Neural Network KLM trigger

by Anthony Little

Belle II
University of Sydney

Belle II TRG Meeting 14/3/23

Motivation

- More sophisticated trigger over current one
- Output useful variables for Richard's Straight Line Fitter
- Improved exclusion of Cosmic Muon Background
- Improved Muon and K_L identification

THE UNIVERSITY OF SYDNEY

Neural Network based KLM TRG

General Framework

- Deep neural network using trigger level info
- Two main outputs: a Muon track/Hadron cluster identifier and angular output of given track/cluster
- First output is a sigmoid probability function, $= 0$ means muon, $= 1$ means hadron
- Second output is a list of 4 numbers, the cosine and sin of the track's/cluster's θ and ϕ
- Separate NNs for EKLM and BKLM (results shown here only BKLM)

THE UNIVERSITY OF SYDNEY

Cluster Identification

- Clustering algorithm was deemed unnecessary
- Used particle gun events so all hits originate from single particle
- Used both Klong and Muon events, plan to do test on general hadron events to see differences (K_L, π, p)

Neural Network overview

Input Features

- Section and Sector ID of Hit
- Total Number of Unique Layers
- Total Number of Hits
- First Layer
- Distance between Maximum and Minimum directional strip hits, in both First and Total Layers
- Z and ϕ for BKLM, θ and ϕ for EKLM

Output Features

- Sigmoid probability of cluster/track
- ϕ representation as $cos(\phi)$, $sin(\phi)$
- θ representation as $cos(\theta)$, $sin(\theta)$

Configuration of Neural Network overview

- Total trainable parameters of 1765
- 70% sparsity pruned

Layer	Nodes	Activation
Trivial Input	9 (non-trainable)	N/A
1st Hidden	64	tanh
2nd Hidden	16	tanh
ID output	1	sigmoid
Angle output	4	linear

THE UNIVERSITY OF SYDNEY

Training of Models

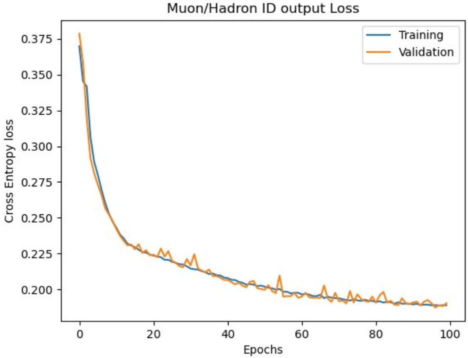
Event distribution

- Only accept events with both 1D strips and in this presentation only showing events from barrel
- 26672 Muon events and 15104 Klong events
- 80% events used for training
- 10% events for validation 10% events for testing

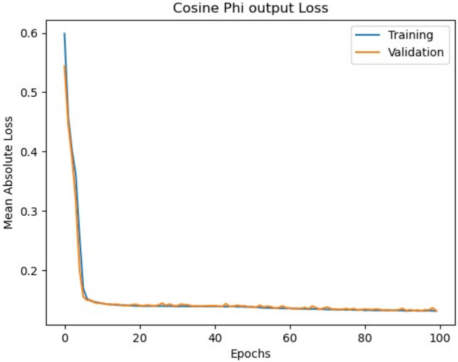
Hyper-parameters

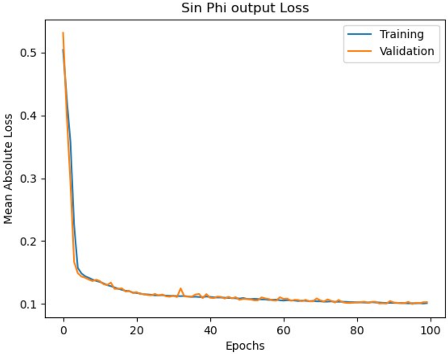
- Learning rate: 0.001
- Batch size: 64
- Epochs: 100
- Loss: Cross Entropy/Mean Absolute Error (ID/Positional)

