Combining Maximum-Likelihood with Deep Learning for Event Reconstruction in IceCube

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SFB 876 Providing Information by Resource-Constrained Data Analysis

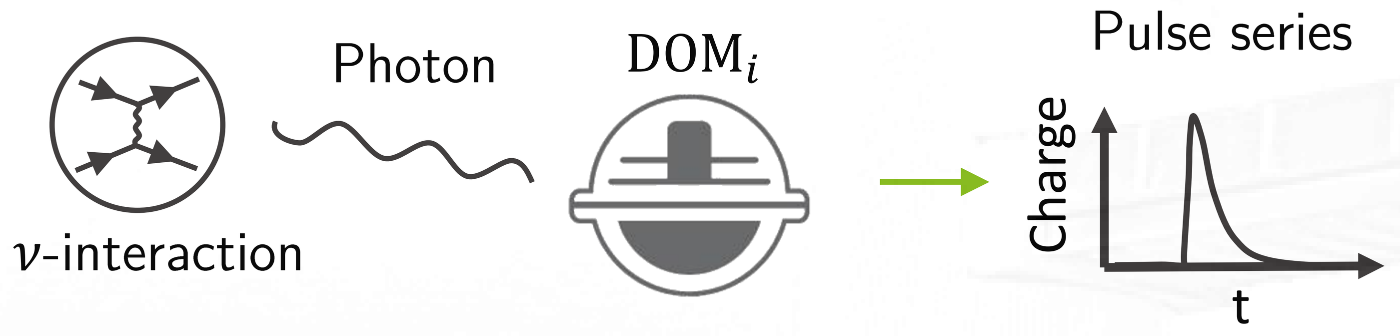
ICECUBE SOUTH POLE NEUTRINO OBSERVATORY

Importance of Domain Knowledge

- Utilization of domain knowledge is crucial to advancing reconstruction performance
- Common deep learning architectures such as CNNs can surpass standard methods[1], but do not fully utilize available information
- In contrast, maximum-likelihood methods can utilize all available information, but are limited due to computational constraints

→ Develop method that combines strengths

Domain Knowledge in IceCube



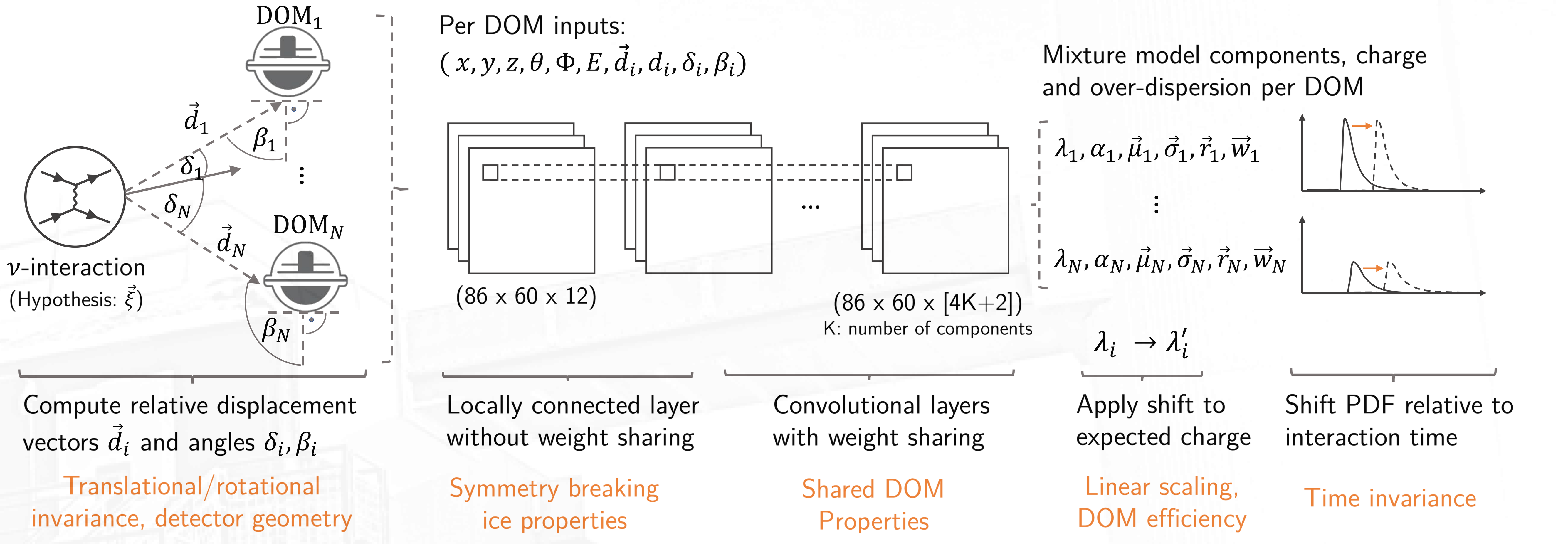
- Processes from neutrino interaction to measured pulse series at each digital optical module (DOM) are simulated and known to great detail [2]
- These processes utilize information such as:
  - Detector geometry
  - Detector properties such as DOM efficiency
  - Optical properties of detector medium including dust layers in glacial ice
  - Translational and rotational invariance of the underlying physics
  - Time invariance
  - Linear relationship of measured charge and deposited energy of neutrino interaction

