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Hauke Schmidt

Applying Dynamic Graph CNN to reconstruct the direction of electrons in JUNO

Big Data Science in Astroparticle Research - Workshop, Aachen, 18.02.2020

on behalf of Simone Frintrop, Caren Hagner, Henning Rebber, Björn Wonsak

Content

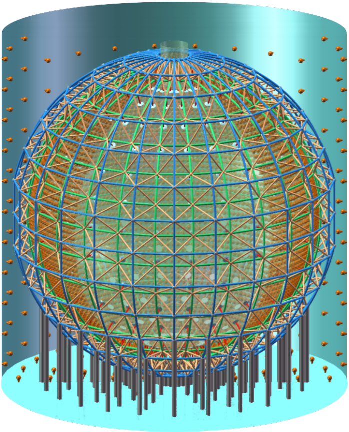
Jiangmen Underground Neutrino Observatory

Experiment:

- under construction near Jiangmen, China
- reactor antineutrino experiment
- neutrino signal (IBD): $\overline{\nu}_e + p \rightarrow e^+ + n$

Detector:

- target 20 kt LAB, ∅ 35.4 m
- PMTs 18000 20” & 25000 3”
- $\sim$77% Coverage



Research fields of JUNO

- determination of neutrino mass hierarchy
- better accuracy for oscillation parameters
- at 53 km distance to reactors best L/E proportion to separate normal and inverted mass order
- observatory for astroparticles, e.g. solar neutrinos
- solar neutrino ν_e scatter elastic with electrons

$$\nu_e + e^- \rightarrow \nu_e + e^-$$

light sources:

- scintillation emits light homogeneously in all directions
- additional ∼5% light is emitted based on Čerenkov effect in direction of flight

direction of electrons:

- electron events with low energy (< 10 MeV) pointlike
- direction gives information about neutrino source

→ discrimination signal and background

- until now: direction reconstruction of low energy electrons not possible in LS detectors

→ JUNO is first LS detector with such a high coverage

PointNet[1]

- artifical neural network for classification and segmentation on 3D point clouds
- each point is a vector of its coordinate (x, y, z) plus extra feature channels
- more efficient in computational costs than previous works based on volumetric or multiview architectures
- lower input file size

- network is robust to various kinds of input corruptions

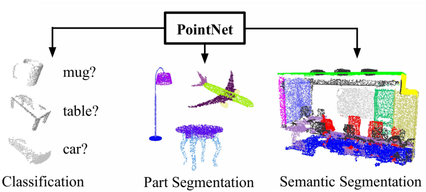


Abbildung: Applications of PointNet

[1] Charles R. Qi et al.: https://arxiv.org/abs/1612.00593v2

Dynamic Graph CNN[2]

- based on PointNet
- constructing a local neighbourhood graph
- closest *k* points in feature space
- edge features with learnable nonlinear function
- symmetric aggregation operation e.g. $\sum$ or max

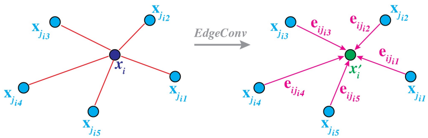


Abbildung: EdgeConv Operation

- rebuild graph in feature space after each layer
- no deterministic neighbourhood relationship

[2] Yue Wang et al.: https://arxiv.org/abs/1801.07829

Input generation

- data from JUNO Detector Simulation, based on Geant4

set	count	energy	position
training	210,000	3 MeV	center and z-axis
validation	5,200	4 MeV	center
energy evaluation	8 x 5,200	1 - 8 MeV	center
vertex evaluation	5 x 5,200	4 MeV	z-axis: 0 to 10 meters

- 1,100 signals per MeV per event
- data: PMT positions and hit times
- PMTs without hits are skipped
- search for energy independent signature

Time correction

- subtract mean estimated time of flight from hit time

$$t = t_{\mathrm{hit}} - T(\vartheta, d)$$

  with $T(\vartheta, d)$ table entry for angle ϑ and distance d between vertex and PMT
- vertex must be known

Time difference in hit times

- Čerenkov light arrives up to 2 nanoseconds earlier
- 4-20 ns decay time for scintillation light components
- Čerenkov light faster because of longer mean wavelength

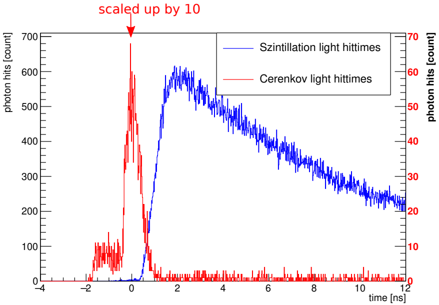


Abbildung: Histogram of hit times after time correction (400 events). Čerenkov light is scaled up by factor 10

