Software for ICARUS-T600

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Regular meetings on Monday afternoon

Welcome participation from others!!!

General Status

- The code is maintained in the LarSoft framework, which is the common choice for the SBN detectors and permits direct comparison of analysis results between different detectors, as well as maximizes the synergies and code reuse.
- Outline of the presentation:
  - Status of the simulation of the different detector components.
  - Status of the present reconstruction code.
  - Possible synergies within SBN already experienced in the joint workshops devoted to the reconstruction/simulation code.

Summary of the II joint SBN analysis workshop

- ~30 participants from both ICARUS and SBND – 19-23 March in Padova https://agenda.infn.it/conferenceDisplay.py?ovw=True&confId=15073
- The agenda and material is available at the link https://sbn-docdb.fnal.gov/cgi-bin/private/DisplayMeeting?conferenceid=2486
- Most of the time devoted to parallel activities organized in subgroups to verify simulation and develop tools for reconstruction and analysis
- Discussions of items of general interest

- Relevant samples of simulated and reconstructed events were made available in advance for the group activities (neutrino events O(100k), single muons, protons, π^0, electrons and cosmics, O(10k) each)

Joint SBN workshop - General Discussions

Different topics were addressed:

- Discussion of a possible common code framework for event selection and SBN analysis
- Possibility to exploit CRT, TPC and light information to reject cosmics and possibly identify neutrino interactions: reconstruction tools needed
- Detailed presentation of GENIE (software tool for neutrino interaction simulation), with critical discussions on the GENIE approach. Present implementation in LArSoft and future tuning/evolution.
- The assumption in the SBN proposal and the necessary tools to be prepared to match them in the real experiment. Discussion mostly focused on the the detectors providing information complementary to the TPC, namely:
  - *the inner PMT light (association between TPC and light topological and time information, to disentangle overlapping cosmics, localize the event and possibly classify them)*
  - *CRT (geometrical and time information to identify and reject overlapping cosmics and fast extraction of a useful sample of events for the detector monitoring and calibration.)*

SBN Common code framework (Joint SBN workshop)

- Developed at Chicago University by A.Mastbaum, G.Putnam, J.Zennamo, D.Schmitz
- Presented and made available during the workshop
- Lightweight framework very useful for event selection and SBN physics analysis
- Easy access to any reconstructed object or MC information from any detector
- Centralizes standard output analysis tree
- Common code very useful not just for high-level analysis, but also for debugging reconstruction algorithms, complementary to scanning of individual events
- Easy inclusion in the analysis process of physicists not directly involved into the code development and technical details.

Joint SBN workshop - Parallel working groups

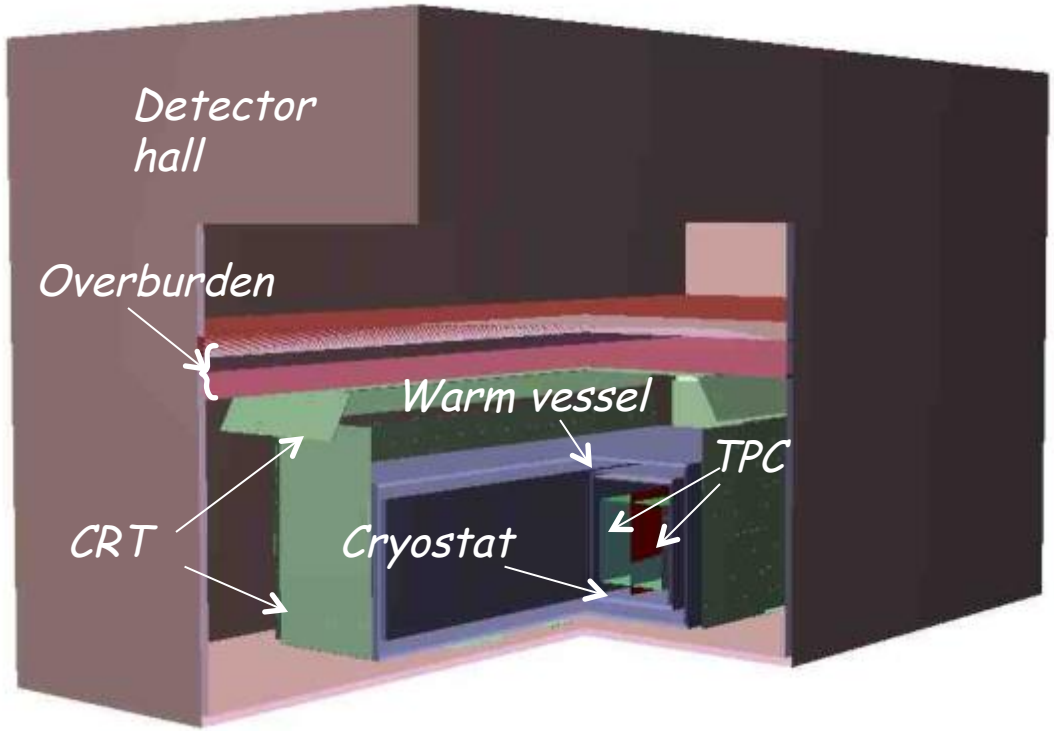
- Groups working in parallel with periodic updates during general sessions:

  A. *Light* – Verify simulation and develop reconstruction. Prepare the objects to be used for trigger studies and other studies for event classification and reconstruction through light.
  B. *CRT* – Verify simulation and geometry. CRT reconstruction. Tools to exploit the CRT information.
  C. *Different neutrino event selections* – Develop tools, identify areas where reconstruction improvements are needed.
  D. *Shower reconstruction* – Try different existing reconstruction algorithms. Identify areas where reconstruction improvements are needed.

