Neural Network for Neck Discrimination

Light Pattern Filtered by Time Pattern

CIEMAT Team

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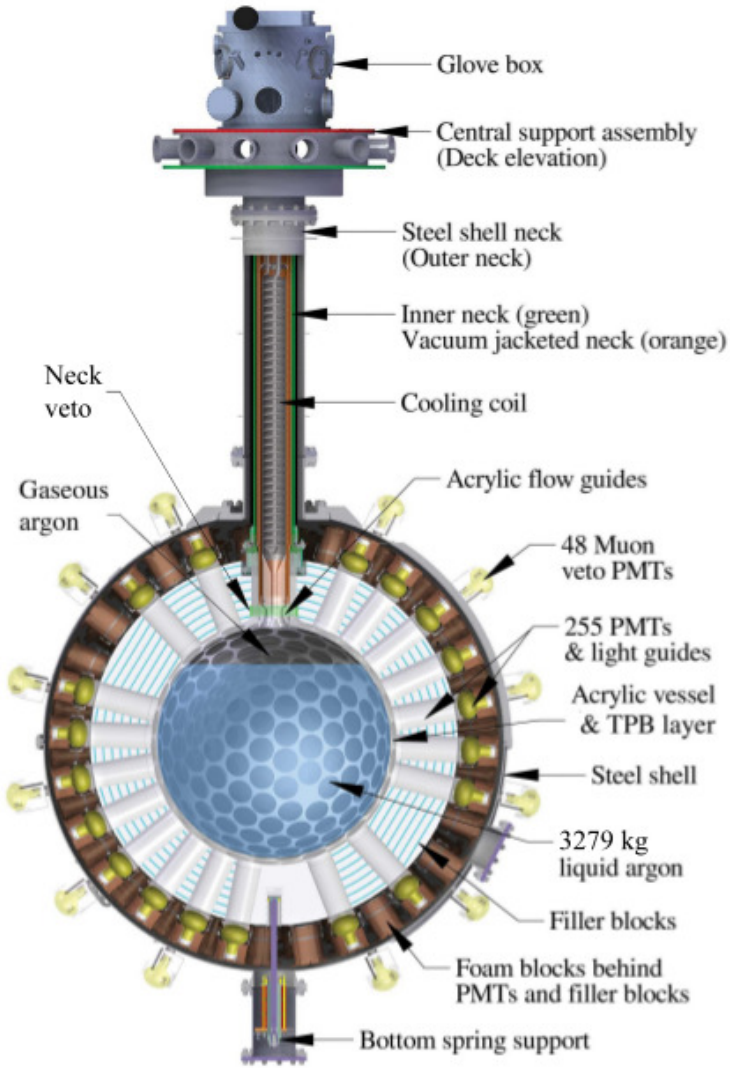
DEAP-3600 detector

- Placed in SNOLAB under 2 km of rock ($\approx$ 6000 mwe of coverage).
- Spherical acrylic vessel with diameter of 170 cm. It is filled with 3279 kg Liquid Argon.
- Single phase detector with 255 PMTs covering the 75% of the sphere. Grouped in 35 rings from 5 to 10 PMTs.



DEAP-3600 analysis

- WIMP dark matter search with 2016-2020 dataset
  - Profile likelihood ratio analysis (open data strategy)
  - Blind analysis on full dataset
- Other searches
  - 5.5 MeV solar axions
  - ^{8}B neutrino absorption signal (inverse beta decay)
- ^{39}Ar Measurements
  - ^{39}Ar specific activity
  - ^{39}Ar half-life
  - ^{39}Ar decay spectrum and nuclear parameters
- Muon veto instrumentation and muon flux measurement
  - Muon flux annual modulation (or absence thereof)

The Problem

- Neck events discrimination (noise) vs. nuclear recoils (signal).

