The NA62 LAV front-end electronics

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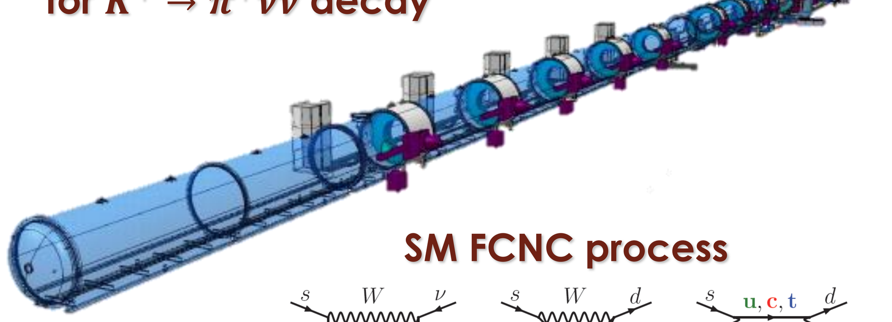
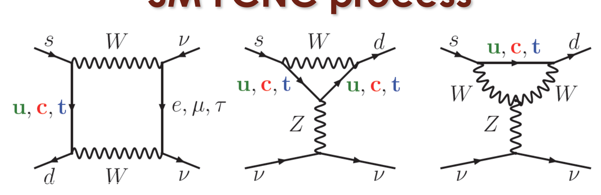
The Large Angle Veto (LAV) at the NA62 experiment

NA62 detector search for $K^+ \to \pi^+ \nu\bar{\nu}$ decay



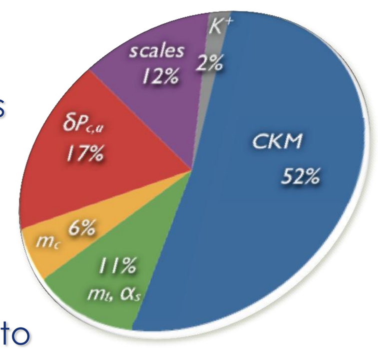
SM FCNC process



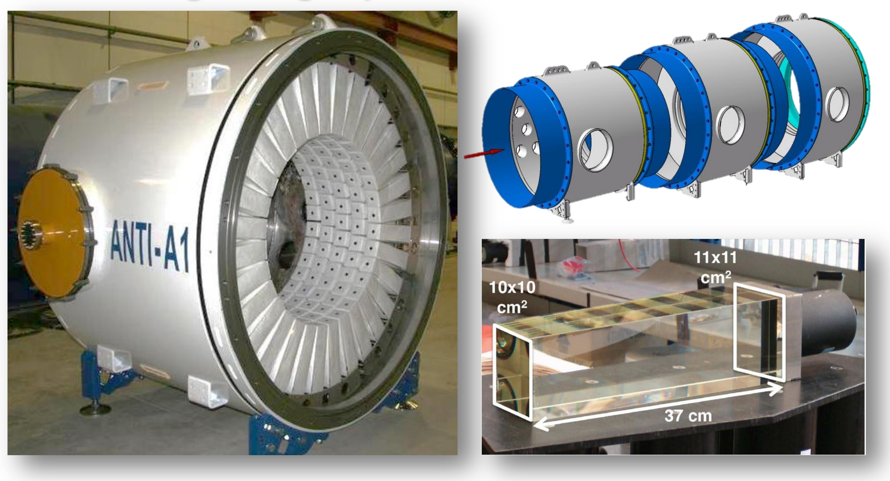
Decay	Short dist.	Theor. BR	Exp. BR
$K^+ \to \pi^+ \nu\bar{\nu}$	88%	$(8.22 \pm 0.75)\cdot 10^{-11}$	$(1.7 \pm 1.1)\cdot 10^{-10}$
$K_L^0 \to \pi^0 \nu\bar{\nu}$	99%	$(2.76 \pm 0.40)\cdot 10^{-11}$	$<2.6\cdot 10^{-8}$ 90%

- Ultra-rare FCNC process, forbidden in SM at tree level
- Dominant (88%) short-distance contribution
- Theoretical SM BR calculable with ~9% precision
- Very sensitive to physics beyond the SM

9% theoretical uncertainties dominated by errors on CKM elements and top mass. Thanks to LHC and new B-factories error will probably decrease to ~6%

