CMS Experiment

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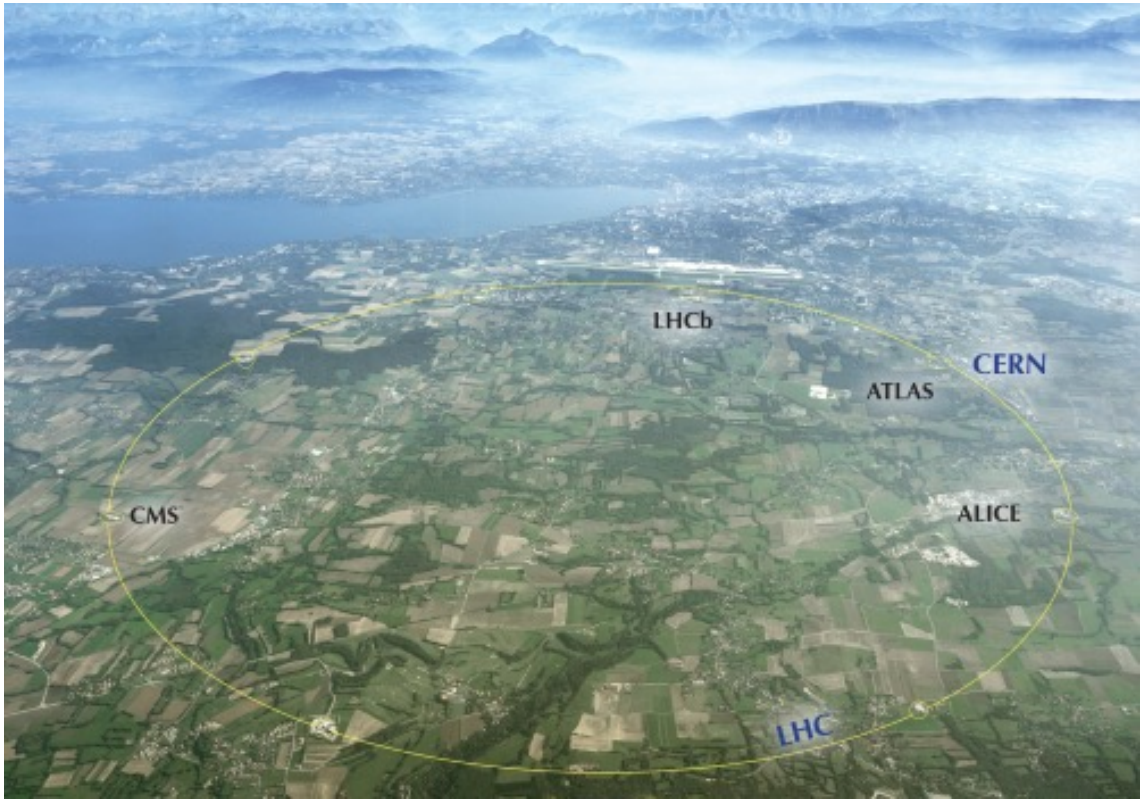
