Optimizing trigger bandwidth

Usually two classes of triggers:

1. Physics triggers, can be statistically limited
2. Calibration triggers, statistics are not the fundamental limitation of a particular measurement.

Example: Measuring the Higgs production cross section.

Higgs decay modes:

$$H \to \gamma\gamma$$
$$H \to ZZ$$
$$H \to WW$$

$$ZZ \to 2\ell 2\ell' \quad \text{or} \quad ZZ \to 2\ell 2\nu$$

Trigger:
Two electrons $p_T^{(1)} > 23$ GeV, $p_T^{(2)} > 12$ GeV
Two muons $p_T^{(1)} > 17$ GeV, $p_T^{(2)} > 8$ GeV
One electron, one muon
Three leptons (lower thresholds)
(JHEP01 (2011) 080) Single electron $p_T > 27$ GeV
Single muon $p_T > 22$ GeV

In $36\ fb^{-1}$ at $\sqrt{s} = 13$ TeV observe 293 $4e$
505 4μ
681 $2e2\mu$
events after full selection. These are small numbers of events: Higgs production is rare.

Lower lepton trigger thresholds increase trigger rates, but does not significantly increase efficiency.

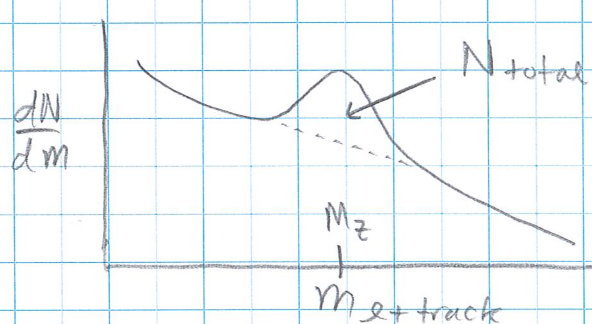
Systematic uncertainties:

1. Lepton trigger and reconstruction efficiencies
2. Background estimates.

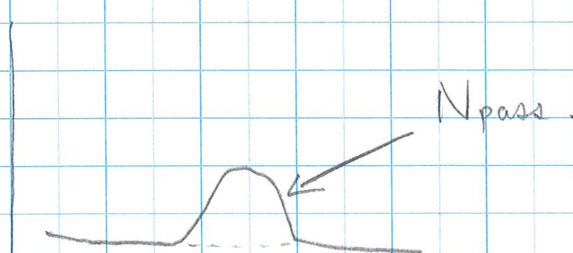
Efficiencies can only be estimated using Monte Carlo simulations but need to be constrained using data.

Measure efficiencies using "tag-and-probe" technique:

1. Trigger on a single lepton.
2. Reconstruct $Z \to \ell + \text{track}$
   - Backgrounds will be large because most tracks are not leptons.
   - Only tracks that are leptons will give a Z mass peak:



3. Apply lepton identification criteria (muon hits, electromagnetic cluster, isolation)



$$\varepsilon = \frac{N_{pass}}{N_{total}}.$$

The tag-and-probe method requires single-lepton triggers but these have a high trigger rate.

Increasing the trigger threshold on a single lepton changes the kinematics so that it might not be comparable to the sample of dilepton triggers used for the analysis.

If we are not statistics limited then maybe we don't need all the events collected using a single lepton trigger.

⟹ Randomly reject a predetermined fraction to control the trigger rate.

Allocate a fixed fraction of the 100 kHz L1 rate to calibration triggers.

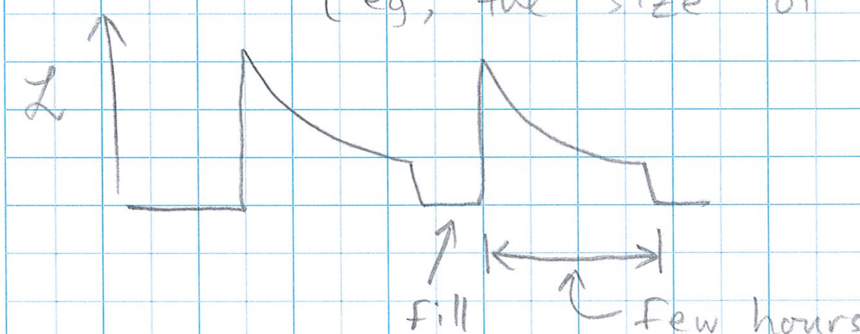
Prescale high rate triggers to control rate.

Optimizing trigger bandwidth

Trigger bandwidth remains fixed (eg, 100 kHz)
but $R = \sigma_{trigger} \times \mathcal{L}$

and the instantaneous luminosity decreases throughout a fill.

- protons interact
- protons are lost
- beam-beam interactions increase emittance (eg, the "size" of the bunches)



Trigger rates at the end of the fill will be lower than at the beginning leaving unutilized bandwidth.

$\Longrightarrow$ Dynamically change prescales throughout the fill. / Only enable high rate calibration triggers at the end.

$\Longrightarrow$ Switch to a different trigger menu part way through the fill.

Another problem is that at the start of a fill the number of pileup interactions can be very large.

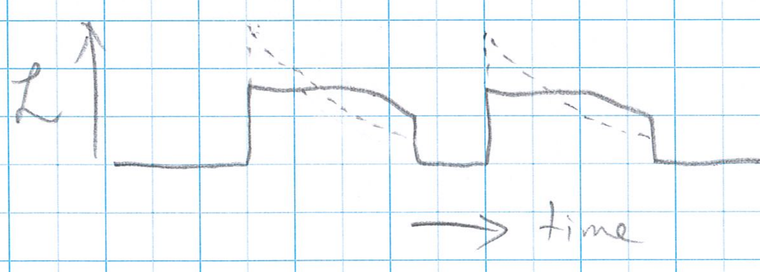
Fake trigger rates can be proportional to combinatorial factors

$$R_{Fake} \propto (\sigma \mathcal{L})^2 \quad \text{or worse}$$

Another approach for optimizing the operation of an experiment is luminosity leveling.

⇒ "defocus" the beams at the start of a fill to reduce the luminosity

⇒ systematically increase the focus to compensate for the loss of protons:



Similar (maybe lower) integrated luminosity but the data collected is of higher quality (larger fraction of physics triggers and fewer pileup interactions).