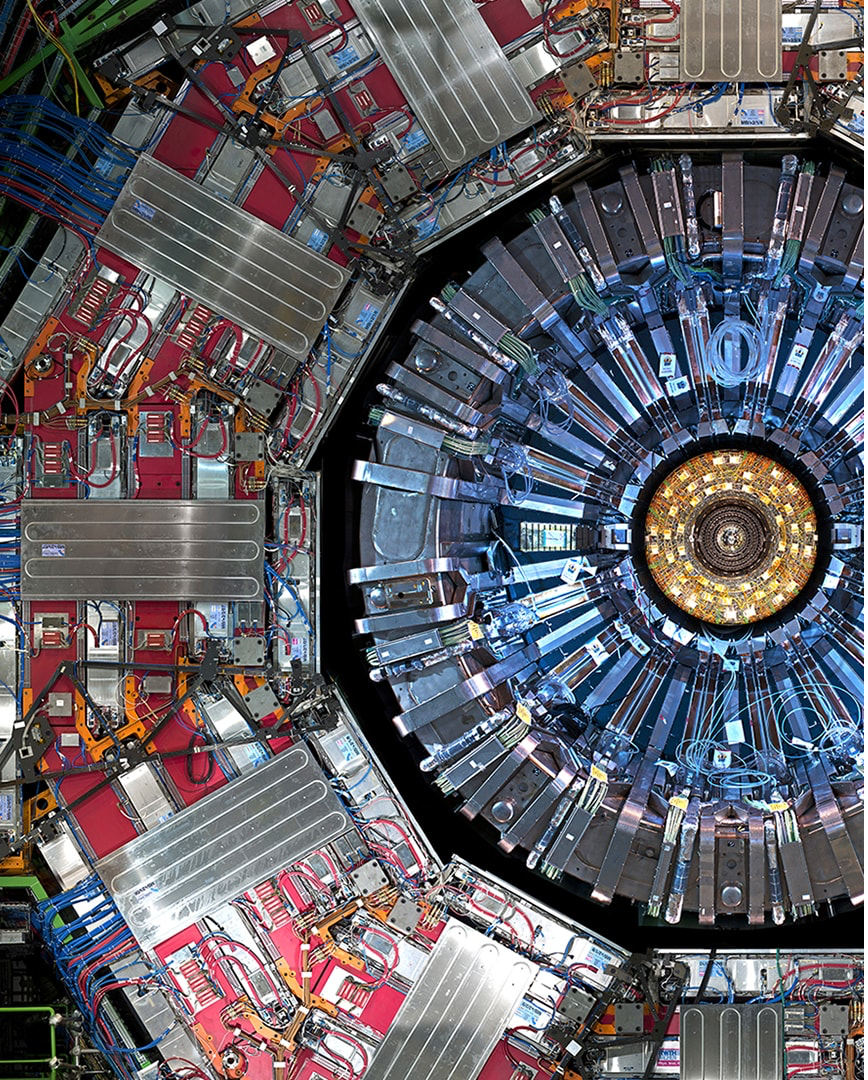


TOPOLOGICAL TRIGGER FOR HH PRODUCTION

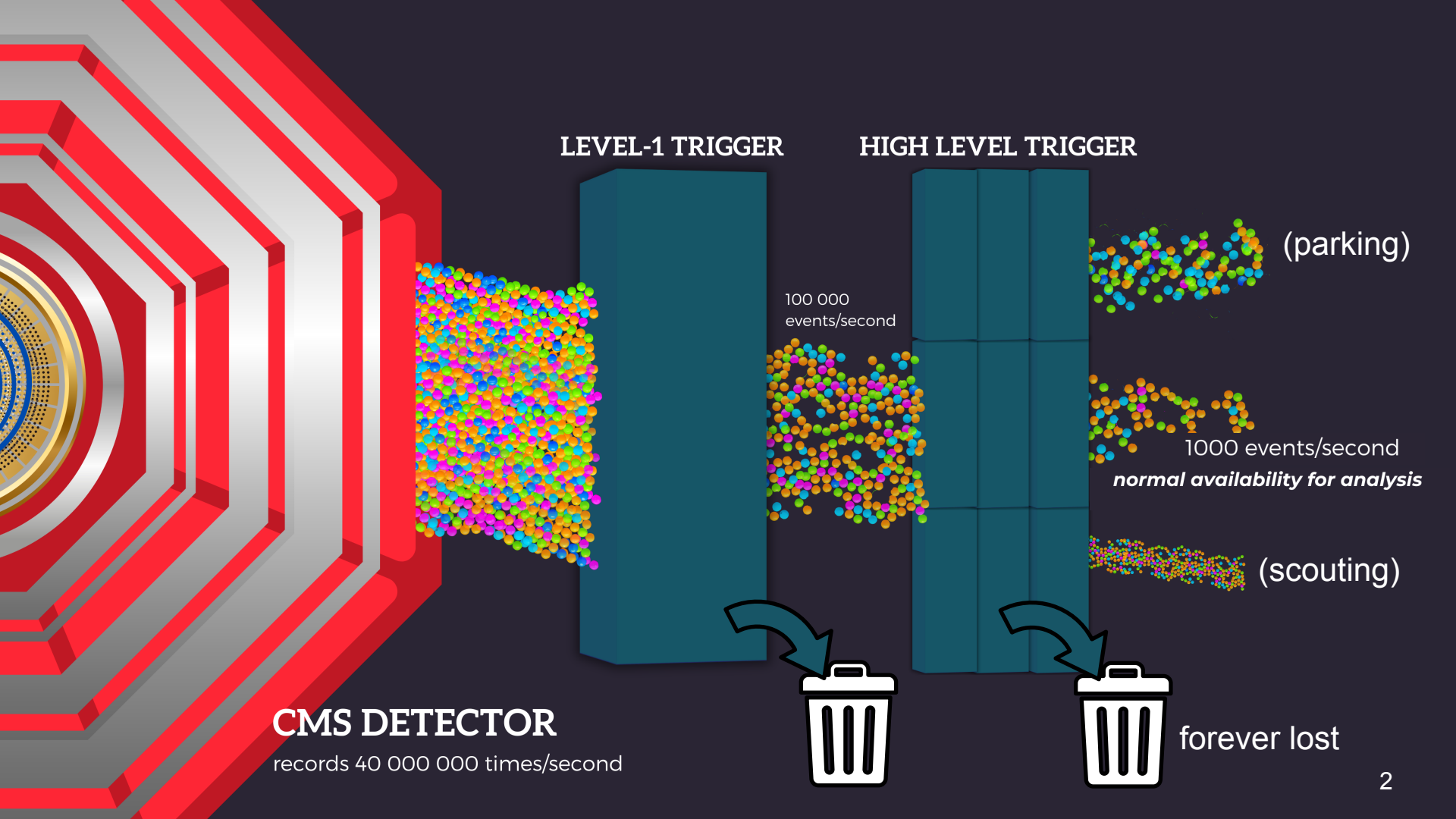
Lukas Ebeling, Johannes Haller,
Artur Lobanov, Matthias Schröder