Uncertainties of hit time and vertex position

- JUNO uses three types of PMTs
- respect Transit-Time Spread (TTS) of photomultiplier tubes

type	**coverage**	σ_{TTS}
MCP	50 %	5.096 ns
dynode	25 %	1.274 ns
small	2 %	1.911 ns
sum	77 %	

- respect uncertainty of vertex position:

$$\sigma = \frac{10cm}{\sqrt{E}}$$

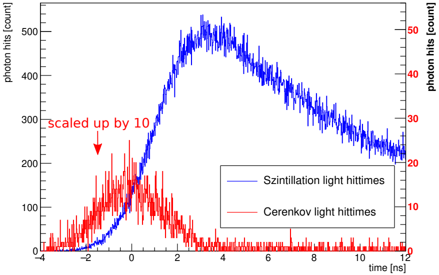


Abbildung: Histogram of hit times with dynode TTS and vertex uncertainty after time correction (400 events). Čerenkov light is scaled up by factor 10

Represent input as 4D point cloud

- represent data as 4D point cloud with PMT positions and hit times
- using time cut to maximize proportion of Čerenkov light
- time cut 0.75 ns after mean time of flight
- Čerenkov/Scintillation rate with time cut: 1/1.2 (with TTS: 1/6)
- **set time as distance between center and data point**

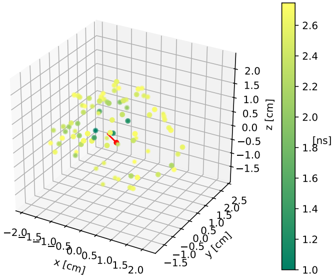


Abbildung: Time cut 2.75 ns after mean time of flight with projection around vertex (offset 2 ns)

Direction Reconstruction Net

- based on implementation of Dynamic Graph CNN
- modified structure:
    1. calculating Edge Feature
    2. calculating Transform Net for permutation invariance of input data
    3. calculating Edge Feature
    4. Direction Reconstruction Net

Name	Type	Output-Shape
dgcnn1	Conv2D	(None, 1024, 8, 16)
pool1	Max_Pool2D	(None, 511, 4, 16)
dgcnn2	Conv2D	(None, 511, 4, 16)
pool2	Max_Pool2D	(None, 255, 2, 16)
dgcnn3	Conv2D	(None, 255, 2, 16)
pool3	Max_Pool2D	(None, 127, 1, 16)
dp1	Dropout(0.6)	(None, 127, 1, 16)
flatten1	Flatten	(None, 2032)
local0	Dense	(None, 640)
local1	Dense	(None, 320)
local2	Dense	(None, 160)
local3	Dense	(None, 80)
dp2	Dropout(0.6)	(None, 80)
prediction/dense	Dense	(None, 3)
prediction/l2_normalize	L2 normalisation	(None, 3)

Tabelle: Direction Reconstruction Net

Angle distribution

- distribution of angle between Monte Carlo truth and reconstructed direction
- 1σ-error is maximum angle for 68% of reconstructed events

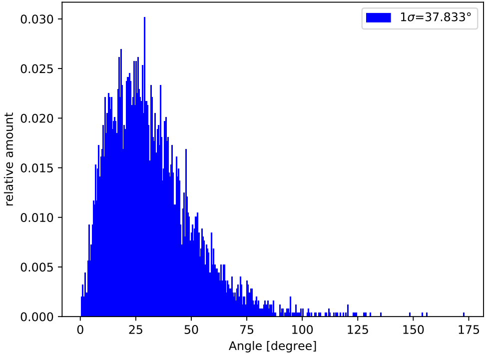


Abbildung: angle distribution of evaluation events of 4 MeV without TTS

Angle distribution for different energies

- all events in the center of the detector
- 1σ-error for 4 MeV without TTS or vertex smearing: 37.8°
- 1σ-error for 4 MeV with Dynode PMTs with 1.274 ns TTS and vertex uncertainty: 89.4°
- 1-5 MeV solar neutrinos, above supernova neutrinos

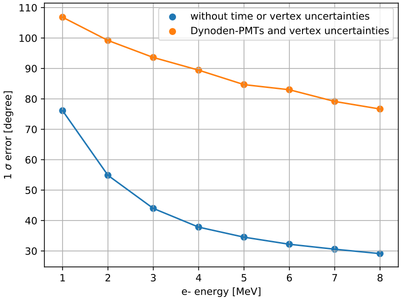


Abbildung: 1σ-error for different energies in the center of the detector

Angle distribution for different vertexes

- all events with 4 MeV energy
- 1σ-error 10 meters from center without TTS or vertex smearing: 38.9°
- 1σ-error with Dynode PMTs with 1.274 ns TTS and vertex smearing: 91.8°
- **new feature** and only possible by projection of points