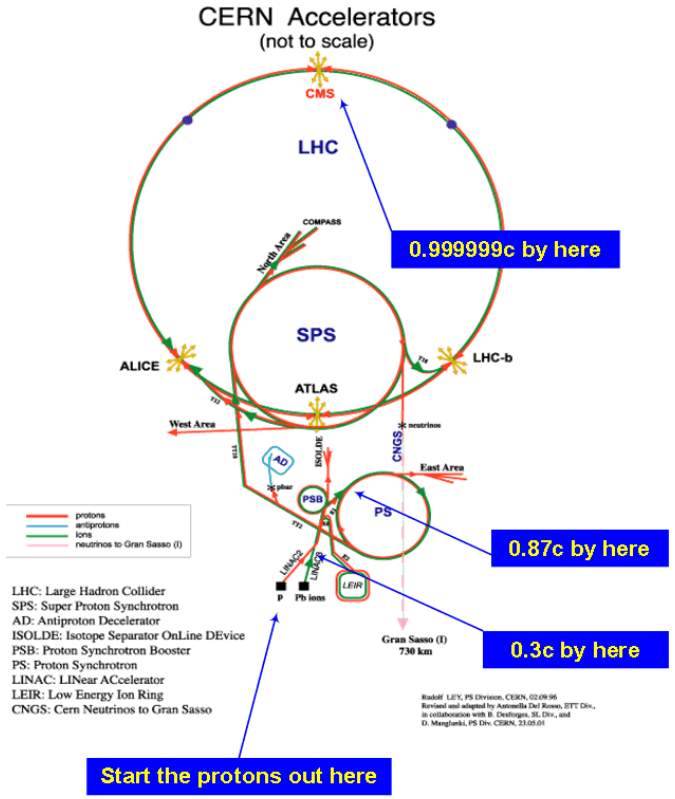
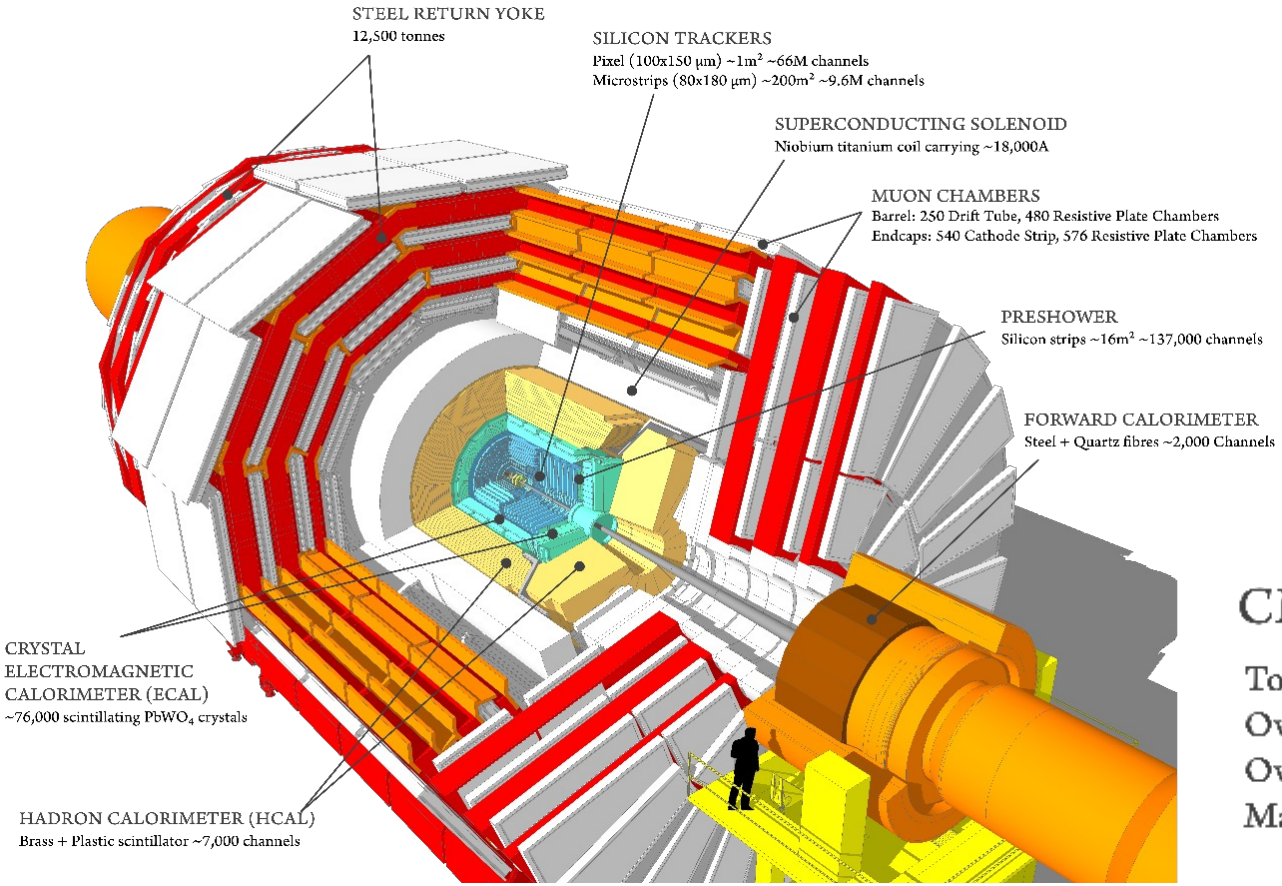
The Large Hadron Collider





