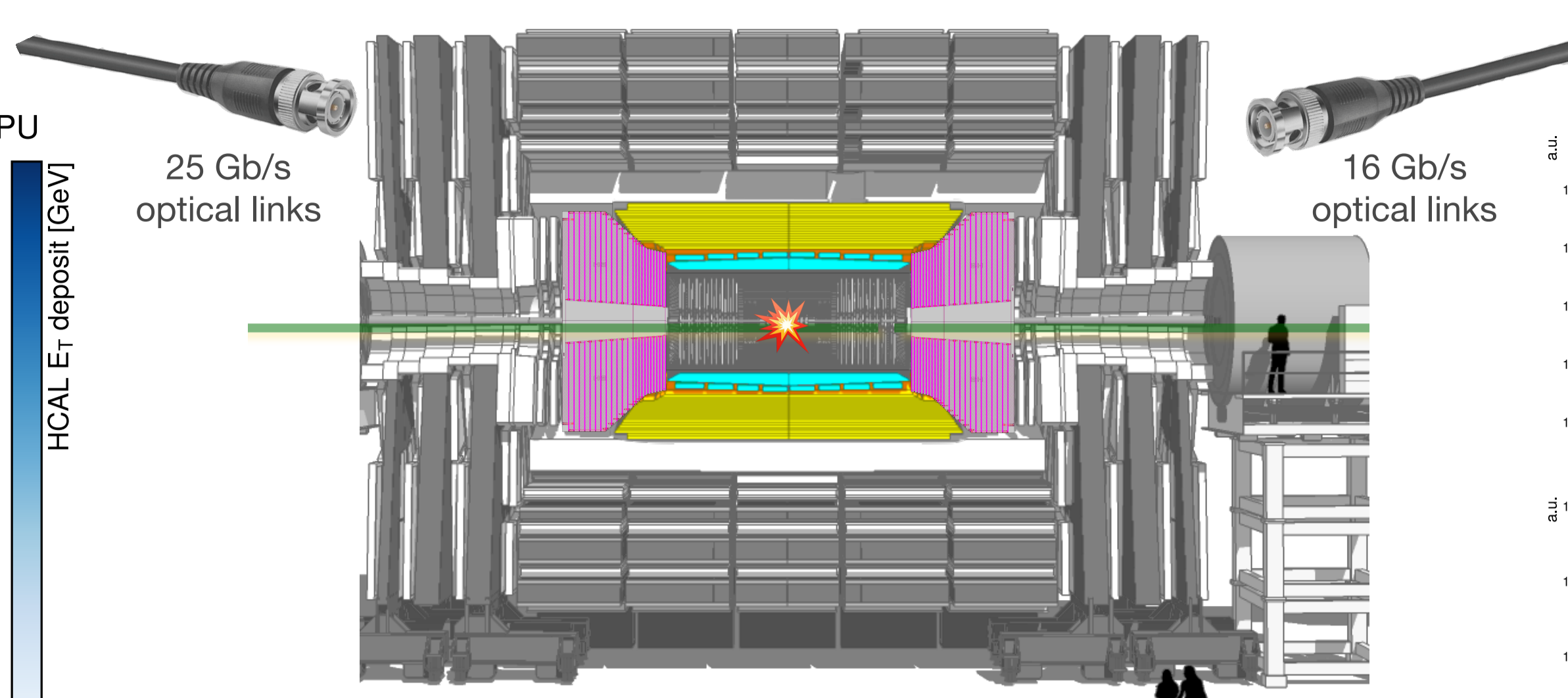
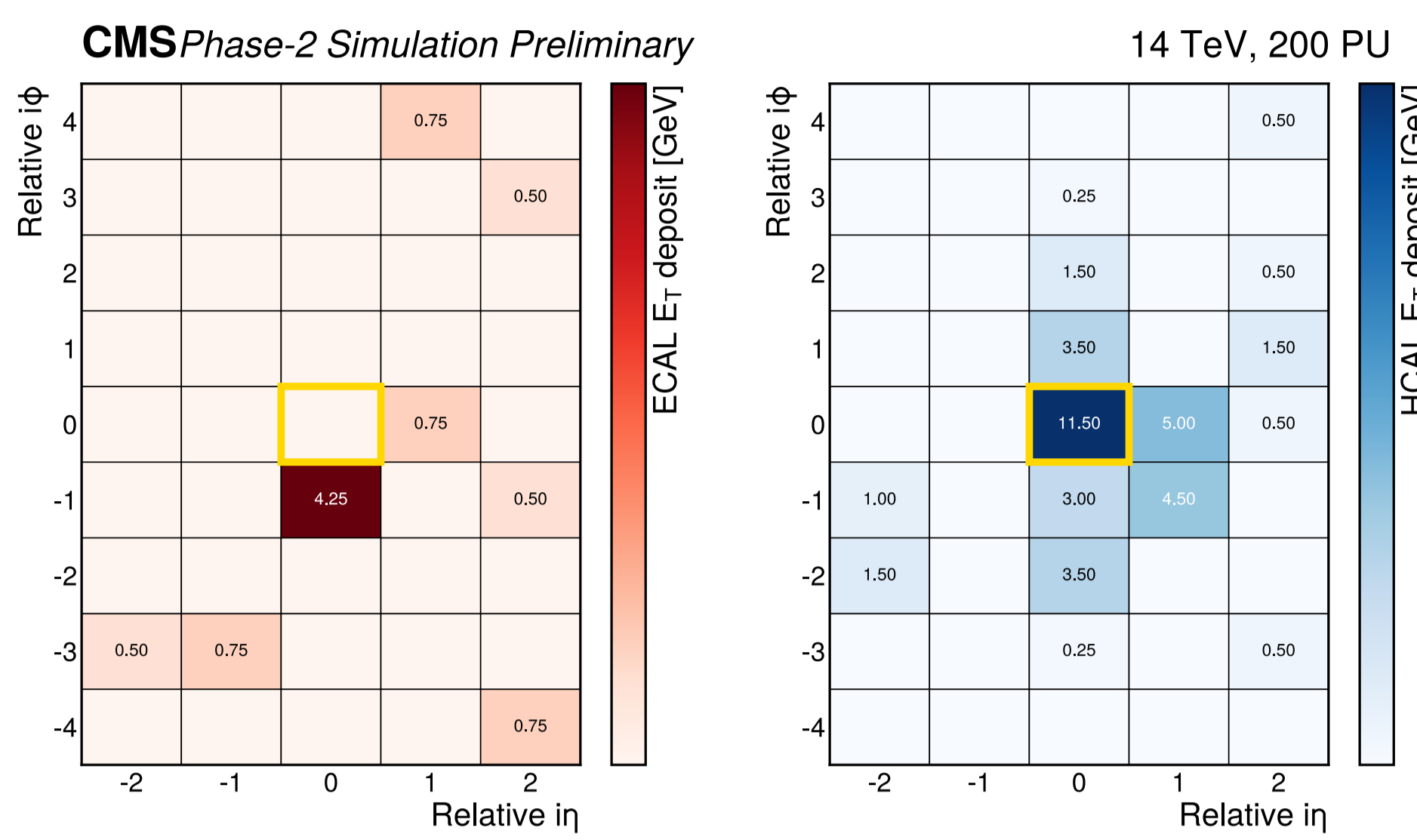


