EuCAIFCon, 19.06.2025
Advancing the CMS Level-1 Trigger: Jet Tagging with DeepSets at the HL-LHC

Sioni Summers, Christopher Brown,
Sebastian Wuchterl, Duc Minh Hoang, **Stella Schaefer**
for the CMS Collaboration

NexTGen
Next Generation Triggers

L1 Trigger - rate reduction through event rejection

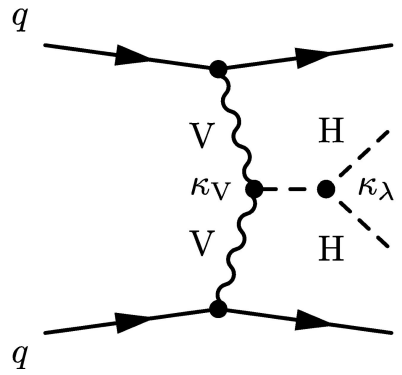
Phase-2 (High-Lumi LHC):

- **Currently: 60 Pile-Up (PU) → Phase-2: up to 200 PU**
- **Tracking information**

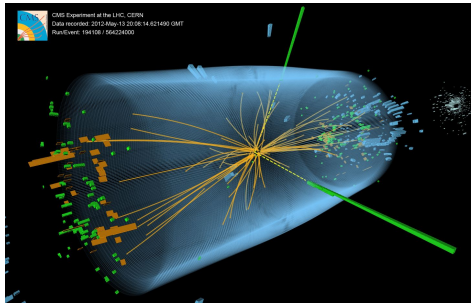
➔ **New seeds / algorithms necessary**

Requirements:

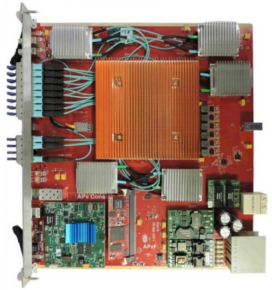
- **Fast (12.5 µs)**
- **Run on FPGAs**



Collisions



40 MHz



L1 Trigger

750 kHz
(before 100 kHz)

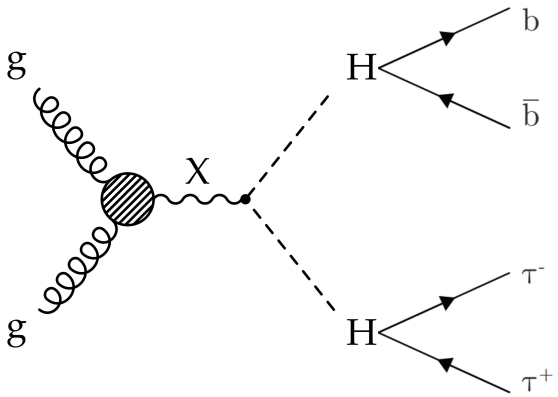
HLT

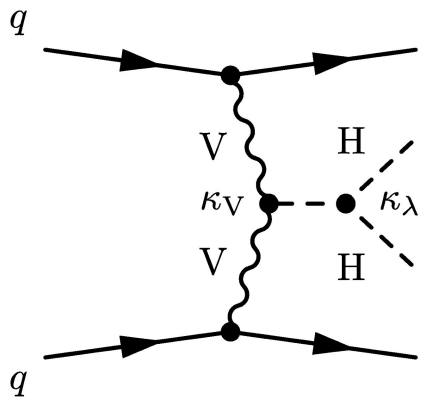
7.5 kHz

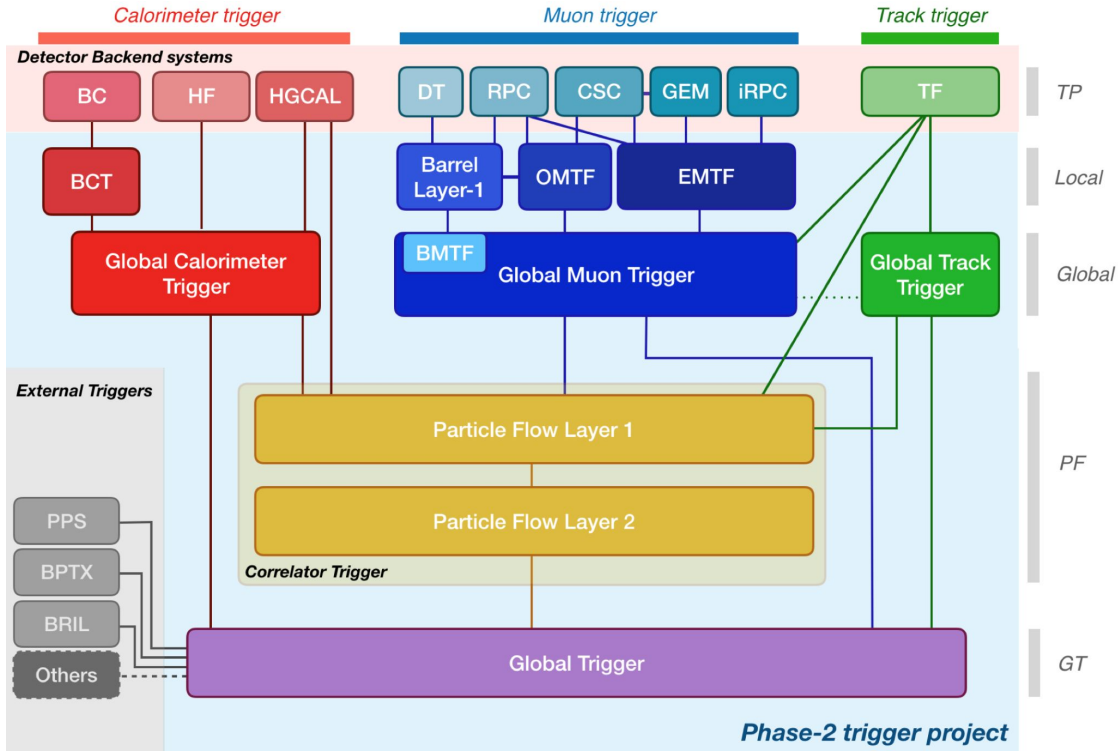
Offline Reco

Jet Tagging at L1

- Reconstruct up to 16 jets per event at L1
- Jet tagging to identify flavour
- Helps identify important physics processes, e.g:
  - Di-Higgs
  - Vector boson fusion (VBF)
- Implementation in correlator trigger