- Working together very useful to promote technical collaboration, code reuse between different detectors

Status of the ICARUS simulation

- The General geometry of the detector components present in LarSoft, includes:
  - Active and passive liquid Argon geometry
  - TPC Wire chamber geometry
  - PMT arrays geometry
  - Cryostats
  - Overburden and experimental hall lay-out
  - CRT geometry description



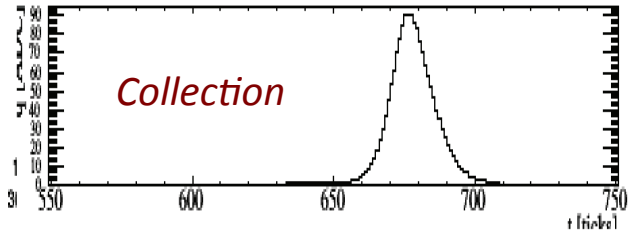
- The detectors have correct composition and dimension, some details are still missing or sketchy (work necessary to obtain more detailed and realistic description)

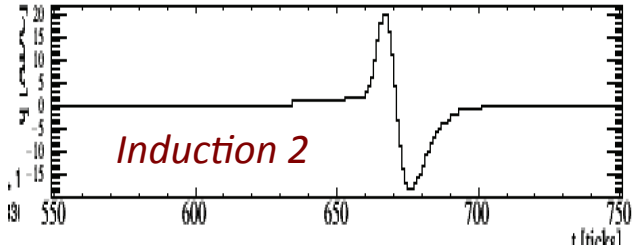
ICARUS TPC reconstruction/simulation

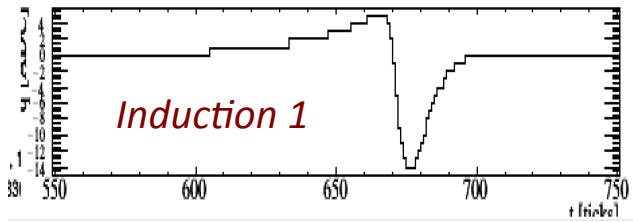
- Implementation of event reconstruction of simulated wire signal and noise is under completion, including simulation of the new electronic signal features.
- Some work is inherited from previous LNGS ICARUS reconstruction software:
  - General description of detector response
  - FFT description of noise at LNGS (until measurement in the new FNAL setup will become available…) with characterization and its filtering out
- New developments profit also of 12-bit digitization and full synchronization of wire signals:
  - ✔ Description of new read-out electronic response
  - ✔ De-convolution procedure to unfold signal shaping, needing to be tuned
  - ✔ Offline integration/filtering of Induction2 signals to handle bipolar signals
  - ✔ Re-optimize hit finding and fitting procedure
  - ✔ Calorimetric measurement in Induction2

Simulation of ICARUS electronic response

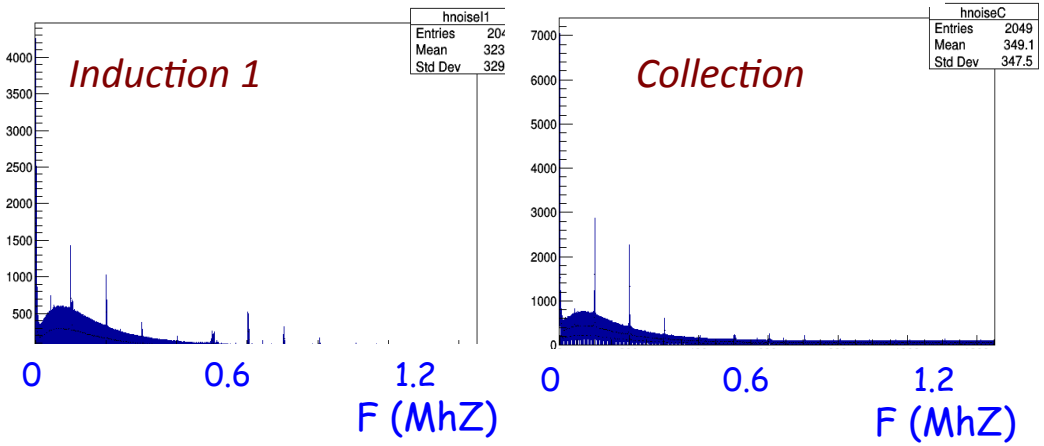
- Electronic response has been simulated, using a common response function for all views:
  $t/\tau\ e^{-t/\tau}$ $(\tau=1.5\mu s)$
- Approximate signal normalization according to the test at CERN (Collection measurements);
- Typical signals for a muon (m.i.p.): →
- Noise distributions extracted from ICARUS frequency spectra measured at LNGS (to be updates as soon as we get noise measurements at FNAL



