A comparison between scintillation light Analog and Digital trigger for large volume Liquid Argon Time Projection Chambers

Gian Luca Raselli

O. Barnabà, A. Menegolli, R. Nardò, M. Piola, M.C. Prata, G.L. Raselli, E. Romano, M. Rossella

INFN and Dep. of Physics of University of Pavia

IPRD19 Siena Conference

Outline

- Liquid argon scintillation light properties.
- Scintillation light approaches for triggering purposes.
- Examples.
- The ICARUS T600 @ Fermilab approach.
- Development of new electronics.
- Conclusions.

Liquid Argon Scintillation Light Emission

- An interaction in Liquid Argon produce:
  - Excitation;
  - Ionization followed by recombination.
- Emission of 128 nm luminescence through 2 processes:

1) Self trapped exciton luminescence

$$Ar^* :$$

$$Ar^* + Ar \rightarrow Ar_2^*$$

$$Ar_2^* \rightarrow 2Ar + h\nu$$

2) Recombination luminescence

$$Ar^+ :$$

$$Ar^+ + Ar \rightarrow Ar_2^+$$

$$Ar_2^+ + e^- \rightarrow Ar^{**} + Ar$$

$$Ar^{**} \rightarrow Ar^* + heat$$

$$Ar^* + Ar \rightarrow Ar_2^*$$

$$Ar_2^* \rightarrow 2Ar + h\nu$$

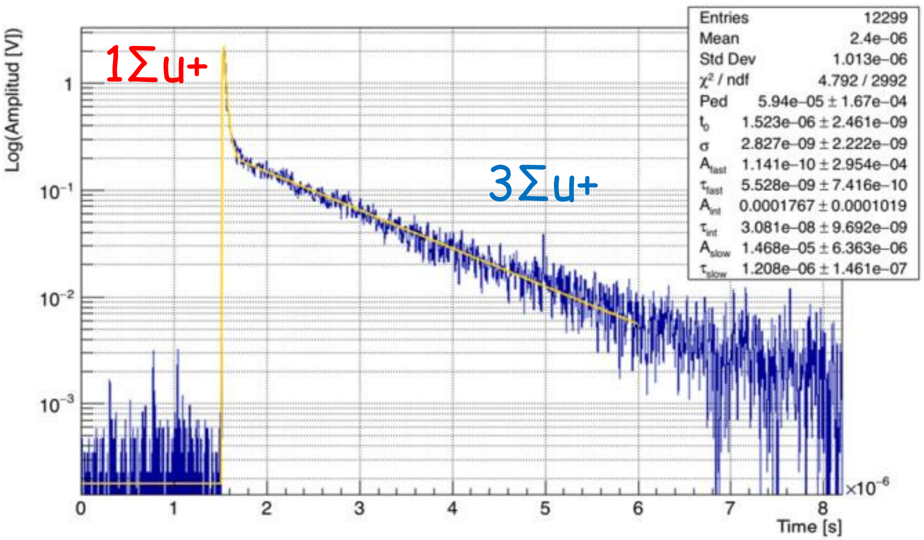
- Both processes:
  - ✓ ending up with the same radiative reaction;
  - ✓ inducing the emission of a 128 nm UV photon.

Liquid Argon Scintillation Properties

- Light yield ~ few 10,000's of photons per MeV.
- Recombination step involves an electron cloud around the track core:
  - LAr purity dependent;
  - E-Field dependent scintillation yield;
  - Charge and light anti-correlation;
  - dE/dx dependent scintillation yield.
- There are two low lying excited states with different decay time:

  A singlet state $1\Sigma u+$
  decays into $2Ar + \gamma$ in 6ns

  A triplet state $3\Sigma u+$
  decays into $2Ar + \gamma$ in ~ 1500ns



- The production of singlets and triplets is not equally weighted between the two processes, being ~ 25% + 65% for the exciton luminescence and ~ 50% + 50% for the recombination luminescence. Dependent on ionization density.

Liquid Argon Scintillation Sum Up

- High photon production but with two decay constants;
- Fast timing information mostly contained in the fast decay component;
- Energy information in both components (for m.i.p. ~ 2/3 on slow component);
- Possible Pulse Shape Discrimination exploiting both decay components.

