CMS Online Event Selection

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EPS
Detectors & Data Handling
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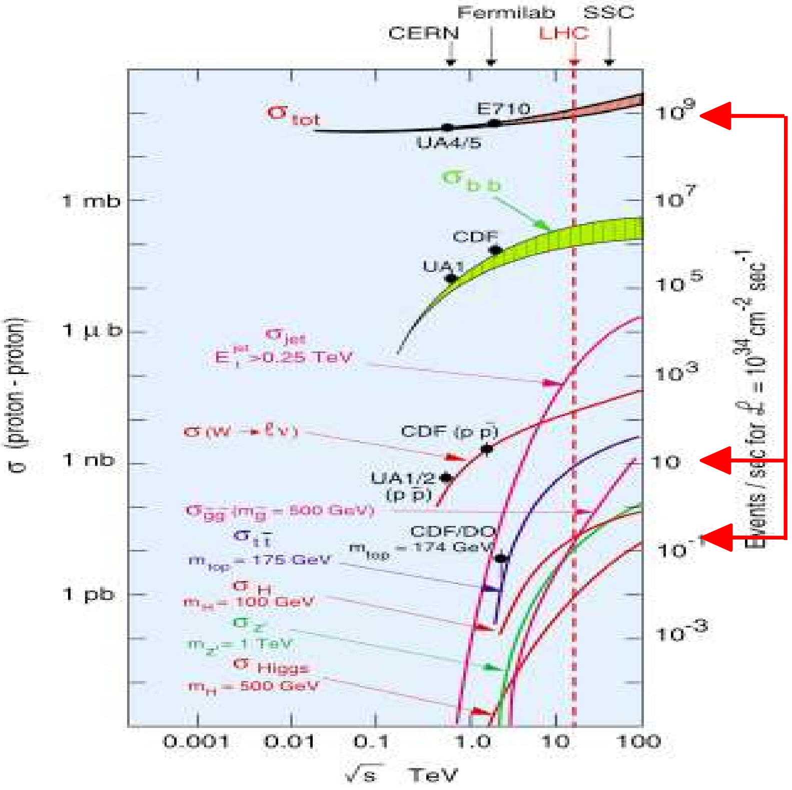
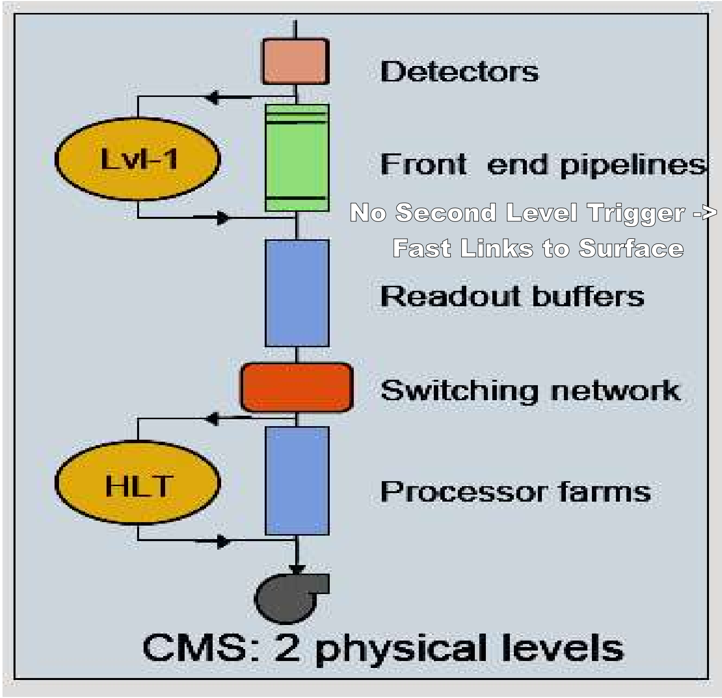
Outline

- Introduction / Challenges
- Level 1 Trigger (L1) :
  - Introduction to algorithms
- High Level Trigger (HLT) :
  - Introduction to algorithms
- L1 & HLT performance study
  - Rates
  - HLT timing
- Conclusion / Perspectives



Road to go :

- **Early rejection of huge QCD in DAQ chain & Dealing with 40 MHz : Level 1 Trigger**
- **Dealing with 50 kHz & selection physics : High Level Trigger**
- L1 & HLT : Selecting
  - Isolated leptons, photons
  - τ-, central-, forward-jets
  - (High) E_T, E_T^{miss}



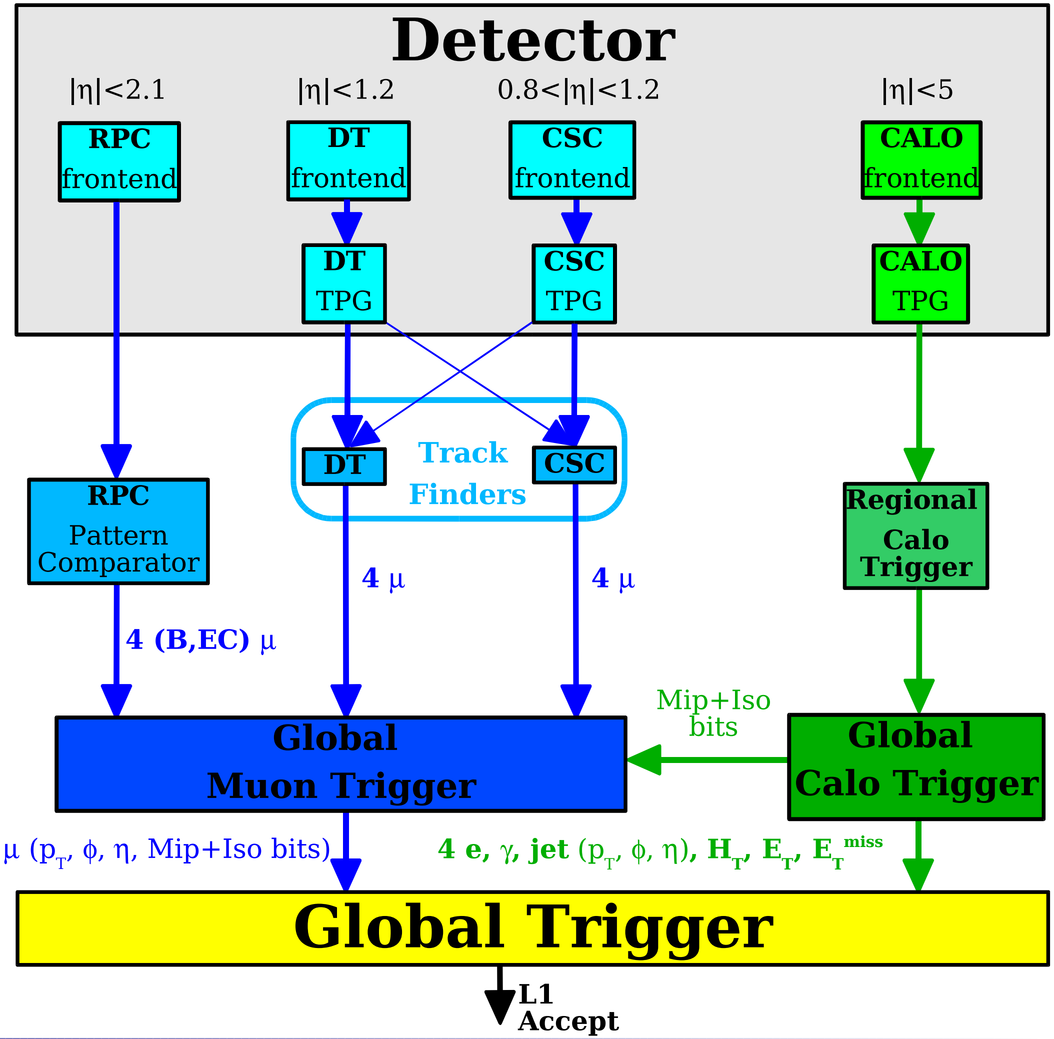
QCD :

