

ISeeCube and Auxiliary

Chen Li

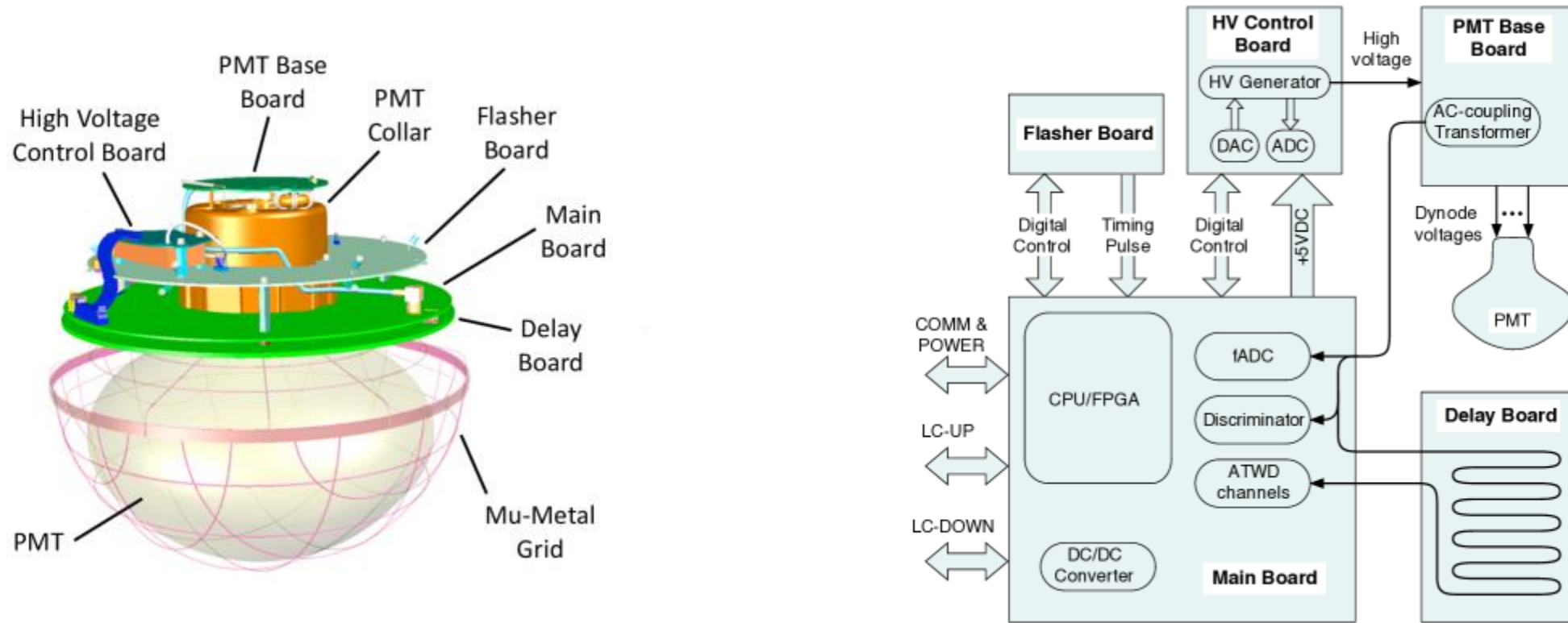
ChenLi2049@outlook.com

July 19th, 2024. at Tsung-Dao Lee Institute.

Content

- §1 ISeeCube
 - §1.1 Basic Component of Neutrino Telescopes: PMT & DOM
 - §1.2 Neutrino Telescope: DOM Array
 - §1.3 Neutrino Events
 - §1.4 Neutrino Events Reconstruction
- §2 Auxiliary
 - §2.1 Why?
 - §2.2 How?
 - §2.2.1 DOM Outputs Waveform
 - §2.2.2 Two Hypothesis for the DOM Array: Local & Global

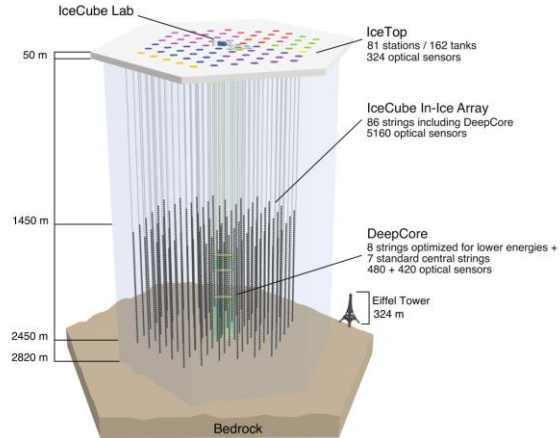
§ 1.1 Basic Component of Neutrino Telescopes: PMT & DOM



