ISeeCube and Auxiliary

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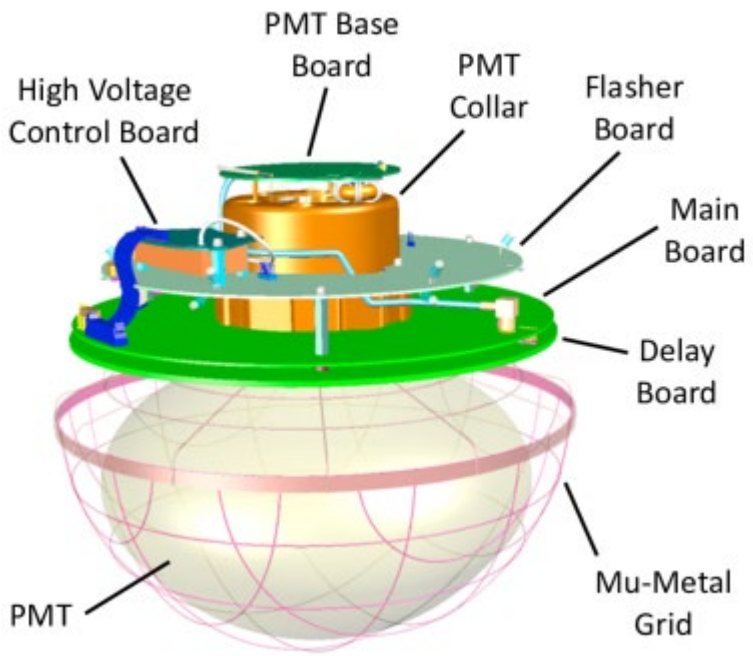
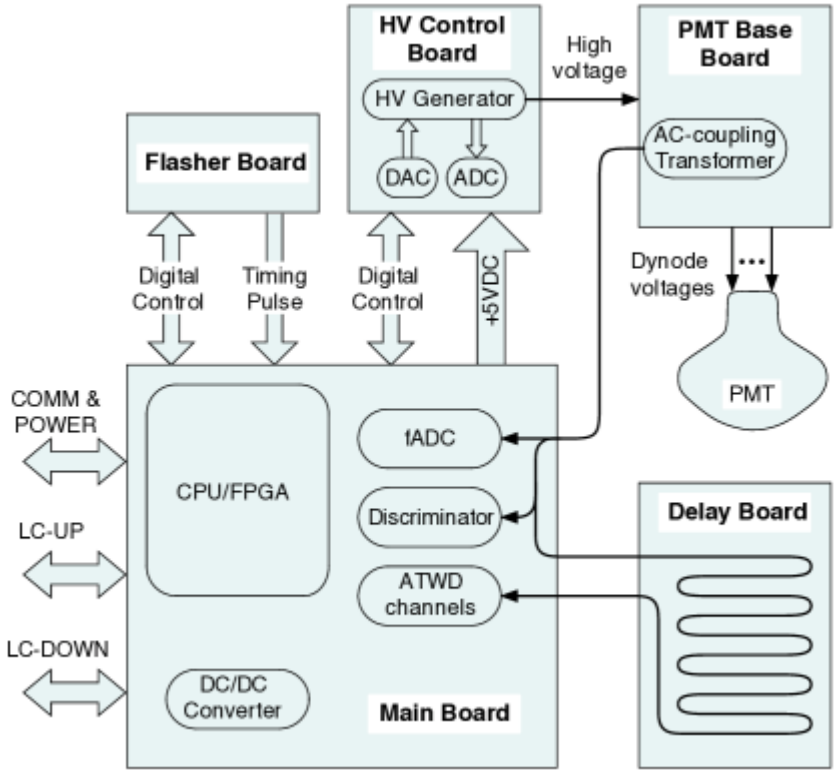
§ 1.1 Basic Component of Neutrino Telescopes: PMT & DOM