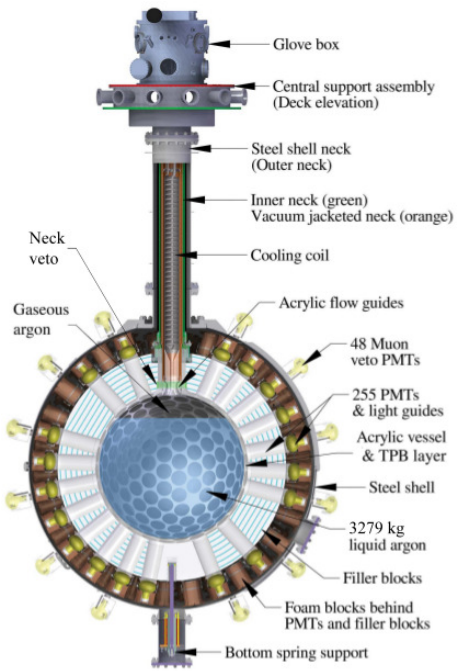
Only light pattern. Rejection 99.9%

pre-AI Rejection 99.0%, $A \approx 18$

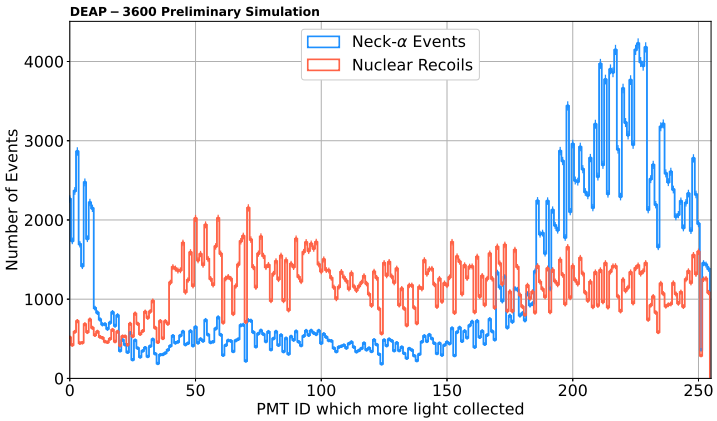
2019 MLP: D256D32 (100k events per label) $A = 41.5$,

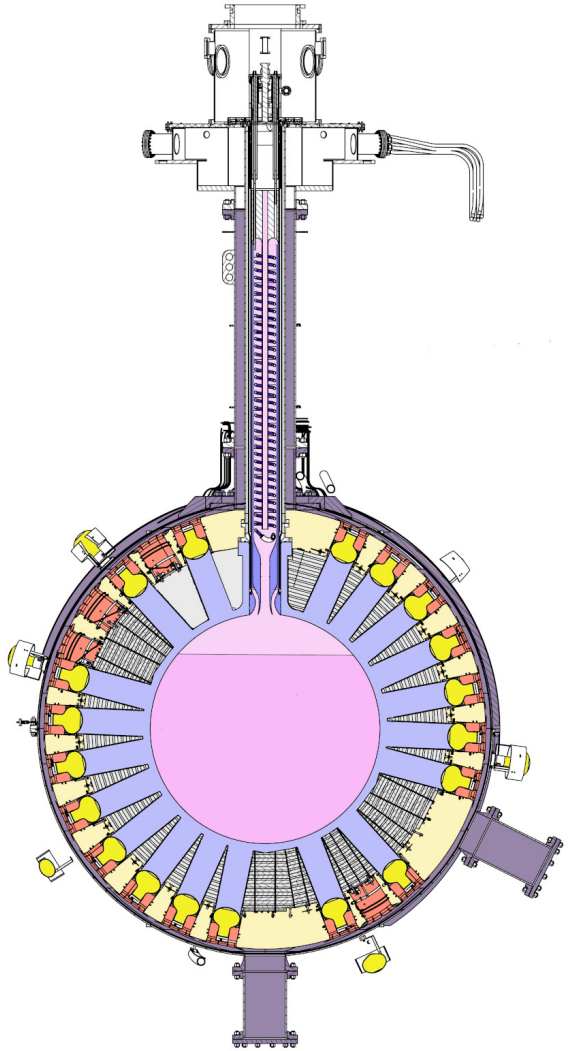
2020 MLP: (300k events per label) $A = 44.7$,