- **σ : Orders of magnitude greater than any "interesting" channel**
- **Contaminating lepton triggers :**
  - Jet fluctuation -> electron background
  - π, K, B decays -> muon background
- Some signal (trilepton) have soft leptons, in the (very) high QCD kinematic region

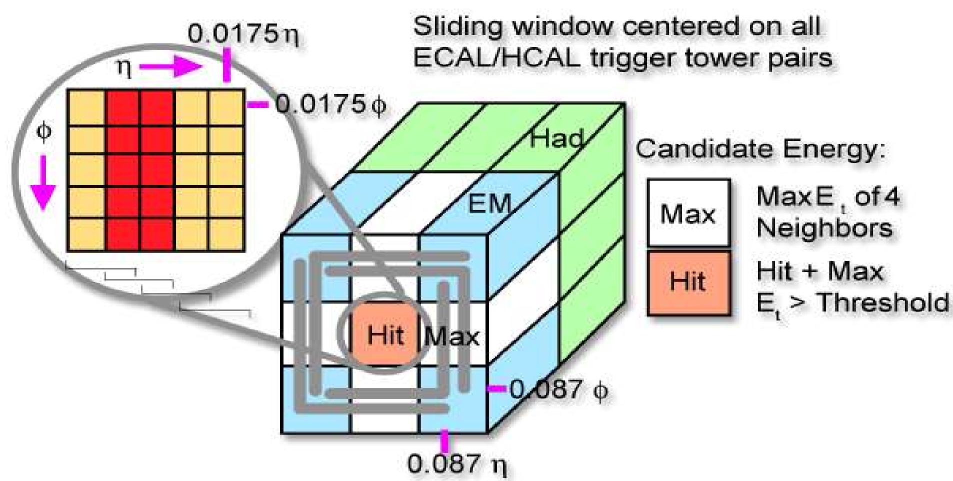
Reduce overwhelming background : 40 MHz -> 50 kHz

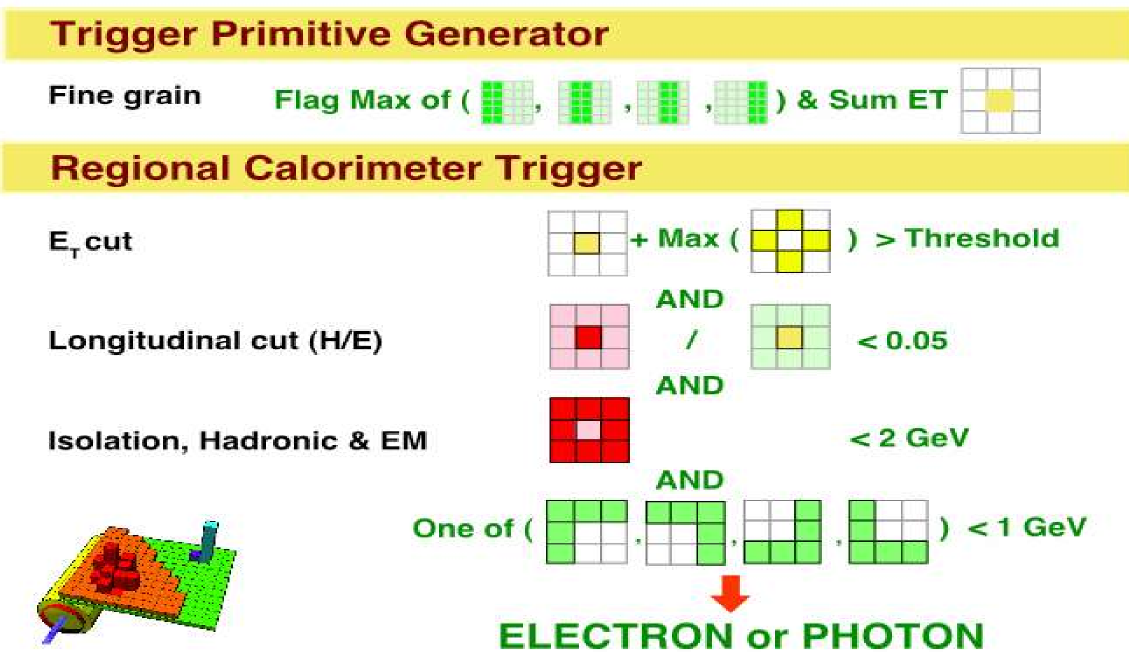
Fast processing

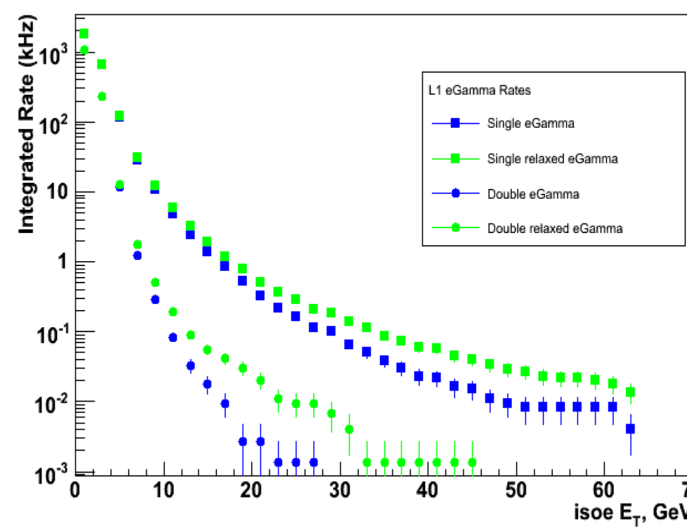
- **Customized hardware processors**
- **Algorithms :** Implemented in re-programmable FPGAs
- **Information from Calorimeter & Muon detectors :**
  - Muon triggers
  - Electron & Photon triggers
  - Jet & missing E_T triggers
- **Synchronous & pipelined :**
  - Bunch x : 25 ns
  - Decision/propagation time ~ 3 µs



- **Electromagnetic trigger based on {3x3} trigger towers**
- ECAL (barrel) : Each tower is {5x5} crystals
- HCAL : Each tower is single-readout
- Hit tower :
  - Local maximum
  - {2x5} strips (crystals) > 90% of E_T