FSP Erforschung von Universum und Materie

CMS

CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

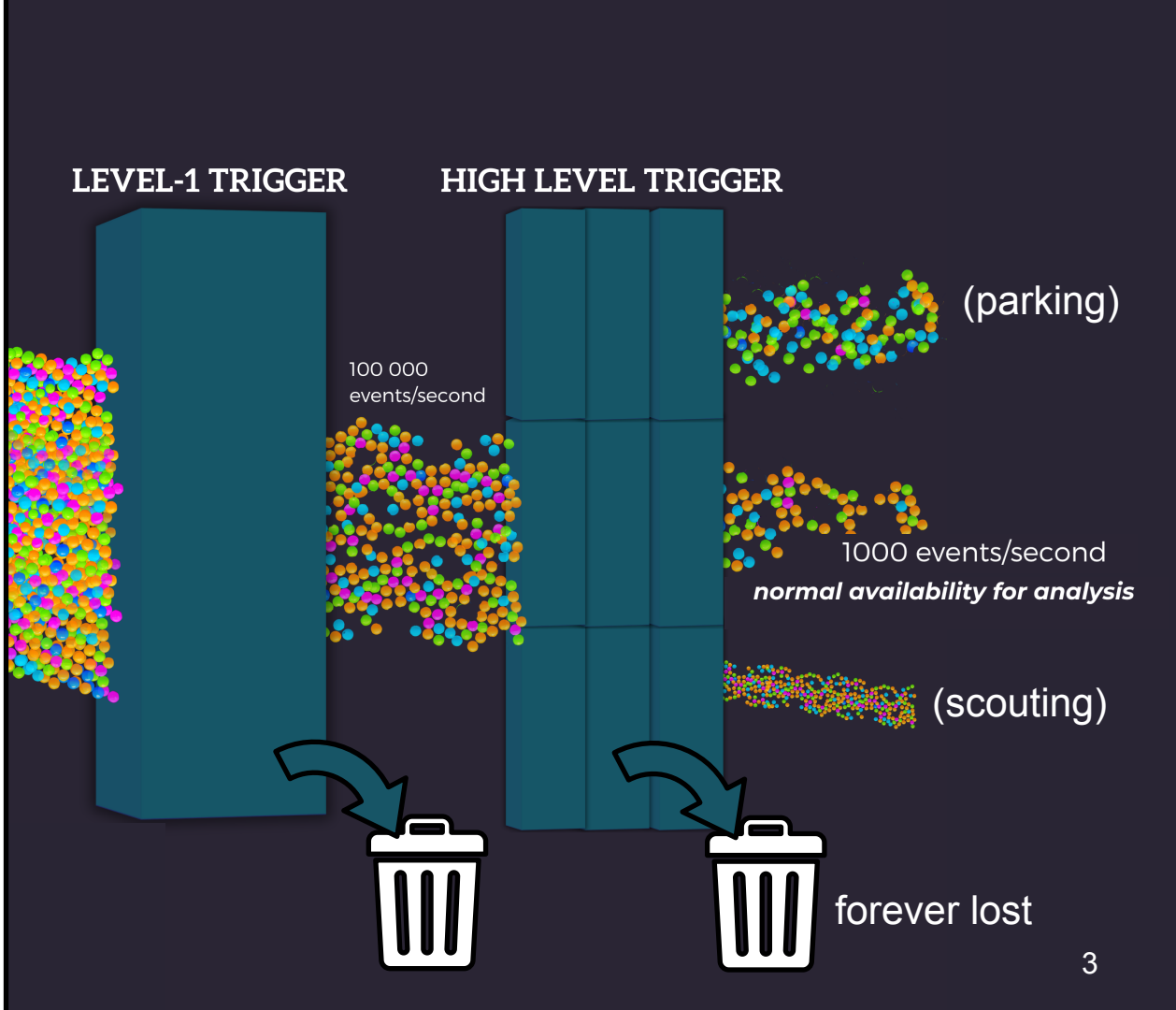

LEVEL-1 TRIGGER
HIGH LEVEL TRIGGER
100 000
events/second
(parking)
1000 events/second
normal availability for analysis
(scouting)
forever lost
CMS DETECTOR
records 40 000 000 times/second

level-1 trigger

- first filter: L1 trigger
- reduction by factor 400
- not triggered = lost

classic trigger algorithms cut on single object properties (e.g. momentum)

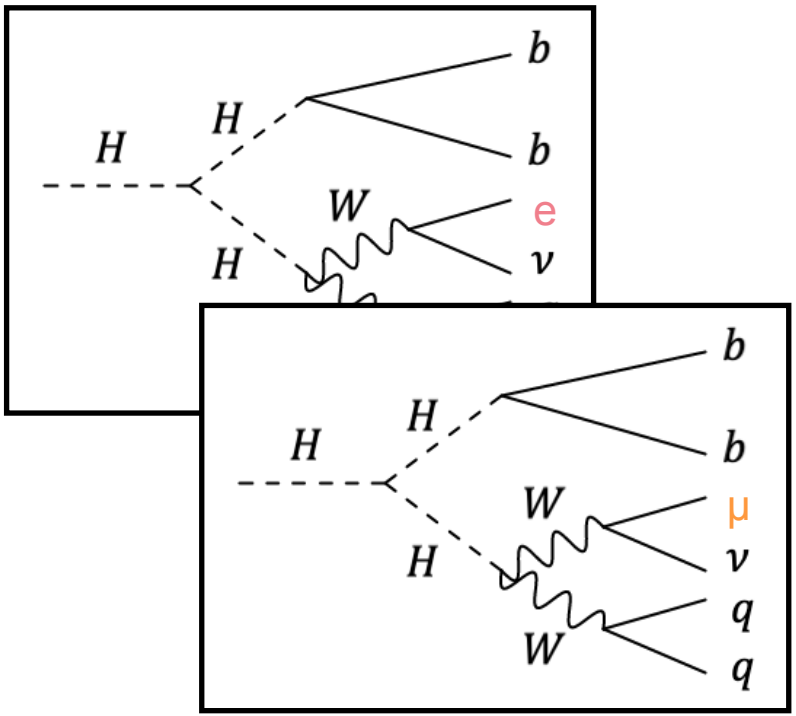
multivariate techniques optimally combine multiple object information



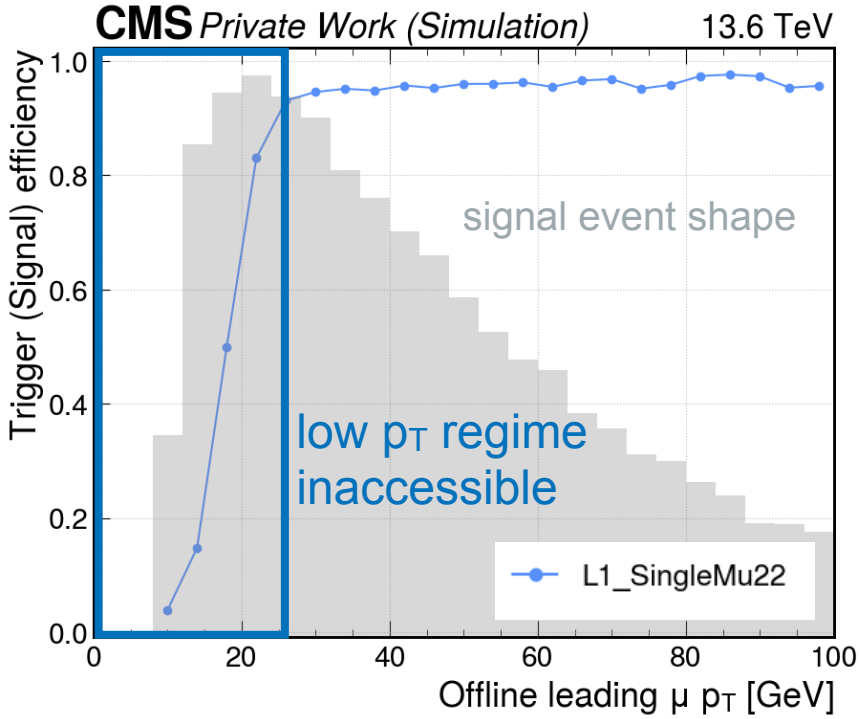
case study: search for HH production

(bbWW final state)

electron channel



muon channel

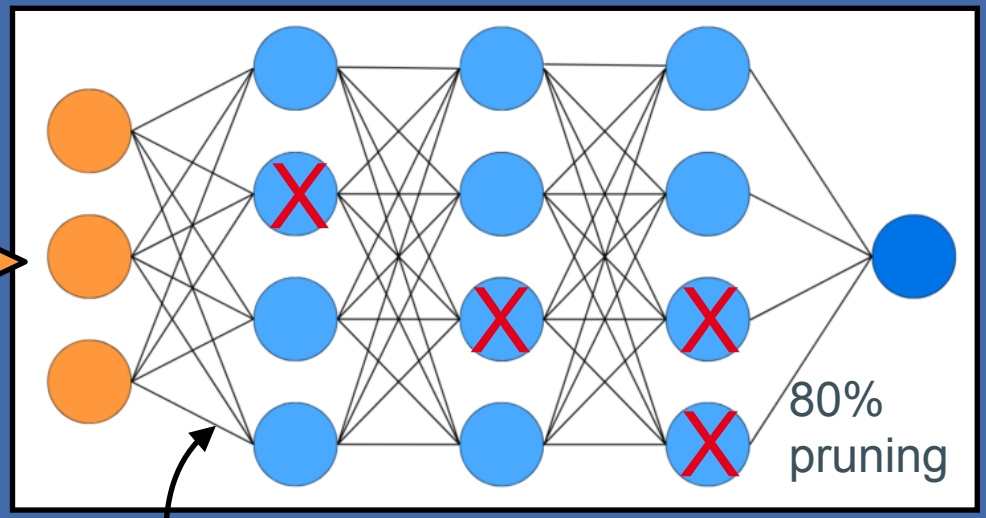


architecture – baseline

object	variable
L1 HT	pt, phi
L1 jets (x4)	pt, eta, phi
L1 EG/Mu (x2)	pt, eta, phi, iso

- feed-forward binary classifier
- cross-entropy loss function
- signal in training restricted to analysis phase space

nodes: 64 ⊕ 32 ⊕ 32



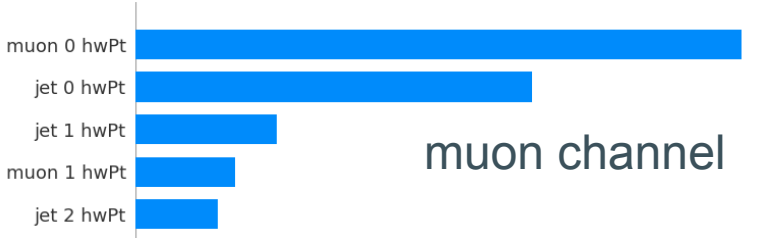
‘relu’ activation function

score ∈ [0,1]

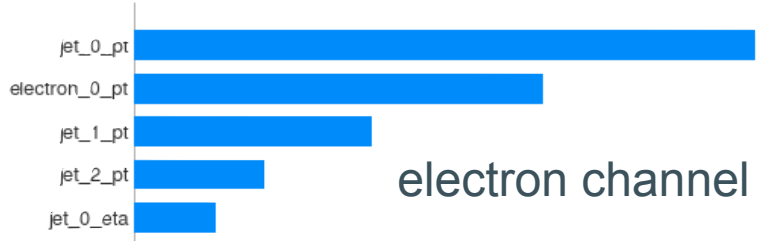
signal: HH(bbWW) simulation
background: minimal bias simulation

architecture – baseline

top 5 features:



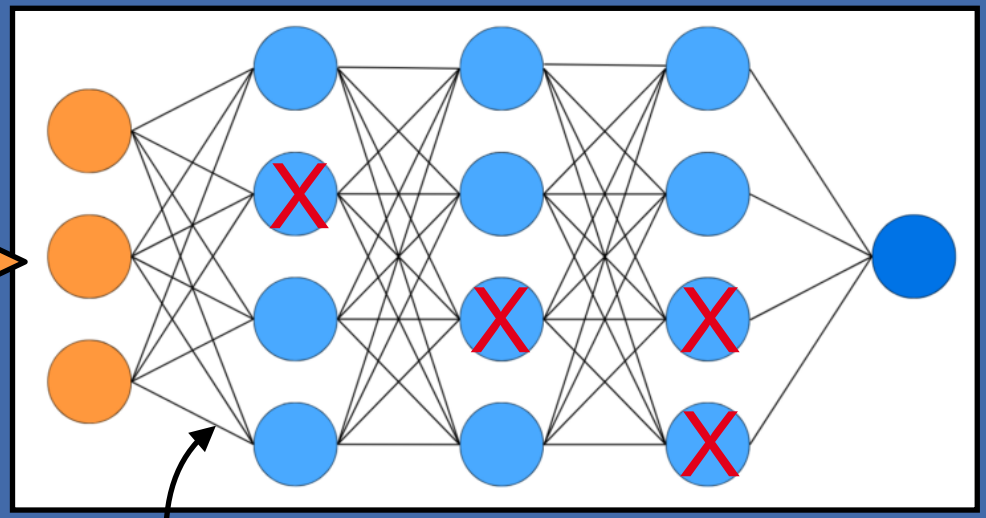
muon channel



electron channel

mean absolute SHAP value

nodes: 64 ⊕ 32 ⊕ 32

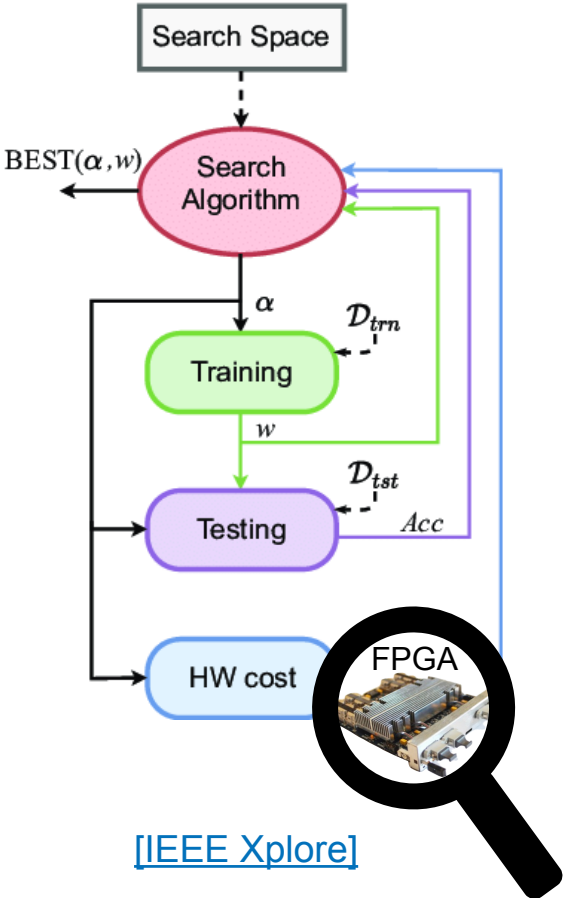


‘relu’ activation function

score ∈ [0,1]

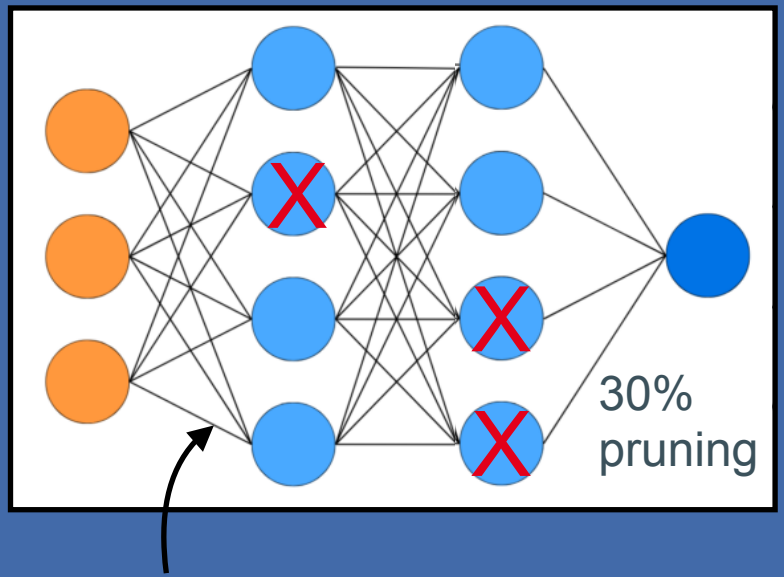
signal: HH(bbWW) simulation
background: minimal bias simulation

architecture – optimised
(electron channel)



[IEEE Xplore]

nodes: 128 ⊕ 32



score
∈ [0,1]

'relu' activation function

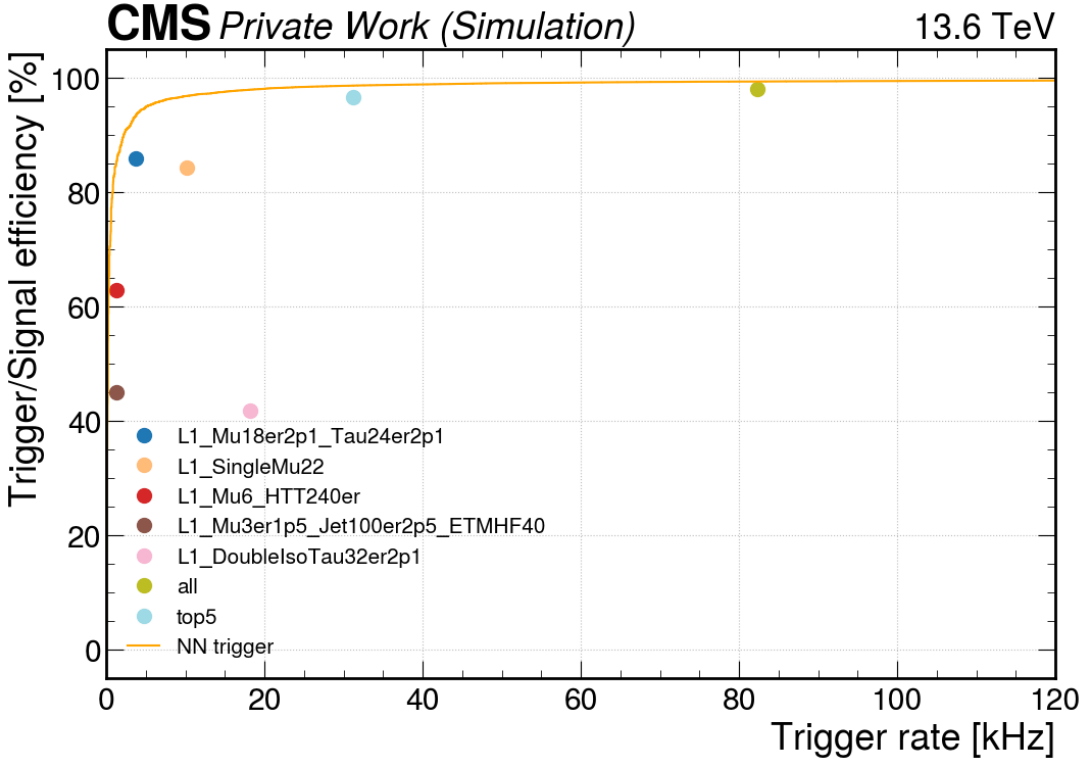
K. Kleinboelting, MSc thesis Uni Hamburg (2025)

