CMS Trigger System

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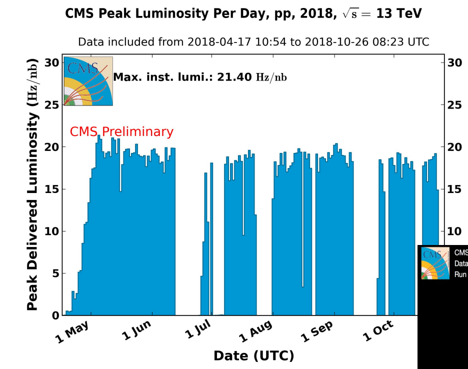
Collisions at LHC

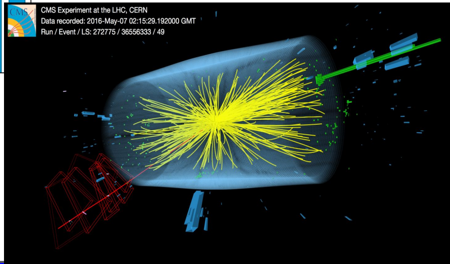
- ❖ Beams of protons or heavy ions accelerated with energy of TeV scale
- ❖ Particles circulate in bunches
- ❖ 25 ns bunch crossing typically gives 40 MHz bunch collision rate
  - ➢ Designed 2808 bunches/beam results in 32 MHz rate



- ❖ Instantaneous luminosity ~ 10^{34} / (s · cm^2) or 10 Hz/nb
  - ➢ Peak instantaneous luminosity ~ 1.8·10^{34} / (s · cm^2)
- ❖ 30-40 collisions per bunch crossing
- ❖ Very large number of collision events per second
- ❖ ~ 40 PB data per second!

Impossible to store

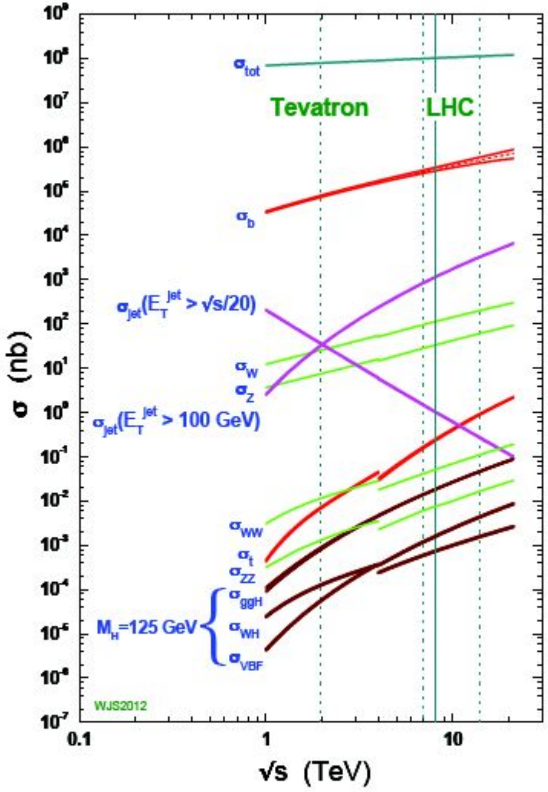
- ❖ Do all events have information we are looking for?



Physics Process Rate

- Probe processes predicted by theory

How often these processes happen?



Luminosity: 10 Hz/nb

Inelastic scattering:	10^9	Hz
W production:	10^3	Hz
tt production:	10	Hz
Higgs production:	0.1	Hz
SUSY particle (m @ TeV) production:	0.01	Hz

