CMS Trigger

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Outline:

Requirements & Overview

Level 1 Trigger

- Calorimeter Trigger
- Muon Trigger
- Global Trigger

Summary

CMS Physics Trigger Requirements

Standard model Higgs (high luminosity)
- H (80 GeV) $\rightarrow \gamma\gamma$
- H (120 GeV) $\rightarrow$ Z Z* (4 leptons)
- H (>500 GeV) $\rightarrow$ leptons (+ ν's)
- H (< $2M_W$ Associated t or W or Z) $\rightarrow$ b b (lepton + X)

SUSY Higgs (low luminosity)
- (standard model Higgs like channels)
- h, H, A $\rightarrow \tau\,\tau$ (lepton + X)
- A $\rightarrow$ Z h ; h $\rightarrow$ bb (lepton + X)
- p p $\rightarrow$ t t X; t $\rightarrow$ H^+ b; $H^+ \rightarrow \tau\,\nu$; t $\rightarrow$ lepton + X

SUSY sparticle searches (low luminosity)
- MSSM sparticle $\rightarrow$ LSP (Missing E_t) + n jets
- MSSM sparticle $\rightarrow$ Same sign dileptons + X

Other new particles
- Z' $\rightarrow$ dileptons
- Leptoquarks: dileptons

Top physics (low luminosity)
- t $\rightarrow$ lepton + X
- t $\rightarrow$ multijets

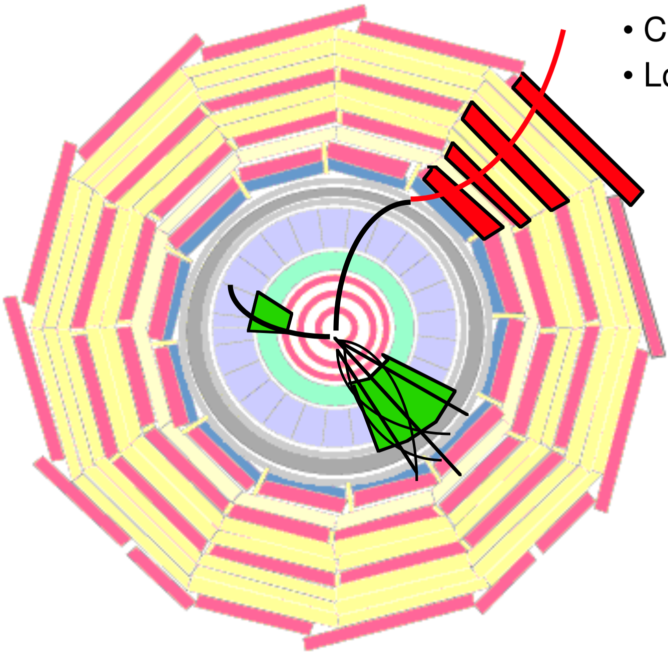
Bottom physics (low luminosity)
- b $\rightarrow$ lepton + X
- b $\rightarrow$ ψk_s (leptons + X)

QCD
- Low luminosity 100 GeV jets
- High luminosity 200 GeV jets

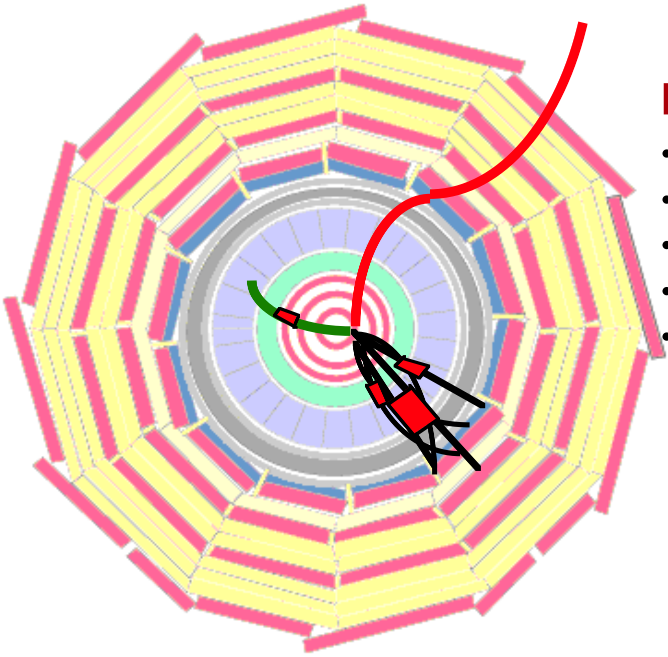
Trigger candidates:
- High luminosity: lepton/γ (30 GeV), dileptons/$\gamma\gamma$ (15 GeV)
  missing E_t (100 GeV), jets (200 GeV)
- Low luminosity: lepton/γ (15 GeV), dileptons/$\gamma\gamma$ (10 GeV)
  missing E_t (50 GeV), jets (100 GeV)

CMS Trigger Levels

40 MHz



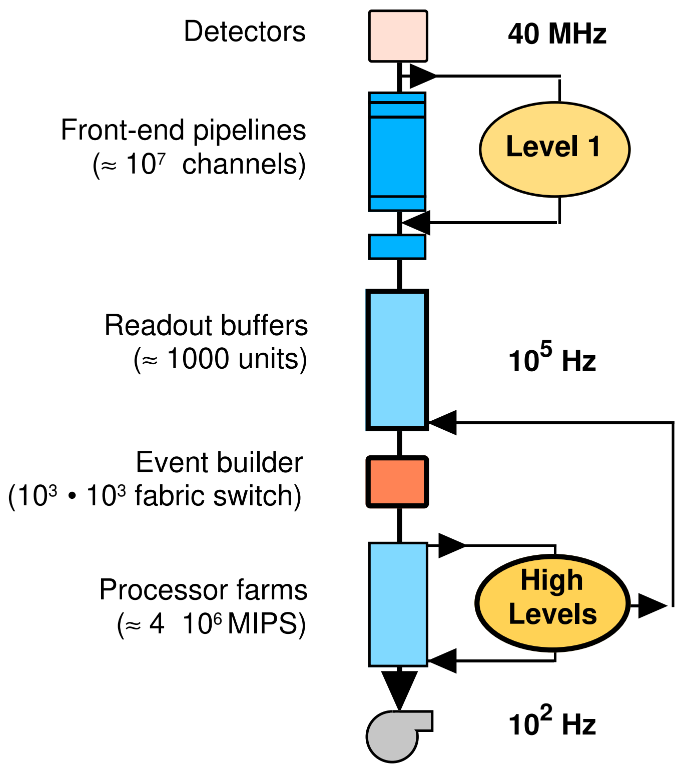
up to 100 kHz



≈ 100 Hz

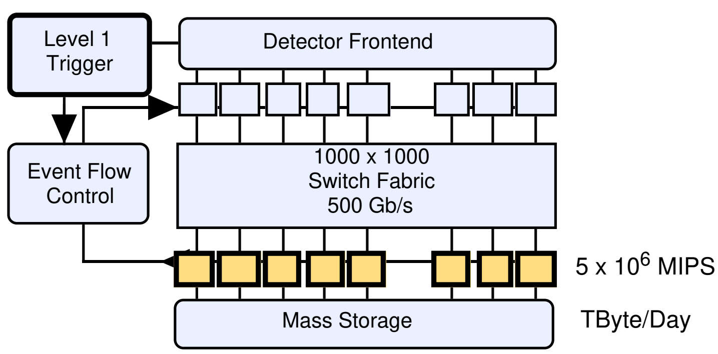
Level-1. Specialized processors

- Particle ID: electron/γ, muon, jets, missing E_T
- Coarse granularity to reduce data volume
- Local pattern recognition and energy sums



High trigger levels. CPU farms

- Clean particle signature (Z, W, quarks..)
- Finer granularity precise measurement
- Kinematics. Effective mass cuts and topology
- Track reconstruction and detector matching
- Event reconstruction and analysis

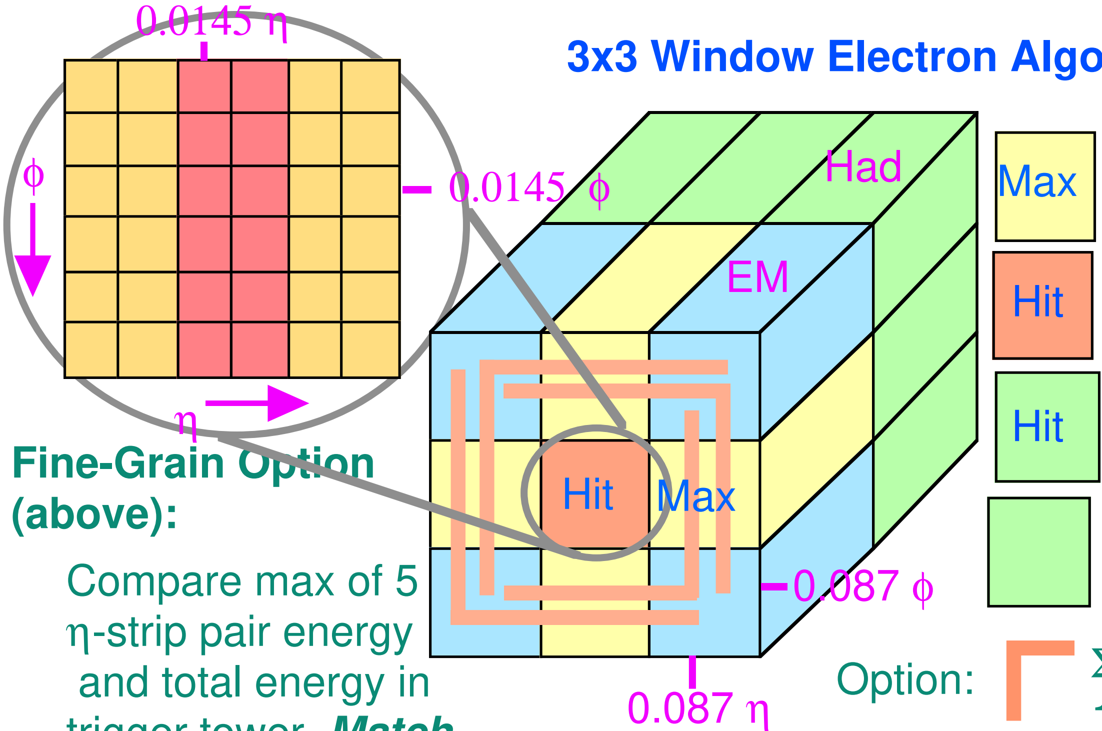


Physics Requirements & Algorithms

Electron/Photon trigger with full efficiency above 40 GeV for design luminosity of 10^{34} cm^{-2} s^{-1} in $0 < \phi < 2\pi$ and $-2.6 < \eta < 2.6$.
(option of lower threshold for b-physics)

Diphoton/Dielectron trigger with full efficiency above 20 GeV for design luminosity in $0 < \phi < 2\pi$ and $-2.6 < \eta < 2.6$.

3x3 Window Electron Algorithm:



Fine-Grain Option (above):

Compare max of 5 η-strip pair energy and total energy in trigger tower. ***Match w/electron on 4x4***

Option: Σ 5 E_T Nghbrs 1 of 4 < 1.0 GeV

Tower count = 72φ x 54η x 2 = 7776

Jet trigger with good efficiency above 200-300 GeV in $0 < \phi < 2\pi$ and $-5 < \eta < 5$, but with prescalable triggers at lower thresholds.

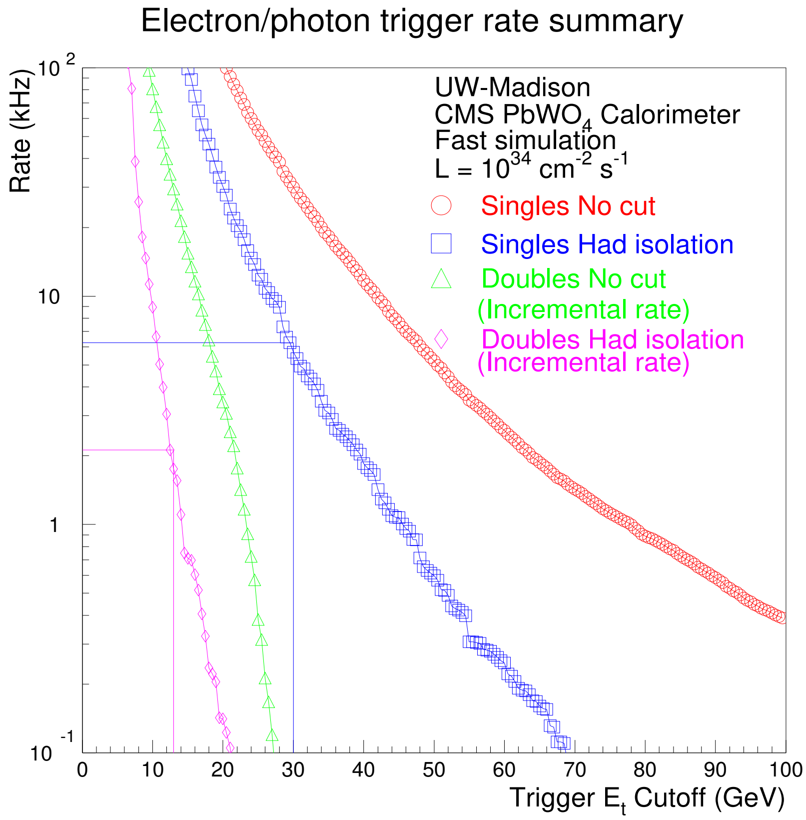
4 x 4 non-overlapping trigger tower sums, i.e., 0.348φ x 0.348η

Missing energy trigger with good efficiency above 100 GeV in $0 < \phi < 2\pi$ and $-5 < \eta < 5$.

E_x, E_y calculated from 4 x 4 non-overlapping jet sums and added over the entire calorimeter including forward region.

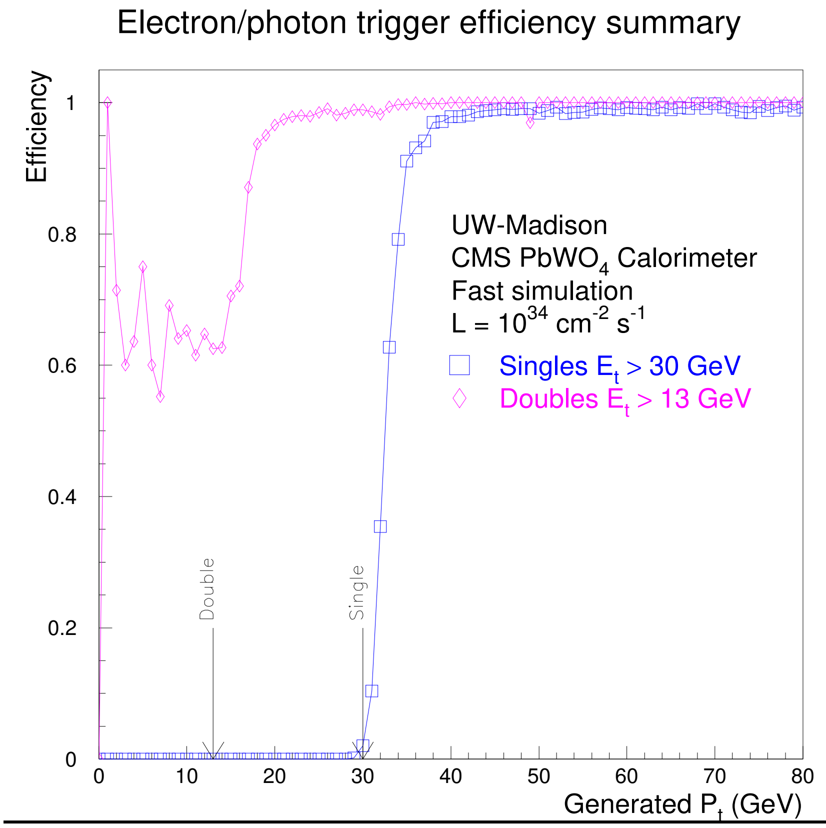
Electron/photon trigger

(fast simulation)



The integrated QCD background rate for singles and the increment over that rate for doubles are plotted versus trigger E_t cutoffs with and without hadronic isolation cuts (H/E<0.05 and H_{surr}<1.5 GeV).