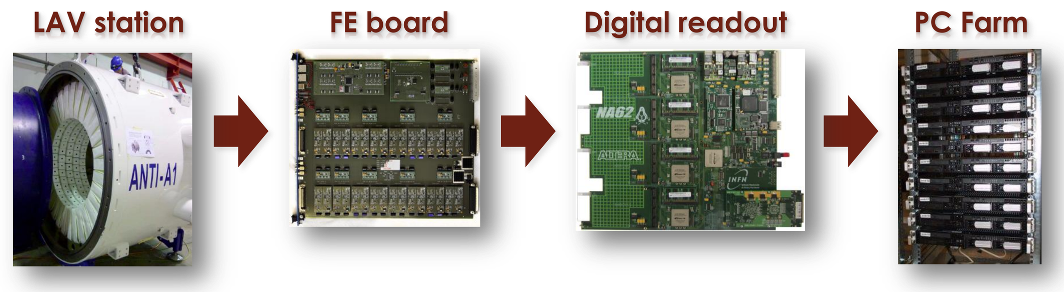


NA62 Large Angle photon Veto detectors



- Designed to reject π^0 from $K^\pm \to \pi^\pm \nu\bar{\nu}$ decays with 10^{-8} inefficiency
- 12 stations along an 80-meter decay region
- 2496 lead glass blocks from OPAL EM calorimeter
- 4-5 rings per station (>20 X_0) to maximize geometrical shower containment
- Single station inefficiency for γ detection $\sim 10^{-4}$ down to 100-200 MeV
- Operation in vacuum: O(10^{-6}) mbar

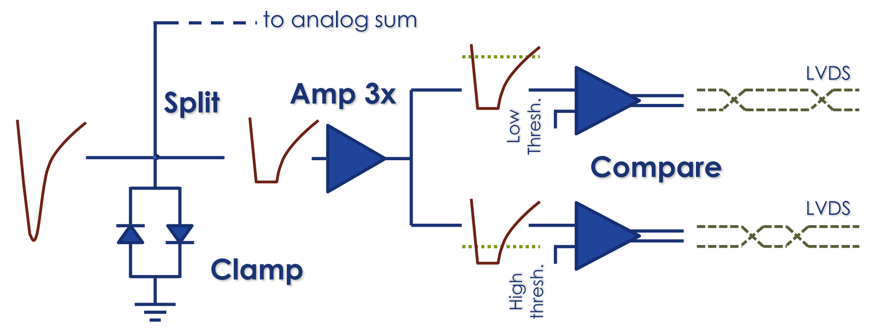
NA62 Large Angle Veto readout chain



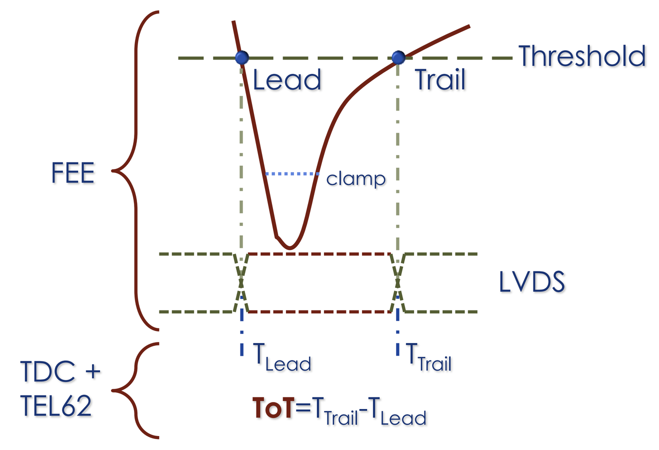
- 2496 readout channels in 12 stations
- ~ 100 KHz max rate per channel
- Time resolution <1ns, energy resolution <10% at 1 GeV

LAV front-end electronics working principle

From analog signal to ToT

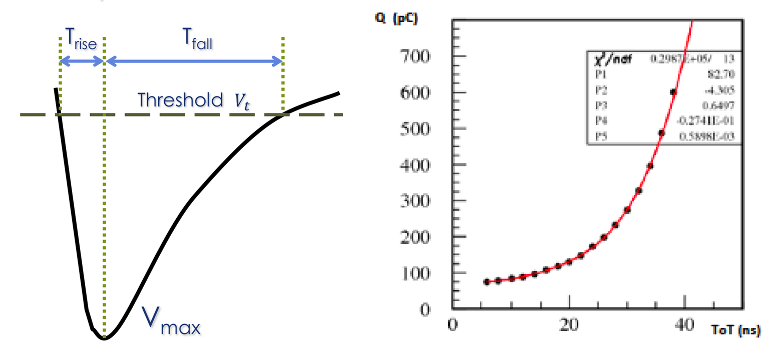


- Split the input signal in two copies: 1 copy to comparator + 1 copy to analog sums;
- Clamp the signal preserving its width;
- Amplify the signal x3 to restore the overdrive;
- Compare the signal with 2 different thresholds. Each threshold is independently adjustable up to 250 mV;
- Produce an LVDS signal and send the signal to the digital read out board;
- Measure the leading and trailing times of the LVDS signal and compute the ToT = Trail - Lead;