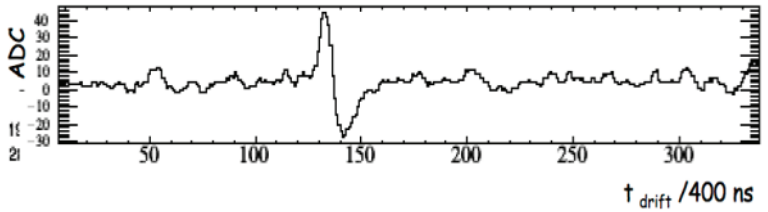




LNGS Noise Frequency spectra



Ind.2 signal simulation, including noise



Reconstruction of ICARUS TPC signals

- TPC wire hits are found and reconstructed by the present code even if additional tuning is required, in particular in the deconvolution case for the Induction 2 plane. With muon tracks:

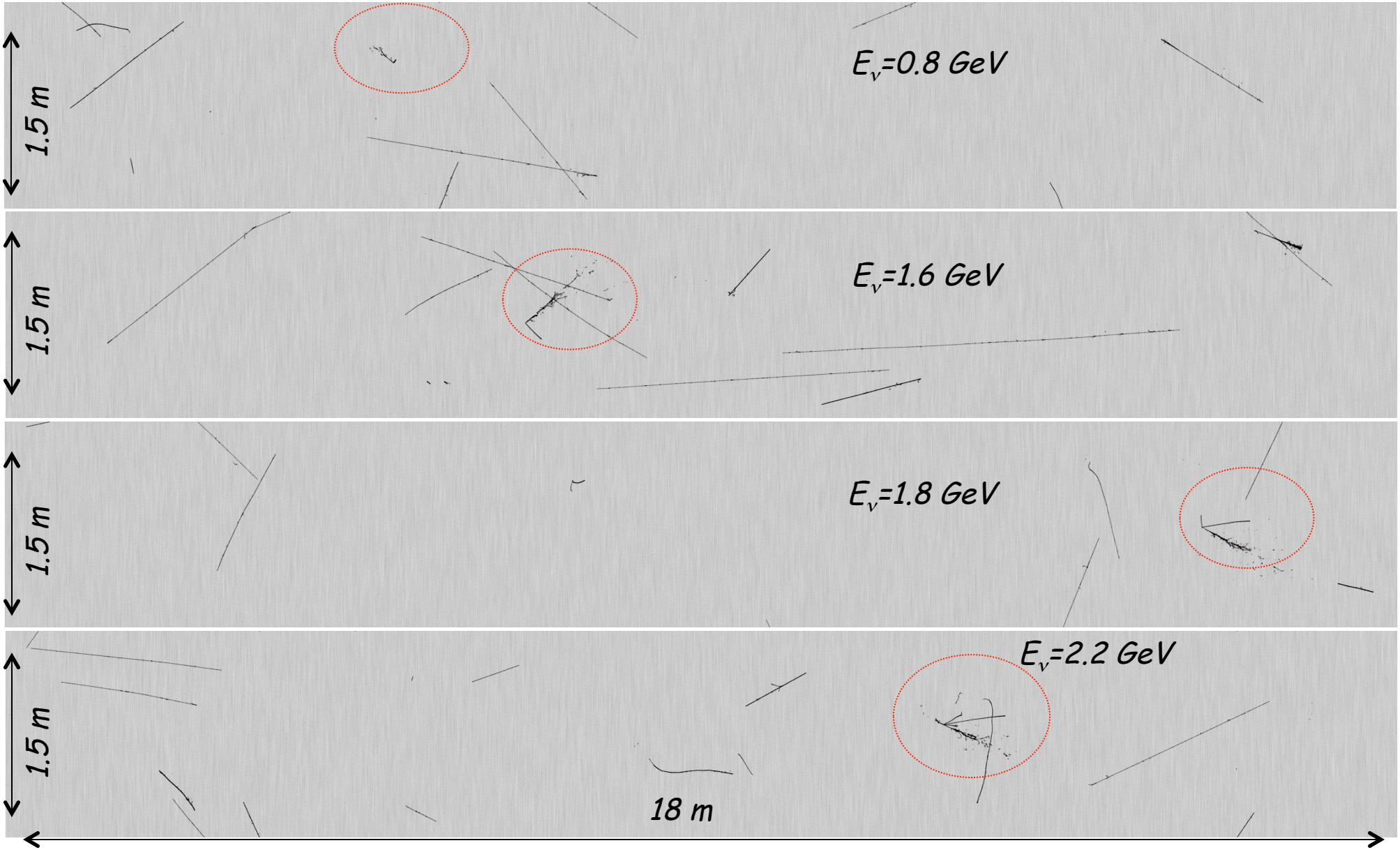
Plane	Efficiency	Fakes per wire
Collection raw	95%	0.01
Induction2 raw	95%	0.11
Induction1 raw	92%	0.06
Collection deconvoluted	99%	0.04
Induction2 deconvoluted	72%	0.6
Induction1 deconvoluted	97%	0.05