topo vs. l1 menu

roc curve
scan network cutoff values

trigger rate
percentage of "minimal bias" events x collision rate

pure rate
percentage exclusively triggered by given trigger



topo vs. l1 menu

roc curve
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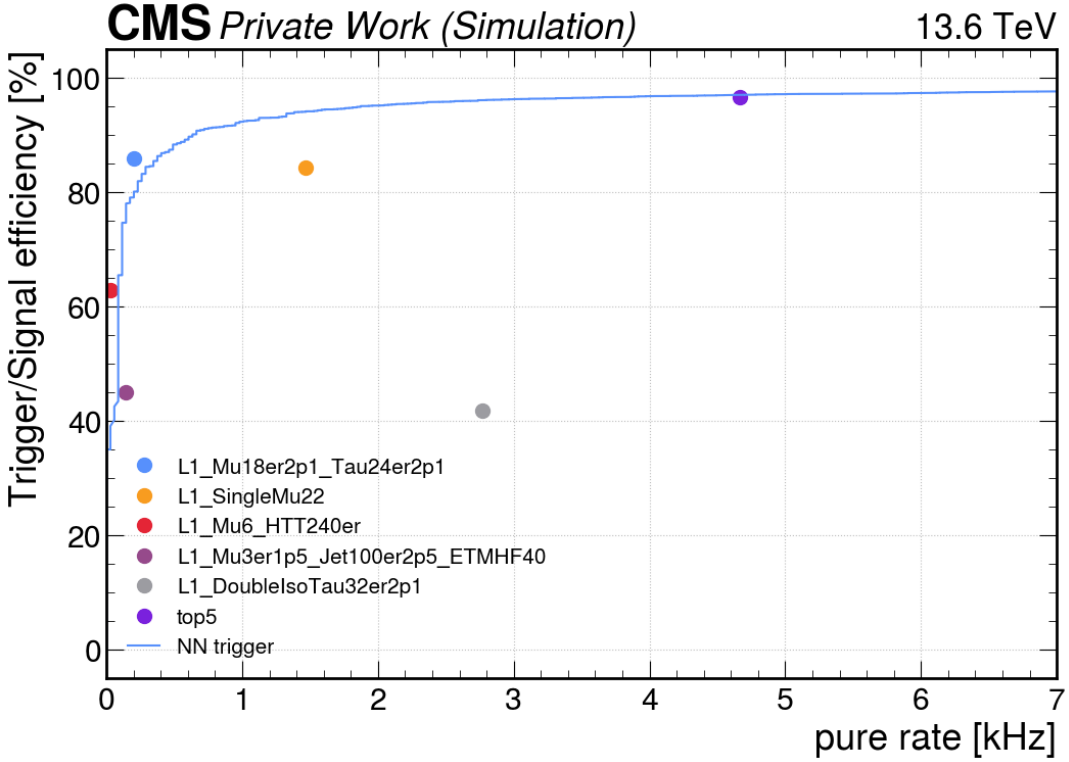
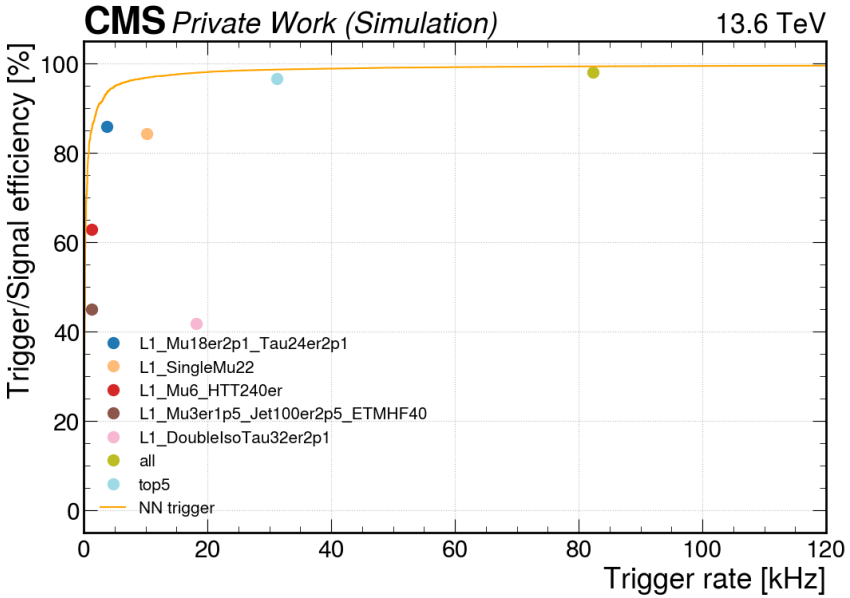
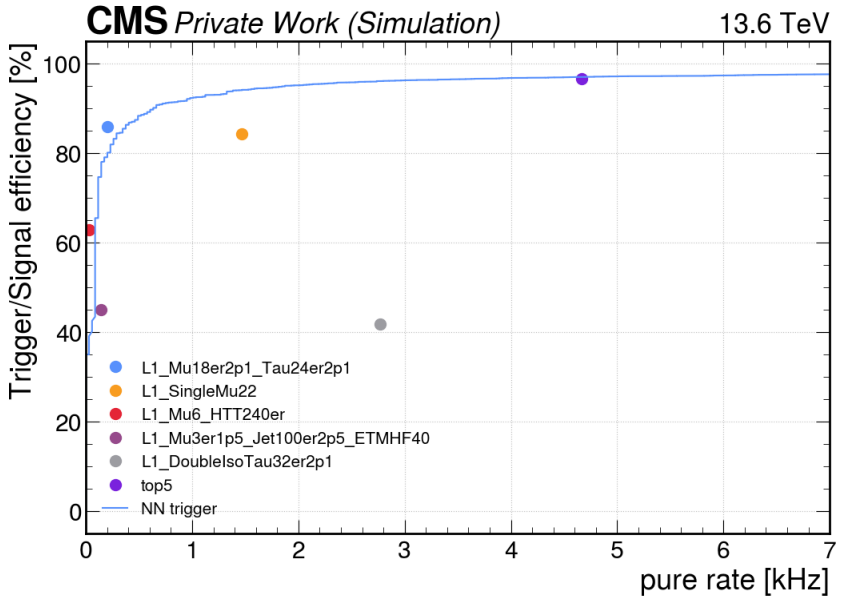


topo vs. l1 menu

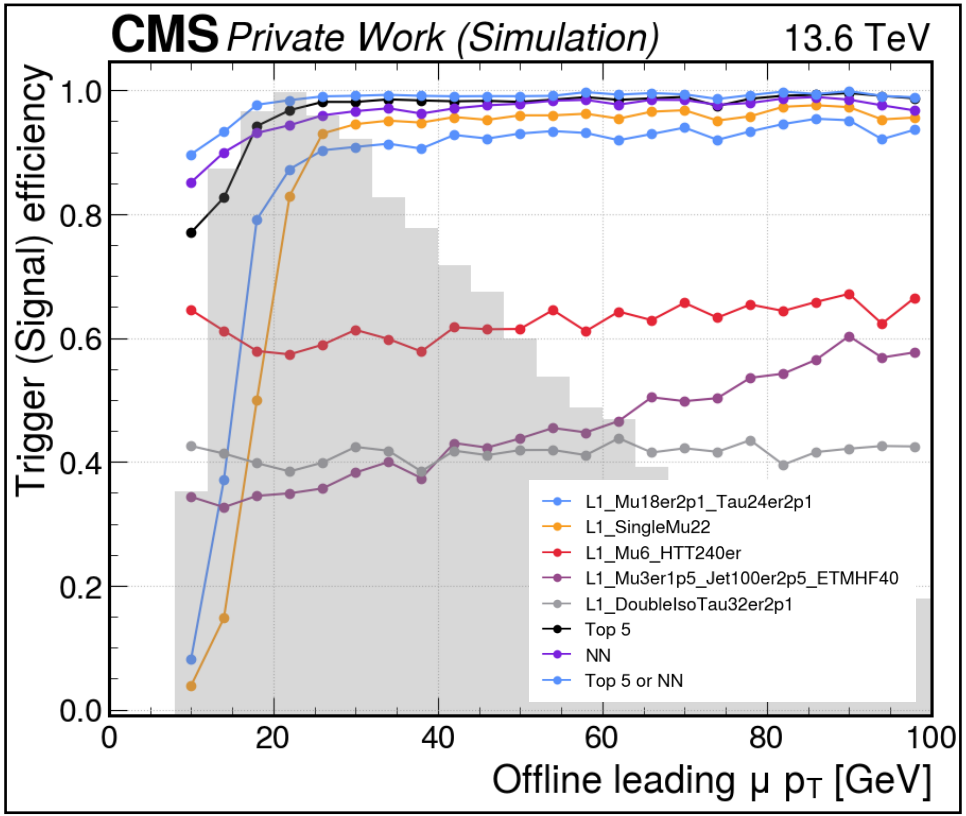


→ better performance than full menu combined



→ low cost: high efficiency, low impact on total L1 rate

low momentum phase space



top 5 + network (logical or)
top 5 (logical or)
neural network topological trigger
single muon trigger

