Jet Correction and Simulation with Quantile Neural Networks

IRIS-HEP Fellows Research Presentation

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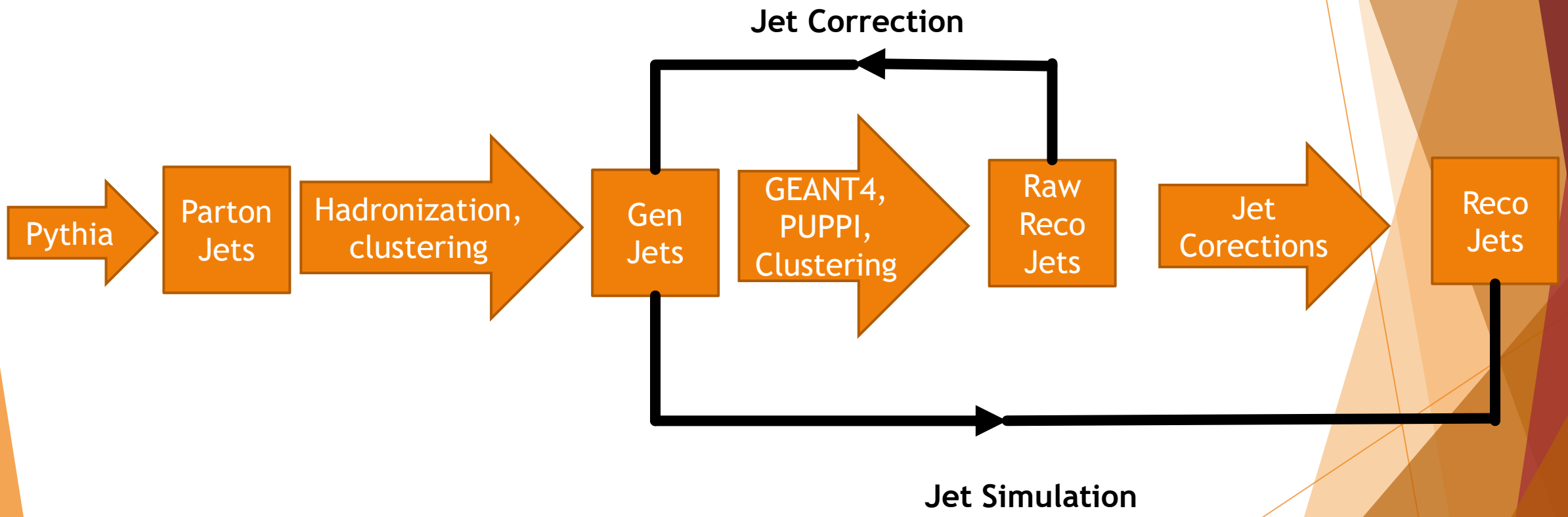
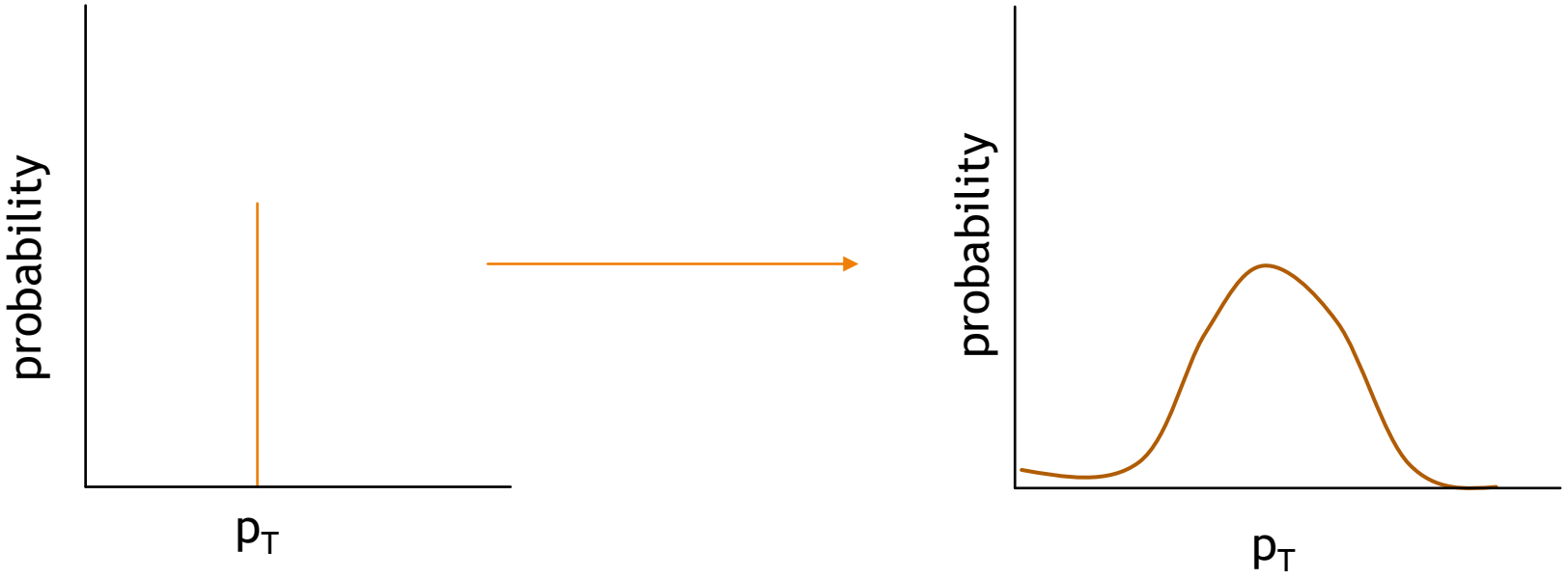
Jet Simulation and Correction



