CMS Trigger Performance in Run 2 and Run 3

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on behalf of the CMS Collaboration

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Triggering at LHC

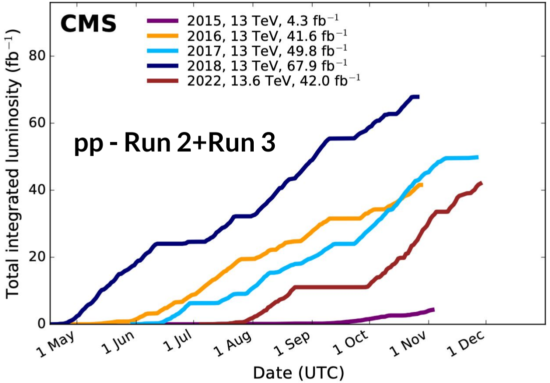
- LHC delivers a large amount of data
  - Collision every 25 ns (pp)
    - → ~40 Million events/s

Run 1 2011-2012 ~30 fb^{-1}	LS1	Run 2 2015-2018 ~150 fb^{-1}	LS2	Run 3 2022-ongoing ~300 fb^{-1}	LS3	. . .

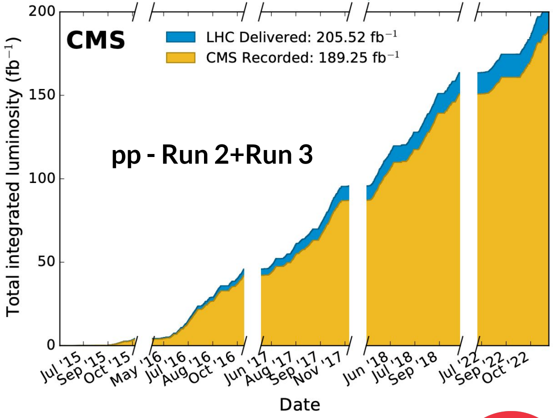
See also S. Morovic talk

  - +special runs (e.g., heavy ions)

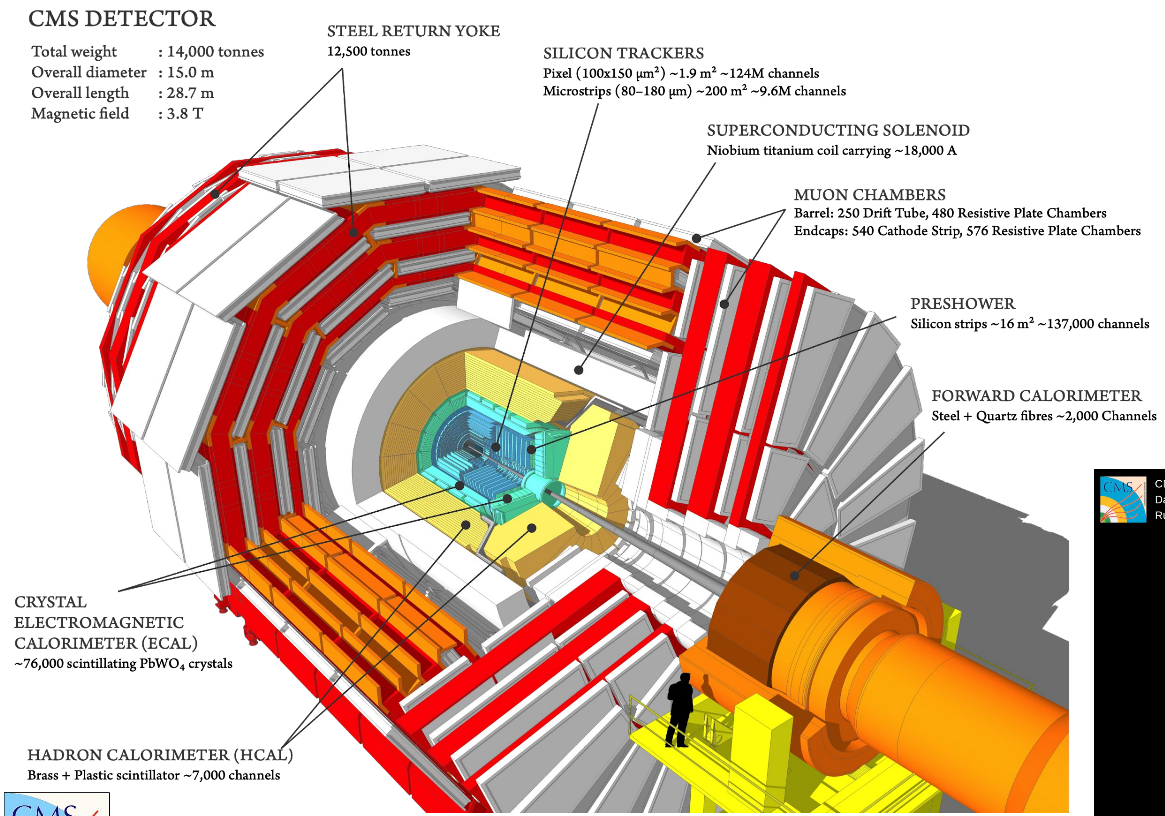
“*Filters*” the data, as fast as possible, based on physics