The cumulative rate of electron/photon triggers is 6.6 kHz well within the e/γ trigger bandwidth allocation.

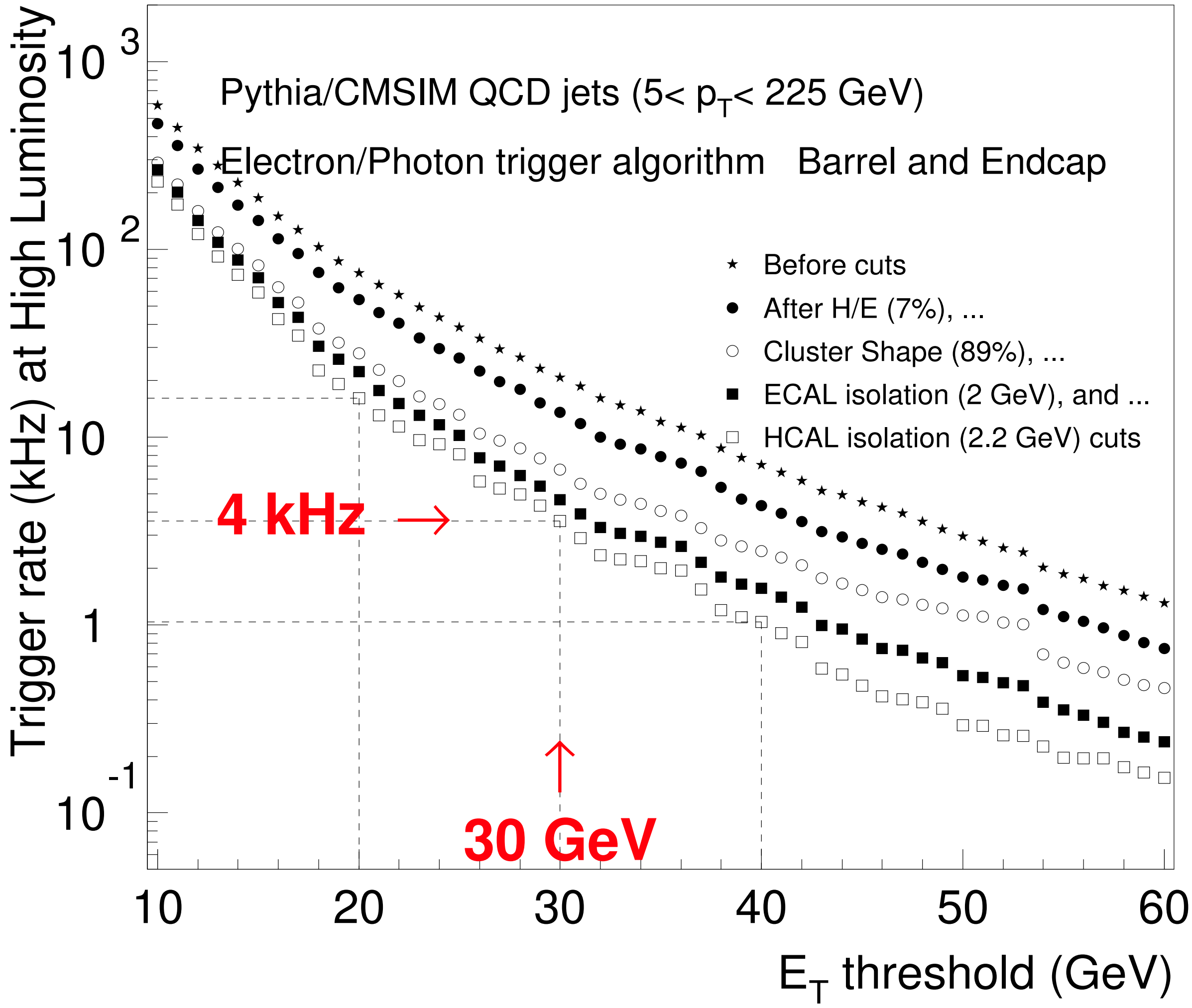


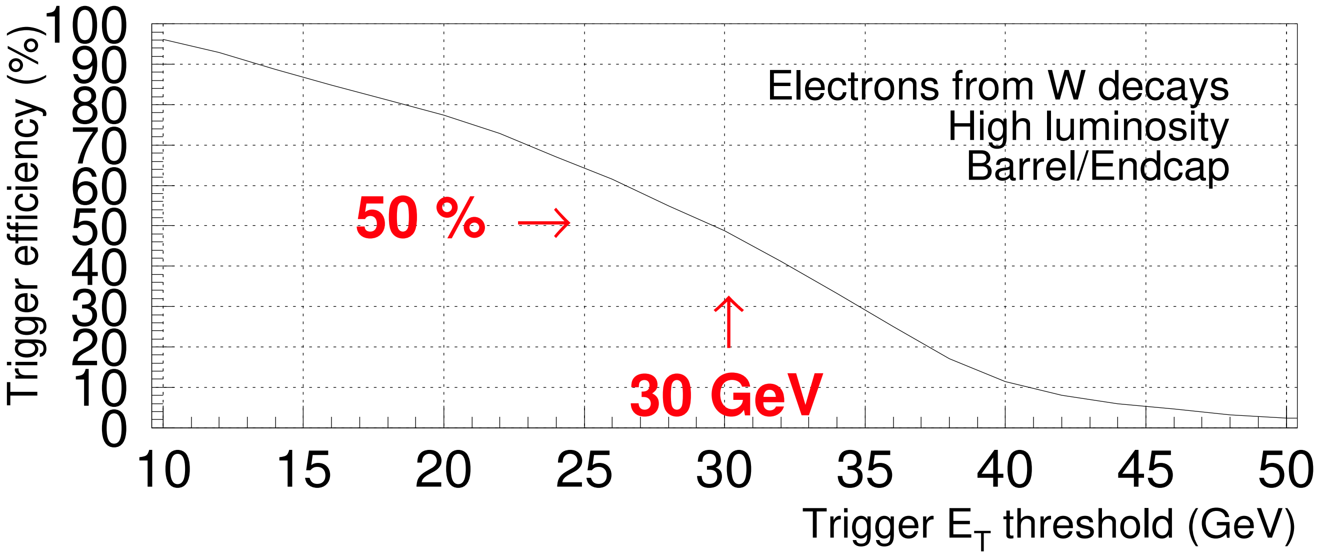
Efficiency turn on is shown versus P_t of the single electrons with trigger E_t cutoff at 30 GeV and P_t of lower of the two photons in the Higgs (80 GeV) decays to two photons with trigger E_t cutoff at 12 GeV.

Cumulative efficiency is 99% above P_t of 40 GeV for singles and 20 GeV for doubles, satisfying the physics requirements.

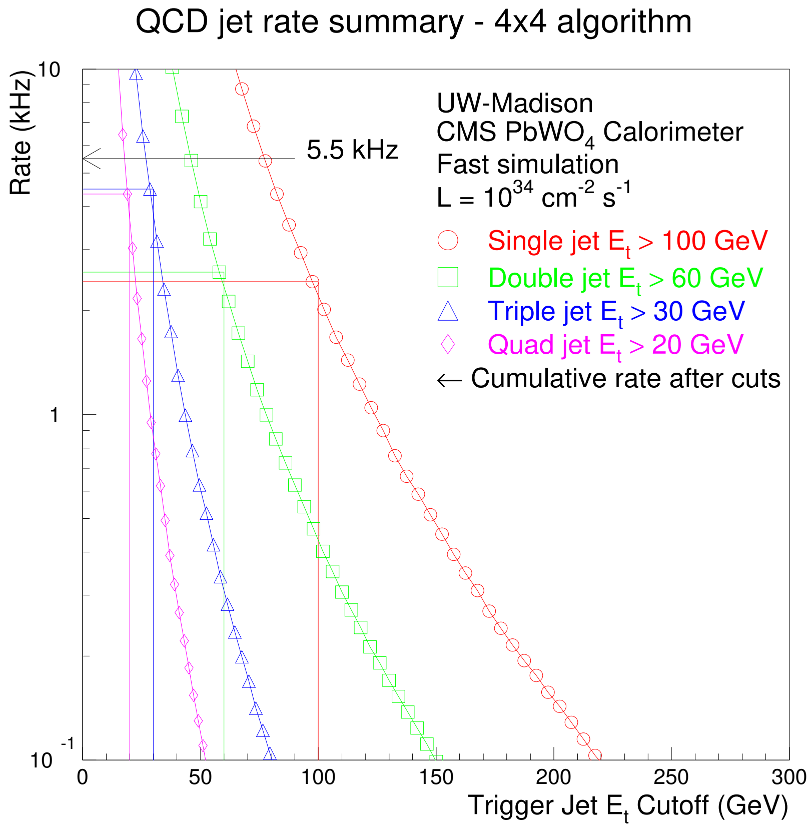
CMSIM Rates & Efficiency

(including fine-and coarse-grain EM isolation)



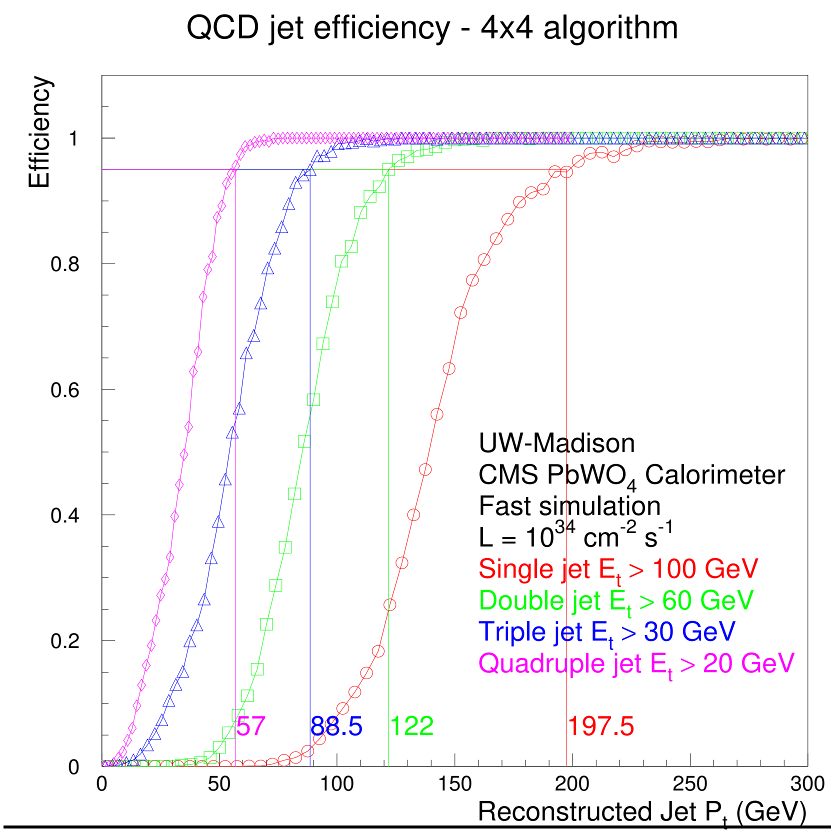


Jet trigger



Integrated rates for single, double, triple and quadruple jet triggers are shown versus E_t cutoff.

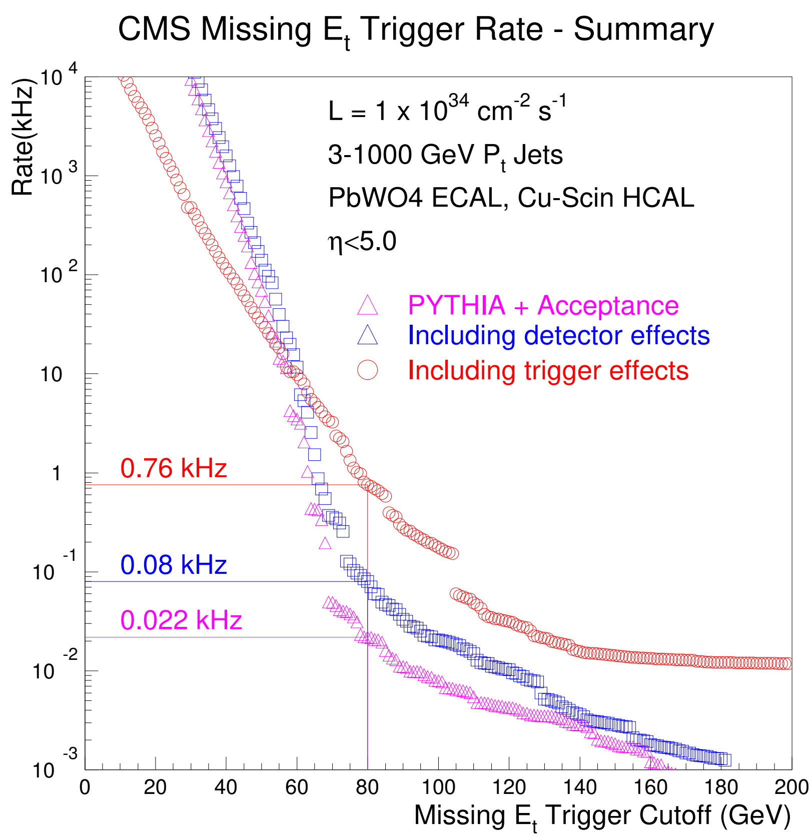
Cumulative rate after the cuts indicated is 5.5 kHz (within the jet trigger bandwidth allocation).



Cumulative efficiency of jet triggers is plotted versus the reconstructed jet P_t.

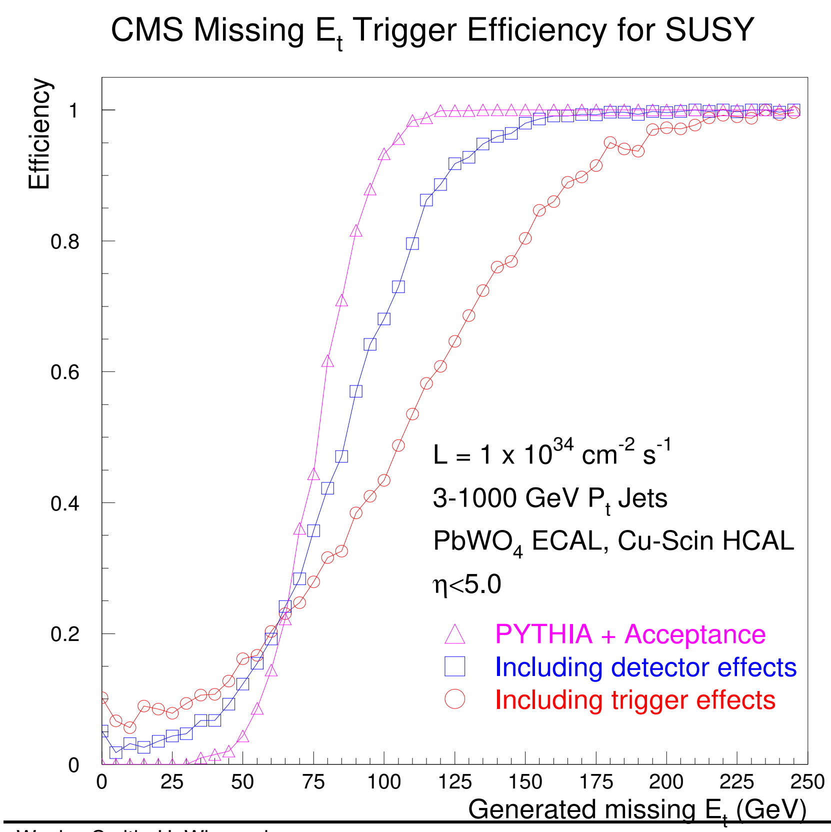
QCD and SUSY physics requirements are satisfied with the thresholds shown at 99.5% effiiciency point.

