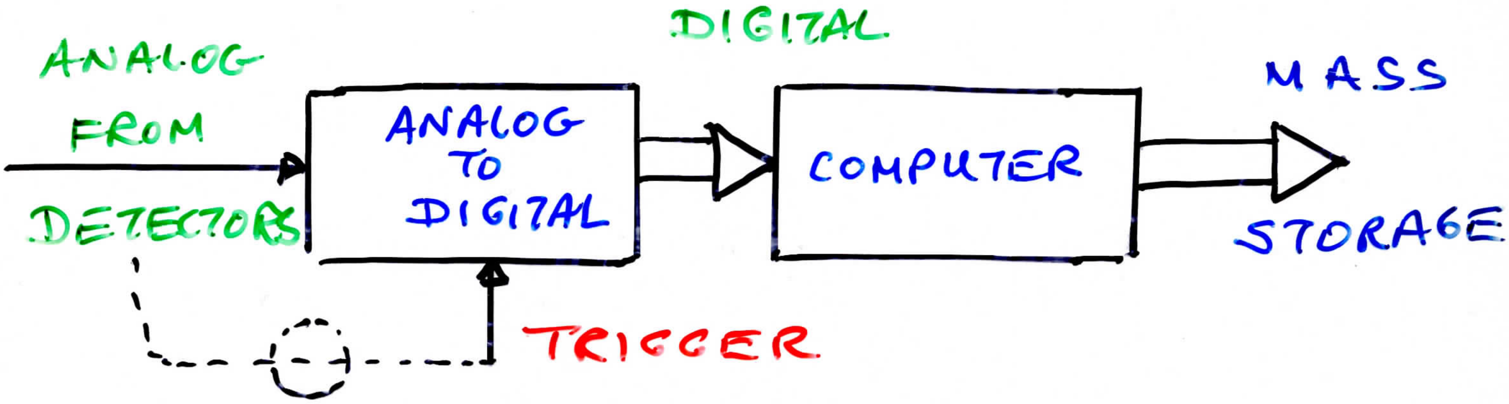
TRIGGERING & DATA ACQUISITION

DATA FLOW IN EXPERIMENT



REASONS FOR TRIGGER

1) A → D CONVERSION

NEED SOME GATE FOR ADCs
START/STOP FOR TDCs

- ANALOG SIGNAL FLOW CONTINUOUSLY FROM DETECTORS
- DECIDE WHEN HAVE "INTERESTING EVENT"
- A → D TAKES TIME

  ~ 10μs

  + COMPUTER READ OUT ~ mS

2) SELECTION OF INTERESTING DATA

- SELECT PHYSICS vs BACKGROUND
- UNBIASED
- UNDERSTANDABLE

3) DEAD TIME

- USUALLY BACKGROUND RATE > SIGNAL RATE
- CONTINUAL A → D → NEVER SEE SIGNAL
  ↓ DEAD TIME

- REAL ~~FAKE~~ EVENTS AT ν Hz
  Δt → CONVERSION TIME

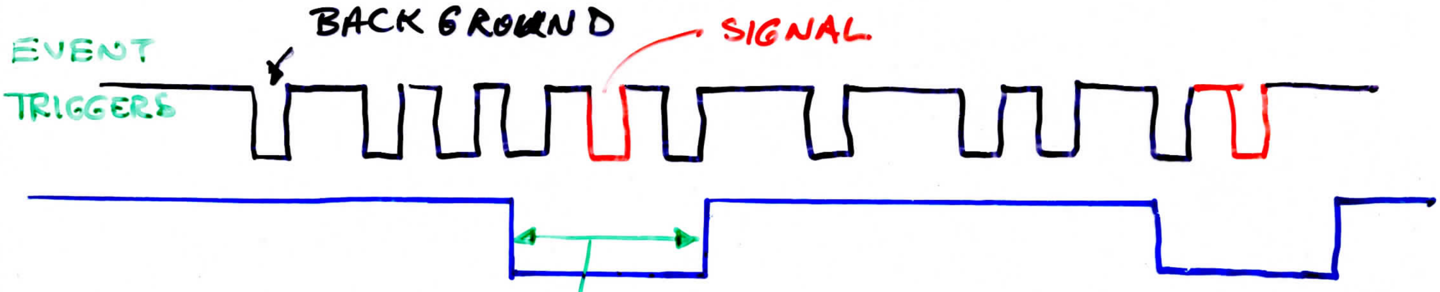
TIME BETWEEN EVENTS $= \frac{1}{\nu} + \Delta t$

OBSERVED RATE $\nu' = \frac{1}{\frac{1}{\nu} + \Delta t}$

LIVETIME $\epsilon = \frac{\nu'}{\nu} = \frac{1}{1 + \nu \Delta t}$

ν → LARGE
Δt → LARGE } DEAD

DEAD TIME



TIME TO DO CONVERSION AND COMPUTER READ OUT AFTER A TRIGGER

└ DEAD TIME

TAKE ARGUS BEAM GAS EXAMPLE

BG RATE ~ 10^3 Hz

READ OUT TIME ~ 1 mS

∴ ~~100%~~ 50% DEAD TIME FROM BG.

" REASONABLE " VALUE OF DEAD TIME ~ 1-10%

IE. WANT EXPERIMENT ALIVE FOR AT LEAST 90% OF THE TIME

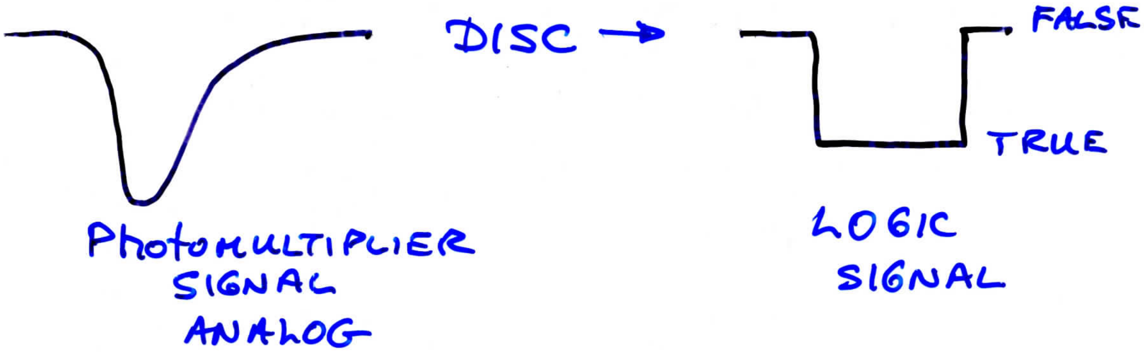
- IN CDF / ZEUS / ATLAS DEADTIME WOULD BE 100%

  └→ MULTI LEVEL DEADTIMELESS TRIGGER

- SIGNALS FROM DETECTOR ELEMENTS — ANALOG

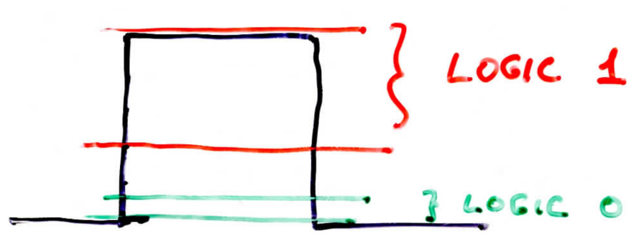
WANT TO MAKE A 'LOGIC' DECISION IN TIME SCALES ~ 100s n Sec

↓ CONVERT ANALOG SIGNALS TO FAST LOGIC PULSES



LOGIC LEVELS

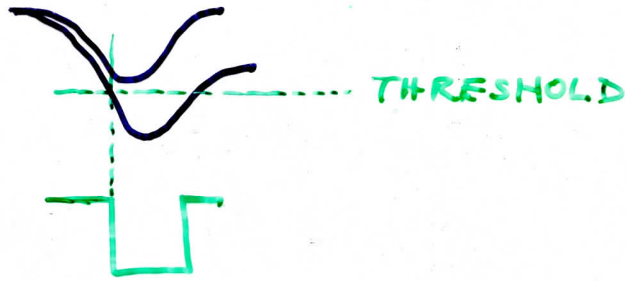
	NIM	TTL	ECL (VERY FAST)
1	-14 → -18 mA	2 → 5V	- 1.75 V
0	-1 → +1 mA	0 → 0.8V	- 0.09V



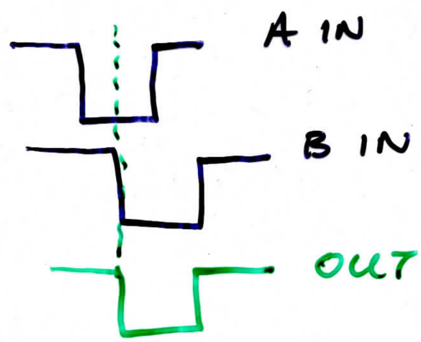
BASIC ELEMENTS

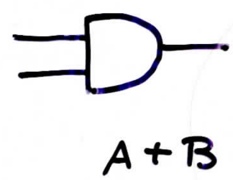
'LEO' GIVES NICE EXPOSITION!

- DISCRIMINATOR

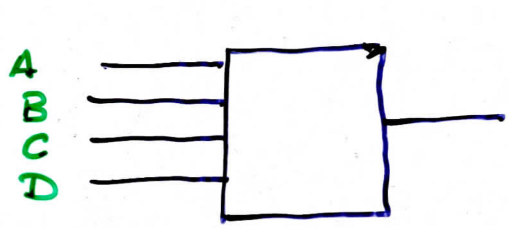


- COINCIDENCE UNIT



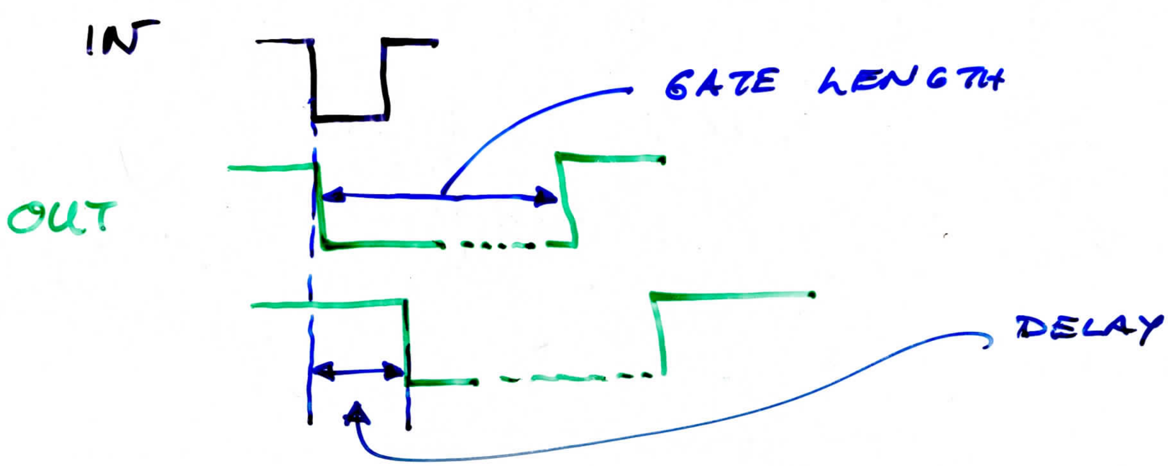


- MAJORITY LOGIC UNIT



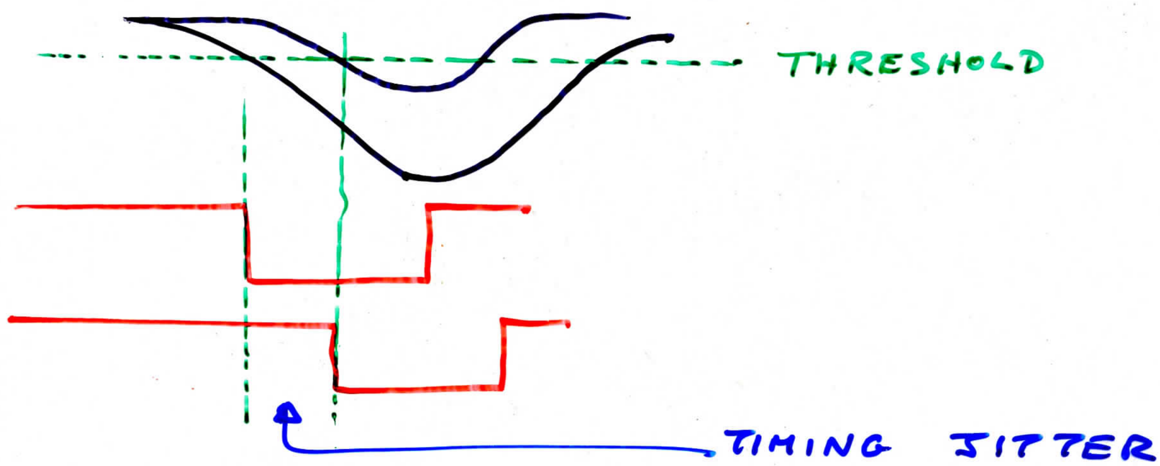
A + B + C
A + B + D
A + C + D
⋮

- GATE / DELAY GENERATOR

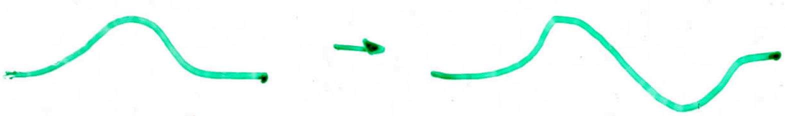


DISCRIMINATORS

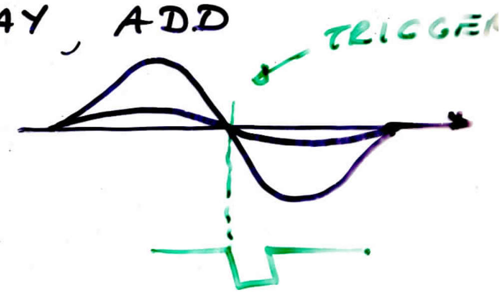
TO FORM A COINCIDENCE, OR MEASURE THE TIME THAT A PULSE ARRIVES WANT THE DISCRIMINATOR TO "FIRE" AT A WELL DEFINED TIME