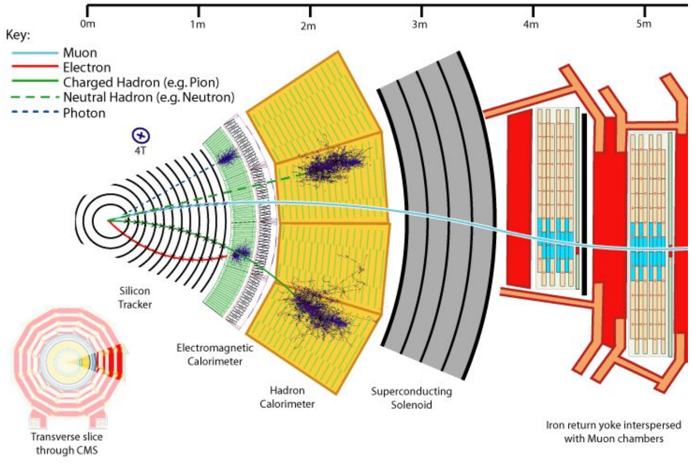


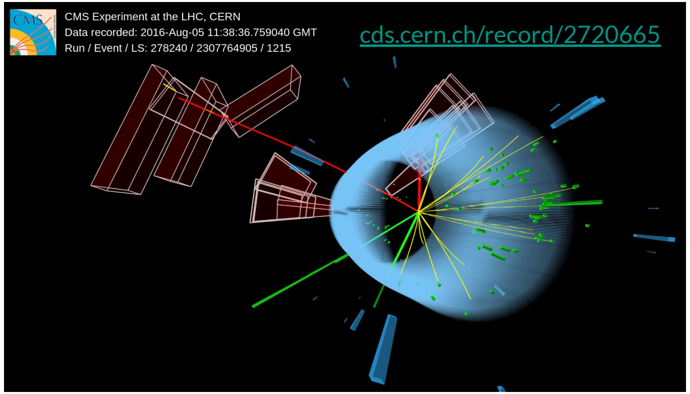
Public CMS Luminosity Information



The CMS detector



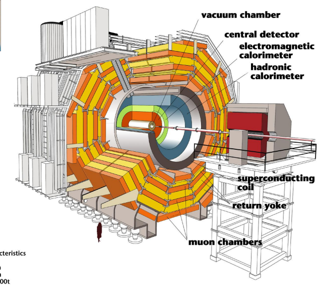




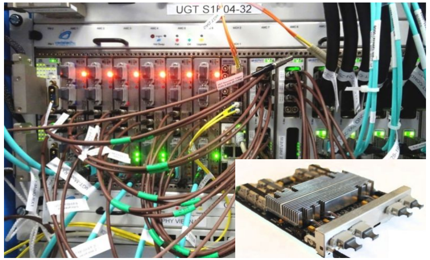
The CMS trigger system

Triggering in two steps

~30 MHz ~ 100 kHz ~1 kHz

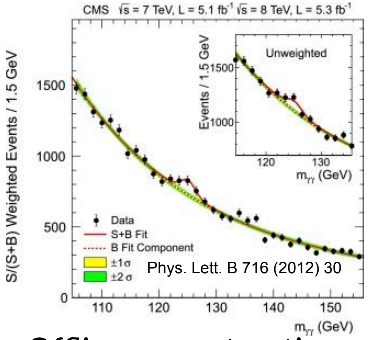


Data from detector



Level-1 (L1) trigger
Hardware based (FPGA)

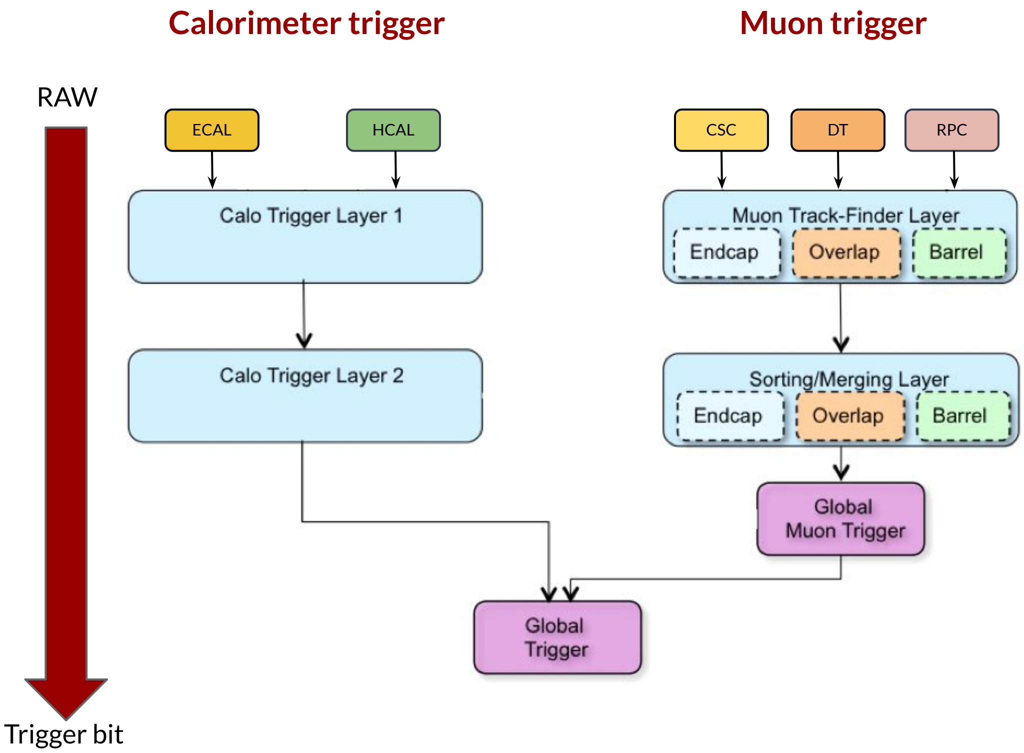
High-level trigger (HLT)
Software based (HLT Farm)



Offline reconstruction and analysis

Level-1 (L1) trigger architecture

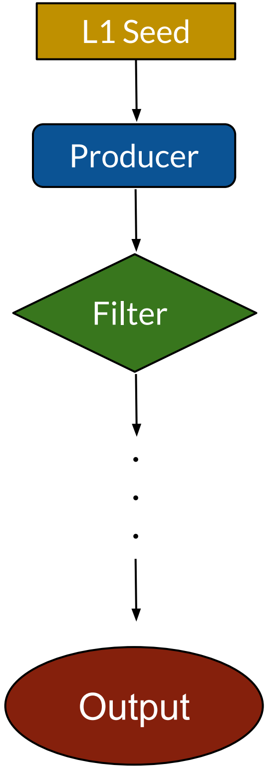
- Hardware-based (FPGA)
- Simplified readout
  - Calorimeters (ECAL and HCAL)
  - Muon system
- Timing
  - decision ~1 μs
  - latency < 4 μs
- Rates
  - Input ~30 MHz
  - output ~100kHz
- Objects
  - jets, e/γ,τ, μ, and energy sums

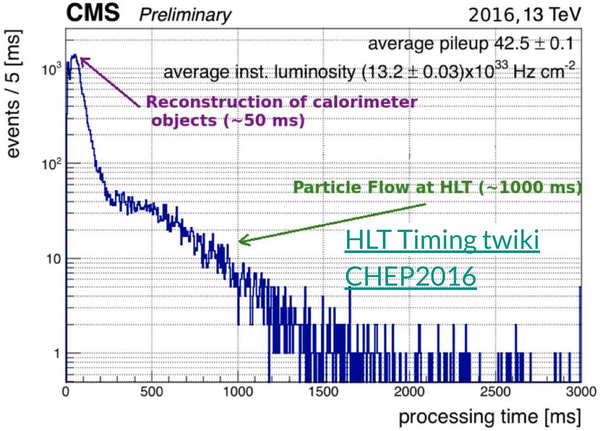


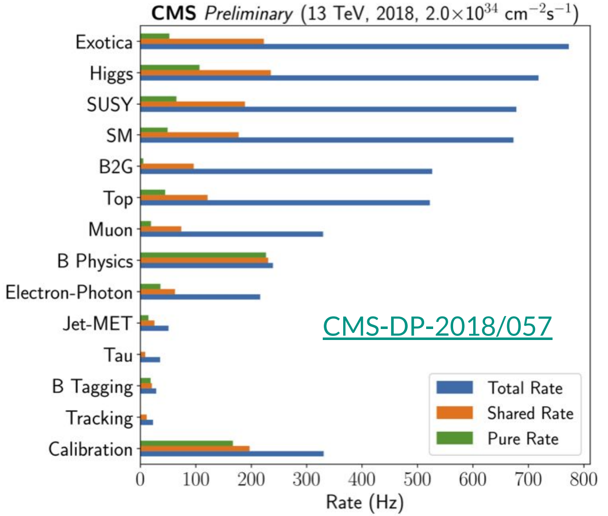
High-level trigger (HLT)

- Software-based (HLT Computer Farm)
  - Run 2: ~26k CPUs in 2017 and ~30k CPUs in 2018
- HLT path (Seeded from L1)
  - Start filtering with simple objects
  - Increase the complexity
  - Output
    - Streams and datasets
- HLT Menu
  - > 400 paths running in parallel
    - producers are shared
- Time latency ~ 260 ms on average
- Rates: Input ~100 MHz, output ~2 kHz