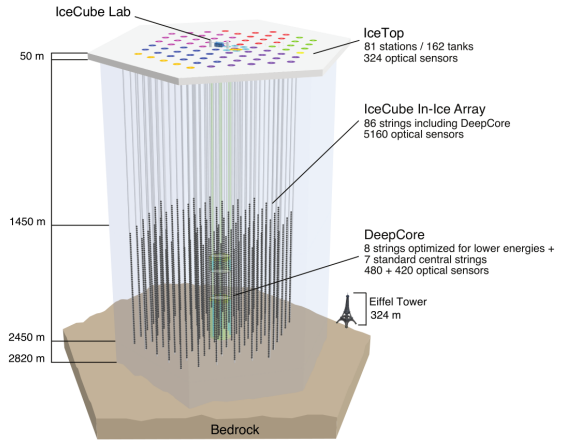




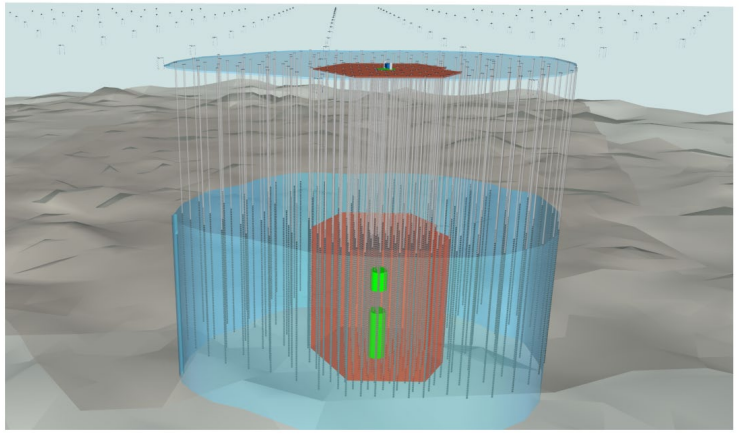
weak light (Cherenkov light / flashing light) → PMT(Photo**multiplier** Tube) → digital signal

DOM is a PMT wrapper.

