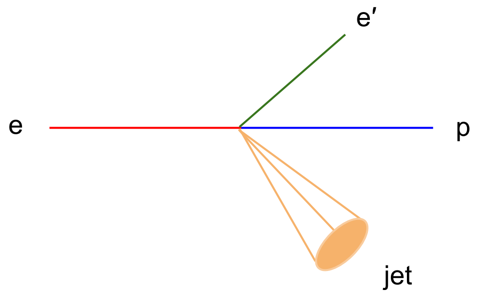
Jet Energy Reconstruction using Bayesian Deep Learning with UQ



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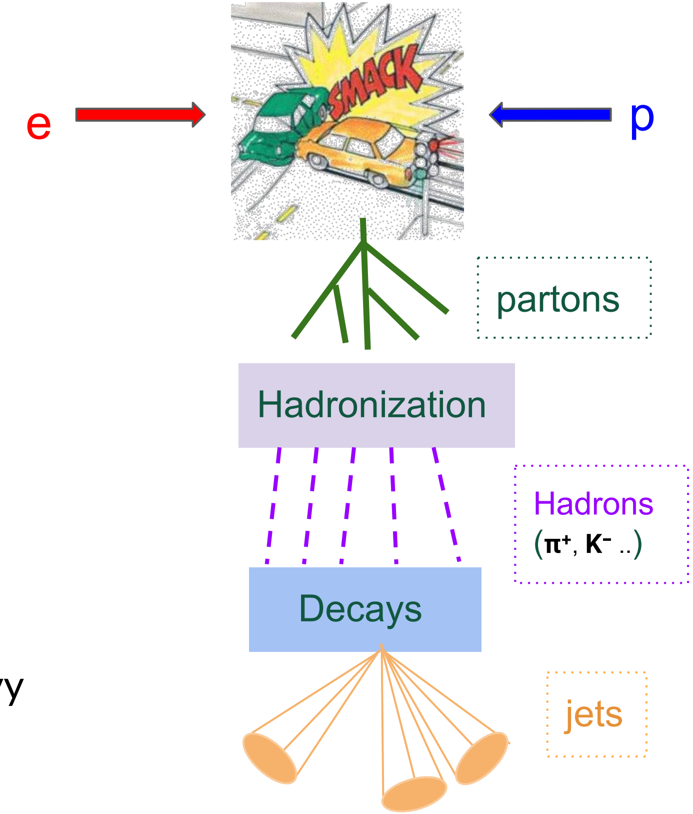
Jets at EIC

- Jets are collimated spray of outgoing particles resulted from Hadronization of Partons (i.e. fundamental particle like quarks and gluons).

- Due to color confinement, quarks and gluons are never found in isolation, they can be found only within Hadrons.



Multiple Physics Goals

- Excellent proxies for the underlying parton kinematics
- acts as a probe to QCD
- acts as a probe of the hot dense medium (QGP) created in heavy ion collision
- And more ….

Source

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Motivation

Measured jet energy differs from theory due to :

- Energy loss in the detector material
- Non-linear response of the detector
- Pileup events - a situation where particle detector detect several events at the same time
- Missing neutrino energy

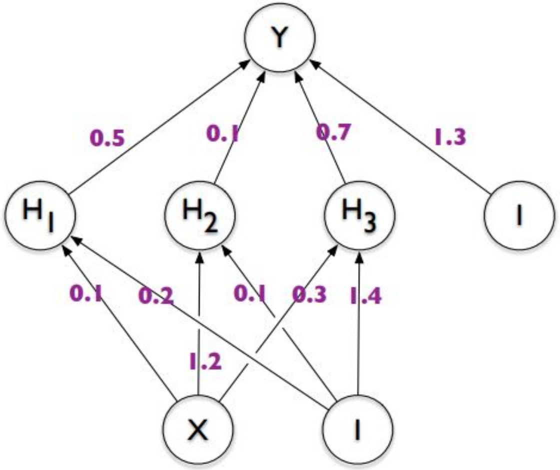
Primary Goal

Develop Bayesian Deep Learning Models that:

- Can overcome the jet energy loss.
- Surpass performance of classical estimates.
- Provide consistent performance with recent Deep Neural Networks.
- Provide robust estimates of epistemic (model) and aleatoric (stochastic) uncertainties to support high precision measurements.