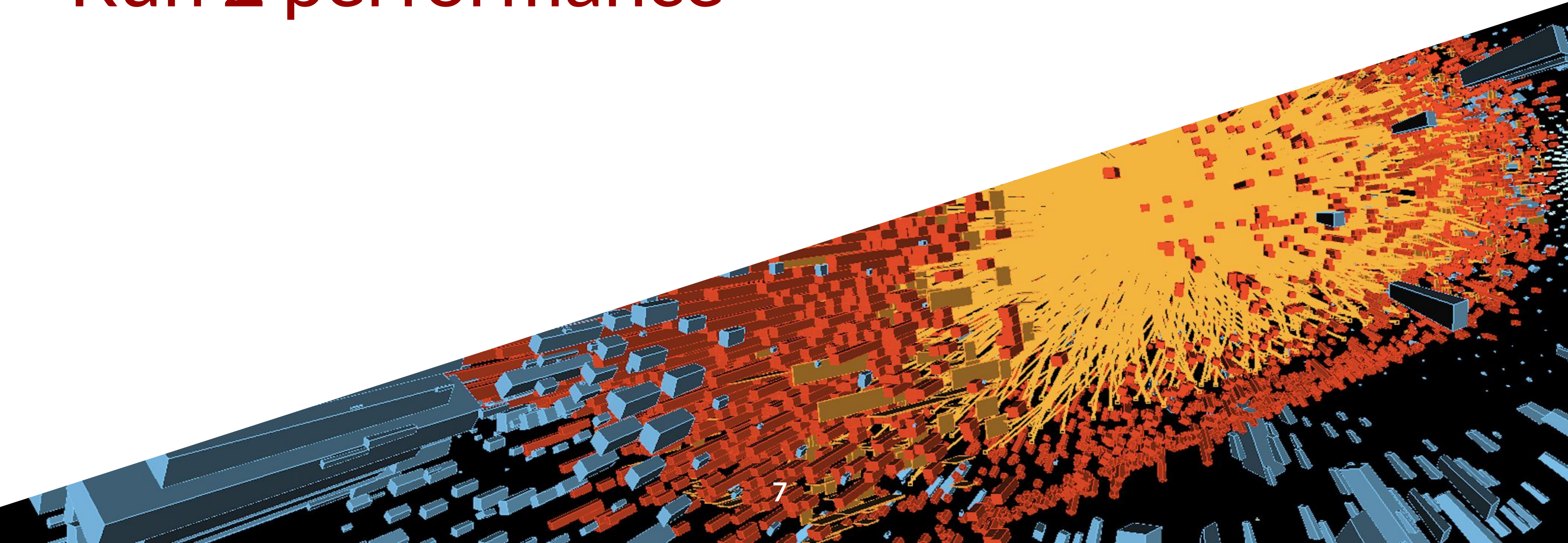
HLT path





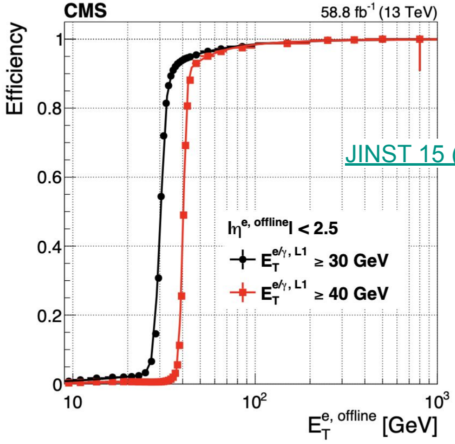


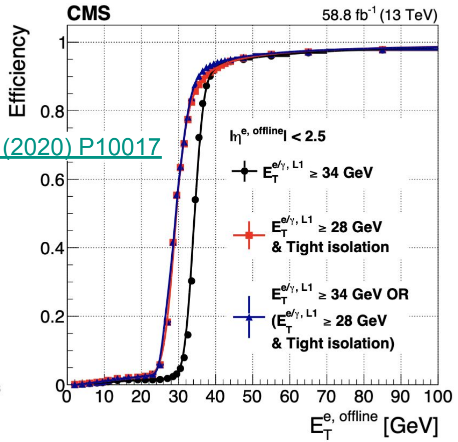
Run 2 performance



Electrons and photons

- L1
  - Clusters from HCAL and ECAL towers
  - 3 levels of isolation (ISO): none, loose, tight
  - ISO as function of E_T, η, and pile-up (PU)
- HLT
  - Tight ISO/ID helps to reduce rates
  - 4-layer pixel detector also help with rates
    - ➔ 1-2% efficiency cost
  - Single *e* ID re-tuned in 2017
    - ➔ recovering specially endcap region





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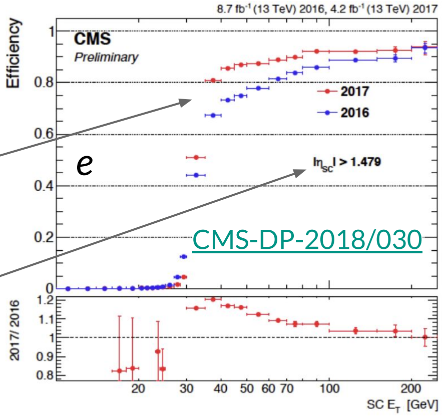
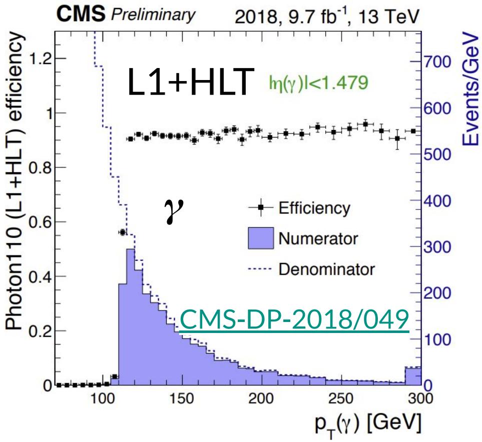


