The Trigger

YETI

7th January 2008

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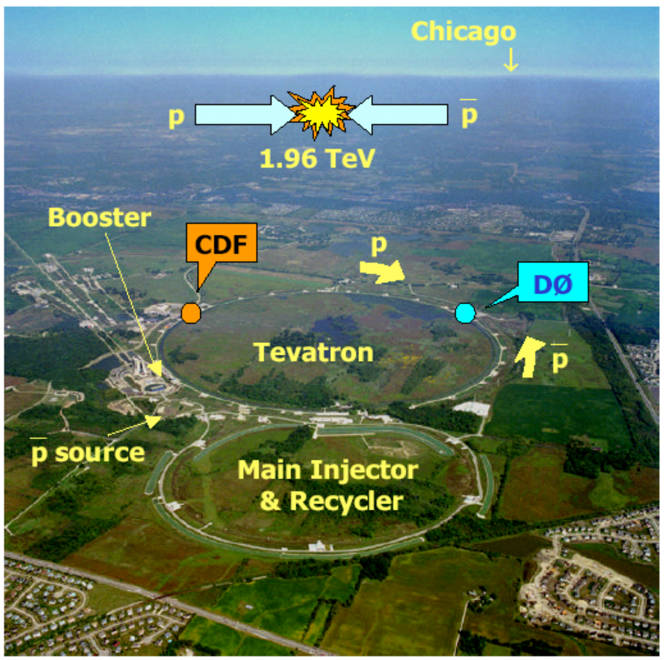
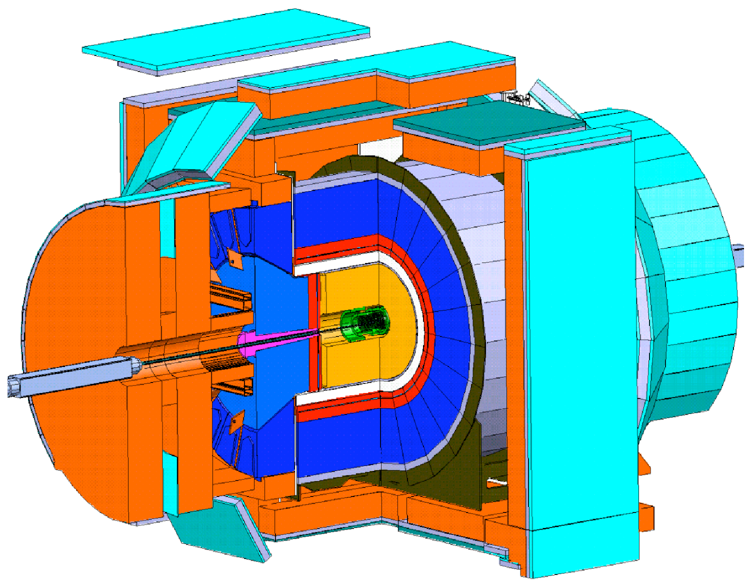
Outline:

- Why do we need a Trigger?
- The trigger system at CDF
- Rate control at CDF
- Triggering on rare events
- Backup Triggers
- The LHC

Triggers

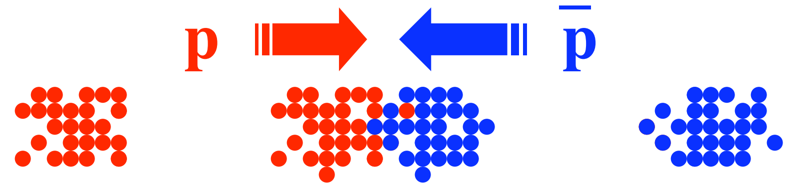
- The trigger is a vital part of collider experiments - if you screw up the trigger the data is lost forever!
- Particularly challenging at hadron colliders:
  - I will use CDF as an example to discuss some of these challenges.



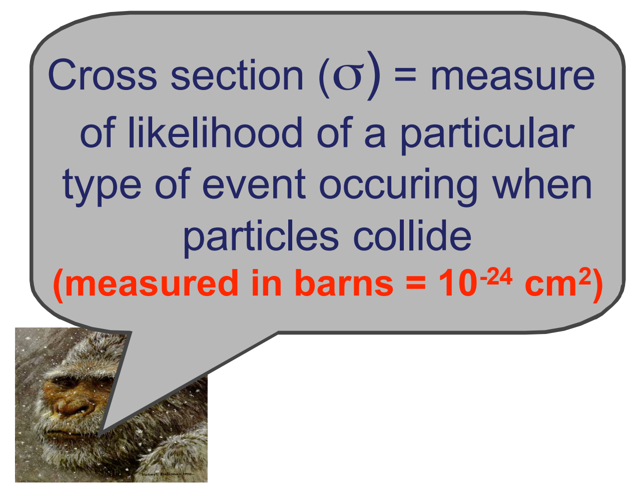


- Silicon tracking detector
- Central drift chambers (COT)
- Solenoid Coil
- EM calorimeter
- Hadronic calorimeter
- Muon drift chambers
- Muon scintillator counters
- Steel shielding

Why do we need a trigger at CDF?

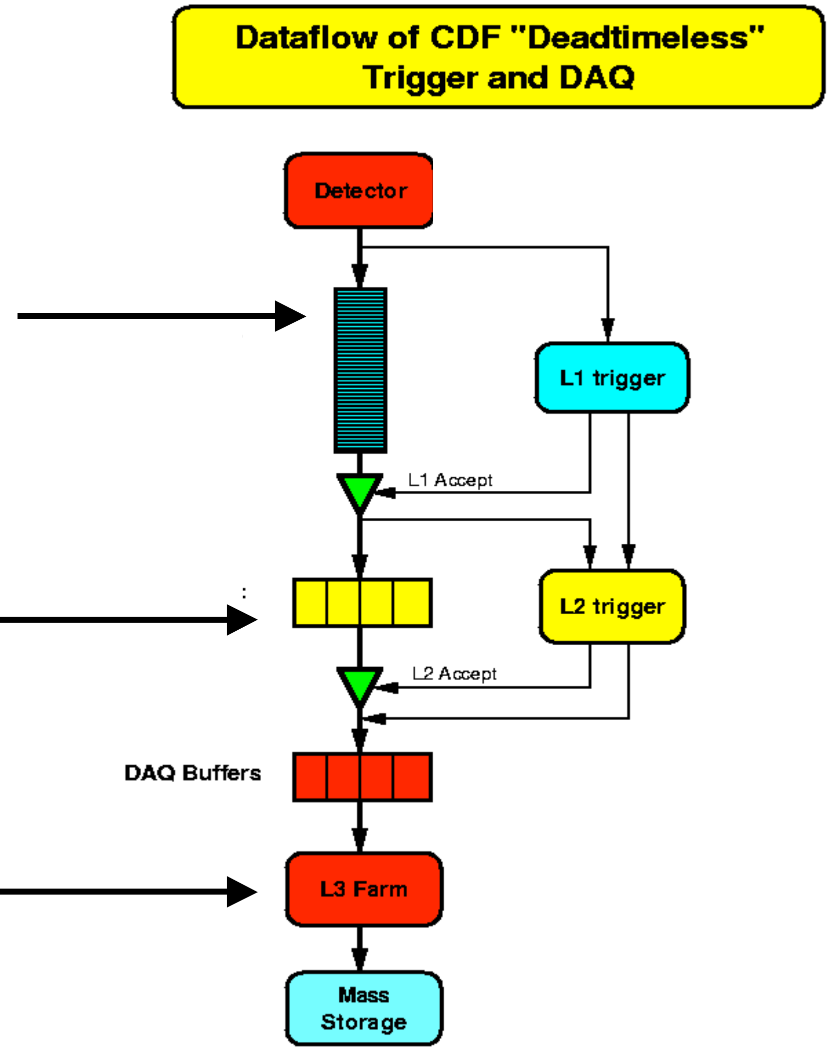


- The Tevatron ring contains *36 bunches of protons* and *36 bunches of antiprotons* with **396 ns** between bunch collisions.
- There is no way we can store the information from the detector for each collision - and nor do we want to:
  - **σ(ppbar)** **~60 mb**
  - **σ(ppbar→$W^{\pm}$)** **~25 nb** **(1 in 2,400,000)**
  - **σ(ppbar→ttbar)** **~7 pb** **(1 in 8,600,000,000)**
  - **σ(ppbar→$W^{\pm}$,H)** **$\leq$ 0.2 pb** **(1 in 300,000,000,000)**
- The trigger decides in real-time whether a particular event is interesting enough to store for data analysis.