Dataset DOI:10.7483/OPENDATA.CMS.J52Q.4T4E

Need for distribution predictions

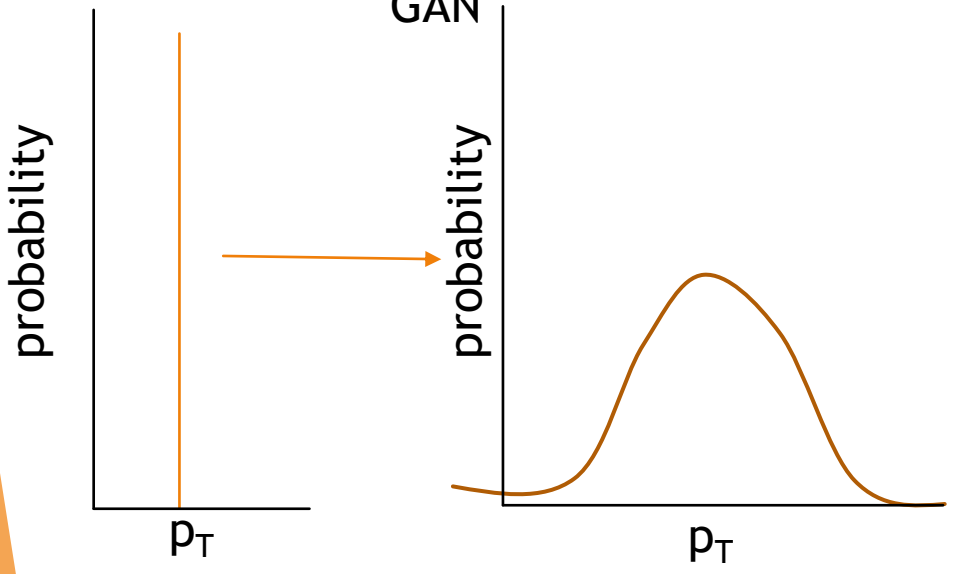


Single Input
(Gen Jet p_T)

Distribution of Outputs
(Reco Jet p_T)

Existing Distribution Prediction Methods

Conditional GAN

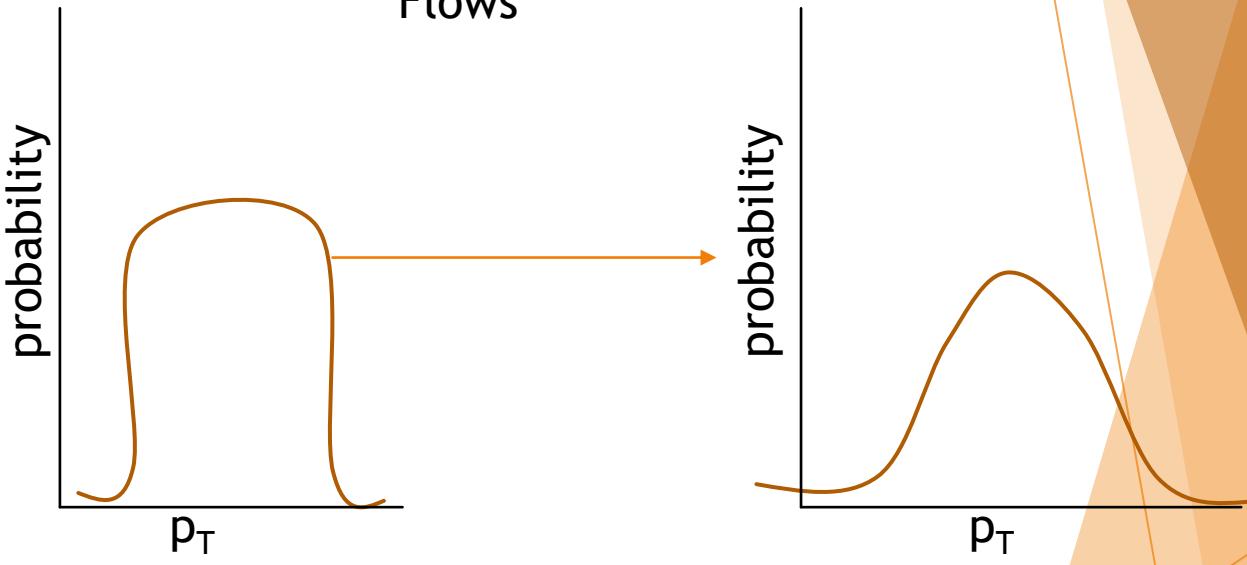


Single Input

Distribution of Outputs

See: arXiv:1912.00477, arXiv:1807.01954, arXiv:1805.00850, arXiv:1712.10321, https://doi.org/10.1051/epjconf/202125103055

