Status of the implementation of *Event-generator* in IceCube-Gen2

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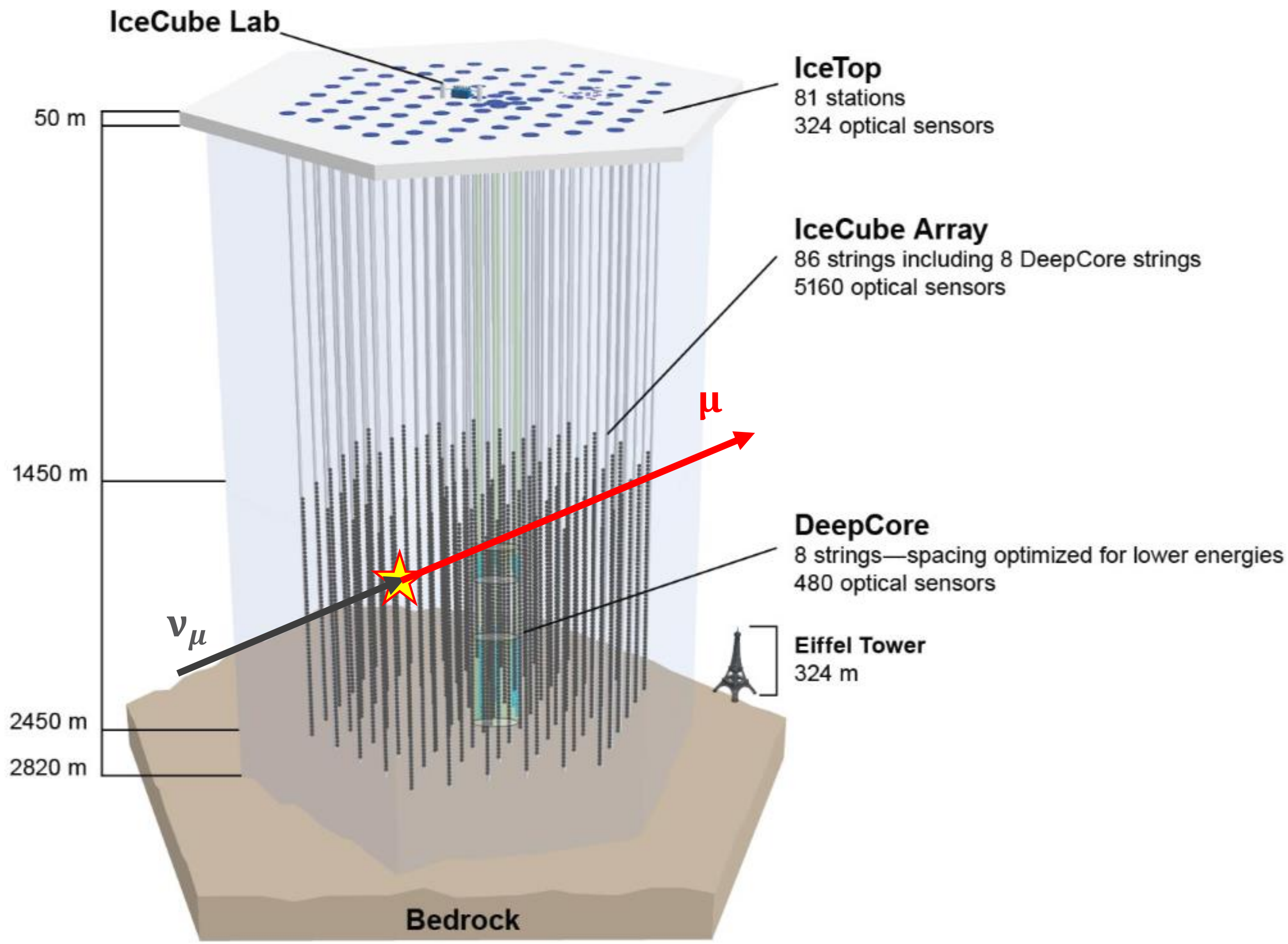
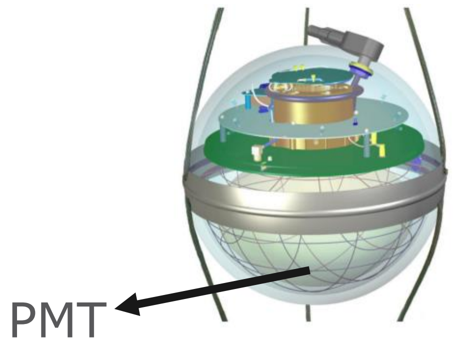
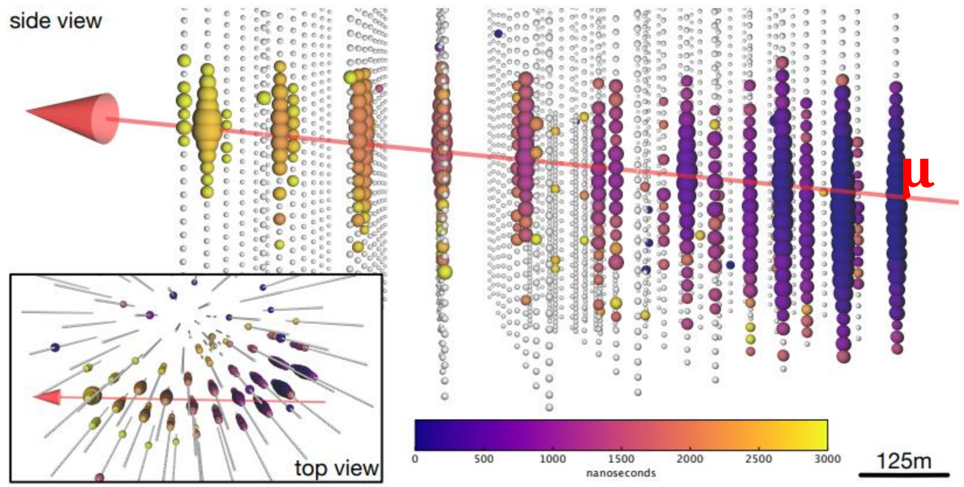
IceCube Neutrino Telescope