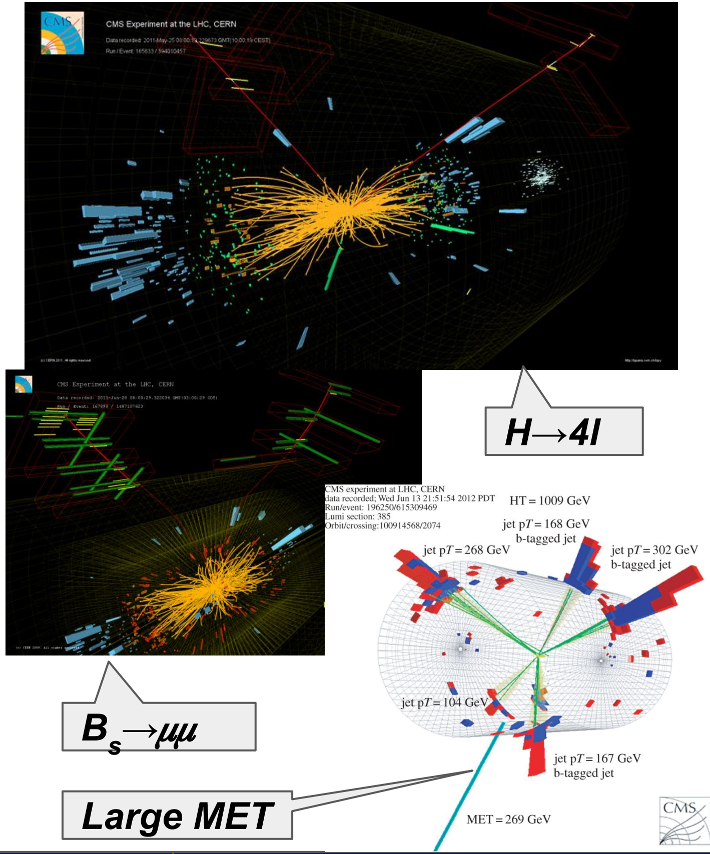
- Interesting events produced in much lower rate
- Store event information at affordable rate
- Select real time interesting events