- Two different approaches are presently adopted to exploit the LAr scintillation light for trigger purposes:
  - ✓ Analog processing (sum up, integration, differentiation) of signals followed by digitization and logic processing:

    "Analog Trigger Approach"

  - ✓ Digitization (fast discrimination) of signals coming from each photo-sensor followed by logic combination of pulses:

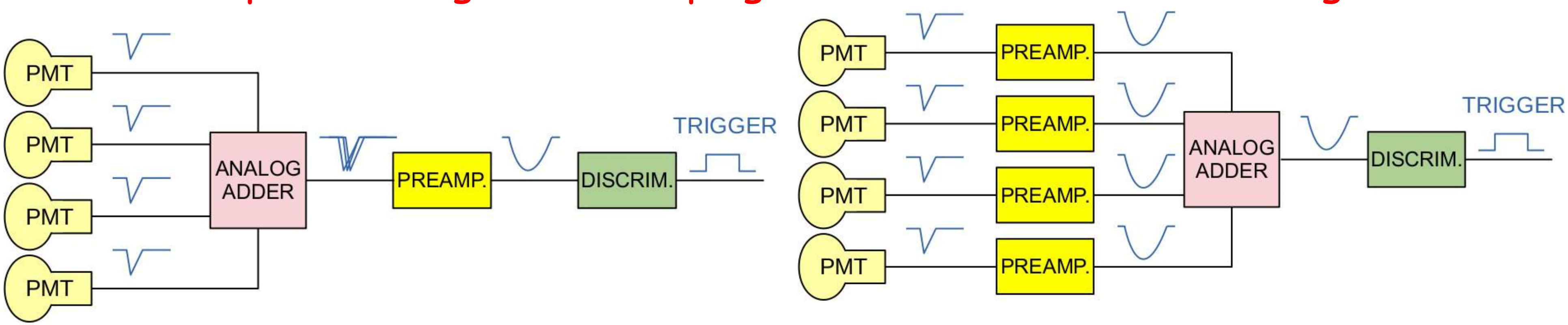
    "Digital Trigger Approach"

- Both discrimination approaches can be adopted simultaneously or at different trigger level.

Analog Trigger Approach

- **Analog Trigger.** This approach is to perform an analog processing (sum up, integration, differentiation) of the signal provided by the photo-detectors in a defined detector region before the discrimination and logic combination of pulses.

Example of integration/shaping before and after the analog sum

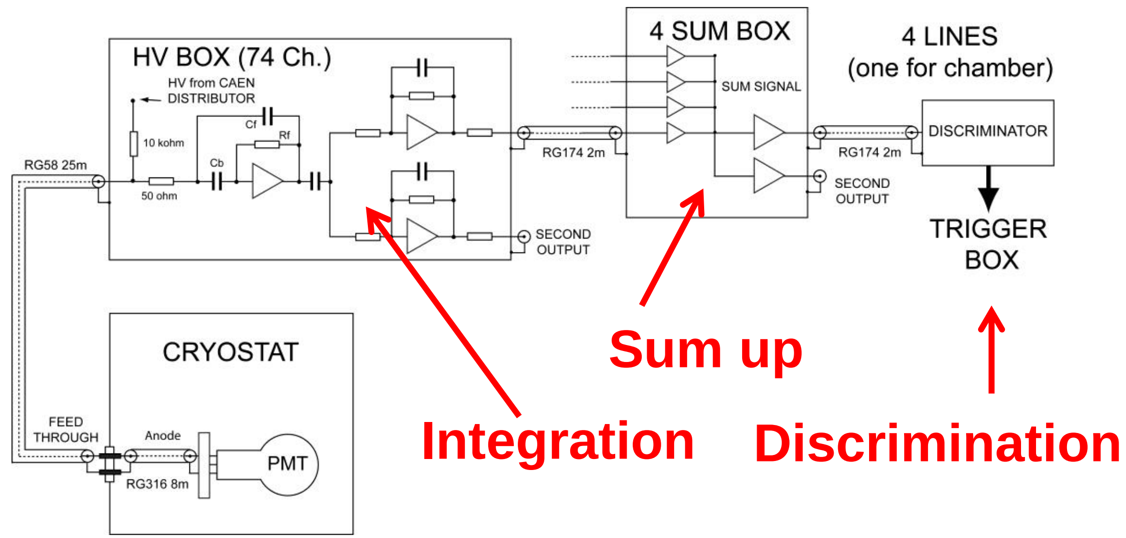


- This approach can take advantage of both the components of the scintillation light, making this technique more effective for small energy deposition.
- Possible Pulse-Shape-Discrimination.
- Main drawbacks are: poor time resolution due to the integration constants and different time response of photo-detectors, increase of electronic noise.
- This approach is suitable for LAr-TPCs for dark matter searches.

