PRELIMINARY STUDY FOR LArTPC SYSTEMATIC ERRORS
1. NEUTRINO PHYSICS

Let’s start with a brief recap on neutrinos
Neutrinos were introduced in Standard Model:

- Massless;
- Electrically neutral;
- Weakly interacting.

\[ | \nu_{\text{mass}} > = \sum_i U_i | \nu_{\text{flavour}} > \text{ where } U \text{ is the PMNS matrix.} \]

\[ P_{\alpha \rightarrow \beta} \sim \sin^2 (\Delta m^2 \cdot L/4E) \]
2. SBN PROGRAM

A brief introduction on the SBN collaboration
Anomalies in LSND and MiniBooNE suggest the possible existence of a 4th “sterile” neutrino. \[1\]

The SBN program aims at detecting non-standard $\nu$ oscillations by measuring $\nu_\mu$ disappearances and $\nu_e$ appearances on short baseline. For $\nu_e$ appearance recognizing $\nu_e$ CC is crucial.

SBN program main physics goals are:

- Explain LSND and MiniBooNE anomalies;
  - Find their sources;
  - Confirm or rule out the existence of a sterile $\nu$;
- Measure low-energy $\nu$-Ar cross section;
- Help the development of the DUNE experiment.

- Incoming charged particles ionise Argon
- An electric field guides electron through one or more induction plane towards a collection plane made of wires
- Wire and time coordinates of signals in each plane give the 2D trajectory
- A 3D trajectory is reconstructed matching all 2D projections
The way to identify $\nu_e$ appearances is to detect CC events, identifying electrons in the final state (discriminating them from NC $\pi^0$).

Electrons in liquid Argon usually shower, producing an electromagnetic cascade. $\pi^0 \rightarrow 2\gamma$ produced in NC neutrino interactions can produce similar signatures.

e$^-\,$ can be distinguished from $\pi^0$ using:

- **Separation** of the shower from vertex of interaction;
- **Invariant mass**;
- Ionization in the first segment of shower (1 MIP or 2 MIPs).

⇒ A good understanding of topology and calorimetry is crucial to identify and analyse neutrino interactions.
Challenges

SBN Program: 3 detectors, same technology, different configuration

Same technology, different configurations:
- Wires orientation;
- Electric field;
- Drift velocity;
- Liquid Argon purity;
- Light collection system & CRT;
- TPC readout electronics.

In particular for the readout electronics:

- **Preamp outside** the detector for ICARUS vs. **inside** for MicroBooNE/SBND.
- Detectors have different **shapers** (i.e. circuits that take signals from the detector, return amplified gaussian-like ones). **Shaping time** (time constant of the shaper) parametrize the differences among amplifiers.
- **Sampling** frequency of the digitizer is slightly different for the detectors.
3. SIMULATION

A simulation on sampling and shaping
Simulation

Starting from a random gaussian signal, two different samplings are performed.

The output signal is then reconstructed using gaussian fits.

SAMPLING

Given a random amount of charge deposited in time, two gaussian signals with different shaping times are generated.

The signal is then sampled and reconstructed.

SHAPING
4. DATA ANALYSIS

Data analysis and comparison with simulation results.
To study the impact of electronics on data, an analysis on topology and calorimetry has been performed using real data.

Real data were taken from LArIAT experiment, because of its small volume (0.24 tons\cite{2}) and negligible electrical noise.

<table>
<thead>
<tr>
<th>SHAPING TIME</th>
<th>GAIN</th>
<th>0 (4.7mV/FC)</th>
<th>1 (14mV/FC)</th>
<th>2 (7.8mV/FC)</th>
<th>3 (25mV/FC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (1.0 mics)</td>
<td></td>
<td>2691</td>
<td>225</td>
<td>202</td>
<td>336</td>
</tr>
<tr>
<td>1 (3.0 mics)</td>
<td></td>
<td>241</td>
<td>271</td>
<td>265</td>
<td>289</td>
</tr>
<tr>
<td>2 (0.5 mics)</td>
<td></td>
<td>226</td>
<td>1428</td>
<td>2004</td>
<td>278</td>
</tr>
<tr>
<td>3 (2.0 mics)</td>
<td></td>
<td>324</td>
<td>2151</td>
<td>839</td>
<td>839642</td>
</tr>
</tbody>
</table>

For the sampling study, **750 tracks** have been selected at 256ns. The corresponding 512ns data set was obtained by software. A study event per event was possible.

For the shaping study **30 tracks** at 1.0μs and 2.0μs have been chosen, both at 256ns. Therefore a **statistical study** was necessary.

\cite{2} LArIAT: Liquid Argon In A Testbeam: arXiv:1406.5560v3
Time resolution is investigated by measuring the **minimum time difference** between hits in the same wire. For sampling time **210 delta rays** have been analyzed.

No visible difference
Time resolution is investigated by measuring the **minimum time difference** between hits in the same wire.

For sampling time **680 events** have been analyzed.

