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Vertex Reconstruction in JUNO

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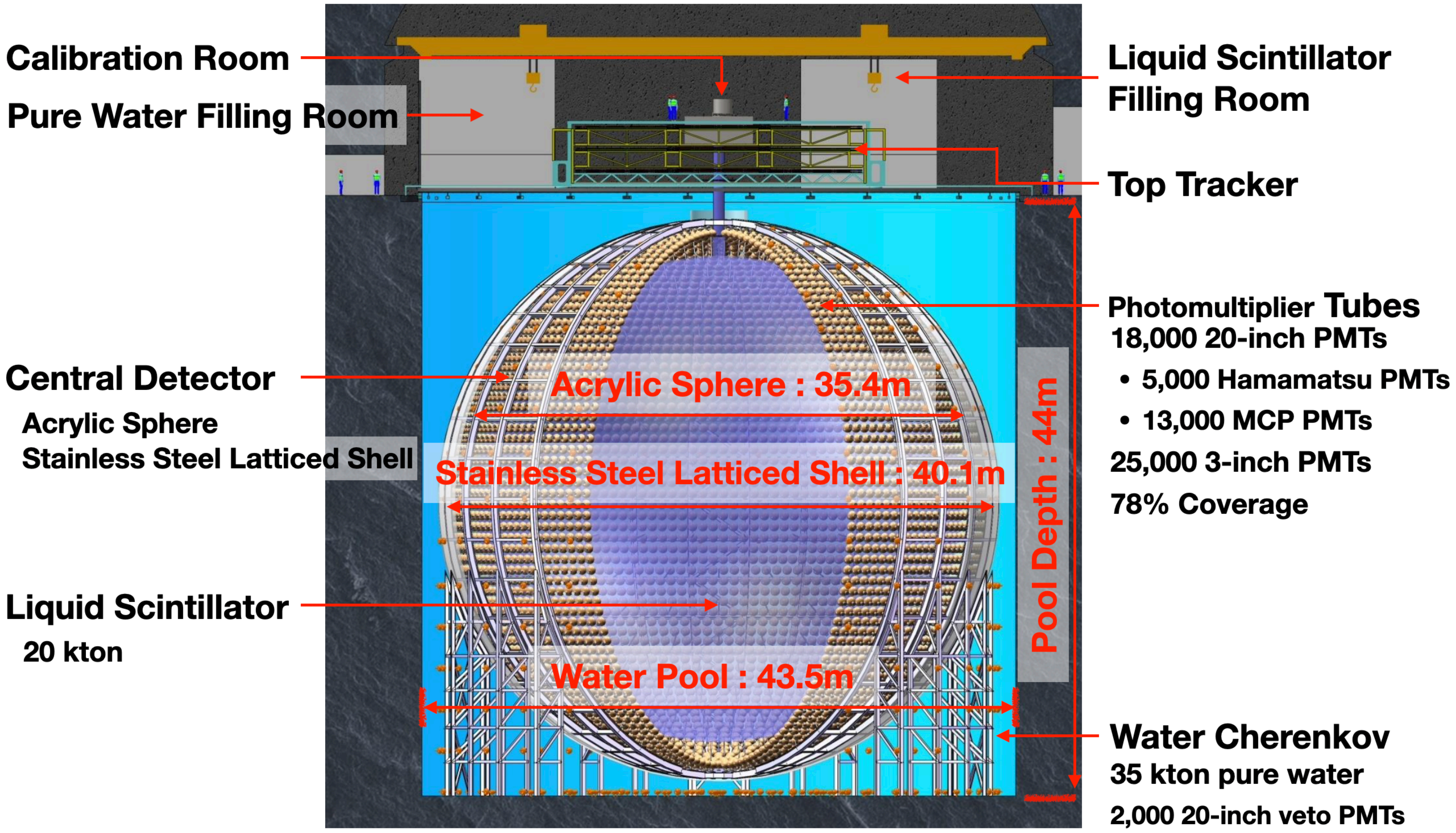
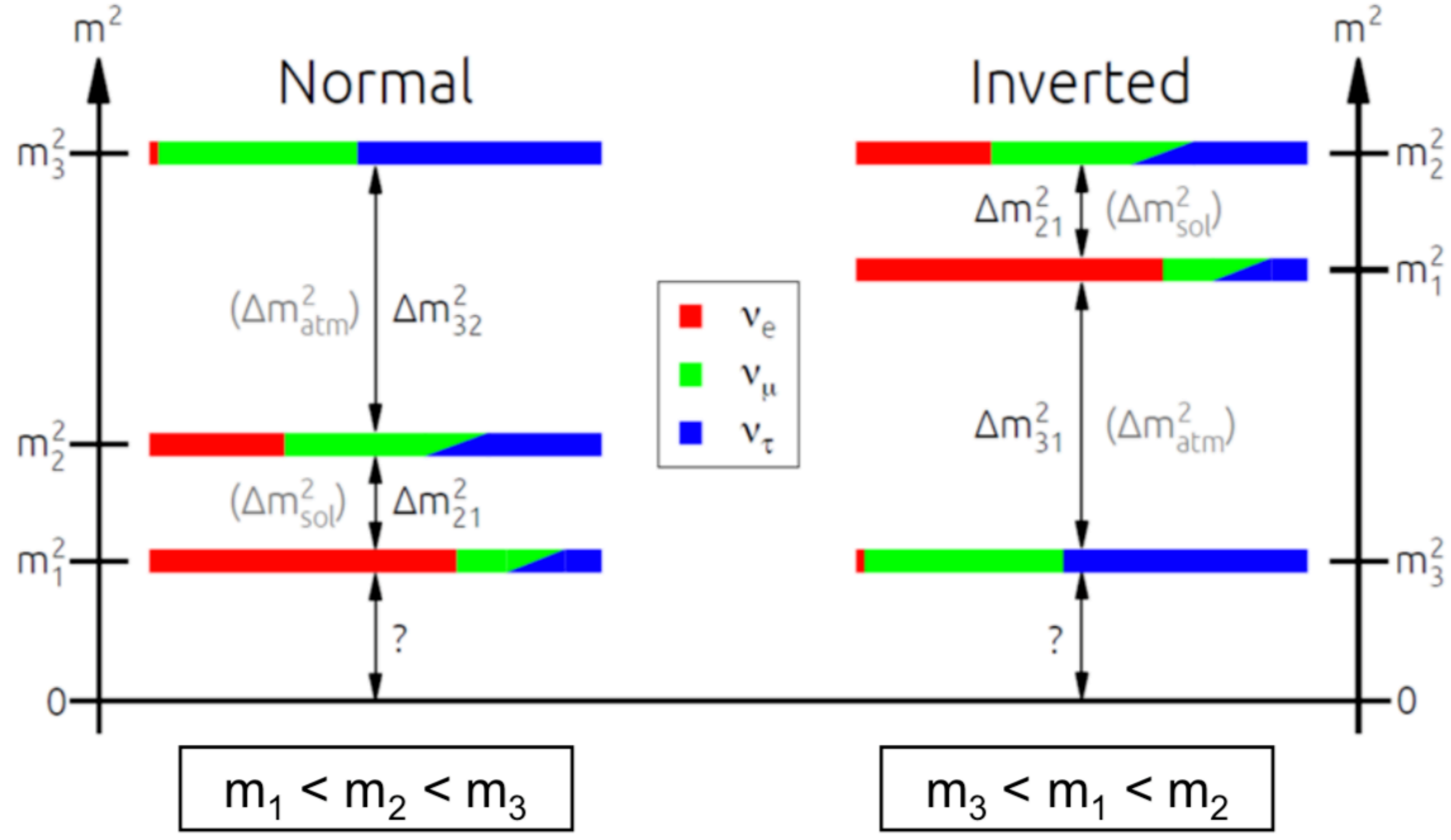




