

# Uncertainty prediction for LAr energy reconstruction neural networks

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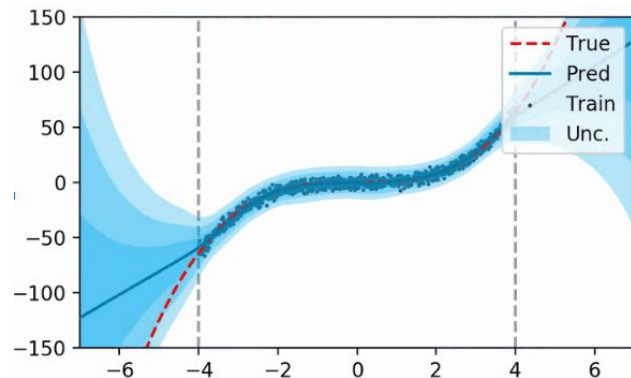
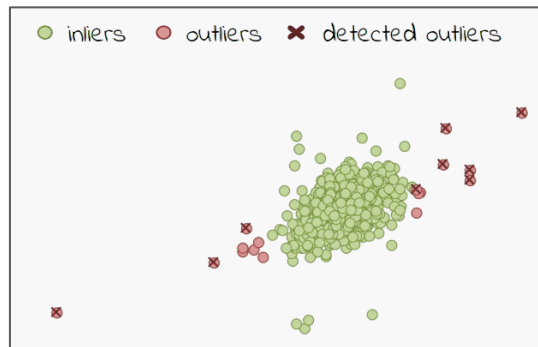
## THINKII Workshop 2025

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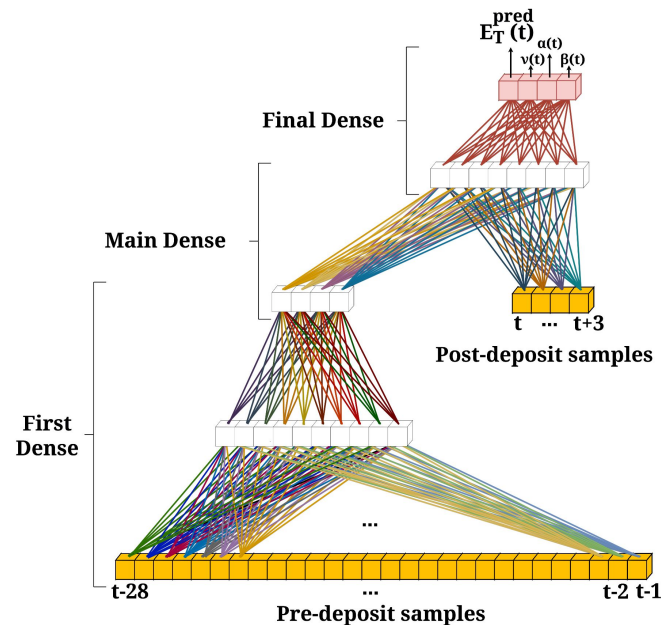
# Deep evidential regression (DER)

- NNs are trained to minimize their prediction errors
  - o Unknown accuracy of the model for individual prediction
  - o It would be interesting to **know when the model is more likely to fail (or the opposite)**
- **Model the energy prediction as a distribution**
  - o Mean of the distribution → **energy prediction**
  - o Standard deviation of the distribution → **uncertainty**
  - o Trained to maximize the likelihood
- Differentiate uncertainties :
  - o **Epistemic**
    - Lack of knowledge, model uncertainty
    - Can be reduced
  - o **Aleatoric**
    - Inherent to data
    - Cannot be reduced



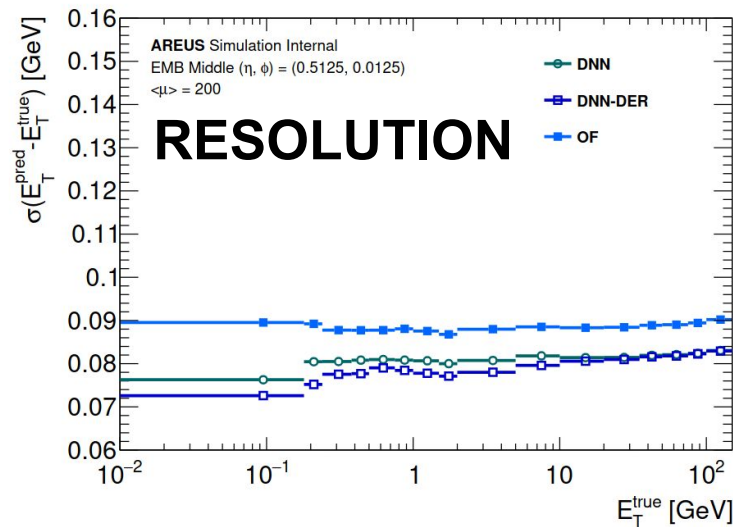
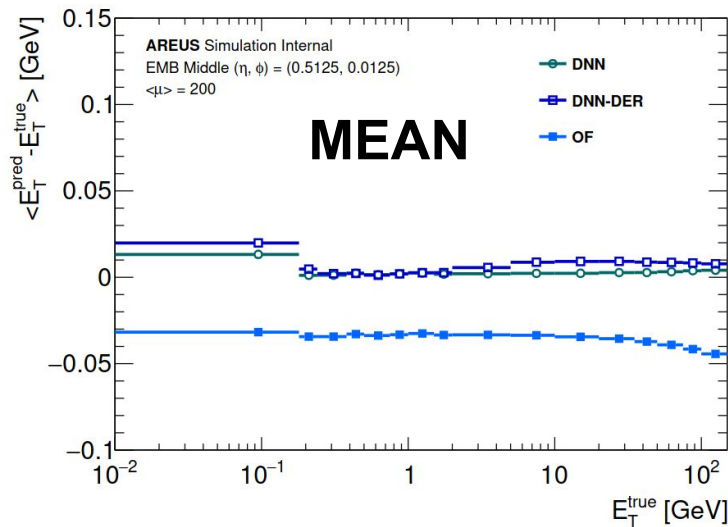
# Deep evidential regression (DER)