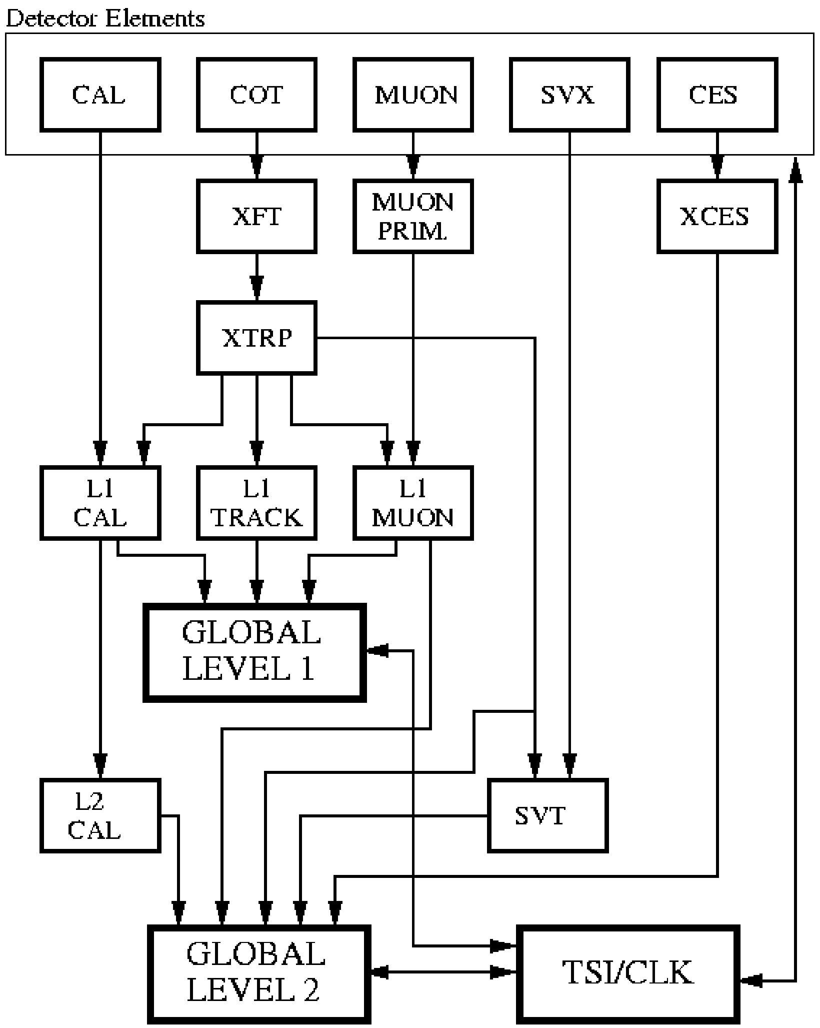
CDF's 3 level trigger

- Level-1:
  - Hardware triggers.
  - Processing in a *parallel pipelined* operation.
  - L1 decision *always* occurs 5.5μs after the collision (i.e. every 14 collisions).
  - The 14 events are stored in a pipelined buffer whilst the L1 decisions are made.
  - Rate reduction: 1.7 MHz→25 kHz (1 : 70)
- Level-2:
  - Hardware and software triggers.
  - Decision takes ~30 μs per event.
  - 4 L2 buffers can store 4 events whilst trigger decision is made.
  - Rate reduction: 25 kHz→600 Hz (1 : 40)
- Level-3:
  - PC farm running offline-type code.
  - Rate reduction: 600 Hz →100 Hz (1 : 6)
- Total data rejection factor is 1: 17000



CDF's 3 level trigger

- Level-1:
  - Calorimeter objects:
    - **Jet object**
    - **EM object**
    - **E_T^{miss}, ΣE_T**
  - COT tracks (p_T > 1.5 GeV)
  - Muon tracks
- Level-2:
  - All L1 information with better granuality
  - Calorimeter *clustering* for jets, taus, electrons and photons.
  - ShowerMax measures EM cluster position
  - Silicon tracks with displaced vertex information for B decays.
- Level-3:
  - Fully reconstructed events using full granuality of detector (electrons, taus, muons, photons, E_T^{miss}, jets, B decays etc)



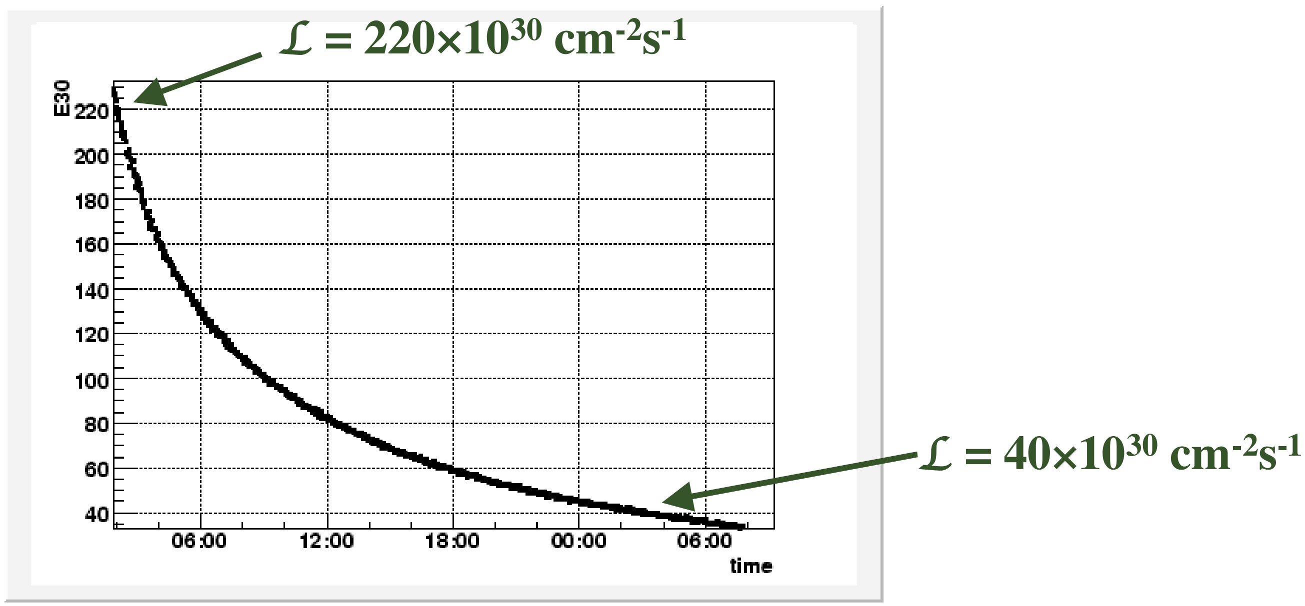
Trigger Table (a.k.a. Menu)

- The CDF physics program is rich and divergent
- Many different triggers are required to select events with different signatures:
  - Higgs searches — e,μ,τ, E_T^{miss}, jets
  - BSM searches — e,μ,τ, E_T^{miss}, jets, γ
  - EWK measurements — e,μ,τ, E_T^{miss}
  - Top physics — e,μ,τ, E_T^{miss}, jets
  - B physics — e,μ, low p_T tracks with displaced vertex
  - QCD — jets
  - etc…

High p_T single e,μ
Low p_T e,μ,τ pairs
Photons
E_T^{miss}
Jets
Di-tracks (with displaced vertex)

Luminosity

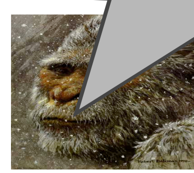
- Luminosity: measure of the probability of a proton-antiproton collision (the more particles per unit volume the higher the luminosity.)
  - **Instantaneous luminosity:** $\mathcal{L}$ **[cm^{-2}s^{-1}]**
  - **Integrated luminosity:** $\mathcal{L}_{int}$ **[cm^{-2}]**
- A Tevatron *store* (period of continuous collisions) runs for ~24 hours - $\mathcal{L}$ starts high and decreases with time.



Trigger rates

- For a given process (e.g. ppbar$\rightarrow$W$\rightarrow\mu\nu$) the rate[Hz] = $\sigma.\mathcal{L}$
  - Which can mean a factor ~5 variation in rate throughout a store!
- The σ of some *triggers* also depends on $\mathcal{L}$:
  - Some increase with $\mathcal{L}$ as there are more ppbar collisions per bunch crossing:
    - ➢ More random hits in tracker $\rightarrow$ more fake tracks.
    - ➢ More energy in calorimeter $\rightarrow$ more fake jets.
  - Some decrease (triggers with isolation cuts become less efficient).
  - Some are ~ constant.

