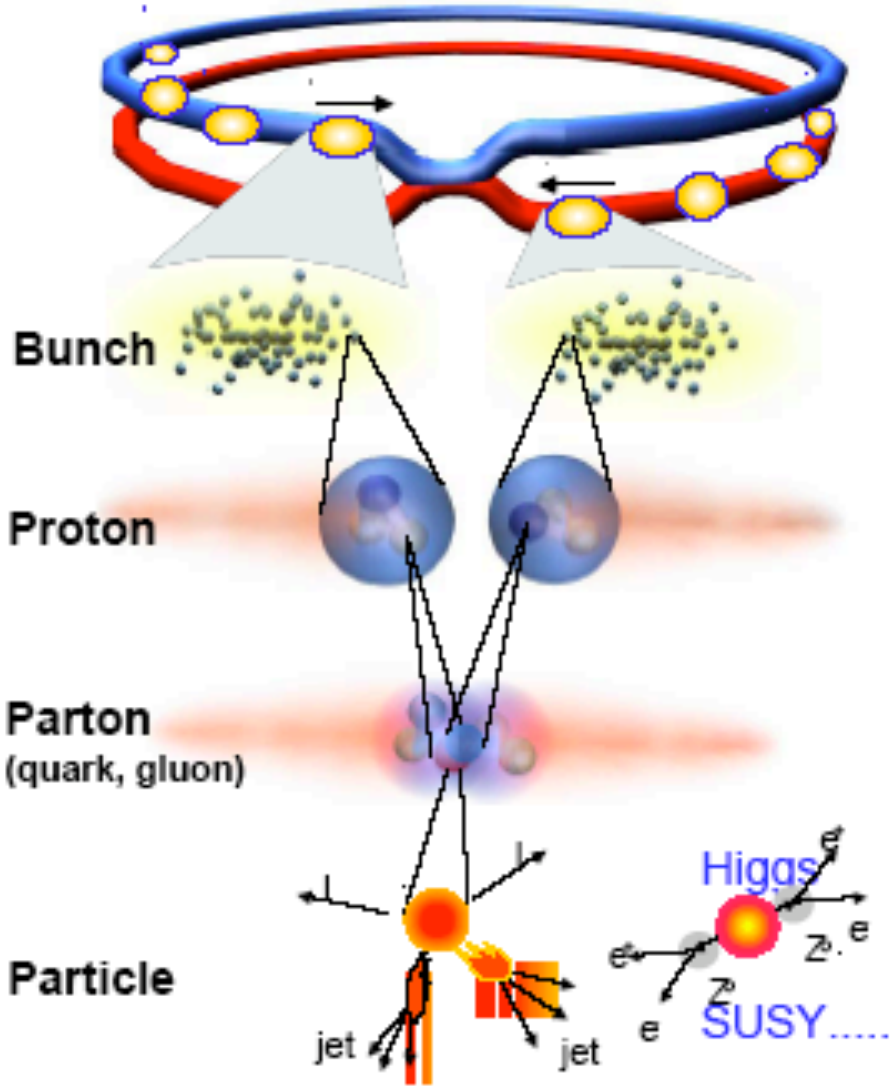
Trigger Intro

Little to no detailed facts.

Instead focus on basic concepts.

Almost all slides are from P.Sphicas SLAC Summer Institute lectures.

Collisions at the LHC: summary



Proton - Proton	2804 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	$10^{34} cm^{-2} s^{-1}$
Crossing rate	40 MHz

