A Trigger system for ICARUS-T600

A. Guglielmi, G.L. Raselli

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Present W.G.: S. Centro, T. Cervi, A. Falcone, A. Fava, A. Guglielmi, W. Ketchum, G. Meng, F. Pietropaolo, G.L. Raselli, A. Rappoldi, M. Rossella, D. Torretta, S. Ventura

… more people welcome!

Expected event rates in ICARUS-T600

- BNB facts - 5 10^{12} pot/spill extracted in ~1.6 μs, 5 Hz repetition rate:
  ~1 in-spill event over 35 spills is expected in ICARUS:
  - ~1 neutrino interaction in T600 LAr-TPC per 180 spills;
  - ~1 beam-associated event every 210 spills, mainly from muon beam halo/ interactions in the material surrounding T600;
  - ~1 in-spill cosmic event every 55 spills.
- NuMI Off-Axis facts - 4 10^{13} pot/spill in ~8.6 μs, 0.53 Hz repetition rate:
  ~ 1 event over 23 spills is expected in ICARUS mainly due to in-spill cosmics,
  ~ 1 neutrino interaction/280 spill;
- Globally a ~0.2 Hz event rate (neutrinos + muons from beam halo + cosmics) inside the proton pulse time windows, is expected corresponding to ~ 4 PB of data for the total 6.6 10^{20} pot exposure if the full ICARUS-T600 detector is read-out (~70 MB event size);
- The trigger system would select genuine ν interactions while rejecting background and noise. For this purpose a staged level trigger has to be adopted, aiming at progressively reducing the data amount from the front-end buffers to the offline storage.

ICARUS DAQ and trigger systems

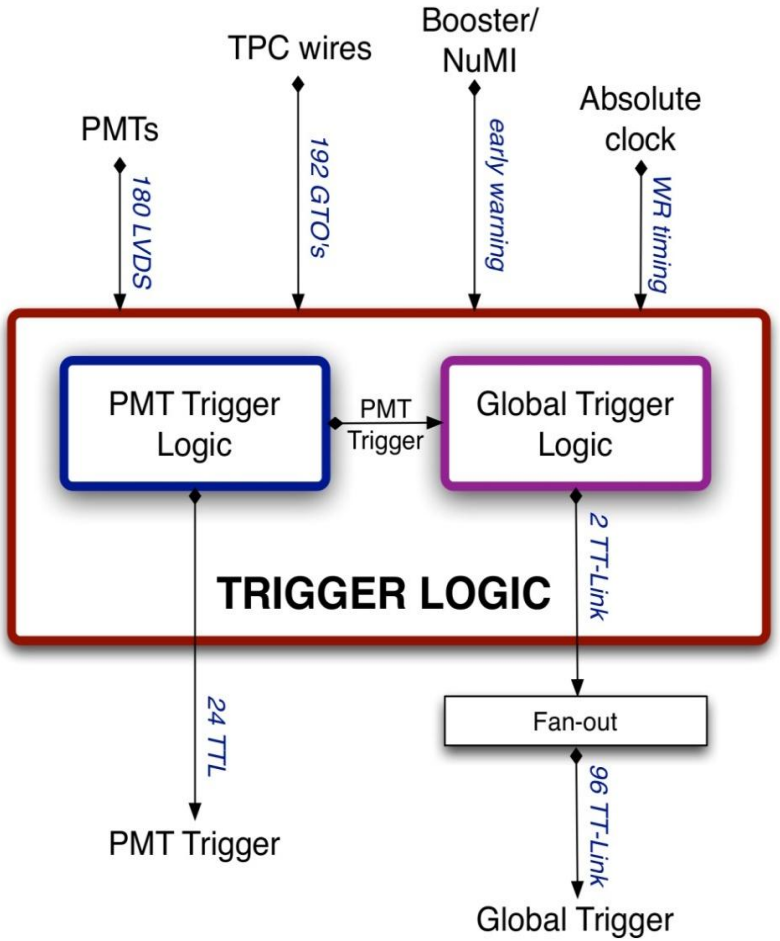
- The adopted FPGA programmable tables in the trigger layout would allow to implement step by step complex trigger logics which can be tuned on real events to match the actual experimental conditions.
- Data taking can initially start by opening a gate in correspondence to neutrino arrival using "early warning" signals of BNB /NuMi proton spill extractions; ~5 Hz trigger rate is well supported by new DAQ.
- This will allow to check DAQ functionality and define trigger logics based on the internal PMT signals, initially set with MC event studies, optimizing the neutrino collection efficiency and the background rejection.
- Collected events can be further thinned out using the CRT- Cosmic Ray Tagger to identify cosmics entering T600. Time comparison of scintillation light in the T600 and signals from *Resistive Wall Monitors* of beam would allow to reject fake triggers by exploiting the bunched beam structure; ~2 ns resolution for PMT/CRT systems as well as for sub-detector synchronization is required.
- The additional feature of triggering on charge collected on TPC wires already implemented at LNGS will be studied. Developed algorithms would offer an independent monitor. This protocol can be also used to filter events before the storage acting as a "software trigger" running in quasi on-line conditions.