Simulated events

- Presently different MC event productions have been prepared and made available for developing and studying reconstruction algorithms
  - Single particles to tune algorithms for particle identification
  - Cosmic rays impinging on the detector, both single particles and all expected overlapping events, within the drift sensitive time (with different cosmic flux simulation like CRY and Korsika codes)
  - Neutrino events from BNB beam based on the official BNB fluxes and using GENIE to simulate the neutrino-argon interaction
- Alternative interaction models would be very relevant to simulate the neutrino interactions and check the reconstruction and identification efficiencies, extremely beneficial to the event analysis

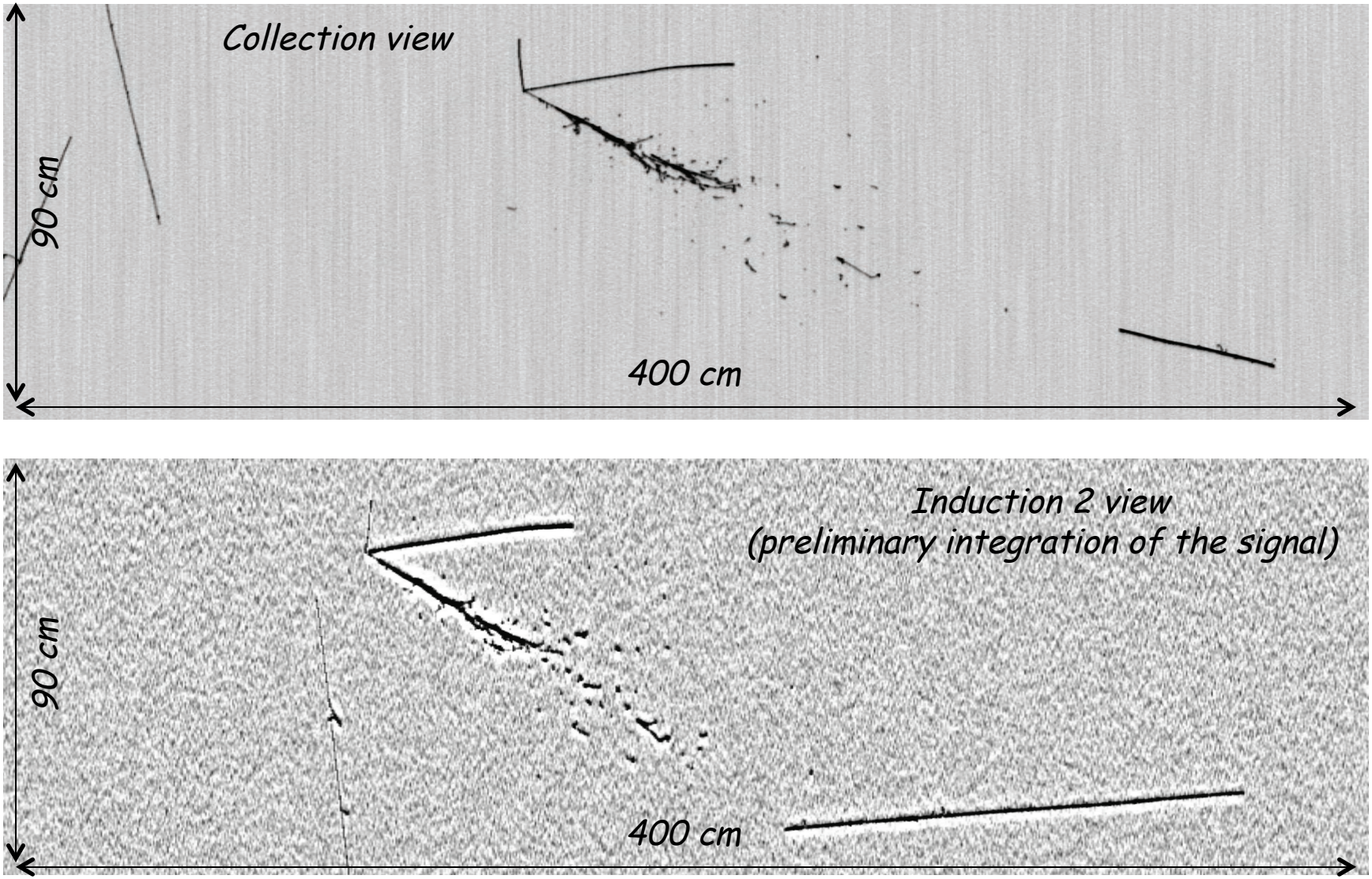
- A production group has to be established to provide/maintain the official production of simulated events for the collaboration and in perspective for real data processing

Few examples of simulated BNB events and cosmics in ICARUS



- Examples of simulated ν_eCC events overlapping with cosmics (collection view)