DOM



Muon track on IceCube



IceCube events

- Two basic topologies:

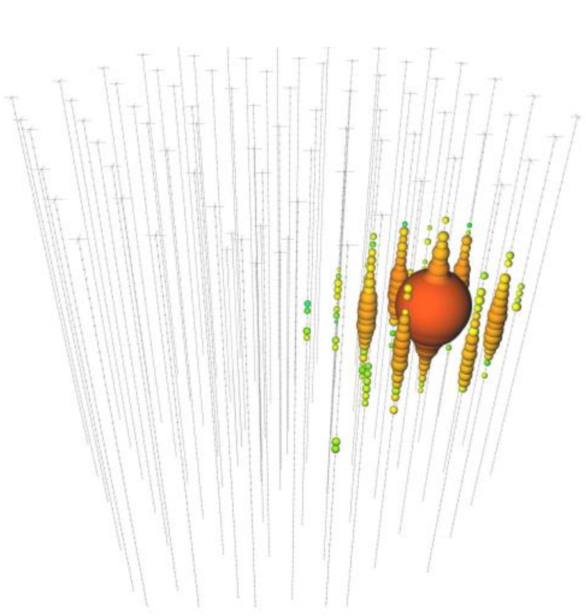
  1. Cascades:
     - ν_e, ν_τ Charged Current (CC)
     - Any neutral current (NC)

  2. Tracks:
     - High energy muons

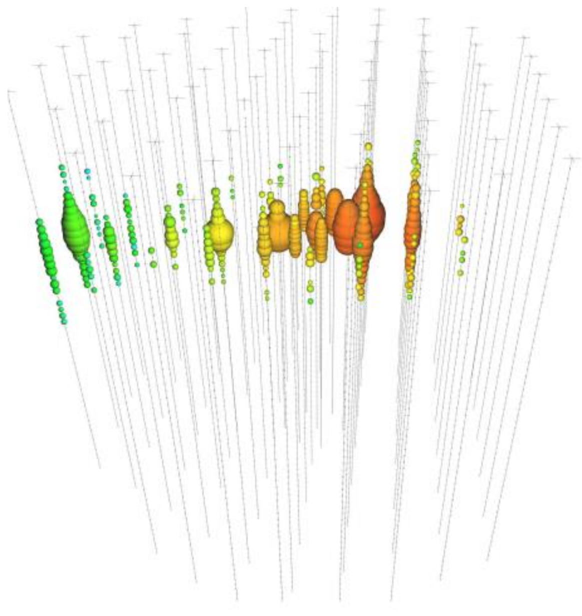
- Information:
  1. Detected photons
  2. Time
  3. Geometry/PMT position

- Reconstruction of:
  1. Neutrino direction
  2. Neutrino energy
  3. Neutrino flavour

Cascade



Track



Size of bubble → Amount of photons detected at a DOM

Colour = Time: Earlier → Later

Standard reconstruction (Maximum Likelihood)

- Reconstruction parameters are estimated by comparing measured data with hypothesis expectations

$$\mathcal{L}(\vec{X} = \{\vec{c}, \vec{t}\} | \vec{\xi})$$

$\vec{\xi}$=hypothesis
$\vec{X}$=measured data (charge/photons, time)