Examples of Analog Trigger System

- **ICARUS T600 @ LNGS.** For ICARUS T600 an analog trigger system was adopted during the LNGS run, because of the low number of PMTs, in order to exploit as much as possible the detected photoelectrons.

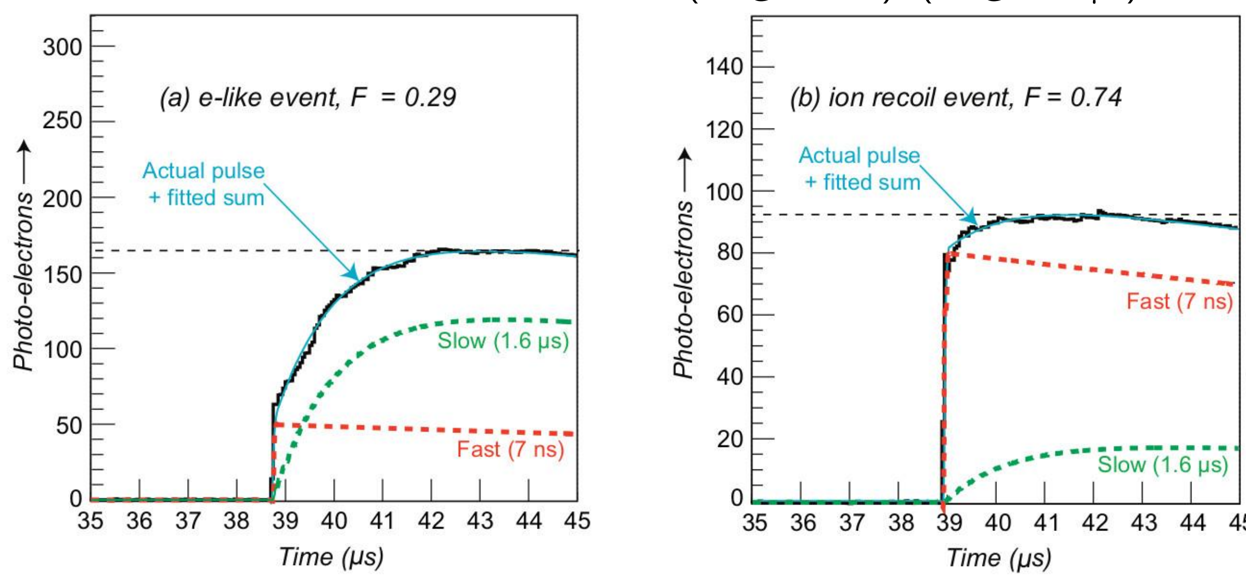
M. Antonello et al.,*The trigger system of the ICARUS experiment for the CNGS beam* JINST 9 9 P08003 (2014)



- **WARP 2.3 litres @ LNGS.** The analog trigger scheme was adopted at second level to distinguish nuclear recoils from ionizing events by PSD.

P. Benetti et al.,*First results from a Dark Matter search with liquid Argon at 87 K in the Gran Sasso Underground Laboratory* ASTROPARTICLE PHYSICS 28 (2008) 495