Detail of one event

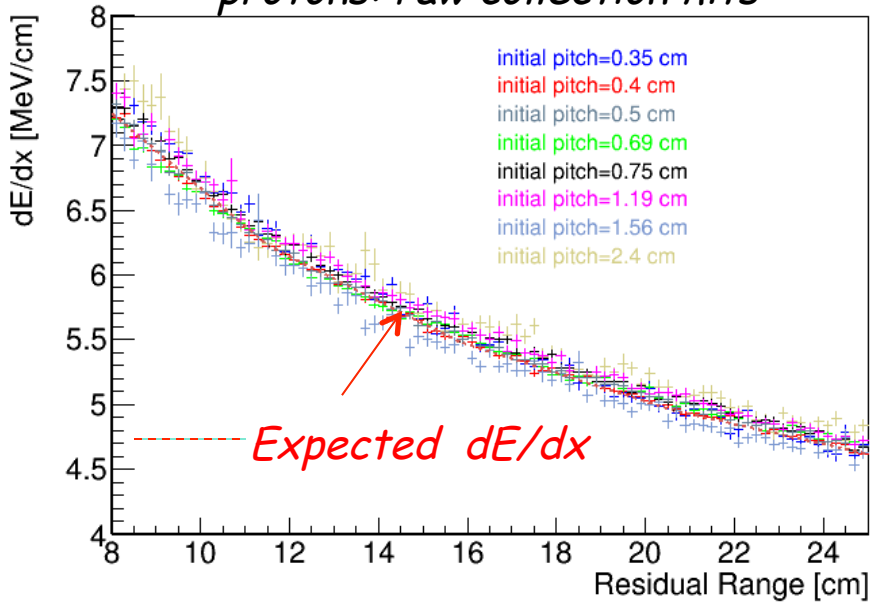


- Close view of one 1.8 GeV ν_eCC

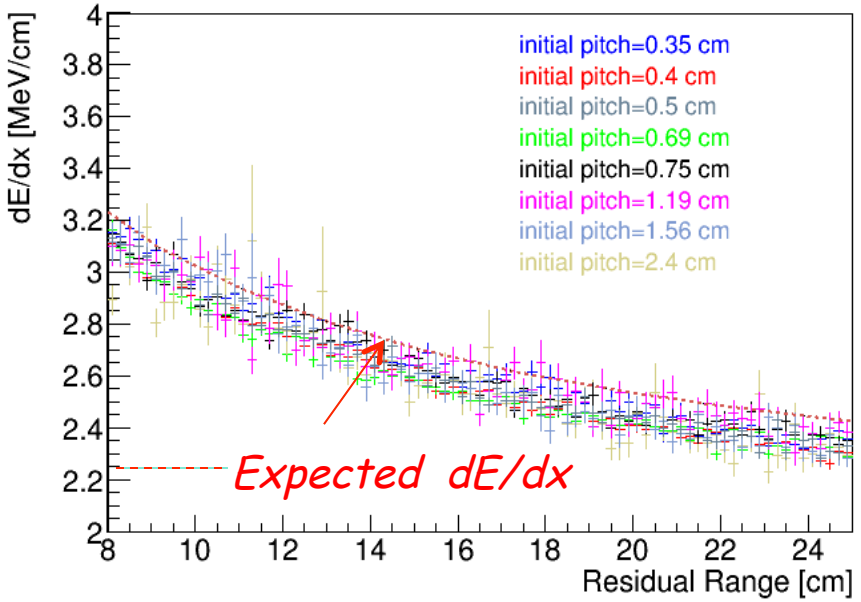
Reconstruction of TPC tracks in ICARUS

- Different clustering and track reconstruction algorithms available in LArSoft have been introduced in the ICARUS event reconstruction
- All the reconstruction algorithm are in place and working but need to be further validated and optimized. Efficiency and purity still to be assessed
- At the moment a 3D track reconstruction with algorithm similar to the one developed for ICARUS and adopted at LNGS were tested
- Geometrical and calorimetric reconstruction applied to dE/dx Vs range, for different track inclinations (with track segments/wire varying from 3.5 mm to 24 mm)