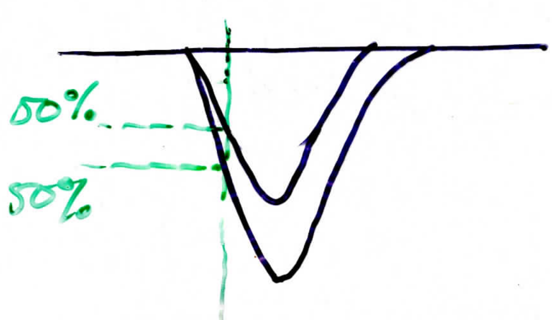
- ZERO CROSSING INVERT, DELAY, ADD



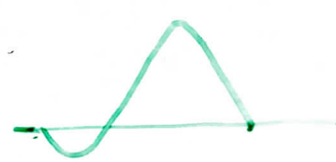
RESOLUTION < 1 ns



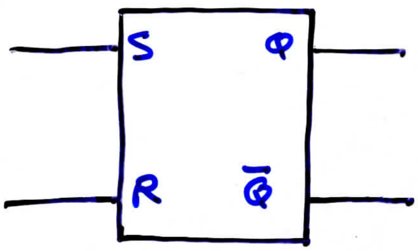
- CONSTANT FRACTION

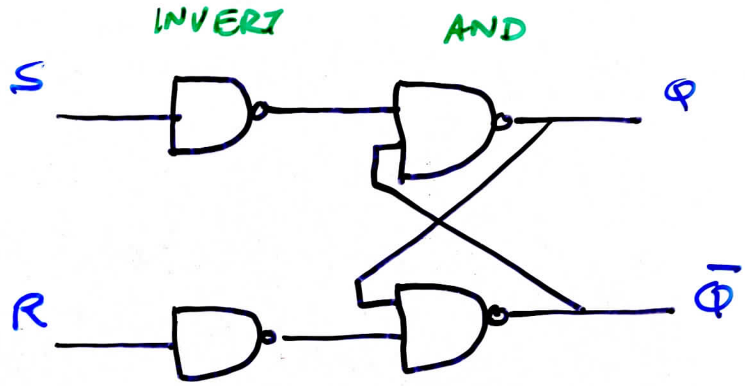


MAKE ZERO CROSSING AT 50%



FLIP - FLOP

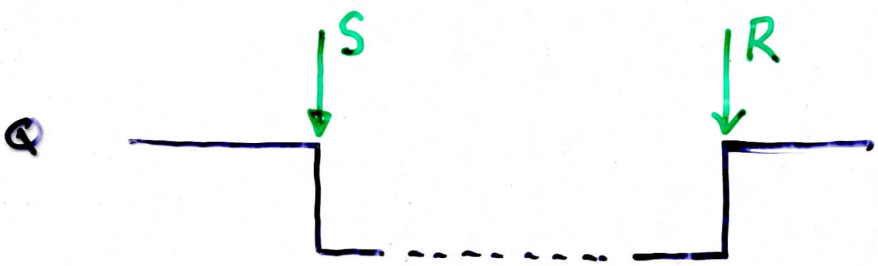




MEMORY ELEMENT

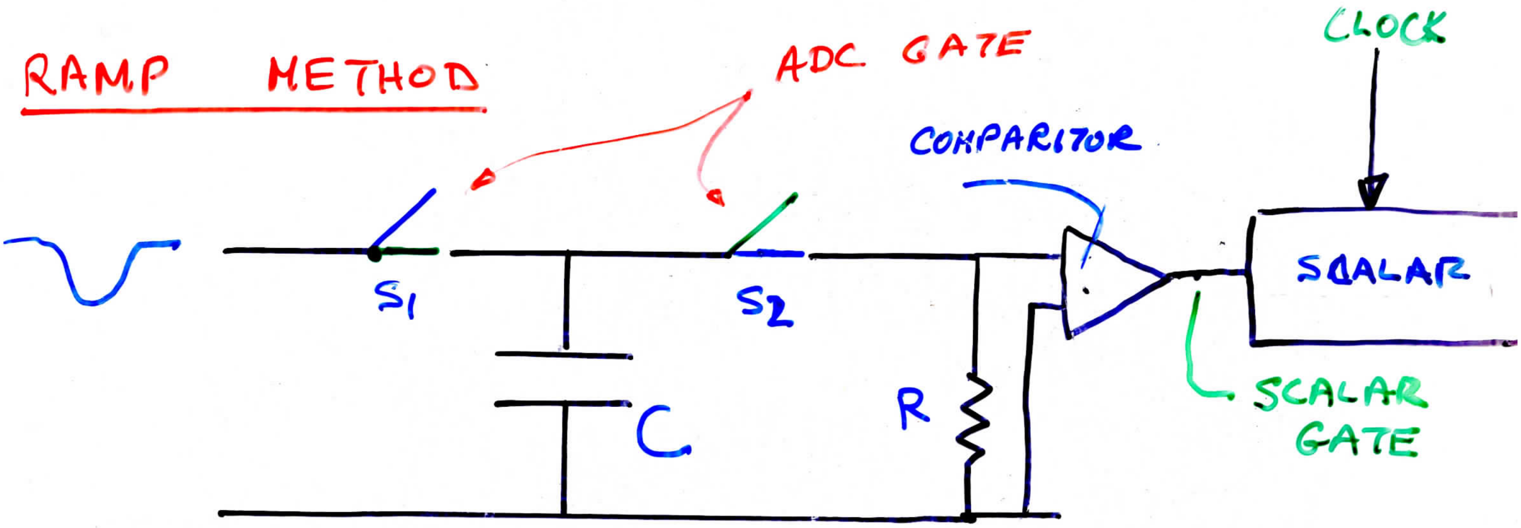
$\underline{S}$ET → Q = TRUE 1

$\underline{R}$ESET → Q = FALSE 0



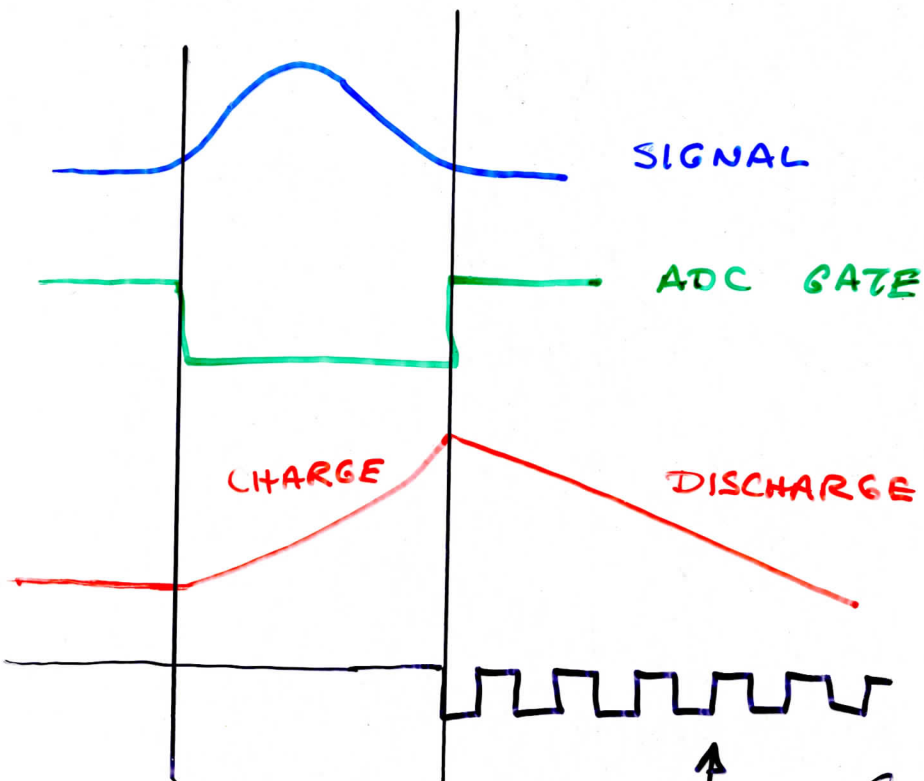
ADC PRINCIPLES

RAMP METHOD



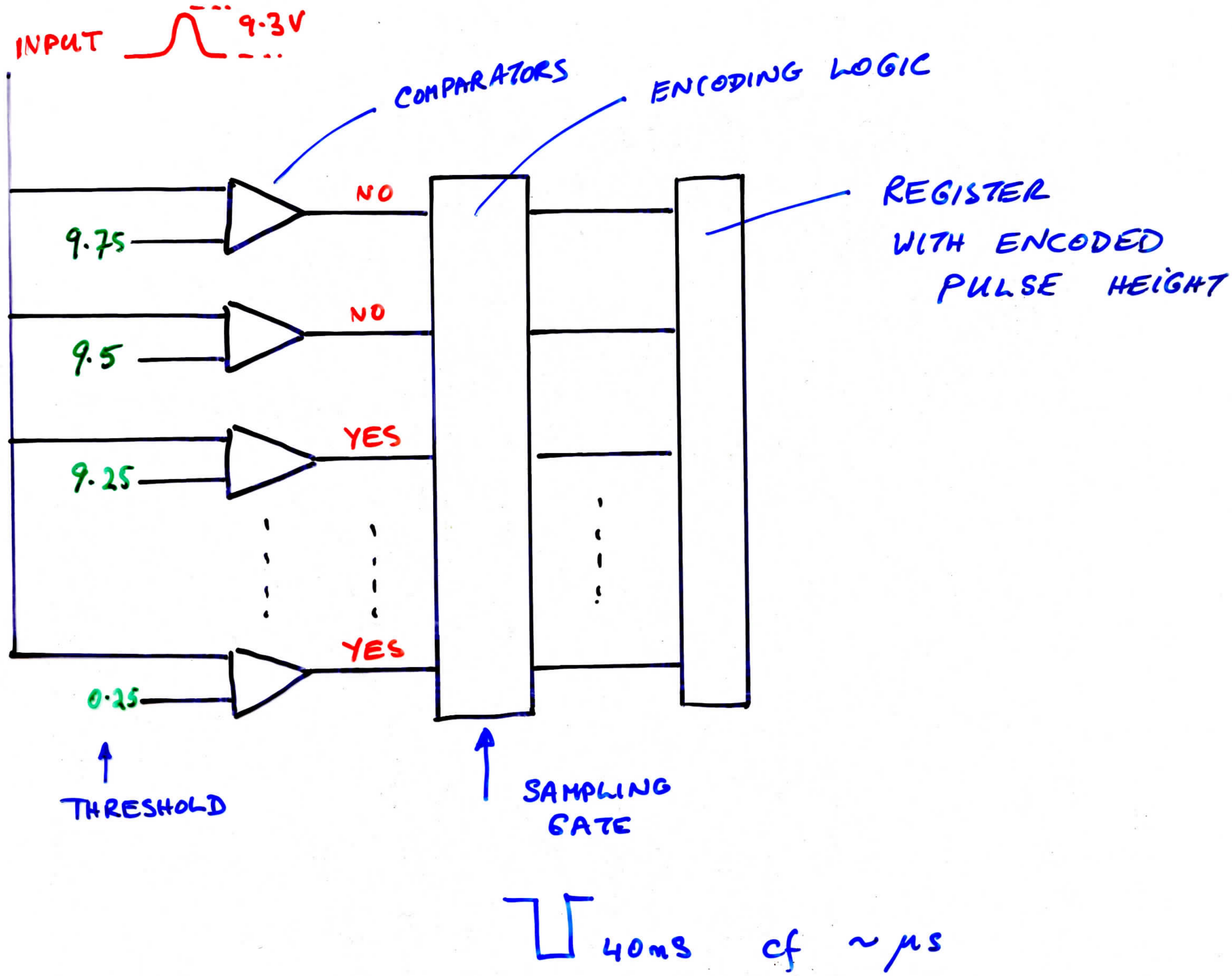
S1 CLOSED S2 OPEN → SIGNAL CHARGES C

S1 OPEN S2 CLOSED → C DISCHARGES
SCALAR COUNTS CLOCK
UNTIL COMPARITOR SHOWS
C DISCHARED.



COUNTED CLOCK
PLUSES EN CODE
PULSE HEIGHT.

PRINCIPLE OF FLASH ADC

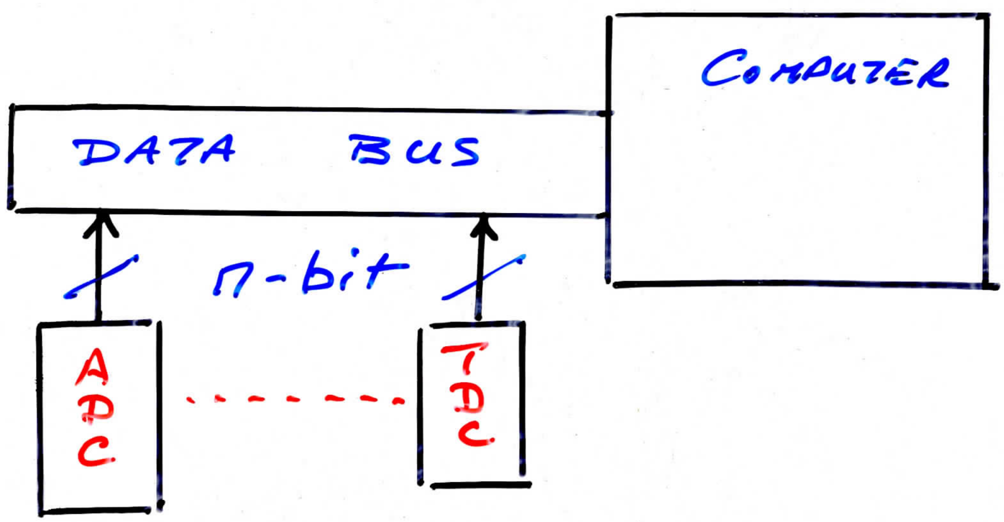


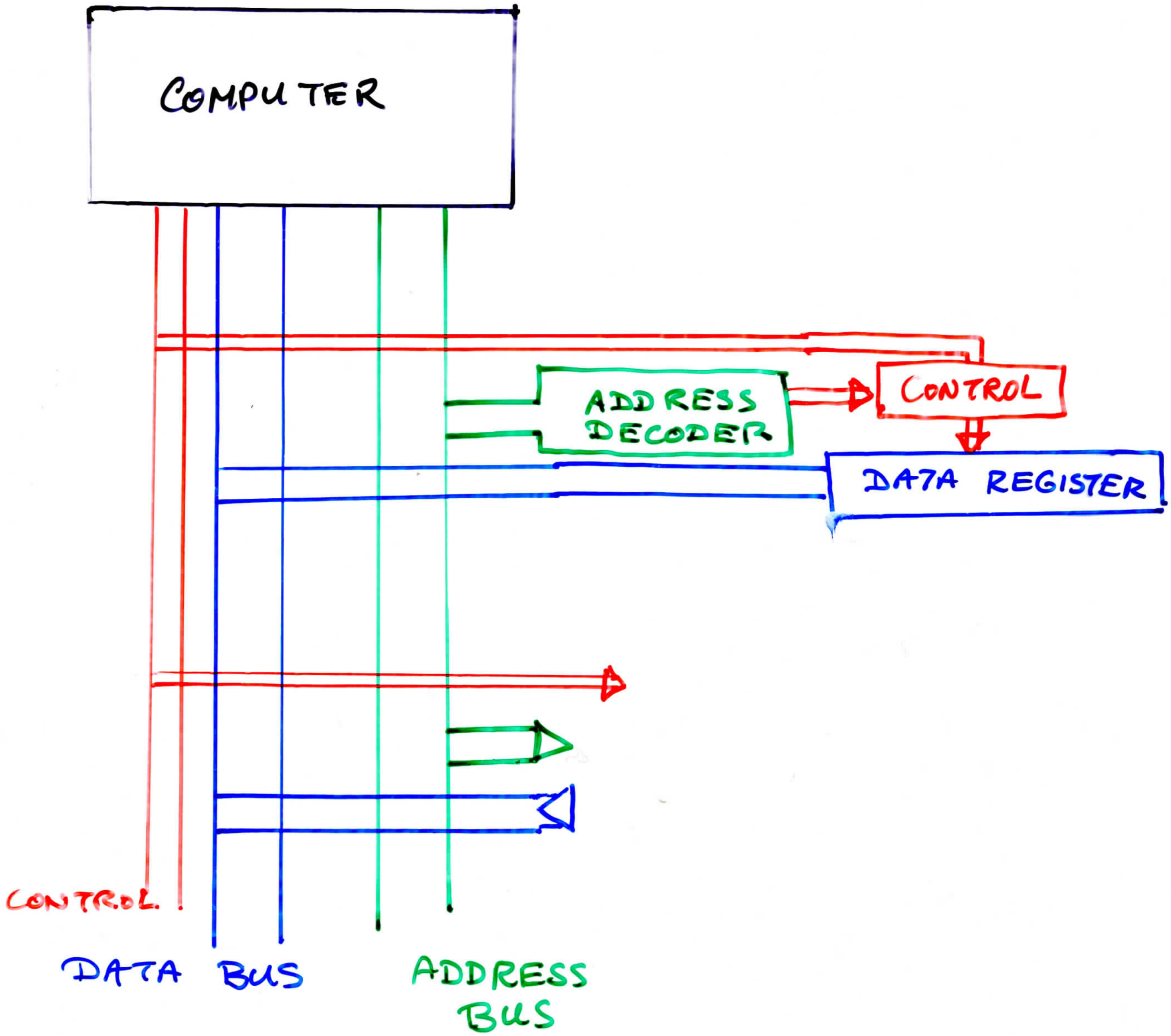
- LARGE NO. OF COMPONENTS
  cf 10^4 CHANNELS