2020 Inception (300k) $A = 57.9$, Inception = CNN.



Patterns

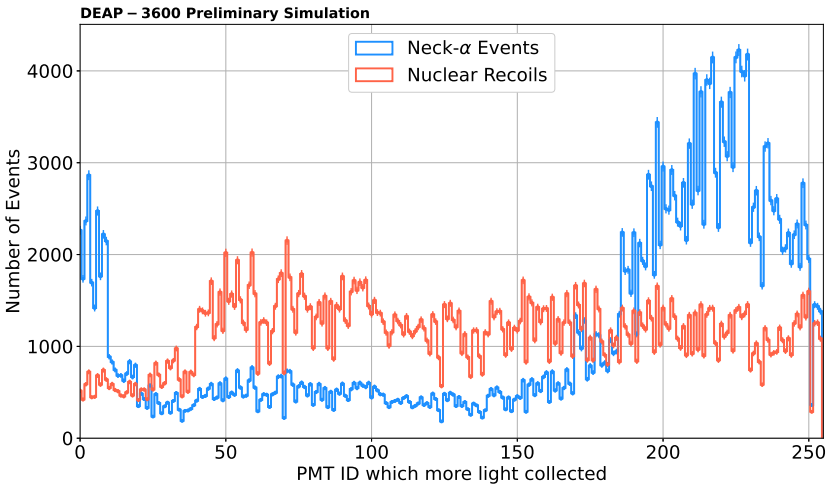


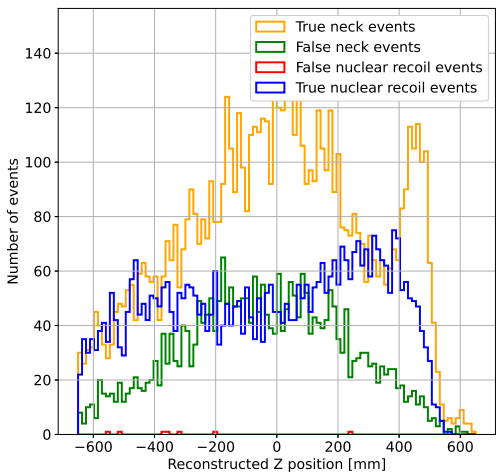


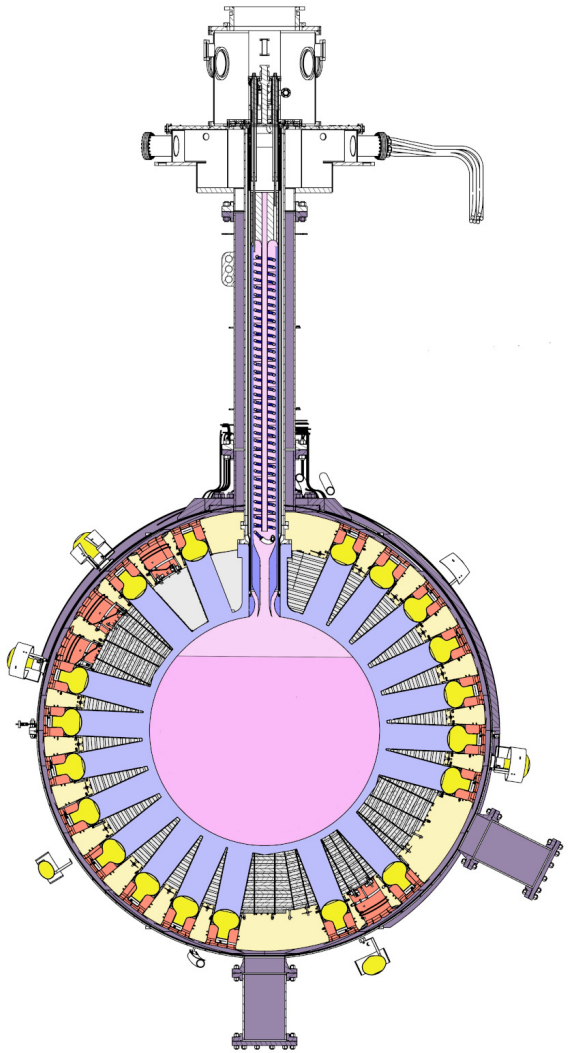
Incorporate time pattern

To optimize the preprocessing of data (dividing the light pattern in windows of time) based on parameters (-Acceptance) obtained from other process (NN discrimining neck events).

Patterns

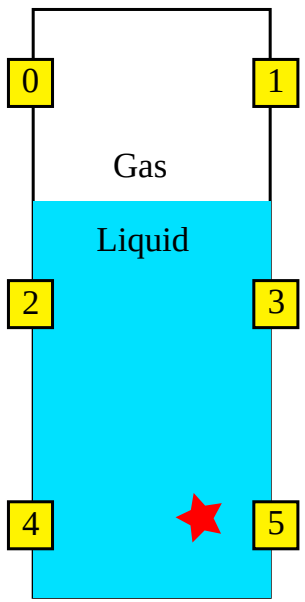

DEAP – 3600 Preliminary Simulation
Neck-α Events
Nuclear Recoils
Number of Events
PMT ID which more light collected
0
1000
2000
3000
4000
0
50
100
150
200
250


True neck events
False neck events
False nuclear recoil events
True nuclear recoil events
Number of events
Reconstructed Z position [mm]
0
20
40
60
80
100
120
140
−600
−400
−200
0
200
400
600



Idea

- To use the time pattern with time windows for filtering the light pattern.
- Low and high end times at -28 and 1000 ns. Optimization of the time divisor needed: (-28,x)(x,1000). Since 1 time divisor is used, the light pattern filtered has the double of the length of the original one (255X2).