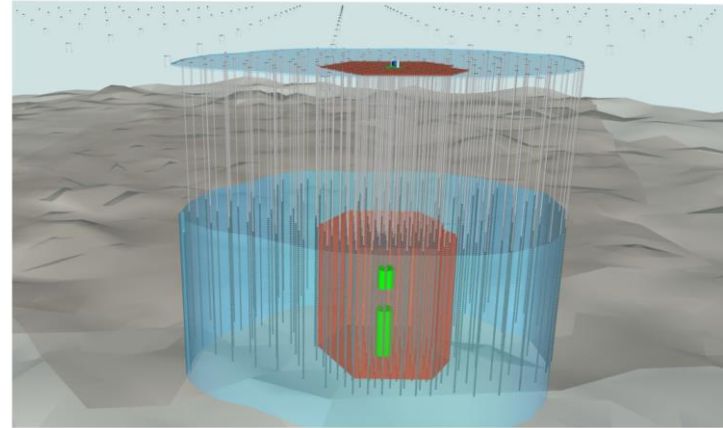
weak light (Cherenkov light / flashing light) → PMT(Photomultiplier Tube) → digital signal

DOM is a PMT wrapper.

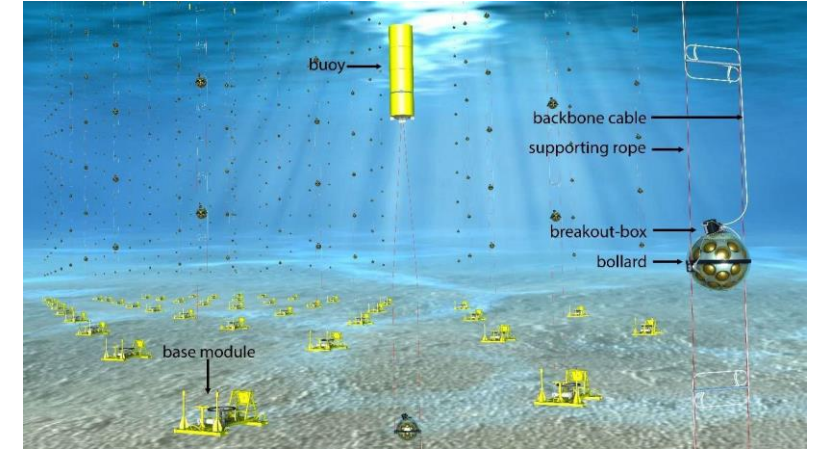
§ 1.2 Neutrino Telescope: DOM Array



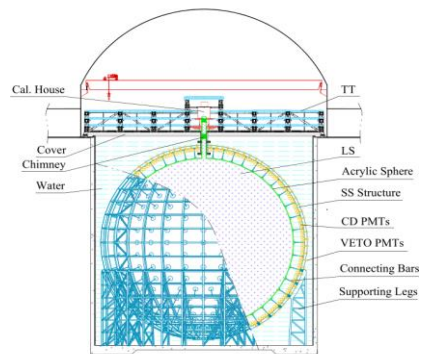
IceCube



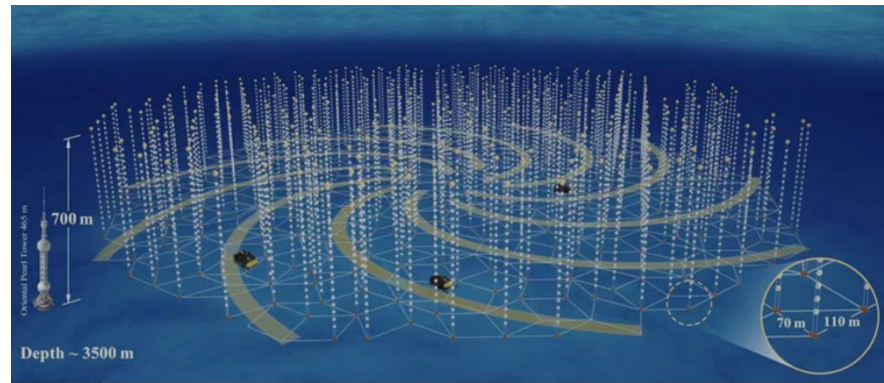
IceCube-Gen2



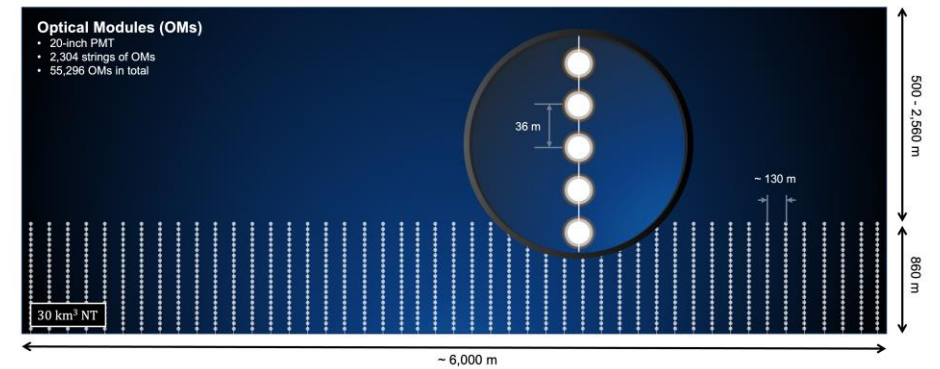
KM3NeT



JUNO



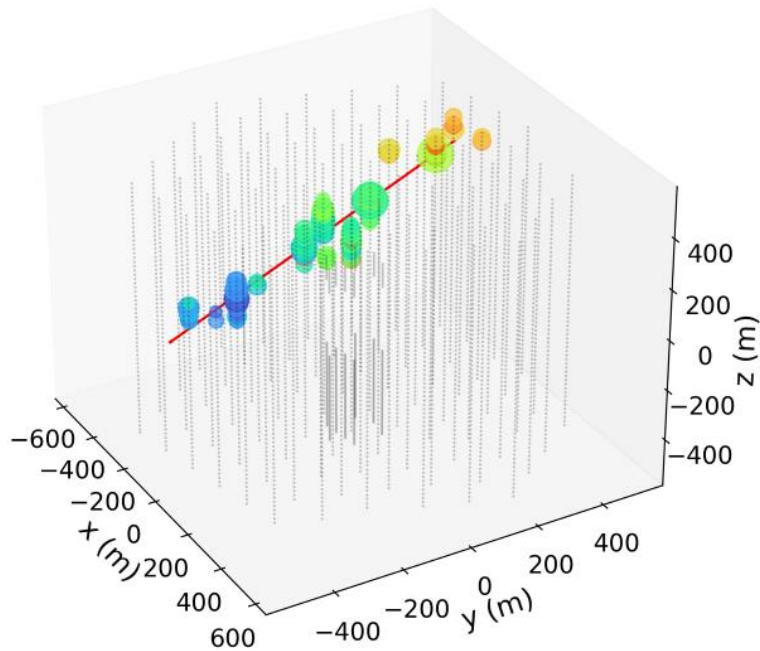