Data Triggering

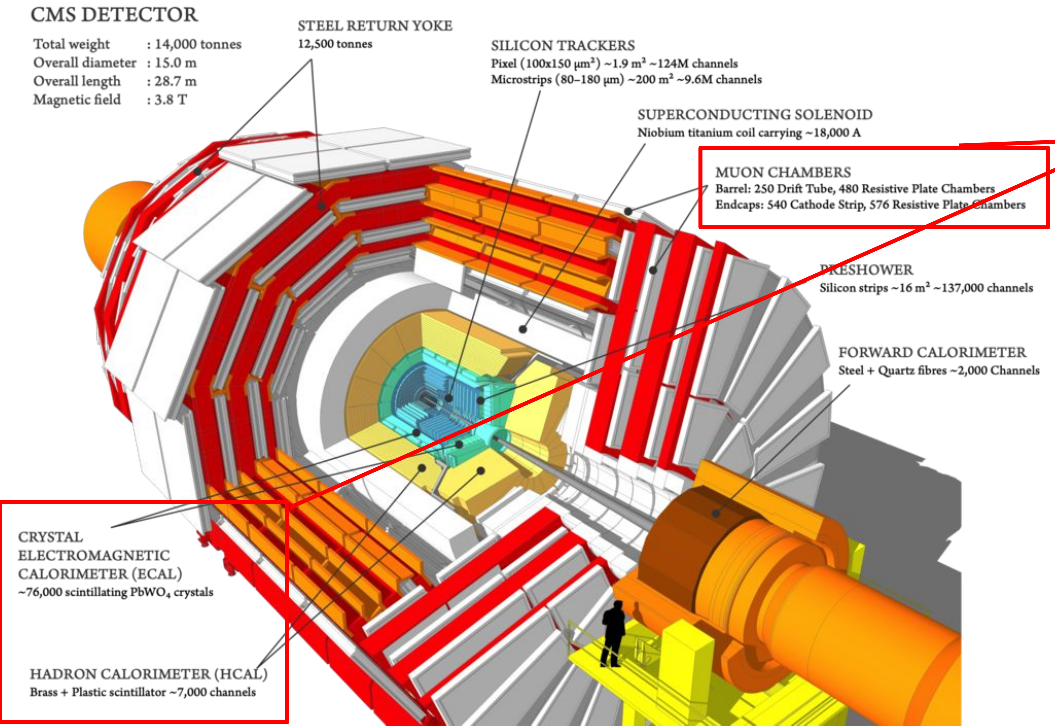
Principles of Trigger Systems

- ❖ Selection of events based on event topology
  - ➢ Final state detector signature
- ❖ Trigger system decides to store or reject an event
  - ➢ *Once rejected by trigger, event is lost forever*
- ❖ Efficient and clean decision
  - ➢ Select (almost) all “signal” events and throw away (almost) all uninteresting events
- ❖ Trigger universality
  - ➢ Ready for unexpected signatures
  - ➢ Should accept wide variety of events
  - ➢ Need unbiased collision event sample (only require activity in detector forward region)
    - ★ Minimum bias events
- ❖ Rate and time constraints
  - ➢ Selected event rate cannot exceed DAQ bandwidth *(100 kHz, 200 GB/s)*
  - ➢ Processing time should fit pipeline and buffer sizes *(3.8 μs)*

★ **CMS looks for events with distinct signature**

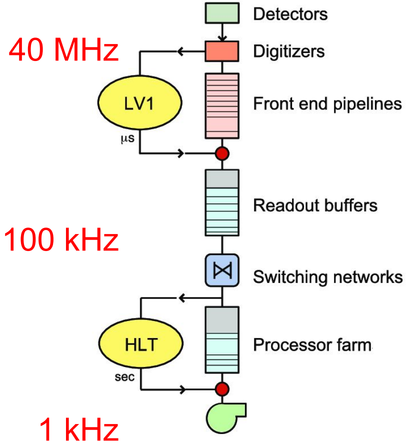


CMS Detector and Trigger



- ❖ Two-level trigger system
  - ➢ Hardware-based level-1 trigger
  - ➢ Software-based high-level trigger
- ❖ Reduce event rate to ~1 kHz from 40 MHz