protons: raw collection hits

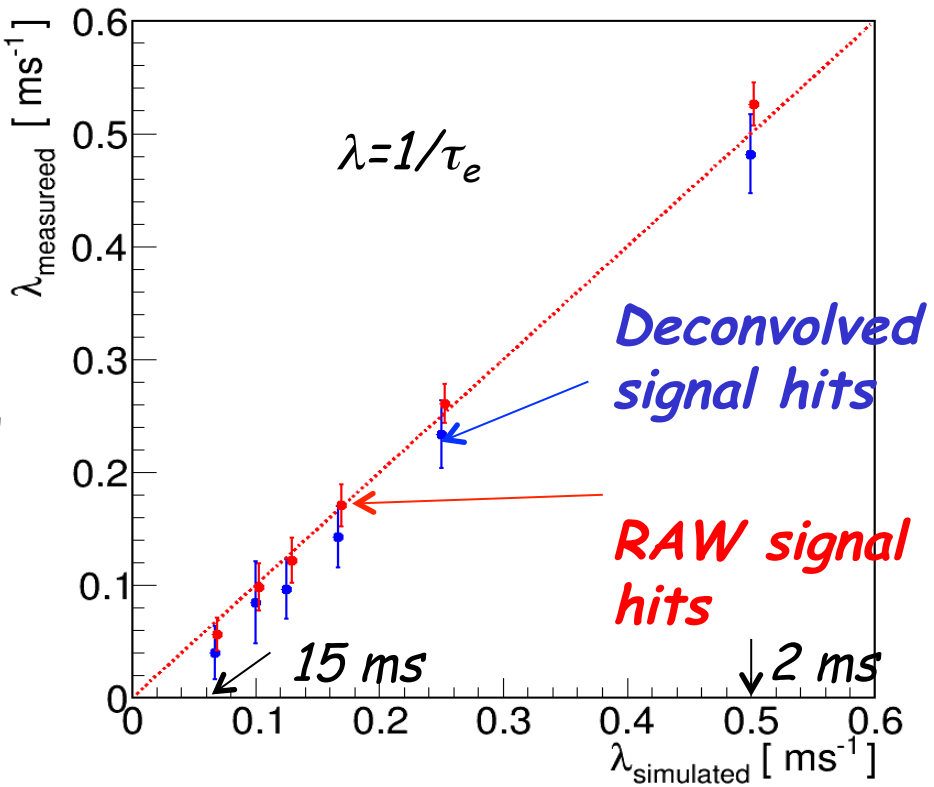


muons: raw collection hits



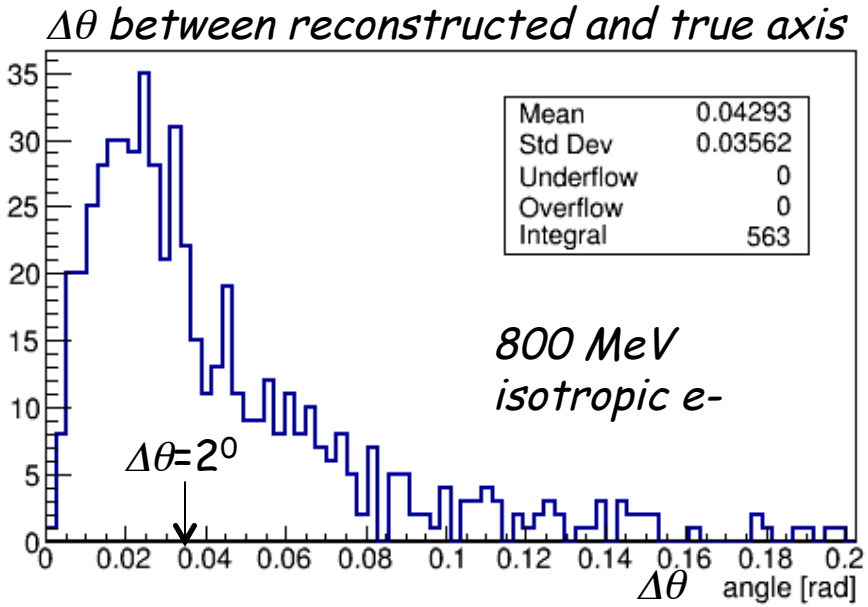
ICARUS argon purity at FNAL

- Application of the present track reconstruction for the measurement of the argon purity with cosmic muons
- The algorithm previously used at LNGS was applied to simulated cosmic ray events. However due to the crowded events in the far detector at shallow depth and the low energy spectrum of cosmic muons, the tracks selection is much more challenging, introducing large fluctuations in the purity measurement.
- Example of simulated purity measurement using 10^4 triggers :
  - Cosmic events generated with various τ_e from 2 ms to 15 ms corresponding to $\lambda = 1/\tau_e$ = 0.5 and 0.067 ms^{-1}
  - Work in progress