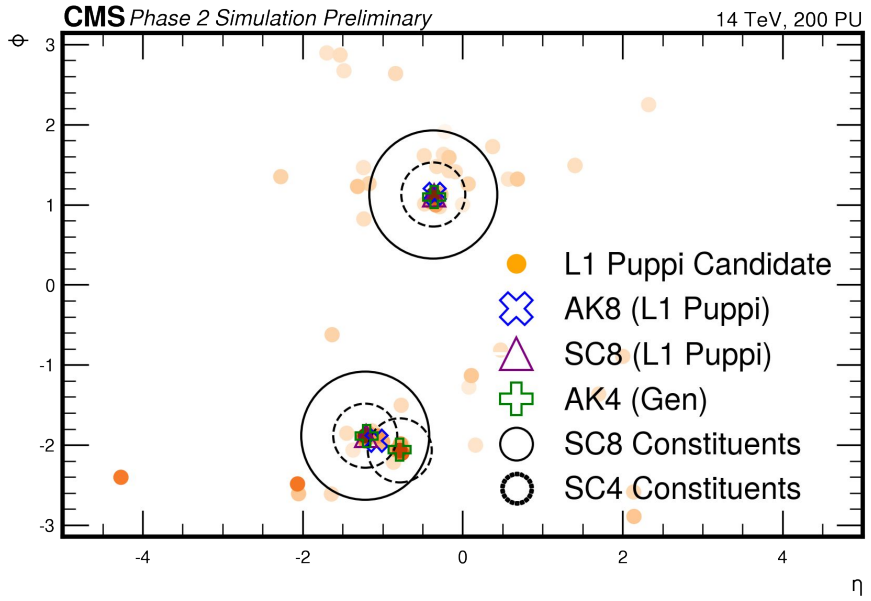
Jet Tagging at L1 so far

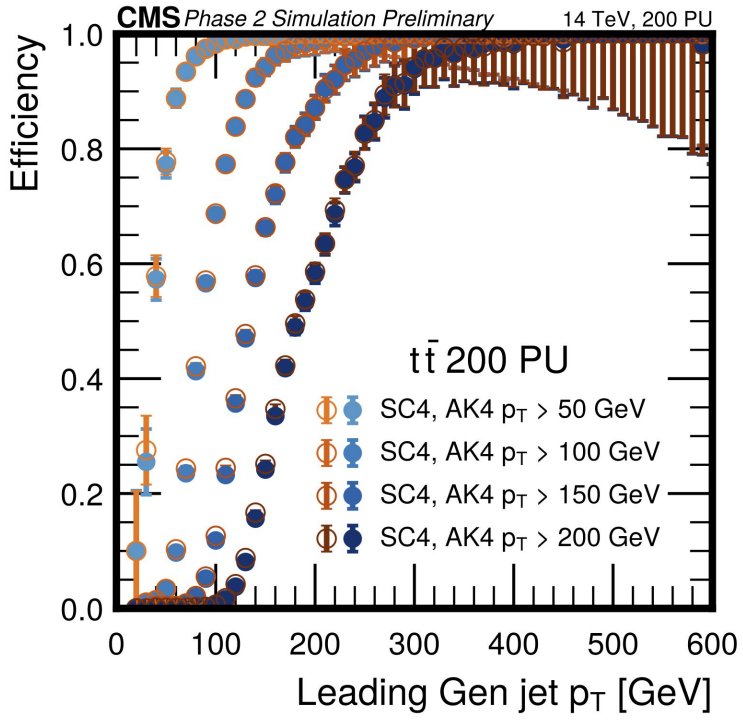
- No tagging in current data taking (at L1)
- b / τ tagging developments for Phase-2
  - Individual binary classifiers (CMSSW btag / NN Puppi Tau)

➔ Jets from Seeded Cone (SC) algorithm

➔ SC performance similar to anti-kt

➔ Tagging possible with constituents!