Normalizing Flows

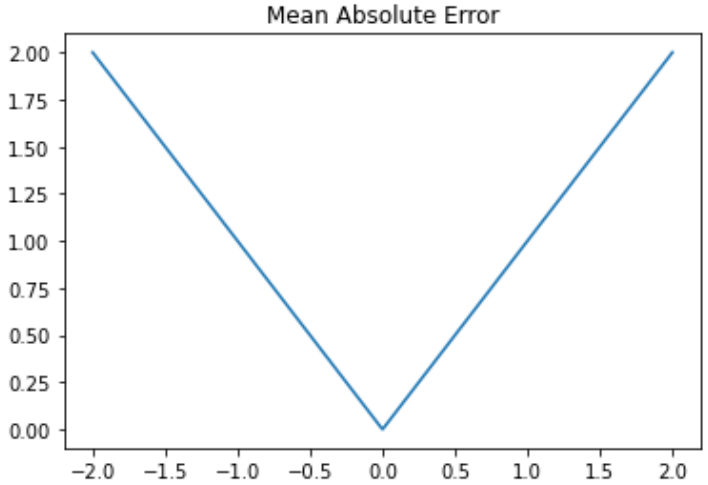


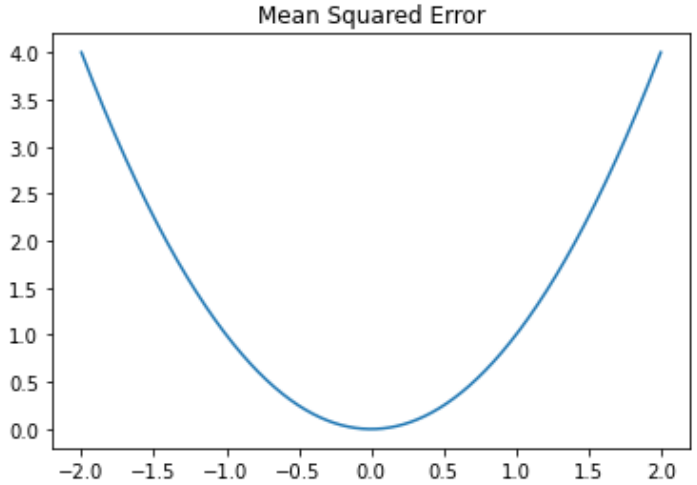
One distribution

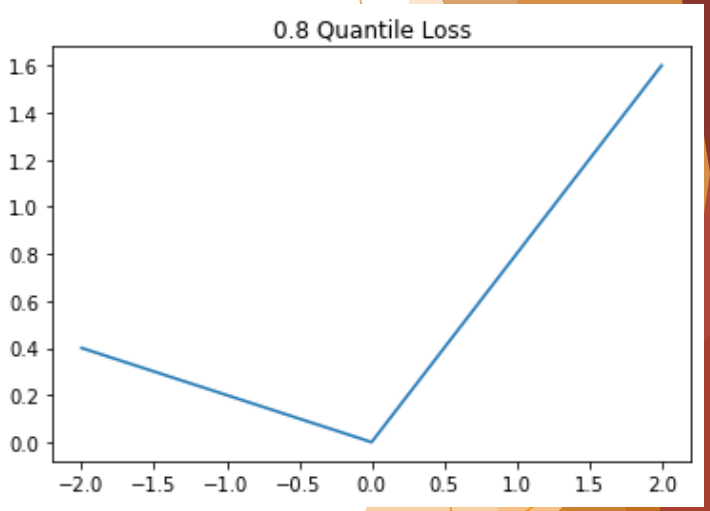
Another distribution

See: arXiv:1904.12072, arXiv:2001.05486, arXiv:2001.10028 arXiv:2012.09873, arXiv:2106.05285

