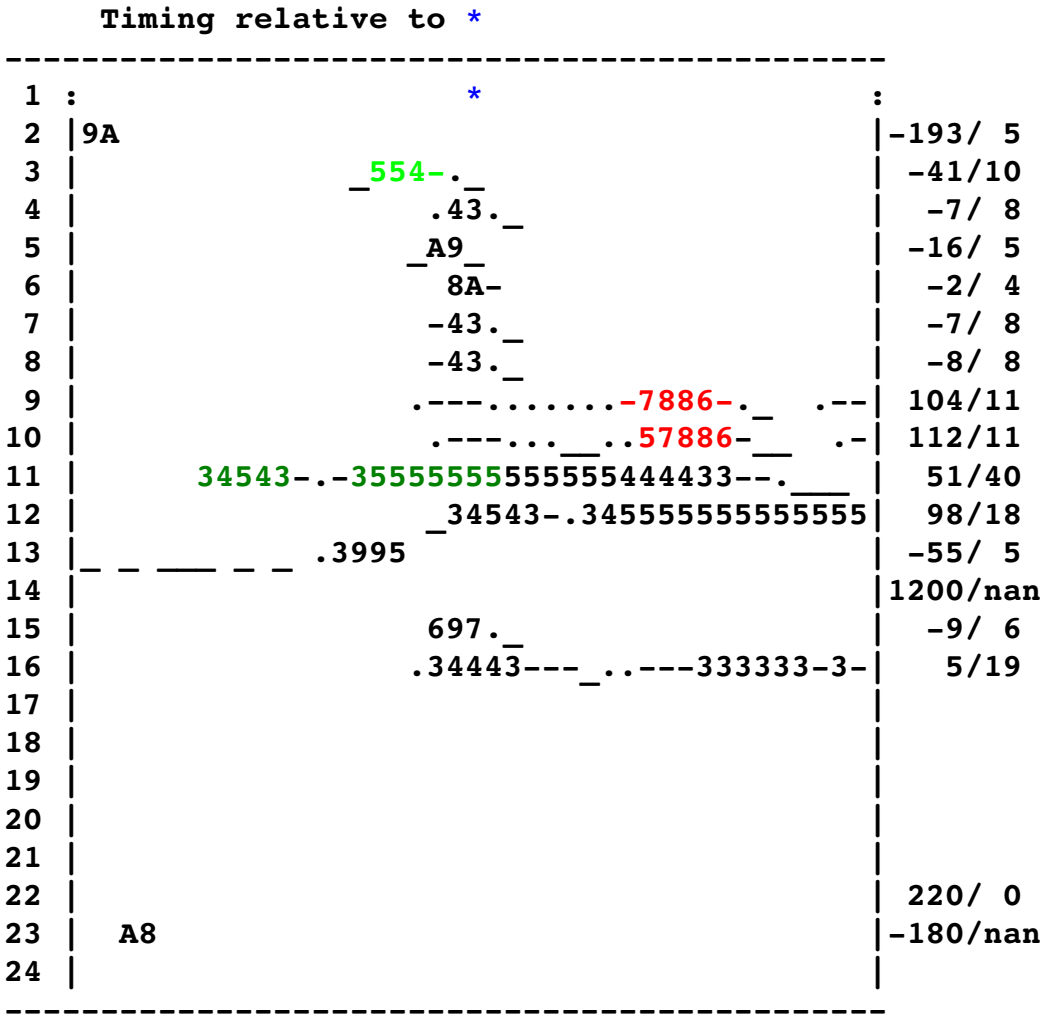
TRLO II – flexible FPGA trigger control



Håkan T. Johansson, Chalmers, Göteborg

With Ana Henriques, Lisbon

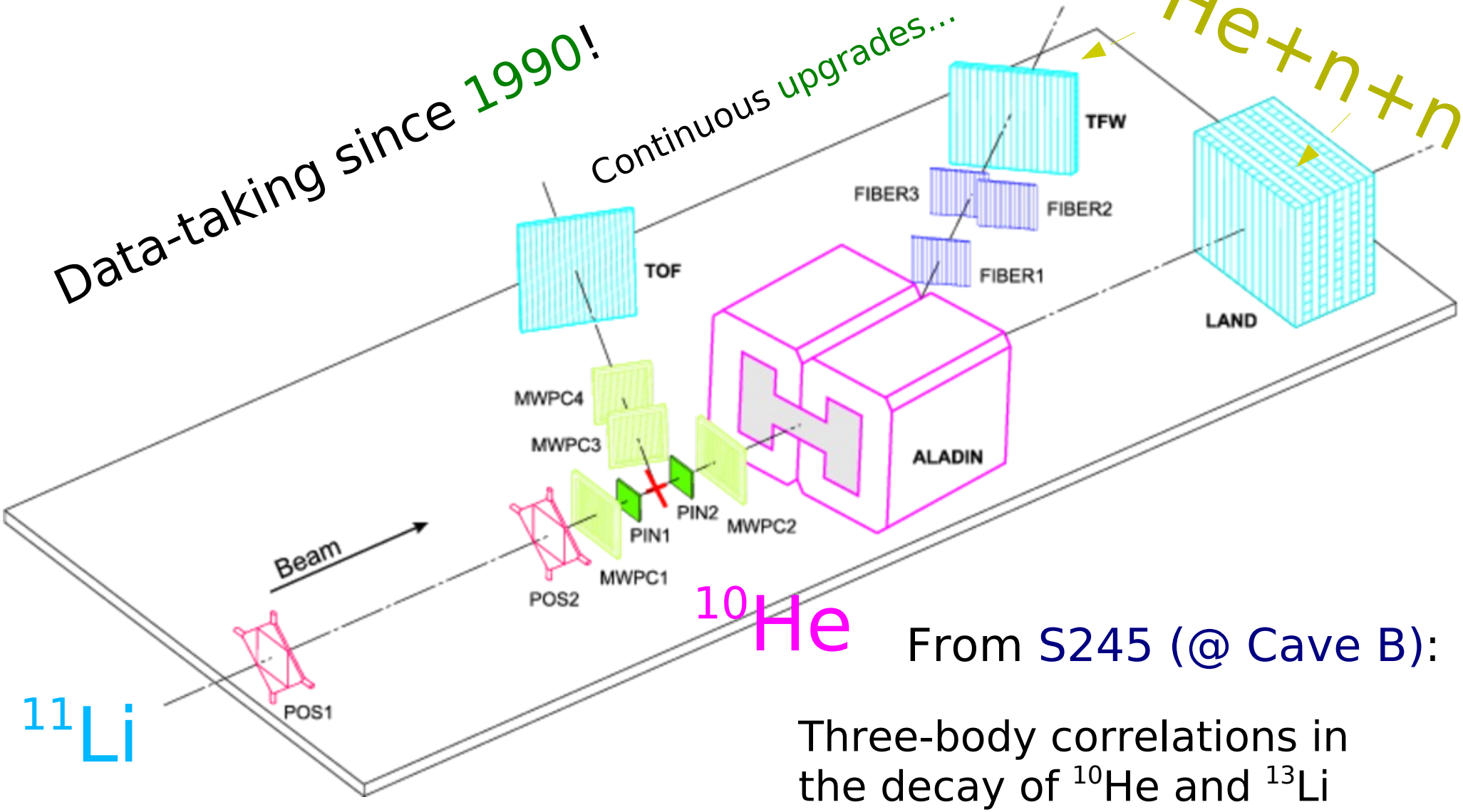
GSI, February 2011

ALADiN-LAND setup → R^{3}B

Data-taking since 1990!

Continuous upgrades...

^{8}He+n+n



^{10}He

^{11}Li

From S245 (@ Cave B):

Three-body correlations in the decay of ^{10}He and ^{13}Li

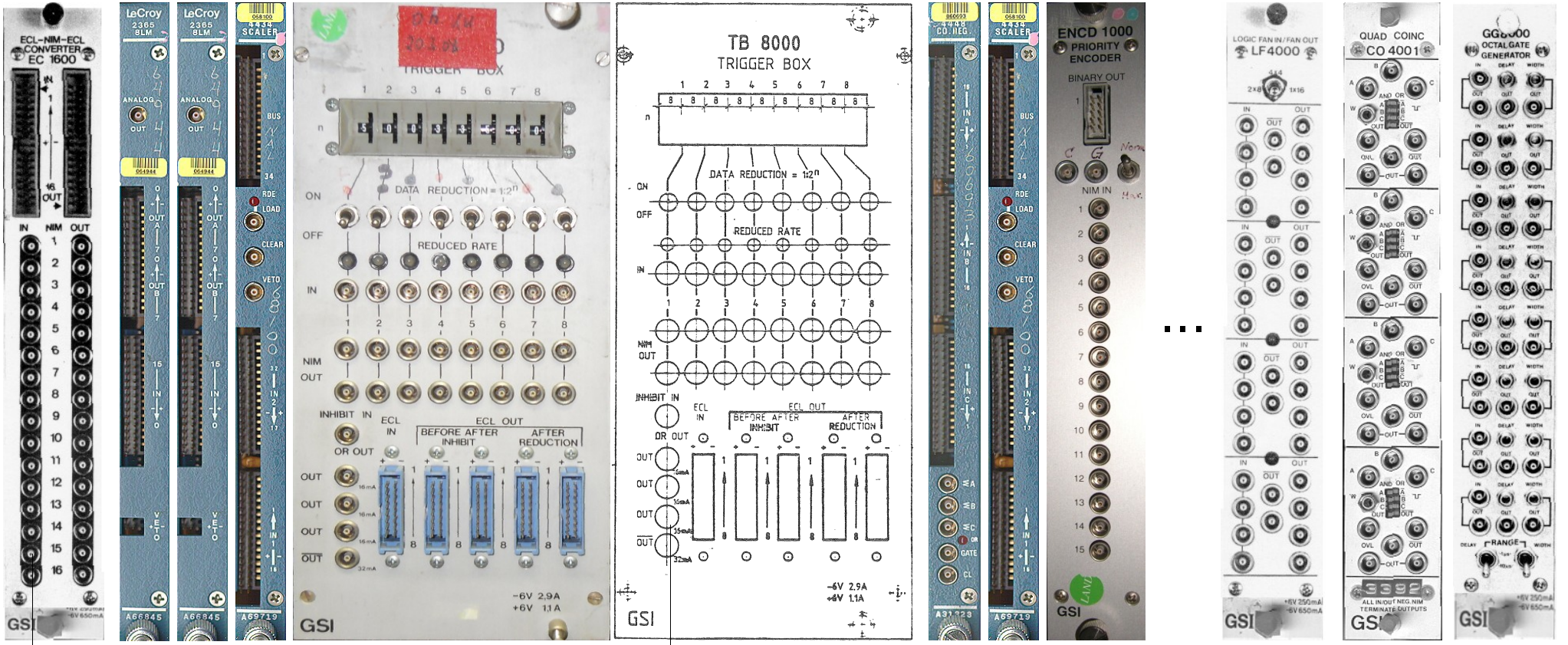
H.T. Johansson, Yu. Aksyutina, et. al.
Nuclear Physics A, Vol 847 (2010) pp. 66-88

The trigger has to be *fast*...

Detector signals
Logic matrix
→ coincidences
Scaler

Trigger boxes:
deadtime veto
downscale

Pattern unit
Scaler
Priority encoder

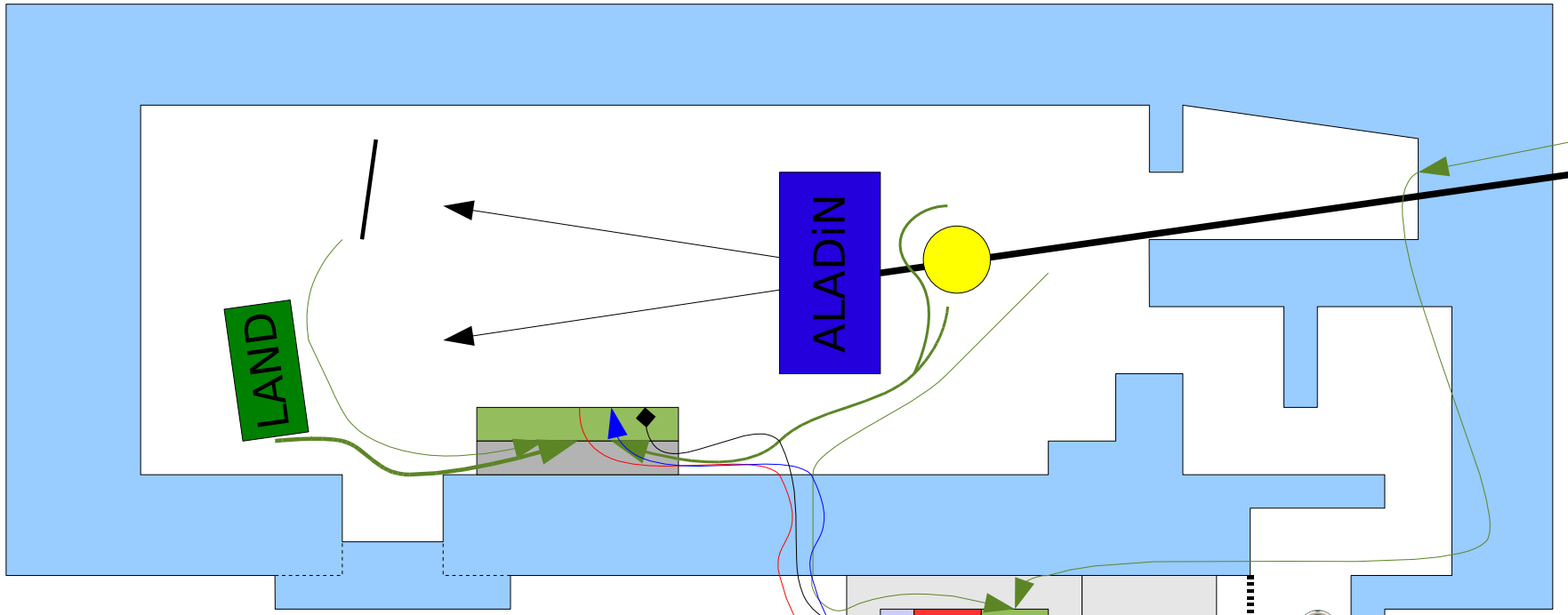


...

Master start in 45 ns

Cave C trigger (2004-)

(Analog to LAND@ Cave B -2004)



Detector signals

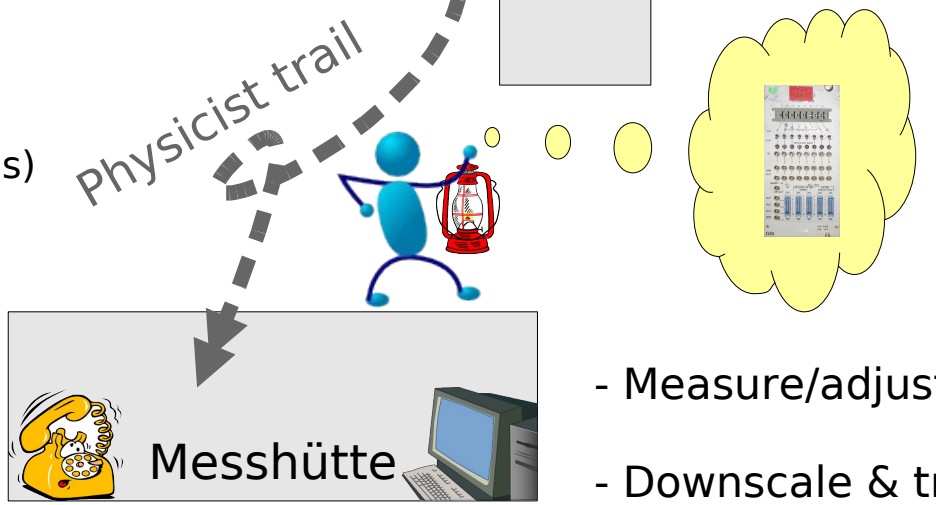
Split, QDC, TDC, CFD
Delays (500 ns)

Detector triggers (<100 ns)

Trigger decision (~50 ns)

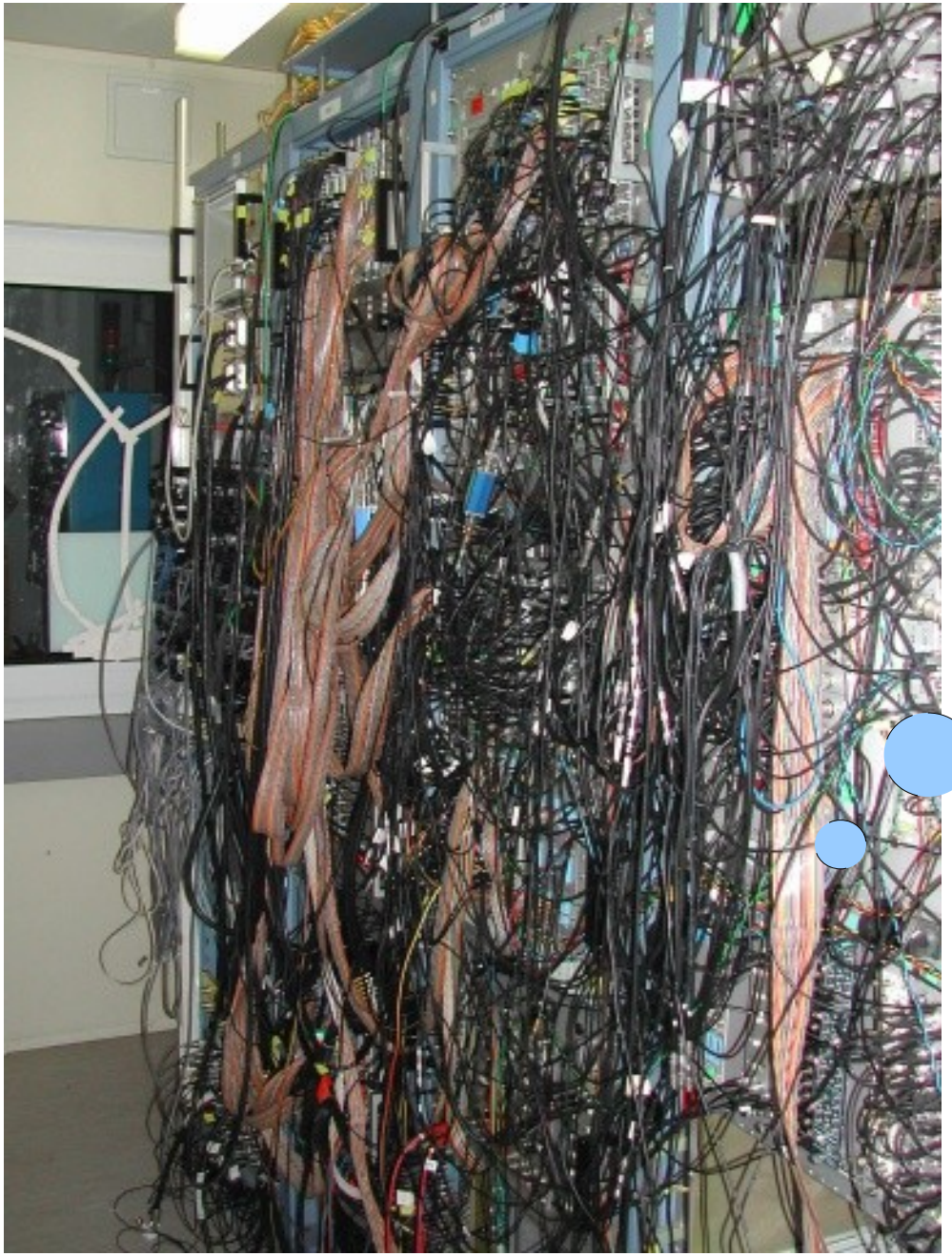
Master start (<100 ns)