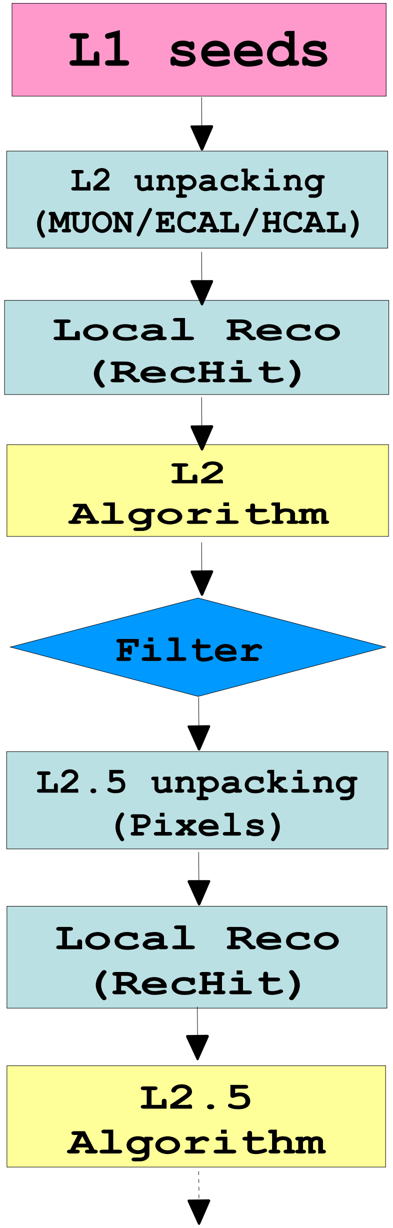






- **GCT :** 4 highest E_T candidates -> GT

High Level Trigger : Global picture



Bring 50 kHz -> 150 Hz

Select as efficiently as possible "σ~0.1 pb physics"

Ability : Build full events @ full L1 output rate

- **Code :** As close as possible to offline reconstruction
- **Seeded** by L1
- Runs on (large) **CPU farms**
- **Trigger "Levels" :**
  - 2 : Use of calorimeter and muon detectors
  - 2.5 : Use of pixel tracker detector
  - 3 : Use of tracker
- **Regionality :**
  - Reconstruction in a small (η,ϕ) region where there are previous levels seeds (L1, L2, L2.5)
  - Data unpacking : Also regional

HLT : Object algorithms

Jets : Reconstruction with iterative cone algorithm

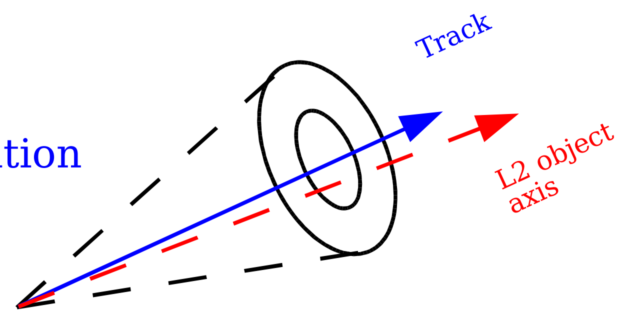
E_T^{miss} **:** Reconstruction with vector sum of towers > $E_{threshold}$

Muons :

- Iterative refinement of p_T
- **L2 :** Reconstruction in Muon system / Calo. Isolation
- **L3 :** Reconstruction in {Muon+Tracker} system / Pixel Isolation

e/γ :

- **L2 :** ECAL/HCAL reconstruction/isolation : clustering (bremsstrahlung recovery), $E_T > E_{threshold}$
- **L2.5 :** Pixel matching (electron)
- **L3 :**
  - Photon : Track-isolation
  - Electron : Track reconstruction / Track isolation



τ :

- **L2 :** Calo. Reconstruction + Isolation
- **L3 :**
  - Hard track (p_T^{max} > 40 GeV/c) with ΔR<0.1 of a jet axis
  - Track Isolation : No p_T > 1 GeV/c track within 0.03<ΔR<0.4 the hard track

HLT : Performance studies for $\mathcal{L} = 10^{32}\ cm^{-2}\ s^{-1}$ (2008 physics-run)

Studies motivated by the need of purchasing the Filter Farm at the end of 2007

1st timing measure on a representative set of (simulated) samples, with a full physics trigger-menu

- Get a L1 bandwidth as realistic as possible
  - Use full L1-emulator (emulation of the harware at the bit-level)
  - Ensure that all L1 bandwidth is used by HLT
- Use software framework to be used for data-taking
  - Include data-unpacking times for the 1st time
- Fit L1/HLT triggers in 17 kHz/150 Hz
  - Balance the trigger menus

LHCC note : LHCC-CERN 2007-021 , LHCC-G-134

$L1$: Triggers & Rates for $\mathcal{L} = 10^{32}\ cm^{-2}\ s^{-1}$ (2008 physics-run)

L1 Trigger	Threshold (GeV)	Prescale	Rate (kHz)
A_SingleMu3	3	1000	0.01 ± 0.00
A_SingleMu5	5	1000	0.00 ± 0.00
A_SingleMu7	7	1	1.11 ± 0.04
A_SingleMu10	10	1	0.47 ± 0.03
A_SingleMu14	14	1	0.18 ± 0.02
A_SingleMu20	20	1	0.09 ± 0.01
A_SingleMu25	25	1	0.06 ± 0.01
A_SingleIsoEG5	5	10000	0.00 ± 0.00
A_SingleIsoEG8	8	1000	0.01 ± 0.00
A_SingleIsoEG10	10	100	0.04 ± 0.01
A_SingleIsoEG12	12	1	2.47 ± 0.06
A_SingleIsoEG15	15	1	1.10 ± 0.04
A_SingleIsoEG20	20	1	0.32 ± 0.02
A_SingleIsoEG25	25	1	0.14 ± 0.01
A_SingleEG5	5	10000	0.00 ± 0.00
A_SingleEG8	8	1000	0.01 ± 0.00
A_SingleEG10	10	100	0.04 ± 0.01
A_SingleEG12	12	100	0.03 ± 0.01
A_SingleEG15	15	1	1.51 ± 0.05
A_SingleEG20	20	1	0.52 ± 0.03
A_SingleEG25	25	1	0.25 ± 0.02

L1 : Triggers & Rates for $\mathcal{L} = 10^{32}\ cm^{-2}\ s^{-1}$ (2008 physics-run)

L1 Trigger
A_SingleMu3
A_SingleMu5
A_SingleMu7
A_SingleMu10
A_SingleMu14
A_SingleMu20
A_SingleMu25
A_SingleIsoEG5
A_SingleIsoEG8
A_SingleIsoEG10
A_SingleIsoEG12
A_SingleIsoEG15
A_SingleIsoEG20
A_SingleIsoEG25
A_SingleEG5
A_SingleEG8
A_SingleEG10
A_SingleEG12
A_SingleEG15
A_SingleEG20
A_SingleEG25

L1 Trigger	Threshold (GeV)	Prescale	Rate (kHz)
A_SingleJet70	70	100	0.02 ± 0.01
A_SingleJet100	100	1	0.43 ± 0.02
A_SingleJet150	150	1	0.07 ± 0.01
A_SingleJet200	200	1	0.02 ± 0.01
A_SingleTauJet40	40	1000	0.02 ± 0.01
A_SingleTauJet80	80	1	0.68 ± 0.03
A_SingleTauJet100	100	1	0.20 ± 0.02
A_HTT250	250	1	2.56 ± 0.06
A_HTT300	300	1	0.65 ± 0.03
A_HTT400	400	1	0.08 ± 0.01
A_HTT500	500	1	0.02 ± 0.00
A_ETM20	20	10000	0.00 ± 0.00
A_ETM30	30	1	5.69 ± 0.09
A_ETM40	40	1	0.40 ± 0.02
A_ETM50	50	1	0.05 ± 0.01
A_ETM60	60	1	0.01 ± 0.00
A_DoubleMu3	3	1	0.28 ± 0.02
A_DoubleIsoEG8	8	1	0.28 ± 0.02
A_DoubleIsoEG10	10	1	0.08 ± 0.01
A_DoubleEG5	5	10000	0.00 ± 0.00
A_DoubleEG10	10	1	0.19 ± 0.02
A_DoubleEG15	15	1	0.05 ± 0.01
A_DoubleJet70	70	1	0.58 ± 0.03
A_DoubleJet100	100	1	0.11 ± 0.01
A_DoubleTauJet20	20	1000	0.02 ± 0.01
A_DoubleTauJet30	30	100	0.08 ± 0.01
A_DoubleTauJet40	40	1	2.36 ± 0.06