Reconstruction of e.m. showers in ICARUS

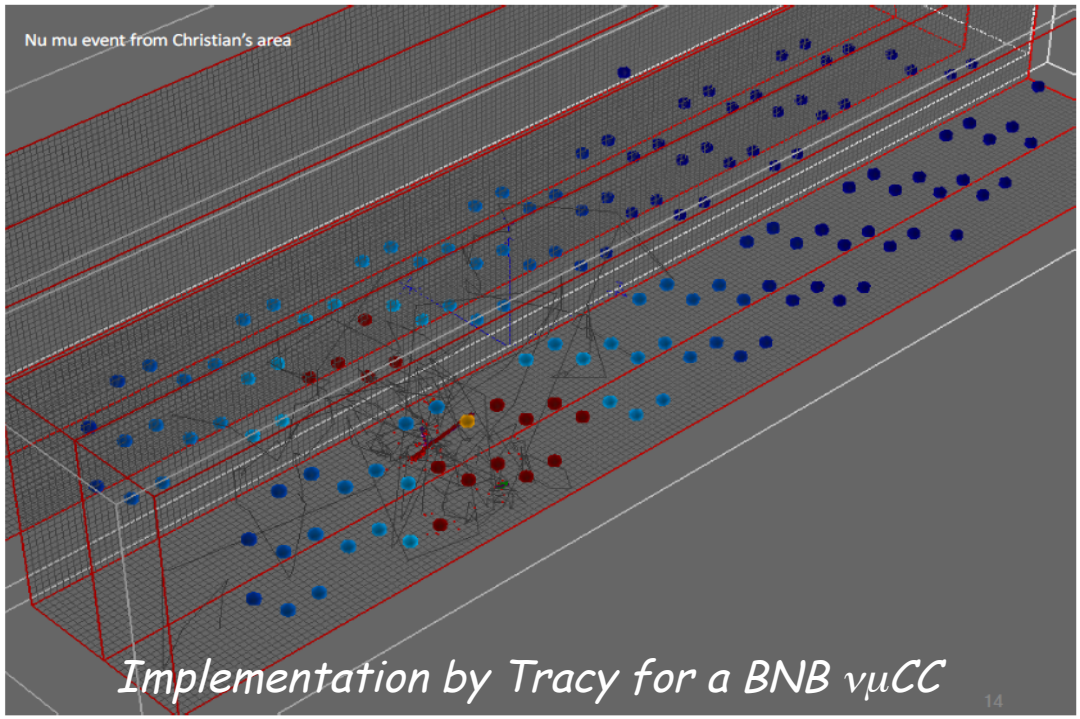
- The electromagnetic shower identification and measurement is a key ingredient for the ν_eCC analysis
- Example of reconstruction of the shower axis based on an algorithm already developed for ICARUS at LNGS
- First results for 800 MeV electrons isotropically oriented
  - The average angle between the true and reconstructed direction is ~2^0
  - Only 56% efficiency: needs improving the hit/cluster reconstruction!



- shower identification tools need to be prepared!
- dedicated regular meetings to share progress on these items already started: very welcome participation and contributions!

Inner light simulation in ICARUS

- A first parameterization of the scintillation light produced in the liquid argon was prepared. It is available and usable to simulate the scintillation signals on the PMT for any MC event.



Hit PMTs present in the event Display as heat-map representation

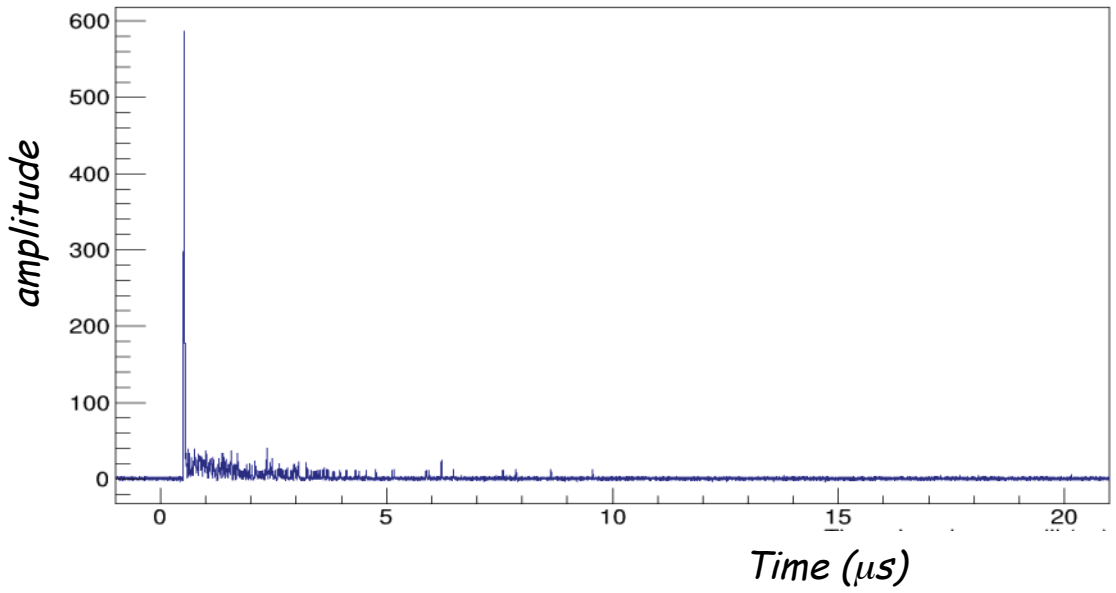
- Light signal amplitude scale to be optimized: too large in the present parameterization

Inner light simulation and reconstruction - 1

- Ongoing activity in view of
  - Complete a more realistic and configurable readout simulation module
  - *Provide input to trigger study*
  - Prepare pattern recognition through light
  - Algorithms for handling light hits and light flashes (multiple hits)