- The World's largest and most powerful particle accelerator
- Started up on 10 September 2008

The Compact Muon Solenoid



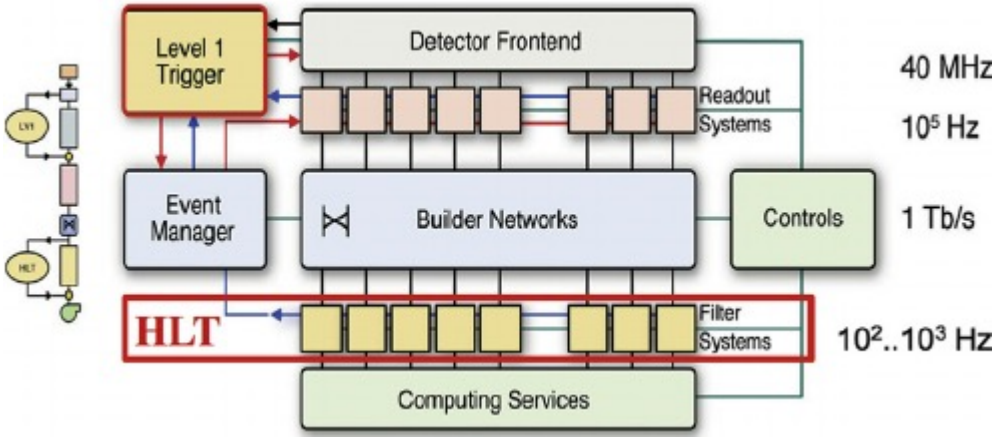
CMS DETECTOR

Total weight	: 14,000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

- Quite **compact** for all the detector material it contains
- Designed to detect **muon** very accurately
- Most powerful **solenoid** magnet ever made

Data Taking

- **Trigger**
  - Deciding on which event to record
  - L1: implemented in HW (fast FPGAs)
    - Reduces 40MHz to 100kHz
  - HLT: run with C++ and Python
    - Reduces 100kHz to 2kHz



  - Ex) HLT_Mu20 trigger will select events with at least one muon with 20 GeV of p_T
- **Data Acquisition (DAQ)**
  - Collect, digitize and store raw data from detectors
  - Configuring and controlling the hardware components
- **Event Reconstruction**
  - Interpret the raw data collected from detectors to identify and reconstruct the properties of individual particle interactions

Data Taking

- Data Quality Monitoring (DQM)
  - Spot problems in the CMS detector while it is running
  - Determine which data can be used for data analysis

Virtual tour

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CMSSW

- WorkBook [Link], Github [Link], Github-webpage [Link]
- CMSSW event processing model
  - Collection of software libraries that the CMS experiment uses in order to acquire, produce, process and even analyze its data
  - Consists of one executable (cmsRun) and many plug-in modules
  - All the code needed in the event processing (calibration, reconstruction, algorithms, etc.) is contained in the modules
- Event Data Model (EDM)
  - Event: C++ object for all RAW and reconstructed data related to a particular collision
  - EDAnalyzer: analyze objects from the event
  - EDProducer: adds objects into the event
  - EDFilter: can stop an execution path and put objects into the event

CMSSW

- What module type to write

  EDAnalyzer

  - Reading data only
  - Creating histograms
  - the standard use case

  EDProducer

  - You want to create new products
  - You want to share your reconstruction code with others
  - You want to make different algorithms plugable