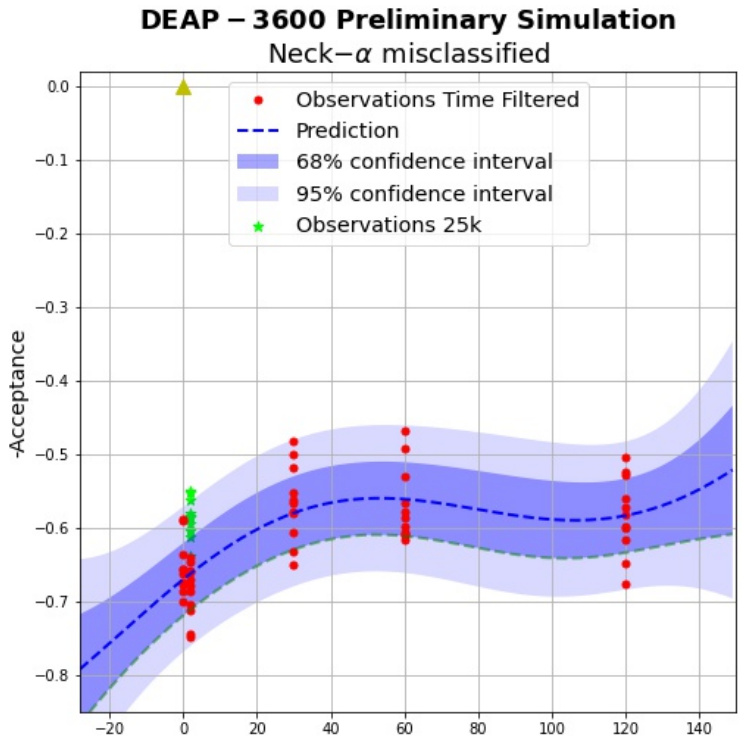



```
Light pattern
[5,5,10,20,20,40]
with  time pattern
[t5,t4,t3,t2,t2,t1]
with filter t<t3 produces
[0,0,0,20,20,40][5,5,10,0,0,0]
= [0,0,0,20,20,40,5,5,10,0,0,0]
```

- 1D input. Lost information in Z coordinate.

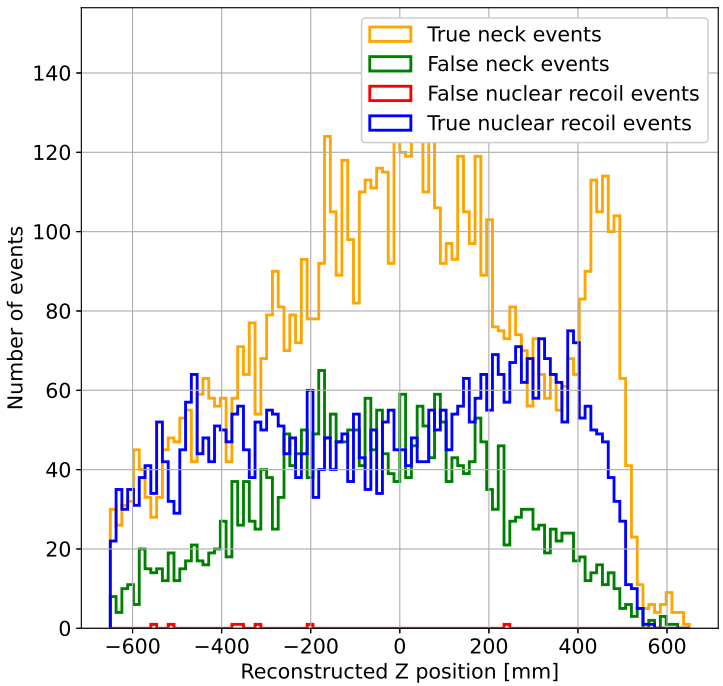
Bayesian Optimization of Time Divisor

- Bayesian optimization of time divisor. 2 time windows created: (-28,time-divisor) and (time-divisor,1000) ns. 11 runs.
- Minimization of *-Acceptance* in the discriminator of neck events. The lower value, the better acceptance.
- 5 time divisor tested: 0, **2** (best), 30, 60 and 120 ns.

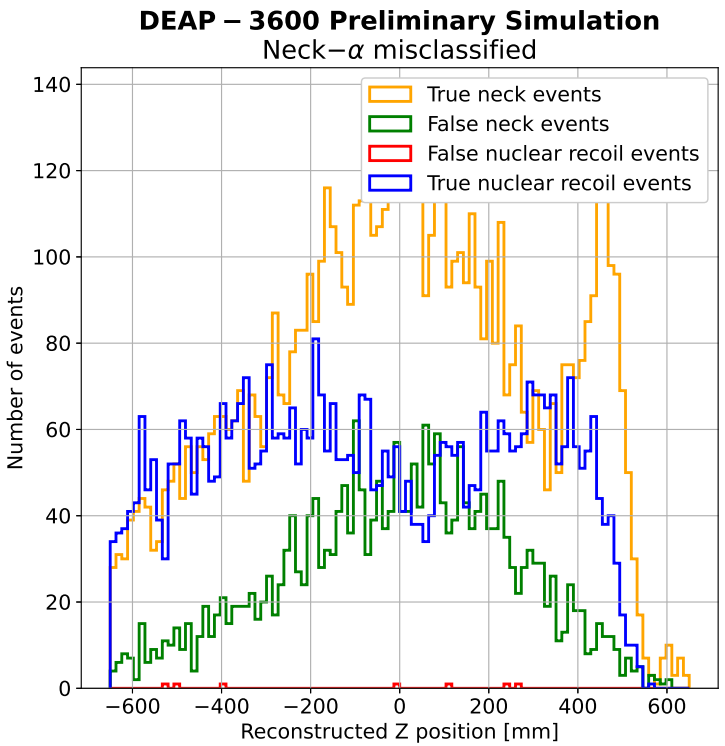


With the whole dataset (imbalanced) the mean Acceptance is (25k per label) **0.686** and **0.587** without filtering.

