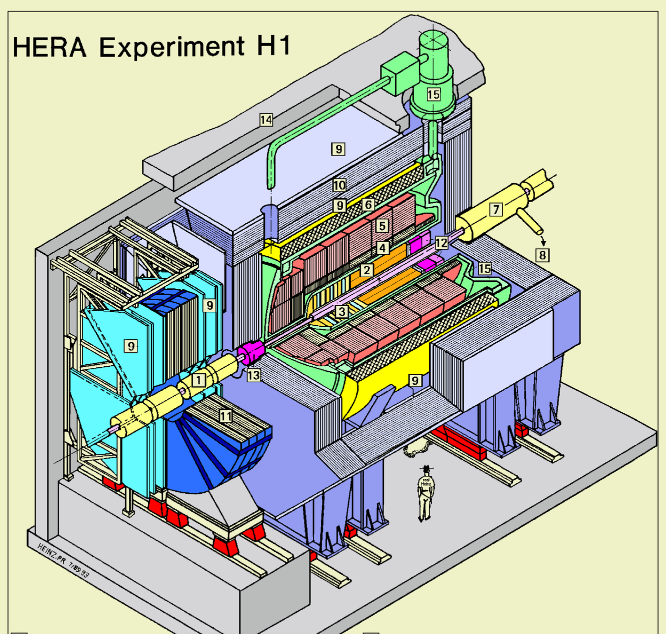
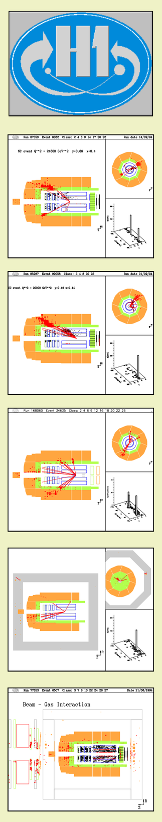
A General Scheme for Optimization of Trigger Rates in an Experiment with Limited Bandwidth

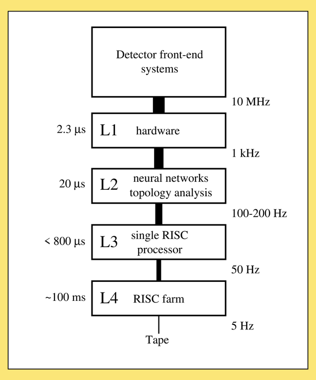
The H1 Detector and its Trigger System

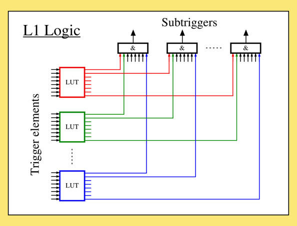


1 Beam pipe and beam magnets
2 Central tracking chambers
3 Forward tracking and Transition radiators
4 Electromagnetic Calorimeter (lead) } Liquid Argon
5 Hadronic Calorimeter (stainless steel) } Liquid Argon
6 Superconducting coil (1.2T)
7 Compensating magnet
8 Helium cryogenics
9 Muon chambers
10 Instrumented Iron (iron stabs + streamer tube detectors)
11 Muon toroid magnet
12 Warm electromagnetic calorimeter
13 Plug calorimeter (Cu, Si)
14 Concrete shielding
15 Liquid Argon cryostat