![Graphs showing 1μs and 2μs shaping time with no visible difference](image)

**No visible difference**
Calorimetry is investigated by measuring the total area under each hit, which is proportional to the collected charge.

290 single tracks for sampling time and 30 single tracks for shaping time have been analyzed.

No visible difference

1 μs
2 μs
256 ns
512 ns
SUMMARY

- **Topology** and **calorimetry not affected** by sampling and shaping parameters!*
- During the analysis lots of issues with analysis software (**LArSoft**) have been found

⇒ This will **help** software **development**.

**Things I learned:**

- **Neutrino events topology**;
- Basic concepts on **readout electronics**;
- **LArTPC** principles of operation.

**Things I liked:**

- **Neutrino physics**: neutrinos are one of the most mysterious topics of modern physics. Studies on them are, to say the least, intriguing.

Many thanks to Raquel, Angela and all the LArIAT people, who followed me in these months.
Thanks for your attention!
A new “matching” algorithm had to be developed, in order to associate each hit with the corresponding one for the other sampling time.

No significative difference has been found in real data (\(\Delta t < 256\text{ns} \)).
The shaper takes the signal coming from the detector, **returning** an amplified and **gaussian**-like signal.

When integrating the signal over a certain period of time, most of the **white noise cancels out**.

The time constant of the circuit is the shaping time.
Events

Single track

Delta ray

Multiple track

Shower
During this study it turned out that all differences were not due to different physical behaviour under different sampling times, but to problems with the fitting algorithm.

A global study on the data showed that this problem does affect both sampling times, confirming that sampling time seems not to affect the identification of hits.
Background for neutrino experiments is difficult to simulate

The SBN collaboration chose to study real data from LArIAT.

LArIAT shares all the readout electronics with MicroBooNE and it is easier to study because of its small volume.

Electronic noise is negligible for LArIAT data, allowing to focus exclusively on electronics.
**ICARUS T600**

ICARUS is the farthest detector of the program.

It is composed by two semi-independent cryostats, holding 2 liquid argon time projection chambers each.

It is located at a distance of 600 meters from the neutrino source, where the sterile neutrino oscillation should be maximum.

It is the largest of the three detectors, with 500 tons of liquid argon in the active volumes.

ICARUS arrived from CERN on July 26 and is now under installation.

**MicroBooNE**

MicroBooNE is the central detector of the three.

Placed at a distance of 470 meters from the source it consists of a liquid argon time projection chamber, with 80 tons of liquid argon in the active volume.

It is located in the exact same place where MiniBooNE took place, in order to try to explain its anomalies.

The cryostat was filled in 2015 and the detector is currently operating; this data will produce neutrino cross section measurements, useful for future experiments, such as DUNE and the SBN program.

**Short-Baseline Near Detector**

SBND will be a 112 ton active volume liquid argon time projection chamber to be located only 110 m from the neutrino source.

The detector is currently in the design phase.

SBND will record over a million neutrino interactions per year. By providing such a high statistics measurement of the un-oscillated content of the booster neutrino beam, SBND is a critical element in performing searches for neutrino oscillations.
We proceeded studying how the sampling time could affect the identification of the peak time.

In order to do this we compared hit by hit two sets of data for through-going clean muon tracks.

A new “matching” algorithm had to be developed, in order to associate each hit with the corresponding one for the other sampling time.

No significative difference has been found ( $\Delta t < 256\text{ns}$ ).
Simulation

Deposited charge

Analog signal

256 ns fit

512 ns fit

PeakTime 256ns - 512ns

PeakTime 1μs - 2μs

Andrea Serafini
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A new “matching” algorithm had to be developed, in order to associate each hit with the corresponding one for the other sampling time.

No significative difference has been found (Δt < 256ns).
Delta ray events have been analyzed in order to understand the minimum discernable time distance between peaks.

Although the behavior seems to be the same for both sampling times, plots differ for a small fraction of events. A critical study of differences could lead to important knowledge on the behaviour of different electronics. A event by event study was done in order to understand these differences.
Calorimetry
(shaping)

**Distribution of deposited charge 1ms**

- Entries: 655
- Mean: 731.2
- Std Dev: 329.4
- Underflow: 0
- Overflow: 0
- Integral: 655
- Skewness: 2.406
- Z^*/r.m.s.: 43.89 / 40
- Prob: 0.3101
- Constant: $348.3 \pm 21.2$
- MPV: $539.5 \pm 5.5$
- Sigma: 75.2 \pm 3.7

**Distribution of deposited charge 2ms**

- Entries: 296
- Mean: 717.4
- Std Dev: 230.1
- Underflow: 0
- Overflow: 0
- Integral: 296
- Skewness: 2.425
- Z^*/r.m.s.: 20.12 / 35
- Prob: 0.8792
- Constant: $183.2 \pm 16.7$
- MPV: $546.4 \pm 8.3$
- Sigma: 62.13 \pm 4.40

Fitted Deposited Charge
(normalized by hits)

- Shaping 1 μs
- Shaping 2 μs