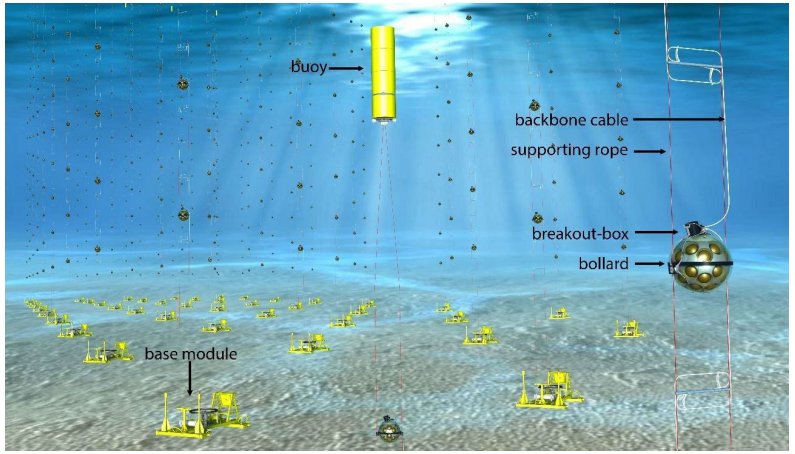
§ 1.2 Neutrino Telescope: DOM Array



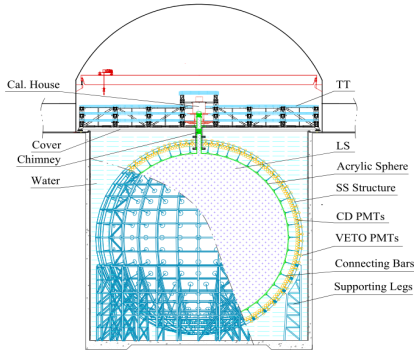
IceCube



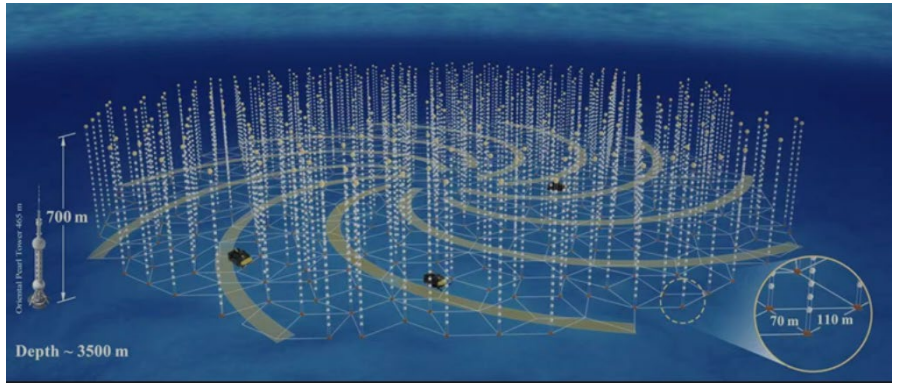
IceCube-Gen2



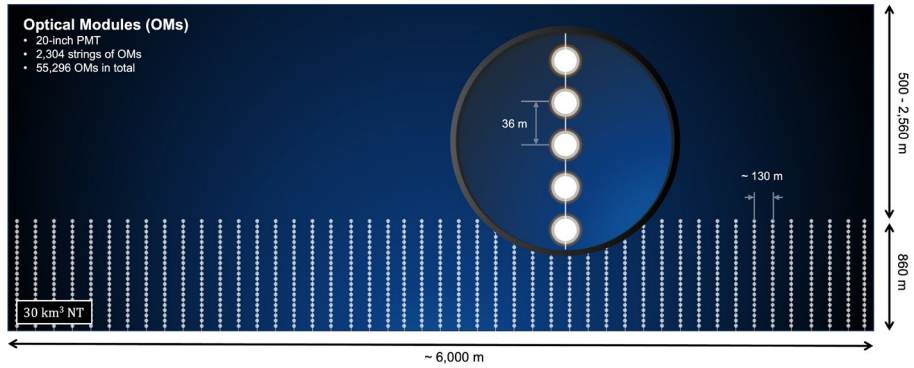
KM3NeT



JUNO



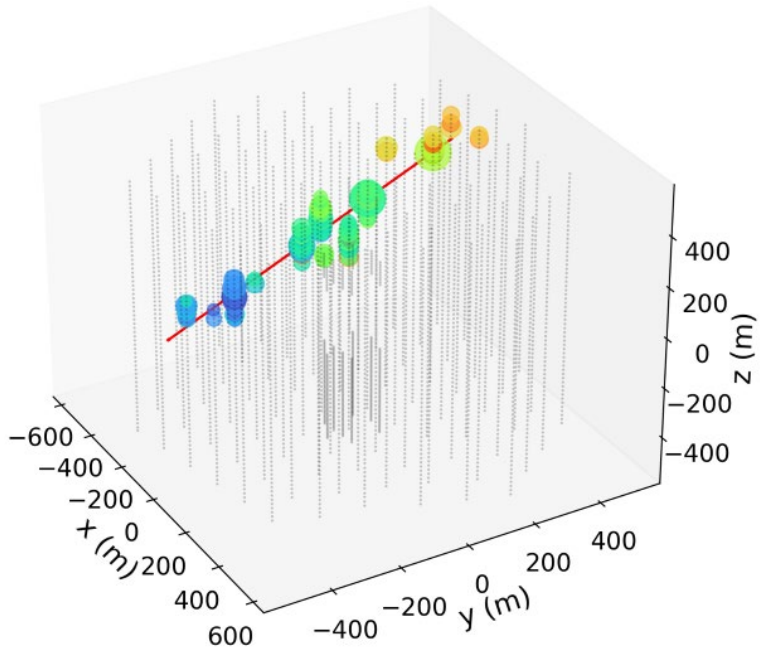
TRIDENT



HUNT

§ 1.3 Neutrino Events