σ of a certain *process* is independent of $\mathcal{L}$ but σ of some *triggers* can depend on $\mathcal{L}$



Prescales

- The rates of some triggers are too high to sustain at high $\mathcal{L}$.
- Options:
  1) Prescale the trigger by a constant factor (wasteful at low $\mathcal{L}$ where we can handle the rate!)
  2) Apply a $\mathcal{L}$ dependent prescale.

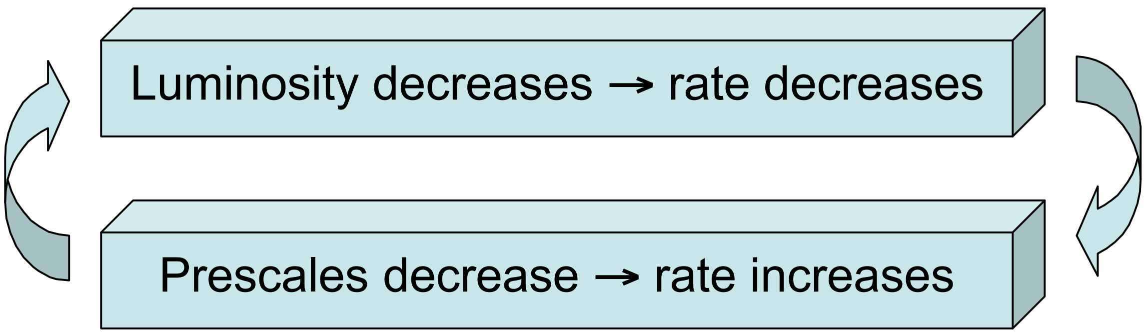
**When a trigger is prescaled a fraction of the events satisfying the trigger criteria are randomly rejected.
A prescale of 10 means only 1 in 10 events will be accepted!**

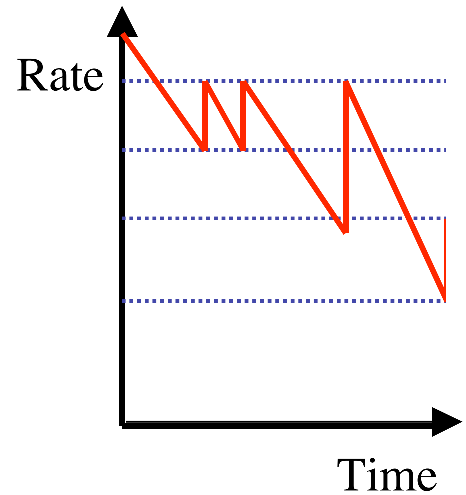
Types of $\mathcal{L}$ dependent prescale:

1) **Multiple tables:** Make a low-$\mathcal{L}$ and a high-$\mathcal{L}$ table with different prescales (change in the middle of a store).
2) **Luminosity enable:** Some triggers are initially switched off then automatically switched on once a certain (low) luminosity is reached.
3) **Dynamic prescale:** Feedback system that adjusts the prescale of triggers throughout a store according to the total trigger rate.

Dynamic Prescale

- Beginning of store:
  - High luminosity → high rate.
  - High rate triggers prescaled by their MAXIMUM value.
- As the store progresses feedback system adjusts prescales:

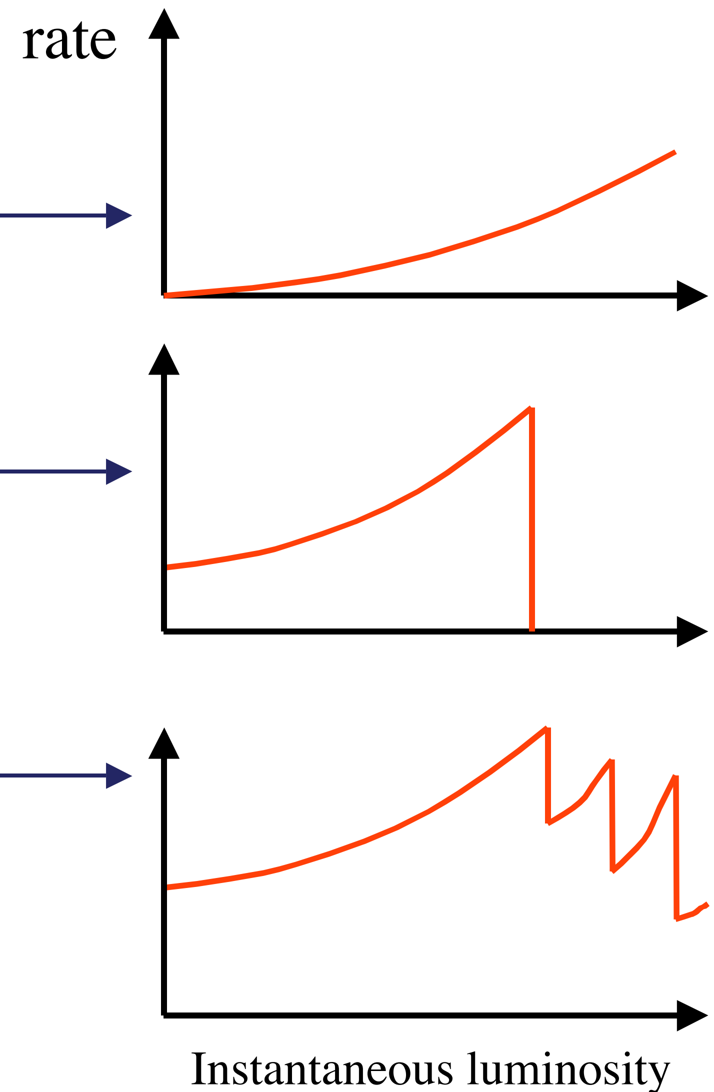




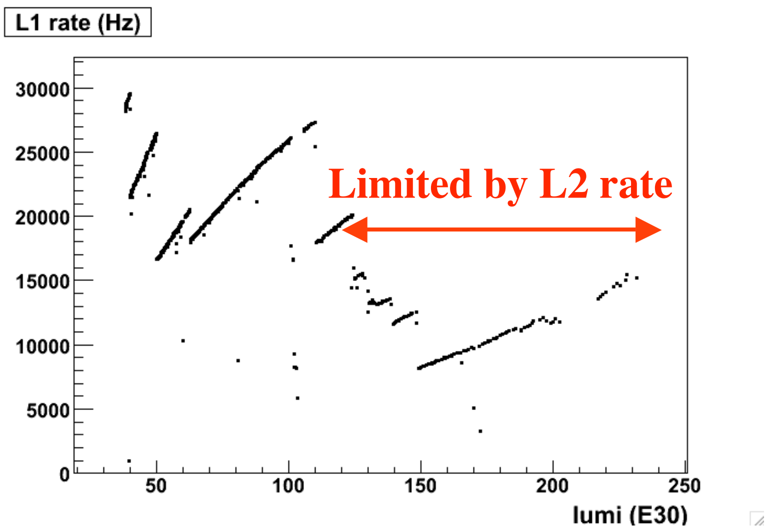
- End of Store:
  - Low luminosity → low rate.
  - High rate triggers prescaled by their MINIMUM value (preferably =1!).
- Many triggers have dynamic prescales, algorithm decides which prescale to change first:
  - Order by **MAXIMUM** prescale then un-prescaled rate.