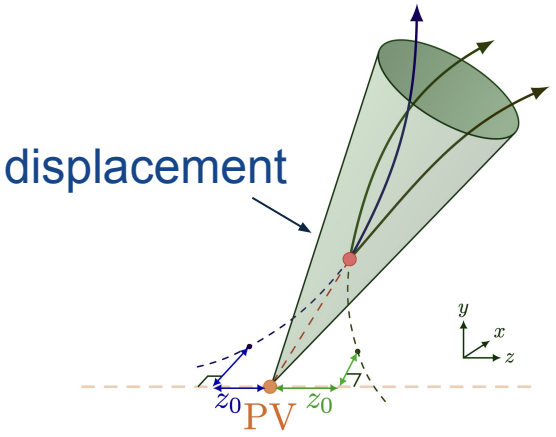


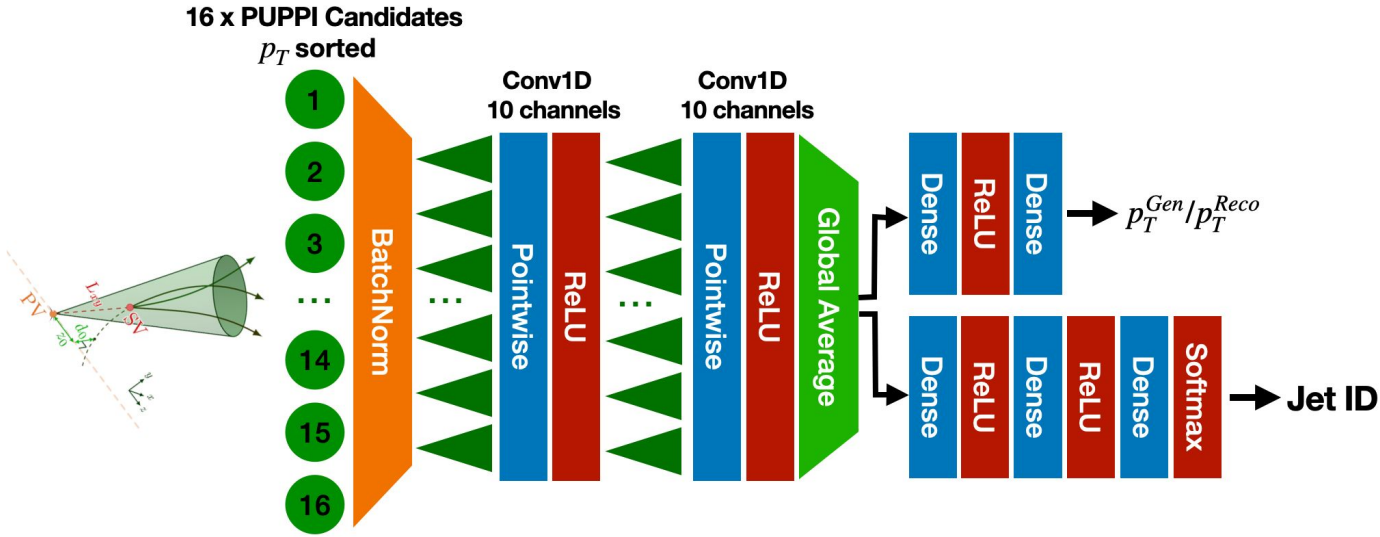


New Jet Tagging Strategy for Phase-2

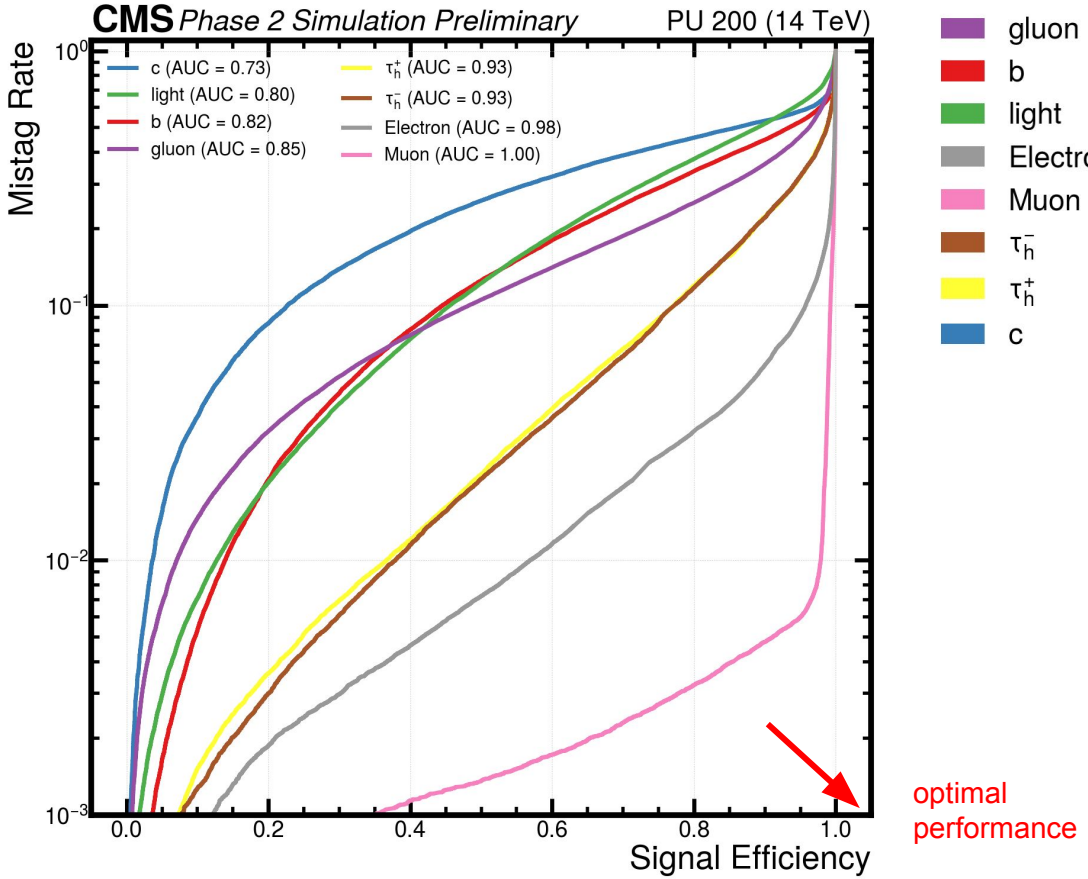
- Multiclass model for
  - Flavour tagging (b, c, light, gluon, τ +/- , e, μ)
  - p_T regression
- 16 leading p_T constituents (of SC Jets)
- Inputs: kinematic, particle IDs (PIDs), “record filled”
  - record filled to flag padded constituents
- Trained on a mixture of physics samples
  - Displaced tracking helps classification
- Small, quantized model necessary
- Investigation of different architectures
- Compromise
  - performance vs. latency/resources