TRIDENT



HUNT

§ 1.3 Neutrino Events

Neutrino Event: $\mathbb{R}^{N \times P} \xrightarrow{\text{embedding}} \mathbb{R}^{N \times d_{\text{model}}}$



P : x, y, z, time, charge, **auxiliary**

A sentence of N tokens $\xrightarrow{\text{embedding}} \mathbb{R}^{N \times d_{\text{model}}}$

Tiktokenizer

gpt2

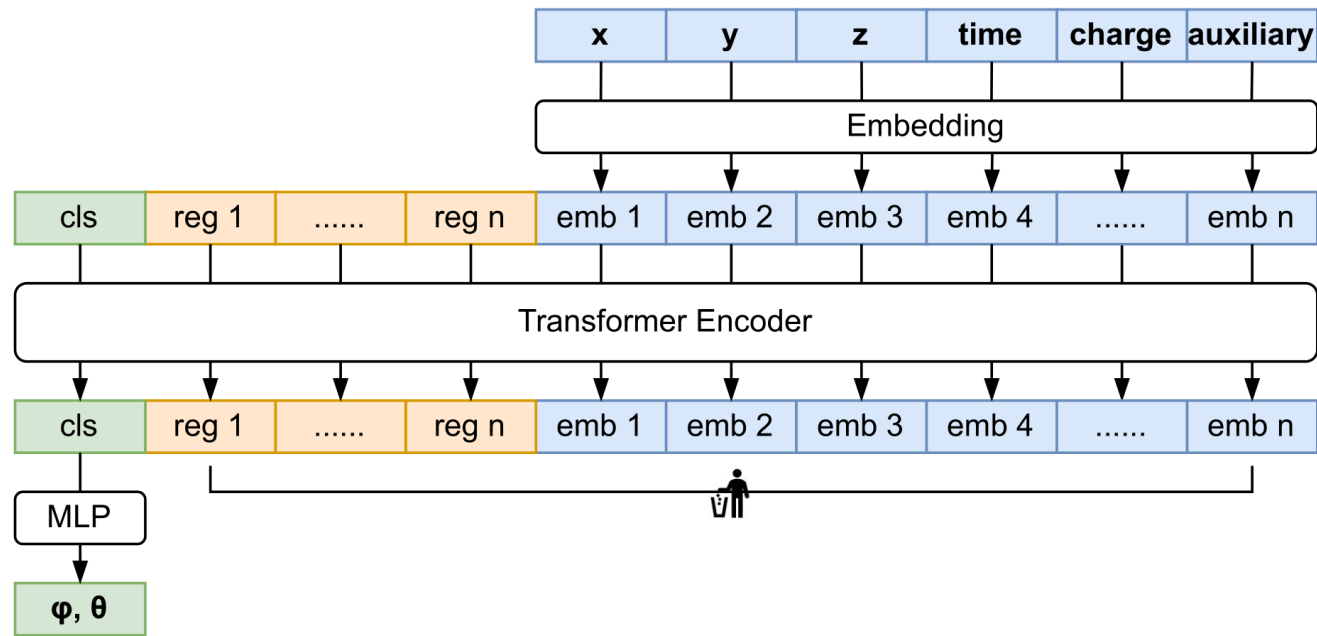
How do you tokenize a loooooooooong made-up word?