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



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

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

Tiktokenizer

gpt2

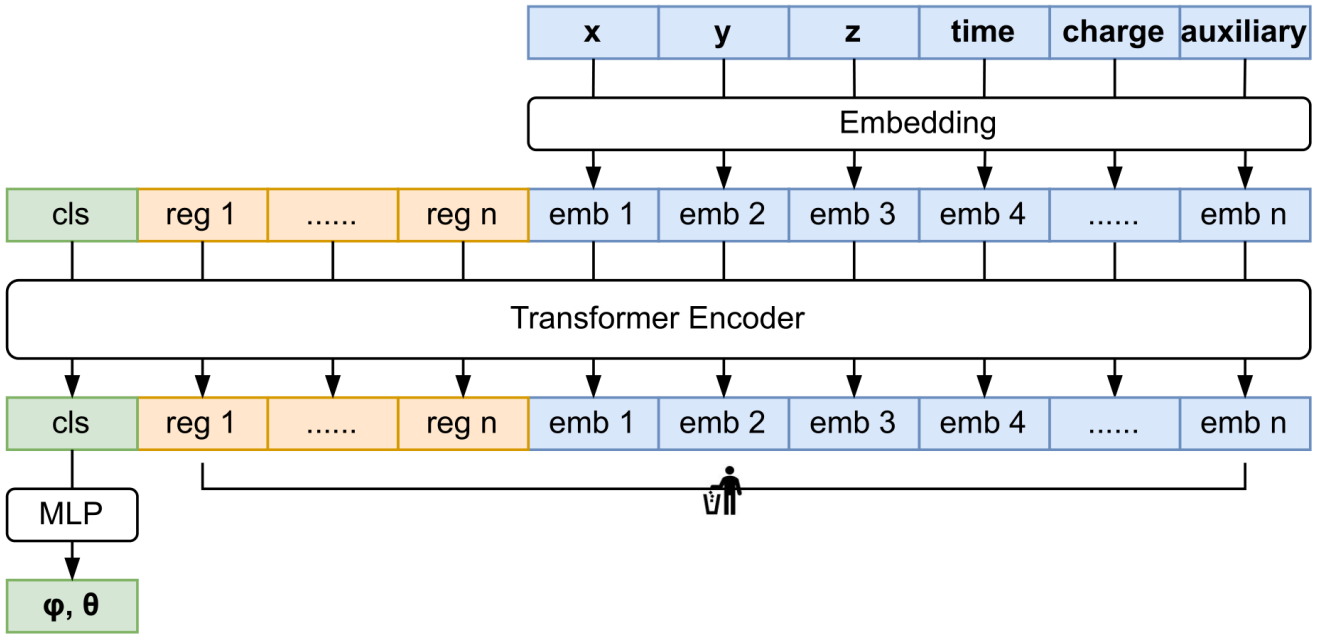
How do you tokenize a looooooooong made-up word?

Token count
14

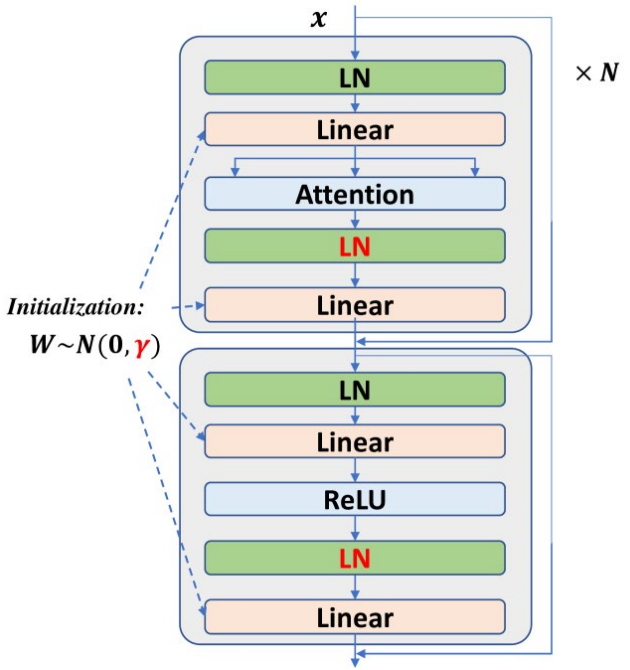
How do you tokenize a looooooooong made -up word?