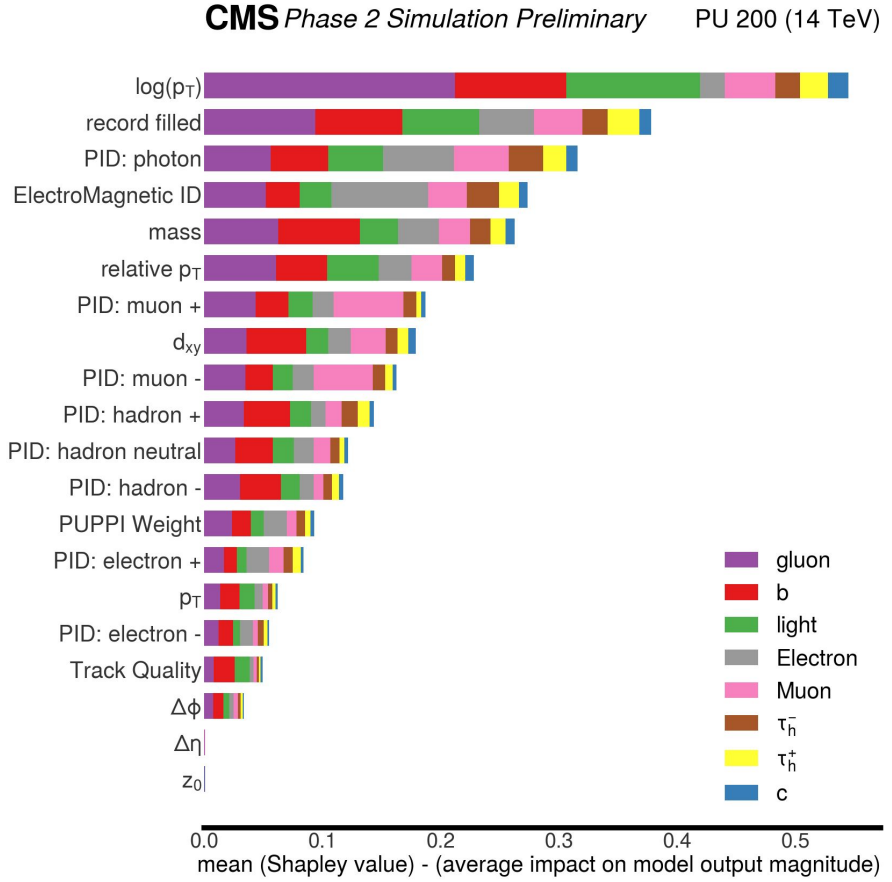
➔ Deep Sets





Results



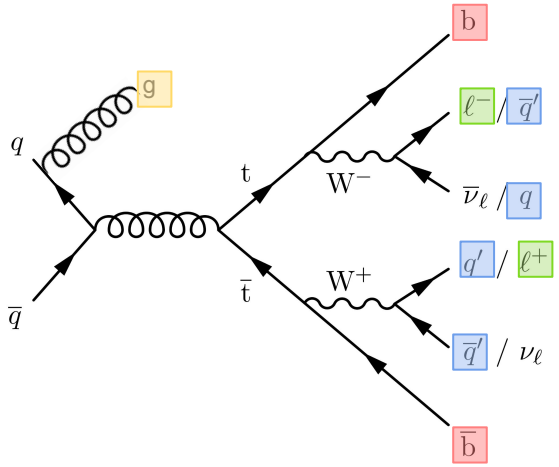


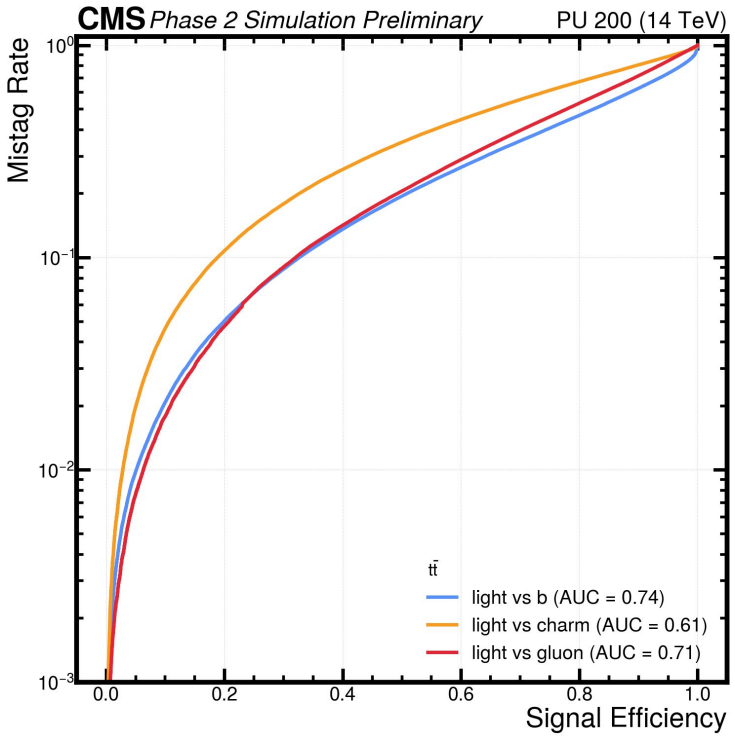
Full results overview for [multiclass jet tagging]