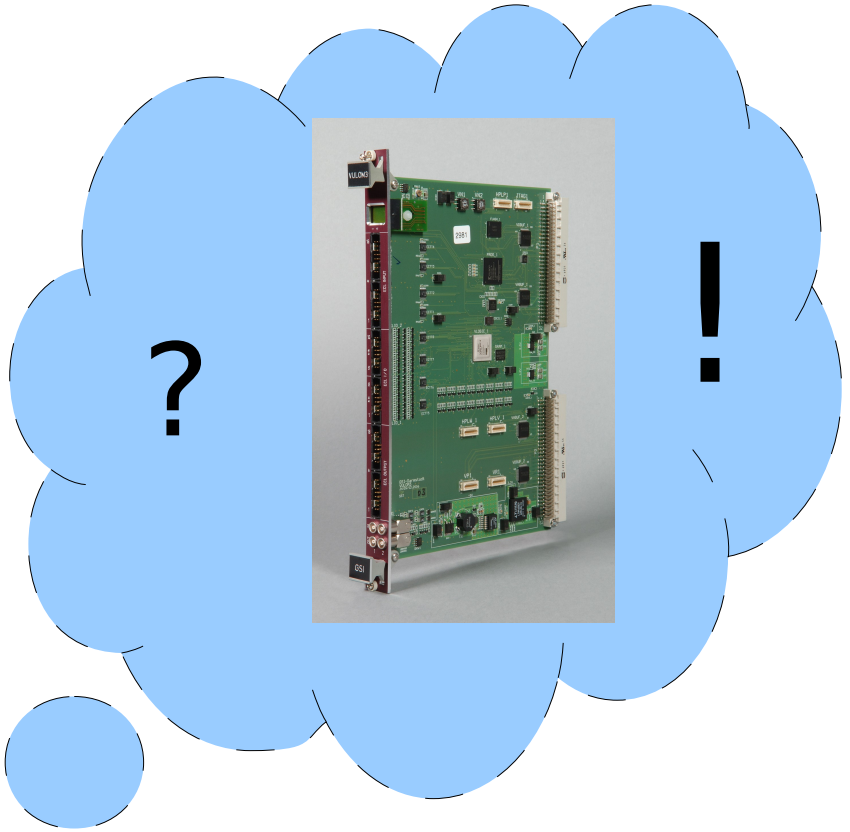
Trigger bus



Access required:

- Measure/adjust trigger alignment
- Downscale & trigger on/off





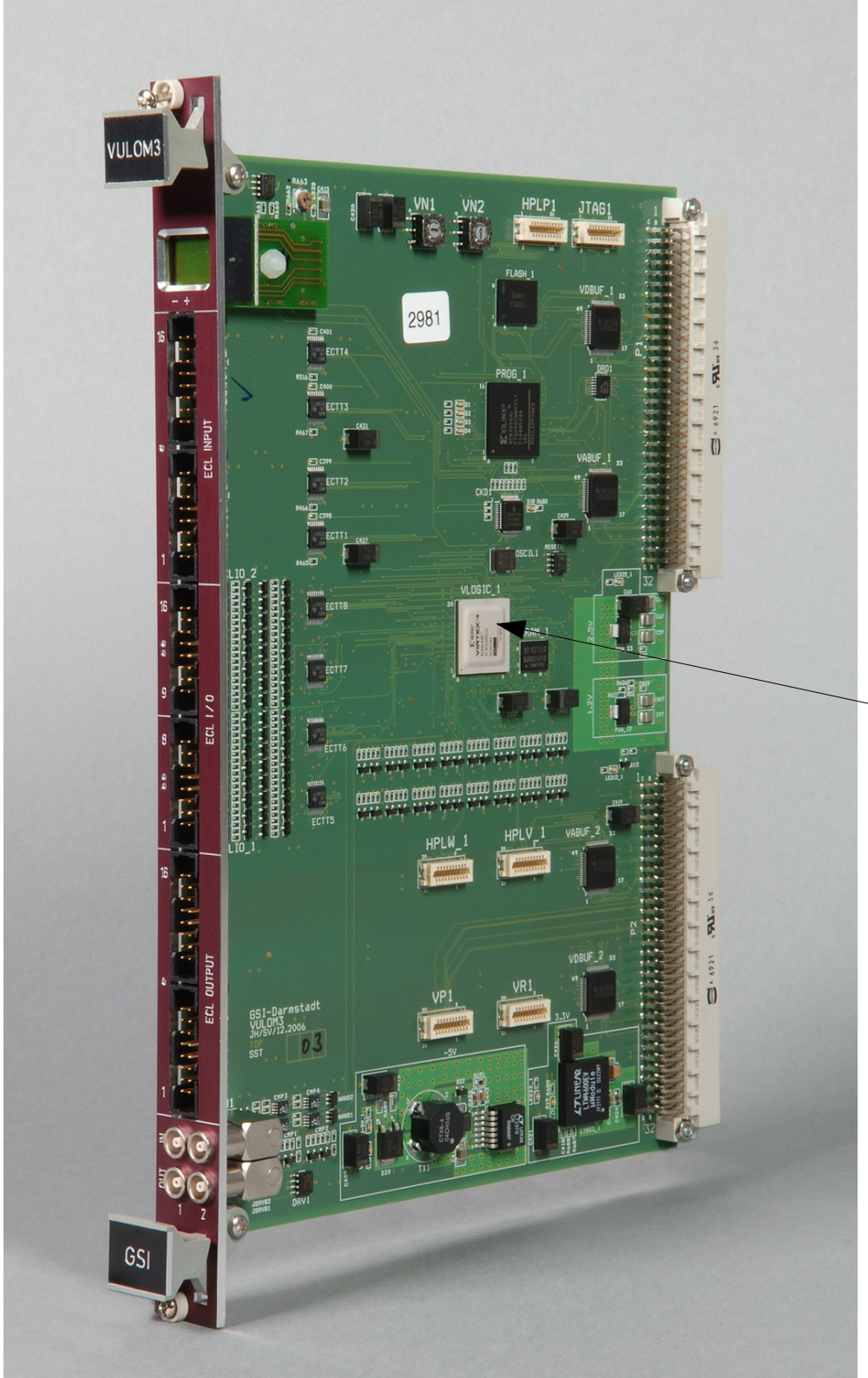
VULOM
(VME universal logic module)

by J. Hoffmann, GSI

Original TRLO firmware
by J. Frühauf, GSI

Inputs

Outputs

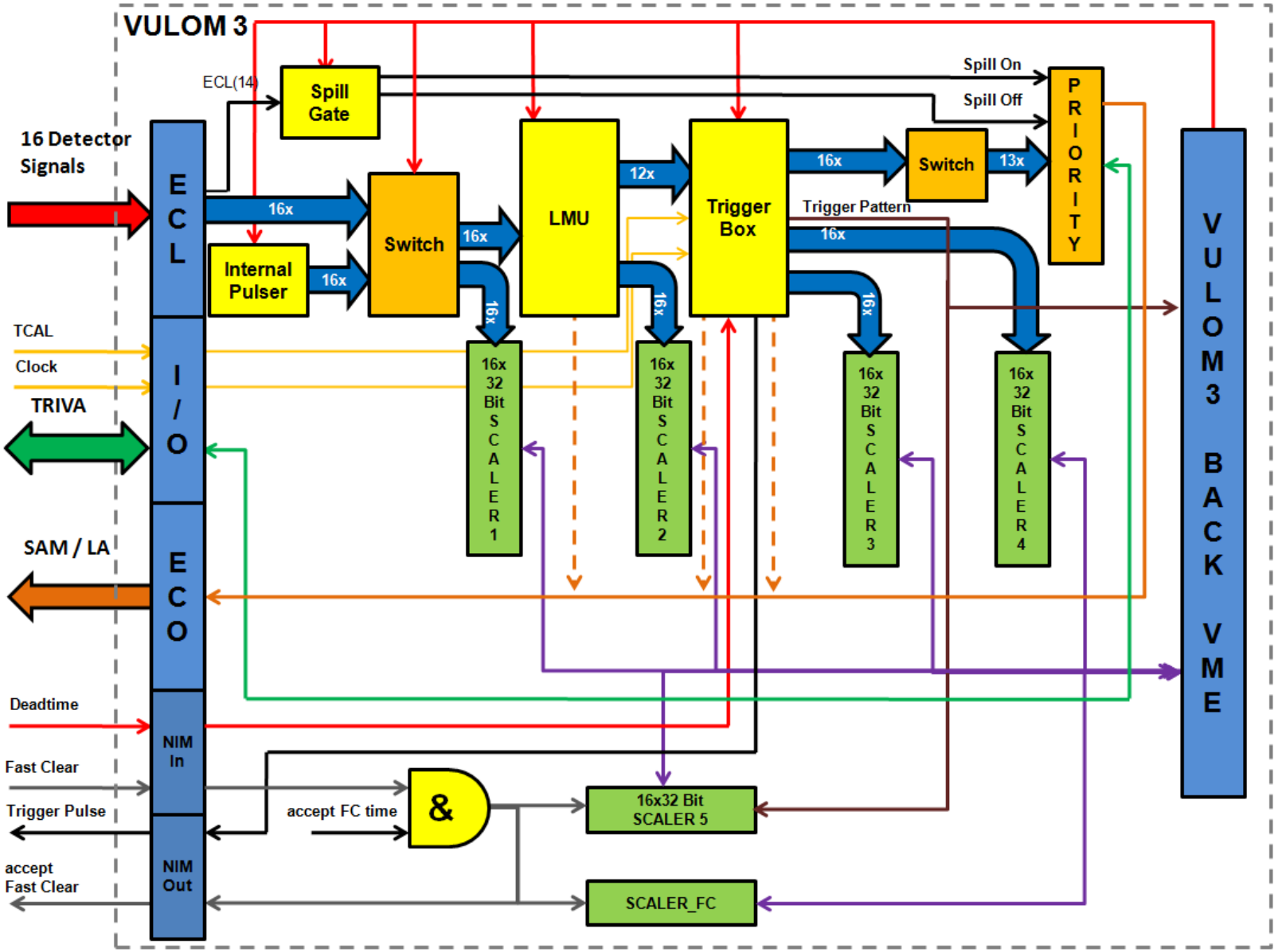


VME

FPGA

Original TRLO schematic

(J. Frühauf)



Fast-path: detector signals → master start

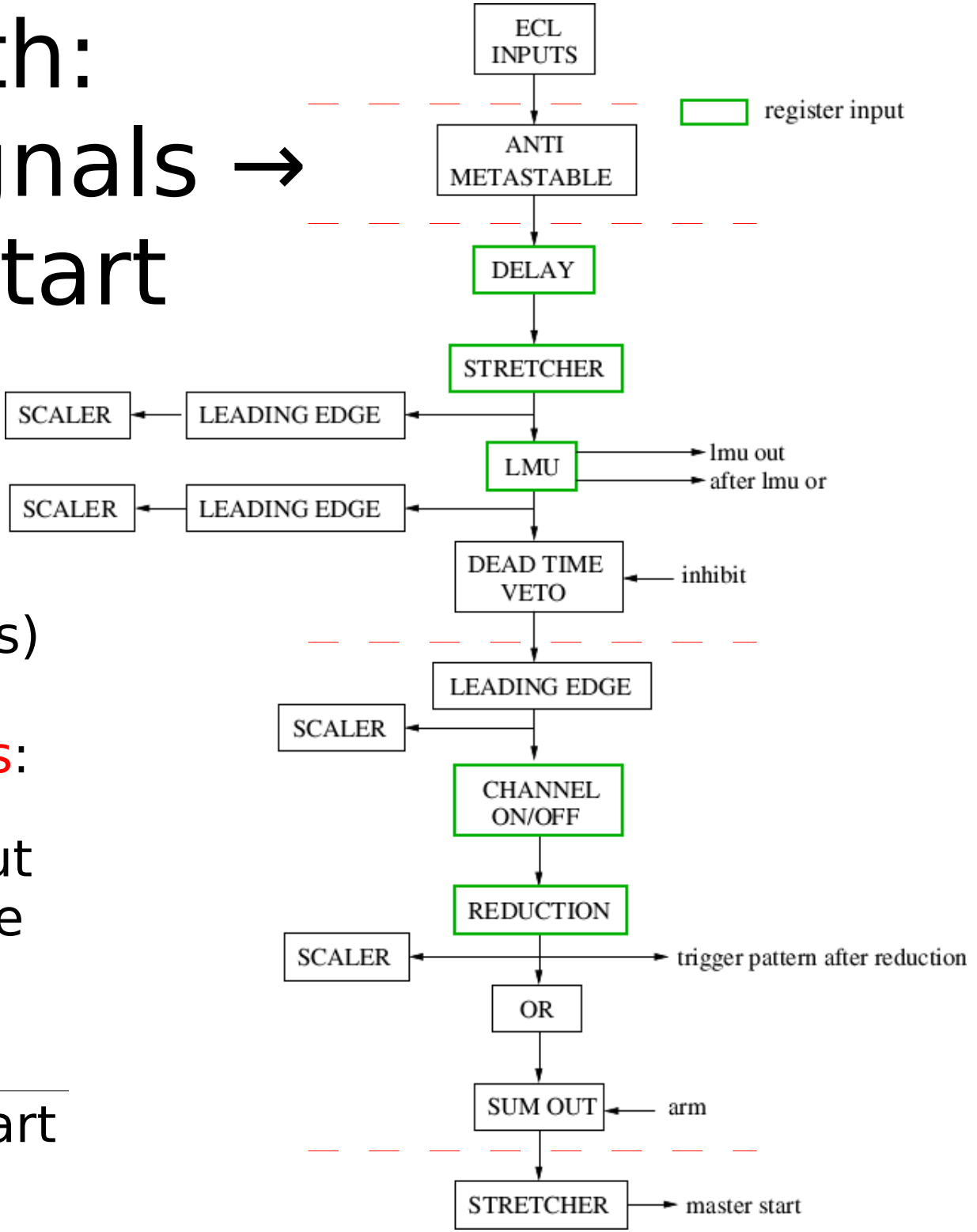
Timing-critical trigger decision

All logics: 100 MHz (10 ns)

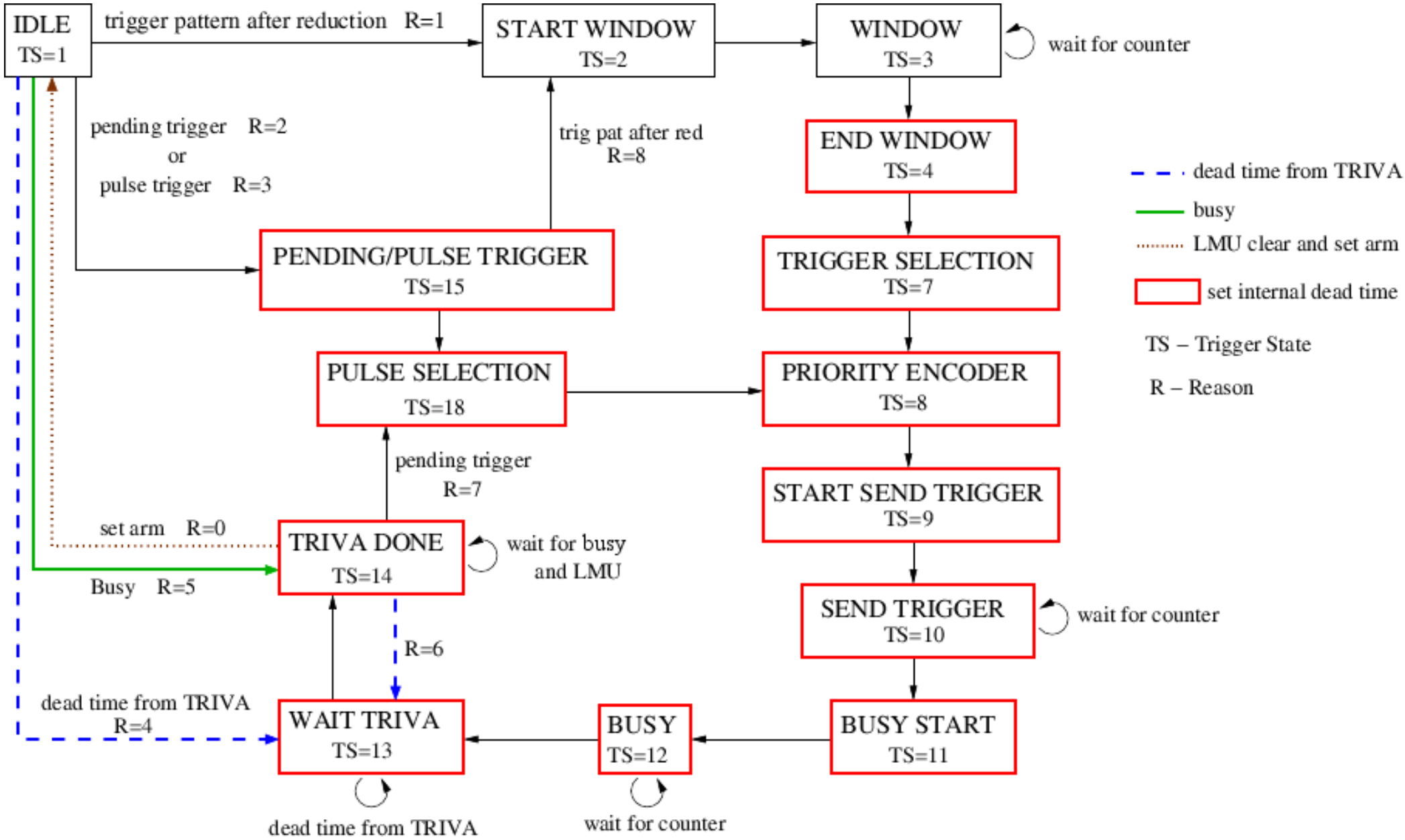
Decision in 2 clock cycles:

- 18 ns: module in + out
- 5 ns: anti-metastable
- 20 ns: decision
- 10 ns: clock jitter

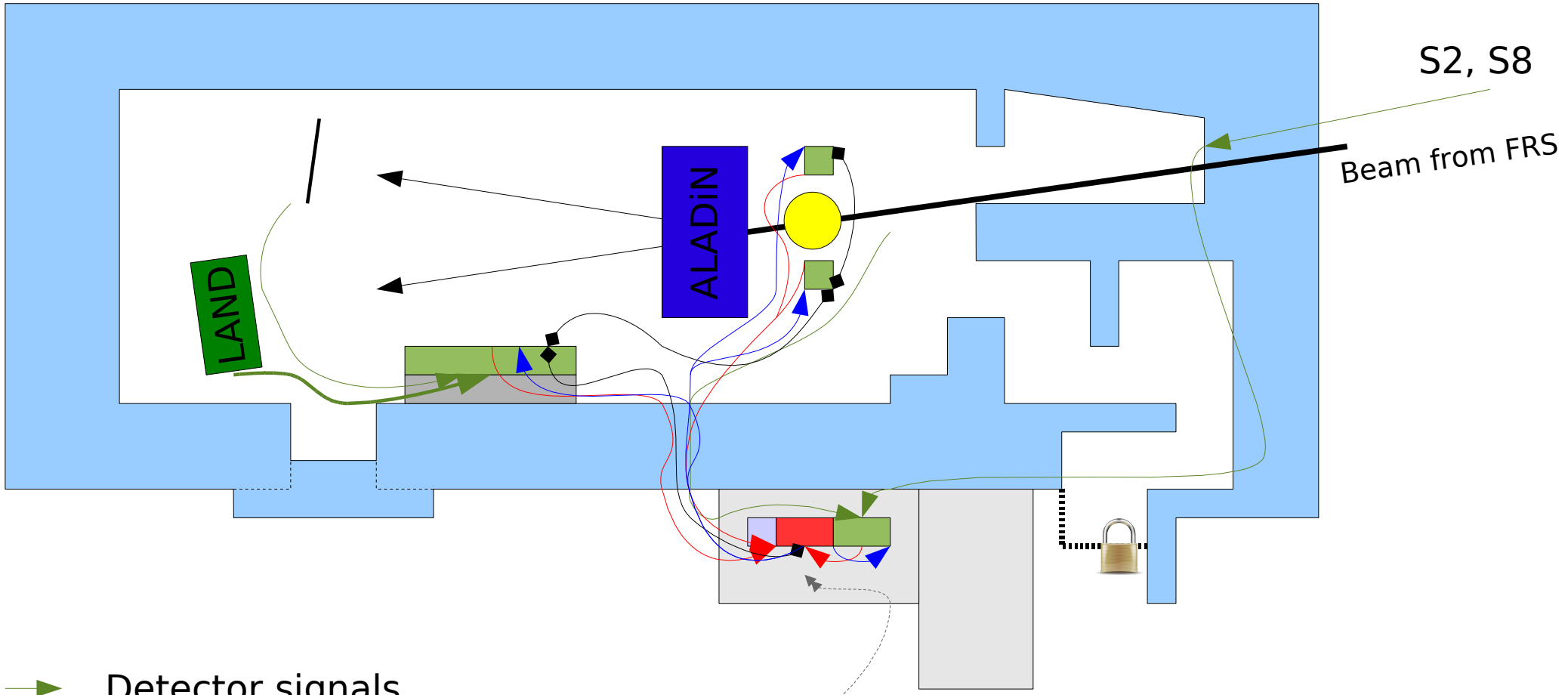
45-55 ns: in → master start



Trigger state machine



Cave C trigger (2010-)



Detector signals

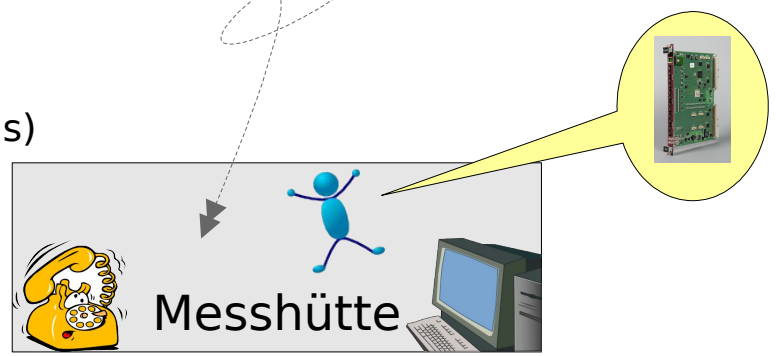
Split, QDC, TDC, CFD
Delays (500 ns)

Detector triggers (<100 ns)

Trigger decision (~50 ns)

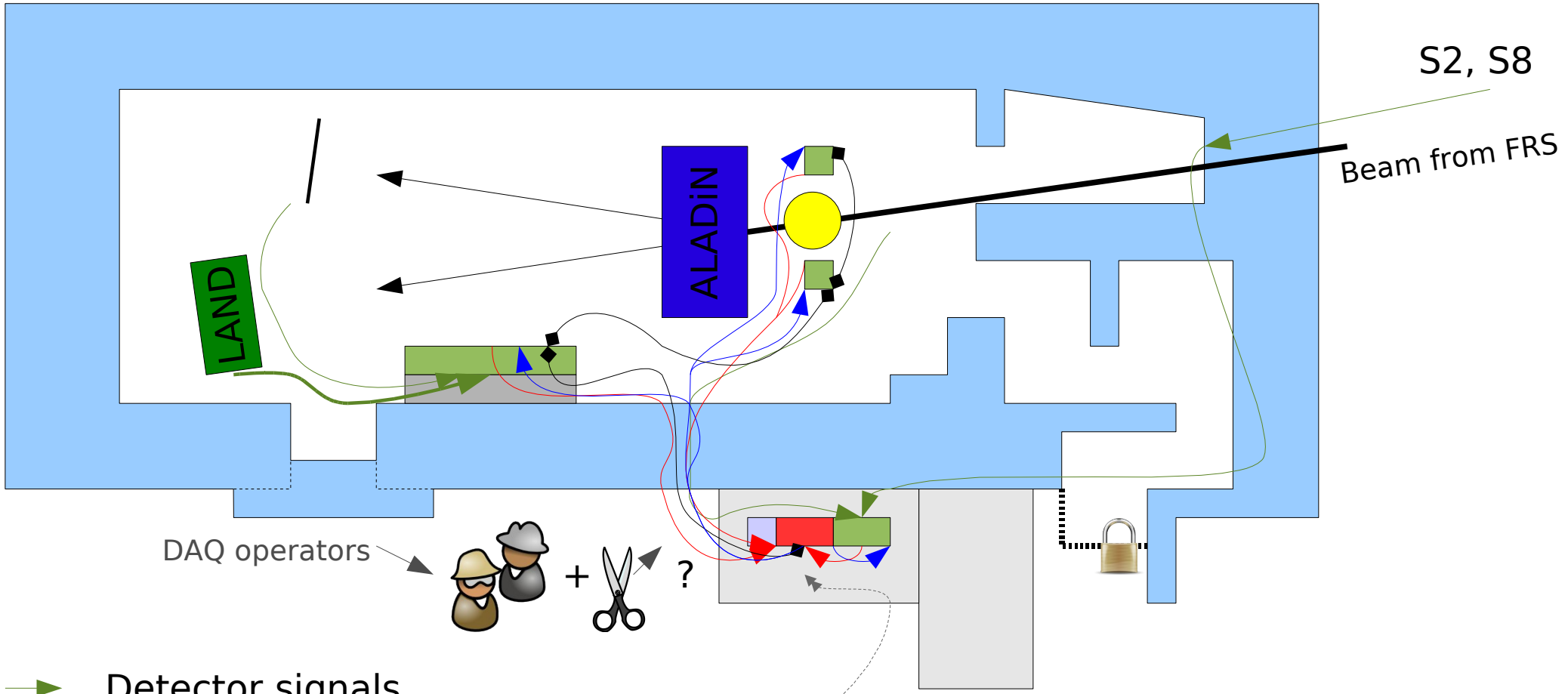
Master start (<100 ns)

Trigger bus



Access not required -
trigger completely
computer-controlled

Cave C trigger (2010-)



Detector signals

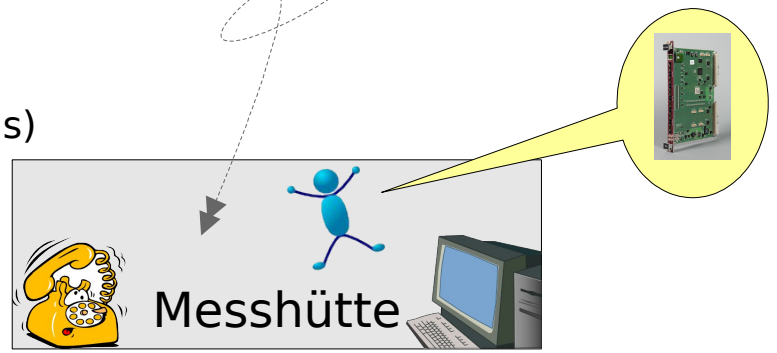
Split, QDC, TDC, CFD
Delays (500 ns)

Detector triggers (<100 ns)

Trigger decision (~50 ns)

Master start (<100 ns)

Trigger bus



Access not required -
trigger completely
computer-controlled

General logic

- Pulsers (programmable frequency).
- PRNG (pseudo-random sequence).
- LMU (not the same as in fast-path).
- Downscale.
- Delay and stretch (a.k.a. gate-and-delay).
- Edge-to-gate conversion (e.g. spill mimic).
- Fan-in (masked all-or).
- Coincidence.

Monitoring

- Scalers. Latched 32-bit with selectable input.

  Hybrid flip-flop / block RAM -> few resources. (25 ff/ch)

- Timer latches (latch global timer on a signal edge).

- Multi-entry buffer for the timer-latches.

  Block RAM fifo.

- Self-triggering soft-scope.

  Block RAM circular recording. Block RAM multi-trace fifo.

- Input pattern latch.

- Front-panel LEDs.

- Front-panel display.

Multiplex everything!

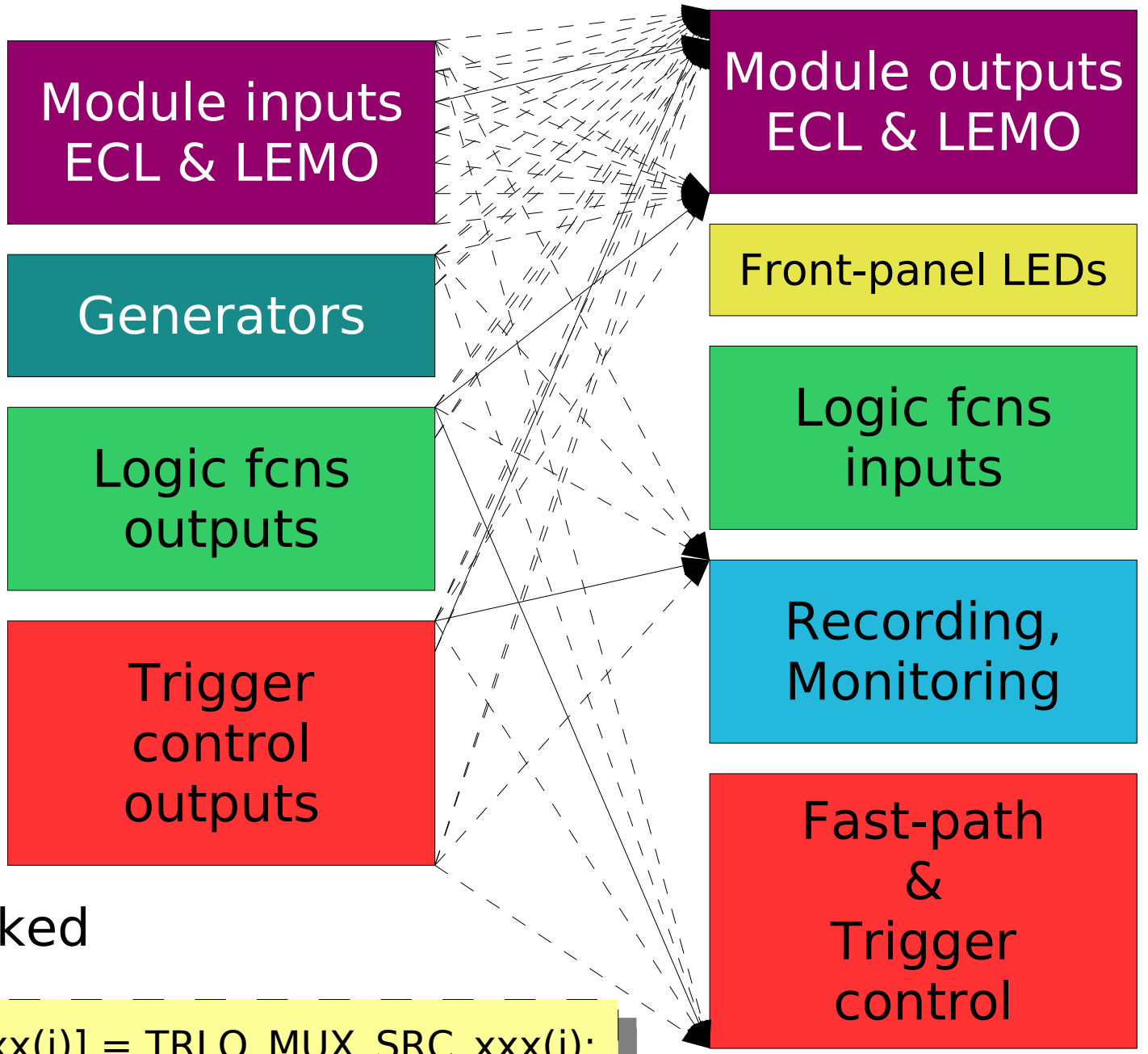
Any signal destination can use any source.