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

§ 1.4 Neutrino Events Reconstruction

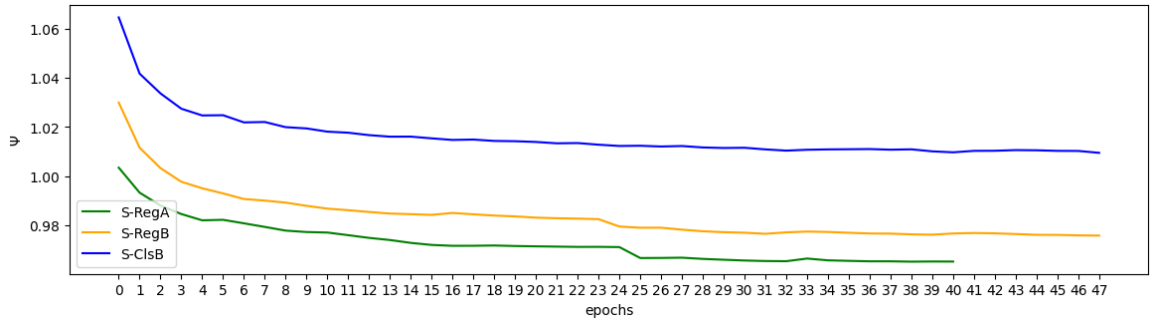


ISeeCube

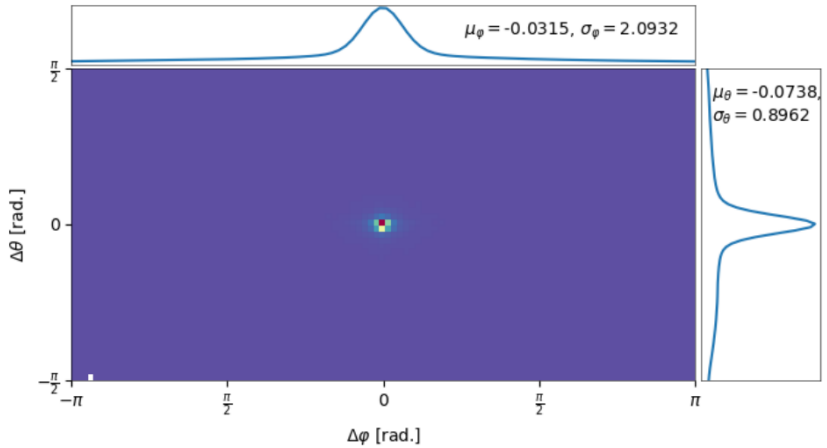


Transformer Encoder

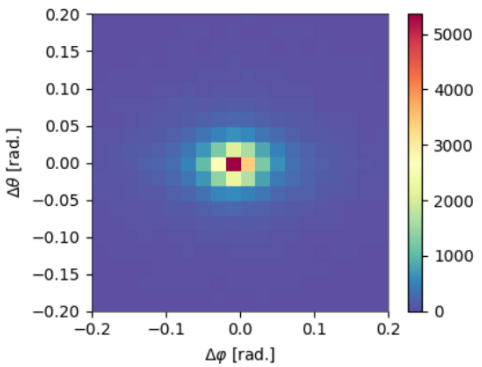
§ 1.4 Neutrino Events Reconstruction



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

§ 1.5 Lines of Code & Performance

	Lines of Code (total)	Lines of Code (simplest model)
ISeeCube	~300	~100
2nd place solution	~1200	~500

Lines of Code in models.py

- To reduce Lines of Code (= To have a conceptually simpler model):
  - Remove GNN, only use Transformer.
  - Instead of 2 Transformer Encoders with different settings, only use 1 Transformer Encoder.