- Normale-Inverse Gamma distribution to describe mean and uncertainty
  - **4 parameters** ( $\gamma, v, \alpha, \beta$ ) rather than one
    - Uncertainty computation
- **DER applied to LAr cells energy reconstruction**
  - Would allow to take into account instantaneous luminosity changes or bunch train structure
- Adapted to the Dense architecture
  - **Use of bias** compared to the other architectures
  - **Still possible to implement in FPGA**
    - **416 MAC units**



# Performance plots DER vs Dense

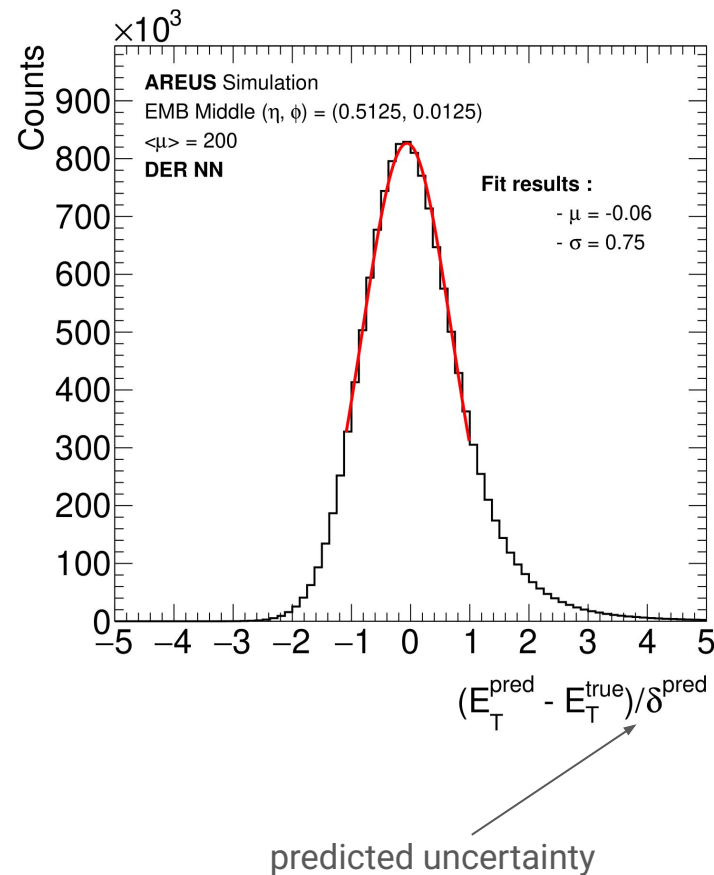
- **Comparable performance** between Dense and DER-Dense architecture
  - Energy range of  $E_T^{\text{pred}} - E_T^{\text{true}}$  slightly biased positively
  - Slightly better performance for DER for  $E_T^{\text{true}} < 10$  GeV