Token count
14

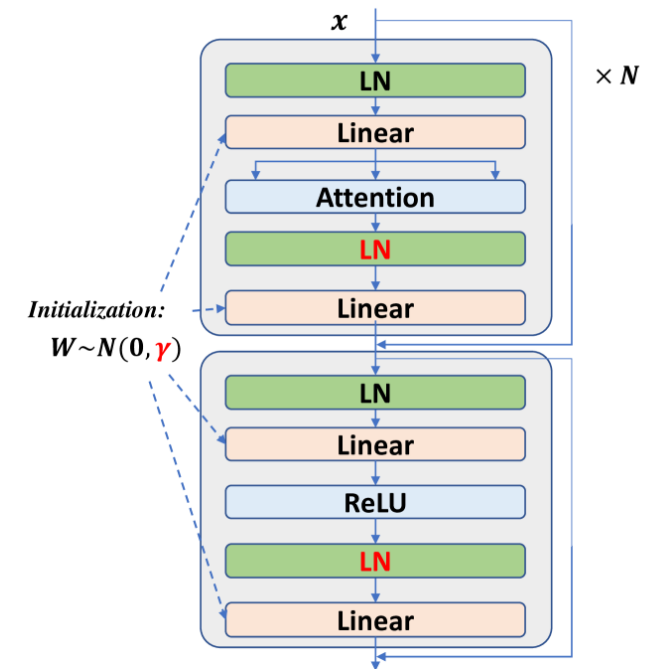
How do you tokenize a loooooooooong made-up word?