Jet classification on $t\bar{t}$ process

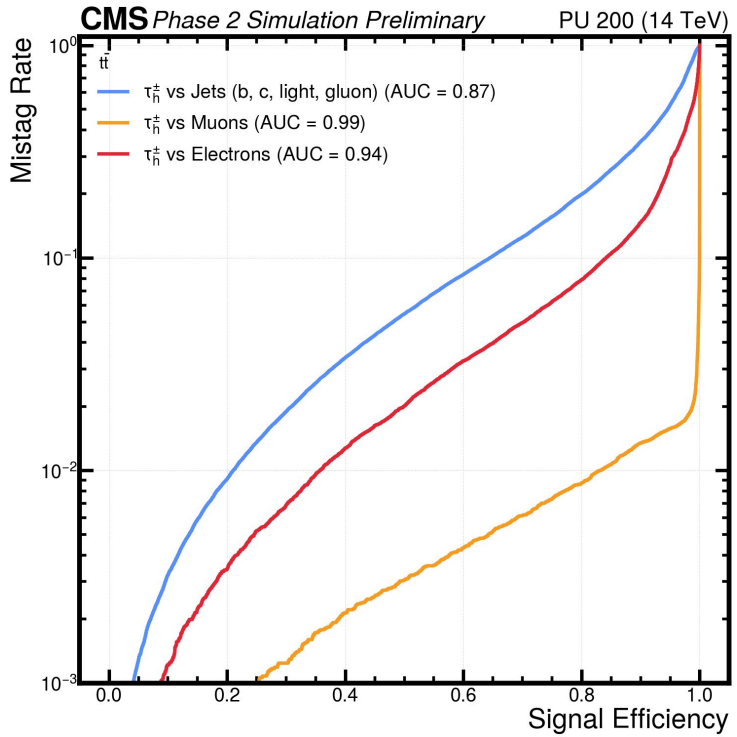
$t\bar{t}$ process:

- **always includes b jets**
- **can include:**
  leptons (e, μ, τ) &
  gluon, light, charm jets





light vs b, charm, gluon



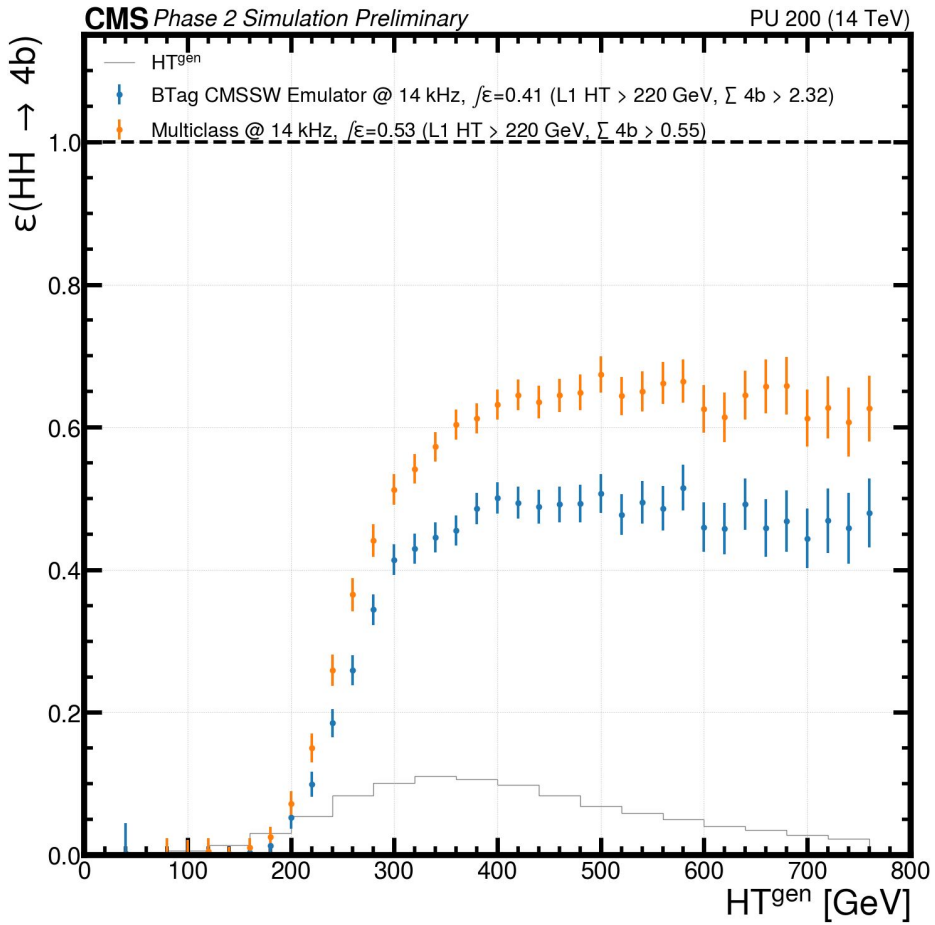
τ vs jets, muons, electrons

➔ **Important one vs. one classifiers: eg. light vs. gluon for VBF, b vs. light for Higgs decay, …**

Process Identification using Jet Tagging: Di-Higgs

Identification of HH → 4b

- Binary b tagging + H_T (220 GeV)
- Multiclass jet tagging + H_T (220 GeV)
- Comparison at same rate ie.: number of selected events
- Overall gain in efficiency
  - important gain in low H_T