- e.g. cascade energy (no noise):

$$\mathcal{L} = \prod_{\mathrm{DOM}_j} \left(\frac{\lambda_j^{k_j}}{k_j!} \cdot \exp(-\lambda_j) \right)$$

k_j = detected photons
λ_j = expected photons = $\Lambda_j E$

E = energy
Λ_j = Light yield scaling

Poisson

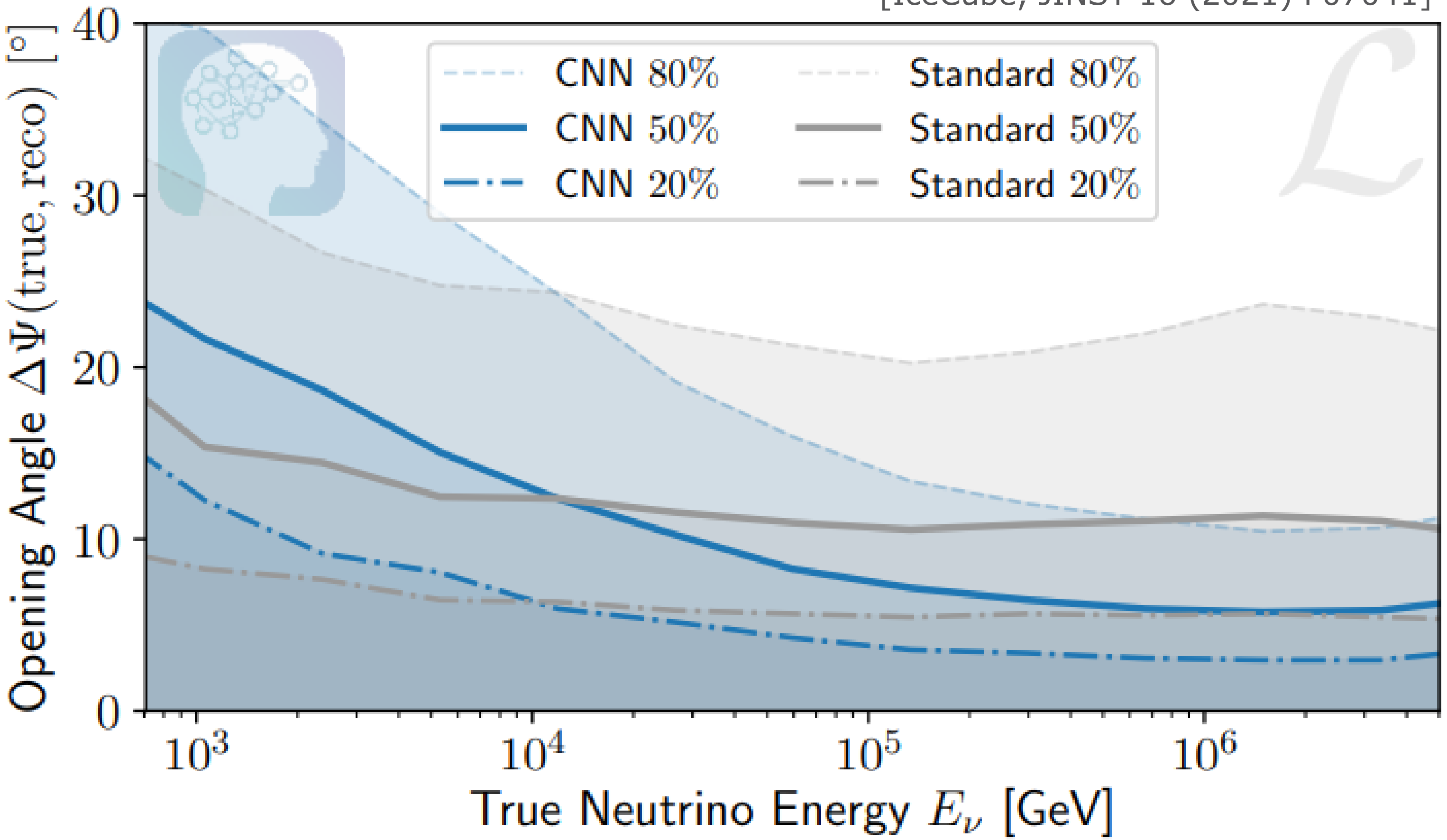
- Expected light yields (Λ_j) are tabulated: depend on 9 parameters ($\vec{r}_{\mathrm{vertex}}, \vec{r}_{\mathrm{pmt}}, \theta, \phi, t$)

→reduced to 6 with approximate azimuthal and lateral symmetry of light propagation