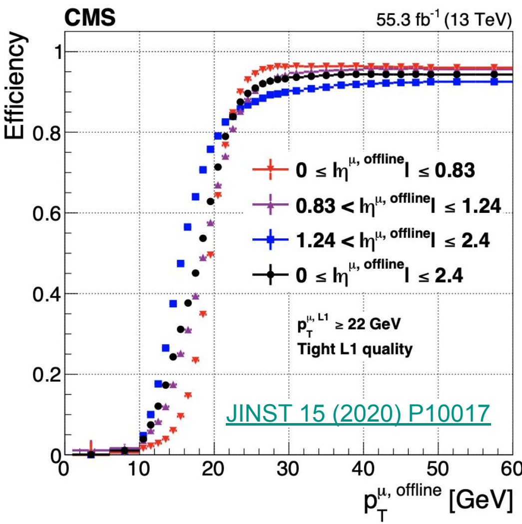
CMS-DP-2018/030

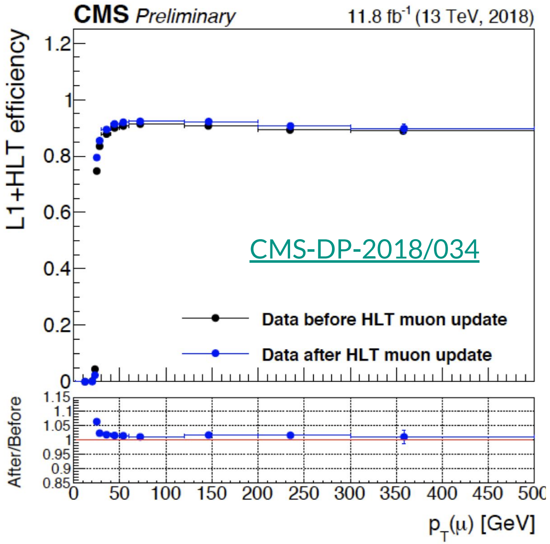


CMS-DP-2018/049

Muons

- L1
  - Muon system (DT, RPT, CSC)
  - 2017 upgrade reduced the rates by a factor 2
    - ➔ overlap region
      - BMFT = DT+RPT (barrel)
      - OMFT = DT+RPT+CSC (overlap)
      - EMFT = RPT+CSC (endcap)
  - Overall efficiency of ~90%
- HLT
  - Inefficiency and data/MC disagreement mainly from L1
  - Isolation inefficiency is very small (2-3%)
  - Without L1 the efficiency is ~99%

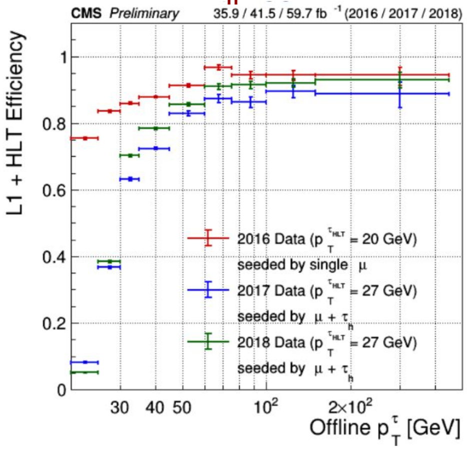




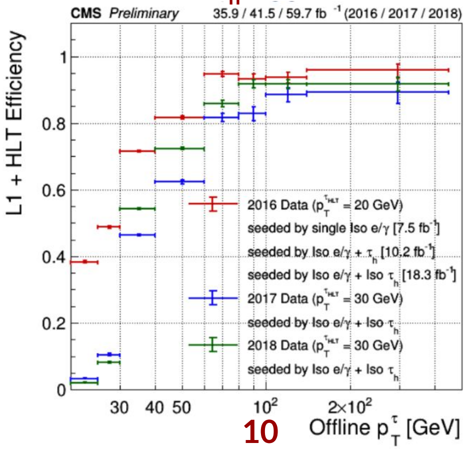
Taus

- At L1 it uses clusters from HCAL and ECAL towers
- Efficiencies calculated using tag and probe
- Discrepancies from 2016 data are observed due
  - different HLT thresholds, differences on L1 seed and different PU
- In 2018 the HadronPlusStrips (HPS) algorithm used offline keeping similar rate
  - charged hadrons and photons are combined in multiple ways and ranked based on their consistency with a genuine tau decay.

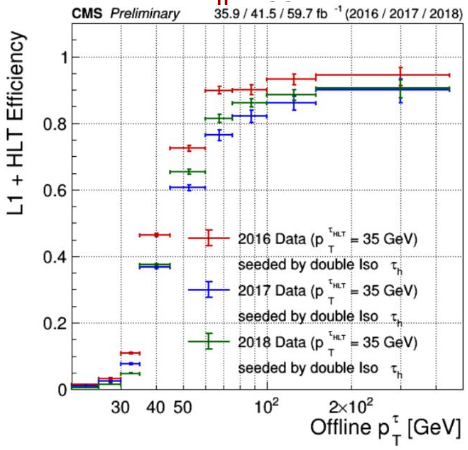
$\mu\tau_h$ trigger



$e\tau_h$ trigger



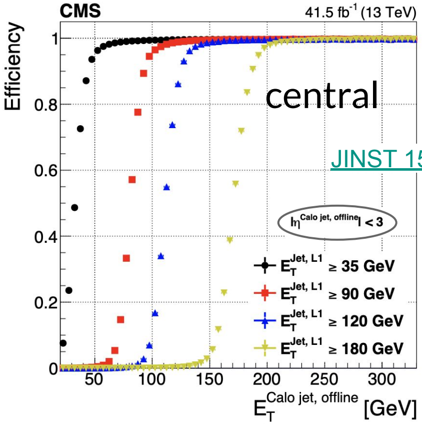
diτ_h trigger



CMS-DP-2019/012

Jets

- L1
  - Calorimeters only
  - Calibrations and PU corrections applied
    - ➔ small PU effect in jet resolution
  - Good jet angular resolution
- HLT
  - Particle flow (PF) added (tracking)
    - ➔ increases p_T resolution
  - Online vs offline: 5% difference
  - Online b-tagging provides 70% efficiency and 5% fake rate
    - ➔ DeepCSV used during Run 2