Timing and beam extraction for SBN

- At Fermilab an "absolute" GPS timing in form of pps (pulse per second) signal will be provided to all SBN detectors and to the beams extraction locations;
- Timestamps, in same "absolute" time reference frame, of several signals related to beam extraction will also be made available:
  - ✓ "early warning" for BNB/NuMI, 35/730 ms in advance of proton on target;
  - ✓ Booster/Main Injector extraction, 0.3/1.75 ms in advance;
  - ✓ Booster off target extraction;
  - ✓ 2GHz recording of Resistive Wall Monitor detectors for both beams (BNB RWM/NuMI RWM).
- Distribution will occur through White Rabbit: Ethernet based network for synchronization of distributed systems with sub-ns accuracy better than 50 ps precision *(See A. Fava talk on DAQ).*

ICARUS trigger system - PMT

- The PMT trigger logic will be implemented in two steps:
  - *PMT Trigger Logic:* for generating, independently for each T300 module, a *PMT-Trigger* signal in correspondence of interactions in LAr as detected by PMT's. It will serve as an input for the next step and to enable PMT signal waveform recording.
  - *Global Trigger Logic* : for generating a *Global Trigger* signal from the previous signal in coincidence with proton extraction from BNB/ NuMI (early warning). It will be sent to different sub-detectors (PMT, CRT, TPC) to enable event read-out as stop of data acquisition in one or in both T300 modules.

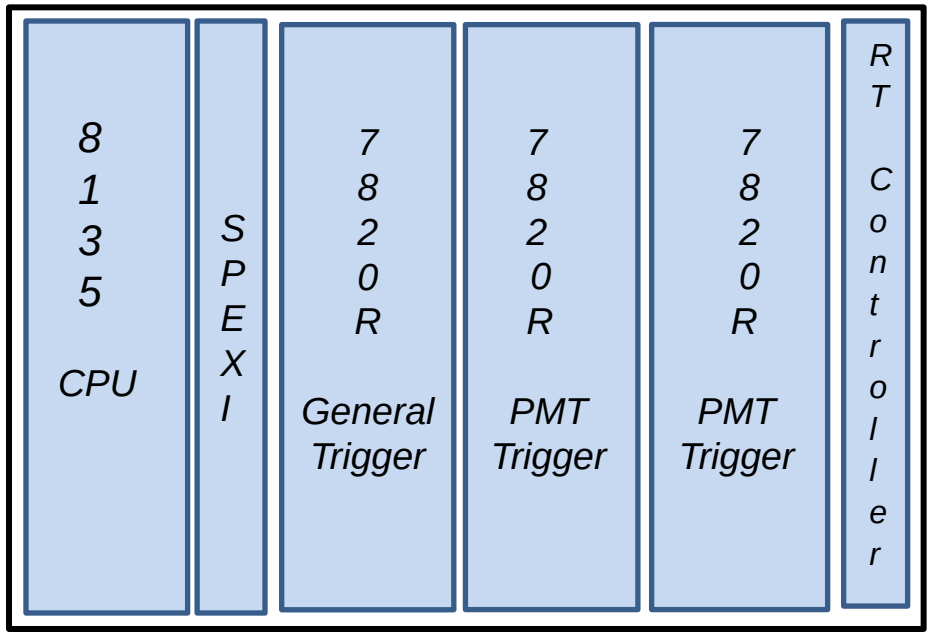


- Dedicated algorithms have to be implemented for the PMT Trigger Logic starting from the study of the features of ν events compared with those of cosmics.