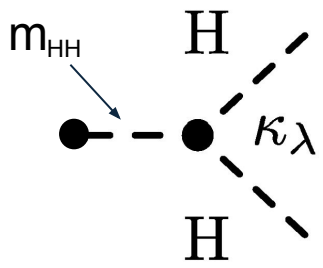


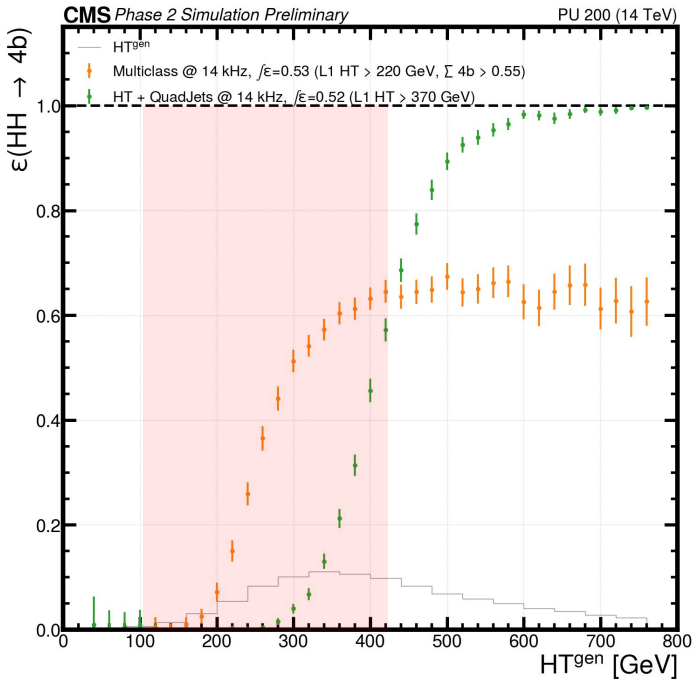
Process Identification using Jet Tagging: Di-Higgs

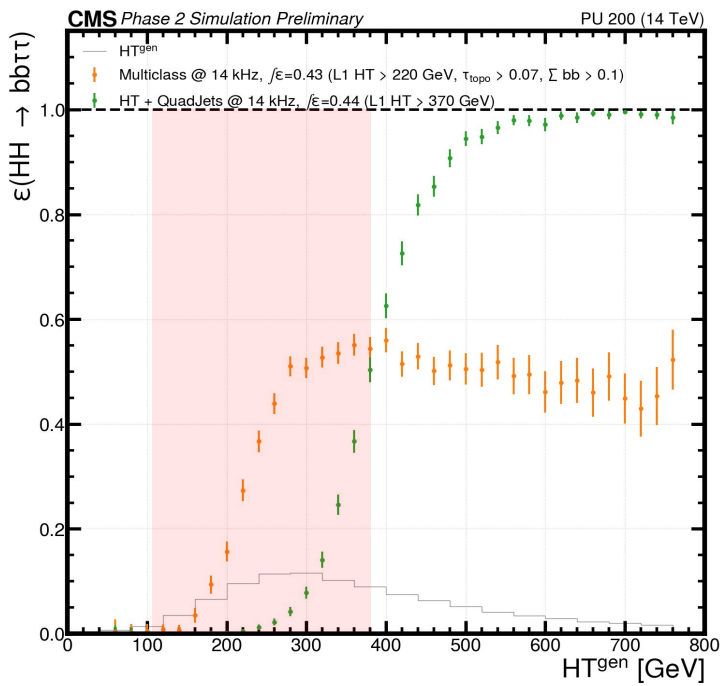
Identification of HH → 4b / bb$\tau\tau$

- Before: No tagging (H_T threshold)
- Multiclass jet tagging
  - Lower fixed H_T threshold
- Significant gain for low
  - H_T ($=\Sigma p_T$)
  - Invariant mass m_{HH}

➔ Optimum: Multiclass OR H_T







FPGA implementation

✅ **Latency and Initiation intervals compatible with L1**
- 148ns (NN) + 86ns (Input preparation) latency taking input at 360 MHz

✅ **NN architecture fits AMD Xilinx VU13P-2 FPGA**

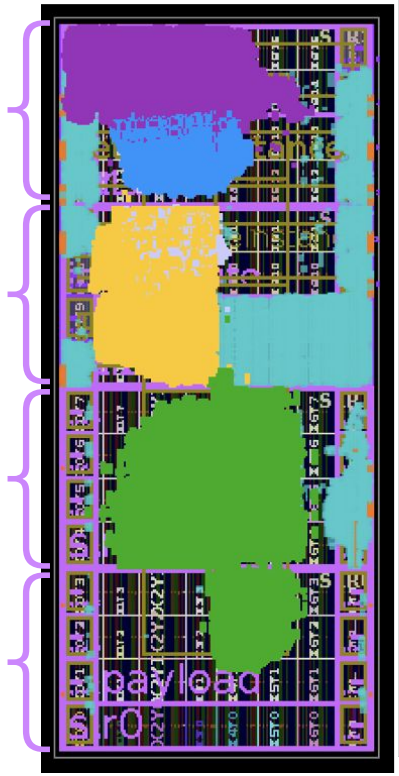
✅ **Firmware results match bit-to-bit with CMS simulation software**