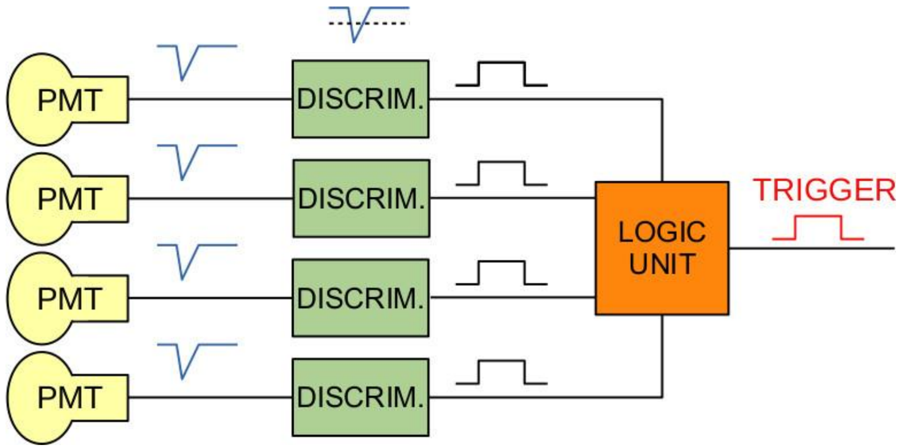
F= Fast Discrimination Parameter = 0.99 (A1 @ 200 ns) / (A2 @ 5.25 μs) - 0.118



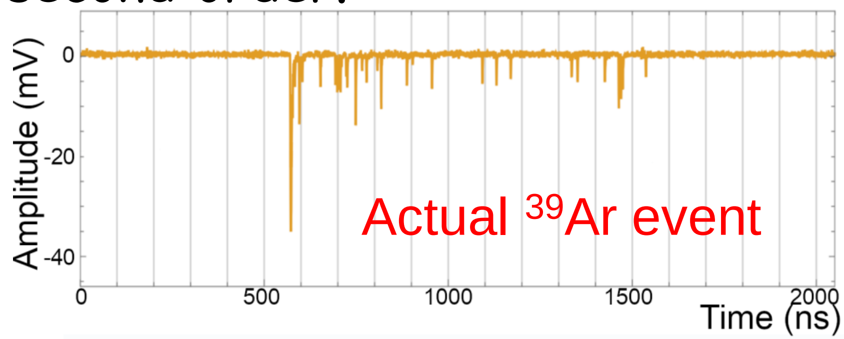
Typical e-like and ion recoil signals resulting from the integration and sum up of pulses coming from the anode of 7 PMTs.

Digital Trigger Approach

- **Digital Trigger.** This approach is to discriminate the signal of each photo-sensor and then process the digital output with programmable logic units, to find coincidence or majority patterns.



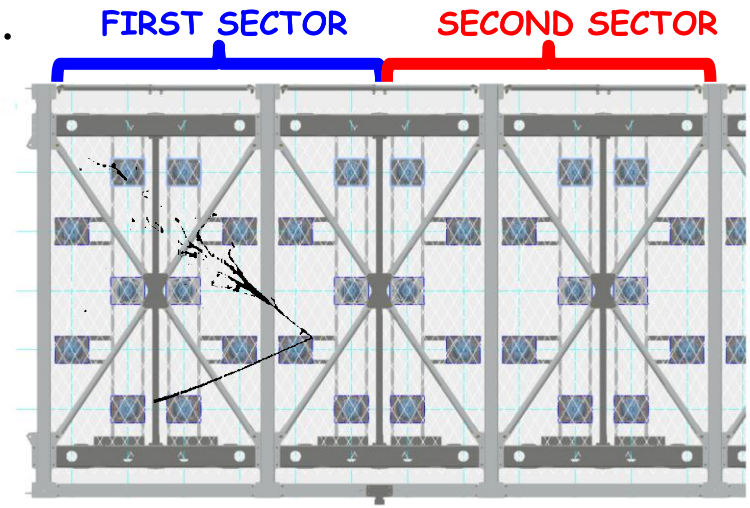
- In this case only the fast component of the scintillation light is exploited, in order to attain time resolution of the sub-nanosecond order.
- Useful for low-energy background rejection such as ^{39}Ar which produce single sparse photons that singularly do not overcome the threshold value.



- This approach is suitable for large volume LAr-TPCs and at first trigger level.

ICARUS T600 @ FNAL SBN program

- ICARUS T600 @ LNGS adopted an analog trigger system because of the low number of PMTs, in order to exploit as much as possible the detected photoelectrons.
- The number of PMTs was increased to 360 (90 behind each wire plane) in view of it operation at FNAL at shallow depth, to cope the huge cosmic rays background.

