Precision-Machine Learning for the Matrix Element Method

Classical analysis

- hand-crafted observables
- binned data

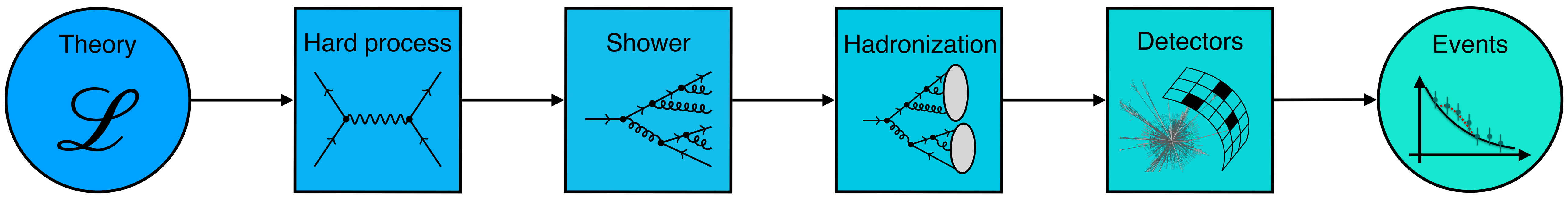
→ loss of information

How can we extract all the available information from LHC data?

Matrix Element Method (MEM)

- based on first principles
- estimates uncertainties reliably
- optimal use of information

→ perfect for processes with few events



Theory parameter α | known from theory | likelihood intractable → learn with neural network | Reconstructed momenta x_reco

$$p(x_\text{reco}\,|\,\alpha) = \int dx_\text{hard}\; p(x_\text{hard}\,|\,\alpha)\; p(x_\text{reco}\,|\,x_\text{hard})\; \epsilon(x_\text{hard})$$

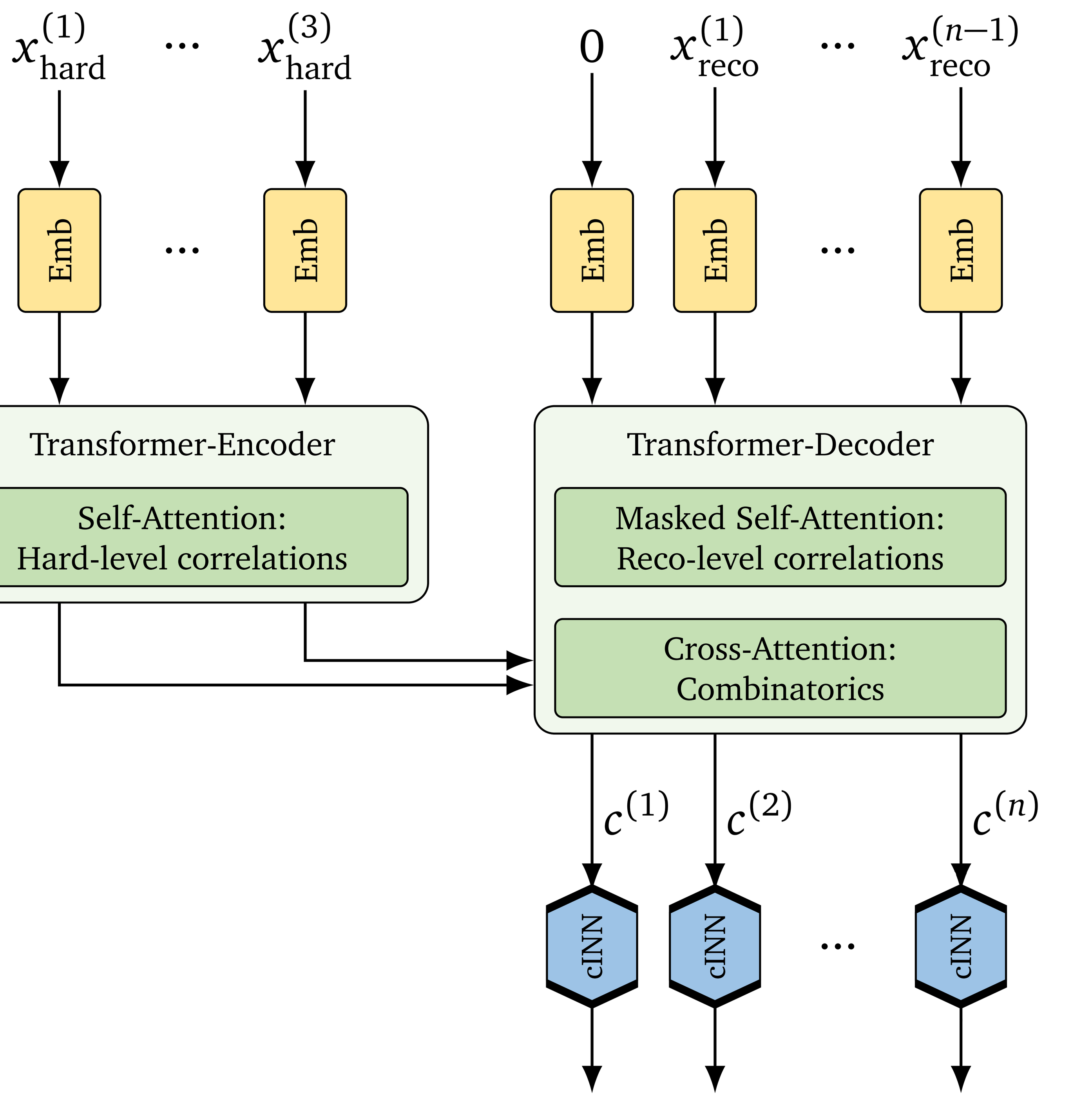
Efficient MC integration
importance sampling with normalizing flow
$x_\text{hard} \sim p(x_\text{hard}\,|\,x_\text{reco}, \alpha)$