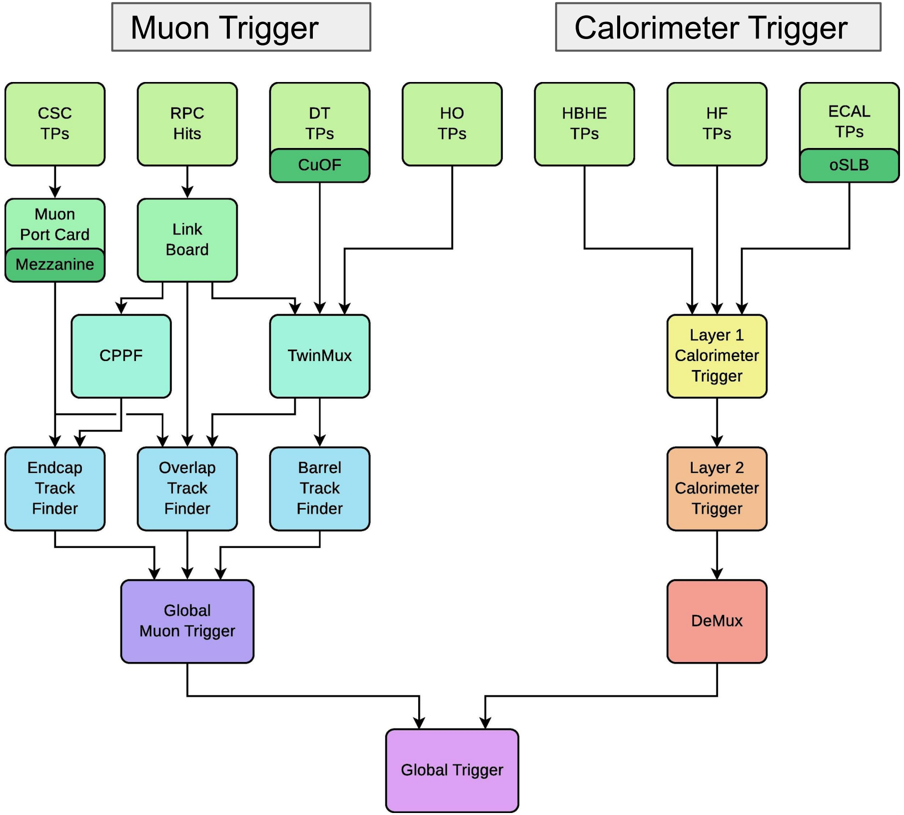
Trigger Rate



- ❖ Multi layer detector with tracker, calorimeter and muon systems
- ❖ Compact and robust

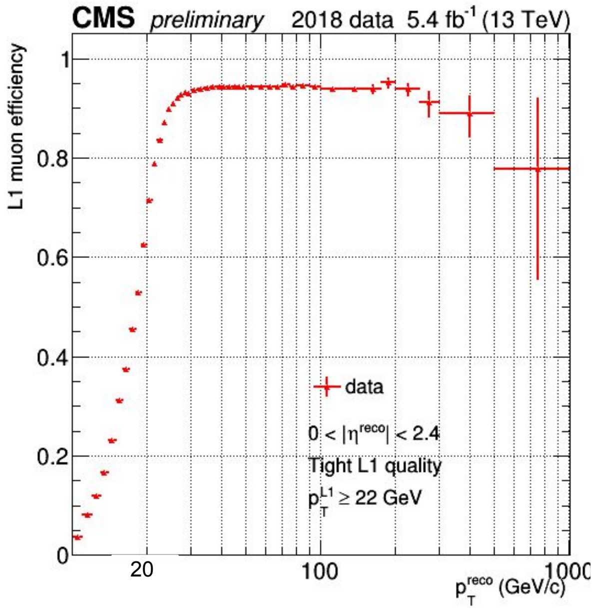
Level 1 (L1) Trigger : I

- Each event is analyzed with information from Calorimeter & Muon systems
- Dedicated electronics @ 40 MHz
- Pipeline processing with 3.8 μs latency
- Reconstruct trigger objects like muon, e/γ, tau candidates, jets and E_T sums
- A set of requirements on trigger objects
  → ***L1 trigger menu***
  ~400 requirements in a logical OR for pp collision
- L1 trigger sends accept signal to detector DAQ to read out full collision event data if at least one requirement passed