Time divisor off-on Z coordinate. 25k events/label



(a) off, A=0.620

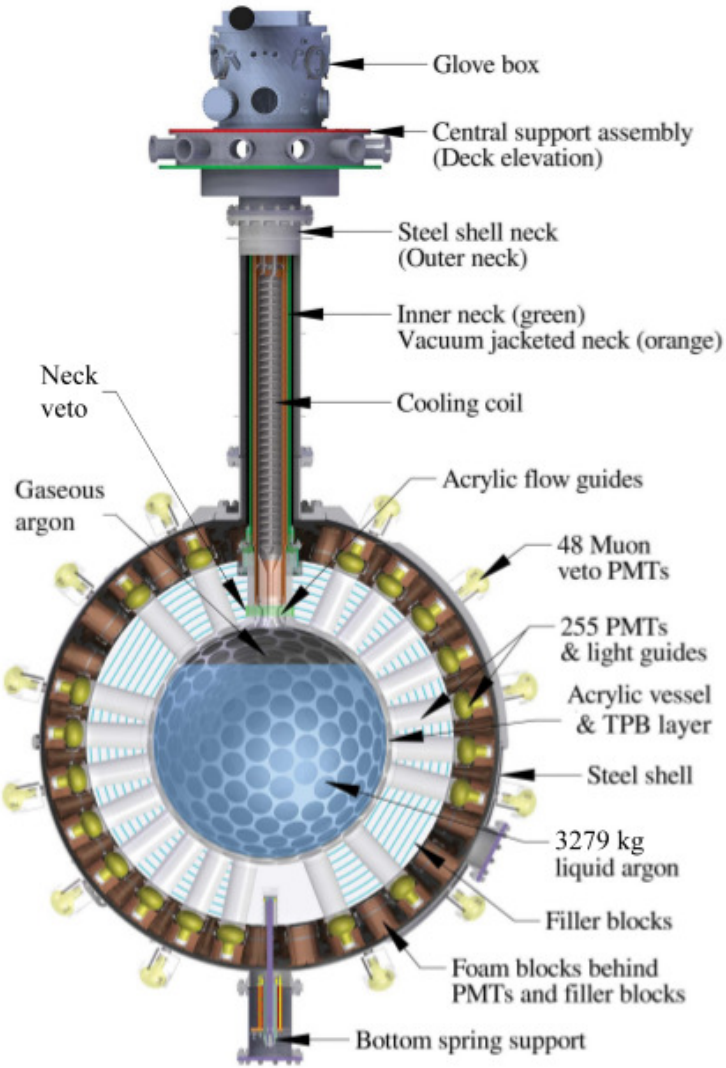


(b) on, A=0.768

Why?