= one crossing per 25ns

Collision rate ≈ 10^{7}-10^{9}

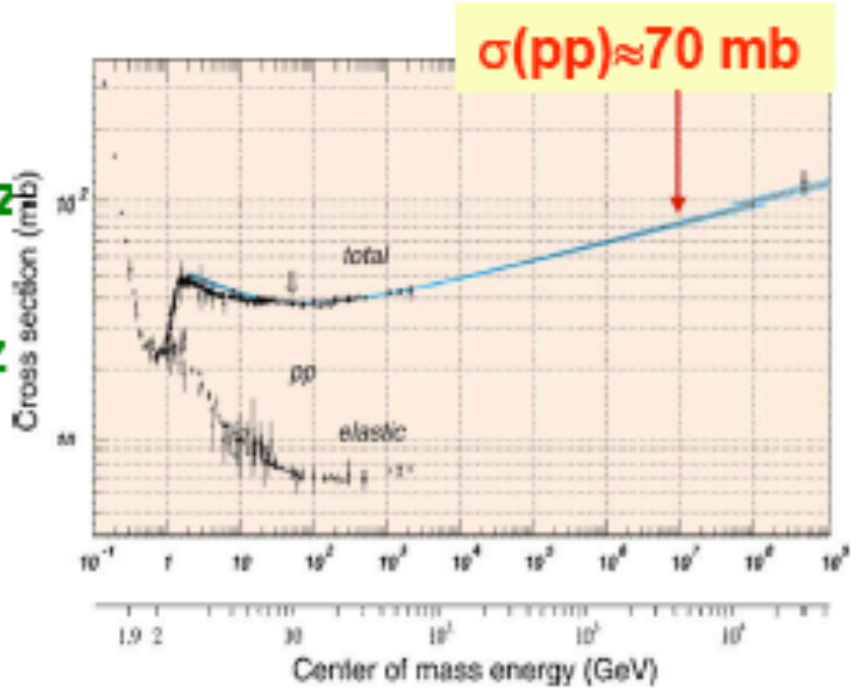
= 0.25-25 collisions/crossing

New physics rate ≈ .00001 Hz

Event selection:
1 in 10,000,000,000,000

pp cross section and min. bias

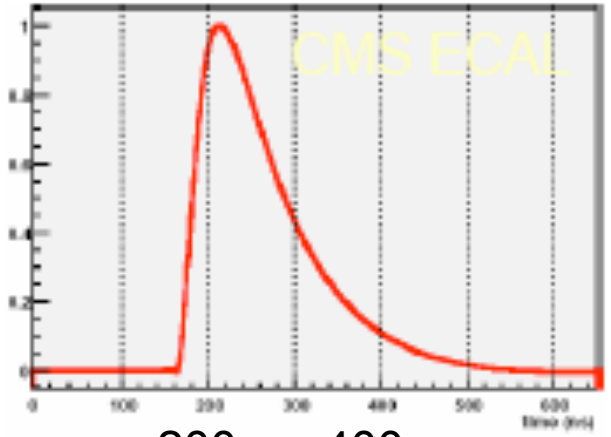
- # of interactions/crossing:
  - Interactions/s:
    - Lum = 10^{34} $cm^{-2}s^{-1}$=$10^{7}mb^{-1}Hz$
    - $\sigma(pp)$ = 70 mb
    - Interaction Rate, R = $7x10^{8}$ Hz
  - Events/beam crossing:
    - Δt = 25 ns = $2.5x10^{-8}$ s
    - Interactions/crossing=17.5
  - Not all p bunches are full
    - 2835 out of 3564 only
    - Interactions/"active" crossing = 17.5 x 3564/2835 = 23



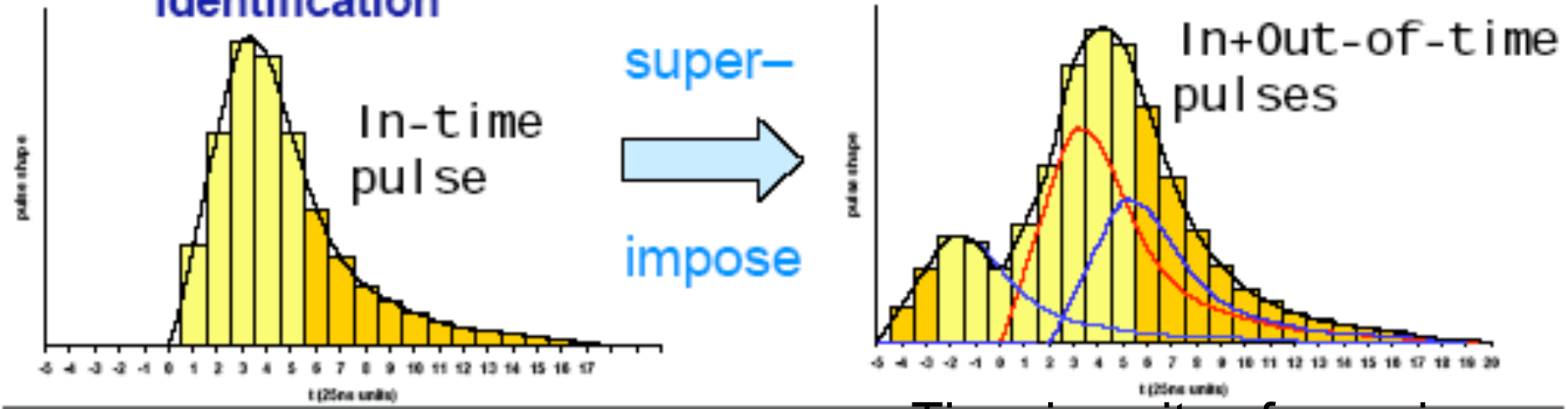
Operating conditions (summary):
1) A "good" event containing a Higgs decay +
2) ≈ 20 extra "bad" (minimum bias) interactions

Pile-up

- "In-time" pile-up: particles from the same crossing but from a different pp interaction
- Long detector response/pulse shapes:
  - "Out-of-time" pile-up: left-over signals from interactions in previous crossings
  - Need "bunch-crossing identification"