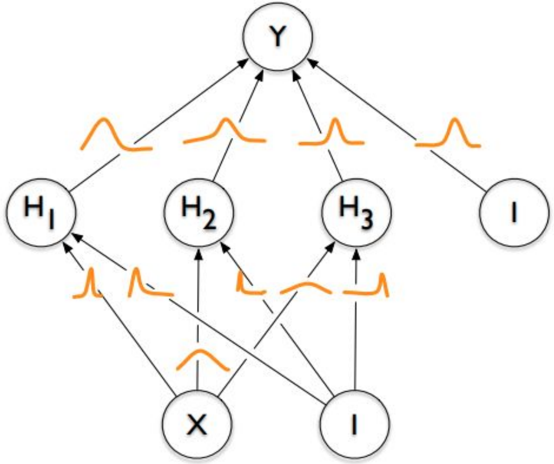
Why bayesian?

Standard Neural Net



- Weights represented by single, fixed values (point estimates)

Bayesian Neural Net



- Weights represented by distributions
- Introduce a prior distribution on the weights *P(w)* and obtain the posterior *P(w|D)* through Bayesian learning
- Uncertainty Quantification (Epistemic Uncertainty, Aleatoric Uncertainty)

Simulation Sample

1. Type of Simulation Sample:
   - D^0 samples:
   - e+P: 5*41
   - Campaign: 25.12.0
   - epic_craterlake/SIDIS/D0_ABCONV/HFsim-PYTHIA/pythia8.306-1.2/ep/5x41/q2_1to10000/hiDiv/

2. Selection cuts:
   - Jet doesn’t have electron
   - No duplicate tracks
   - genJet E > 5 GeV
   - recoJetE > 0 GeV
   - $|\eta| <= 2.5$
   - Track pT > 0.2GeV/c
3. For this study we are using charged particle jet