Charge reconstruction algorithm

The ToT is the sum of rise T_{rise} and fall time T_{fall} of the signal. T_{rise} only depends on the PMT construction parameters while T_{fall} depends on the signal amplitude V_{max} and on the time constant $\tau = C_{PMT} \cdot R$ for discharge of the PMT capacitance C_{PMT} across the output resistor R.

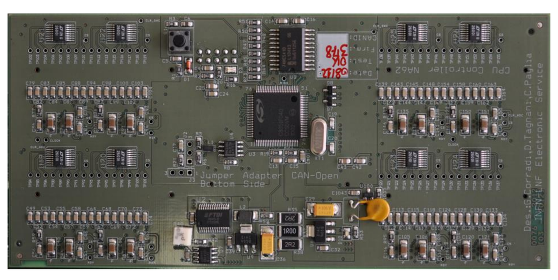


As shown in the plot above, Q is unequivocally defined by a given value of ToT.
The actual dependence of Q on ToT can be obtained using a fit to the distribution of Q vs. ToT. This relation is in principle the same for all the LAV PMTs. The sensitivity of the method is reduced at high charge due to the exponential dependence of Q on ToT.

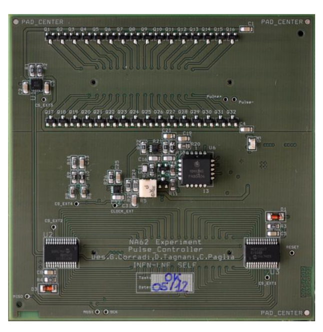
Charge reconstruction in NA62 LAV

- Measure ToT vs. charge using QDC and TDC only during calibration not during experiment
- Fit the function Q(ToT) (i.e. polynomial function)
- During data taking, measure the time using a TDC only

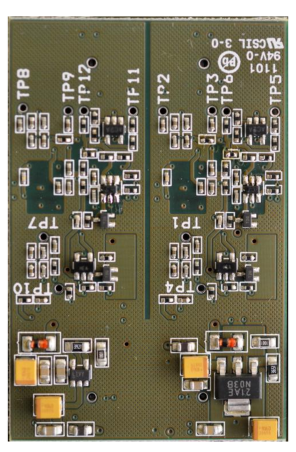
The front-end electronics board



Board controller (1x)
Communicate using CAN-Open
Allows setting and reading:
Thresholds (set/read)
Power connection (read)

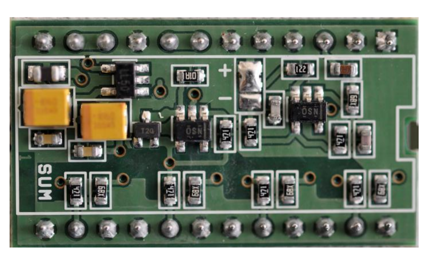


Test pulse controller (1 x)
Can set for each channel:
Pulse height (set/read)
Pulse width (set/read)
Pulse rate (set/read)



ToT mezzanine card (16 x)
2 channels and 2 threshold per board.
Includes the circuits for:
Clamp, Amplifier,
Comparator & LVDS driver.

Inputs	Type	Outputs	Type
Power connection	VME J1	64 LVDS output	2 x SCSI2
32 analog signals	2 x DB37	8 analog sums of 4 ch	8 x LEMO-00
		2 analog sum of 16 ch	2 x LEMO-00
1 CAN-Open	RJ11	1 CAN-Open	RJ11