# DER Pull plot

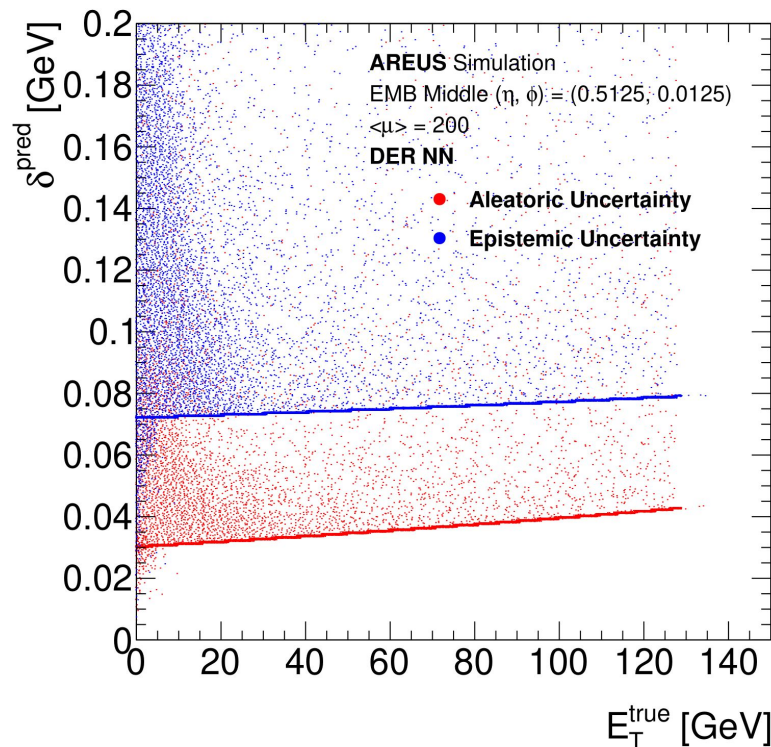
- Overall **good pull distribution**

- Estimated uncertainty comparable to  $E_T^{\text{pred}} - E_T^{\text{true}}$
- **Slightly biased**
  - Right tails
  - Uncertainty overestimated by 25%



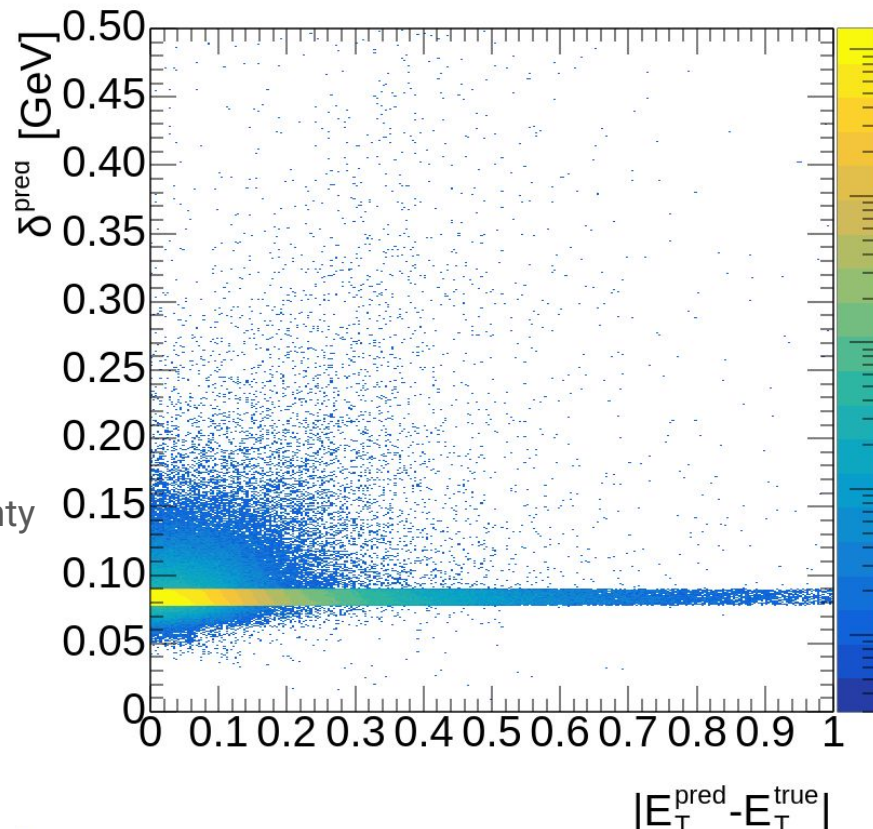
# Aleatoric vs epistemic uncertainties

- Aleatoric  $\Rightarrow$  data uncertainty
  - Intrinsic spread of the data
  - Cannot be reduced
- Epistemic  $\Rightarrow$  model uncertainty
  - Can be reduced with more parameters/data
- Epistemic and aleatoric uncertainties are constant
- Epistemic uncertainty is dominant in the total uncertainty



# Correlation plot

- Two components
  - Thin band around  $\sim 0.85$  MeV
    - Most of the predicted uncertainties are inside this band
  - Gaussian
    - Few values
- Low correlation : 5%
- The DER-NN fails to capture errors dependly on  $|E_T^{\text{pred}} - E_T^{\text{true}}|$ 
  - Too few number of outliers to capture uncertainty
  - The network is predicting a mean uncertainty



# Conclusion

- **Uncertainty on energy prediction using DER technique**
  - **Accurate uncertainty** prediction
  - Possible to **implement in FPGAs**
  - **Similar performance** than Dense architecture
- Model uncertainty is dominant in the total uncertainty
- Some improvements are needed