→ INTEGRATED CIRCUIT

INTERFACE TO COMPUTER

- VERY SIMPLE MODEL OF SIMPLE SYSTEM
- ADC + TDC VALUES 16, 32, 64 bit numbers
  - → MANY 1000s
  - → RATE FEW → 100s Hz
- MUST READ OUT BY COMPUTER





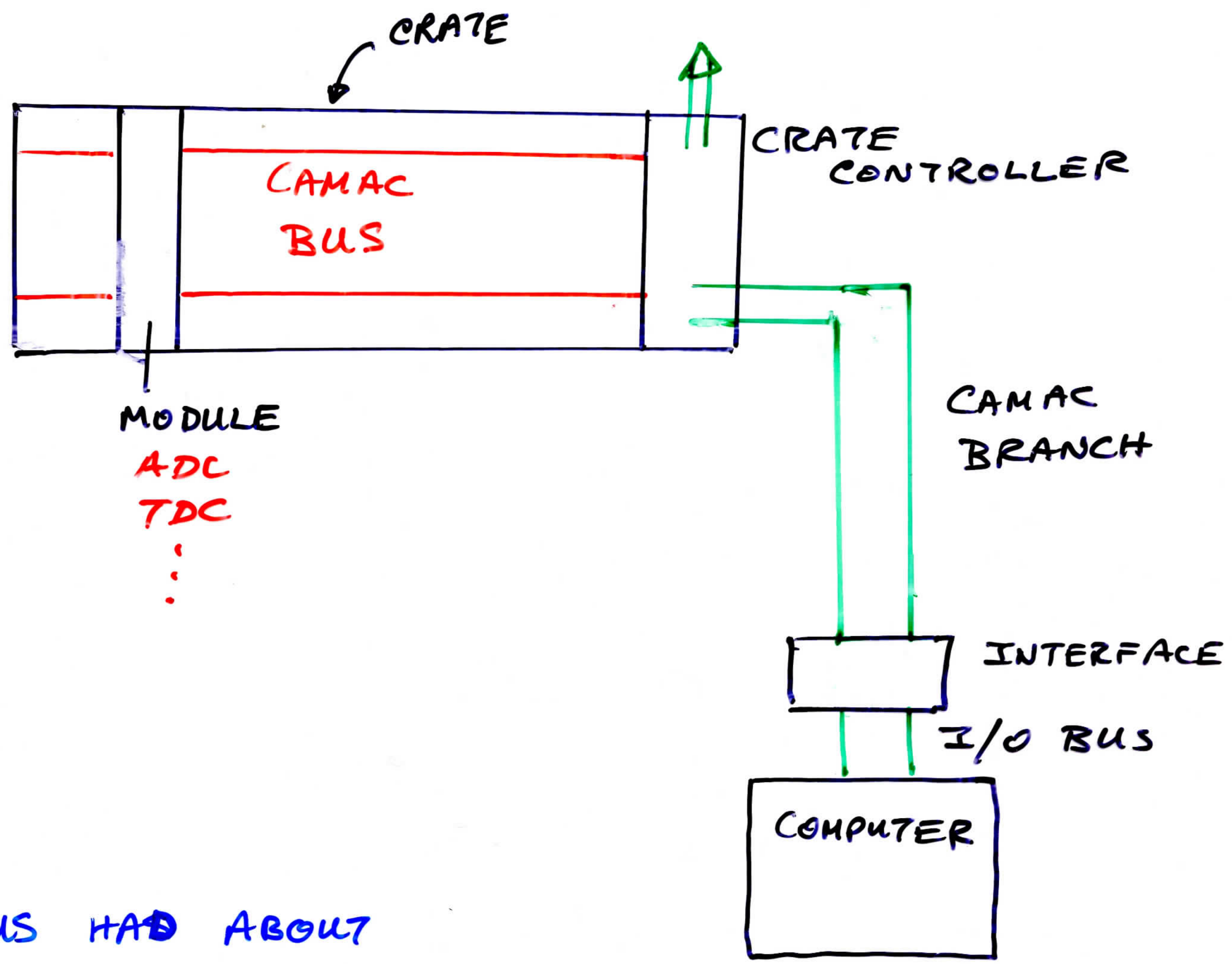
- COMPUTER PUTS MODULE ADDR + CONTROL WORD ON BUS (EQ, "PUT YOUR REGISTER CONTENTS ON DATA BUS")
- ADDRESSED MODULE DECODES IT'S ADDRESS AND RESPONDS

CAMAC

"ONLY USED IN VERY SIMPLE SYSTEMS"

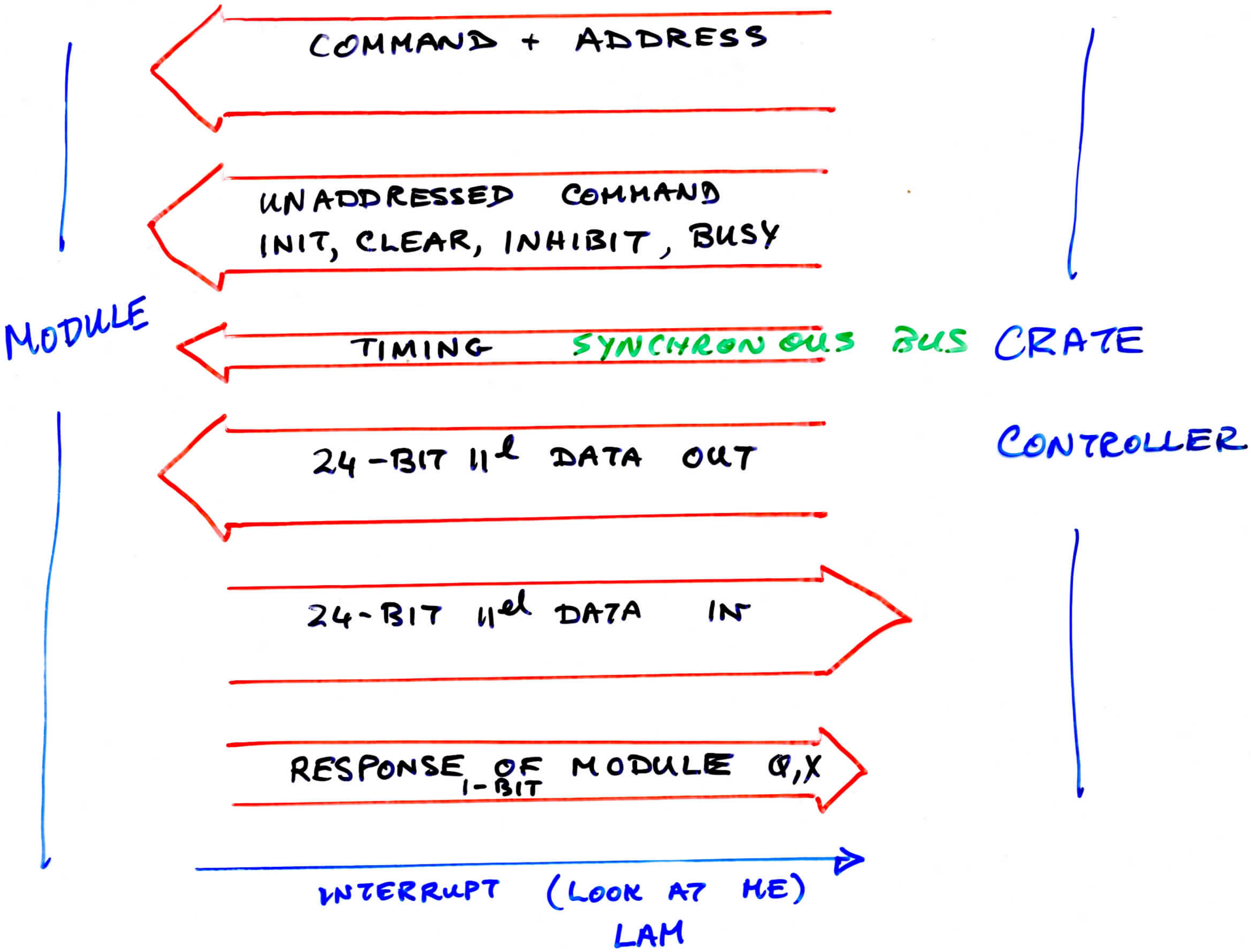
- MANY MODULES IN AN EXPERIMENT
- MANY MANUFACTURES

∴ NEED MECHANICAL AND BUS STANDARD



ARGUS HAD ABOUT TWENTY CAMAC CRATES

- CDF WOULD NEED HUNDREDS
- ATLAS THOUSANDS ?

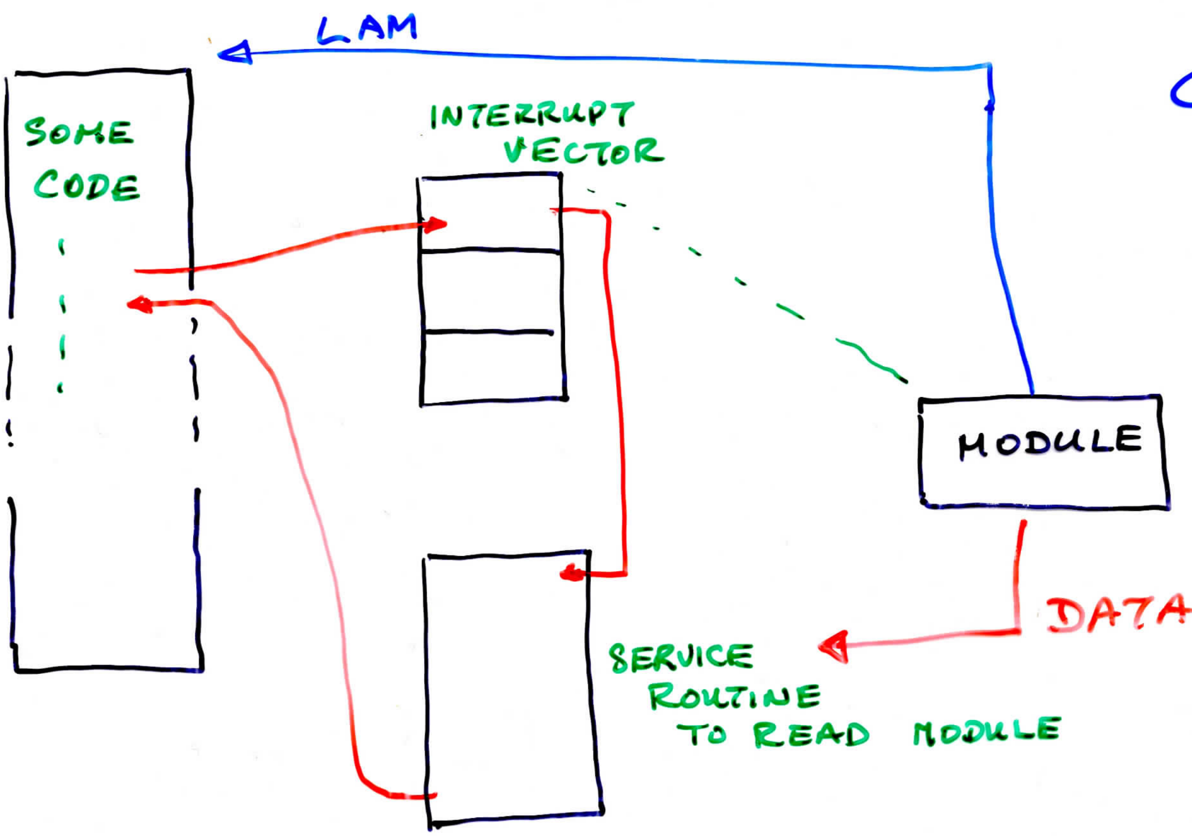

COMMAND + ADDRESS
UNADDRESSED COMMAND
INIT, CLEAR, INHIBIT, BUSY
MODULE
TIMING
SYNCHRONOUS BUS
CRATE
CONTROLLER
24-BIT ll^l DATA OUT
24-BIT ll^el DATA IN
RESPONSE OF MODULE Q,X
1-BIT
INTERRUPT (LOOK AT ME)
LAM

INTERRUPTS

- TRIGGER STARTS ADC CONVERTING
- WHEN CONVERSION DONE MODULE 'INTERRUPTS' COMPUTER

LOOK AT ME! — L A M

CAMAC



- COMPUTER EXECUTING SOME CODE
- LAM CAUSES INTERRUPT
- CONTROL JUMPS VIA INTERRUPT VECTOR TO SERVICE ROUTINE TO READ MODULE
- COMPUTER STARTS WHERE IT LEFT OFF WITH "SOME CODE"