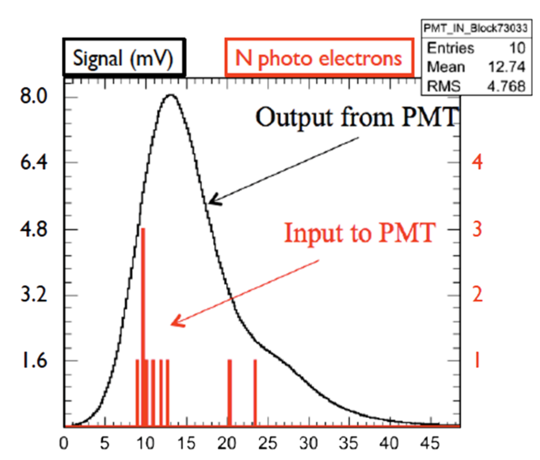


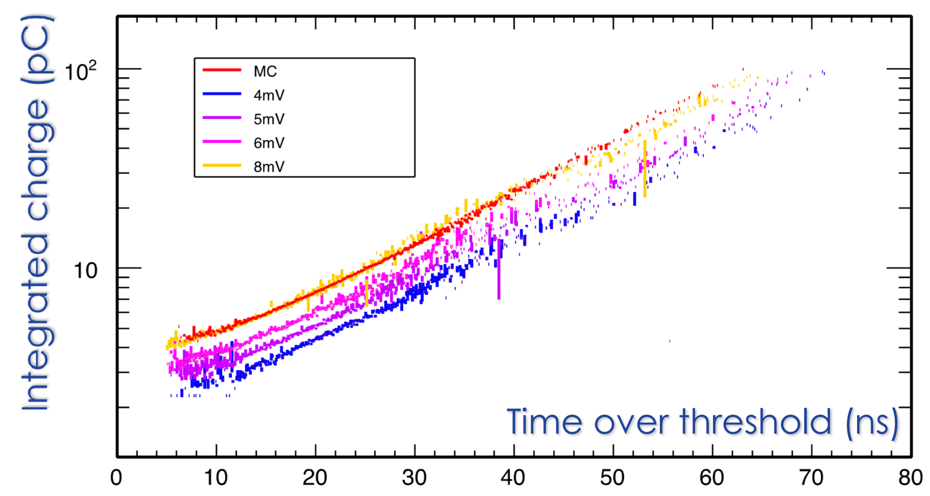
Sum mezzanine card (16 x)
Sum 4 analog channels (8 x)
Sum 16 analog channels (2 x)
Connected to a 50W LEMO out

Simulation

INPUT to simulation from GEANT4

- Number of photons in each event
- Arrival time of each photon
- Photon wavelength





Digitization simulation OUTPUT

- Photomultiplier analog signal
  Reproduces amplitude and shape
- Photomultiplier total charge
  Reproduces the MIP total charge and fluctuations
- Monte Carlo Q vs. ToT curve
- Reproduces the MIP Q vs. ToT measured
- The comparison with data sets (obtained during test beam with different threshold values) shows good agreement with nominal value only

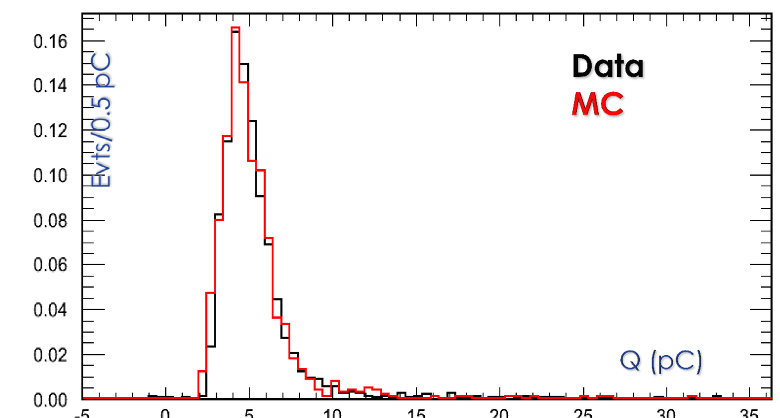
Digitization simulation

PMT simulation correctly treats:

- Path fluctuations for optical photons
- PMT photocathode QE(λ)
- Dynode by dynode gain fluctuations

Front end electronic simulation includes

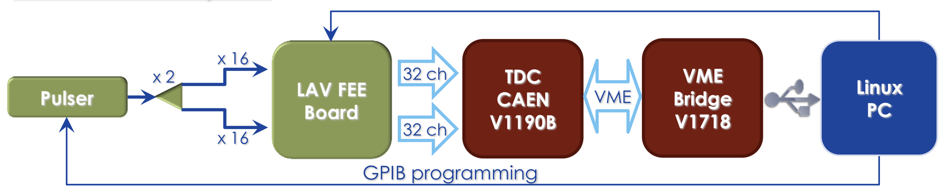
- Cable length simulation
- Threshold simulation
- Hysteresis simulation