Missing E_t trigger



Integrated rate for missing E_t trigger is plotted versus trigger cutoff.

~1 kHz rate is expected with 80 GeV cutoff.



Efficiency of missing E_t trigger for SUSY events (CMS TP Scenario A) is plotted versus generated missing E_t. Degradation of performance upon including inevitable detector and trigger effects is shown.

However, the combined efficiency of missing E_t and jet triggers for this high rate process is satisfactory.

Physics at high luminosity

Trigger Type	Et Cutoff (GeV)	Rate (kHz)		
		Indiv.	Cumul.	Increm.
Sum Et	400	0.48	0.48	0.48
Miss Et	80	1.29	1.7	1.22
1 e	25	6.84	8.34	6.64
2 e	12	1.45	9.52	1.18
1 jet	100	2.06	10.7	1.16
2 jet	60	2.17	11.6	0.93
3 jet	30	3.16	13.3	1.7
4 jet	20	2.96	14.3	1.01
Jet + e	50 +12	1.35	14.9	0.59

$\mathcal{L} = 10^{34}\ cm^{-2}\ s^{-1}$

QCD Background

The sum and missing E_t cutoffs are chosen to give ~ 2 kHz.

e/γ triggers are emphasized, with ~ 8 kHz rate out of available 15 kHz.

The remaining 5 kHz is available for jet triggers.

Process	Eff (%)
H (80 GeV) $\rightarrow \gamma\gamma$	97.4
H (120) $\rightarrow$ Z Z $\rightarrow$ e e $\mu\mu$	76.4*
H (200) $\rightarrow$ Z Z $\rightarrow$ e e j j	99.1
p p $\rightarrow$ t t $\rightarrow$ e X	88.3
p p $\rightarrow$ t t $\rightarrow$ H+X $\rightarrow$ t X	81.7
SUSY (MLSP = 45, Mspart ~ 300 GeV)	83.0

Signal Efficiency

High efficiency for all channels with e & γ.

Difficult-to-trigger top decay events have high efficiency, enabling studies of associated Higgs production.

*Inclusion of μ trigger $\rightarrow$ full efficiency

Physics at low luminosity

Trigger Type	Et Cutoff (GeV)	Rate (kHz)		
		Indiv.	Cumul.	Increm.
Sum Et	150	1.04	1.04	1.04
Miss Et	40	2.11	2.82	1.78
1 e	12	10.3	12.3	9.5
2 e	7	1.54	13.1	0.764
1 jet	50	1.98	13.5	0.42
2 jet	30	1.63	13.9	0.422
3 jet	20	1.02	14.1	0.178
4 jet	15	0.68	14.2	0.077
Jet + e	15 + 9	5.98	15.2	1.02

$\mathcal{L} = 10^{33}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

QCD Background

The sum and missing E_t cutoffs are chosen to give ~ 2 kHz.

e/γ triggers are emphasized, with ~ 10 kHz rate out of available 15 kHz.

The remaining 3 kHz is available for jet triggers.

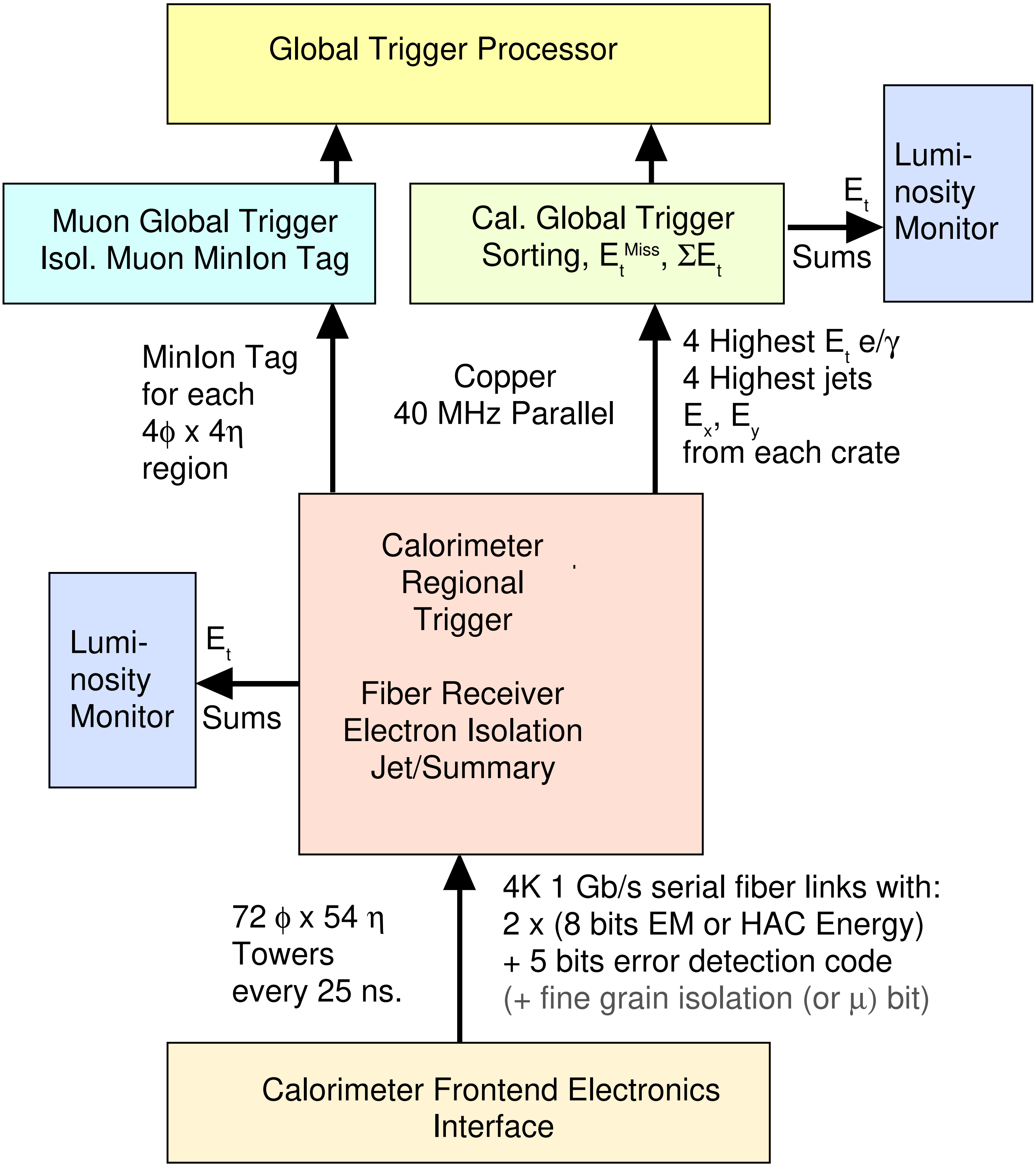
Process	Eff (%)
p p $\rightarrow$ t t $\rightarrow$ e X	99.3
p p $\rightarrow$ t t $\rightarrow$ H+X $\rightarrow$ t X	99.0
p p $\rightarrow$ b b (hadronize), B $\rightarrow$ e X	0.2 (400 Hz)
SUSY (MLSP = 45, Mspart ~ 300 GeV)	97.8
SUSY Neutral Higgs Range: tan β and M(H)	45 - 98

Signal efficiency

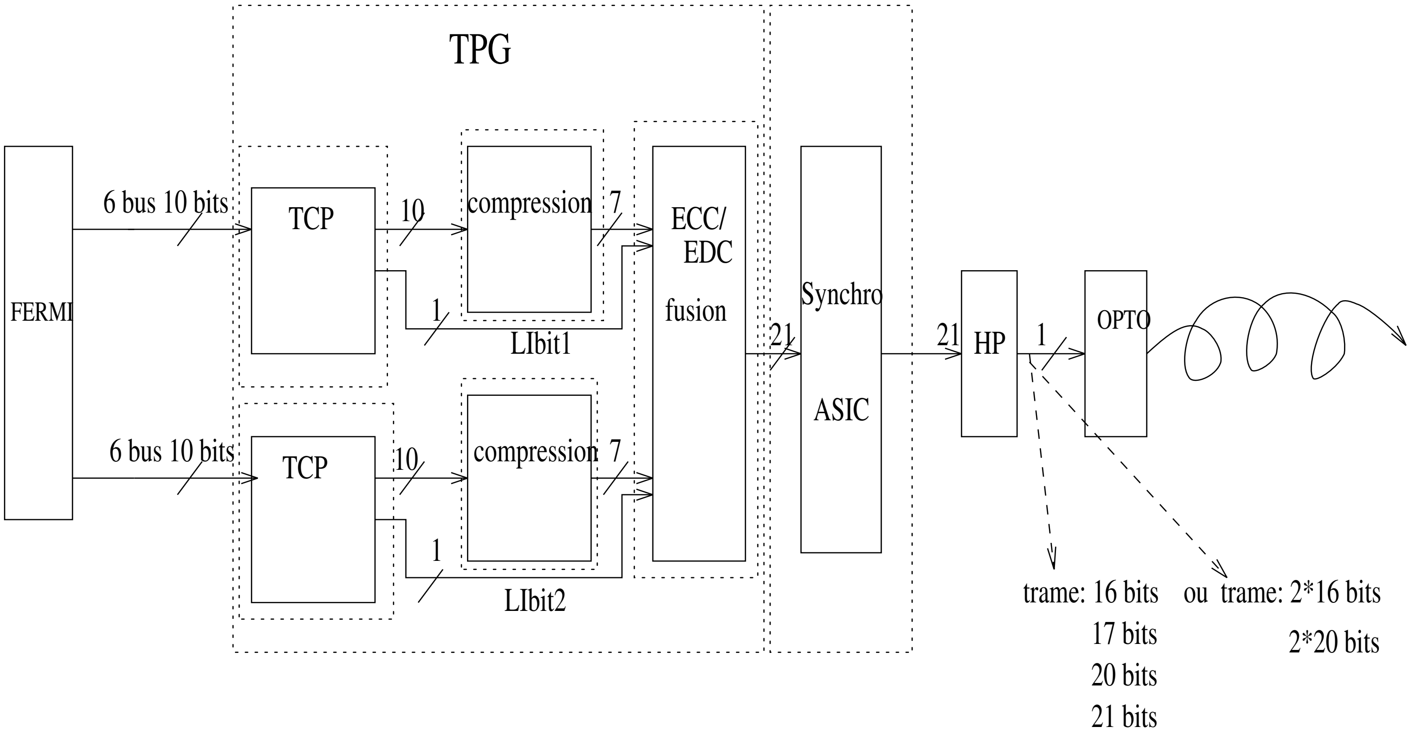
High efficiency is realized for the benchmark processes involving top decays and SUSY sparticles.

There is also high rate of B signal in level-1 sample.

Level 1 Calorimeter Trigger



Trigger Primitive Generator Design



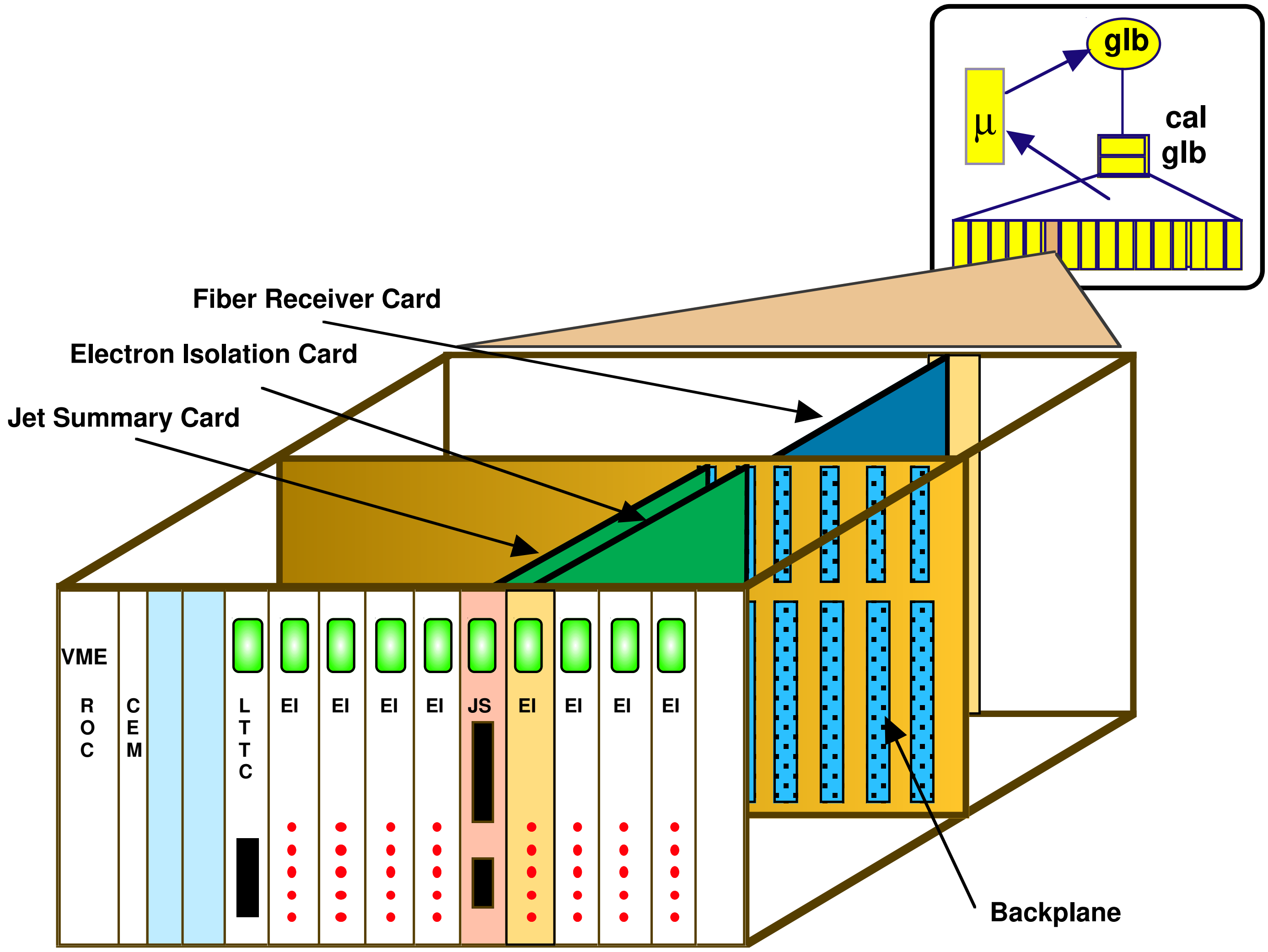
Proposed Architecture:

- 2 Trigger Cell Processors (TCP)
- 2 Compression Units
- 1 Error Detection Code Fusion Unit

Inputs/Outputs

- 2 x 6 10-bit input busses from 12 FERMI Calorimeter Readout Channels
- 1 21 (or 16)-bit output bus to Synchronization ASIC
  - Choice depends on design of optical link system