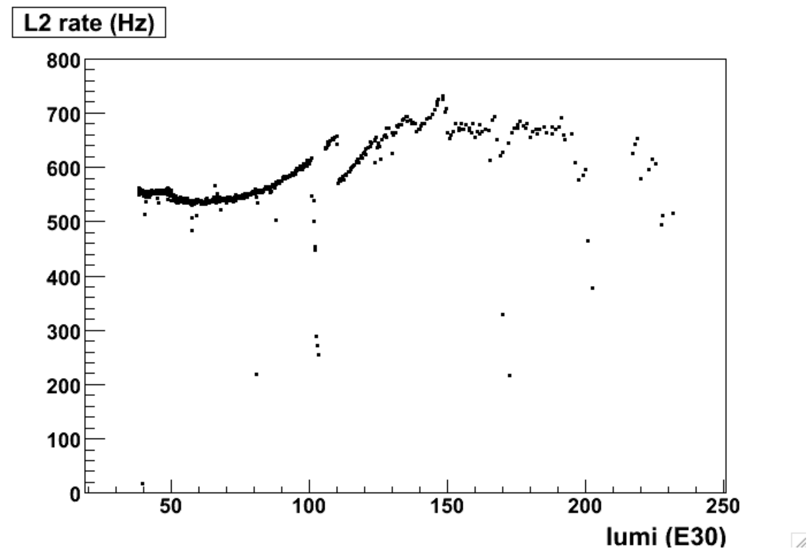
Trigger rate control at CDF

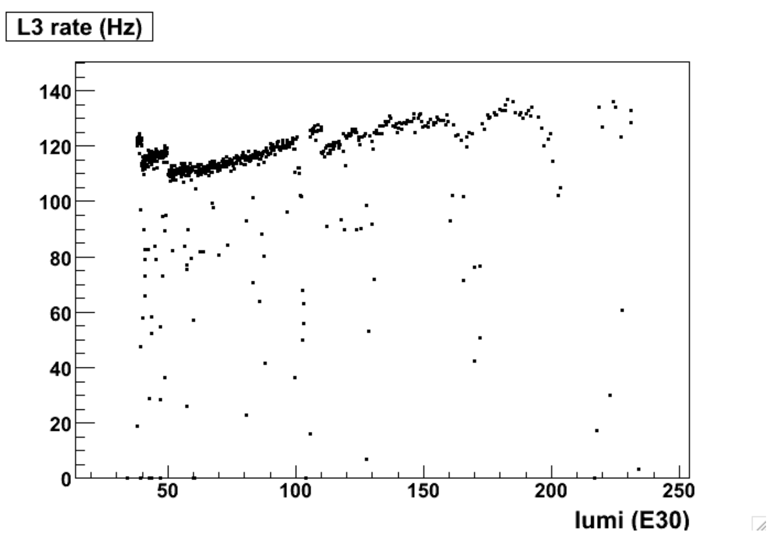
- Fixed Prescale (P): Accept 1/P of all events.
- Luminosity Enable: Switch on a trigger at a certain inst. lumi.; Takes no data at high lumi. where the rate is too high.
- Dynamic Prescale [DPS]: Prescale decreases through-out the run, depending on the total trigger rate.

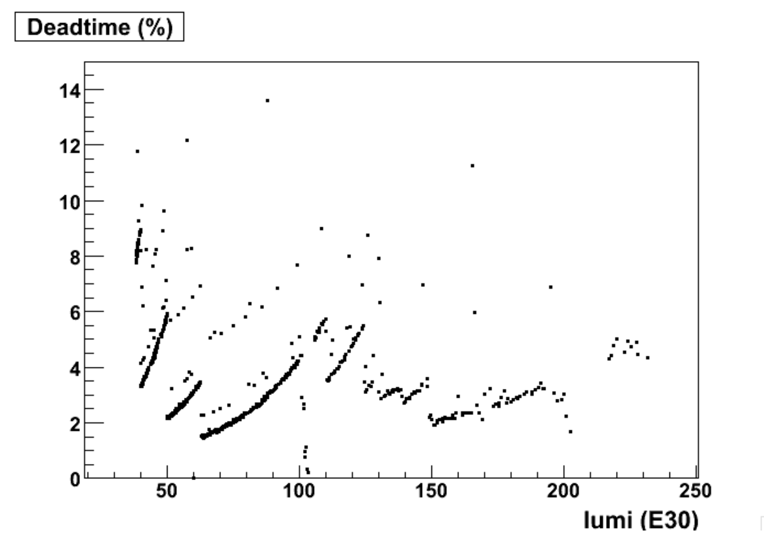


Trigger rates versus luminosity



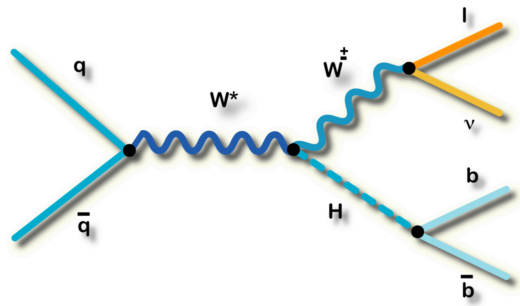


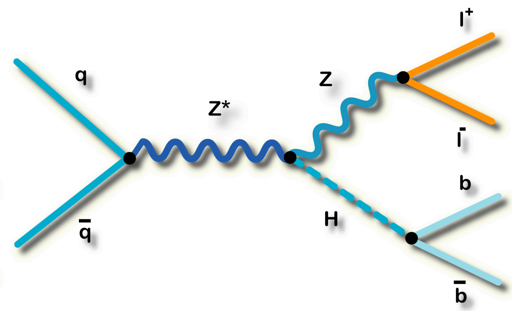


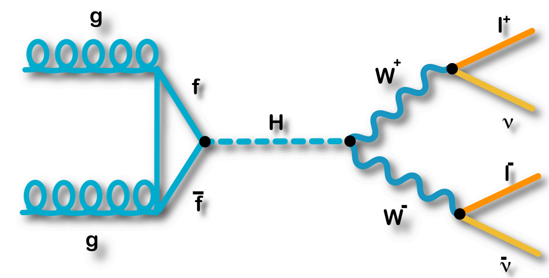


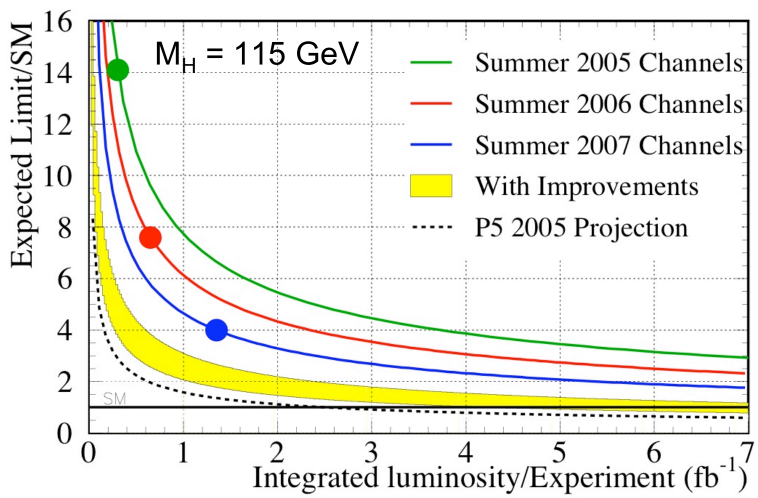
Triggering on rare events :
Higgs searches at CDF

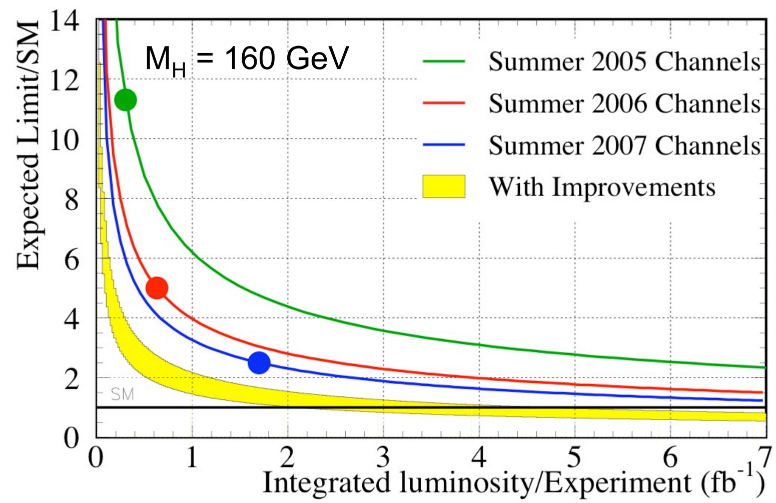
CDF and D0 are in with a *fighting* chance of discovering the SM Higgs.