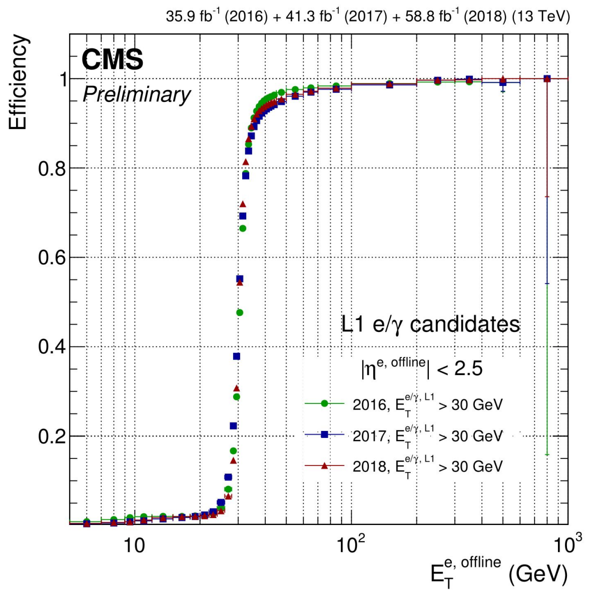


L1 trigger Performance

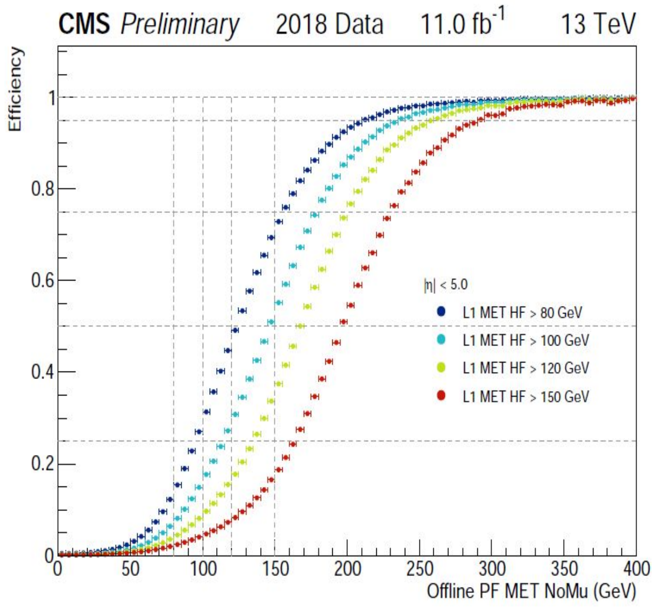
- ❖ Trigger performances measured in collisional data
  - ➢ Are triggers efficient to select events that we want to analyse “offline”?



- ★ Efficiency of selecting muon
- ★ Measured in $Z \rightarrow \mu\mu$ events



- ★ Efficiency of selecting e/γ candidate
- ★ Measured in $Z \rightarrow ee$ events



- ★ Efficiency of L1 missing E_T
- ★ Measured in single muon triggered events

High Level Trigger (HLT)

- HLT selection runs on online event filter farm with over *30,000* CPU cores & *60,000* threads

- 100 kHz input rate allows ~350 ms per event to reach decision with present computing resource

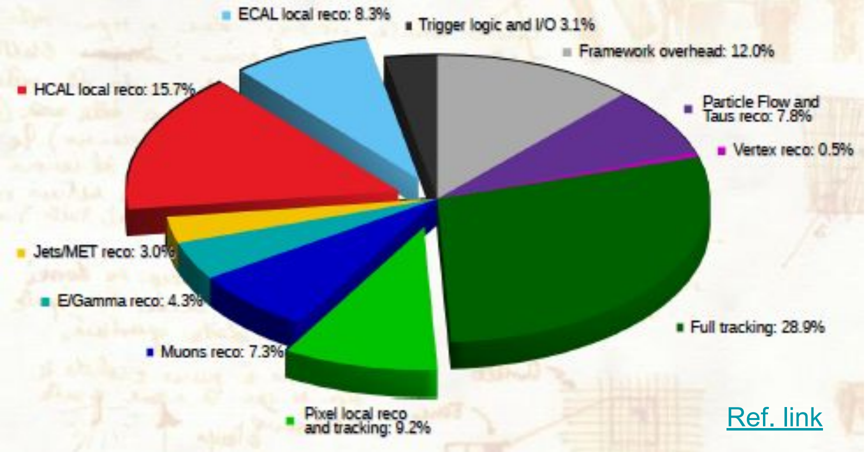
- Two parts: event building and trigger filtering

- Trigger decision structured around HLT "paths"
  - ***HLT menu***
    ~700 requirements in a logical OR for pp collision