$3\%/\sqrt{E}$ energy resolution is required. To meet this requirement, precise vertex reconstruction is essential to correct for non-uniformity

Time Likelihood Vertex Reconstruction

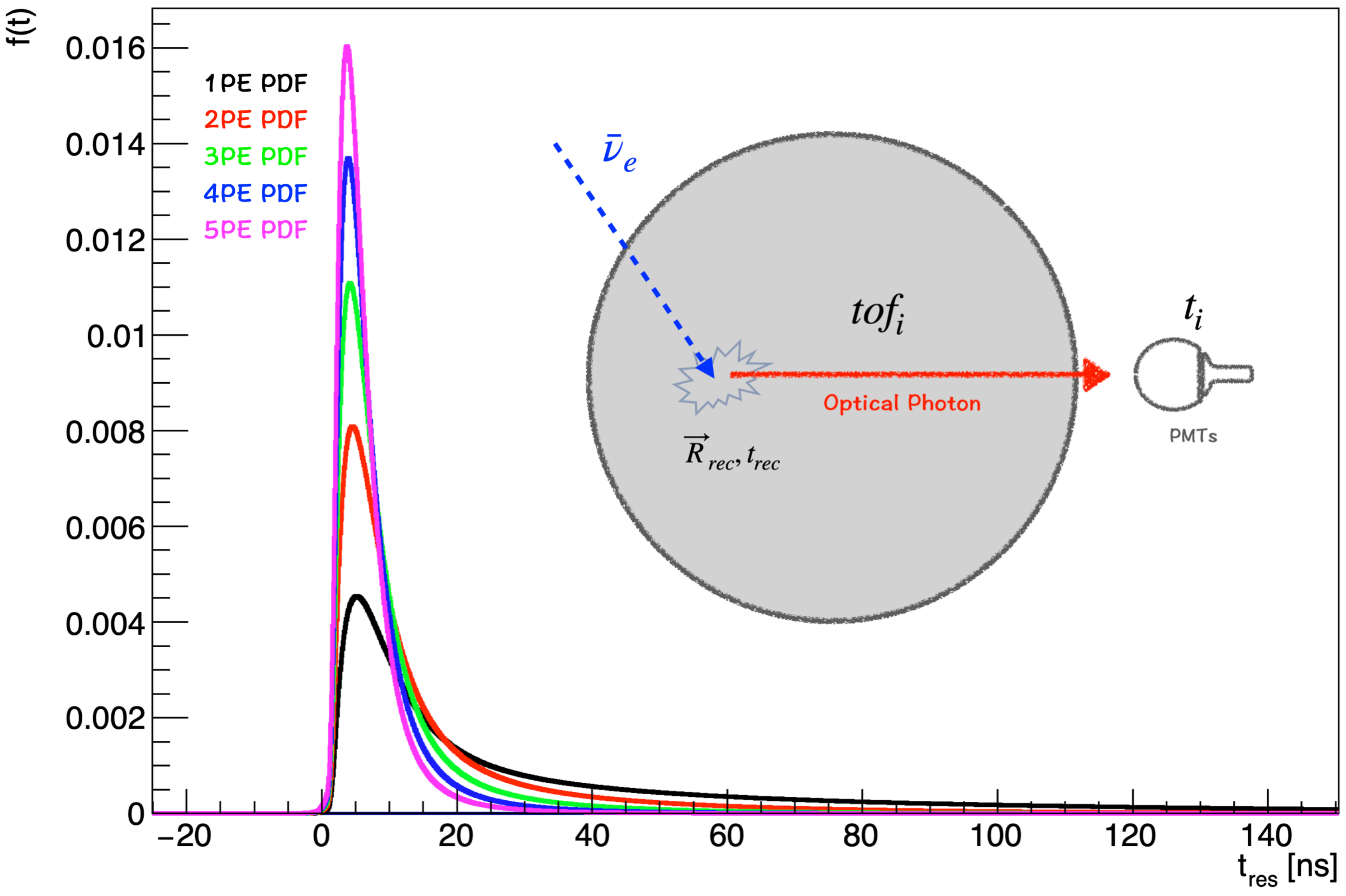
The vertex of a scintillation event is reconstructed using the timing information of the optical photons detected by the PMTs.