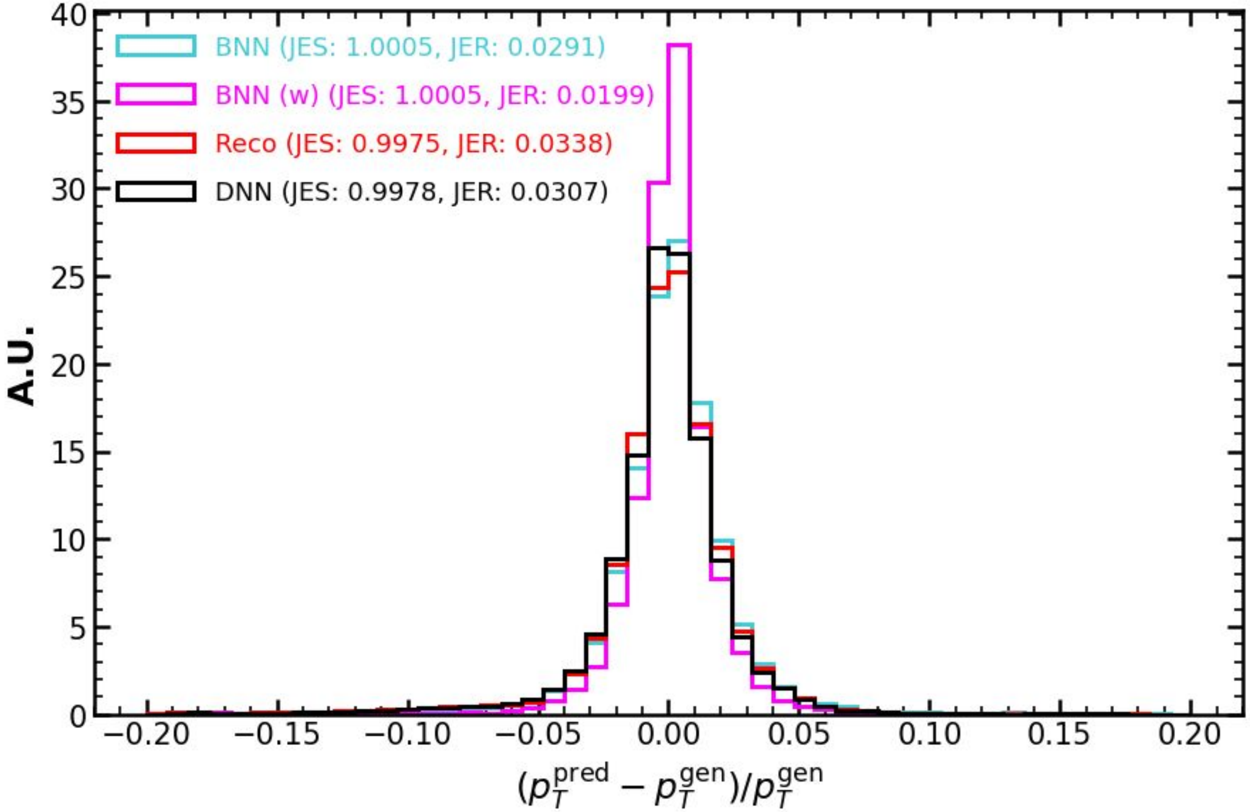
Features

1. Input features:
    a. Jet Mass (m)
    b. Jet Eta (η)
    c. Jet Phi (Φ)
    d. Jet Multiplicity
    e. Jet Girth

2. Target: jet pT

Preliminary results

$$r = \frac{p_{T,i}^{\text{pred}} - p_{T,i}^{\text{gen}}}{p_{T,i}^{\text{gen}}}$$



$$\text{JES} = 1 + \frac{1}{N}\sum_{i=1}^{N} r$$

$$\text{JER} = \sqrt{\langle r^2 \rangle}$$

JER Improvement (relative to Reco)