Deep Learning reconstructions

- Several approaches:
  - ➢ Recurrent NN
  - ➢ Graph NN
  - ➢ Convolutional NN
- Monte Carlo data is fed to the models that infer the rules that govern it
- Proved to be able to outperform the standard approach

[IceCube, JINST 16 (2021) P07041]



Median (50%)
Percentiles (20% and 80%)

Pros and cons of both approaches

	Deep Learning	Maximum Likelihood
Explicit use of domain knowledge	✘	✓
Computationally inexpensive	✓ (once trained)	✘

Domain knowledge in IceCube:

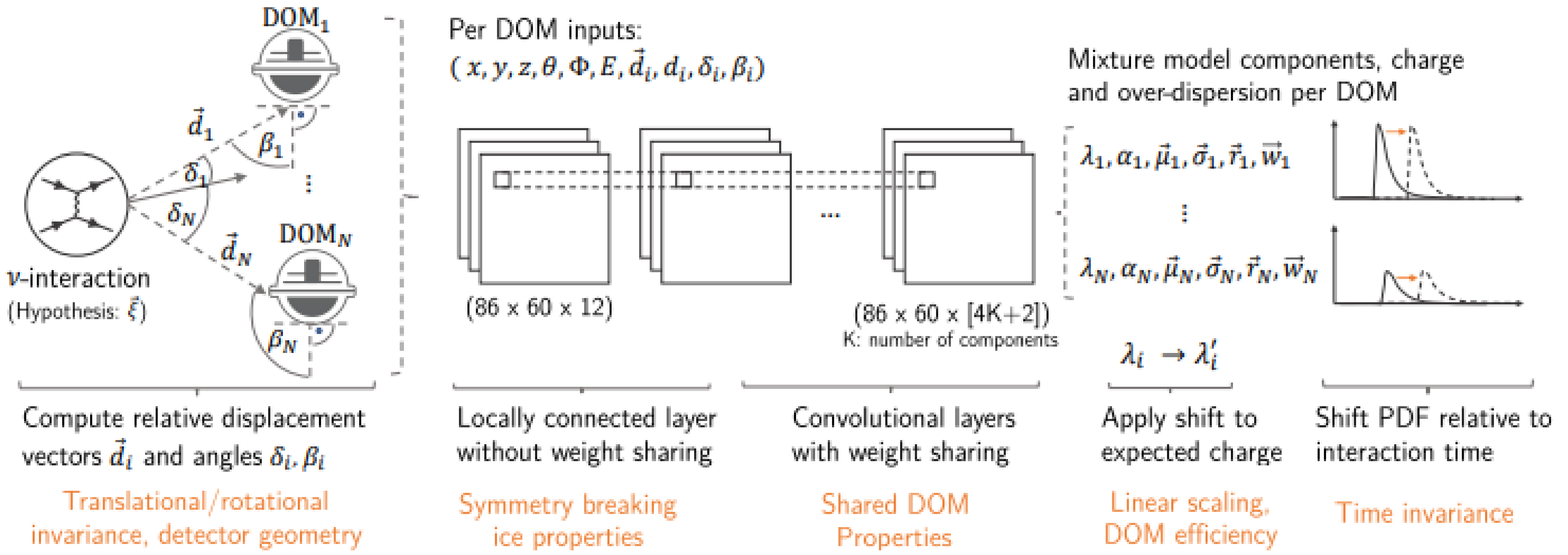
- geometry of the detector
- translational and rotational invariance of neutrino interaction
- linear scaling between collected charge and deposited energy
- optical properties of ice

Event-generator: Best of both worlds

Generative model:

$$G\left(\vec{\xi}\right) = \left\{\vec{\lambda}, \overrightarrow{P(t)}\right\},$$

- $\vec{\xi} = (x, y, z, \theta, \phi, E, t)$=hypothesis
- $\vec{\lambda}$=output charge
- $\vec{P}(t)$= pulse arrival time PDF = $\sum_j^k w_j \cdot AG(t|\vec{\mu_j}, \vec{\sigma_j}, \vec{r_j})$