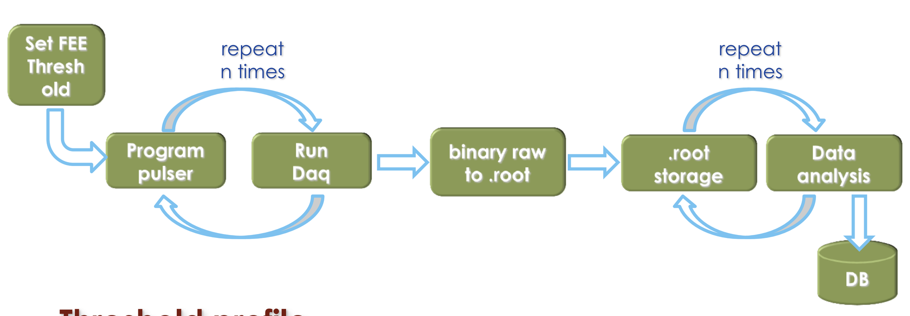
Performance of LAV front-end boards

Test stand setup at LNF

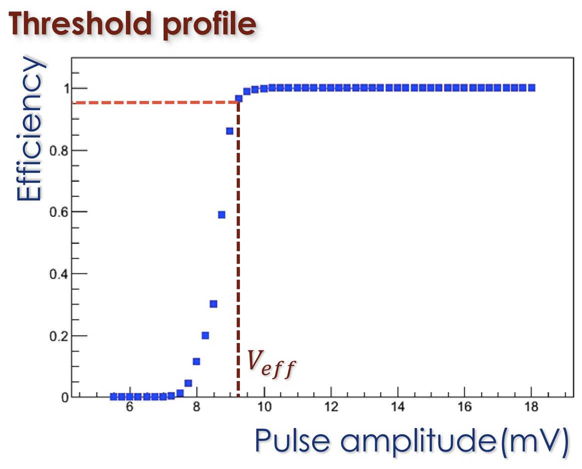
Hardware layout



Software flow chart

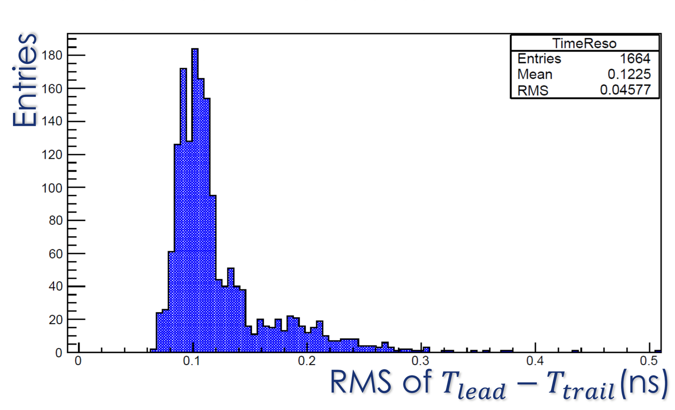


Threshold profile



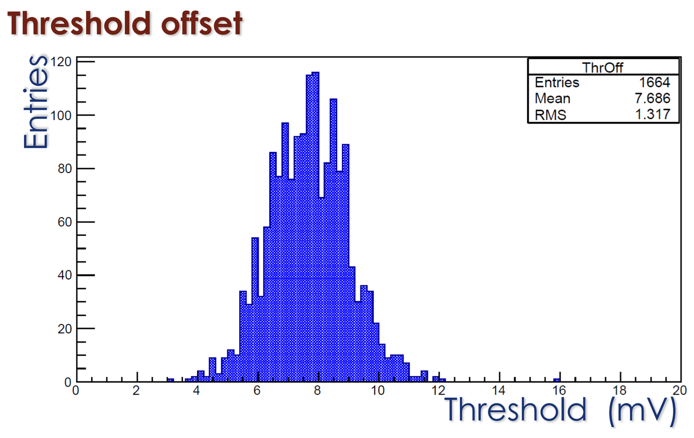
- Obtained using fixed threshold and variable pulse amplitude
- Single step at 0.25 mV
- Effective threshold (V_{eff}) extrapolated for efficiency at 95%