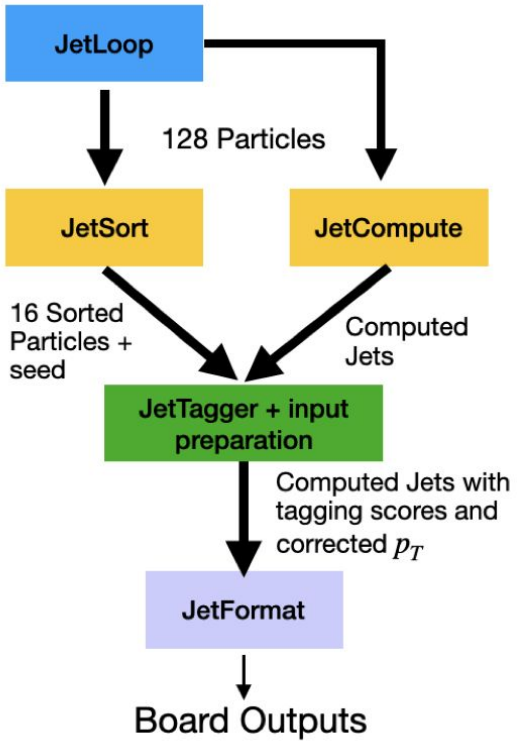
	II (clock)	Latency	BRAM	DSP	FF	LUT	URAM
Jet Tagger	1	148 ns	0	52	51	107	0
Input Preparation	1	86 ns	3	10	27	29	0

Resources % SLR

VU13P-2

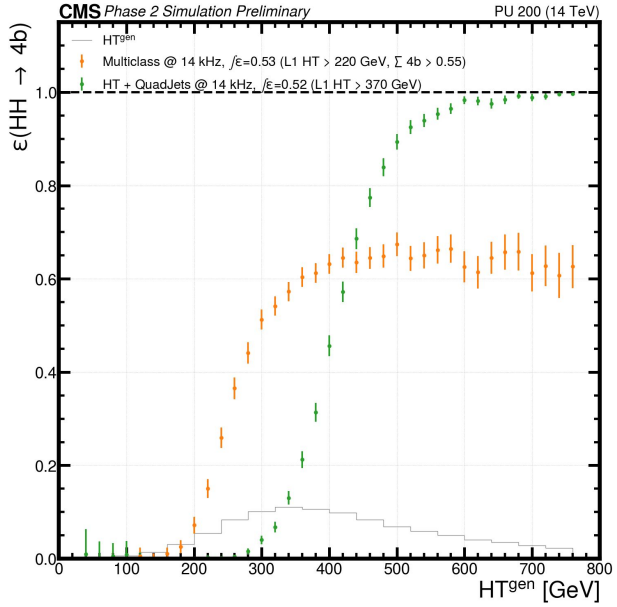
4 SLRs





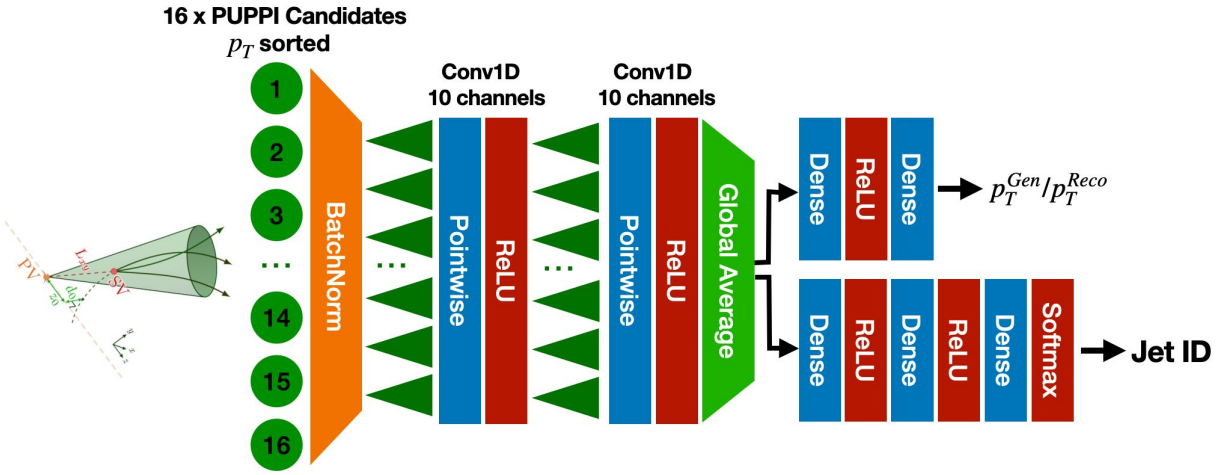
Summary + Outlook

- Triggers for di-Higgs, VBF, …
  - Extensive jet descriptions necessary
- Deep Sets Multiclass Tagger
  - Compromise of performance and latency / resources
- Significant b-tagging improvements
  - eg. ~30% improvement for HH → 4b
- First time quark vs. gluon tagging at L1

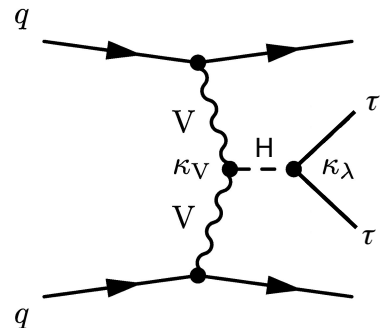


Plans:

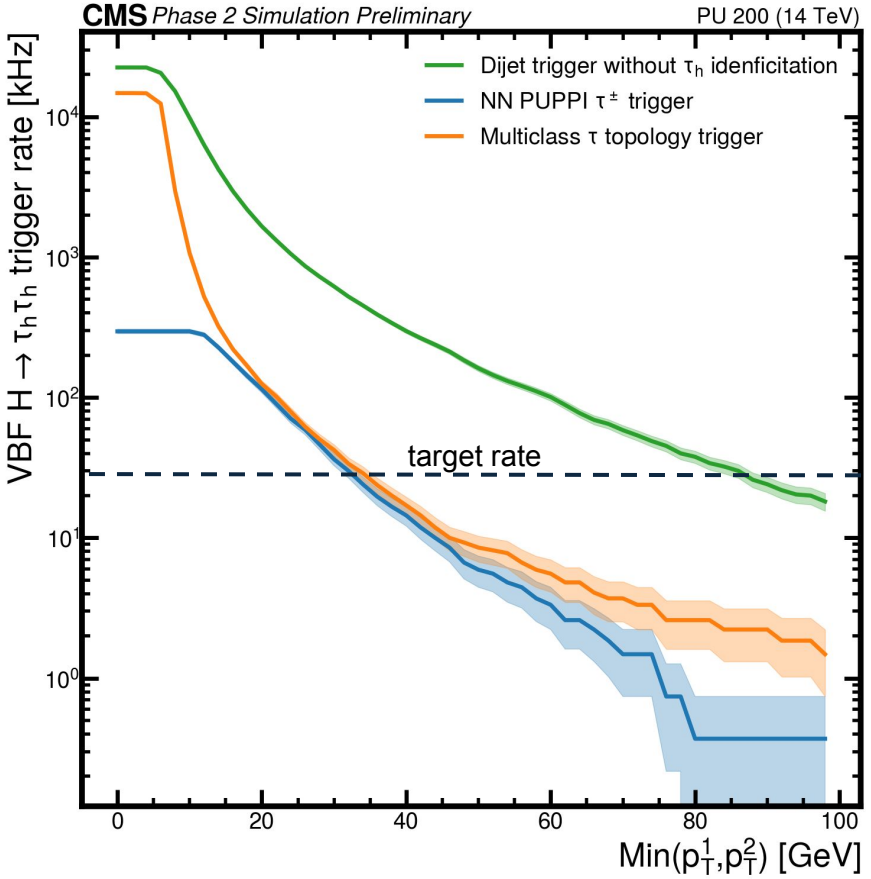
- Masking to remove padding
- PU classification to reject PU objects
- Jet-level features to help classification
- Improve jet energy regression



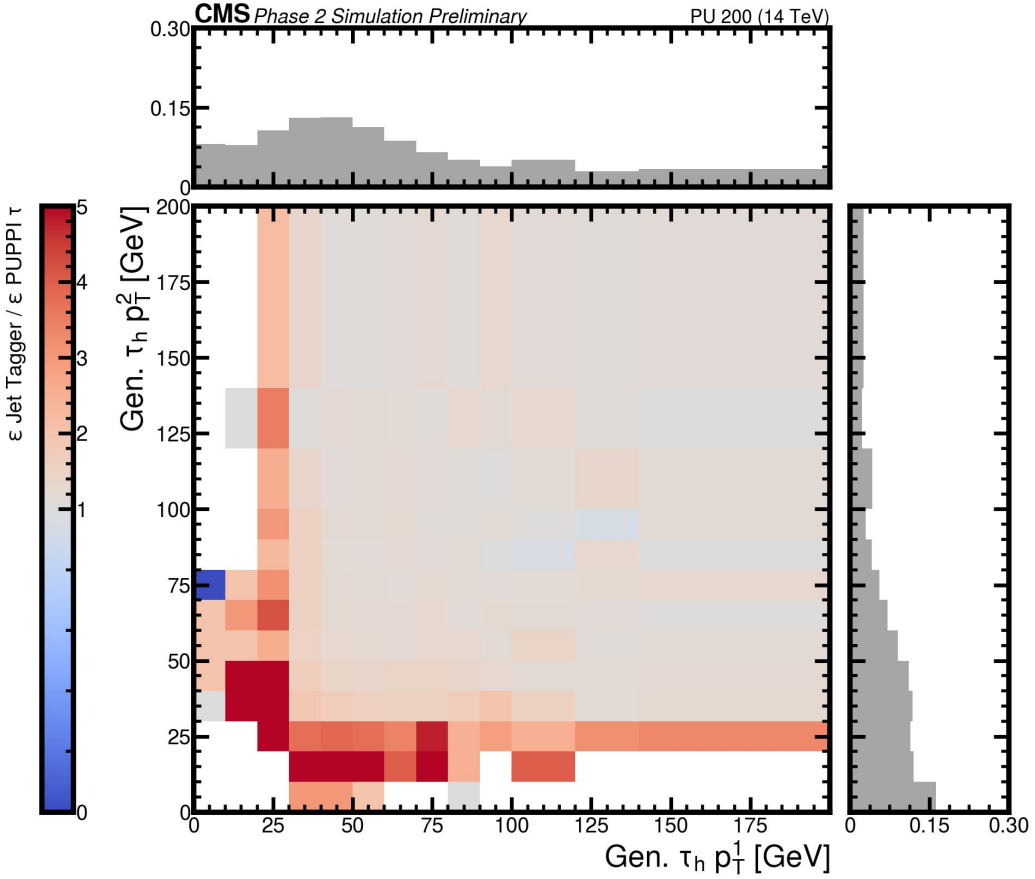
Process Identification using Jet Tagging: VBF→H→$\tau\tau$



$$\tau_{topo} = (p^1_{\tau^-} + p^2_{\tau^-}) \cdot (p^1_{\tau^+} + p^2_{\tau^+})$$



Dijet trigger w.o. τ identification
NN PUPPI τ
Multiclass τ topo trigger



➔ **Yet to match NN Puppi baseline, but better at low τ p_T**

Process Identification using Jet Tagging: Di-Higgs

Identification of HH → 4b / bb$\tau\tau$

- Before: No tagging (H_T threshold)
- Multiclass jet tagging
  - Lower fixed H_T threshold
- Significant gain for low
  - H_T ($=\Sigma p_T$)
  - Invariant mass m_{HH}

➔ Optimum: Multiclass OR H_T