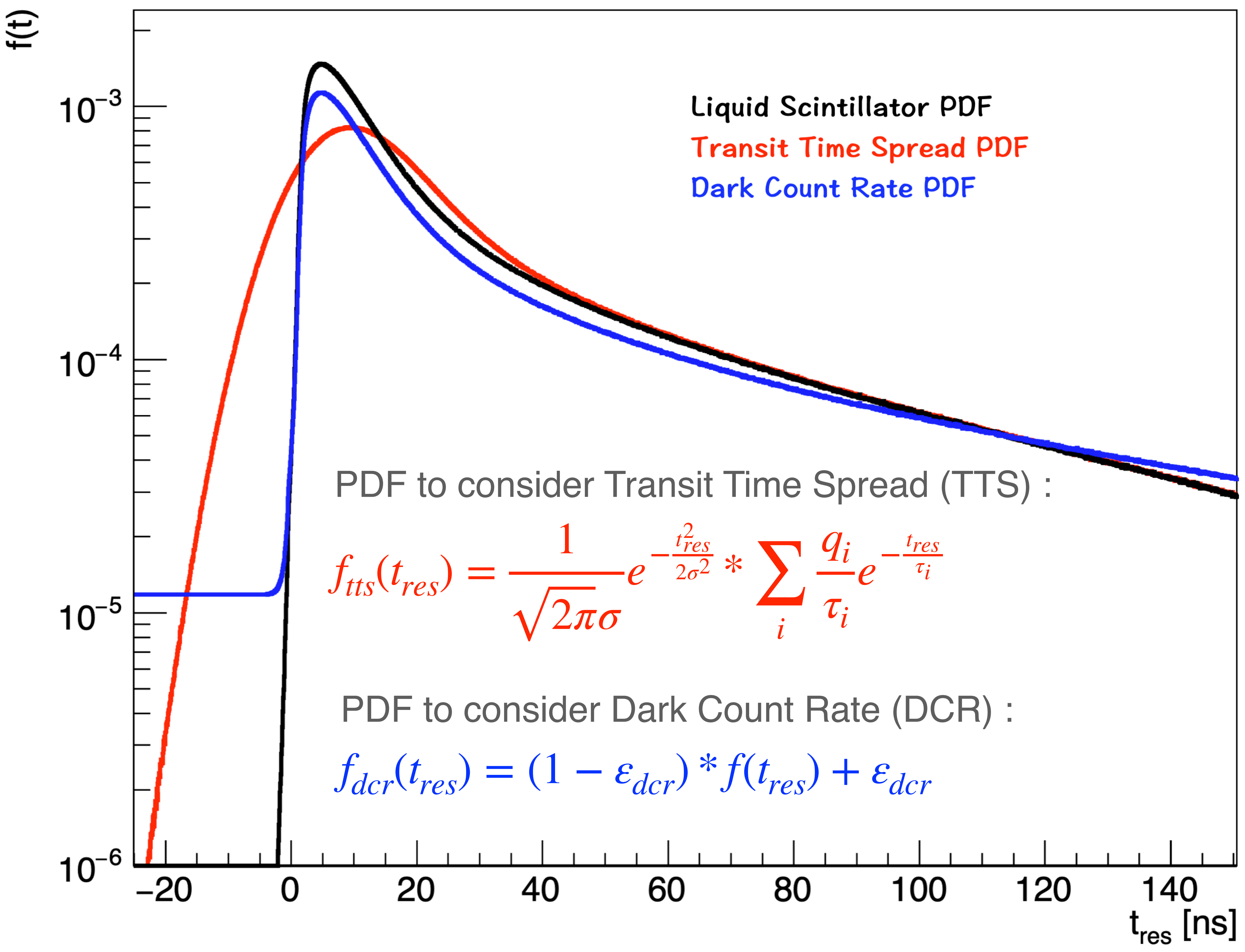
Residual hit time is used to construct the probability density function (PDF) : $t_{i,res}(\vec{R}_{rec}, t_{rec}) = t_i - tof_i - t_{rec}$

The PDF for a single photoelectron (PE) is derived from a Monte Carlo simulation, PDF for nPE : $f_n(t_{res}) = nf(t_{res})(\int_{t_{res}}^{\infty} f(x)dx)^{n-1}$