ICARUS trigger system - PMT

- The General Trigger layout is based on NI PXIe instrumentation in a single NI crate. NI boards already employed at LNGS are being replaced: new CPU (PXIe-8135), Real Time (RT) controller, SPEXI board by Incaa Computers and 3 NI boards (PXIe-7820R), one for the General Trigger and two for PMT Trigger:
  - RT controller implements all features for communication with DAQ, monitoring of available buffer/veto generation;
  - SPEXI synchronizes timing of whole detector, handles beam extraction messages, and generates signals for TPC readout, Clock & Reset for PMT;
  - PMT trigger boards: generate PMT Trigger & start to the fast PMT pulse digitizers of PMT activity recording;
  - General Trigger board combines inputs from PMT Trigger boards with SPEXI signals to generate Global Trigger.

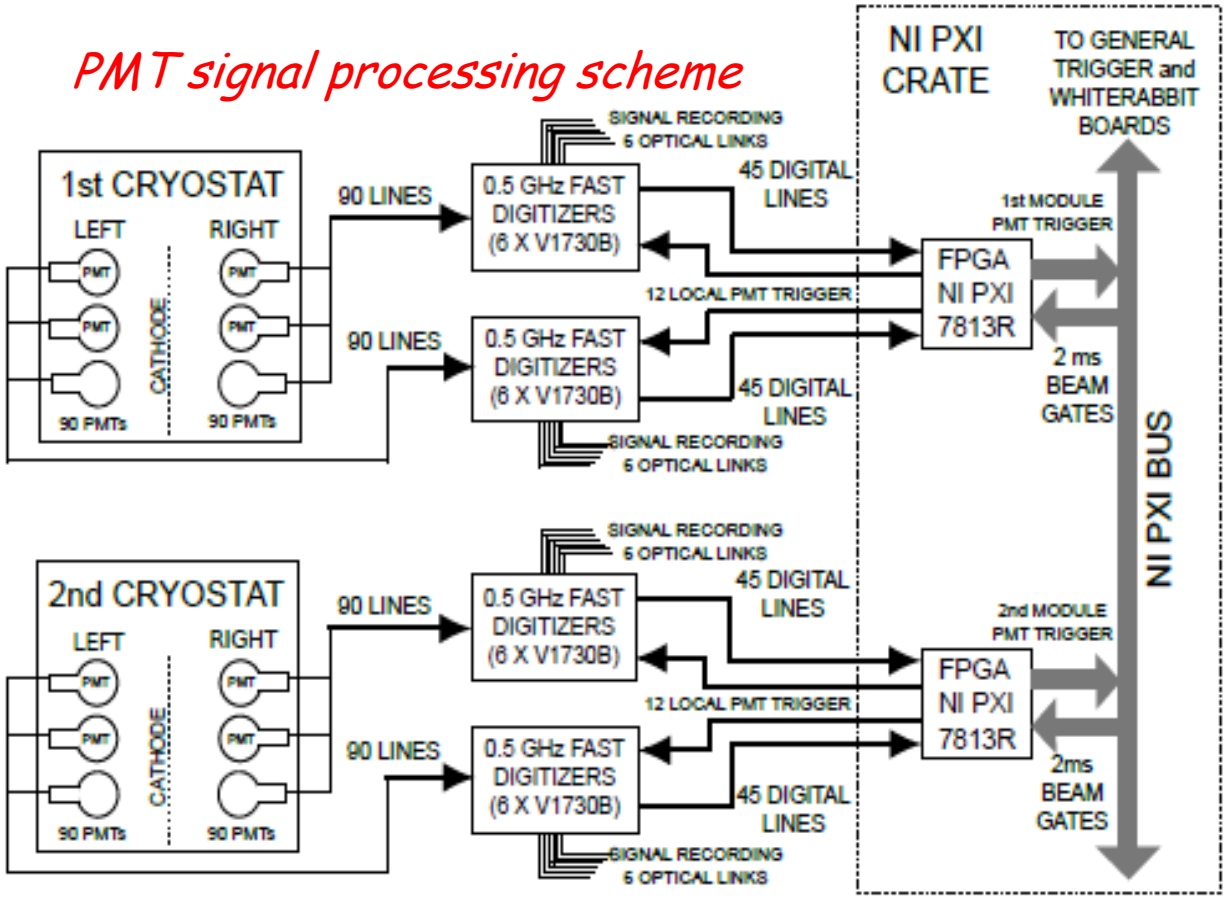
ICARUS Trigger NI Crate



PMT Trigger scheme (1)

- For each T600 chamber, 90 PMTs are directly connected to 6 CAEN V1730B boards, 16 channels each.
- The boards will provide the sampling of PMT signals (500 MS/s, 14 bit res.) which will be available through dedicated CONET2 optical links, one per V1730B
- V1730B will also generate a set of discriminated output signals (LVDS) in term of OR/AND of pairs of adjacent channels for triggering purposes.
- Thresholds (~ phe) have to be set to guarantee the full detection efficiency of interactions with deposited energy >50 MeV in the full T600 LAr active volume.

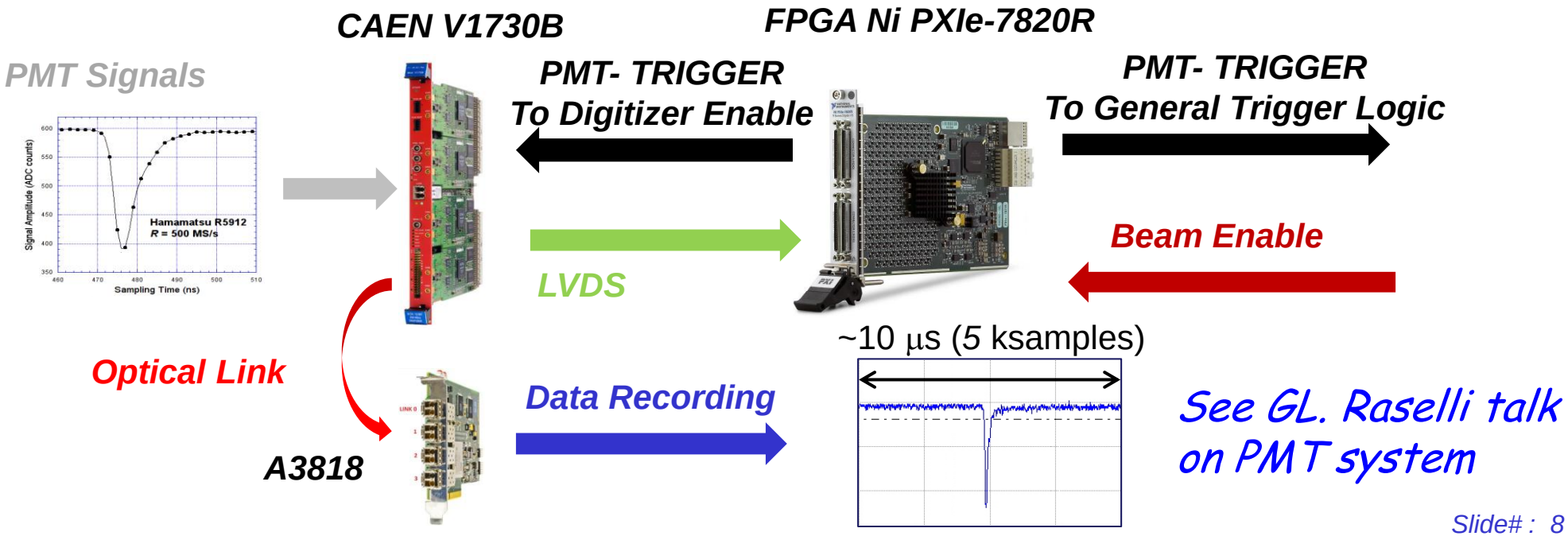
PMT signal processing scheme



See GL. Raselli talk on PMT system

PMT Trigger scheme (2)