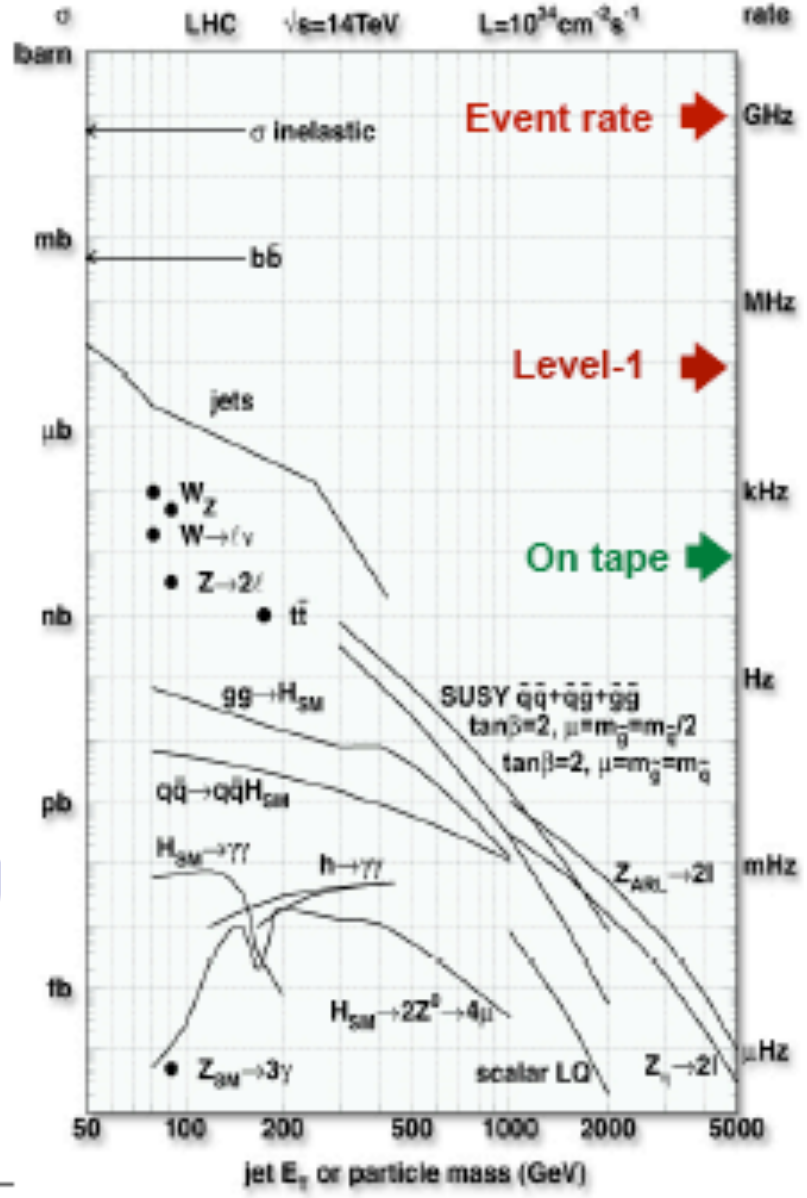
200ns 400ns



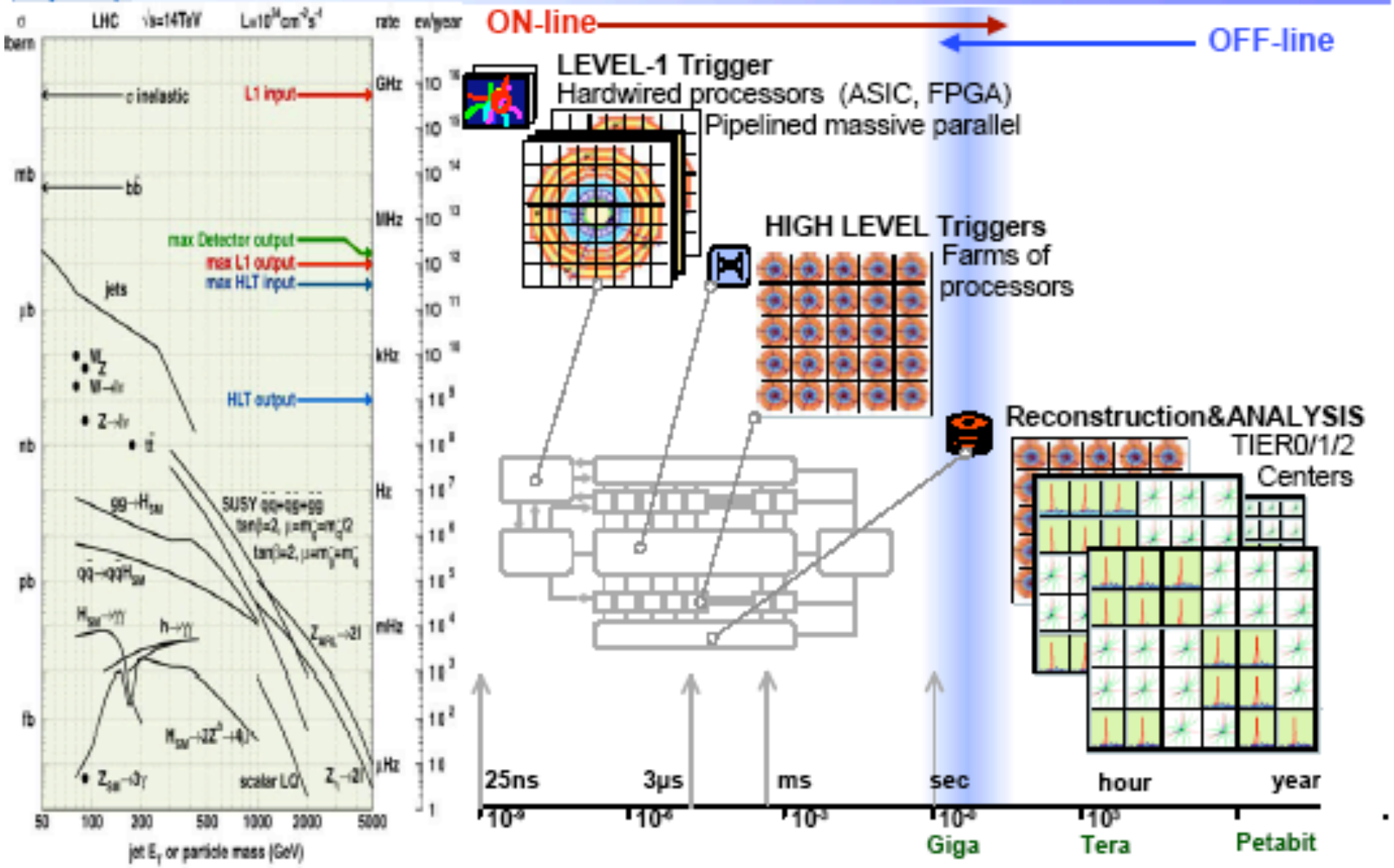
Time in units of crossings

Selectivity: the physics

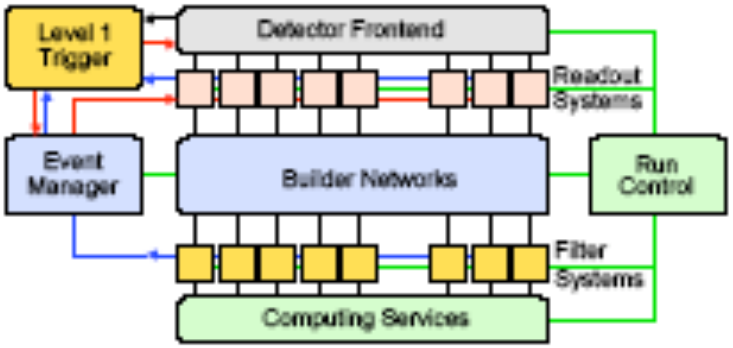
- **Cross sections of physics processes vary over many orders of magnitude**
  - Inelastic: 10^9 Hz
  - $W \rightarrow \ell \nu$: 10^2 Hz
  - t t production: 10 Hz
  - Higgs (100 GeV/c^2): 0.1 Hz
  - Higgs (600 GeV/c^2): 10^{-2} Hz
- **QCD background**
  - Jet E_T ~250 GeV: rate = 1 kHz
  - Jet fluctuations → electron bkg
  - Decays of K, π, b → muon bkg
- **Selection needed: 1:10^{10-11}**
  - Before branching fractions...