- HLT paths consist of reconstruction and filtering algorithms

- The event taken if at least one path passed

Fraction of HLT event reconstruction time spent



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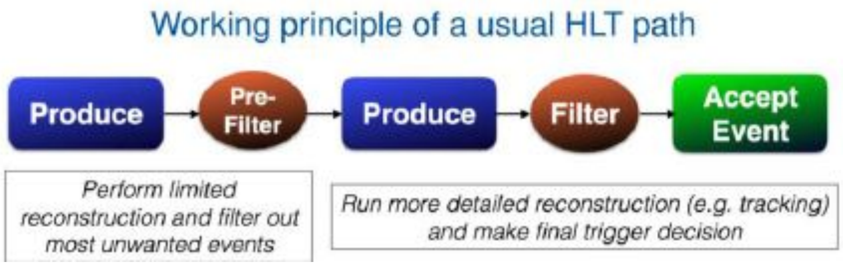
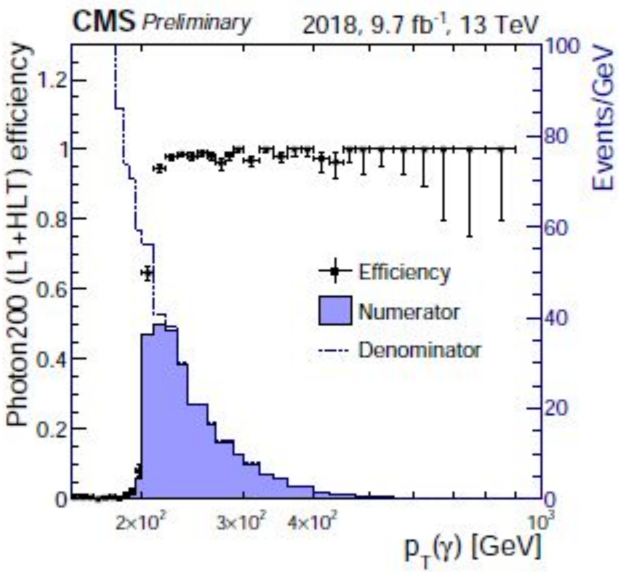
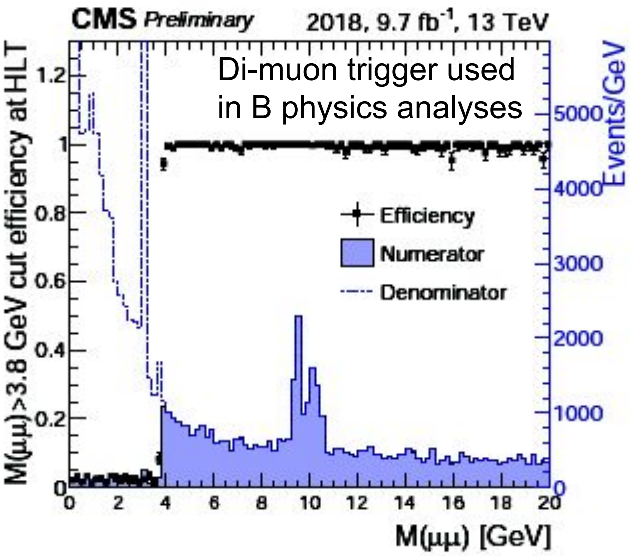


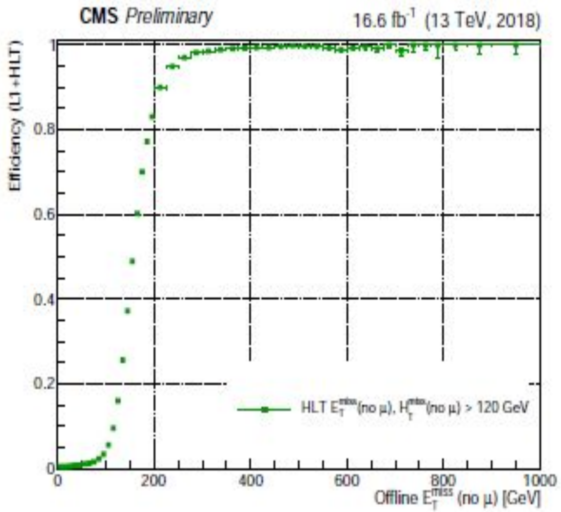
Two stages filtering to reduce processing time

HLT Performance

❖ Trigger requirements depend on the given physics analysis strategy







- ★ Single photon triggers show almost 100% efficiency
- ★ Used in many SM and BSM analyses with an isolated photon the in final state (γ+jet, Z(νν)γ..)