  EDFilter

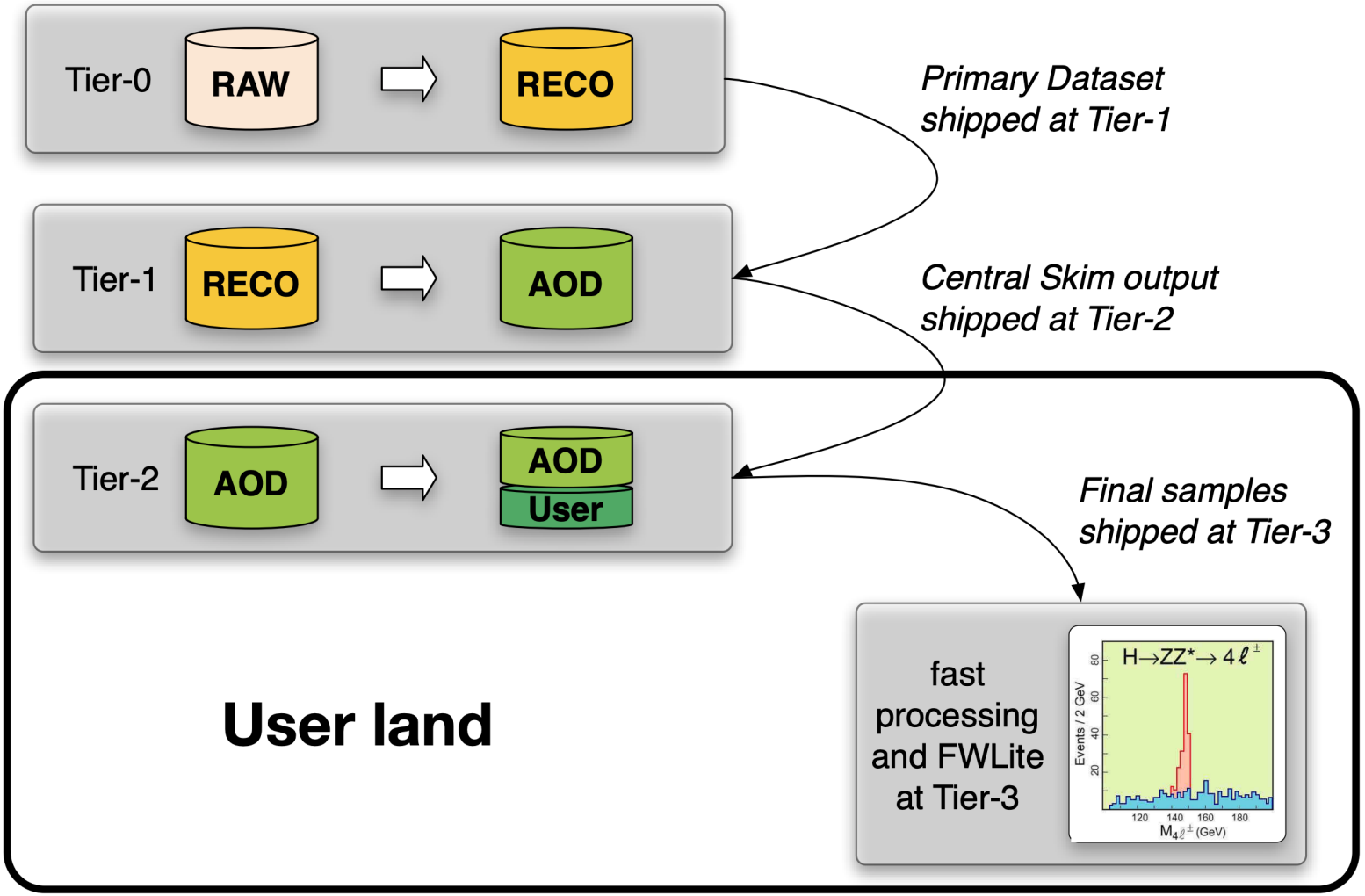
  - You want to know if an object could be produced
  - You want to control the analysis flow or make skimming

Data Format

- CMS DAS (Data Aggregation System) [Link]
- RAW: Data like they come from the detector
- RECO (Reconstruction): Output of the event reconstruction
- AOD (Analysis Object Data): Subset of data needed for standard analysis
- MinoAOD (PAT) [Link]: Small and quickly derived data format (Targeting 10% of the size of the AOD format)
- nanoAOD (flat ntuple) [Link]: Not a CMSSW EDM file but several EDM features are available in this simplified format
- RAWSIM, RECOSIM, …: with additional simulation information