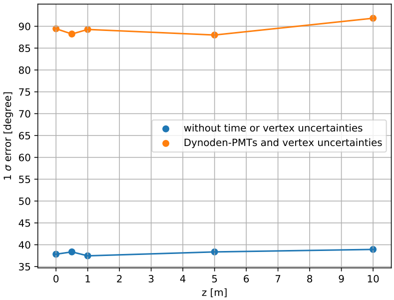


Abbildung: 1σ-error for different vertexes at 4 MeV energy

Summary

- additional feature: direction reconstruction of electrons to identify direction of ν_e neutrinos in JUNO
- time cut to separate Čerenkov light from scintillation light
- used modified version of Dynamic Graph CNN
- 1σ-error for 4 MeV event without TTS or vertex smearing: 37.8°
- 1σ-error for 4 MeV with Dynode PMTs with 1.274 ns TTS and vertex uncertainty: 89.4°
- only small vertex dependency

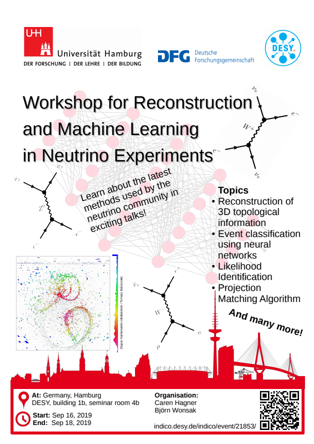
Outlook

- still improving network and data preparation
- testing to use all PMTs but with different weights

our next workshop:

- at Brookhaven National Laboratory
- October 5th-9th 2020
- 2 days tutorials
- 3 days talks + poster sessions

image source: bnl.gov



Poster from last workshop

Thank you for your attention

Example of Data Projection

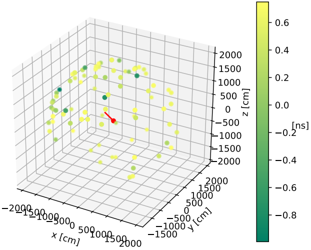


Abbildung: Time cut 0.75 ns after mean time of flight

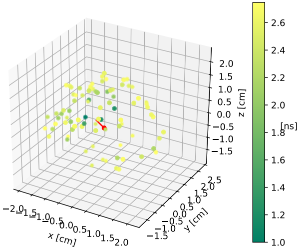


Abbildung: Time cut 2.75 ns after mean time of flight with projection around vertex

Cosine distribution

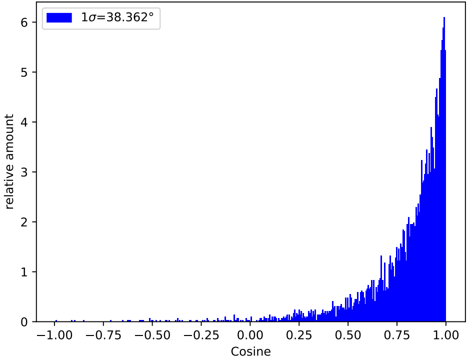


Abbildung: cosine distribution of evaluation events of 4 MeV without TTS

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Transform Net

Name	Type	Output-Shape
tconv1	Conv2D	(None, 1024, 8, 64)
tconv2	Conv2D	(None, 1024, 8, 128)
reduce_max	Reduce_max	(None, 1024, 1, 128)
tconv3	Conv2D	(None, 1024, 1, 1024)
tmaxpool	Max_Pool2D	(None, 1, 1, 1024)
tfc1	Fully_connected	(None, 512)
tfc2	Fully_connected	(None, 256)
transform_XYZ/weights	MatMul	(None, 16)
transform_XYZ/biases	BiasAdd	(None, 16)

Example of Input Data

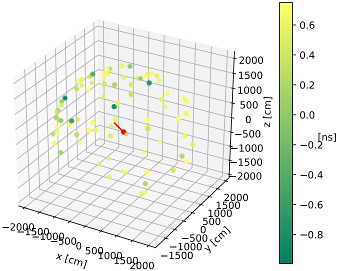

Abbildung: Time cut 0.75 ns after mean time of flight

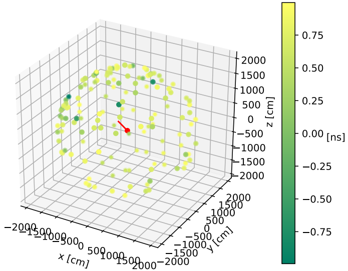

Abbildung: Time cut 1.0 ns after mean time of flight