- The 45 signal outputs from a single TPC chamber, are processed by a programmable logic unit FPGA (NI-PXIe 7820R, one for each T300).
- A PMT-TRIGGER signal defined by majority/coincidence patterns, will enable fast PMT digitizers if this occurs inside a 2 ms wide BNB/NuMI beam gates to record all the PMT activity during the TPC time drift window.
- This signal will be also used to generate the GENERAL TRIGGER in coincidence with the BNB/NuMI beam spill to enable the event read-out
- Each PMT pulse is recorded by considering a 10 μs sampling size.

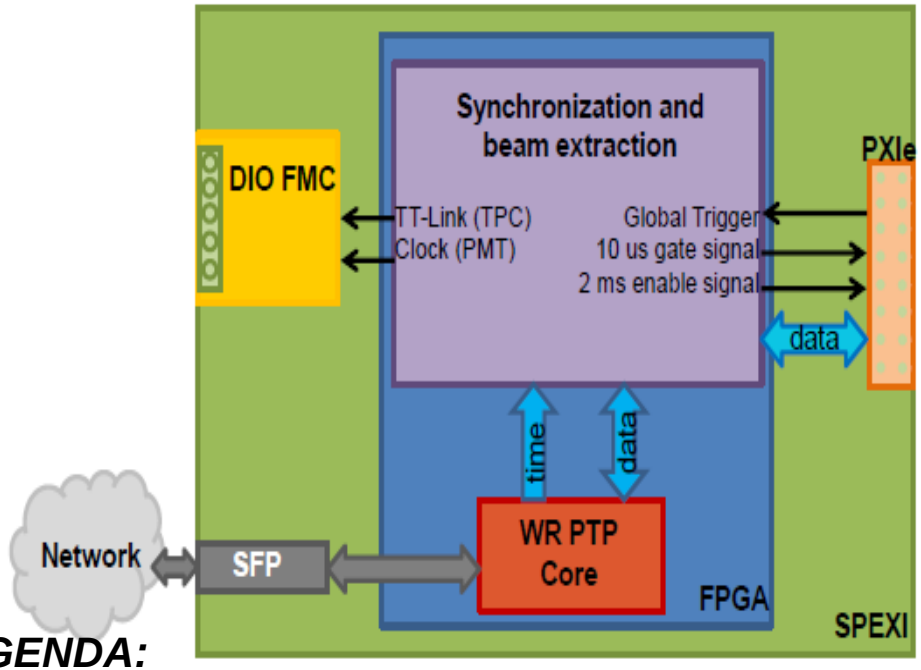


PMT DAQ + Trigger Test Bench

- A test bench for PMT signal DAQ and Trigger has been set up with two V1730 digitizers and a A3818 optical link to a server PC.
- The trigger instrumentation: 7820 board + SPEXI board + 8135 CPU + 1062Q crate + LVDS-TTL level-shifter prototype + Laser system.
- On going studies/ tests:
  - programming simple trigger logics (AND/OR) to combine PMT signals;
  - programming the SPEXI board to generate TT-Link, Clock and Beam Gate signals (see next slides);
  - studying the Clock distribution and synchronization of the different boards used in the Trigger chain;
  - studying of the timing resolution of different PMT 's lit by the laser system in order to optimize the PMT time alignment.

ICARUS SPEXI board Block diagram

- ICARUS SPEXI board will generate:
  1. TT-Link for TPC readout. This is a single wire bus that distributes clock & commands like triggers, start/stop acquisition, reset, …
  2. Clock (50MHz) for PMT digitizers;
  3. 10 μs wide beam gate signal based on information of Early Warning for generating the Global Trigger;
  4. 2 ms wide beam enable signal (1 ms before 10 μs gate signal) for activating PMT readout.