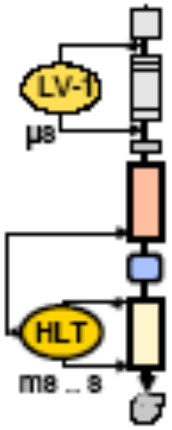


Physics selection at the LHC



Two physical entities



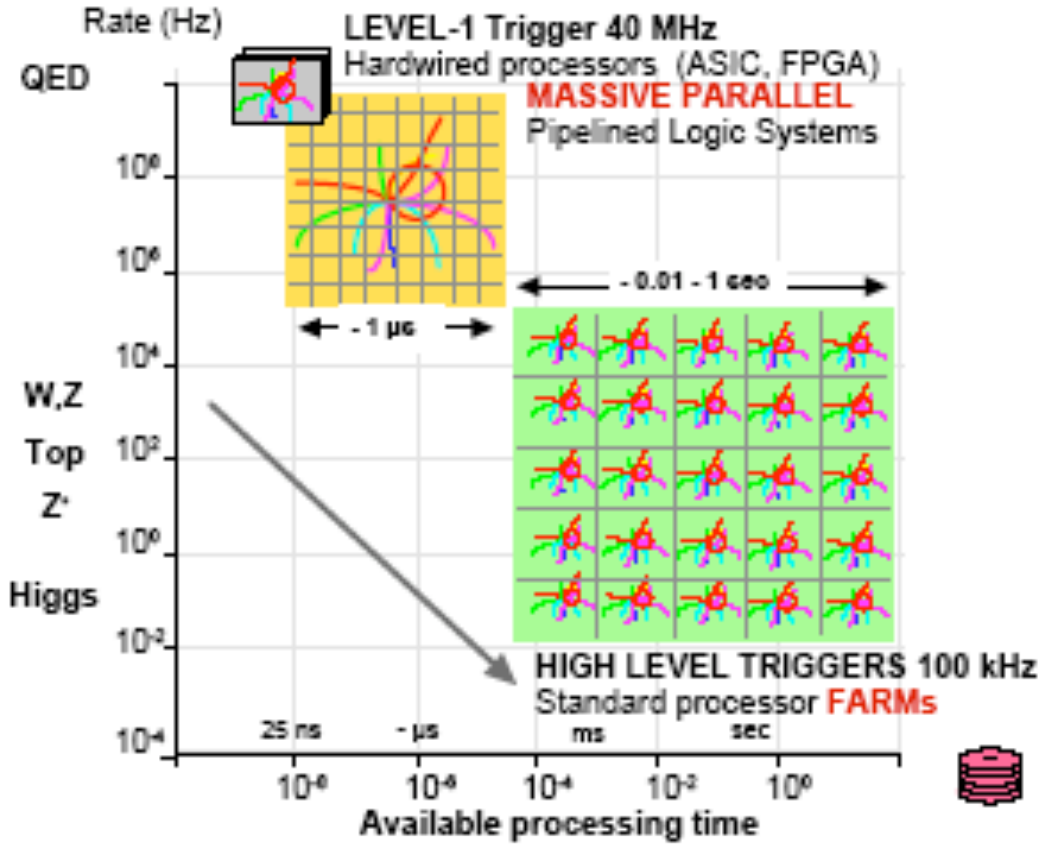


40 MHz

10^5 Hz

1000 Gb/s

10^2 Hz



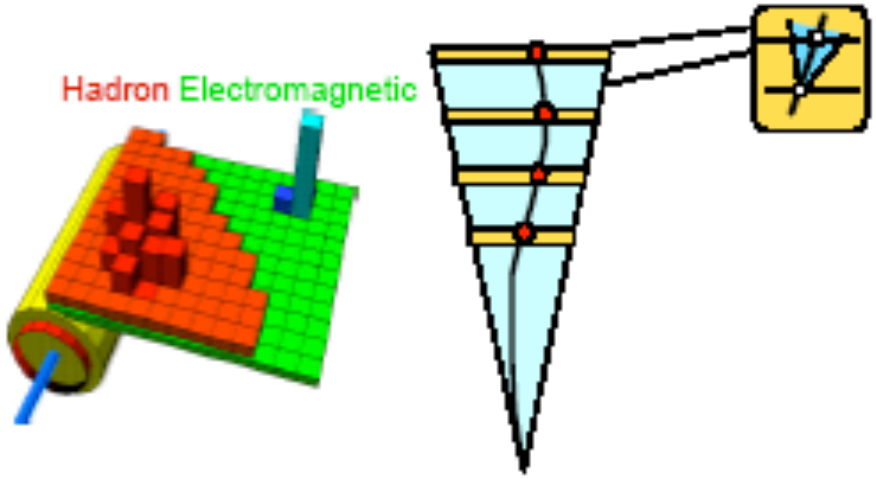
L1 gets us from 40MHz to 100kHz using a fixed 3µs to decide.
HLT gets us from 100kHz to 100Hz using 0.01-1sec to decide.

Level-1 trigger algorithms

- **Physics facts:**
  - pp collisions produce mainly hadrons with P_T~1 GeV
  - Interesting physics (old and new) has particles (leptons and hadrons) with large transverse momenta:
    - $W \rightarrow e\nu$: $M(W)=80$ GeV/c^2; $P_T(e)$ ~ 30-40 GeV
    - $H(120\ \text{GeV}) \rightarrow \gamma\gamma$: $P_T(\gamma)$ ~ 50-60 GeV
- **Basic requirements:**
  - Impose high thresholds on particles
    - Implies distinguishing particle types; possible for electrons, muons and "jets"; beyond that, need complex algorithms
  - Typical thresholds:
    - Single muon with P_T>20 GeV (rate ~ 10 kHz)
      - ➔ Dimuons with P_T>6 (rate ~ 1 kHz)
    - Single e/γ with P_T>30 GeV (rate ~ 10-20 kHz)
      - ➔ Dielectrons with P_T>20 GeV (rate ~ 5 kHz)
    - Single jet with P_T>300 GeV (rate ~ 0.2-0.4 kHz)