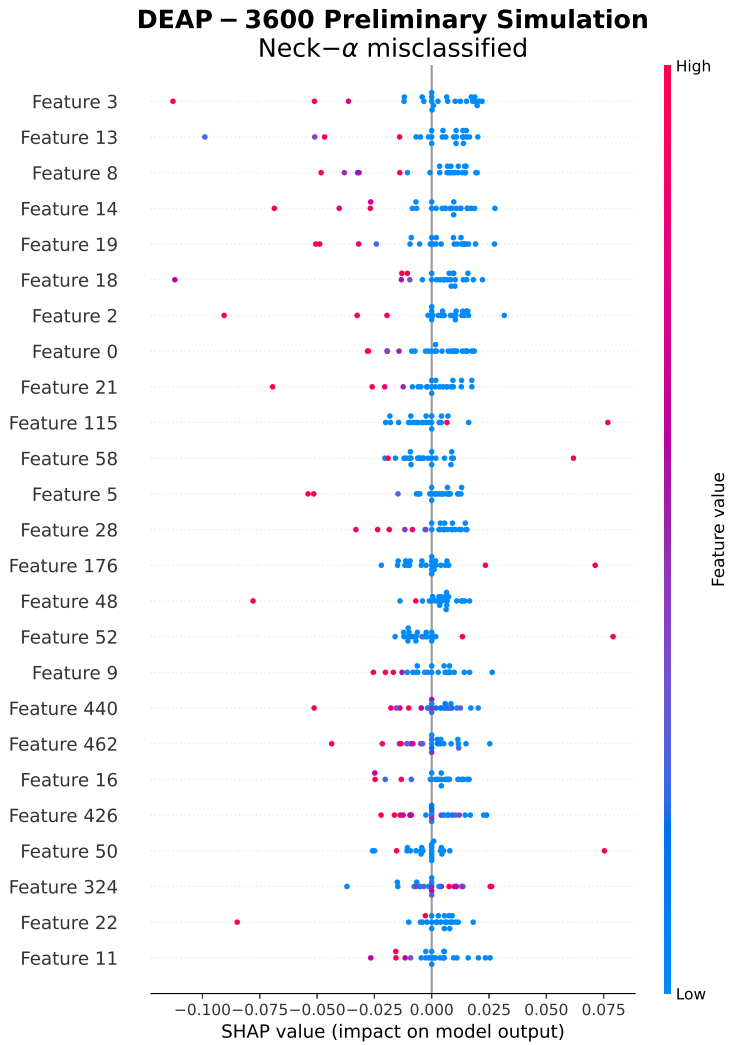
Toy model/explanation

- $\frac{1}{v_g} = 7.5 \pm 0.007 \pm 0.05(sys)$ ns/m, $\lambda = 128$ nm. Propagation of scintillation light in Liquid Argon: M. Babicz et al 2020 JINST 15 C03035
- $v_g \times 2ns = 0.266$ m, $v_g \times 3ns = 0.400$ m from -1 ns to 2 ns ?? related to acrylic vessel of radious 0.850 m.



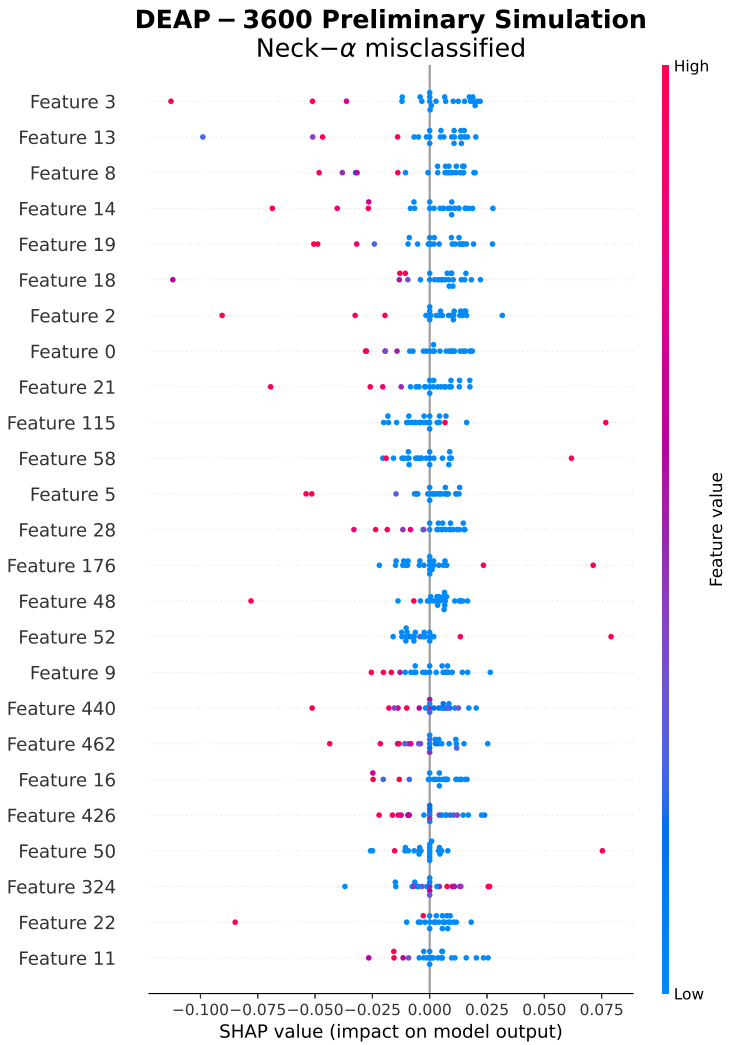
XAI: SHAP

- Analysis for 25 events (memory exhausted by Shap).
- The first window (-28,2) ns of the top PMT are critical for the classification: 3, 13, 8, 14...
- Exception in features 440 (second time-window of PMT 185), 462 (207), 426 (171), 324 (69), all in liquid.
- Larger number of blue dots (no/low light) than red ones because the sparse light pattern.