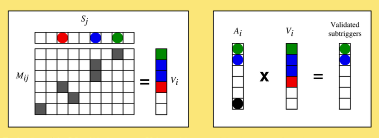
The H1 Trigger System





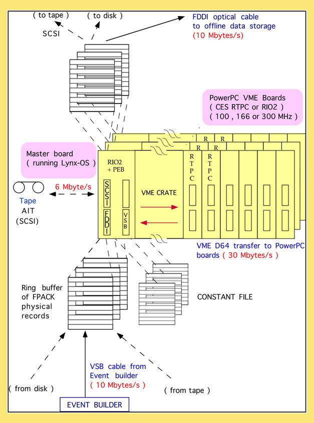
- L1 Trigger
  [IEEE Transactions on Nuclear Science, vol. 42 pp. 900-904, 1995]
  - Phase-locked to HERA-Clock signal of 10.4 MHz
  - Fully pipelined and deadtime free
  - Receives 256 Trigger Elements from Subdetectors
  - Generates 128 Subtrigger conditions
  - Downscaling for individual Subtriggers possible
  - Positive L1 decision after 2.4 µs
- L2 Trigger
  [IEEE Transactions on Nuclear Science, vol. 45, pp. 810-816, 1998]
  - L2 Topological trigger
  - L2 Neural Network trigger
  - Individual validation of L1 subtriggers
  - L2 decision after 20 µs
  - L2 output rate of 40-50 Hz without L3

L2 Logic



Evaluation of the L2 validation vector V_i by multiplying the L2 subtrigger mask S_i with Matrix M_{ij}.

L2 validation of L1 subtrigger mask A_i using the validation vector V_i.



- L4 Online Filtering
  [IEEE Transactions on Nuclear Science, vol. 39 pp. 255-258, 1992]
  - Asynchronous event filtering
  - Online event classification
  - Farm of RISC processors running a reduced version of the offline reconstruction code
  - Event processing time ~ 100 ms/event
  - Input rate presently limited to 40-50 Hz
  - L4 output rate to tape: 5-10 Hz

Authors

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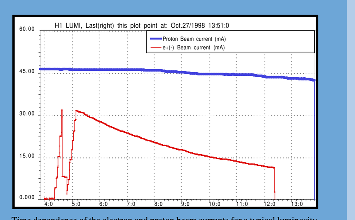
Abstract

Nowadays, general purpose high energy physics experiments are prepared to record the events of physics processes which greatly differ in rate. Both rare signatures with trigger rates of order 1 Hz and minimum bias interactions with rates sometimes approaching 1 MHz have to be triggered at the same time. The typical means of accommodating these requirements within a limited bandwidth is to downscale individual trigger channels appropriately. This paper is concerned with finding an optimized set of downscale factors that is automatically adapted to the beam conditions of the collider. A first application at the H1 experiment at HERA showed that the number of events recorded for specific channels could be greatly increased.

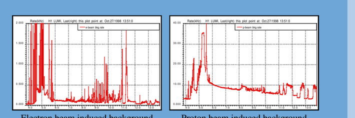
Adjusting Trigger Rates

Nature of the Problem

- Environment
  - Relative short beam lifetimes
  - Changing event rates with time
  - Varying background conditions
  - Bandwidth-limited acquisition system
- Trigger Conditions
  - Stable, low rate triggers for saving rare processes
  - Unbiased triggers with large event rates
  - Different background susceptibility, i.e. large impact of beam conditions on subtrigger behaviour
- Triggering Tasks
  - Allow acquisition of minimum bias data ...
  - ... without compromising efficiency for triggering rare or potentially new physics
- Solutions
  - Time dependent downscaling
  - Automatic optimization of time evolution

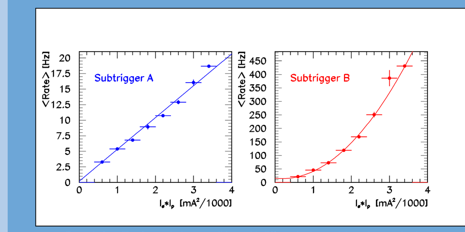


Time dependence of the electron and proton beam currents for a typical luminosity fill lasting approximatly 10 hours.