Calorimeter Regional Trigger Crate



Data from calorimeter FE on optical fibers

- Into rear-mounted Receiver Cards

160 MHz point to point backplane

- Receiver, Electron Isolation, Jet Summary Cards Operate @ 160 MHz

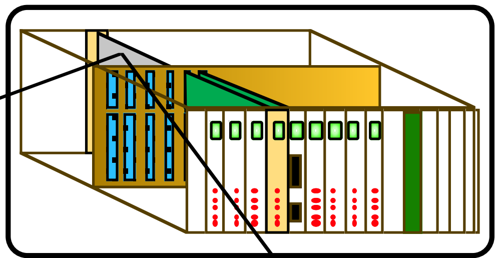
Output to calorimeter global trigger

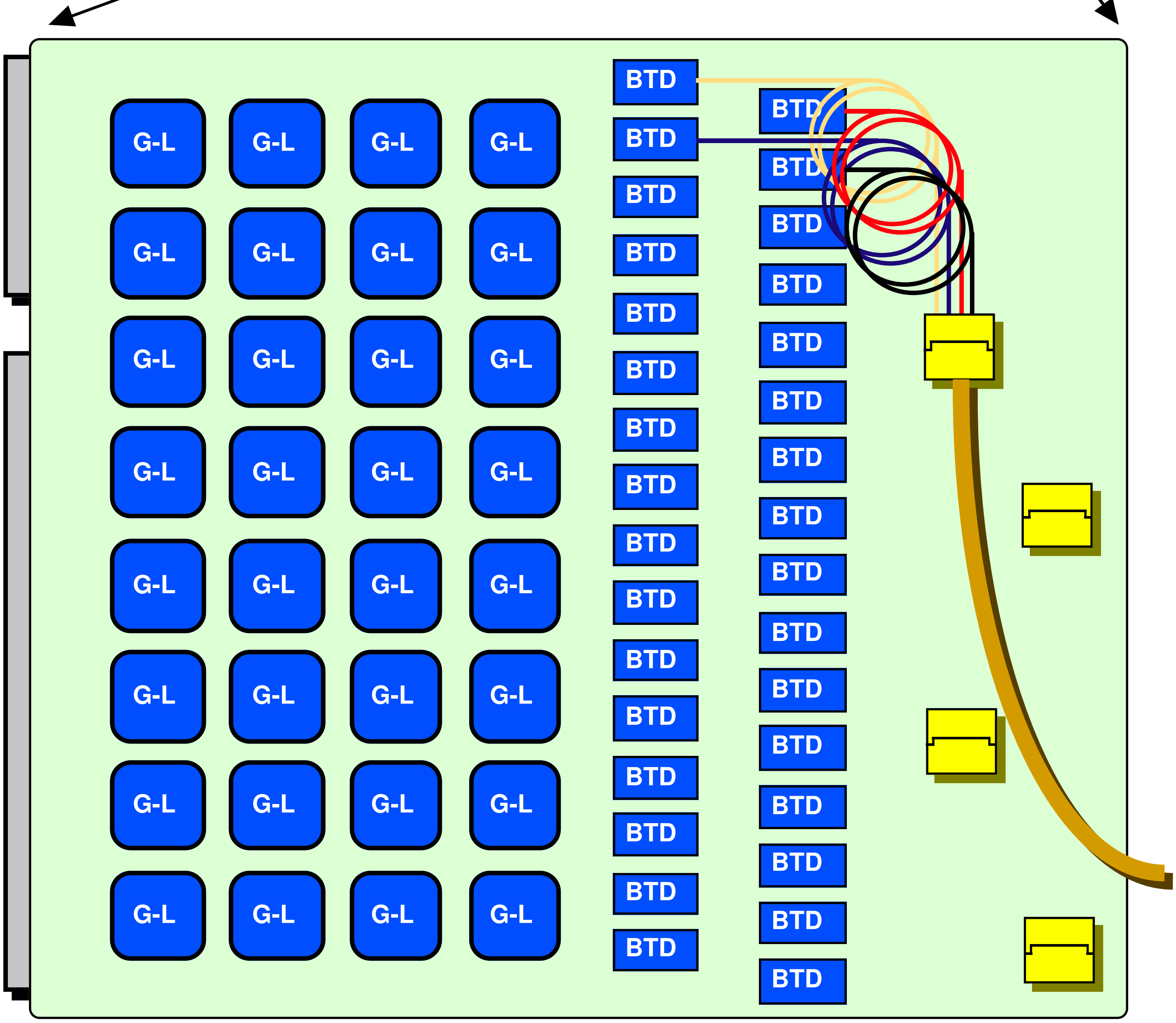
- From Jet Summary Card

"Quiet" bits to muon trigger

Fiber Receiver Card - Rear

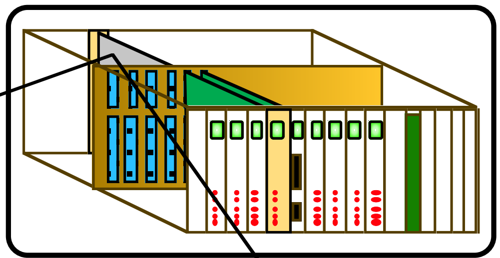
- 9U x 400 mm
- 32 Channels
- 960 Mbaud fiber receivers
- 16 bit (2x8) data + 5 bit error det. codes
- BTD optical-electrical
- HP GLink serial-parallel
- VME control on 128-pin DIN

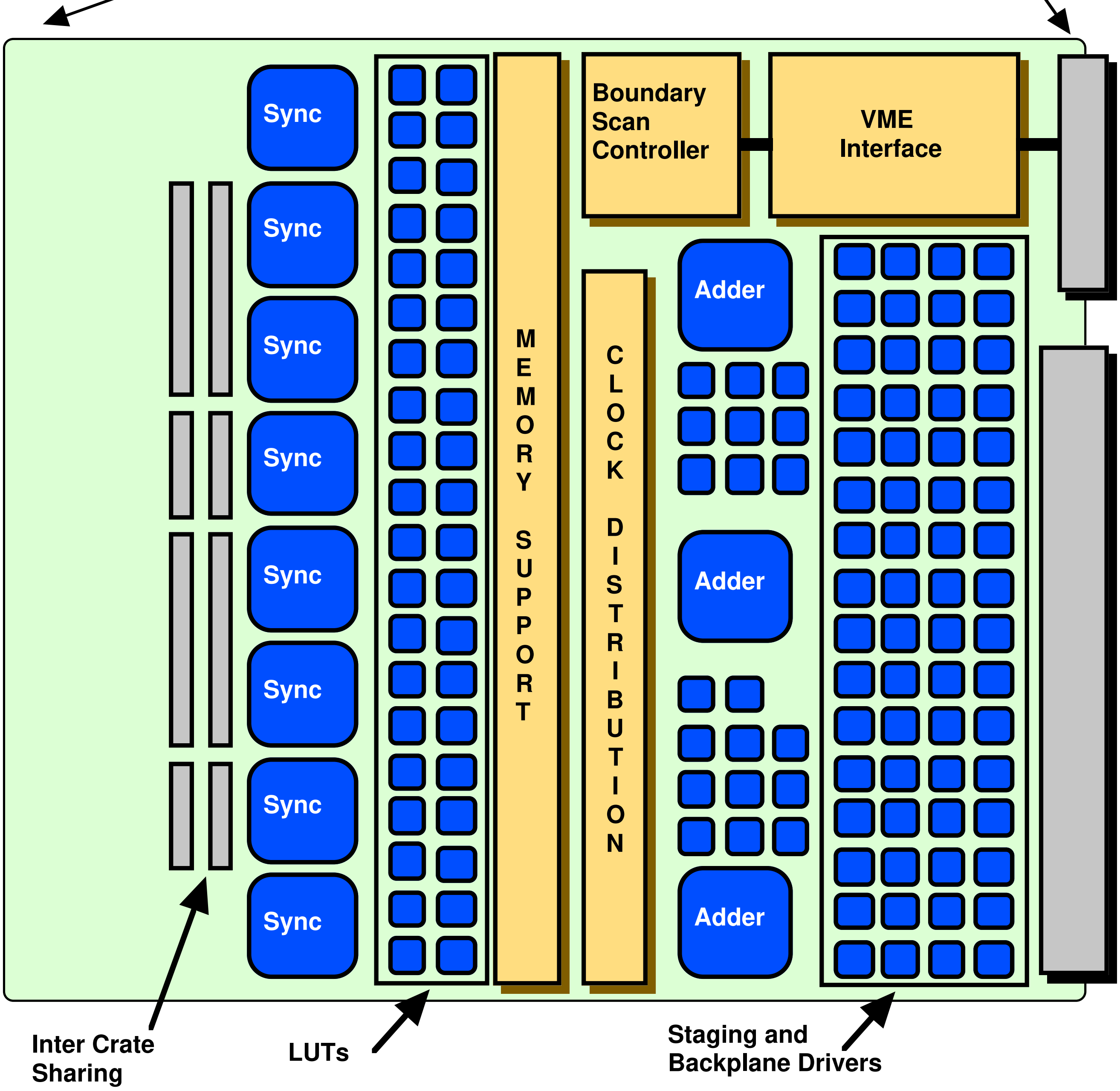




Fiber Receiver Card - Front

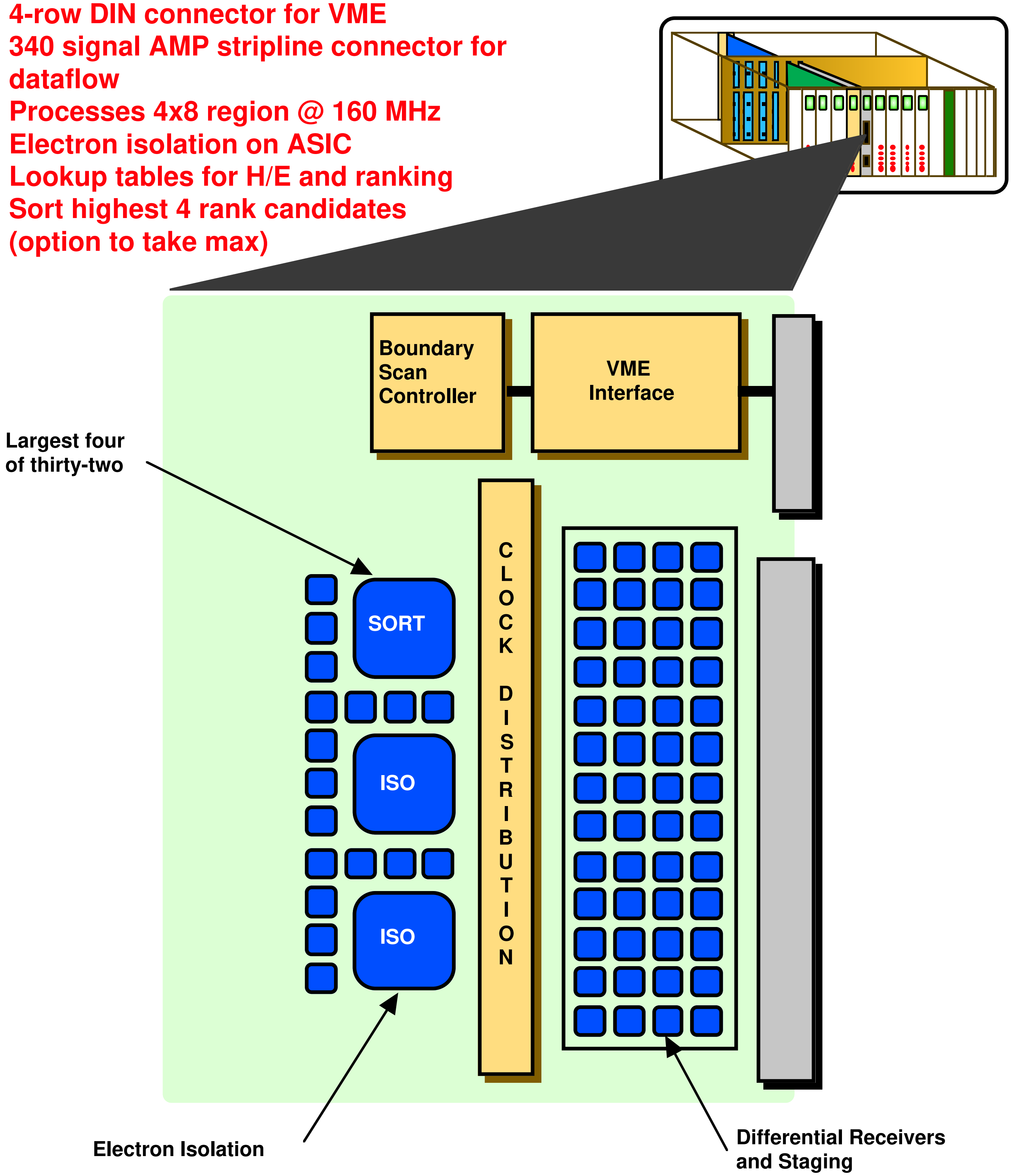
- Data from Rear
- Synchronization by Sync ASIC
- Memory Lookup tables @ 160 MHz
- Adder ASIC: 8 operands @ 160 MHz
- Differential Outputs @160 MHz
- 340 Pin AMP Stripline connector
- Error logic bit for each 4x4





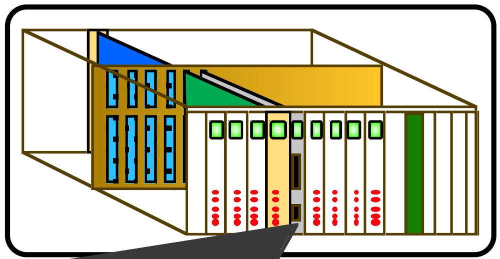
Electron Isolation Card

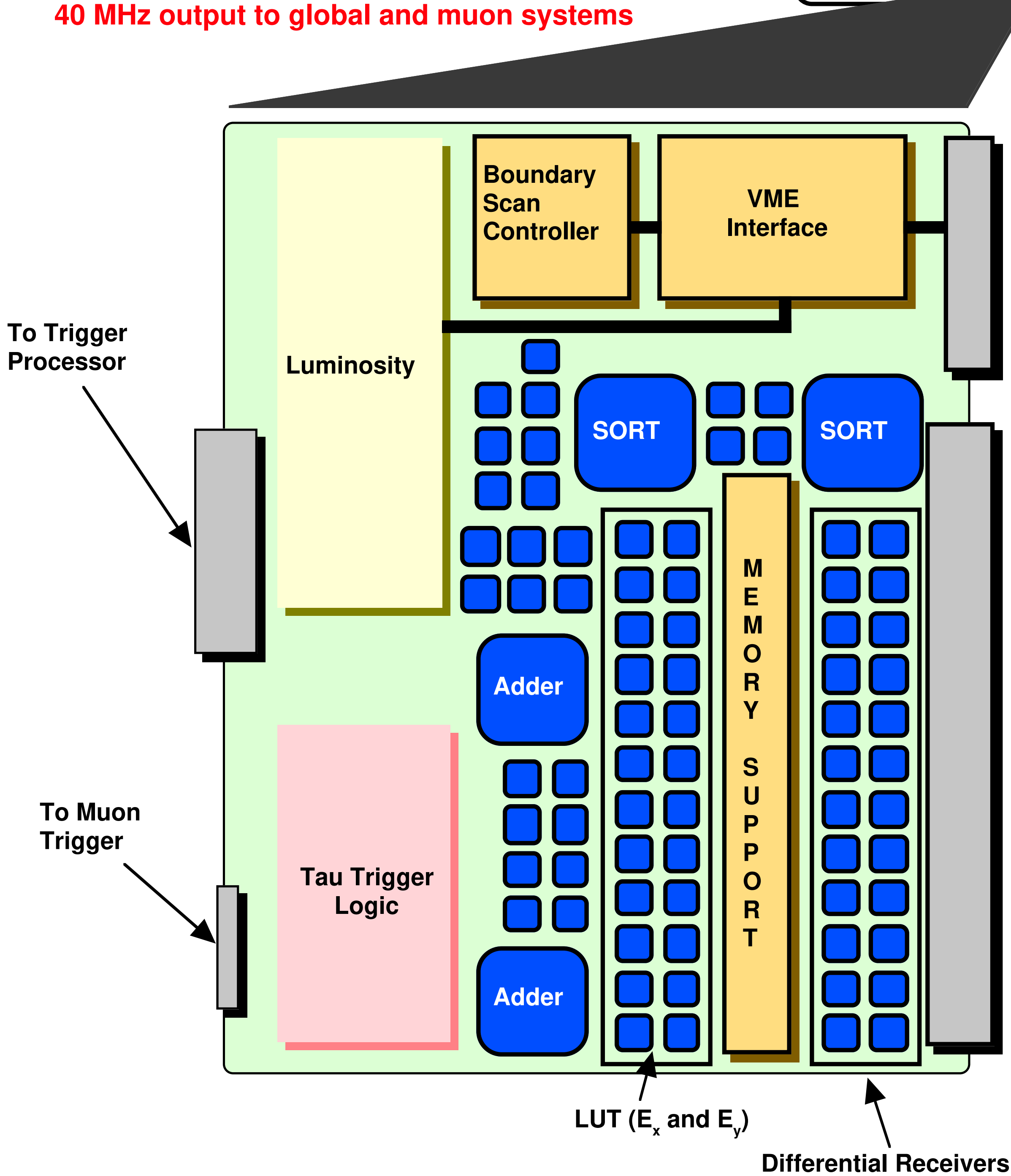
9U x 280 mm
4-row DIN connector for VME
340 signal AMP stripline connector for dataflow
Processes 4x8 region @ 160 MHz
Electron isolation on ASIC
Lookup tables for H/E and ranking
Sort highest 4 rank candidates
(option to take max)