- t_i : first hit time of i PMTs
- tof_i : time of flight for optical photon
- $\vec{R}_{rec}$: vertex position of an event
- t_{rec} : interaction time of an event
- q_i : fraction of scintillation components
- τ_i : scintillation decay time
- ε_{dcr} : fraction of dark count rate

The event vertex is calculated by minimizing the likelihood : $\mathscr{L}(\vec{R}_{rec}, t_{rec}) = -\sum_i \ln(f_n(t_{i,res}))$

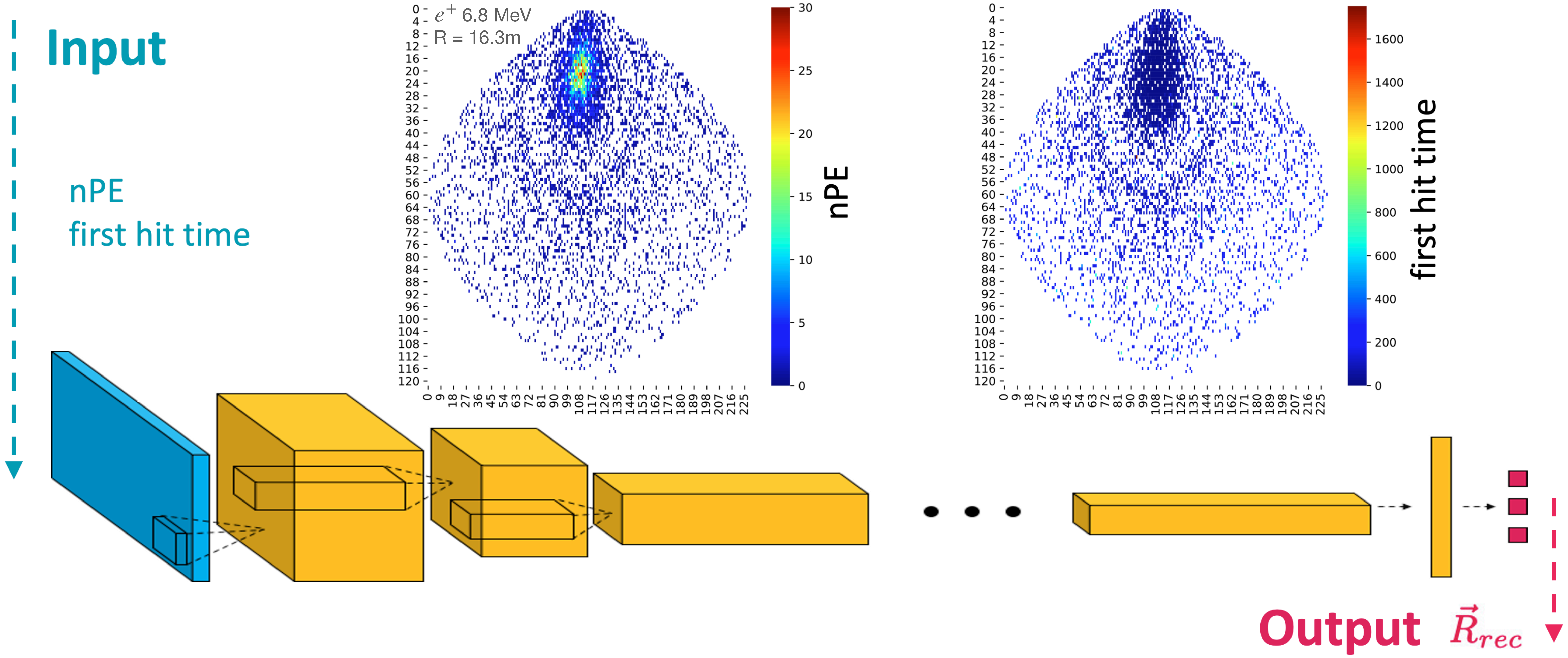


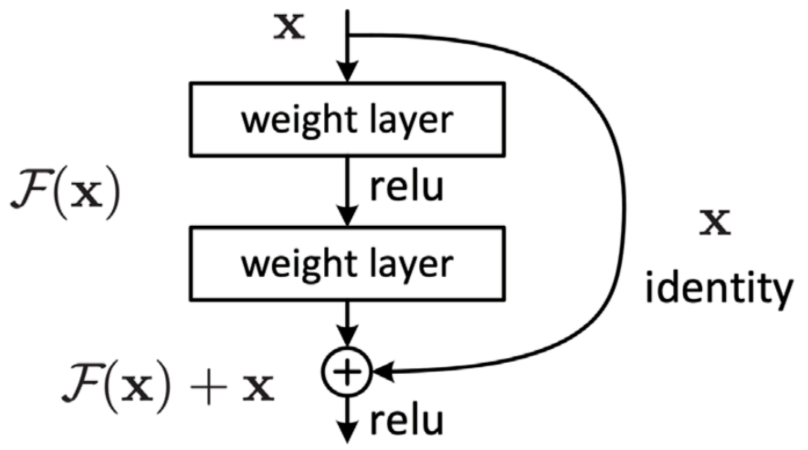


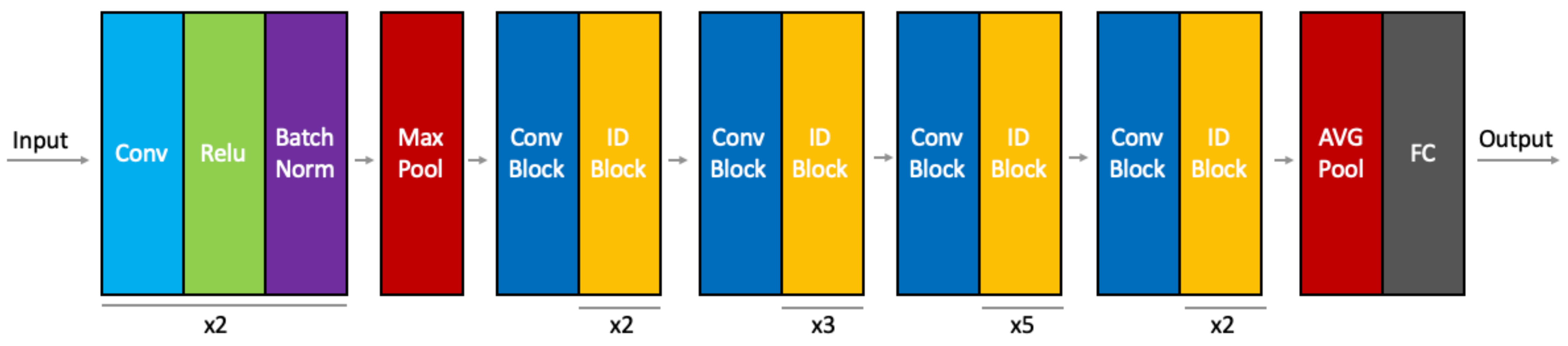
Deep Learning Vertex Reconstruction

Deep Learning : Able to find the complex relation between input and output automatically.

Convolutional Neural Networks (CNN) : One of the architectures in Deep Learning, successful in image classification, suitable for JUNO detector with lots of PMTs.







Detector Projection : Sinusoidal projection

- Keep the relative location information of each PMTs;
- Build a 230 * 126 * 2 matrix.

Structure and hyper parameters :

- Residual block to go deeper;
- Adam Optimizer;
- CNN structure : 50 convolutional layers with about 35 million parameters.

Loss function : $loss = (\vec{R}_{rec} - \vec{R}_{true})^2$

Training :