Electron beam induced background

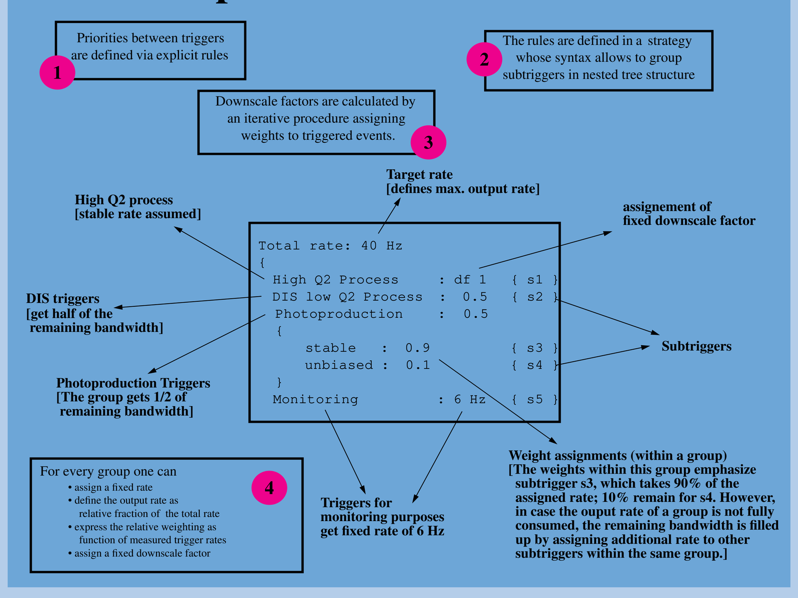
Proton beam induced background



Example from H1 of two subtrigger conditions with different background dependence on luminosity $L \sim I_e{*}I_p$, where I_e and I_p are the electron and proton beam currents. The rate of subtrigger A rises linearly with luminosity L, while that of B varies with L^2

- Requirements
  - Knowledge of the dependence of indivdual trigger rates on beam conditions
  - Estimation of the beam quality from measured trigger rates
  - A strategy defining the relative prioritiesof subtriggers based on physics goals and the desired dependence on beam conditions.

Optimization Procedure



Performance

Minimum Bias Run

Goal: Special data taking of unbiased data in order to improve measurements of photoproduction processes and to measure the longitudinal structure Function F_L in DIS.

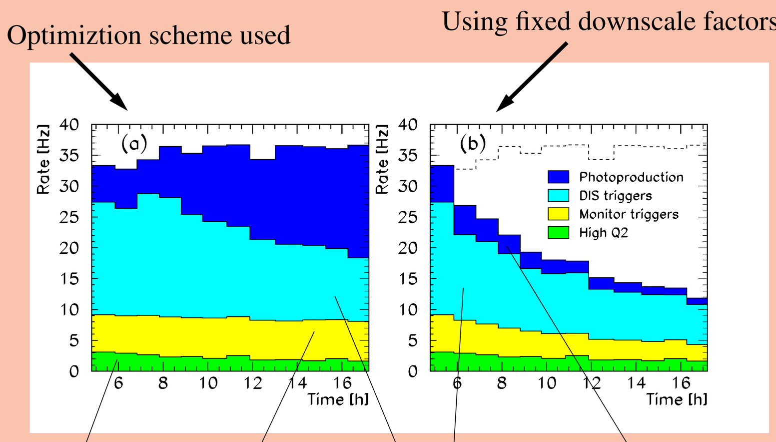
Integrated Luminosity in nb^{-1} for some triggers defined during the minimum bias data taking; (a) given the actual recorded luminosity, while the other would have been taken without any adaptation of trigger rates.

	Subtrigger	downscaling optimized	fixed downscale factors
High Q2	several	171.9	171.9
DIS Triggers	s0	171.9	171.9
	s9	146.6	28.6
	s3	171.9	19.6
Photoprod.	s69	77.6	13.2
	s70	62.5	9.6
	s80	1.5	0.1
	s105	2.0	0.1

- Two weeks of dedicated data taking
- Four subtrigger classes defined
  - High Q2 and triggers dedicated to rare signatures
  - DIS triggers for measurement of F_L
  - Photoproduction triggers
  - Monitor triggers
- Special optimization strategy developed
- Reevaluation of downscale factors once per hour
- Luminosity gain up to a factor of 20

Optimiztion scheme used

Using fixed downscale factors



Rate of high-Q2 triggers stays rather constant since prescale is kept one and backgrounds do not depend on luminosity.