ID Model Training Results



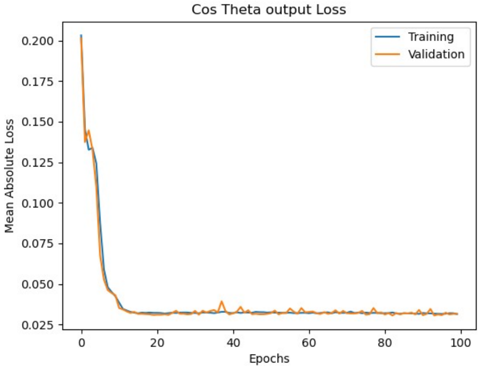
ϕ Model Training

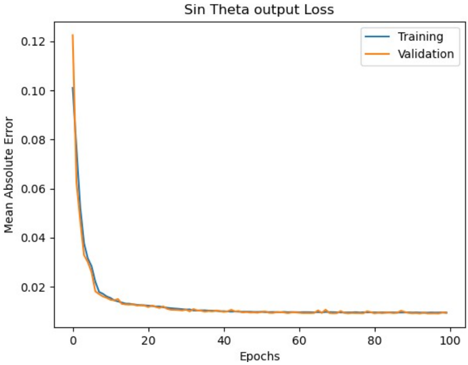




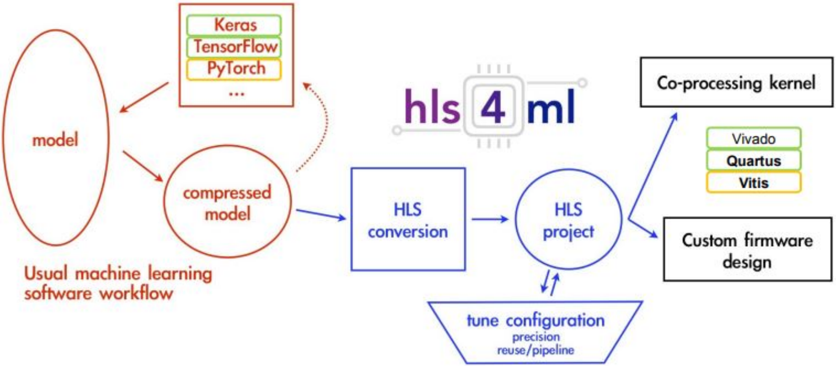
THE UNIVERSITY OF SYDNEY

θ Model Training





hls4ml



FastML Team. hls4ml (Version v0.8.0) [Computer software]. https://doi.org/10.5281/zenodo.1201549

hls4ml details

hls4ml in this experiment?

- Reconstructed via RAM as this greatly reduced resource usage
- All internal layers use 16 total bits with 8 integer bits
- Output Layers use 10 total bits, with 2 integer bits
- FPGA part used: XCVU080-FFVB2104-2-E

Comparison and Synthesis of Model on FPGAs

Synthesis/Performance

- Latency and resource usage
- Bit restriction can hurt performance slightly
- hls4ml predict function vs keras predict function

Resource Definitions/Jargon

- LUT (Look Up Table): Basic logic of FGPA, generic functions that build the algorithm
- FF (Flip Flops): Build the pipeline of data with the clock pulse
- DSP (Digital Signal Processor): Performs arithmetic in the FPGA
- BRAM (Block RAM): Additional Memory usage

THE UNIVERSITY OF SYDNEY

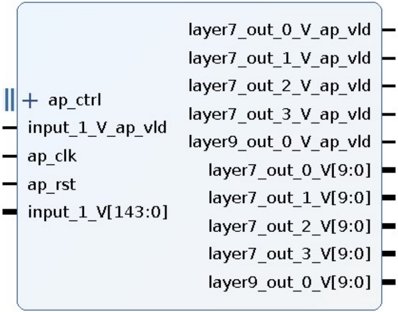
Model Synthesis/Performance

Total Latency	Cycles	BRAM	DSP	FF	LUT
91 ns	13	1%	41%	$< 1\%$	6%

Result	Loss/Accuracy	Keras Model	hls4ml Model
ID	Accuracy	91.79%	91.13%
$cos(\phi)$	Mean Absolute Error	0.1245	0.1391
$sin(\phi)$	Mean Absolute Error	0.1052	0.1040
$cos(\theta)$	Mean Absolute Error	0.0297	0.0571
$sin(\theta)$	Mean Absolute Error	0.0095	0.0245

THE UNIVERSITY OF SYDNEY

IP Core

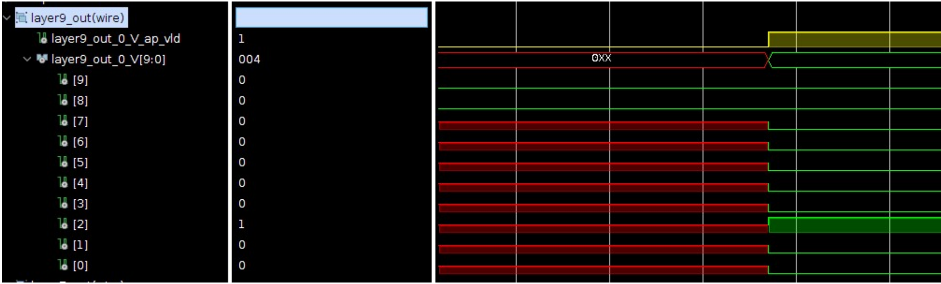


- Inputs: clock, reset, validation, 9 input variables
- Output: Validation of outputs, Track probability, Angular output