N tokens, each token is $\mathbb{R}^{d_{\text{model}}}$

§ 1.4 Neutrino Events Reconstruction

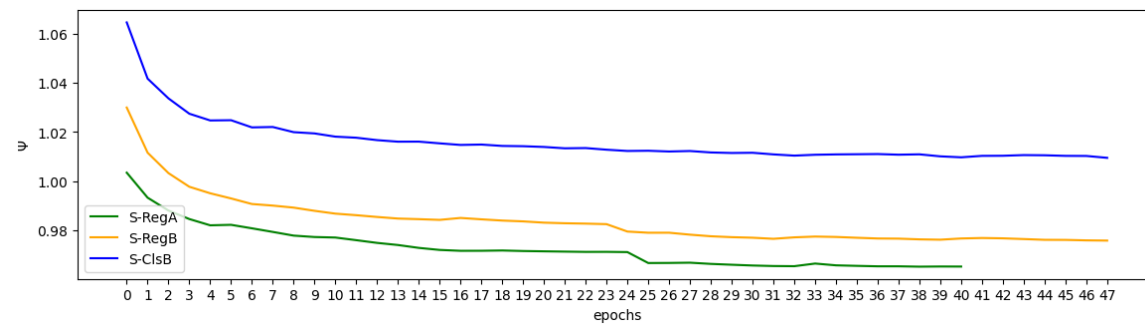


ISeeCube

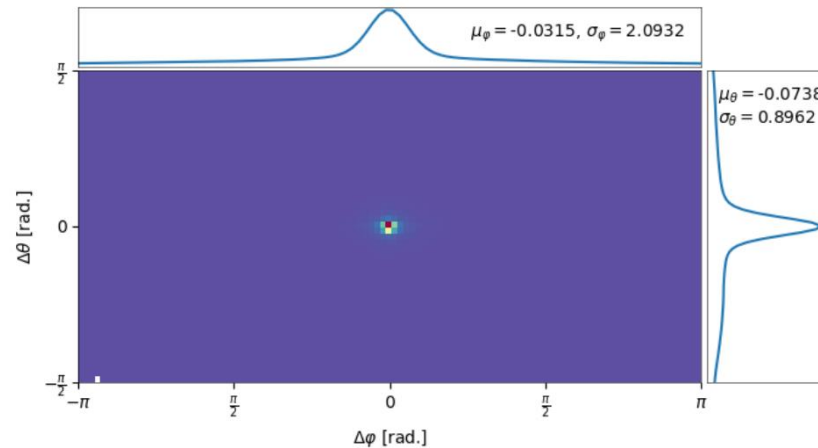


Transformer Encoder

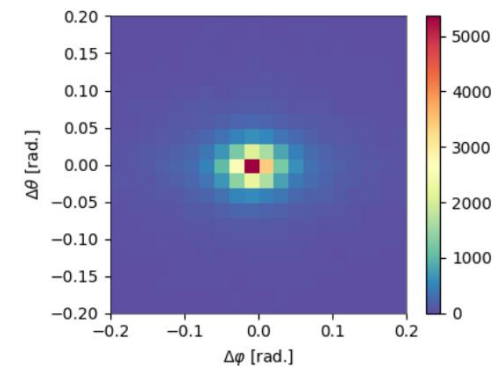
§ 1.4 Neutrino Events Reconstruction



Loss curve



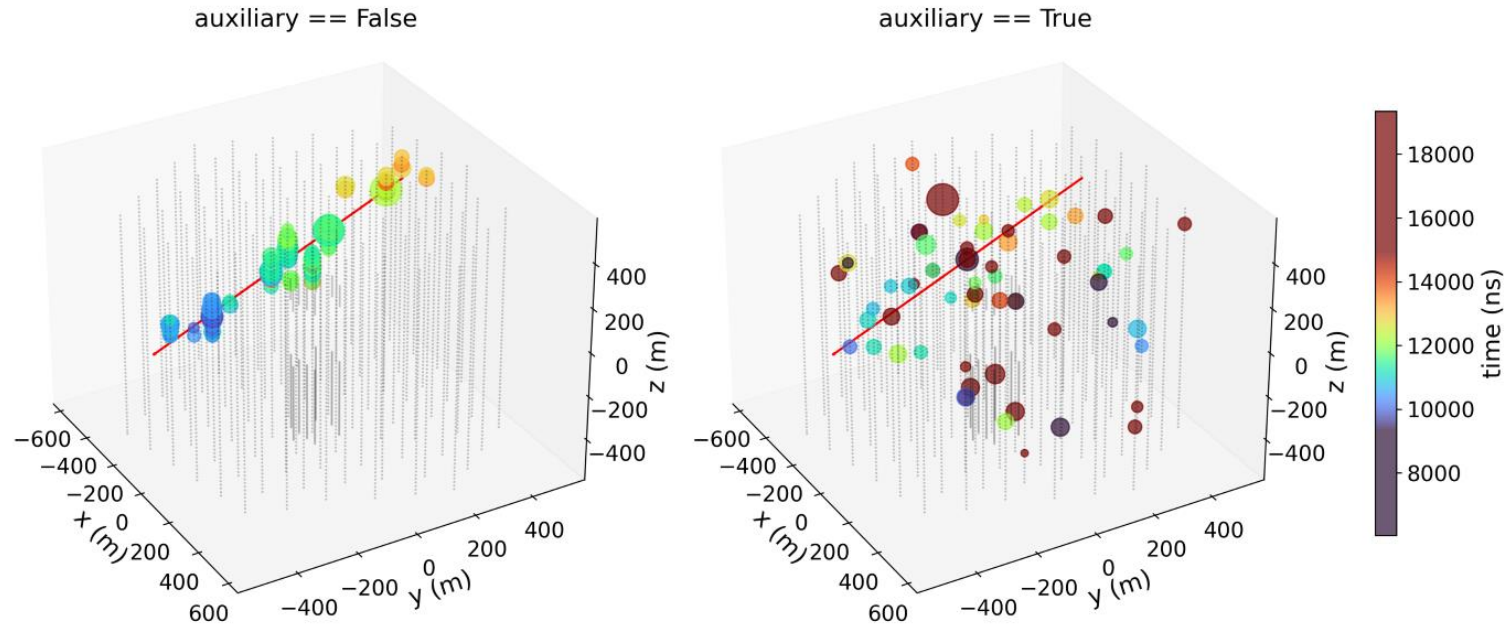
(c) Azimuthal and zenithal error of ensemble ($\Delta\varphi$ and $\Delta\theta$).



(d) Azimuthal and zenithal error of ensemble ($\Delta\varphi$ and $\Delta\theta$), zoomed in.