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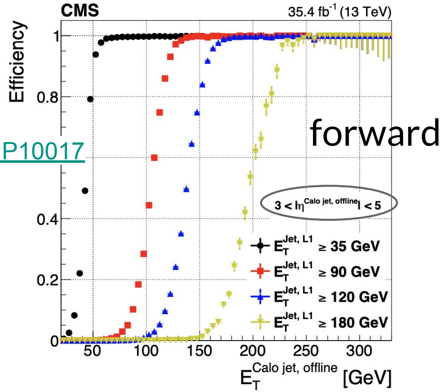
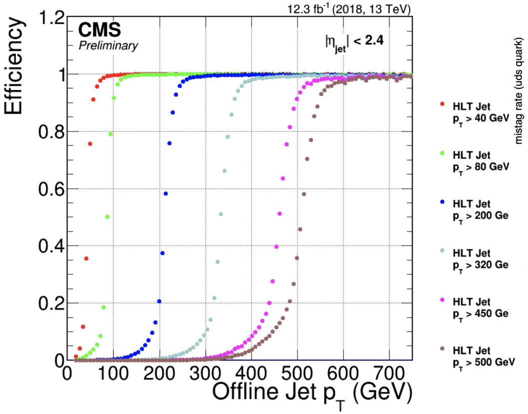
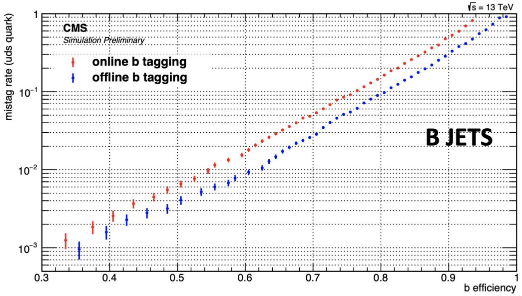
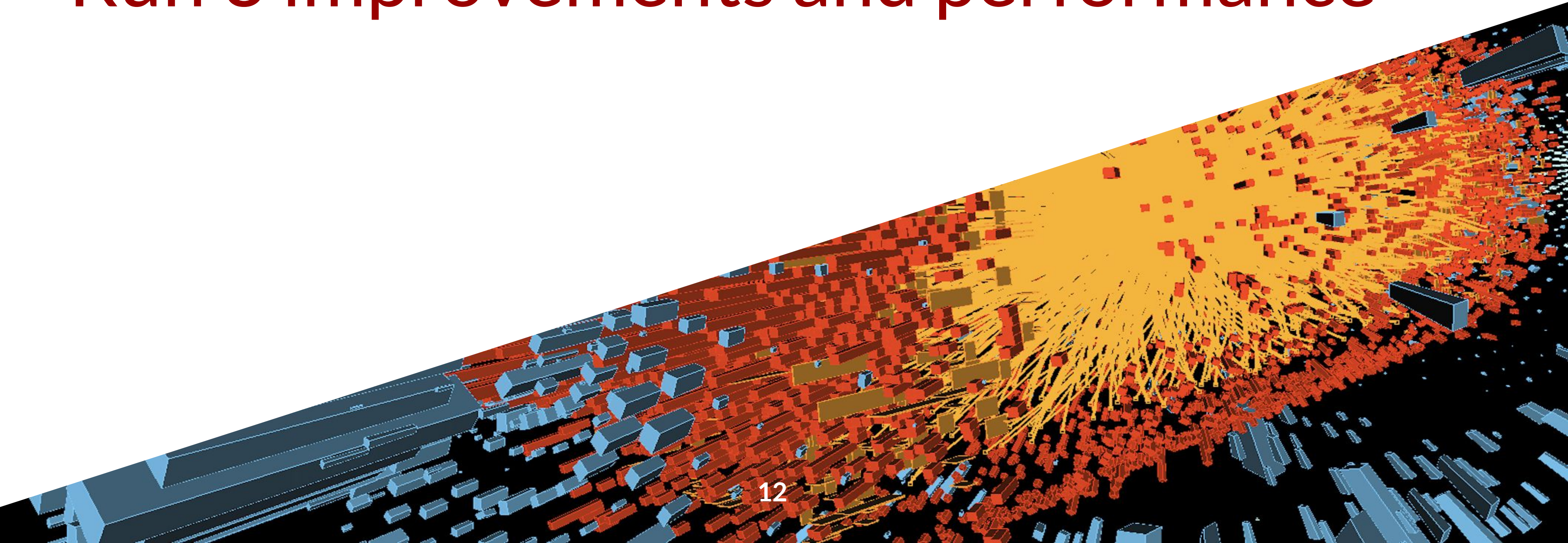






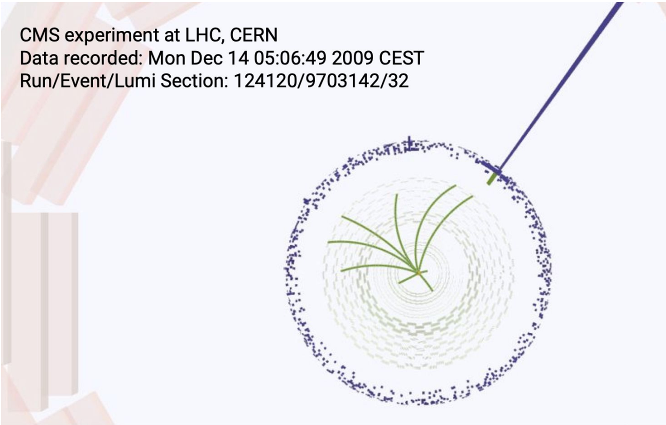
CMS-DP-2018/037

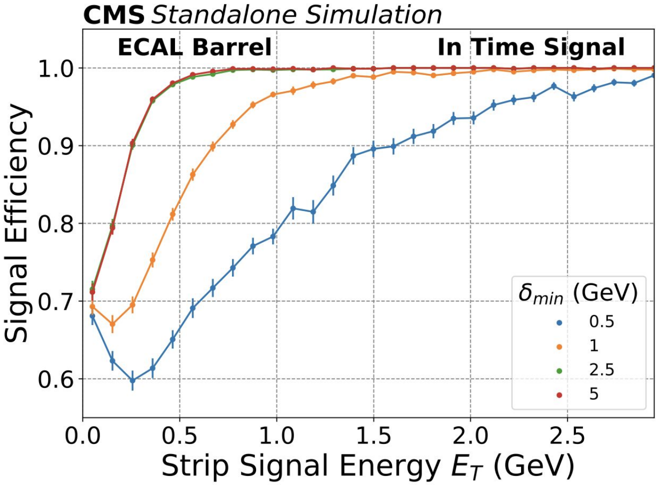
Run 3 improvements and performance



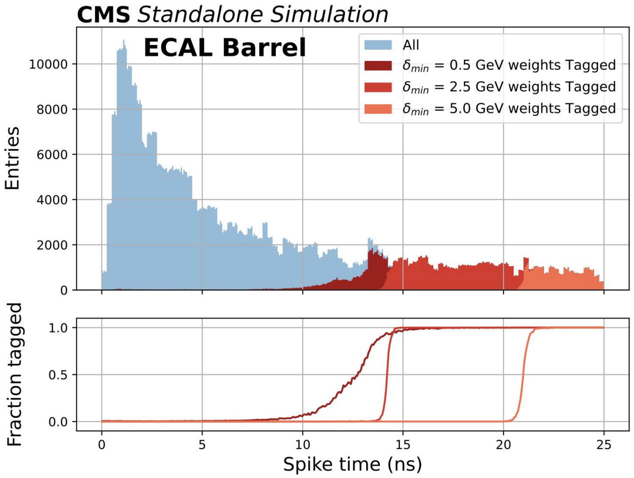
New L1 trigger strategies: ECAL "spike" rejection

- "Spikes": Fake high energy deposit caused by caused by the ionisation in the ECAL
  - Two sets of L1 amplitude weights optimized to remove unwanted spikes
  - Minimum deviation from signal-like energy deposit (δ_{min}) = 2.5 GeV for best signal eff