Loss function choices

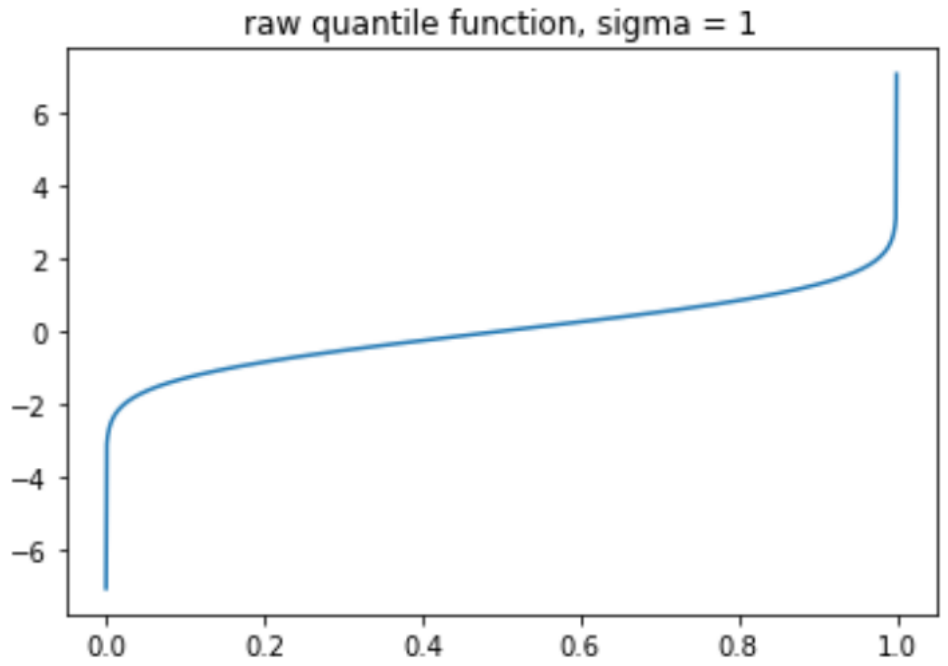






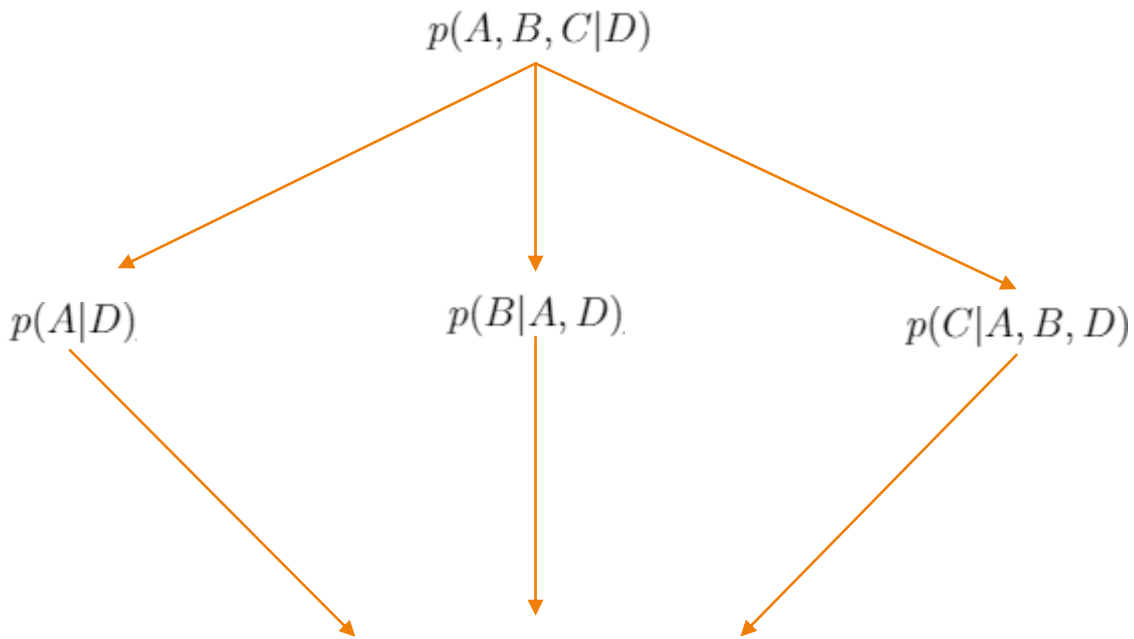
$$\mathcal{L}(f, x, y, \tau) = \begin{cases} \tau(y - f(x, \tau)) & y \geq f(x, \tau) \\ (\tau - 1)(y - f(x, \tau)) & y < f(x, \tau) \end{cases}$$

Quantile Crossing Regularization



$$\begin{cases} \left(\frac{dy}{d\tau}\right)^2 & \frac{dy}{d\tau} < 0 \\ 0 & \frac{dy}{d\tau} \geq 0 \end{cases}$$

Higher dimensional distributions



$$p(A, B, C|D) = p(A|D)p(B|A, D)p(C|A, B, D)$$

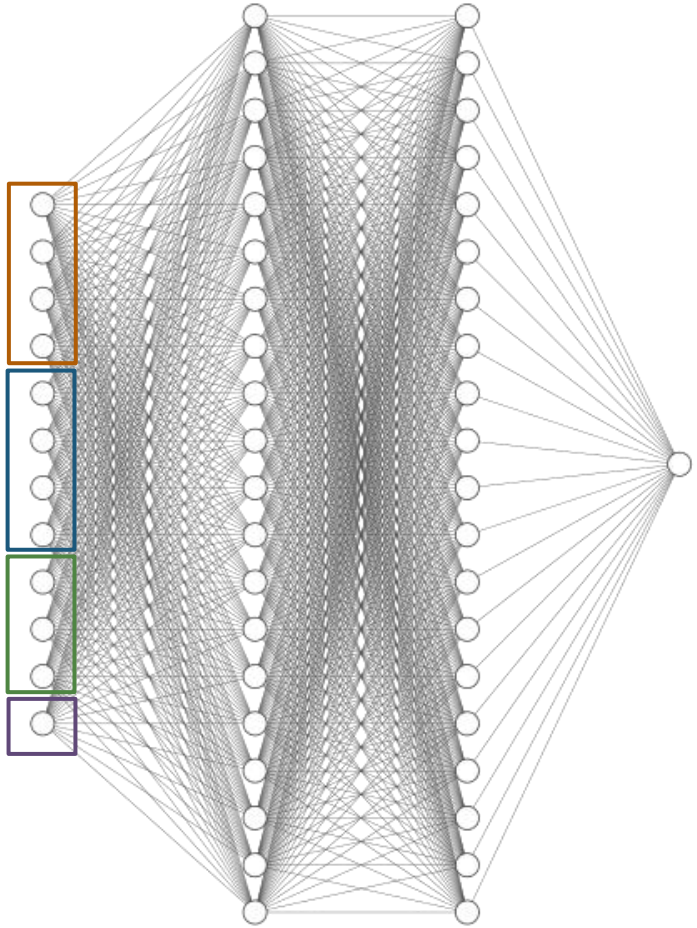
Quantile Network Design

Input jet (p_T, η, φ, mass)