Angular Error

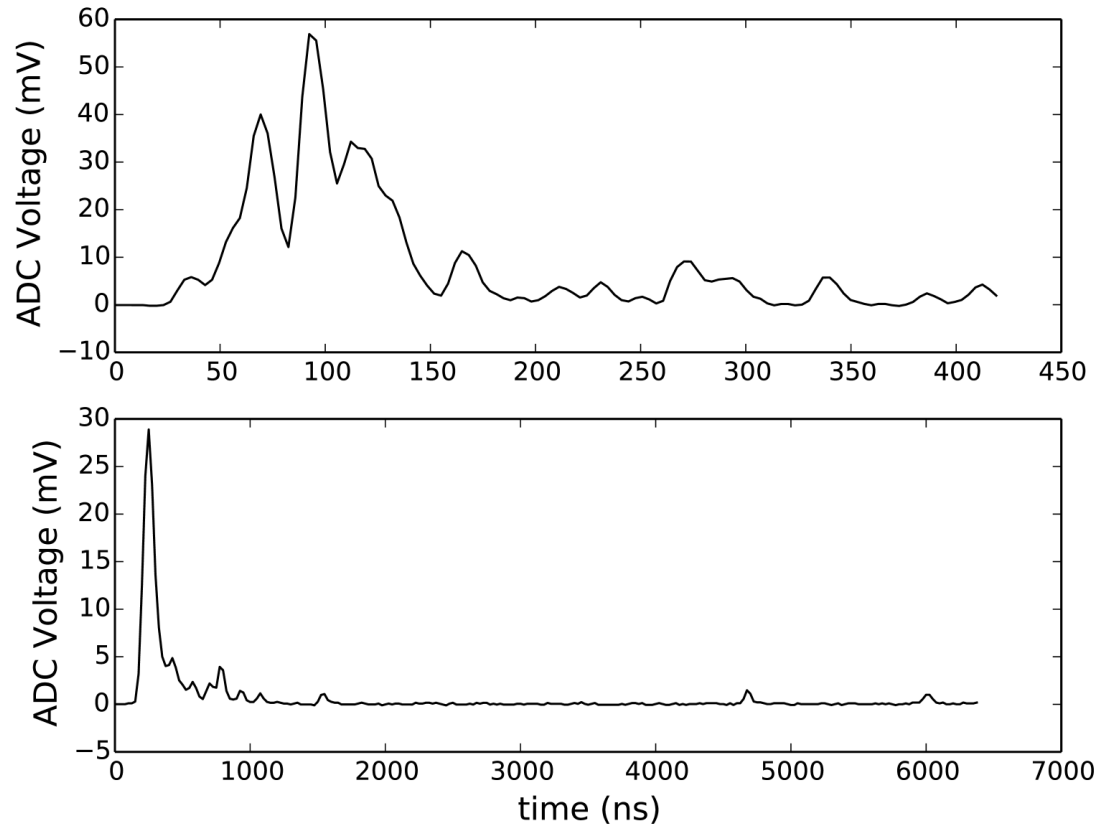
§ 2.1 Why Auxiliary?



When *auxiliary = False*, it means that at least one neighboring DOM on the same string also records a signal within $1\mu s$.

- Intuitively, the shape is more compact with *auxiliary == False*.
- Practically, choosing *auxiliary == False* gives better result:
 - Use *auxiliary == False*: 2nd place solution in Kaggle competition, ISeeCube
 - Not use *auxiliary == False*: 3rd place solution

§ 2.2.1 DOM outputs waveform



From 1612.05093:

Digitization of the PMT waveforms, using a custom integrated circuit (**ATWD**: Analog Transient Waveform Digitizer [27]) and a continuously sampling fast ADC (**fADC**).

Figure 6: The same signal sampled in the ATWD (top) and the fADC (bottom)