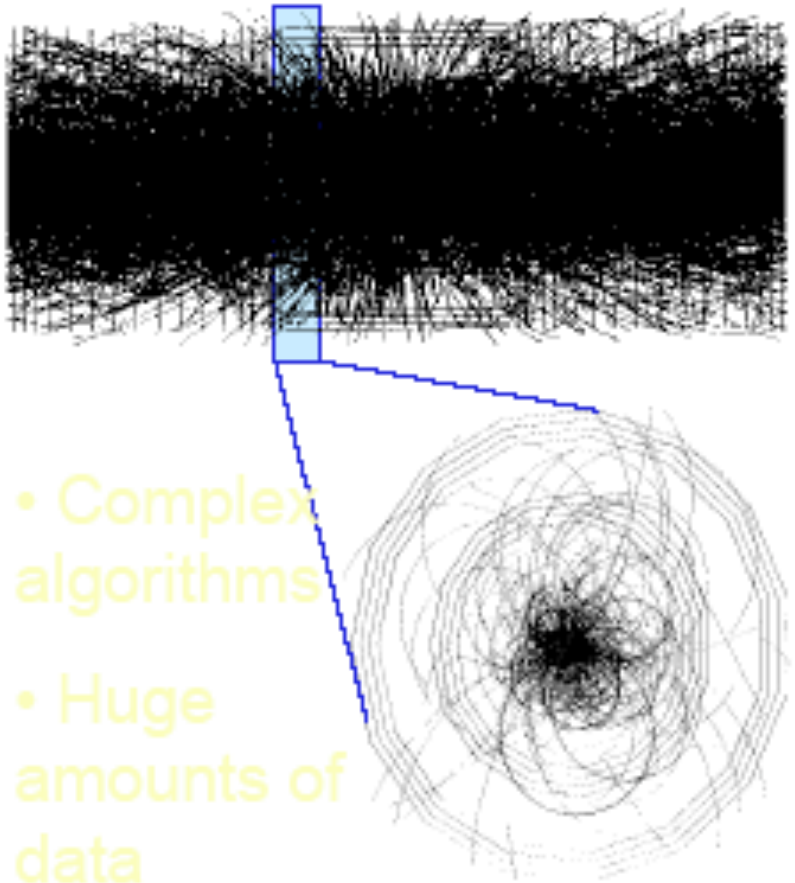
At Level-1: only calo and muon info

- **Pattern recognition much faster/easier**

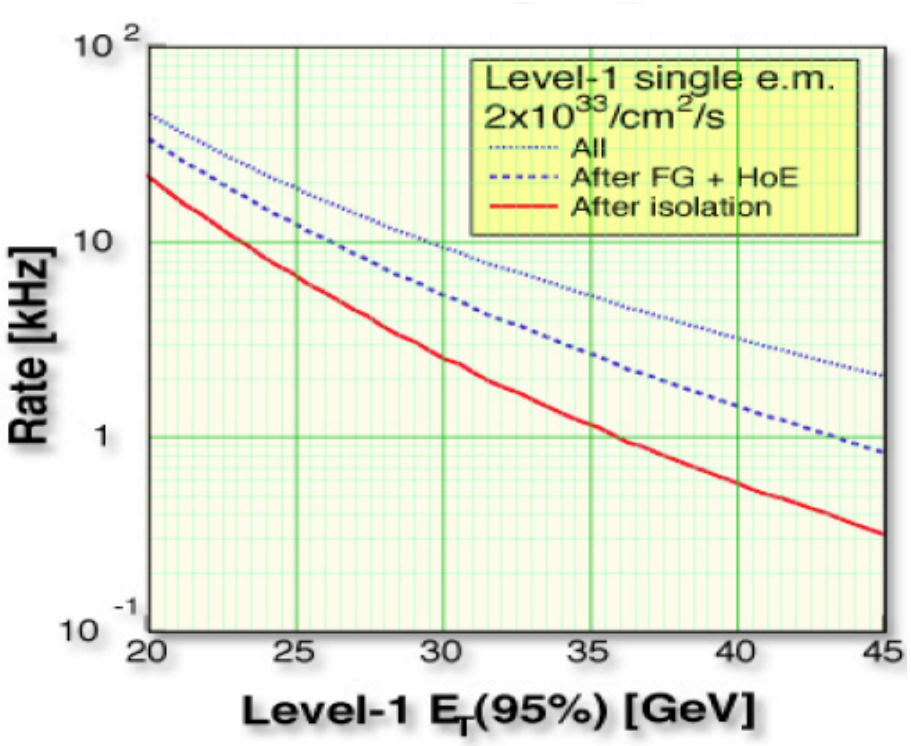


- **Simple algorithms**
- **Small amounts of data**
- **Local decisions**

- **Compare to tracker info**



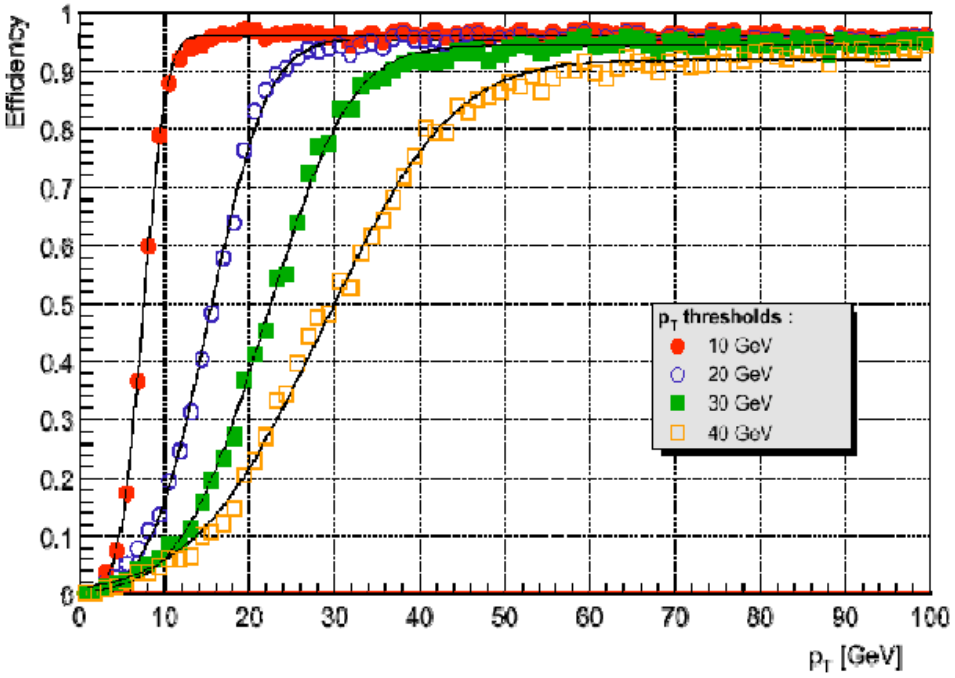
- Complex algorithms
- Huge amounts of data
- Need to link sub-detectors



Two characteristic features.

Rate decreases exponentially with threshold.

Thresholds are never sharp.



Global Trigger

- A very large OR-AND network that allows for the specification of complex conditions:
  - 1 electron with P_T>20 GeV OR 2 electrons with P_T>14 GeV OR 1 electron with P_T>16 and one jet with P_T>40 GeV…