L1 : Triggers & Rates for $\mathcal{L} = 10^{32}\ cm^{-2}\ s^{-1}$ (2008 physics-run)

L1 Trigger	Threshold (GeV)	Prescale	Rate (kHz)
A_Mu3_IsoEG5	3,5	1	0.95 ± 0.04
A_Mu5_IsoEG10	5,10	1	0.04 ± 0.01
A_Mu3_EG12	3,12	1	0.09 ± 0.01
A_Mu3_Jet15	3,15	20	0.30 ± 0.02
A_Mu5_Jet15	5,15	1	1.62 ± 0.05
A_Mu3_Jet70	3,70	1	0.10 ± 0.01
A_Mu5_Jet20	5,20	1	1.18 ± 0.04
A_Mu5_TauJet20	5,20	1	0.66 ± 0.03
A_Mu5_TauJet30	5,30	1	0.38 ± 0.02
A_IsoEG10_Jet15	10,15	20	0.15 ± 0.01
A_IsoEG10_Jet30	10,30	1	1.95 ± 0.05
A_IsoEG10_Jet20	10,20	1	3.04 ± 0.06
A_IsoEG10_Jet70	10,70	1	0.26 ± 0.02
A_IsoEG10_TauJet20	10,20	1	1.95 ± 0.05
A_IsoEG10_TauJet30	10,30	1	1.33 ± 0.04
A_TauJet30_ETM30	30,30	1	1.96 ± 0.05
A_TauJet30_ETM40	30,40	1	0.26 ± 0.02
A_TripleMu3	3	1	0.01 ± 0.00
A_TripleJet50	50	1	0.22 ± 0.02
A_QuadJet30	30	1	0.58 ± 0.03
A_MinBias_HTT10	10	large	0.40
A_ZeroBias	0	large	0.40
Total L1 Trigger Rate (kHz)			16.67 ± 0.15

A_SingleMu3	A_SingleJet70
A_SingleMu5	A_SingleJet100
A_SingleMu7	A_SingleJet150
A_SingleMu10	A_SingleJet200
A_SingleMu14	A_SingleTauJet40
A_SingleMu20	A_SingleTauJet80
A_SingleMu25	A_SingleTauJet100
A_SingleIsoEG5	A_HTT250
A_SingleIsoEG8	A_HTT300
A_SingleIsoEG10	A_HTT400
A_SingleIsoEG12	A_HTT500
A_SingleIsoEG15	A_ETM20
A_SingleIsoEG20	A_ETM30
A_SingleIsoEG25	A_ETM40
A_SingleEG5	A_ETM50
A_SingleEG8	A_ETM60
A_SingleEG10	A_DoubleMu3
A_SingleEG12	A_DoubleIsoEG8
A_SingleEG15	A_DoubleIsoEG10
A_SingleEG20	A_DoubleEG5
A_SingleEG25	A_DoubleEG10
	A_DoubleEG15
	A_DoubleJet70
	A_DoubleJet100
	A_DoubleTauJet20
	A_DoubleTauJet30
	A_DoubleTauJet40

- **Muon :** 1.5 kHz
- **eγ :** 2.5 kHz
- **Jets :** 3.5 kHz
- **τ :** 3 kHz
- **MET :** 5.5 kHz
- **Cross-channel :** 8 kHz

Safety factor 3 for L1 bandwidth :

- Uncertainty on QCD cross-sections (Tevatron : factor=2)
- Not simulated conditions : beam, noise spikes, electronics…

- **Lepton thresholds low :** Study efficiencies @ low p_T
- **Jet thresholds :** Covers range -> Tevatron
- **L1 MET :** Combined with jets @ HLT
- **Cross-channel triggers** present @ L1

HLT : Triggers & Rates for $\mathcal{L} = 10^{32}\ cm^{-2}\ s^{-1}$ (2008 physics-run)

HLT path	L1 condition	Thresholds (GeV)	HLT Rate (Hz)	Total Rate (Hz)
Single Isolated μ	A_SingleMu7	11	18.3 ± 2.2	18.3
Single Relaxed μ	A_SingleMu7	16	22.7 ± 1.5	37.7
Double Relaxed μ	A_DoubleMu3	(3, 3)	12.3 ± 1.6	48.5
$J/\psi \to \mu\mu$	A_DoubleMu3	(3, 3) $M_{\mu\mu} \in [2.9, 3.3]$	2.0 ± 0.8	49.4
$\Upsilon \to \mu\mu$	A_DoubleMu3	(3, 3) $M_{\mu\mu} \in [8, 12]$	1.8 ± 0.5	50.5
$Z \to \mu\mu$	A_DoubleMu3	(7, 7) $M_{\mu\mu} \in [80, 100]$	0.1 ± 0.0	50.5
Triple Relaxed μ	A_TripleMu3	(3, 3, 3)	0.1 ± 0.0	50.5
Same-sign double μ	A_DoubleMu3	(3, 3)	5.7 ± 1.2	52.5
$b \to \mu$ tag 1-jet Prescale 20	A_Mu5_Jet15	20 $\Delta R(\mu, j) < 0.4$	4.0 ± 0.1	56.1
$b \to \mu$ tag 2-jets	A_Mu5_Jet15	120, $p_T^{rel}(\mu) > 0.7$ $\Delta R(\mu, j) < 0.4$	0.5 ± 0.0	56.1
$b \to \mu$ tag 3-jets	A_Mu5_Jet15	70, $p_T^{rel}(\mu) > 0.7$ $\Delta R(\mu, j) < 0.4$	0.3 ± 0.0	56.1
$b \to \mu$ tag 4-jets	A_Mu5_Jet15	40, $p_T^{rel}(\mu) > 0.7$ $\Delta R(\mu, j) < 0.4$	0.4 ± 0.0	56.1
$b \to \mu$ tag H_T	A_HTT250	300, $p_T^{rel}(\mu) > 0.7$ $\Delta R(\mu, j) < 0.4$	2.6 ± 0.2	56.6
$b \to J/\psi(\mu\mu)$	A_DoubleMu3	(4, 4) $M_{\mu\mu} \in [2.95, 3.25]$	0.7 ± 0.1	56.8
$\mu + b$-jet	A_Mu5_Jet15	(7, 35)	0.1 ± 0.0	56.8
$\mu + b \to \mu$-jet	A_Mu5_Jet15	(7, 20)	0.1 ± 0.1	56.8
μ + jet	A_Mu5_Jet15	(7, 40)	6.3 ± 0.7	60.8
$e + \mu$	$\star$	(8, 7)	0.5 ± 0.4	61.2
$e + \mu$ relaxed	$\star$	(10, 10)	0.1 ± 0.0	61.3
$\mu + \tau$	A_Mu5_TauJet20	(15, 20)	0.0 ± 0.0	61.3
Single-Jet	A_SingleJet150	200	9.3 ± 0.1	70.1
Double-Jet	A_SingleJet150 A_DoubleJet70	150	10.6 ± 0.0	74.4
Triple-Jet	†	85	7.5 ± 0.1	78.8
Quad-Jet	‡	60	3.9 ± 0.1	80.5
$\not\!E_T$	A_ETM40	65	4.9 ± 0.7	84.0
Acopl. Double-Jet	A_SingleJet150 A_DoubleJet70	125	1.4 ± 0.0	84.0
Acopl. Single-Jet + $\not\!E_T$	A_ETM30	(100, 60)	1.6 ± 0.0	84.2
Single-Jet + $\not\!E_T$	A_ETM30	(180, 60)	2.2 ± 0.1	84.4
Double-Jet + $\not\!E_T$	A_ETM30	(125, 60)	1.0 ± 0.0	84.4
Triple-Jet + $\not\!E_T$	A_ETM30	(60, 60)	0.6 ± 0.0	84.4
Quad-Jet + $\not\!E_T$	A_ETM30	(35, 60)	1.2 ± 0.1	84.6
$H_T + \not\!E_T$	A_HTT300	(350, 65)	4.4 ± 0.1	86.2
Single Jet Prescale 10	A_SingleJet100	150	3.5 ± 0.0	87.9
Single Jet Prescale 100	A_SingleJet70	110	1.5 ± 0.0	89.1
Single Jet Prescale 1000	A_SingleJet30	60	0.8 ± 0.4	89.9