- DNN : 9.2%
- BNN : 14.2%
- BNN (weighted): 41.3%

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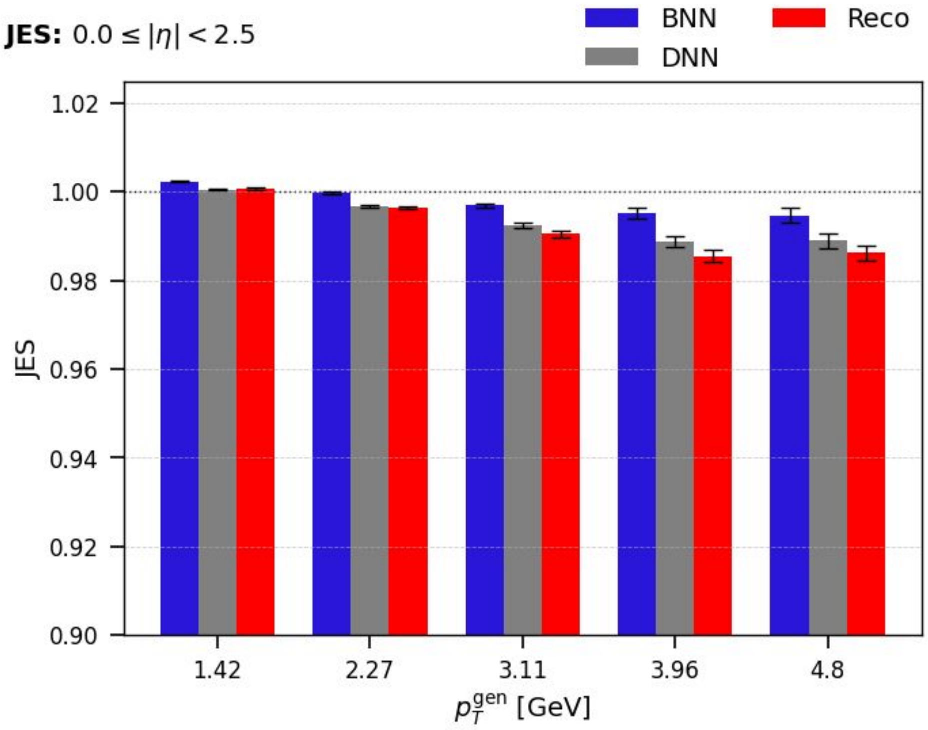
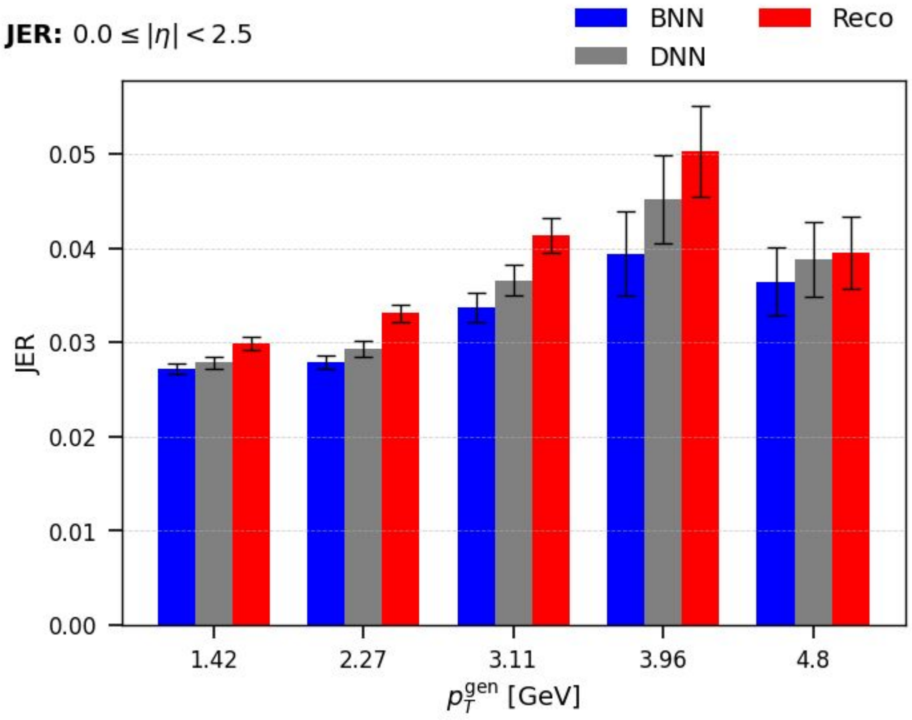
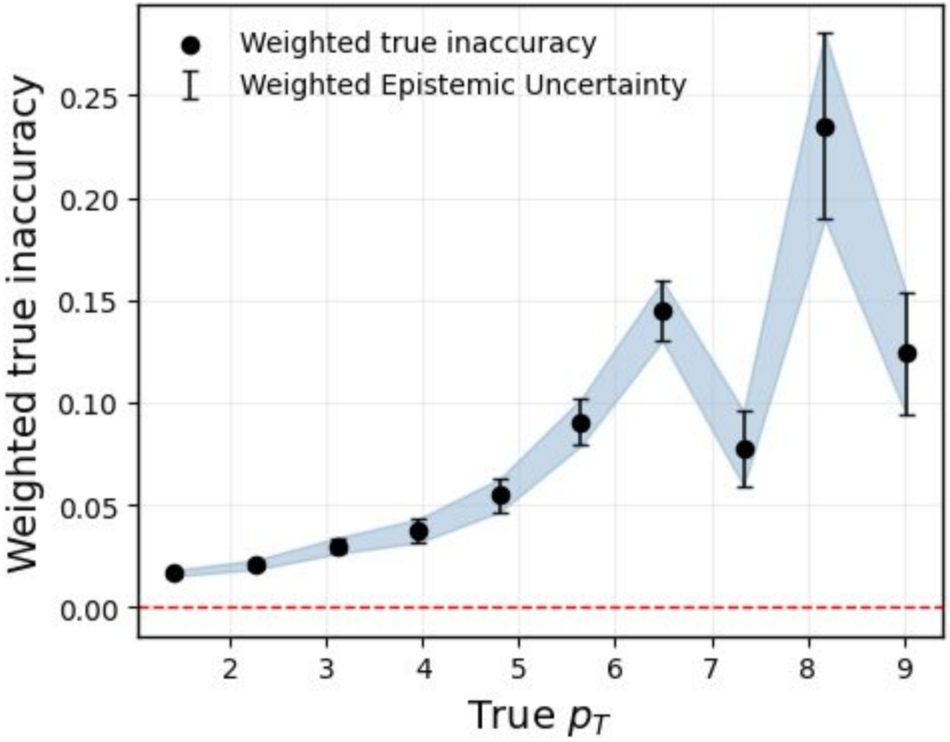
Preliminary results