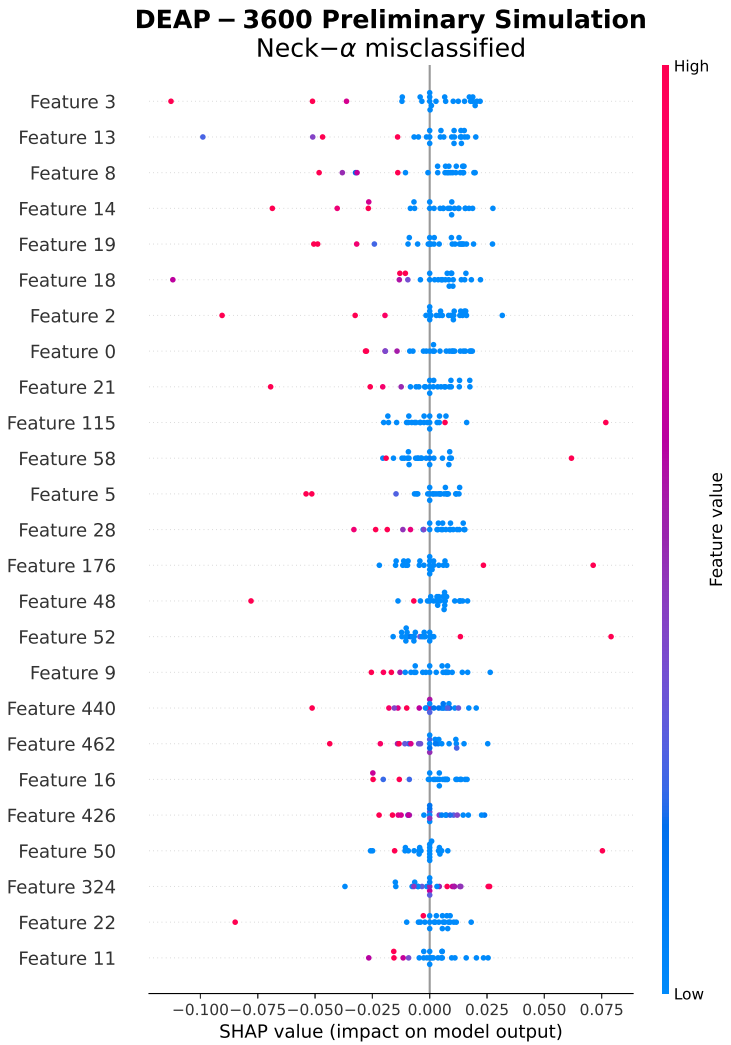
XAI: SHAP

- Not red points in both sides of shap values a single feature. Strong relevance for the classification.
- Strongly negatively correlated: low values of variables (blue dots) (low or not light in PMTs) slightly increase the shap value (moves the classification toward the class 1).
- Exception in few features (52, equatorial PMT) with positive correlation.