single muon and HT

logic or: top 5
→ 95% efficiency at about **20 GeV**

logic or: top 5 + NN
→ 95% efficiency at about **16 GeV**

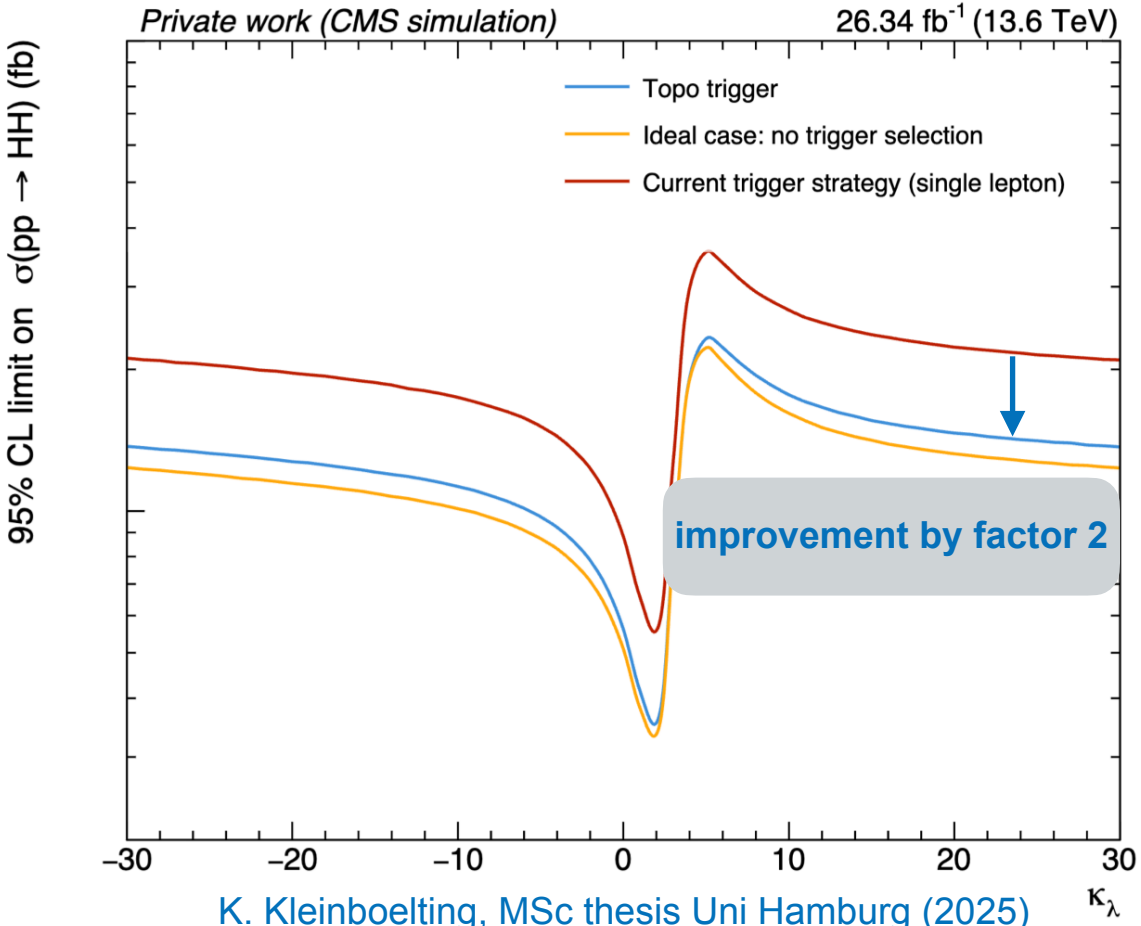
analysis impact

test in full analysis chain

current strategy
single lepton trigger path

topological trigger
assuming HLT is 100% efficient

perfect trigger
assuming 100% tigger efficiency / unlimited bandwidth



K. Kleinboelting, MSc thesis Uni Hamburg (2025)

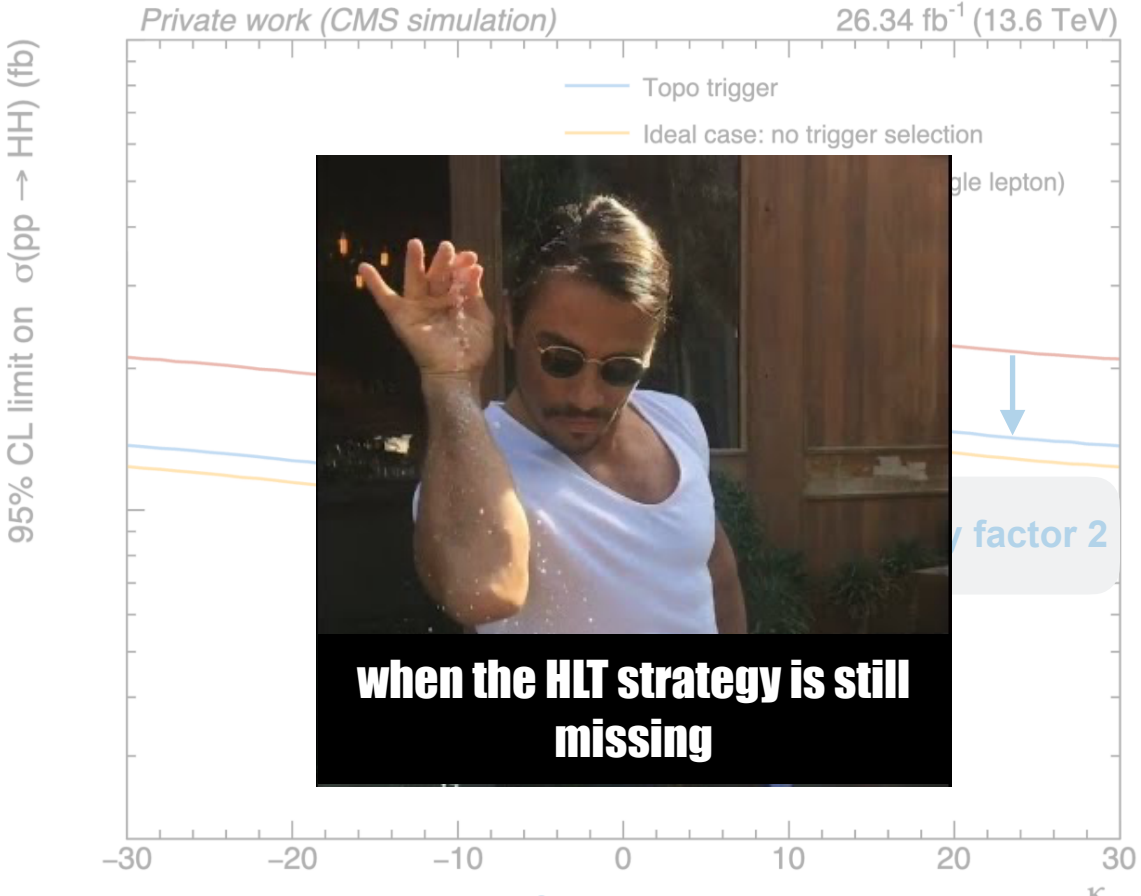
analysis impact

test in full analysis chain

current strategy
single lepton trigger path

topological trigger
assuming HLT is 100% efficient

idealised case
assuming 100% tigger efficiency



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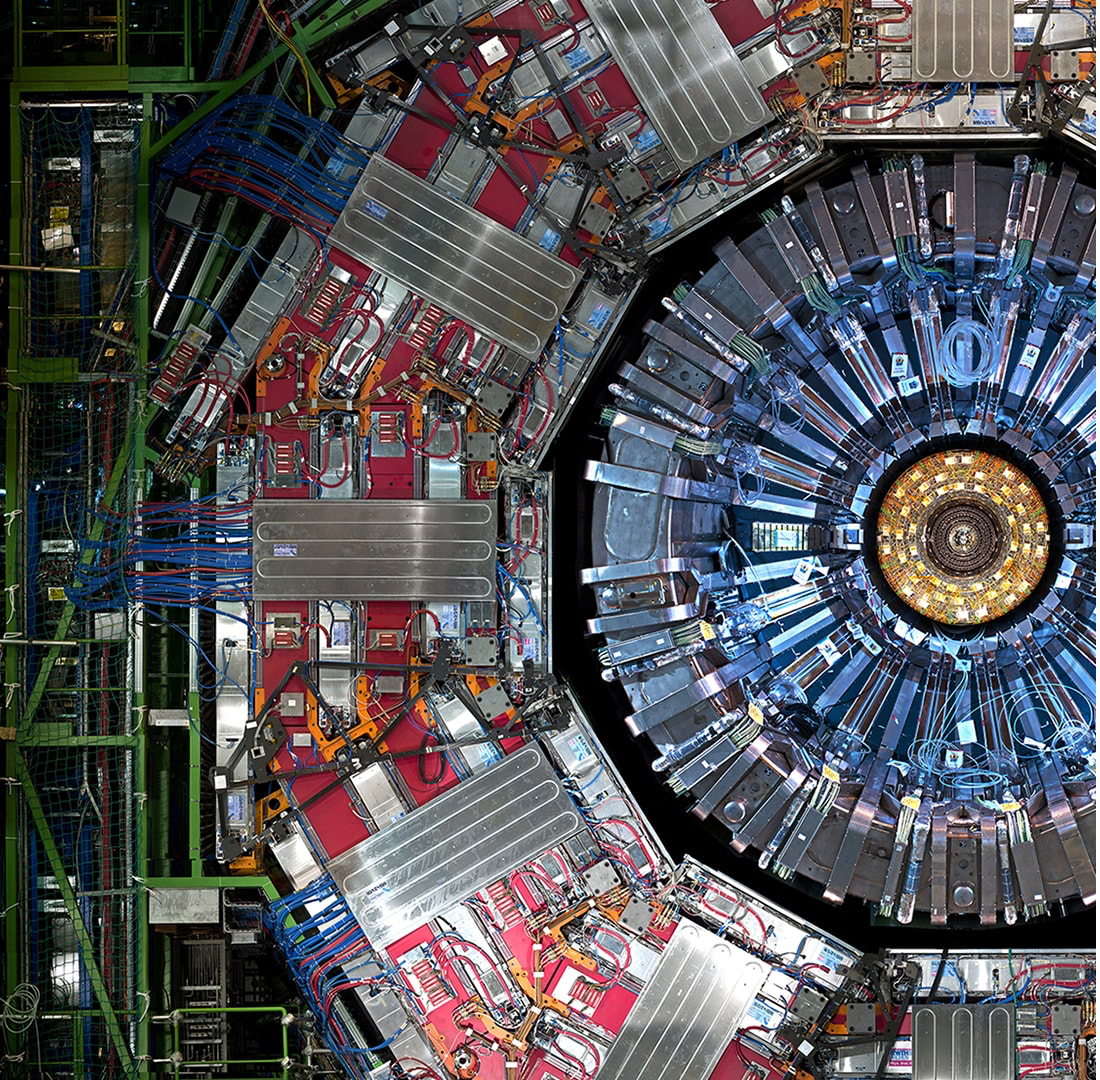
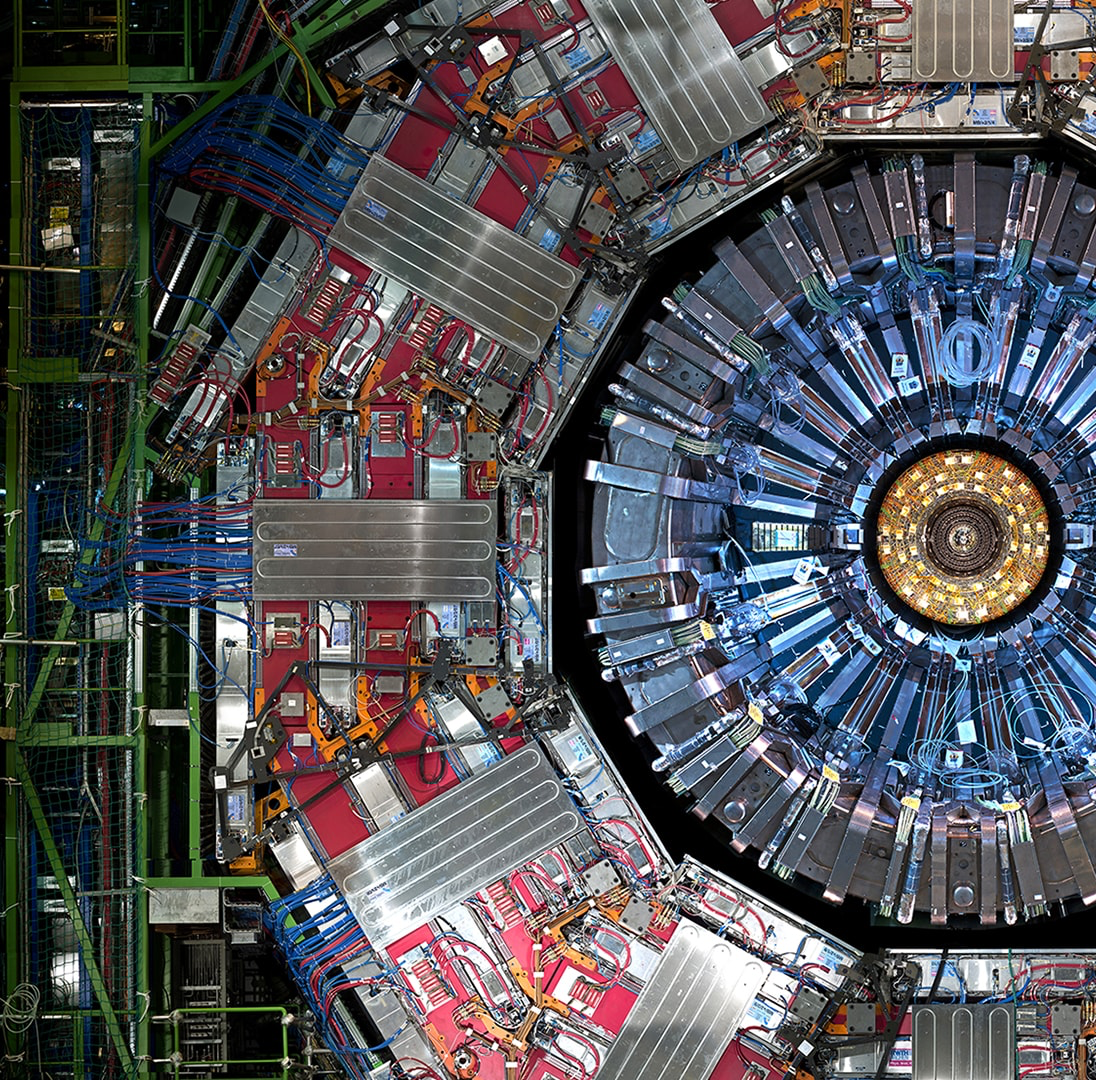
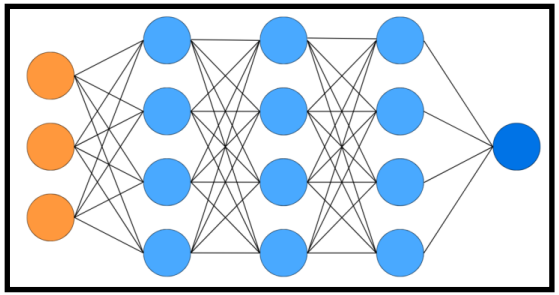