§ 2.2.2 Two Hypothesis for the DOM Array: Local & Global

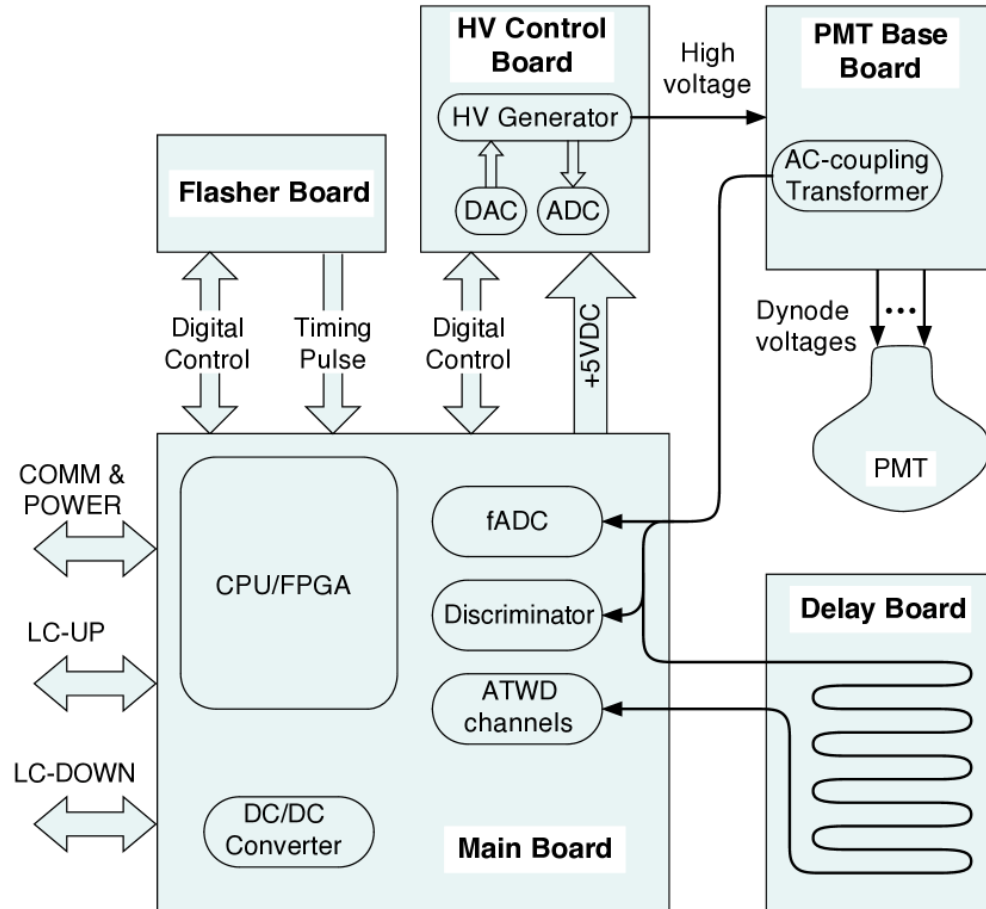
Total time of a neutrino event through IceCube: $10^3 m \div (3 \times 10^8 m/s) = 3.3\mu s$

- Local: each DOM talks with each other before sending out the signal, with a time window of $1\mu s$. We have the following possible difficulties:
 - The timestamp of each DOM is not accurate, the error is larger than $1\mu s$.
 - The Internet speed is not enough to transmit all the waveforms
- Global: auxiliary is computed with a global timestamp for all the DOMs.

§ 2.2.2 Two Hypothesis for the DOM Array: Local & Global

auxiliary==False	auxiliary==True
Hard Local Coincidence hits (“HLC” hits)	Soft Local Coincidence hits (“SLC” hits)
full detail, full waveform	less detail

§ 2.2.2 Two Hypothesis for the DOM Array: Local & Global



From 1612.05093:

The time window is configurable and is set to $\pm 1\mu\text{s}$ for both in-ice and IceTop DOMs.

Local coincidence hits (“HLC” hits) often have complex PMT waveforms indicating multiple photons detected in each DOM and are therefore saved in full detail; otherwise, the DOM saves abbreviated information appropriate to single photon detection (section 6.3.4).

§ 2.2.2 Two Hypothesis for the DOM Array: Local & Global

From 1612.05093 §6.3.4 (also see 0810.4930 § 4.4):

The content of the DOM hit payloads transmitted to the surface depends on whether **local coincidence** was satisfied, i.e. whether the hit was flagged as **HLC or SLC**. The DOM Main Board ID and the timestamp of the hit in DOM clock counts are always transmitted, along with trigger and LC flags.

For HLC hits, the digitized ATWD and fADC waveforms are transmitted. Waveforms from lower-gain ATWD channels are only included if the signal amplitude in the higher-gain channel exceeds 75% of the digitizer range. **The waveforms are compressed losslessly in the DOM** using a delta-compression algorithm that encodes the difference between subsequent samples. The difference values are packed into words of length 1, 2, 3, 6, or 11 bits depending on magnitude, and special values in the bitstream are used to transition between different word lengths.

For both HLC and SLC hits, a chargestamp is included that provides an estimate of the amplitude/charge even if, **as in the SLC case, the full waveform is not transmitted**. For in-ice DOMs, the chargestamp consists of three samples of the fADC waveform centered around the peak value, along with the peak sample number. For IceTop DOMs, the chargestamp is the sum of all samples of the ATWD waveform, after pedestal subtraction.