HLT : Triggers & Rates for $\mathcal{L} = 10^{32}$ cm^{-2} s^{-1} (2008 physics-run)

HLT path	L1 condition	Thresholds (GeV)	HLT Rate (Hz)	Total Rate (Hz)
Single Isolated μ	A_SingleMu7	11	18.3 ± 2.2	18.3
Single Relaxed μ	A_SingleMu7	16	22.7 ± 1.5	37.7
Double Relaxed μ	A_DoubleMu3	(3, 3)	12.3 ± 1.6	48.5
$J/\psi \to \mu\mu$				
$\Upsilon \to \mu\mu$				
$Z \to \mu\mu$				
Triple Relaxed μ				
Same-sign double μ				
$b \to \mu$ tag 1-jet Prescale 20				
$b \to \mu$ tag 2-jets				
$b \to \mu$ tag 3-jets				
$b \to \mu$ tag 4-jets				
$b \to \mu$ tag H_T				
$b \to J/\psi(\mu\mu)$				
μ + b-jet				
$\mu + b \to \mu$-jet				
μ + jet				
$e + \mu$				
$e + \mu$ relaxed				
$\mu + \tau$				
Single-Jet				
Double-Jet				
Triple-Jet				
Quad-Jet	‡	60	3.9 ± 0.1	80.5
$\not{E}_T$	A_ETM40	65	4.9 ± 0.7	84.0
Acopl. Double-Jet	A_SingleJet150 A_DoubleJet70	125	1.4 ± 0.0	84.0
Acopl. Single-Jet + $\not{E}_T$	A_ETM30	(100, 60)	1.6 ± 0.0	84.2
Single-Jet + $\not{E}_T$	A_ETM30	(180, 60)	2.2 ± 0.1	84.4
Double-Jet + $\not{E}_T$	A_ETM30	(125, 60)	1.0 ± 0.0	84.4
Triple-Jet + $\not{E}_T$	A_ETM30	(60, 60)	0.6 ± 0.0	84.4
Quad-Jet + $\not{E}_T$	A_ETM30	(35, 60)	1.2 ± 0.1	84.6
$H_T + \not{E}_T$	A_HTT300	(350, 65)	4.4 ± 0.1	86.2
Single Jet Prescale 10	A_SingleJet100	150	3.5 ± 0.0	87.9
Single Jet Prescale 100	A_SingleJet70	110	1.5 ± 0.0	89.1
Single Jet Prescale 1000	A_SingleJet30	60	0.8 ± 0.4	89.9

HLT path	L1 condition	Thresholds (GeV)	HLT Rate (Hz)	Total Rate (Hz)
VBF Double-Jet + $\not{E}_T$	A_ETM30	(40, 60)	0.2 ± 0.0	89.0
SUSY 2-jet+$\not{E}_T$	A_ETM30	(80,20,60)	2.0 ± 0.1	90.4
Acopl. Double-Jet + $\not{E}_T$	A_ETM30	(60, 60)	1.0 ± 0.0	90.4
Single Isolated e	A_SingleIsoEG12	15	17.1 ± 2.3	107.5
Single Relaxed e	A_SingleEG15	17	9.6 ± 1.3	109.3
Double Isolated e	A_DoubleIsoEG8	10	0.2 ± 0.1	109.4
Double Relaxed e	A_DoubleEG10	12	0.8 ± 0.1	109.9
Single Isolated γ	A_SingleIsoEG12	30	8.4 ± 0.7	118.1
Single Relaxed γ	A_SingleEG15	40	2.8 ± 0.2	118.5
Double Isolated γ	A_DoubleIsoEG8	(20,20)	0.6 ± 0.4	119.0
Double Relaxed γ	A_DoubleEG10	(20,20)	1.8 ± 0.5	120.1
High E_T e	A_SingleEG15	80	0.5 ± 0.0	120.4
High E_T e	A_SingleEG15	200	0.1 ± 0.0	120.4
Lifetime b-tag 1-jet	◇	180	1.3 ± 0.0	120.5
Lifetime b-tag 2-jets	◇	120	2.1 ± 0.0	121.2
Lifetime b-tag 3-jets	◇	70	1.7 ± 0.0	121.8
Lifetime b-tag 4-jets	◇	40	1.8 ± 0.0	122.6
Lifetime b-tag H_T	◇	470	2.5 ± 0.1	123.1
Single τ	A_SingleTauJet80	15	0.2 ± 0.0	123.2
$\tau + \not{E}_T$	A_TauJet30_ETM30	15	1.8 ± 0.2	124.7
Double τ (Calo+Pixel)	A_DoubleTauJet40	15	4.9 ± 0.6	129.4
e + b-jet	A_IsoEG10_Jet20	(10, 35)	0.1 ± 0.0	129.4
e + jet	A_IsoEG10_Jet30	(12, 40)	11.6 ± 1.2	135.8
$e + \tau$	A_IsoEG10_TauJet20	(12, 20)	0.2 ± 0.0	135.8
Prescaled e/γ	See Table 3.9		5.0 ± 0.0	140.8
Prescaled μ	See Table 2.4		3.0 ± 0.0	143.8
Min.Bias	A_MinBias_HTT10	—	1.5 ± 0.0	145.3
Pixel Min.Bias	A_ZeroBias	—	1.5 ± 0.0	146.8
Zero Bias	A_ZeroBias	—	1.0 ± 0.0	147.8
Total HLT rate (Hz)				148 ± 4.9

- **Muon :** 50 Hz
- **eγ :** 30 Hz
- **Jets/MET/H$_T$:** 30 Hz
- **τ :** 7 Hz
- **b-jets :** 10 Hz
- **Cross-channel :** 20 Hz
- **Prescaled :** 15 Hz

Safety factor 2 for HLT bandwidth :