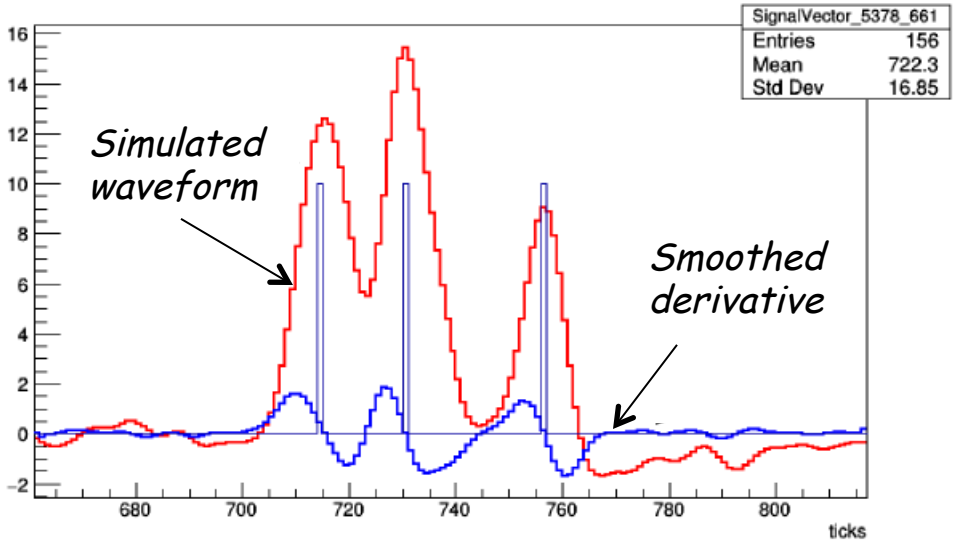
- New electronics simulation code available (more detailed description of the adopted electronics and trigger will be soon included)

Simulated signal on a PMT



Inner light simulation and reconstruction - 2

- At present the simulation is producing PMT waveforms which can be analyzed to find hits (first implementation available)
  - Some work left to get correct timing



- Light hit finding in place, with the possibility to reuse existing LArSoft code
- Should be able to start a light flash reconstruction
  - Implement the BNL "many-to-many" track/flash matching approach to help facilitate the cosmic ray identification

- Very relevant area for the event reconstruction and classification needs development and support.

CRT simulation/reconstruction

- The CRT geometry is described in the present version of the code.
- Validation of Geant 4 simulation in progress
  - Some issues with anomalous energy deposits in the CRT layers have been understood
  - Comparison of CRT rates for different single particles simulations
- Necessary developments to:
  - Implement the physical detector response for the three different subsystems (top, lateral, and bottom)
  - Develop CRT reconstruction to identify cosmic rays in the TPC

ICARUS Event Display

- This is a very important tool which proved extremely relevant to the detector commissioning, permitting the detailed debug of the complete data collection and reconstruction chain
- The Qscan event display permitted at LNGS an extremely sophisticated interaction with the physicist to access the reconstructed quantities as well as the raw information from the detector
- The new Event Display must include the additional detector information, namely
  - Time, geometrical and amplitude information from the inner PMT system
  - Time and geometrical information from the external CRT system
- Plans to improve the present LArSoft Event Display by the LArSoft team
- Necessary to preserve and extend some functionalities of the ICARUS system
- Very welcome contributions…

Data Storage and Computing Model

- ICARUS raw data consist of waveforms generated by sampling the signals induced on ~54000 TPC wires and 360 PMTs at 2.5 and 500 MHz respectively and compressed, resulting in ~70 MB/event.
- ~0.5 Hz data acquisition rate is expected in normal run conditions- mainly affected by cosmics- corresponding to ~40 MB data throughput. Therefore ~1PB/year of data is expected during continuous operation of T600
- Raw data will then processed by automated filters to recognize/select various event types (cosmic, beam, backgr, etc.) and rewrite them in a more flexible format, suitable for the analysis.
- Full raw data & processed sets will be stored at Fermilab using local facility. However, ICARUS Collaboration plans to have mirror sites in Europe, both for redundancy and to provide more direct data access to European groups. Besides CERN, one replica site could be located at CNAF INFN Tier1, which can provide necessary resources (in terms of storage space/ computing power).

Computing resources @ CNAF

- ICARUS is expected to be soon operational and run for 3 years. Computing resources/storage are required to start production of MC events, as well as for development/test of DAQ and raw data processing during commissioning.
- The required resources, the sharing between disk and tape storage and the amount of necessary CPUs, are estimated from past LNGS experience:
  - Expected 1 PB/year + 1 PB of additional data during commissioning
  - Data will be replicated to European sites (CERN, CNAF)
  - 500 CPU cores foreseen for initial data analysis needs in Italy
  - Working group is focusing on setting up a common FNAL-CNAF environment
  - A system prototype is being developed.
- These requests have been judged congruent by CNAF (similar to other CSN2 experiments) and approved by INFN CCR (Commissione Calcolo e Reti)
- **Assigned for 2018 :** CPU: 4000 HS06 (10 HS06/core);
  DISK: 500 TB TAPE: 1500 TB
- Required collaboration with US experts to deploy a working environment for the data replica and the interface between FNAL and CNAF site. Reference people: A. Cocco and A. Rappoldi.

Summary

- Some tools need to be finalized, in particular
  - simulation and reconstruction of the inner PMT
  - simulation and reconstruction of the external CRT system
  - shower reconstruction and identification
  - neutrino event identification and reconstruction
- By this summer complete event simulations including the information and reconstruction of inner PMTs and CRT detectors should be made available to:
  - set-up cosmic identification and rejection tools
  - provide selection tools of beam events using inner light, CRT detector and TPC reconstruction
  - Provide information for event selection (Trigger)
- Contributions from new groups for the different items are very relevant and welcome