Routing cost:
2 cycles = 20 ns

Exceptions for timing-critical fast-path:

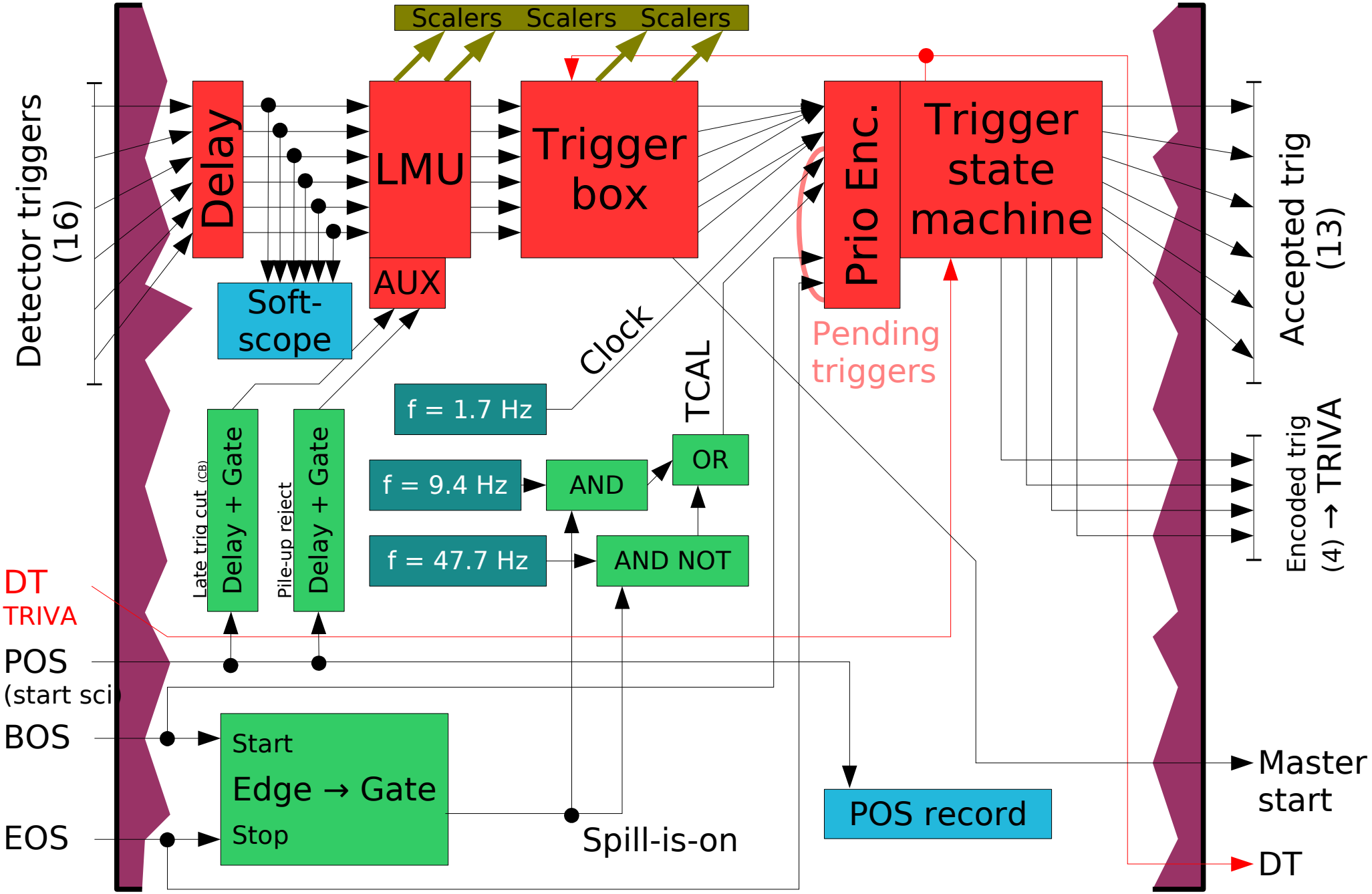
use fixed ECL in

master-start to any output, bitmasked

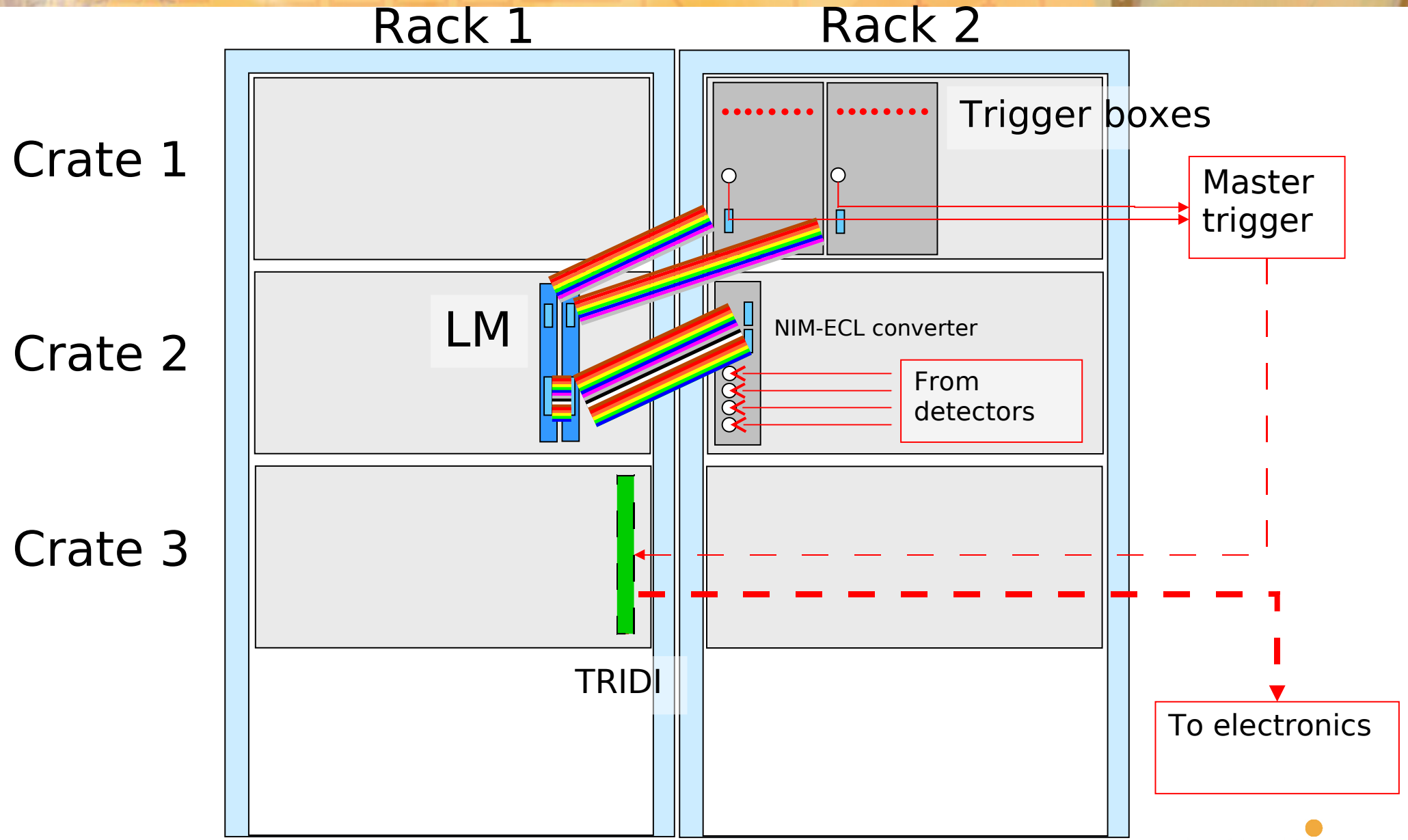



```
mux[TRLO_MUX_DEST_xxx(j)] = TRLO_MUX_SRC_xxx(i);
```

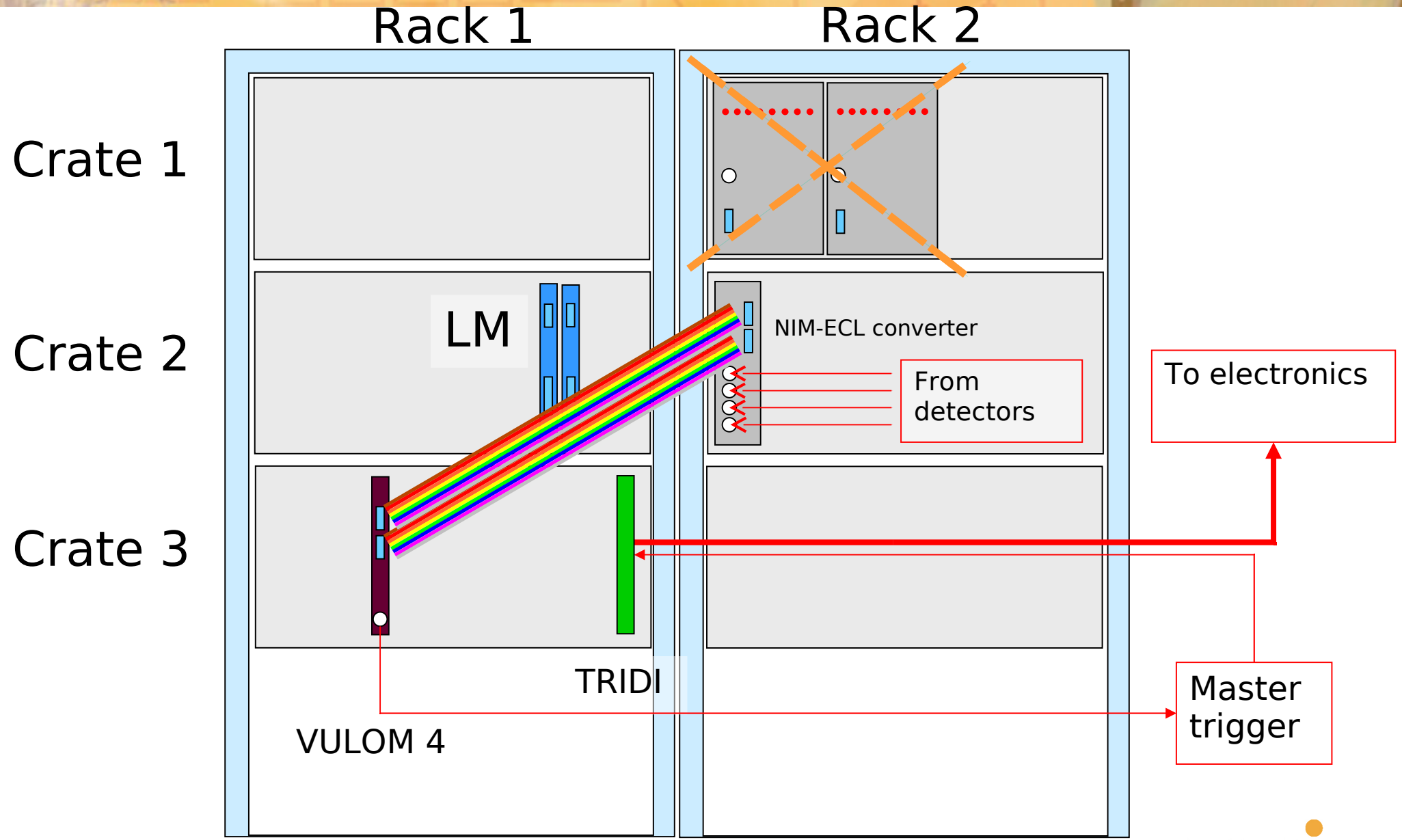
TRLO II @ Cave C / LAND-setup



Old trigger logic

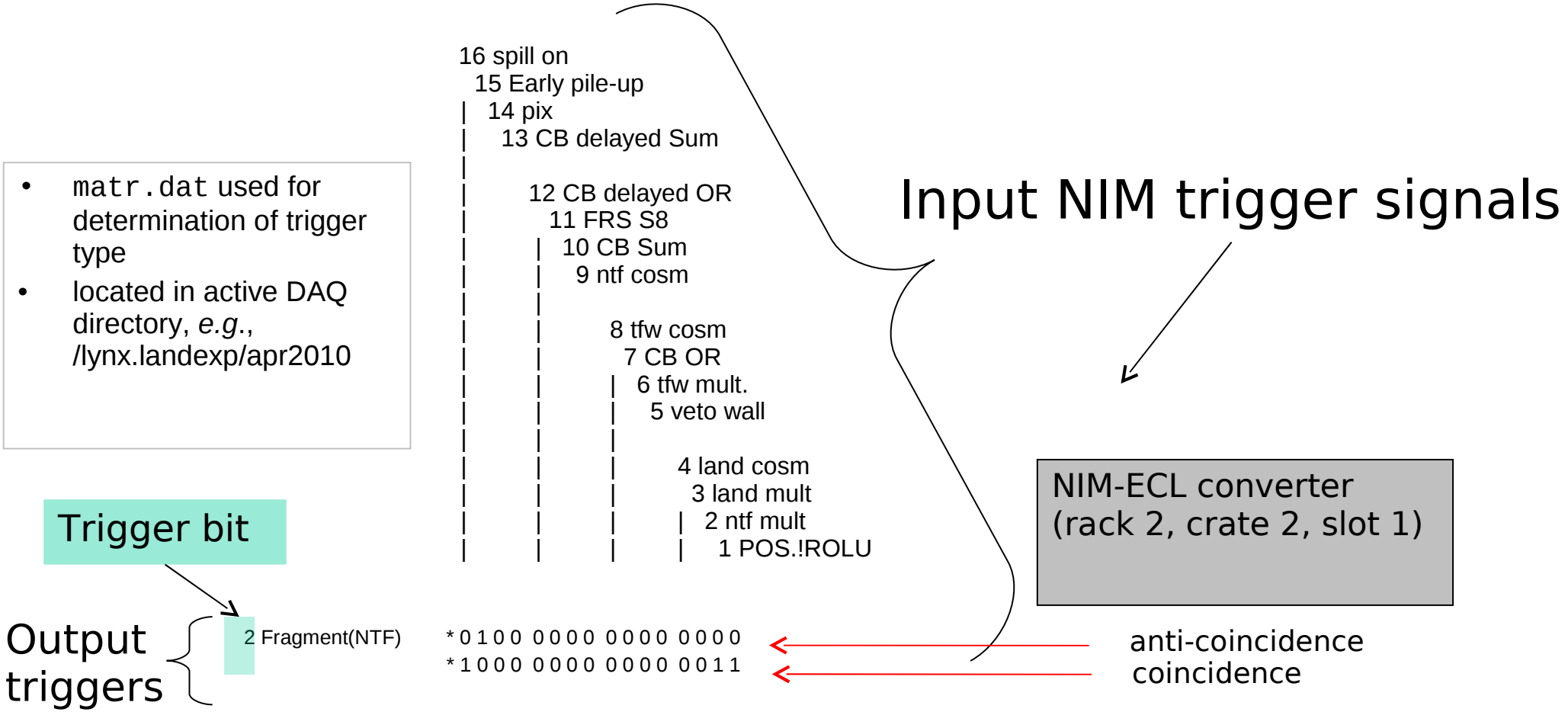


New trigger logic



matr.dat

- `matr.dat` used for determination of trigger type
- located in active DAQ directory, *e.g.*, /lynx.landexp/apr2010



Trigger logic control

- No more blinking lights on trigger boxes: how can I see which triggers are switched on and at which rate?

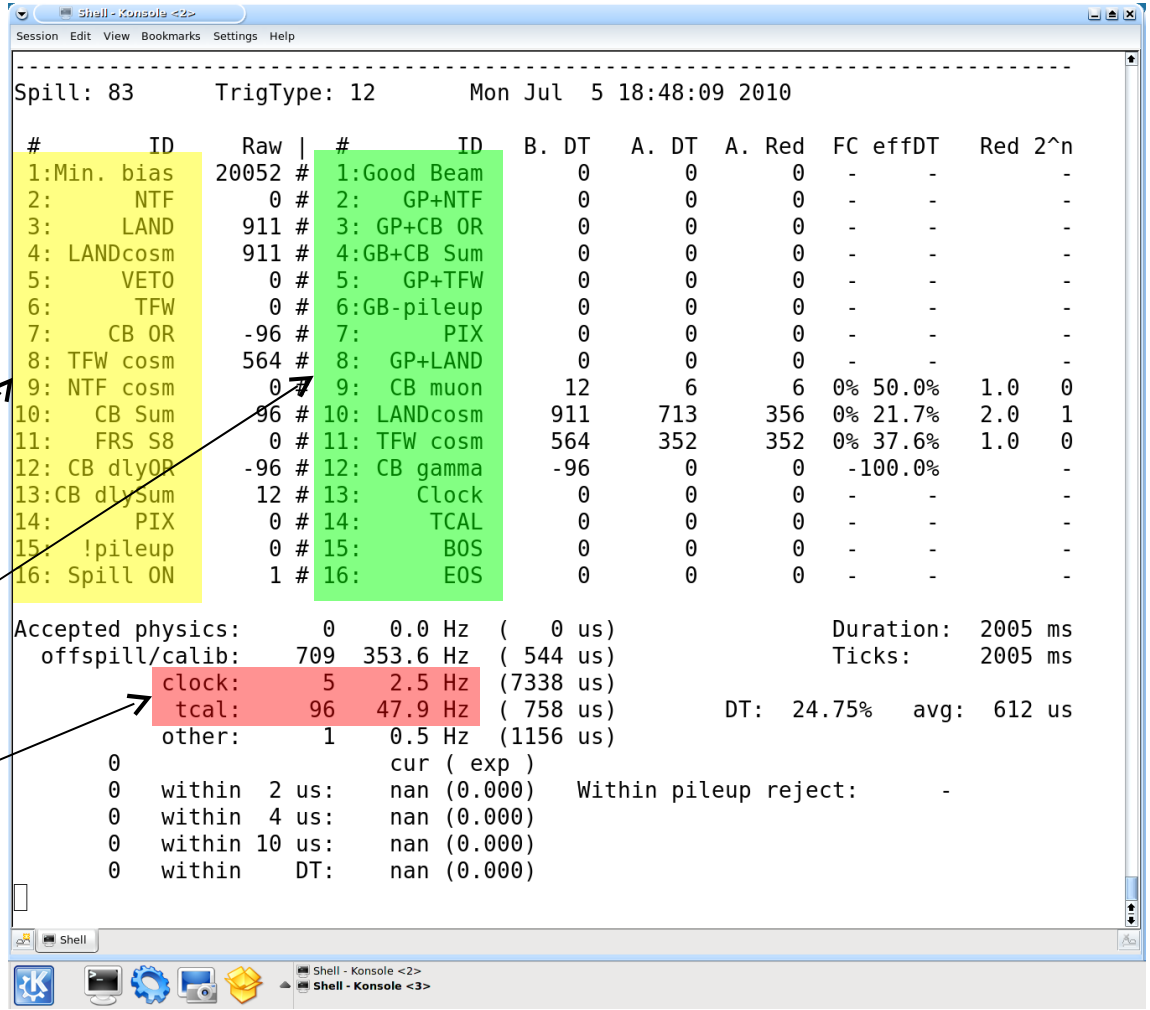
➢ Use the `udp_reader`:

  - ➢ `ssh land@lxgs08`
  - ➢ type `udp_reader --trig`

Input NIM trigger signals

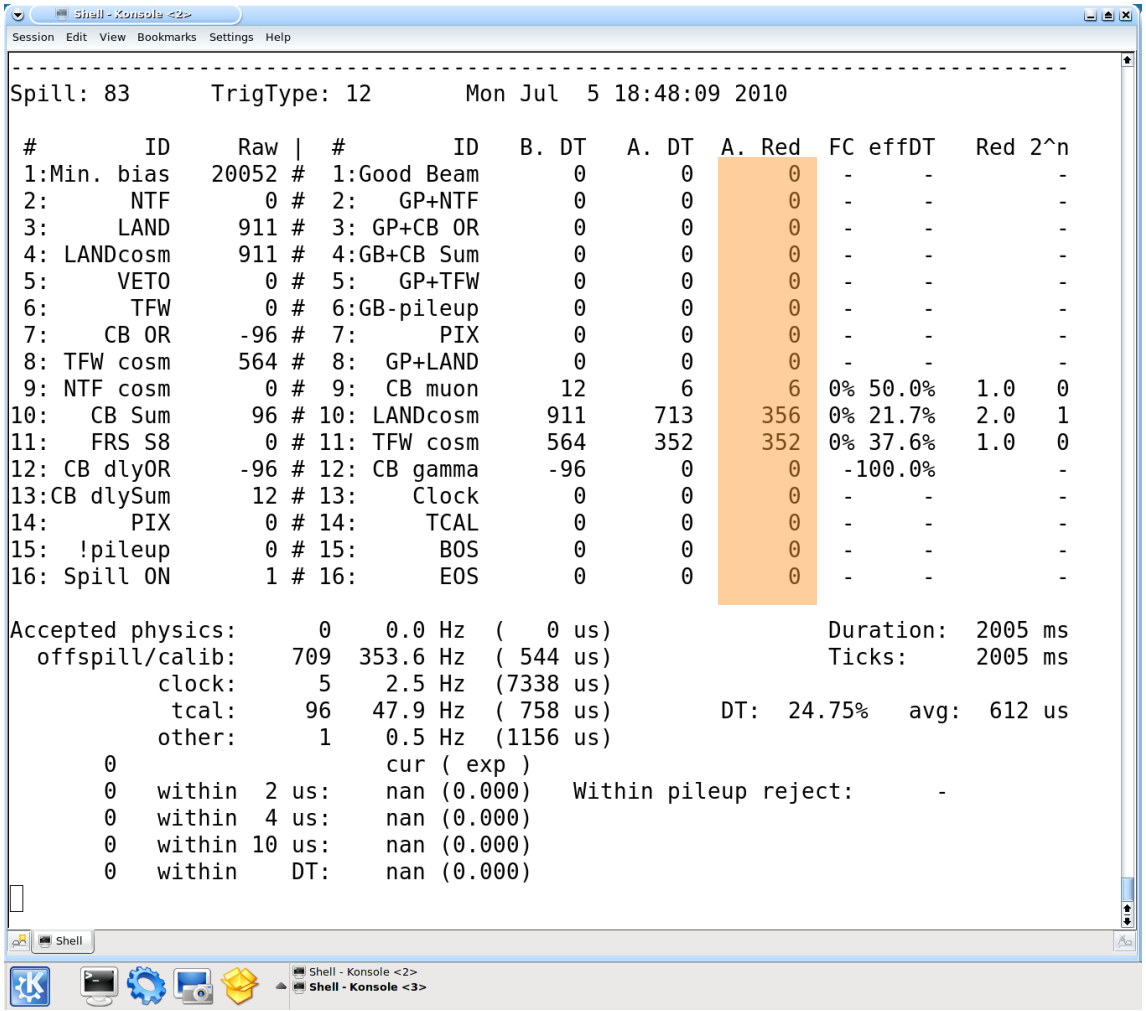
Trigger types

Clock + tcal triggers (internal triggers)



Trigger logic control

- The trigger I want to use is not switched on or does not come with the correct rate!
- ➢ Use the trigger logic control routine:
  - ➢ `ssh land@[some_machine]` (the following `rsh` is easier if you are already land)
  - ➢ `rsh r3-15` (main DAQ processor; change if necessary)
  - ➢ your present location: `/land/usr/land`
  - ➢ `cd landexp/apr2010/west` (`apr2010` is the current DAQ; change if necessary)
  - ➢ `./trloctrl --[option]`



trloctrl

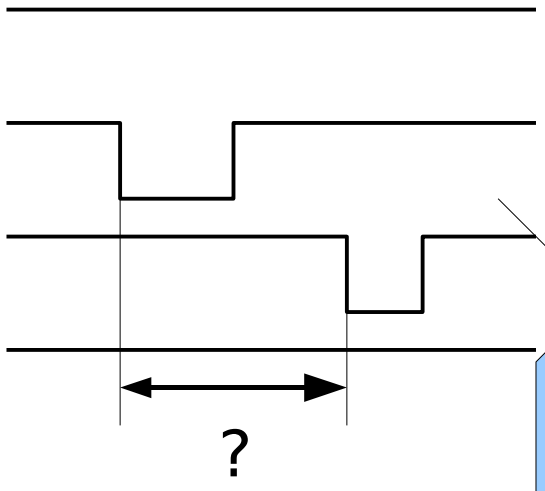
```
R3-15:/land/usr/land/landexp/apr2010/west 3$ ./trloctrl --help
TRLO II control program (for the LAND DAQ).

Usage: ./trloctrl <options>

  --reduction=TPAT=RED     REDuction factor for TPAT (LMU out).
  --tpat-enable=0xBITMASK  Mask of TPATs to enable.
  --tpat-enable=A,B,C      List of TPATs to enable.
  --tcal=on|off            Switch TCAL trigger on/off.
  --clock=on|off           Switch CLOCK trigger on/off.
  --spill-mimic=on|off     Enable/disable the spill mimic.
                           Also issues an EOS signal on 'off'.
  --spill-on               Issues a BOS input signal.
  --spill-off              Issues an EOS input signal.
  --silent-input           Clear TRLO input settings.
```

- `--reduction=TPAT=RED`:
  - down-scales trigger `TPAT` by 2^{RED}
  - *e.g.*: `./trloctrl --reduction=10=2` down-scales the LAND cosmic trigger by a factor 4 (*c.f.* previous slide)
  - tcal and clock triggers can also be reduced
- `--tpat-enable=0xBITMASK`:
  - must first calculate `BITMASK` to be activated
  - in order to deactivate all triggers, use: `--tpat-enable=0x0`
- `--tpat-enable=A,B,C`:
  - enables only specified TPATs and switches all others off
  - in order to deactivate all triggers, use: `--tpat-enable=`
- `--spill-mimic=on|off`:
  - switch off spill-mimic for most calibration runs
  - make sure it is switched on for beam!

Trigger alignment - measurement



The triggers need to be aligned to make good coincidences

FPGA: self-triggered multi-event softscope

VME readout

```
...
Ch 22:  138-255e
Ch 23:  98-110
End
Start
Ch  9:  125-142
Ch 10:  126-143
Ch 11:  114-131
Ch 12:  127-144
Ch 21:  0-255e
End
Start
Ch  9:  125-142
Ch 10:  126-143
...
```

Analysis (histogramming)

```
     Timing relative to *
-----------------------------------------------
 1 :                     *                     :
 2 |9A                                         |-193/ 5
 3 |                 _554-._                   | -41/10
 4 |                     .43._                 |  -7/ 8
 5 |                    _A9_                   | -16/ 5
 6 |                      8A-                  |  -2/ 4
 7 |                     -43._                 |  -7/ 8
 8 |                     -43._                 |  -8/ 8
 9 |                    .---.......-7886-._  .--| 104/11
10 |                    .------..__..57886-__  .-| 112/11
11 |       34543-.-3555555555555444433--.___   |  51/40
12 |                    _34543-.345555555555555|  98/18
13 |_ _ ___ _ _ .3995                          | -55/ 5
14 |                                           |1200/nan
15 |                     697._                 |  -9/ 6
16 |                    .34443---_.---333333-3-|   5/19
17 |                                           |
18 |                                           |
19 |                                           |
20 |                                           |
21 |                                           |
22 |                                           | 220/ 0
23 |  A8                                       |-180/nan
24 |                                           |
-----------------------------------------------
```

2-log counts/bin (_ . - = 0,1,2)

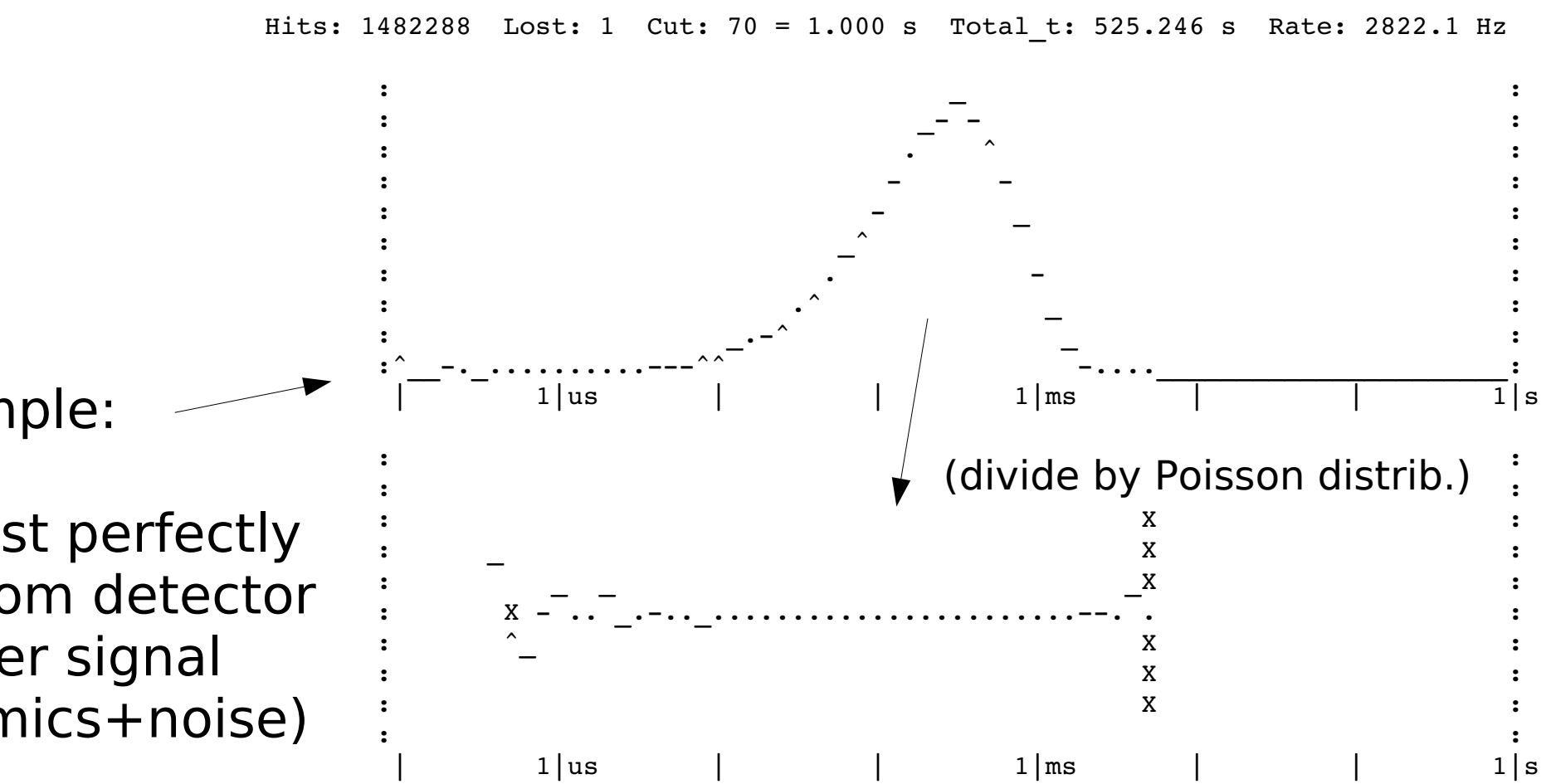
Pile-up measurements

Record inter-arrival times of signals

Every ion entering the cave → off-line pile-up rejection

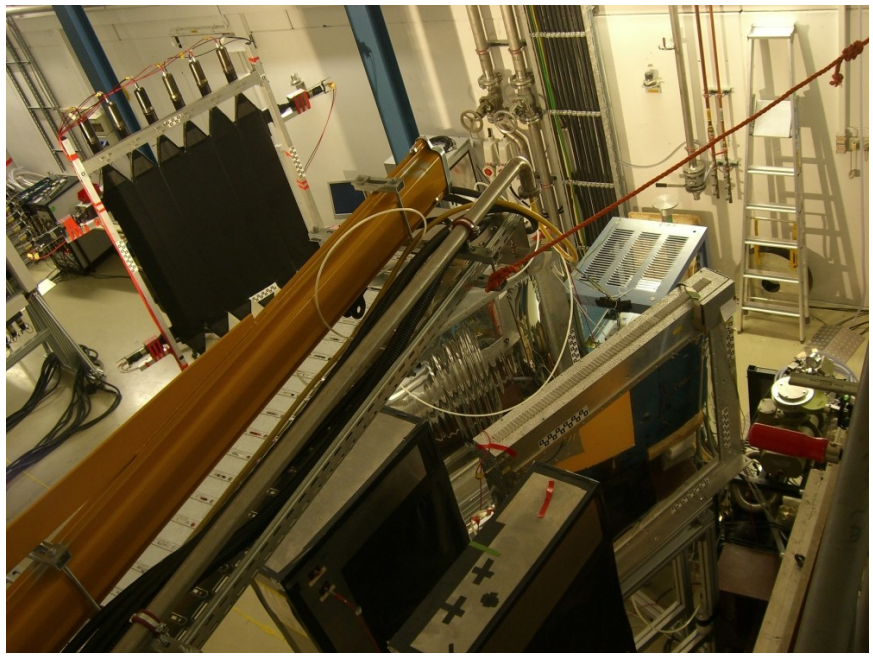
Example:

almost perfectly random detector trigger signal (cosmics+noise)



In operation:

S393 S306b S389

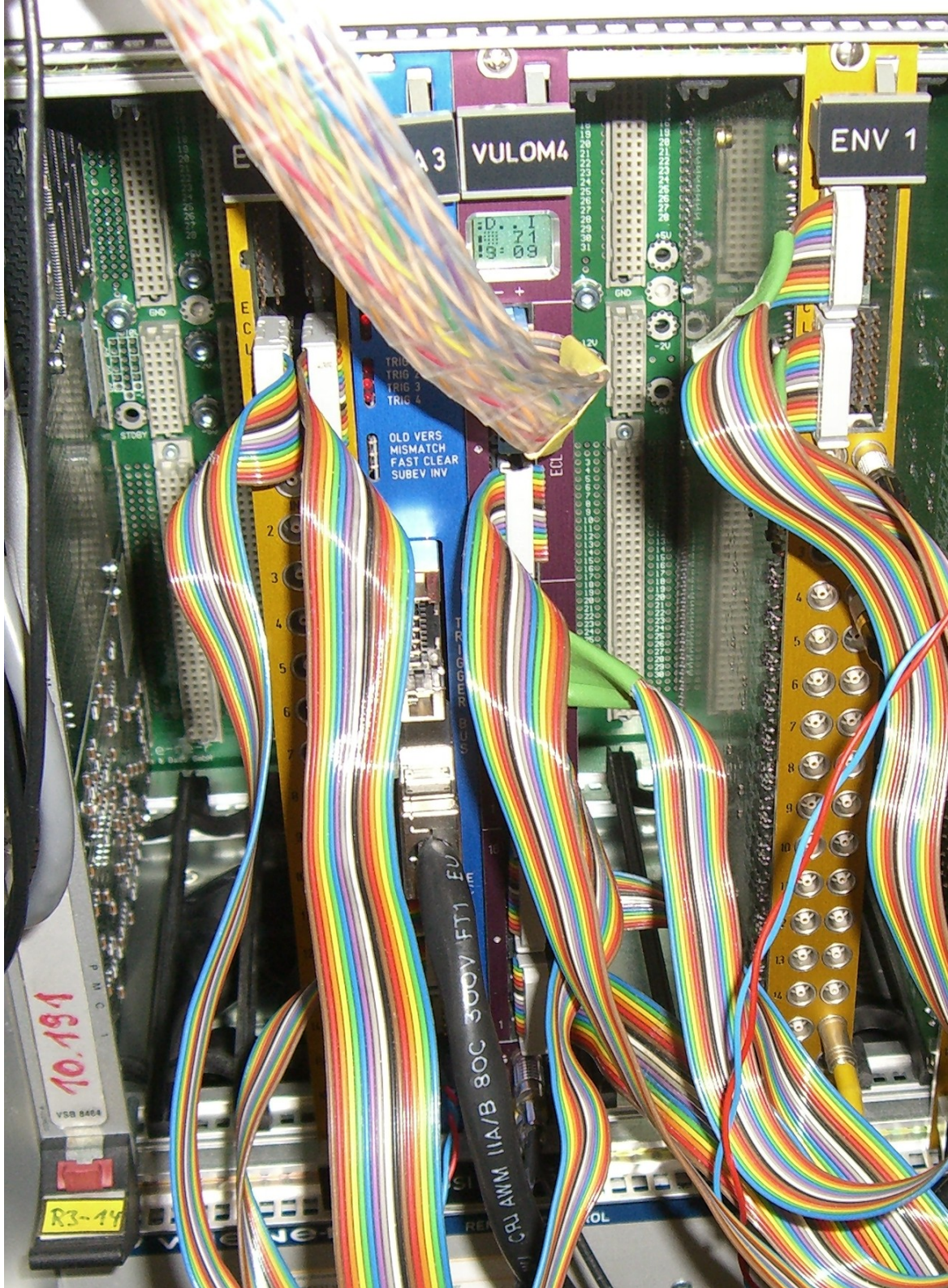


(Aug - Oct 2010)