Data Flow

Simplified picture



NanoAODRDFrame

- gitlab [Link], github [Link]
- With this package, we can do the following to NanoAOD files
  - Apply good JSON
  - Calculate b-tag weights for MC
  - Apply Jet/MET corrections
  - Skim events
  - Process events with applying selections
  - SF and uncertainty calculation
- Faster with RDataFrame by reading columnar data format
  - No event loops. Instead, should be able to use a lot of functions
- Admit that nanoAOD can make workflow simple but with limited flexibility

CMS Meetings

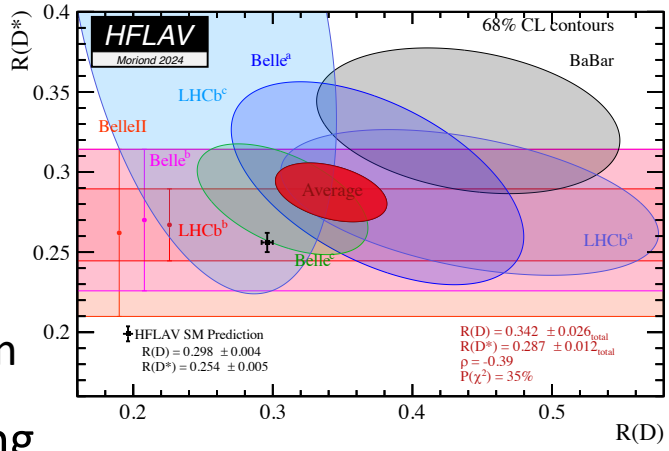
- CMS Physics meeting indico [Link]
  - CMS General Meeting WGM [Link]: Thursday 4 pm or 11 pm (KST) (9 am or 4 pm (CERN), weekly
- Top group:
  - Top General [Link]: Tuesday 9 pm (KST), 2 pm (CERN)
  - ttX [Link]: Wednesday 9 pm (KST), 2 pm (CERN)
  - Top Mass and Properties [Link]: 9 pm (KST), 2 pm (CERN)
- Muon POG [Link]: Friday 10 pm (KST), 3 pm (CERN), weekly
- RPC POG [Link]: Wednesday 9 pm (KST), 3 pm (CERN)
- BTV POG [Link]: Monday 11 pm (KST), 4 pm (CERN)
  - DQM Roundtable: Tuesday 10 pm (KST), 3 pm (CERN)

Top PAG News

- Recent Top PAG meeting [Link]
- 17th International Workshop on Top Quark Physics: from Sep 22 to 27
- Reminder: Path Towards Pre-Approval and Publication in Top [twiki]
- Systematics twiki [Link]
  - Updates: top p_{T} reweighting (strong interplay with MiNNLO and DCTR)
- Move to Run3
  - Starting next month new CADI lines will be required to include Run3 data
- Upcoming Events
  - DeepDive on NanoAOD next Tuesday starting at 9 am [Link]
  - Physics Days on “EFT effort across PAGs” from Sep 12 to 13 [Link]
  - CMS upgrade week from Sep 16 to 20 [Link]
  - Physics Days on “Physics opportunities during special LHC runs in Run3” from Nov 7 to 8
  - open LHCtopWG meeting from Nov 11 to 14 [Link]

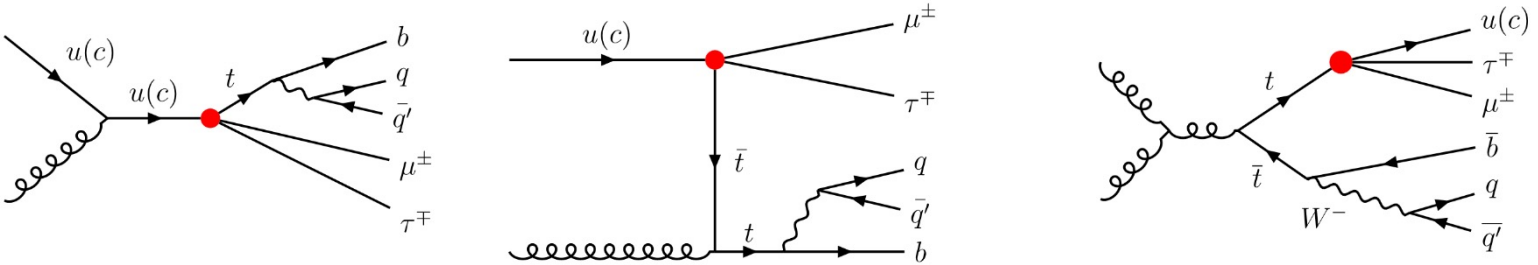
Search for charged Lepton Flavor Violation in Run2