Development and firmware implementation of a machine learning based hadronic tau lepton Level-1 Trigger algorithm in CMS for the HL-LHC

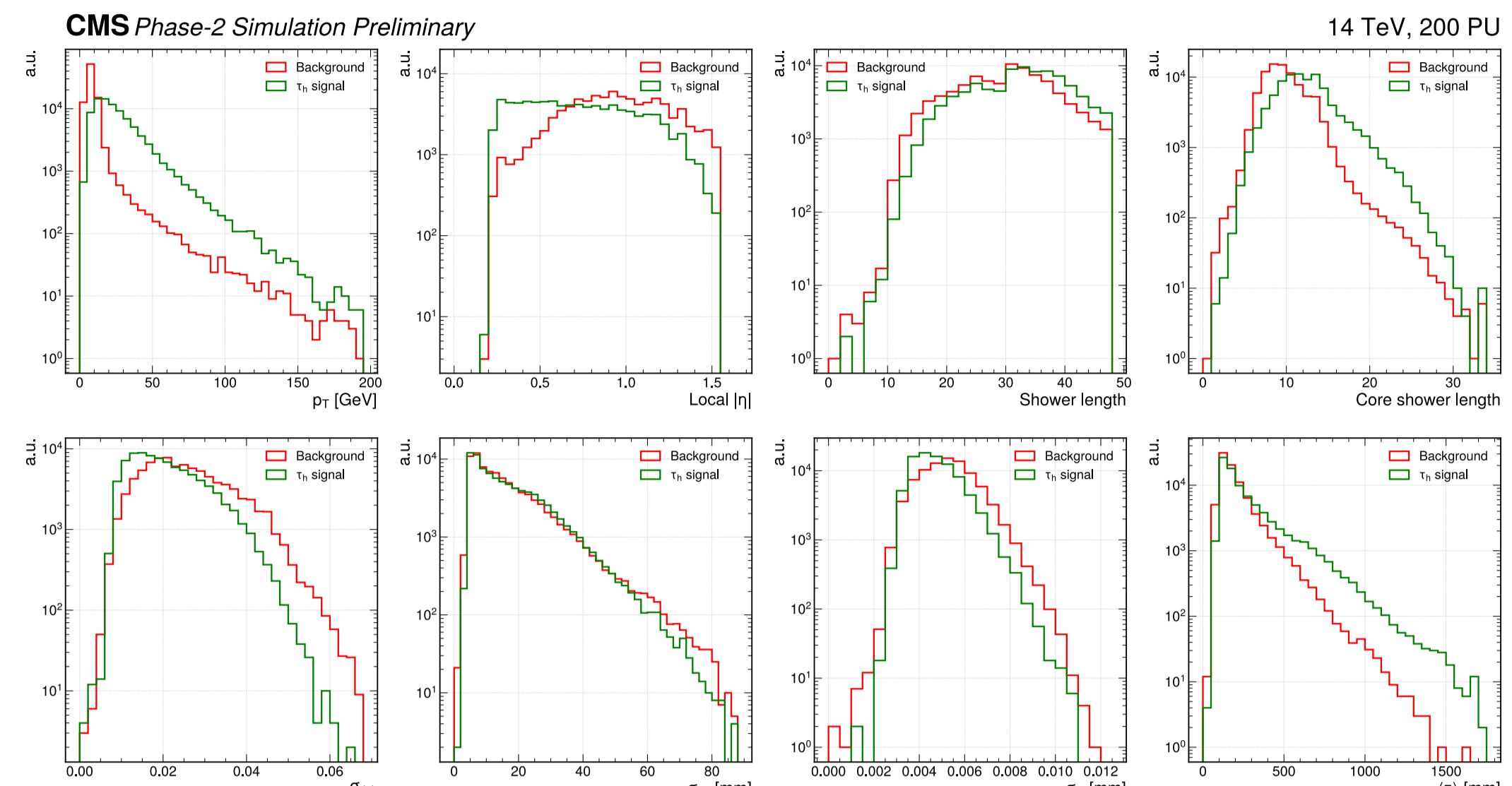
Jona Motta* on behalf of the CMS Collaboration - EPS HEP 2023 (Hamburg, Germany)

WHEN: At the HL-LHC **WHO:** The Level-1 Trigger **WHERE:** Calo-Trigger w/ Calo-Info **HOW:** Machine-Learning in FPGA thanks to hls4ml
WHY: To help tracker algos in reaching 100% L1 efficiency at high p_T , and to improve on the current cut-based algo