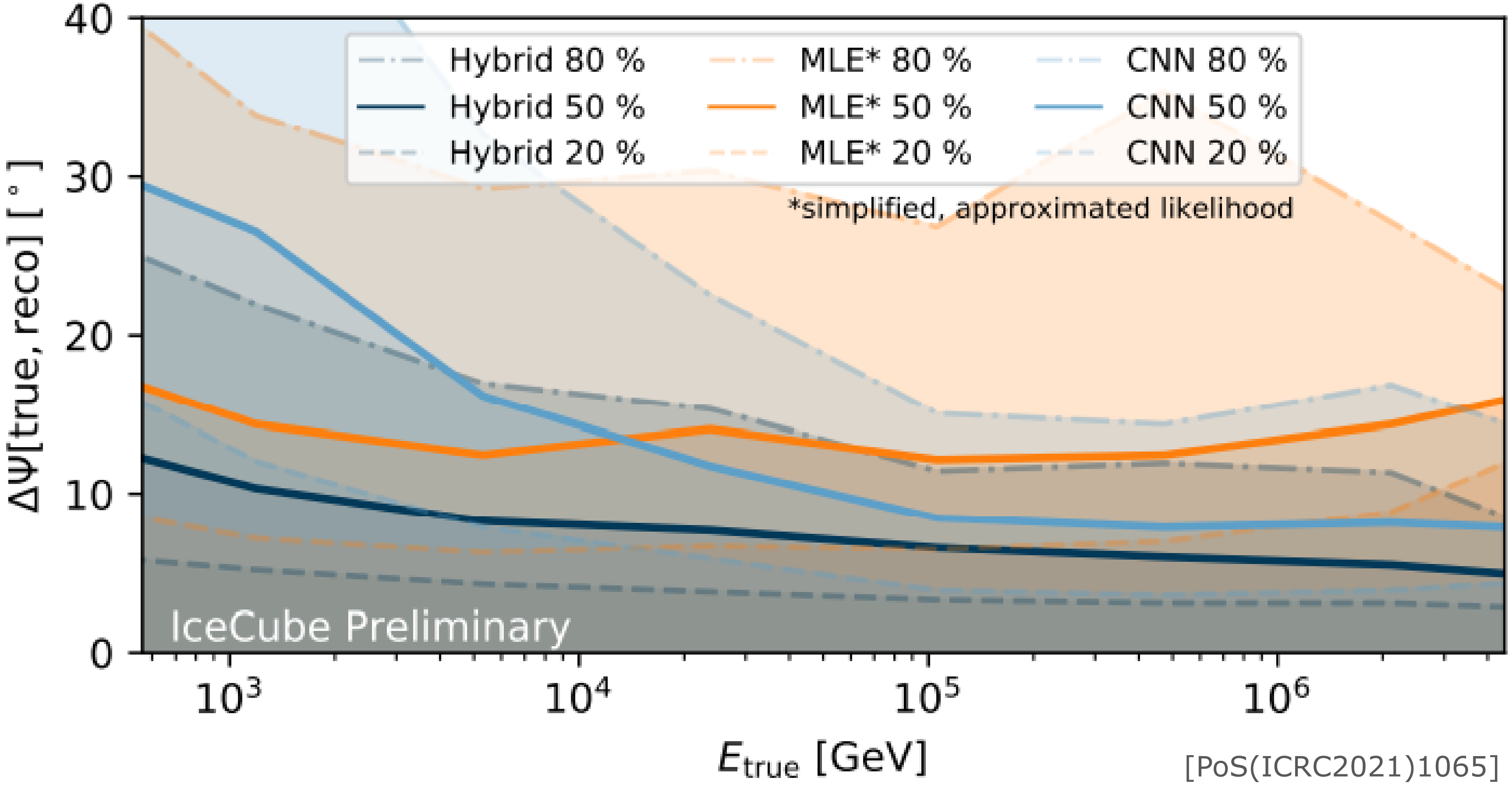


Domain knowledge

[PoS(ICRC2021)1065]