WE'RE DONE!



OR ARE WE?

goal: l1 hardware



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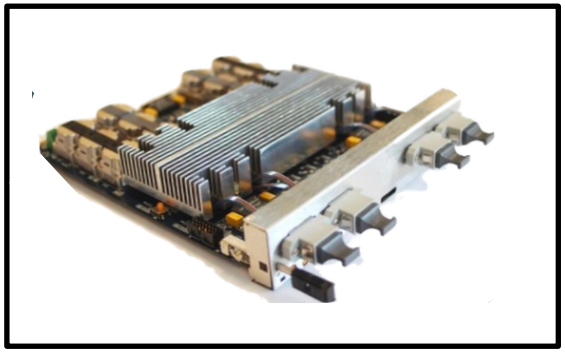
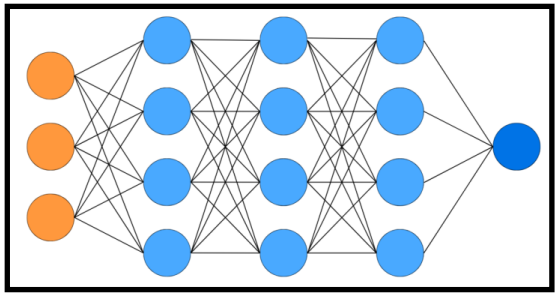


feed
forward
neural
network

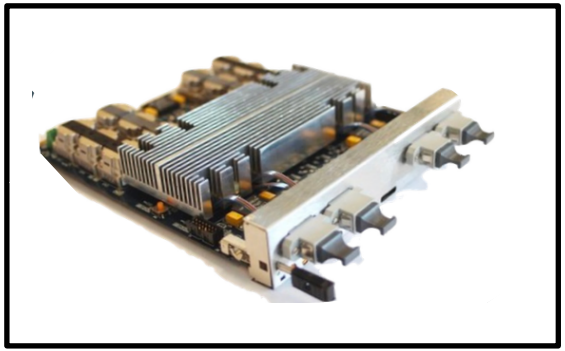
field
programmable
gate
array

goal: l1 hardware



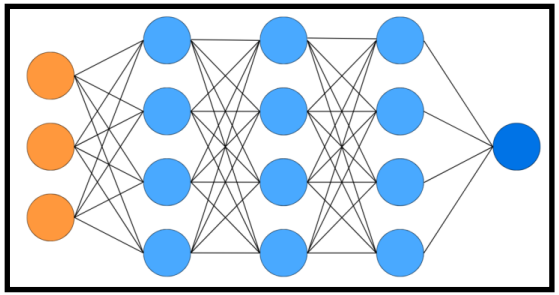
feed
forward
neural
network

quantisation / pruning
firmware synthesis

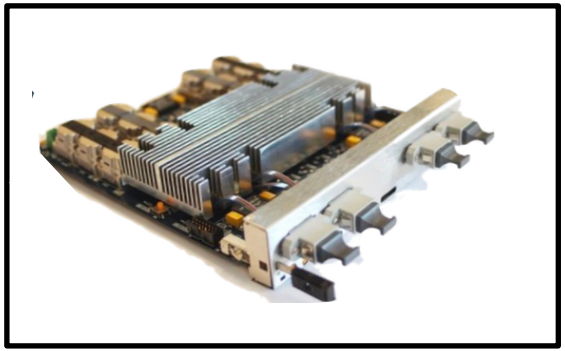


field
programmable
gate
array

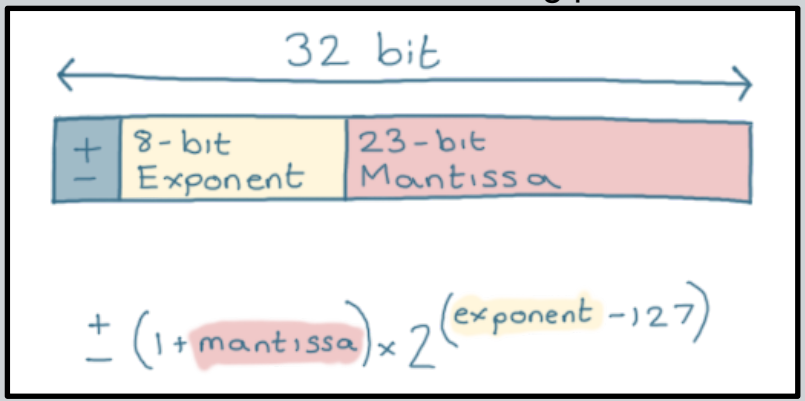
goal: l1 hardware

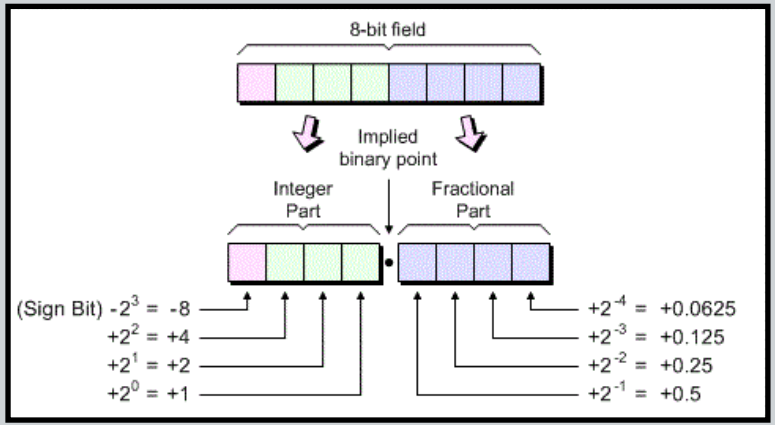


quantisation / pruning
firmware synthesis



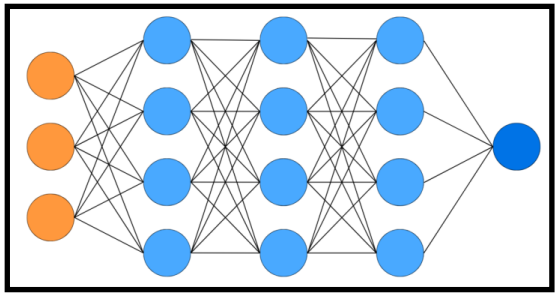
floating point number



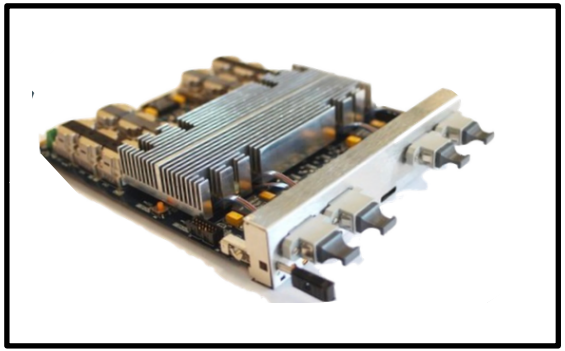


fixed point number (i.e. 16/6 bits)