One-hot encoding which indicates whether the output should be p_T, η, φ, or mass

Previously sampled p_T, η, φ

Uniformly sampled quantile



Normal neural network architecture

Loss function depends on randomly sampled quantile

Image credit: https://alexlenail.me/NN-SVG/

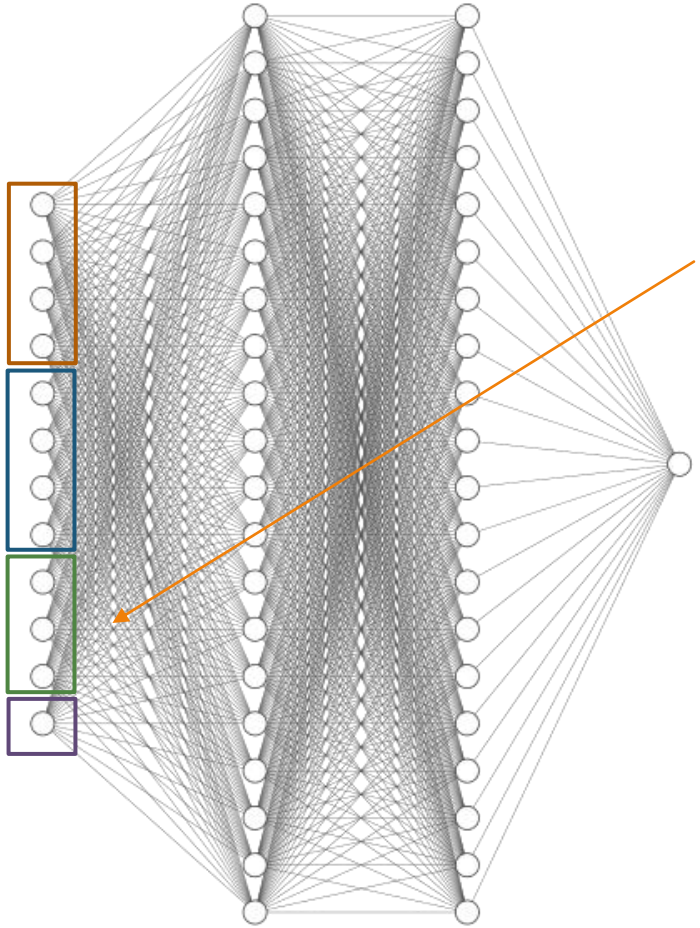
Quantile Network Inference

Input jet (p_T, η, φ, mass)

One-hot encoding which indicates whether the output should be p_T, η, φ, or mass

Previously sampled p_T, η, φ

Uniformly sampled quantile

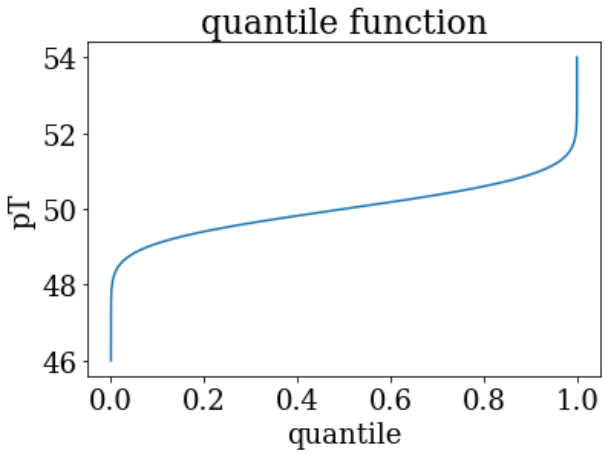


Normal neural network architecture

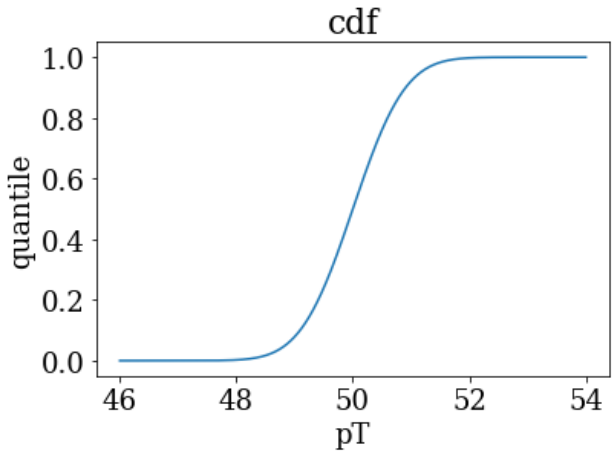
Output is sent back into network if the full four vector has not yet been sampled