Monitor rate fixed at a few Hz

Rate of DIS triggers saturates towards the end of the fill leaving space for opening up photoproduction triggers.

Photoproduction triggers only open up at end of fill where the relative background fraction is expected to be small

Optimizing Bandwidth Distribution

[a thought experiment with only two trigger conditions]

- Assumptions
  - Only two trigger conditions
  - Signal-to-background ratios for (a) Subtrigger A is 1:1 (b) Subtrigger B is 1:L²
  - Maximum output rate of 40 Hz
  - Beam lifetime: 10 hours
- Considered Scenarios
  - Equal rate splitting
  - Rate evolution via downscaling controlled by a relative weight κr_A^2 [where κ is chosen such that the total luminosity taken for subtrigger A stays constant.]
- Results
  - The second scenario leads to a gain in integrated luminosity of ~ 20%
  - Improvement depends on duration of a luminosity fill
  - Development of an optimized rate evolution possible (but non-trivial).

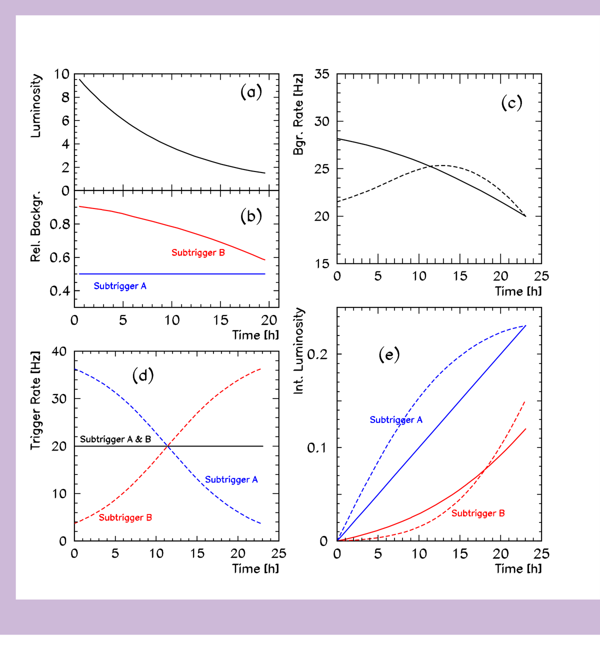
Scenario 1

```
Total rate: 40 Hz
{
   Subtrigger A:  20 Hz { s1 }
   Subtrigger B:  20 Hz { s2 }
}
```

Scenario 2

```
Total rate: 40 Hz
{
   Subtrigger A:  1.0            { s1 }
   Subtrigger B:  k*rate(s1)^2   { s2 }
}
```

An example of the performance gain due to non-trivial rate adjustment of two subtriggers A and B. Two different scenarios are considered: one (full lines) where the maximum rate is equally split between the two subtriggers, and one (dashed lines) where the downscale factors are distributed according to a relative weight $\sim \kappa r_A^2$ with κ chose such that the total luminosity taken for subtrigger A stays constant. (a) Luminosity (arbitrary units) evolution . (b) assumed backround fractions as a function of time for subtriggers A and B; (c) resulting background rates; (d) rate evolution with time; (e) recorded luminosity (arbitrary units) for A and B in the two cases considered.