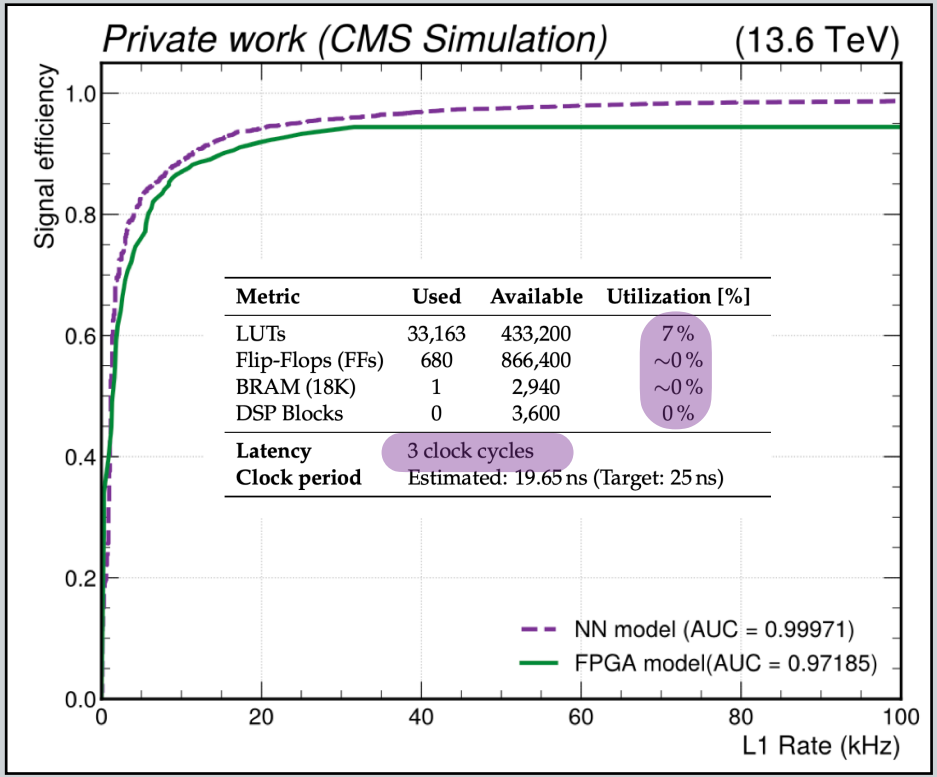
goal: l1 hardware



quantisation / pruning
firmware synthesis



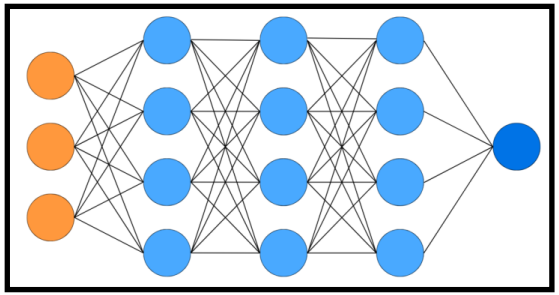
K. Kleinboelting, MSc thesis Uni Hamburg (2025)



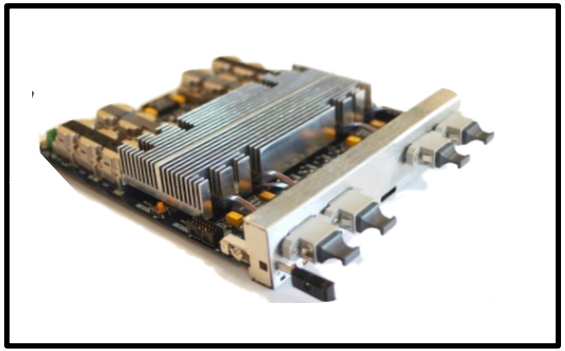
Metric	Used	Available	Utilization [%]
LUTs	33,163	433,200	7 %
Flip-Flops (FFs)	680	866,400	~0 %
BRAM (18K)	1	2,940	~0 %
DSP Blocks	0	3,600	0 %
Latency	3 clock cycles		
Clock period	Estimated: 19.65 ns (Target: 25 ns)		