Event-generator Applications: Reconstruction

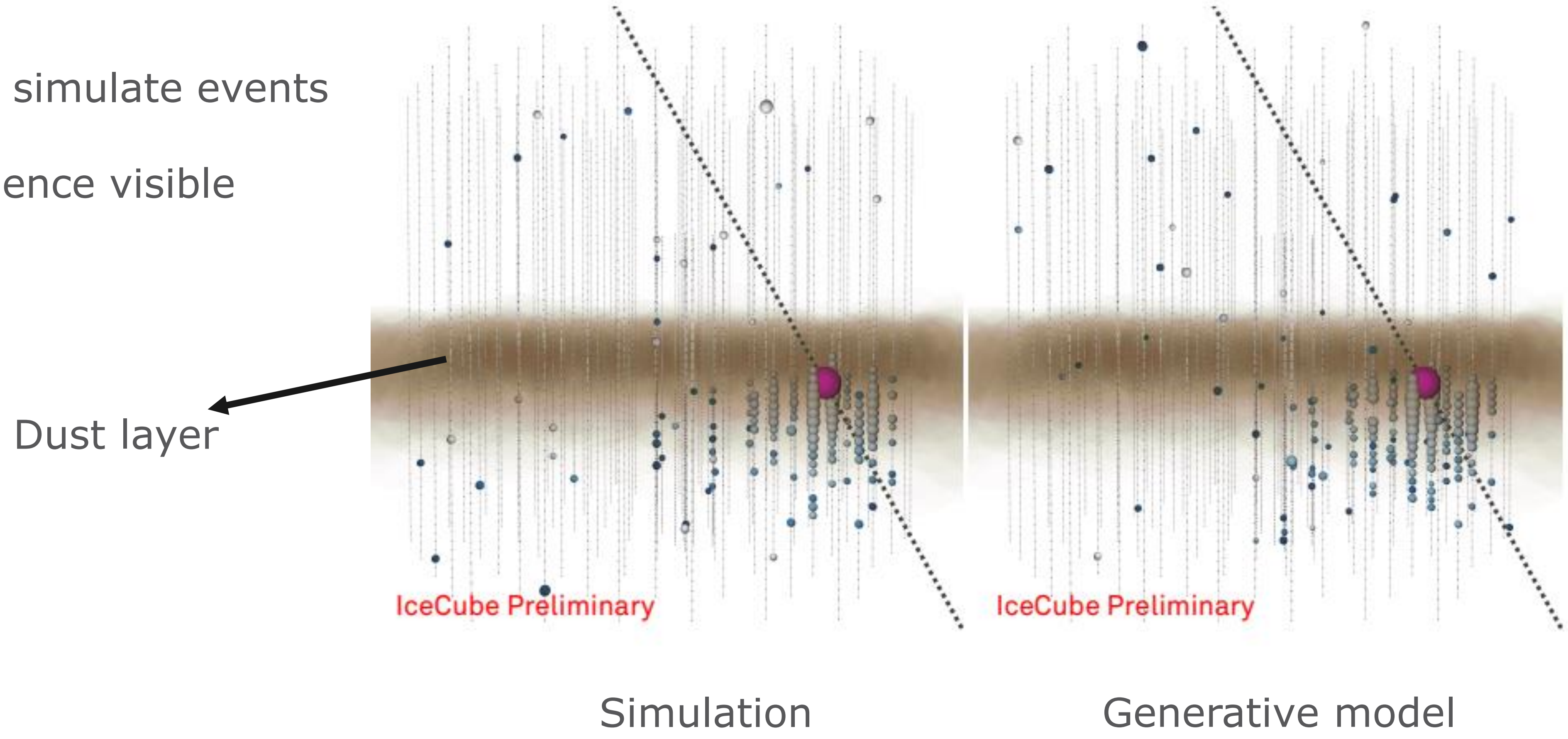
- Generated expectations can be used in maximum likelihood reconstruction
- Significant enhancement with respect to the conventional approaches



[PoS(ICRC2021)1065]