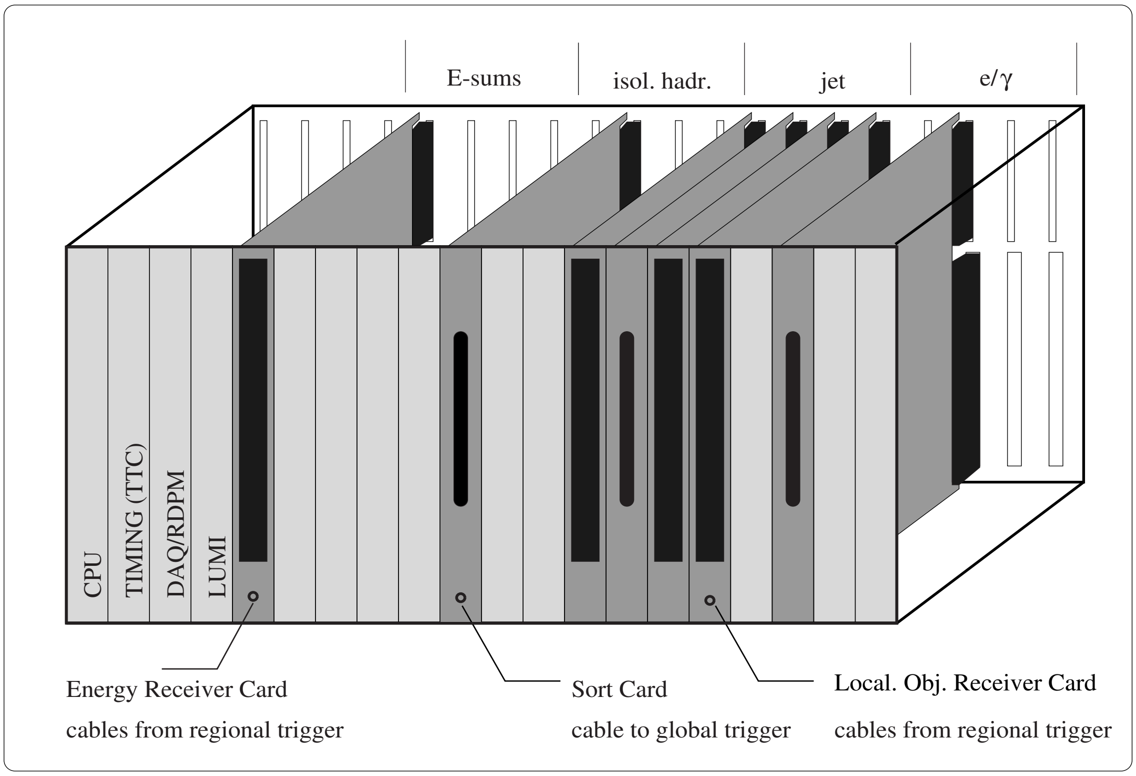
Jet/Summary Card

- 9U x 280 mm card summarizes full crate
- Sorts 32 electron ranks to find top 4 in crate
- Sorts 32 4x4 E_t sums to find top 4 jets in crate
- LUTs to generate E_x and E_y from E_t for 4x4 region
- Adder tree for crate E_t, E_x and E_y sums
- Quiet/MinI bits for each 4x4 region
- Reserved space for Tau and Lumi sums
- 40 MHz output to global and muon systems

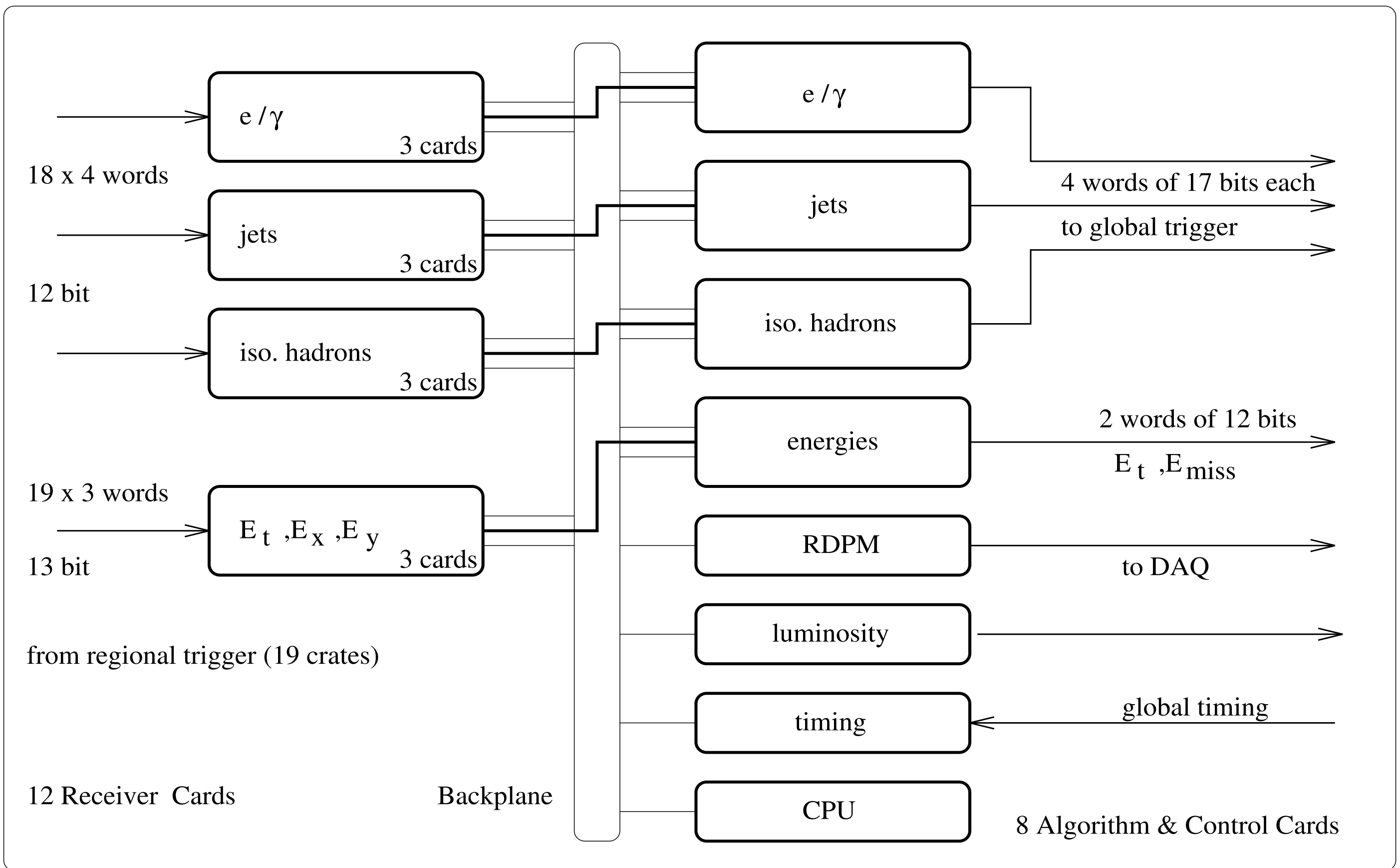




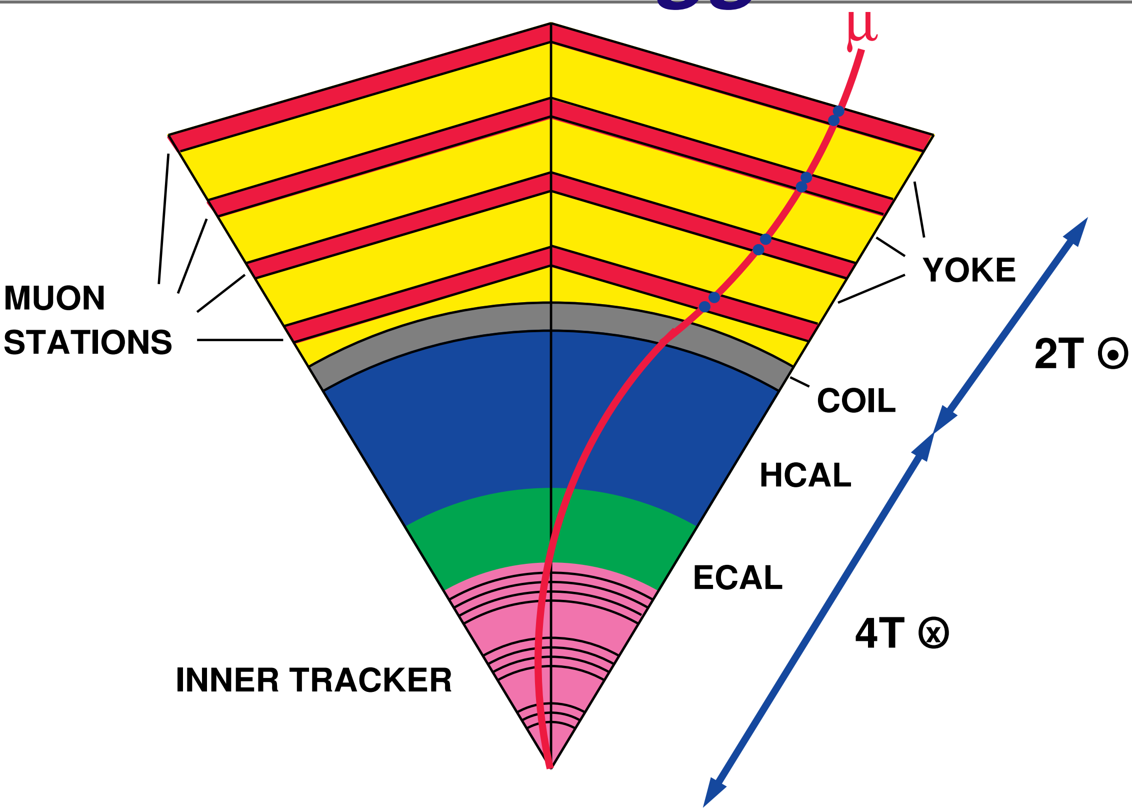
Global Calorimeter Trigger



standard crate mechanics
high density backplane
20 slots, 0.8" wide
cards 9U x 40 cm
3U VME connector
high density connector
for trigger
DAQ
TTC signals



Muon Trigger



The CMS Muon Trigger is based on:

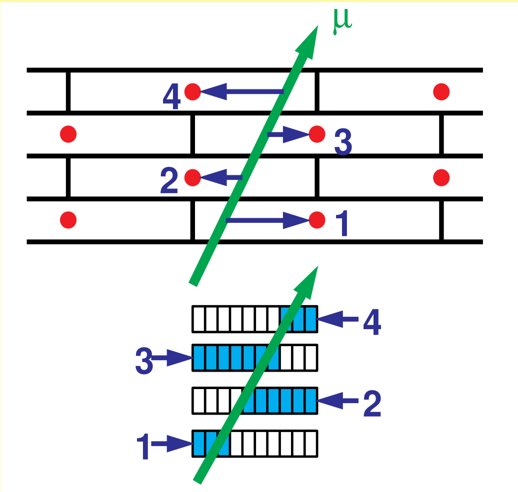
dedicated trigger detectors (RPC)
- precise timing
- unambigous position
- crude momentum measurement

muon chambers (Drift Tubes, CSC)
- vector per station
- more precise momentum measurement

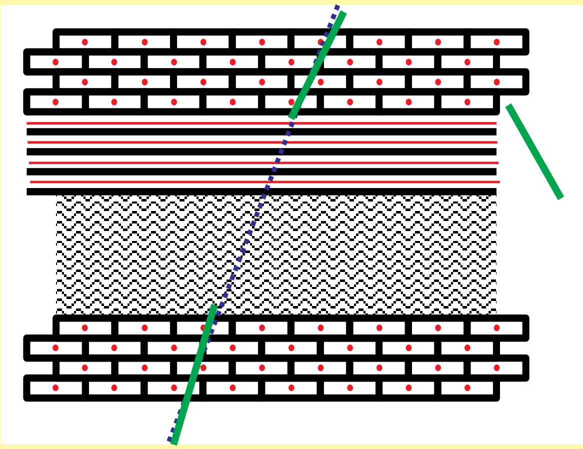
Two component trigger provides
- sure bunch crossing identification
- sharp p_t cut
- powerful background rejection
- large flexibility: p_t cut = 3-100 GeV
  $L = 10^{32}\text{-}10^{34}\ cm^{-2}\ s^{-1}$

Muon Chamber Trigger Logic

Drift Tubes

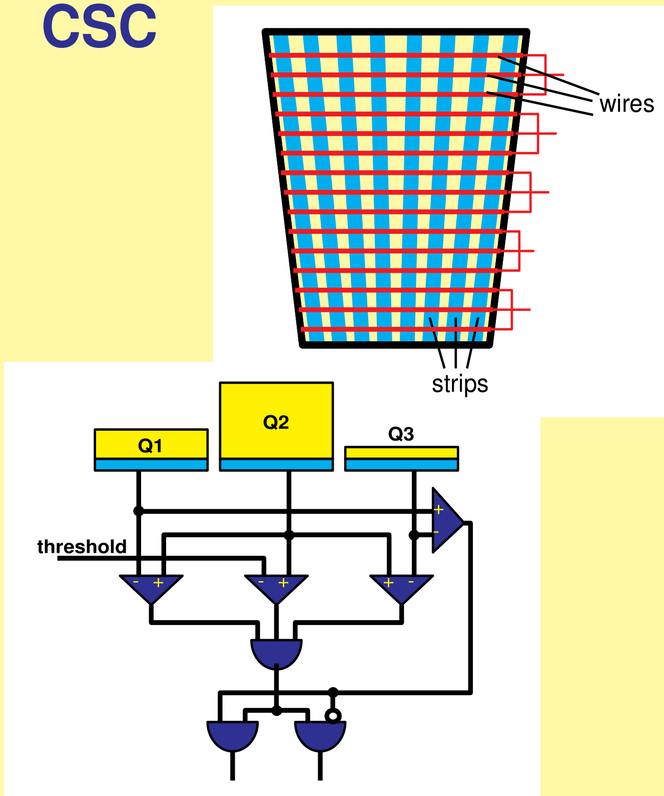


Meantimers recognize tracks and form vector / quartet.