→ Reconstruction methods may benefit from utilizing this information

Combining Maximum-Likelihood with Deep Learning

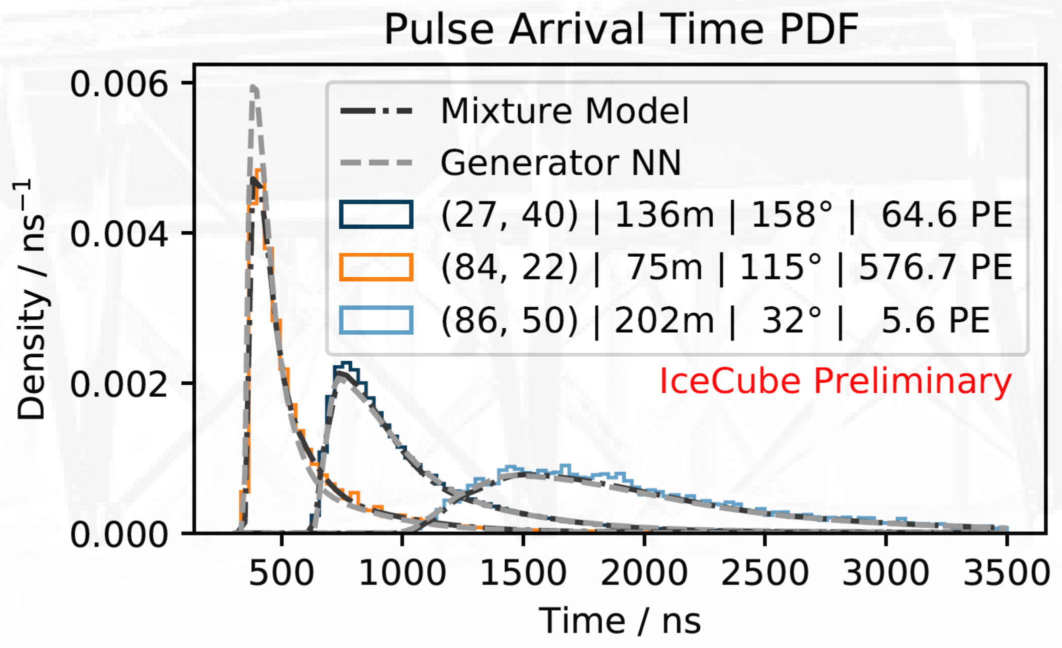
- Standard maximum-likelihood reconstructions in IceCube[3] can utilize available information, but are forced to simplifications due to computational complexity
- Neural Networks (NN) are universal approximators that excel at interpolating high-dimensional data
- Common deep learning (DL) architectures fail at utilizing all available information

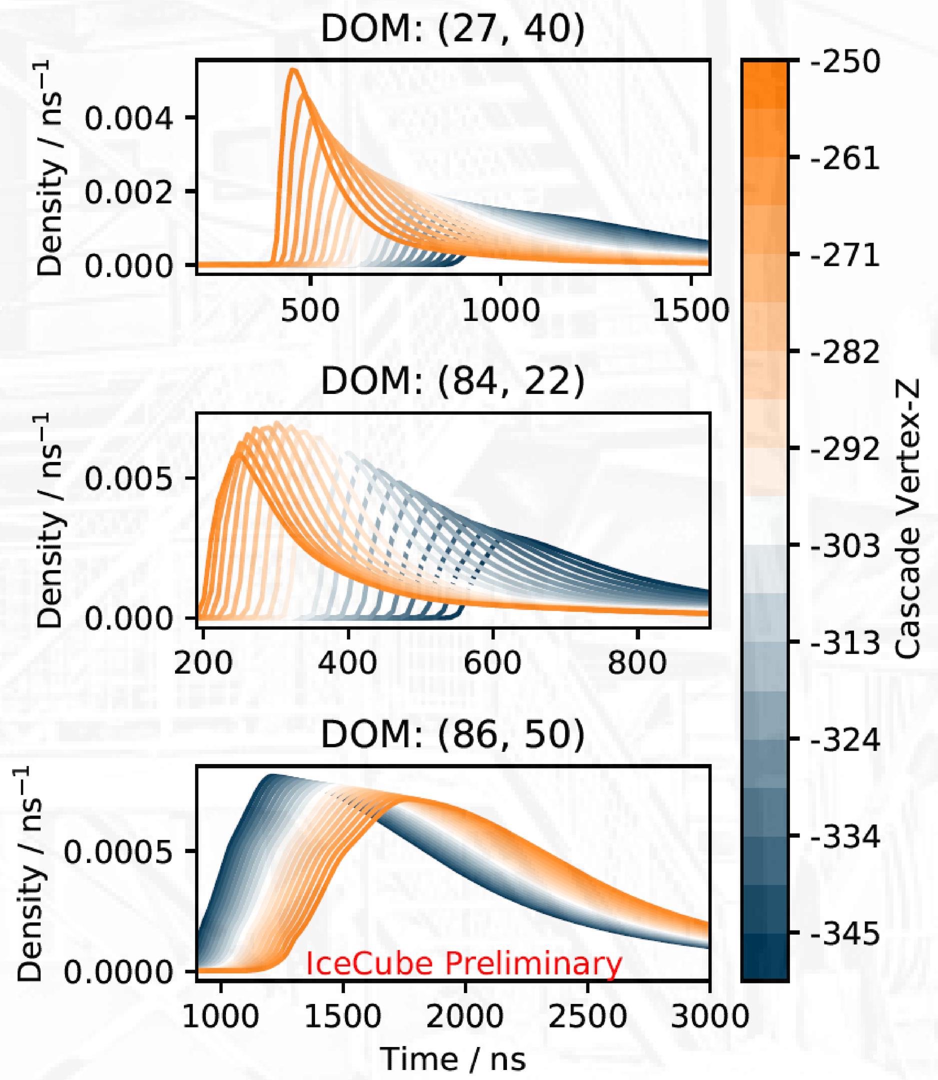
→ Combine strengths of maximum-likelihood and DL:
  - Utilize generative model to approximate pulse arrival time PDF and expected charge at each DOM
  - Parameterize time PDF via mixture model of asymmetric Gaussians[4]
  - Directly include available domain knowledge in network architecture, analogously to simulation