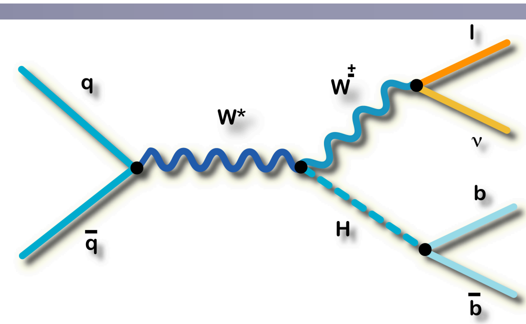






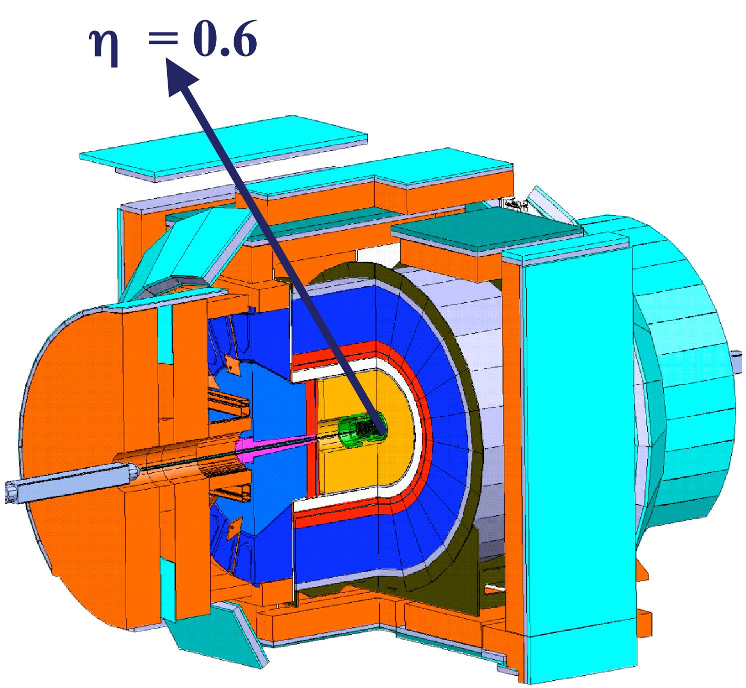
- As well as more luminosity we need more improvements to existing analyses.
- The trigger plays a vital role in the acceptance of Higgs events - there has been a recent surge in effort to improve Higgs triggers at CDF

Triggering on rare events: an example analysis



- Higgs production in association with a W: H→bb, W→μν
- Events can be selected by a number of different triggers:

✓ tight central muon: 29%



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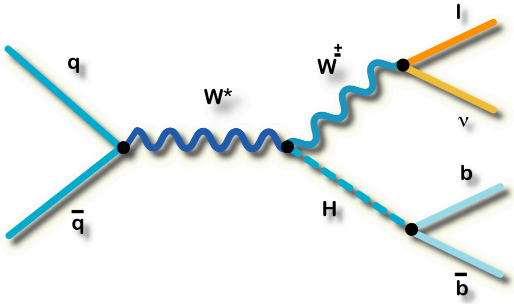
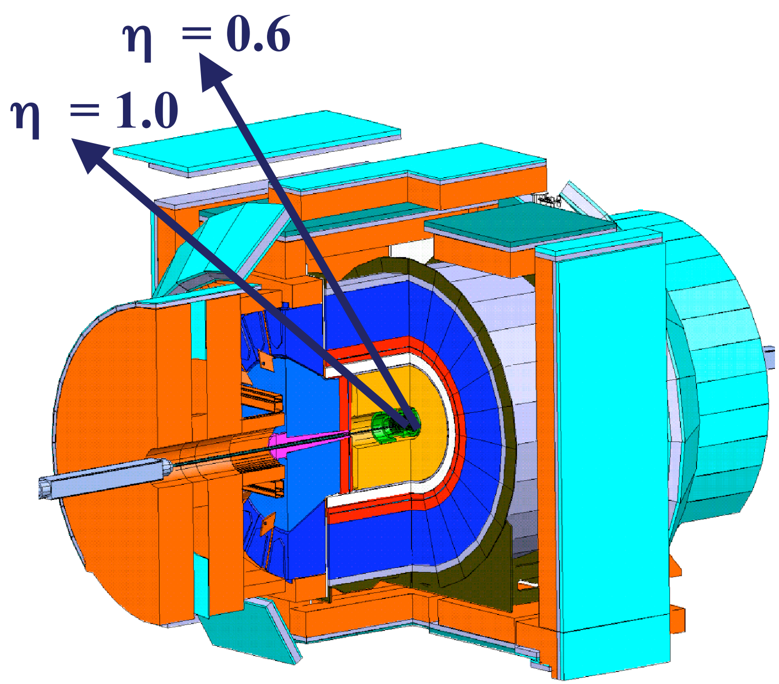


- Higgs production in association with a W: $H \rightarrow bb$, $W \rightarrow \mu\nu$
- Events can be selected by a number of different triggers:

  - ✓ tight central muon: 29%
  - ✓ central muon extension: + 9%



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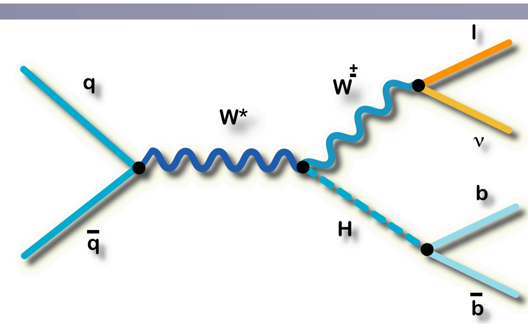
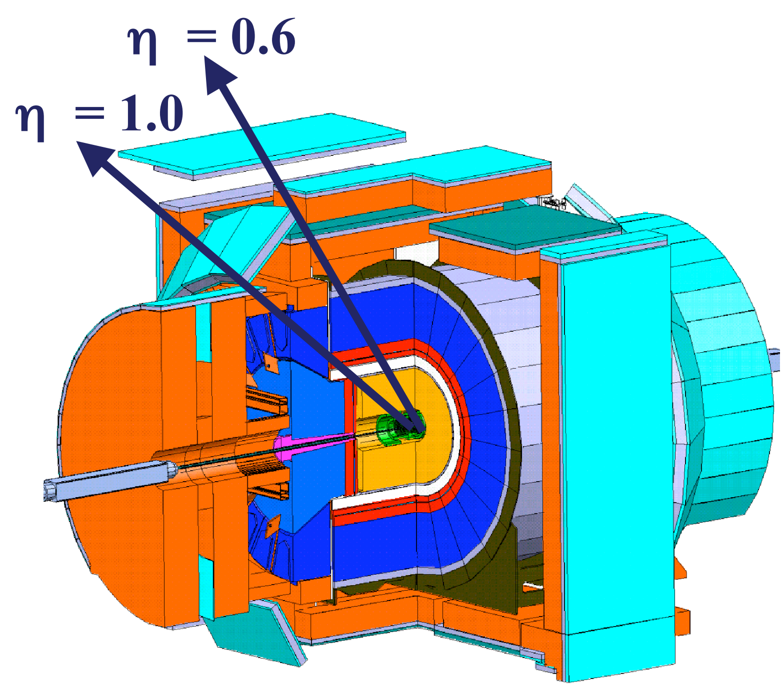


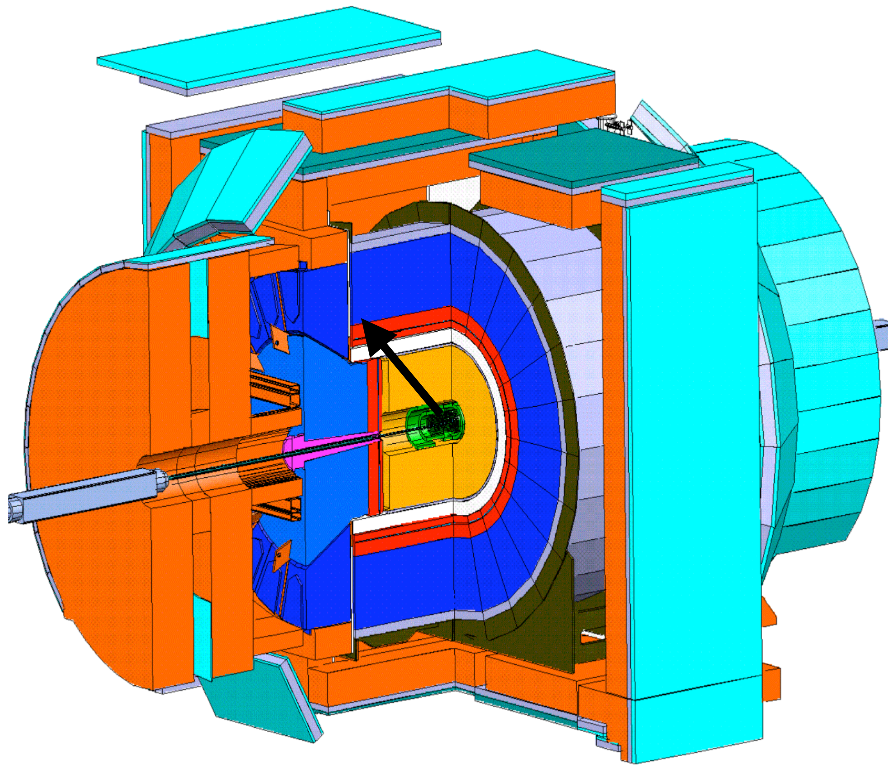
✓ tight central muon:	29%
✓ central muon extension:	+ 9%
× E_T^{miss}:	+28%
× E_T^{miss} + jet:	+14%
× loose central muon:	+ 4%
TOTAL =	**84%**