CALORIMETER TRIGGER TOWERS



HGCAL HIGH GRANULARITY CLUSTERS



Processing performed in state-of-the-art FPGAs on industry standard ATCA boards

$CL^{5 \times 9}$ IMAGE - $(\eta, \phi)_{seed}$ POSITION

MINATOR

CL^{3D} FEATURES - $CL^{5 \times 9}$ IMAGE - $(\eta, \phi)_{seed}$ POSITION

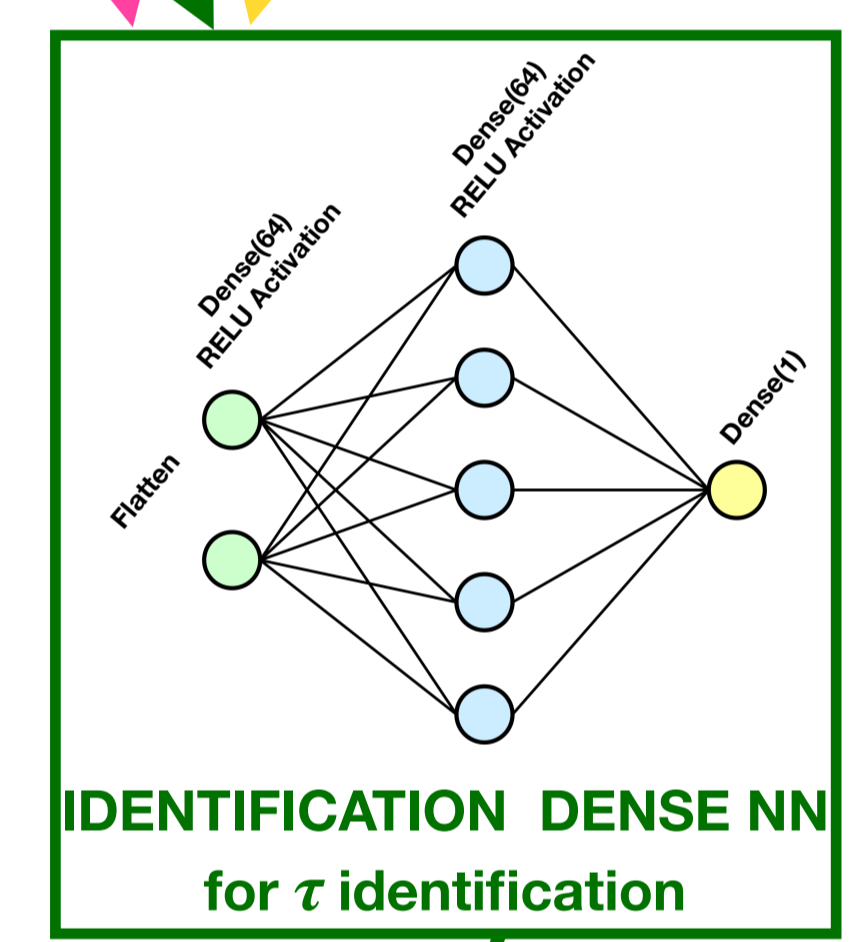
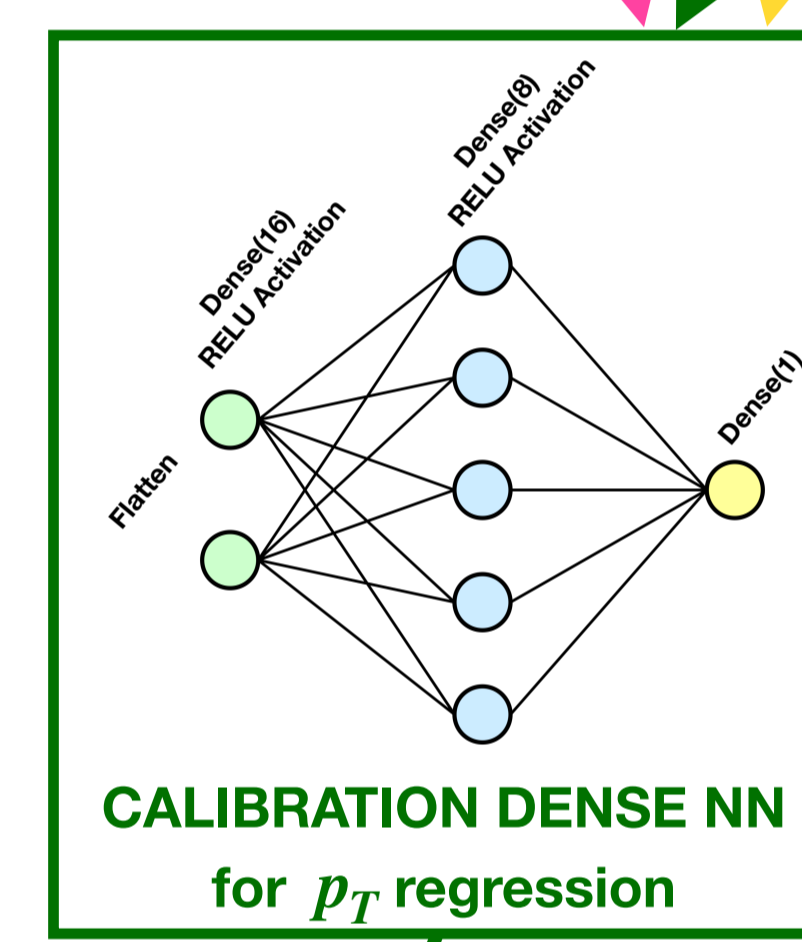