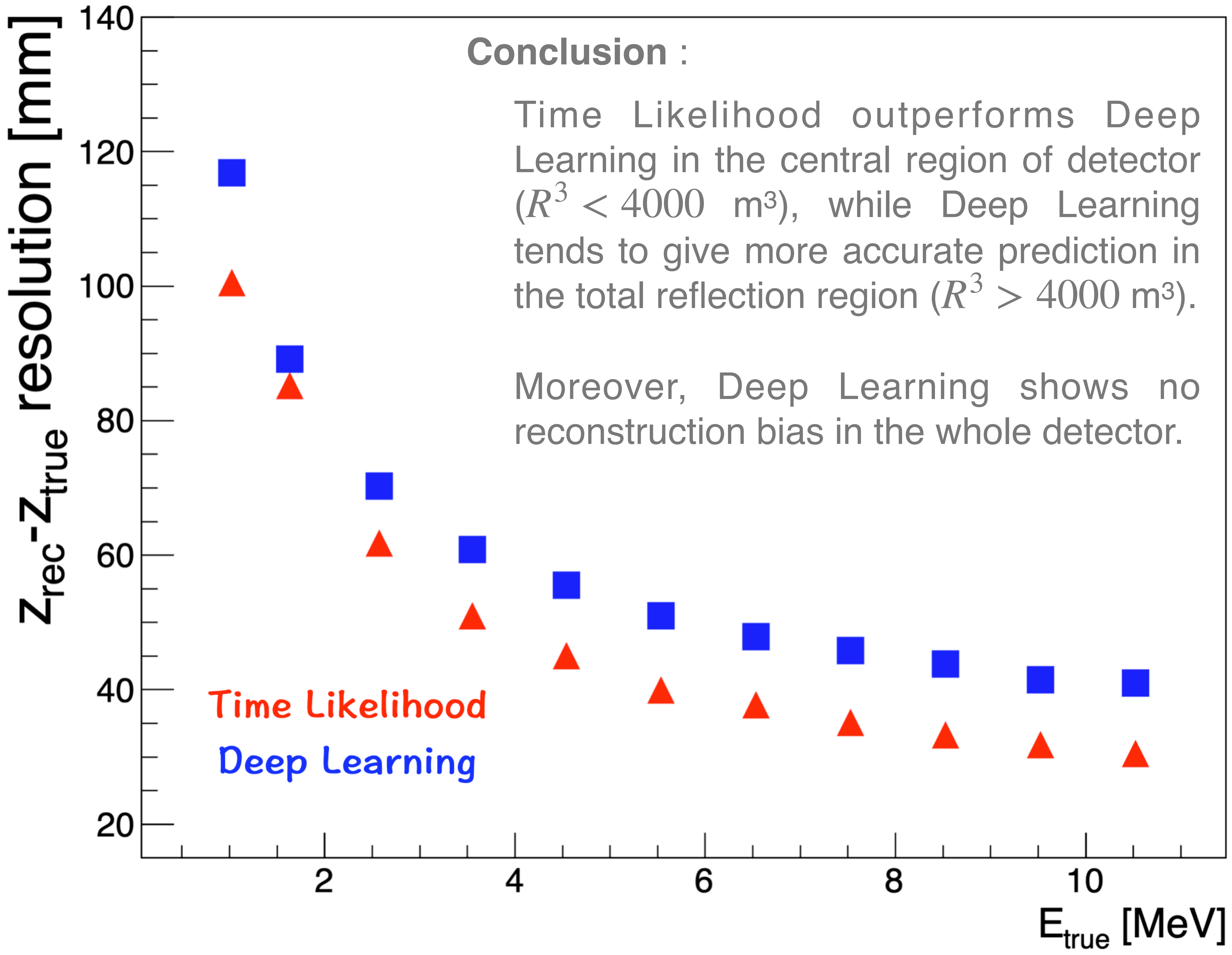
- Data Set : 2 million Monte Carlo e^+, energy from 1-10 MeV, uniformly distributed within the central detector;
- Input Variables : (nPE, first hit time) of each PMTs;
- Output Variables: Vertex $\vec{R}_{rec}$

Testing :

- Data Set : Monte Carlo e^+, momentum (0, 1, …, 10) MeV, 11 * 10k events, uniformly distributed within the central detector;