Image credit: https://alexlenail.me/NN-SVG/

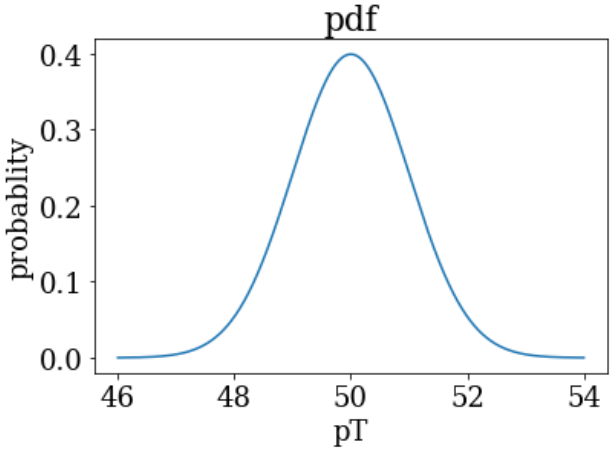
Quantile Network Predictions



Invert

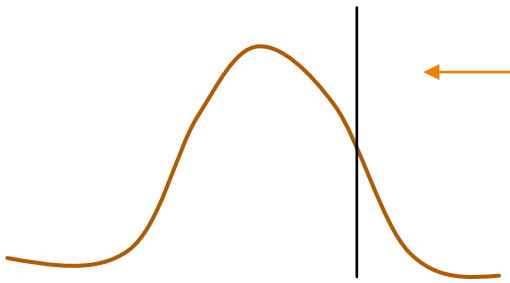


Derivative



Uniform sampling of the quantile function yields a sampling of this distribution