- Uncertainty on heavy-flavor cross-sections
- Uncertainties in simulation

- **Lepton triggers :** Gateway for many physics channels
- **Variety of physics covered :** J/ψ -> $\mu\mu$ -> Trileptons -> t-tbar -> μ+jets
- **Prescaled triggers :** accompany physics triggers

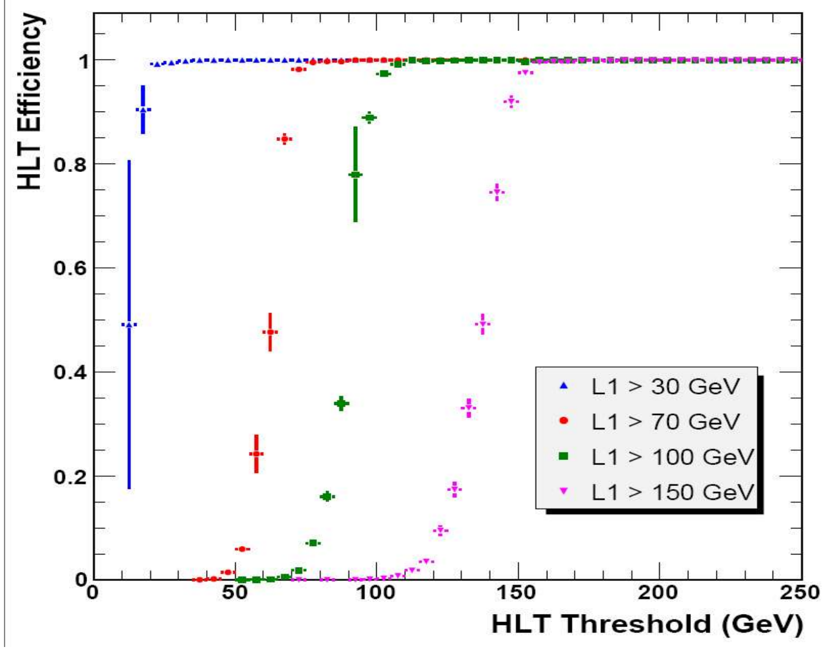
HLT : Efficiencies for benchmark channels

Muon HLT efficiency for benchmark channels

Signal	HLT Single Relaxed muon eff.(%)	HLT Double muon eff.(%)	HLT Single Isolated muon eff.(%)	(Level-1)*HLT acceptance (%)
$Z \to \mu\mu$	98.6	91.2	95.8	98.1
$W \to \mu\nu$	86.9	-	81.4	76.7

Electron HLT efficiency for benchmark channels

Signal process	Isolated single electron	Relaxed single electron	Isolated double electron	Relaxed double electron
HLT: $Z \to ee$	83.3	85.2	63.8	64.4
HLT: $W \to e\nu$	62.5	61.2	-	-
L1*HLT: $Z \to ee$	80.0	82.6	62.6	63.2
L1*HLT: $W \to e\nu$	52.1	52.4	-	-



Higgs and photons

Signal process	Isolated single photon	Relaxed single photon	Isolated double photon	Relaxed double photon
HLT: $H \to \gamma\gamma (m_H$=120 GeV)	80.5	76.8	75.8	75.7
L1*HLT: $H \to \gamma\gamma (m_H$=120 GeV)	78.8	76.8	75.8	75.7

Higgs and taus

Table 5.2: Efficiencies and rates of the SingleTau HLT path.

	$H^{\pm} \to \tau\nu$ $M_H = 200\,GeV/c^2$	$H^{\pm} \to \tau\nu$ $M_H = 400\,GeV/c^2$	QCD $\hat{p}_T$ 120-170
Level-2 $\not{E}_T$ cut	59%	81%	6%
Level-2 Jet Reconstruction and Ecal Isolation	81%	85%	53%
Level-2.5 SiStrip Isolation	67%	76%	27%
Level-3 SiStrip Isolation	70%	72%	18%
HLT	23%	38%	0.15%
L1 * HLT	16%	29%	-

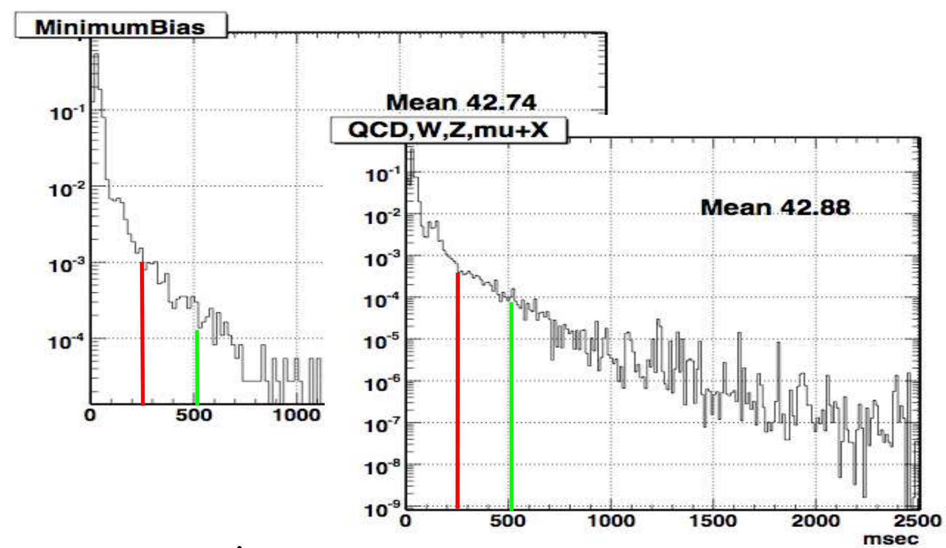
Time budget : Dictated by L1 output rate & Number of CPU nodes

150 kHz / 2000 = $\langle Time \rangle_{machine}$ = 40 ms

- Average processing time for different samples
- Weight by σ and L1 efficiency
- Compare weighted sum with time of L1-accepted MinBias events

Sample	L1 efficiency (%)	L1 eff. $\times \sigma$ (pb)	Average time (ms)
Minimum bias	0.19 ± 0.01	$(1.50 \pm 0.09) \times 10^8$	42.7
QCD $\hat{p}_T \in [0, 15]$ GeV/c	0.08 ± 0.01	$(4.36 \pm 0.49) \times 10^7$	31
QCD $\hat{p}_T \in [15, 20]$ GeV/c	2.08 ± 0.11	$(3.04 \pm 0.17) \times 10^7$	36
QCD $\hat{p}_T \in [20, 30]$ GeV/c	5.75 ± 0.18	$(3.64 \pm 0.11) \times 10^7$	40
QCD $\hat{p}_T \in [30, 50]$ GeV/c	21.70 ± 0.41	$(3.54 \pm 0.07) \times 10^7$	47
QCD $\hat{p}_T \in [50, 80]$ GeV/c	63.36 ± 0.84	$(1.37 \pm 0.02) \times 10^7$	53
QCD $\hat{p}_T \in [80, 120]$ GeV/c	95.96 ± 1.23	$(2.96 \pm 0.04) \times 10^6$	73
QCD $\hat{p}_T \in [120, 170]$ GeV/c	99.87 ± 1.18	$(4.93 \pm 0.06) \times 10^5$	143
QCD $\hat{p}_T \in [170, 230]$ GeV/c	100.00 ± 0.00	$(1.01 \pm 0.00) \times 10^5$	264
QCD $\hat{p}_T \in [230, 300]$ GeV/c	100.00 ± 0.00	$(2.45 \pm 0.00) \times 10^4$	385
$pp \rightarrow \mu X$	42.96 ± 0.37	$(1.03 \pm 0.01) \times 10^7$	74
$W \rightarrow e\nu$	93.18 ± 0.59	$(7.36 \pm 0.05) \times 10^3$	280
$W \rightarrow \mu\nu$	84.67 ± 0.80	$(8.29 \pm 0.08) \times 10^3$	123
$Z \rightarrow ee$	99.54 ± 0.67	$(8.16 \pm 0.05) \times 10^2$	739
$Z \rightarrow \mu\mu$	98.99 ± 1.20	$(7.82 \pm 0.09) \times 10^2$	184
Weighted sum of QCD, W, Z and $pp \rightarrow \mu X$ contributions			42.9 ± 5.6