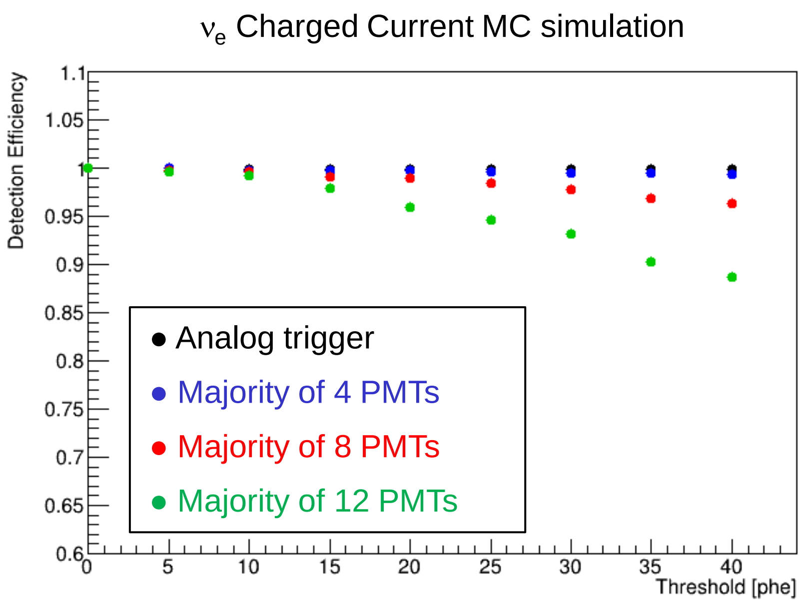


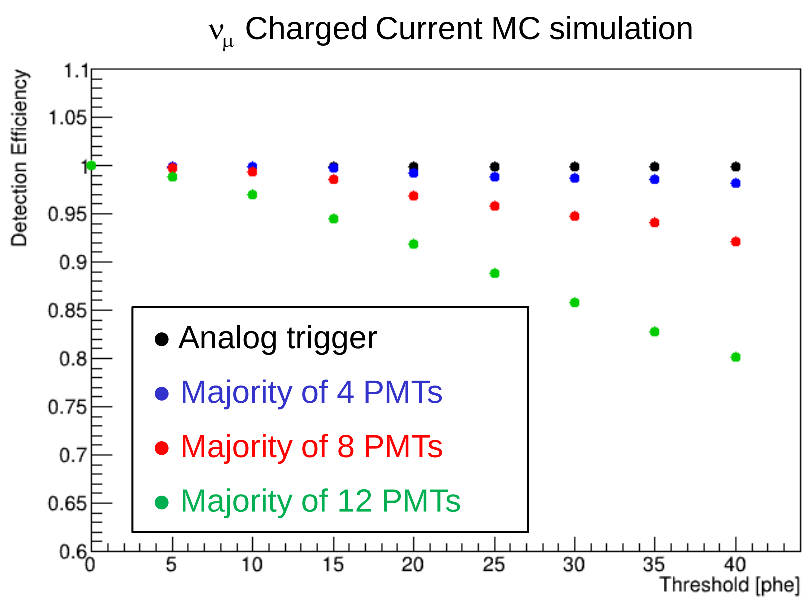
Neutrino interactions are expected to be spatially confined in a small section of the detector, suggesting to longitudinally divide the detector in 3m long 6 sections, corresponding to 15 PMTs.

- Both trigger approach will be adopted for each sector:
  - **Digital Trigger** based on FPGA logic on prompt discriminated signal. This will permit to identify each interaction in each sector with 1 ns precision in coincidence with the neutrino beam and to cope the cosmic background. 95 % of events localized along the beam direction within 30 cm using only PMT signals with threshold > 10 phe.
  - **Analog Trigger** analog sum of 15 PMTs to identify lowest energy deposition.

Detection efficiency

- Monte Carlo simulations demonstrate that the use of an analog trigger system permits the compensation of detection efficiency losses due to the adoption of high multiplicity (majority) of PMT signals and high discrimination threshold levels in the digital trigger sector.