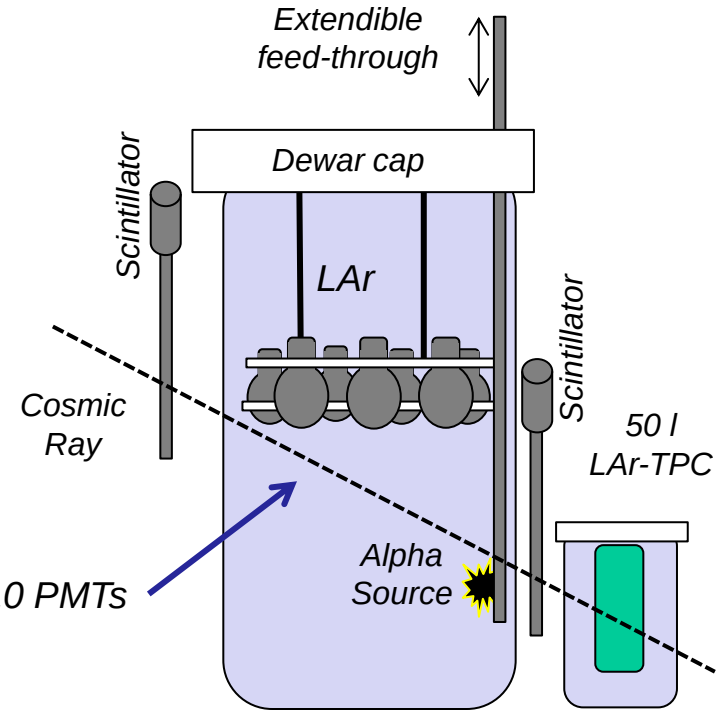
LEGENDA:

SPEXI *: Simple PXI express FMC Carrier Board*
DIO FMC *: Digital Input /Output Mezzanine Card*
WR PTP *: White Rabbit Precision Time Protocol*
PXIe *: PCI extension for instrumentation*
SFP *: Small Form-factor Pluggable-optical transceiver*

- Firmware for programming FPGA:
  - VHDL codes for generating the TT-Link and clock are ready for test;
  - VHDL codes for reception of Early Warning info's are in preparation ;
  - LabVIEW driver for SPEXI/FMC-DIO hardware to be done by Pavia group.
- Software for WR calibration/configuration is being prepared by FNAL group.

LAr test facility to test DAQ/ Trigger systems (CERN)

- A small scale LAr test facility is in preparation at CERN to test DAQ, on-line and define electronic synchronization (trigger/wire/PMT) and the DAQ timing.
- 10 R5912 Hamamatsu PMTs equipped with laser calibration system are arranged into an existing ~1600 liters LAr cryostat at CERN. It can be exposed to c-rays and an α source inserted in LAr to initially calibrate PMT response.
- The PMT array is complemented aside with the already operational ICARUS 50 l LAr-TPC which is provided by LAr recirculation/filtering system.
- Cosmic muons crossing both TPC dewars will be selected by external plastic scintillators.
- The PMT system and TPC wires synchronization will be guaranteed by a common clock generation and by the handshake between trigger and DAQ.
- PMT waveform recording, initially performed with CAEN software, will later be based on ArtDAQ



Planning for implementation of Trigger system

- The T600 trigger preparation is advancing in the Trigger Working Group which includes people involved in the read-out electronics and DAQ/online group from Padova, Pavia, FNAL and CERN (Conveners: A.G., GL.R.);
- Technical design is in progress:
  - New NI modules are replacing obsolete ones used at LNGS;
  - Expected White Rabbit protocol is under study with the help of Fermilab;
  - On-line codes are in preparation in Padova, Pavia, FNAL.
    They will exploit the ArtDAQ system to handle raw data.
- A small scale LAr test facility is in preparation at CERN with the available NI modules to test DAQ, timing of event building and gradually implement the trigger system. Full test must be completed by September.
- On the other side dedicated MC event studies to define the "the trigger logic" are required to address the specific items of interest for trigger implementation: waiting for a first MC data release from Software Group.

See D. Gibin talk