§ 1.5 Lines of Code & Performance

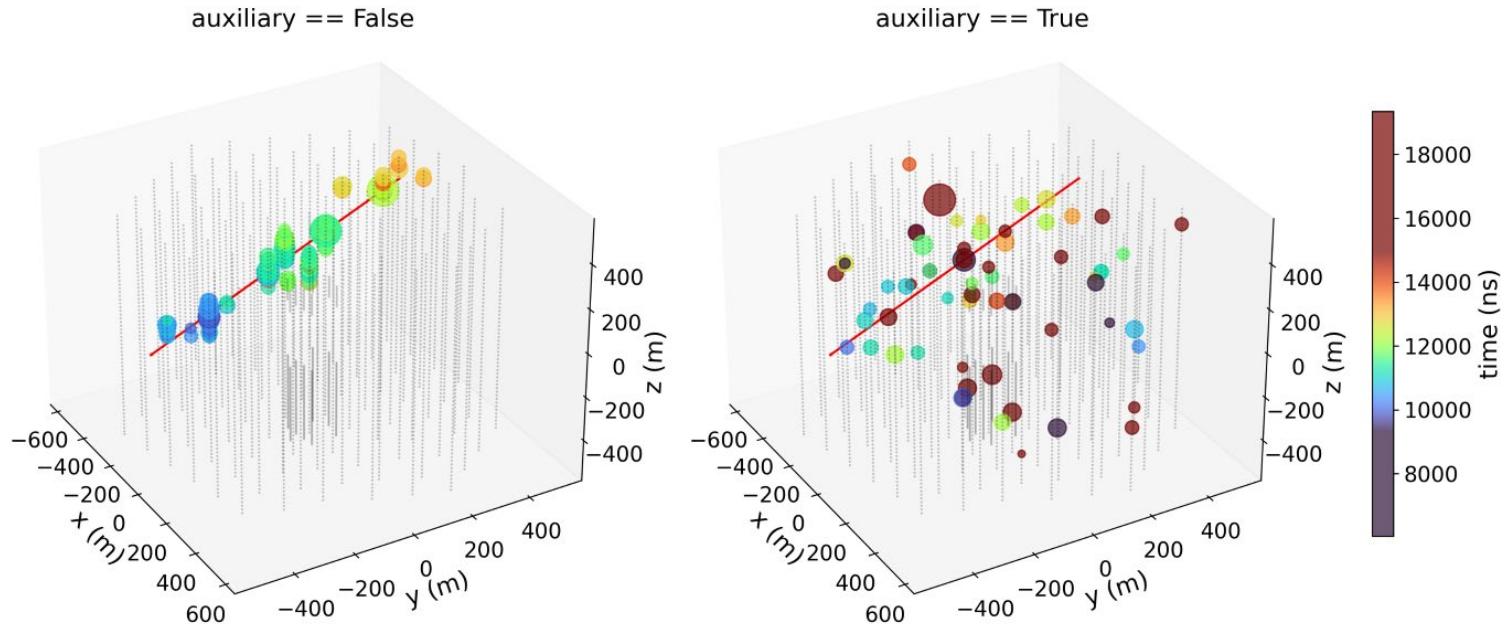
Table 3. Hyper-parameters and score of 2nd place solution without the models that are a combination of Transformer and GNN. "T", "S" and "B" refers to "Tiny", "Small" and "Base". "d32" or "d64" means the dimension of the head is 32 or 64. CV512 means the number of pulses in an event is 512 when inferencing on the validation dataset (batch 655 ~ batch 659). Public LB and Private LB refers to the score in the Kaggle competition using public test dataset and private test dataset. The score for competition metric is the smaller the better.