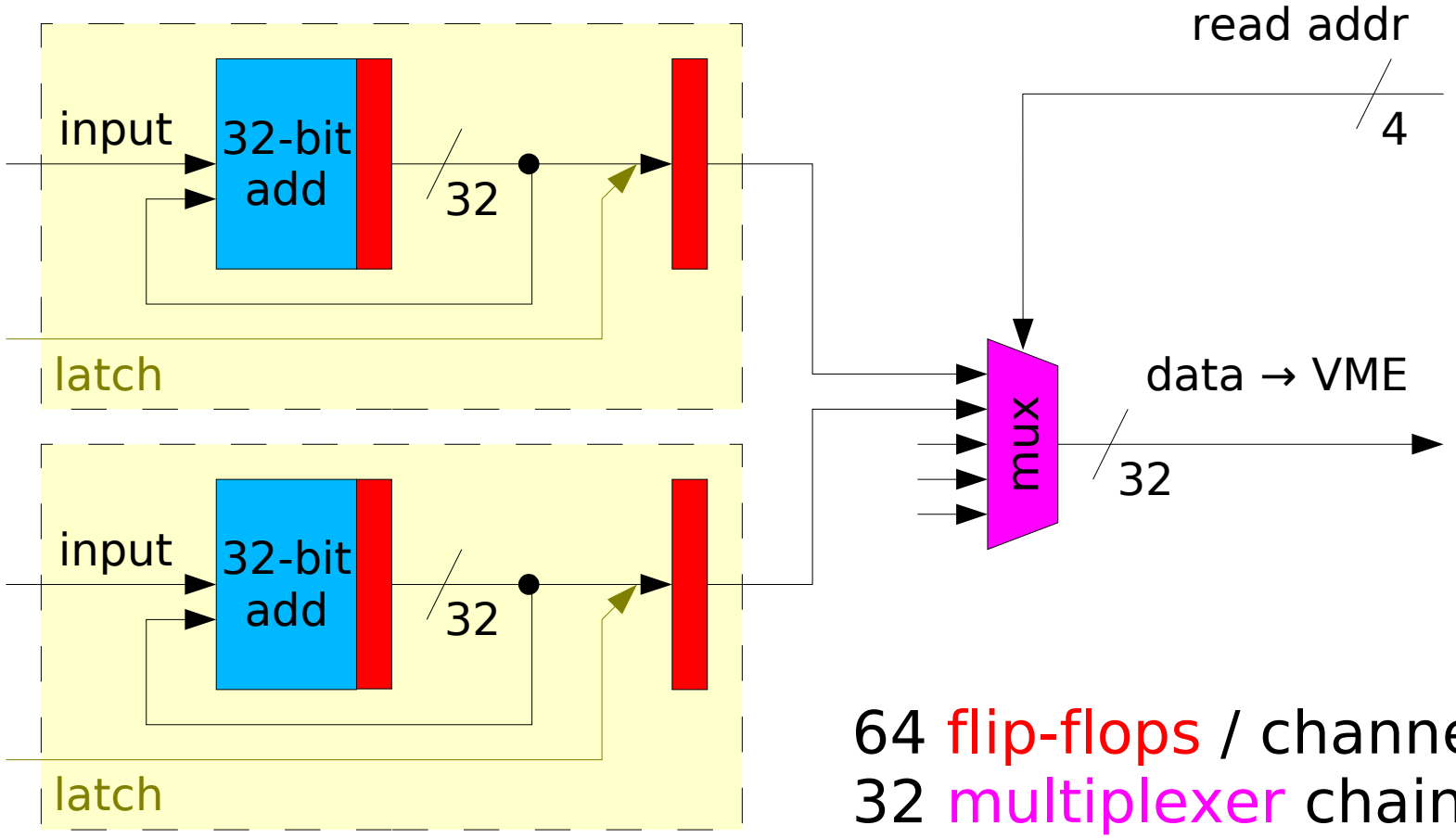
Preceded by intense *code* inspection (~300 kB) →

0 critical bugs found

2 minor bugs found in the wild



Plain 32-bit scaler



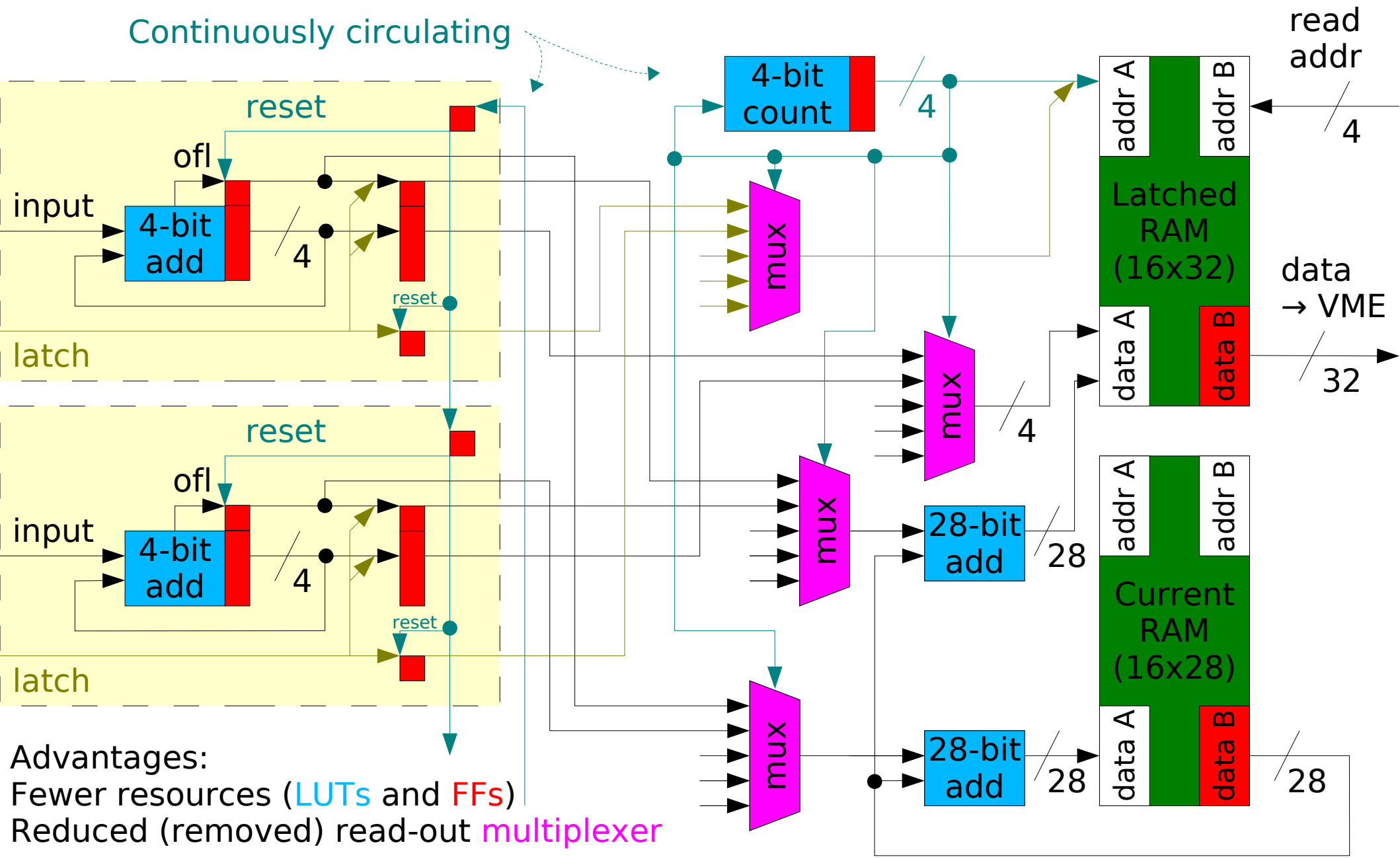
64 flip-flops / channel
32 multiplexer chains

*

4*16 = 64 trigger scalers
+ 8 general
+ 112, for each mux'ed signal
(DAQ debug)

> 50 % of VULOM4 FPGA resources

Hybrid flip-flop / block RAM scaler



Stable VME interface definition

VME registers as C structure, with named entries, generated by compilation

Version number is MD5 of full VHDL code

Named constants

Setup registers in block RAM for readback.

Aggressive checksumming of output data.

```
#define TRLO_MD5SUM_STAMP           0xccb60dee

// Constants for 'direct_mode':

#define TRLO_DIRECT_MODE_LOGIC              0x0
#define TRLO_DIRECT_MODE_DIRECT             0x1
#define TRLO_DIRECT_MODE_LOGIC_OR_DIRECT    0x2

typedef struct trlo_output_map_t
{
  /*     0 0x0000 */ uint32_t version_md5sum;
  /*     1 0x0004 */ uint32_t compile_time;
  /*     2 0x0008 */ uint32_t timing_tick;
  /*     3 0x000c */ uint32_t deadtime_tick;

typedef struct trlo_setup_map_t
{
  /*     0 0x2000 */ uint32_t mux[122];
  /*   122 0x21e8 */ uint32_t direct_mux[26];
  /*   148 0x2250 */ uint32_t direct_mode[26];
  /*   174 0x22b8 */ uint32_t direct_or[3];
  /*   177 0x22c4 */ uint32_t scaler_mode[8];

// MUX src indices:

#define TRLO_MUX_SRC_ECL_IN(i)         ( 0+(i))
#define TRLO_MUX_SRC_ECL_IO_IN(i)      (16+(i))
#define TRLO_MUX_SRC_LEMO_IN(i)        (24+(i))
#define TRLO_MUX_SRC_WIRED_ZERO        (32)
```

Work-in-progress

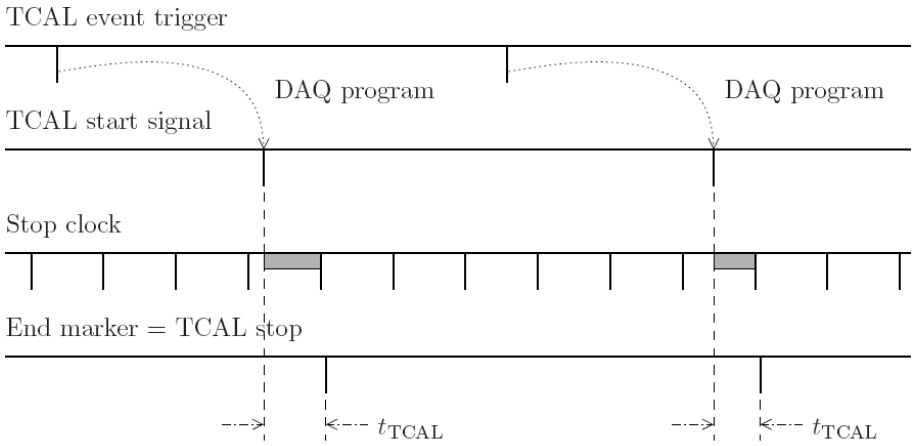
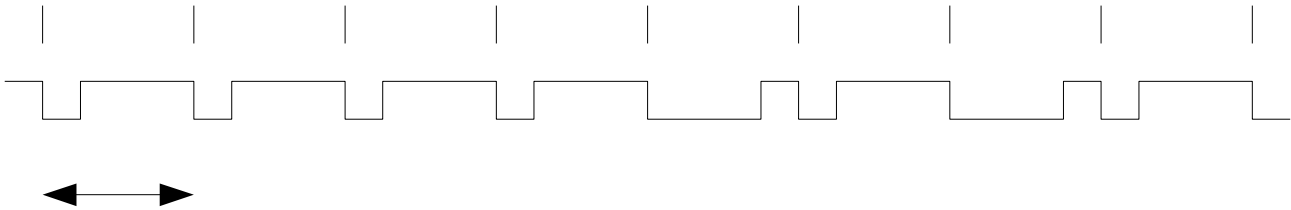


Figure 9.2: At the arrival of a TCAL start pulse, the next clock pulse is used as TCAL stop.

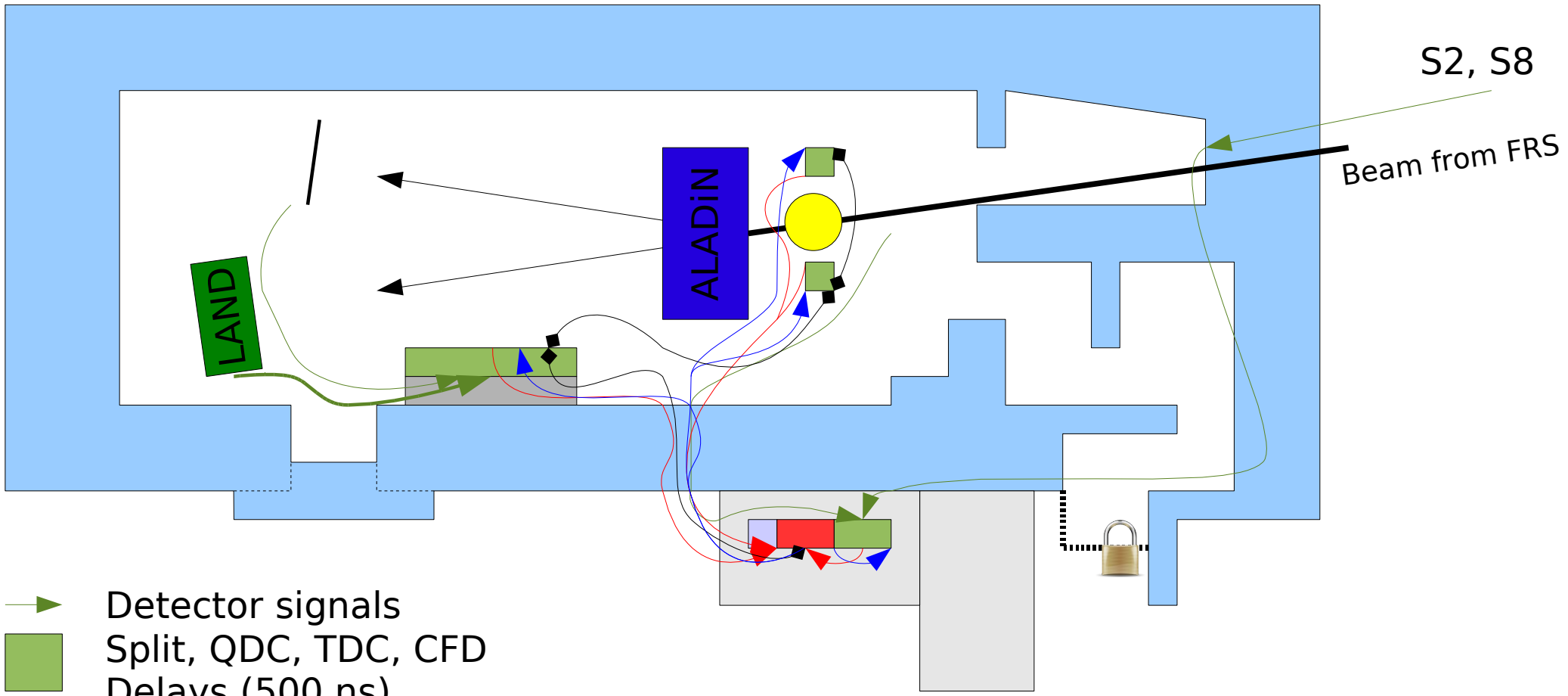
- Random TCAL
  (generate and measure semi-random pulses).
- 64-bit timestamps
  (10 ns resolution, 32 bits wrap after 42.9 s). ✓
- Serial timestamps send + receive
  (for event synchronisation between systems over one signal line, 'survive' disconnections). ✓



320 ns / 32 cycles

1 message cycle: 82 µs

Reminder: Cave C trigger (2010-)



Detector signals

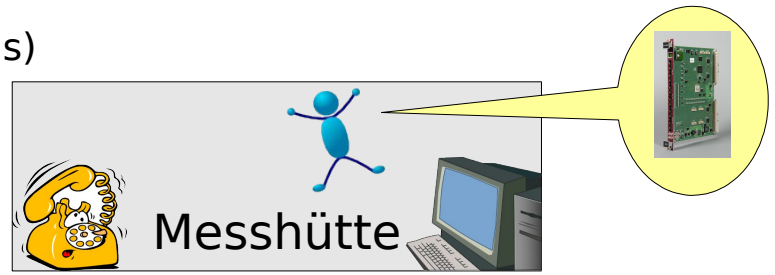
Split, QDC, TDC, CFD
Delays (500 ns)

Detector triggers (<100 ns)

Trigger decision (~50 ns)

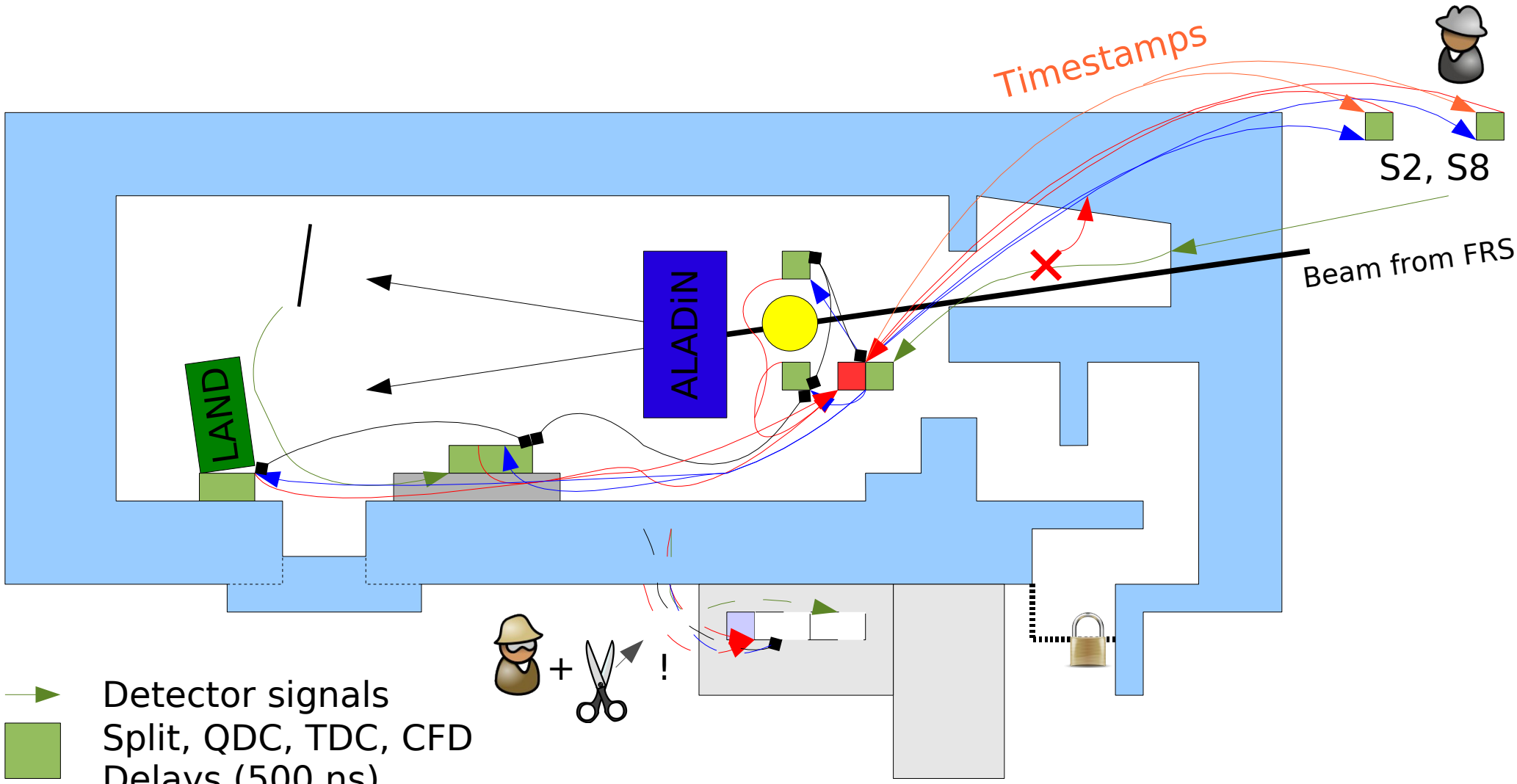
Master start (<100 ns)

Trigger bus



Access not required - trigger completely computer-controlled

Cave C trigger (201x-) ?