THE UNIVERSITY OF SYDNEY

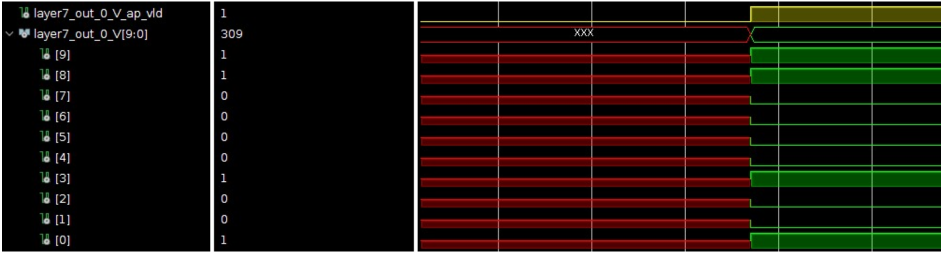
Testbench Output Waveview: ID output

- True Answer: 0
- Tb Prediction: $2^{-6} = 0.01562$



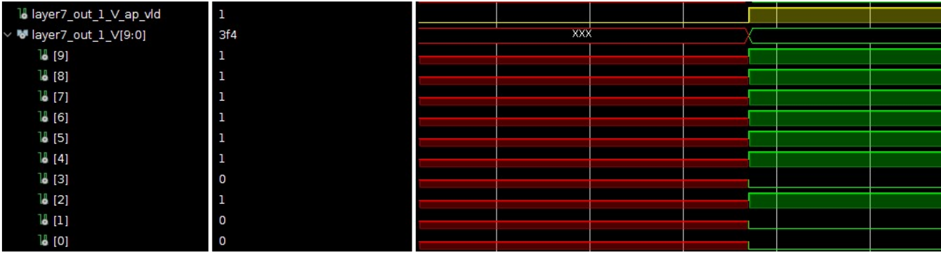
Vivado Waveview: $cos(\phi)$ output

- True Answer: -0.9976462
- Tb Prediction: $-1 + 2^{-5} + 2^{-8} = -0.964844$



Vivado Waveview: $sin(\phi)$ output

- True Answer: -0.06857163
- Tb Prediction: -0.046875

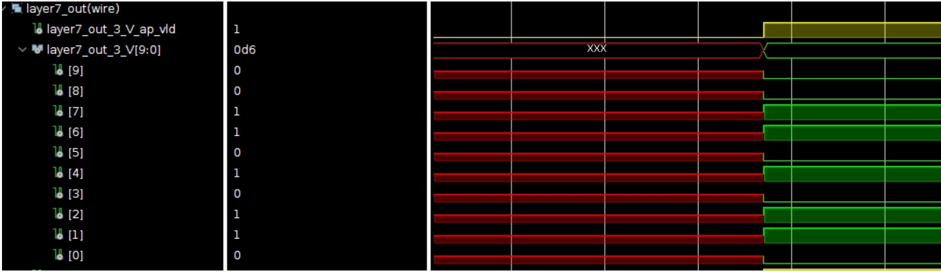


Vivado Waveview: $cos(\theta)$ output

- True Answer: -0.49273366
- Tb Prediction: -0.484375

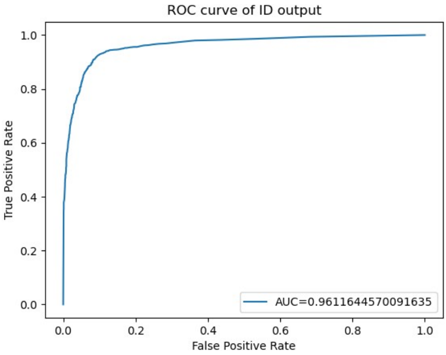
Vivado Waveview: $sin(\theta)$ output

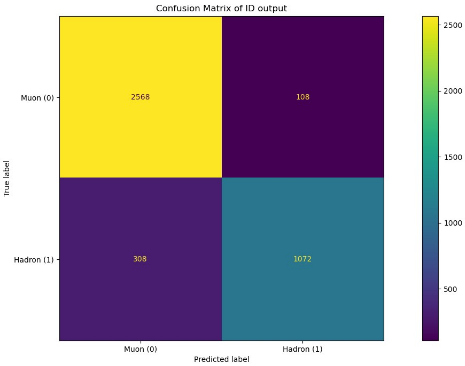
- True Answer: 0.87018018
- Tb Prediction: 0.835938



Multi-event simulation analysis

4056 events





Multi-event simulation analysis

Results

Result	Loss/Accuracy	Simulation results
ID	Accuracy	89.74%
$cos(\phi)$	Mean Absolute Error	0.1881
$sin(\phi)$	Mean Absolute Error	0.1551
$cos(\theta)$	Mean Absolute Error	0.0504
$sin(\theta)$	Mean Absolute Error	0.0222

Future work

- Check over results in EKLM
- Compatibility with Richard Pscheke Straight Line Fitter
- Investigate impact of general hadron data
- Investigate models ability on raw and cosmic data
- Addition of dz variable if needed
- Implementation into trigger and basf2