OTHER BUSES

e.g. TEST BEAM / LAB

CAMAC — ESSENTIALLY 16 BIT. — ONE MASTER

SMALL SYSTEMS — 1 μs CYCLE — 1 MByte/sec

VME — INDUSTRY STANDARD FOR 32 Bits

MODERN EXPERIMENTS — 40 MByte/SEC BAND WIDTH

FAST BUS — > 10 MBytes/sec

CDF

32 BIT

ASYNCHRONOUS OPERATION

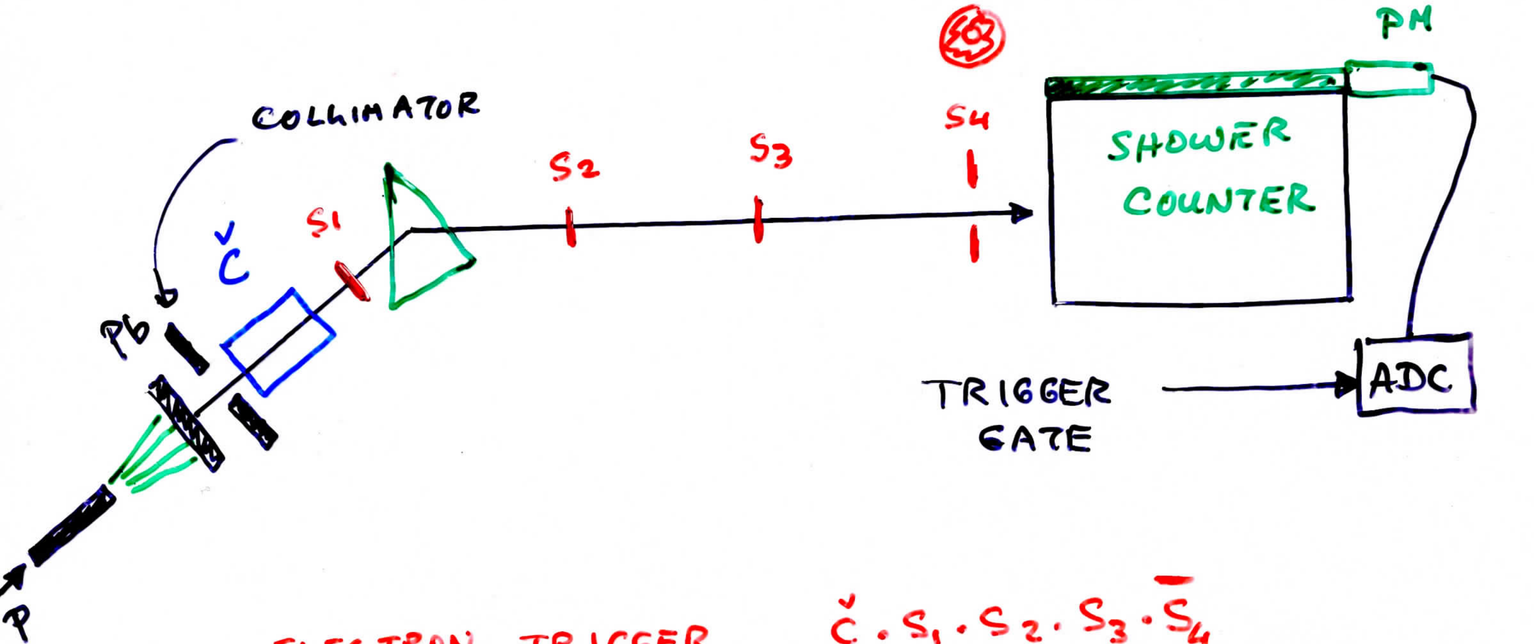
MODULE ↔ MODULE COMMUNICATION

(MANY MASTERS)

LARGE MODULES → MANY CHANNELS

TRIVIAL EXAMPLE

CALIBRATION OF A SINGLE EM. CALORIMETER.



ELECTRON TRIGGER $\check{C} \cdot S_1 \cdot S_2 \cdot S_3 \cdot \bar{S}_4$

$pp \to pp \; \pi^+ \pi^- \; \pi^0$; $K^+ K^-$; $\pi^0 \to \gamma\gamma$, $\gamma \to e^+ e^-$

WITH COLLIMATOR OPEN

e^+ BEAM OF DEFINITE MOMENTUM

WITH COLLIMATOR CLOSED

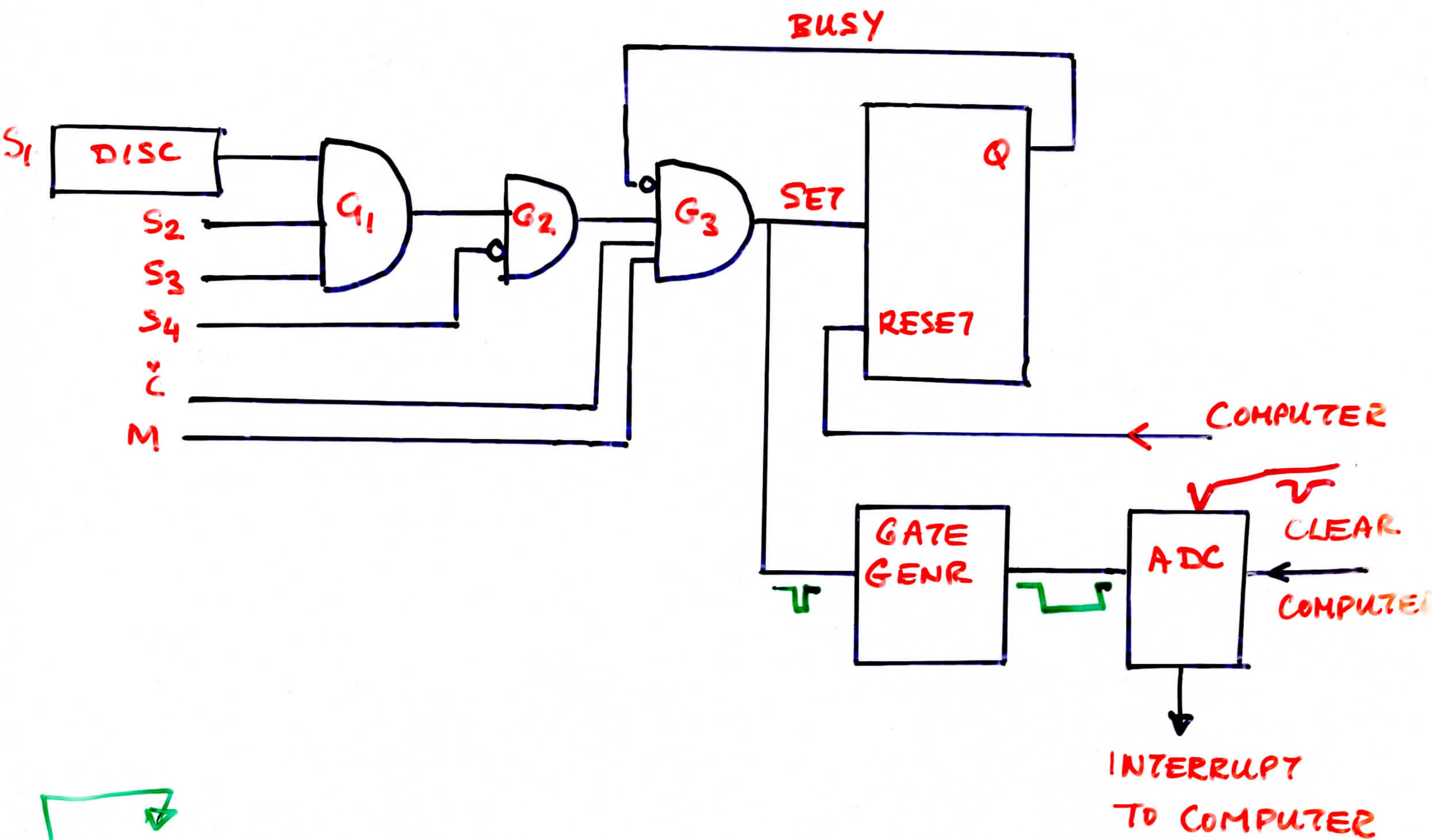
μ^+ BEAM FROM $\pi, K \to \mu\nu$

WANT A TRIGGER WHEN

- BEAM PARTICLE — $S_1 \cdot S_2 \cdot S_3$
- NO "HALO" PARTICLE — $\bar{S_4}$ ← NOT
- ELECTRON — $\check{C}$
- ACCELERATOR ON — M

THEN

- GENERATE GATE TO PHOTOMULTIPLIER ADC
- INHIBIT ANOTHER TRIGGER DURING
  CONVERSION
  +
  COMPUTER READ OUT



- TRIGGER GENERATED

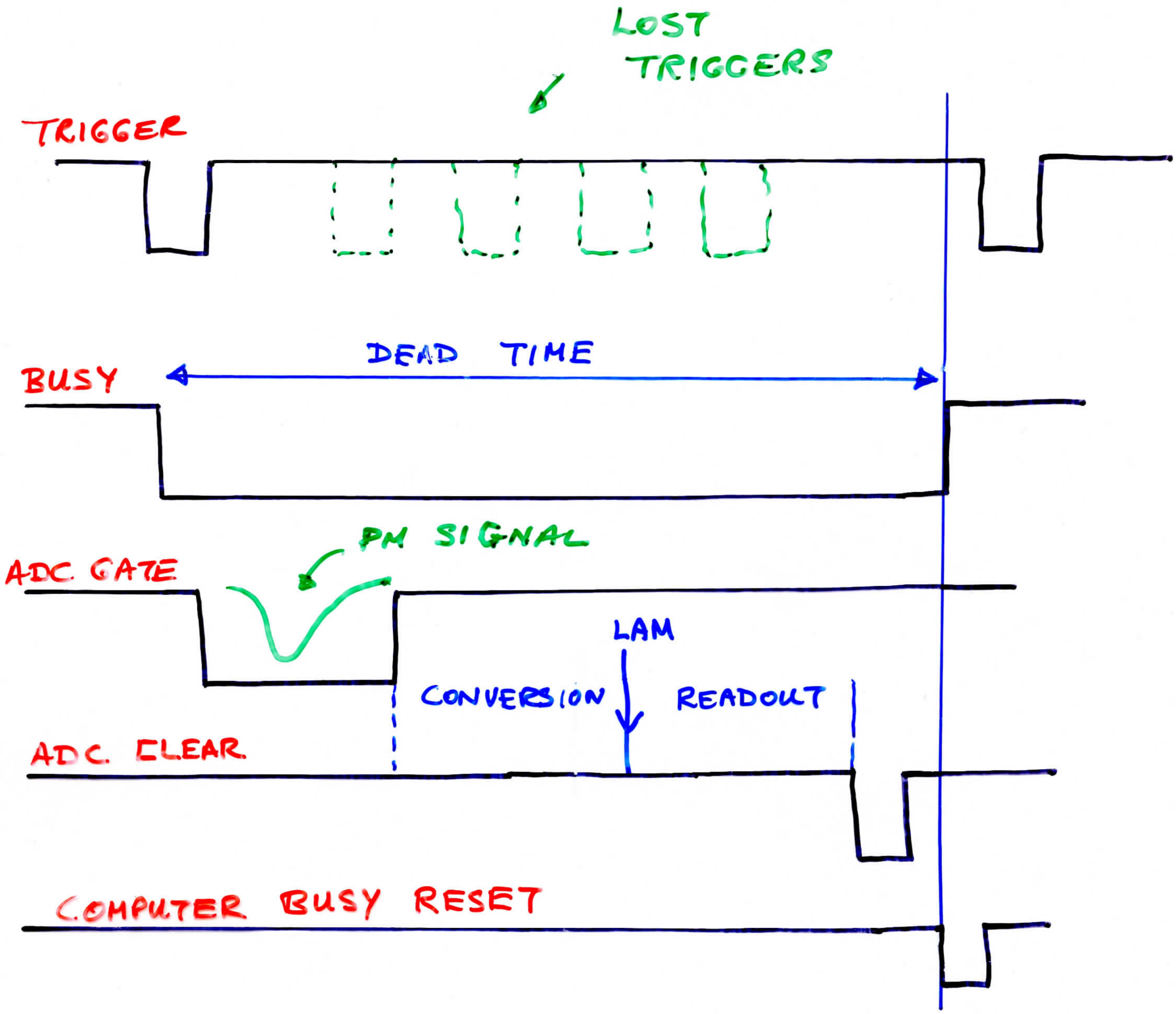
$$S_1 . S_2 . S_3 . \overline{S_4} . \check{C} . M . \overline{BUSY}$$

- TRIGGER SETS BUSY — CLOSES G_3
  NO MORE TRIGGERS

- TRIGGER ALSO STARTS ADC GATE

- WHEN ADC HAS FINISHED CONVERSION IT INTERRUPTS THE COMPUTER

- COMPUTER READS OUT ADC AND CLEARS IT, THEN RESETS FLIP-FLOP → ALLOWS A NEW TRIGGER TO SET OFF WHOLE PROCESS AGAIN

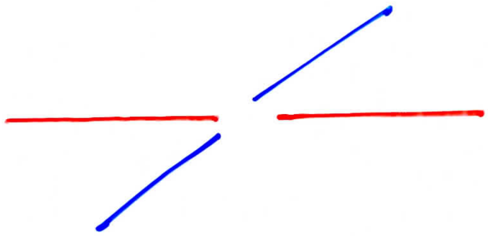


LOST TRIGGERS
TRIGGER
DEAD TIME
BUSY
PM SIGNAL
ADC GATE
LAM
CONVERSION
READOUT
ADC CLEAR
COMPUTER BUSY RESET

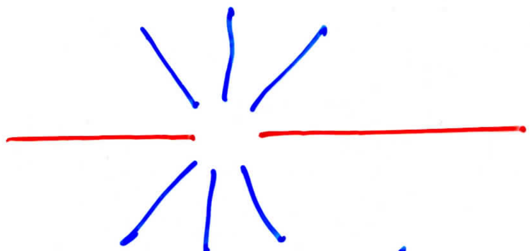
ARGUS EXAMPLE

SIMPLE EXAMPLES INSTRUCTIVE !