- CADI: TOP-22-011 / PAS CDS [Link]
- Motivation
  - Observation of neutrino oscillations confirms the existence of neutrino mass and neutral LFV
  - Average result of anomaly measurement of R(D) and R(D*) shows 3σ of differences from SM prediction



- Final states of **muon, tau, c-jet** from the EFT coupling

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{eff} = \mathcal{L}_{SM} + \Sigma_i \frac{c_i}{\Lambda^{D-4}} O_i$$



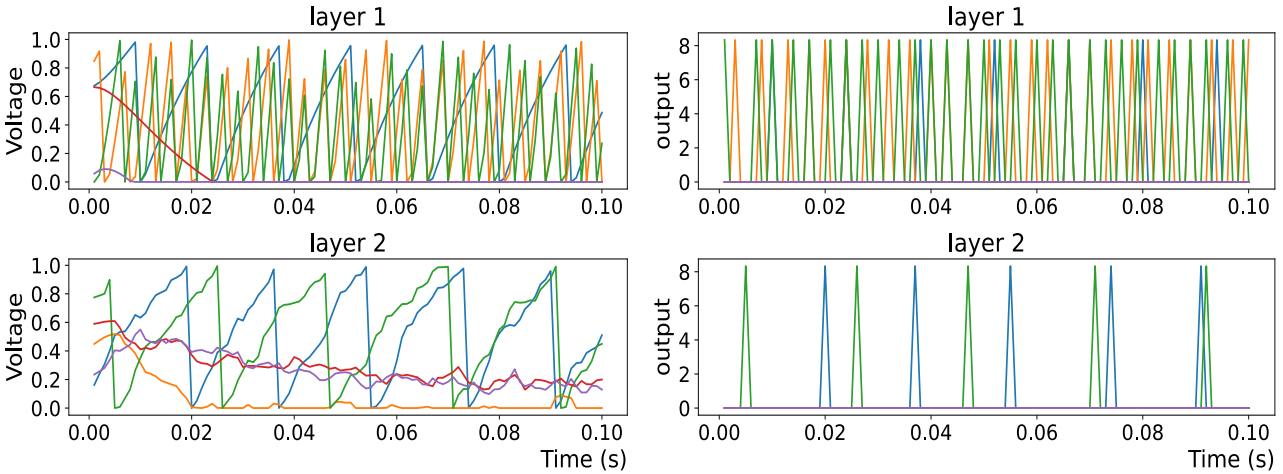
ST LFV processes

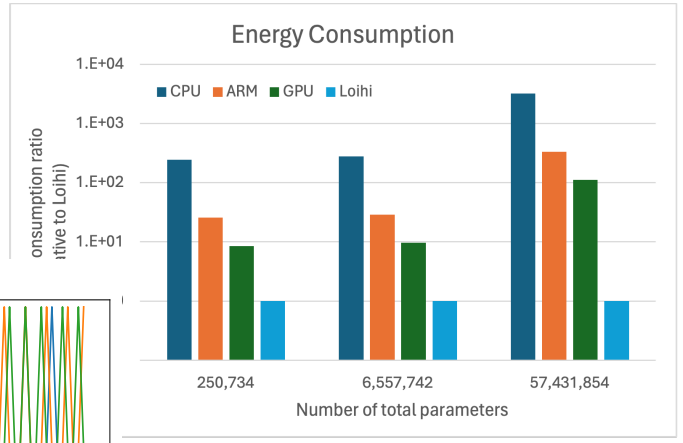
TT LFV processes

- Signal extraction with Deep Neural Network
- Upper limits on branching fraction in the CLFV top processes are set

ttbar classification with SNN on neuromophic chip

- Spiking Neural Network (SNN)
  - Mimicking biological neural systems' sparse and event-driven nature
  - Loihi neuromorphic chip is designed to run SNNs efficiently, optimizing power consumption and inference speed
- We can make timing info from detectors at HL-LHC
- Neuron activities of SNN on Loihi chip



