



A look at Interaction Network

○ *Allocating Networks*



A look at Interaction Network

- *Message passing*



A look at Interaction Network

- *Feature engineering*



A look at Interaction Network

○ *Classification*