Detector signals

Split, QDC, TDC, CFD
Delays (500 ns)

Detector triggers (<100 ns)

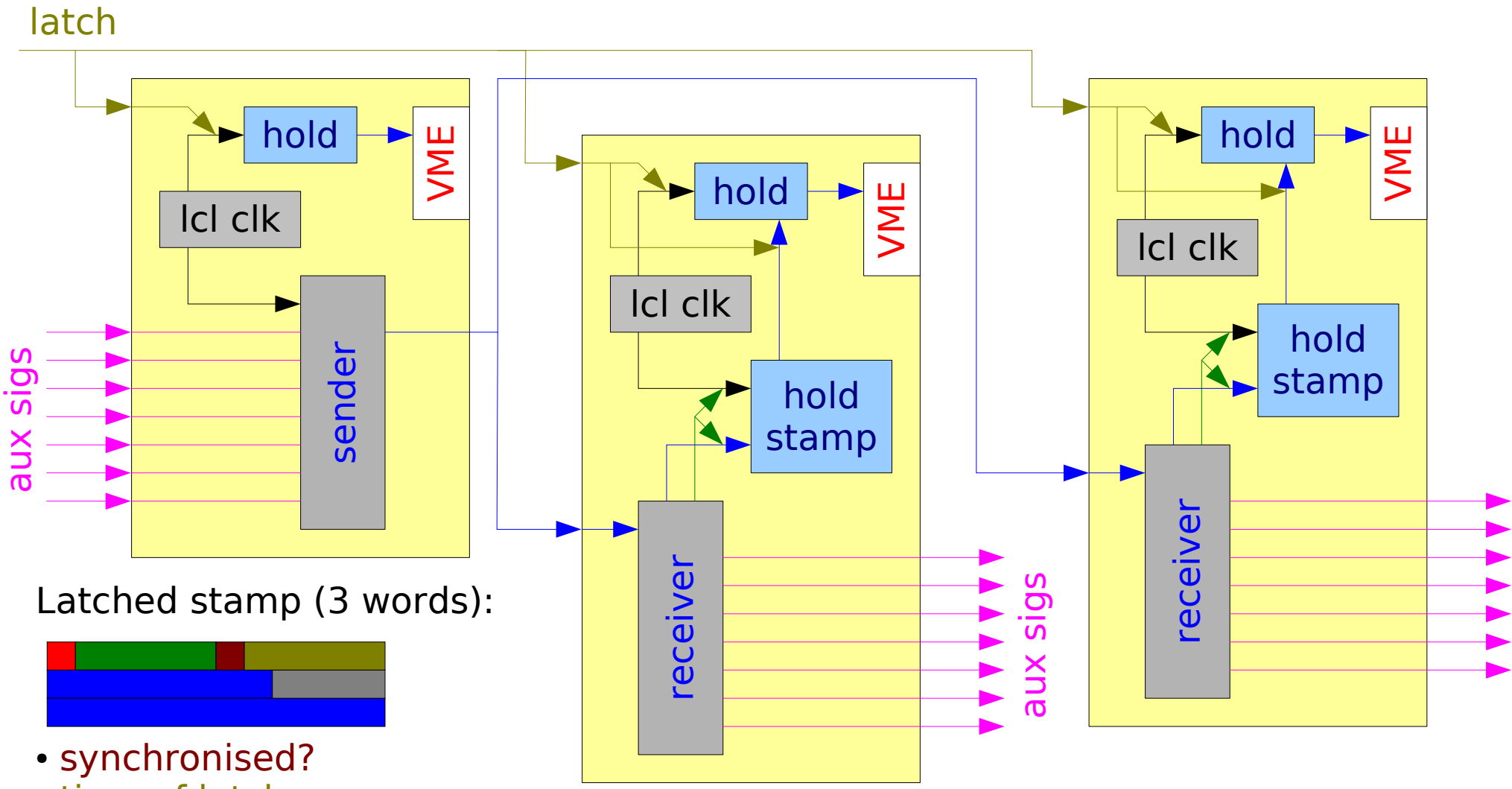
Trigger decision (~50 ns)

Master start (<100 ns)

Trigger bus

Trigger fully
computer-controlled
→ move into Cave

Serial timestamps with mux



Latched stamp (3 words):

- synchronised?
- time of latch
- time of last reception
- last received time
- current drift-correction

$t = t_{stamp} + (t_{latch} - t_{reception}) + t_{driftcorr}$

Difference between local and remote clock frequency.

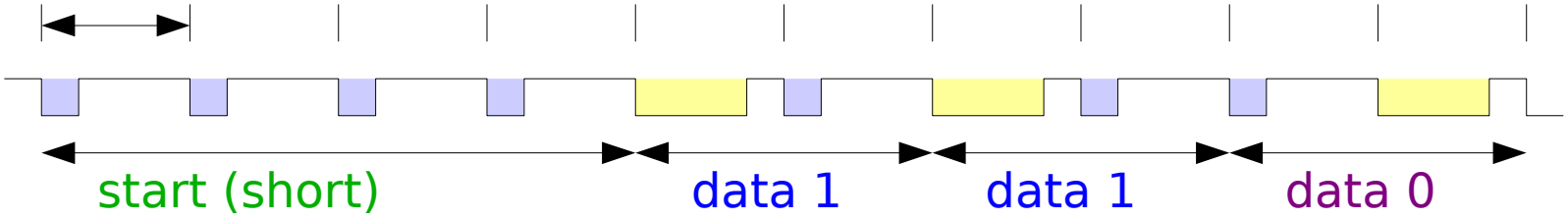
Serial timestamp protocol

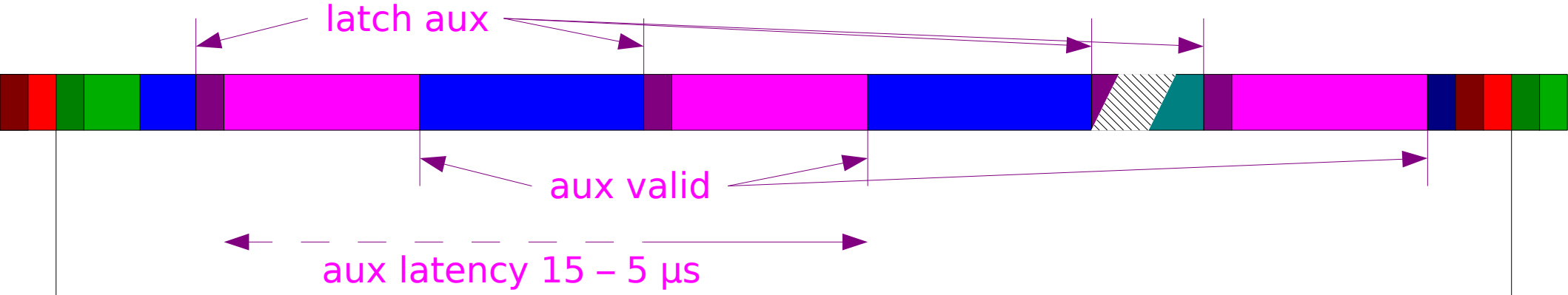
Pulses short (¼) or long (¾)

Each payload bit sent as two pulses, second inverted

Pattern of 4 short pulses for start-synchronisation

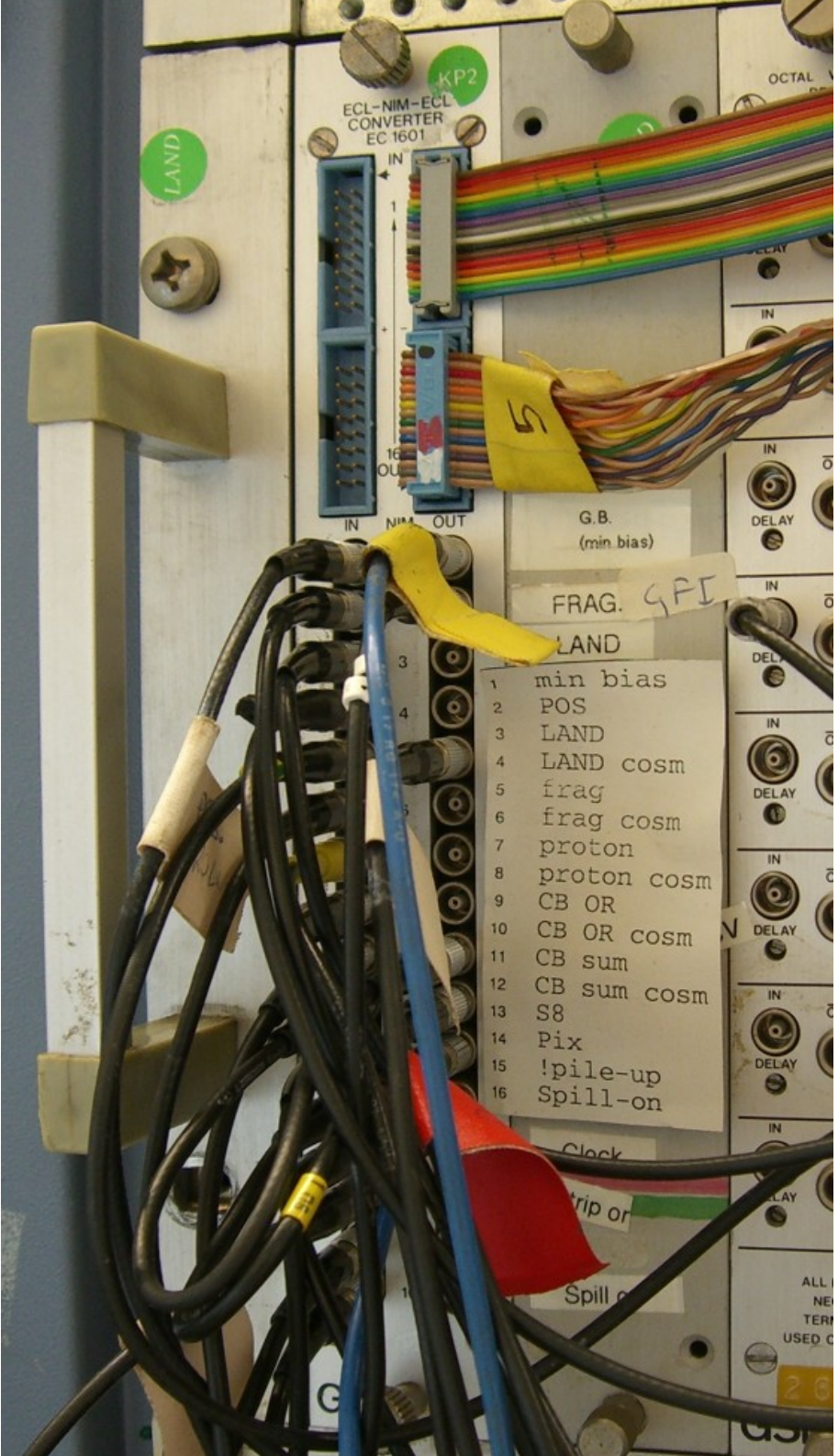
320 ns = 32 clock cycles





(2x128 pulses: start, 51 time bits, 7 aux bits, 8*(7+1) aux sigs, parity, end)

1 message: 82 µs



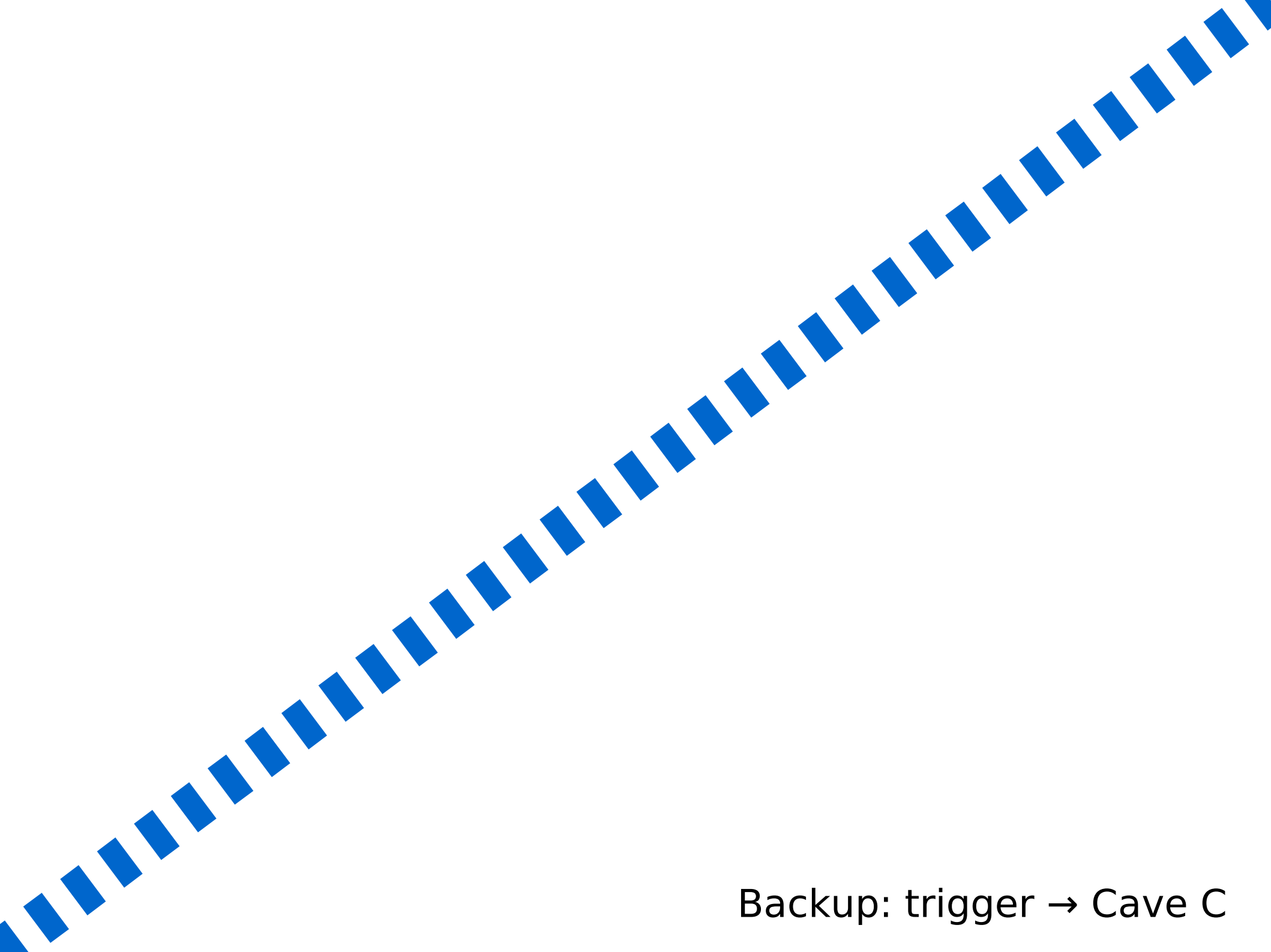
Finale!

Thank you!