Time resolution of 26 boards



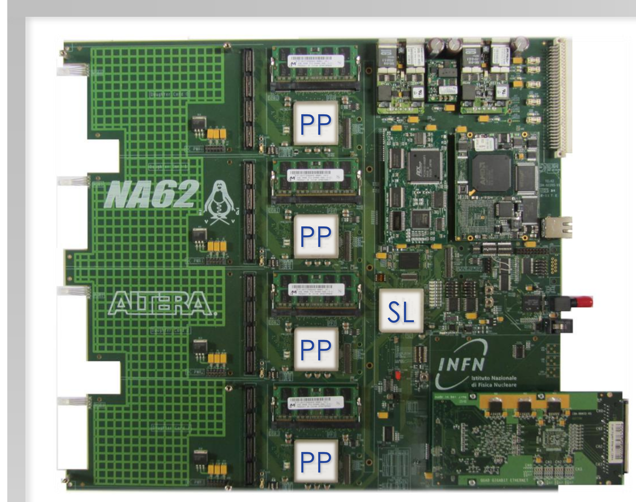
- Cumulative distribution of 26 boards (1664 ch)
- Time resolution obtained dividing by $\sqrt{2}$
- Average time resolution ~ 85 ps
- The tail on the right is due to noisy channels

Threshold offset



- Minimum effective threshold < 12 mV
- Small dispersion (RMS = 1.3 mV)
- High and Low threshold channels can be swapped reducing the minimum threshold

LAV firmware on TEL62 board



- Common digital readout board TEL62 (based on LHCb TELL1)
- 4 slots for custom mezzanine boards
- 4 PP FPGA (1/slot) with 2Gbyte DDR2 memory each
- 1 SL FPGA receiving data from the 4 PPs

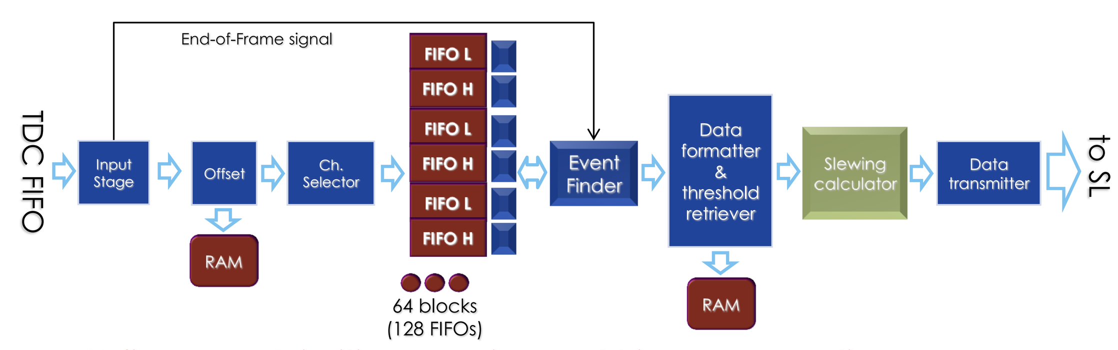
LAV in NA62 Trigger

- Rejects $\pi^+\pi^0$ events with γ at large angle
- Tags photons in LAVs keeping random veto below 1%
- Level-0 (10 to 1 MHz) implemented in TEL62 FPGA
- Level-1 (1 to 0.1 MHz) γ veto using the full LAV detector 12 stations (software)
- Level-2, (100 to 10 KHz) implemented in software (LAV not used)

LAV firmware performance	
Latency	~ 350 clk (2.2 μs)
Maximum Rate	~ 5 MHz / 128 ch
Correction precision	2 LSB (~ 200 ps)

PP firmware: High and Low threshold crossing association and slewing correction:

- Adds an independent time offset to each channel
- Reconstructs physical events:
  Matches High and Low High threshold crossing of the same hit
- Performs slewing correction using H and L thr. crossing times
  $t = t_{low} - \frac{(t_{high} - t_{low}) \cdot V_{low}}{V_{high} - V_{low}}$ where V_{high} and V_{low} are threshold voltages
- Deliver data (corrected times and EoF) to SL on a 32-bit bus
- Error on FIFO L/H full



SL firmware: Primitive merging and trigger generation:

- Merges physical hit times from the 4 PPs
- Groups together hits within a given time interval (5 ns window)
- Evaluates event times averaging times belonging to each cluster
- Sort event times
- Produce a Multiple Trigger Packet (MTP)
- Error on primitive lost