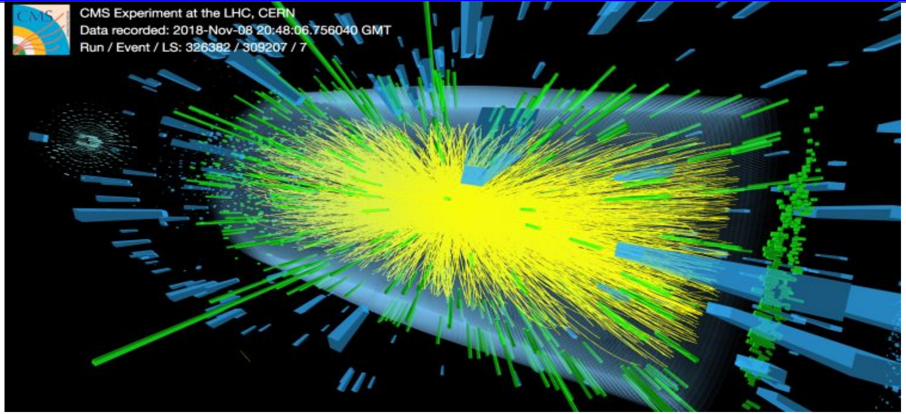
- ★ Lepton (e, μ) triggers provide clean event samples with ~100% efficiency
- ★ Used in many analyses containing W, Z, Higgs bosons, t, b quarks, exotic particles...

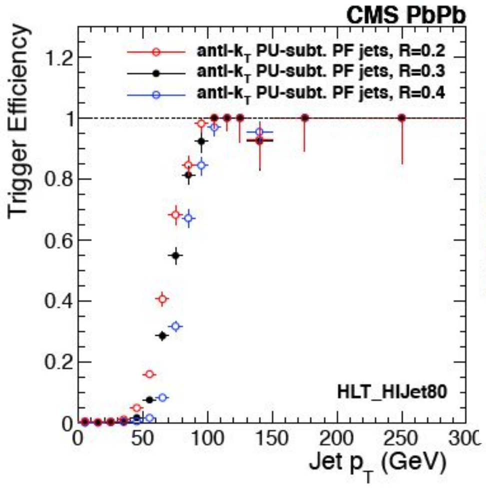
- ★ MET and hadronic activity triggers have high efficiency but slow turn on
- ★ Used mostly in BSM analyses

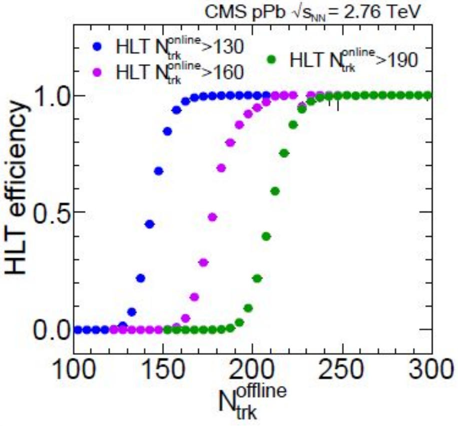
Heavy Ion Trigger

- ❖ Same L1 & HLT trigger system used for heavy ion (HI) collision data taking
- ❖ Different L1 & HLT requirements
- ❖ Condition for HI is different from pp collision
  - ➢ Larger bunch spacing (75 or 100 ns)
  - ➢ Lower inst. Luminosity ~$10^{27}/(s \cdot cm^2)$
  - ➢ Interaction rate @~200 kHz
- ❖ Larger number of particles in head-on collision
  - ➢ Larger event size ~3 MB
- ❖ Type of physics objects or events used in trigger
  - Hadronic interactions (minimum bias)
  - Electrons, muons
  - Photons
  - Jets
  - High-multiplicity events

Lower threshold on p_T, E_T







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Summary

- ❖ LHC produces pp and heavy ion collision data with very high rate
- ❖ CMS stores collision data with affordable rate utilizing two-level trigger system
- ❖ Efficient real-time event selection for physics analysis
- ❖ First step in any analysis we do; very important!
- ❖ A lot of (wo)man power towards the maintenance and improvement of trigger system

Thank You!

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