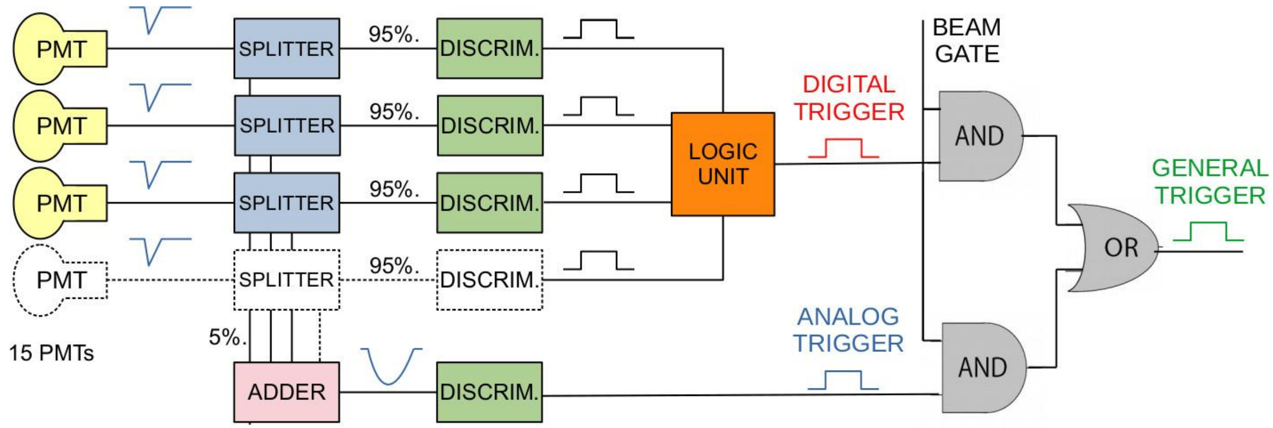




Figures show the detection efficiency for simulated ν_e Charged Current (left) and ν_μ Charged Current (right) interactions in a single detector section, 3 m long.
In each plot the colored dots represent the detection efficiency for different values of discrimination threshold (photoelectrons) and coincidence (in terms of majority) of PMT signals, as resulting from a pure digital trigger scheme. The black dots refer to a combination of digital and analog trigger scheme.

ICARUS T600: Trigger Scheme

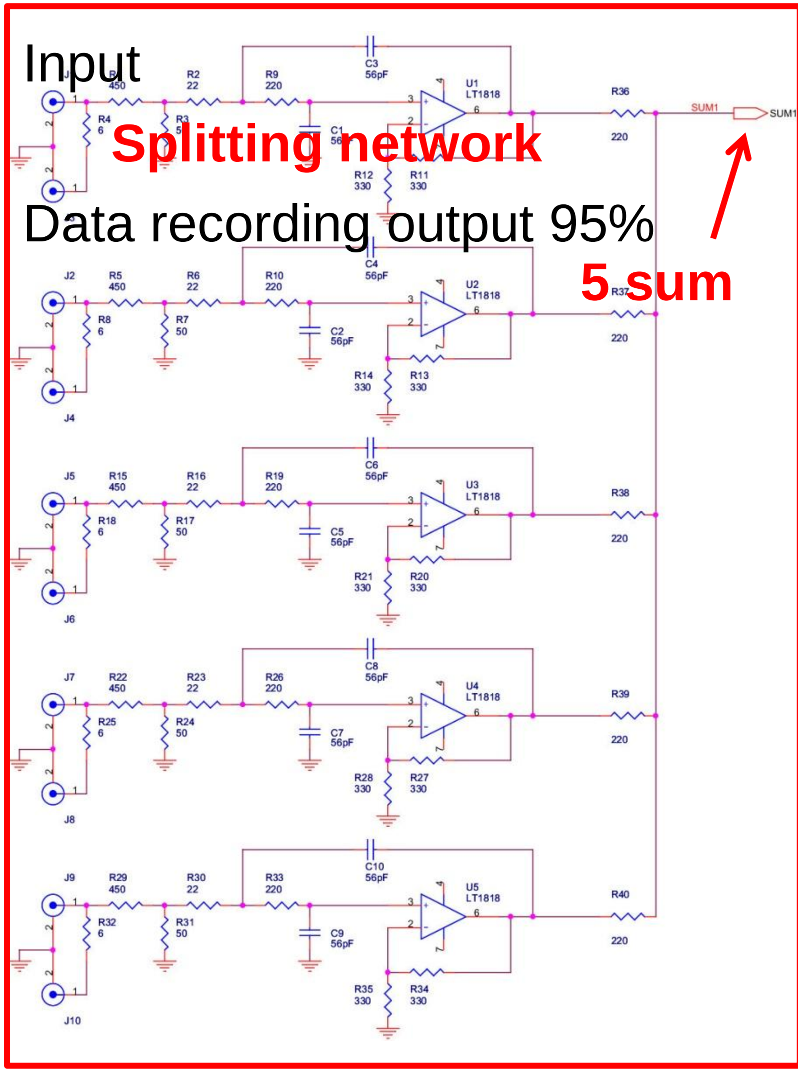
- By means of passive splitters, 15 PMT signals are sent to the discrimination stage with 95% of the original amplitude. The remaining 5% of the amplitude is summed up by an analog adder which performs a slight integration (20 ns) of the signal to cope with the different arrival times.