  - The top-level logic requirements (e.g. 2 electrons) constitute the "trigger-table" of the experiment
    - Allocating this rate is a complex process that involves the optimization of physics efficiencies vs backgrounds, rates and machine conditions

Triggers change as instantaneous luminosity changes, and we learn more about the operating conditions!

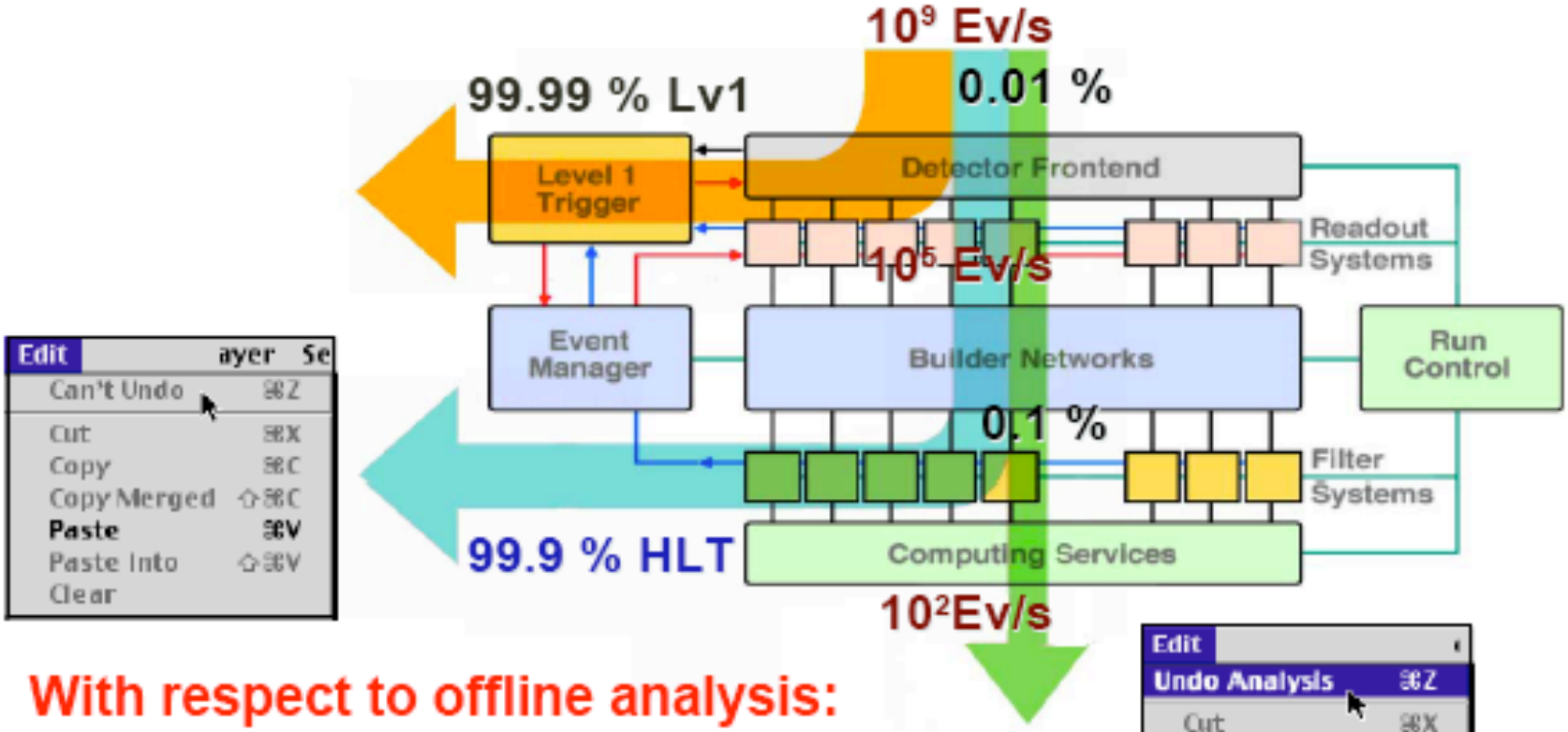
Table E.11: The Level-1 Trigger Menu at $\mathcal{L} = 2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ Individual and cumulative rates are given for the different trigger paths and selected kinematic thresholds.