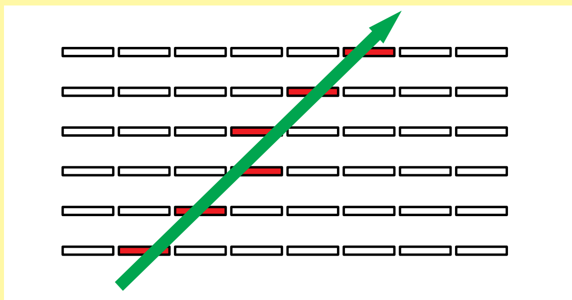


Correlator combines them into one vector / station.

CSC

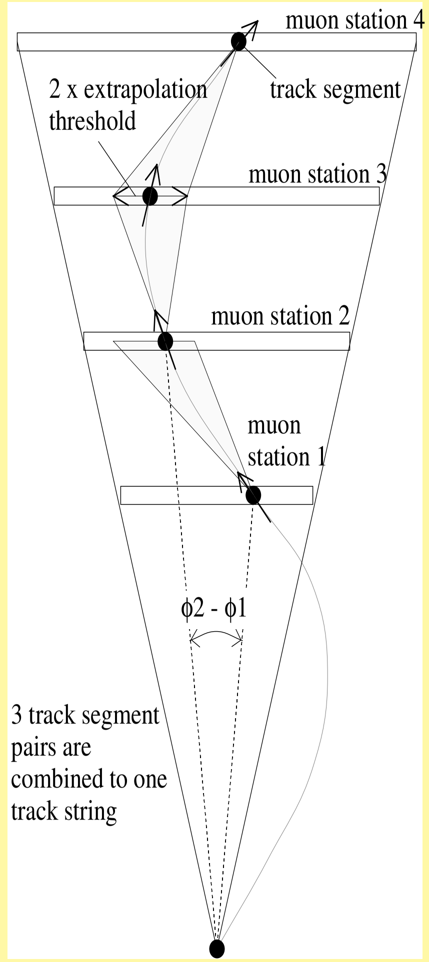


Comparators give 1/2-strip resol.



Hit strips of 6 layers form a vector.

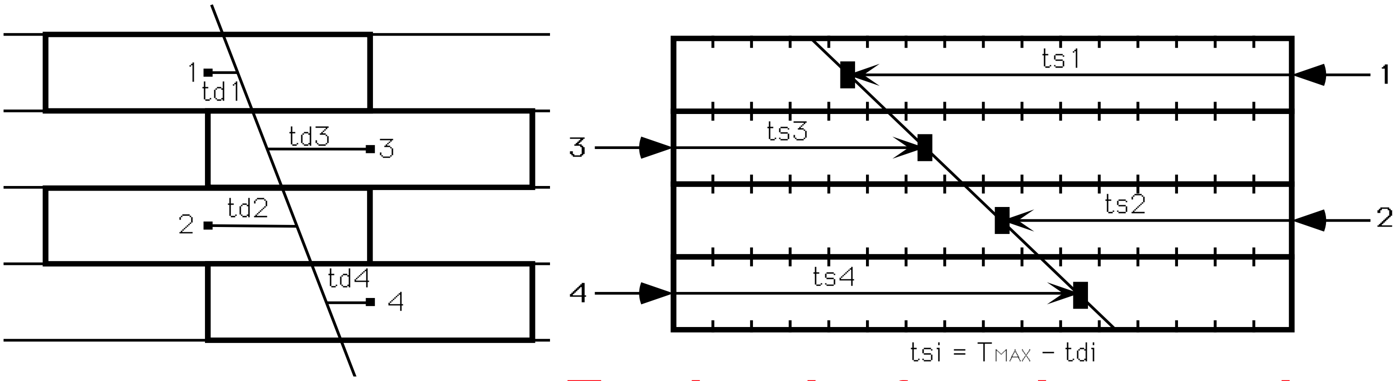
Track Finder



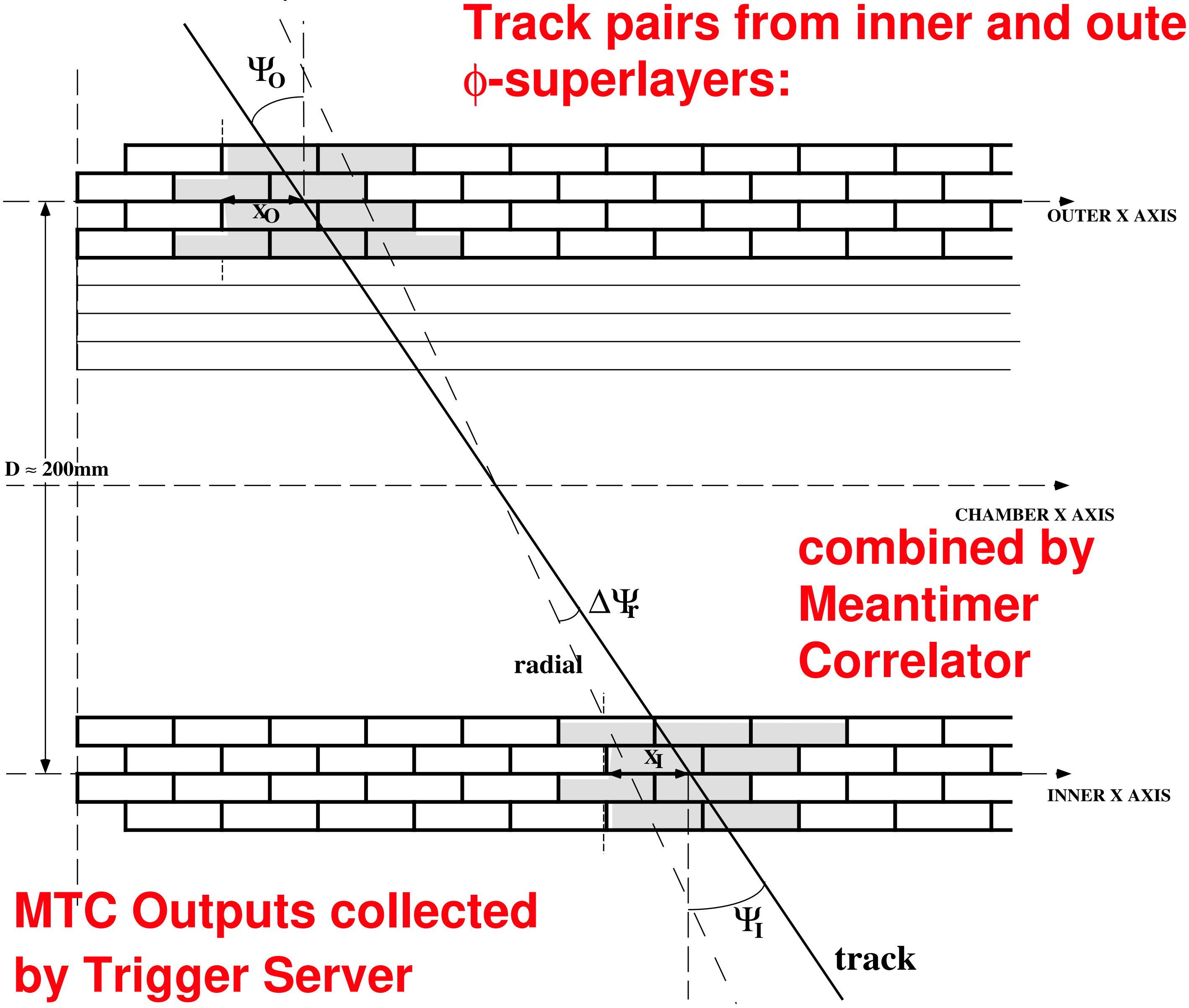
- combines vectors,
- forms a track,
- assigns p_t value.

Drift Tube Trigger Algorithm

Meantimer: Superlayer (4 planes)



Track pairs from inner and outer ϕ-superlayers:

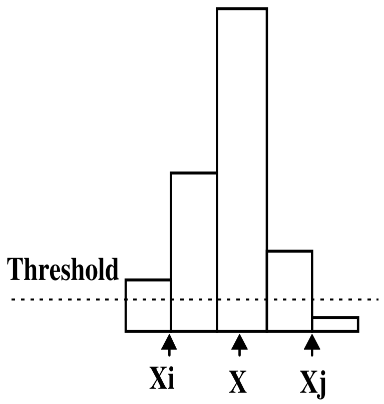


combined by Meantimer Correlator

MTC Outputs collected by Trigger Server

CSC Strip Trigger Algorithm

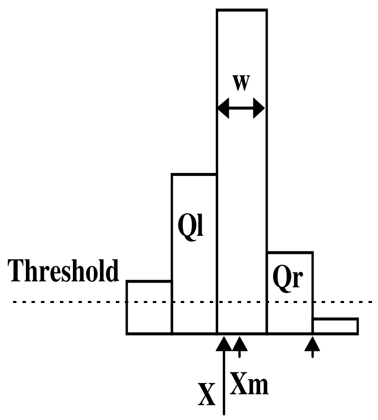
Algorithm for MF1/1:



X = 1/2 (Xi + Xj).

where:
X - hit coordinate
Xi, Xj - coordinates of extreme strips in the cluster.

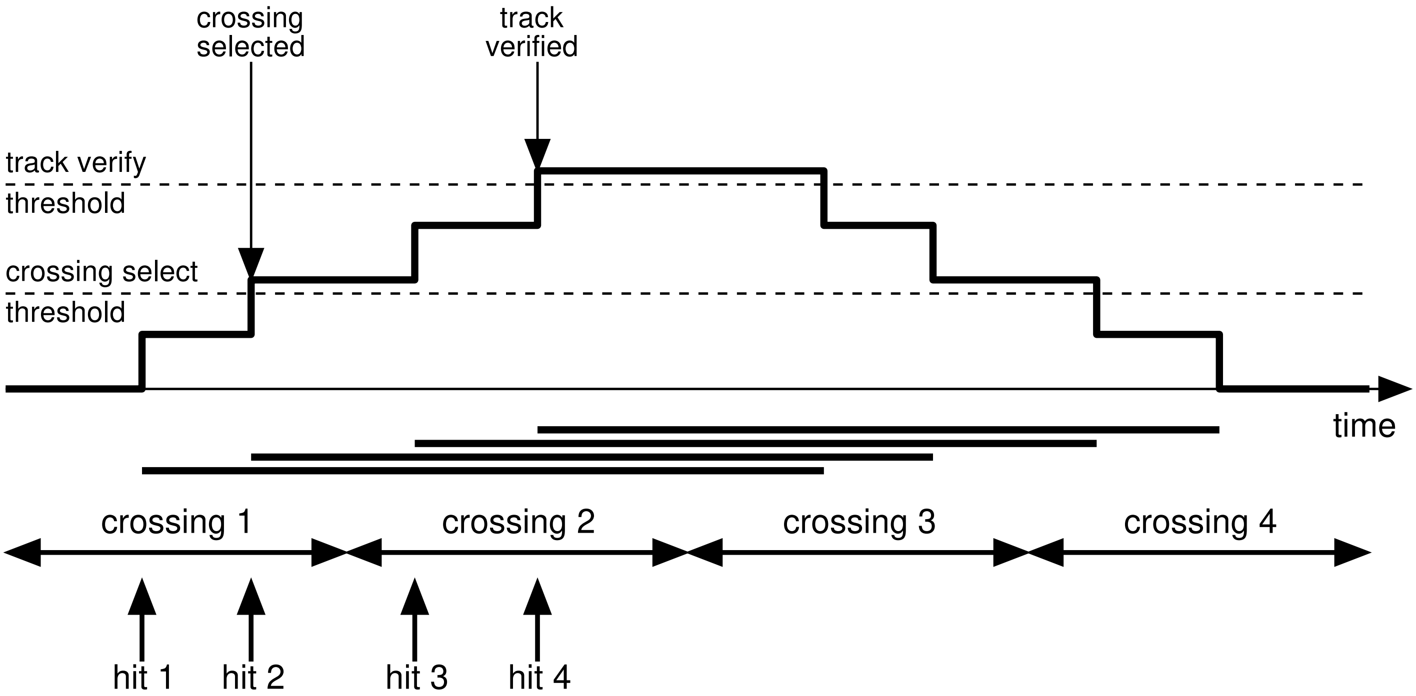
Algorithm for MF1/2 - MF4:



X = Xm , for one strip;
X = Xm - w/4, if Ql > Qr;
X = Xm + w/4, if Qr > Ql.

where:
Xm - strip coordinate with max. charge;
w - strip width ;
Ql, Qr - the charge on left and right strips of the cluster.

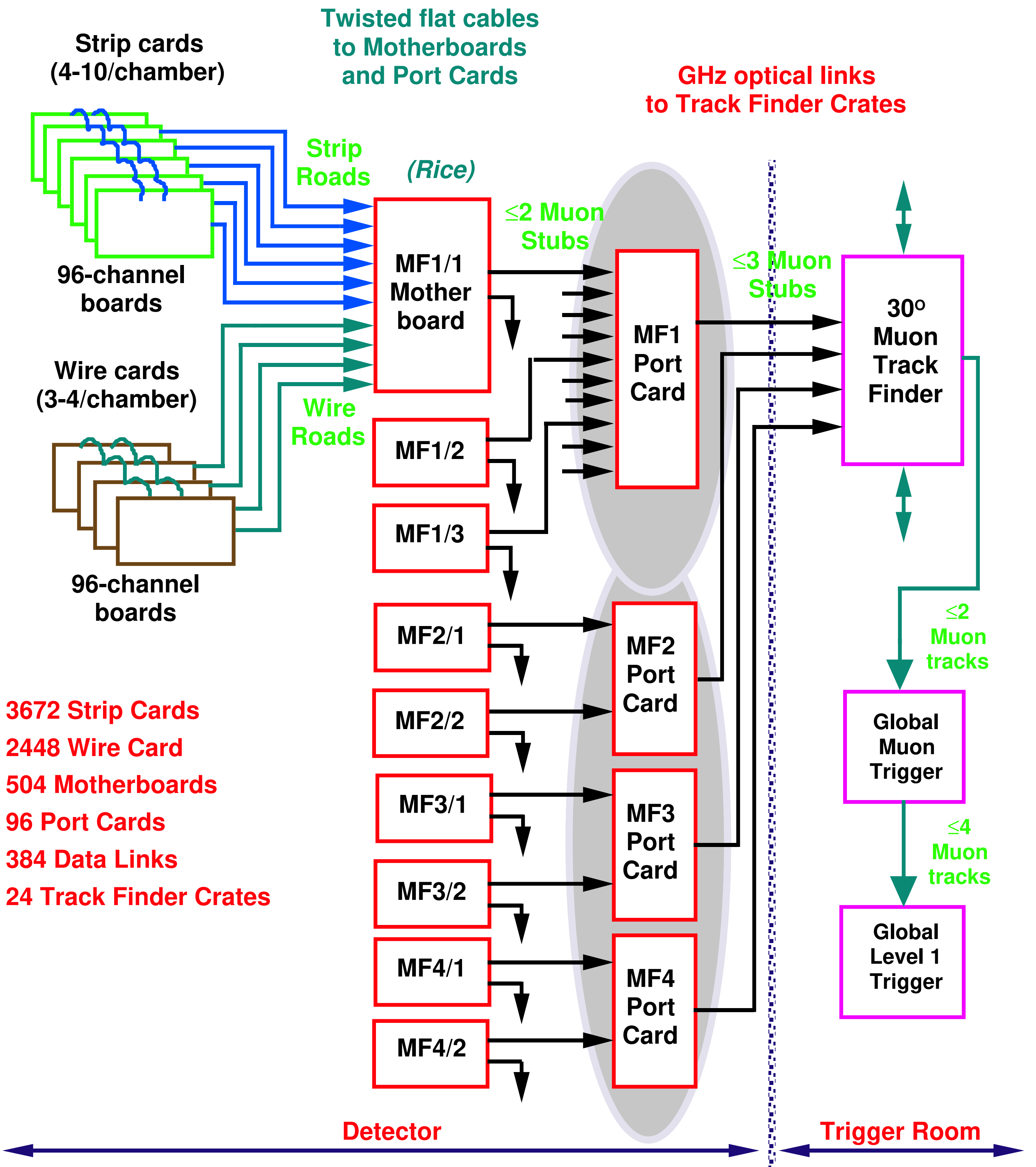
CSC Wire Trigger Algorithm



Recognize Bunch Crossing:

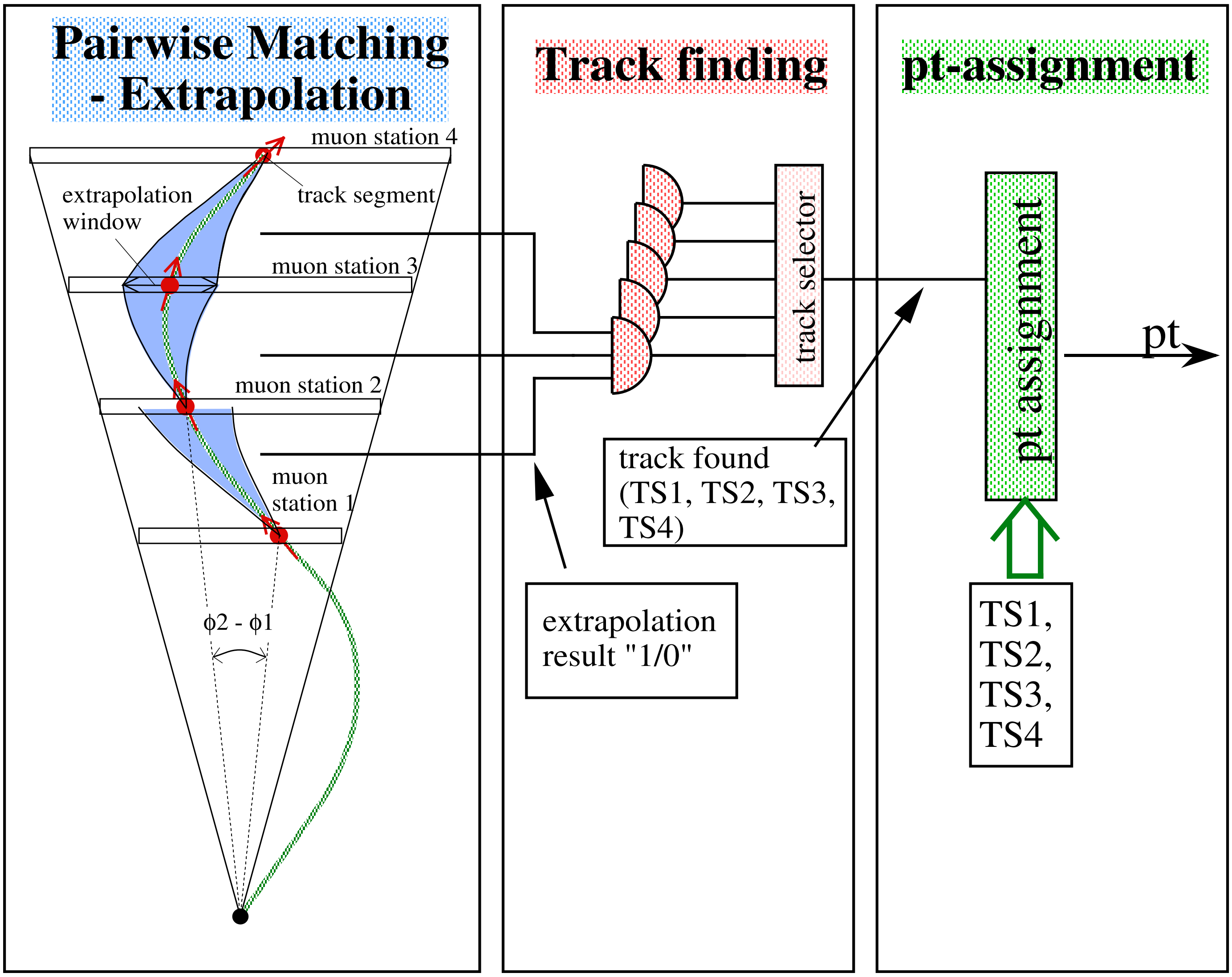
- Each CSC hit produces a pulse for t_w
- A second hit selects a candidate crossing
- Two additional hits within t_w required for validation (at least 4 total required)
- Validated crossing is crossing of first hit
- t_w = 50 ns for MF1, 75 ns for MF1/2-4

CSC Trigger Layout



3672 Strip Cards
2448 Wire Card
504 Motherboards
96 Port Cards
384 Data Links
24 Track Finder Crates

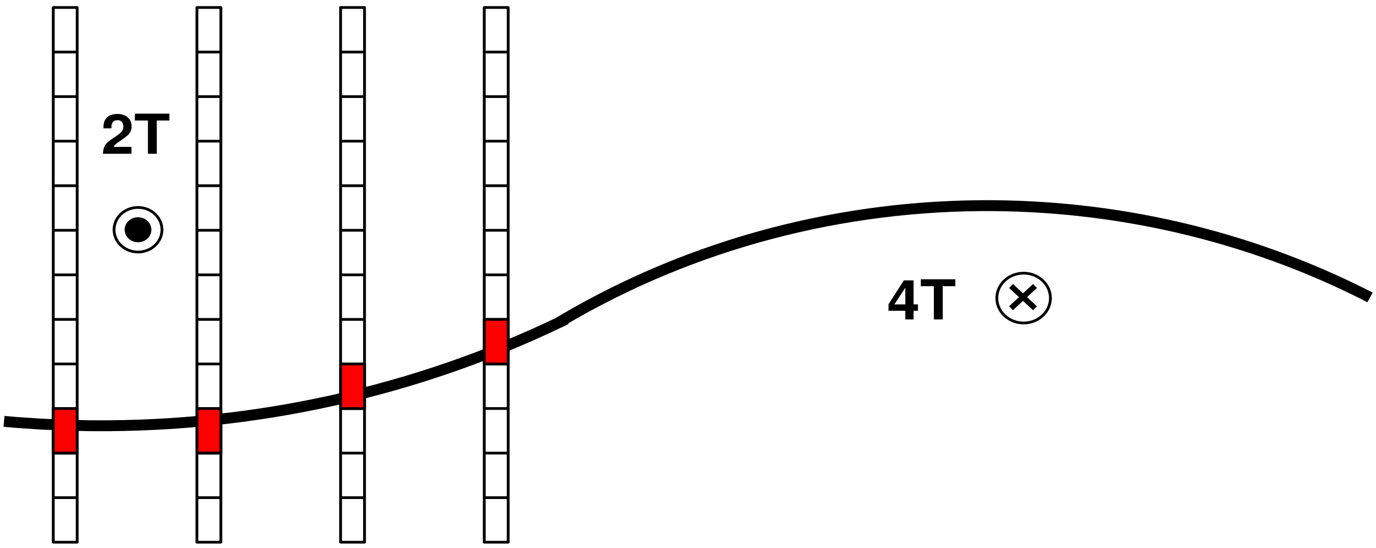
Track-Finding Algorithm



Combine DT & CSC track segments:

- **Sector Processor:** $\Delta\eta$ **x** $\Delta\phi = 0.35$ **x** $30°$
  - extrapolates btw. muon stations
  - finds matched pairs
  - combines matched pairs into tracks
  - assigns p_t to tracks

RPC Trigger Algorithm



Based on 4 RPC Planes

- **Strips cover $\Delta\eta$ x $\Delta\phi = 0.1$ x $5/16°$**
- **Pattern Comparator Logic (PACT):**
    - compares hits in 4 planes with predefined valid patterns
    - requires at least 3 hits (3/4 quality bit)
- **Output of PACT logic is a segment**

Muon & Cal. Trigger Rates

High Luminosity: $\mathcal{L} = 10^{34}\ cm^{-2}\ s^{-1}$

trigger type	threshold [GeV]	rate [kHz]	cumulative rate [kHz]
μ	20	7.8	7.8
$\mu\ \mu$	4	1.6	9.2
μ e	4, 8	5.5	14.4
μ j	4, 40	0.3	14.4
$\mu\ E_t^{miss}$	4, 60	1.0	15.3
$\mu\ \Sigma E_t$	4, 250	0.2	15.3
μ	7	9.8	9.5
$\mu\ \mu$	2-4	0.5	10.1
μ e	2-4, 6	2.5	12.2
$\mu\ e_b$	2-4, 5	3.5	13.4
μ j	2-4, 12	2.2	14.5
$\mu\ E_t^{miss}$	2-4, 40	0.8	14.7
$\mu\ \Sigma E_t$	2-4, 150	0.8	14.7

Low Luminosity: $\mathcal{L} = 10^{33}\ cm^{-2}\ s^{-1}$

Global Trigger - I

Crate Layout:

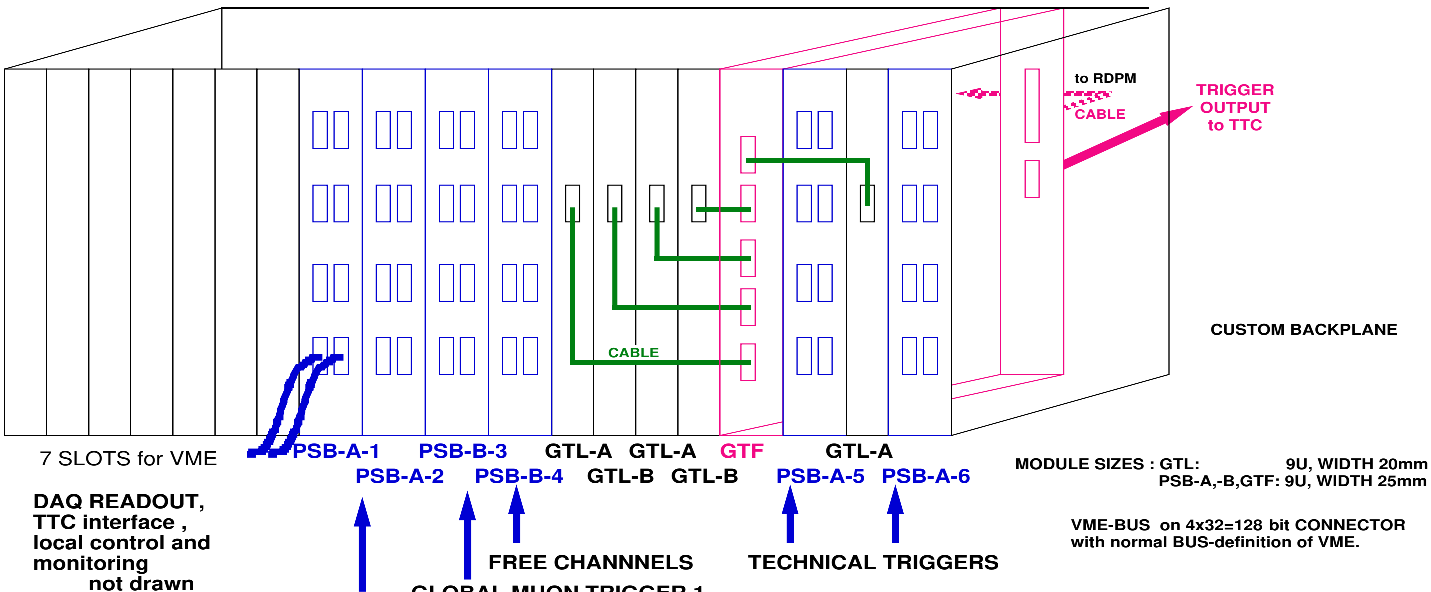


Fig.1 GLOBAL TRIGGER CRATE

Calorimeter Trigger:

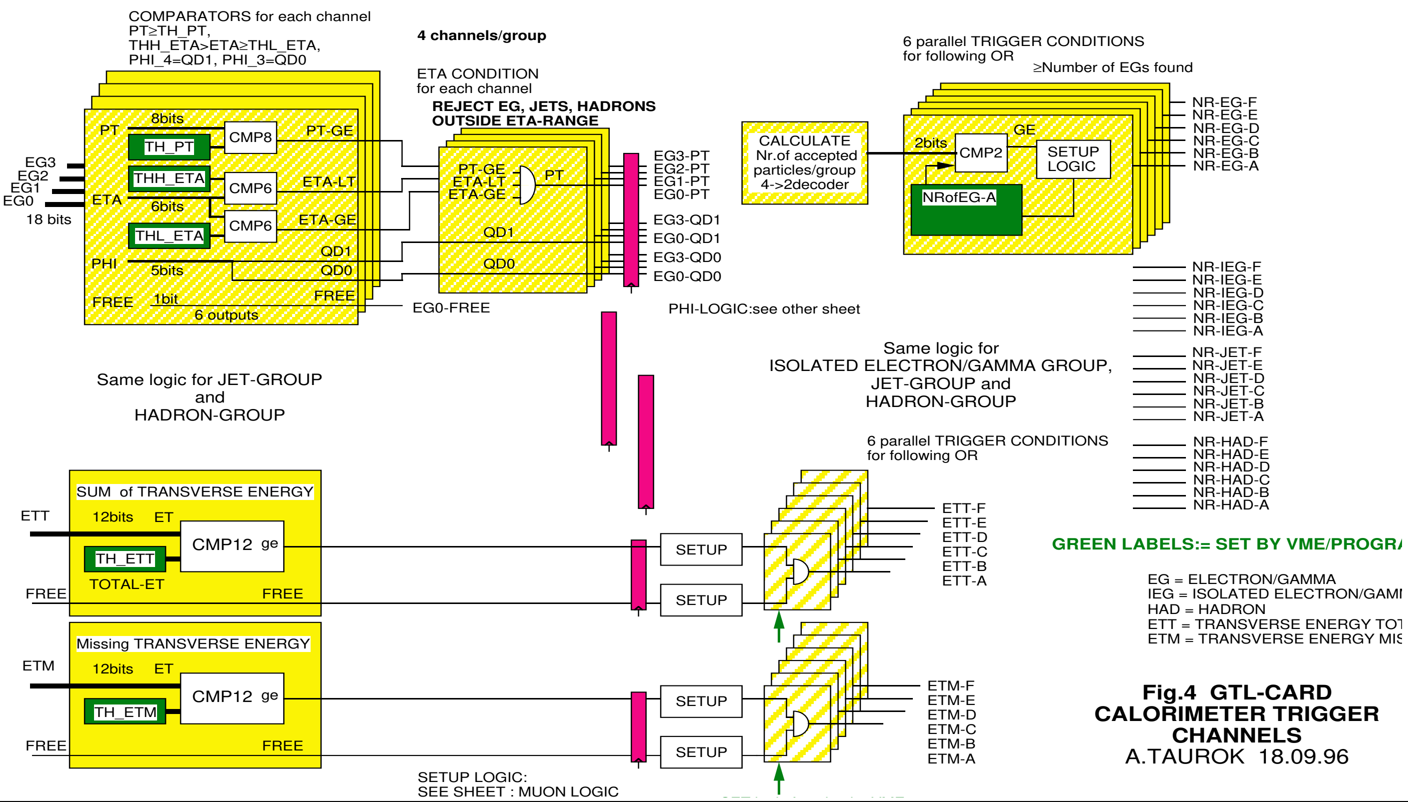


Fig.4 GTL-CARD CALORIMETER TRIGGER CHANNELS
A.TAUROK 18.09.96

Global Trigger -II

Muon Trigger:

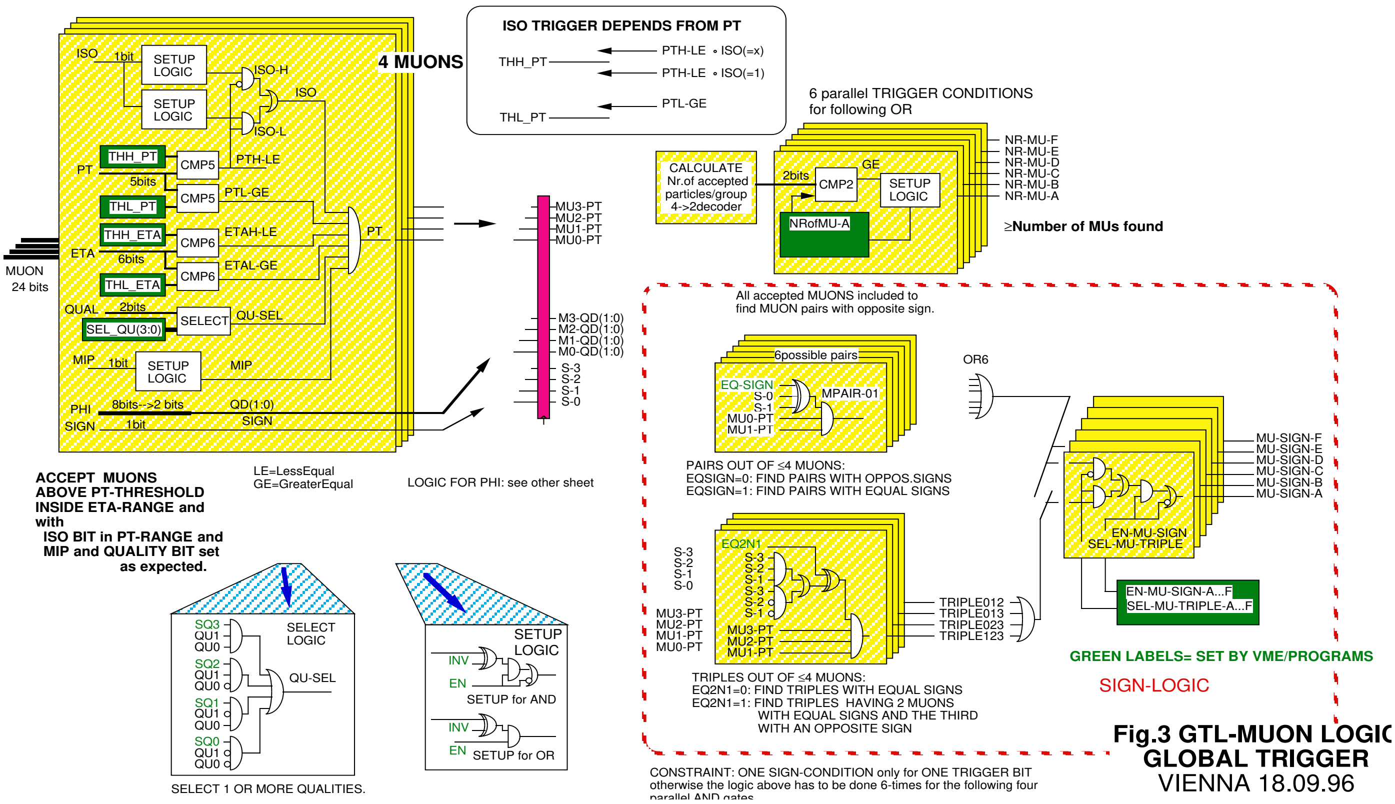


Fig.3 GTL-MUON LOGIC
GLOBAL TRIGGER
VIENNA 18.09.96

Final Decision Logic:

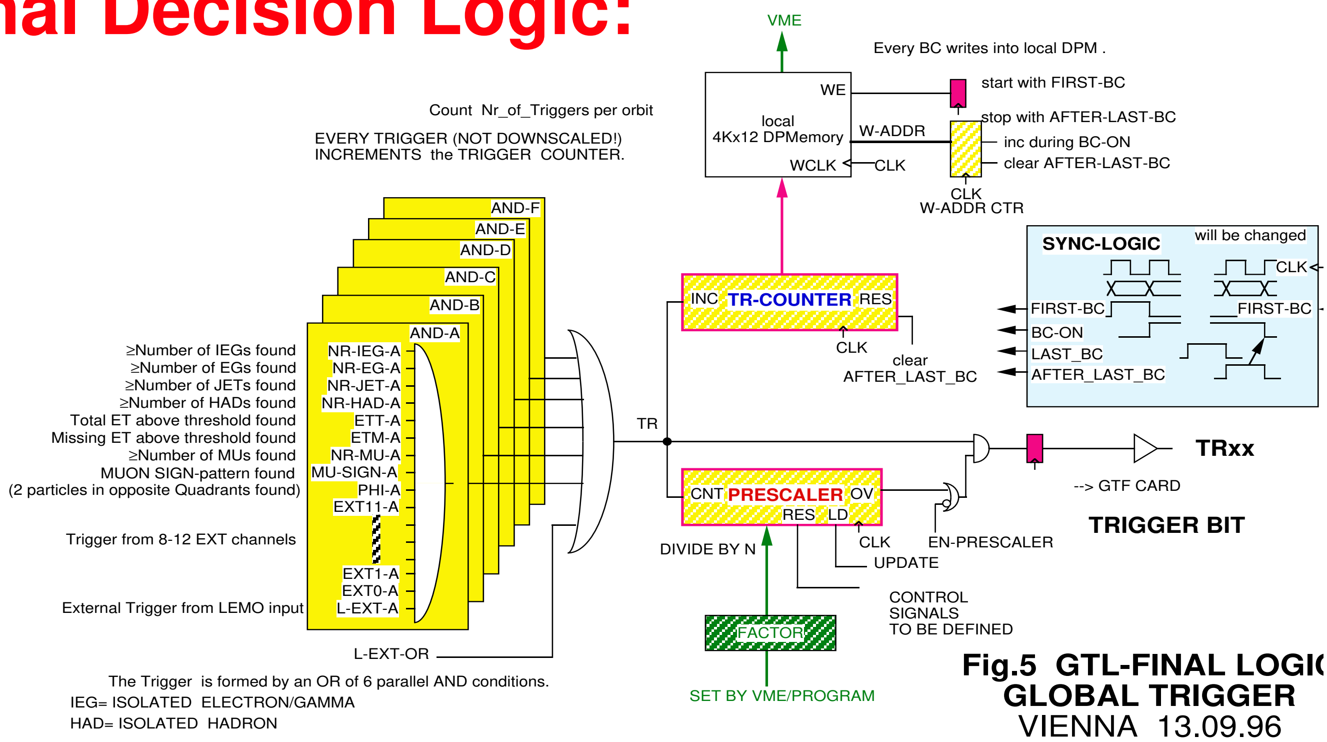
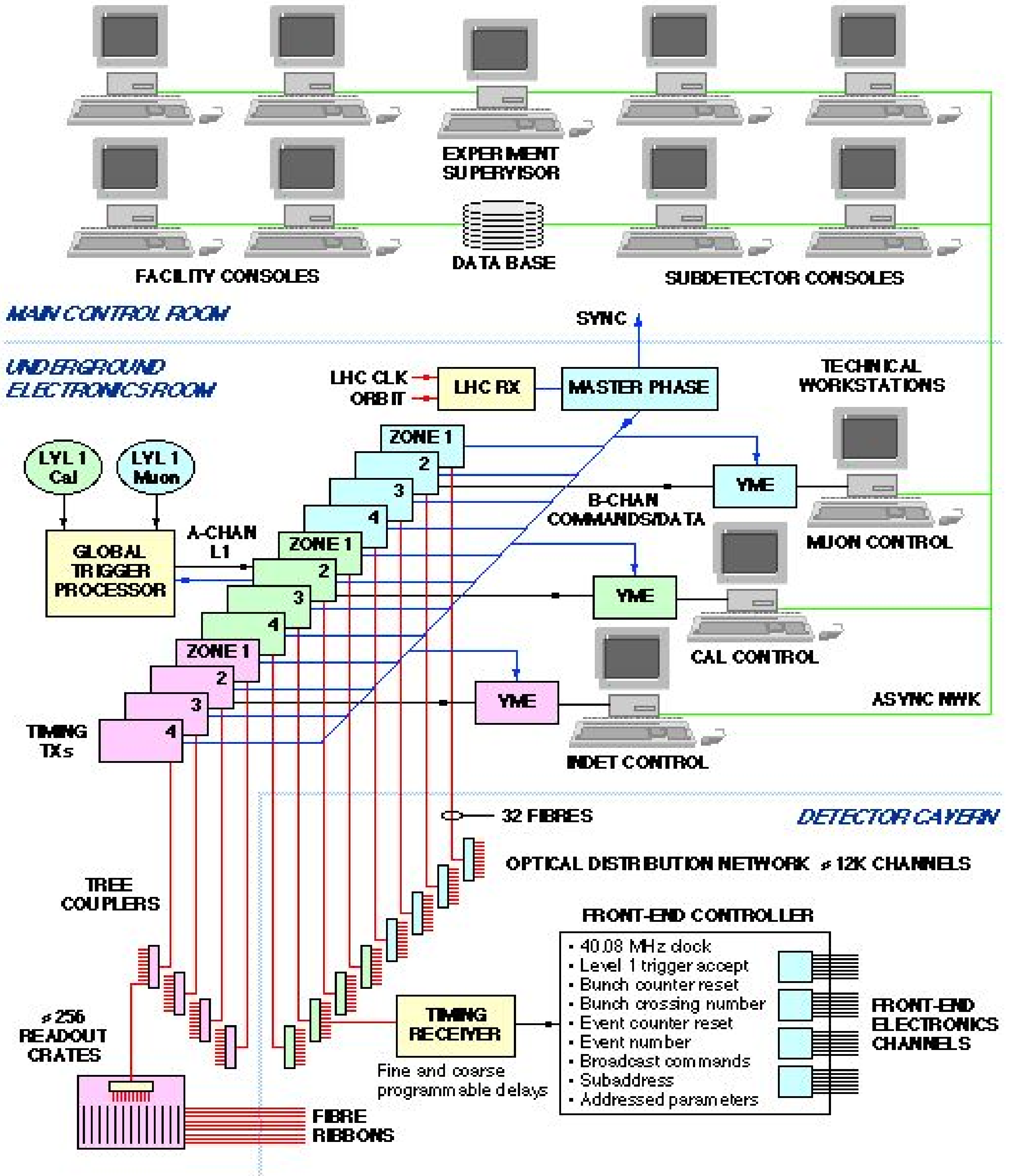
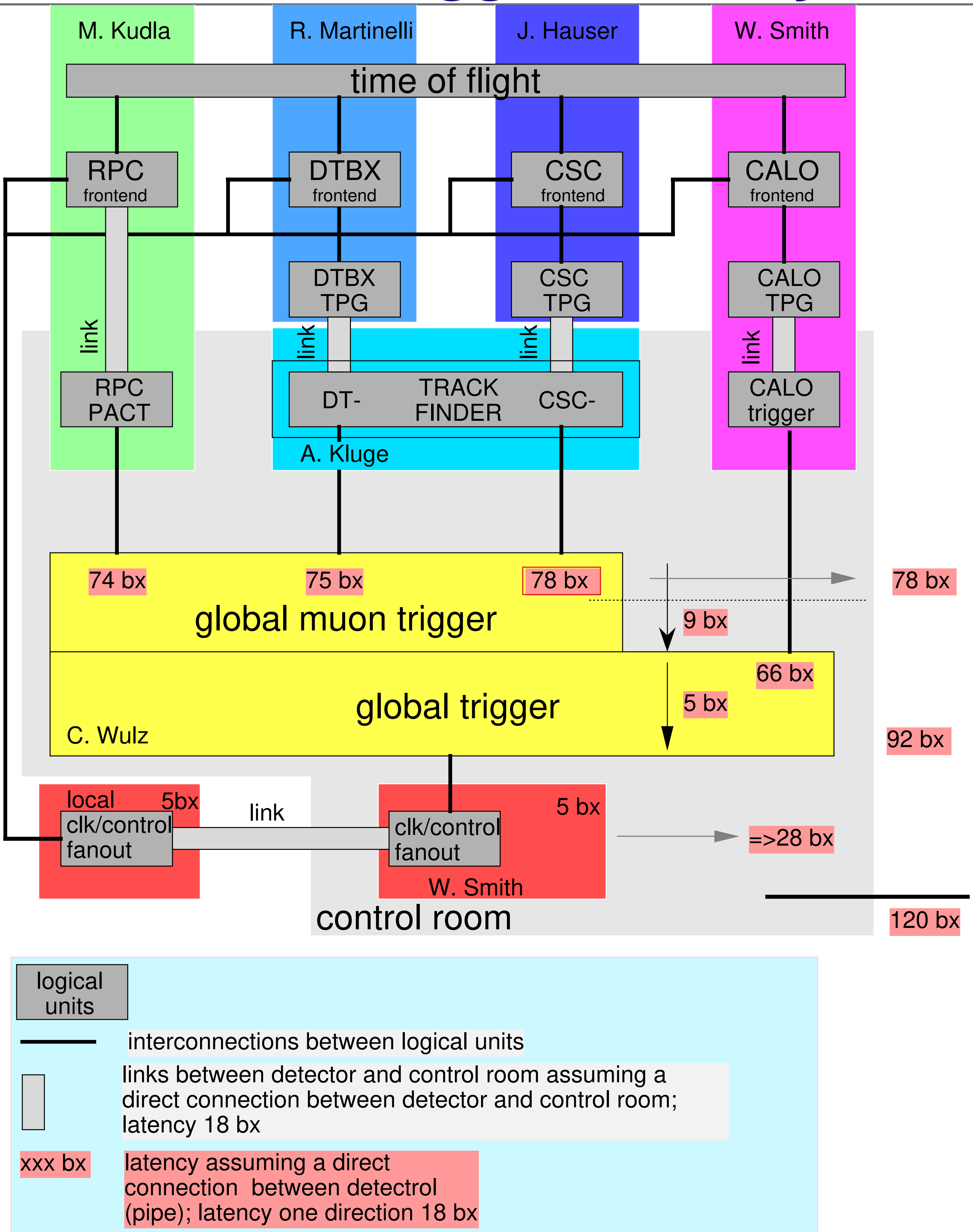


Fig.5 GTL-FINAL LOGIC
GLOBAL TRIGGER
VIENNA 13.09.96

Trigger Timing & Control



Level 1 Trigger Latency



Summary: CMS Trigger

- **Level 1 Trigger Rates @ 10^{34} :**
  - 15 kHz Calorimeter L1:
    - **Single e/γ > 30 GeV**
    - **Double e/γ > 15 GeV**
    - **Jet > 140 GeV**
    - **Missing E_t > 150 GeV**
  - 15 kHz Muon L1:
    - **Single muon > 20 GeV**
    - **Dimuon > 10 GeV**

- **Captures CMS Physics Signals**

- **Feasible Design:**
  - Much more work to make this a reality in 2005!