Example Strategy

as used by H1 in the October 1997 Minimum Bias Run

Strategy File

```
Total rate: 40.0 Hz [35Hz,45Hz]
{
  low Q2 triggers: 1
  {
    Fl triggers:  20 {s9}
    F2:           10 {s0}
    kin peak:      1 {s3}
  }

  etag triggers: 0.05+5*rate(s9)/(5+rate(s69)^2)
  {
    etag33 && Track :        20 {s69}
    etag33 && SpaCal:        10 {s70}
    etag44 && Track :         1 {s80}
    etag44 && SpaCal:         1 {s105}
    etag8  && Track :         1 {s81}
    etag8  && SpaCal:         1 {s82}

    etag33 && FPS && Track : 1 Hz {s127}
    etag33 && FPS && SpaCal: 1 Hz {s125}
    etag44 && FPS && Track : 1 Hz {s124}
    etag44 && FPS && SpaCal: 1 Hz {s126}
    etag8  && FPS && Track : 1 Hz {s83}
    etag8  && FPS && SpaCal: 1 Hz {s84}
  }

  etag monitoring: 1 Hz {s86,s90,s99}

  background monitoring: 0.5 Hz
  {
    zvtx-t0:       1 {s104}
    SPCLe_ToF_E_1: 1 {s72}
  }

  pilot bunch triggers:      1 Hz {s101,s116-119}
  FPS calibration triggers:  1 Hz {s107,s112}

  lumi monitoring: 3.3 Hz
  {
    :1.2 Hz {s91}
    :0.3 Hz {s92}
    :0.6 Hz {s93}
    :0.6 Hz {s94}
    :0.6 Hz {s95}
  }

  sacred cows:        df 1 {s24,s25,s66,s67,s71,s75,s77}
  SpaCal and FNC LED: df 1 {s121,s123}

}
```

Output File

```
***********************************************************************
*  Rates with new prescale gaps after optimization                    *
***********************************************************************
Total rate:  40.000 ( 40.000 +/- 1.566 ) Hz
  low Q2 triggers:  28.479 ( 28.095 +/- 1.439 ) Hz
    Fl triggers (s9):  19.294 3 -> 1 * ( 18.100 +/- 1.251 ) Hz
    F2 (s0):  10.733 3 -> 2 * ( 9.799 +/- 0.668 ) Hz
    kin peak (s3):   1.073 10 -> 4 * ( 2.200 +/- 0.320 ) Hz
  etag triggers:   2.029 ( 2.412 +/- 0.280 ) Hz
    etag33 && Track  (s69):   0.048 20 -> 1350 * ( 0.048 +/- 0.005 ) Hz
    etag33 && SpaCal (s70):   0.048 50 -> 954 * ( 0.048 +/- 0.008 ) Hz
    etag44 && Track  (s80):   0.483 500 -> 984 * ( 0.483 +/- 0.084 ) Hz
    etag44 && SpaCal (s105):   0.483 1000 -> 739 * ( 0.483 +/- 0.125 ) Hz
    etag8  && Track  (s81):   0.483 500 -> 845 * ( 0.483 +/- 0.090 ) Hz
    etag8  && SpaCal (s82):   0.483 1000 -> 579 * ( 0.867 +/- 0.195 ) Hz
    etag33 && FPS && Track  (s127):   1.000 10 -> 1 * ( 0.000 +/- 0.000 ) Hz
    etag33 && FPS && SpaCal (s125):   1.000 1 -> 1 * ( 0.000 +/- 0.000 ) Hz
    etag44 && FPS && Track  (s124):   1.000 20 -> 1 * ( 0.000 +/- 0.000 ) Hz
    etag44 && FPS && SpaCal (s126):   1.000 10 -> 1 * ( 0.000 +/- 0.000 ) Hz
    etag8  && FPS && Track  (s83):   1.000 20 -> 1 * ( 0.000 +/- 0.000 ) Hz
    etag8  && FPS && SpaCal (s84):   1.000 10 -> 1 * ( 0.000 +/- 0.000 ) Hz
  etag monitoring:   1.000  ( 1.000 +/- 0.185 ) Hz
    s86:   0.333 100000 -> 58590 * ( 0.333 +/- 0.130 ) Hz