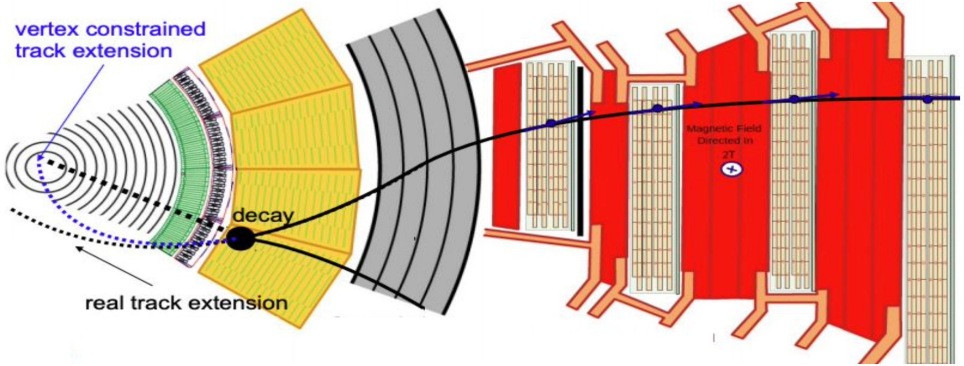


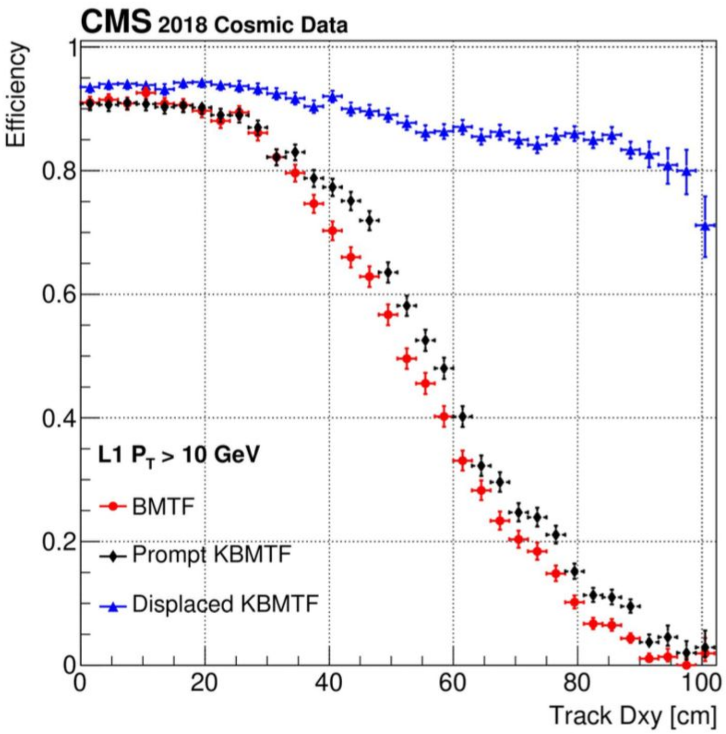
CMS-DP-2022/007



New L1 trigger strategies: displaced muons

- New algorithms in the L1 trigger targeting muons displaced from the collision vertex
  - No beamspot matching and no extra constraints
    - p_T, d_{xy} and di-object invariant mass
  - Remove overlap with jets/τ's using ΔR at L1
  - Useful for search for Long Lived Particles (LLP)

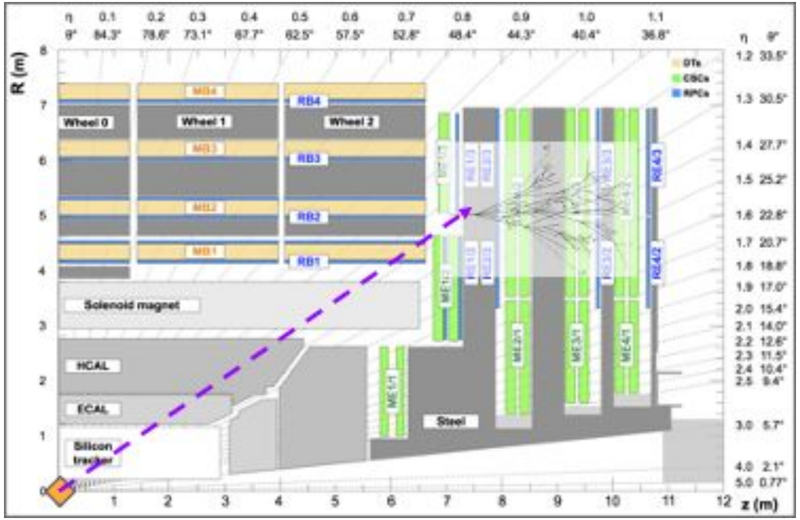


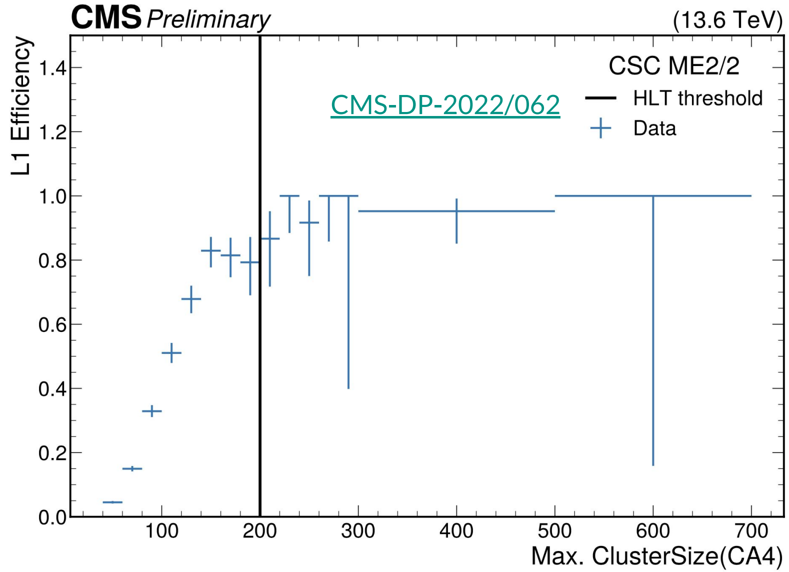


143rd LHCC Meeting

New L1 trigger strategies: HMT / Muon showers

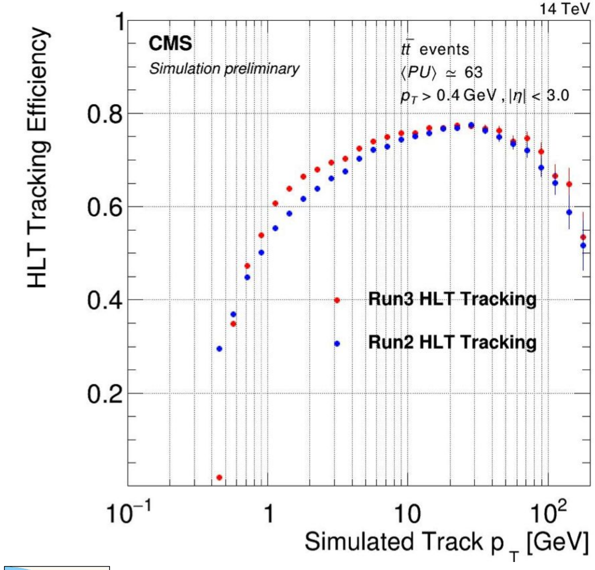
- CSC High Multiplicity Trigger (HMT)
  - Search for exotic LLP using hadronic showers in CSC
  - Signal acceptance 20x better than Run 2 triggers
  - Opportunity to study the LLPs with lifetimes comparable to a few meters
  - Possibility to study EM-initiated processes