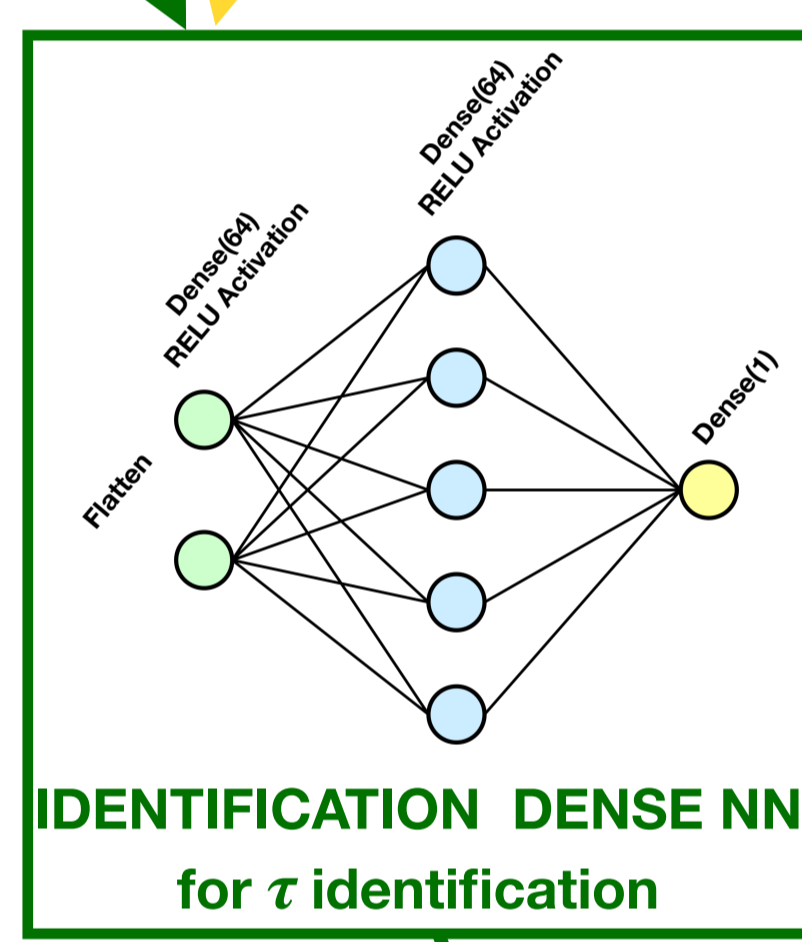
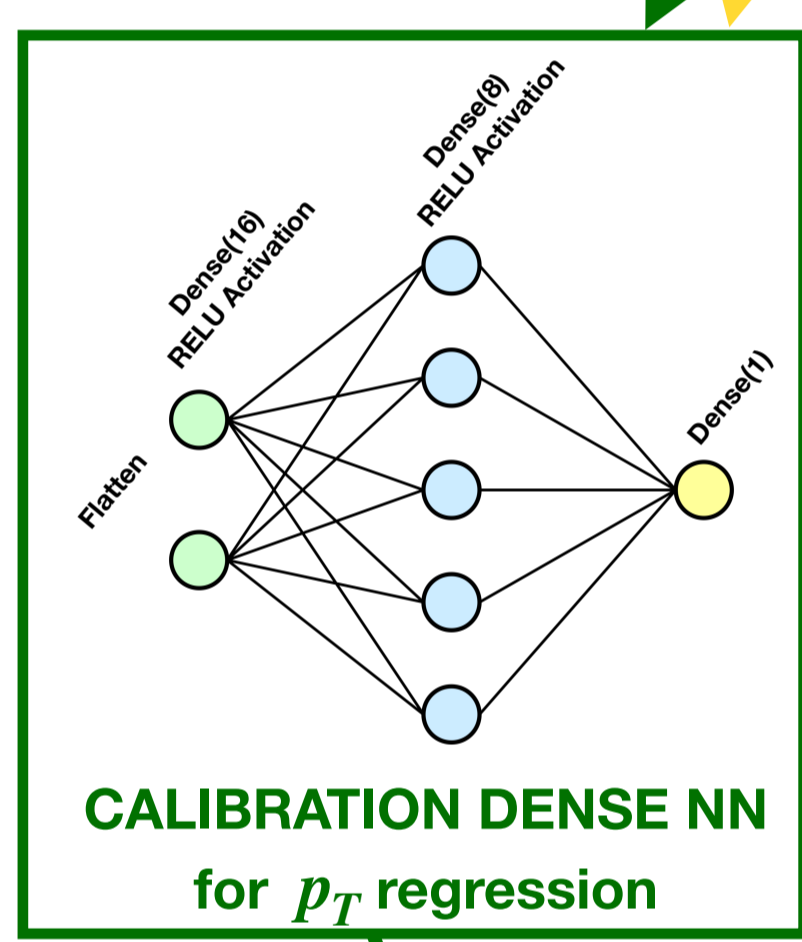
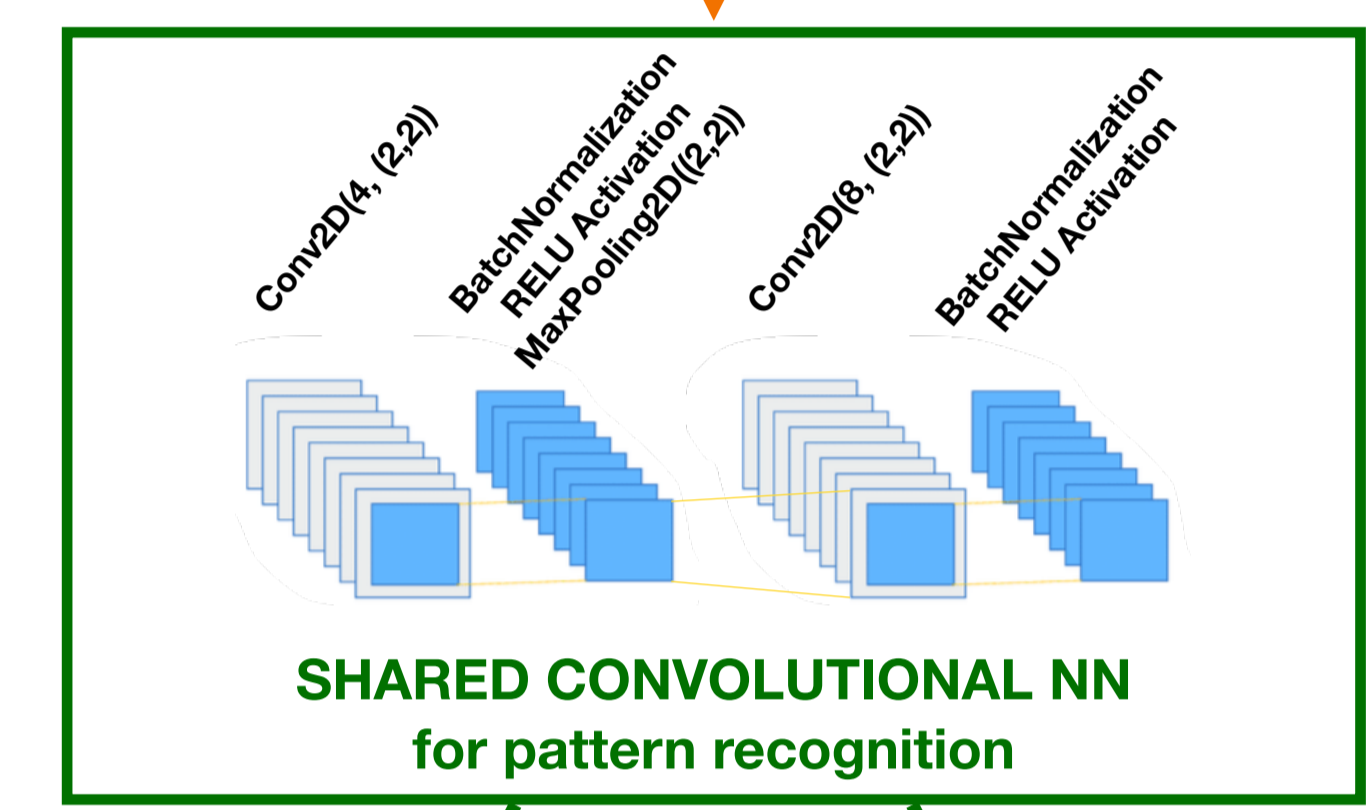
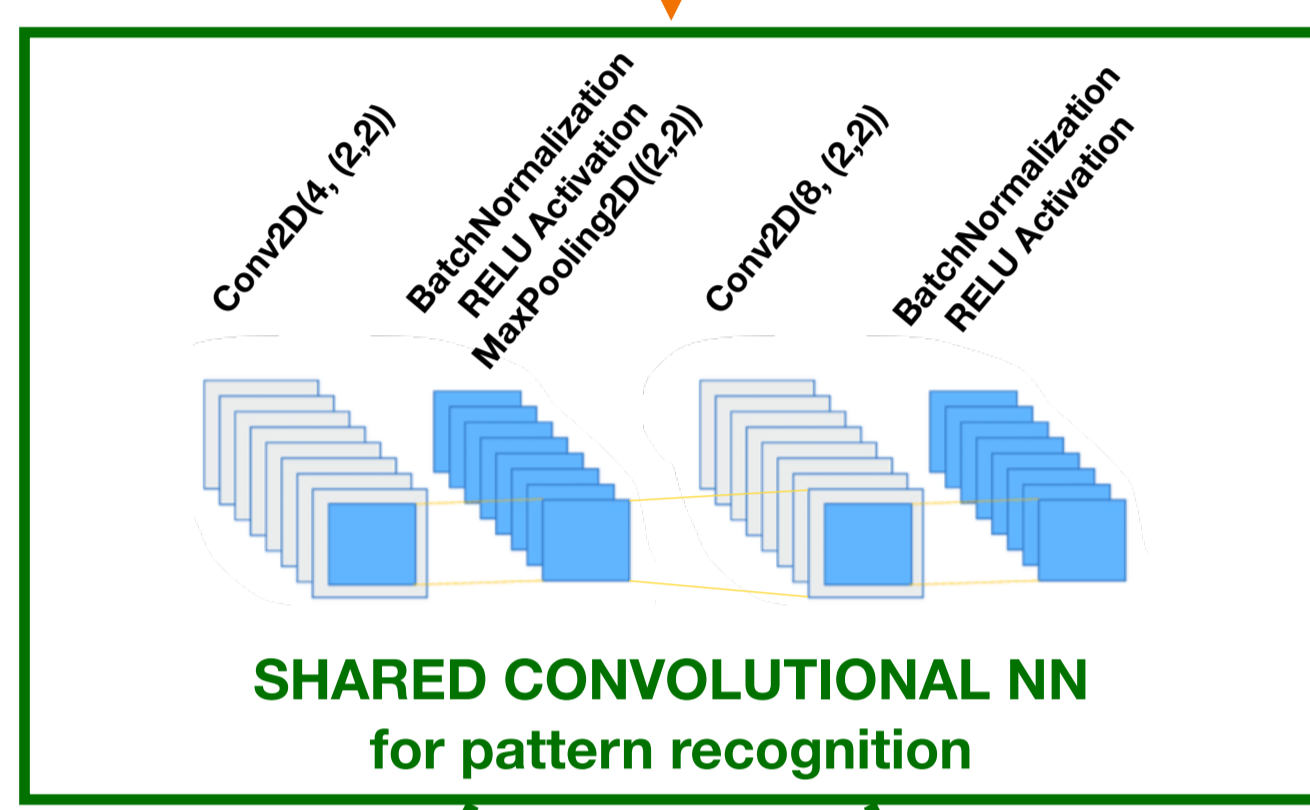
BARREL $|\eta| < 1.55$ **ENDCAP** $|\eta| > 1.55$