Theory knowledge
diff. cross-section
$\frac{1}{\sigma(\alpha)}\frac{d\sigma(\alpha)}{dx_\text{hard}}$

Transfer function
density estimation: normalizing flow and transformer

Acceptance function
learn with simple classifier network

Learning the transfer function



$$p(x_\text{reco}|x_\text{hard}) = p(x^{(1)}_\text{reco}|c^{(1)}) \;\cdots\; p(x^{(n)}_\text{reco}|c^{(n)})$$

- transformer
  correlations between momenta, combinatorics
- normalizing flow
  likelihood for individual momenta
- Bayesian networks
  estimate training uncertainties

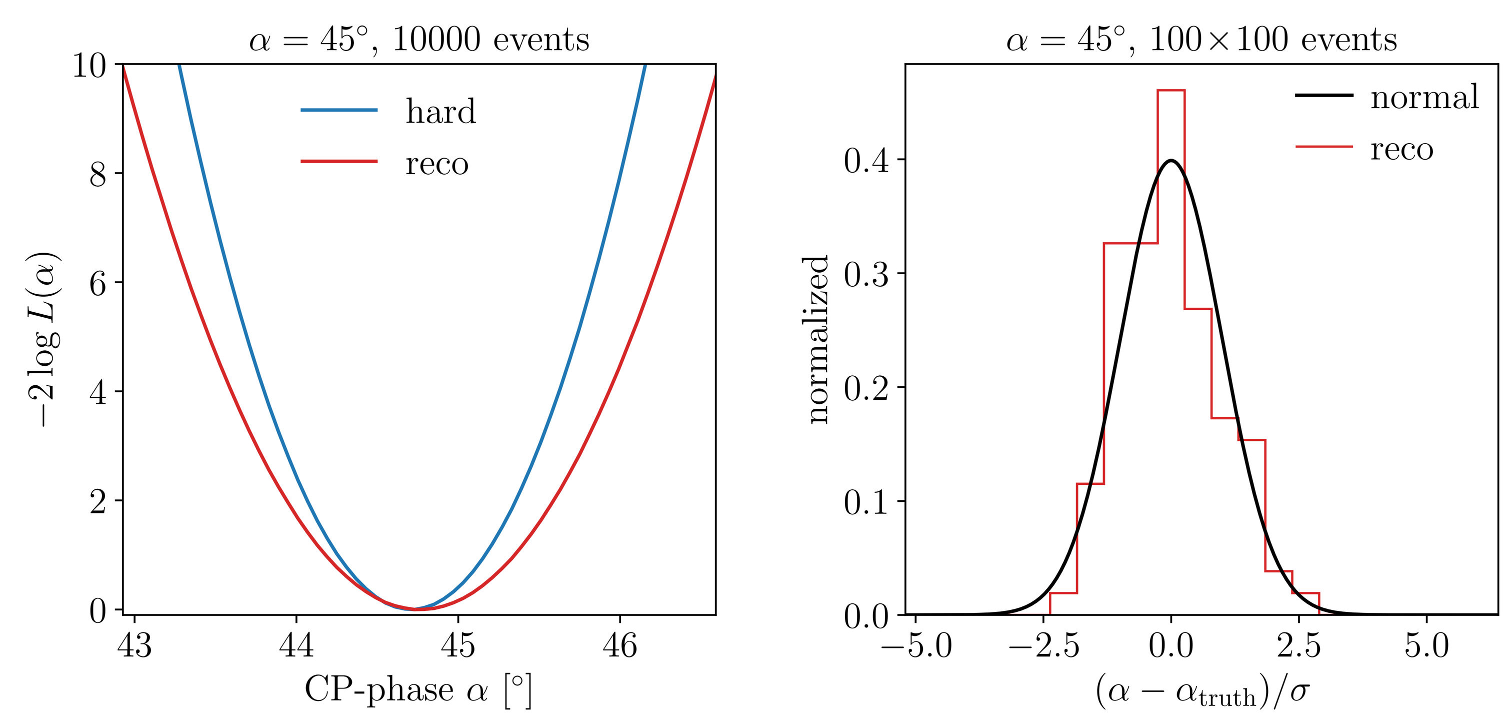
LHC example

Single top and Higgs production with anomalous CP-phase α
Hadronic decay of top + ISR: $\text{tHq} \rightarrow (\text{bjj})\,(\gamma\gamma)\,\text{j} + \text{QCD jets}$

- low total cross section (few events)
- low variation of rate
- kinematic observables still sensitive

→ ideal use case for MEM

Results



- smooth and well-calibrated likelihoods, both for low and high event counts
- close to optimal information
- Uncertainty bands: MC integration error & systematic error from limited training statistics (BNN)

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"Generative Precision Networks for Particle Physics" with Anja Butter

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