model	d_{model}	heads	layers	params	CV512	Public LB	Private LB
T d32	192	3/6	4 + 12	7.57M	0.9704	0.9693	0.9698
S d32	384	6/12	4 + 12	29.3M	0.9671	0.9654	0.9659
B d32	768	12/24	4 + 12	115.6M	0.9642	0.9623	0.9632
B d64	768	12/24	4 + 12	115.6M	0.9645	0.9635	0.9629

Table 4. Hyper-parameters and score of ISeeCube. "S-RegA", "S-RegB" and "S-ClsB" refers to different "Small" models (see section 3.3). The score for competition metric is the smaller the better.

model	N	d_{model}	d_{ffn}	heads	layers	rel pos buckets	max rel pos	params	score
S-RegA	196	384	1536	12	16	32	256	31.7M	0.9651 (CV256)
S-RegB	196	384	1536/1536	12/12	6 + 12	32/0	196/0	35.1M	0.9757 (CV196)
S-ClsB	196	384	1536/1536	12/12	6 + 12	32/0	196/0	43.6M	1.0095 (CV196)

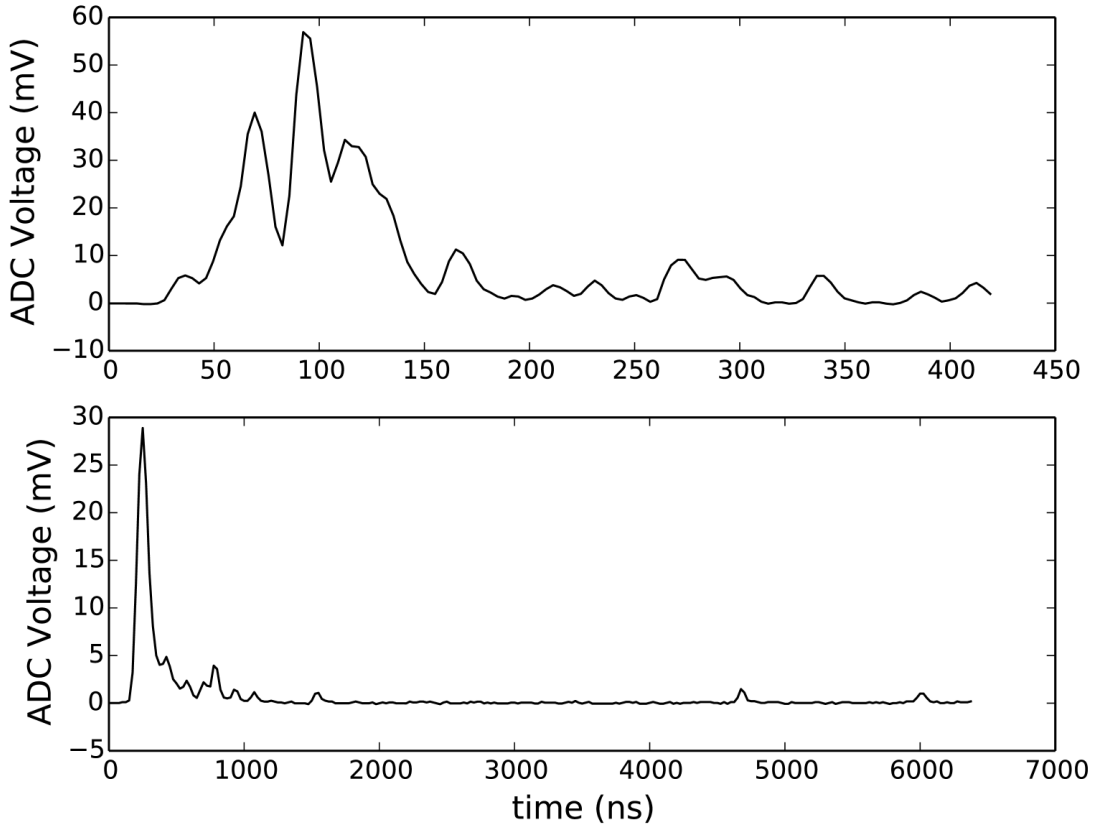
§ 2.1 Why Auxiliary?