Event-generator Applications: Simulation

- Can be used to simulate events
- Dust layer influence visible



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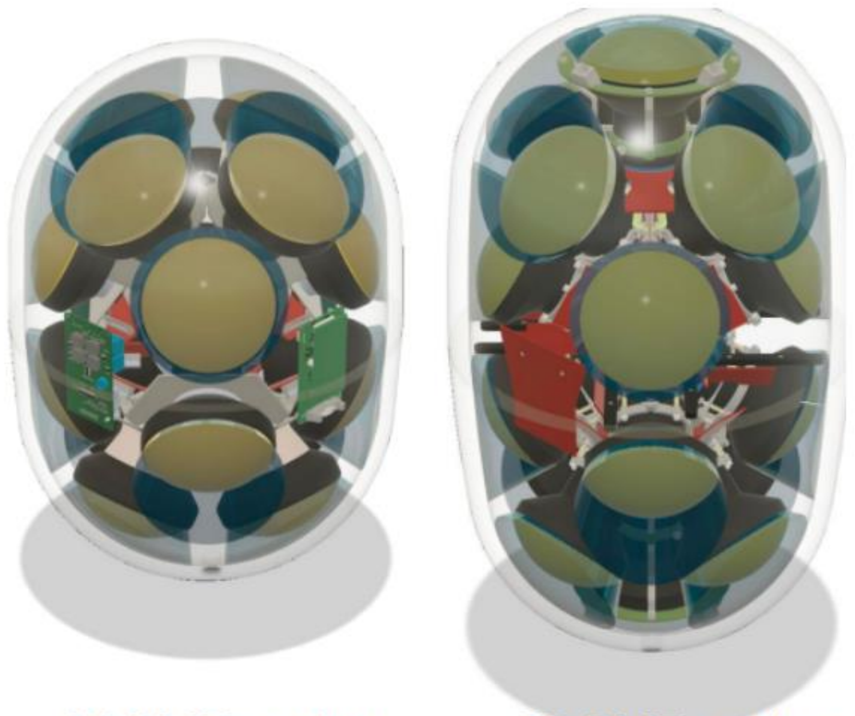
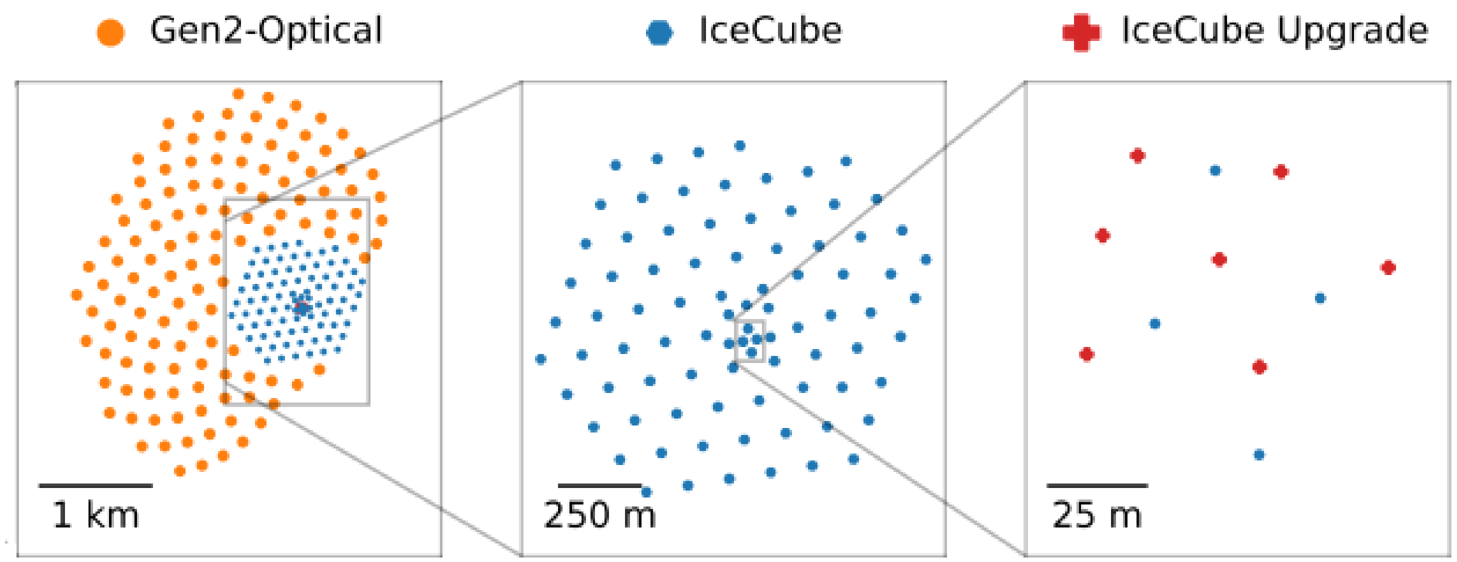
IceCube-Gen2



16 PMT option
(LOM-16)

18 PMT option
(LOM-18)

Top view of string positions



- Target high energies
- ~ ×8 IceCube volume
- New multi-PMT optical modules

Event-generator in IceCube-Gen2: Status

Why?

- Tool for reconstruction with segmented modules:

→ Lookup tables for multi-PMT modules are extremely computationally expensive

- Fast simulation production

Status:

- Code needs to generalize to support Gen2 layout
  - Number of strings
  - Modules per string
  - Multi-PMT modules
- Currently no LOM Monte Carlo is available:

→ Gen2 sensitivity studies are carried with iso-pDOMs (high QE DOM with isotropic acceptance)

- Test version with iso-pDOMs could be trained

Event-generator in IceCube-Gen2: Future

- Create and train different NNs for each kind of module: LOM, DOM, mDOM? and D-Egg?
- Integrate everything properly so as share in GitHub