Table 8.4: Average processing wall-clock times for running the High-Level Trigger Menu at $\mathcal{L} = 10^{32}$ cm^{-2} s^{-1} on Level-1-accepted events at an idle Core 2 5160 Xeon 3.0 GHz machine.



Slow events : Will autosave events if T > 600ms : saves time

Alternative scenarios :

- Give more bandwidth to τ, i.e more tracking : L1 single-tau : 80->60 GeV; L1 double-tau : 40->35 GeV. <T> : 43ms -> 45.8ms (MinBias)
- Cope with 2.10^{33} cm^{-2} s^{-1} : Raise L1 thresholds => More sensitive to higher QCD bins : Processing time increases (busy events)
  - Naïve extrapolation : <T> ~ 56ms

HLT : Timing performance for $\mathcal{L} = 10^{32}$ cm^{-2} s^{-1} (2008 physics-run)

Keys for present performance :

- **Profiling studies** revealed slowest pieces of code
- **Use zero-suppressed data :** Reduces data-unpacking time
- **Regional reconstruction :** Muon, e/γ
- **Data-unpacking :**
  - Regional for ECAL
  - Fast(er) for siStrip
- **Machine :**
  - Core-2
  - Data cache (memory allocation), sometimes more important than clock speed
- **Optimizing trigger logic** (τ-, b-triggers) **:** Filter more before event enters time-consuming steps
- Equal bandwidth distribution for leptons, jets, E_T^{miss}

So far so good... It's not where we want to stay

Coming improvements :

- **Regional reconstruction :** Everywhere in HLT
- **Regional unpacking :** For the tracker
- Library for track-fitting (clhep -> S-Matrix) : avoid too much data-copying in new versions

Conclusion / Perspectives

- **Choice of physics explored :** Already made at Level 1 Trigger
  - Only with calorimeter and muon system
- **Full object reconstruction at High Level Trigger**, with higher resolution
- **Most extensive study of HLT algorithms, efficiencies, rates, timing :**
  - Performance consistent with CMS physics program and resources

What if...

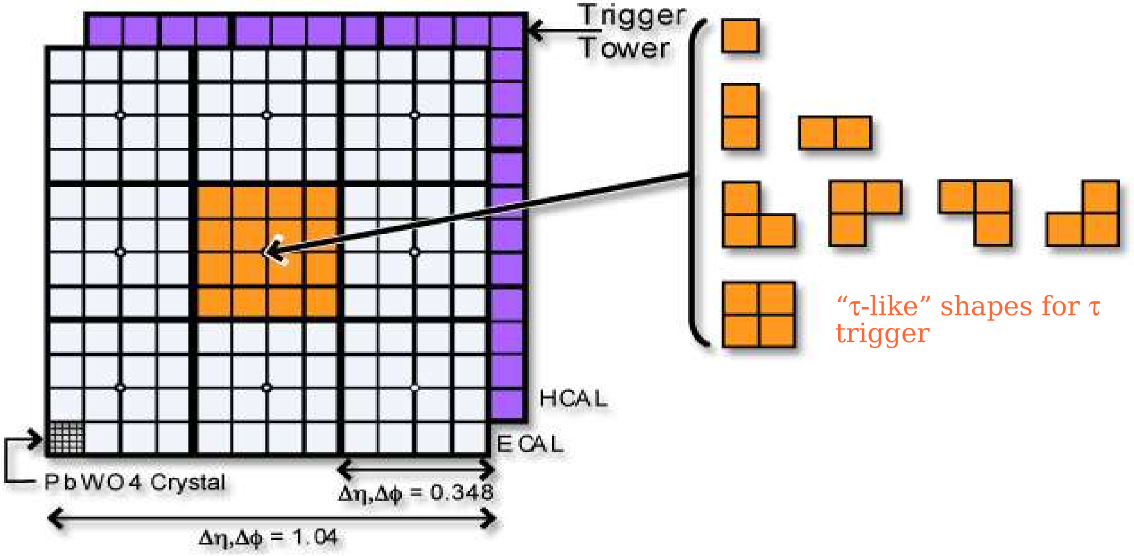
- **Rates go high :**
  - Underestimated σ **:** Safety factor of 3/2 for L1/HLT
  - Busy event (impacts the timing) : Shielded with L1 seeding & Regionality
- ... Timing improvements in pipeline

When/How do we start :

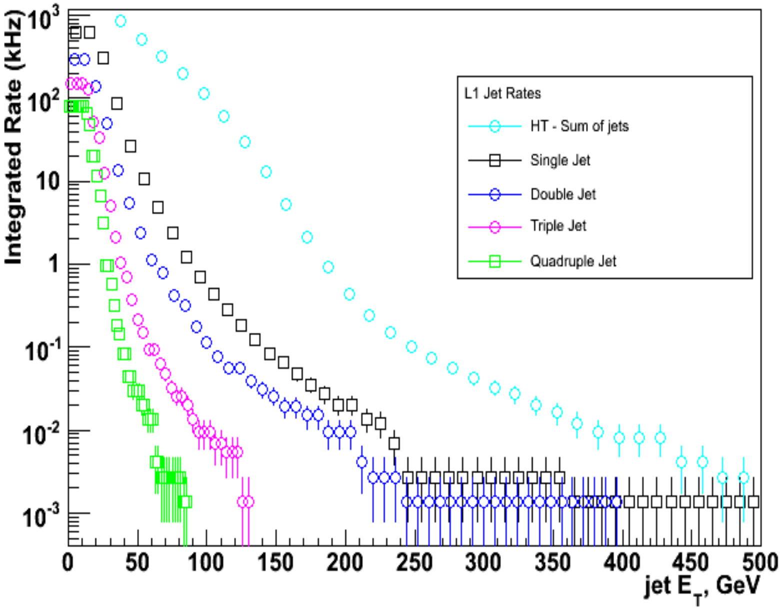
- **Varying conditions in 2008 :** L : 10^{21} -> 10^{32} cm^{-2} s^{-1} / Δt : 75 ns -> 25 ns
- **L < 10^{31} cm^{-2} s^{-1} :** Understand Trigger & Detector in real LHC conditions
  - Minimum Bias
  - Relax algorithm cuts
  - Calibration/alignment triggers
    - ECAL : π^0
    - Jet Energy Scale : γ + jets
    - Tracks : $J/\psi \rightarrow \mu\mu$, isolated $\pi^{\pm}$
  - Trigger redundancies -> Trigger efficiencies with Data
- **L ≥ 10^{31} cm^{-2} s^{-1} :** Rediscover SM and... beyond