only minor performance losses

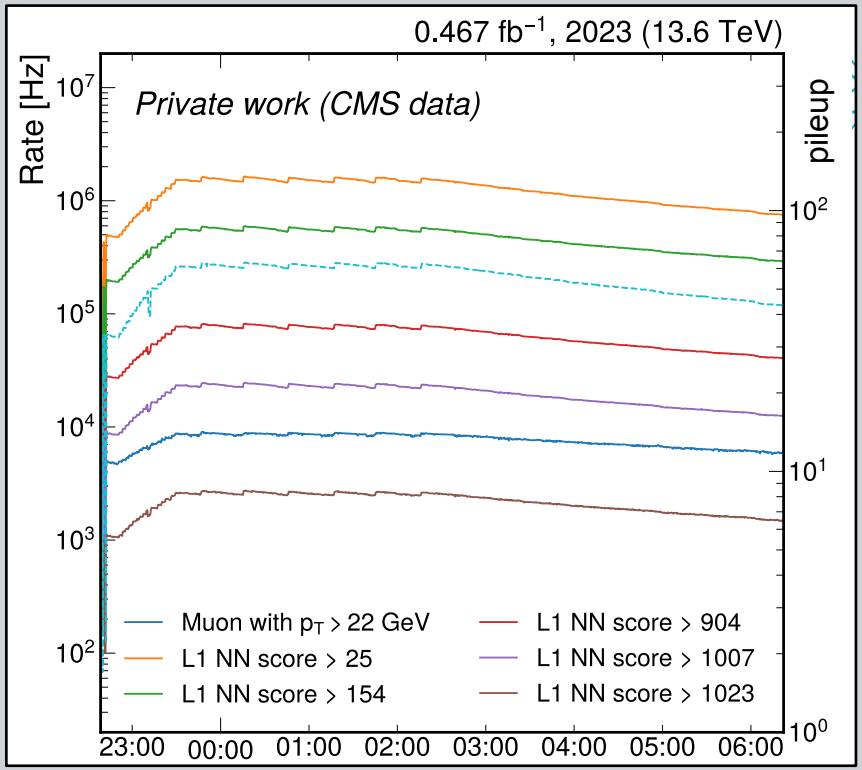
goal: l1 hardware



quantisation / pruning
firmware synthesis

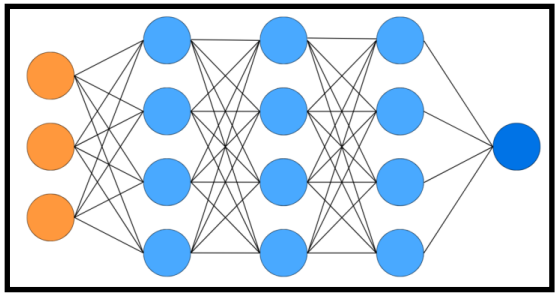


F. Labe, Dissertation Uni Hamburg (2024)

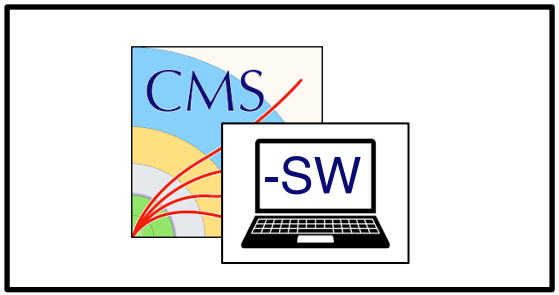


run in test crate: well behaved,
rate follows luminosity linearly

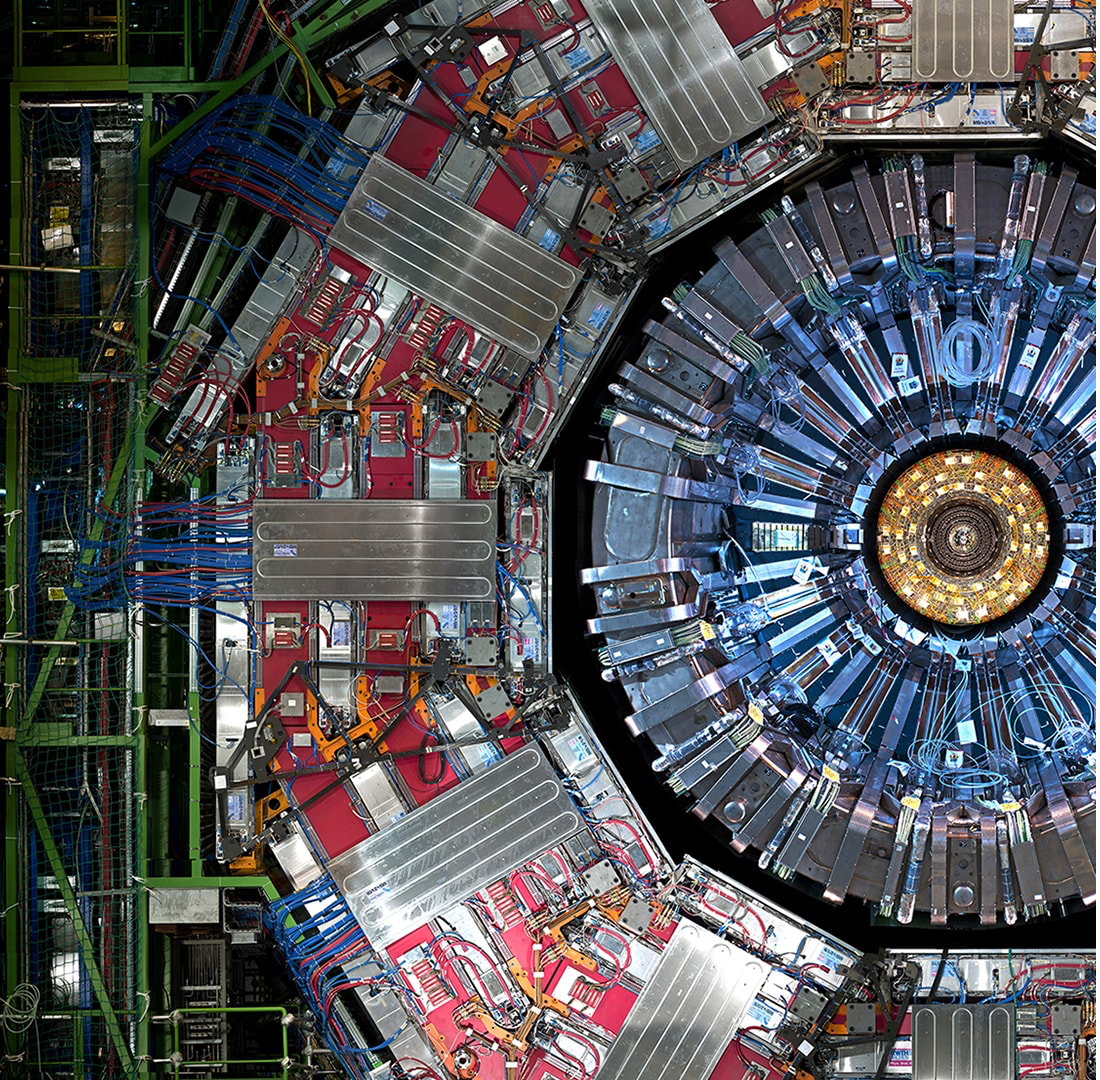
next: l1 menu



level-1 menu emulator

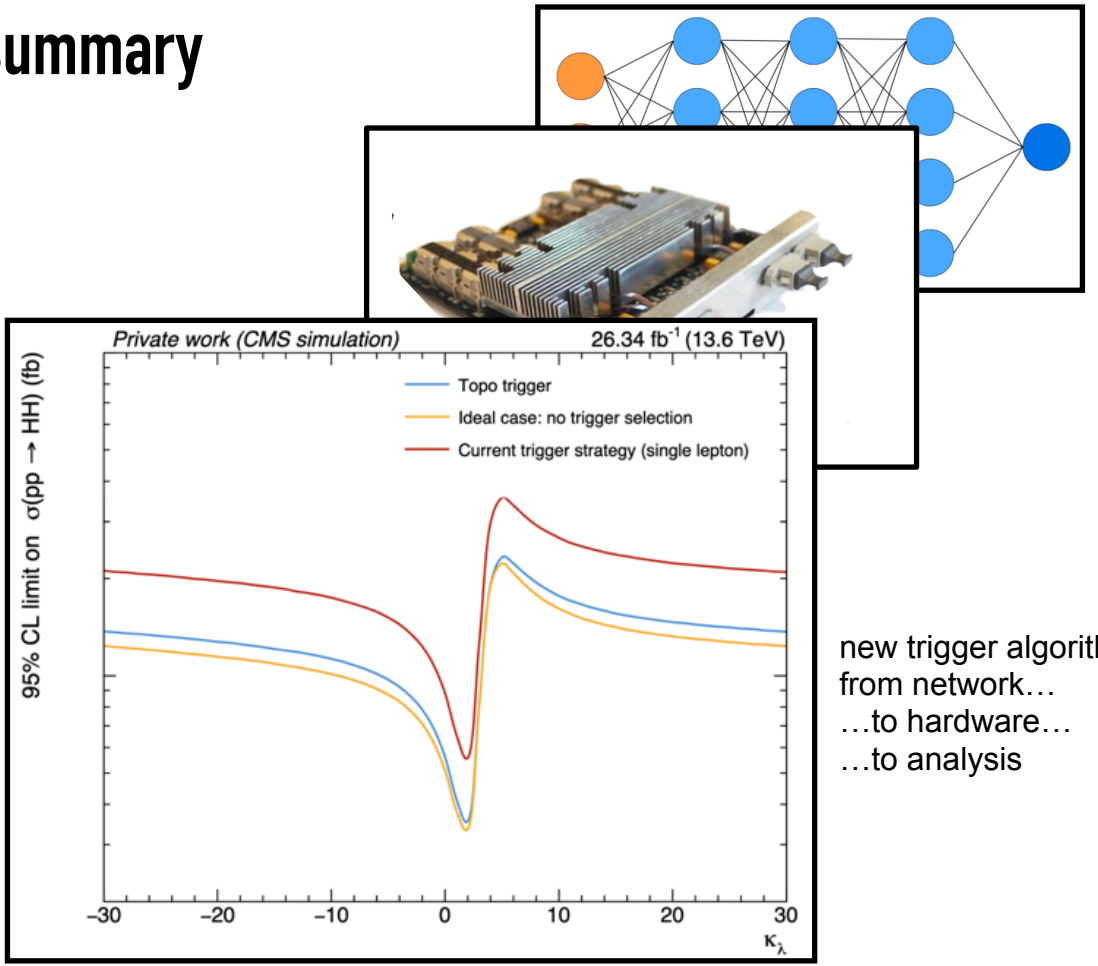


no performance loss after c-code conversion and compilation, bug in emulator code?



ALMOST DONE..

summary



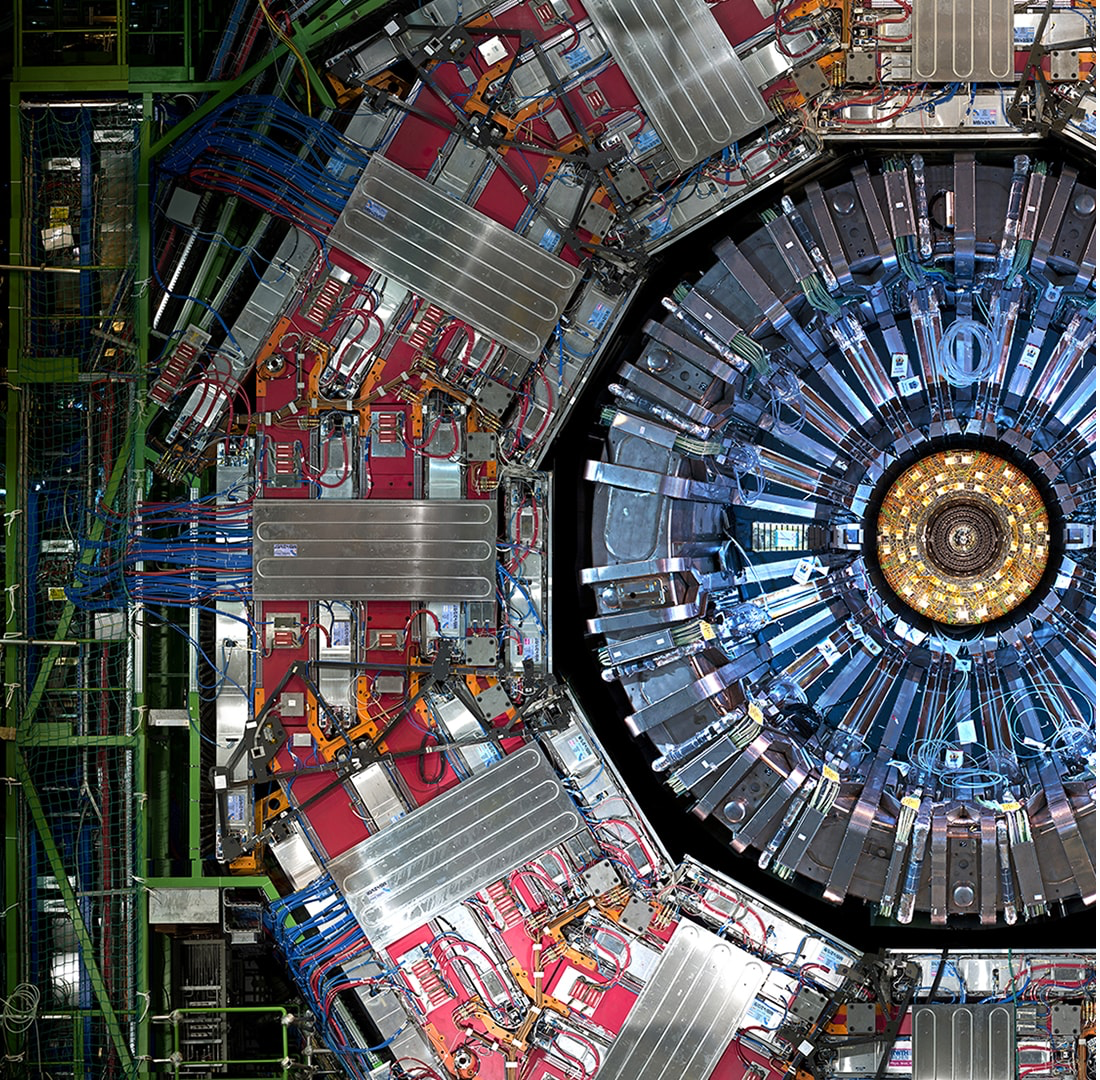
new trigger algorithm
from network…
…to hardware…
…to analysis

use case
trigger limited signals (*hhbbWW*) with low momentum leptons

ml based topological trigger very promising

→ **large efficiency gain**

next up
full menu emulation
automated workflow



THANKS FOR LISTENING!