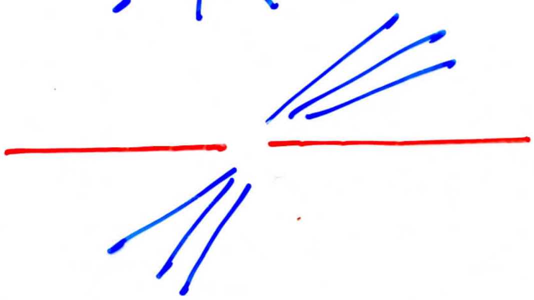
EXAMPLE SIGNALS



$e^+e^- \rightarrow e^+e^-$

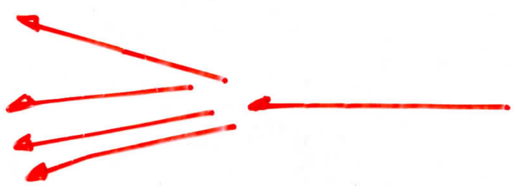


$e^+e^- \rightarrow B\bar{B}$ ↳ MANY TRACKS

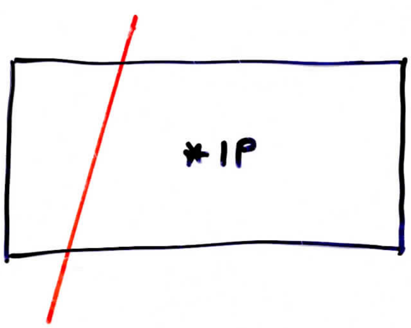


$e^+e^- \rightarrow q\bar{q} \rightarrow$ 2 JETS

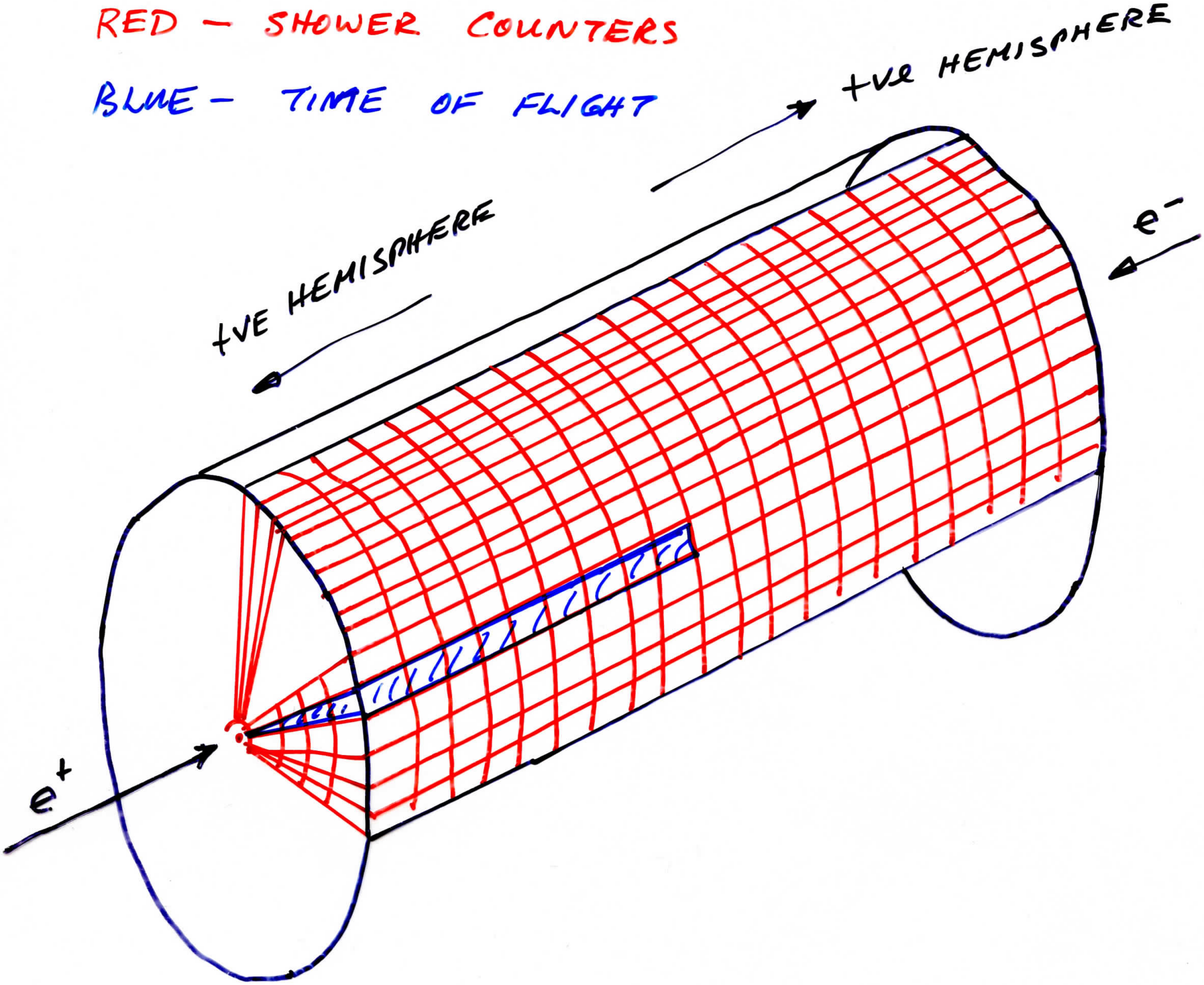
EXAMPLE BACKGROUNDS



BEAM GAS



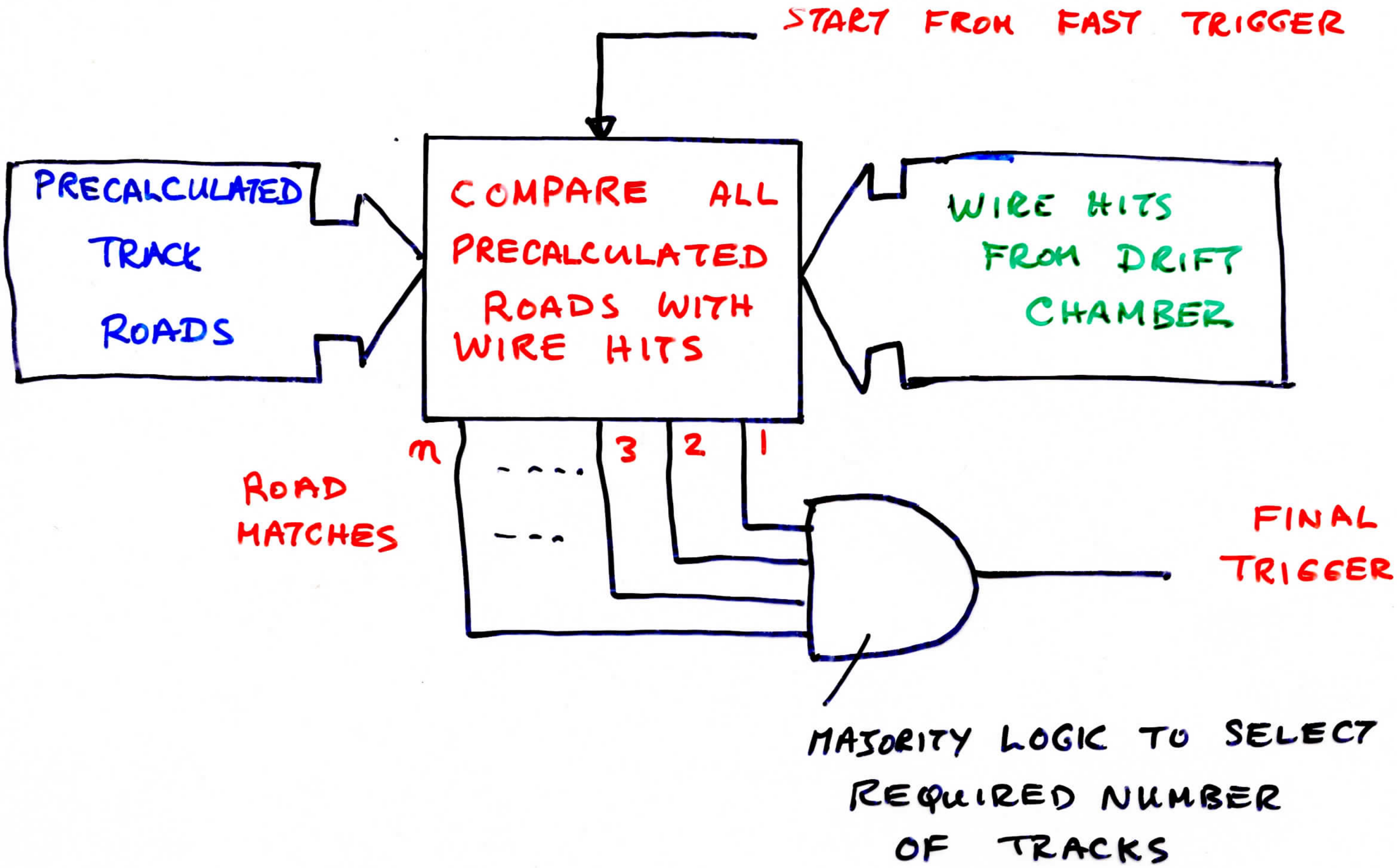
COSMIC



$e^+ e^- \rightarrow e^+ e^-$ ~ 5 GeV IN EACH HEMISPHERE

$e^+ e^- \rightarrow B\bar{B}$, $q\bar{q}$. ONE GROUP OF SC + TOF IN EACH HEMISPHERE

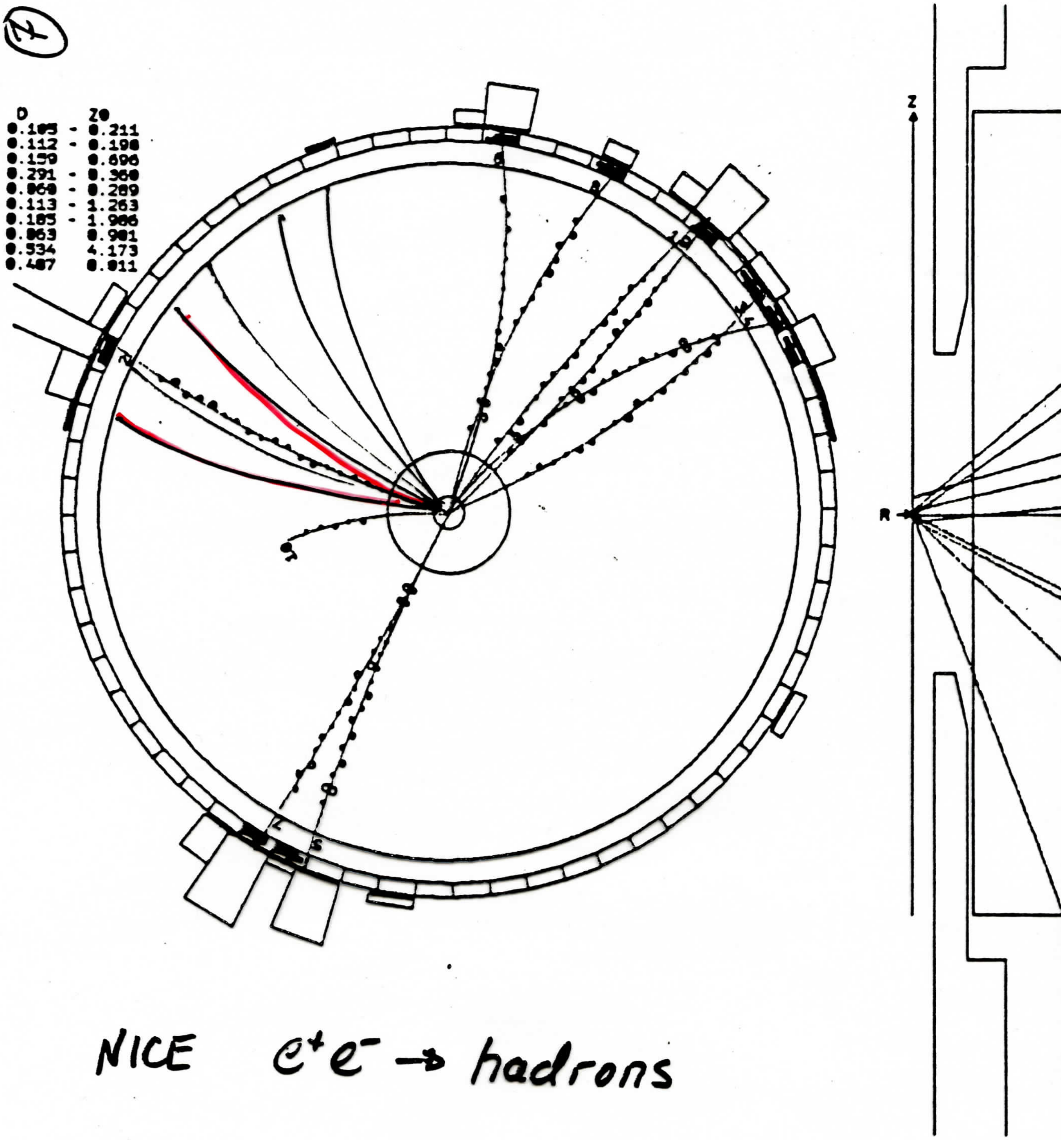
TRACK FINDER



USE OF PRECALCULATED "LOOK-UP-TABLE" OF ROADS MAKES THIS VERY FAST, BUT ALSO FLEXIBLE

R	1
N	2203
T	4044
IB	0
OJ	RZ
AL	0.060

P	D	Z0
-1.218	0.105	-0.211
-0.308	0.112	-0.198
0.507	0.159	0.696
-0.414	0.291	-0.360
1.446	0.060	-0.289
0.482	0.113	-1.263
-2.018	0.185	-1.986
-0.482	0.063	0.901
1.250	0.534	4.173
0.306	0.487	0.011



NICE $e^+e^- \rightarrow$ hadrons

MODERN COLLIDER TRIGGER

e.g. ZEUS, ATLAS, CDF II

- BEAMS CROSS EVERY 96 ns ZEUS
  25 ns ATLAS

  - VERY HIGH BACKGROUND
    BEAM - GAS ZEUS
    BEAM - BEAM ATLAS

  CANNOT EVEN MAKE FAST COINCIDENCE DECISION IN THIS TIME

  ? 100% DEAD TIME

  ↳ DEADTIME LESS TRIGGER

- MANY COMPLEX INTERESTING CHANNELS WITH LOW RATE

  Higgs
  SUSY
  t - quark

  → COMPLICATED, TIME CONSUMING CALCULATIONS

  - TRACK 4-VECTOR
  - $\not{E}_T$
  - INVARIANT MASSES

ZERO DEAD TIME → PIPELINED TRIGGER

- STORE ANALOG INFO FROM **EVERY** CHANNEL IN PIPELINE MEMORY
  - ANALOG INFO FLOWING INTO PIPELINE CLOCKED BY BEAM CROSSING
  - NEW ENTRY EVERY 96ns (ZEUS)
  - 5μS PIPELINE
    - PROCESS DATA + MAKE 1ST LEVEL DECISION IN < 5μS

- ON 1ST LEVEL ACCEPT (1kHz – ZEUS)
  - STOP PIPELINE
  - CLOCK DATA OUT OF PIPELINE
  - DIGITIZE DATA
  - RE-ENABLE PIPELINE
  - DATA STARTS FLOWING INTO PIPELINE

DEAD TIME

- 2ND LEVEL TRIGGER
  - CRUDE RECONSTRUCTION
  - DECIDE IF EVENT LOOKS INTERESTING
  - PASS TO 3RD LEVEL (100 Hz)

GOVERNED BY PROCESSING POWER → (100 Hz)

- 3RD LEVEL
  - MANY (100 – 1000) GENERAL PURPOSE PROCESSORS LOOKING AT EVENTS IN PARALLEL
  - FULL RECONSTRUCTION

    VERTICES

    $\not{E}_T$

    INVARIANT MASSES

    PARTICLE ID.