✓ Already used in analysis
× Trigger already running
× New trigger, recently added



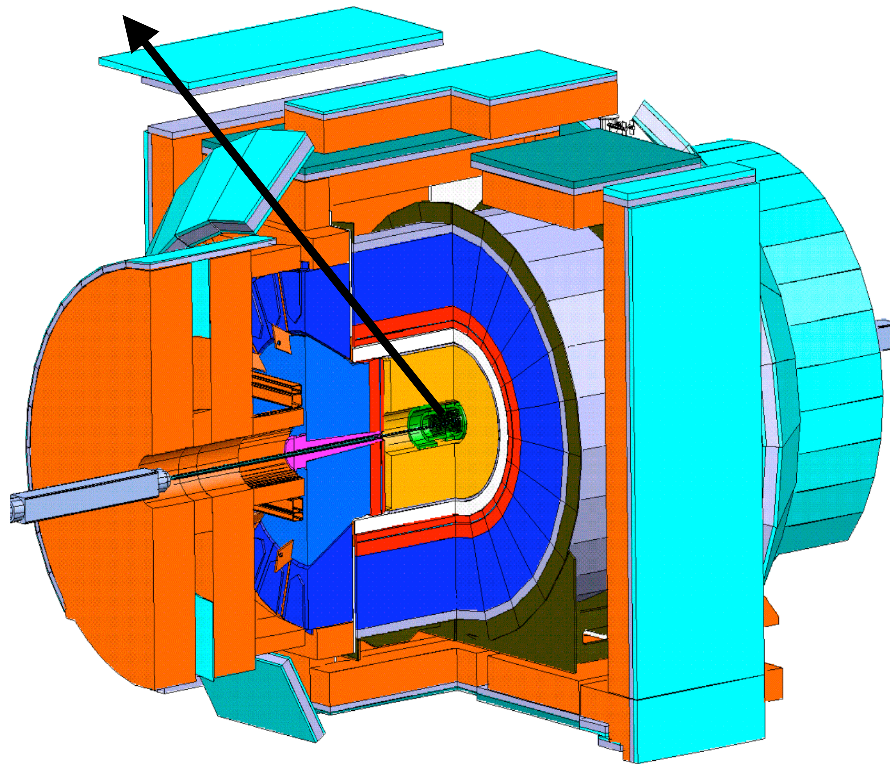
The history of the CMX trigger

- Level 1:
  - 8 GeV central track



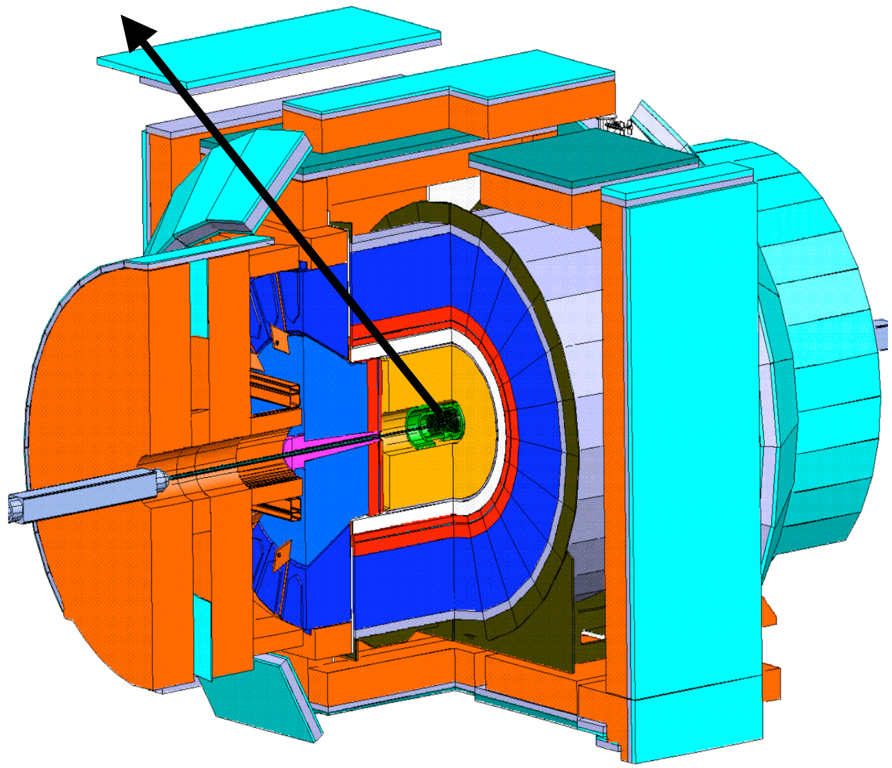
The history of the CMX trigger

- Level 1:
  - 8 GeV central track
  - Matched in ϕ to muon drift chamber and scintillator hits.



The history of the CMX trigger

- Level 1:
  - 8 GeV central track
  - Matched in ϕ to muon drift chamber and scintillator hits.
- Level 2:
  - Increase track p_T threshold to 15 GeV.
  - Tighter matching cuts.
- Level 3:
  - Increase track p_T threshold to 18 GeV.
  - Tighter 3D matching cuts.



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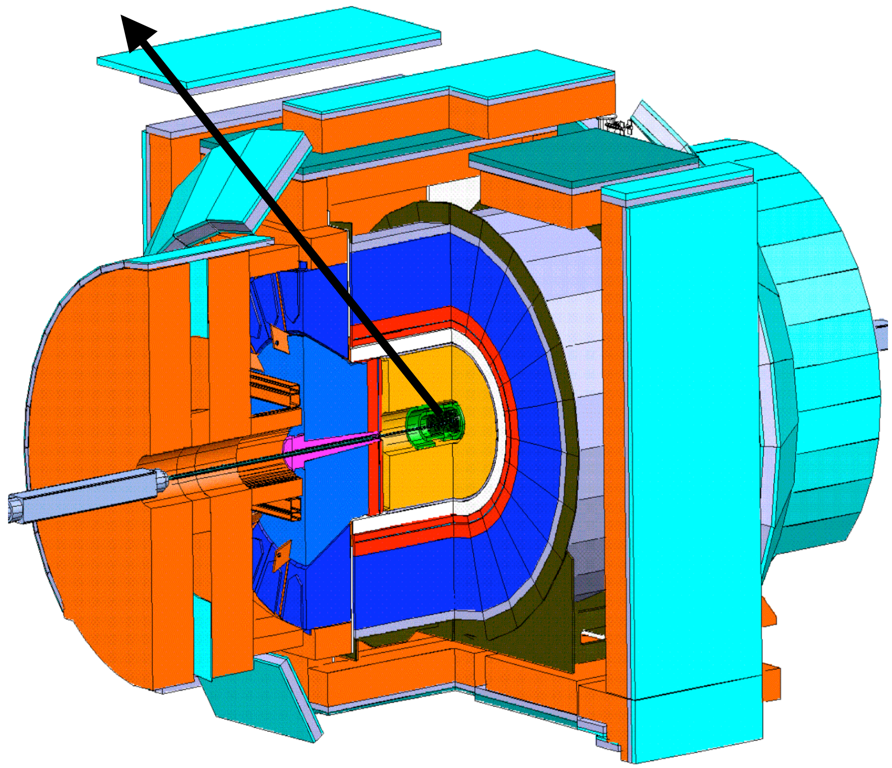
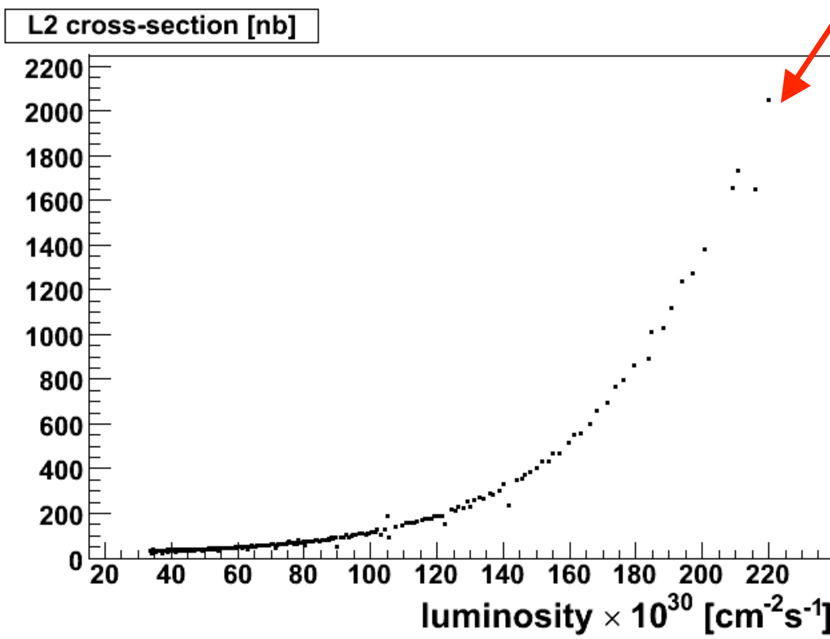
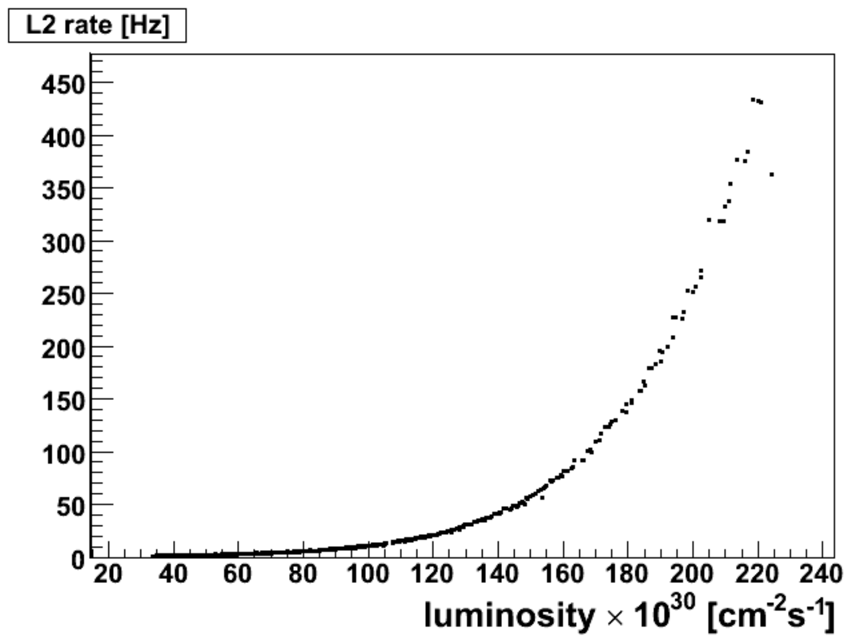