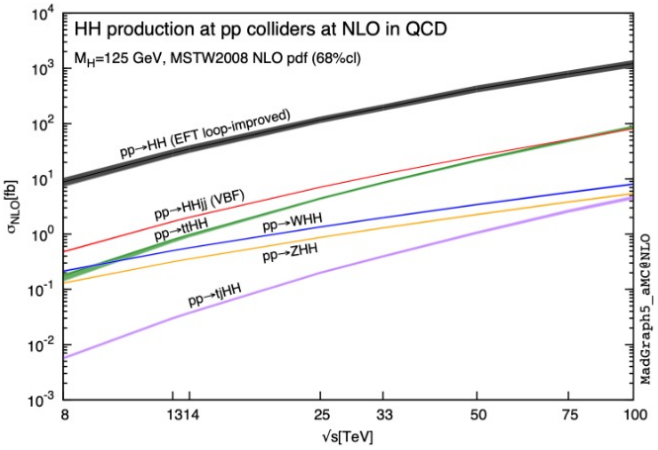


- Voltage: increases as input spikes received and decrease over time
- Output spike: generated when the voltage meets the threshold

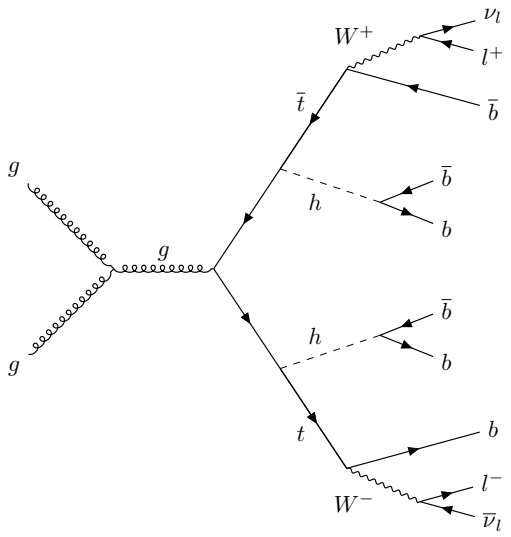
- ttbar classification
  - Signal: $t\bar{t}H(b\bar{b})$
  - Background: $t\bar{t}b\bar{b}$, $t\bar{t}bj$, $t\bar{t}c\bar{c}$, and $ttlf$
  - Total accuracy of SNN is 34.72%, when traditional DNNs is 35.47%

Feasibility of ttHH in HL-LHC

- $t\bar{t}HH$ is promising process at future colliders :
  - Fast growing cross section w.r.t. $\sqrt{s}$.
  - 20% of events contain λ_{HHH}.
  - Higgs compositeness at HL-LHC.



- Challenges :
  - ~1 fb SM cross section at HL-LHC. (3000 events.)
  - Various decay modes from H, t. (Disperesed small signal.)
  - Huge Jet multiplicity + BTagging.
  - Combinatorial problem when reconstructing Higgs.
  - Lepton isolation in dirty background.
  - Very similar backgrounds (ttH, ttZH).



- Approch :
  - Combine SS2l, OS2l channel.
  - DNN Higgs reconstuction & event classification.

Performance of muons using Z boson events in Run3

- Z boson reconstruction in Run 3 data from 2022 to 2024
  - The CMS Run3 data is taking from 2022 to 2024
  - We need to understand about Run 3 data
  - CMS is specialist in detecting muons. Understanding about muon data is important
  - Z boson reconstruction is good indicator of muon performance
- Z boson mass in Run2022 data (2023 and 2024 are in progress…)
  - Integrated luminosity with golden JSON : 34.6 fb^{-1}
  - Total # of events : 705,231,262
  - Z boson is reconstructed with two muons
    - muon pair is selected when the sum of muons is closest to Z boson mass (91.2 GeV) in event

* Global muon: Reconstructed muon with a track of inner tracker and standalone muon.
* Standalone muon: Reconstructed muon in the muon chambers(DTs, CSCs and RPCs).