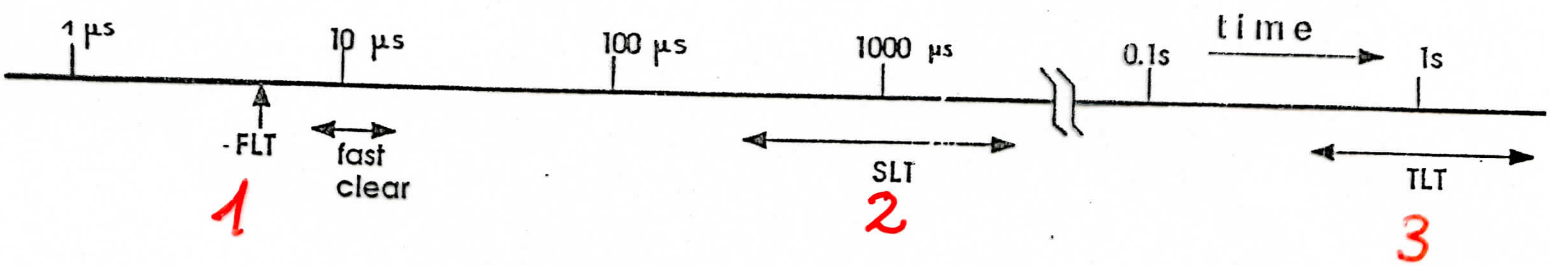
    (3 Hz – ZEUS)

MULTI-LEVEL TRIGGER (ZEUS)

1) MAKE FAST DECISON

2) READ OUT DETECTORS → START PIPELINE

3) PROCESS DATA SIMPLY ↓ COMPLETELY



ZEUS TRIGGER

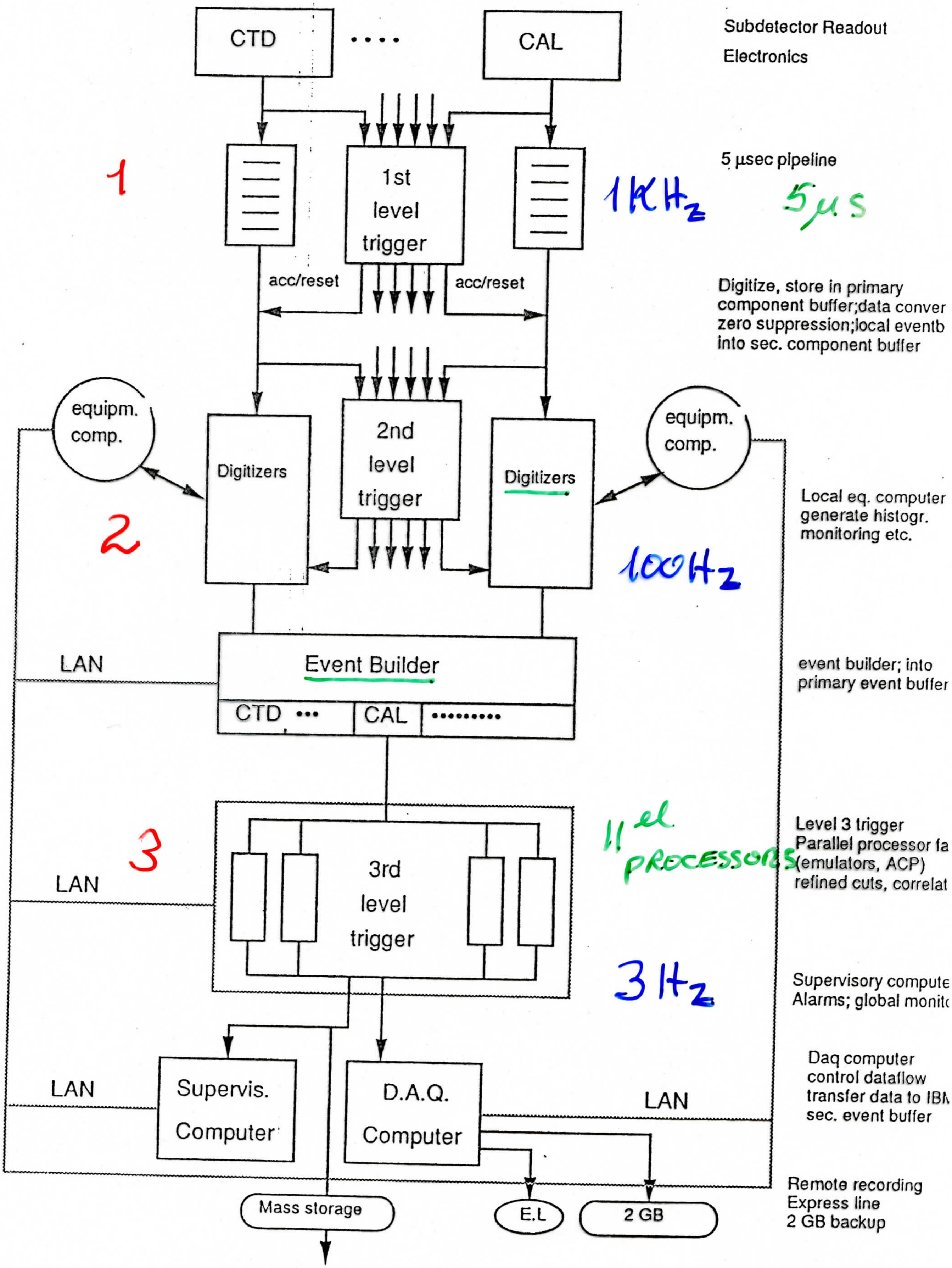
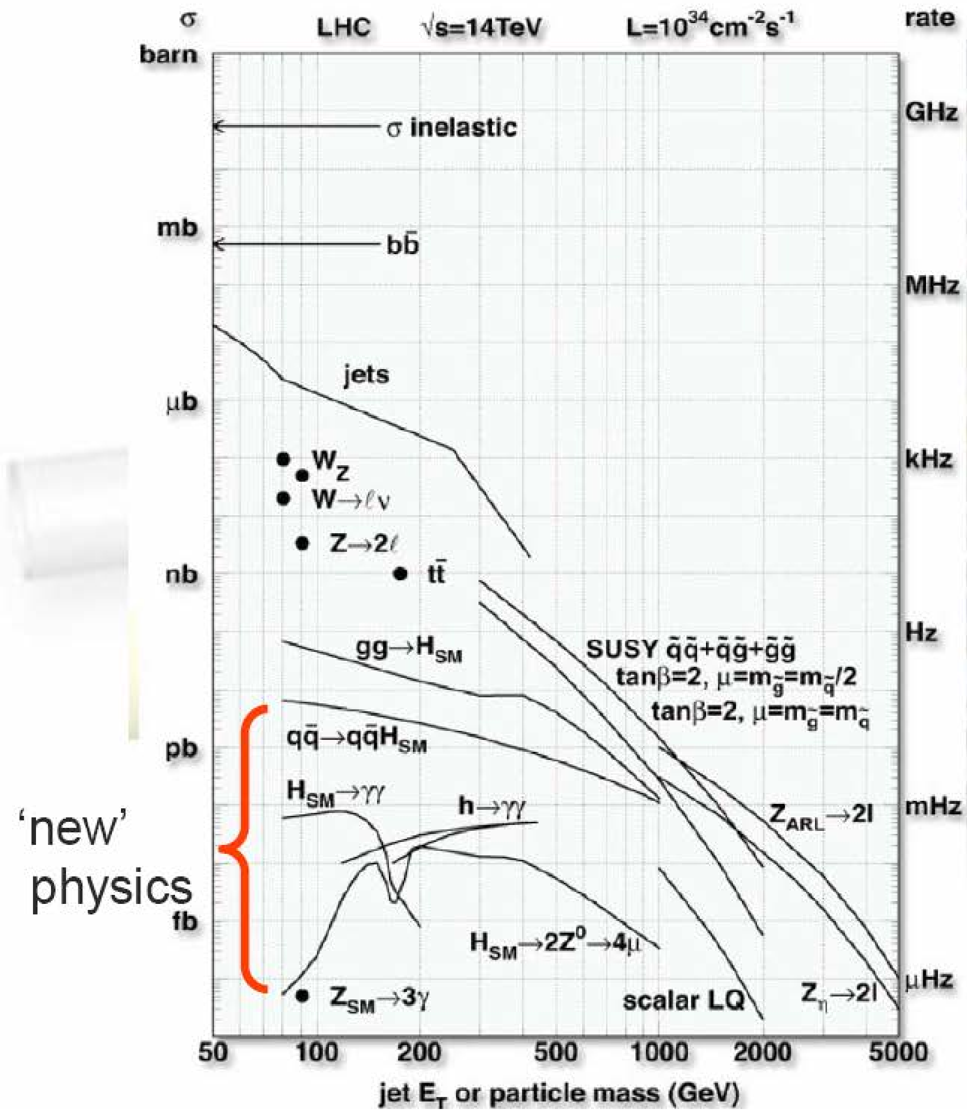


Fig. 15.2.1 Outline for the ZEUS Data Acquisiti...



Interaction rate: ~1GHz
event size: 1.5MB (140 million channels)
1PB/sec
! affordable 300MB/sec
online rejection:
99,9995% !

Storage rate: ~200Hz

Enormous rate reduction necessary !

Powerful trigger needed!

3-Level Trigger System:

LVL1:

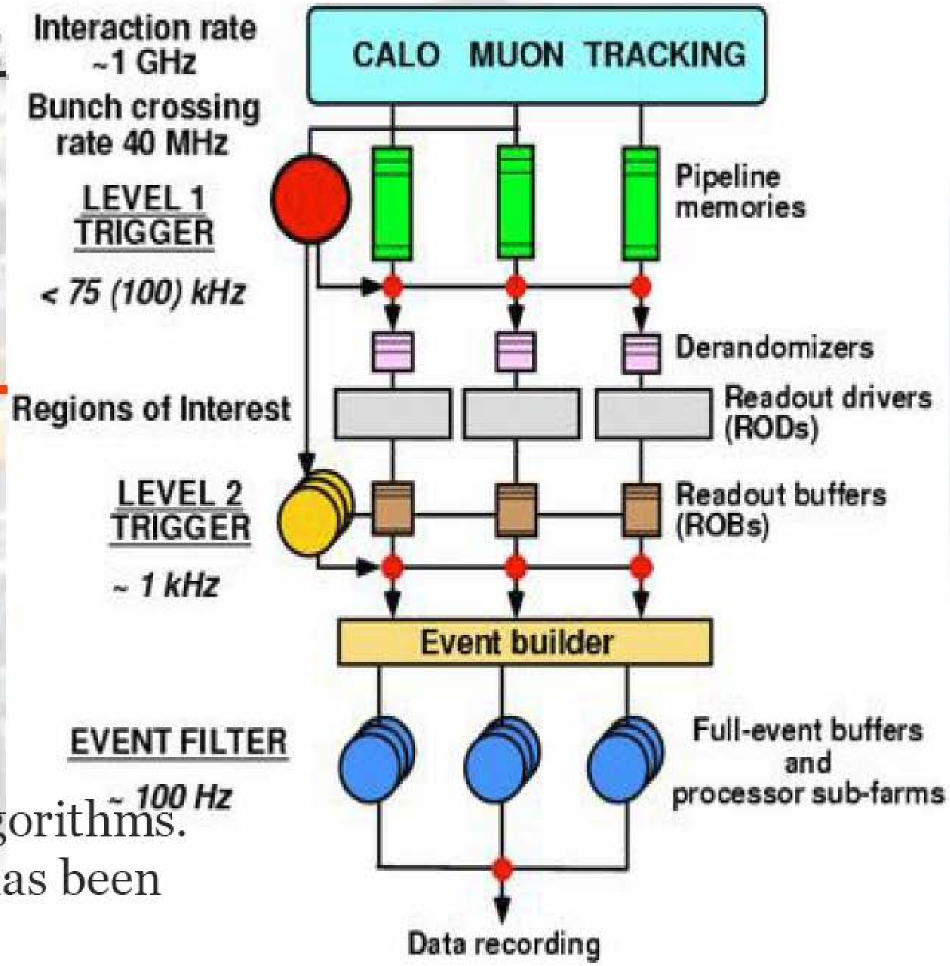
Hardware based system.
Coarse Information from calorimeters and muon trigger chambers.

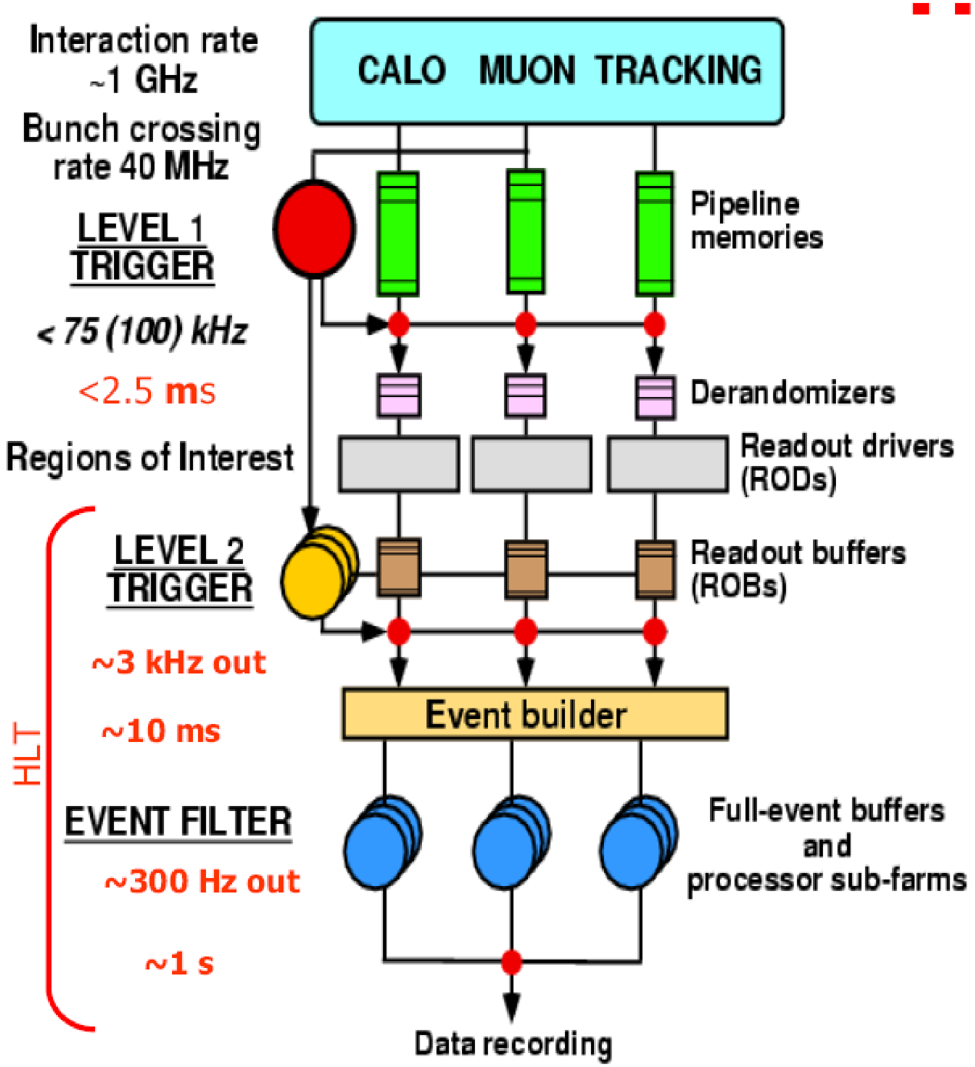
LVL2:

Based on optimized software algorithms.
Full granularity data in RoIs, defined by LVL1, available.