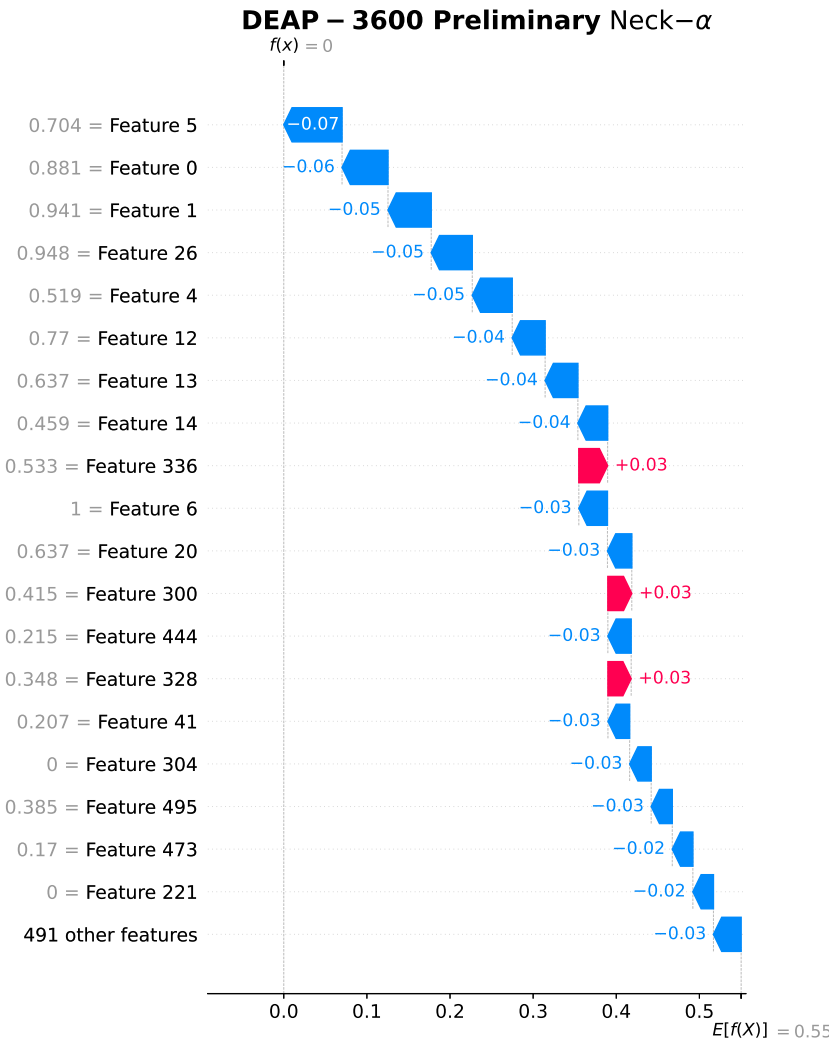


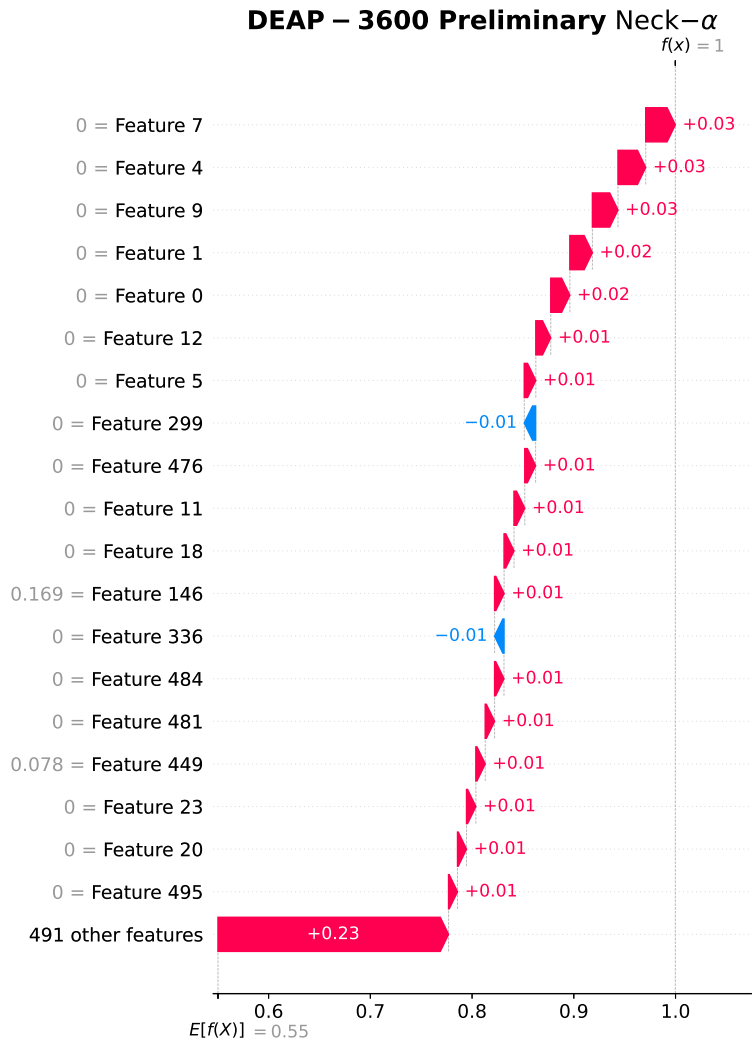
XAI: SHAP

- Few cases with high values (red dots) (a lot of light) in PMTs of low index drive to reduce the shap value (class 0).
- Oppositely in equatorial PMTs (115, 176) increase the shap value (move them to class 1).



XAI: SHAP


DEAP – 3600 Preliminary Neck–α
f(x) = 0
0.704 = Feature 5
0.881 = Feature 0
0.941 = Feature 1
0.948 = Feature 26
0.519 = Feature 4
0.77 = Feature 12
0.637 = Feature 13
0.459 = Feature 14
0.533 = Feature 336
1 = Feature 6
0.637 = Feature 20
0.415 = Feature 300
0.215 = Feature 444
0.348 = Feature 328
0.207 = Feature 41
0 = Feature 304
0.385 = Feature 495
0.17 = Feature 473
0 = Feature 221
491 other features
−0.07
−0.06
−0.05
−0.05
−0.05
−0.04
−0.04
−0.04
+0.03
−0.03
−0.03
+0.03
−0.03
+0.03
−0.03
−0.03
−0.03
−0.02
−0.02
−0.03
0.0
0.1
0.2
0.3
0.4
0.5
E[f(X)] = 0.55


DEAP – 3600 Preliminary Neck–α
f(x) = 1
0 = Feature 7
0 = Feature 4
0 = Feature 9
0 = Feature 1
0 = Feature 0
0 = Feature 12
0 = Feature 5
0 = Feature 299
0 = Feature 476
0 = Feature 11
0 = Feature 18
0.169 = Feature 146
0 = Feature 336
0 = Feature 484
0 = Feature 481
0.078 = Feature 449
0 = Feature 23
0 = Feature 20
0 = Feature 495
491 other features
+0.03
+0.03
+0.03
+0.02
+0.02
+0.01
+0.01
−0.01
+0.01
+0.01
+0.01
+0.01
−0.01
+0.01
+0.01
+0.01
+0.01
+0.01
+0.01
+0.23
0.6
0.7
0.8
0.9
1.0
E[f(X)] = 0.55

Skills

- Deep Learning under Particle Physics vision, where Explainability plays a key role.
- Adaptability to requirements: format input, most suitable architecture, custom loss, problem category, etc.