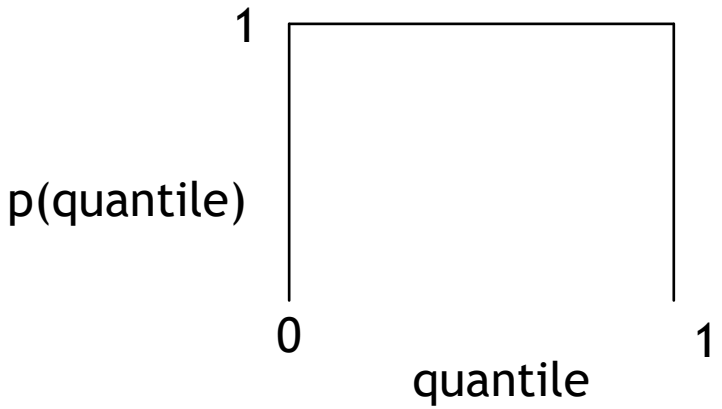
Validating predicted distributions



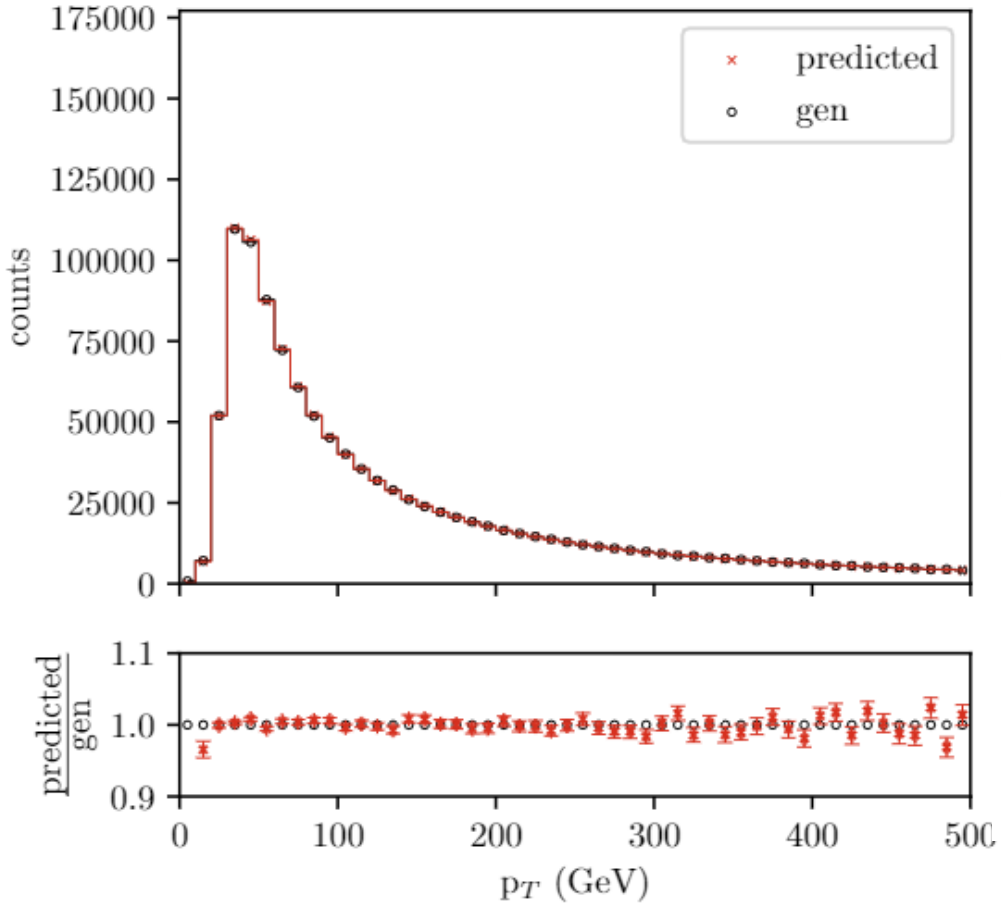
Predicted Distribution

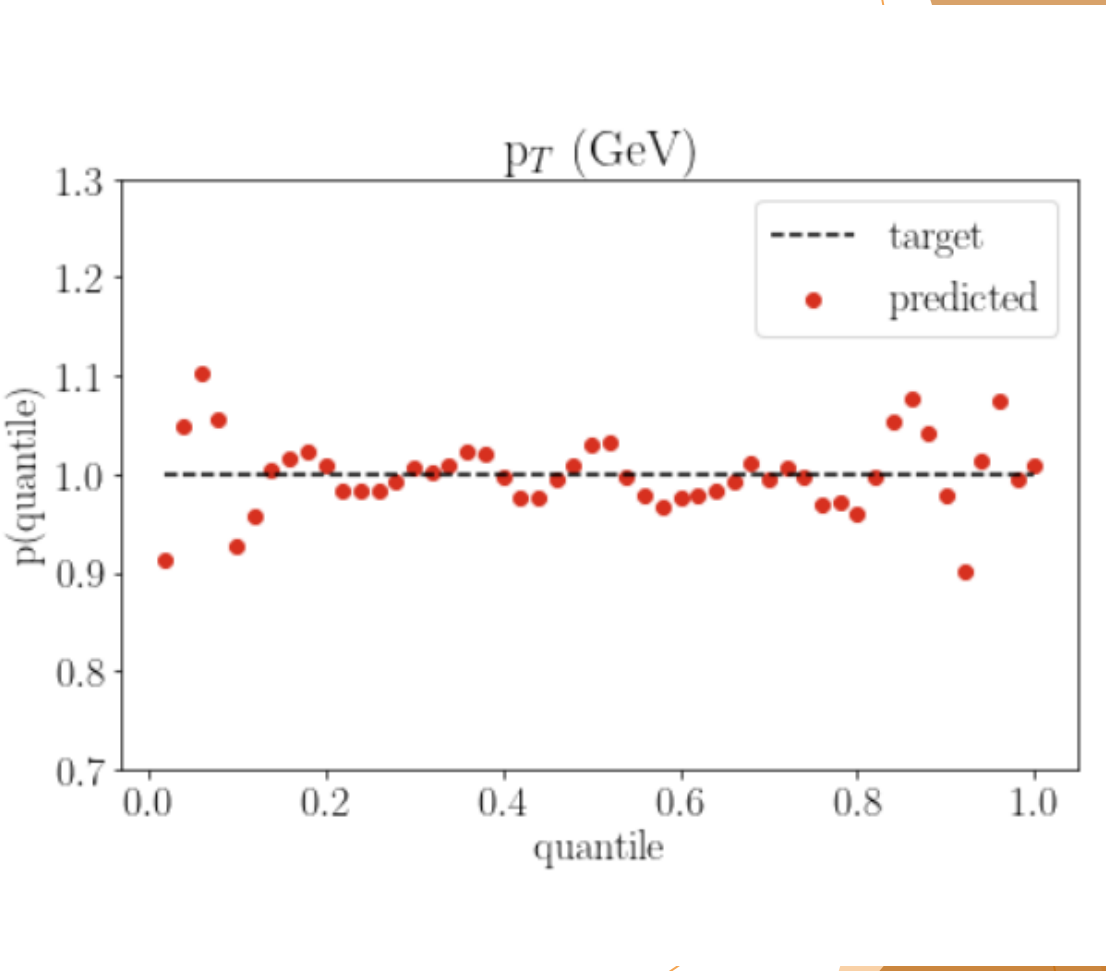
Target value from test set, determine its quantile from the predicted distributions