Model Performance

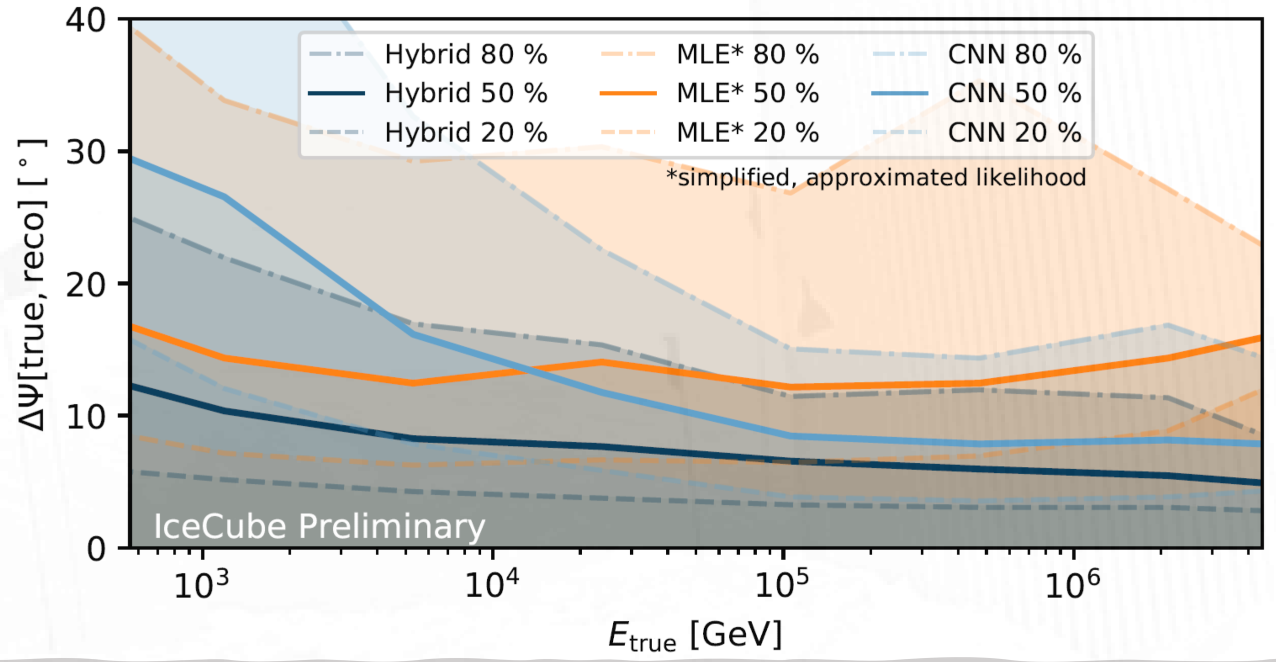
- Generative NN is able to model PDF (bottom)
- NN is more interpretable: individual components (such as z-dependence on the right) can be visualized and cross-checked





Conclusions

- Generative model to approximate high-dimensional PDF
- Generator NN able to utilize available information
- Improved reconstruction resolution of developed hybrid method due to exploitation of symmetries and available domain knowledge, without need for simplifications



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References:

[1] **IceCube** Collaboration, R. Abbasi *et al.* arXiv:2101.11589 [hep-ex].

[2] **IceCube** Collaboration, M. Aartsen *et al.* JCAP 10 (2019) 048.

[3] **IceCube** Collaboration, M. Aartsen *et al.* JINST 9 (2014) P03009.

[4] T. Kato, S. Omachi, and H. Aso *Lecture Notes in Computer Science* (2002) 405–413.

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