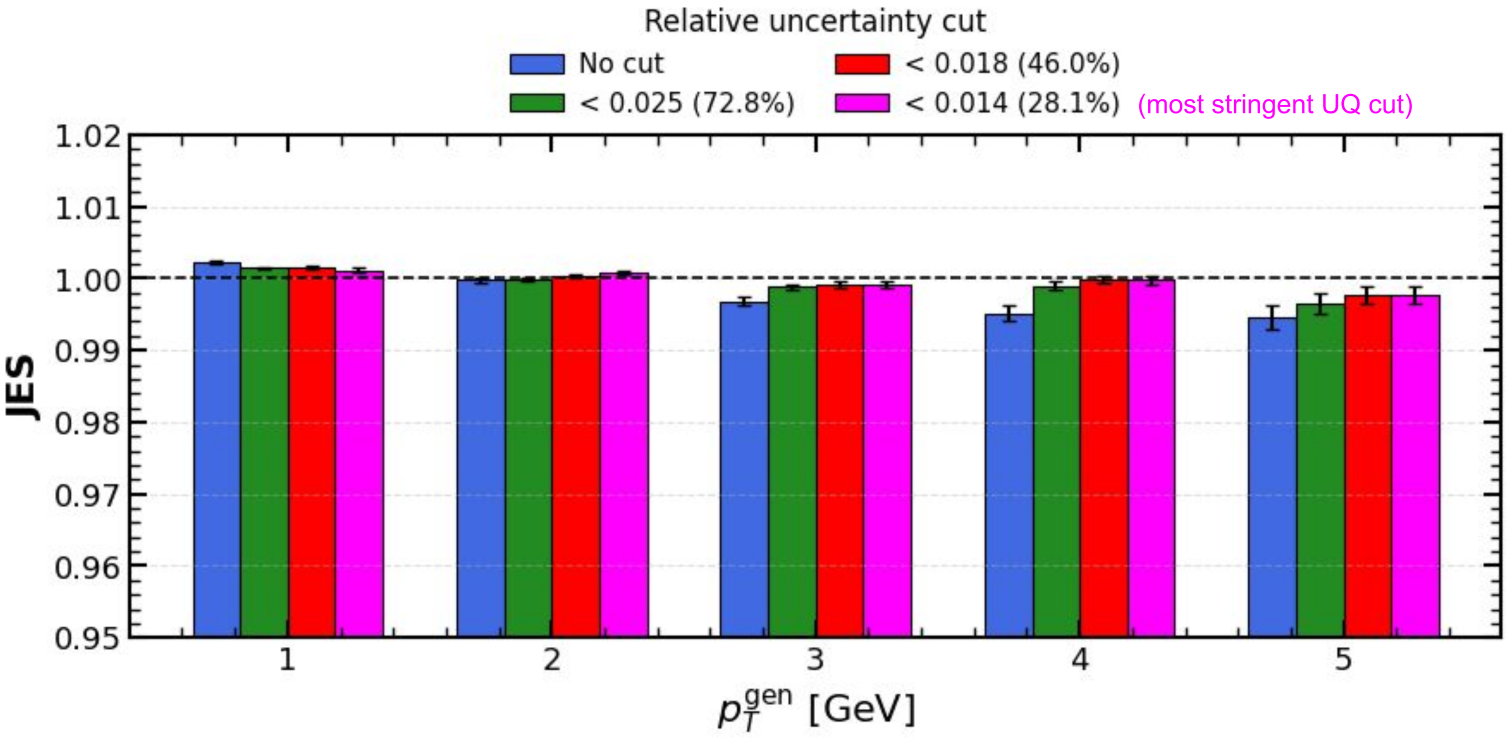


Preliminary results



Epistemic uncertainty increases with the inaccuracy, as expected

Uncertainty-based Cuts: Preliminary results



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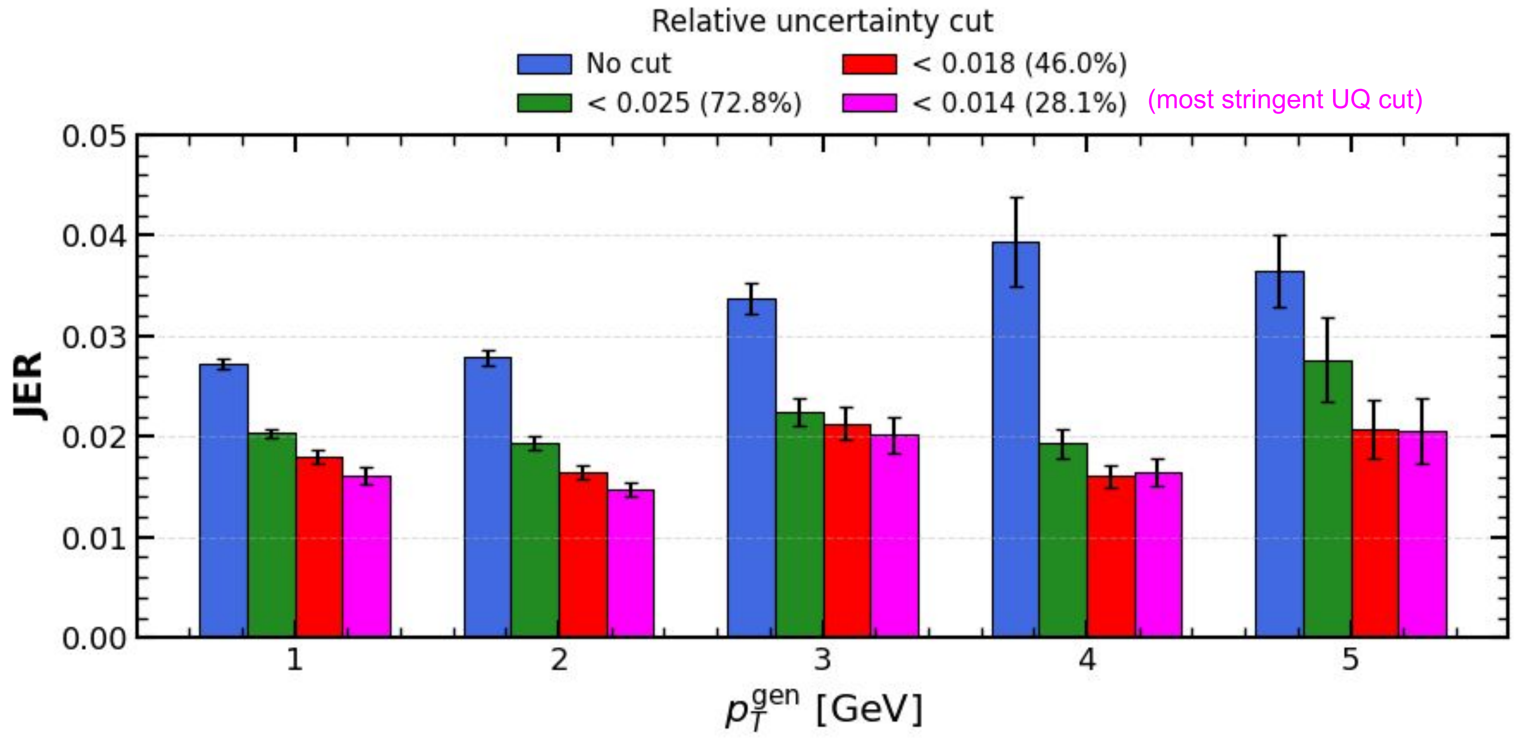

Summary

To summarize,

- Bayesian deep learning improves jet energy reconstruction over both reconstructed jets and conventional neural networks.
- It provides calibrated uncertainty estimates.
- Those uncertainties can be used to select high-quality events, leading to further improvements in jet energy resolution.