Vertex Reconstruction Performance

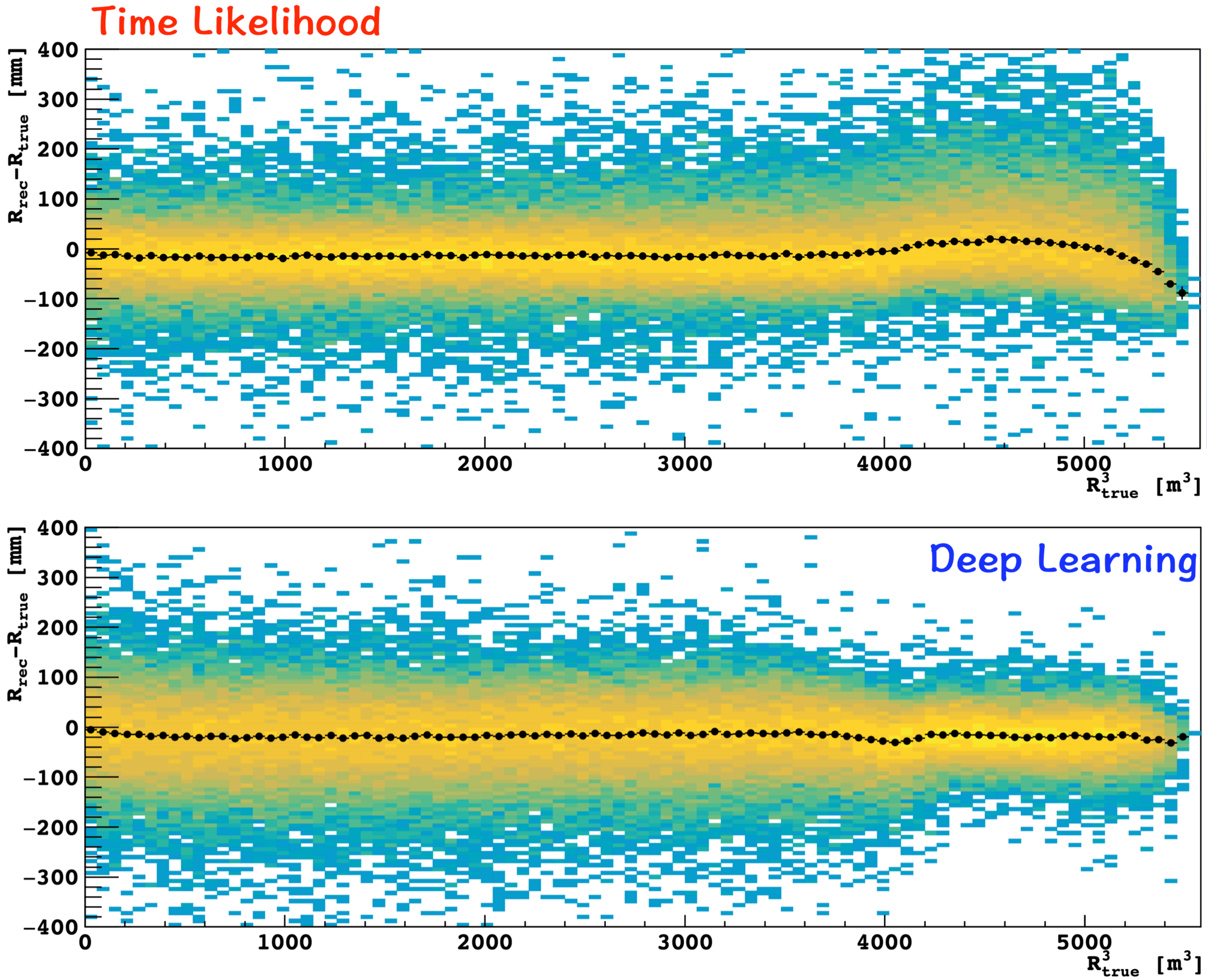
The main factors affecting the resolution of vertex reconstruction include the PMTs Transit Time Spread (TTS) and Dark Count Rate (DCR). The TTS of Hamamatsu PMTs and MCP PMTs is designated as 2.7 ns and 18 ns, respectively, while the DCR is designated as 15 kHz and 32 kHz, respectively.



Conclusion :

Time Likelihood outperforms Deep Learning in the central region of detector ($R^3 < 4000$ m³), while Deep Learning tends to give more accurate prediction in the total reflection region ($R^3 > 4000$ m³).

Moreover, Deep Learning shows no reconstruction bias in the whole detector.



Vertex Mean Bias vs. R^3