    s90:   0.333 300000 -> 1091584 * ( 0.333 +/- 0.049 ) Hz
    s99:   0.333 100000 -> 63392 * ( 0.333 +/- 0.122 ) Hz
  background monitoring:   0.500 ( 0.500 +/- 0.158 ) Hz
    zvtx-t0 (s104):   0.250 100000 -> 80339 * ( 0.250 +/- 0.091 ) Hz
    SPCLe_ToF_E_1 (s72):   0.250 100001 -> 42557 * ( 0.250 +/- 0.129 ) Hz
  pilot bunch triggers:   1.000 ( 1.000 +/- 0.210 ) Hz
    s101:   0.200 5000 -> 6960 * ( 0.200 +/- 0.065 ) Hz
    s116:   0.200 10001 -> 2545 * ( 0.200 +/- 0.126 ) Hz
    s117:   0.200 5000 -> 7082 * ( 0.200 +/- 0.063 ) Hz
    s118:   0.200 5000 -> 3770 * ( 0.200 +/- 0.089 ) Hz
    s119:   0.200 30000 -> 17246 * ( 0.200 +/- 0.100 ) Hz
  FPS calibration triggers:   1.000 ( 0.063 +/- 0.063 ) Hz
    s107:   0.500 2 -> 1 * ( 0.063 +/- 0.063 ) Hz
    s112:   0.937 2 -> 1 * ( 0.000 +/- 0.000 ) Hz
  lumi monitoring:   3.300 ( 3.300 +/- 0.260 ) Hz
    s91:   1.200 300000 -> 436893 * ( 1.200 +/- 0.121 ) Hz
    s92:   0.300 300000 -> 492204 * ( 0.300 +/- 0.048 ) Hz
    s93:   0.600 1000000 -> 1459162 * ( 0.600 +/- 0.082 ) Hz
    s94:   0.600 50000 -> 82718 * ( 0.600 +/- 0.094 ) Hz
    s95:   0.600 200000 -> 259703 * ( 0.600 +/- 0.091 ) Hz
  sacred cows          :   0.000 ( 2.846 +/- 0.300 ) Hz
    s24:   0.000 1 -> 1 * ( 0.000 +/- 0.000 ) Hz
    s25:   0.000 1 -> 1 * ( 0.063 +/- 0.045 ) Hz
    s66:   0.000 1 -> 1 * ( 0.095 +/- 0.055 ) Hz
    s67:   0.000 1 -> 1 * ( 0.443 +/- 0.118 ) Hz
    s71:   0.000 1 -> 1 * ( 0.569 +/- 0.134 ) Hz
    s75:   0.000 1 -> 1 * ( 0.095 +/- 0.055 ) Hz
    s77:   0.000 1 -> 1 * ( 1.897 +/- 0.245 ) Hz
  SpaCal and FNC LED  :   0.000 ( 0.854 +/- 0.164 ) Hz
    s121:   0.000 1 -> 1 * ( 0.854 +/- 0.164 ) Hz
    s123:   0.000 1 -> 1 * ( 0.854 +/- 0.164 ) Hz

Analysis converged OK.
```

Prediction of Rates and Cross Section Calculation

Probability

for an event to be accepted after downscaling

$$P_{jk} = 1 - \prod_{i=1}^{N_s}\left(1 - \frac{r_{ij}}{d_{ik}}\right)$$

- N_s = Number of subtriggers
- N_e = Number of triggered events
- N_d = Number of sets of downscale factors
- r_{ij} = 0 or 1; Binary decision of subtrigger i in event j
- d_{ik} = downscale factor for subtrigger i for set k
- T = active time during which events are triggerd
- L_k = luminosity when set k was active
- ε = combined trigger efficiency

Rate Prediction

for a new set of downscale factors k' using a sample of N_e triggered events

$$\nu_{k'} = \frac{1}{T}\sum_{j=1}^{N_e}\frac{P_{jk'}}{P_{jk}}$$

Raw Cross Section

determined by averaging over long time periods with constant trigger conditons, but varying sets downscale factors to avoid large variations over event weights

$$\sigma^{raw} = \frac{1}{\varepsilon}\sum_{j=1}^{N_e}\sum_{k=1}^{N_d}\left[L_k\left(1 - \prod_{i=1}^{N_s}\left(1 - \frac{r_{ij}}{d_{ik}}\right)\right)\right]^{-1}$$