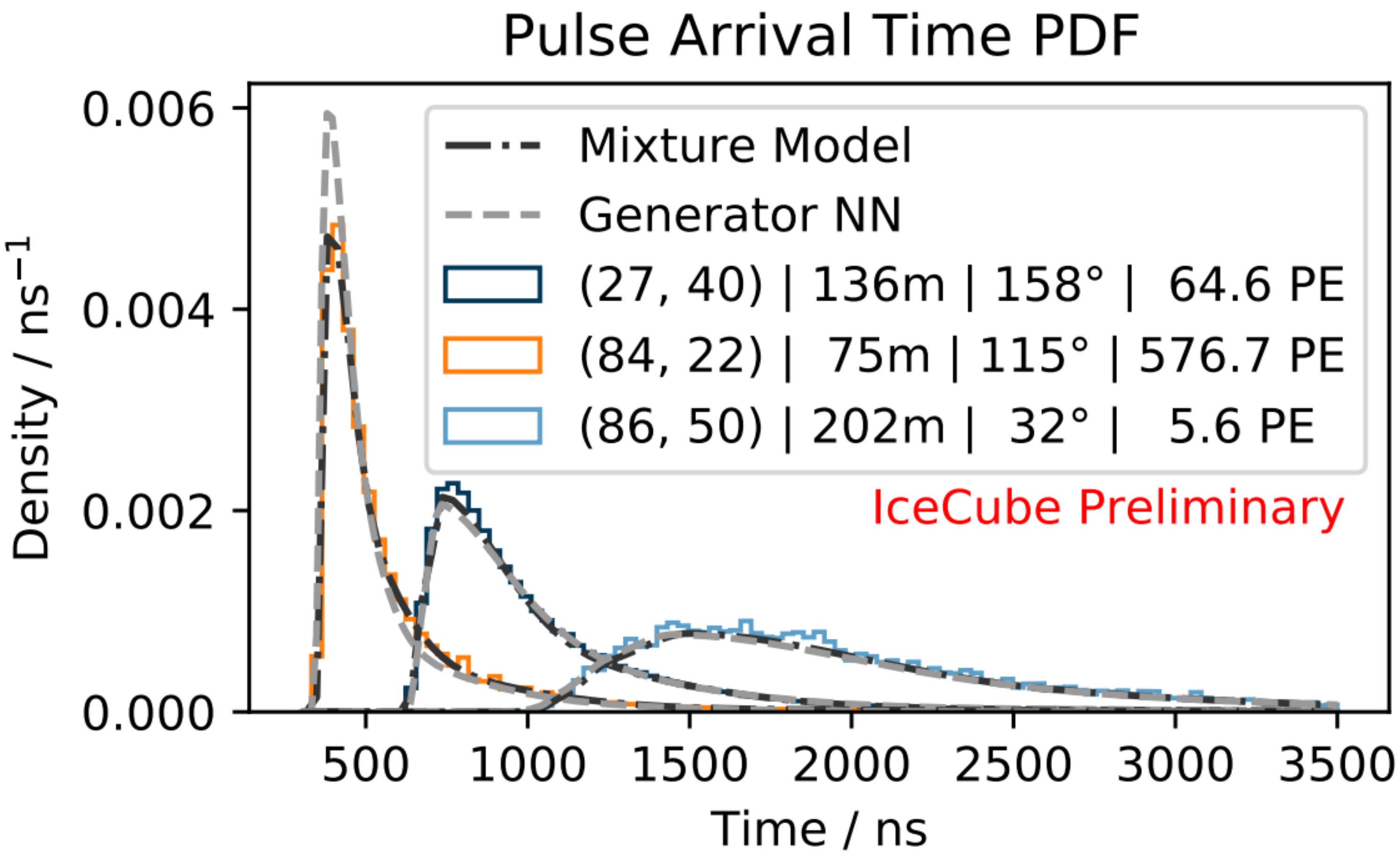
Summary

- *Event-generator* is a generative NN that uses the available domain knowledge to model the expected charge and pulse arrival time PDF
- Work is currently underway to implement it in IceCube-Gen2
- Starting with iso-PDOMs. LOMs will be implemented in the near future

Backup

Event-generator Applications: Pulse PDF

Generated vs simulated pulse arrival time PDF



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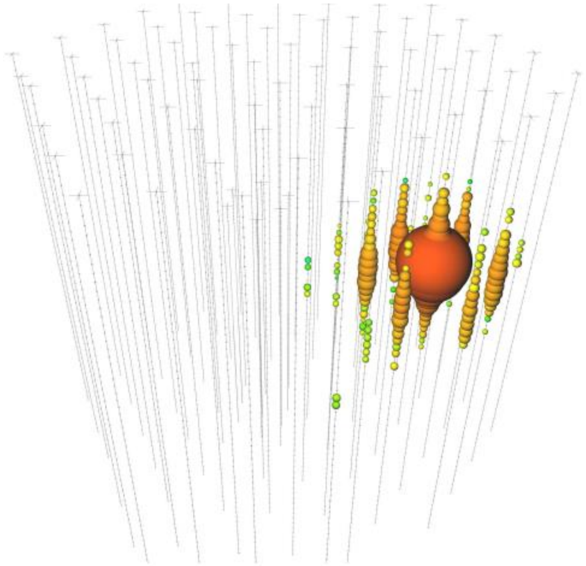

Track