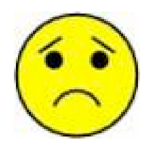
The history of the CMX trigger

Cross section increases due to fakes!



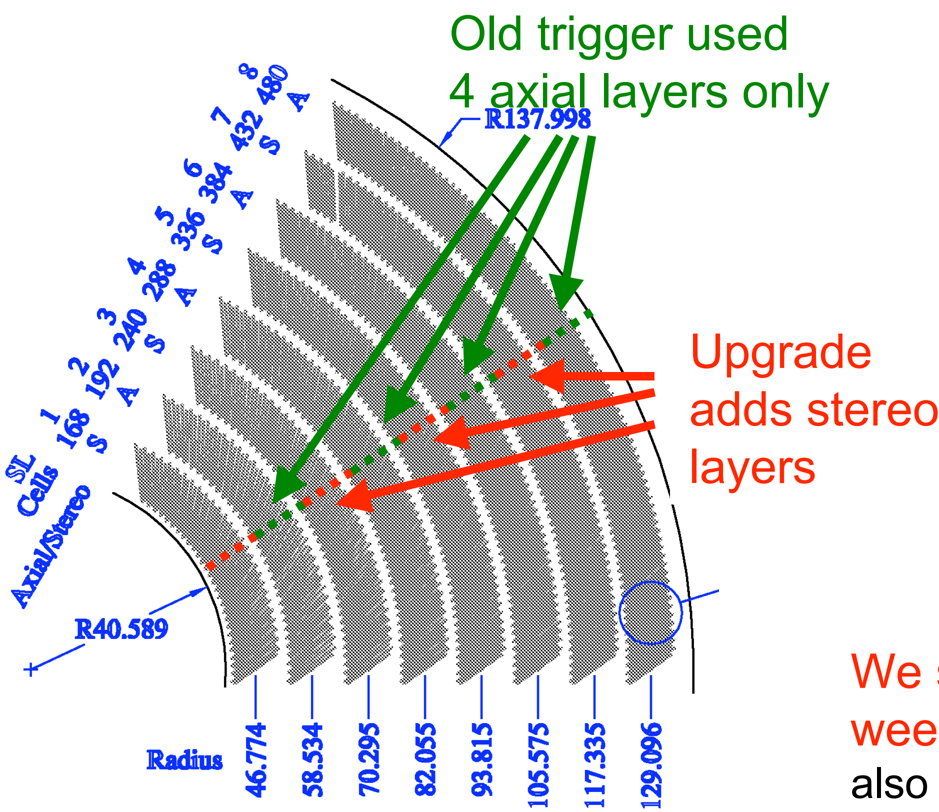


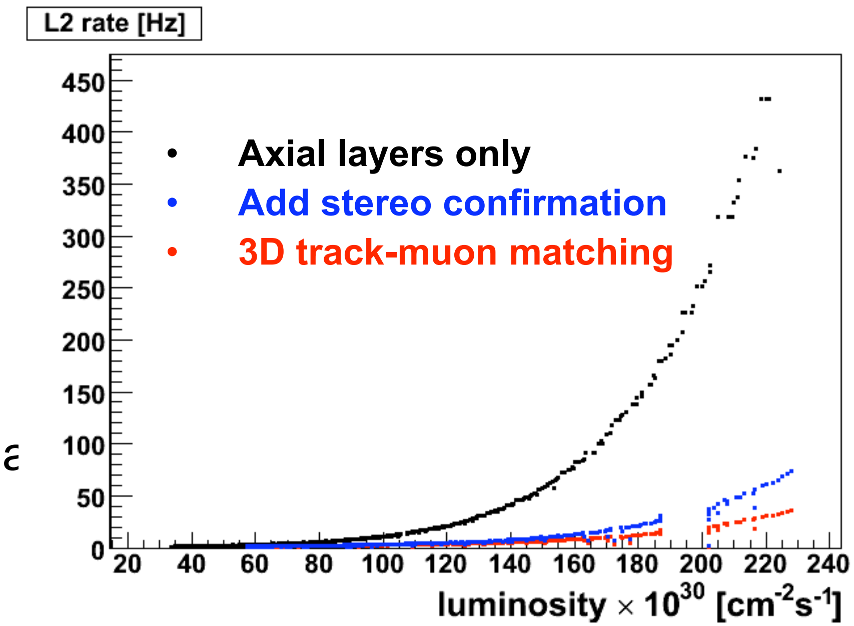
A rate of 400Hz at L2 for one trigger is too much! (total available ~650Hz).
Emergency solution was to prescale this trigger at high luminosity



CMX trigger: saved by a track trigger upgrade?

The Central Outer Tracker consists of 8 layers of cells: 1,3,5 and 7 are axial (giving r-ϕ information only). 2,4,6 and 8 are at a small stereo angle giving z information.

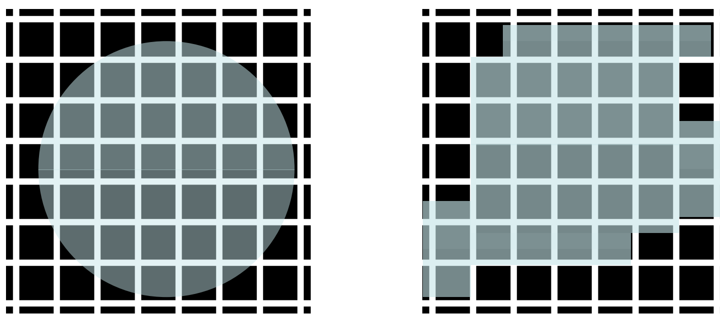




We should start running the 3D trigger this week with no prescale! (The axial only trigger will also run on Dynamic Prescale).

L2 calorimeter trigger

- The L2 calorimeter trigger was also recently upgraded to cope with high luminosities.
- Smarter jet algorithm uses "cone" instead of "continuous" clustering, reducing luminosity growth terms.