Event Filter:

Implemented using (complex) software algorithms.
Performs its task only after the full event has been assembled in the Event Builder.





LEVEL 1

- hard ware based: FPGAs, ASICs
- uses larger granularity of the calorimeter and muon information
- identify **R**egions **o**f **I**nterest for further processing
- reduction from 1 GHz to 75 kHz
- **latency of 2.2 μs**

LVL1: hardware

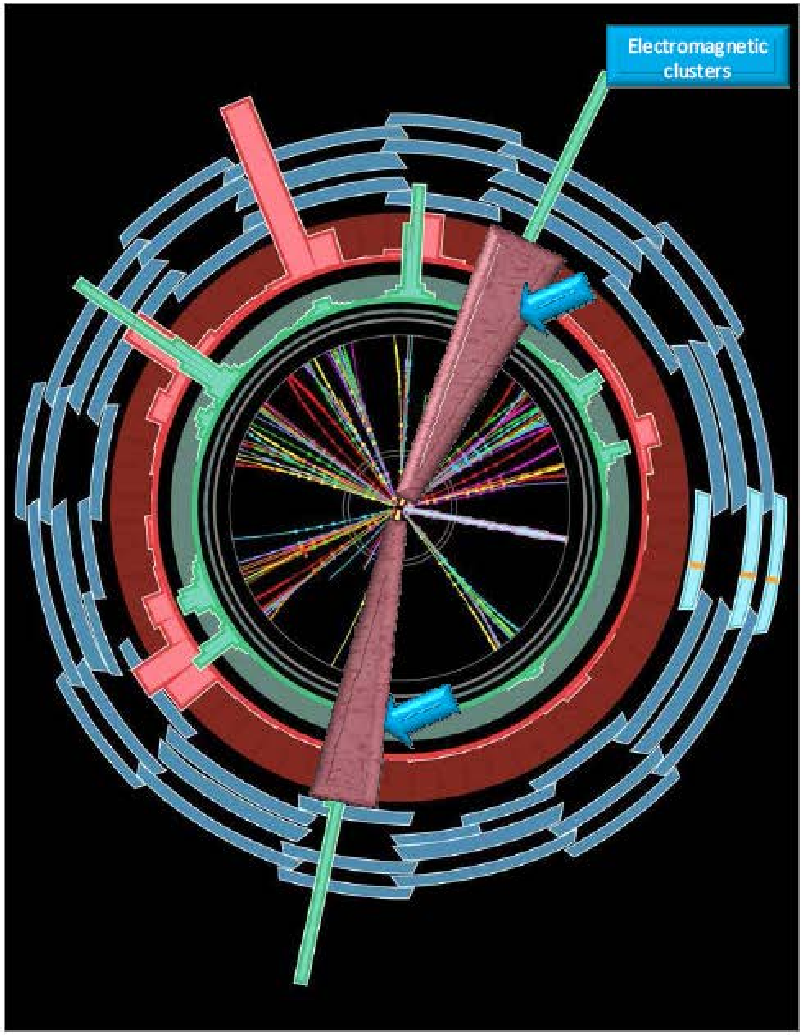
LEVEL 2

- full granularity within the **RoI**
- seeded by LVL1-trigger
- fast reconstruction
- only data within **RoI processed**
- combination of detectors within **RoI**
- reduction from 75 kHz to 1 kHz
- **execution time of ~ 40 ms**

EVENT FILTER

- seeded by level 2
- full event information available
- full granularity of detectors
- "offline like" algorithms
- reduction from 1kHz to 200 Hz
- **averaged execution time of 4 s**

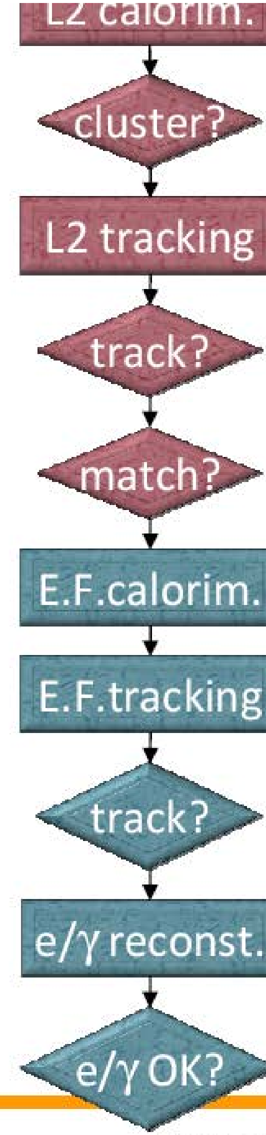
HLT (LVL2 + EF): software



Level1:
Region of Interest is found and position in EM calorimeter is passed to Level 2

Level 2 seeded by Level 1
- Fast reconstruction algorithms
- Reconstruction within RoI

Ev.Filter seeded by Level 2
- Offline reconstruction algorithms
- Refined alignment and calibration



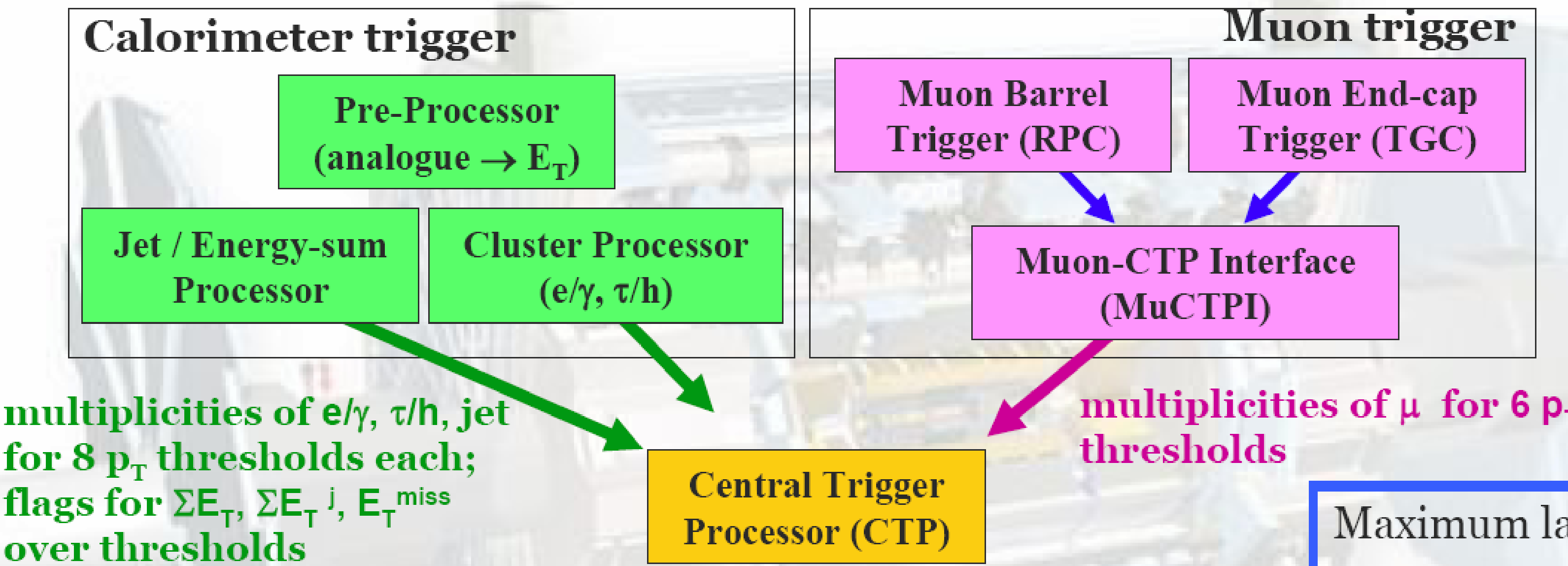
TRIGGER MENU CLASSES

Object	Examples of physics coverage	Nomenclature
Electrons	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W, top	e25i, 2e15i
Photons	Higgs (SM, MSSM), extra dimensions, SUSY	γ60i, 2γ20i
Muons	Higgs (SM, MSSM), new gauge bosons, extra dimensions, SUSY, W, top	μ20, 2μ10
Jets	SUSY, compositeness, resonances	j360, 3j150, 4j100
Jet+missing E_T	SUSY, leptoquarks	j60 + xE60
Tau+missing E_T	Extended Higgs models (e.g. MSSM), SUSY	τ30 + xE40

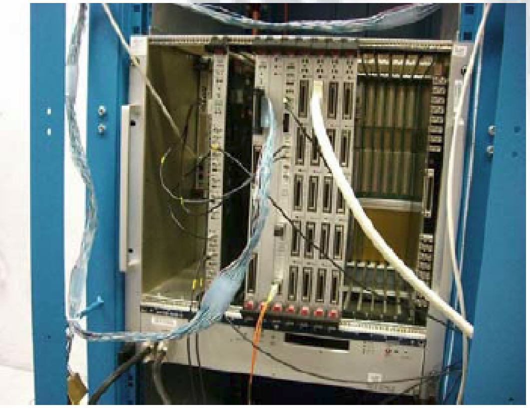
Trigger menu 'NoXXi':

- 'N'= min. number of objects required
- 'o'= type of selection ('e'=electrons, 'γ'=photons, 'μ'=muons, 'b'=b-tagged jet; 'xE'=missing E_T; 'E'=total E_T; 'jE'=total E_T using only jets).
- 'XX'= threshold in transverse Engery
- 'i'= indicates an isolation requirement

LEVEL1 OVERVIEW



central part of LVL1 trigger system.
calculation of trigger decision
based on inputs from L1Calo and L1Muon.

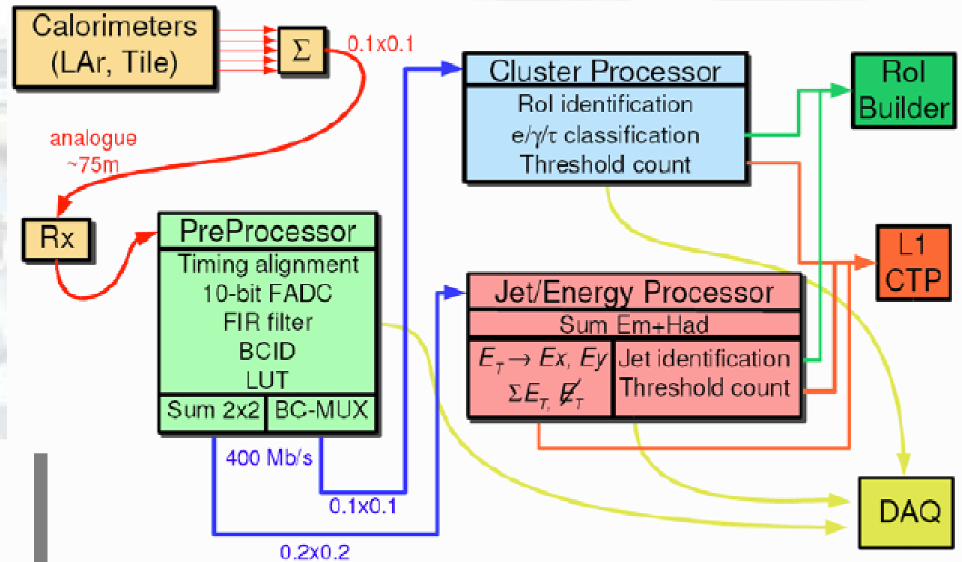


Maximum latency:
~2.5 μs
(=100 BC!)

Data fragments held in pipelined Memories. Upon LVL1 acceptance transferred to Read Out Buffers (ROB).

LVL1 CALORIMETER TRIGGER

Electronics on detector: **summation of signals** to form **~7200 Trigger Towers** granularity **Δη x Δφ = 0.1 x 0.1**

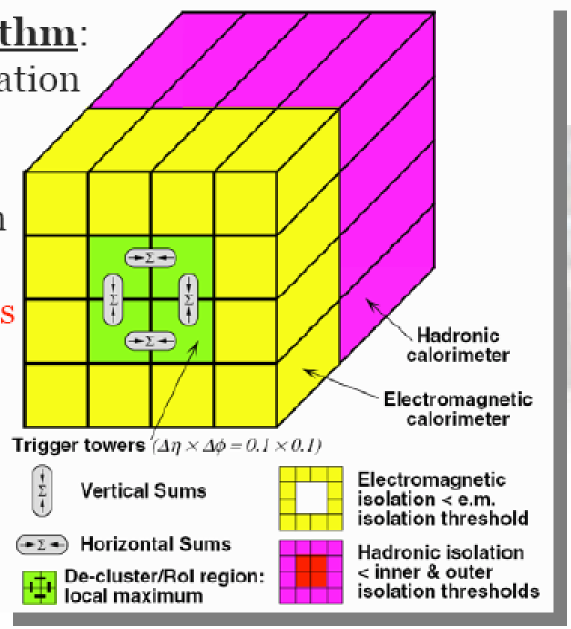


electronic components :

- PPr: digitisation of analogue signals from calorimeters and bunch crossing ID
- JEP: jet finding and energy sums
- CP: e/γ and τ/ had. cluster finding

example: e/γ algorithm:

- goal: good discrimination e/γ ↔ jets
- identify 2x2 RoI with local ET maximum
- cluster/ isolation cuts on various ET sums

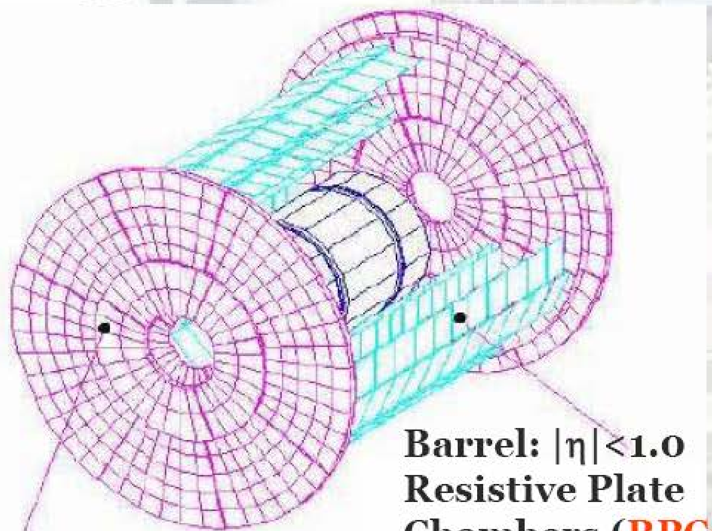


output:

- at 40 MHz: multiplicities for e/γ, jets, τ/had and flags for energy sums to Central Trigger (CTP)
- accepted events: position of objects (RoIs) to LVL2 and additional information to DAQ

LVL1 MUON Trigger

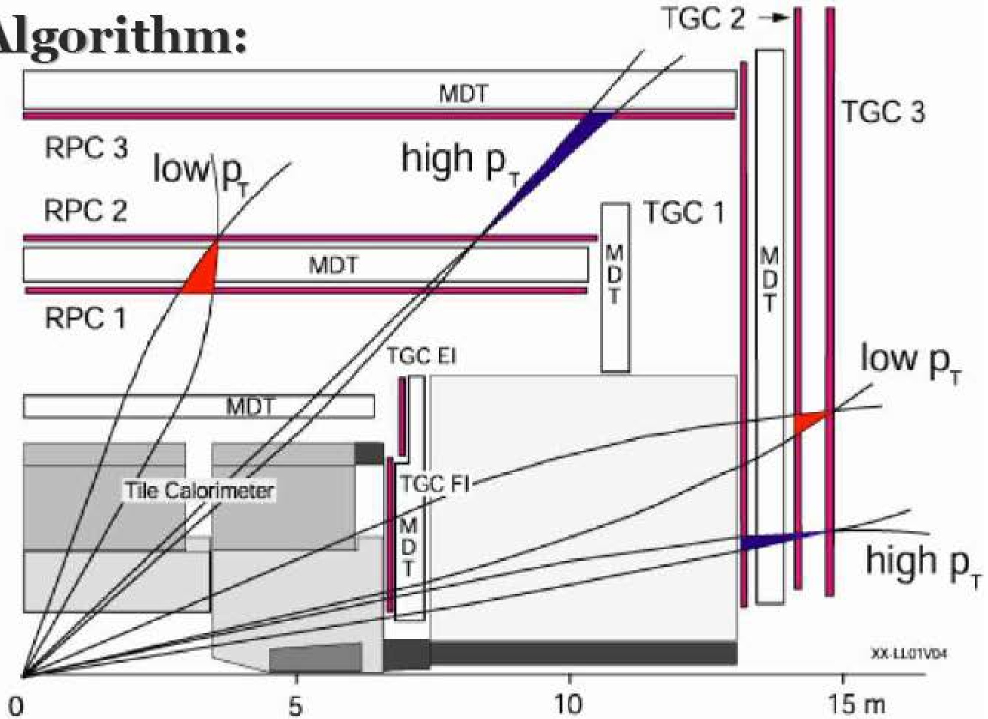
Trigger Chambers:



Barrel: |η|<1.0
Resistive Plate Chambers (RPCs)

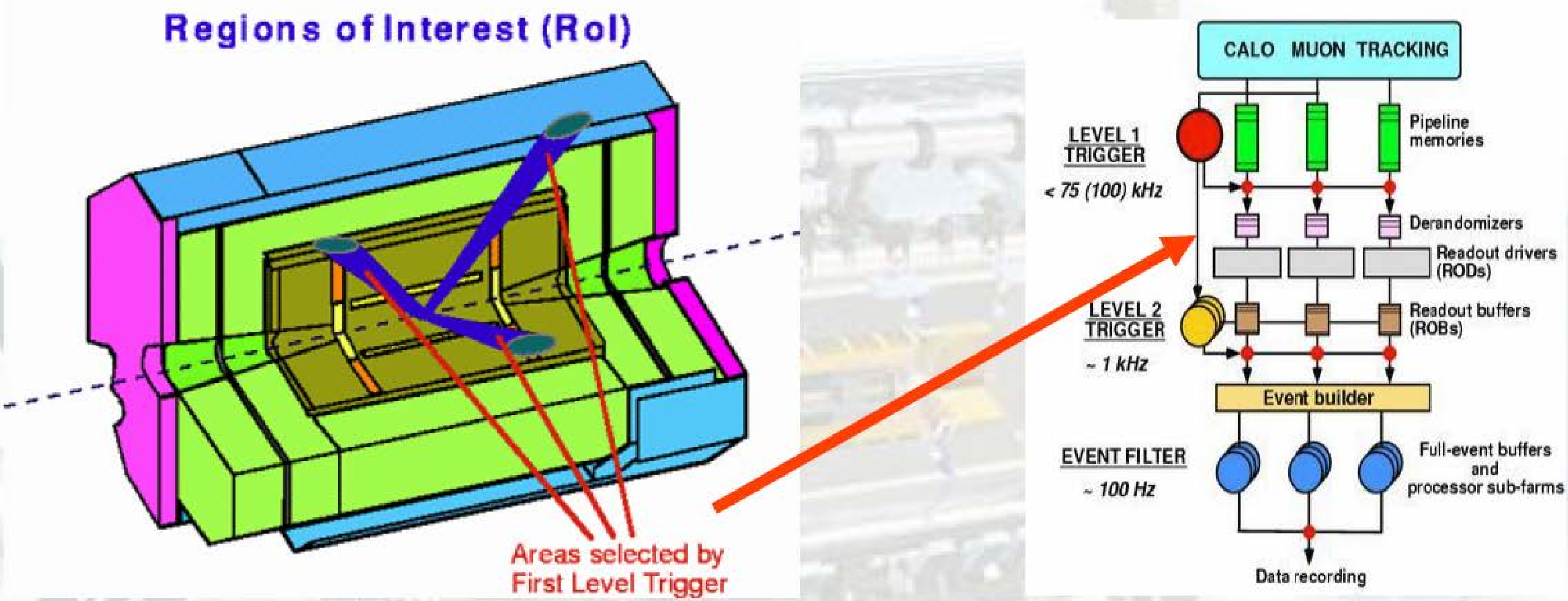
End-caps: 1.0< |η|< 2.4
Thin Gap Chambers (TGCs)

Algorithm:



- **deflection** depends on muon p_T
- programmable width of **6 coincidence windows** determines the p_T threshold.
- MuCTPI collects information form RPC and TGC triggers does overlap removal.
  Sends results to the CTP for LVL1 event decision

REGIONS of INTEREST

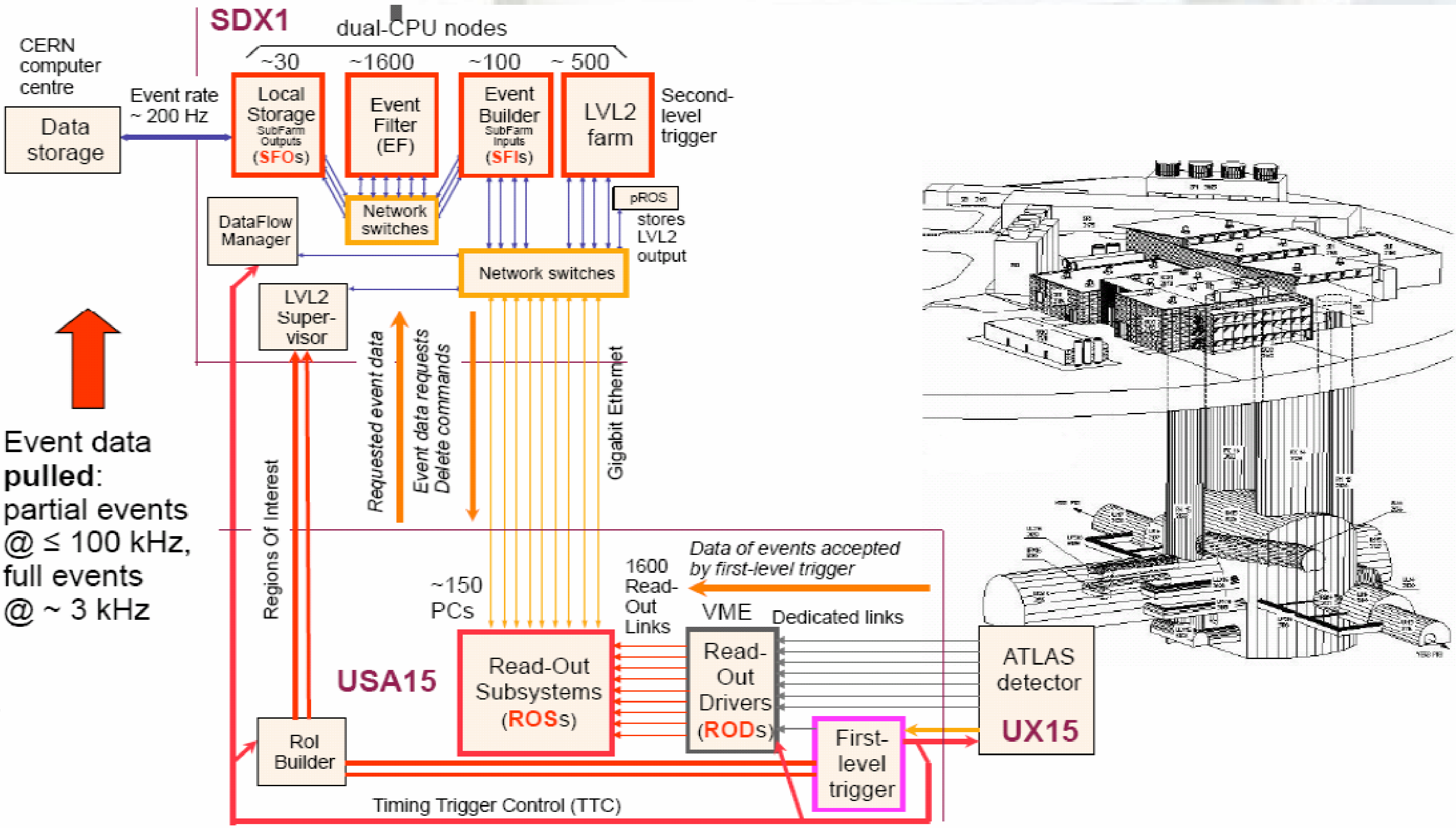


- LVL1 sends Regions of Interest to LVL2 for high p_T $e/\gamma/\tau$/jet-/μ candidates.
- RoIs are used to 'seed' the LVL2 selection.
- LVL2 uses (in these regions) full precision from the inner tracker in addition to full granularity data from the calorimeters.

total amount of transferred data is small

→ **~2% of the total event data!**

LVL2 and EF run in large PC farms on the surface



Event data **pushed** @ ≤ 100 kHz, 1600 fragments of ~ 1 kByte each

Step- wise processing and decision:

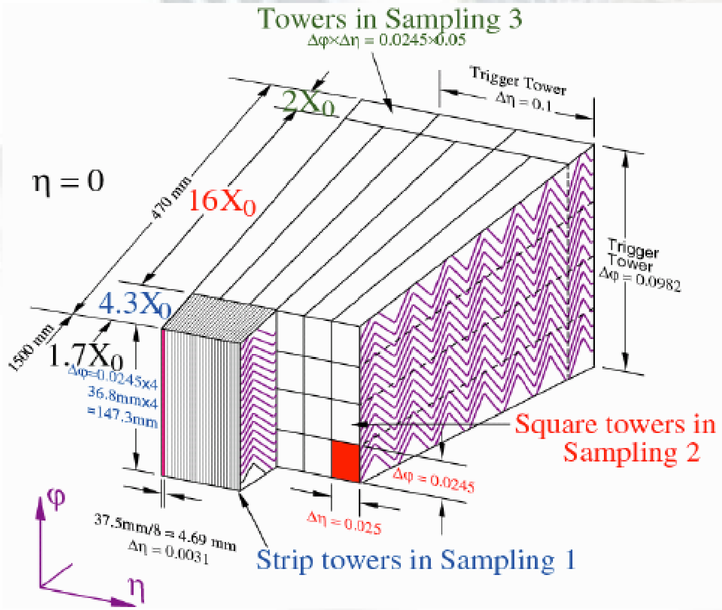
- Inexpensive (data, time) algorithms (clustering) first. complicated last (i.e. tracking).

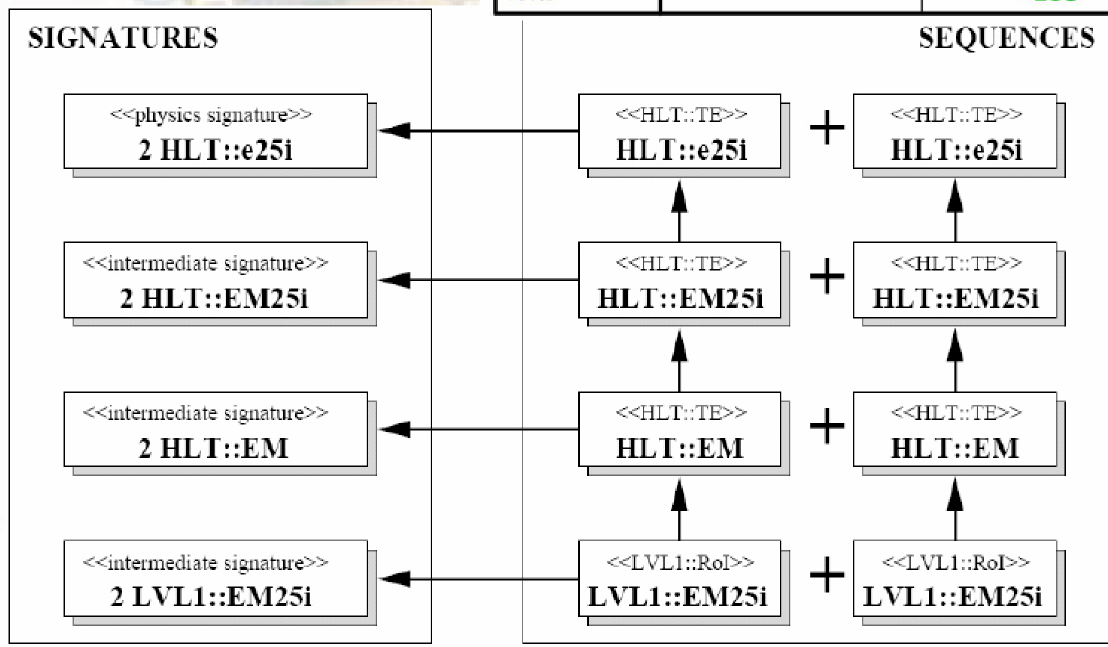
Seeded reconstruction:

- Algorithms use results from previous steps.

HLT Output Rates

Selection	$2{*}10^{33}$ cm^{-2}s^{-1}	Rates (Hz)
Electron	e25i, e15i	~40
Photon	γ60i, 2γ20i	~40
Muon	μ20, 2μ10	~40
Jets	j400, 3j165, 4j110	~25
Jet & E_T^{miss}	j70 + xE70	~20
tau & E_T^{miss}	τ35 + xE45	~5
b-physics	2μ6 with m_B /$m_{J/\psi}$	~10
Others	pre-scales, calibration, ...	~20
Total		~200





LVL2 confirms & refines LVL1

EF confirms & refines LVL2