FPGAs are FUN!

http://fy.chalmers.se/~f96hajo/trloii/

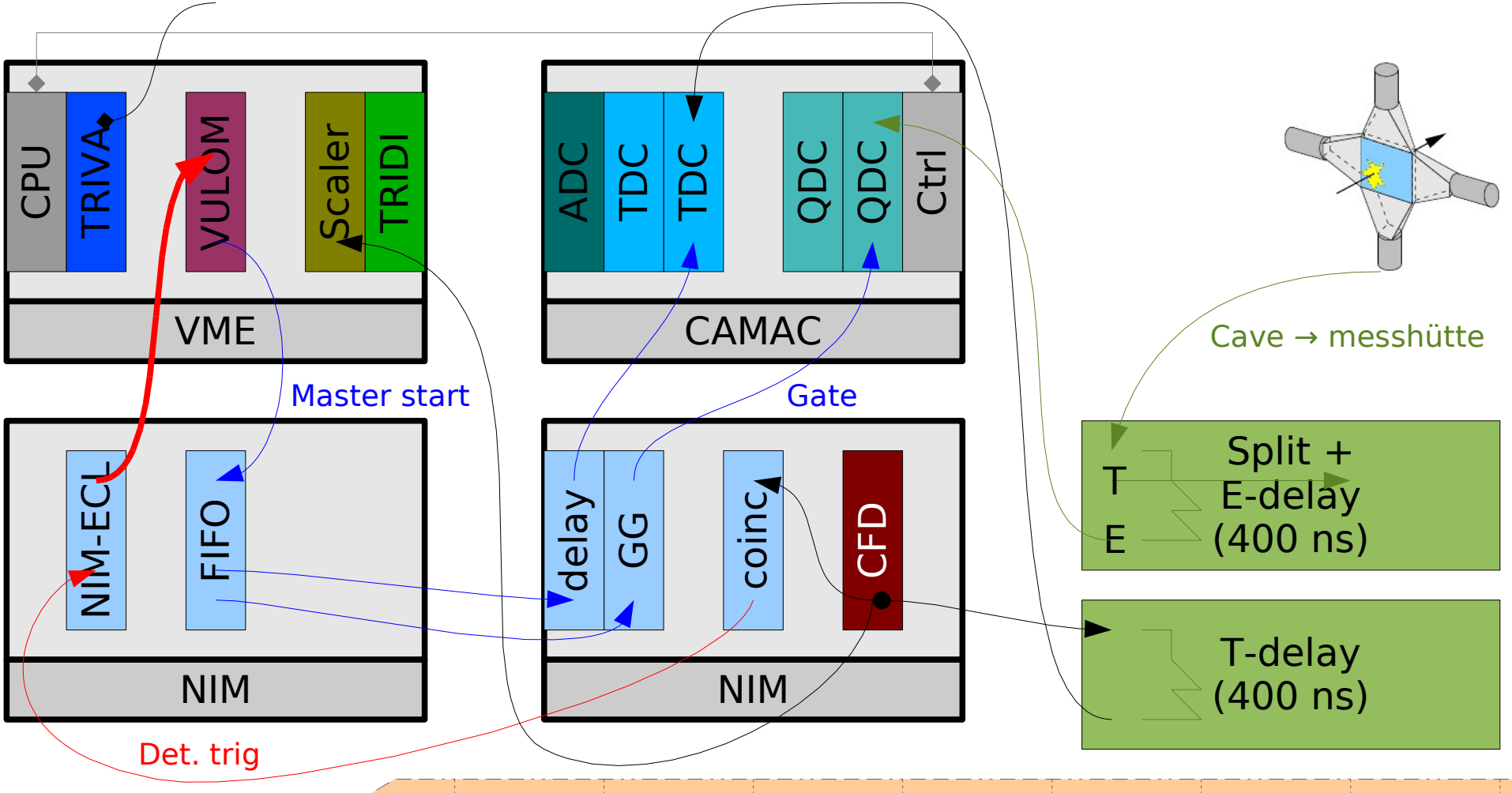
Live by the compiler timing messages!

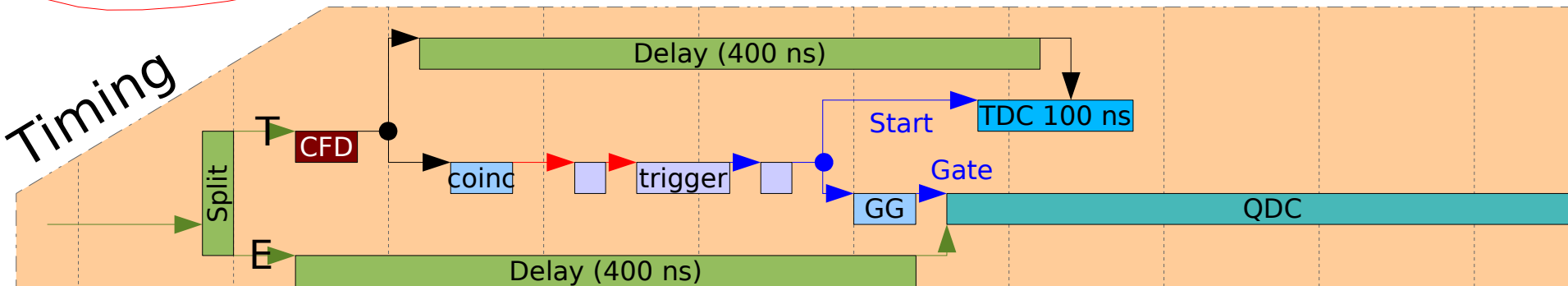


Backup: trigger → Cave C

Now: Beam detectors (Messcontainer)

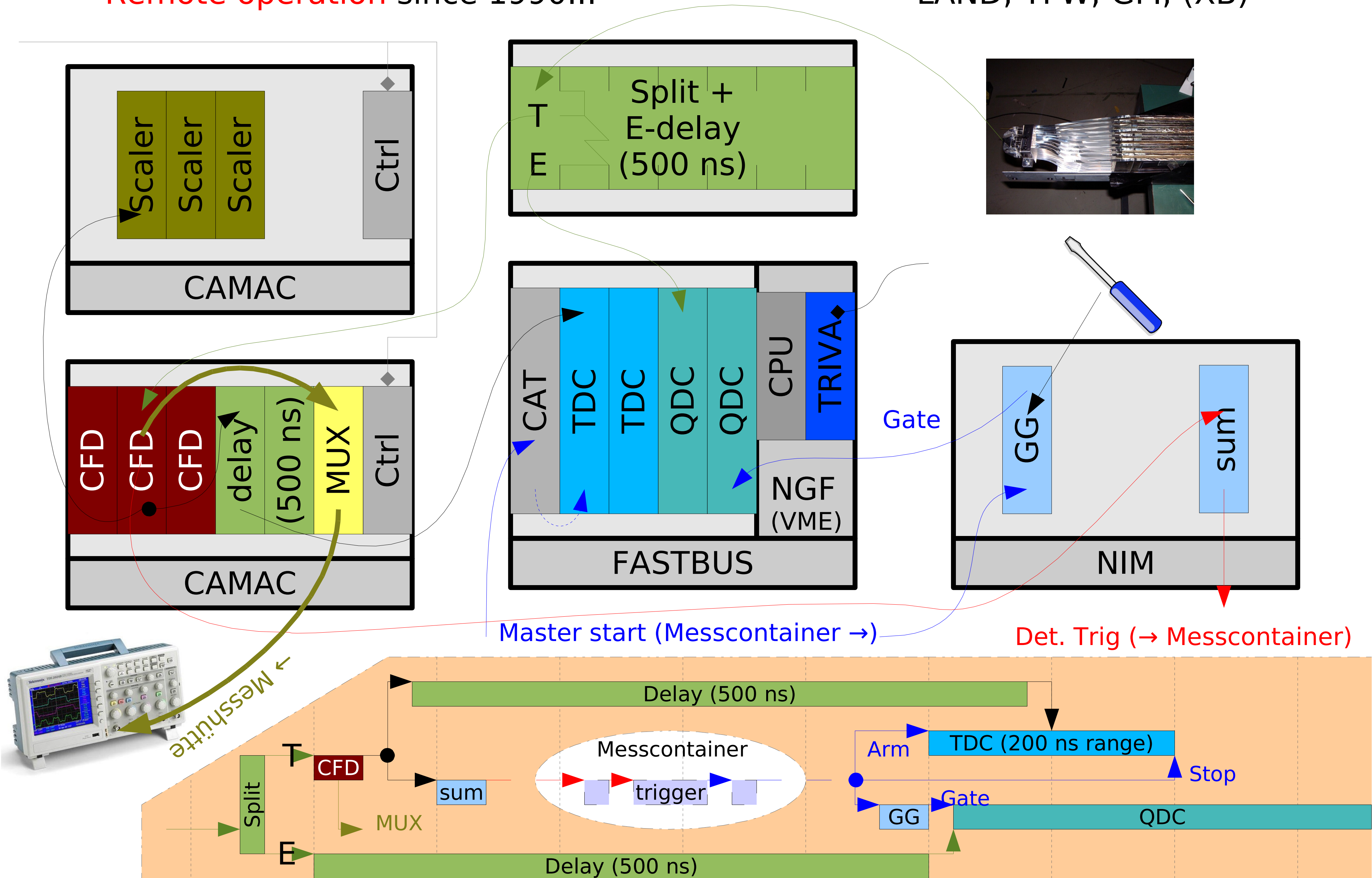
POS, PIX, PSP, SCI (S2,S8), ZST (MWPC)



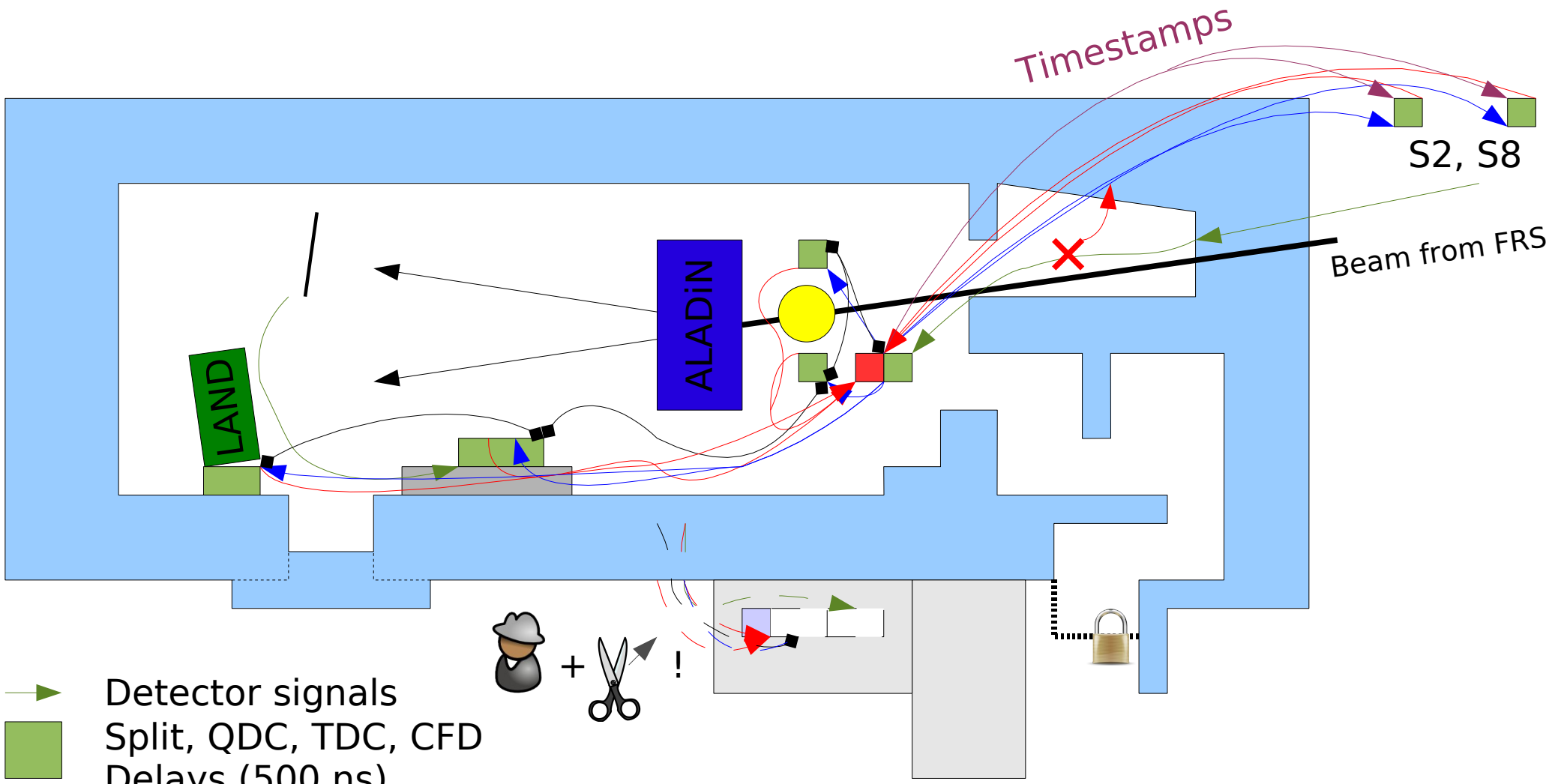


Now/Recent: CAMAC + FABU (Cave)

Remote operation since 1990... LAND, TFW, GFI, (XB)



(Again): Cave C trigger (201x-) ?



Detector signals

Split, QDC, TDC, CFD

Delays (500 ns)

Detector triggers (<100 ns)

Trigger decision (~50 ns)

Master start (<100 ns)

Trigger bus

Trigger fully computer-controlled

→ move into Cave

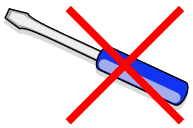
Master + Beam detectors in Cave ?

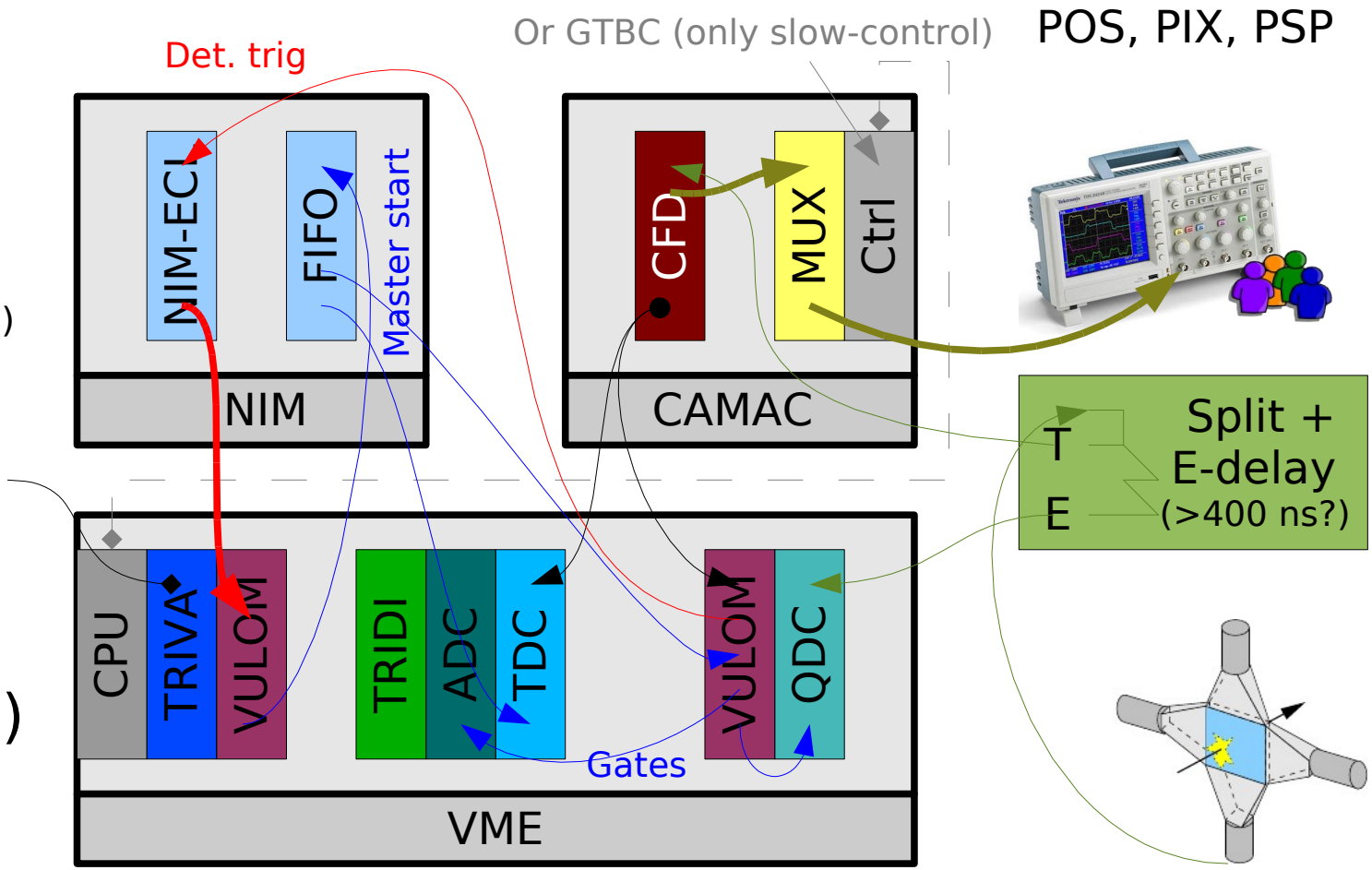
Multi-multi TDC
→ no delay adj.

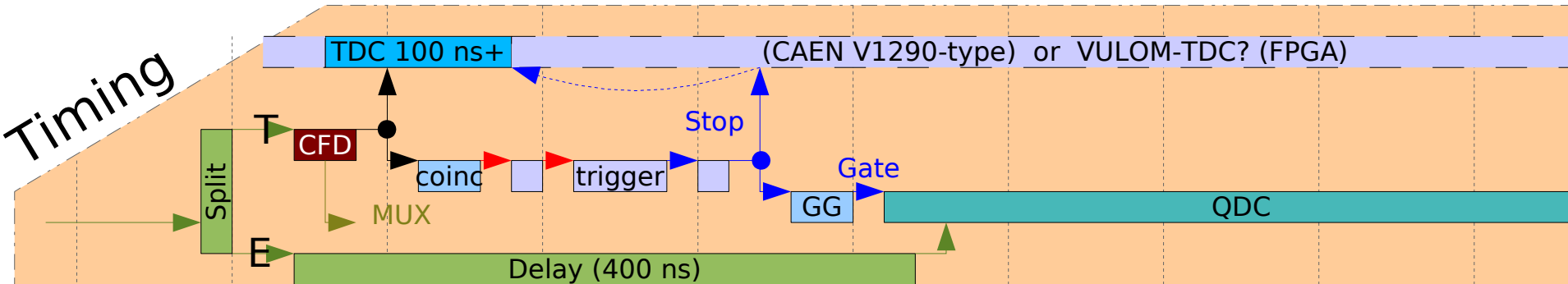
1 trigger VULOM
(due to master, many inputs)

1 local VULOM
(coinc + gates)

CF810x + MUX
(for multiplexing)







S2- & S8-elecronics @ S2 & S8 ?

SCI (S2,S8), ZST (MWPC)

Reduced copy of
cave beam/master

1 local VULOM
(coinc + gates)
(local trigger-capability)

Time-stamped
(no trigger-bus)