- Better calorimeter granuality used for E_T^{miss} trigger.
- Sharper turn on curves → better efficiencies

"Backup" Triggers

Most analyses require "backup" triggers in addition to "signal" triggers:

- Measurement of trigger efficiencies :
  - W_NOTRACK trigger selects $W \rightarrow e\nu$ events based on E_T^{miss} and tight EM cuts but no track $\rightarrow$ track trigger efficiency for high p_T electrons.
- Background studies :
  - ~low E_T jet triggers to measure probability of a jet faking a lepton (fake rate).
  - A non-isolated version of τ triggers (with a prescale) can be used to estimate backgrounds.
- Detector calibration :
  - Low E_T electron trigger used to study time dependence of calorimeter gain.
- Trigger studies :
  - Trigger that passes any L2 accept through L3 (prescaled!) - allows unbiased trigger studies.

LHC triggers

- Even more challenging than the Tevatron!:
  - 40 MHz crossing rate with ~10^9 events per second at design luminosity.
- Level-1 :
  - Hardware trigger
  - CAL and MUON only (no track)
  - 40 MHz → 50 -100 kHz
- High Level Triggers :
  - Software using full detector resolution.
  - Start with “Region Of Interest” (only reconstruct regions of the detector triggered at Level-1).
  - Eventually reconstruct entire event
  - 50 -100 kHz → 100 Hz

Summary : points to remember

1) Rate control : try to utilise available bandwidth at all luminosities (non-trivial!)
2) Beware of luminosity growth terms in trigger cross-sections!
3) Remember to “or” your triggers
   - Can lead to considerable increases in acceptance, maximise the significance of your result!
4) Design your trigger table carefully:
   - Remember to include backup triggers to measure efficiencies and backgrounds!
   - But don’t sacrifice golden search channels with backups gone wild!

Back-up slides

(1) Are our highest priority triggers running un-prescaled at all luminosities?

RunIIb Physics Priority & Triggers Committee's **Straw Table** @ 3E32 (CDF 8055, Ristori et al.)

	Trigger	Level 1		Level 2
High p_T lepton	Central Electron	L1_CEM8_PT8		L2_CEM16_PT8
	Central Muon	L1_CMUP6_PT4		L2_CMUP6_PT15_3D
	Muon Extension	CMX6_PT8_CSX		L2_CMX6_PT15_3D_JET10_DPS
	Single Jet/Electron-70	L1_JET20		L2_JET90
	Single Isolated Photon	L1_EM12		L2_EM21_ISO_PASS4
	Missing Et	L1_MET25		L2_MET35
SUSY di-lepton	e-central e-central	L1_CEM8_PT8		L2_CEM4_PT4_CES3_&_CEM8_PT8_CES3
	e-central mu-central	L1_CEM8_PT8		L2_CEM8_PT8_CES3_&_CMUP6_PT4
		L1_CMUP6_PT4		L2_CEM4_PT4_CES3_&_CMUP6_PT8
	e-central mu-extension	L1_CEM8_PT8		L2_CEM8_PT8_CES3_&_CMX1.5_PT4_CSX
		L1_CMX6_PT8_CSX		L2_CEM4_PT4_CES3_&_CMX6_PT8_CSX
	e-central e-plug	L1_EM8_&_CEM4_PT4		L2_CEM4_PEM8
	mu-central mu-central	L1_TWO_CMU1.5_PT1.5		L2_CMUP4_CMUP8
	mu-central mu-extension	L1_CMU1.5_PT1.5_&_CMX1.5_PT2_CSX		L2_CMUP4_CMX4
	e-plug mu-central	L1_EM8_&_CMU1.5_PT1.5		L2_CMUP4_PEM8
	e-plug mu-extension	L1_EM8_&_CMX1.5_PT2_CSX		L2_CMX4_PEM8
TAU + lepton	Tau+electron	L1_CEM8_PT8		L2_TAU4_PT5_CEM8_PT8_CES3
	Tau+muon central	L1_CMUP6_PT4		L2_CMUP6_PT8_&_TRK5_3D
	Tau+muon extension	L1_CMX6_PT8_CSX		L2_CMX6_PT8_&_TRK5_3D_DPS
	Plug e + Missing Et	L1_EM8_&_MET15		L2_PEM20_L1_EM8_&_MET15
	Super Photon-70	L1_JET20		L2_JET90
	Di-Gamma/Z-notrack	L1_TWO_EM8		L2_TWO_EM_16
	Top Multijet	L1_JET20		L2_FOUR_JET15_SUMET175

Note: colour code indicates what is needed to conform to Straw Table projections. many other triggers will be helped by the upgrades.

Done
L2 XFT upgrade
L2 CAL upgrade
Not yet needed

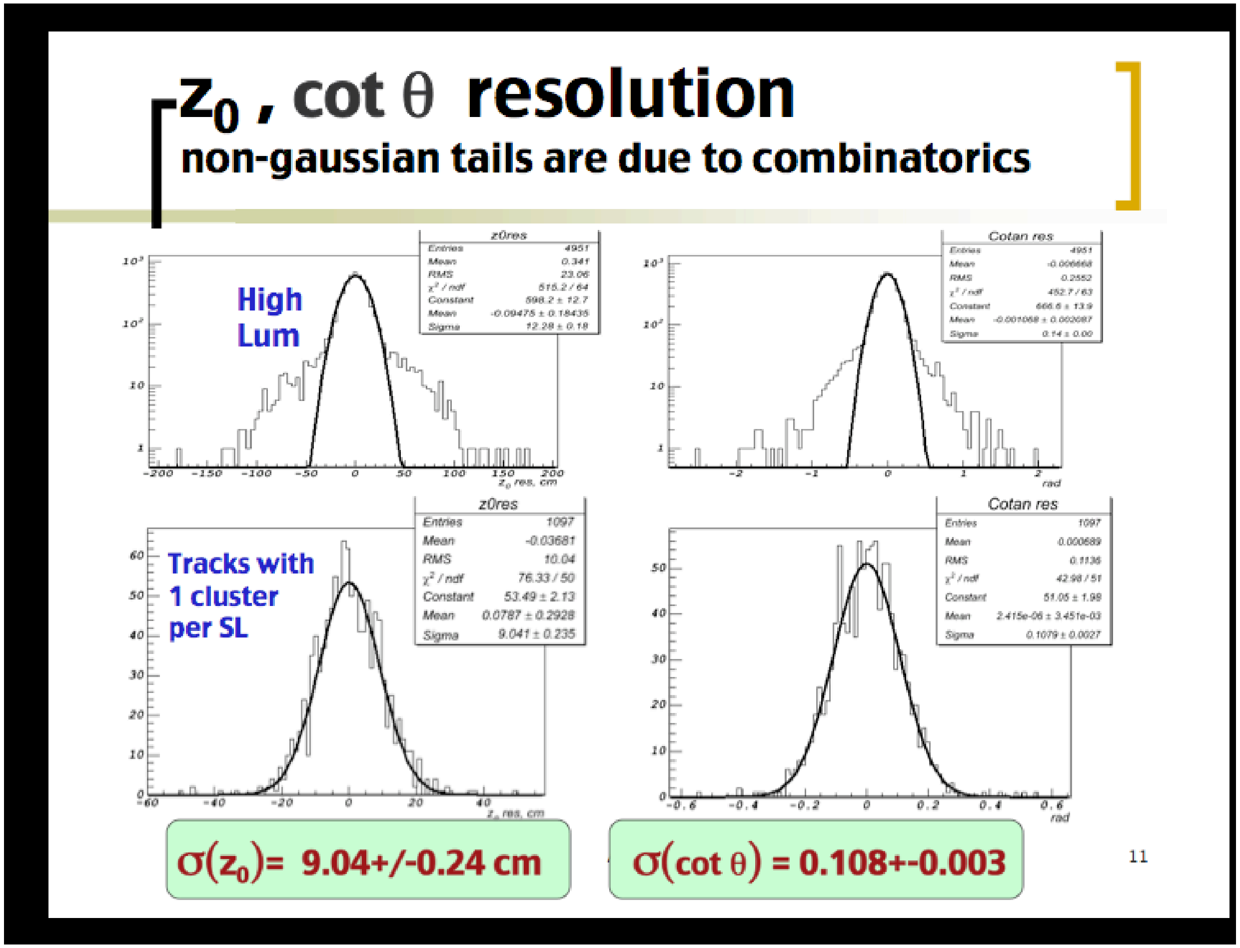
= prescaled at high lumi

- XFT hits are mapped to muon stubs at L2 based on a 3 sigma multiple scattering term a misalignment parameter (dominates at high PT).
- The default value of the misalignment parameter was 1.5 degrees (CMX and CMU).
- On April 5th (runs after 238243) tighter matching was added to the muon triggers:

CMX: misAlign=0.6

CMUP: misAlign=0.8

L2 stereo reconstruction



$\sigma(p_T)/\, p_T^2 \sim 2\%$, $\sigma(\varnothing) \sim 6$ mR