- The Digital Trigger layout makes use of commercial fast programmable logic arrays FPGA (Field Programmable Gate Array) to implement coincidence patterns or majority of fired PMTs. M. Babicz et al., *Scintillation light DAQ and trigger system for the ICARUS T600 experiment at Fermilab* NIM A936 (2019) 358
- The signal splitting and analog sum are included in a custom designed module. Each analog sum will be discriminated at a proper discrimination level intended to maximize the neutrino interaction detection efficiency.
- Both outputs will be then set in coincidence with the beam gates to generate the detector General Trigger signal.

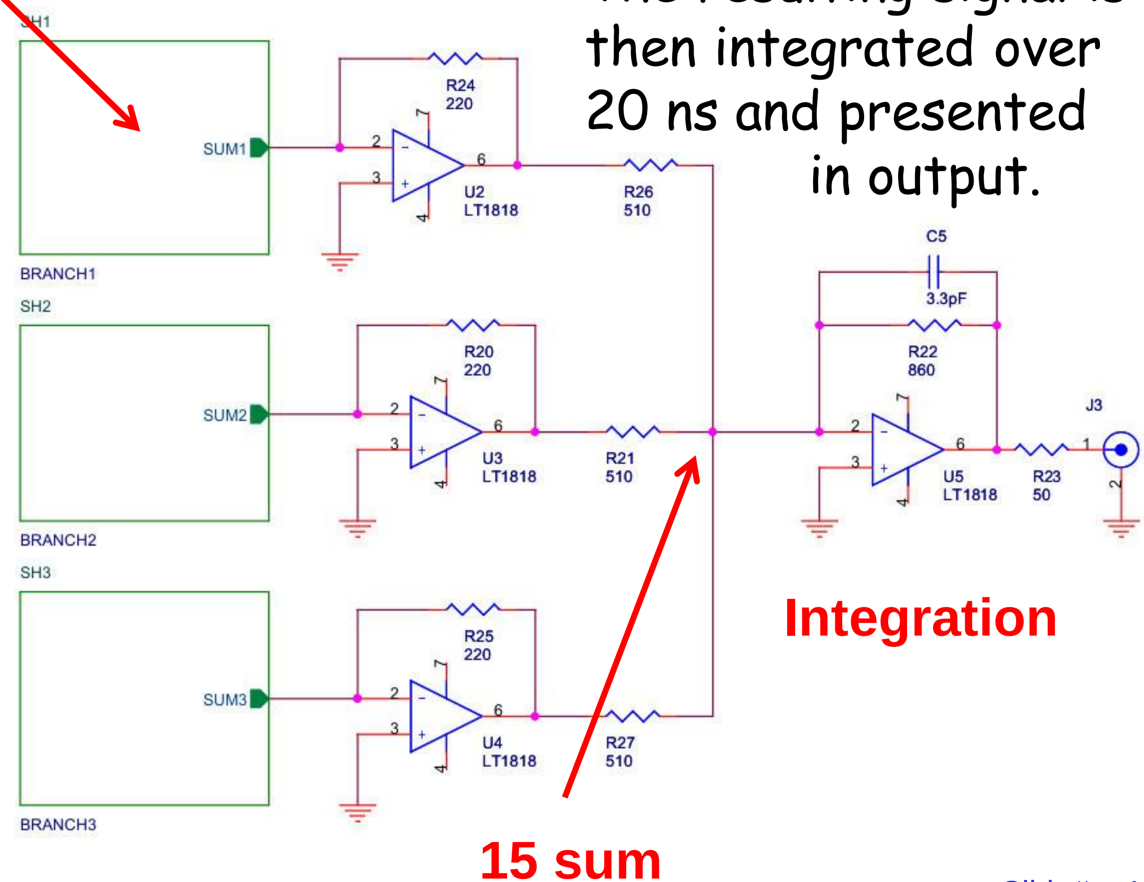
Analog Adder

The analog adder consists of 3 independent branches, each summing up 5 input signals with 5% amplitude and returning the 95% amplitude for data recording.



The 3 sums coming from the 3 branches are then added to give a 15 analog sum.

The resulting signal is then integrated over 20 ns and presented in output.

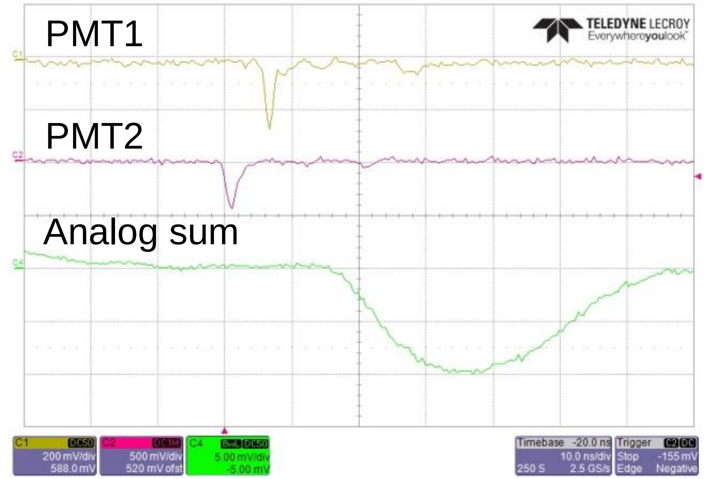


Analog Adder Testing and Prototipes

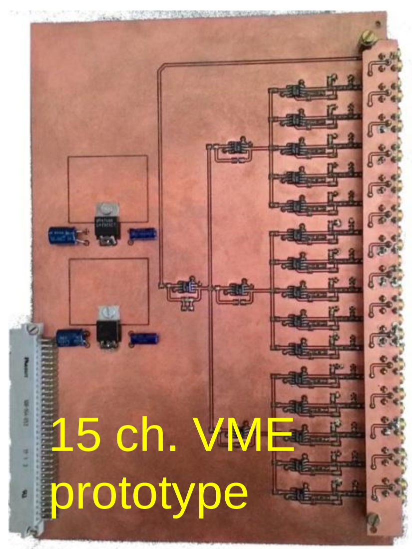
- Different prototypes have been realized and tested with actual PMT signal detecting scintillation light of LAr at the CERN 10-PMT facility.

M.Babicz et al., *Measurement of Liquid Argon Scintillation Light Properties by means of an Alpha Source inside the CERN 10-PMT Facility, poster presentation at* this conference

Detection system of the CERN 10-PMT-facility.



Example of the resulting signal for 2 PMTs in input.



Final series of 24 modules under production.

Design and prototypes realized by SERVEL of INFN and University of Pavia.

Conclusions

- Two different discrimination approaches are presently adopted in LAr-TPC to exploit the LAr scintillation light for trigger purposes:
  - ✓ Analog processing (sum up, integration, differentiation) of signals followed by digitization and logic processing:

    "Analog Trigger Approach"

  - ✓ Fast discrimination of signals followed by logic combination of pulses:

    "Digital Trigger Approach"

- A comparison of these two technique have been presented showing the main advantages of each implementation.
- Both trigger approach will be adopted by ICARUS T600 in the SBN program at FNAL.
- The Digital Trigger layout makes use of commercial fast programmable logic arrays FPGA (Field Programmable Gate Array) to implement coincidence patterns or majority of fired PMTs.
- Besides, for the Analog Trigger, a custom electronic module has been designed and produced.

Thank you