Plot distribution of quantiles, should be uniform

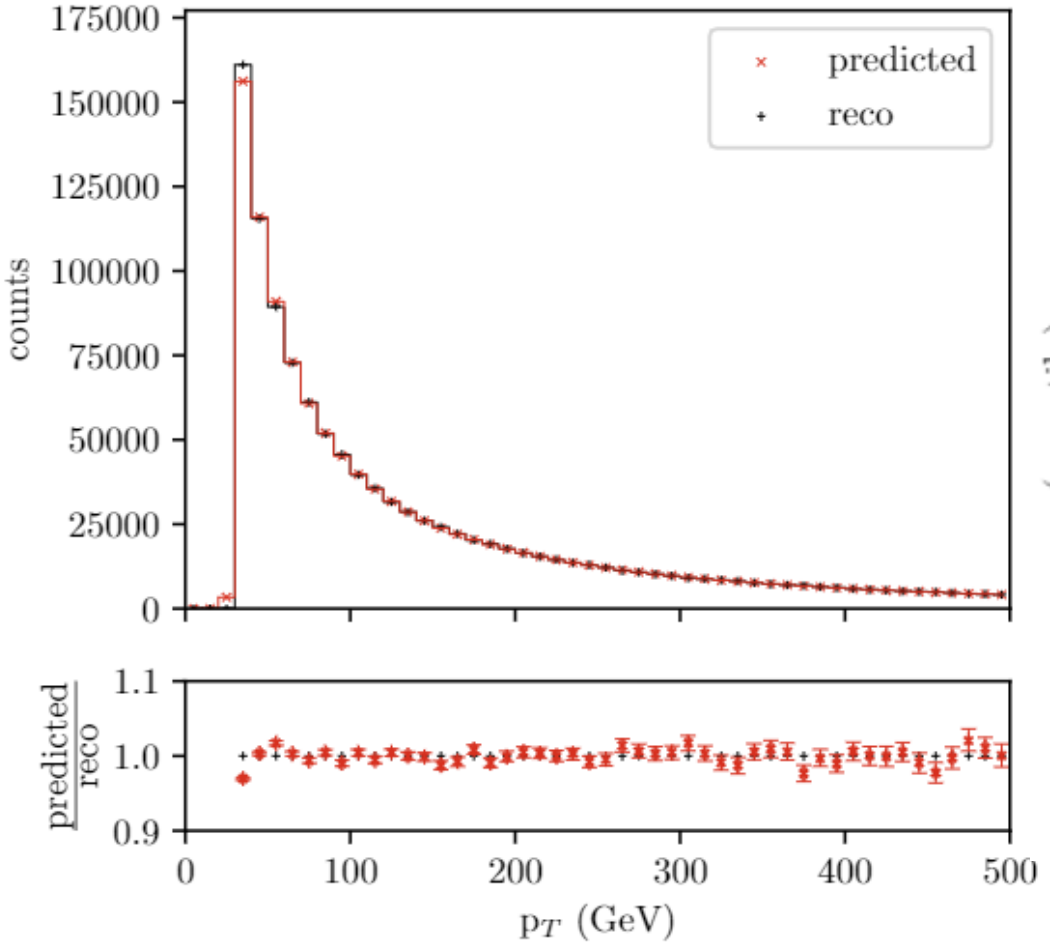


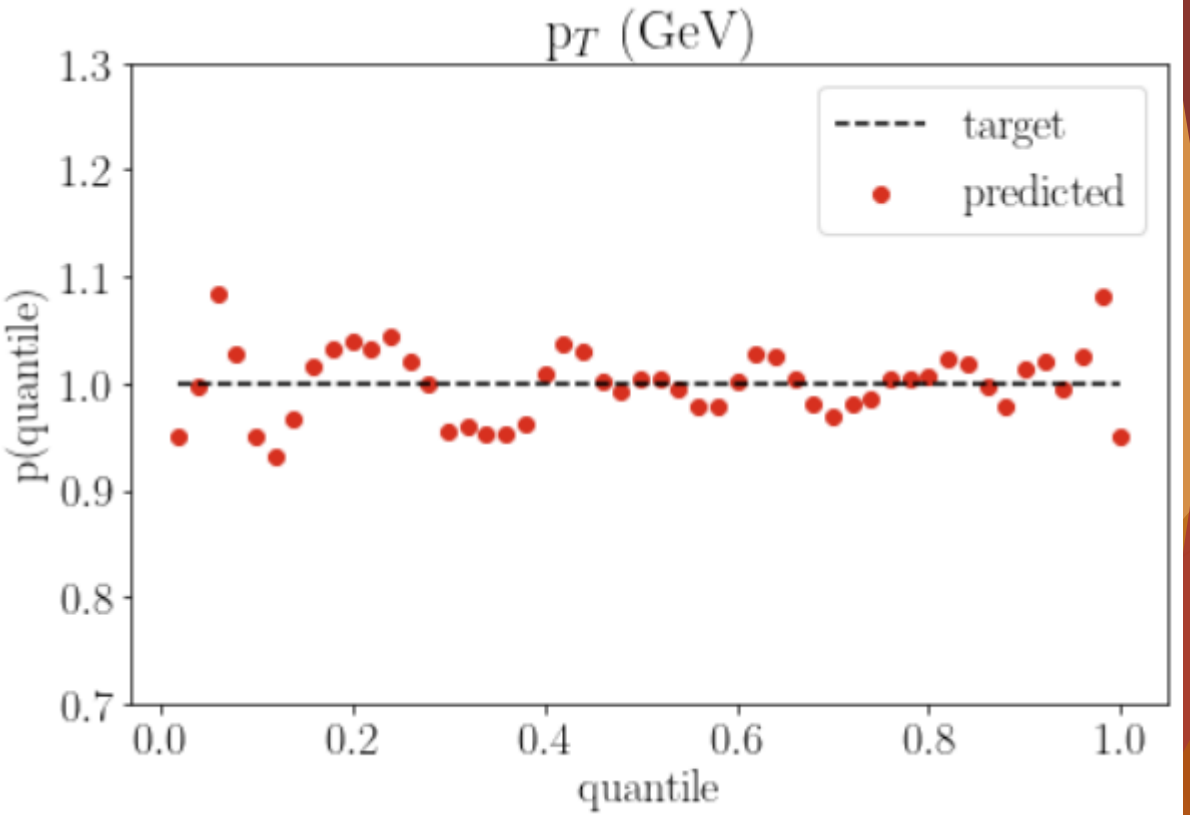
Jet Correction Distribution Results





Jet Simulation Distribution Results





Questions?

Jet Correction Median Results

Variable	Average error of predicted median	Average error of typical reconstruction	SD of predicted median error	SD of typical reconstruction error
p_T	**16.407**	16.794	27.121	**27.105**
Eta	**0.0146**	0.0152	**0.0215**	0.0225
Phi	0.0302	**0.0301**	**0.303**	0.304
Mass	**3.732**	4.274	**4.740**	5.329

Jet Simulation Median Results

Variable	Average error of predicted median	Average error of typical reconstruction	SD of predicted median error	SD of typical reconstruction error
p_T	**16.021**	16.794	**27.039**	27.105
Eta	**0.0143**	0.0152	**0.0211**	0.0225
Phi	0.0302	**0.0301**	**0.303**	0.304
Mass	**3.165**	4.274	**4.345**	5.329

Questions?