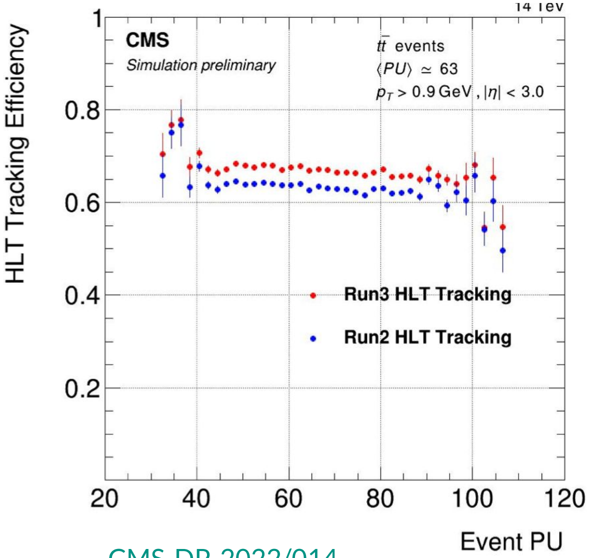


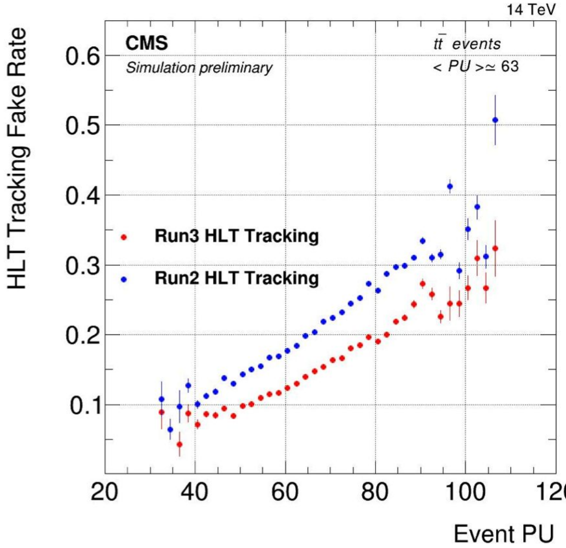


HLT tracking performance for Run 3

- HLT tracking using optimized pixel track reconstructions, called “Patatrack”
  - Allows HLT to run in a single iteration
  - Shows a better track performance even in higher PU
  - Can be offloaded to GPU’s: improvement in reconstruction timing





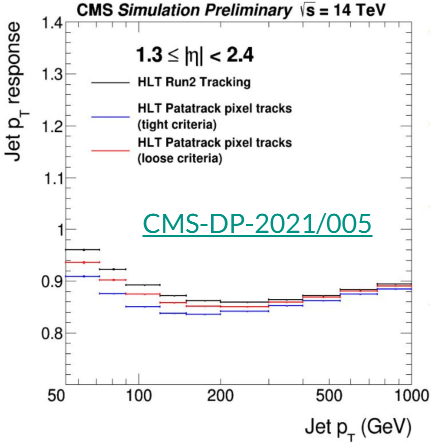


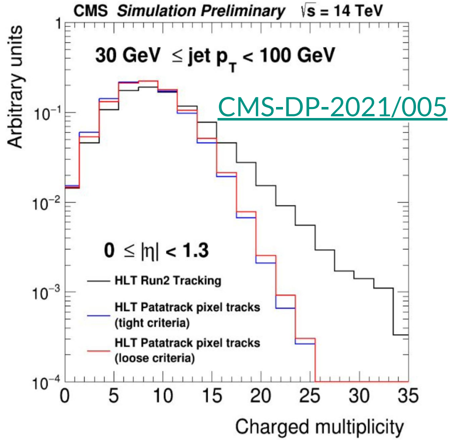
CMS-DP-2022/014

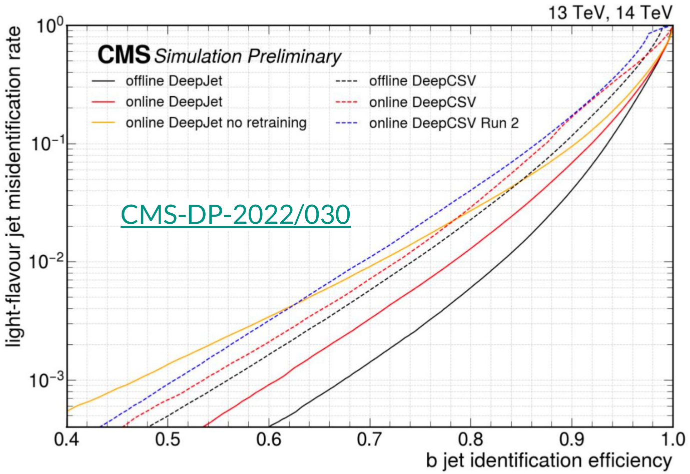
HLT jet performance for Run 3

- Improve performance of jets using Patatrack
  - Pixel tracks as input of PF jets
    - Reduction in fake rate for high p_T tracks in PF jets

- Usage of Neural Network for jet flavour classification
  - Model training on online reconstruction
  - DeepJet+Particle Net

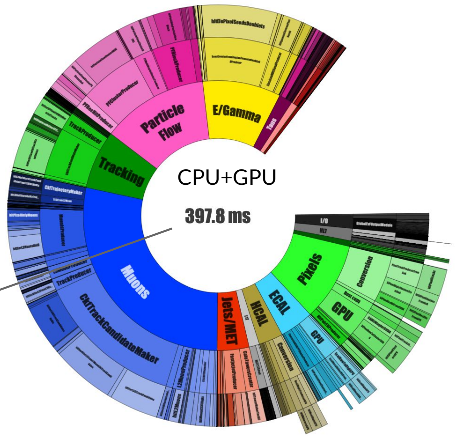




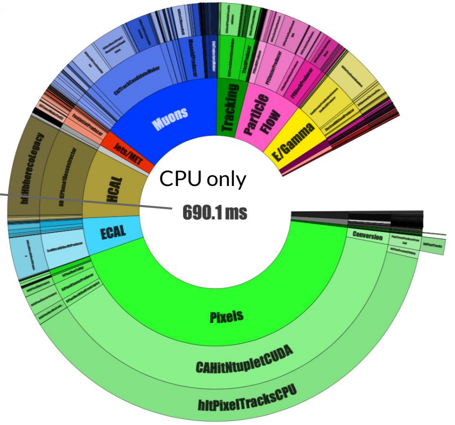


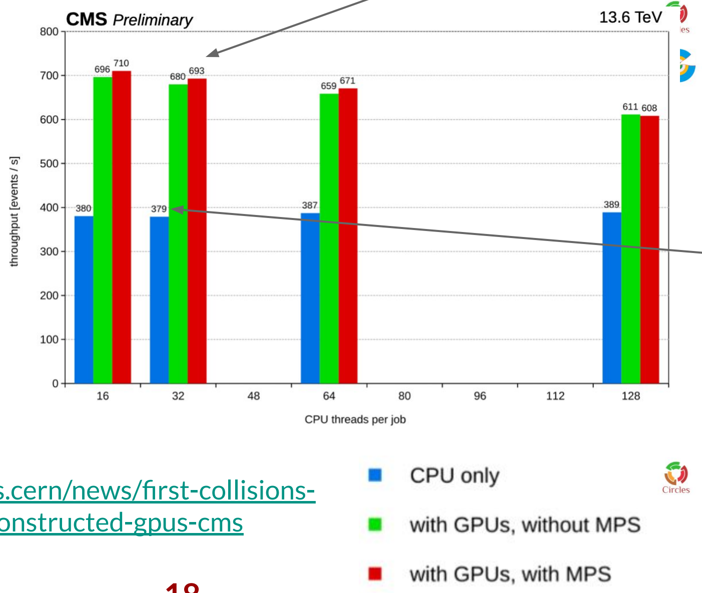
HLT farm for Run 3

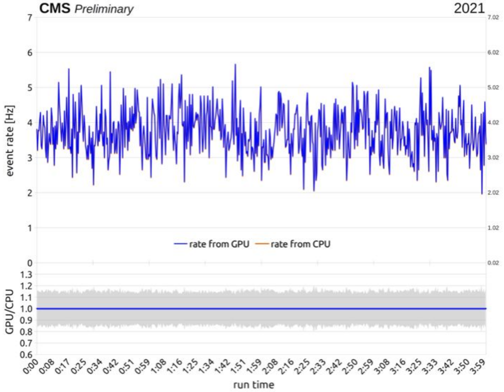
- Hybrid CPU+GPU farm
  - 200 nodes (25600 CPU + 400 GPU)
    - 2 AMD Milan 64-core CPUs and 2 NVIDIA Tesla T4 GPUs
  - ~40% of HLT reconstruction offloaded to GPUs
    - Pixel, ECAL and HCAL
  - Fully commissioned for Run 3