Trigger	Level-1 Threshold (GeV)	Level-1 Rate (kHz)	Cumulative Level-1 Rate (kHz)
Inclusive $e\,\gamma$	22	3.9 ± 0.3	3.9 ± 0.3
Double $e\,\gamma$	11	1.0 ± 0.1	4.6 ± 0.3
Inclusive μ	14	2.5 ± 0.2	7.1 ± 0.3
Double μ	3	4.0 ± 0.3	11.0 ± 0.4
Inclusive τ	100	2.2 ± 0.2	12.9 ± 0.5
Double τ	60	3.0 ± 0.2	14.9 ± 0.5
1-,2-,3-,4-jets	150,100,70,50	2.2 ± 0.2	15.8 ± 0.5
H_{T}	275	2.0 ± 0.2	16.2 ± 0.5
$E_{\mathrm{T}}^{\mathrm{miss}}$	60	0.4 ± 0.1	16.3 ± 0.5
$H_{\mathrm{T}} + E_{\mathrm{T}}^{\mathrm{miss}}$	200, 40	1.1 ± 0.1	16.6 ± 0.5
jet + $E_{\mathrm{T}}^{\mathrm{miss}}$	100, 40	1.1 ± 0.1	16.7 ± 0.5
$\tau + E_{\mathrm{T}}^{\mathrm{miss}}$	60, 40	2.7 ± 0.2	18.8 ± 0.5
$\mu + E_{\mathrm{T}}^{\mathrm{miss}}$	5, 30	0.3 ± 0.1	19.0 ± 0.6
$e\,\gamma + E_{\mathrm{T}}^{\mathrm{miss}}$	15, 30	0.5 ± 0.1	19.1 ± 0.6
μ + jet	7, 100	0.2 ± 0.1	19.1 ± 0.6
$e\,\gamma$ + jet	15, 100	0.6 ± 0.1	19.2 ± 0.6
$\mu + \tau$	7, 40	1.2 ± 0.1	19.8 ± 0.6
$e\,\gamma + \tau$	15, 60	2.6 ± 0.2	20.5 ± 0.6
$e\,\gamma + \mu$	15, 7	0.2 ± 0.1	20.5 ± 0.6
Prescaled			22.3 ± 0.6
Total Level-1 Rate			22.3 ± 0.6

Table E.8: Comparison of HLT bandwidth given to various trigger paths calculated in this study with the DAQ TDR. See text for details on different kinematic cuts and changes in the HLT algorithms.

Trigger	DAQ TDR Rate (Hz)	New Rate (Hz)
Inclusive e	33.0	23.5 ± 6.7
e-e	1.0	1.0 ± 0.1
Relaxed e-e	1.0	1.3 ± 0.1
Inclusive γ	4.0	3.1 ± 0.2
γ-γ	5.0	1.6 ± 0.7
Relaxed γ-γ	5.0	1.2 ± 0.6
Inclusive μ	25.0	25.8 ± 0.8
μ-μ	4.0	4.8 ± 0.4
$\tau + E_{\mathrm{T}}^{\mathrm{miss}}$	1.0	0.5 ± 0.1
$\tau + e$	2.0	< 1.0
Double Pixel τ	1.0	4.1 ± 1.1
Double Tracker τ	1.0	6.0 ± 1.1
Single jet	1.0	4.8 ± 0.0
Triple jet	1.0	1.1 ± 0.0
Quadruple jet	7.0	8.9 ± 0.2
jet + $E_{\mathrm{T}}^{\mathrm{miss}}$	5.0	3.2 ± 0.1
b-jet (leading jet)	5.0	10.3 ± 0.3
b-jet (2^{nd} leading jet)	5.0	8.7 ± 0.3

A parting thought



With respect to offline analysis:

Same hardware (Filter Subfarms)

Same software (

But different situations