Backup slides

Jet finder : "Square" finder

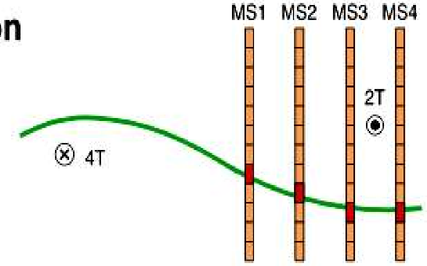


- Sliding window
- E_T(central {4x4} region) > others
  - (η,ϕ) : from {12x12} towers
  - E_T({12x12} towers) > cut
- τ-jet : Isolated- and narrow-deposit Jet
- Single-, double-, triple- & quad-thresholds
- Possible to cut on N(jets)
- All cuts programmable
- Also $H_T = \Sigma E_T$(jets), ΣE_T, E_T^{miss} triggers



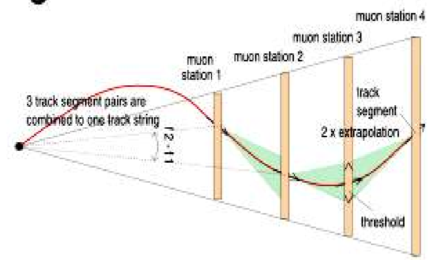
- **Resistive Place Chambers :** Dedicated trigger detector : Excellent time resolution
- **Drift Tubes** (barrel) **& Cathod Strip Chambers** (endcap) **:** Precise position resolution

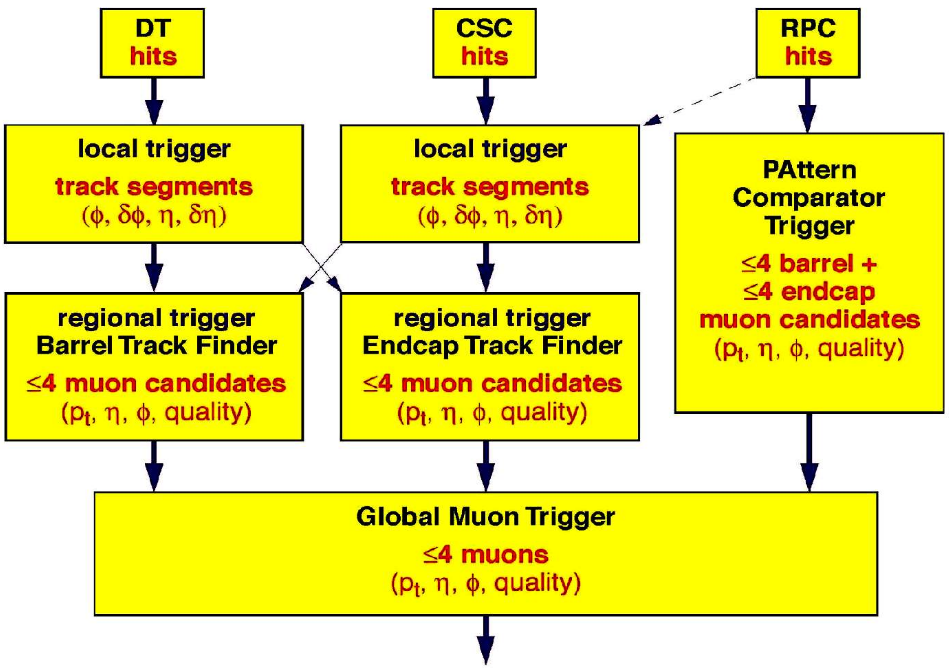
RPC pattern recognition
- Pattern catalog
- Fast logic

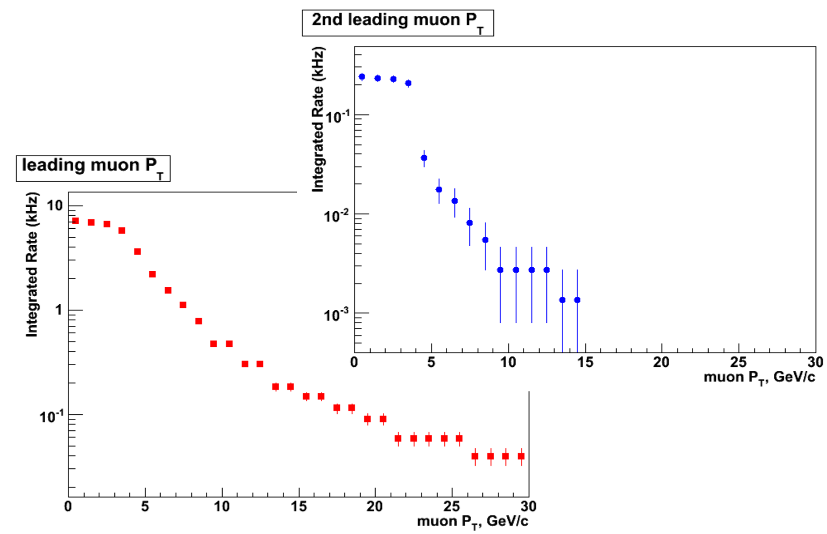


Muon candidate : RPC and (DT or CSC) no quality
OR RPC or DT or CSC + high quality

DT and CSC track finding:
- Finds hit/segments
- Combines vectors
- Formats a track
- Assigns p_t value

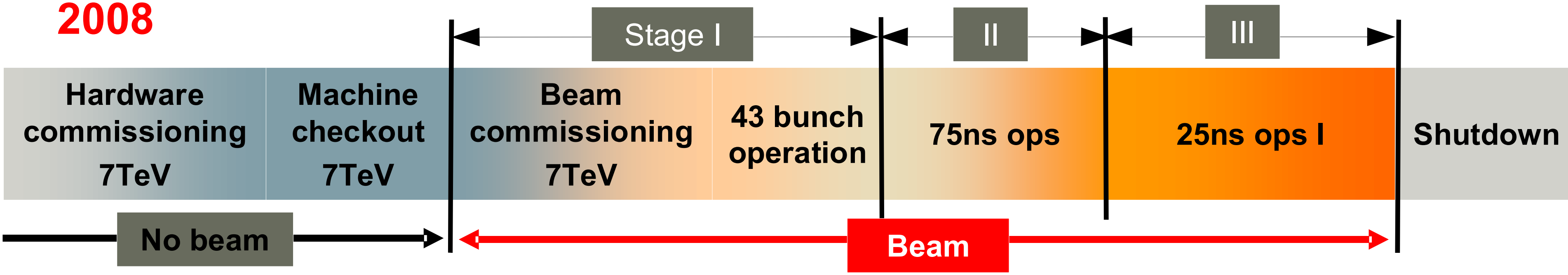






Comissioning plan for protons at 7 TeV

2008



2009

Mike Lamont

Bunches	β^*	I_b	Luminosity	Event rate
1 x 1	18	10^{10}	10^{27}	Low
43 x 43	18	3×10^{10}	3.8×10^{29}	0.05
43 x 43	4	3×10^{10}	1.7×10^{30}	0.21
43 x 43	2	4×10^{10}	6.1×10^{30}	0.76
156 x 156	4	4×10^{10}	1.1×10^{31}	0.38
156 x 156	4	9×10^{10}	5.6×10^{31}	1.9
156 x 156	2	9×10^{10}	1.1×10^{32}	3.9