~40% better performance







cms.cern/news/first-collisions-reconstructed-gpus-cms

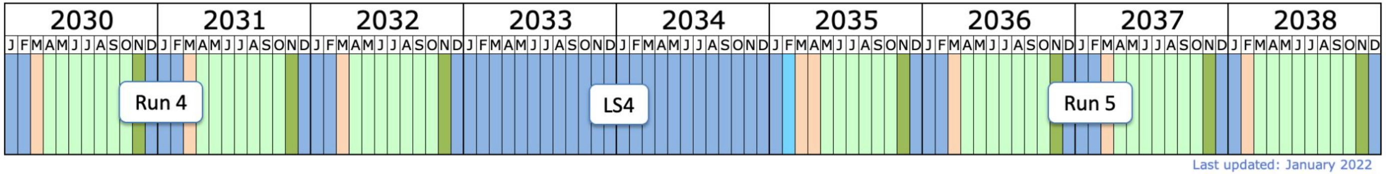
[CMS-DP-2023/004](CMS-DP-2023/004)

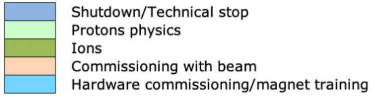
Summary and conclusions

- The CMS trigger system has proven to be robust, reliable and highly performant during the entire Run 2
  - Showing great performance during the entire period
    - Essential for all physics analysis at CMS
- The first year of Run 3 was a success
  - New L1 algorithms and new HLT Farm using GPUs (specially needed for high PU)

And there is much more coming, stay tuned!!!

Long term LHC schedule





Thank You

The work of the UIC HENP group is supported by the DOE-NP grant


CMS
CMS Experiment at the LHC, CERN
Data recorded: 2010-Nov-08 10:22:07.828203 GMT(11:22:07 CEST)
Run / Event: 150431 / 541464
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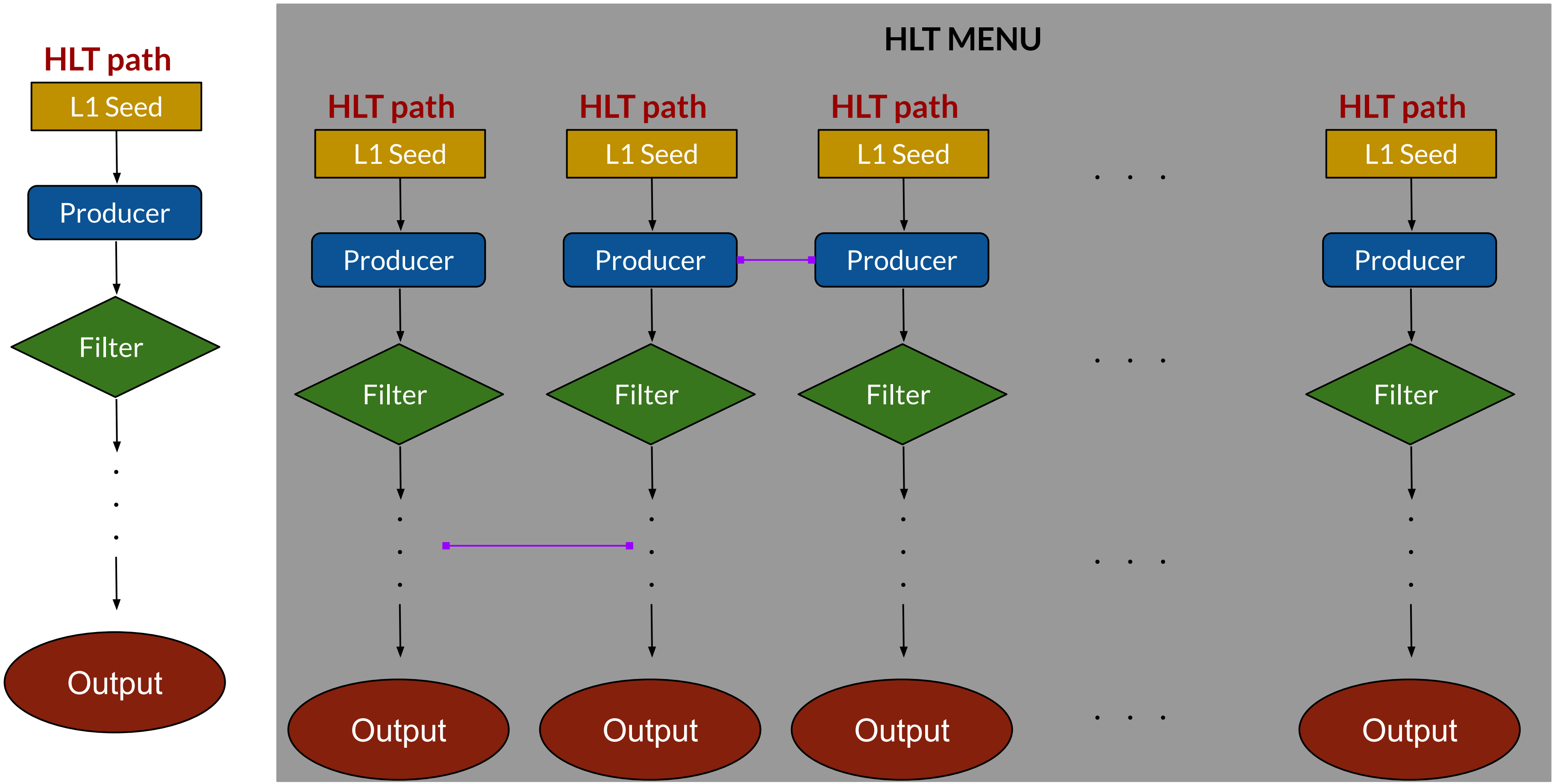
Backup


HLT path
L1 Seed
Producer
Filter
Output
HLT MENU
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L1 Seed
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HLT path
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Output
HLT path
L1 Seed
Producer
Filter
Output

L1 Vector Boson Fusion (VBF)

- VBF is sensitive to H→**ττ** and invisible decay's
  - Since 2017 VBF invariant mass calculation is implemented at L1
  - Trigger strategy: target VBF-induced jets rather than Higgs bosons decay products.
- The addition of the VBF algorithms increased the acceptance on the VBF H(ττ) signal by more than 40%.