Software developed in Keras TensorFlow

Firmware translation with hls4ml

Firmware implemented in Xilinx UltraScale+ VU13P

Firmware tested in Xilinx Alveo U200 Accelerator

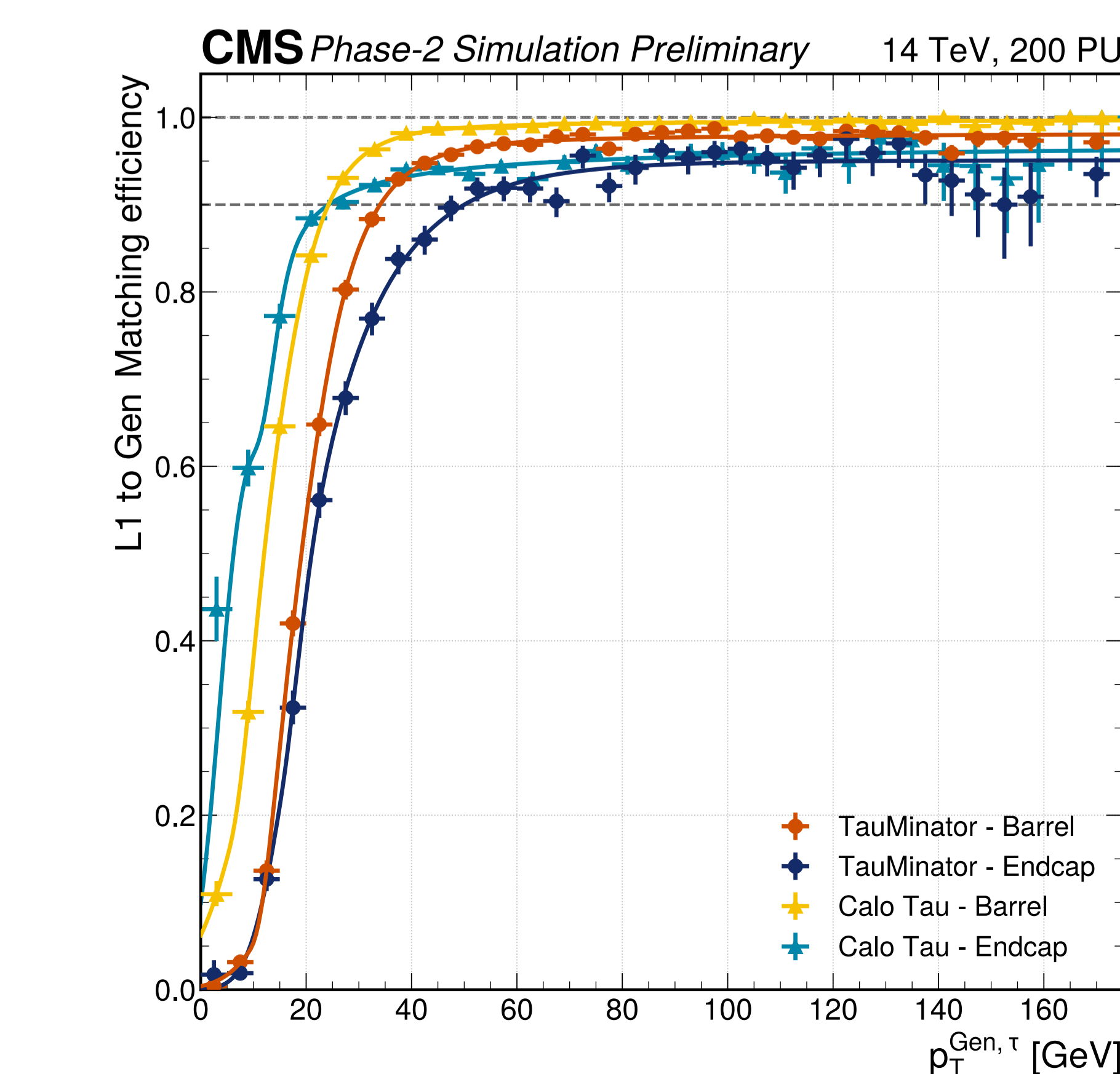
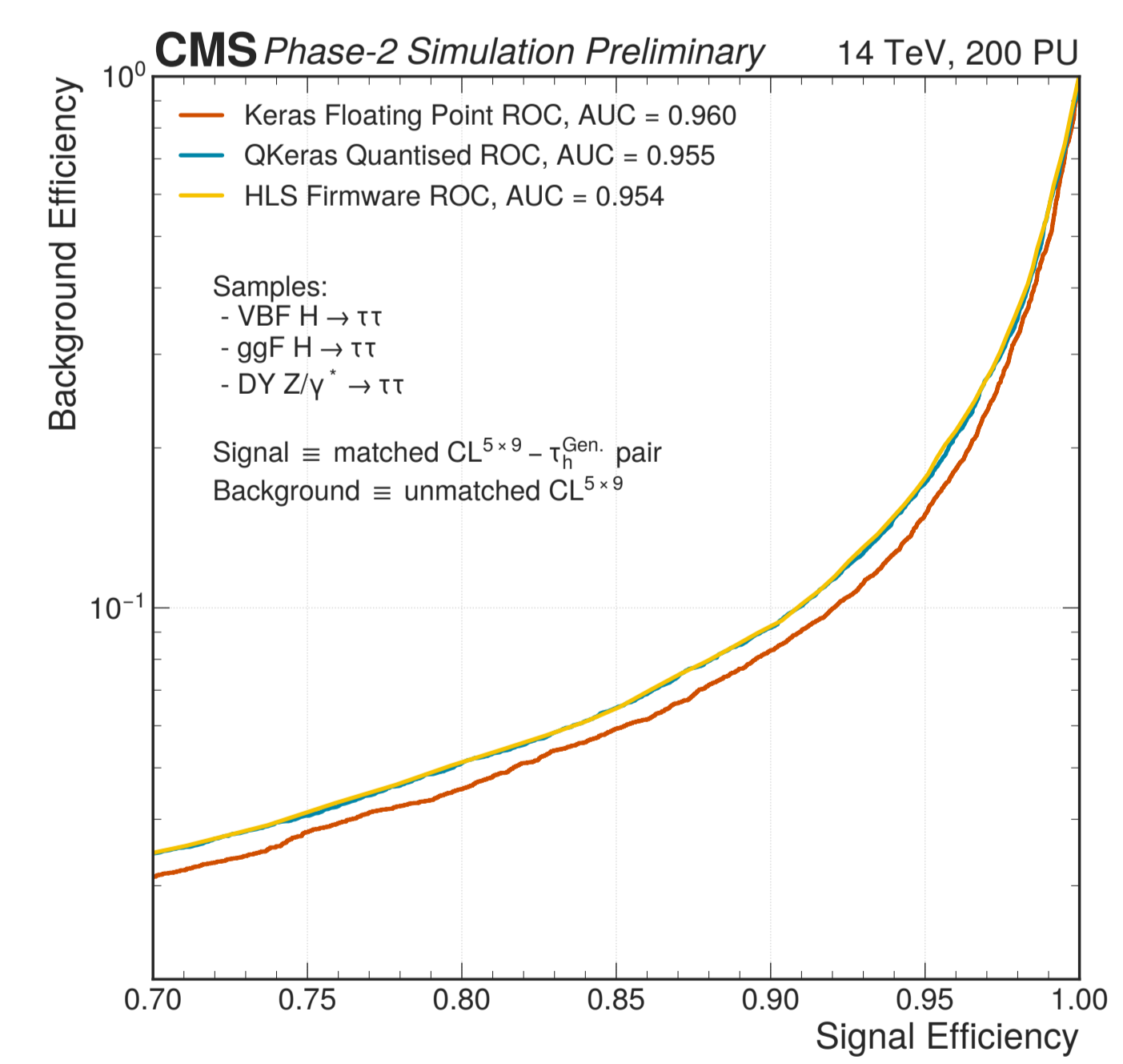
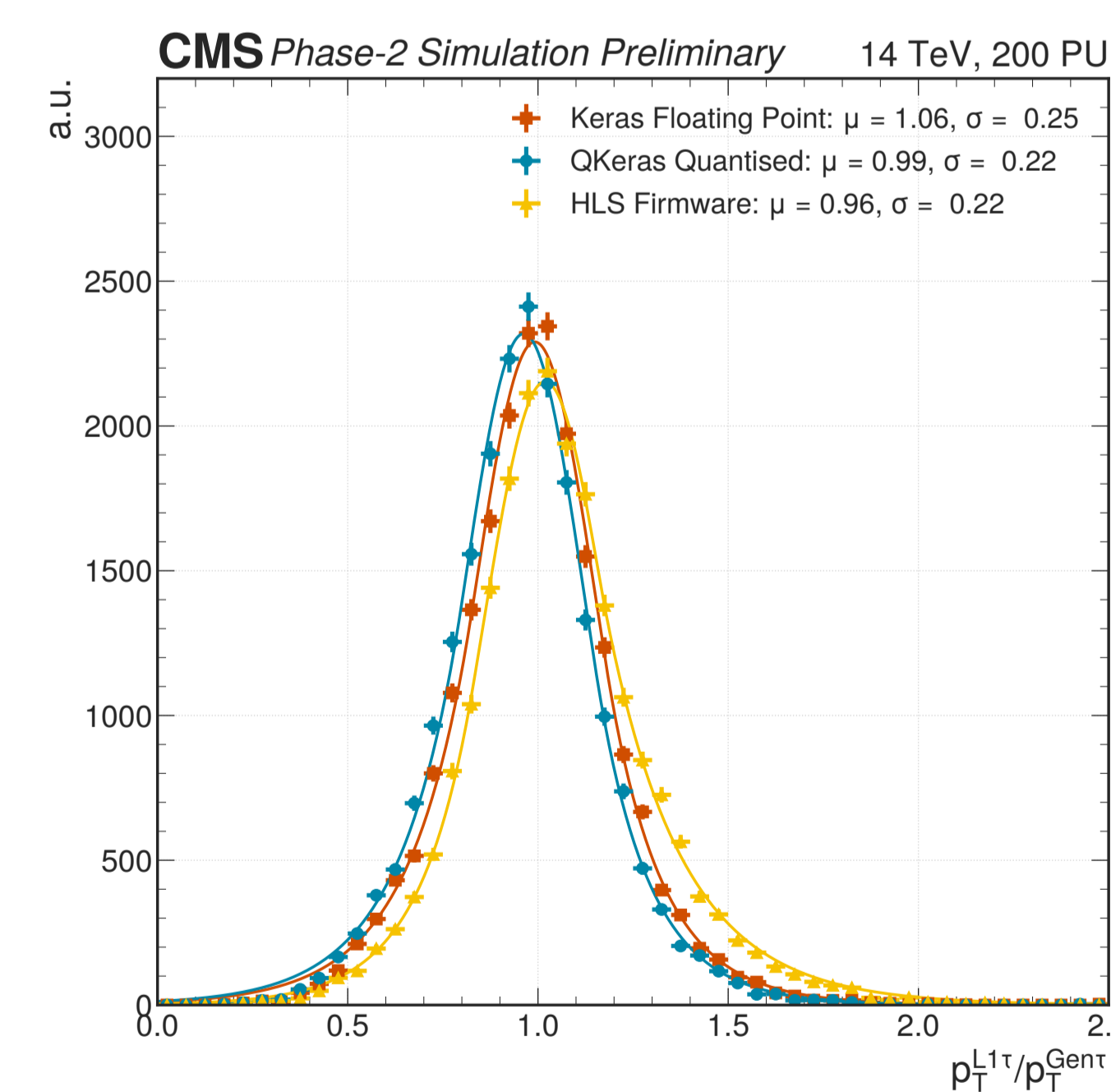
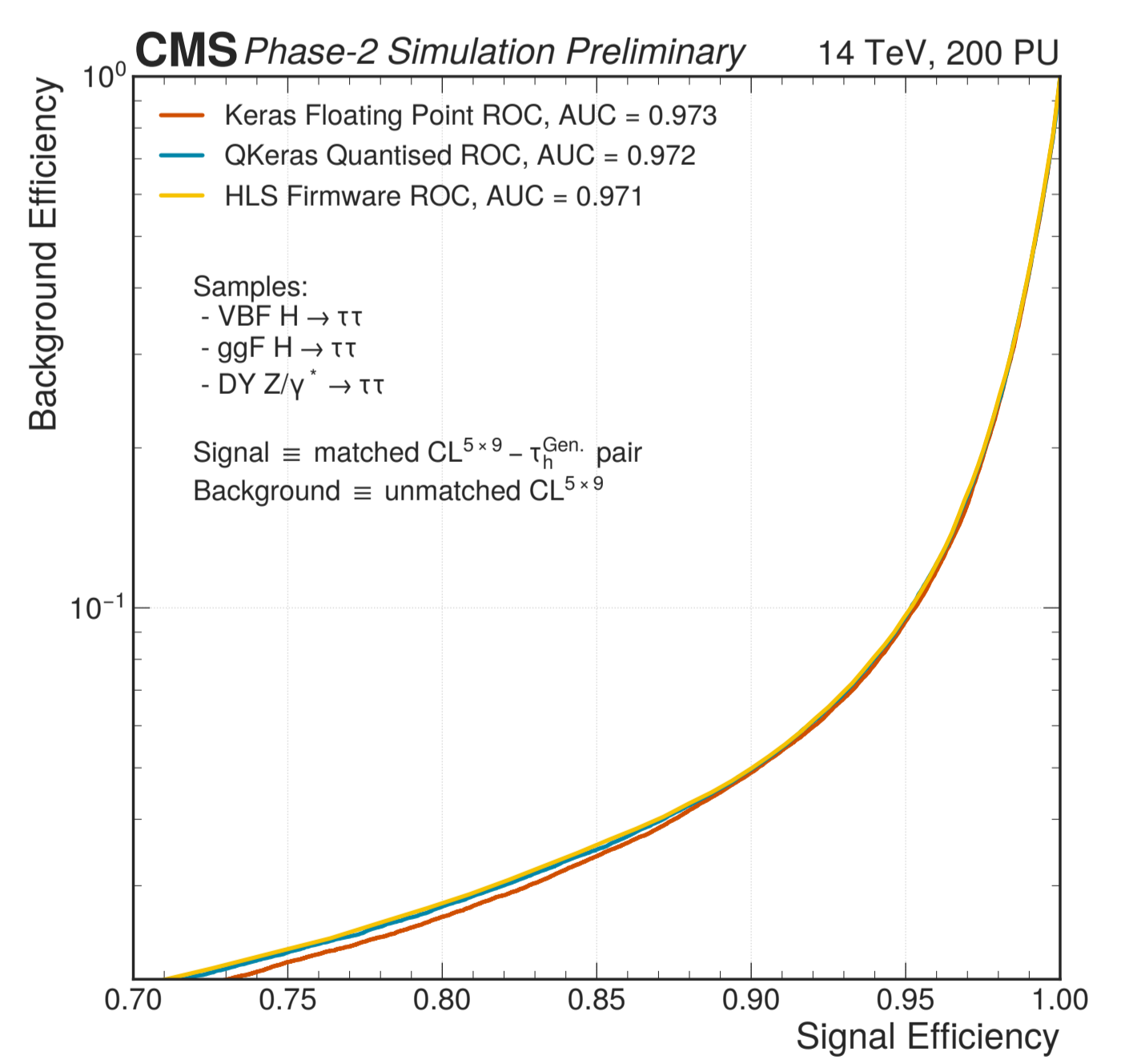
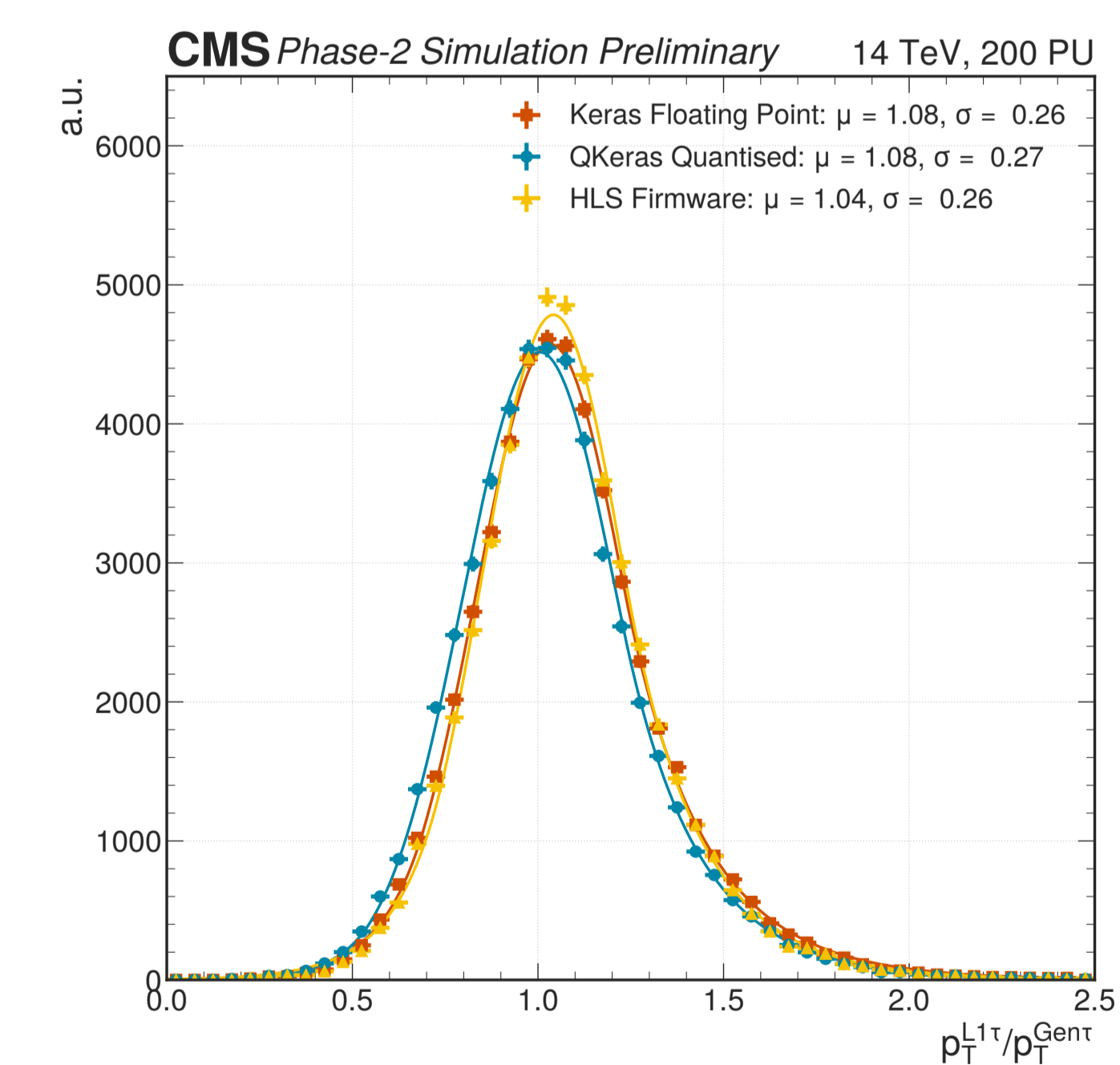


Resources in VU13P

	LUT	FF	BRAM	DSP	II [ns]	Lat. [ns]
Shared Convolutional NN	1.07%	0.48%	0.00%	0.00%	22.2	55.6
Identification Dense NN	0.40%	0.09%	0.02%	0.17%	2.78	30.6
Calibration Dense NN	1.68%	0.39%	0.00%	3.28%	2.78	38.9

Resources in VU13P

	LUT	FF	BRAM	DSP	II [ns]	Lat. [ns]
Shared Convolutional NN	1.06%	0.40%	0.00%	0.00%	22.2	55.6
Identification Dense NN	0.53%	0.03%	0.02%	0.16%	2.78	27.8
Calibration Dense NN	1.22%	0.11%	0.00%	0.44%	2.78	27.8



TauMinator performance

- ▶ τ_h challenging object → innovative CNN approach
- ▶ Phase-2 L1T powerful FPGAs → modest resources usage
- ▶ Steep efficiency onset & 98/99% plateau
- ▶ 37% reduction of single- τ_h rate at $p_T^{off.} > 150$ GeV
- ▶ 21% reduction of double- τ_h rate at $p_T^{off.} > 90$ GeV → 40(35)% improvement in barrel(endcap)