§ 2.2.2 Two Hypothesis for the DOM Array: Local & Global

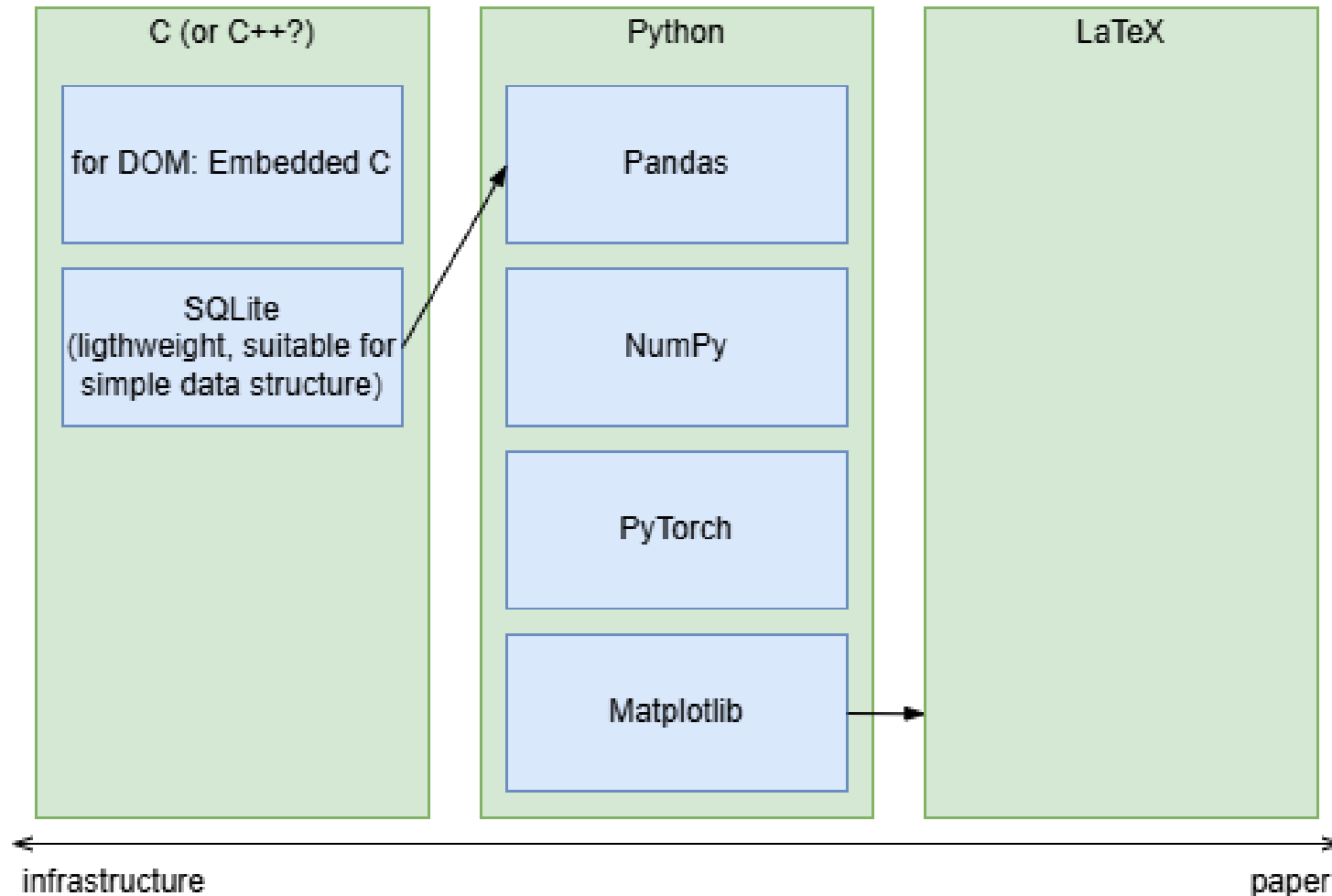
Total time of a neutrino event through IceCube: $10^3 m \div (3 \times 10^8 m/s) = 3.3 \mu s$

- Local: each DOM talks with each other before sending out the signal, with a time window of $1 \mu s$. We have the following possible difficulties:
 - The timestamp of each DOM is not accurate, the error is larger than $1 \mu s$.
 - The Internet speed is not enough to transmit all the waveforms
- Global: auxiliary is computed with a global timestamp for all the DOMs.

TRIDENT?

Thanks!

Alternative Tech Stack in TRIDENT?



- <https://sqlite.org/whentouse.html>, [libsql](#)
- [pandas.read_sql](#)
- Don't: ORM, Spreadsheet, Microservice, Laptop as Server, Docker