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

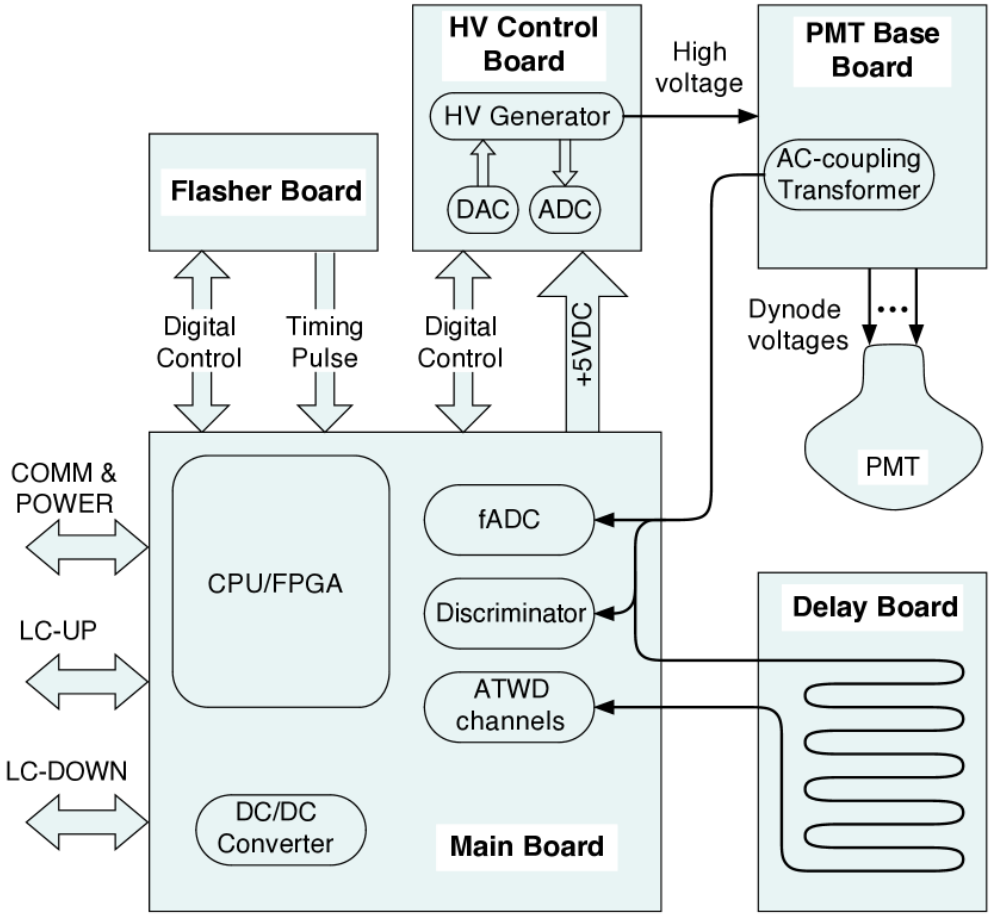
Total time of a neutrino event through IceCube: $10^3 m \div (3 \times 10^8\ m/s) = 3.3\mu s$

- 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 bandwidth 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 $\pm 1\mu s$ 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.

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TRIDENT?

Summary

- Similarity between neutrino events and language → Transformer
- ISeeCube:
  - Reduce Lines of Code.
  - (Slightly) better performance.
- Auxiliary is the first filtering mechanism, before Machine Learning approach.

Thanks!